UNIVERSITÀ DEGLI STUDI DI PADOVA

PhD course of National Interest in Technologies for Fundamental Research in Physics and Astrophysics

Annual report

Name and surname: Muhammad Waqas
Cycle and a.a.: XXXIX 2023-2024
Supervisor: Dr.Valerio Formato

- ## Research activity carried out during the year

I have been the part of AMS-Italy at Tor Vergata university, which has been working on the Alpha Magnetic Spectrometer 02. Major portion of my literature review has been to understand the AMS02 detection pipeline, The Alpha Magnetic Spectrometer 02 (AMS-02) is a high-energy particle physics experiment installed on the International Space Station the 19th of May 2011 and has been operating continuously since then. The AMS-02 has been designed to accurately separate all species of charged cosmic rays in a large rigidity (momentum/charge) range, from fraction of GigaVolts (GV) to multi TeraVolts (TV), to search for primordial complex anti-matter, indirect detection of Dark Matter through the measurement of features in the spectral shapes of cosmic rays anti-particle spectra as e+ and p-, precisely measure the most abundant cosmic rays species (e^-, p, He, nuclei with $Z > 2$) and constrain models describing cosmic rays origin, acceleration and propagation.

In the first year, my efforts were directed towards visa procurement, coursework completion, and an extensive literature review. Recognizing that AMS-02 comprises several sub-detectors, Silicon Tracker (STK), permanent magnet, Transition Radiation Detector (TRD), anticoincidence, counters (ACC), Time of Flight (TOF), 3-D sampling calorimeter (ECAL), Ring Imaging Cerenkov Counter (RICH). All sub-detectors collectively contribute to the integrity and precision of the data. Studying and understanding their respective part is very crucial for the later analysis part of the research to have a concise and complete picture of the solution and its robustness.

A significant focus of my research has been on the Silicon Tracker, crucial for accurately reconstructing charged particle trajectories. I reviewed recent advancements and identified the potential of Graph Neural Networks (GNNs) for particle tracking. Since GNNs are more suited for particle tracking in AMS02 because they naturally handle graph-structured data, where nodes of the silicon tracker represent individual hits and edges will be the trajectory of their spatial or temporal connections. Unlike traditional deep learning pipelines, which often require data to be transformed into grid-like structures and might struggle with irregular, sparse data. In our 2nd year of PhD research, we will build a pipeline of GNN on test beam data, which was done before second alignment at the CERN facility using the primary 400 GeV/c proton beamline with deferent combinations of positions and orientations to simulate the cosmic rays arrival at AMS in space. Once we will build this pipeline, we will then apply it on real data to analyze the flux of heavy nuclei like Silicon.

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- **List of attended courses and passed exams**
    - High-Energy Particle Physics Detectors In Space (approved/passed)
    - Machine Learning for Physics (final presentation is forthcoming)
    - Complex Networks: Big Data modelling and learning (has not been started)
    - Cyber Security course from INFN Tor Vergata.

- **List of attended conferences, workshops and schools, with mention of the presented talks**
    - Participated in the AMS-Italy analysis meetings.
    - Introduction on the NAIA dataset framework and tools, held at Roma Tor Vergata.
    - AMS general Meeting at CERN from 18^{th} Sep to 20^{th} Sep at CERN, SWISS.
    - Padua Kick-off Meeting.

- **List of published papers/proceedings**

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- **Thesis title: "**Enhancing Particle Identification and Reconstruction in AMS-02 Silicon Tracker Using Graph Neural Networks"

Date: 12/09/2024 **Signature:**

Seen, the supervisor