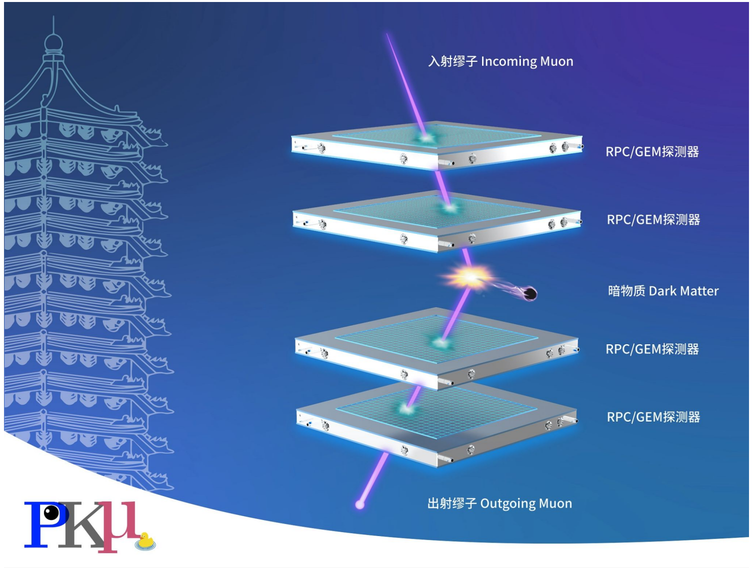
缪子(电子)散射项目

Probing and Knocking with Muons



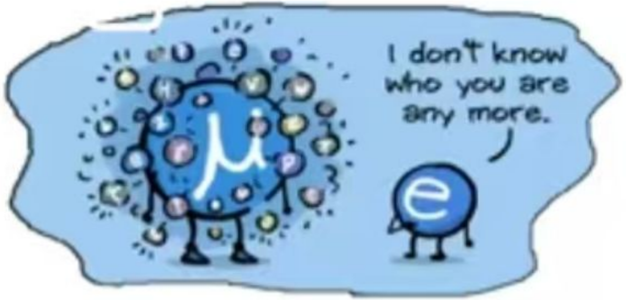
Qiang Li, Qite Li, Chen Zhou
(Peking University),
for the PKMu working group

2025/09/20

JPG52 (2025) 075002, MPLA (2025) 2530008, PRD111 (2025) 11, 116018, arXiv:2507.23458, and PRAB 28 (2025) 5, 053401

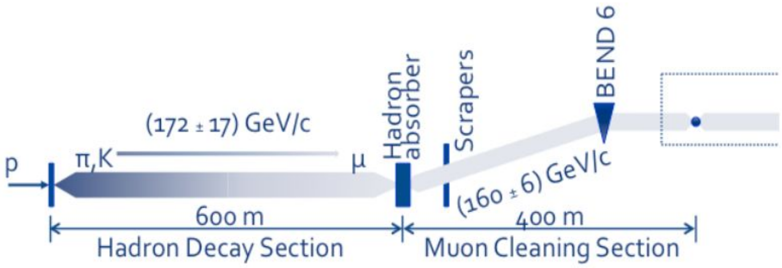
世界范围内的缪子散射、打靶实验

- 对第二代带电轻子缪子的研究及应用相对较少，其科学和应用潜力巨大。
- **欧洲核子研究中心 EMC、NA64 和MUonE等实验利用高能缪子与靶散射**
  - **核性质、散射截面测量；新物理探寻 ...**
- 缪子散射蕴含大量的物理课题有待挖掘
  - **不同能量的缪子束互补**
  - **New Ideas?!**



- **中国之前没有开展的 缪子物理实验。近年来条件有了很大 变化：**
  - 中国散裂中子源升级启动 -> Melody
  - 国家“十二五”重大科学工程项目“强流加速器装置(HIAF)”建设重离子加速器；
    - **2025-2026年验收，第一条中国高能 (1-10 GeV) 缪子束流？ 机遇！**
  - “十四五” “加速器驱动嬗变系统(CiADS)” 建设连续流直线质子加速器

arXiv:1911.01498 欧洲核子研究中心近年 缪子散射实验



Studies for New Experiments at the CERN M2 Beamline within "Physics Beyond Colliders": AMBER/COMPASS++, NA64mu, MuonE

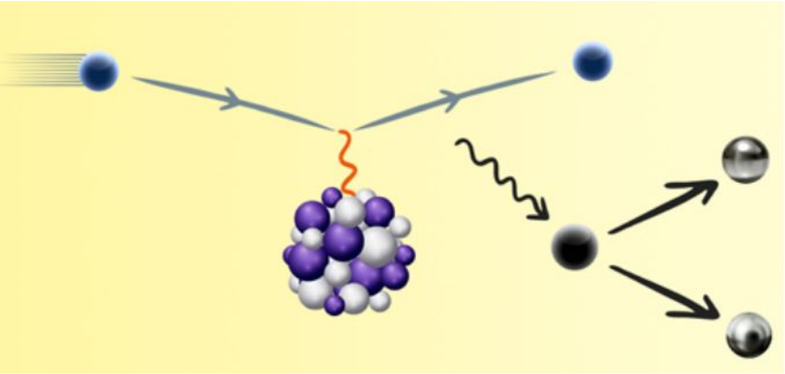
与质子、核子、电子散射

Johannes Bernhard, Dipanwita Banerjee, Eva Montbarbon, Markus Brugger, Nikolaos Charitonidis, Serhii Cholak, Gian Luigi D'Alessandro, Lau Gatignon, Alexander Gerbershagen, Bastien Rae, Marcel Rosenthal, Maarten van Dijk, Benjamin Moritz Veit

The "Physics Beyond Colliders (PBC)" study explores fundamental physics opportunities at the CERN accelerator complex complementary to collider experiments. Three new collaborations aim to exploit the M2 beamline in the North Area with existing high-intensity muon and hadron beams, but also aspire to go beyond the current M2 capabilities with a RF-separated, high intensity hadron beam, under study. The AMBER/COMPASS++ collaboration proposes an ambitious program with a measurement of the proton radius with muon beams, as well as QCD-related studies from pion PDFs / Drell-Yan to cross section measurements for dark sector searches. Assuming feasibility of the RF-separated beam, the spectrum of strange mesons would enter a high precision era while kaon PDFs as well as nucleon TMDs would be accessible via Drell-Yan reactions. The NA64mu collaboration proposes to search for dark sector mediators such as a dark scalar A' or a hypothetical Z_mu using the M2 muon beam and complementing their on-going A' searches with electron beams. The MuonE collaboration intends to assess the hadronic component of the vacuum polarization via elastic mu-e scattering, the dominant uncertainty in the determination of (g-2)_mu. An overview of the three new experimental programs will be presented together with implications for the M2 beamline and the experimental area EHN2, based on the studies of the PBC "Conventional Beams" Working Group.

[PRL132, 211803 (2024)](#)

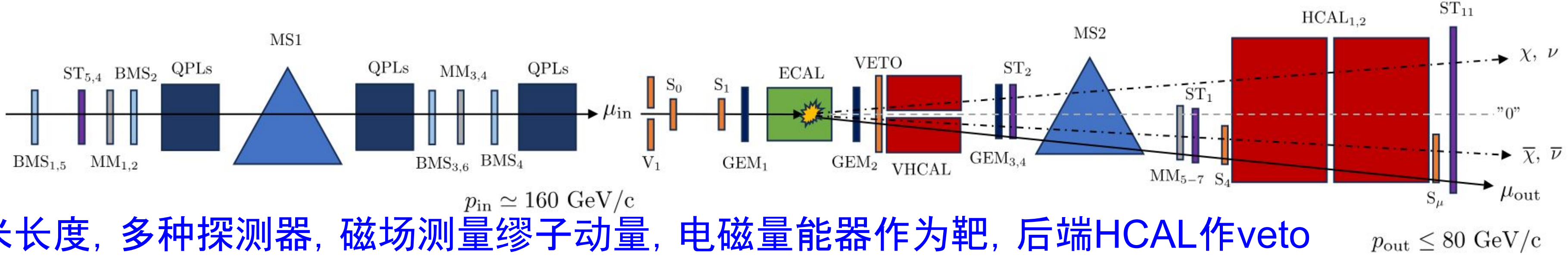
缪子与核散射：NA64μ 寻找新物理



Careful Accounting Could Reveal the Dark Sector

May 21, 2024 • *Physics* 17, s54

An experiment at CERN seeks signs of dark matter by looking for missing energy and momentum in the debris of particle collisions.

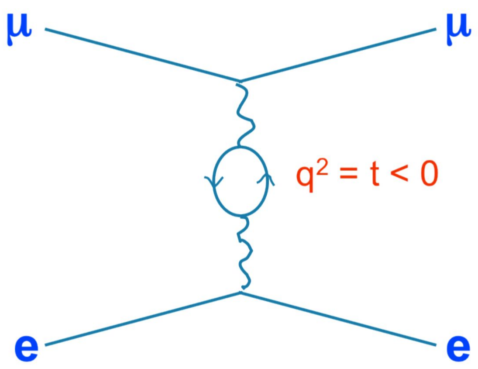


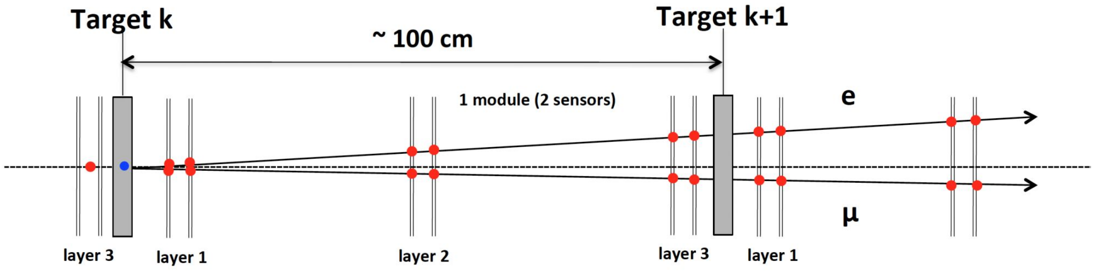
百米长度，多种探测器，磁场测量缪子动量，电磁量能器作为靶，后端HCAL作veto

FIG. 2. Schematic illustration of the NA64μ setup and of a signal event topology. Well-defined incoming muons with momentum $p_{in} \simeq 160$ GeV$/c$ are reconstructed in the first magnet spectrometer and tagged by a set of scintillator counters before arriving at the active target (ECAL). In the collision of muons with the target nuclei the bremsstrahlunglike reaction and subsequent invisible decay, $\mu N \to \mu N(Z' \to \text{invisible})$ is produced. The resulting scattered muon with momentum $p_{out} \leq 80$ GeV$/c$ is measured in the second spectrometer (MS2).

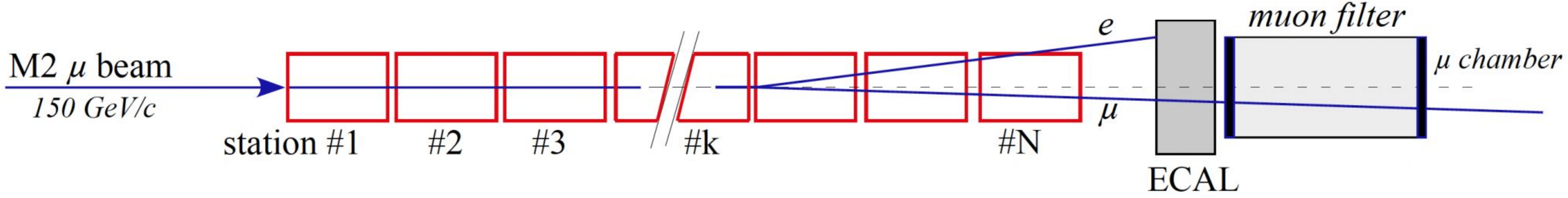
缪子与电子散射：MUonE 精密测量SM

https://web.infn.it/MUonE/





轻靶，无磁场，良好的径迹探测器，电磁量能器/末端缪子探测器提供PID。
模块化，每模块约1米长。

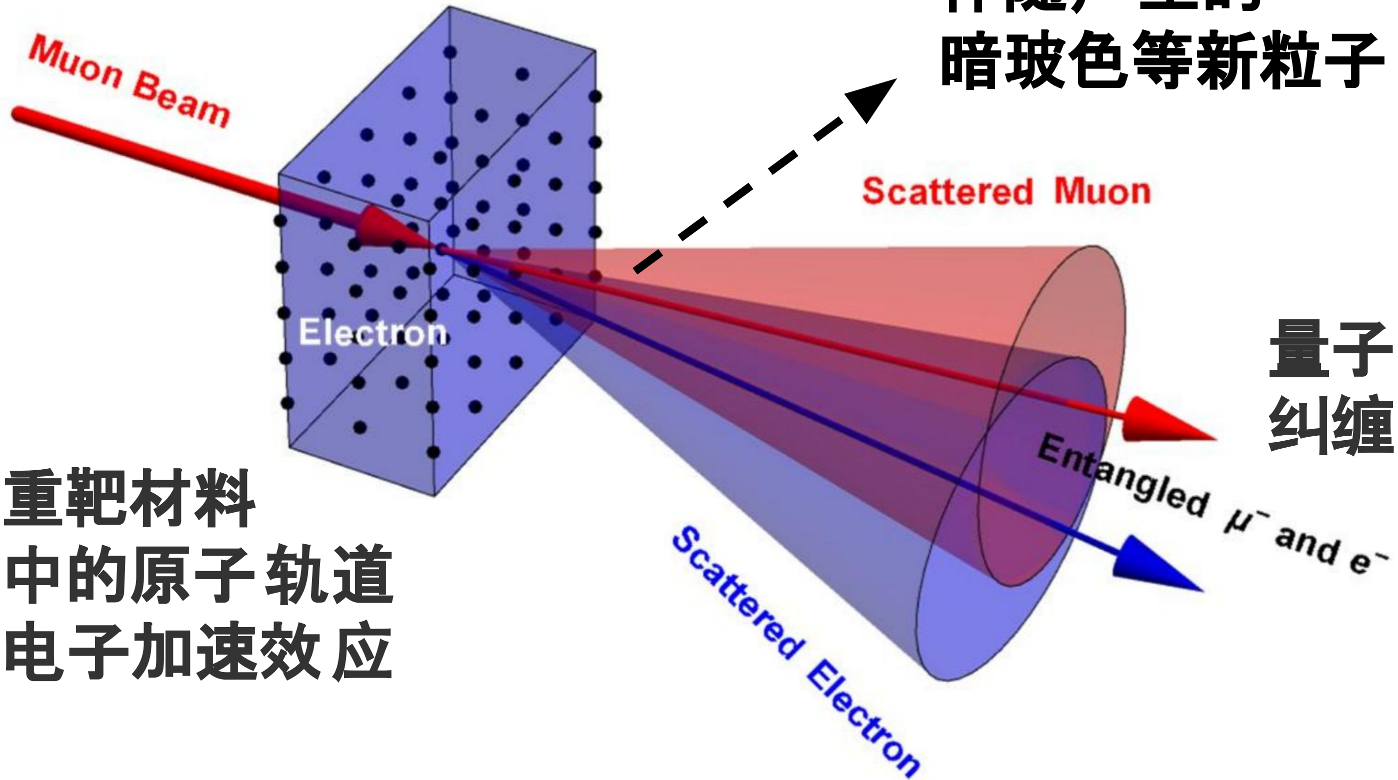


缪子(与电子)散射

周边的亲缪型暗物质

宇宙射线
或
缪子束流

伴随产生的
暗玻色等新粒子



量子
纠缠

重靶材料
中的原子轨道
电子加速效应

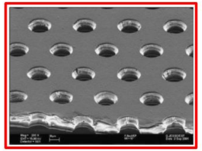
- 简介
- 例1：寻找亲缪子型暗物质
- 例2：寻找暗玻色子
- 例3：级联散射、量子纠缠
- 更多可能
- 展望

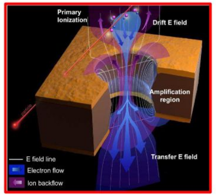
some parts still in progress and results may be preliminary

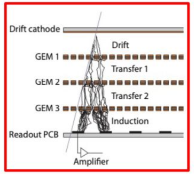
北大缪子探测器研发

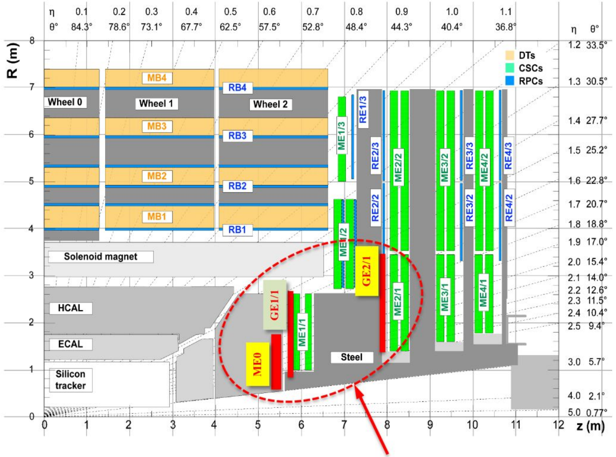
- ➔ **CMS Muon Trigger RPC**: assembled and tested at PKU at around 2002
- ➔ **RPC R&D for nuclear physics**
- ➔ **CMS GEM** upgrade program

北大基地生产的第一个CMS GEM模块









CMS端盖缪子探测器 GEM升级

北京大学、清华大学、中山大学、北京航空航天大学

Combination of glass RPC & Delay-line Readout

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

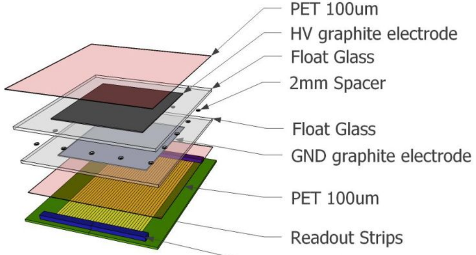
journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Study of spatial resolution properties of a glass RPC

Qite Li, Yanlin Ye *, Chao Wen, Wei Ji, Yushou Song, Rongrong Ma, Chen Zhou, Yucheng Ge, Hongtao Liu

School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China



Reference:

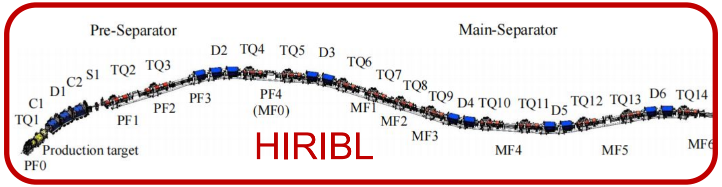
- 许金艳,**李奇特***, 等, ***物理实验*** 41(2021)23
- **Qi-Te, Li,** et al. ***Chinese Physics C*** 37 (2013)016002.
- S. Chen, **Q. Li***, et al, ***JINST***: 10 (2014)10022.

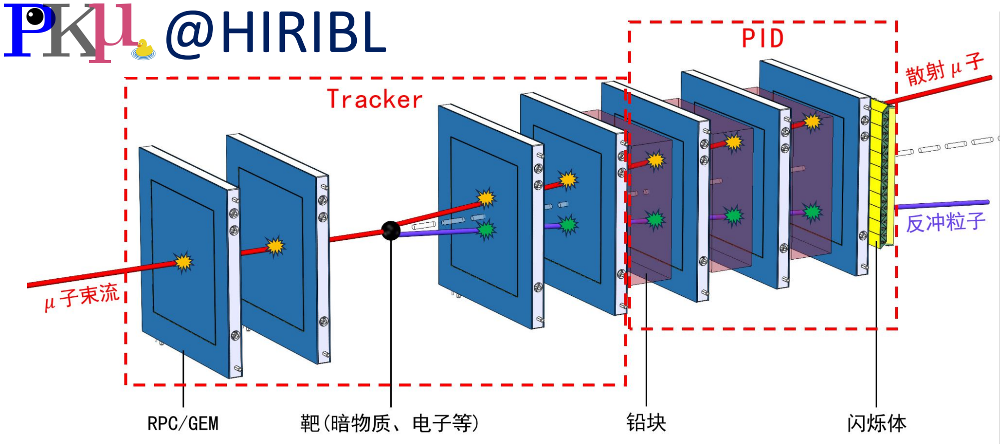
90% R134a+9% $i\text{-}C_4H_{10}$+1% SF_6 50ml/Min

基于HIAF-HIRIBL装置的缪子散射实验

PKMu(Probing and Knocking with Muons)：由**北京大学**物理学院技术物理系、核物理与核技术全国重点实验室原创提出的缪子散射实验合作项目，旨在结合缪子散射成像技术与前沿物理研究，通过对缪子散射的测量研究核物理、标准模型和超出标准模型的新物理。

HIRIBL：**中国科学院近代物理研究所** 建设的强流重离子加速器(HIAF)可加速从质子到铀的重离子。放射性次级束流分离器(HIRIBL)是HIAF上重要装置，可传输动量高达 7.5 GeV/c 的π/μ粒子。研究表明，基于该装置，可获得流强可达 10^6–10^7/s的GeV能量缪子束流，动量展宽约4%，束斑直径约10cm。



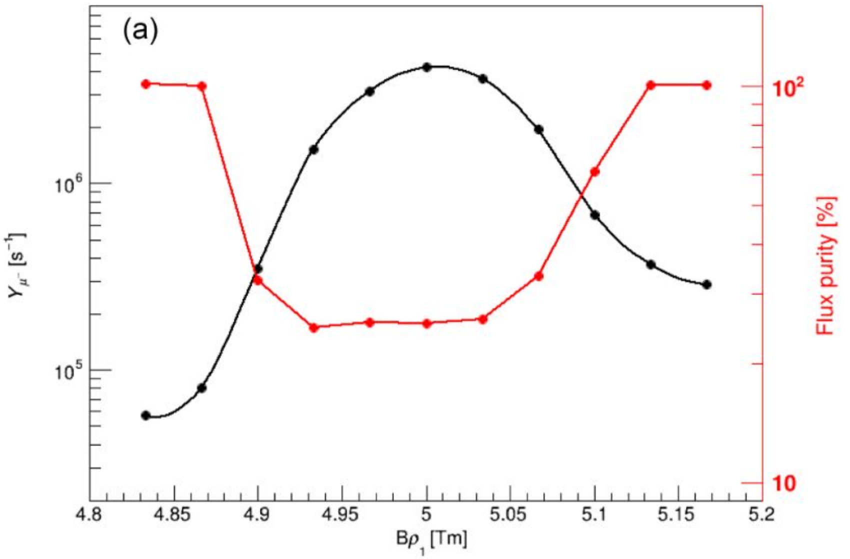


参考文献:[1] Phys. Rev. D 110, 016017 [2] arxiv:2410.20323 [3] arXiv:2411.12518 [4] Nucl. Instrum. Methods. Phys. Res. A 663 (2012) 22-25

HIAF-HIRIBL高能缪子束流

TABLE IV. The maximum muon flux intensities with proton, $^{18}O^{6+}$, and $^{78}Kr^{19+}$ projectiles, and the corresponding muon beam momenta and purities.

	Proton	$^{18}O^{6+}$	$^{78}Kr^{19+}$
μ^+ beam			
Momentum (GeV/c)	3.5	1.5	1.0
Flux intensity (μ^+/s)	8.2×10^6	3.5×10^6	1.8×10^6
Muon purity	2.0%	0.80%	0.60%
μ^- beam			
Momentum (GeV/c)	2.3	1.5	1.0
Flux intensity (μ^-/s)	3.8×10^6	4.2×10^6	1.6×10^6
Muon purity	13%	20%	23%



PID among muon, pion and electron are important for muon beam experiment.

Phys.Rev.Accel.Beams 28 (2025) 5, 053401

PKMu (R&D) MUonE (ongoing)

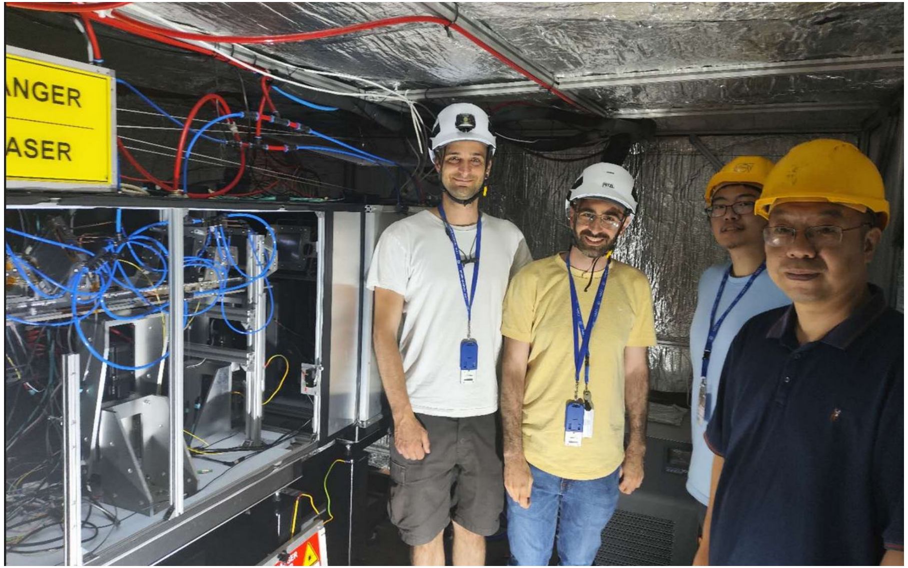
PKMu: Muon on target experiment proposed by PKU for multi-purpose including cosmic ray, dark boson, and **quantum entanglement**.

HIRIBL: **1-10GeV 10^6−10^7/s muon** beam line from the HIAF facility from the imp, cas, China.

MUonE: a Muon Electron scattering exp at CERN exploiting a **150-160 GeV 10^7−10^8/s** beam, aims at an independent and precise determination of the leading hadronic contribution to the muon g-2.

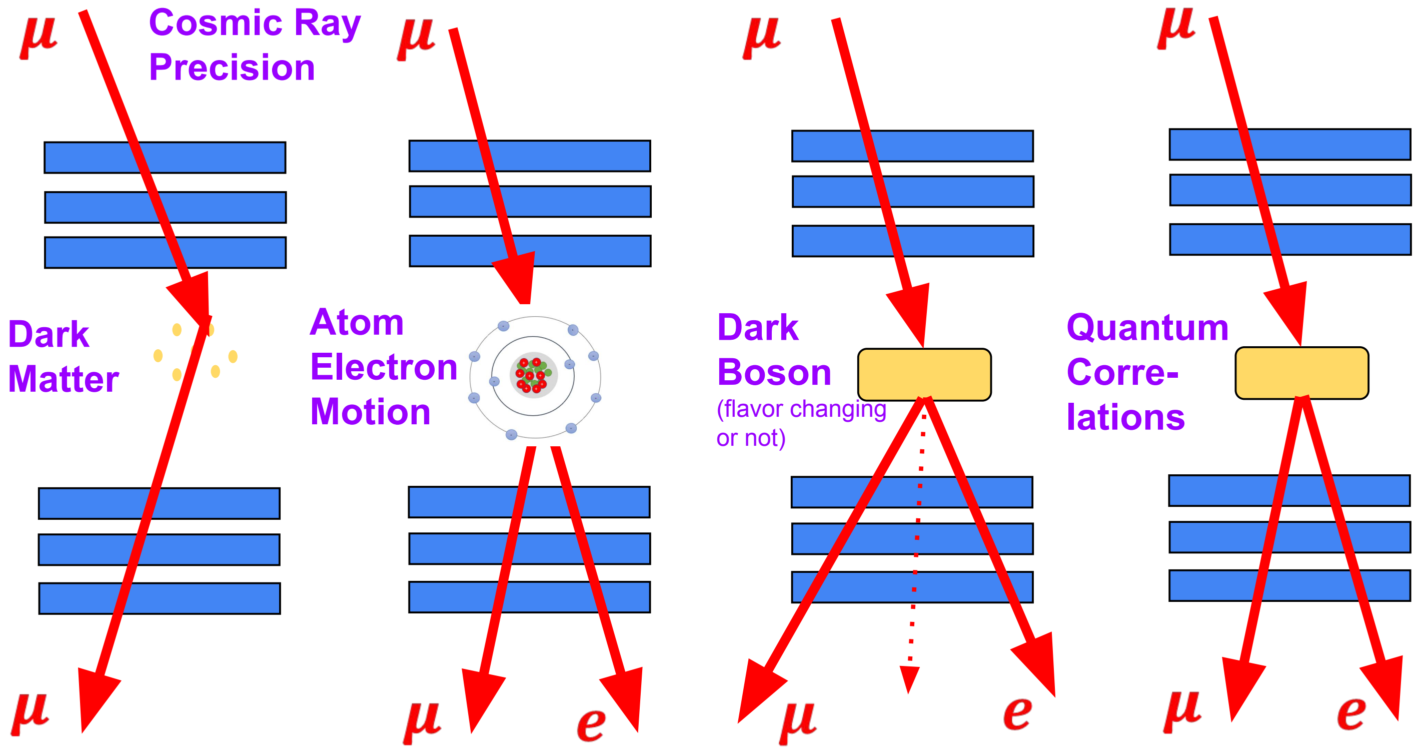
HIAF, Hui Zhou

MUonE CERN



Rich Physics via Probing and Knocking with Muons

Cosmic muons (Local lab) or muon beams (HIAF, CERN…)



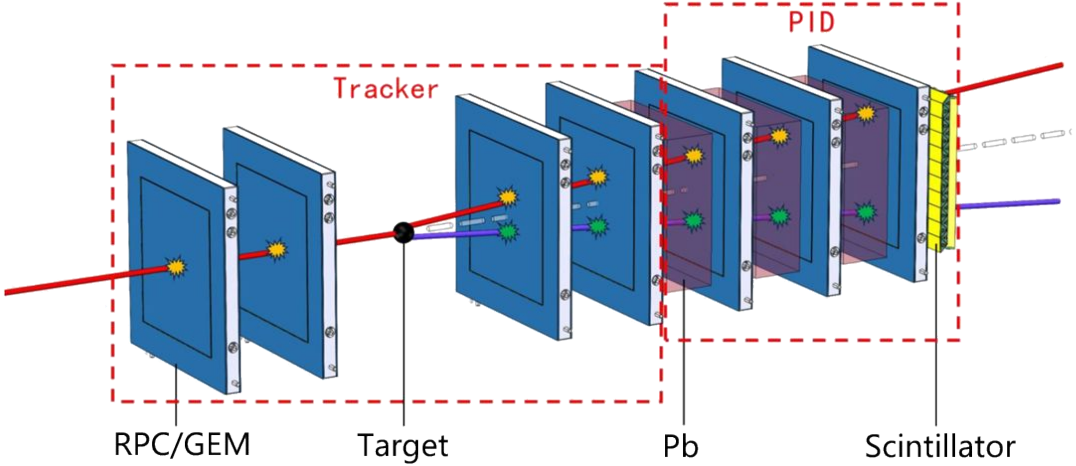
Detector Legos

Tracking:
RPC, GEM, SStrip, LGAD

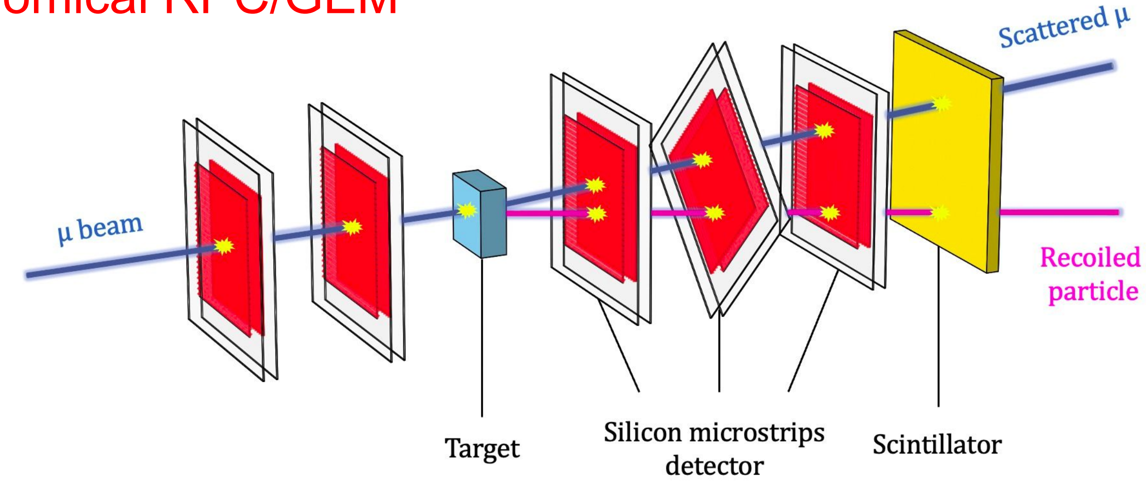
PID, veto:
Scintillator
Absorber

Readouts:
delay line, 2D, multi-leptons

arXiv: 2507.23458; arXiv:2507.03914, PRD 110, 016017 (2024); JPG52 (2025) 075002; PRD 111, 116018 (2025), arXiv:2507.23458, MPLA 40 (2025) 24, 2530008



Economical RPC/GEM



Mimicking one-station MUonE

Flexibility, multi-purpose

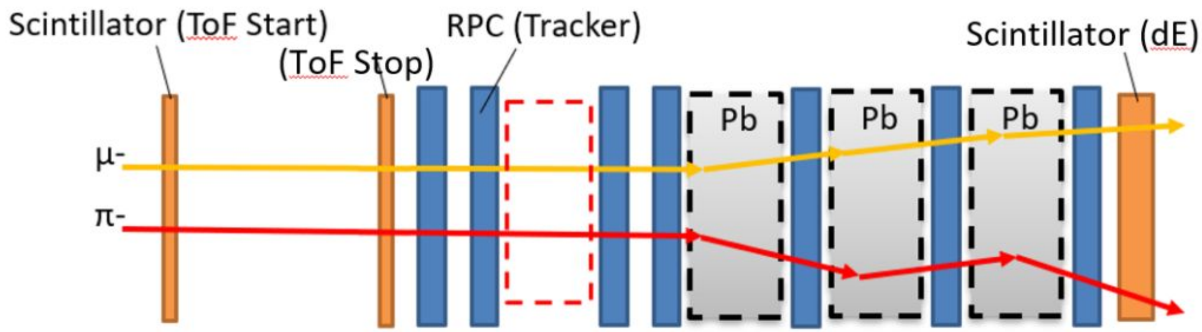
Detector Legos

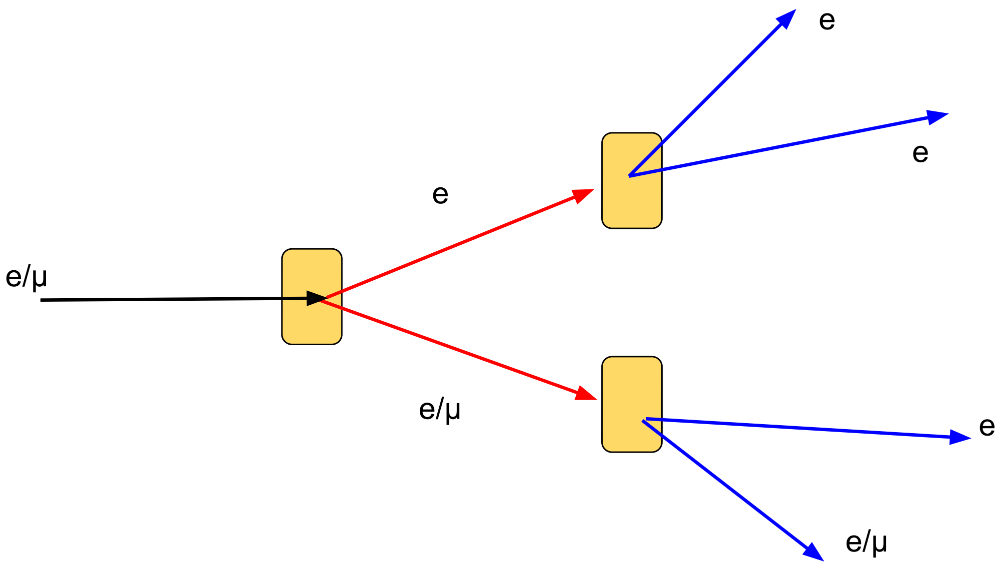
Tracking:
RPC, GEM, SStrip, LGAD

PID, veto:
Scintillator
Absorber

Readouts:
delay line, 2D, multi-leptons

Flexibility, multi-purpose





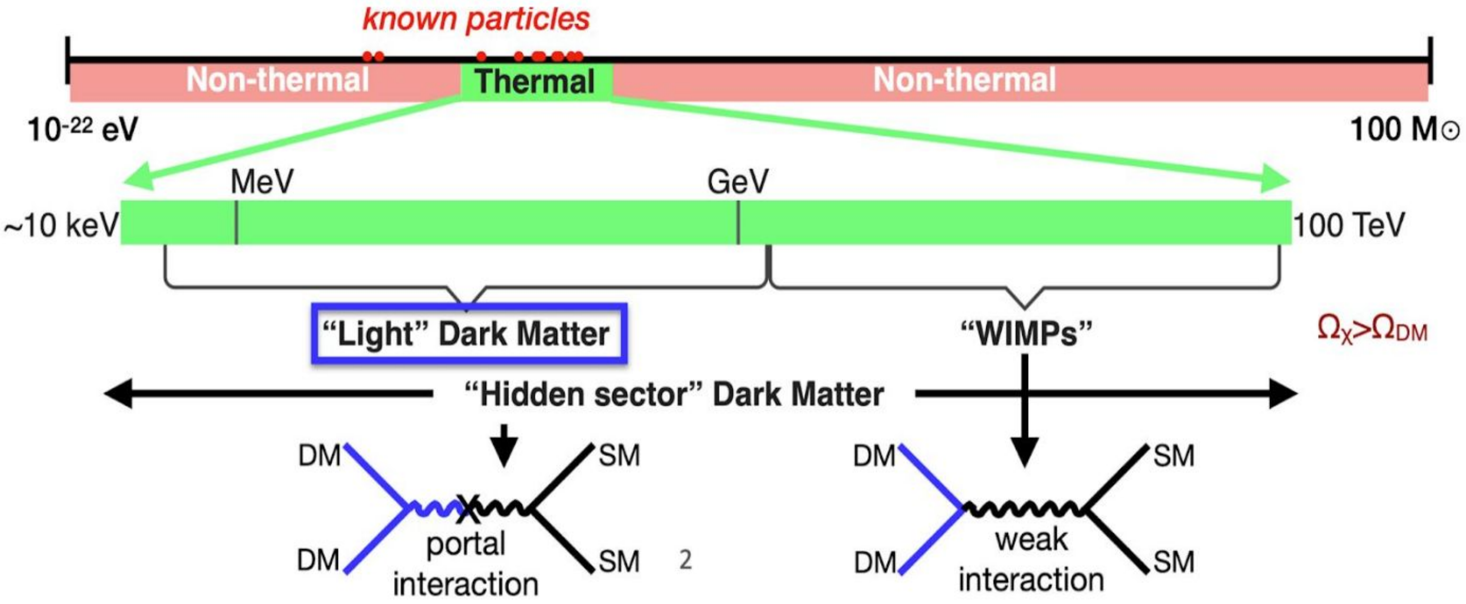
Detector Legos

Interfacing with HIAF beams

or for secondary scattering

- **简介**
- 例1：寻找亲缪子型暗物质
- 例2：寻找暗玻色子
- 例3：级联散射、量子纠缠
- 更多可能
- 展望

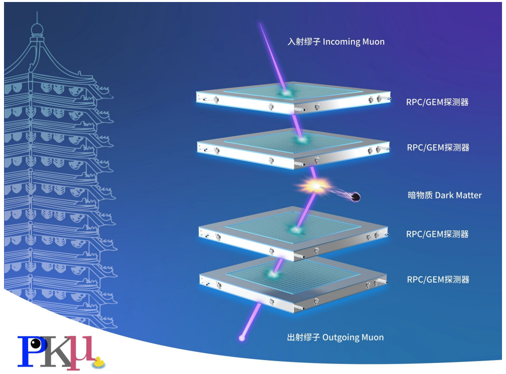
Light Dark Matter 需要更大的 Dark Sector

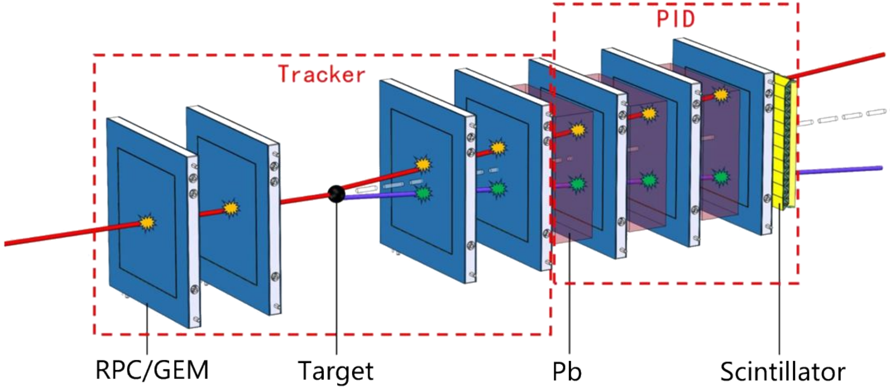


Minimal scenarios with light (sub-GeV) dark matter whose relic density is obtained from thermal freeze-out must include new light mediators. In particular, a very well-motivated case is that of a new "dark" massive vector gauge boson mediator. JHEP03(2018)084 Granada19 LDMX2024

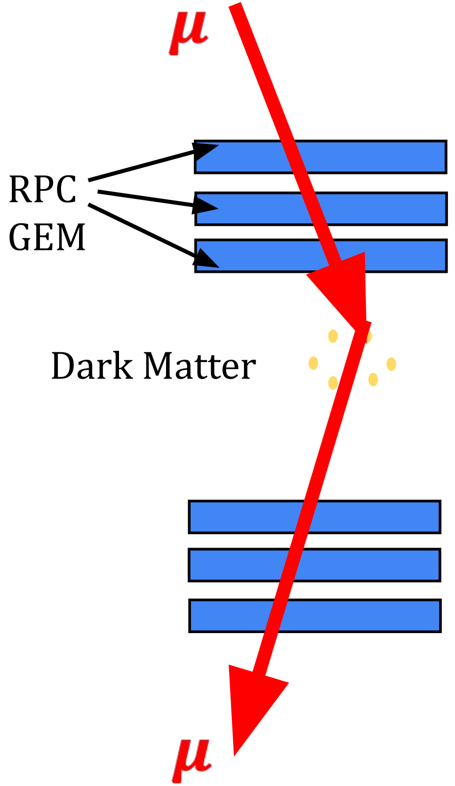
寻找轻暗物质、暗玻色子的 轻子打靶实验

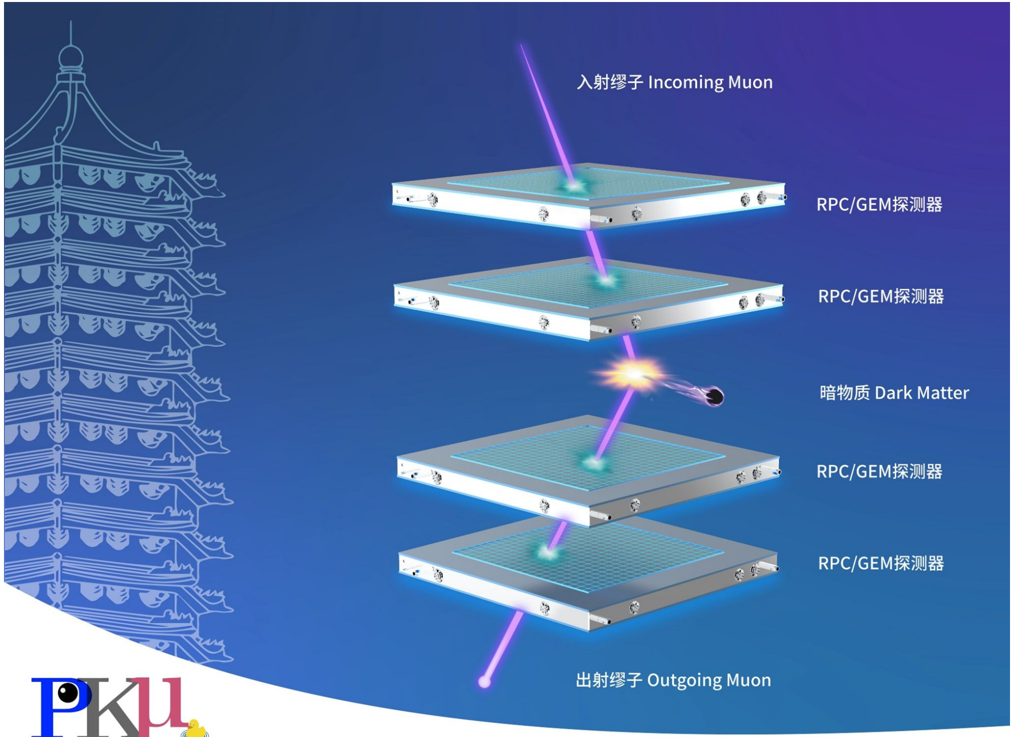
- Muon Philic Dark Matter may be possible or even <u>necessary</u>!
    - $L\mu - L\tau$ gauged model (χ, Z')
  - 1) **寻找亲缪子的轻暗物质**
    - PKMu_DM: <u>PRD 110 (2024) 1, 016017</u>, <u>arXiv:2507.23458</u>
  - 2) **寻找暗玻色子** (see also <u>cosmology constraints</u>)
    - <u>LDMX</u>,<u>DarkShine</u>; eN → eNZ', Z'→$\nu\bar{\nu}$ or Z'→$\chi\chi$ (dark matter)
    - <u>NA64μ</u>, <u>MMM</u> μN → μNZ', Z'→$\nu\bar{\nu}$ or Z'→$\chi\chi$ (dark matter)
    - <u>MuonE</u> (pheno.) μe → μeZ', Z'→$\nu\bar{\nu}$ or Z'→$\chi\chi$ (dark matter)





1) 寻找亲缪子的轻暗物质



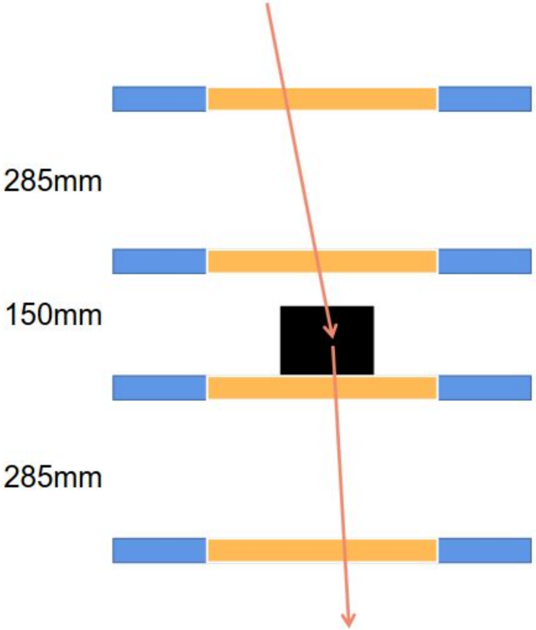


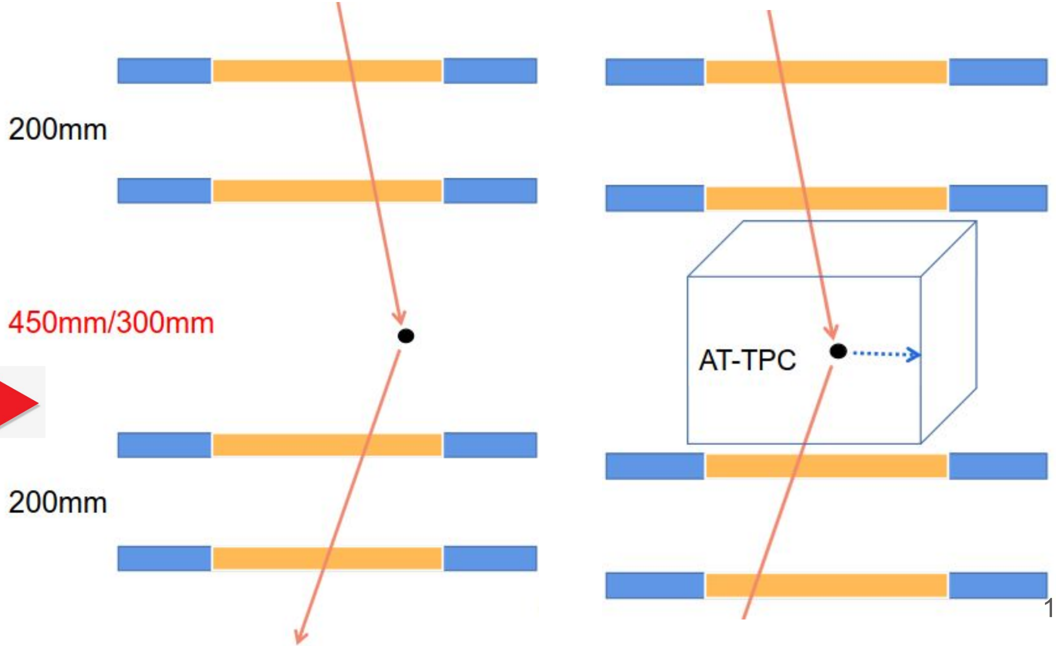
PRD 110 (2024) 1, 016017, arXiv:2507.23458

缪子成像 与 亲缪子暗物质的寻找

Muon Tomography 缪子成像 ↔ Dark Matter Search 暗物质寻找

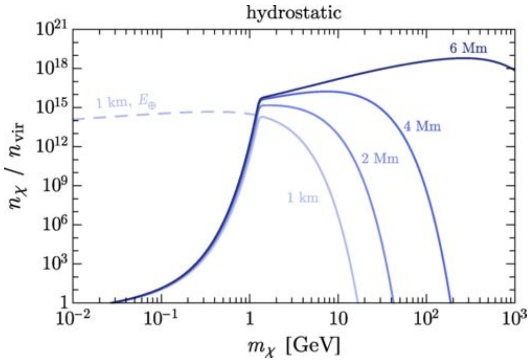
Phys.Rev.D 110 (2024) 1, 016017

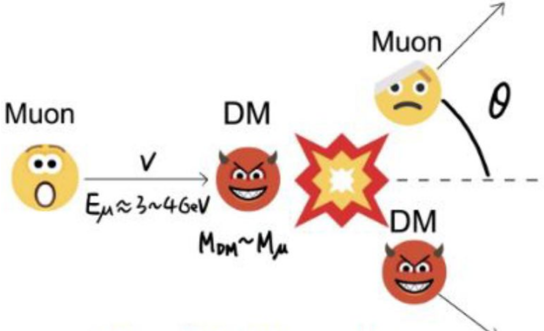




慢暗物质：　子弹↔猎物

- Earth bounded Dark Matter: terrestrial density of strongly-coupled relics
  PRL. 131 (2023), 011005,　PRD 109 (2024), 075027　PRD 103, 115031 (2021)
  - A fraction (fD) of strongly interacting dark matter
  - can be trapped in the Earth, and distributed more uniformly.
  - The density (fE) can be large! **fE=fD×nD** ~ fD*10^15/cm^3
- Alternative detection techniques needed
  - to detect such a large density of slowly moving DM
  - Superconducting Cloud Chamber (for Milli-charged Particle though)
- **<u>For slow or frozen DM, no proposal yet!</u>**
  - **→ limits on both cross section and <u>fE=fD×nD</u>**





Muon-DM elastic scattering

Different from XENON/PandaX:
Relativistic muon hit quasi-static DM

软件开发 及 模拟研究

PKMuon Collaboration

PKMuon Collaboration

3 followers · China · https://lyazj.github.io/pkmuon-site/ · seeson@pku.edu.cn

Overview · Repositories 10 · Projects · Packages · People 2

Pinned

PKMUON_G4sim Public
Forked from yuxdPKU/PKMUON_G4sim
Geant4-based simulation of PKMUON
C++

geomu Public
Forked from lyazj/geomu
Geographic Muon Simulation
C++

pkmuon-site-src Public
Forked from lyazj/pkmuon-site-src
source code of PKMUON site
Stylus

root-easy-debug Public
Forked from lyazj/root-easy-debug
Debug CERN ROOT macros in an extremely easy way
C

PHYSICAL REVIEW D **110,** 016017 (2024)

Proposed Peking University muon experiment for muon tomography and dark matter search

Xudong Yu,* Zijian Wang, Cheng-en Liu, Yiqing Feng, Jinning Li, Xinyue Geng, Yimeng Zhang, Leyun Gao, Ruobing Jiang, Youpeng Wu, Chen Zhou,† Qite Li,‡ Siguang Wang, Yong Ban, Yajun Mao, and Qiang Li§

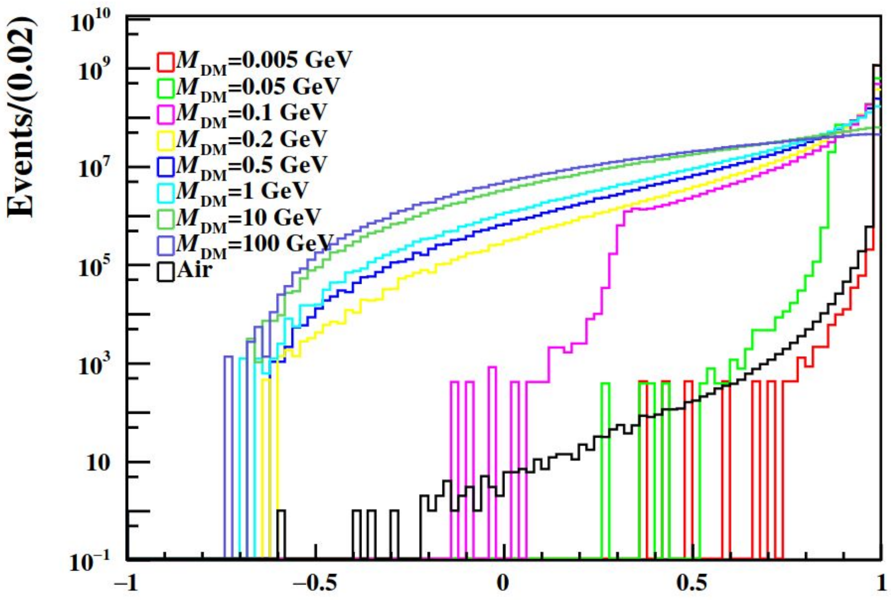
State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing, 100871, China

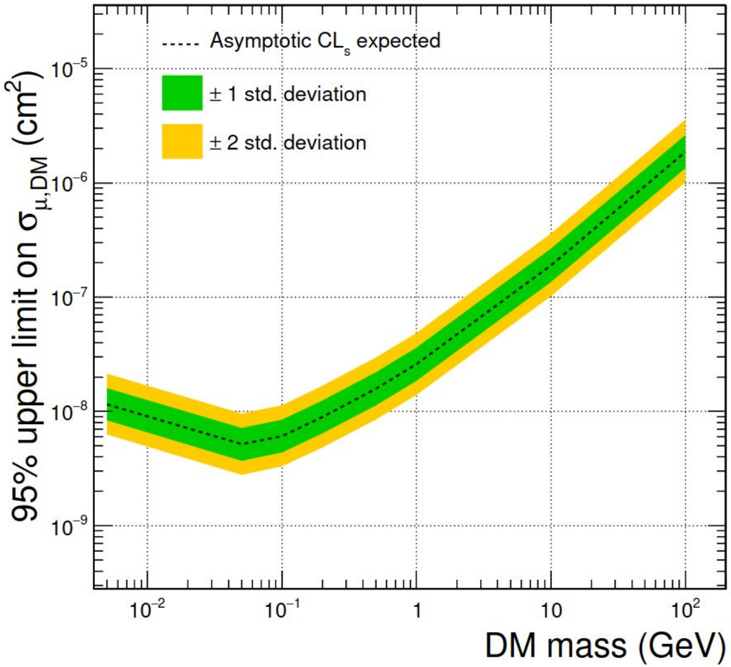
(Received 23 March 2024; accepted 24 June 2024; published 19 July 2024)

A set of new methods are proposed here to directly detect light mass dark matter through its scattering with abundant atmospheric muons or accelerator beams. A first plan is to use the free cosmic-ray muons interacting with dark matter in a volume surrounded by tracking detectors, to trace the possible interaction between dark matter and muons. Secondly, the same device can be interfaced with domestic or international muon beams. Due to the much larger muon intensity and focused beam, it is anticipated that the detector can be made further compact, and the resulting sensitivity on dark matter searches will be improved. Furthermore, it may also be possible to measure precisely directional distributions of cosmic-ray muons, either at mountain or sea level, and the differences may reveal possible information about dark matter distributed near the Earth. Specifically, methods described here can have advantages over "exotic" dark matters that are either muonphilic or slowed down due to some mechanism, and the sensitivity on dark matter and muon scattering cross section can reach as low as microbarn level.

DOI: 10.1103/PhysRevD.110.016017

基于大气缪子的本地实验的预期结果





- “Asimov” data is used
- Binned maximum likelihood fits
- UL determined by CLs method
- Only take statistical uncertainty into consideration

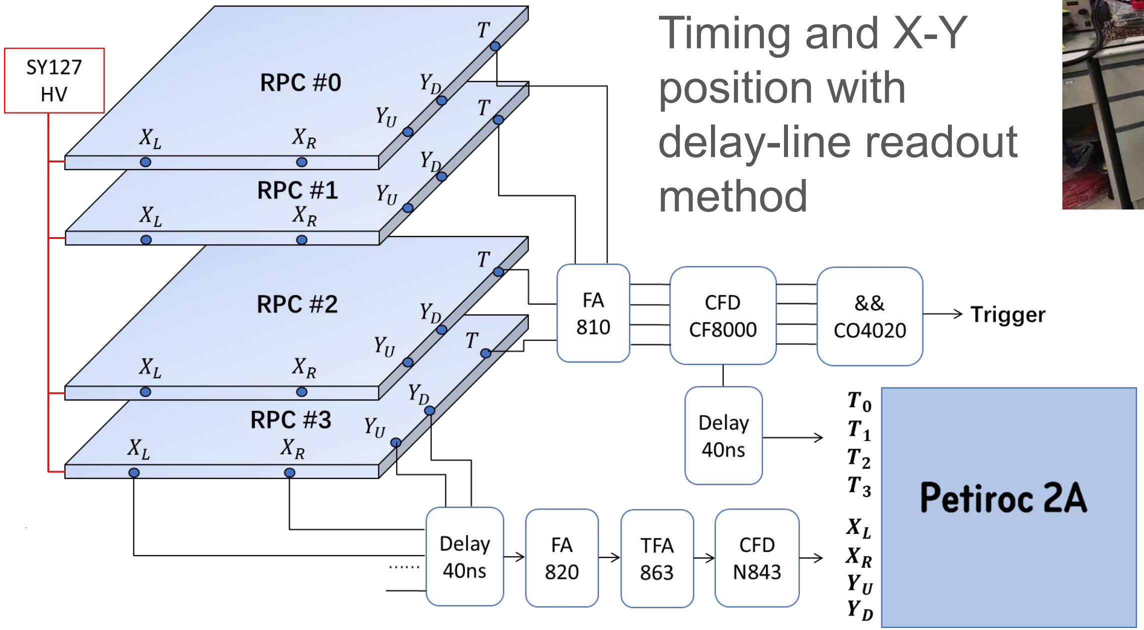
In the exotic DM scenario as mentioned previously, the limit can approach μb

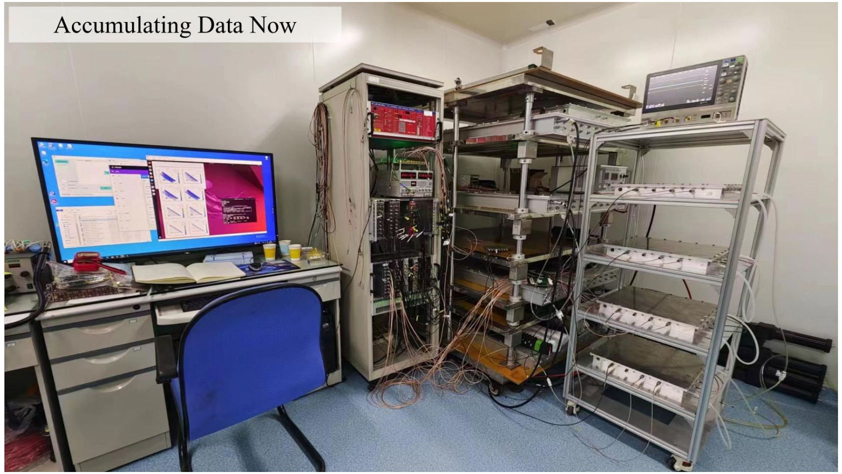
基于大气缪子的本地实验的进展：arXiv:2507.23458 submitted to PRL

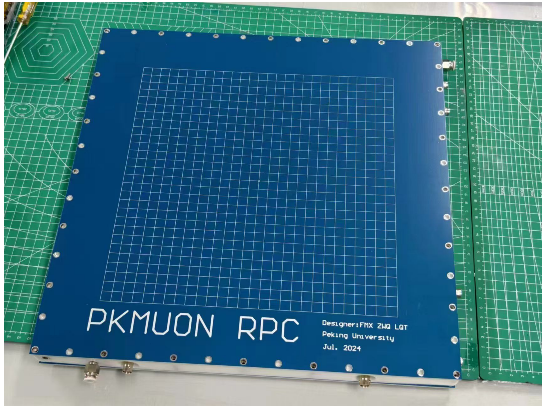
recent report from Cheng-en Liu and Qite Li

4-station 28 cm*28 cm RPC for the moment
A spatial Resolution of 0.7 mm
Petiroc 2A is a 32-channel front-end ASIC

Timing and X-Y position with delay-line readout method



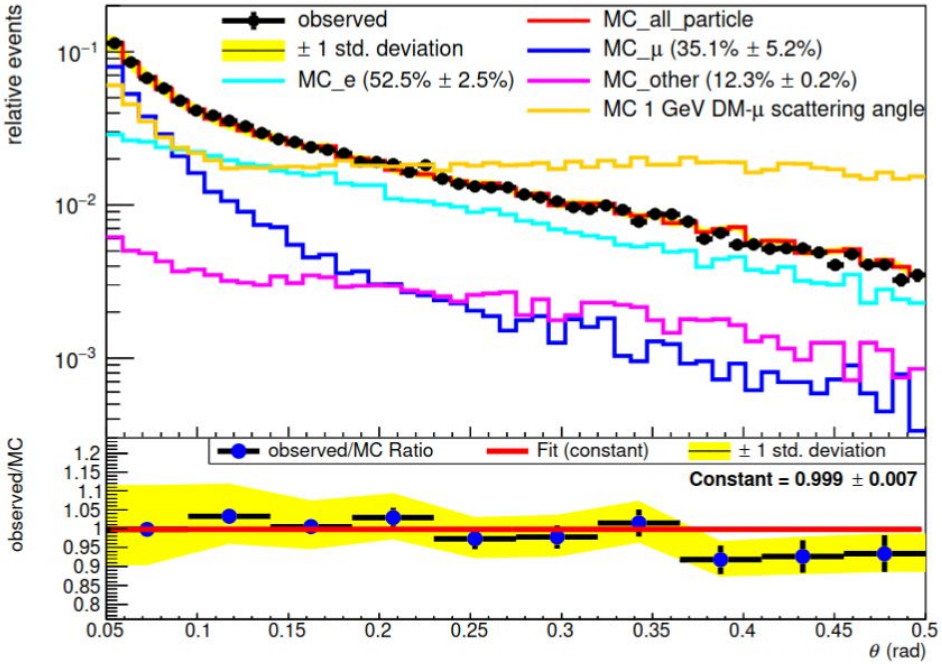


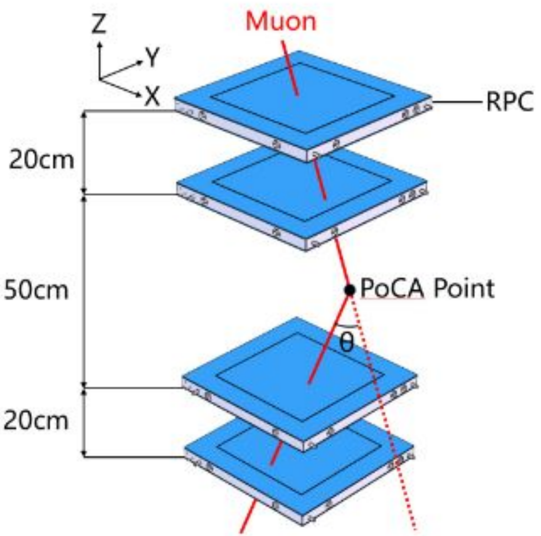


附加产品: 宇宙射线次级成分精细测量

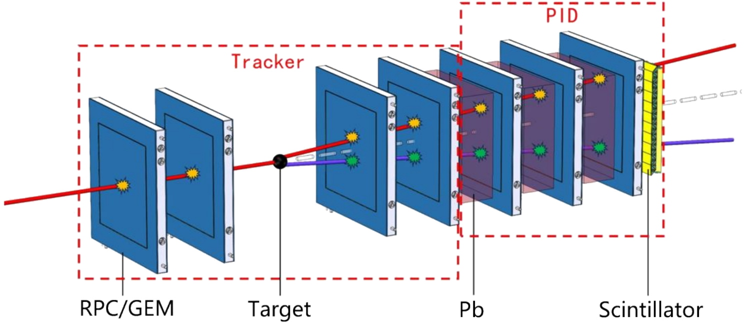
During a **63-day** campaign from February 12, 2025, **1.18 million** cosmic ray scattering events were recorded and analyzed. **The scattering angle observable is sensitive to the cosmic ray component fractions!**

arXiv:2507.23458 submitted to PRL





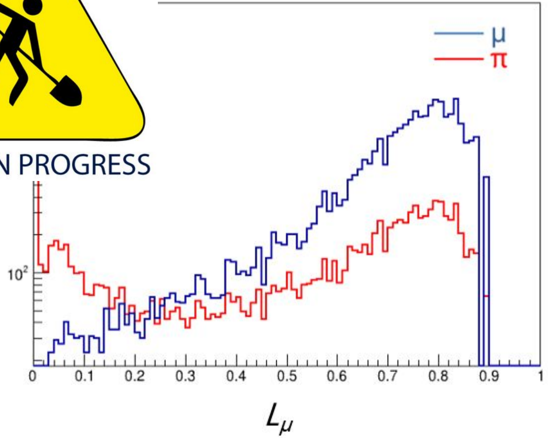
束流实验进展 Jinning Li@MIP2025



10cm-thick Pb
Plastic scintillators

A prototype detection system@HIRIBL for muon beam condition monitoring, detector testing, and preliminary experiments (scattering, tomography)

- Beam profile and divergence
- Beam particle identification
  - Mass difference: ToF, dE
    - Different physical processes: dE



3 GeV/c muons and pions (simplified simulation: 4% momentum spread; equal numbers of muons and pions)

PID based on the product of likelihoods of 3 variables:
(ToF / energy deposition / square residual of linear track)
Over 70% muon\pion efficiency in this preliminary version.
Upgrade: detailed simulation, delicate detectors (ECal/RICH…)

- 简介
- 例1：寻找亲缪子型暗物质
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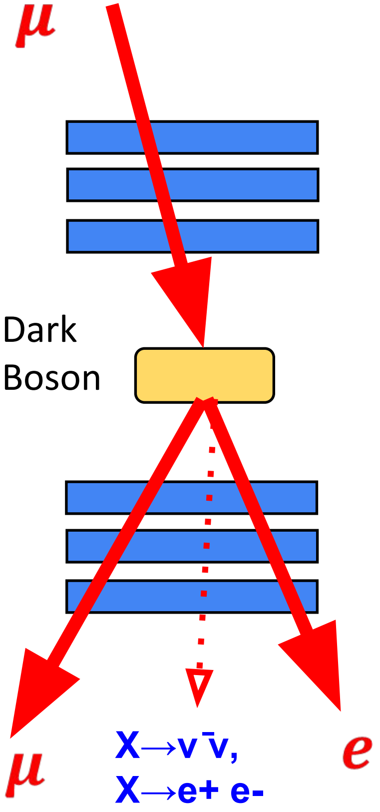
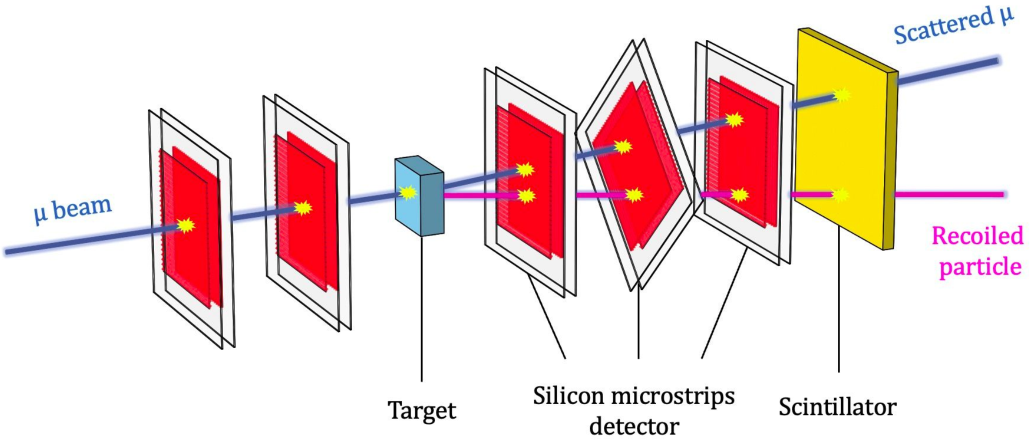
- 更多可能
- 展望

2) 寻找暗玻色子



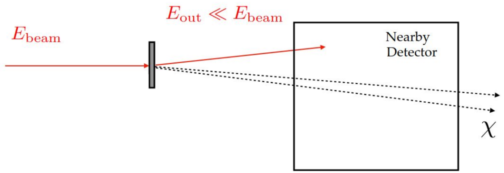


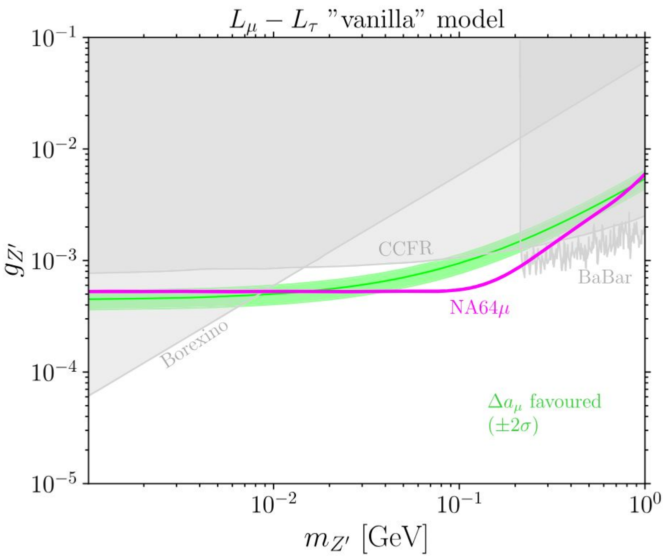
MUonE-like but for 1-10 GeV Muon beam

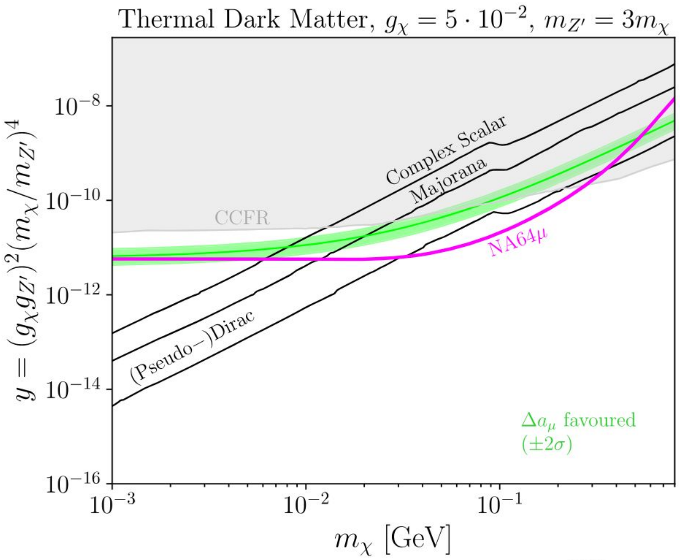
NA64μ recent results

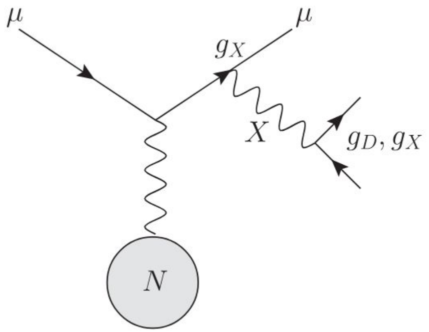
$$\mathcal{L} \supset -\frac{1}{4}F'_{\alpha\beta}F^{\alpha\beta\prime} + \frac{m_{Z'}^2}{2}Z'_\alpha Z^{\alpha\prime} - g_{Z'}Z'_\alpha J^\alpha_{\mu-\tau},$$

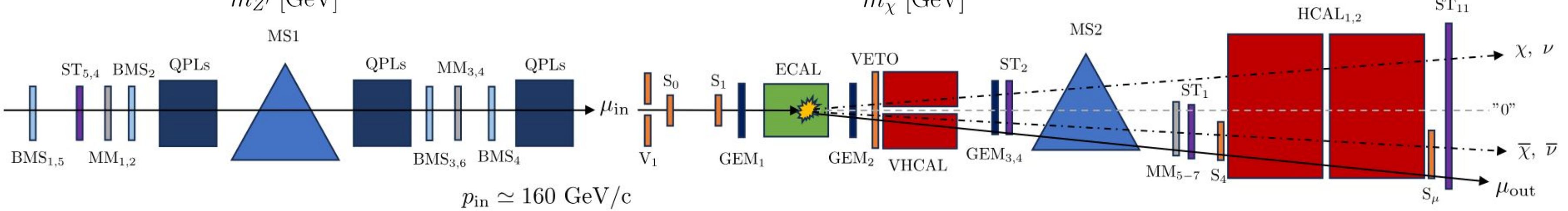
$$-g_\chi Z'_\alpha J^\alpha_\chi,$$



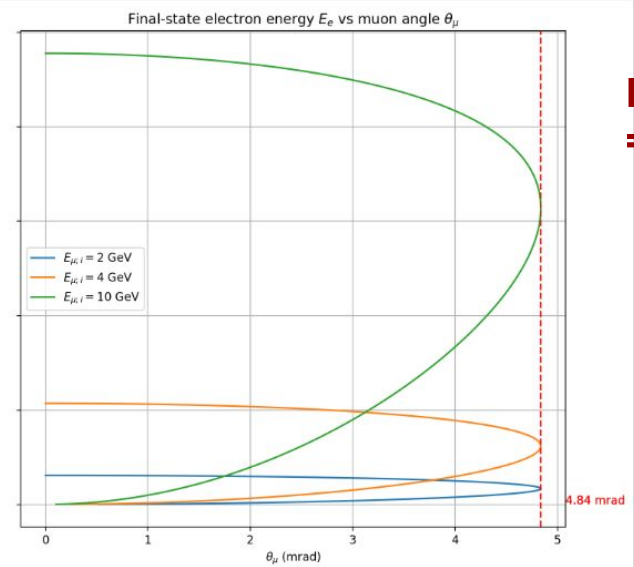








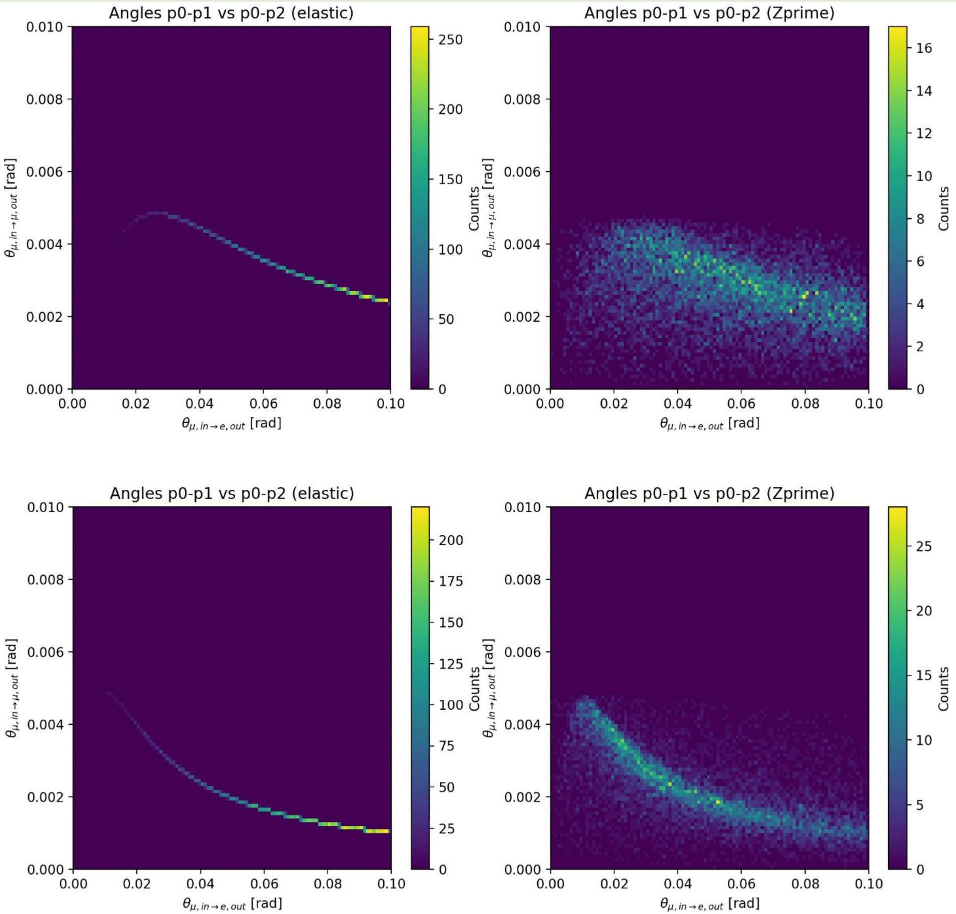
PKMu@HIRIBL for Dark Z boson



We can use the two-dimensional correlation between the muon scattering angle/electron scattering angle and energy to select the signal region where the background of the SM process is 0 (theoretically).

Ebeam =4GeV

Ebeam= 10GeV



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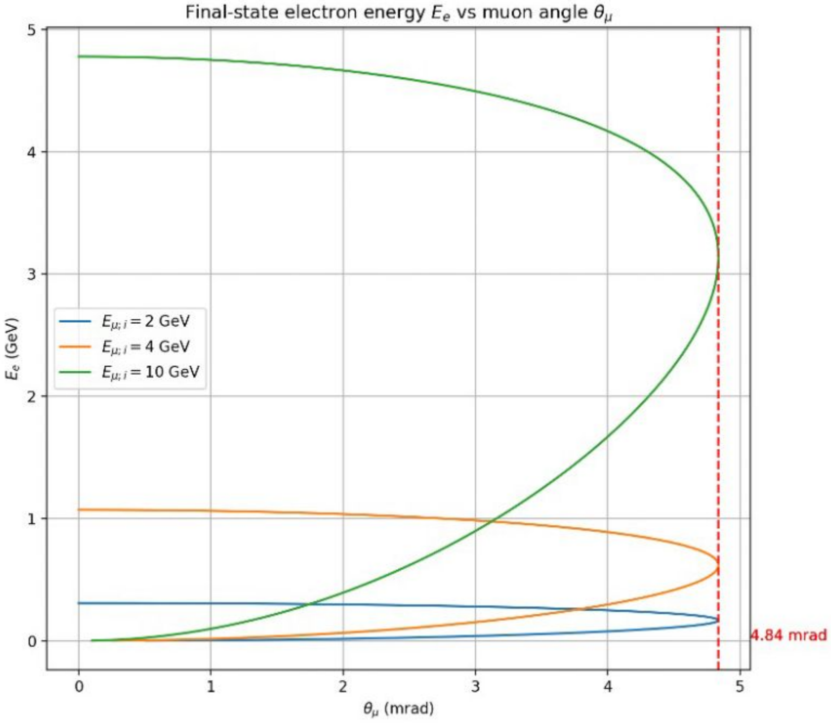

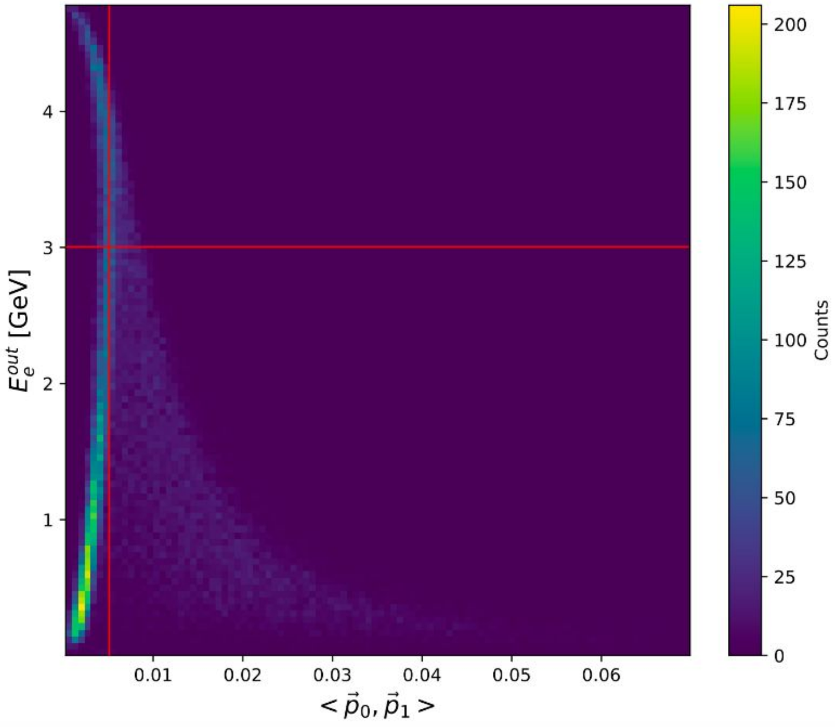

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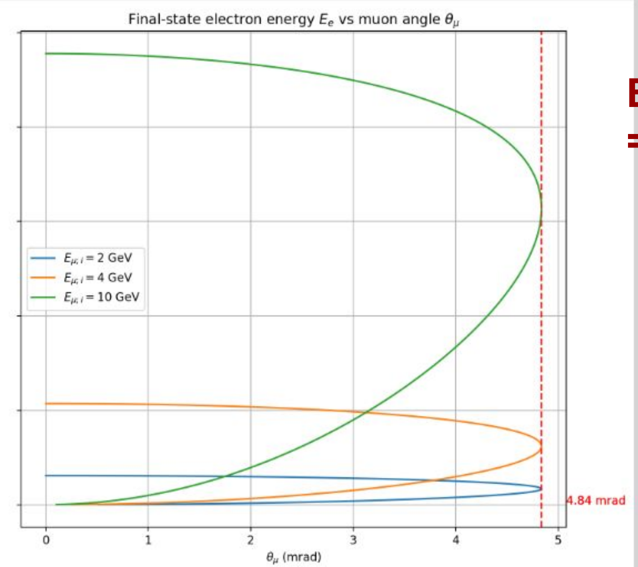

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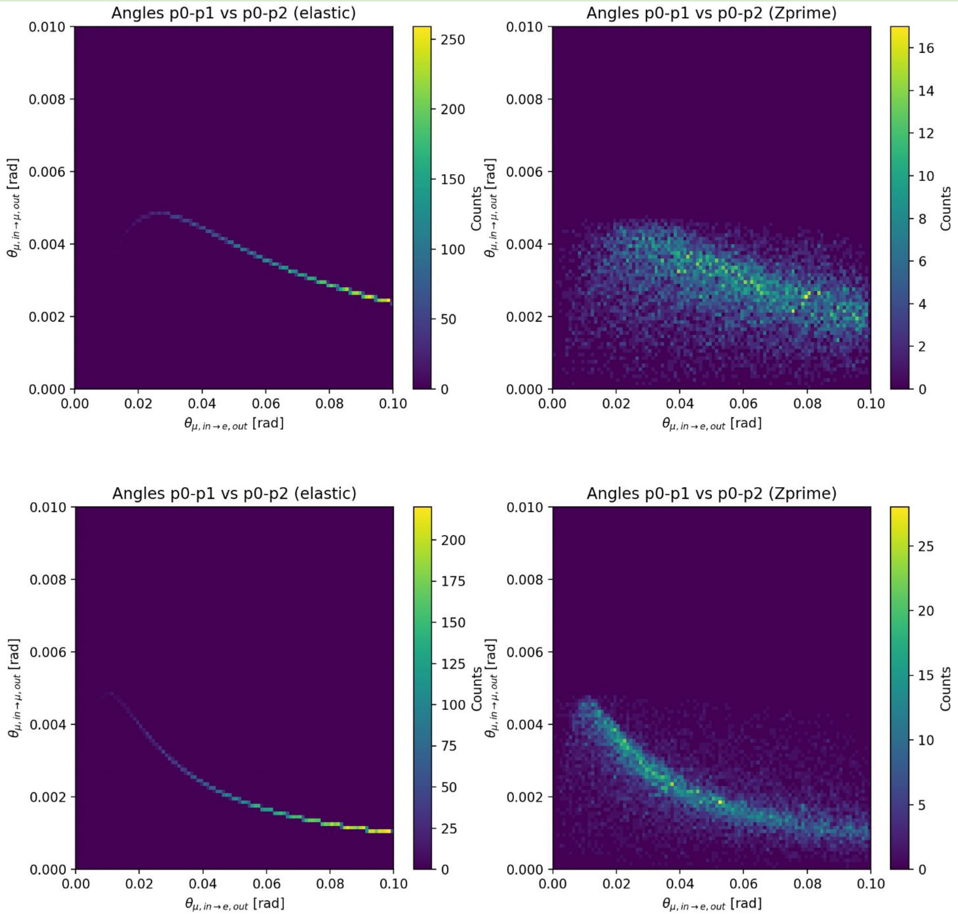
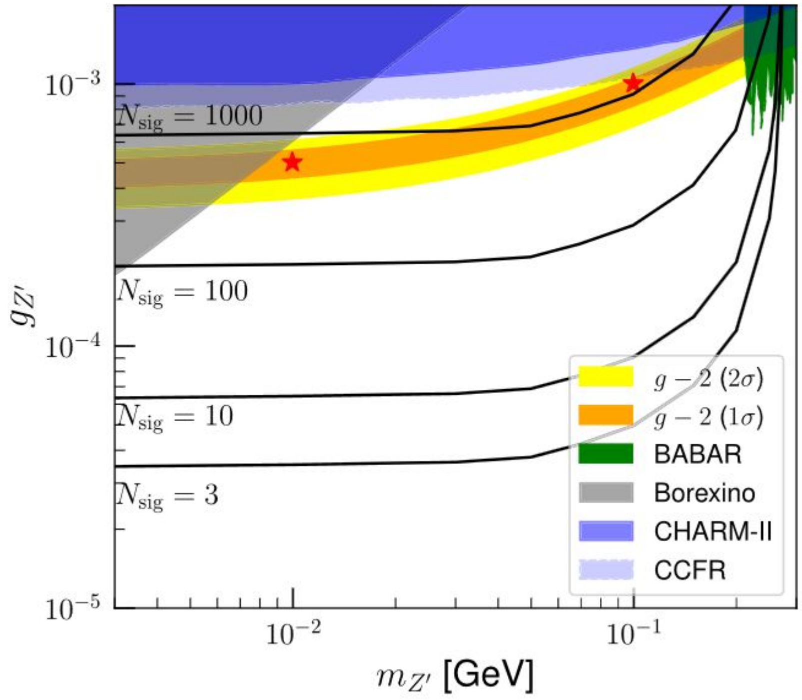
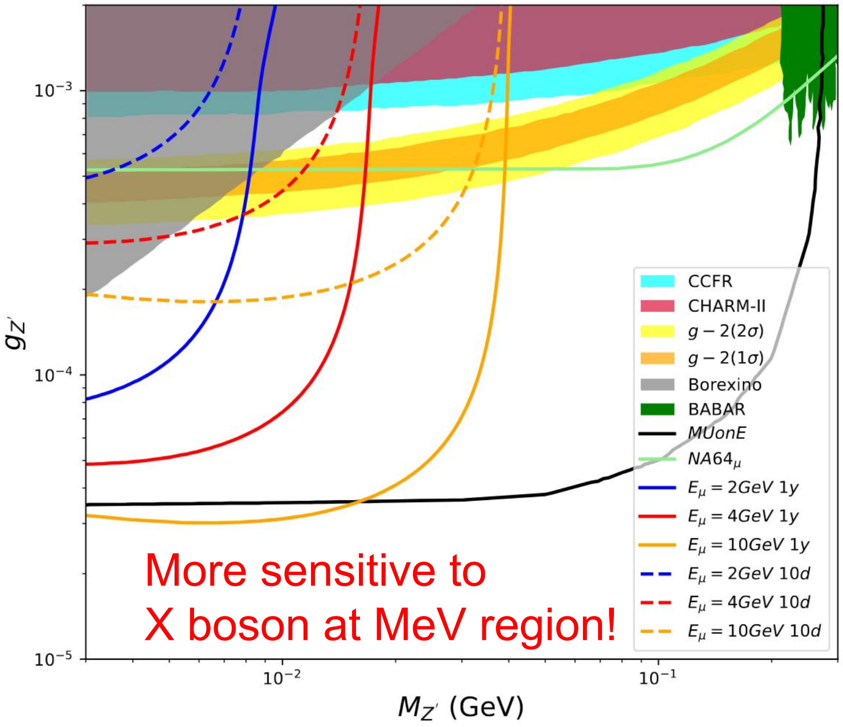


PKMu@HIRIBL



[Phys.Rev.D 106 (2022) 5, L051702]



Preliminary results

- 简介
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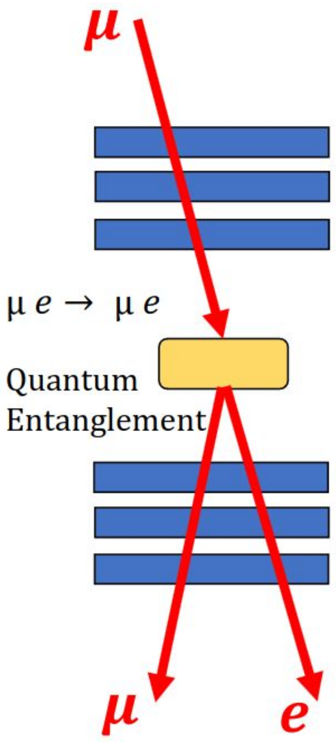
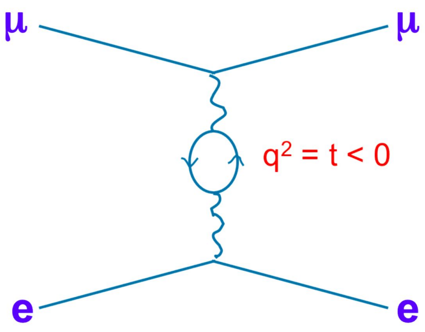
- 展望

缪子电子散射

- MuonE exploits 160 GeV Muon beam to measure muon electron scattering, and a precise determination of the leading hadronic contribution to the muon g-2.
- **Muon electron scattering at lower energy (~GeV)** may be interesting to SM test itself, and Quantum entanglement probe PRD 107, 116007 (2023):





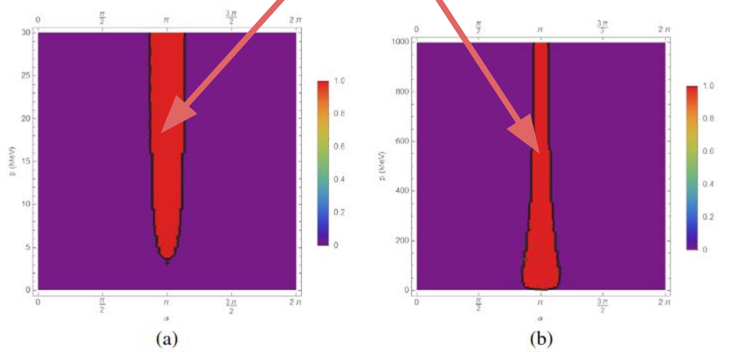


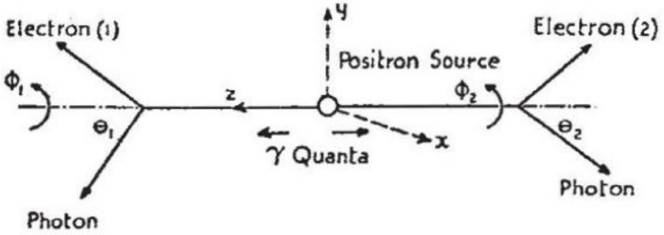
FIG. 15. The red regions correspond to the values of p and θ for which the final state is entangled at low—< 30 MeV—(a) and high—< 1 GeV—(b) energies.

arXiv:2502.07597 arXiv:2411.12518

量子纠缠简介

- C. N. Yang (IJMPA 2015): the first experiment on quantum entanglement is the **Wu-Shaknov** Experiment (PR1950) which measures **the angular correlation of two Compton-scattered photons arising from e^+e^- annihilation**

- The violation of **Bell inequality (**PPF1964**)** was demonstrated in 1970s and afterwards using entangled photons, confirming the non-locality of our universe.
- Alain Aspect, John Clauser and Anton Zeilinger won the Nobel Prize in Physics in 2022 for demonstrating the potential to investigate and control particles (photons) that are in entangled states.



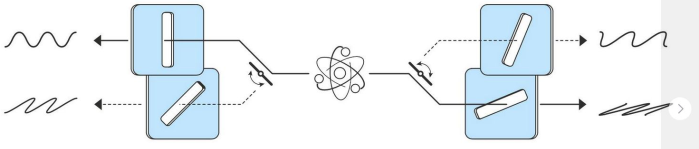
The Angular Correlation of Scattered Annihilation Radiation*

C. S. Wu and I. Shaknov

Pupin Physics Laboratories, Columbia University, New York, New York

November 21, 1949

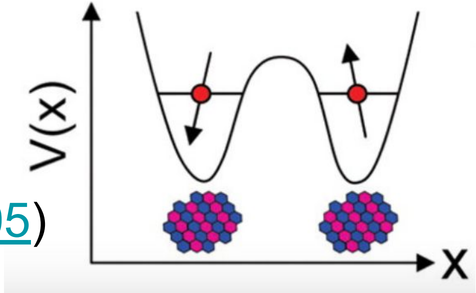
AS early as 1946, J. A. Wheeler[1] proposed an experiment to verify a prediction of pair theory, that the two quanta emitted in the annihilation of a positron-electron pair, with zero relative angular momentum, are polarized at right angles to

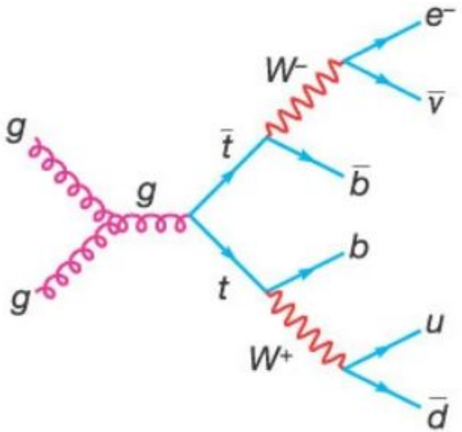


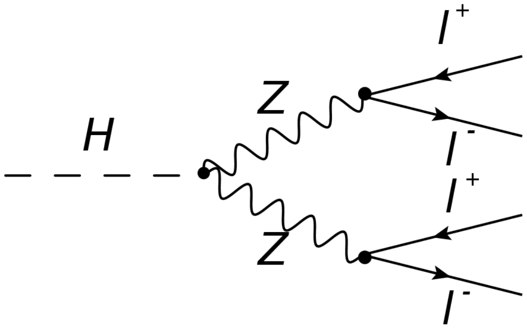
Alain Aspect developed this experiment, using a new way of exciting the atoms so they emitted entangled photons at a higher rate. He could also switch between different settings, so the system would not contain any advance information that could affect the results.

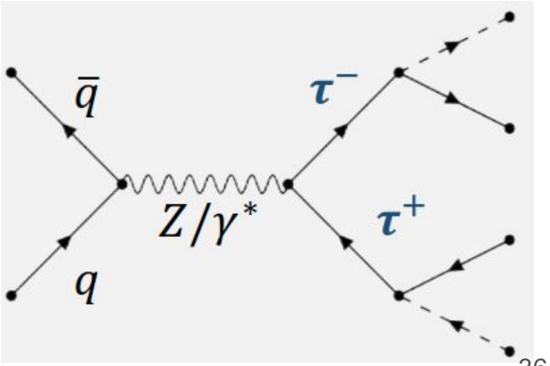
高能量前沿的量子 纠缠研究

- The ATLAS and CMS Collaborations recently observed quantum entanglement involving top quarks at a center-of-mass energy of 13 TeV
  - marking the highest energy measurements of QE
- Recent proposals on vector bosons, and tau leptons
- Less attention has been given to **electrons and muons**
  - **Confined electron pairs** (Science309(5744)1116955,2005)
    - confined in semiconductor quantum dots
    - entangled states were prepared, coherently manipulated









自由电子、缪子之间的量子纠缠

- None similar experiment has been done with free-traveling electrons as **measuring the spin of a single traveling electron poses a significant** **challenge** due to interference from its orbital motion

Original Articles

Does a flying electron spin?

B. M. Garraway & S. Stenholm

Pages 147-160 | Published online: 08 Nov 2010

Cite this article https://doi.org/10.1080/00107510110102119

bobbi_john jfcbat.com <bobbi_john@jfcbat.com>
To: Qiang Li <qliphy@gmail.com>

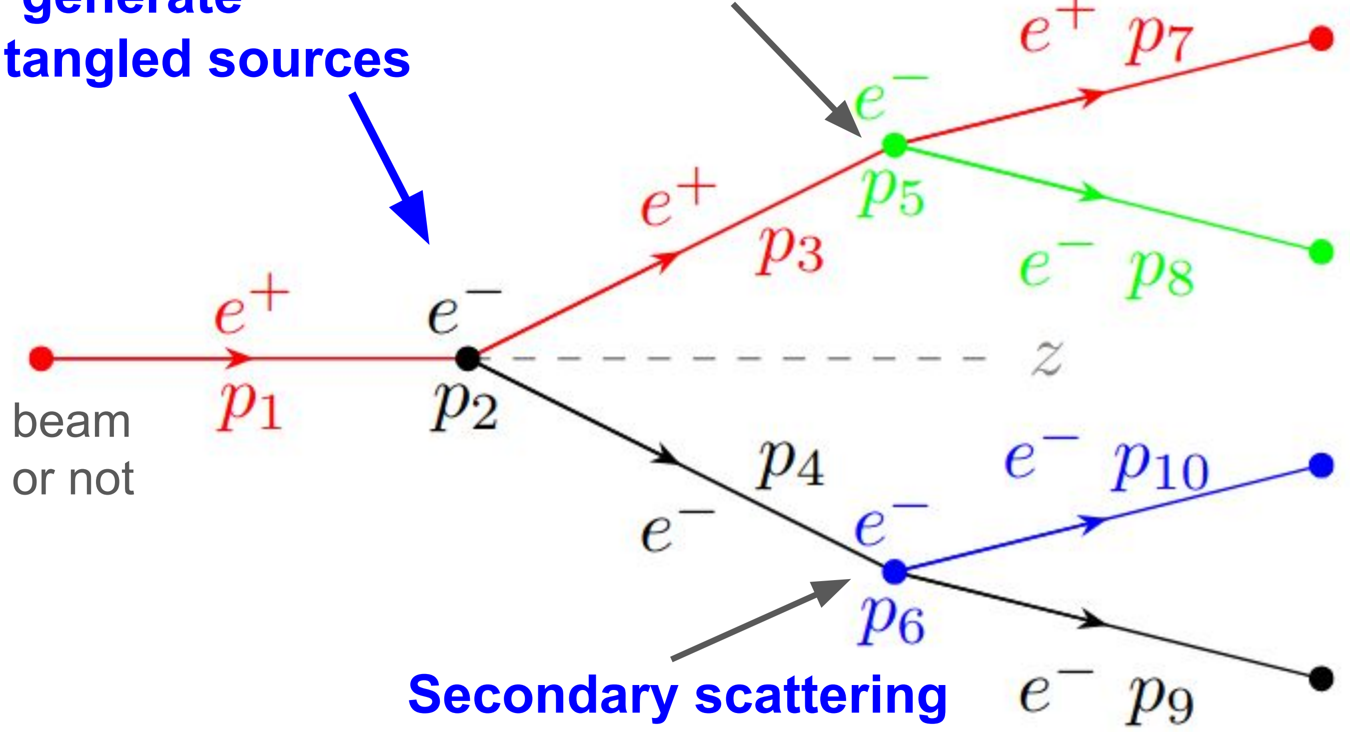
Dear Qiang Li
Please be aware that Stern Gerlach magnets, because they also have a finite magnetic field, cannot separate a charged g=2 electron beam into 2 spin states. This fact was first noted (and proven for g=2) by Nils Bohr. It is obscurely reported (only) in Mott and Massey's book, Theory of Atomic scattering.
John Clauser

- **Our proposal:**
  - a first measurement on **polarization correlations**
    - **between charged lepton beams**
  - through **joint measurements** of their individual polarization-sensitive scatterings off two separate targets.

级联散射构想

Primary scattering to generate entangled sources

Secondary scattering as a polarimetry



Incoming beam polarized or not

Secondary scattering as a polarimetry

A new kind of Wu experiment

Take $0.05\ \mathrm{rad} \leq \theta_3 \leq 0.1\ \mathrm{rad}$ in a 1 GeV positron on-target experiment as an example:

- The state of the primary products is approximately 1% $(RL+LR)/\sqrt{2}$, 1% $(RL-LR)/\sqrt{2}$, 7% $(RR-LL)/\sqrt{2}$, and 90% $(RR+LL)/\sqrt{2}$ in the lab frame
- The optimized ratio of the yields of $(LL+RR)/\sqrt{2}$ to UU is $1.29 \pm 0.03(\mathrm{MC})$, corresponding to 4.4×10^3 post-optimization efficient signal event counts and an expected signal yield over a **27-second** run; the result for $(LR+RL)/\sqrt{2}$ is $0.78 \pm 0.02(\mathrm{MC})$ in comparison
- Other uncertainties, such as those from process modeling and background suppression, may dominate the real experimental analysis
- For the 20% polarized targets, the ratios are 1.010 ± 0.009 and 0.986 ± 0.009 generated from 25 times the number of Monte Carlo events, corresponding to 2.5×10^4 efficient event counts accumulated in **680 seconds**

A new kind of Wu experiment

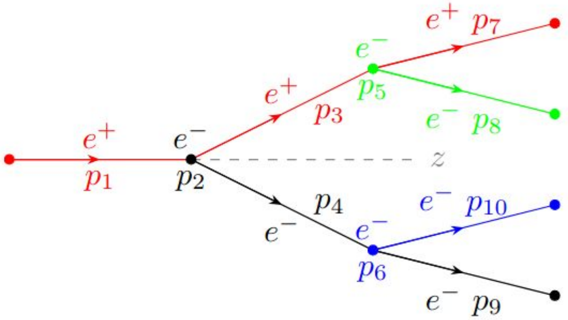


FIG. Proposed cascade experiment for measuring polarization correlations of the primary products

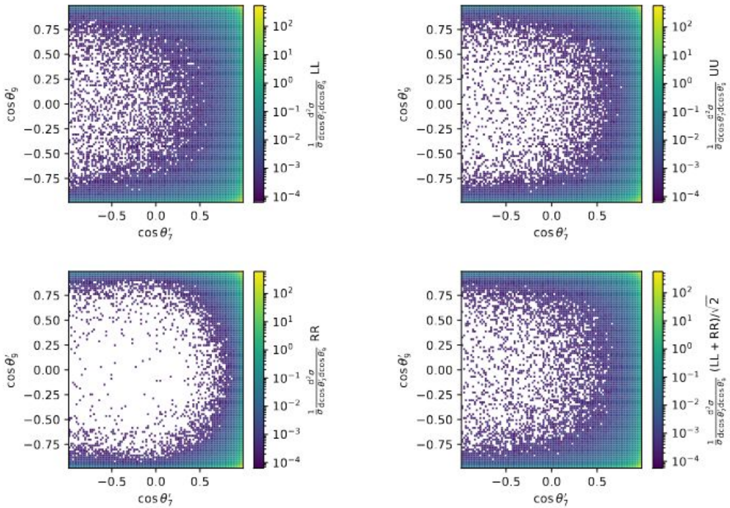


FIG. Joint angular distribution densities of the two secondary scattering processes

Simulation setup:

- $0.05\ \mathrm{rad} \leq \theta_3 \leq 0.1\ \mathrm{rad}$ in a 1 GeV positron on-target experiment
- The spins of target electrons 5 and 6 are aligned with the beam direction
- Consider the main component of the primary state, $(LL + RR)/\sqrt{2}$

Assuming the two secondary targets are $10\ \mathrm{cm}$ thick iron, the event rate in $\cos\theta_7' \leq 0.5 \wedge -0.75 \leq \theta_9' \leq 0.75$ is $\mathbf{1.4 \times 10^2}$/s for the state $(LL + RR)/\sqrt{2}$.

A new kind of Wu experiment

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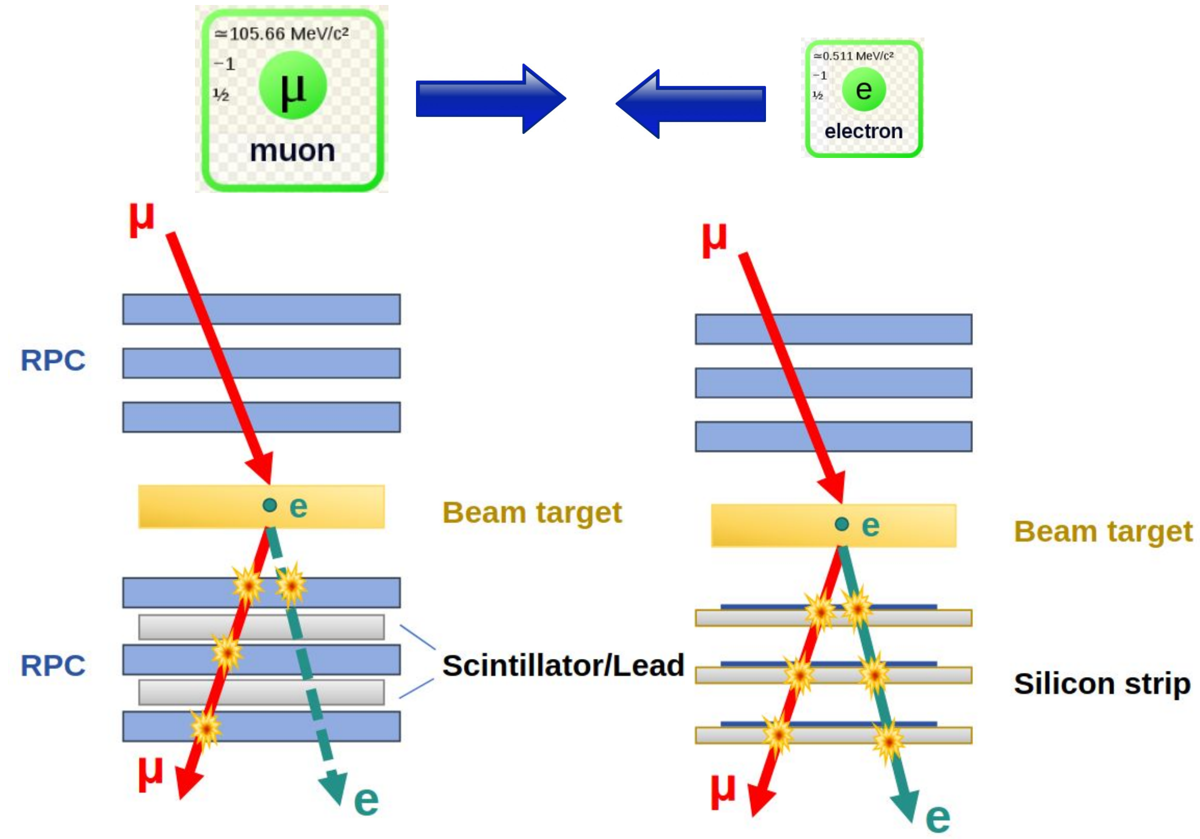
基于本地实验室的电子缪子‘对撞’

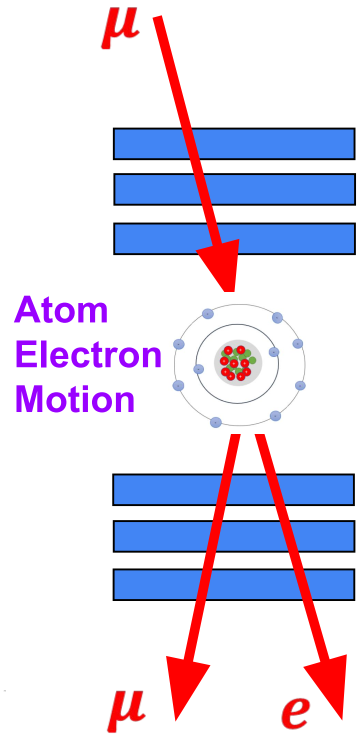


- Muon Electron Collisions can be observed at a Lab, ~10-100 events/day?

- Non-trivial combination of detector legos
- Benefit development of multi-lepton readouts

- Precise measurements of cosmic rays
- Trace of high energy particles from environment such as lightning storm

Atoms as Electron Accelerators



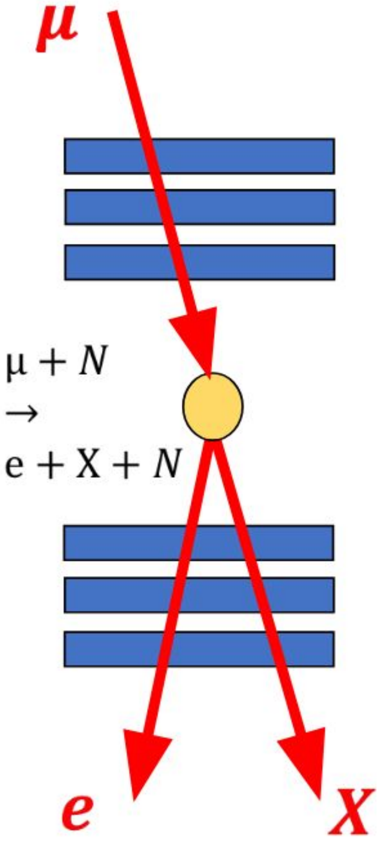
arXiv:2504.00100, *PRL*134 (2025) 6, 061802, *PRL*132 (2024) 26, 261801

- Due to Heisenberg's uncertainty principle, atomic electrons localized around the nucleus can be accelerated to relativistic momentum (~O(10) MeV).

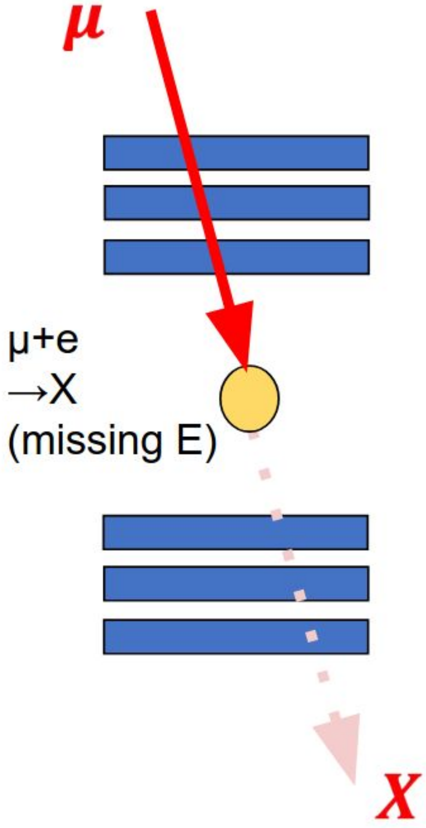
- In fixed-target experiments, **atoms can effectively act as electron accelerators**, increasing the centre-of-mass energy in collisions with beam particles.

- This effect **at high energy is still to be observed**.
- And then can be applied to **material science, new physics searches**, etc.

Flavor Changing DM



- Dark matter interacting with one muon and one electron.
- Rates can be enhanced via resonance production of mu+ and e-.
- PID, veto may be crucial for detector degin.



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ChatGPT ⌄

what is PKMu experiment

Exploring the potential of Muons and Muon Scattering

Why PKMu Matters

- **Model-Independent**: It can detect dark matter without assuming specific interactions.
- **Low-Energy Advantages**: Lower muon energies (~1–10 GeV) allow compact detector design and high angular sensitivity.
- **Unique Window**: Targets parameter space that complements existing high-energy muon experiments.
- **Multidisciplinary Reach**: Not just dark matter, but fundamental symmetries, rare decays, and quantum effects.

In Summary

The PKMu experiment is a cutting-edge proposal that leverages both cosmic and beam-generated muons to explore frontier physics—dark matter, new bosons, charged lepton flavor violation, and even quantum entanglement—through innovative detection methods and simulation-driven designs.

Together we build for the potential future

PKMu (抛砖引玉)
DREAMuS
LUNE
CANTON-mu
…
MACE
…

JHEP 09 (2018) 153

缪子与核散射：MMM 寻找新物理