J-PARC/MLF

Japan Proton Accelerator Research Complex/Materials and Life Science Facility (Tokai, Japan)

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University of Maryland College Park
Experimental Nuclear Physics Group

- Muon Physics
- J-PARC/MLF
- Decay Beamline
- Super-Omega Muon Beamline

Collaborators

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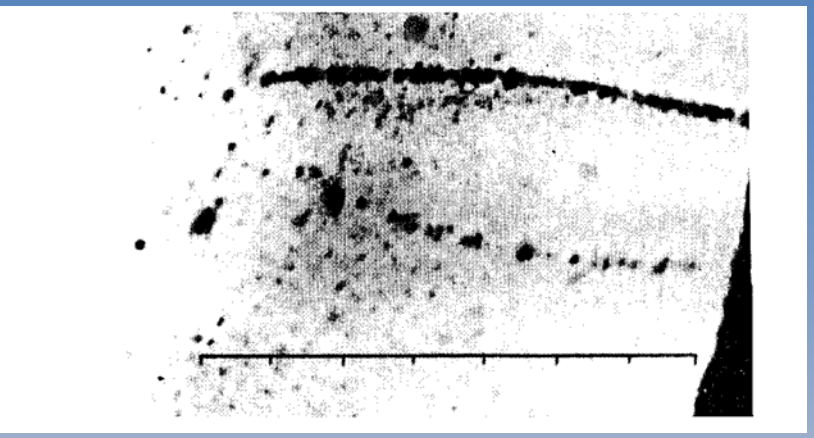
RIKEN:
K.Ishida

University of Tokyo:

Y.Matsuda

Muons?



Observed in 1933 (Kunze: “particle of unknown nature”)

Confirmed in 1936 (Neddermeyer and Anderson)

~~Explain strong nuclear force?~~

- muon lifetime, lepton flavor violation, g-2...(SM tests)
- Use as a probe (μSR)

- Production of positive “surface muons” (E_{max}=4.2MeV, P_{max}=30MeV/c) ⇐ decay of pions near target surface
- Production of negative “decay muons” (up to 120MeV/c) ⇐ in-flight decay

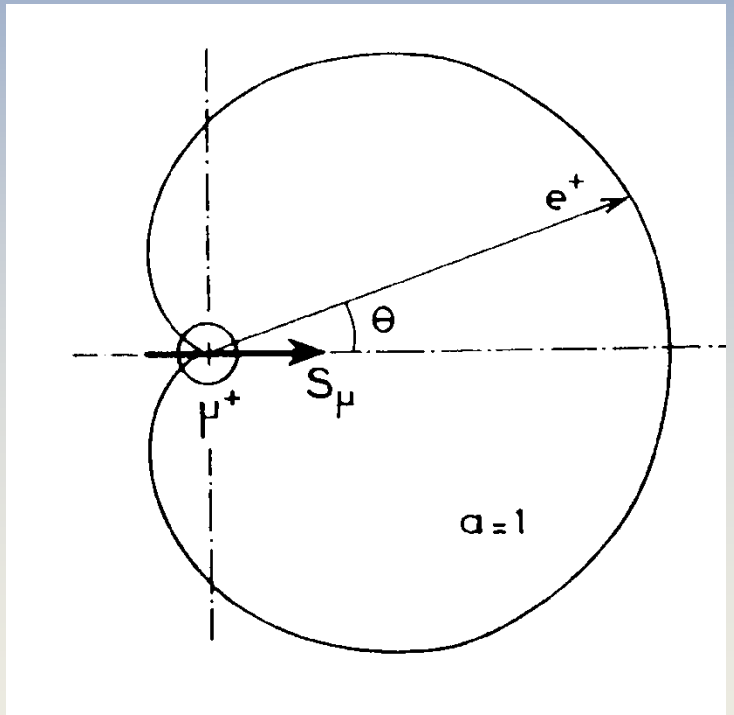
Physics at MLF

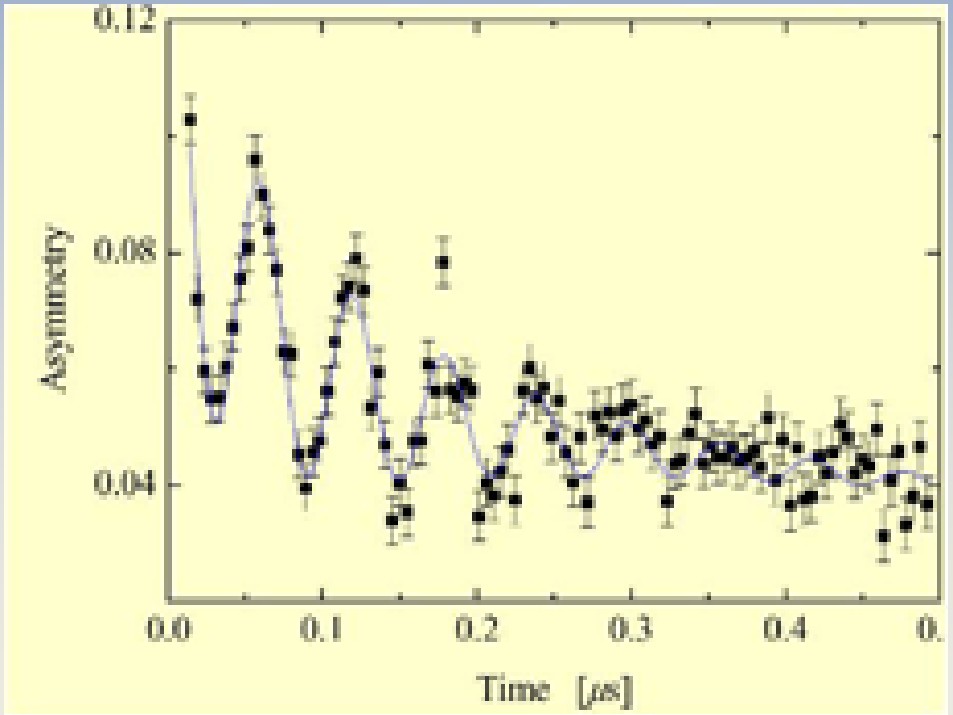
- μSR with surface and ultra-slow muons
- Charged Lepton Flavor Violation
- μCF – muon catalyzed fusion
- g-2 (*)

μSR

- Probe the internal magnetic field distribution of a material using surface muons (30MeV/c μ^+)
  1. Pions decay with ~100% polarized muons
  2. Positrons decay preferentially in the direction of spin: $W(\theta)=1+a_0\cos(\theta)$

$$\mu^+ \rightarrow \overline{\nu_\mu} + \nu_e + e^+$$



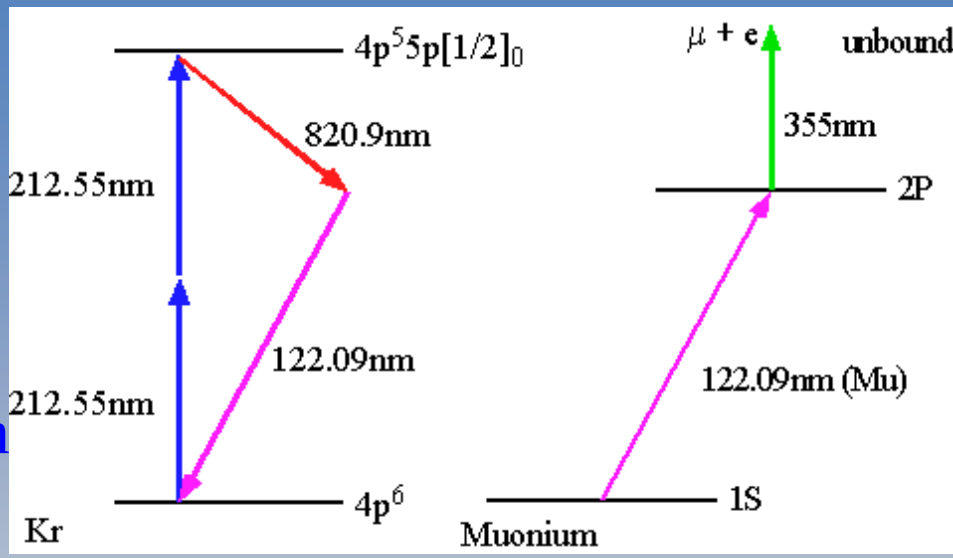


Bulk until now ➔ push field into surface/interface physics

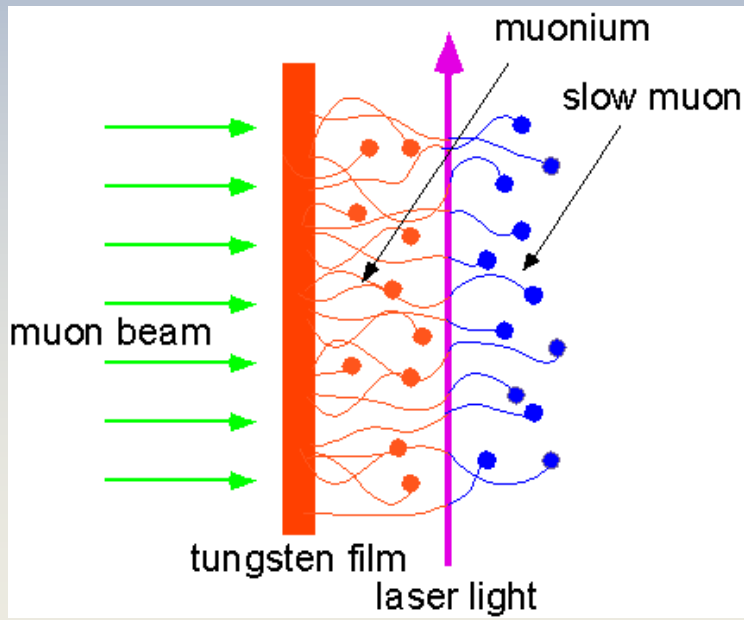
Ultra-slow muons

- few eV~keV muons for surface/interface physics

Laser resonant ionization: muonium production and subsequent ionization



	Laser Resonant Ionization	Moderator
Location	J-PARC, RIKEN/RAL, KEK	PSI, TRIUMF
Beam Energy	0-30 keV	0-30 keV
Energy Spread	0.2 eV	10-100 eV
Beam Size	0.5-1 mm	10-15 mm
Temporal Resolution	100 ps - ~ns	10 ns



In its relative infancy ➔ higher yields needed to be practical

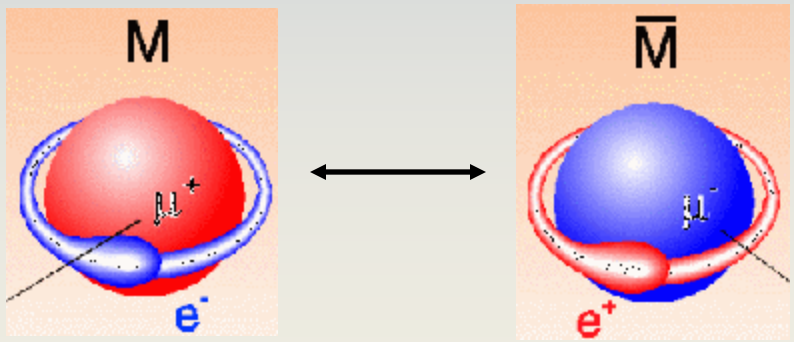
Mu anti-Mu Conversion

- Hadronic sector shows quark mixing ➔ leptonic sector??

LFV through muonium anti-muonium conversion

- neutrino oscillations may suggest large LFV in supersymmetric theories
- Record (PSI): 5.6×10^{10} muonium events (8×10^{6} μ^+/s,) ➔ $P \leq 8.3 \times 10^{-11}$ L. Willmann et al., PRL 82, 49 (1999)

  New PSI LEM beamline ~ 3.5×10^{8} μ^+/s (DC)
- J-PARC/MLF: 4×10^{8} μ^+/s (pulsed)



μCF

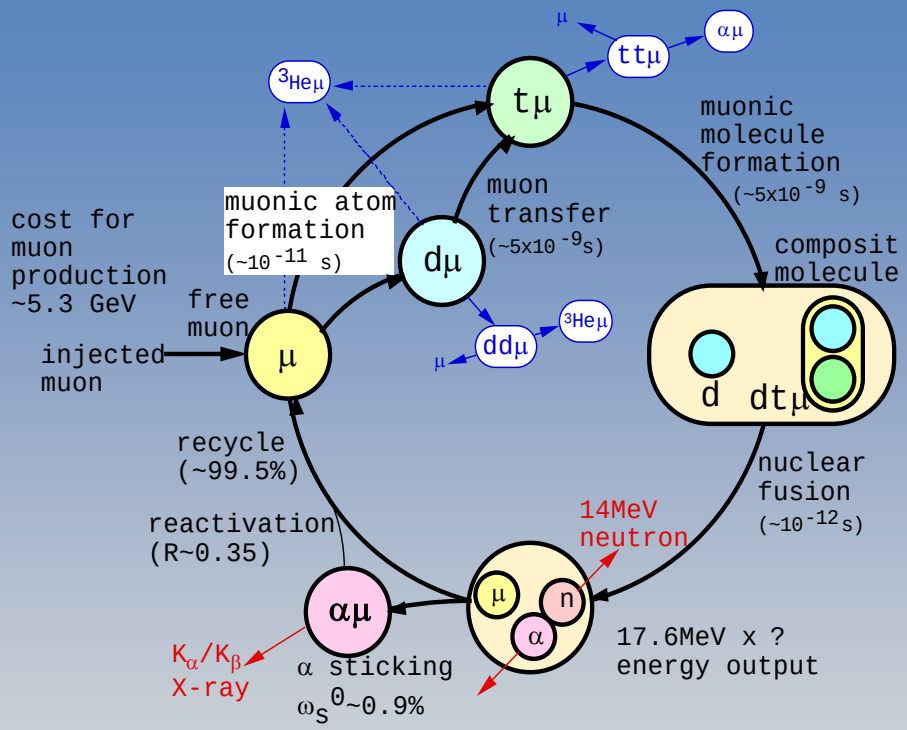
- Muon-catalyzed fusion
  - 50~60MeV/c negative muons

    D + T → α + n (17.6 MeV)

    D + D → ^{3}He + n (3.27)

  - break-even ~300 fusions/muon
  - technical break even ~900-1000 fusions/muon

  - currently ~150 fusions/muon
  - fusion cycle limited due to α-sticking



Muon Facilities

- TRIUMF: 10^5 μ^+/s (DC)
- RIKEN/RAL: 1×10^6 μ^+/s (pulsed)
- PSI: 3.5×10^8 μ^+/s (DC)
- J-PARC/MLF: 4×10^8 μ^+/s (pulsed)

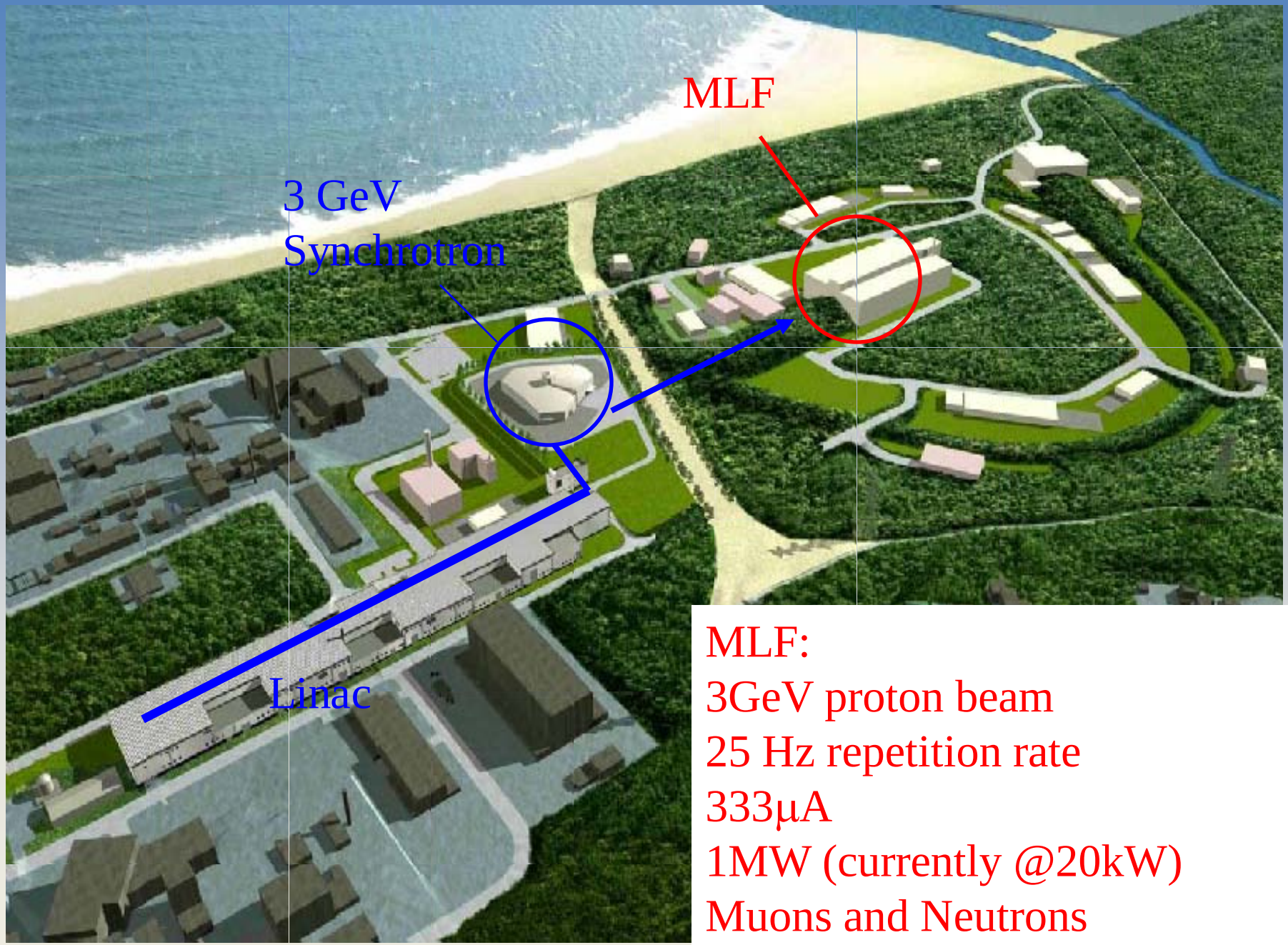
Pulsed muons have certain advantages over continuous beams

Need a high intensity muon beamline!

J-PARC

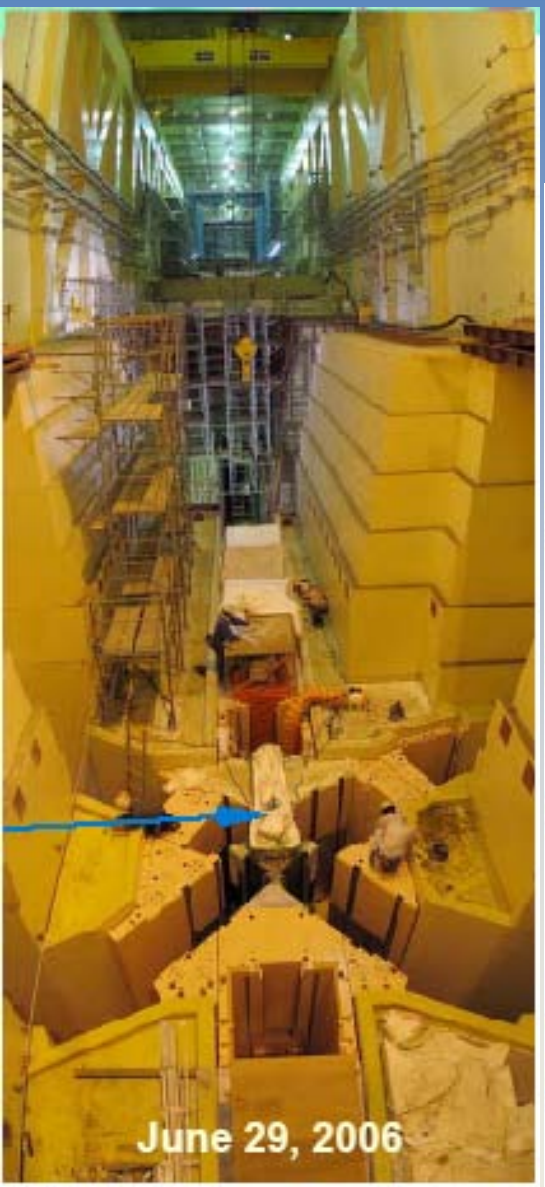
3 GeV
Synchrotron
(RCS: Rapid
Cycling
Synchrotron)
MLF
Linac 400 MeV

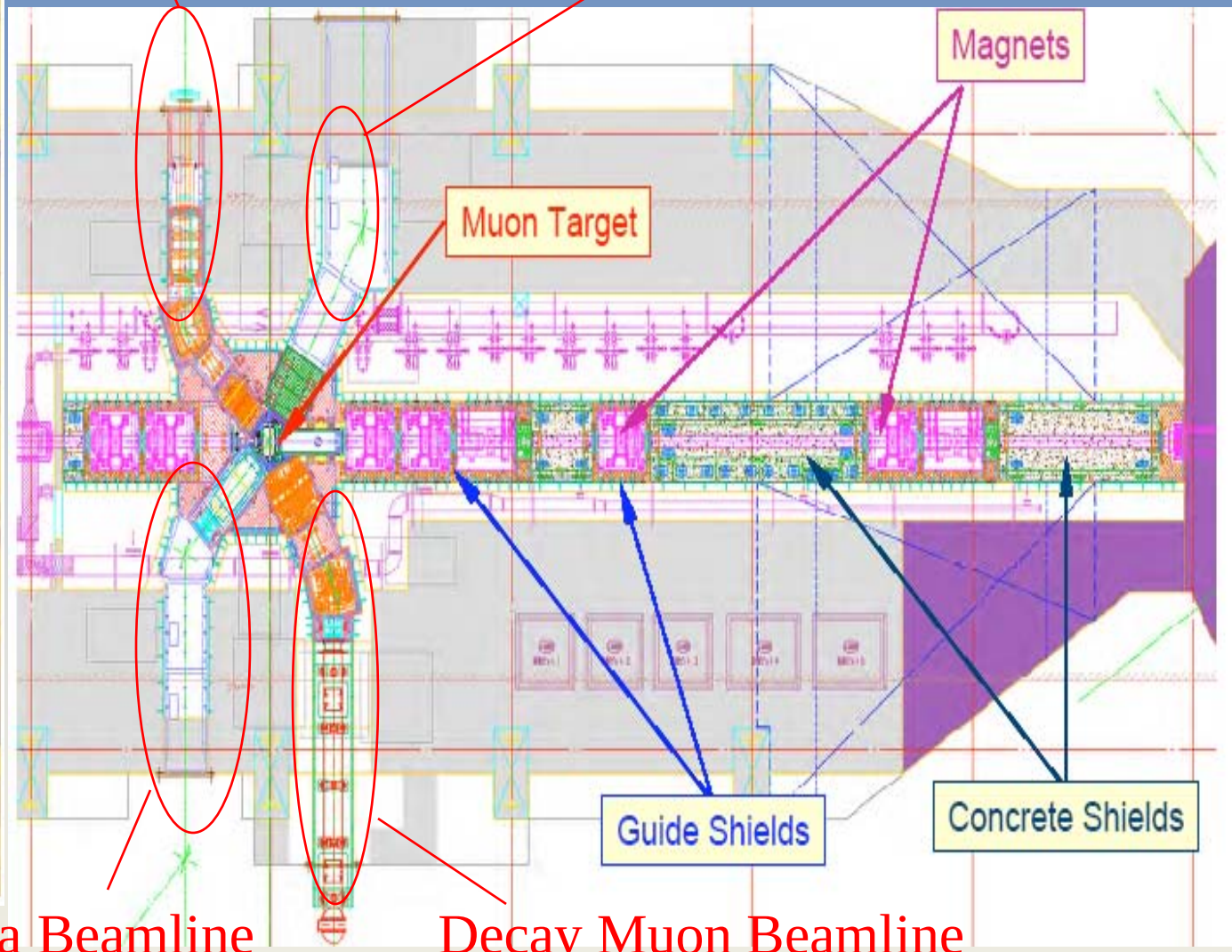
J-PARC/MLF



MLF:
3GeV proton beam
25 Hz repetition rate
333μA
1MW (currently @20kW)
Muons and Neutrons

J-PARC/MLF

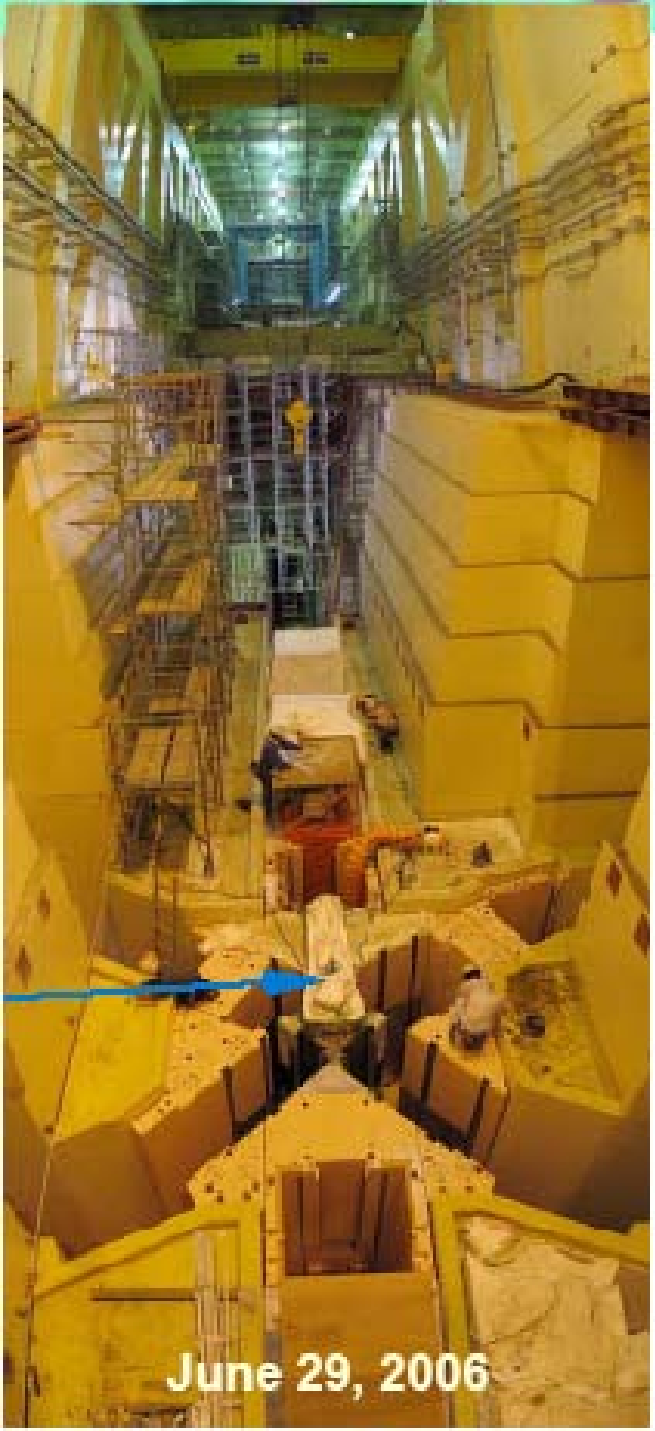

June 29, 2006


Surface Muon line
High Momentum line
Magnets
Muon Target
Guide Shields
Concrete Shields
Super Omega Beamline
Decay Muon Beamline

Primary Beamline

- Beamline is 1.6m above floor level
- All maintenance to be performed at FL+4m above floor level through remote-handling
  - All magnets, vacuum, power, and water connections must be remotely accessed

- Muons evaporating from the target surface ("surface muons"). E_{max}~4.2MeV (30MeV/c)
- In-flight "decay muons" (120MeV/c)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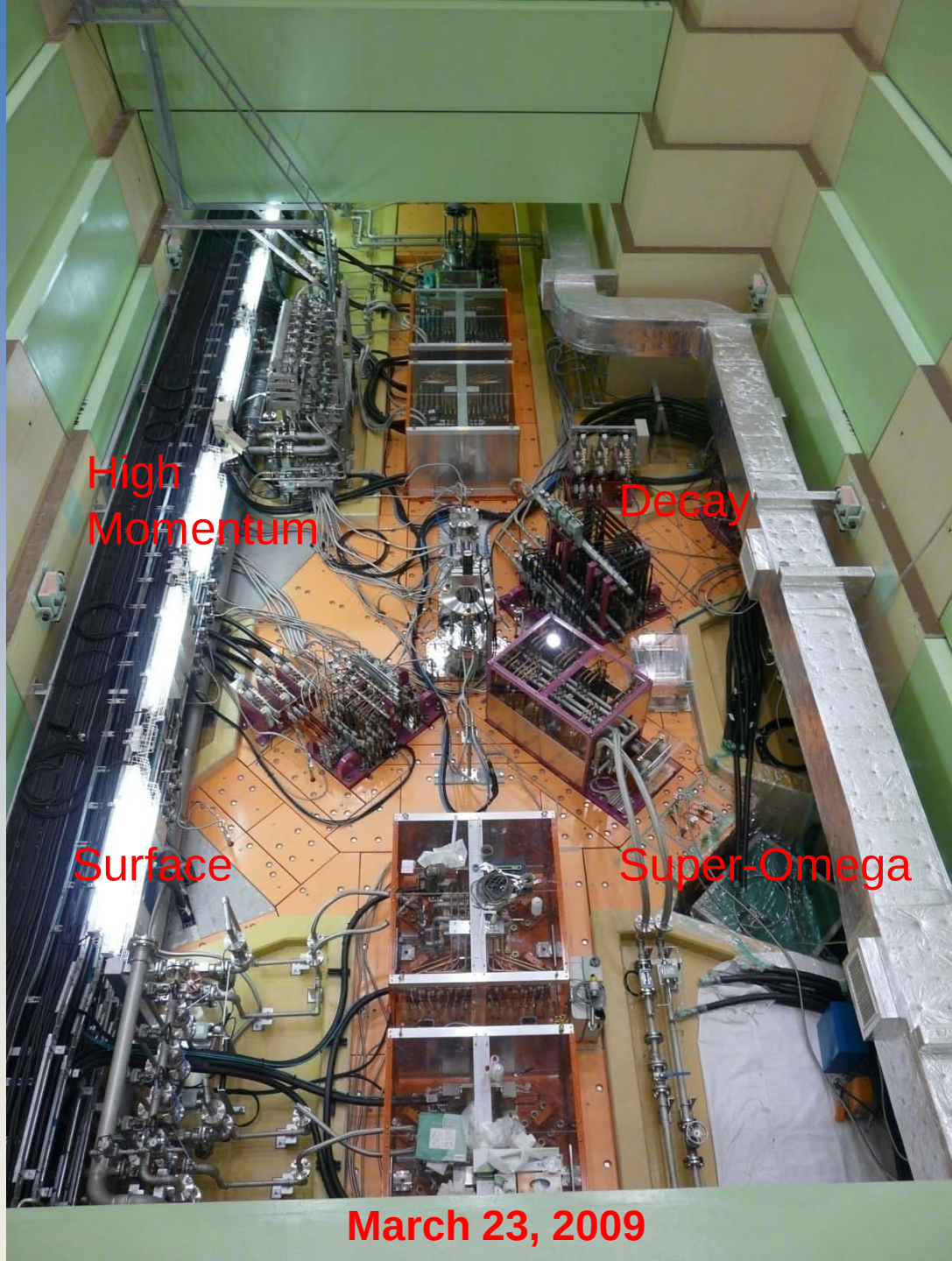
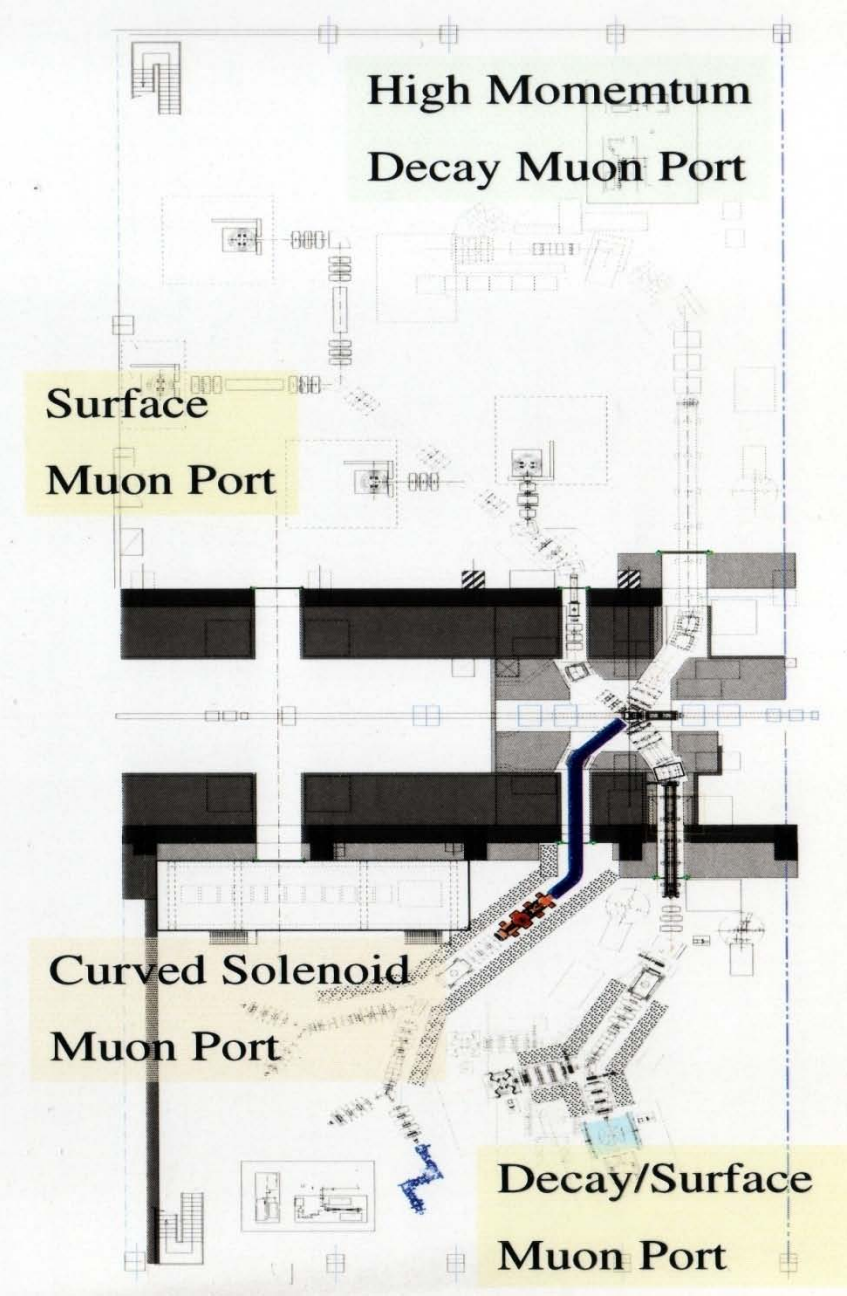

High
Momentum
Decay
Surface
Super-Omega
March 23, 2009

Surface/High Momentum/Decay Muon Beamline

- Decay Muon Beamline: First muon beamline to be completed at J-PARC/MLF – 2 channels (eventual simultaneous running)
- Simultaneous capture of μ^+ and μ^-
- 40 msr solid angle acceptance ~ 3×10^7 μ^+/s (expected)

- Commissioning Sep. 2008: Tuned to about 7×10^6 μ^+/s ← needs more work
  - **Initial muon lifetime spectra seen!**
- Experiments started Dec.2008: Initial μSR spectra seen!
- Most recent run (Feb. 2009) ended with problems with RCS.

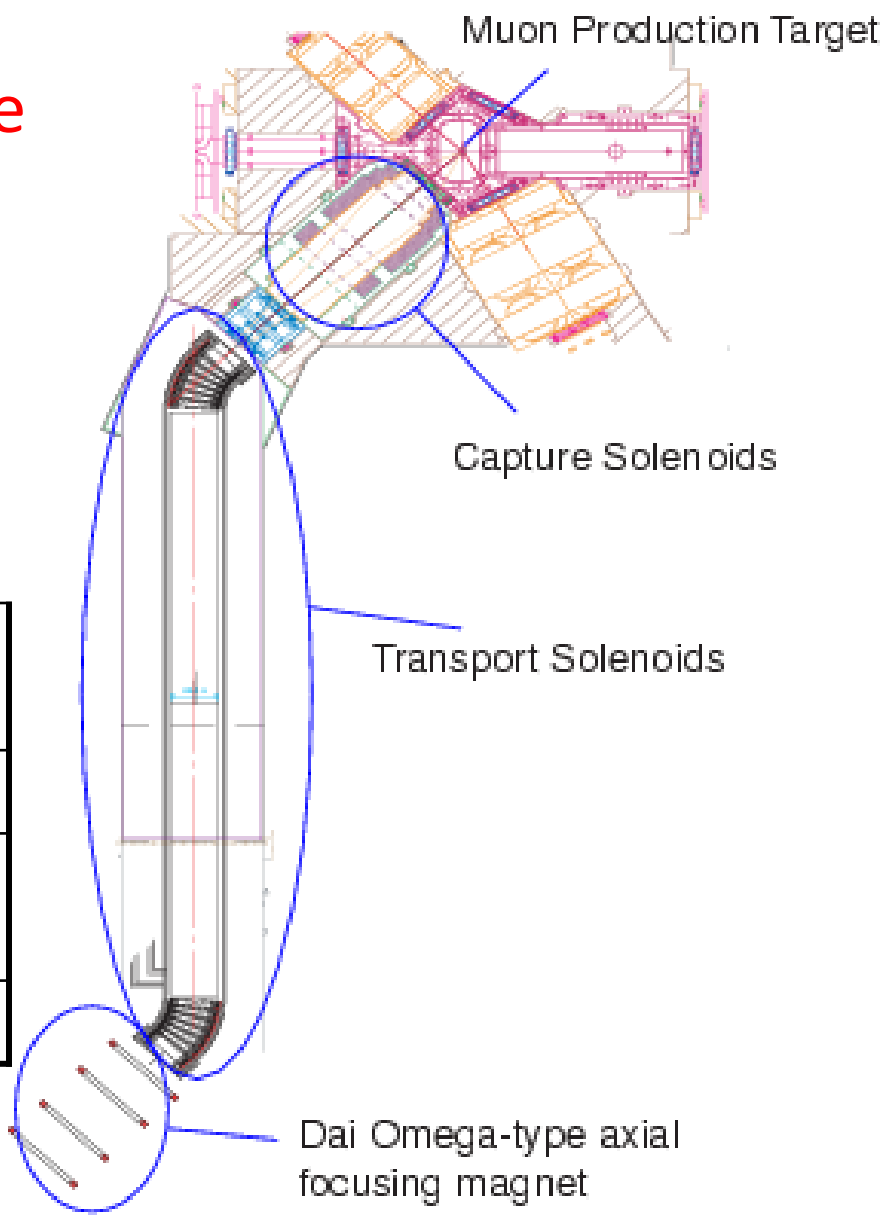


The Super Omega Muon Beamline

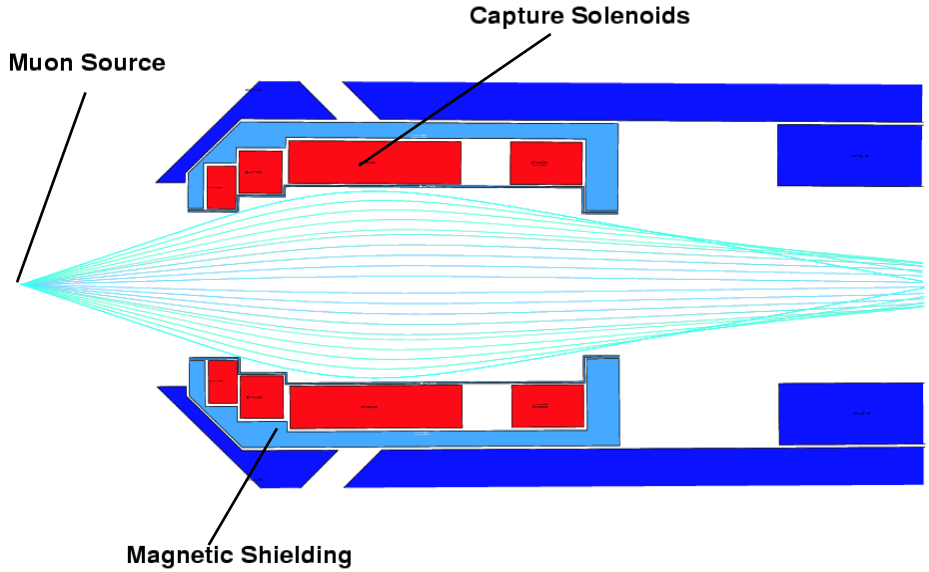
Build the highest intensity pulsed muon beamline in the world

Capture μ^+ and μ^- simultaneously

Conventional beamlines	**Super-Omega**
30-40 msr	400 msr
Quadrupole triplets (capture)	Large acceptance solenoid
Bending magnet	Curved solenoid



Capture Solenoids

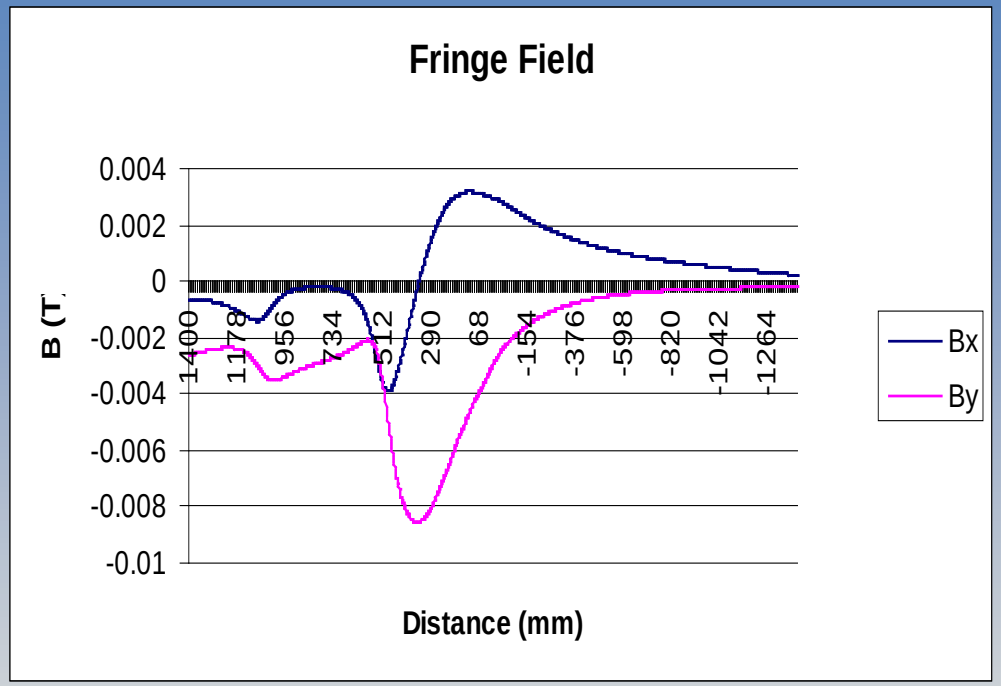


- normal conducting capture solenoids
- radiation-resistant hollow conductor mineral insulation cable

Maximum current	2000A (1000A @30MeV/c)
Peak central field	0.3T
Coolant	130 l/s
Muon capture rate	5×10^8 μ^+/s @ 30 MeV/c
Solid angle acceptance	400 mSr ($\pm 20^o$ initial angle)

Effects on Neutron Program

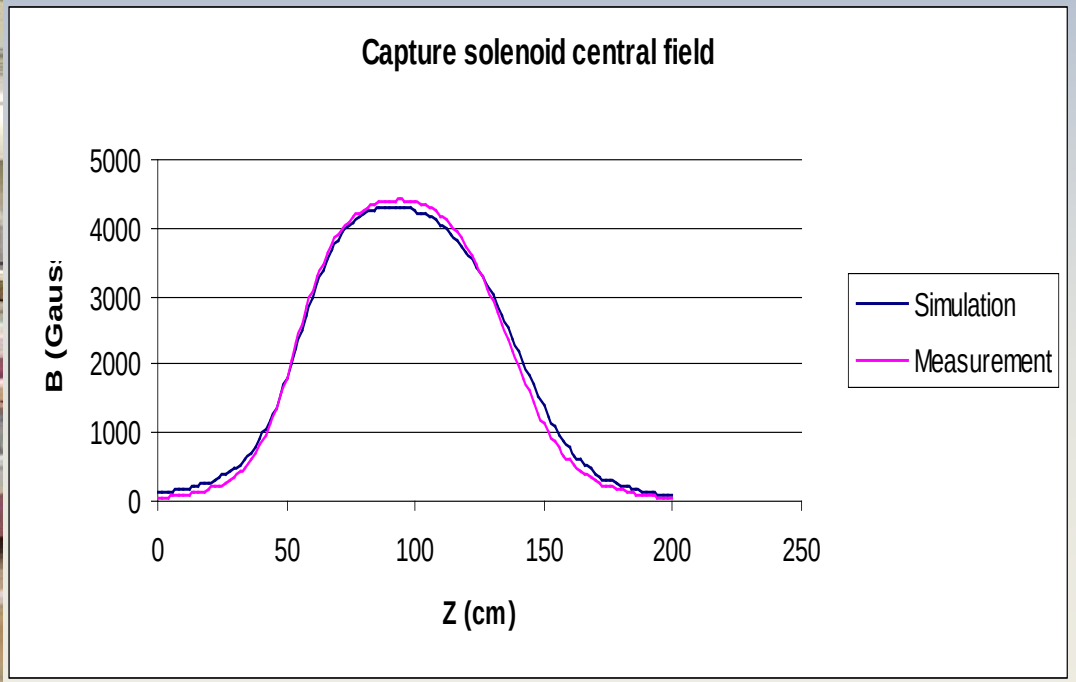
- ~ 10% beam loss at muon production target
- Effects of leakage field on primary proton beam
- Maximum kick of steering downstream steering magnets
- ~ 3 mrad
- Horizontal kick ~0.1 mrad, vertical fields cancel



Bx		θ y	0.097	mrad
steering magnet				
Kick angle due to fring		θ x	3	mrad

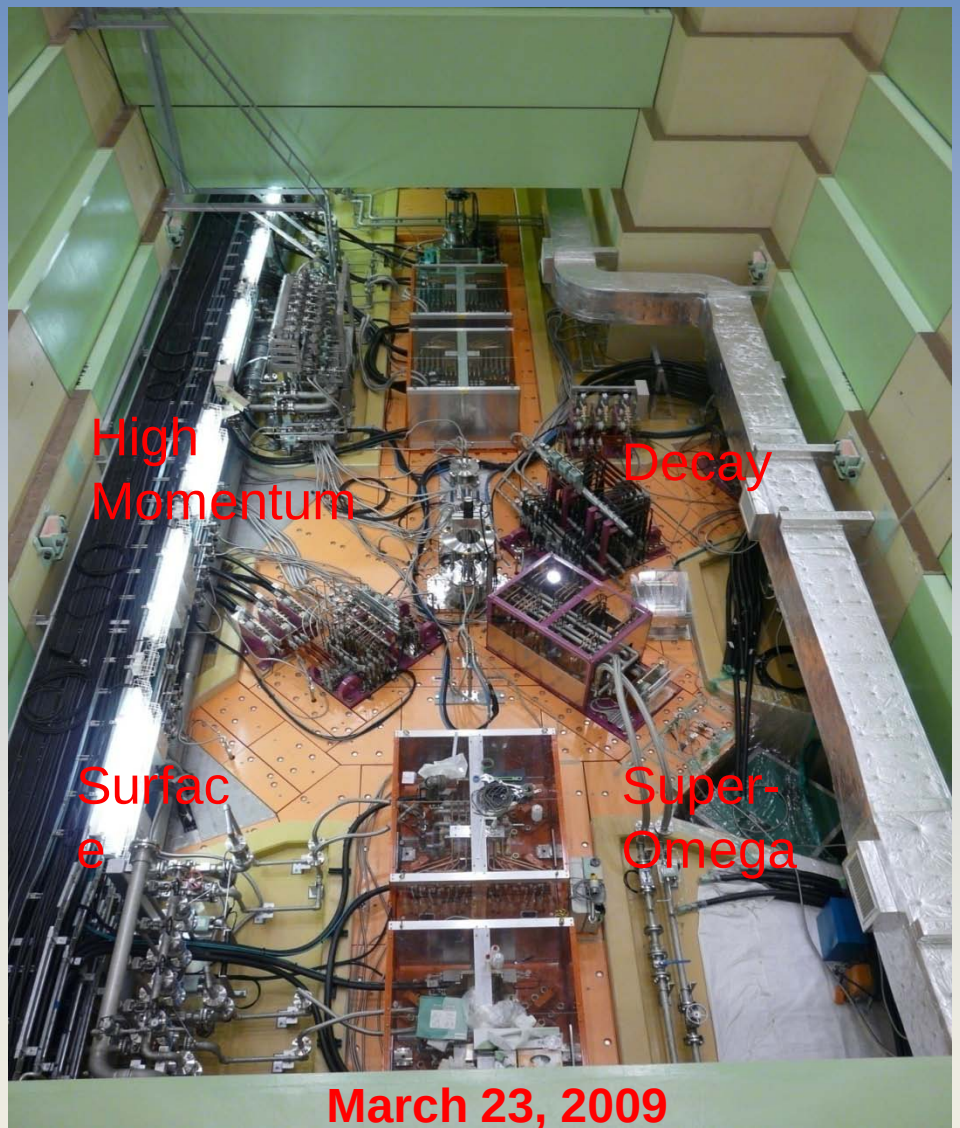
Construction Complete!

- Field mapping performed at NEC/TOKIN



Capture Solenoids: Status

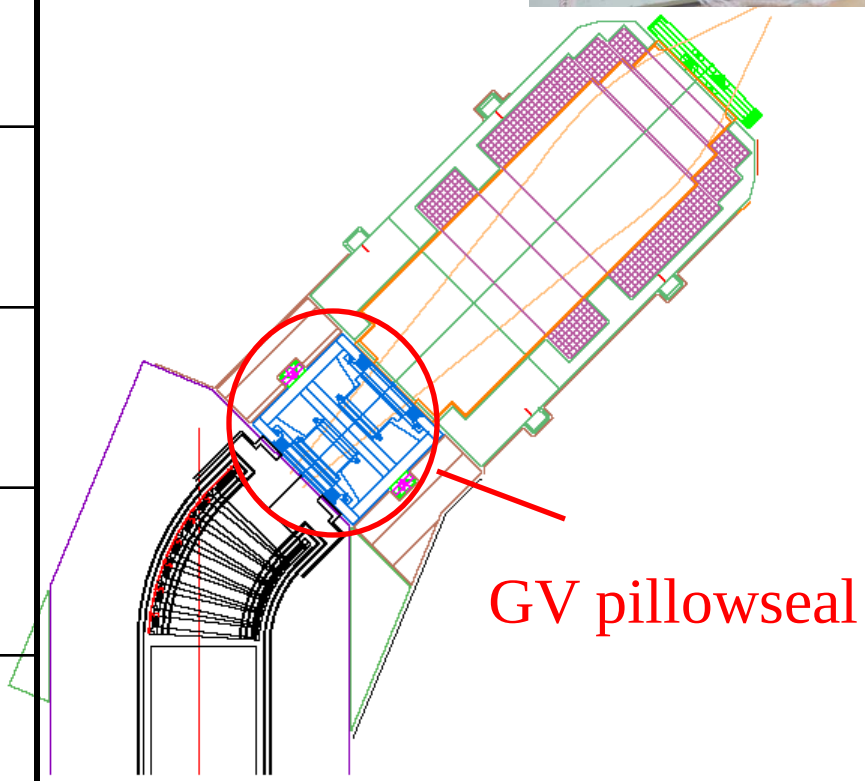
- Construction complete: March 08
- Installation on beamline: March 09



GV-Pillowseal

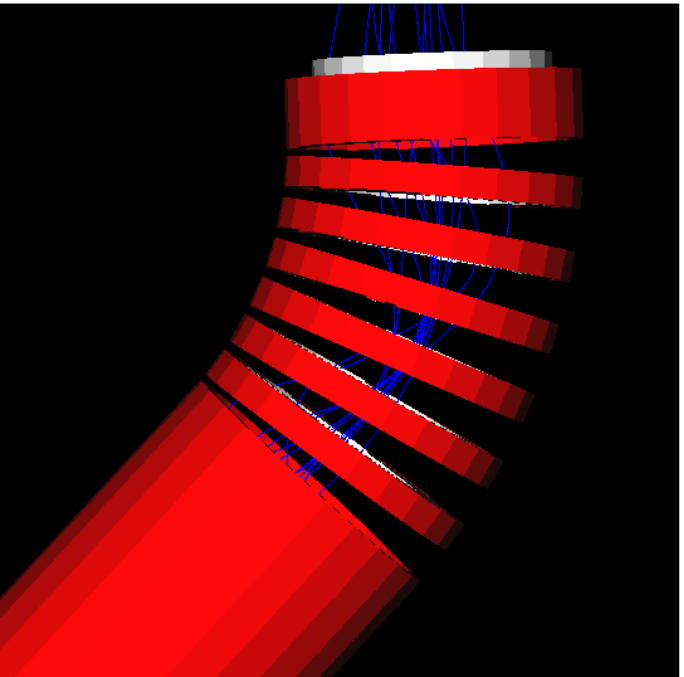
- The pillowseal used to connect vacuum components
- Gatevalve can be closed to perform maintenance
- GV-Pillowseal constructed (Oct.08). Installation in March 09
- Apertures increased to reduce beam loss
- 2/3 of all beamloss appears at the gatevalve

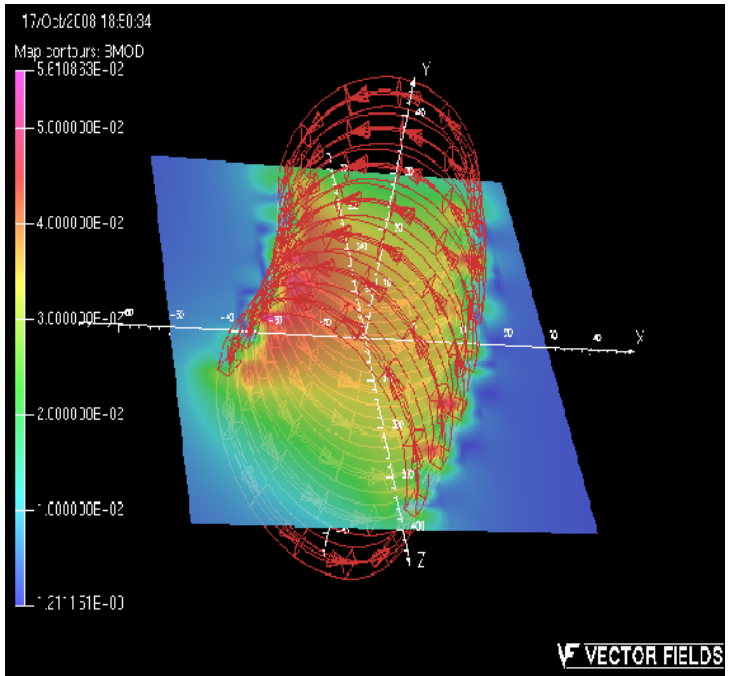
	Original Design	New Design
Capture-side aperture	240mm	360mm
Transport-side aperture	240mm	240mm
GV diameter	200mm	250mm
Rate loss (30MeV/c)	27%	12%

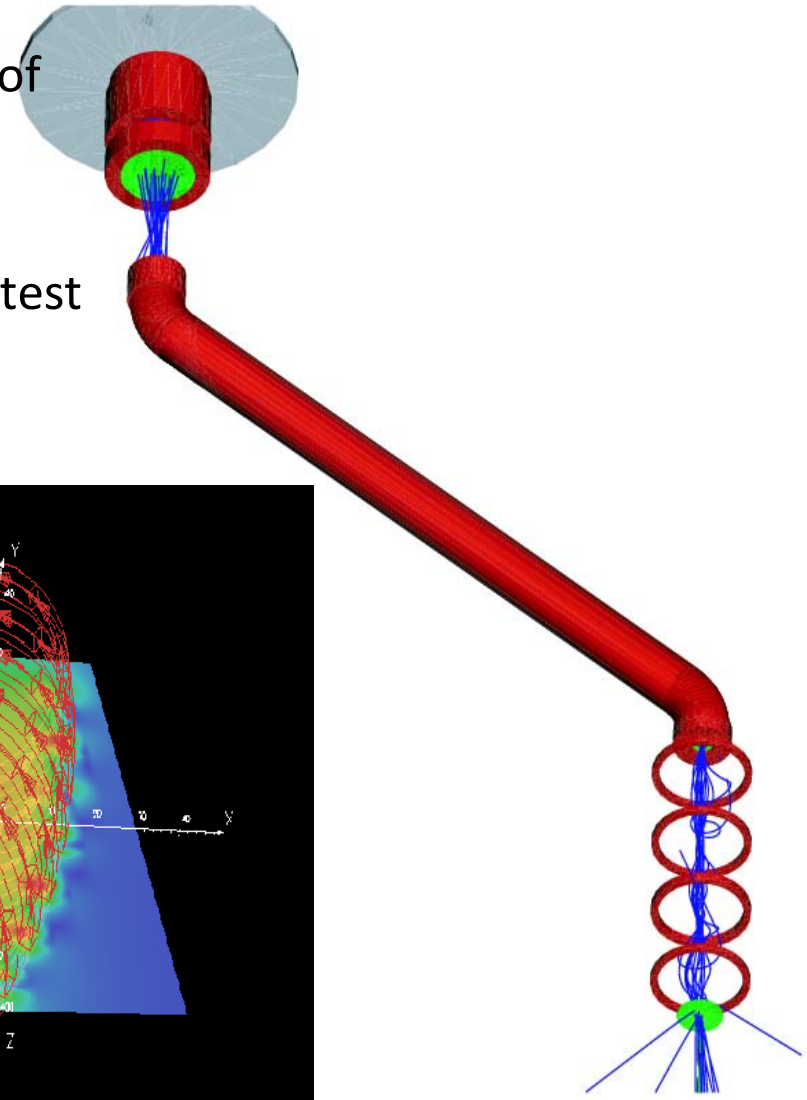


Transport Solenoids

- Superconducting curved transport solenoids
- Two segmented 45° curved sections (background rejection) and a ~6m straight section
- Total heat load of 10~15W, cooled by a series of GM refrigerators
- 80% transport efficiency at 30 MeV/c
- Prototype solenoids are being constructed to test the feasibility of the curved section

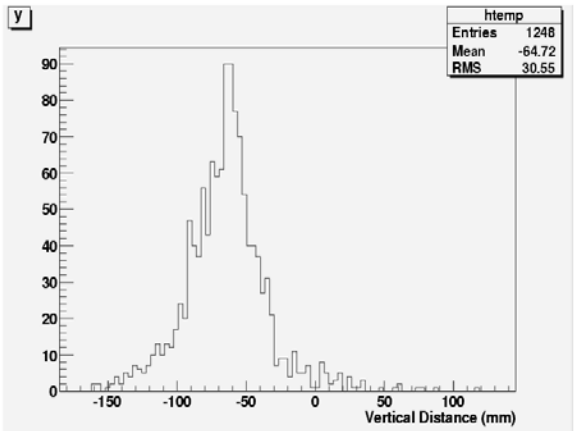


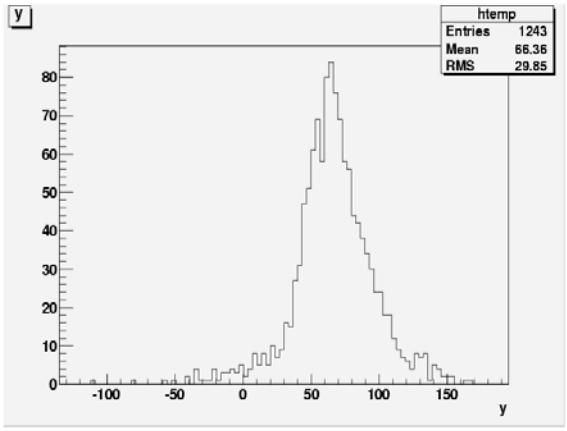


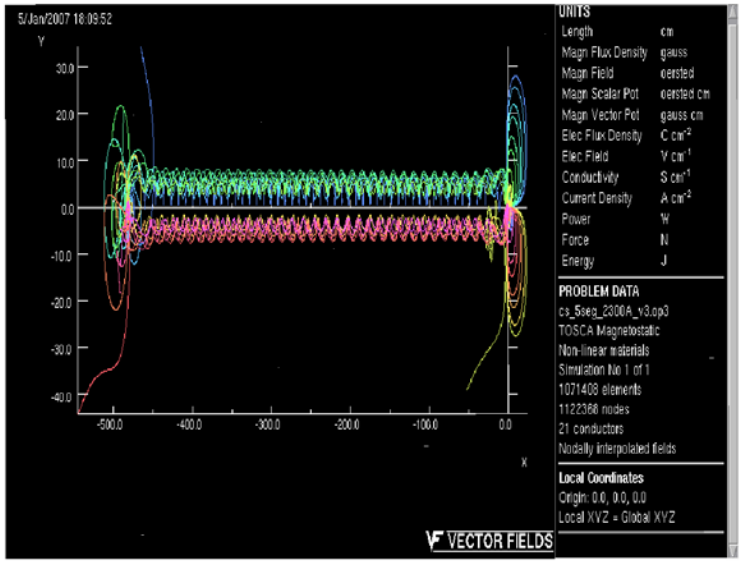


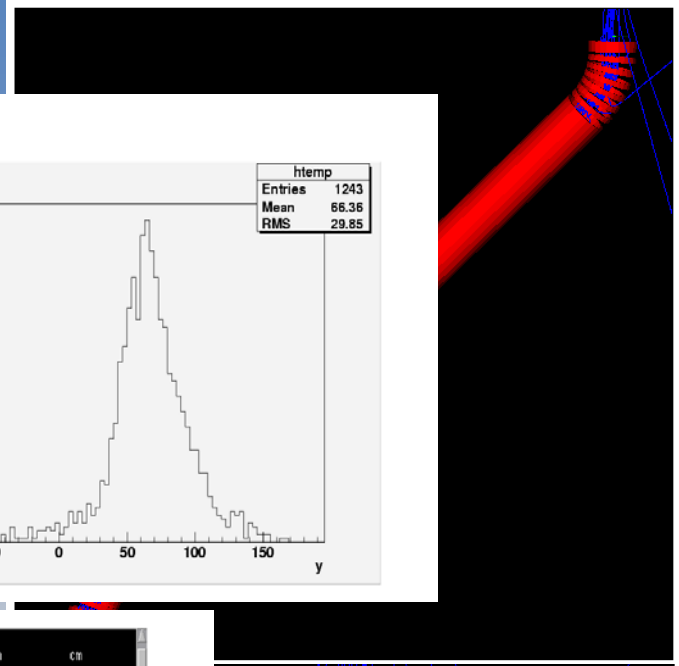
Transport Solenoids

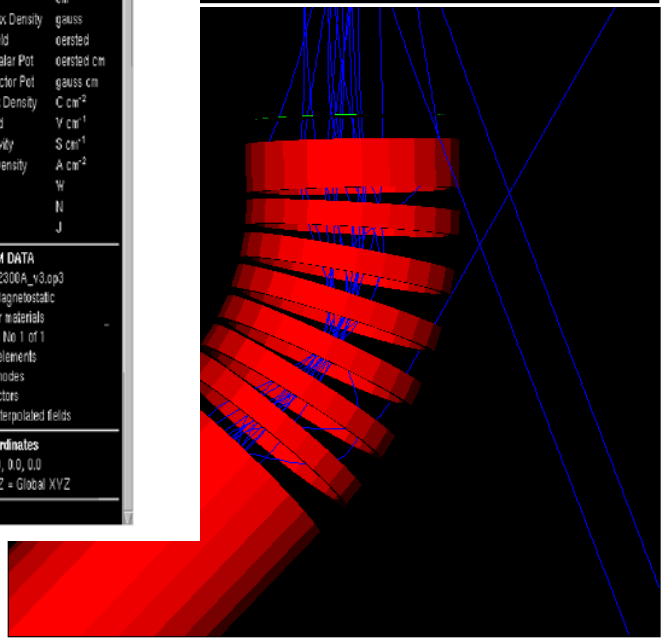
- Superconducting curved solenoid
- Two 45° b
  - Separa
  - Backgr
- 1.4T field
- Currently under c
  - Cryogenics – E collaboration v cryogenic grou (A.Yamamoto, T.Ogitsu,T.Ada





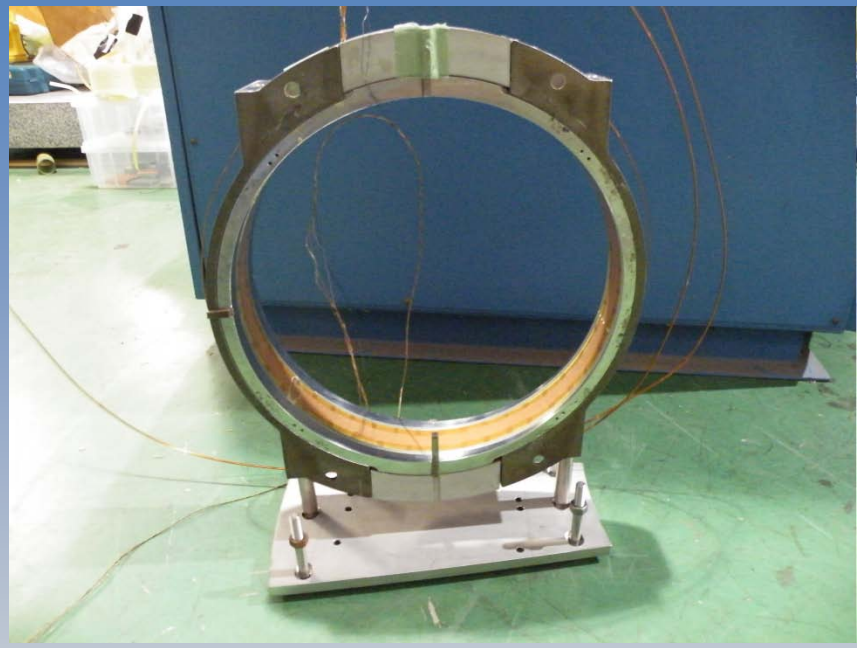


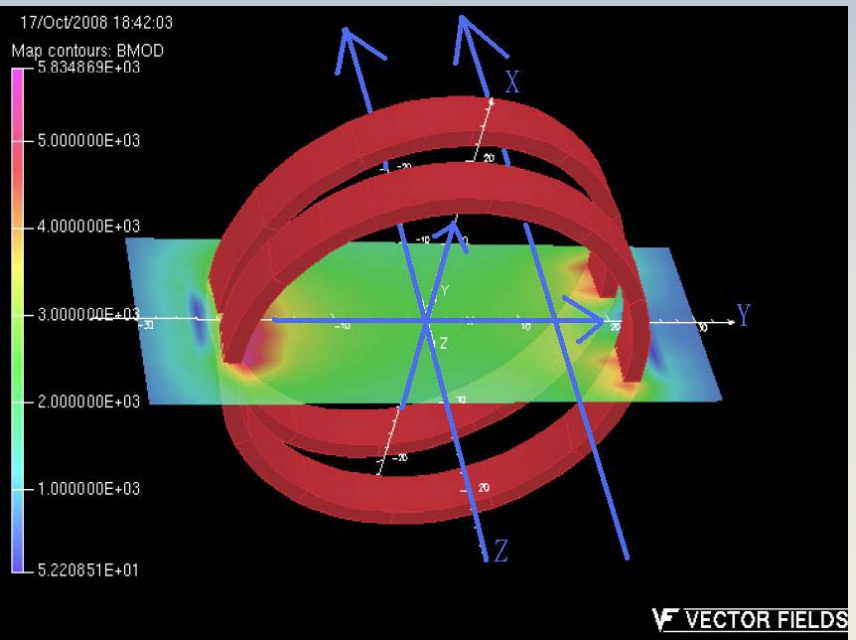


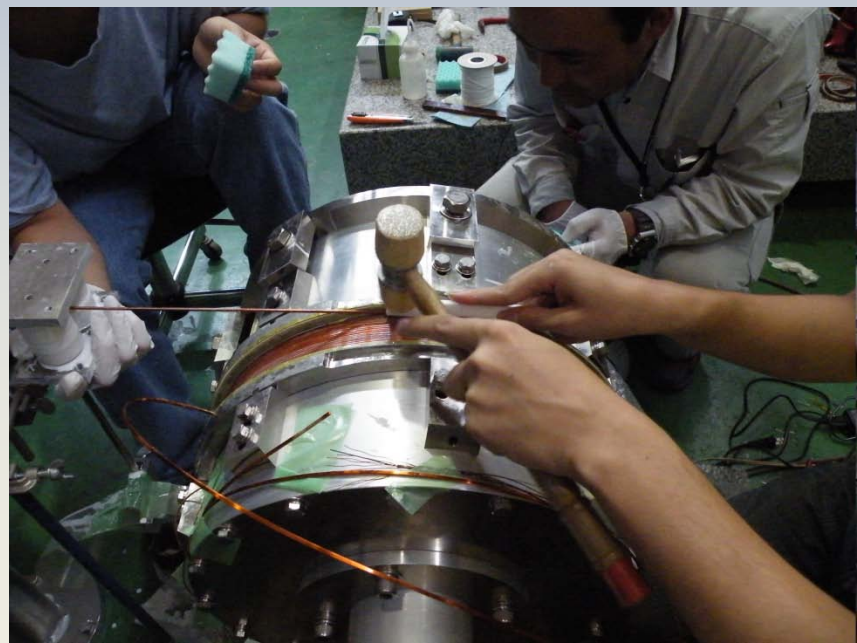


Prototype Solenoids

- Prototype segments being fabricated
- Testing to occur at the KEK cryogenics center
- NbTi coils, hand-made solenoids







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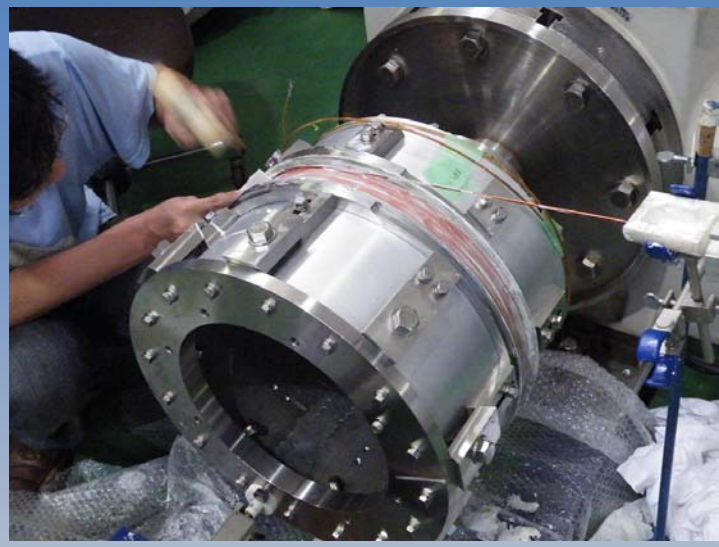
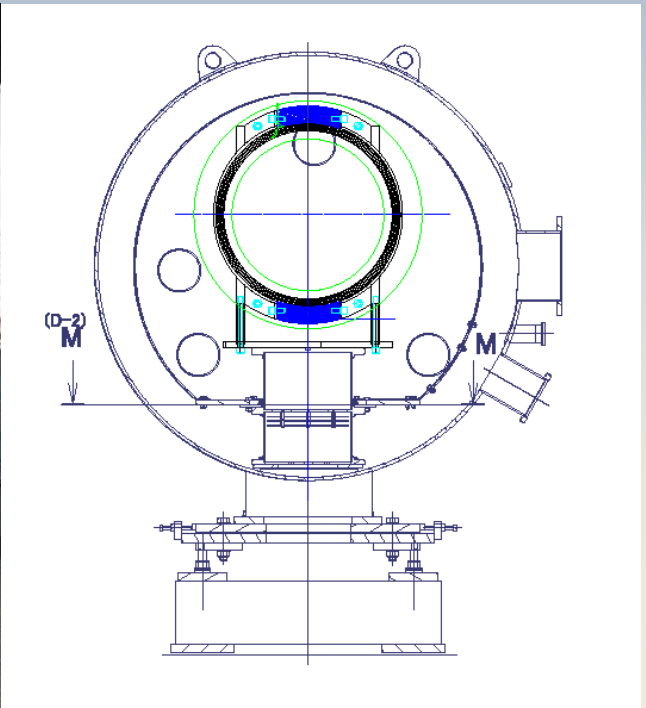
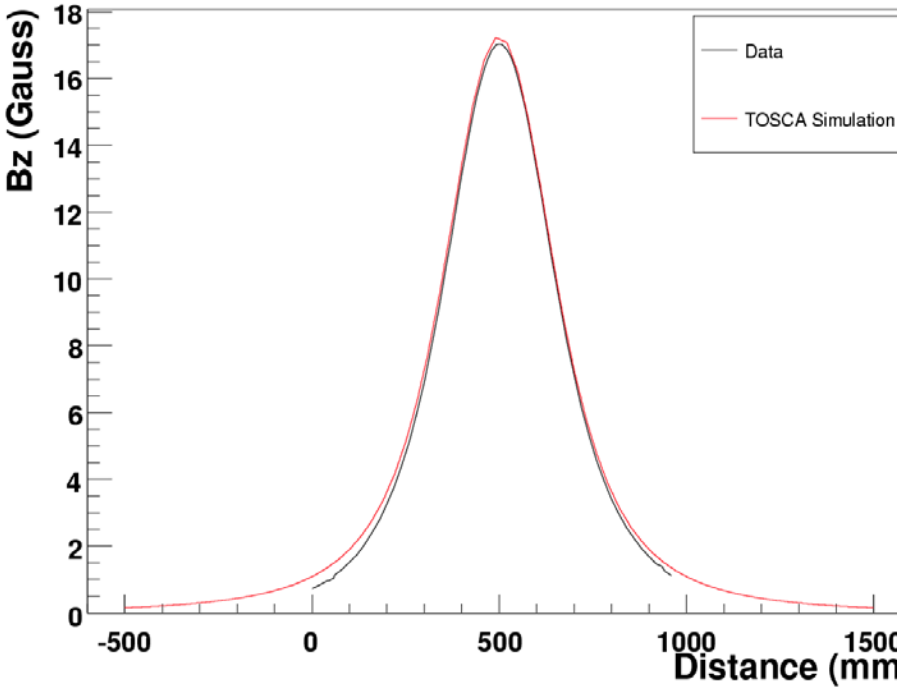




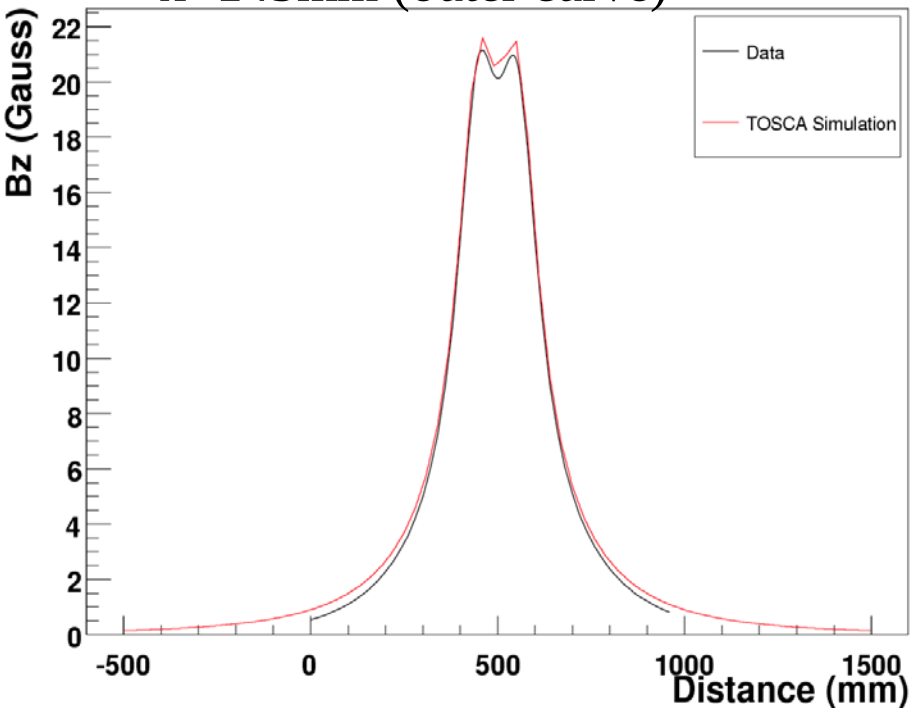
Initial Tests

- Initial “warm tests” with 2A
- Field matches with simulation to ~1.2% at peak – well within tolerance

Central Field

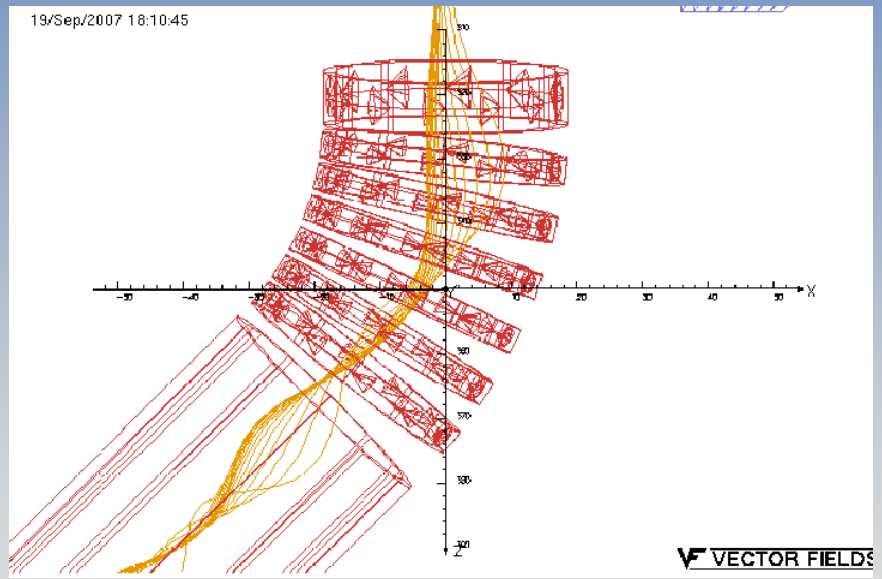


x=145mm (outer curve)



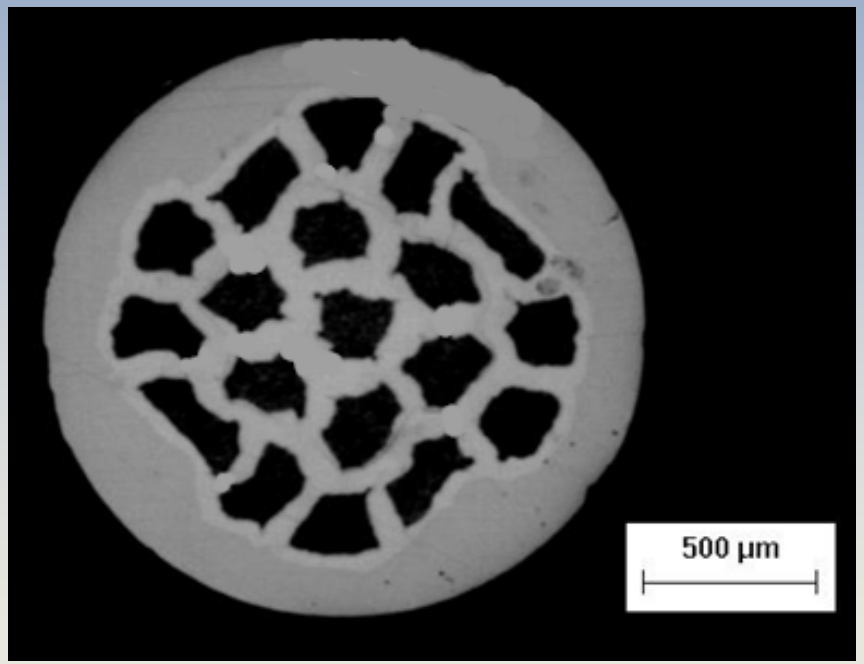
Cryogenic System

- Mostly structural heat load
  - 70K and 10K cryogenic shields
  - Gifford-McMahon refrigirator
  - 5~10W heat load
- Heat load from radiation (mostly neutrons) calculated using GEANT4 ~1-2W
- NbTi superconductors may require too many GM refrigirators ➔ considering the use of MgB2 superconductors and operate at 10~20K



MgB2 Superconductors

- Discovered to have superconducting properties in 2001 (Akimitsu et al. 2001)
- Tc=39K, Hc(@4.2K)=60T (MgB2)
- Tc=9K, Hc(@4.2K)=10T (NbTi)



Columbus Superconductors Inc.

Pros:

-**Comparable costs**

- **In use with 0.5T MRI**

- **higher operating temperature ➔ less cooling power**

Cons:

- **Unknown tolerance to higher fields (3T)**

- **Unknown tolerance to radiation**

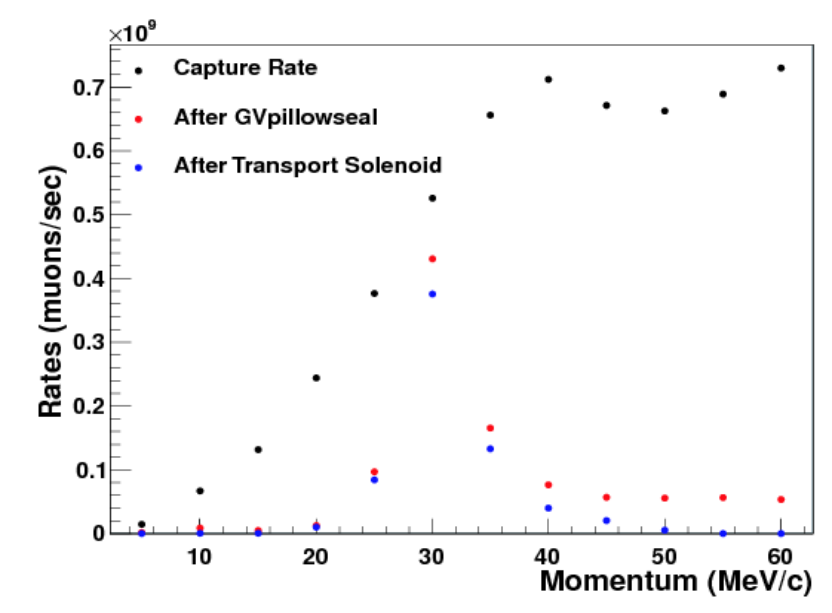
- **Requires large bending radius**

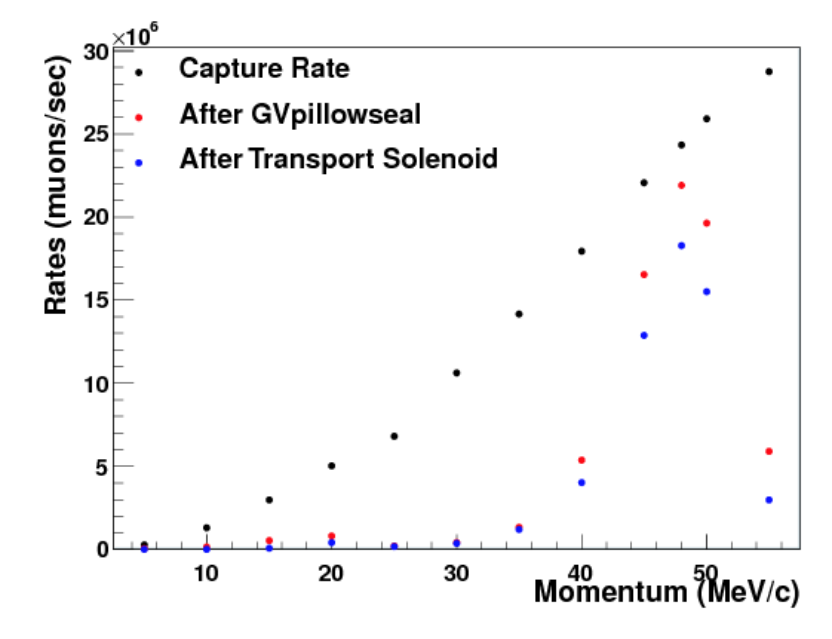
Prototype solenoids wound!! (1 @Toshiba, 1 @KEK)

Rates

The expected muon rates are calculated using GEANT4. Surface muon rate of 4×10^8 μ^+/s at 30MeV/c

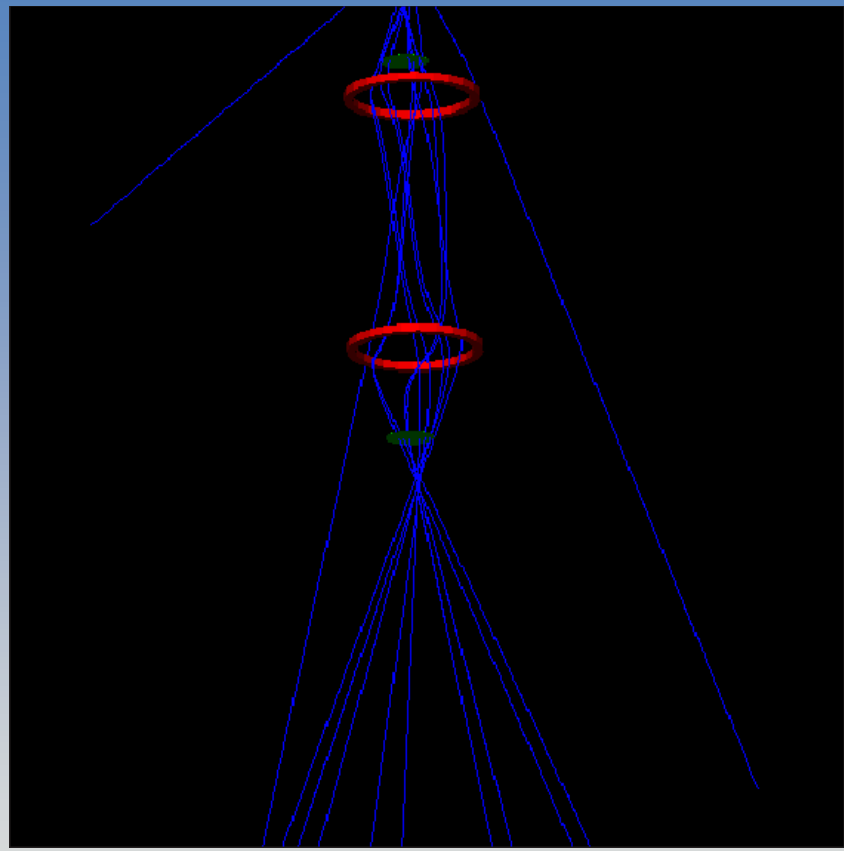
- Negative muon rate of 1×10^7 μ^-/s at 30MeV/c
- Negative muon rates fall off rapidly at higher momentum. Capture and transport solenoids must be tuned to recover the loss in rate

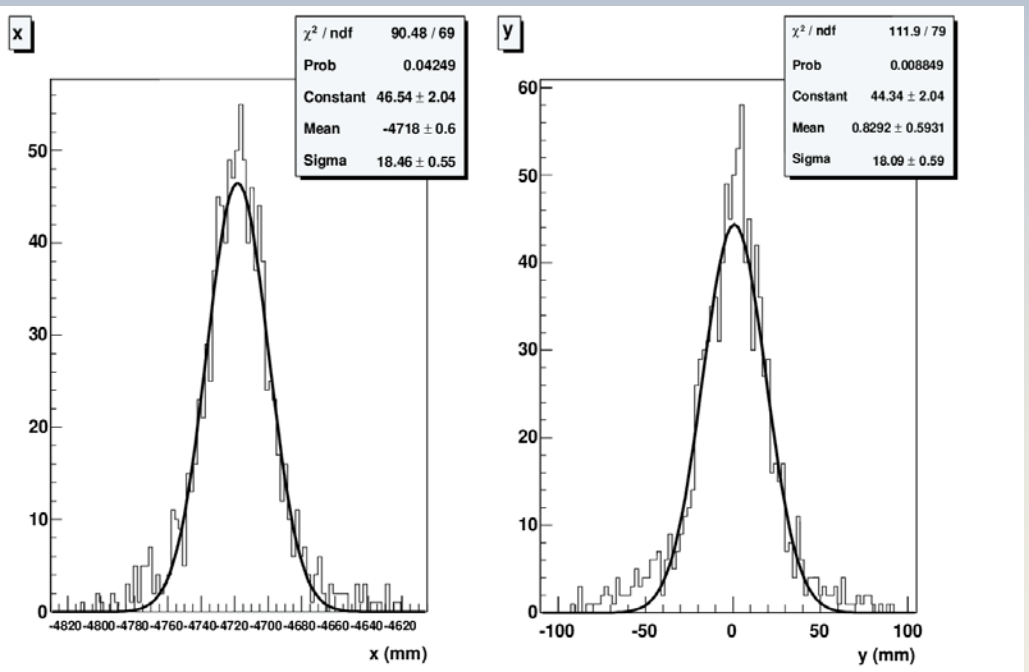




Axial Focusing

- How many transported muons can be focused onto the experimental target?
- Laser width ~ $1\times3\text{cm}^2$
- Solenoids used to focus the beam onto the target
- ~1×10^8 μ^+/s for laser resonant ioniz.





Expected Advantages

Large acceptance, curved beamline:

- Ultra-slow muon production
  - Riken/RAL ~ 10^2 ultra slow muons/s
  - Super-Omega muon beamline ~10^5 ultra slow muons/s
- Mu anti-Mu conversion
  - High rates (up to 4×10^8 μ^+/s)
  - low background
- Capable of accepting μ^+/ μ^- over a range of momenta

Summary

- Super-Omega muon beamline under construction to create the worlds' most intense pulsed muon beam
- Variety of physics extending across several fields.
- Front-end capture solenoids constructed/installed
- GV-pillowseal constructed
- Transport solenoids currently being designed
- Challenging/ambitious project to make use of MgB_2 superconductors
- Test solenoids fabricated ➔ currently being tested
- Axial-focusing magnets currently being studied

Muonium/Ultra-slow muon Production

~1985: Production of (Mu;μ^+e^-) in vacuum

by Mills, Imasato, Nagamine et.al(W) &
Matsushia, Murata, Nagamine et.al(Pt)

~1987: Ionization of Mu through1s-2s excitation (QEDtest)

by Chu, Mills, 久我, Yodh, Miyake, Nagamine, et.al

1990-1998: Ultra-slow muon project @KEK

by Miyake, Shimomura, Birrer, Nagamine et.al

1999~: Ultra-slow muon project @RIKEN/RAL

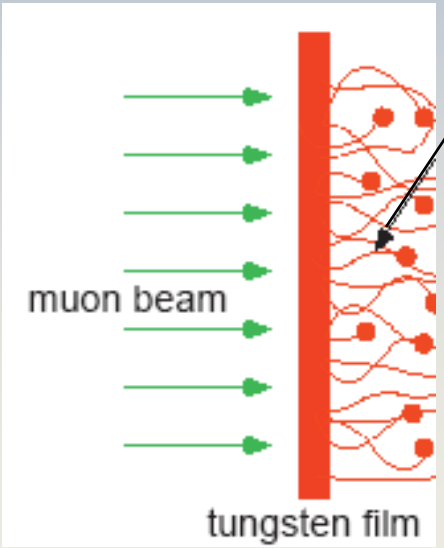
by Matsuda, Bakule, Miyake, Shimomura, Ikedo,
Makimura, Nagamine et.al

2007~: High-intensity pulsed ultra-slow muon source at J-PARC

Muonium Production

- Surface muons ➔ muonium
- One of the main motives for the construction of the Super-Omega muon beamline

Muonium production by bombarding μ^+ onto a tungsten target



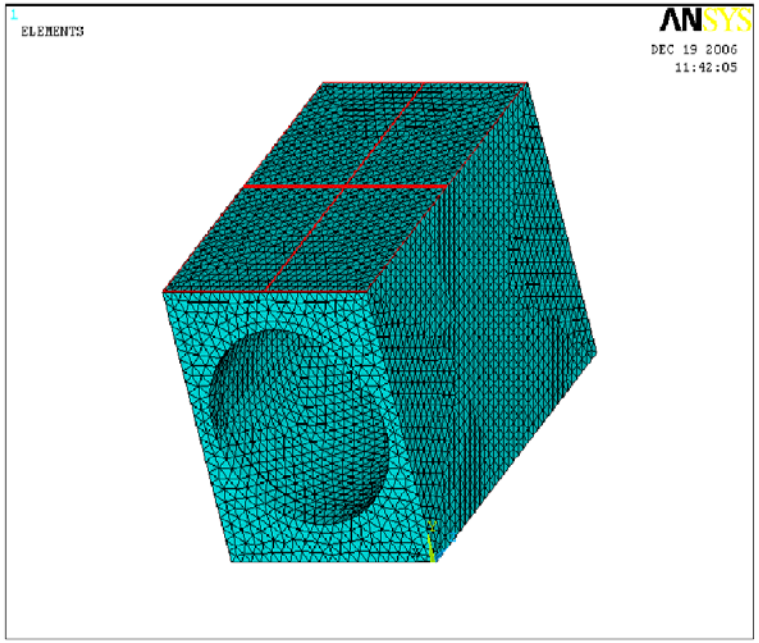
Muonium evaporation

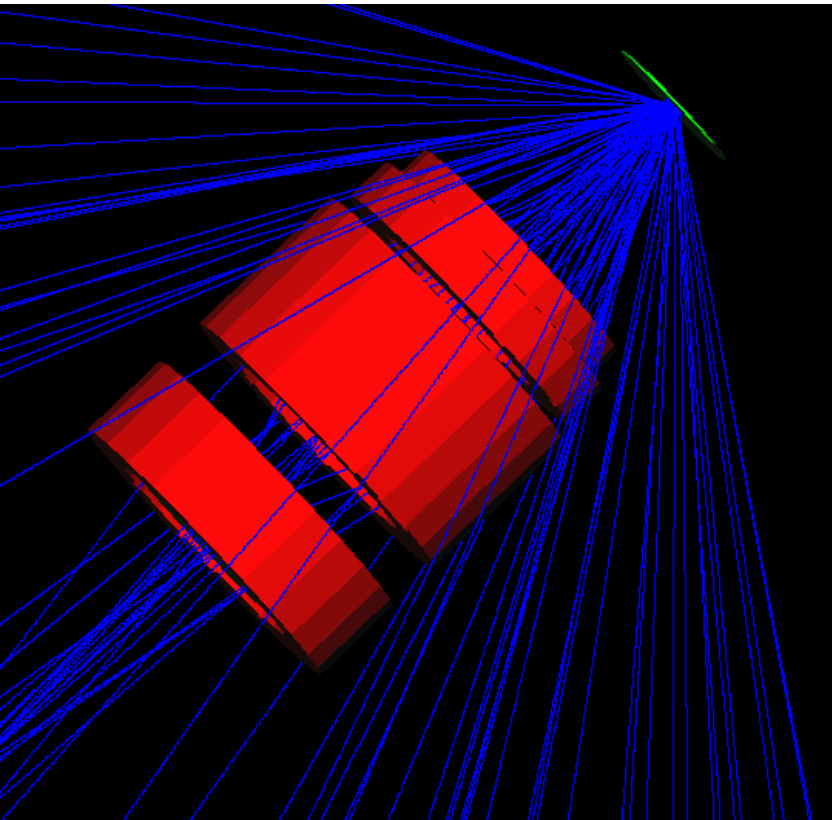
Mu anti-Mu conversion

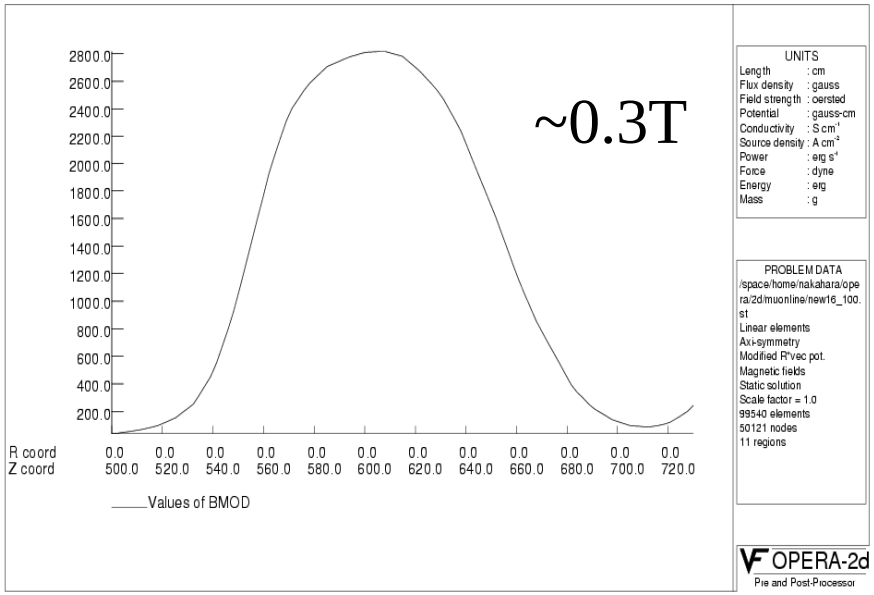
Ultra-slow muons

Simulation

- Field calculation: TOSCA
- Beam intensity: GEANT4
- Structural calculations: ANSYS







Current Status

- Decay Muon Beamline constructed: captures both μ^+ and μ^-. Two ports: experiments have started Dec 2008. (7×10^6 muons/sec)
- Surface Muon Beamline: front-end capture section completed. Primarily used to capture surface muons
- High Momentum Beamline: No construction yet.
- Super-Omega Muon Beamline: Front-end capture section constructed and installed.

- Periods of development to continue interwoven with data-taking in active ports.

The Super-Omega Muon Beamline

Construction of a new high intensity pulsed muon beam:

- Up to 30 MeV/c surface muons (μ^+)
- Up to 50~60 MeV/c in-flight decay muons (μ^-)