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MU2E

Title: Calibration of the Mu2e calorimeter

Description: The calorimeter of the Mu2e experiment is composed by two disks of pure CsI crystals, readout by two custom array of large area UV-extended Silicon Photo-Multipliers (SiPMs). The experiment is currently in the construction phase, with the calorimeter assembly expected to be completed by Spring 2024. The calorimeter will then start the commissioning and calibration phase, where its performance will be assessed. This will be obtained by acquiring half calorimeter disk at a time, corresponding to about 350×2 channels, on a Vertical Slice Test with final detector components and electronics. Laser runs will be used to monitor and calibrate the gain of the SiPMs, and to measure the time resolution of the readout channels. Validation and calibration of the calorimeter response will be carried out with Cosmic Ray data using 3D-traced minimum ionizing particles selected by two segmented scintillator counters to be installed above and below the calorimeter disk under test. Selected events will provide calibration of the energy response (<1%), time offset alignment (< 50 ps), and measurement of the crystals Longitudinal Response Uniformity. A dedicated data-MC comparison of energy and time resolution will also be carried out before and after calibration.

Activities: The activity will be focused on the development and tuning of the reconstruction and calibration algorithms based on cosmic ray and laser events. The candidate will acquire technical competence on electromagnetic calorimetry and its calibration techniques, and expertise in professional software coding in C++, Python and ROOT.

Tutor: Simona Giovannella (simona.giovannella@lnf.infn.it)

Activity period: September - October 2024

Local Secretariat: Maria Cristina D'Amato (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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LHCb

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

Description: LHCb is one of the main experiment collecting data at the Large Hadron Collider accelerator. One of its primary goal is to study with high accuracy the properties of b-hadrons that are 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-> D mu 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 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 on key aspects of the data analysis using both data collected in Run II and the data that will be collected till this summer. 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.

Some knowledges in computing (e.g. python, C++, root) are desirable but not mandatory.

Tutor:
Marcello Rotondo (marcello.rotondo@lnf.infn.it)
Barbara Sciascia (barbara.sciascia@lnf.infn.it)

Activity period: 1 June - 31 July, 1 September - 31 October 2024

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

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EXOTIC ATOMS MEASUREMENTS AT THE DAFNE COLLIDER

Title: Kaonic atoms measurements with SIDDHARTA-2 experiment at the DAFNE collider: a strangeness adventure!

Description: The SIDDHARTA-2 experiment is performing unique measurements of kaonic atoms X-ray transitions using the kaons beam delivered by the DAFNE collider. These measurements will contribute to a better understanding of the strong interaction in systems with "strangeness" (i.e. with strange quarks). The experiment is measuring for the first time the X rays produced in the de-excitations of kaonic deuterium by using new Silicon Drift Detectors, developed to perform precision X-ray spectroscopy. Other detectors (CdZnTe and HPGe) are used to measure intermediate and heavy mass kaonic atoms, such as kaonic carbon or kaonic lead. SIDDHARTA-2 is installed on DAFNE, an electron-positron collider unique in the world, delivering kaons, and will be in data taking and data analyses, also using Machine Learning techniques, in 2024, a very exciting period for a student! The kaonic atoms measurements play a fundamental role in understanding how strong interaction works in the strangeness sector, with implications going from particle and nuclear physics to astrophysics (equation of state of neutron stars).

Activities: The student will be involved in all the exciting phases of the experiment, from the data taking of SIDDHARTA-2 on the DAFNE collider, one of the very few working colliders in the world, to the optimizations of various detector sub-systems and of the data taking chain, along the run. He/she will be also introduced to data analyses, also by using Machine Learning techniques, and advanced Monte Carlo simulations. A real 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 DAϕϕNE 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 2024

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

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QUANTUM FOUNDATIONS: experimental tests of Quantum Gravity (via the Pauli Exclusion principle) and of quantum collapse models

Title: The Schrödinger cat is meowing: testing Quantum Foundations within the VIP experiment. Search for violation of the Pauli Exclusion principle and gravity related collapse models

Description: The VIP experiment, installed at the Gran Sasso underground laboratory, LNGS-INFN, is performing experimental searches of signals coming from possible violations of standard quantum mechanics, such as atomic transitions violating the Pauli Exclusion Principle (PEP) and spontaneous radiation coming from modified Schrödinger equation within the so-called collapse models, proposed to solve the measurement problem (connected also to the Schrödinger cat paradox).. The VIP collaboration developed a series of radiation detectors and data analyses methods, based on Machine Learning protocols, which allowed to set extremely competitive limits on PEP violation probability and collapse models. Presently, the experimental apparatuses are under optimization, in parallel with the data taking at Gran Sasso and data analyses, to either set even stronger limits or find signals of violations of standard quantum mechanics, which, of course, would represent a revolution in whole science. The obtained results are also relevant for upcoming quantum technologies.

Activity: The student will be involved in all the exciting phases of the experiment, from the preparation and testing of the detector systems to data analyses, using advances statistical methods and machine learning. He/she will be also introduced to interpretation of results in the framework of modern theories, including gravity related collapse models and quantum gravity models.
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 2024

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a-C COATINGS FOR EIC

Title: SEY investigation of a-C coatings

Description: Electron cloud is a serious issue for EIC proton beam. Electrons, produced by ionization of the residual gas by the passage of short spaced high-intensity bunches, can be accelerated toward the vacuum chamber walls by the proton beam, thereby releasing more electrons from the walls. This can create an electron avalanche that builds up rapidly in the beam vacuum chamber (that is electron cloud). This can cause detrimental effects (as heat load, gas desorption, vacuum degradation, …) giving rise to beam instabilities.
The key parameter governing the electron cloud formation is the Secondary Electron Yield (SEY, which is the number of electrons emitted per incident one). To prevent electron cloud buildup, the choice of the vacuum chamber' surface material is crucial and a SEY close to (or below) 1 is needed. SEY, indeed, is an intrinsic material property, highly sensitive to surface modifications. Then, when working at cryogenic temperature, the physisorption of residual gas species in the vacuum system may strongly affect SEY characteristics, especially in the low energy region of the spectrum.
It is known that an amorphous carbon (a-C) layer on Cu substrate can reduce SEY down to a value ~1. In the beampipe of the RHIC superconducting magnets, a Cu plated screen coated with a-C is planned to be installed. Chemical, structural, and morphological characteristics of the a-C coating may affect the SEY and low temperature behavior.

In close collaboration with Brookhaven National Laboratory (BNL), this project aims to test and validate various material surfaces proposed to be used in the EIC hadron ring vacuum chamber using all the surface science spectroscopies available in the laboratory (SEY, XPS, RGA). SEY investigations will be made at room and cryogenic temperatures, with physisorbed gas monolayers and as a function of electron irradiation at various electron impacting energies to investigate any induced modification. Moreover, the project will also include activities in the design, realization and commissioning of an ultra-high vacuum system dedicated to SEY measurements and electron irradiations.

Activities: Experimental activities

Tutors:
Marco Angelucci (Marco.Angelucci@lnf.infn.it)
Roberto Cimino (Roberto.Cimino@lnf.infn.it)
Luisa Spallino (Luisa.Spallino@lnf.infn.it)

Activity period: June - July or September - October 2024

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ELECTRONS TO CURE MIRROR CHARGING

Title: Determination of Surface Charging/Discharging Conditions by Secondary Electron Yield Investigations

Description: Electrostatic charge forming on the Gravitational Wave (GW) mirrors severely affects detection sensitivity. At LIGO, a charging mitigation method has been successfully applied. This requires long mirror's exposures to a relatively high pressure of N_2 ions flux. It is impossible to apply this method when mirrors are at cryogenic temperatures, since a significantly thick condensed gas layer will develop on the mirror surface severely affecting its performance. An intense effort needs to be devoted to find new charging neutralization methods compliant with the constraints derived by the use of cryogenic optics. A possibility is given by selected energy electrons (between 10 to 100 eV) which, at very low doses, can impinge on the surface mirror. It is known, indeed, that according to their energy, the Secondary Electron Yield (SEY, which is the number of electrons emitted per incident ones) could be ≤ 1 or ≥ 1, i.e. removing or adding electrons at will on the mirror's dielectric surface. Even if conceptually simple, the actual refinement of this method and its implementation are a challenge. A first mandatory step is to know how much electronic charge is delivered (or removed) as a function of dose and energy of the impinging electron flux in realistic small samples, representative of materials composing the mirrors. This project aims to address this issue by using all the surface science spectroscopies available in the laboratory to first determine the SEY of mirrors samples in neutral and unperturbed conditions. After identifying and checking a measurement technique to quantify the surface charge, the goal is to define the electron beam parameters to induce on purpose charging/discharging on surface.

Activities: Laboratory and data analysis activity

Tutor:
Luisa Spallino (Luisa.Spallino@lnf.infn.it)
Roberto Cimino (Roberto.Cimino@lnf.infn.it)
Marco Angelucci (Marco.Angelucci@lnf.infn.it)

Activity period: June - July or September - October 2024

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PADME

Title: Search of dark matter signals in positron-electron annihilations

Description: PADME - Positron Annihilation into Dark Matter Experiment - is devoted to the search of light dark matter signals produced in positron-electron annihilations. The experiment consists of an active diamond target, where annihilations occur, a charged particle magnetic spectrometer and a system of calorimeters for photon detections. The main goal of the experiment has been the search for a dark photon produced in association to an ordinary one.
The PADME collaboration is international and consists of Italian, Bulgarian and American researchers. After the commissioning in 2018, the experiment had three data acquisition periods in 2019 (Run I) 2020 (Run II) and 2022 (Run III). The analysis of the collected data is ongoing while the preparation of Run IV, foreseen for the second half of 2024, will start next spring.
More information on the PADME experiment is available at the experiment web site: https://padme.lnf.infn.it/.

Activities: The student will be inserted in the analysis group that at present is mainly involved in the search for a signal of a hypothetical new particle of mass ~ 17 MeV (X17) that has been proposed to explain the anomalies observed by some recent nuclear physics experiments studying de-excitation of light nuclei via e^+e^- emission. PADME has tried to produce resonantly this particle during Run III with a reverse process: $e^+e^-\rightarrow X17$.

Tutor: Tommaso Spadaro (tommaso.spadaro@lnf.infn.it)

Activity period: June - July 2024.

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ANALYSIS IN THE H-> ZZ*-> 4l DECAY CHANNEL

Title: Study of the Higgs Boson properties in the H->ZZ*->4l decay channel using early Run 3 data collected by the ATLAS detector at LHC

Description: The Higgs boson is a fundamental particle in the Standard Model and precision measurements are of outmost importance in High Energy Physics. Within the project, the candidate will work together with the H-> ZZ*-> 4l analysis team, learning how to study the Higgs boson properties using the most recent analysis techniques and produce results on their own.

Activities: Analysis coding, machine learning, team building, presenting at ATLAS CERN internal meetings.

Tutor:
Chiara Arcangeletti (chiara.arcangeletti@lnf.infn.it)
Giada Mancini (giada.mancini@lnf.infn.it)
Mario Antonelli (mario.antonelli@lnf.infn.it)

Activity period: Candidate can choose between 2 periods: 9 weeks across June-July OR 9 weeks across September-October

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

Other information:
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CYGNO

Title: CYGNO Dark Matter and Solar neutrino research

Description: The CYGNO experiment is harnessing advancements in commercial scientific Active Pixel Sensors (APS) based on CMOS technology to develop a large gaseous Time Projection Chamber (TPC) for Dark Matter and Solar neutrino research. The project is currently collecting data at LNGS using a prototype named LIME, which is being studied to compare its performance against Monte Carlo expectations. Additionally, tests on new hardware are ongoing at the LNF laboratory to finalize the selection of the full-scale demonstrator intended for installation in the underground lab by the beginning of 2015. This process involves a continuous integration of experimental tests and data analysis. The candidate will be involved in this work within the CYGNO international collaboration, focusing on conducting tests at the LNF and LNGS labs and interpreting the results. This will include utilizing cutting-edge analysis tools such as machine learning methods.

Tutor: Giovanni Mazzitelli (giovanni.mazzitelli@lnf.infn.it)

Activity period: September - October 2024

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

Other information:
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Belle II

Title: Optimization of K_L reconstruction and identification 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 2025 the unprecedented luminosity $10^{35}cm^{-2}s^{-1}$, which will allow Belle II to collect a huge-statistics dataset of B, D and τ 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 to measure and optimize the K_L reconstruction and particle identification. 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

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

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ALICE

Title: Tuning of NΩ meson-exchange model potential with femtoscopy data from LHC by ALICE.

Description: The ALICE Collaboration has released unique data on baryon-baryon interactions in the strangeness S=-3 sector. Notably, the p-Ω correlation function, measured in proton-proton collisions at the LHC, stands out as the most accurate dataset on hadron interactions at low relative momentum in this sector.

Meson-exchange models, rigorously tested and constrained by data in the |S|<2 sectors, predict an attractive strong interaction at all distances for the NΩ interaction. Such an interaction potential implies the potential existence of a di-baryon bound state. The identification of such a state would constitute the first observation of a di-baryon (six quark state) with strangeness content.

The NΩ potential consists of several components: the long-range part is constructed through meson-exchange mechanisms and is well-constrained by existing data. However, the short-range part requires specific input from the NΩ system, for which Lattice QCD calculations were employed in the absence of experimental data.

With the availability of ALICE data, there is now an opportunity to, for the first time, fine-tune the potential and extract relevant parameters by fitting the correlation function data. This approach sheds light on the question of the existence of an NΩ quasi-bound state.

[1] ALICE Coll., *Nature 588 (2020) 232-238*, arXiv: 2005.11495 [nucl-ex]
[2] T. Sekihara, Y. Kamiya, and T. Hyodo, *Phys. Rev. C 98, 015205 (2018)*, arXiv: 1805.04024 [hep-ph].

Activities: Tune of theoretical models. Use of LHC ALICE data. Determination of bound state characteristics.

Tutor: Oton Vazquez Doce (Oton.VazquezDoce@lnf.infn.it)

Activity period: September-October 2024.

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