A new intense DC muon beam from a pion capture solenoid, MuSIC

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Outline

- Motivation
- About MuSIC
  - What's MuSIC?
  - New pion capture solenoid system
  - Collection dipole field
  - Schedule
- MuSIC beam tests
  - Estimation of muon yield
- Summary

Motivation ~muon science~

Particle Physics — $10^{8\text{-}9}$ μ^+/sec

- search for charged lepton flavor voilation

Nuclear Physics

- nuclear muon capture — $10^{5\text{-}6}$ μ^-/sec
- pion capture and scattering

Chemistry

- chemistry on pion/muon atoms — $10^{5\text{-}6}$ μ^-/sec

Material Science — $10^{5\text{-}6}$ μ^-/sec (polarized)

- μSR

Accelerator / Instruments R&D

- Superconducting solenoid magnet
- FFAG, RF
- cooling methods
- muon acceleration, deceleration and phase rotation

COMET
ν-factory
muon collider etc...

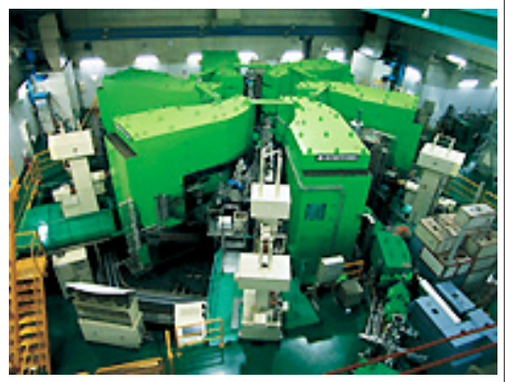
High intense muon beam source is needed!

What is the MuSIC ?

MuSIC

- The DC muon beam source being constructed in RCNP, Osaka univ.
- Design muon intensity :

$10^{8\text{-}9}\,\mu$/s @392MeV, 1 μA proton beam



- 400W proton beam from RCNP ring cyclotron
- The world's highest muon collection efficiency
  ($>10^3$ than conventional muon beam line)

Technical points

- The first pion capture solenoid system
- A muon transport solenoid with collection dipole field
  - possible to select the momentum / charge of muons

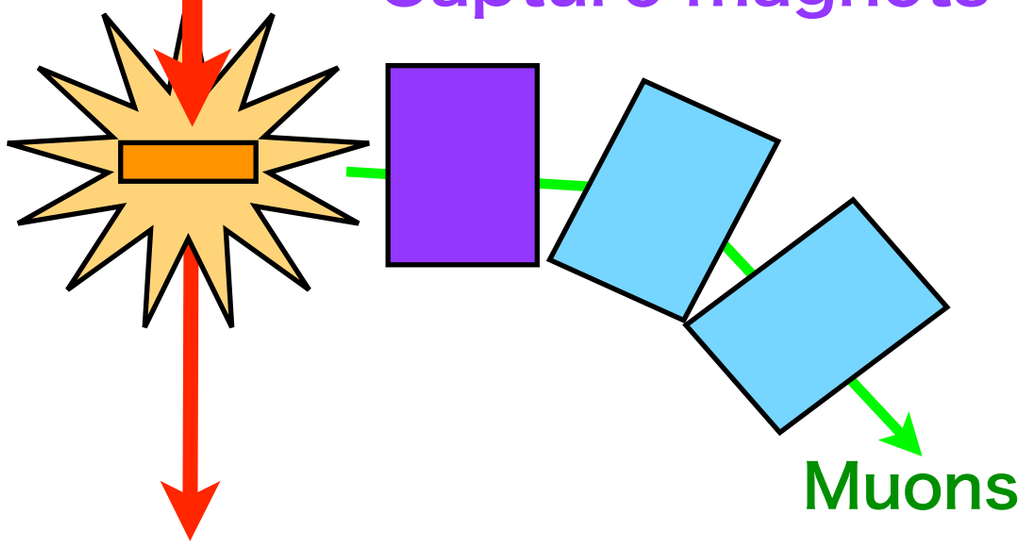
Muon Collection System

Conventional muon beam line

Proton beam

Target
graphite
t :**20mm**
Φ:70mm

Capture magnets

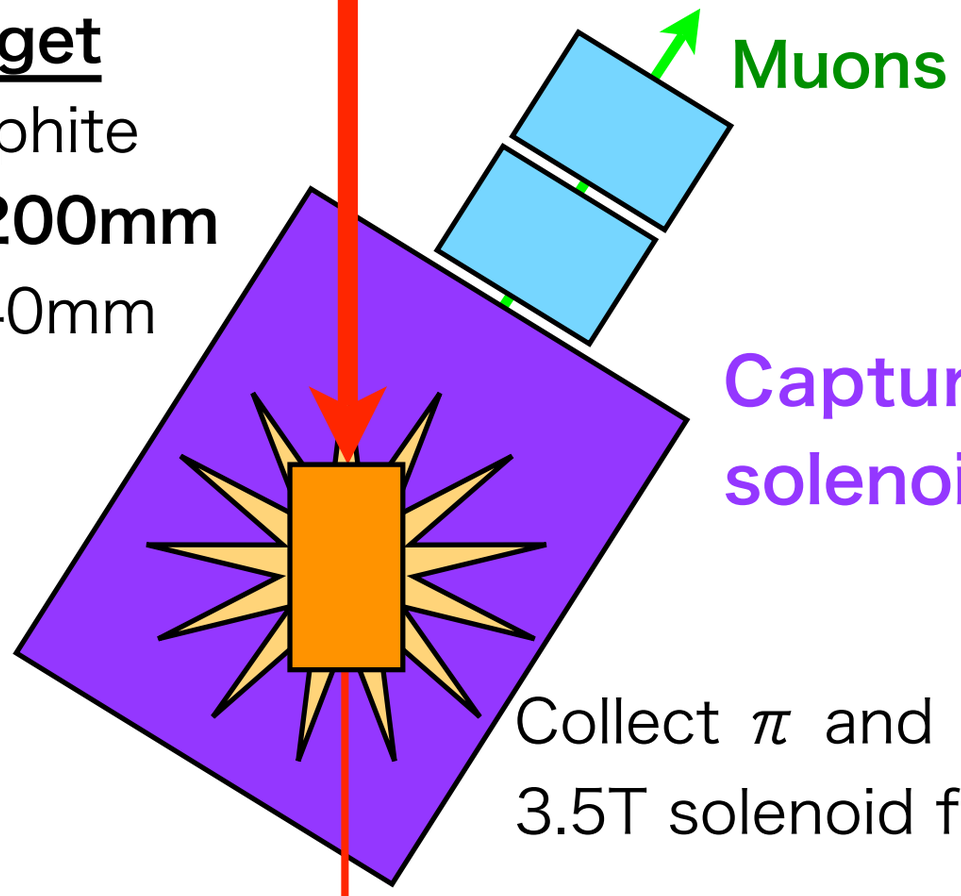


To downstream experiments
(proton beam loss < 5-10%)

MuSIC

Proton beam

Target
graphite
t :**200mm**
Φ:40mm



Collect π and μ by 3.5T solenoid field

To the beam dump

Thick target & Large solid angle

COMET,
Mu2e,
ν-factory,
Muon collider

Comparison

	MuSIC (JAPAN)	J-PARC (JAPAN)	PSI (Switzerland)
Beam power	**0.4 kW**	**1000 kW**	**1200 kW**
Muon intensity	**10^8-10^9 /sec**	**~10^8 /sec**	**10^8-10^9 /sec**
Muon production efficiency	**10^5~10^6 /sec/W**	~10^2 /sec/W	10^2~10^3 /sec/W
Time structure	**continuous**	**pulsed (25Hz)**	**continuous**
Beam polarization	medium (to be studied)	high	high
Multiple use	only 1 channel	many channels	many channels

Japan will be the only country which bas both DC and pulsed muon beam facilities.

Momentum / charge selection by solenoid field

- In transport solenoids, charged particles moves helically.
- If solenoid is bended, the center of helical movement drifts perpendicular to the bending plane.

$$\text{Distance of drift :}\quad D = \frac{p}{qB}\,\theta_{\text{bend}}\,\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

- If there is additional dipole field (=Dipole magnet) which is perpendicular to the bending plane, the center of helical motion is compensated. (it depends on the momentum and charge of the beam)

$$\text{Dipole magnet :}\quad B_y = \frac{p}{qr}\,\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

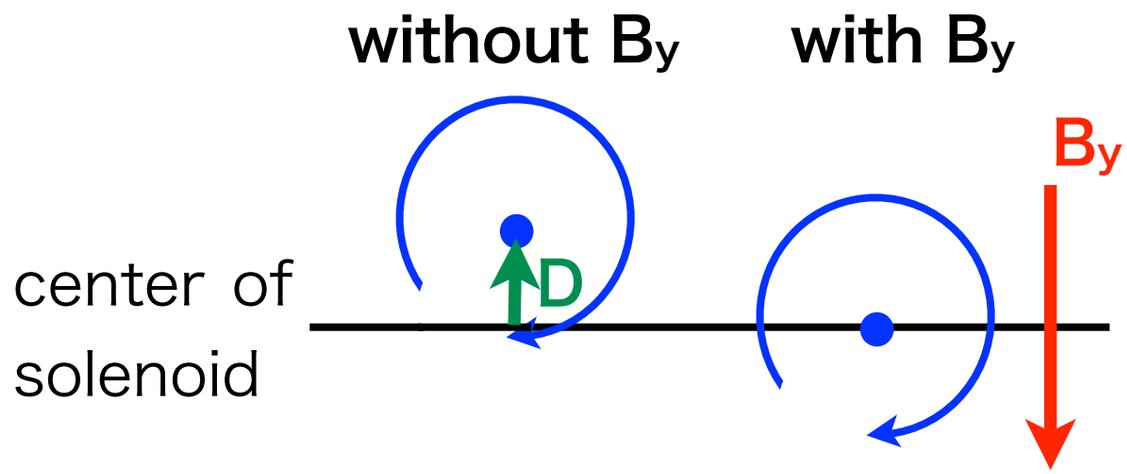
p : Momentum of the particle

q : Charge of the particle

B : magnetic field

θ_{bend} : Bending angle of the transport solenoid

$\theta = \text{atan}(p_T/p_L)$

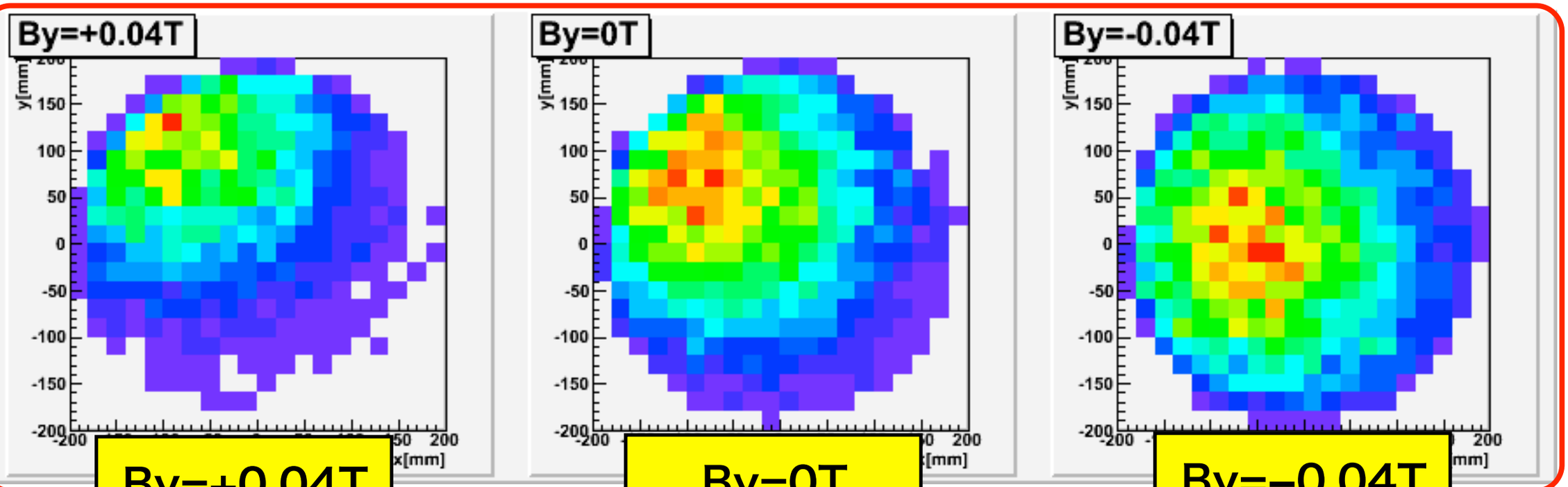


Muon beam from MuSIC

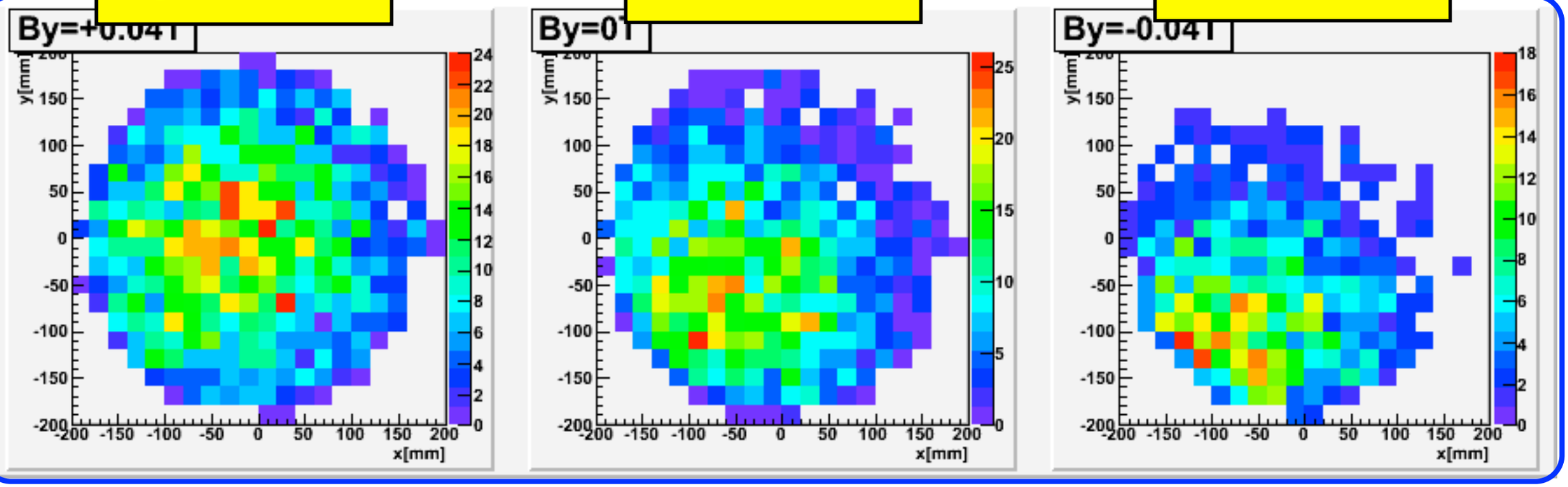
Simulation by g4beamline, QGSP_BERT

…… Position distribution @ transport solenoid 36° exit ……

μ^+



μ^-

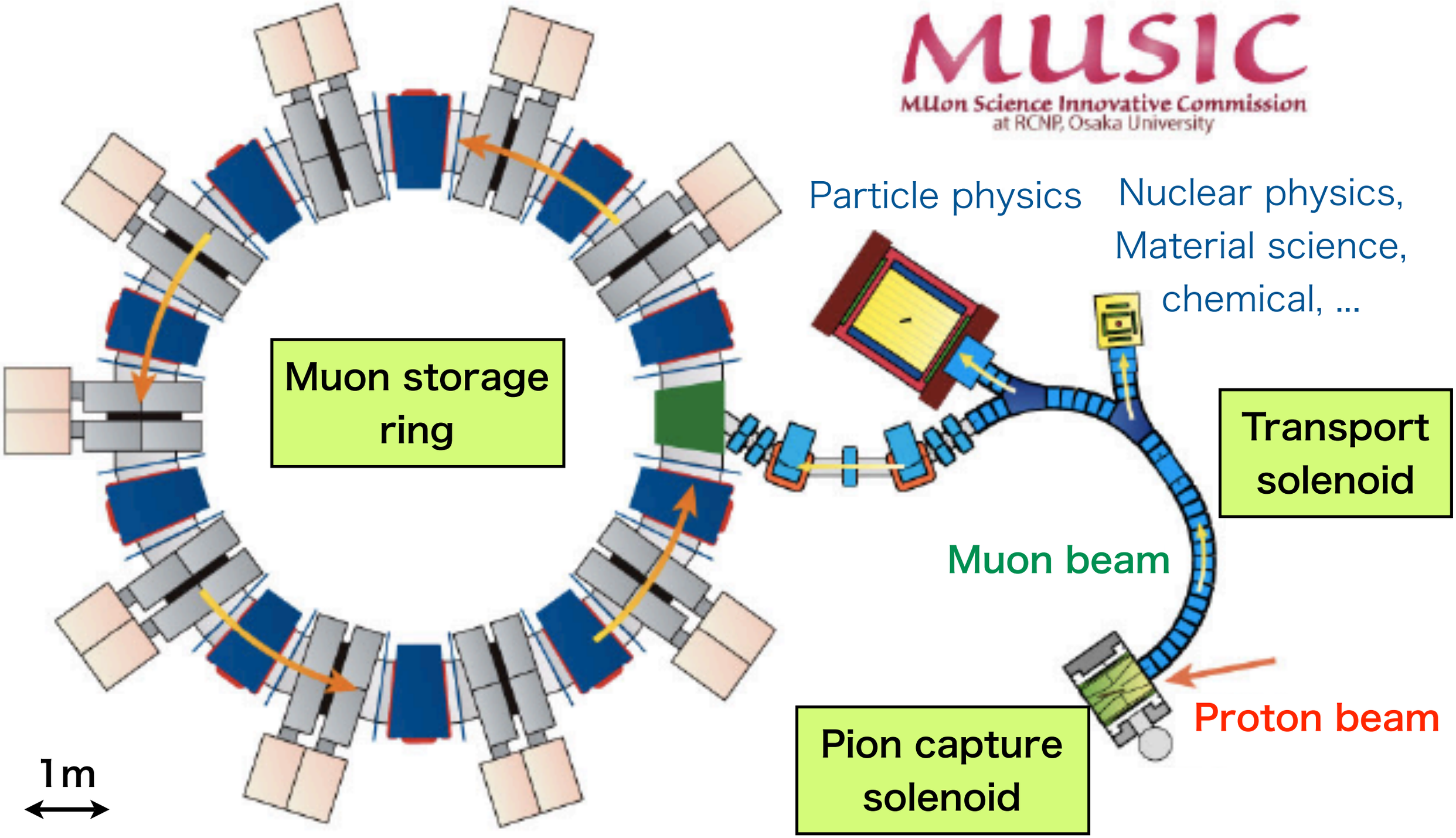


Final Layout of MuSIC

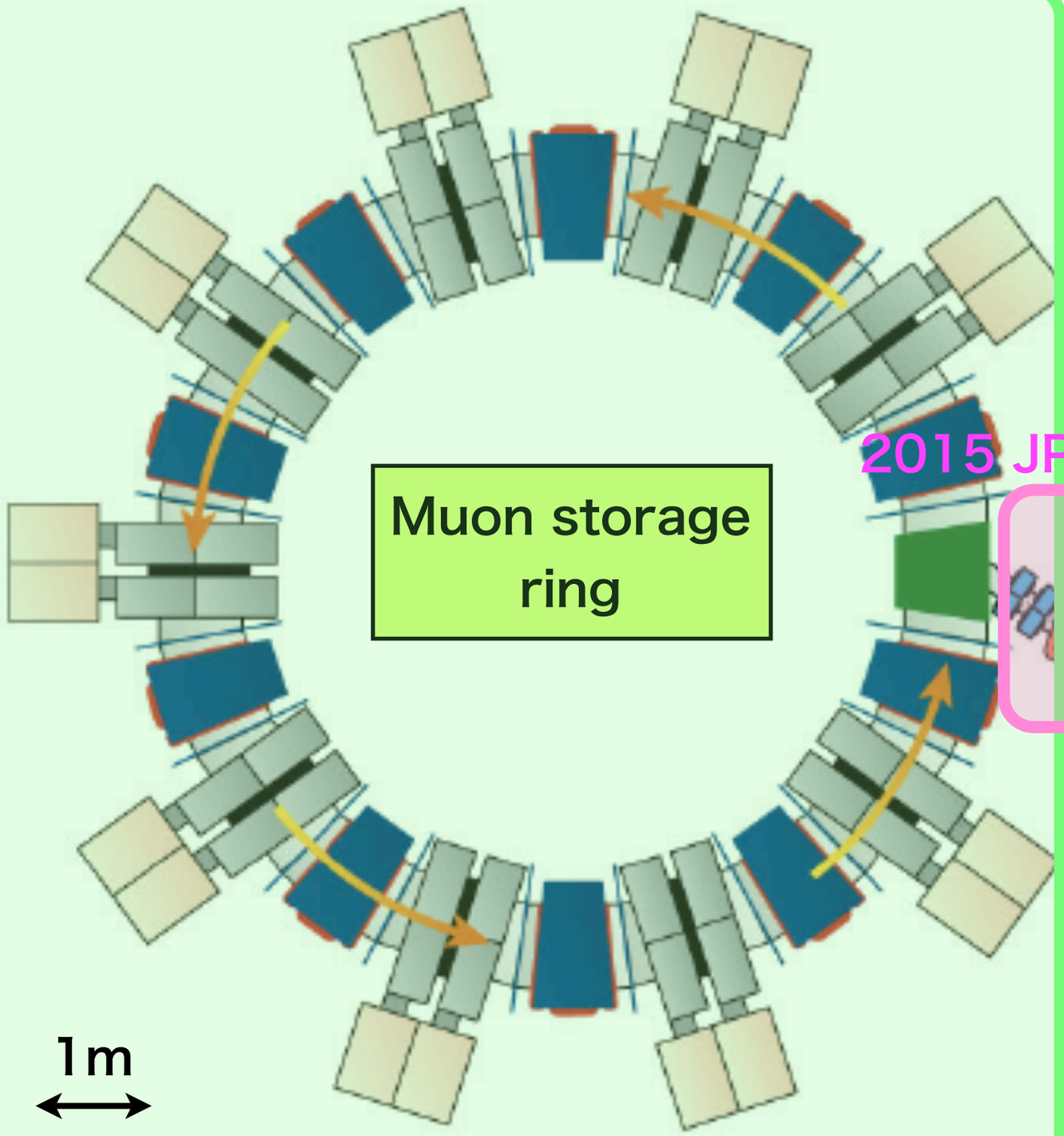
MUSIC
Muon Science Innovative Commission
at RCNP, Osaka University

Particle physics

Nuclear physics,
Material science,
chemical, ...



Schedule



2015-16 JPY

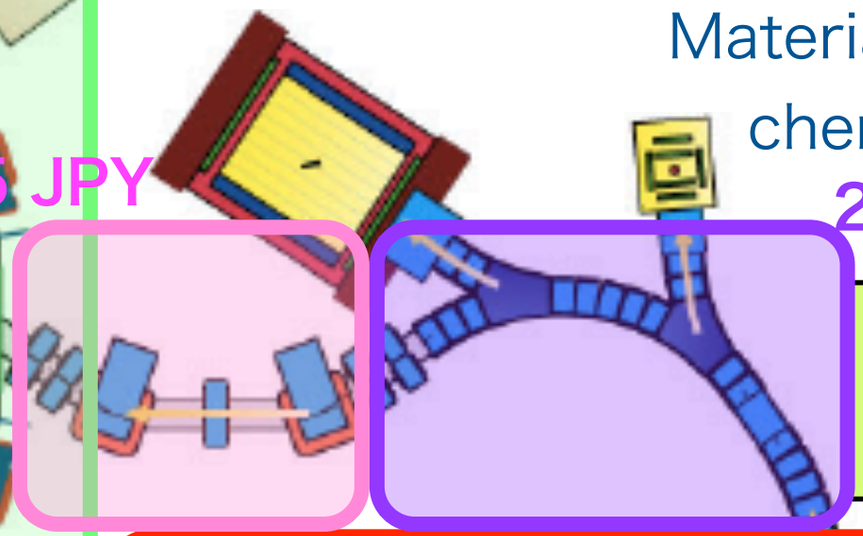
MUSIC
Muon Science Innovative Commission
at RCNP, Osaka University

Particle physics

Nuclear physics,
Material science,
chemical, ...

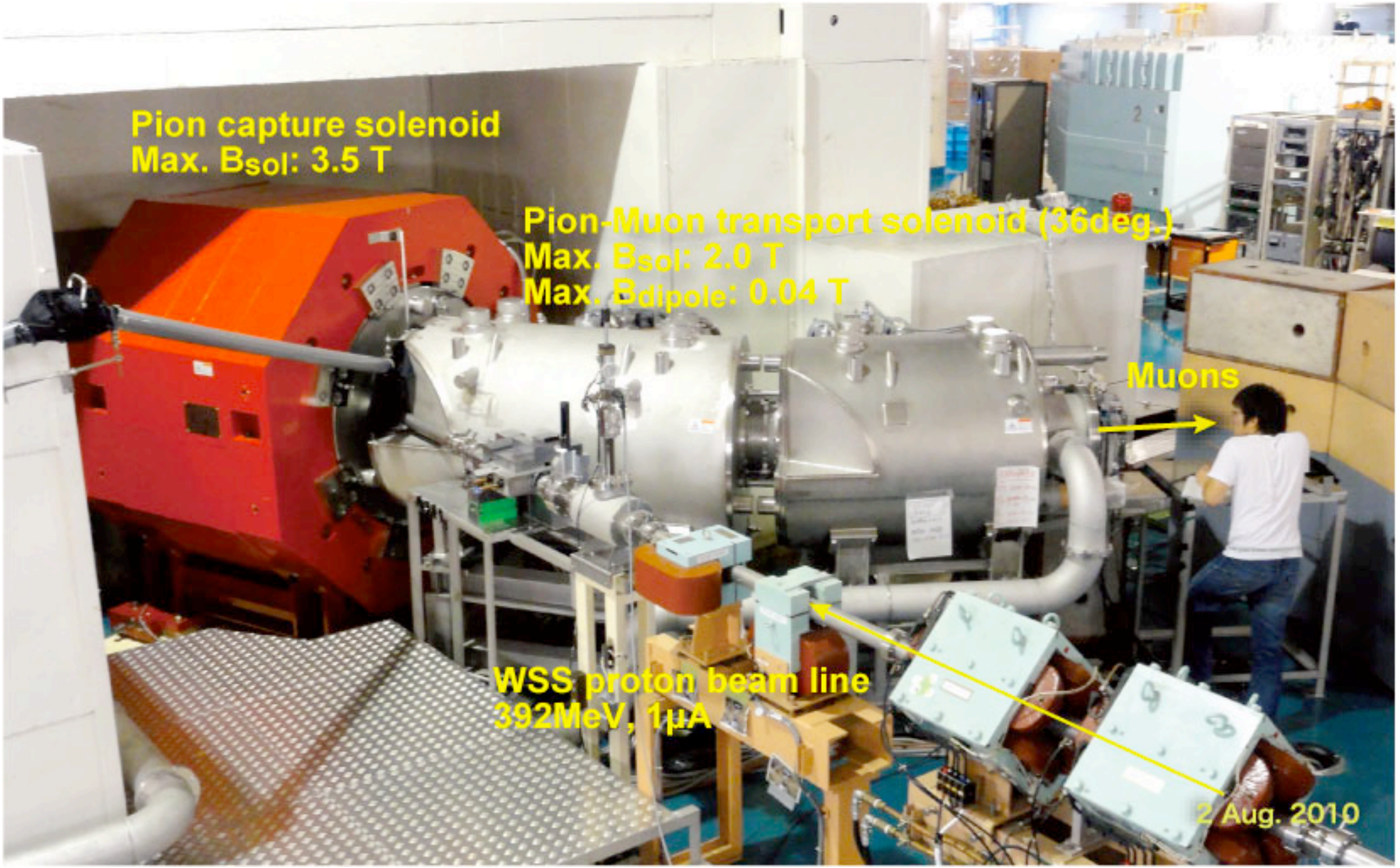
2015 JPY

2013-14 JPY



Constructed in 2009 JPY

MuSIC @RCNP, (~2012 Feb)



History of MuSIC Project

2009 JPY ----------

- Construction of a proton beam line, pion capture system and transport solenoid (up to 36 degree)

2010 JPY ----------

1st beamtest … checked that every system worked successfully

2nd beamtest … muon lifetime measurement

2011 JPY ----------

3rd beamtest … muon lifetime measurement with higher statistics
muonic X-ray measurement

4th beamtest … muonic X-ray measurement with higher statistics
measurement of neutron flux and energy

- Radiation shielding block were located

2012 JPY----------

5th beamtest … measurement of energy and spatial distributions

Just finished! operate systems with proton beam current 1 μA

MuSIC beam test

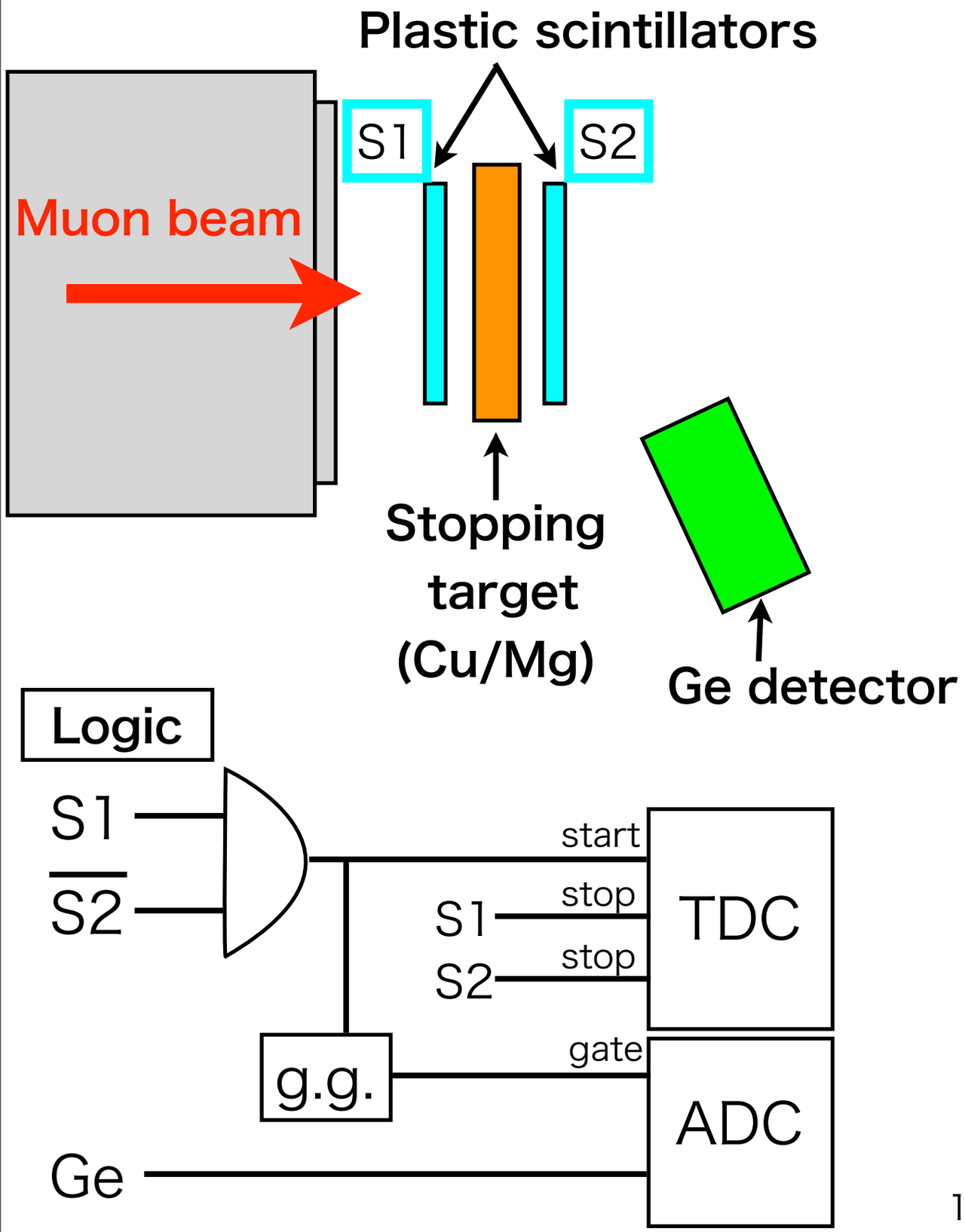
Measurement of

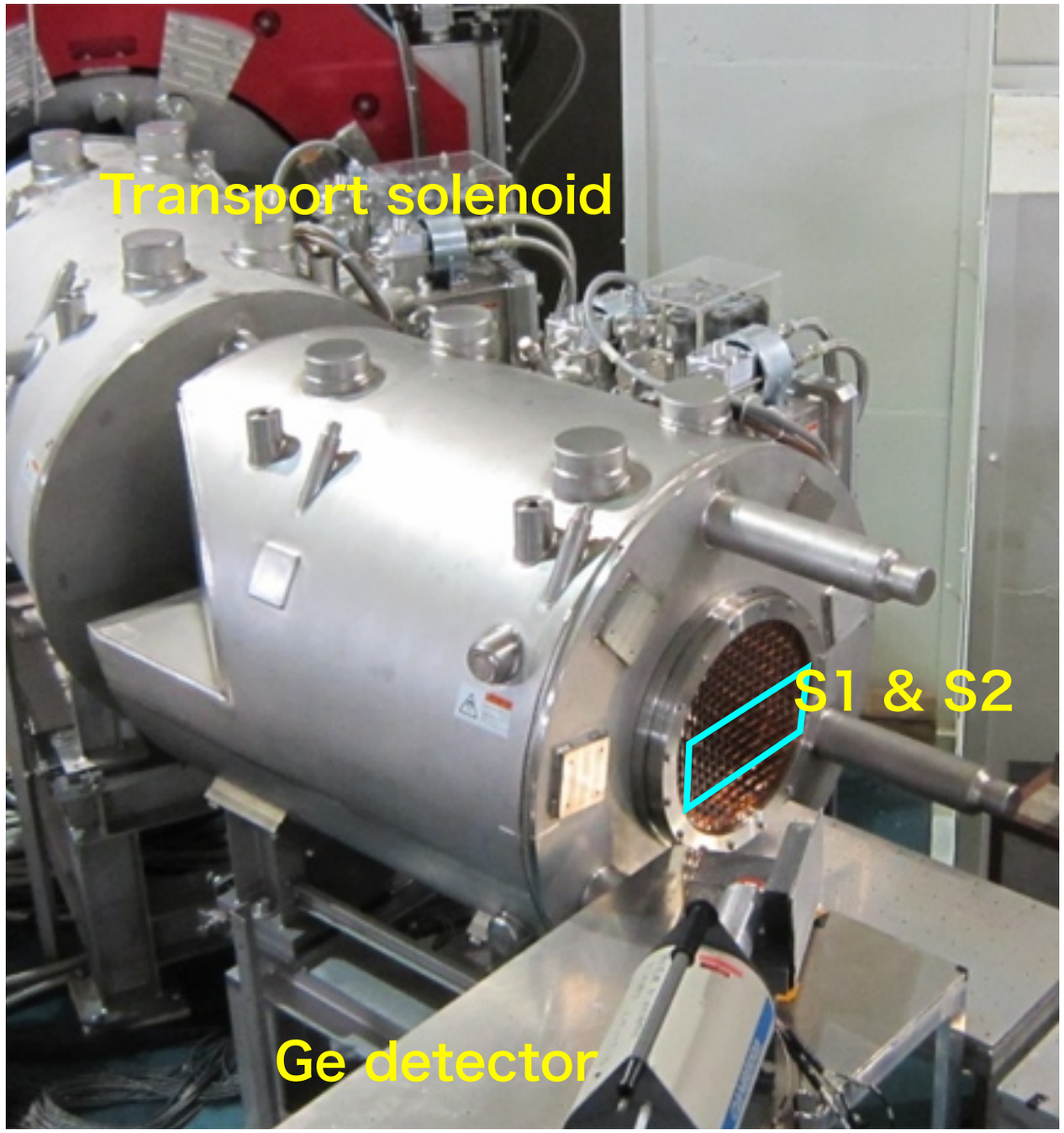
- Muon lifetime …… μ^+ and μ^- yield
- Muonic X-rays …… μ^- yield

with small proton beam current (~500pA)

→Estimate the muon yield with 1 μA proton beam

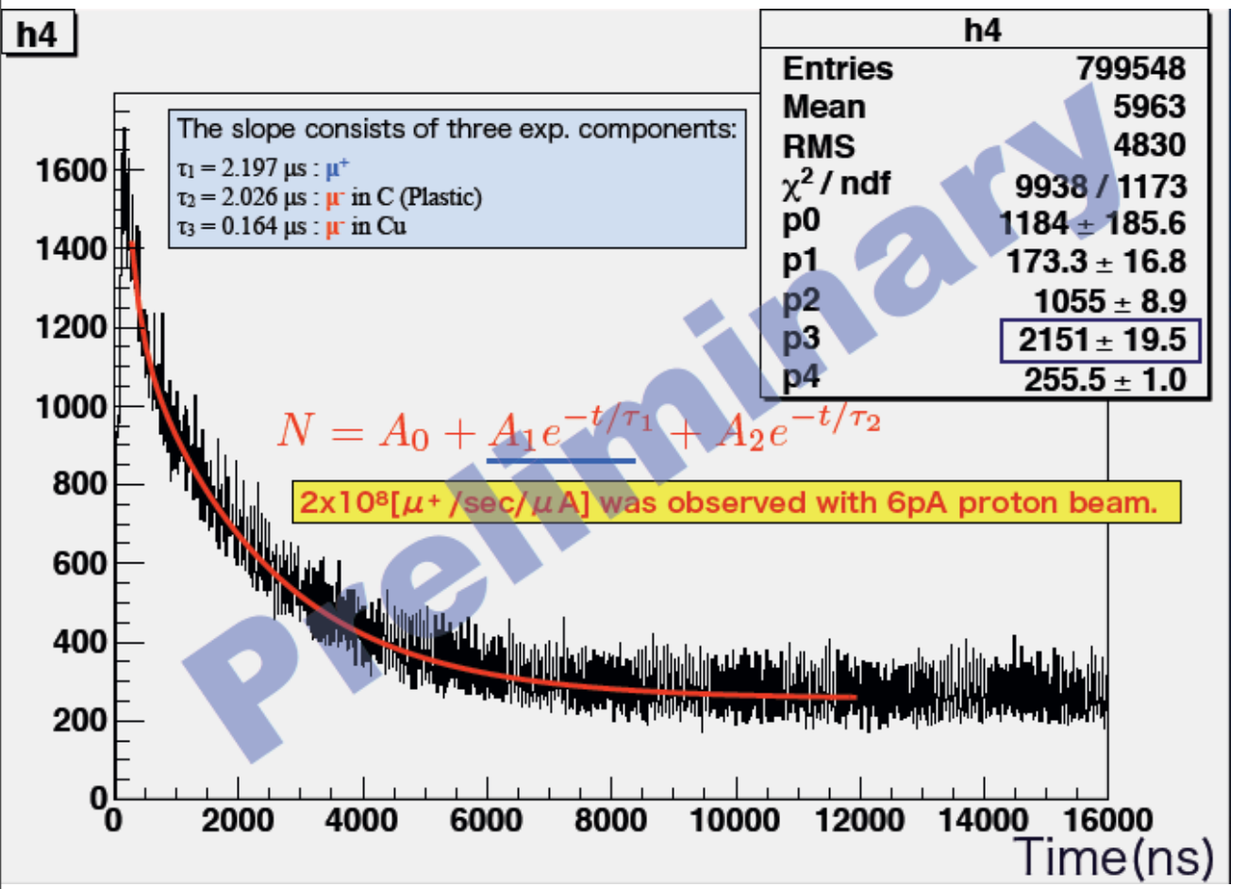
Setup of MuSIC beam test



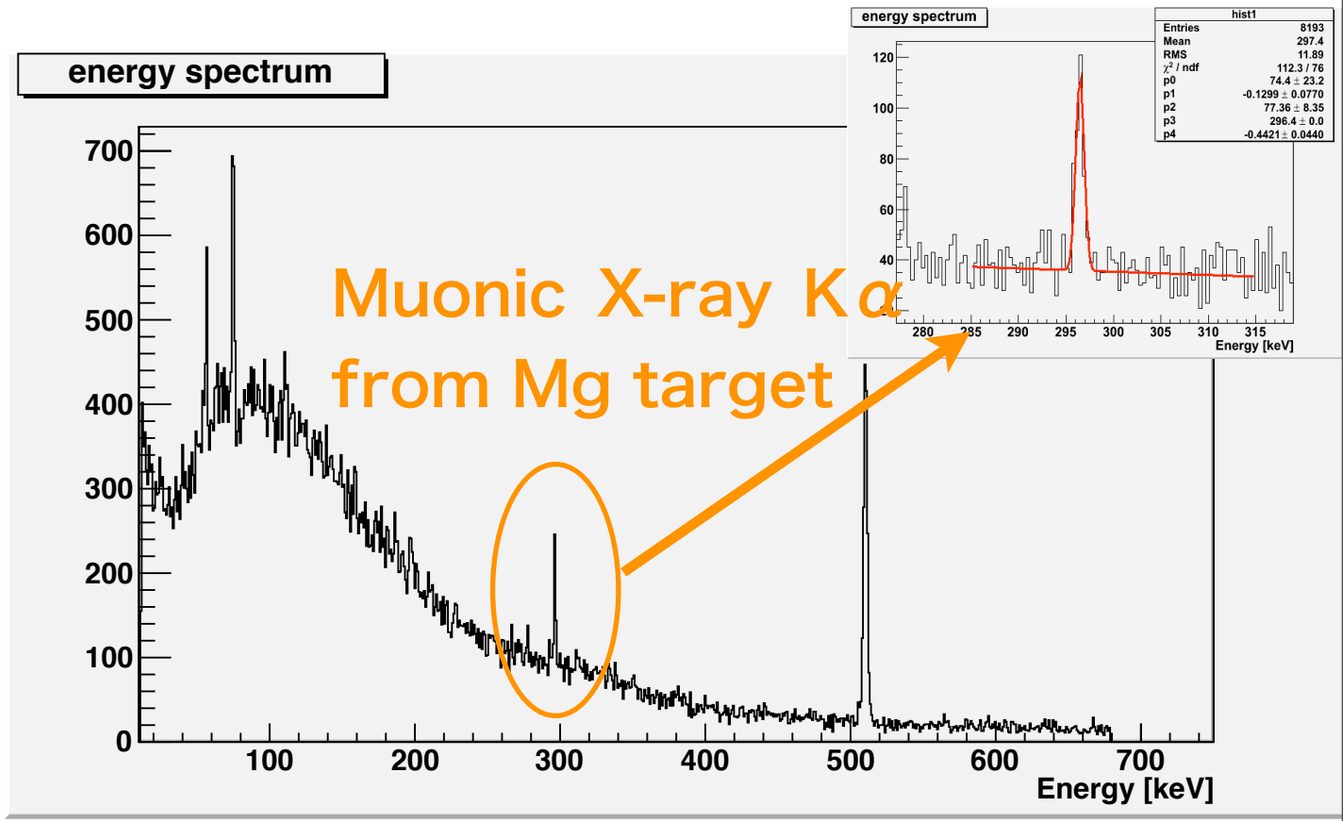


Results of Beamtest

Muon Lifetime



Muonic X-ray



	Beamtest	Simulation
Number of μ^+ [μ/sec/μA]	2×10⁸	3×10⁸
Number of μ^- [μ/sec/μA]	(1.7±0.3)×10⁸	1.4×10⁸

The measured muon yield are consistent with simulation results!

Summary

- MuSIC is a high intense DC muon beam facility at RCNP, Osaka Univ.
- Using the first pion capture solenoid system, MuSIC can achieve the highest muon collection efficiency in the world.
- By measurement of muon lifetime and muonic X-rays at MuSIC, we estimated muon yield and confirmed that systems work well as designed, at a point of muon yield.
- MuSIC has made experimental demonstration of the pion capture system, which would make future muon particle physics experiments possible.

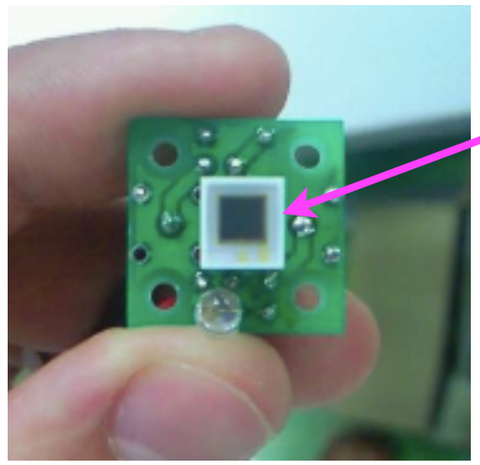
Backup slides

Trigger counters (in 5th beamtest)

	S1 (Upstream)	S2 (Downstream)
Material	Plastic scintillator	
Size	30mm×380mm	50mm×380mm
Thickness	0.5mm	10mm
Light collection	Fiber	Light guide
Readout	MPPC	
Sensitive area	1.3mm×1.3mm	3mm×3mm

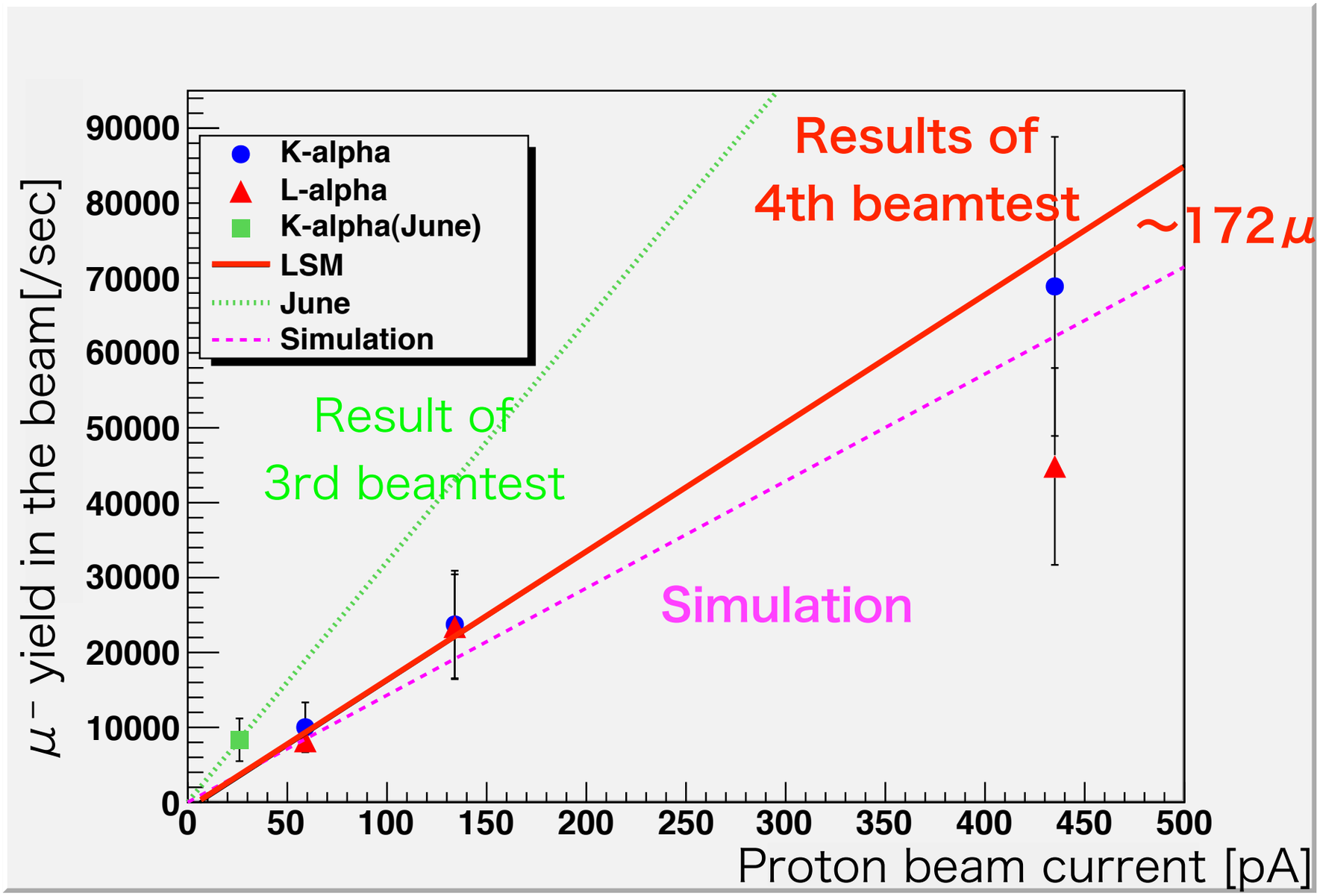
●Readout…**MPPC**

- Usable with low voltage(～70V) and at room temperature
- Not affected by magnetic field



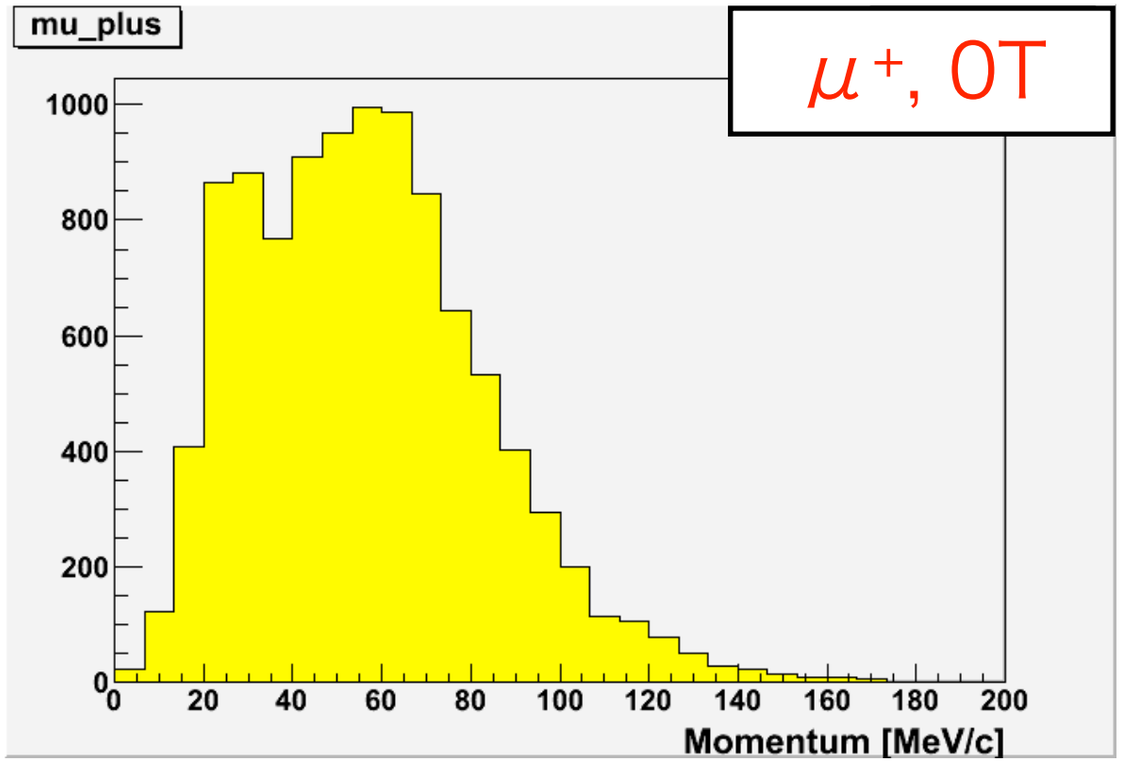
μ^- yield vs. beam current

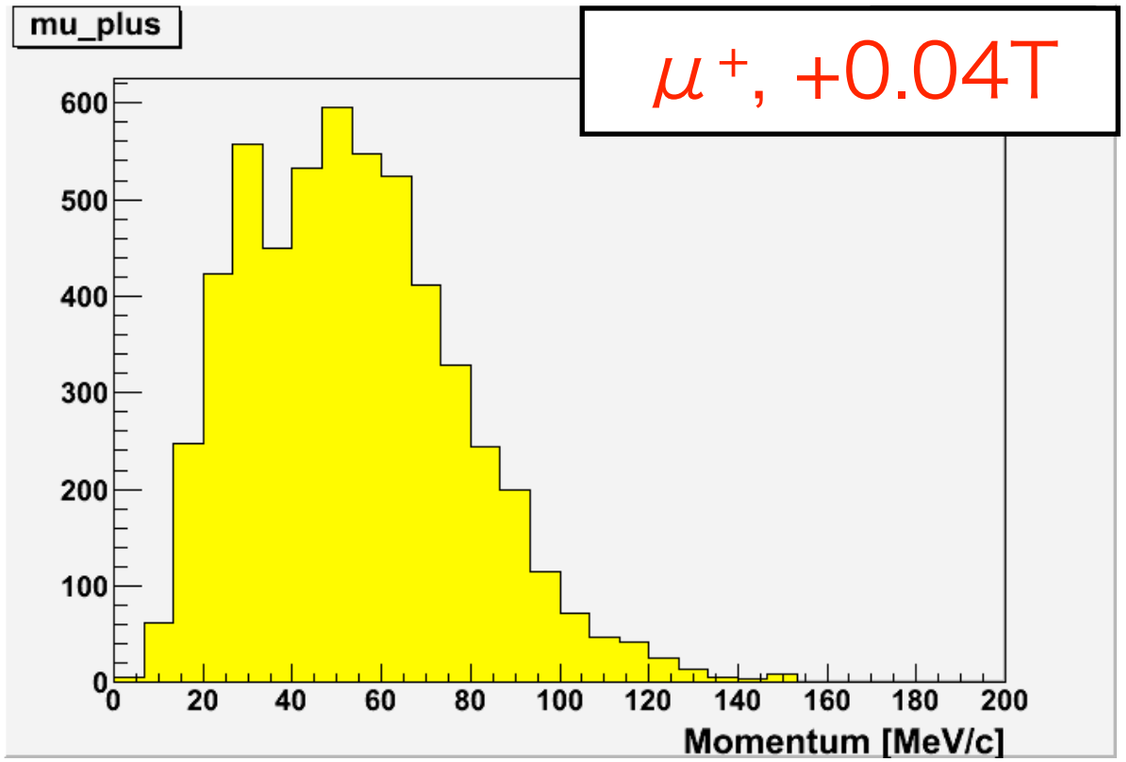
From the results of muonic X-ray measurement

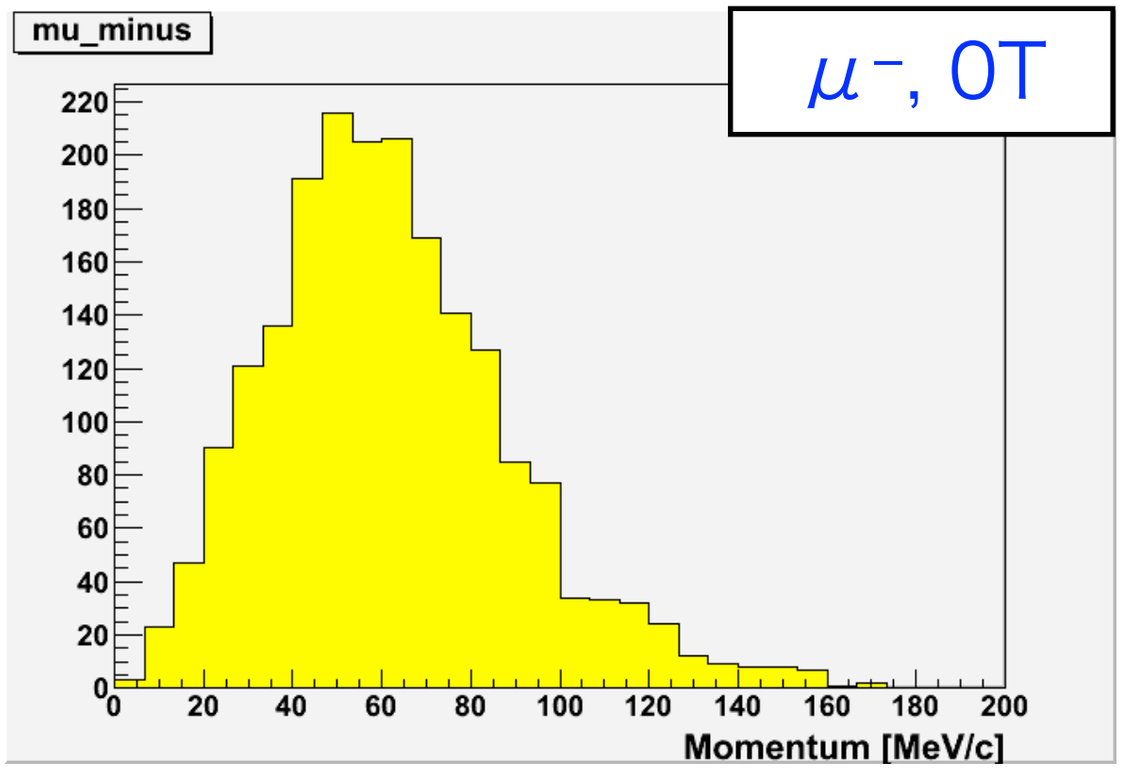


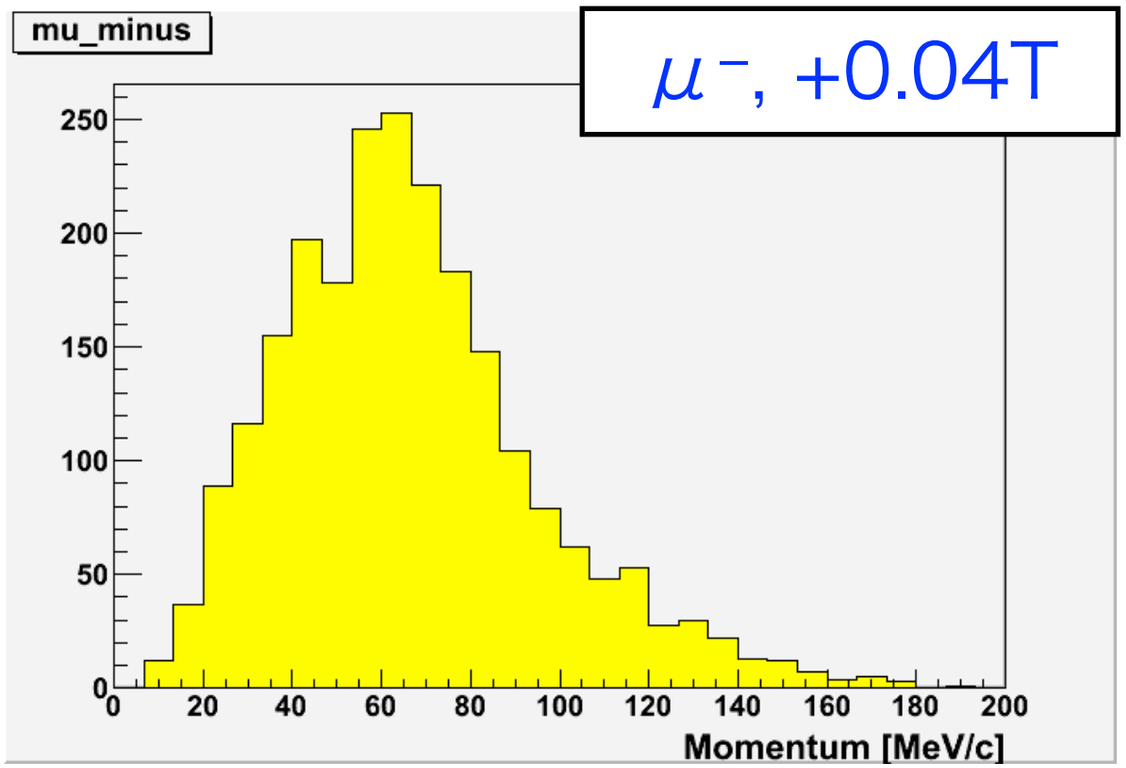
μ^- yield increase linearly to the beam current, so we can estimate the value at high current.

Momentum distribution





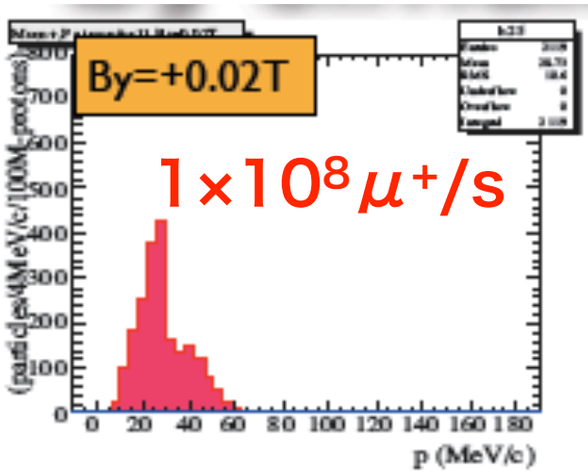


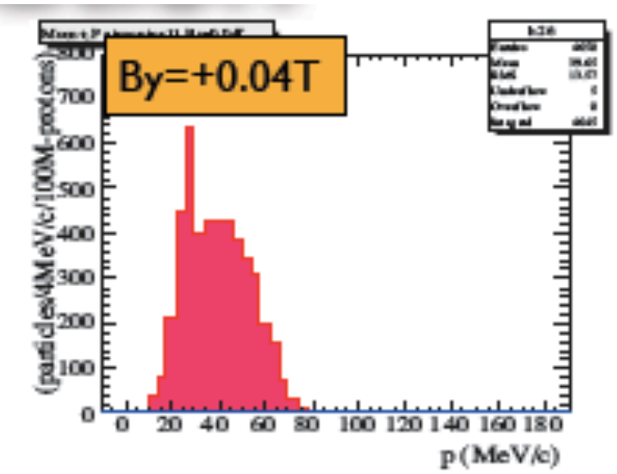


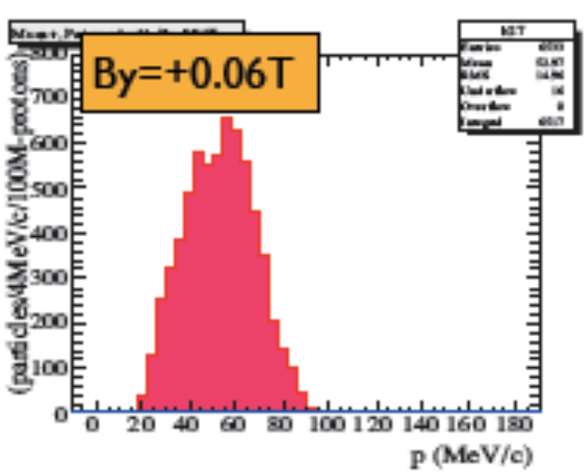
Muon beam from MuSIC

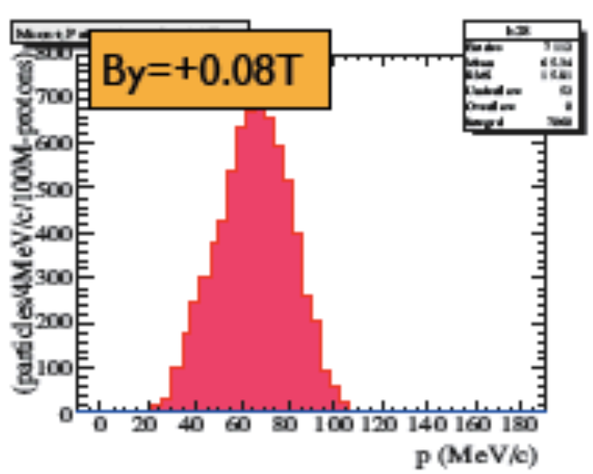
Simulation by g4beamline, QGSP_BERT

…… Momentum distribution ……

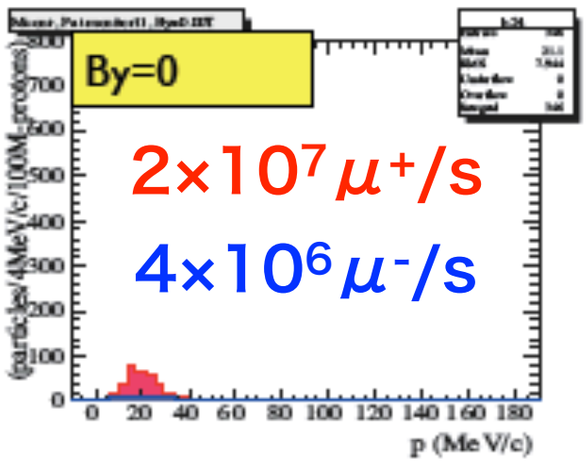








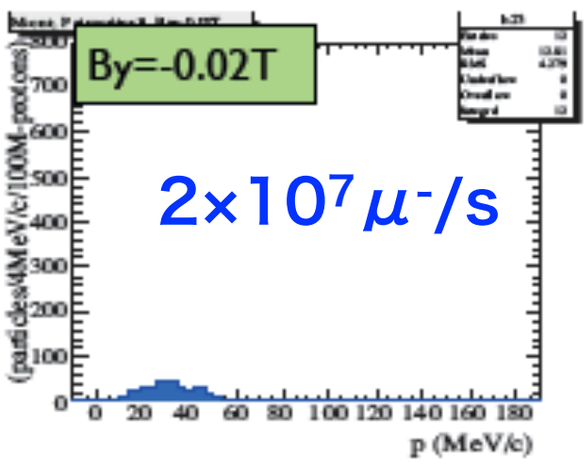
4×10⁸μ⁺/s

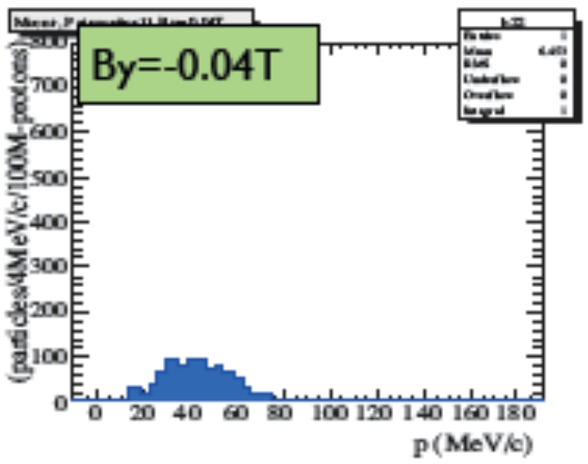


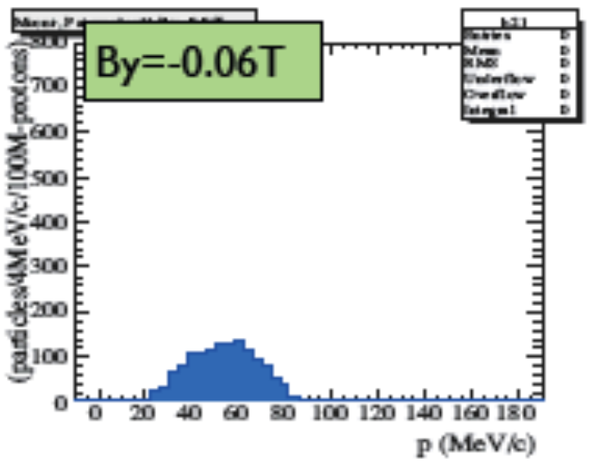
red：positive muon

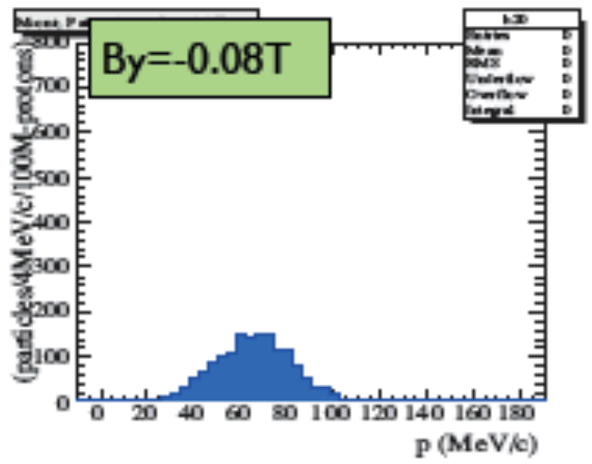
blue：negative muon

1×10⁸μ⁻/s

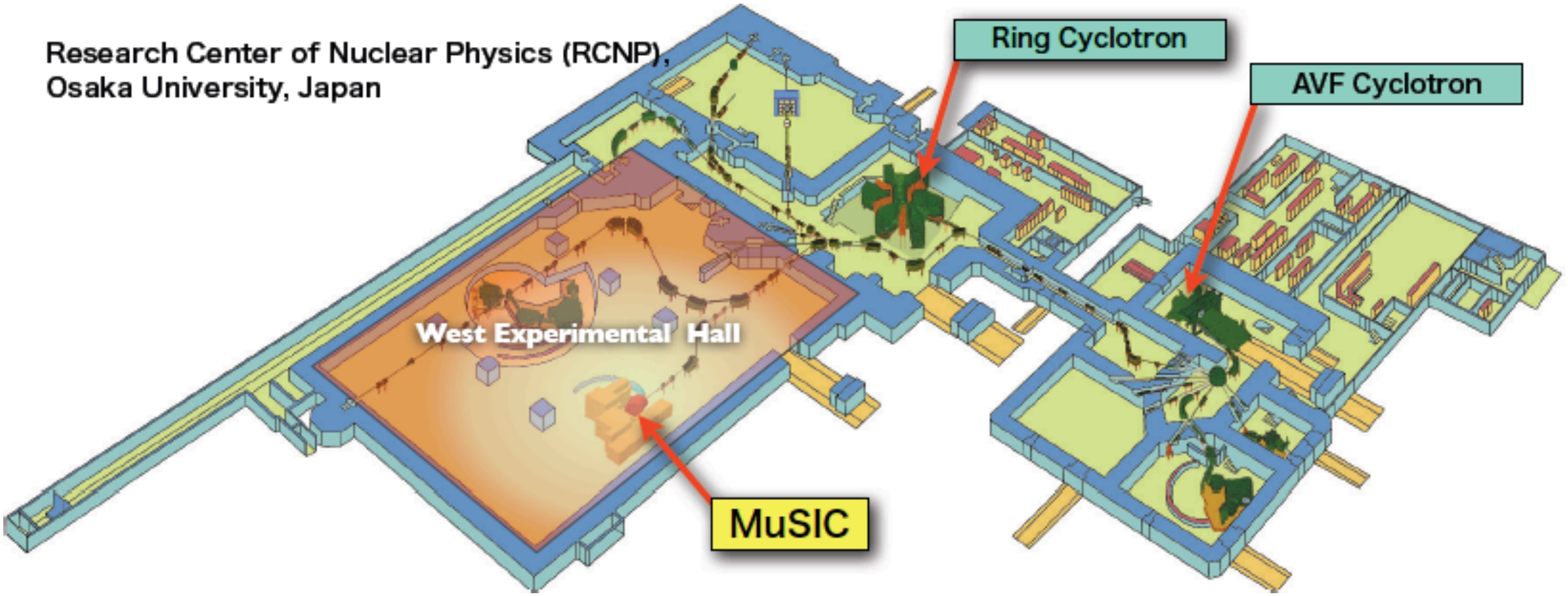








MuSIC @RCNP, Osaka Univ.



- A proton beam with **392MeV (=1 μA)** is provided from the Ring Cyclotron (up to 5 μA in near future).
- MuSIC is in the largest experimental hall (**the west experimental hall**).

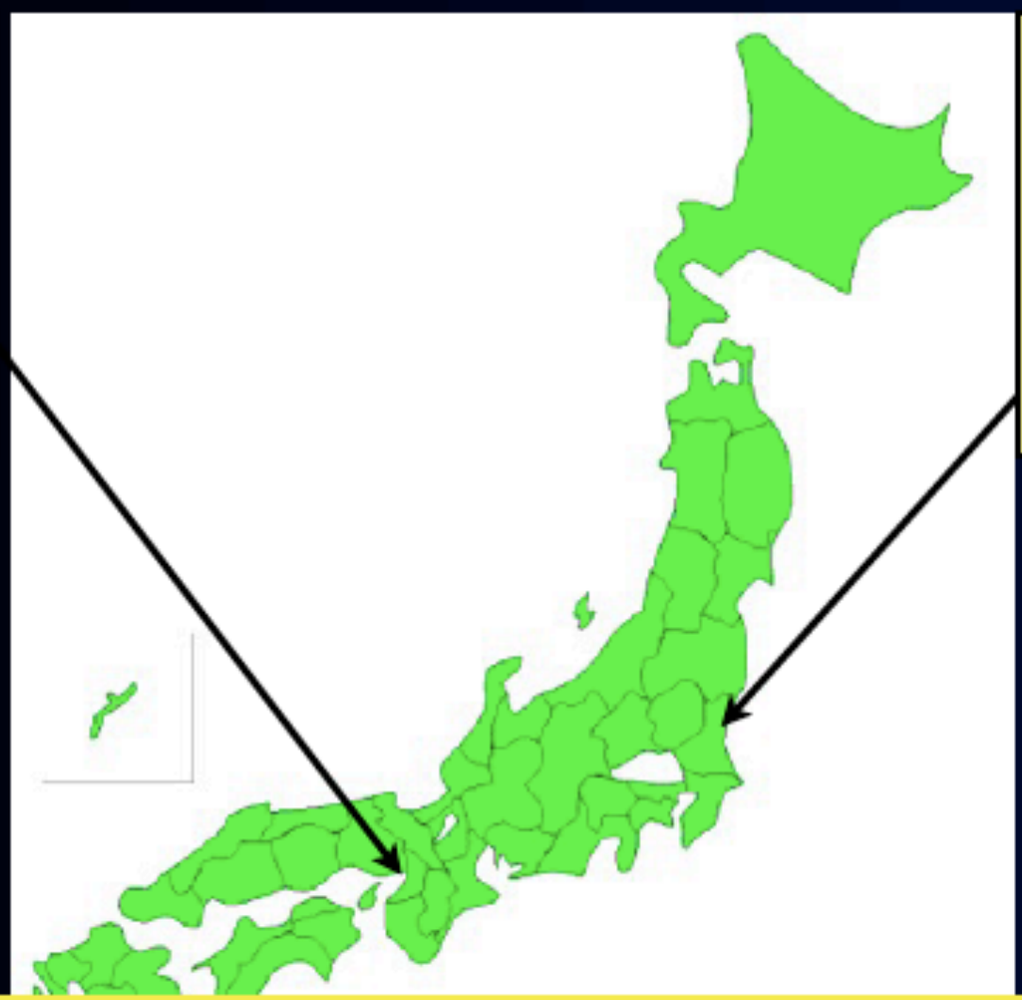
Muon facility in Japan

Muon Science in Japan

DC muon

Muon Facility
MuSIC
(Osaka)

400W
CW
10^8 /sec
single channel



Pulsed muon

Muon Facility
MUSE
(J-PARC)

1000kW
pulsed (25 Hz)
10^8 /sec
many channels

Japan will be the only country which has both DC and pulsed muon beam facilities.

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