Status of MELODY

Muon station for sciEnce technoLOgy and inDustrY

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CSNS

IHEP

2026.4.25

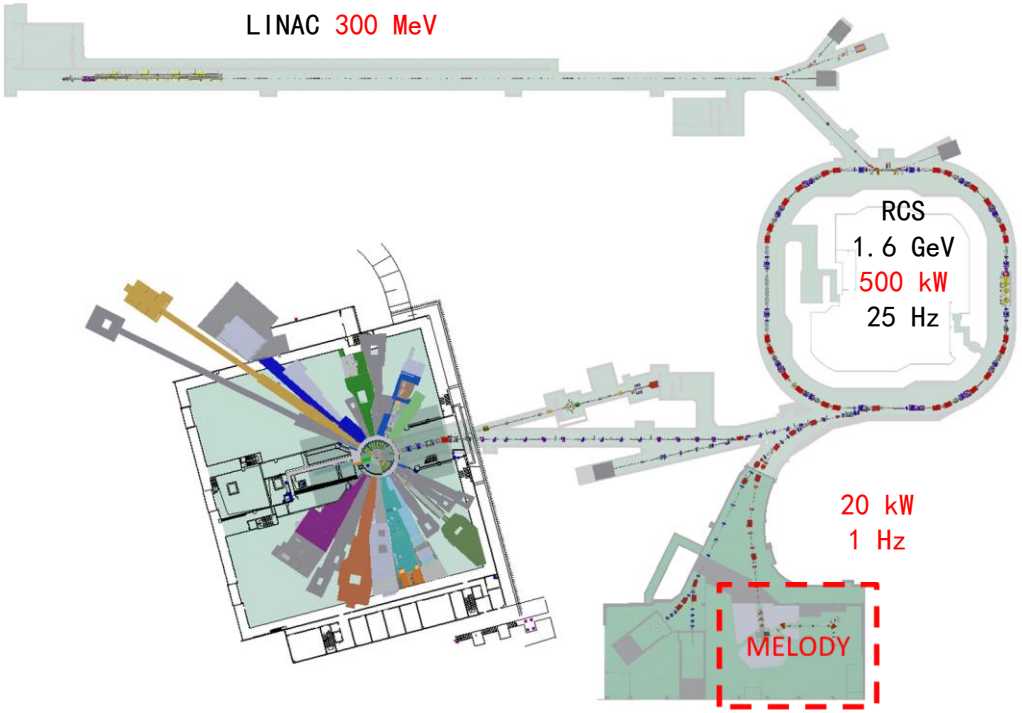
Outlines

- China Spallation Neutron Source
- Design of MELODY
- Application of MELODY
- Progress of MELODY
- Summary

China Spallation Neutron Source

CSNS II Project (Approved on Jan. 11, 2023)

CSNS II: Beam power upgrade to 500 kW, 9 more neutron spectrometers, one high-energy proton terminal, and a muon source: MELODY



Overview of MELODY

Target Station

- Stand-alone target: more freedom to design
- Shielding and cooling service areas

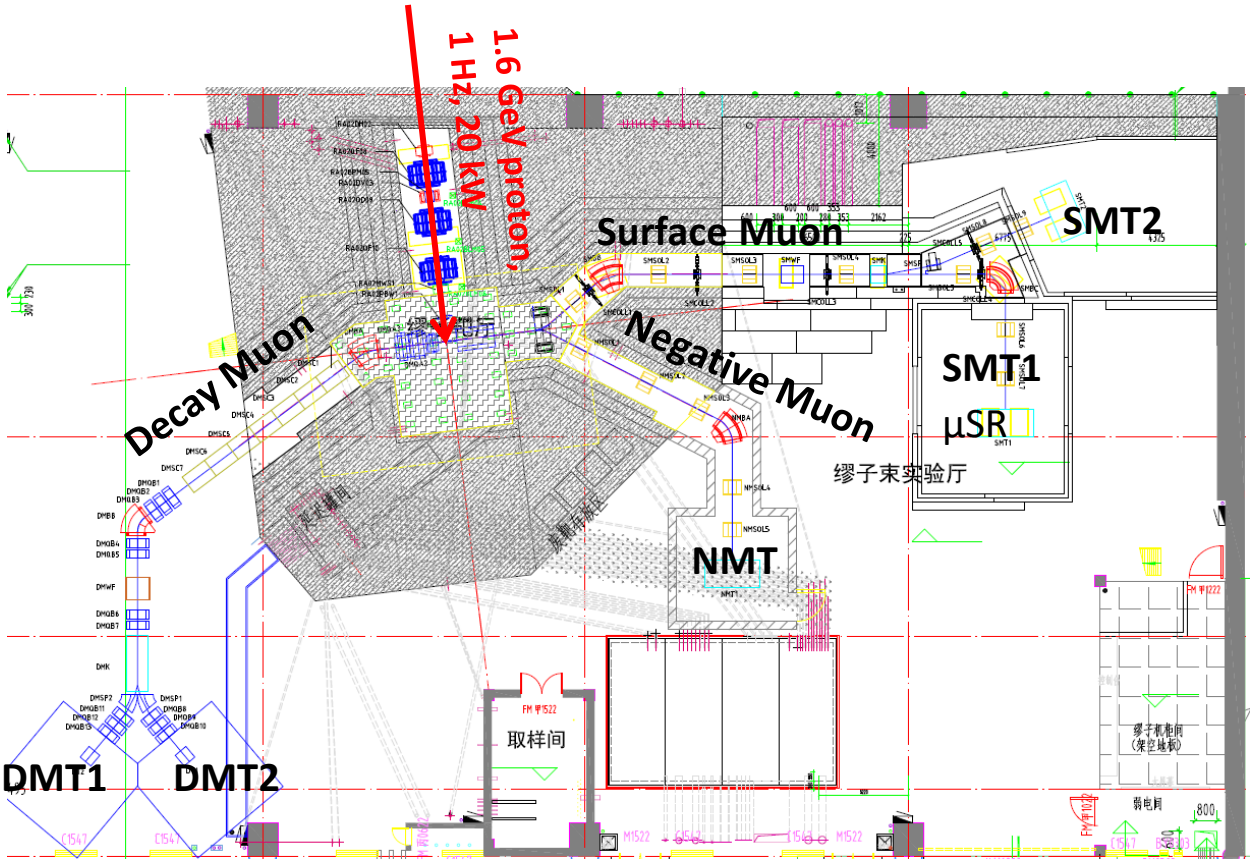
Muon Beamlines

- Surface Muon: Solenoid focusing; ML optimized; Large acceptance
- Negative Muon: by-product, low cost, dedicated μ^- beam
- Decay Muon: Large acceptance; wide applications

Terminals

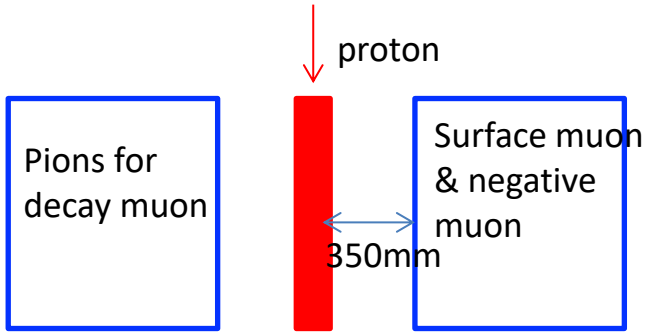
SMT1 for μSR spectrometer

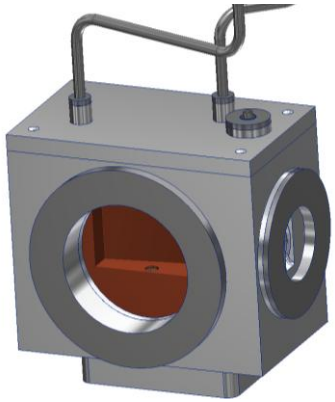
- High Asymmetry: 0.3
- Large number of detectors: 3024 units

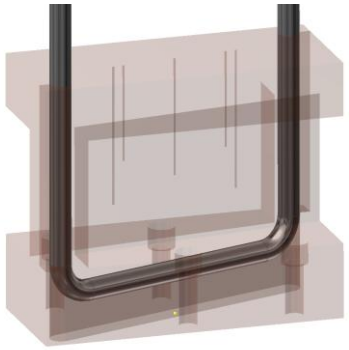


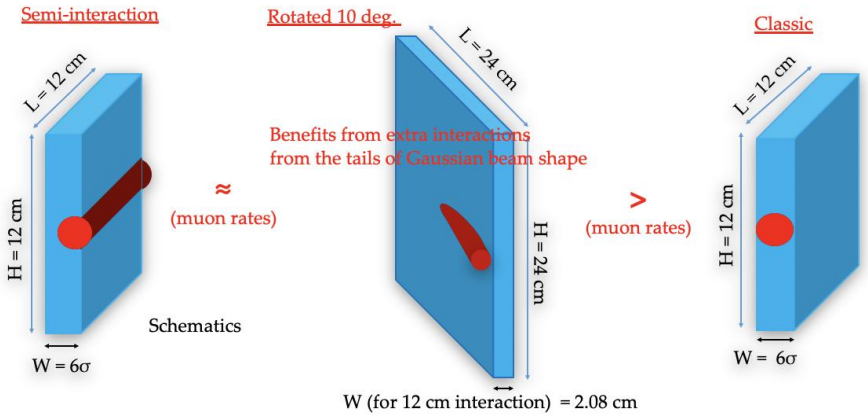
Muon Production Target

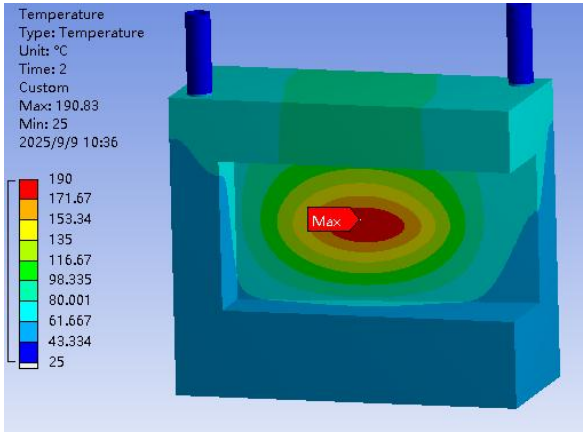
- Copper target: high production, better heat conductivity
- Optimize the target with multiple parameters
  - 24cm*24cm*10mm, tilted by 7degree
- Edge water cooling， < 200°









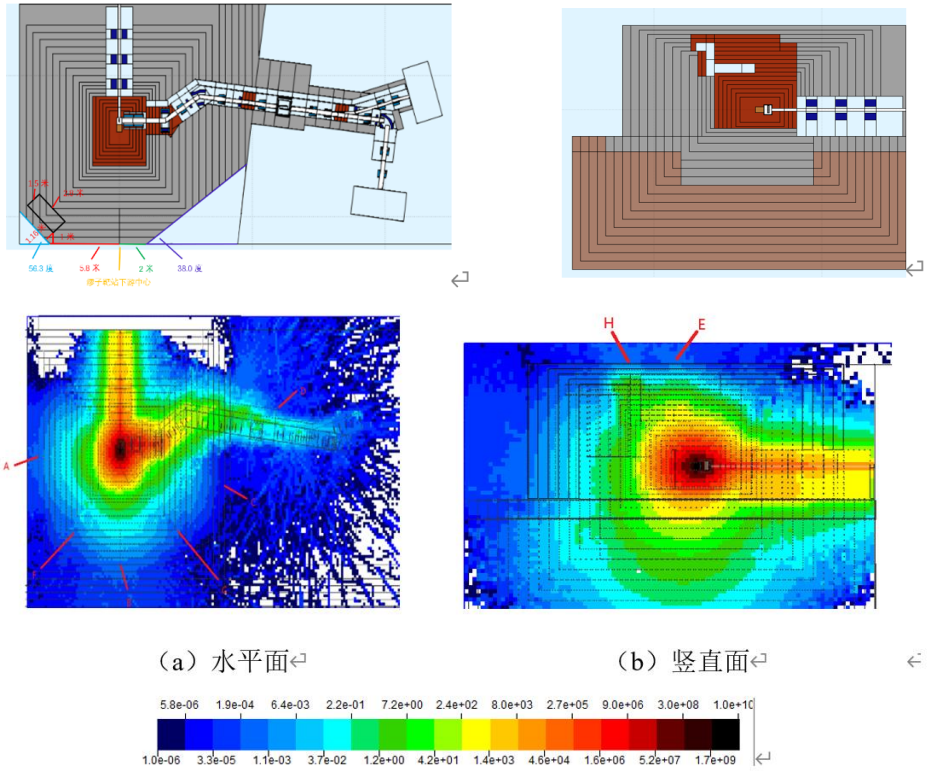


Radiation Shielding

Two layers:

1. Mild steel
2. Concrete

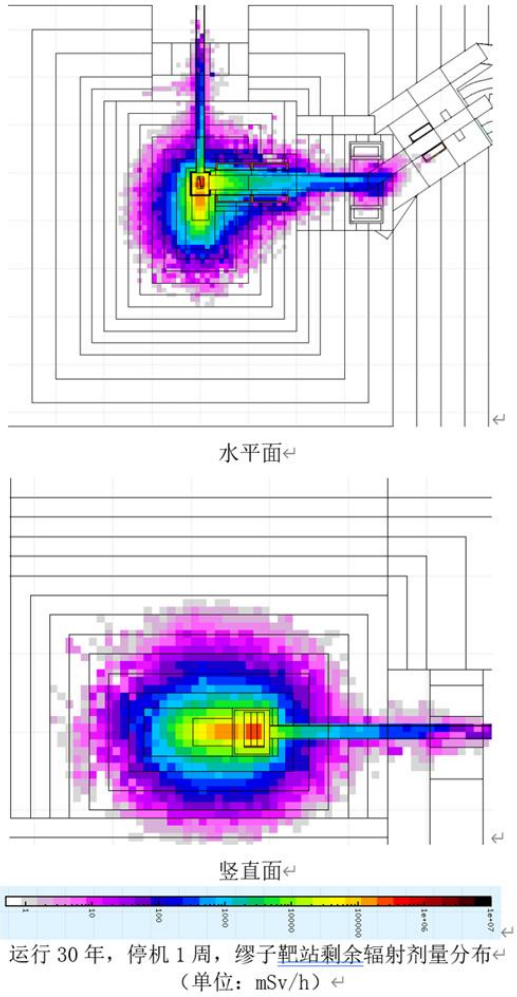
Prompt dose



（a）水平面　　（b）竖直面

图 4-8 现设计方案下缪子实验终端辐射剂量分布（mSv/h）

Residual dose after 30 y running
1 week after shutting down



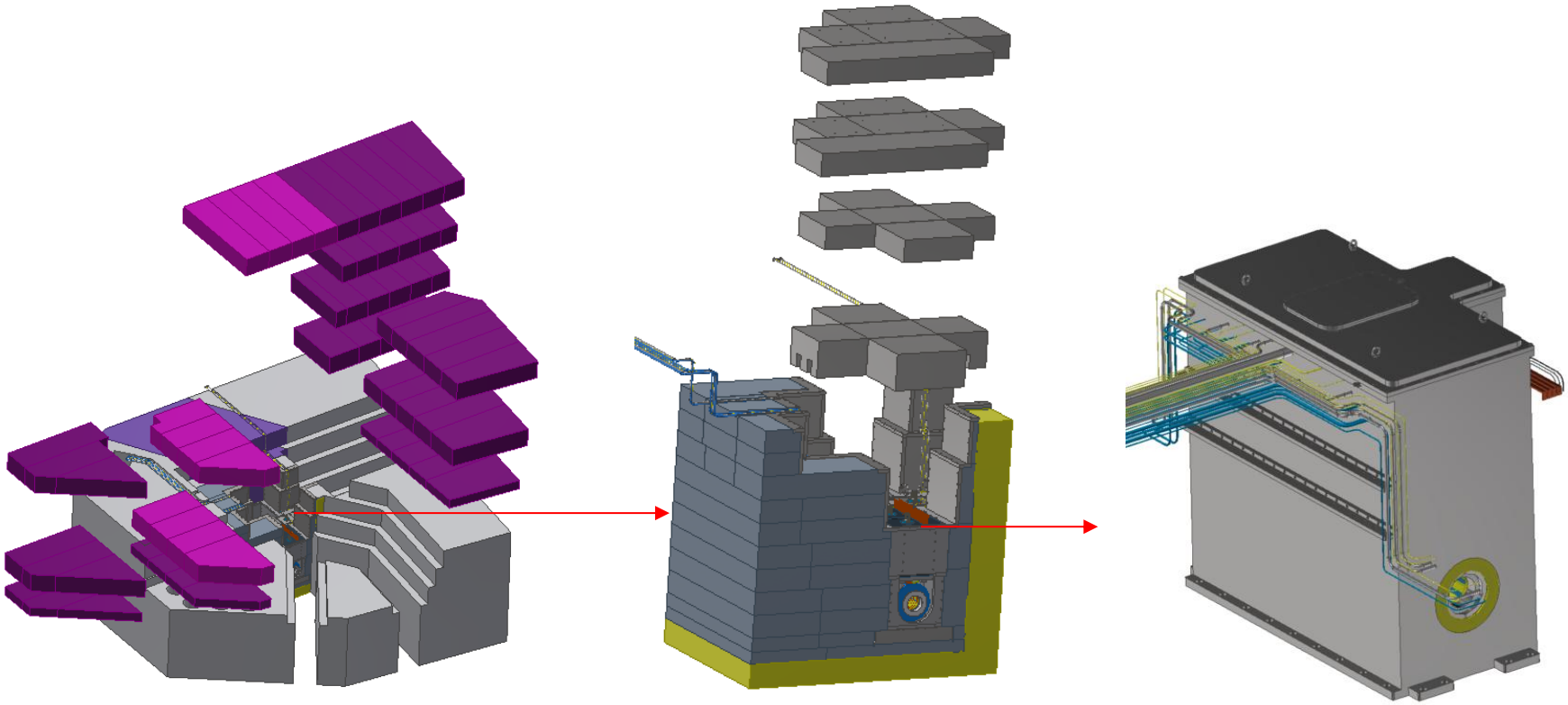
水平面

竖直面

运行 30 年，停机 1 周，缪子靶站剩余辐射剂量分布
（单位：mSv/h）

Maintenance and Air-tight Design

- Removable steel shielding for target access
- Sealed gas tank to confine activated air
- Service connections arranged in relatively low-dose region



Status of the Target Station

- Engineering Design reviewed in July 2025
- Foundation of the target station constructed
- Several key parts under manufacturing

高能所散裂中子源二期工程会议纪要

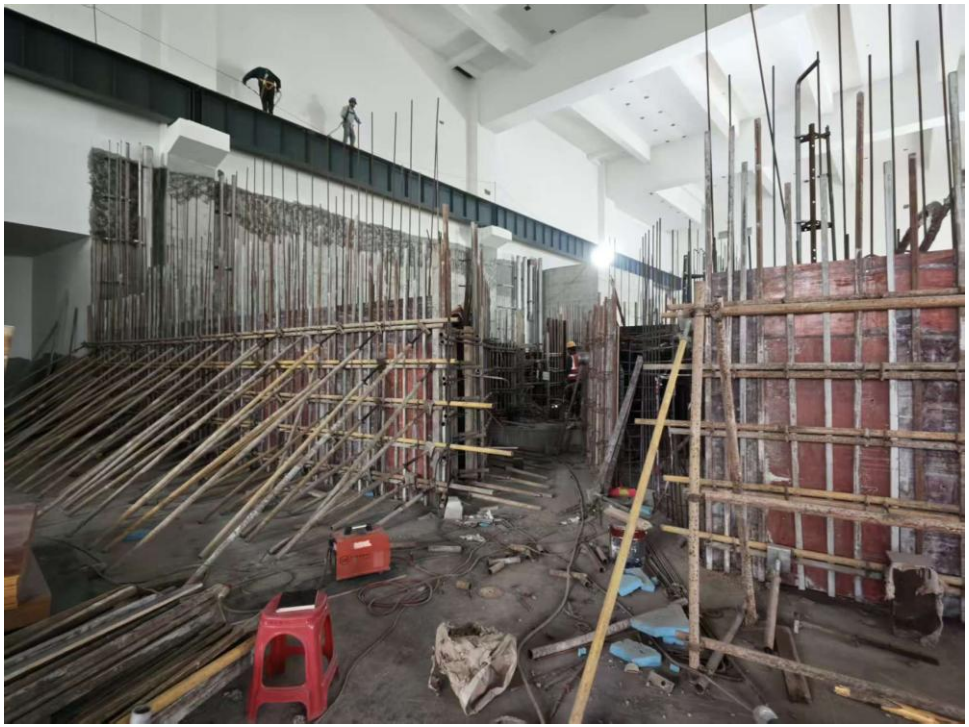
2025（散靶技字 58 号）

靶站分总体会议　　签发：齐欣

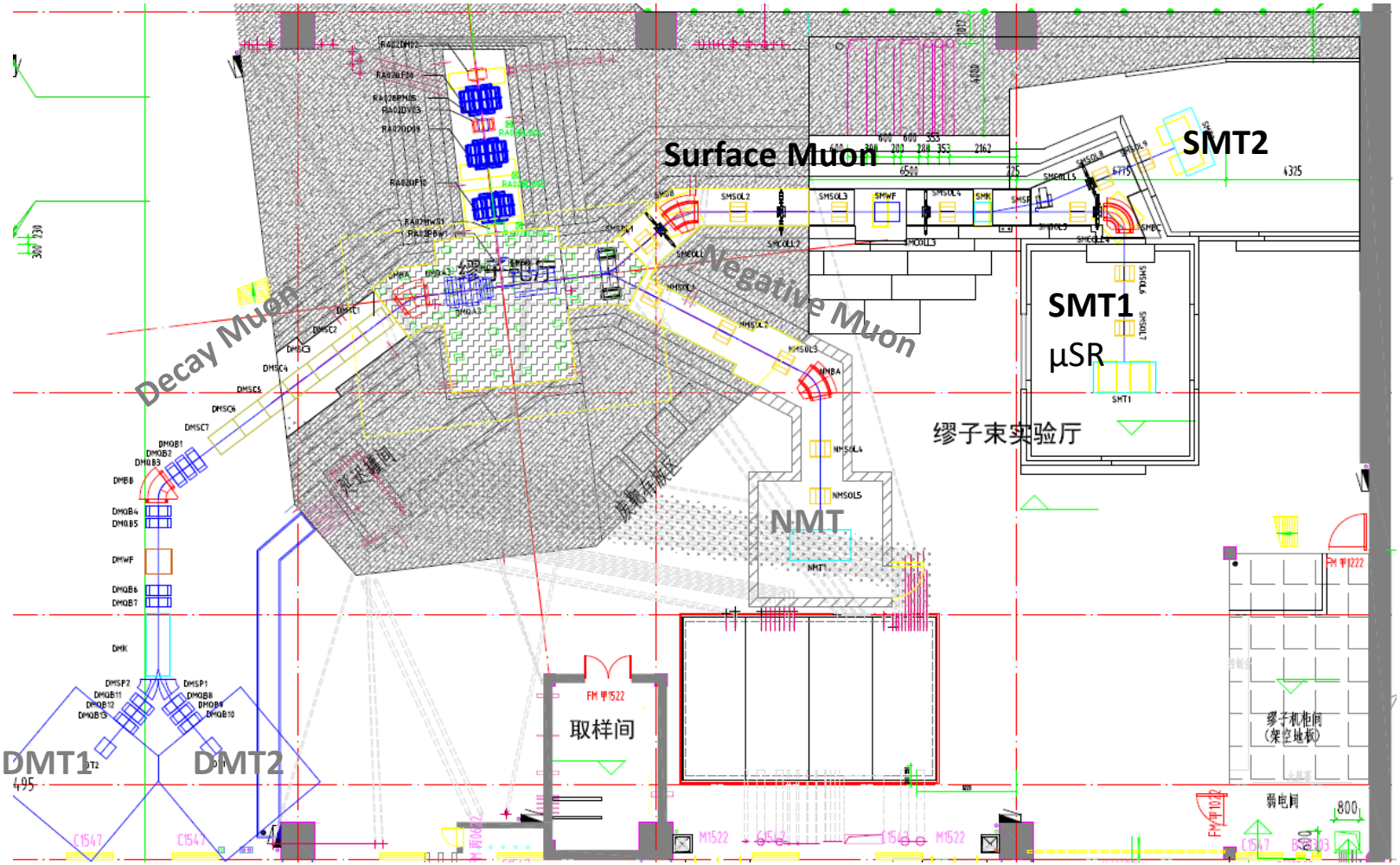
散裂中子源二期工程靶站分总体
缪子源靶站工程设计评审会
会议纪要

时间：2025 年 9 月 9 日下午 14:00-17:00

地点：A1-102

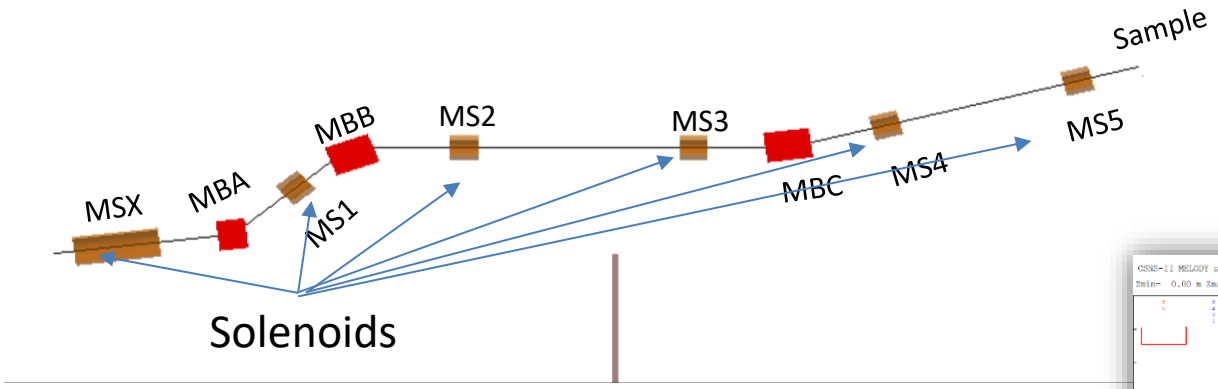


Surface Muon Beamline

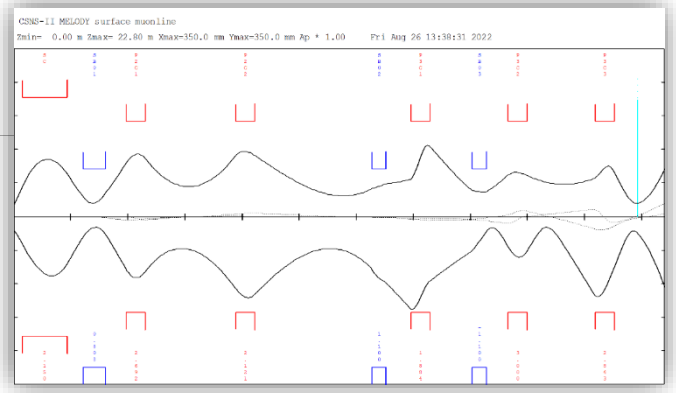


- Energy： 4 MeV
- Intensity： 10^5~10^7 μ^+/s
- Polarization: >95%
- Time Resolution: 120 ns

Design of the Surface Muon Beamline



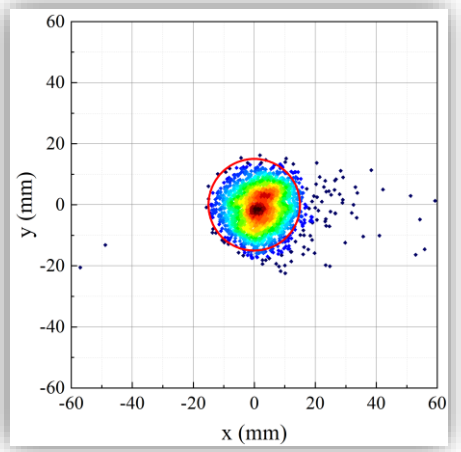
Designed by Transport



Use all solenoids for focusing

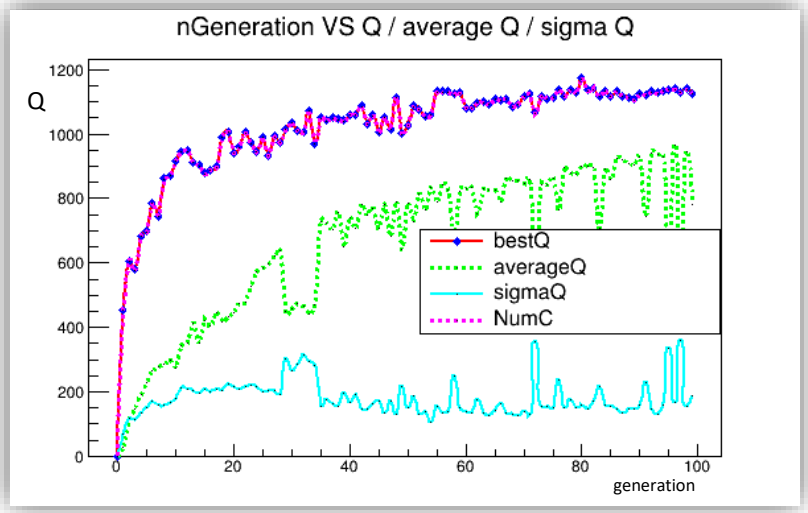
- Optics design：
  - Transport
- Simulation:
  - G4beamline with 10^{11} POT
- Fringe field shielding:
  - Reduce the fringe field at sample position

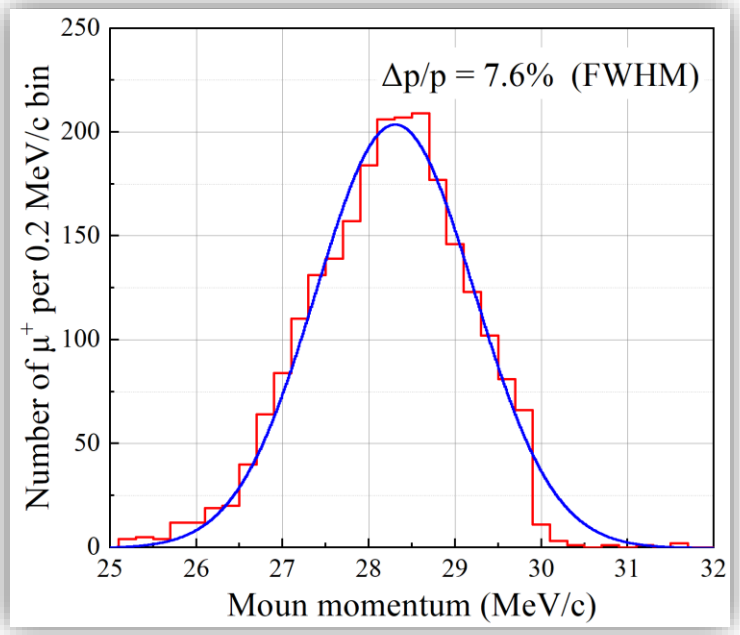
Simulated by G4beamline



Machine Learning Based Optimization

- Maximize the number of muons in the Φ=30mm sample area
- Set the strength and positions of the 6 solenoids as tune parameters
- Start from a set of random parameters

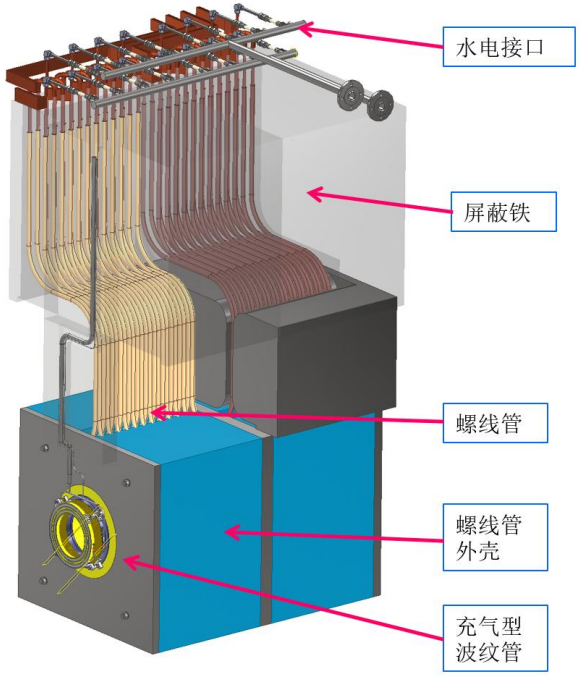




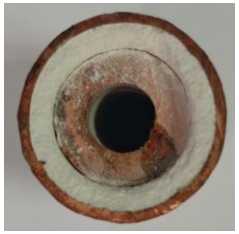
Parameters	G4bl simulation
x (FWHM)	1.64 cm
y (FWHM)	1.84 cm
Δp/p (FWHM)	~ 7.6%
μ+ rate	18.2×10^5 μ+/s
μ+ rate on ϕ30 mm	**15.7×10^5 μ+/s**
Core ratio	91.24%
Polarization	**~ 95%**
e^+/μ^+	<0.01

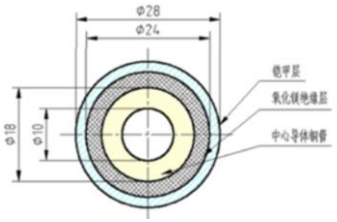
Key prototypes: SOLX with MIC

Designed model of SOLX

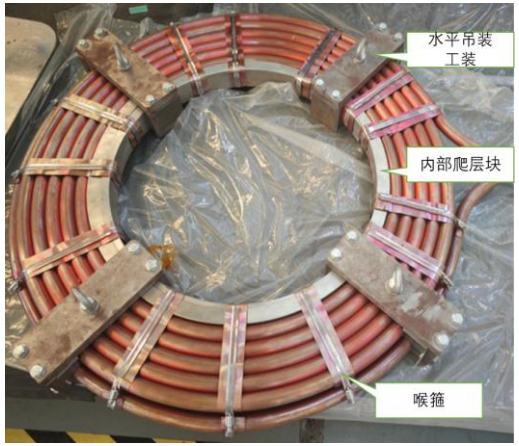


MIC cable：





Using steel to tighten



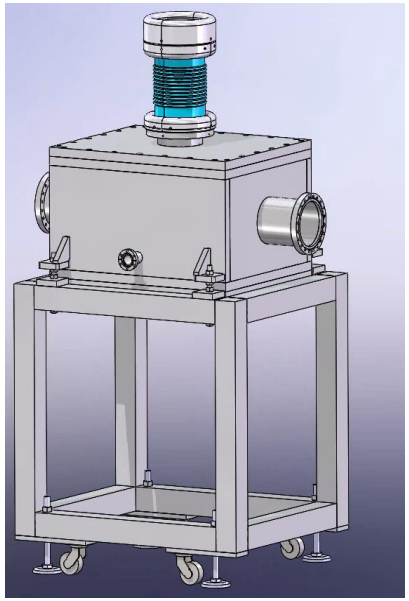
Tested the insulation: 1500V，1 min, no breakdown

Water leakage test: 6 kg, no leakage

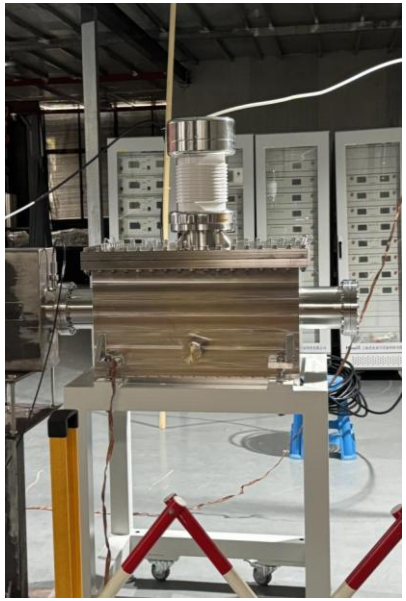
Key prototypes: Wien Filter

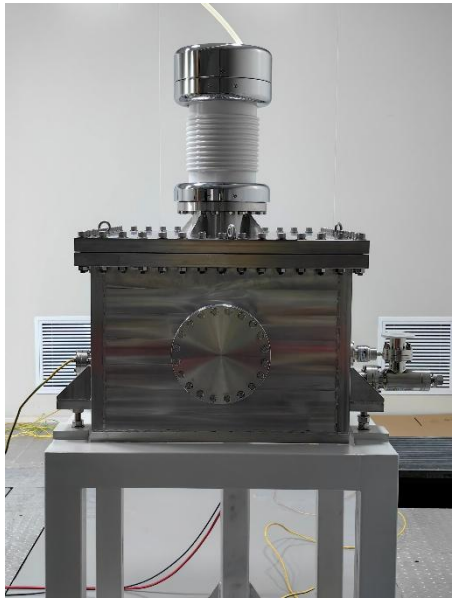
A Wien filter prototype have been developed and tested at CSNS campus.

- Vacuum : 1.7E-6Pa。
- It works 5 hours with a voltage of 120 kV.



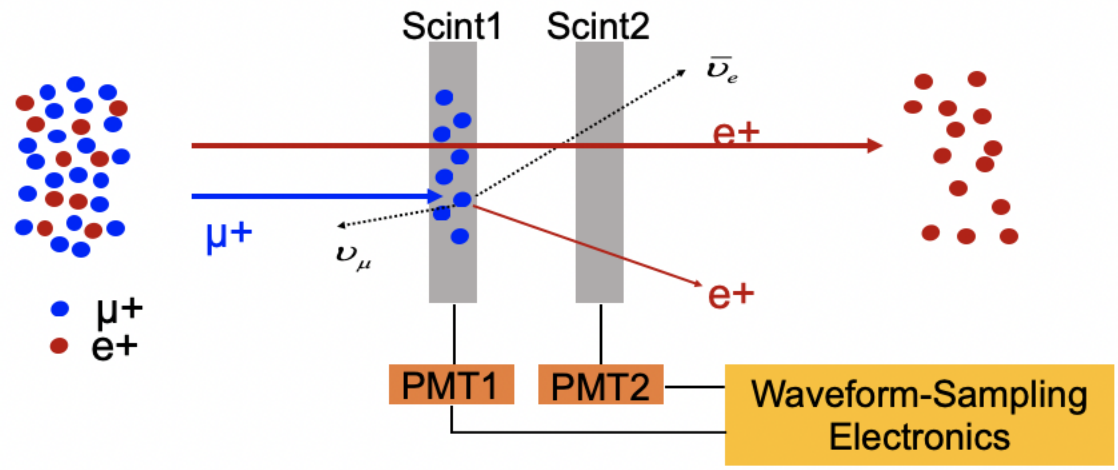
SMWF prototype model



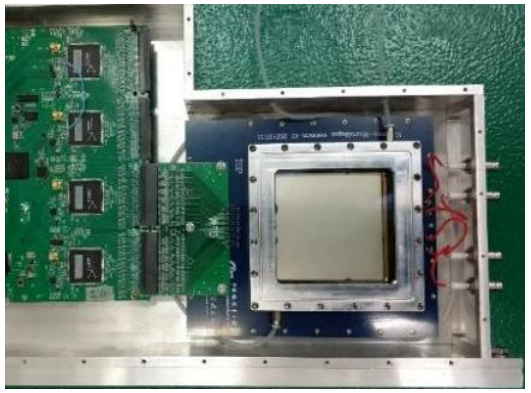


Prototype picture

Beam Measurement

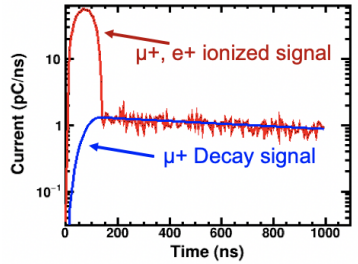


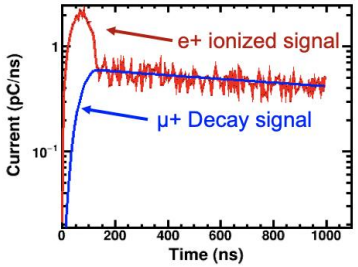
Beam intensity measurement



Beam spot monitor

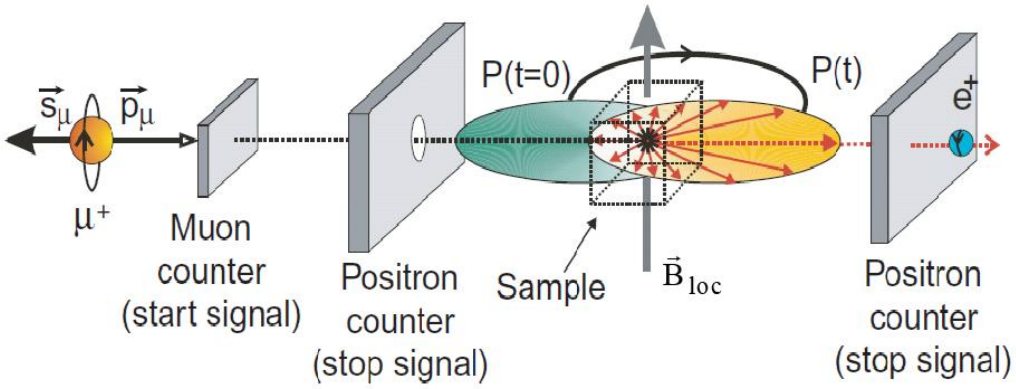
- Measure muon beam intensity by double scintillators
  - ➢ Distinguish positron content
- Measure beam spot size with a MicroMegas detector
- **Tested with ISIS muon beam**

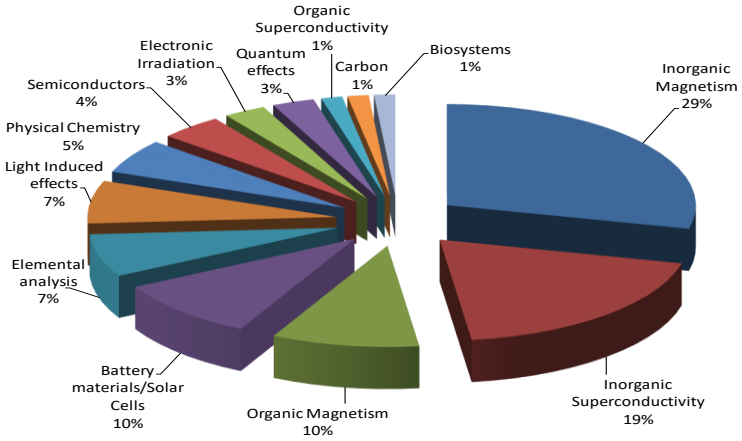




Surface Muon Application: μSR

Principle of μSR

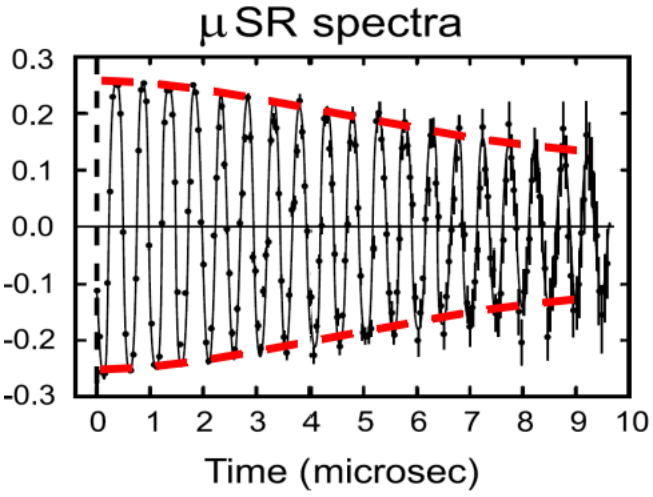




μSR: Magnetic material, superconductivity, battery, semiconductor

Advantage: high magnetic sensitivity, short range magnetic order, all element

$A_0P(t)$ ~ Muon Spin Polarization



$A_0P(t)$ contains the physics:

frequency: $\omega_L = \gamma_\mu B_{loc}$, value of field at muon site

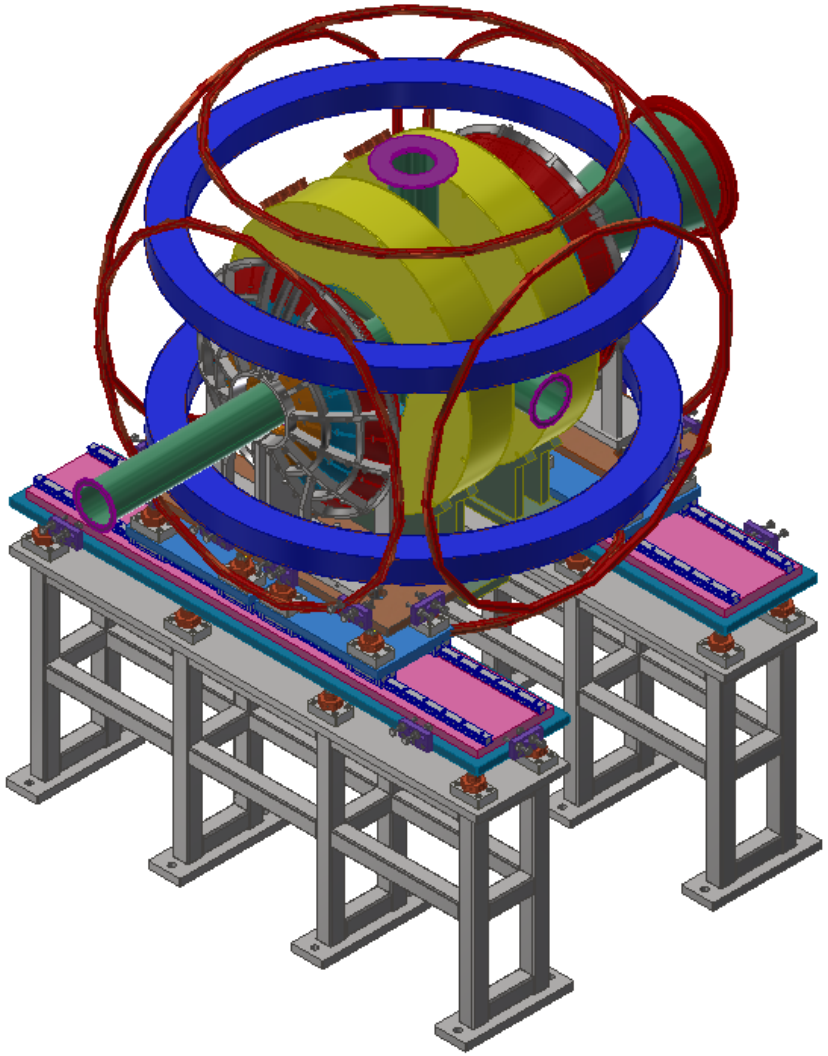
damping: width of field distribution, fluctuations

amplitude: magnetic/non-magnetic volume fraction, or Mu fraction

$A_0P(t) = [F(t) - B(t)] / [F(t) + B(t)]$

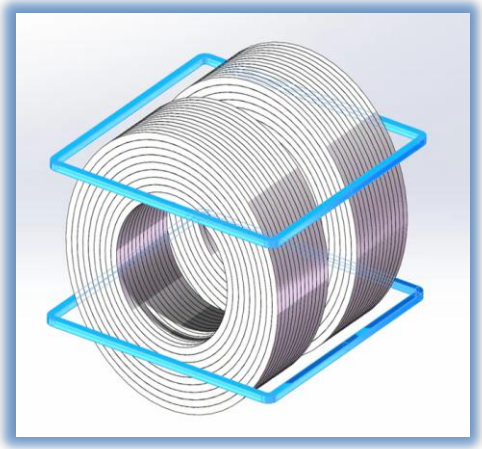
μSR Spectrometer

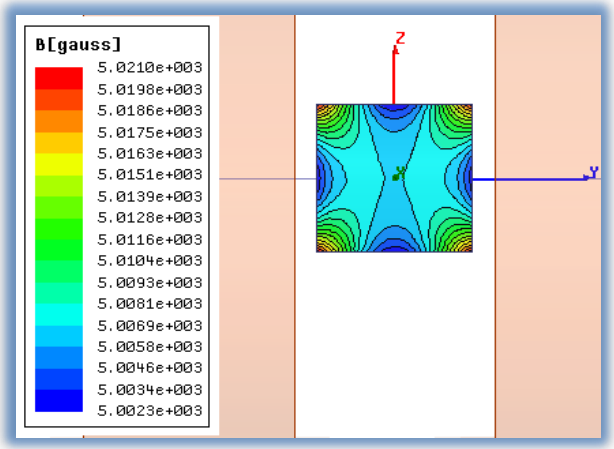
- **Feature:** High single-pulse intensity
- **Detector unit**: ~ 3000 scintillator-SiPM units pointing to the sample
- **Electronics**: ASIC based font-end electronics + multi-stop TDC
- **Fly-pass structure**

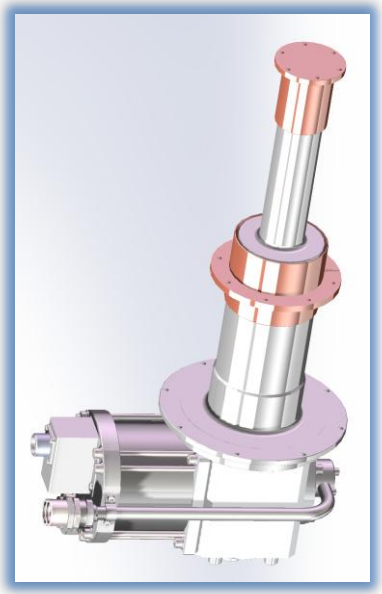


Sample Environment

- Magnetic field：
  - LF: up to 5000 G， TF: up to 400 G
  - Field Homogeneity: < 100ppm over 40*40*10 mm sample volume
- Temperature range：
  - 2 K ~ 300K Cryostat at Start-up
  - Future options: 10 K ~ 600K CCR and 300 mK low temperature insert







Pros and Cons

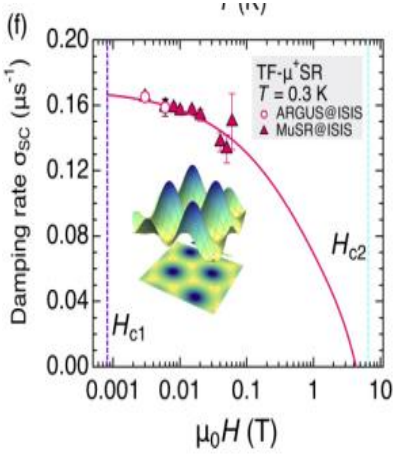
High single pulse intensity:

- Sensitive to Weak relaxing signal detection
- Enables small beam spot measurements
- Enables beam slicing to 10 ns for better time resolution

High asymmetry:

- Supports high-precision μSR measurements

Organic SC



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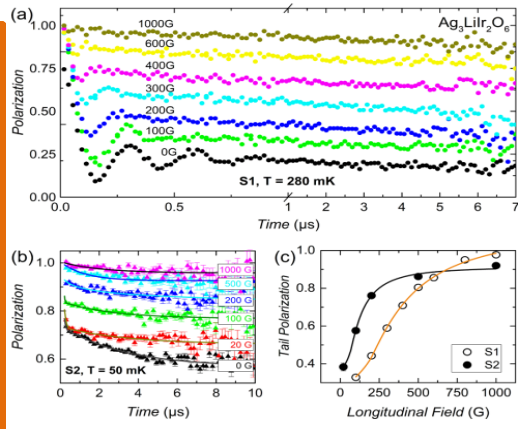
Spin Liquid



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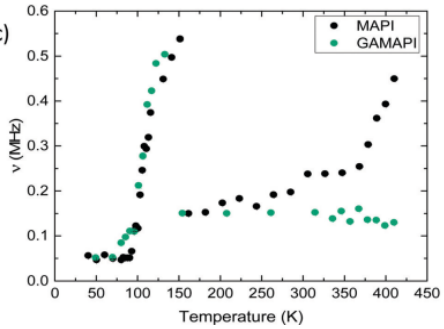
Batteries



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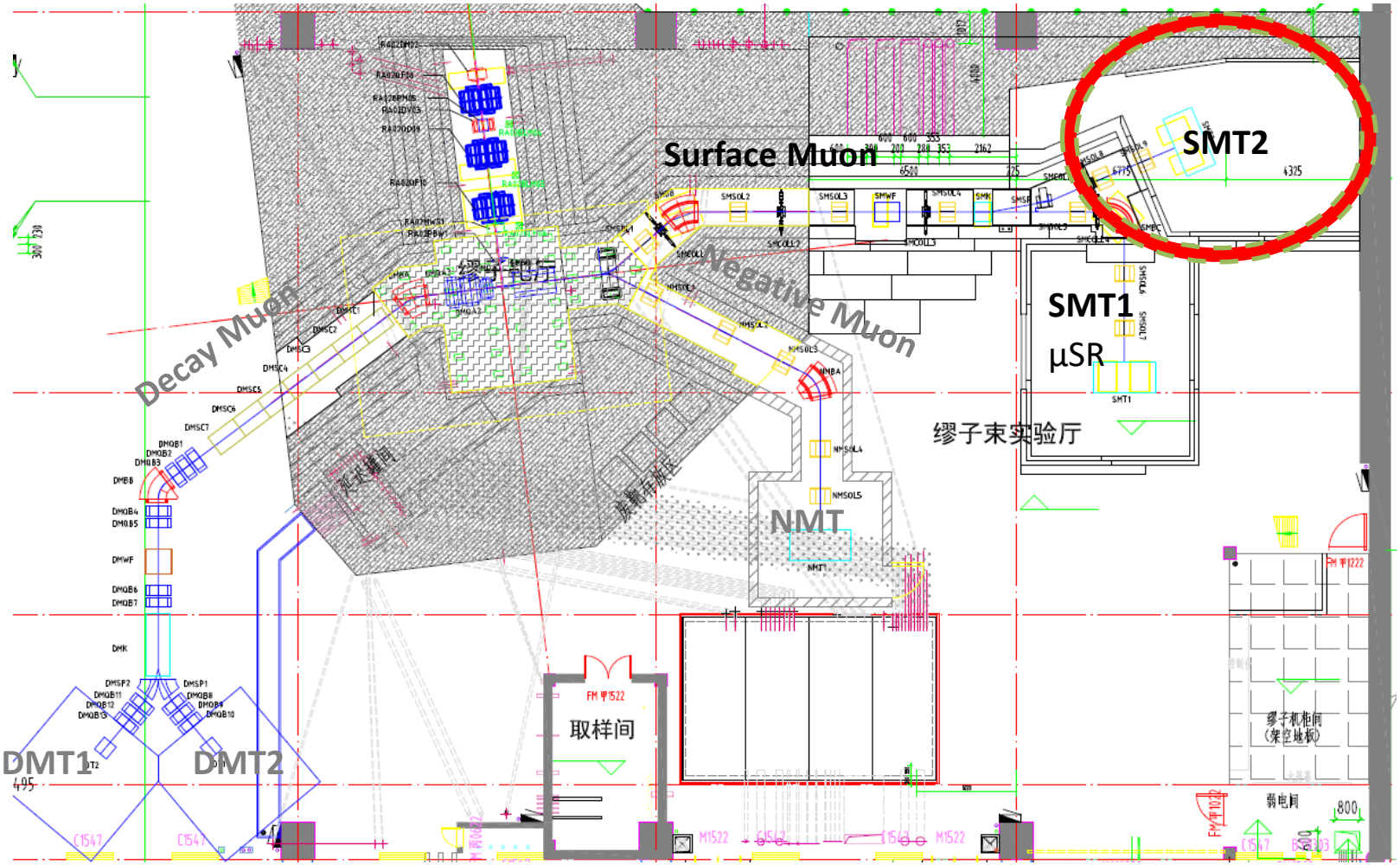
Low repetition rate:

- More detector units

Large pulse width:

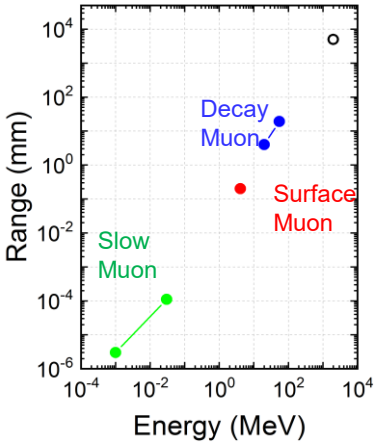
- Beam slicing

Surface Muon Test Beam Port

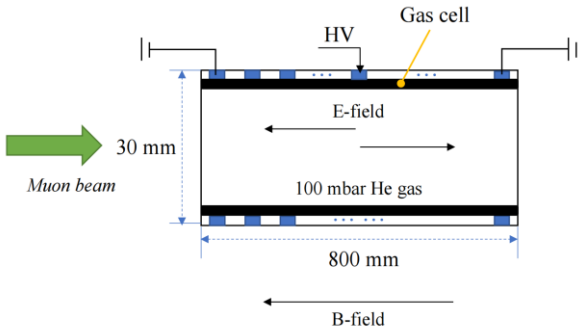


- Energy： 4 MeV
- Intensity： 10^5~10^7 μ^+/s
- Polarization: >95%
- Time Resolution: 120 ns

Muon Moderation R&D



Slow muon, 1–30 keV tunable
Depth: 1–300 nm
Depth sensitive μSR:
magnetic
spin microprobe for thin films,
multilayers,
nanomaterials …

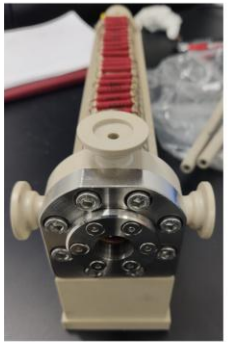


- Use helium gas to stop muons
- Use electric field to steer muon out of the gas cell
- Simulated efficiency: ~0.1% to ~300 eV

Demonstrated with proton at CSNS

FCD Experiment

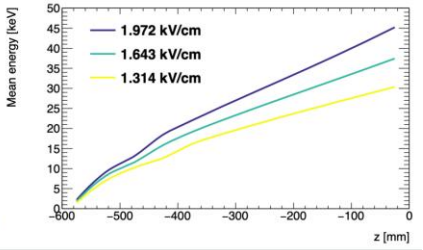
Gas cell



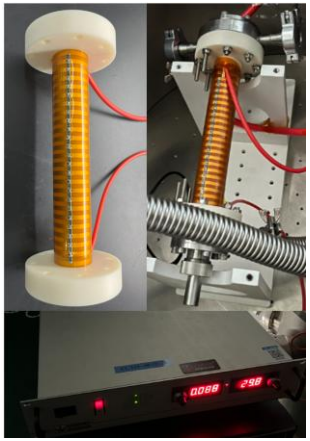
Proton source:
Am–241 + Mylar foil

Frictional cooling demonstration experiment with proton

G4bl simulation
He gas: 1 mbar, 293 K
Proton initial energy: 1 eV
Proton initial z ~ –600 mm



Planning to test at ISIS



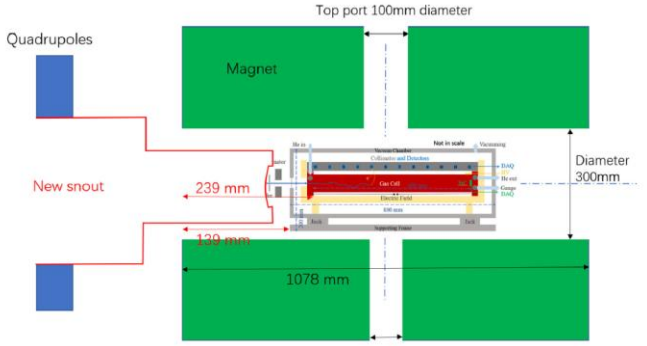
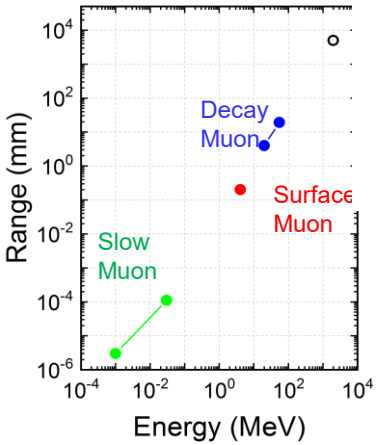
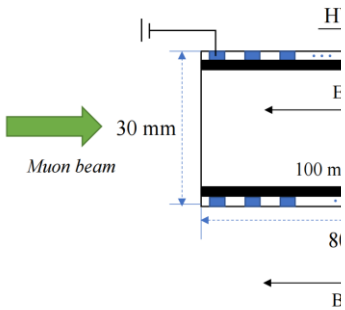


Figure 2: Planned modifications to the HiFi beamline, with the experimental setup shown in the magnet (not to scale).

Muon Moderation R&D





- Use helium gas to
- Use electric field t
  out of the gas cell
- Simulated efficien
  ~300 eV

MOU FOR ISIS – CSNS MUON COLLABORATION

SIGNED for and on behalf of Science and Technology Facilities Council as part of United Kingdom Research and Innovation by:

Philip King Digitally signed by Philip King DN: cn=Philip King, c=GB, o=STFC / UKRI, ou=ISIS Neutron & Muon Source, email=philip.king@stfc.ac.uk Date: 2023.07.11 21:05:43 +01'00'

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Philip King
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11 July 2023

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Date

SIGNED for and on behalf of the China Spallation Neutron Source by:

Sheng Wang

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Professor Sheng Wang
Director, China Spallation Neutron Source

18 July 2023

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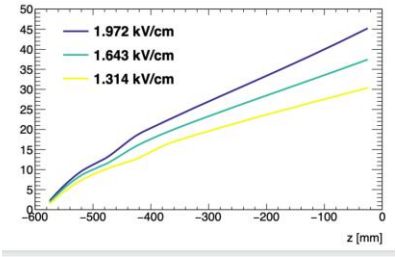
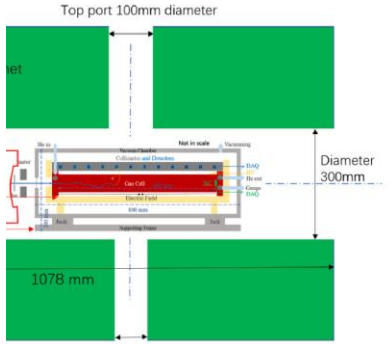
Date

onstration experiment with proton

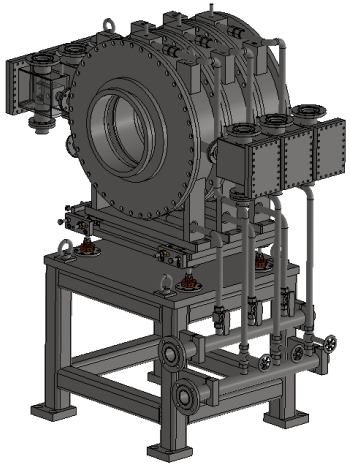




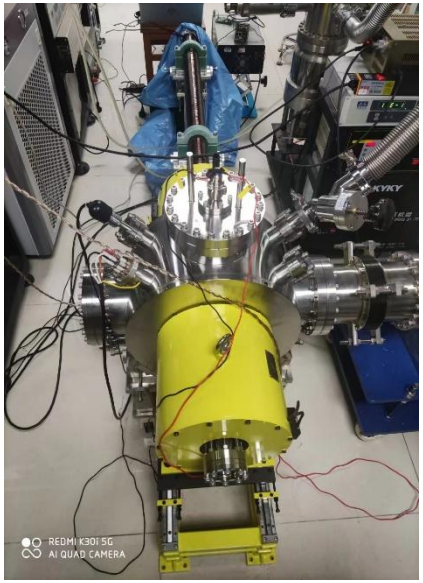
HiFi beamline, with the experimental setup shown in the

Future Muon Technologies

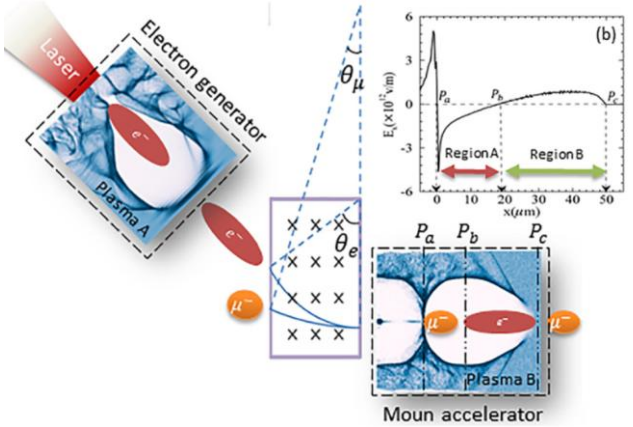
Develop technologies for future muon experiments



Induction cavity for phase rotation

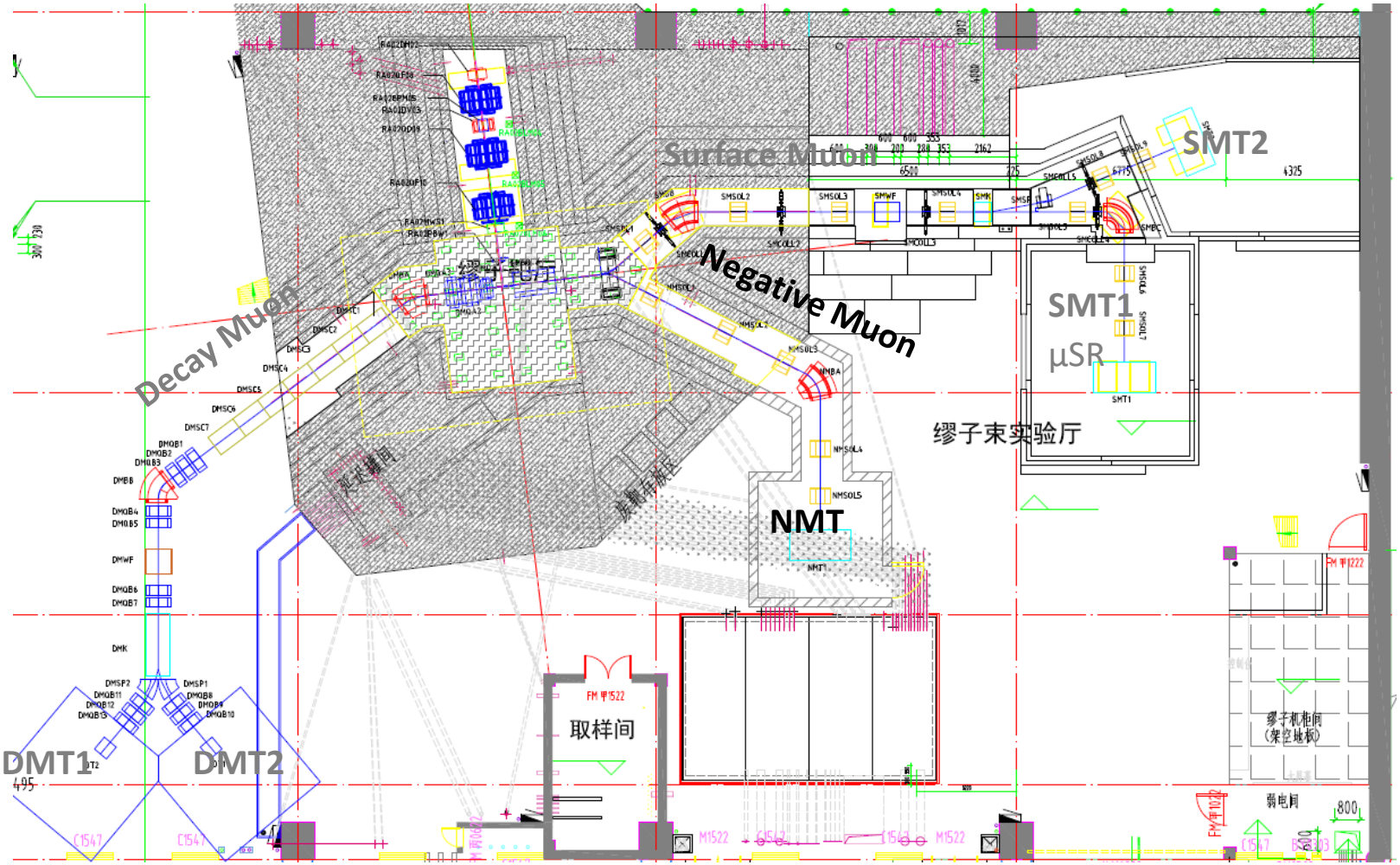


Magnetic mirror for muonium physics



Muon acceleration by plasma wakefield (PKU)

Near Future: Negative Muon Beam



NMBT: Dedicated μ^- beam

- 5 focusing solenoids
- 1 dipole magnet
- 1 Wien filter

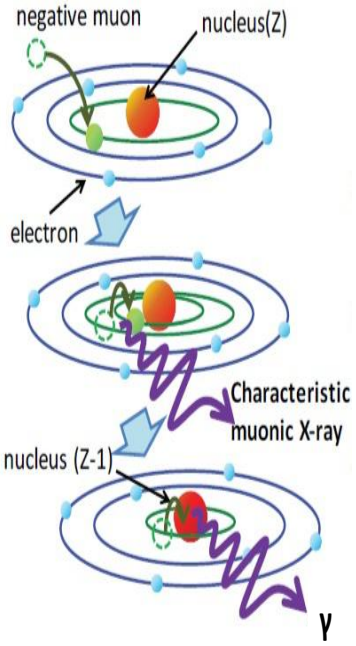
- Momentum： 20~60 MeV/c
- Beam size： Φ20~Φ100 mm
- Beam intensity： 4.4×10^5 Hz (Φ100 ratio>90%)

Negative Muon Applications - MIXE

μ^- capture in the atom（Muonic atom）

μ^- induce the X-ray to the ground state

μ^- decays or captured by the nuclei, and emits an gamma ray



- Non-destructive elemental analysis:
  - Sensitive for almost all elements (including C, N, O)
  - No activation for samples
  - Archeology:
    - Palace Museum
    - National Museum
    - Xi'an Heritage Conservation

Proposals accepted by PSI beam time

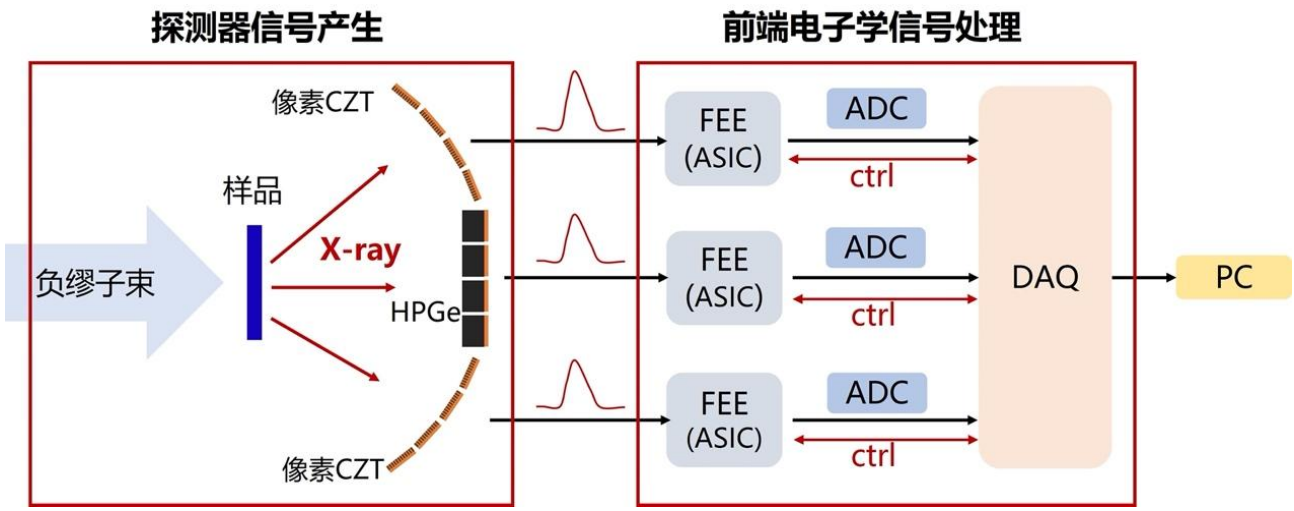
- Palace Museum

Proposal	20251251
Instrument	GIANT/MIXE
Title	Elemental Analysis of Northern Song Dynasty Iron Coins using MIXE
Status	**Accepted**

- Xi'an Heritage Conservation

Proposal	20251248
Instrument	GIANT/MIXE
Title	Quantitative Analysis of Elements in Chinese Blue-and-White Porcelain by MIXE
Status	**Accepted**

MIXE Spectrometer Construction

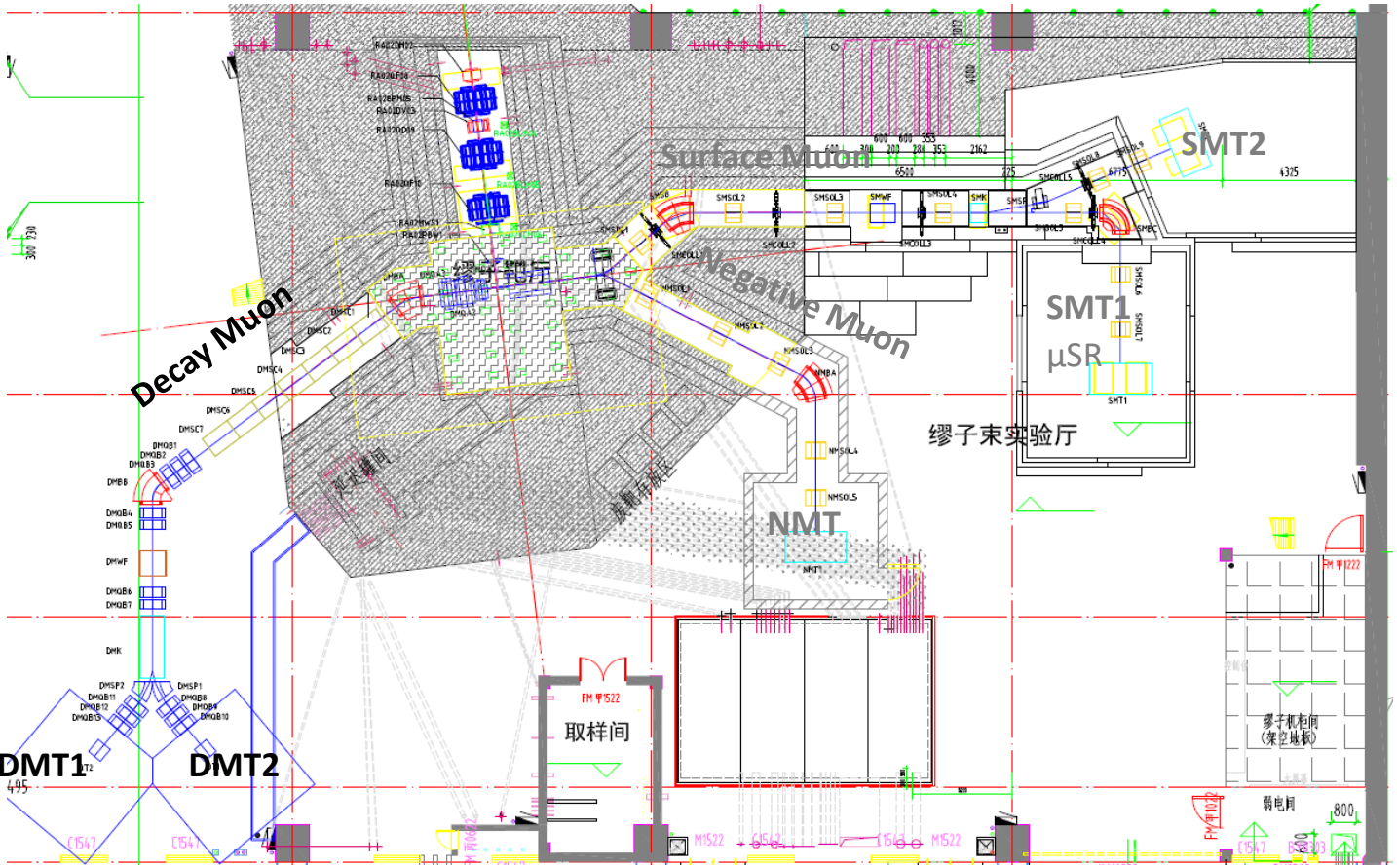


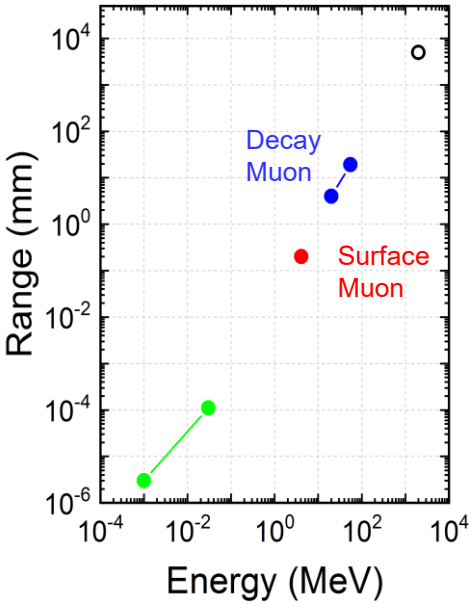
MIXE Spectrometer construction:

- **CZT detector array for counting rate**
- **HPGe for high resolution**

Recently Funded by Chinese Academy of Sciences !

Future: Decay Muon Beamline

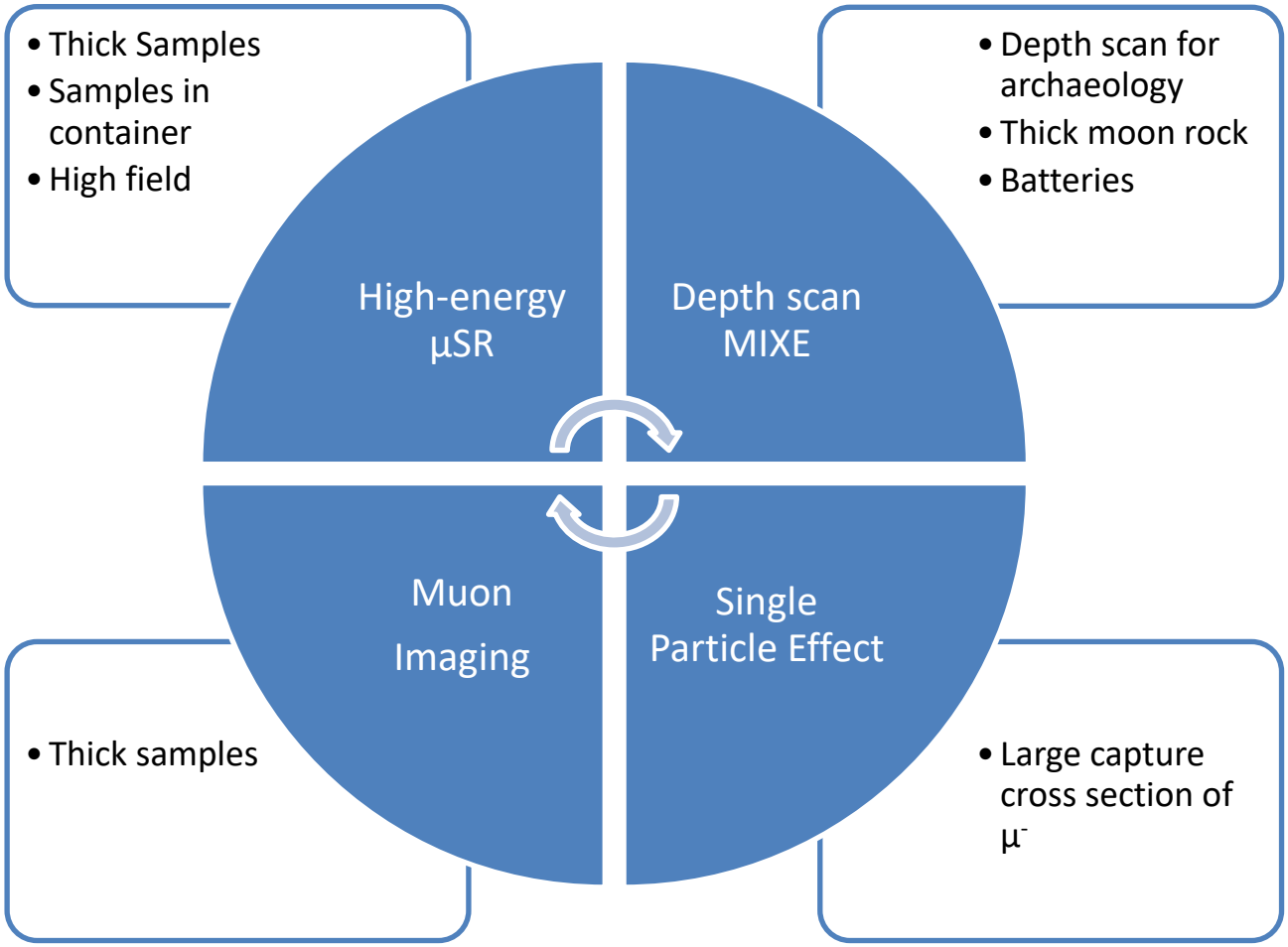




- Momentum: 20 ~ 120 MeV/c
- Charge: + or -
- Intensity: 10^5~10^7 muon/s
- Penetration in Cu: 1 ~ 50 mm
- Polarization: 50% ~ 99%

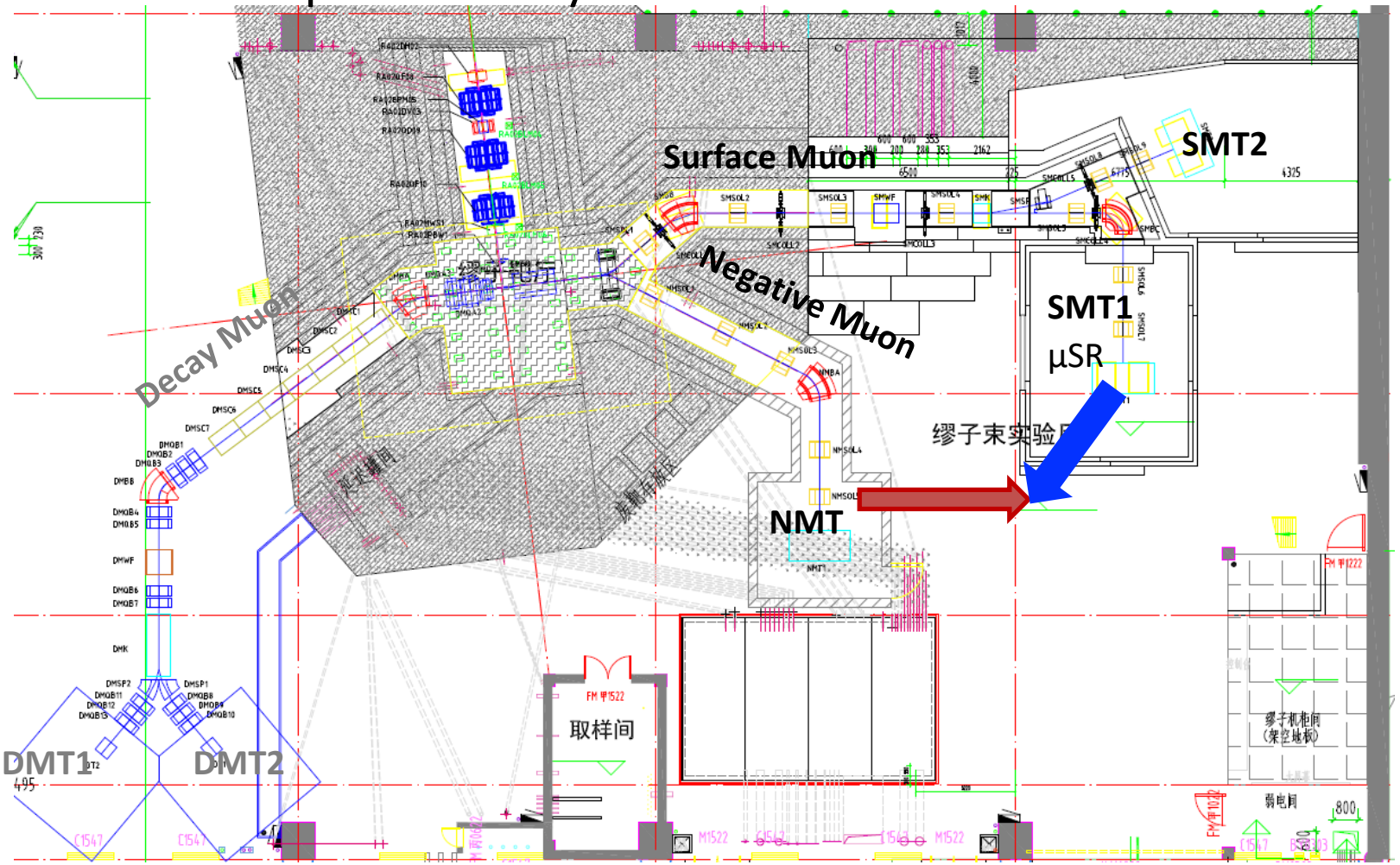
Decay Muon Applications

Extending MELODY from surface studies to bulk-sensitive applications



Future: True Muonium Production ?

True muonium $\mu^+\mu^-$ bound state has not yet been observed experimentally!

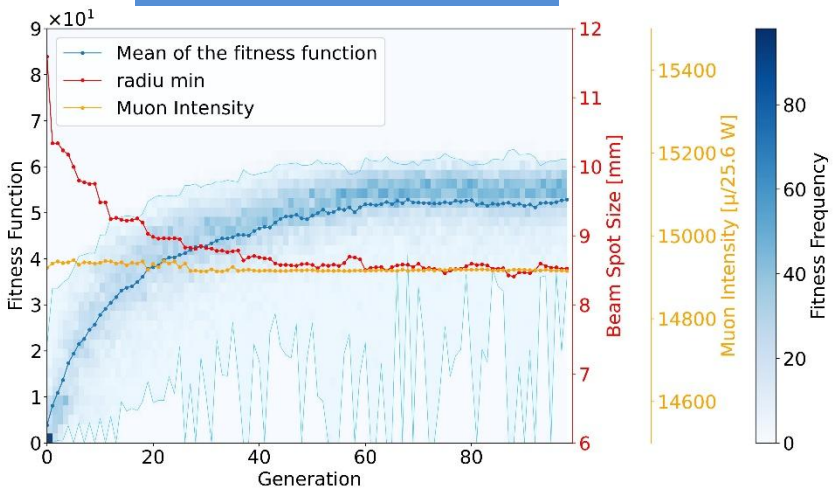


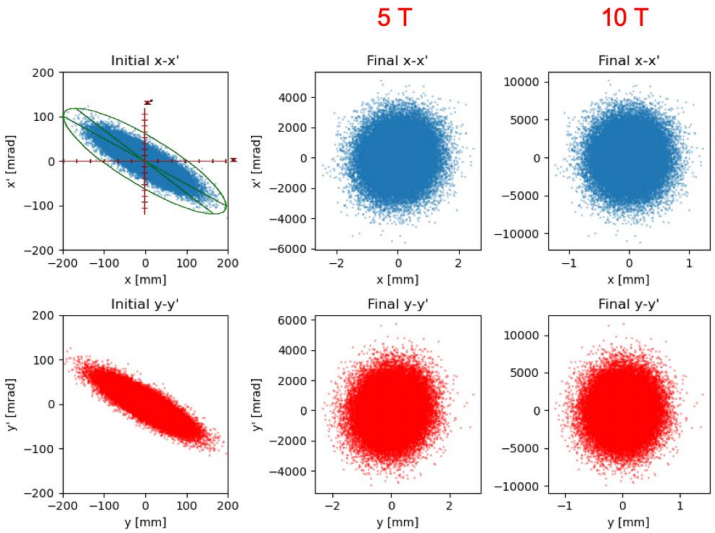
Possible route: overlap high-intensity μ^+ and μ^- beams

First Step: Beam compression

- Increase the luminosity
- First test: compressed to r<1mm with 10% efficiency under 10 T

ML optimization



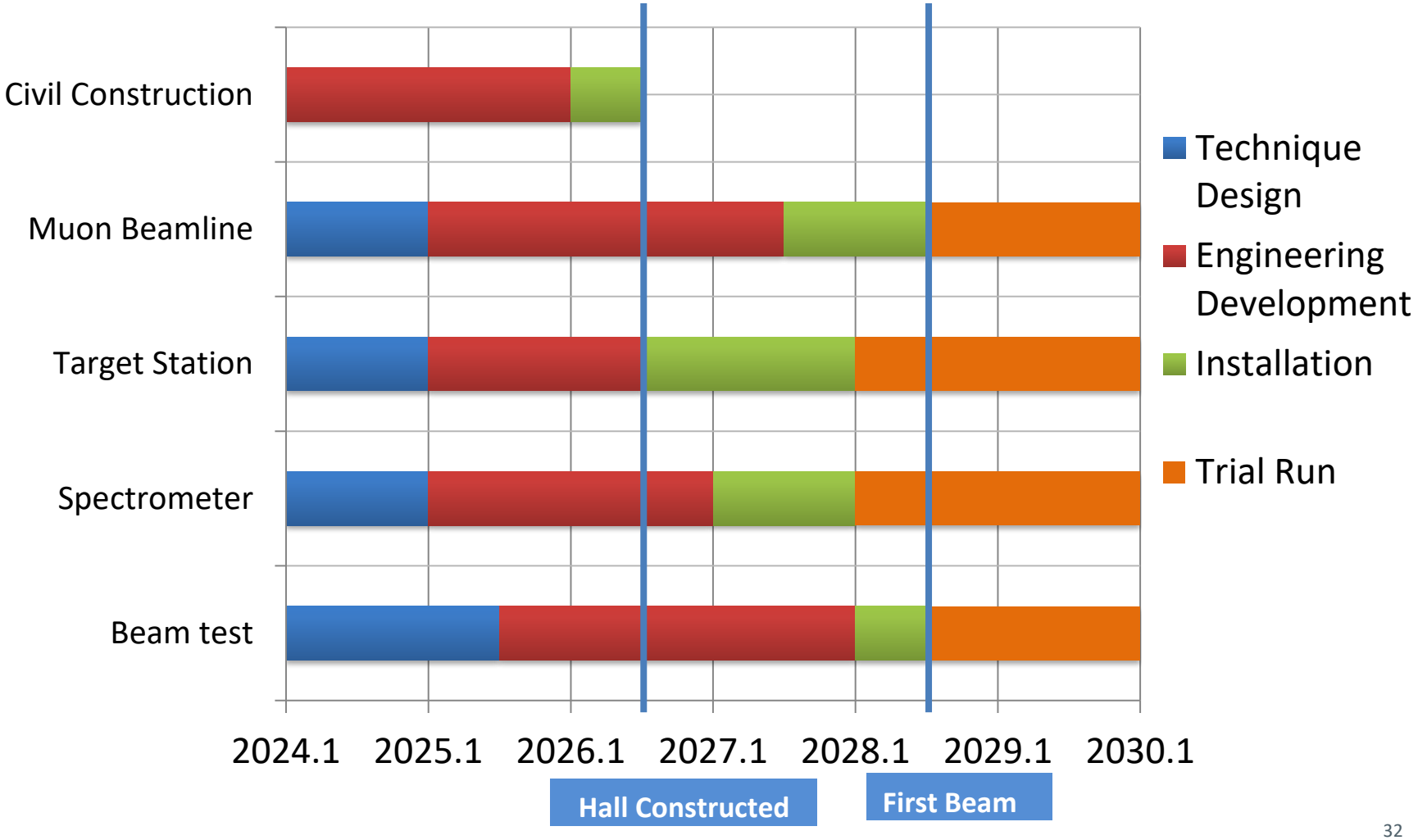


Parameters of Muon Beamlines

	Surface Muon	Negative Muon	Decay Muon
Proton Power（kW）	20	Up to 100	Up to 100
Pulse width (ns)	130 to 10	500	130 to 10
Muon intensity（/s）	10^5 ~ 10^6	Up to 5*10^6	Up to 5*10^6
Polarization（%）	>95	>95	50~95
Positron（%）	<1%	NA	<1%
Repetition（Hz）	1	Up to 5	Up to 5
Terminals	2	1~2	2
Muon Momentum（MeV/c）	30	30	10 to 120
Full Beam Spot（mm）	10 ~ 30	10 ~ 30	10~30

MELODY Timeline

We are strictly on time!



Civil Construction

Will be completed this August

MELODY Workshop

- MELODY2026 is coming in October!

Welcome to CSNS !