**LNF – FRASCATI NATIONAL LABORATORY**

**Belle II**

**Title:** Optimization of reconstruction and identification of $K_L$ mesons in Belle2 with Machine Learning techniques.

**Description:** The Belle II experiment runs at the $e^+e^-$ SuperKEKB collider in Japan. SuperKEKB currently holds the world record of instantaneous luminosity and aims to reach by early 2026 the unprecedented luminosity $10^{35}\text{cm}^{-2}\text{s}^{-1}$, which will allow Belle II to collect a huge-statistics dataset of $B$, $D$ and $\tau$ decays (among others).
The reconstruction and particle identification of $K_L$ mesons is key in Belle II for time-dependent charmonium or charmless decays such as $B^0 \to J/\psi K_L$ and $B^0 \to \eta' K_L$. The optimization of detector and analysis performance of $K_L$ mesons is also crucial to control systematic uncertainties in analyses such as dark matter searches or decays with neutrinos in the final state, which are sensitive probes of New Physics and are unique to Belle II.

**Activities:** The student will perform the analysis of data collected by the Belle II detector, including those from $e^+e^- \to {D_{(s)}}^{*+}{D_{(s)}}^{*-}$ decays, to measure and optimize the $K_L$ reconstruction and particle identification in an ample range of $K_L$ momenta. This will involve a deep understanding of the electromagnetic and hadronic calorimetry used to the detect the $K_L$ mesons, as well as the use and development of sophisticated machine-learning techniques to improve the identification efficiency and reduce contamination from unwanted sources. Knowledge of the Python and C++ programming languages is required.

**Tutor:** Giuseppe Finocchiaro (giuseppe.finocchiaro@lnf.infn.it)

**Activity period:** June-July or September-October 2025

**Local Secretariat:** Maria Cristina D'Amato (maria.cristina.damato@lnf.infn.it)

**Other information:**
Accommodation: students may be accommodated, free of charge, in the LNF guesthouse (for information: http://www.lnf.infn.it/funz/concorsi/foresterie.html).
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**LNF – FRASCATI NATIONAL LABORATORY**

**SIDDHARTA - Kaonic atoms at the DAFNE collider**

**Title: Kaonic Atoms with the SIDDHARTA-2 Experiment at the DAFNE Collider: A Strangeness Adventure!**

**Description:** Are you ready to embark on a journey into the world of strangeness? Join the SIDDHARTA-2 experiment, a groundbreaking effort to study and explore kaonic atoms at the DAFNE collider, the only one of its kind in the world! Using a kaon beam, SIDDHARTA-2 is making history by measuring X-ray transitions in kaonic atoms (atoms where electrons were replaced by kaons – i.e. particles containing the "strange" quark), unveiling the secrets of strong interaction in systems with strange quarks.
Equipped with cutting-edge Silicon Drift Detectors for precision X-ray spectroscopy, alongside advanced detectors like CdZnTe and HPGe, the experiment is not only probing for the first time kaonic deuterium but also heavier kaonic atoms such as carbon and lead. The results will provide unprecedented insights into the strong interaction and its implications, ranging from the microcosm of particle and nuclear physics to the cosmic scale of neutron stars.
With data analysis and theoretical interpretation ramping up in 2025, including the use of Machine Learning techniques, together with tests of brand-new radiation detectors for future kaonic atoms measurements (in Italy and/or Japan) this is the perfect moment for a student to dive into this thrilling field and make a real impact.

**Activities:** As part of the team, the student will play a key role in analyzing data to identify kaonic deuterium signals, a crucial step toward determining isospin-dependent antikaon-nucleon scattering lengths. Hie/her contributions will deepen our understanding of the strong interaction in the strangeness sector and open windows into its implications for the physics of neutron stars.
The student will gain hands-on experience with advanced data analysis tools, including Machine Learning, and advanced Monte Carlo simulations. As if that weren't enough, he/she will help test pioneering detector systems designed for future kaonic atom measurements. This is more than just a summer project—it's a genuine strangeness adventure!

Reference: The modern era of light kaonic atom experiments, C. Curceanu et al., Rev. Mod. Phys. 91, 025006 (2019); Kaonic atoms at the DAϕNE collider: a strangeness adventure, C. Curceanu et al., Front.in Phys. 11 (2023) 1240250

**Tutor:** Catalina Curceanu (catalina.curceanu@lnf.infn.it)

**Activity period:** June-July or September-October 2025

**Local Secretariat:** Alessandra Tamborrino Orsini (alessandra.tamborrinoorsini@lnf.infn.it)

**Other information:**
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**LNF – FRASCATI NATIONAL LABORATORY**

**VIP - Testing Quantum Foundations Underground**

**Title: Exploring Quantum Frontiers Underground: Probing Pauli Exclusion Principle Violation and Gravity-Related Collapse Models**

**Description:** Are you intrigued by the fascinating quantum mechanics and its possible limits? Join the VIP experiment, located in the underground laboratory of the Gran Sasso National Laboratory (LNGS-INFN), where we explore the frontiers of physics by testing fundamental quantum principles. Our mission includes searching for violations of the Pauli Exclusion Principle (PEP), through atomic transitions prohibited by PEP, and detecting spontaneous radiation predicted by quantum collapse models, which aim to address the biggest problem of quantum physics: the measurement problem, related to the Schrödinger cat paradox. These investigations are at the cutting edge of quantum mechanics, with the potential to uncover signals that could revolutionize whole science.
The VIP collaboration has developed state-of-the-art radiation detectors and Machine Learning-based data analysis methods, achieving world-leading constraints on PEP violation probabilities and collapse model predictions. As we optimize our experimental apparatus and analyze data, we strive to push these limits even further—or, perhaps, reveal the first signs of new physics. The implications extend beyond fundamental science, offering insights relevant to emerging quantum technologies.
**Activity:** As part of this project, the student will dive into every exciting aspect of the VIP experiment. From preparing and testing cutting-edge detector systems to analyzing data with advanced statistical tools and Machine Learning, he/she will gain hands-on experience at the forefront of experimental physics.
The student will also contribute to interpret the results within modern and beyond the Standard Model theoretical frameworks, including gravity-related collapse models and quantum gravity scenarios. This is real and unique chance to contribute to one of the most fascinating and groundbreaking endeavors in quantum foundations!

References: Underground test of gravity-related wave function collapse, A. Donadi et al., Nature Physics volume 17, pages 74–78 (2021) and Experimental test of noncommutative quantum gravity by VIP-2 Lead, K. Piscicchia et al., Phys. Rev. D 107, 026002 – Published 4 January 2023

**Tutor:** Catalina Curceanu (catalina.curceanu@lnf.infn.it)

**Activity period:** June-July or September-October 2025

**Local Secretariat:** Alessandra Tamborrino Orsini (alessandra.tamborrinoorsini@lnf.infn.it)

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**LNF – FRASCATI NATIONAL LABORATORY**

**JLAB12**

**Title:** Kaon electroproduction with the CLAS12 detector

**Description:** The Thomas Jefferson National Accelerator Facility, in Newport News, VA (USA), with its high intensity and high polarization electron beam, is one of the world leading facilities in the study of the internal structure of the nucleon. The Hall B of the Lab is equipped with various, unpolarized as well as polarized, targets and with the CLAS12 spectrometer, that allows the identification of charged and neutral particles in a wide kinematic acceptance.
In recent years, the electroproduction of two hadrons in the Deep Inelastic Scattering region has emerged as one of the most interesting reactions to investigate the partonic distributions functions of the nucleons. In particular, if one of the two detected hadrons is a kaon (as for example in ep→epKX) one can get access to the distribution functions of the strange quarks, poorly known so far.
The identification of charged kaons in CLAS12 is performed by the two modules of the RICH detector, whose design, construction and installation has been completed in a project lead by INFN scientists.

**Activities:** The student will perform the physics analysis of channels involving one proton and one charged kaon in the final state. Machine Learning techniques will be used to analyze the data, to increase the detection efficiency and suppress the contamination from misidentified particles. Detailed studies of the kaon identification with the RICH detector with real and simulated data, which is one of the most relevant ingredients of this analysis, will be done.
By the end of this internship, benchmark observables (like for example the beam spin asymmetry) will be extracted in a fully multidimensional analysis.

**Tutor:** Marco Mirazita (marco.mirazita@lnf.infn.it)

**Activity period:** June-July 2025

**Local Secretariat:** Alessandra Tamborrino Orsini (alessandra.tamborrinoorsini@lnf.infn.it)

**Other information:**
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**LNF – FRASCATI NATIONAL LABORATORY**

**CYGNO**

**Title:** 3D reconstruction of low energy electron track in a CYGNO Dark Matter detector prototype.

**Description:** The CYGNO project aims to enhance the detection capabilities of dark matter through the development of a directional detector by means of a high-precision gas Time Projection Chamber (TPC), read out optically by an sCMOS camera and multiple photomultipliers. The information from these devices is merged to retrieve the three-dimensional shape of the particle track. The proposed activity focuses on the three-dimensional reconstruction of low-energy electron tracks within the CYGNO detector prototype. Utilizing advanced algorithms based on machine learning, the candidate will work to determine spatial resolution and directional sensitivity and to demonstrate the ability to accurately reconstruct electron tracks with energies as low as a few keV.

**Activities:** data acquisition in laboratory, analysis of the data collected, participation to the activity of the CYGNO experiment.

**Tutor:**
Giovanni Mazzitelli (giovanni.mazzitelli@lnf.infn.it)
Giorgio Dho (giorgio.dho@lnf.infn.it)

**Activity period:** June-July or September-October 2025

**Local Secretariat:** Maddalena Legramante (maddalena.legramante@lnf.infn.it)

**Other information:**
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**LNF – FRASCATI NATIONAL LABORATORY**

**LHCb**

**Title: R&D activities for the fixed target at LHCb**

**Description:** The internal gas target at LHCb offers exceptional opportunities for an extensive physics program spanning heavy-ion, hadron, spin, and astroparticle physics. The combination of a storage cell placed in the LHC primary vacuum, an advanced Gas Feed System, the availability of multi-TeV proton and ion beams, and the recent upgrade of the LHCb detector make this project unique worldwide. In 2024, LHCb collected exceptional beam-gas data, demonstrating that fixed-target collisions can occur simultaneously with collider mode operations without compromising efficient data acquisition and high-quality reconstruction of beam-gas and beam-beam interactions.

**Activities:** The current fixed target system provides unpolarized collisions. The ongoing R&D efforts aims to upgrading the system to a polarized target system, which would be the only way to achieve polarized collisions at the LHC. The student's activity will focus on understanding and studying the polarized Atomic Beam Source and addressing other key aspects to ensure the system's compliance with the LHC.

**Tutor:**
Pasquale Di Nezza (pasquale.dinezza@lnf.infn.it)
Marco Santimaria (marco.santimaria@lnf.infn.it)

**Activity period:** June-July or September-October 2025 (preferred)

**Local Secretariat:** Maria Cristina D'Amato (maria.cristina.damato@lnf.infn.it)

**Other information:**
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**LNF – FRASCATI NATIONAL LABORATORY**

**LHCb Semileptonics**

**Title:** Search for New Physics in semileptonic decays of the B_s meson

**Description:** LHCb is one of the main experiments collecting data at the Large Hadron Collider accelerator. One of its primary goals is to accurately study the properties of b-hadrons copiously produced in the proton-proton collisions at LHC. The semileptonic decays of the B mesons have been studied with great precision at B-Factories. These decays are processes like B—>Dmu nu_mu, where the b-quark inside the B meson transforms in a c-quark (giving the D meson in the final state) with the emission of a virtual W-boson, which subsequently couples to the muon and the anti-neutrino in the final state. At present, there are various puzzles and anomalies observed in studying semileptonic decays of these mesons. Some of these anomalies could be hints of Physics Beyond the Standard Model. It is paramount to study semileptonic decays in other b-hadron species to check these anomalies in alternative environments and to access other observables very sensitive to new physics contributions. The LHCb group in Frascati is deeply involved in the study of semileptonic decays of B_s mesons. The B_s mesons (contain an anti-b quark and a s-quark instead of a u- or d-quark, as in ordinary B meson) are interesting because they offer various advantages compared with the B mesons on both the experimental and theoretical side.

**Activities:** The student will be deeply involved in key aspects of the data analysis using data collected in 2024 and the beginning of 2025, and also part of older data collected in 2016-2018. Depending on her/his interests and when she/he will be with us, the work can focus on:

- The development of novel algorithms to control the soft photon efficiency, which is required by some of the measurements we are interested in;
- The optimization of signal selection to reduce the most dangerous backgrounds using Neural Networks or other Machine Learning approaches;
- The final multi-dimensional fit to extract the parameters of interest from data unfolded for resolution and corrected for efficiencies.

Some knowledge in computing (e.g. Python, C++, root) is desirable but not mandatory.

**Tutor:**
Marcello Rotondo (marcello.rotondo@lnf.infn.it)
Elisa Minucci (elisa.minucci@lnf.infn.it)
Patrizia de Simone (patrizia.desimone@lnf.infn.it)

**Activity period:** June-July or September-October 2025

**Local Secretariat:** Maria Cristina D'Amato (maria.cristina.damato@lnf.infn.it)

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**PROJECT AVAILABLE ONLY FOR THE LNF SUMMER STUDENT PROGRAM**

**PROJECT Title:** Development and Characterization of Micro-Pattern Gaseous Detectors

**Description:** The detectors are assembled in a cleanroom, equipped with electronics, and characterized using an X-ray gun and cosmic rays.

**Tutor:** G. Bencivenni - G. Morello

**Activity period:** 2-months period, June–July

**Local Secretariat:** Maria Cristina D'Amato (maria.cristina.damato@lnf.infn.it)

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