李政道研究所
TSUNG-DAO LEE INSTITUTE
中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES
上海科技大学
ShanghaiTech University
SHINE
SHANGHAI HIGH REPETITION RATE XFEL AND EXTREME LIGHT FACILITY
硬X射线自由电子激光装置

Current Status of The SHINE Muon Source

Jun Kai Ng (TDLI/SJTU)

MIP 2026| IMP,CAS Huizhou

25 Apr 2026

Muon: Advancing Discovery

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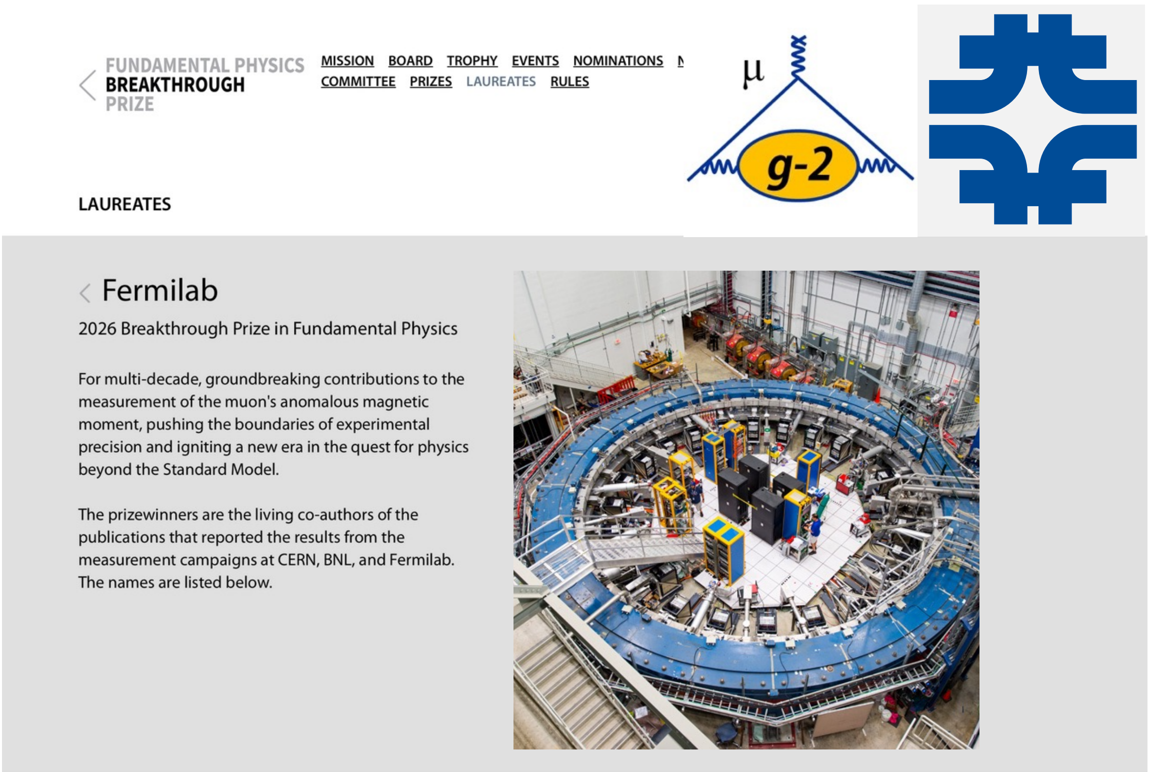
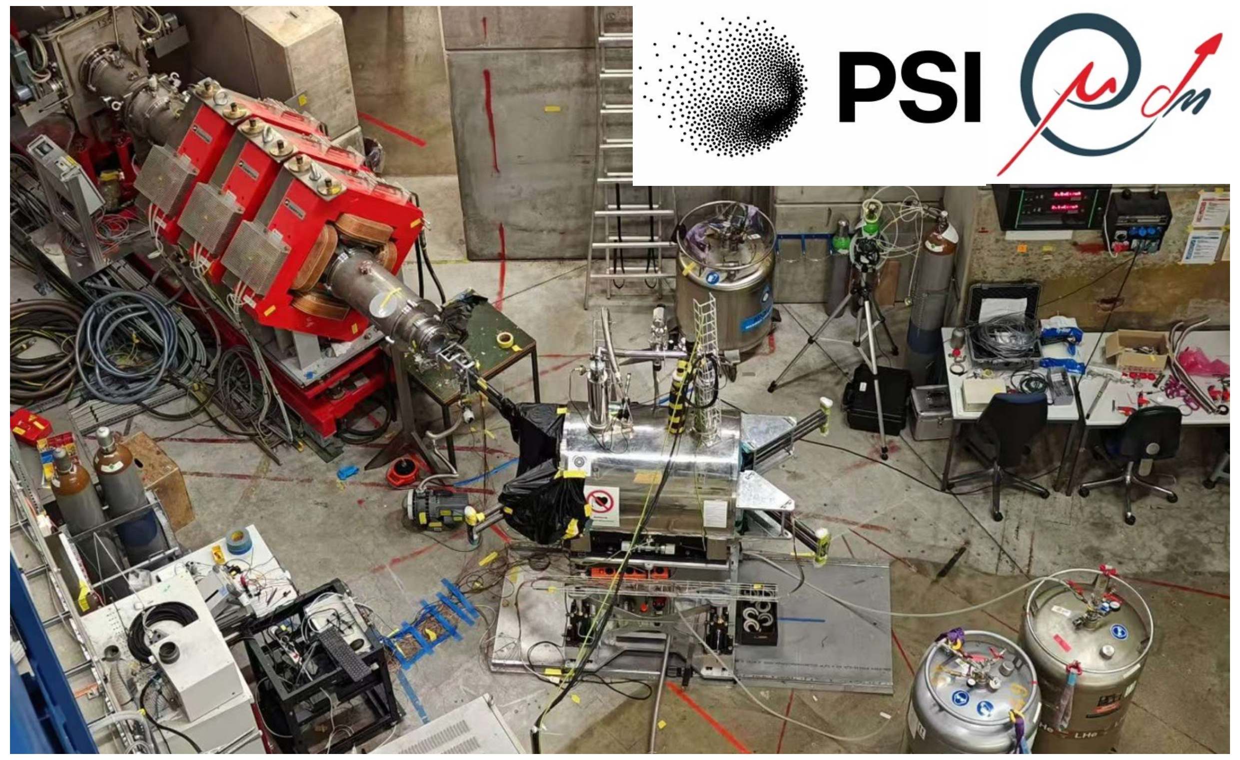
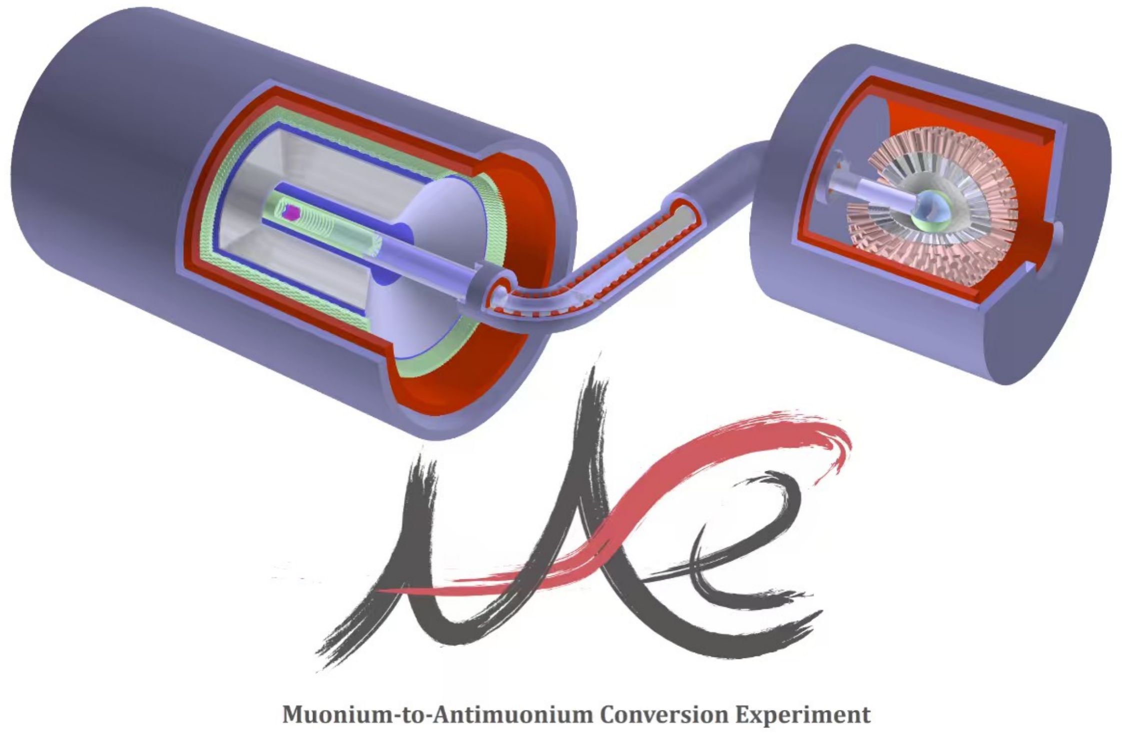


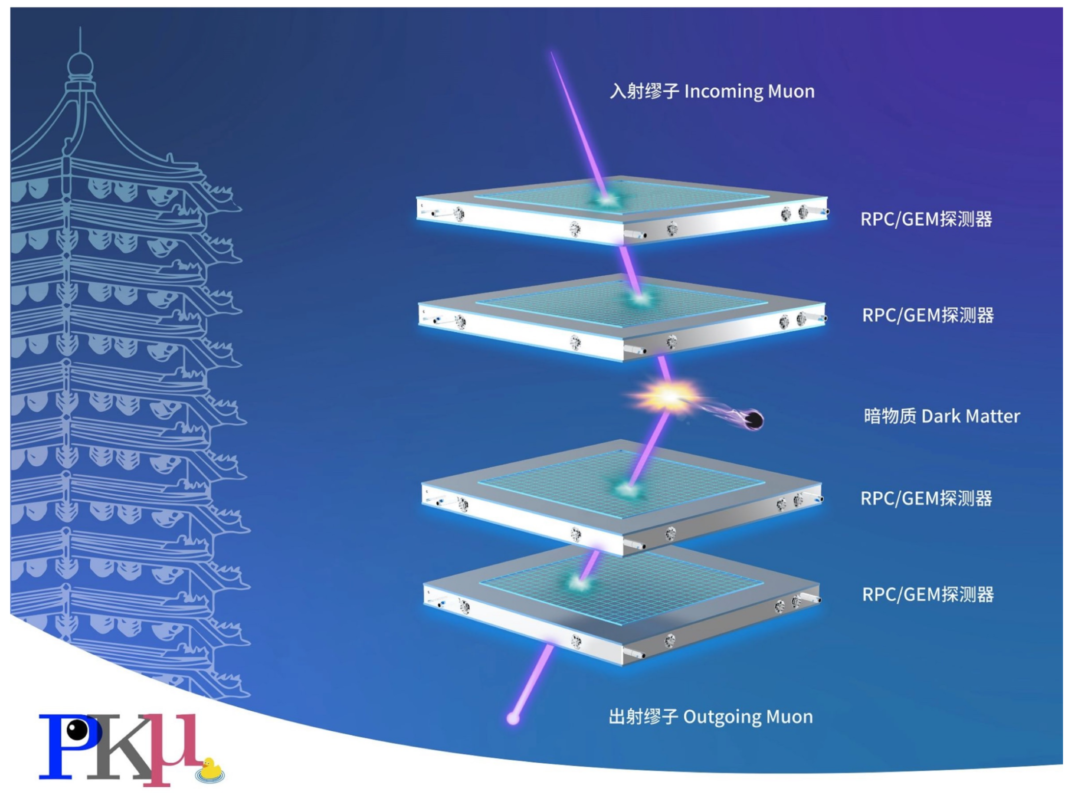
Precision SM test (Yonghao's Talk)



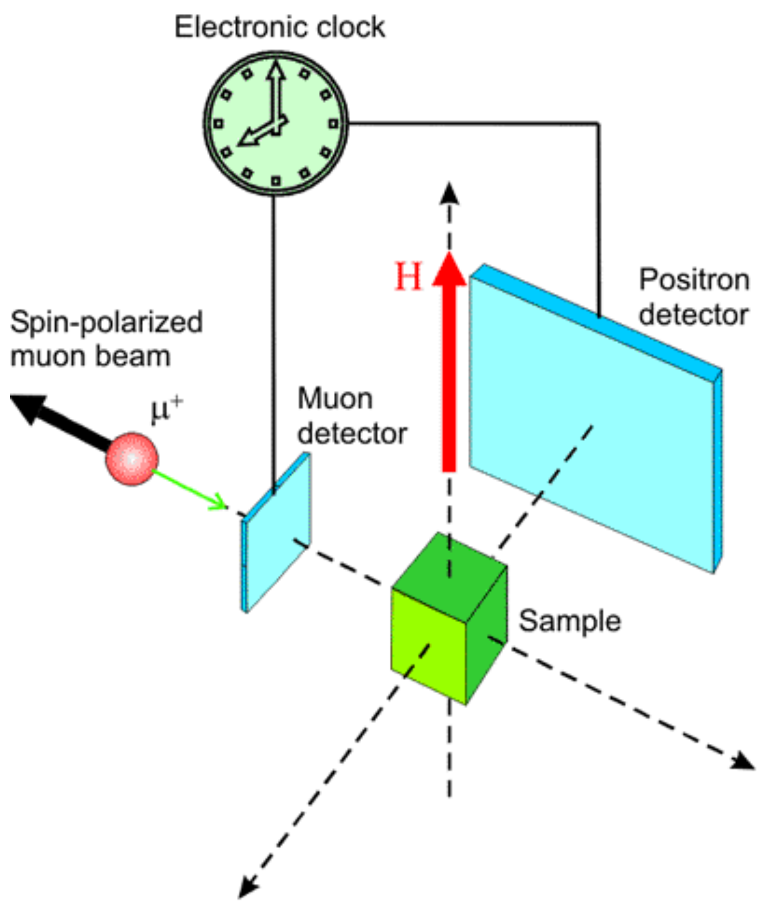
CPV (Philipp's Talk)



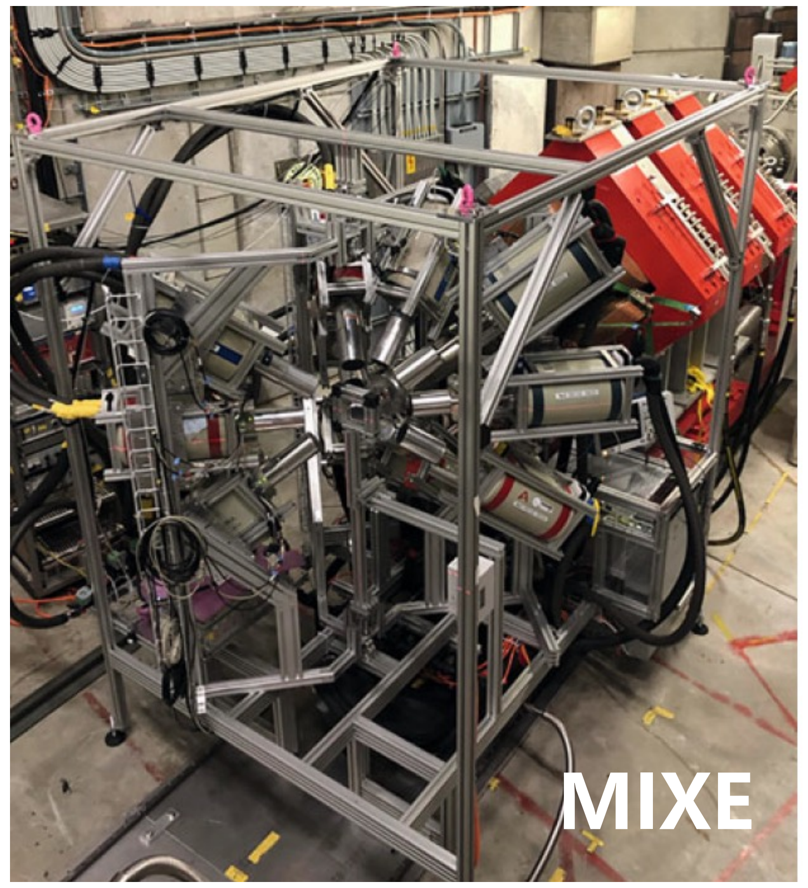
CLFV (Siyuan's Talk)



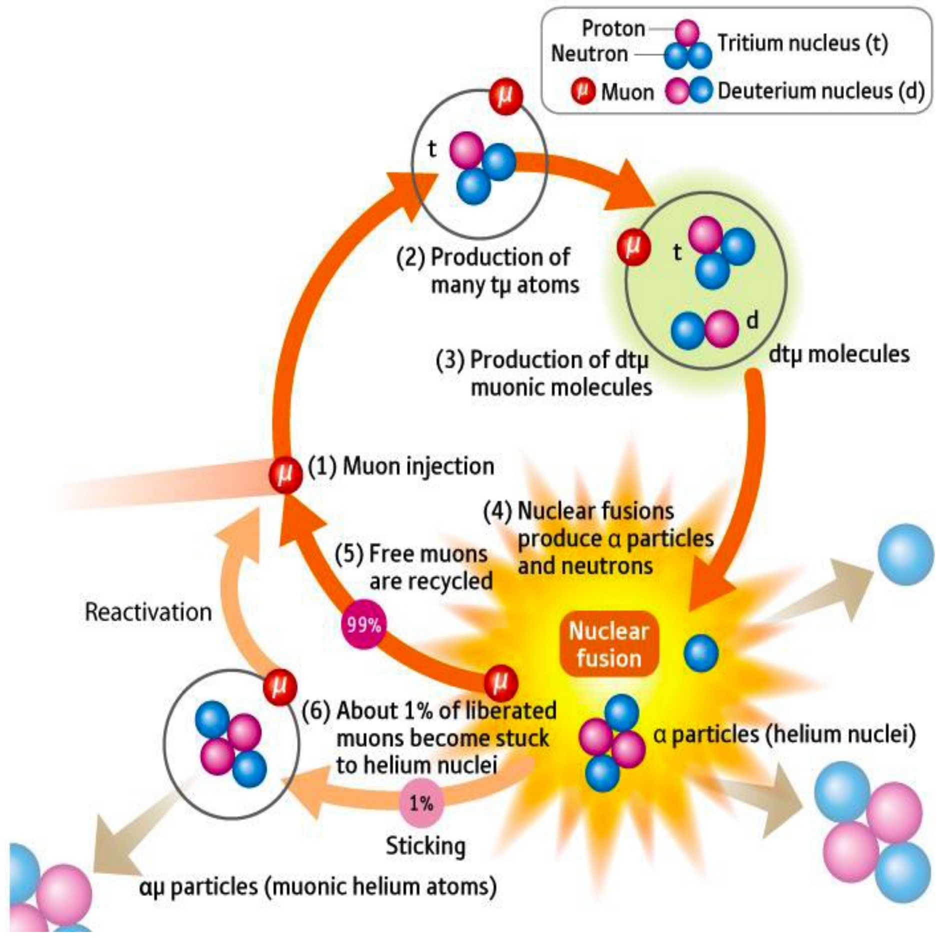
DM (Qite's Talk)



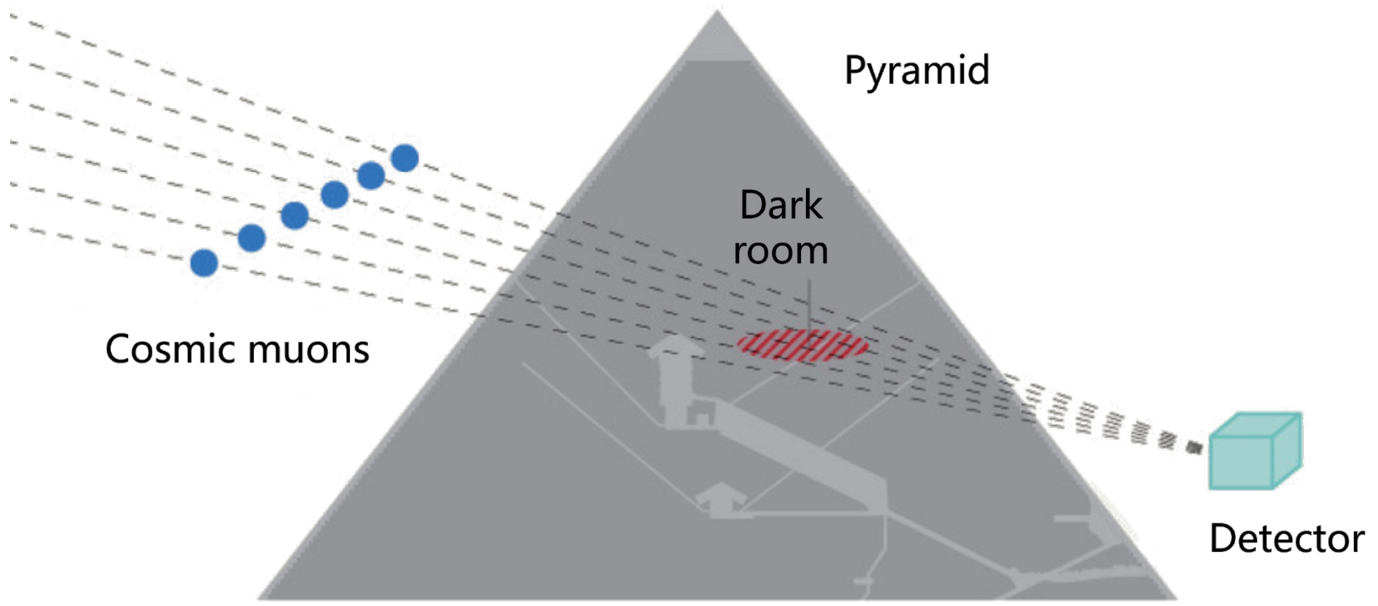
μSR (Vadim & Ziwen Talks)



MIXE (Maxim & You Lyu Talks)



μCF (Tingting's Talk)



Muography (Zibo's Talk)

Many Demands, Few Factories !

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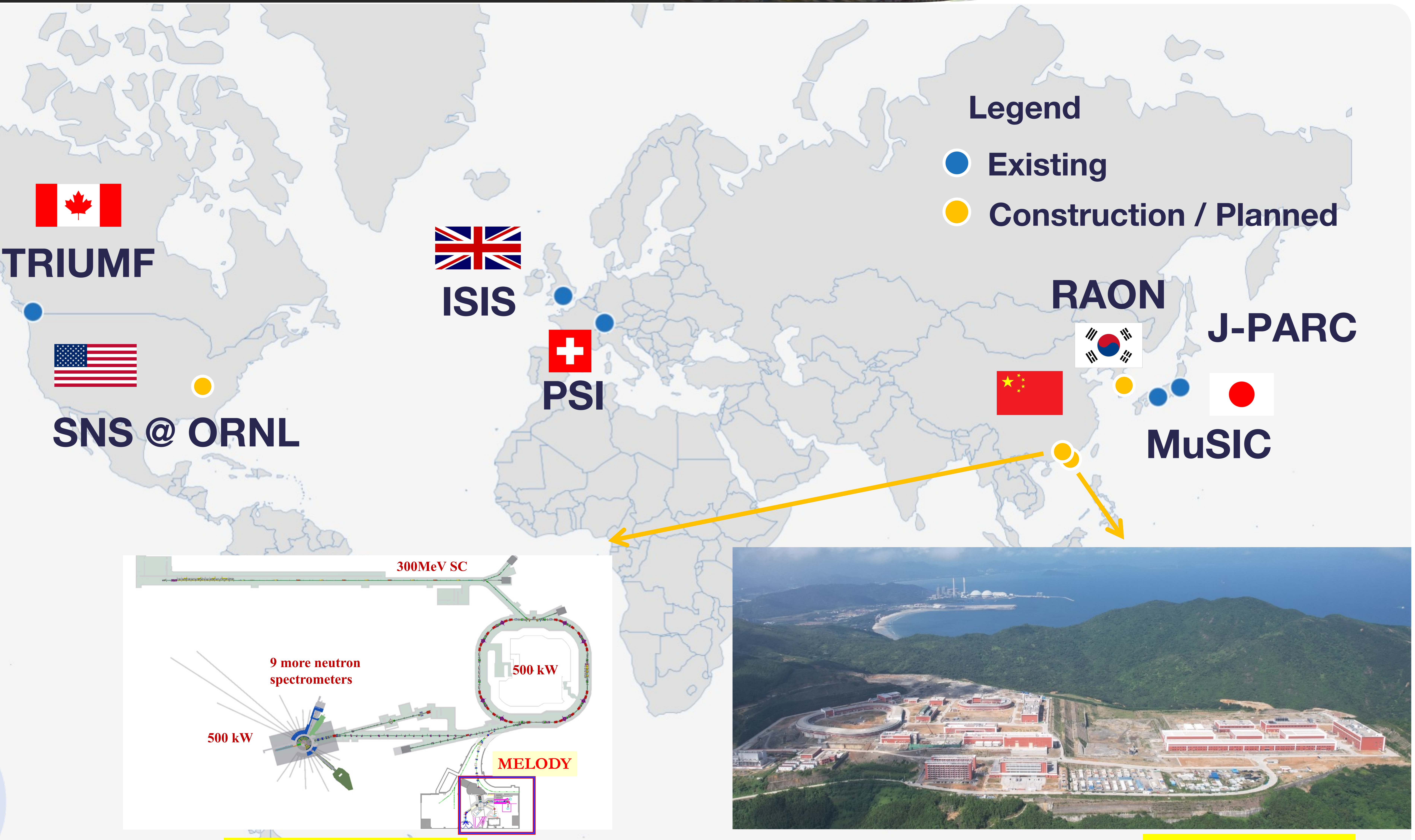
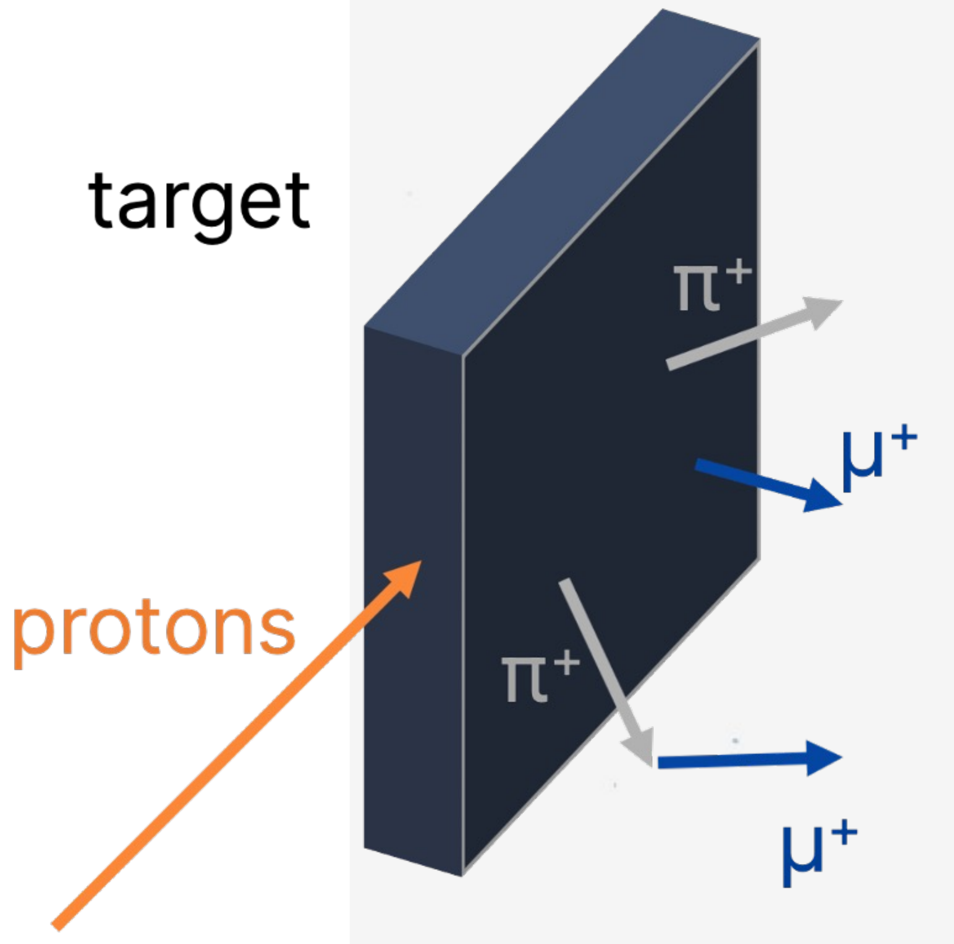


MELODY @ CSNS

HIRIBL @ HIAF

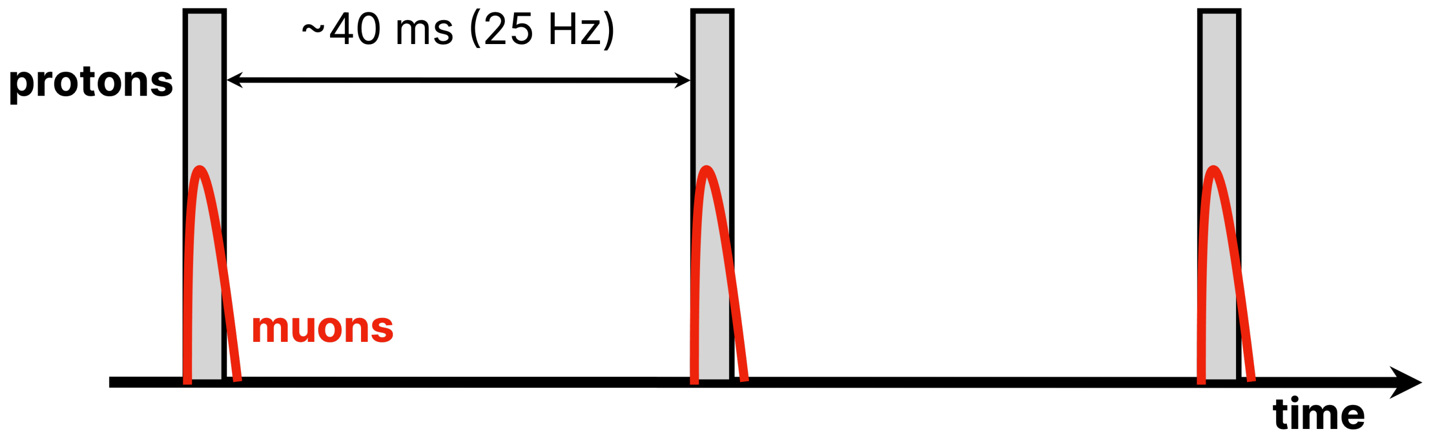
MuST @ CiADS



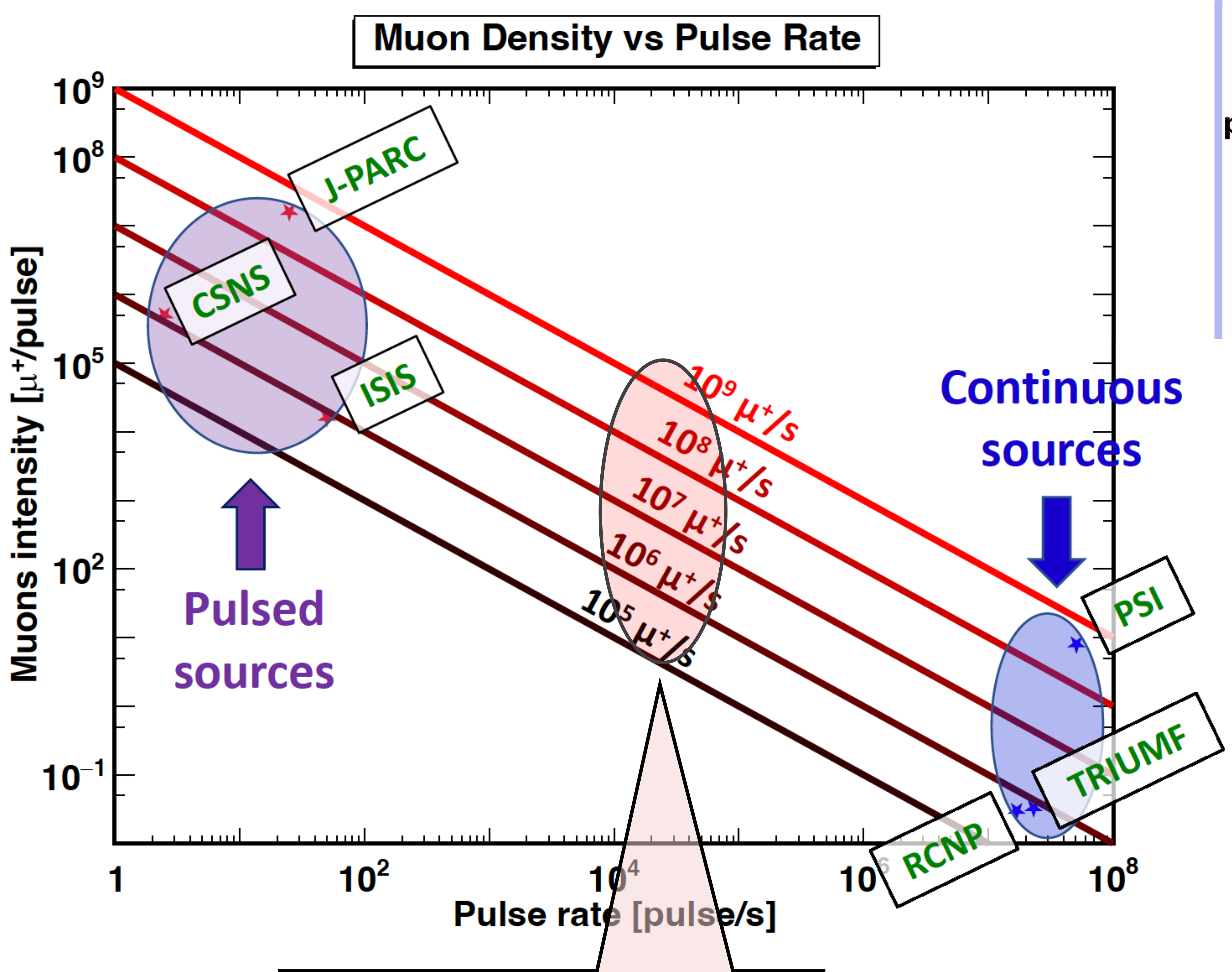
$$p + p \to p + n + \pi^{+}$$
$$p + p \to p + p + \pi^{+} + \pi^{-}$$
$$\pi^{+} \to \mu^{+} + \nu_{\mu}$$

Proton-driven Muon Sources

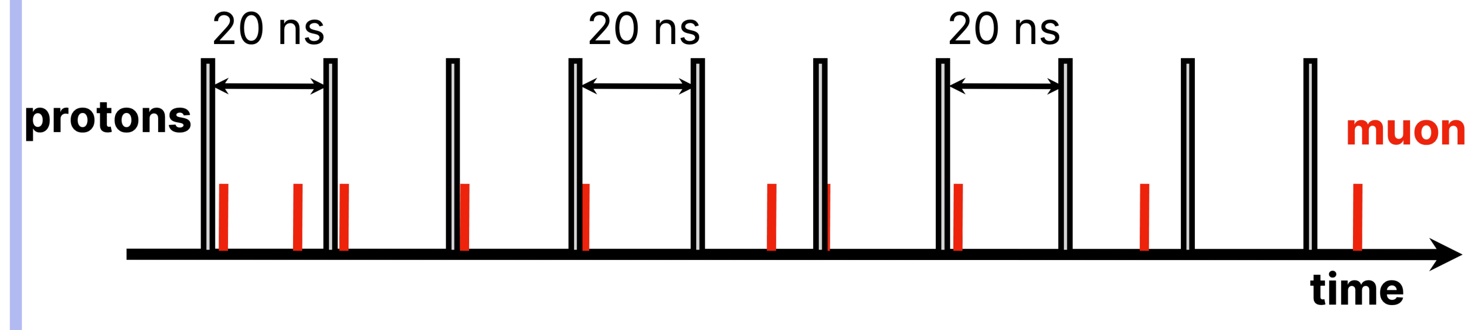
Pulsed Sources



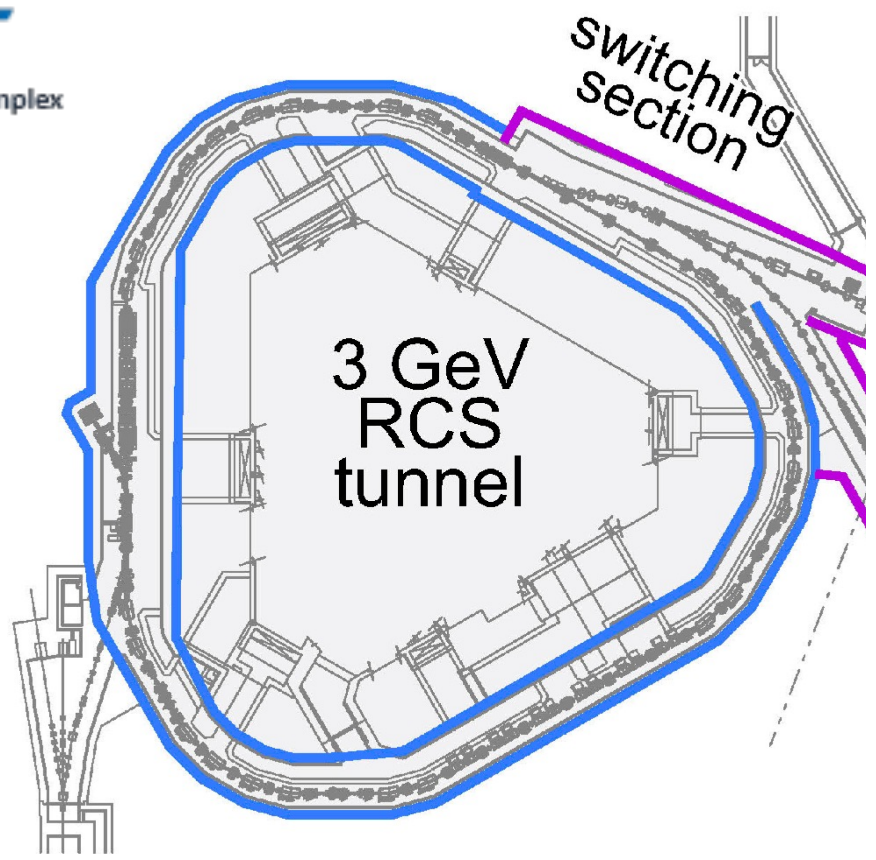
- Good statistics as many μ arrive at a time (large # of detectors)
- Time resolution limited by time between pulses (long)

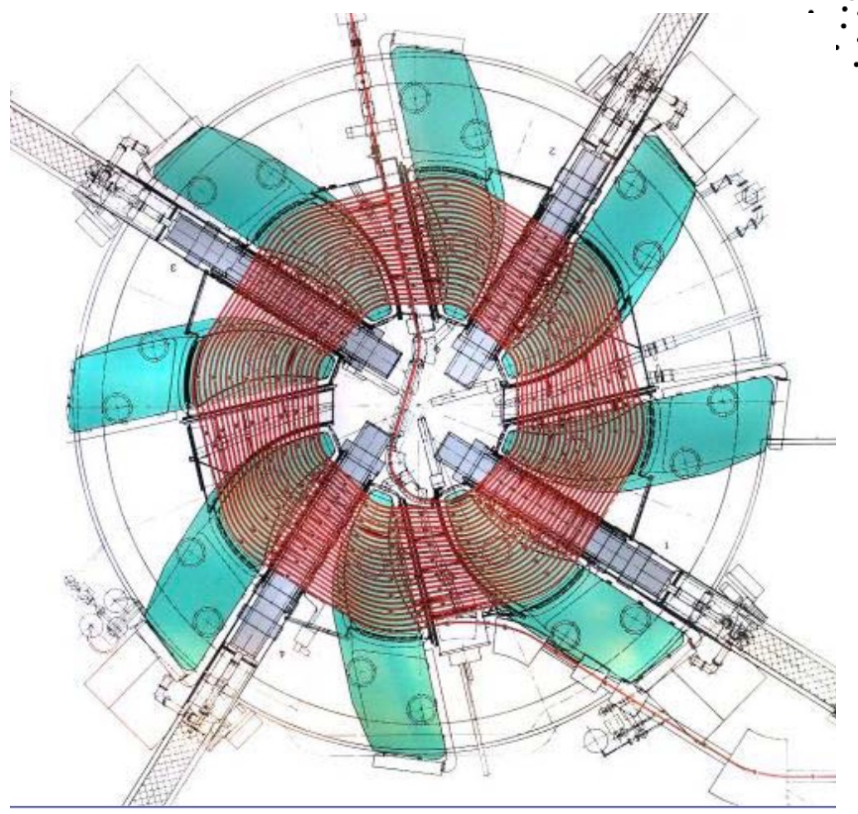


Continuous Sources



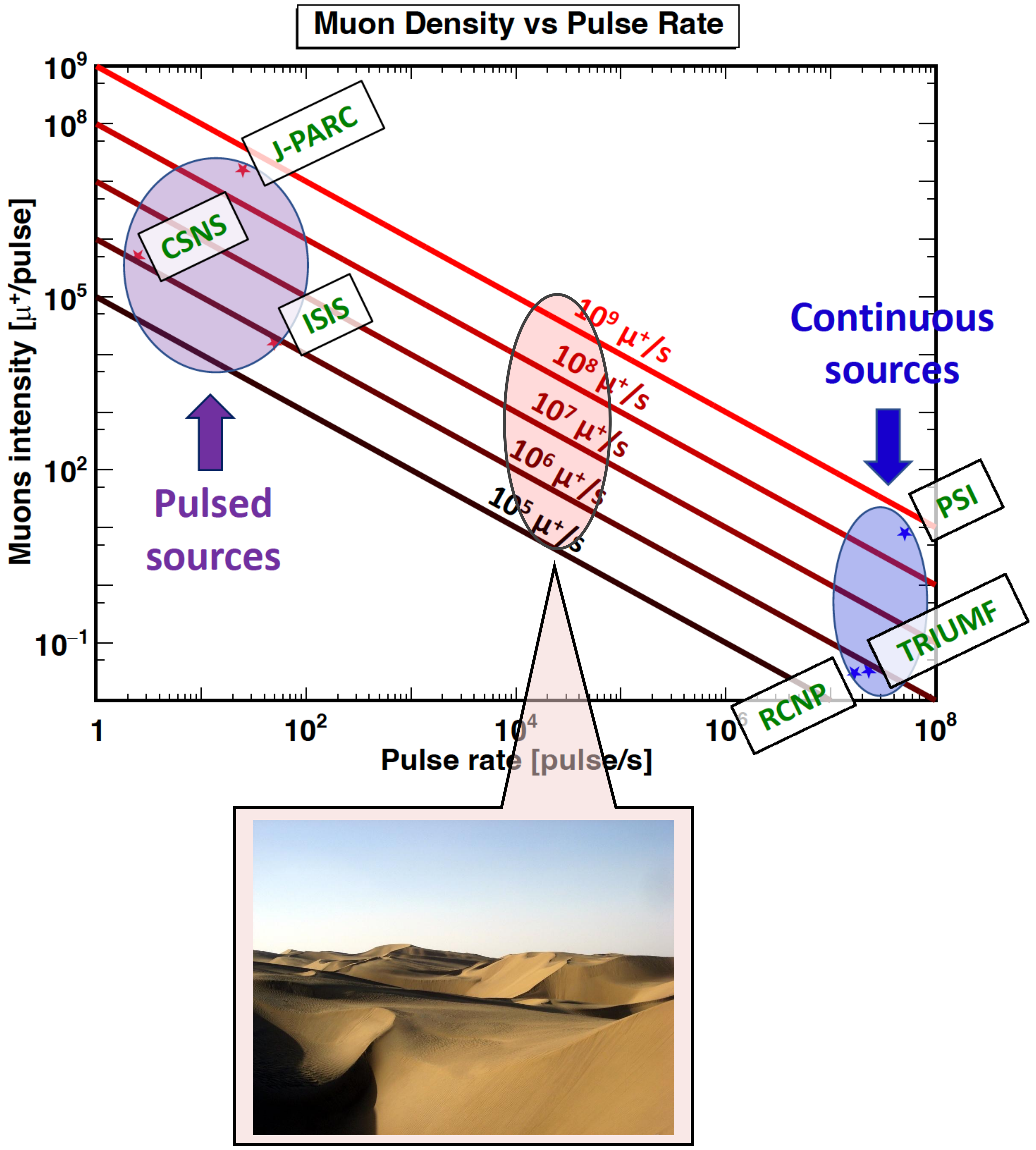
- Good time resolution, only limited by electronics.
- Muon rate limited by pile-up, resulting in less statistics.



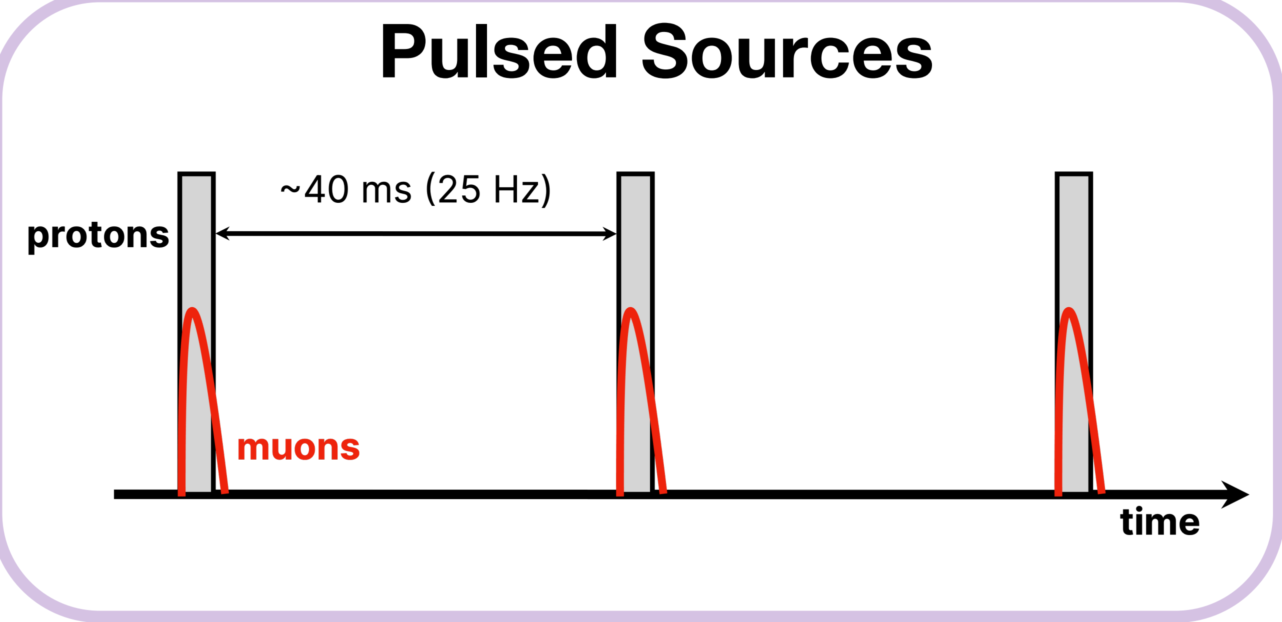


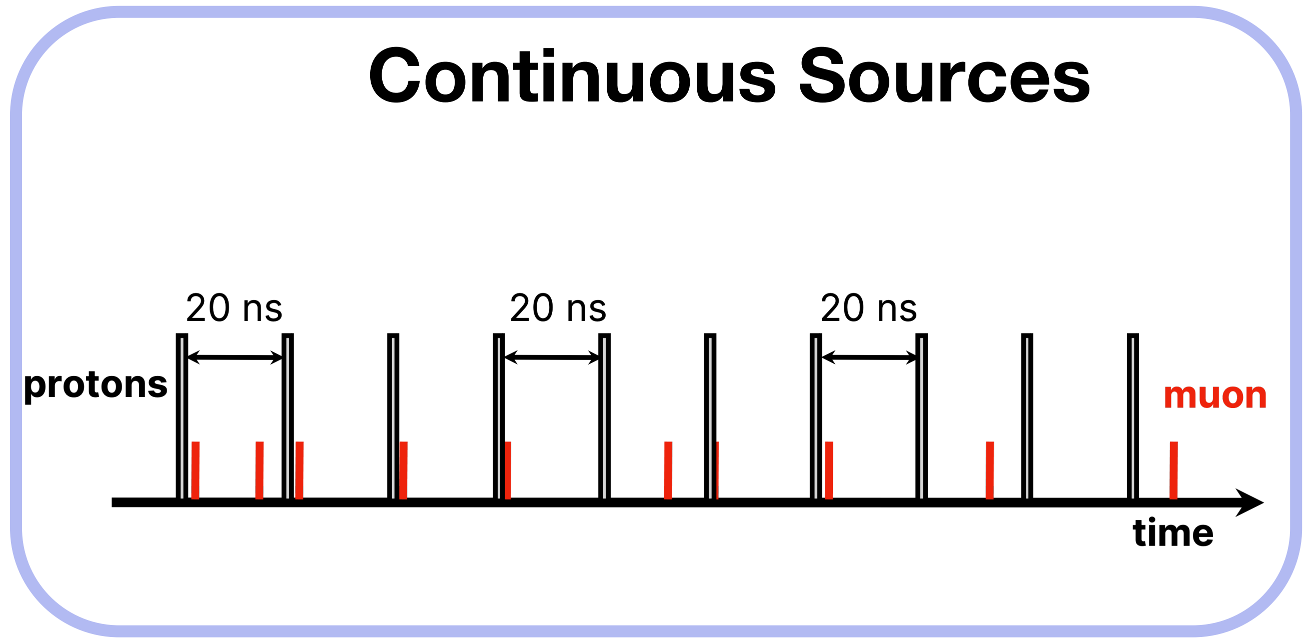
High-repetition Pulsed Beam

Tsung-Dao Lee Institute



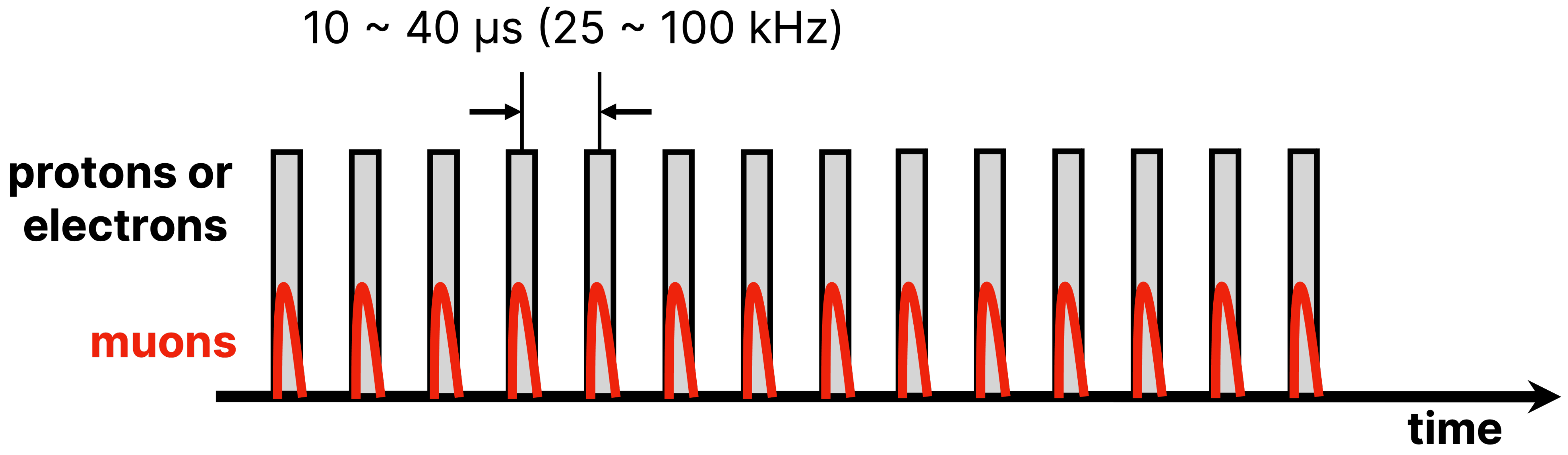
Typical measurement duration : ~ 5 to 10 τ_μ





- Higher duty cycle with relatively low muon count per bunch
  - ⇨ Fewer muons per bunch reduces pile-up
  - ⇨ Rate is compensated by more frequent bunches
- Sufficient interval between bunches
  - ⇨ Background can decay between pulses.

High-repetition-rate pulsed beam



Attempts on Proton Machines

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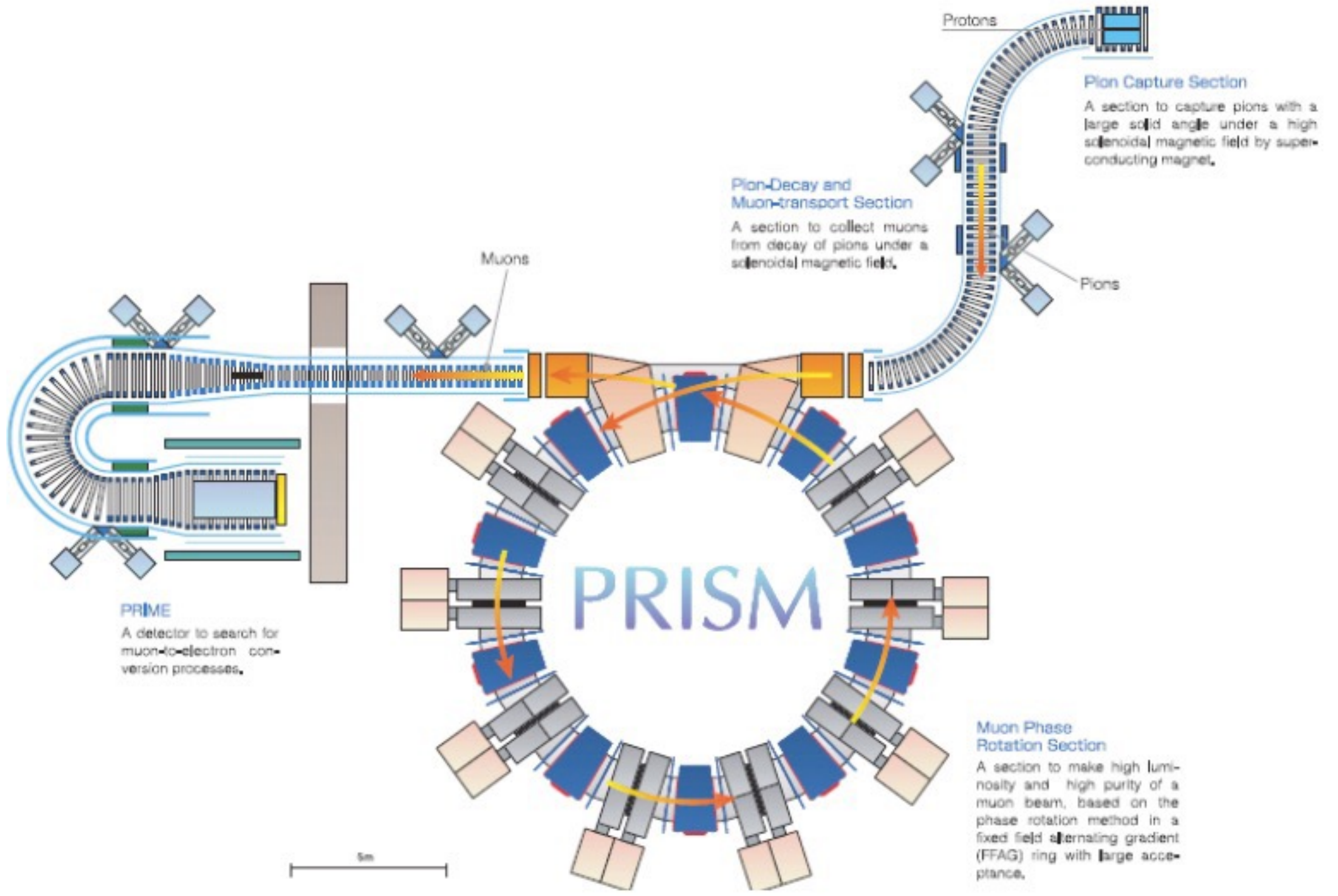
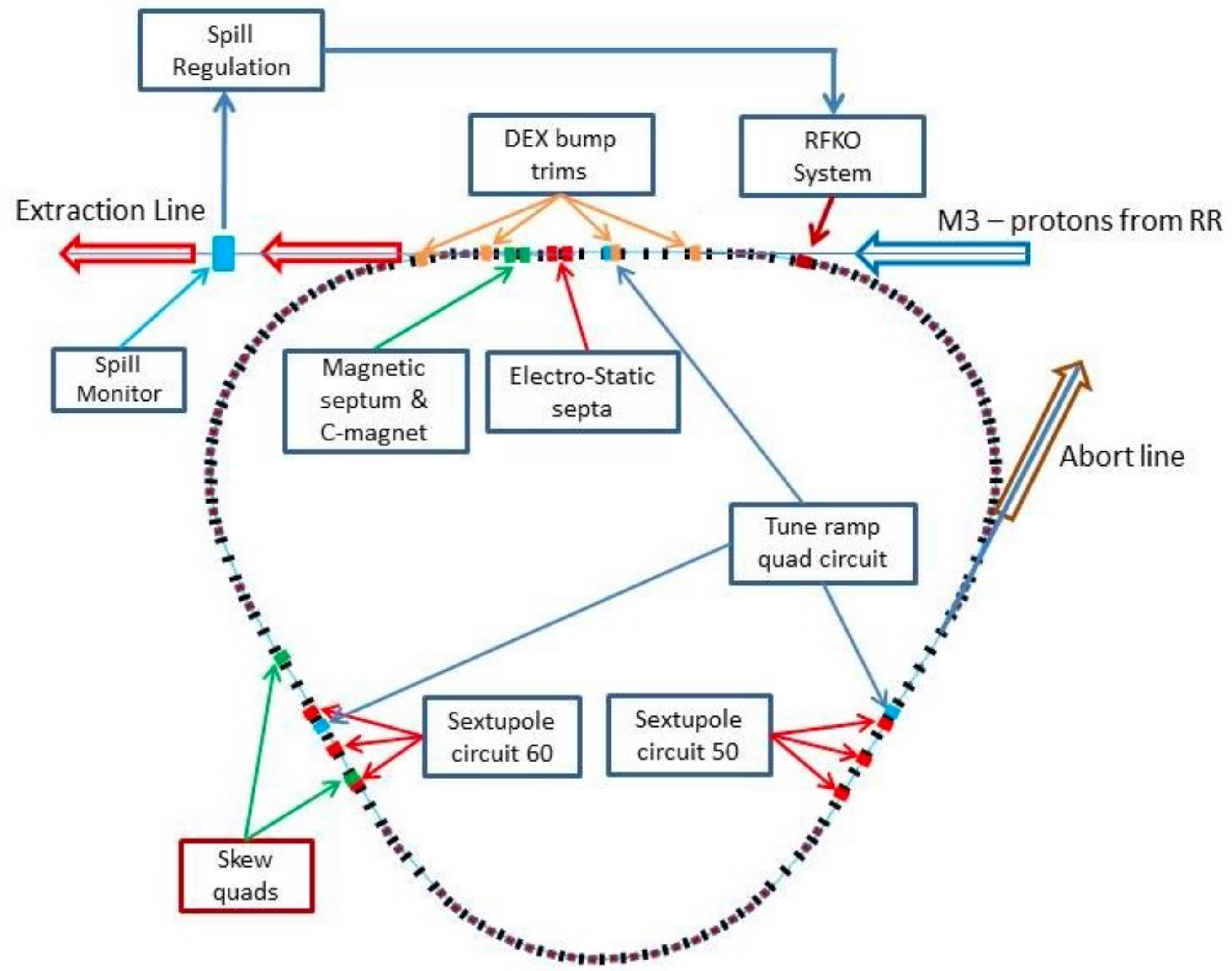
Fixed Field Alternating Gradient (FFAG) Synchrotron @ J-PARC



- **Intensity** : 10^{11}-10^{12} μ±/sec, 100-1000Hz
- **Energy** : 20±0.5 MeV (=68 MeV/c)
- **Purity** : π contamination < 10^{-20}

Research in progress

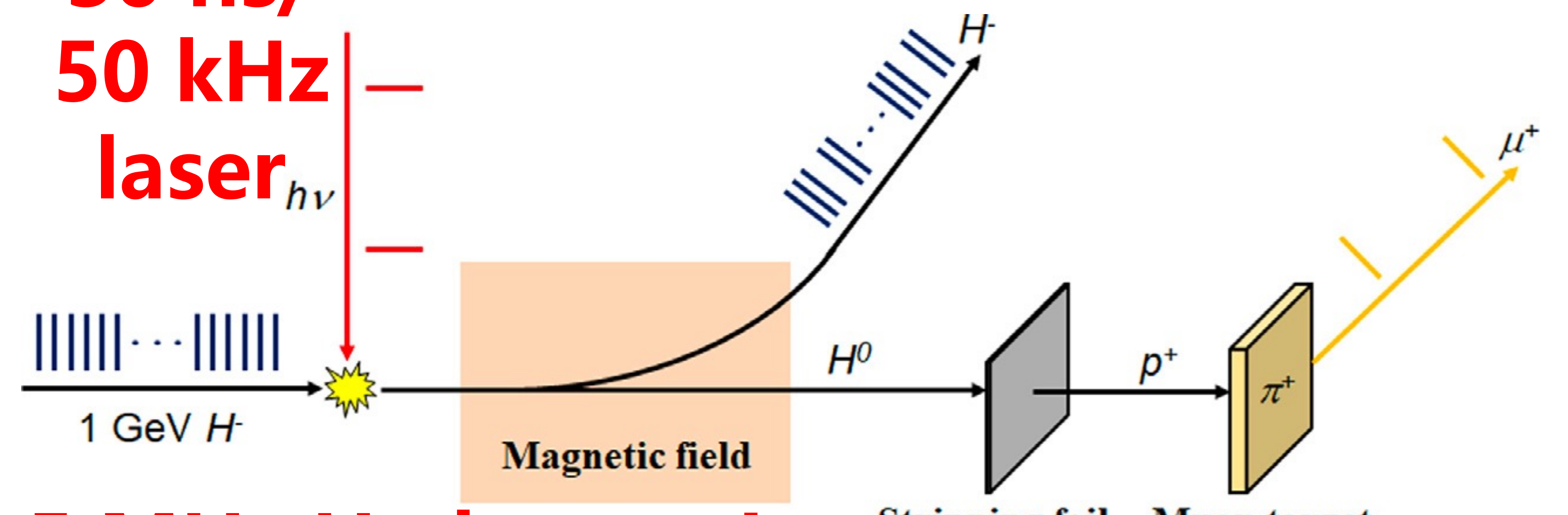
Resonant extraction Mu2e@FNAL



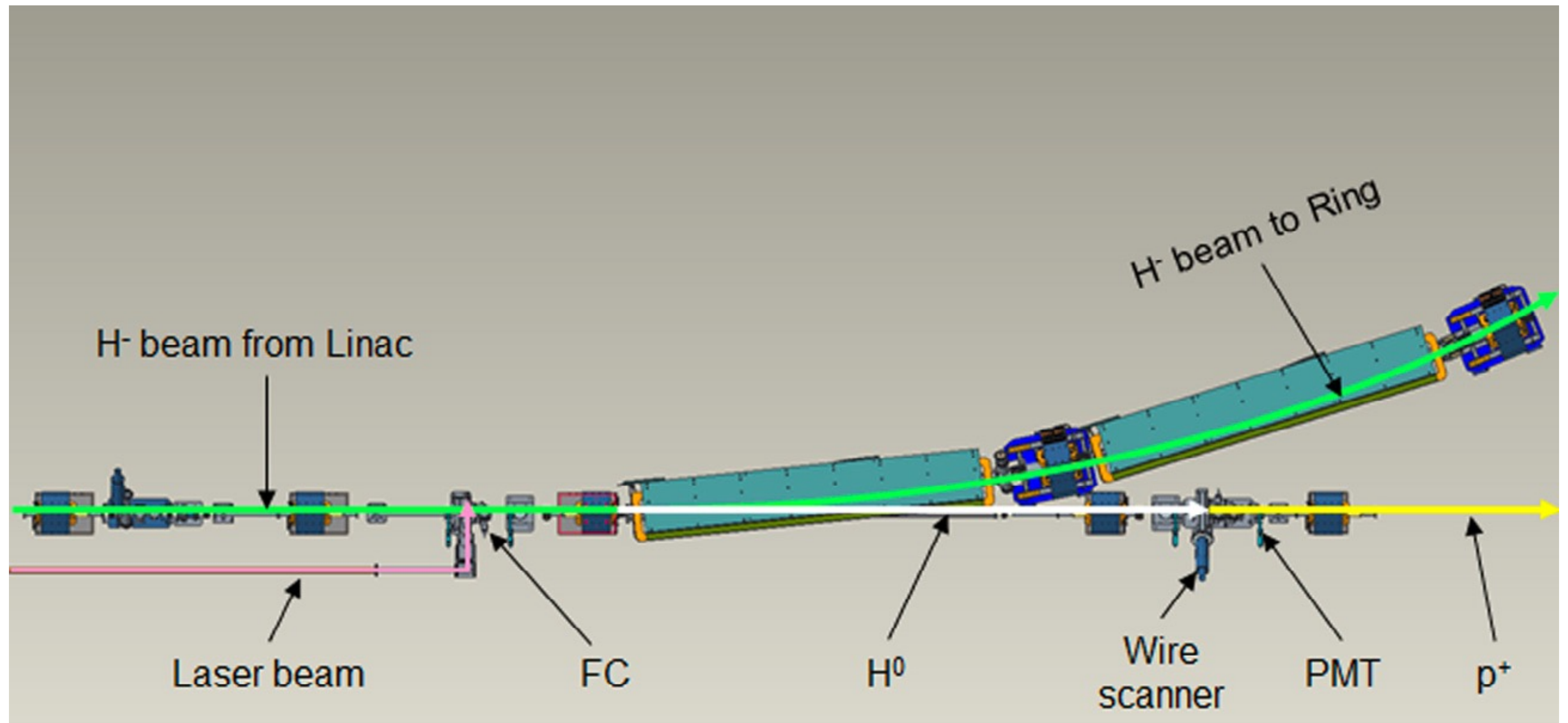
Effectively achieve 0.59 MHz!
(same idea for COMET@J-PARC)

Laser neutralization @ ORNL

30 ns/ 50 kHz laser



402.5 MHz Hydrogen Ion



Successfully demonstrated
30 ns/50 kHz proton pulses in 2019

NIM A 962 (2020) 163706

Alternative Drivers: Electron

Tsung-Dao Lee Institute

Secondary Beams From Electron Accelerators

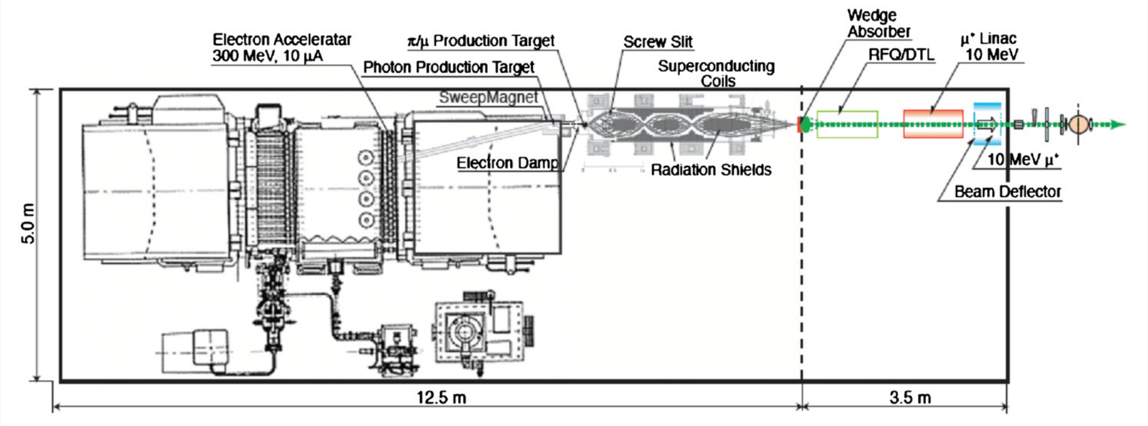
Contents lists available at ScienceDirect

Physica B

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

Compact muon source with electron accelerator for a mobile μSR facility

K. Nagamine [a,b,c,*], H. Miyadera [d], A. Jason [d], R. Seki [e]



300 MeV, 10 μA electron microtrton
→ 8 × 10³ μ⁺/s

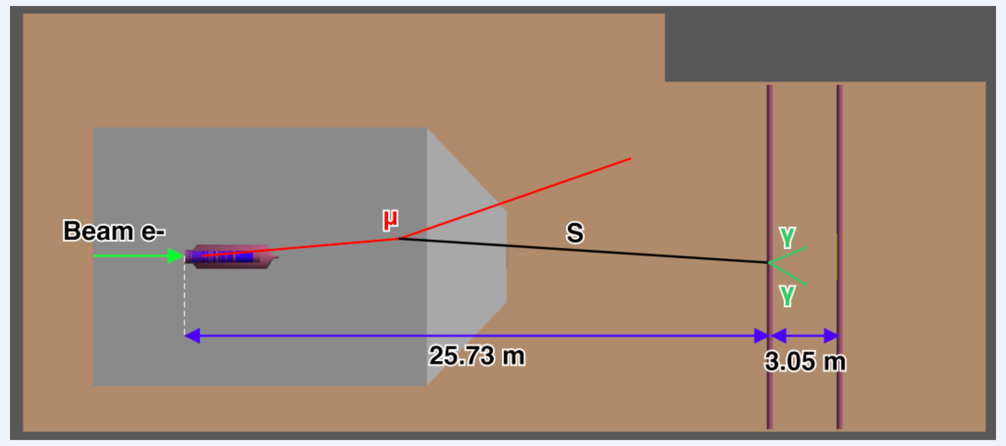
instruments

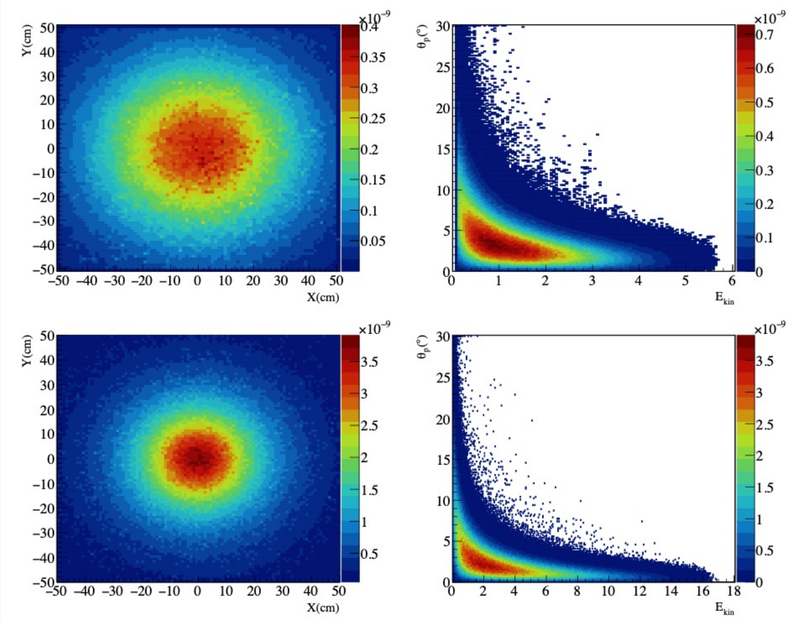
Article

Secondary Beams at High-Intensity Electron Accelerator Facilities

Marco Battaglieri [1], Andrea Bianconi [2,3], Mariangela Bondí [4], Raffaella De Vita [1], Ant
Stefano Grazzi [1,5], Hyon-Suk Jo [6], Changhui Lee [6], Giuseppe Mandaglio [4,5], Valerio Ma
Alessandro Pilloni [4,5], Marco Spreafico [1,7], Luca J. Tagliapietra [8], Luca Venturelli [2,3]

CEBAF@JLAB
11 GeV, 50 μA
→ ~ 10⁸ μ± /s



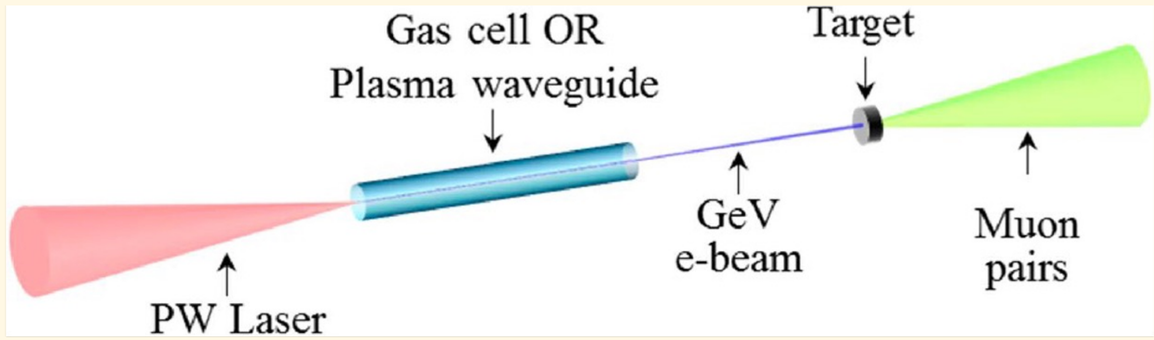


Laser Wakefield Acceleration Muon Production

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 12, 111301 (2009)

Dimuon production by laser-wakefield accelerated electrons

A. I. Titov,[1,2,3] B. Kämpfer,[1,4] and H. Takabe[3]

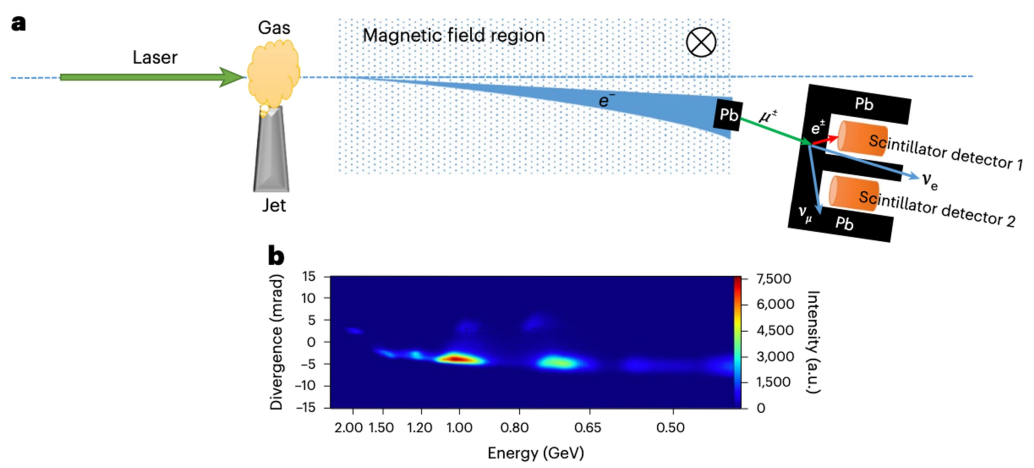


10 GeV, 100 pC electron
→ 8 × 10³ μ± /s

nature physics

Article https://doi.org/10.1038/s41567-025-02872-2

Proof-of-principle demonstration of muon production with an ultrashort high-intensity laser



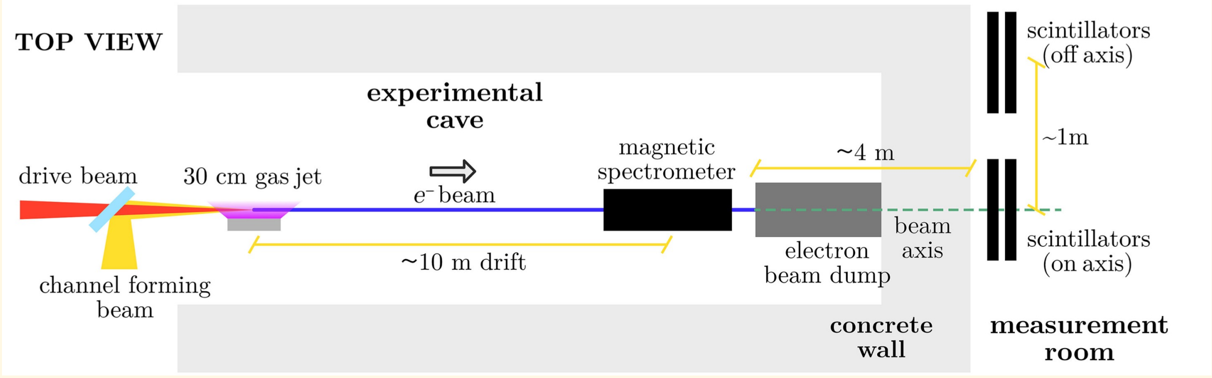
Shanghai Superintense Ultrafast Laser Facility (SULF)

PHYSICAL REVIEW ACCELERATORS AND BEAMS 28, 103401 (2025)

BeLLA

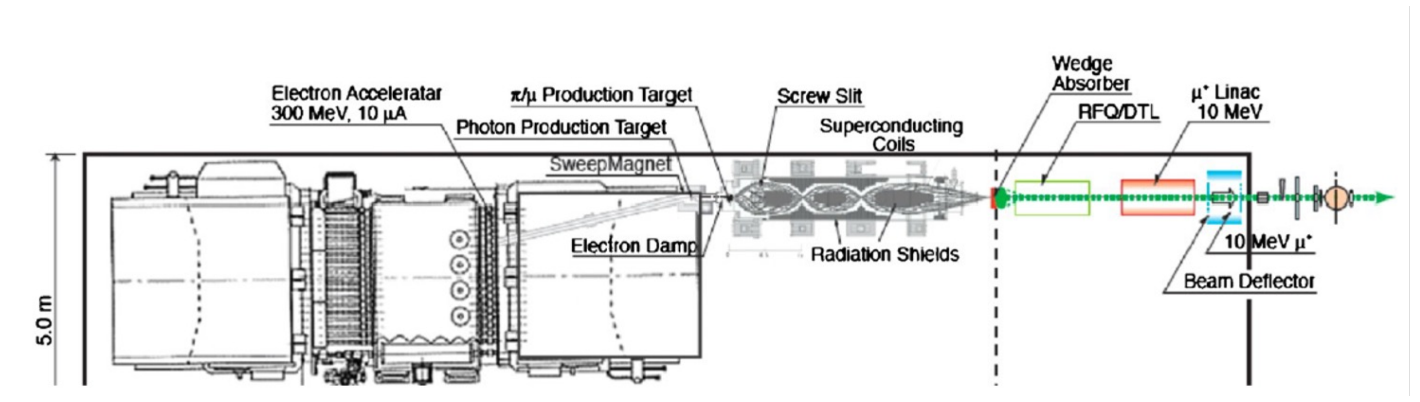
Measurement of directional muon beams generated at the Berkeley Lab Laser Accelerator

Davide Terzani,[1,*] Stanimir Kisyov,[1] Stephen Greenberg,[1,2] Luc Le Pottier,[1,2] Maria Mironova,[1] Alex Picksley,[1] Joshua Stackhouse,[1,3] Hai-En Tsai,[1] Raymond Li,[1,3] Ela Rockafellow,[4] Bo Miao,[4] Jaron E. Shrock,[4] Timon Heim,[1] Maurice Garcia-Sciveres,[1] Carlo Benedetti,[1] John Valentine,[1] Howard M. Milchberg,[4] Kei Nakamura,[1] Anthony J. Gonsalves,[1] Jeroen van Tilborg,[1] Carl B. Schroeder,[1,3] Eric Esarey,[1] and Cameron G. R. Geddes[1]

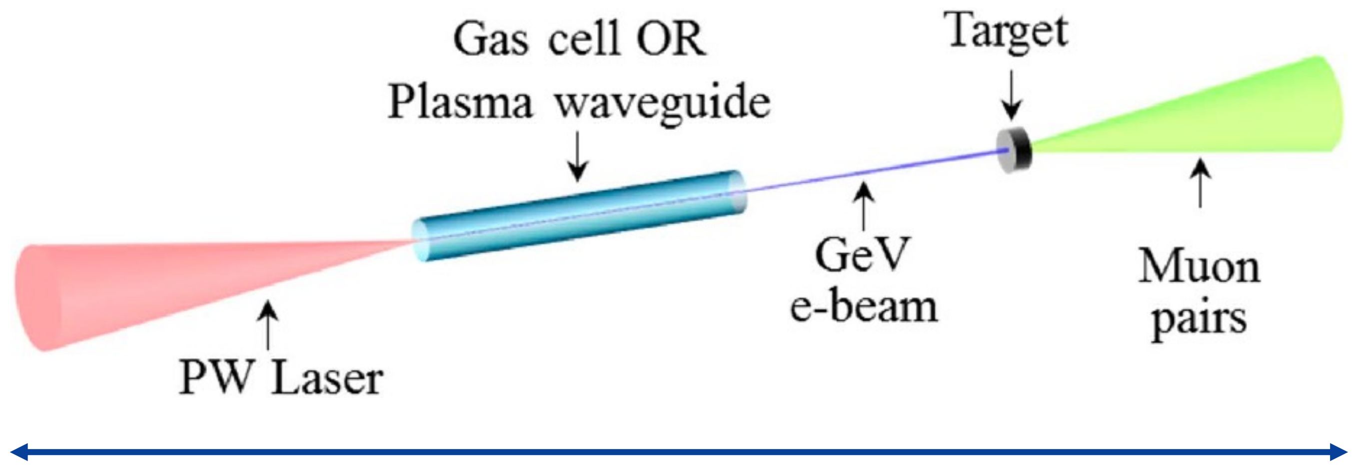


ELI & Many more…

Advantage ?



Existing electron facilities



LWFA-based machines

Compact, portable, low-cost

μSR

Physica B 404 (2009) 1024–1027
Contents lists available at ScienceDirect
Physica B
journal homepage: www.elsevier.com/locate/physb
ELSEVIER

Towards a dedicated high-intensity muon facility

R. Cywinski[a,*], A.E. Bungau[a], M.W. Poole[b], S. Smith[b], P. Dalmas de Reotier[c], R. Barlow[d], R. Edgecock[e], P.J.C. King[e], J.S. Lord[e], F.L. Pratt[e], K.N. Clausen[f], T. Shiroka[f]
[a] School of Applied Sciences, University of Huddersfield, Huddersfield HD1 3DH, UK
[b] ASTeC, STFC Daresbury Laboratory, Warrington, Cheshire WA4 4AD, UK
[c] CEA/INAC, 17, rue des Martyrs, 38054 Grenoble cedex 9, France
[d] School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK
[e] ISIS Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, UK
[f] Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

that the threshold for double pion production is ~600 MeV, the second alternative affords higher muon production rates and, therefore, represents the preferred choice.

Proton driver frequency: The 50 Hz pulsed operation of ISIS is sub-optimal for μSR studies. Typically, time resolved spectra are collected over no more than 32 μs (i.e. ~15 muon lifetimes), giving an effective duty cycle of only 0.16%. While advantageous for some types of experiments (e.g. those involving pulsed sample environments), the 50 Hz operation is generally inefficient: ideally a muon-source proton driver should operate at ~25 kHz.

$\mathrm{Mu} - \overline{\mathrm{Mu}}$

SciPost
SciPost Phys. Proc. 5, 009 (2021)

Muonium-antimuonium conversion

Lorenz Willmann* and Klaus Jungmann
Van Swinderen Institute, University of Groningen, 9747 AA, Groningen, The Netherlands
* L.Willmann@rug.nl

PAUL SCHERRER INSTITUT PSI
Review of Particle Physics at PSI
doi:10.21468/SciPostPhysProc.5

$\overline{\mathrm{M}}$ grows in time to a maximum at $2\tau_\mu$ (see Figure 9.5). Thus the ratio of M to $\overline{\mathrm{M}}$ decays grows with t^2. In case of a multiple coincidence, as in MACS, this implies that the potential $\overline{\mathrm{M}}$ signal/background increased. Therefore a new experiment should be considered, e.g., in connection with the muon source of a muon collider, provided high muon beam quality, i.e. a narrow μ^+ momentum band at subsurface μ^+ momentum. We note that for such an improved experiment beam repetition rates of up to several 10 kHz with μ^+ bunches of up to $\approx \mu$s length would be ideal.

With a new experiment, from the viewpoint of signal to background ratio, an improved value for G_{MM} by at least 2 orders of magnitude should be possible, i.e., 4 orders of magnitude in the conversion probability. At such sensitivity there would be strong constraints for the development of models beyond standard theory [5–8].

Muon EDM

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. 37 (2010) 085001 (7pp) doi:10.1088/0954-3899/37/8/085001

Compact storage ring to search for the muon electric dipole moment

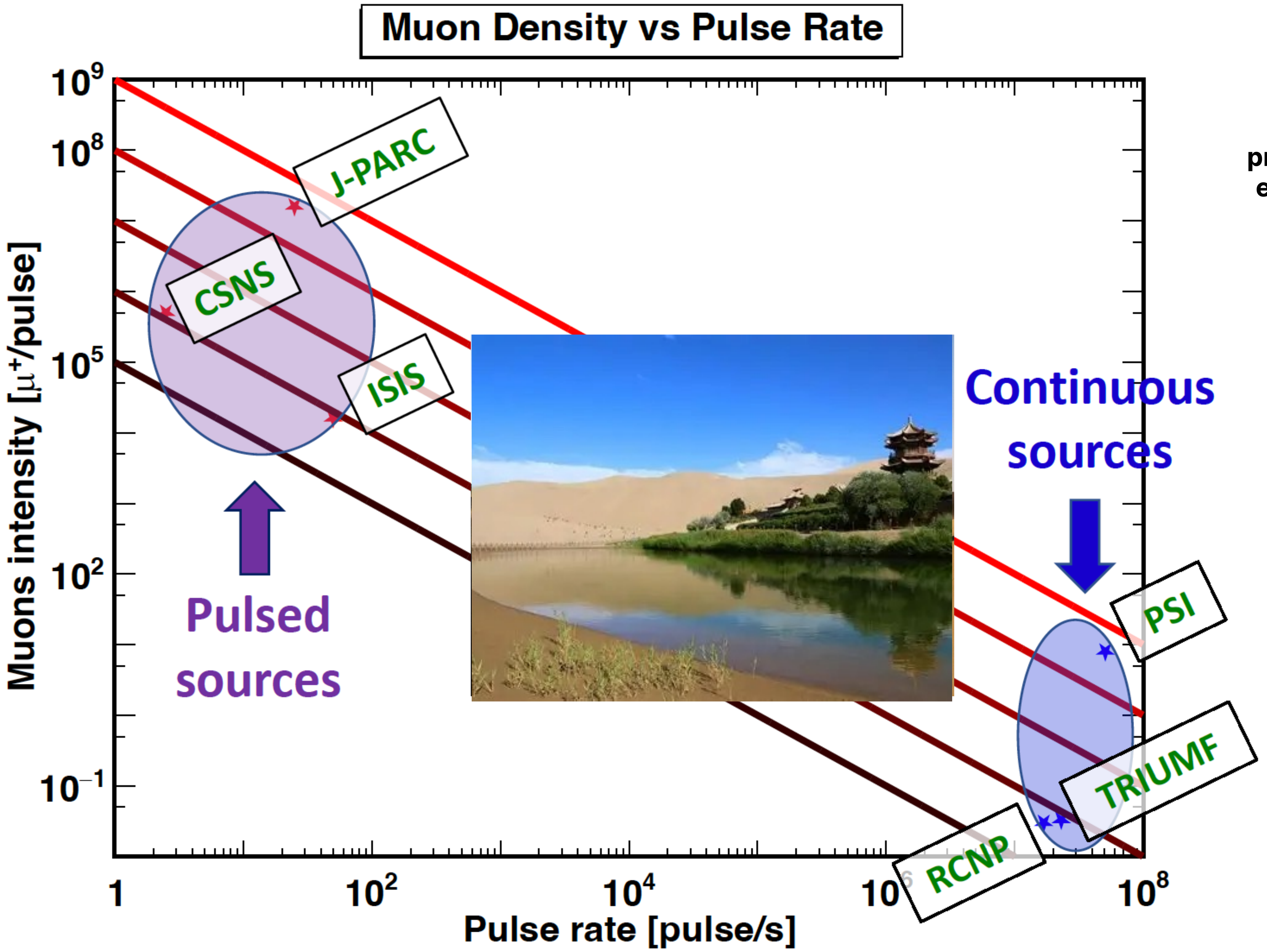
A Adelmann[1], K Kirch[1,2], C J G Onderwater[3] and T Schietinger[1]
[1] Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
[2] Eidgenössische Technische Hochschule Zürich, CH-8093 Zürich, Switzerland
[3] Kernfysisch Versneller Instituut and University of Groningen, NL-9747AA Groningen, The Netherlands

J. Phys. G: Nucl. Part. Phys. 37 (2010) 085001 A Adelmann *et al*

of the difference between the measured anomalous magnetic moment and its SM prediction. It would furthermore test various SM extensions, in particular those that do not respect lepton universality.

In view of the possible advent of new, more powerful pulsed muon sources, the same experimental scheme can be realized but with considerably more muons per bunch being injected into the ring. It appears realistic to expect accelerators with on the order of 100 kHz repetition rates and more than 10^4 muons stored per bunch. The statistical sensitivity of the described approach would then reach down to a few times 10^{-25} e cm. Although systematic issues at this level of precision have been discussed in some detail in [19], more detailed studies would be needed.

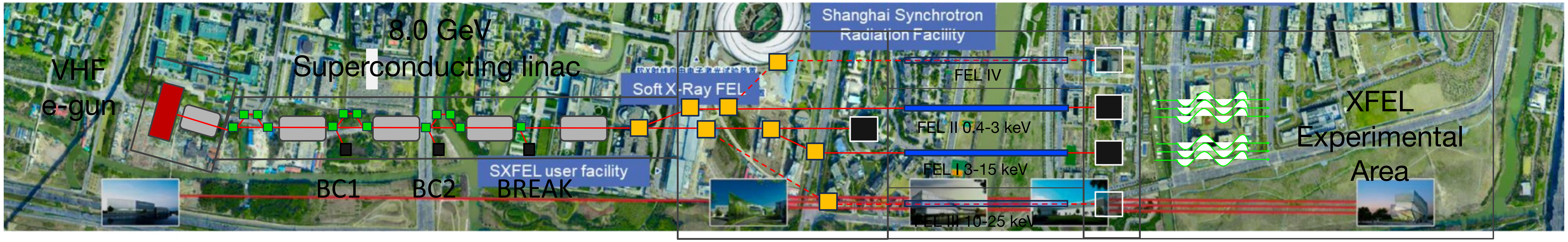
How Do We Start ?



Shanghai HIgh RepetitioN-rate XFEL and Extreme Light Facility

Tsung-Dao Lee Institute

Shanghai Tech. Univ.



Shaft #1 **Shaft #2** 1.9 km Undulators 2.3 km 3.1 km

Jointly Developed by

- Shanghai Advanced Research Institute, CAS
- Shanghai Tech. Univ.

中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

上海科技大学
ShanghaiTech University

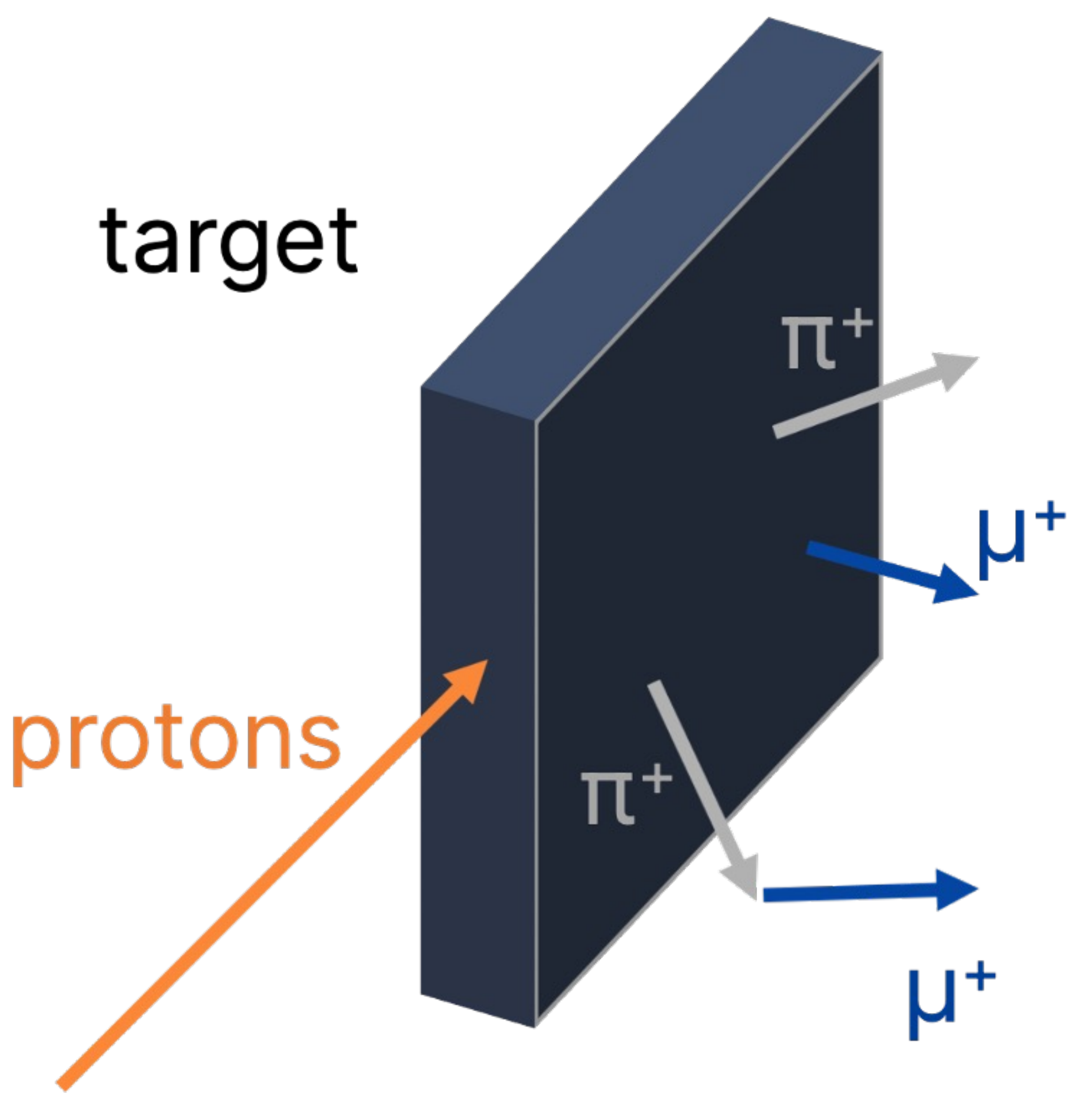
SHINE
SHANGHAI HIGH REPETITION RATE XFEL AND EXTREME LIGHT FACILITY
硬X射线自由电子激光装置

Design Parameters

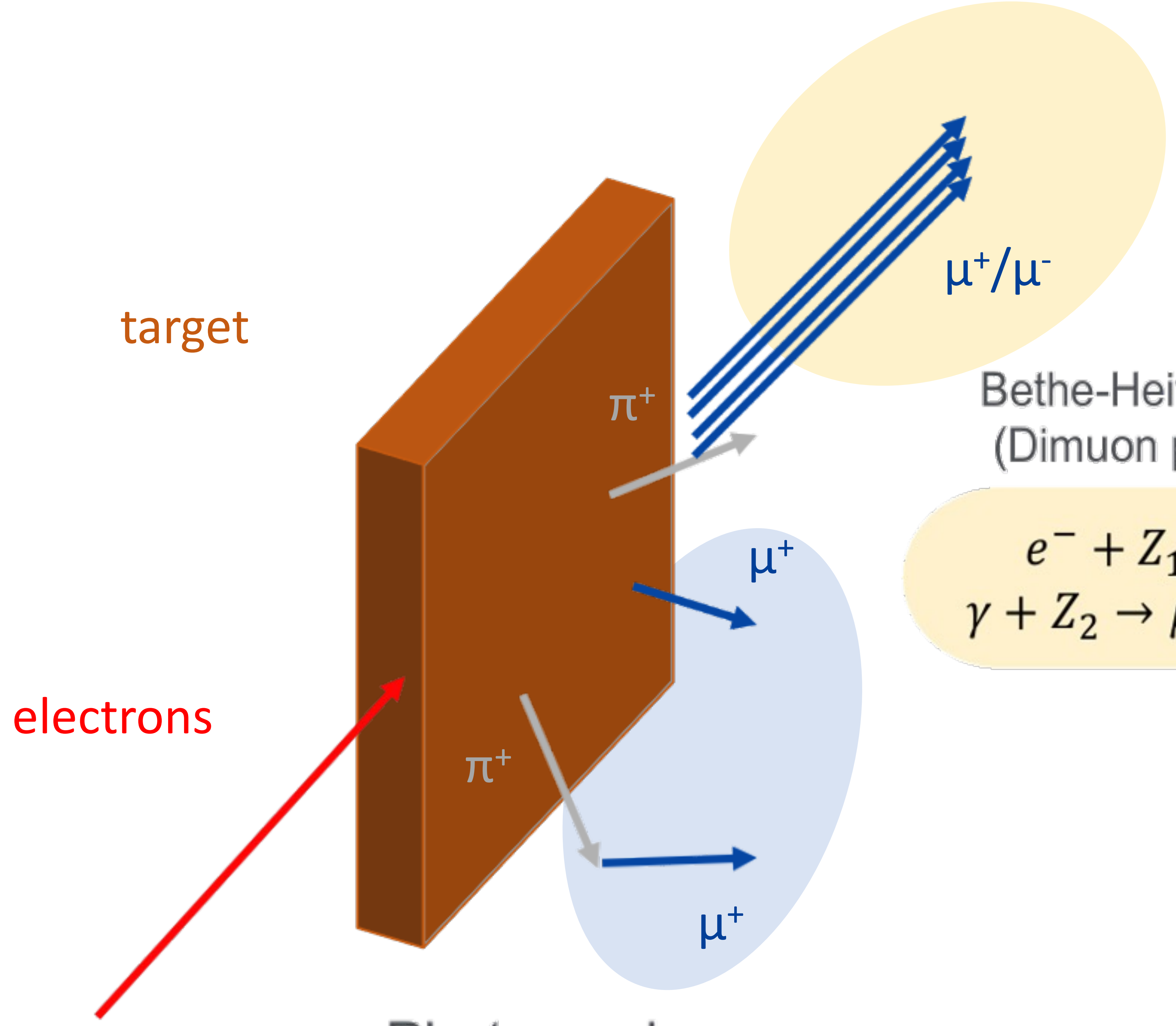
- 8 GeV CW SCRF electron linac
- 1 MHz repetition rate
- 100 pC / bunch

Only 4 km From TDLI !

Proton-on-target vs Electron-on-target



$$p + p \rightarrow p + n + \pi^+$$
$$p + p \rightarrow p + p + \pi^+ + \pi^-$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$



Bethe-Heitler process
(Dimuon production)

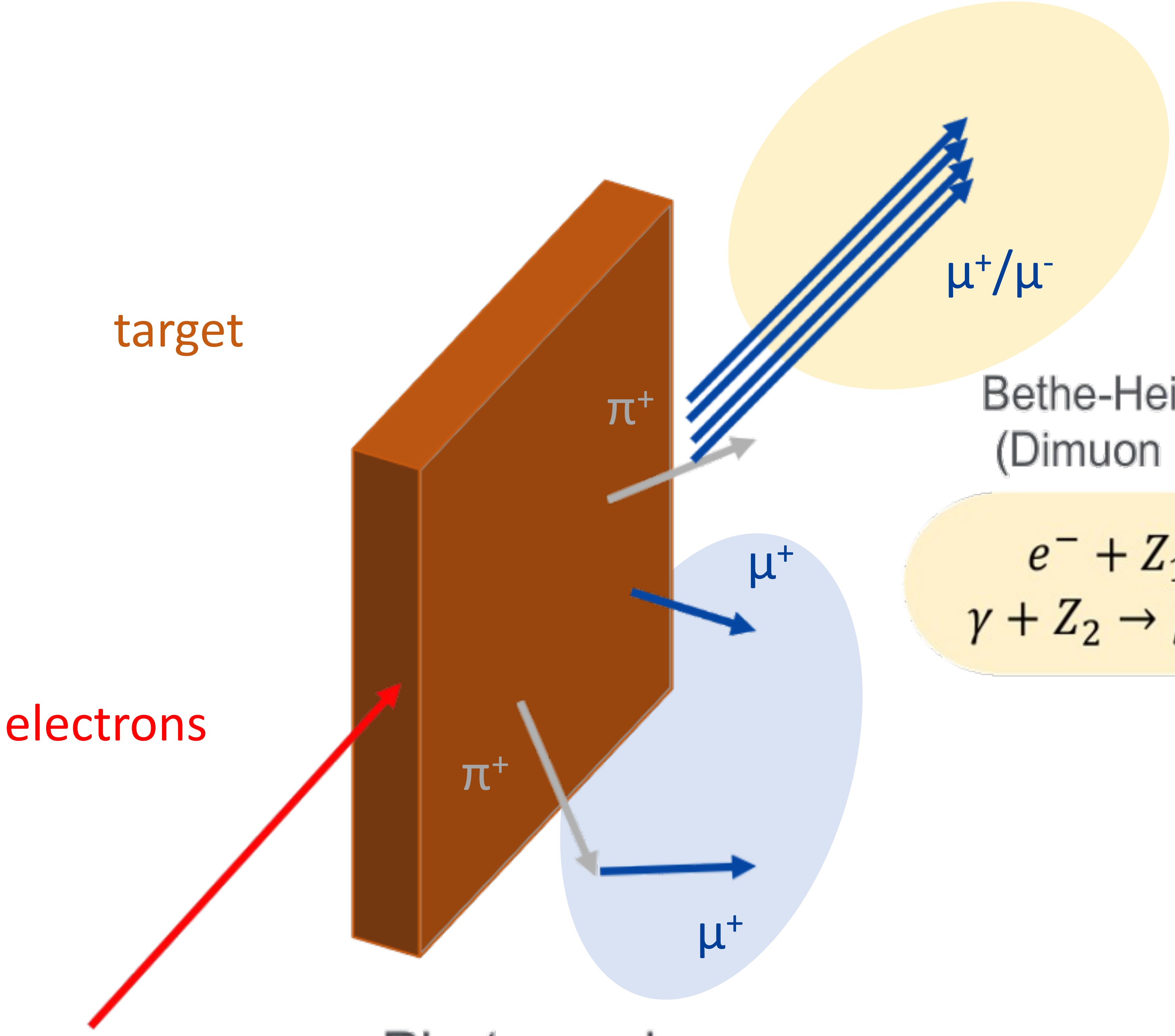
$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \mu^+ + \mu^- + Z_2$$

Photo-nuclear process

$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \pi^\pm + Z_3$$

Proton-on-target vs Electron-on-target

Tsung-Dao Lee Institute



Bethe-Heitler process (Dimuon production)

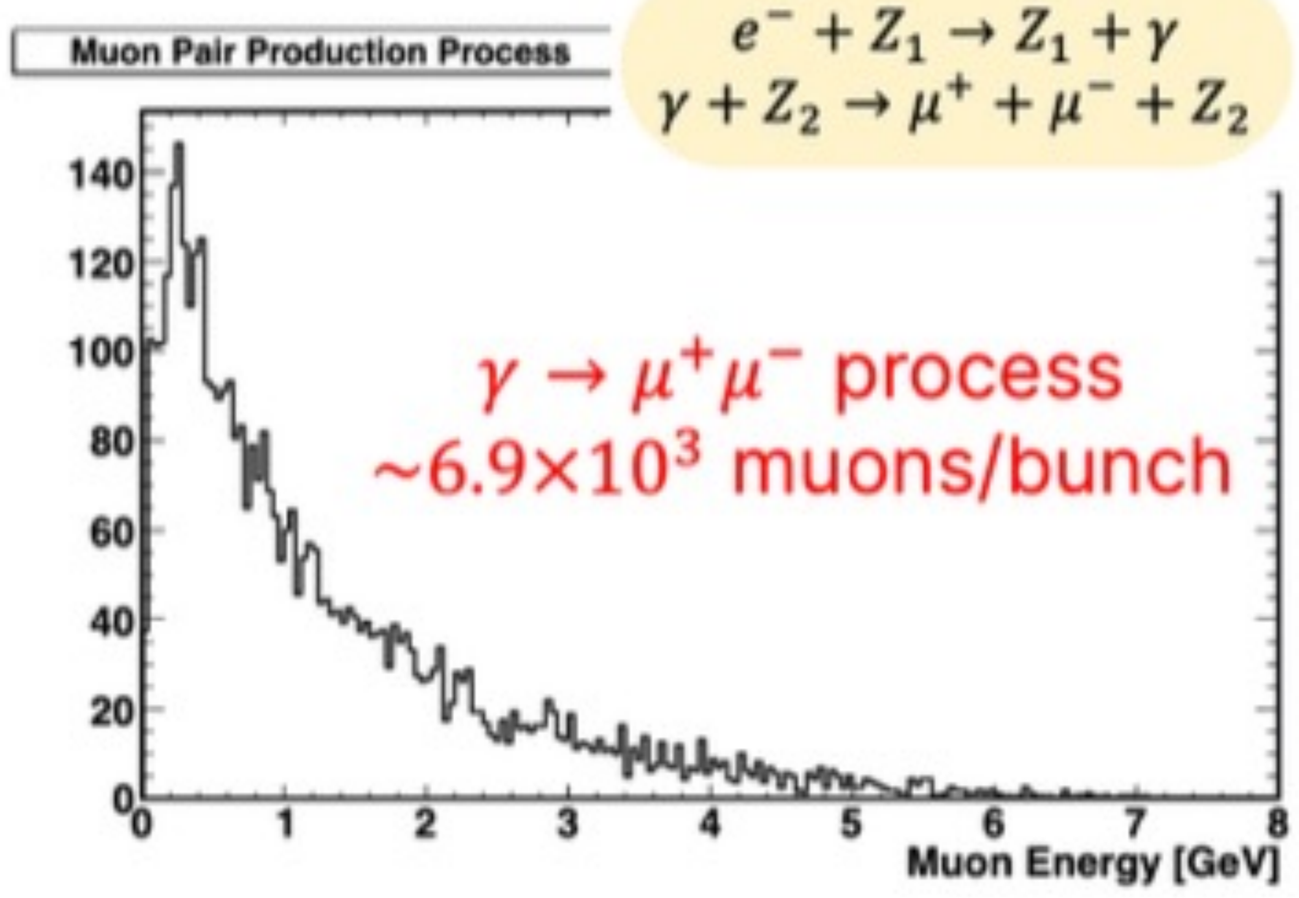
$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \mu^+ + \mu^- + Z_2$$

Photo-nuclear process

$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \pi^\pm + Z_3$$

Bethe-Heitler process

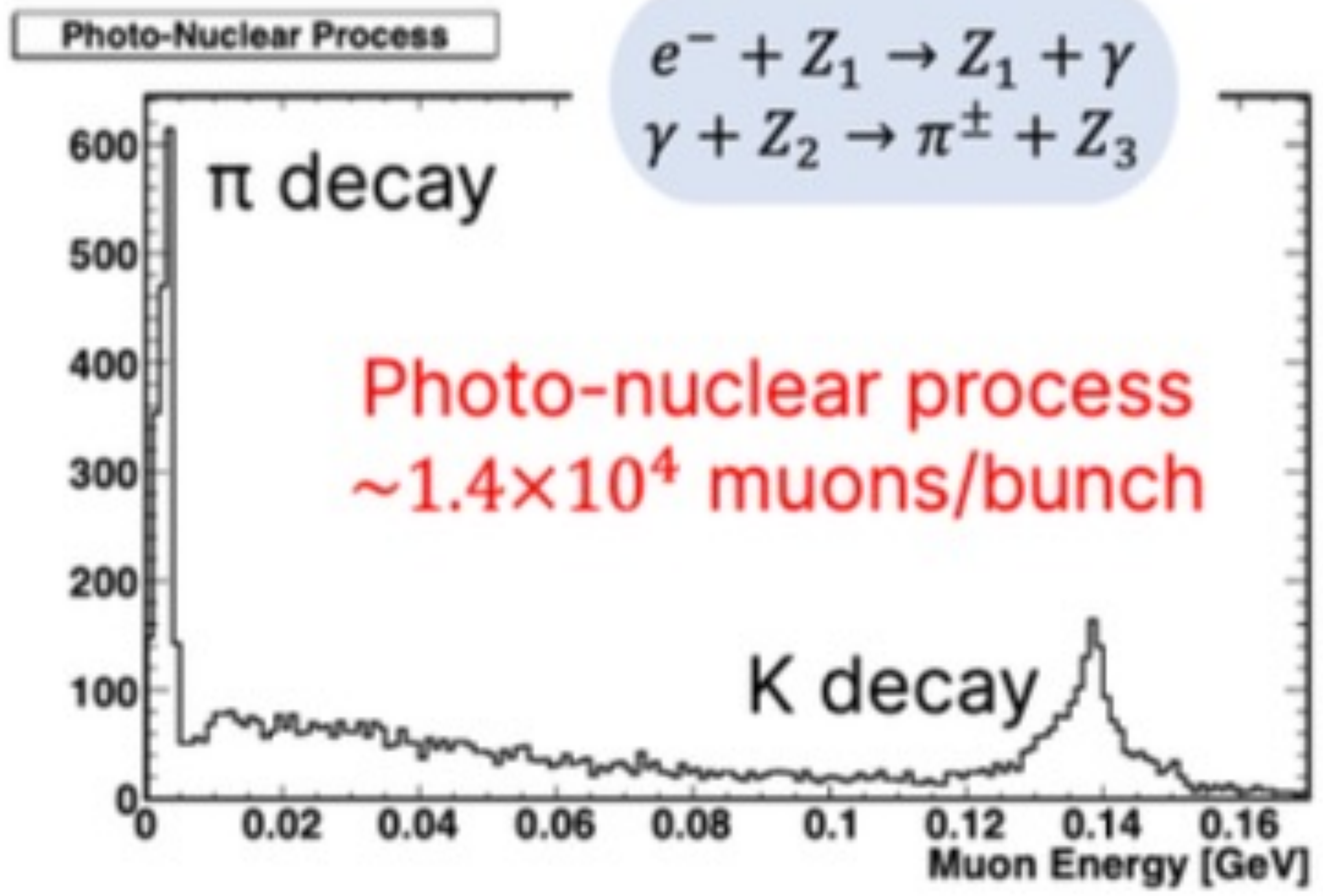
$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \mu^+ + \mu^- + Z_2$$

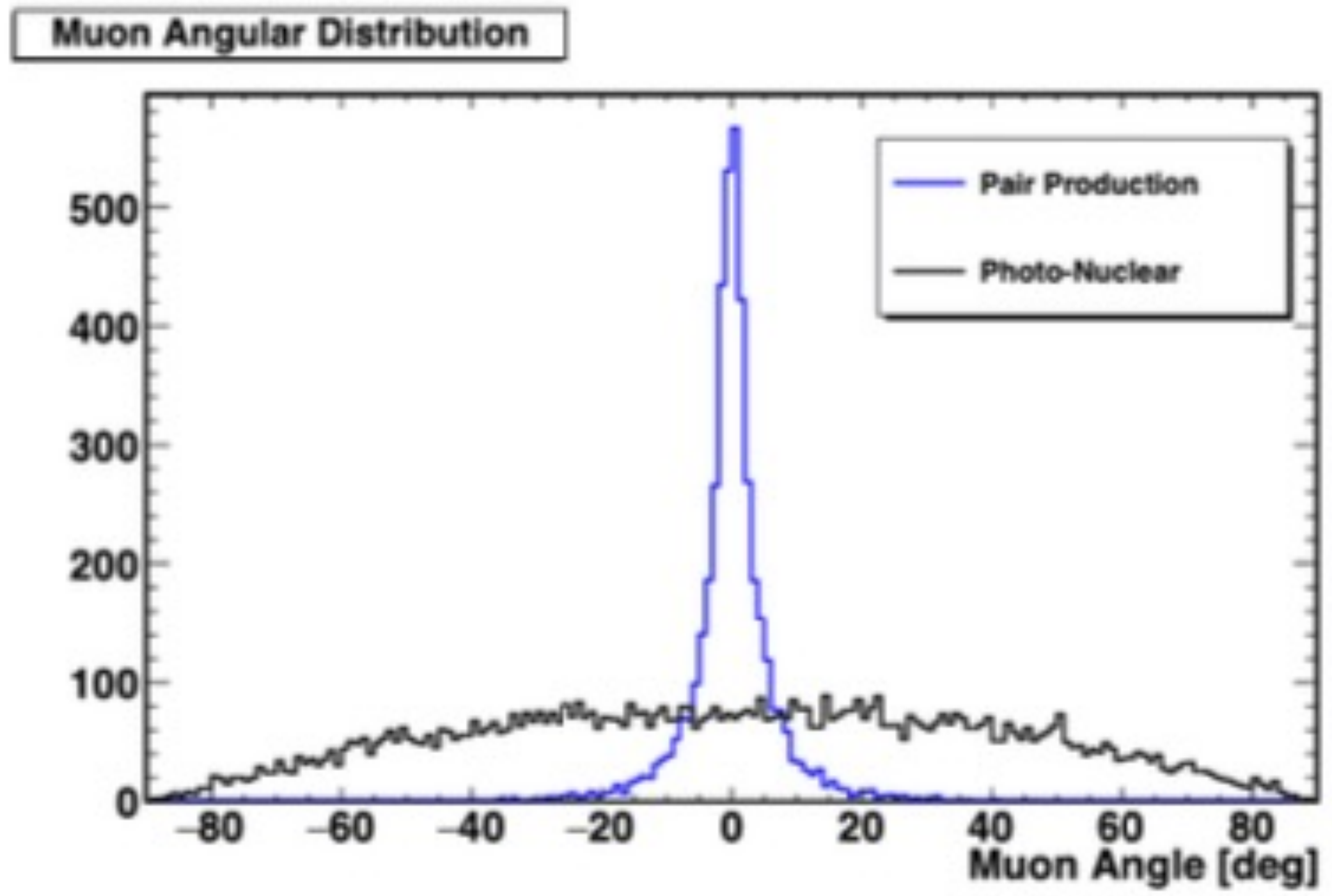


IPAC'23 proceedings

Photo-nuclear process

$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \pi^\pm + Z_3$$

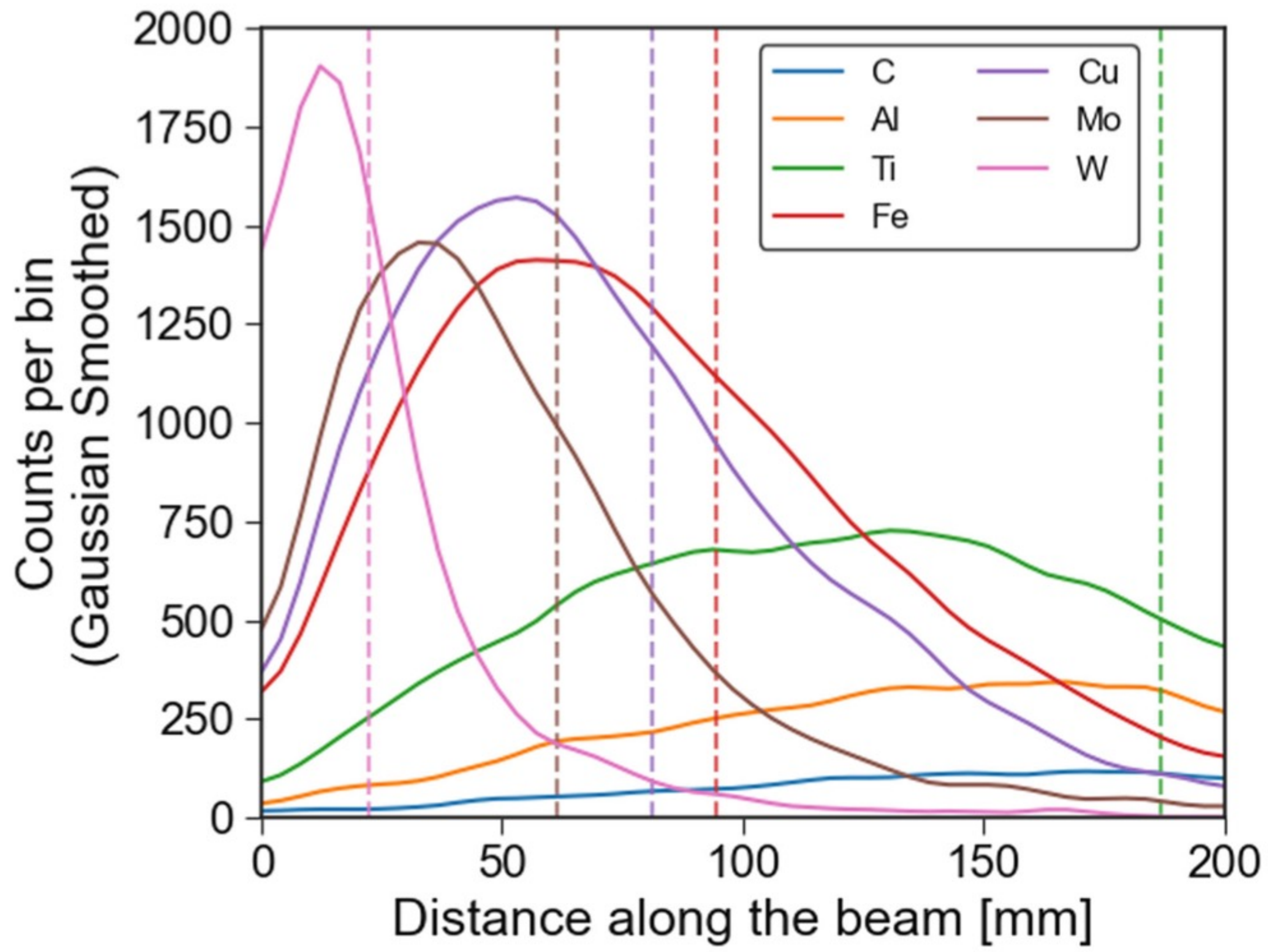


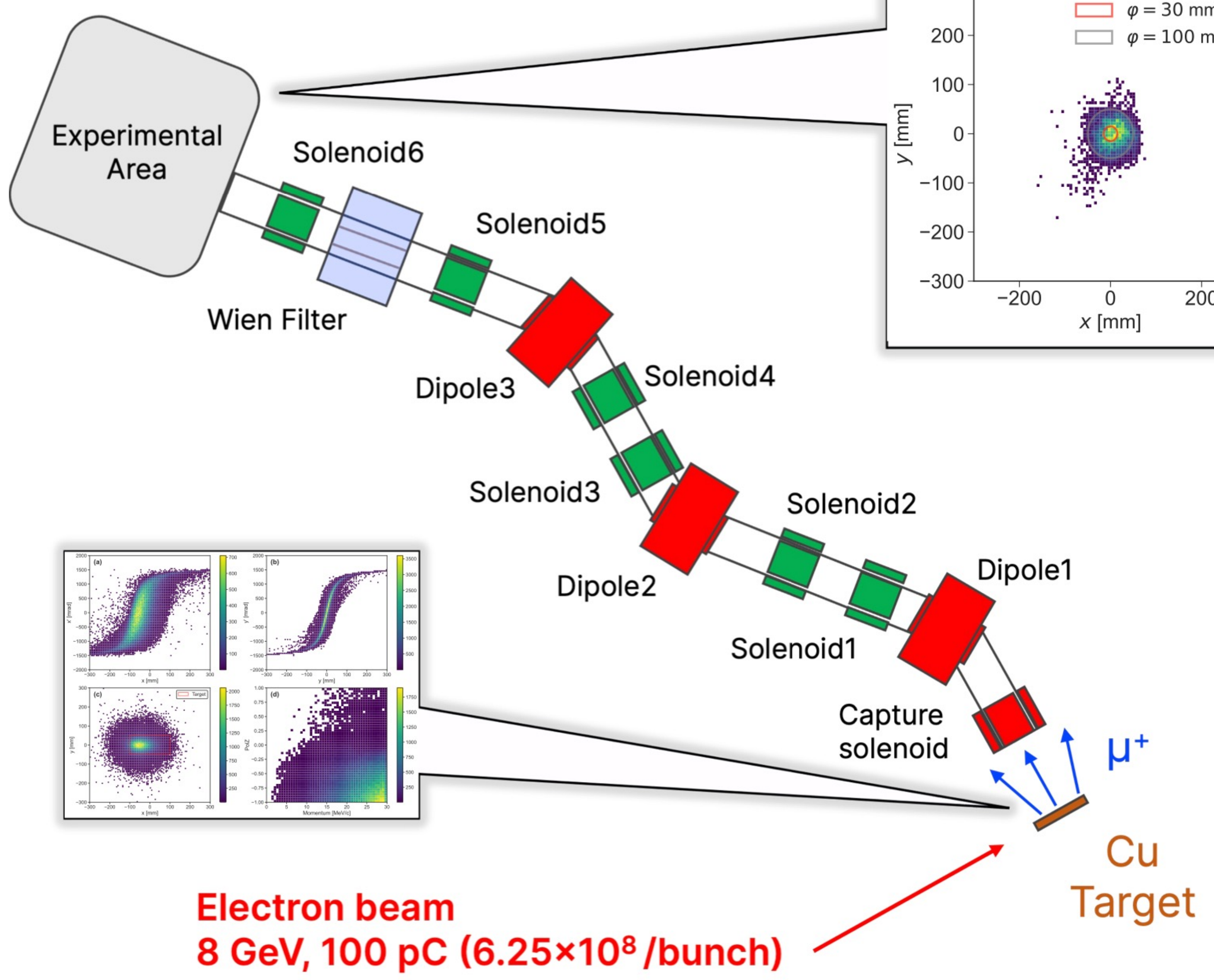


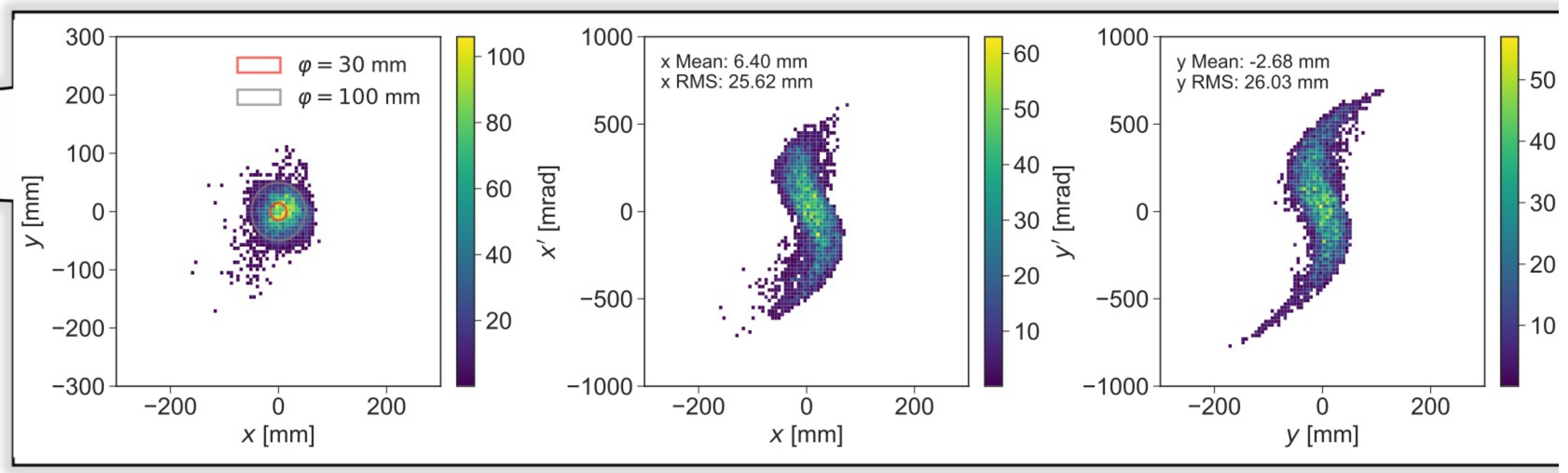
High-rep. Electron-driven Surface Muon Production Scheme

TSUNG-DAO LEE INSTITUTE 李政道研究所

- Optimized the production target, and performed beamline simulation in g4beamline.
- Considering capture and transport, expect **3×10^6 surface μ+/s** at beamline exit.







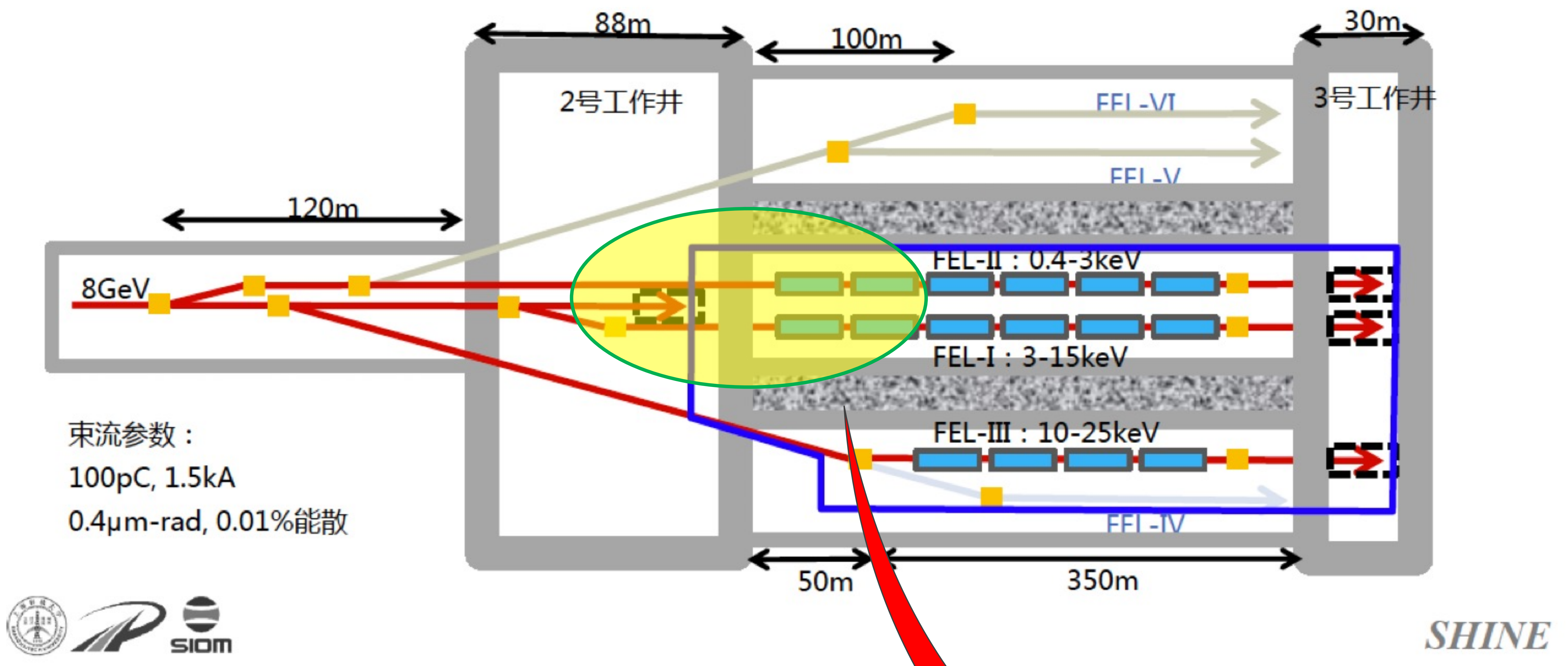
Parameters	Value
x/x' (rms)	25.6 mm/221 mrad
y/y' (rms)	26.0 mm/246 mrad
Mean momentum	27.6 MeV/c
$\Delta p/p$	3.69%
Polarization (before Wien filter)	97%
Polarization (after Wien filter)	88%
μ^+ rate (all)	3.1×10^6 μ^+/s
μ^+ rate (ϕ30 mm)	4.7×10^5 μ^+/s

@50 kHz repetition rate
(1/20) of SHINE capability

Phys. Rev. Accel. Beams, **28**, 083401 (2025)

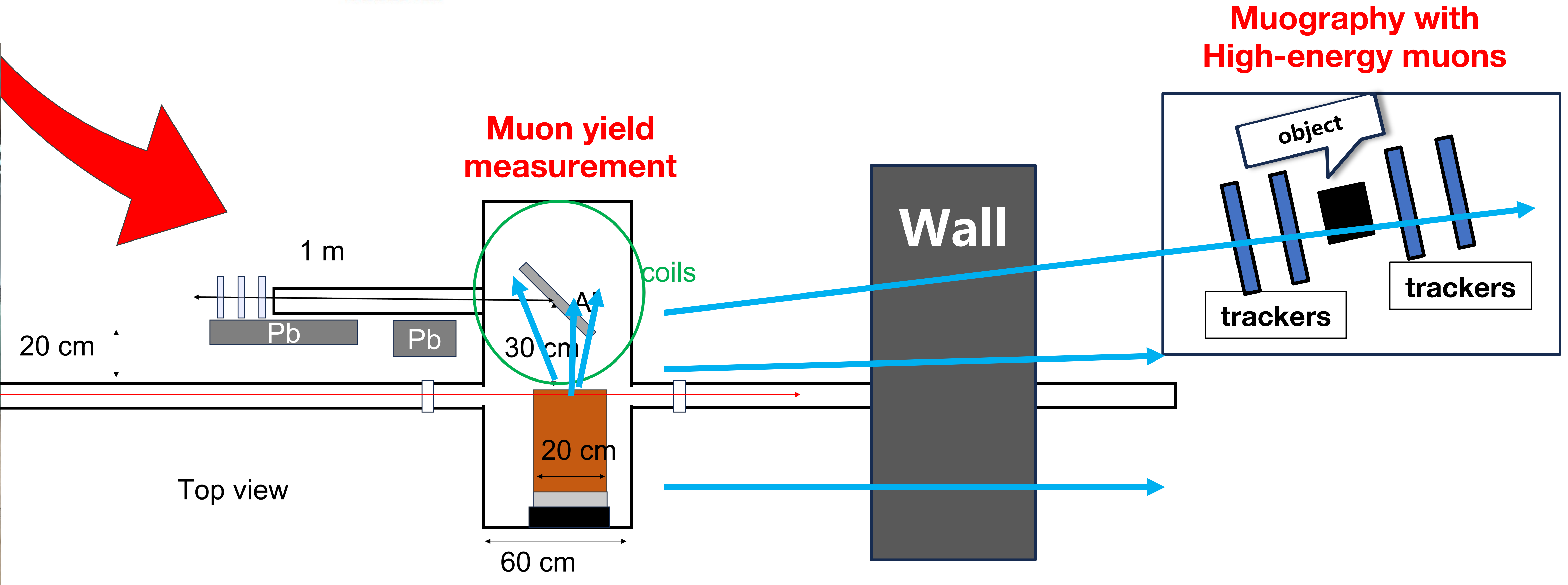
So far no experimental validation on the production scheme and surface muon yield !

Beam Test 2026 @ FEL-II



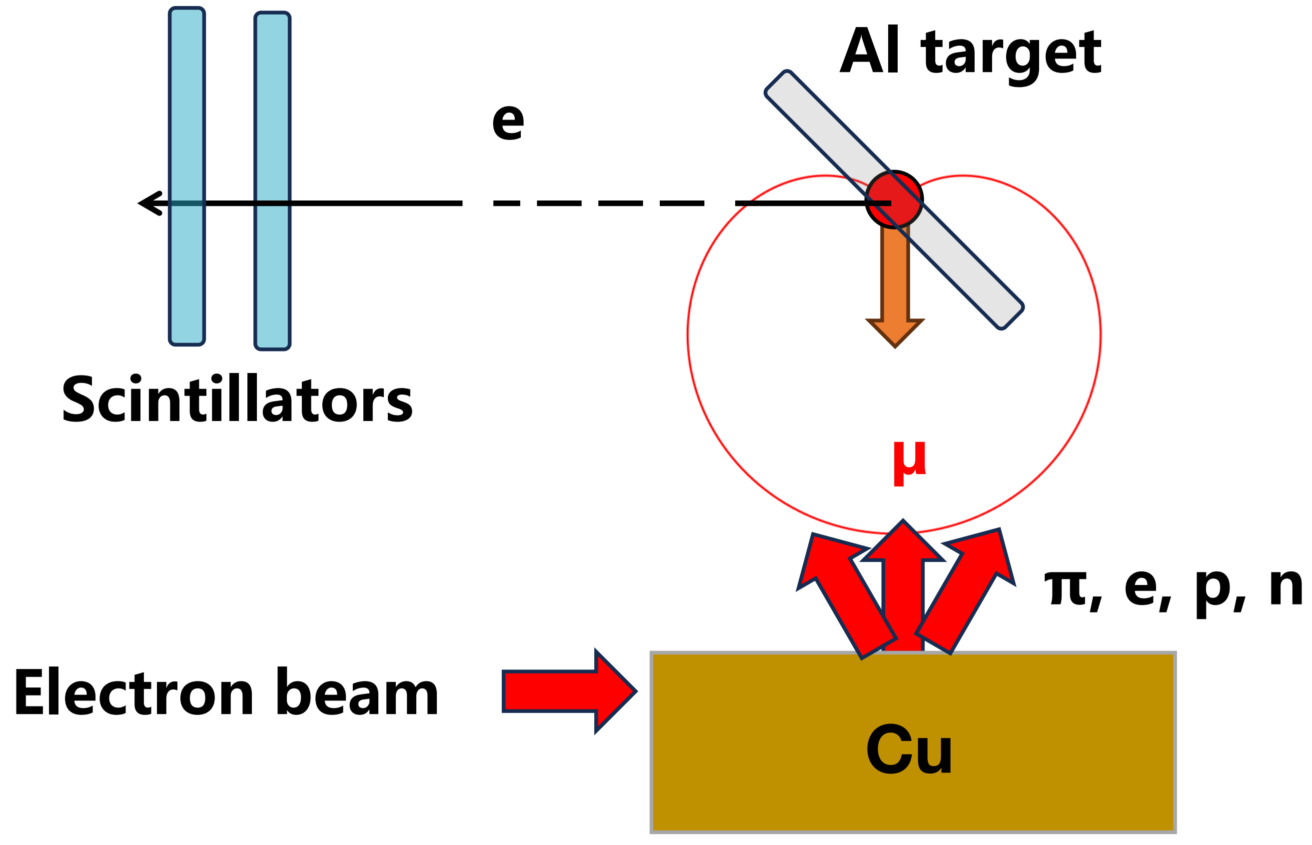
- Injector commissioning finished @ 2024 & L1 commissioning finished @ 2025
- FEL-II commissioning expected in Aug-Sep 2026 (tight beam window)

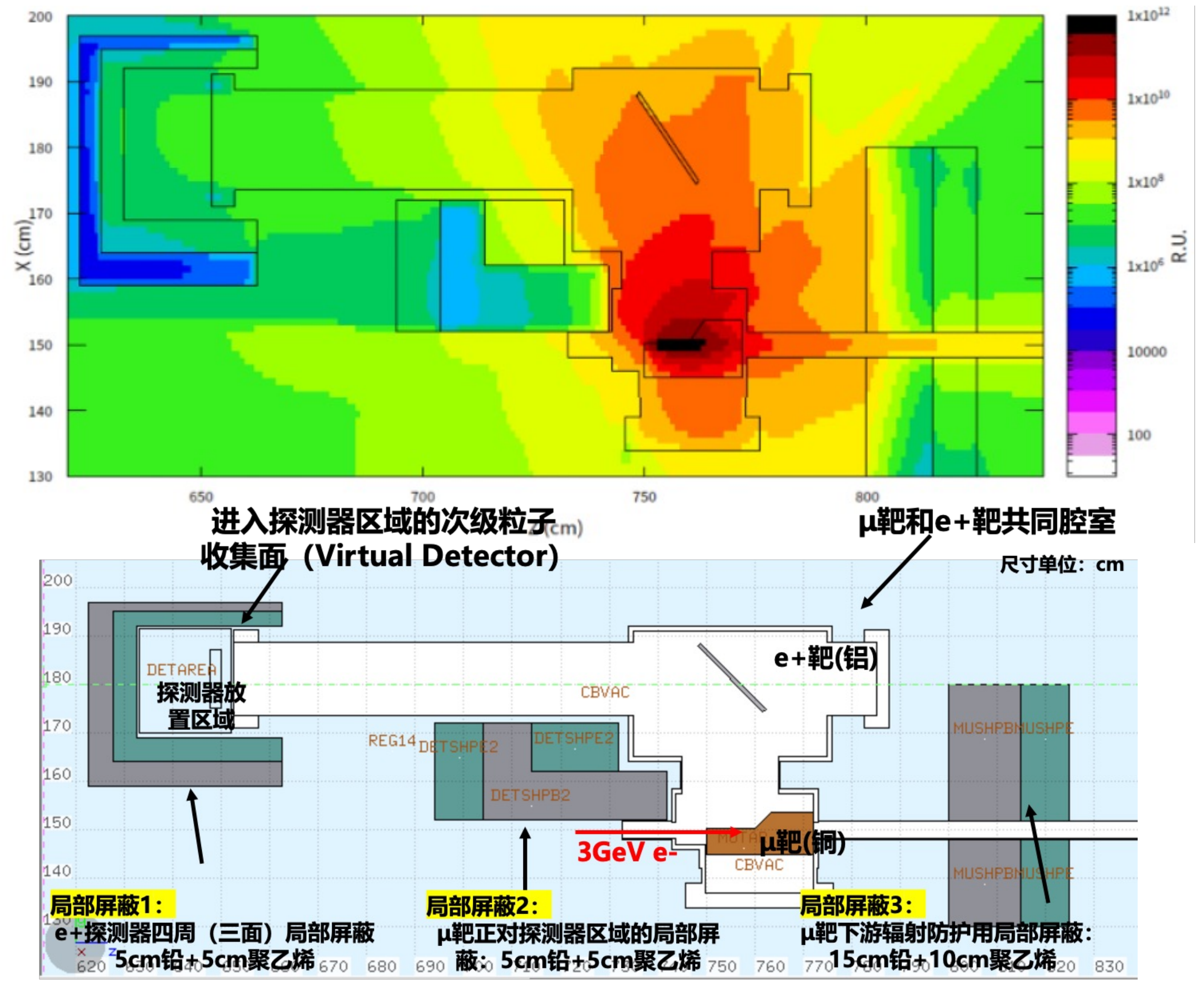
Kill two birds with one stone !



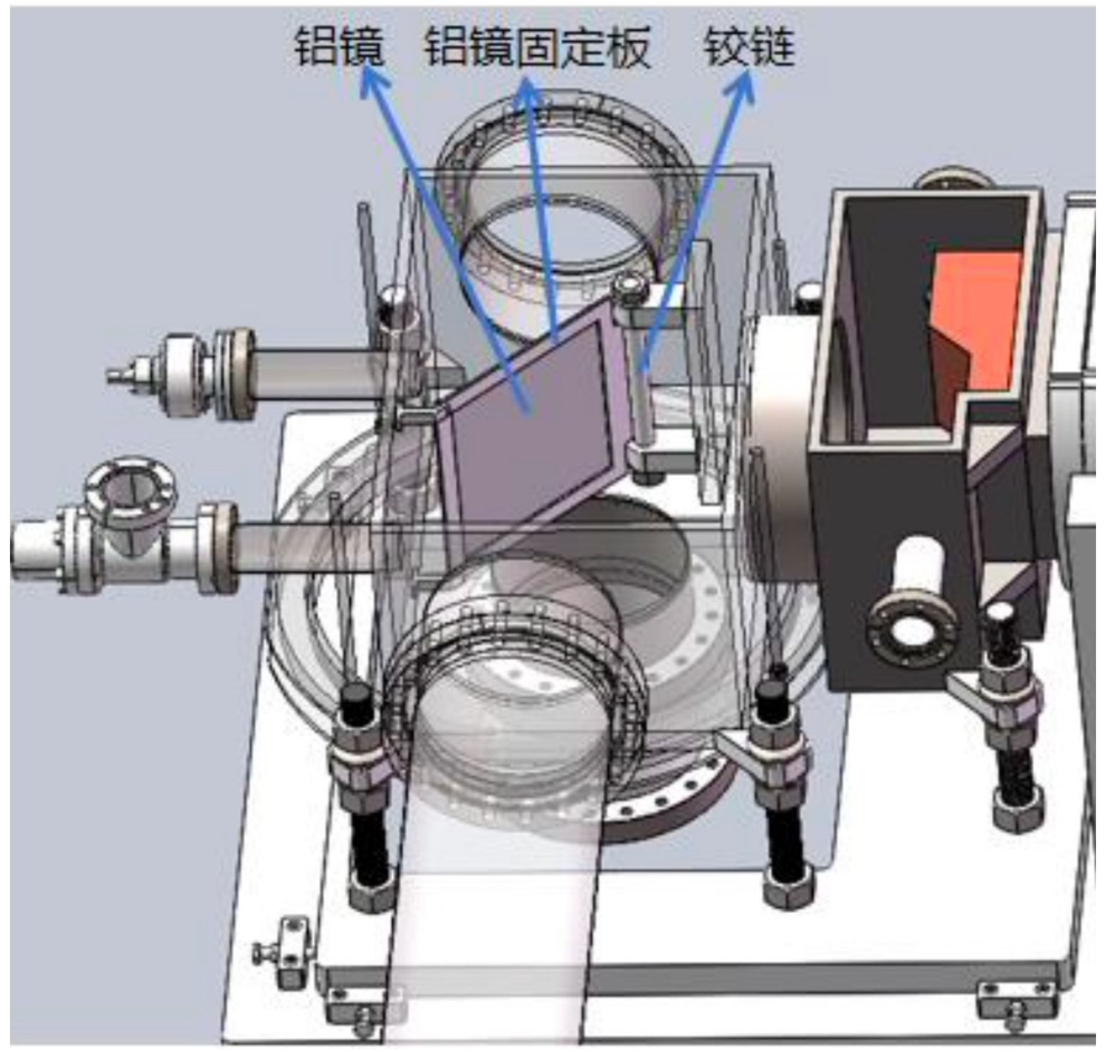
Muon Yield Measurement

- As a first step towards beamline construction
- Synergy between beam, radiation and detector (We) !

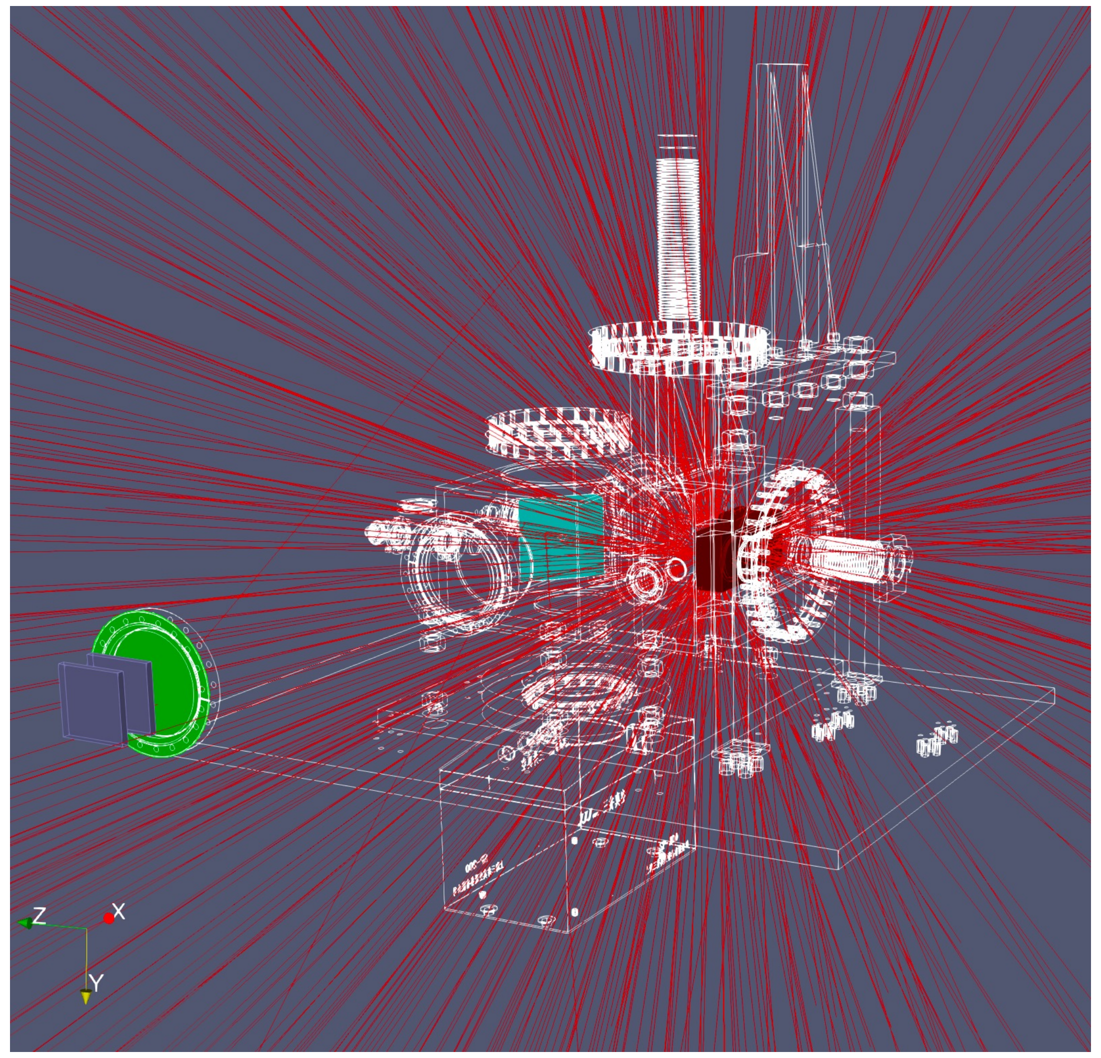


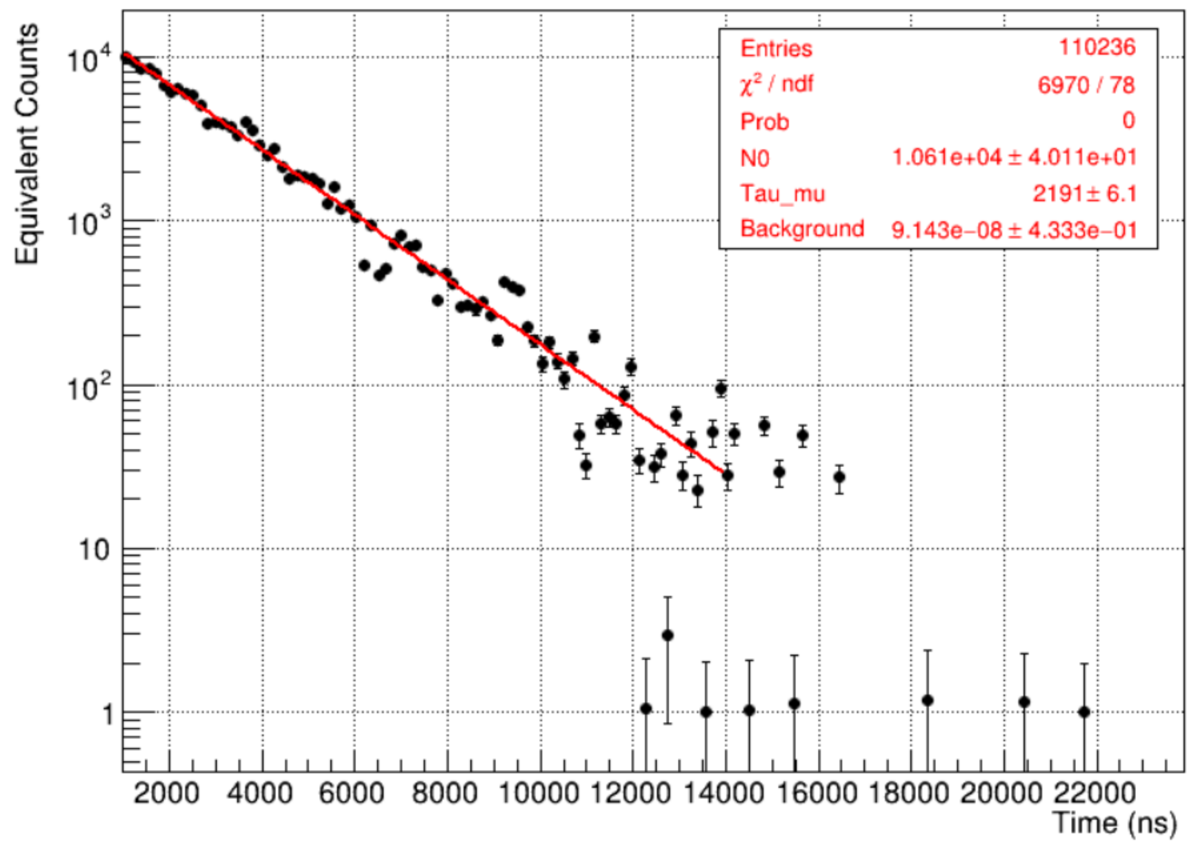


Beam and Radiation shielding
(Wenzhen Xu, SHINE)



Mechanical Design
(Qisheng Tang, SHINE)

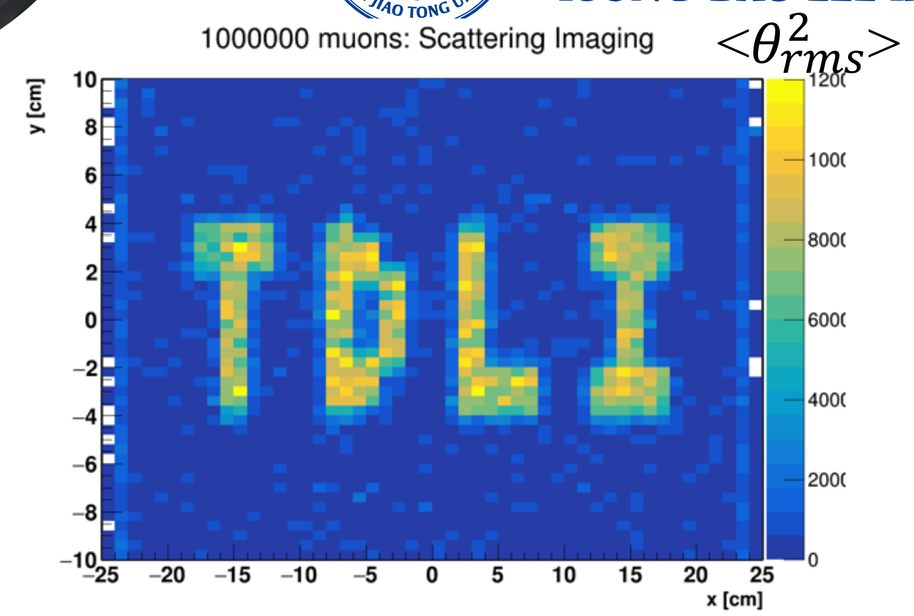


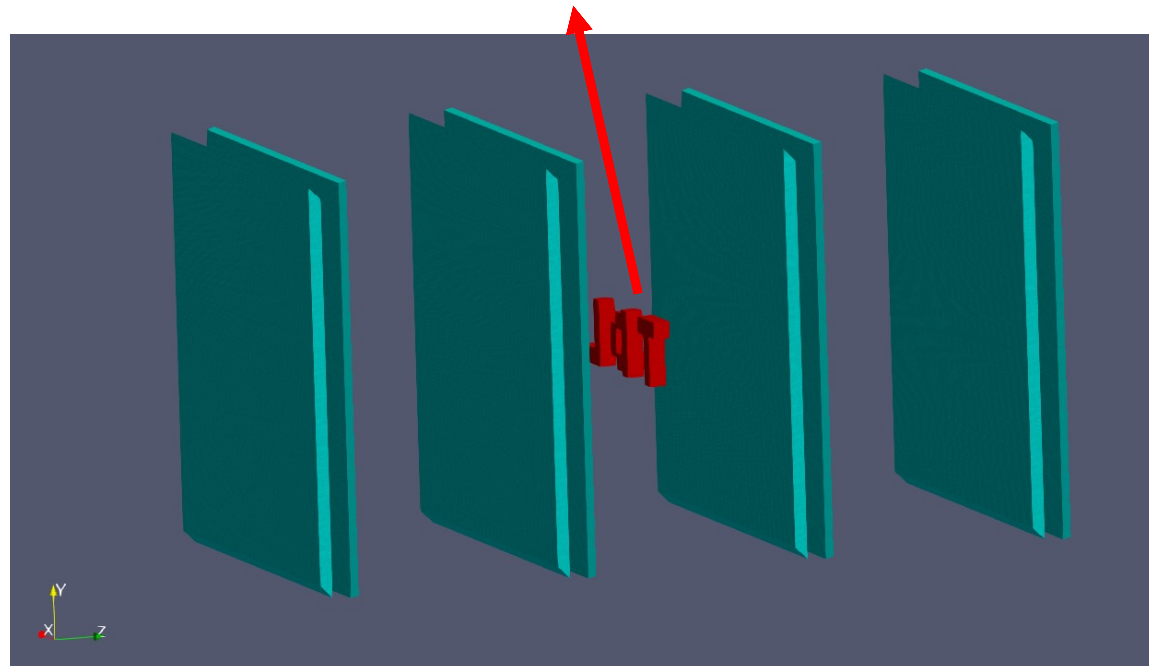


Detector Design & Feasibility Study
(Jia Cheng's Poster)

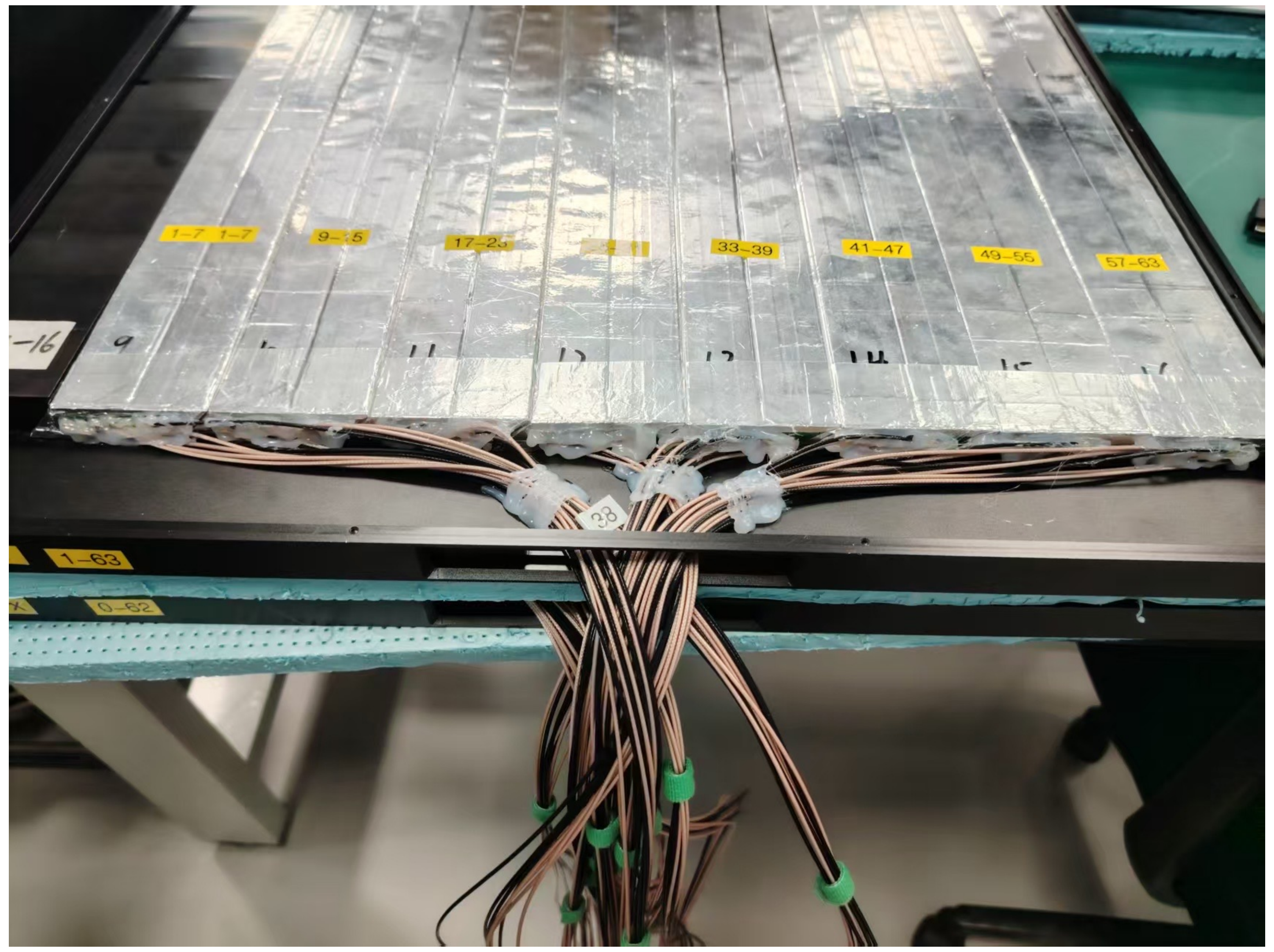
Accelerator Muography

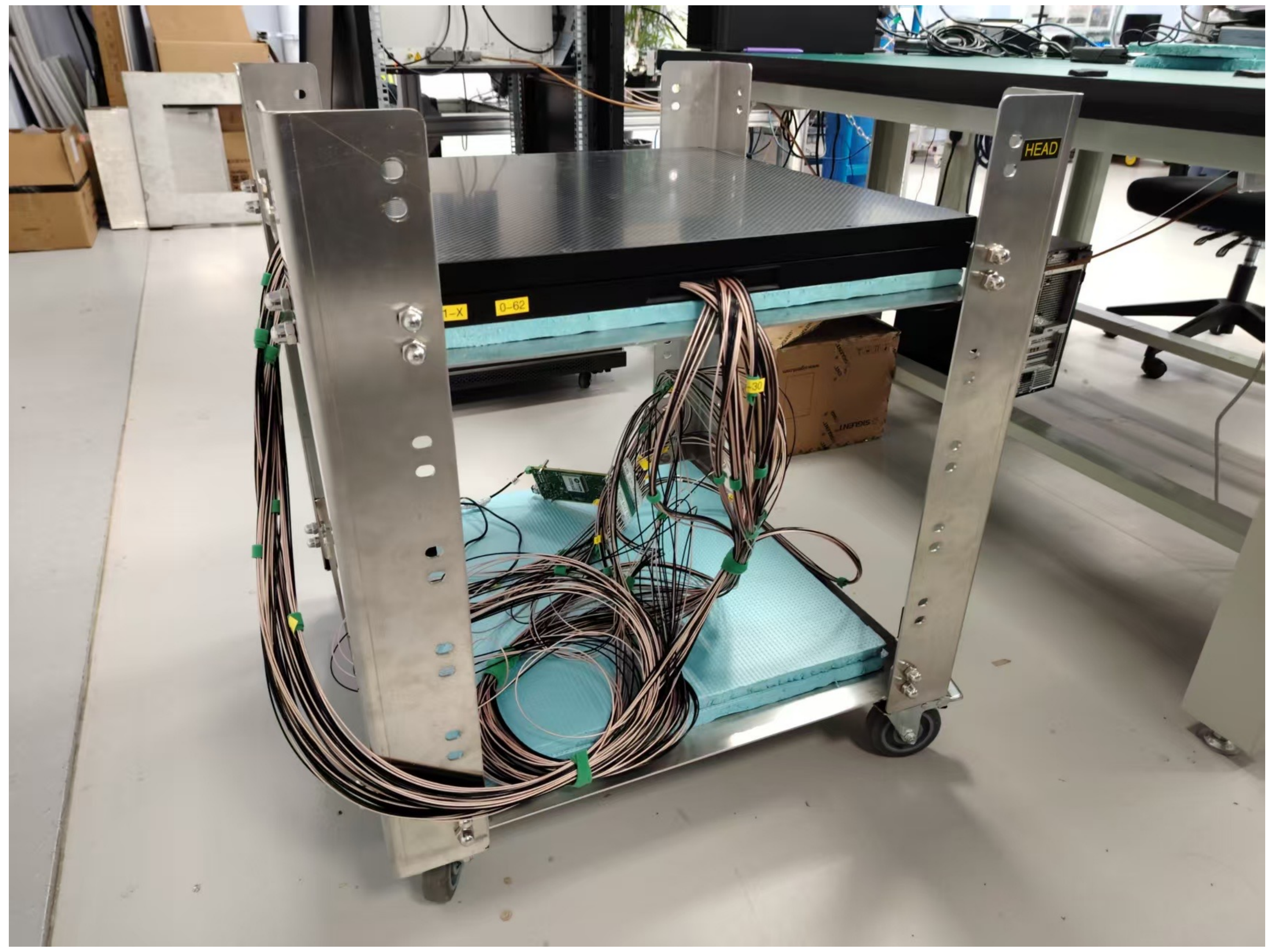
李政道研究所
TSUNG-DAO LEE INSTITUTE





Detector Design & Feasibility Study
(Jiangtao's Poster)





Summary

- The demand for muon beams is growing across a wide range of physics programmes .
- Electron-driven muon production offers a complementary and modular approach.
- SHINE provides a unique opportunity to demonstrate this concept at scale.
- Test beam at SHINE shaft #2 is expected in Aug-Sep 2026, with: muon yield measurement and muography.

20 Jan 25: Shaft#2 Visit

28 Nov 25: The 1st SMS Workshop

23 Apr 26: SMS Team @ SSRF

Let's discuss potential applications and opportunities for collaboration!

Milestones

Tsung-Dao Lee Institute

2023

Demonstration of the Electron-driven Surface Muon Production Scheme

ISBN: 978-3-95450-231-8
14th International Particle Accelerator Conference,Venice, Italy
ISSN: 2673-5490
JACoW Publishing
doi: 10.18429/JACoW-IPAC2023-TUPA087

A PULSED MUON SOURCE BASED ON A HIGH-REPETITION-RATE ELECTRON ACCELERATOR

Poster @ IPAC23

2025

Demonstration of the Electron-driven Surface Muon Beamline

- End-to-end simulation studies
- Target optimization
- Beamline optimization

PHYSICAL REVIEW ACCELERATORS AND BEAMS **28,** 083401 (2025)

Simulation studies of a high-repetition-rate electron-driven surface muon beamline at SHINE

Fangchao Liu,[1,*] Yusuke Takeuchi,[1,*] Si Chen,[2] Siyuan Chen,[1] Kim Siang Khaw,[1,†] Meng Lyu,[1] Ziwen Pan,[3] Dong Wang,[2] Jiangtao Wang,[1] Liang Wang,[1] and Wenzhen Xu[2]
[1]*Tsung-Dao Lee Institute and School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 201210, China*
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(Received 19 March 2025; accepted 16 July 2025; published 18 August 2025)

Poster @ IPAC25
PRAB paper

2026

Experimental Validation of Surface Muon Production Scheme

Aug - 2026 : Test beam at SHINE shaft #2

- 3 GeV, 50 pC electron beam @ 50 Hz ***preparation is ongoing***

Nov 2026

- Demonstration of the feasibility of electron-driven surface muon production (**10^4 muons/s equivalent**) based on beam test result.

Poster @ IPAC26
Publication (planned)

2030s

Project approval, funding, construction...

Acknoledgement

李政道研究所
TSUNG-DAO LEE INSTITUTE

中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

Dong Wang, Si Chen, Lixin Yin, Wenzhen Xu

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University of Science and Technology of China

Ziwen Pan

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Kim Siang Khaw*, Yusuke Takeuchi† (Assist. Prof. @ Nagoya U.), Meng Lyu (PhD @ Univ. of Tokyo)
Fangchao Liu, Jiangtao Wang, Jun Kai Ng, Jia Cheng Yap, Min Yang Tan, Guan Ming Wong

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Luetkens Hubertus (PSI), Yu Bao (CSNS), Jianhui Chen (Suzhou Lab)

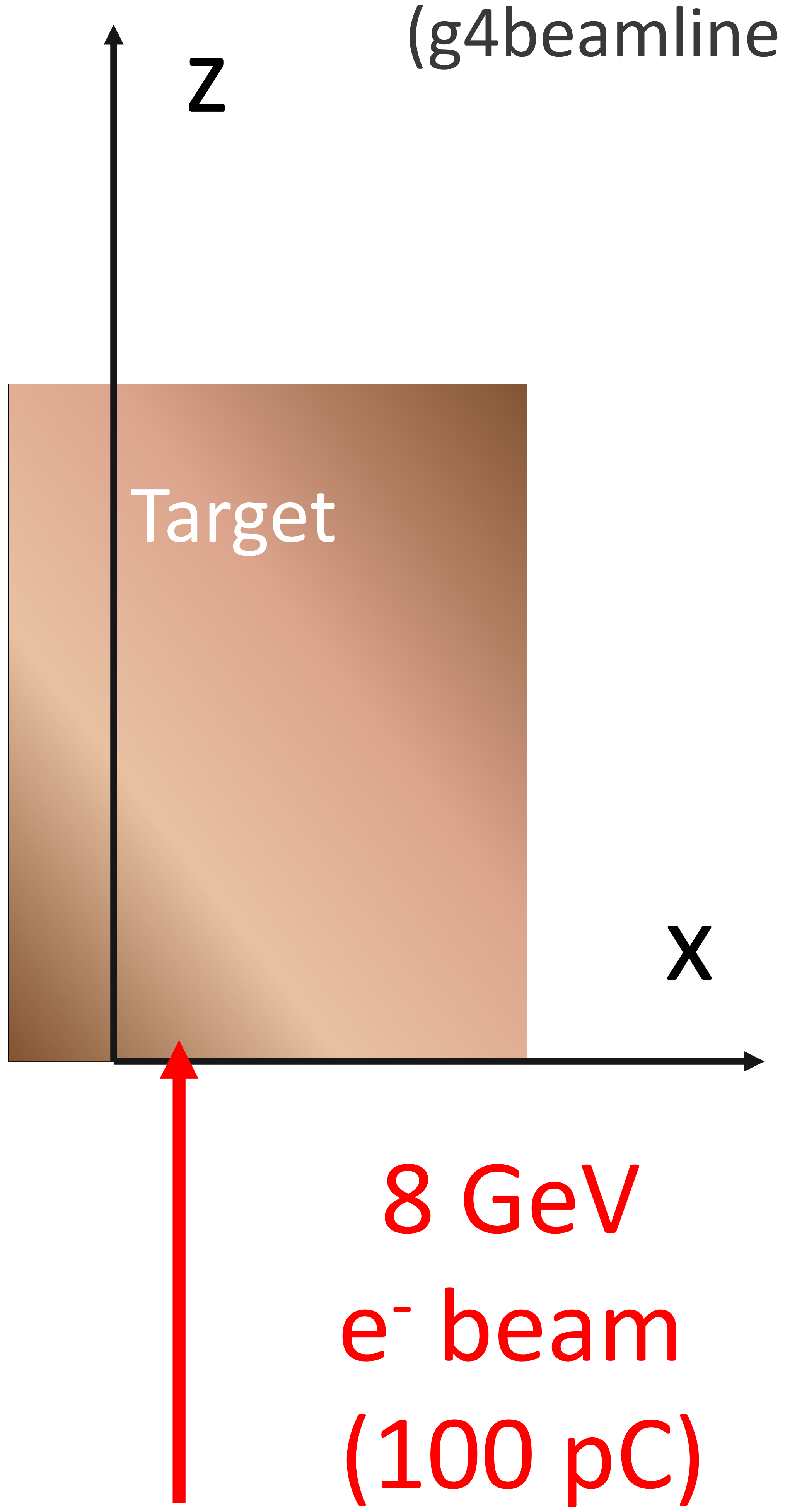
Funded by: *Shanghai Pilot Program for Basic Research (21TQ1400221)
†the K. C. Wong Educational Foundation

Backup Slides

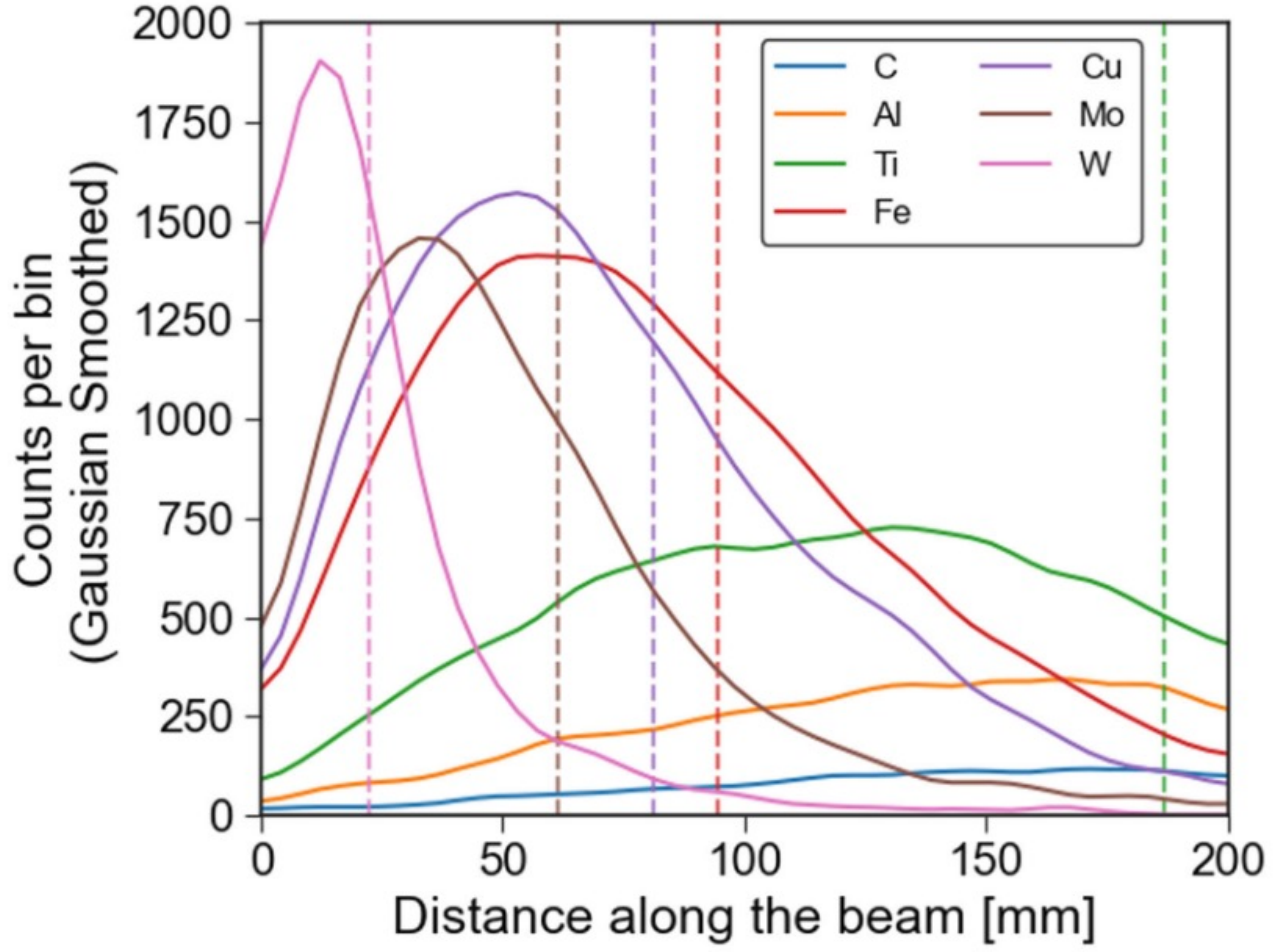
Material selection

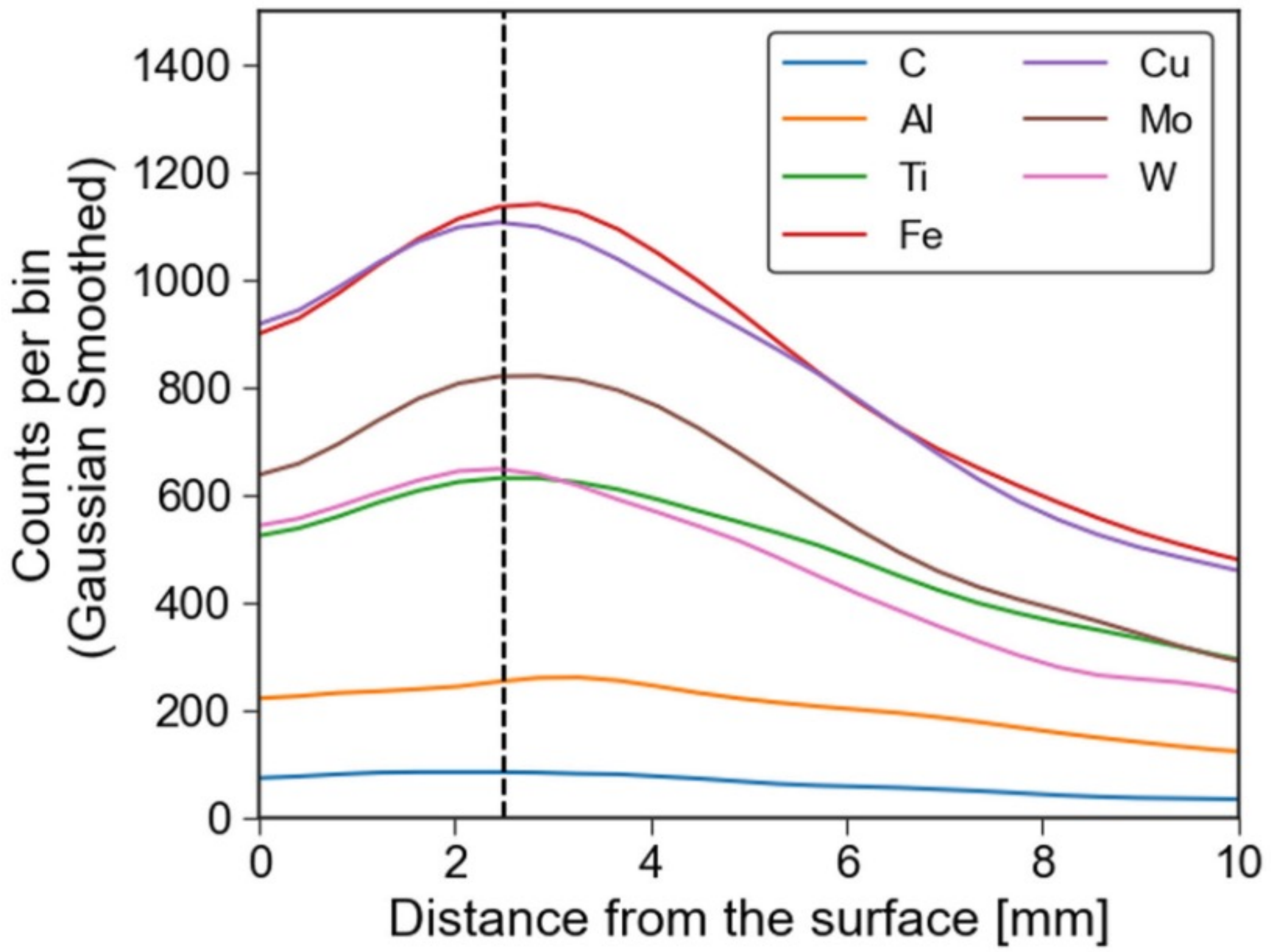
Simulation Setup

(g4beamline)



Pion distributions





Along the beam (Z):

- Peak ⇨ slightly below z_{max}
- Depth of EM shower maximum

$$z_{\max} \approx X_0\left[\ln(E_0/E_c) - 0.5\right]$$

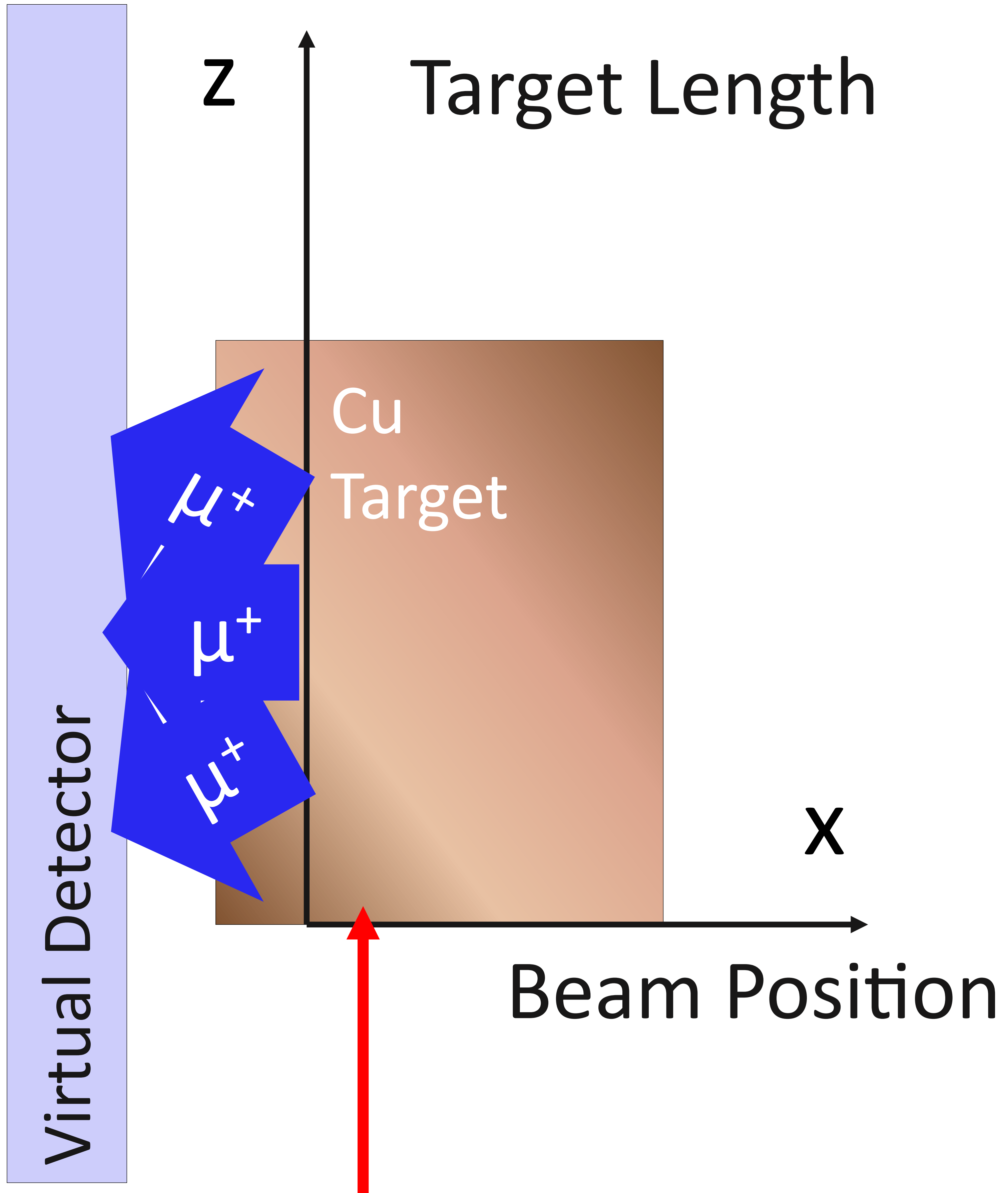
E_0: incident beam energy
E_c: critical energy
X_0: radiation length

From the surface (X):

- The number of pions near surface contributing to surface muon is important
- Medium-Z materials (e.g., Fe, Cu) show highest number
- Copper is considered to be the optimal choice
  ⇨ good thermal conductivity (~400 W/mK)

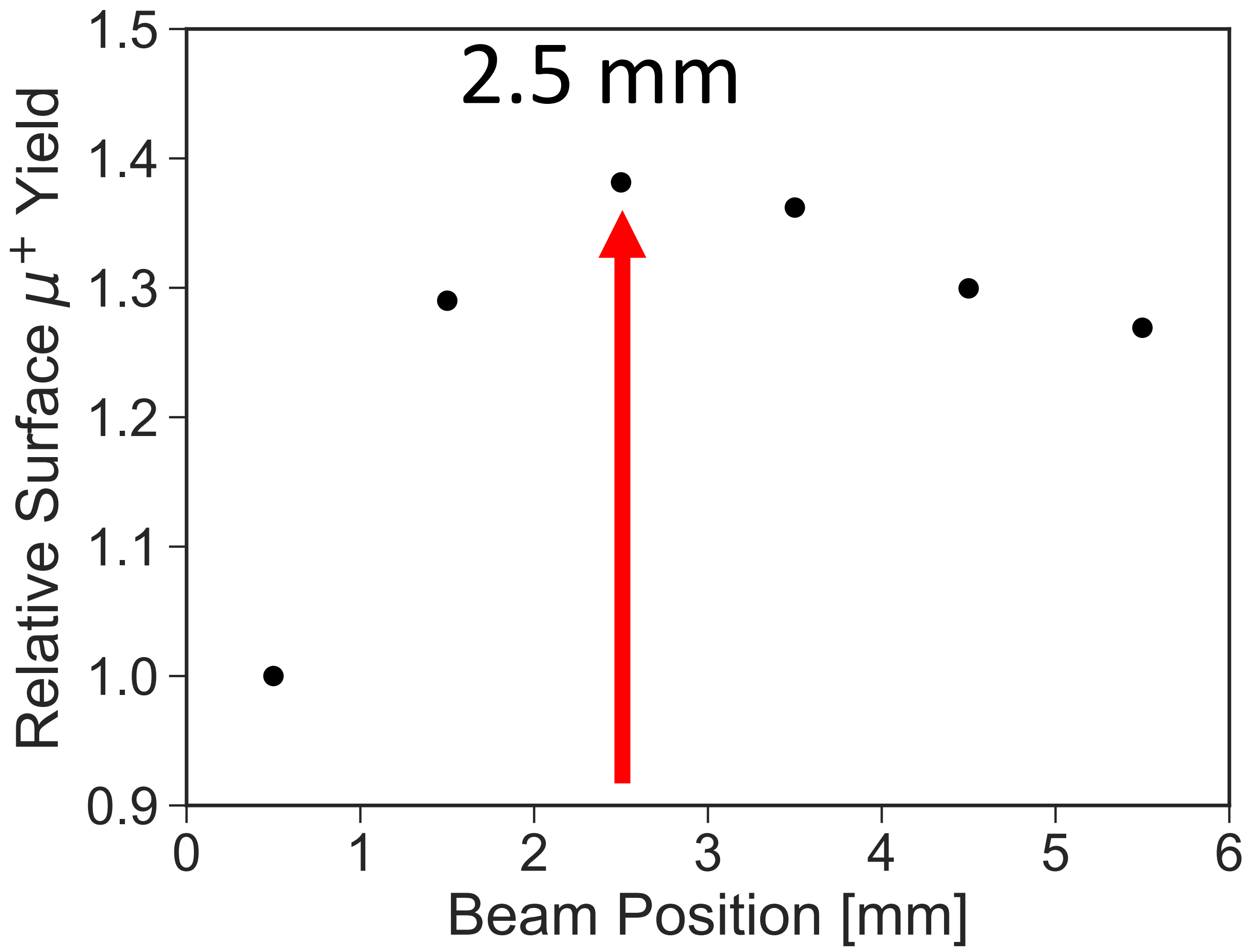
Cu target optimization

Simulation Setup

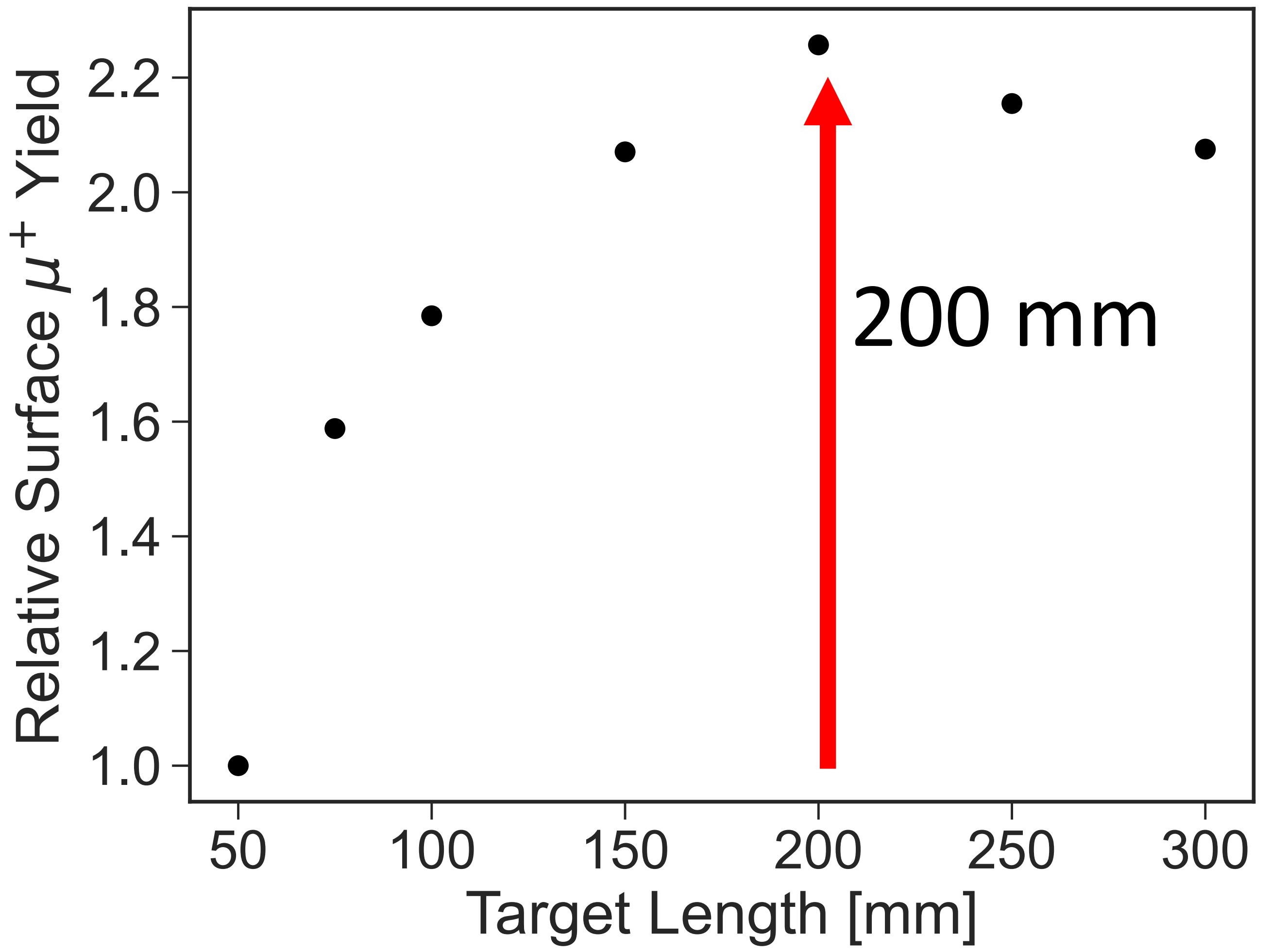


8 GeV e⁻ beam (100 pC)

Scan beam position and target length



- < 2.5 mm:
  Insufficient development of electron shower (too close to target surface)
- > 2.5 mm:
  The number of pions resulting in surface muons is reduced (too far from target surface)



- No significant gain is expected in length over 200 mm.
- Consistent with the pion distribution

Results

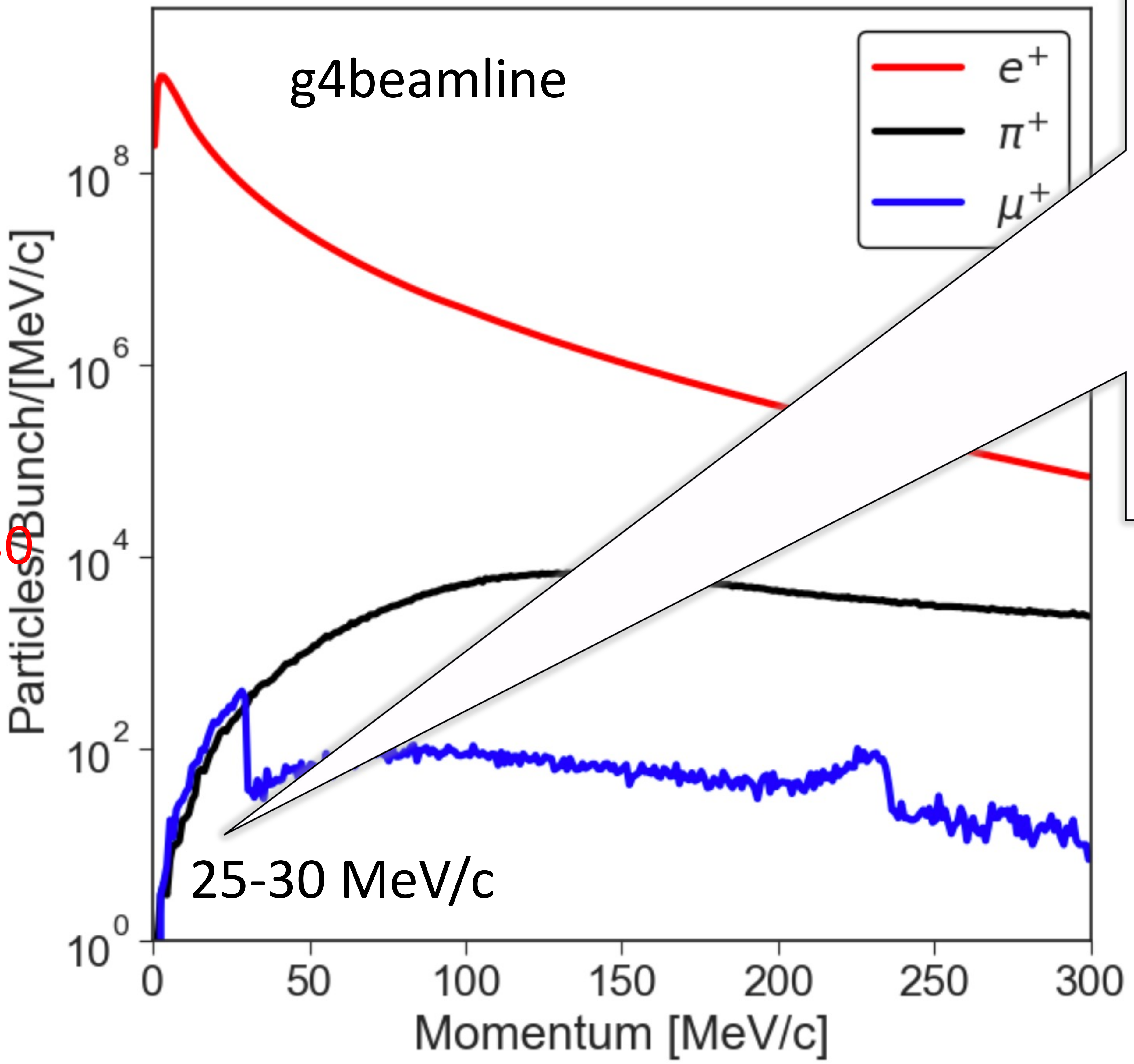
- Optimal beam position:
  2.5 mm from target surface
- Optimal target length: **200 mm**

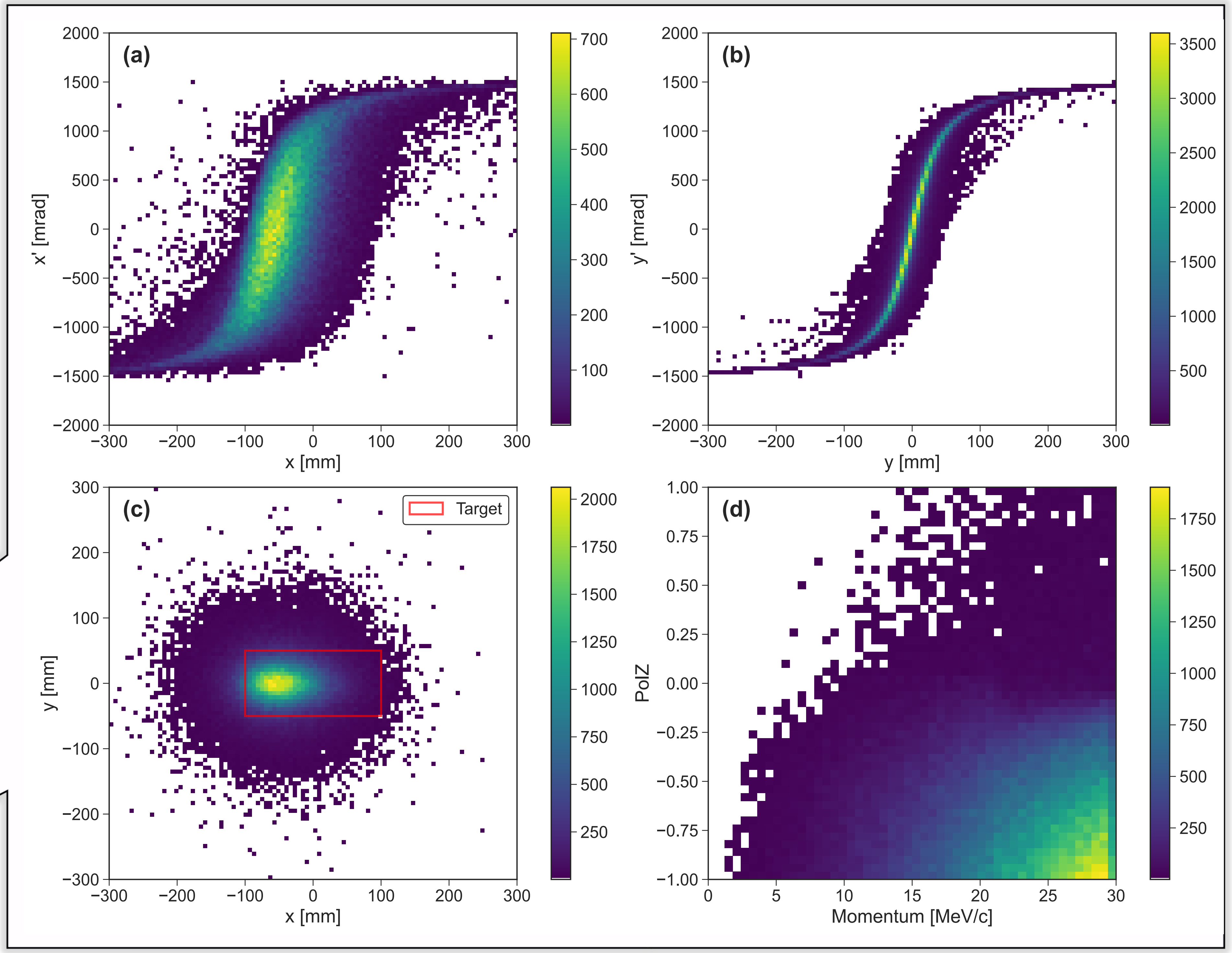
Particle yields from Cu target

Full simulation with g4beamline for beamline design

- Total muon yield: ~10^4 per bunch (below 300 MeV/c)
- Surface muon yield: 2×10^3 per bunch (25-30 MeV/c range)
- Expected intensity: 1×10^8 μ^+/s at 50 kHz operation

- Momentum distribution characteristics:
  - Two distinct peaks were observed:
    - Pion decay: ~30 MeV/c
    - Kaon decay: ~230 MeV/c
  - Broad energy distribution, decreasing at higher energies

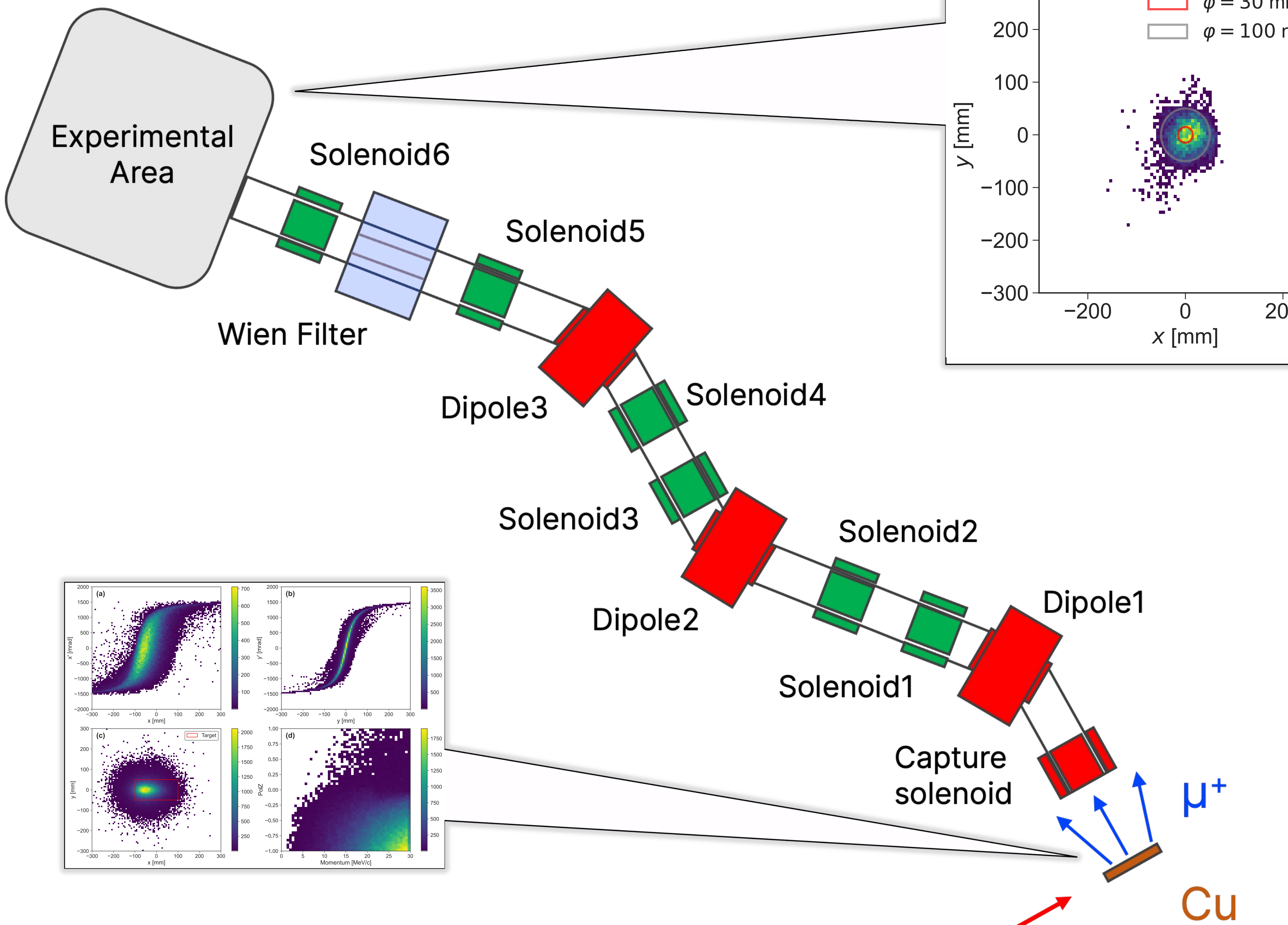


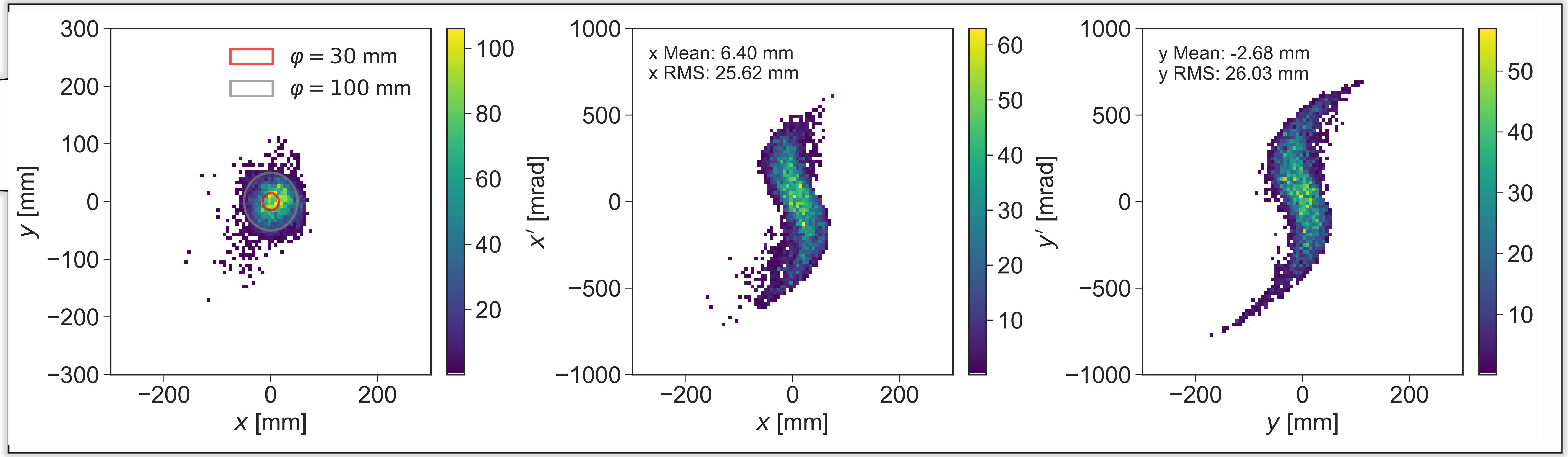


Parameters	Value
Mean Momentum P_0 / Momentum Spread σ_P	22.9 MeV/c / 5.5 MeV/c
Horizontal Position $< x >$/ Width σ_x	-45.2 mm / 73.7 mm
Horizontal Divergence $< x' >$/ Width $\sigma_{x'}$	-14.6 mrad / 696.7 mrad
Horizontal RMS Emittance	3814 π cm mrad
Vertical Position $< y >$/ Width σ_y	-0.1 mm / 67.5 mm
Vertical Divergence $< y' >$/ Width $\sigma_{y'}$	-1.2 mm / 696.9 mrad
Vertical RMS Emittance	3180 π cm mrad
Mean Polarization	-0.63

Similar to those of existing facilities.

Surface muon beamline design





Electron beam
8 GeV, 100 pC (6.25×10^8 /bunch)

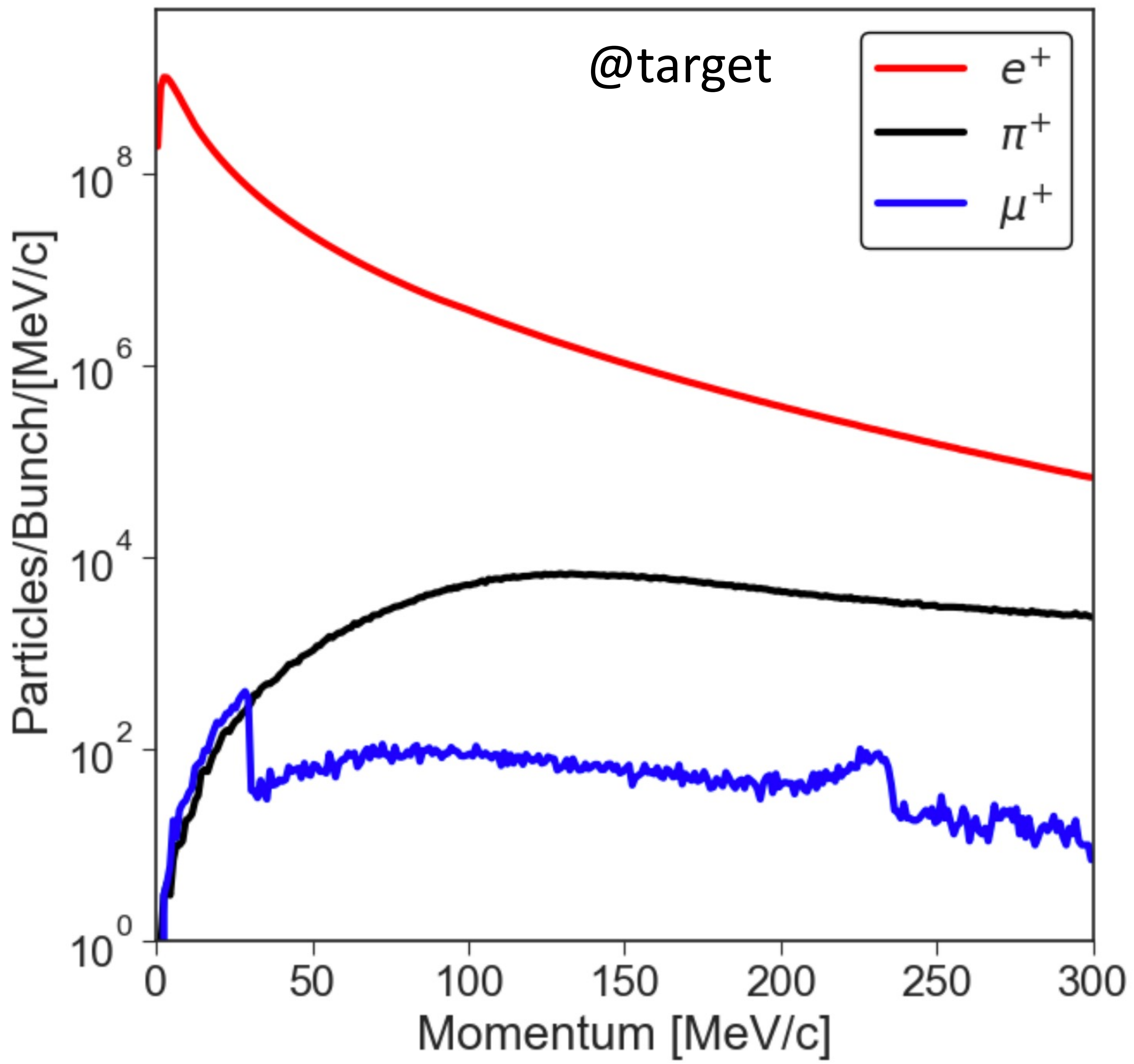
Parameters	Value
x/x' (rms)	25.6 mm/221 mrad
y/y' (rms)	26.0 mm/246 mrad
Mean momentum	27.6 MeV/c
$\Delta p/p$	3.69%
Polarization (before Wien filter)	97%
Polarization (after Wien filter)	88%
μ^+ rate (all)	$3.1\times10^6\ \mu^+/s$
μ^+ rate (ϕ30 mm)	$4.7\times10^5\ \mu^+/s$

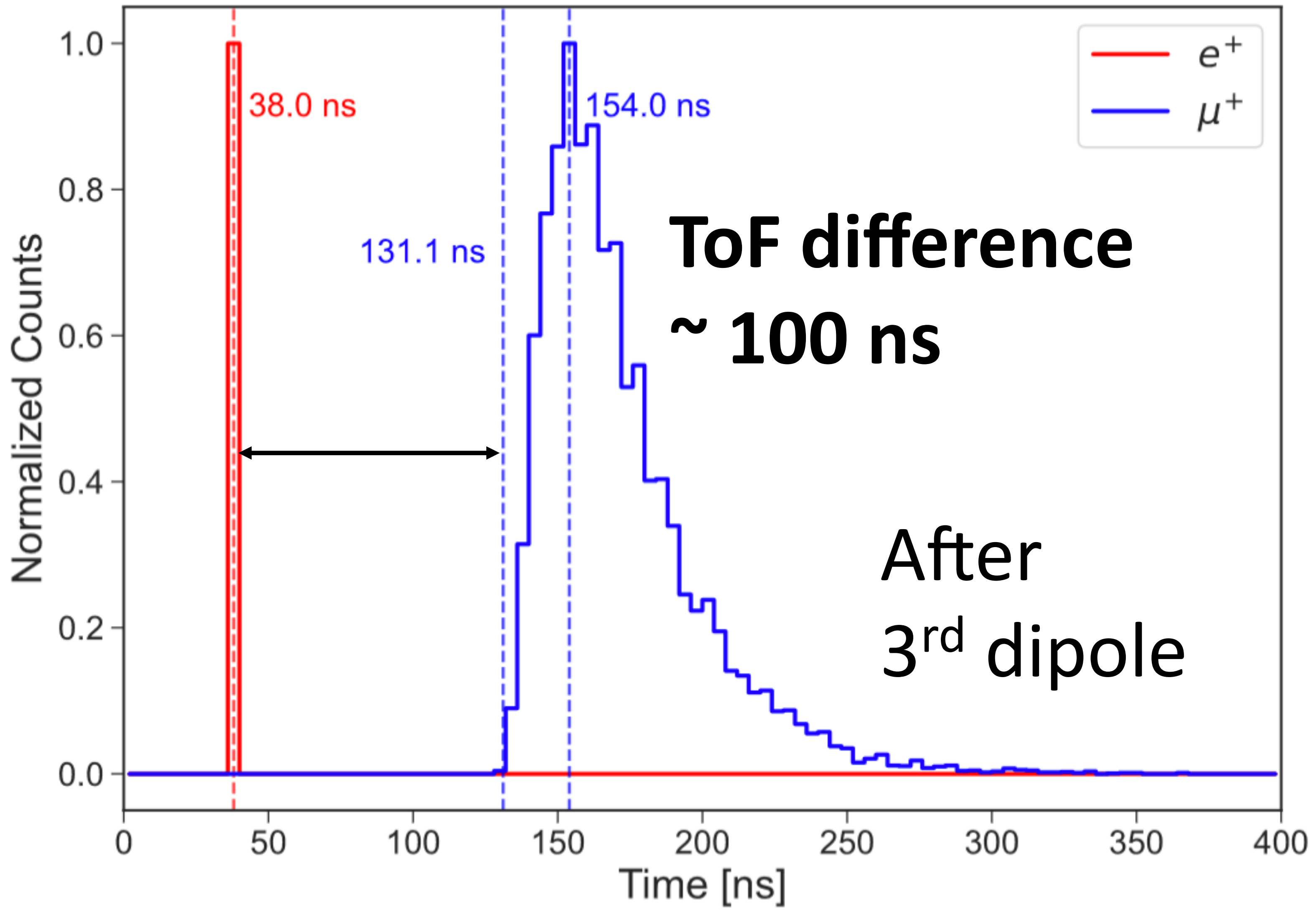
@50 kHz repetition rate
(1/20) of SHINE capability

Positron background

Many positrons!

⇨ Conventional way (Wien filter) may not be sufficient.



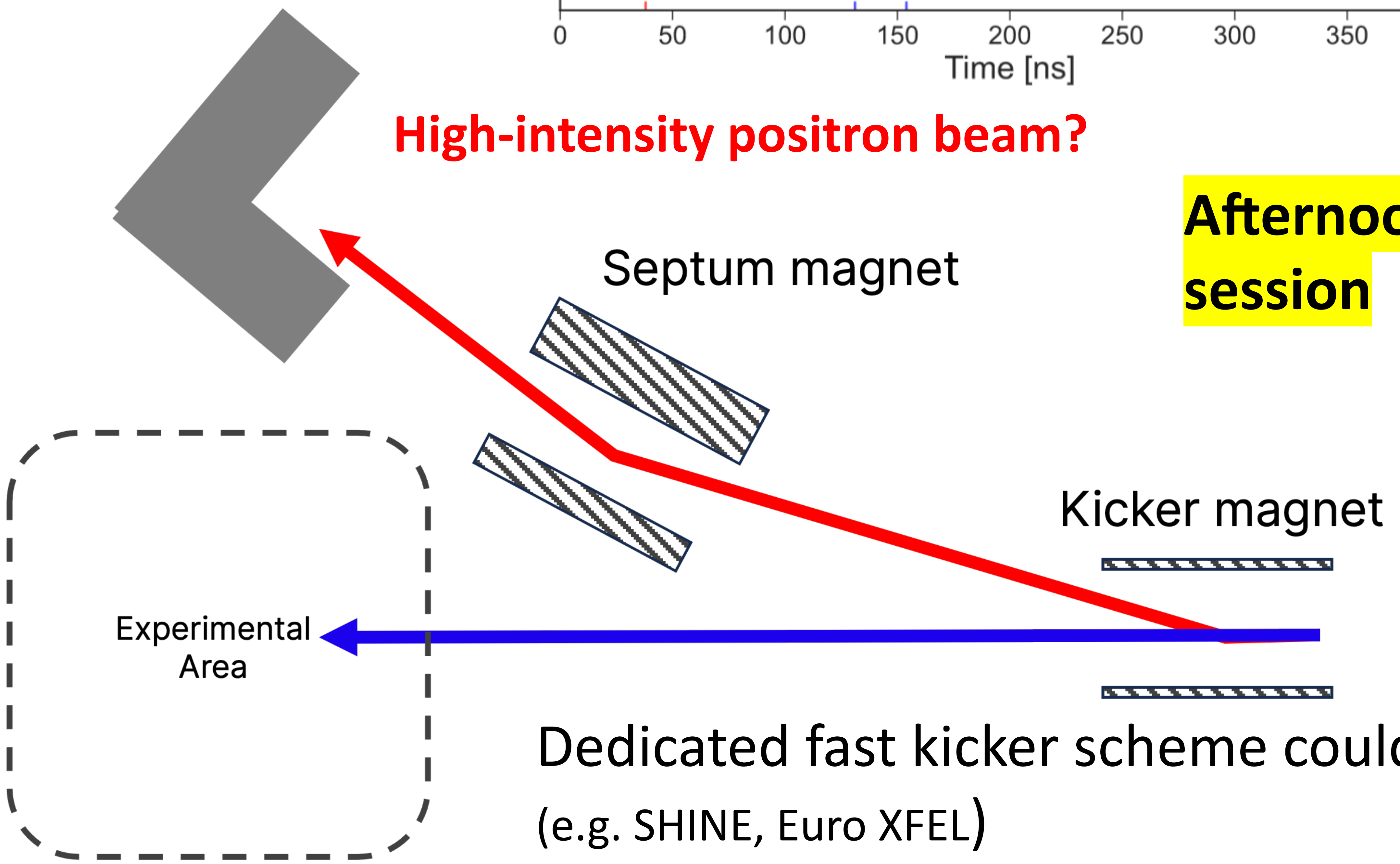


ToF difference ~ 100 ns

After 3rd dipole

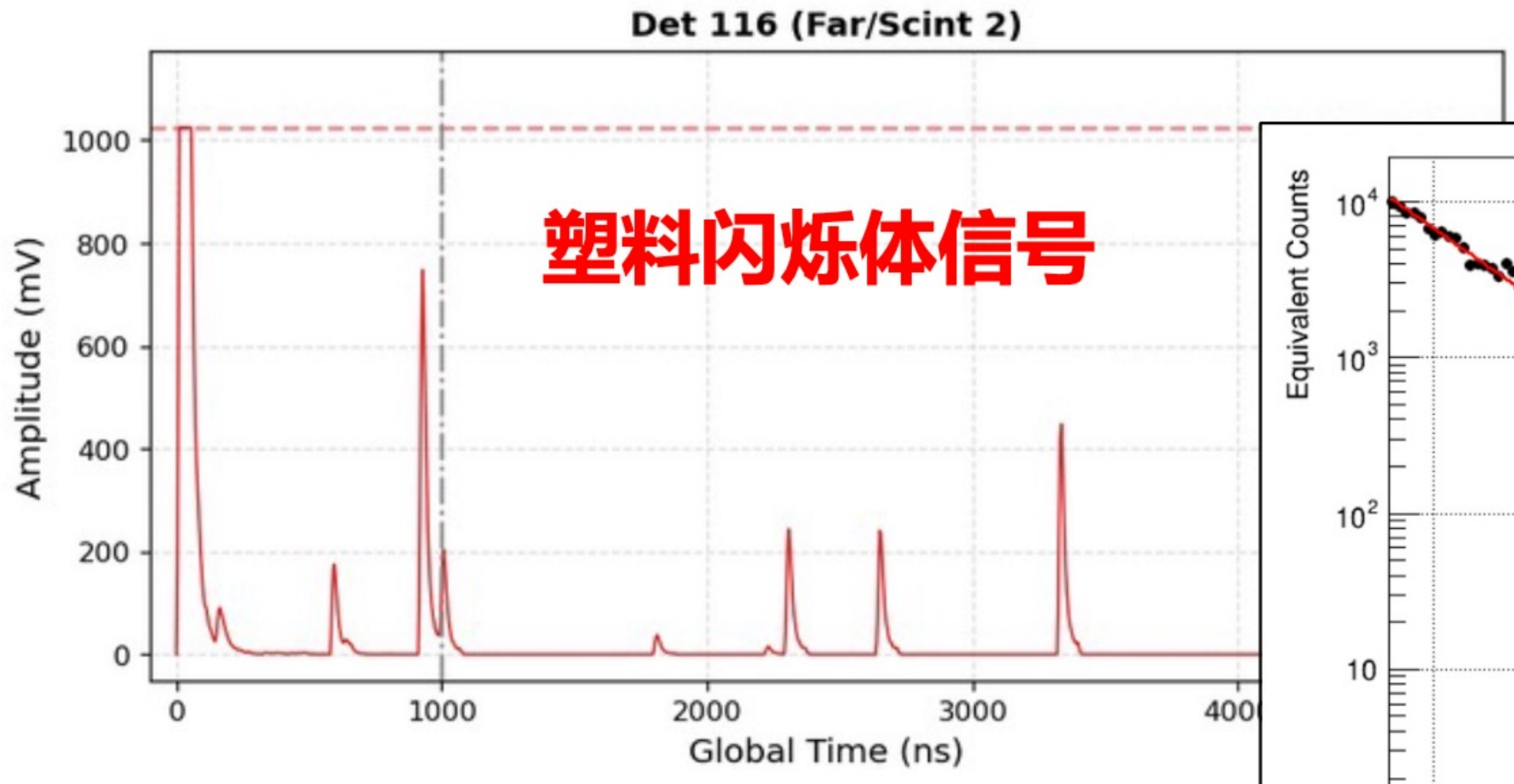
High-intensity positron beam?

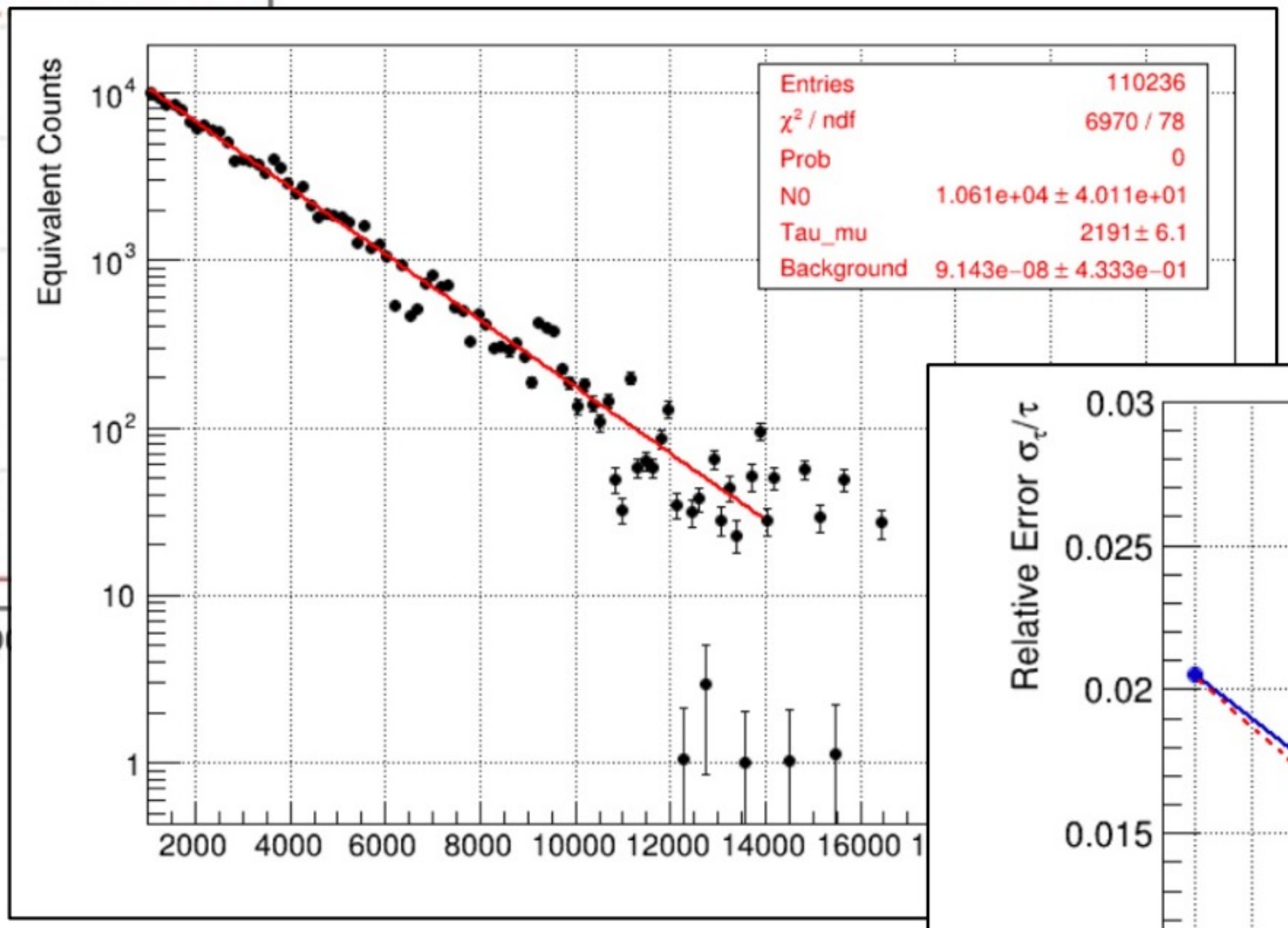
Afternoon session

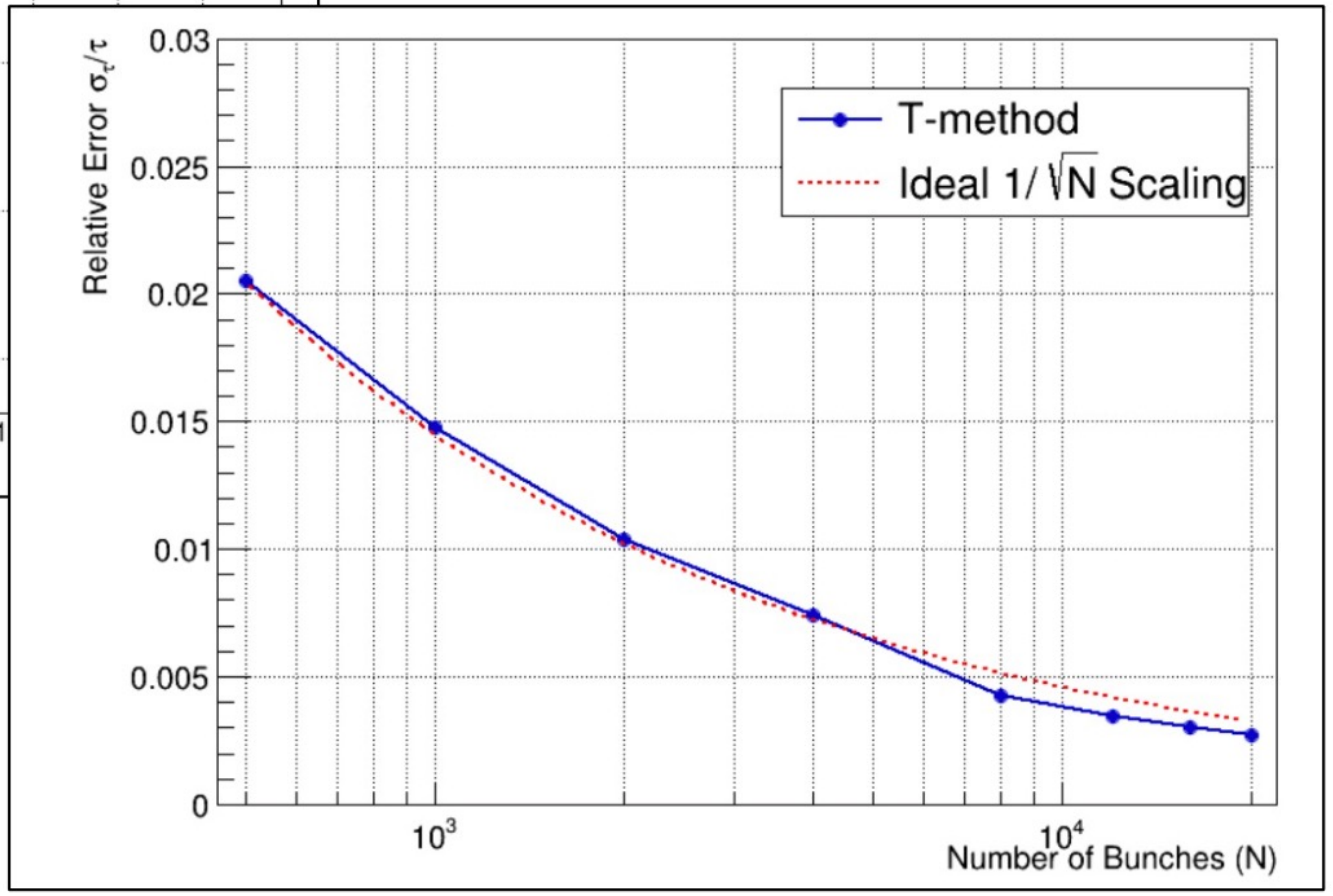


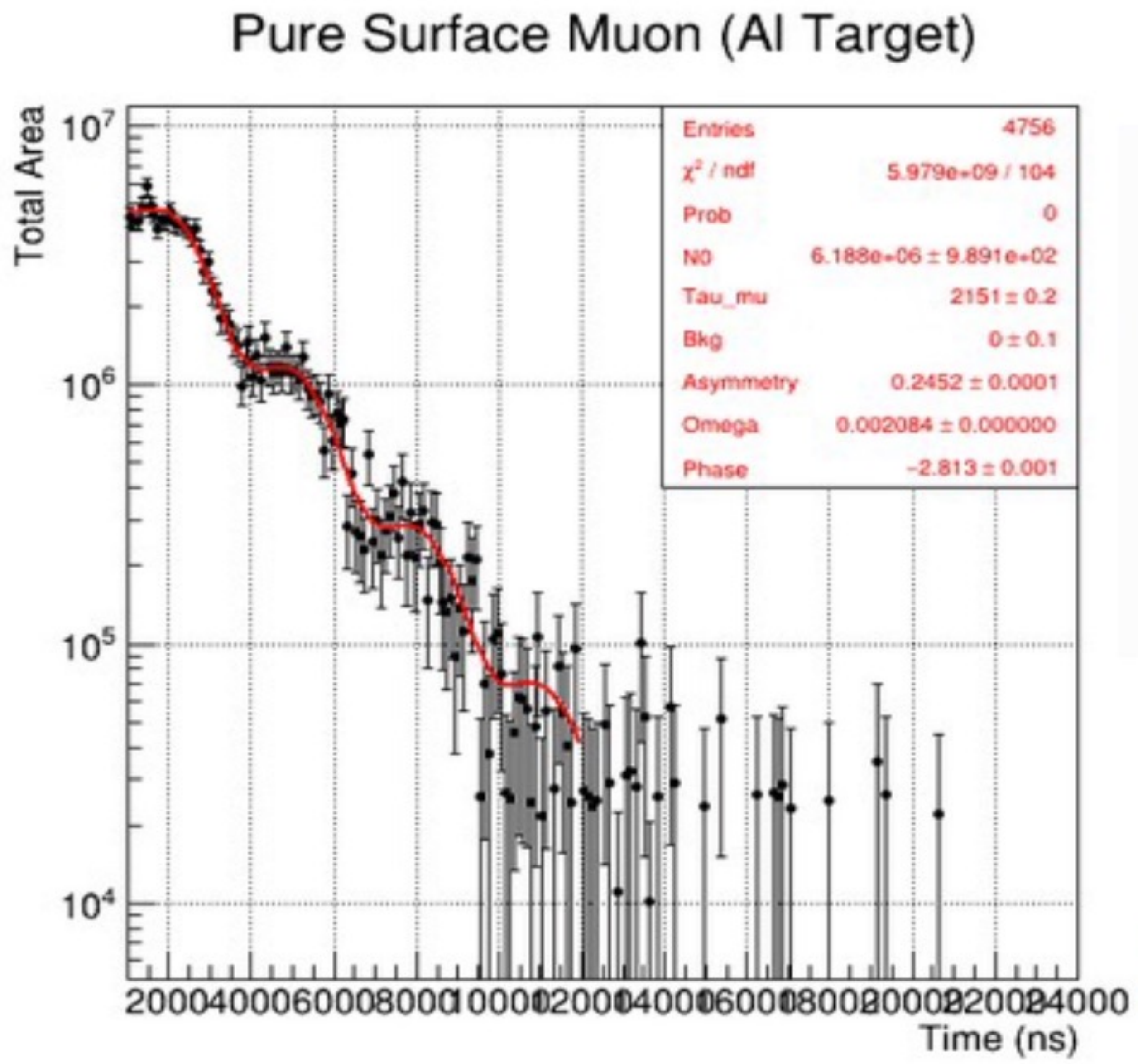
Dedicated fast kicker scheme could solve this (e.g. SHINE, Euro XFEL)

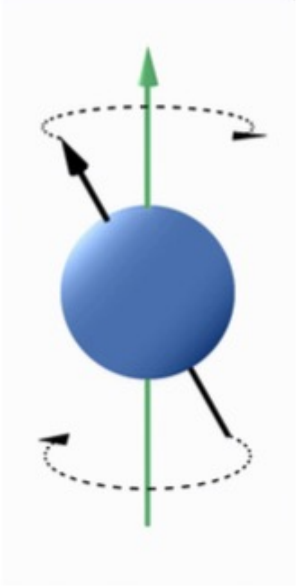
缪子产额测量方案







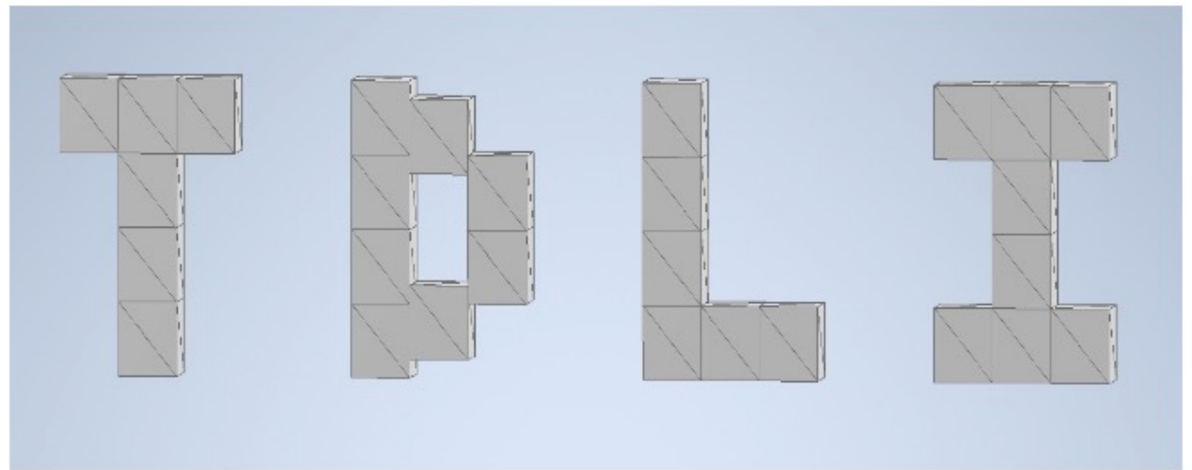




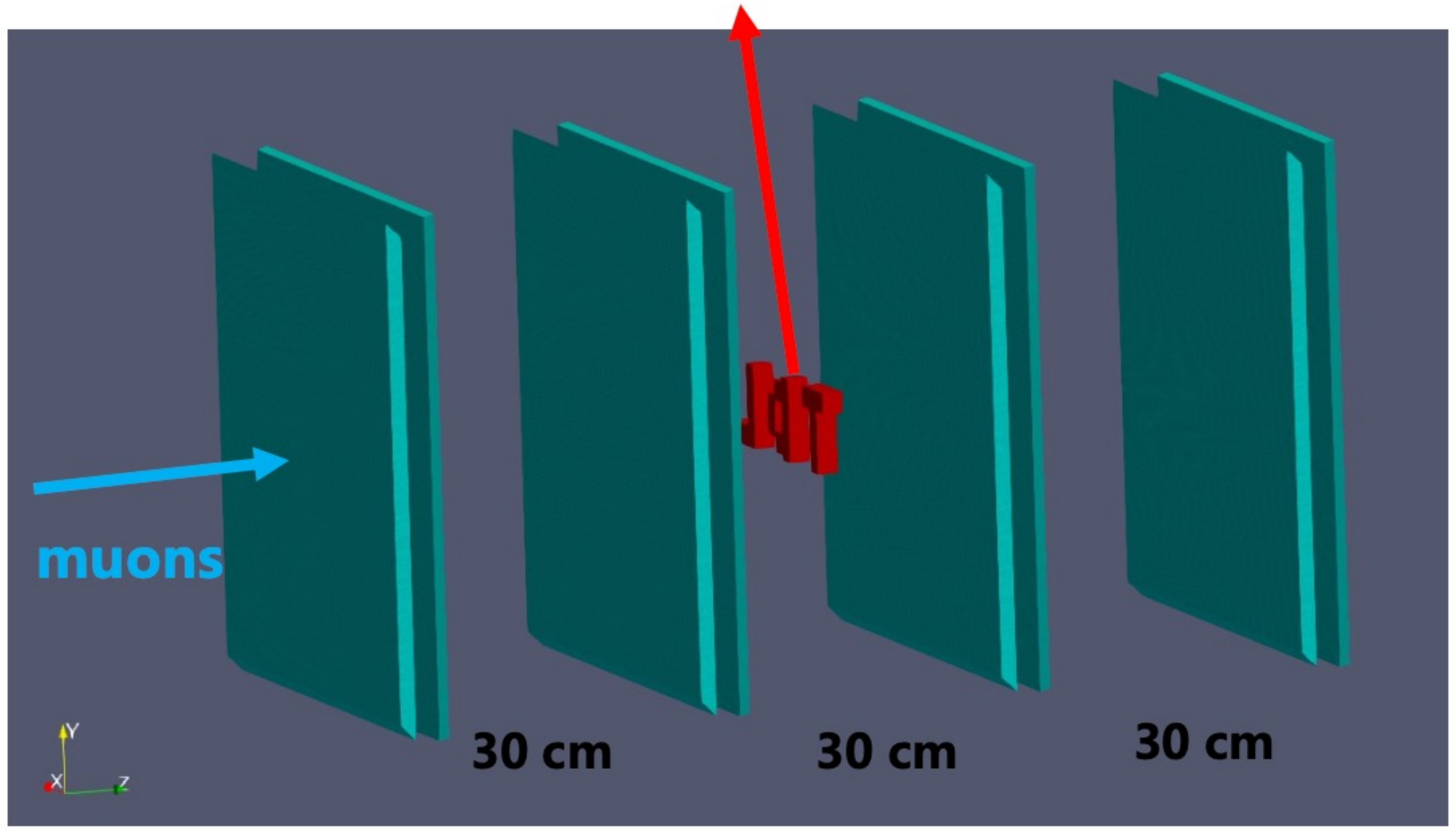
磁场内测量
统计量需求更高
20万bunch以上

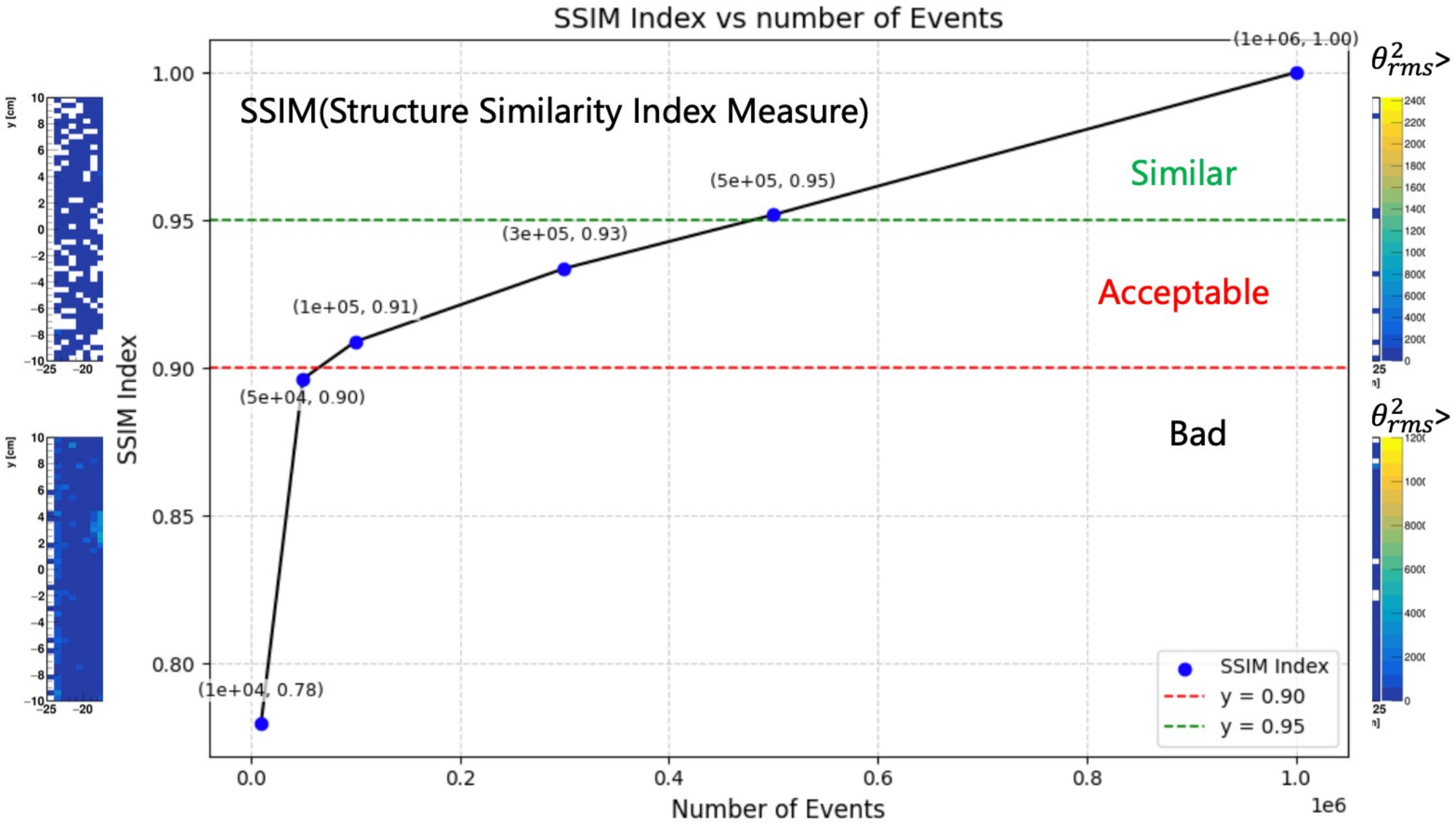
预计数千bunch就可达到1%的误差
(考虑到本底的干扰，我们需要50倍以上的数据)
需求=10万bunch（约17分钟@100 Hz)

缪子成像测试方案



2-cm thickness, Pb

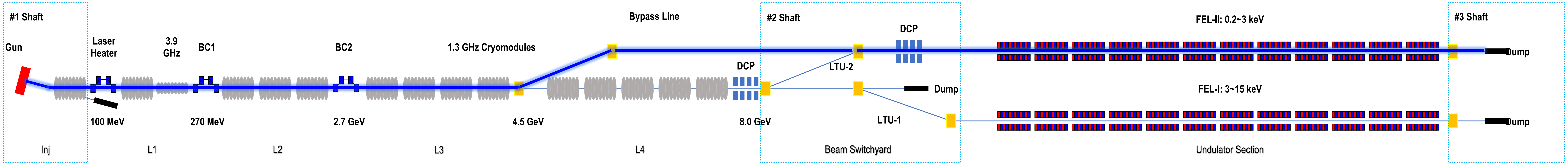




需求=10万bunch（约17分钟@100 Hz）
与缪子产额测量一起进行

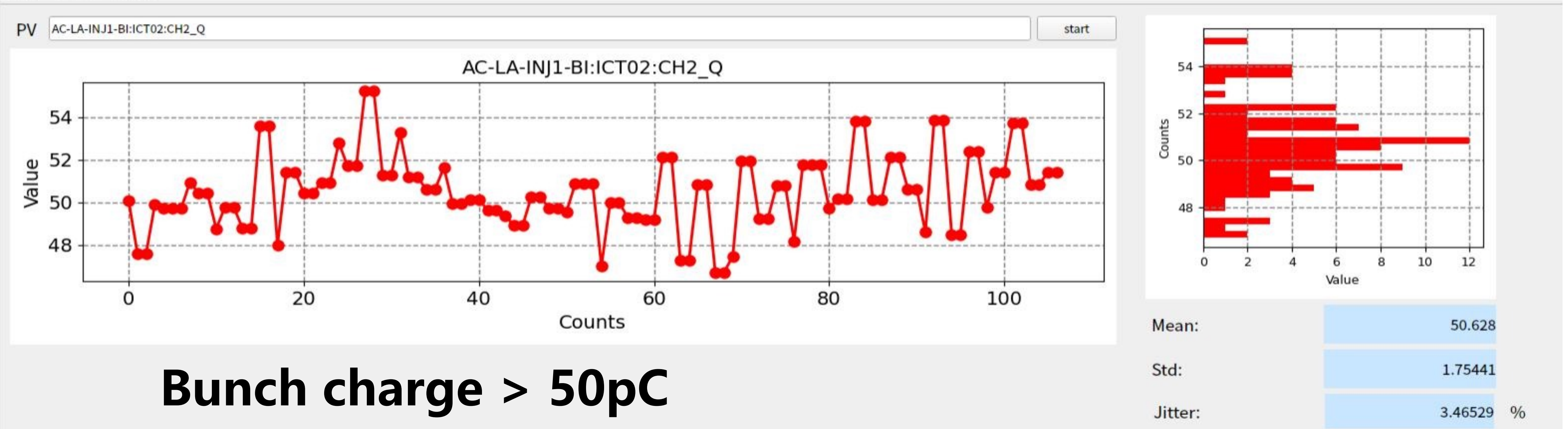
SHINE: 从注入器到XFEL

TSUNG-DAO LEE INSTITUTE 李政道研究所

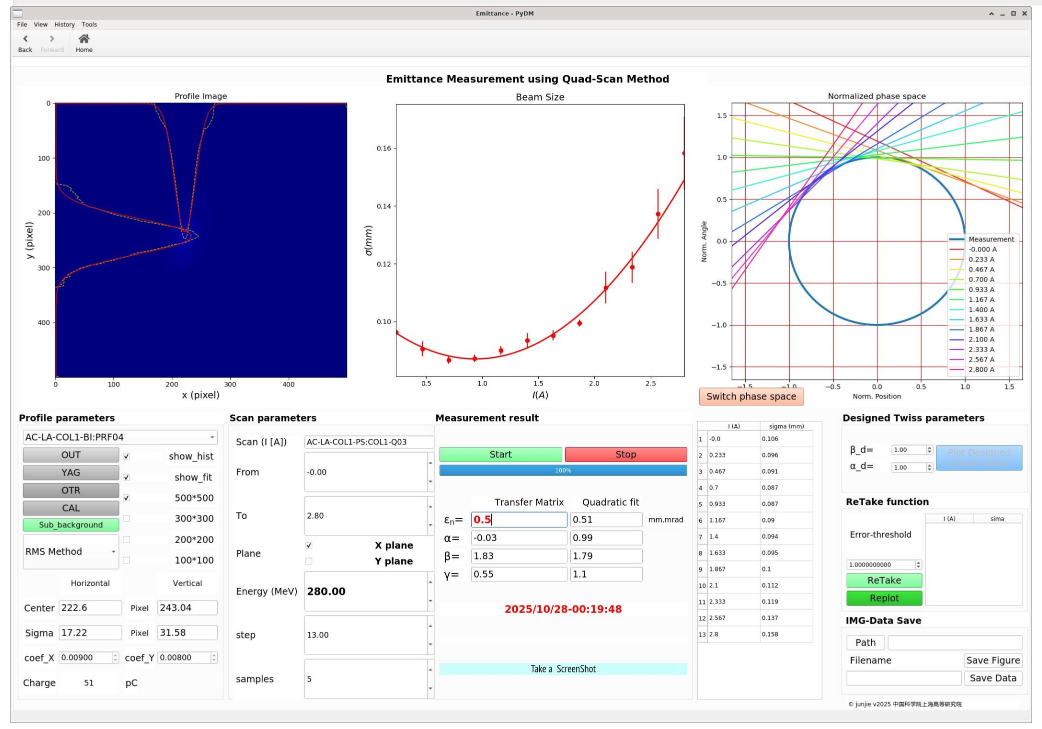


加速器及波荡器部分总长：**1300** (INJ/LA) + **300** (BSY) + **300** (UND) m；地下~**30m**

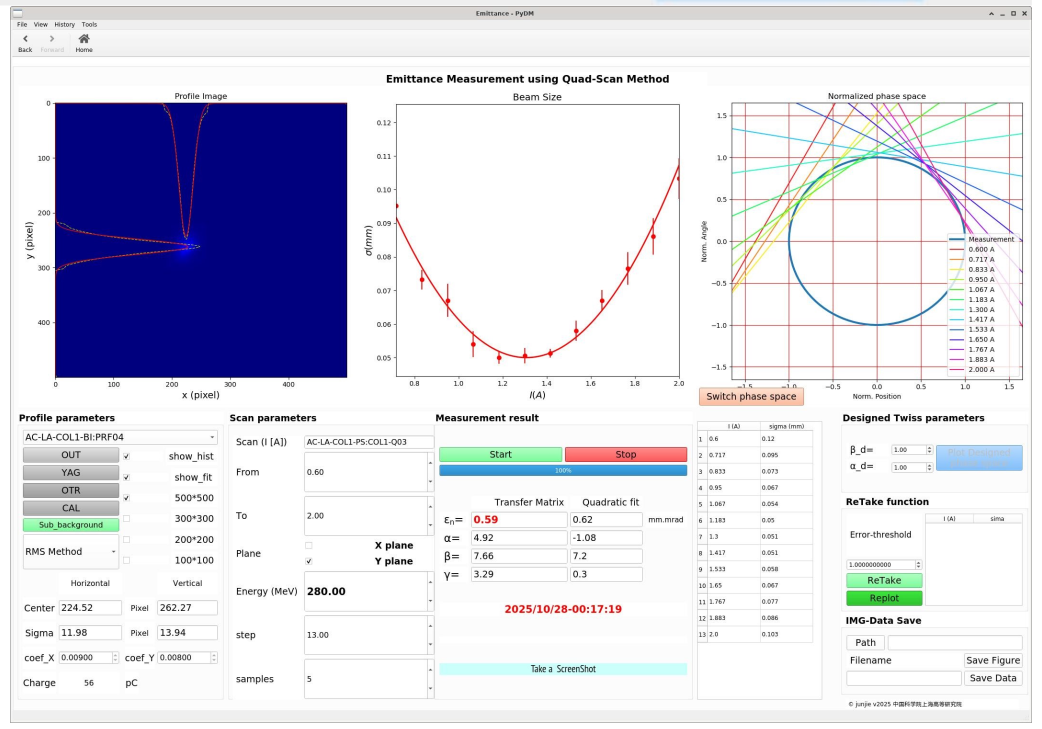
- 高性能甚高频VHF光阴极电子枪：
  10~100 pC, 0.5 μm-rad(norm., rms), 1 MHz(max)
- 1.3 GHz超导直线加速器@~2K，最高电子束流能量达~
  8 GeV(max)
- 三阶束团长度压缩器(Bunch Compressor)，可用于产生
  峰值流强~1.5 kA@100 pC
- BC3/L4之间引出分支线到FEL-II线 ~ **4.5 GeV(max)**
- 束流分配系统实现最大三条波荡器线间逐束团分配，并兼容分支线。
- 2条FEL波荡器线(FEL-I/FEL-II)用于产生不同光子能量范围的XFEL，未来可以扩展更多



Bunch charge > 50pC



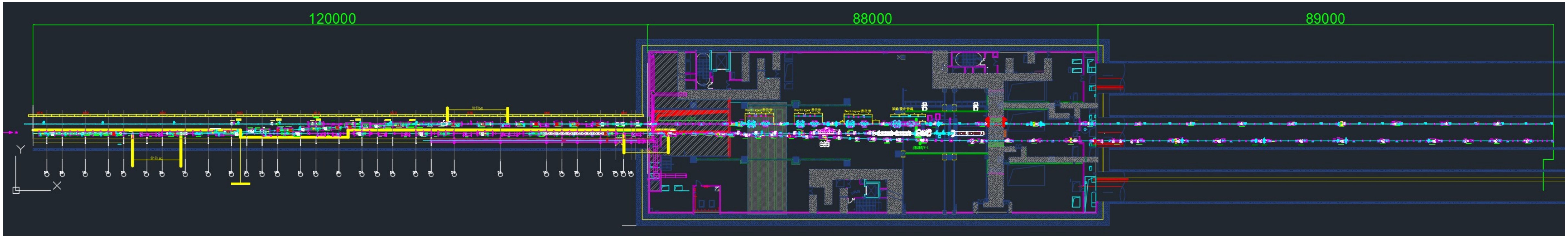
$\varepsilon_x/\varepsilon_y$ ~ 0.50 mm•mrad 0.59 mm•mrad



注入器调试完成@2024 & 直线L1段调试完成@2025，束流能量达300MeV，归一化发射度达到0.5 μm-rad

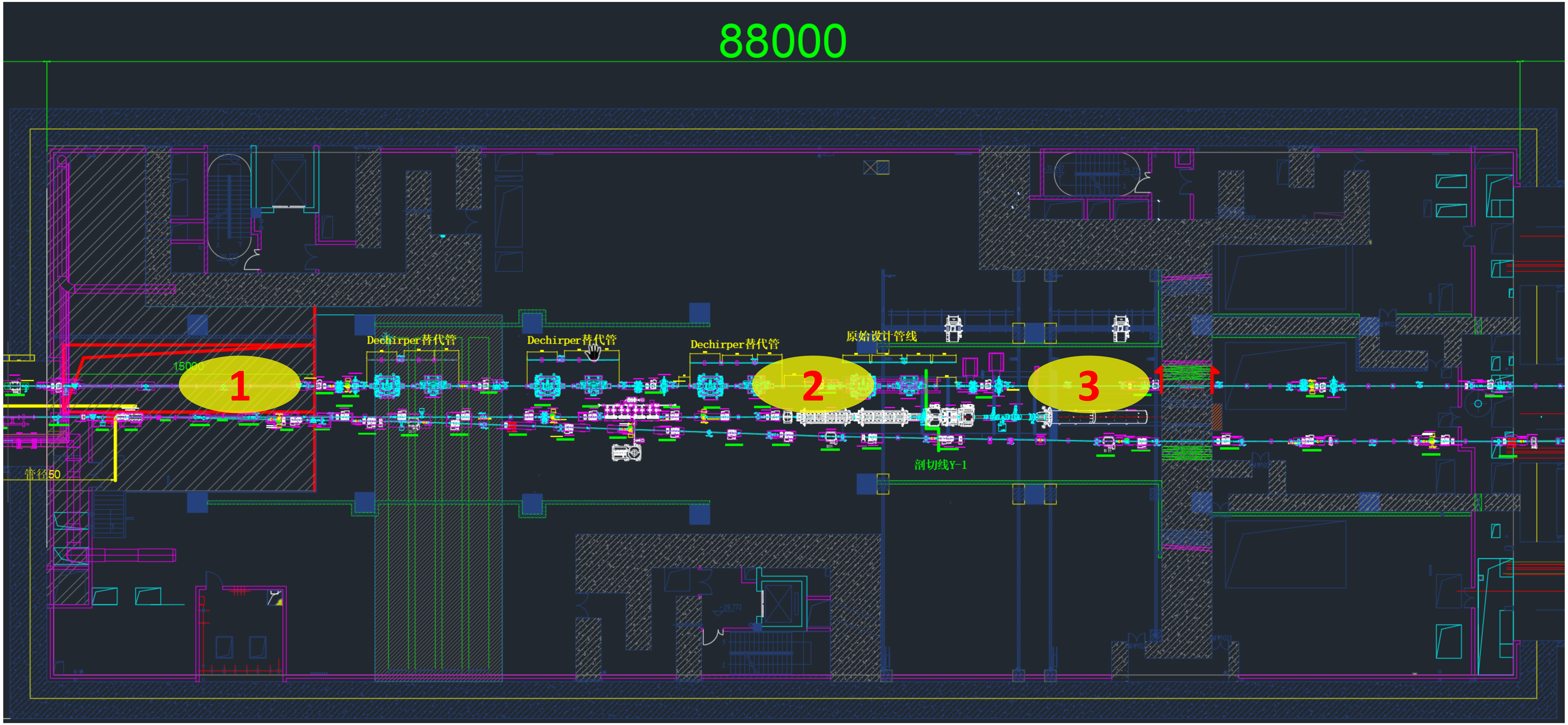
可能的安装位置

- 背景：SHINE装置首期调试将基于直线加速器分支线束流，经2号井束流分配段LTU-2线到FEL-II
- 参数：4.5GeV（最高），100pC（最大），重复频率1~50Hz（首期调试阶段）
- 目标：完成SHINE-MUON实验，同时不影响当前布局，且不影响后续FEL调试
- 位置：直线加速器隧道末端到FEL-II波荡器前，根据实际情况选择



位置	直线加速器隧道末端	2号井隔离墙前LTU2 FODO段	2号井隔离墙后LTU2 FODO段
优势	距离波荡器较远 纵向空间较大	距离波荡器较远 横向空间较大	横纵向空间均较大
劣势	横向空间有限 辐射影响安装	元件相对较密集	距离波荡器较近

可能的安装位置


88000
15000
1
2
3
Dechirper替代管
Dechirper替代管
Dechirper替代管
原始设计管线
剖切线Y-1
管径50

束斑尺寸与结构设计

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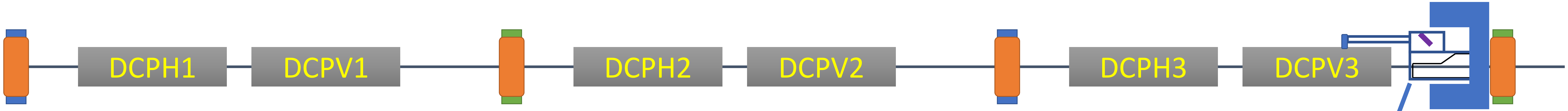
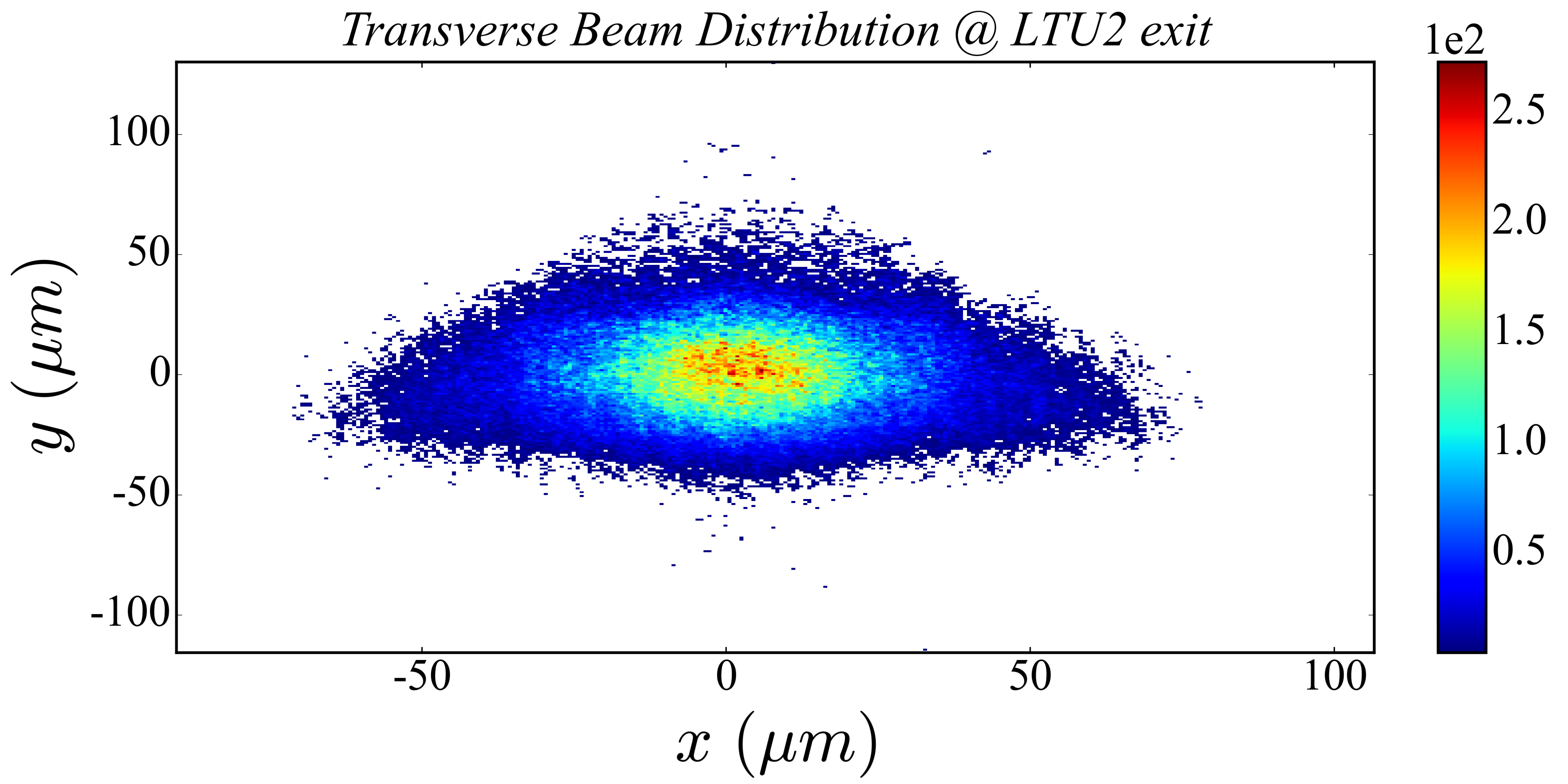
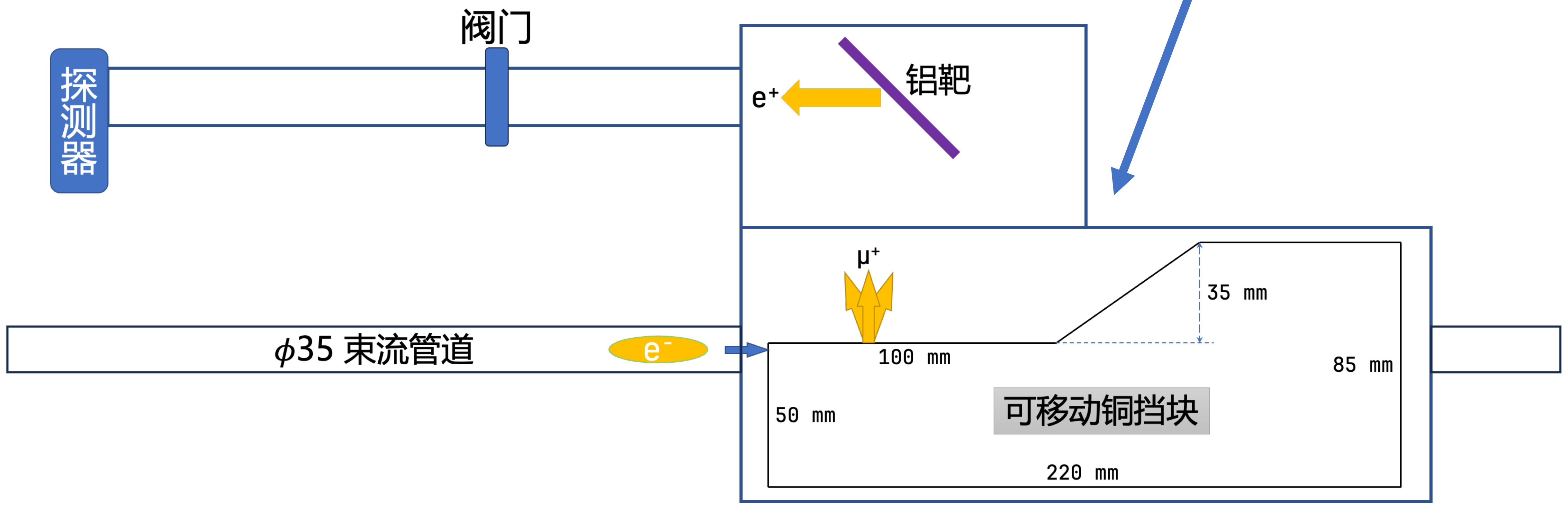




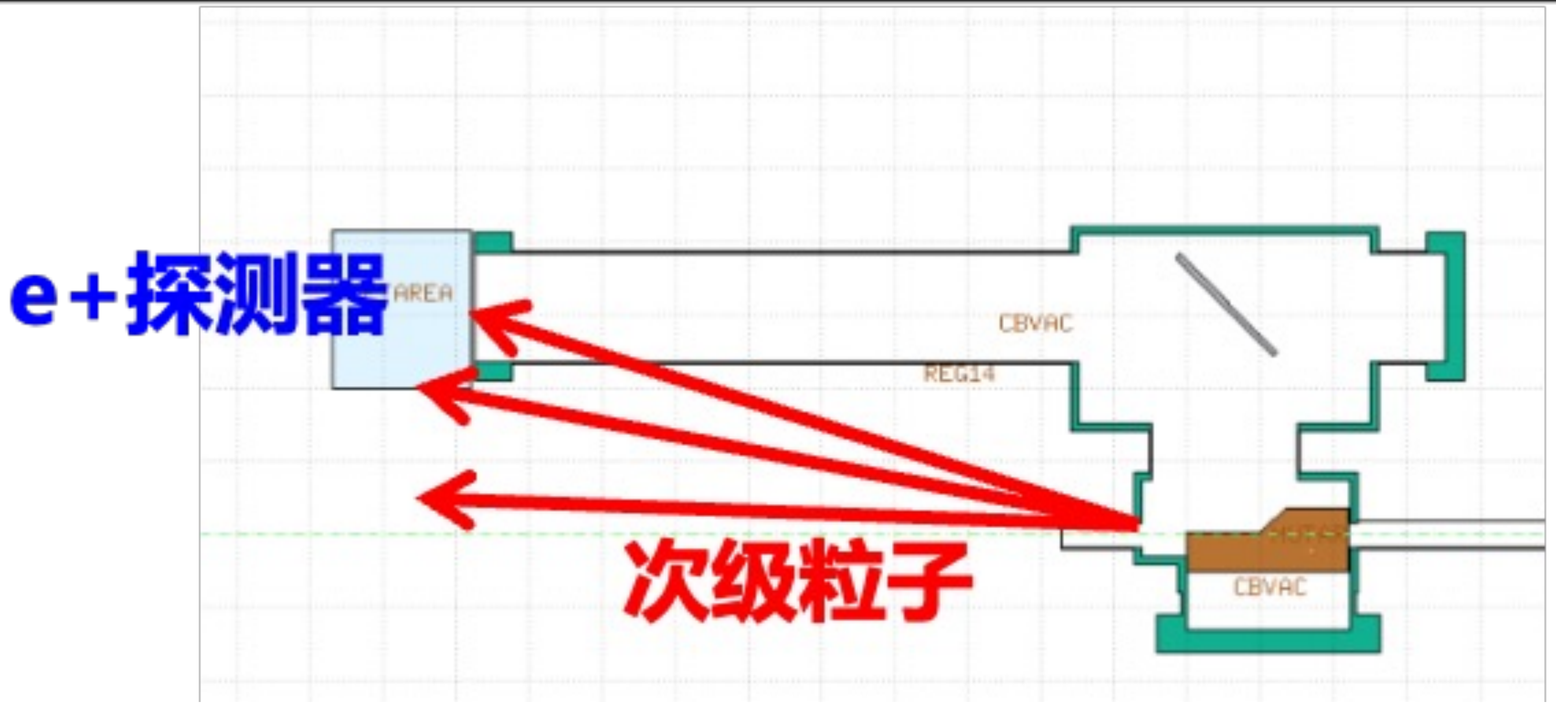


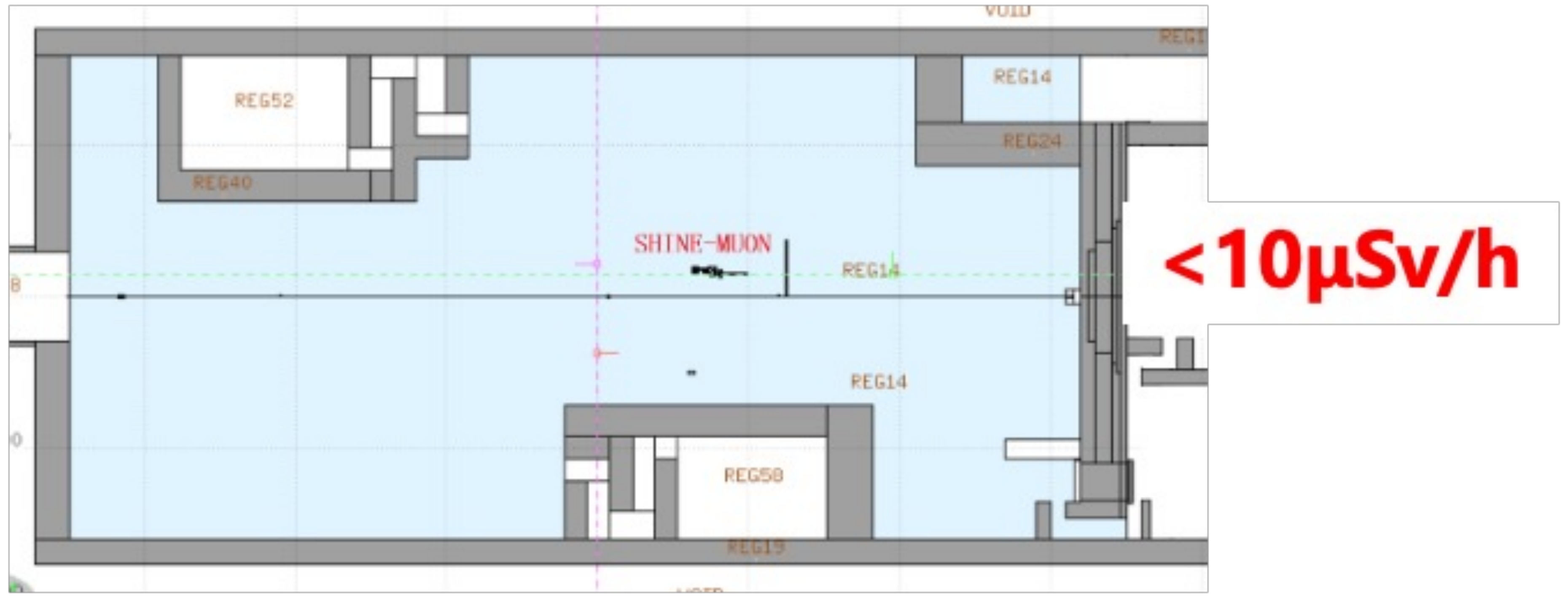
束流能量~4 GeV，归一化发射度~0.5mm-mrad，横向包络函数~50 m，挡块束团横向尺寸~0.05-0.1 mm，根据实际调试情况可能略有浮动

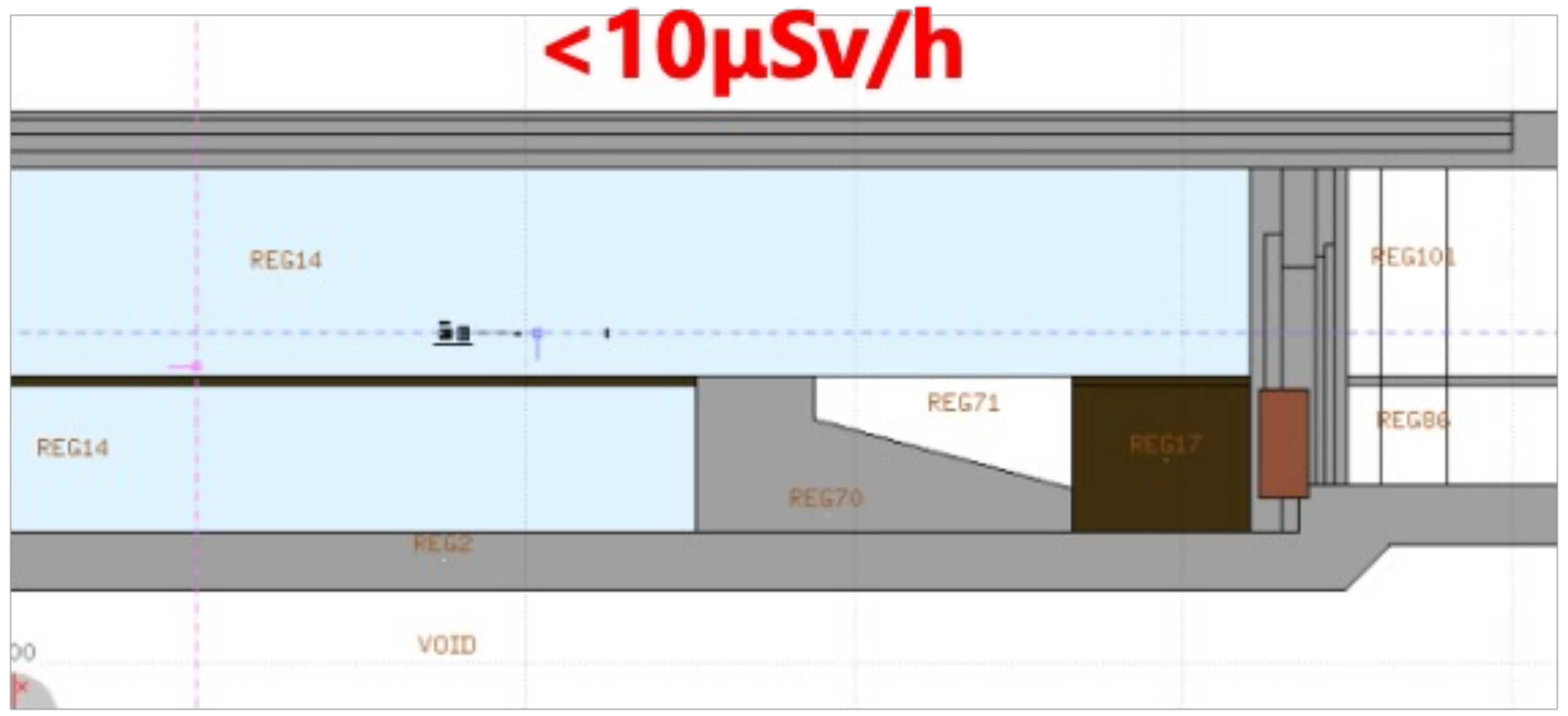
- 参考SHINE可移动挡块型准直器设计，挡块替换为铜挡块，前半部分用于MUON实验，后半部分做渐变凸台以降低尾场。挡块可全部移出，插入时可完全阻塞下游真空管道。
- 可移动挡块到铝靶整体置于真空内，正电子探测器置于真空外，中间采用膜窗隔离。真空部分要求与SHINE真空管道一致，挡块真空室与铝靶真空室之间有铜插板阀，用于抑制尾场。

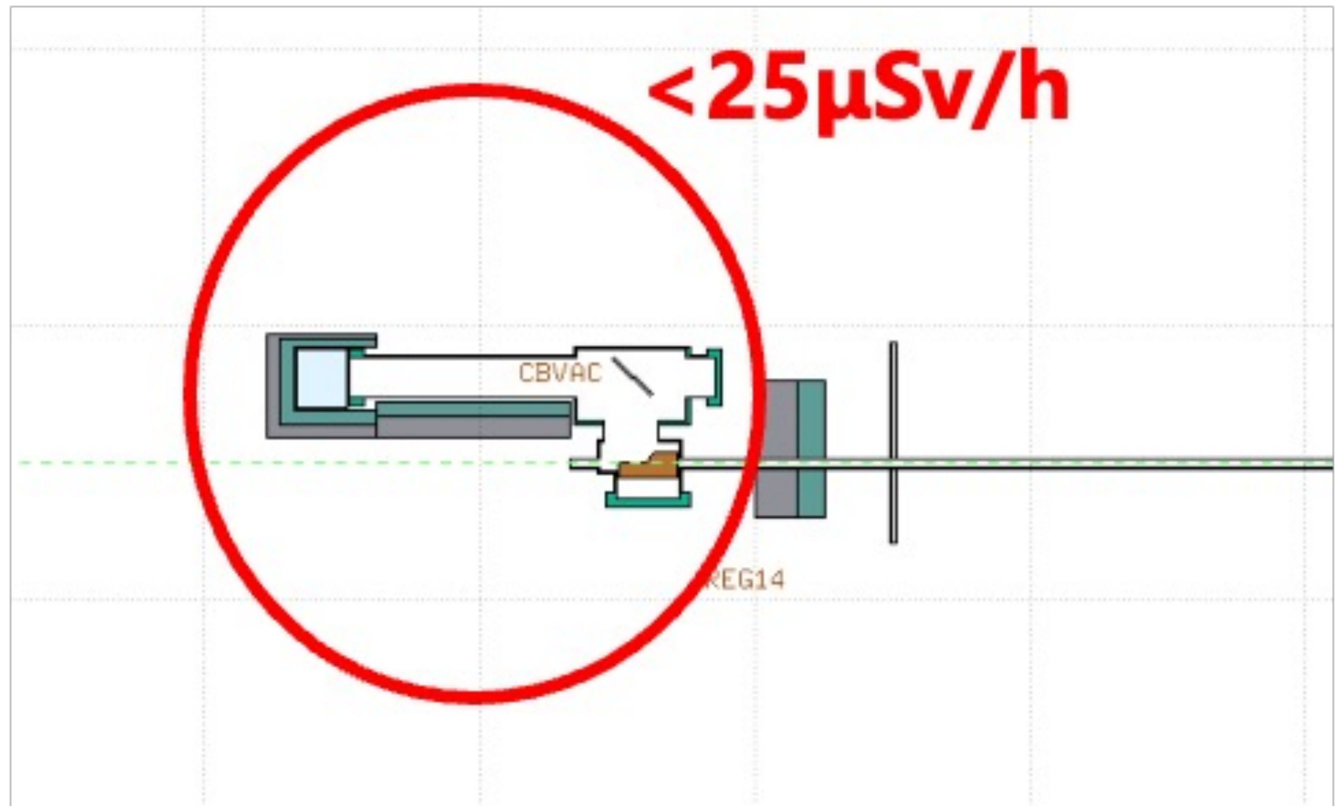
辐射防护设计目标及技术指标

辐射安全设计目标	
瞬发辐射	主体屏蔽墙外关键点位瞬发**辐射剂量率 <10μSv/h**
感生放射性辐射影响	长时间持续出束后，停机4h后允许进入靠近设备附近区域 **(距设备1m处剂量率<25μSv/h)**
实验期间人身安全	**设置辐射安全联锁系统和辐射监测系统**
μ→e粒子探测	
增加局部屏蔽措施，减少muon靶站次级粒子对μ→e事件测量的背景干扰（**最小化**）	

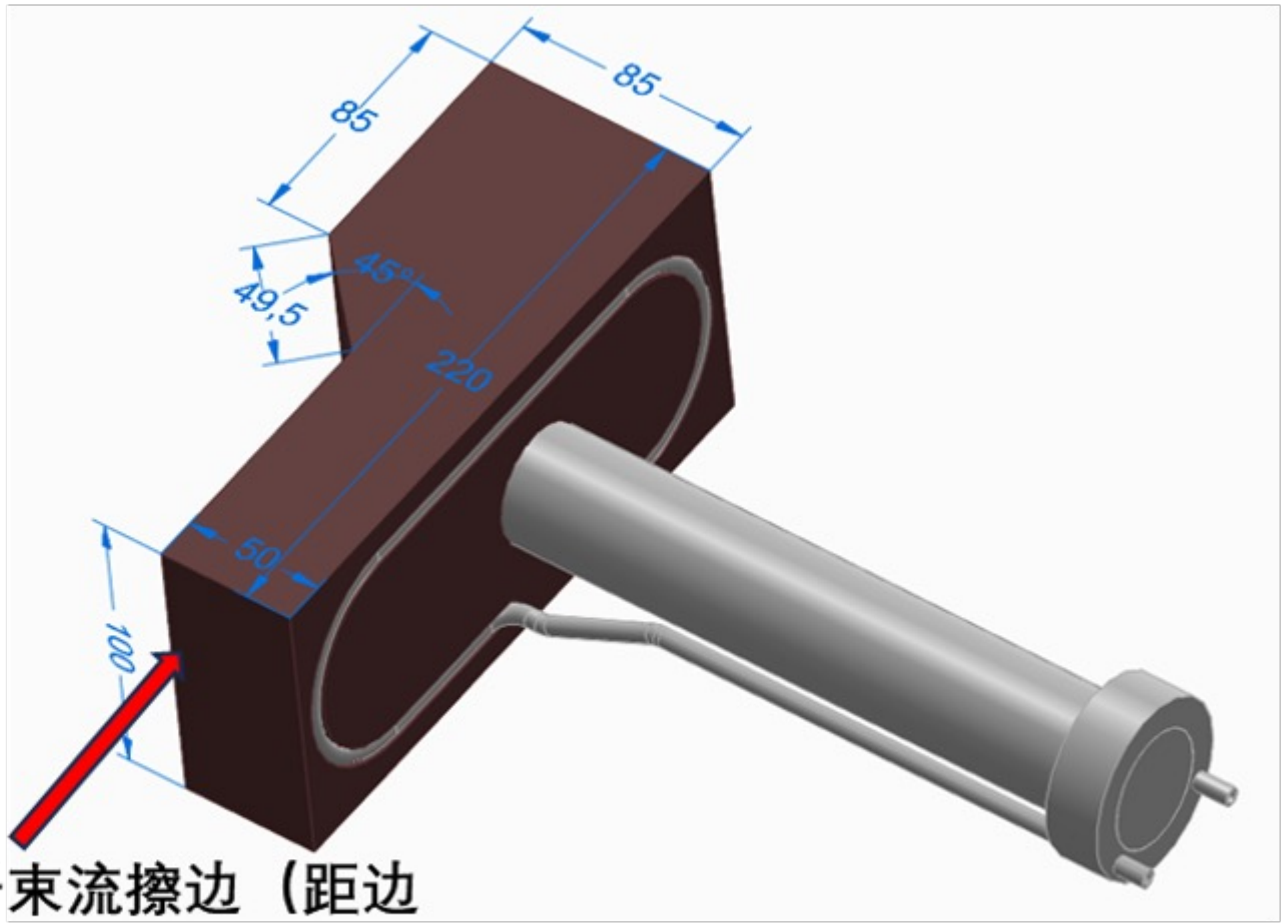




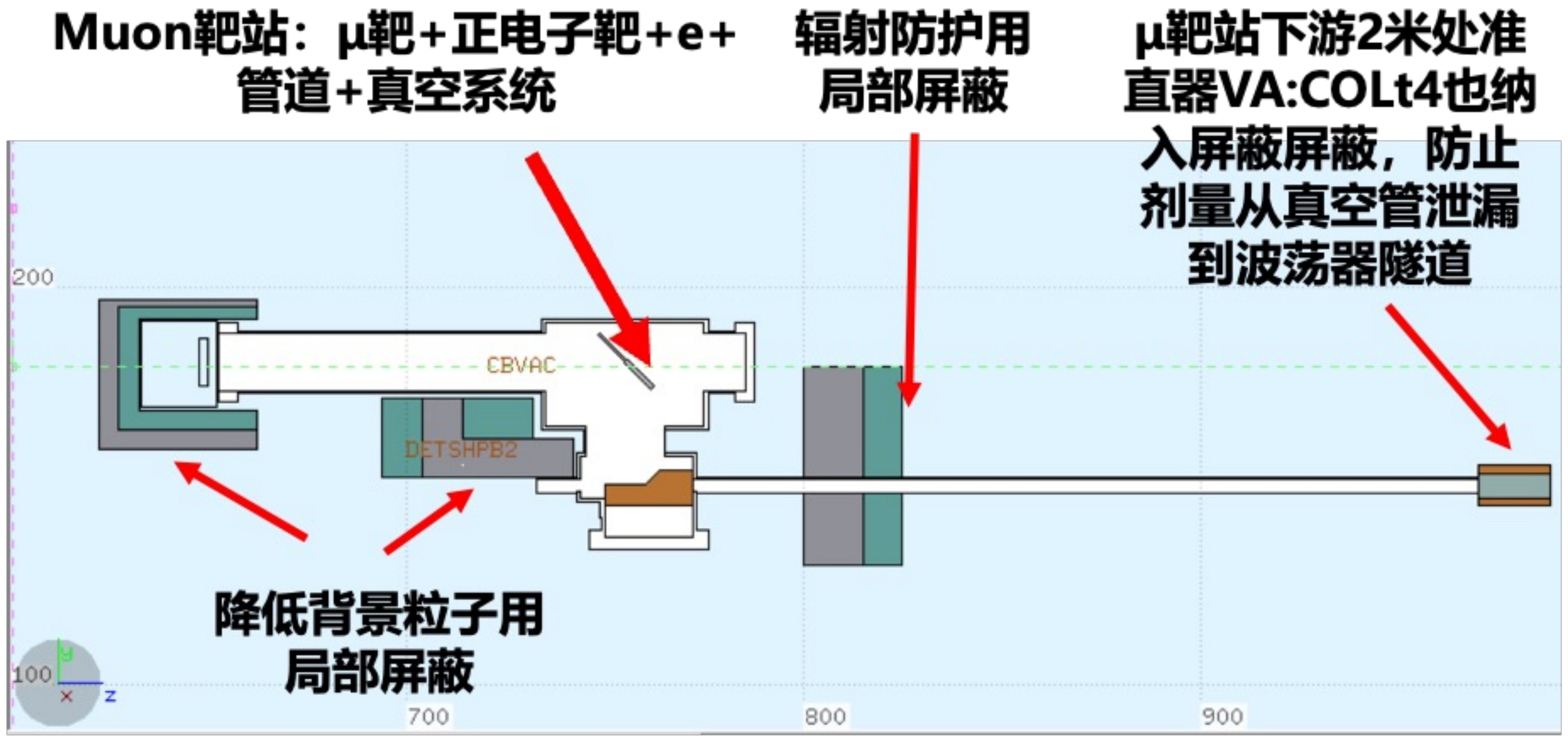




计算模型及主要参数



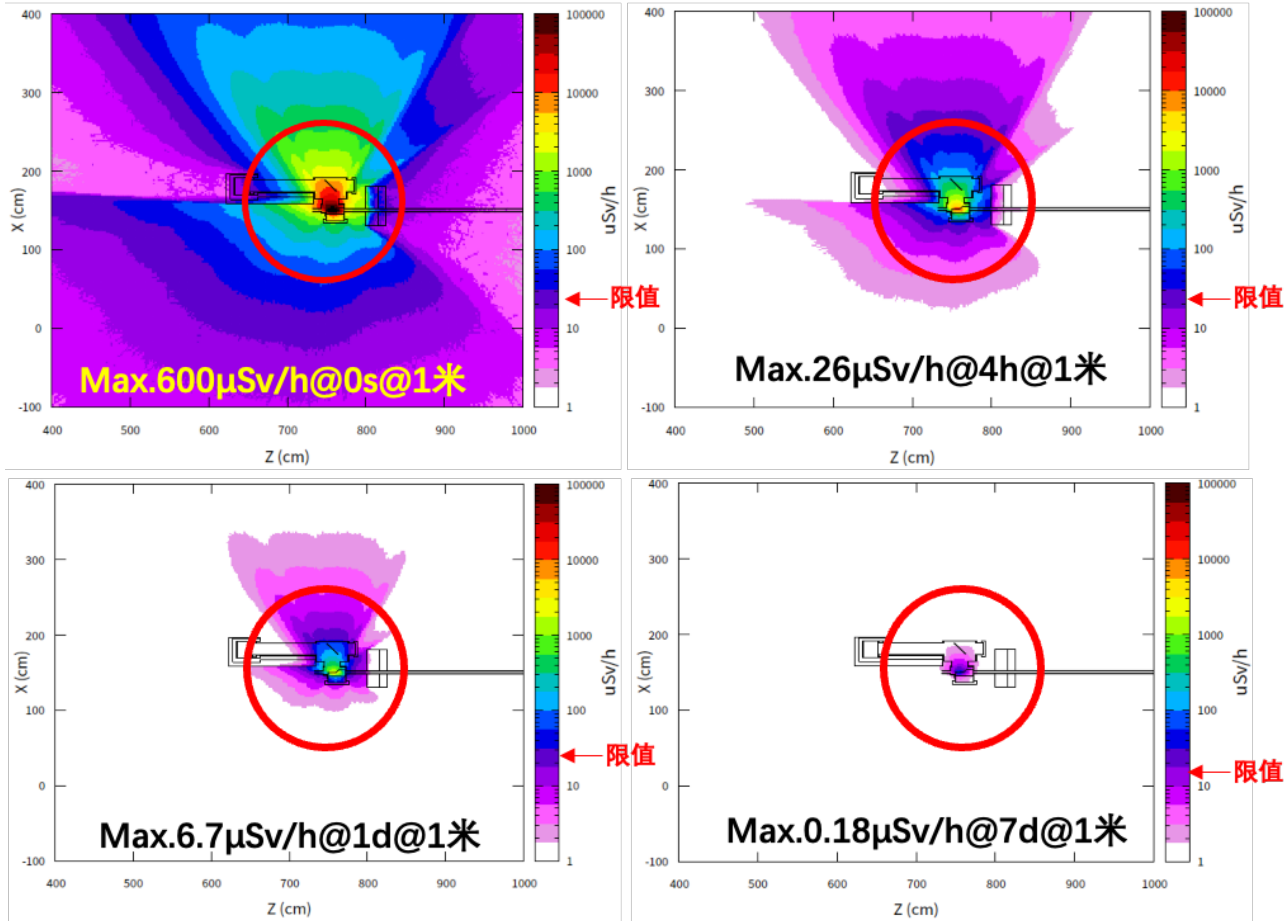
电子束流擦边（距边缘2mm）进入靶体

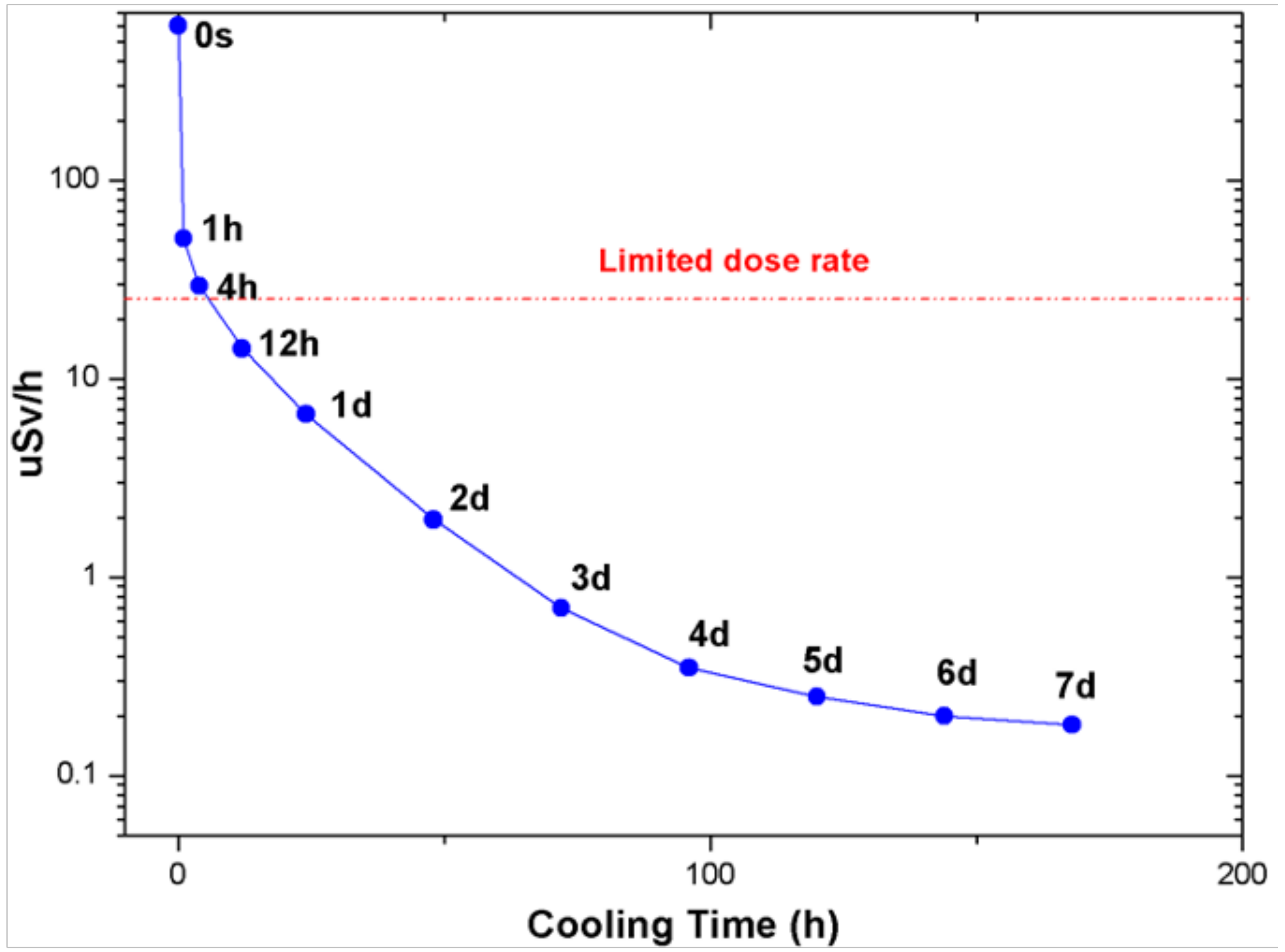


靶体尺寸 (局部楔形结构)	材质	电子能量 GeV	束斑 σX，mm	束斑 σY，mm	稳态功率 W
宽：8cm (前段5cm，后短8cm，中间楔形) 高：10cm（$4R_M$） 长：22cm（$15X_0$辐射长度）	无氧铜	3.0 (μ实验) 4.5 (e-调束)	0.1	0.1	● Muon测量试验(最大) 15W(最大工况) (0.1nC*50Hz*3GeV) ● SHINE调束： 0.9W (0.1nC*2Hz*4.5GeV)

感生放射性辐射剂量影响(1)

模式一：50Hz重频短时间连续出束（10h）

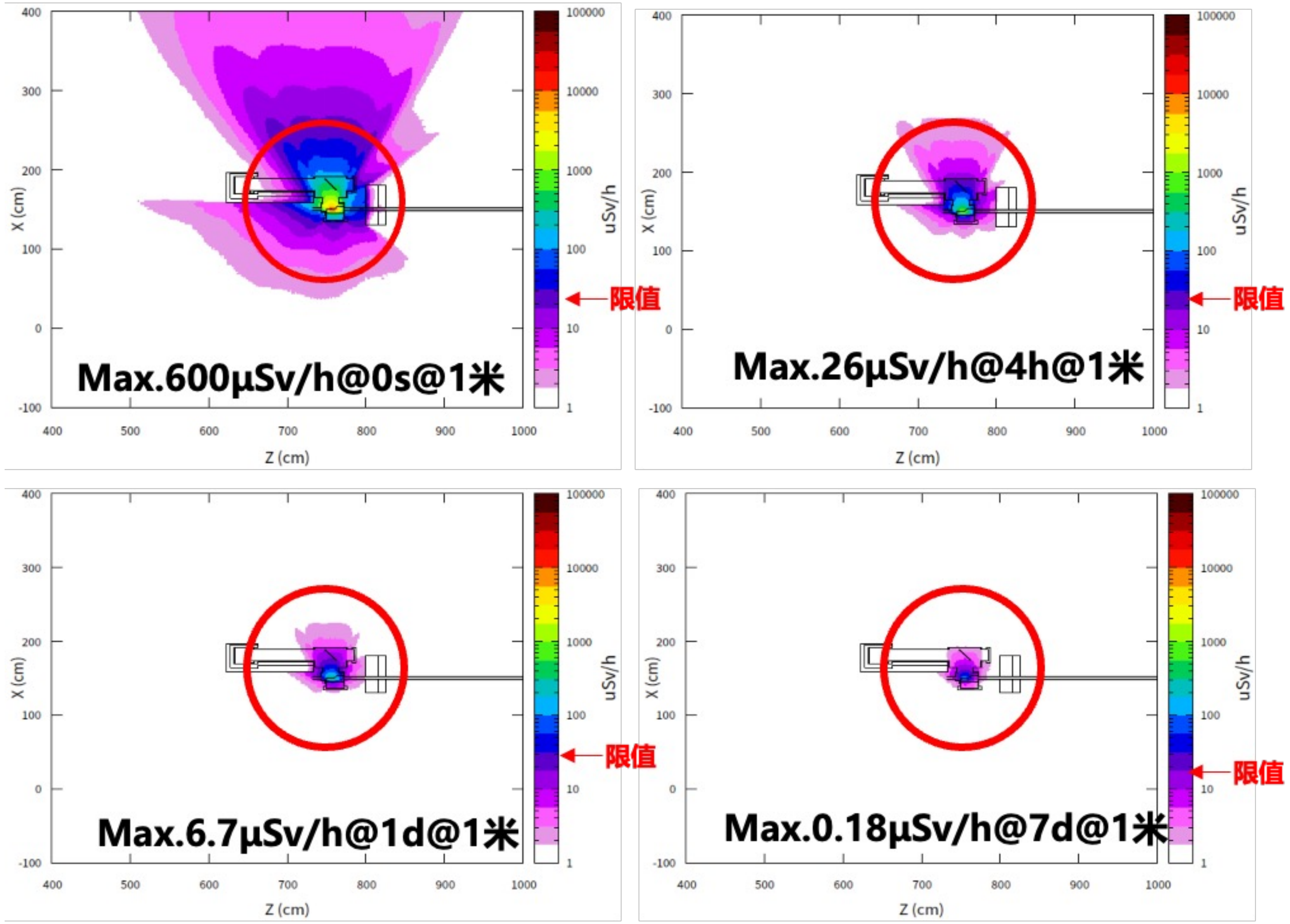


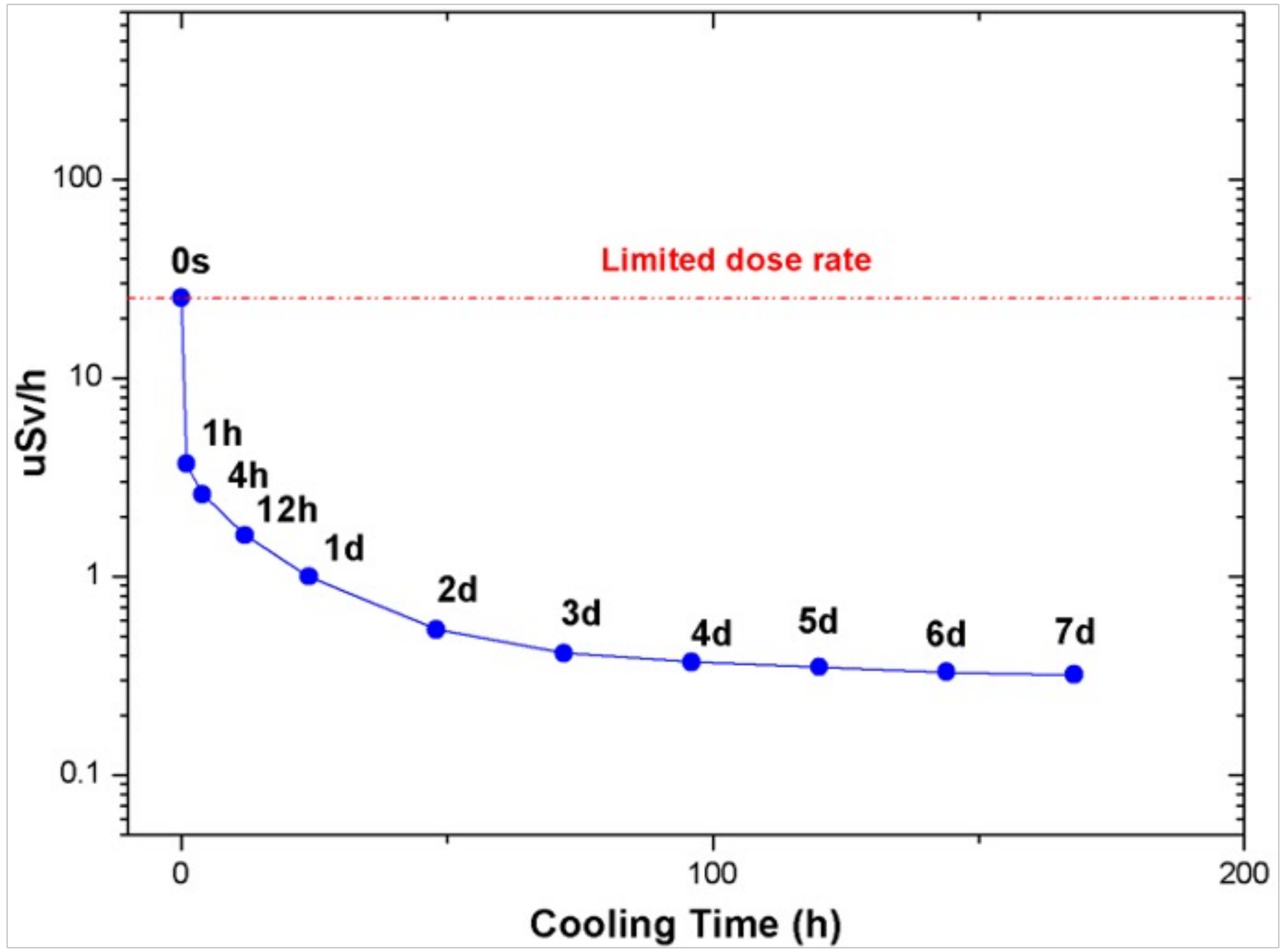


50Hz重频模式感生放射性剂量水平正好在管理限值左右

感生放射性辐射剂量影响(2)

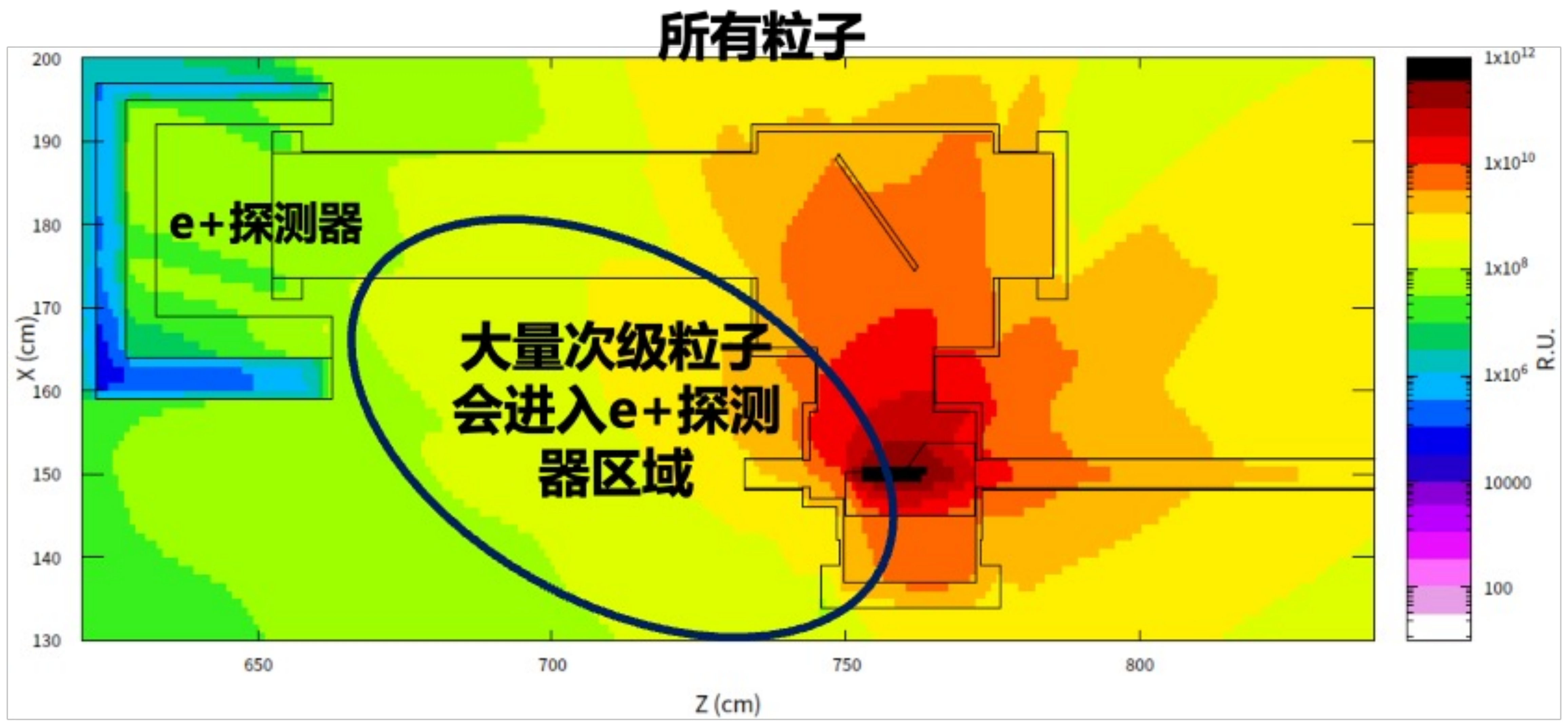
模式二：2Hz重频长时间连续出束（1月）

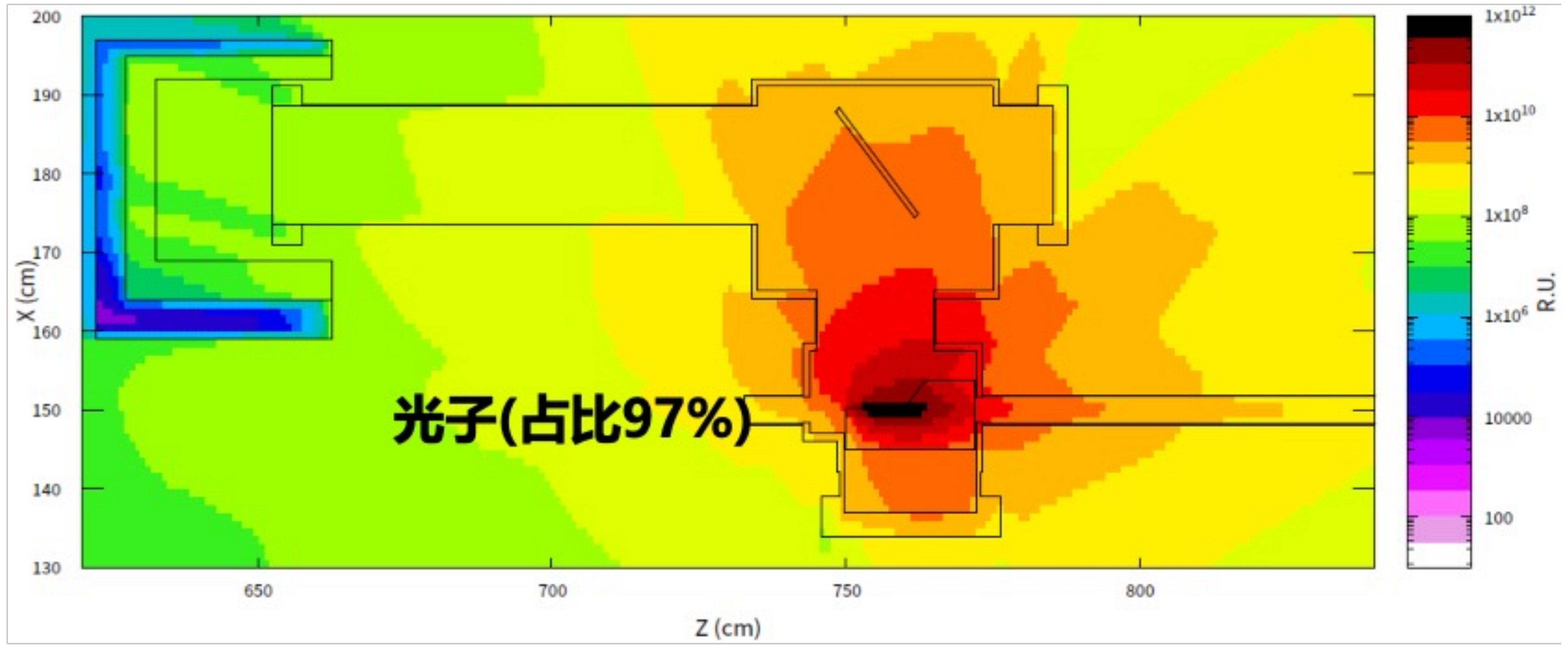


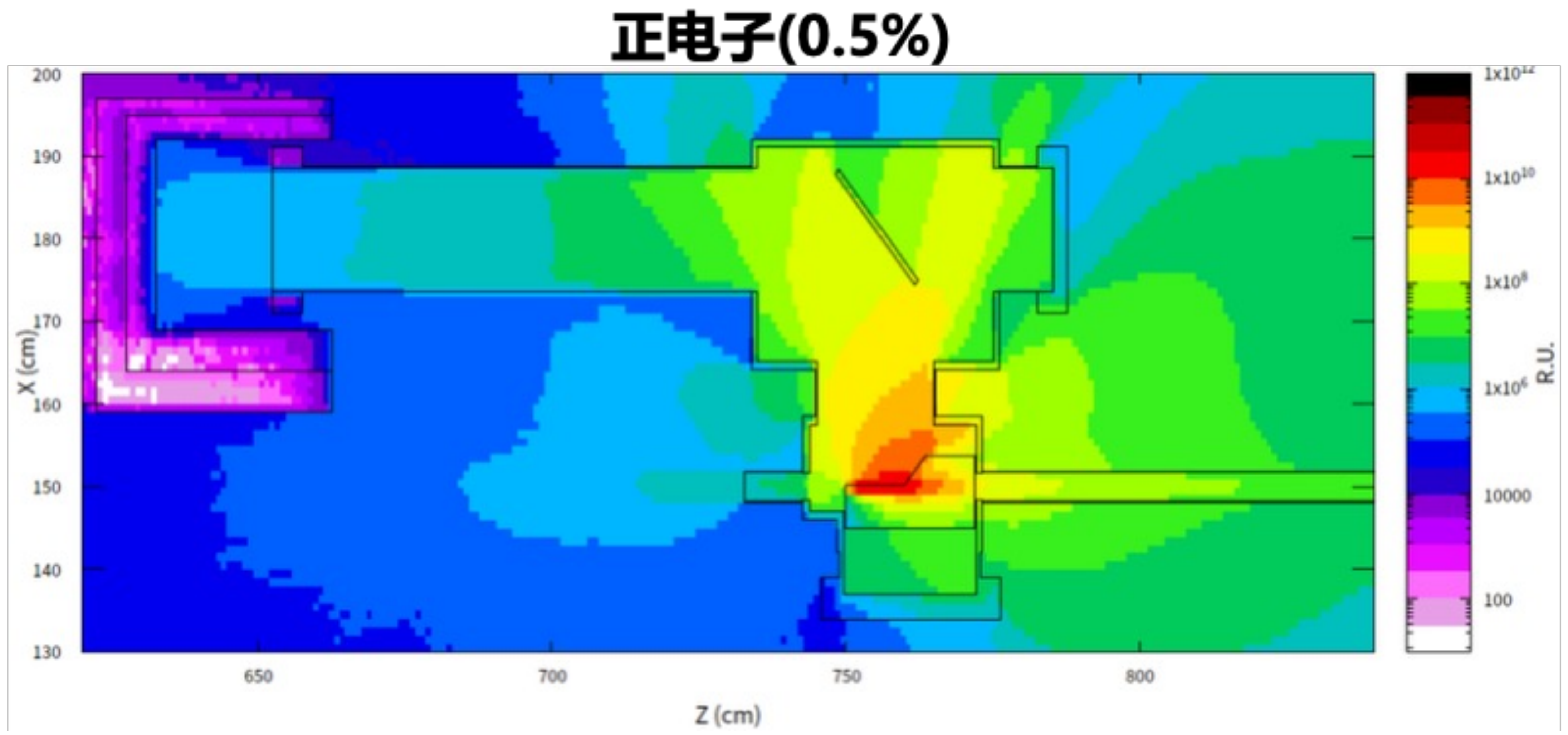


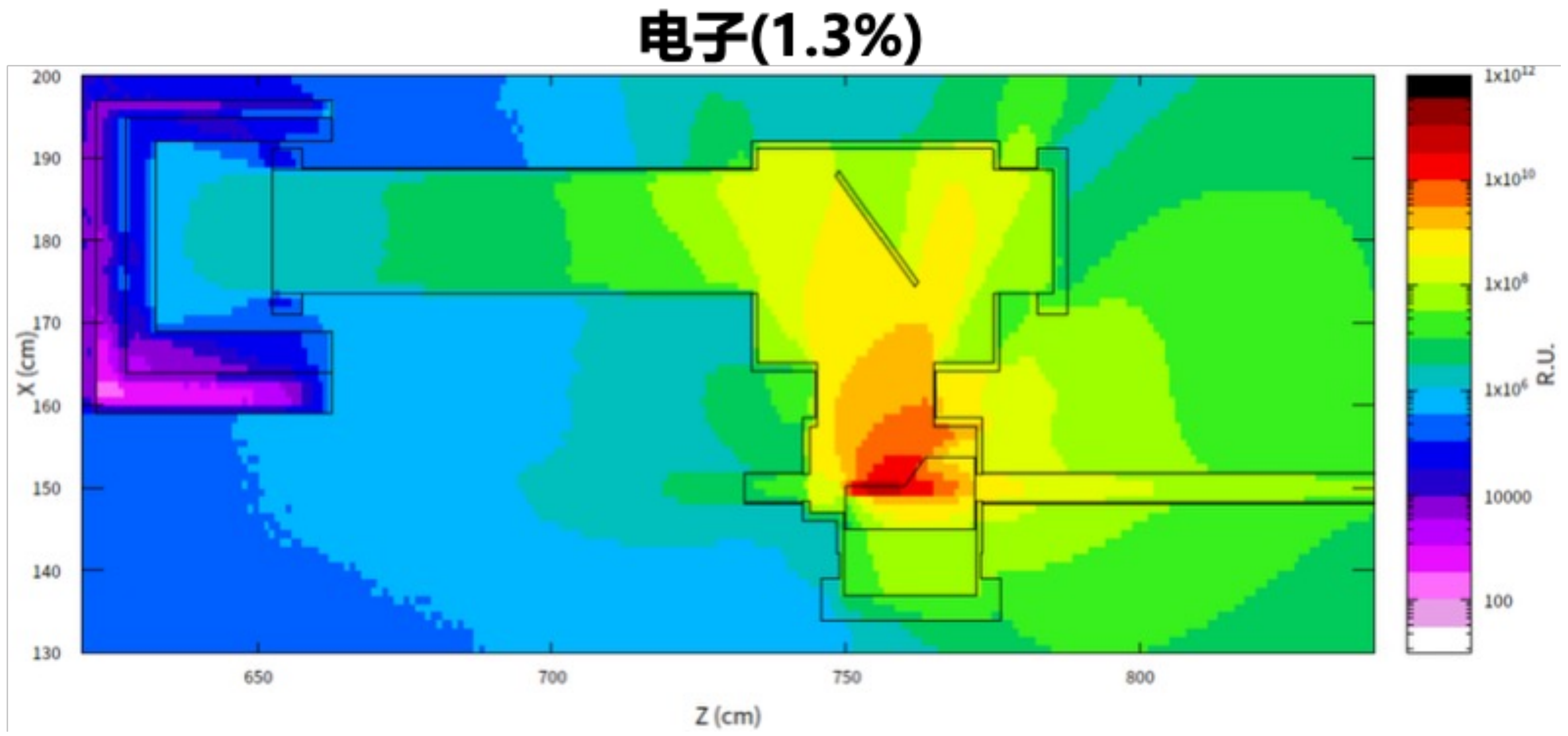
2Hz重频模式感生放射性剂量水平较低，满足短时间停机后对SHINE-Muon靶站维护的管理要求

局部屏蔽探测背景粒子


所有粒子
e+探测器
大量次级粒子
会进入e+探测
器区域
X (cm)
Z (cm)
R.U.
200
190
180
170
160
150
140
130
650
700
750
800
1x10¹²
1x10¹⁰
1x10⁸
1x10⁶
10000
100


光子(占比97%)
X (cm)
Z (cm)
R.U.
200
190
180
170
160
150
140
130
650
700
750
800
1x10¹²
1x10¹⁰
1x10⁸
1x10⁶
10000
100


正电子(0.5%)
X (cm)
Z (cm)
R.U.
200
190
180
170
160
150
140
130
650
700
750
800
1x10¹²
1x10¹⁰
1x10⁸
1x10⁶
10000
100


电子(1.3%)
X (cm)
Z (cm)
R.U.
200
190
180
170
160
150
140
130
650
700
750
800
1x10¹²
1x10¹⁰
1x10⁸
1x10⁶
10000
100

局部屏蔽探测背景粒子

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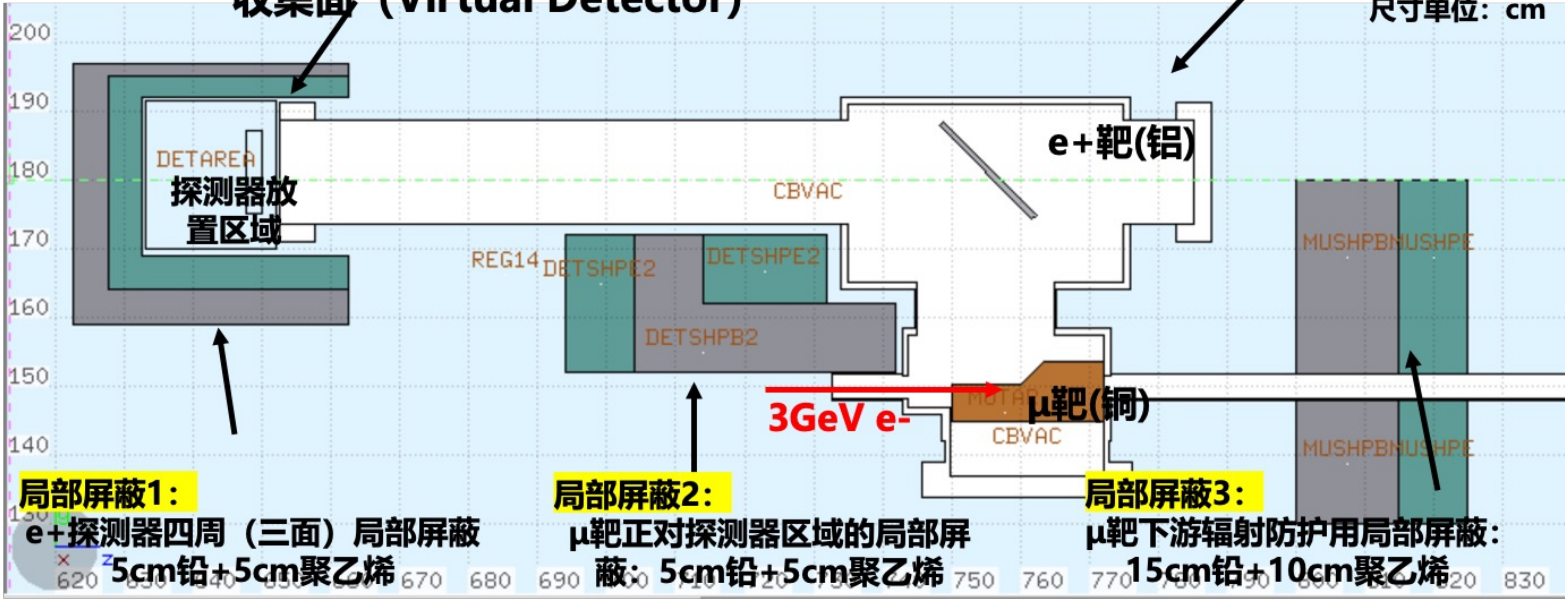
进入探测器区域的次级粒子收集面（Virtual Detector）

μ靶和e+靶共同腔室

尺寸单位：cm

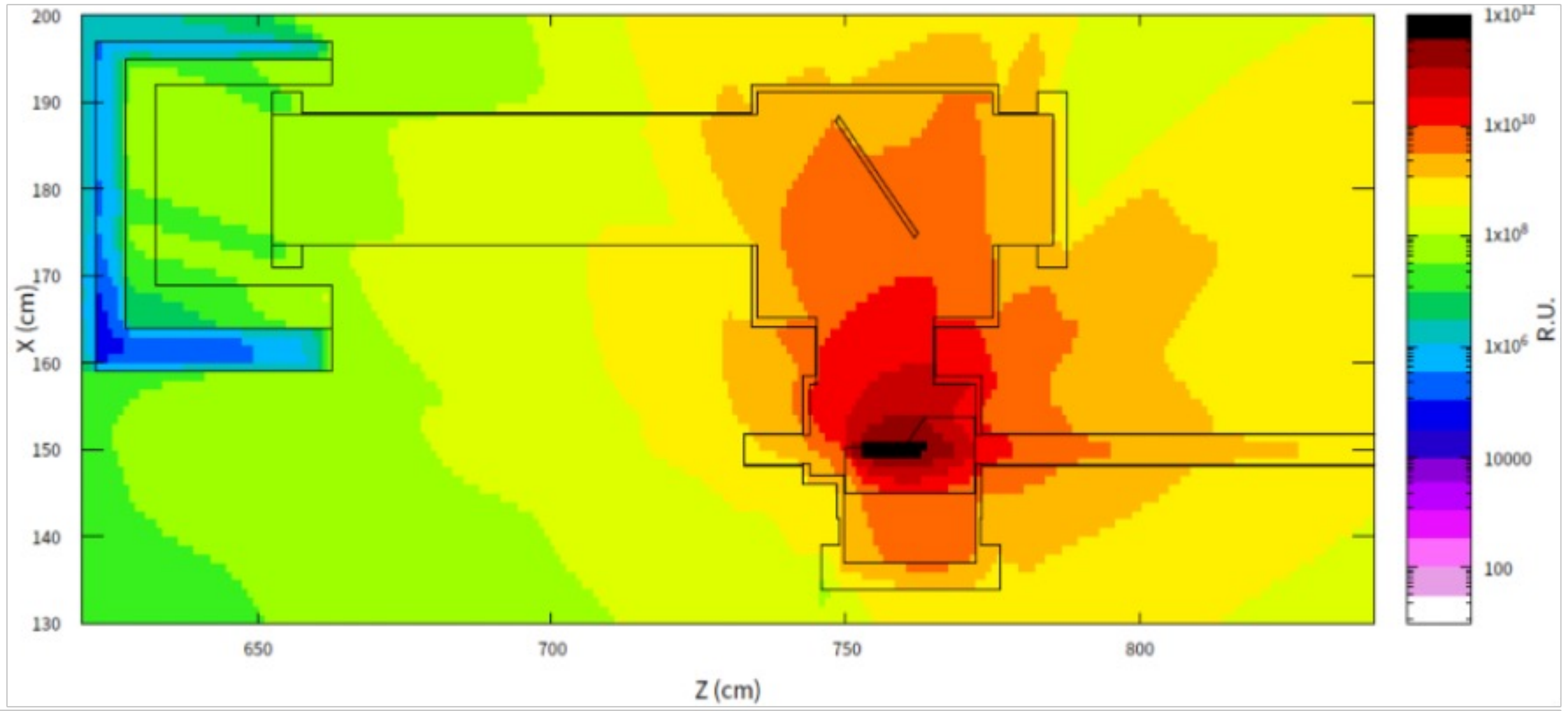


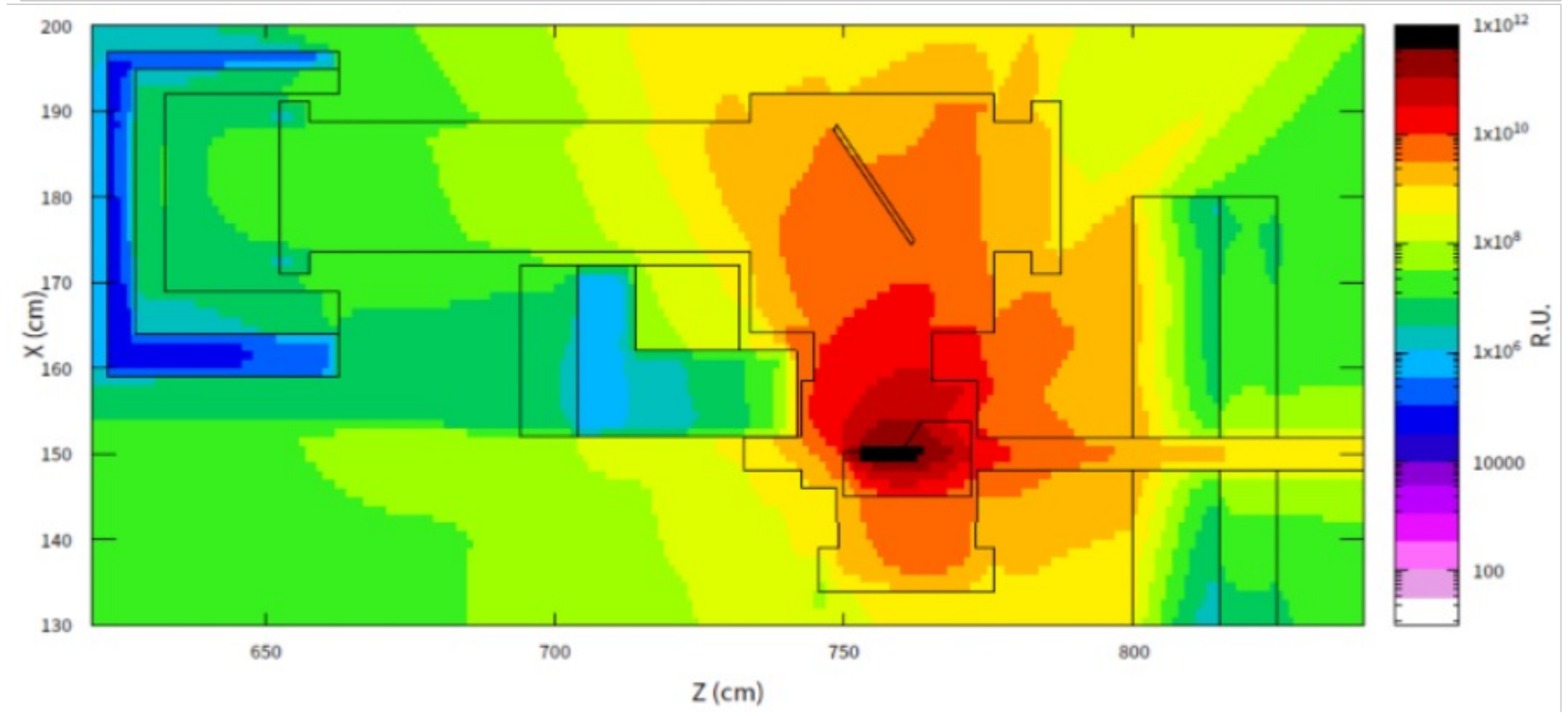
局部屏蔽1:
e+探测器四周（三面）局部屏蔽
5cm铅+5cm聚乙烯

局部屏蔽2:
μ靶正对探测器区域的局部屏蔽：5cm铅+5cm聚乙烯

局部屏蔽3:
μ靶下游辐射防护用局部屏蔽：
15cm铅+10cm聚乙烯

局部屏蔽探测背景粒子





屏蔽效果比较

		No Shield (N/pulse)	Shield (N/pulse)	Shielding Effective	所有粒子中占比 %	
					No Shield	Shield
正电子探测区	e-	3.62E+06	3.05E+06	-0.14	1.3	6.1
	e+	1.28E+06	1.18E+06	-0.07	0.5	2.4
	photon	2.71E+08	4.45E+07	-0.81	97.1	89.5
	neutron	3.29E+06	9.69E+05	-0.57	1.2	2.0
	mu	252	6.9	-0.91	9.0E-05	1.39E-05
高能μ探测	High energy mu+	1.47E+03	266	-0.55	_	_
	High energy mu-	1.36E+03	256	-0.56	_	_

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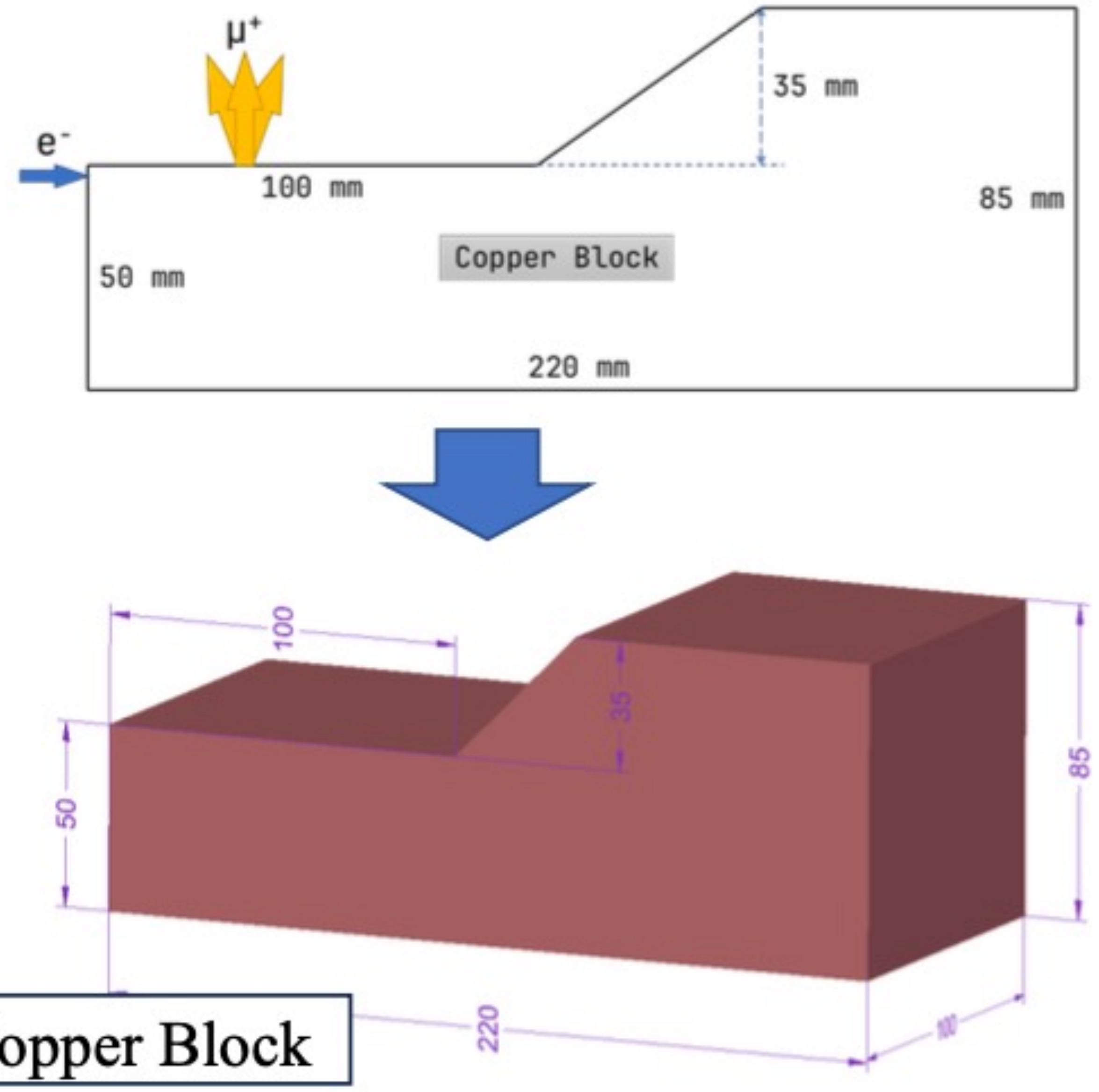
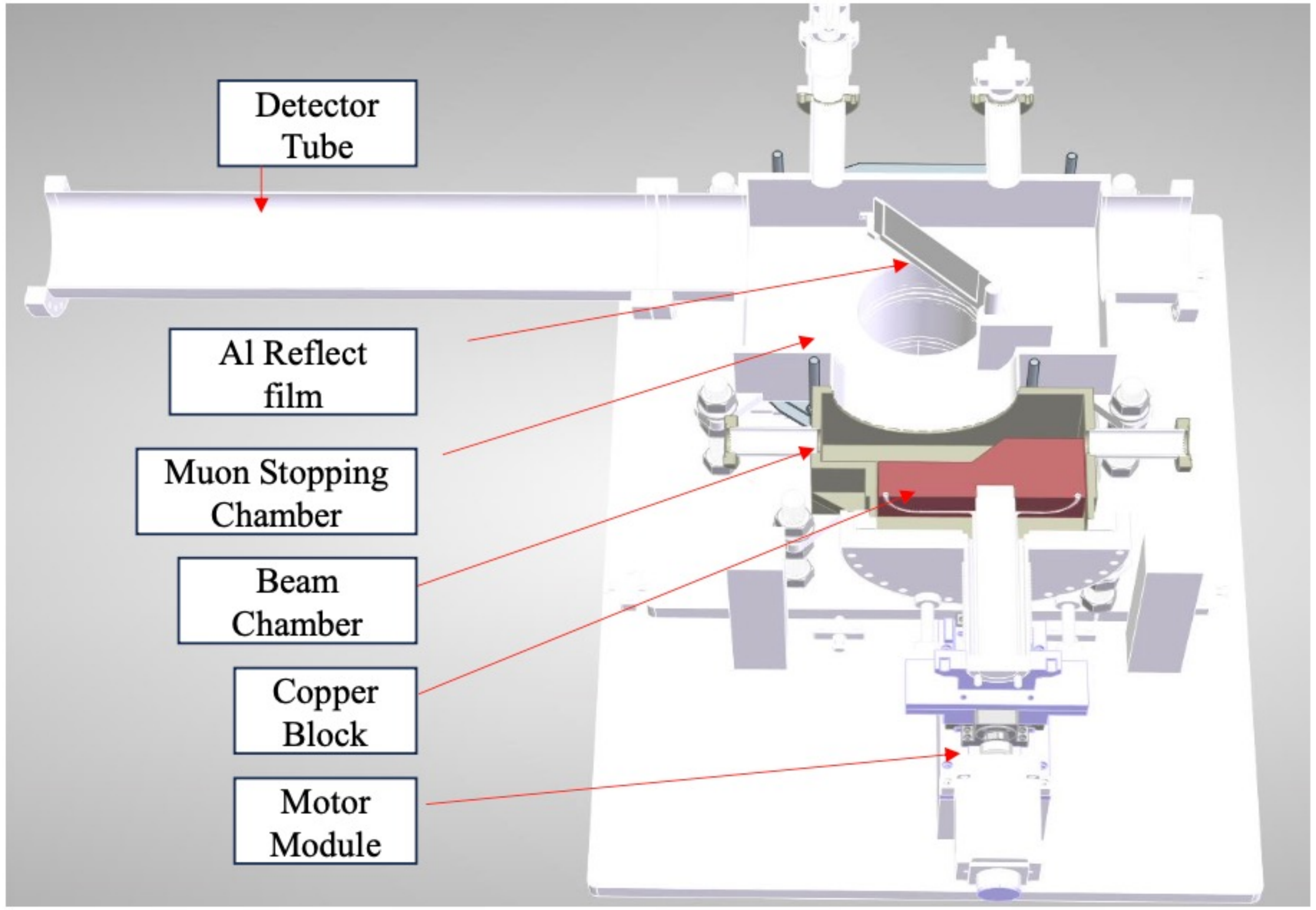
腔体结构设计

整体腔室

- 束流室与收集室、探测室三者真空联通
- 束流室与收集室之间置有铜插板，降低阻抗、不隔真空
- 铜挡块前部分用于产生u子，后半部分凸台用于阻挡电子束

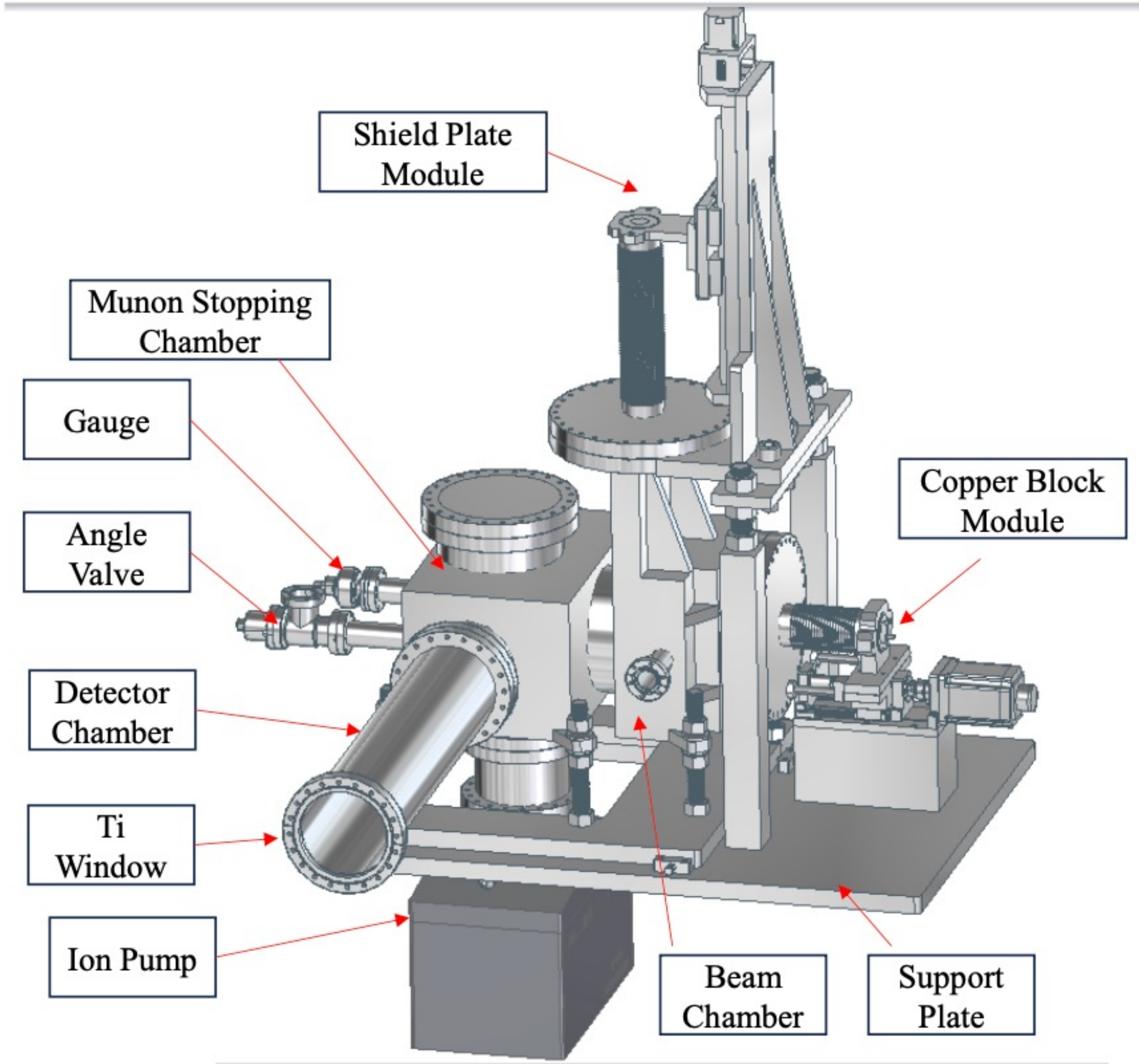


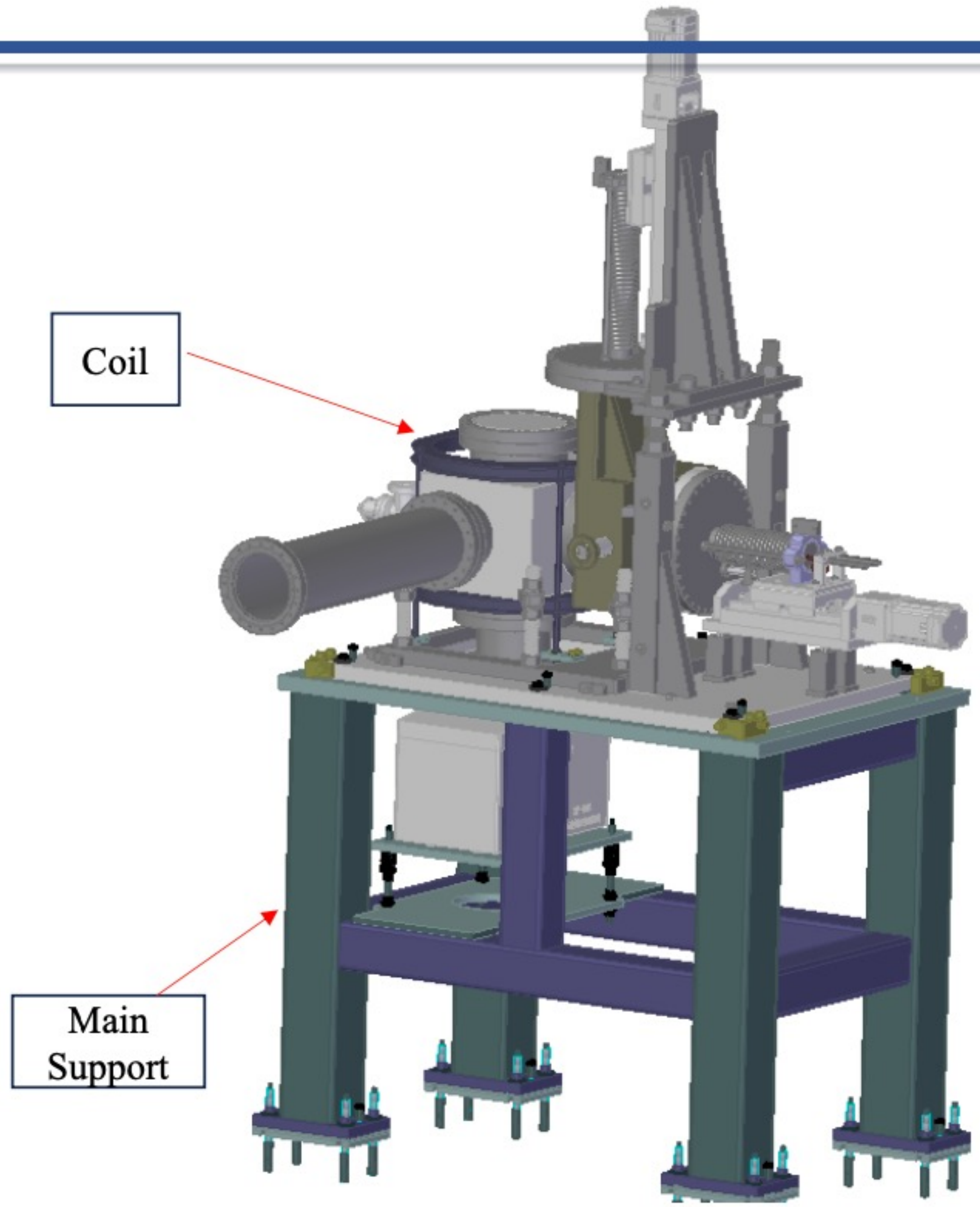
Copper Block



腔体结构设计

整体腔室


Shield Plate Module
Munon Stopping Chamber
Gauge
Angle Valve
Detector Chamber
Ti Window
Ion Pump
Beam Chamber
Support Plate
Copper Block Module


Coil
Main Support

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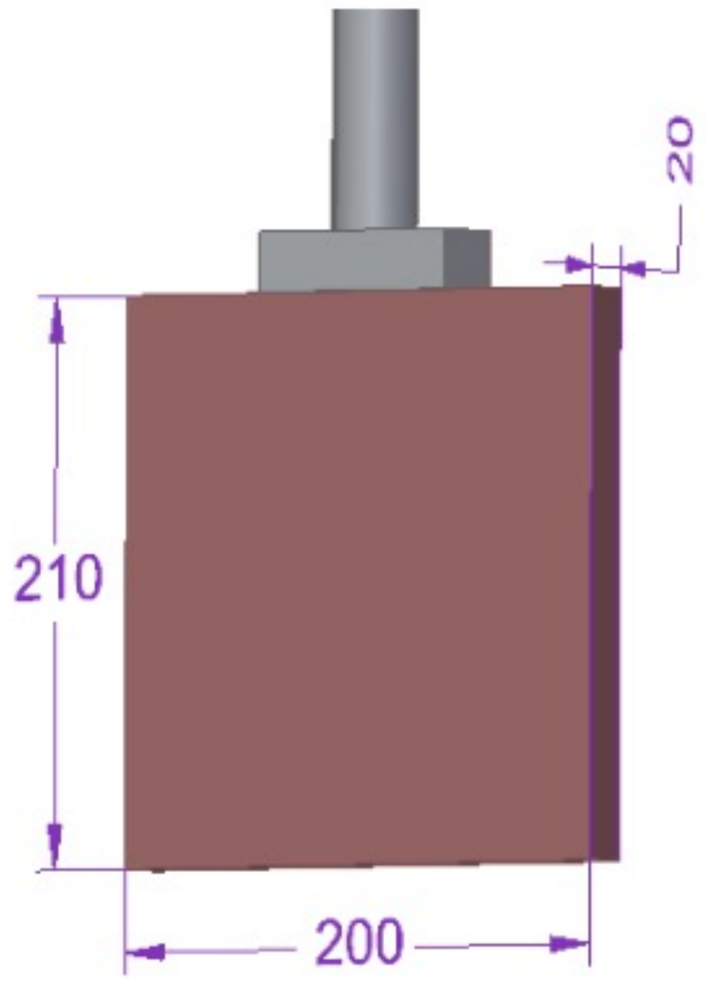
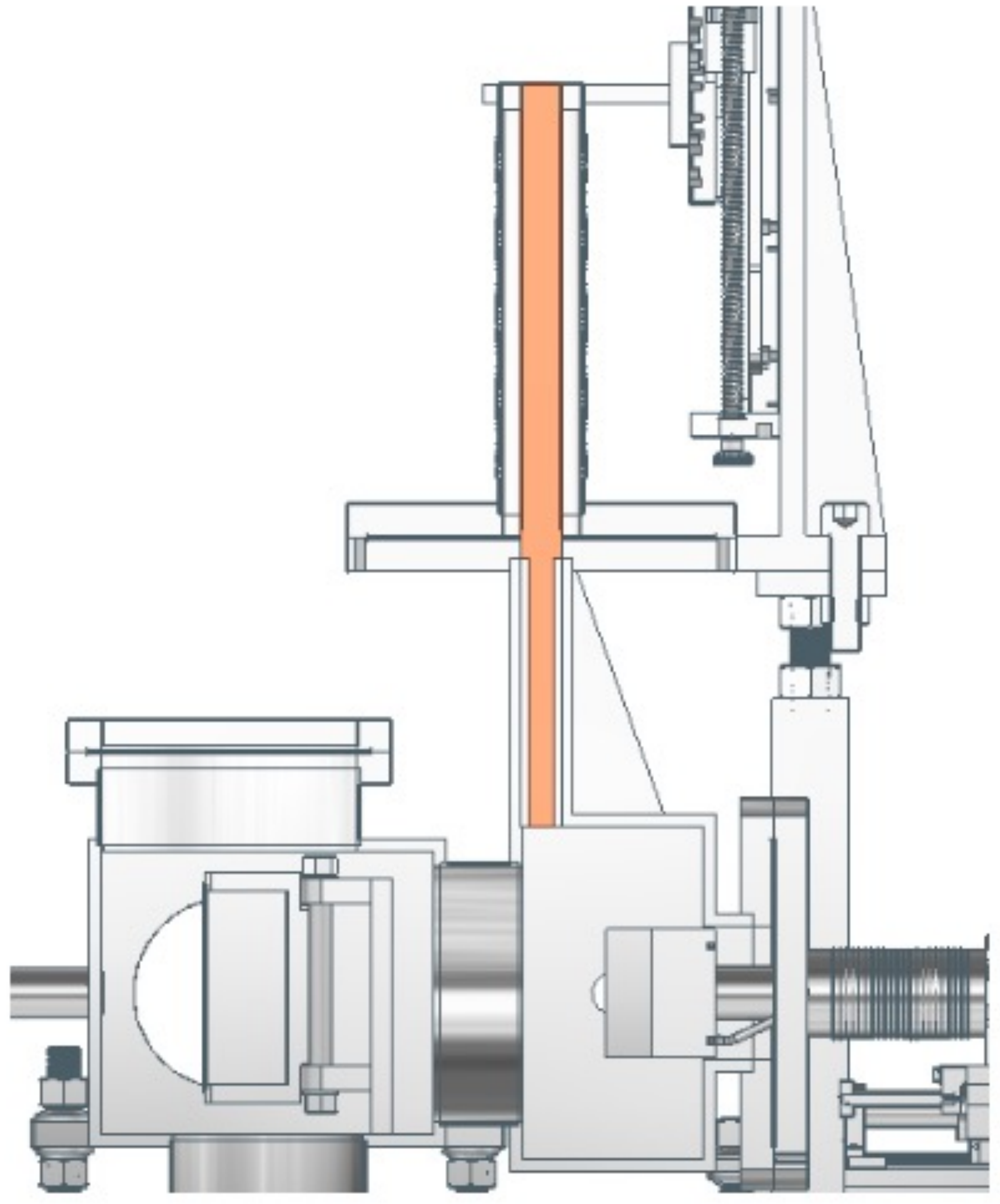
腔体结构设计

铜屏蔽板组件

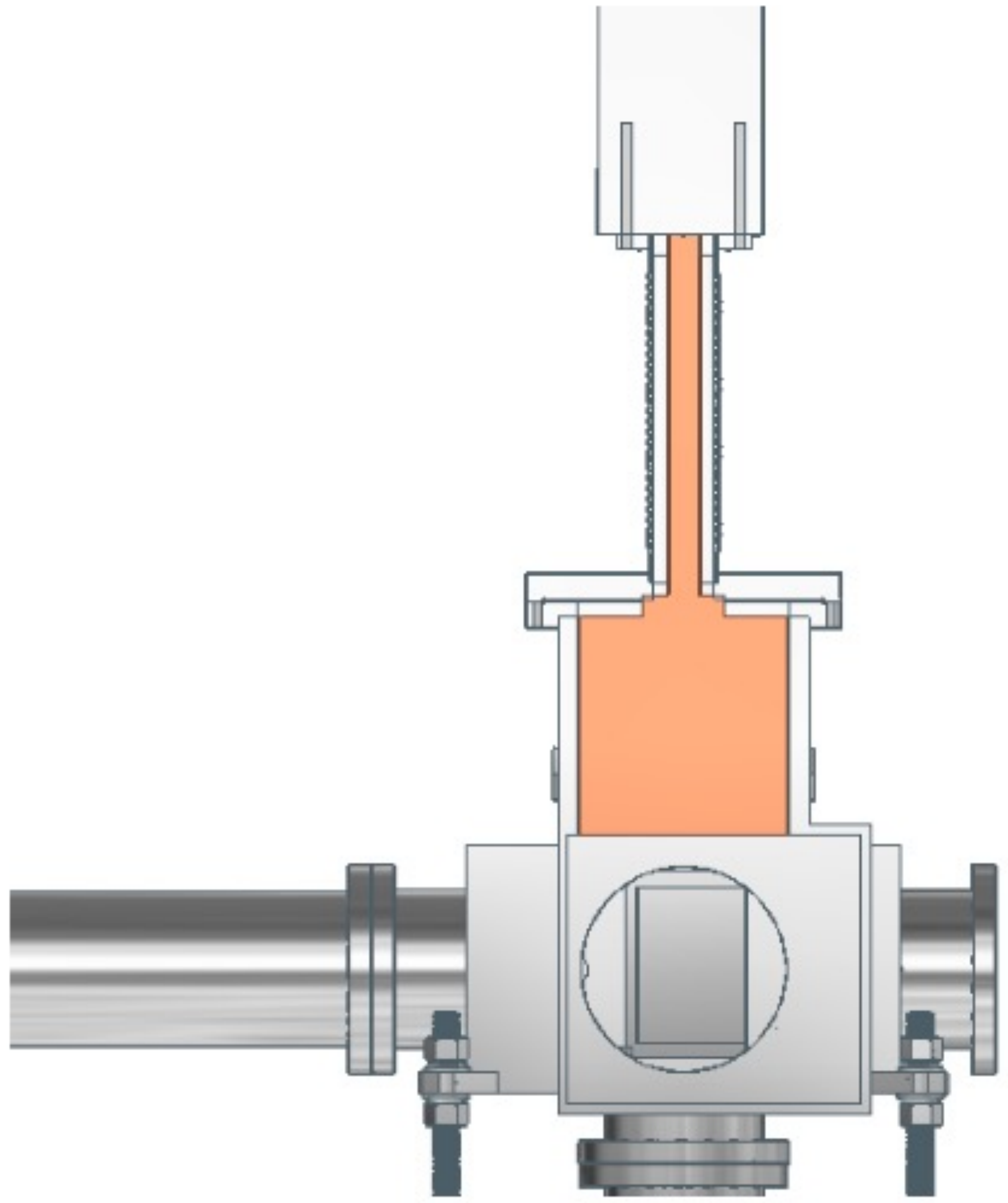
- 平台工作时，屏蔽板提起；反之落下
- 电机驱动，远程控制

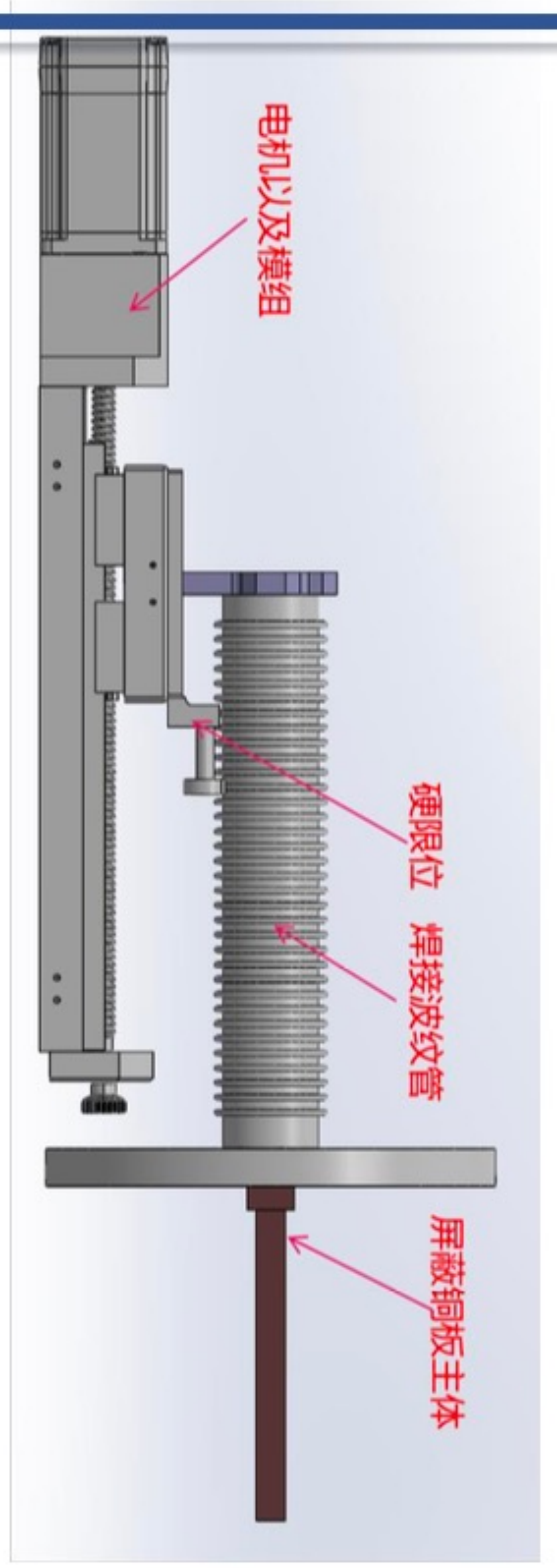


侧视



正视





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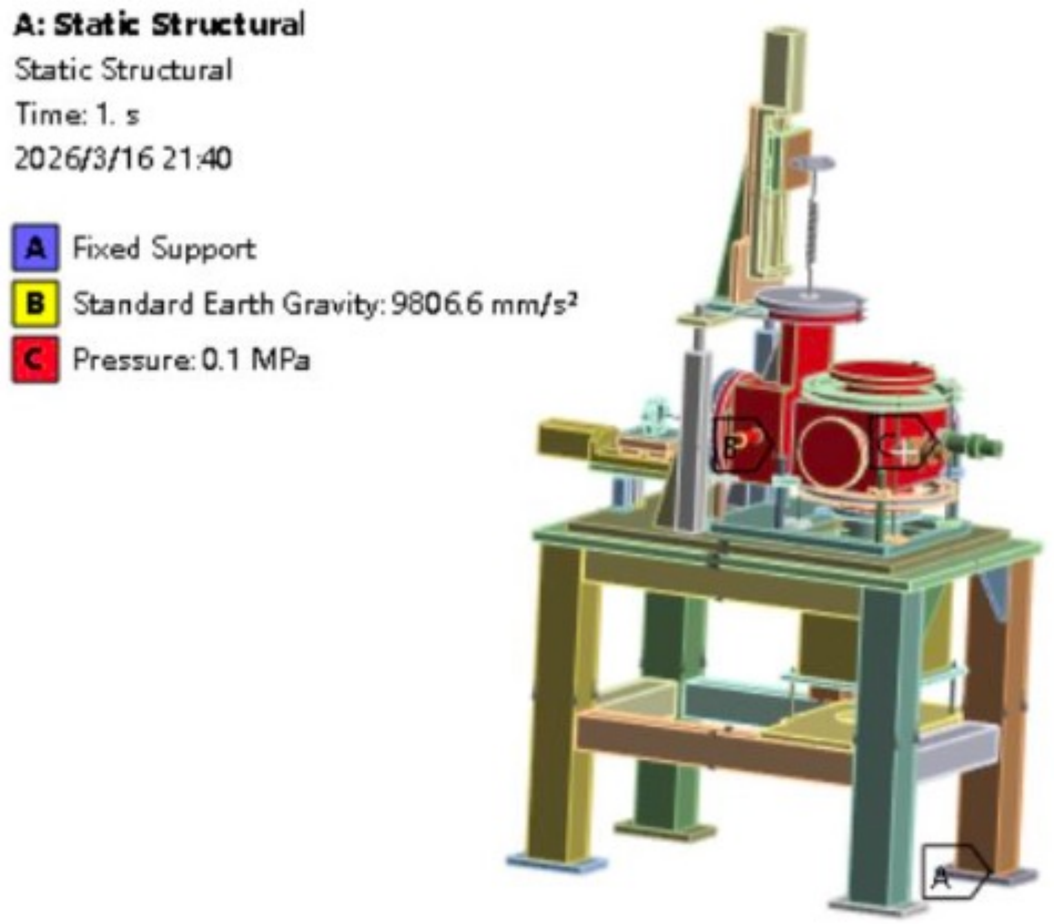
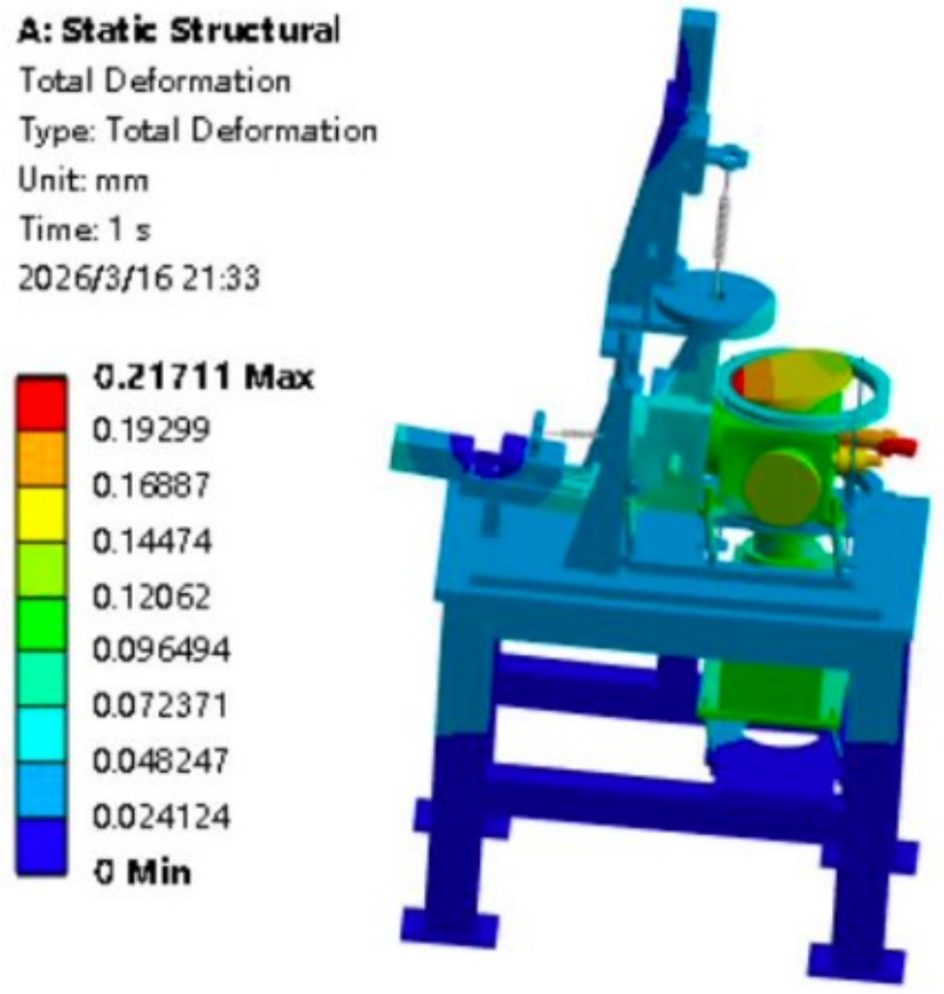
整体支撑设计

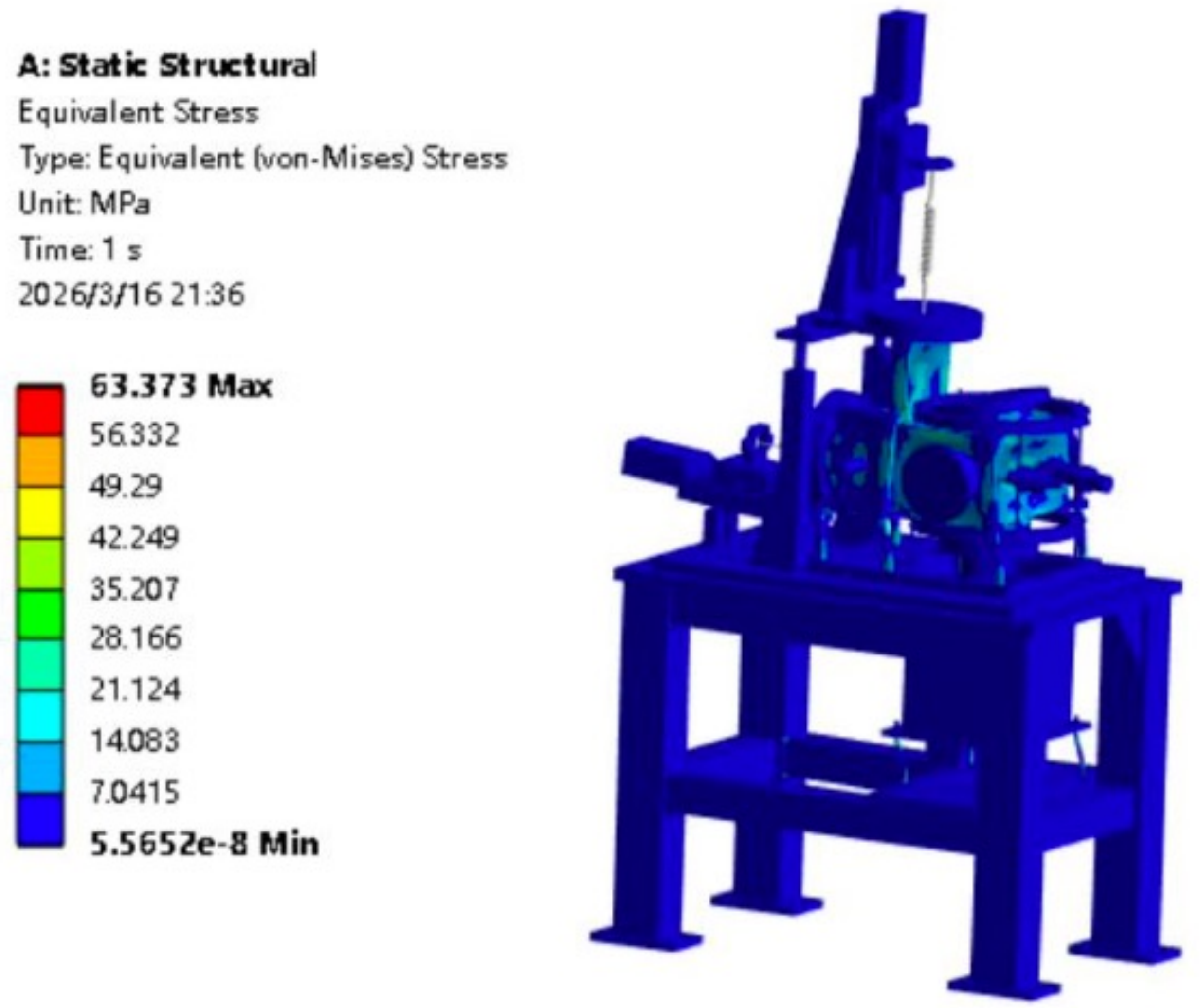
机械支撑结构静力校核



边界条件:
腔体外部一个大气压
结构自重



最大变形0.22mm

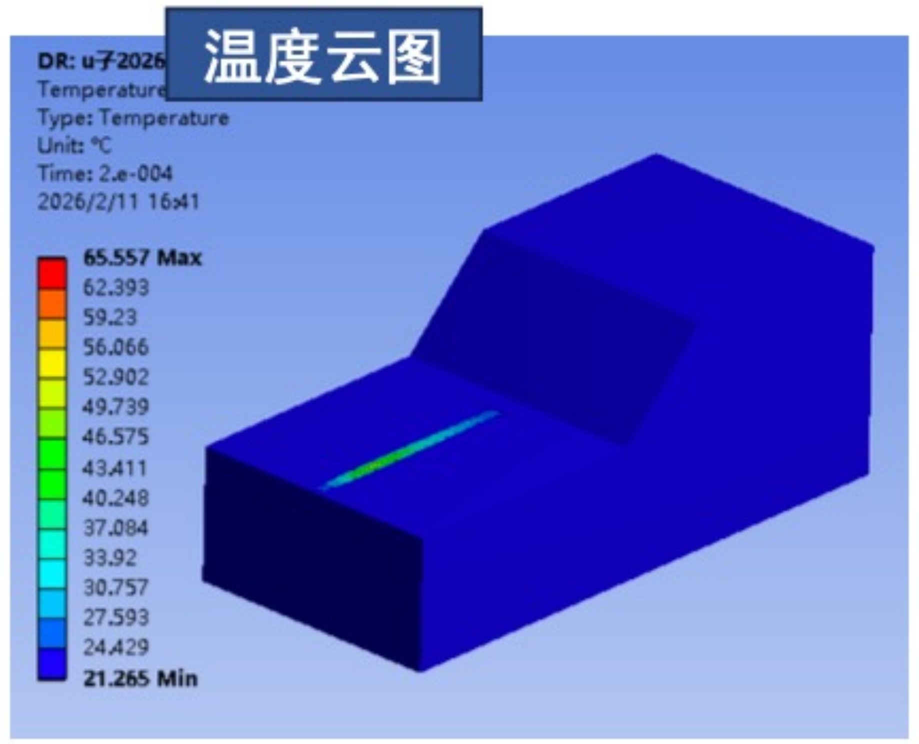


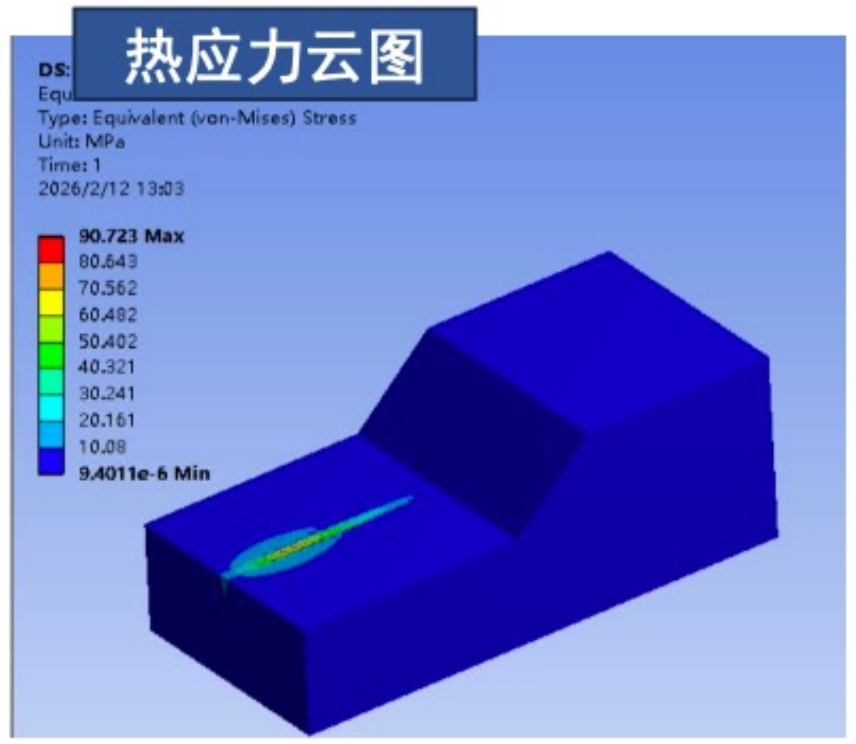
最大应力63.3MPa

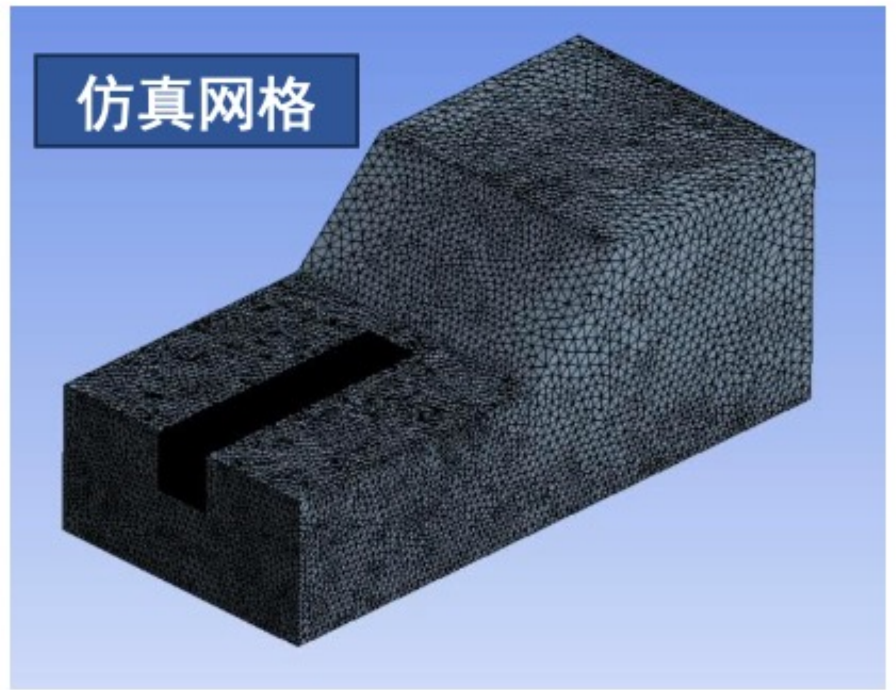
热力及真空仿真

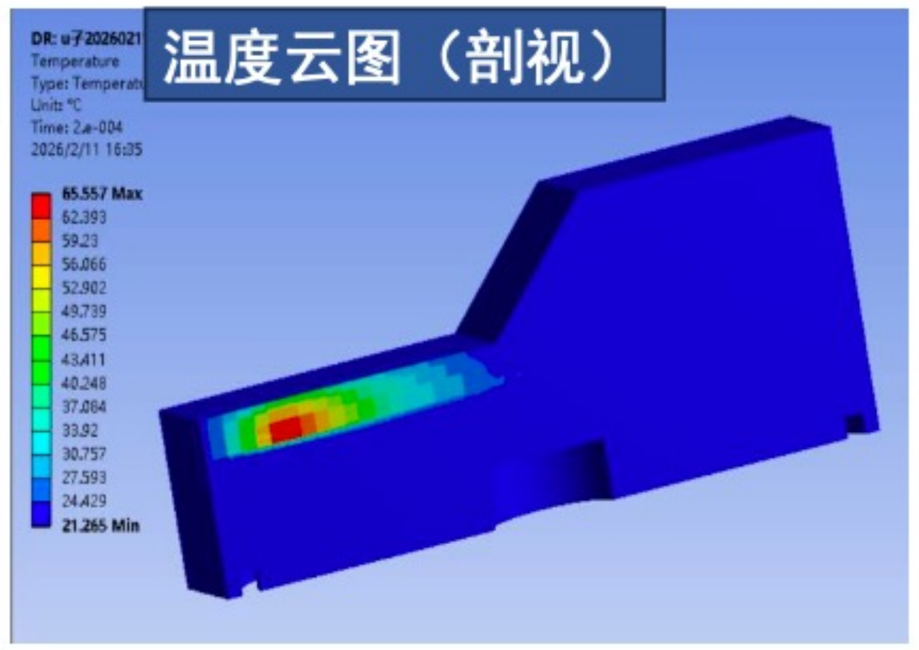
热力情况

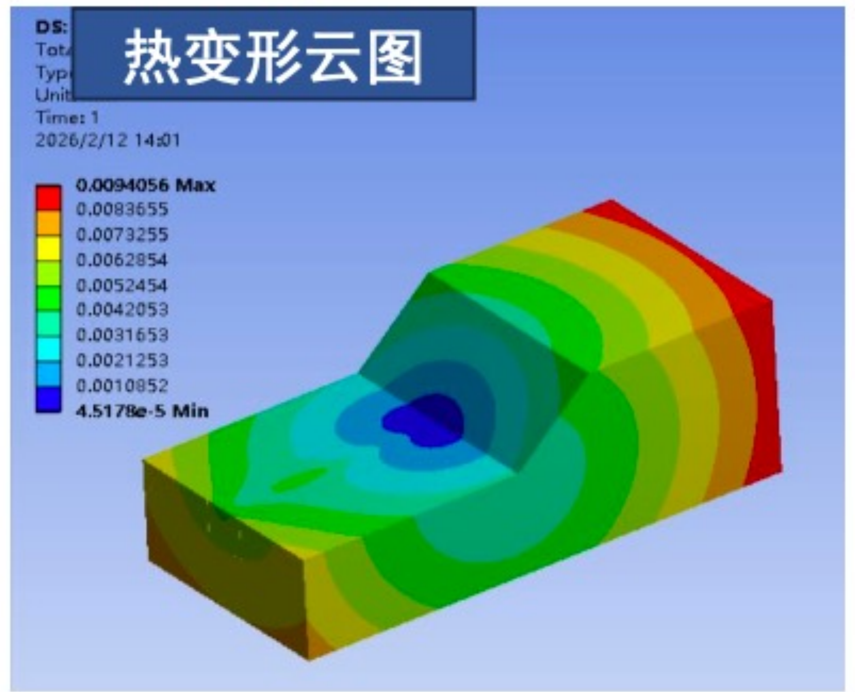
- 铜挡块上最高温度65.6℃
- 最大热应力 90.7MPa
- 最大变形9um





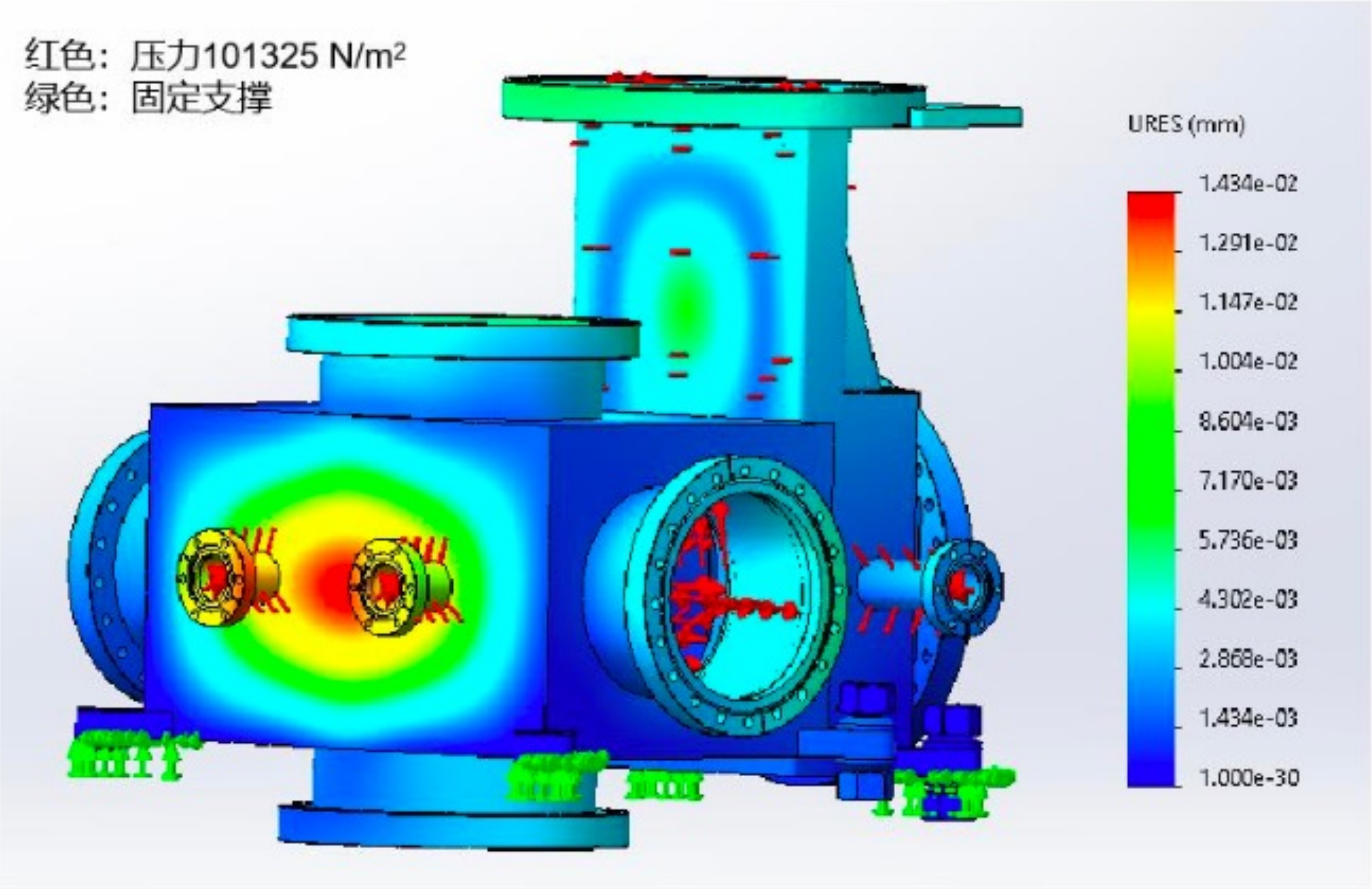




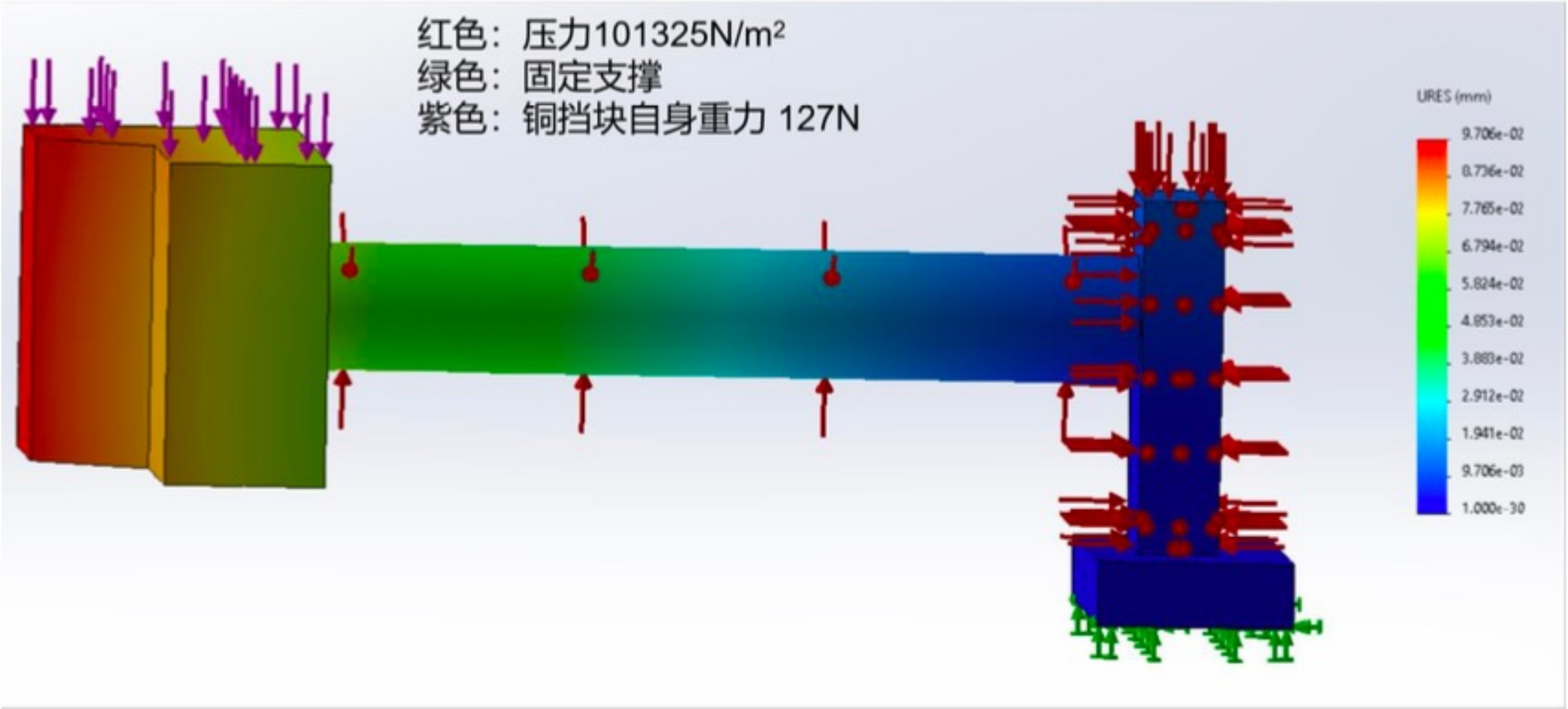


热力及真空仿真

真空压差及重力引起变形



抽真空后最大变形
0.01434mm



铜挡块变形最大为0.097mm

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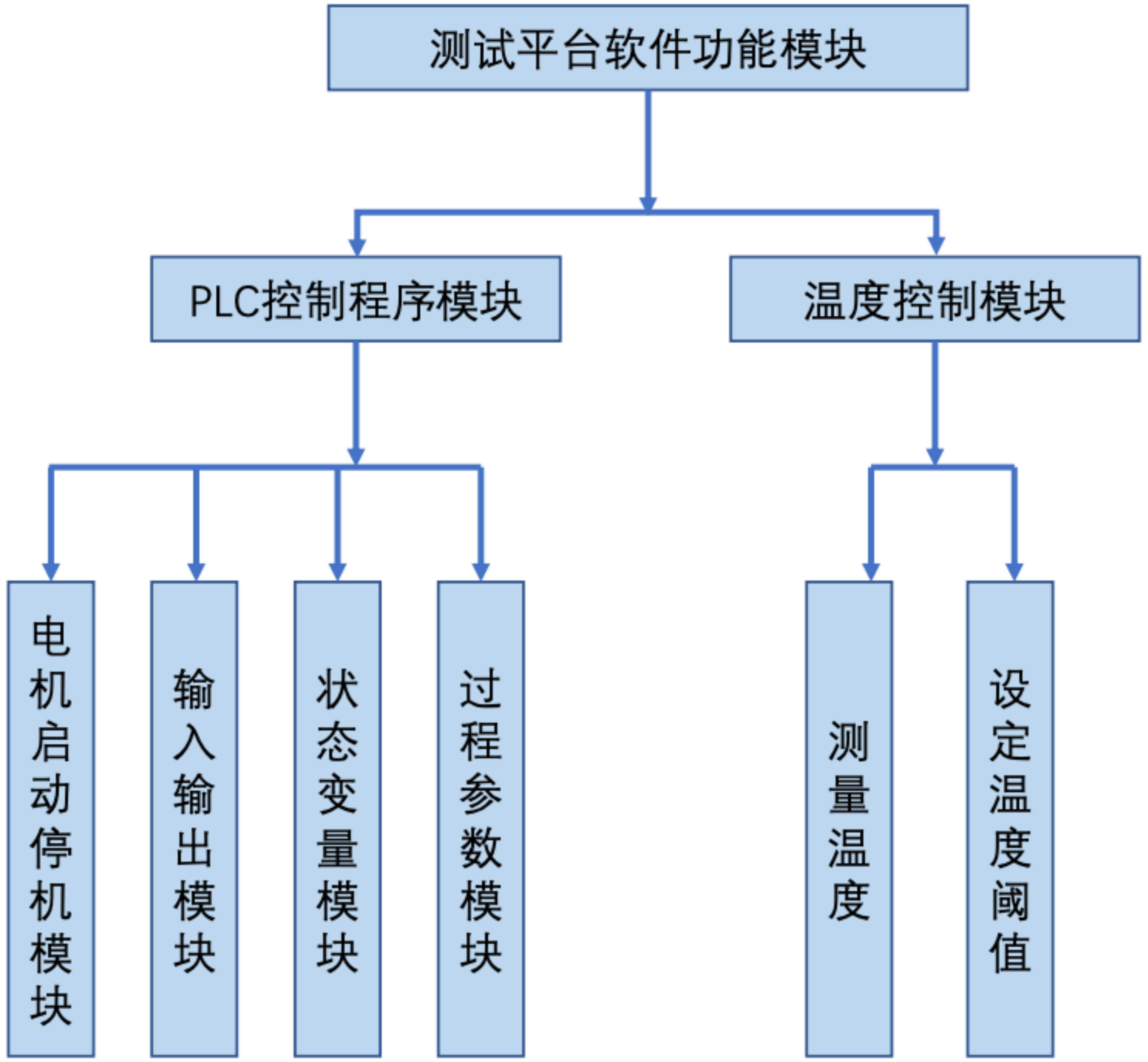
运动及控制设计

软件架构及程序编写



- **软件编写**
  - ◆ 电气原理图
    EPLAN软件
  - ◆ PLC程序和工控软件
    TIA V18
- **PLC程序**