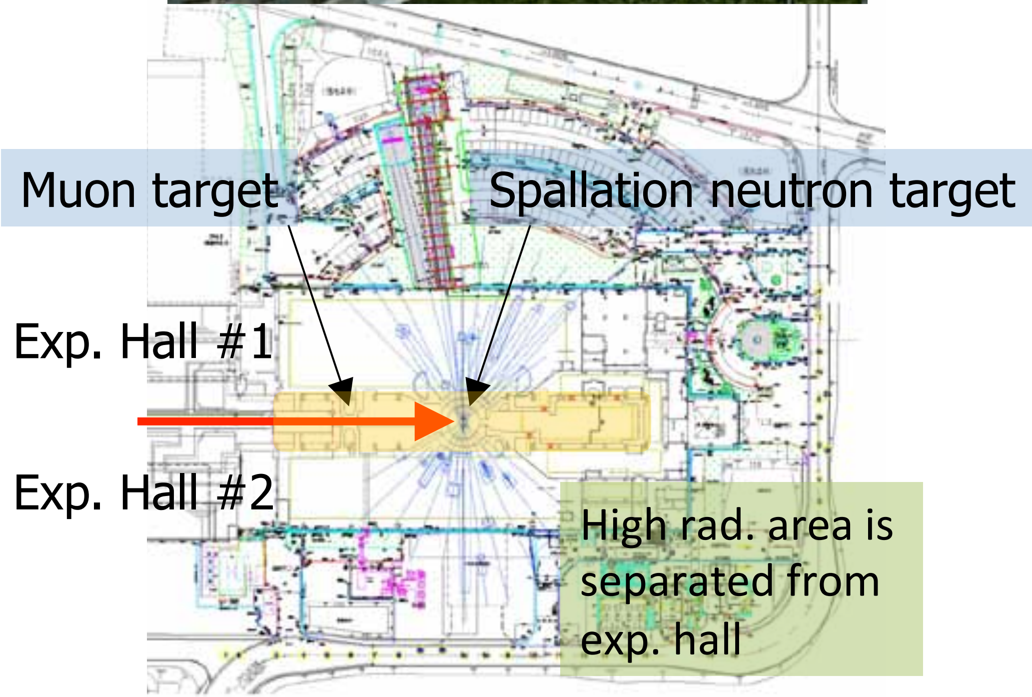
TRIUMF-IMSS Collaboration Meeting, March 8-9th, 2012

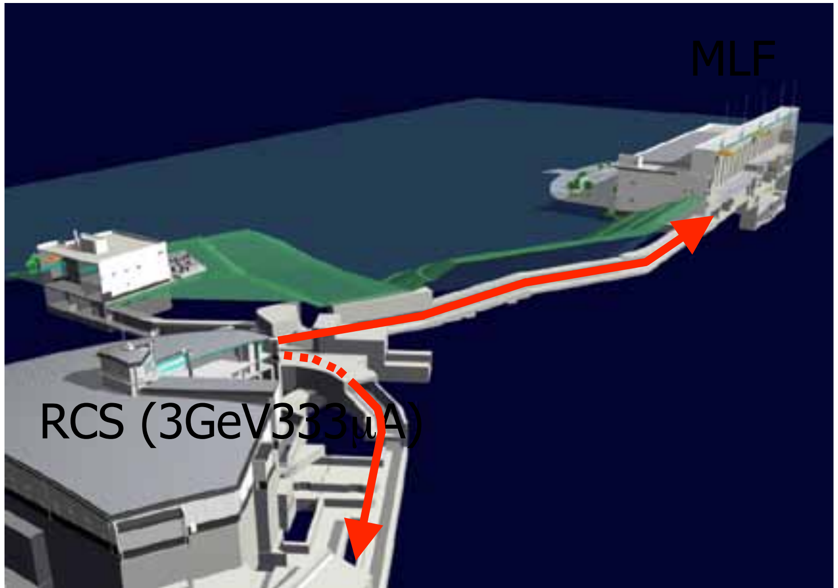
U-Line :

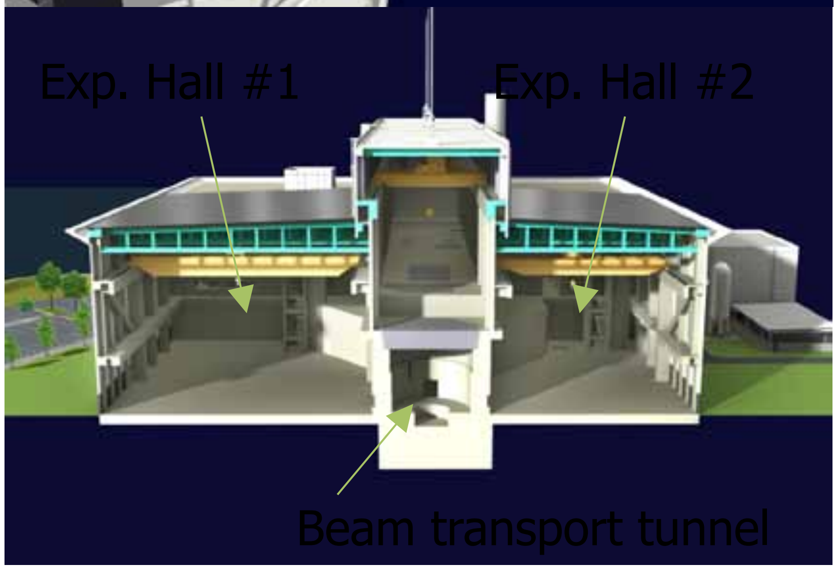
Intense Muon Beam Line Dedicated for Ultra Slow Muon

Y. Miyake (KEK)

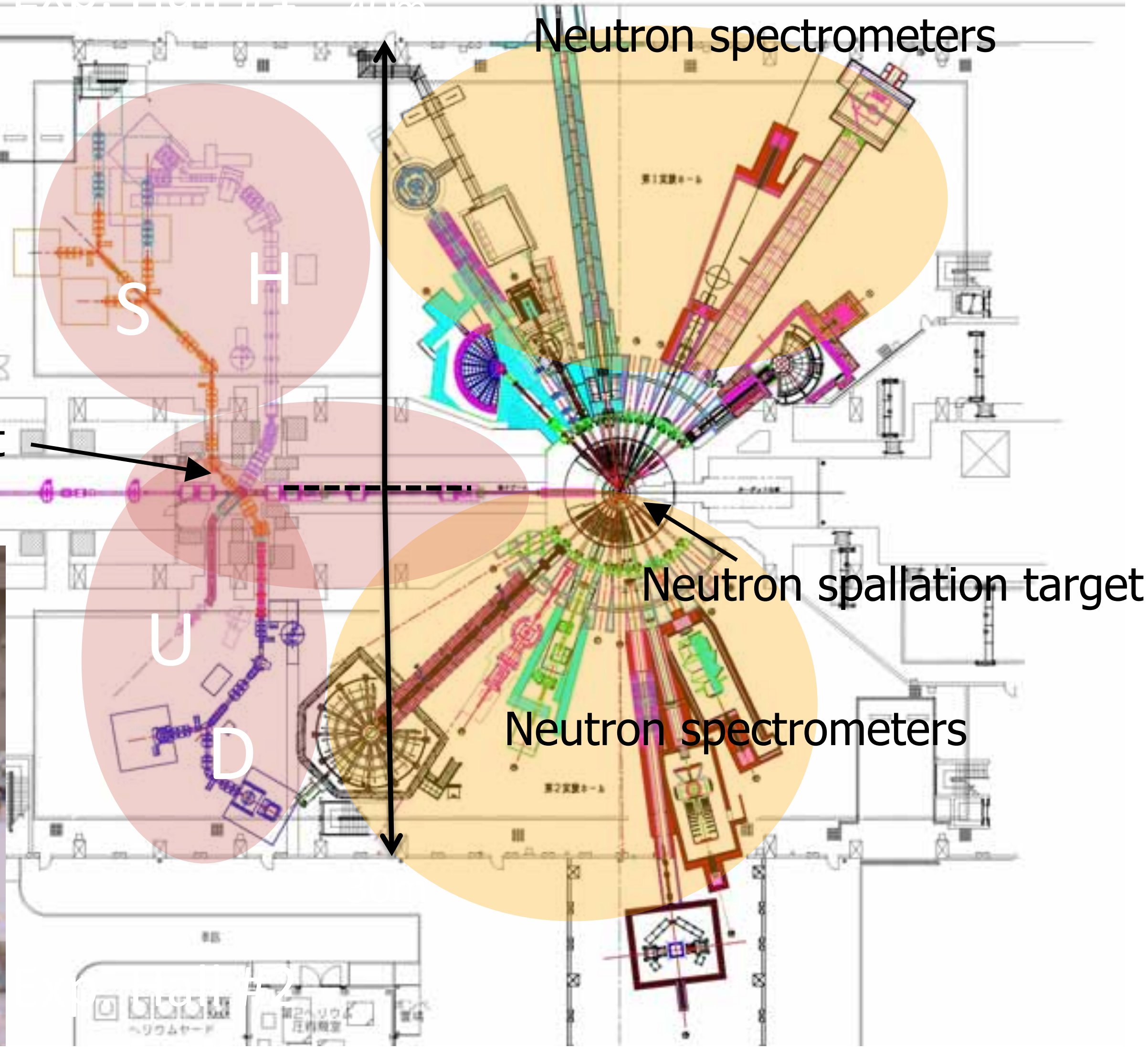
Materials and Life Science Facility





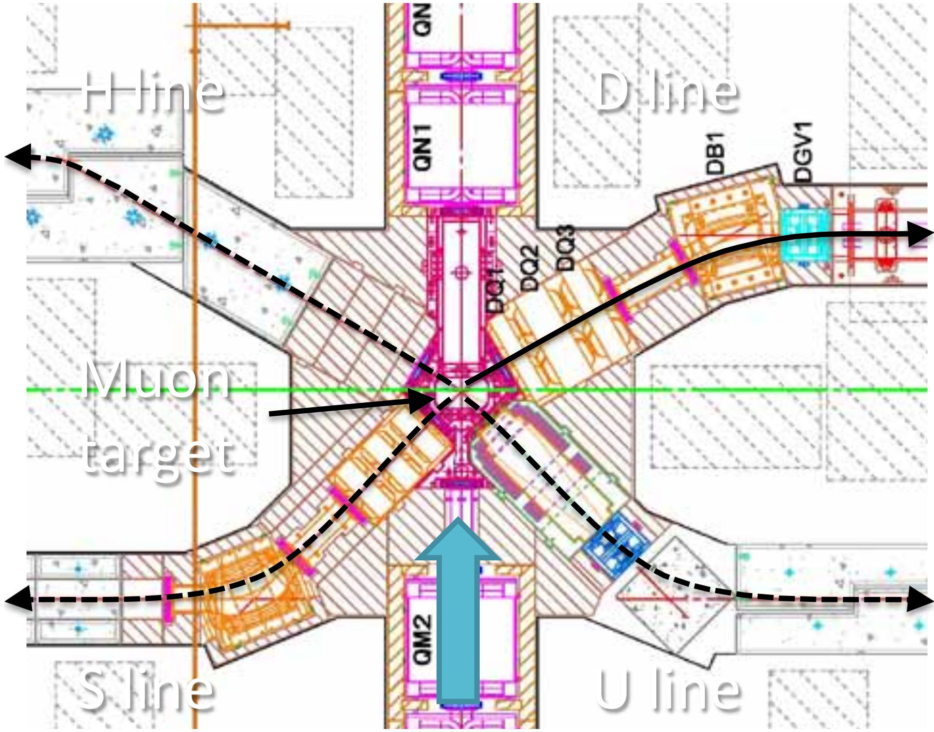


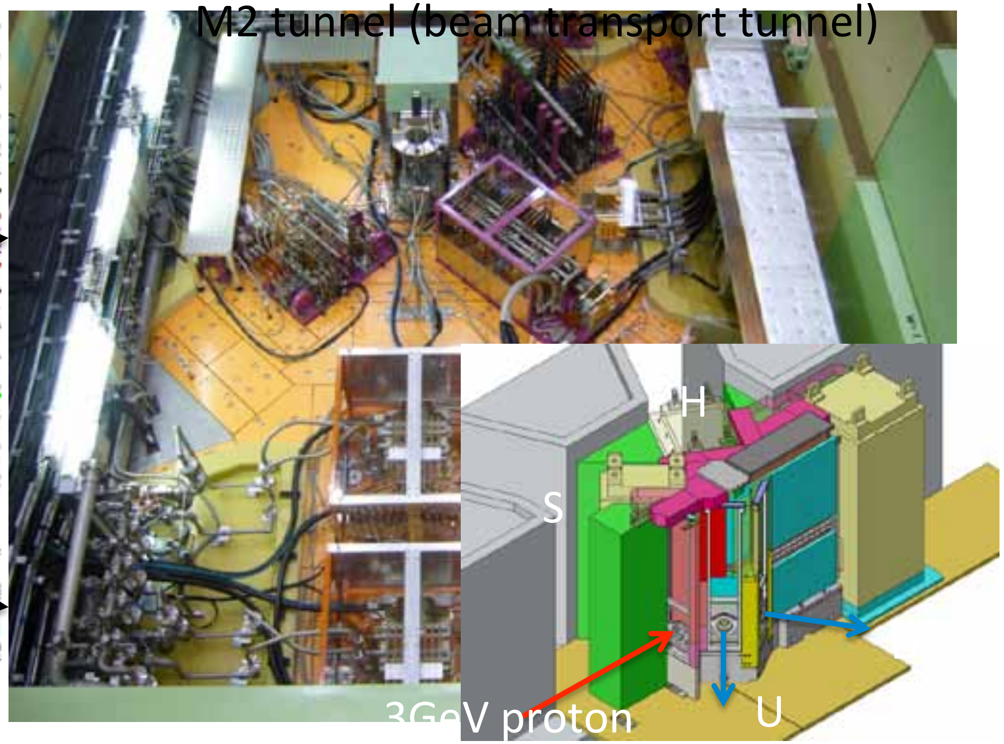
Materials and Life Science Facility



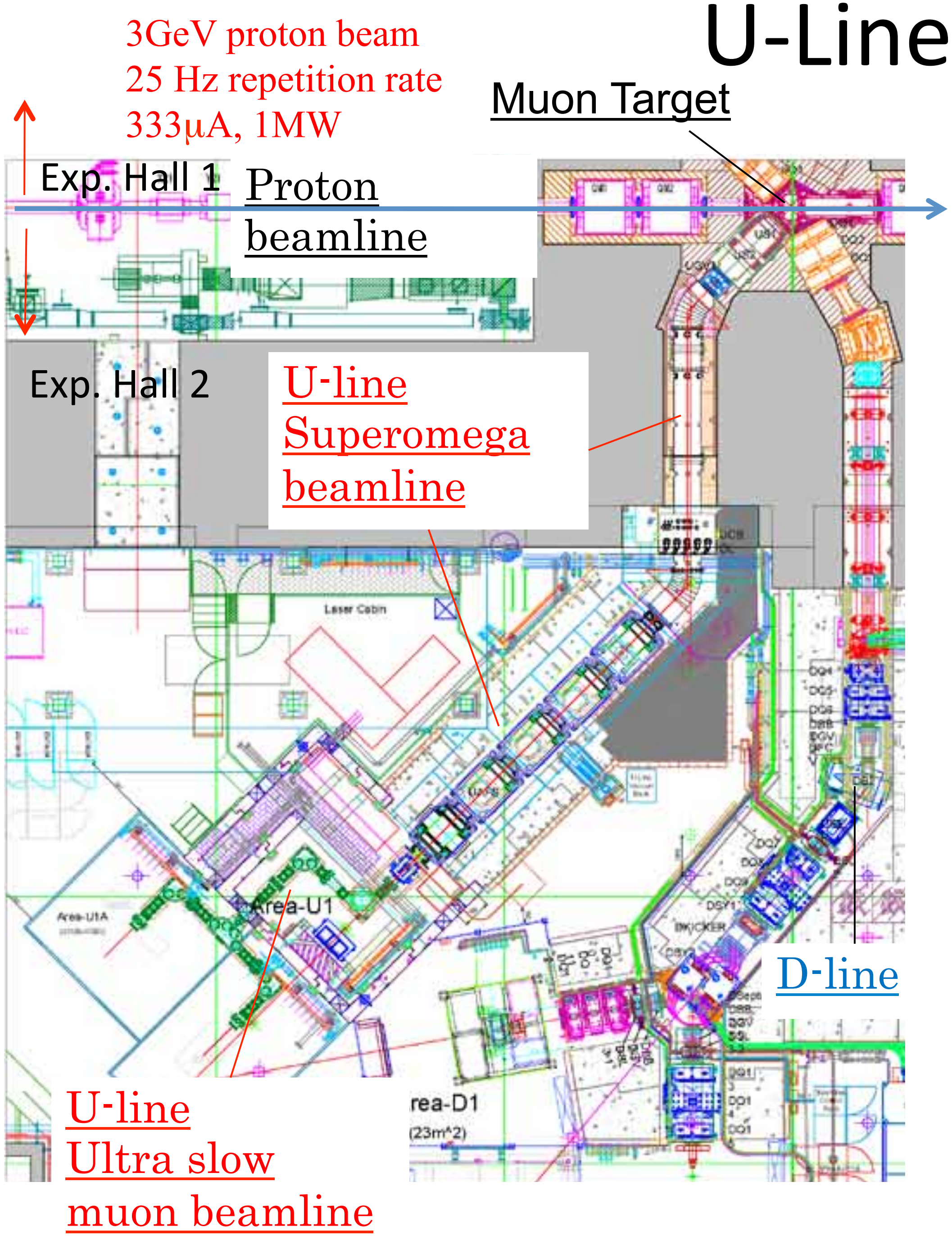
Present status of Muon beamlines

- 4 secondary beamlines can be extracted.
  - D line: complete (kicker was installed in this FY)
  - U line: frontend has been installed. Const. starts this FY
  - S line: frontend has been installed .
  - H line: nothing (temporary rad. shield is installed)





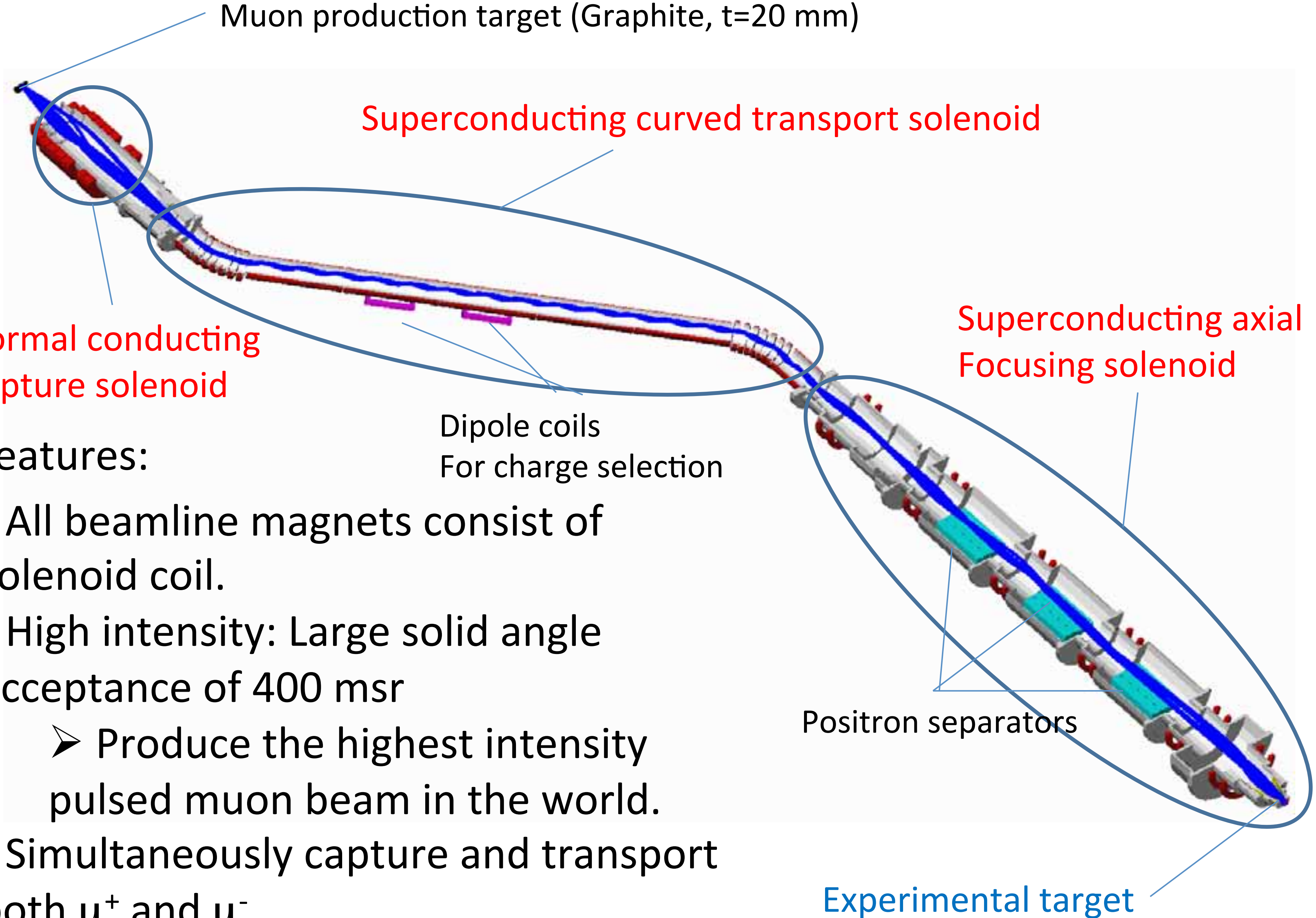
U-Line



Superomega beamline

- The second muon beamline under construction on U-line in MLF/J-PARC.
- First aim of Superomega is surface muon source for Ultra Slow muon beam with high intensity and high luminosity.
  - D-line: In operation.
    Decay and surface muon.
    Intensity: 1 .5x 10^7 μ^+/s
  - U-line: Under construction.
    Superomega beamline.
    Design to capture and transport muons up to 45 MeV/c.

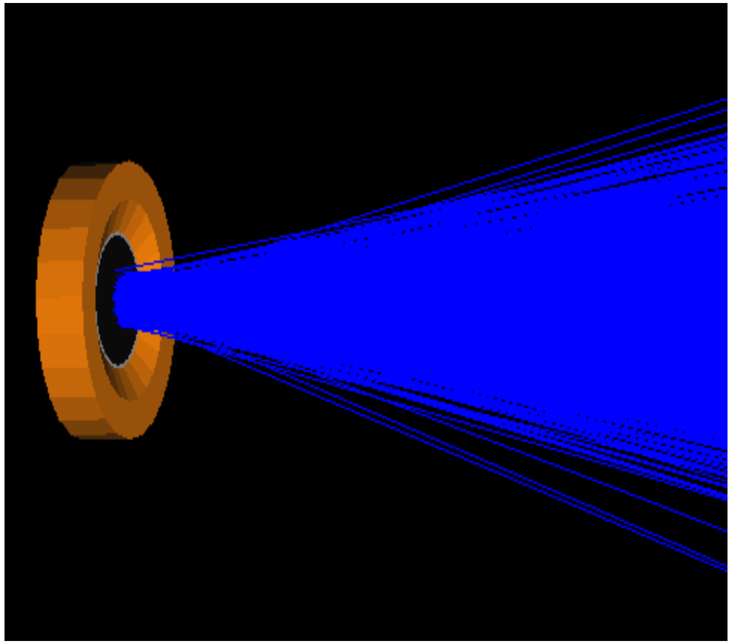
Superomega muon beamline



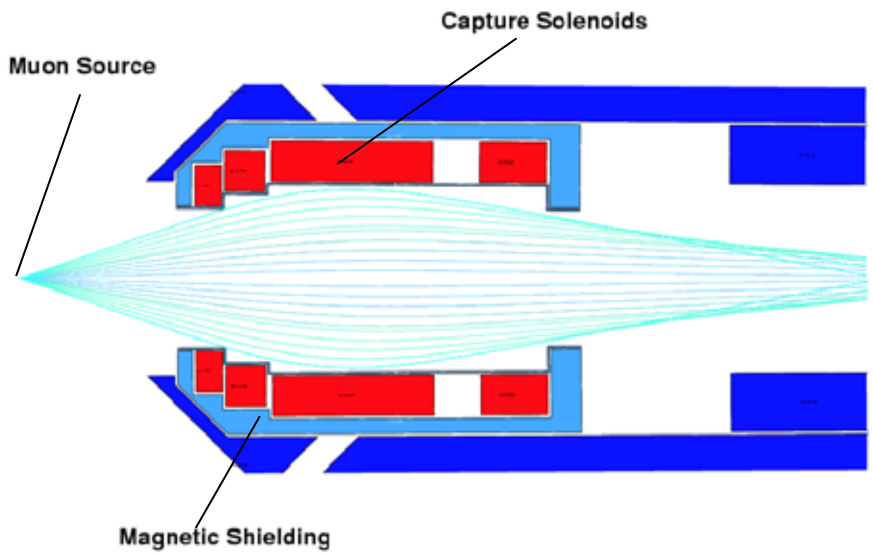
Features:

- All beamline magnets consist of solenoid coil.
- High intensity: Large solid angle acceptance of 400 msr
  - ➢ Produce the highest intensity pulsed muon beam in the world.
- Simultaneously capture and transport both μ^+ and μ^-.

Capture solenoid



Surface muons from muon production target (graphite, t=20 mm)



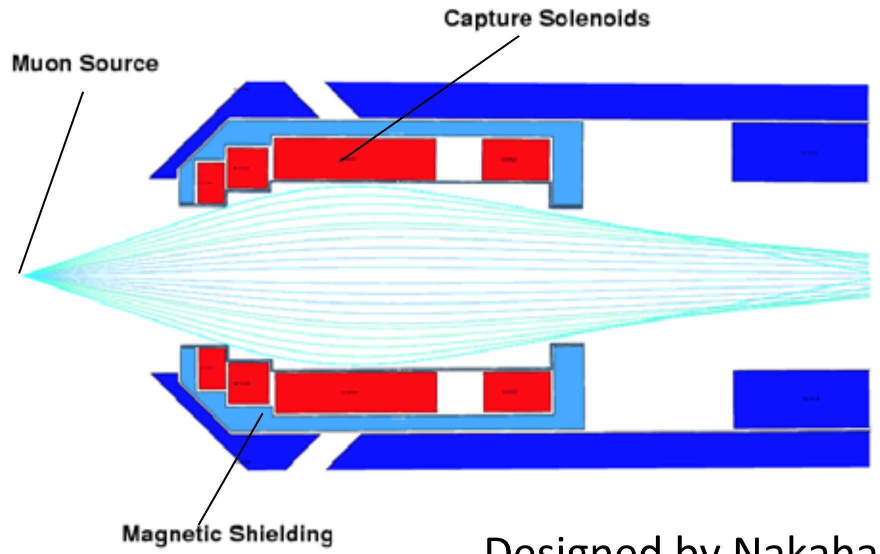
Designed by Nakahara

Capture solenoid is designed to capture the muons produced in muon target with a solid angle acceptance of 400msr.

Superomega captures 5 x 10^8 muons/s from the muon target (Surface muon, @3GeV, 1 MW proton beam).

Normal Conducting (MIC) Capture Solenoid

The capture solenoid
• consists of eight normal-conducting solenoids
• designed to capture the muons produced in muon target with a solid angle acceptance of 400msr.
• can be simultaneously captured μ^+ and μ^- with the momentum up to 50 MeV/c.
•Due to the high level of exposure to radiation, the solenoids are wound with radiation-resistant mineral insulation cables(**MIC**).



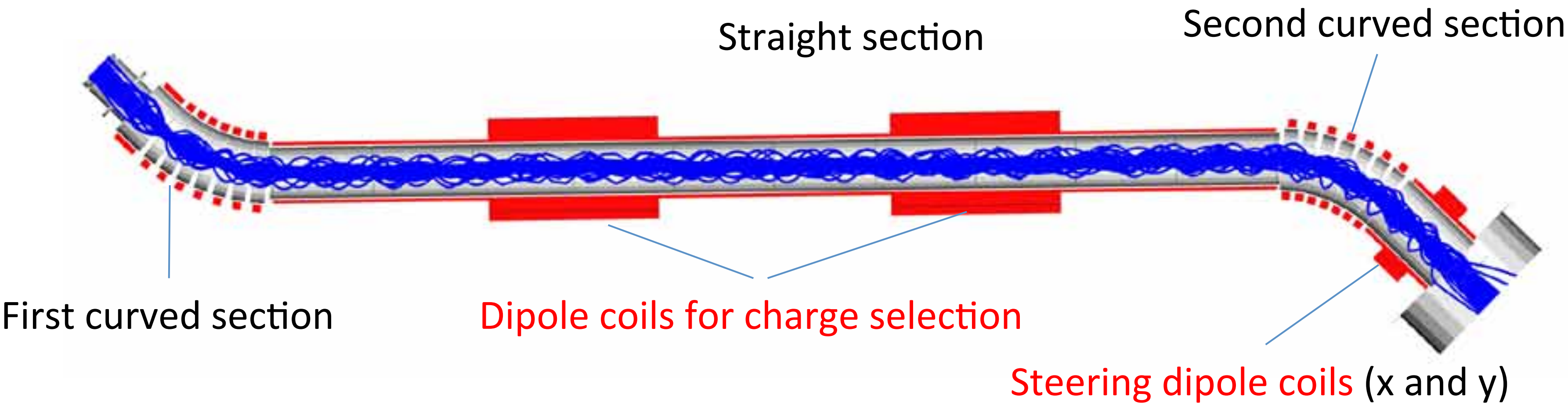
Designed by Nakahara

Maximum current	1500A
Peak central field	0.3T
Coolant	130 l/s
Muon capture rate	$5\times10^{8}\ \mu^+$/s @ 30 MeV/c
Solid angle acceptance	400 mSr (±20^o initial angle)

Normal Conducting Capture Solenoids

- Beamline is 1.6m above floor level
- All maintenance to be performed at FL+4m above floor level
- All water and power cables are connected at FL+4m
- To keep radiation levels low, multiple layers of shielding are adopted to maintain.
- Installation on beamline has been completed on March 2009.

Superconducting Curved Transport Solenoid



• The transport solenoid is designed to transport the captured muons to experimental hall 2.

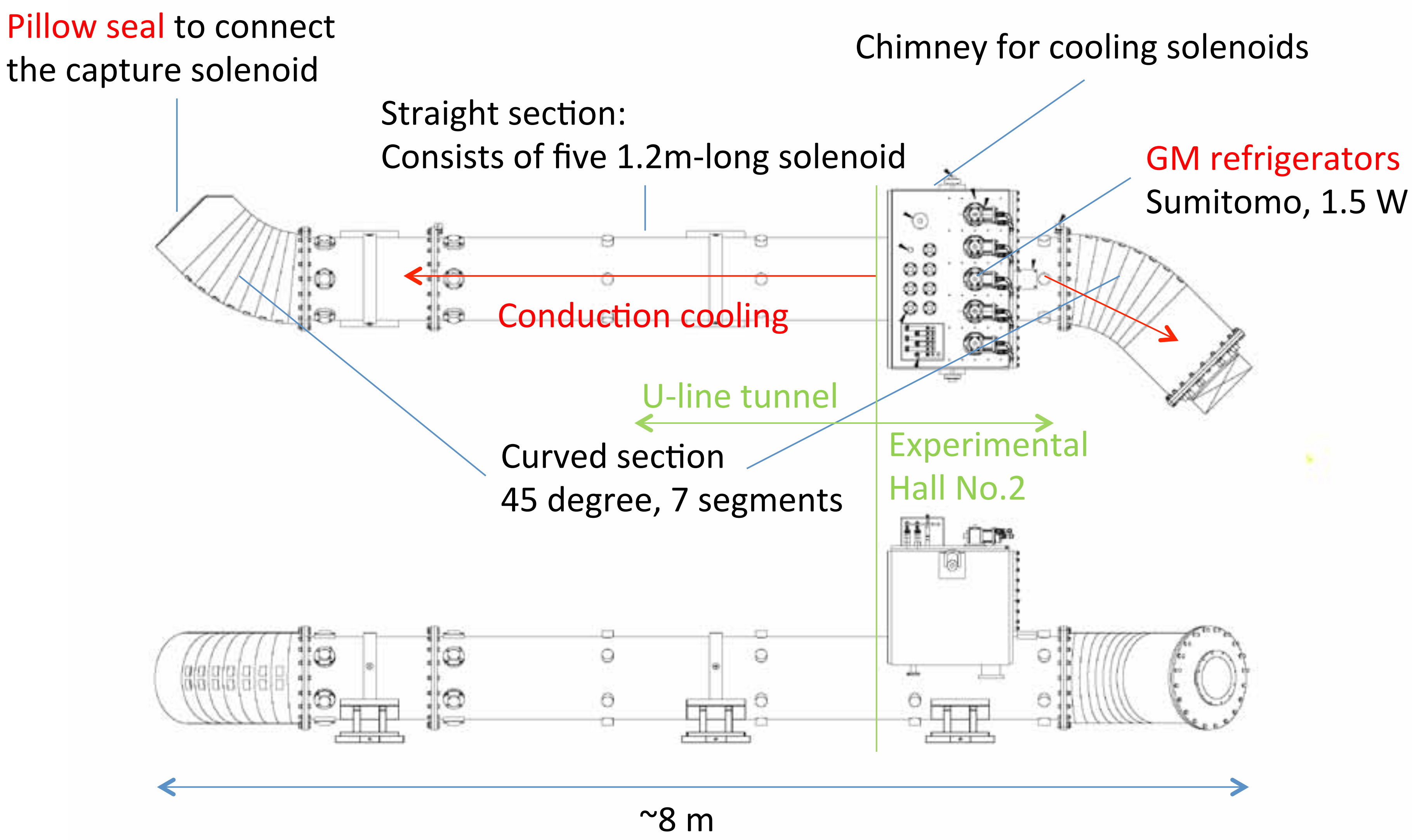
• The solenoid has two 45 degree curved sections (7-segment) for reduction of radiation from neutral particle, and one 6-m-long straight section.

• A set of correction dipole coils for the charge selection and for steering beam direction, are mounted onto the solenoid structure.

• Cryogenics – Extensive collaboration with the KEK cryogenic group.

•A series of five Gifford–McMahon (GM) refrigerators are used to cool down the superconducting coils.

Structure of Superconducting Curved transport Solenoid

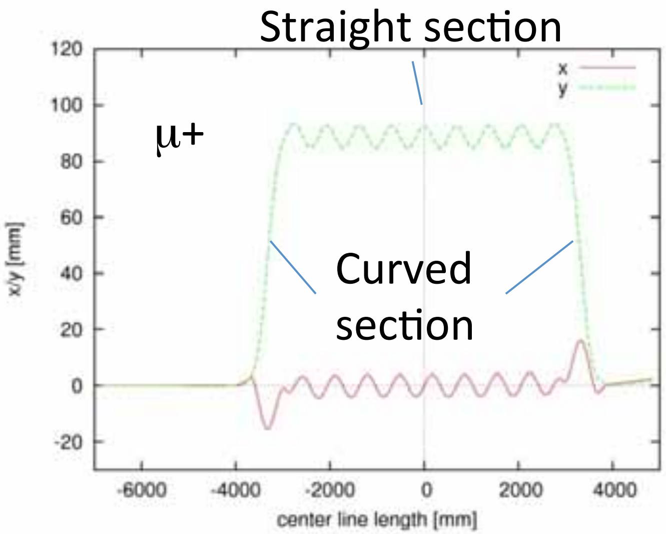


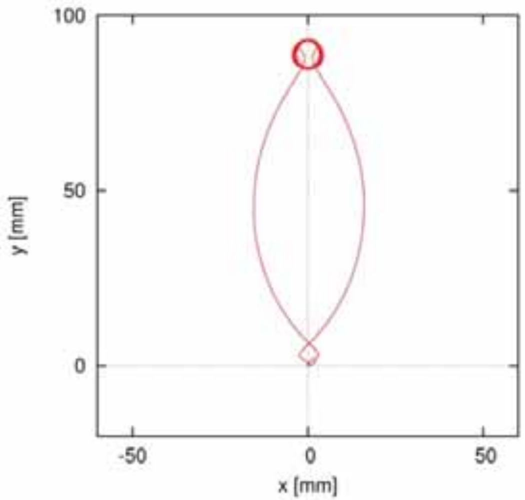
The superconducting solenoids are cooled down by conduction cooling method using five GM refrigerators.

Beam trajectory simulation

G4Beamline :

Geant4 based Monte Carlo beam simulation program



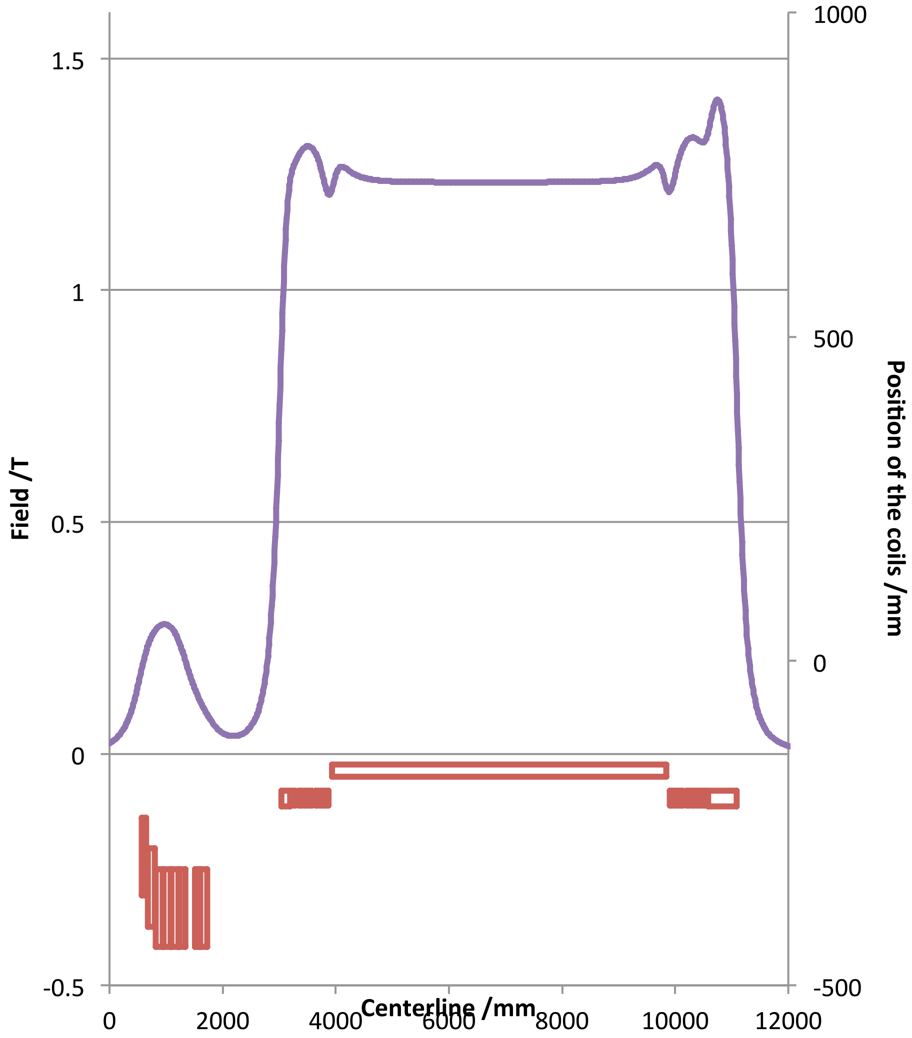


Projection on to the normal plane of solenoid center axis

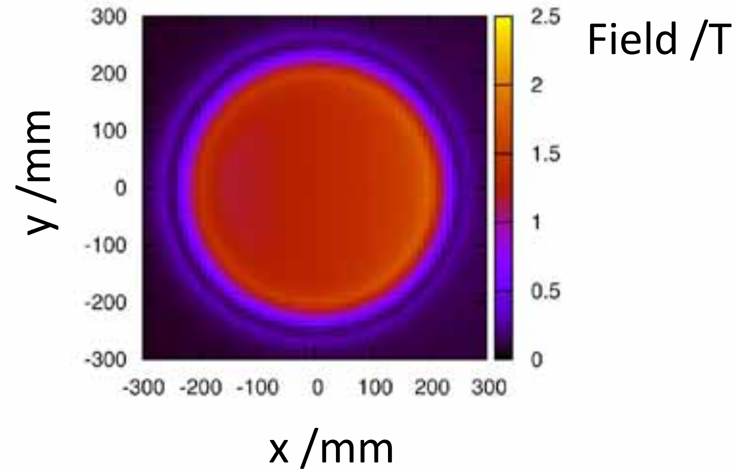
- The trajectory of muon which injected from the center of the muon target along the solenoid center axis are calculated.
- At the curved section, trajectory of positive (negative) muon drift up (down) due to the field flux effect.
- In the straight section, muons move in a spiral along with solenoid field.
- Optimize the beam trajectory
  - ➢ Minimizing the horizontal shift of the Lamour rotation center at straight section. The shift occurred by stray field from straight section at curved section. (Entrance matching solenoid)
  - ➢ Achieving the symmetric trajectory about the center point of the straight section. (Straight section)
  - ➢ Minimize the radius of the Lamour rotation in the straight section. (Curved section)

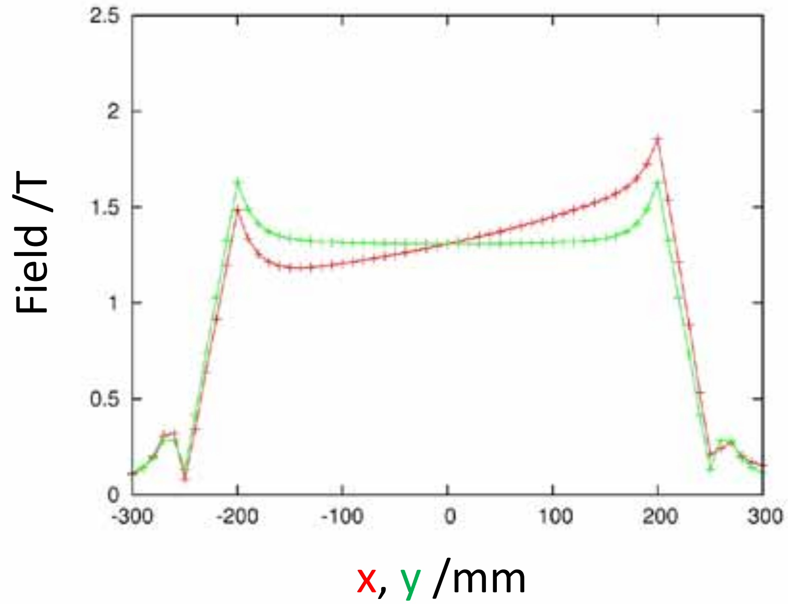
Field Distribution

The optimized field distribution along the centerline axis of the capture solenoids and the curved solenoid



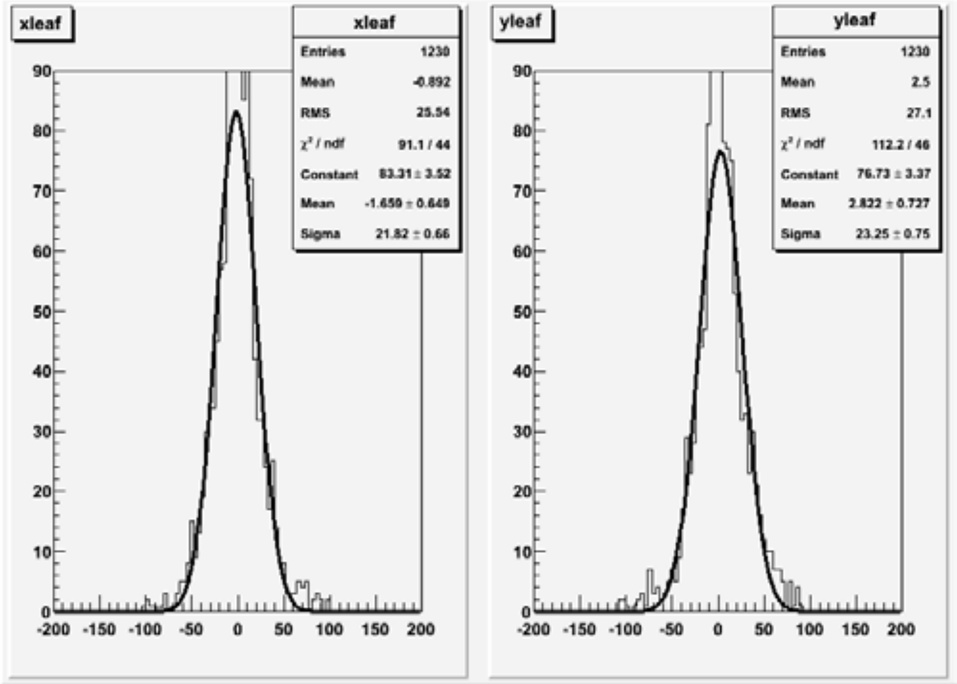
The cross section of the field at curved section



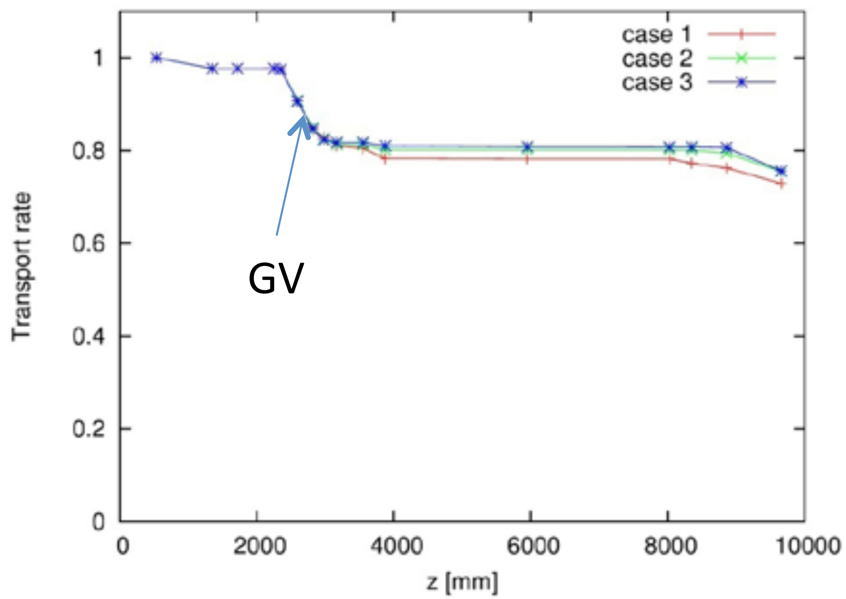


Beam Transport Simulation

Beam profile at the exit of the curved solenoid

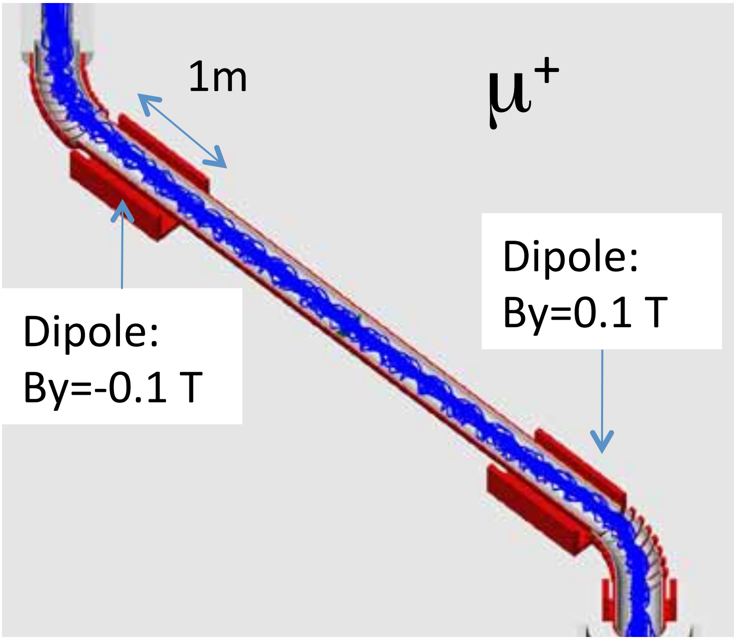


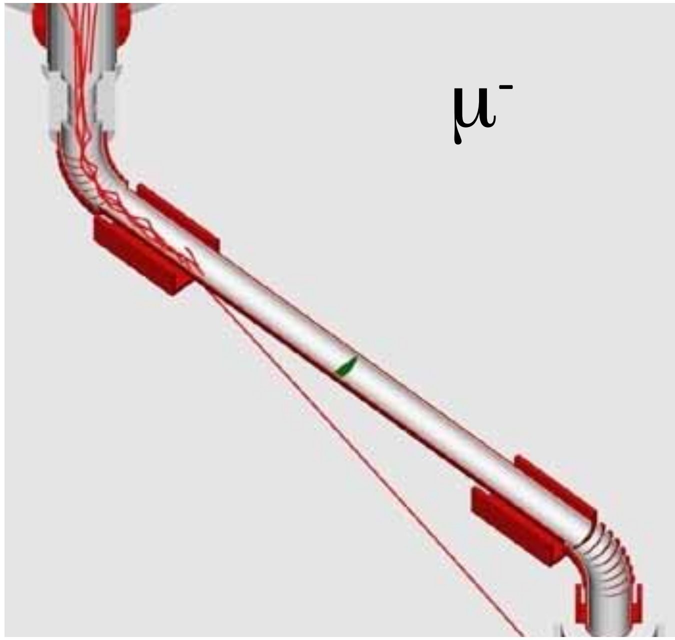
Transport rate



- The beam center at the exit of curved solenoid is almost identical to that of the solenoid axis. The beam full width is about 44 mm (one σ).
- Total beam loss is approximately 20% for 30 MeV/c muons.
- The almost all beam loss appears at gate valve pillow seal which located between capture and curved solenoid (minimum aperture: 220 mm).
- The injected beam of the curved solenoid can be transported with rate of ~100%.
- Total beam extraction at 1 MW is 4 x 10^8 μ^+/s for surface muon, and **1 x 10^7 μ^-/s for cloud muon**. They are ten times larger than the currently available pulsed muon source.

Dipole correction coils on straight section



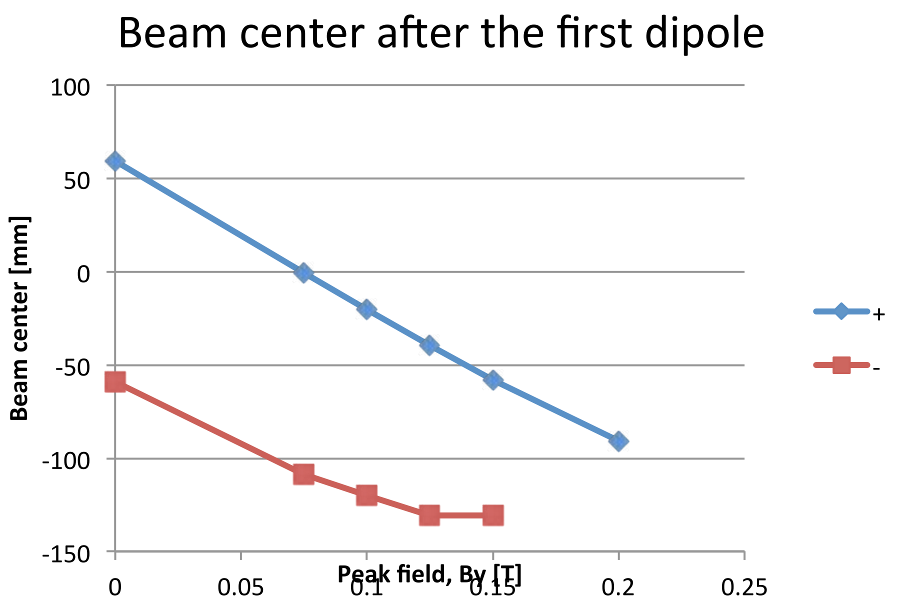


• Although the simultaneously transport of the both μ^+ and μ^- is an advantage of the Super Omega beamline, it is necessary to equip a charge selecting system in the case of the experiments that require only one side charged particle, and also that make serious BG signals from the other charged particle.

• Superimposing dipole field on solenoid field, it is enable to decline beam trajectory of the both charged particle to the same direction.

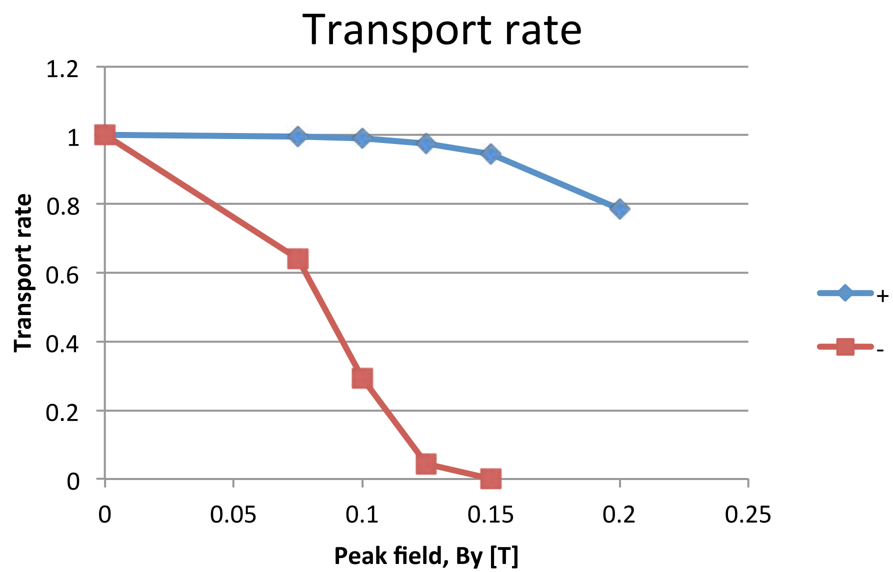
• Add a set of dipole coil with opposite field direction at the straight section of the curved solenoid.

Transport rate with charge selection



- The beam center of the both μ^+ and μ^- beam is lowered with increasing the field.
- The beam center positions are proportional to the peak field:
  -75 mm @ 0.1 T

- Transport rate for μ^- reduces with lower field than that of μ^+.
- Transport rate at the exit of the curved solenoid is not changed by applying a set of the dipole field.
- Transport rates of the both μ^+ and μ^- with applying field of 0.15 T are:
  μ^+ : 0.95, μ^-: 0.00 @ 0.15 T

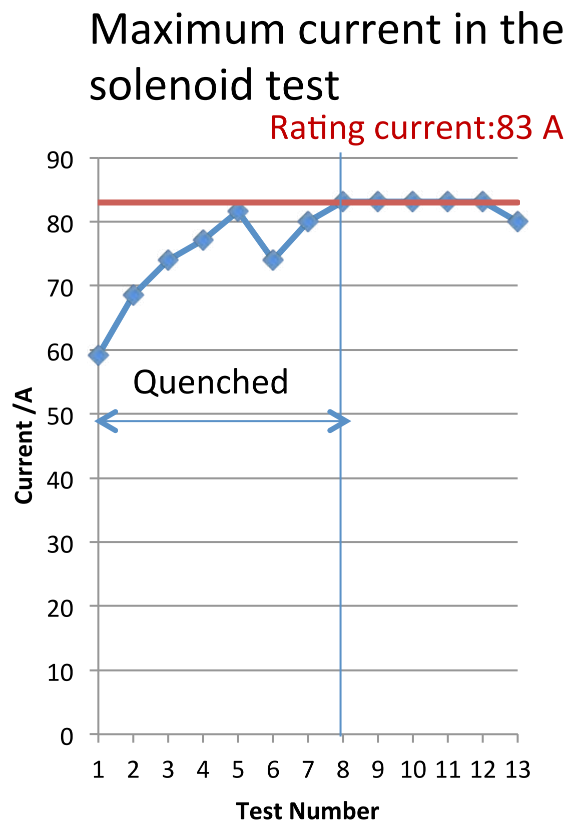


Curved solenoid under fabrication in Toshiba

Chimney:
five GM refrigerators

The first curved section:
Consists on seven thin solenoids

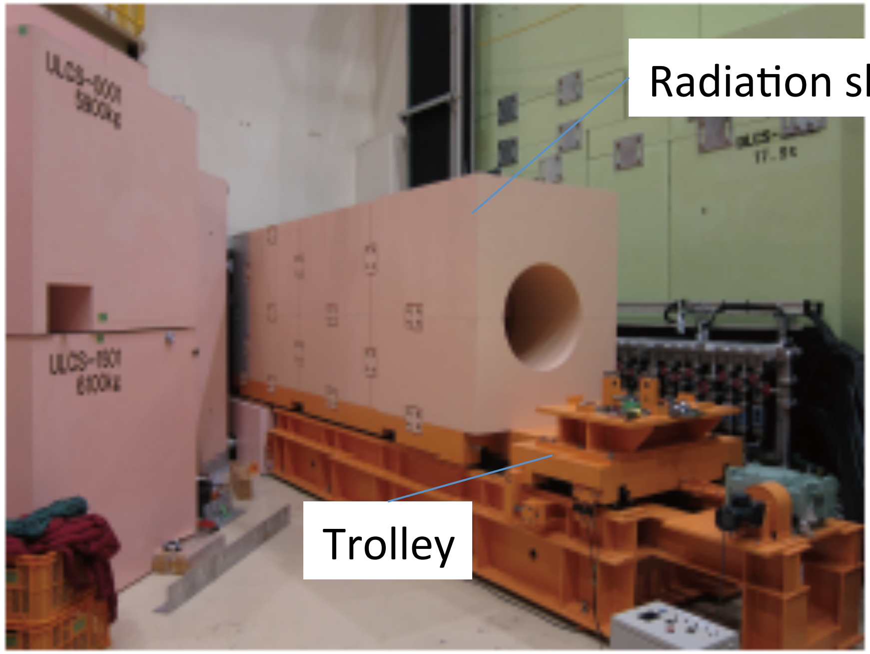
Cooling and excitation test for curved solenoid



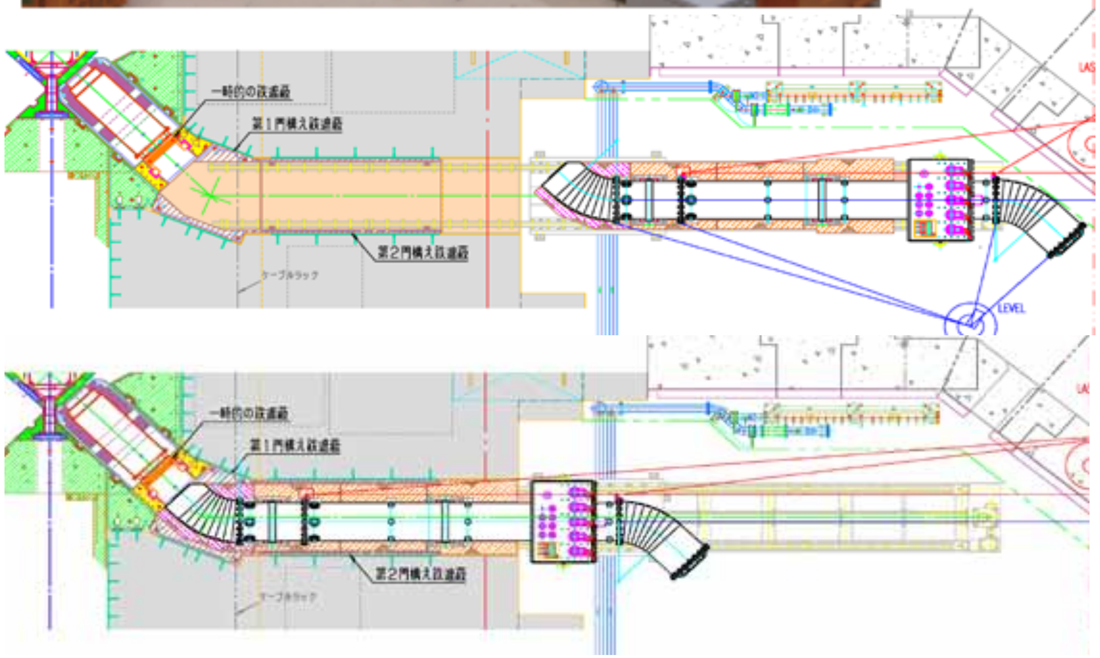
Curved solenoid is successfully applied up to rating current of 83 A in February of 2012.

Installation test for Curved solenoid

Insertion test of radiation shields



Exit of U-line tunnel



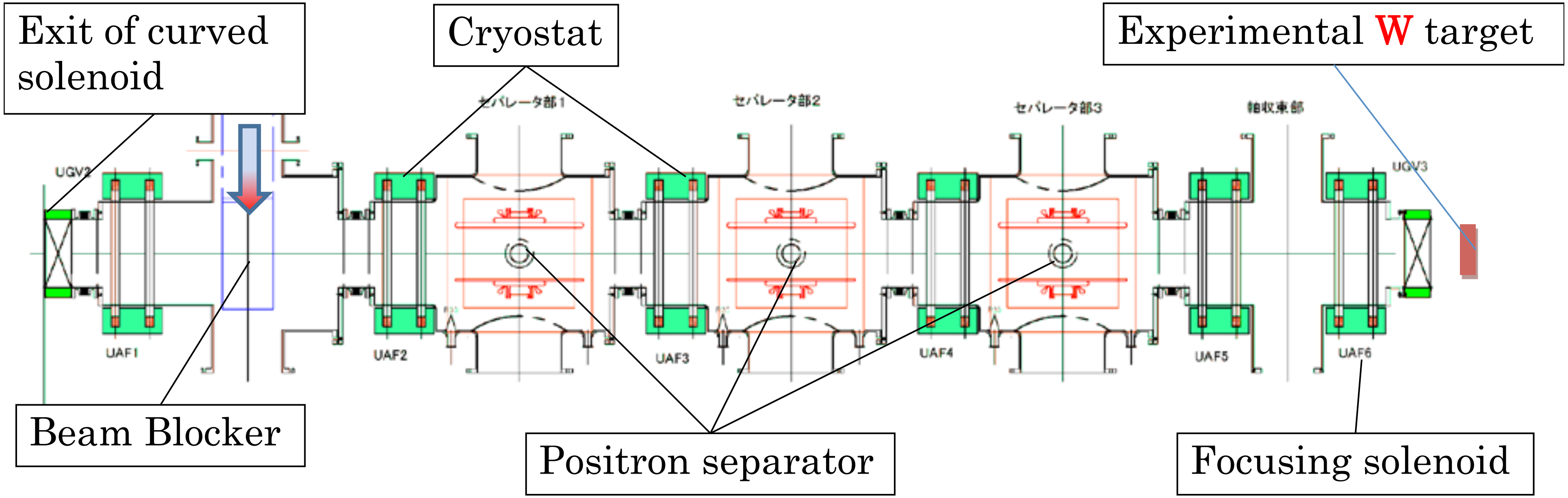
- Curved solenoid is placed on the trolley with radiation shields.
- And linearly inserted into U-line tunnel on the linear guide.

Superconducting Axial Focusing solenoid

Required function of the Axial Focusing solenoid

- The transported muon beam through the curved solenoid must be further transported about 7-m long (restriction from configuration of the experimental hall 2 and reduction of radiation exposure) and will be focused on the experimental target efficiently.
- Transported positron (electron) with muon beam estimated more than ten time larger than muon beam. Positron background should be eliminated from the muon beam for improving the muon beam quality.
- Beam blocker is needed to insert into the upstream of the beamline for reducing radiation exposure, when users will enter a experimental area for setting up apparatus etc.
- The axial focusing solenoids, used to focus the muon beam on the **W** target, is under consideration with particular emphasis on its compatibility with the positron separator.

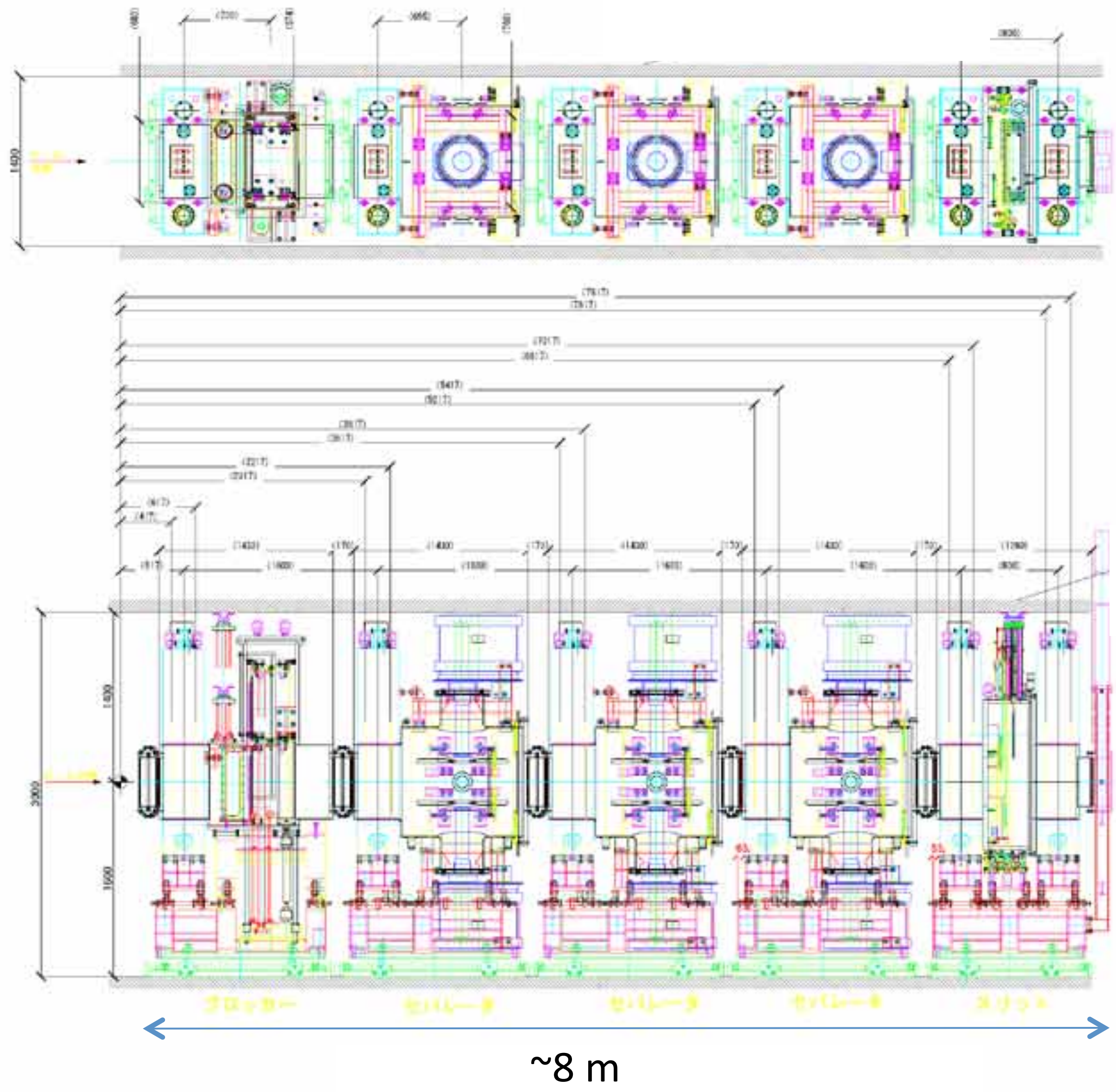
Superconducting Axial focusing solenoid



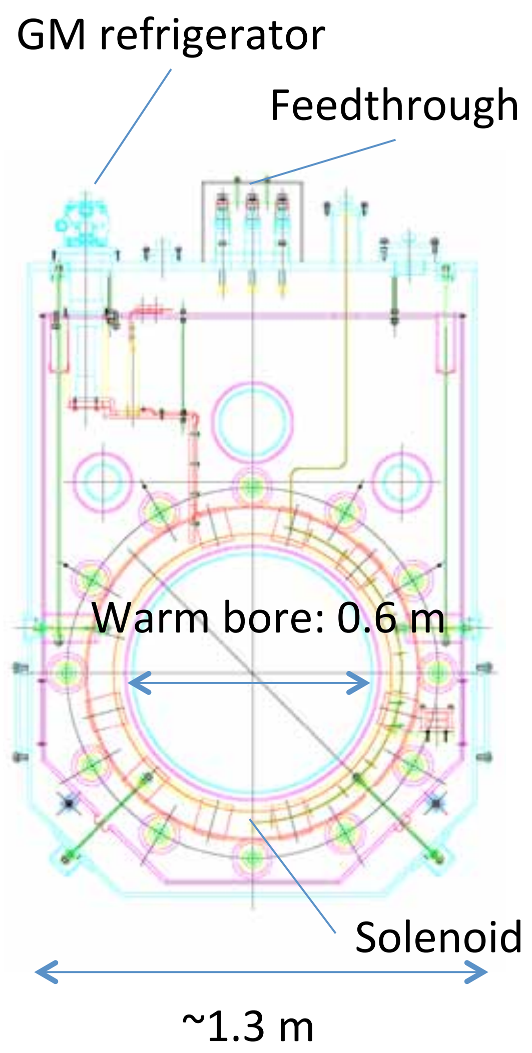
Further transports muons and focuses on the experimental target.

- Cryostat: A pair of thin superconducting solenoids are placed in a cryostat. The six cryostats are aligned in the beamline to transport muons.
- Beam Blocker: Cupper block of 30-cm thickness for stopping muon, neutron and gamma ray.
- Positron separator: Three-stage Wien filter type separator.
- Focusing solenoids: Focus on the experimental target using two last solenoids.

Design of Axial focusing solenoid



Five beamline ducts and six cryostats



Cryostat

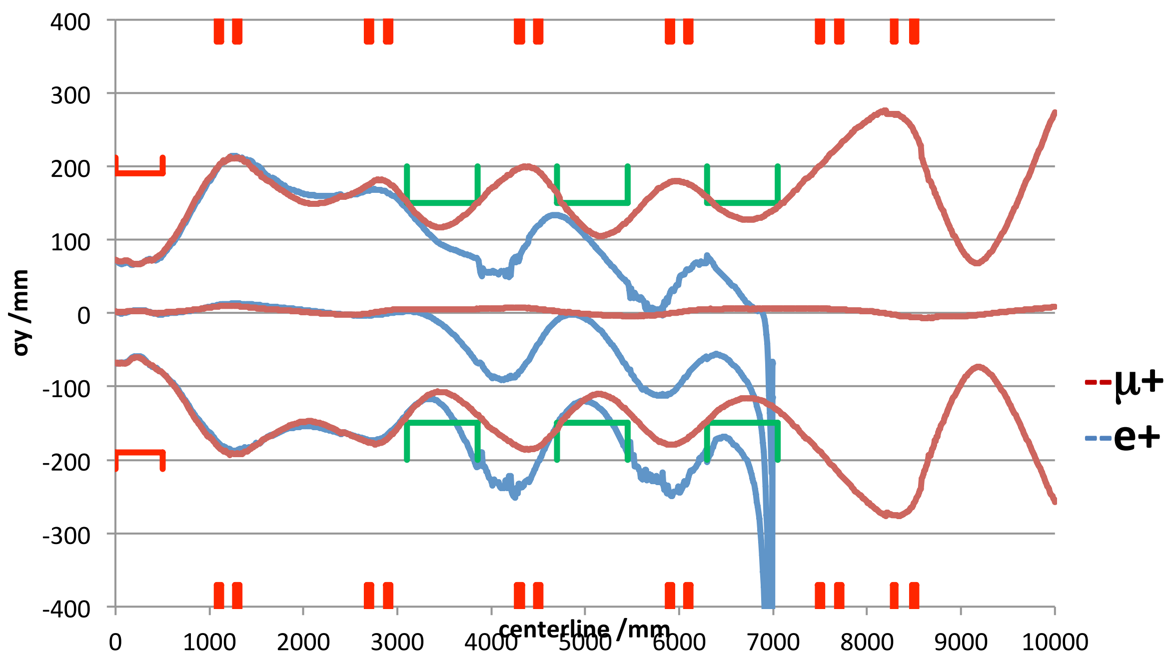
Positron separator

Three-stage Wien filter type separator

- Gap: 300 mm
- Electrode: 500 mm (width) x 750 mm (length)
- Rating voltage ±400 kV (E = 2.67 MV/m)
- Correction magnetic dipole coil (360 A 48 V)
  0.0456 T (central field)

Simulated using G4Beamline

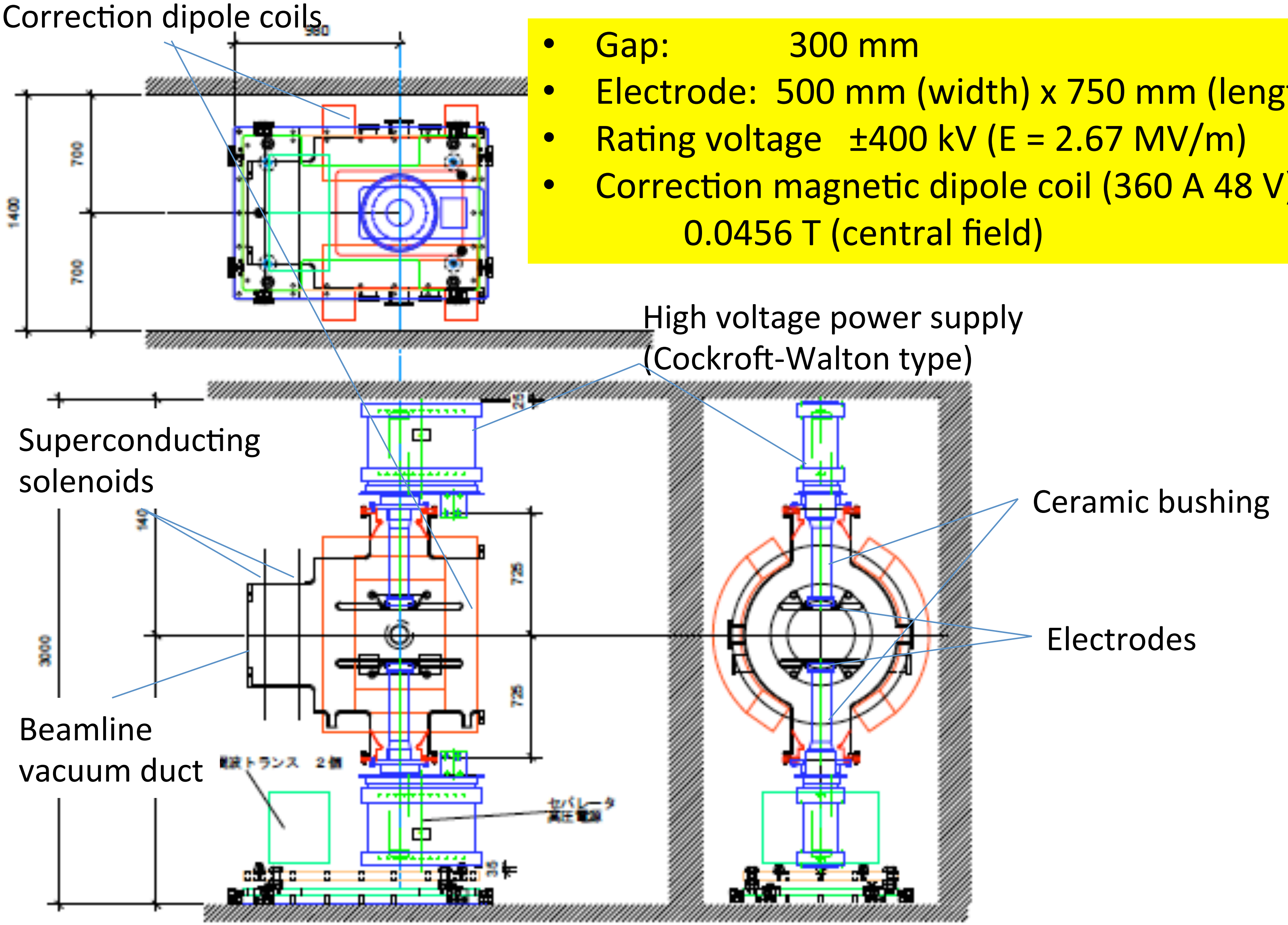
Beam transport simulation in Axial focusing solenoid



Almost all positrons can be eliminated from the beam at the third separator.

Design of Positron separator

- Gap: 300 mm
- Electrode: 500 mm (width) x 750 mm (length)
- Rating voltage ±400 kV (E = 2.67 MV/m)
- Correction magnetic dipole coil (360 A 48 V)
  0.0456 T (central field)



Electrode

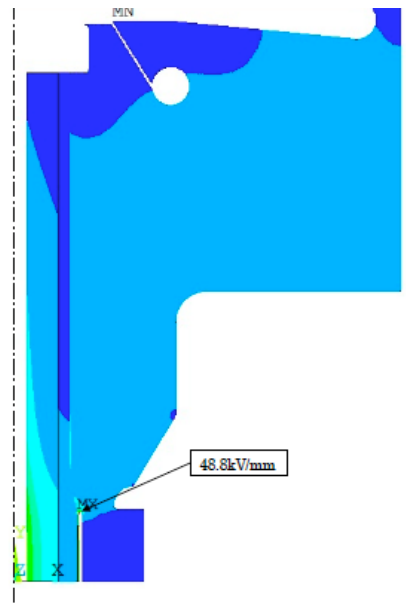
- Large curvature (R >= 20mm) for reducing electric field
- Light weight

  made by thin plate (1.5 mm, Stainless steel)

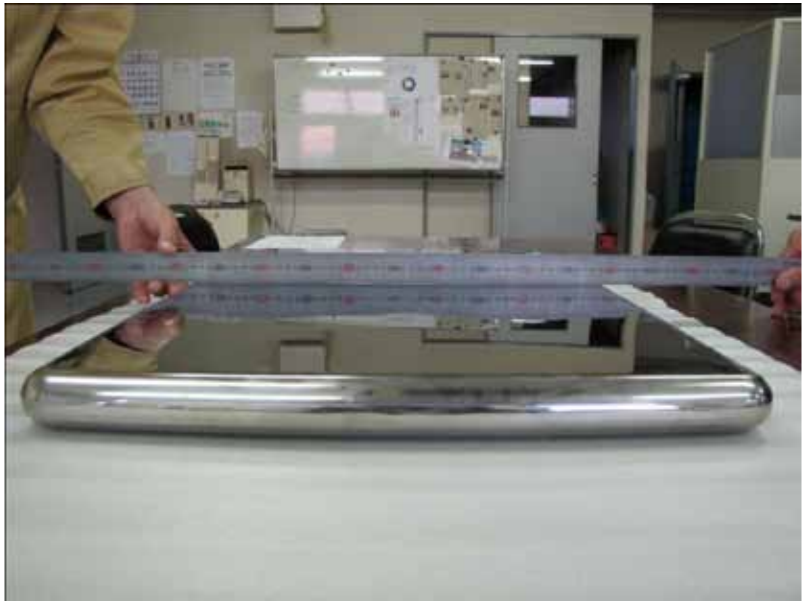
  manufactured using extrusion process and welding
- Buffing and electro polishing

  Flatness: < 1 mm

  Surface roughness: Ra = 0.02-0.03μm



Electric field distribution



Electrode plate (midair)

Colona rings

Test for HV power supply of separator

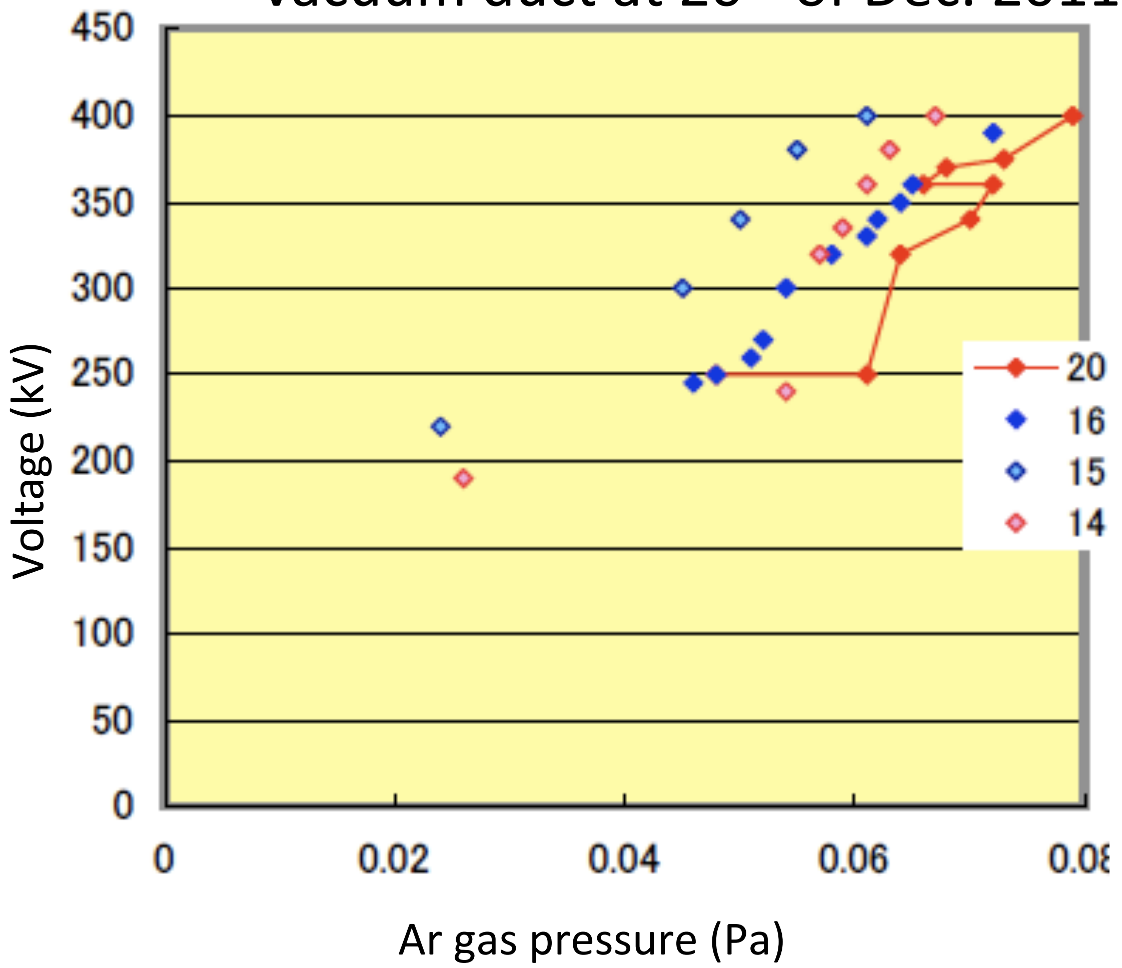
Installation to the vacuum duct

Positive Negative

- Cockroft-Walton type high voltage power supply(+-400kV)
- HV power supply is placed directory on the vacuum duct.

Test for applying HV with Ar gas

Achieved to apply ±400 kV (Ar: 0.08 Pa) in the vacuum duct at 20th of Dec. 2011



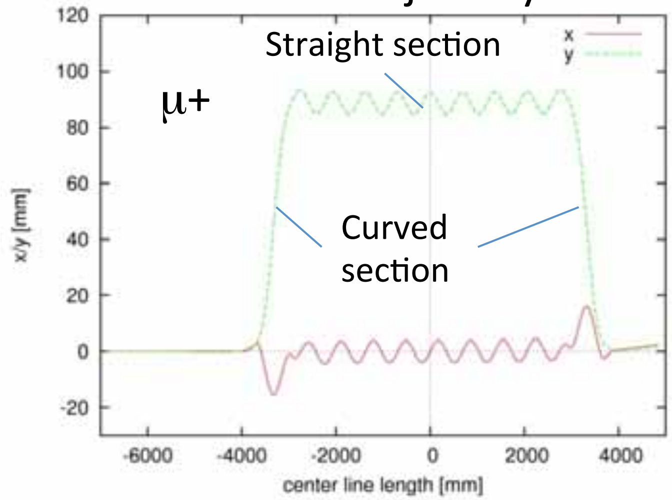
Simulation of Superomega beamline

G4Beamline : Geant4 based Monte Carlo beam simulation program

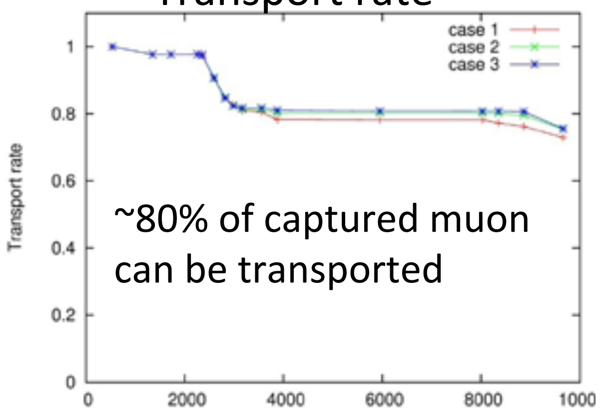
Surface muon production:
using calculation results by Ishida (RIKEN)
Superomega captures 5 x 10^8 muons/s from the muon target (Surface muon, @1 MW proton beam).
→ confirmation using another program is in progress. (GEANT4, Fluka)

Curved solenoid

Beam trajectory

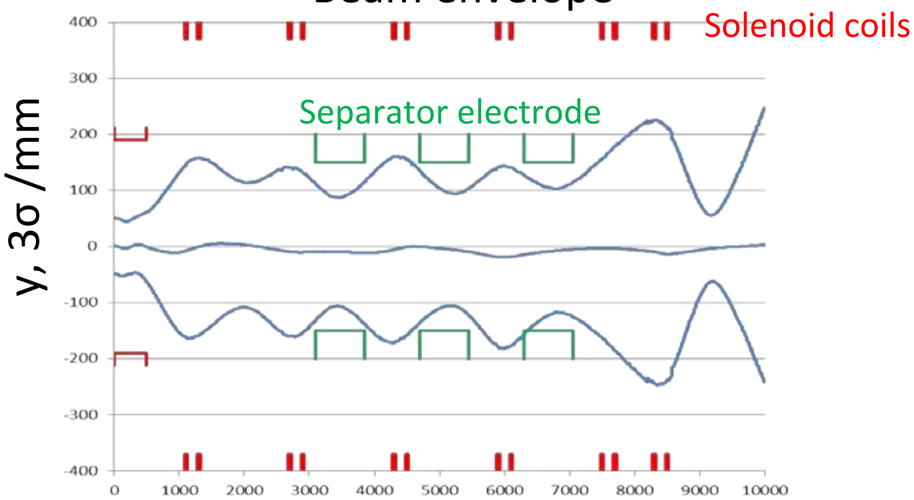


Transport rate



Axial focusing solenoid

Beam envelope

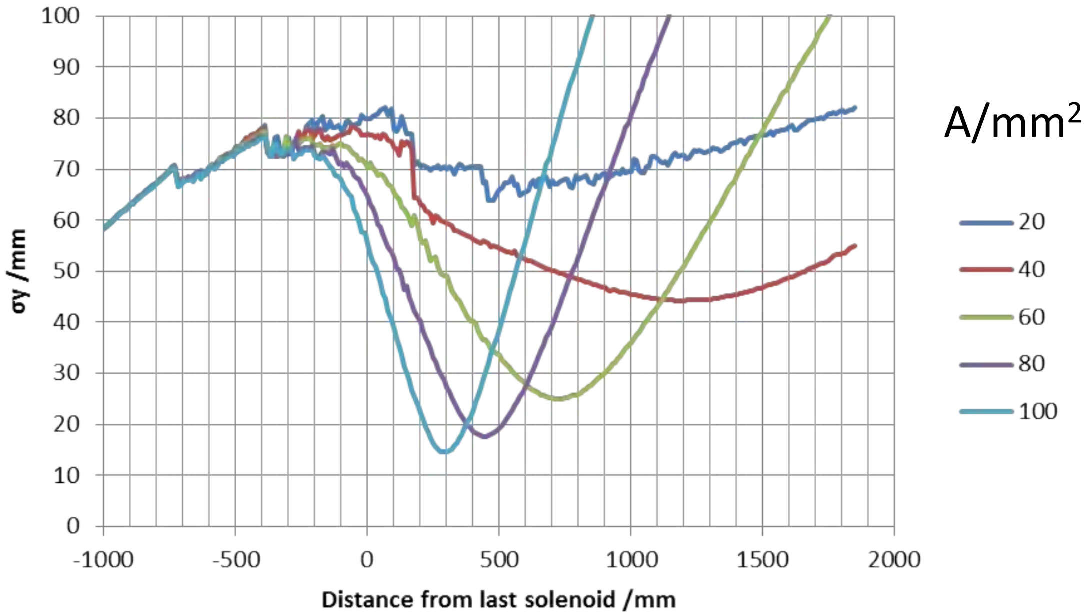


Simulation of the final focusing

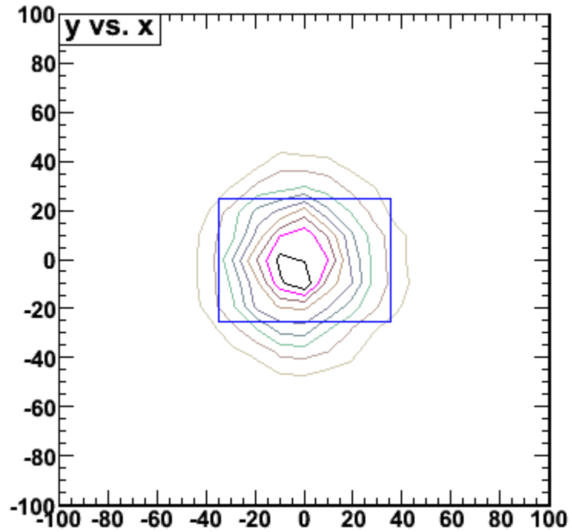
Beam size and focal length

Dependence of current density of the last coil

σ = 18 mm, Focal length 460 mm
σ = 25 mm, Focal length 700 mm



Beam profile at the final focusing point（700mm）



W Target (70 x 40 mm^2)

Intensity: **2 x 10^8 μ^+/s**, incident on the **W** experimental target (1 MW proton beam)

MLF Experimental Hall No.2 (last year)

U-line tunnel exit

D-line

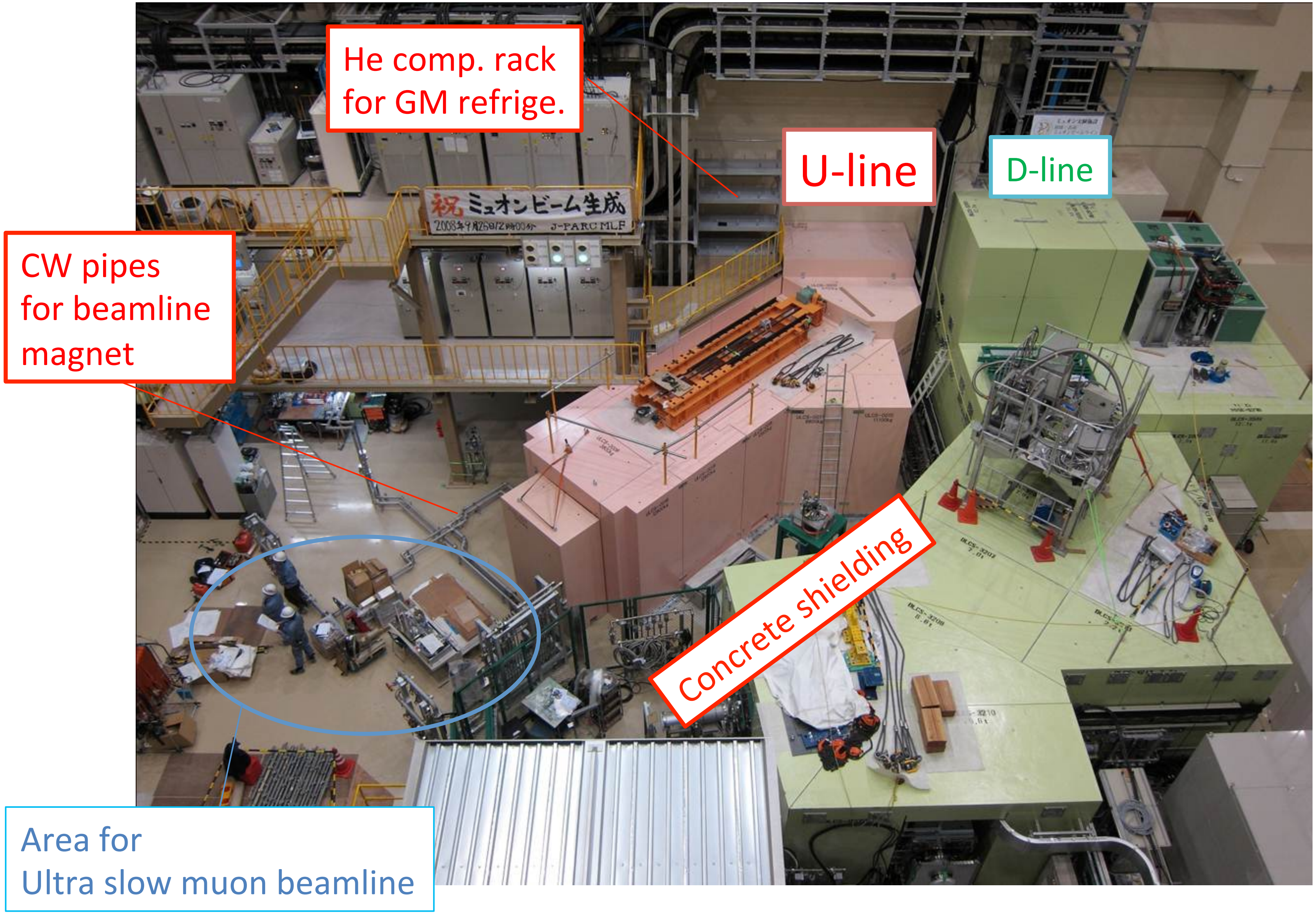
Superomega will be installed here.

D2 area

D-line User’s room

D1 area

MLF Experimental Hall No.2 (Feb. 2012)



Summary and Future plan

- Superomega beamline, the second muon beamline of MLF/J-PARC , is under construction.
- Normal conducting capture solenoids

  → installed on March 2009
- Superconducting curved transport solenoid

  → completed at Toshiba. → Delivered this June, 2012!
- Superconducting axial focusing solenoid

  → under fabrication. → Delivered this June, 2012!
- Superomega will be installed in the summer of 2012.
- The first beam extraction experiment of Superomega will be conducted on October 2012.
- Ultra slow muon beamline will be installed right after commissioning of Superomega.

Collaborators:

IMSS, KEK
Y. Miyake、K. Shimomura、
P. Strasser、N. Kawamura、K. Nishiyama、
S. Makimura、H. Fujimori、Y. Kobayashi、
A. Koda、T. Nagatomo、J. Nakamura

University of Tokyo
T. Adachi, Y. Matsuda

CSC, KEK
T. Ogitsu、K. Ohata、T. Nakamoto、
A. Yamamoto

IPNS, KEK
Y. Makida、M. Yoshida、T. Okamura

Osaka University
A. Sato

MEC, KEK
R. Okubo

JAEA
W. Higemoto

University of Maryland
K. Nakahara

RIKEN
K. Ishida