13th Cosmic-Ray International Studies and Multi-messenger Astroparticle Conference

Monday, 17 June 2024 - Friday, 21 June 2024

Trapani

Book of Abstracts

Contents

Galactic and Solar Cosmic Rays / 2

HERD: an innovative detector to expand energy limits in direct detection of cosmic rays

Author: Davide Serini[1]

Co-author: Pietro Betti [1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Authors: betti@fi.infn.it, davide.serini@ba.infn.it

The HERD (High Energy cosmic-Radiation Detection facility) experiment is a future experiment for the direct detection of high energy cosmic rays that will be installed on the Chinese space station in 2027. Is is constituted by an innovative calorimeter built by about 7500 LYSO scintillating crystals of side 3 cm assembled in a spheroidal shape, such that it has an homogeneous response for particle entering in the calorimeter from every direction. It is surrounded on five faces by multiple sub-detectors, so that he can detect particles entering from five sides. Thanks to this innovative geometry, HERD will have a geometric factor more than one order of magnitude bigger than that of
current in orbit experiments, which detect particles only form one side. Thus, HERD will extend direct measurements of cosmic rays of more than one order of magnitude in energy. Indeed, it will measure proton and nuclei fluxes up to the PeV/nucleon energy region, performing the first direct measurement of the cosmic proton and Helium knee. Moreover, HERD will measure the electron+positron flux up to tens of TeV, looking for possible indirect signals of dark matter and possible local sources of high energy electrons/positrons. In addition, HERD will measure high energy photon flux to search for possible indirect signals of dark matter, high energy cosmic rays sources and perform multi-messenger astronomy.
In this talk we would like to introduce the HERD experiment, with its scientific objectives and its innovative detector.

Ultra-High Energy Cosmic Rays / 3

Strange hadron production in high-multiplicity hadronic collisions with cosmic ray monte carlo simulations for atmospheric air showers and beyond: simulation study

Author: Abd Al Karim Haj Ismail[None]

Corresponding Author: abd.hajismail@gmail.com

In this paper, we conduct a Monte Carlo simulation study to investigate the production of strange and multi-strange hadrons in high-multiplicity proton-proton collisions. Our objective is to refine and validate the hadronic interaction models crucial for air shower simulations such as EPOS, QGSJET, SIBYLL, and PYTHIA. These models play a pivotal role in predicting the propagation of extensive air showers in the atmosphere and comparing them with experimental data from cosmic ray observatories such as high-multiplicity proton-proton collisions in the ALICE experiment. In the case of (K0S) mesons, at low multiplicity classes, we found that EPOS and PYTHIA can show a better prediction of the data than QGSJET and SIBYLL, while QGSJET exhibits favourable predictions at higher multiplicity classes. On the other hand, when looking at (Λ) baryons, the EPOS model is the only model that shows the best comparison to data. In addition, We employ the Tsallis distribution to extract the effective temperature (Teff) and the non-extensivity parameter (q).

Flash Talks-1 / 4

Are there critical aspects in the time, energy and angular distributions of SN1987A?

Authors: Francesco Vissani[1]; Giulia Ricciardi[2]; Giuseppe Matteucci[3]; Riccardo Maria Bozza[3]; Veronica Oliviero[4]; Vigilante di Risi[2]

[1] *LNGS*

[2] *Università di Napoli Federico Secondo*

[3] *INFN NA*

[4] *Istituto Nazionale di Fisica Nucleare*

Corresponding Authors: veronica.oliviero@na.infn.it, giuseppe.matteucci@unina.it, vigilante.dirisi@unina.it, ricciard@na.infn.it, francesco.vissani@lngs.infn.it, riccardomaria.bozza@unina.it, veronica.oliviero2@unina.it

Supernova neutrinos are of considerable importance for ongoing research in astrophysics, nuclear and particle physics. Existing simulations of this complex event are increasingly sophisticated, but the accuracy with which they describe the emission is unknown. The only event observed so far with neutrino telescopes, SN1987A, still plays a crucial role and deserves to be studied meticulously. With this in mind, we have undertaken a refined analysis of the observations, taking into account the knowledge gained over the past decades. In this work, we consider a new parameterised model of electron antineutrino emission and test its adequacy in describing the observed distributions of energy, time and angle. The values of the model parameters derived from the data and their uncertainty intervals are presented and their significance is discussed.

Innovative Detectors and Data Handling Techniques / 5

The novel direction detector on board of the second China Seismo-Electromagnetic Satellite.

Author: Umberto Savino[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: umberto.savino@to.infn.it

In the field of multi-messenger astronomy, the China National Space Administration started a program to study the lithosphere - atmosphere - ionosphere coupling mechanism. The project aims to realize a constellation of satellites to unveil the time correlation between the main earthquake shocks and an increase in the electron flux in the inner Van Allen belt.
For this purpose, a second CSES (China Seismo-Electromagnetic Satellite) will be sent to Space by the end of this year, hosting an High Energy Particle Detector, namely HEPD-02, entirely realized by the Italian Limadou collaboration.
One of the most interesting features of the HEPD, is the direction detector (DD); it consists of monolithic silicon pixel sensors (MAPS), called ALTAI, and represents the first attempt to employ MAPS for particle tracking in Space. The main advantages in using such a technology are the ultra-low material budget, the high spatial resolution and low noise.
The technology is based on the Tower Jazz 180 nm semiconductor manufacturing process investigated for the ALICE (A Large Ion Collider Experiment) ITS upgrade at CERN.
The scientific and mechanical/thermal requirements of the mission will be discussed showing the results of the DD qualification tests, with a particular focus on the control power consumption of MAPS, the trade-off for mechanical support to guarantee a proper thermal control and the DD mechanical stability.

Galactic and Solar Cosmic Rays / 6

The AMS-02 mission after 13 years of operations on the ISS

Author: Valerio Vagelli[1]

[1] *ASI & INFN-PG*

Corresponding Author: valerio.vagelli@asi.it

The magnetic spectrometer detector AMS-02 has been successfully operating since May 19th, 2011 outside of the International Space Station. More than 230 billion events have been collected by the AMS-02 instrument in 13 years of data taking. The analyses of the high-precision data collected by AMS-02 have been providing novel details and new insights on the composition, spectra, and time dependencies of antimatter and matter cosmic rays up to TeV energies. In this contribution we review the status and prospectives of the AMS mission, the recent AMS-02 measurements and the achieved advances in the understanding of cosmic ray origin, acceleration and propagation physics.

Galactic and Solar Cosmic Rays / 7

The Calorimetric Electron Telescope (CALET): results of the first 8 years of cosmic-ray direct measurements.

Author: Lorenzo Pacini[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: lorenzo.pacini@fi.infn.it

Direct measurements of cosmic rays are unique probes for investigating astroparticle propagation and acceleration in the Galaxy and searching for dark matter signatures. The Calorimetric Electron Telescope (CALET) has been installed on the International Space Station with the main goals of detecting electron, proton, and nuclei spectra. The detector has been continuously operating since 2015 without significant interruptions in data collection. The instrument consists of a plastic charge detector, an imaging calorimeter with tracking capabilities and a total absorption calorimeter. This design allows excellent performance for electron measurements in terms of energy resolution and particle identification. Furthermore, protons, nuclei, and photons are accurately detected by CALET thanks to its general-purpose design. Since the first years of the mission, the collaboration has obtained relevant results regarding all the main goals of the experiment, making substantial contributions to cosmic ray observations.

The performance of the instrument and the main results obtained by CALET will be reported in this contribution. The recent paper about cosmic ray electrons observed up to an unexplored energy range will also be discussed

Galactic and Solar Cosmic Rays / 9

The latest results from the DAMPE experiment

Author: Pengxiong Ma[None]

Corresponding Author: mapx@pmo.ac.cn

Since its launch in December 2015, the Dark Matter Particle Explorer (DAMPE) has been operating smoothly for over eight years, showcasing its superior performance in the detection of cosmic rays above the TeV energy region among space-based experiments. Recently, DAMPE has reported new measurement results that further underscore its distinctive contributions to our comprehension of Galactic cosmic rays. To date, DAMPE has recorded over 15 billion events, with the vast majority of these abundant cosmic rays being processed by the collaboration. In this talk, we will present the latest findings and the analysis process employed.

Gamma-Ray and Multi-Messenger Astronomy / 10

Discovery of Very High Energy emission from the distant FSRQ OP 313 by the Large-Sized Telescope prototype.

Authors: Federico Di Pierro[1]; for the CTA-LST Project[None]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: federico.dipierro@to.infn.it

In December 2023 the Large-Sized Telescope prototype (LST-1) of the Cherenkov Telescope Array Observatory (CTAO) observed the distant (z=0.997) Flat Spectrum Radio Quasar (FSRQ) OP 313 following an alert of increased activity by the Fermi-LAT Space Telescope. Thanks to its very low energy threshold and large effective area LST-1 detected very-high-energy (VHE, E>100 GeV) emission from OP 313.

OP 313 is the tenth FSRQ ever detected in the very-high-energy regime and the furthest blazar ever detected so far at these energies.

This result represents the first scientific discovery of the LST-1, showing the exceptional capabilities of CTAO, whose LST northern array is currently under construction in La Palma (Canary Islands, Spain). The status and perspectives of the LST project will be also presented.

Gamma-Ray and Multi-Messenger Astronomy / 11

Two 100 TeV neutrinos coincident with the Seyfert galaxy NGC 7469

Author: Giacomo Sommani[1]

[1] *Ruhr-Universität Bochum*

Corresponding Author: sommani@astro.ruhr-uni-bochum.de

In 2013, the IceCube collaboration announced the detection of a diffuse high-energy astrophysical neutrino flux. The origin of this flux is still largely unknown. The most significant individual source is the close-by Seyfert galaxy NGC 1068 at 4.2-sigma level with a soft spectral index. To identify sources based on their counterpart, IceCube releases realtime alerts corresponding to neutrinos with a high probability of astrophysical origin. Two neutrino alerts, IC220424A and IC230416A, were spatially coincident with the Seyfert galaxy NGC 7469 at a distance of 70 Mpc. We evaluated, a-posteriori, the chance probability of such a coincidence. To calculate the chance coincidence considering neutrino emission from a specific source population, we performed a Goodness-of-Fit test with a test statistic derived from a likelihood ratio that includes the neutrino angular uncertainty and the source distance. We applied this test first to a catalog of AGN sources and second to a catalog of Seyfert galaxies only. Our a-posteriori evaluation excludes the chance coincidence of the two neutrinos with the Seyfert galaxy NGC 7469 at 3.3-sigma level. Previous non-detection in TeV neutrinos of the source indicate a hard spectral index or a recent onset of the neutrino activity.
We discuss the source as a possible neutrino emitter based on its multi-wavelength properties and in comparison to NGC 1068.

Flash Talks-2 / 14

Cosmic ray mass composition at the knee using azimuthal fluctuations of air shower particles detected at ground

Author: Nicusor Arsene[1]

[1] *Institute for Space Sciences - Subsidiary of INFLPR*

Corresponding Author: nicusor.arsene@spacescience.ro

The presence of hadronic sub-showers in vertical extensive air showers produces non-uniformities in the azimuthal distribution of secondary particle densities at ground.
At a fixed distance from the shower axis, these non-uniformities are more pronounced in the case of showers induced by protons compared to those induced by iron nuclei, primarily due to larger fluctuations in the heights of primary interaction points.
In this study, we will demonstrate that these non-uniformities, quantified by the LCm parameter, can be successfully used as a mass discriminator of primary cosmic rays in experiments employing a relatively compact grid of detectors.
Based on the experimental data recorded by the KASCADE experiment, we reconstructed the mass composition of primary cosmic rays in the energy range lg(E/eV) = [15.0 - 16.0] using the LCm discriminator.
The results obtained through this method are in excellent agreement with the results previously obtained by the KASCADE and IceTop experiments based on different observables and techniques.
Considering that this reconstruction method is minimally dependent on the hadronic interaction model considered in the simulation process, we believe that this LCm parameter could be a valuable tool for forthcoming measurements of the LHAASO experiment to enhance our knowledge about the origin and acceleration mechanisms of cosmic rays.
Additionally, we will present various approaches aimed at maximizing the information provided by the non-uniformities of secondary particle densities for the purpose of mass composition studies.

Gamma-Ray and Multi-Messenger Astronomy / 15

Advancements in Gamma-Ray Burst science with High Energy Particle Detectors on CSES Satellites: current status and prospects

Author: Roberto Iuppa[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: roberto.iuppa@tifpa.infn.it

The CSES-Limadou collaboration, responsible for the development and operation of High Energy Particle Detectors (HEPD) aboard the China Seismo-Electromagnetic Satellites (CSES), has significantly propelled the study of Gamma-Ray Bursts (GRBs). Initially, utilizing the HEPD-01 detector onboard CSES-01, our collaboration published findings on five GRB events, revealing the instrument's unexpected sensitivity to these phenomena. More recently, a novel analysis framework has expanded our detection rate and further unveiled the potential of HEPD's LYSO crystals in the MeV-tens of MeV energy range. Looking ahead, the imminent launch of HEPD-02 on CSES-02 marks a pivotal advancement. Unlike its predecessor, HEPD-02 features a dedicated trigger system tailored explicitly for GRB detection, promising heightened sensitivity and precision. This technological leap positions the CSES-Limadou collaboration as a significant contributor to the global network of GRB observatories. Our contribution will comprehensively present HEPD-01 findings and its sensitivity to different classes of GRBs. Additionally, we will briefly outline the HEPD-02's Data Acquisition (DAQ) design solutions, facilitating precise measurement of photon fluxes in the MeV-tens of MeV energy range with a time resolution of 5 milliseconds. Finally, we will discuss the anticipated scientific contributions from this enhanced detection capability, extending into the future to 2030 and beyond.

Flash Talks-1 / 16

Calibration and monitoring system of the KM3NeT Neutrino telescope

Author: Giovanna Ferrara[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: giovanna.ferrara@lns.infn.it

The KM3NeT Collaboration is building two neutrino telescopes in the Mediterranean Sea. One is the ARCA detector, optimised for searches for high-energy neutrino sources in the Universe and it is under construction at the Capo Passero site, Italy, 80 km offshore at a depth of 3500 m; and the other is ORCA detector, near Toulon, France, 40 km offshore at a depth of 2500 m, aimed at the study of neutrino properties, like the mass ordering, with atmospheric neutrinos. In the final configuration, ARCA will consist of 2 Building Blocks (BB), each one of 115 Detection Units (DU), and ORCA of 1BB. The DUs are vertical strings anchored on the sea floor to form a three-dimensional array of 18 Digital Optical Modules (DOM), pressure resistant glass spheres, containing 31 photo-multipliers tubes (PMTs) able to detect Cherenkov light produced by neutrino-induced particles. To achieve the KM3NeT physics goals, ARCA will instrument ~ 1 km^3 volume of seawater and a nano-second time synchronisation between PMTs and a 20 cm DOM position reconstruction accuracy is needed. At the present moment, 28 DUs have been already deployed in ARCA and 19 in ORCA.
In this contribution, the current strategy and the setup for the calibration procedures of the KM3NeT telescope are presented. The equipment test and procedure to check the proper functionality of the sea sensors dedicated to the monitoring of the deep-sea environment are also presented.

Galactic and Solar Cosmic Rays / 17

The High-Energy Particle Detector (HEPD-01) in orbit since 2018: achieved results and ongoing studies

Author: Francesco Palma[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: francesco.palma@roma2.infn.it

Since February 2018, the High-Energy Particle Detector (HEPD-01) has been studying the wide plethora of galactic, solar and trapped particles along the Sun-synchronous and low-Earth orbit of the China Seismo-Electromagnetic Satellite (CSES-01). Entirely designed and built in Italy, this light and compact payload is equipped with a silicon tracking system, a segmented plastic scintillator plane as trigger, a range calorimeter - comprising a tower of plastic scintillator planes and a matrix of LYSO crystals - and a plastic scintillator anti-coincidence system. The combination of these sub-detectors optimizes the measurement of electrons, protons and light nuclei in the 3-100 MeV, 30-300 MeV and 30-300 MeV/n energy ranges, respectively. During these years in orbit, HEPD-01 proved well suited for the study of both short time-scale, impulsive and transient space weather phenomena, among which the G3-class geomagnetic storm of August 2018 and the solar energetic particle event of October 2021, and long time-scale effects, such as the solar modulation of galactic cosmic-ray protons. In addition, HEPD-01 provided new results on some particle populations inside the Earth' s magnetosphere: the stably trapped protons in the South Atlantic Anomaly, the downward-going, albedo protons, and the re-entrant leptons above the few MeVs energy threshold.
In this work, I will present the main scientific results already obtained by HEPD-01 concerning the above-mentioned topics, the ongoing analyses and, very briefly, the future studies with the second High-Energy Particle Detector (HEPD-02), which will be launched on board the CSES-02 satellite in late 2024.

Gamma-Ray and Multi-Messenger Astronomy / 18

Searching for TeV-emitting candidates among the X-ray bright blazar population

Authors: Antonio Iuliano[1]; Chiara Righi[2]; Davide Miceli[1]; Elisa Prandini[3]; Michele Doro[1]; Paolo Da Vela[4]; Roberta Zanin[5]; Stefano Marchesi[6]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *INAF - OABrera*

[3] *University of Padova and INFN*

[4] *INAF OAS Bologna*

[5] *CTAO gGmbH*

[6] *Università di Bologna*

Corresponding Authors: roberta.zanin@cta-observatory.org, michele.doro@pd.infn.it, chiara.righi@inaf.it, paolo.davela@inaf.it, davide.miceli@pd.infn.it, antonio.iuliano@na.infn.it, stefano.marchesi@inaf.it, elisa.prandini@pd.infn.it

Extragalactic surveys search for unexpected and serendipitous phenomena, resulting in sources catalogues of unvaluable scientific interest. A Very High Energy survey would be able to add data in a still mostly unknown energy band, finding crossmatches for existing X-ray sources and improving their modelling.
The purpose of this work is to understand if, among the blazars not detected by Fermi-LAT, a population of TeV emitting sources could be detected by current or future Cherenkov telescopes. We cross-matched the 5BZCAT catalog of blazars with the most recent catalogs of point-like sources detected by XMM-Newton, Chandra, Swift-XRT. After the recent eROSITA-DE Data Release 1, we performed a crossmatch of the blazars located in the part of the sky covered by this survey.
Finally, we studied the sources without a 4FGL-DR4 counterpart to assess their expected TeV emission. We focused on the objects with a maximum chance of being detected by current or future TeV detectors, based on selections on their X-ray to radio flux ratio and their synchrotron peak frequency. In conclusion, we determined if the X-ray emission can be used as an effective proxy to find and characterize candidate TeV-emitting blazars.

Flash Talks-2 / 19

Precision Monthly Fluxes Measurement of Lithium, Beryllium, Boron, Carbon, and Oxygen in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

Author: Jian Tian[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: jian.tian@cern.ch

Cosmic Rays (CR) inside the Heliosphere are subject to the effects of the Solar Modulation, resulting from their interaction with the solar wind and with the interplanetary magnetic field. These effects are strongly related to the solar activity and lead to a temporal variation of the cosmic ray intensity near Earth for rigidities up to few tens of GV.

In this contribution, properties of time structures of light nuclei (3 <= Z <= 8) fluxes in cosmic rays have been measured for 147 Bartel rotations ranging from May 2011 to November 2022 in the rigidity range between 2 and 60 GV with 5.3×10^6 lithium, 2.6×10^6 beryllium, 7.8×10^6 boron, 26.1×10^6 carbon, 6.6×10^6 nitrogen, and 22.1×10^6 oxygen nuclei collected with the Alpha Magnetic Spectrometer aboard the International Space Station. This period covers a full solar cycle from the ascending phase of solar cycle 24 to the similar phase of solar cycle 25. The fluxes show similar time variations with amplitudes of the time structures decreasing with increasing rigidities. This provides new information on the propagation of cosmic rays in the heliosphere.

Flash Talks-1 / 20

Effects of light exposure and temperature on the quantum efficiency of PMTs for the KM3NeT Neutrino Telescope

Author: Antonio De Benedittis[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: antonio.debenedittis@na.infn.it

The cubic-kilometre neutrino telescope (KM3NeT), currently under construction on the Mediterranean seabed, is a deep-sea infrastructure composed of two neutrino telescopes, consisting of large-scale 3D-arrays of photomultiplier tubes (PMTs).

PMTs play a fundamental role in detecting Cherenkov radiation emitted by charged particles. Their reliable performance is critical, due to their exceptional sensitivity to low-intensity light, which is crucial for detecting high-energy particles such as astrophysical neutrinos. PMTs, being highly sensitive photosensors, can suffer significant damage to the photocathode coating when exposed to intense light. This scenario, uncommon in controlled environments, could become relevant during certain phases of the experiment.

We therefore intend to present a work on the analysis of the damage threshold and recovery time of bialkali metal-coated photomultipliers. The investigation involved the measurement of Quantum Efficiency (QE) before and after exposing the PMTs to the illumination of a Xenon lamp for different durations with the intention of simulating sun exposure for several days. In addition, QE was also measured before and after subjecting PMTs to thermal stress to comprehensively evaluate their performance under different conditions.

Galactic and Solar Cosmic Rays / 21

Fostering Curiosity and Learning: The Journey from Tool Development to Practical Education.

Authors: Angelo Maggiora[1]; Cristina Mattone[2]; Francesco Rogo[3]

Co-authors: Alessandro Cortopassi [4]; PAOLA GAROSI [4]

[1] *TO*

[2] *CAEN SpA*

[3] *CAEN S.p.a.*

[4] *CAEN SPA*

Corresponding Authors: c.mattone@caen.it, p.garosi@caen.it, angelo.maggiora@to.infn.it, a.cortopassi@caen.it, f.rogo@caen.it

In recent years, Universities and Research institutions have increasingly developed programs and outreach initiatives aimed at making physics and other scientific disciplines accessible and engaging for a broader audience. The primary goal of these initiatives is to stimulate interest in science, promote understanding of fundamental principles of physics, and inspire future generations of scientists.
Concurrently, CAEN, an important INFN spin-off committed to collaboration with the Research World, has also moved in this direction by focusing on student needs. CAEN has developed several modular Educational Kits featuring experiments of varying difficulty levels. All Educational Kits serve as modern and flexible platforms for teaching the fundamentals of Statistics, Particle Detection, and Nuclear Imaging. The main objective of CAEN Educational branch is to inspire students and guide them toward the analysis and comprehension of different physics phenomena using state-of-the-art technologies, instruments, and methods.
With a focus on young students, CAEN has developed dedicated educational kits for applications

in environmental radiation, including both cosmic rays and terrestrial radiation. Specifically, to enhance student familiarity with cosmic ray radiation, special educational solutions have been designed: Cosmic Hunter and Detection System Plus.
The Cosmic Hunter is a user-friendly educational kit for cosmic ray detection, consisting of a coincidence module that supplies bias voltage to two scintillating tiles and counts hits produced by muons on each one.
The Detection System Plus is a compact system for cosmic ray detection, serving as both a didactic instrument and an external trigger system for other experimental setups.
Both devices are suitable for high school and university-level physics labs and, specially, serve as valuable tools for introducing individuals to modern physics through explanations of the scientific method via cosmic ray experiments. Indeed, cosmic ray experimental activities enable students to integrate theoretical knowledge with hands-on setup operations, data analysis, and critical synthesis of results.

Innovative Detectors and Data Handling Techniques / **22**

Compact Space-Borne Telescope for Efficient VHE Gamma-Ray Detection with Oriented Crystals

Author: LAURA BANDIERA[1]

Co-authors: Alessia Selmi [2]; Alexei Sytov [3]; Andrea Mazzolari [1]; Elisabetta Cavazzuti [4]; Erik Silvio Vallazza [1]; Francesco Longo [1]; Gianfranco Paternò [1]; Lorenzo Malagutti [5]; Luigi Costamante [6]; Marco Romagnoni [1]; Mattia Soldani [1]; Michela Prest [1]; Nicola Canale [1]; Pietro Monti-Guarnieri [1]; Riccardo Negrello [1]; Richard Gaitskell [7]; Sara Cutini [1]; Savvas Koushiappas [7]; Stefano Carsi [8]; Valerio Vagelli [9]; Vincenzo Guidi [5]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Università degli Studi dell'Insubria*

[3] *Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara; Korea Institute of Science and Technology Information*

[4] *T*

[5] *INFN Ferrara*

[6] *ASI*

[7] *Brown University*

[8] *Università degli Studi dell'Insubri*

[9] *ASI & INFN-PG*

Corresponding Authors: sytov@fe.infn.it, aselmi@studenti.uninsubria.it, sara.cutini@pg.infn.it, monti.guarnieri.p@gmail.com, mattia.soldani@lnf.infn.it, bandiera@fe.infn.it, nicola.canale@fe.infn.it, elisabetta.cavazzuti@asi.it, mazzolari@fe.infn.it, erik.vallazza@mib.infn.it, romagnoni@fe.infn.it, valerio.vagelli@asi.it, riccardo.negrello@unife.it, francesco.longo@ts.infn.it, scarsi@studenti.uninsubria.it, michela.prest@ts.infn.it, luigi.costamante@asi.it, gianfranco.paterno@fe.infn.it

Aligning a beam of electrons/photons with the crystallographic axes or planes of a crystal within a some mrad enhances the probability of bremsstrahlung/pair production. This reduces the radiation length, X0, and consequently the electromagnetic shower extent, as recently demonstrated by our team for tungsten [1] and high-Z scintillator (PWO) crystals [2].
We present the possibility of exploiting the X0 reduction for a satellite-based gamma module composed of a converter/tracker and calorimeter system entirely made of oriented crystals.
In case of a pointing strategy, the increased pair production cross-section would improve the detector sensitivity; one might consider reducing the total converter-tracker length. Furthermore, we experimentally demonstrated that the shower enhancement in PWO scintillator crystals is maximal in the direction of gamma rays within about a mrad (0.06°) with the crystallographic axis, thereby increasing the signal-to-background discrimination in such a small angular size. A detector with good angular resolution and enhanced sensitivity in the source direction would be highly advantageous for measuring unidentified gamma-ray sources or investigating the gamma excess in GC for indirect dark matter (DM) searches.
At the same time, the e.m. showers initiated by gamma rays with energies from a few GeV to hundreds of GeV - multi-TeV would be contained in a much smaller volume in a calorimeter composed of oriented crystal scintillators compared to standard detectors [3,4]. Since minimizing the size and

weight of onboard detectors is crucial for space missions, a gamma-ray satellite based on the presented technology should lead to a substantial reduction in mission cost. This advantage can be readily adapted in future missions to:
- Increase the detector transverse size to capture more photons.
- Realize lighter detectors, enhancing the space mission feasibility and/or that can rotate fast enough to measure HE/VHE transient/multi-messenger signals.

In general, oriented crystals add new features and sensitivities for measuring particles inside of the crystallographic axis acceptance, while large-angle showers feature equal developments as in not-oriented standard detectors. A compact satellite based on oriented crystals will open unprecedented opportunities in several astrophysics frontiers, currently unexplored due to operational technology limitations. It will provide complementary and unique information to that expected in the next era of VHE gamma-ray sky observation with ground-based IACTs like the CTA observatory.
In this contribution we present the scientific opportunities that will be opened by the use of oriented crystal compact calorimeters in gamma-ray and astroparticle space missions, and the test campaign done at CERN PS&SPS that have been conducted to verify and optimize the approach.

[1] M. Soldani et al., Eur. Phys. J. C 83 (2023) 101
[2] L. Bandiera et al., Phys. Rev. Lett. 121 (2018) 021603
[3] L. Bandiera et al., Frontiers in Physics 11(2023) https://doi.org/10.3389/fphy.2023.1254020
[4] L. Bandiera, V. Haurylavets and V. Tikhomirov Nucl. Instrum. Methods Phys. Res. A 936 (2019) p.124-126
ylavets and V. Tikhomirov Nucl. Instrum. Methods Phys. Res. A 936 (2019) p.124-126

Astrophysical Neutrino / 23

Self-experience of BVI Inclusion in astronomy through outreach and research

Author: Enrique Pérez Montero[1]

[1] *Instituto de Astrofísica de Andalucía - CSIC*

Corresponding Author: epm@iaa.es

Giving visibility to BVI (Blind and visually impaired) researchers is fundamental to provide valuable references and encourage young people with a disability to begin a STEM career. In this contribution I describe the objectives, methodologies and activities carried out in the framework of the outreach project "Astroaccesible", aimed at the teaching of astronomy in an inclusive way (i.e. utilizing supplementary resources other than those based on the sense of vision(, leaded by a BVI researcher.
In addition, I will describe my own experience doing research with a visual disability and the main obstacles that can be found but, at same time, the great advantages that the inclusion of a person with different abilities can provide for any research group and centre, forcing the working environment to adapt communication strategies that, at last, clearly enrich the productivity and clarity of all obtained results.

Gamma-Ray and Multi-Messenger Astronomy / 24

Probing a unified model for the origin of UHECRs and neutrinos with X-ray observations

Author: Shigeru Yoshida[1]

Co-author: Kohta Murase [2]

[1] *Chba University*

[2] *The Pennsylvania State University*

Corresponding Author: syoshida@hepburn.s.chiba-u.ac.jp

The generic unification model to account for the observed neutrinos with energies greater than ~ 100 TeV and UHECRs we had constructed can evaluate whether a given astronomical object class is qualified as the common origin of UHECRs and neutrinos. In this talk, we discuss which objects among the known astronomical class meet the criteria for UHECR accelerators in the unified UHE particle emission scheme. We argue that the most plausible candidates are transient objects associated with X-ray emissions in the optically thin environment. We present how the multimessenger observations by X-rays and neutrinos can place significant constraints on the parameters characterizing the UHECR-neutrino common sources such as the cosmic ray loading factor. It nails down the unifed origin or fully rules out the unification scenario. Searches for transient soft X-ray emissions sensitive enough to detect a X-ray object flaring at > 1e45 erg/s within a distance of 400 Mpc will provide a decent test of the low-luminosity GRBs hypothesis as the common UHE particle emission candidates.

Flash Talks-1 / 25

Astrophysical interpretations of the data measured at the Pierre Auger Observatory

Author: Teresa Bister[1]

[1] *Radboud University Nijmegen*

Corresponding Author: teresa.bister@ru.nl

The Pierre Auger Observatory measures several characteristics of ultra-high-energy cosmic rays (UHECRs), in particular the energies, the shower maximum depths of the air-shower profiles, and the arrival directions. Using the energy spectrum and the distributions of shower maximum depth in a combined fit, the parameters of homogeneously distributed UHECR sources can be constrained. We find that the data are well reproduced if two extragalactic populations of sources are considered, one emitting a soft spectrum dominating below the ankle, and one with a very hard spectrum and mixed composition dominating at the highest energies. In the case of very strong extragalactic magnetic fields between the closest sources and Earth, the spectral index of the high-energy population can be much softer and even in agreement with the expectations from shock acceleration. When taking into account also the arrival directions, it is revealed that adding a population of nearby starburst galaxies to the homogeneous background leads to an improvement of the model likelihood on the 4.5 sigma significance level. The energy-dependency of the arrival directions at the highest energies is well described by the modeled contribution from the starburst catalog or by that of the nearby radio galaxy Centaurus A.

Ultra-High Energy Cosmic Rays / 26

Constraints on UHECR sources and extragalactic magnetic fields from directional anisotropies

Authors: Glennys R. Farrar[1]; Teresa Bister[2]

[1] *New York University*

[2] *Radboud University Nijmegen*

Corresponding Authors: teresa.bister@ru.nl, gf25@nyu.edu

A dipole anisotropy in the ultra-high-energy cosmic ray (UHECR) arrival directions, of extragalactic origin, is now firmly established at energies >8 EeV. Furthermore, the UHECR angular power spectrum shows no power at smaller angular scales than the dipole, apart from hints of possible individual hot or warm spots for energy thresholds ≳40 EeV. We model the extragalactic source distribution

following the large-scale structure of the universe and use a fit to the data of the Pierre Auger Observatory to constrain parameters of the source injection. The effects of the Galactic magnetic field are taken into account, and possible variations due to different models are presented. The model gives good agreement with both the direction and magnitude of the measured dipole anisotropy as well as their energy evolutions. We exploit the magnitude of the dipole and the limits on smaller-scale anisotropies to place constraints on two quantities: the extragalactic magnetic field and the number density of UHECR sources or the volumetric event rate if UHECR sources are transient.

Gamma-Ray and Multi-Messenger Astronomy / 27

Status of the prototype Schwarzschild Couder Telescope

Author: Francesco Giordano[1]

[1] *University of Bari and Istituto Nazionale di Fisica Nucleare*

Corresponding Author: francesco.giordano@ba.infn.it

The Schwarzschild Couder Telescope (SCT) is a dual mirror medium-sized telescope proposed for the Cherenkov Telescope Array Observatory (CTAO), the next-generation very-high energy (from about 20 GeV to 300 TeV) gamma-ray observatory. The innovative design of SCT consists of a dual-mirror optics and a high resolution camera with a field of view (FoV) of 8 degrees squared, which will allow exceptional performance in terms of angular resolution and background rejection. A prototype telescope (pSCT) has been installed at the Fred Lawrence Whipple Observatory in Arizona, USA. With a partially instrumented camera of 2.7°, the pSCT has successfully detected the Crab Nebula with a statistical significance of 8.6 standard deviations. Currently, a major upgrade of the focal plane is ongoing, aimed to equip the full camera with 11382 upgraded sensors and electronics, enhancing the telescope field of view from the current 2.7° to the final 8° and allowing for a lower trigger threshold. In this presentation, an overview of the pSCT project and obtained results will be given, together with the camera upgrade status and expected performance.

Flash Talks-1 / 28

“Discovering cosmic rays”: a high school physics teachers’course as a link between education and research

Authors: Alessia Giampaoli[1]; Antonio Iuliano[1]; Attanasio Candela[1]; Carla Aramo[1]; Ilaria Veronesi[2]; Massimiliano De Deo[3]; Nicola D’Ambrosio[1]; Roberta Antolini[1]; Sabine Elisabeth Hemmer[1]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *University of Salerno/Istituto Nazionale di Fisica Nucleare*

[3] *LNGS*

Corresponding Authors: attanasio.candela@lngs.infn.it, carla.aramo@na.infn.it, sabine.hemmer@pd.infn.it, nicola.dambrosio@lngs antonio.iuliano@na.infn.it, roberta.antolini@lngs.infn.it, massimiliano.dedeo@lngs.infn.it, ilaria.veronesi@na.infn.it, alessia.giampaoli@lngs.infn.it

This contribution describes the course “Discovering cosmic rays” for in-service high school physics teachers, organized in the context of the Italian Plan for Resilience and Recovery (PNRR) “CTA+”program.

Proposed as part of the OCRA (Outreach Cosmic Ray Activities) activity, the 3-day course was held at Laboratori Nazionali del Gran Sasso (LNGS) of the National Institute of Nuclear Physics (INFN) in Italy in December 2023. After introductory lessons to the physics and detection techniques of cosmic rays, the teachers built a compact and effective muon telescope in the laboratory, the Cosmic Ray Cube (CRC), designed by LNGS-INFN.

After a lesson on data analysis and measurement of atmospheric muon flux, the teachers developed original educational pathways, creating a concrete output ready to be implemented in the classroom. The feedback and analysis results from their classes will be the input for a future session of the course.

Flash Talks-2 / 29

Annual quasiperiodicity in muon rate observed by PolarquEEEst detectors at 79°N

Author: Ombretta Pinazza[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Authors: ripoli@sa.infn.it, ombretta.pinazza@bo.infn.it

Since 2019, three scintillator-based cosmic ray telescopes, readout by SiPM and controlled by low-cost electronics, are installed in the scientific research site in Ny Ålesund (Svalbard) at 79°N, recording muons from secondary cosmic rays. The detectors are part of the EEE project, involving almost 100 secondary schools in Italy.
After collecting nearly 5 years of data, we were able to analyze the muon rate time series and observe an evident oscillating component with a period of about one year. Applying spectral techniques and sinusoidal fit optimization (Lomb-Scargle periodogram) we could quantify the annual component and verify its independence from environmental and experimental factors.
Finally, we compared the observed periodicity with open data provided by other muon experiments and by neutron counters from the NMDB network.

Astrophysical Neutrino / 30

Search for Earth skimming ultra-high-energy neutrinos from space

Author: Roberto Aloisio[1]

[1] *GSSI and INFN-LNGS*

Corresponding Author: roberto.aloisio@gssi.it

The detection capabilities of Cherenkov telescopes for observing signals generated by upward-moving extensive air showers (EASs), caused by earth-skimming neutrinos and high-energy cosmic rays, will be examined. We will delve into two detection frameworks: sub-orbital instruments (such as balloon-borne) and low Earth orbit satellites, with a particular emphasis on the Terzina instrument aboard the NUSES satellite. Additionally, we will provide an overview of the broader perspectives of this detection technique, including its potential with future large-area instruments.

Gravitational Waves / 31

The Einstein Telescope, the next generation detector for gravitational-wave observation

Author: Domenico D'Urso[1]

[1] *University of Sassari and INFN*

Corresponding Author: domenico.durso@infn.it

The detection of Gravitational Waves (GWs) opened a new window on the Universe. The combined observation of GW and electromagnetic signals from astrophysical phenomena in 2017 signed the beginning of the Multi-messenger Astronomy.
While LIGO-Virgo-KAGRA Collaborations keep on detect GWs, a new generation of GW observatories is under preparation and will take over in the next decade, allowing to probe almost the entire Universe. The Einstein Telescope (ET) is the European project for the future GW detection.
An overview of the scientific objectives, the status of detector design, its technological challenges and the expected implications to the Gravitational Wave Astronomy progress will be presented.

Flash Talks-1 / **32**

20 years of Arrival Direction Studies at the Pierre Auger Observatory

Author: Maximilian Stadelmaier[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: maximilian.stadelmaier@mi.infn.it

The Pierre Auger Observatory is the largest detector for ultrahigh-energy astroparticles in the world. Located in the Argentinean pampa, it observes cosmic rays from approximately 80% of the sky, including the Galactic Center. The Observatory is sensitive to cosmic rays at energies of approximately 10 PeV up to 100 EeV, and has made significant discoveries in cosmic-ray research; for example, the discovery of a modulation in right ascension above 8 EeV with a current significance of 6.9 σ confidence level, suggesting an extragalactic origin of ultrahigh-energy cosmic rays. Furthermore, searches for localized and intermediate-scale excesses are ongoing.
We present latest results of searches for anisotropy in the Auger data, and we outline future prospects utilizing novel analysis methods and Phase2 of the Observatory.

Flash Talks-1 / **33**

Energy spectrum and mass composition of cosmic rays from Phase I data measured using the Pierre Auger Observatory

Author: Vladimir Novotny[1]

[1] *IPNP, Charles University*

Corresponding Author: novotnyv@ipnp.mff.cuni.cz

The Pierre Auger Observatory concluded its first phase of data taking after seventeen years of operation. The dataset collected by its surface and fluorescence detectors (FD and SD) provides us with the most precise estimates of the energy spectrum and mass composition of ultra-high-energy cosmic rays yet available. We present measurements of the depths of the shower maximum, the main quantity used to derive species of primary particles, determined either from the direct observation of longitudinal profiles of showers by the FD, or indirectly through the analysis of signals in the SD stations. The energy spectrum of primaries is also determined from both FD and SD measurements, where the former exhibits lower systematic uncertainty in the energy determination while the later exploits unprecedentedly large exposure. The data for primaries with energy below 1 EeV are also available thanks to the high-elevation Auger telescopes of FD and the denser array of SD, making measurements possible down to 6 PeV and 60 PeV, respectively.

Ultra-High Energy Cosmic Rays / 34

Outlook for future Ultra-High-Energy Cosmic Ray experiments.

Author: Shunsuke Sakurai[None]

Corresponding Author: ssakurai2023@gmail.com

Twenty years have passed since the first measurements from the Pierre Auger Observatory (Auger) and the Telescope Array experiment (TA) began to reveal the origin of ultra-high-energy cosmic rays (UHECRs). However, definite conclusions are yet to be made, with tensions between the spectra, mass composition and anisotropy of the two experiments raising additional questions. In this talk, I review the experimental details and prospects of AugerPrime and TAx4, upgraded versions of Auger and TA respectively, which hope to unravel the source of these differences in the coming years. Furthermore, I summarize the scientific objectives and current status of next-generation UHECR projects (GCOS, GRAND, JEM-EUSO/POEMMA) intended to be deployed over the next few decades with unprecedented detection areas.

Gravitational Waves / 35

The LISA orbiting gravitational wave observatory

Author: William Joseph Weber[1]

[1] *Università di Trento / TIFPA (INFN)*

Corresponding Author: williamjoseph.weber@unitn.it

In January 2025, the European Space Agency (ESA) adopted the Laser Interferometry Space Antenna (LISA) to be implemented as the second "Large Mission" of the Cosmic Vision program, with a target launch date of 2035. LISA aims to create an orbiting observatory for gravitational waves, opening the astrophysically rich band from 0.1 mHz to 1 Hz. It will use laser interferometry to measure the gravitational tidal deformation on a constellation of geodesic reference test masses, which are free-falling inside three drag-free satellites at the corners of an orbiting triangular configuration with sidelength 2.5 million km. LISA promises high resolution observation of sources ranging from solar mass binaries in our galaxy out to supermassive black hole mergers at cosmological distances. In this talk we present the scientific potential for a mHz observatory and discuss the status of the mission, particularly regarding the two main measurement science challenges: pm-level interspacecraft interferometry and sub-femto-g free-falling test masses.

Flash Talks-1 / 36

Photo-hadronic pair creation in magnetospheric current sheets of accreting black holes

Authors: Despina Karavola[1]; Maria Petropoulou Petropoulou[2]

[1] *PhD Candidate at University of Athens*

[2] *National and Kapodistrian University of Athens*

Corresponding Authors: dkaravola@phys.uoa.gr, maroulaaki@gmail.com

A ubiquitous feature of accreting black hole systems is their hard X-ray emission which is thought to be produced through Comptonization of soft photons by electrons and positrons (pairs) in the vicinity of the black hole. The origin and composition of this hot plasma source, known as the corona, is

a matter open for debate.
In this contribution we investigate the role of relativistic protons accelerated in black-hole magnetospheric current sheets in the pair enrichment of AGN coronae.
We find cases where photohadronic interactions between protons and photons in the magnetospheric region can produce enough secondary pairs to create coronae with Thomson optical depths, $\tau \sim 0.10 - 10$. More importantly we find a significant dependence of the secondary pair density on the Eddington ratio, defined here as the ratio of the intrinsic X-ray luminosity to the Eddington luminosity of the source: systems with the same Eddington ratio are found to behave in similar ways.
We also present the predicted high-energy neutrino spectrum and discuss our results in light of the recent IceCube observations of TeV neutrinos from NGC 1068. We finally discuss the implications of our model for coronae of stellar-mass black hole systems.

Innovative Detectors and Data Handling Techniques / 37

The Spoke 2 of the ICSC National Centre, with a focus on deep learning applications in astroparticle physics and satellite imagery

Author: Gioacchino Alex Anastasi[1]

[1] *Università di Catania & INFN Catania*

Corresponding Author: gialex.anastasi@dfa.unict.it

The National Research Centre (CN) for High Performance Computing, Big Data and Quantum Computing, managed by the ICSC Foundation, has been founded under the National Recovery and Resilience Plan as part of the Education and Research Mission. The CN includes an Infrastructure Spoke (Spoke 0) plus 10 thematic Spokes and, besides building a world-class supercomputing cloud infrastructure, its purpose is to carry out research in computing and high-performance data analysis, identified as strategic areas for any future scientific and technological development. In particular the Spoke 2, dedicated to "Fundamental Research & Space Economy", addresses the challenges of increasing computational needs in the field of theoretical and experimental collider physics, astroparticle physics and gravitational waves investigation. In this contribution, after a short overview of the CN and of the planned infrastructure, the status and perspectives of the Spoke 2 are presented. Furthermore, two use-cases are illustrated: i) data-driven identification of signals in different experimental apparatuses (in particular a Liquid Argon TPC and a ground array of water-Cherenkov detectors) using autoencoders, i.e. self-supervised neural networks; ii) analysis of satellite imagery for the segmentation of wildfire-affected areas, employing supervised deep learning techniques on the data from the Copernicus Sentinel-2 mission and the Copernicus Emergency Management Service.

Gamma-Ray and Multi-Messenger Astronomy / 38

The Virtual Observatory in the age of multimessenger Astroparticle Physics

Author: Claudio Galelli[1]

Co-authors: Bruno Khélifi [2]; Catherine Boisson [1]; Mathieu Servillat [1]

[1] *LUTH - Observatoire de Paris*

[2] *APC - Université Paris Cité*

Corresponding Author: claudio.galelli@obspm.fr

The International Virtual Observatory Alliance (IVOA) plays a pivotal role in advancing the FAIR principles within the domain of astrophysics, ensuring that scientific data is Findable, Accessible,

Interoperable, and Reusable (FAIR). The IVOA establishes standardized models for data and metadata, and data access protocols. Using Virtual Observatory (VO) compatible tools, it enables seamless retrieval of data from different datasets and catalogs, fostering the connection and interoperability between different observatories, surveys, and research groups. Until recent times the very-high-energy astrophysics and astroparticle physics domains have not been specifically integrated into the IVOA initiatives. However, a growing effort is present in the community to delineate standards and data formats that can adapt the IVOA guidelines to the field's specificities. This effort has begun to pay off with the first integration of high-level data products from H.E.S.S. into the VO environment, and the creation of the common data format for gamma-ray astronomy (GADF), which is currently being reworked into the very-high-energy open data format (VODF), a data and metadata format for gamma-ray and multimessenger astrophysics as much compliant as possible with the future VHE features of the IVOA standards.

Innovative Detectors and Data Handling Techniques / 39

Gammapy: a python package for (not only) gamma-ray astronomy

Author: Claudio Galelli[1]

Co-authors: Bruno Khélifi [2]; Catherine Boisson [1]; Regis Terrier [2]

[1] *LUTH - Observatoire de Paris*

[2] *APC - Université Paris Cité*

Corresponding Author: claudio.galelli@obspm.fr

Gammapy is a community-driven open-source Python package to analyse very high-energy gamma-ray astronomical data. Created in 2014, it has since expanded to support analysis methods in multiwavelength and multimessenger astrophysics. Currently, in version 1.2, Gammapy is utilized by various instruments like HESS, VERITAS, HAWC, and Fermi-LAT, and tested with X-ray and neutrino data, and is the base for the science analysis tools of the Cherenkov Telescope Array. Operating on the common open FITS-based data format GADF, it ensures interoperability between different experiments. The package's analysis pipeline handles data, instrument response functions, and dependencies on time, energy, and sky location. It offers diverse methods for background estimation and data reduction, producing standardized datasets. Gammapy includes spatial, spectral, and temporal models, supporting custom model integration and permitting maximum-likelihood fitting on datasets. Additionally, it provides tools for accessing flux points, likelihood profiles, and light curves, facilitating comprehensive time-domain analyses. Gammapy has de facto become the reference software for VHE gamma-ray analysis, and strives to be integrated in the open science framework with the FAIR4RS guidelines, and will adopt the VODF format in future versions.

Flash Talks-1 / 40

POEMMA-Balloon with Radio: Mission Overview

Author: Julia Burton[1]

[1] *Colorado School of Mines*

Corresponding Author: julia_burton@mines.edu

The Probe of Extreme Multi-Messenger Astronomy (POEMMA) on a super-pressure balloon with radio (PBR) is a planned instrument designed as a successor mission of EUSO-SPB2 and a prototype for a space-based POEMMA mission. The three primary science objectives are to make the first observations of Ultra-High-Energy Cosmic Rays (UHECR) from above using fluorescence light

measurements, to measure high-altitude horizontal air-showers (HAHAs), and to search for Earth-skimming astrophysical neutrinos with PeV energies. To accomplish these goals, PBR will fly three main instruments. The Fluorescence Camera (FC) will measure the fluorescence light emission of UHECR induced air-showers of
$gtrsim$ EeV range energies from above. The Cherenkov Camera (CC) will observe Cherenkov light produced by above-the-limb cosmic rays with energies of ~0.5 PeV and search for Earth-skimming neutrino signatures below the limb. Finally, PBR will fly a Radio Instrument (RI) consisting of two low-frequency sinuous radio antennas to measure radio signatures of HAHAs and Earth-skimming neutrino candidates both in individual trigger mode as well as utilizing the external triggers from the FC and CC.

The FC and CC will be placed on a combined focal surface in a 1.1m diameter aperture Schmidt optics telescope comprised of a 1.9m×2m primary mirror with a radius of curvature of 1.66m. This telescope and the RI will be able to rotate in elevation angle from nadir to $\sim 12^{\circ}$ above horizontal and 360° in azimuth to enable follow-up measurements of transient astrophysical sources of interest using the Target of Opportunity methodology. The predicted sensitivity is expected to achieve instantaneous single source sensitivities similar to or exceeding current ground-based experiments at energies above $\sim$ 10 PeV. PBR will also fly an infrared camera to monitor cloud coverage and a gamma/x-ray particle detector to search for signals from cosmic ray air-showers or other gamma-ray sources. The combination of these instruments makes PBR a unique experiment, which is able to probe the physics of extensive airshowers in ways currently inaccessible to ground-based detectors.

Gamma-Ray and Multi-Messenger Astronomy / 41

TeV detection and insights into the emission regions of two gamma-ray fast-flaring blazars

Authors: Davide Cerasole[1]; Dijana Dominis Prester[2]; Elina Lindfors[3]; Francesco Giordano[1]; Giacomo Bonnoli[4]; Leonardo Di Venere[5]; Lovro Pavletić[6]; Marina Manganaro[None]; Serena Loporchio[5]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Department of Physics, University of Rijeka*

[3] *Tuorla Observatory, University of Turku*

[4] *Università di Siena & INFN Pisa*

[5] *INFN Bari*

[6] *Faculty of Physics, University of Rijeka*

Corresponding Authors: giacomo.bonnoli@unisi.it, davide.cerasole@ba.infn.it, lpavleti@gmail.com, serena.loporchio@ba.infn.it, leonardo.divenere@ba.infn.it, francesco.giordano@ba.infn.it, elilin@utu.fi, marina.manganaro@uniri.hr, dijana@phy.uniri.hr

The gamma-ray blazars B2 1811+31 and GB6 J1058+2817 exhibited strong flaring activity in 2020 and 2021, respectively. These high states were observed by the Large Area Telescope on board the Fermi Gamma-ray Space Telescope in the high-energy gamma-ray band (HE, 100 MeV < E < 100 GeV), triggering observations in the very-high-energy gamma-ray band (VHE, E > 100GeV) with the MAGIC telescopes, in the UV and X-rays with the Swift satellite, and in radio and optical bands with several ground-based telescopes. MAGIC telescopes observations led to the first detection at VHE of both sources. In this contribution, we present the details of these detections and the results of the first-time simultaneous multi-wavelength observational campaigns organized for these sources during the flaring states. Long-term gamma-ray light curves were derived using Fermi-LAT data, and the time periods in which the two sources persisted in a quiescent state identified. Archival data collected in the radio to X-ray wavelengths showed that during their low-state periods, both sources exhibited characteristics of intermediate-synchrotron-peaked BL Lacs, which are rather rare sources in the TeV sky. In HE gamma rays, we identified strong spectral hardening and variability on time scales less than a day that provide valuable insights on the gamma-ray emitting regions during the flare.

Ultra-High Energy Cosmic Rays / 42

Multimessenger studies from above: The EUSO-SPB2 mission and first results

Author: Tobias Heibges[None]

Corresponding Author: theibges@mines.edu

The Extreme Universe Space Observatory on a Super Pressure Balloon 2 (EUSO-SPB2) mission launched from Wanaka NZ on May 13, 2023 and was terminated about 36h later over the Pacific Ocean due to a leak in the balloon. The payload included two main instruments. The Fluorescence Telescope (FT) pointed in nadir to search for the first Ultra-High Energy Cosmic Ray (UHECR) induced extensive airshower (EAS) signatures in fluorescence light from above. First analysis of our flight data does not indicate any observations of UHECRs. The Cherenkov Telescope (CT) looked for Cherenkov light signatures from EAS. These EAS can be induced by above the limb Cosmic Rays (CRs) as well as PeV-scale Earth-Skimming neutrinos. By using the Earth as a tau-neutrino to tau-lepton converter EUSO-SPB2 has sensitivities toward these Earth skimming tau-neutrinos. During a first analysis several above the limb CR candidates have been found, demonstrating the instruments ability to measure Earth-skimming neutrino signatures.
As part of EUSO-SPB2, we planned Target of Opportunity (ToO) observations to follow up on possible neutrino sources by catching parts of the sources'path across the sky in the CT's field of view. Possible neutrino source candidates include gamma ray bursts, tidal disruption events and other steady or flaring sources. During its descent, there was a loss of control over the payload azimuth rotation, interrupting plans for targeted ToO observations. However, some sources crossed the CT' s field of view during the descent of the balloon. These chance-coincident observations allow us to demonstrate the viability of conducting ToO follow-up observations from a near space environment. Despite the short flight of EUSO-SPB2, we can show that our instruments were operational and prepared to do observations of CRs and neutrinos at high energies. The knowledge and experiences gained during the EUSO-SPB2 flight can be utilized in the planned POEMMA Balloon with Radio mission.

Galactic and Solar Cosmic Rays / 43

Cosmic Ray Studies with the High-Altitude Water Cherenkov (HAWC) Observatory

Author: Wayne Springer[1]

[1] *University of Utah*

Corresponding Author: wayne.springer@utah.edu

The High-Altitude Water Cherenkov (HAWC) observatory is a continuously operated, wide field of view detector principally designed to observe astrophysical sources of gamma rays. HAWC can reliably estimate the energy and arrival direction of cosmic and gamma rays arriving from zenith angles of up to 450. As the Earth rotates over one day, HAWC observes a swath of the sky from -260 to 640 in Declination and 0 to 24 hours in Right Ascension, roughly 2/3 of the sky. This nearly all-sky coverage enables the measurement of large-scale as well as small-scale anisotropy in the arrival direction distribution of cosmic rays. The HAWC detector area of approximately 22,000m2 located at an altitude of 4100 m results in significant sensitivity to gamma rays and cosmic rays with energies from several hundred GeV up to several hundred TeV. Precise measurements of the energy spectrum and arrival direction dependence of the cosmic ray flux have been performed using several billion events after selection cuts from a data set including trillions of air shower triggers. The large statistics have enabled measurement of spectra of the light-components, protons plus helium, using analysis techniques guided by CORSIKA simulations. HAWC observations of the emission of gamma-rays in astrophysical objects also provide constraints on the possible sources of galactic cosmic rays. This presentation will review the techniques and results of these cosmic ray measurements performed by HAWC.

Galactic and Solar Cosmic Rays / 44

Indirect search for dark matter with cosmic-ray antinuclei: the GAPS experiment

Author: Alessio Tiberio[1]

Co-author: GAPS Collaboration

[1] *INFN*

Corresponding Author: alessio.tiberio@fi.infn.it

The General Antiparticle Spectrometer (GAPS) is a balloon-borne experiment designed to perform low-energy cosmic-ray antinuclei measurements searching for indirect signatures of dark matter annihilation or decay. A wide range of well-motivated dark matter models predicts antinuclei fluxes about two orders of magnitude above the expected astrophysical background below 250 MeV/n. The coverage of this unexplored low-energy region allows GAPS to achieve an unprecedented sensitivity for antideuteron and antihelium nuclei fluxes. GAPS will collect extensive statistics of low-energy antiprotons, extending the measurement of the antiproton spectrum to the unexplored region below 100 MeV. The GAPS experiment will perform three long-duration balloon flights over Antarctica, the first of which is planned for the 2024/2025 Austral summer. The experimental apparatus consists of a Si(Li) tracker surrounded by a time-of-flight system made of plastic scintillator paddles. GAPS uses a novel identification technique based on the formation of an exotic atom and its de-excitation and decay. This contribution will first illustrate the scientific potential of the GAPS experiment and its impact on indirect dark matter searches. It will then describe the experimental apparatus and the detection technique exploited to identify antinuclei events. The expected sensitivity for antinuclei, based on detailed instrument simulations, will be then discussed. Finally, the payload integration and the results of the system's ground tests will be summarized.

Gravitational Waves / 45

Gravitational wave observations with LIGO, Virgo and KAGRA: status and prospects

Author: Barbara Patricelli[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: barbara.patricelli@pi.infn.it

Starting with the first detection of gravitational waves (GWs) in September 2015, a total of 90 compact binary coalescences have been identified during the first three observing runs of the LIGO-Virgo-KAGRA (LVK) collaboration, including mergers between black holes (BHs), neutron stars (NSs) and mixed NS-BHs. These GW observations allowed us to infer some properties of the NS and BH populations, such as the mass distributions and the merger rates, and to better understand the astrophysics of binary mergers and the origin of these systems.
On May 2023 the fourth LVK observing run has started and it will continue until the beginning of 2025: dozens of GW candidates are being found with online analysis, and these observations will be key to further expand our comprehension of the population of merging binary compact objects.
This talk will give an overview of the GW detections so far, their astrophysical implications and the prospects for the upcoming years.

Flash Talks-2 / 47

Anti-deuteron identification in cosmic rays with an Helium Calorimeter

Author: Francesco Nozzoli[1]

Co-authors: Gregorio Giovanazzi [1]; Irina Rashevskaya [1]; Leonardo Ricci [2]; Francesco Rossi [1]; Pietro Fedele Spinnato [1]; Enrico Verroi [3]; Paolo Zuccon [4]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Universita degli Studi di Trento*

[3] *INFN-TIFPA*

[4] *TIFPA*

Corresponding Authors: leonardo.ricci@unitn.it, francesco.nozzoli@tifpa.infn.it, paolo.zuccon@unitn.it, enrico.verroi@tifpa.infn.it, piero.spinnato@tifpa.infn.it, irina.rashevskaya@tifpa.infn.it, gregorio.giovanazzi@unitn.it, francesco.rossi-9@unitn.it

The possible presence of low energy anti-deuterons in cosmic rays is a golden channel to test the antimatter asymmetry in the Universe or to identify annihilating Dark Matter particles in the galactic halo.
The "PHeSCAMI"(Pressurized Helium Scintillating Calorimeter for AntiMatter Identification) project is aiming to study a new signature for the identification of anti-deuteron and anti-protons in cosmic rays.
In particular, when a Z=-1 relatively heavy particle is stopping in the detector, it can produce an exotic atom and for the particular case of the helium target, the captured antiparticle can orbit the helium nucleus for microseconds before the annihilation.
This characteristic "double-event"due to the delayed annihilation is a very distinctive signature able to identify the antimatter nature of the stopping particle and rejecting the large fraction of the ordinary matter particles in cosmic rays.
Thus a possible experiment searching for anti-deuterons in cosmic rays onboard a circumpolar balloon based on the "PHeSCAMI"signature would use pressurized helium scintillating calorimeters surrounded by plastic scintillator layers for the particle velocity measurement.
Anti-deuterons are identified by combining the spectrometric measurement of the mass of the stopping particle (velocity vs energy) with the number of delayed outgoing tracks due to charged pions emitted by the antiparticle annihilation.
A preliminary 1L stainless steel prototype of the pressurized calorimeter, filled by 200 Bar Helium acting as a scintillator, has been characterized with cosmic muons and with 70-240 MeV proton beam in the INFN-TIFPA laboratory. An energy resolution better than 10% and a time resolution better than 300ps has been achieved for this scintillating helium calorimeter.
The development and test of an advanced, calorimeter prototype, based on an automotive COPV (composite overwrapped pressure vessel) is ongoing in the INFN-TIFPA laboratory. This allows to store 40L of Helium with a pressure of 200 Bar by keeping the wall grammage within 1.5g/cm^2, permitting the detection of anti-deuterons in the 50-150MeV/n energy window.
The sensitivity of a possible detector based on the "PHeSCAMI"signature will be summarized and the results of the measured performance of Helium calorimeter prototypes will be shown.

Galactic and Solar Cosmic Rays / 48

Recent outreach activities of the EEE project

Corresponding Author: ripoli@sa.infn.it

The Extreme Energy Events project is an educational and scientific initiative lead by the Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi (CREF) and the Istituto Nazionale di Fisica Nucleare (INFN), two research institutes under the control of the Italian Ministero dell'Universita'e Ricerca (MUR). The EEE project studies cosmic rays by means of a series of detectors (60) located inside Italian high schools or INFN/University laboratories. The detectors have been build and are operated with the strong cooperation of the students and teachers. Data from the different EEE detectors are centrally collected, reconstructed, and analyzed for scientific publications. However, they are also distributed to the students, who actively participate in the study of the properties of the muon flux and present their work at general meetings organized monthly both online or in presence. It is important to underline that the project involves the student during an entire year (and sometimes even more) allowing a continuous interaction with the researchers involved. A description of the several outreach activities and of the impact on the students' learning curve will

be provided, together with a few examples of activities that lead to a publication with the signature of the students.

Flash Talks-1 / 49

Search for point sources with KM3NeT/ARCA and ANTARES neutrino telescopes

Authors: Aart Heijboer[1]; BARBARA CAIFFI[2]; Giulia Illuminati[2]; Julien Aublin[3]; Matteo Sanguineti[2]; Rasa Simone Muller[2]; Sandra Zavatarelli[2]; Sergio Alves Garre[4]; Thijs van Eeden[1]; Vittorio Parisi[2]; Vladimir Kulikovskiy[2]

[1] *Nikhef*

[2] *Istituto Nazionale di Fisica Nucleare*

[3] *Université Paris Cité, CNRS, Astroparticule et Cosmologie*

[4] *Instituto de Física Corpuscular (CSIC-UV)*

Corresponding Authors: muller@bo.infn.it, sandra.zavatarelli@ge.infn.it, giulia.illuminati3@unibo.it, barbara.caiffi@ge.infn.it, salves@ific.uv.es, julien.aublin@apc.in2p3.fr, vittorio.parisi@ge.infn.it, t.juan.van.eeden@nikhef.nl, vladimir.kulikovskiy@ge.infn.it, aart.heijboer@nikhef.nl, matteo.sanguineti@ge.infn.it

In recent years, the adoption of a multi-messenger methodology within astrophysics has emerged as an innovative approach for enhancing our comprehension of the high energy Universe. Neutrino telescopes are crucial for highlighting hadronic component of these phenomena, testing known sources of gamma rays.
In this contribution, we present the combined analyses of the data collected by two neutrino telescopes located in the depths of the Mediterranean Sea. The ANTARES detector, operational for over 15 years off the coast of Toulon (France), and KM3NeT/ARCA, one of the two detectors constituting the next-generation neutrino telescope KM3NeT, optimized for astrophysical neutrinos exceeding 1 TeV in energy and presently collecting data while being under construction near Portopalo di Capo Passero (Italy). A list of approximately one hundred point-like and extended sources is subjected to scrutiny for neutrino emissions. This catalogue encompasses bright γ-ray emitters, galactic γ-ray sources displaying indications of a hadronic presence (TeVCat catalogue), such extragalactic sources as radio-loud AGNs and the most significant candidate sources studied by IceCube.

Gamma-Ray and Multi-Messenger Astronomy / 50

Multimessenger astrophysics at the Pierre Auger Observatory

Author: Antonella Castellina[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: antonella.castellina@to.infn.it

The complementary information carried by photons, gravitational waves, neutrinos and cosmic rays about individual cosmic sources and source populations provides a very powerful tool for studying the properties of the Universe. In the extreme energy regime, above 10^{17} eV, the Pierre Auger Observatory plays a central role in multimessenger astronomy, thanks to its ability to distinguish extensive showers generated by ultra-high energy photons and neutrinos from those of hadronic origin. The search for diffuse fluxes or point-like sources of neutrinos and photons allows us to study different candidate sources and to set limits to the emission of these neutral messengers by mergers producing gravitational waves. Neutrinos and photons also allow us to test the existence of possible effects beyond the Standard Model of particles, such as the decay of super-heavy dark matter, or the violation of Lorentz invariance.

An overview of the multimessenger activities carried out by the Pierre Auger Collaboration is provided, and the improvements that can be achieved with the upgrade of the Pierre Auger Observatory, AugerPrime, are discussed.

Gravitational Waves / 51

An online follow-up system for gravitational waves in Super-Kamiokande

Author: Aurora Langella[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: aurora.langella@na.infn.it

Super-Kamiokande is a 50-kton Cherenkov water detector currently operating in Japan, primarily aimed at the study and detection of neutrinos. Many efforts are being made to detect neutrinos from astrophysical origin, especially in the context of multi-messenger astronomy. In this contribution, the development of an online follow-up system for gravitational waves detected during the current LIGO/Virgo/KAGRA O4 Run will be described. This system allows to do a realtime search of neutrino signals in temporal coincidence with gravitational waves events in an energy range that goes from few MeVs to hundreds of GeV.

Ultra-High Energy Cosmic Rays / 52

Auger Open Data and Pierre Auger Observatory International Masterclasses

Author: Eva Santos[1]

[1] *FZU - Institute of Physics of the Czech Academy of Sciences*

Corresponding Author: esantos@fzu.cz

The Pierre Auger Observatory has a public data policy following the FAIR principles (Findable, Accessible, Interoperable, and Reusable). We aim to share the data with the scientific community as part of the multi-messenger effort at different levels and for educational activities to engage the general public. Following the first portal created in 2007, a new portal hosted at https://opendata.auger.org was established in February 2021. The portal is regularly updated and comprises 10% of the recorded cosmic ray data organized in various datasets, each with a specific DOI provided by Zenodo. Moreover, a catalog with the 100 most energetic events is available. The portal adopts a "dual" concept, offering not only the download of public data but also a series of Jupyter notebooks. These notebooks allow the general public to reproduce some of the most important results obtained by the Pierre Auger Collaboration and understand the main mechanisms governing the development of the extensive air showers produced by the interaction of cosmic rays in the Earth's atmosphere.
In 2023, the Pierre Auger Observatory joined the International Particle Physics Outreach Group (IPPOG). The successful debut enrolled 550 high-school students at 12 research institutions from 5 countries and was repeated this year, embracing yet more students and countries worldwide. During this day, the participants attend seminars about cosmic rays and are asked to reconstruct subsets of public data events using an Auger 3-D event display. Finally, they participate in a Zoom session with scientists at the Auger site.

Ultra-High Energy Cosmic Rays / 53

Hadronic and Shower Physics with the Pierre Auger Observatory

Author: Lorenzo Cazon[1]

[1] *IGFAE - USC*

Corresponding Author: lorenzo.cazon@usc.es

Extensive air showers initiated by ultra-high-energy cosmic rays are a unique opportunity to probe hadronic interactions in energy and phase-space regions out of the reach of man-made accelerators. The Pierre Auger Observatory, now entering its Phase II with the AugerPrime upgrade, is a multi-hybrid detector capable of extracting numerous shower observables. These observables directly probe the air shower dynamics and hadronic interactions therein, as well as test the most up-to-date models describing high-energy hadronic interactions.
In this contribution, we will review the most relevant results from the Observatory.

Ultra-High Energy Cosmic Rays / 54

Velocity decorrelation functions of high-energy cosmic rays propagating in magnetic fields

Author: Olivier Deligny[1]

[1] *CNRS/IN2P3 - IPN Orsay*

Corresponding Author: deligny@ipno.in2p3.fr

Diffusion tensor coefficients play a central role in describing cosmic-ray transport in various astrophysical environments permeated with magnetic fields, which are usually modeled as a fluctuating field on top of a mean field. In this article, a formal derivation of these coefficients is presented by means of the calculation of velocity decorrelation functions of particles. It relies mainly on expanding the 2-pt correlation function of the (fluctuating) magnetic field experienced by the particles between two successive times in the form of an infinite Dyson series and retaining a class of terms that converge to a physical solution. Subsequently, the velocity decorrelation functions, themselves expressed as Dyson series, are deduced from an iteration procedure that improves on the partial summation scheme. The results are shown to provide approximate solutions compared to those obtained by Monte-Carlo simulations as long as the Larmor radius of the particles is larger than at least one tenth of the largest scale of the turbulence.

55

Exploring cosmic rays with educational outreach activities: a long-term study of the correlation between atmospheric conditions and muon counts

Authors: Davide Miceli[1]; Elena Panciera[2]; Elisa Prandini[3]; Iolanda Masiero[2]; Jacopo Cavaleri[2]; Linda Pullara[2]; Michele Doro[1]; Viola Di Toro[None]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Liceo Scientifico Statale Ugo Morin*

[3] *University of Padova and INFN*

Corresponding Authors: viola.ditoro@gmail.com, davide.miceli@pd.infn.it, elisa.prandini@pd.infn.it, michele.doro@pd.infn.it

The Earth atmosphere is constantly reached by cosmic rays, energetic and subatomic particles coming from all directions. A muon telescope is hosted in the Legnaro National Laboratories (LNL) of the Italian Istituto Nazionale di Fisica Nucleare (INFN). This instrument is used to introduce the students to research activities in the field of particle physics. In particular, during the International Cosmic Day (ICD) and in following Pathways for Transversal Competences and Orientation (PCTO) activities, students can do measurements and data analysis of the muon flux reaching the Earth's surface. It is indeed well known that this flux is affected by the atmospheric condition where the measurement is done. In this contribution, we present the long-term investigation performed with high school and bachelor students in Physics at the University of Padova, of the anticorrelation between muon counts and atmospheric pressure as measured with the muon telescope in LNL using the data collected from 2022 to 2024. The results from our analysis confirm the stability of this anticorrelation during the data taking. Further analyses allow us to investigate also the time variation of these correlations in different months, indicating a possible effect due to summer and winter conditions. Currently we are investigating also the impact of other atmospheric-related correlations, such as temperature and humidity.

Flash Talks-1 / **56**

Machine learning applications at the Pierre Auger Observatory

Author: Margita Kubátová[1]

[1] *FZU - Institute of Physics of the Czech Academy of Sciences*

Corresponding Author: majercakova@fzu.cz

The Pierre Auger Observatory is the largest currently running detector, that studies the extensive air showers of ultra-high energy cosmic rays. In this contribution, we provide an overview of three machine-learning techniques used to improve the understanding of data measured by the surface detector of the Observatory. All of these methods use the spatial and temporal information contained in the shower footprint that is measured by the surface detector stations.

The first of these methods demonstrates the application of deep learning and large simulation datasets to reconstruct the energy of the impinging cosmic ray. This approach has the potential to reduce a composition bias when compared to the techniques that rely on fitting the lateral signal distribution. One of the primary objectives of the Observatory is to understand the evolution of mass composition with energy. We can achieve this using observables such as the depth of the shower maximum and the number of muons in the shower. In the second study, Long Short-Term Memory and convolutional neural networks are employed to determine the depth of the shower maximum. Furthermore, the neural networks allow for the examination of its development of the mean and standard deviation as a function of energy.

The third work focuses on estimating the depth of the shower maximum and the number of muons in the air shower using signals from the upgraded stations of the surface detector. Transformer networks are used for this purpose. Using simulated data, the study demonstrates the promising potential for an accurate reconstruction of the primary mass by combining the measurements of shower maximum and muon number.

Innovative Detectors and Data Handling Techniques / **57**

The Detector Design of the Southern Wide-Field Gamma-Ray Observatory

Author: Wayne Springer[1]

[1] *University of Utah*

Corresponding Author: wayne.springer@utah.edu

The Southern Wide-Field Gamma-Ray Observatory (SWGO) observatory will use water Cherenkov detector (WCD) technology to construct a large-area, high-altitude observatory to measure the energy and arrival direction of gamma and cosmic rays. The proposed observatory will have a sensitive area of approximately 0.3 km2 with possible extensions to 1 km2 and be located at a high altitude (>4400m) between 10-degrees and 30-degrees south latitude. The high altitude of the observatory facilitates the detection and measurement of gamma and cosmic rays by placing the detector well into their extensive air shower (EAS) for energies down to several hundred GeV. The large detector area provides significant sensitivity to energies into the PeV range. The location in the southern hemisphere offers a view of sources in the southern sky, including the Galactic Center. WCDs can be operated during daylight, continuously monitoring the overhead sky, enabling coverage of a large fraction of the sky. The detector design also seeks to optimize gamma-hadron discrimination to distinguish the gamma-ray-induced EAS from those induced by the far more numerous cosmic rays. The reference design utilizes double-chamber WCD detector units. The larger volume of the WCD's upper compartment provides calorimetry and timing information for the electromagnetic component of the EAS. The lower compartment will be used for muon tagging to aid in the rejection of muon-rich hadronic showers. The array layout of the individual WCDs is optimized to provide the best performance at the lowest cost. Excellent sensitivity and gamma-hadron separation over a wide range of energies with good angular resolution will be achieved by varying detector unit spacing, with a dense inner core and an outer region populated at a lower density. This presentation will describe the research and development program for mechanical design, photosensors, readout electronics, and data-acquisition systems to produce the optimal detector for SWGO.

Galactic and Solar Cosmic Rays / 58

Scaler data from the Pierre Auger Observatory and solar activity

Author: carla taricco[1]

[1] *Department of Physics, University of Torino, Italy*

Corresponding Author: carla.taricco@unito.it

The modulation of low-energy cosmic rays reflects interplanetary magnetic field variations and can provide information on solar activity in the past. The secondary particles, which originate from the interaction of cosmic rays with the atmosphere, can be revealed by an array of ground detectors. In this study, we present the investigation of the low-threshold rate (scaler) time series recorded in 16 years of operation by the surface detectors of the Pierre Auger Observatory in Malargüe (Argentina). Using advanced spectral methods we extracted the significant variations from the series with periods ranging from the decadal to the daily scale. In order to investigate the possible solar origin of the detected modulations, besides the number and surface area of sunspots, we considered the absolute value and the radial component of the heliospheric magnetic field, along with the coronal magnetic field.

Gravitational Waves / 59

Gravitational waves. Detector concepts and future perspective.

Author: Ettore Majorana[1]

[1] *Università di Roma Sapienza*

Corresponding Author: ettore.majorana@roma1.infn.it

Although based upon a well established theory, gravitational wave detection was seen as an exotic research. Nowadays, observational astrophysics is strongly dependent on the technology advancements meant to further improve the sensitivity of present detectors.
The path that drove to the present scenario and the overall perspective
about the main features of the various detectors, including the most
demanding challenges, will be presented.

Innovative Detectors and Data Handling Techniques / 61

GINGER Status report

Author: Angela Dora Vittoria Di Virgilio[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: angela.divirgilio@pi.infn.it

Angela D.V. Di Virgilio for the GINGER collaboration

Measurements of the Earth's rotation speed made with laser gyroscopes, otherwise known as ring lasers, certainly important for the Earth sciences, are also relevant for fundamental physics tests, as they contain terms of general relativity, such as de Sitter and Lense Thirring and provide unique data to investigate Lorentz's violations. Ring lasers ensure long-term continuous operation with record sensitivity. The limit to be reached for studying the fundamental physics of 1 part in 109 of the Earth's rotation speed has already been demonstrated by existing prototypes.
The GINGER project is based on ring lasers, its status will be described.

Ultra-High Energy Cosmic Rays / 62

UHECR measurements and physics at man-made accelerators: mutual constraints

Author: Maria Vittoria Garzelli[None]

Corresponding Author: maria.vittoria.garzelli@mi.infn.it

Measurements of the products of UHECR interactions with the Earth's atmosphere, as obtained in Extended Air Shower Experiments and at Very Large Volume Neutrino Telescopes, offer important information concerning hadronic interactions,
which for some aspects overlaps and for many others complements the information extracted by measurements of collisions at man-made accelerators. In this contribution I discuss some of the constraints that the UHE astroparticle and accelerator fields exercise one over each other, emphasizing the importance of further new measurements, through new experiments or observations, in both fields.

Astrophysical Neutrino / 63

Hunting for Ultra-High-Energy Neutrinos with the Pierre Auger Observatory

Author: Emanuele De Vito[1]

Co-author: Pierre Auger Collaboration

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: emanuele.devito@le.infn.it

Ultra-High-Energy Neutrinos are expected to be produced both by point-like sources and by the interaction of Ultra-High-Energy Cosmic Rays (UHECRs) with background photons. The Pierre Auger Observatory has the potential to detect such neutrinos with its Surface Detector (SD) array. Its capability to distinguish between cosmic ray and neutrino-induced showers is particularly high for inclined showers (zenith above 60°) with its maximum sensitivity being reached in the earth-skimming region. In addition, the Fluorescence Detector (FD) can be exploited to search for steeply upward-going showers in a phase space that is not accessible with the SD and in a complementary energy range. In this contribution, we will present upper limits on the neutrino flux derived from the non-observation of neutrino candidates which will be used to set constraints on neutrino production models and on source properties of UHECRs in the EeV range. The upper limit for upward-going shower events derived by the FD will also be presented and discussed in the context of multimessenger astronomy.

Gravitational Waves / 64

PULSAR TIMING ARRAYS AND THE DETECTION OF ULTRA LONG PERIOD GWs

Author: Andrea Possenti[None]

Corresponding Author: andrea.possenti@inaf.it

The rotational stability of a subset of the "recycled"pulsars not only paves the way to high precision tests of the gravity theories, but allows us to use them as components of a galactic scale gravitational wave detector, dubbed Pulsar Timing Array (PTA). That provides the possibility to search for gravitational waves (GWs) in the ultra-long period range, between a few months to few decades, thus complementing the capabilities of other current or future GW detectors. The most recent results from the various PTA experiments are very promising, manifesting the first evidence for a detection, yet to be supported by additional results. The talk will describe the underlying ideas, the status, and the perspectives of these experiments, with a particular attention devoted to the European contribution, emerging from two decades long efforts of the European Pulsar Timing Array (EPTA) team.

Gamma-Ray and Multi-Messenger Astronomy / 65

CTA+: an Italian program to enhance the Southern Cherenkov Telescope Array Observatory

Author: Serena Loporchio[1]

[1] *INFN Bari*

Corresponding Author: serena.loporchio@ba.infn.it

The "CTA+"is a research program proposed by INAF, INFN, and Italian universities, in the context of the Italian Resilience and Recovery Plan (PNRR). The program, led by INAF, is aimed at enhancement of the Southern Cherenkov Telescope Array Observatory (CTAO-S) site to be constructed at Paranal, Chile. The approved and funded program has formally begun on January 1st, 2023, and must be completed no later than December 31st, 2025. The main goal is the construction of two Large Sized Telescopes (LSTs) at the CTAO-S, 5 Small Sized Telescopes (SSTs). In addition, a R&D program is foreseen to improve the technology for a future upgrade of the CTAO southern site. The baseline design of the mechanical structure of the foreseen LSTs will be based on the design of the northern site LSTs, apart from some changes to be compliant with the CTAO-S environmental specifications. In particular, the cameras will be almost identical to those of the northern LSTs. The procurement

and the production of cameras sub-system has already begun though industrial contracts supervised by the CTA+ management, led by University of Siena, Politecnico di Bari and INFN. In this talk the current status and the main objectives of the project will be presented, with focus on the scientific implication and improvement achievable thanks to the CTA+ program.

Gamma-Ray and Multi-Messenger Astronomy / 66

Outreach, Education and Communication of the CTAO

Author: Alba Fernández-Barral[1]

[1] *CTAO*

Corresponding Author: alba.fernandezbarral@cta-observatory.org

The CTAO (Cherenkov Telescope Array Observatory) will be the world's largest ground-based gamma-ray observatory to explore the extreme Universe, which will open to all scientific communities as a resource for data from unique, high-energy astronomical observation. Currently, the Obsevatory is entering a new phase of growth, which is flourishing in 2024 with a significant increase in personnel and the development of key infrastructures to prepare for the construction of telescope arrays.

In this talk, we will present the educational strategy of the CTAO, focusing on the "Astrodiversity Project,"particularly into "Building from Diversity,"a monthly series of articles that features leading figures from underrepresented groups in science (women, LGTBQIA+, people with disabilities, etc.), and contributions to the AMANAR programme, an educational initiative to bring science to children living in refugee camps in Tindouf (Algeria). Additionally, we will discuss the use of environmentally friendly online communication and outreach programmes and tools. Finally, we will present some of the communication strategies carried out for the new phase of the Observatory.

Innovative Detectors and Data Handling Techniques / 67

The Antarctic Demonstrator for the Advanced Particle-astrophysics Telescope (ADAPT)

Author: Leonardo Di Venere[1]

[1] *INFN Bari*

Corresponding Author: leonardo.divenere@ba.infn.it

The Antarctic Demonstrator for the Advanced Particle-astrophysics Telescope (ADAPT) is a suborbital mission designed to detect MeV to GeV gamma rays. The instrument consists of four layers of a scintillating fiber tracker plus an active converter tracker made of CsI scintillating crystals read out by wavelength shifting (WLS) fibers. Both scintillating and WLS fiber signals will be detected with Silicon Photomultipliers (SiPM). Fast and low power front-end electronics are being developed based on the SMART ASIC for SiPM signal amplification before the successive digitization stage. The ADAPT project will serve as technology demonstrator for the larger Advanced Particle-astrophysics Telescope (APT) mission, which will have a much larger area of 3x3 m2. The ADAPT instrument will feature a 30-day balloon flight, with the possibility of detecting prompt signals from Gamma-Ray Bursts (GRBs) with degree-scale localization and polarization constraints. In this contribution, we will present the ADAPT project and its current status, with a particular focus on the FEE electronics development.

Innovative Detectors and Data Handling Techniques / 68

New single photon counting ASIC for muography camera based on SiPMs

Author: Giovanni Contino[1]

Co-authors: Osvaldo catalano [2]; Davide Mollica [3]; Fabio Paolo Lo Gerfo [1]; Giuseppe Sottile [4]; Maria Concetta Maccarone [5]; Giuseppe Leto [6]; Salvatore Garozzo [7]; Davide Marano [7]; Giovanni Pareschi [8]

[1] *INAF IASF Palermo*

[2] *IASF Palermo/INAF*

[3] *INAF*

[4] *INAF IASF PA*

[5] *CT*

[6] *INAF-Osservatorio Astrofisico di Catania*

[7] *INAF OACT*

[8] *INAF - Osservatorio Astronomico di Brera*

Corresponding Authors: salvatore.garozzo@inaf.it, fabio.logerfo@inaf.it, davide.marano@inaf.it, cettina.maccarone@ifc.inaf.it, osvaldo.catalano@inaf.it, giovanni.contino@inaf.it, gle@oact.inaf.it, giuseppe.sottile@inaf.it, giovanni.pareschi@inaf.it, davide.mollica@inaf.it

MUCH (MUography CHerenkov) is a project that aims to carry out non-invasive radiography and tomography of large tectonic and geological structures. This multidisciplinary project is an evolution of the ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) concept and represents an innovative application of modern astronomy technologies, leaded by the Italian National Institute for Astrophysics.
The idea of looking inside the volcano through the Cherenkov light produced by penetrating particles such as muons, namely muography, originated from the presence of the ASTRI-Horn Cherenkov telescope, located in the Fracastoro astrophysical observatory, from where the Etna volcano is visible.
Muons are particles created as a result of the interaction of cosmic rays with the Earth's atmosphere reaching the Earth's surface, losing energy when they go through matter with a reduction in flux that depends on the thickness and density of the material they cross. By measuring the absorption of muons in the massive structure, it is possible to trace the distribution of densities within it, recognizing any internal structures.
The Cherenkov light produced by the muon crossing the target is intercepted by the telescope optics and focused on the focal plane of the camera, where the characteristic Cherenkov ring is formed. The reconstruction of the physical parameters, such as direction of arrival and energy of muon, is simple and is based on the reconstruction of the Cherenkov ring produced on the multipixel SiPM sensors camera. The reconstruction of the Cherenkov ring and the determination of the position on the target allows to measure the density distribution of the interior of the massive structure.
The project presents some aspects of technological innovation; one of the most innovative is the RADIOROC ASIC, a front-end to the SiPM sensors which was designed and manufactured expressly for MUCH by Weeroc microelectronics company. The characteristics of the RADIOROC, capable of operating above 100 MHz in single photon counting, allow the diffuse background of the night sky to be drastically reduced.
In this presentation, we illustrate the advantages deriving from the use of this technique and then move on to the characterization of RADIOROC in the laboratory.

Flash Talks-2 / 69

Calibration procedures for the ASTRI Mini-Array Cherenkov cameras

Author: Davide Mollica[1]

Co-authors: Osvaldo catalano [2]; Giovanni Contino [3]; Milvia Capalbi [1]; Mattia Corpora ; Fabio Paolo Lo Gerfo ; Pierluca Sangiorgi [4]; Giuseppe Sottile [5]; Giuseppe Leto [6]; Teresa Mineo ; Salvatore Scuderi [7]; Giovanni Pareschi [8]

[1] *INAF*

[2] *IASF Palermo/INAF*

[3] *INAF IASF Palermo*

[4] *INAF - IASF Palermo, Via Ugo La Malfa 153, 90146, Palermo, Italy*

[5] *INAF IASF PA*

[6] *INAF-Osservatorio Astrofisico di Catania*

[7] *INAF-IASFMI*

[8] *INAF - Osservatorio Astronomico di Brera*

Corresponding Authors: osvaldo.catalano@inaf.it, fabio.logerfo@inaf.it, sangiorgi@ifc.inaf.it, salvatore.scuderi@inaf.it, mattia.corpora@inaf.it, giovanni.contino@inaf.it, gle@oact.inaf.it, davide.mollica@inaf.it, giuseppe.sottile@inaf.it, milvia.capalbi@inaf.it, giovanni.pareschi@inaf.it, teresa.mineo@inaf.it

The ASTRI Mini-Array is an international project led by the Italian National Institute for Astrophysics (INAF) to deploy an array of nine Imaging Atmospheric Cherenkov Telescopes at the Teide Observatory in Tenerife. The system will study astronomical sources emitting in the very high-energy band above 1 TeV up to 200 TeV. The telescope array is an improved version of the ASTRI-Horn telescope (Mt. Etna, Italy), a 4 m diameter small-sized telescope (SST) prototype, developed by INAF in the initial phase of the ASTRI Project in the CTA context.
The Cherenkov camera for the Mini-Array, based on Silicon Photo-Multiplier (SiPM) detectors, is an evolution of the ASTRI-Horn telescope camera. The camera focal plane is equipped with 2368 SiPM pixels with dimensions of 7mm x 7mm arranged in tiles of 8 x 8 pixels. Each tile together with two CITIROC-1a ASICs and the FPGA board constitutes a Photon Detection Module (PDM). 37 PDMs are arranged to match the spherical focal surface. Camera electronics, based on a peak detection circuit, is designed to perform self-trigger of the whole focal plane in order to detect Cherenkov signal while ensuring a small amount of data transfer.
In this contribution we present the camera calibration strategy and tools developed thanks to the lessons learned with the ASTRI-Horn telescope. These calibration procedures are essential tasks to extract SiPMs calibration coefficients, which are needed for the Cherenkov data analysis, as well as camera configuration parameters, that ensure system stability and a uniform trigger efficiency over the whole focal plane. Moreover, thanks to the internal calibration system, these procedures allow system performance and camera health to be monitored during regular data taking.

Galactic and Solar Cosmic Rays / 70

The HELIX experiment

Author: Nahee Park[None]

Corresponding Author: nahee.park@queensu.ca

Recent discoveries of new features in Galactic cosmic-ray fluxes emphasize the importance of understanding the propagation of cosmic rays in our Galaxy. A better understanding of cosmic ray propagation is also important to study the Galactic diffuse emission of high-energy gamma rays and high-energy neutrinos. HELIX (High Energy Light Isotope eXperiment) is a balloon-borne experiment designed to measure the chemical and isotopic abundances of light cosmic-ray nuclei at energies above 0.1 GeV/n. The detector is optimized to improve the measurements of the propagation clock isotopes Be-10 and stable secondary isotopes Be-9 with a good mass resolution. This data will be essential to study the propagation of the cosmic rays in our Galaxy. The first flight of HELIX is scheduled to be launched from Sweden in the 2024, aiming to collect beryllium isotopes up to 3 GeV/n. I will review the scientific goals of HELIX in light of the multi-messenger era and report its current status and project plans.

Innovative Detectors and Data Handling Techniques / 71

The NUSES space mission

Author: Pierpaolo Savina[None]

Corresponding Author: pierpaolo.savina@gssi.it

The NUSES space mission is a novel project designed to explore cosmic and gamma rays, high-energy astrophysical neutrinos, the Sun-Earth environment, space weather and magnetosphere-ionosphere-lithosphere coupling (MILC).
Additionally, NUSES aims to pave the way for future missions by testing innovative technologies and observational strategies.

The satellite will house two payloads known as Terzina and Zirè.

Zirè will measure fluxes of electrons, protons, and light nuclei ranging from a few to hundreds of MeV.
It will also evaluate new tools for detecting cosmic MeV photons and monitoring MILC signals.

Terzina will monitor near-UV and visible light emissions from the Earth's limb on a nanosecond timescale, thereby testing the concept of detecting Cherenkov light from extensive air showers produced by UHERC's or Earth skimming high energy neutrinos.

This presentation will discuss the current status of the NUSES project design, as well as the scientific and technological objectives of the mission.

Flash Talks-2 / 72

Crystal Eye: a wide sight instrument for the study of astrophysical MeV photons

Author: Ritabrata Sarkar[1]

[1] *GSSI*

Corresponding Author: ritabrata.sarkar@gssi.it

Crystal Eye is a new concept of space-based all sky monitor for the observation of 30keV-30MeV photons exploiting a new detection technique,
which foresees enhanced localization capability with respect to current instruments.
This is now possible thanks to the use of new materials and sensors. The primary scientific goal is the detection of the electromagnetic signal of extreme phenomena in the Universe.
In order to enhance their study with many messengers, the satellite will provide an alert to both space and ground based experiments.
A full scale model of the Crystal Eye detector is now under design and construction.
Furthermore, a smaller prototype is being set up to fly aboard the Space Rider (ESA) on a LEO orbit for two months in 2025-2026.
We present here the instrument setup and its performances.

Flash Talks-1 / 73

Status and expected performance of the Radio Detector of the Pierre Auger Observatory

Author: Mohit Saharan[1]

[1] *IMAPP, Radboud Universiteit, Nijmegen And Nationaal instituut voor subatomaire fysica (Nikhef)*

Corresponding Author: m.saharan@science.ru.nl

The Pierre Auger Observatory is a hybrid ground-based detector that measures cosmic rays above 10^17 eV with an array of 1660 water-Cherenkov detector (WCD) stations spread over 3000 km2 and overlooked by 27 fluorescence telescopes. Over the last two decades, it has significantly contributed to our understanding of cosmic rays and multi-messenger astroparticle physics. However, fundamental questions about the origin, composition, acceleration mechanism, and propagation of ultra-high-energy cosmic rays remain unanswered. The ongoing AugerPrime upgrade will improve the estimation of the mass composition of cosmic rays at the highest energies, which is closely related to the other open questions and improves multi-messenger capabilities. For inclined air showers with zenith angles greater than 65 degrees, this will be achieved by using the newly added Radio Detector (RD) antenna array. The RD consists of an antenna installed on top of each WCD to measure the radio emission from the air shower in the 30-80 MHz band. For inclined showers, the WCD predominantly measures the muonic component, and the RD measures the electromagnetic component. Over 600 fully upgraded stations are now taking data in the field, and the upgrade is expected to finish this year. Currently, the RD measures data when triggered by the WCD. For inclined showers induced by neutral particles, especially photons, the muon content is often insufficient to trigger the WCD. Therefore, an RD self-trigger is also under development to enhance the sensitivity to neutral particles. In this contribution, we present an overview of the AugerPrime RD upgrade and its expected performance for cosmic rays and photons. The significance of the RD in the current era of multi-messenger astroparticle physics is also discussed.

Gamma-Ray and Multi-Messenger Astronomy / 74

Limits on photon fluxes from data of the Pierre Auger Observatory and implications on super-heavy dark matter

Author: Olivier Deligny[1]

[1] *CNRS/IN2P3 - IPN Orsay*

Corresponding Author: deligny@ipno.in2p3.fr

The first interactions of photon-induced showers are of electromagnetic nature, and the transfer of energy to the hadron/muon channel is reduced with respect to the bulk of hadron-induced showers. This results in a lower number of secondary muons. Additionally, as the development of photon showers is delayed by the typically small multiplicity of electromagnetic interactions, their maximum of shower development is deeper in the atmosphere than for showers initiated by hadrons. These salient features have enabled searches for photon showers at the Pierre Auger Observatory that will be summarized. They have led to stringent upper limits on photon fluxes over four orders in magnitude in energy. Not only these limits are of considerable astrophysical interest, but they also allow us to constrain beyond-standard-physics scenarios. For instance, dark matter particles could be superheavy, provided their lifetime is much longer than the age of the universe. Constraints on specific extensions of the Standard Model of particle physics that meet the lifetime requirement for a superheavy particle will be presented. They include limits on instanton strength as well as on mixing angle between active and sterile neutrinos.

Flash Talks-2 / 75

A New Computational Approach to Gamma-Ray Flux Modeling for WIMP Annihilation Detection

Author: Daniele Ambrosino[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: danieleambrosino93@gmail.com

The majority of the mass of the universe is composed of Dark Matter (DM), whose unknown nature has to be determined via expansions of the standard model of particle physics (SM). A class of candidates frequently taken into account are Weakly Interactive Massive Particles (WIMPs): stable and massive particles coupled with SM via weak interaction. According to different models, WIMPs may annihilate each other, producing a shower of SM particles. The radiation created by this process may theoretically be observed as an additional high-energy component in regions with a high DM density, such as the galactic core or dwarf galaxies. The main challenge in characterizing such signals is the theoretical definition of both the spectral and spatial distribution of the diffuse source. This work introduces a new computational method to define the spatial distribution of the extensive gamma-ray flux resulting from WIMP pair annihilation, commonly referred to as the J-factor. This method has been developed and implemented in Python classes compatible with Gammapy, the official analysis tool used by the Cherenkov Telescope Array Collaboration. For WIMP masses of the order of TeV, the Cherenkov Telescope Array Observatory (CTAO) could be able to observe such radiation, thus providing information on the nature of DM. Additionally, the practicability of this method is showed presenting the detectability study of this signal with CTAO in the Large Magellanic Cloud, also considering an astrophysical background of various known sources.

Galactic and Solar Cosmic Rays / 76

Phenomenology and theory of galactic cosmic-ray propagation

Author: Carmelo Evoli[1]

[1] *Gran Sasso Science Institute*

Corresponding Author: carmelo.evoli@gssi.it

Cosmic rays are the most energetic particles in the local Universe as they are known to reach energies above few Joules. How and where they are produced have been a science puzzle for several decades now, whose solution has been driving the rising of multi-messenger astrophysics as well as novel theoretical approaches. Of particular interest is the energy range below ~PeV as we expect that these particles have been all accelerated in the most extreme objects in our own Galaxy. Additionally, the past decade has seen an unprecedented improvement in the quality and quantity of data about their energy spectrum and chemical composition, allowing us to infer global properties as the galactic grammage and the average residence time. These quantities are crucial to test any more fundamental description of the transport of charged particles in the interstellar plasma. Even more thrilling, these new measurements, together with a deeper scrutiny of the diffuse gamma-ray emission from the Galactic plane, have revealed unexpected new features in the cosmic-ray elemental spectra that are challenging the commonly accepted scenario of how these particles are energized and propagate through interstellar space. In my talk I will provide an overview of these recent findings, and discuss some of the new ideas proposed to explain these anomalies.

Gamma-Ray and Multi-Messenger Astronomy / 77

The beginning of space gamma-ray astronomy with silicon detectors: From GILDA to AGILE and Fermi and future projects

Author: Aldo Morselli[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: aldo.morselli@roma2.infn.it

During the design of the silicon plane calorimeter of the TS93 balloon experiment, we realized that a detector consisting of silicon planes interspersed with converter planes would be an excellent gamma ray detector. We therefore designed the GILDA experiment which would be the starting point for the AGILE and Fermi experiments. During the talk, I will therefore describe the birth of gamma astronomy with silicon detectors and possible future developments.

Flash Talks-2 / 78

Radiation Hardness Assessment and Annealing Strategies for Silicon Photomultiplier Sensors on the Terzina Telescope on board the NUSES space mission

Author: Shideh Davarpanah[None]

Corresponding Author: shideh.davarpanah@unige.ch

NUSES is a pathfinder for new satellite platforms developed by THALES and
cutting-edge photo sensing technologies, such as SiPM and their associated low-power-consuming electronics. NUSES is financed by the Italian Ministry and conducted by GSSI, with INFN sections and the University of Geneva. NUSES hosts two payloads: Ziré is devoted to low-energy cosmic rays and gamma-rays from gamma-ray bursts and space weather, and the Terzina telescope to the first observation from space of the Cherenkov light emitted by atmospheric particle showers induced by ultra-high energy cosmic rays along its optical axis and Earth skimming neutrinos above about 100 PeV. This faint light may only be detected viewing the dark side of the earth and atmosphere, hence the satellite maintains a sun-synchronous orbit at 535 km altitude. Such a space-based telescope would not be constrained by the day-night cycle, allowing for continuous exposure while using a small telescope compared to ground-based ones, viewing a large atmospheric region. Terzina is a Schmidt-Cassegrain telescope with dual mirror optics with a 935 mm effective focal length and a primary mirror with a diameter of 454 mm and a camera composed of 2 rows of 5 tiles of 8 × 8 SiPM pixels of 3x3 mm2 . The University of Geneva collaborated to define the SiPM for Terzina with the FBK Research Foundation and research into how this technology might degrade when exposed to the cosmic radiation background.
Understanding the light noise in situ are vital for future larger missions or constellations of such satellites in the plans in the US and Europe. For this purpose we utilized a 50 MeV proton beam and a beta-radioactive source, Strontium-90, to carefully estimate the effect of radiation damage on the SiPMs. Then, we developed an annealing approach suitable for a space-based middle-size satellite to limit the effect of radiation damage while efficiently lowering the SiPM's energy detection threshold.

Ultra-High Energy Cosmic Rays / 79

The five sigma measurements in ultra-high energy cosmic rays and more

Corresponding Author: ioana.maris@ulb.be

The two observatories with largest effective areas in the world, Pierre
Auger and Telescope Array have been contiuosly operating for more than
20 years gathering an impressive statistics on cosmic rays with energies
up to above 10^20 eV. I will review the major achievements from these
two Observatoires, with a focus on the similitude between their measurements, in the same time highlighting the diversity of the science cases of ultra-high energy cosmic rays. While several measurements, like
the suppression of the cosmic rays flux at the highest energies or the
anisotropic dipolar pattern in the arrival direction, have reached more

than five sigma evidence, a few of the measurements are expected to reach a similar level in next years.

Gamma-Ray and Multi-Messenger Astronomy / 80

Recent results from the High Altitude Water Cherenkov observatory

Author: Miguel Mostafa[1]

[1] *Penn State Univ.*

Corresponding Author: miguel@psu.edu

High energy γ-ray observations are an essential probe of cosmic-ray acceleration mechanisms. The detection of the highest energy γ rays and the shortest timescales of variability are the key to improve our understanding of the acceleration processes and the environment of the cosmic accelerators. The High Altitude Water Cherenkov (HAWC) experiment is a large field-of-view, multi-TeV, γ-ray observatory continuously operating at 4100 m a.s.l. since March, 2015. The HAWC observatory has an order of magnitude better sensitivity, angular resolution, and background rejection than the previous generation of water-Cherenkov arrays. The improved performance allows us to discover new TeV sources, to detect transient events, to study the Galactic diffuse emission at TeV energies, to measure or constrain the TeV spectra of GeV γ-ray sources, to search for Galactic Pevatrons, and to improve the upper limits on indirect searches for dark matter and the constrains on Lorentz invariance violation. I will present the most recent results from the HAWC observatory and I discuss their implications for cosmic-ray acceleration and propagation.

Gravitational Waves / 81

Communicating gravitational wave science in a global context

Authors: Isabel Cordero-Carrión[1]; Livia Conti[2]; Vincenzo Napolano[3]

[1] *Universitat de València*

[2] *Istituto Nazionale di Fisica Nucleare*

[3] *EGO - European Gravitational Observatory*

Corresponding Authors: vincenzo.napolano@ego-gw.it, livia.conti@pd.infn.it, isabel.cordero@uv.es

Gravitational wave science exerts on the general public the fascination of Astronomy and, at the same time, stimulates the curiosity of fundamental physics. Probably also for this reason, it enjoys considerable popularity: discoveries and results, concerning this field of research, are often in the limelight of global communication.
This popularity offers a range of unprecedented opportunities for outreach and communication, but also of course greater complexity in planning and managing these activities at all levels: from site visits and events for the large public to the production of content for social media and national and international media relations. How do we manage, for example, the cultural and linguistic differences of the different research groups of a scientific collaboration, such as Virgo, in the planned communication activities? What narratives and contents could allow the general public approach this field, be part of its progress, but also be aware of the uncertainty of knowledge processes? How to manage confidential information within such large groups? How to manage the contradiction between the reality of scientific research as a collective effort and the need for personalization, for example, on social media? Retracing some recent moments and experiences in the public communication and outreach activities concerning gravitational waves (developed by Virgo and EGO also in a global

context) could probably shed light on the contemporary issues of communication of fundamental research.

Galactic and Solar Cosmic Rays / 82

Recent observations of galactic cosmic rays

Author: Andrii Tykhonov[None]

Corresponding Author: andrii.tykhonov@cern.ch

Recent results from high energy space-based missions have revealed unexpected, peculiar structures in cosmic electron, proton and nuclei spectra.

Our knowledge is also improving above the PeV region, due to new observations from ground based detectors that can extend the measurements to very high energies, even if with larger systematics.

In this talk, first, we will dive into the recent experimental results of space-borne cosmic ray missions, complemented with the observations of ground-based facilities at higher energies.
Finally, we will conclude with an outlook for future experiments.

Galactic and Solar Cosmic Rays / 83

Atmospheric Monitoring for Astroparticle Physics Observatories

Author: Bianca Keilhauer[1]

[1] *Karlsruhe Institute of Technology KIT*

Corresponding Author: bianca.keilhauer@kit.edu

For many observatories recording high-energy cosmic rays, gamma rays, or neutrinos, the Earth's atmosphere is either an integral part or at least a considerable aspect of the detector setup. Several aspects of the influence of the atmosphere and its variability on the development of the observed particle cascades and the signal detected from them will be discussed. Also some atmospheric monitoring strategies implemented by the different observatories will be described. Examples of the impact of atmospheric parameters and profiles on the core data of these observatories will be given.

Gravitational Waves / 84

Redefining time-domain astronomy with gravitational waves

Author: Eleonora Troja[1]

[1] *University of Rome Tor Vergata*

Corresponding Author: eleonora.troja@roma2.infn.it

For over three decades, extragalactic high-energy transients were divided into two main classes: long duration gamma-ray bursts (GRBs) from the core-collapse of massive stars, and short duration GRBs from the coalescence of two compact objects. This common notion was confirmed by the ground-breaking discovery of the gravitational wave transient GW170817, which provided direct

and unambiguous evidence linking a short GRB to the merger of two neutron stars and to the kilonova AT2017gfo, powered by the radioactive decay of heavy metals.
However, our simple picture of the high-energy sky was recently challenged by observations of long GRBs followed by luminous kilonovae, short GRBs produced by magnetar giant flares, and mysterious fast X-ray transients with little or no gamma-rays. In this talk, I will discuss how gravitational wave observations will help us map the broad diversity.

Gamma-Ray and Multi-Messenger Astronomy / 85

Probing cosmic-ray accelerators with neutrinos and gamma-rays

Author: Marcos Santander[1]

[1] *University of Alabama*

Corresponding Author: jmsantander@ua.edu

The discovery of high-energy astrophysical neutrinos by IceCube has opened a new window to study some of the most energetic cosmic sources and their ability to accelerate particles to extreme energies, in particular hadronic cosmic rays. These high-energy neutrinos should be accompanied by gamma rays at production, so their joint detection (or a lack of it) can cast light on the properties of the emission region and its opacity to high-energy photons. I will summarize recent results in joint neutrino and gamma-ray studies and present an overview of new opportunities to appear in the near future as new multi-messenger instruments go online over the next few years.

Gamma-Ray and Multi-Messenger Astronomy / 86

Welcome

Corresponding Authors: antonio.insolia@ct.infn.it, guarino@na.infn.it

Welcome & Outreach / 87

Outreach

Corresponding Author: sabine.hemmer@pd.infn.it

Gamma-Ray and Multi-Messenger Astronomy / 88

Neutrino-Gamma Ray Synergies

Corresponding Author: jmsantander@ua.edu

Gamma-Ray and Multi-Messenger Astronomy / 89

HESS - MAGIC - VERITAS

Corresponding Author: rlopezcoto@gmail.com

Gamma-Ray and Multi-Messenger Astronomy / 91

LST

Corresponding Author: federico.dipierro@to.infn.it

Gamma-Ray and Multi-Messenger Astronomy / 96

16 years of Gamma Ray Discoveries with Fermi

Corresponding Author: elisabetta.bissaldi@ba.infn.it

In the year 2024, the Fermi Gamma-ray Space Telescope is celebrating its 16th year of operation. The Large Area Telescope (LAT) is the main instrument onboard the Fermi satellite and is designed to be sensitive to gamma rays in the energy range from about 20 MeV up to the TeV regime. From its launch, the LAT has collected more than 4.53 billion photon events, providing crucial information to improve our understanding of particle acceleration and gamma-ray production phenomena in astrophysical sources. The Gamma-ray Burst Monitor (GBM), the secondary intrument onboard Fermi, has a field of view several times larger than the LAT and provides spectral coverage of gamma-ray bursts (GRBs) and other transients phenomena that extends from the lower limit of the LAT down to 10 keV. GBM has detected more than 3800 bursts to date, including the famous short GRB 170817A jointly detected in gravitational waves, thus providing the first direct evidence that colliding neutron stars can produce GRBs. In this talk, some of the main results obtained by the Fermi LAT and GBM collaborations will be reviewed, with a particular focus on GRB science.

Welcome & Outreach / 97

Welcome

Corresponding Authors: antonio.insolia@ct.infn.it, guarino@na.infn.it

Galactic and Solar Cosmic Rays / 98

Review of recent observations of galactic cosmic rays

Corresponding Author: andrii.tykhonov@cern.ch

Galactic and Solar Cosmic Rays / 99

CR @ LHAASO

Innovative Detectors and Data Handling Techniques / 100

Deep Learning in Astroparticle Physics

Author: Jonas Glombitza[None]

Corresponding Author: jonas.glombitza@fau.de

Algorithms based on machine learning have been extraordinarily successful across many domains, including computer vision, machine translation, engineering, and science.
Moreover, in the field of physics, the importance of machine learning is growing fast, driven by the necessity for precise and efficient algorithms that can effectively handle vast amounts of complex and high-dimensional data.
Recently, with the help of these novel algorithms, providing improved reconstructions, new insights into astroparticle physics could be gained.
Could it even become a new paradigm for data-driven knowledge discovery?

In this contribution, we review the state of machine learning in astroparticle physics after introducing the fundamental concepts.
We outline the potential of this emerging technology, illustrate the wide variety of possible applications in the context of astroparticle physics, and debate the latest breakthroughs.
Finally, we present novel approaches and techniques and discuss future applications and challenges in the field.

Gamma-Ray and Multi-Messenger Astronomy / 101

SWGO: a Southern hemisphere wide field of view gamma-ray observatory

Author: Andrea Chiavassa[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: andrea.chiavassa@to.infn.it

The SWGO collaboration is proposing the construction of a wide field of view observatory to explore the Southern hemisphere sky in the 100 GeV-1 PeV energy range. Nowadays only the HAWC and LHAASO experiments operate with these characteristics, both are in the Northern hemisphere, while the Southern hemisphere sky is not covered by such an observatory. The array will be located in a site at latitude between 10 and 30 degrees south and at an altitude above 4400 m a.s.l.. The baseline detection technique chosen by the collaboration is Water Cherenkov Detectors, the array will have a central region (140-220 m radius) with high fill factor (>60%) and a large (about 1 km^2 square) outer region with a much lower fill factor (around 4-5%). In this communication I will provide an overview of the goals and the status of the project.The SWGO collaboration is proposing the construction of a wide field of view observatory to explore the Southern hemisphere sky in the 100 GeV-1 PeV energy range. Nowadays only the HAWC and LHAASO experiments operate with these characteristics, both are in the Northern hemisphere, while the Southern hemisphere sky is not covered by such an observatory. The array will be located in a site at latitude between 10 and 30 degrees south and at an altitude above 4400 m a.s.l.. The baseline detection technique chosen by the collaboration is Water Cherenkov Detectors, the array will have a central region (140-220 m
radius) with high fill factor (>60%) and a large (about 1 km^2 square) outer region with a much lower fill factor (around 4-5%). In this communication I will provide an overview of the goals and the status of the project.

Gamma-Ray and Multi-Messenger Astronomy / 102

Aftermath of the current generation of IACTs: glance to the latest results and peep into the future

Author: Ruben Lopez Coto[None]

Corresponding Author: rlopezcoto@gmail.com

The current generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) has been taking data for more than 20 years with an extraordinary performance that overcomes that of the previous generation by a factor of a few. Discoveries of sources like Gamma Ray Bursts, pulsars or novae and the identification of elusive PeVatrons in the Very High Energy regime would have not been possible without the low energy threshold, accurate angular resolution and excellent sensitivity and energy resolution of this generation of telescopes. In this presentation I will give a glance to the latest results of this generation of instruments and a quick look to the future of the field.

Astrophysical Neutrino / 103

The Giant Radio Array for Neutrino Detection

Author: Xishui Tian[1]

[1] *Department of Astronomy, School of Physics, Peking University, Beijing, China*

Corresponding Author: tianxs@stu.pku.edu.cn

Ultra-high-energy (UHE) cosmic neutrinos, with energies above 100 PeV, are
unparalleled probes of the most energetic astrophysical sources and weak interactions at energies beyond the reach of accelerators. GRAND is an envisioned observatory of UHE particles -neutrinos, cosmic rays, and gamma rays - consisting of 200,000 radio antennas deployed in sub-arrays at different locations worldwide. GRAND aims to detect the radio emission from air showers with inclined arrival direction induced by UHE particle interactions in the atmosphere and underground. The reconstruction of these very inclined air showers is a new challenge for next-generation radio experiments. For neutrinos, GRAND aims to reach a flux sensitivity of ~ 10^{−10}GeV cm^{−2} s^{−1} sr^{−1}, with a sub-degree angularmresolution, which would allow it to test the lowest predicted diffuse fluxes of UHE neutrinos and to discover point sources. The GRAND Collaboration operates three prototype detector arrays simultaneously: GRAND@Nançay in France, GRANDProto300 in China, and GRAND@Auger in Argentina. The primary purpose of GRAND@Nançay is to serve as a testbench for hardware and triggering systems. On the other hand, GRANDProto300 and GRAND@Auger are exploratory projects that pave the way for future stages of GRAND. GRANDProto300 is being built to demonstrate autonomous radio-detection of inclined air showers and study cosmic rays near the proposed transition between galactic and extragalactic sources. All three arrays are in the commissioning stages. It is expected that by 2028, the detector units of the final design could be produced and deployed, marking the establishment of two GRAND10k arrays in the Northern and Southern hemispheres. We will survey preliminary designs, simulation results, construction plans, and the extensive research program made possible by GRAND.

Flash Talks-2 / 104

A multiPMT for SWGO water Cherenkov detectors

Author: Muhammad Waqas[1]

[1] *Prof Fausto Gaurino*

Corresponding Author: muhammad.waqas.phy043@gmail.com

Water Cherenkov detectors are playing a central role in neutrino physics, gamma-ray astronomy, and cosmic-ray research. These detectors usually rely on the use of large area photomultiplier tubes

(PMTs) to detect Cherenkov radiation emitted by particles moving faster than the speed of light in water. Recent studies suggest that using multiple small area PMTs in a compact structure enhances the performance of these detectors. Such a solution has been adopted in several experiments.
This work focuses on the design and optimization of an hemispherical module with several 3" PMTs, called multiPMT, and of related electronics for a possible use in the water Cherenkov detectors of the SWGO Experiment. This study shows that such devices have promising features in terms of both cost and performance compared to large-area PMTs.
The cost per area of photocathode is similar to large PMTs even including the additional channels of electronics. Dividing the signal into multiple PMTs reduces requirements on the electronics max rate and max dynamic range. The enclosure which keeps the PMT face dry provides convenient housing for the electronics and allows for easy access in case of repair.
Finally, the intrinsic directionality may prove useful for shower reconstruction and to the discrimination of gamma initiated showers against the hadron background.

Gravitational Waves / 105

Final Remarks

Astrophysical Neutrino / 106

Tau neutrinos from GeV to EeV

Corresponding Author: mbustamante@nbi.ku.dk

Tau neutrinos are the least known of the active neutrinos. As such, by studying them even far from the precision regime, we stand to gain new insight into their properties and their sources. Doing so endows us with novel probes of fundamental physics and astrophysics that are particularly valuable at high, barely trodden energies. Because tau neutrinos are hard to make and detect, they remain poorly studied experimentally—though maybe not for much longer. Fortunately, there is a host of experiments, active today and planned for the near future, that target the detection of tau neutrinos across a broad range of energies. They range from GeV energies—in short-baseline, long-baseline, and atmospheric experiments—through TeV energies—in forward-physics experiments—up to PeV energies—using high-energy cosmic neutrinos—and EeV energies—using the long-sought ultra-high-energy neutrinos. I will give a brief overview of the status, challenges, recent developments, and future hopes for tau neutrinos, focusing on those of cosmic origin.

Astrophysical Neutrino / 107

Radio detection of high energy neutrinos

Corresponding Author: lilly.pyras@desy.de

Radio detection of neutrinos is a promising technique to achieve the gigantic detection volumes required to measure neutrinos at energies beyond the PeV-scale flux established by IceCube. It relies on the geomagnetic (in air) and charge excess (dominant in dense media) emission following a particle cascade of secondaries of a neutrino interaction. Several detector topographies are currently being studied: The Earth-skimming tau neutrino detectors in mountainous regions, e.g. BEACON, TAROGE and GRAND, aim to measure the radio emission from air showers. RNO-G and the planned radio array of IceCube-Gen2 exploit the polar ice and its large attenuation length at radio frequencies to detect neutrino induced particle cascades in ice and the subsequent Askaryan emission. The balloon-borne PUEO (successor to ANITA) accesses both air-shower and in-ice detection channels

at energies >1e18eV. In this contribution I will review the current status of the radio neutrino detection, highlight future experimental efforts, and elaborate on open questions and future experimental challenges.

Astrophysical Neutrino / 108

Final state radiation and (ultra)high energy neutrinos

Corresponding Author: rplestid@caltech.edu

Neutrinos are most easily detected via their charged current scattering off nucleons. The final state will then contain electromagnetically charged particles, and is subject to QED radiative corrections. Naively power counting suggests that these effects are small, being only relevant for precision observables. In this talk I will explain why this is not the case, and how final state radiation can impact observables at a level that is comparable to current experimental sensitivities in neutrino telescopes. I will discuss applications/implications for HE and UHE neutrino detection, and suggest implementations for experimental collaborations at the level of an event generator.

Astrophysical Neutrino / 109

Highliths on KM3NeT

Corresponding Author: coniglione@lns.infn.it

The KM3NeT collaboration is building two underwater neutrino detectors in the Mediterranean: the ARCA (Astroparticle Research with Cosmics in the Abyss) and ORCA (Oscillation Research with Cosmics in the Abyss) detectors.
ARCA is located off the Sicilian coast of Capo Passero and aims to detect and identify astrophysical neutrino sources. The ORCA detector, located off the French coast of Toulon, has been optimised for the detection of atmospheric neutrinos in the GeV range, with the main aim of studying the fundamental properties of neutrinos.
The two detectors, ARCA and ORCA, will allow the study of neutrino astronomy from MeV to tens of PeV. The KM3NeT detectors are already active in multi-messenger astronomy.
The first detection units, which are strings containing the optical sensors, have already been deployed by the KM3NeT collaboration at the French and Italian sites.
The two detectors are currently taking data in partial configurations and are already producing some physics results, demonstrating the great potential of the two detectors for the coming years.
Recent results in both astrophysics and neutrino oscillation will be presented, together with the status of the detector construction and the future perspectives.

Astrophysical Neutrino / 110

Eyes on the extreme Universe: Neutrino telescopes across the globe

Corresponding Author: donglianxu@sjtu.edu.cn

With the detection of a diffuse extragalactic neutrino flux and the first compelling evidence for associated sources, IceCube has opened up a new era for high-energy neutrino astronomy. Leveraging on these exciting discoveries made by IceCube, several proposals are under way across the globe to either upgrade existing detectors or build new ones. To definitively unveil the origin of high energy cosmic rays and probe new physics over astronomical baselines via the weak sector, it is essential in designing next-gen neutrino telescopes to have improved source identification capability and appreciably boost statistics of all-flavor neutrinos. In this talk, I will give an overview on the new detectors under construction and briefly discuss their future prospects.

Astrophysical Neutrino / 111

Review on extra-galactic neutrinos

Corresponding Author: maroulaaki@gmail.com

Astrophysical Neutrino / 112

Recent Results from the IceCube Neutrino Observatory

Corresponding Author: jlazar@icecube.wisc.edu

The IceCube Neutrino Observatory consists of a cubic kilometer of clear, Antarctic ice instrumented with light-detecting optical modules. These modules detect light produced by charged by-products of neutrino interactions, allowing IceCube to study neutrinos with energies between a few GeV and several PeV. This enables a broad science program, including studies of fundamental neutrino physics; beyond Standard Model physics; and, perhaps most notably, the astrophysical flux of neutrinos. In this last area, IceCube has continued to characterize the flavor and energy composition of the diffuse neutrino flux and recently has identified sources of galactic and extragalactic emission. In this talk, I will highlight recent results from the IceCube Neutrino Observatory, highlighting those results with potential connections between astrophysical neutrinos and high-energy cosmic rays.

Gamma-Ray and Multi-Messenger Astronomy / 113

Corsika 8 - astroparticle simulation framework

Author: Felix Riehn[None]

Corresponding Author: friehn@lip.pt

Astrophysical Neutrino / 114

Review on galactic neutrinos

Author: Andrii Neronov[1]

[1] *University of Geneva*

Corresponding Author: andrii.neronov@gmail.com

Interactions of high-energy protons and nuclei in the Galaxy contribute to the gamma-ray and neutrino signals from the sky in the TeV-PeV energy range. I will review recent results on the search of neutrinos from the Milky Way in this energy range with IceCube and ANTARES telescopes, including recently reported evidence for the overall diffuse emission from the interstellar medium and emission from parts of the Milky Way disk, such as the Galactic Ridge and Cygnus region. I will compare the Galactic neutrino search results for the diffuse emission and individual isolated sources with the recent gamma-ray measurements and discuss implications of these multi-messenger results for the understanding of Galactic cosmic rays.

115

Corsika 8 - astroparticle simulation framework

Author: Felix Riehn[None]

Corresponding Author: friehn@lip.pt

Corsika 8 is a framework/toolkit for simulating the passage of particles through matter with a focus on applications in the context of astroparticle physics.
It provides a wide range of functionality including tracking, geometry, various media and many (external) models for different types of particle interactions and physics processes.
Processes that are currently included are electromagnetic interactions of leptons and hadrons, hadronic interactions and particle decays. The framework is thought to be a project of the wider astrophysics community. It is written and developed in modern C++ so to be readily extensible for new processes and applications.

In this contribution I will present the current status of the development, show predictions of various different applications implemented in the framework as well as comparisons of the air shower application with the legacy CORSIKA 7.