PRISM Project

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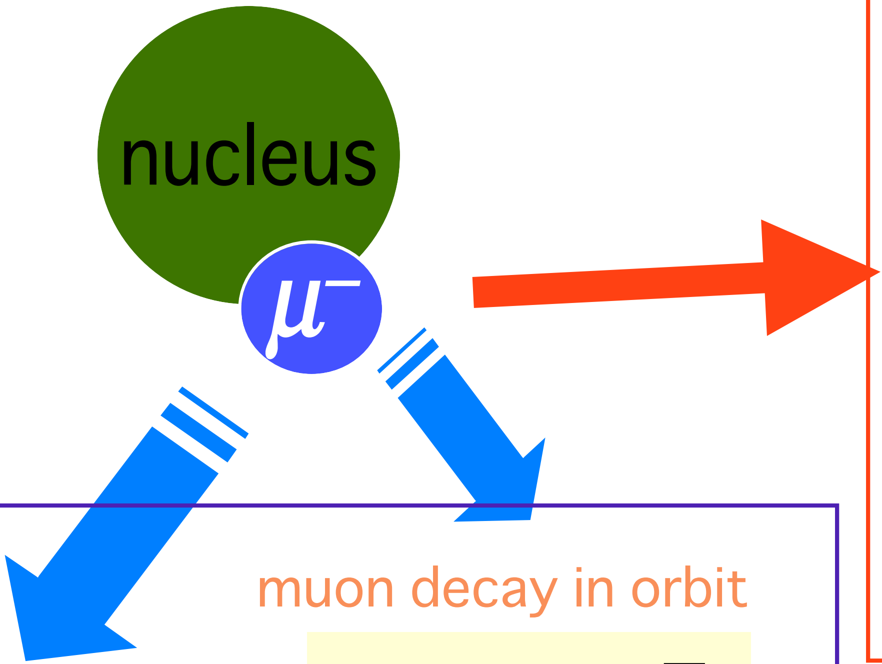
- Summary

Muon - Electron Conversion

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

within the Standard Model

If a new physics beyond the SM exist,

Neutrino-less muon nuclear capture (=μ-e conversion)

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

signal :

$$m_\mu - B_\mu \sim 105 MeV$$

$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

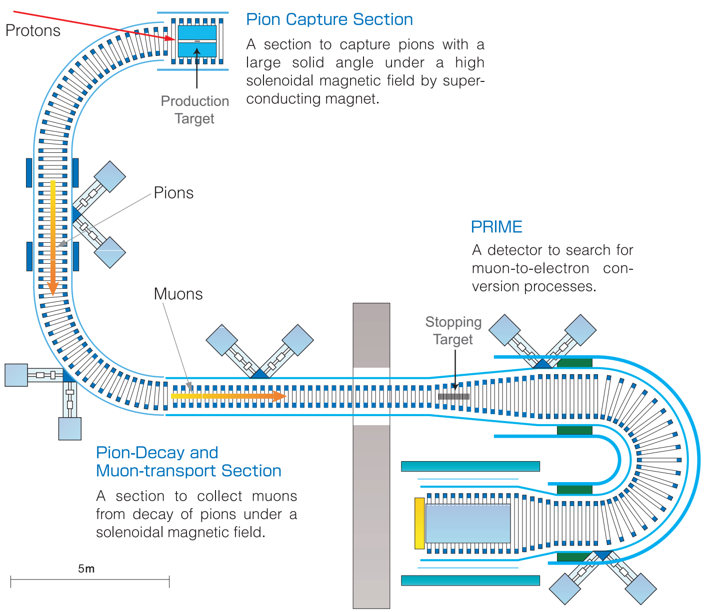
current upper limit by SINDRUM II
B(μ Ti -> e Ti) < 4.3 x 10^{-12}

Many models with new physics predict
B~10^{-14}~10^{-18}

Japanese staging plan of μ-e conversion

PRISM

1st Stage : COMET

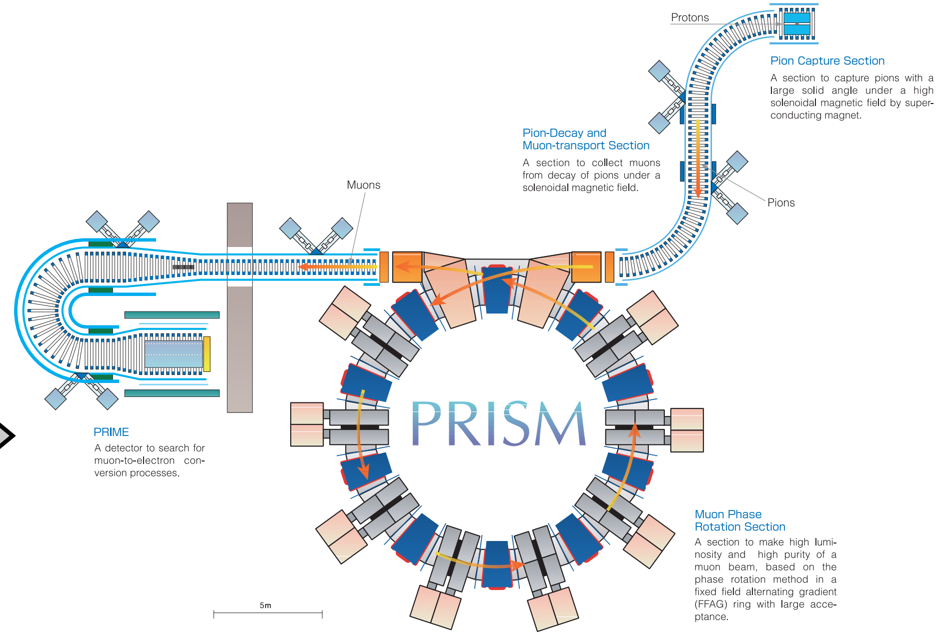


$$B(\mu^- + Al \rightarrow e^- + Al) < 10^{-16}$$

- without a muon storage ring. (MECO-type)
- with a slowly-extracted pulsed proton beam.
- at the J-PARC NP Hall.
- for early realization (~2017)

The sensitivity is limited by backgrounds: pion induced electrons, decay in orbit electrons, and so on.

2nd Stage : PRISM/PRIME



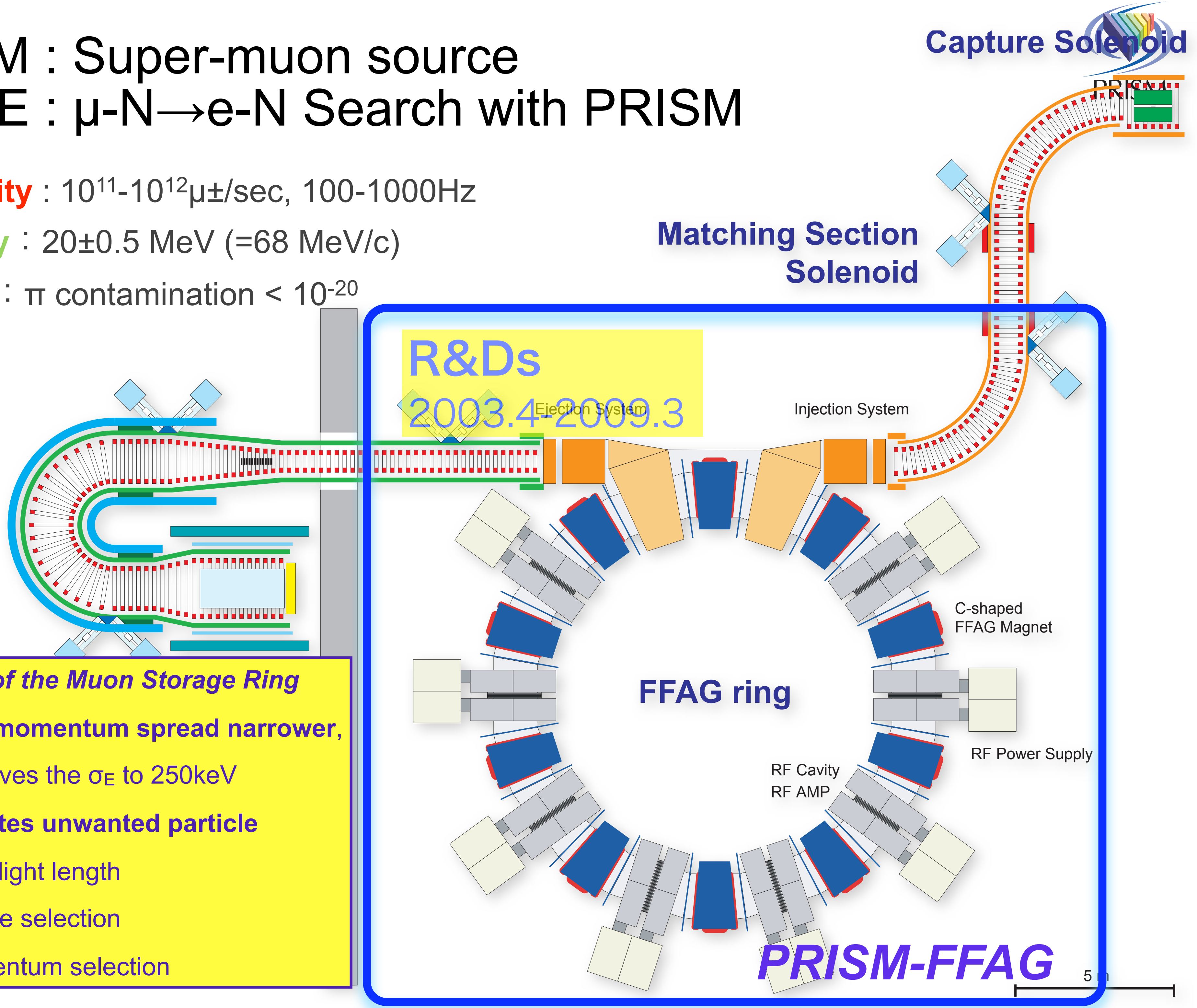
$$B(\mu^- + Ti \rightarrow e^- + Ti) < 10^{-18}$$

- with a muon storage ring.
- with a fast-extracted pulsed proton beam.
- need a new beamline and experimental hall.
- Ultimate search

A muon storage ring can solve the problem.

PRISM : Super-muon source
PRIME : μ-N→e-N Search with PRISM

- **Intensity** : 10^{11}-10^{12} μ±/sec, 100-1000Hz
- **Energy** : 20±0.5 MeV (=68 MeV/c)
- **Purity** : π contamination < 10^{-20}

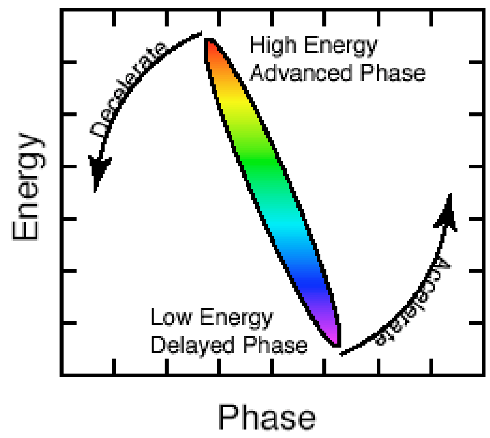


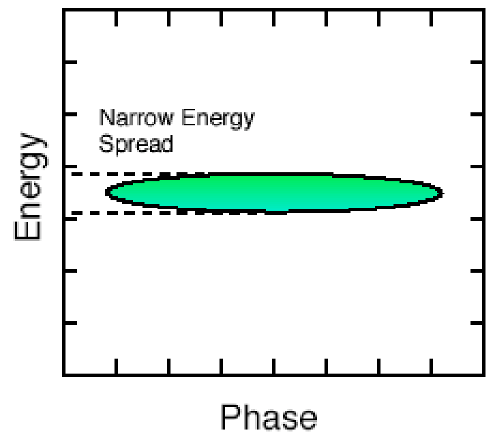
Functions of the Muon Storage Ring

- **Makes momentum spread narrower,**
  - improves the σ_E to 250keV
- **Eliminates unwanted particle**
  - long flight length
  - charge selection
  - momentum selection

Phase rotation in PRISM-FFAG

- To achieve a mono-energetic muon beam, a technique of phase rotation is adopted.
- The phase rotation is to decelerate fast beam particles and accelerate slow beam particles by RF.
- To identify energy of beam particles, a time of flight (TOF) from the proton bunch is used.
  - Fast particle comes earlier and slow particle comes late.
- Proton beam pulse should be narrow (< 10 nsec).
- Phase rotation is a well-established technique, but we need to apply this to a low energy muons (P_μ~68MeV/*c*) for stopping muon experiments.

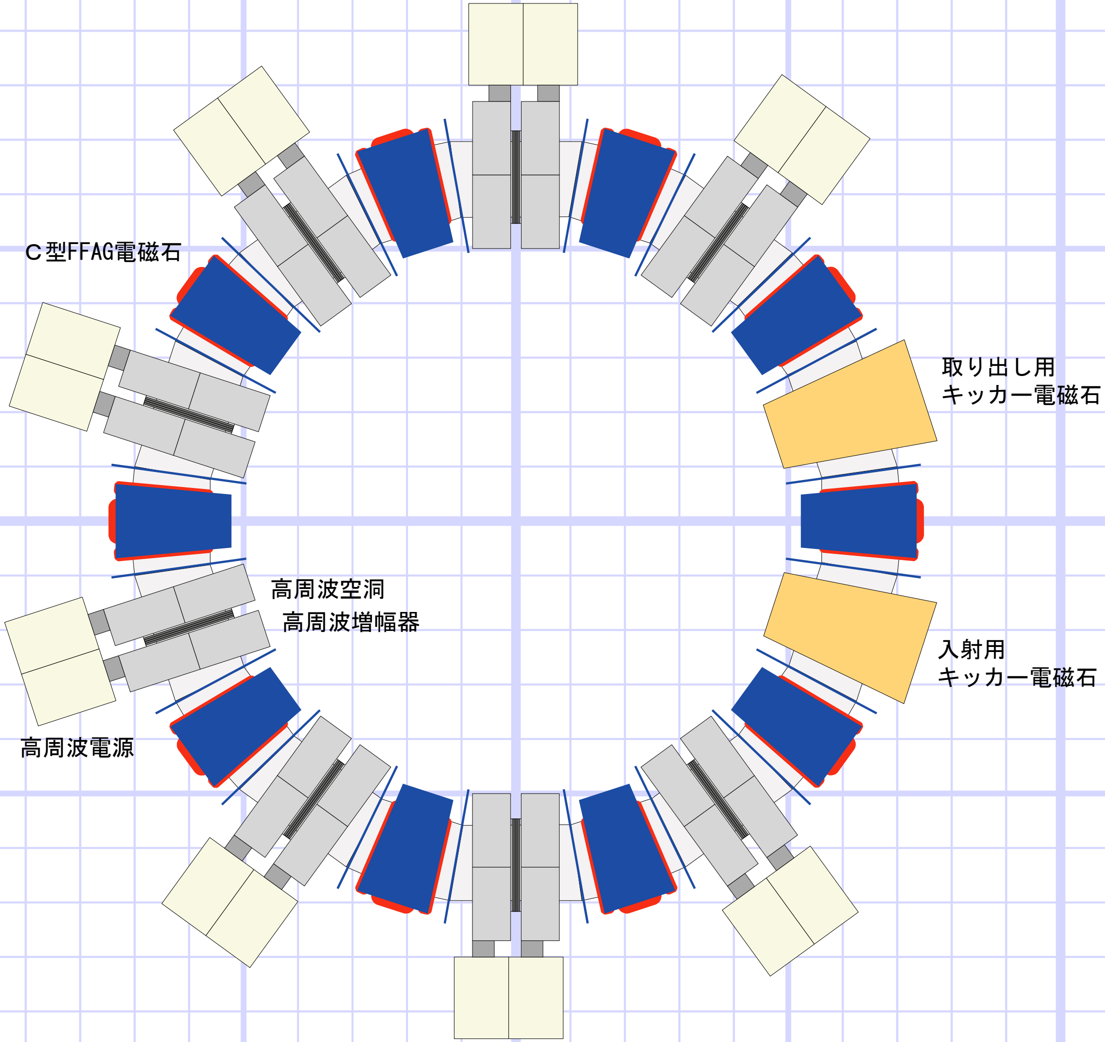




Design of PRISM-FFAG

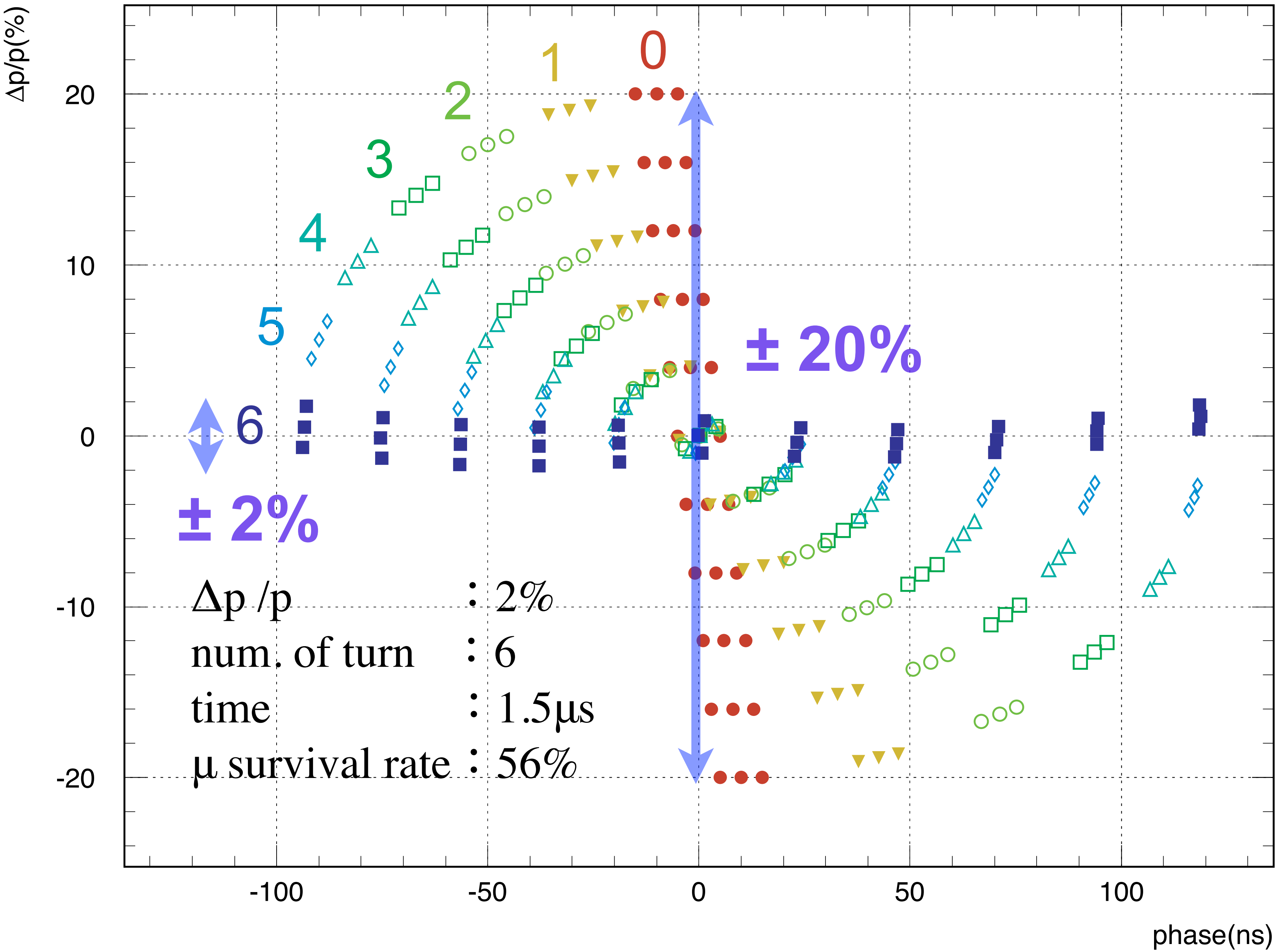
PRISM-FFAG

- N=10
- k=4.6
- F/D(BL)=6.2
- r0=6.5m for 68MeV/c
- half gap = 17cm
- mag. size 110cm @ F center
- Radial sector DFD Triplet
- $\theta_F/2=2.2$deg
- $\theta_D=1.1$deg
- Max. field
- F : 0.4T
- D : 0.065T
- tune
- h : 2.73

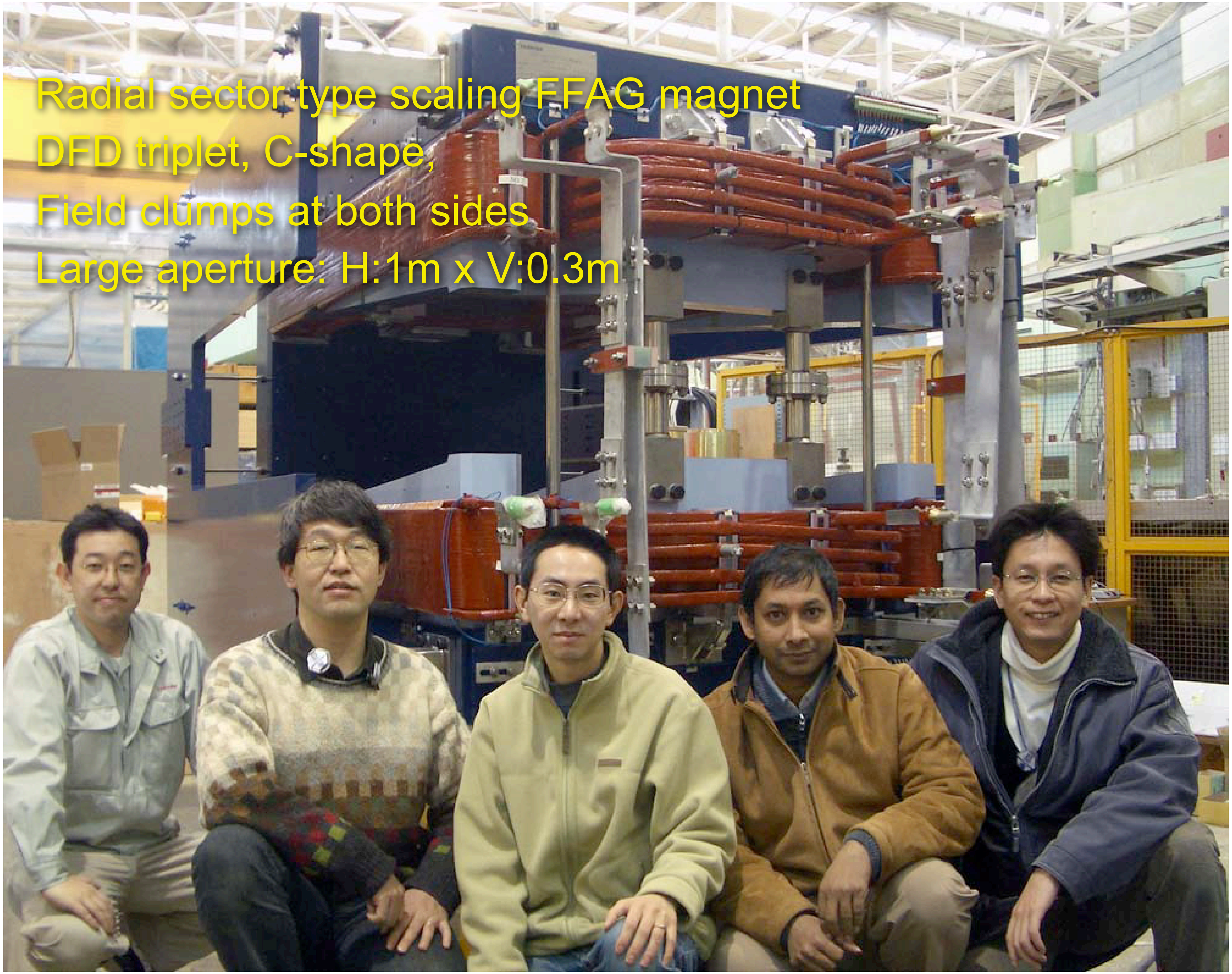


- Large transverse acceptance
  - Horizontal : 38,000 π mm mrad
  - Vertical : 5,700 π mm mrad
- High field gradient RF system
  - field gradient ~170kV/m (~2MV/turn)
    - quick phase rotation (~1.5μs)
    - large mom. acceptance (68MeV/c +- 20%)

Expected phase rotation with PRISM-FFAG



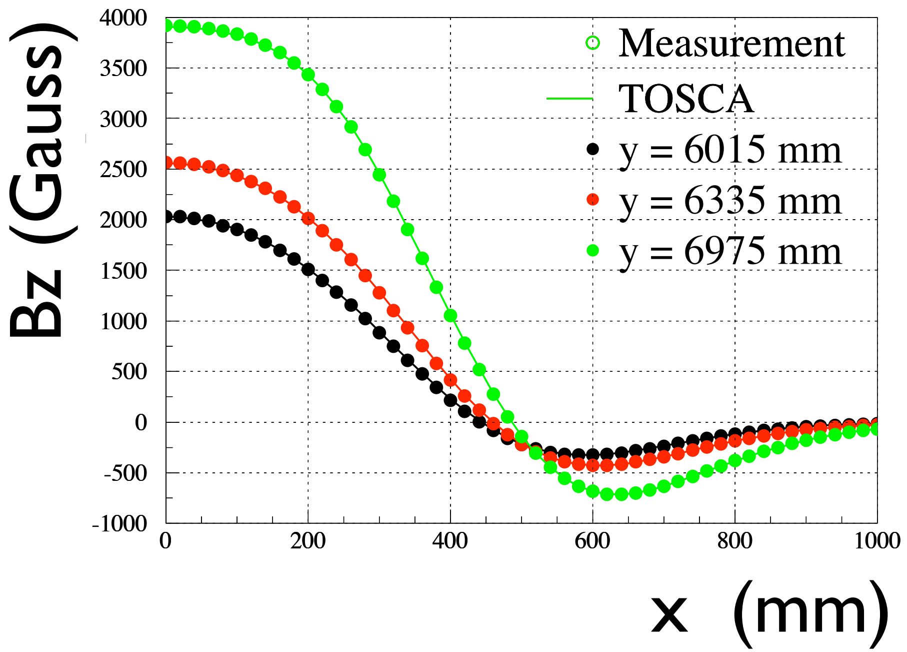
The First PRISM-FFAG Magnet

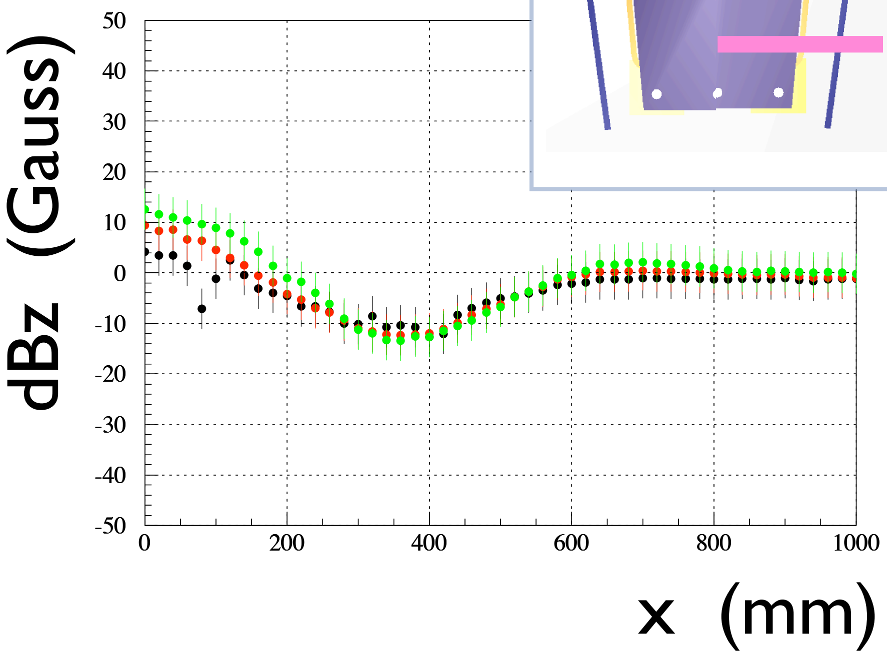


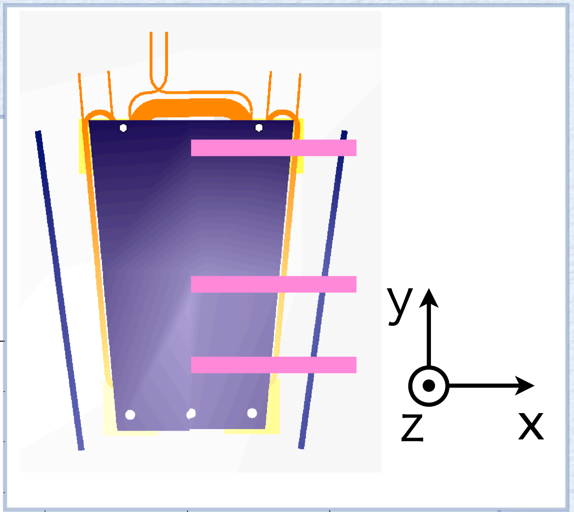
Results of Field Measurements

On median plane

tosca_vs_meas.kumac



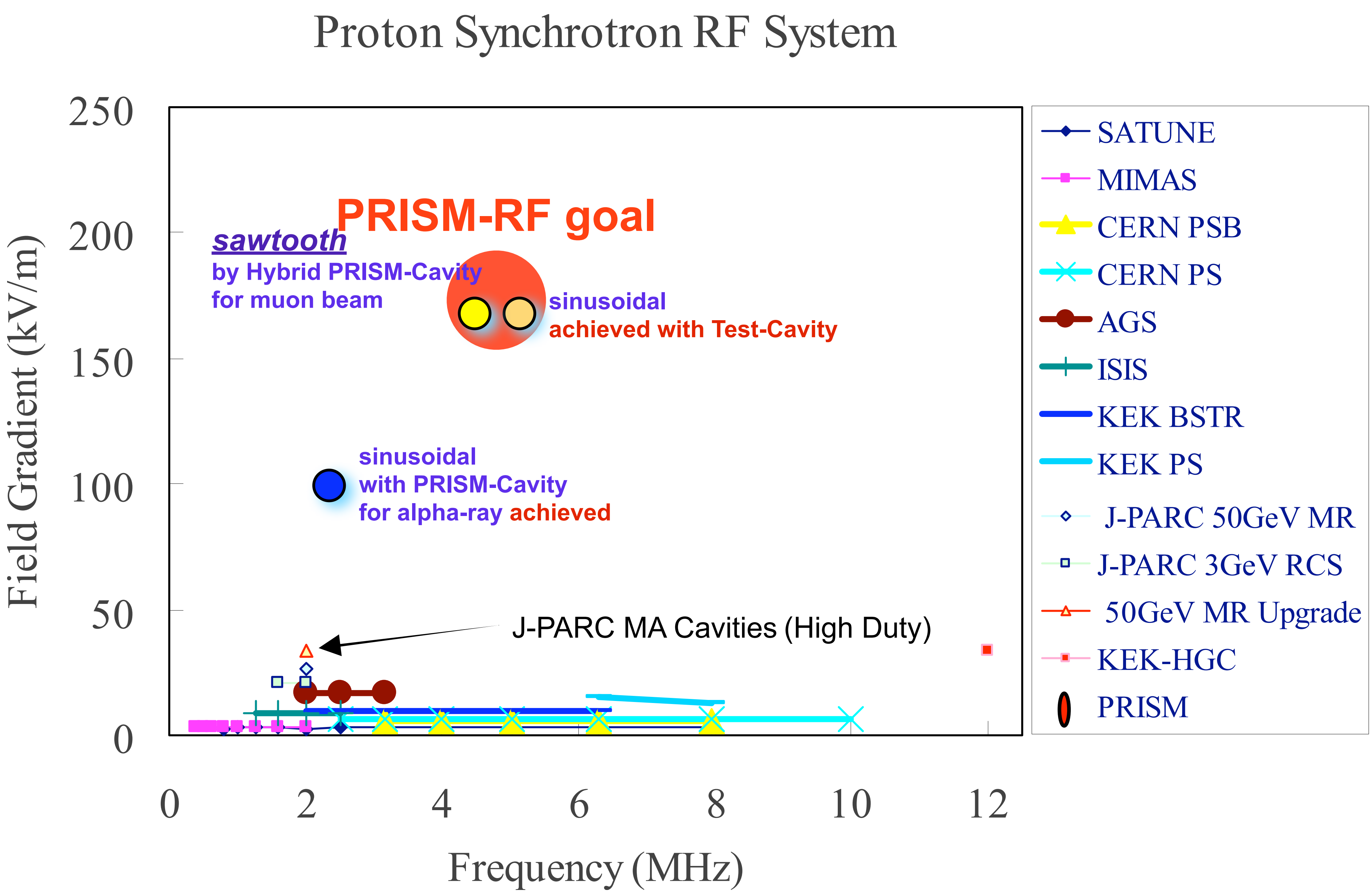




Difference between TOSCA and measurement is about 10 Gauss

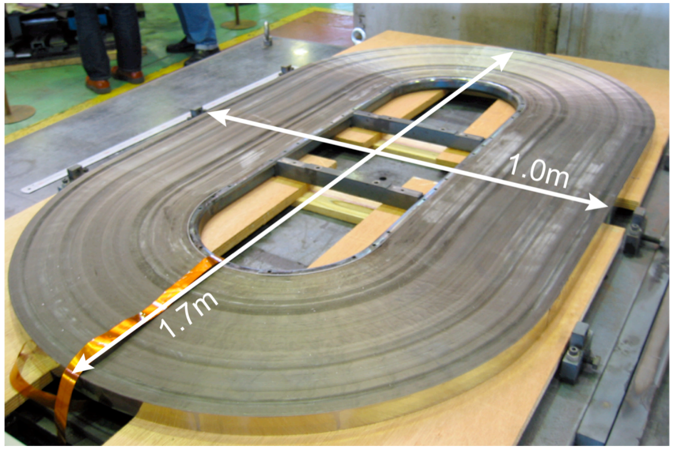
The RF system

Field gradient of PRISM-FFAG



How to realize the 4MHz sawtooth RF

- Requirements on RF system for PRISM-FFAG
  - high field gradient：＞170kV/m @4MHz
  - Sawtooth-RF
- Magnetic Alloy cores have been adopted
  - Q＜１：enable to add higher harmonics
  - large aperture is possible
- Adjust the frequency
- **Solution 1：cut core**
  - used in RF cores for J-PARC MR
  - too expensive for PRISM-cores due to their size
- **Solution 2：hybrid RF system**
  - tested for J-PARC RCS
  - can use for PRISM-cavities



Hybrid RF system

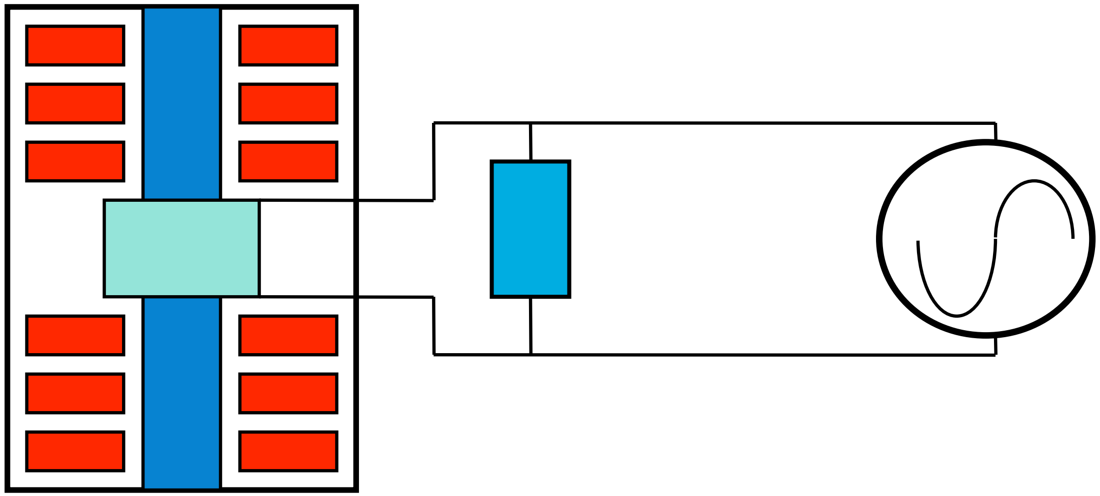
- Proposed by A. Schnase.
- Combination of MA cavity with a resonant circuit composed by inductor and capacitor.
- Developed for J-PARC RCS cavities.

$$f = 1/2\pi\sqrt{LC}$$

$$1/L = 1/L_{core} + 1/L_{ind}$$

$$Q = R_p/\omega L$$

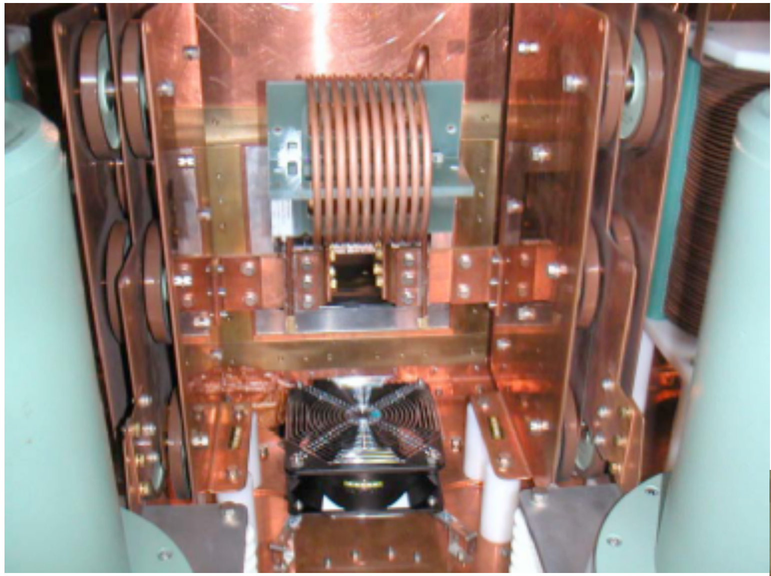
Rp: shunt



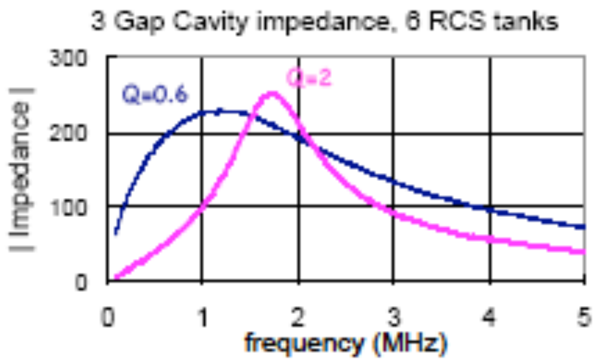
J-PARC: add C and L to control Q and f

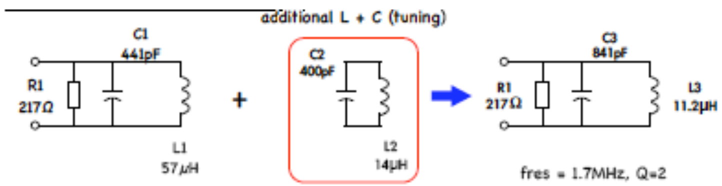
PRISM : add L to control f

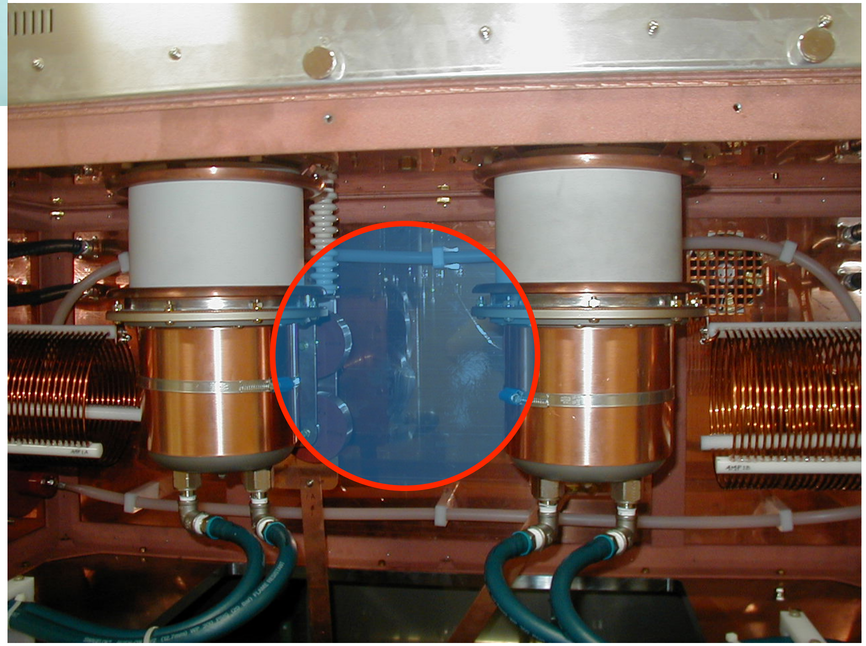
Hybrid RF system



Parallel inductor for J-PARC







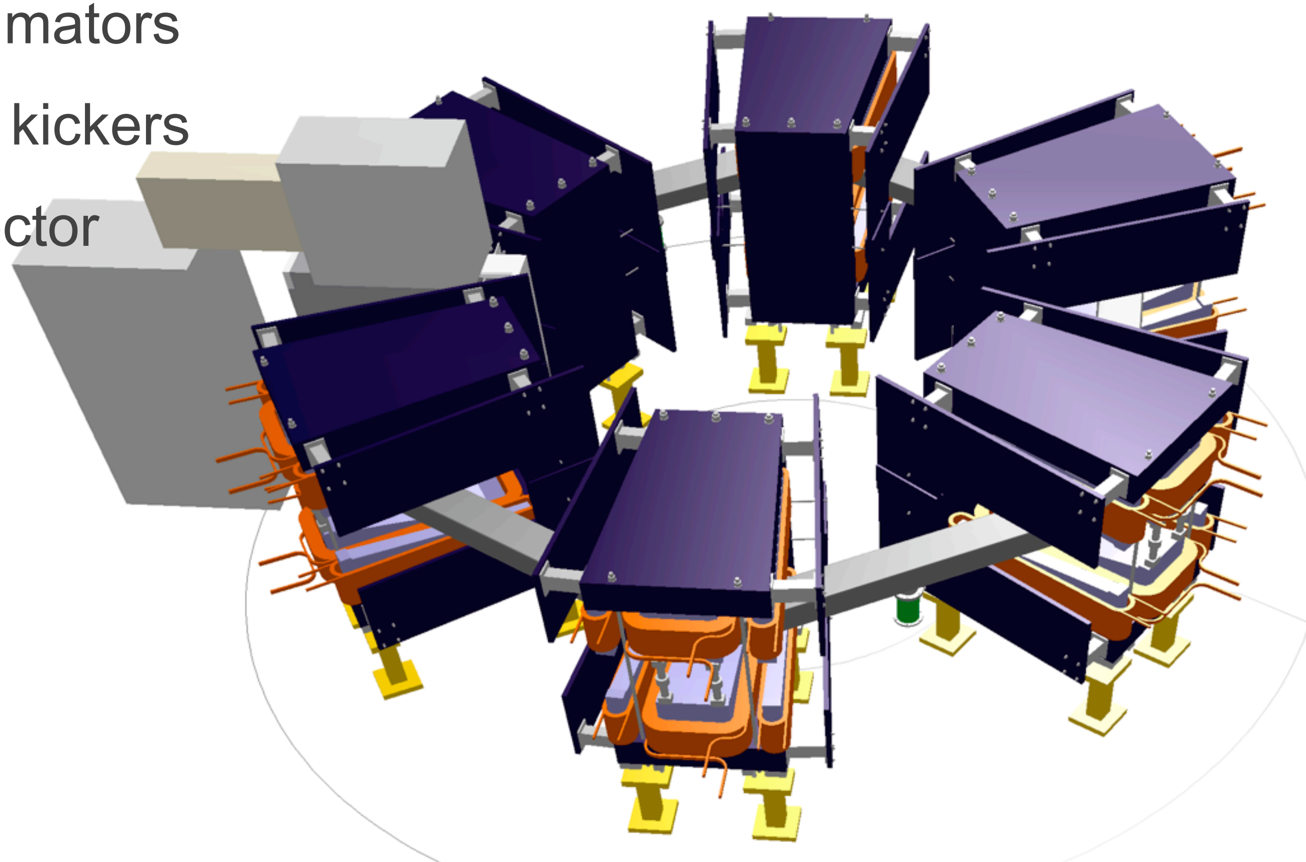
Inside of PRISM AMP

This will be tested in this year.

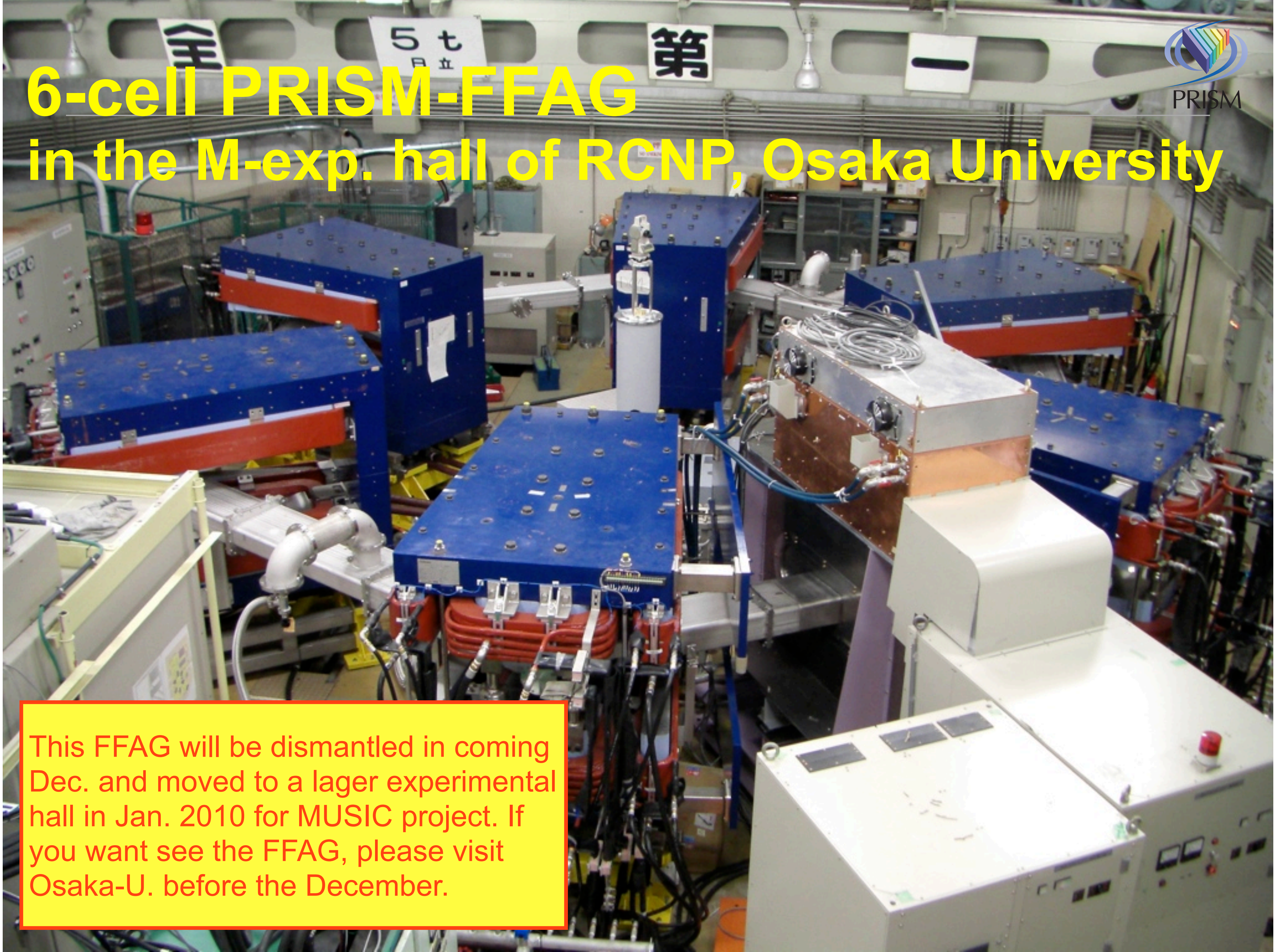
6-cell PRISM-FFAG

Demo. of Phase Rotation with α-particles

- FFAG-ring
  - PRISM-FFAG Magnet x 6、RF x 1
- Beam : α-particles from radioactive isotopes
  - ^{241}Am 5.48MeV(200MeV/c) → degrade to 100MeV/c
  - small emittance by collimators
  - pulsing by electrostatic kickers
- Detector : Solid state detector
  - energy
  - timing

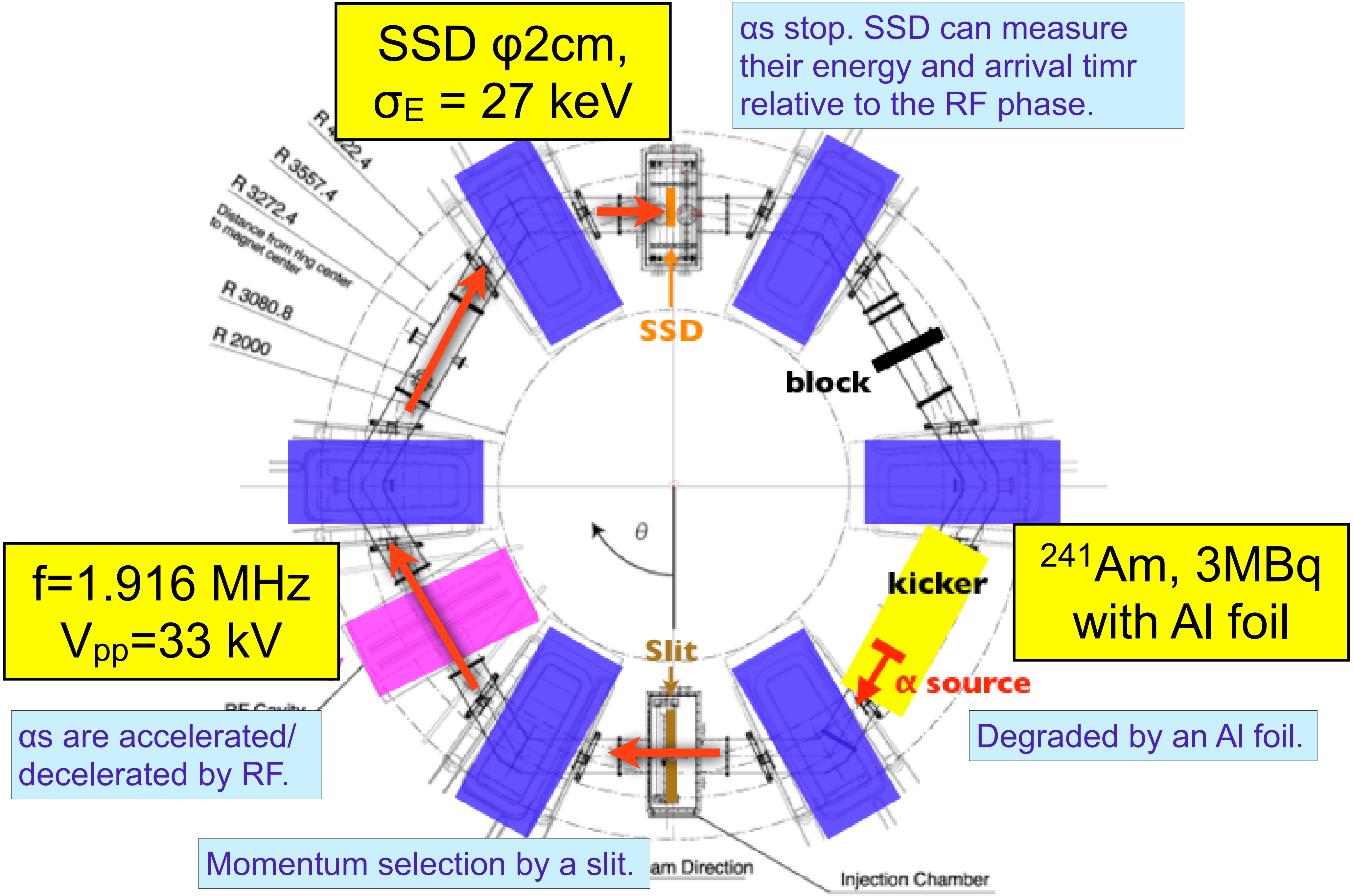


6-cell PRISM-FFAG in the M-exp. hall of RCNP, Osaka University

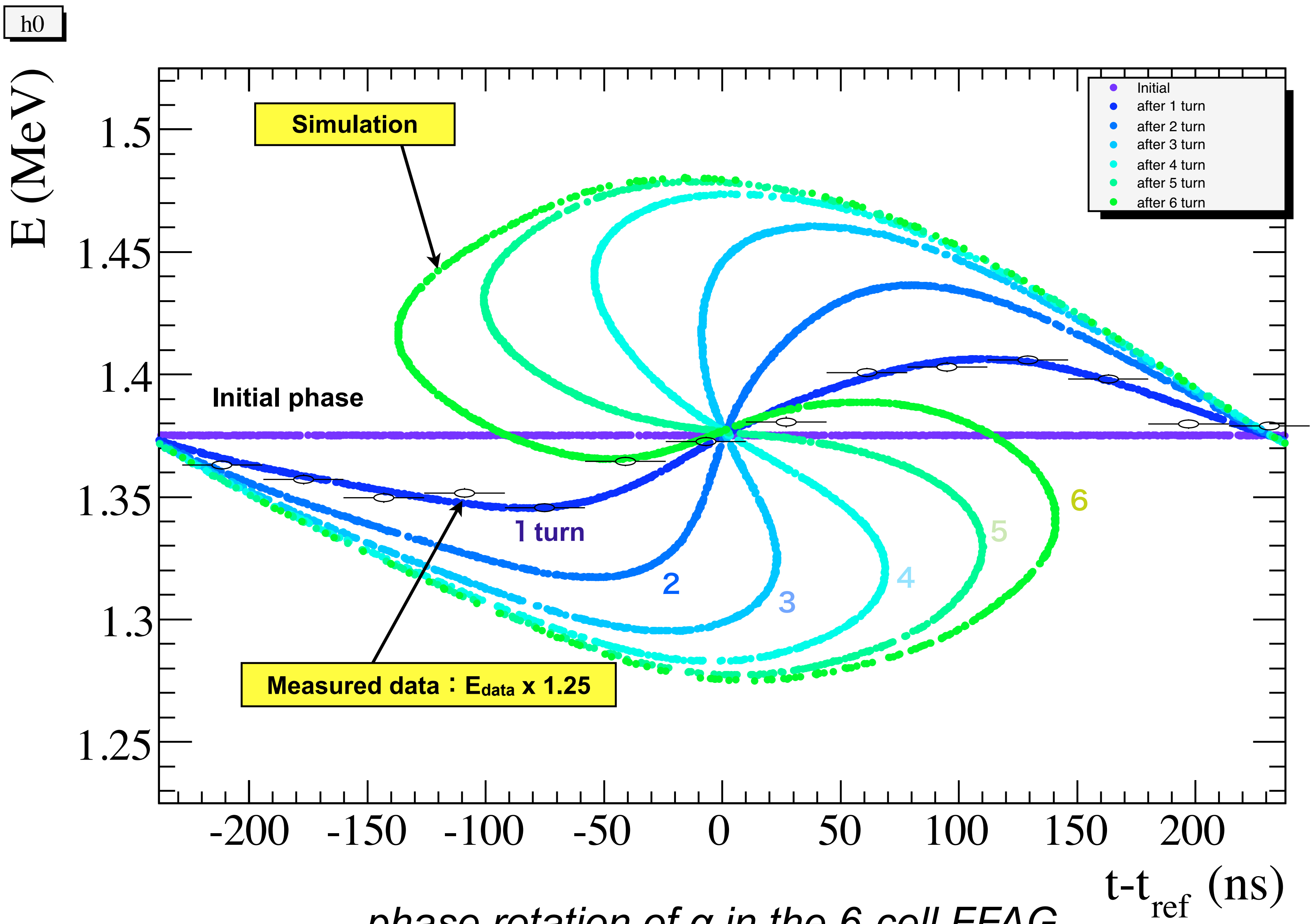


This FFAG will be dismantled in coming Dec. and moved to a lager experimental hall in Jan. 2010 for MUSIC project. If you want see the FFAG, please visit Osaka-U. before the December.

Apparatus for the test of phase rotation

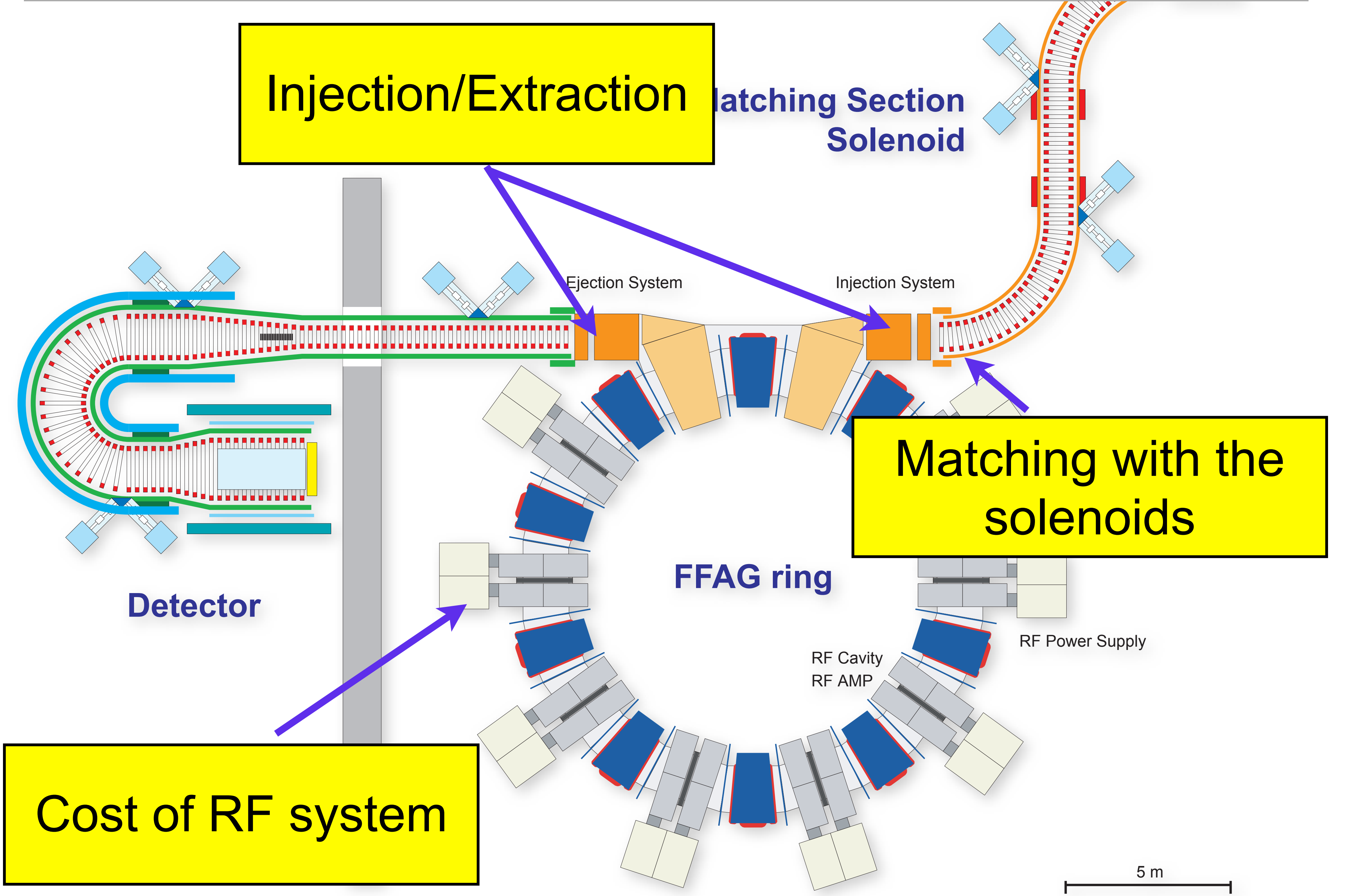


Comparison b/w data and simulation



phase rotation of α in the 6-cell FFAG

Issues related on the PRISM-FFAG



PRISM Task Force

- The PRISM-FFAG Task Force was proposed and discussed during the last PRISM-FFAG workshop at IC (1-2 July'09).
  - UK, JP, US, EU
- The aim of the PRISM-FFAG Task Force is to address the technological challenges in realizing an FFAG based muon-to-electron conversion experiment,
  - but also to strengthen the R&D for muon accelerators in the context of the Neutrino Factory and future muon physics experiments.
- It was proposed to achieve a conceptual design of the PRISM machine at the end of 2010/beginning 2011.

PRISM Task Force (cont.)

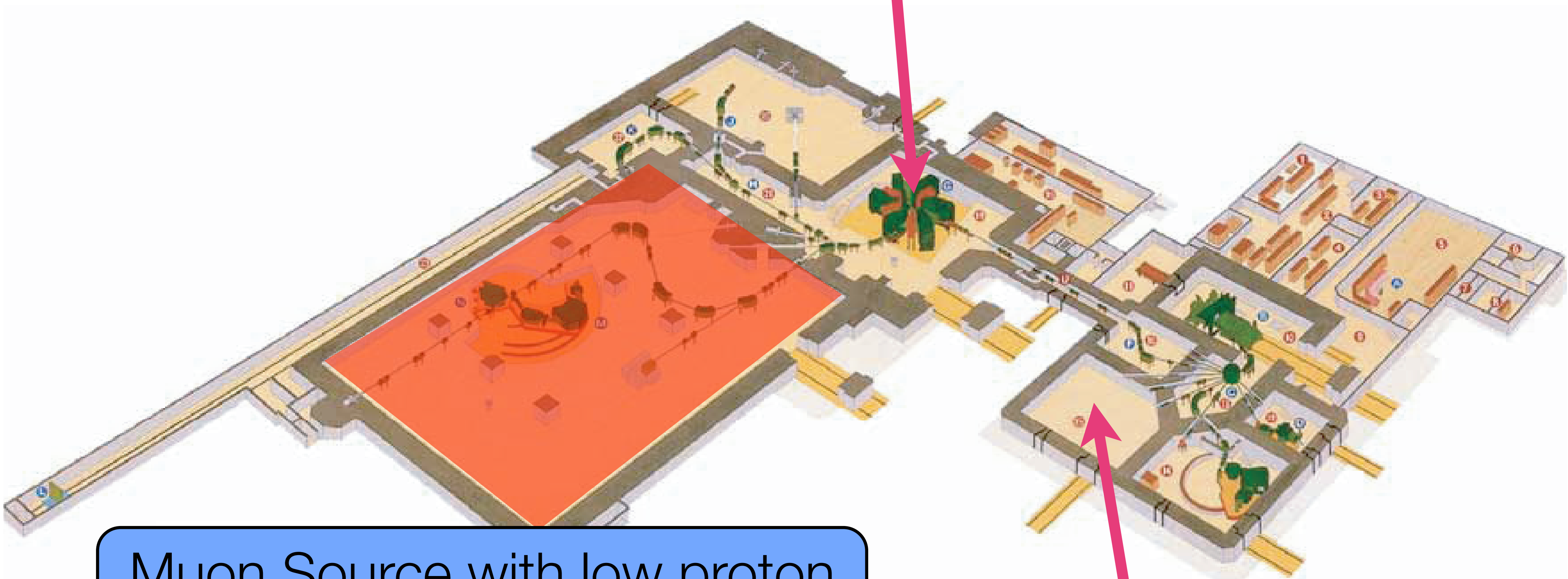
- The following key areas of activity were identified and proposed to be covered within the Task Force:
  - - the physics of muon to electron conversion,
    - proton source,
    - pion capture,
    - muon beam transport,
    - injection and extraction for PRISM-FFAG ring,
    - FFAG ring design including the search for a new improved version,
    - FFAG hardware R&D for RF system and injection/extraction kicker and septum magnets.
- Monthly video meetings and biannual meeting
  - injection/extraction
  - new lattices with insertion/racetrack
  - RF issues
- Please join! j.pasternak@imperial.ac.uk

MUSIC project

Muon beam is coming to the RCNP, Osaka-Univ.

Research Center for Nuclear Physics (RCNP), Osaka University

Research Center for Nuclear Physics (RCNP), Osaka University has a cyclotron of 400 MeV with 1 microA. The energy is above pion threshold.



Muon Source with low proton power at Osaka U.?

PRISM-FFAG R&D

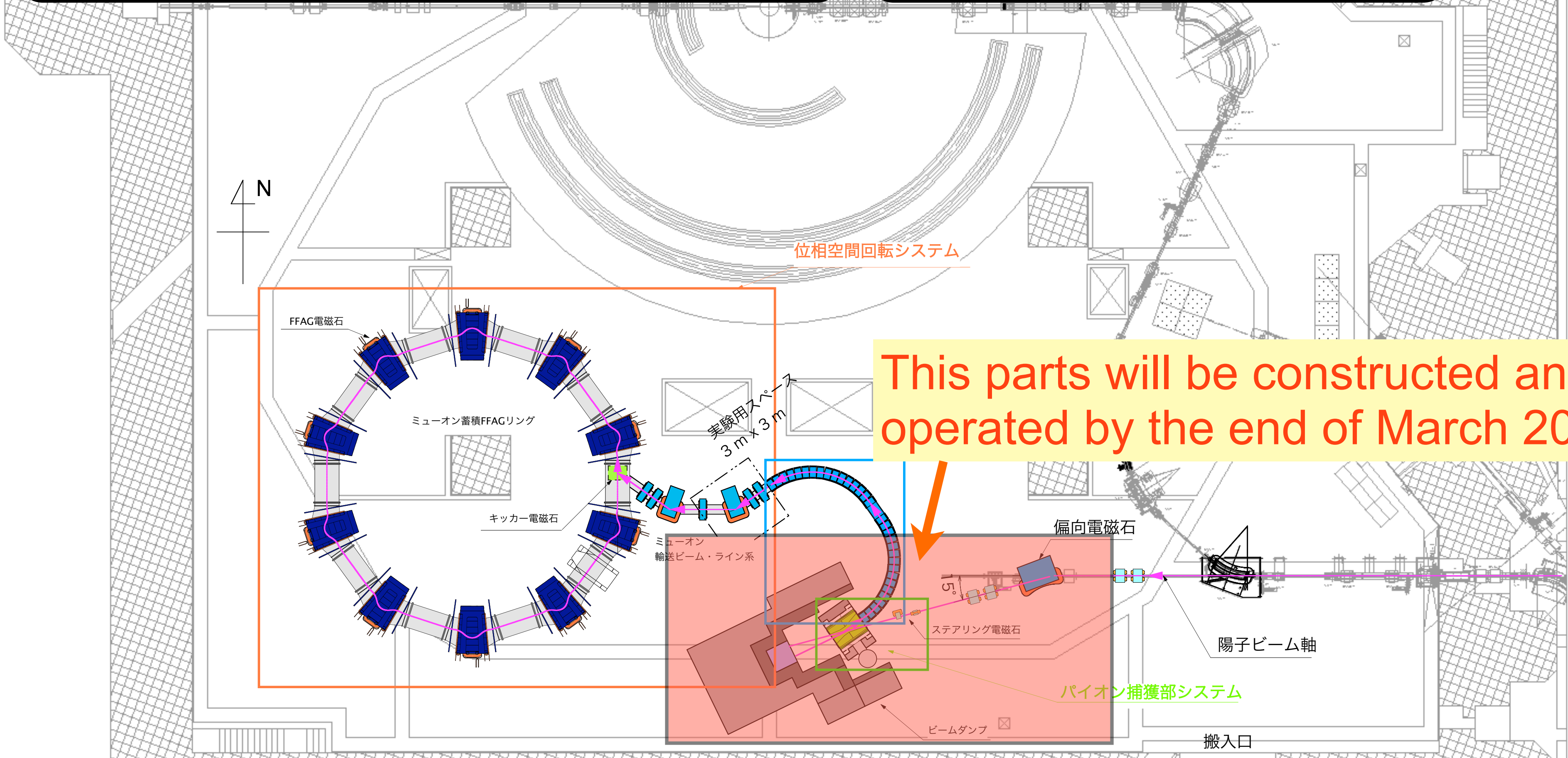
MUSIC (=MUon Science Innovative Commission)

muon yield estimation

0.4 kW (400MeV, 1μA protons)

10^9 muons/sec (for MUSIC)

Nuclear and particle physics, material science chemistry, and accelerator R&Ds will be possible.



This parts will be constructed and operated by the end of March 2010.

We are also considering to finalize the 10-cell PRISM-FFAG R&D using the muon beams in the MUSIC project.

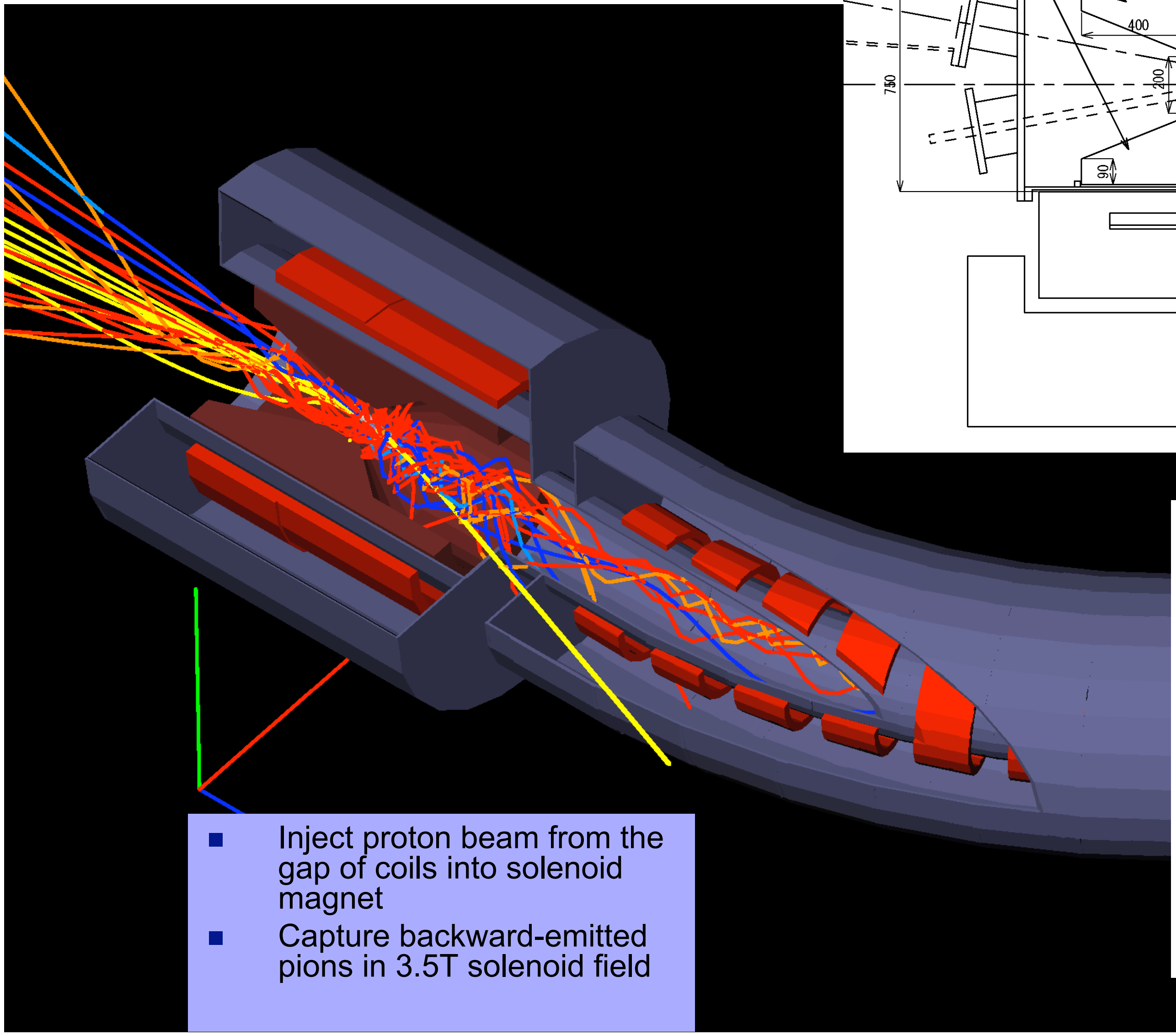
Muon Physics Examples at MUSIC

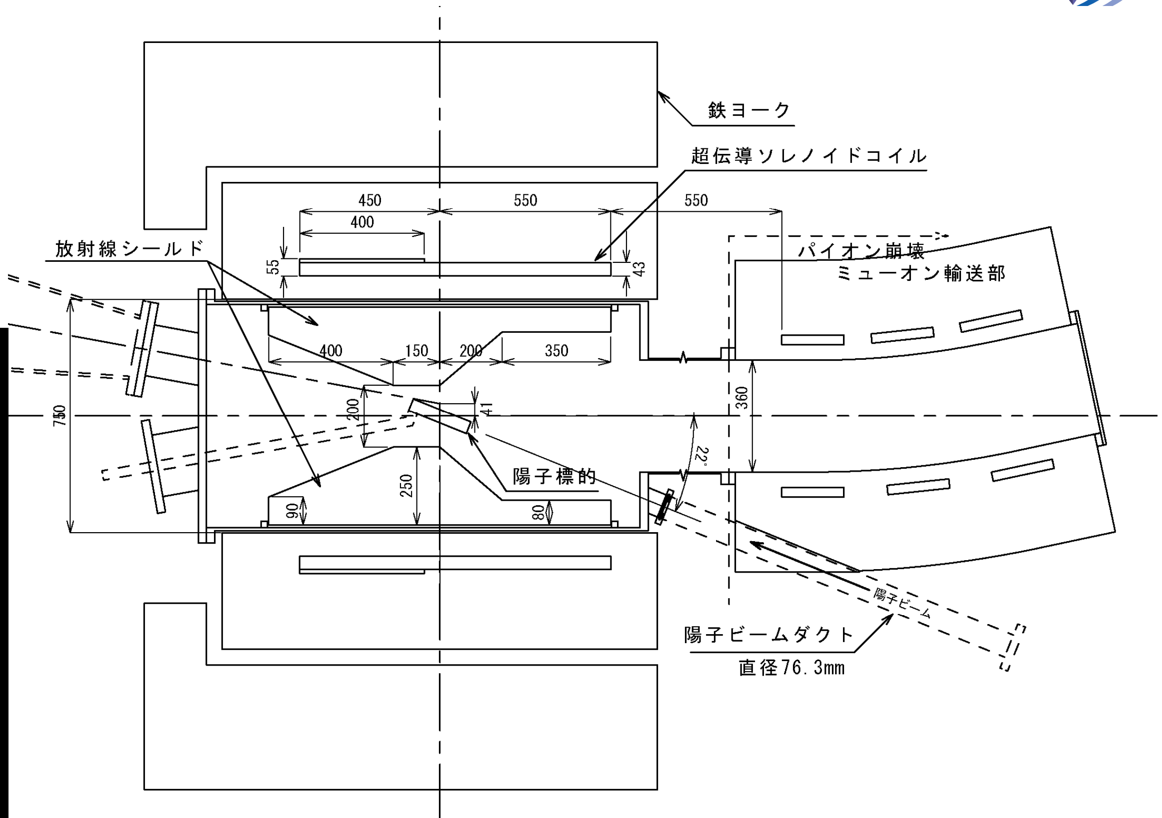
- Particle Physics :
  - search for μ→eee (muon LFV)
    - DC continuous beam is critical
    - TPC to track 3 electrons/positrons
- Nuclear Physics :
  - nuclear muon capture (NMC)
  - pion capture and scattering
- Materials Science :
  - μSR (a μSR apparatus is needed)
- Chemistry
  - chemistry on pion/muon atoms
- Accelerator / Instruments R&D (for neutrino factory/muon collider)
  - Superconducting solenoid magnets
  - FFAG, RF
  - cooling methods

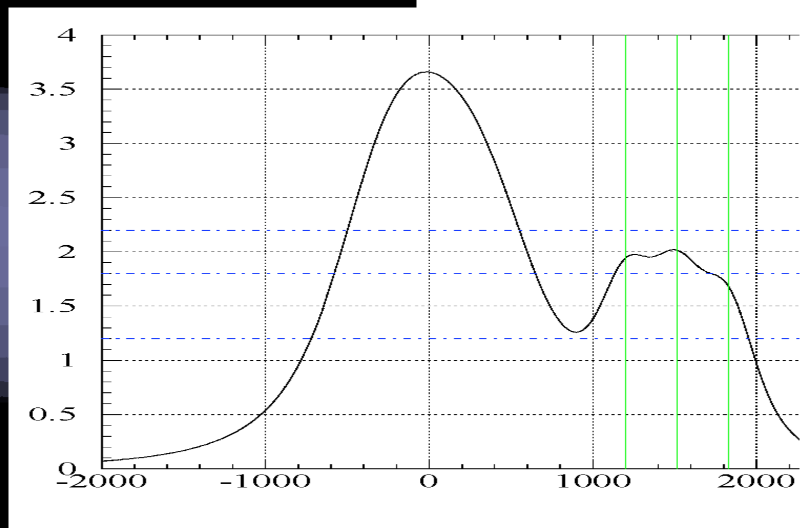
10^8 muons/sec

We are also considering to finalize the 10-cell PRISM-FFAG R&D using the muon beams in the MUSIC project.

Pion Capture System

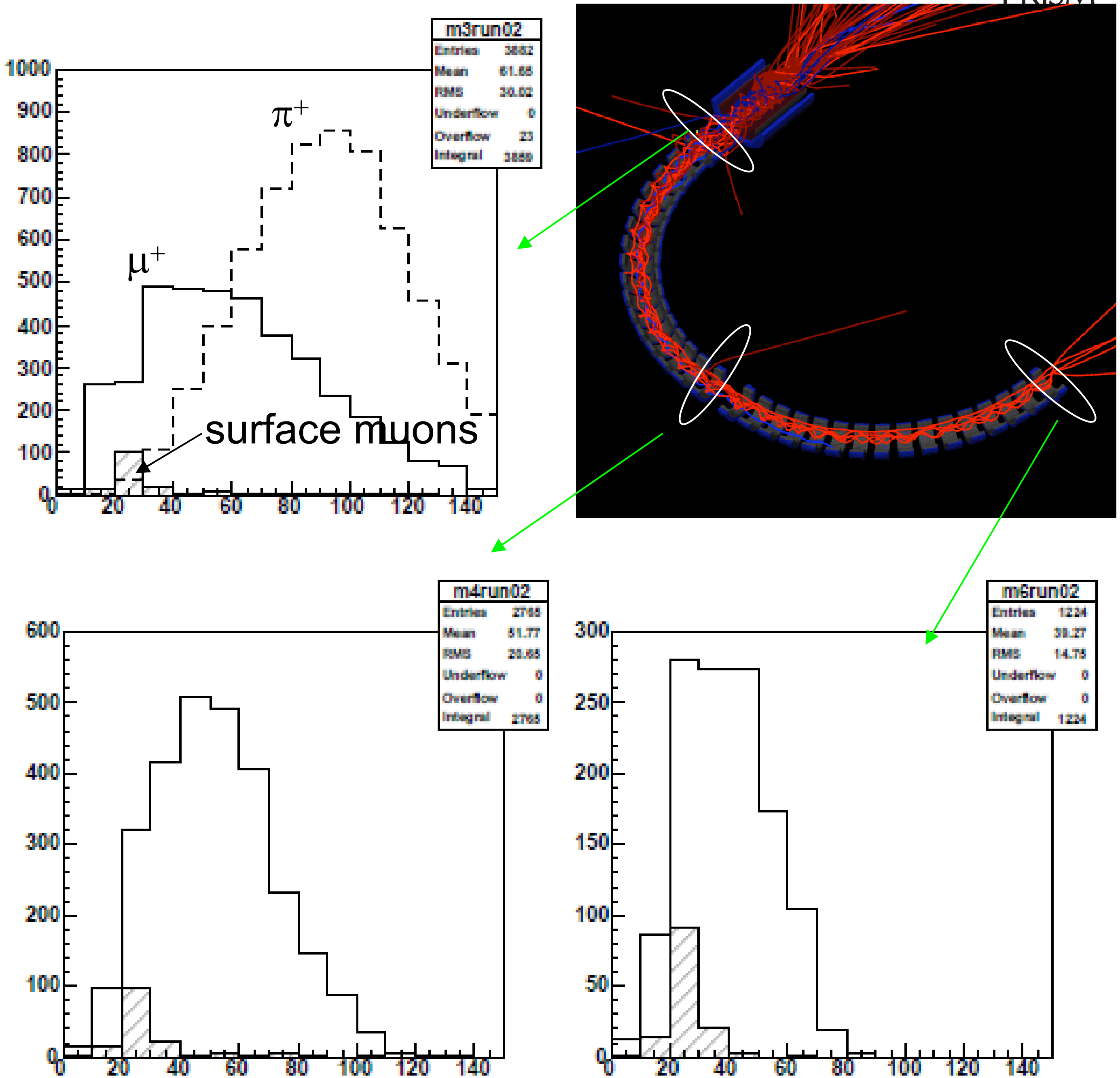






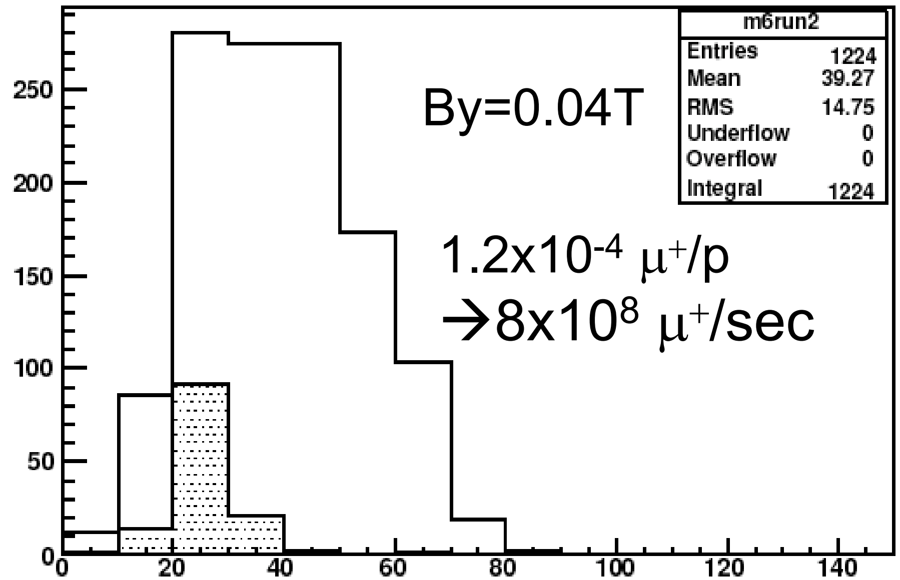
- Inject proton beam from the gap of coils into solenoid magnet
- Capture backward-emitted pions in 3.5T solenoid field

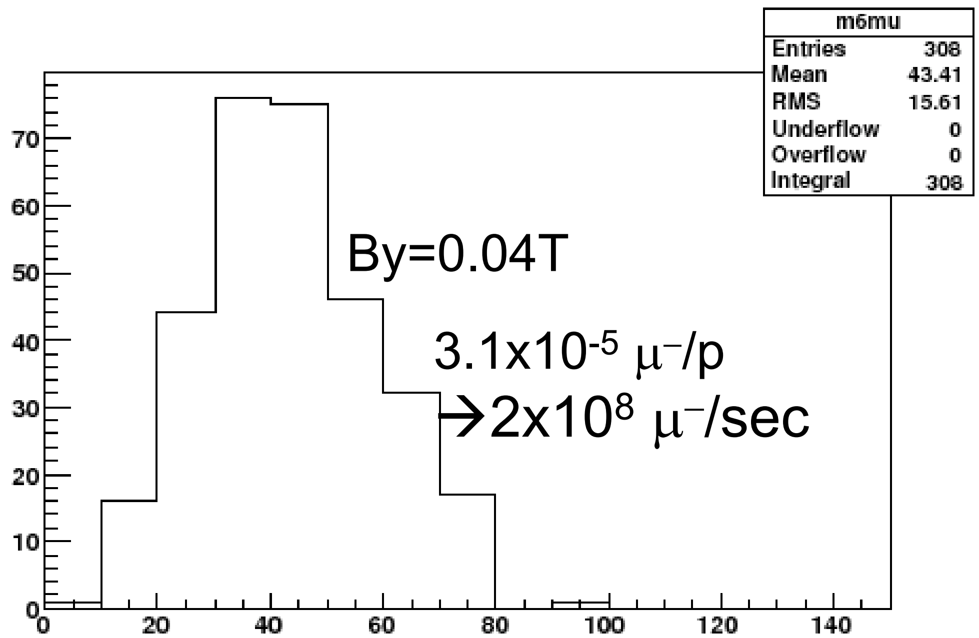
Muon momentum distribution in transport solenoid



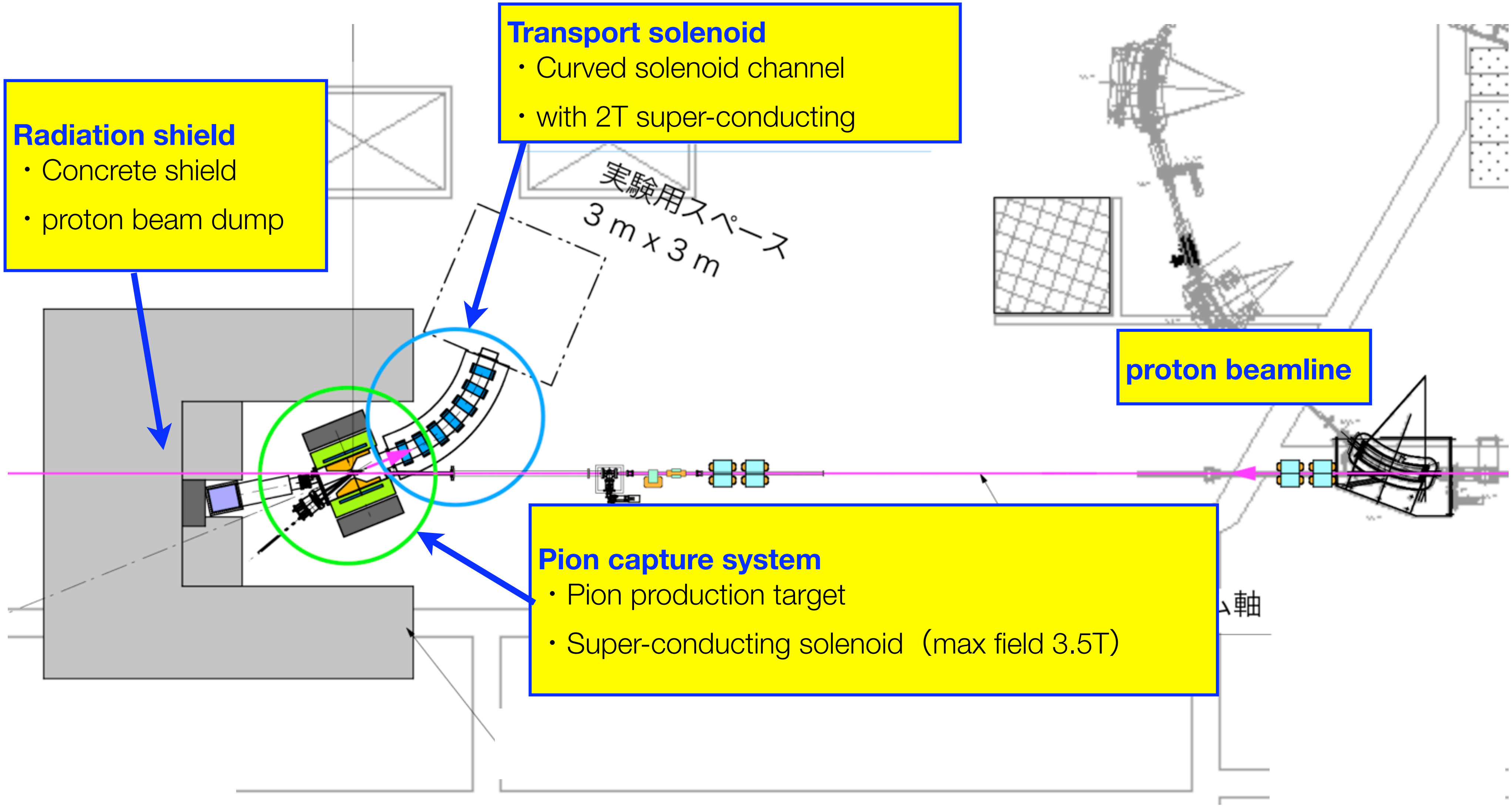
Muon beam intensity

- 8×10^8 μ^+/sec with By=0.04T
  - surface muons of 8×10^7 μ^+/sec
- 2×10^8 μ^+/sec with By=0
- 2×10^8 μ^-/sec with By=0.04T
- 5×10^7 μ^-/sec with By=0





Layout of the MUSIC at March 2010



Radiation shields around the production target

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- Nuclear Physics :
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- Chemistry
  - chemistry on pion/muon atoms
- Accelerator / Instruments R&D (for neutrino factory/muon collider)
  - Superconducting solenoid magnets
  - FFAG, RF
  - cooling methods

10^8 muons/sec

Summary

- PRISM provides a solution to **improve the μ-e conv. sensitivity less than 10^{-17} adopting a muon storage ring**, which make mono-energetic and pure muon beam. A staging scenario of mu-e conversion experiment (COMET - PRISM) was proposed in Japan.
- We had **R&D program on the muon storage ring from 2003 to 2009**. Many successful outcomes were achieved.
  - large aperture FFAG,
  - high field gardened RF system
  - 6-cell FFAG and phase rotation test.
  - Hybrid RF to realize the 4MHz sawtooth (this year)
- *Prospects*
  - **The collaboration and task force for the PRISM-FFAG** have been created. We will continue to study the PRISM-FFAG to realize the ultimate μ-e conv. experiment.
  - **A new muon beamlin (MUSIC) is now under construction** at RCNP, Osaka Univ., and PRISM-FFAG study can be continue with the muon beam.