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

Annual report

Name and surname: Muhammad Ali
Cycle and a.a.: 39th cycle
Supervisor: Dr. Rosamaria Venditti/ Dr. Salvatore My

- **Research activity carried out during the year**

I am working on Micro Pattern Gaseous Detectors (MPGDs) with CMS and Muon Collider team at INFN- Bari.
The research project is focused on developing the hadron calorimeter (HCal) using the MPGD technology as the active layer for an experimental facility at a future muon collider, a machine that would allow to investigate the Standard Model with unprecedented precision. One of the major challenges for the experiment design, is the muon beam-induced background (BIB), that poses potential limitations on the detector performance and requirements on radiation hardness. Some of the physics goals of the Muon Collider include precision measurements of the Higgs boson couplings, which require excellent separation between Z and Higgs boson events, even in their hadronic decay channels. This demands the identification and the four-momentum estimation of neutral and charged hadrons, as well as the clustering in jets, that depends on the correct assignment of the calorimeter hits to the reconstructed particles, which requires a combination of an excellent tracking system with high-granularity calorimeters. Therefore the HCal for the future experimental facility should be designed to accomplish such tasks. The MPGD-based HCAL proposed in this project consists of a sampling of absorber material and resistive Micro Pattern Gas Detectors (MPGD) as the active layer, featuring high rate capability (MHz/cm^2), flexible spatial and good time resolution ($\mathcal{O}$(1ns)), good response uniformity (30%), and modest cost for large area instrumentation.
Recently the Bari group designed and built several prototypes of resistive micromegas and μ-RWELL with 20x20 cm^2 active area and with a readout board segmented in 384 pads of 1x1 cm^2, with the goal to study their performance and implement a first HCAL prototype. During the first year of the PhD I started the characterization studies of such prototypes, both in lab and with test beam, and a first implementation of the HCal prototype in GEANT4, as detailed below:

1. **Characterization of resistive μ-RWELL:**
   The characterization of the μ-RWELL prototype has been performed in Bari lab, with the goal to evaluate the basic parameters of a MPGD: the effective gas gain and the response uniformity. The μ-RWELL is flushed with Argon (Ar) and Carbon dioxide (CO_2) gas mixture with a concentration ratio of (Ar:CO_2|70:30). I set up the measurement, that employs an X-ray beam generated by an AmpTek device to create photo-electrons in the detector gas volume. The detector is powered through a high-voltage power supply in order to establish the electric

fields. The power supply measures also the currents drawn by the electrodes with a resolution of the order of 50 pA. First results show that the gain Ar:CO_2|70:30 is under the usual operational conditions and that the response uniformity, measured as gain variation across the whole detector surface, is around 25%.
Future plans: measure the gas gain and uniformity with the mixture Ar:CO2:CF4/45:15:40 for all the μrwell detectors developed for this project.

2. **First look at the data collected during the test beam of the resistive MPGD and the HCAL prototype in July 2024:** The test beam campaign took place at CERN in July 2024 with the goal to measure the performance of the single MPGD (three MicroMegas and five μ-RWELL) and the full HCAL prototype . I am involved in the data analysis of the MPGD performance. I am currently developing a code to identify and remove the noisy channels.
Future plans: measure the efficiency and response uniformity of the MPGD with muon beams.
3. **A simplified simulation of the MPGD-HCAL apparatus with GEANT4**: I have implemented a simplified geometry of the MPGD-HCAL apparatus in GEANT4, with a surface of 100 cm² in the XY plane and segmented in 50 layers along the z direction. Each layer consists of a sampling of iron and argon. I investigated the response of such a system to Pions ($\pi-$, $\pi+$) and Kaon beams (K^0 and $\bar{K}^0$) at energies 1, 5, 10, 20, and 50 GeV. The purpose of this exercise is to gain confidence with GEANT4 software and the design of a calorimeter.
Future plans: study the performance of the actual prototype with GEANT4, in terms of response to muons and pions and compare the results with test beam data.

I arrived in Italy in mid-April 2024, therefore activity 1. and 2. started in that period. The Geant4 exercise described in 3. has been carried out while I was in Pakistan.

Additional future plans include the characterization of the modules of the ME0 station for the Phase II upgrade of the CMS experiment. These modules are based on triple GEM technology and will be produced by the Bari group in the next months.

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- **List of attended courses and passed exams**

1. Gaseous detectors for experimental particle physics *(will start next tuesday, Sept 10)*
2. Machine learning programming in physics *(will start in late Sept.)*
3. Design of readout integrated circuits for particle physics *(will start Nov)*

- **List of attended conferences, workshops and schools, with mention of the presented talks**

  - XXXV Edition of the International School “Francesco Romano” on Nuclear, Subnuclear and Astroparticle Physics - Monopoli (Italy) - 6-13 October 2024. https://agenda.infn.it/event/40753/
  - DRD1 Gaseous Detectors School November 27, 2024 to December 6, 2024 CERN, Switzerland. https://indico.cern.ch/event/1384298/

- **List of published papers/proceedings**

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- **Thesis title (even temporary)**

  Hadron Calorimeter MPGD-based development for future Muon Collider Experiment.

Date

6 September 2024

Signature…

Seen, the supervisor