

# Ph.D. Annual Report

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My Ph.D. activity focuses on Light Dark Matter (LDM) search through experiments at accelerators. In particular, my PhD project is developed in the context of the POKER (POsitron resonant annihilation into dark mattER) experiment, performing a missing-energy measurement employing positron beams impinging on an active thick target. The beam interaction with this detector could produce feebly interacting massive particles, exiting from it undetected and carrying away a significant fraction of the primary positron energy. The POKER activity is integrated into the NA64 experimental program, operating at the H4 beamline at CERN, searching for LDM through the same experimental technique, and performing a complementary electron-beam measurement.

During the third year of my Ph.D. activity, I contributed to the NA64 data analysis, studying the first 70 GeV positron-beam dataset collected by NA64 in 2023 with the existing, non-optimised configuration. In parallel, I contributed to the ongoing POKER electromagnetic calorimeter *R&D* program. Starting from March 2023, I obtained a one-year Doctoral Student position at CERN. During this extended period, I strongly contribute to many aspects of the NA64 experimental project. I actively collaborated with detector experts and was involved in planning measurements, preparing the experimental setup, and participating in data collection efforts.

The 70 GeV positron-beam data analysis was based on statistics of  $(1.6 \pm 0.1) \times 10^{10}$  positrons on target collected by the experiment in summer 2023. In the analysis, I focused on the selection cuts optimisation to maximise the sensitivity to the LDM production signal. After the unblinding, no events were found in the signal region. This result allowed us to set exclusion limits that prove the effectiveness of varying the positron beam energy to scan the LDM parameter space. Moreover, these measurements allowed the characterisation of background sources at 70 GeV, representing a crucial step towards the POKER program at this beam energy.

The crucial element of the POKER project is the high-resolution  $\text{PbWO}_4$  electromagnetic calorimeter employed as the active target. A prototype of this calorimeter, POKERINO, consists of a 3x3 matrix of  $\text{PbWO}_4$  crystals with a SiPM-based read-out system, which I contributed to design and build. In the summer of 2023, the POKERINO's response to high-energy particles was measured for the first time at the H8 beamline of the Super Proton Synchrotron (SPS) at CERN. My presence in the lab allowed me to interact with the beamline experts and define the optimal beam configurations for measurements.

I was responsible for the data analysis, measuring the detector’s response linearity, resolution and stability. Evaluating the saturation effects in the POKERINO response was a crucial purpose of the studies due to the finite number of pixels in SiPMs. The analysis showed that saturation effects are limited and properly correctable. Moreover, the POKERINO energy resolution was studied at different beam energies, resulting being  $\sigma_E/E \simeq 1\%$  in the energy range between 40 GeV and 100 GeV. A second, dedicated on-beam characterisation of POKERINO was carried out at the SPS H6 beamline in July 2024. I joined the experimental effort, working on the detector test and data-taking shifts. I plan to analyse the data collected during these measurements in the coming months.

**List of publications:**

- Andreev, Yu. M. et al. “First Results in the Search for Dark Sectors at NA64 with the CERN SPS High Energy Muon Beam”. 10.1103/PhysRevLett.132.211803
- Oberhauser, B. Banto et al. “Development of the fully Geant4 compatible package for the simulation of Dark Matter in fixed target experiments”. 10.1016/j.cpc.2024.109199
- Andreev, Yu. M. et al. “First constraints on the  $L_\mu - L_\tau$  explanation of the muon g-2 anomaly from NA64-e at CERN”. 10.1007/JHEP07(2024)212

**List of presentations:**

- P. Bisio “The POKERINO prototype” - Poster within the 16th Pisa Meeting on Advanced Detectors (PM 2024). May 2024, La Biodola.

**List of attended courses and exams given:**

- Neutrinos and Nuclear Astrophysics (S. Zavatarelli)
- The Double Trouble of the Missing Matter in the Universe (E. Branchini)