Consuntivi Scientifici 2022

C.M. Carloni Calame

Consiglio di Sezione, Pavia
14 giugno 2023

Istituto Nazionale di Fisica Nucleare

PRIN 2022

- **Cinque** associati/dipendenti del nostro gruppo teorico sono risultati vincitori dei finanziamenti PRIN 2022

⇝ Alessandro Bacchetta

⇝ Chiara Macchiavello

⇝ Lorenzo Maccone

⇝ Paolo Perinotti

⇝ Fulvio Piccinini

Iniziative Specifiche (fotografia 2022)

Iniziativa Specifica	*Responsabile Locale*	*Resposabile Nazionale*
BELL [4]	Paolo Perinotti	Angelo Bassi (TS)
GEOSYM_QFT [4]	Annalisa Marzuoli	Annalisa Marzuoli (PV)
NINPHA [3]	Marco Radici	Mariaelena Boglione (TO)
QFT@COLLIDERS [2]	Carlo Carloni Calame	Gian Paolo Vacca (BO)
TaSP [5]	Andrea Tiengo	Fiorenza Donato (TO)
CC3M/ASIMOV	Marco Radici	Francesco Vissani (LNGS)

Linee scientifiche di CSN4:

[1] Teoria dei Campi e Stringhe, **[2]** Fenomenologia delle particelle elementari,

[3] Fisica Nucleare e Adronica, **[4]** Fondamenti e Metodi Matematici, **[5]** Fisica astroparticellare,

[6] Fisica Statistica e Teoria di Campo Applicata

Iniziative Specifiche (fotografia attuale)

Iniziativa Specifica	*Responsabile Locale*	*Resposabile Nazionale*
BELL [4]	Paolo Perinotti	Angelo Bassi (TS)
GEOSYM_QFT [4]	*Claudio Dappiaggi*	*Francesco Bonechi (FI)*
NINPHA [3]	Marco Radici	Mariaelena Boglione (TO)
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BELL

Linea 4

Fondamenti & Metodi Matematici

Anagrafica BELL 2022

Cognome	Nome	Esperimenti	F
Bisio	Alessandro	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
D'Ariano	Giacomo	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Erba	Marco	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Lugli	Matteo	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Macchiavello	Chiara	80% - (PV:CSN4) **BELL** (*Ricercatore*)	
Maccone	Lorenzo	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Mangini	Stefano	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Nicrosini	Oreste	40% - (PV:CSN4) **BELL** (*Ricercatore*)	
Perinotti	Paolo	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Tosini	Alessandro	100% - (PV:CSN4) **BELL** (*Ricercatore*)	
Vaglini	Leonardo	100% - (PV:CSN4) **BELL** (*Ricercatore*)	

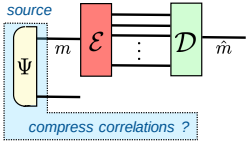
QUit
quantum information theory group

Paolo Perinotti

Gruppo IV
BELL

Generalized Shannon theory

Published in Physical Review A 105 (5), 052222 (2022) & The Quantum-Like Revolution, Springer Book (2023)

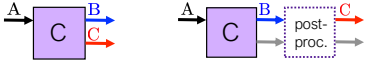


We introduced the **information content** as generalization of Shannon entropy to every physical system encoding information. As case of study we have proved the **fermionic** systems **source coding theorem**.

$$\{\Psi_i, \Psi_j^\dagger\} = \delta_{ij}$$

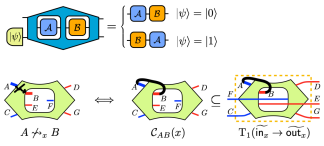
Incompatibility of quantum devices as a resource

J. Phys. A 55, 394006 (2022) & To appear in Quantum (2023)



We found two **inequivalent notions of incompatibility** of quantum devices, based on parallel and sequential simulability, respectively. We **unified** them into one **hierarchy of resource theories of communication** between separated parties.

No-signalling constrains quantum computation with indefinite causal structure



Quantum processes with indefinite causal structure are described within the framework of **higher-order quantum theory** (maps from transformations to transformations …. hierarchy of maps of increasingly higher order). We show that the **composition rules** for arbitrary higher order maps are **determined by** the physical notion of **signalling**.

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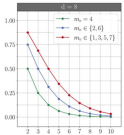
Chiara Macchiavello

Gruppo IV
BELL

Entanglement properties of hypergraph states

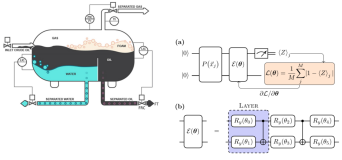
Published in J. Phys. A 55, 415301 (2022)



Multipartite entanglement properties of hypergraph states in finite dimension have been studied, highlighting interesting differences between prime and non-prime dimension.

Quantum computation and machine learning

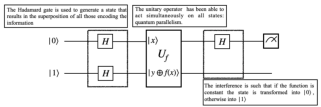
Published in Quantum Machine Intelligence 4, 13 (2022)



We proposed a quantum pipeline, comprising a quantum autoencoder followed by a quantum classifier, which are used to first compress and then label classical data coming from a separator, i.e., a machine used in one of Eni's Oil Treatment Plants. This work represents one of the first attempts to integrate quantum computing procedures in a real-case scenario of an industrial pipeline, in particular using actual data coming from physical machines.

Quantum education

Published in Physics 4, 1150 (2022); J. Phys. Conf. Series 2297, 012018 (2022)



We presented an educational path for teacher professional development whose primary purpose is to enhance physics teachers' knowledge and awareness of topics related to quantum computation and quantum information, and an extracurricular course on quantum physics concepts and quantum technologies for high school students.

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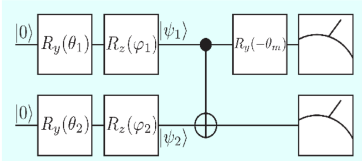
quantum information theory group

Lorenzo Maccone

Gruppo IV
BELL

Testing quantum foundations with quantum computers

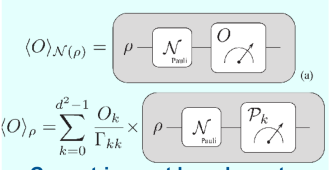
Phys. Rev. Research 4, L022001 (2022)



We devised a quantum algorithm to test the Born rule, one of the postulates of quantum mechanics, and we ran it on a couple of quantum computers (IBM and Rigetti).Research performed in collaboration with the Raman Research Institute, Bangalore

Qubit noise deconvolution

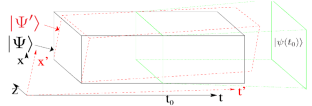
European Journal of Physics, Quantum Technology 9, 29 (2022),
PHYSICAL REVIEW A 107, 022419 (2023)



A method to remove (deconvolve) noise at the measurement stage of quantum algorithms.

Geometric event-based quantum mechanics

New J. Phys. 25, 023027 (2023).



A novel approach to relativistic quantum mechanics and to construct a quantum spacetime.

GEOSYM_QFT

Linea 4

Fondamenti & Metodi Matematici

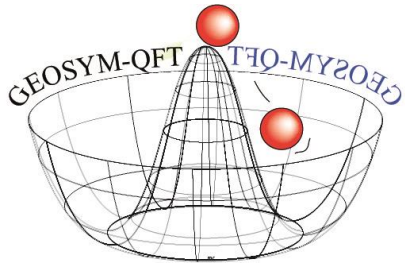
Geometry and Symmetry in Quantum Field Theory
Consuntivo PV 2022

Staff:

Mauro Carfora
Claudio Dappiaggi
Giancarlo Jug
Annalisa Marzuoli
Michele Schiavina (da 1/1/2023)

Francesca Familiari
(postdoc fino a 31/12/23)

Alberto Bonicelli
Luca Sinibaldi
(2° anno Dottorato in Fisica)



- Algebraic, topological and geometric methods in Quantum Field Theory and Relativistic Cosmology
- Applications to condensed matter systems and optics

• Algebraic Quantum Field Theory

During the calendar year 2022, Claudio Dappiaggi and various collaborators have focused their attention on two problems. On the one hand we have shown how to implement dynamical boundary conditions on anti-de-Sitter spacetime, studying in addition the response of an Unruh-De Witt detector on a Bertotti-Robinson spacetime. In this context we have also discussed the existence of a previously ignored freedom in the construction of ground states for Bosonic free field theories on static background with a timelike boundary. On the other hand, we have continued our efforts aimed at investigating how to apply microlocal techniques to the analysis of stochastic PDEs developing a notion of wavefront set tailored to Besov spaces (in collaboration with P. Rinaldi and F. Sclavi).

(Several papers and preprints for this line of research)

- **Geometric analysis, mathematical cosmology and Ricci Flow**

✓ Cosmography and analysis of the physical past lightcone. We have extended the analysis of the distance functional recently introduced by us for what concerns a detailed analysis of the observational past lightcone and a careful comparison with the standard Friedman-Lemaitre-Robinson-Walker model past lightcone. (M. Carfora and F. Familiari)

✓ Applications of the Ricci-Perelman flow in General Relativity

Research monography: M Carfora, A Marzuoli "Einstein constraints and Ricci flow: a geometrical averaging of initial data sets" pp.XII+173, Mathematical Physics Studies, Springer ISBN 978-981-19-8539-311 - January 2023

- **Topological structures in optical fields**

There have been proposed novel topological and geometrical characterizations to handle ‘structured light’, namely optical fields with shaped spatial and temporal features –such as knotted and braided configurations- recently observed in experiments. (A Marzuoli and N Sanna)

- **Theory and phenomenology of amorphous solids**

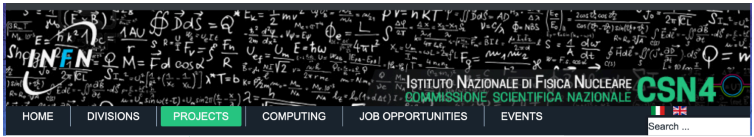
Research work has been carried out along these directions by G. Jug and collaborators:

1) The theoretical analysis of experimental data for the magnetization of glasses to extract information on their heterogeneous structure. 2) The development of a topological theory for the melting of glasses based on the established heterogeneous structure. 3) An improvement of the microscopic quantum theory for the explanation of the intrinsic magnetism of glasses.

NINPHA

Linea 3

Fisica Adronica e Nucleare



Fields and String Theory
Phenomenology of Elementary Particles
Nuclear and Hadronic Physics
Mathematical Methods
Astroparticle Physics
Statistical Physics and Applied Field Theory

NINPHA

National INitiative in Physics of HAdrons

Coordinatore nazionale: M. Boglione (Torino)
5 sedi: Torino, Pavia, Genova, Perugia, Cagliari

2022 performance: ~**25** FTE, **28** pubblicazioni, **52** talks, **16** tesi (undergr. & PhD)

Pavia

Coordinatore locale: M. Radici

INFN	Univ.
- M. Radici (Primo Ric.)	- A. Bacchetta (P.O.), B. Pasquini (P.O.) - A. Signori assegnista (borsa Marie-Curie internazionale), dal 01-07-2022 RTD-B presso Dip. Fisica - Università di Torino - F.G. Celiberto (assegnista al 50% con TIFPA-Dot4) - M. Cerutti, S. Venturini, L. Rossi (studenti Dottorato)

Main goal

Understand the mechanisms
of QCD confinement
by mapping in detail
the non-linear dynamics of
partons inside **hadrons**

New tools :

- TMDs → 3D maps in mom. space
- GPDs → 3D maps in position space
- GTMDs (Wigner distrib.) → maximum info
- QCD Energy-momentum tensor $T^{\mu\nu}$ → N mass

phenomenology

extraction of TMDs (GPDs) from
(global) fits of exp. data

properties

evolution eqs., universality, etc..
renormalisation, scheme dependence,
operator mixing, etc..

modeling

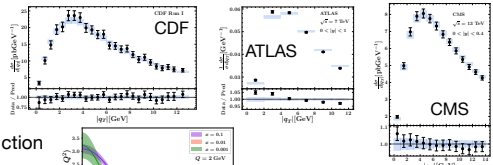
support to experiments

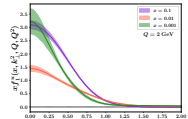
NINPHA-PV at the forefront in many fields : examples

phenomenology

First extraction of TMD of unpolarized quark in proton at top N³LL accuracy from global fit of ~ 2K data from Drell-Yan, Z-boson production and SIDIS data

A. Bacchetta et al. (MAP Collaboration) JHEP 10 (22) 127, arXiv:2206.07598

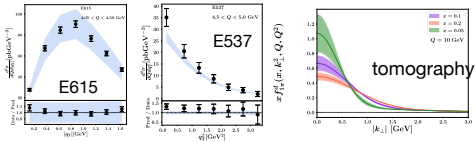




TMD(k_T) at x=10^{-3},10^{-2}, 0.1 tomography of proton

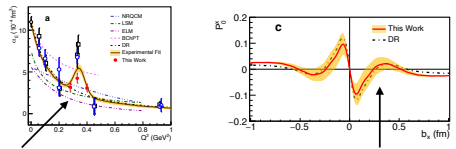
Extraction of TMD of unpolarized quark in pion at N³LL accuracy from Drell-Yan

M. Cerutti et al. (MAP Collaboration) P.R.D 107 (23) 014014, arXiv:2210.01733



Unexpected behavior of proton electric generalized polarizability from Virtual Compton Scatt. data

R. Li,.., B. Pasquini et al. Nature 611 (22) 7935, 265, arXiv:2210.11461



not predicted by theory; new structure in induced polarization at 0.25-0.35 fm

NINPHA-PV at the forefront in many fields : examples

properties and exploratory studies

- Gravitational form factors of electron in QED: energy, angular momentum and mass structure

  A. Freese, A. Metz, B. Pasquini, S. Rodini
  P.L. B839 (23) 137768, arXiv:2212.12197

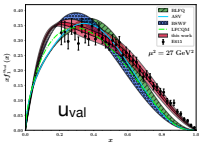
- formal analogies between di-hadron and hadron-in-jet fragmentation functions

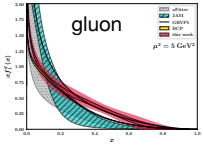
  A. Bacchetta, M. Radici, L. Rossi
  arXiv:2303.04314

modeling

- Light-Front wave functions of pion, parameters fitted to pion form factor and PDF (xFitter); can consistently build pion PDFs, TMDs, GPDs for valence/sea quarks and gluons

  B. Pasquini, S. Rodini, S. Venturini (MAP Coll.)
  arXiv:2303.01789

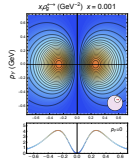




- First tomography of T-odd gluon TMDs in spectator model with mass spectral density, and applications to heavy-flavor production

  A. Bacchetta, F.G. Celiberto, M. Radici
  arXiv:2206.07815, 2208.06252

probability density of gluons linearly polarized in ⊥ plane in unpolarized proton



Also...

- **prominent role in EIC Users Group structure:**

- M.Radici: Co-Chair of the Steering Committee (Chair from 01-06-2023), member of the Council Board, of the Charter Committee; convener of SIDIS WG in ePIC Collaboration
- A.Bacchetta: convener of the EICUG Theory Working Group

- **and in other structures:**

- B. Pasquini: member of Scientific Board ECT*, member of IAC, CFNS (Stony Brook-US), Co-Director of ILCAC
- A. Bacchetta: member of PAC at JLab

- **various memberships** in IAC and Organiz. Committees of international conferences, Editorial Boards of refereed journals, Committees in selection procedures

- **M. Cerutti**: best talk at EICUG Early Career Workshop, 24-25 July 2022, Stony Brook (US)
- **S. Venturini**: best th. poster at Gordon Research Conference 2022 - Photonuclear reactions, 7-12 Aug. 2022, Holderness (US)

- **outreach:**

- M.Radici: local coordinator of INFN CC3M-Asimov; member of Scientific Committee Premio Asimov 2022; co-organizer of Premio Asimov 2022 - Lombardia; presentation at ICHEP2022 (W.M. Alberico,.., M. Radici et al., POS(ICHEP2022) 376)
- various seminars and lectures by all members

Other funds - Strong2020 A. Bacchetta spokesperson of WP22 “TMD-next”
B. Pasquini local coordinator of WP22 “TMD-next”

IAC: International Advisory Commitee, Center for Frontiers in Nuclear Sciences (CFNS), Stony Brook
ILCAC: International Light-Cone Advisory Commitee
PAC: Program Advisory Committee, JLAB

QFT@COLLIDERS

Linea 2

Fenomenologia delle particelle elementari

QFT@COLLIDERS

Responsabile nazionale: Gian Paolo Vacca (BO)
Responsabile locale: C.M. Carloni Calame

Nodi: BO, CS, FI, MIB, PV

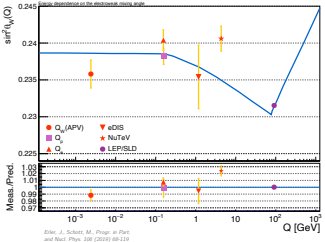
Partecipanti 2022:
E. Budassi (dottorando)
C.M. Carloni Calame (70%)
M. Chiesa (85%)
Clara L. Del Pio (dottoranda)
A. Gurgone (dottorando)
G. Montagna (90%)
M. Moretti (FE)
O. Nicrosini (50%)
F. Piccinini (85%)
M. Syed Hasan (post-doc)

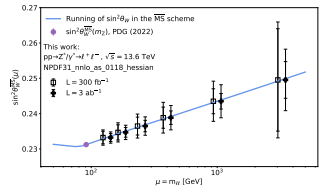
Collaborazioni:
G. Abbiendi (BO)
A. Denig (Mainz)
U. Marconi (BO)
P. Nason (MIB)
M. Passera (PD)
A. Signer (PSI)
G. Venanzoni (PI)
A. Vicini (Milano) *e molte altre...*

Keywords: Monte Carlo generators, NLO/NNLO QCD & EWK calculations, perturbative resummation, QCD in the high energy limit, phenomenology of the SM and BSM

LHC physics

High-precision Monte Carlo event generator for Drell-Yan
`Z_ew-BMNNPV` code available at `https://powhegbox.mib.infn.it/`





- Implementation of $\overline{\text{MS}}$ scheme and $\sin^{\overline{\text{MS}}}_{\theta}$ sensitivity study at the LHC and HL-LHC

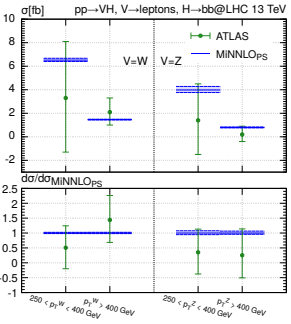
  S. Amoroso, M. Chiesa, C. L. Del Pio, K. Lipka, F. Piccinini, F. Vazzoler and A. Vicini: PoS ICHEP2022 890, arXiv:2302.10782

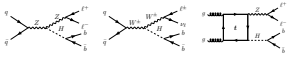
- Participation to the subgroup "Drell-Yan physics and EW precision measurement" of the LHC EWWG, with particular contribution in the $\sin^{\text{eff}}_{\theta}$ measurement

LHC physics

High-precision Monte Carlo event generator for Higgsstrahlung $pp \to HV$, $(H \to b\bar{b})$ with production and decay at NNLO QCD accuracy matched with parton shower

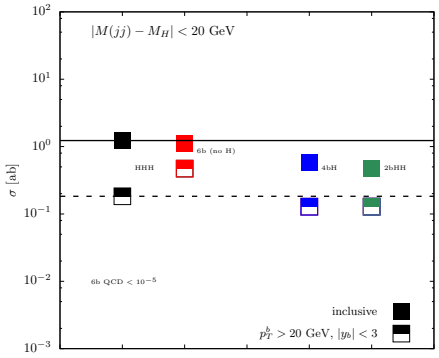
S. Zanoli, M. Chiesa, E. Re, M. Wiesemann and G. Zanderighi, JHEP **07** (2022), 008





- Full predictions for ZH and $W^{\pm}H$ with $H \to b\bar{b}$ including spin correlations and off-shell effects
- Accuracy at NNLO+PS in production and decay achieved for the first time
- Good agreement with recent Higgsstrahlung cross section measurements

Background simulation studies at the μ-coll (preliminary)

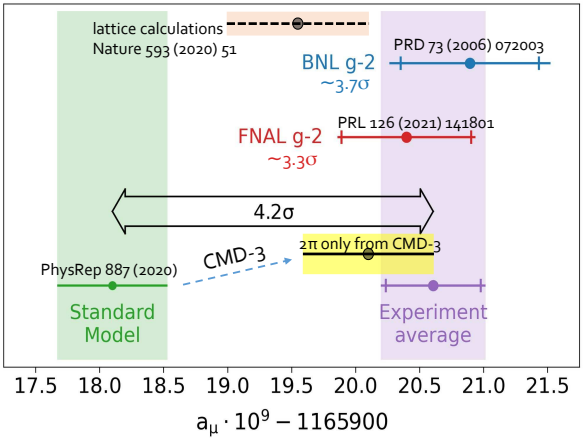


- Background simulation studies for triple-Higgs production
- Monte Carlo simulations for high-multiplicity processes might be non-feasible with available MC tools
- dedicated `ALPGEN` version developed for $6b\nu\overline{\nu}$ simulation

MUonE

- $|a_\mu^{\text{SM, } e^+e^- \text{ data}} - a_\mu^{\text{exp}}| \simeq 4.2\sigma$
- $|a_\mu^{\text{SM, lattice QCD}} - a_\mu^{\text{exp}}| \simeq 1.5\sigma$
- $|a_\mu^{\text{SM, new CMD3 } \pi^+\pi^- \text{ data}} - a_\mu^{\text{exp}}| < 1\sigma$

✓ MUonE can shed light over this cumbersome picture, by providing an independent determination of a_μ^{HLO} with space-like data, *i.e.* by a high precision measurement of $\Delta\alpha_{\text{had}}(q^2)$ in $\mu e \to \mu e$ scattering



MUonE

- The Pavia HEP group is among the proponents of the experiment
- By scattering 160 GeV muons on at-rest electrons of a low-Z target, $\Delta\alpha_{\text{had}}(q^2)$ can be measured and a **new** and **independent** evaluation of a_μ^{HLO} can be provided
- **A *test run* with reduced apparatus is scheduled in August/September 2023**
- The challenge is to measure the elastic $\mu e \to \mu e$ differential cross section with an unprecedented accuracy, at the 10^{-5} level
- A high-precision Monte Carlo generator, including EWK NLO, QED NNLO and QED higher-order corrections, is mandatory for data analysis. Also relevant backgrounds need to be precisely simulated.

  The generator **Mesmer** is under constant development in Pavia and it is extensively used by the collaboration for feasibility studies and current simulations

  github.com/cm-cc/mesmer

QFT@COLLIDERS

- ✓ Papers
  - ⇝ Budassi *et al.*, "Single π^0 production in μe scattering at MUonE", Phys. Lett. B 829 (2022) 137138
  - ⇝ Zanoli *et al.*, "NNLO event generator for VH production with H$\to b\bar{b}$ decay", JHEP 07 (2022) 008
  - ⇝ Franzosi *et al.*, "Vector boson scattering processes: Status and prospects", Rev. Phys. 8 (2022) 100071
  - ⇝ 7 contributions to Snowmass2021 activities: "Snowmass report: Theory of Collider Phenomena", "Event Generators for high-energy physics experiments", "NNLO+PS with MiNNLO$_{PS}$: status and prospects", "Muon Collider Physics Summary", "The physics case of a 3 TeV muon collider stage", "Prospects for precise predictions of a_μ in the Standard Model", "Initial state QED radiation aspects for future e^+e^- colliders"
  - ⇝ several proceedings of international conferences
- ✓ Coordination / Organization activities
  - ⇝ Carloni Calame, co-organizer of the topical workshop "The Evaluation of the Leading Hadronic Contribution to the Muon g-2: Toward the MUonE Experiment", Mainz Institute for Theoretical Physics, Mainz, 14-18 November 2022
  - ⇝ Piccinini, co-convener dell'ECFA WG2 (Physics and Analysis Methods) dell'ECFA "Study on Physics, Experiments and Detectors at a future Higgs/EW/Top factory" (organization of topical meetings, talks, member of the program committee of the First ECFA Workshop on e^+e^- Higgs/EW/Top factories, Hamburg, october 2022)
- ✓ Several talks at international conferences, workshops and collaboration meetings by all the members

TaSP

Linea 5

Fisica Astroparticellare

Iniziativa Specifica chiusa a Pavia nel 2023

TaSP

- Activity by Marco Roncadelli (INFN):

  1) Explanation of the very high-energy emission of the Gamma-ray burst GRB221009A (observed by LHAASO on October 11 up to 18 TeV and the day after by Carpet-2 up to 251 TeV) in terms of ALPs oscillation into photons.

  2) Moreover, ALPs induce a polarization effect on the radiation from far-away very high energy sources. We have extensively investigated this topic.

G. Galanti, M. Roncadelli, F. Tavecchio, E. Costa, "ALP induced polarization effects on photons from galaxy clusters", Phys. Rev. D 107, 103007 (2023)
G. Galanti, M. Roncadelli, F. Tavecchio "ALP induced polarization effects on photons from blazars", arXiv:2301.08204
G. Galanti, M. Roncadelli, F. Tavecchio, "Assessment of ALP scenarios for GRB 221009A", arXiv:2211.06935
G. Galanti, L. Nava, M. Roncadelli, F. Tavecchio, "Observability of the very-high-energy emission from GRB 221009A", arXiv:2210.05659

G. Galanti, M. Roncadelli, "Axion-like Particles Implications for High-Energy Astrophysics", Universe 8 (2022) no.5, 253, arXiv:2205.00940

- Activity by Andrea De Luca (IASF & INAF) and Andrea Tiengo (IUSS & INAF):

  Systematic analysis of the X-ray observations of the ultraluminous X-ray source XMMU J122939.7+075333. The recurrence of flares together with the observation of the soft spectrum of the X-ray flares would be strikingly similar to the quasiperiodic eruptions recently discovered in galactic nuclei.