A New DC Muon Beam line at MuSIC

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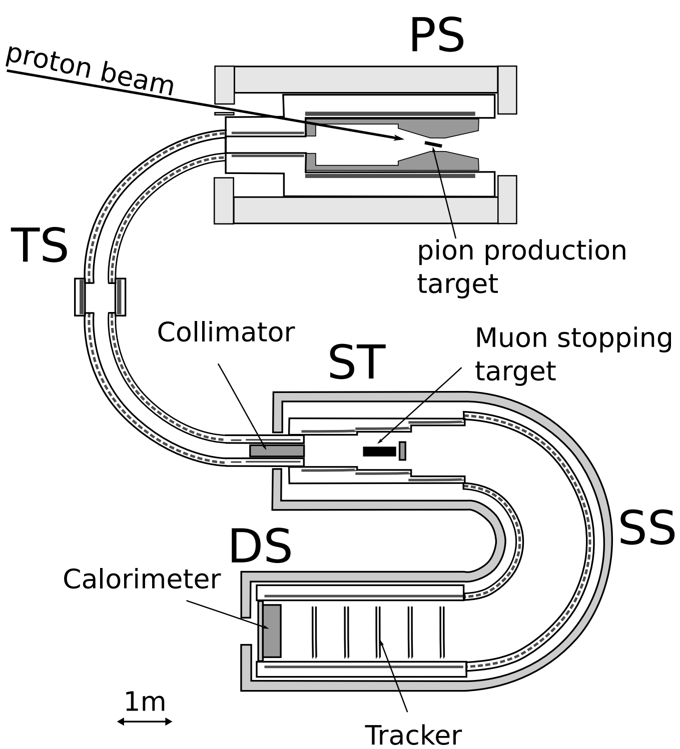
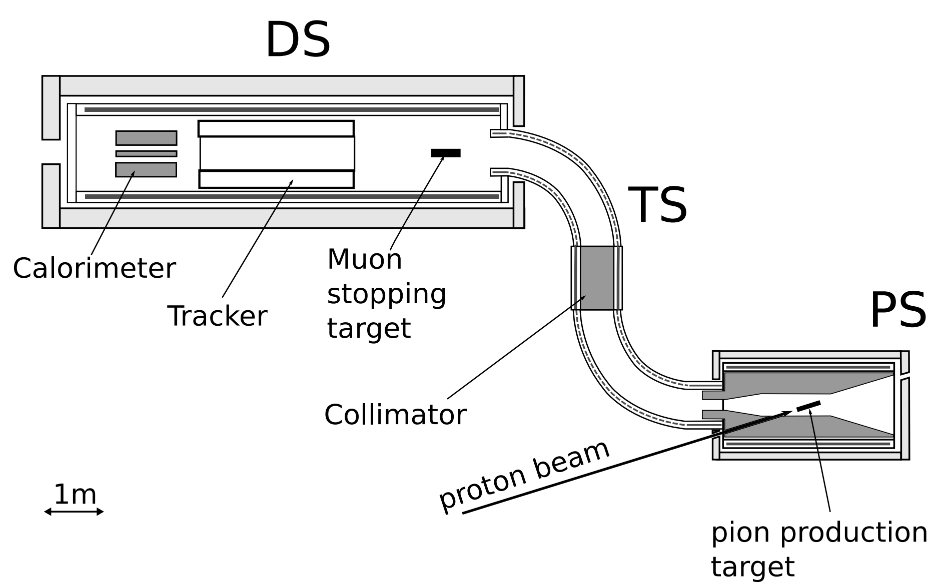
NuFact2013, IHEP, Beijing, China
25+5 min

Pion Capture Solenoids in future μ/ν programs

COMET 5T, 56kW

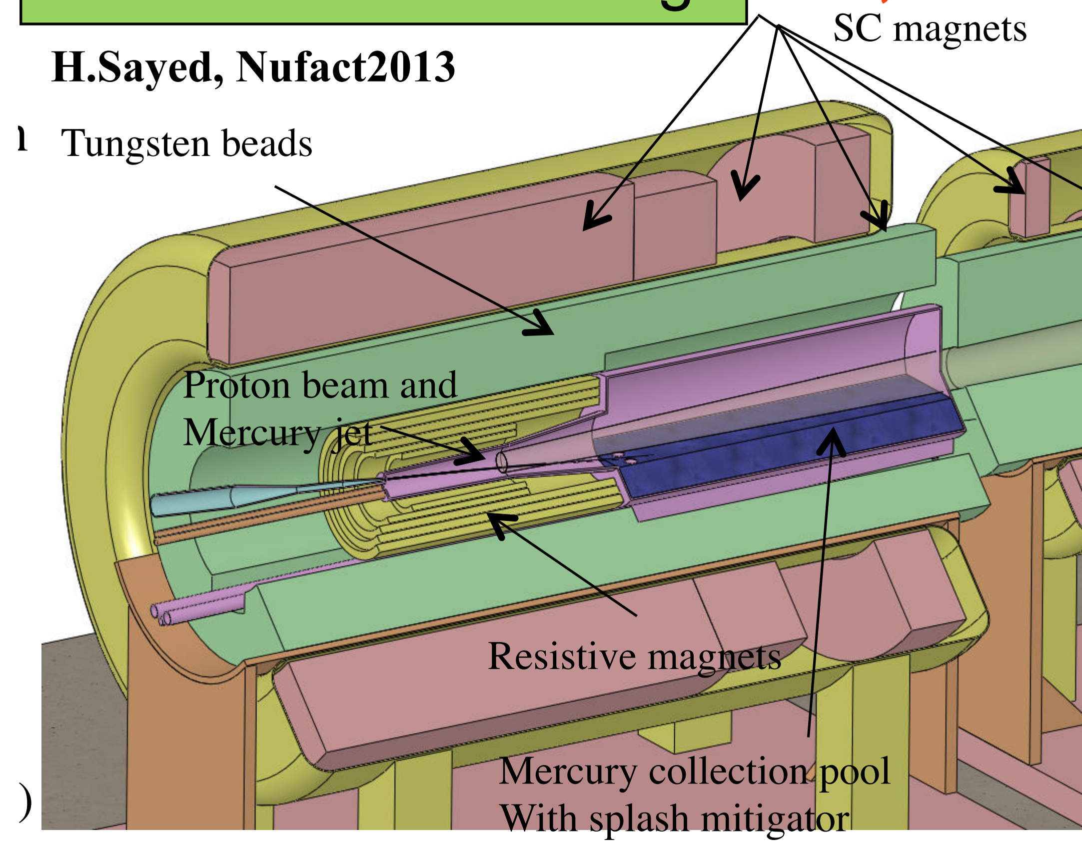


Mu2e 4.6T, 8kW



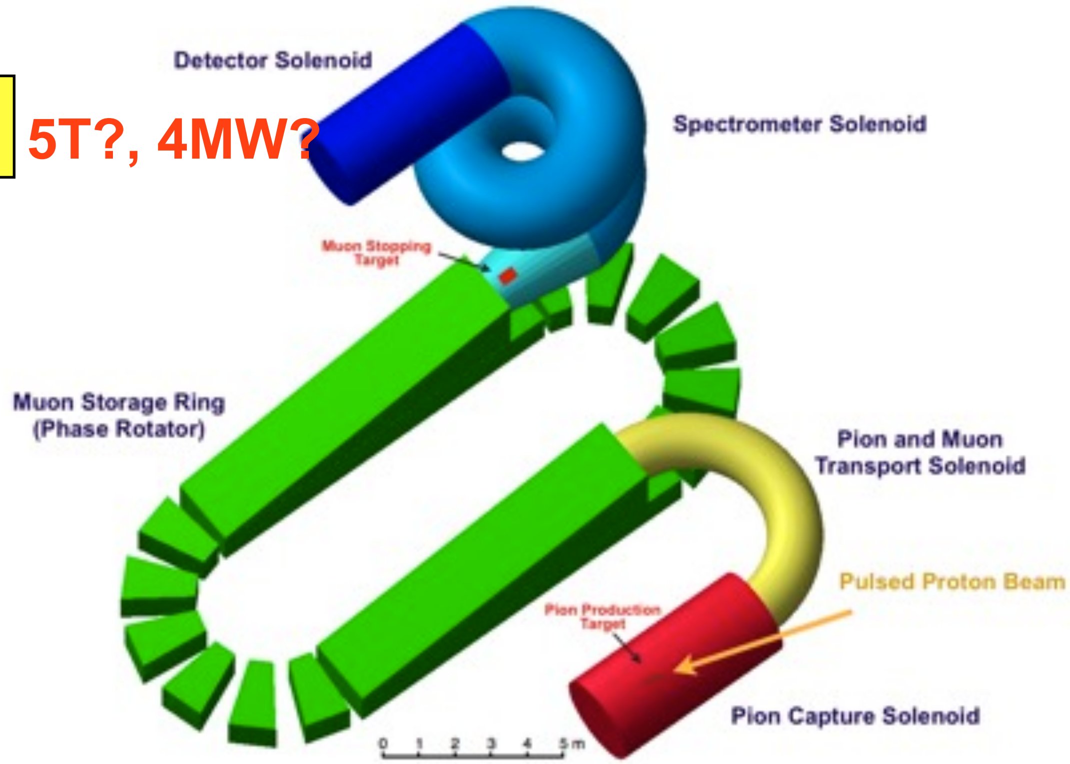
NuFact baseline design 20T, 4MW

H.Sayed, Nufact2013

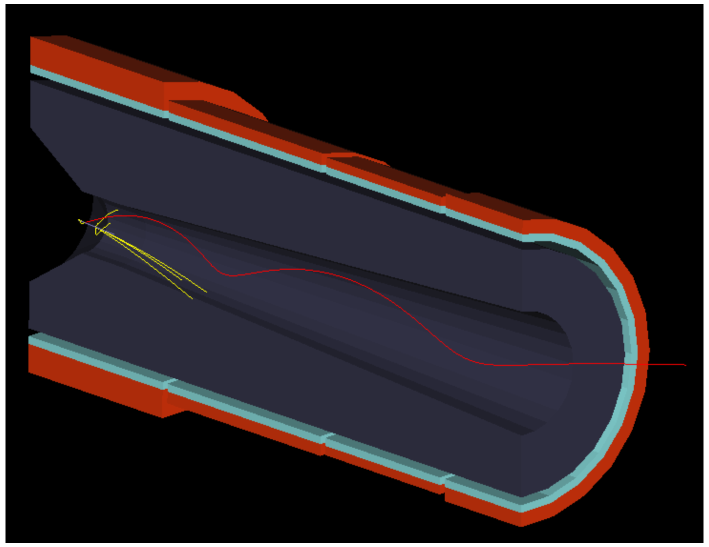


5-T copper magnet insert; 10-T Nb3Sn coil + 5-T NbTi outsert.
Desirable to eliminate the copper magnet (or replace by a 20-T HTS insert).

PRISM 5T?, 4MW?



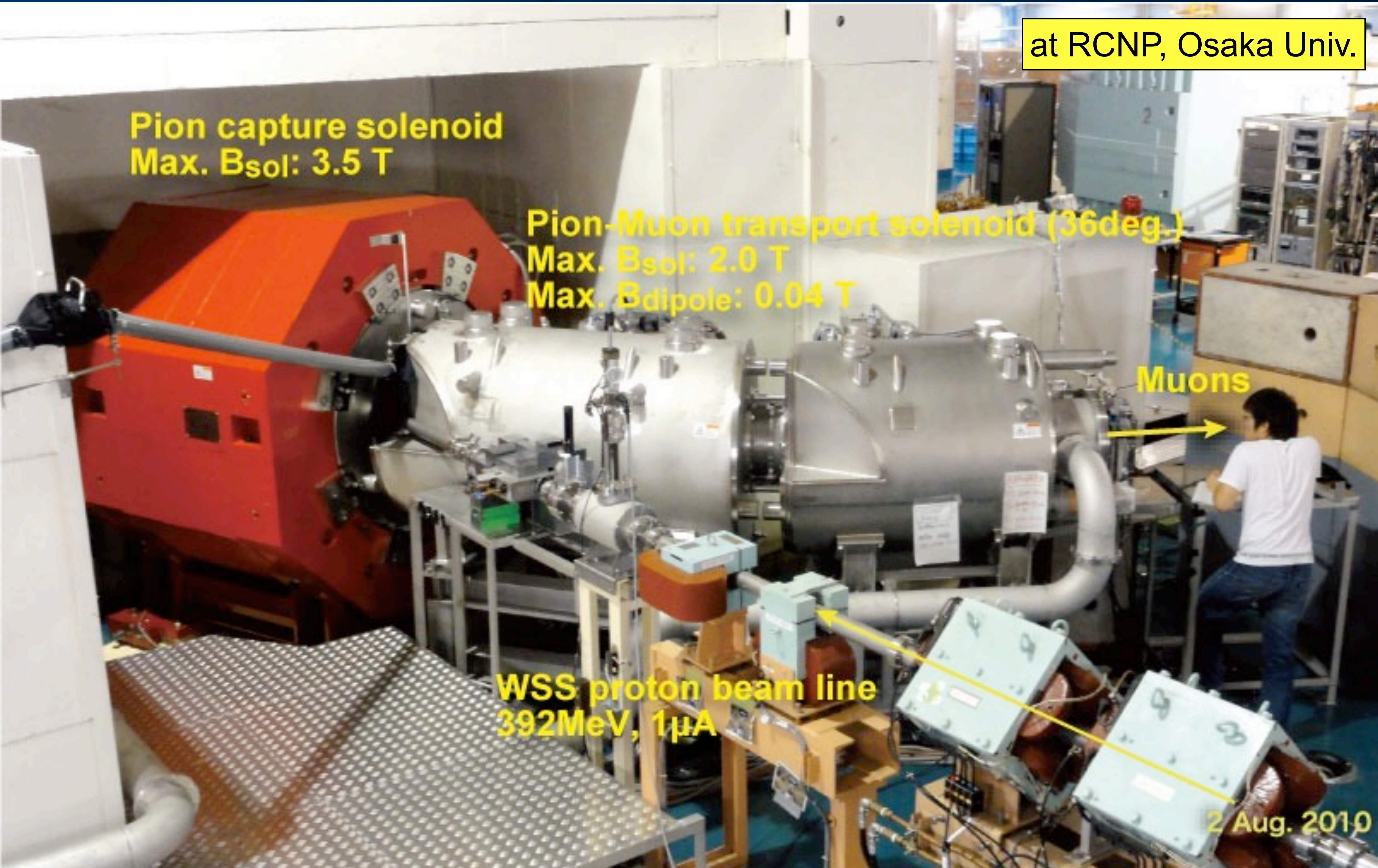
China's medium baseline SB



7T, 15MW?

The 1st pion capture system : MuSIC

at RCNP, Osaka Univ.



What is the MuSIC?

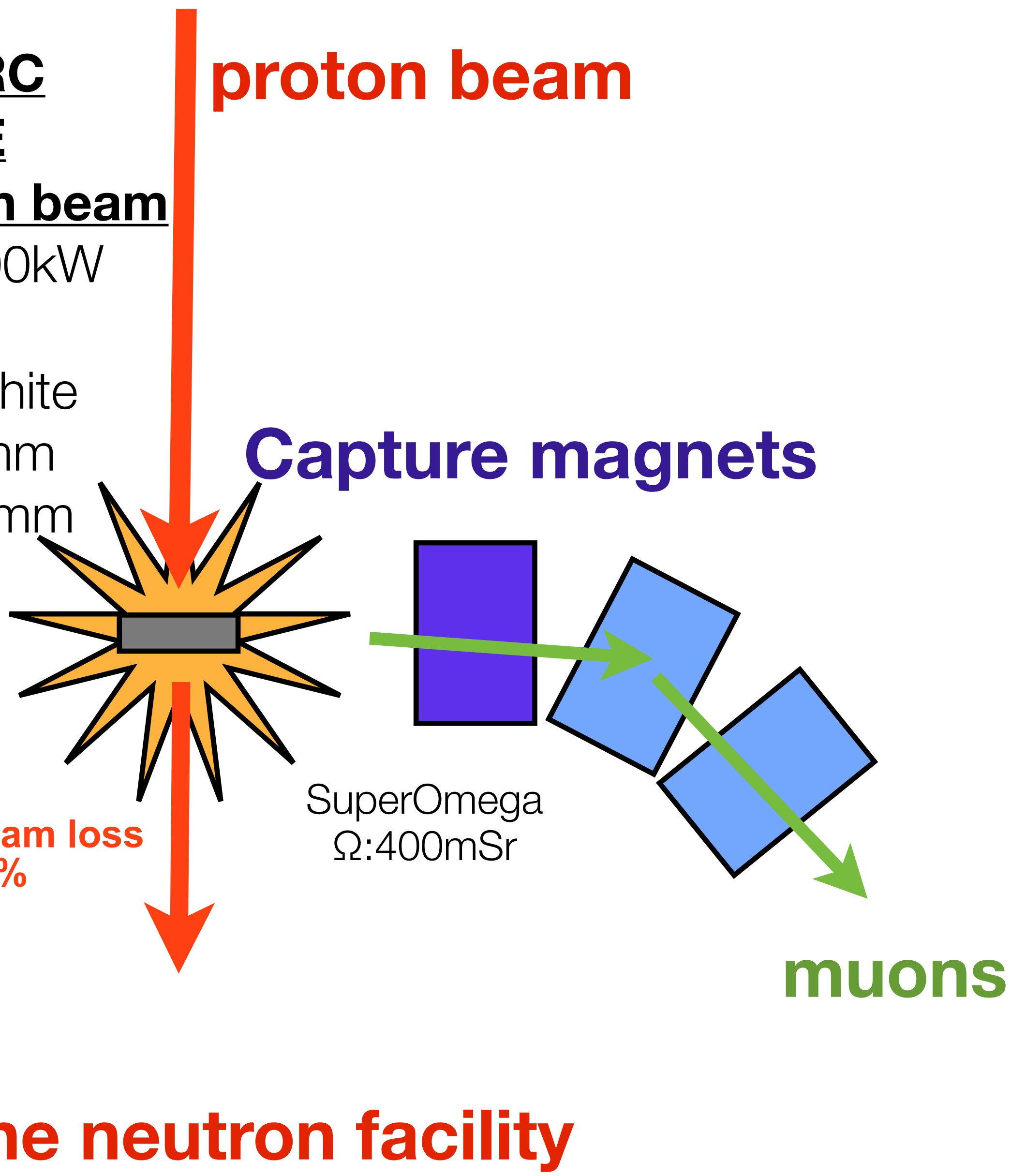
- **MuSIC**
  - The world's most efficient DC muon beam source using the first pion capture solenoid system.
  - Design muon intensity :
    - $10^{8\text{-}9}$ μ/s @392MeV,1 μA (400W) proton beam from the RCNP ring cyclotron
- **Technical points of the MuSIC**
  - The first pion capture solenoid system
    - muon collection efficiency > 10^3 than conventional muon beam lines.
    - Radiation issues (coil cooling for the heat load)
  - A muon transport solenoid with dipole field
- **Task of the MuSIC**
  - Develop superconducting magnet technologies
  - Demonstrate and test the performance of the pion capture system.
  - Start muon programs at RCNP

Overview

Muon collection at the MuSIC

Conventional muon beam line

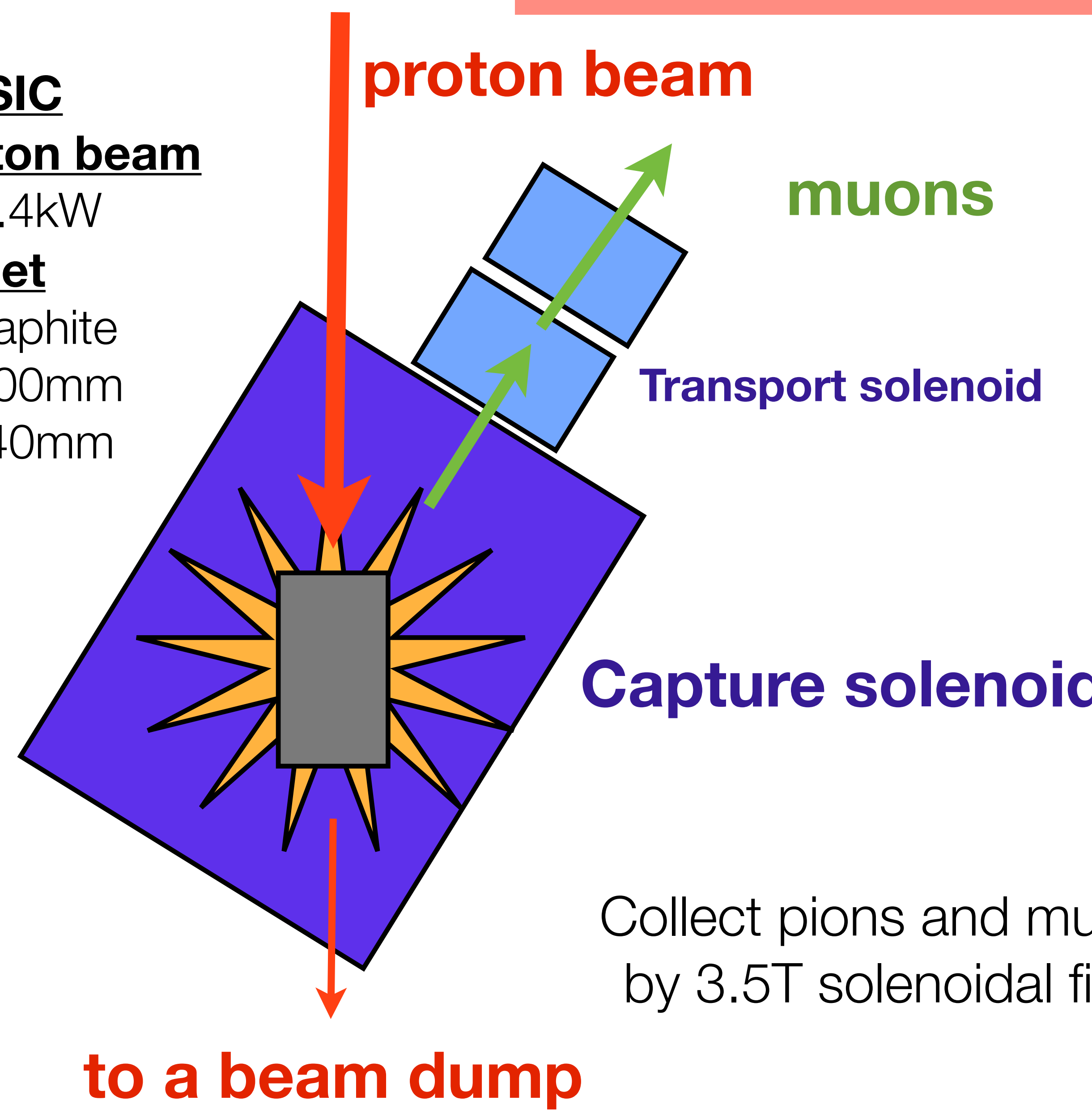
J-PARC
MUSE
proton beam
-1000kW
target
graphite
t20mm
ϕ70mm



MuSIC

MuSIC,COMET/Mu2e,PRISM,
Neutrino factory,
Muon collider

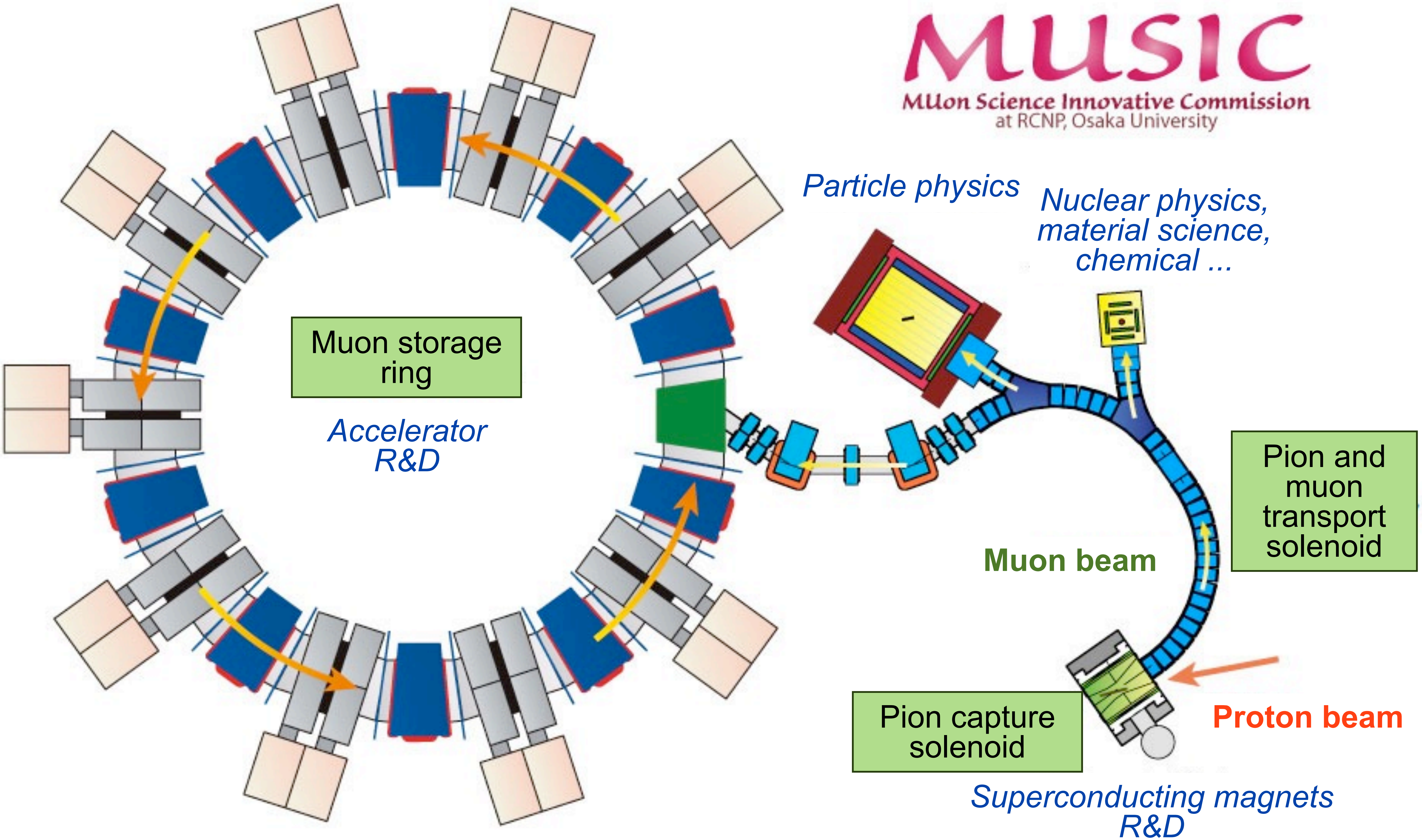
MuSIC
proton beam
-0.4kW
target
graphite
t200mm
ϕ40mm



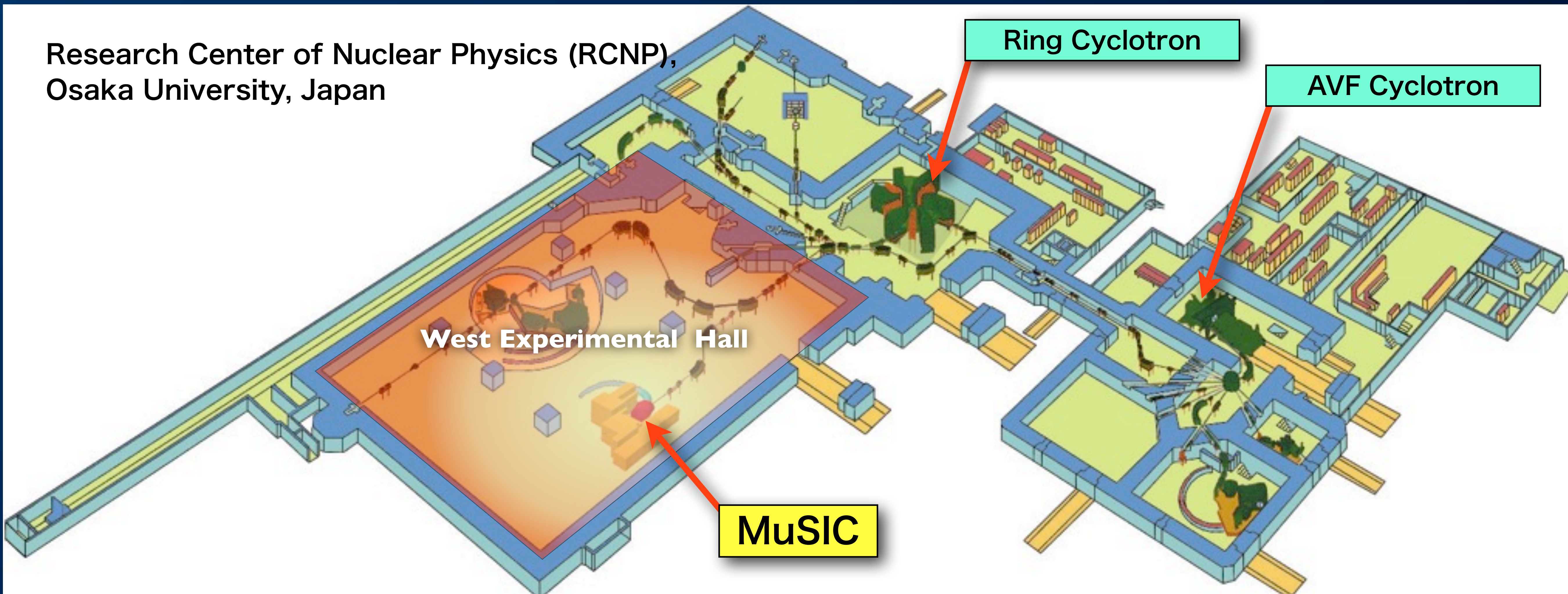
Collect pions and muons by 3.5T solenoidal field

Large solid angle & thick target

The Final Layout of MuSIC

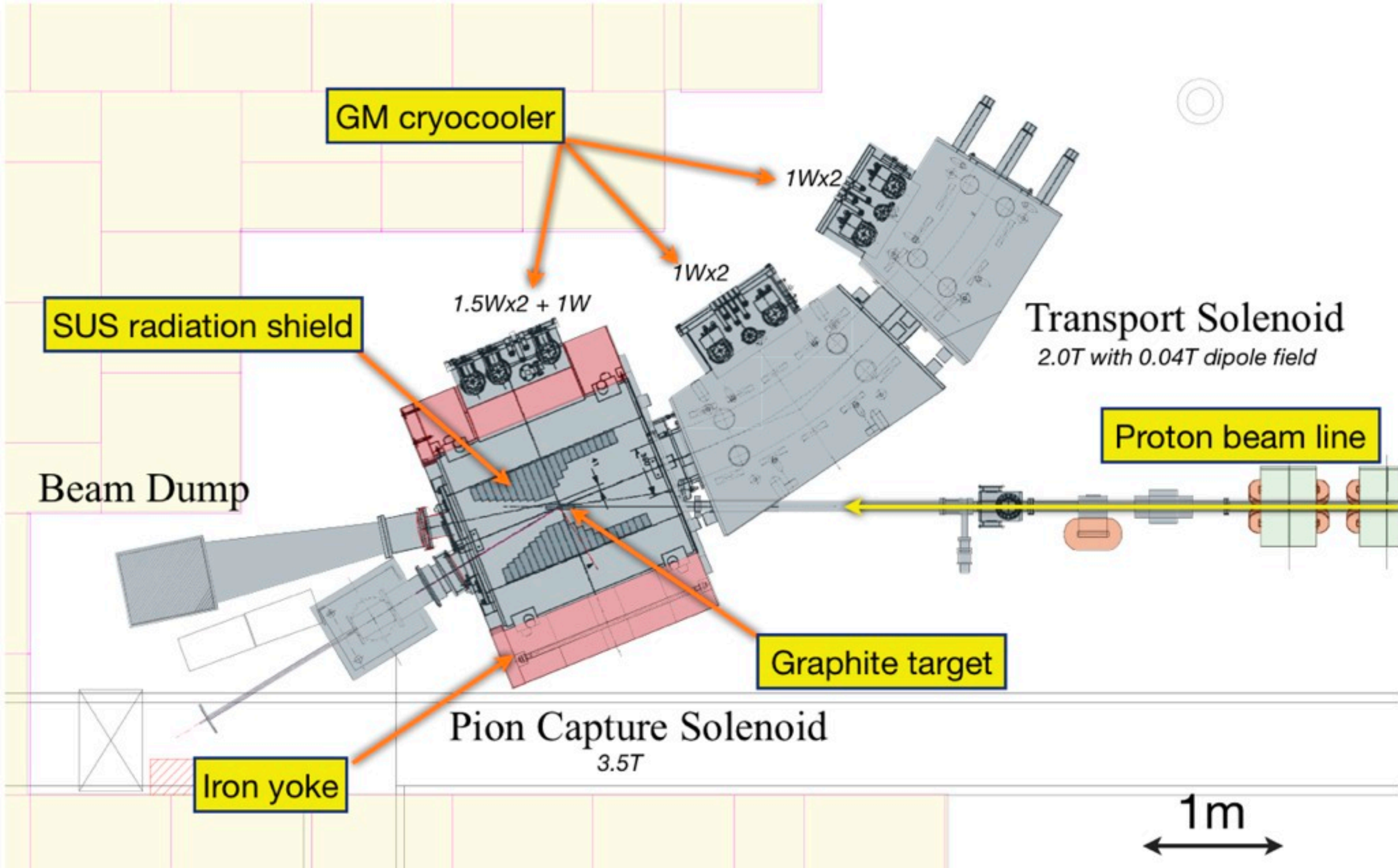


MUSIC@RCNP, Osaka Univ.



- RCNP has two cyclotrons. A proton beam with 392MeV, 1μA is provided from the Ring Cyclotron (up to 5μA in near future).
- The MuSIC is in the largest experimental hall, the west experimental hall.

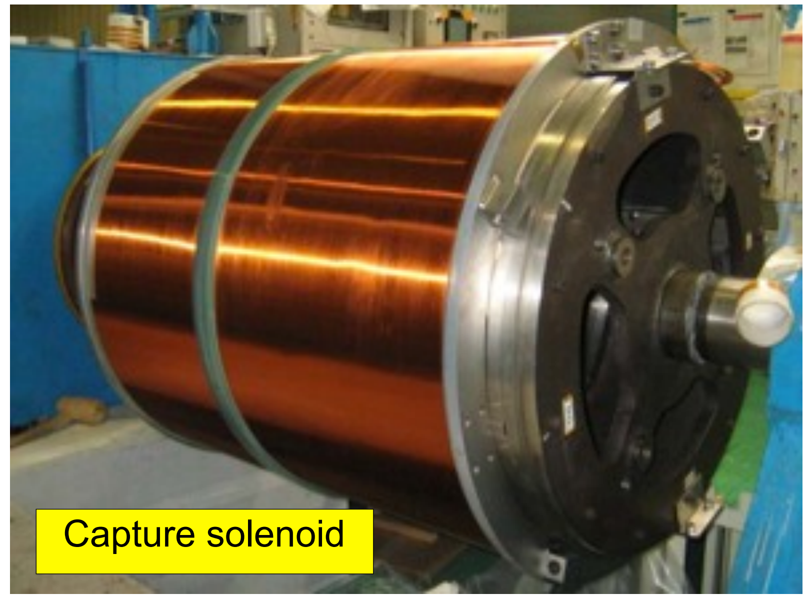
MuSIC: Present Layout

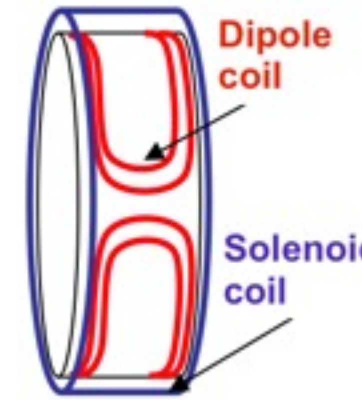


Superconducting Magnets

Superconducting Coils

Conductor	Cu-stabilized NbTi
Cable diameter	Φ1.2 mm
Cu/NiTi ratio	4
RRR (R_{293K}/R^{10K} at 0T)	230-300





Operation current	145 A
Max field on axis	3.5 T
Bore	Φ900 mm
Length	1000 mm
Inductance	400 H
Stored energy	5 MJ
Quench back heater (Cu wire)	1.2 mm dia. ~1Ω@4 K

Solenoid coil of the capture solenoid

Operation current	145 A
Max field on axis	2.0 T
Bore	Φ480 mm
Length	200 mm x 8 coils
Inductance	124 H
Stored energy	1.4 MJ
Quench back heater (Cu wire)	1.3 mm dia. ~0.05Ω/coil@4K

Solenoid coil of the transport solenoid

Operation current	115 A
Max field on axis	0.04 T
Bore	Φ460 mm
Length	200 mm/coil
Inductance	0.04 H/coil
Stored energy	280 J/coil

Dipole coil of the transport solenoid

History of MuSIC Projects

- 2009JPY
  - Construction of a proton beam line, pion capture system, and transport solenoid (up to 36 deg)
- 2010JPY
  - Commissioning of super-conducting magnets of pion capture and transport
  - 2010, Jul. : 1st beamtest (I_{proton}=3nA)
    - proton beam hits the production target,
    - Every system worked successfully,
    - observed secondary particles ay the end of the transport solenoid
  - 2011, Feb. : 2nd beam test (I_{proton}=~4nA)
    - muon beam was counted form their life spectrum,
- 2011JYP
  - 2011, Jun. : 3rd beam test (I_{proton}=~4nA)
    - muon life measurements with a higher statistics
    - muonic-Xray measurements
      - the design muon collection efficiency was confirmed by the measurement
  - 2011, Oct. : 4th beam test (I_{proton}=~4nA)
    - muonic-Xray measurements with a higher statistics
    - measurement of neutron flux and energy around the MuSIC
  - 2012, Mar. : East side radiation shielding blocks were located.
- 2012JYP
  - 2012, Jun 18-22 : 5th beam test
    - measurements for muon energy and spatial distribution
    - the system was operated with a high current proton beam **(I_{proton}=~1microA)**

Construction

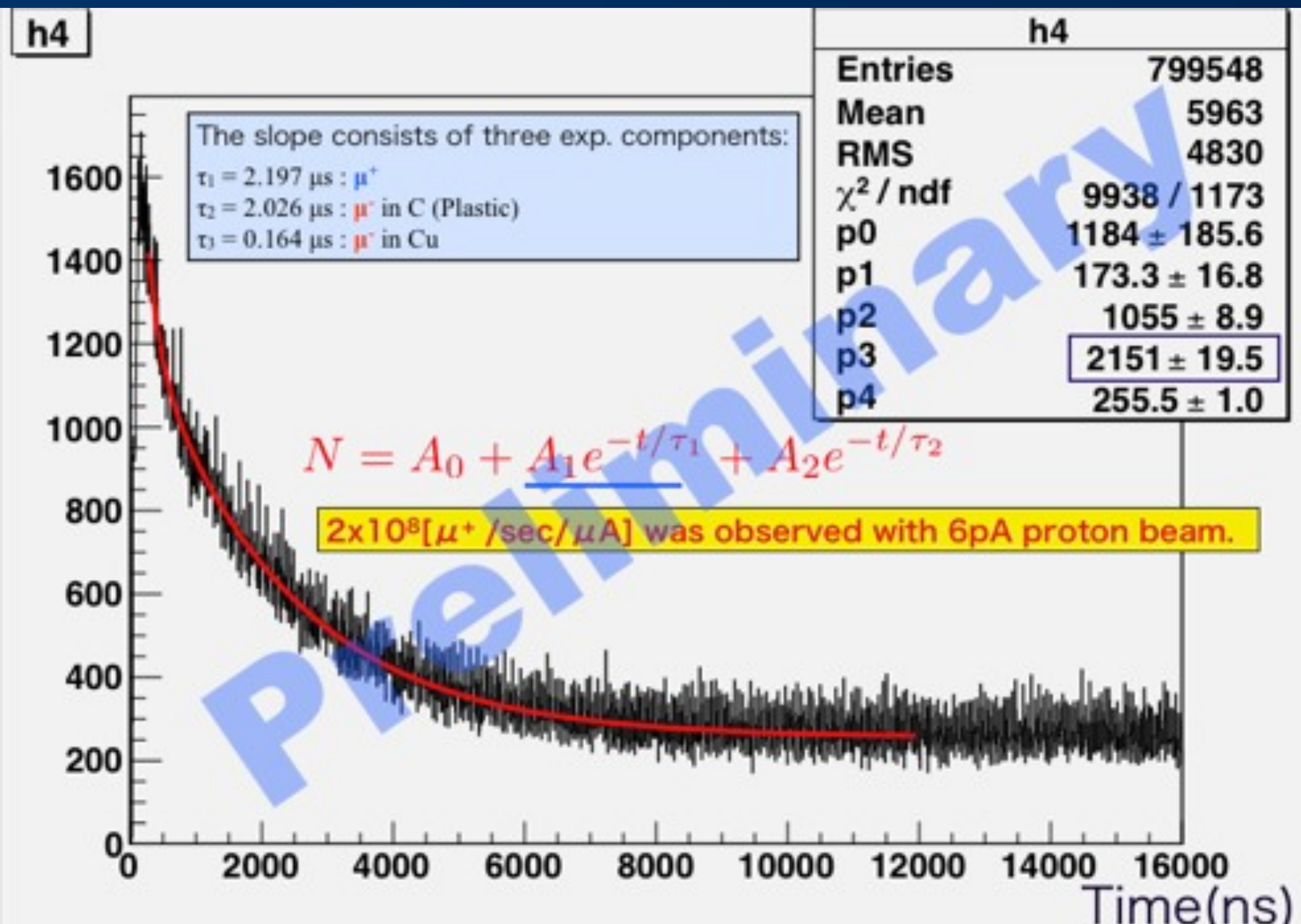
Commissioning

Muon collection efficiency

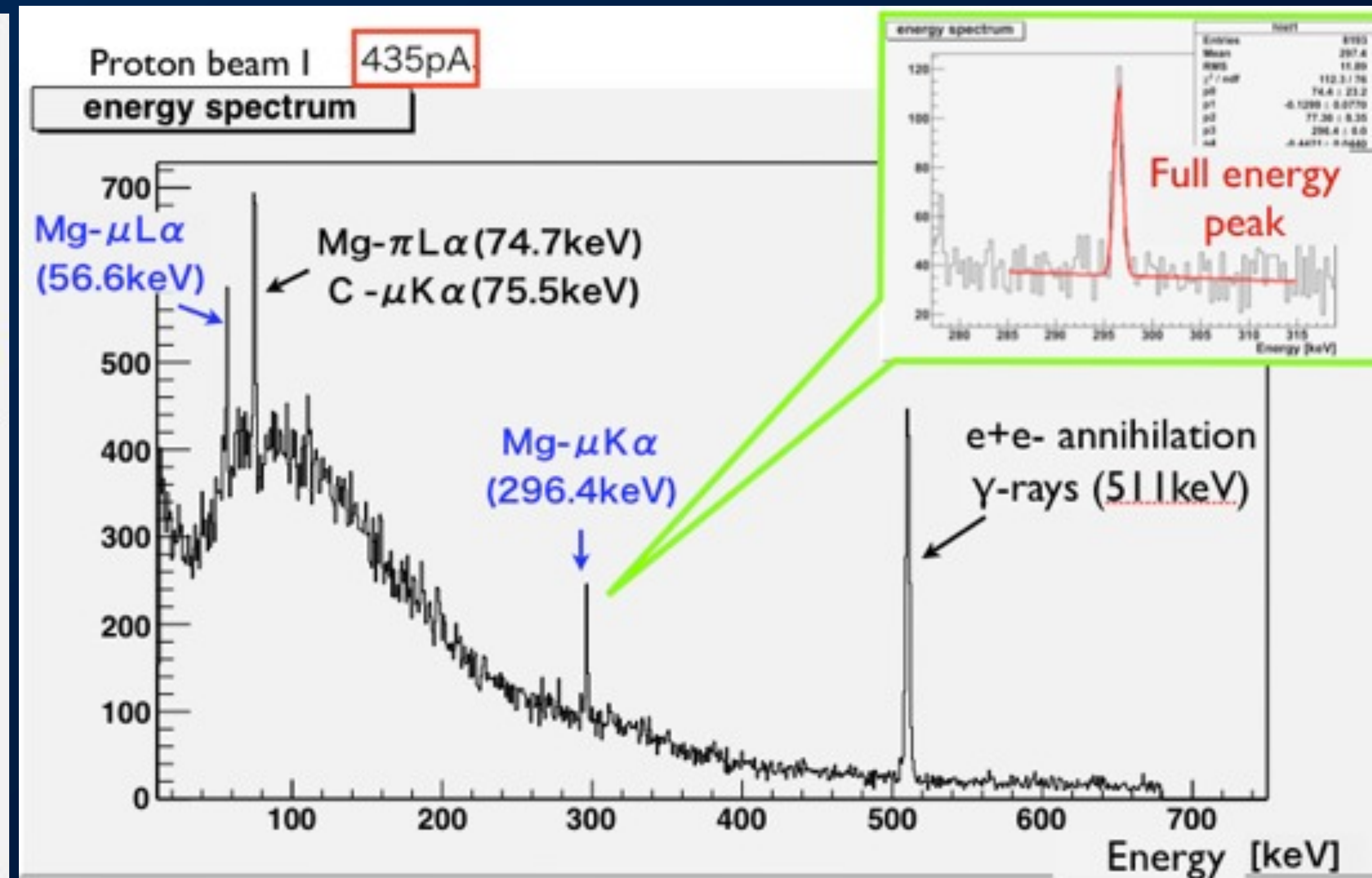
High current operation

Muon yield measurements

Muon life（Stopping target: Cu）



Muonic X-rays（Stopping target: Mg）



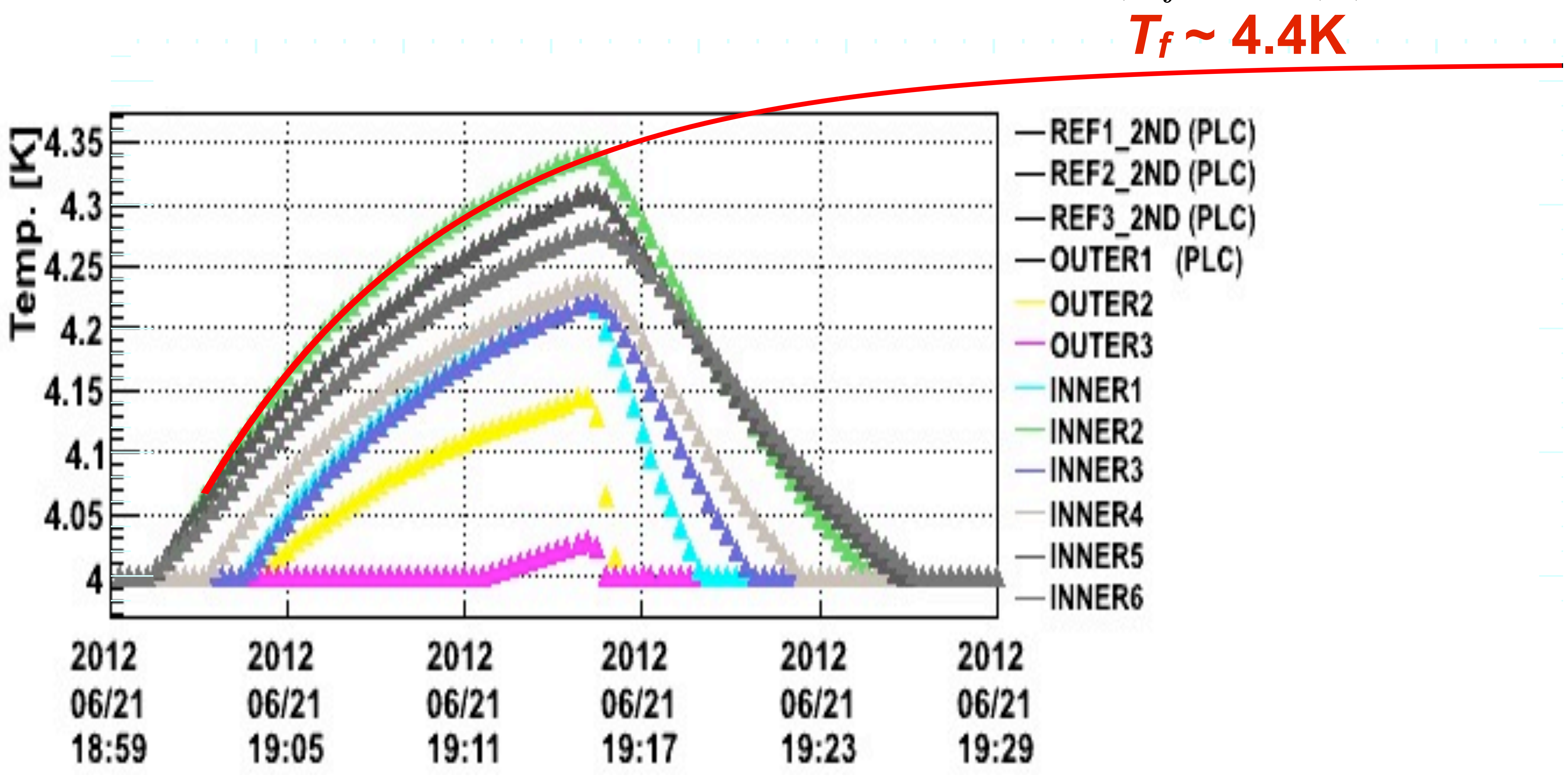
Measured muon yield at the exit of the 36° transport solenoid

	simulation	measurement
positive muon [μ+/sec/μA]	2 x 10^8	3 x 10^8
negative muon [μ-/sec/μA]	1.4 x 10^8	(1.7 ± 0.3) x 10^8

The μ production efficiency shows good agreement with the design value.

Terminal Temperature

$$T = T_0 + (T_f - T_0)(1 - e^{-t/\tau})$$

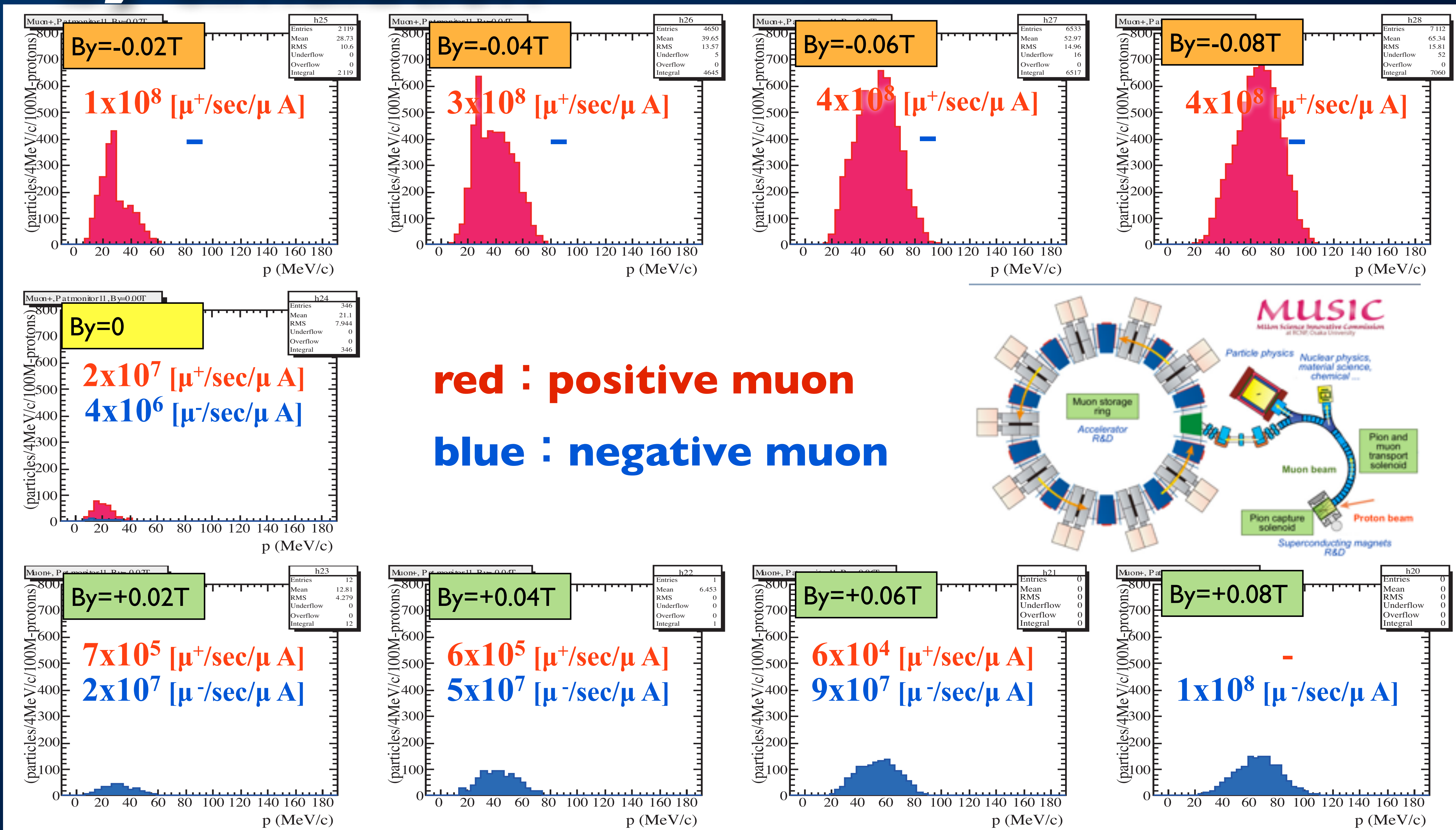


The coil temperature up to ~6.5K is acceptable.
MuSIC can work with 400W proton beam.

Muon beam from MuSIC by simulation

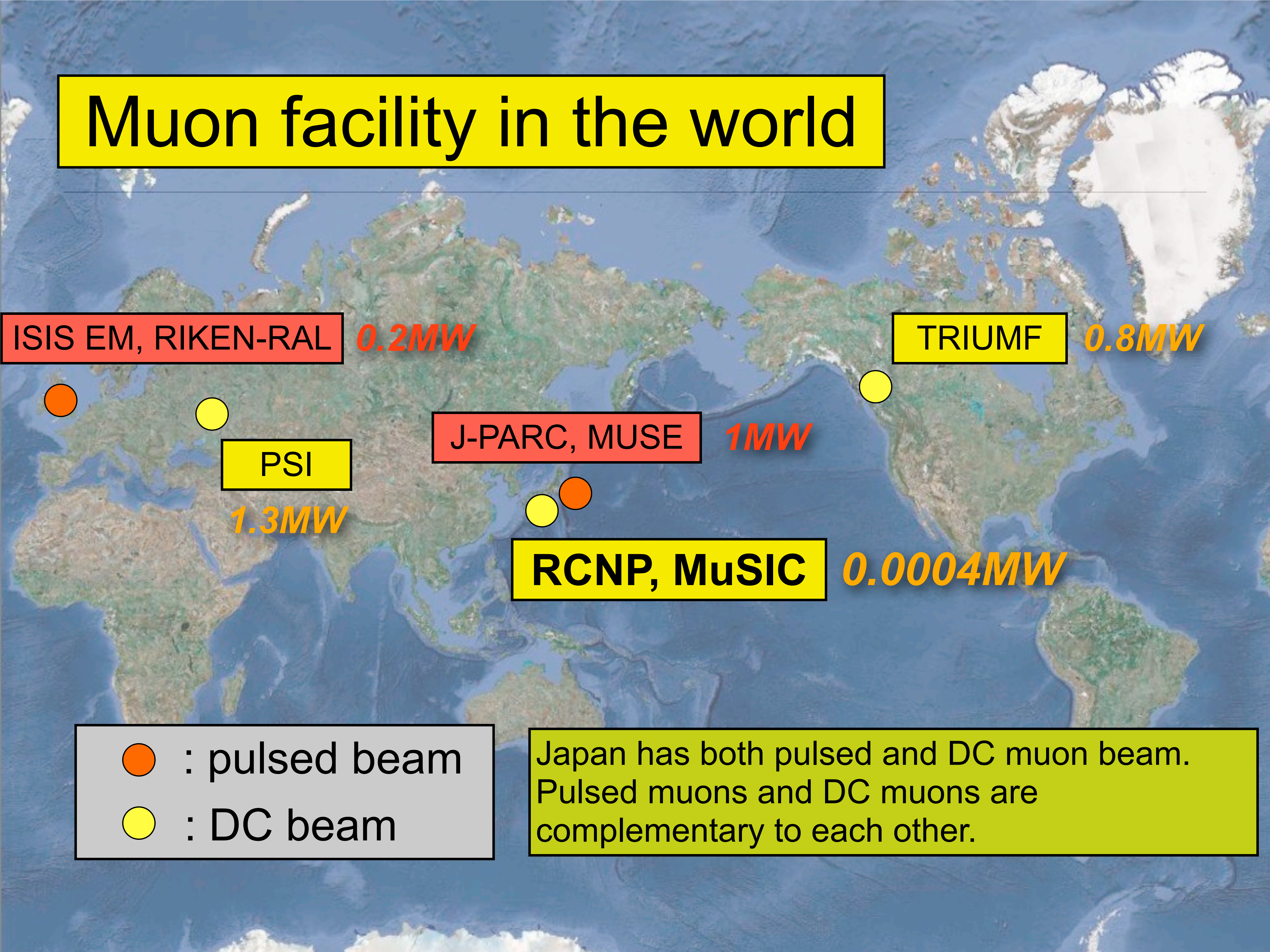
at the exit of 180° transport solenoid

by g4beamline, QGSP_BERT, E_p=392MeV



- Changing magnitude and direction of the dipole field, we can select charge and momentum of the beam.

Muon facility in the world



Japan has both pulsed and DC muon beam. Pulsed muons and DC muons are complementary to each other.

Examples of DC Muon Science at MuSIC

+ **Particle Physics :**
  - search for $\mu \rightarrow eee$ (muon LFV) $10^{8\text{-}9}\mu^+$/sec
    - DC continuous beam is critical
+ **Materials Science :**
  - μSR (a μSR apparatus is needed) $10^{5\text{-}6}\mu^+$/sec, po
- **Nuclear Physics :**
  - nuclear muon capture (NMC) $10^{4\text{-}5}\mu^-$/sec
    - nuclear matrix element study for $0\nu\ \beta\beta$ decay
  - pion capture and scattering
- **Chemistry :**
  - chemistry on pion/muon atoms $10^{4\text{-}5}\mu^-$/sec
- **Accelerator / Instruments R&D**
  - (for PRISM/neutrino factory/muon collider) :
    - Superconducting solenoid magnets
    - FFAG, RF
    - cooling methods
    - muon acceleration, deceleration, and phase rotation

DC muon is necessary to reduce accidental BGs

cf. COMET(μ-e) needs a pulsed muon beam.

with a good time resolution

<u>measure muonic Xrays</u>

high trigger rate is possible

cf. with pulsed muons, the trigger rate is limited by pulse rate.

Examples of DC Muon Science at MuSIC

Needs a long SC solenoid channel.

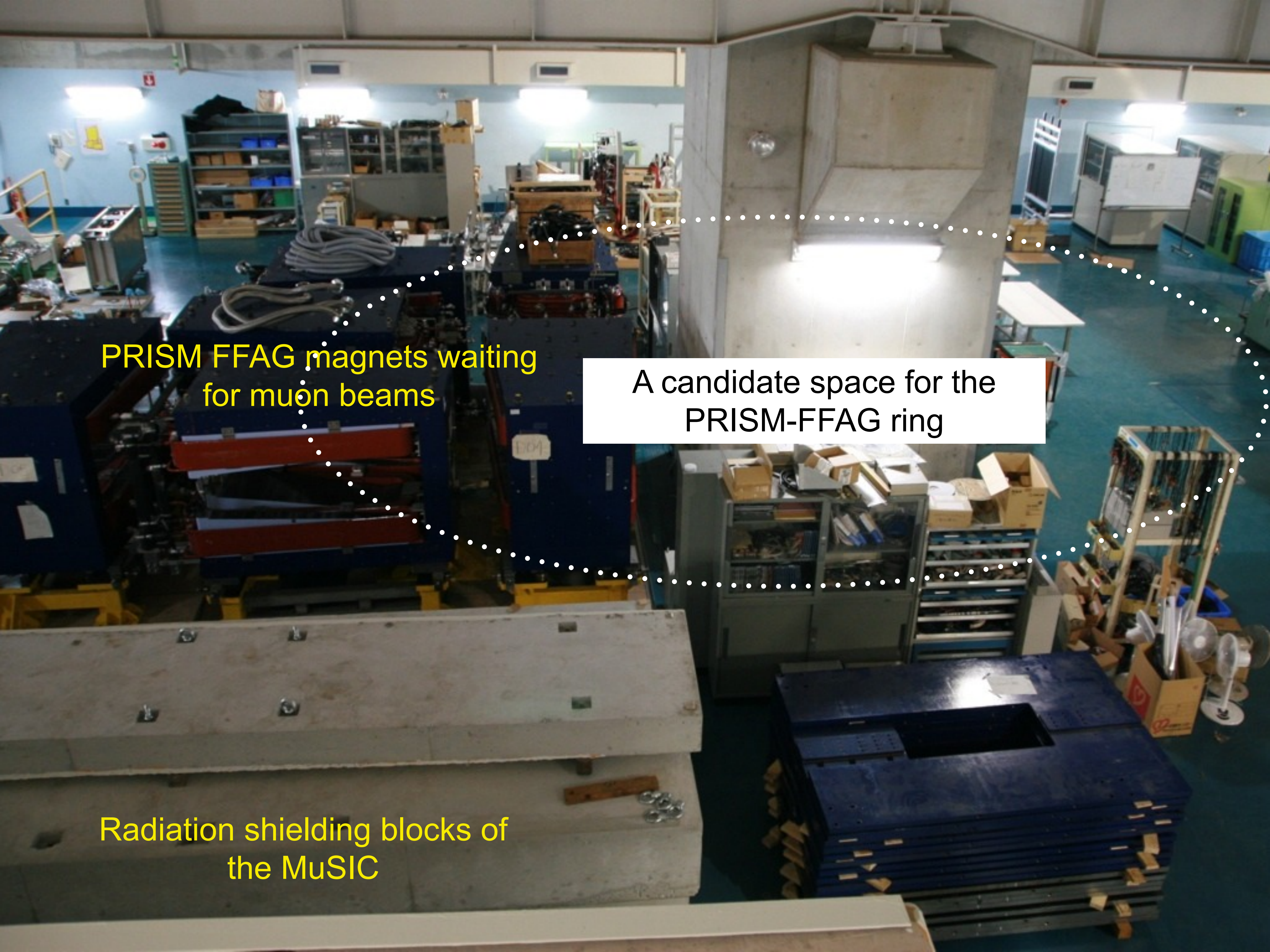
Stage-2

- + **Particle Physics :**
  - search for $\mu \rightarrow eee$ (muon LFV) $10^{8\text{-}9}\mu^{+}$/sec
    - DC continuous beam is critical
- + **Materials Science :**
  - μSR (a μSR apparatus is needed) $10^{5\text{-}6}\mu^{+}$/sec, polarized
- - **Nuclear Physics :**
  - nuclear muon capture (NMC) $10^{4\text{-}5}\mu^{-}$/sec
    - nuclear matrix element study for $0\nu\ \beta\beta$ decay
  - pion capture and scattering
- - **Chemistry :**
  - chemistry on pion/muon atoms $10^{4\text{-}5}\mu^{-}$/sec

A beam line can be consist of Q,D magnets.

Stage-1

- **Accelerator / Instruments R&D**
  - (for PRISM/neutrino factory/muon collider) :
    - Superconducting solenoid magnets
    - FFAG, RF
    - cooling methods
    - muon acceleration, deceleration, and phase rotation


PRISM FFAG magnets waiting for muon beams
A candidate space for the PRISM-FFAG ring
Radiation shielding blocks of the MuSIC

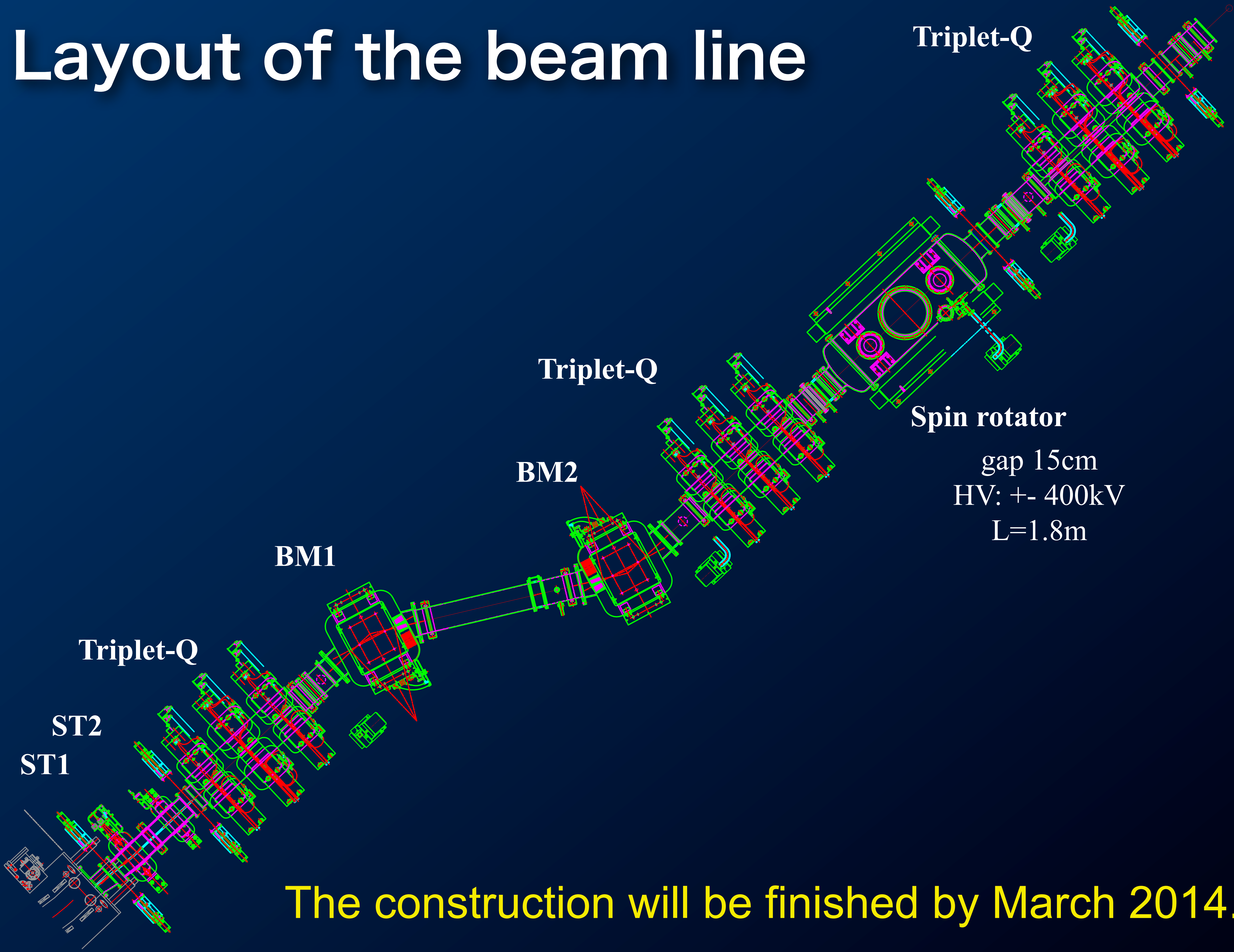
A muon beam line for MuSIC stage-1

Target beam performance

- Positive muon : DC-μSR
  - beam size : ϕ10mm
  - angle : < 50mrad
  - intensity : 2~4 x 10^4/sec

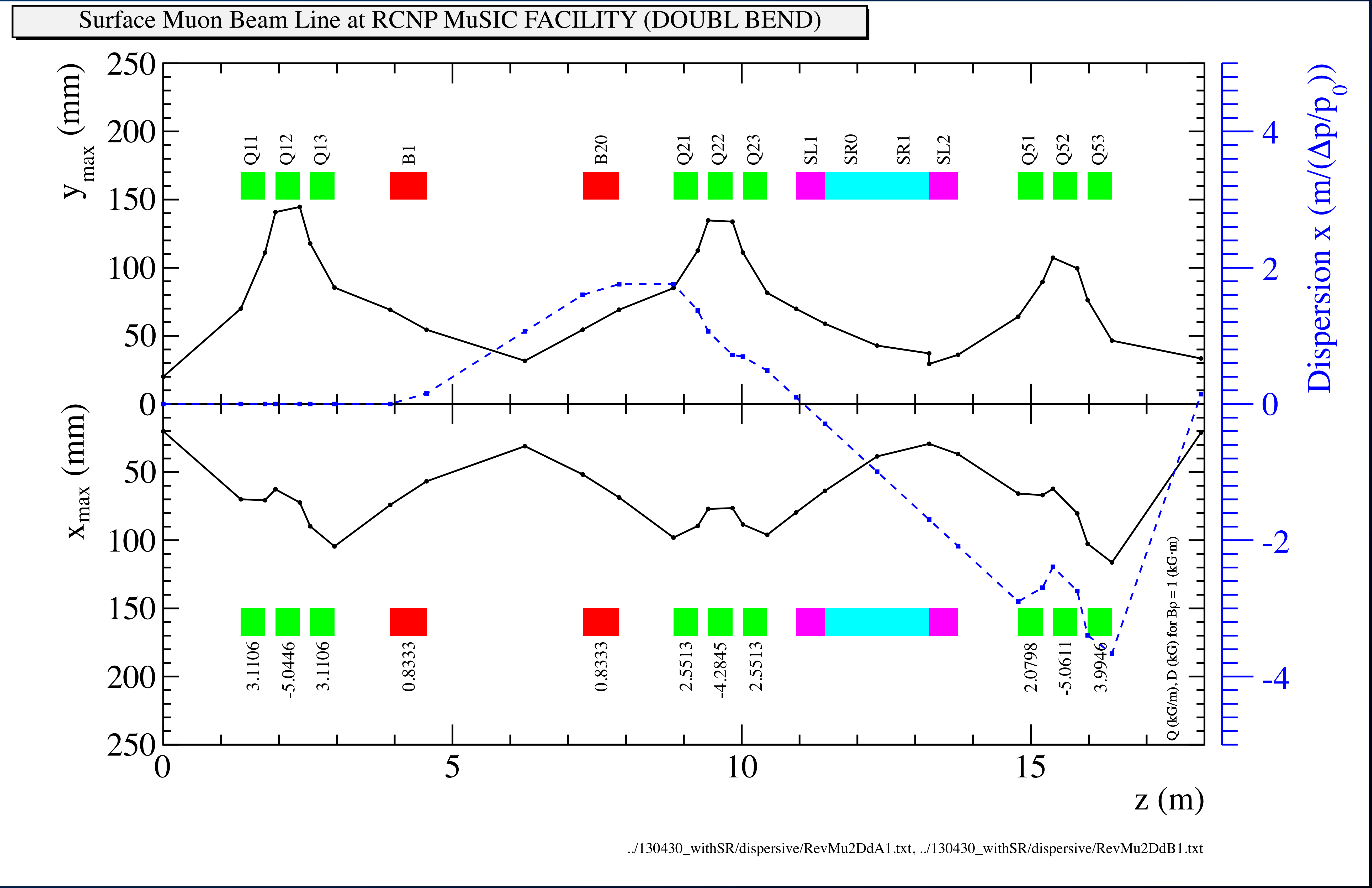
- Negative muon : nuclear phys. chemi. μ-X
  - beam size : ϕ10mm~Φ50mm
  - angle : < 200mrad
  - intensity : 2×10^4 ~2×10^5/sec

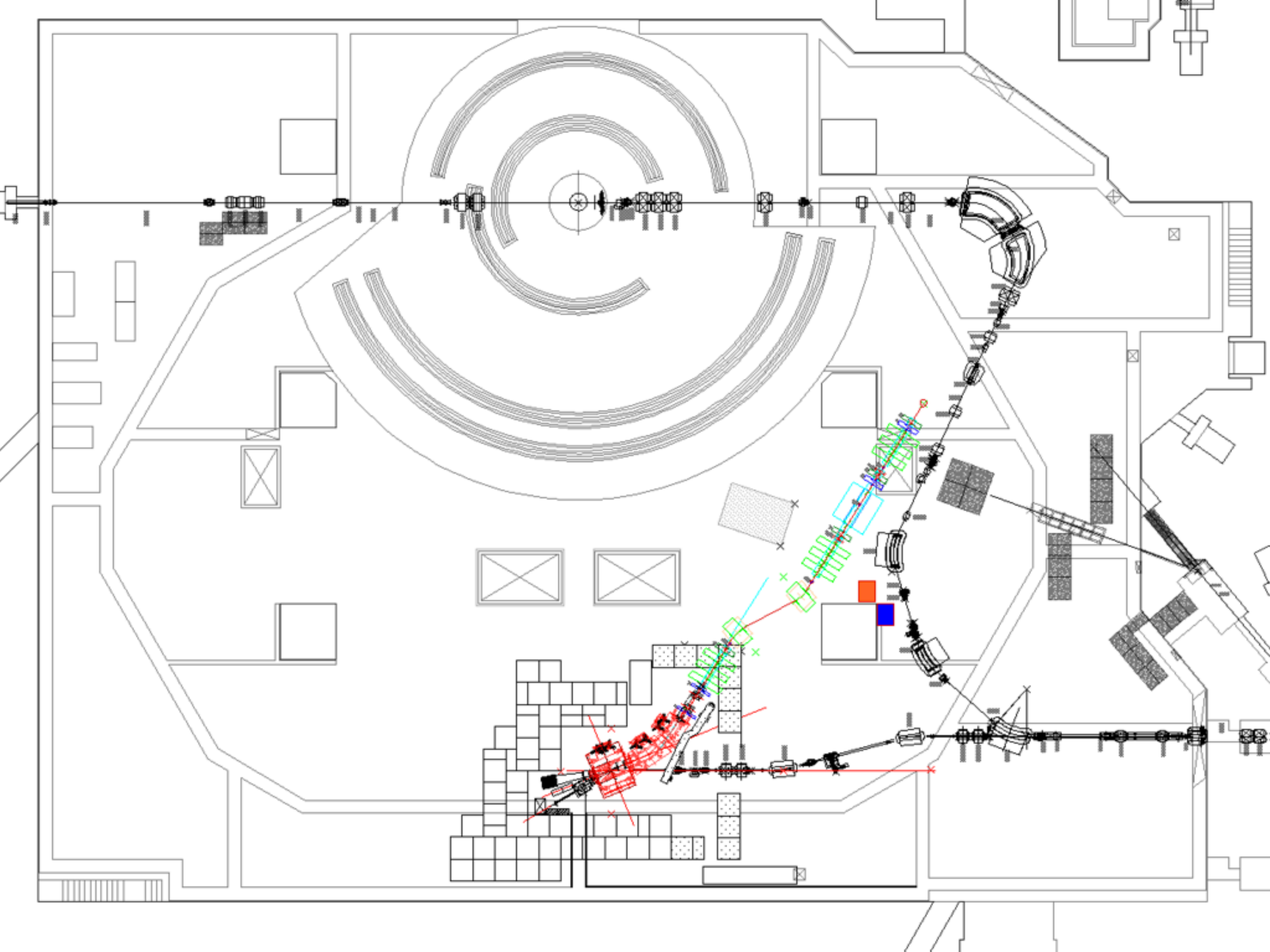
Layout of the beam line

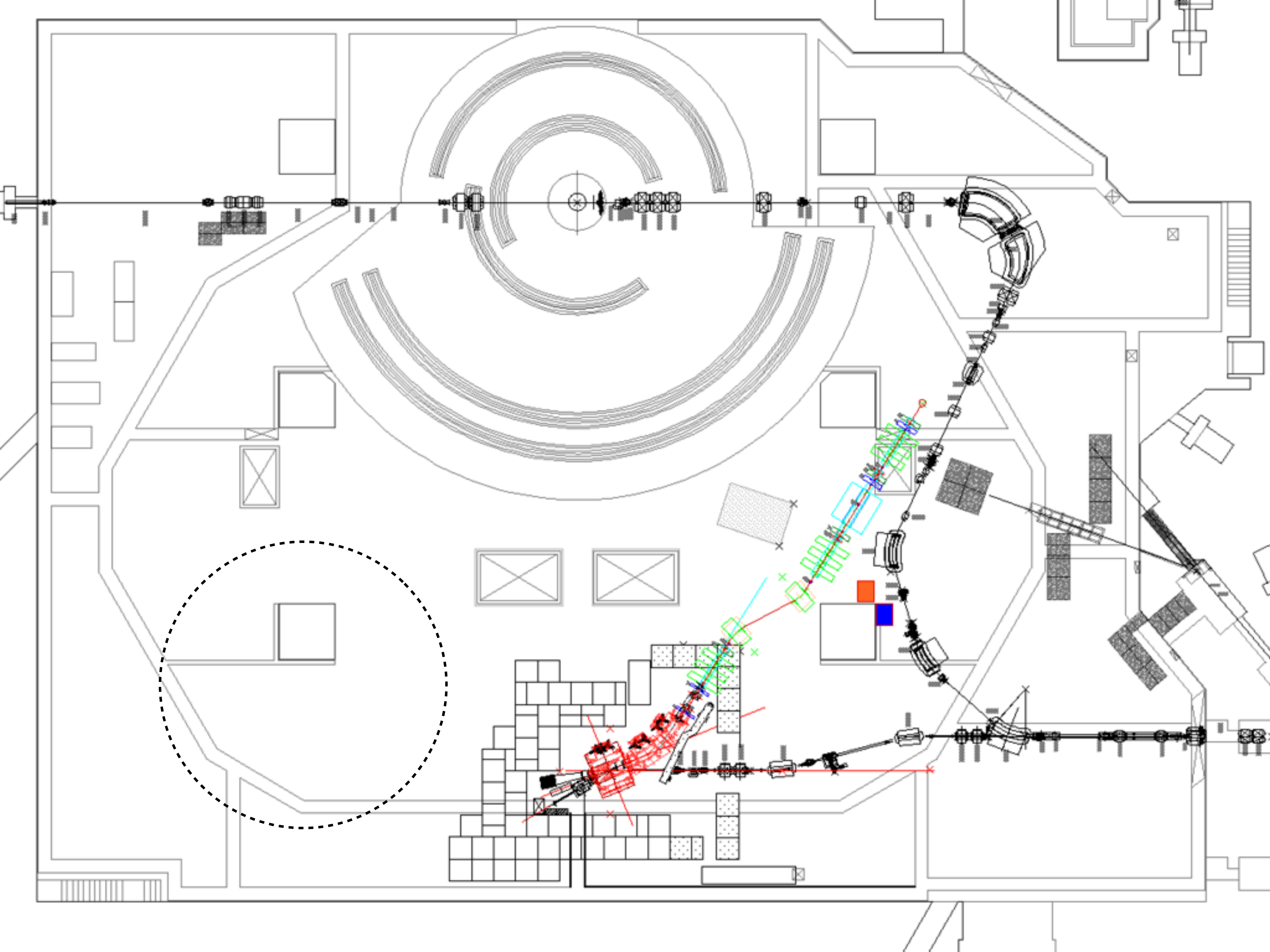


The construction will be finished by March 2014.

Example of the optics







Summary

MuSIC has successfully demonstrated the performance of a pion capture system.

Now we are working very hard to construct a DC muon line for the low intensity application as a stahe-1 of the MuSIC.

(+) **Materials Science** :

- μSR (a μSR apparatus is needed) $10^{5\text{-}6}\,\mu^{+}$/sec, polarized

(-) **Nuclear Physics** :

- nuclear muon capture (NMC) $10^{4\text{-}5}\,\mu^{-}$/sec
  - nuclear matrix element study for $0\nu\ \beta\beta$ decay
- pion capture and scattering

(-) **Chemistry** :

- chemistry on pion/muon atoms $10^{4\text{-}5}\,\mu^{-}$/sec

Stage-1