



Sino-Thai International Summer School on High Energy Physics and Astrophysics in 2026

Accelerator muons and their applications

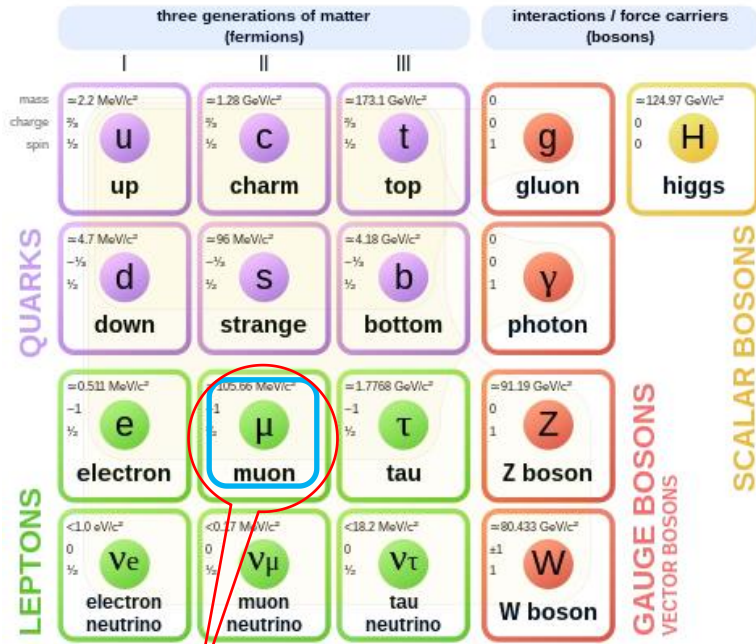
Huan Jia, Han-Jie Cai

Institute of Modern Physics, Chinese Academy of Sciences

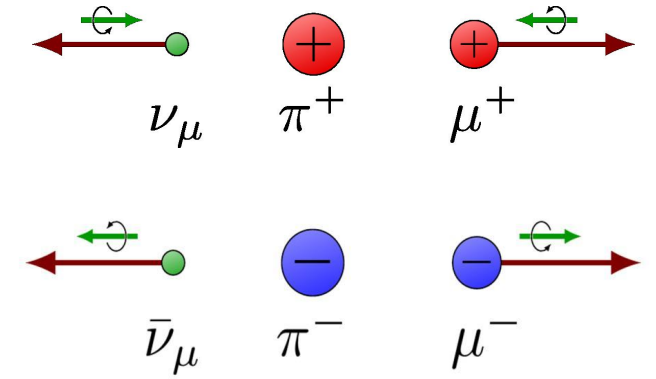
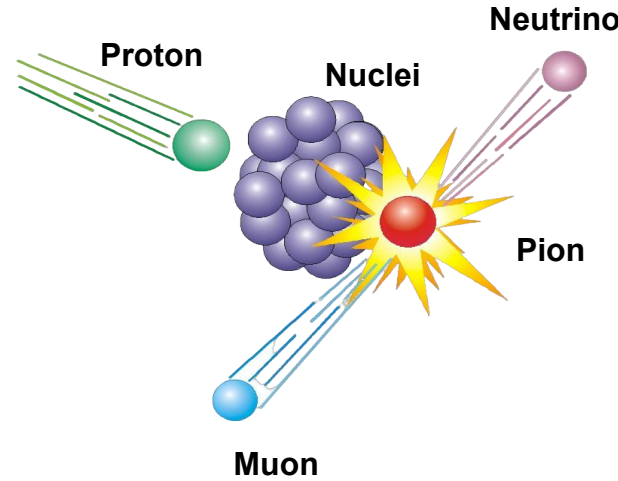


- **Muon Science and Applications**
- **Muon Beam Facilities around the world**
- **Muon Beam Facilities in China**
- **Summary & Prospective future**

Standard Model of Elementary Particles

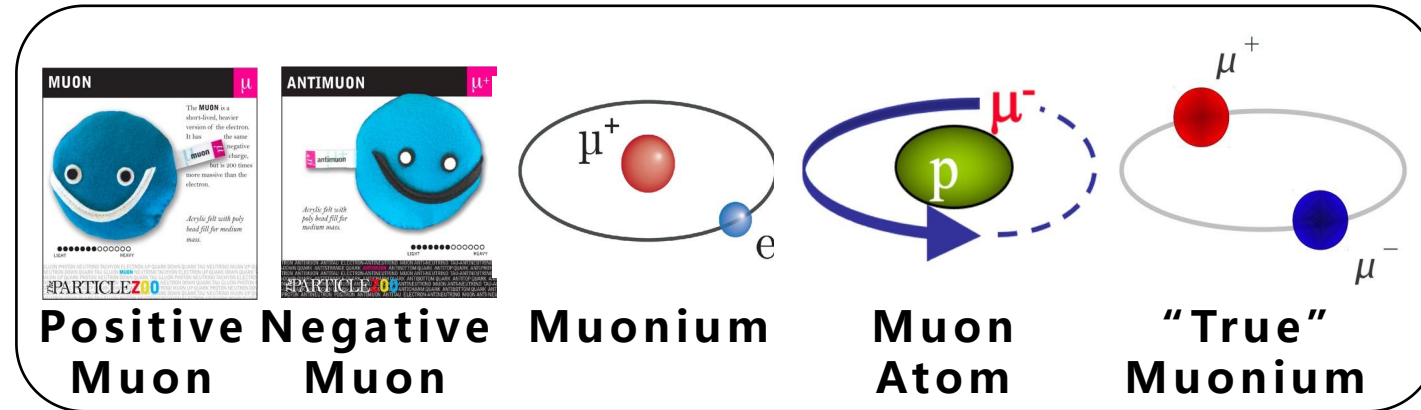


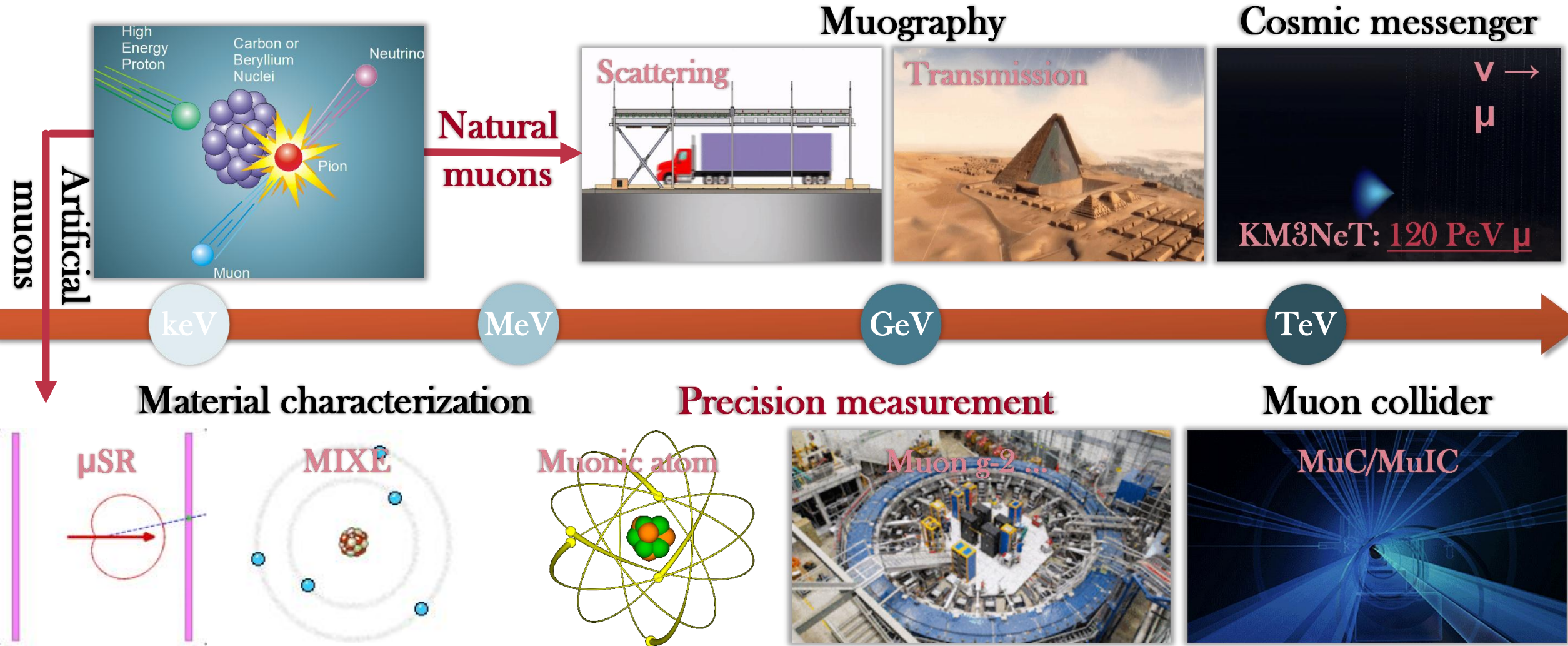
缪子的产生



Forms of Muons

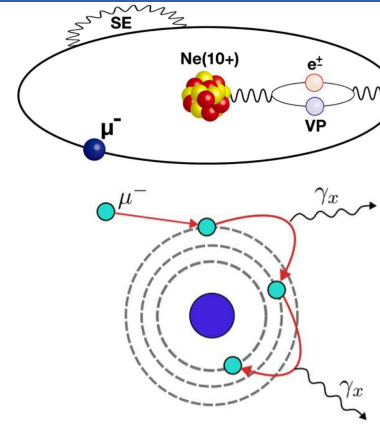
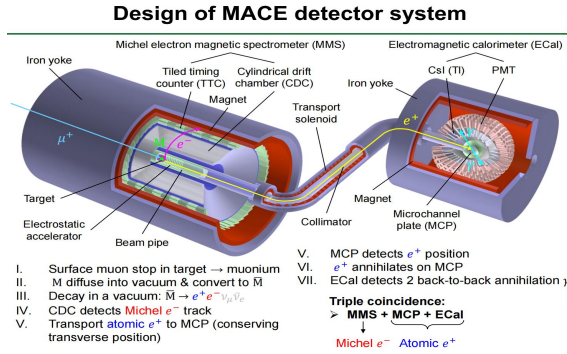
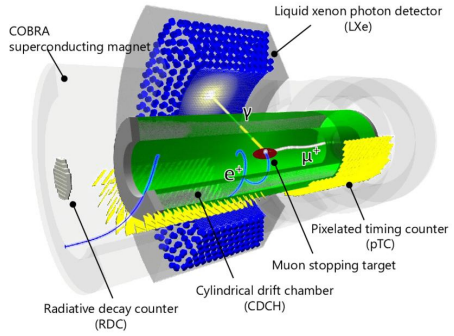
- Second generation lepton
- Moderate Mass: $m_\mu \sim 207 m_e \sim 1/9 m_p$
- Moderate lifetime": $\sim 2.2 \mu s$
- Spin 1/2, surface muon with $\sim 100\%$ polarization







Muon Science and Applications

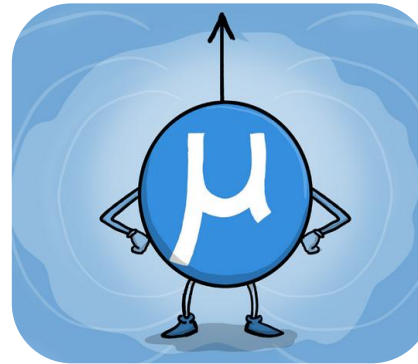


MIXE Elemental Analysis: asteroid samples, cultural relics, pharmaceutical samples, industrial applications, etc.

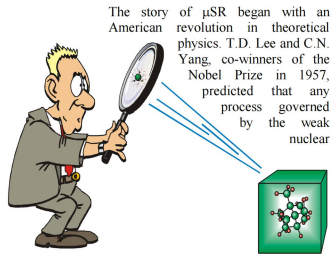


Particle Physics (MEG, Mu3e, Mu2e, COMET, MACE, anomalous magnetic moment, electric dipole moment, etc.)

Condensed Matter Physics (Magnetic materials, superconductors, semiconductors; quantum spin liquid, etc.)

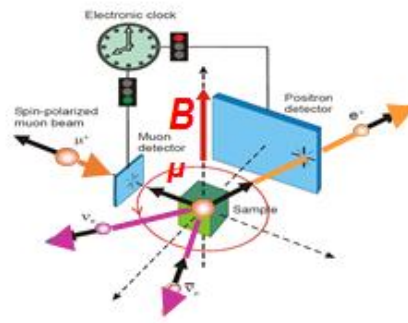


Nuclear/Atomic Physics (strong-field QED test, nuclear structure, high-precision spectroscopy, elemental Analysis);
Muography; Biophysics; Chemistry; Catalyzed Fusion

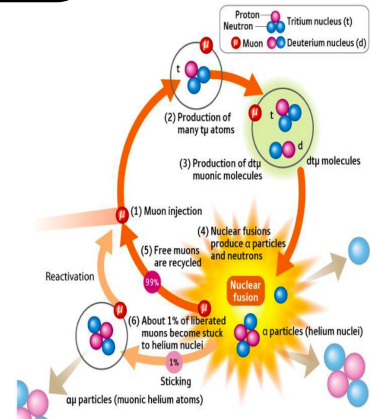
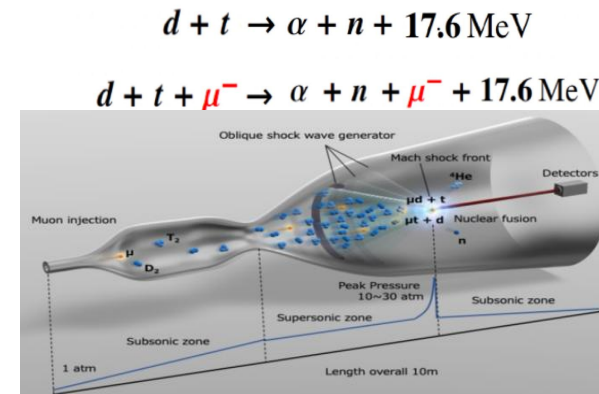


The story of μ SR began with an American revolution in theoretical physics. T.D. Lee and C.N. Yang, co-winners of the Nobel Prize in 1957, predicted that any process governed by the weak nuclear

μ SR is a collection of methods that uses the muon spin to look at structural and dynamical processes in the bulk of a material on an atomic scale.



Various Applications of Muon Source

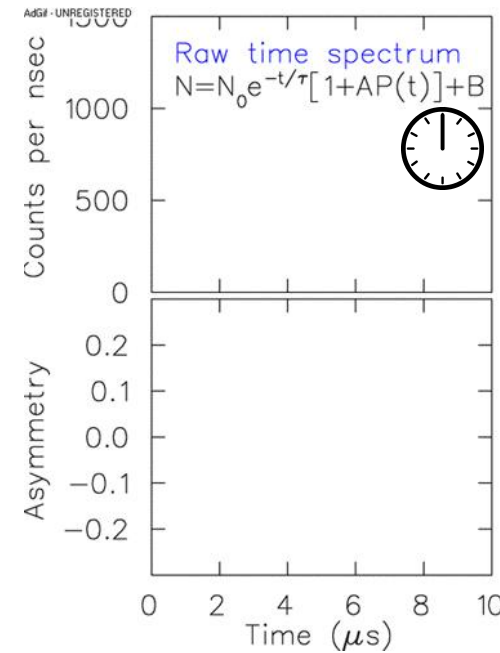
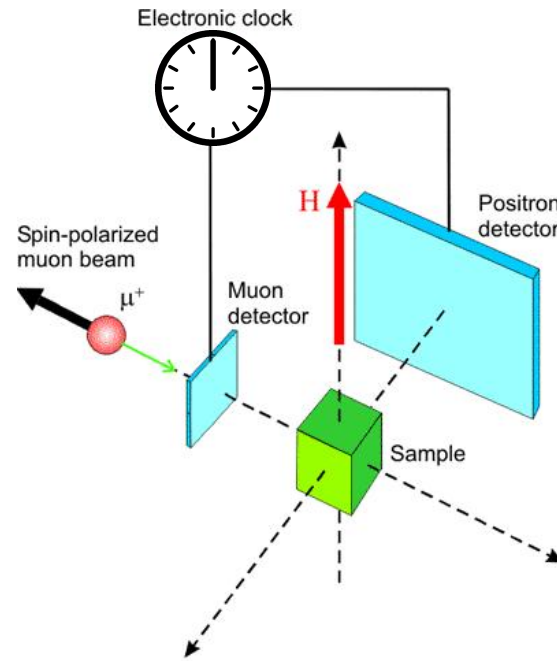
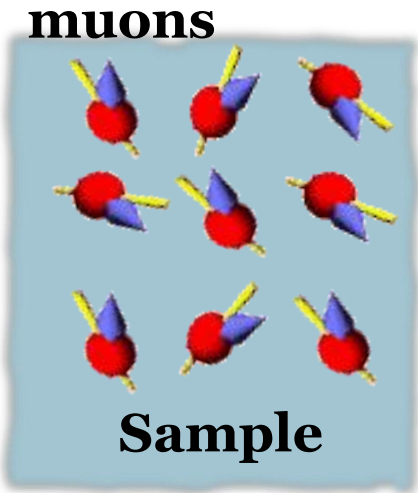


Precession
(spin interaction)

Asymmetry
(positron detection)

μSR spectra
(analysis)

Material
(properties)



- Static/dynamical effect
- Magnetic fluctuation
- SC / magnetic phase
- Magnetic volume
- Charge diffusion
- Radicals
- ...

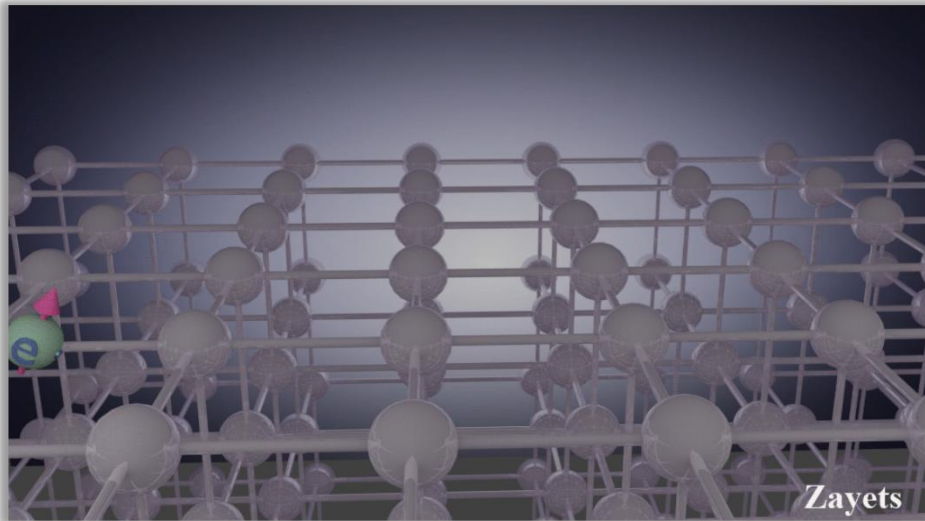
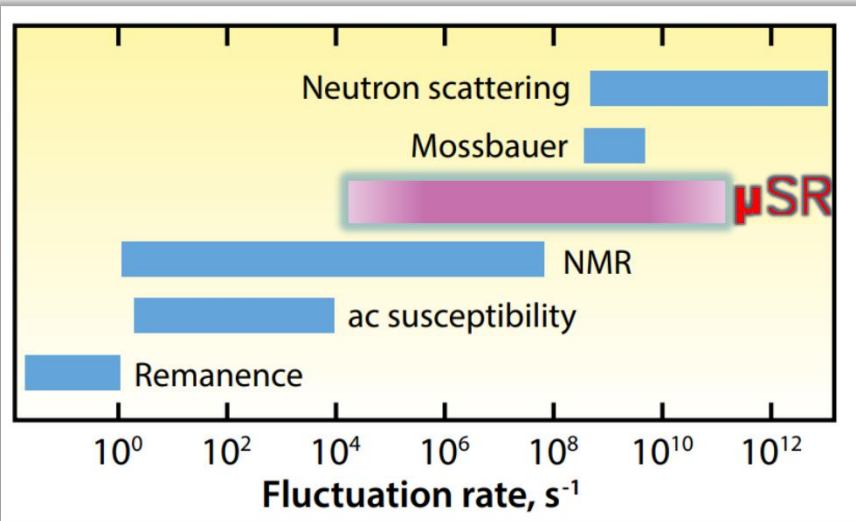
$$\frac{d\mathbf{S}_\mu(t)}{dt} = \gamma_\mu \mathbf{S}_\mu(t) \times \mathbf{B}_{loc}(t)$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\frac{N_F(t) - N_B(t)}{N_F(t) + N_B(t)} = AP(t)$$

$$\omega = \gamma_\mu \mathbf{B}_{loc}$$

Courtesy of Ziwen Pan

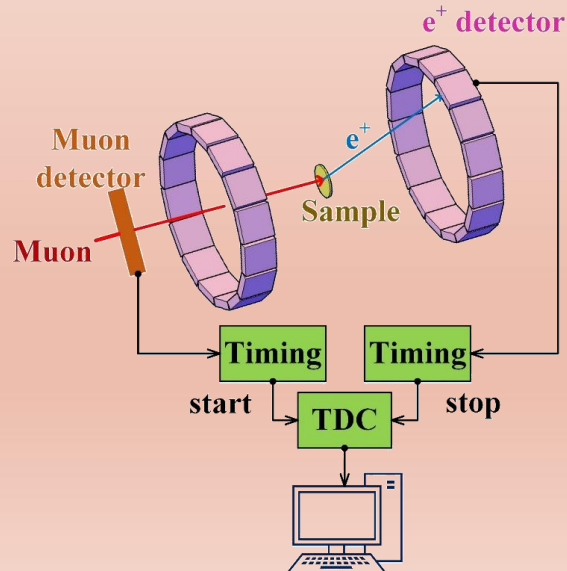


- **A local quantum magnetic probe** (no need to search reciprocal space)
- **Unique & wide time scale** (complementary to NMR/neutron scattering)
- **Very weak effects** (small moment magnetism $\sim 10^{-3} \mu_B/\text{Atom}$)
- **Random & inhomogeneous magnetism** (e.g. spin glasses, quantum spin liquid)
- **Short range order** (where neutron scattering is not sensitive)
- **Full polarization in zero field** (independent of temperature, unique measurements without disturbance of the system)
- **Single particle detection** (with extremely high sensitivity)
- **No sample restrictions** (in choice of materials to be studied)

Coutesy of Ziwen Pan

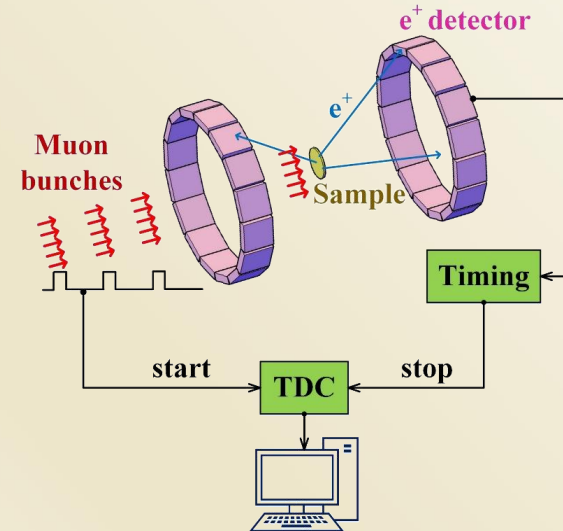
Continuous

- ◆ One μ^+ & one e^+
- ✓ High time resolution $O(0.1 \text{ ns})$
- ✓ Sensitive to fast relaxing signals
- × Coincidence background
- ✓ 0 – 10 μs or shorter



Pulsed

- One μ^+ bunch & multi e^+
- × Low time resolution $O(100 \text{ ns})$
- ✓ Sensitive to slow relaxing signals
- ✓ No coincidence background
- ✓ 0 – 32 μs or longer



Courtesy of Ziwen Pan



Muon Science and Applications in China



1. μ SR with condensed matter and material science

- Superconducting, semiconductor, magnetic material, quantum system, Fermi fluid (FUDAN, ECNU, IOP, ZJU, USTC, SJTU etc)

2. Experiment for Muon parameters and related rare process

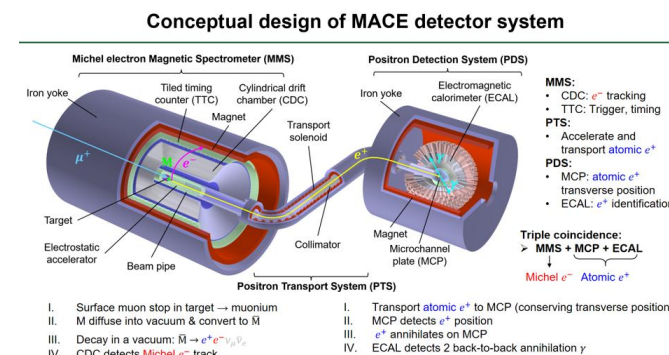
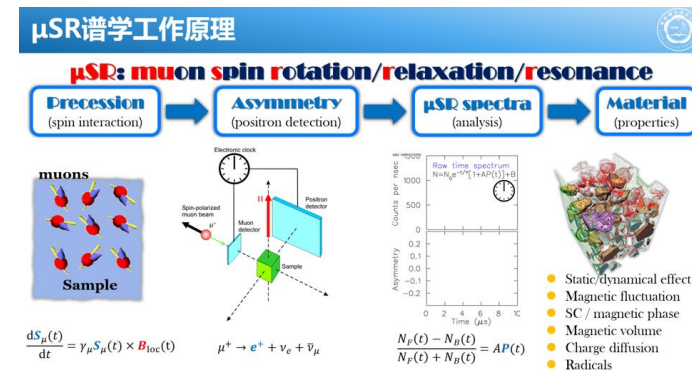
- Mu2e, COMET, g-2/ μ EDM international collaboration (IHEP, SJTU, SYSU, IMP, etc)
- MACE experiment, CDR published (SYSU etc)

3. Hyperfine structure for Muon atomic physics and MIXE technology

- Muon Atom X-ray for QED model (IMP etc)
- Muon Atom X-ray for nuclear structure (ECNU, IMP etc)
- Muon induced X ray for element analysis and 3 D reconstruction (USTC, USC, IMP etc)

4. Muon tomography

(LZU, USC, NCEPU, TSINGHUA, USTC, IMP)



From 中山大学 赵诗涵@惠州 2026年1月

科学背景: 缪原子精密谱提取原子核电荷半径

The size of the proton 2025年7月

R. Pohl, A. Antognini, F. Nez, F. D. Amaro, F. Biraben... - nature, 2010 - nature.com

... -proton ... (a proton orbited by a negative muon); its much smaller Bohr radius compared to ordinary atomic hydrogen causes enhancement of effects related to the finite size of the p

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... -proton ... (a proton orbited by a negative muon); its much smaller Bohr radius compared to ordinary atomic hydrogen causes enhancement of effects related to the finite size of the

☆ 50 被引用次数: 2064 相关文章 所有 36 个版本 网页快照

Science 353, 669-673 (2016) Nature 575, 147-150 (2019) Annu. Rev. Nucl. Part. Sci. 63, 175-204 (2013)

Science 358, 79-85 (2017) Science 370, 1061-1066 (2020) Nature Reviews Physics 2, 601-614 (2020)

Nature Physics 14, 1111-1121 (2018) Nature 575, 147-150 (2019) Nature 575, 147-150 (2019)

Science 367, 1007-1012 (2019) Science 367, 1007-1012 (2019) Science 367, 1007-1012 (2019)

From IMP 汶伟强@惠州 2026年1月



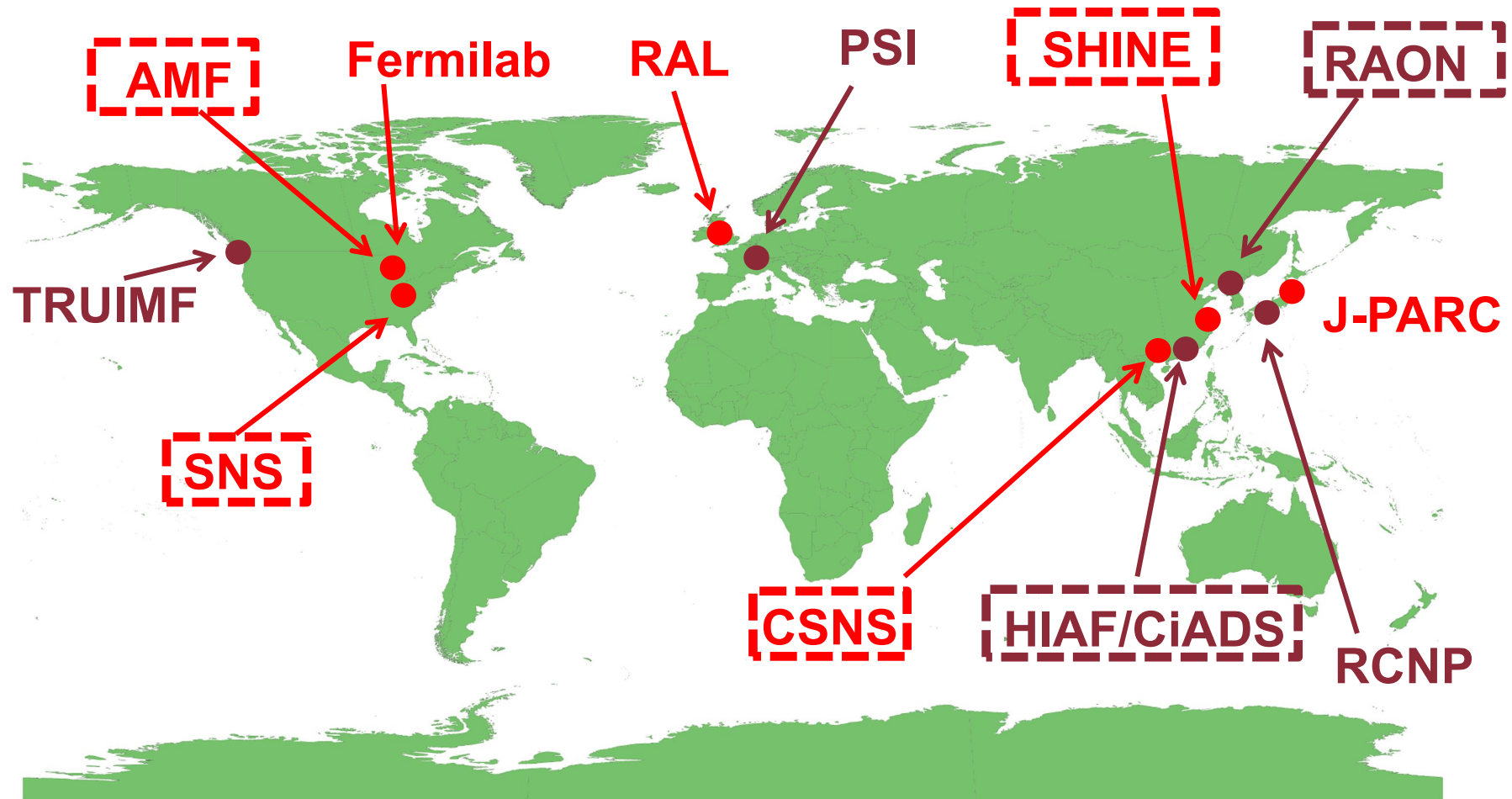
Outline



- Muon Science and Applications
- **Muon Beam Facilities around the world**
- Muon Beam Facilities in China
- Summary & Prospective future



Muon Beam Facilities around the world



- CW muon
- Pulsed muon

Coutesy of Liangwen Chen



Muon Beam Facilities around the world



Beam mode	Facility	Beam Energy (MeV)	Beam Power (kW)	Surface Muon Flux (s ⁻¹)
Pulsed	Jparc	3000	1000	10 ⁷
	ISIS	800	160	10 ⁶
CW	PSI	590	1200	10 ⁸
	RCNP	400	0.4	10 ⁵
	TRIUMF	520	75	10 ⁶



The needs and the trends



1. Higher intensity

- Future high-precision experiments and $LE\mu$ applications call for an intensity of $10^9 \sim 10^{11} \mu/s$

High Energy Physics - Experiment

[Submitted on 10 Nov 2021]

Science Case for the new High-Intensity Muon Beams HIMB at PSI

M. Aiba, A. Amato, A. Antognini, S. Ban, N. Berger, L. Caminada, R. Chislett, P. Crivelli, A. Crivellini, G. Dal Maso, S. Davidson, M. Hoferichter, R. Iwai, T. Iwamoto, K. Kirch, A. Knecht, U. Langenegger, A. M. Lombardi, H. Luetkens, F. Meier Aeschbacher, T. Mori, J. Nuber, W. Ootani, A. Papa, T. Prokscha, F. Renga, S. Ritt, M. Sakurai, Z. Salman, P. Schmidt-Wellenburg, A. Schöning, A. Signer, A. Soter, L. Stingelin, Y. Uchiyama, F. Wauters

In April 2021, scientists active in muon physics met to discuss and work out the physics case for the new High-Intensity Muon Beams (HIMB) project at PSI that could deliver of order $10^{10} s^{-1}$ surface muons to experiments. Ideas and concrete proposals were further substantiated over the following months and assembled in the present document. The high intensities will allow for completely new experiments with considerable discovery potential and unique sensitivities. The physics case is outstanding and extremely rich, ranging from fundamental particle physics via chemistry to condensed matter research and applications in energy research and elemental analysis. In all these fields, HIMB will ensure that the facilities $S\mu S$ and CHRISP on PSI's High Intensity Proton Accelerator complex HIPA remain world-leading, despite the competition of muon facilities elsewhere.

Comments: 116 pages, 42 figures

Subjects: **High Energy Physics - Experiment (hep-ex)**; Materials Science (cond-mat.mtrl-sci); High Energy Physics - Phenomenology (hep-ph)

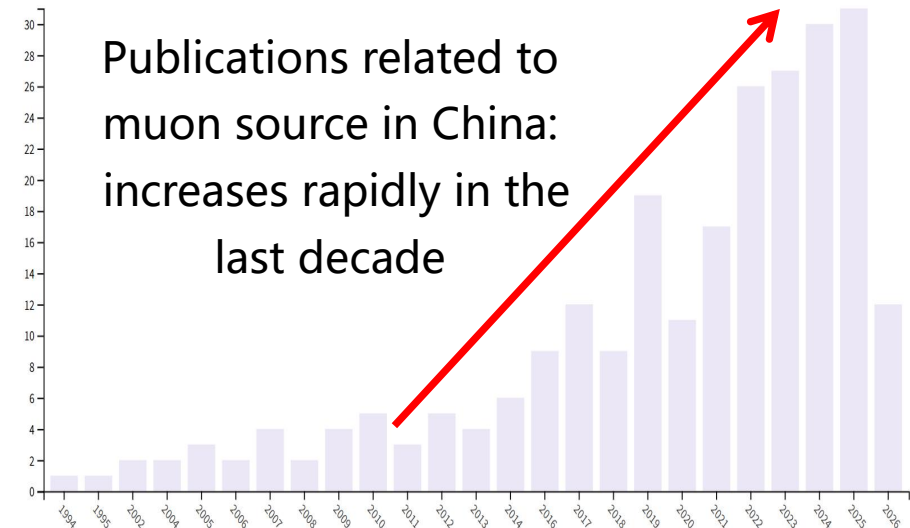
Cite as: [arXiv:2111.05788 \[hep-ex\]](https://arxiv.org/abs/2111.05788)

(or [arXiv:2111.05788v1 \[hep-ex\]](https://arxiv.org/abs/2111.05788v1) for this version)

<https://doi.org/10.48550/arXiv.2111.05788>

2. New facility

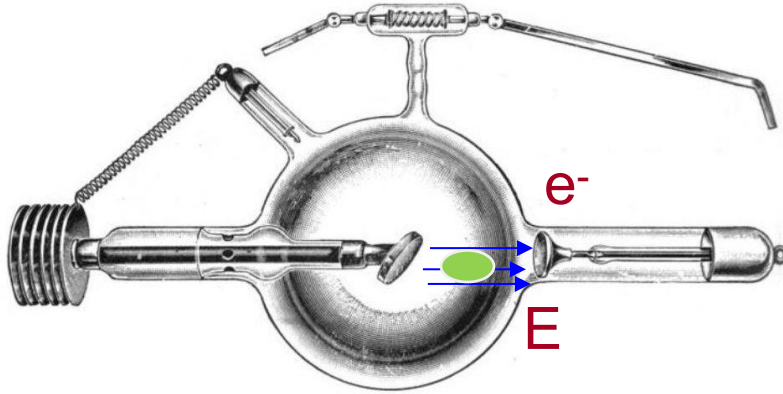
- Several muon experiments and applications have been proposed in China



- New technologies are needed (high-power accelerator, new target solution, high-efficiency collection, cooling/acceleration, new detector)

- Efforts are underway to develop muon facilities at CSNS, HiAF, **CiADS** and SHINE
- Soon, we will see first muon beam in China

Positive
Voltage

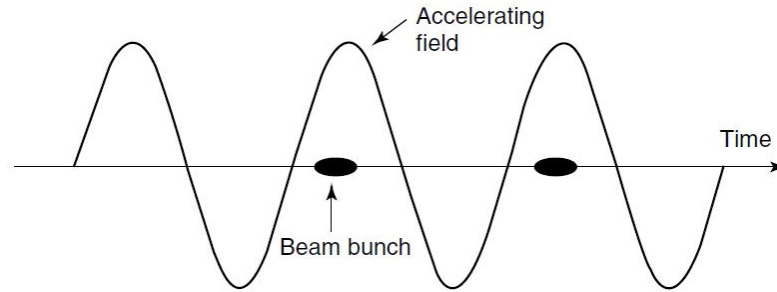


Negative Voltage

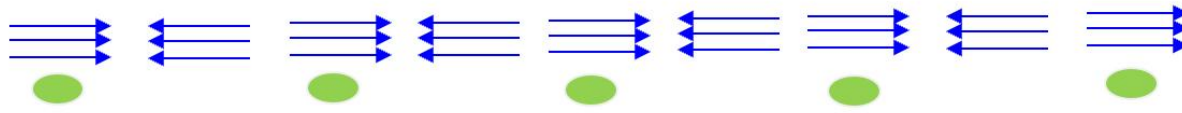
Original particle Accelerator——X-ray tube



E-Static
Acceleration



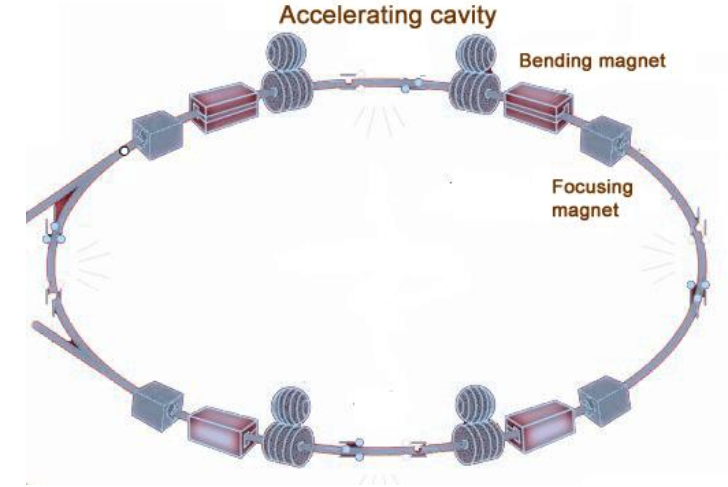
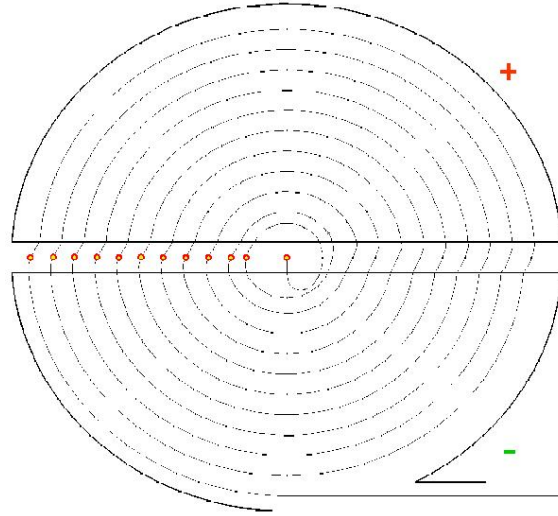
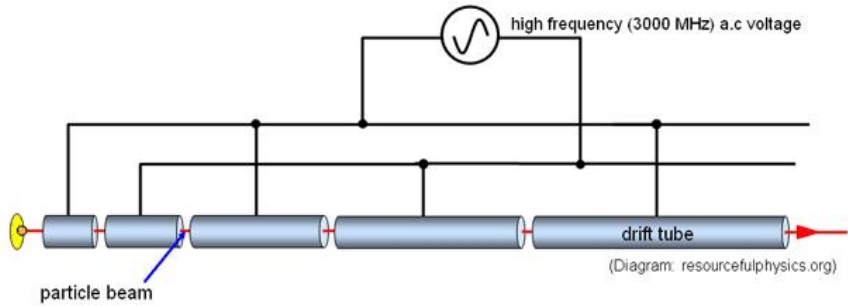
RF
E-field E_p



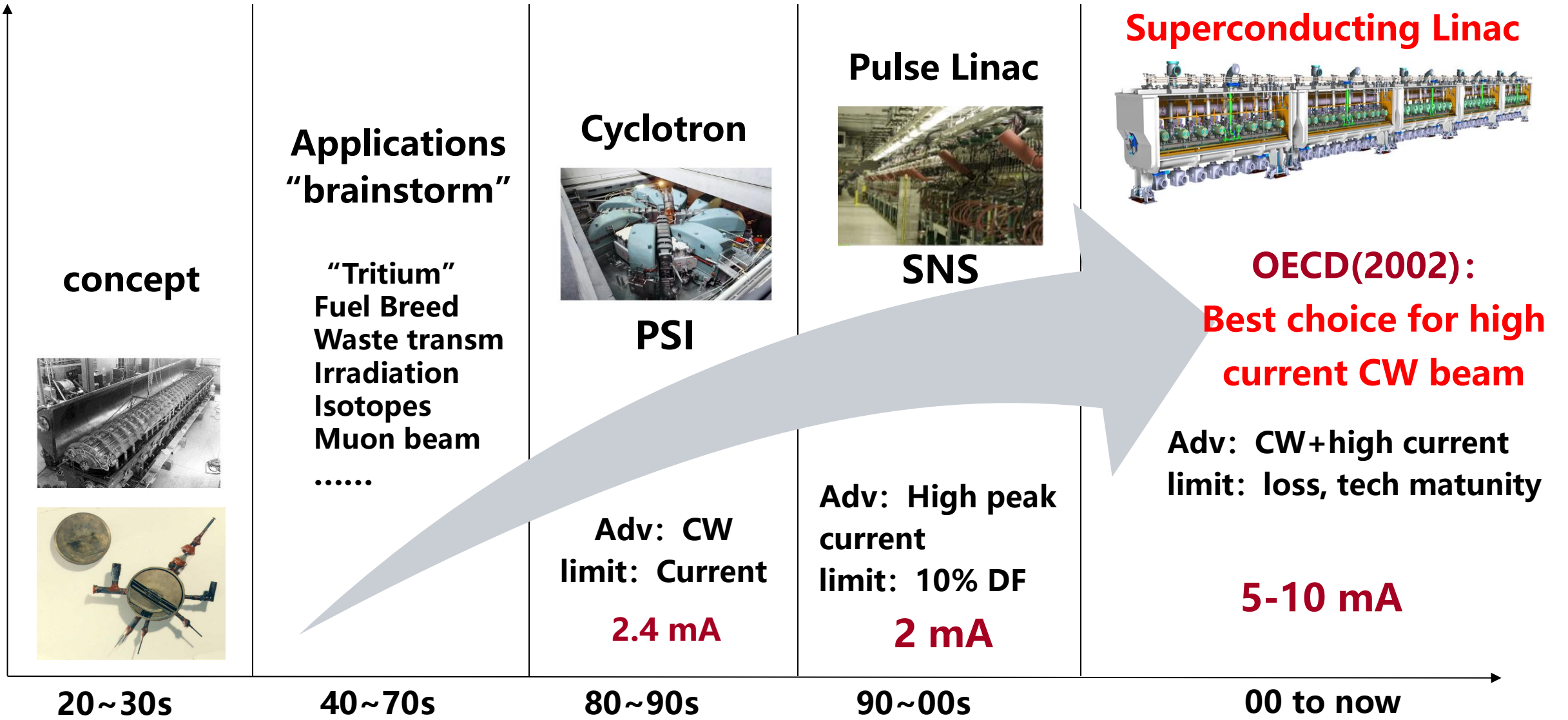
Principle of RF acceleration

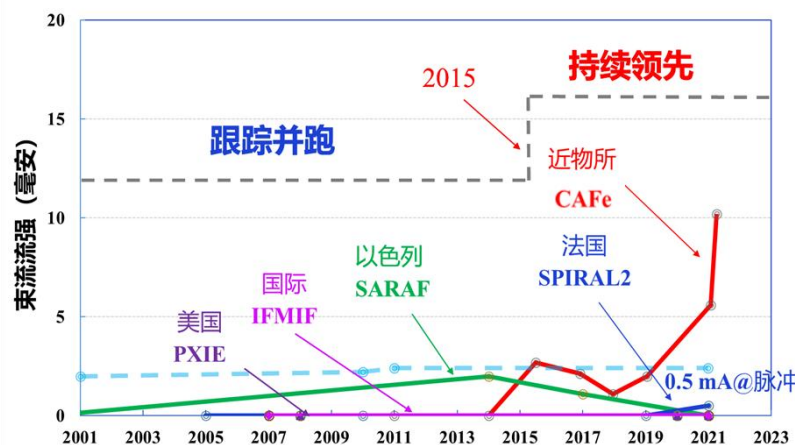
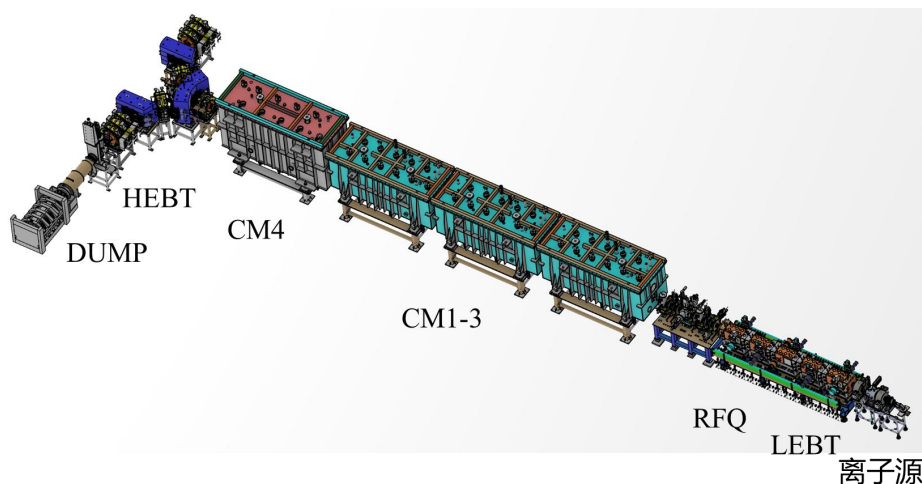


RF
Acceleration



	Linac	Cyclotron	Synchrotron
Acceleration times per gap	Once	Multi	Multi
Focising magnet	static	static	time-varying
Energy constraint	length and gradient	radius and B field	radius and B field
highest energy	~GeV	$\approx 1\text{GeV}$	7 TeV





2021 10mA CW beam commissioning
world leading, Milestone in high current Acceleration



Outline



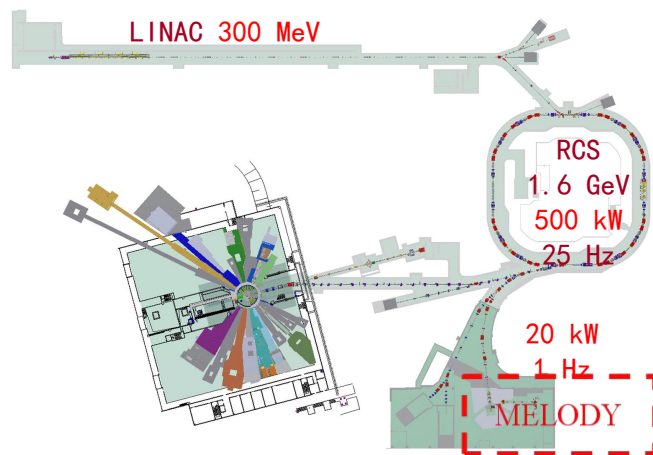
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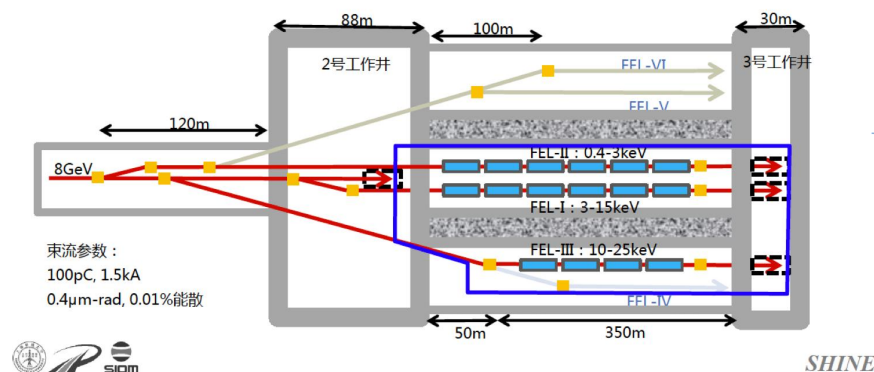
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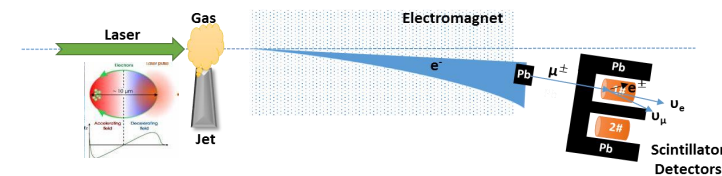
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MELODY @ CSNS



High repetition muon source
@ SHINE



Laser driven Muon Source
@ SULF



High energy muon source @ HIAF

MUST @ CiADS



Muon Beam Facilities in China



Beam mode	Facility	Beam Energy (MeV)	Beam Power (kW)	Surface Muon Flux (s ⁻¹)
Pulsed	CSNS	1600	20	10 ⁵ ~10 ⁷
	SHINE	8000 (e ⁻)		10 ⁶
	SULF	-	-	10 ² ~10 ³
	HIAF	3500	~10	10 ⁶
CW	CiADS	600	300~3000	10 ⁸ ~10 ¹⁰



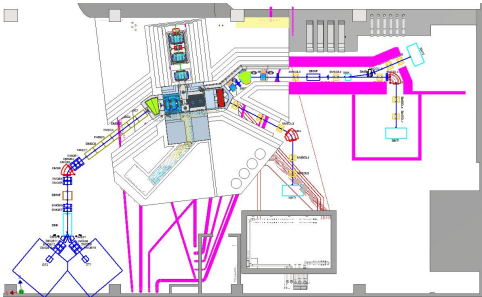
Muon Beam Facilities in China



- **MELODY @ CSNS**
- High repetition muon source @ SHINE
- Laser driven Muon Source @ SULF
- High Energy Muon Source @ HIAF
- MUST @CiADS

- **Scientific goals:** First Muon Source in China, for multidisciplinary applications
- **Design goals:** Proton power 20 kW/1Hz, muon intensity from $10^5\mu^+/s$ to $10^7\mu^+/s$

International Review On Physics Design

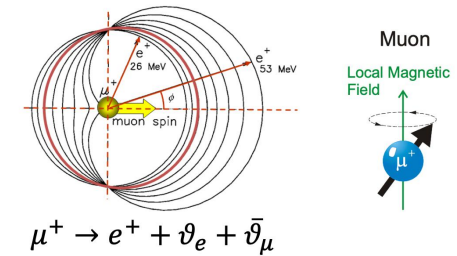


**Passed Technique
Review of MELODY**

MELODY Parameters

Parameter	Value
Proton Energy (GeV)	1.6
Proton Power (kW)	20
Muon Intensity (μ^+/s)	$10^5 \sim 10^7$
Polarization	$> 90\%$
Muon Momentum (MeV/c)	27
Beam spot (mm)	10~100
Momentum dispersion (dp/p)	6%
Detector Units	1584
Counting rate (Mevents/h)	38
Asymmetry	0.3

Applications



muSR: superconductors, condensed matter, magnetic material ...



MIXE: elementary analysis, heritage study, Lithium batteries...

Coutesy of Yu Bao

- Experimental hall will be completed in July, 2026.
- Devices installation will start in August 2026.
- Key components have been demonstrated.



Prototype of the
radiation-hard magnet
and the Wein Filter



Construction of experimental hall

Coutesy of Yu Bao

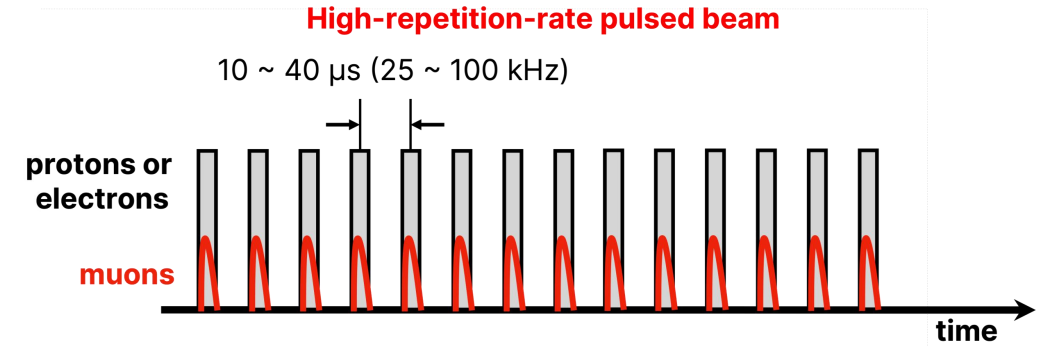
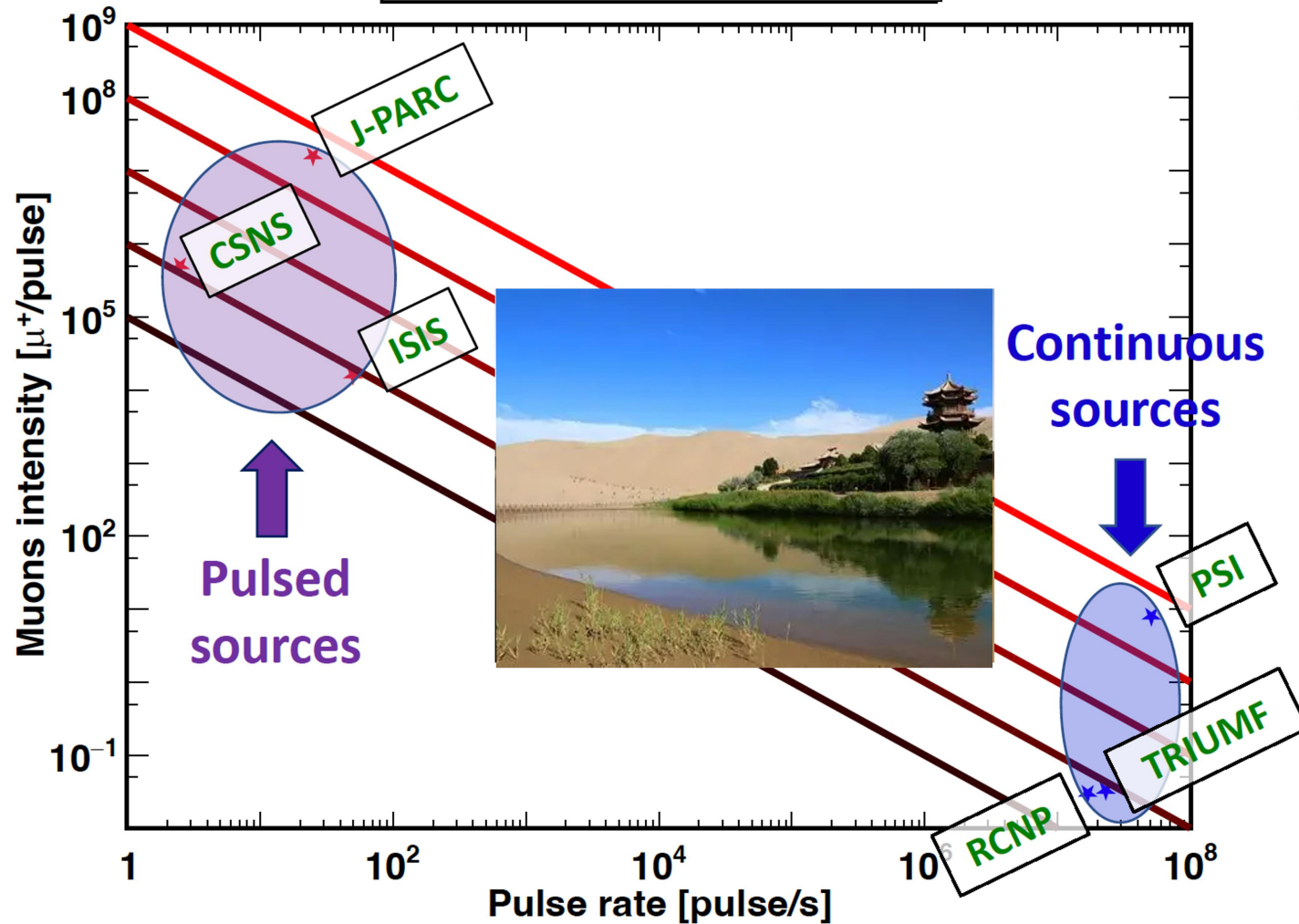


Muon Beam Facilities in China

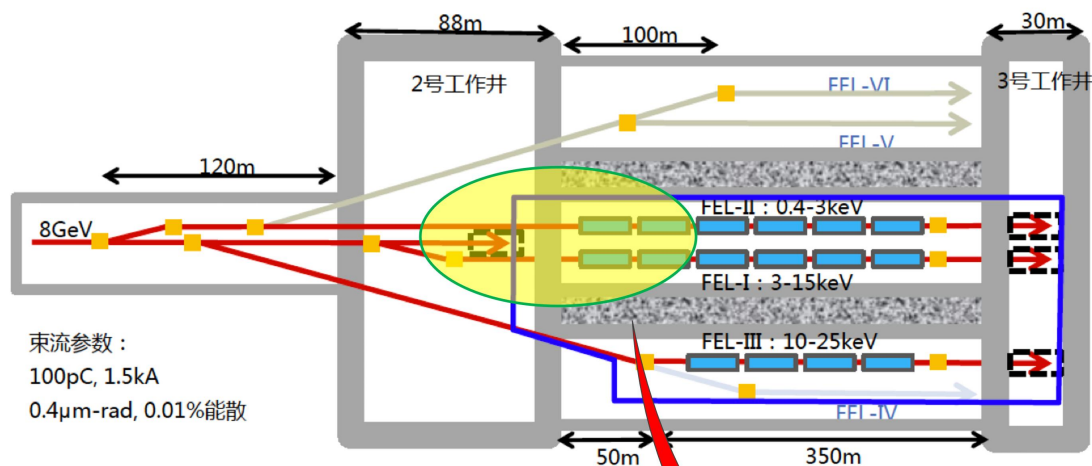


- MELODY @ CSNS
- **High repetition muon source @ SHINE**
- Laser driven Muon Source @ SULF
- High Energy Muon Source @ HIAF
- MUST @CiADS

Muon Density vs Pulse Rate



Coutesy of Kim Siang Khaw

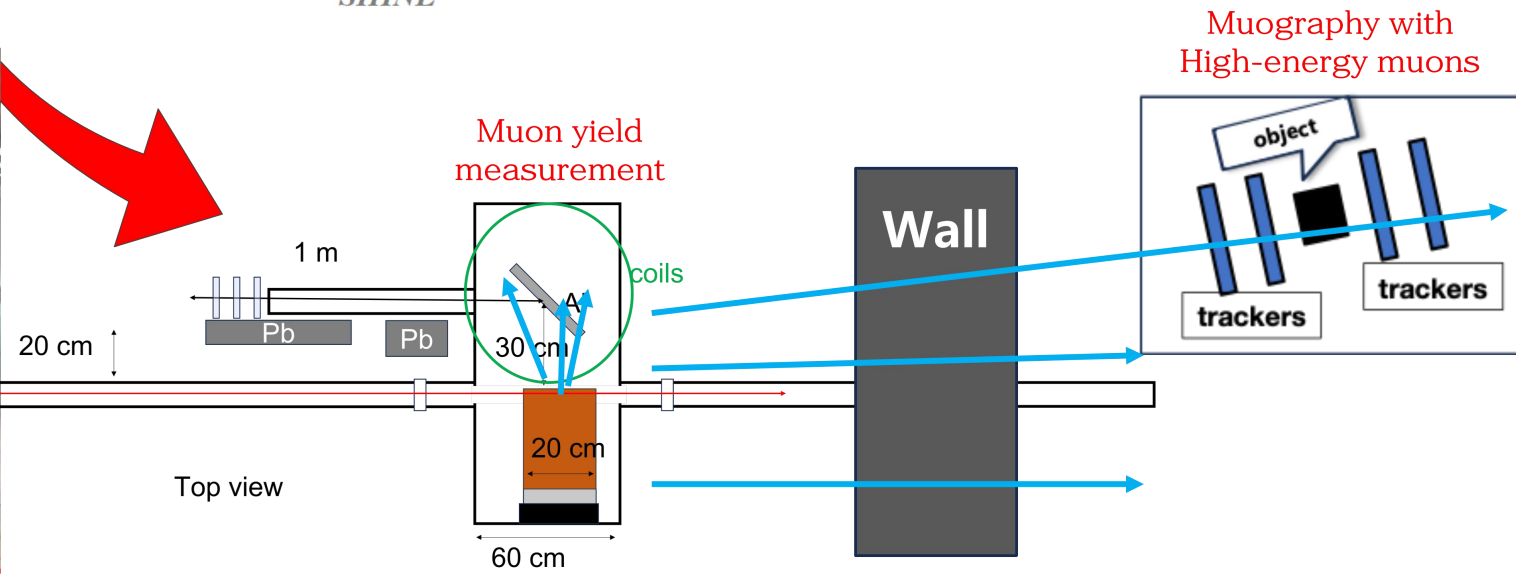
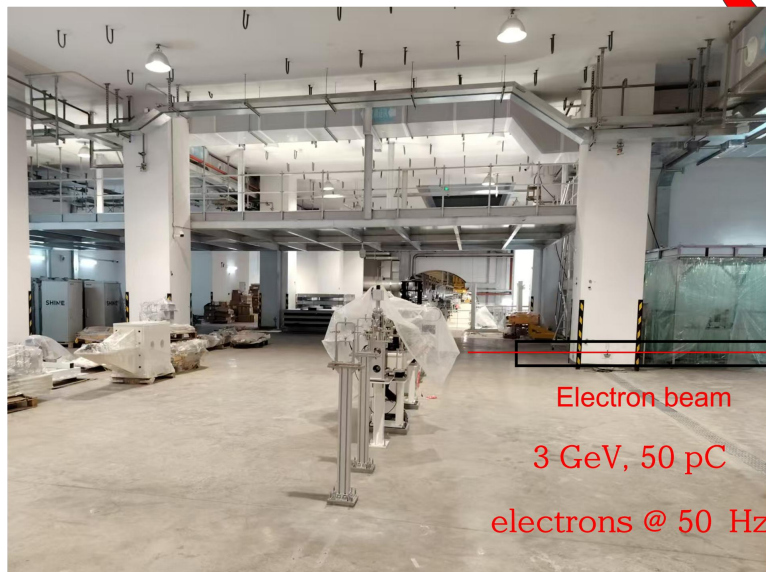


- Injector commissioning finished @ 2024 & L1 commissioning finished @ 2025
- FEL-II commissioning expected in Aug-Sep 2026 (tight beam window)

Kill two birds with one stone !



SHINE



Coutesy of Kim Siang Khaw

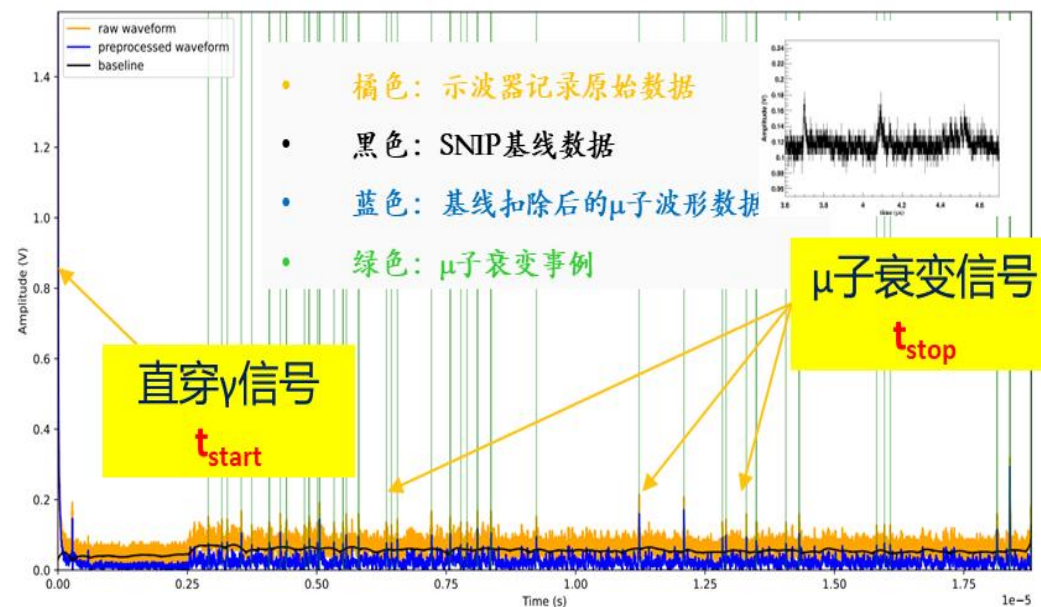
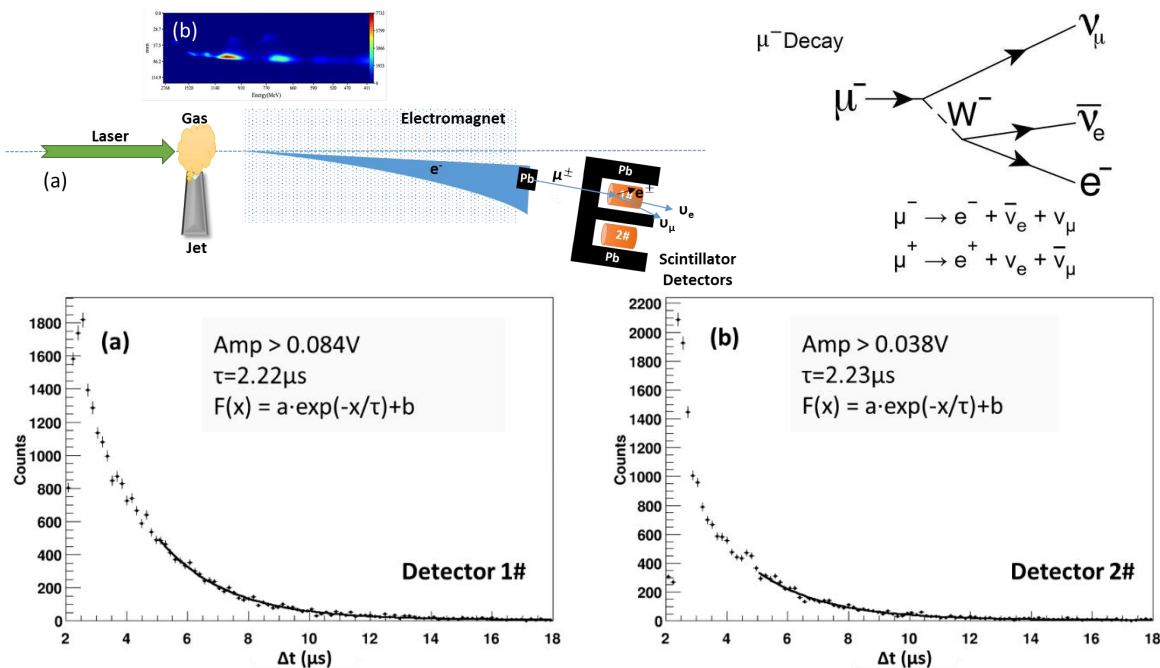


Muon Beam Facilities in China



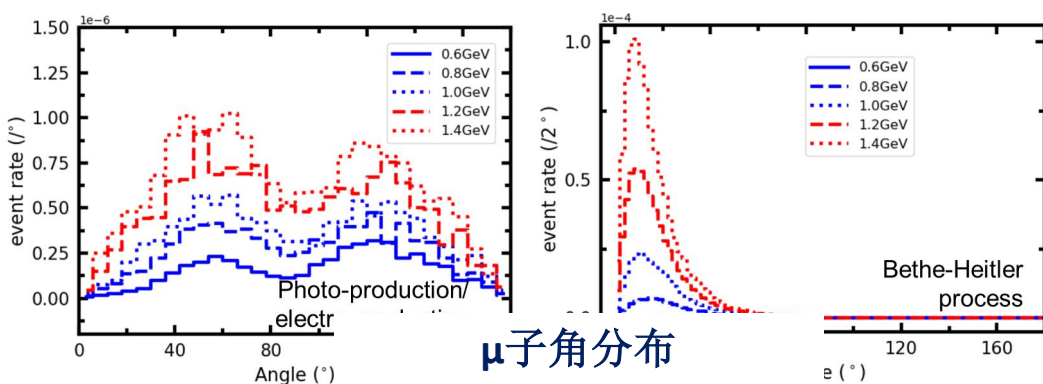
- MELODY @ CSNS
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- **Laser driven Muon Source @ SULF**
- High Energy Muon Source @ HIAF
- MUST @CiADS

- ◆ Implemented the globally first laser-driven muon generation experiment at Shanghai SULF (Xi-he Laser Facility)
- ◆ Confirm muon production in experiments with an innovative identification strategy
 - **特征独特:** 2.2 μs , 在自然界中独一无二, 排除干扰有效, 提升信噪比
 - **寿命较长:** 探测衰变正电子信号可以避开瞬态本底影响, 多发次累计统计量

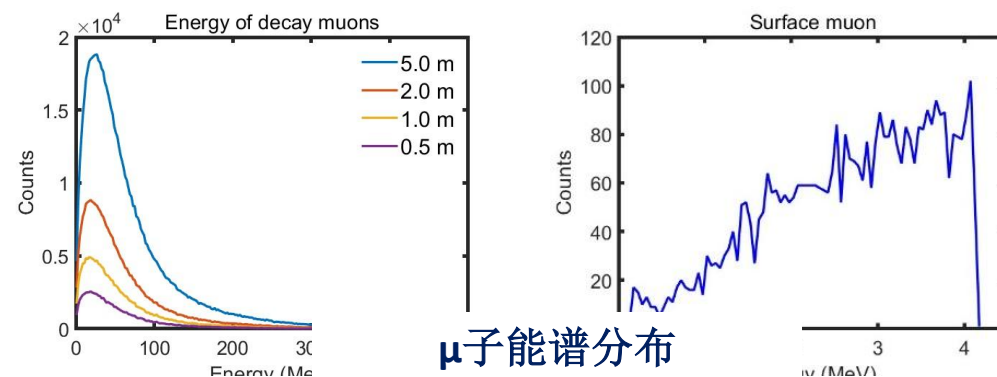


Courtesy of Feng Zhang

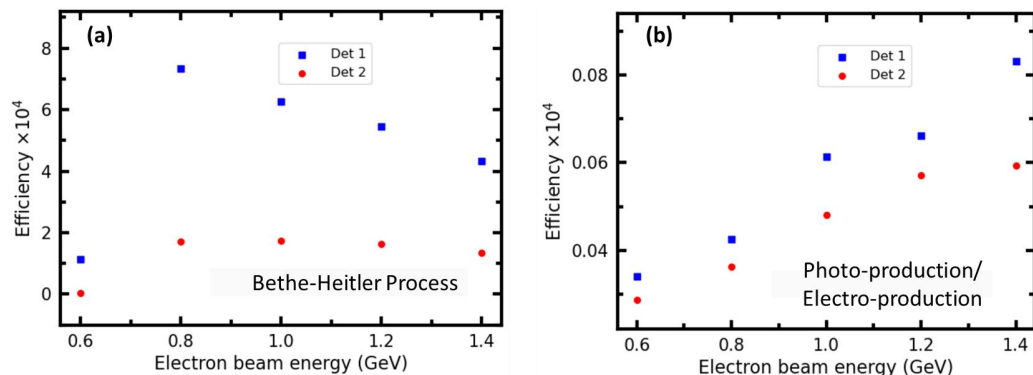
- This work clarifies that laser-generated mu-ons reported to-date mainly stem from photo-/electro-production channels involving pion-decay processes.
- The muon production yield can reach $0.01 \mu/e$. High-polarization mu-ons with a yield up to $\sim 1000/s$ are anticipated by virtue of state-of-the-art ultra-short ultra-intense laser techniques.



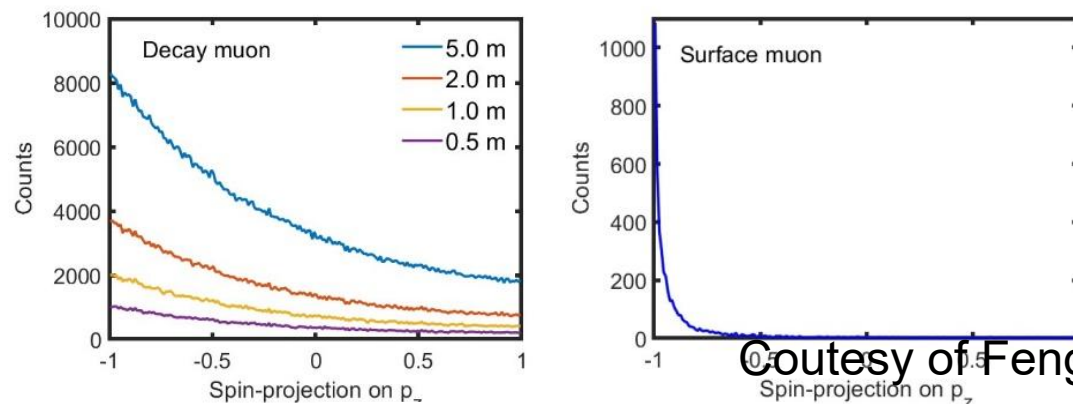
μ子角分布



μ子能谱分布



μ子探测效率



μ子极化度分布

Courtesy of Feng Zhang



Laser driven Muon Source @ SULF



Coutesy of Feng Zhang

Guangzhou, July 14, 2026

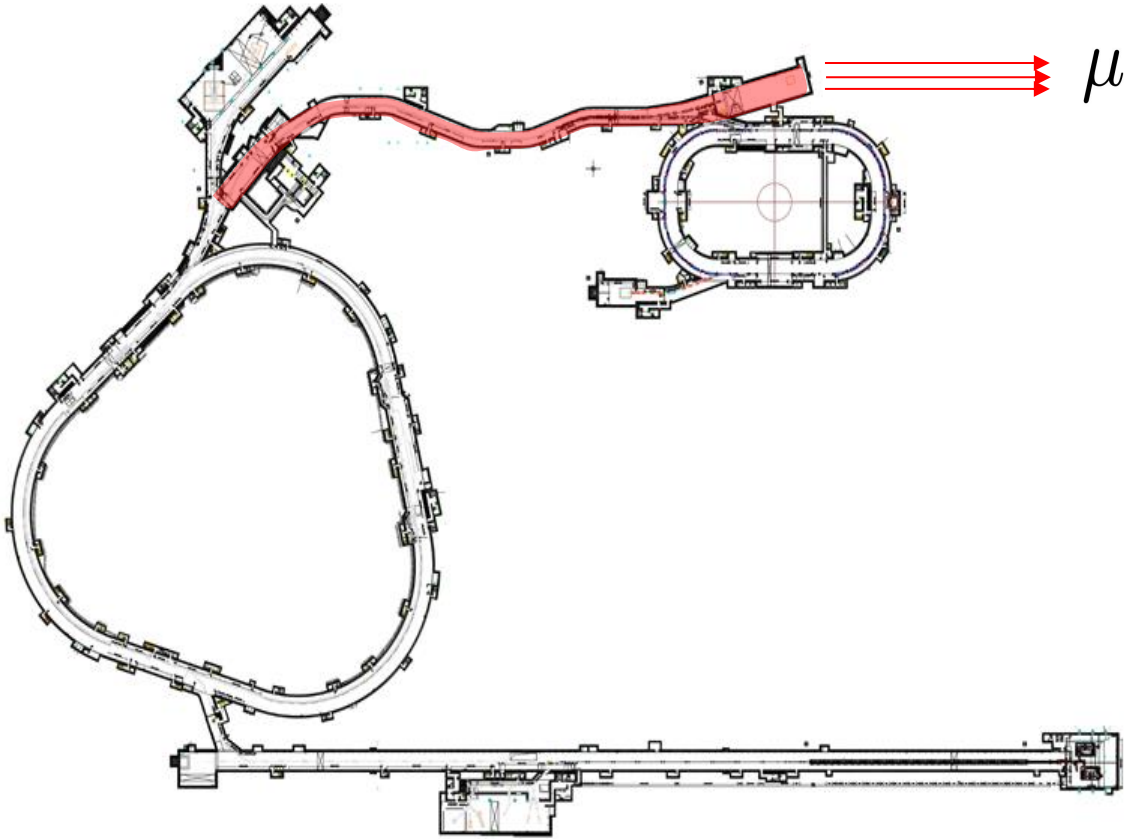


Muon Beam Facilities in China



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- MUST @CiADS

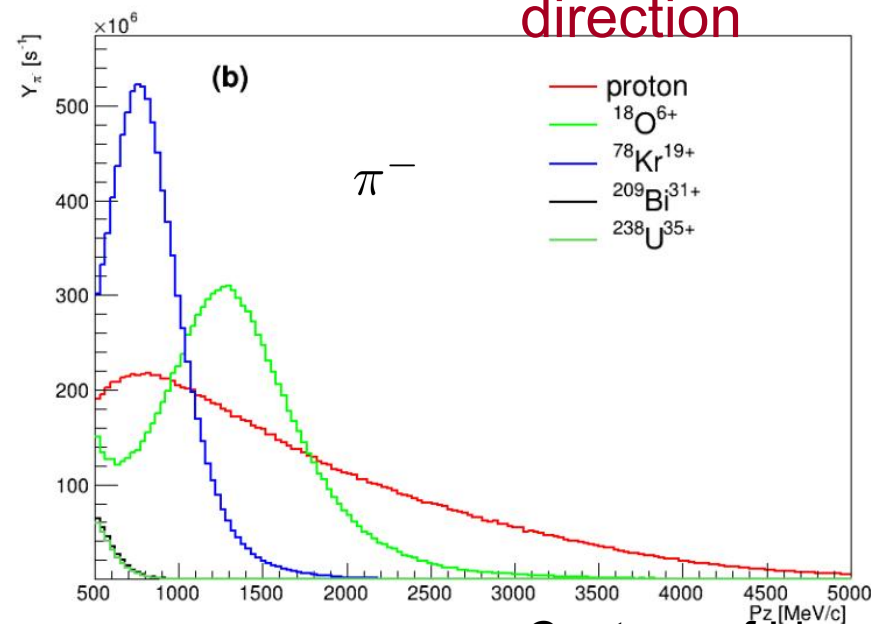
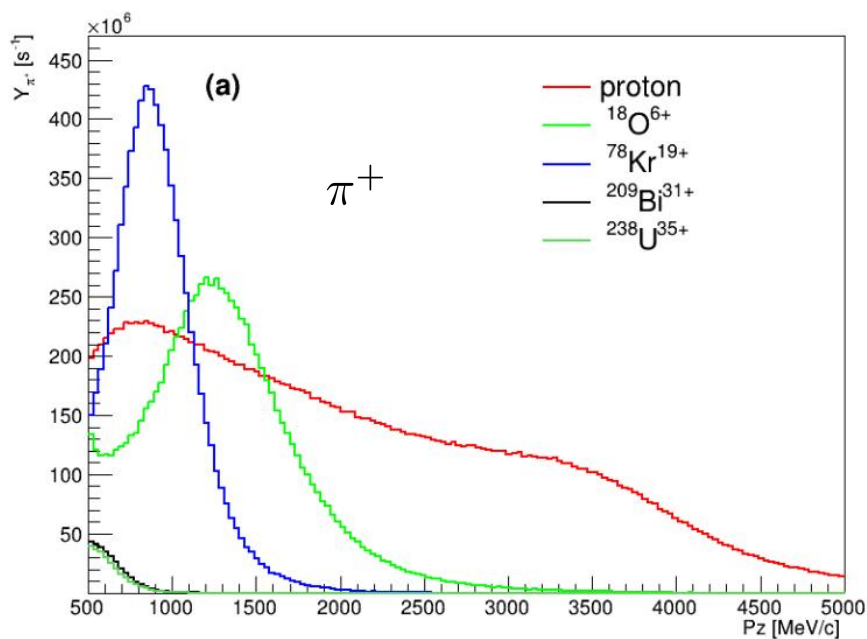
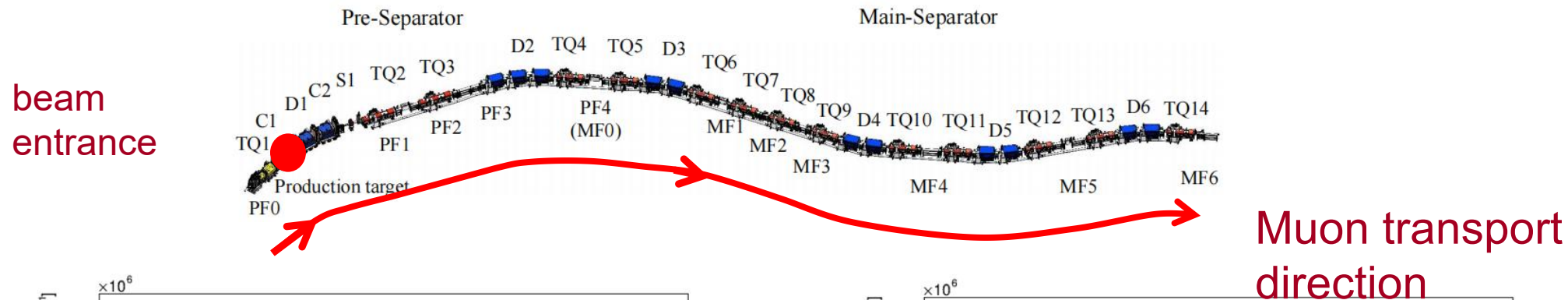
HIRIBL



Muon beam@HIAF-HIRIBL

Projectile	Muon	
	Intensity (μ^+ /s)	Momentu m(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

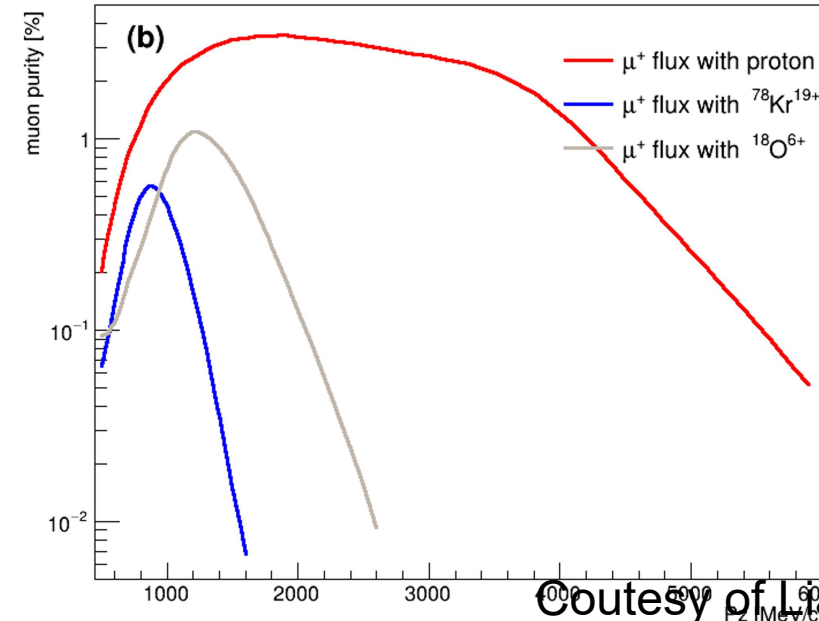
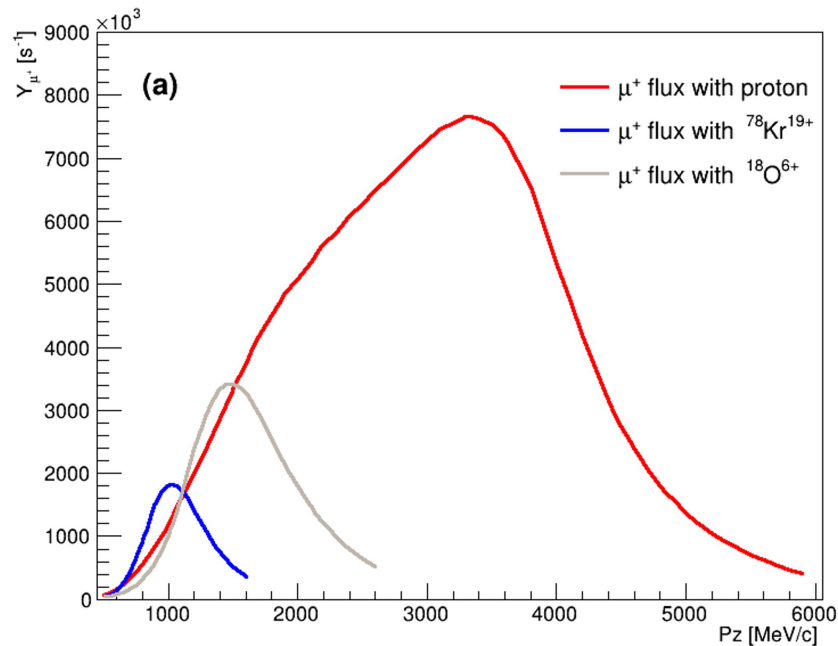
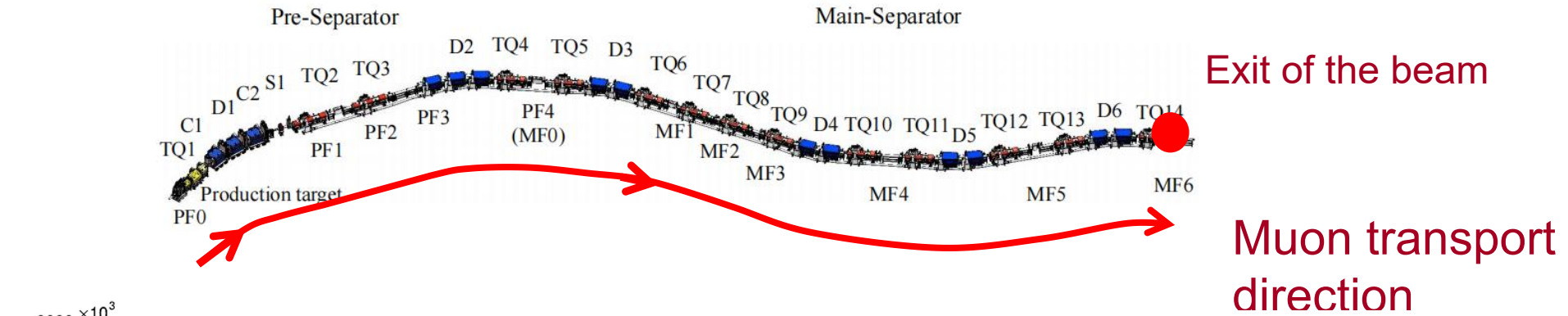
- Pion production at the beam entrance



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

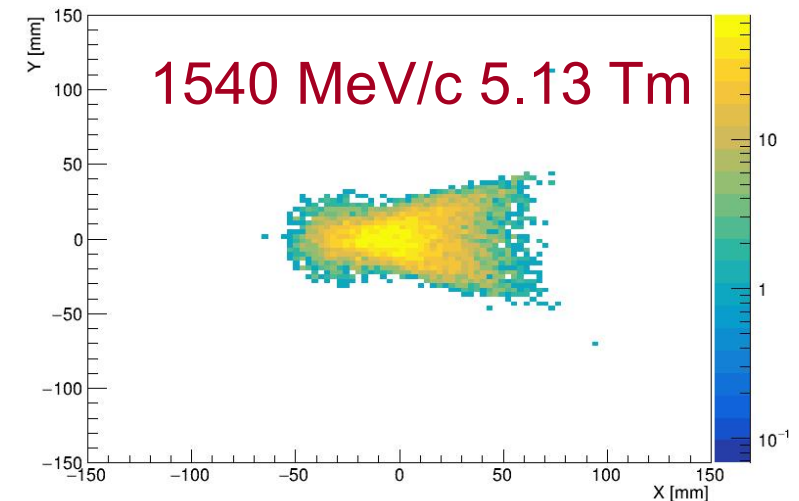
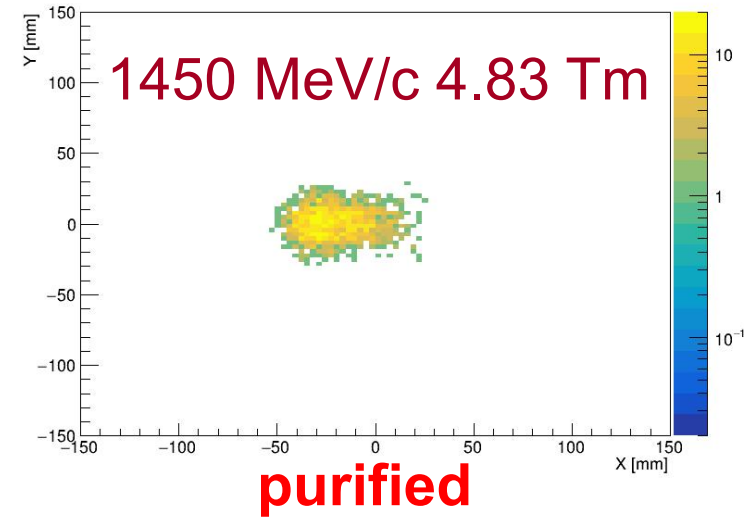
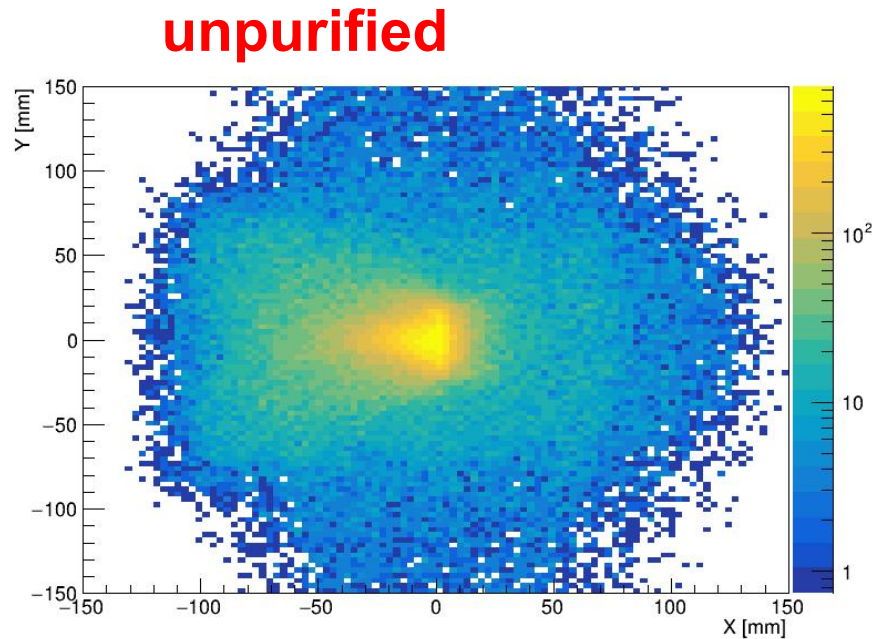
Courtesy of Liangwen Chen

- Muon yield and the corresponding purity

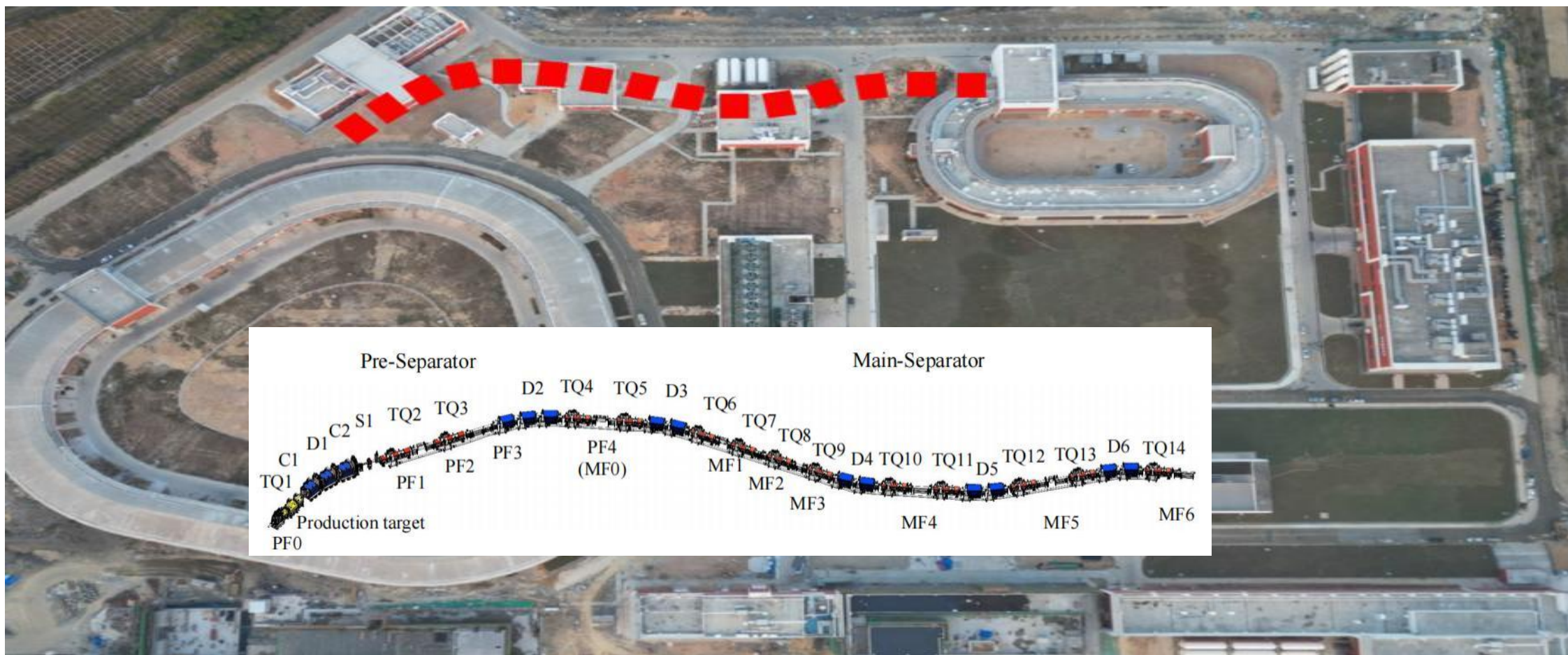


Courtesy of Liangwen Chen

- Projectile $^{18}\text{O}^{6+}$
 - muon momenta 1.5 GeV/c
- (Beam line Magnetic rigidity 5 Tm)



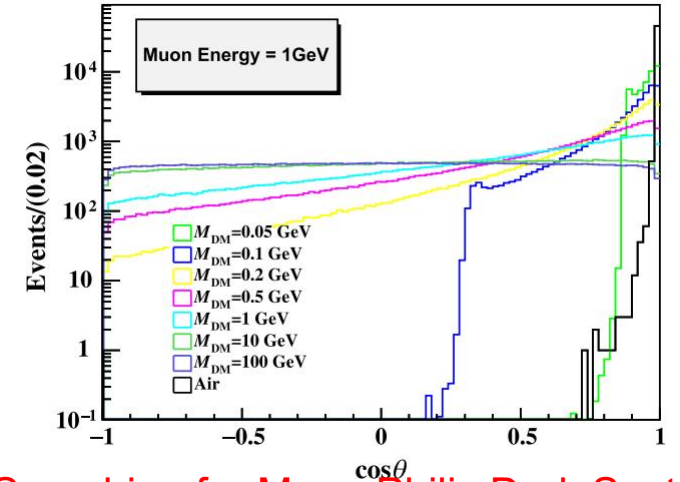
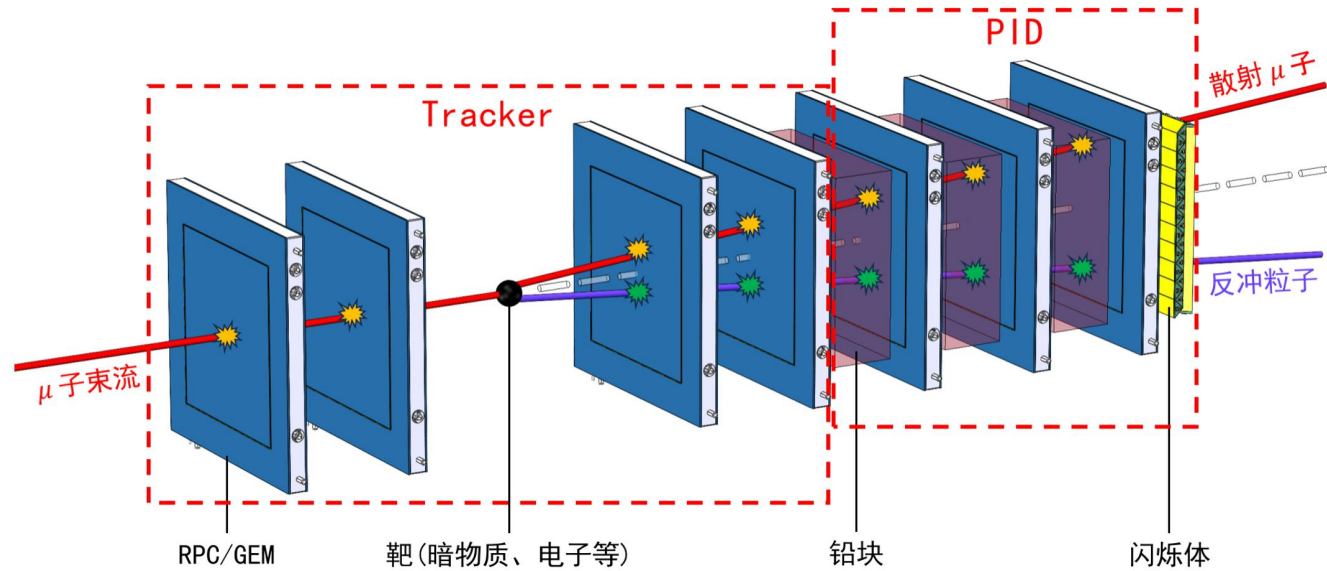
Courtesy of Liangwen Chen



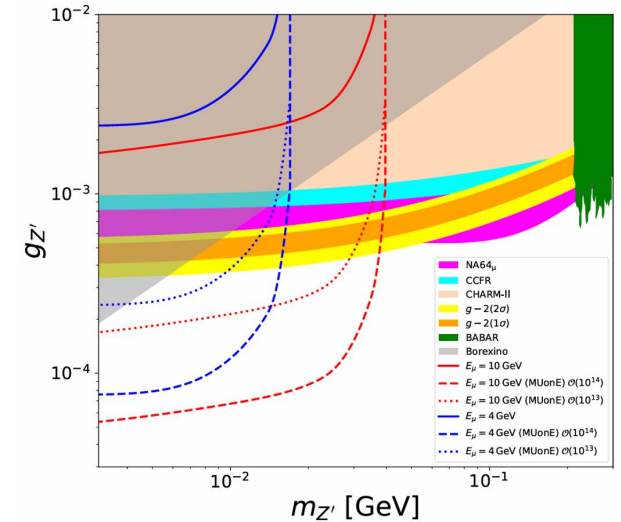
Coutesy of Liangwen Chen

Probing and Knocking with Muons

- One of the highest intensity ($4e6/s$) GeV energy muon around world
- Direct searches for DM
- Searching dark boson



Searching for Muon Philic Dark Sector



Could be more sensitive to X boson at 1-10 MeV region!

Credit: Prof. Qite Li
Prof. Chen Zhou
Prof. Qiang Li

PKμ@HIRIBL

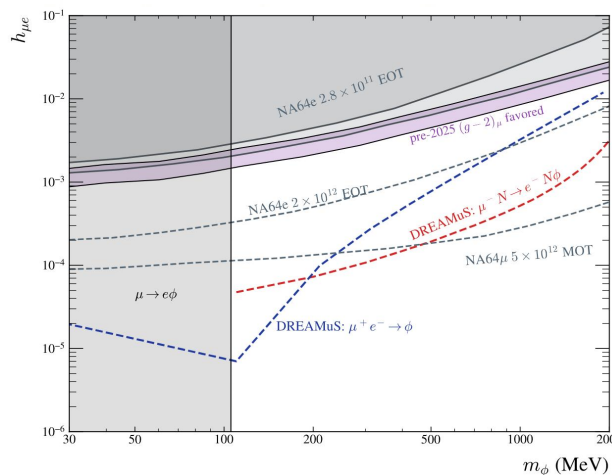
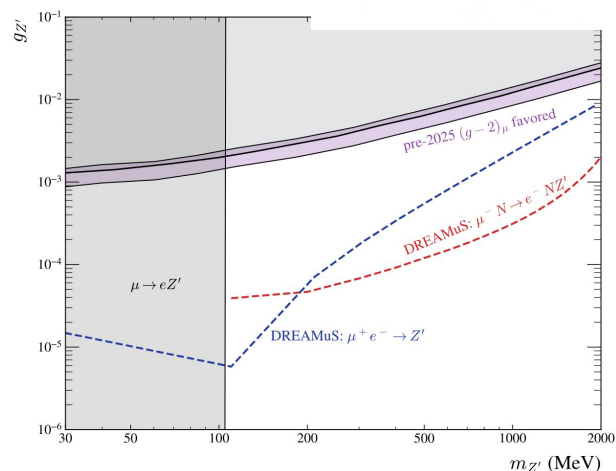
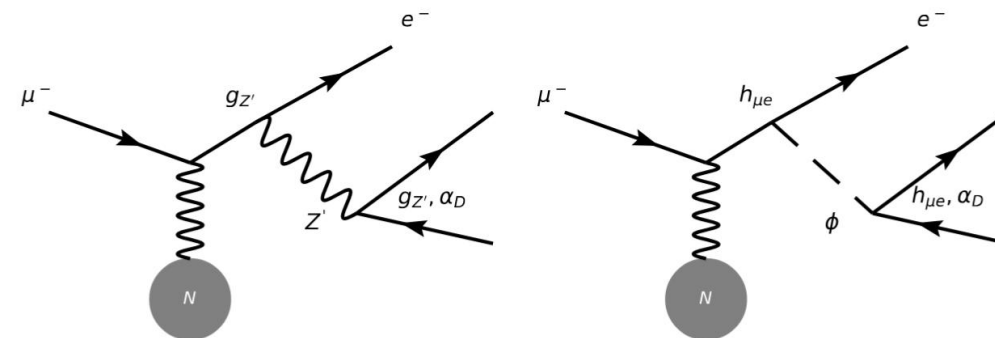
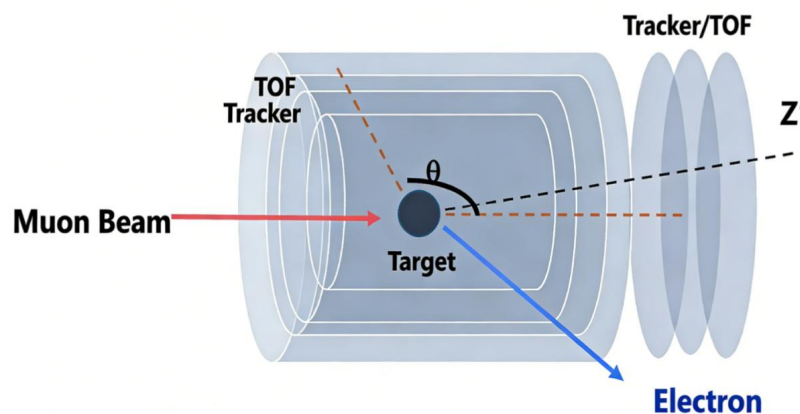
Phys. Rev. D 110, 016017

J.Phys.G 52 (2025) 7, 075002

Int.J.Mod.Phys.A 40 (2025) 35, 2550164

DREAMuS: Dark matter REsearch with Advanced Muon Source

- Dark matter (χ) from a flavor-violating Z' or ϕ scalar particle
- 3 GeV muon interaction with 22cm lead target



Best limit on flavor violating scalar ϕ model in the low mass region

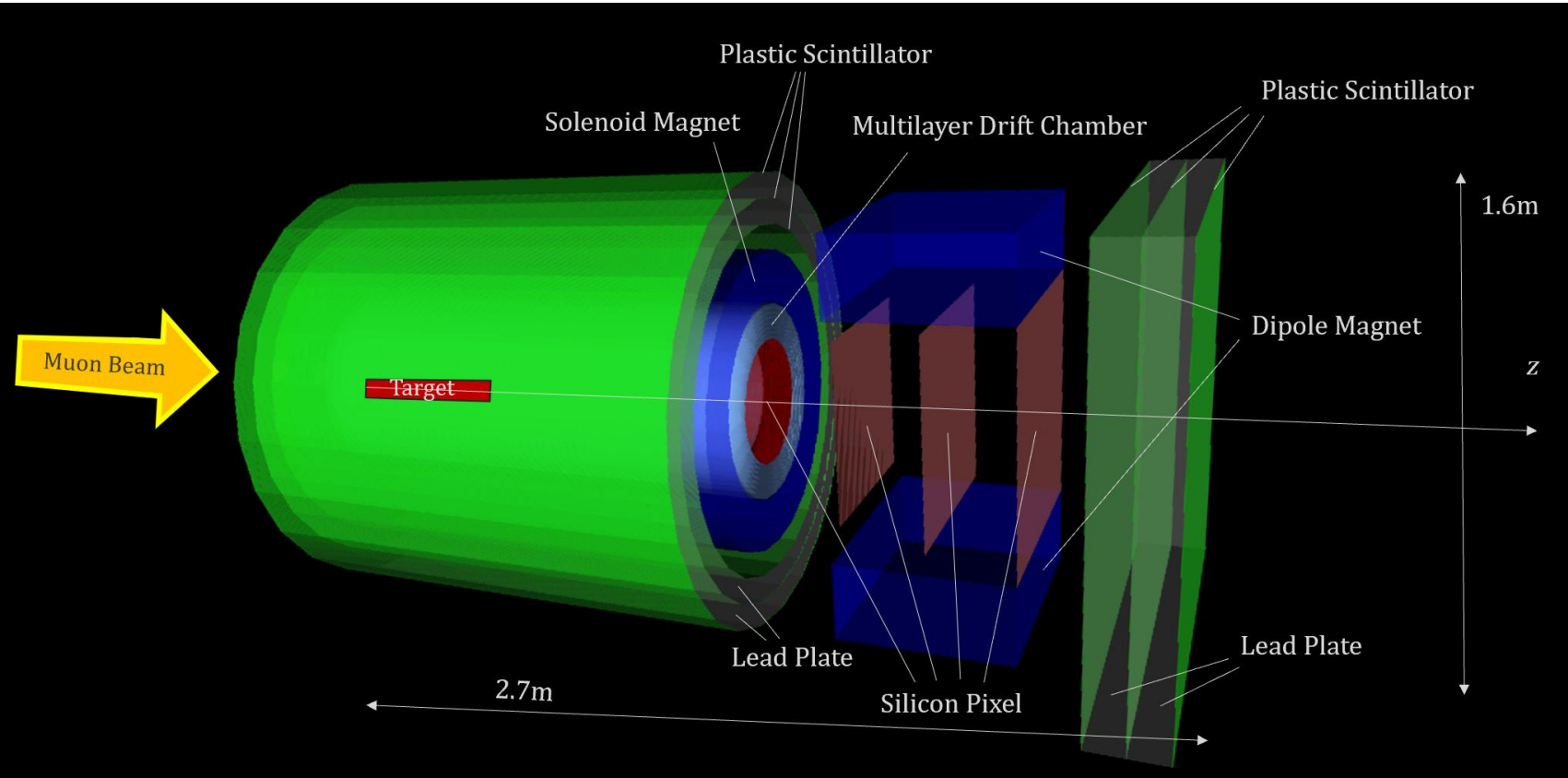
- 90% C.L. limit on $g_{Z'}$: $\sim 10^{-4} - 10^{-5}$
- 90% C.L. limit on $h_{\mu e}$: $\sim 10^{-4} - 10^{-5}$

Credit: Prof. Liang Li
arXiv: 2604.10257

LUNE :Low-energy mUon-Nucleon scattering Experiment

Phase-I: demonstration phase (< 10 M CNY)

Phase-II: full operation phase



Analyses	Impacts
Proton charge radius	★★★★★
Two photon exchange	★★★★
Proton Form factors	★★★★
Resonances	★★★
DIS	★★★★★
Semi inclusive DIS	★★★★★
DVCS	★★★★
NP (Dark matter)	★★★★
Neutron charge distri.	★★★★★
Short range corr./EMC	★★★★★
Coulomb Distortion	★★★★★

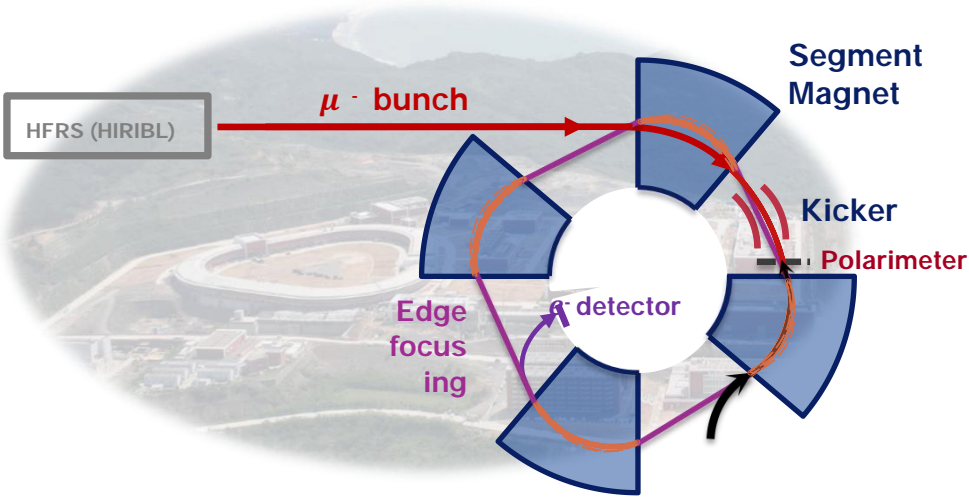
Credit: Prof. Hang Yin

CANTON- μ : Coherent Anomalous magNetic momenT Observation with muon

- A next-generation muon $g-2$ experiment targeting sub-0.1 ppm precision — the first proposal to surpass the Fermilab record (0.13 ppm)
- By prioritizing *negative* muons, it offers both precision SM test and probe to unique CPT symmetry sensitivity.

	CERN/BNL/FNAL g-2	J-PARC g-2	HIAF g-2 (CANTON- μ)
Muon momentum	3.1 GeV/c	300 MeV/c	2-4 GeV (HIAF) 10-20 GeV (HIAF-U)
Magnet	Full-ring magnet	Full-ring magnet	Sector magnet
Storage	B-field & E-field	B-field	Edge B-field
Precision	μ^+ : 0.14 ppm (FNAL) μ^- : 0.7 ppm (BNL)	μ^+ : 0.46 ppm $\rightarrow$ 0.1ppm (?)	μ^-/μ^+ : 0.1 ppm $\rightarrow$ 0.05 ppm

arXiv: 2512.11486

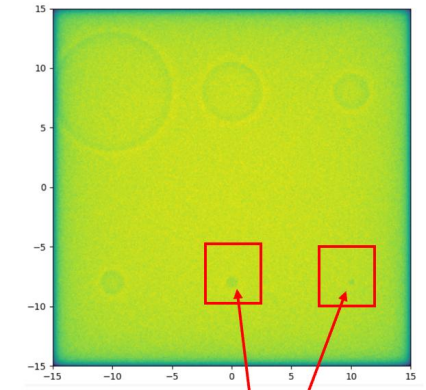
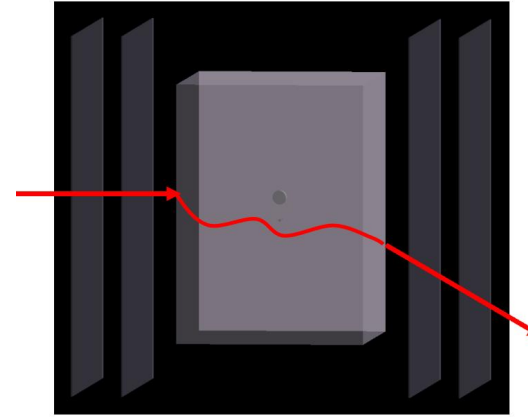
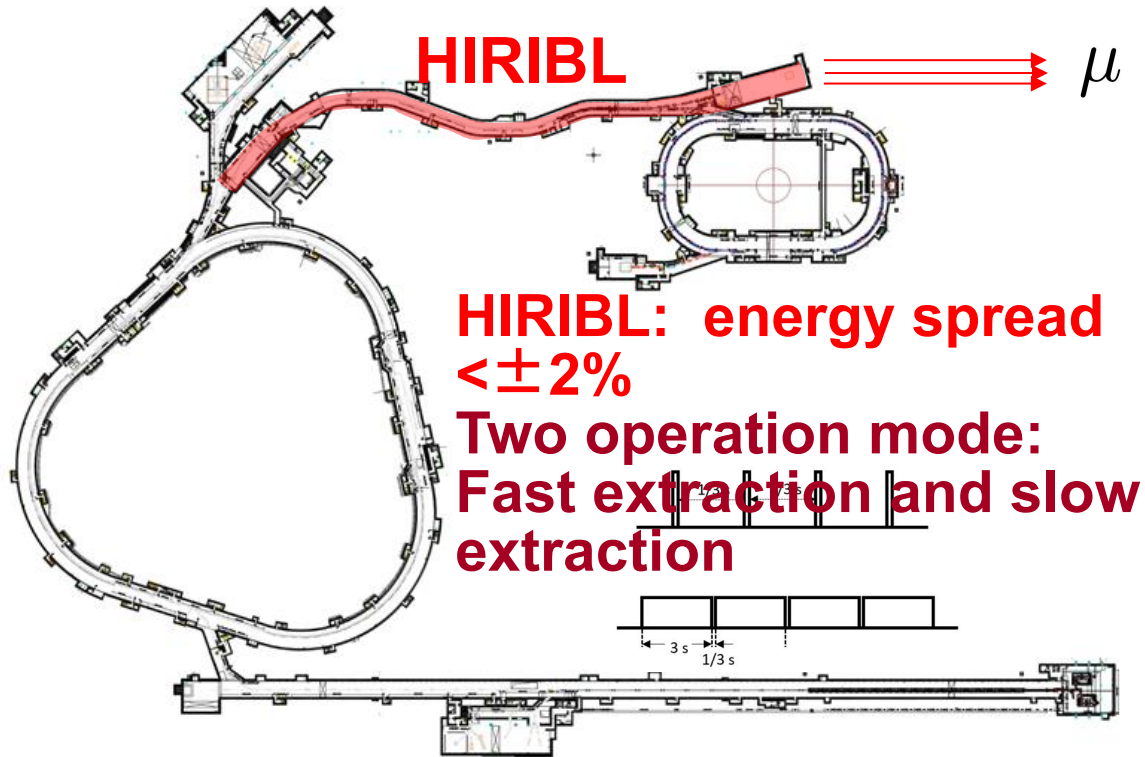


Credit: Dr. Ce Zhang

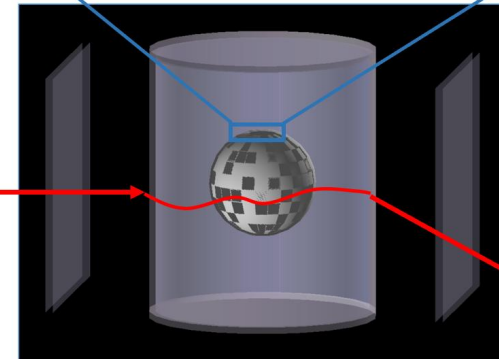
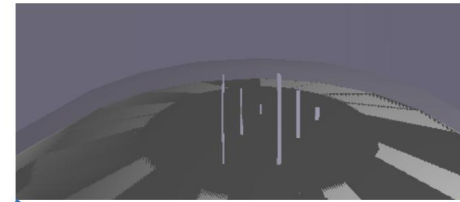
Polarized proton
(for B-field calibration)

Accelerator-based muon tomography

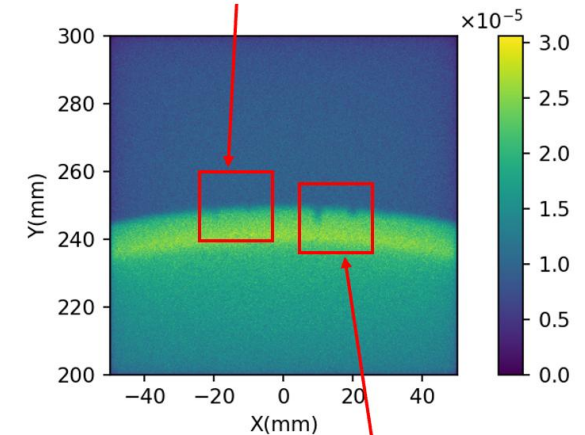
- resolve sub-millimeter-sized bubbles within a 13-centimeter-thick titanium block
- identify centimeter-length cracks within a meter-scale water tank



直径1mm, 0.5mm空气泡



截面1mm, 长度10cm/5cm缝



截面2mm, 长度10cm/5cm缝

Courtesy of Liangwen Chen



Muon Beam Facilities in China



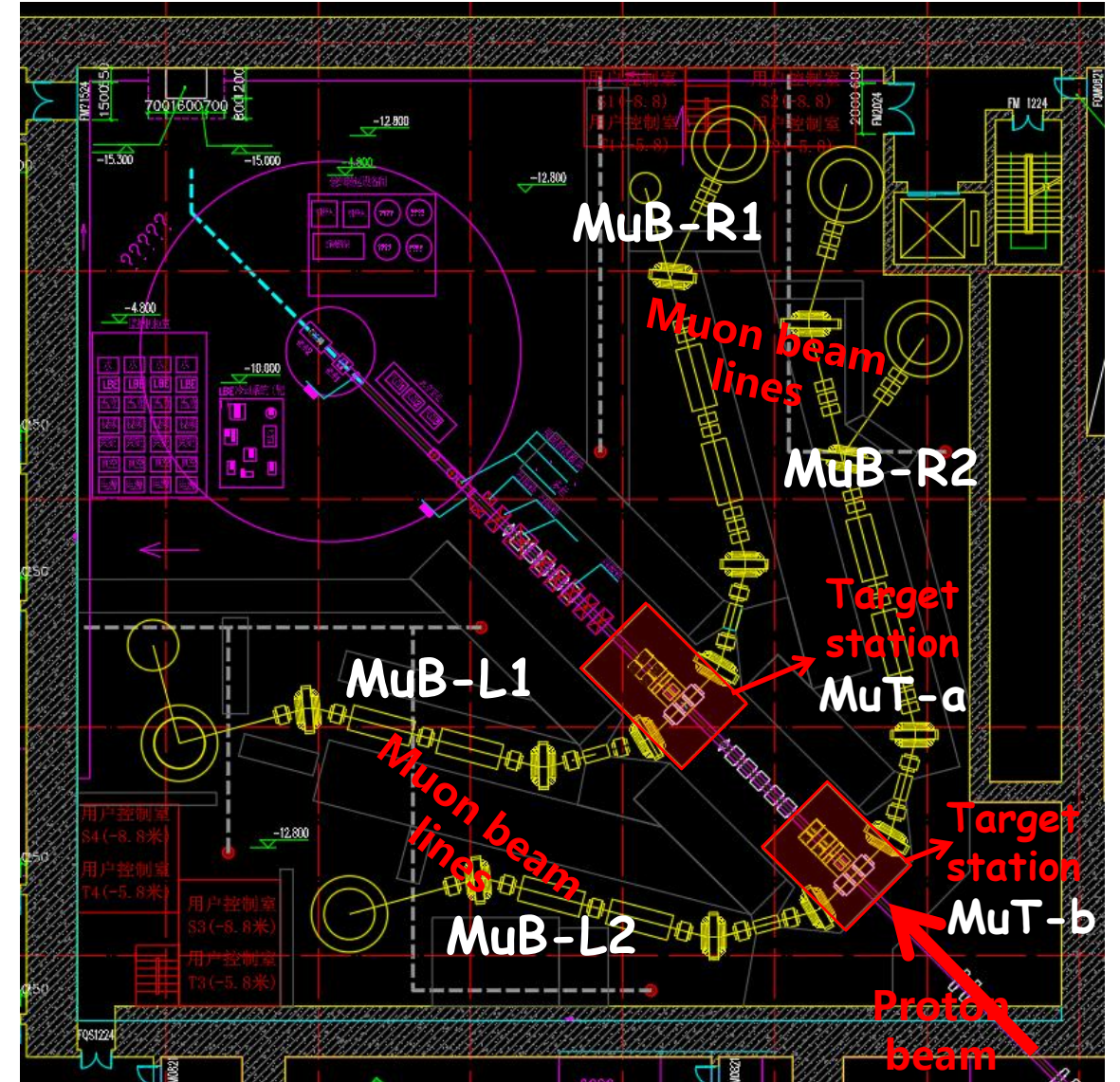
- MELODY @ CSNS
- High repetition muon source @ SHINE
- Laser driven Muon Source @ SULF
- High Energy Muon Source @ HIAF
- **MUST @CiADS**

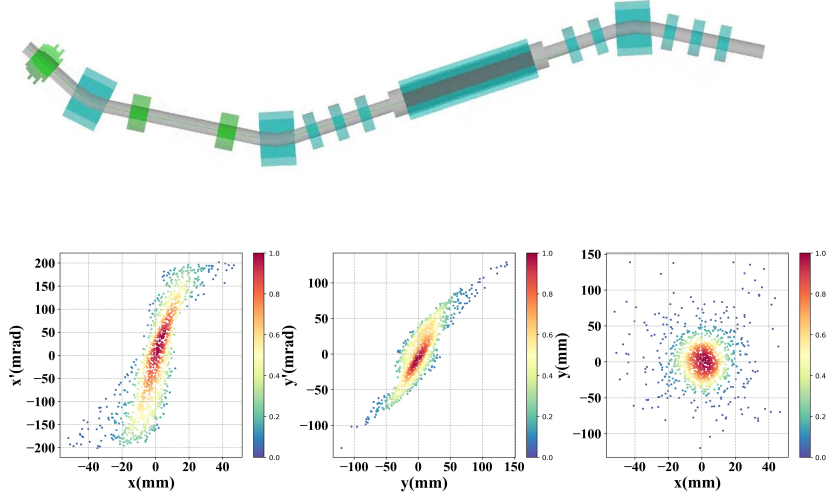
□ Conceptual Layout:

- Each of the two tandem target feeds two muon beamlines, approximately mirror-symmetric to each other
- To deliver muon beams to 5 terminals, with the intensity varies from $10^7/s \sim 10^{10}/s$

□ Plan with two phases:

Phase	Target	Muon beamlines	Applications
Phase I 2025~2029	Tgt a (MuT-a)	$\Phi 300$ up to $10^8 \mu/s$ @0.5mA	R1: ~30MeV/c $\mu SR/MACE$
			L1: to 90MeV/c MIXE/ μCF
Phase II 2029~2032	Tgt b (MuT-b)	$\Phi 500$ up to $10^{10} \mu/s$ @5mA	R2: to 90MeV/c $\mu SR/MACE$
			L2: to 120MeV/c Muography/MI XE





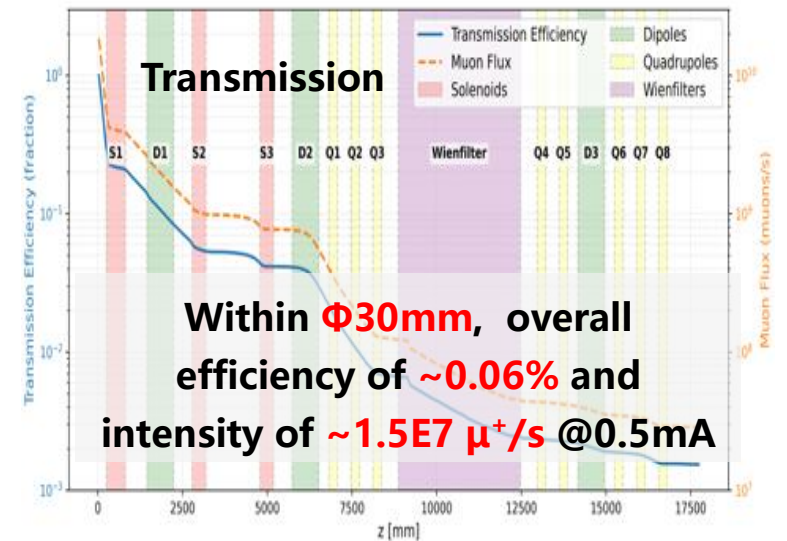
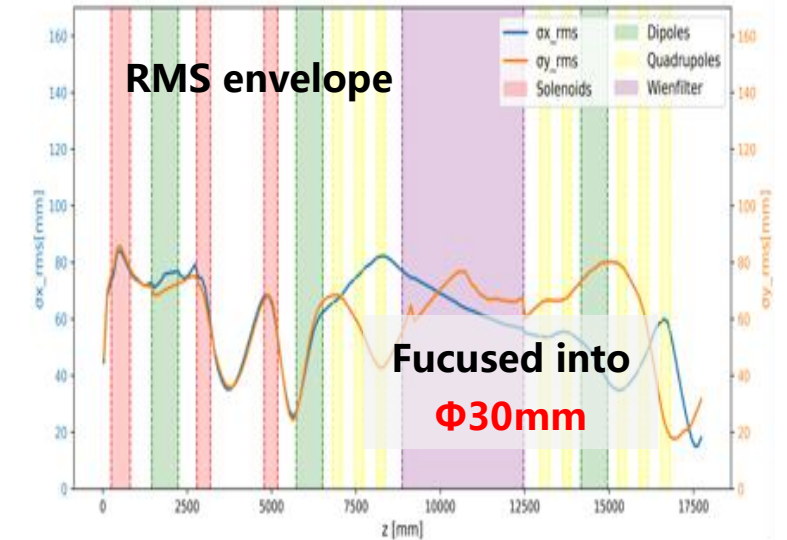
Design of muon beamline

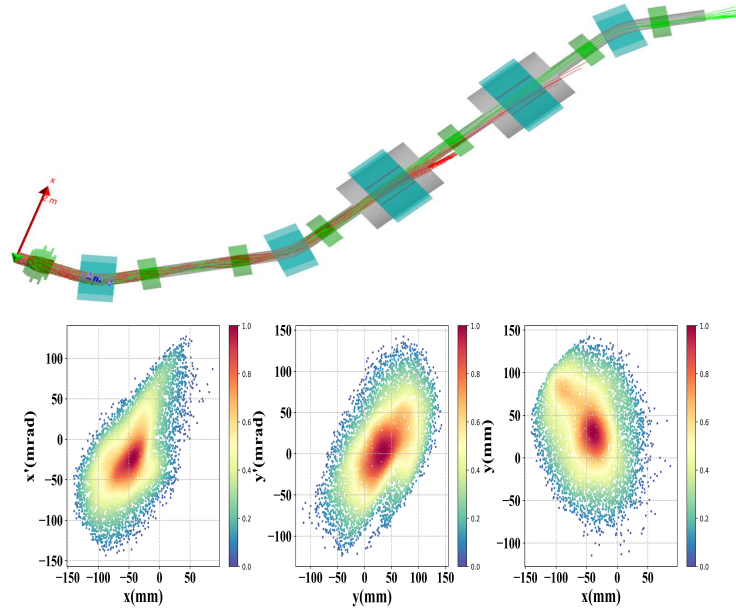
- ❑ Three dipoles to avoid a direct line-of-sight to the target
- ❑ Solenoid + QM focus surface muon beam into $\Phi 30\text{mm}$ for μSR experiments
- ❑ Intensity: $\sim 1.6\text{E}7 \mu^+/\text{s}$ @0.5mA, Polarization $\sim 96.5\%$, Background_rate < 0.1%, Momentum $\sim 28.5 \pm 0.8\text{MeV}$

Phase I, Line R1



Conceptual layout of 4 beamlines





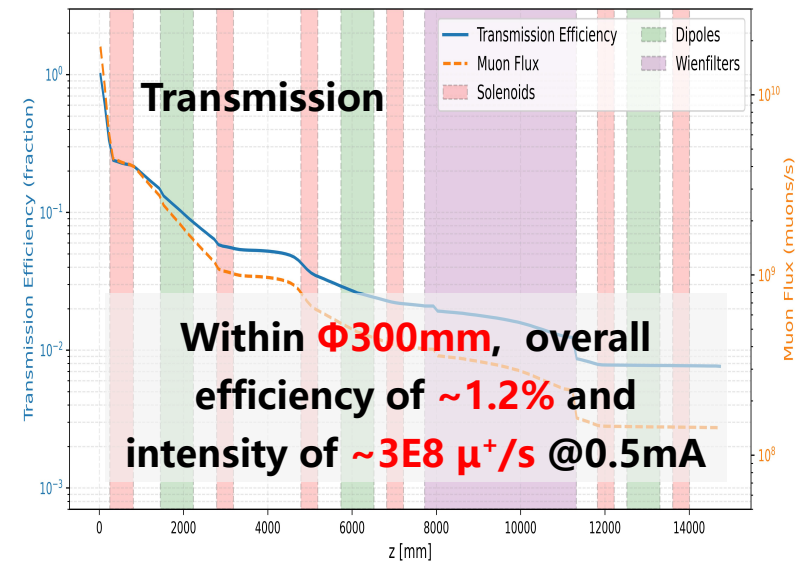
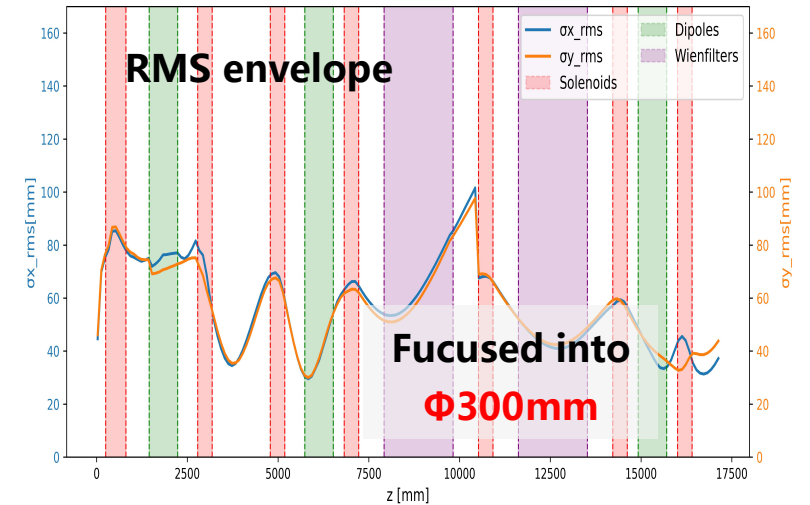
Design of muon beamline

- Full solenoid focusing for high-intensity surface/decay muons.
- Aperture of $\Phi 300\text{mm}$ to be cost-effective
- An overall efficiency of $\sim 1.2\%$ and $\sim 3\text{E}8$ μ^+/s surface muons at 0.5mA

Phase I, Line L1



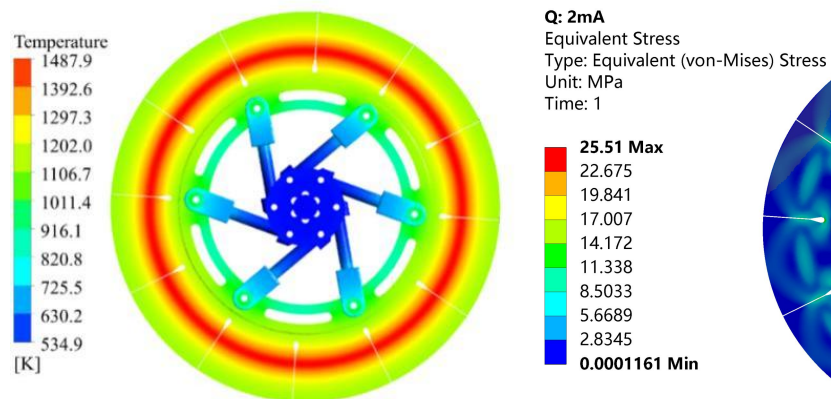
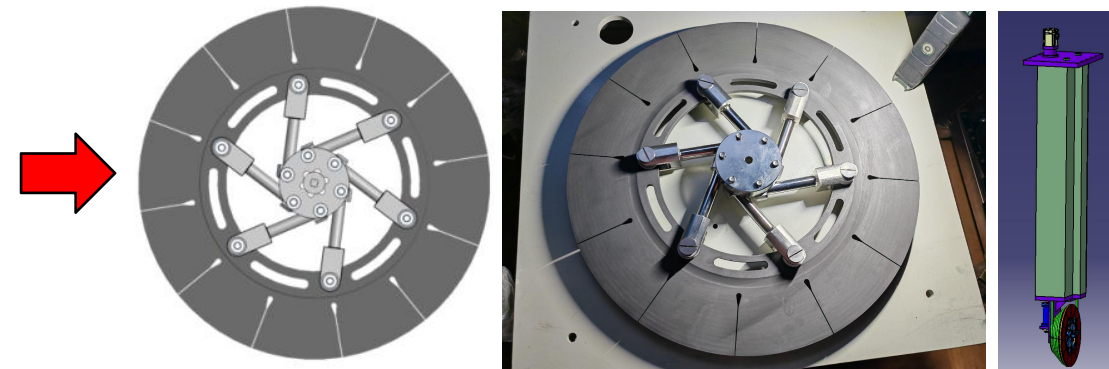
Conceptual layout of 4 beamlines



The first prototype



The second prototype



Compact structure ($\Phi 400\text{mm}$) can operate well under a thermal power of $\sim 25\text{ kW}$.

slant angle of 10° , effective thickness of 2 cm

Current(mA)	Temperature ($^\circ\text{C}$)	Thermal stress (MPa)	Deformation (mm)
0.5	622	<8.8	0.50
1.0	1096.4	<14.9	0.64
2.0	1359.3	<23.8	0.79

slant angle of 20° , effective thickness of 1 cm

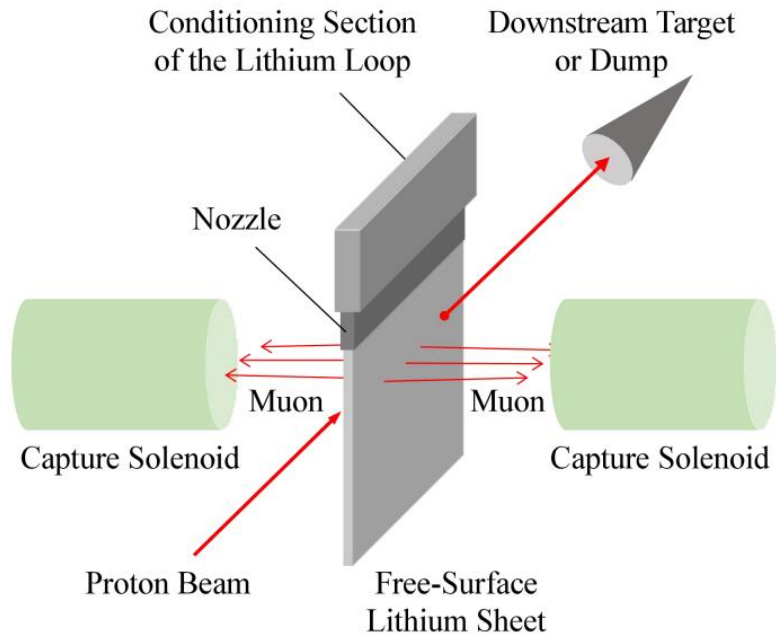
束流 流强 (mA)	能量 沉积 (kW)	靶峰值 温度 (K)	靶峰值 应力 (MPa)	靶最大 形变 (mm)	辐条峰值 温度 (K)	辐条峰值 应力 (MPa)	辐条最大 形变 (mm)
0.5	2.44	748.36	5.14	0.40	541.79	7.11	0.28
1	4.88	903.66	9.09	0.51	617.37	11.70	0.35
2	9.76	1109.72	15.35	0.65	711.89	18.07	0.43
3	14.65	1259.96	20.38	0.74	774.59	22.67	0.53
5	24.42	1487.96	28.37	0.86	860.07	29.39	0.56

- **Liquid Lithium target**
- 5 mA proton beam
- Muon beam $\sim 10^{10} \mu^+/\text{s}$

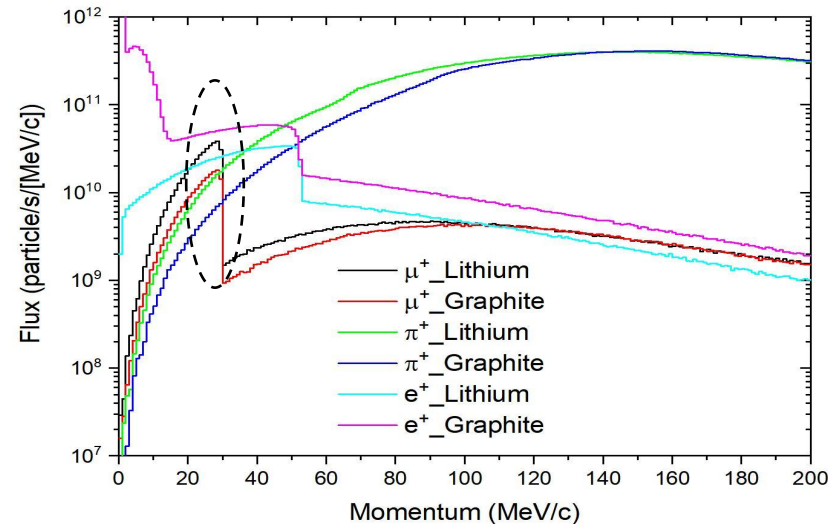
□ Benefits

- High power resistance
- More muons and compactness
- Lower irradiation and background

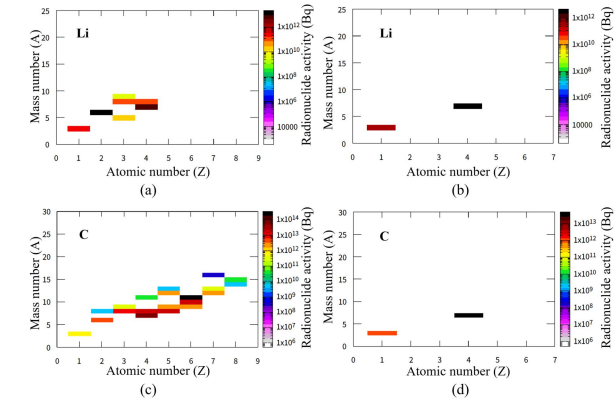
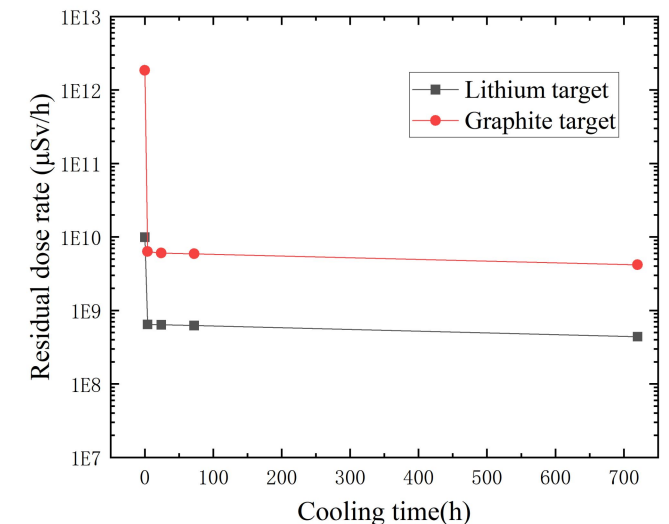
Conceptual design

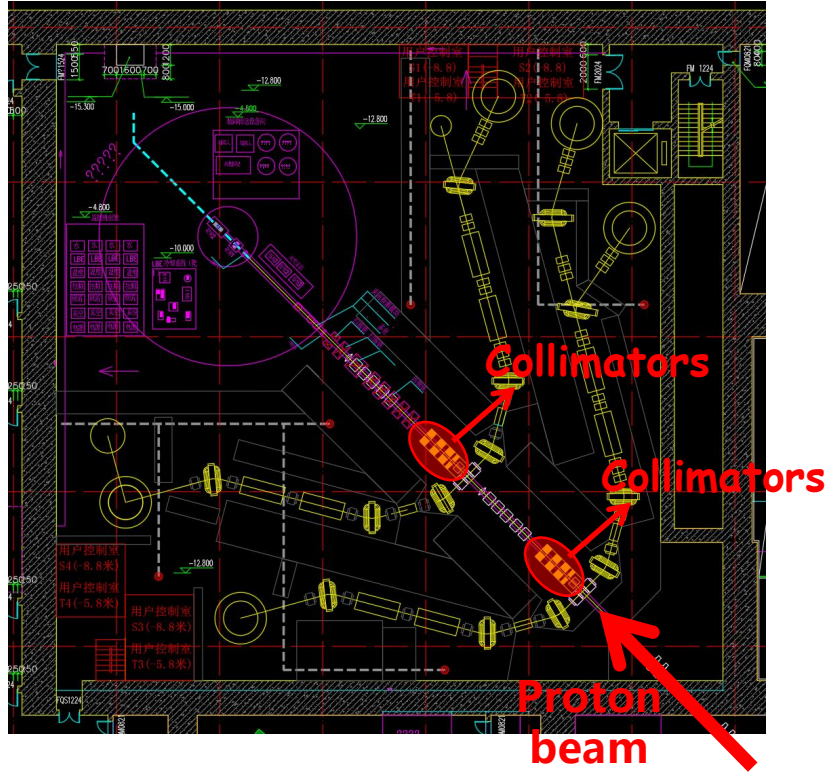


Lithium VS Carbon: Energy spectrum

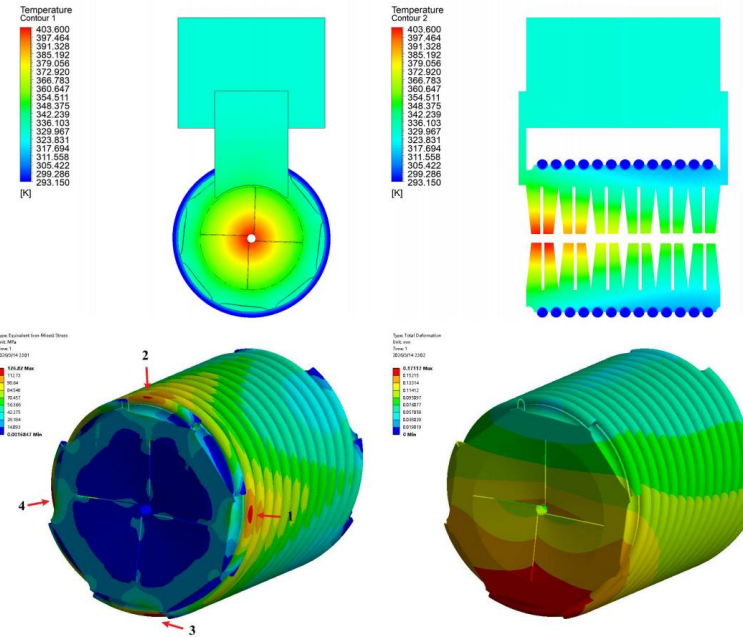
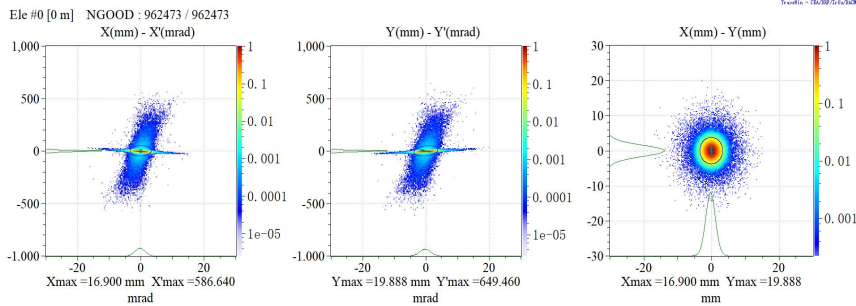


Lithium VS Carbon: radioactivity





- The emittance will increase significantly after the beam penetrating the target: from $\sim 1 \text{ mm} \cdot \text{mrad}$ to $\sim 30 \text{ mm} \cdot \text{mrad}$
- A combination of collimators and quadrupole magnets is used to control the beam envelope and suppress beam loss
- After optimization, the beam loss along the whole line is **well below 10 W/m**



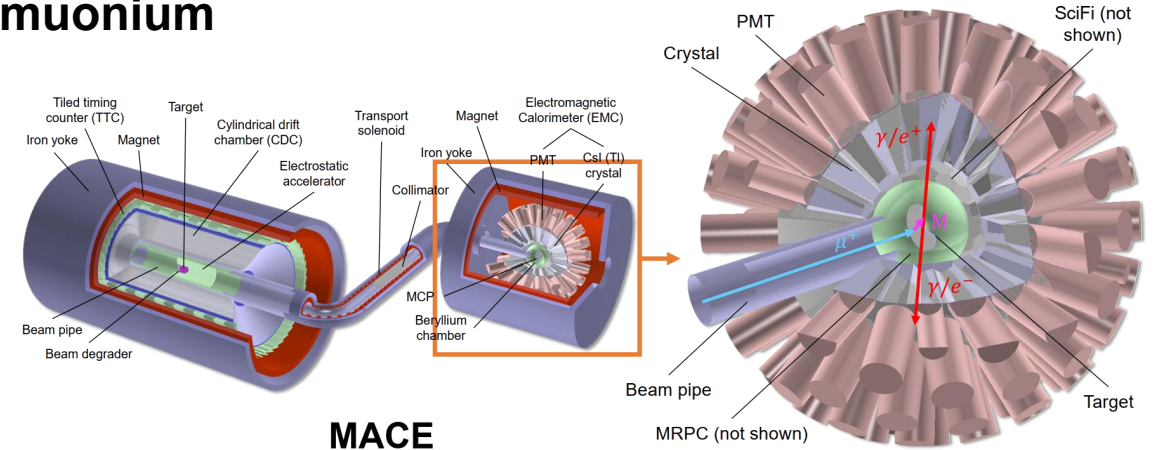
- Collimators were designed to work at 3-MW-proton beam

Thermal performance under a heat load of 32kW

■ High-precision tests of rare processes of muon and muonium

- ✓ $(\mu^+ e^-) \rightarrow \mu^- e^+$, $(\mu^+ e^-) \rightarrow e^+ e^-$, $(\mu^+ e^-) \rightarrow \gamma\gamma$
- ✓ $(\mu^+ e^-) \rightarrow \text{invisible}$
- ✓ Experiments like Mu2e, COMET, MEG, Mu3e...

*Searching for charged lepton flavor violation,
new physics beyond the standard model, CPT test*



MACE

Sun Yat-sen University

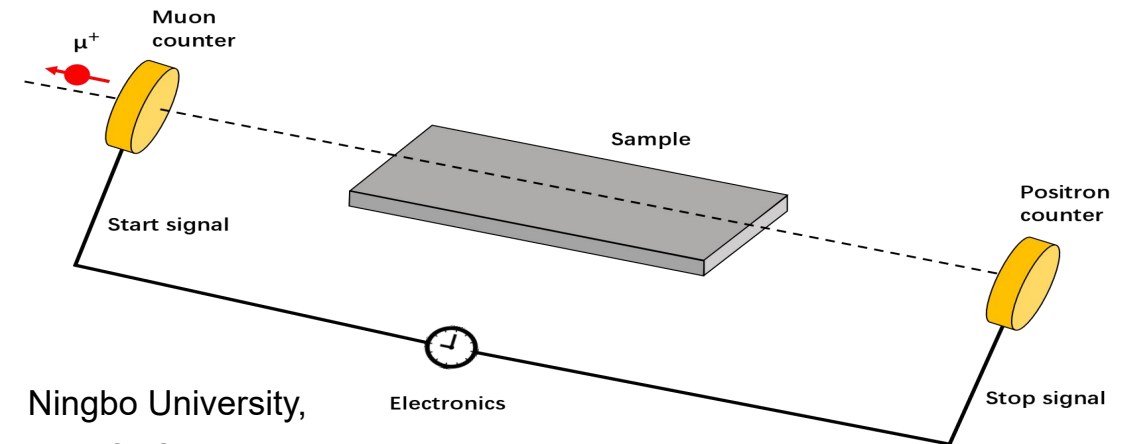
MACE Phase-I

■ High-precision measurement of muon spin rotation

*Searching for NEW spin-dependent interaction at long
range (mediated by light axion-like particle or light boson)*

eg.:
$$V_{SP}(r) = \frac{\hbar^2 g_S g_P}{8\pi m} \left(\frac{1}{\lambda r} + \frac{1}{r^2} \right) \frac{\exp(-r/\lambda)}{r} \vec{\sigma} \cdot \hat{r}$$

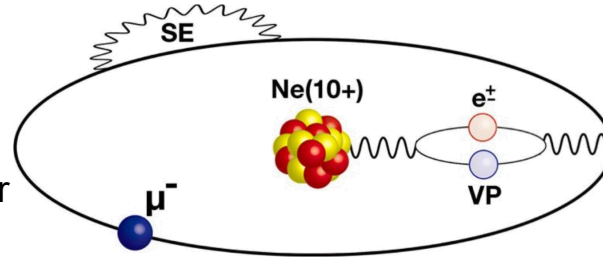
$$V_{VA}(r) = \frac{\hbar g_V g_A}{2\pi} \frac{\exp(-r/\lambda)}{r} \vec{\sigma} \cdot \vec{v}$$



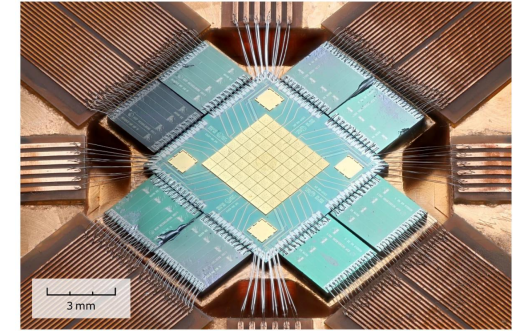
Ningbo University,
IMP, CAS

■ High-precision X-ray measurement of muonic atom

Muon orbits with a much smaller distance to charge center



Superconductor transition-edge calorimeter for X-ray measurement

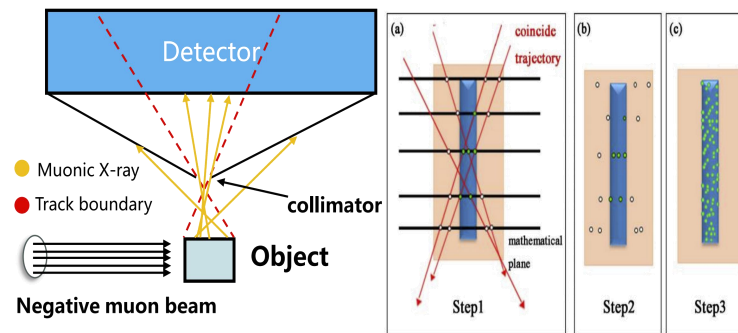
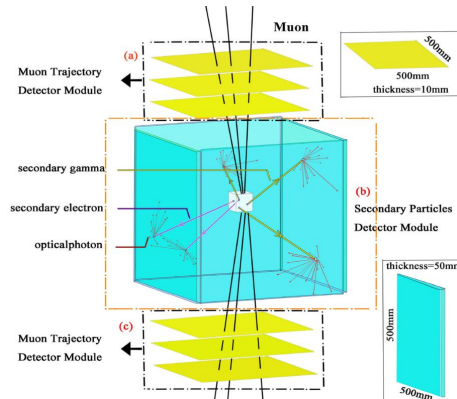


Precision test of strong field QED, and looking for the fifth interaction in muonic atom!

■ μ SR experiment for condensate matter study

One powerful probe for experimental studies of quantum critical behavior, high-temperature superconductor, magnetic material... [Domestic: Fudan University, Shanghai Jiao Tong University, USTC...]

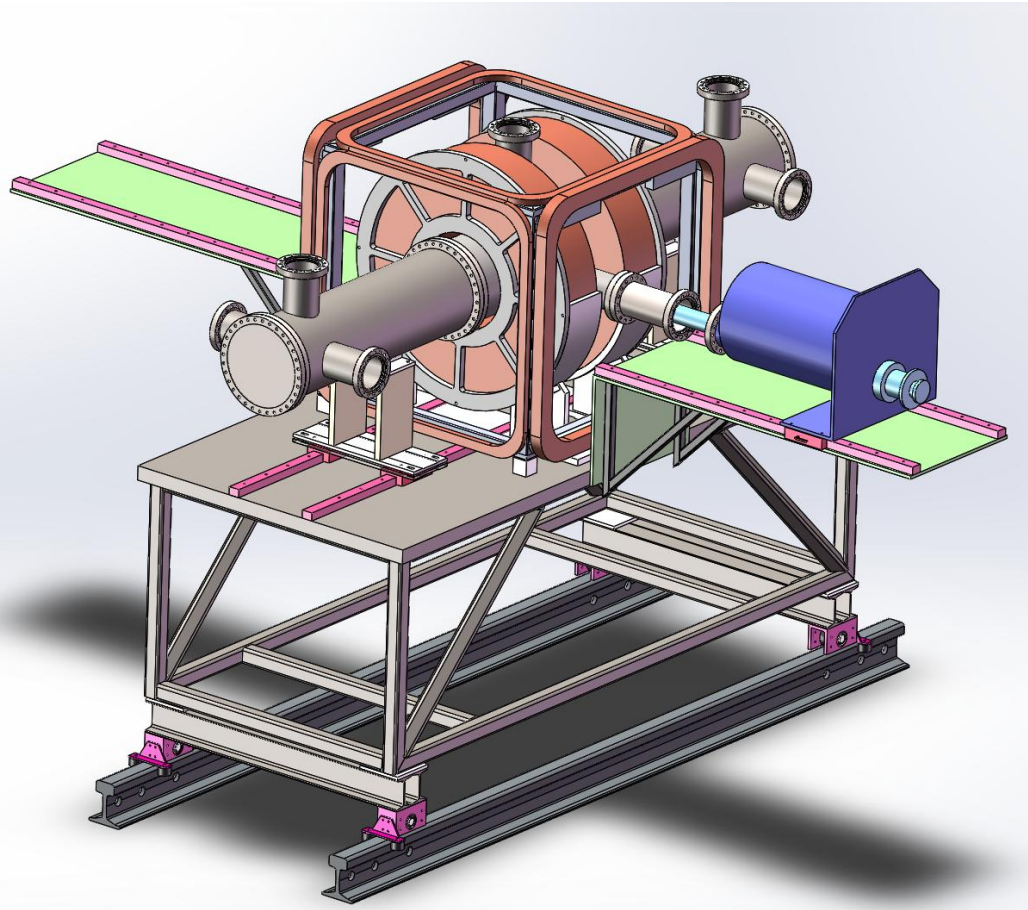
■ Elemental analysis and new muon tomography technology with muon induced X-ray



University of South China

■ Conceptual design of a general-purpose μ SR spectrometer

■ Objective performance

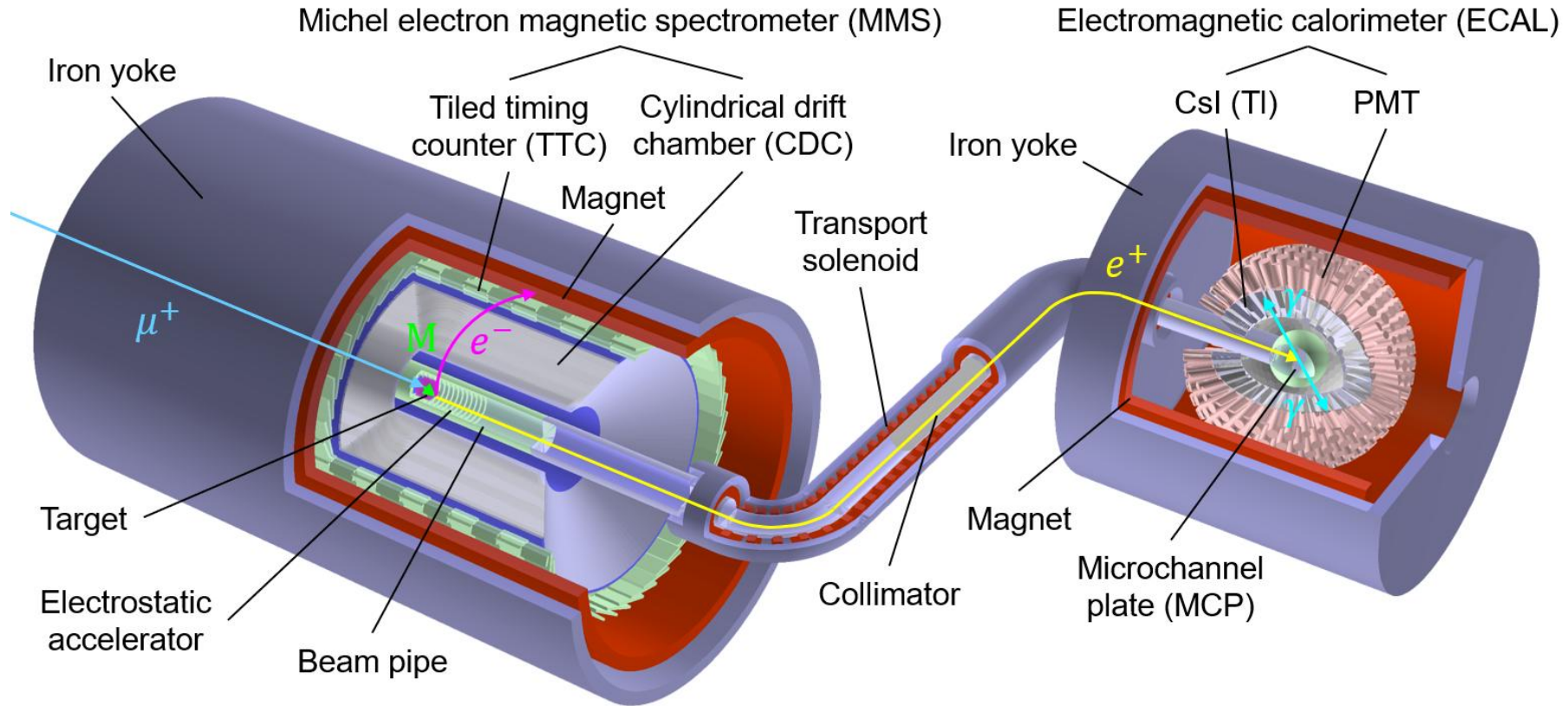


Function	Objective performance
Beam time structure	Continuous (complement and synergy with Melody in China)
Beam spot size at sample	3 – 5 mm (FWHM)
Temperature environment	2.0 K – 300 K (CCR & He-4 flow); 20 mK – 10 K (DR)
Longitudinal magnetic field	0 – 0.5 T (uniformity better than 100 ppm over 10 mm range)
Zero-field environment	$< 50 \text{ mG} = 5 \times 10^{-6} \text{ T}$
Transverse magnetic field	0 – 0.4 T (muon spin rotation with 70°)
Detector time resolution	$< 300 \text{ ps}$
Muon spin polarization degree	$> 95\%$
Beam electron background ratio	$< 1\%$
Muon energy range	Surface muon
Sample size	$\phi < 10 \text{ mm}$
Sample thickness	$\sim > 250 \text{ mg/cm}^2$
Time measurement range	10 μs
Muon count rate at sample	$5 \times 10^4 - 1 \times 10^5 \text{ Hz}$

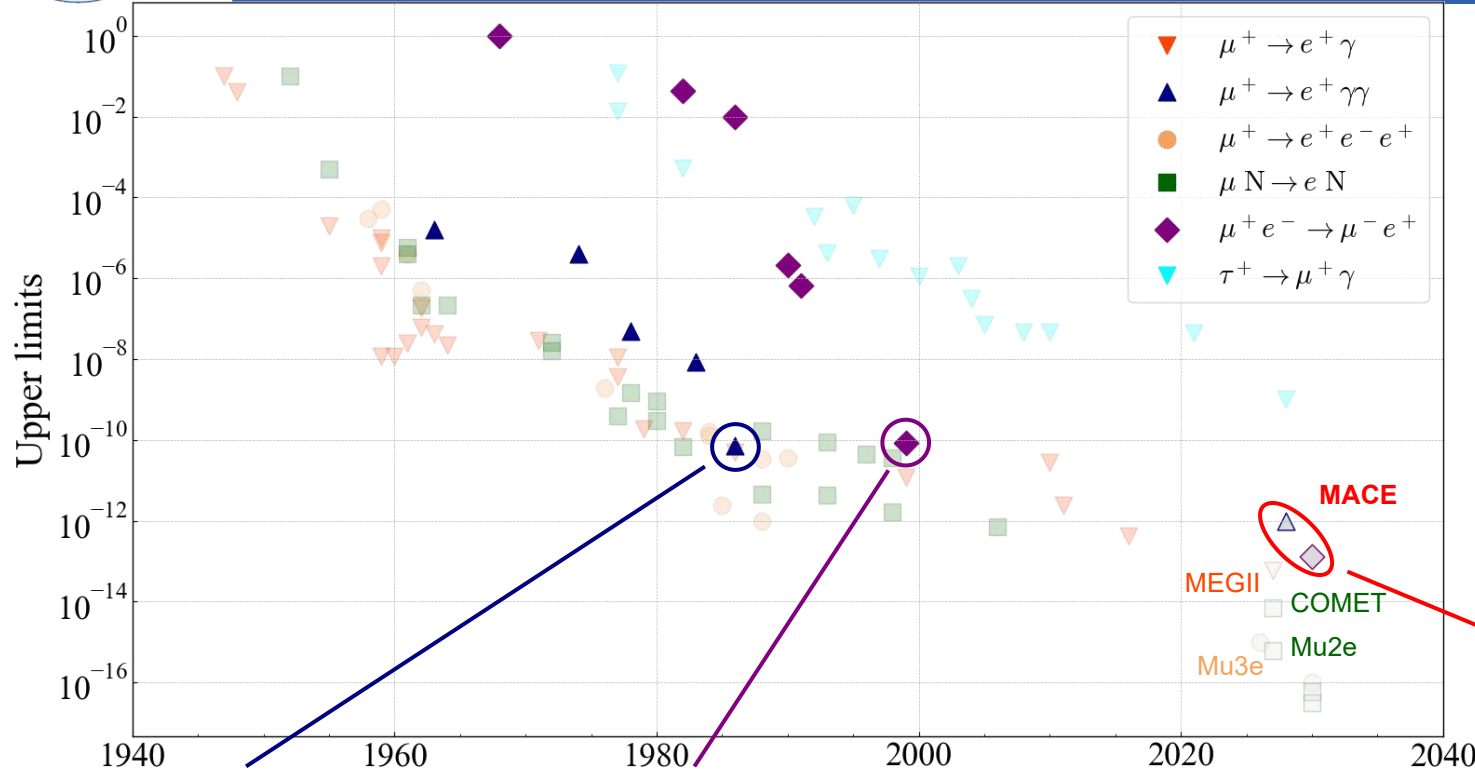
Cooperated with Ziwen Pan, USTC



MACE Experiment @ CiADS



Coutesy of Jian Tang



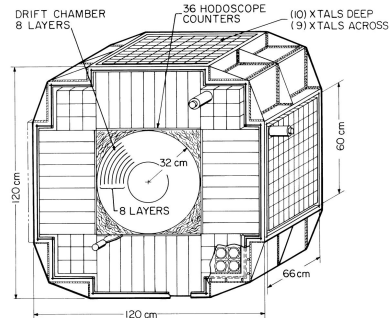
Towards new muon cLFV experiments

- Construction of intense muon beamlines soon in China.
- Development of particle detection technology

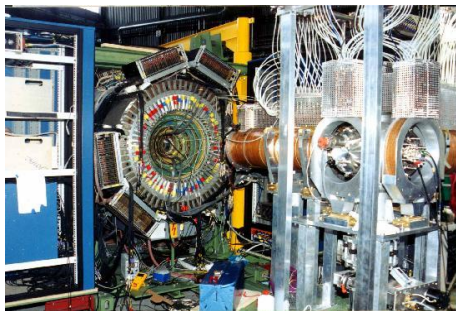
$\mathcal{O}(10^{-13})$ sensitivity!

Coutesy of Jian Tang

Crystal Box, 1986
 $BR < 7.2 \times 10^{-11}$



MACS, 1999
 $P_{M \rightarrow \bar{M}} < 8.3 \times 10^{-11}$



MEG II
(PSI)
 $\mu^+ \rightarrow e^+ \gamma$



Mu3e
(PSI)
 $\mu^+ \rightarrow e^+ e^- e^+$



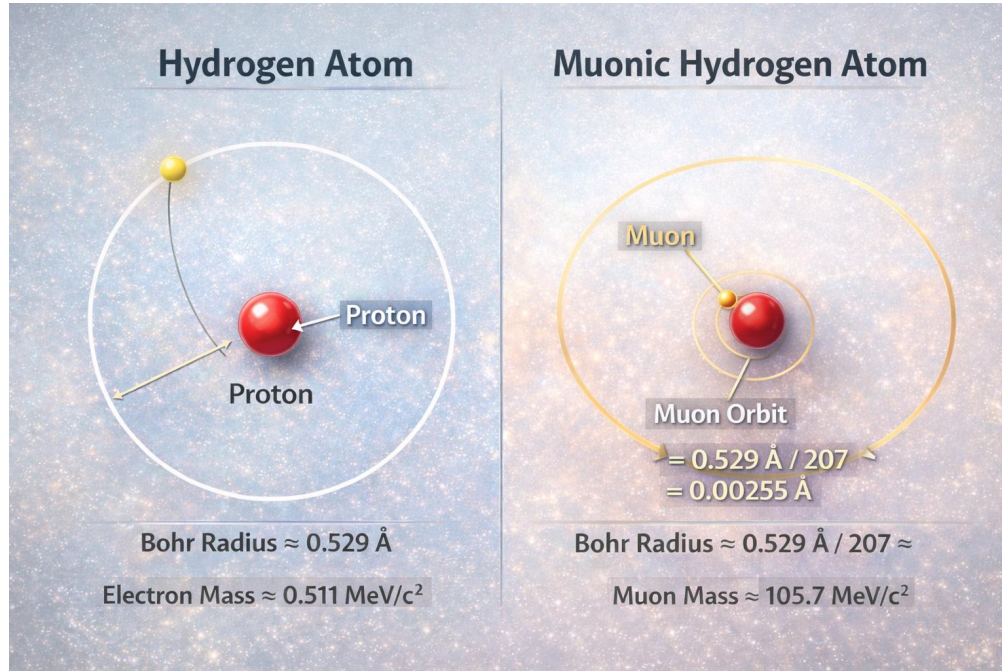
Mu2e
(Fermilab)
 $\mu^- N \rightarrow e^- N$



COMET
(J-PARC)
 $\mu^- N \rightarrow e^- N$

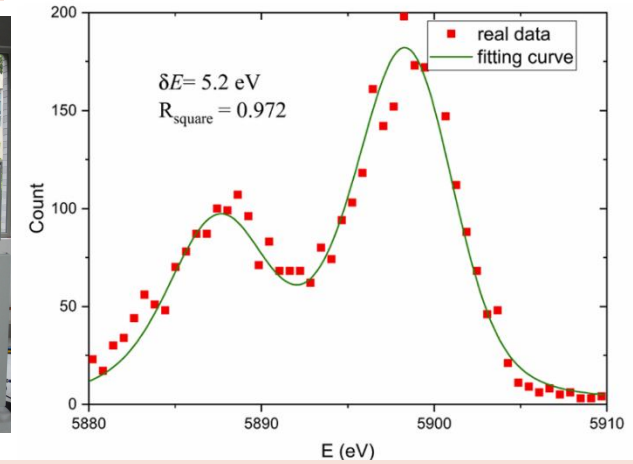


MACE (China)
 $M \rightarrow \bar{M} (\mu^+ e^- \rightarrow \mu^- e^+)$

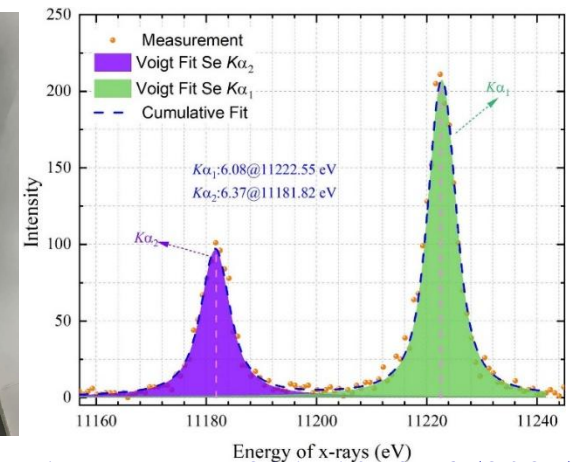
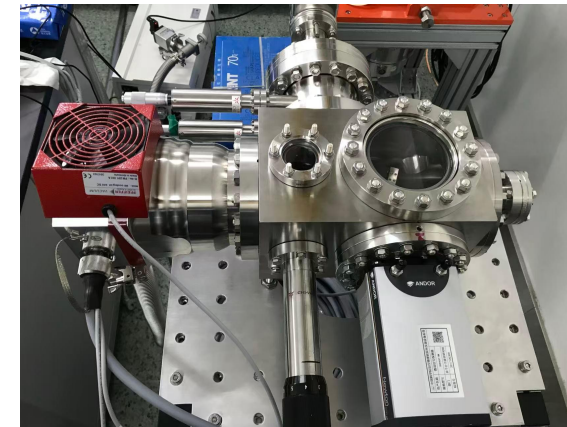


- Muonic atoms + X-ray detector
- Testing strong field QED effects
- Study of nuclear properties, including nuclear charge radius and Zemach radius as well as magnetic momentum distribution

TES superconducting X-ray detector 5.2 eV @6 keV

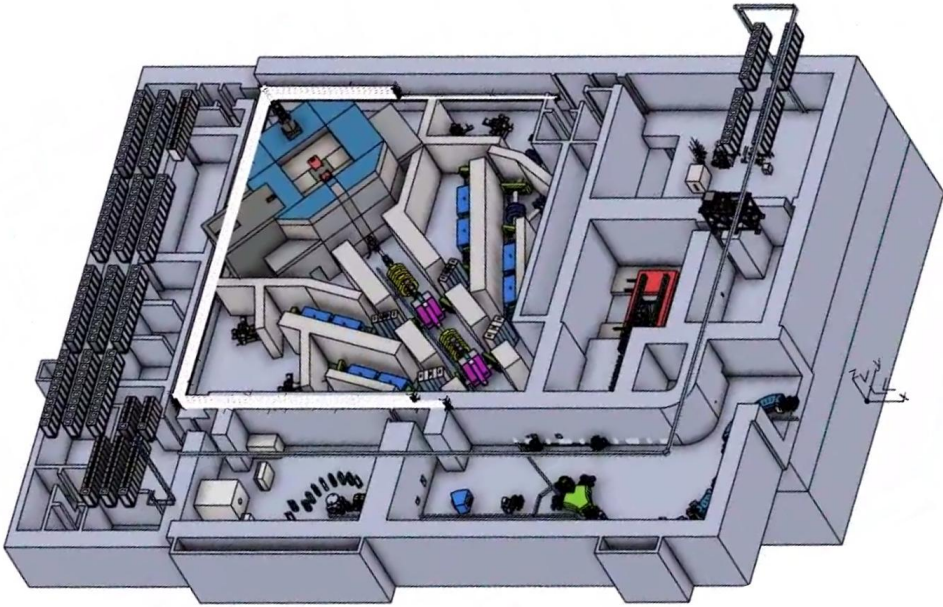


Crystal X-ray detector and the resolution is 6.1 eV @11keV



Caojie Shao et al., *Spectrochimica Acta Part B* 231, 107256 (2025)

- The conceptual design of the muon beamlines has been completed.
- Development of the targets, the proton beam collimators, the muon beamline components and the MuSR spectrometer is ongoing, and good progress has been achieved.
- Civil engineering design has been finalized. The building will be completed in 2026.





Outline



- Muon Science and Applications
- Muon Beam Facilities around the world
- Muon Beam Facilities in China
- **Summary & Prospective future**



Summary and Perspective Future



- **As the scientific demands are increasing, the muon beam facilities are in rapidly development in China. Both pulsed and cw muon beams with low and high energy are under construction, i.e CSNS, SHINE, SULF, HIAF and CiADS. The first muon beams will be delivered from 2026 to 2028, with muon beam flux from 10^5 to 10^8 /s.**
- **Both particle physics and condensed matter physics experiments are proposed based on these facilities, like DUNE, MACE, μ SR, MIXE, μ CF.**
- **It is a growing society of Muon Science and Application in China. We will see a perspective future of Muon beams. Welcome to join this new emerging era.**



Thank you !