北京大學
PEKING UNIVERSITY

PKMu缪子散射探测与新物理探索
PKMu: Probing and Knocking with Muons at Peking University

Qite Li（李奇特）, Zhou Chen（周辰）, Qiang Li（李强）
On behalf of the PKMu collaborators

International Workshop on Muon Physics at the Intensity and Precision Frontiers (MIP2026)
2026.4.25 Huizhou, China

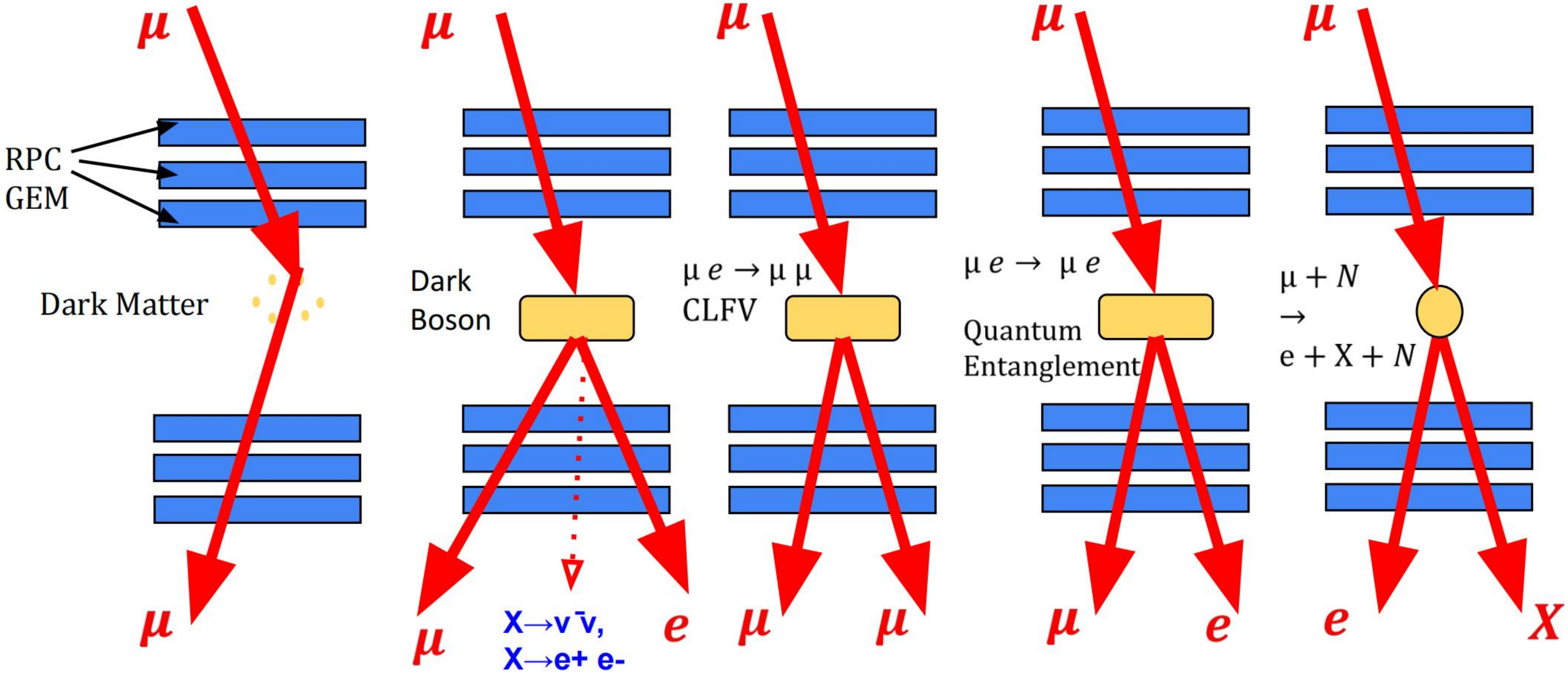
The PKMu Initiative: Probing and Knocking with Muons

- **Core Goal:** A comprehensive muon-scattering experiment program to explore intresting and new physics.
- **Our Strategy — Innovation, Agility, and High Impact**
  - **Phase I:** Use cosmic-ray muons + self-developed high-precision RPC/GEM detectors
  - **Phase II:** Transition to high-intensity muon beams at Chinese facilities

PKMu Research Landscape:

Innovative and Affordable Muon Scattering Experiment

Mod. Phys. Lett. A 40, 2530008 (2025)
Chin. Sci. Bull. 71, 894 (2026) DOI: 10.1360/CSB-2025-5452



Phys. Rev. D 110, 016017
Phys. Rev. Lett. 136, 151001
Phys. Rev. D 113, 072008
Int. J. Mod. Phys. A 40, 2550164
J. Phys. G: Nucl. Part. Phys. 52 075002

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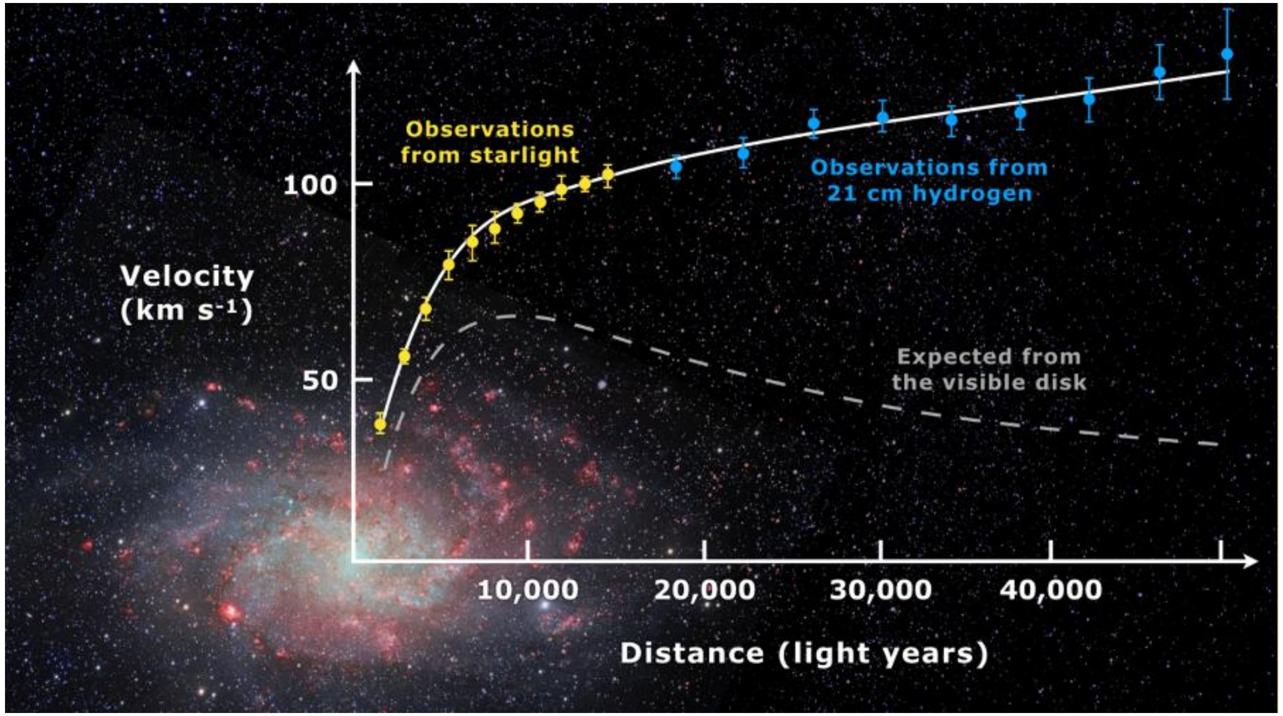
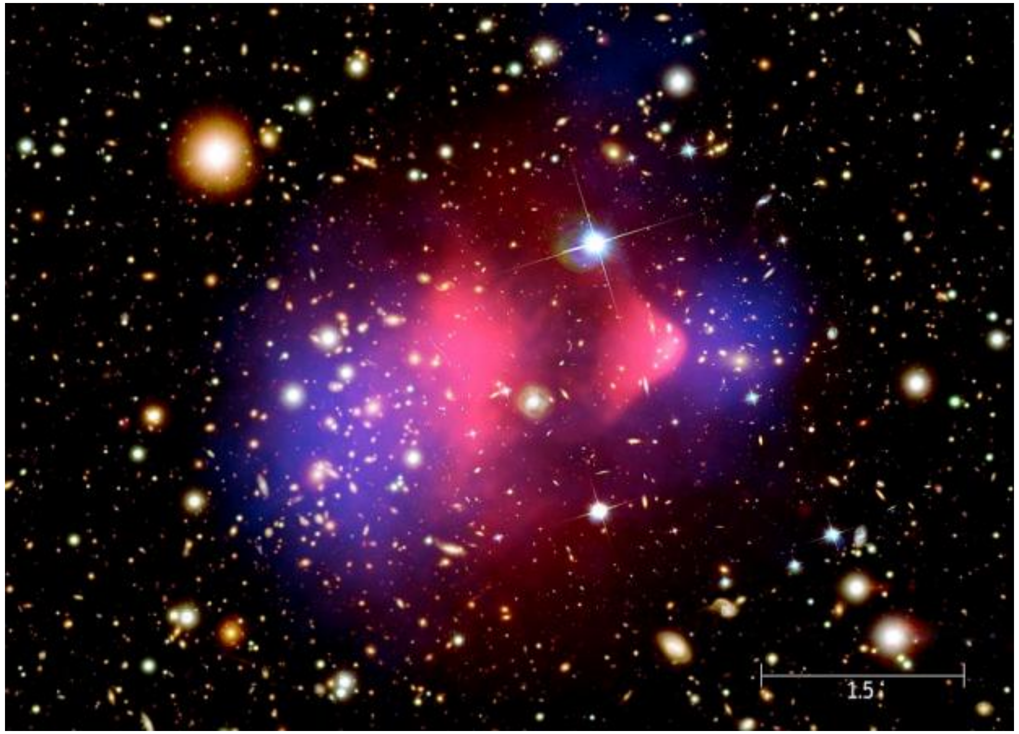
目录

Evidence for the Existence of Dark Matter

- Galaxy rotation curve: Observed vs. predicted mismatch.(1933/1970s)
- Bullet Cluster: Dark matter in galaxy collision.
- Normal Matter : Dark Matter : Dark Energy = 5 : 27 : 68



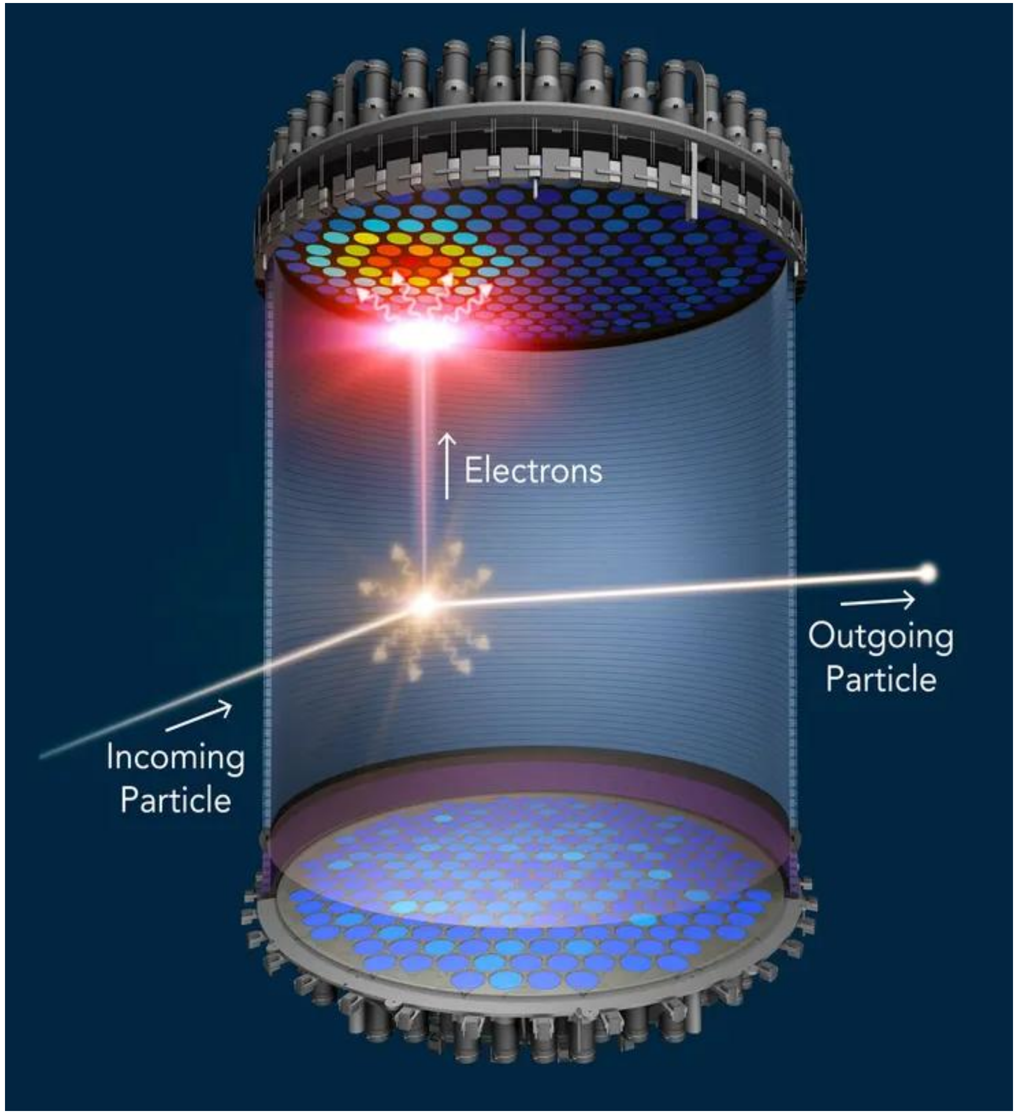
Credit: Mario De Leo. CC BY-SA 4.0.



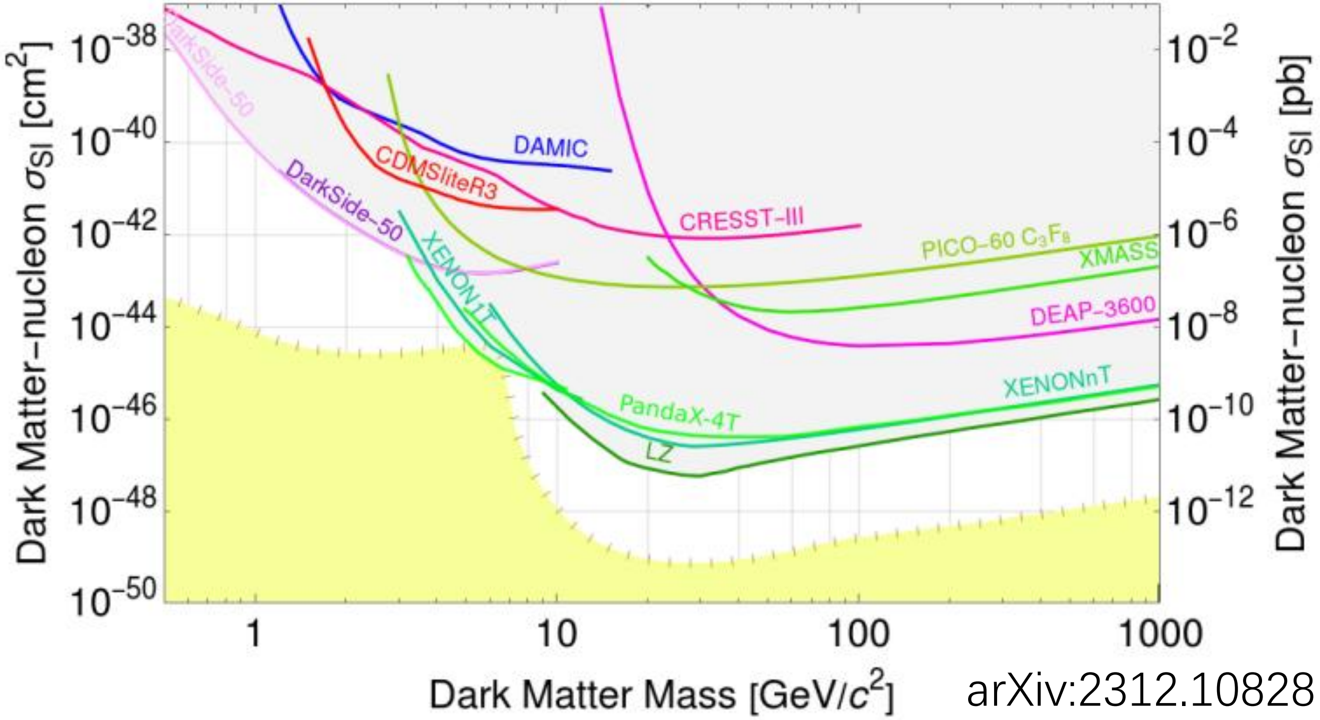
Credit: x-ray: NASA/CXC/CfA/M. Markevitch et al.; optical: NASA/STScI, Magellan/U. Arizona/D. Clowe et al.; lensing map: NASA/STScI ESO WFI, Magellan/U. Arizona/D. Clowe et al.

- Gravitational lensing, microwave background radiation。

Direct Search for Dark Matter (WIMPs)



Credit: LZ Experiment



arXiv:2312.10828

13 December 2024 Nature News:

First sighting of ‘neutrino fog’ sparks excitement

– but is it bad news for dark matter?

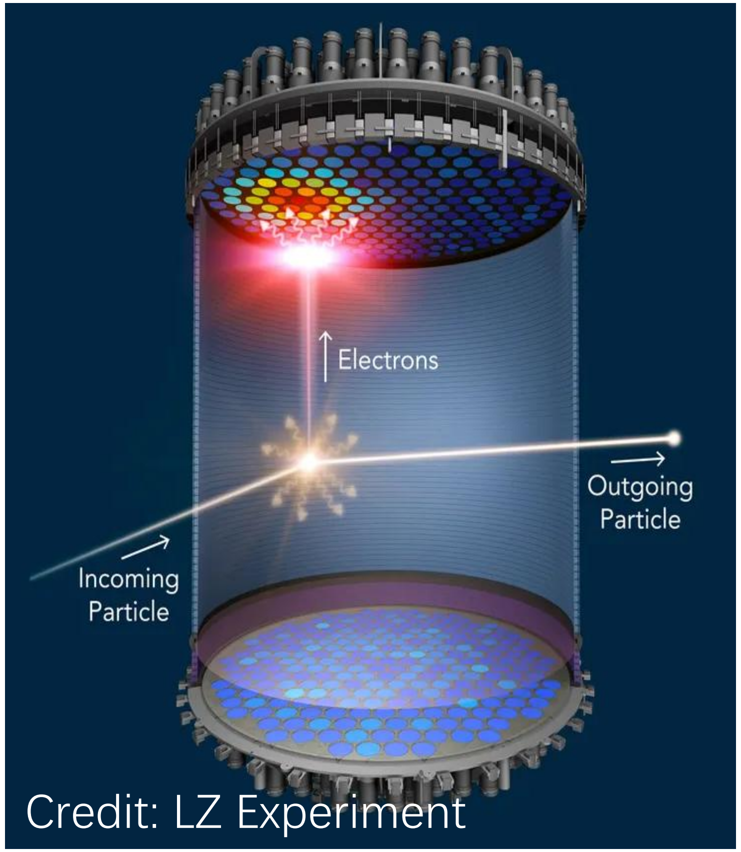
Phys. Rev. Lett. 133, 191001 (2024). && Phys. Rev. Lett. 133, 191002 (2024).

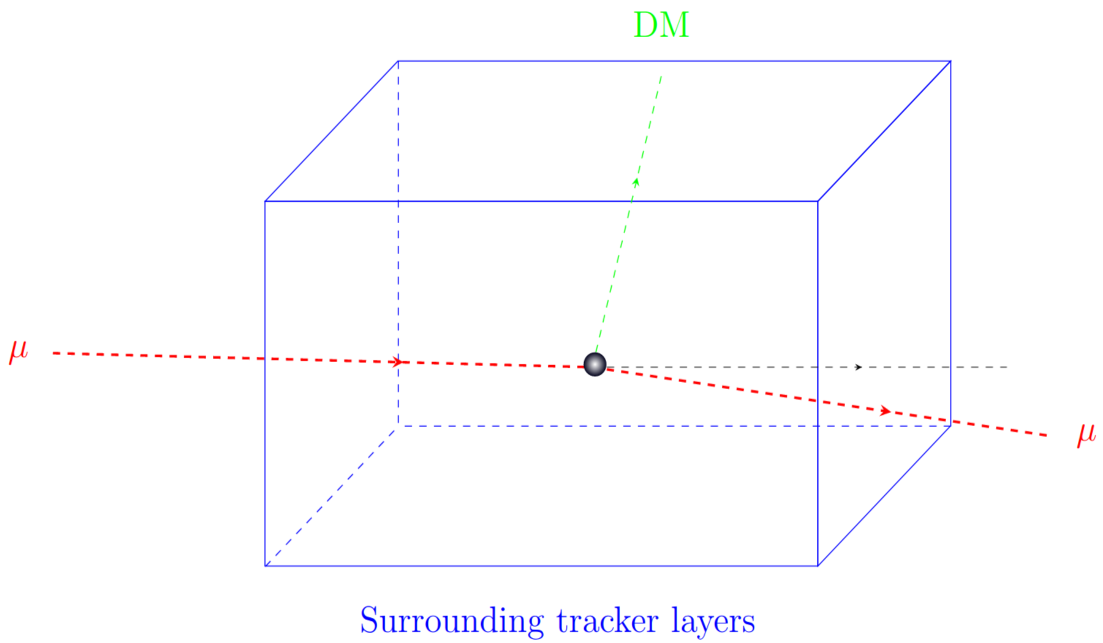
Phys. Rev. Lett. 135, 011802 (2025)

Using Muons to Probe Dark Matter

Muon-dark matter interactions remain understudied. Muons are second-generation leptons in the Standard Model. Free muons are short-lived/rare in the universe.

1. **Passive Waiting to Active Knocking:** Enhanced sensitivity to light-mass dark matter
2. **Cosmic Muon from Background to SIGNAL:** Complementary approaches





If DM scatters muons, the observable is the deflection angle

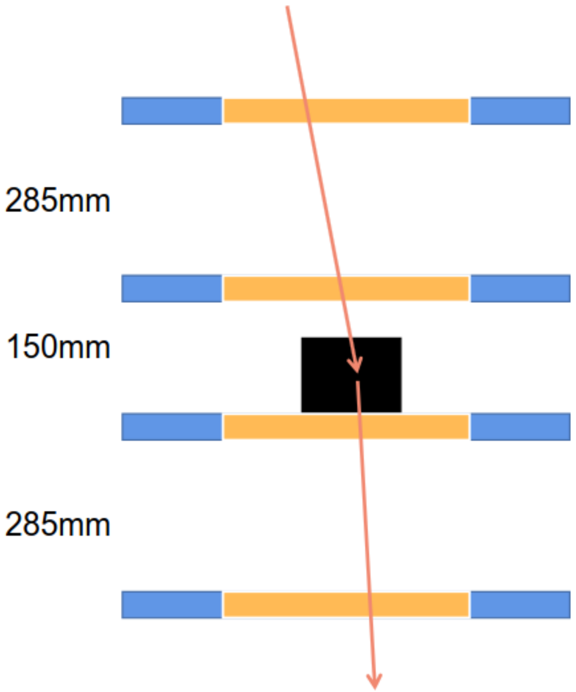
PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology
Phys. Rev. D 110, 016017(2024)

Open Access

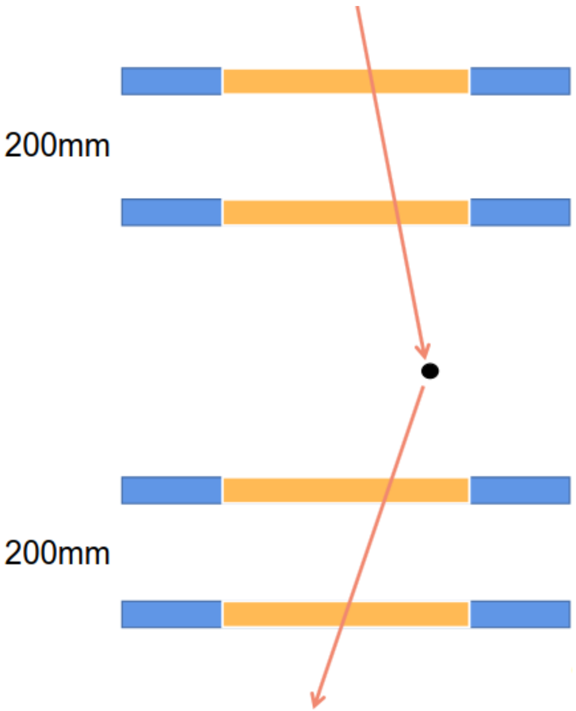
Proposed Peking University muon experiment for muon tomography and dark matter search

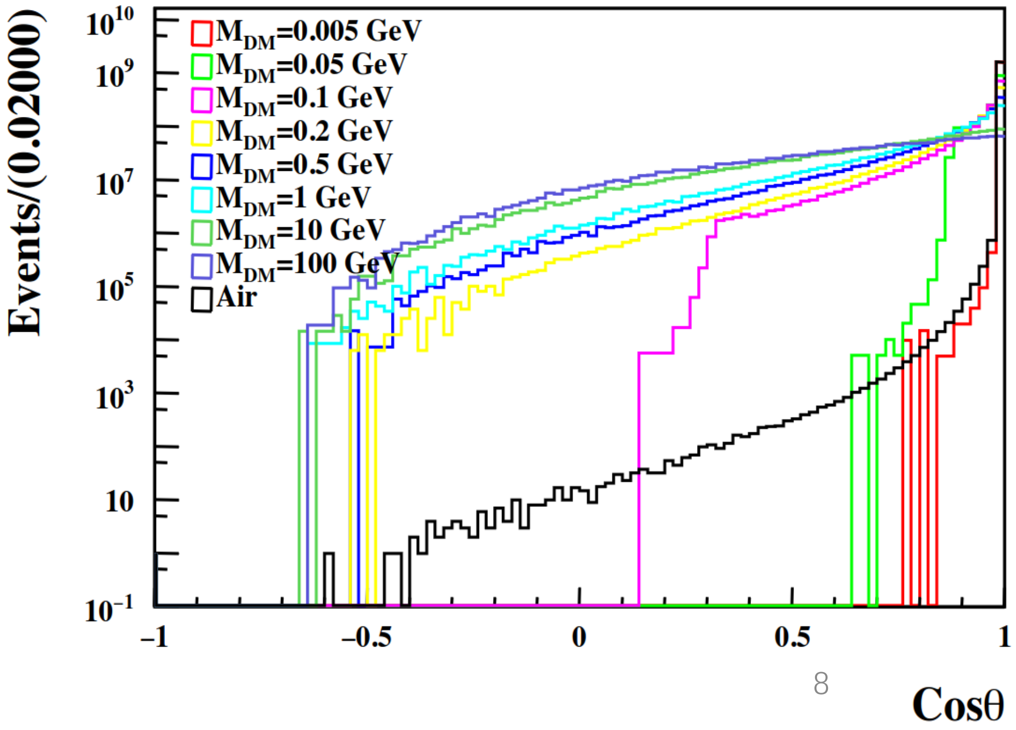
缪子穿过1m厚度空气及不同质量暗物质的散射角模拟结果
Geant4 simulation results for muon scattering with 1m thick air or DM

Muon Tomography 缪子散射成像
测量样品散射角



Dark Matter Search暗物质寻找
测量缪子暗物质散射角

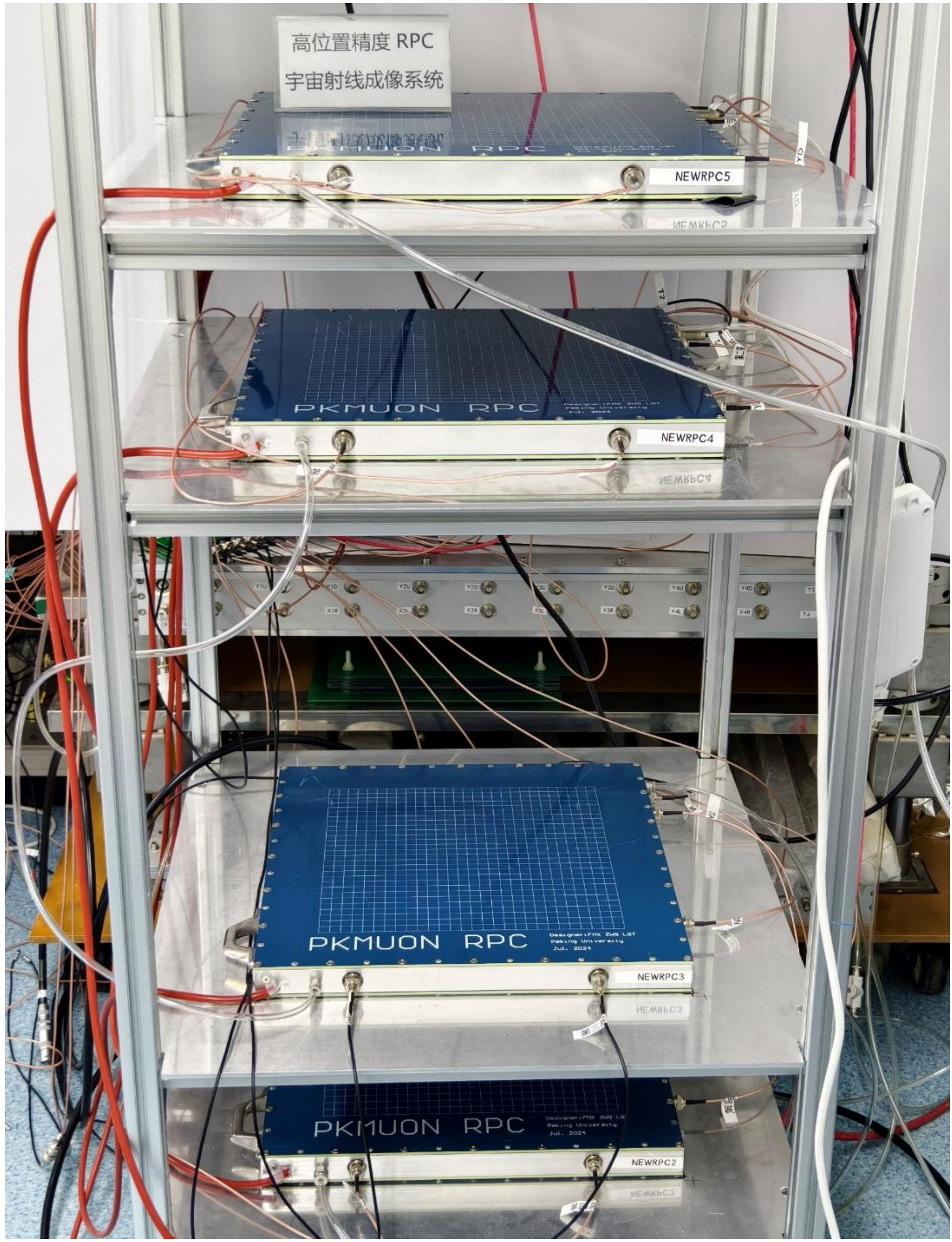




PKMu Cosmic Ray Tomography System(2025)

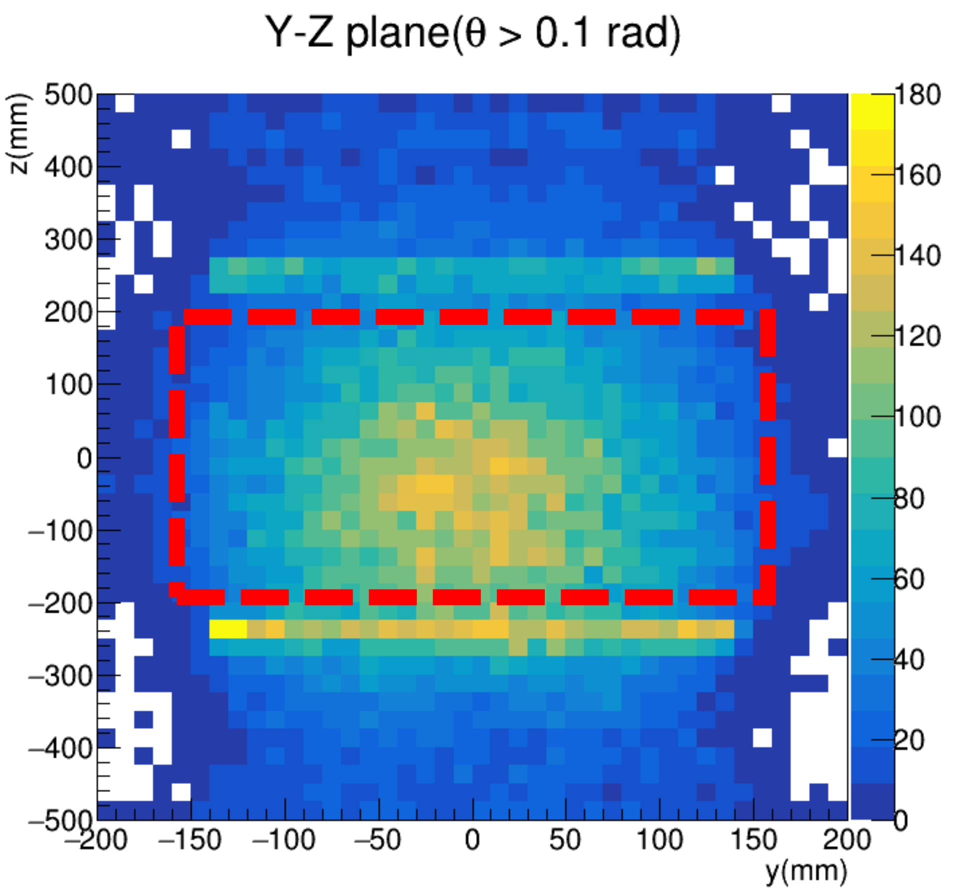
- 4 layers of glass RPC with LC delay-line readout
  - Active area 28×28 cm²
  - vertical spacing 20–50–20 cm
  - Single RPC spatial resolution σ ≈ 0.5-0.7 mm

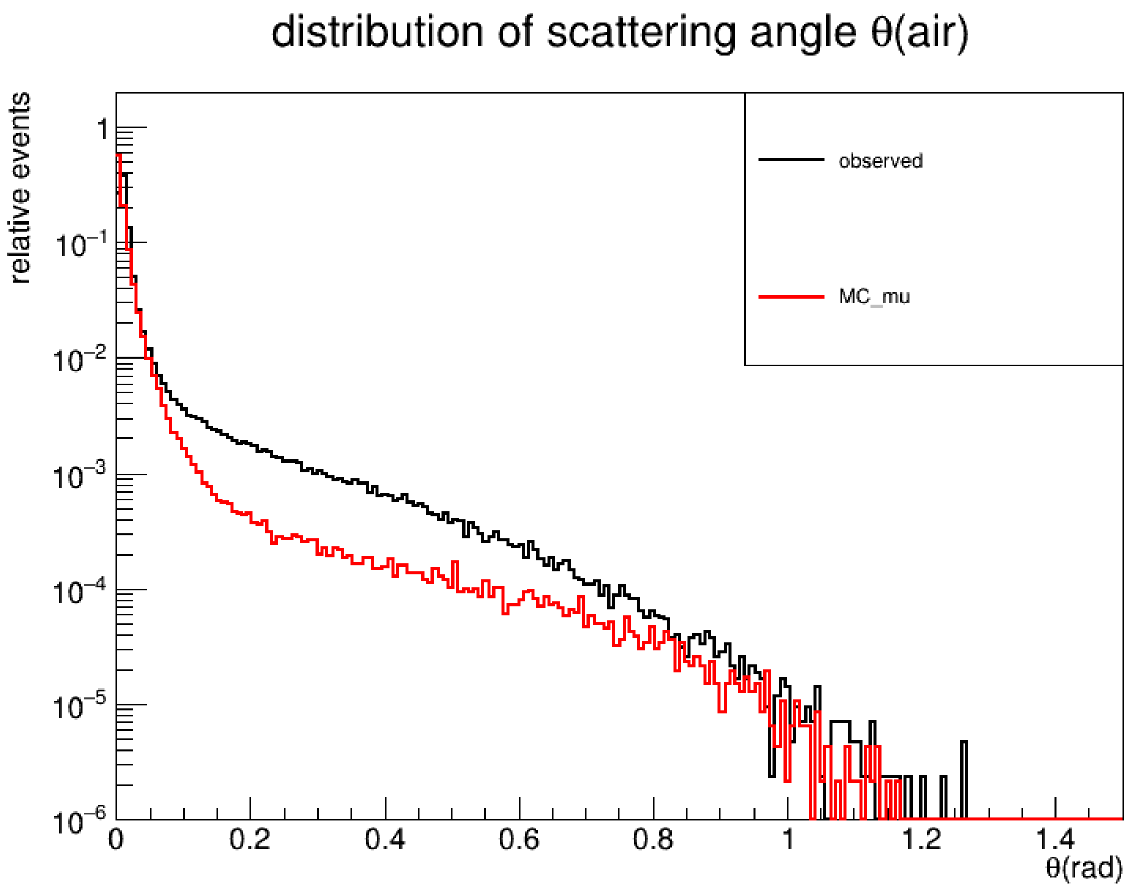
- 63-day continuous physics run: 1.18 million effective events recorded



Scattering Angle Distribution in ROI Area

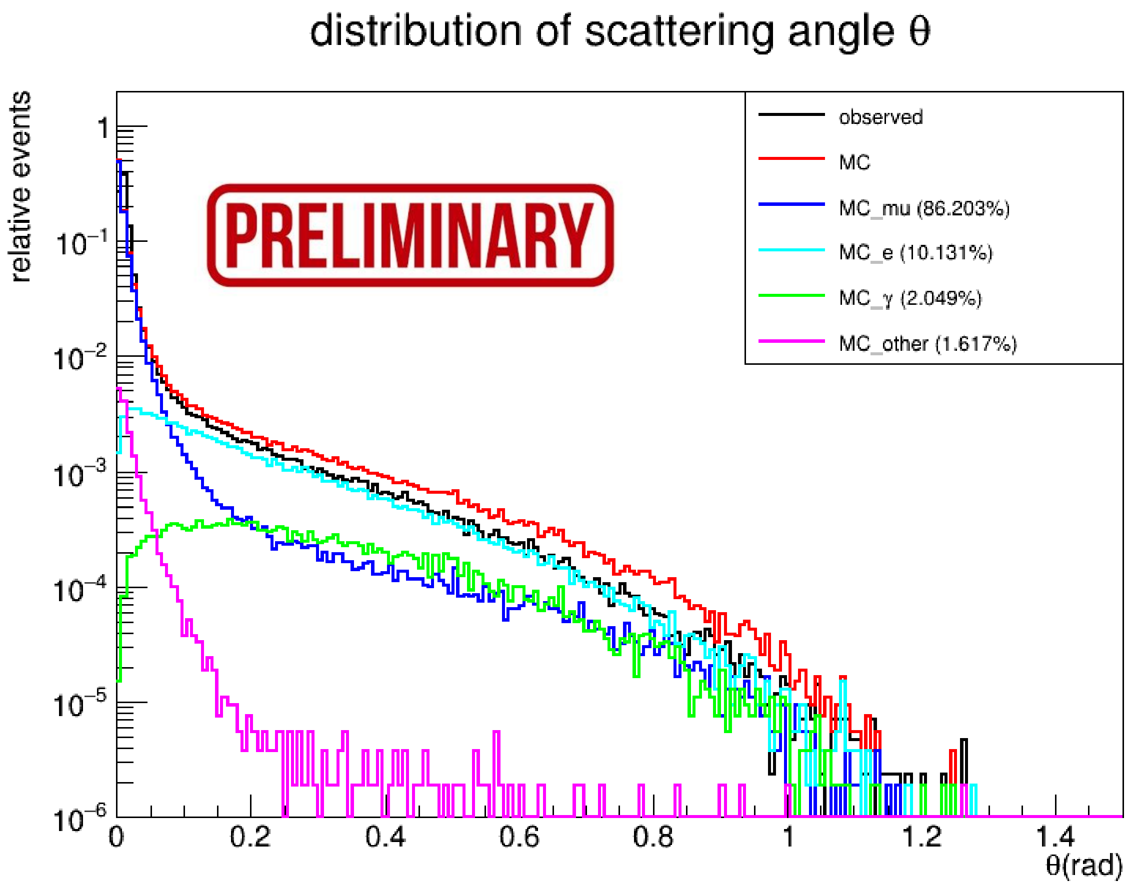
- Analyzed angular distribution within detector's sensitive volume (-200 mm<z<200 mm)
- Large-angle scattering events persist after selection





Simulation of Cosmic Rays at Sea Level(All-Particle Composition)

- Simulated particle components at sea level: $\mu, e, \gamma, p, n, \pi$
- Small-angle scattering dominated by muons
- Large-angle scattering primarily from electrons and photons
- Possible discrepancies between measured particle composition and simulation results.



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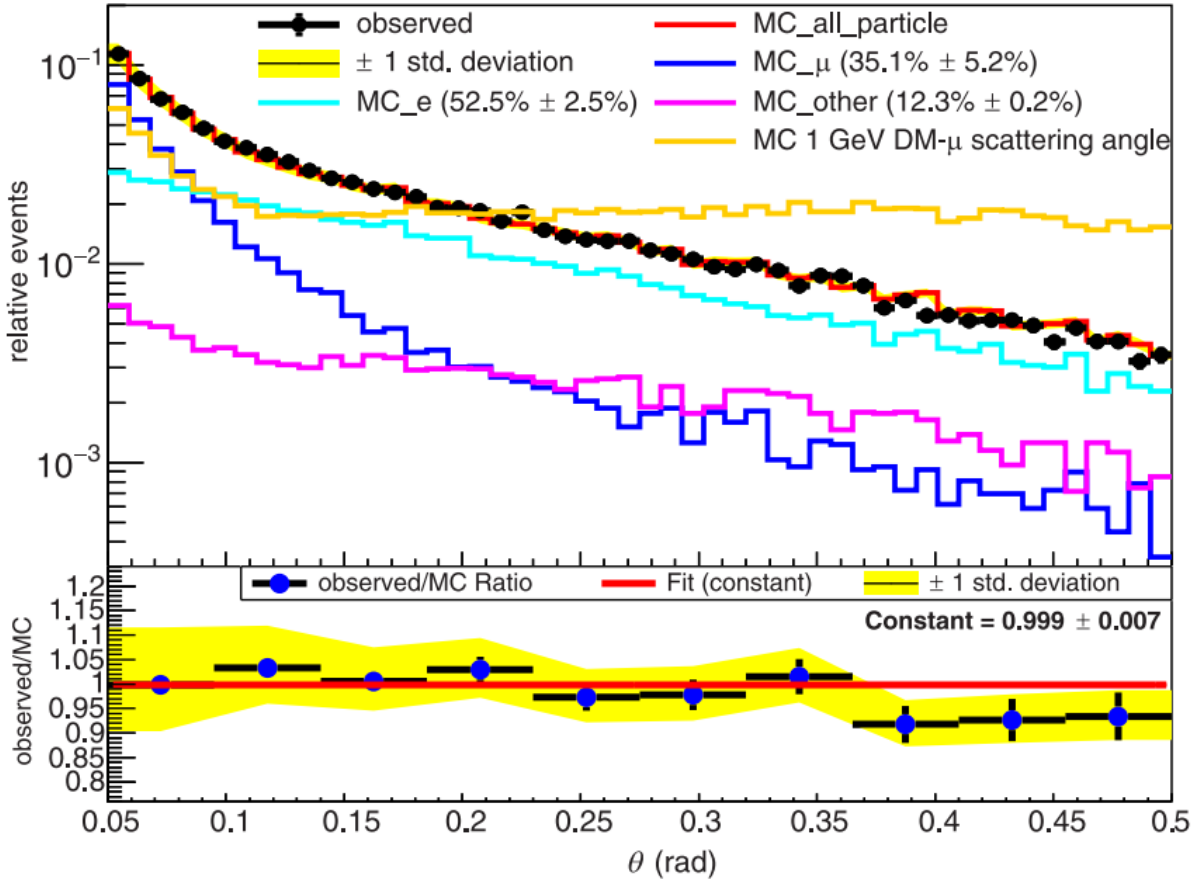


PKMu cosmic ray DM search

- At the 95% confidence level, the limit reaches 1.62×10^{-17} cm^2
- for 1 GeV slow DM, demonstrating sensitivity limit to light muon-coupled slow DM.
- the first limit from direct muon-DM scattering measurement.
- New DM search method
- Projection: 1 m³ detector + 1 year exposure + full angular range → 4–5 orders of magnitude improvement

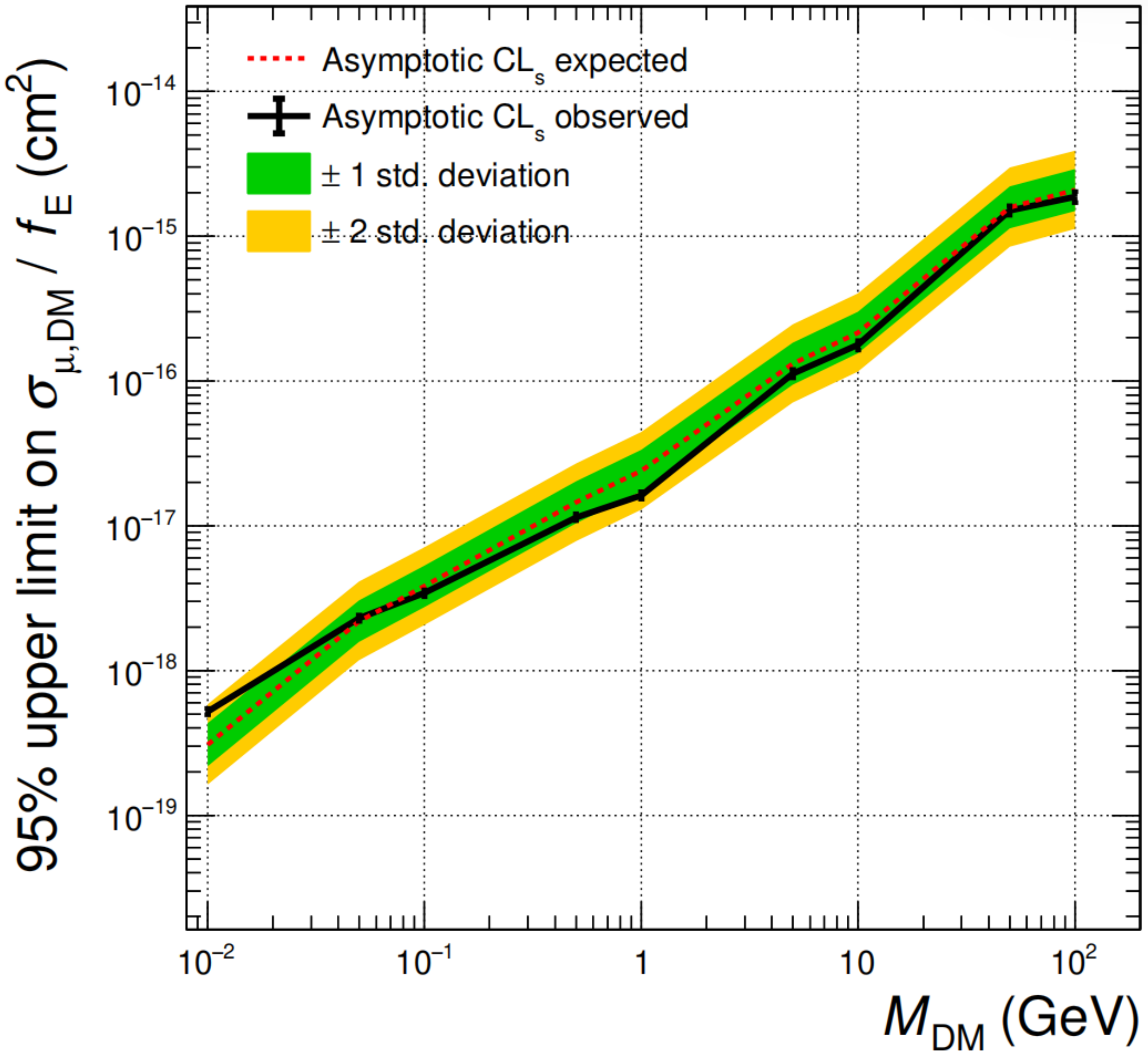


FIG. 4: Expected and observed 95% CL upper limits on the DM-muon interaction cross section versus $M_{\rm DM}$. he green and yellow bands represent the 1σ and 2σ regions, respectively.

Phys. Rev. Lett. 136, 151001 Take-Home Message

- ✅ Precision sea-level electron fraction (~2%)
- ✅ First direct cosmic-ray muon-DM scattering limit (1.6×10^{-17} cm^2 @ 1 GeV)
- ✅ Deep understanding of secondary backgrounds
- ✅ Cosmic Muon from Background to SIGNAL
- →**Cheng-en Liu's Poster**

⭐⭐⭐⭐ APS promotion ⭐⭐⭐⭐

北京大学研究人员筛选百万个宇宙线散射事件，在地球搜寻暗物质 | APS期刊重点内容

原创 APS APSPhysics 2026年4月24日 11:59

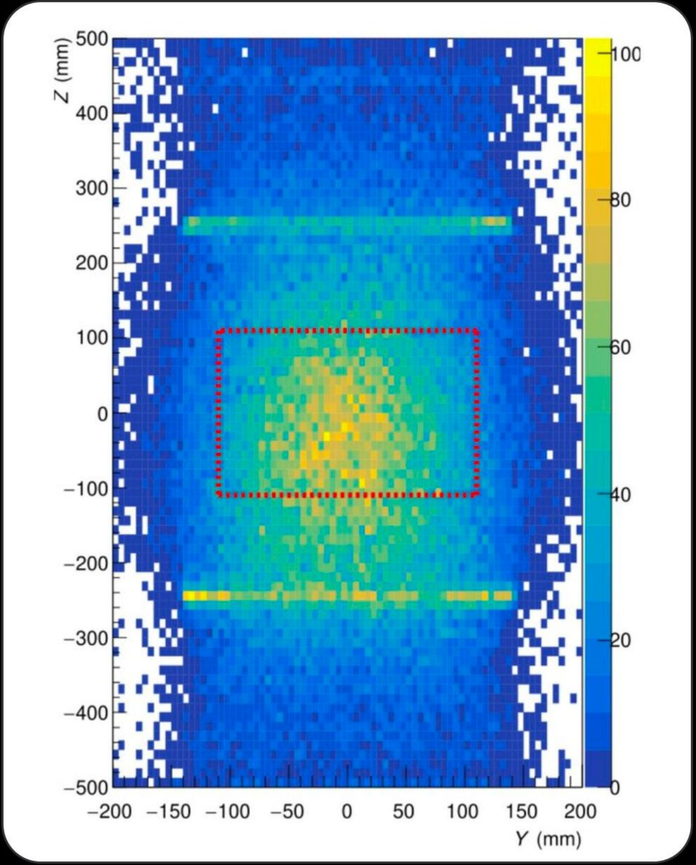
北京 2人

American Physic... @APS... · 12小时 ···

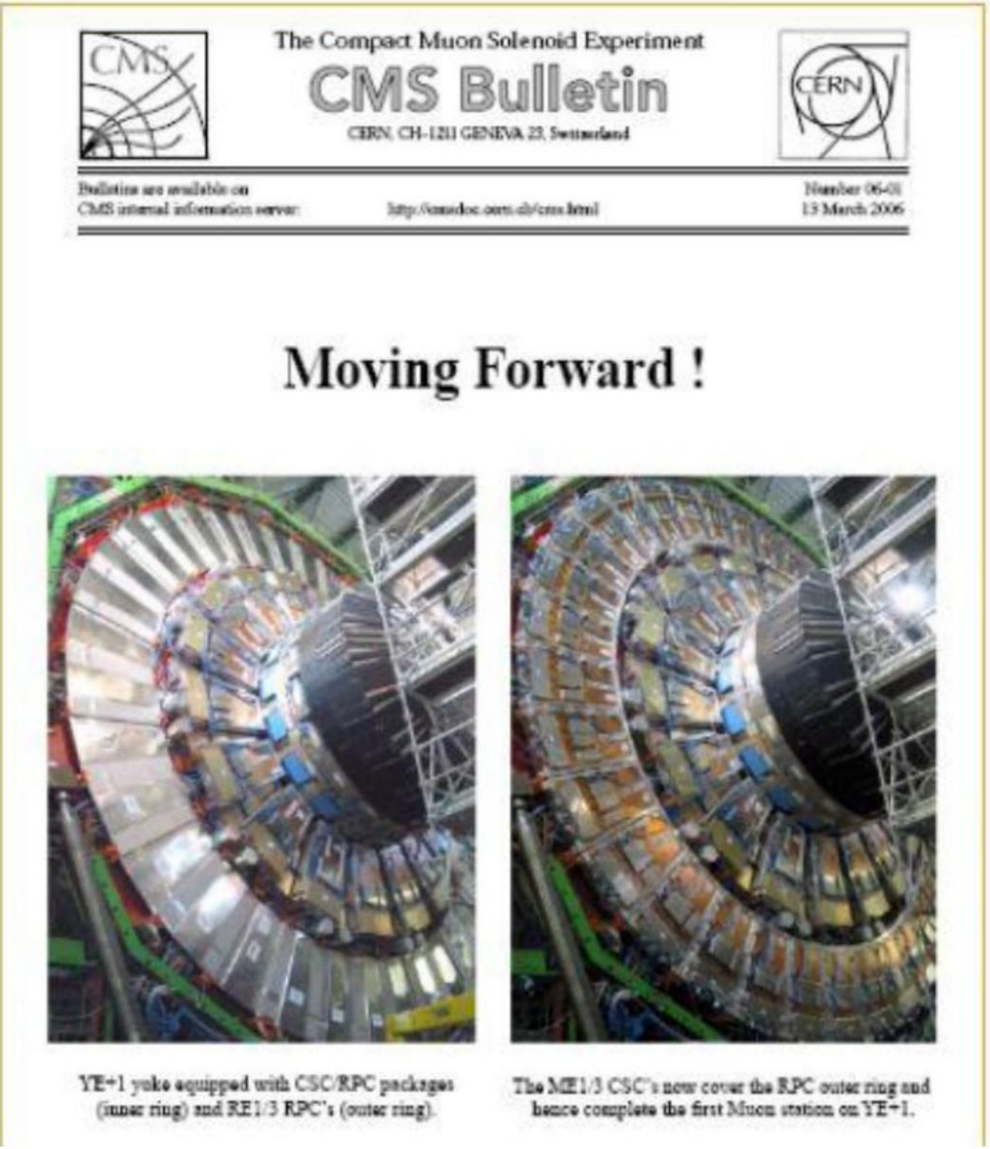
Can #CosmicRays help us detect #DarkMatter on Earth? 🌍

By tracking more than 1 million muon scattering events from secondary cosmic rays, researchers place new constraints on how dark matter might interact with ordinary matter. Read the paper in @PhysRevLett:

显示更多



PKU RPC R&D History


The Compact Muon Solenoid Experiment

CMS Bulletin

CERN, CH-1211 GENEVA 23, Switzerland

Bulletins are available on CMS internal information server: http://cmsdoc.cern.ch/cms.html

Number 06-01
13 March 2006

Moving Forward !

YE+1 yoke equipped with CSC/RPC packages (inner ring) and RE1/3 RPC's (outer ring).

The ME1/3 CSC's now cover the RPC outer ring and hence complete the first Muon station on YE+1.

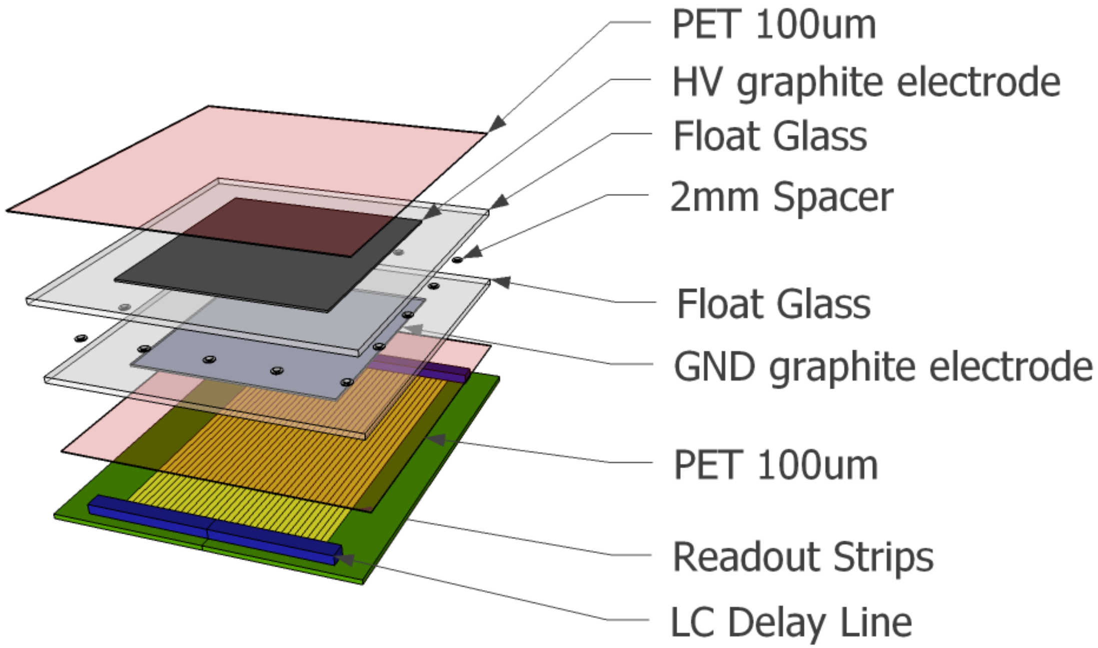
- Resistive Plate Chamber
  – R. Santonico(in 1980s)

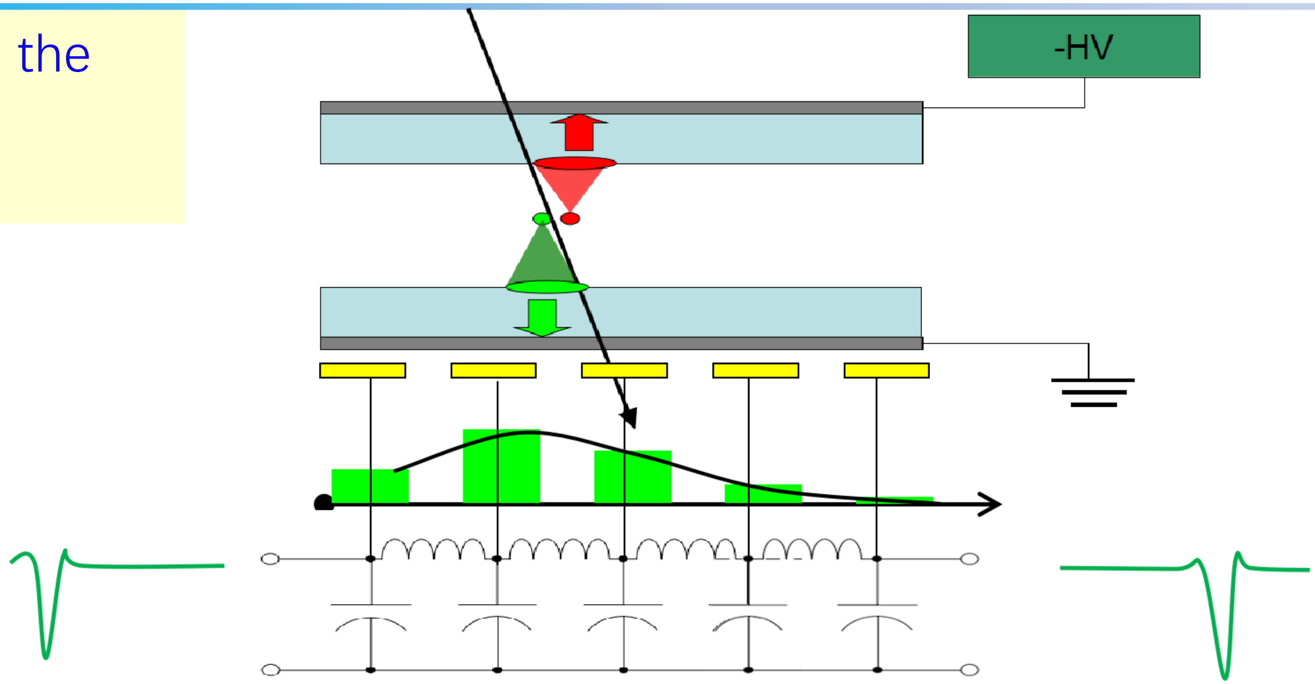
- Large Area ~ m²
- Good Time Solution~1ns
- Acceptable Spatial Resolution
  – ~3mm ~1cm

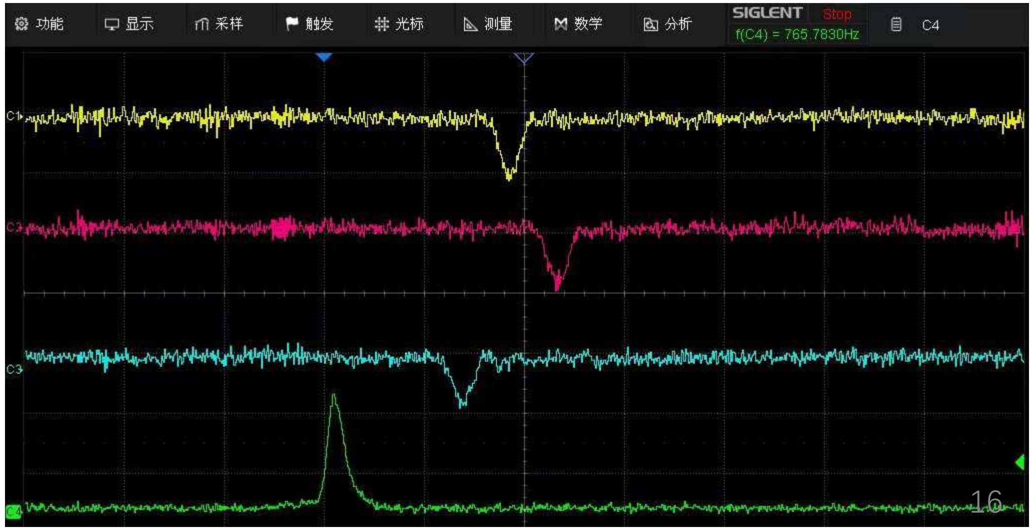
CMS Muon Trigger RPCs
Assembled and tested by PKU (~2002)

High resolution RPC R&D (2012~2013) Li Qite and Ye Yanlin, *et al.*

Innovatively combine the large-area glass RPC with the delay-line readout technology. 2 TDC/1 dim
Spatial resolution of muons. 0.3~0.4 mm (σ)





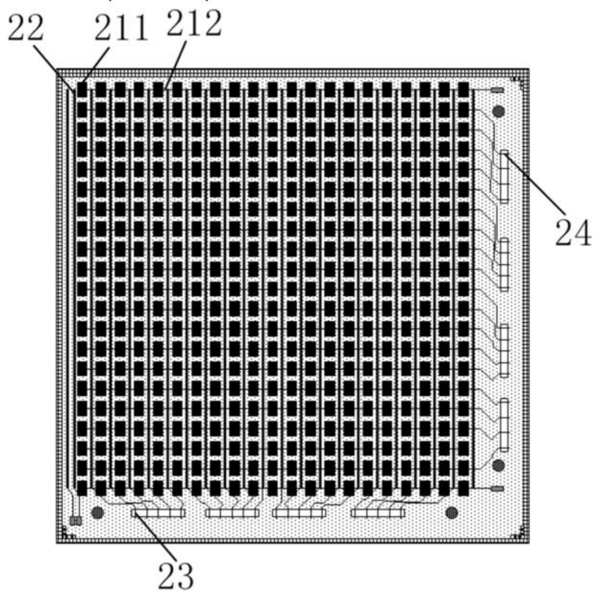


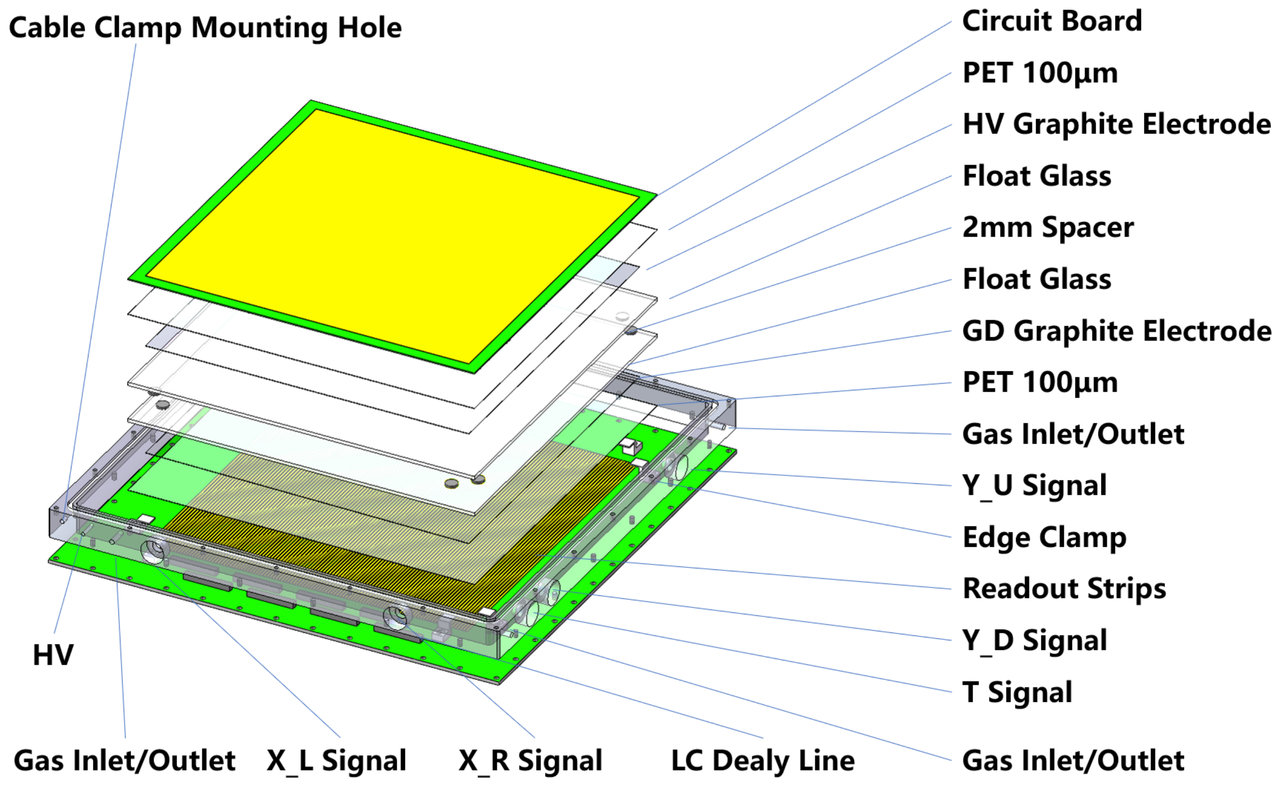
Ref:

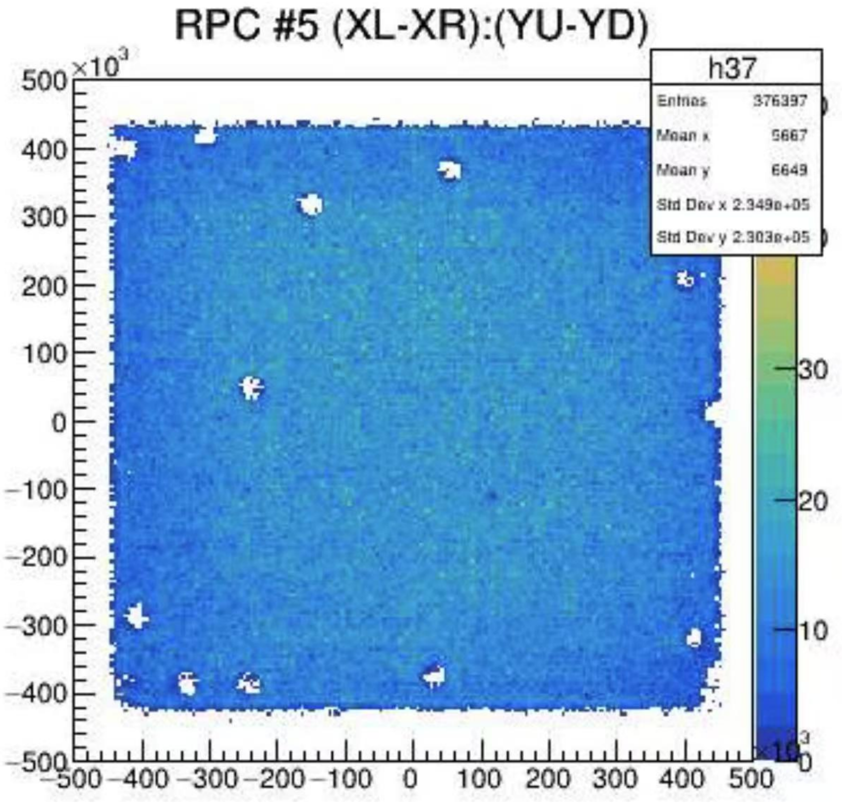
- **Li, Qite**, *et al. **NIMA*** 663.1 (2012): 22-25.
- **Qi-Te, Li,** *et al. **Chinese Physics C*** 37 (2013)016002.
- S. Chen, **Q. Li*,** *et al*, ***JINST***: 10 (2014)10022.
- 许金艳,**李奇特***, 等, ***物理实验***, 41(2021)23

2D RPC Readout Strip Design（2024)

- Enables 2D position readout from **a single RPC layer.**
- Reduced detector material，simplified detector structure
- Simple and elegant position reconstruction
- **National Invention Patent Granted**
- **国家发明专利：一种二维位置读出阻性板气体室探测器及探测系统**
- **专利号：ZL 2025 1 1044987.1**

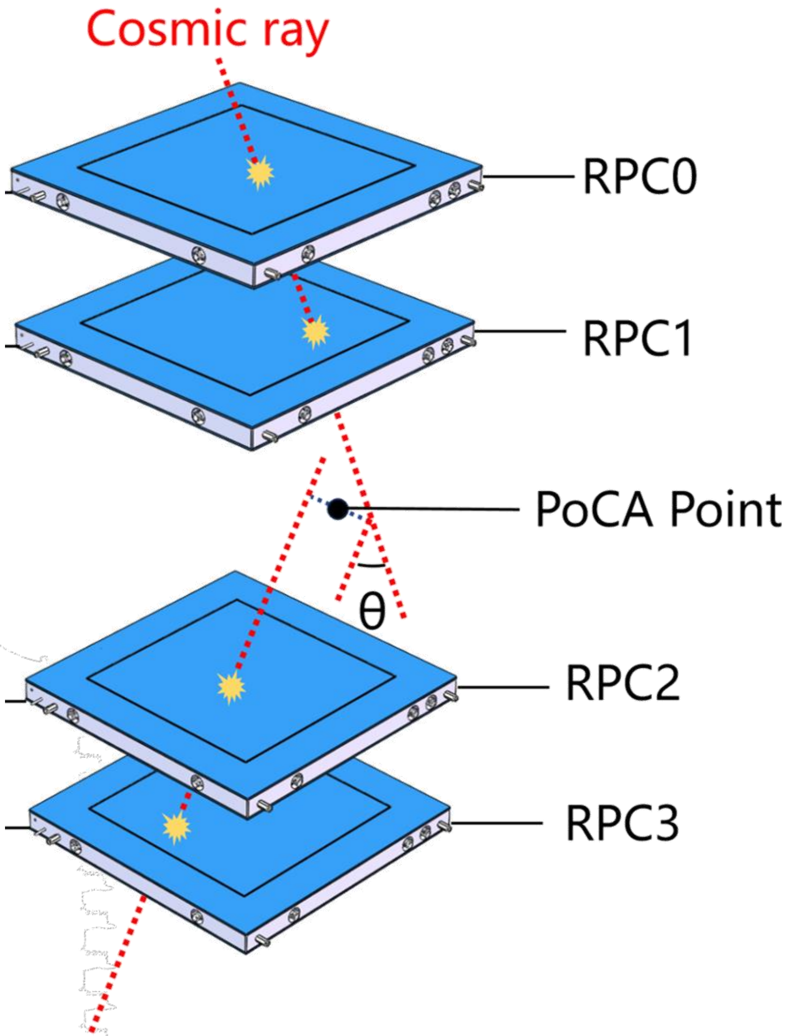


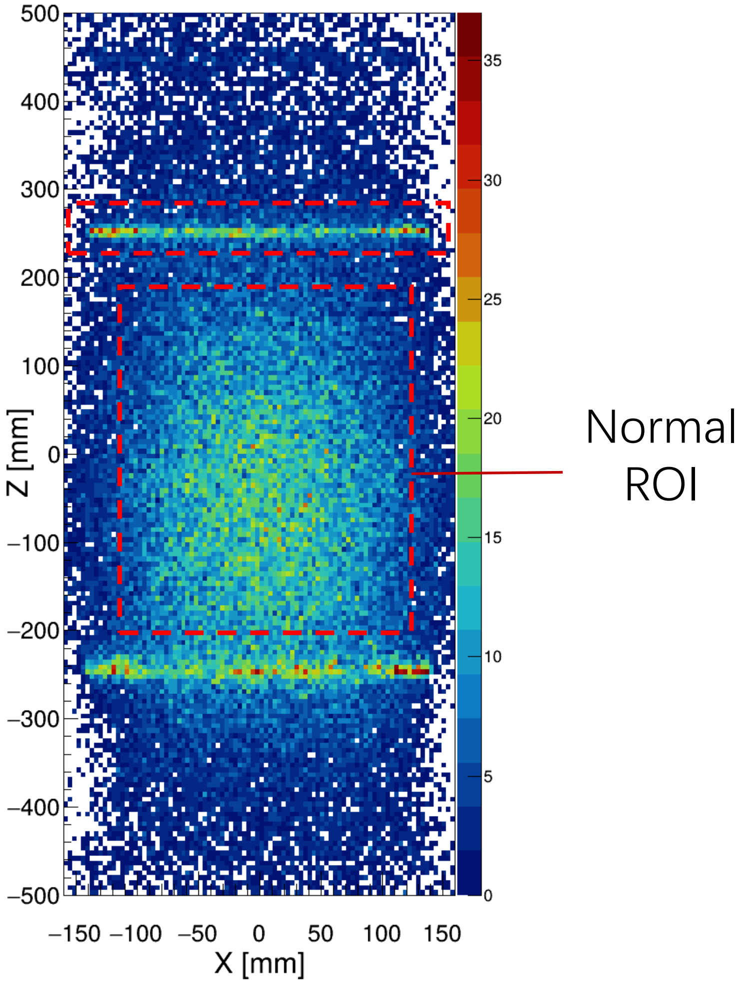




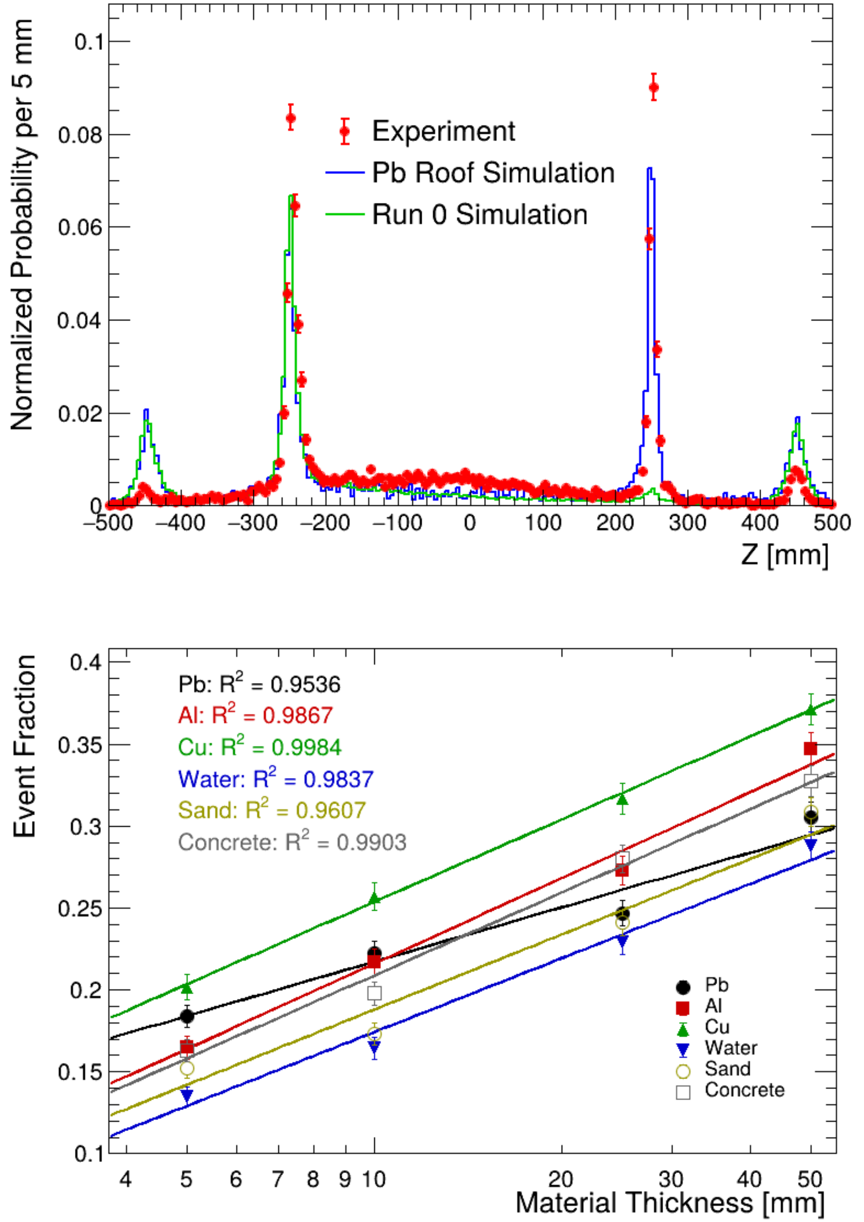
Student Innovation 1: Rongfeng Zhang(张荣峰) — “Noise” Becomes Signal Secondary Particle Signatures in Muography

J. Appl. Phys. 139, 014903 (2026)



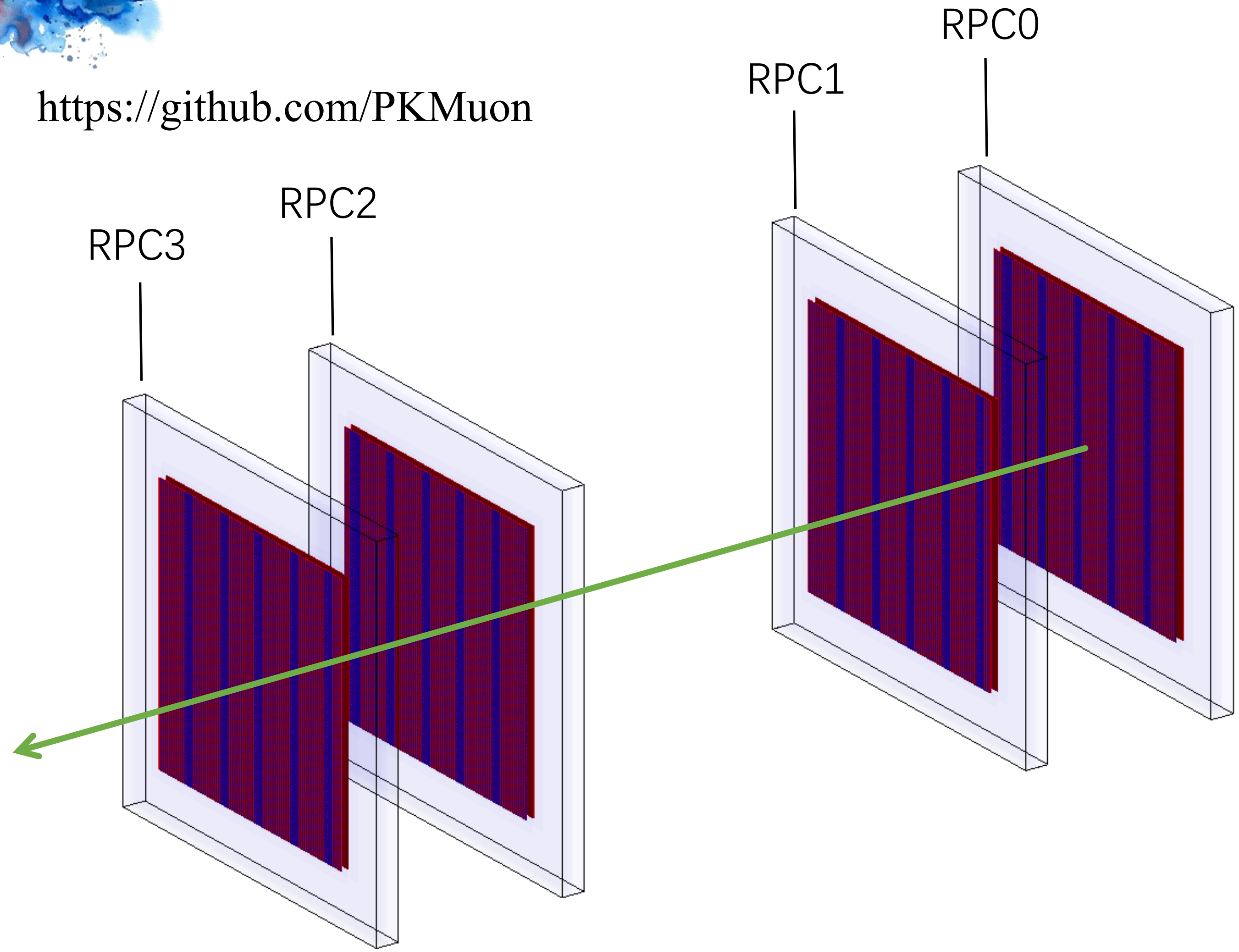


x–z distribution of PoCA points

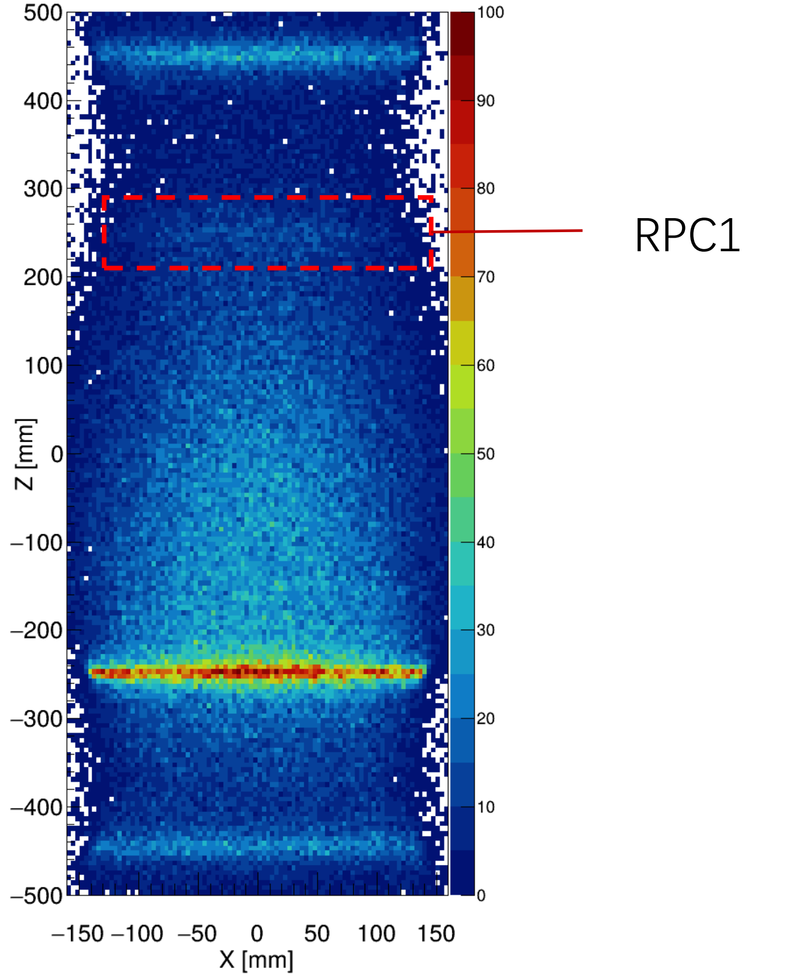


Geant4 Simulation version 1

https://github.com/PKMuon

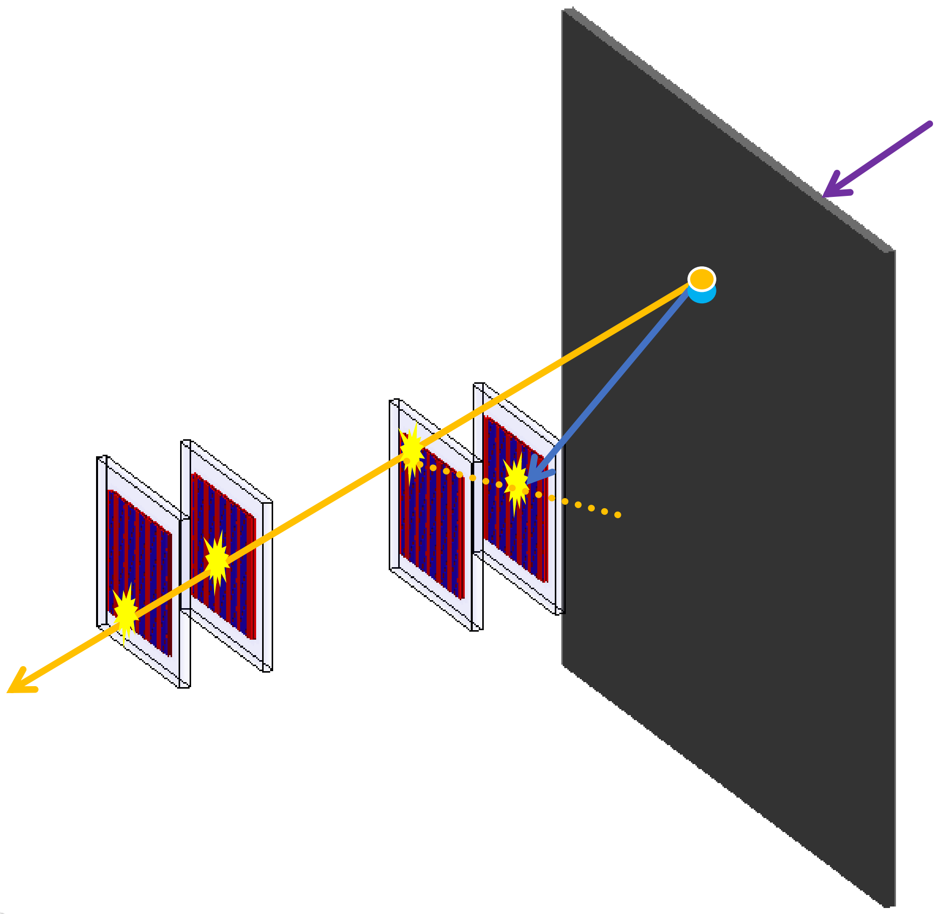


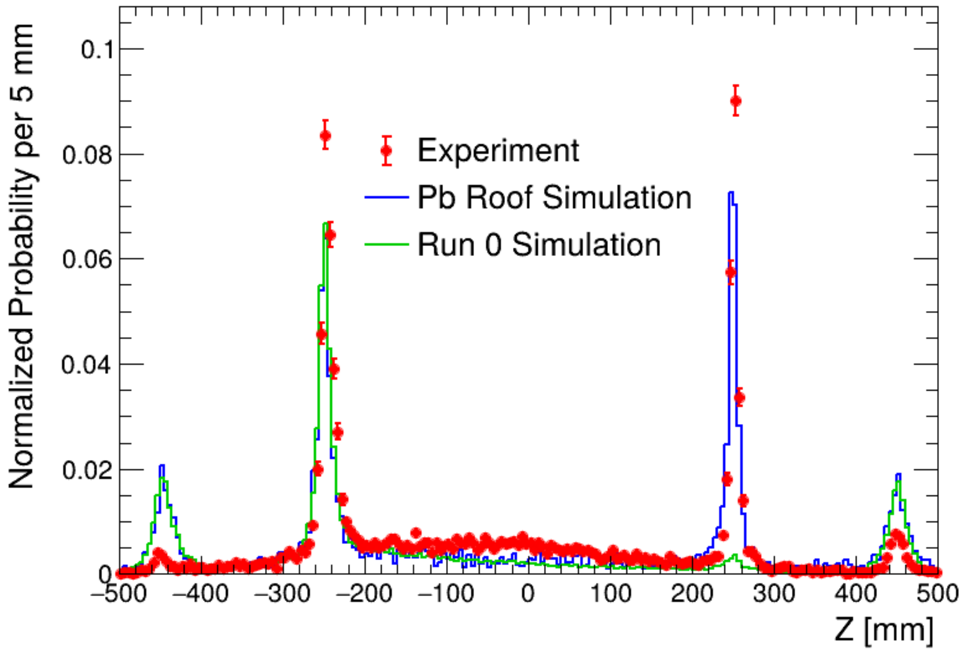
Simulation run0: Cosmic rays generated by CRY, with particles produced immediately above the top of RPC0
CRY: https://doi.org/10.1109/nssmic.2007.4437209

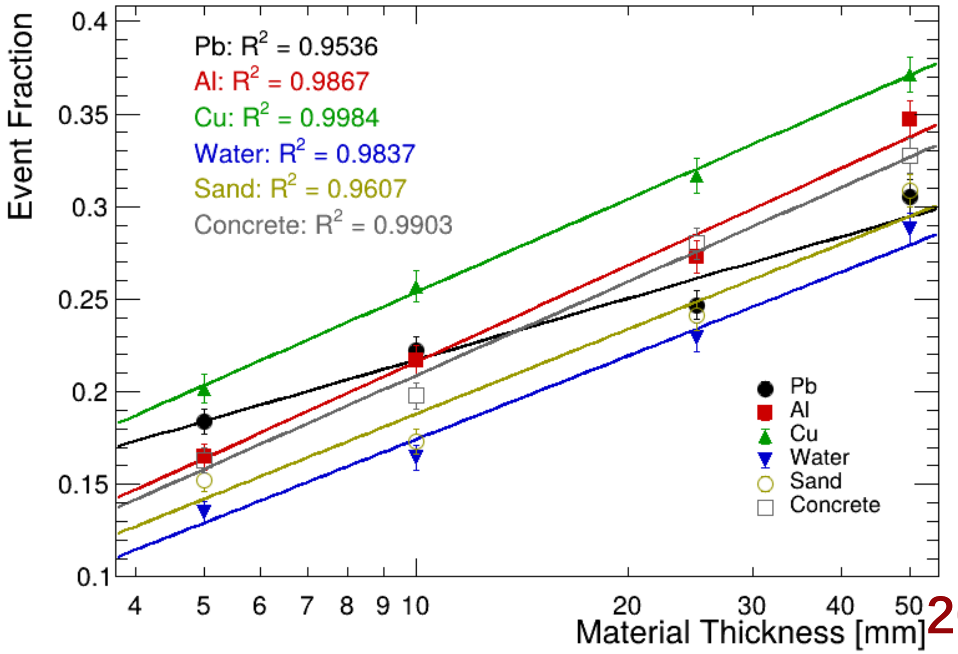


x–z distribution of PoCA points simulating air scattering

J. Appl. Phys. 139, 014903 (2026)
Rongfeng Zhang’ s Poster







simulation run1:A large-area material simulating the roof effect is placed above the detection system, with particles generated at the top of this "roof."

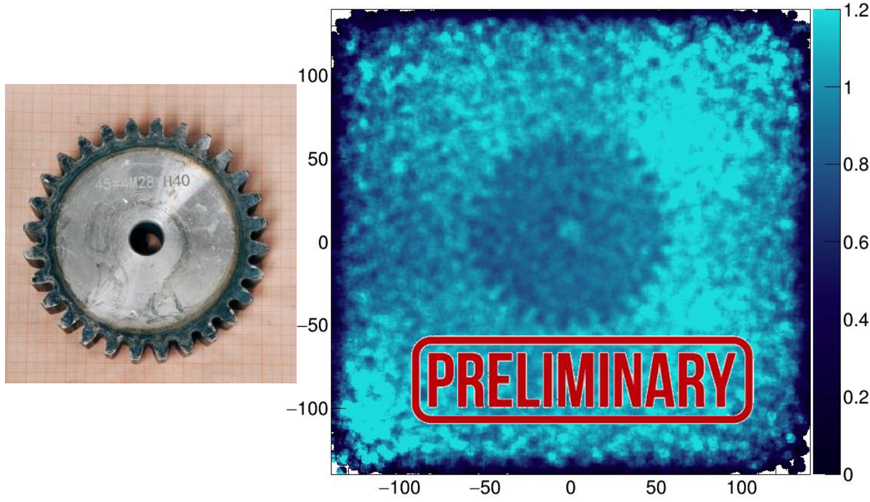
Student Innovation 2: **Zibo Qin(秦梓博) — arXiv:2512.19747**
PμMA: Millimeter-Resolution cosmic muon Imaging

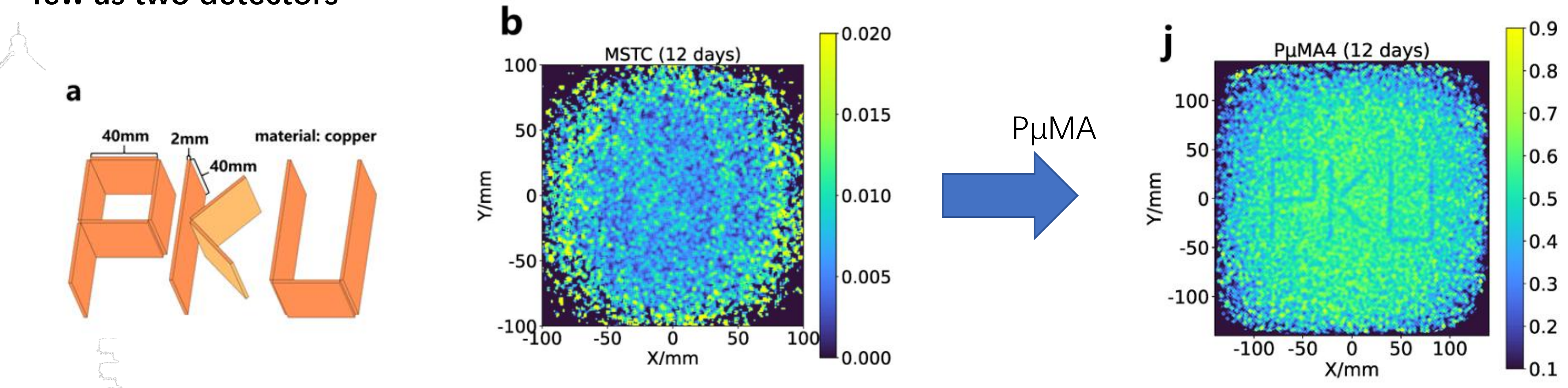
Problem: PoCA-based MST has poor spatial resolution for mm-scale object

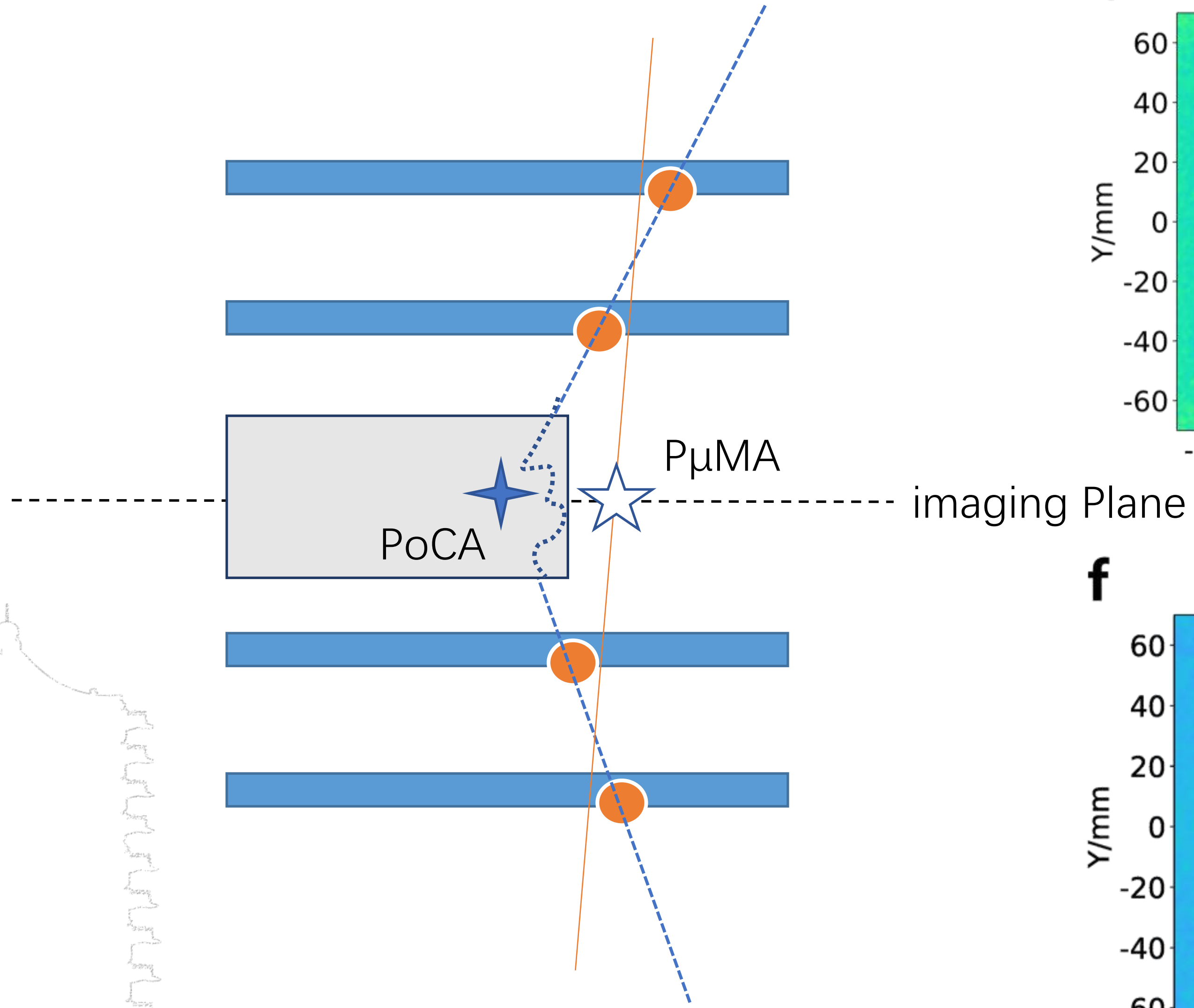
Projection-shifted MUon transMission tomogrAghy (PμMA)

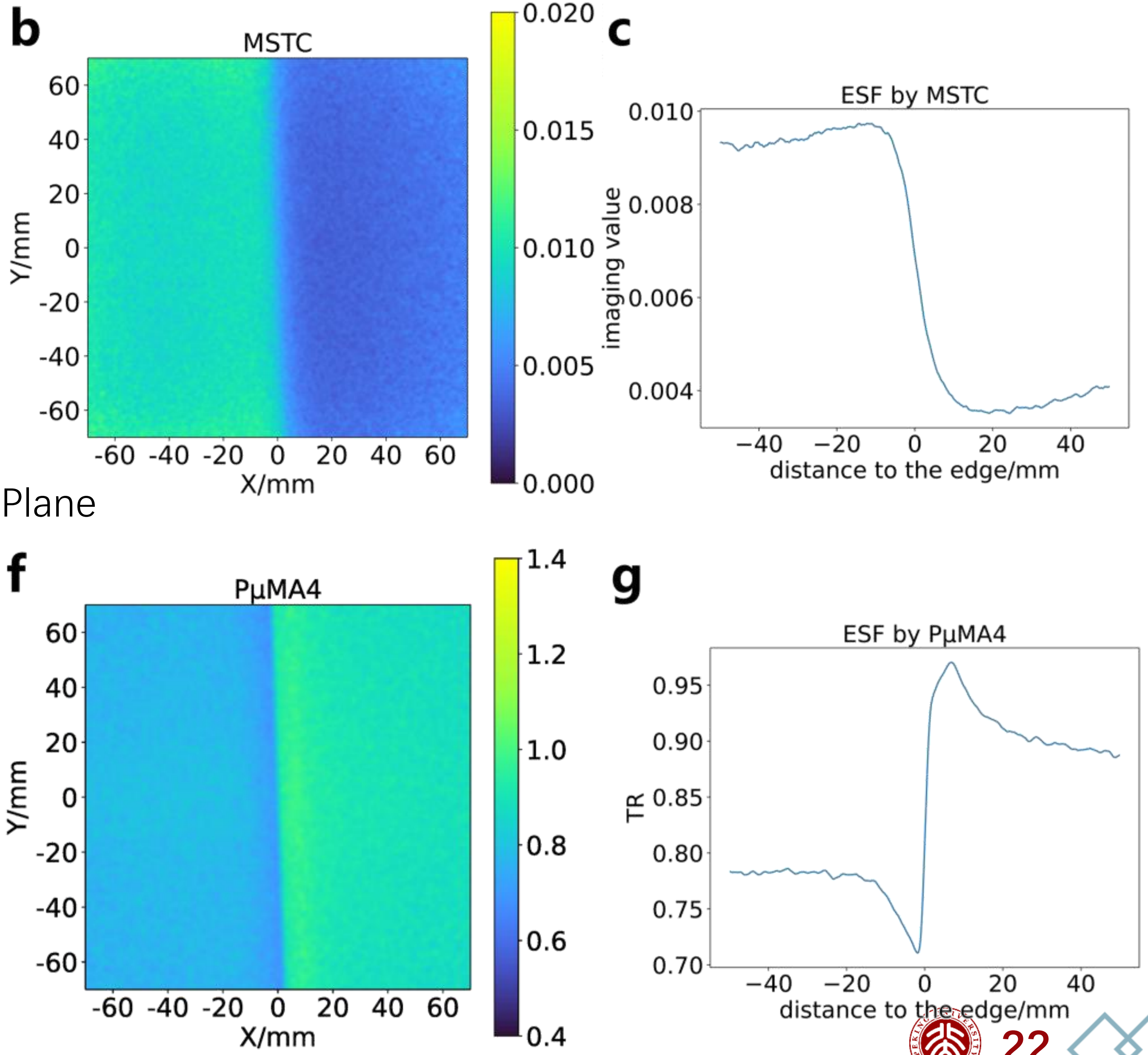
Unlike conventional approaches that rely on scattering-angle measurements to locate scattering points, PμMA constructs transmission tracks by connecting hit positions in upstream and downstream detectors. The material-induced angular deflection is then projected as a detectable shift in an imaging plane. This approach **allows millimeter-resolution cosmic-ray imaging with as few as two detectors**

PμMA image of a gear

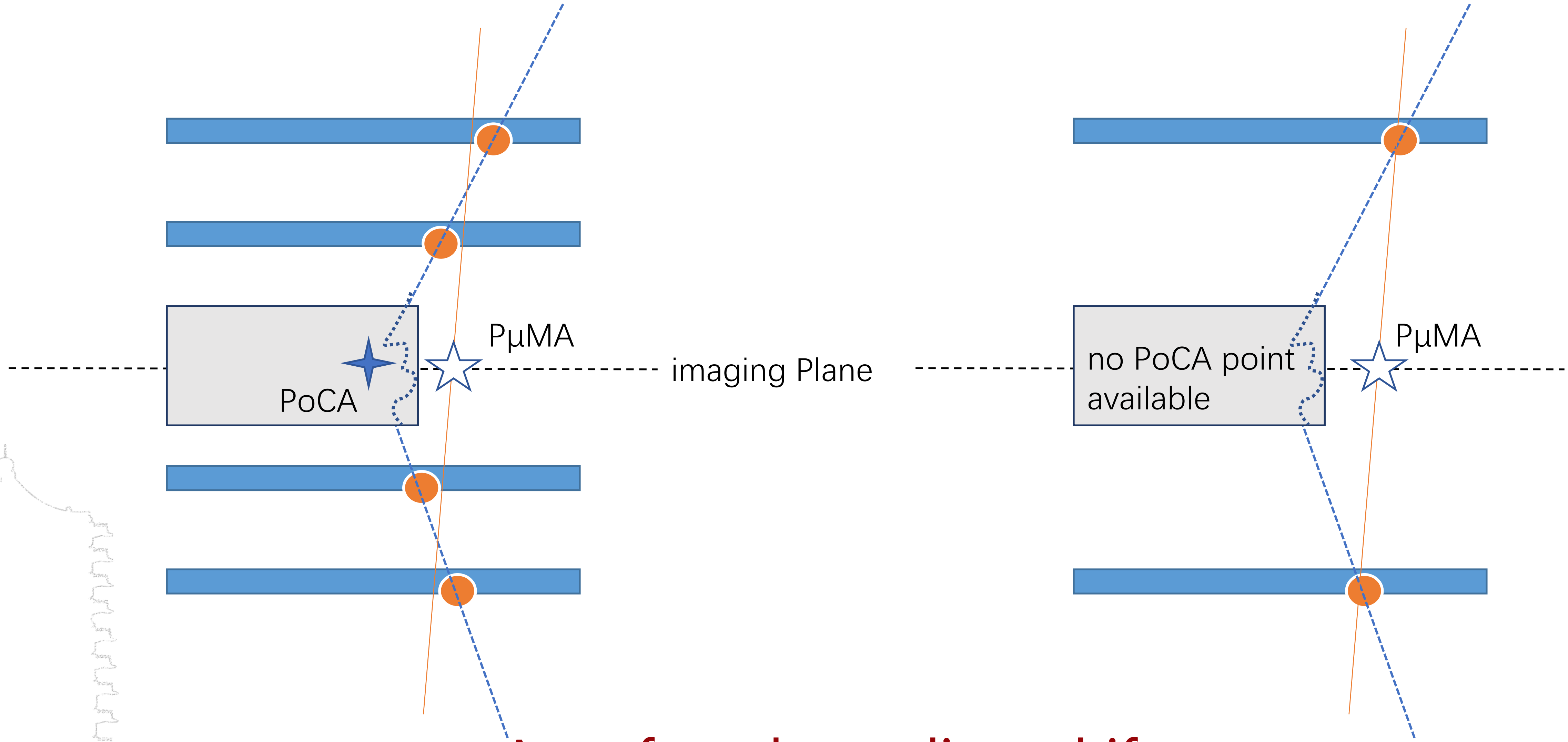





PμMA
imaging Plane
PoCA

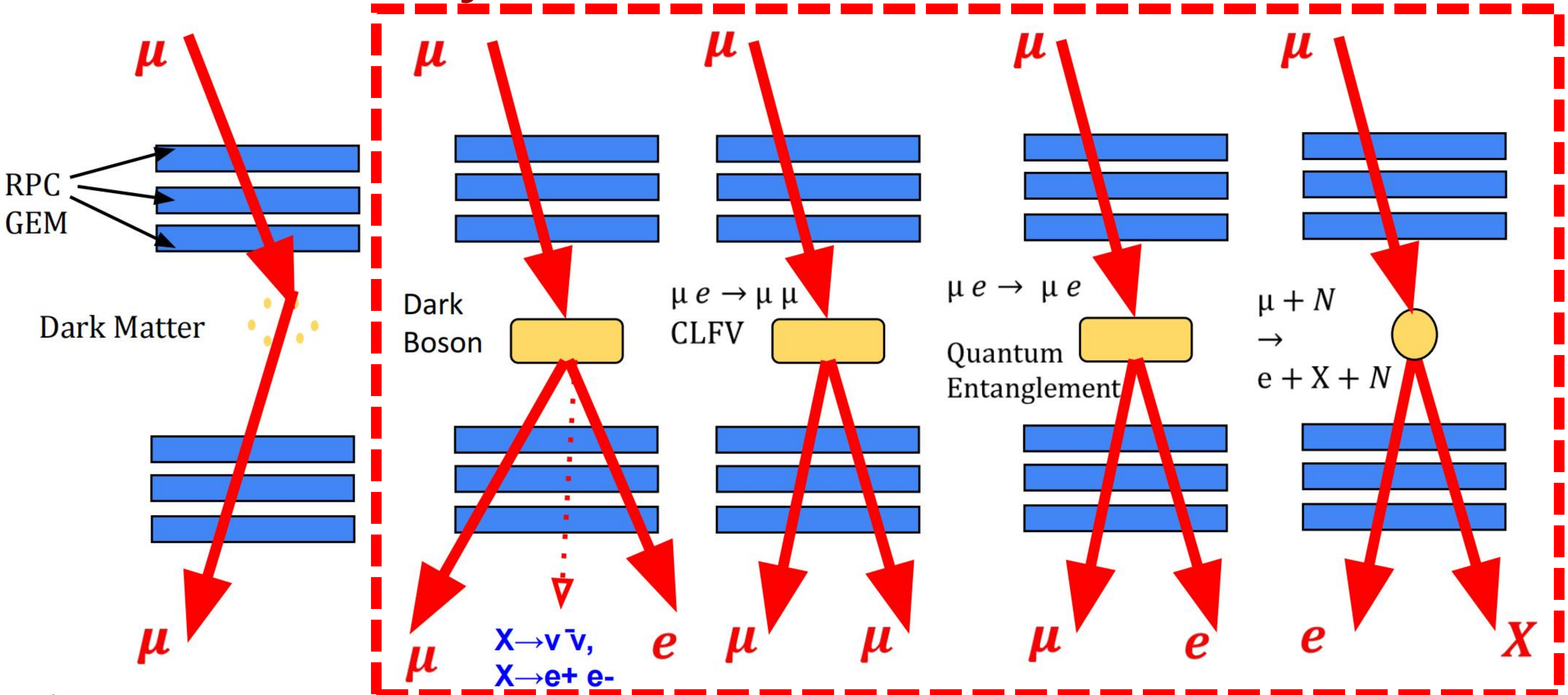

b
MSTC
0.020
0.015
0.010
0.005
0.000
Y/mm
X/mm
c
ESF by MSTC
imaging value
distance to the edge/mm
f
PμMA4
1.4
1.2
1.0
0.8
0.6
0.4
g
ESF by PμMA4
TR
distance to the edge/mm

Zibo Qin's Talk on Sunday afternoon



A profound paradigm shift:
give muon tomography back to the muon.

PKMu The Next Phase
From Cosmic Rays to Accelerator Beams

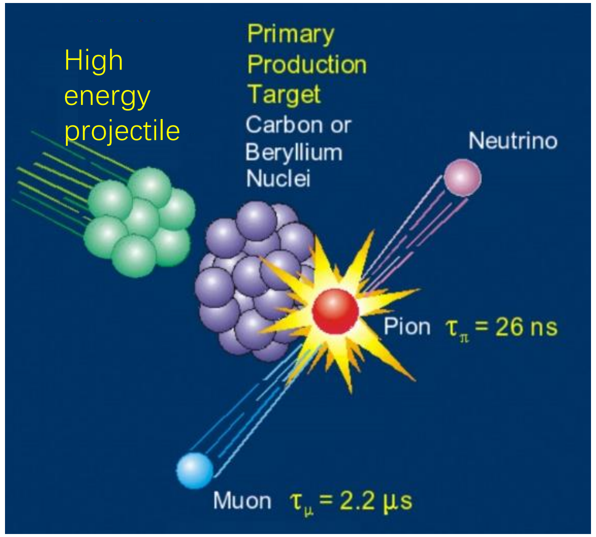


Phys. Rev. D 110, 016017
Phys. Rev. Lett. 136, 151001
Phys. Rev. D 113, 072008
Int. J. Mod. Phys. A 40, 2550164
J. Phys. G: Nucl. Part. Phys. 52 075002

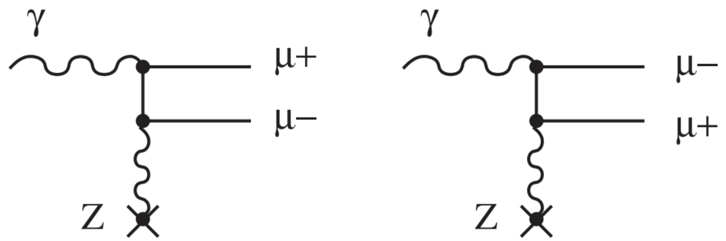
Muon Beam world wide

From Xu Yu / Liangwen Chen

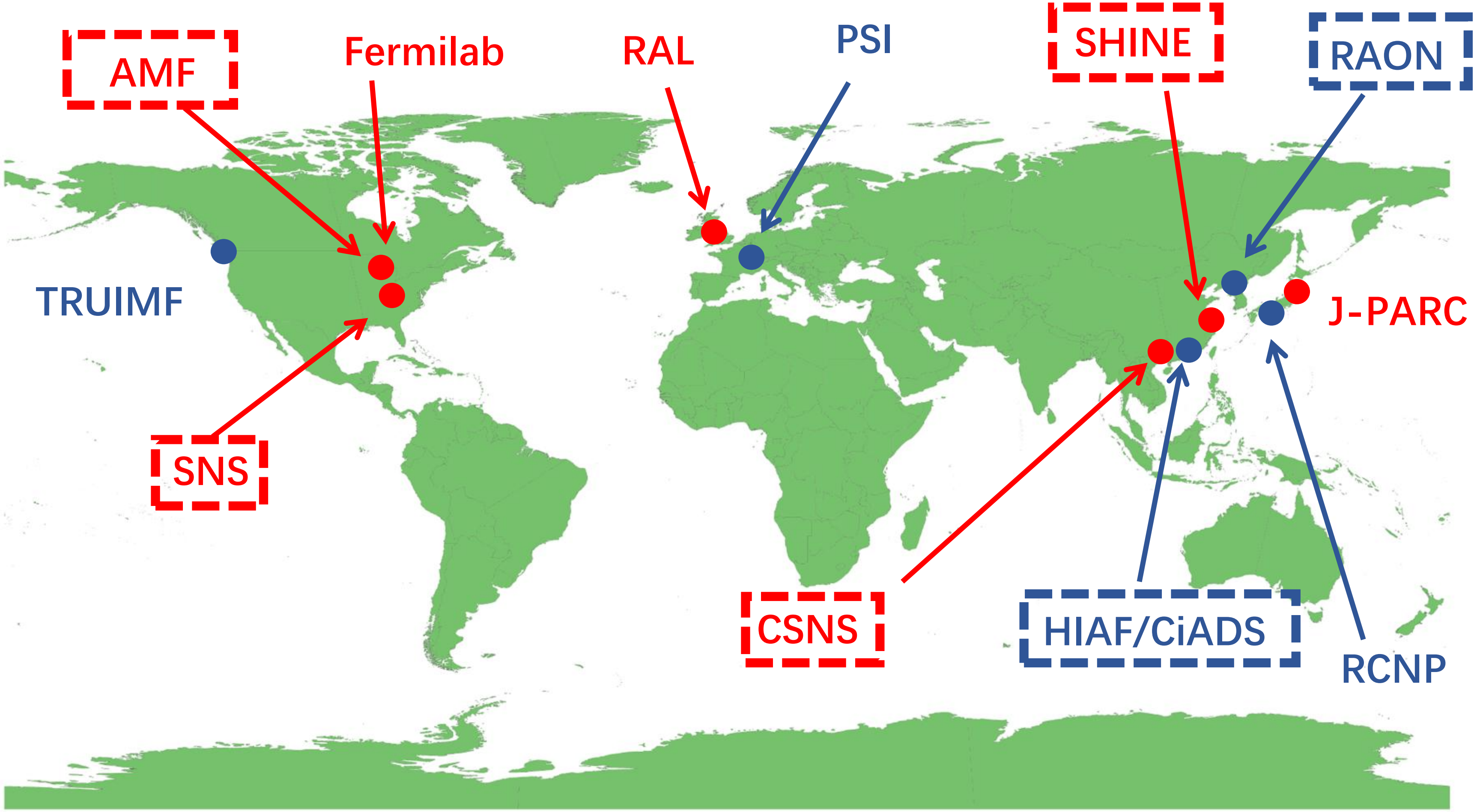
Accelerator generation:



Muon from pion decay



Bethe-Heitler process



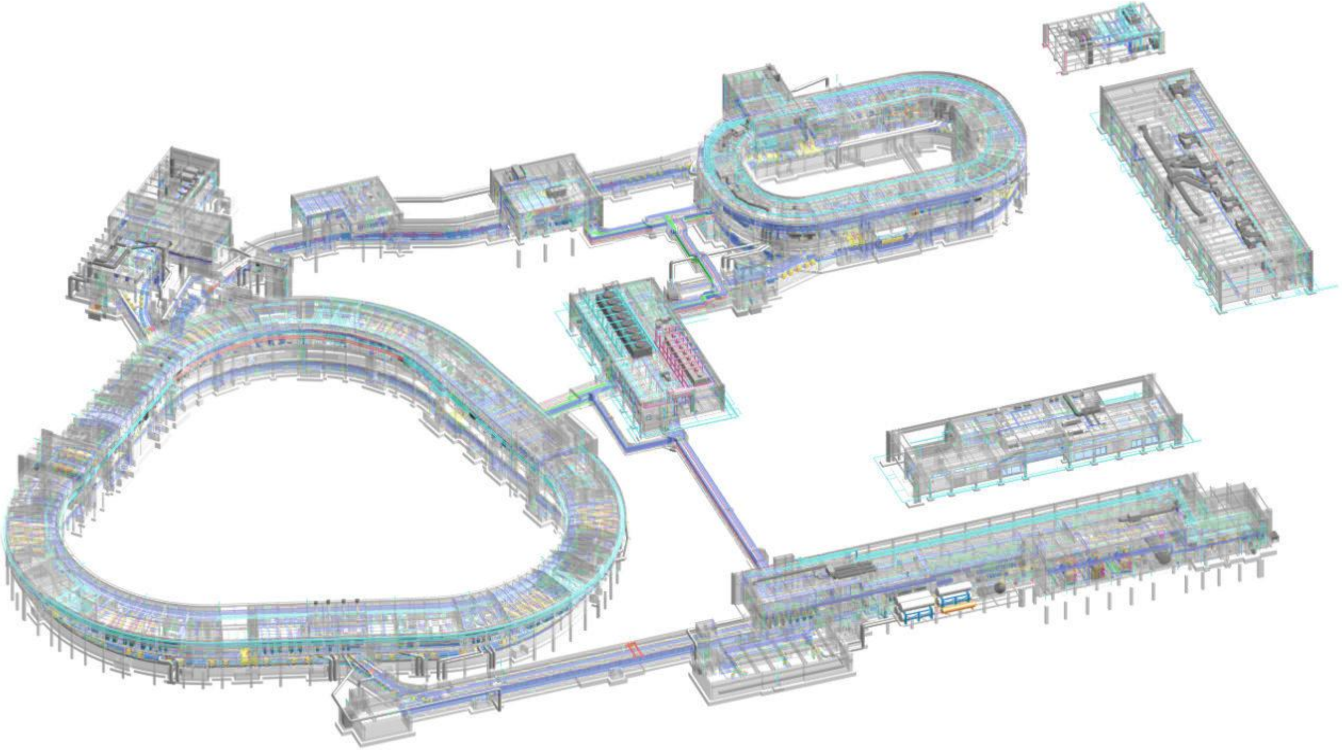
● DC muon

● Pulsed muon

PHYSICAL REVIEW ACCELERATORS AND BEAMS 28, 053401 (2025)

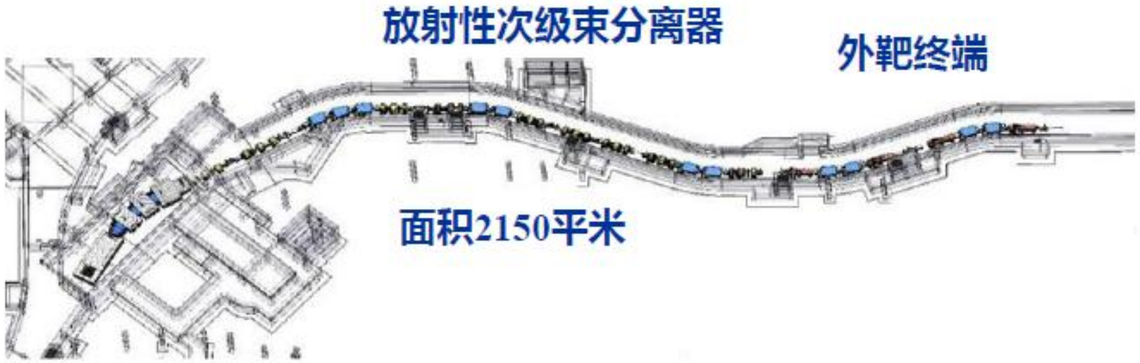
Feasibility study of the GeV-energy muon source based on the High Intensity Heavy-Ion Accelerator Facility

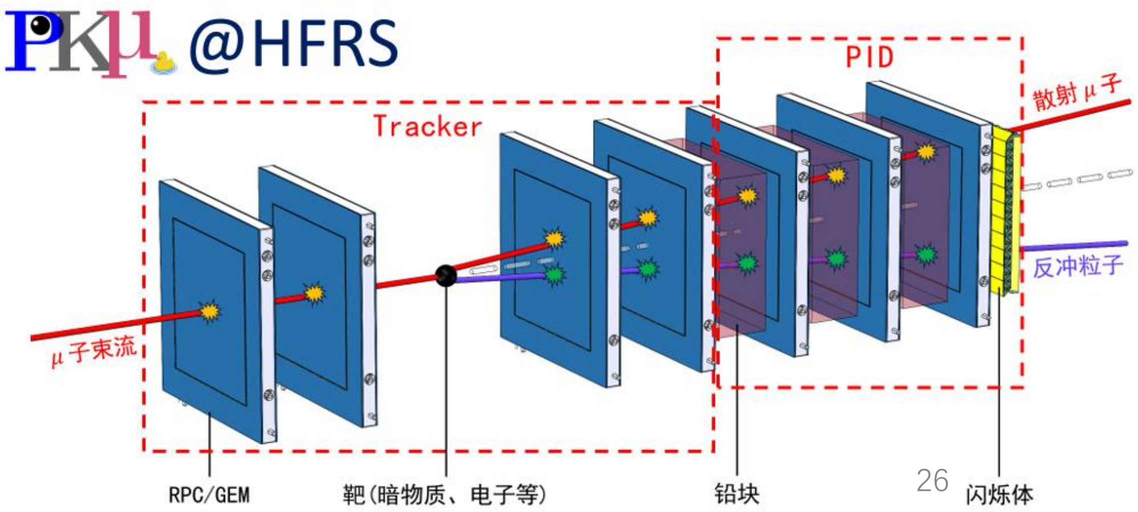
Yu Xu,[1,2] Xueheng Zhang,[1,2,3] Yuhong Yu,[1,2,3] Pei Yu,[1,2] Li Deng,[1,2] Jiajia Zhai,[1,2] Liangwen Chen,[1,2,3,*] He Zhao,[1,2,3] Lina Sheng,[1,2,3] Guodong Shen,[1,2,3] Ziwen Pan,[4] Qite Li,[5] Chen Zhou,[5] Qiang Li,[5] Lei Yang,[1,2,3] and Zhiyu Sun[1,2,3,†]



PKMu Proposed by Peking University together with HIAF-HIRIBL from Institute of Modern Physics, Chinese Academy of Sciences, China:

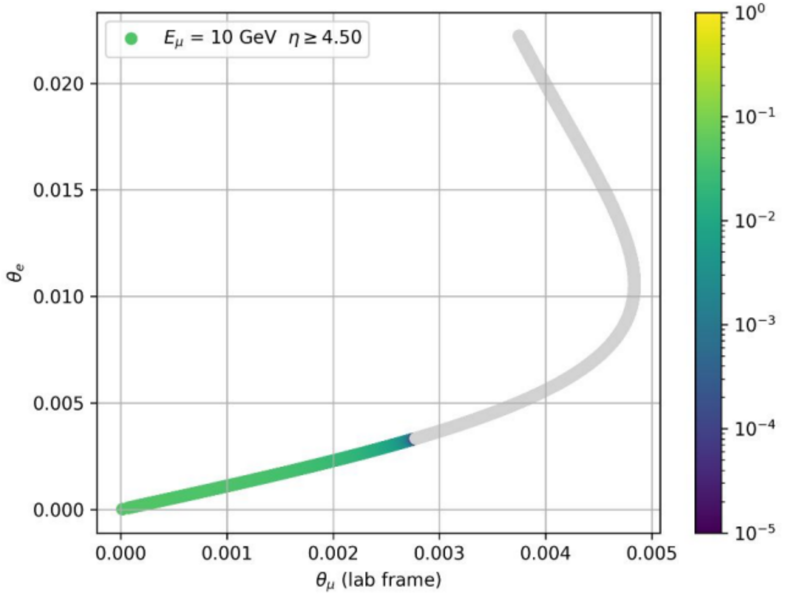
using ~ GeV Muon to probe new physics beyond the Standard Model





Z' and X at PKMu@HFRS

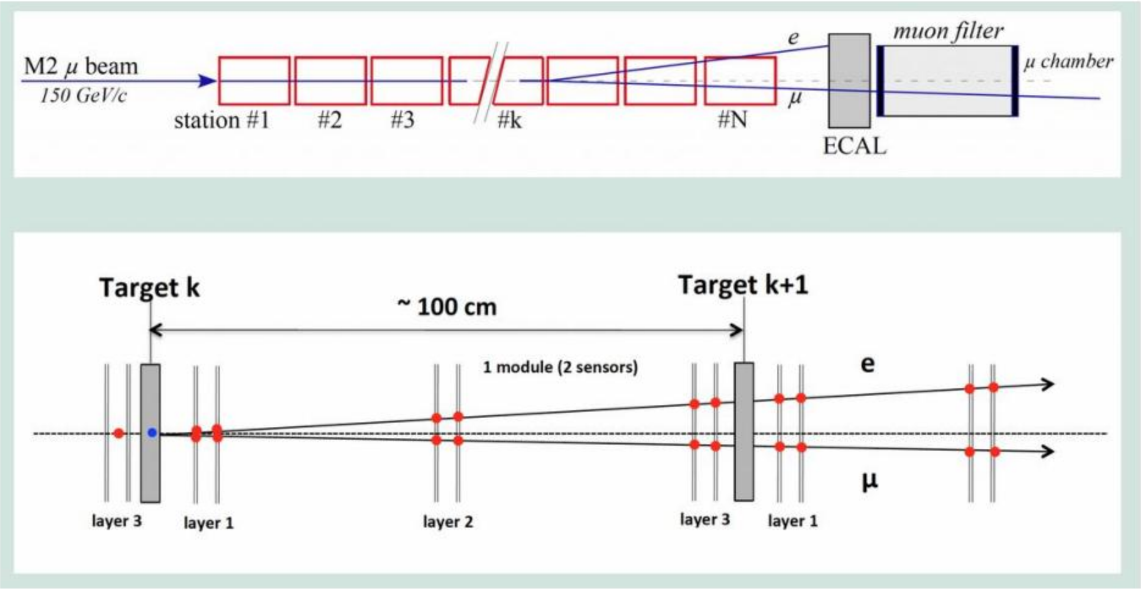
- **1-10 GeV muon scattered on electrons in target:**
  - C.O.M energy is around 10 MeV!
  - Sensitive to $L_\mu - L_\tau$ Z' boson at around 1-100 MeV:
    - $\mu e \rightarrow \mu e Z'$, $Z' \rightarrow \nu \bar{\nu}$
  - Also matches the mass range for ATOMKI X17 MeV anomaly
    - $\mu e \rightarrow \mu e X$, $X \rightarrow \nu \bar{\nu}$, e+ e-;
    - Search for pseudoscalar bosons decaying into e+e− pairs in the NA64 experiment at the CERN SPS: *PRD* 104 (2021) 11, L111102 e-N→e-N + a, a → e+ e-
    - See also tensor and scalar options in arXiv:2501.05507
      - *"the measurements from the two experiments (ATOMKI and MEGII) remain compatible within 2σ" and "A CP-even scalar could serve as potential solution to the anomalies observed in the Helium and Carbon data and that will become relevant in case the null result from the MEG-II search in Beryllium transitions will be confirmed."*

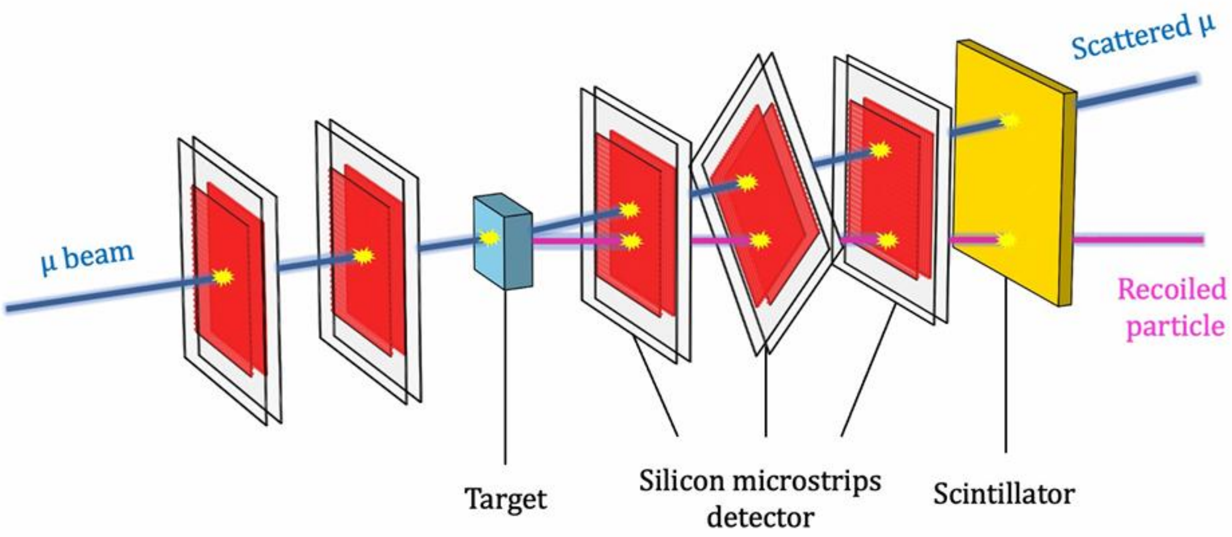


arXiv:2411.12518

PKMu@HFRS vs. MuonE

- Muon Beam energy: 150 GeV vs. 1-10 GeV
- C.O.M energy for PKMu@HFRS is around 10 MeV
  - suitable for low mass searches
- Detector Can be more compact





NA64 has limited angle acceptance (the beam energy is high as 150GeV), that may be the reason it is not sensitive to Mx>16 MeV

Zijian Wang(王子健)’s Talk Tomorrow Afternoon

Also **Lingzhi Dong（董凌志）**’s Poster (Muon Decay search)

PHYSICAL REVIEW D **113**, 072008 (2026)

Search for light dark sectors with GeV muon beams

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(Received 19 November 2025; accepted 19 March 2026; published 13 April 2026)

Sub-GeV light dark matter often requires new light mediators, such as a dark Z boson in the $L_\mu - L_\tau$ gauge theory. We study the search potential for such a Z' boson via the process $\mu e^- \to \mu e^- X$, with X decaying invisibly, in a muon on-target experiment using a high-intensity 1–10 GeV muon beam from facilities such as HIAF-HIRIBL. Events are identified by the scattered muon and electron from the target using the silicon strip detectors in a single-station telescope system. Backgrounds are suppressed through a trained boosted decision tree classifier, and activity in downstream subdetectors remains low. We find that this approach can probe a Z' in the 10 MeV mass range with improved sensitivity.

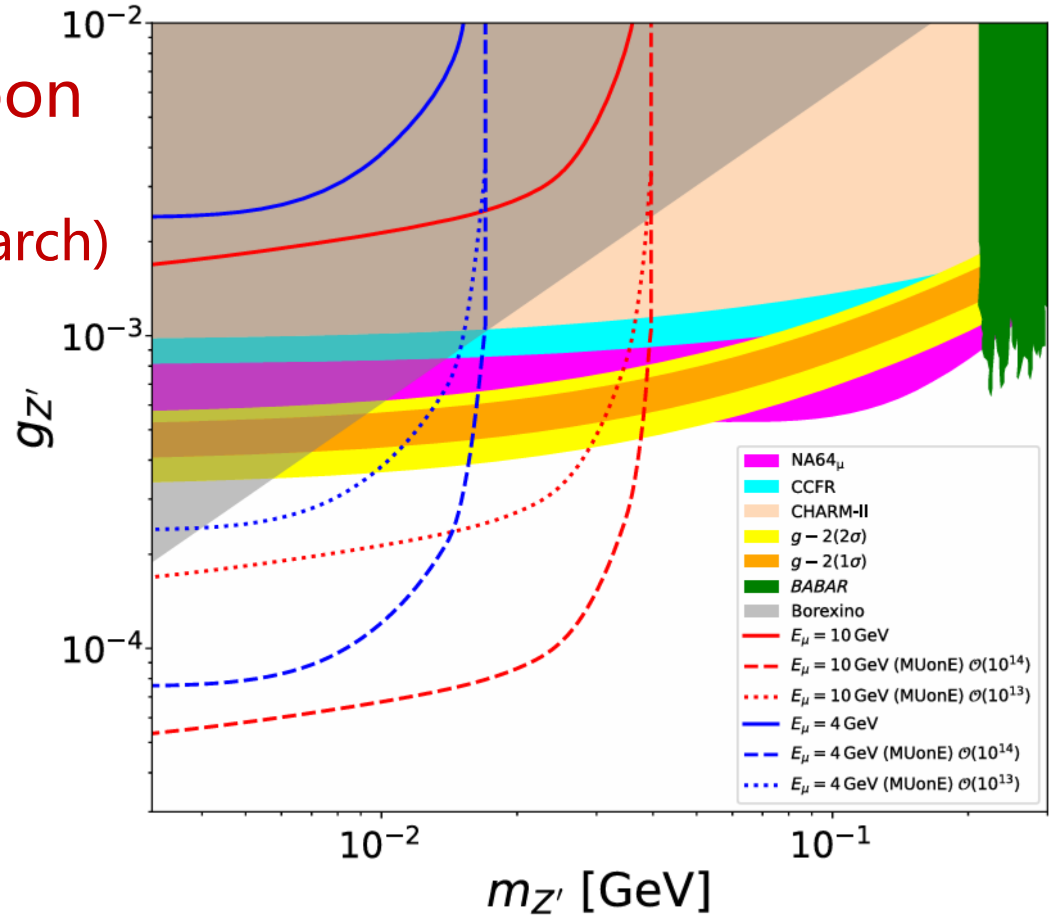


FIG. 7. Upper limits on the coupling $g_{Z'}$ as a function of the Z' mass $m_{Z'}$. The solid red and blue lines represent the limits obtained for muon beam energies of 10 and 4 GeV, respectively, using the HIAF setup, assuming one year of data taking. The shaded regions in light brown, light blue, purple, green, and gray are excluded by CHARM-II [32], CCFR [33], NA64$_\mu$ [13], *BABAR* [34], and Borexino [35], respectively. The orange and yellow bands show the regions favored by the muon $g-2$ anomaly at the 1σ and 2σ levels, respectively [36–44].

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

PKMu: Probing and Knocking with Muons

- A comprehensive muon scattering program from Peking University
- PRL 2026: First direct cosmic-ray muon-DM scattering limit + precision cosmic-ray composition.
  Technologies outcomes: Sub-mm RPC(2D readout), PμMA, secondary-particle imaging

- Future beam program: Dark bosons, CLFV, quantum entanglement

- Driven by innovation, open for collaboration

Special Thanks
特别致谢

Ref:

[1] Phys. Rev. Lett. 136, 151001 (2026) Cosmic muon-DM search experiment
[2] Chin. Sci. Bull. 71, 894 (2026) PKMu Introduction
[3] Phys. Rev. D 110, 016017 (2024) Muon Tomography for DM
[4] Phys. Rev. D 113, 072008 (2026) Light Dark Sectors
[5] J. Appl. Phys. 139, 014903 (2026) Secondary Particle Signatures in Muography
[6] Phys. Rev. Accel. Beams, 28, 053401(2025) HIAF Muon Beam
[7] Mod. Phys. Lett. A 40, 2530008 (2025) PKMu Overview
[8] J. Phys. G: Nucl. Part. Phys. 52 075002 (2025) for QE
[9] Int. J. Mod. Phys. A 40, 2550164 (2025) for CLFV

李奇特 Qite Li liqt@pku.edu.cn

Group Photo of PKMu Team

backup

GE2/1 GEM：探测器部件生产进展

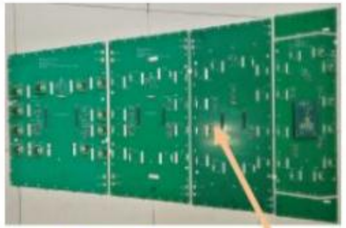
PKU Lab

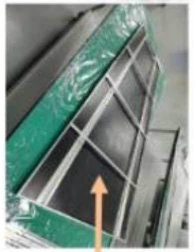
北大基地生产的第一个CMS GEM模块

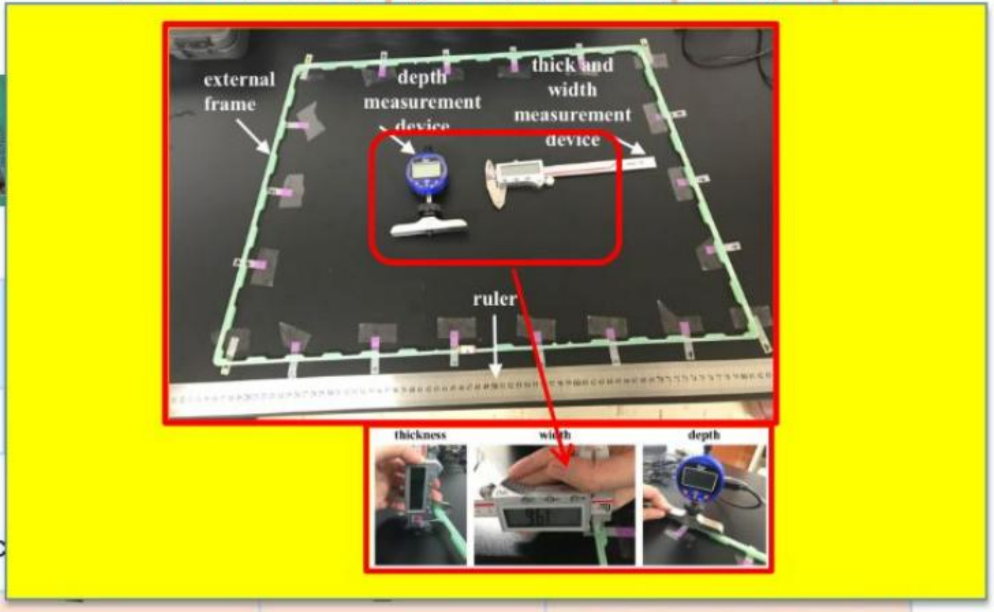
Module Components

Components	GEM Foils	External Frames	Internal Frames	O-rings	Drift PCB	RO PCB	T-nuts	Pull-outs
% Produced	82%	COMPLETED	COMPLETED	COMPLETED	27% - 41%	27% - 41%	42.4 %	27.6 %

(> 50% expected by Aug. 2023) (> 50% expected by Sep.2023)







On-detector electronics

Components	GEB	OH	VFAT (Plug-in Card)
% Produced	COMPLETED	COMPLETED	60.2 %

In progress
(>50% expec

北大基地GEM测试设备

Chamber components

Components	Mechanics	On-detector Fibers	HV filters	Cooling	On-detector Cabling (HV/LV/GND)
% Produced	COMPLETED	COMPLETED	~30%	50% - 100%	COMPLETED

中国组负责生产的GEM部件均已按计划完成并通过CERN检测！

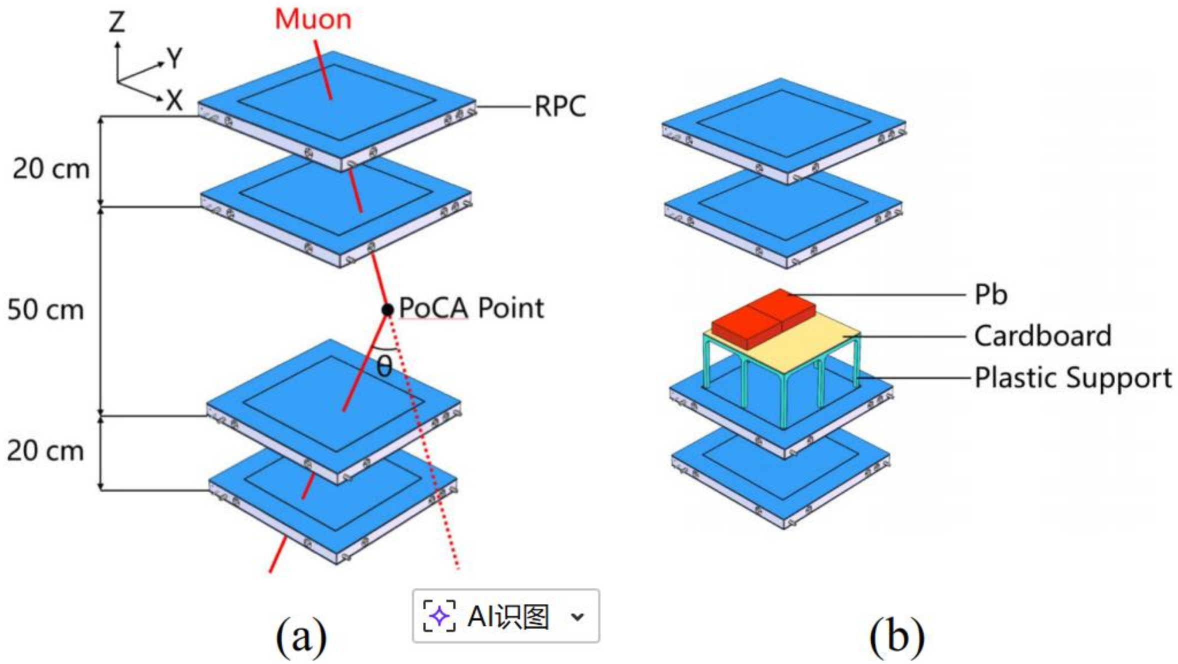


FIG. 1. Experimental configurations. (a) Physics Run: four vertically aligned glass RPCs (28×28 cm^2) with spacings of 20, 50, and 20 cm; the muon scattering angle θ is defined. (b) Control Run: two lead blocks ($12 \times 12 \times 3$ cm^3) placed 150 mm above the third RPC, centered at the origin ($X \in [-120, 0]$ mm, $Y \in [-120, 120]$ mm).

Using the same simulation framework described earlier, the configuration of the Control Run, as shown in Fig. 1(b), is replicated to obtain simulated cosmic-ray data under identical detector conditions. This setup enables a clear division of the scattering region into a lead block zone, defined by scattering coordinates $X \in$ (−110 mm, −50 mm), and an air zone, defined by $X \in$ (50 mm, 110 mm). Applying the same fitting method, it is found that in the lead block region, muons account for $(96.6 \pm 0.2)\%$ and electrons for $(0.7 \pm 0.2)\%$. In the air region, the muon and electron fractions are $(32.3 \pm 1.4)\%$ and $(54.6 \pm 1.4)\%$, respectively. The low electron fraction in the lead block region is expected, as electrons are less penetrating than muons and cannot traverse the lead to reach the downstream RPC layers. The same fitting method is applied to a Physics Run, with results shown in Fig. 3.

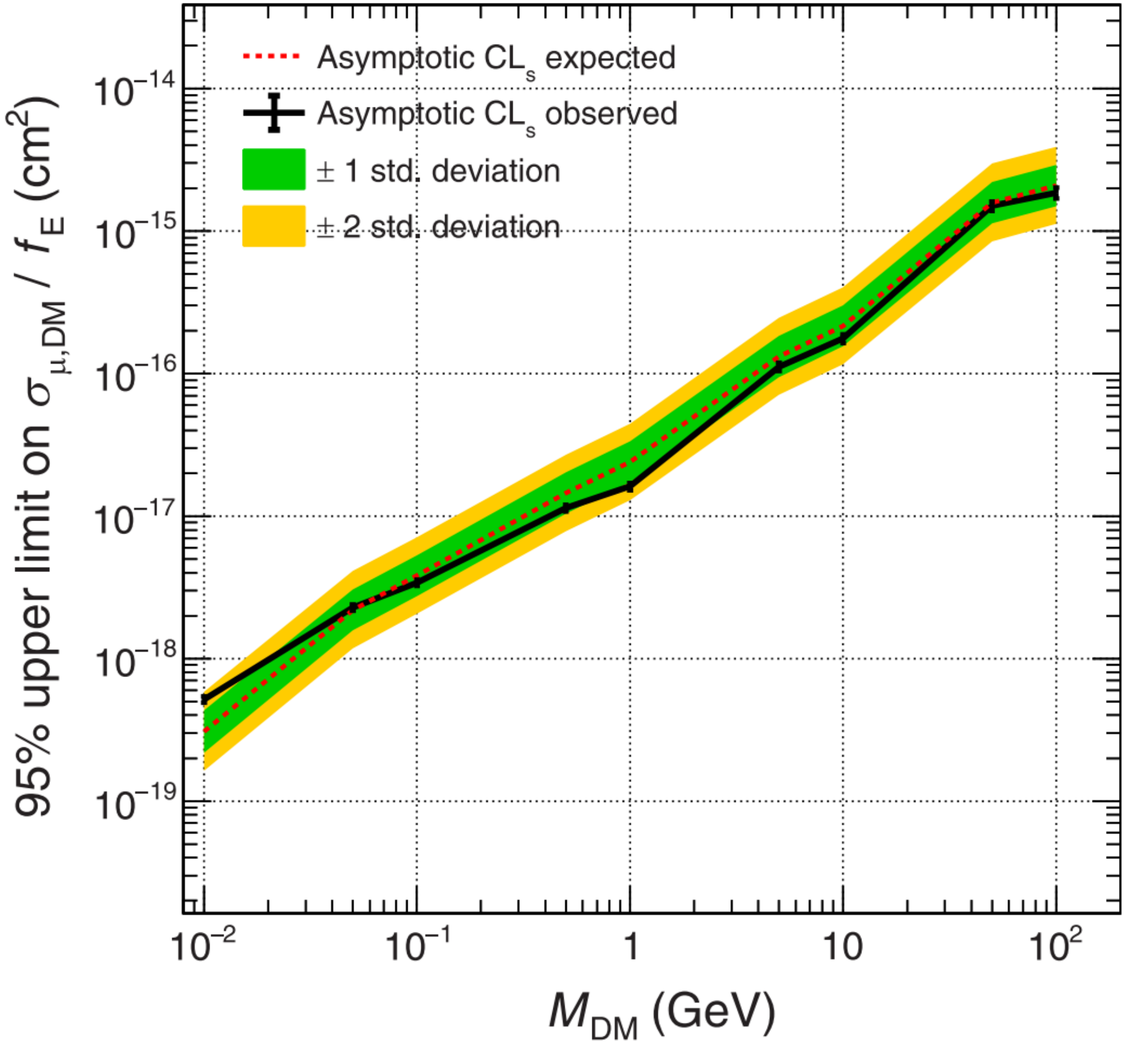


FIG. 4. Expected and observed 95% CL upper limits on the DM-muon interaction cross section versus M_{DM}, assuming a local DM density enhancement factor of 10^{15} arising from Earth-bound thermalized component. The green and yellow bands represent the 1σ and 2σ regions, respectively.

Equation (2) follows from the above considerations.

$$dN/dt = \rho V/M_{\mathrm{DM}} \times \sigma_{\mu,\mathrm{DM}} \times F_{\mu} \times \epsilon_1 \times \Omega_a \times \epsilon_2. \quad (2)$$

However, if a strongly interacting dark matter component is captured and thermalized within Earth, its local surface density can be enormously enhanced for DM with a mass of 1 GeV, the density may increase by a factor of 10^{15} [26,27]. To account for this possibility, an enhancement factor $f_E = 10^{15}$ is introduced, such that $D_{\mathrm{E}} = f_E\rho/D_{\mathrm{DM}}$, where D_{E} denotes the number density of the exotic slow DM under investigation, and D_{DM} is the M_{DM} in unit GeV.

[26] D. McKeen, D. E. Morrissey, M. Pospelov, H. Ramani, and A. Ray, Phys. Rev. Lett. **131**, 011005 (2023).
[27] A. Berlin, H. Liu, M. Pospelov, and H. Ramani, Phys. Rev. D **109**, 075027 (2024).

Report of the 2023 Particle Physics Project Prioritization Panel / USA

Illuminate the Hidden Universe

Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

Determine the Nature of Dark Matter. The gravitational evidence for dark matter is overwhelming. We have many ideas for what dark matter could be, with a handful of particularly compelling candidates with viable cosmological histories. The number of strong candidates inspires a multifaceted campaign to determine the nature of dark matter, leveraging underground facilities, quantum sensors, telescopes, and accelerator-based probes.

National Natural Science Foundation of China

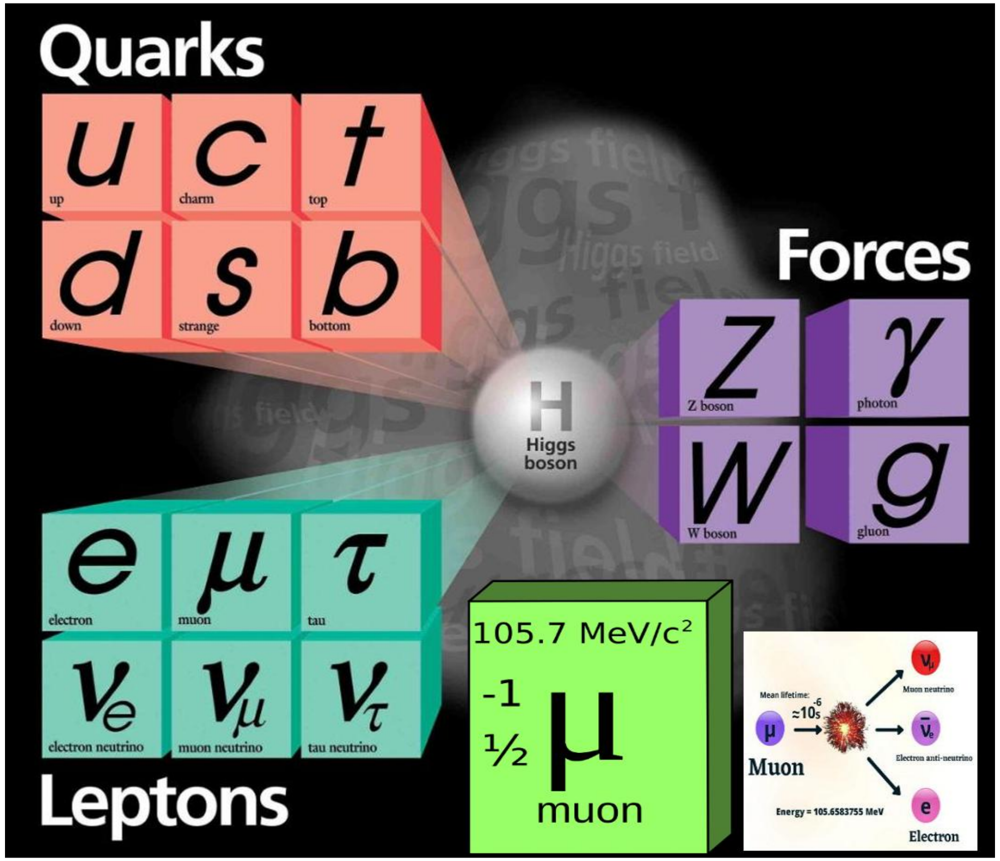
“十四五”优先发展领域（115项）

7.暗物质、暗能量以及星系巡天研究
围绕宇宙的起源和演化前沿科学问题，重点研究暗物质和暗能量的本质，宇宙网络中的星系形成与演化，超大质量黑洞的起源与演化。

Using Muons to Detect Dark Matter

- Why Muon Scattering?

1. Muon-dark matter interactions remain understudied.
2. Muons are second-generation leptons in the Standard Model.
3. Free muons are short-lived/rare in the universe.
4. Enhanced sensitivity to light-mass dark matter
5. Complementary to traditional DM detection approaches----**Muon from background to SIGNAL**
6. Experimental Advantages:
   - Expertise in cosmic-ray muon detection/tomography.
   - Future muon sources in China(MELODY, HIAF, CiADS, SHINE)

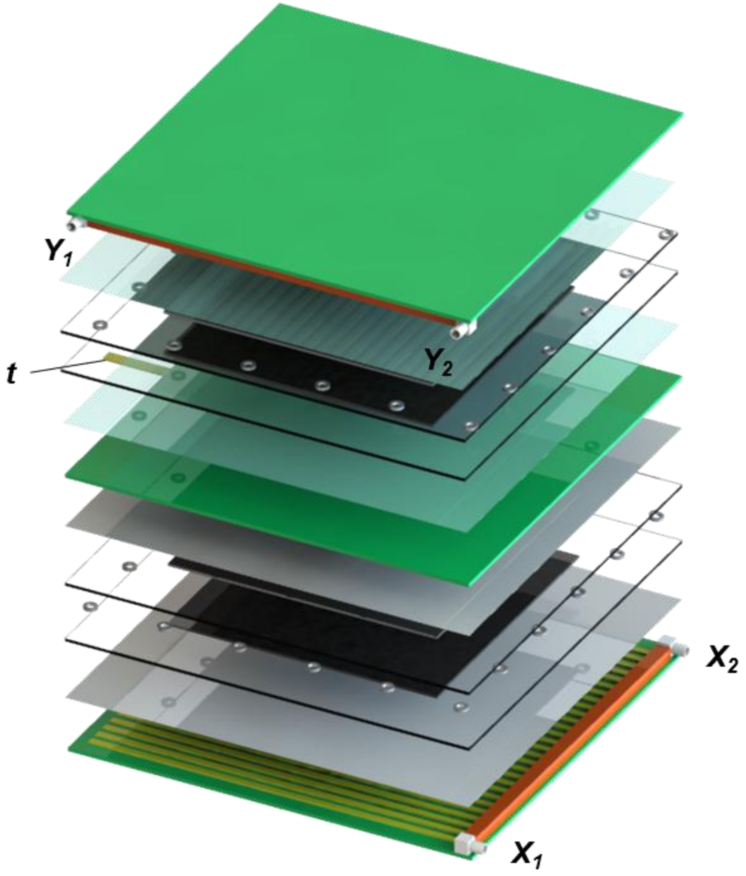


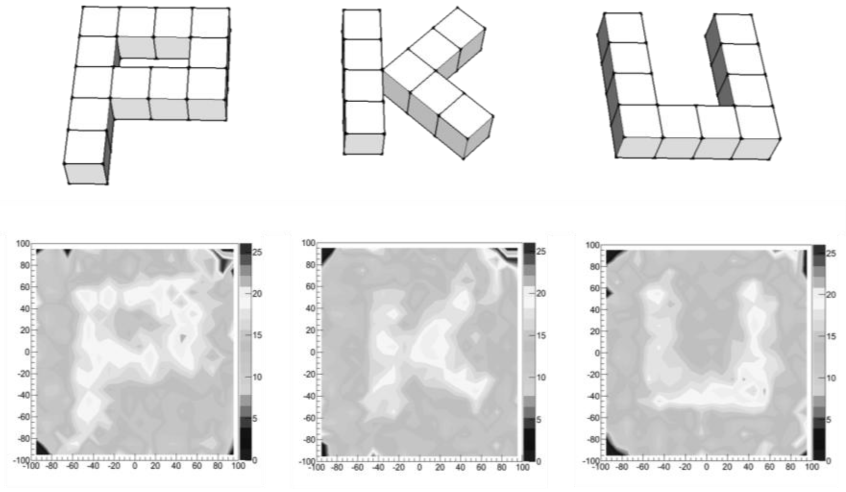
3D Imaging Test(2013~2014)

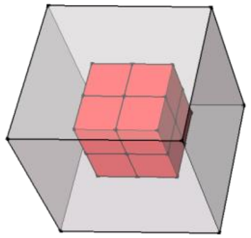
4 X-Y readout RPC Boxs, distance 285mm

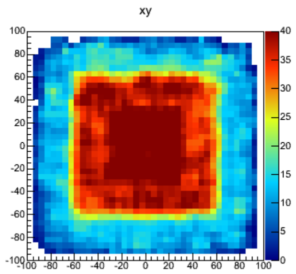
Active area 203mm*203mm

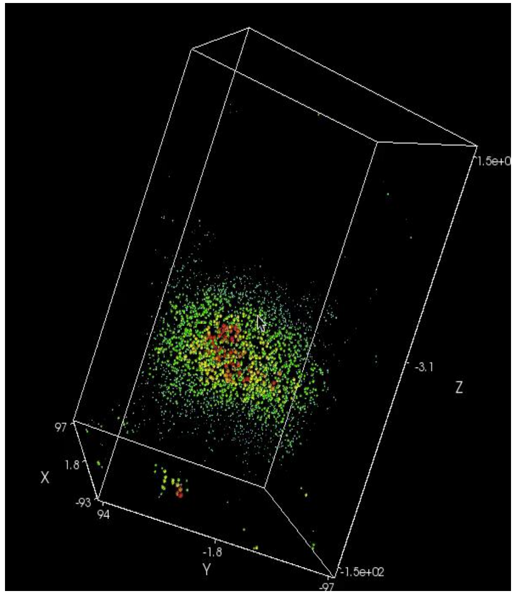
Using only 20 TDC channels







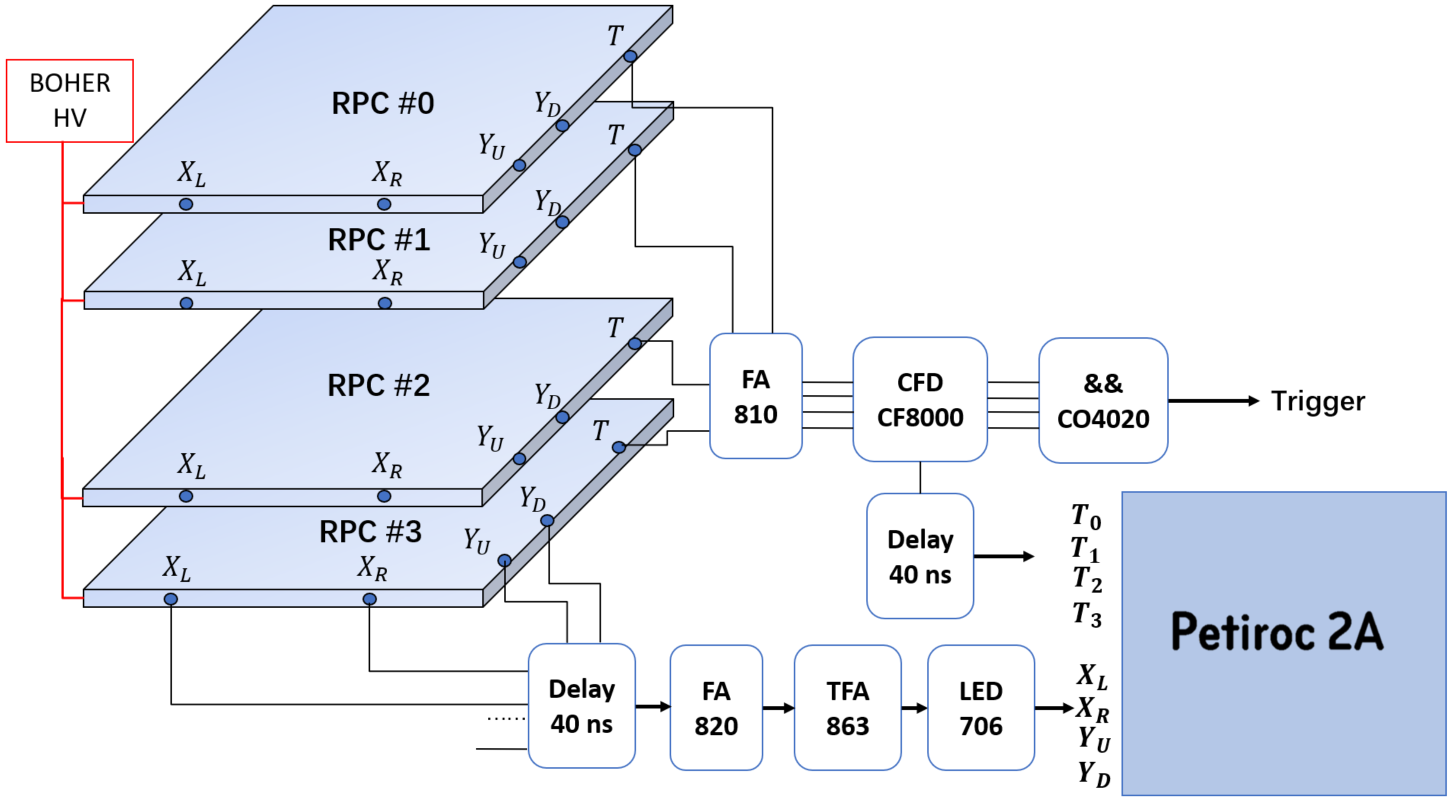


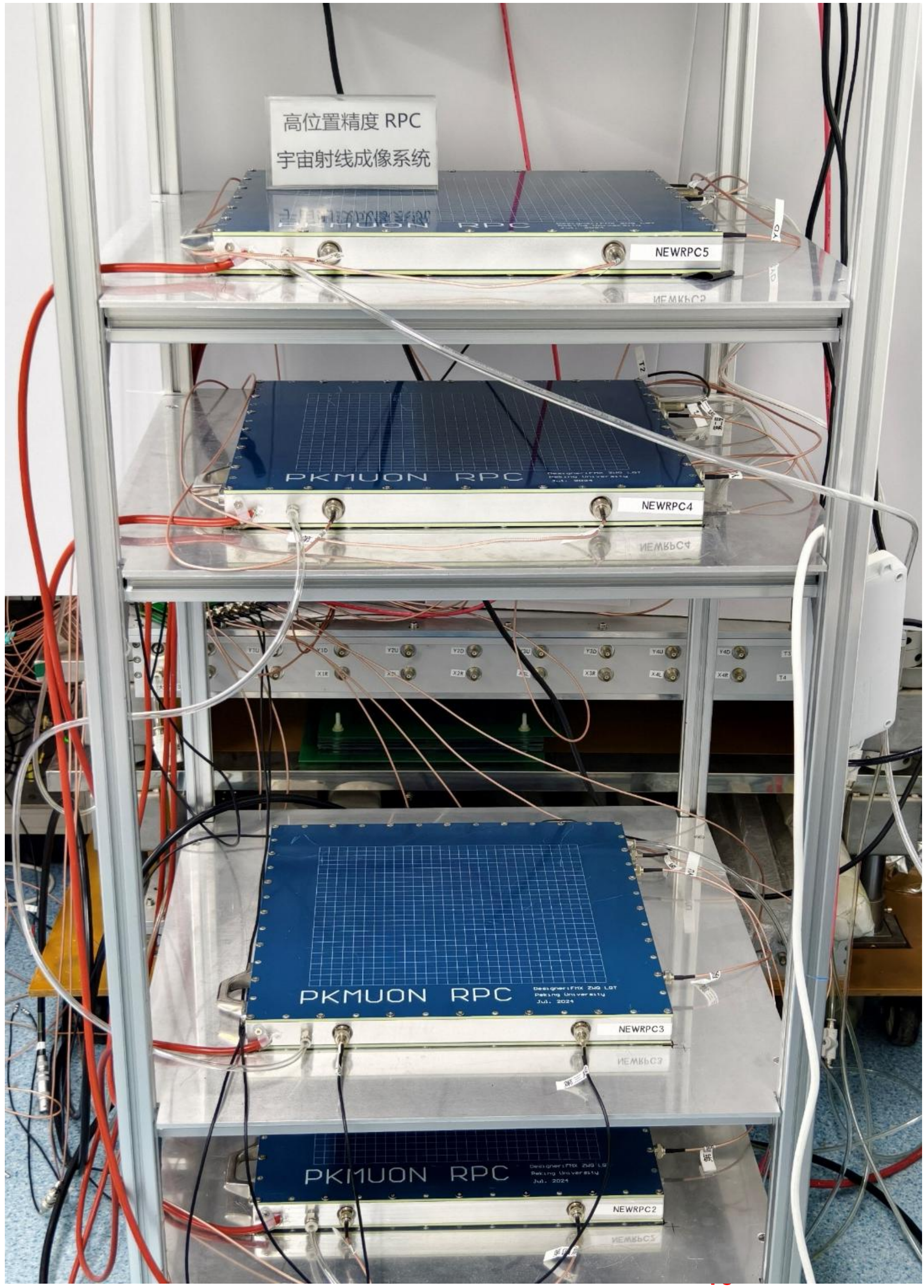


4RPCs Muon Tomography System(2025)

- RPC 280mm×280mm 20cm-50cm-20cm
- **Petiroc 2A ASIC DAQ by USTC**

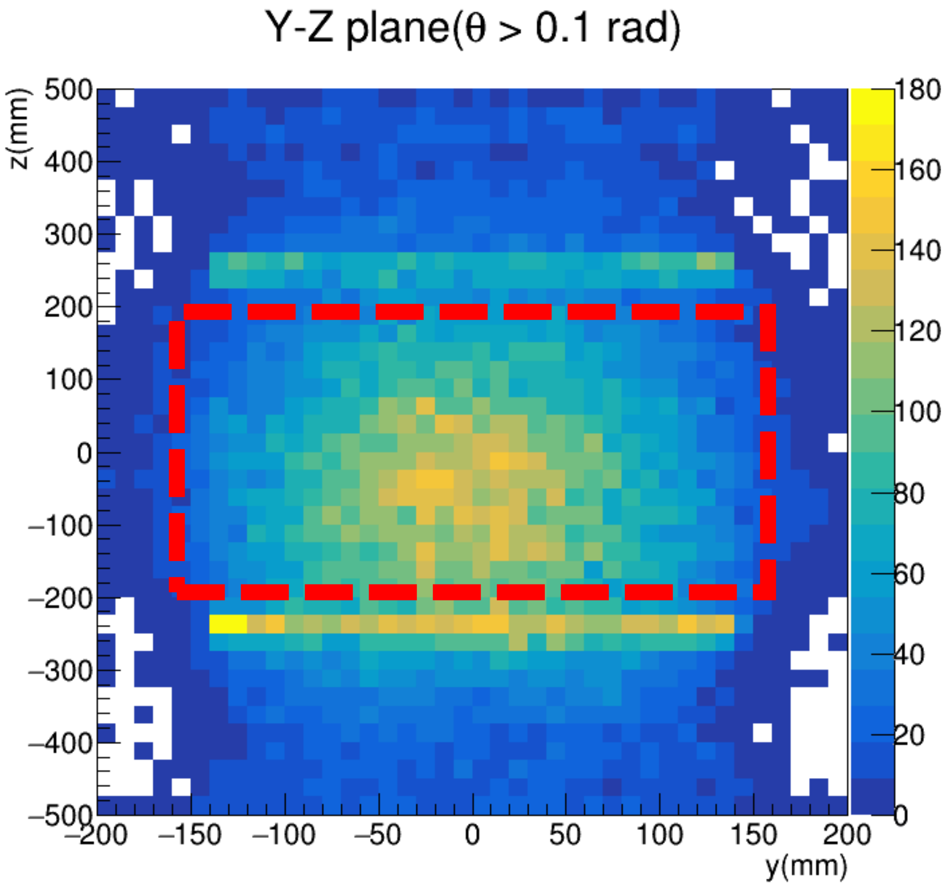
- Air: 63days 1.18M events

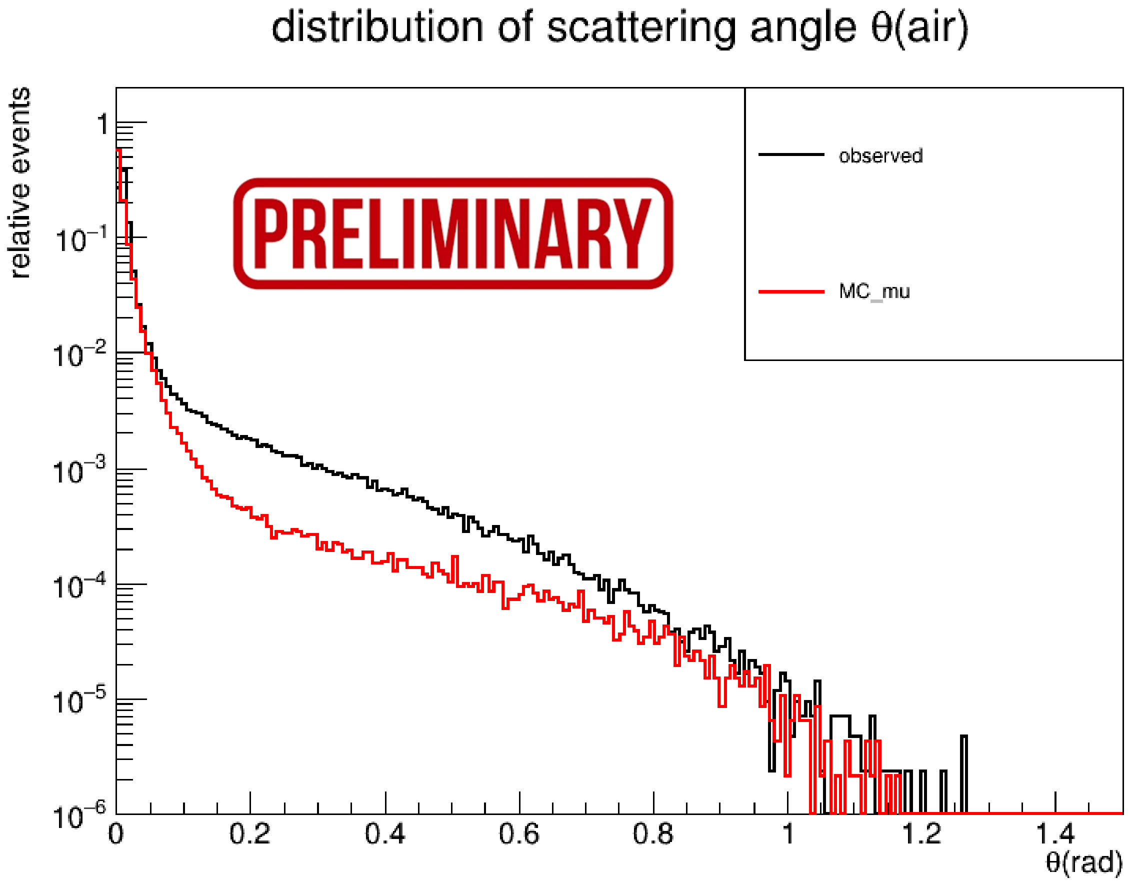




Scattering Angle Distribution in ROI Area

- Analyzed angular distribution within detector’ s sensitive volume (-200 mm<z<200 mm)
- Large-angle scattering events persist after selection





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

19 Apr 2024, 02:00 → 22 Apr 2024, 12:20 Asia/Shanghai

Peking University

Chen Zhou (Peking University (CN)), Qiang Li (Peking University (CN)), Qite Li (Peking University)

MIP2024

Several possible Chinese Muon beams in the near future:
Melody,
CIADS, HIAF

基于强流重离子加速器装置的缪子散射实验研讨会成功举行

发布日期：2025-04-29　浏览次数：　120
供稿：技术物理系 ｜ 编辑：曲音璇 ｜ 审核：李强

2025年4月25日，基于“十二五”国家重大科技基础设施—强流重离子加速器装置（HIAF）的缪子散射实验研讨会在北京大学物理学院西206举行。本次研讨会由北京大学物理学院李强教授、李奇特高级工程师和周辰研究员，中国科学院近代物理研究所章学恒研究员、陈良文副研究员，以及先进能源科学与技术广东省实验室（东江实验室）徐宇助理研究员共同主办。国内外多个单位共40余人线上线下参会。研讨会同步通过蔻享平台直播，约4000余人次观看。

中国科学院近代物理研究所建设的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上的重要装置。基于HIAF-HIRIBL装置，可获得性能良好的GeV能量缪子束流。PKMu（Probing and Knocking with Muons）是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的缪子散射实验项目，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，来寻找超出标准模型的新物理如暗物质和暗玻色子、探测自由轻子之间的量子纠缠、研究缪子与核散射的物理规律，等等。此次会议旨在推进国内高能缪子束流的发展应用及相关基础研究，为迎接HIAF的验收以及运行做好准备。

图1：专题报告现场

9月19日至21日，“高能缪子散射物理研讨会”在广东省惠州市召开

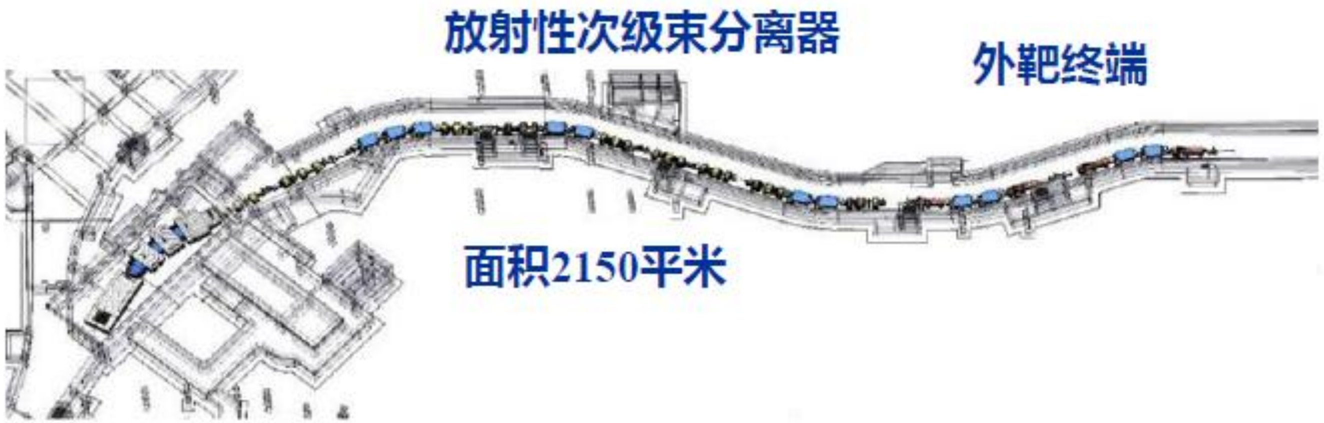
基于HIAF可提供的高能缪子束流，与会的专家学者提出了多个新型的实验方案，涵盖了标准模型精确测量和新物理寻找等多个重要研究领域。北京大学李强教授报告了缪子电子散射实验(PKMu);上海交通大学李亮教授介绍了基于先进缪子源的暗物质研究实验(DREAMuS);华中师范大学尹航教授分享了低能缪子-核子散射实验(LUNE)的相关情况;利物浦大学张策博士提出了中国负缪子反常磁矩实验(CANTON-μ)的设想方案。这些实验方案的分享，引发了线上线下与会专家学者的热烈讨论。

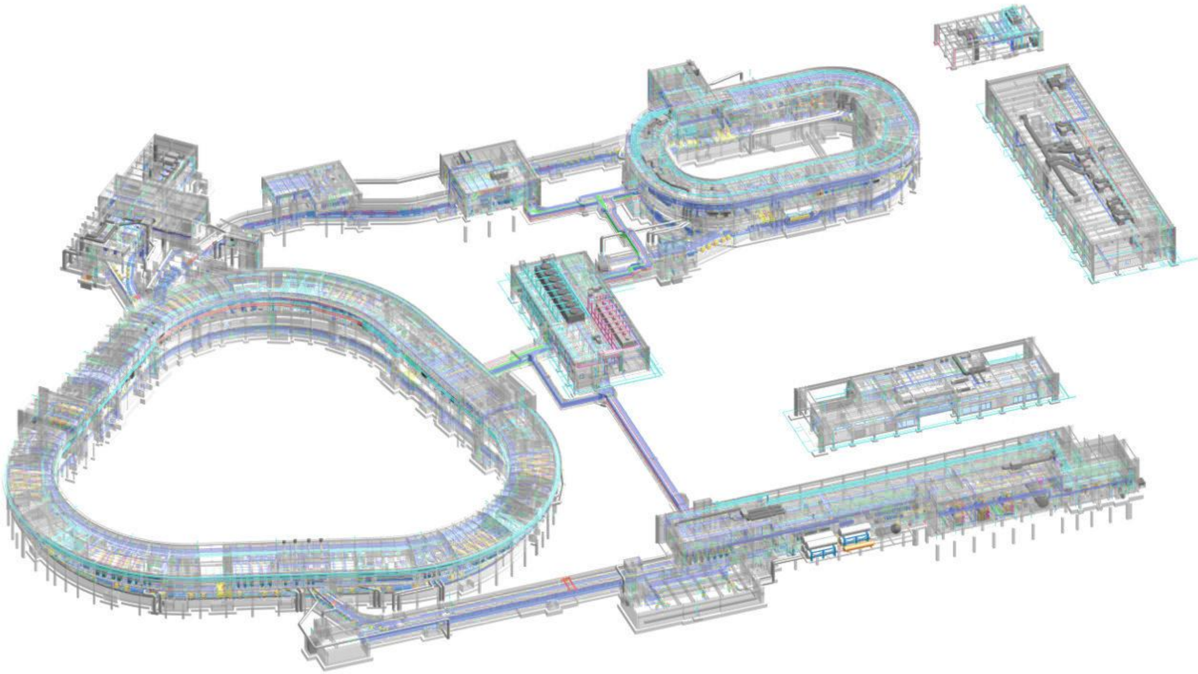
High-rigidity Radioactive Ion Beam Line (HIRIBL)

From Xu Yu

- The radioactive beamline with the highest magnetic rigidity: 25 T·m

- Designed for cutting-edge nuclear physics research with radioactive beams, it can:
- Separate and purify exotic particles produced in projectile fragmentation and fission reactions;
- Separate and purify pions generated in projectile-induced reactions, as well as muons originating from their decays.



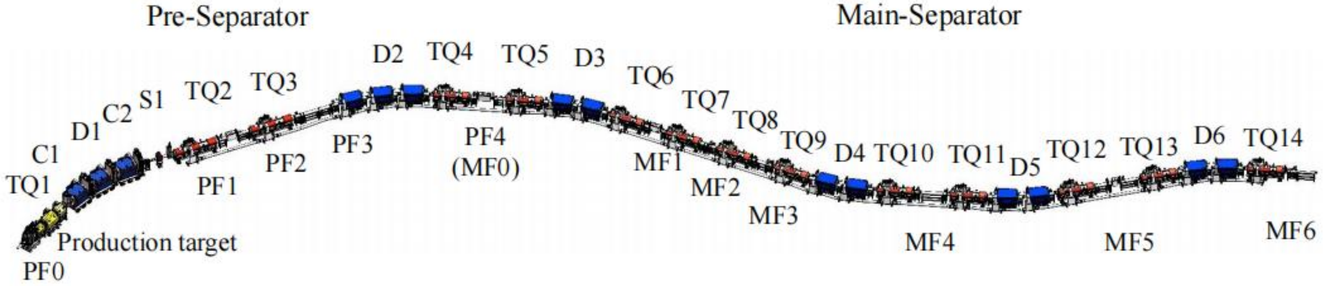


Muon Beam on HIAF HIRIBL

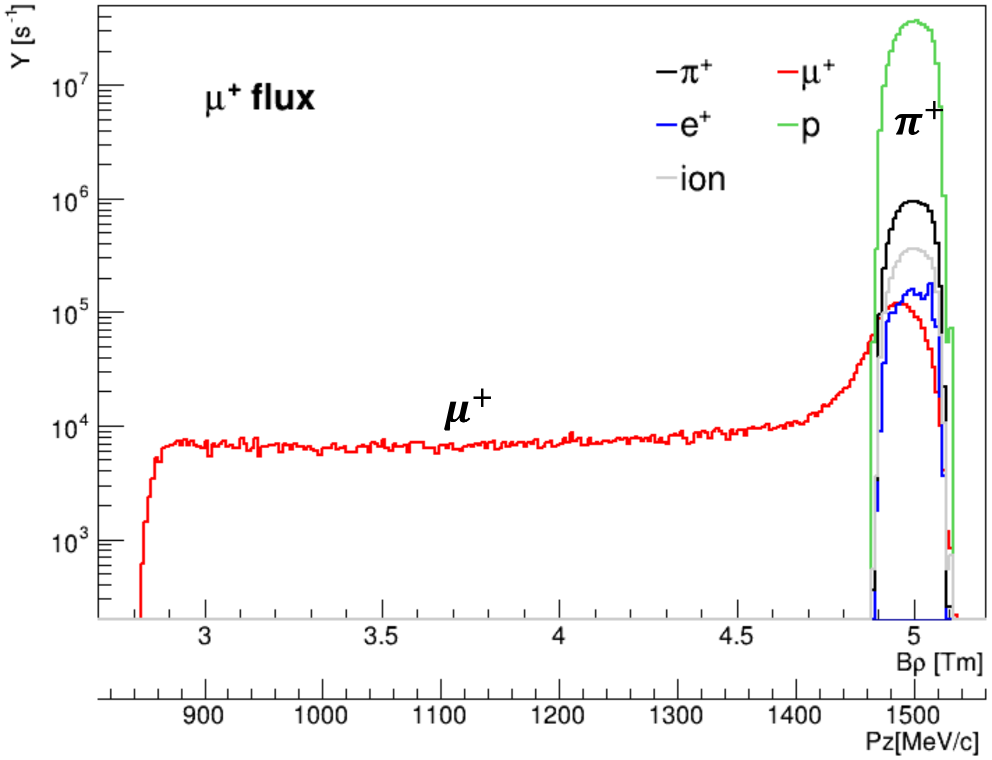
from Xu Yu

先进能源科学与技术广东省实验室
ADVANCED ENERGY SCIENCE AND TECHNOLOGY GUANGDONG LABORATORY

- Beamline magnetic rigidity setting: 5 T·m, corresponding to a particle momentum of 1500 MeV/c.
- The muon beam composition is complex:
  - The μ^- beam contains π^-, μ^-, e^-, etc.
  - The μ^+ beam additionally contains protons (constituting over 90% of the beam) as well as some heavy ions.
- Particle momenta:
  - The momentum distribution of contaminant particles such as electrons and protons is 1500 ± 2% MeV/c.
  - The muon momentum spectrum exhibits a long tail originating from pion decays during beam transport.
  - The momentum difference between muons and contaminant particles can be exploited to obtain a purified muon beam.



束流成分@MF6



GE2/1 GEM：探测器部件生产进展

PKU Lab

北大基地生产的第一个CMS GEM模块

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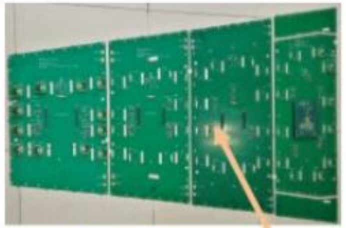

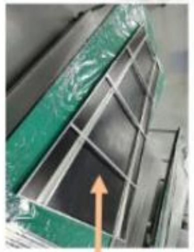

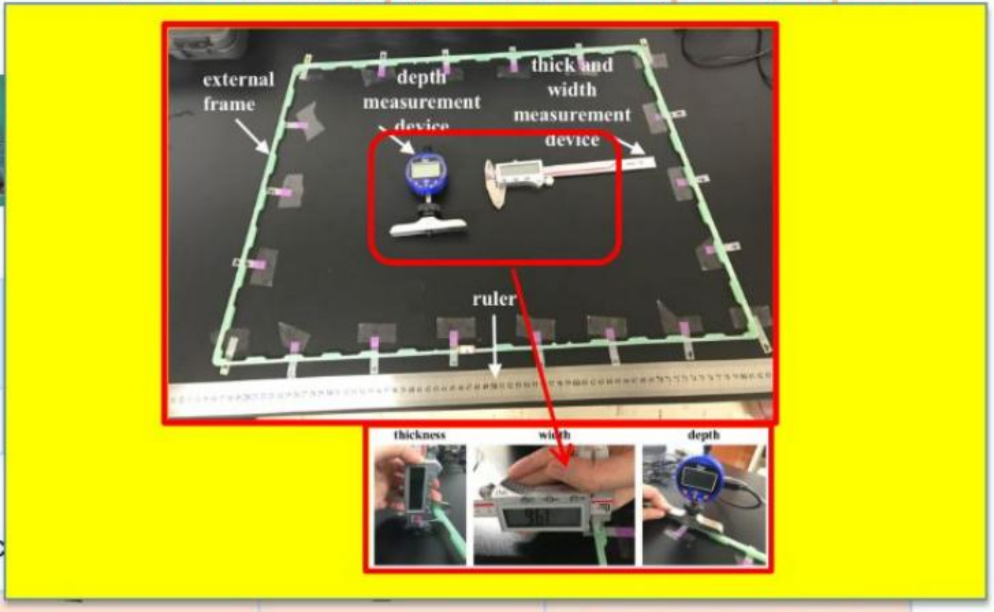

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In progress
(>50% expec

Chamber components

Components	Mechanics	On-detector Fibers	HV filters	Cooling	On-detector Cabling (HV/LV/GND)
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中国组负责生产的GEM部件均已按计划完成并通过CERN检测！

PKU HEP-CMS Group

7 faculties: Yong Ban, Ya-Jun Mao, Qiang Li, Da-Yong Wang, Si-Guang Wang, Chen Zhou, Xiaohu Sun

2 engineers: Qite Li, Z.H.Xue

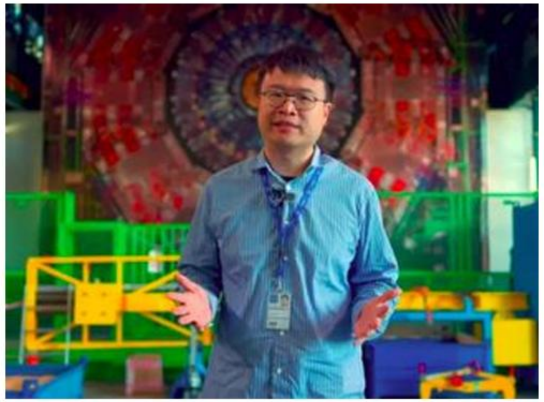
5 postdocs: Andrew Levin, Antonios Agapitos, Zhiyuan Li, Qianying Guo, …

30 students

+ One large theo. group focusing on QCD and TeV Physics

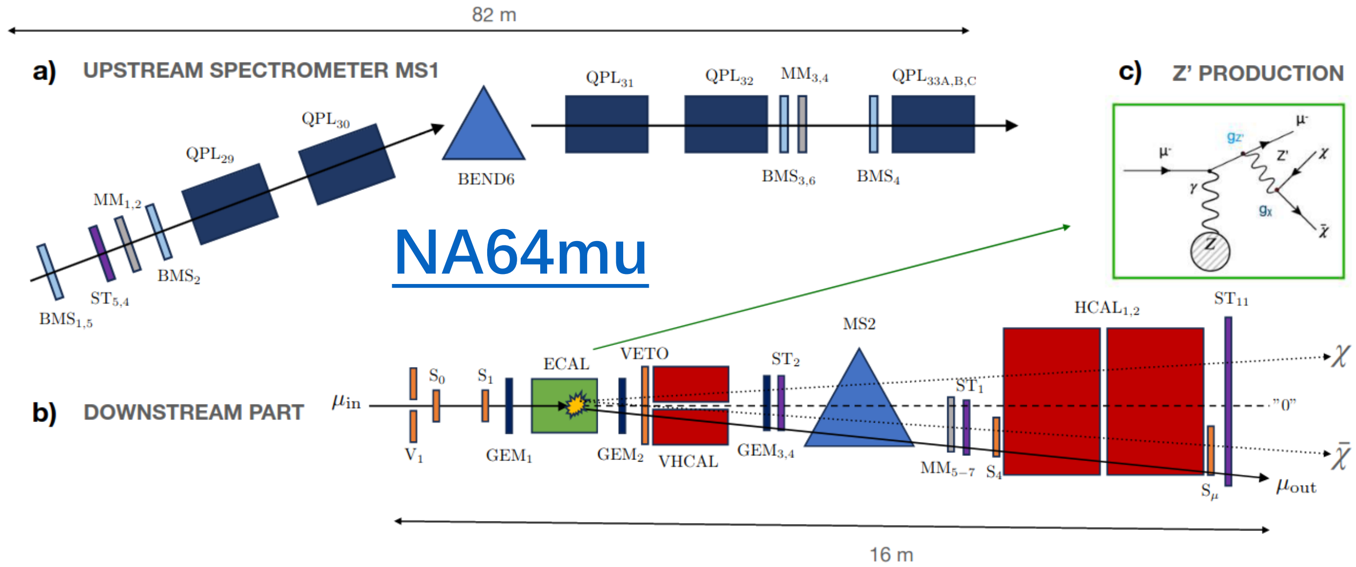
In CMS since 1996, Stable support from Government

RPC and GEM ; VBS; $B \to K\mu\mu$; Boosted Jet



Prelude: NA64, DarkShine, LDMX, MMM

- **Muon Philic Dark Matter** may be possible or necessary! (arXiv: 1804.03144)
- Some Electron/Muons on Target Experiments
  - DarkShine is ~ LDMX based on Shanghai Synchrotron Radiation Facility
  - MMM (M3) is a US proposed muon-LDMX experiment
    - Intrigued by a proposal based on CERN NA64
    - “a lower-energy, e.g. 15 GeV, muon beam allows for greater muon track curvature and, therefore, a more compact experimental design...”



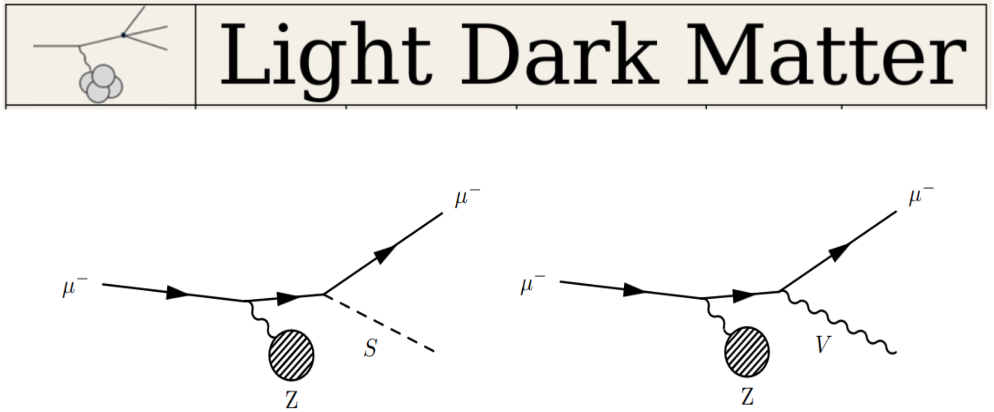
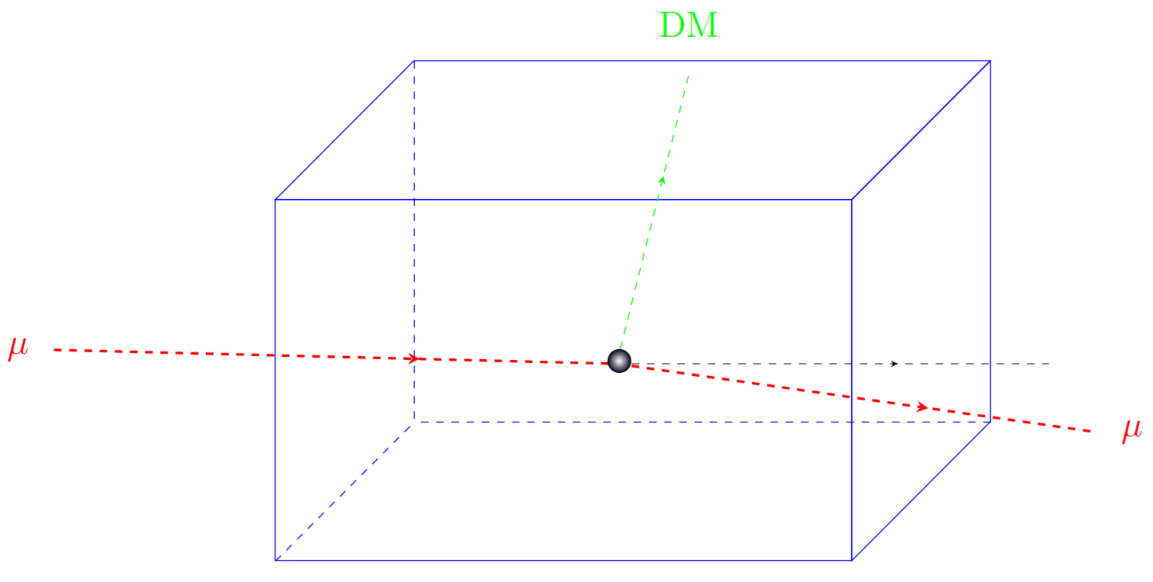


Figure 1. Dark bremsstrahlung signal process for simplified models with invisibly decaying scalar (*left*) and vector (*right*) forces that couple predominantly to muons. In both cases, a relativistic muon beam is incident on a fixed target and scatters coherently off a nucleus to produce the new particle as initial- or final-state radiation.

Phase I: Muon Tomography for Muon-DM scattering



Notice for high speed muons, it is appropriate to treat DM as frozen in the detector volume (V), and the estimated rate per second could be:

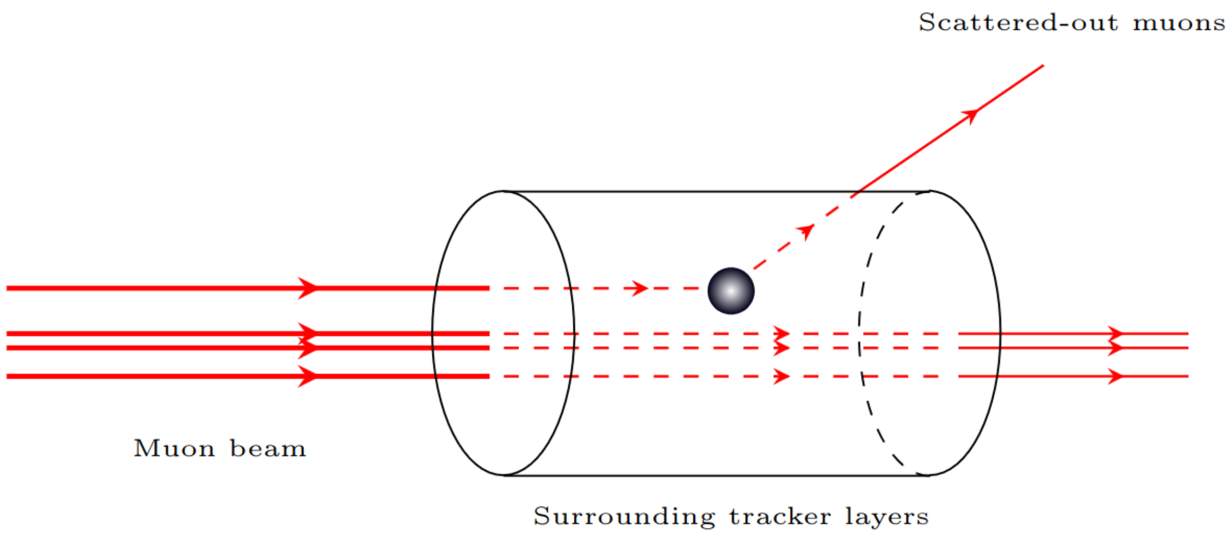
$$\rho V/\mathrm{M_D} \times \sigma_D \times F_\mu,$$

The local density of DM is at the order of $\rho \sim 0.3$ GeV/cm^3 and with a typical velocity of $v = 300$ km/s. While F_μ is the muon flux $\sim 1/60/\mathrm{s/cm^2}$ at the sea level. For Dark Matter mass $M_D \sim 0.1$ GeV, and detector box volume as $V \sim 1\,\mathrm{m}^3$. Thus the sensitivity on Dark Matter Muon scattering cross section for 1 year run will be around

$$\sigma_D \sim 10^{-12}\mathrm{cm}^2$$

One year

Phase II: Muon Beam scattered with DM



The estimated rate per second:

$$dN/dt = N_\mu \times \sigma_D \times L \times \rho/\mathrm{M_D},$$

For $M_D = 0.03\,\mathrm{GeV}$, $L = 1\,\mathrm{m}$, and $N_\mu \sim 10^6/\mathrm{s}$ (e.g., CSNS Melody design), and one year 10^7s.

$$N = 10^{13} \times \sigma_D \times 100/\mathrm{cm}^2,$$

Thus the sensitivity on Dark Matter Muon scattering cross section for 1 year run will be around

$$\sigma_D \sim 10^{-15}\mathrm{cm}^2$$

One year

Notice the surrounding area is around 100 cubic centimeters.