Workshop on Muon Physics at the Intensity and Precision Frontiers

Saturday, 15 April 2023 - Sunday, 16 April 2023

Tsung-Dao Lee Institute

Book of Abstracts

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Link the new physics processes at muon colliders to the early universe

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缪子对撞机具有高对撞能量和干净本底的优势，对于寻找新物理过程有着特别的潜力。而当前粒子物理对于早期宇宙的诸多问题还尚未有确切的答案，比如宇宙正反物质不对称该如何解释，电弱相变的确切图案是怎样的？缪子对撞机的高对撞能量给予了检验早期宇宙这些问题的可能性，其干净的本底和较大的亮度有望让我们对上述问题的参数空间有着更进一步的检验。在这个报告中，我们将寻找缪子对撞机上的新物理过程与早期宇宙的关联，尤其是揭示宇宙正反物质不对称的轻子生成机制，和电弱相变图案。

Muon Physics Topic 8 / 4

Neutrino Physics at or from a Muon Collider

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1. We propose a neutrino lepton collider where the neutrino beam is generated from TeV scale muon decays. Such a device would allow for a precise measurement of the W mass based on single W production. Although it is challenging to achieve high instantaneous luminosity with such a collider, we find that a total luminosity of 0.1/fb can already yield competitive physics results
2. We further propose a novel neutrino neutrino collider where the neutrino beam is generated from TeV scale muon decays. Such collisions can happen between either neutrinos and anti-neutrinos, or neutrinos and neutrinos.

Refs:

- https://arxiv.org/abs/2204.11871
- https://arxiv.org/abs/2205.15350

- https://arxiv.org/abs/2211.05240
- https://arxiv.org/abs/2301.02493
- https://arxiv.org/abs/2302.09874

Muon Physics Topic 8 / 5

Constraining rare B decays by μ+μ− ⟶ tc at future lepton colliders

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Motivated by the recent rare B decays measurements, we study the matching procedure of operators O9,O10 in the low energy effective Hamiltonian and operators in the Standard Model effective theory (SMEFT). It is noticed that there are more related operators in the SMEFT whose coefficients can not be determined only from the low-energy data from B physics. We demonstrate how to determine these coefficients with some new physics models, like Z′ model and leptoquark models, and then consider how to probe these operators of SMEFT at high energy by using the process μ+μ− ⟶ tc at future muon colliders, which can provide complementary information except for μ+μ− ⟶ bs on the underlying models which lead to rare B decay processes. We perform a Monte Carlo study (a hadron level analysis) to show how to separate the signal events from the SM background events and estimate the sensitivity to the Wilson coefficients for different models.

Muon Physics Topic 3 / 6

Recent progress of the J-PARC Muon g-2/EDM experiment.

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In this presentation, I plan to review recent progress of the J-PARC Muon g-2/EDM experiment currently prepared in Japan. This experiment contains novel features of cooling of positive muon down to thermal velocity, three dimensional spiral injection without a horizontal kick, a compact magnetic storage ring. These features might be useful for other applications elsewhere.

Muon Physics Topic 3 / 7

Development of a muon linac for the J-PARC Muon g-2/EDM experiment

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At J-PARC, a muon linac is being developed for future muon $g-2$/EDM experiments. The muon linac starts with an ultra-slow muon (USM) source that generates muons with an extremely small momentum of 3 keV/c (kinetic energy W=25 meV) by laser ionization of thermal muonium. The generated USM accelerated to 5.6 keV by an electrostatic field and injected into a radio frequency quadrupole (RFQ). The injected muons are accelerated to 0.34 MeV by the 324-MHz RFQ. Then, the energy of the muon beam is boosted to 4.5 MeV with a 324-MHz interdigital H-type drift tube linac (IH-DTL). Following the IH-DTL, 1296-MHz disk-and-washer (DAW) structures accelerate the muon up to 40 MeV. Finally, the muons are accelerated from 40 MeV to 212 MeV using a 2592-MHz disk-loaded traveling wave structure (DLS). In this presentation, details of the linac design and the recent progress toward the realization of the world's first muon linac will be presented.

Muon Physics Topic 5 / 8

Muon generation, detection and acceleration in laser wakefield

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Muon generation, detection and acceleration in laser wakefield
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Muons produced by short pulse laser can serve as a new type of muon source having potential advantages of high intensity, small source emittance, short pulse duration, and low cost. To validate it in experiments, a suitable muon diagnostics system is needed since high muon flux generated by short pulse laser shot is always accompanied by high radiation background, which is quite different from cases in general muon researches. A detection system is proposed to distinguish muon signals from radiation background by measuring the muon lifetime. It is based on the scintillator detector with water and lead shields, in which water is used to adjust energies of muons stopped in the scintillator and lead to against radiation background. A Geant4 simulation on the performance of the detection system shows that efficiency up to 52% could be arrived for low energy muons around 200 MeV and this efficiency decreases to 14% for high energy muon energy above 1000 MeV. The simulation also shows that the muon lifetime can be derived properly by measuring attenuation of the scintilla light of electrons from muon decays inside the scintillator detector. Furthermore, muons produced by the Bethe-Heitler process from laser wakefield accelerated electrons interacting with high Z materials have velocities close to the laser wakefield. It is possible to accelerate those muons with laser wakefield directly. Therefore for the first time we propose an all-optical "Generator and Booster" scheme to accelerate the produced muons by another laser wakefield to supply a prompt, compact, low cost and controllable muon source in laser laboratories. The trapping and acceleration of muons are analyzed by one-dimensional analytic model and verified by two-dimensional particle-in-cell (PIC) simulation. It is shown that muons can be trapped in a broad energy range and accelerated to higher energy than that of electrons for longer dephasing length. We further extrapolate the dependence of the maximum acceleration energy of muons with the laser wakefield relativistic factor γ and the relevant initial energy E0. It is shown that a maximum energy up to 15.2 GeV is promising withγ= 46 and E0 = 1.45 GeV on the existing short pulse laser facilities.

[1] Zhang, F; Deng, Z G; Shan, L Q, et al., All-optical mu(-) acceleration in the laser wakefield, High Power Laser Science and Engineering, 2018, 6: e63
[2] Zhang, F; Li, B Y; Zhang Z M, et al., A new method on diagnostics of muons produced by a short pulse laser, High Power Laser Science and Engineering, 2017, 5: e16

Muon Physics Topic 6 / 10

An Overview of Muon Tomography

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宇宙射线缪子是由来自太空的高能宇宙射线与大气层相互作用产生的次级射线粒子，具有极强的穿透能力，不易受高 Z 屏蔽体的干扰，没有人工辐射，避免了从业人员辐照损伤的风险，这使得缪子成像技术在近十年得到了广泛的关注和应用。在过去的几十年间，有关宇宙射线缪子探测技术研究课题的数量在持续增长，成果应用范围也不断拓展。当前宇宙射线缪子成像技术主要可分为两大类：基于多次角度散射和基于强度衰减的两种机理的成像技术。缪子成像技术也被国际辐射探测成像和粒子探测领域公认为 21 世纪极具开发价值与应用前景的新型成像技术，本报告将重点讲述当前国内外有关缪子成像的研究，并介绍南华大学在该领域取得的一些成果。

Poster session and buffet dinner / 11

Revealing the origin of neutrino masses through the Type II and Type III Seesaw mechanism at high-energy muon colliders.

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Dear organizing committee,

I will be representing our group to introduce our recent progress in the form of a poster presentation. Our work is focused on revealing the origin of neutrino masses through the Type II and Type III Seesaw mechanism at high-energy muon colliders.Here are the related papers we published on this work

https://arxiv.org/abs/2301.07274 and https://arxiv.org/abs/2205.04214

abstract of this work

The future muon collider with high energy and high luminosity can be an ideal place to search for new physics. In this work, we study the search potential of the heavy charged Higgs in the Type II Seesaw mechanism and the heavy leptons in the Type III Seesaw mechanism at muon colliders. The impact of up-to-date neutrino oscillation results is taken into account for realizing the decay modes of the heavy charged Higgs bosons and heavy leptons.

In the study of the Type II Seesaw mechanism, the pair production of doubly charged Higgs is through direct positive and negative muon pair annihilation and vector boson scattering (VBS) processes at muon collider. The associated production of singly charged and doubly charged Higgs can only be induced by VBS processes. We simulate both the purely leptonic and bosonic signal channels of the charged Higgs. We show the required luminosity for the discovery of the charged Higgses and the reachable limits on the leptonic decay branching fractions. In the study of the Type III Seesaw mechanism, we consider the pair production of heavy charged leptons through both muons annihilation and VBS processes. The channel
\begin{equation}
E^+E^-\to ZZ\ell^+\ell^-
\end{equation}
can be further utilized to fully reconstruct the heavy leptons and distinguish neutrino mass patterns. The pair production of heavy neutral lepton and heavy charged lepton are only induced by VBS

processes and lead to lepton-number-violating (LNV) signature. We also study the search potential of LNV processes at future high-energy muon collider with c.m. energy of 30 TeV.

Thank you for considering my submission. I look forward to the opportunity to present my work at the conference.

Sincerely,
Yuan Man

Poster session and buffet dinner / 12

Application of Machine Learning in the simulation of the Fermilab Muon g-2 Experiment

Authors: Yimin Wan[1]; Yiming Zhu[1]; Xingyun Huang[1]; Jun Kai Ng[2]

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The Fermilab Muon g-2 experiment aims to measure the magnetic anomaly of the muon at the precision level of 140 ppb. The data model to extract the anomalous precession frequency is subjected to various beam dynamics corrections, contributing significantly to the systematics of the extracted frequency. These beam dynamics corrections were estimated by monte-carlo simulations, which often are not computationally efficient, given the target statistics of the experiment. Modeling these effects using machine learning-based models can provide a more efficient solution to this problem. We explored various machine learning models (such as Boosted Decision Tree, PDEFoam, Artificial Neural Network, and K-nearest neighbors) of the acceptance of positron events in the calorimeters. The models' performances are compared, and the BDT and PDEFoam models can achieve an Area Under the Receiver Operation Curve (AUROC) of over 0.8.

Poster session and buffet dinner / 13

Feasibility study of a muon polarization monitor: Monte-Carlo simulation of muon detection and decay position reconstruction

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In this project, we proposed a feasibility study of muon polarization measurement using a self-designed detector to monitor the muon beam's polarization in J-PARC. The detector utilizes the asymmetric angular distribution of positrons decayed from polarized muons to measure polarization indirectly. Monte-Carlo simulation is applied to optimize the structure of the detector and estimate its performance, such as efficiency and accuracy. The whole program is divided into 3 phases. In the first two phases, we use atmospheric muon to study the feasibility and performance of our detector. In phase 3, a simulation of the muon beam at J-PARC is conducted.

The detector is designed to have scintillator bars and a copper target of 10 mm thickness, which stops muon and helps measure the polarization. In phase 1, four layers of scintillators are used to detect atmospheric muons and positrons generated by muon decay to analyze angular distribution. Two energy cuts are applied to select muon decayed in the copper target and to distinguish positrons from other particles. An overall efficiency of 0.2% can be obtained. After correcting errors, the relationship between asymmetry and muon polarization shows good linearity. In phases 2 and 3, detectors are installed at four corners. Each corner has three layers, improving accuracy and enabling the reconstruction of the position tracks. The spatial resolution is estimated to be around 20 mm.

Muon Physics Topic 7 / 14

The muon EDM experiment at PSI

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A permanent electric dipole moment (EDM) in any elementary particle implies CP symmetry violation and thus could help explain the matter-antimatter asymmetry observed in the universe. Within the Standard Model (SM) prediction, the Muon EDM is extremely small (1e-36 e cm), but in some of the BSM theories with LFUV, the muon EDM could be as large as 1e-22 e cm. The 17-order magnitude difference between the current experiment limit (1e-19 e cm) and the SM prediction means it is not experimentally reachable shortly. Any detected signal is a strong hint of new physics/BSM.
Several ongoing experiments are aiming to measure the muon EDM with higher precision. At Fermilab, we aim to perform a more sensitive search of the muon EDM using tracker-based and calorimeter-based approaches (1e-21 e cm sensitivity). Meanwhile, at PSI, we aim to measure muon EDM with the frozen-spin technology to reach 1e-23 e cm sensitivity. In the near future, some expectations of BSM will be verified by the experiment directly. In this meeting, we will present the overview and experimental progress of muon EDM measurement, which concerns muon behavior at the combination of the magnitude and electric field when EDM exists.

Poster session and buffet dinner / 15

Research and development of a muon entrance trigger for the muEDM experiment at PSI

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The first phase of the muEDM experiment at Paul Scherrer Institute (PSI), Switzerland, aims to probe the muon electric dipole moment (EDM) using the frozen-spin technique in a compact storage ring, at a sensitivity of 3×10⁻²¹ e·cm. A fast entrance detector is expected to work in concert with a magnetic pulse generator to kick muons to the desired orbit. At the same time, the entrance detector is expected to veto muons that are beyond the apparatus' admittance without introducing significant multiple scatterings. We developed a prototype entrance trigger detector consisting of a thin scintillator to detect incoming muons and four wall scintillators as veto detectors. The prototype was tested at 27.5 MeV/c at PiE1 beamline, PSI. A total of 7×10⁵ events were collected, which were readout by SiPMs coupled to the plastic scintillators with two different beam tunes. These events were analyzed to characterize the detector's performance, which was also cross-checked with Monte-Carlo simulations that considered the beam phase space and scintillation processes.

Muon Physics Topic 3 / 16

The Muon g-2 experiment at Fermilab

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The Fermilab Muon g-2 Experiment aims to search for evidence of new physics by measuring the anomalous magnetic moment of muons, represented by the quantity (g-2)/2. The experiment injects muons into a storage ring, where the precession frequency is measured to determine (g-2)/2.

The analysis of the experiment involves two main components: measuring the difference frequency (ωa) between the muon spin precession and cyclotron frequencies and measuring the magnetic field in the storage ring (ω'p) using nuclear magnetic resonance probes calibrated in terms of the equivalent proton spin precession frequency in a water sample.

In the run-1 stage, precise measurements of ωa and ω'p were performed, and the combined result with the previous BNL measurement determined (g-2)/2 to be (116592061 ± 41) × 10^-11, which is 4.2 standard deviations greater than the standard model prediction based on dispersion relation.

Improvements have been made in subsequent runs, including improvements in the stability of storage ring components and data analysis techniques, which are expected to reduce further the uncertainty in the measurement of (g-2)/2.

This talk will cover the published run-1 results and the latest improvements made in the run-2 and run-3 stages of the experiment.

Poster session and buffet dinner / 17

Muon beams for Neutrino CP violation: A bridge between Energy and Neutrino Frontiers

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Here I present our recent proposal for connecting neutrino and energy frontiers by exploiting collimated muon beams for neutrino oscillation. As know, neutrino oscillation is one the most important problems beyond standard model physics. Its observations enable us to infer that neutrinos have masses, although tiny. Another crucial problem within neutrino physics is the violation of Charge and Parity conservation, or namely CP violation. Here in our proposal we examine possible sensitivity on CP violating phase through oscillation mdoes of ν_μ, ν_e and their antineutrinos into $\nu_\tau(\overline{\nu}_\tau)$, produced from $\mu^+ \to e^+\overline{\nu}_\mu\nu_e$ and $\mu^- \to e^-\nu_\mu\overline{\nu}_e$ decay channel. Interfacing with long baseline neutrino detectors such as DUNE and T2K, this proposal can be used to measure CP violating phase, δ_{CP} and also serve as bright ν_τ factory. The symmetric μ^+ and μ^- beams produces symmetric neutrino and anti-neutrino sources and importantly, signals for neutrino and antineutrino oscillation can be collected simultaneously. With rich flux of muon sources, 5 σ deviations of sensitivity can be easily reached for CP phase as $|\pi/2|$, within only 1-2 years of data taking.

Poster session and buffet dinner / 18

Pileup Study for the Precession Frequency Analysis in the Fermilab Muon g-2 Experiment

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The Muon g-2 experiment at Fermilab aims to achieve an unprecedented precision of 140 ppb in measuring the muon's anomalous magnetic moment. This high-precision experiment necessitates a thorough examination of factors that could potentially bias the fitted anomalous precession frequency, omega_a, including the multi-positron pileup effect. During Run-1, we observed biases up to 100s of ppb caused by unresolved pileup. Three established methods for correcting pileup contamination exist: the shadow window method, the empirical method, and the probability density function method. Our group implemented the shadow window method to correct the time and energy spectra of reconstructed positrons. However, as the statistics increase, triple coincidence pileup becomes more significant, and the accuracy of higher-order corrections becomes more crucial. In this research, we employ a simplified toyMC model to simulate the pileup effect, aiming to identify a more accurate formula for high-order corrections within the shadow window method. A preliminary result will be presented in this poster.

Poster session and buffet dinner / 19

search for the lepton flavor violating decay J/psi->emu

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We present a search for the lepton flavor violating decay ⊠/⊠⟶⊠⊠ using 8.998×10ˆ9 ⊠/⊠ events collected with the BESIII detector at the BEPCII ⊠+ ⊠− storage ring. No excess of signal above background is observed; we therefore set an upper limit on the branching fraction of ⊠(⊠/⊠⟶⊠⊠)< 4.5×10ˆ(−9) at the 90% confidence level. Improving the previous best result by a factor of more than 30, this measurement places the most stringent limit to date on lepton flavor violation in the heavy quarkonium sector.

Poster session and buffet dinner / 20

Different-sign Longitudinally Polarized WW Scattering at the Muon Collider

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Longitudinally polarized Vector Boson Scattering (VBS) process provides us with a perfect probe to precisely measure electroweak observables and Higgs coupling as massive vector bosons have longitudinally polarized components originating from the Higgs mechanism. A TeV-scaled muon collider that would effectively be a "high-luminosity weak boson collider", has great potential to measure VBS processes. In this research, we choose W+W- scattering to validate the feasibility of the muon collider from the physical side using multi-variable analysis method. The significance of longitudinally polarized W+W- can obtain a 5 standard deviation discovery at a 14 TeV muon collider, which shows good potential to reach the first longitudinally polarized WW scattering discovery on a muon collider.

Poster session and buffet dinner / 21

Comparison study of muon sources

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Muon plays an essential role in both fundamental physics research and applied sciences. And the high quality of muon beam is the key to realizing research and application. A muon beam is typically produced in a proton accelerator complex through the proton-on-target process. Recently, other types of particles, such as high-energy electrons, gamma rays, and laser beams, have been proposed to produce high-intensity muon beams. Here we compared the number, energy distribution, and angle distribution of muons generated under the drive of proton, electron, and photon by the Geant4 simulation. Through the analysis of the simulation results, it is found that the energy and angle distribution of the muon driven by the three particles is similar. For graphite targets with low atomic numbers, the number of muons driven by electrons and photons is 2 or 3 orders of magnitude smaller than that of protons for the same incident particle number. For tungsten targets with a higher atomic number, the number of muons increases by one order of magnitude. Using Shanghai SHINE's parameters, we estimated the intensity of the muon beam to be around 108 /s. This research provides a check for the feasibility of using the electron beams of the SHINE to generate muon beams.

Poster session and buffet dinner / 22

MuGrid:A scintillator detector towards cosmic muon absorption imaging

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Muography is believed to have a wide range of applications especially in the cross-disciplinary area as it can probe the internal composition of objects in a non-destructive way. We designed a cosmic muon tracking detector MuGrid using plastic scintillators with a novel construction. Preliminary progress of the MuGrid detector and its demonstrator are shown in this poster.

Poster session and buffet dinner / 23

Muon Beam Monitor in the COMET experiment

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Signs of charged lepton flavor violation (cLFV) processes directly indicate the existence of new physics beyond the standard model. The COMET experiment is located at the Japan High Current Proton Accelerator Center (J-PARC), and its goal is to find the charged lepton flavor violation process μN⟶eN with an accuracy of more than 10-17. In order to obtain high-precision experimental results, it is necessary to accurately measure and real-time monitor the various properties of the accelerator muon beam.

Muon Physics Topic 7 / 24

Models for the Muon EDM

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Electric dipole moments (EDMs) of elementary particles are powerful probes of physics beyond the Standard Model with CP violation. The reported discrepancy in the muon anomalous magnetic moment motivates us to explore to what extent new physics with CP violation to address the discrepancy is probed by ongoing and projected searches for the muon EDM. In this talk, we discuss two benchmark models. The first model is a CP-violating two-Higgs-doublet model where the muon exclusively couples to one Higgs doublet. Since contributions to flavor violating processes as well as the electron EDM are suppressed, the muon EDM becomes an essential probe of the model. Our result shows that some viable parameter space leads to the muon EDM probed by the projected PSI experiment. The second is a model of dark matter (DM) that can explain the muon g−2 anomaly. The model contains a DM fermion and new scalars whose exclusive interactions with the muon radiatively generate the observed muon mass. Constraints from DM direct and indirect detection experiments as well as collider searches are safely evaded. The model parameter space that gives the observed DM abundance and explains the muon g–2 anomaly leads to the muon EDM that can be probed by the PSI experiment. Another viable parameter space even achieves a value of the muon EDM reachable by the ongoing Fermilab muon g−2 experiment and the future J-PARC experiment.

Poster session and buffet dinner / 25

R&D of the J-PARC muon spin polarization monitor (hardware development)

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In this project's hardware phase, we have designed and developed a detector to measure the polarization of atmospheric muons. The detector consists of scintillator bars read out by silicon photomultipliers (SiPMs) to detect muons as well as their decay electrons and positrons. The SiPM signals are processed and stored using a high-performance CAEN DT5702 front-end digitizer board. Through data analysis, we can reconstruct the trajectory of muons as they traverse the scintillator bars. We fit the spectra of energy deposition to a Landau distribution and performed the ADC-to-MeV energy calibration by comparing the most probable value (MPV) with the one extracted from a Geant4 simulation. This calibration process facilitates the application of our selection algorithm to actual experimental data for subsequent polarization measurements.

Muon Physics Topic 4 / **26**

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

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In the standard model (SM), neutrinos are massless and lepton flavor is conserved. However, the discovery of neutrino oscillations indicates that neutrinos are massive and there is lepton mixing. On the one hand, tiny neutrino masses result in extremely low weak-interaction-induced lepton flavor violation branching ratio, making it impossible to observe. On the other hand, if the tiny neutrino masses are generated in the SM, the corresponding Yukawa coupling strength would be extremely weak. Therefore, it is believed that there are new physics related to the neutrino masses. The new particles and interactions in these new models may induce the charged lepton flavor violation (cLFV). The lepton flavor experiment searching for these processes is a sensitive probe for new physics. Muonium is a bound state consisting of a positive muon and an electron, and can be considered as a leptonic isotope of hydrogen. There are new physics predicting the existence of the muonium conversion process, a cLFV process that a muonium spontaneously converts into an anti-muonium, which violates the lepton flavor or lepton number by 2 units. The search for this process can further constrain the parameter space of related new scalar or vector bosons that carrying two $\mathrm{U}(1)$ charges. Therefore, it can be complementary to the search for the μe conversion, $\mu \to e\gamma$, $\mu \to eee$ and other cLFV processes that violate the lepton flavor by only 1 unit. The latest result of the muonium conversion was established in 1999, and no new experiments have been proposed for more than 20 years thereafter. The sensitivity of muonium conversion experiment is limited by the background level and muon yield. Over the past 20 years, with the development of detector technology, muon targetry, and muon beam, we believe there is a great opportunity to do substantially better. The proposed MACE experiment aims to improve the upper limit of muonium conversion by more than two orders of magnitude by improving muon yield and detector performance, and is expected to reach the order of 10^{-14}, providing more evidence for new physics related to cLFV.

Poster session and buffet dinner / **27**

Widening the $U(1)_{L_\mu - L_\tau}$ Z' mass range for resolving the muon $g-2$ anomaly

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Exchanging a Z' gauge boson is a favored mechanism to solve the muon $(g-2)_\mu$ anomaly. Among such models the Z'
from $U(1)_{L_\mu - L_\tau}$ gauge group has been extensively studied. In this model the same interaction addressing $(g-2)_\mu$, leads to an enhanced muon neutrino trident (MNT) process $\nu_\mu N \to \nu_\mu \mu \bar{\mu} N$ constraining the Z'
mass to be less than a few hundred MeV. Many other Z' models face the same problem. It has long been realized that the coupling of Z' in the model can admit $(\bar{\mu}\gamma^\mu \tau + \bar{\nu}_\mu \gamma^\mu L \nu_\tau) Z'_\mu$ interaction which does not contribute to the MNT process. It can solve $(g-2)_\mu$ anomaly for a much wider Z' mass range. However this new interaction induces $\tau \to \mu \bar{\nu}_\mu \nu_\tau$ which rules out it as a solution to $(g-2)_\mu$ anomaly. Here we propose a mechanism by introducing type-II seesaw $SU(2)_L$ triplet scalars to evade constraints from all known data to allow a wide Z' mass range to solve the $(g-2)_\mu$ anomaly. This mechanism opens a new window for Z' physics.

Muon Physics Topic 5 / 31

MuSIC at RCNP

Muon Physics Topic 2 / 34

Theoretical aspects between low-energy cLFV and collider experiments

Muon Physics Topic 2 / 35

Search for LFV with the Z’ model in future lepton colliders

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Charged lepton flavor violation (CLFV) is a clear signature of possible new physics beyond the standard model. By exploiting a typical example model of extra Z′ gauge boson, we perform a detailed comparative study on CLFV searches at several future lepton colliders, including a 240 GeV electron-positron collider and a TeV scale muon collider. Based on detailed signal and background Monte-Carlo studies with fast detector simulations, we derive the potentials in searching for Z′ mediated CLFV couplings with $e\mu$, $e\tau$ and $\mu\tau$ of different future colliders. The results are compared with the current and prospect limits set by either low-energy experiments or the high-energy LHC experiments. The sensitivity of the τ related CLFV coupling strength at future lepton colliders will be significantly improved in comparison to the current best constraints and the prospect constraints for the $\mu\tau$ channel.

Muon Physics Topic 4 / 39

Overview of Lepton Flavor Physics

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Muon Physics Topic 4 / 41

The Mu2e experiment at Fermilab

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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.

Poster session and buffet dinner / 42

Deep Learning Based Tracking Reconstruction and Magnetic Field Measurement Research in the Muon g-2 Experiment

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The Run1 result of the Fermilab muon g-2 experiment have shown a 4.2 standard deviation between the experimental measurement and theoretical prediction of a_μ, strongly indicating a new physics signal.

The experiment already accumulated 21x data compared to the BNL experiment. The J-PARC muon g-2 experiment will collect ˜3.5x statistics compared to Fermilab. It can be expected that, with the increases of the collected data volume, and limited by the speed and accuracy, the existing tracking reconstruction and magnetic field measurement method may not fully satisfy the requirement of the experiment.

The breakthrough of the deep learning inspires new analysis method in the muon g-2 experiment. In this poster, we will present some preliminary research of the tracking reconstrcution based on RNN and the magnetic field measurement based on PINN (physics informed neural network). The preliminary result shows that the deep learning method has enormous potential in these topics.

Muon Physics Topic 6 / 43

Development of Chinese muSR apparatus

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Muon spin spectroscopy, known as a collection of muon spin rotation, relaxation and resonance (μSR) techniques, uses highly polarized muons to study the microscopic magnetic structure and dynamics of condensed matter. The interaction between muon spins and the local field inside materials forms the physical basis of μSR techniques. Such information is extracted by the detection of positrons decaying from muons inside a sample and asymmetrically emitted at the solid angle of 4 π steradians. Currently, there are five international muon facilities providing continuous or pulsed muon beams for material characterization. In addition to the existing facilities, the first Chinese muon source, the Muon station for sciEnce technoLOgy and inDustrY (MELODY), is planned to be constructed at Phase II of the China Spallation Neutron Source (CSNS). It aims to provide intense and pulsed muon beams to conduct μSR applications in multiple disciplines, including condensed matter physics, material science, chemistry, and energy science. The group from the University of Science and Technology of China (abbreviated as the USTC group) participated in the collaboration with the CSNS accelerator group for the construction of the muon source. The USTC group dominated the R&D of the first-generation photomultiplier tube (PMT)-based μSR spectrometer and the design of the second-generation silicon photomultiplier (SiPM)-based spectrometer. The PMT-based spectrometer is a 128-channel prototype to demonstrate and develop key detector and electronics technologies for the planned MELODY. After several iterative designs and updates of detectors and electronics, the spectrometer prototype achieved a 7-ns dead time, which is shorter than that of the ISIS spectrometer and can record more positrons in each pulse. Based on the technologies developed from the first-generation spectrometer, the second-generation spectrometer will use SiPMs to accommodate over 2500 detector units to make full use of muons in MELODY. The development of μSR spectrometers will greatly boost the construction of MELODY and provide high-quality data to users to interpret material properties.

Muon Physics Topic 2 / 44

Progress on Muon Source Project at CSNS

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A Muon station for sciEnce, technoLOgy and inDustrY (MELODY) has been listed in the CSNS II upgrade plan, and the infrastructure construction is scheduled to start by the end of 2023. Up to 5Hz of proton pulses will be extracted from the RCS ring to a stand-alone target station. One surface muon and one decay muon beamline are designed to provide multi-terminals for applications. In this report, we describe the design of MELODY and prospect for future applications.

Muon Physics Topic 6 / 45

muSR study of unconventional superconductors

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In this talk, I will introduce the muon spin rotation/relaxation (muSR) method in application to study superconducting materials. I will also present our experimental results obtained on several unconventional superconducting systems, including Sr2RuO4, Ba1-xKxFe2As2 and FeSe, under various experimental conditions (in zero and applied magnetic field, under hydrostatic and uniaxial pressure) down to mK temperatures [1-5]. In this study, we mainly focused on studying one of the most unusual properties of unconventional superconductivity is the possibility of generating superconducting currents spontaneously while cooling the samples below the superconducting transition

temperature. The related spontaneous magnetic fields are tiny and can be as small as fractions of Oersted. Therefore, most of the existing experimental techniques are not capable of detecting these currents. Here I will show how these small magnetic fields can be observed by muSR.

1. Vadim Grinenko et al., μSR measurements on Sr2RuO4 under ⟨110⟩ uniaxial stress, Physical Review B, 2023, 107: 024508.
2. Vadim Grinenko et al., Split superconducting and time-reversal symmetry-breaking transitions in Sr2RuO4 under stress, Nature Physics, 2021, 17(6): 748-754.
3. Vadim Grinenko et al., Unsplit superconducting and time reversal symmetry breaking transitions in Sr2RuO4 under hydrostatic pressure and disorder, Nature Communications, 2021, 12(1).
4. Vadim Grinenko et al., Superconductivity with broken time-reversal symmetry inside a superconducting s-wave state, Nature Physics, 2020, 16(7): 789-794.
5. Vadim Grinenko et al., Low-temperature breakdown of antiferromagnetic quantum critical behavior in FeSe, Physical Review B, 2018, 97(20): 201102.

Muon Physics Topic 7 / **46**

Development and observation experiments of the high spatial resolution muon tomography prototypes based on Micromegas detectors

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Muon (μ) tomography imaging technology, as an important supplement to existing technologies such as X-ray and neutron imaging, has a wide range of important applications in fields such as natural disaster warning, mineral exploration, as well as interdisciplinary fields such as geology and archaeology. MPGD based muon track detection is one of the important technical schemes for high-resolution muon imaging research. The research group at the USTC has developed small (150mm × 150mm) and large area (400mm × 400mm) scattering and transmission imaging device prototypes (μSTC: μ(muon) Scattering tomography & Transmission imaging faCility) with X-Y two-dimensional readout, using thermal bonding Micromegas detectors, AGET readout electronics, and encoding readout circuits. Imaging observation experiments were also carried out on high-z samples (tungsten, lead, etc.), subway tunnels, and an ancient volcano (Hefei Dashushan). In 2022, the research group conducted observation experiments on the geological structure of the upper layer of the subway tunnel and the structure of the ancient volcano. During the test period, the prototype operated normally in a construction environment with a large amount of dust and water vapor, as well as strong vibrations, which verified its adaptability to complex environments. In the observation experiment of the ancient volcano, the prototype was placed in a van, and the experiment equipment could be operated and monitored remotely in the laboratory through 4G network and a camera. Currently, more than three months of continuous operation and data acquisition have been completed, and the system stability has been further verified. The imaging results will be also presented.

Muon Physics Topic 4 / **47**

The COMET Experiment at J-PARC

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The COMET (COherent Muon to Electron Transition) experiment at the Japan Proton Accelerator Research Complex (J-PARC) is a cutting-edge high-energy physics experiment that aims to search for the muon-to-electron conversion process, which is a rare phenomenon that would be a clear indication of physics beyond the Standard Model. The COMET experiment utilizes a high-intensity proton beam from the J-PARC accelerator to produce a substantial quantity of muons, thereby enabling it to enhance the existing record sensitivity of muon-to-electron conversion search by a remarkable factor of 10,000. During this presentation, we will provide an introduction to the COMET experiment, its objectives, its experimental configuration, as well as its present progress.

Muon Physics Topic 5 / 48

A Pulsed Muon Source Based on a High-Repetition-Rate Electron Accelerator

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Muons have been playing an important and unique role in both fundamental physics and applied sciences. Recent results of the muon magnetic anomaly hint at physics beyond the Standard Model; Muon spin rotation techniques have been widely applied to the study of superconductivity and magnetic materials. A typical muon experiment measurement time of 10 muon lifetimes means that an ideal muon source should operate at around 50 kHz in the pulsed mode. However, current muon sources are either driven by several 10 Hz pulsed proton accelerators (e.g. J-PARC) or DC proton accelerators (e.g. PSI), resulting in low-duty cycles for many types of muon experiments. Here we explore the use of a high-repetition-rate pulsed electron beam at the Shanghai SHINE facility as a muon source driver. SHINE is based on an 8-GeV CW superconducting RF linac, with a bunch rate of 1 MHz and a bunch charge of 100 pC. Downstream of undulators, the electron beam is deflected and absorbed in a beam dump. Based on a GEANT4 Monte Carlo simulation, we estimated the maximum intensity of the muon beam to be around 10ˆ9. The main production channels are photo-nuclear and Bethe-Heitler processes, and each of these processes generates muon beams with different kinematics and time profiles. Such muon beams can improve the performance of current muon physics experiments, such as the muonium to anti-muonium conversion and the muon spin rotation technique.

Muon Physics Topic 1 / 49

CiADS and Plan for Muon Research

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With a design power of 2.5 MW and a proton beam energy of 500 MeV, the CiADS superconducting linear accelerator (Linac) will be the most powerful continuous wave proton accelerator. In

addition, the CiADS accelerator possesses a upgrade plan at the beginning. From the perspective of beam energy and power, CiADS accelerators are well suited for driving a high-intensity muon sources. In this presentation, the construction background of the CiADS project is introduced firstly. Secondly, main design parameters and current development progress of CiADS are reported briefly. Thirdly, the research objectives of the device, the experimental terminal layout, the operation mode and future upgrade plan of the Linac are introduced. Moreover, the demands for a high-intensity muon source or dedicated muon beam line for the high-precision experiments and the muon application technologies are discussed, Finally, the preliminary scheme and future possibilities of a high-intensity muon source based on the CiADS Linac are presented.

Muon Physics Topic 8 / 50

Muon Colliders

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Muon collider is a potential accelerator solution for future particle physics in energy frontier. It provides unique properties to the research in multi-TeV energy range, as compared to other accelerator solutions such as proton-proton colliders and linear electron-positron colliders. This talk reviews the worldwide study history of muon colliders since 1990's, different design schemes, R&D efforts and outputs. It will also introduce the ongoing international efforts, especially the International Muon Collider Collaboration (IMCC) and the roadmap. The extreme challenges on the technologies and R&D efforts to realize a muon colliders are also commented.

Muon Physics Topic 1 / 51

Toward a Muon Source in HIAF project

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As a fundamental subatomic particle, muon has many unique properties that make it an important tool for research in Physics, Chemistry, and Materials science. In recent years, abundant achievements have been made in the generation and application of muon beam, such as μSR, muon tomography, muon cooling, and muon collider. However, because we did not have suitable proton accelerators before, the technology and conditions for muon research are still lacking in China. HIAF (High Intensity heavy ion Accelerator Facility) is a new accelerator facility for advances in nuclear physics and related research fields in China. Featuring unprecedentedly intense ion beams from proton to uranium, HIAF will bring researchers to the forefront of promoting the most vigorous and fascinating fields in nuclear physics. Especially, it will provide an excellent platform for building a high-flux muon source. The construction of HIAF started in December of 2018, and the civil engineering and infrastructure are being constructed on time and will be completed in July, 2023. R&D on key accelerator techniques is going smoothly, and prototypes of core devices have been developed and fabricated in cooperation with domestic and foreign collaborators. In this talk, the progress and present status of the HIAF project will be given, and the future plans for muon studies will be discussed.

Poster session and buffet dinner / 52

Search for the semi-muonic weak decay Jpsi to D mu nv

Author: Zhijun Li[1]

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Charmonium weak decay is allowed in the Standard Model but has never been observed. Using $(10087 \pm 44) \times 10^6$ 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 a search for the charmonium rare semi-muonic decay $J/\psi \to D^-\mu^+\nu_\mu$ and its charge conjugation ($c.c.$) mode. Since no significant signal above the background is observed, we set an upper limit of the branching fraction to be $\mathrm{BF}(\mathrm{J}/\psi \to \mathrm{D}^-\mu^+\nu_\mu + \mathrm{c.c.}) < 5.6 \times 10^{-7}$ at a confidence level of 90%. This is the first search for the weak decay of charmonium with a muon in the final state and the measurement is compatible with the SM theoretical predictions.