WORKSHOP OF MELODY2023

Muon station for sciEnce technoLOgy and inDustrY (MELODY) @CSNS II

Yu Bao

On Behalf of MELODY Collaboration

2023.4.15 @ TDLI

Outlines

- Introduction on CSNS and CSNS II project
- MELODY design
  - Target station
  - Muon beamlines
  - μSR Spectrometer
  - Beam measurement
- Prospect of MELODY II:
  - Muon beam technology
  - Muon physics? - future muon facility?
- Summary

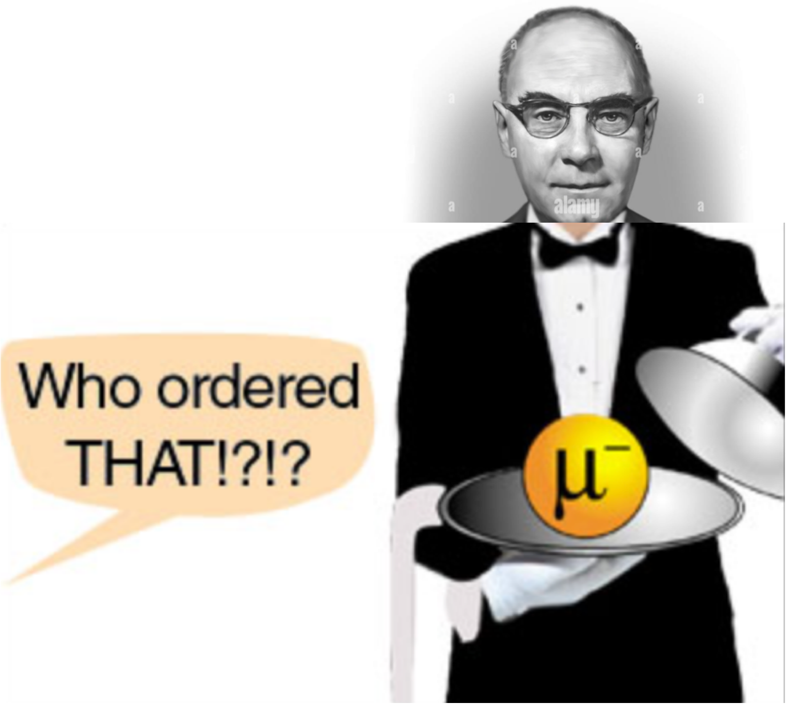
Birth of muon


Science & Technology

Who Ordered the Muon?

THE HUNTING OF THE QUARK

By Marcia Bartusiak

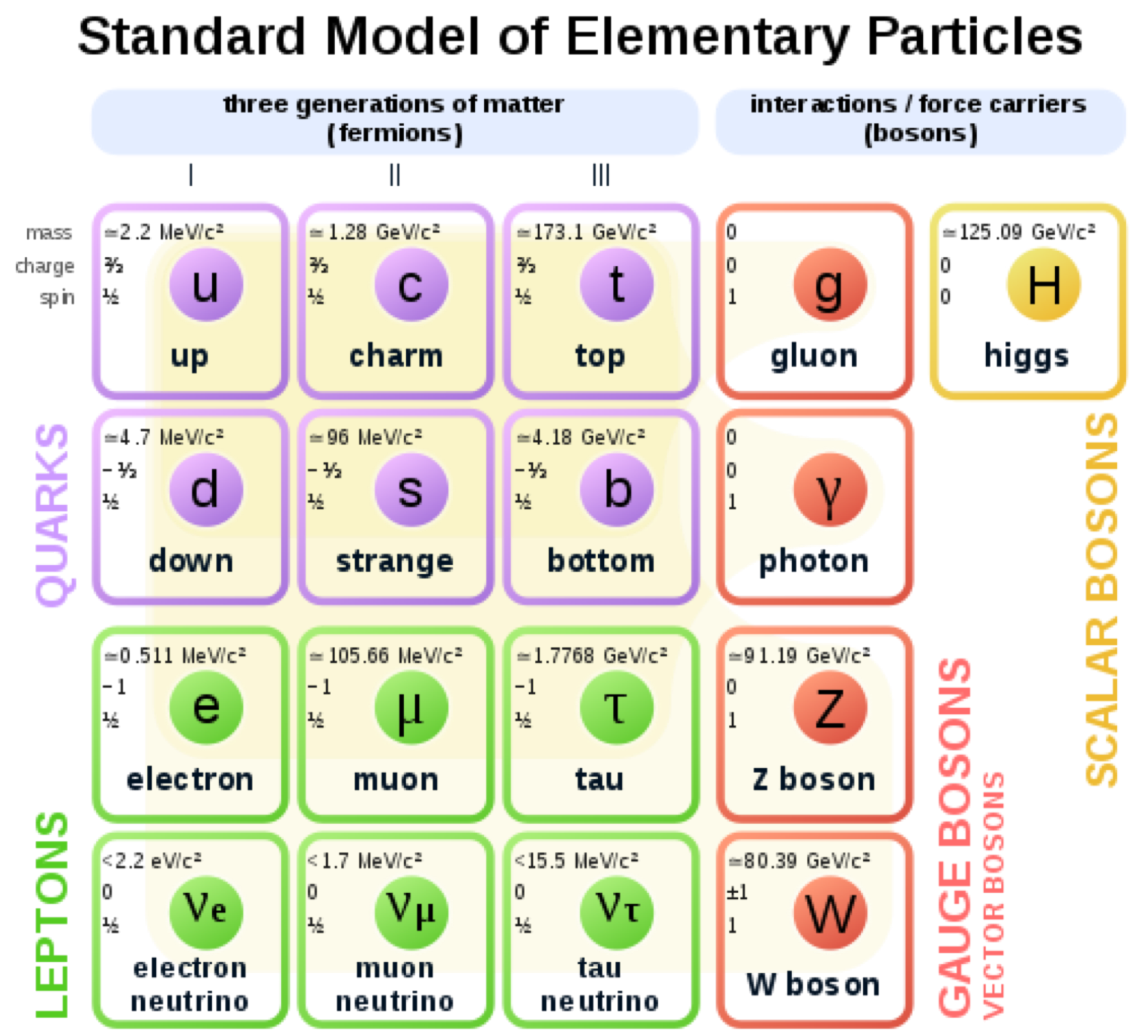


Carl Anderson
Nobel Price 1936

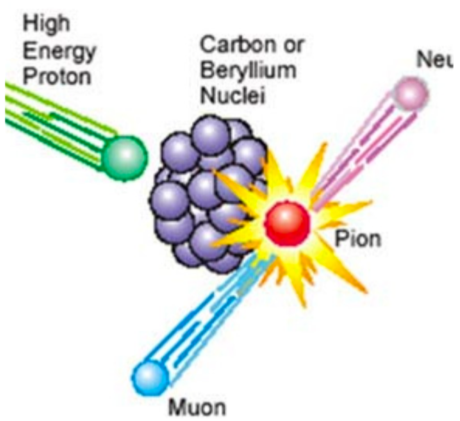
I. I. Rabi
Nobel Price 1944

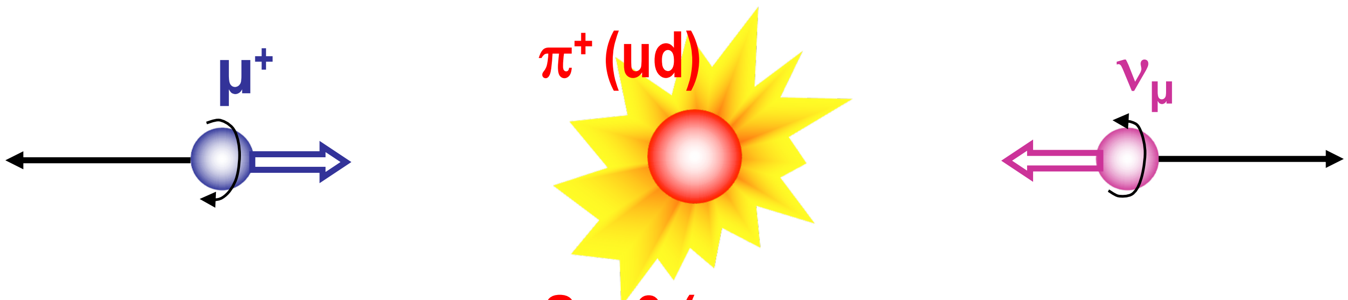
Muon

- Mass: 106MeV/c2
- Charge: mu-、mu+
- Life: 2.2us



Production of Muons



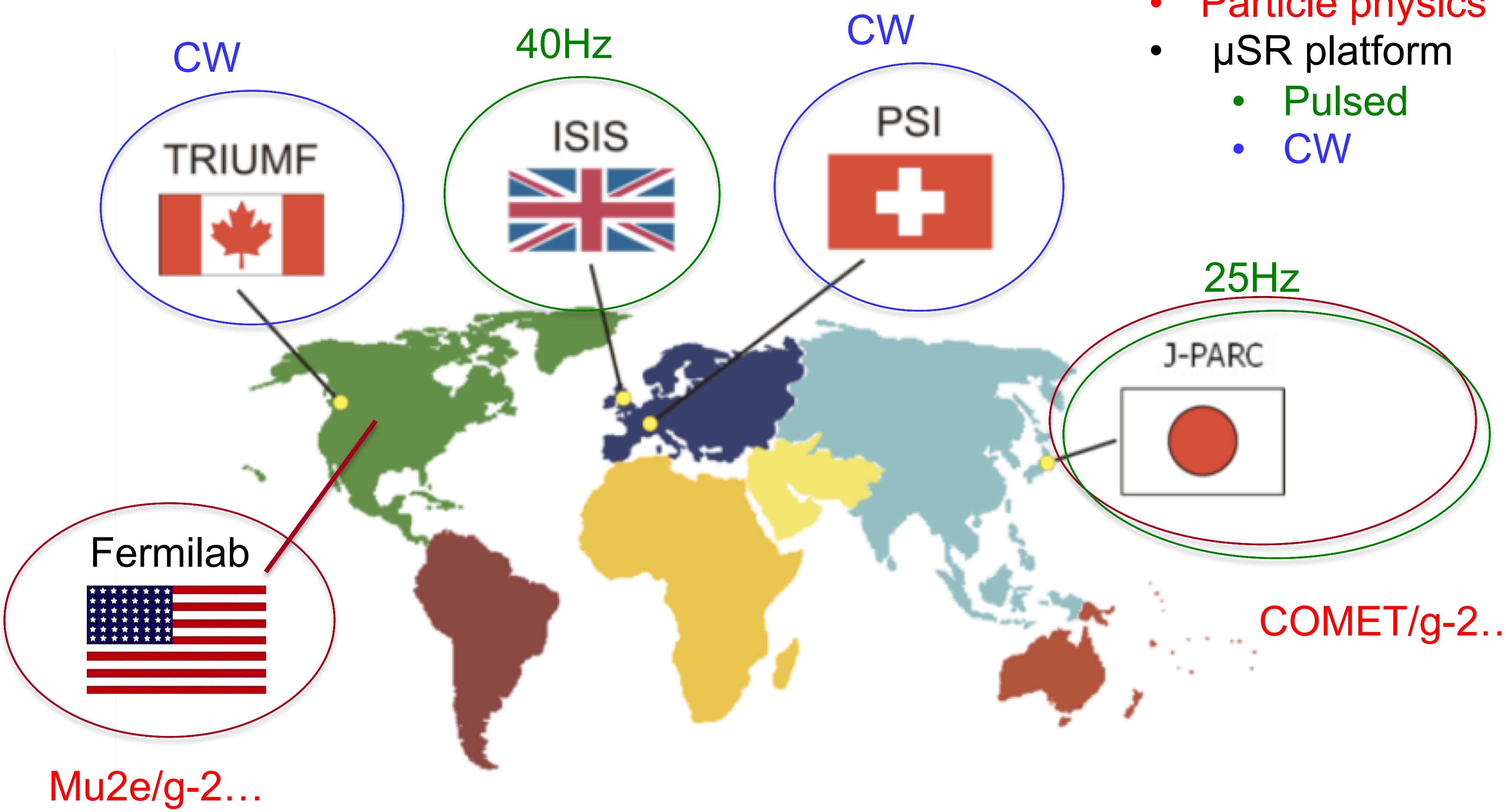


Two-body decay reference ▶ muon has always the energy 4.1 MeV in the frame of the pion (assuming m_ν = 0)

Spin pion = 0 ▶ Muon has a spin 1/2 and is 100% polarized (as only left-handed neutrinos are produced)

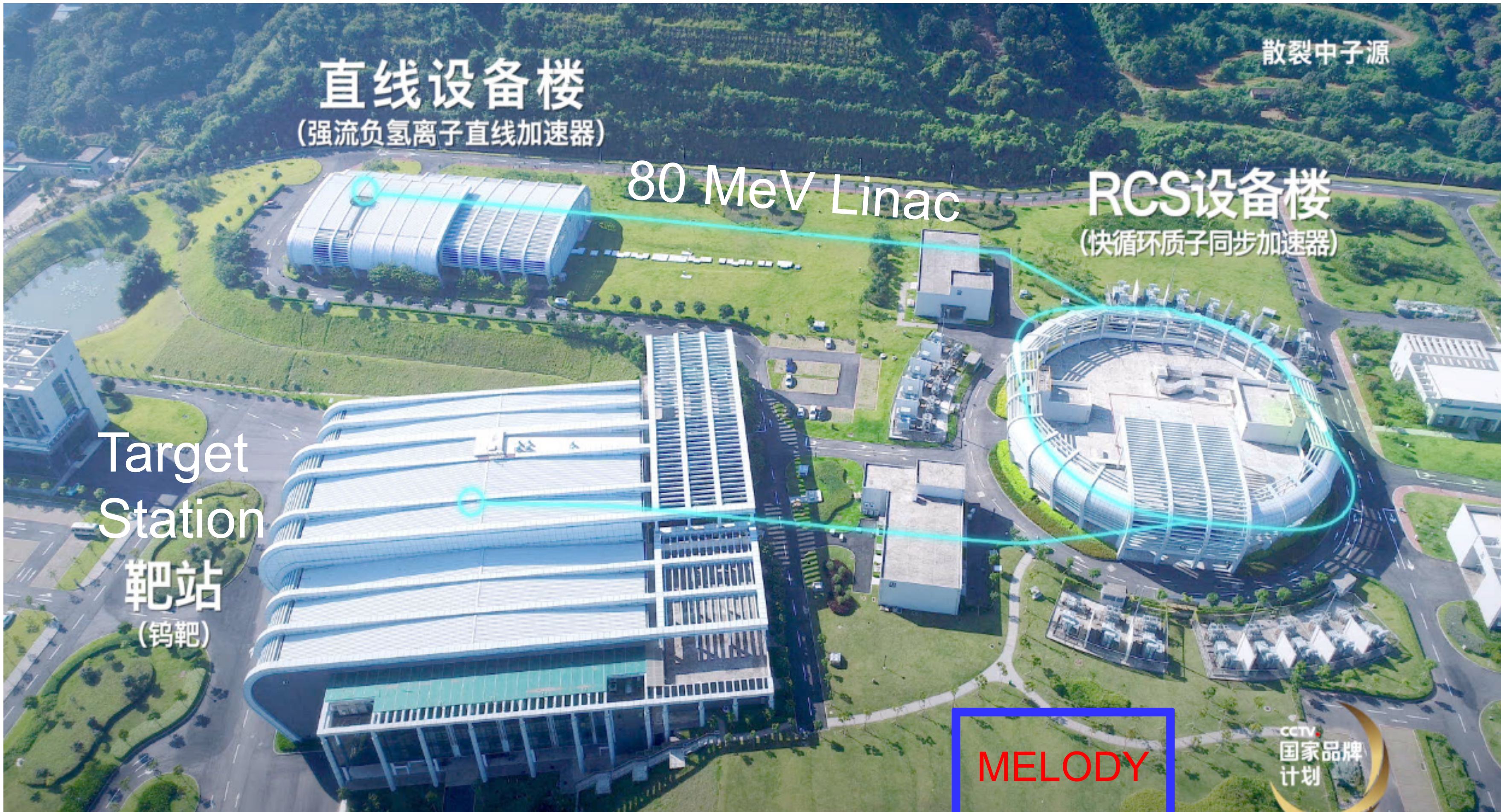
Muon facilities

- Particle physics
- μSR platform
  - Pulsed
  - CW



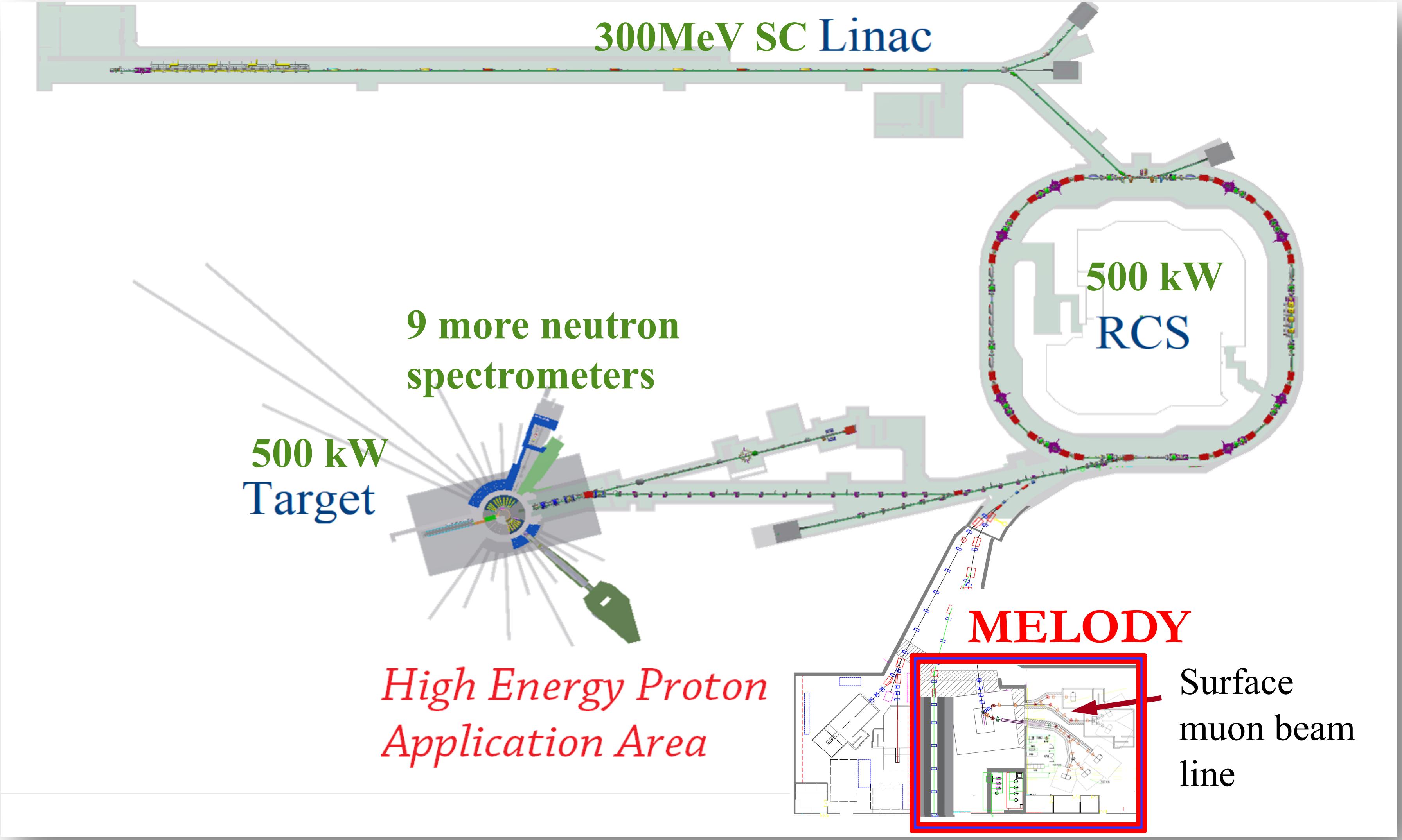
China Spallation Neutron Source

China Spallation Neutron Source (CSNS)

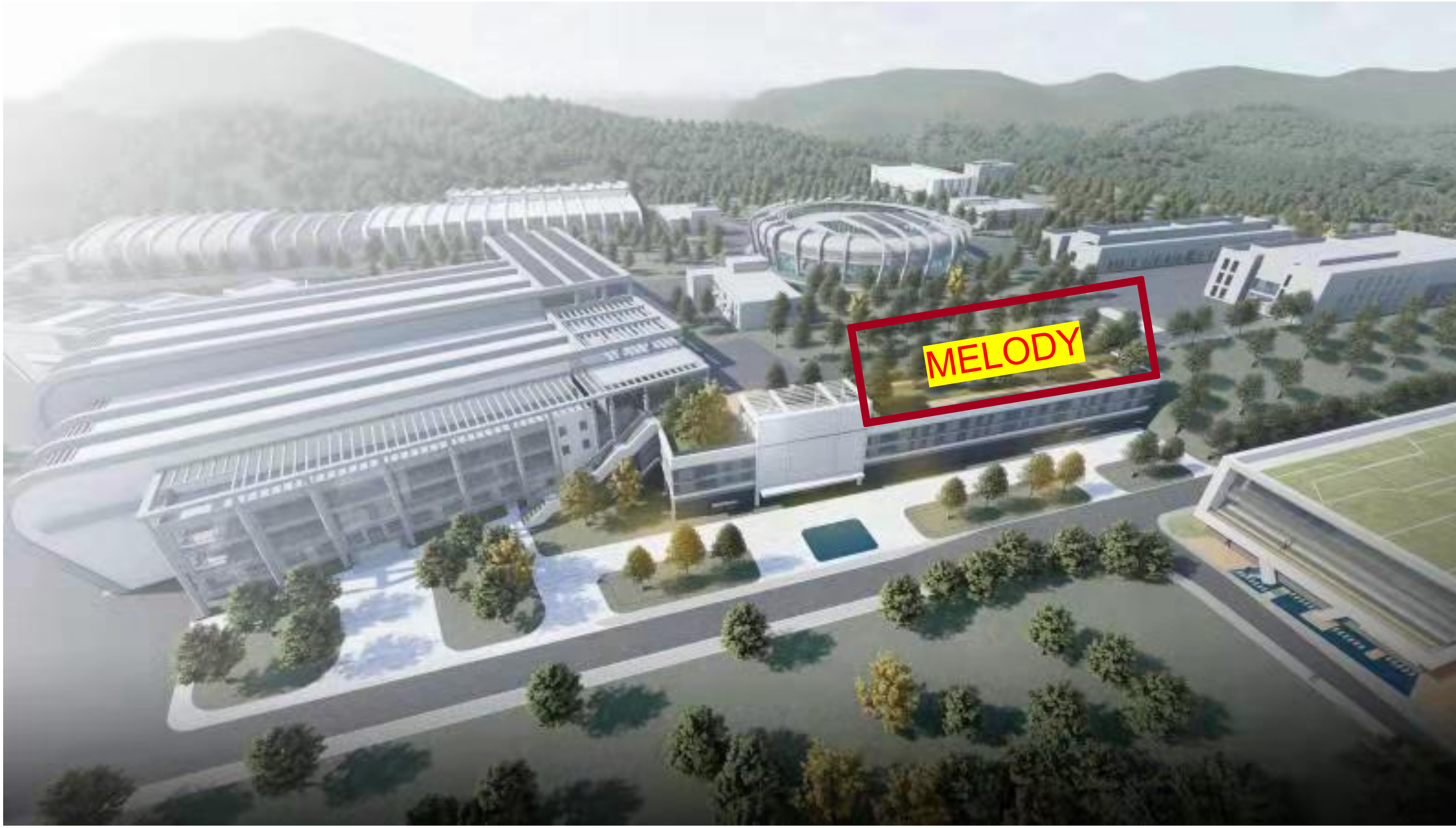


Accelerator: 100kW 25Hz 1.6GeV proton beam
Neutron Spectrometers: 7 built and 3 under construction

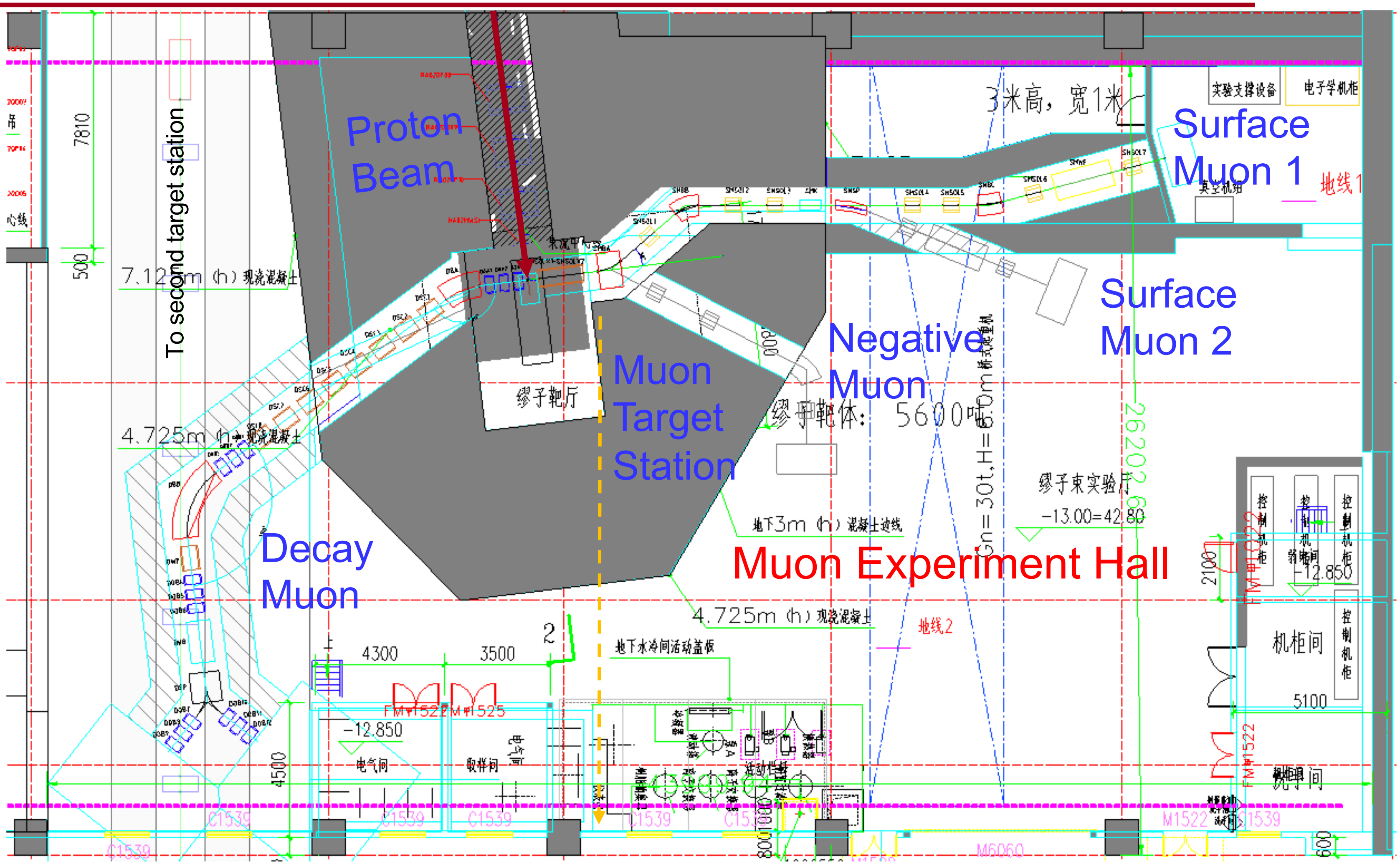
CSNS II Project



Architectural Design of MELODY

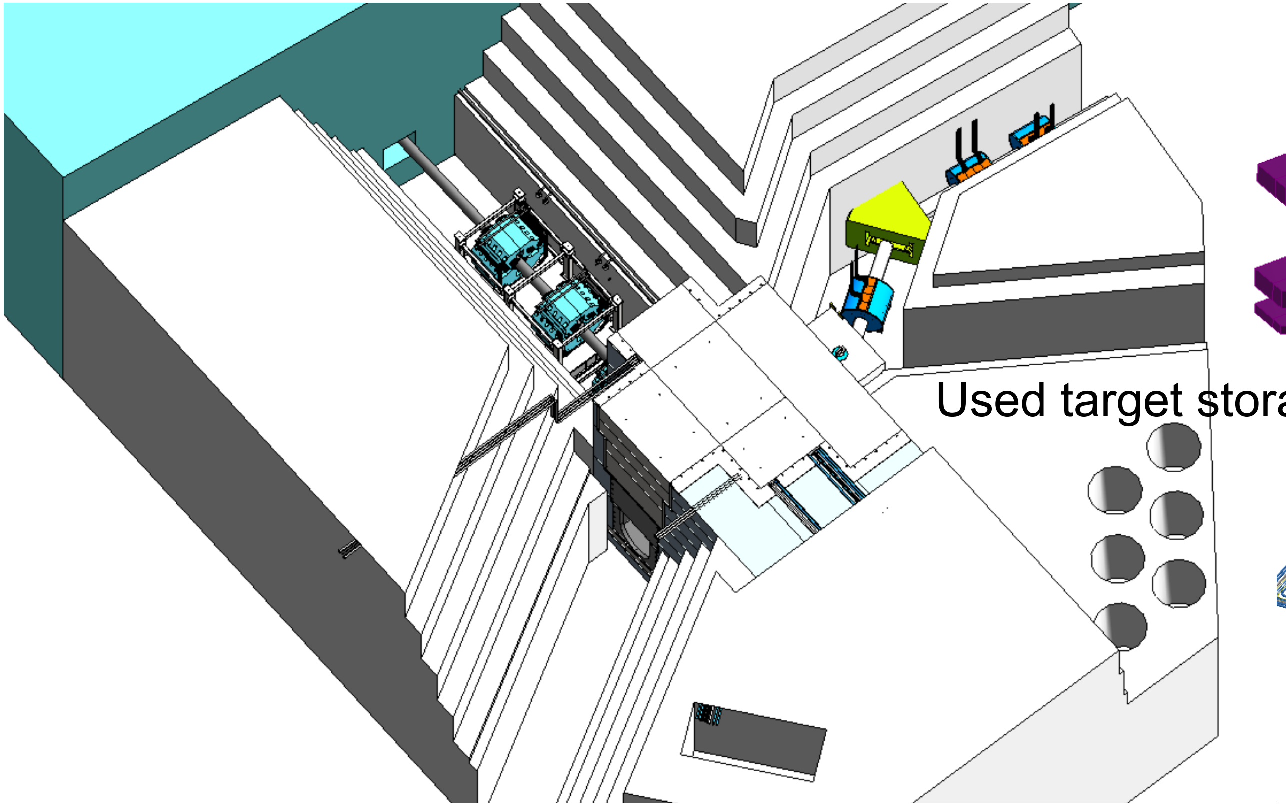


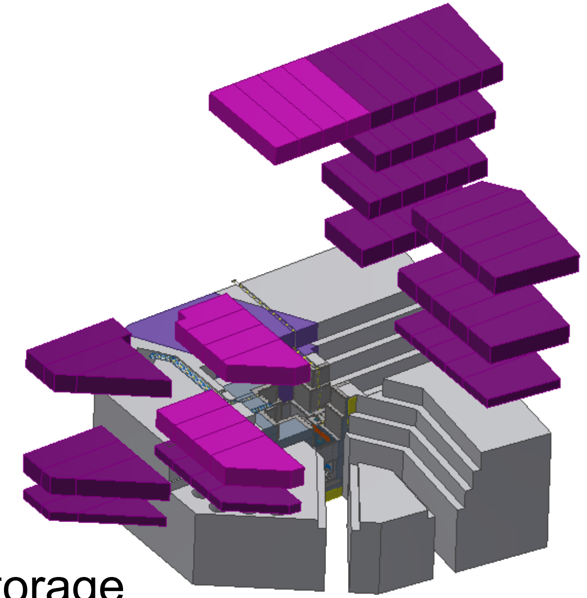
MELODY Design

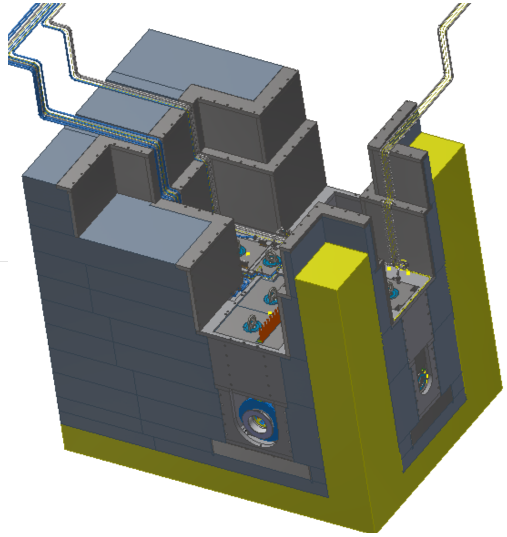


- Protons: 1.6GeV, 1 Hz (up to 5Hz), 130ns double pulses
- Muon beamlines: one **surface muon** and one decay muon beam
- Spectrometers: **1 μSR spectrometer** and more…

Muon Target Station

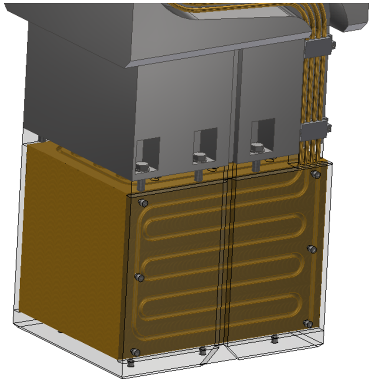






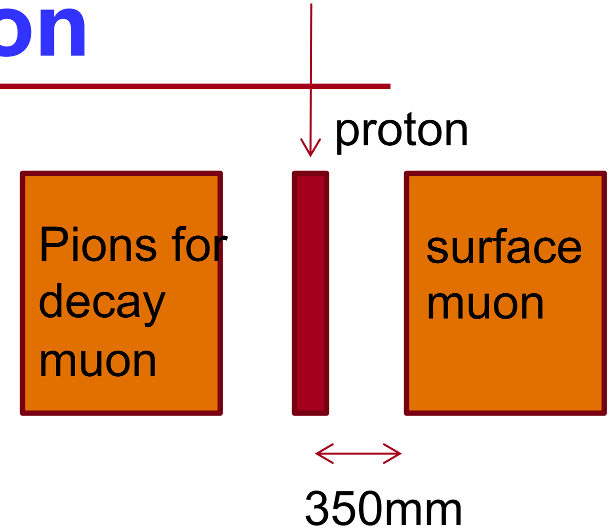
Shielding: Iron 5m*4m*4m
Concrete 5.5*5.5m*1m

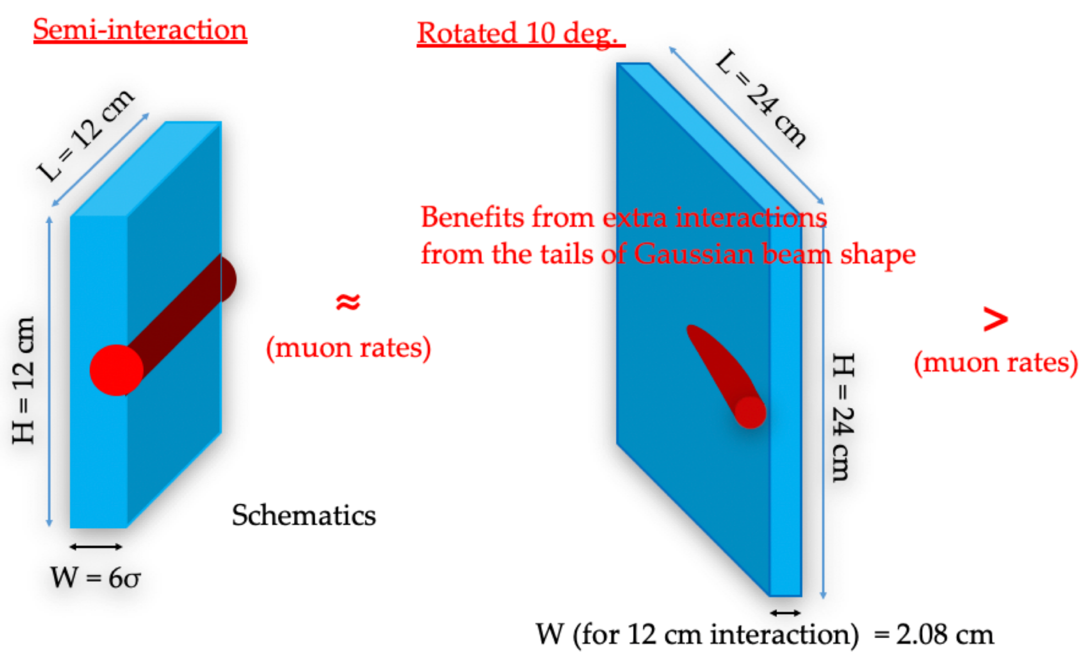
Beam absorber: Copper

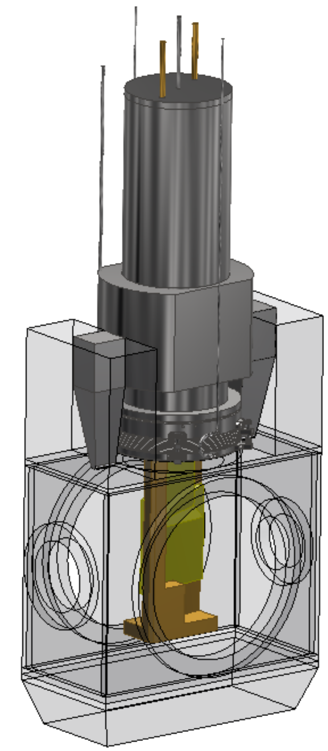


Muon Target Optimization

- Use Copper/Graphite as target
- Optimize the surface muon production with rotation of 11°
- Optimum: 240*240*11 mm for Cu
  240*240*14 mm for C

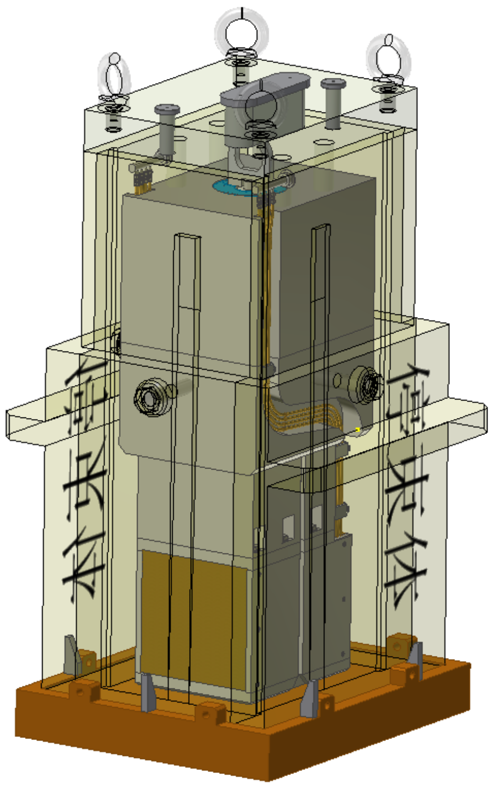




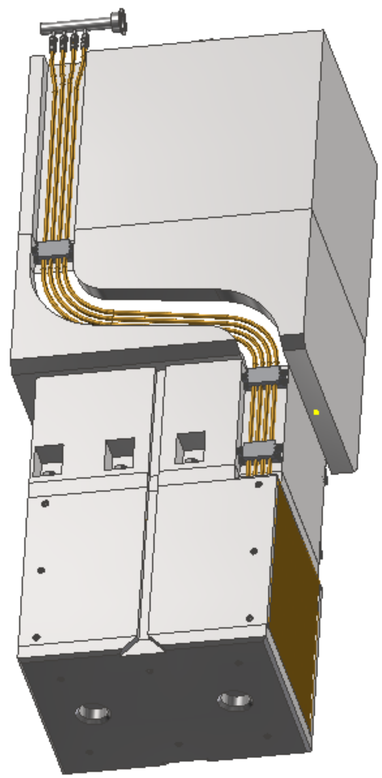


Maintenance

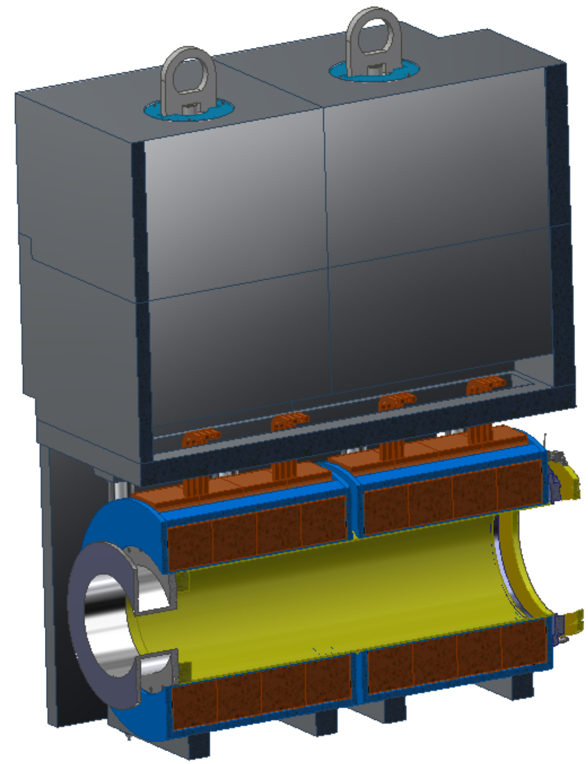
Target flask



Beam dump

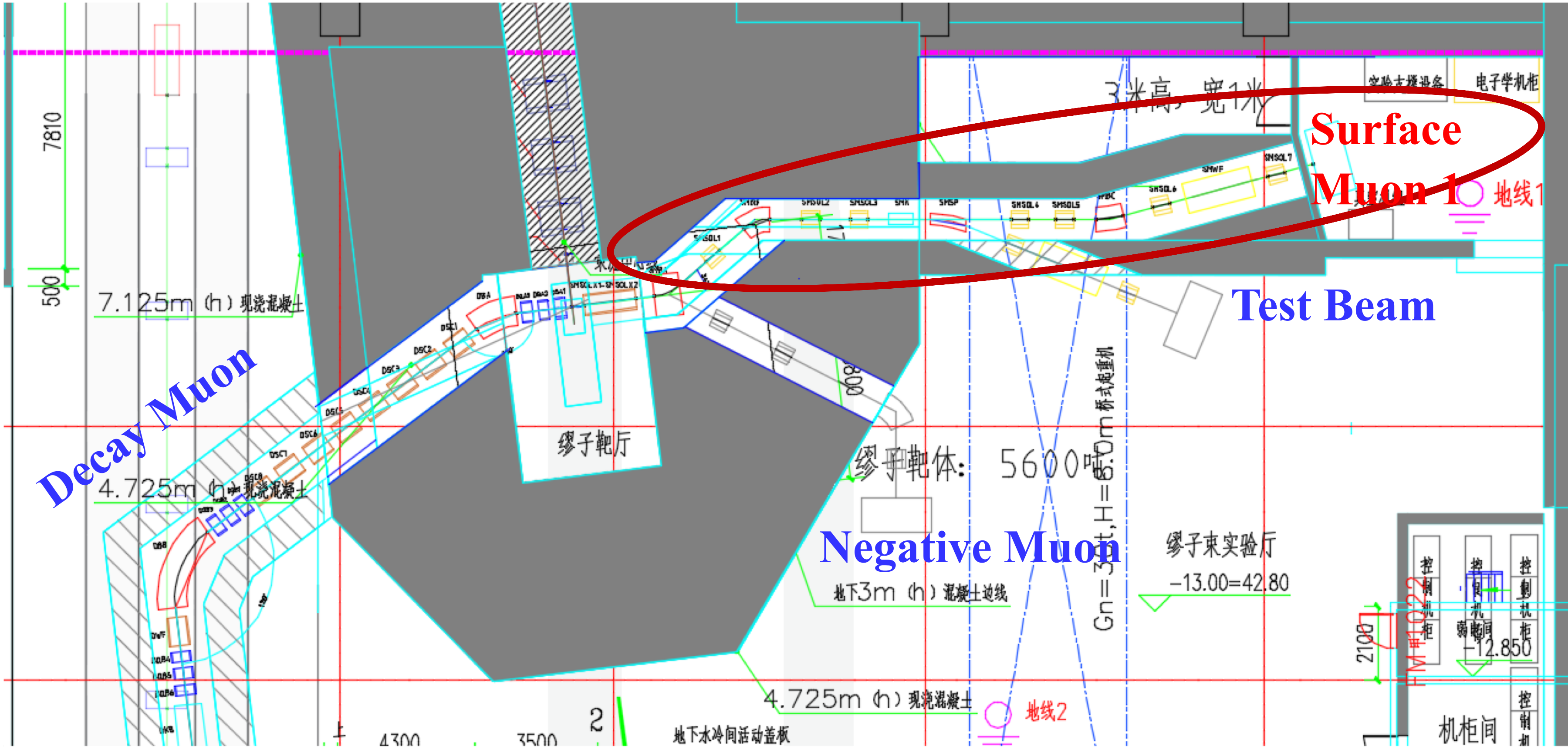


First solenoid



- Remote maintain from the top
- Target/magnets/absorber/flange
- Water cooling system

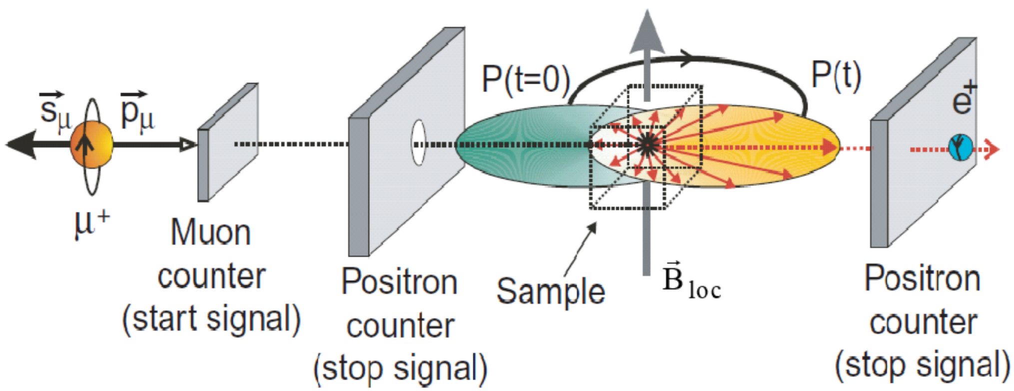
Surface Muon Beam

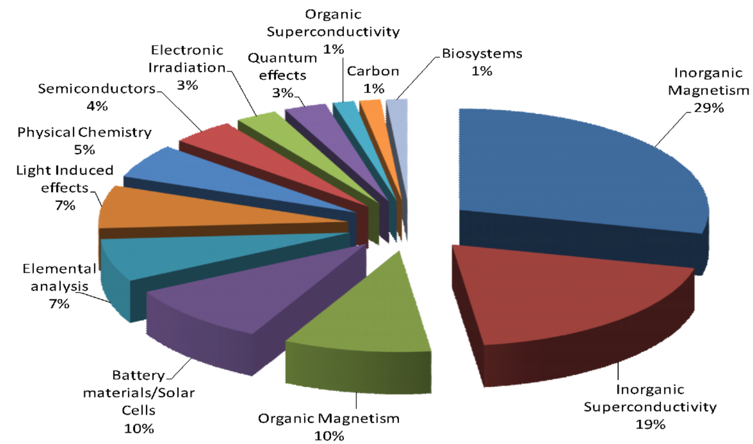


- **Energy：4 MeV**
- **Polarization: >95%**
- **Intensity：10^5~10^7 μ^+/s**
- **Time Resolution: 120ns**

Surface Muon application

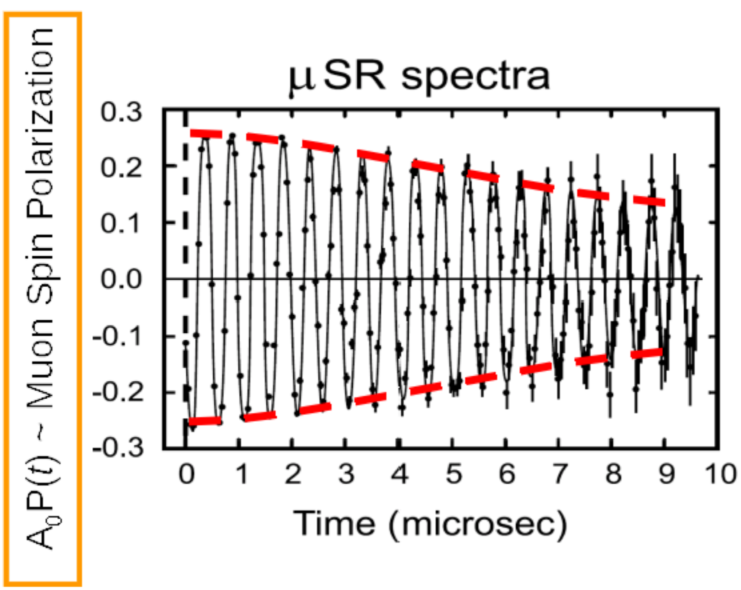
Principle of MuSR





MuSR：Magnetic material, superconductivity, battery, semiconductor

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



$A_0P(t)$ contains the physics:

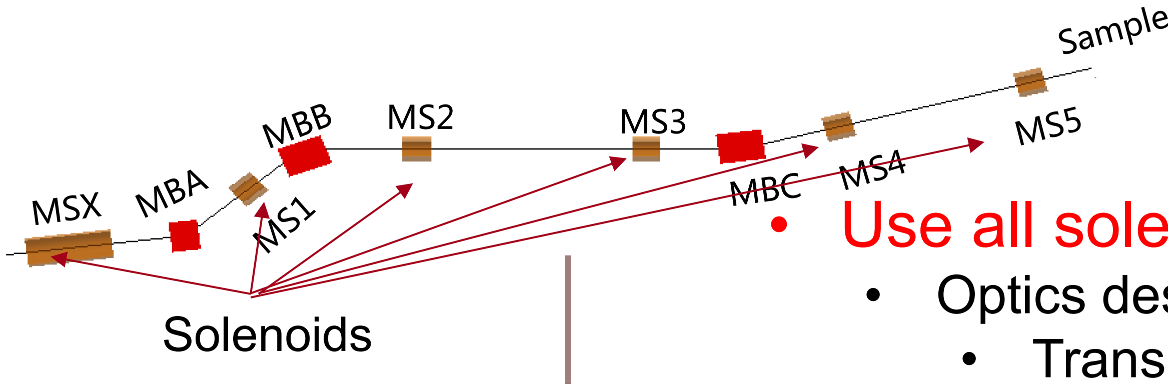
frequency: $\omega_L = \gamma_\mu B_{loc}$, value of field at muon site

damping: width of field distribution, fluctuations

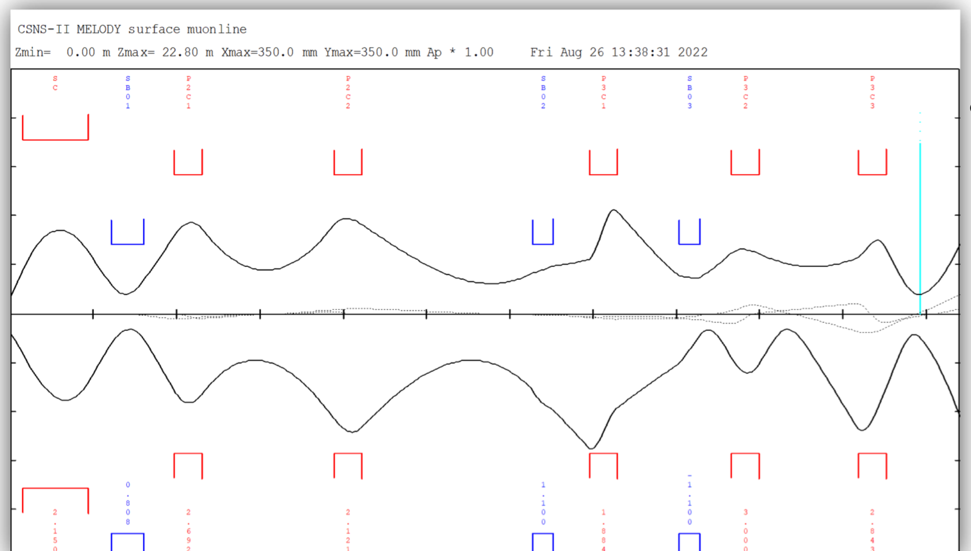
amplitude: magnetic/non-magnetic volume fraction, or Mu fraction

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

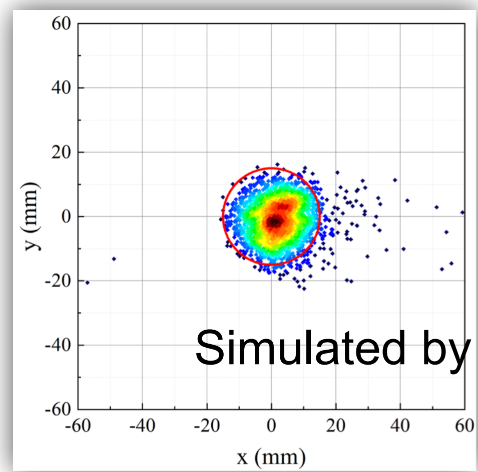
Surface Muon Beamline Design



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



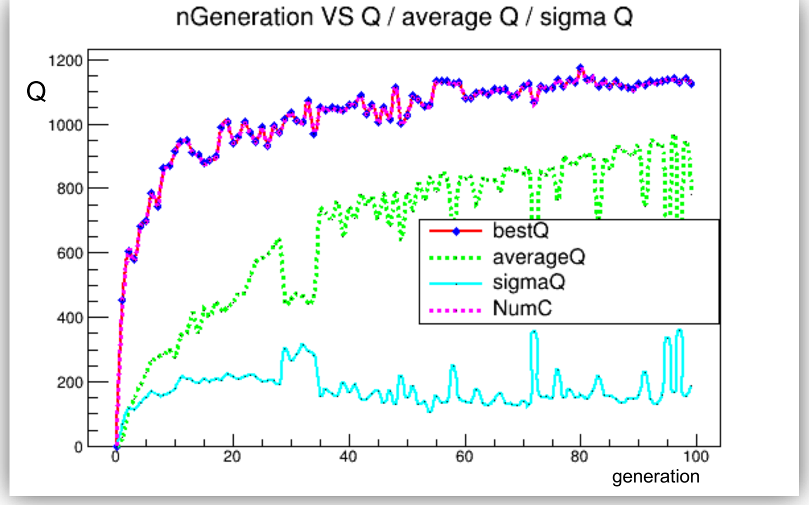
Designed by Transport

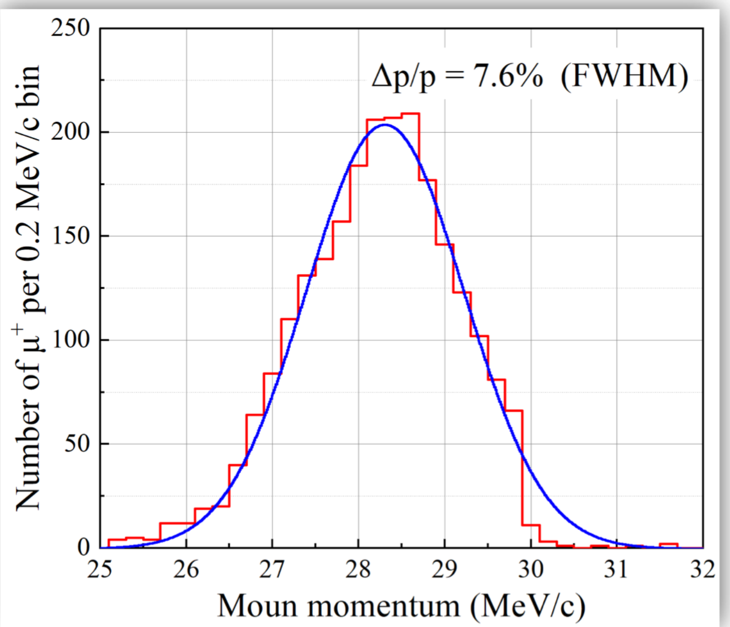


Simulated by G4beamline

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

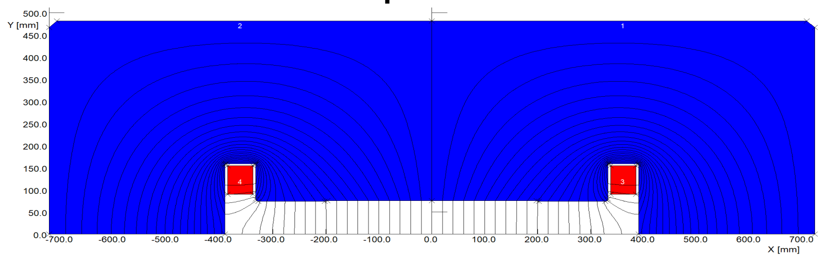




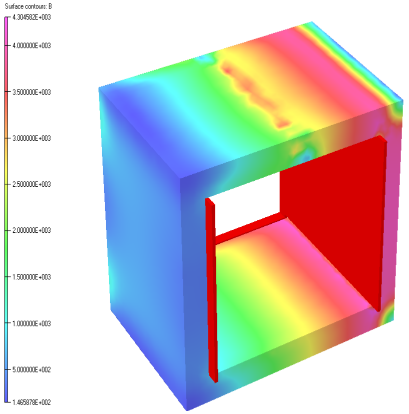
Parameters	G4bl simulation
x (FWHM)	1.64 cm
y (FWHM)	1.84 cm
Δp/p (FWHM)	~ 7.6%
μ+ rate	18.2×10^5 μ^+/s
μ+ rate on ϕ30 mm	**15.7×10^5 μ^+/s**
Core ratio	91.24%
Polarization	**~ 95%**
e^+/μ^+	<0.01

Technique design of the magnets

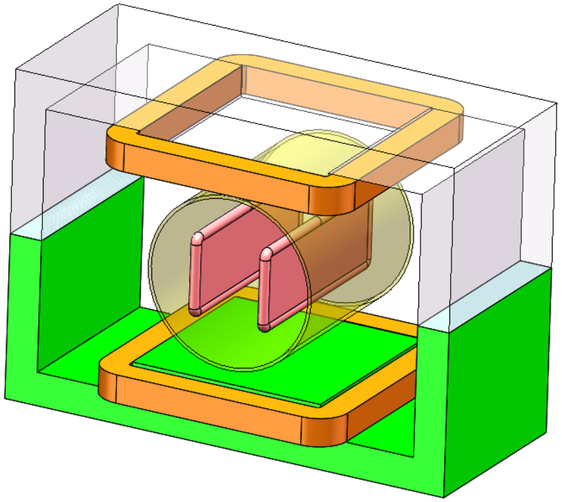
Dipole

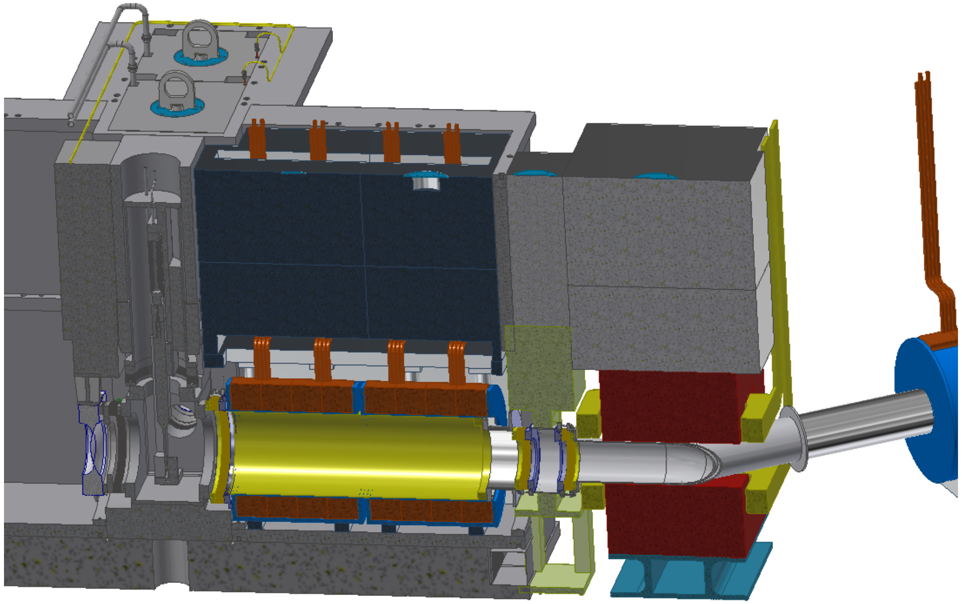


Kicker



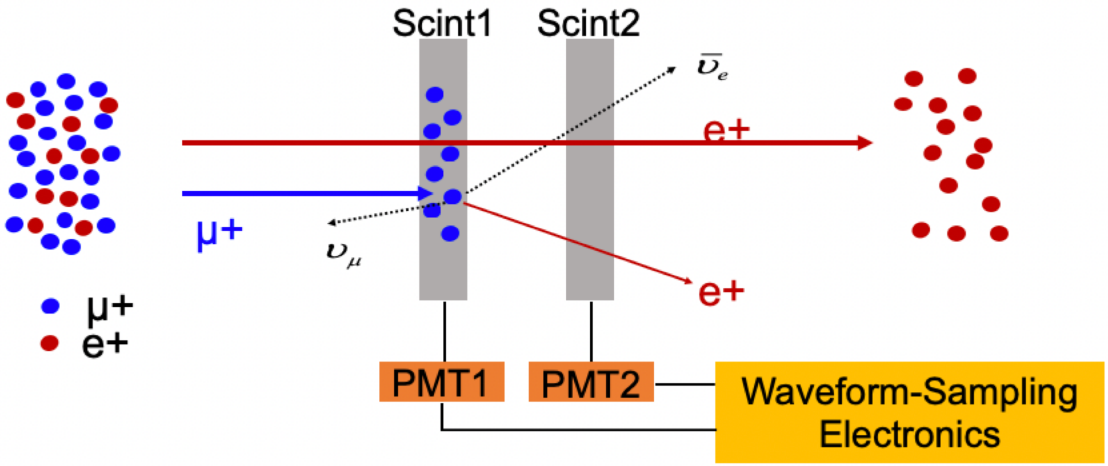
Wein fielter



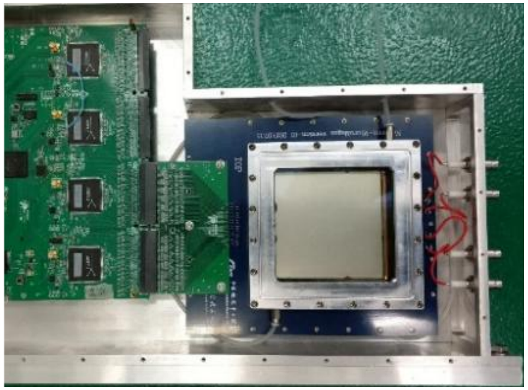


Mechanical design of the magnets

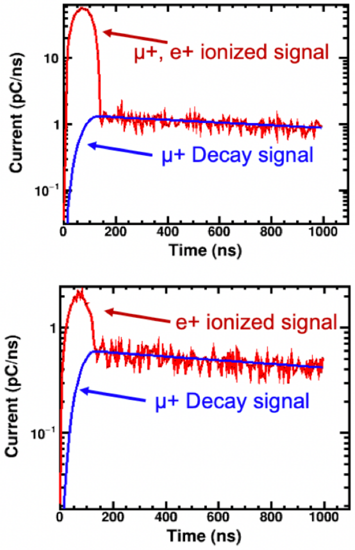
Beam measurement



Beam intensity measurment



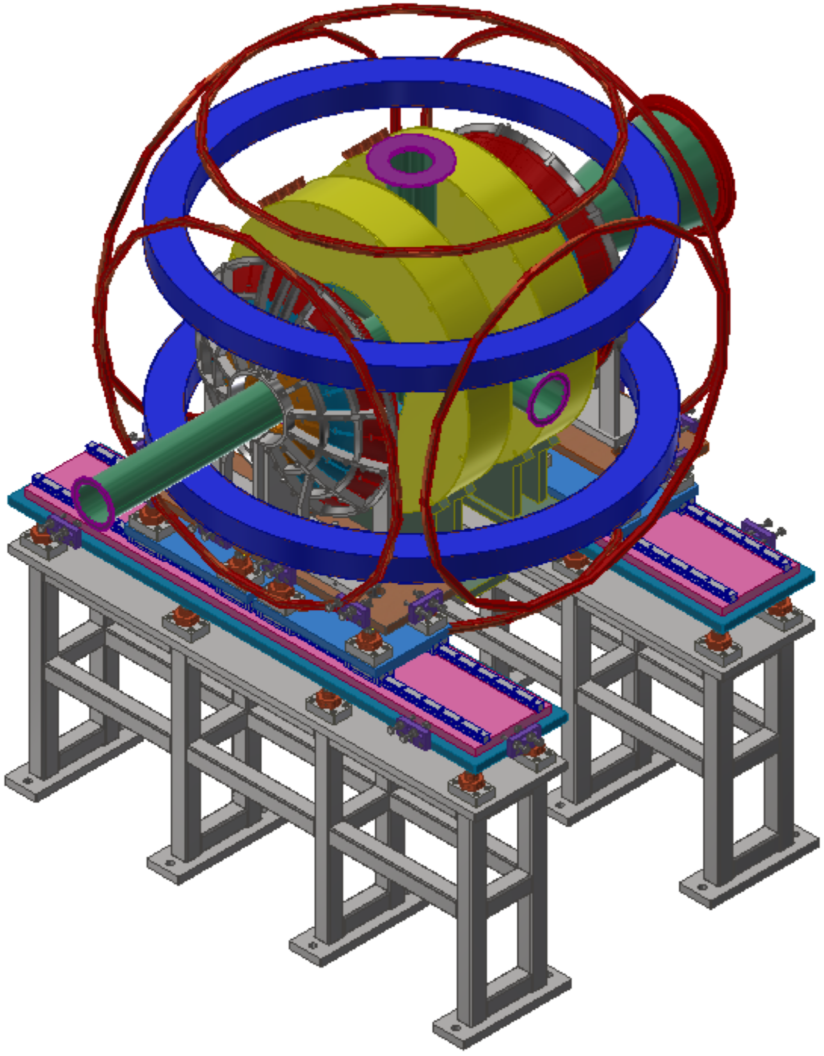
Beam spot monitor



- Measure muon beam intensity by double scintillators
  - ➢ Distinguish positron content
- Measure beam spot size with a MicroMegas detector
- Challenge: high intensity in one pulse
  - ➢ Need more online tests

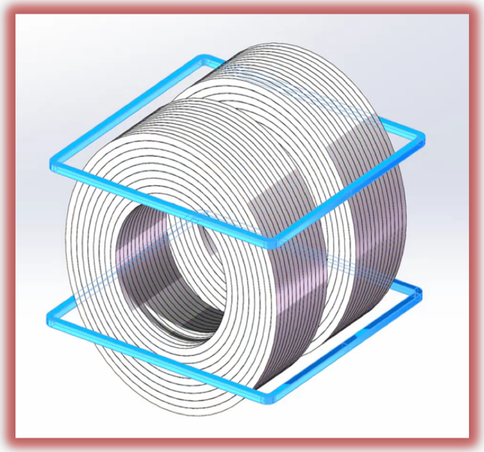
μSR Spectrometer

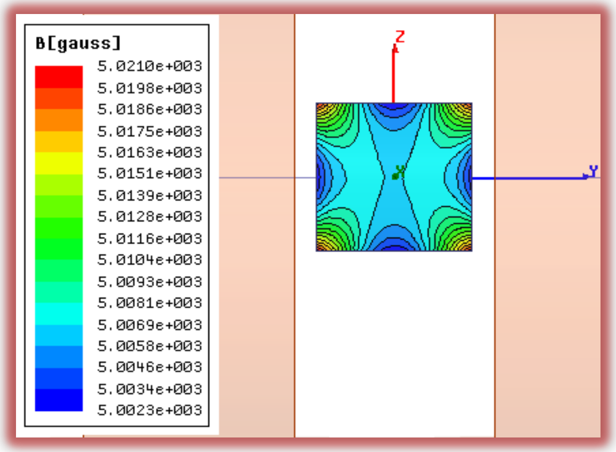
- **Feature:** High single-pulse intensity
- **Detector unit**: ~ 3000 detectors (scintillator+SiPM) pointed to sample
- **Electronics**: ASIC based FEE + multi-stop TDC
- **Fly-pass structure**

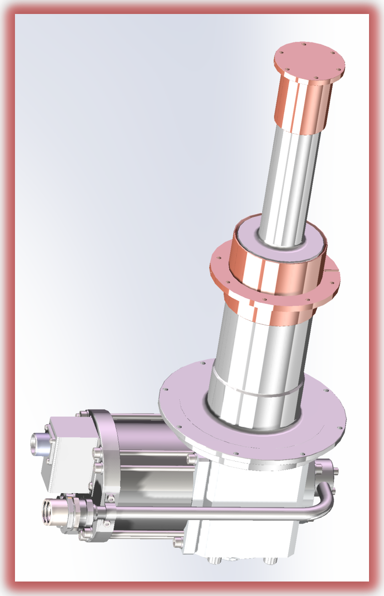


Sample Environment

- Magnetic field：
  - LF:5000G，TF:400G
  - Homogeneity < 100ppm @ 40*40*10mm sample area
- Low temperature：
  - CCR: 10 K ~ 600K (Start-up)
  - Cryostat: 2 K ~ 300K (Future)
  - Upgrade to 300mK (Future)

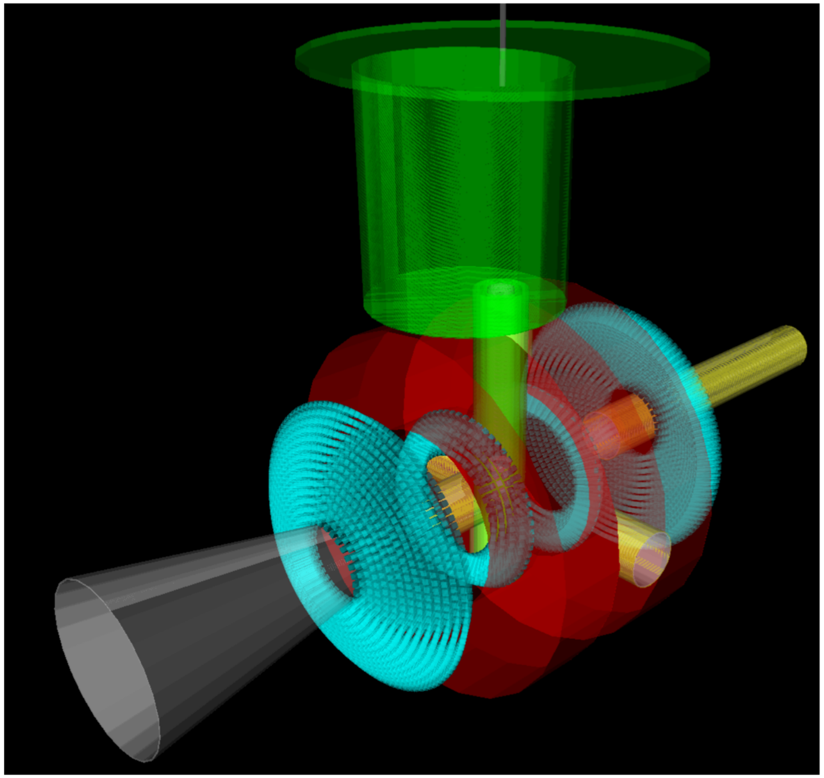


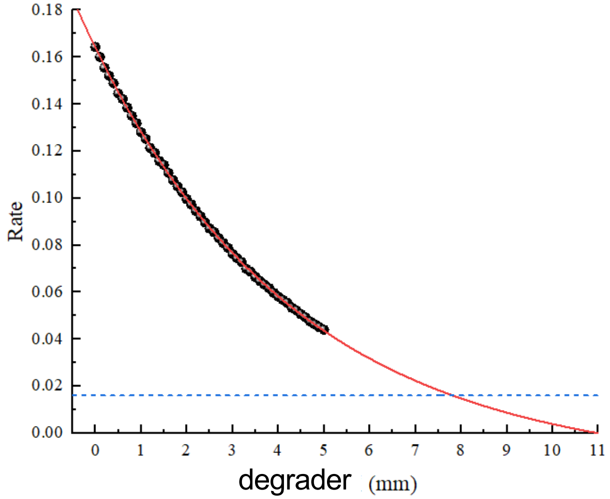


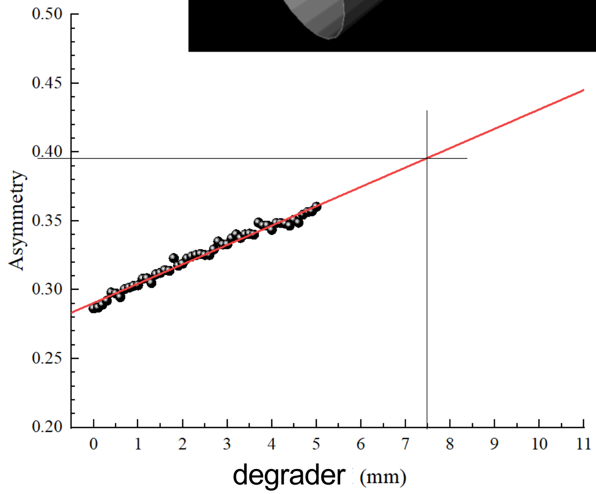


Simulation

- Investigated the boundary conditions:
- Use thick degrader to increase the Asymmetry
- Simulated results:
  - Counting rate: 80 Mevents/h
  - Asymmetry: 0.31







Pros and cons

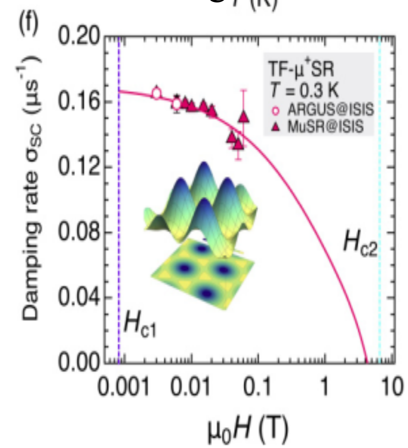
- High single pulse intensity：
  - Weak relaxing signal detection
  - Small beam spot
  - Beam slice to 10ns

- High asymmetry：
  - High precision

- Low repetition rate：
  - Low counting rate
    - ➢ More detectors

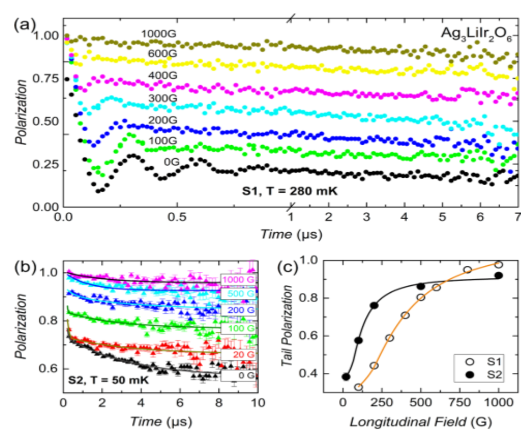
- Large pulse width：
  - Low time resolution
    - ➢ Beam slicing

Organic SC



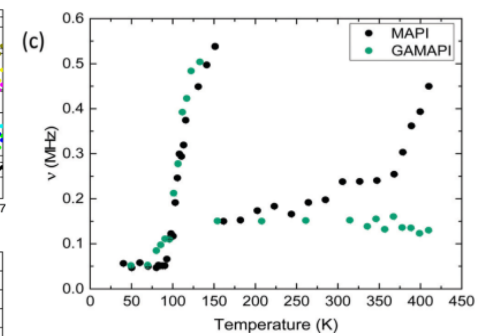
Phys. Rev. B **103** (2021) 125202

Spin Liquid



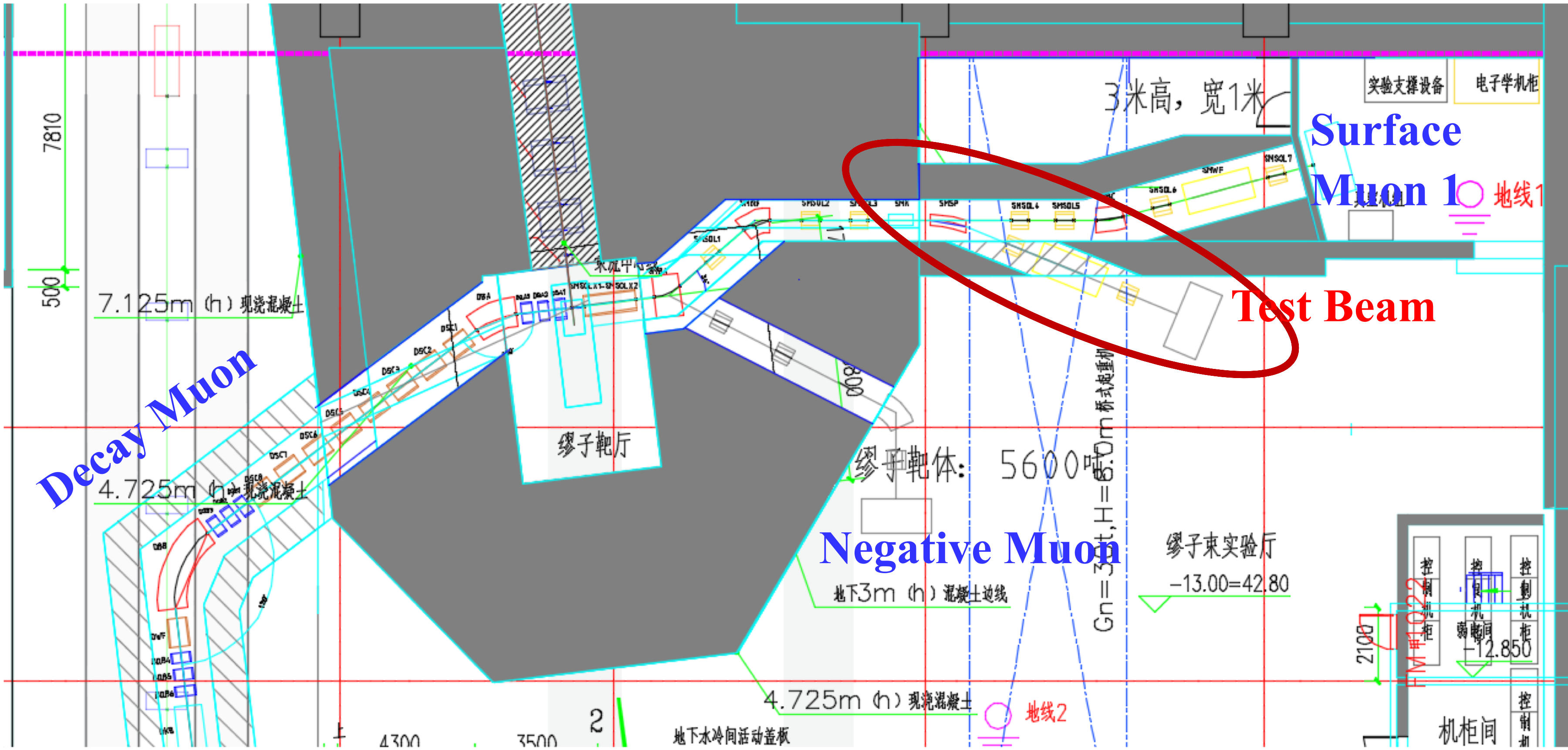
Phys. Rev. B **103**, (2021) 94427

Batteries



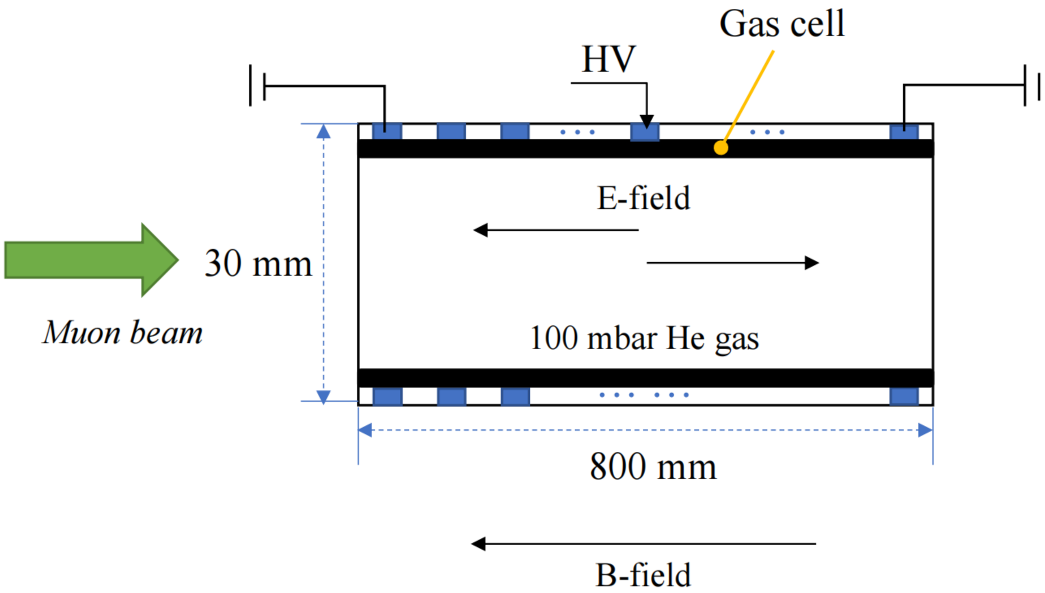
Energy Environ. Sci. **12**, (2019) 2264

Test Beam Port



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

Muon moderation technology



- μ^+ beam: 28 MeV/c, $\frac{\Delta p}{p} = 8\%$ (FHWM), $10^6\ \mu^+$
- Beam spot size: ϕ10 mm
- Energy degrader: 0.78 mm–thick carbon foil
- He gas: 100 mbar, 293 K
- Gas cell: ϕ30 mm, length 800 mm
- Electric field: ~ 0.11 kV/mm; HV applied at the center of the gas cell, i.e., decelerating (accelerating) E–field for the first (second) half
- Magnetic field: 5 T

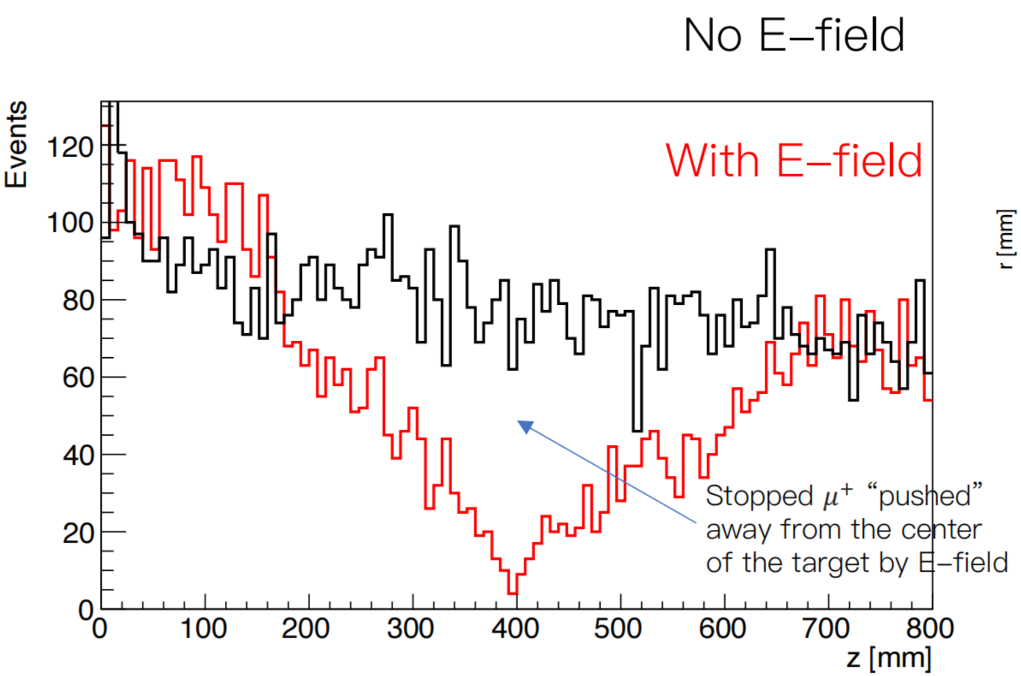
- Use helium gas to stop muons
- Use electric field to steer muon out of the gas cell
- Bring 0.1% muons to 300 eV

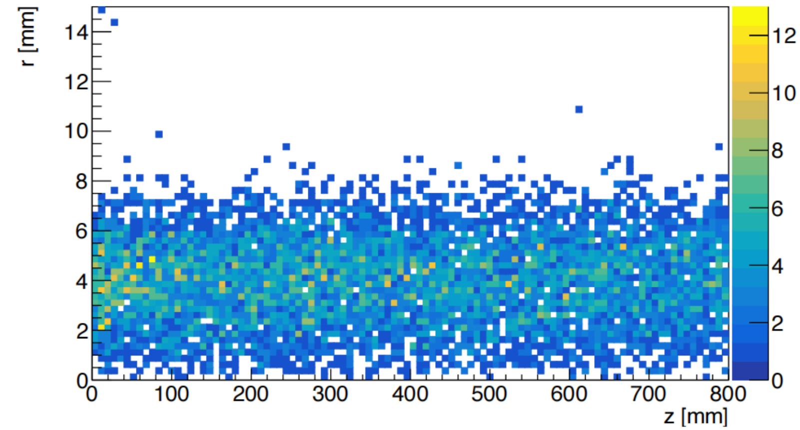
Key: use ESD material to remove the charge and to avoid breakdown in helium gas

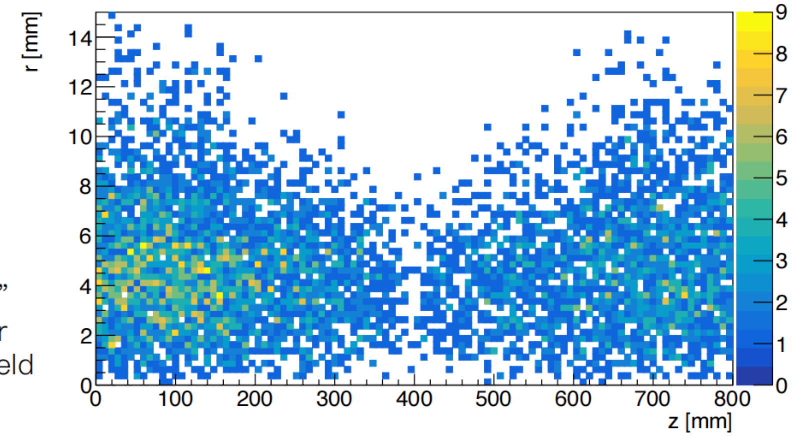
Muon moderation technology

Simulation

μ^+ stopped in He gas





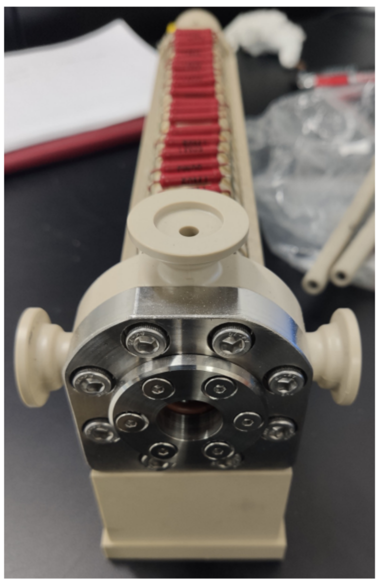


Going to be tested at ISIS...

Muon moderation technology

FCD Experiment

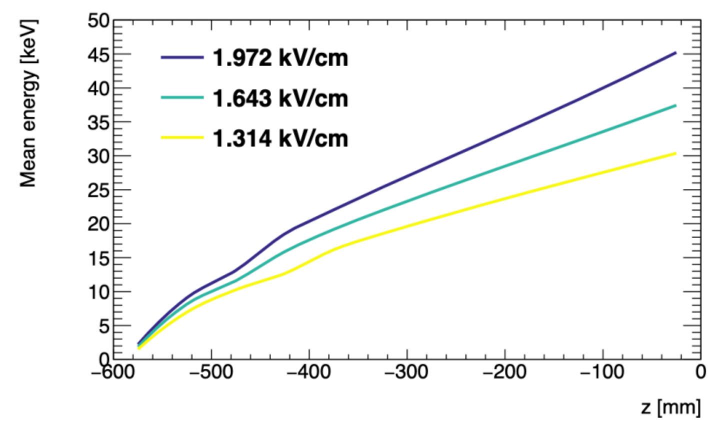
Gas cell



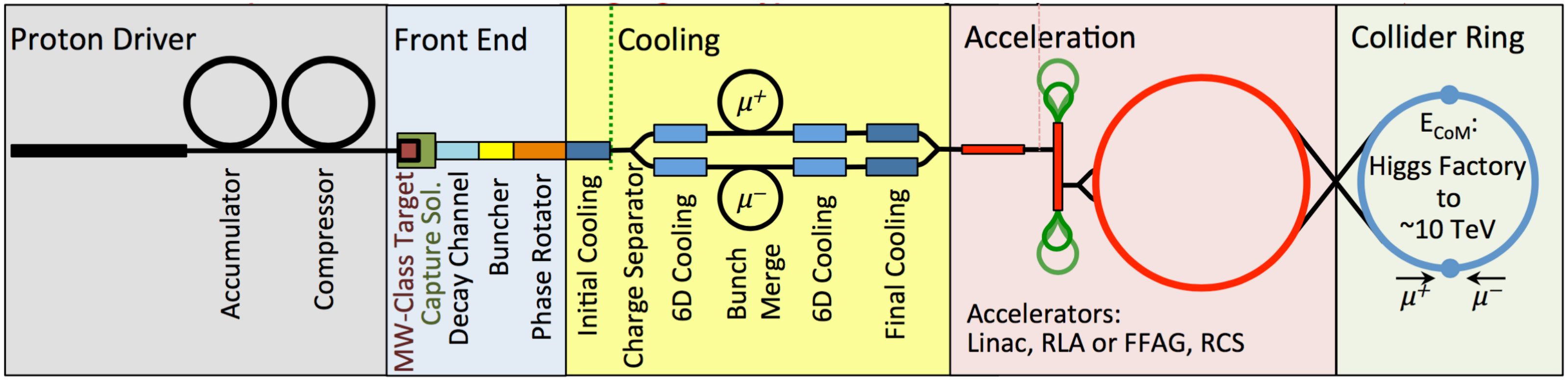
Proton source:
Am−241 + Mylar foil

Frictional cooling demonstration experiment with proton

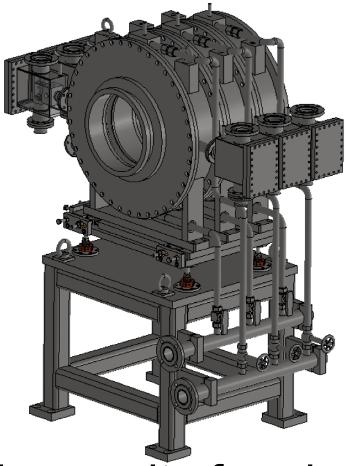
G4bl simulation
He gas: 1 mbar, 293 K
Proton initial energy: 1 eV
Proton initial z ~ −600 mm



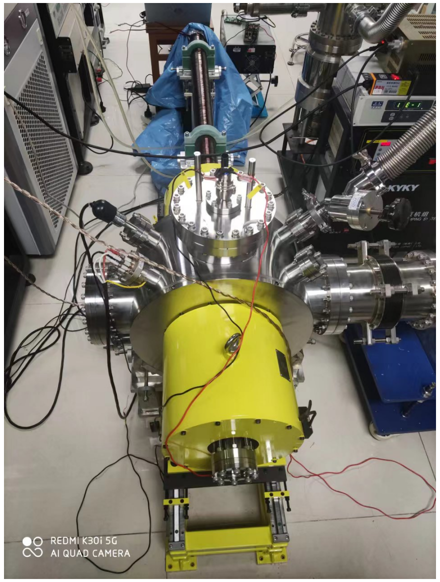
Muon de/acceleration/cooling



- Develop technologies for Muon Collider/Neutrino factory
  - Muon cooling
  - Phase rotation
  - Muon acceleration



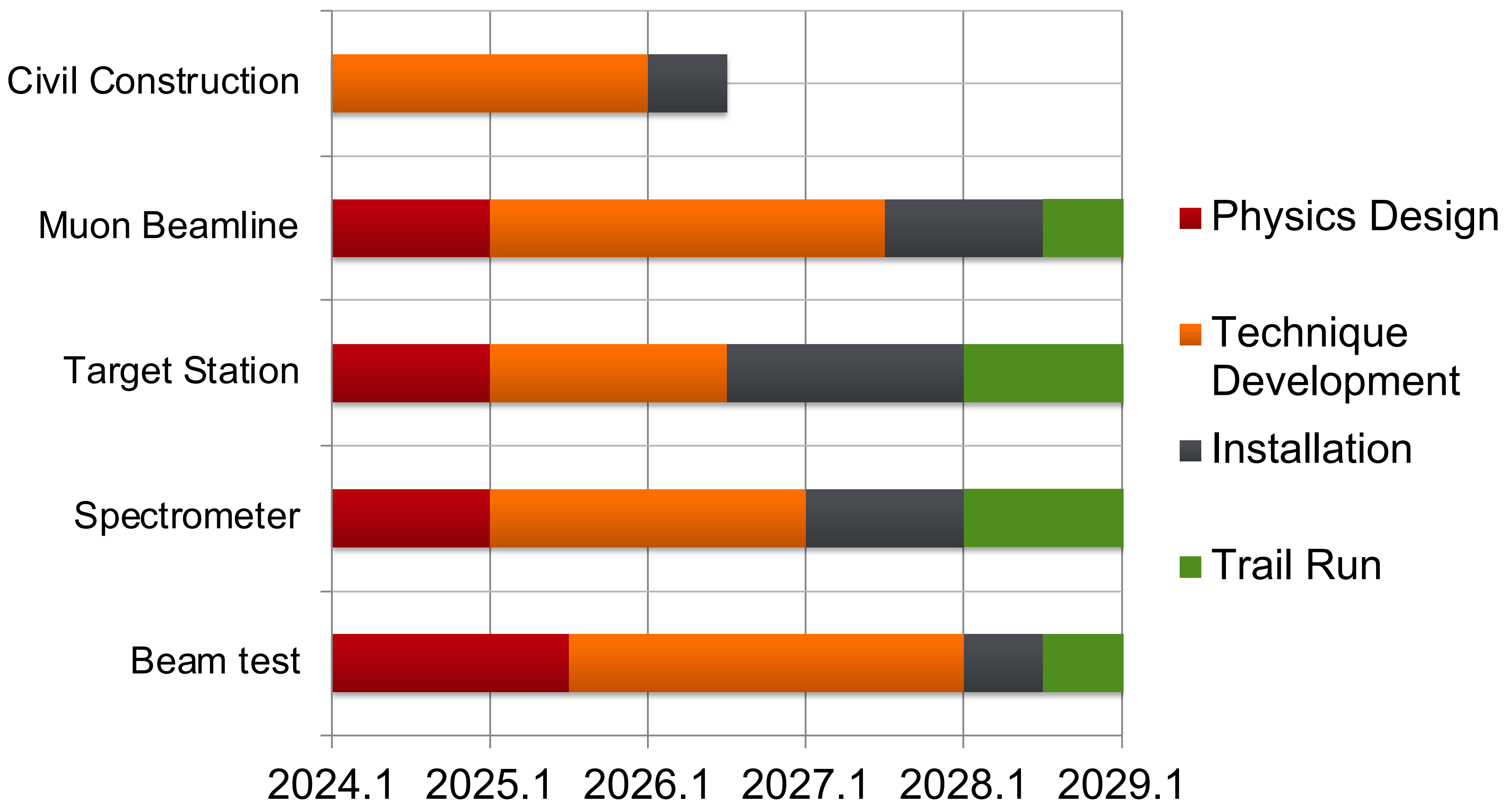
Induction cavity for phase rotation



Magnetic mirror for muonium physics

Timeline of MELODY

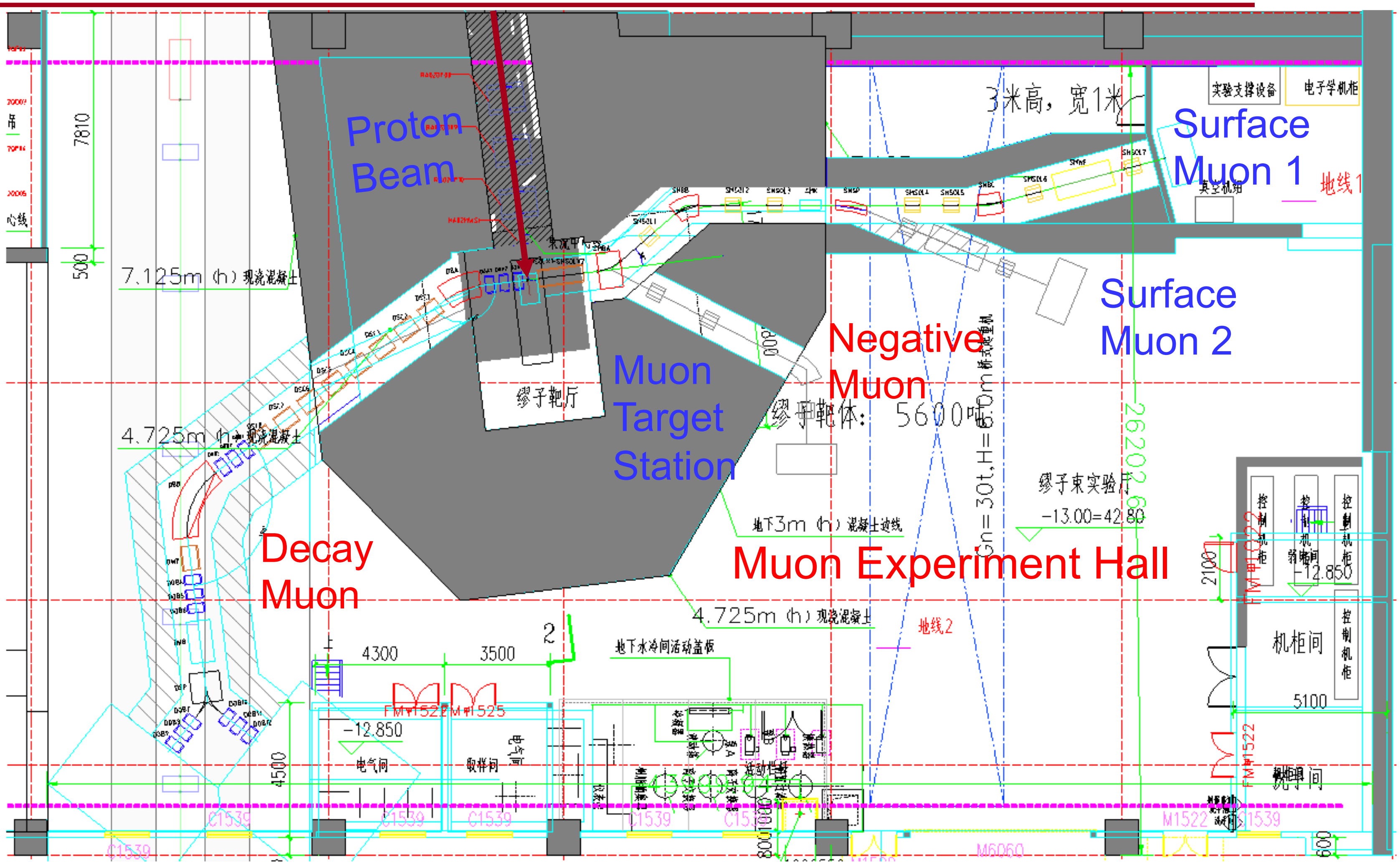
Project has been approved and will be built in 5years.



First Geosurvey

First Geosurvey has been carried out at the muon hall

Prospect with MELODY II

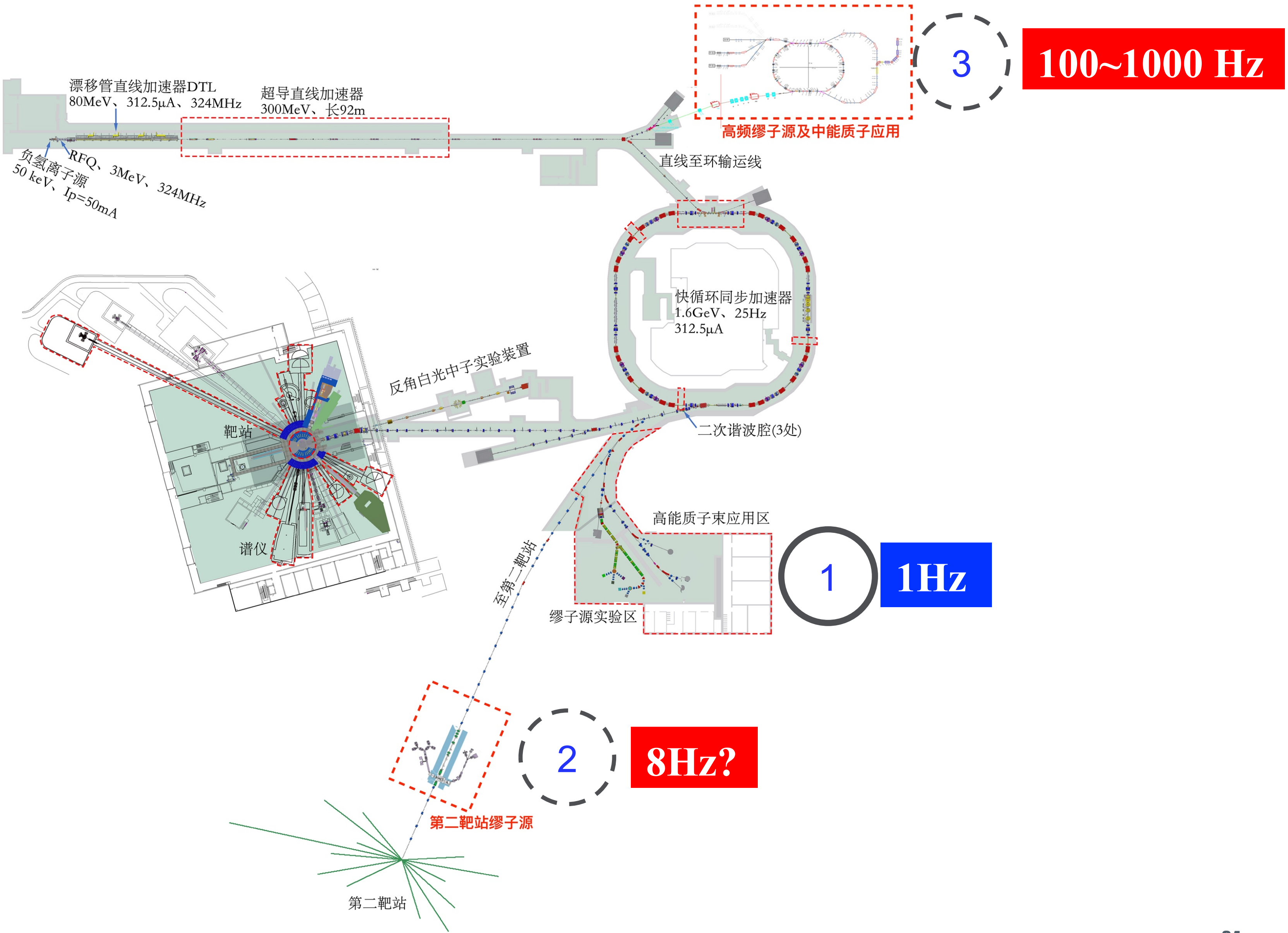


- Pion/Decay muon beam：120MeV/c
- Negative muon beam: 30MeV/c
- Higher repetition rate: up to 5 Hz
- More terminals：
  - Various spectrometers
  - Muon imaging
  - Muonic X-ray

Muon Beam Parameters

	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)	$10^5 \sim 10^6$	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	Up to 120
Full Beam Spot (mm)	10 ~ 30	10 ~ 30	10~30

High rEpetition Muon Source (HEMS)



Summary

- MELODY has been approved by the government, and will start construction soon.
- Phase I of MELODY will build a target station with one surface muon beam and one muSR spectrometer.
- A negative muon beam and a decay muon beam will be built in the future.
- A high repetition muon source is under consideration.

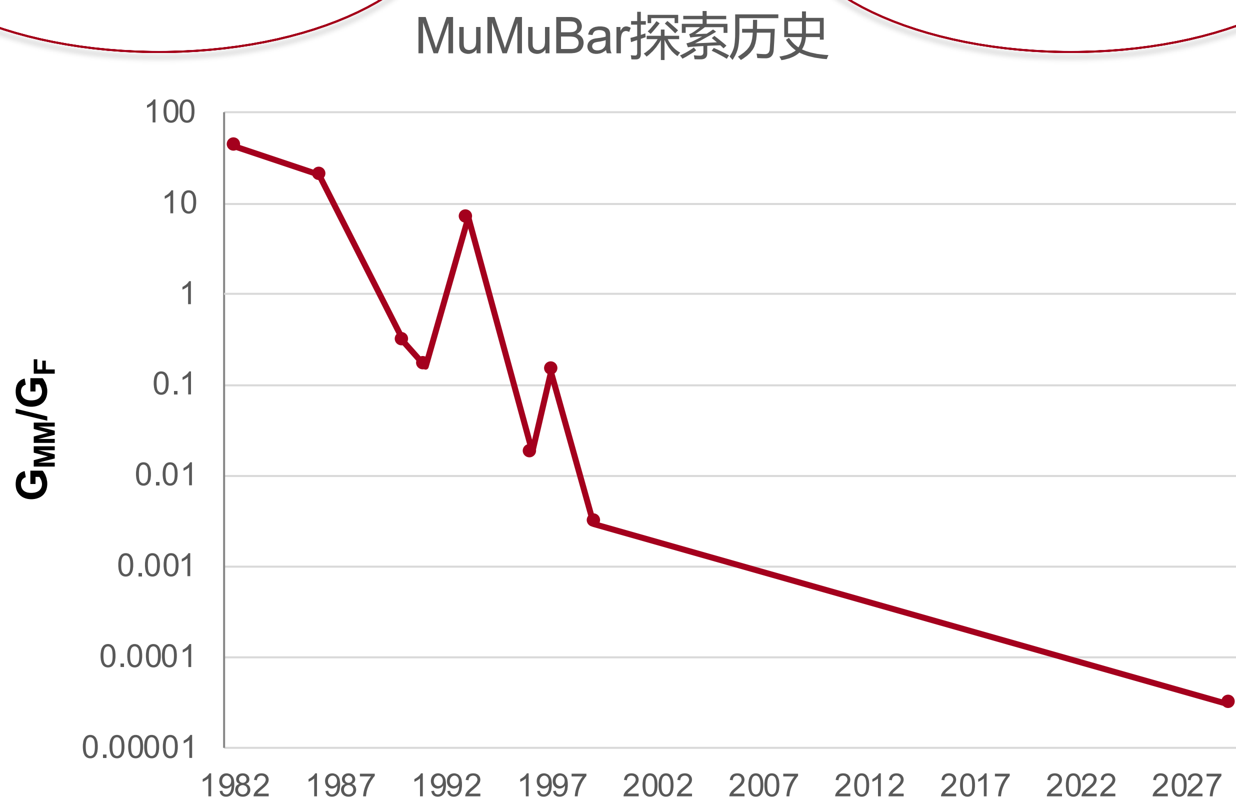
All collaboration is welcome!

THANK YOU !

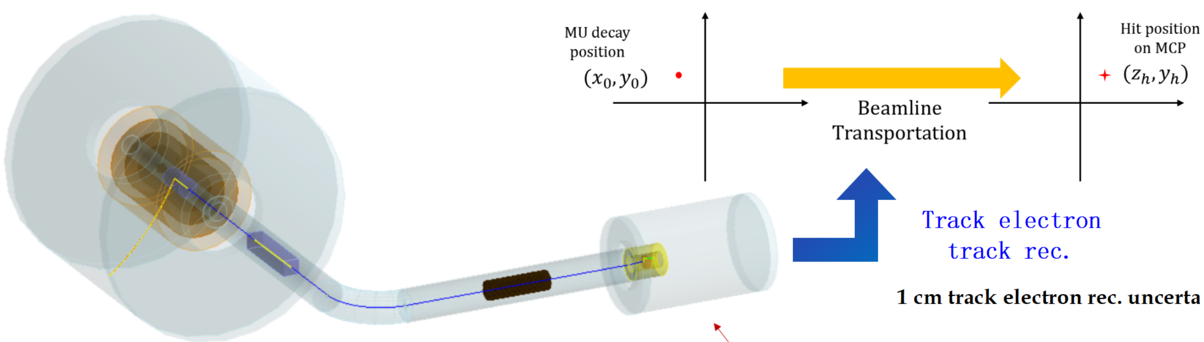
backups

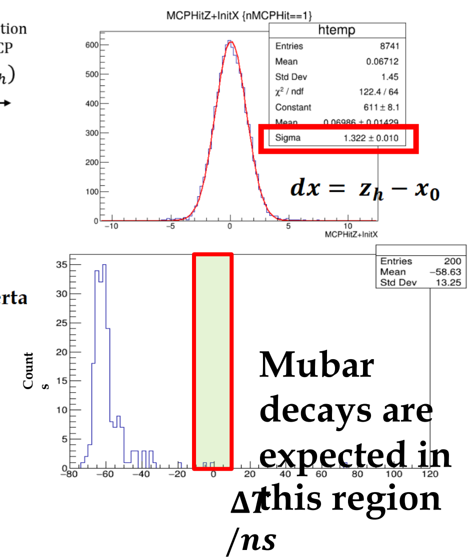
Potential muon physics - MuMuBar?

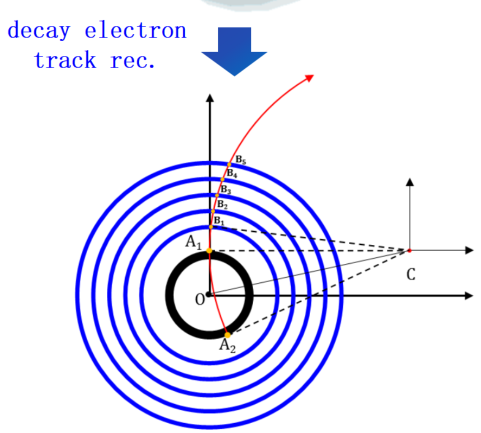
Muonium (Mu) **Anti-muonium ($\overline{Mu}$)**

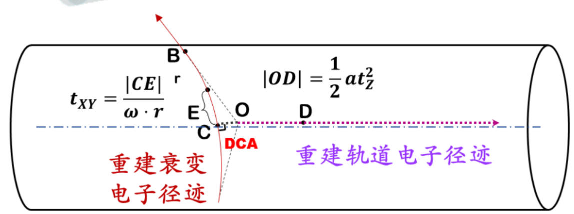


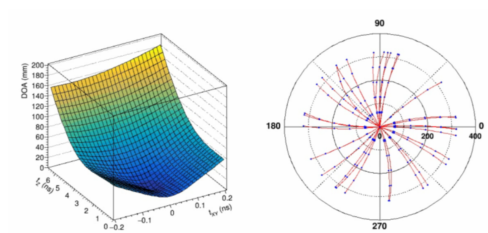
MuMuBar in history







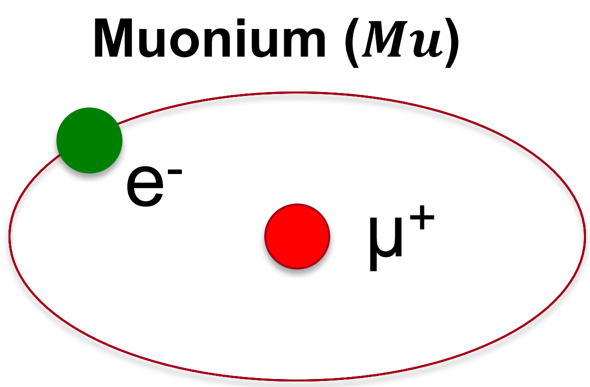




- DCA (Distance of Closest Approach) is calculated according to the rec tracks.
- ΔT (bias to the expected TOF of track electron) is also acquired from track rec.

- We have reconstructed the PSI experiment
- We are developing the data analysis software and detector system for MuMuBar
- However...

MuMuBar requires High Repetition Muons

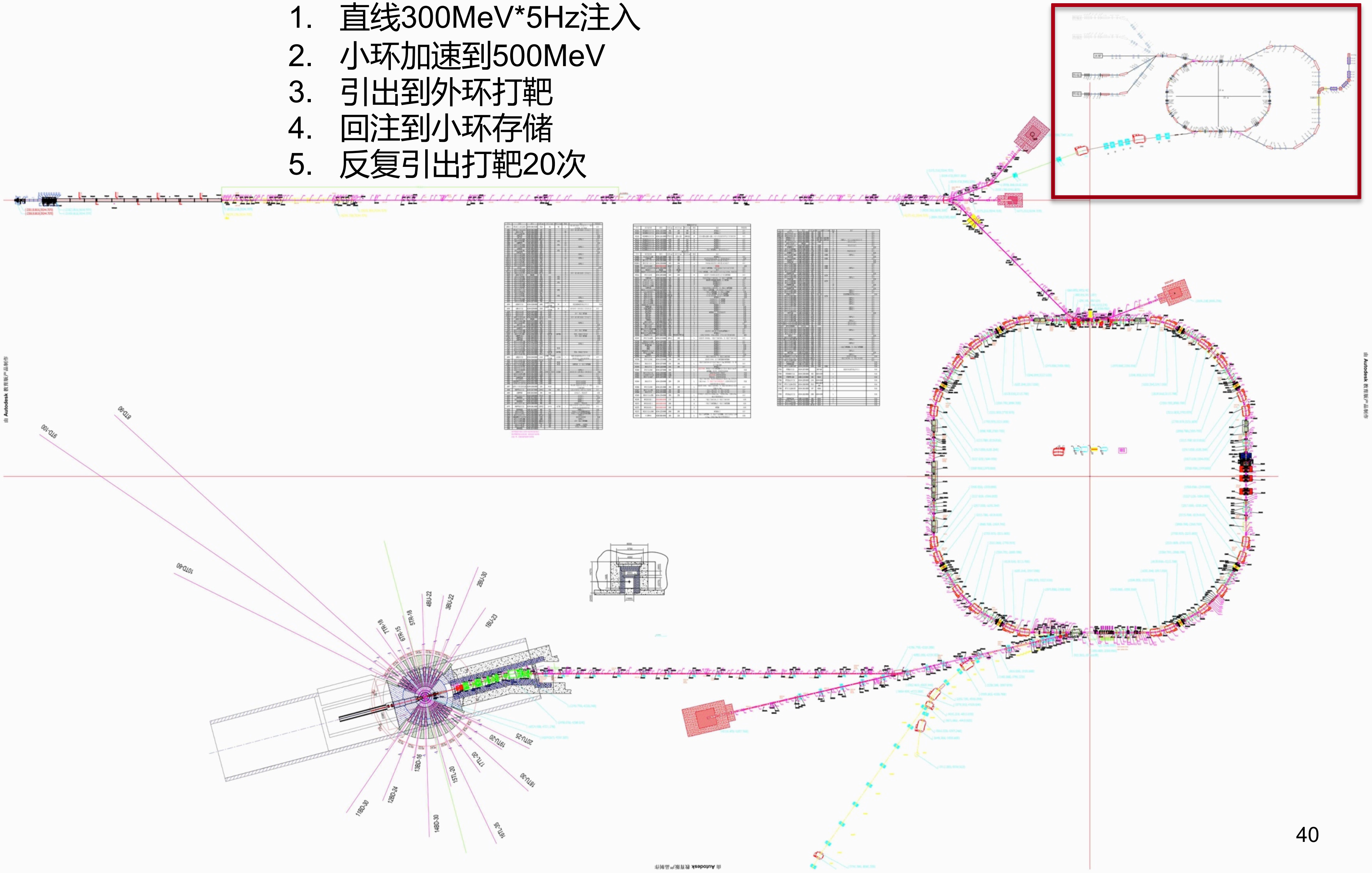


Total intensity : > $2*10^8$ μ^+/s
Single Pulse intensity : < $5*10^6$

→ Repetition>40Hz

High rEpetition Muon Soure - HEMS

1. 直线300MeV*5Hz注入
2. 小环加速到500MeV
3. 引出到外环打靶
4. 回注到小环存储
5. 反复引出打靶20次

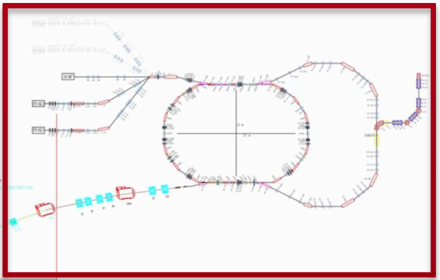


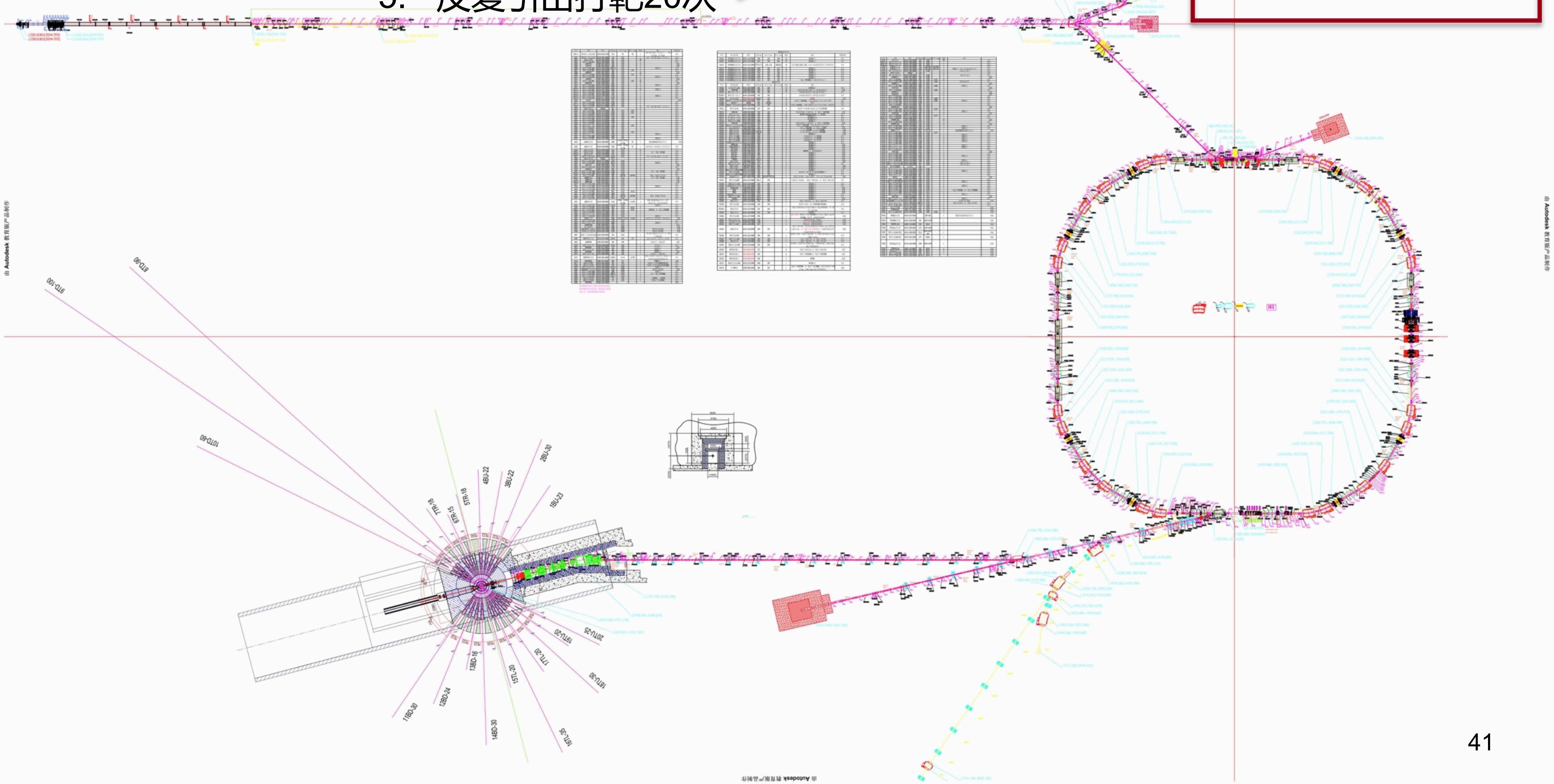
High rEpetition Muon Soure - HEMS

不影响大环/
中子靶运行

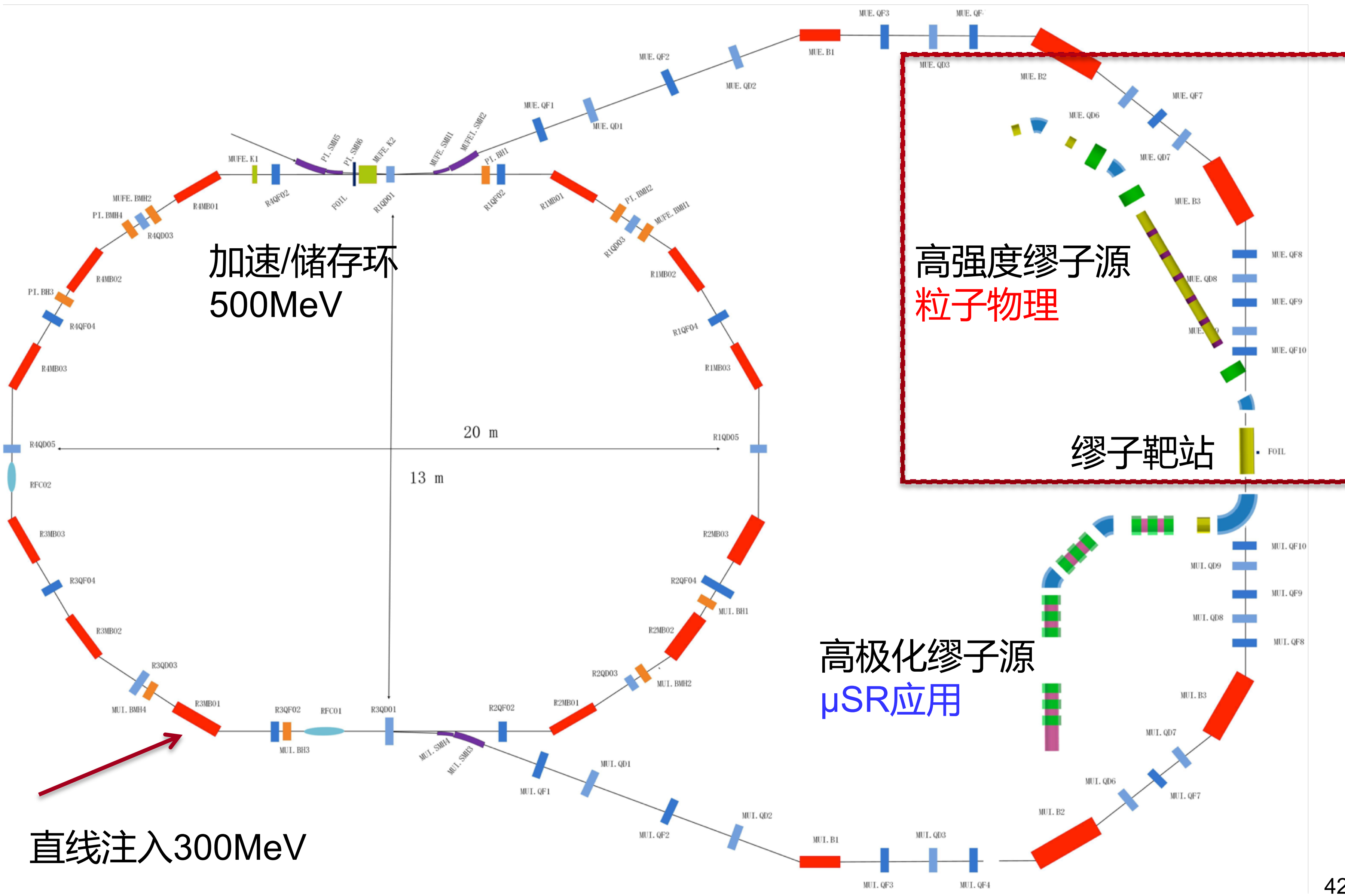
1. 直线300MeV*5Hz注入
2. 小环加速到500MeV
3. 引出到外环打靶
4. 回注到小环存储
5. 反复引出打靶20次

重复频率
100Hz





HEMS 高强度缪子束线



HEMS parameters

参数	HEMS	PSI	ISIS	JPARC
μSR应用				
重复频率[Hz]	100	CW	40	25
μ+强度[μ+/s]	5E6	1.5E7~4E8	5E5	3E6
动量范围[MeV/c]	20-200	10-350	20-200	20-300
计数率[MEvent/h]	Up to 800	~20	20-200	180
粒子物理实验				
MuMuBar	3E8 μ^+/s	8E6 μ^+/s	NA	NA
μ-EDM	$5*10^6$ μ^+/s	<$5*10^4$ μ^+/s	NA	

in the far future, but who knows...

Summary

yubao@ihep.ac.cn

- MELODY has been approved！
- Now: We are going to build a surface muon beam and a muSR spectrometer.
- Future: We reserve the space for more applications in the future.
- Far future: We expect muon physics and HEMS
- We welcome all kinds of suggestions and collaborations.

Thank you!

backups

CSNS II Project