# PhD Program in Technologies for Fundamental Research in Physics and Astrophysics

## Curriculum: Computing and Information Technology

**Kickoff meeting - Padova - 10-11/7/2024**

# The Crucial Role of Computing and Information Technology in Fundamental Research

- Information technology and computing technologies have become essential to address the challenges of modern physics and astrophysics
- this curriculum trains experts capable of developing and applying innovative solutions for:
  - processing enormous amounts of data (Big Data) from experiments and simulations
  - utilizing supercomputers for complex simulations and advanced data analysis
  - implementing artificial intelligence algorithms for data analysis and pattern recognition
  - efficient management and storage of scientific data

# Educational Objectives of the Curriculum

- **Acquisition of advanced skills in:**
  - High-performance computing (HPC) techniques and supercomputing
  - Methods for Big Data analysis and management
  - Application of artificial intelligence in the scientific context
  - Development of software and algorithms for fundamental research
- **Preparation for successful careers in:**
  - National and international research centers
  - High-tech industry and sectors that require advanced data analysis skills
  - Academia and universities

# Training Path: An Overview of the Curriculum's Courses

- The curriculum offers a comprehensive and multidisciplinary set of courses, which includes theoretical and practical/hands-on courses covering fundamental topics in CS/AI:
  - Deep Neural Networks & Structured Learning: Machine learning models for structured data, with applications in various fields
  - Statistical Learning: Statistical techniques for data analysis in non-linear and unsupervised contexts
  - Complex Networks: Big Data modelling and learning: Fundamental concepts of complex networks and their use in machine learning
  - Machine Learning ad advanced Scientific Programming in Physics and Sciences
  - System Engineering and project management

# COURSES' DETAILS

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Machine learning and numerical techniques for inverse problems and design of electrical and electronic systems | 15 | 2 | The course provides the main numerical models for the design and simulation of electrical and electronic systems. The most important machine learning models and their use in the field of numerical modeling will be described. Furthermore, applications of finite element and finite difference calculus will be shown for the simulation of the main systems of electrical and electronic engineering. All the methods and techniques presented during the course will be applied and performed on the computer through different programming languages and software platforms. | ROMA3 |

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| Deep Networks & Structured Learning | 18 | 2 | Modern AI is growingly faced with complex problems, characterized by heterogeneous forms of structured evidences in input and complex decisions. In medicine historical data, biological phenomena or images manifest through streams of structured data, usually digitally represented into sequences, trees or graphs. Machine Learning methods for structured learning have been studied whereas some mathematical paradigms (such as dimensionality reduction, structured kernels or neural embedding) have been proposed as modelling tools. In Natural Language Processing, Machine Translation and other Natural Language Inference (NLI) tasks, such as Question Answering or Textual Entailment, have been approached via kernels or neural models of the input representation. These achieved accurate state-of-the-art classification and prediction capabilities by enabling the exploration of huge spaces of possible solutions (e.g. target sequences or decisions). In this way, they correspond to both enabling technologies and software tools as well as to models of investigation able to systematically select hypothesis and validate controversial theories about linguistic phenomena. The application of these empirical methodologies to other areas like biology, medicine and medical robotics is more than promising, given the similar complexity of the domains targeted by AI and Life Sciences. The course will try promote this interesting research perspective in Deep Learning to PhD students with a specific focus, but not limited to, Life Science phenomena. Learning Outcomes: Knowledge about the state-of-the-art neural inference methods through their applications to structured input (sequences, trees and graphs) for classification, transduction and discovery tasks. The course will discuss fruitful integration of deep neural and kernel-based learning methods as modelling tools for complex structures. | ROMA2 |

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Statistical Learning | 18 | 2 | The course is aimed at introducing, from an hands-on perspective, some techniques for statistical learning in non-linear or unsupervised frameworks. Content: Refresher of statistical inference, bootstrapping for standard error and bias estimation. Non-parametric regression based on additive models. Logistic regression. Random forest regression and classification. Techniques for unsupervised statistical learning. | ROMA2 |
| Complex Networks: Big Data modelling and learning | 20 | 2.5 | The increasing availability of high dimensional and heterogeneous data samples (big data) makes urgent the development of a scientific background including data science and machine learning techniques, with applications in many fields. This course introduces the fundamental concepts in complex networks and exploits this framework for learning purposes. We will cover the most popular network models: random graphs, small-world networks, scale-free networks; besides, we will explore how supervised and unsupervised learning algorithms including random forests, artificial neural networks, support vector machines and deep learning, can proficiently exploit the knowledge content provided by complex networks. After explaining the basic centrality measures for nodal and edge characterization, we will discuss the matrix representation of a graph and the necessary steps for automated learning: hypothesis space, overfitting, bias and variance, trade-offs between representational power and learnability, evaluation strategies and cross-validation. The course will be accompanied by hands-on problem solving with programming in R and some tutorial sessions. | UNIBA |

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Machine Learning Programming in Physics | 20 | 2.5 | The course aims to introduce the fundamental concepts related to the development of algorithms capable of taking advantage of machine learning models, optimized for use in physics applications. The selected programming language for this course is Python.<br>Initially, the most important aspects related to Python programming will be introduced, such as the concept of variables, data structures, modules, namespaces, functions, and classes. Script writing, file interaction, and exception handling will be also introduced in this section. This phase related to Python introduction will be complemented by the treatment of the main techniques used for exploration, visualization, cleaning, and manipulation of large data structures using Python modules such as NumPy, Pandas, Matplotlib, and Seaborn. The last part of this course will focus on the most basic aspects of machine learning algorithms (supervised algorithms, unsupervised algorithms, deep learning, and convolutional neural networks) and the most important techniques used for optimization and performance evaluation. Examples of such algorithms will be demonstrated using frameworks like PyTorch, Keras, and TensorFlow. Lastly, the main techniques for speeding up the execution of these algorithms using parallel computing architectures will be described. | UNIBA/ INFN BA |

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Advanced scientific programming in Matlab | 30 | 4 | The course aims to provide advanced skills in scientific programming, and to teach sound methodologies for the development of reliable, optimized and maintainable codes.<br>A basic knowledge of MATLAB and the C language represents a prerequisite of this course.<br>During this course, many common methods used in Scientific Computing will be presented, with particular attention to the most recent programming techniques in MATLAB.<br>At the end of the course, the student will have expanded his/her knowledge of MATLAB and will be able to choose the best approach for the solution of numerical problem he/she will face. | POLITO |
| System on Chip (SoC) programmabili per l'acquisizione e il processamento dati | 20 | 2.5 | Il corso fornisce una panoramica dei dispositivi programmabili odierni quali le FPGA di ultima generazione che sono ormai dei System on Chip che affiancano ai registri, look-up tables e porte logiche tipiche delle FPGA uno o più processori ARM, blocchi dedicati quali DSP e PLL, transceiver a decine di Gb/s, memorie integrate e processori dedicati all'implementazione di reti neurali. Il corso fornirà le basi di utilizzo dell'ambiente di sviluppo Vitis AI proponendo un workflow che parta dalla scrittura di semplici codici VHDL che verranno implementati in un sistema più complesso che include processori, memorie e transceiver embedded. | INFN ROMA 3 |

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Adaptive Optics for Astronomy | 12 | 1.5 | Adaptive optics (AO) is a technology that can be used to improve the image quality of astronomical telescopes by compensating for the blurring effects of the Earth's atmosphere. AO systems work by measuring the distortions in the atmosphere in real time and then using a deformable mirror to correct for these distortions.<br>AO has revolutionized the field of astronomy, allowing astronomers to make observations that were previously not possible. For example, AO has been used to image the surfaces of planets, resolve individual stars in crowded star clusters, and study the dynamics of active galactic nuclei.<br>This course will introduce students to the principles of AO and its applications in astronomy. Students will learn about the different types of AO systems, how they work, and how they are used to make astronomical observations.<br>The course will cover the following topics:<br>- The physics of the Earth's atmosphere and its effects on astronomical observations<br>- The principles of adaptive optics<br>- Different types of AO systems<br>- The design and implementation of AO systems<br>- Applications of AO in astronomy<br>This course is suitable for students with a background in physics or astronomy. No prior knowledge of AO is required. | INAF Padova |
| Fondamenti di system engineering e project management per grandi progetti scientifici | 12 | 1.5 | Il system engineering è un approccio multidisciplinare per la realizzazione di sistemi complessi, come può essere un grande strumento scientifico o un programma di ricerca. Il project management è una disciplina per la pianificazione, l'organizzazione e la realizzazione di progetti a tutte le scale. le due discipline sono complementari e formano un bagaglio di base per lavorare collaborativamente ed entrare attivamente nelle dinamiche dei progetti di ricerca, sia scientifici che tecnologici.<br>il corso è di 12 ore (6 lezione e 6 moduli esercitazione) nelle quali verranno descritti i concetti principali e gli strumenti di lavoro per entrambe le discipline e verranno proposti e discussi insieme esercizi e casi d'uso. | INAF Arcetri |

| DENOM. INSEGNAMENTO | N. ORE TOTALI SULL'INTERO CICLO | CFU | DESCRIZIONE CORSO | UNIVERSITA' |
|---|---|---|---|---|
| Machine Learning for Physics | 24 | 3 | In physics, the use of machine learning algorithms has led to important discoveries earlier than expected and is increasingly present in multiple research areas, from data analysis, detector design, anomaly detection, to generation of simulations. | UniCa |
| Simulation of optical photon propagation for generic scintillator-based detectors | 20 | 2 | This course aims to provide the student with knowledge of radiation measurements and detection techniques. It will also provide the student the capability to implement a dedicated MC simulation of the performances of a generic scintillator-based detector using the GEANT 4 toolkit with hands-on sessions. | POLIBA |

# OTHERS ACTIVITIES (SEMINARS, LABS, HANDS-ONs, …)

| TIPO DI ATTIVITA' | DESCRIZIONE DELLE ATTIVITA' (E DELLE MODALITA' DI ACCESSO ALLE INFRASTRUTTURE DEI DOTTORATI NAZIONALI |
|---|---|
| Attività presso Infrastrutture di ricerca | SOSC - School on Open Science Cloud (INFN)<br>The School is multi-disciplinary and targeted at postgraduate researchers including bachelor degree or equivalent in fields such as physics, statistics, computer science, computer vision, biology, bioinformatics, medicine, engineering working at any research institute, with experience and interest in data analysis, in computing or in related fields. |
| Attività presso Infrastrutture di ricerca | ESC - International School on Efficient Scienfic Computing (INFN)<br>The aim of the ESC school is to offer the participants the opportunity to improve their computing competences, learning from qualified and experienced scientists how to best exploit modern hardware and software technologies in their daily scientific work.<br>The program proposes introductory lectures on trends in hardware architectures and parallel programming, with more in-depth lessons on modern C++, effective memory usage, floating-point computation and programming in a heterogeneous world combining<br>multi-threading, GPUs and clusters.<br>The school is organized as a small class of about 30 students, alternating lectures, hands-on sessions and self-managed time slots for the best learning experience, with lecturers available during the whole week for insights and discussions. |
| Attività di presso Infastruttura di ricerca / seminari / attività di laboratorio | We will illustrate the design of Deep Neural Network (DNN) algorithms for both very low latency (inference <500ns/event) and higher latency systems (inference <1ms/event) with DNNs implemented on both traditional processors equipped with ML extensions and on commercial accelerators (NVIDIA GPU, Xilinx Alveo, ACAP, Edge/DPU (ZCU102/103/104), etc.), for real-time applications in the field of high-energy physics and technological/industrial applications. The front lectures/seminars will be supplemented by hands-on sessions for the practical implementation of all the various steps of the development pipeline. |

| TIPO DI ATTIVITA' | DESCRIZIONE DELLE ATTIVITA' (E DELLE MODALITA' DI ACCESSO ALLE INFRASTRUTTURE DEI DOTTORATI NAZIONALI |
|---|---|
| Seminari | Seminars of Computational techniques for the search of gravitational waves (INFN): we propose a series of seminars devoted to introduce students to various computational techniques to be used in the general context of advanced signal processing, with a specific focus on the search of gravitational waves (GWs).<br>Covered topics will include: basic concepts in signal processing; Fourier analysis; matched and Wiener filtering; image processing techniques (e.g. 2D Fourier transform); pattern recognition methods (e.g. Hough transform, Radon transform); machine learning methods (denoisers, classifiers); code and data access optimisation; introduction to GPU programming; introduction to the use of CPU/GPU clusters |
| Attività presso Infrastrutture di ricerca | Physics with Accelerators: Introduction to the Standard Model of elementary particles, principles of accelerator operation, radiation-matter interaction, principles of particle detector operation, examples of experimental apparatus, and triggers. The course will be conducted in the form of a residential summer school at one of the INFN National Laboratories (LNGS or LNF) and includes theoretical lessons, lab visits, and hands-on activities. |
| Attività presso Infrastrutture di ricerca | Astroparticle Physics: Introduction to astroparticle physics. Study of rare events in underground experiments. Ground and space experiments for the study of neutrinos and cosmic radiation. Systems for the detection of gravitational waves. The course will be conducted in the form of a residential summer school at one of the INFN National Laboratories (LNGS or LNF) and includes theoretical lessons, lab visits, and hands-on activities. |
| Seminari | Nuclear Safety applied to basic physics research facilities: A systematic approach to safety in basic physics research facilities cannot do without applying the investigation methods and risk analysis techniques developed by Nuclear Safety for over sixty years. During the seminar, the main themes of the subject will be introduced starting from the principles of Radioprotection, to the theory of Defense in Depth, with some application examples of safety analysis methods for research applications. |

| TIPO DI ATTIVITA' | DESCRIZIONE DELLE ATTIVITA' (E DELLE MODALITA' DI ACCESSO ALLE INFRASTRUTTURE DEI DOTTORATI NAZIONALI |
|---|---|
| Corso di formazione | The aim of this course is to give Introduction to Parallel Programming for Shared Memory and Message Passing paradigms. The basic functionalities of two of the widest used parallel programming tools are presented: the MPI (Message Passing Interface) library for distributed architectures and OpenMP system for shared memory and multicore architectures.<br><br>MPI is a message-passing library specification which provides a powerful and portable way for expressing parallel programs.<br><br>OpenMP is a portable and scalable model that gives shared-memory parallel programmers a simple and flexible interface for developing parallel applications for platforms ranging from desktop to supercomputers.<br><br>Implementations of both MPI and OpenMP are available for all modern computer architectures. Programs can be written in C/C++ or FORTRAN.<br><br>Large part of the course will be devoted to practical sessions where students will use the concepts discussed in the presentations to parallelise the proposed programs. |
| Corso di formazione | This course will introduce the fundamentals of C++ language, using both procedural and object oriented programming approach. The student will be presented with the key topics of the language in order to have a good starting point for further investigations that will be required according to the specific field of application. |
| Summer School | High Performance Computing (HPC) is widely used in many areas of science, engineering and industry to tackle problems that are very compute or data-intensive. HPC techniques are essential for any scientist who must solve computational problems and for any software developer who wants to take full advantage of modern multicore processors and parallel architectures. The same HPC techniques can be used to program powerful supercomputers with hundreds of thousands of processors or to exploit the full potential of a multi-core laptop.<br><br>The Summer School on Parallel Computing is an intense, five days, graduate level course in HPC, with the objective of providing the participants the fundamentals to program and exploit modern parallel computing systems to solve computational problems. It will comprise full theoretical and practical lessons on Marconi 100 Cineca cluster.<br><br>The school covers key topics focusing on HPC lexicon, parallel architectures, parallel programming models and methods. |

# Current PhD students: Neeraj Yadav

- PhD Supervisor: Dr. Stefano Bagnasco, INFN
- Hosting Institution: INFN Sezione di Torino
- Curriculum: Technologies for Fundamental Research in Physics and Astrophysics
- Grant title: Advanced Computing Systems for Gravitational-wave Research
- Research Topic: Advanced tools for low-latency alert generation and management
- Publication: S. K. Sahoo, N. Yadav, and I. Banerjee, "Imprints of Einstein-Maxwell-dilaton-axion gravity in the observed shadows of Sgr A* and M87*", Physical Review D, vol.109, no.4, pp.044008, American Physical Society 2024 ( https://doi.org/10.1103/PhysRevD.109.044008 )

INFN TORINO
Istituto Nazionale di Fisica Nucleare
Sezione di Torino

# Current PhD students: Robert Panai

## National PhD in Technologies for foundamental physics and astrophysics

- Curriculum: computing and IT systems
- Host: University of Cagliari (UniCa)
- Supervisor: Andrea Contu
  Cosupervisor: Pierluigi Bortignon, Diego Reforgiato
- Research project: application of machine learning and quantum computing for data analysis in gravitational waves physics

**Current project: normalizing flows for boost GW pipeline**

- NF: deep learning model using invertible transformation to map complex distribution to a simple ones (e.g. Gaussian)
- Objective: Model the distribution of galaxy coordinates conditioned on redshift and luminosity power
- Model: Gaussian base distribution, coupled rational quadratic splines.
- Input: a.r, dec - Context: z, L^a
- **Next step: boost a GW inference framework to identify host galaxies**

**Current project: benchmarking superconductor vs neutral atoms quantum computers**

- Objective: Develop algorithms for data manipulation (e.g. quantum superposition rotations of data strings) to benchmark and test quantum error correction
- Approach: Implement data manipulation techniques using a high number of quantum gates. Compare performance of superconducting and neutral atoms quantum computers

**Next step: explore the potential of developing quantum machine learning models for gravitational waves research**

**Purpose of the thesis and next projects:**

- Boost data analysis research with machine/deep learning models
- Development of machine learning models for extract GW parameters
- Explore applications of quantum machine learning in physics

INFN CAGLIARI
Istituto Nazionale di Fisica Nucleare
Sezione di Cagliari

Università degli Studi di Padova

# Current PhD students: Ali Saim

The research project aims to design and develop **efficient** and **parallelized** models for **big data analysis**, leveraging advanced visualization techniques and algorithmic solutions on modern H**PC computing systems**. This endeavor focuses on discovering astrophysical patterns from cosmological simulations.

Furthermore, the project is focused on creating innovative solutions for processing large datasets and accelerating computation. This involves developing portable algorithms with multi-platform paradigms and optimizing image reduction pipelines, potentially utilizing GPU platforms and AI libraries.

**Tool:** VisIVO Server is a tool for creating customized views of 3D renderings from astrophysical data tables.

**Data:** In this project we will use large box-sized cosmological N-body simulations, the so-called Dark Energy and Massive Neutrino Universe" (DEMNUni) suite.

**Hosting Research Centre:** INAF Astrophysical Observatory of Catania

**Supervisors:** Dr. Fabio Roberto Vitello, **Co Supervisor:** Dr. Eva Sciacca

worked on the **Characterization** and **assembly** of **Silicon sensors** for the phase II upgrade of CMS outer tracker.

Dark matter analysis using **CMS** data and Heavy ion Physics analysis using **ALICE** data.

# Current PhD students: Muhammad Waqas

Supervisor : Dr Valerio Formatto

## Alpha Magnetic Spectrometer (AMS 02)

AMS purpose is to perform high precision, high statistics, and log measurement of charged cosmic rays in .5GeV to 1.5 Tev

## Graph Neural Network (GNN) in Particle Tracking

### Track finding & Track fitting

- Identify and group measurements (hits) from same particle trajectory
- Estimating the trajectory of a particle using the hits

### • Deep Learning (DL)

- Convolutional Neural Networks (CNNs) works Grid-like data (images)
- Recurrent Neural Networks (RNNs) deals with sequential data (Text, Time series)

### Geometric Deep Learning (GDL)

Graph Neural network (GNN)is designed for data that can be represented as graphs (nodes connected by edges)

INFN ROMA TOR VERGATA

Istituto Nazionale di Fisica Nucleare
SEZIONE DI ROMA TOR VERGATA



# *Neeraj Yadav*

## *PhD Kick-off Event*

## *July 10-11, 2024*

# BACKGROUND DETAILS

- Integrated M.Sc. in Physics ans Astronomy (2018-2023) from National Institute of Technology Rourkela (NIT), India
- Master's Thesis Advisor: Professor Indrani Banerjee
  - Title: A study of Einstein-Maxwell dilaton-axion (EDMA) gravity in the light of the observed shadows
- Publication: S. K. Sahoo, N. Yadav, and I. Banerjee, "Imprints of Einstein-Maxwell-dilaton-axion gravity in the observed shadows of Sgr A* and M87*", Physical Review D, vol.109, no.4, pp.044008, American Physical Society 2024 ( https://doi.org/10.1103/PhysRevD.109.044008 )

# CURRENT PHD POSITION

- PhD Supervisor: Dr. Stefano Bagnasco, INFN
- Hosting Institution: INFN Sezione di Torino
- Curriculum: Technologies for Fundamental Research in Physics and Astrophysics
- Grant title: Advanced Computing Systems for Gravitational-wave Research
- Research Topic: Advanced tools for low-latency alert generation and management

# National PhD in Technologies for foundamental physics and astrophysics

**Bachelor Degree**:
Physics, UniCa. (2017-2021)
**Thesis**: A diatonic non-singular black hole with magnetic charge
**Supervisor**: Salvatore Mignemi

Theoretical study of solutions to Einstein's equations with coupling to the dilatonic and electromagnetic fields. The result is a singularity-free black hole with magnetic charge.

**Master Degree**:
Experimental physics of foundamental interaction, UniCa. (2021-2023)
**Thesis**: A software framework for systematics effects in continuous gravitational waves research
**Supervisor**: Andrea Contu

A code has been developed to perform software injections of continuous gravitational wave signals into the O3 run data of Virgo and LIGO. The injected data is used to study possible systematic effects of a search pipeline based on the Hough transform.

**Skills and scientific interest:**

- **General relativity/ Gravitational waves**
- **Machine Learning**
- **Quantum computing**

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Istituto Nazionale di Fisica Nucleare
Sezione di Cagliari

Robert Panai - Padua, 10/07/2024

Università degli Studi di Padova

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- Explore applications of quantum machine learning in physics

Robert Panai - Padua, 10/07/2024

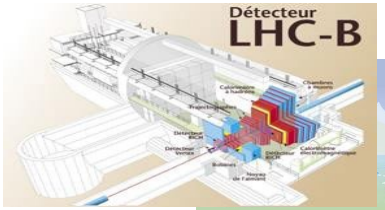
INFN CAGLIARI
Istituto Nazionale di Fisica Nucleare
Sezione di Cagliari

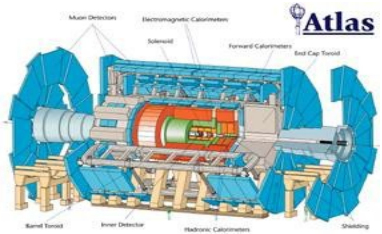
Università degli Studi di Padova

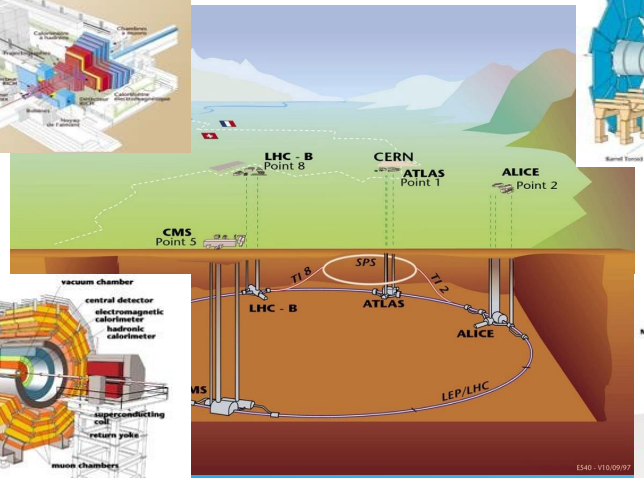
Saim Ali
PhD Student
University of Padua
INAF Catania

# Characterization of Silicon Sensors of the CMS Outer Tracker, Dark Matter analysis using CMS Data and ALICE Data for Heavy ion collisions

- Bachelor of Studies in Physics with Research in **Plasma Physics.**
- Master of Philosophy in **Experimental High Energy physics** at **National Centre for Physics** Pakistan in Collaboration with **CMS** and **ALICE** experiment at **CERN.**
- I have worked on the **Characterization** and **assembly** of **Silicon sensors** for the phase II upgrade of CMS outer tracker.
- Dark matter analysis using **CMS** data and Heavy ion Physics analysis using **ALICE** data.

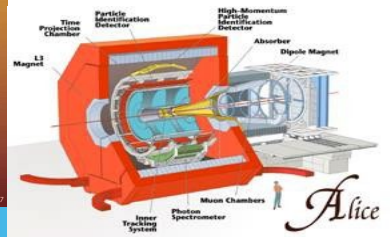








# Title: Analysis of astrophysical phenomena using efficient and parallelized models on HPC computing systems

The research project aims to design and develop **efficient** and **parallelized** models for **big data analysis**, leveraging advanced visualization techniques and algorithmic solutions on modern H**PC computing systems**. This endeavor focuses on discovering astrophysical patterns from cosmological simulations.

Furthermore, the project is focused on creating innovative solutions for processing large datasets and accelerating computation. This involves developing portable algorithms with multi-platform paradigms and optimizing image reduction pipelines, potentially utilizing GPU platforms and AI libraries.

**Tool:** VisIVO Server is a tool for creating customized views of 3D renderings from astrophysical data tables.

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**Hosting Research Centre:** INAF Astrophysical Observatory of Catania

**Supervisors:** Dr. Fabio Roberto Vitello, **Co Supervisor:** Dr. Eva Sciacca

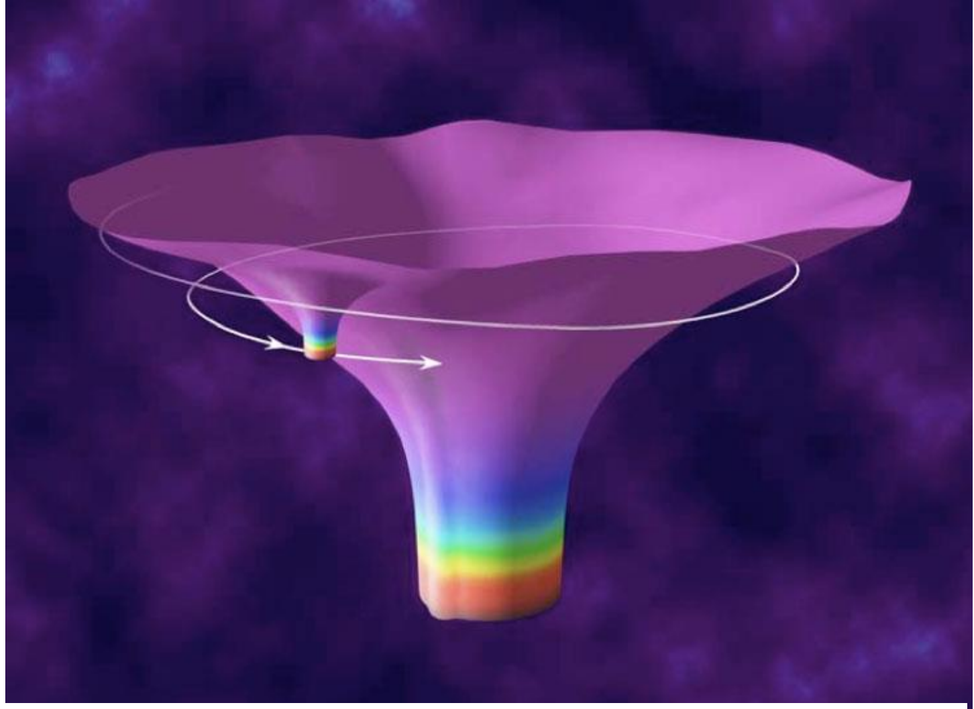
Istituto Nazionale di Fisica Nucleare
SEZIONE DI ROMA TOR VERGATA

UNIVERSITÀ DEGLI STUDI DI PADOVA

# "Exploring the Cosmos: My Path from Previous Work to High Energy Astrophysics Research"

Muhammad Waqas
PhD 1st Year - 39th Cycle
Supervisor : Dr Valerio Formatto
INFN Tor Vergata
09 July, 2024

# From Passion to Purpose: My Pre-PhD Journey



## Education and Training

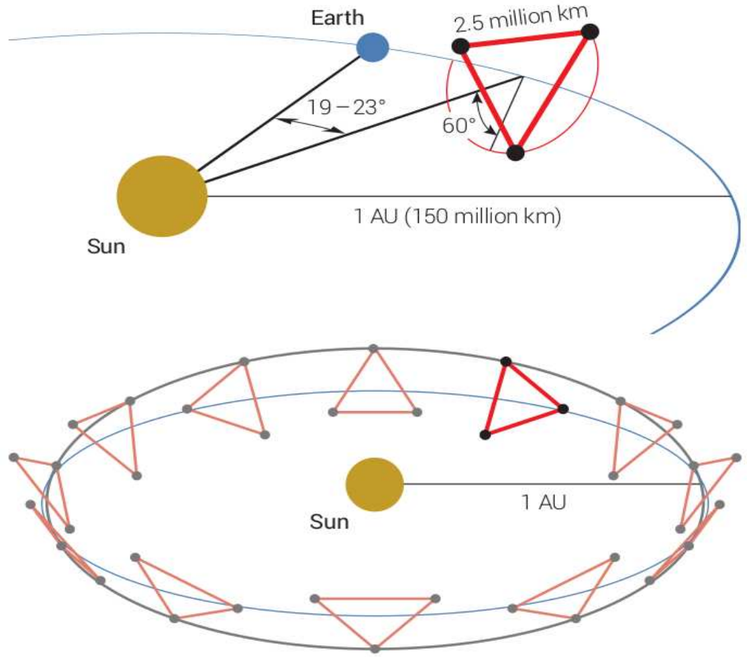
**MS Astronomy and Astrophysics**
(Institute of Space Technology, Islamabad, Pakistan)
Thesis Title : Event Rate of Extreme Mass-Ratio Inspiral Systems in M32 Galaxy

## Teaching Experience

**Lecturer of Physics** - National Excellence Institute, Islamabad, Pakistan

## Industry Experience

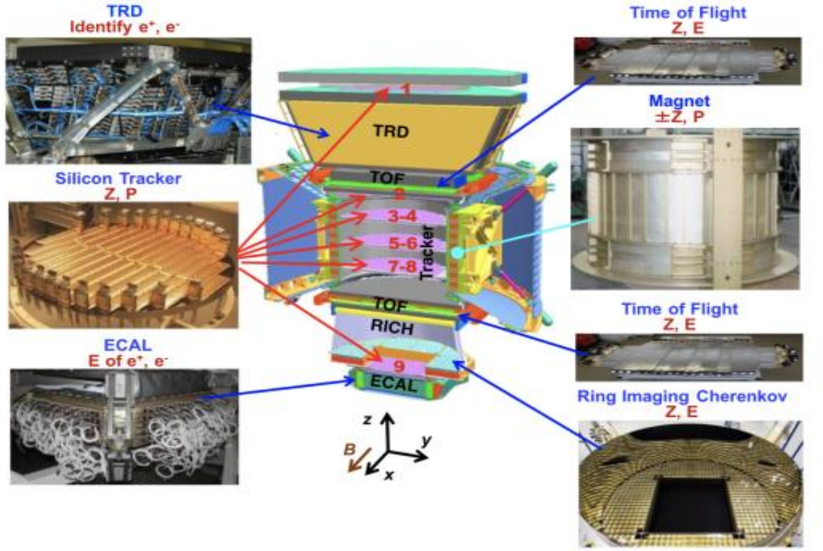
**Telecom Engineer** (LCC International, Islamabad, Pakistan)
2G & 3G Drive Testing for GSM & WCDMA



# Alpha Magnetic Spectrometer (AMS 02)

AMS purpose is to perform high precision, high statistics, and log measurement of charged cosmic rays in .5GeV to 1.5 Tev

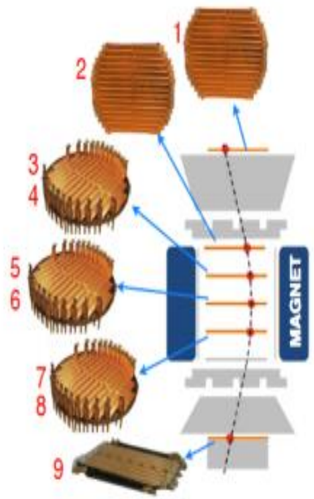
AMS 02 Launch Date : 16th May 2011 by NASA
400 km above the ground
3m*4m*6*m in volume



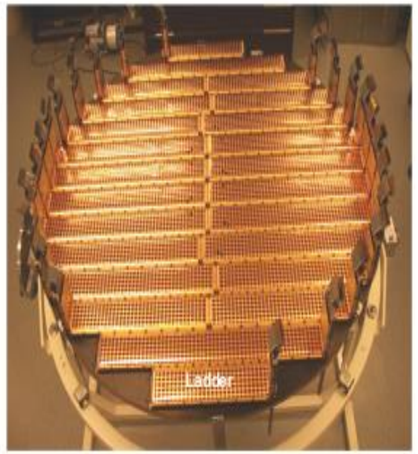

AMS Scientific Goals are :

- Search for cosmic matter
- Search for Dark matter signatures
- Measurment of cosmic ray spectra, relative abundances, and isotopes
- Search for new form of matter

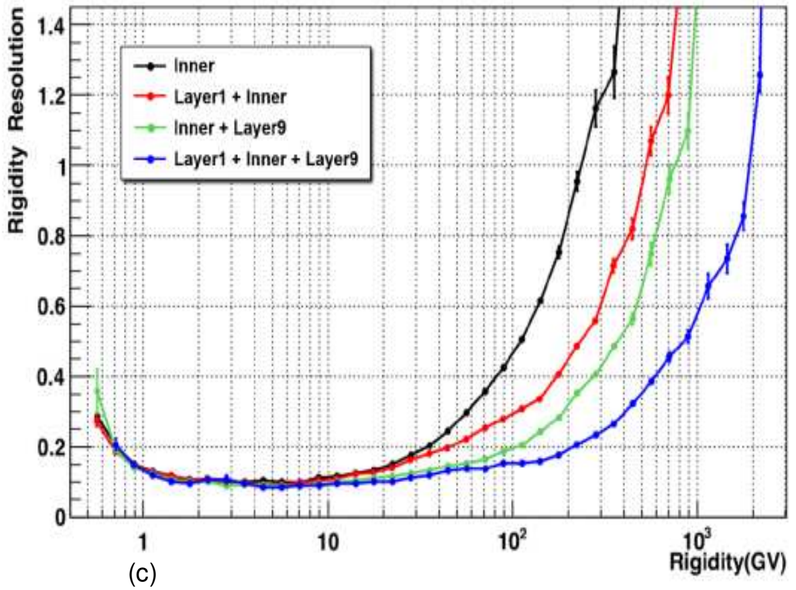
# Silicon Tracker (STK) & Magnet



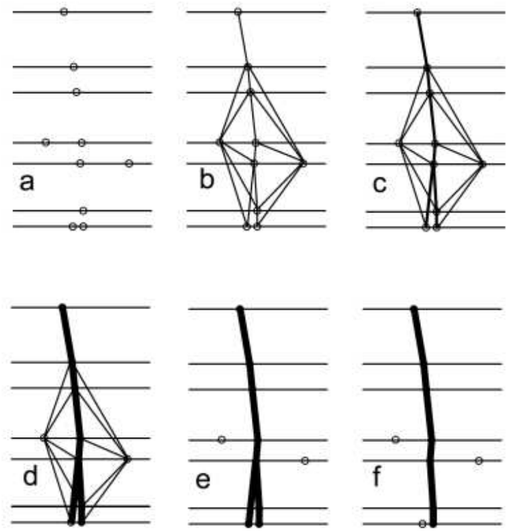

(a)




(b)




(c)




d) Illustration of cellar automaton reconstruction

a) The AMS-02 STK 9 layers
b)Real view of a silicon tracker inner plane
c) STK rigidity resolution for protons as estimated from the Monte Carlo simulation
d) Illustration of cellar automaton reconstruction

- Functions are Momentum **P**, Charge **q**, and Magnetic Rigidity **Z= P/Z.**
- It accurately r**econstructs the charged particle trajectory** traversing the apparatus.
- **charge-sign** can be determined with the complementary direction information from the **TOF**
- Working Principle
- Alignment
- Track Trajectory

# Graph Neural Network (GNN) in Particle Tracking

## Track finding & Track fitting

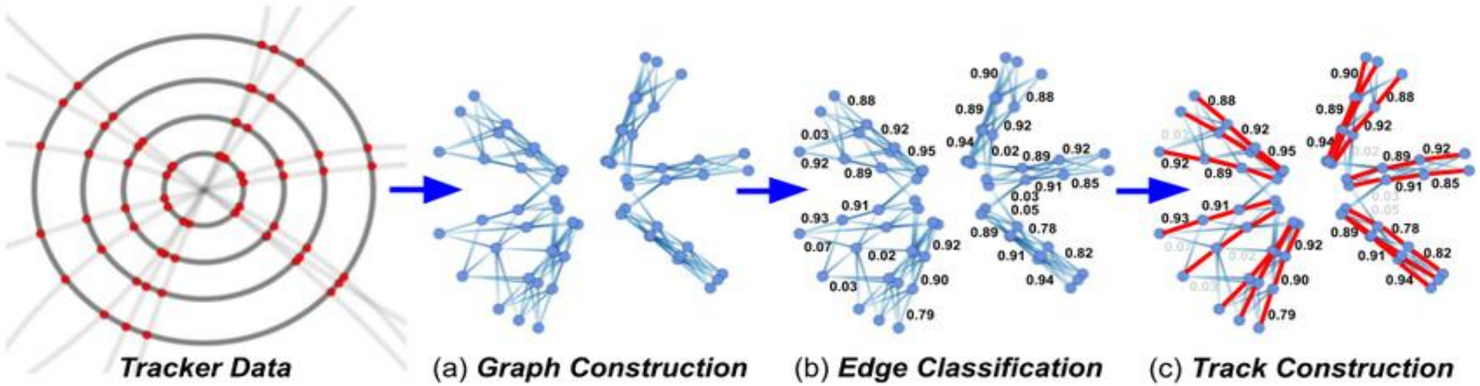
- Identify and group measurements (hits) from same particle trajectory
- Estimating the trajectory of a particle using the hits

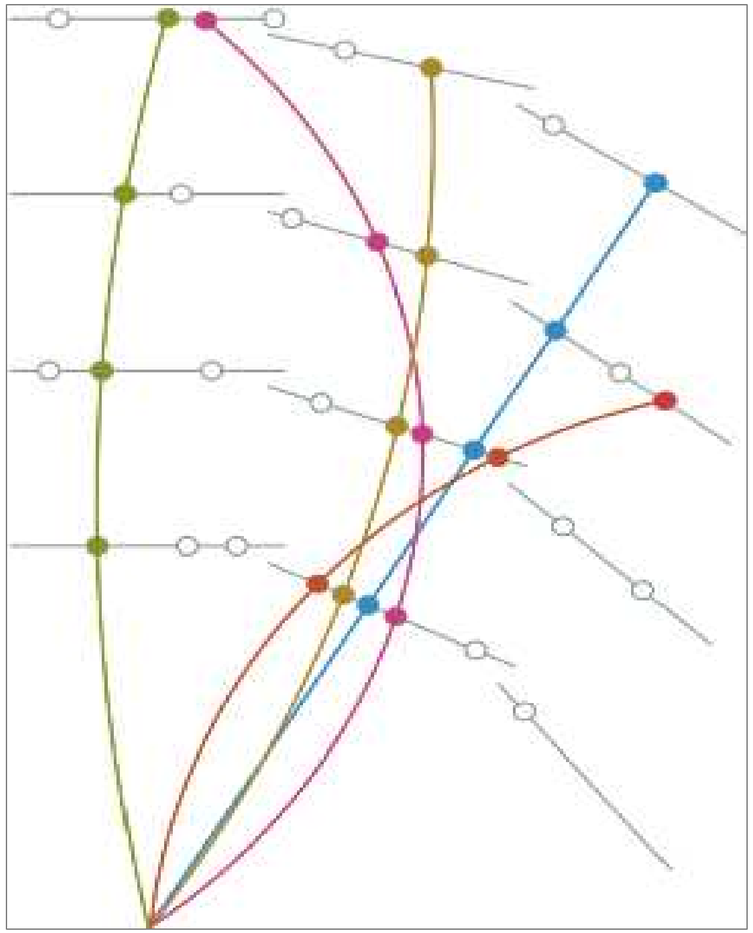
## • Deep Learning (DL)

- Convolutional Neural Networks (CNNs) works Grid-like data (images)
- Recurrent Neural Networks (RNNs) deals with sequential data (Text, Time series)

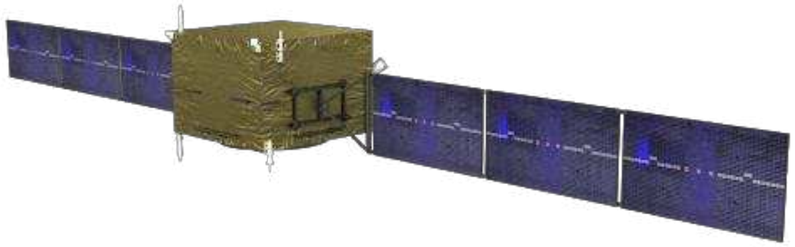
## Geometric Deep Learning (GDL)

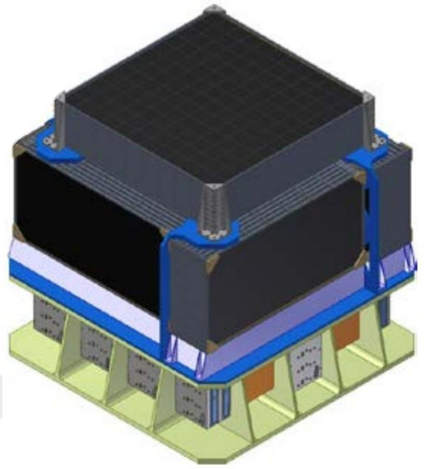
Graph Neural network (GNN)is designed for data that can be represented as graphs (nodes connected by edges)



- Colored curve are trajectory of a charged particle in cons **B**
- solid circles are hits by the particle
- Empty circles are noise hits not created by a reconstructible particle.





# Thank You