Workshop on Muon Physics at the Intensity and Precision Frontiers (MIP 2024)

Friday, 19 April 2024 - Monday, 22 April 2024

Peking University

Book of Abstracts

Contents

1

Registration

Corresponding Authors: yuxd@stu.pku.edu.cn, ruobing.jiang@cern.ch, 2000011500@stu.pku.edu.cn, wuyoupeng2001@outlook.com

2

Plenary Session 1

3

Openning

4

Plenary Session

5

Plenary Session

Plenary-1 / 7

multi body final states production in electron-positron annihilation and their contributions to (g−2)μ

Author: lingyun dai[1]

[1] *Hunan University*

Corresponding Author: dailingyun@hnu.edu.cn

正负电子湮灭到多体轻强子末态过程及其对 g-2 的贡献: 我们用手征有效场论研究了正负电子湮灭到 KKpi，4pi 等过程，抽出了形状因子，计算了截面，并以此为基础估计了它们对缪子反常磁矩的贡献。我们的结果与传统的数据驱动方法较为接近。

Plenary-2 / 8

Muons in Beauty/charm decays at LHCb

Author: Jibo He[1]

[1] *University of Chinese Academy of Sciences (CN)*

Corresponding Author: jibo.he@cern.ch

In this talk, experimental studies on muons in Beauty/Charm decays at LHCb will be presented, aiming to trigger more discussions on the synergy between flavour physics and others.

Plenary-2 / 9

Higgs self-coupling and Top Yukawa measurement through VBS in muon collider

Author: Junmou Chen[1]

Co-authors: Yongcheng Wu [2]; yutong liu [3]; Chih-Ting Lu [4]

[1] *Jinan University*

[2] *Oklahoma State University*

[3] *Nankai University*

[4] *Nanjing Normal U., China*

Corresponding Authors: chenjm@jnu.edu.cn, timluyu@gmail.com, yutongliu@mail.nankai.edu.cn, ycwu0830@gmail.com

We study the measurement of Higgs self-couplings with 2-to-3 VBS, as well as top Yukawa with 2-to-2 and 2-to-3 VBS in muon collider. By taking Goldstone equivalence, we analyze their amplitudes in high energy and demonstrate they are highly sensitive to deviation of couplings to the SM values. We then implement the full processes numerically and do background analysis to estimate their prospects of measurements. We emphasize the importance of choosing helicities and apply appropriate pT cuts in the final states, after which the results are shown to be very promising.

Plenary-1 / 10

The LFV andLNV processes at the same-sign muon colliders

Author: jinlei yang[1]

Co-author: Chaohsi Chang [2]

[1] *Hebei University*

[2] *ITP*

Corresponding Author: jlyangjl@163.com

The contributions from three types of NP to the leptonic di-flavor violation (LFV) processes $\mu^\pm\mu^\pm \to e^\pm e^\pm$, $\mu^\pm\mu^\pm \to \tau^\pm\tau^\pm$ and the leptonic di-number violation (LNV) processes $\mu^\pm\mu^\pm \to W_i^\pm W_j^\pm$ $(i,\ j = 1,\ 2)$ at the same-sign muon colliders are present. The results lead to the conclusion that observing the NP factors through the LFV and LNV processes at TeV-energy $\mu^\pm\mu^\pm$ colliders has significant advantages that cannot be achieved elsewhere. Therefore, in developing the techniques

of muon acceleration and collisions, the option of building the same-sign muon high-energy colliders should be considered seriously too.

Plenary-2 / 11

Progress of Muonium-to-Antimuonium Conversion Experiment (MACE)

Authors: Shihan Zhao[1]; MACE working group[None]

[1] *Sun Yat-sen University*

Corresponding Author: zhaoshh7@mail2.sysu.edu.cn

Muonium-to-Antimuonium Conversion Experiment (MACE) aims to probe the spontaneous conversion from muonium to antimuonium. With a high-intensity muon beam, a high-resolution Michel electron spectrometer, a precise positron transport solenoid, and a near-4\pi coverage positron spectrometer, MACE is expected to enhance the sensitivity to the rare process by more than two orders of magnitude, from the current stringent constraint obtained by the PSI experiment two decades ago. This talk will introduce the current status of MACE, including its considerations on physical goals, detection system designs, and simulation results. Recent efforts on detector R&D, muonium in-vacuum production scheme updates, positron solenoid design, and progress on sensitivity and background study will be presented.

Poster (For two days) / 12

Searching for Majorana neutrinos at a same-sign muon collider

Authors: Tianyi Yang[1]; Ruobing Jiang[1]; Sitian Qian[1]; Qiang Li[1]; Yong Ban[1]; Zhengyun You[2]; Jingshu Li[2]

[1] *Peking University*

[2] *SYSU*

Majorana properties of neutrinos have long been a focus in the pursuit of possible new physics beyond the standard model, which has motivated lots of dedicated theoretical and experimental studies. A future same-sign muon collider is an ideal platform to search for Majorana neutrinos through the Lepton Number Violation process: $\mu^+\mu^+ \to W^+W^+$. Specifically, this t-channel kind of process is less kinematically suppressed and has a good advantage in probing Majorana neutrinos at high mass regions up to 10TeV. We perform a detailed fast Monte Carlo simulation study by examining three different final states: 1) pure-leptonic state with electrons or muons, 2) semi-leptonic state, and 3) pure-hadronic state in the resolved or merged categories. Furthermore, we perform a full simulation study on the pure-leptonic final state to validate our fast simulation results.

Plenary-1 / 13

New mechanism of TeV muon acceleration driven by laser plasma

Author: Xueqing Yan[1]

Co-authors: Jinqing Yu [2]; Xinlu Xu [1]; Xuezhi Wu [1]

[1] *Peking University*

[2] *Hunan University*

Corresponding Authors: x.yan@pku.edu.cn, xinluxu@pku.edu.cn, xz.wu@pku.edu.cn, jinqing.yu@hnu.edu.cn

激光等离子体驱动 TeV 缪子加速新机制: 缪子加速器 (对撞机) 是一种重要的粒子加速器候选方案。由于缪子是一种次级粒子束，对于未来的加速器技术主要存在着俘获困难，慢化效率低和寿命短等瓶颈问题，这对它们在衰变前加速和碰撞提出了挑战。这需要创新的加速器设计和束流处理技术，以在 μ 衰变之前最大限度地利用 μ 介子。本文提出了基于激光等离子体加速缪子的新方案，采用等离子体慢波结构来捕获和持续加速缪子到 200MeV，捕获效率比常规射频加速器高 3-5 个量级。未来进一步采用尾波加速可以将缪子加速到 TeV，可以为高能对撞机提供一种新的理论方案。

Plenary-2 / 14

Study of low energy cosmic-ray muons with a spin spectroscopy array

Author: Mingchen Sun[1]

Co-author: Jian Tang [2]

[1] *Sun Yat-Sen University*

[2] *Sun Yat-Sen University(CN)*

Corresponding Authors: tangjian5@mail.sysu.edu.cn, sunmch3@mail2.sysu.edu.cn

Muon spin spectroscopy, known as muon spin rotation/relaxation/resonance (μSR). Through the μSR technique, the polarization of muons can be accurately measured. Cosmic-ray muons represent secondary particles produced by high-energy cosmic-ray interacting with Earth atmosphere. Cosmic-ray muons as a nature wide energy range muon source, their polarization is an important feature. The research group at Sun Yat-Sen University (SYSU) develops a prototype Cosmic-Ray Muon Spin Spectroscopy (CRmuSR), aiming to measure the polarization of cosmic-ray muons. The system is instrumented with plastic scintillator coupled with SiPM readout by 512 channel electronics. The first round test exhibits a time resolution superior to 2ns. CRmuSR has achieved stable operation for a cumulative time exceeding 500 hours. Meanwhile, the Geant4 simulation and analysis tool is ready. Preliminary results will be reported in the talk. CRmuSR can help us measure the cosmic-ray muons polarization and explore the feasibility of constructing a μSR apparatus. In the future, we wish that CRmuSR could be deployed in array and potentially aid in the assessment of low energy cosmic-ray muon properties. Combined analysis with atmospheric neutrinos can be expected.

Plenary-1 / 15

Finding axions at muon experiments

Author: Lorenzo Calibbi[1]

[1] *Nankai University*

Corresponding Author: calibbi@nankai.edu.cn

In this talk, I will review recent ideas on how to discover axions and axion-like particles (ALPs) at present and future muon facilities. ALPs with flavour-conserving and flavour-violating couplings with the Standard Model (SM) leptons are a generic consequence of a broad class of new physics

models featuring spontaneously-broken global U(1) symmetries. The talk will focus on the potential of the upcoming generation of low-energy/high-intensity muon experiments (targeting lepton-flavour-violating processes, such as MEGII, Mu3e, COMET, Mu2e) in detecting the decay of muons into electrons and invisible axions/ALPs. I will also briefly discuss the capability of the proposed high-energy muon colliders of testing ALP couplings with muons.

Plenary-2 / 16

Transverse Spin Asymmetry as a New Probe of SMEFT Chirality-Flip Operators

Author: Xin-Kai Wen[1]

Co-authors: Bin Yan [2]; Zhite Yu ; C.-P. Yuan [3]; Haolin Wang [4]; Hongxi Xing [5]

[1] *PKU*

[2] *IHEP*

[3] *Michigan State University*

[4] *Nankai University*

[5] *South China Normal University*

Corresponding Authors: yuzhite@msu.edu, hxing@m.scnu.edu.cn, xinkaiwen@pku.edu.cn, 2120170129@mail.nankai.edu.cn, yanbin@ihep.ac.cn, yuan@pa.msu.edu

Electroweak chirality-flip operators in the Standard Model Effective Field Theory (SMEFT) are important indirect probes of quantum effects of new physics beyond the Standard Model (SM), yet they remain poorly constrained by current experimental analyses for lack of interference with the SM amplitudes in constructing traditional cross-section observables. In this talk, we point out that chirality-flip operators flip fermion helicities so are ideally studied through transverse spin asymmetries. We illustrate this at a future electron-positron collider with transversely polarized beams, where such effect exhibits as azimuthal $\cos\phi$ and $\sin\phi$ distributions which originate from the interference of the dipole operators with the SM and are linearly dependent on their Wilson coefficients. We also propose to investigate the semi-leptonic scalar/tensor four-fermion operators of leptons and quarks through the transverse double spin asymmetry (DSA) at Electron-Ion Collider, where both the lepton and nucleon beams could be highly transversely polarized, and which could lead to non-trivial azimuthal $\cos 2\phi$ and $\sin 2\phi$ distributions that are also linearly dependent on their Wilson coefficients. This new method can improve the current constraints on the chirality-flip couplings by one to two orders of magnitude, without depending on other new physics operators, and can also simultaneously constrain both their real and imaginary parts, offering a new opportunity for probing potential CP-violating effects. Therefore, our work opens up a new avenue to utilize these transverse spin asymmetries for exploring the new physics effects from the chirality-flip operators, which could be extended to muon collider and muon-ion collider.

Plenary-2 / 17

The elemental investigation of dinosaur teeth by the Muon Induced X-ray Emission (MIXE) technique

Author: Narongrit Ritjoho[1]

[1] *Suranaree University of Technology (TH)*

Corresponding Author: narongrit.ritjoho@cern.ch

The Muon-Induced X-ray Emission (MIXE) technique was used to investigate elemental components of dinosaur tooth samples. In this technique, a high rate of negative muon beam at the PiE1 area

of Paul Scherrer Institute (PSI), Switzerland, impinged on the samples. A muon orbited around a nucleus in a high excitation state. The muon cascaded down to a lower level together with characteristic X-ray emission. The energy and intensity of the characteristic X-rays could unveil unknown elemental components and a relative amount of them, respectively. The stopping depth of the muons depended on the beam momentum, therefore, this technique can investigate depth-dependently with a resolution order of millimeters. Moreover, the MIXE technique is non-destructive since it will not cause the sample radioactive or heat. Thus, the MIXE technique is suitable for valuable or areological samples. The dinosaur teeth of Carchrodontosaur theropod, Iguanodontian ornithopod, and Spinosaurid found in Nakhon Ratchasima province, Thailand, were tested with the MIXE technique. The elemental components in the enamel and dentin layers of the teeth were investigated and compared.

Plenary-2 / 18

Muon Beam for Neutrino CP Violation: connecting energy and neutrino frontiers

Author: Alim Ruzi[1]

[1] *PKU*

Corresponding Author: alim.ruzi@pku.edu.cn

We propose here a proposal to connect neutrino and energy frontiers, by exploiting collimated muon beams for neutrino oscillations, which generate symmetric neutrino and antineutrino sources. Interfacing with long baseline neutrino detectors such as DUNE and T2K, this experiment can be applicable to measure tau neutrino properties, and also to probe neutrino CP phase, by measuring muon electron (anti-)neutrino mixing or tau (anti-)neutrino appearance, and differences between neutrino and antineutrino rates.

Plenary-2 / 19

A proposed PKU-Muon experiment for muon tomography and dark matter search

Author: Xudong Yu[1]

[1] *PKU*

Corresponding Author: yuxd@stu.pku.edu.cn

We propose here a set of new methods to directly detect light mass dark matter through its scattering with abundant atmospheric muons or accelerator beams. Firstly, we plan to use the free cosmic-ray muons interacting with dark matter in a volume surrounded by tracking detectors, to trace possible interaction between dark matter and muons. Secondly, we will interface our device with domestic or international muon beams. Due to much larger muon intensity and focused beam, we anticipate the detector can be made further compact and the resulting sensitivity on dark matter searches will be improved. In line with above projects, we will develop muon tomography methods and apply them on atmospheric and environmental sciences, archaeology and civil engineering. Furthermore, we will measure precisely directional distributions of cosmic-ray muons, either at mountain or sea level, and the differences may reveal possible information of dark matter distributed near the earth. In the future, we may also extend our study to muon on target experiments.

Plenary-2 / 20

Search for Higgs boson decaying to muon pair at LHC

Author: Hongtao Yang[1]

[1] *University of Science and Technology of China (CN)*

Corresponding Author: hongtao.yang@cern.ch

In this talk I will discuss the ATLAS and CMS searches for H->mumu at LHC.

Plenary-2 / 21

Joint muography and machine learning detection method for fractured zones inside mountain slopes

Authors: Ning Qiu[1]; Chunwu Pan[2]; Bin Liu[2]

[1] *South China Sea Institute of Oceanology, Chinese Academy of Sciences*

[2] *South China Sea Institute of Oceanology,, Chinese Academy of Sciences*

Corresponding Authors: n.qiu.mail@gmail.com, 1657154400@qq.com, 2773378047@qq.com

The creep collapse and high-level dangerous rock collapse disasters in the internal fractured zone of mountain slopes are common and serious problems. However, traditional monitoring methods have shortcomings in real-time and accuracy. Therefore, it is necessary to develop a reliable evaluation model to verify the effectiveness of the joint muography and machine learning recognition method for the fractured zone inside mountain slopes.

This study aims to evaluate the feasibility and accuracy of the joint Muography and machine learning recognition method for the internal fracture zone of mountain slopes through theoretical simulation numerical calculations.

We established a theoretical model based on the geological characteristics of the internal fractured zone of mountain slopes and simulated the density structure changes of the fractured zone using numerical calculation methods. Then, we apply joint Muography and machine learning recognition methods to process and analyze the simulated data to evaluate its accuracy and feasibility in identifying fractured zones.

The theoretical simulation numerical calculation results show that the joint Muography and machine learning recognition method for the fractured zone inside mountain slopes have shown high accuracy and feasibility in model evaluation. The simulation results match the expectations of the theoretical model, verifying the effectiveness and reliability of this method in identifying fractured zones.

The feasibility and accuracy of the joint muography and machine learning recognition method for the internal fracture zone of mountain slopes have been demonstrated through theoretical simulation and numerical calculations. Although lacking support from measured data, this method has potential application value in disaster monitoring and early warning. It is recommended to further study and apply this method, combined with on-site monitoring data, to verify its accuracy and practicality in the assessment of internal fractured zone disasters in mountainous slopes.

Plenary-2 / 22

Precision test of the weak interaction with slow muons

Author: Xin Chen[1]

[1] *Tsinghua University (CN)*

Corresponding Author: xin.chen@cern.ch

We propose to use slow muons facilities combined with cyclotron radiation detection for precision test of the weak interaction in the muon decays. Slow positive muon bunches are first injected into a cylindrical superconducting vacuum chamber with uniform strong axial magnetic fields to radially confine the muons. The positrons resulting from muon decays can be detected by their cyclotron radiation, which can be transported to low-noise electronic devices through waveguides coupled to the chamber. The decay positron's energy can be precisely measured down to eV level in the low energy region, which is sensitive to new physics effects such as Majorana neutrinos and new structures of weak interactions.

Plenary-1 / 23

GNN-Based Tracking Reconstruction for the Fermilab Muon g-2 Experiment

Author: Bingzhi Li[1]

[1] *Zhejiang Lab*

Corresponding Author: bingzhi.li@zhejianglab.com

The Fermilab Muon g-2 Experiment recently released its Run2-3 findings with a precision of 0.2 ppm, consistent with previous Run1 and BNL results. As a key component of the data reconstruction and analysis, tracking reconstruction provides essential beam dynamics parameters and muon weighting parameters, and determines the precision of muon EDM measurements. This presentation introduces the latest tracking reconstruction development within the experiment, particularly the graph neural network (GNN)-based approach. Leveraging message-passing mechanisms and the Louvain algorithm, the GNN method efficiently identifies tracks. Preliminary studies on synthetic and experimental data demonstrate promising results, indicating the significant potential of the GNN-based method in tracking reconstruction.

Poster (For two days) / 24

Preliminary Design of a CsI(Tl) Calorimeter for Muonium-to-Antimuonium Conversion Experiment

Author: Siyuan Chen[None]

Co-authors: Shihan Zhao ; Weizhi Xiong [1]; Jian Tang [2]

[1] *Shandong University*

[2] *Sun Yat-Sen University(CN)*

Corresponding Author: chensy339@mail2.sysu.edu.cn

The Muonium-to-Antimuonium Conversion Experiment (MACE) is proposed to search for this charged lepton flavour violating process and obtain a two orders of magnitude higher sensitivity than the MACS experiment at PSI in 1996, taking advantage of recent technique developments.One clear signature of the conversion is given by positron produced by antimuonium decay. This paper introduce a parameterized near-4π-coverage calorimeter for probing e^+e^- annihilation in MACE, the energy resolution of which reaches 8% at 511 keV. Detailed Monte-Carlo simulation with Geant4 toolkit and MACE offline software is presented for geometry optimization, coincidence system design, background estimation, and benchmark detector validation.

Plenary-1 / **25**

Progress of MELODY

Author: Yu Bao[None]

Corresponding Author: yubao@ihep.ac.cn

Progress of MELODY

Plenary-1 / **26**

The Application of MuSR on the Study of Quantum Materials

Author: Lei Shu[1]

[1] *Fudan*

Corresponding Author: leishu@fudan.edu.cn

The Application of MuSR on the Study of Quantum Materials

Plenary-1 / **27**

MuSR study on the quantum magnetism of 2D frustrated compounds

Author: Jie Ma[1]

[1] *SJTU*

Corresponding Author: jma3@sjtu.edu.cn

MuSR study on the quantum magnetism of 2D frustrated compounds

Plenary-1 / **28**

Search for Muon to Electron Conversion in a Muonic Atom

Author: Yoshitaka KUNO[1]

[1] *Osaka University and USTC*

Corresponding Author: kuno@phys.sci.osaka-u.ac.jp

Charged Lepton Flavor Violation (CLFV) serves as a crucial probe to search for physics beyond the Standard Model. This talk focuses the physics motivation and the latest developments in the experimental search for muon to electron conversion, in particular the COMET experiment in Japan. Additionally, we review the future prospects of muon to electron conversion experiments, including advancements in experimental techniques. Furthermore, we examine related physics subjects that can be explored

through these experiments. Through these investigations, we aim to illuminate the exciting prospects for exploring CLFV and implications in particle physics.

Poster (For two days) / 29

MuGrid: a novel plastic scintillator detector with light guide array and WLS fibers

Author: tao yu[None]

Co-author: Jian Tang [1]

[1] *Sun Yat-Sen University(CN)*

Corresponding Authors: yutao35@mail2.sysu.edu.cn, tangjian5@mail.sysu.edu.cn

Muography, traditionally recognized as a potent instrument to visualize the internal structure of gigantic objects, has spawned some novel interdisciplinary applications such as an underground navigator. To better serve interdisciplinary purposes and cope with various challenging environments, we develop a scintillation detector called MuGrid for the sake of stability and low cost. By coupling the plastic scintillator with the light guide array, MuGrid could achieve a higher spatial resolution and a larger acceptance angle with fewer readout channels, compared to the other strategies. Simulation results indicate that a spatial resolution better than 3mm is attainable on a 30cm x 30cm planar scintillator, though the light guide transparency moderates the detection efficiency. It is promising to improve the light guide transparency in the current design so that both the detection efficiency and the spatial resolution can be further enhanced to meet requirements in interdisciplinary applications.

Plenary-2 / 30

Study of Charged Lepton Flavor Violation at electron-muon collider

Author: Ran Ding[1]

[1] *Sun Yat-Sen University (CN)*

Corresponding Author: ran.ding@cern.ch

Charged Lepton Flavor Violation (CFLV) process is one of the important signal channels for studying new physical beyond the standard model. Given the advantages of lepton collisions with different flavors, we investigate the possible CLFV process supported by an extra gauge boson Z' on an electron-muon collider. Based on the Monte Carlo calculation and detector fast simulation, we study the signal and possible background and give the sensitivity results of CLFV signals at 95% confidence level. Compared with current and prospect limits set by other experiments, the electron-muon collision demonstrates significant advantages in the coupling strength sensitivity of final state, and can provide result for some rare processes such as $^+e^-\to e^{+-}$.

Poster (For two days) / 31

Muon Anomalous Frequency Analysis in the Muon g-2 Experiment at Fermilab

Author: Zejia Lu[None]

Corresponding Author: lzj777@sjtu.edu.cn

The Fermilab Muon g-2 Experiment conducts high-precision measurements of the muon's anomalous magnetic moment. The latest results from Run-2/3 were published in 2023. This poster presents the anomalous frequency analysis and consistency checks performed during Run-2/3. It also shows recent progress for Run-4/5/6 analysis, focusing on the modulation of the residual slow term in the data as a key improvement for reducing systematic uncertainties.

Plenary-2 / 32

High-Energy Atmospheric Muon Study with the TRIDENT Neutrino Telescope

Author: Cen Mo[1]

[1] *Shanghai Jiao Tong University (CN)*

Corresponding Author: mo_cen@sjtu.edu.cn

The TRopIcal DEep-sea Neutrino Telescope (TRIDENT) is a next-generation underwater Cherenkov neutrino telescope, set to be deployed 3 km below sea level in a 7 km^3 area of the South China Sea. TRIDENT's mission to explore cosmic ray phenomena using high-energy astrophysical neutrinos faces challenges from high-energy atmospheric muons. These muons, triggering detections at a kHz rate, significantly obscure neutrino signals. However, the abundant data from these interactions also offer a unique opportunity for the calibration of the TRIDENT simulation framework. This study focuses on the simulation and analysis of high-energy atmospheric muons under deep-sea conditions and presents a preliminary strategy for calibrating the TRIDENT simulations using atmospheric muon data.

Plenary-1 / 33

Status design of CiADS Muon Source

Author: Huan Jia[1]

[1] *IMP*

Corresponding Author: jiahuan@impcas.ac.cn

Status design of CiADS Muon Source

Poster (For two days) / 34

Validation of the Geant4-based Calorimeter Acceptance Model in Fermilab Muon g-2 Experiment

Author: Jun Kai Ng[1]

[1] *Shanghai Jiao Tong University*

Corresponding Author: ngjunkai@sjtu.edu.cn

In the Fermilab Muon g-2 experiment, the anomalous precession frequency of the muon was extracted from calorimeter data that recorded the energy and time spectrum of the positrons. The probability of a calorimeter detecting a positron from muon decay exhibits spatial and energy dependence, as well as variations due to the materials in the vicinity of the calorimeter. Coupled with muon beam dynamics, this acceptance effect introduces systematic shifts in the calorimeter time spectrum. These related systematic effects have been studied with a Geant4-based model of calorimeter acceptance, which has raised concerns regarding its validity. We generate a muon beam distribution from a Geant4-based simulation of muon beam motion, augmented with a synthetic data approach. Combining with the acceptance model of the calorimeters, the simulated time spectra of the detected positrons $N(t)_{sim}$ at the calorimeters were calculated and compared with the $N(t)$ of the positrons obtained from experiment data. The behavior of $N(t)_{sim}$ was found to agree with the experiment at an average level. Ongoing investigations are underway to delve deeper into these results and elucidate any underlying implications.

Poster (For two days) / 35

Optimization of the High-Repetition-Rate Pulsed Electron-Driven Muon Beamline based on SHINE Facility

Author: Fangchao Liu[1]

[1] *Shanghai Jiao Tong University*

Corresponding Author: liufangchao@sjtu.edu.cn

The Shanghai SHINE facility is in the throes of construction at the Zhangjiang Science Park in Shanghai. This state-of-the-art facility is poised to generate a pulsed electron beam with an energy of 8 GeV, a charge of 100 pC, and the potential to achieve a maximum repetition rate of 1 MHz. Marking a departure from traditional proton-driven muon sources, our approach involves the use of a magnetic kicker to select the electron beam bunches at the desired repetition rate of 50-100 kHz for a muon beamline. This frequency is aligned with the requirements of μSR experiments where the measurement time is ranging from 10 to 20 μs. Our poster presents a comprehensive overview of the target optimization process for an 8 GeV incident electron beam, alongside the development of a large-aperture solenoid-based surface muon beamline. Simulations indicate that the refined beamline is capable of delivering between 10ˆ6 to 10ˆ7 surface muons per second at the final focus, achieving a total transmission efficiency of about 9 % at the final beam spot area of 100 mm diameter.

Poster (For two days) / 36

Anomalous Precession Frequency Analysis with a focus on the beam dynamics modelling in the Fermilab Muon g-2 Experiment

Author: Yonghao Zeng[None]

Corresponding Author: zyh1678783412@sjtu.edu.cn

The Muon g-2 Experiment at Fermilab aims to achieve an unprecedented precision of 140 ppb in measuring the muon's anomalous magnetic moment. The experiment is designed to determine the difference frequency (ω_a) between the muon spin precession and cyclotron motion, as well as the magnetic field (ω_p) experienced by the muons. This high-precision experiment requires meticulous analysis strategies for two equally important quantities. In August 2023, the collaboration released their second results, which incorporated data from Run-1, Run-2, and Run-3. These results showed a significant discrepancy from the Standard Model prediction, reaching the 5σ level. The final central value, including data from Run-4, Run-5, and Run-6, is expected to be released in late 2025. This

poster will present a detailed analysis of the anomalous precession frequency (ω_a), highlighting improvements in the analysis since the 2021 results, with a focus on the beam dynamics modeling.

Plenary-1 / 37

Muon source project at SHINE

Author: Yusuke Takeuchi[1]

[1] *Shanghai Jiao Tong University*

Corresponding Author: y.takeuchi@sjtu.edu.cn

Muons have been playing an important role in particle and nuclear physics and materials science. Furthermore, they are increasingly in demand for applications in archaeology and disaster prevention. Typical muon experiments are performed with approximately a few muon lifetimes, meaning that the ideal muon source for these experiments is a pulsed-mode operation with a repetition rate of tens of kHz. Nowadays, a copious number of muons can be produced artificially by irradiating targets with high-intensity proton beams from accelerator facilities. However, the muon beam repetition rates currently available at these facilities are essentially limited to two modes: pulsed mode (25-50 Hz, e.g., J-PARC) and continuous mode (e.g., PSI). There are several plans to generate high-repetition proton beams for ideal repetition-rate muon sources, but these have not yet been realized or are not versatile enough. On the other hand, muon sources using electron beams have also been proposed; high-repetition-rate (kHz to MHz) electron beams with linear accelerators have already been established, and their beam dump combined with a thin target could be an ideal muon source. We are currently planning to utilize a high-repetition-rate electron beam from an XFEL facility called SHINE for a muon source. The SHINE facility is under construction in Zhangjiang, Shanghai, with an electron accelerator (8 GeV energy, 1 MHz repetition rate, 100 pC charge, 6.25×10^{8} electrons/bunch) scheduled for commissioning in 2025. Preliminary simulations indicate that a muon yield of $\sim10^{3}$ muons per bunch is expected with a bunch rate tunable from kHz to MHz with the electron beam. Currently, target studies using simulations, design and optimization of muon extraction beamlines, and preparations for a proof-of-principle test using the existing 1.6 GeV SXFEL electron beamline are underway. In this talk, an overview of the muon source project at SHINE and the current status will be presented.

Plenary-1 / 38

Preliminary Study of Muon Beam CT and Integration of MuDirac and Geant4 for Muonic X-ray Simulation

Authors: Zhihao Zhou[1]; Yang Li yangli[None]; Jingyu Tang[None]

[1] *Institute of High Energy Physics, Chinese Academy of Sciences*

Corresponding Authors: yangli@ihep.ac.cn, tangjy@ihep.ac.cn, zhouzhihao@ihep.ac.cn

Muon beam imaging and muonic atom X-ray emission spectroscopy are two important techniques for multidisciplinary applications of muon sources. Thanks to the strong penetrating power, imaging with cosmic-ray muons becomes a unique way to see through large objects. To investigate the possibility of imaging using muon beams in accelerator-based muon sources, we perform a simulation study of muon beam computed tomography with Geant4. In this report, the detector design and imaging results of muon beam CT are presented. Additionally, muonic X-rays emitted from the muonic atom cascade process can be used to investigate elemental components of bulk samples. However, the generation of Muonic X-rays in Geant4 has discrepancy with experimental results. A preliminary approach to solve this issue by integrating MuDirac, an open-source Dirac equation Solver, with Geant4 is presented. We discuss the development of Python scripts for generating a

muonic X-ray database using MuDirac for various isotopes, as well as new Geant4 classes to manage the database.

Plenary-1 / 39

Sensitive Search of The Muon EDM with the Frozen-spin Technique

Author: Guan Ming Wong[1]

[1] *CERN*

Corresponding Author: guan.ming.wong@cern.ch

The permanent electric dipole moment (EDM) of an elementary particle is a charge-parity violating (CPV) observable. Consequently, precision searches for EDMs serve as a sensitive probe for new physics beyond the Standard Model (BSM). For the first time, the Paul Scherrer Institute (PSI) will conduct a dedicated search for the muon EDM. Utilizing the frozen-spin technique, the experiment will potentially increase the EDM sensitivity by more than three orders of magnitude compared to the current best limit, set by the BNL Muon g-2 collaboration. The muEDM experiment adopts a phased approach, with the final expected sensitivity reaching $d = 6 \times 10^{-23}\ e \cdot cm$, which is three orders of magnitude lower than the current limit. The first phase of the experiment involves injecting surface muons into a compact storage solenoid via a superconducting channel. Muons suitable for storage are then selected with an entrance detector and stored in the central region of the solenoid on a stable orbit. The implementation of the frozen-spin technique, which involves applying a radial electric field to the stored muons to cancel the g-2 precession, effectively freezes the muon spin direction relative to the direction of its motion. Thus, any observed precession would be attributable solely to a non-zero muon EDM. This presentation provides an overview of the experiment and reports the latest developments.

Poster (For two days) / 40

Muon yield estimation for the Beam Test at the SXFEL beam dump

Authors: Jiangtao Wang[1]; SIyuan Chen[2]; liang Wang[2]

Co-authors: Fangchao Liu [2]; Kim Siang Khaw [3]; Meng Lyu ; Yusuke Takeuchi [2]

[1] *Tsung Dao Lee Institute, SJTU*

[2] *Shanghai Jiao Tong University*

[3] *Tsung-Dao Lee Institute (CN)*

Corresponding Authors: wangliang-021@sjtu.edu.cn, liufangchao@sjtu.edu.cn, 18930143913@163.com, jiangtao_wang@sjtu.edu.cn, kim.siang.khaw@cern.ch, y.takeuchi@sjtu.edu.cn, meng.lyu@cern.ch

Muon sources are critical in advancing both fundamental physics research and various applied sciences. High-Repetition-Rate (HRR) muon beams, in particular, are optimal for numerous precision experiments in fundamental physics. To assess the accuracy of the simulation model for the HRR muon beam produced at the SHINE facility (The Shanghai High repetition rate XFEL and Extreme light facility), a comparative analysis was conducted using simulated data for the 1.6 GeV,10 Hz electron beam at the SXFEL facility (The Shanghai Soft X-ray Free-Electron Laser User Facility) with a beam dump. The simulation model facilitated an examination of the intensity, trajectory, and temporal distribution of the muons, as well as background particles. Leveraging these particle characteristics, we have devised and preliminarily confirmed the viability of experimental approaches for muon detection. In the case of positive muons, a stopping target captures the particles, and their intensity is quantified by recording the temporal distribution of resultant positrons using a plastic

scintillator detector. This is predicated on the distinctive rest lifetime characteristic of the positive muon. Conversely, negative muons are detectable through capture by a metallic target, whereupon the emission of muonic X-rays is observed via LaBr3 crystal detectors. The intensity of the negative muons can be determined from the peak's amplitude.

Poster (For two days) / 41

Development of fast electronics for the muon entrance detector of the PSI muEDM experiment

Author: Tianqi Hu[None]

Corresponding Author: hutianqi@sjtu.edu.cn

The investigation of a permanent electric dipole moment (EDM) in elementary particles offers a compelling avenue to explore Charge-Parity symmetry violation, a phenomenon intimately connected with the observed matter-antimatter asymmetry in the universe. The Standard Model (SM) of particle physics predicts an exceedingly small muon EDM, on the order of $10^{-38}\ e \cdot cm$. However, several Beyond the Standard Model (BSM) theories suggest mechanisms that could significantly enhance this value. Our research at the Paul Scherrer Institute (PSI) is focused on detecting the muon EDM with an unprecedented sensitivity target of $10^{-23}\ e \cdot cm$ using the frozen-spin method. Our group has been developing a muon entrance trigger system crucial for the muon injection and storage. The system consists of plastic scintillators read out by silicon photomultipliers (SiPM). It is engineered to trigger on muons within the acceptance phase space and send a trigger signal within 30 ns to a pulsed magnetic field system. This pulsed magnetic field will stop the incoming muon in the central region of a solenoid. This stringent timing requirement has propelled us to undertake significant research and development in SiPM readout electronics to minimize all possible system delays. Recent progress in the R&D of this electronics will be presented.

Poster (For two days) / 42

Development of Fast HV Electronics for a Spark Chamber

Author: Xingyun Huang[1]

Co-authors: Meng Lv ; Yimin Wan [2]

[1] *Shanghai Jiao Tong University Tsung-Dao Lee Institute*

[2] *Shanghai Jiao Tong University*

Corresponding Authors: yellow-luck@sjtu.edu.cn, meng.lv@sjtu.edu.cn, wan2368402722@sjtu.edu.cn

The effectiveness of a spark chamber in detecting charged particles is contingent upon the timely recombination of ions after a Townsend avalanche, typically occurring over several microseconds. To achieve optimal spark efficiency, the system necessitates fast electronics capable of operating within a delay time of less than 500 ns. The spark chamber's electronic system is composed of three primary components: the discriminator, the logic module, and the high-voltage generator. As charged particles pass through the scintillators, photons are emitted and subsequently converted into current pulses by Photomultiplier Tubes (PMTs). Three discriminators are employed to process the signals from the PMTs, transforming them into digital signals. These signals are then fed into a 3-input AND gate, functioning as a coincidence module, with the output pulse width fine-tuned by a monostable multivibrator. The generated coincidence signal activates an Insulated-Gate Bipolar Transistor (IGBT), which is positioned between the capacitors and ground. This action causes the capacitors to discharge, resulting in a high-voltage pulse that induces a breakdown and subsequent sparking between the gaps of the spark chamber. The total delay time of the electronics, from the PMT output to the capacitor discharge, is approximately 350 ns. This rapid response is critical for the chamber's ability to reliably detect the presence of charged particles via the spark formation process.

Plenary-1 / 43

The Fermilab Muon g-2 Experiment

Author: Hoh Siewyan[1]

[1] *Tsung Dao Lee Institute, Shanghai Jiao Tong University*

Corresponding Author: hohsiewyan@sjtu.edu.cn

The muon anomalous magnetic moment, $a_\mu = (g-2)/2$, is a low-energy observable that can be measured and calculated at a sub-ppm (part-per-million) precision, making it a stringent test of the Standard Model (SM) prediction and a probe for new physics. The Fermilab Muon g-2 experiment aims to measure a_μ with a precision of 140 ppb, marking a four-fold improvement in precision compared to its predecessor, the Brookhaven (BNL E821) experiment. In April 2021, our collaboration published the first results, based on the first year of data taking combined with BNL's data, a discrepancy between experimental measurement and the SM prediction (2020 Muon g-2 Theory Initiative) is established at $a_\mu(\mathrm{Exp}) - a_\mu(\mathrm{SM}) = (251 \pm 59) \times 10^{-11}$, with significance of 4.2σ. Later, in August 2023, inclusion of datasets collected during Run-2 and Run-3 had increased the significance to 5σ. The result based on complete dataset (inclusion of Run-4/5/6) is expected to be announced in 2025. If the central values of both measured and predicted values remain the same, it will lead to a tantalizing experiment-theory discrepancy of 8σ, which is definite evidence of beyond SM physics. In this talk, the overview of the Fermilab Muon g-2 experiment with a focus on the ω_a analysis, including improvements and upgrades made between the 2021 and 2023's results, will be discussed.

Poster (For two days) / 44

Design and Construction of a Spark Chamber

Author: Yimin Wan[1]

Co-authors: Meng Lv ; Xingyun Huang [2]

[1] *Shanghai Jiao Tong University*

[2] *Shanghai Jiao Tong University Tsung-Dao Lee Institute*

Corresponding Authors: wan2368402722@sjtu.edu.cn, meng.lv@sjtu.edu.cn, yellow-luck@sjtu.edu.cn

The spark chamber is a particle detector for visualizing the paths of electrically charged particles through the Townsend avalanche effect. At TDLI, we are developing a spark chamber prototype with dimensions of 525 mm × 370 mm × 130 mm using aluminum plates, designed for both demonstration and educational purposes. Our design process has encountered challenges in three main areas: sealing, the gas system, and the electronic trigger mechanism. We have successfully constructed a prototype that integrates a sealing and gas system with an electronic trigger system. Helium was selected as the working gas due to its relatively lower breakdown voltage. Additionally, a box-type acrylic chamber was chosen to minimize gas leakage and enhance operability. To further improve performance, we have rounded the edges of the aluminum plates and minimized circuit connections within the gas environment, which helps to reduce unwanted edge sparking and prevent corona discharge in the electronic components. The prototype allows for adjustable gap widths, ranging from 5 mm to 10 mm in 1 mm increments, using spacers to find the optimal setting. Gas leakage rates have been rigorously tested in a negative pressure atmosphere of -0.047 MPa, showing similar rates of approximately 0.002 MPa/min for both helium and air. Looking ahead, we plan to expand the spark chamber prototype to include 21 layers of aluminum plates. This enhancement aims to enable the clear detection of muon decay events, further extending the research and educational utility of the spark chamber.

Poster (For two days) / 45

Beam Injection and Storage Study for the muEDM Experiment at PSI

Author: Yuzhi Shang[1]

[1] *Tsung-Dao Lee Institute, Shanghai Jiao Tong University*

Corresponding Author: yz.shang@sjtu.edu.cn

Permanent electric dipole moments (EDMs) of elementary particles violate CP symmetry. Compared with the current muon EDM limit($|d_\mu| < 1.8 \times 10^{-19} e \cdot cm$) obtained from the BNL Muon g-2 Collaboration, the contribution to the muon EDM from the standard model is negligible ($|d_\mu| \sim 1.4 \times 10^{-38} e \cdot cm$), making the EDMs of elementary particles very sensitive probes for searching Beyond Standard Model (BSM) Physics for additional CP violation sources. The latter is one of the three criteria proposed by Sakharov for creating matter-antimatter asymmetry in the universe. The muon EDM experiment at PSI using frozen-spin technique expect to reach a sensitivity of $3 \times 10^{-21} e \cdot cm$ in phase I. The study of muon beam injection and storage is one of the critical parts of the experiment. Muons are injected into the solenoid through a superconducting channel and an entrance detector. When muons pass through the entrance detector, a signal is produced to trigger a pulsed magnetic field, which will deflect the trajectory of muons into a stable orbit in the central solenoid region. A Geant4 simulation incorporating all electric and magnetic fields in the solenoid will be developed to simulate the beam injection and storage from the exit of the superconducting channel to the central region of the solenoid. Four different magnetic fields will be used in the simulation: a PSC solenoid field, correction coil fields, a weakly-focusing coil field and a pulsed magnetic field. Finally, the storage efficiency will be studied. In this poster, we will present the status of the beam injection and storage simulation.

Plenary-1 / 46

The MUonE Experiment: Understanding Muon g–2 Puzzle via Muon-electron Scattering

Author: Ce Zhang[1]

Co-author: Riccardo Pilato [1]

[1] *University of Liverpool (GB)*

Corresponding Authors: ce.zhang@cern.ch, r.pilato@liverpool.ac.uk

The MUonE experiment aims at a precise measurement of the shape of the differential cross-section of the μ-e elastic scattering to extract the running of the QED coupling. By using an innovative method, this will lead to an independent determination of the leading hadronic contribution to the muon anomalous magnetic moment, a_μ(HLO). This could clarify the present tensions of 5σ discrepancy between the theoretical and experimental value of the muon g-2.

The experiment will be carried out at CERN North Area by injecting the high-intensity 160 GeV muon beam into a low-Z target. The main challenge of the experiment lies in the control of the systematic uncertainties to an unprecedented level of precision for a scattering experiment. A test run was performed in September 2023 with a reduced detector to validate the basic concepts of the proposal. The status and future plans of the experiment will be presented.

Plenary-2 / 47

Development of large area, high spatial resolution Micromegas detectors for muon tomography imaging

Author: Zhiyong Zhang[None]

Corresponding Author: zhzhy@ustc.edu.cn

As an important supplement to existing technologies such as X-ray and neutron imaging, muon (μ) tomography technology has been widely studied in interdisciplinary fields such as natural disaster early warning, mineral exploration, geology, and archaeology. Muon track detection based on MPGD is one of the important technical solutions for high-resolution muon imaging research. The research team at USTC has long been committed to the research of large-area high-resolution detectors and their readout electronics, and has built several μSTC (muon Scattering tomography and Transmission imaging faCility) prototypes for muon imaging research. In this talk, we will present the lastest developments on the muon detectors and muography study, Micromegas detectors with large area of 400 mm×400 mm to 600 mm×600 mm were achieved, and high spatial resolution of better than 150 μm and detection efficiency of higher than 95% were validated by cosmic ray test. The μSTC prototypes was used to explore the possible internal structure of Dashu Mountain, a 60-million-year-old ancient volcano. Another interesting attempt is the imaging study of iron-making blast furnaces, related results will also be reported.

Poster (For two days) / 48

Solenoid Design for Muonium to Antimuonium Conversion Experiment

Authors: Gui-Hao Lu[1]; Shihan Zhao[None]

Co-author: Jian Tang [2]

[1] *SUN YAT-SEN UNIVERSITY*

[2] *Sun Yat-Sen University(CN)*

Corresponding Authors: tangjian5@mail.sysu.edu.cn, lugh7@mail2.sysu.edu.cn, zhaoshh7@mail2.sysu.edu.cn

The Muonium-to-Antimuonium Conversion Experiment (MACE) is proposed to search for this charged lepton flavor violating process and obtain a higher sensitivity than the 1990's experiment in PSI, taking advantage of recent technique developments. One clear signature of the conversion is given by positron produced by antimuonium decay. We have designed a positron transport solenoid using G4beamline. The purpose of this design is to transport low-energy orbital positrons collected by an accelerating electric field to a microchannel plate (MCP). The transport solenoid has been designed with magnetic compensation, which allows it to operate with 450 μm spatial resolution and a reliable position reconstruction. Our subsequent research topics involve integrating this design into the software and designing the accelerating electric field to further refine the experimental design.

Poster (For two days) / 49

The first search for the weak interaction between muon and charmonium

Authors: Zhengyun You[1]; Zhijun Li[2]

[1] *SYSU*

[2] *Sun Yat-Sen University (CN)*

Corresponding Author: zhijun.li@cern.ch

Using about $(10087 \pm 44) \times 10^6$ J/ψ events collected with the BESIII detector at the BEPCII e^+e^- storage ring at the center-of-mass energy of $\sqrt{s} = 3.097$ GeV, we present the first search for

the weak interaction between muon and charmonium through the semi-muonic charmonium decay $J/\psi \to D^- \mu^+ \nu_\mu + c.c.$. Since no significant signal is observed, we set an upper limit of the branching fraction to be $\mathcal{B}(J/\psi \to D^- \mu^+ \nu_\mu + c.c) < 5.6 \times 10^{-7}$ at 90% confidence level. This is the first exploration of muon interaction with quarkonium matter and provides the most stringent constraint globally.

Poster (For two days) / 50

Search for R-parity Violation induced Charged Lepton Flavor Violation at future lepton colliders

Author: Xunye Cai[1]

[1] *Sun Yat-Sen University (CN)*

Corresponding Author: xunye.cai@cern.ch

Interest in searches for Charged Lepton Flavor Violation (CLFV) has continued in the past few decades, only since the observation of CLFV will indicate new physics beyond the Standard Model. As many future lepton colliders with high luminosities have been proposed, the search for CLFV will reach an unprecedented level of precision. Many model of physics beyond the Standard Mode (BSM) allow CLFV processes at tree level, such as R-parity-violating (RPV) Minimal Supersymmetric Standard Model (MSSM), which is a good choice for benchmark. In this paper, we perform a detailed fast Monte Carlo simulation study on RPV induced CLFV process at future lepton colliders, including 240 GeV circular electron positron
collider and a 6 or 14 TeV muon collider. As a result, we found that the upper limits of the τ related CLFV coupling will be significantly improved and some new limits on CLFV couplings can be set, which are inaccessible by low-energy experiments.

51

Registration (WIFI: mip2024pku PWD: same)

Plenary-1 / 52

Openning

Corresponding Authors: x.yan@pku.edu.cn, gaoyn@tsinghua.edu.cn

Plenary-1 / 53

Position Sensitive Detectors and Applications at CIAE

Corresponding Authors: lixm@iris.ciae.ac.cn, lixm@ciae.ac.cn

This report will mainly introduce two new types of position-sensitive detectors and their applications in imaging. Integrated Micromegas detector is a new type of micro-pattern gas detector utilizing photoetching technology for its production. Capacitance testing across each channel has confirmed good uniformity, gain and energy resolution under varying Ar and CO2 ratios. The detector is now

capable of mass production with all processes conducted domestically. Additionally, we have developed a sealed version of the micro-pattern gas detector, which has demonstrated reliable operability at ambient temperature and pressure for a duration exceeding 21 days. In cooperation with Fudan University and Peking University, we completed the R&D, production, and testing tasks for the electromagnetic calorimeter of the sPHENIX experiment. This marks the first use of innovative technologies such as tungsten powder, scintillating fibers with SiPM readouts technology for calorimeter signals in high-energy collision experiment. By establishing the Beijing Development Center at the Atomic Energy Institute, we developed 320 scintillating fiber detectors for the sPHENIX experiment, achieving a yield rate of 97%. Currently, these detectors have been applied to X-ray, muon and neutron experiments.

Plenary-1 / 54

MEG II

Corresponding Author: satoshi.mihara@cern.ch

The MEG II Collaboration has presented the first results of its search for flavor-violating muon decay, μ -> e + γ. MEG II, the upgrade of MEG, began taking physics data in late 2021 and continues to accumulate data in its quest to detect lepton-flavor-violating muon decay with a target sensitivity of 6x10ˆ-14 at 90% confidence level, representing an order
of magnitude improvement over MEG. The upgraded detectors offer larger acceptance, increased granularity, and better resolution, enabling them to handle higher background rates compared to the previous MEG detectors. The analysis of the data collected in 2021, which approaches the final MEG result in sensitivity, will be presented.

Plenary-1 / 55

International Muon Collider (Zoom)

Corresponding Authors: donatella.lucchesi@pd.infn.it, donatella.lucchesi@cern.ch

meeting ID: 390-597-013 pwd:446459

Plenary-1 / 56

NA64mu (Zoom)

Corresponding Author: paolo.crivelli@cern.ch

meeting ID: 390-597-013 pwd:446459

Plenary-2 / 57

The Application of MuSR on the Study of Quantum Materials

Corresponding Author: leishu@fudan.edu.cn

Plenary-2 / 58

MuSR study on the quantum magnetism of 2D frustrated compounds

Corresponding Author: jma3@sjtu.edu.cn

Plenary-2 / 59

Preliminary Study of Muon Beam CT and Integration of MuDirac and Geant4 for Muonic X-ray Simulation

Corresponding Author: zhouzhihao@ihep.ac.cn

Plenary-1 / 60

The Mu2e experiment at Fermilab

Author: Zhengyun You[1]

[1] *Sun Yat-Sen University (CN)*

Corresponding Author: zhengyun.you@cern.ch

Lepton flavor is a conserved quantity of nature in the standard model. With the discovery of neutrino oscillation, charged lepton flavor violation (CLFV) is predicted to exist by various New Physics theories beyond the standard model. The Mu2e experiment at Fermilab will search for the CLFV process of neutrinoless muon to electron conversion in the field of a nucleus. Mu2e aims to measure the CLFV process to the precision of 10ˆ-17, which is an improvement of four orders of magnitude over the current best limit of 7 x 10ˆ-13 (90% CL) by the SINDRUMII experiment. I will present the Mu2e detector apparatus and beam, the signals and main backgrounds, as well as its current status, goal of the Mu2e Run 1 and the schedule.

Plenary-1 / 61

J-PARC Muon g-2/EDM

Corresponding Authors: tyosioka@gmail.com, tyosioka@icepp.s.u-tokyo.ac.jp

Poster (For two days) / 62

Towards a muon scattering tomography system for both low-Z and high-Z materials

Authors: Huiling Li[1]; Jiahui Chen[None]

Co-authors: Pingcheng Liu ; Yiyue Li

[1] *Shandong Institute of Advanced Technology (SDIAT) (CN)*

Corresponding Author: huiling.li@cern.ch

Muon scattering tomography (MST) is a non-destructive technique to image various materials by utilizing cosmic ray muons as probes. A typical MST system with a two-fold track detectors is particularly effective in detecting high-Z materials (e.g. nuclear materials), but difficult to recognize low-Z materials (e.g. explosive materials). In this poster, we present a concept of MST system to discriminate both low-Z and high-Z materials by extra measuring momentum of low-energy muons with a Cherenkov detector. Based on momentum-dependent track reconstruction and image reconstruction algorithm, we evaluate separation powers of different materials in the system. The results show that momentum measurement of low-energy muons and accurate track reconstruction can improve separation power of low-Z materials significantly.

Poster (For two days) / 65

Muon Ring

Corresponding Author: wuyoupeng2001@outlook.com

Poster (For two days) / 66

Neutrino Neutrino Collisions

Corresponding Authors: seeson@pku.edu.cn, leyun.gao@cern.ch

https://iopscience.iop.org/article/10.1088/1361-6471/ad2b7d

Plenary-2 / 67

Searching for heavy neutral lepton and LNV through VBS at muon colliders

Authors: Tong Li[1]; Changyuan Yao[2]; Man Yuan[1]

[1] *Nankai University*

[2] *Nankai University and DESY*

Corresponding Authors: yuanman@mail.nankai.edu.cn, litong@nankai.edu.cn, yaocy@nankai.edu.cn

High-energy muon collider can play as an emitter of electroweak gauge bosons and thus leads to substantial vector boson scattering (VBS) processes. In this work, we investigate the production of heavy neutral lepton (HNL) N and lepton number violation (LNV) signature through VBS at high-energy muon colliders. They provide clean and robust LNV signatures to tell the nature of Majorana HNLs and thus have more advantageous benefits than direct $\mu\mu$ annihilation. We analyze the potential of searching for Majorana HNL and obtain the exclusion limits on mixing $V_{\ell N}$. Based on this same-sign lepton signature, we also obtain the sensitivity of muon collider to the Weinberg operator.

Poster (For two days) / 68

Preliminary Conceptual Design of Proton Charge Radius Experiment using Future Muon Beam at CiADS

Author: YUAN LI[1]

[1] *Shandong University*

Corresponding Author: liyuan2002@mail.sdu.edu.cn

Accurate knowledge about proton charge radius is essential to high-precision QED calculations of atomic energy levels, and to test the Standard Model. It also has a strong impact on the Rydberg constant. Typically, one can measure the proton charge radius using ordinary hydrogen spectroscopy or elastic e-p scattering. However, in 2010, the first muonic hydrogen spectroscopy experiment, with an unprecedented precision (0.1%), yielded a proton charge radius result that was 7 smaller than previous measurements. This unexpected discrepancy is often referred to as the "proton charge radius puzzle". In the past decade, significant progress has been made in both theory and experiment, yet many problems remain. For example, the form factor results are inconsistent between PRad and Mainz experiments, and the cause of this discrepancy is still unknown. Furthermore, there has been no result published from μ-p elastic scattering experiments until now. Therefore, we propose a high-precision measurement of proton charge radius using the μ-p scattering technique, based on the future muon beam of CiADS at HIAF. It aims to collect μ-p, e-p, as well as e-e elastic scattering simultaneously, which will offer a unique opportunity for a direct test of the lepton universality, and help resolve the "proton charge radius puzzle". In this poster, we will present a potential conceptual design of this experiment, including projected results for the main physics observables.

Plenary-1 / 69

Towards a high-intensity muon source at CiADS

Author: Han-Jie Cai[1]

[1] *IMPCAS*

Corresponding Author: caihj@impcas.ac.cn

A high-intensity muon source driven by a continuous-wave superconducting linac holds the potential to significantly advance the intensity frontier of muon sources. Alongside advancements in accelerator technologies, breakthroughs in muon production target and collection schemes are essential. Here a novel muon production target is proposed, utilizing a free-surface liquid lithium jet capable of handling the heat power generated by the CiADS proton beam with an energy of 600 MeV and a current of 5 mA. It is predicted by our simulation studies that the lithium target is more efficient in surface muon production compared to the rotating graphite target. The parameter space of the front end consisting of a lithium target and a large aperture capture solenoid is explored, from the perspective of production efficiency, capture efficiency, and characteristics of the surface muon beam. The CiADS muon source is planned to be developed in two stages. In the first phase, the proton beam power will be 300 kW and the surface muon rate in the experimental area is expected to be 3.E9 /s. The conceptual layout and the design progress of the Phase I project are reported. The simulation study based on the preliminary design of the beamlines indicates that an overall transmission rate of more than 10% can be achieved. In the second phase, the beam power is expected to be upgraded to 3 MW and the liquid lithium jet target will be employed. The surface muon rate is expected to be 5.E10 /s. We believe that the unprecedented rate will enable entirely new experiments with considerable discovery potential and unique sensitivities in particle physics, condensed matter physics, and materials science.

Poster (For two days) / 70

Simulation study of the liquid lithium target for the CiADS muon source

Author: Niu Jianwei[1]

[1] *IMPCAS*

Corresponding Author: niujw2023@impcas.ac.cn

To meet the requirement of the next-generation muon source driven by cw superconducting linac, a new solution of for the muon production target is essential. In comparison to the rotating graphite target, the free-surface liquid lithium target proposed in this paper offers advantages in surface muon production efficiency, heat-removal ability, and target geometry compactness. Owing to its properties of low melting point, extremely low saturated vapor pressure, high heat capacity, and good compatibility with structural materials, liquid lithium has been widely used as a neutron production target, a radionuclide production target, and an ion beam charge stripper. The stability of the jet is the key. Here the simulation study of the parameters for a stable lithium jet is introduced. The influence of the press fluctuation on the stability of the target body as well as the free surface is investigated.

Plenary-2 / 71

Muonic X-ray track density imaging algorithm based on Geant4

Authors: Feng Chuntian[1]; Xiaodong Wang[1]

[1] *University of South China*

Corresponding Authors: 1259804429@qq.com, wxdusc@yahoo.com

A method for reconstructing the production positions of muon atoms using muon-X-ray momentum was proposed. By utilizing information on muon-X-ray positions and momentum, a trajectory density imaging method was used to reconstruct the position of the target object where muon atoms were produced, and the three-dimensional contour range of the target object was reconstructed. The imaging results demonstrate the capability to identify a 5mm cubic titanium block, suggesting the feasibility of the proposed non-destructive 3D elemental analysis method based on muon X-rays for bulk material analysis.

Poster (For two days) / 72

First-principles study of quantized muons in materials

Author: Li Deng[None]

Corresponding Author: lideng@gdlhz.ac.cn

With advancements in muon science, muon spin rotation/relaxation/resonance (MuSR) has emerged as a standard tool for characterizing spin states and has found widespread application across various fields. The current first-principles methods of the muon, combining density functional theory with the point muon approximation (DFT+Mu) can efficiently predict muon positions and simulate phenomena such as hyperfine coupling but yet they overlook the significant quantum effects due to the muon's lighter mass. To address these issues, this poster proposes to integrate advanced first-principles computational approaches, including two-component density functional theory and quantum Monte Carlo and aims to conduct comprehensive research on the quantum effect of the muon. It is found that considering the quantum properties of muons is necessary and meaningful for the MuSR spectra analysis.

Plenary-2 / 73

Application of muon imaging technology in archeology and mineral exploration

Author: Kaiqiang Yao[1]

[1] *Lanzhou Univ.*

Corresponding Author: yaokq20@lzu.edu.cn

缪子成像技术在考古与矿藏勘探中的应用
Muography has unique advantages for imaging large targets. We have developed the first mass-produced plastic scintillator-based muon imaging system in China, with a detection efficiency of nearly 98% and a positional resolution of about 2.5 mm. Based on detectors, we have completed the first technical validation for archaeological and mineral exploration in China. Through the Muography, we reconstructed the low-density region between the wall bricks and rammed earth on the north side of the city wall and the power distribution room above the city wall. Meanwhile, the reconstruction results of the Zaozigou gold mine determined the distribution of lode and goaf These works will be of great significance to the Muography in the field of cultural relics protection and mineral exploration.

Poster (For two days) / 74

A new muon transmission imaging algorithm

Author: Guorui Liu[1]

[1] *Lanzhou Univ.*

Corresponding Author: liugr21@lzu.edu.cn

一种新的缪子透射成像算法
Muography is a promising non-destructive probing method with unique advantages for geophysical detection and historical relics protection, among others. It utilizes muon absorption for large-scale object imaging. However, traditional algorithms have limitations in reconstructing anomalies distant from the detectors, leading to deformation or "fake"anomalies. To address this problem, we propose the innovative "seed" algorithm. Testing it in synthetic scenarios and mineral exploration, we demonstrate its superior capability in shaping and evaluating distant anomalies. The successful application of the "seed" algorithm expands the range of muography, particularly for on-site experiments.

Poster (For two days) / 76

Design of a segmented high purity germanium detector for muonic X-ray spectroscopy and imaging at a pulsed muon source

Authors: Mingxin Yang[1]; Yang Tian[1]; Yulan Li[2]

[1] *Tsinghua Univ.*

[2] *Tsinghua University*

Corresponding Authors: yulanli@mail.tsinghua.edu.cn, yangt@mail.tsinghua.edu.cn

The muonic X-rays emitted in the capture and absorption process of negative muons in matter have higher energy than characteristic X-rays, which can be used for nondestructive analysis of ˜10 μm to ˜cm scale material samples. The excellent energy resolution of high purity germanium (HPGe) detector makes it a desirable solution to accurately distinguish the X-ray peaks and determine the specific elements in samples. We propose an HPGe detector with cross-strip electrode design, which can be operated
at high count rate and measure multiple X-ray events, suitable for the application at a pulsed muon source. The detector design also has high position resolution. A two-dimensional imaging of elements at a given analysis depth is possible. The novel combined electrode technique will be used in the fabrication to simplify the precise electrode design. The design, simulation, and prototype fabrication are in progress.

Plenary-2 / 77

Exploring Exotic Spin-Dependent Interactions in Muons and Electrons Across Microscopic and Macroscopic Ranges

Author: Haiyang Yan[None]

Corresponding Author: h.y_yan@qq.com

Experiments have explored exotic spin-dependent interactions across distances from micrometers to astronomical scales, corresponding to energy scales below roughly 10 eV. Most research in the macroscopic domain has focused on protons, neutrons, and electrons, leaving interactions involving other fermions, like muons, largely unexplored. Muons are particularly intriguing due to their connection to several unsolved problems in physics. We've used the anomalous magnetic moment and electric dipole moment (EDM) of muons and electrons to investigate these exotic interactions. The muon magnetic moment may point to the existence of pseudo-scalar interactions. We've established constraints on scalar-pseudo-scalar interactions for muons within our range of interest. For electron pseudo-scalar interactions, we've set new limits from nanometers to around 1 millimeter. Given that all current experiments have failed to detect new forces, it's plausible that these forces might interact exclusively with muons. We suggest employing muon spin rotation techniques in the continued search for these elusive interactions.

Poster (For two days) / 78

Research on static detection of ICF targets based on muonic X-ray encoded imaging

Author: Dikai Li[None]

Corresponding Author: lidikai@sztu.edu.cn

Abstract: Muonic X-ray Emission (MIXE) was discovered by Chinese physicist Zhang Wenyu as early as 1947, and it can conduct non-destructive elemental analysis inside samples. Research has shown that MIXE can retain the high efficiency of direct imaging while benefiting from the low noise of pinhole imaging through encoding holes. The related technology significantly improves the counting rate while maintaining imaging quality. The ball encoding technology effectively solves the imaging blurring caused by the tilting of the encoding system, and successfully images micrometer sized X-ray sources. This project will combine MIXE and X-ray coding imaging techniques, including ball coding and zone plates, to study the method of non-destructive deep structure imaging of ICF targets and obtaining sub element distribution. This method aims to develop a new method for ICF target detection, which is particularly important for inertial confinement fusion. At the same time, this method can be used to detect and analyze materials that are difficult to penetrate or sensitive, and is expected to solve the problem of element resolution and imaging that traditional technologies cannot overcome. It will provide new methods for the future development of multiple fields such as particle physics, material science, and X-ray optics.

Poster (For two days) / 79

Research on a novel cosmic ray muon imaging system based on plastic scintillation

Author: Siyuan Luo[1]

[1] *USC*

Corresponding Author: 20202010210608@stu.usc.edu.cn

This report presents two innovative muon detection systems developed by the University of South China for transmission imaging technology. The first system introduces a muon detector employing large-area plastic scintillator four corner coupling PMT for pit exploration methods. The second approach involves the design of a compact muon imaging system utilizing plastic scintillator strips coupled with SIPM, tailored specifically for drilling methods enabling deep underground exploration. Simultaneously, a spatial angle muon positioning algorithm suitable for this system was developed. Furthermore, a novel density inversion algorithm was devised for mineral resource exploration, leveraging the capabilities of the two distinct muon imaging systems. Integration of muon imaging data with gravity data enabled the coupling of multiple imaging technologies for enhanced mineral resource exploration. The outcomes of this project are expected to introduce groundbreaking technologies and equipment for imaging the exploration of deep precious metal mineral resources.

Poster (For two days) / 80

Investigating the Correlation Between Muon Flux Variations and Atmospheric Conditions

Author: Jiayi Hao[1]

[1] *SJTU*

Corresponding Author: 1919635884@qq.com

Motivated by the potential insights into Earth's weather, we investigated the correlation between muon flux and meteorological parameters, including atmospheric pressure at sea level, temperature, and humidity. Utilizing muon detectors comprised of plastic scintillators and photomultiplier tubes, we monitored the muon flux over February and March 2024. We performed a detailed analysis of the unevenly spaced dataset to discern patterns and correlations between muon flux variations and the specified atmospheric conditions. Preliminary results demonstrate a notable negative correlation between muon flux and atmospheric pressure (average correlation coefficient: -0.15), suggesting increased muon absorption at higher pressures. A similar analysis revealed a positive correlation between decreasing temperatures and muon flux reductions (average correlation coefficient: 0.20), while humidity exhibited a minimal correlation (average correlation coefficient: 0.10). Intriguingly, during specific time intervals, such as between January 30 and February 4, 2024, we observed heightened correlations, with pressure and temperature correlation coefficients reaching -0.66 and 0.69, respectively. These observations suggest a substantial influence of atmospheric conditions on muon flux levels. In conclusion, the study elucidates a significant relationship between muon flux variations and atmospheric parameters, particularly pressure and temperature. These findings not only enhance our understanding of particle interactions with Earth's atmosphere but also highlight the potential of muon flux monitoring as a tool for atmospheric and particle physics research, paving the way for future studies in this promising interdisciplinary field.

Plenary-1 / 81

Brief review of MIP/Muon series in China

Corresponding Authors: zhangzx@itp.ac.cn, l.li@cern.ch, tangjy@ihep.ac.cn

Poster (For two days) / 82

Preliminary Progress of Dark Matter Exploration with RPCs-based Muon Scattering Imaging System

Corresponding Authors: fengyq2001@gmail.com, 2301210069@stu.pku.edu.cn

83

MIP2025 Institution Introductions

84

Awards, MIP2025 etc.