Progress and Prospect of MELODY

Muon station for sciEnce technoLOgy and inDustrY

Yu Bao

CSNS

IHEP

2026.10.24

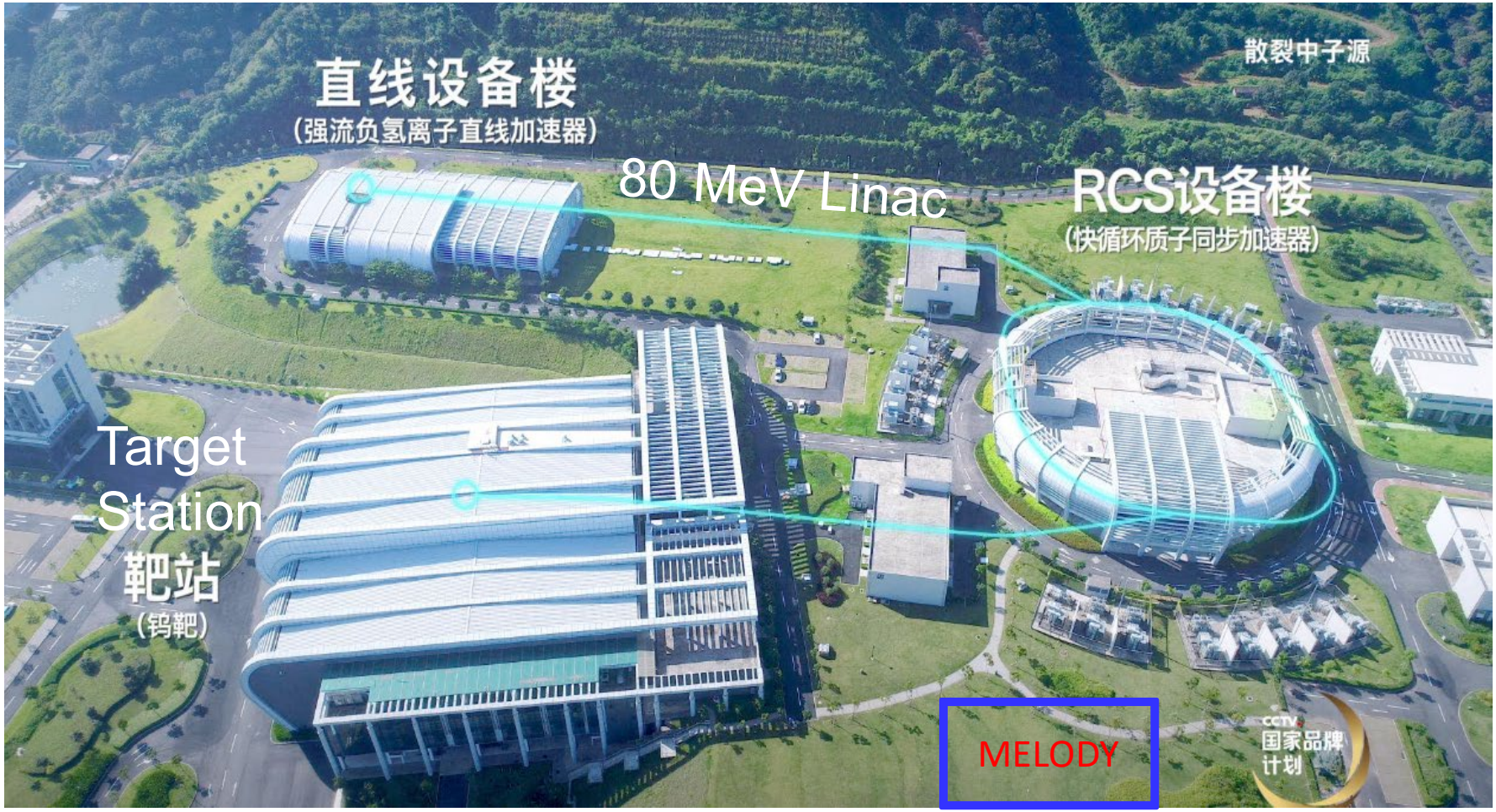
Outlines

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

China Spallation Neutron Source

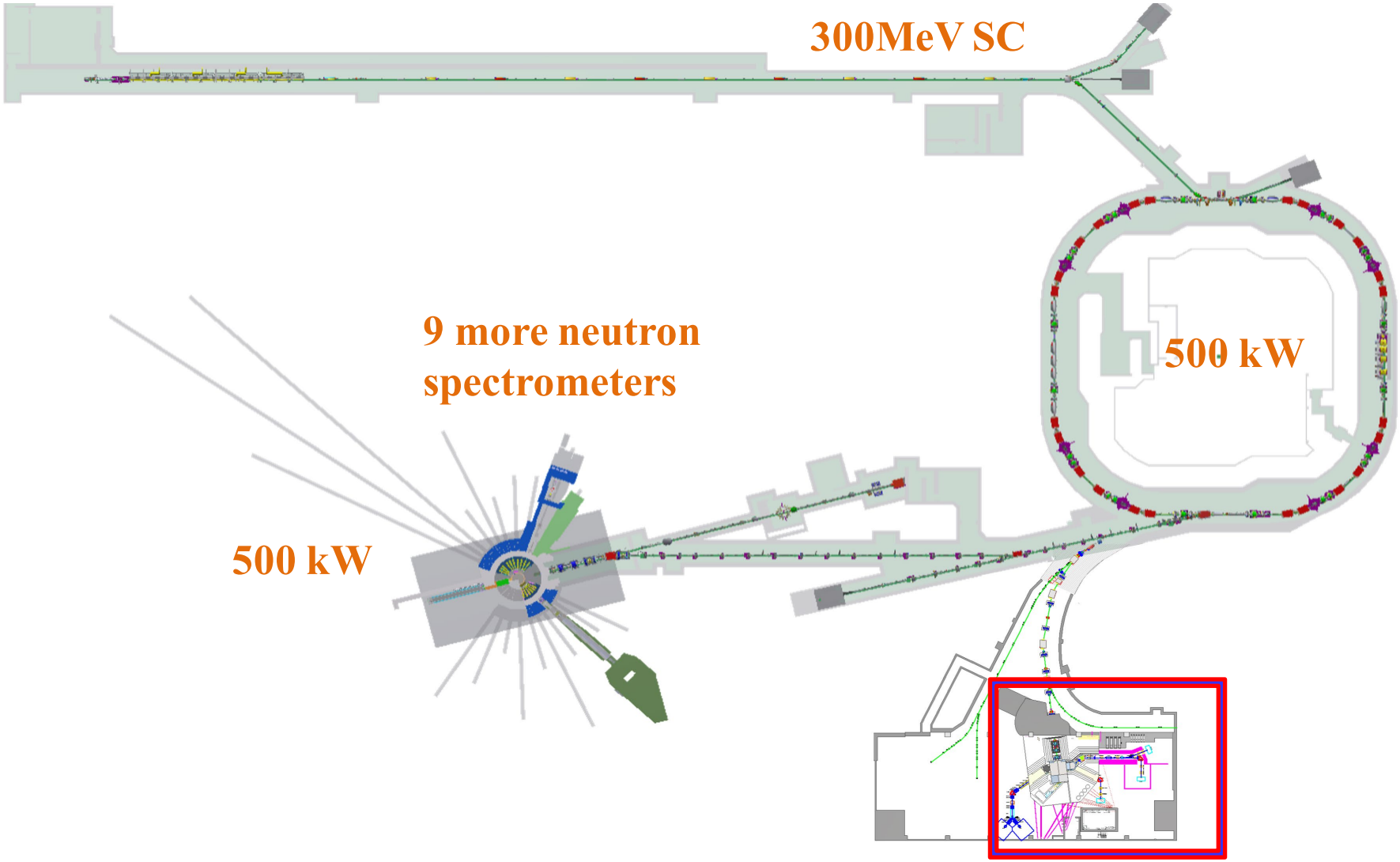


China Spallation Neutron Source（CSNS）



Accelerator: 200kW 25Hz 1.6GeV proton beam
Neutron Spectrometers: 11 built and 9 under construction

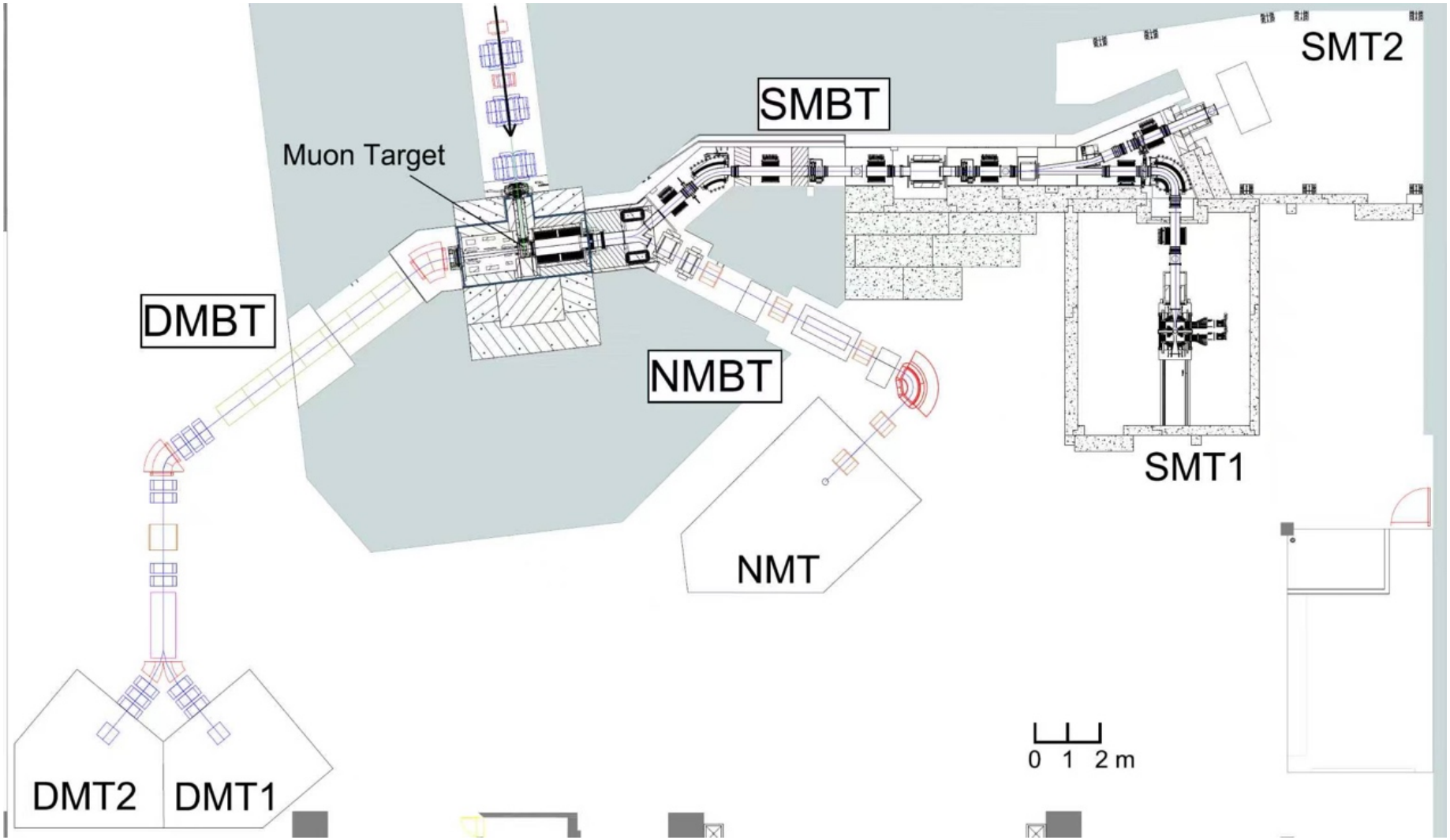
CSNS II Project (Started in Jan., 2024)



Architectural Design of MELODY



Overall of MELODY

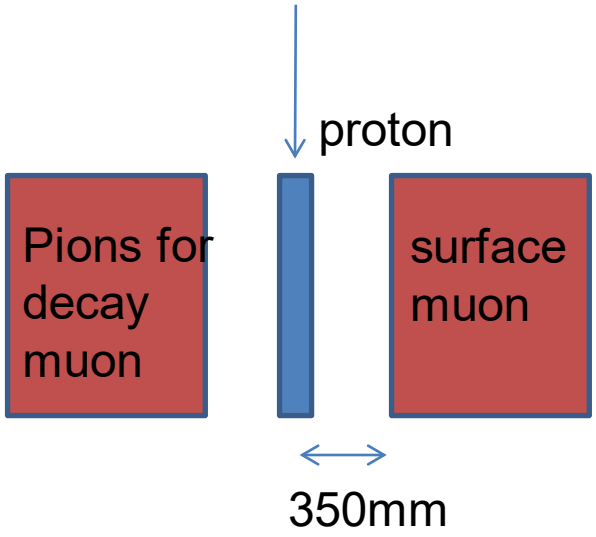


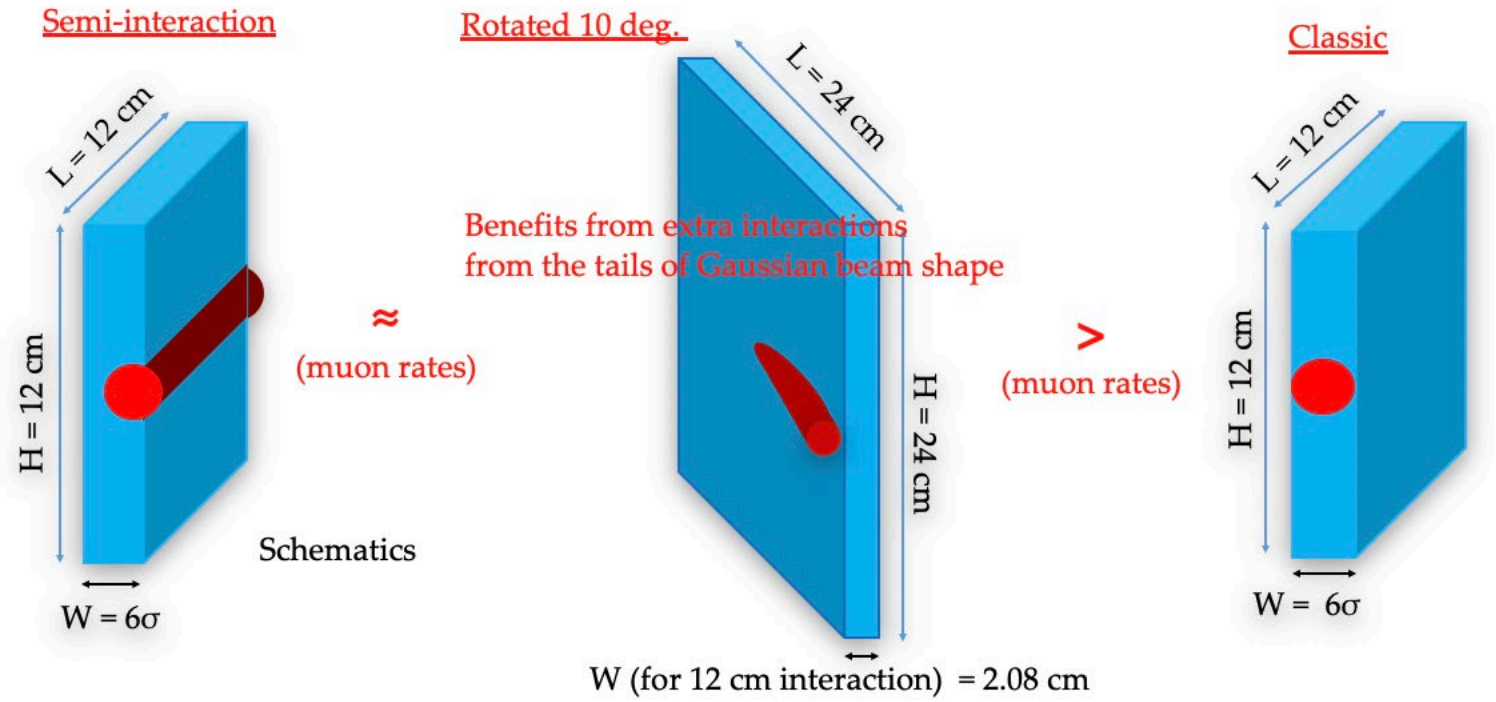
Design Features

- Target
  - Stand-alone target: more freedom to design
  - Thick target: 10 cm interaction length
  - Copper Target: high production
- Beamlines
  - Surface Muon: Solenoid focusing; AI optimized; Large acceptance
  - Negative Muon: by-product, low cost, dedicated μ^- beam
  - Decay Muon: Large acceptance; wide applications
- muSR spectrometer
  - High Asymmetry: 0.3
  - Large number of detectors: 3024 units
- MIXE spectrometer
  - CZT + HPGe Detectors: high counting rate + high resolution

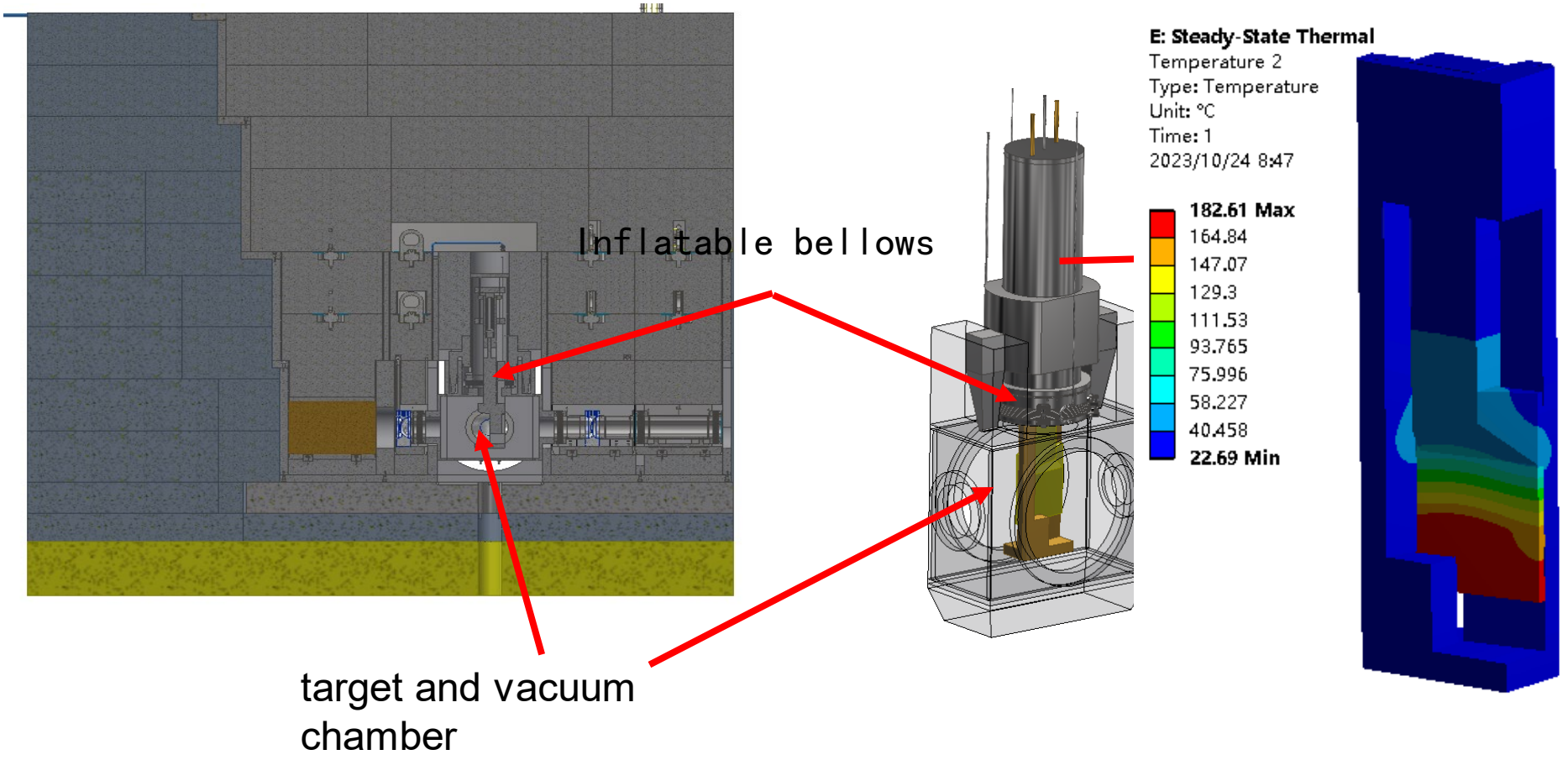
Muon Target

- Copper target: high production, better heat conductivity
- Optimize the target with three different strategies





Target design

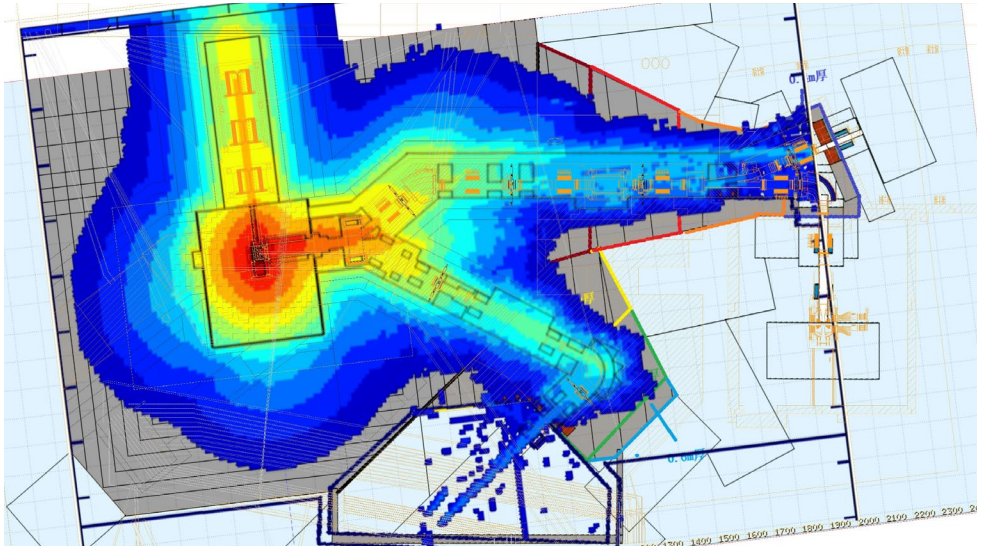


- **Fixed target，Cu,24cm*24cm*10mm，tilt by 7degree**
- **Edge water cooling，＜200°**
- **Pillow seals connection**

Radiation Shielding

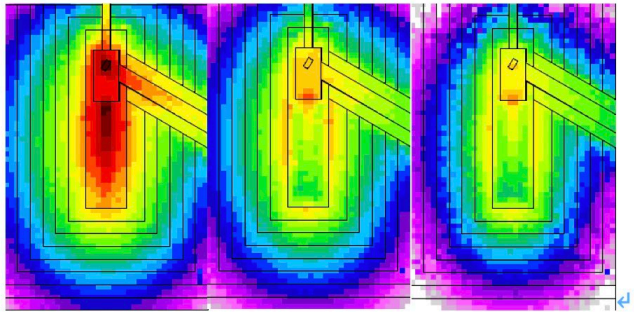
Two layers:

1. Mild steel
2. Concrete

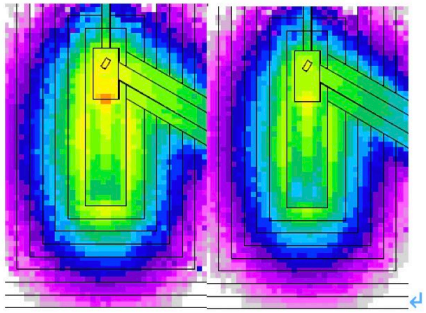


Prompt dose



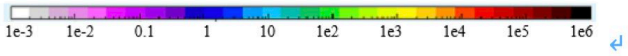


刚停机　　停机 4 小时　　停机 1 天



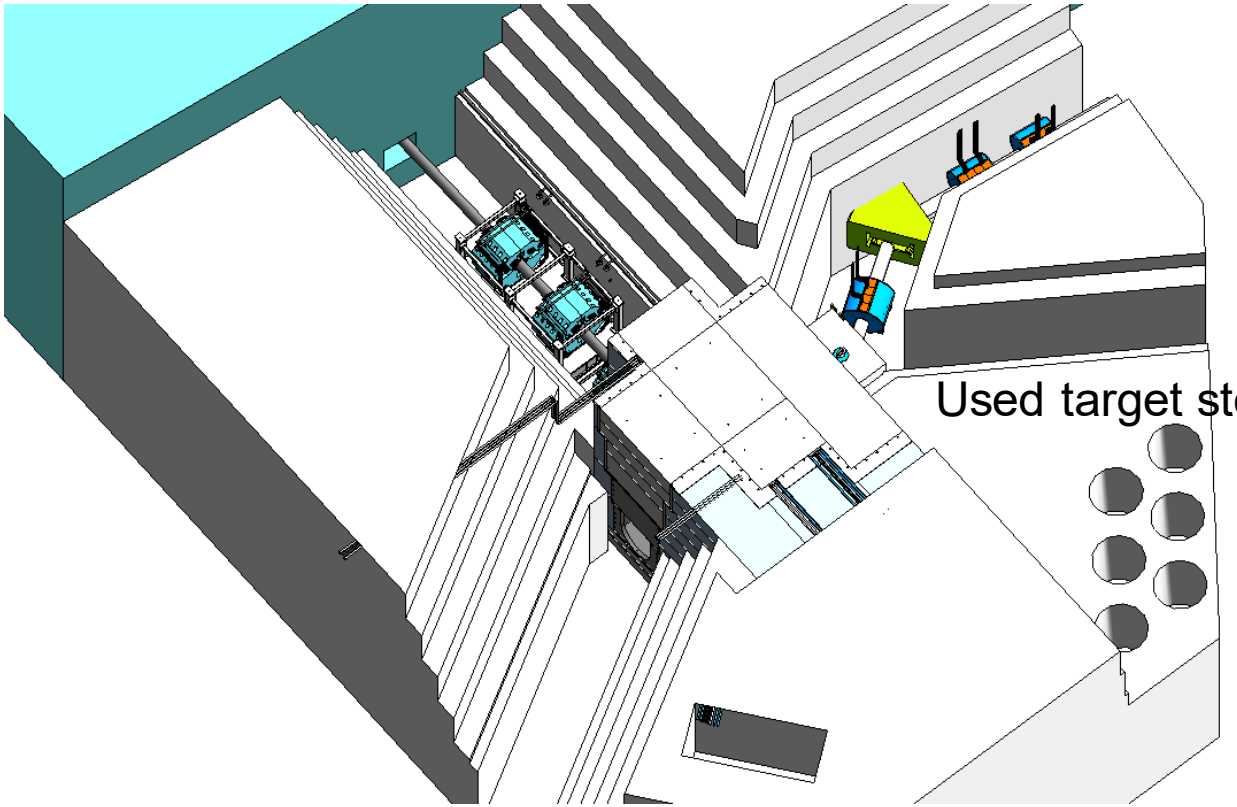
停机 1 周　　停机 2 月

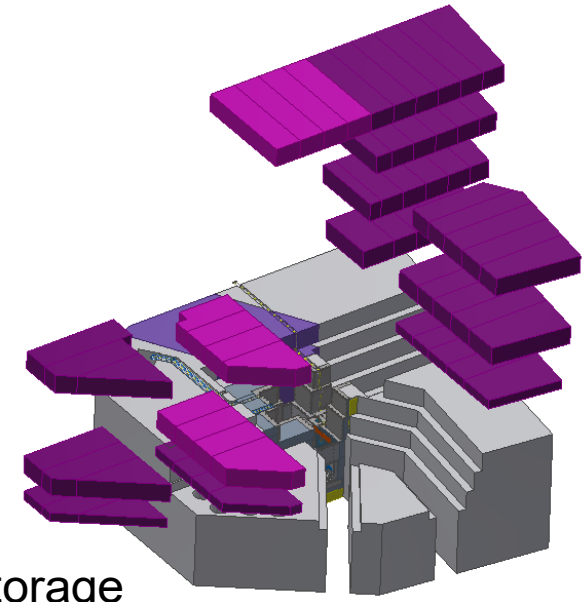
Residual dose



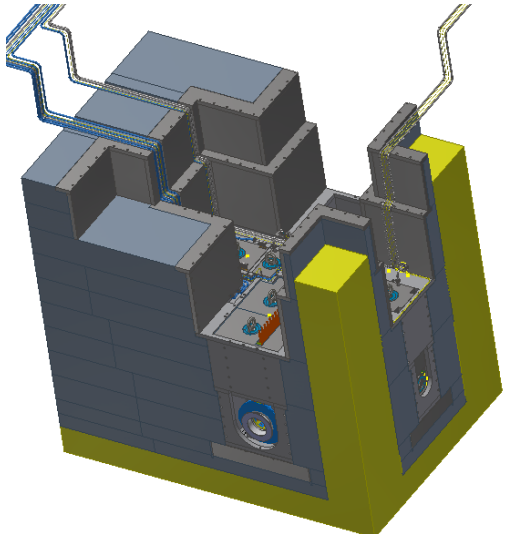
(单位：mSv/h)

Muon Target Station



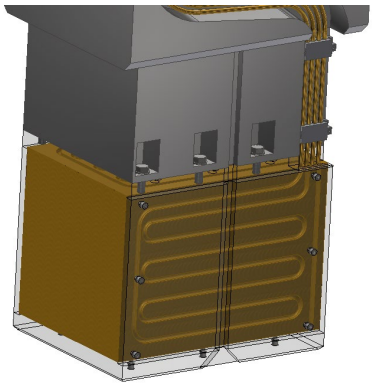


Used target storage



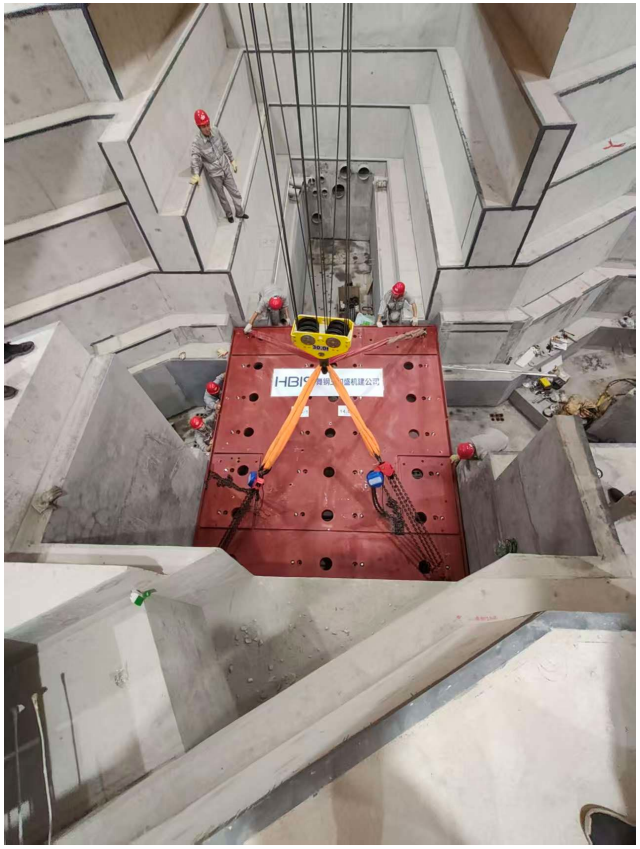
Shielding: Iron 5m*4m*4m
Concrete 5.5*5.5m*1m

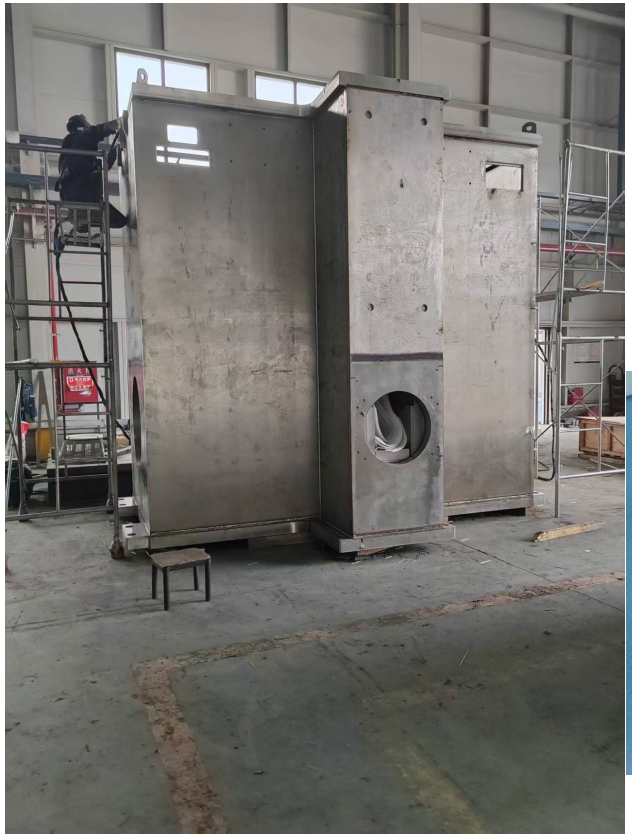
Beam absorber: Copper



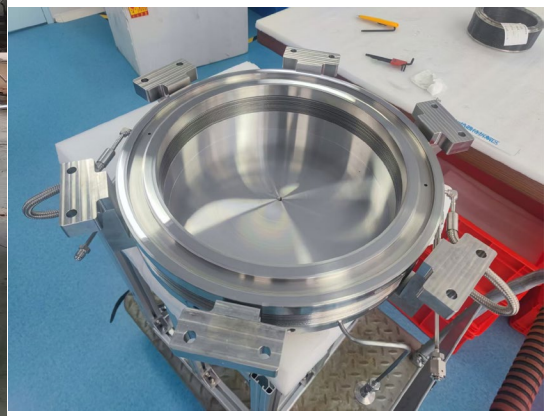
Status of the target station

- Concrete shielding constructed!
- Base plate of the target station in place!
- Several key parts under manufacturing

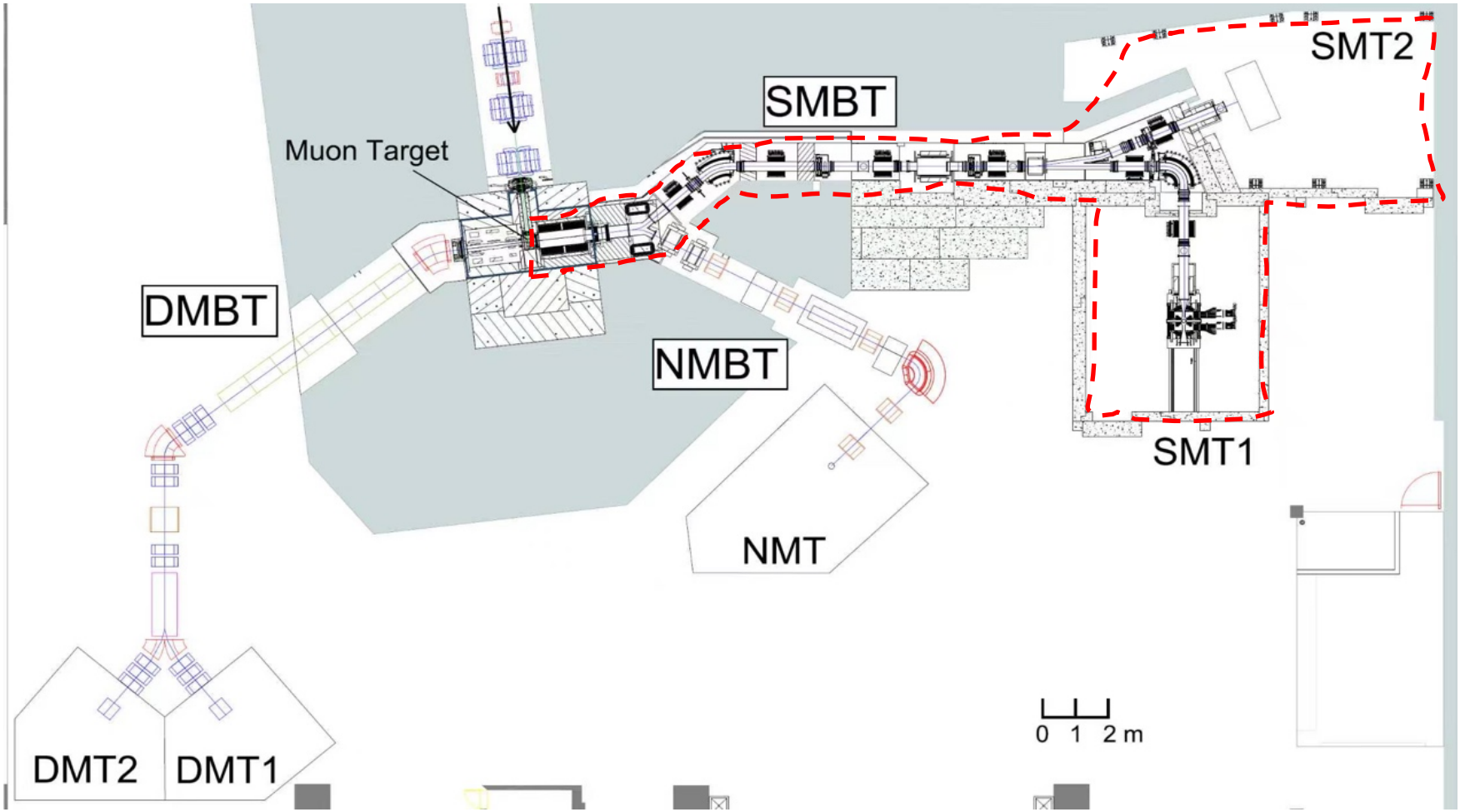




Pillow seal produced by Weina Co. Lmtd. (合肥微纳)



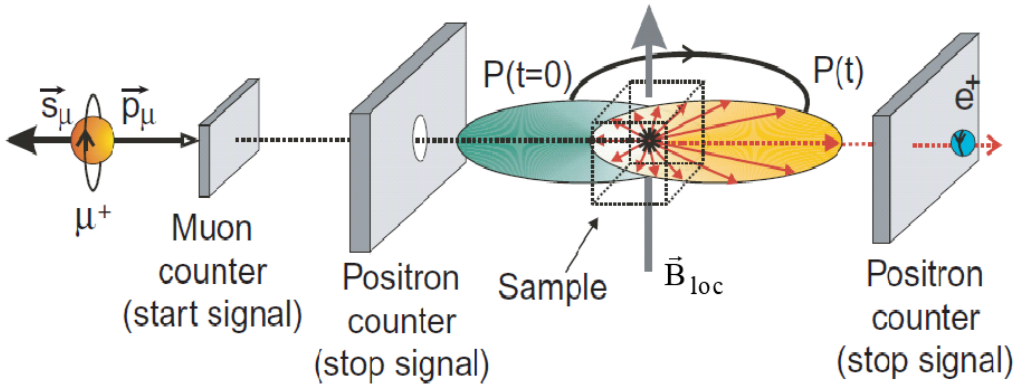
Surface Muon Beam

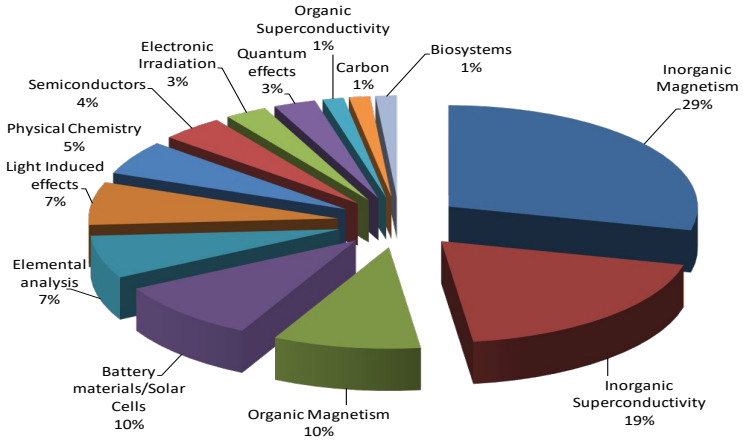


- **Energy： 4 MeV**
- **Polarization: >95%**
- **Intensity： 10^5~$10^7 \mu^+$/s**
- **Time Resolution: 120ns**

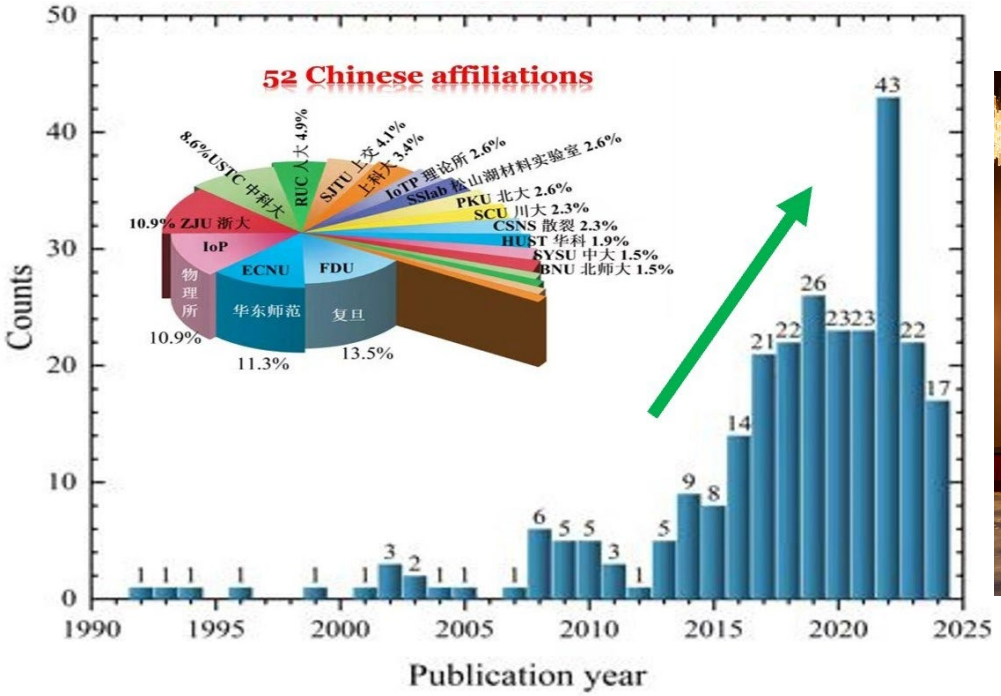
Surface Muon application（T1）：muSR

Principle of MuSR



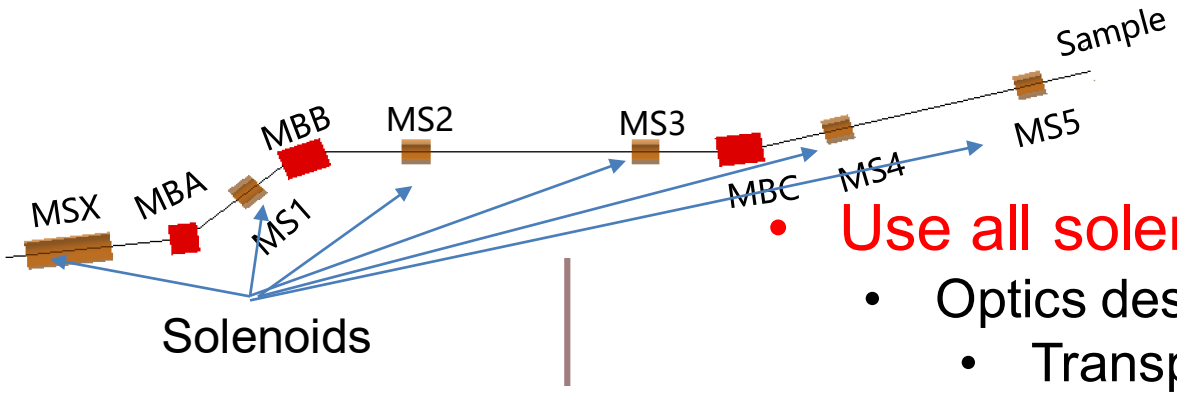


MuSR：Magnetic material, superconductivity, battery, semiconductor

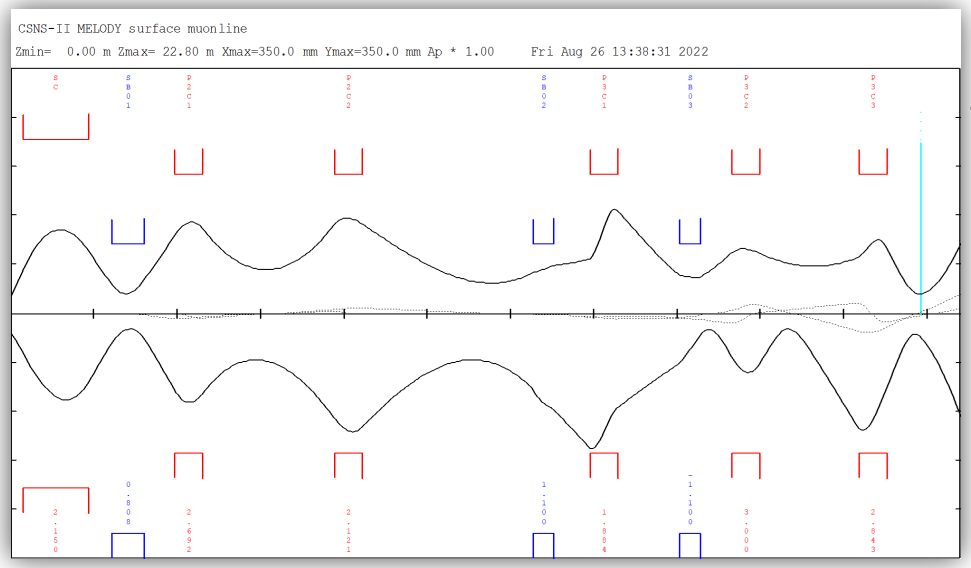




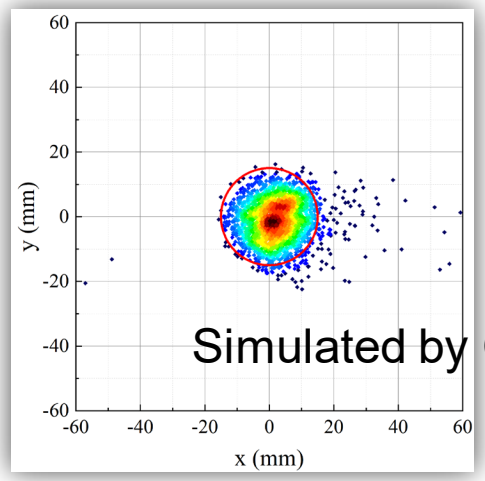
Surface Muon Beamline Design



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



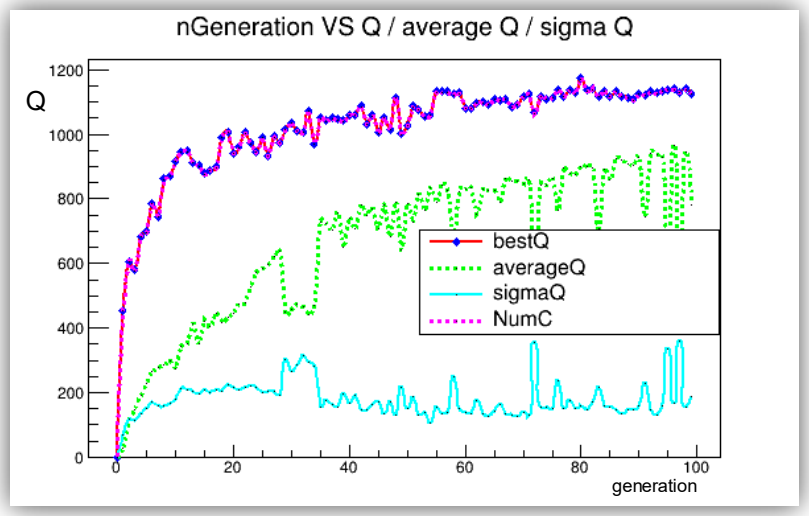
Designed by Transport

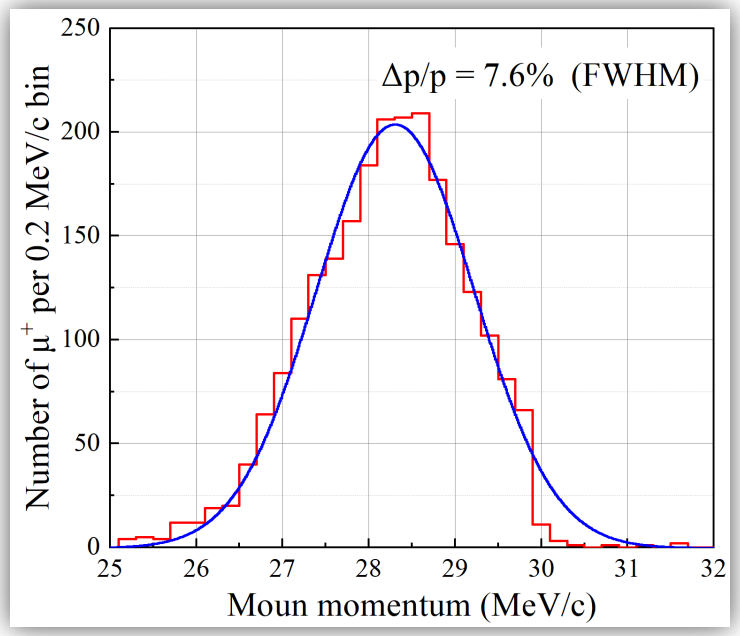


Simulated by G4beamline

Optimization by A.I.

- 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

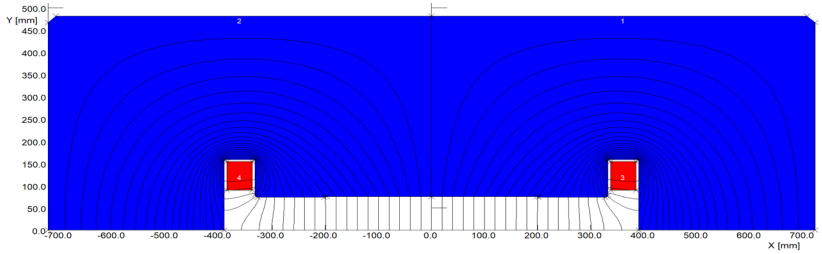




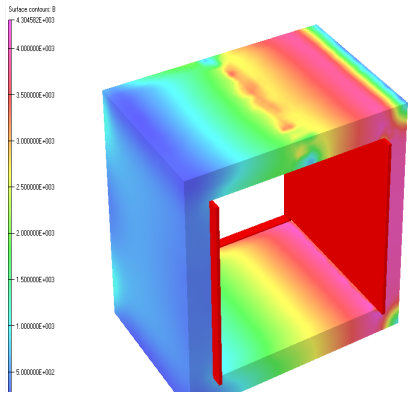
Parameters	G4bl simulation
x (FWHM)	1.64 cm
y (FWHM)	1.84 cm
Δp/p (FWHM)	~ 7.6%
μ+ rate	1.8×10^{6} μ+/s
μ+ rate on ϕ30 mm	**1.6×10^{6} μ+/s**
Core ratio	91.24%
Polarization	**~ 95%**
e^{+}/μ^{+}	<0.01

Design of the magnets

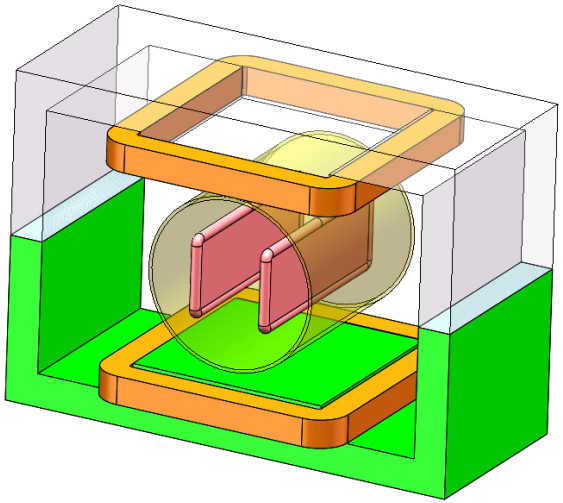
Dipole

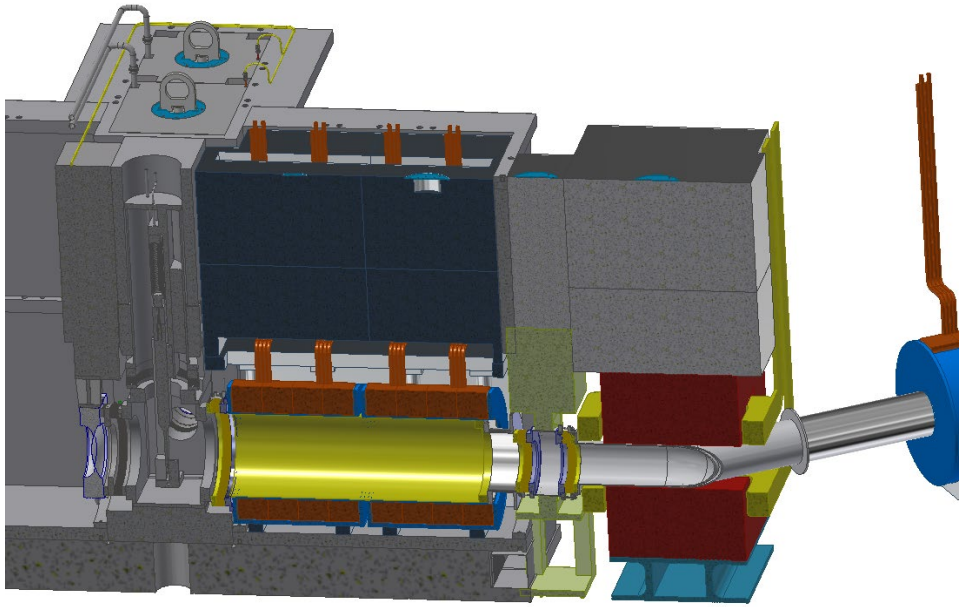


Kicker



Wein fielter

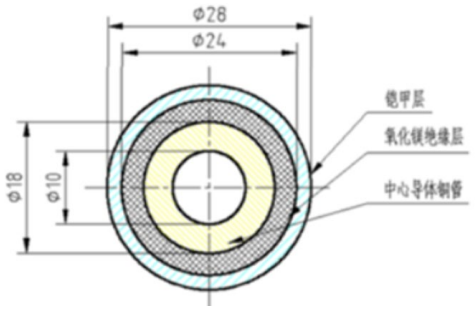


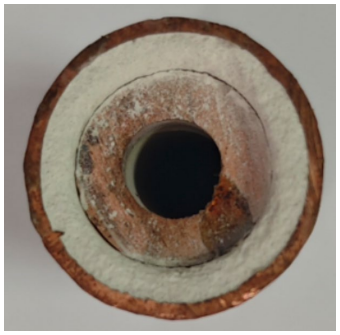


All ordered and will be delivered from December 2026.

Prototype of the MIC coil

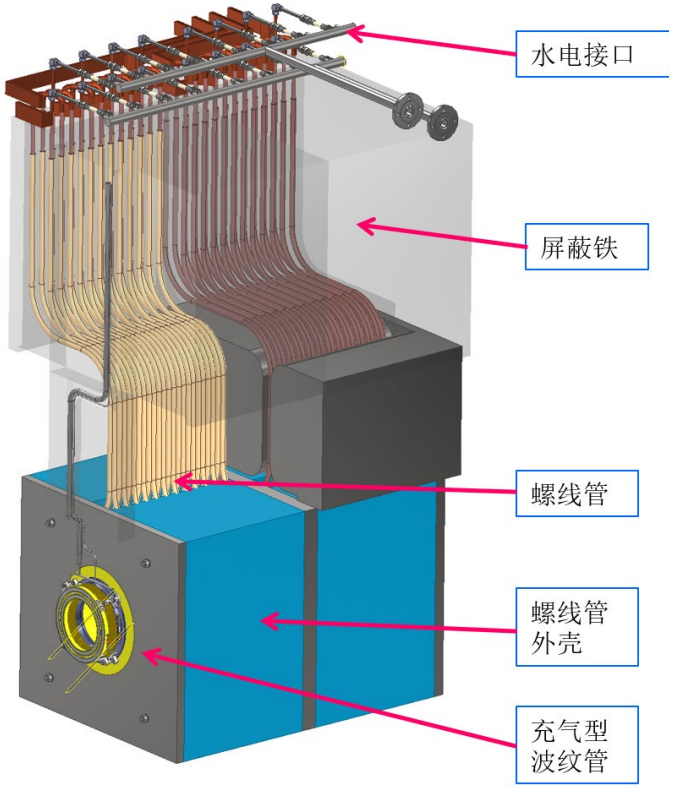
矿物电缆：

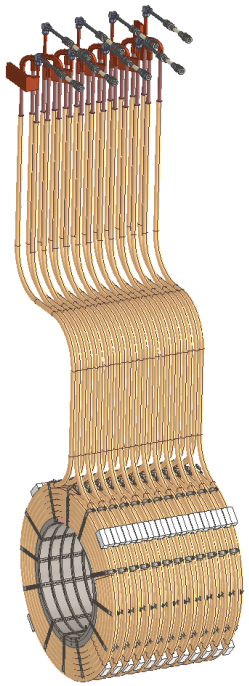




	基准值	实测值		基准值	实测值
中心导体铜管	ø10	ø9.19	铠甲层	ø24	ø23.64
		ø8.98			ø23.68
		ø8.92			ø23.99
		ø8.86			ø23.59
	ø18	ø17.66		ø28	ø25.89
		ø17.48			ø26.04
		ø18.13			ø26.1
		ø17.9			ø25.94

Designed model of SOLX





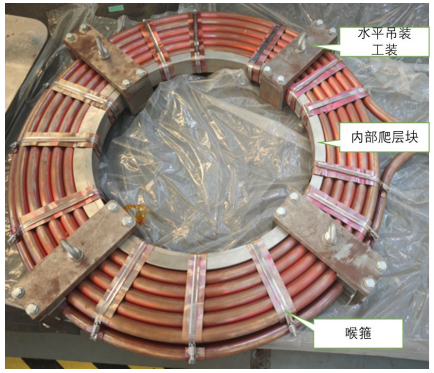
Manufacture of the MIC coil

being manufactored at Kelin Co. Lmtd. (上海克林)



Using steel to tighten it







Tested the insolation:

- 1500V，1 min, no breakdown

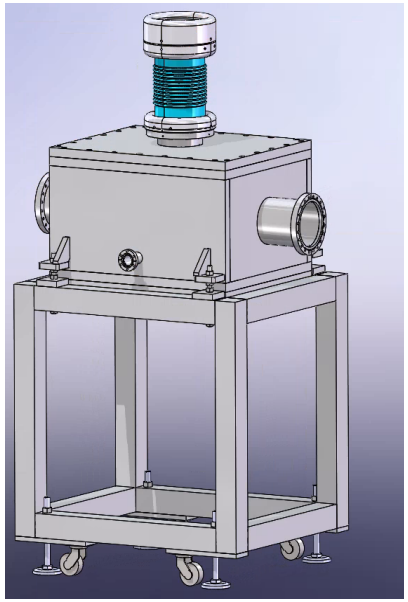


Water leakage test:
6 kg, no leakage

Wien Filter prototype

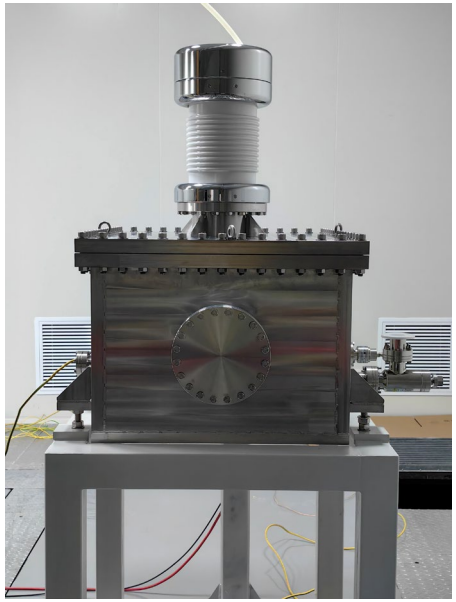
◆A Wien filter prototype have been developed and tested at CSNS campus.

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



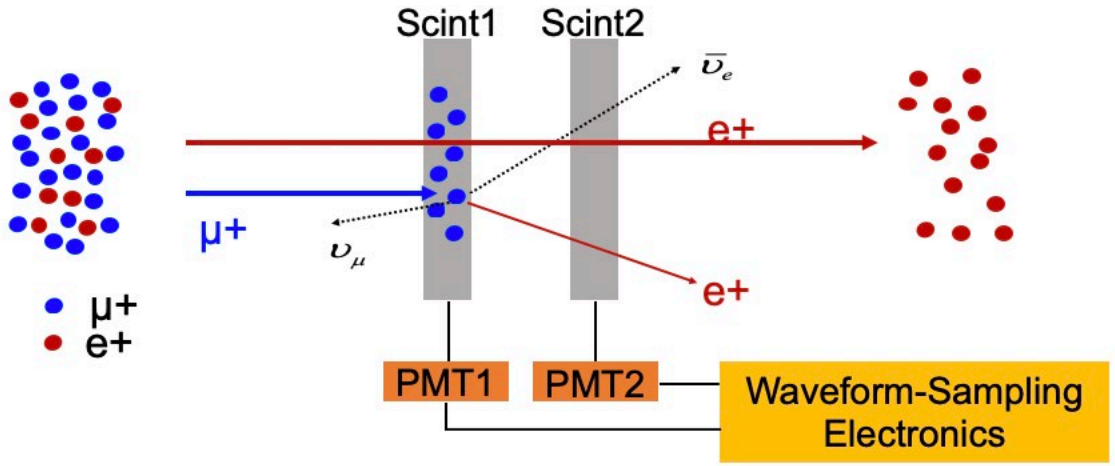
SMWF prototype model



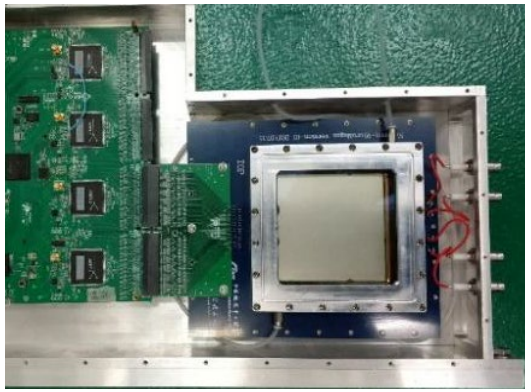


Prototype picture

Beam measurement

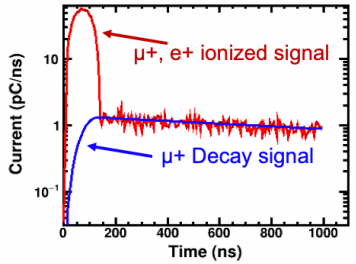


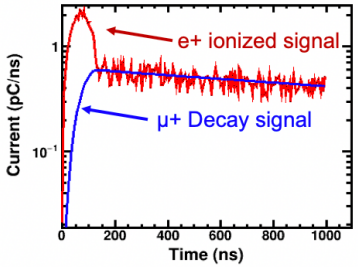
Beam intensity measurment



Beam spot monitor

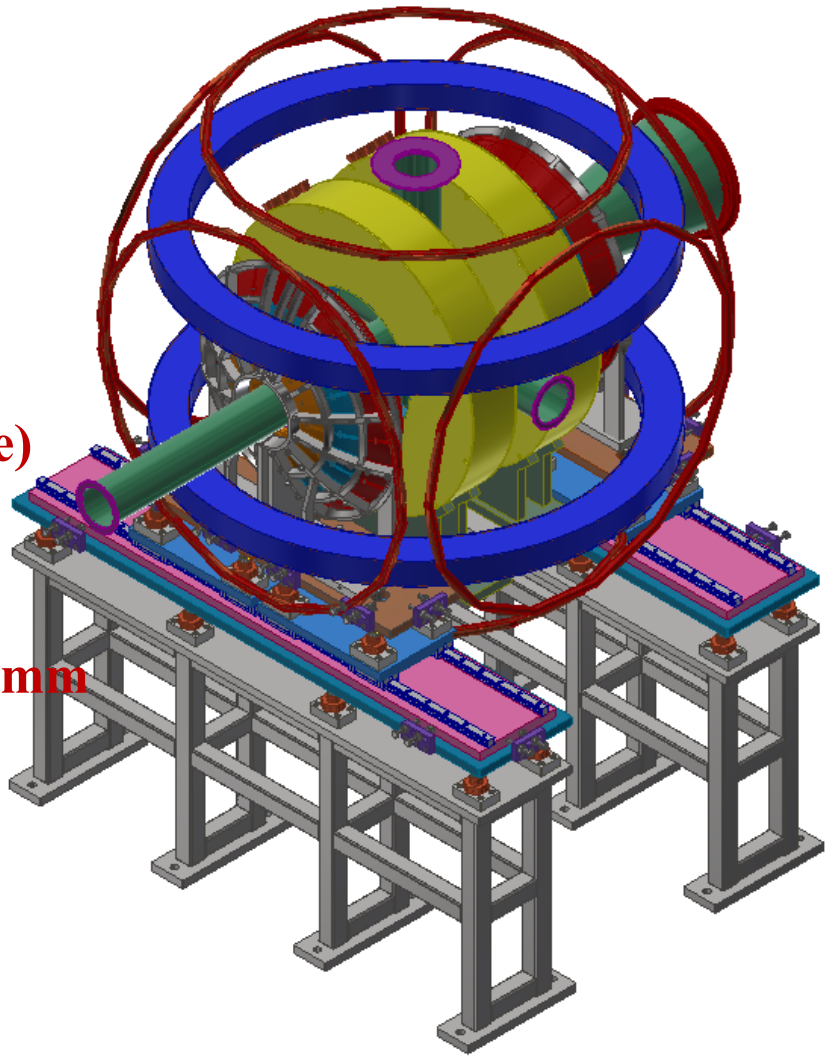
- Measure muon beam intensity by double scintillators
  - ➢ Distinguish positron content
- Measure beam spot size with a MicroMegas detector
- **Tested with ISIS muon beam**





μSR Spectrometer

- **~1584 detector units** (~3024 in total)
- **Counting Rate：** ~76 ME/h @ 1 Hz
- **Asymmetry：> 0.3**
- **Pulse length：~130 ns**
- **Temperature: 2-300 K (0.3K upgrade)**
- **LF: 0-5000 G**
- **TF: 0-400 G**
- **Homogeneity < 100ppm @ 40*40*10mm sample area**
- **Beam spot: Φ10-30 mm**

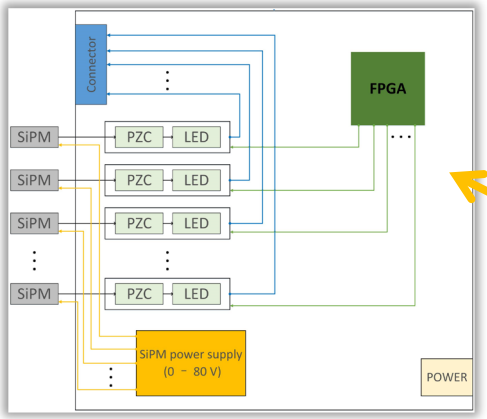


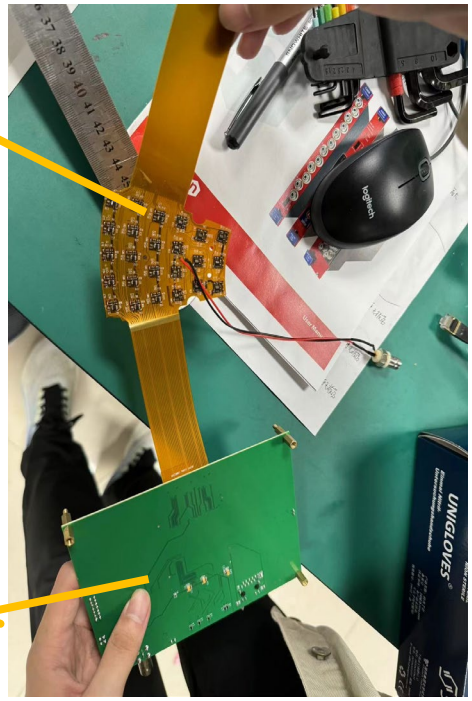
Detectors and Electronics

Leading-edge discrimination + TDC

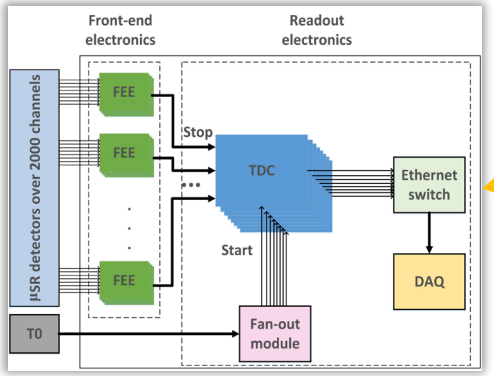
Beam test at ISIS muon source

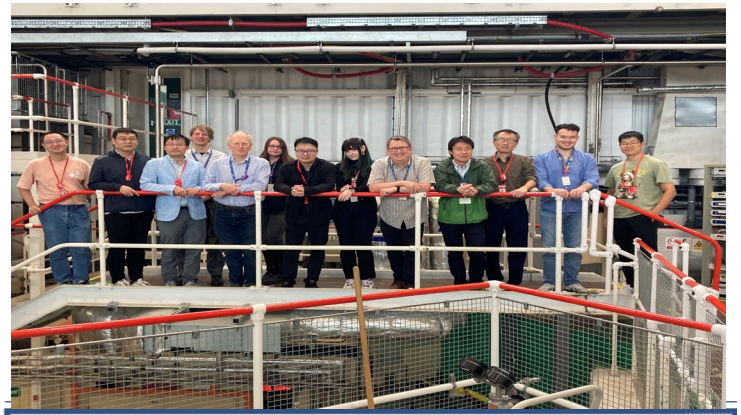
Front-End Electronics

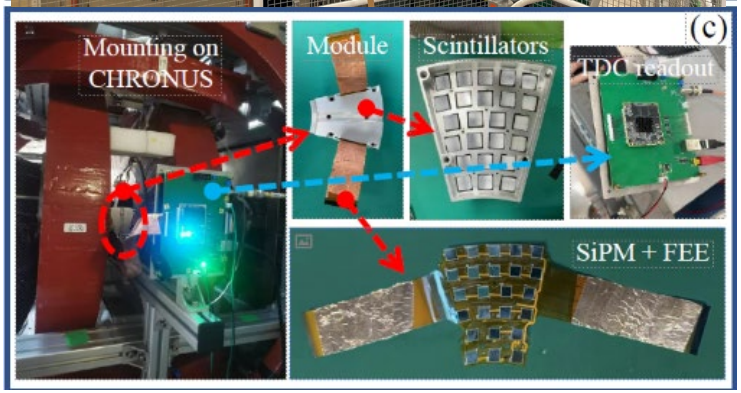


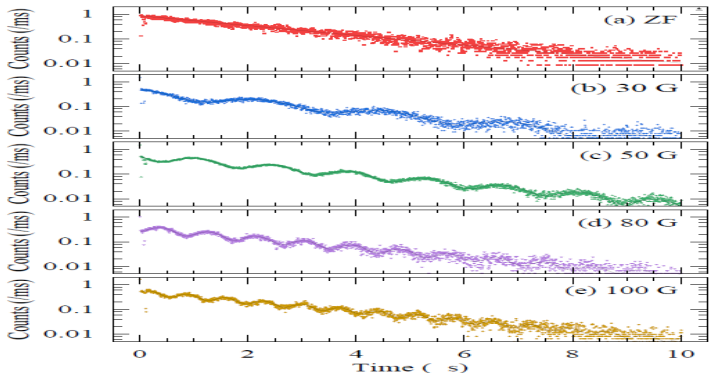


TDC Readout





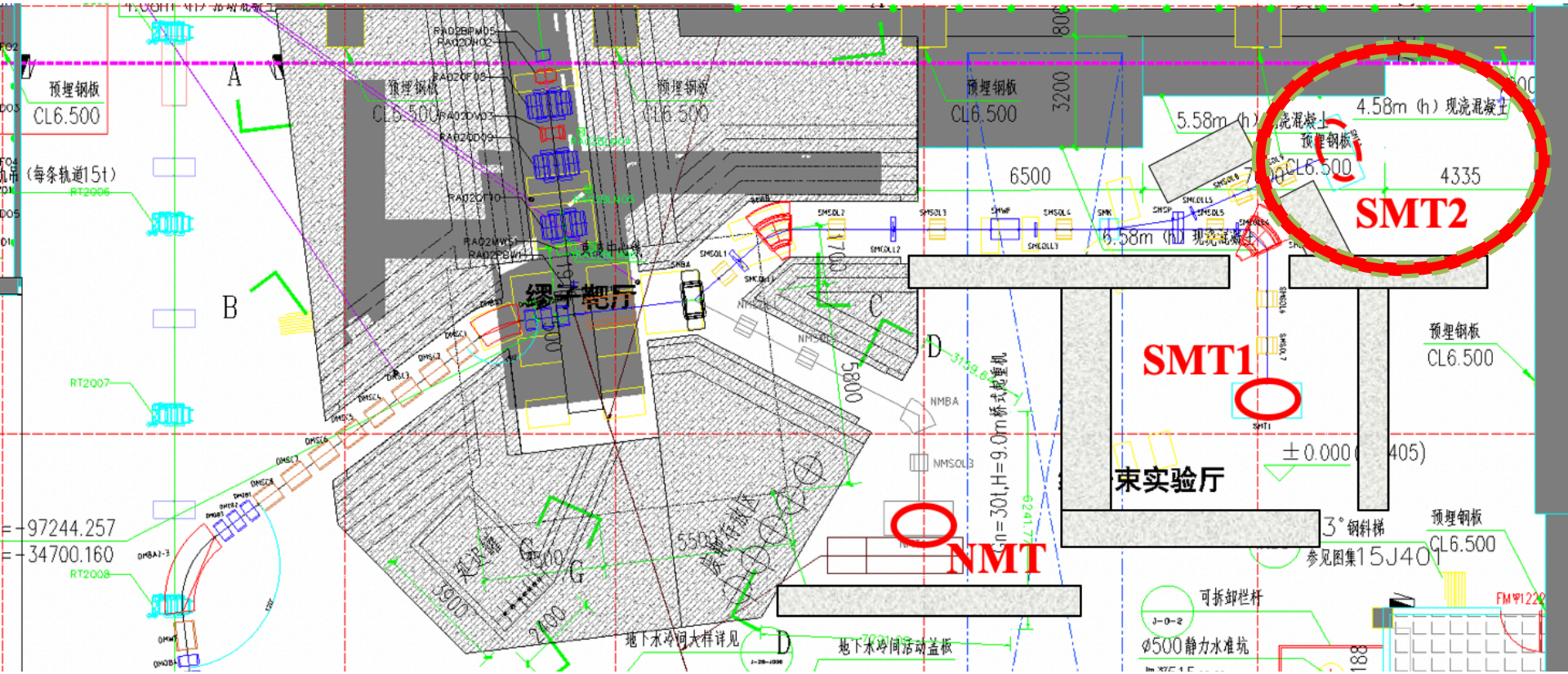




T_0 signal input to TDC as time start signal

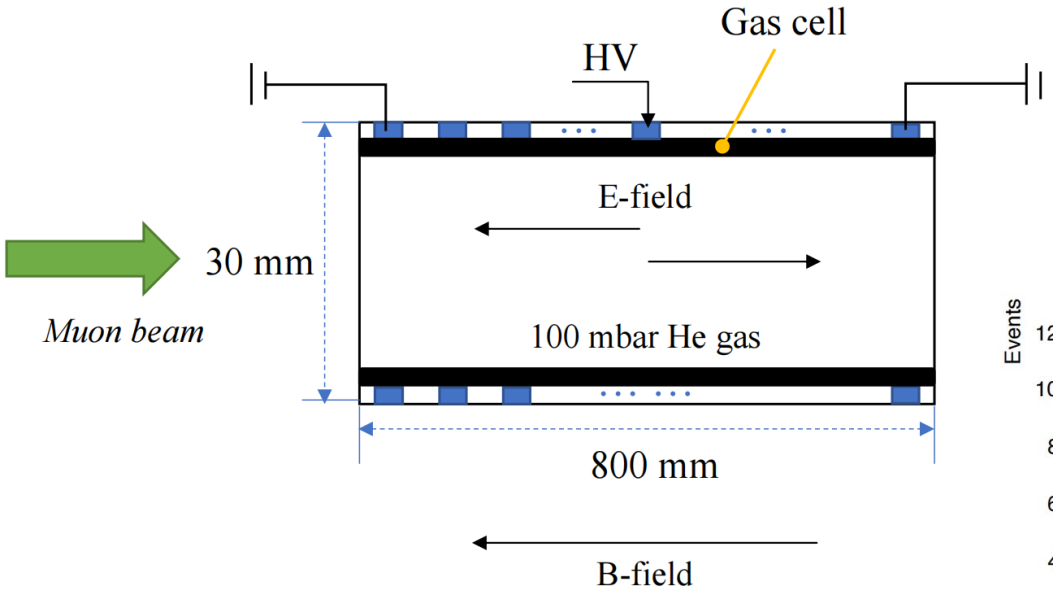
Detector event signal input to TDC as time stop signal

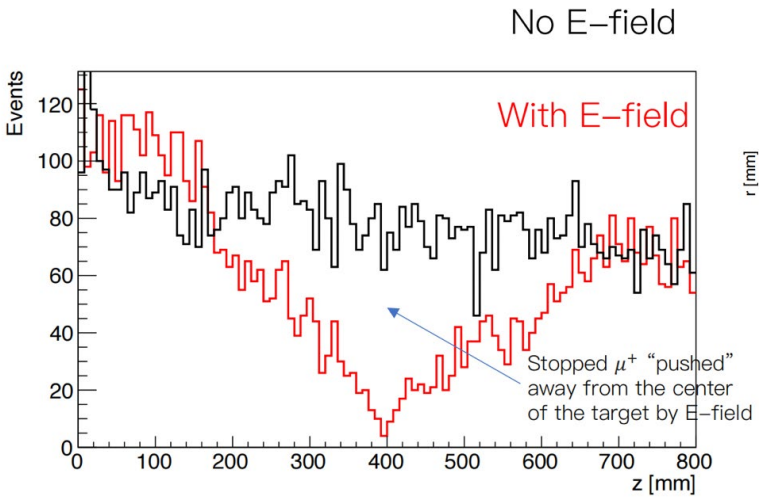
Test Beam Port



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

Muon moderation technology





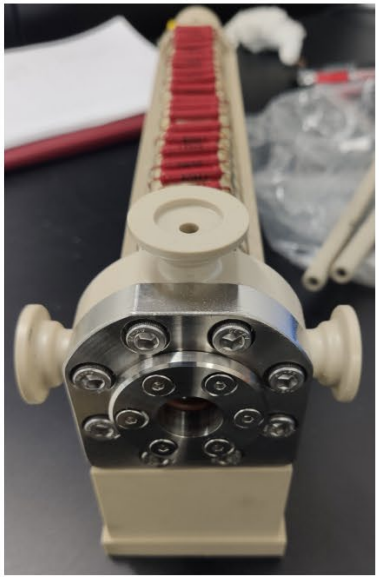
- Use helium gas to stop muons
- Use electric field to steer muon out of the gas cell
- Bring 0.1% muons to 300 eV

Key: use ESD material to remove the charge and to avoid breakdown in helium gas

Muon moderation technology

FCD Experiment

Gas cell

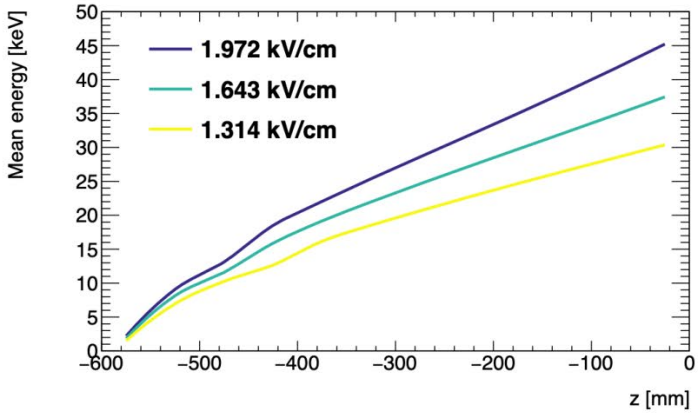


Proton source:
Am–241 + Mylar foil

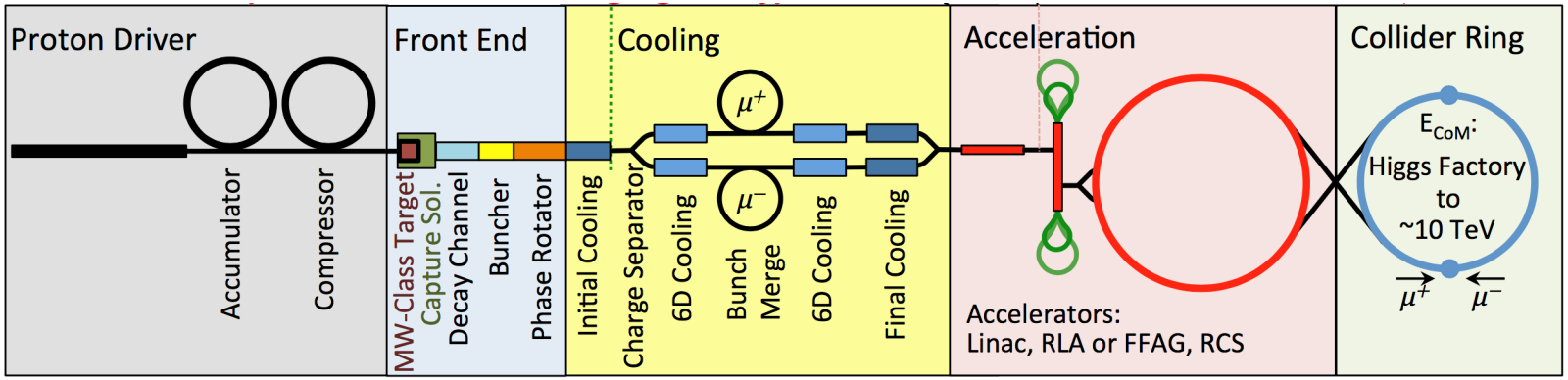
Frictional cooling demonstration experiment with proton



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



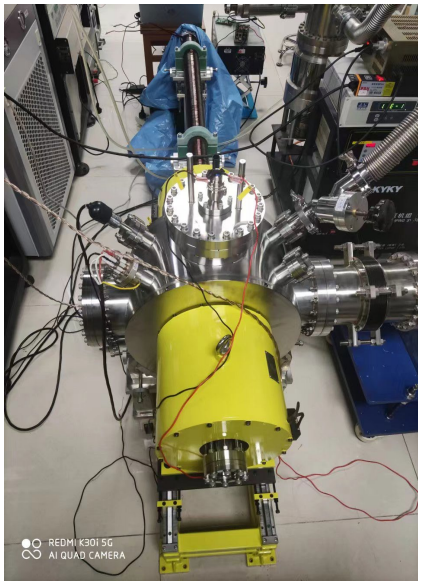
Muon acceleration/ Muonium



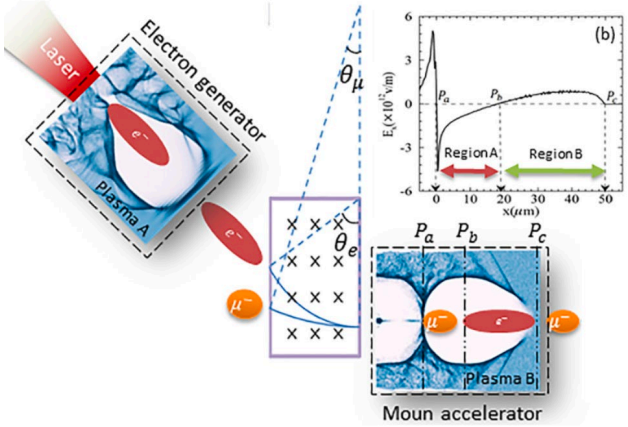
- Develop technologies for future muon experiments



SC magnet for tests



Magnetic mirror for muonium physics



Muon acceleration by plasma wakefield (PKU)

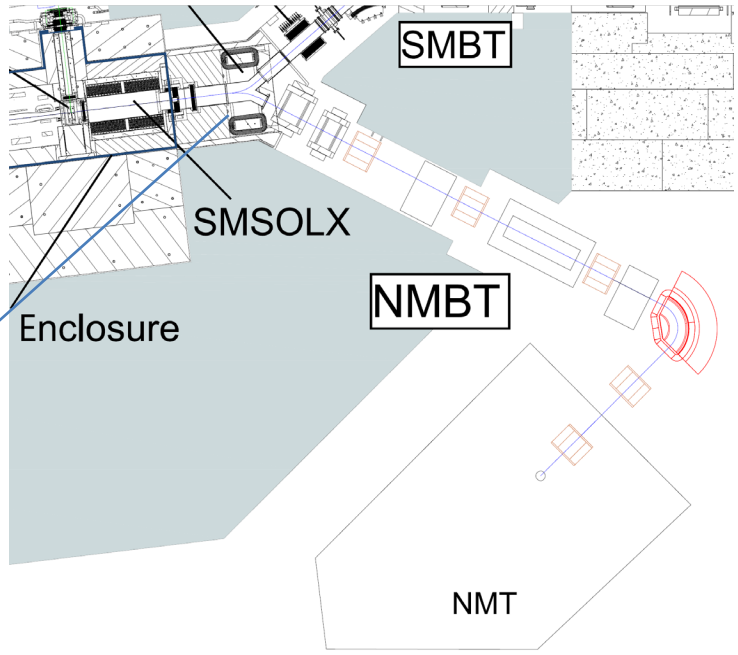
Negative Muon Beam

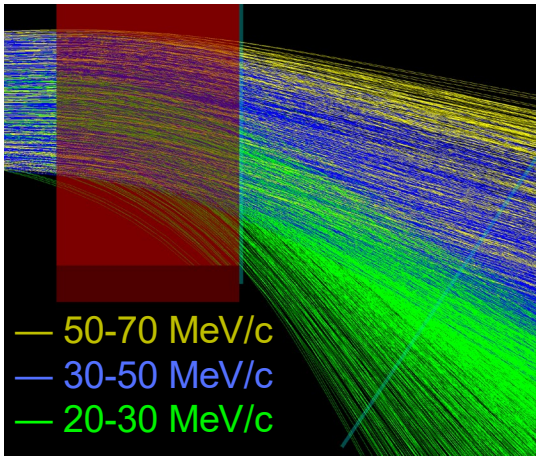
◆NMBT: Dedicated μ⁻ beam

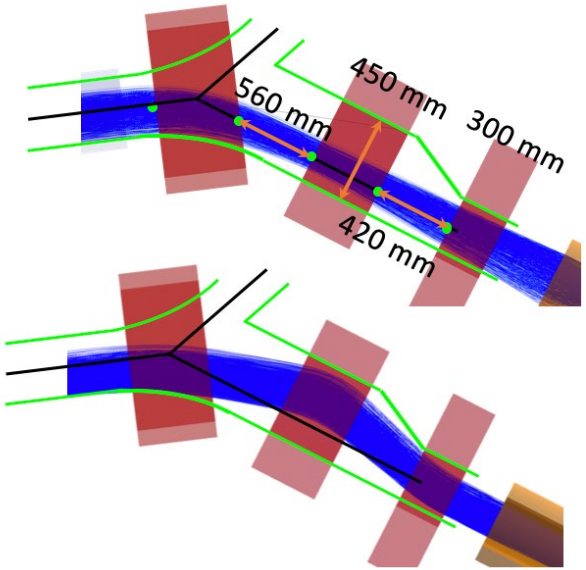
- 5 focusing solenoids
- 3 dipole magnet
- 1 wien filter

◆Beam parameters

- Momentum：20~60 MeV/c
- Beam size： Φ20~Φ100 mm
- Beam intensity： 10^4 ~10^5 Hz (Φ100 ratio>90%)





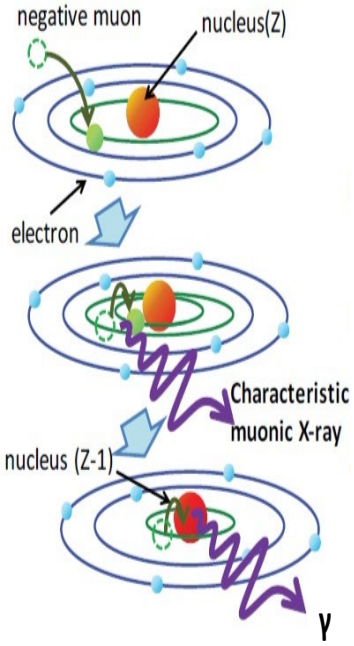


Negative Muon Applications - MIXE

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

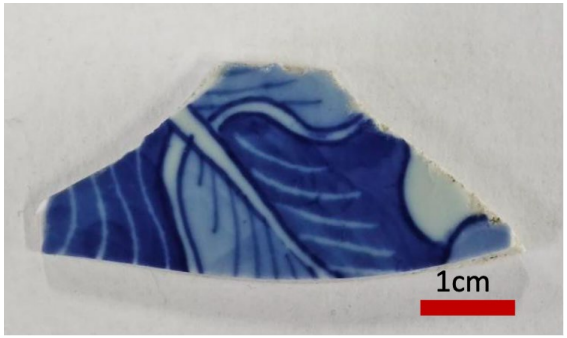


- Non-destructive elemental analysis:
  - Sensitive for almost all elements (including C, N, O)
  - No activation for samples
  - Archeology:
    - Palace Museum
    - National Museum
    - Xi'an Heritage Conservation

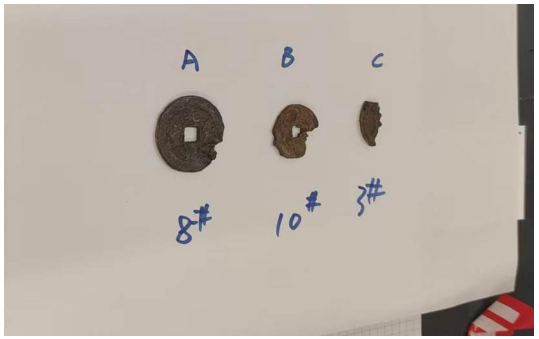
Experiments done PSI in August

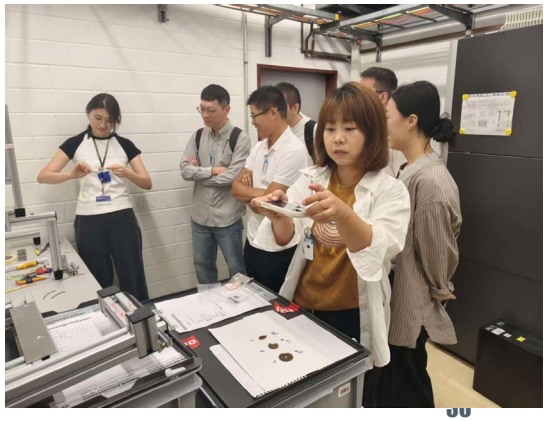
4 teams at PSI

Palace Museum

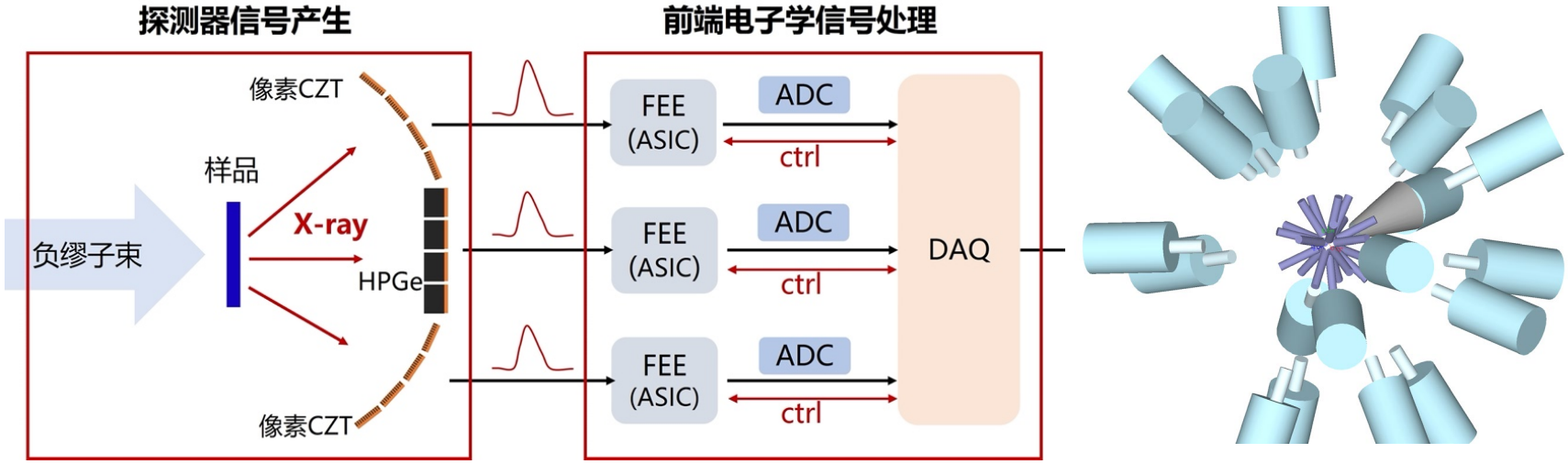


Xi'an Heritage Conservation





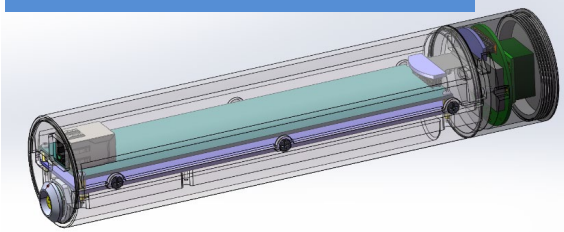
MIXE Spectrometer for MELODY



MIXE Spectrometer construction:

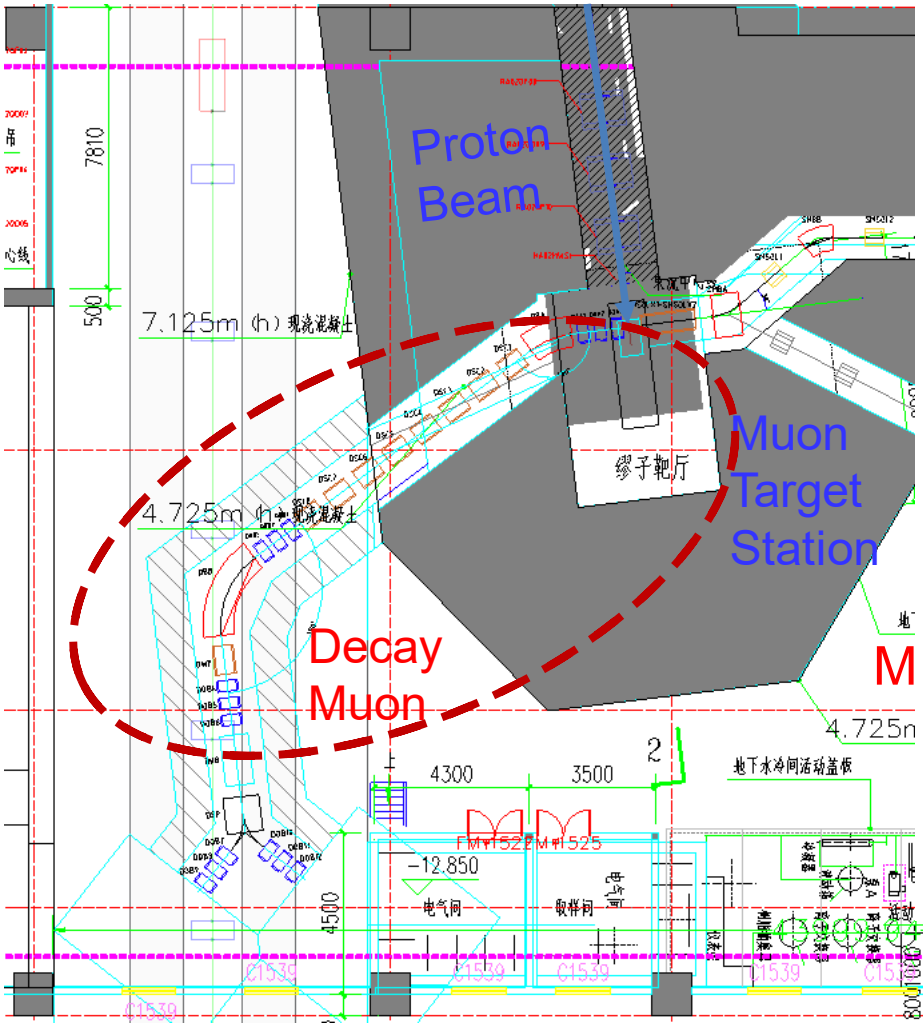
- **CZT detector array for counting rate**
- **HPGe for high resolution**

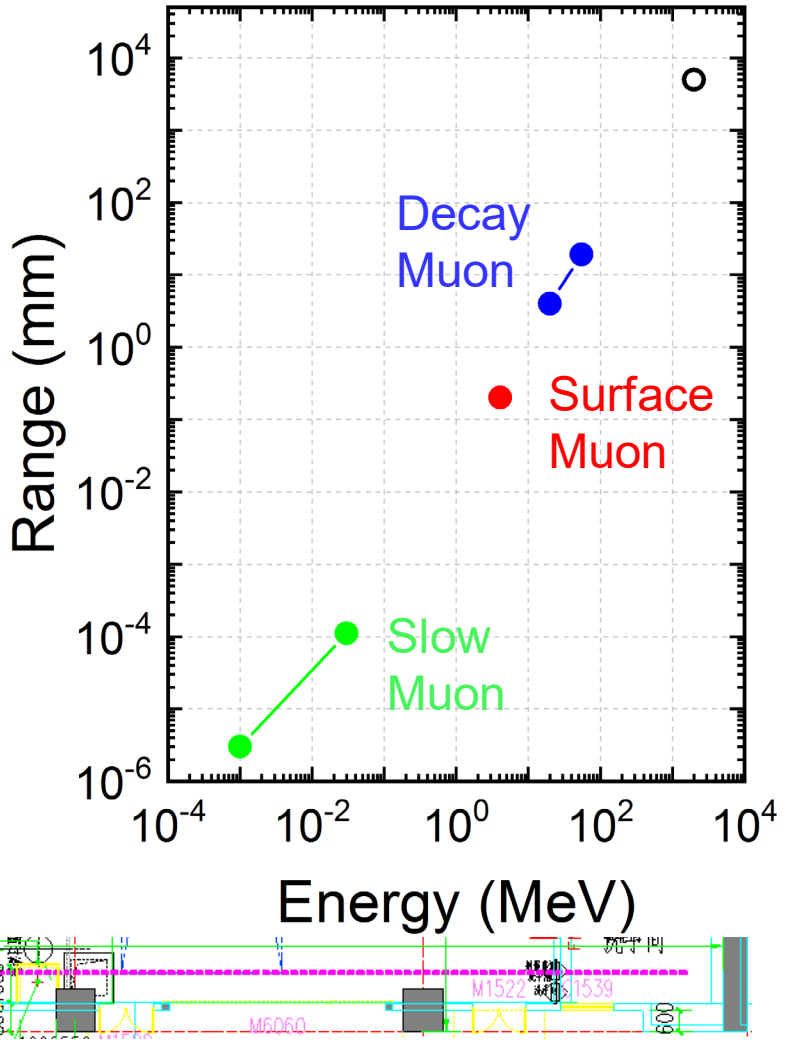
Prototype of CZT



Recently Funded by Chinese Academy of Sciences !

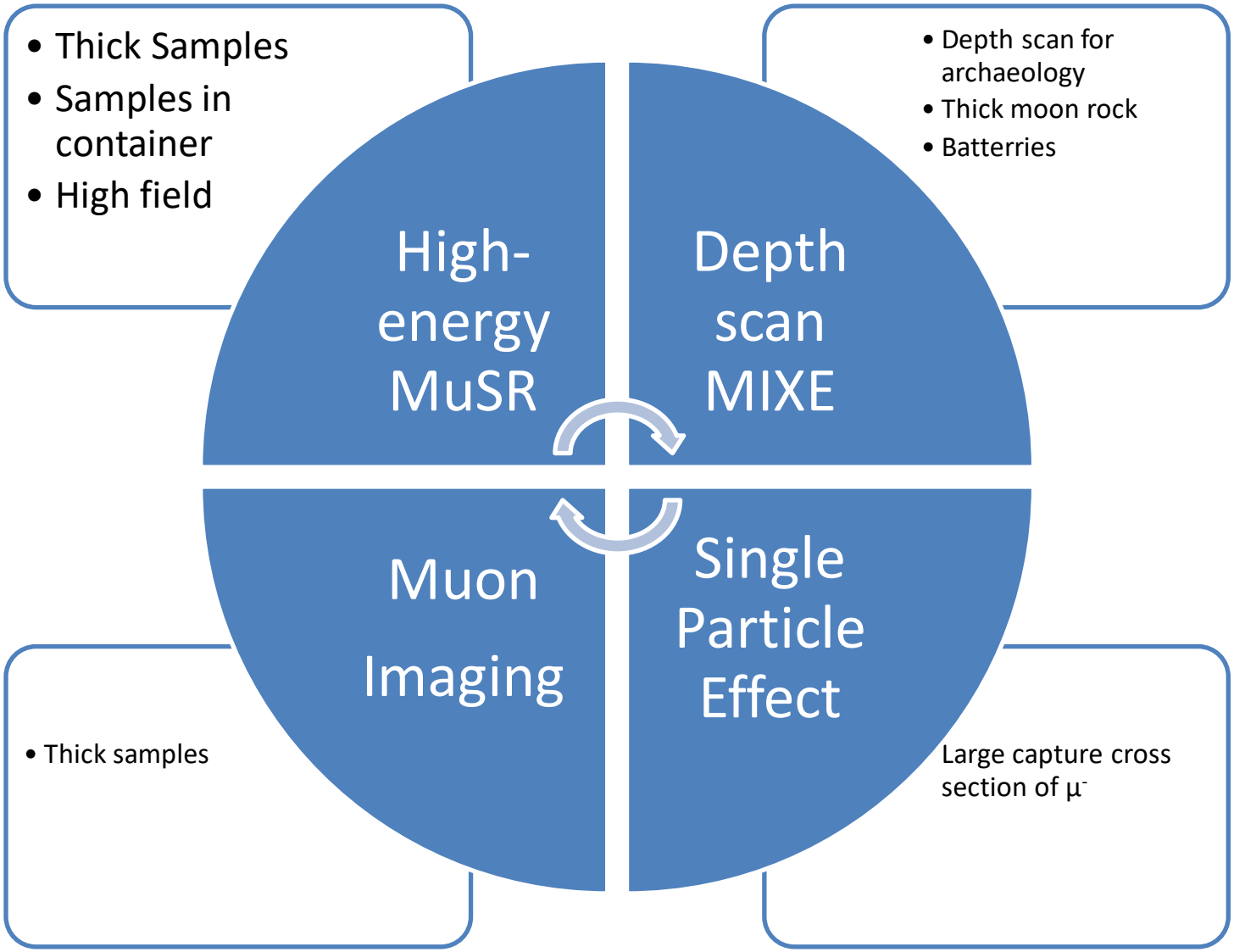
Decay Muon Beam





- 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

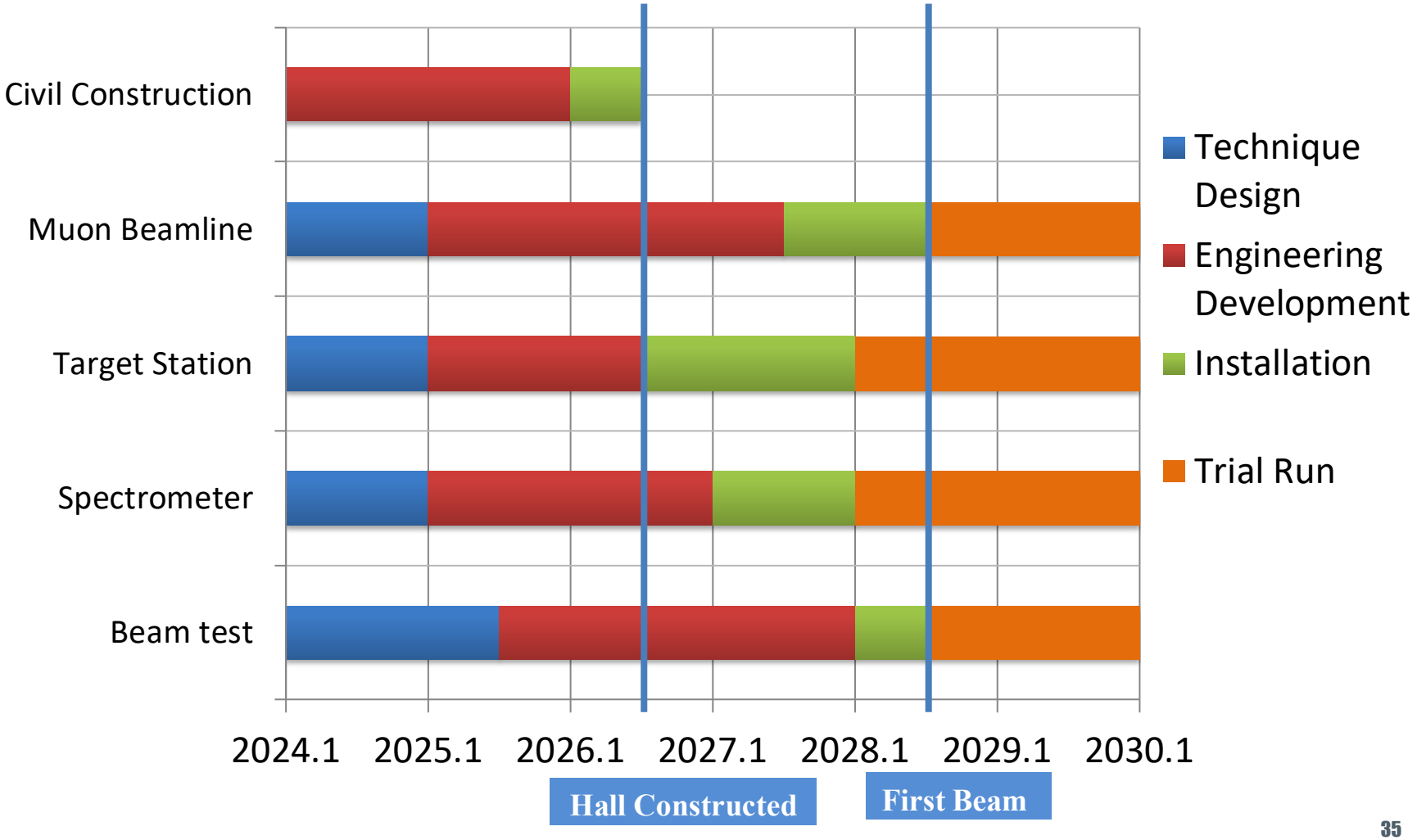


Muon Beam Parameters

	Surface Muon	Negative Muon	Decay Muon
Proton Power（kW）	20	20	20
Pulse width (ns)	130 to 10	500	130 to 10
Muon intensity（/s）	10^5 ~ 10^6	10^4 ~10^6	Up to 5*10^6
Polarization（%）	>95	NA	50~95
Positron（%）	<1%	NA	<1%
Repetition（Hz）	1	1	1
Terminals	2	1	2
Muon Momentum（MeV/c）	30	20 to 60	10 to 120
Full Beam Spot（mm）	10 ~ 30	10 ~ 30	10~30

MELODY Timeline

We are strictly on time!



Civil Construction



Constructed in 2.5 years

Workshops of MELODY





Welcome to CSNS !

MELODY team

- Target：Chen Wu、Lei Liu、Gang Zhang、Ning He、Zhiduo Li、Nikos Vasiloploss、Jiaxin Chen、Zhixin Tan、Yu Liu、Congju Yao、Yongji Yu、Guangyuan Wang、Junsong Zhang、Huihong Liang、Huayan He、Yuanguang Xia
- Beamlines：You Lv、Cong Chen、Guangdong Liu 、Changdong Deng、Yuwen Wu、Junhao Wei、Xin Qi、Wenqing Zhang、Pengcheng Wang、Yuliang Zhang、Yongcheng He
- Spectrometer：Qiang Li、Ziwen Pan、Yang Li、You Lv、Hao Liang、Tianyi Yang、Bangjiao Ye
- Assistant：Xiaoyin Mo, Jucheng Shi
- Coordinator: Yu Bao