

Probing and Knocking With Muons



Qiang Li, 2026/10, Wuhan

- **Core Goal:** A **comprehensive muon-scattering experiment program** to explore **precision 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**

Muon can connect Micro- and Macro worlds! Fundamental and Application Researches!

AI may not be able to do everything in Physics: asking it How large is the muon flux at the moon!

The replies from chatgpt, basically it just reads from our paper <https://arxiv.org/abs/2607.10403>

How large is the muon flux at the moon?

The muon flux at the Moon depends on the muon energy threshold, the detector's altitude, and whether you count muons moving upward or downward.

For the lunar surface, a recent simulation estimates a muon flux of roughly $30\text{--}46 \text{ m}^{-2} \text{ s}^{-1}$ for muons with kinetic energies above 100 MeV. This is about 3–5 muons per second through a $10 \times 10 \text{ cm}$ detector, assuming the quoted flux is interpreted per unit area and integrated over the relevant directions.  arXiv

An important difference from Earth is that **the Moon has essentially no atmosphere. Most cosmic-ray muons on Earth are produced when cosmic rays interact with the atmosphere,** whereas lunar muons are generated mainly by cosmic-ray interactions in the lunar soil and the subsequent decay of particles escaping from it.  AGU Journals

Numerical estimate

A 2026 simulation gives the following results for **upward-going lunar muons** with kinetic energy above 100 MeV:

 arXiv

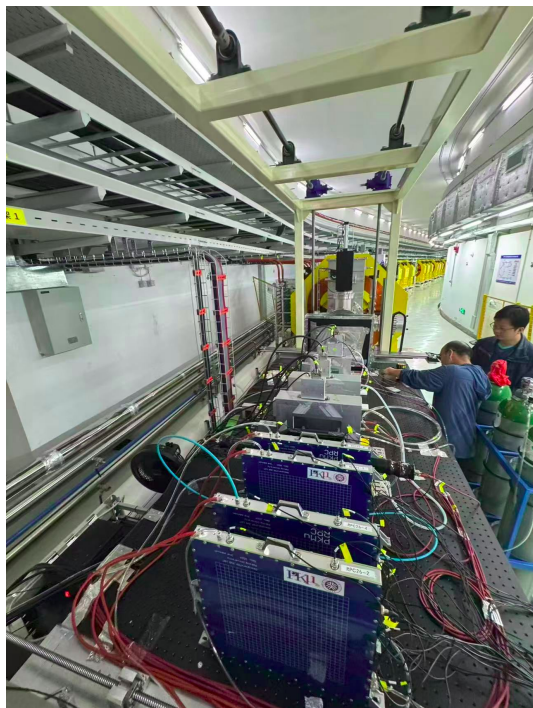
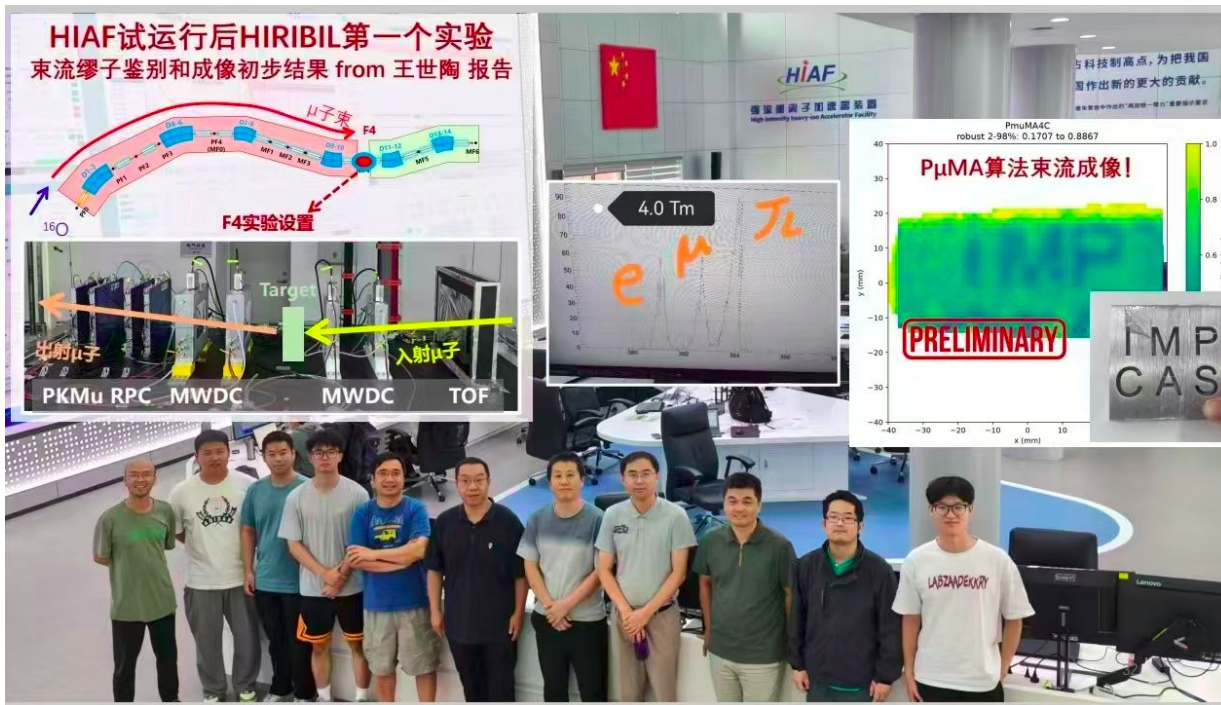
We can still be creative than current AI!

“the flux is strongly dependent on altitude. The same study predicts a flux more than ten times greater at 1 km above the lunar surface, because charged pions escaping the regolith can decay into muons during their flight through the vacuum. “

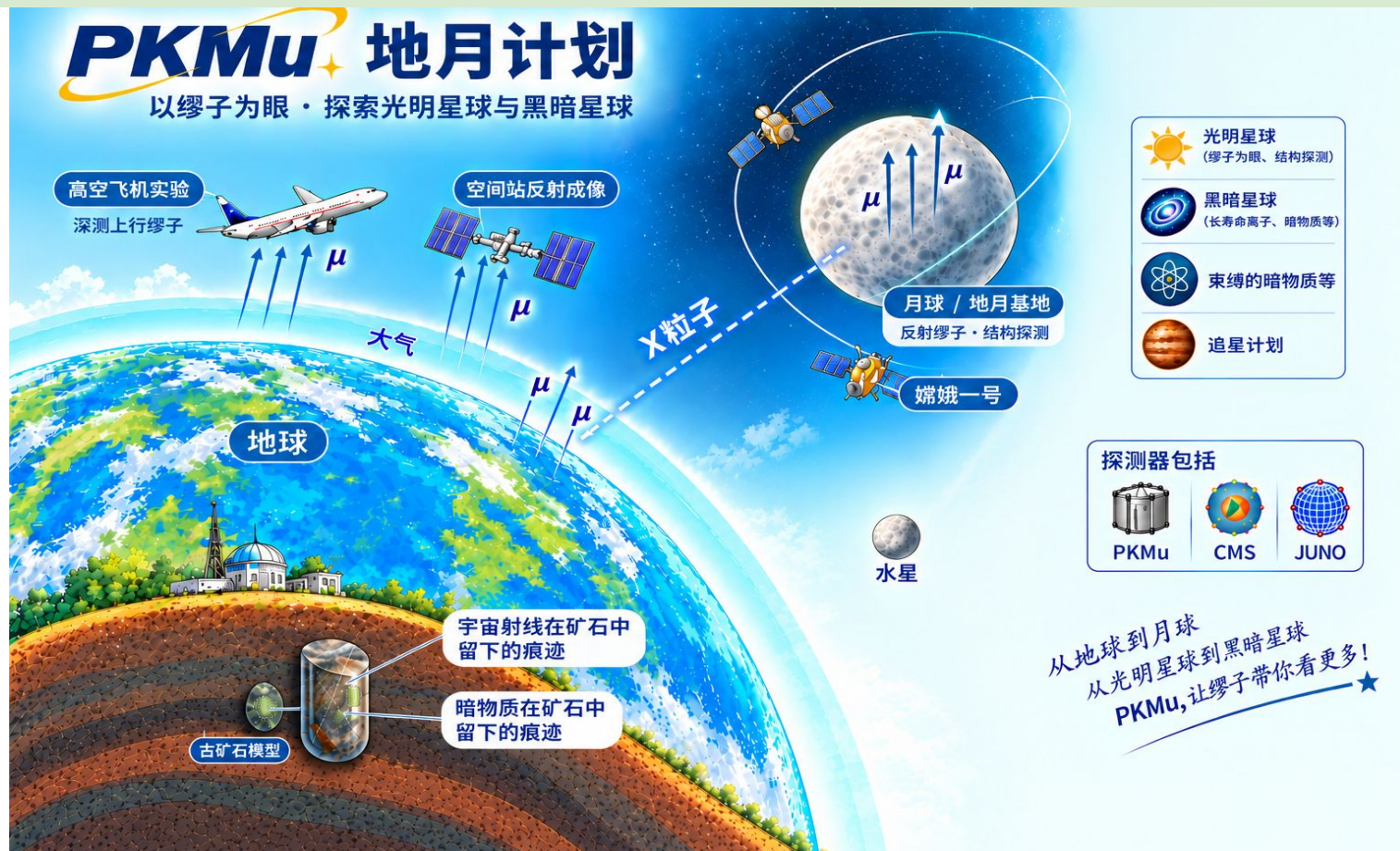
The PKMu beam program

Beam test in 2026/2027!

HIAF/HIRIBL Muon 'Spectrometer'



The PKMu Planet program

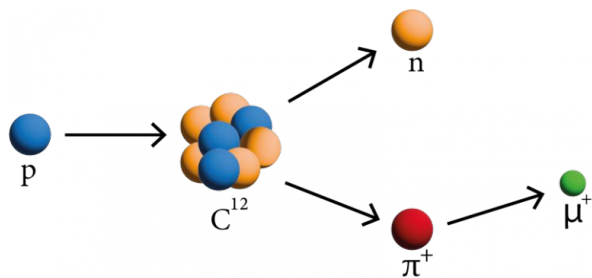
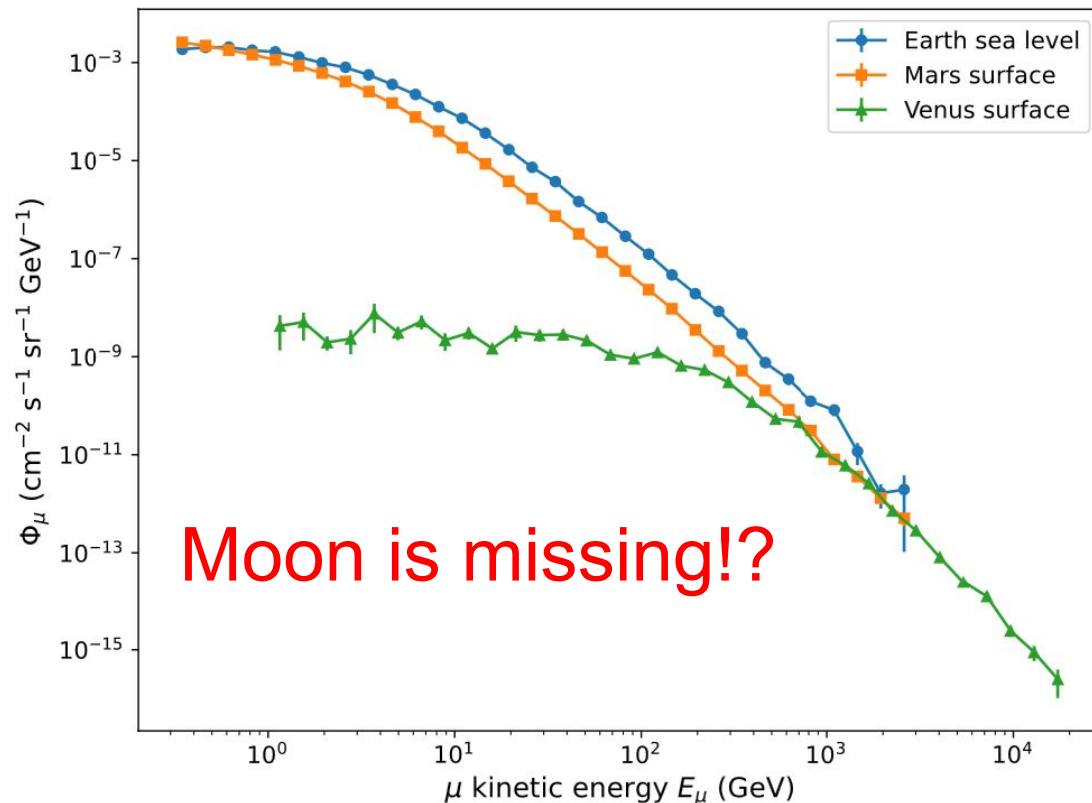


Cosmic Ray at Planets

[arXiv:2610.16607](https://arxiv.org/abs/2610.16607)

CorsikaAgent

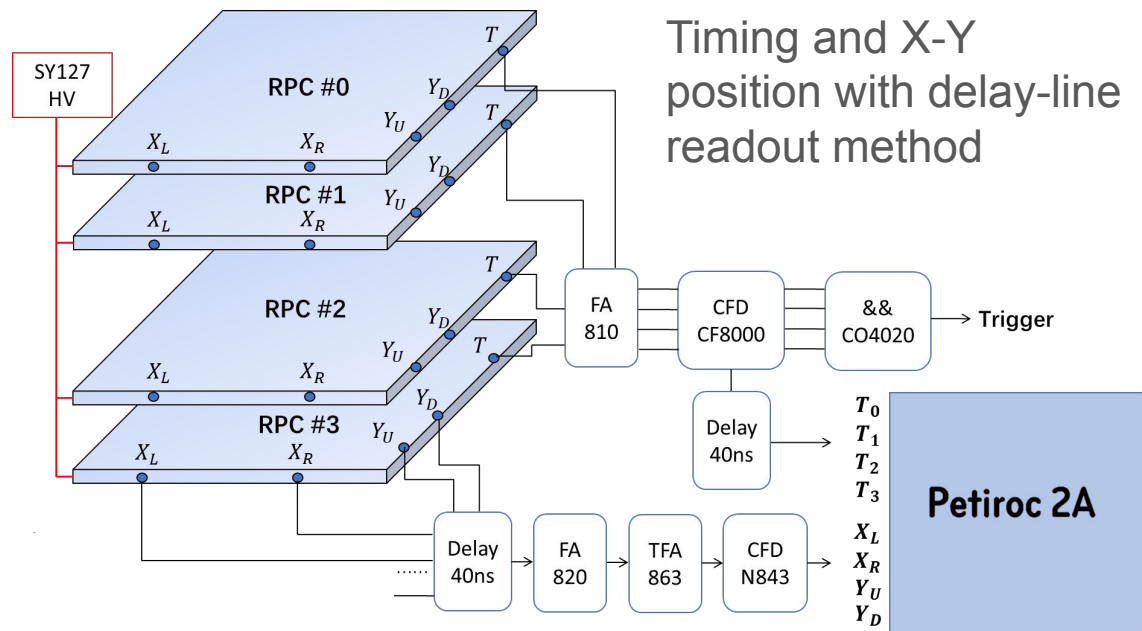
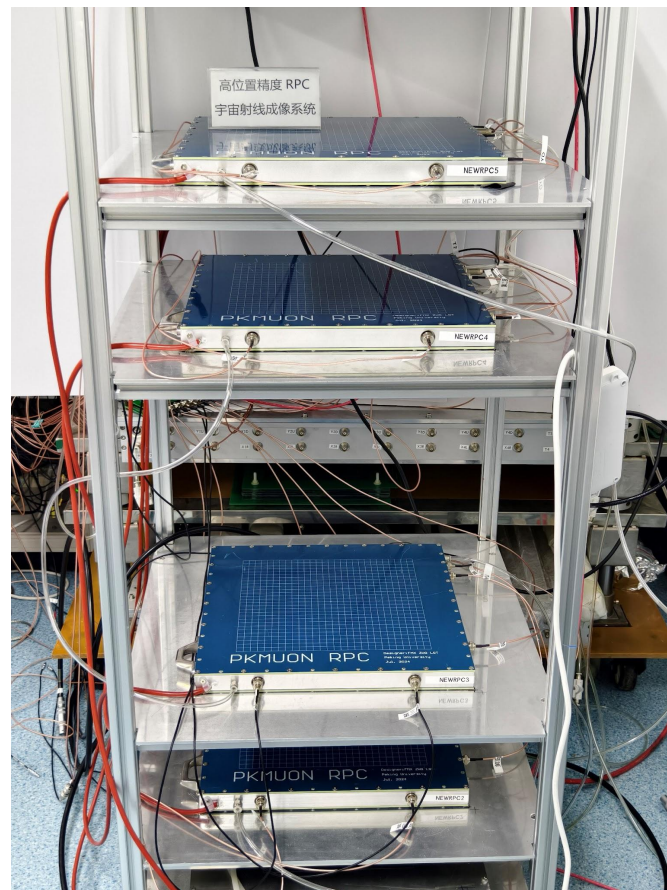
From Earth to Mars
and Beyond: AI-Driven
Cosmic-Ray Validation
and Prediction



A small CR Exp

PRL136 (2026) 15, 151001

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



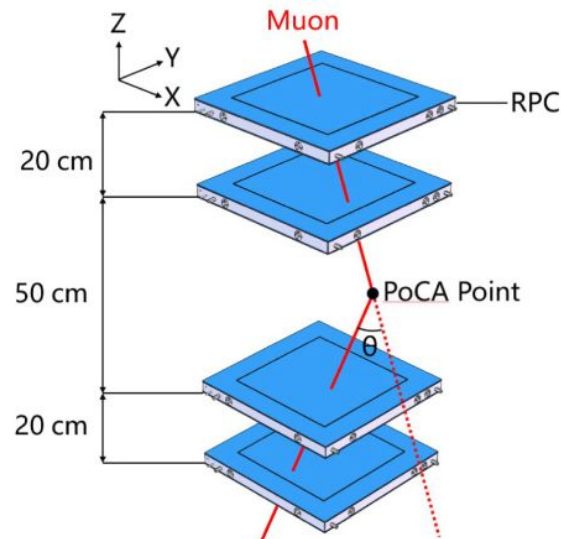
During a 63-day campaign from February 12, 2025, 1.18 million cosmic ray scattering events were recorded and analyzed. **The scattering angle observable is sensitive to the cosmic ray component fractions and DM**

PHYSICAL REVIEW LETTERS **136**, 151001 (2026)

Probing Cosmic Ray Composition and Muonphilic Dark Matter via Muon Tomography

Cheng-en Liu[✉], Rongfeng Zhang[✉], Zijian Wang[✉], Andrew Michael Levin[✉], Leyun Gao[✉], Jinning Li[✉],
Minxiao Fan[✉], Youpeng Wu[✉], Zibo Qin[✉], Yong Ban, Zaihong Yang[✉], Qite Li^{✉*},
Chen Zhou^{✉,†} and Qiang Li^{✉‡}

(PKMu Collaboration)



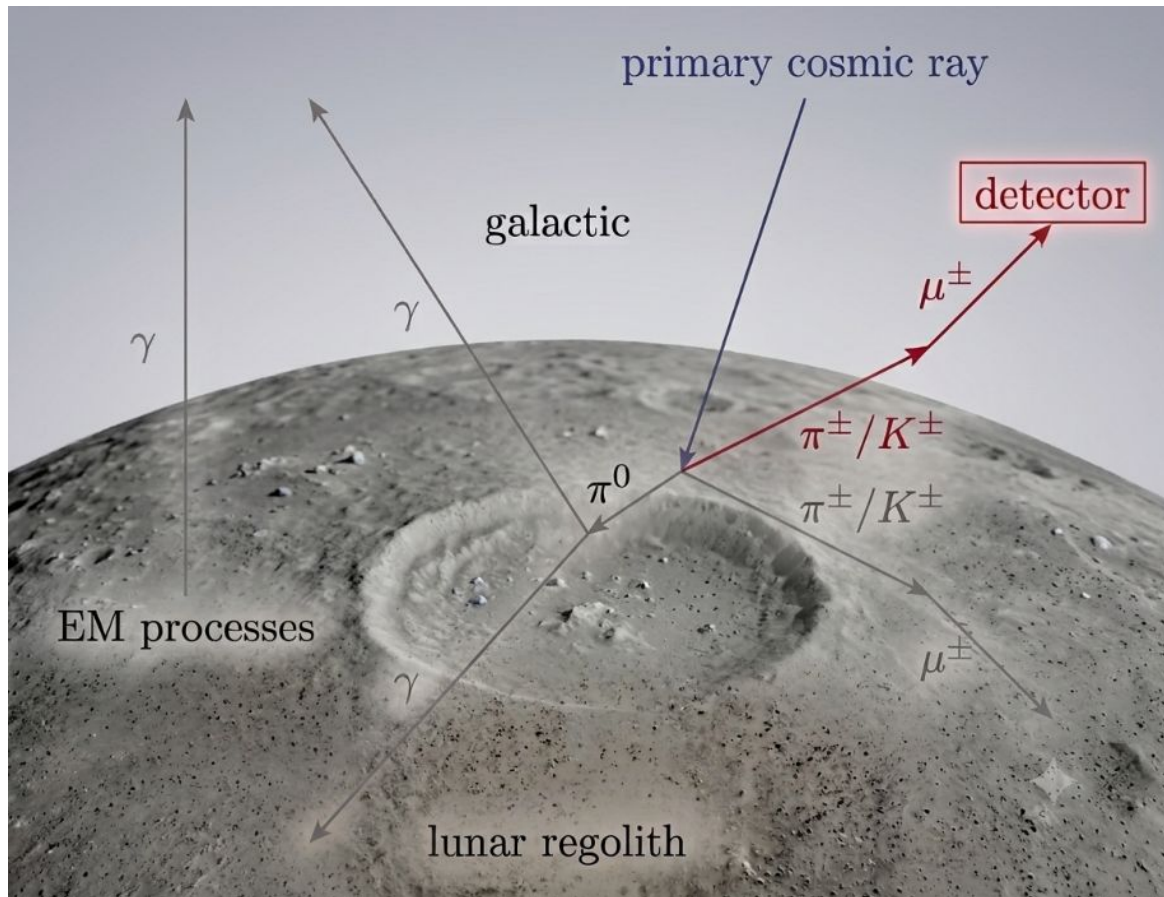
Why the Moon is special?

No atmosphere.

A dense regolith below and a near-vacuum environment above.

Most downward-going hadrons are absorbed before decaying,

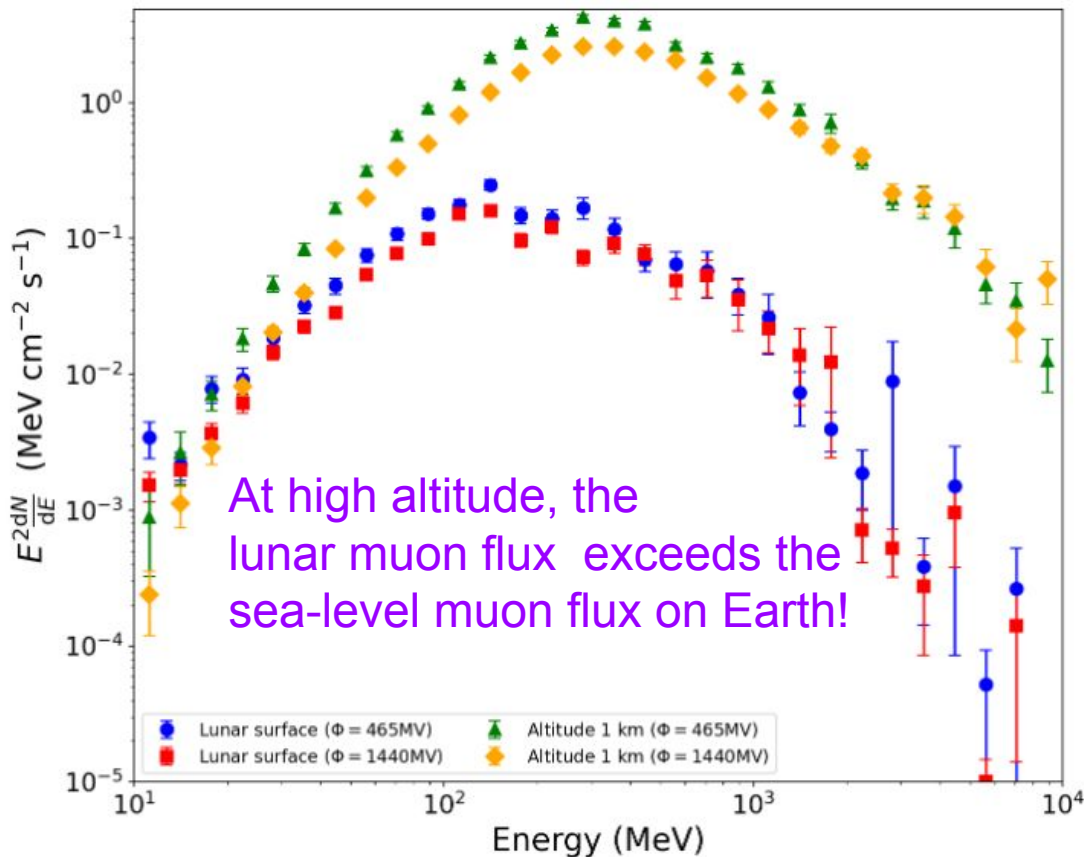
Upward-going hadrons escaping the regolith can decay in flight, producing a significant source of lunar muons.



Using **FLUKA** to simulate
the production
and propagation of
secondary cosmic-ray

Lunar regolith:
Moskalenko—
Porter 2007 model

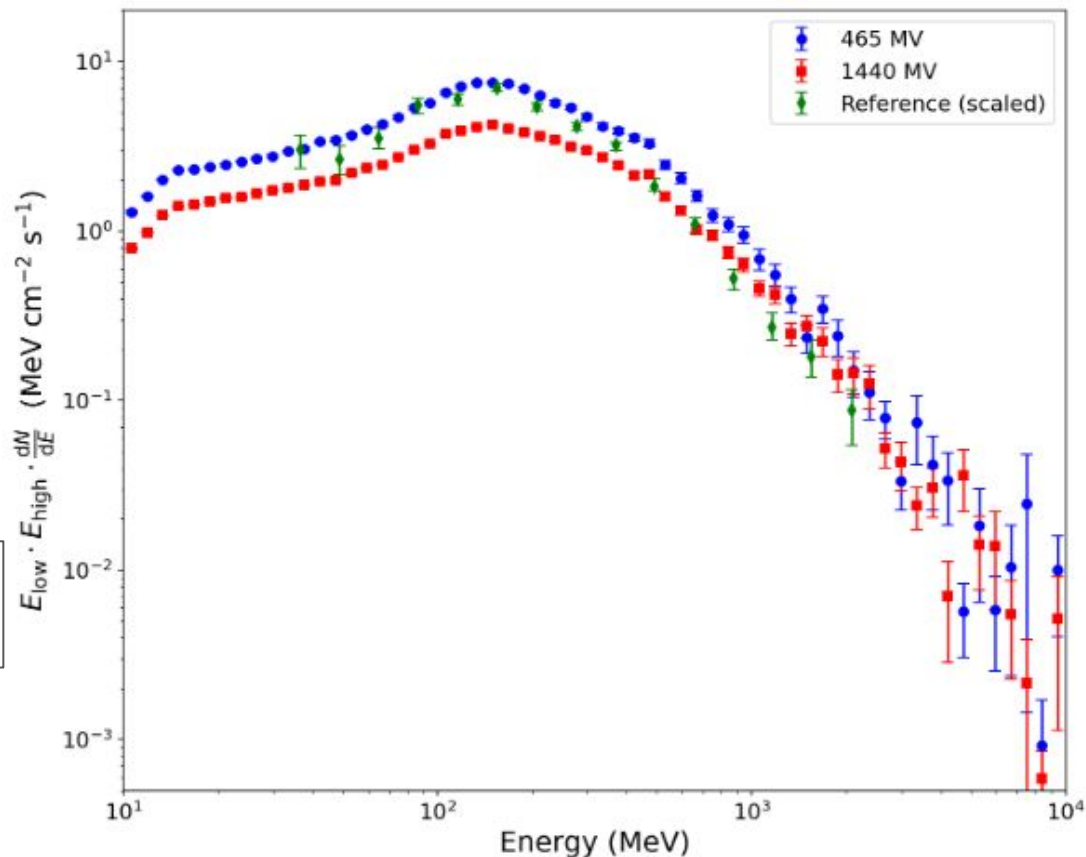
Hadronic interactions:
DPM-JET and RQMD in
FLUKA



Verified with the
FERMI-LAT
gamma ray
measurement

PHYSICAL REVIEW D **93**, 082001 (2016)

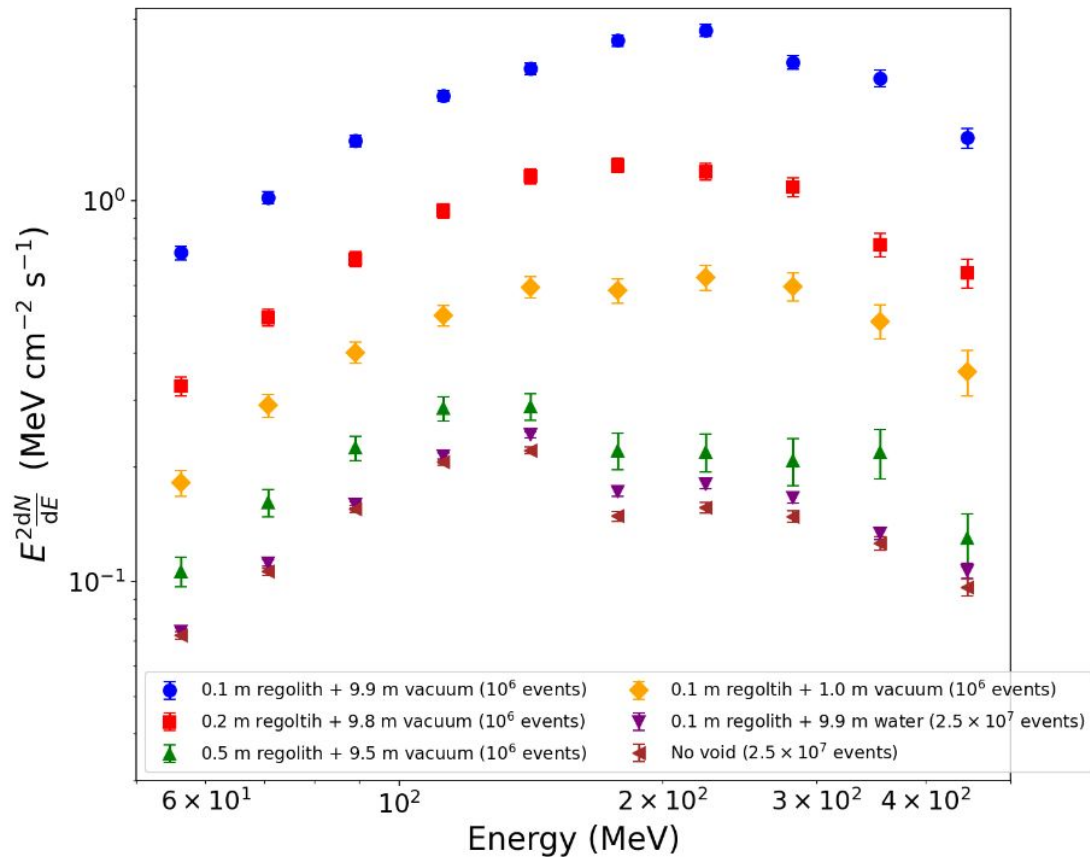
Measurement of the high-energy gamma-ray emission from
the Moon with the Fermi Large Area Telescope

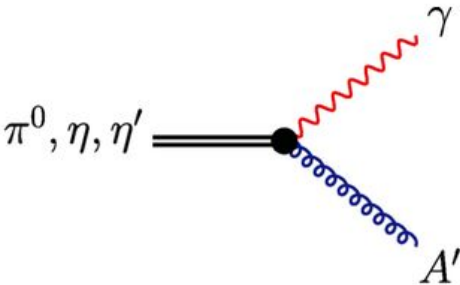
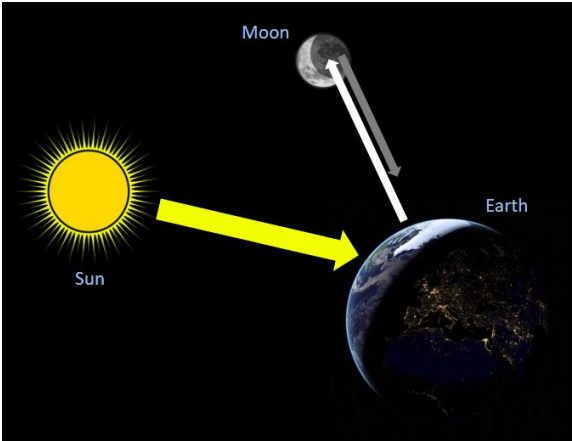
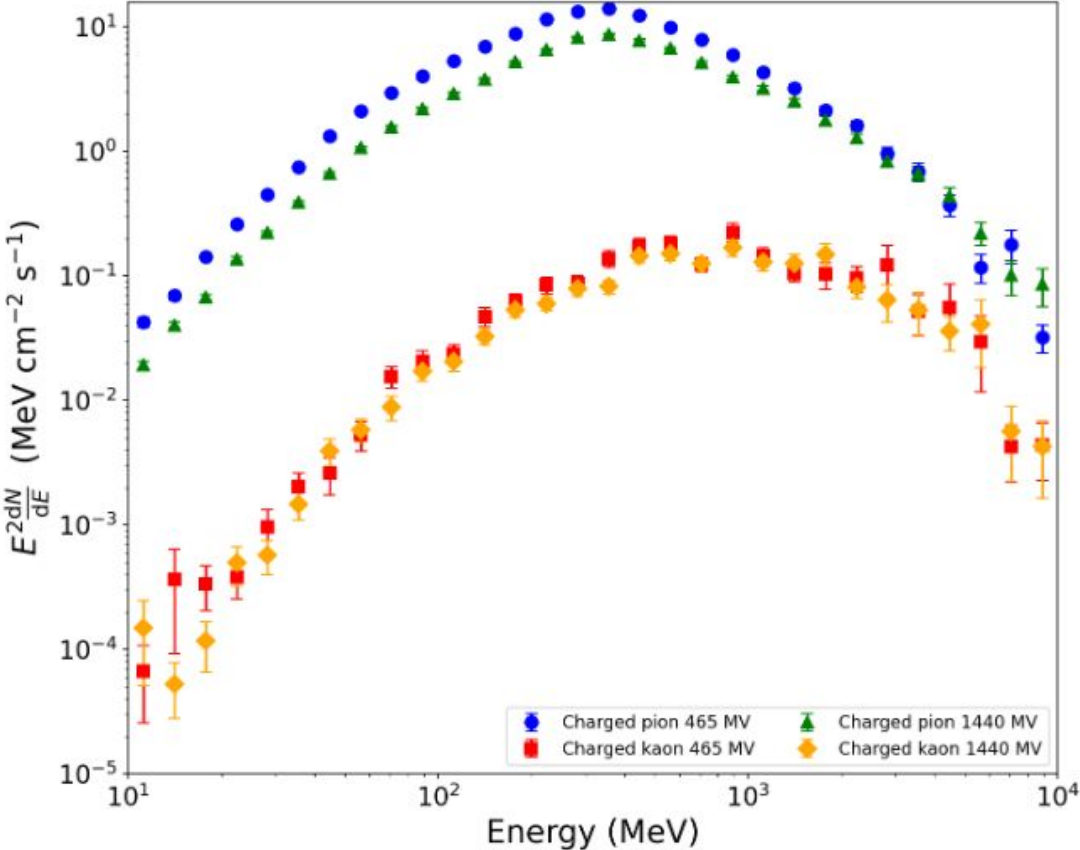


Muon's Moonshot

Could be
sensitive to
Moon structure

Moon
subsurface
tomography





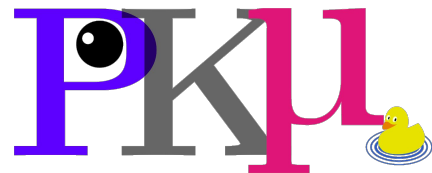
AI for Cosmic Ray

Special muon ray from Moon

<https://lyazj.github.io/pkmuon-site/>

Moon tomography

Bright or Dark Moon



Earth: upward-going muon?

第二届高能缪子散射物理研讨会

Dec 4 – 7, 2026

北京

Asia/Shanghai timezone



Overview

Call for Abstracts

Timetable

Contribution List

My Conference

My Contributions

Registration

Participant List

Previous Workshop

一、会议简介

- 2026年12月4日至7日（12月4日周五报到），北京大学物理学院将举办“高能缪子散射物理研讨会”。本次研讨会由北京大学、中国科学院近代物理研究所、先进能源科学与技术广东省实验室、上海交通大学、华中师范大学、山东大学、中山大学联合主办。会议主要围绕高能缪子束散射实验展开深入讨论，加强理论物理学家及实验物理学家在高能缪子物理前沿与实验技术前沿领域的交流与合作，引领高能缪子物理领域国内研究水平的共同进步、推动国内高能缪子物理相关研究工作的国际学术影响力，并着重探讨依托强流重离子加速器装置HIAF以及加速器驱动嬗变研究装置(CiADS)的缪子源开展粒子物理与原子核物理研究的可行性，形成初步方案建议。
- **12月5日周六的会议报告，主要由Program Committee单独邀请；**
- **12月6日周日的会议报告，通过邀请以及网页提交。**

二、会议基本信息

- 会议地点：北京市海淀区 北京大学物理学院 物理楼
- 会议时间：2026年12月4-7日。4日报到，5、6两日报告，7日自由讨论。
- 报名方式：线上报名，网址为 <https://indico.ihep.ac.cn/event/30837>
- 报名截止时间：2026年11月15日

Backup

Muons can be everywhere and interesting

《Nature》 Muon Tomography LETTER

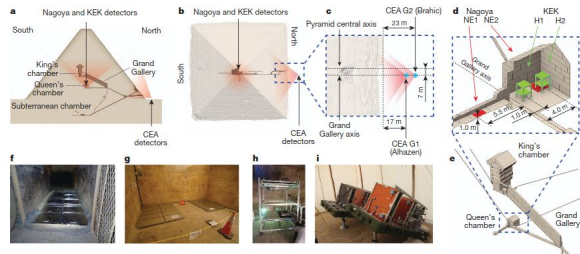
doi:10.1038/nature24647

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

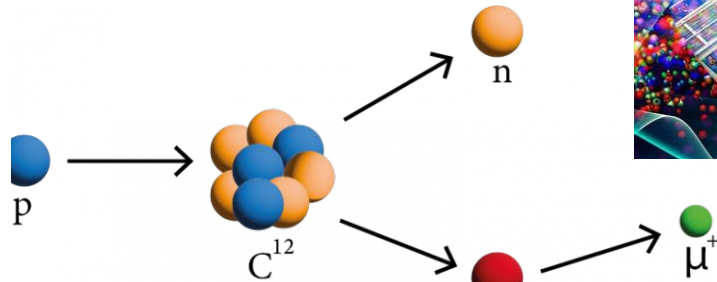
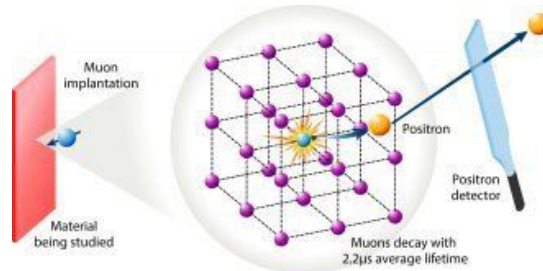
Kunihiko Morishima¹, Mitsuaki Kuno¹, Akira Nishio¹, Nobuko Kitagawa¹, Yuta Manabe¹, Masaki Moto¹, Fumihiko Takasaki², Hirofumi Fujii², Kotaro Satoh², Hideyo Kodama², Kohel Hayashi², Shigeru Odaoka², Sébastien Procureur³, David Attie⁴, Simon Boutefille⁵, Denis Calvet⁵, Christopher Filosa⁵, Patrick Magnier⁵, Irakli Mandajidze⁵, Marc Riallot⁵, Benoît Marini⁵, Pierre Gable⁵, Yoshikatsu Date⁶, Makiko Sugiyama⁶, Yasser Elshayeb⁶, Tamer Elmadhy⁶, Mustapha Ezzy⁶, Emmanuel Guerriero⁶, Vincent Steiger⁷, Nicolas Serikoff⁷, Jean-Baptiste Mouret^{8,9,10,11}, Bernard Charles¹², Hany Helal¹³ & Mehdi Tayoubi¹⁴

The Great Pyramid, or Khufu's Pyramid, was built on the Giza plateau in Egypt during the fourth dynasty by the pharaoh Khufu (Cheops)¹, who reigned from 2509 BC to 2483 BC. Despite being one of the oldest and largest monuments on Earth, there is no consensus about how it was built^{2,3}. To understand its internal structure better, we imaged the pyramid using muons, which are by-products of cosmic rays that are only partially absorbed by stone⁴⁻⁶. The resulting cosmic-ray muon tomography allows us to visualize the known and any unknown voids in the pyramid in a non-invasive way. Here we report the discovery of a large void (with a cross-section similar to that of the Grand Gallery and a minimum length of 30 metres) situated above the Grand Gallery. This constitutes the first major inner structure found in the Great Pyramid since the nineteenth century⁷. The void, named ScanPyramids' Big Void, was first observed with nuclear emulsion films⁸ installed in the Queen's

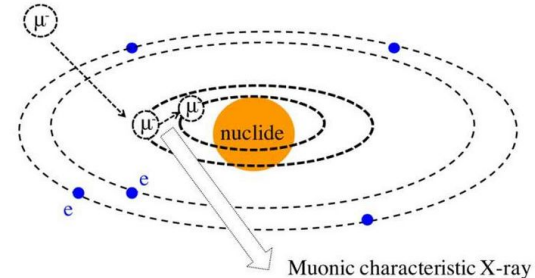
chamber, then confirmed with scintillator hodoscopes^{10,11} set up in the same chamber and finally re-confirmed with gas detectors⁹ outside the pyramid. This large void has therefore been detected with high confidence by three different muon detection technologies and three independent analyses. These results constitute a breakthrough for the understanding of the internal structure of Khufu's Pyramid. Although there is currently no information about the intended purpose of this void, these findings show how modern particle physics can shed new light on the world's archaeological heritage. The pyramid of Khufu is 139 m high and 230 m wide¹². There are three known chambers (Fig. 1), at different heights of the pyramid, which all lie in the north-south vertical plane: the subterranean chamber, the Queen's chamber, and the King's chamber. These chambers are connected by several corridors, the most notable one being the Grand Gallery (8.6 m high × 46.7 m long × 2.1–1.0 m wide). The Queen's



Muon g-2 Experiments



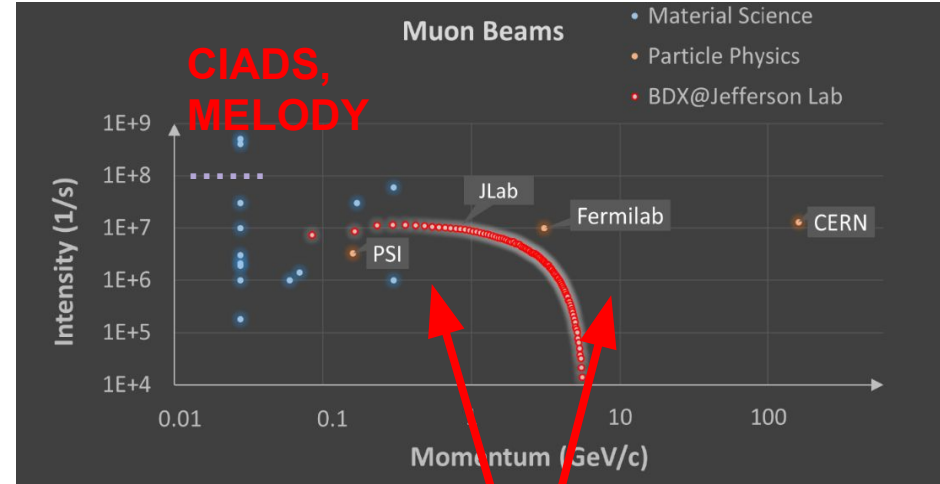
Muonic x-ray spectroscopy



Muon Spin Rotation and Relaxation Spectroscopy

Muon beam Worldwide

- **~150GeV Mu Beam@CERN:**
AMBER, MUonE, NA64
 - **Nuclear Properties,**
 - **New Physics Searches**
- **US JLab has a similar plan**
- **Many Possible Muon beams to appear in China soon**



[PRAB 28 \(2025\) 053401](#)

PHYSICAL REVIEW ACCELERATORS AND BEAMS **28**, 053401 (2025)

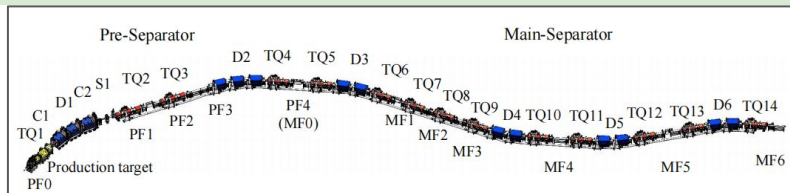
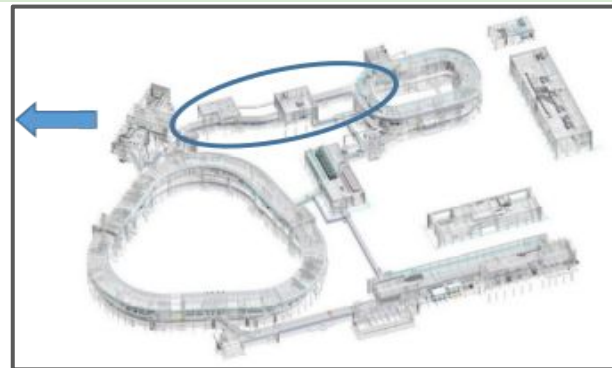
Feasibility study of the GeV-energy muon source based on the High Intensity Heavy-Ion Accelerator Facility

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 Pan⁴,
Qite Li⁵, Chen Zhou⁵, Qiang Li⁵, Lei Yang^{1,2,3} and Zhiyu Sun^{1,2,3,†}

- HIAF can use HIRIBL to produce muon beam
- Kinetic Energy Range: 500 MeV/c – 7.5 GeV/c
 - Muon Yield: 10^6 – 10^7 muons per second
 - Muon Beam Spot Size: 30 mm (radius)

Upgraded HIAF (HIAF-U) can reach 20+ GeV with 100 more intense muon beam

HIRIBL(HFRS)@HIAF



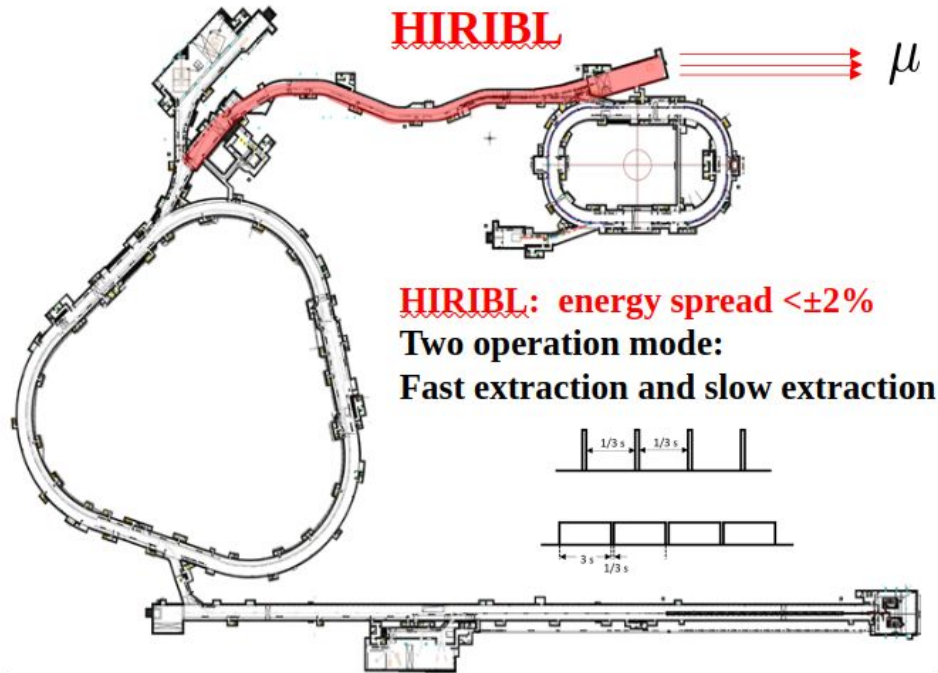
Max. magnetic rigidity	25Tm (II stage) 15Tm (I stage)
Angular acceptance	H: ± 30 mrad V: ± 25 mrad
Momentum acceptance	$\pm 2.0\%$
Ion-optical mode	Achromatic mode, Dispersive mode
Beam size at target	Slow ext.: $\pm 1/\pm 1.5$ Fast ext.: $\pm 4/\pm 6$
First order Momentum resolution ($x=\pm 1\text{mm}$)	Pre: 850 Main: 700 / 1100

- High-performance next-generation secondary beam separator
- Production, separation, purification, and transport of short-lived exotic nuclei
- Unique beam optics to realize both high-efficiency separator and high-precision spectrometer

HIRIBL is capable of producing muons with GeV energies

HIAF: GeV Muon beam in 2026?

- HIAF is capable of delivering high-energy muon beam with a narrow energy spread
- Polarized muon can also be obtained



Muon beam@HIAF-HIRIBL

Projectile	Muon	
	Intensity (μ^+/s)	Momentum (GeV/c)
$^{78}\text{Kr}^{19+}$	1.8×10^6	1.0
$^{18}\text{O}^{6+}$	3.5×10^6	1.5
Proton	8.2×10^6	3.5