International Conference on Muon Catalyzed Fusion and Related Topics μCF-07, Dubna,18-21 June, 2007

J-PARC Muon Science Facility and its physics

KEK Y. Miyake

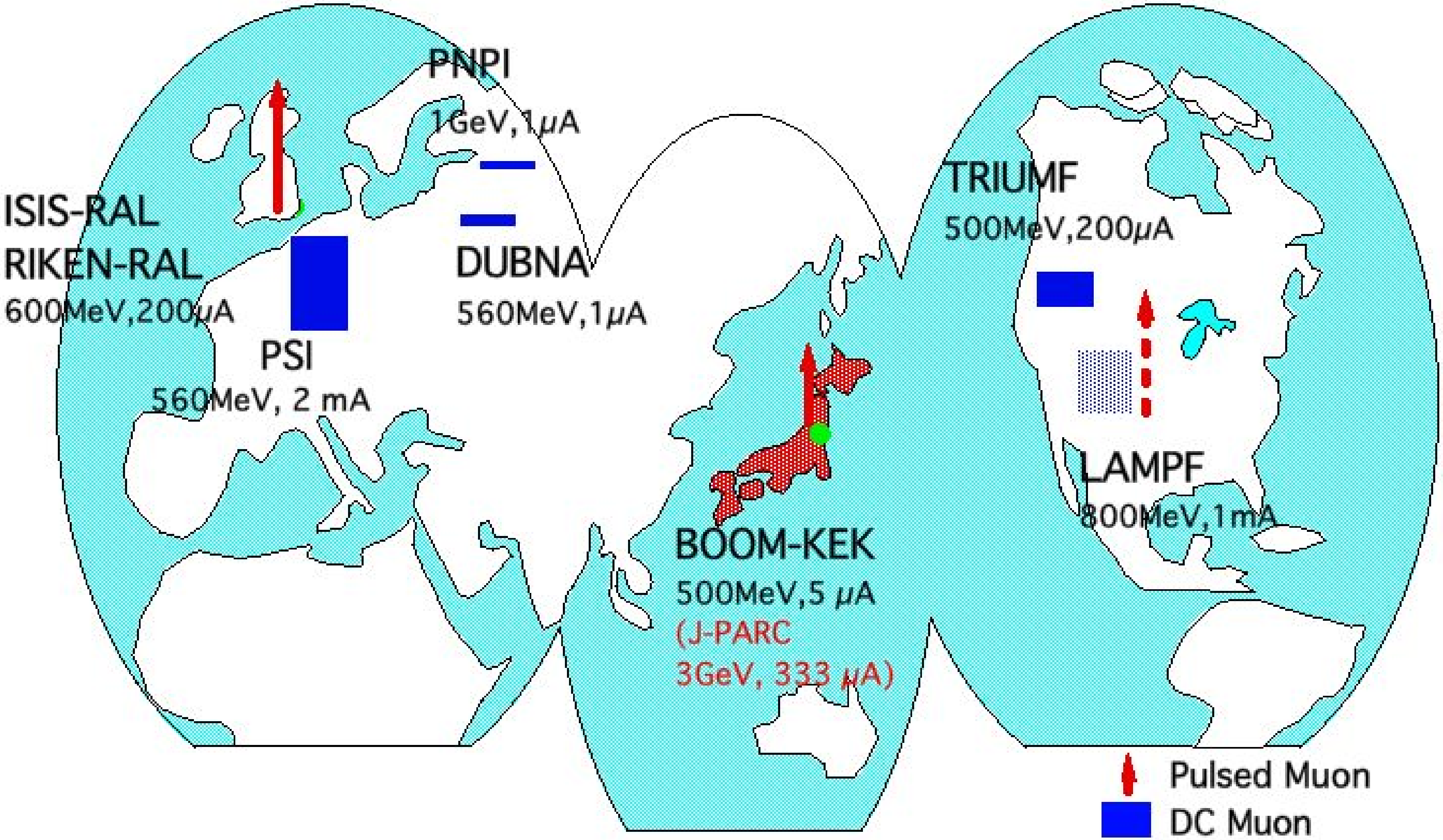
Collaborators for the construction of the Muon Science Facility

KEK: N. Kawamura, P. Strasser, S.Makimura , K.Shimomura, A. Coda
H. Fujimori, K. Nakahara, M. Kato, J.L. Beveridge, N. Sato, R.Kadono, S. Takeshita,
K.Fukuchi, K.Nagamine and K.Nishiyama

RIKEN: K.Ishida,T.Matsuzaki, Y.Matsuda, I. Watanabe,

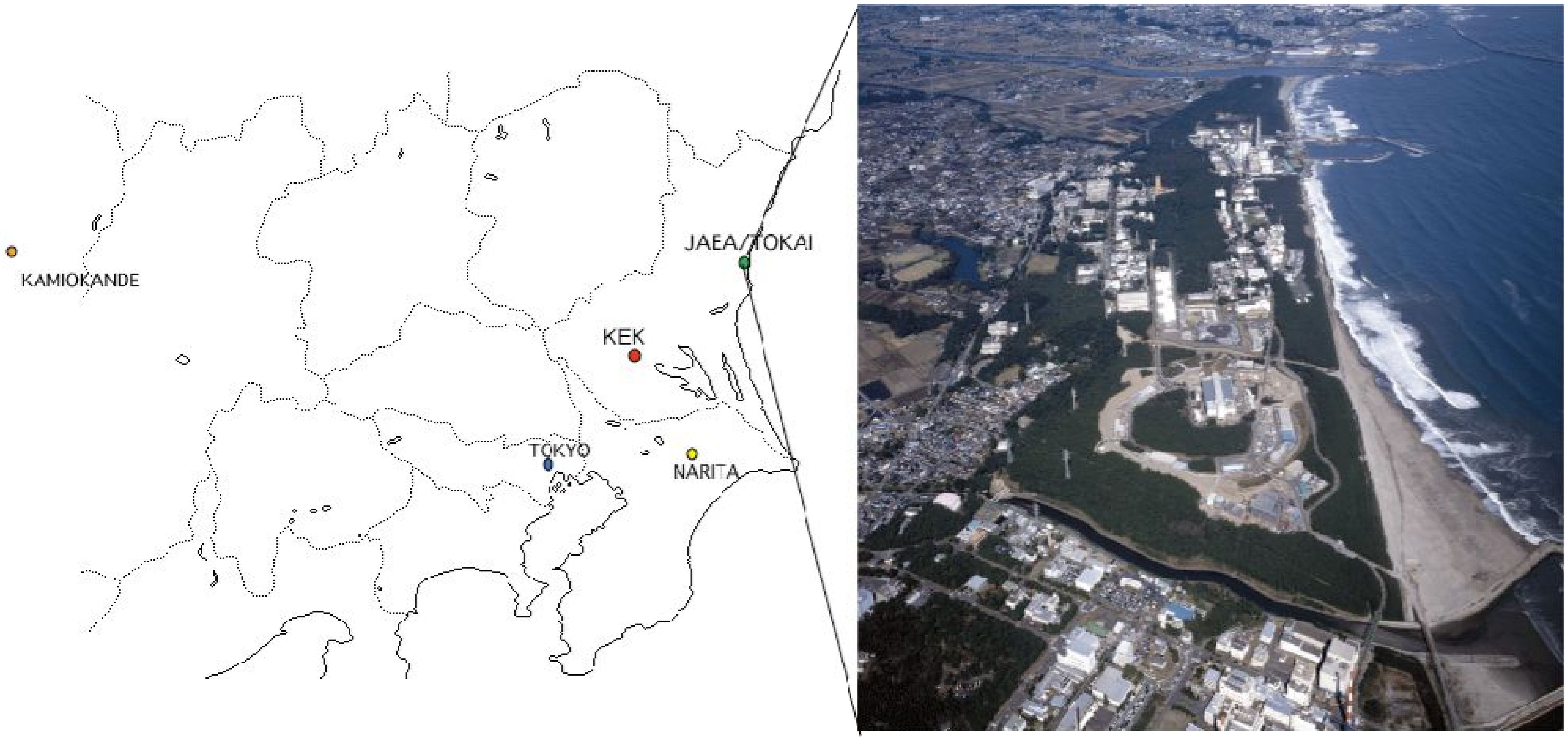
JAEA: W.Higemoto, S. Meigo, S.Sakamoto

J-PARC Muon Science Facility



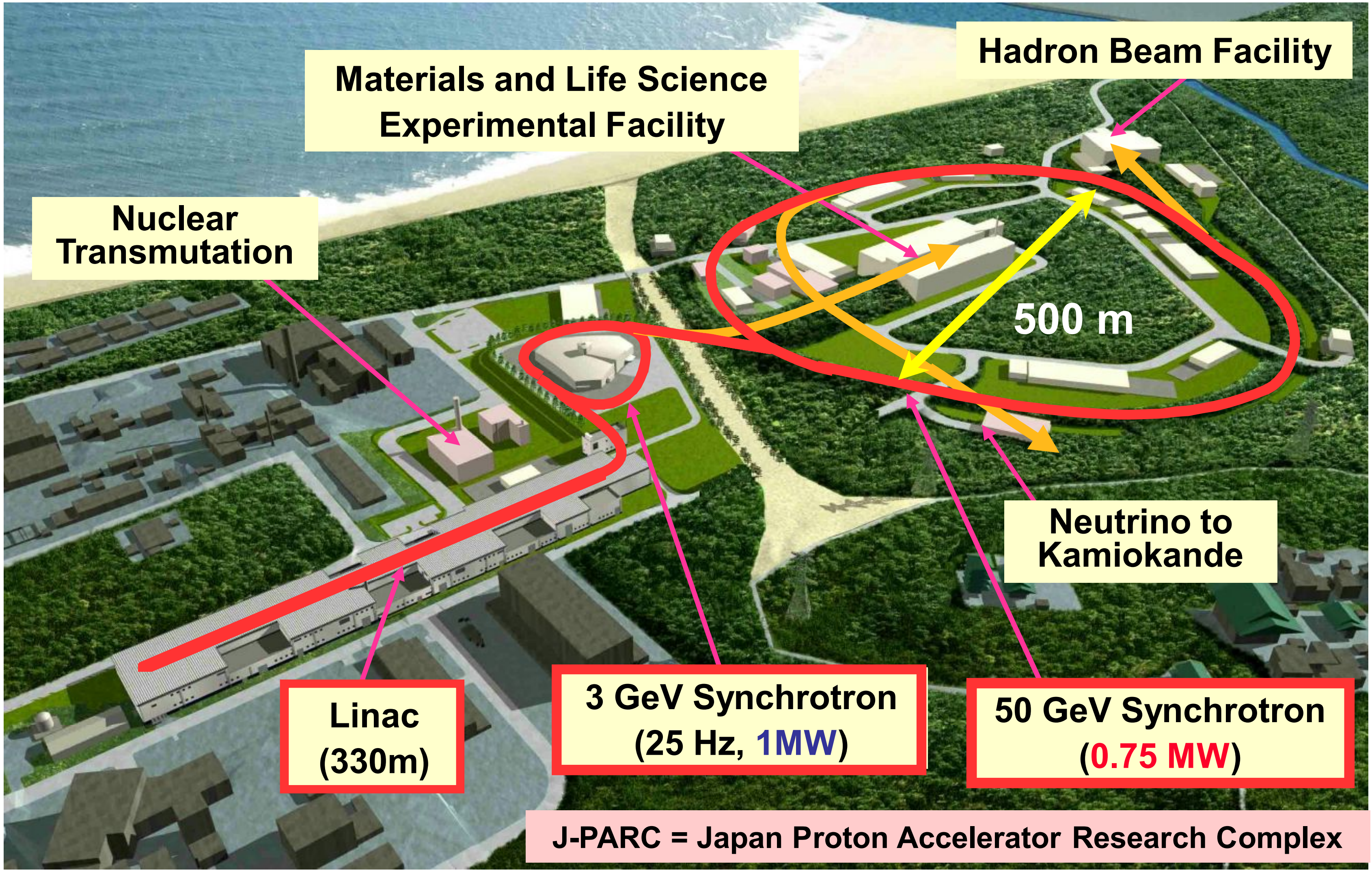
Muon Sources in the World

J-PARC Project at JAEA/TOKAI

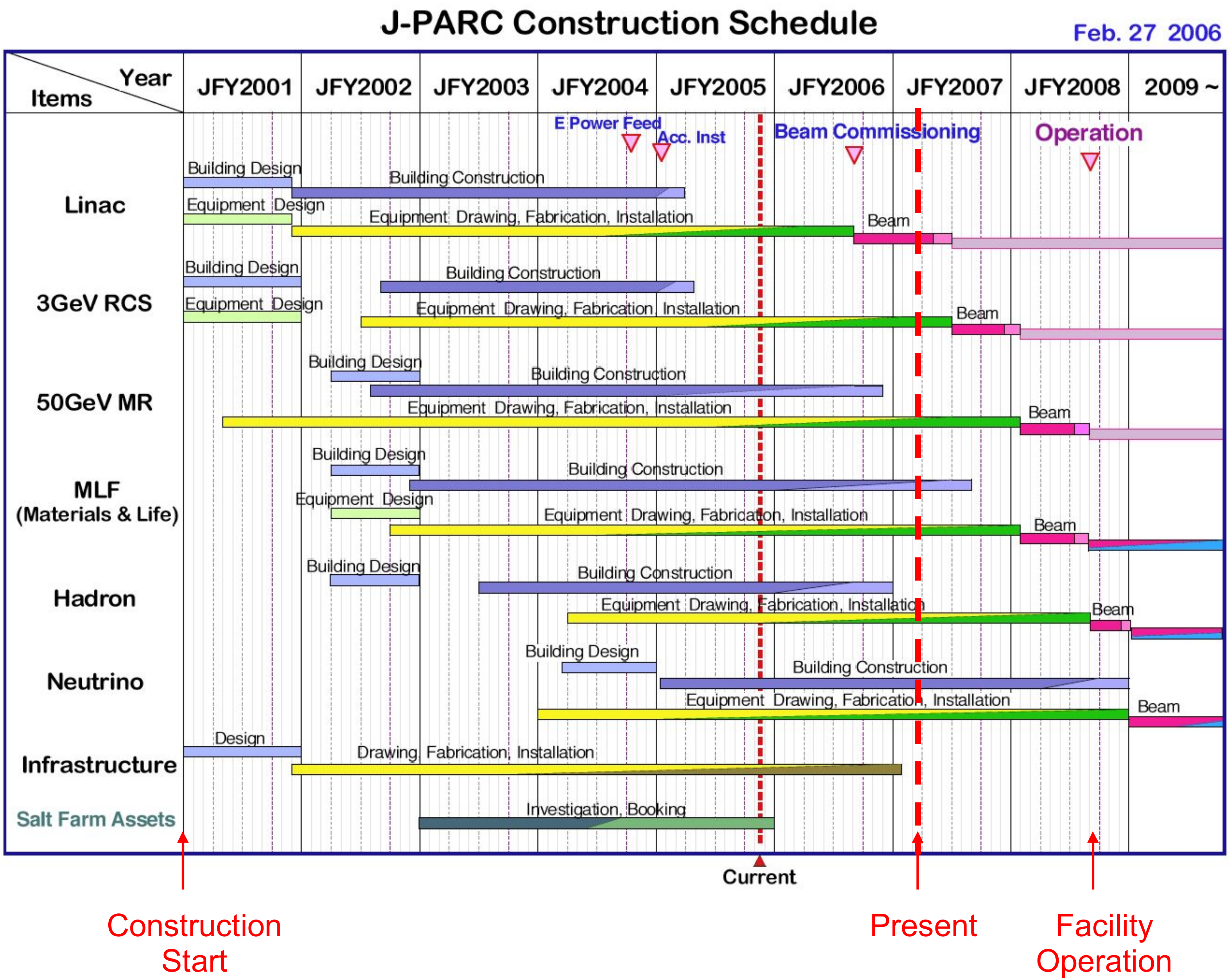


J-PARC is constructed at the cite of JAEA, Tokai-mura

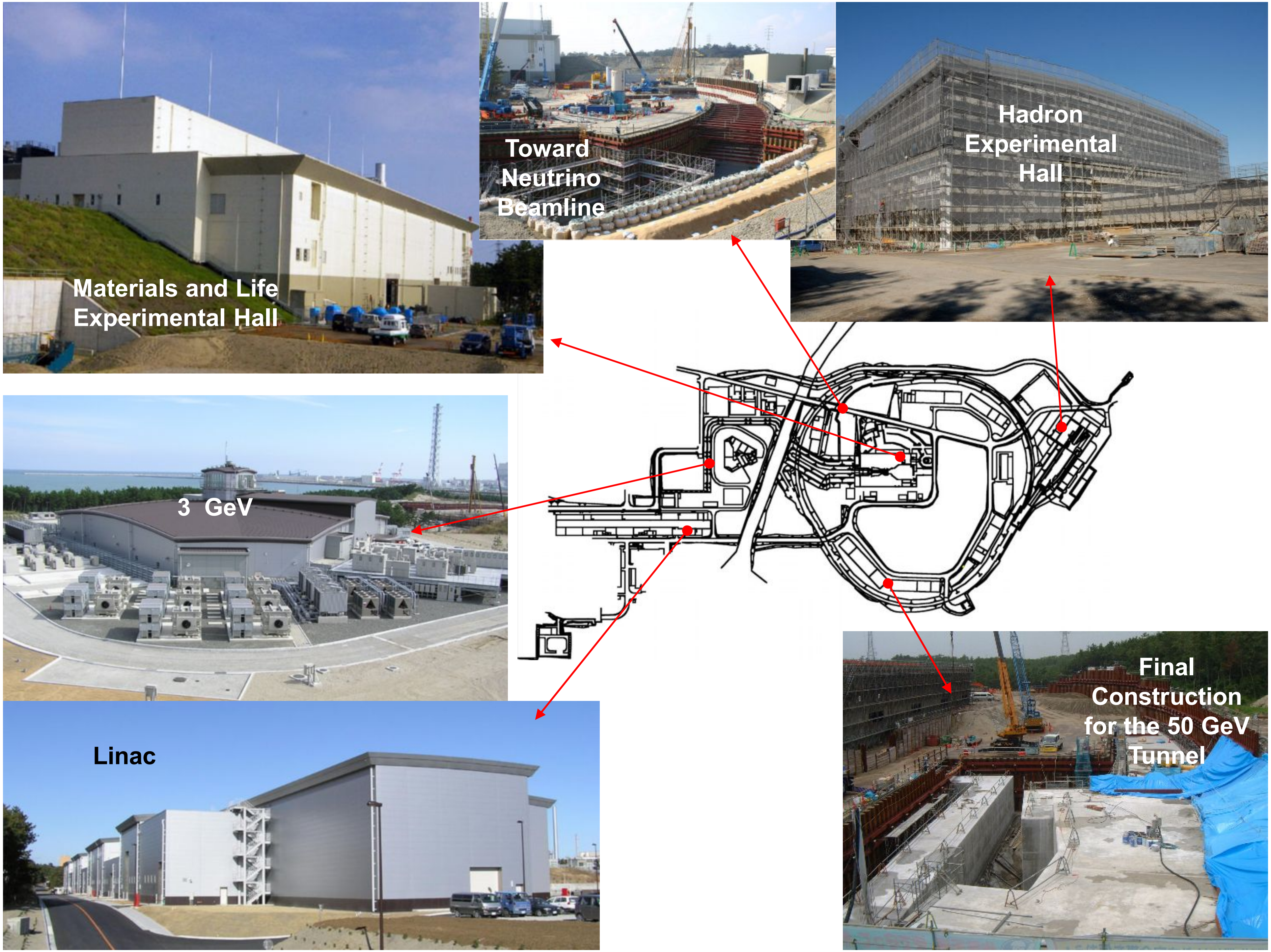
J-PARC Facility



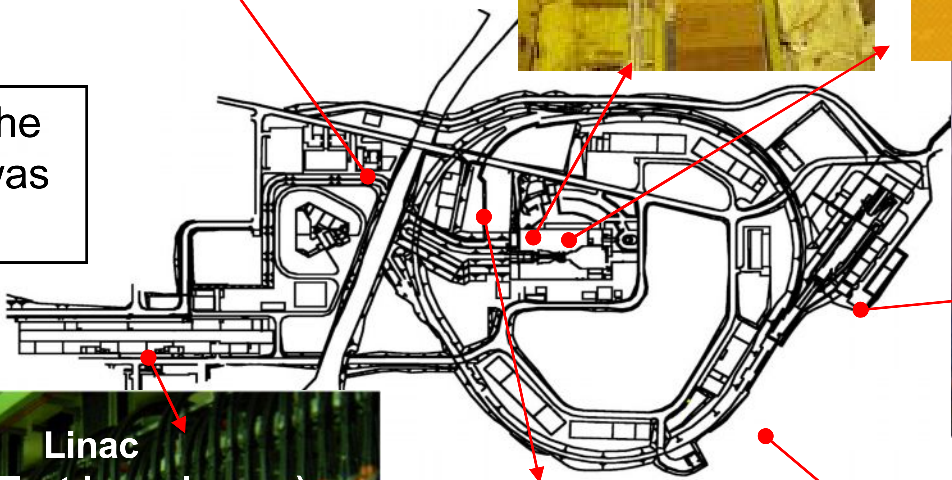
Joint Project between KEK and JAEA

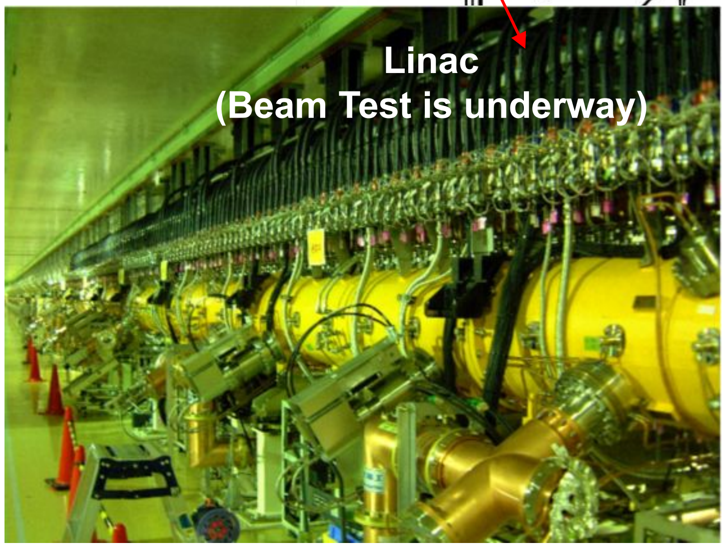


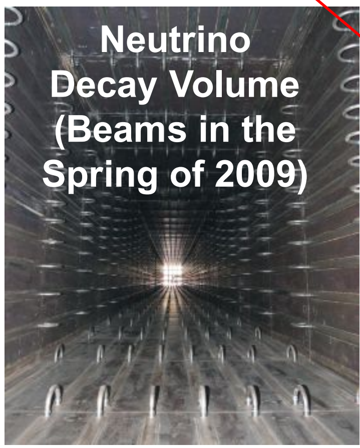
J-PARC Construction Schedule
Feb. 27 2006
Year
Items
JFY2001
JFY2002
JFY2003
JFY2004
JFY2005
JFY2006
JFY2007
JFY2008
2009 ~
E Power Feed
Acc. Inst
Beam Commissioning
Operation
Linac
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
3GeV RCS
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
50GeV MR
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
MLF
(Materials & Life)
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
Hadron
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Neutrino
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Infrastructure
Design
Drawing, Fabrication, Installation
Salt Farm Assets
Investigation, Booking
Current
Construction Start
Present
Facility Operation


Materials and Life
Experimental Hall
Toward
Neutrino
Beamline
Hadron
Experimental
Hall
3 GeV
Linac
Final
Construction
for the 50 GeV
Tunnel

Over 70% of the construction was completed







Linac Beam on January 24, 2007

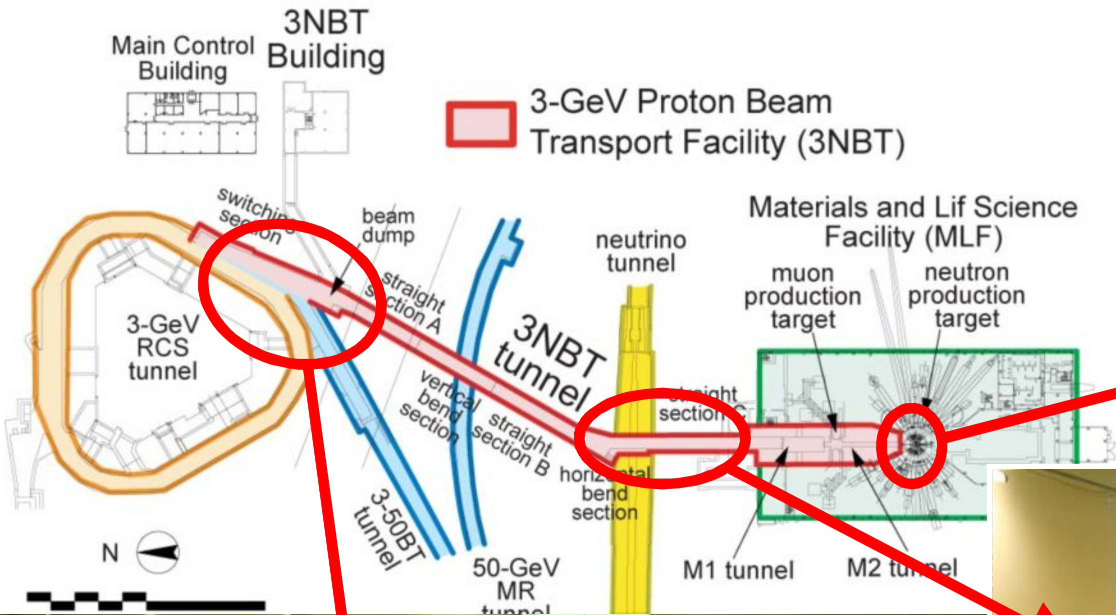
3GeV　Proton Beam
&
Proron Beam Line
In the vicinity of Muon Target

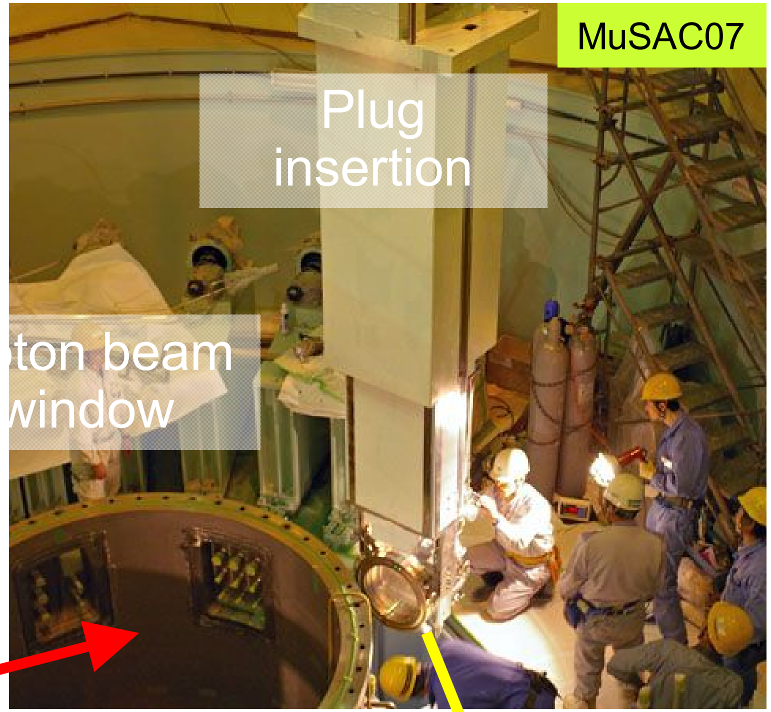
Proton beam from 3-GeV Rapid Cycling Synchrotron (*RCS*)

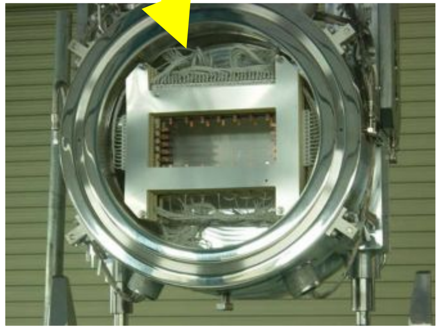
•**Beam energy**	**3 GeV**
•**Number of protons**	**8.3×10^{13} / pulse**
•**Repetition rate**	**25 Hz**
•**Average beam current**	**333 μA (In the case LINAC 400 MeV)**
•**Average beam power**	**1 MW (In the case LINAC 400 MeV)** **0.6MW (In the case LINAC 181 MeV)**
•**Transverse emittance (ε)**	**81π mm·mrad (beam core)** **324π mm·mrad (max. halo)**
•**beam profile**	**not known yet**

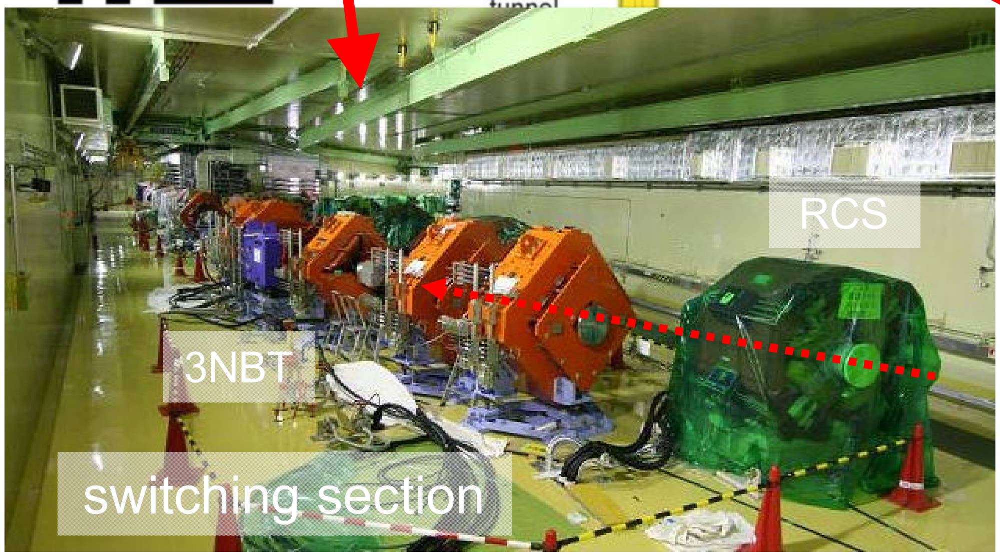
MuSAC07

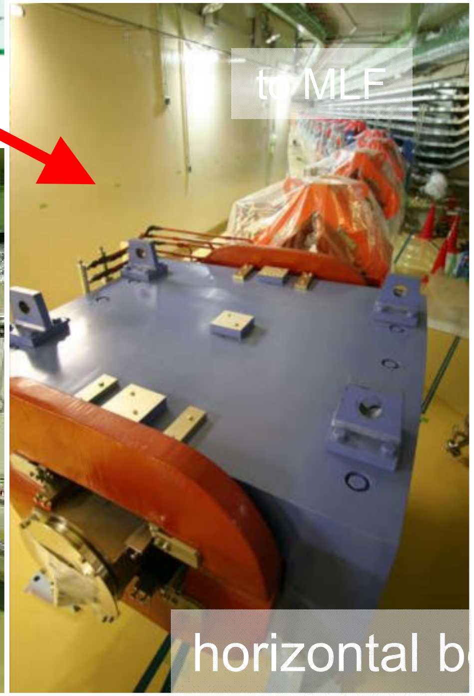
3-GeV Beam Transport Line (3NBT)





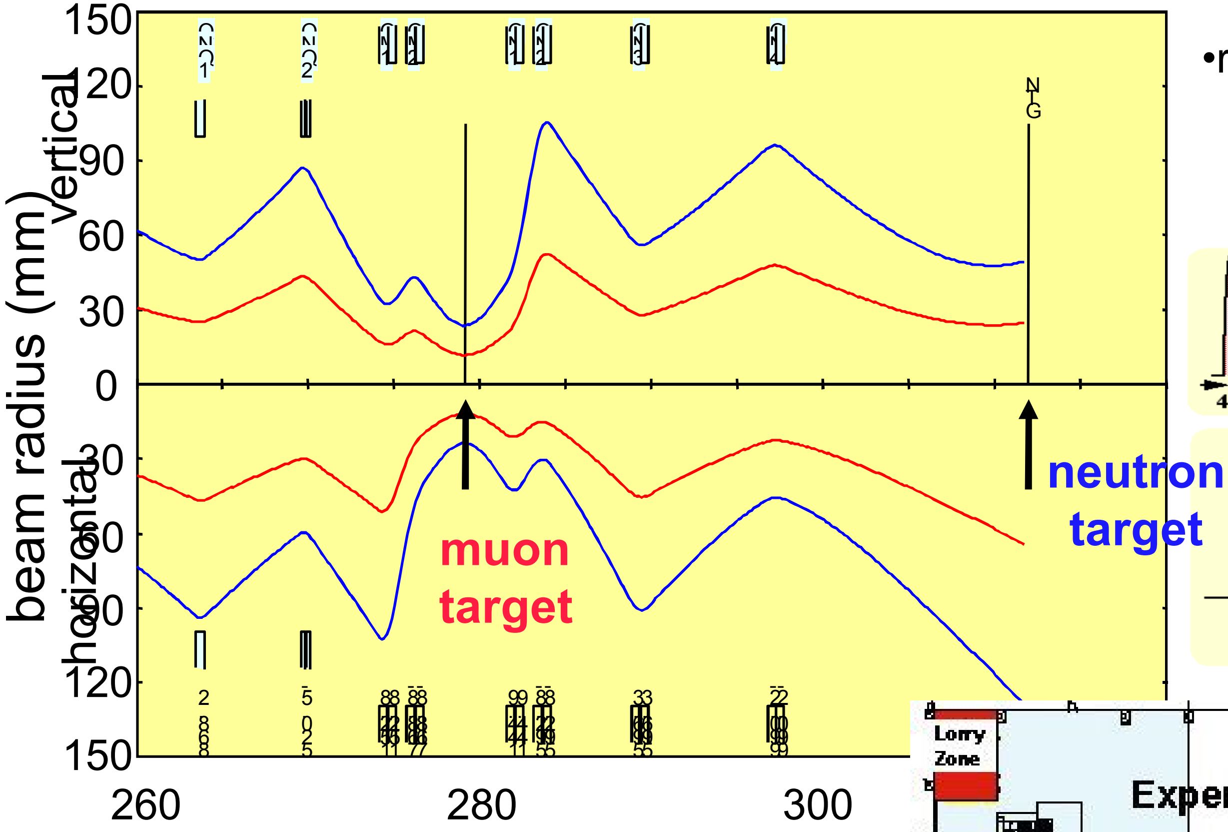






Proton Beam Envelope in MLF

core (81π mm·mrad)
max. halo (324π mm·mrad)

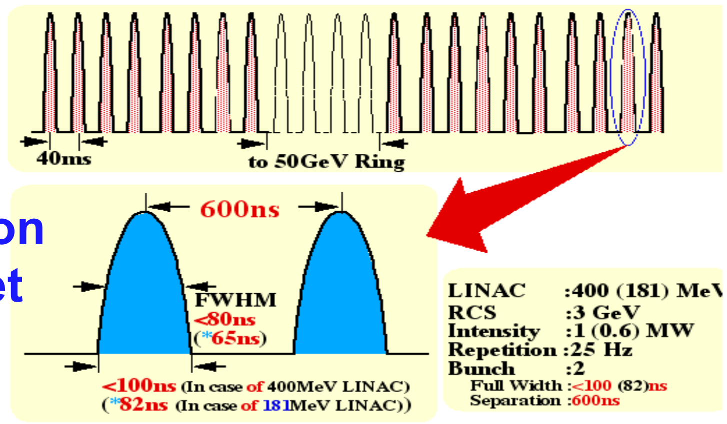


•strong focusing on

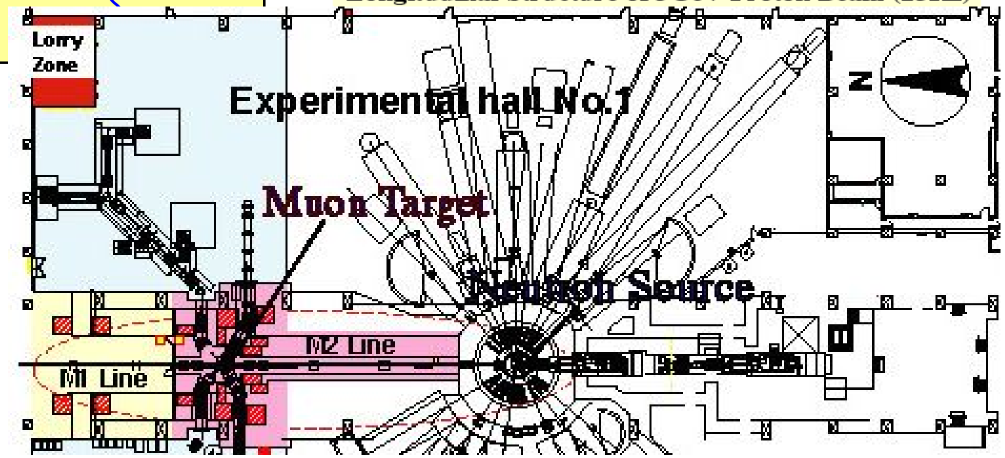
muon target --> ϕ **24mm**

•rectangular profile on

neutron source **W130mm H50mm**



Longitudinal Structure of 3GeV Proton Beam (25Hz)

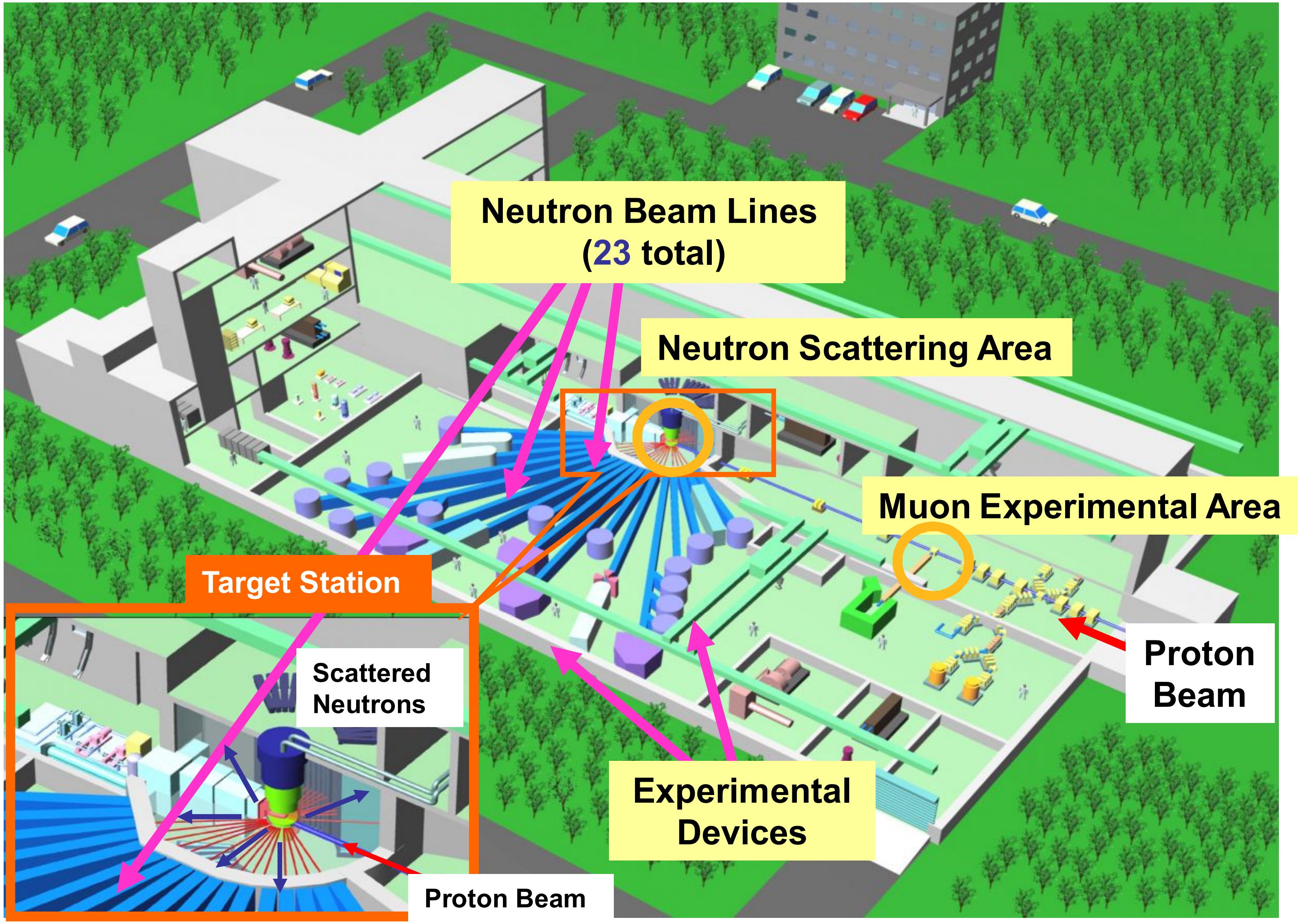


Construction of Materials Life Science Facility (MLF) building

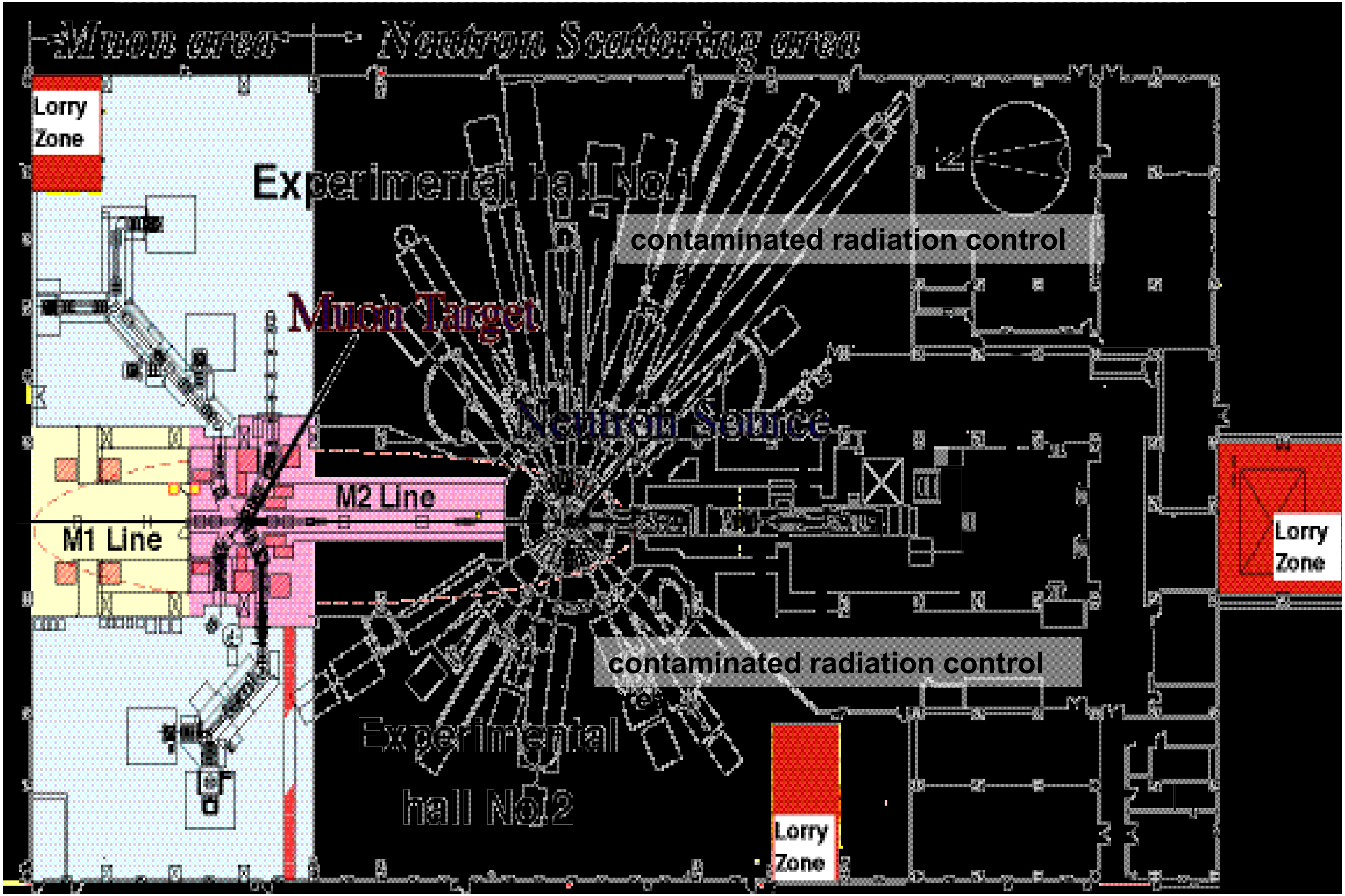
Early Days (2004)
for Construction

End of Dec., 2006
completed.

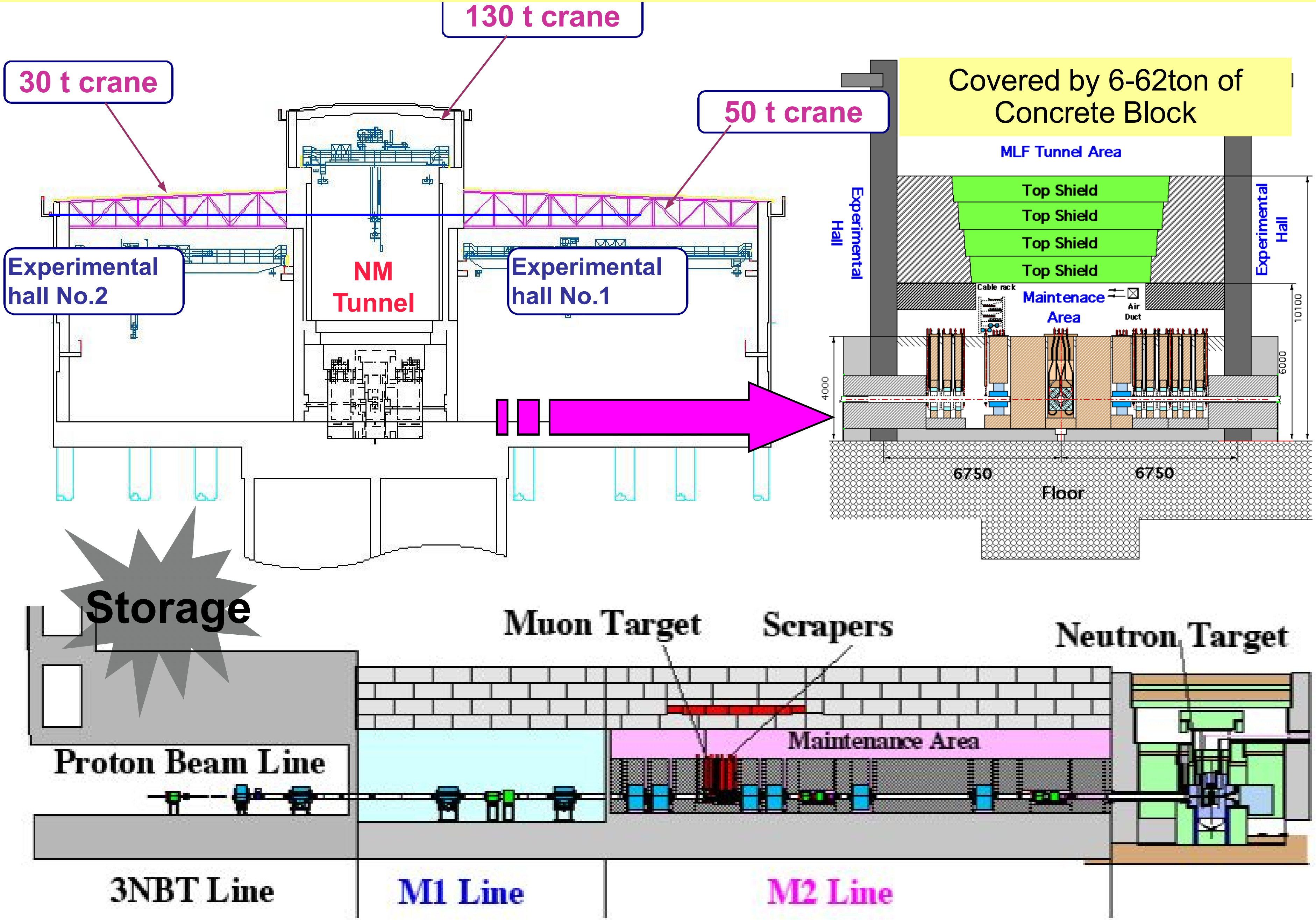
Materials & Life Experimental Facility (*MLF*)



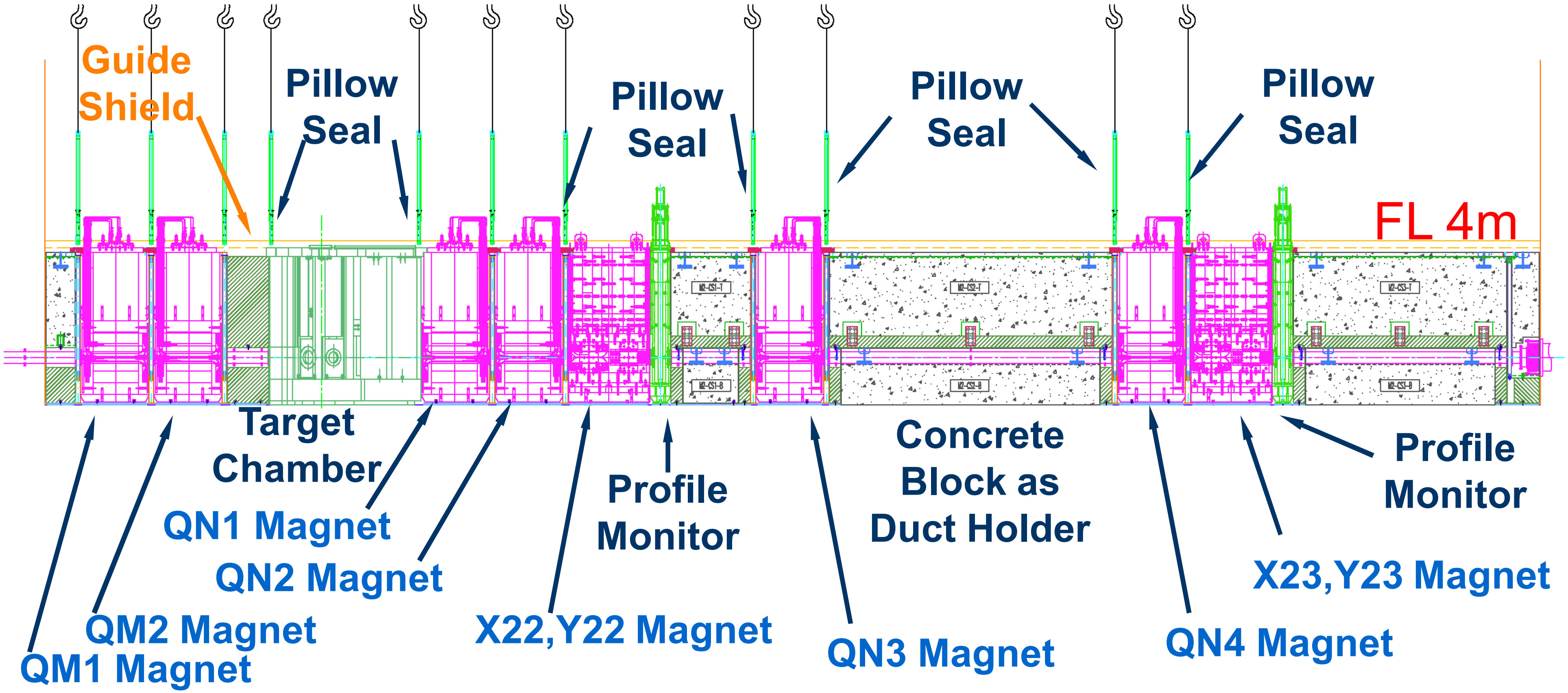
MLF Layout (TOP VIEW)



MLF Tunnel Structure（Crossed View）

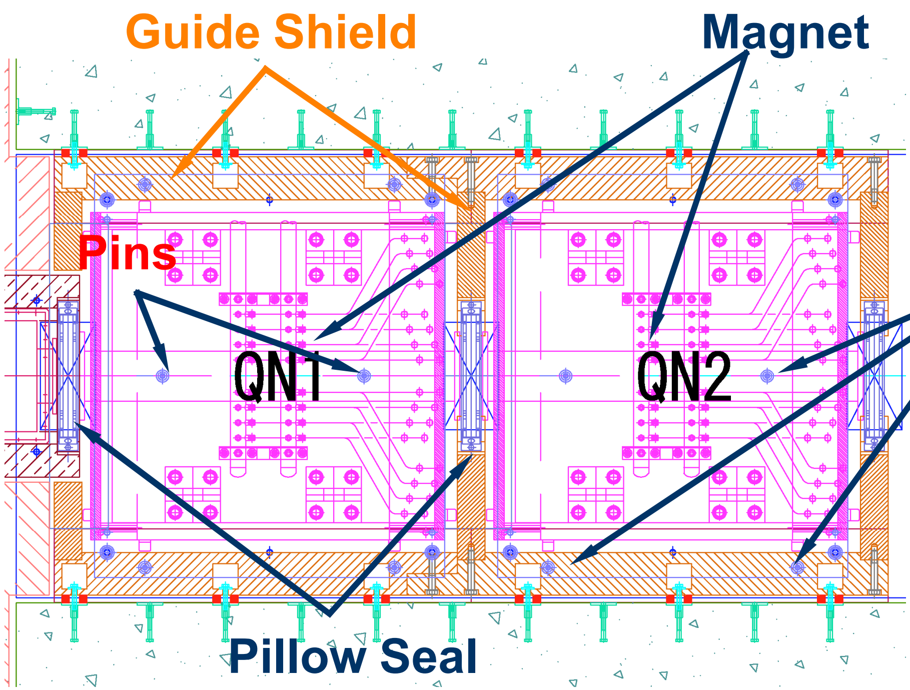


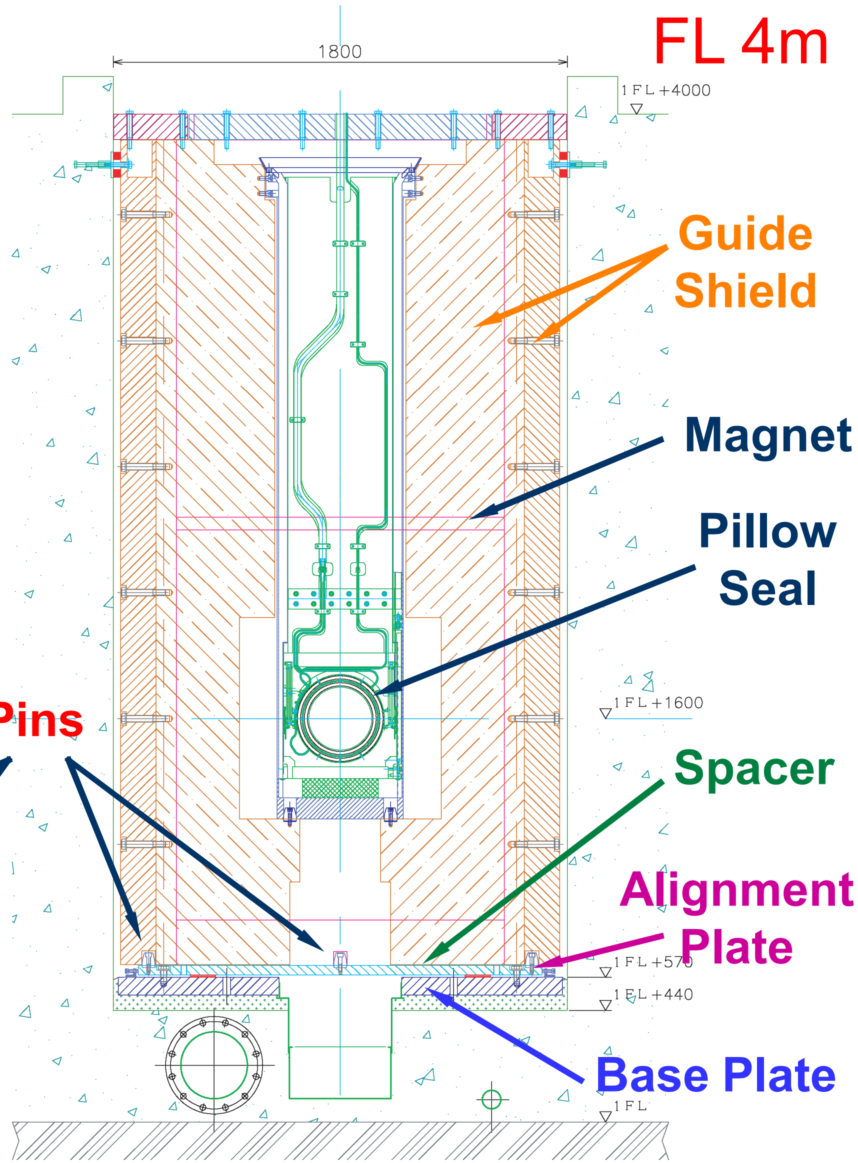
All beamline components in M2-tunnel (in the vicinity of muon target) need to be remotely installed from the maintenance area (FL 4m).



Installation of M2 line Components

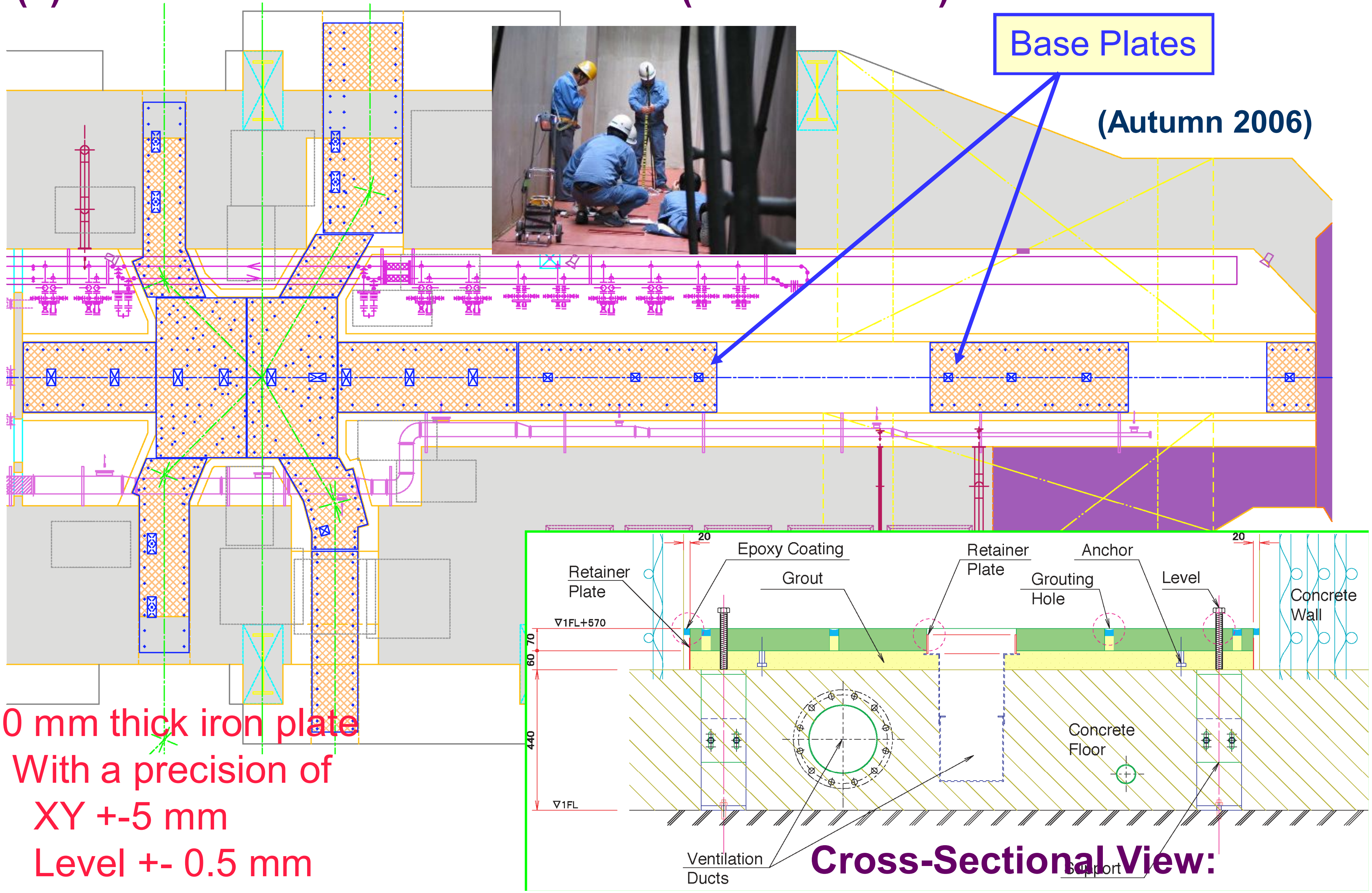
- Beamline components (magnets, …) installed using an "Alignment Plate" with pins and a "Guide Shield".
- Later height adjustment possible using "Spacer" attached at the bottom of each component.





M2-Tunnel Beamline Layout (1)

(1) Installation of Muon Base Plates (Autumn 2004)

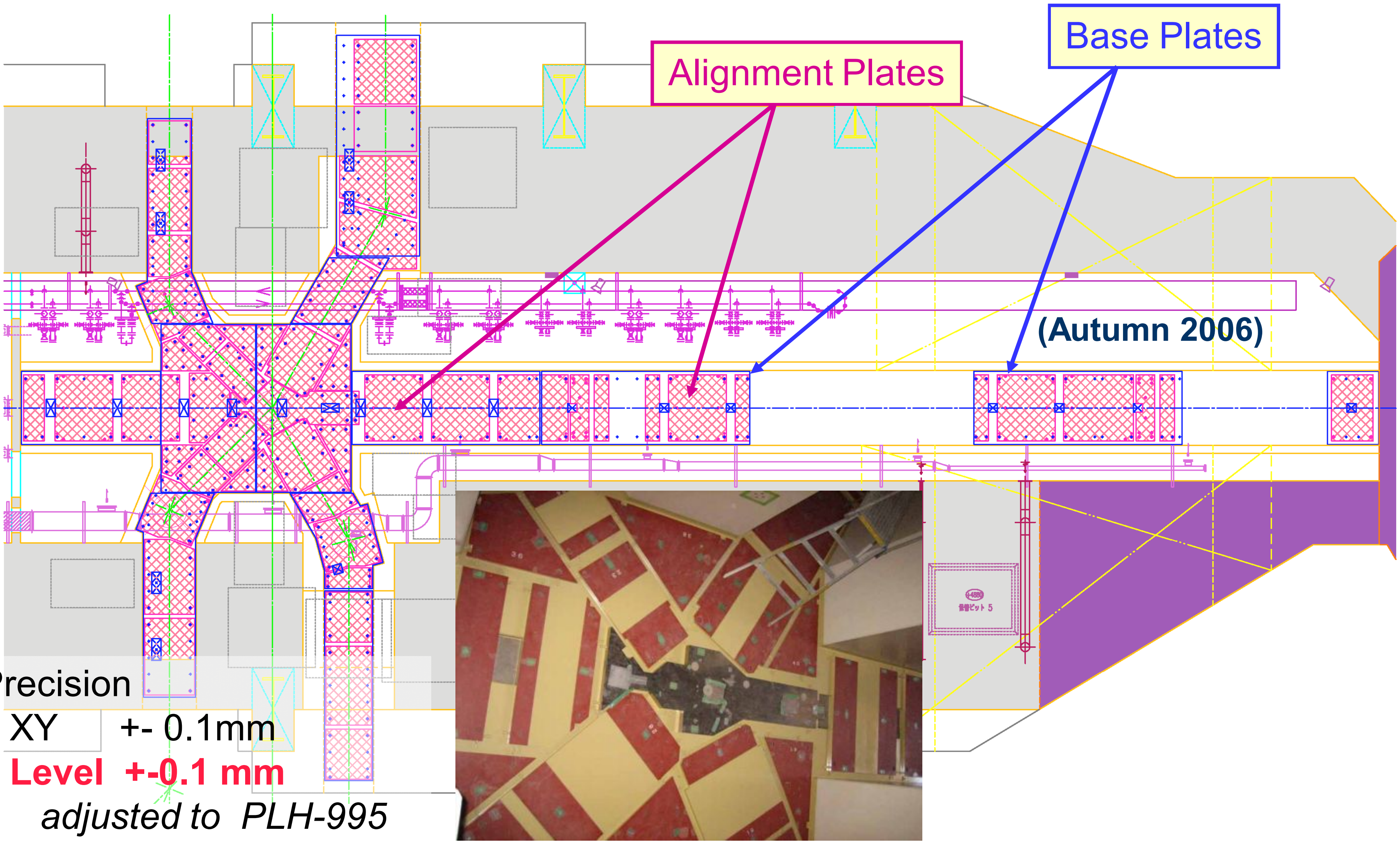


70 mm thick iron plate
With a precision of
XY +-5 mm
Level +- 0.5 mm

Cross-Sectional View:

M2-Tunnel Beamline Layout (2)

(2) Installation of Alignment Plates (February-March 2006)



Precision

XY +- 0.1mm

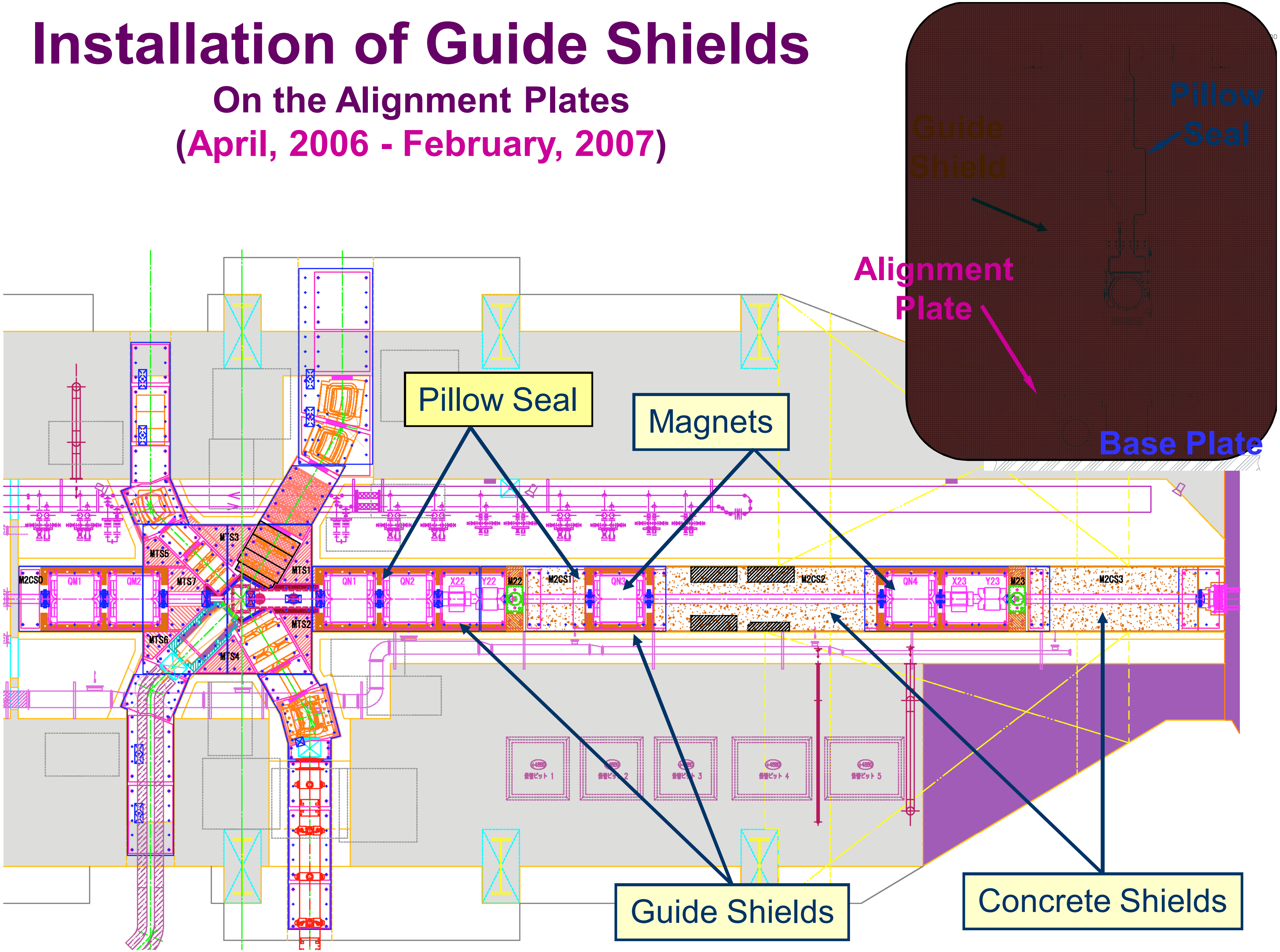
Level +-0.1 mm

adjusted to PLH-995

Installation of Guide Shields

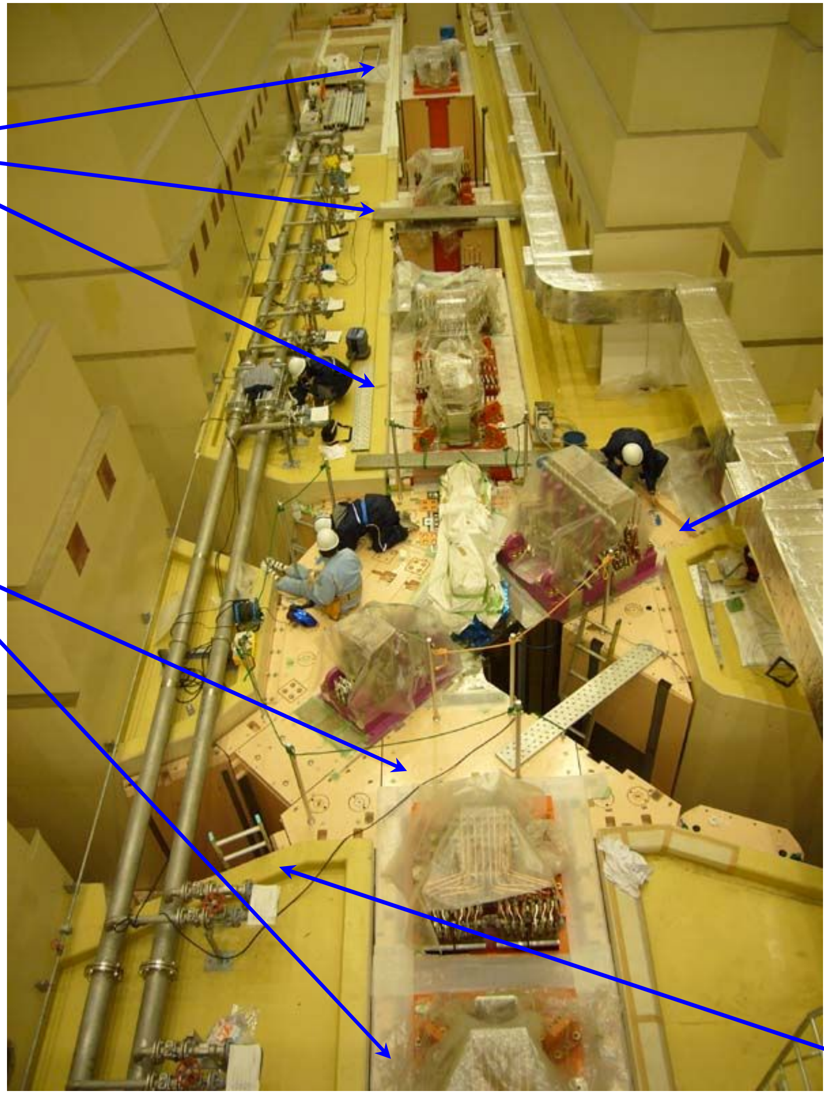
On the Alignment Plates

(April, 2006 - February, 2007)



Installation of Guide Shield

(April, 2006 - February, 2007)



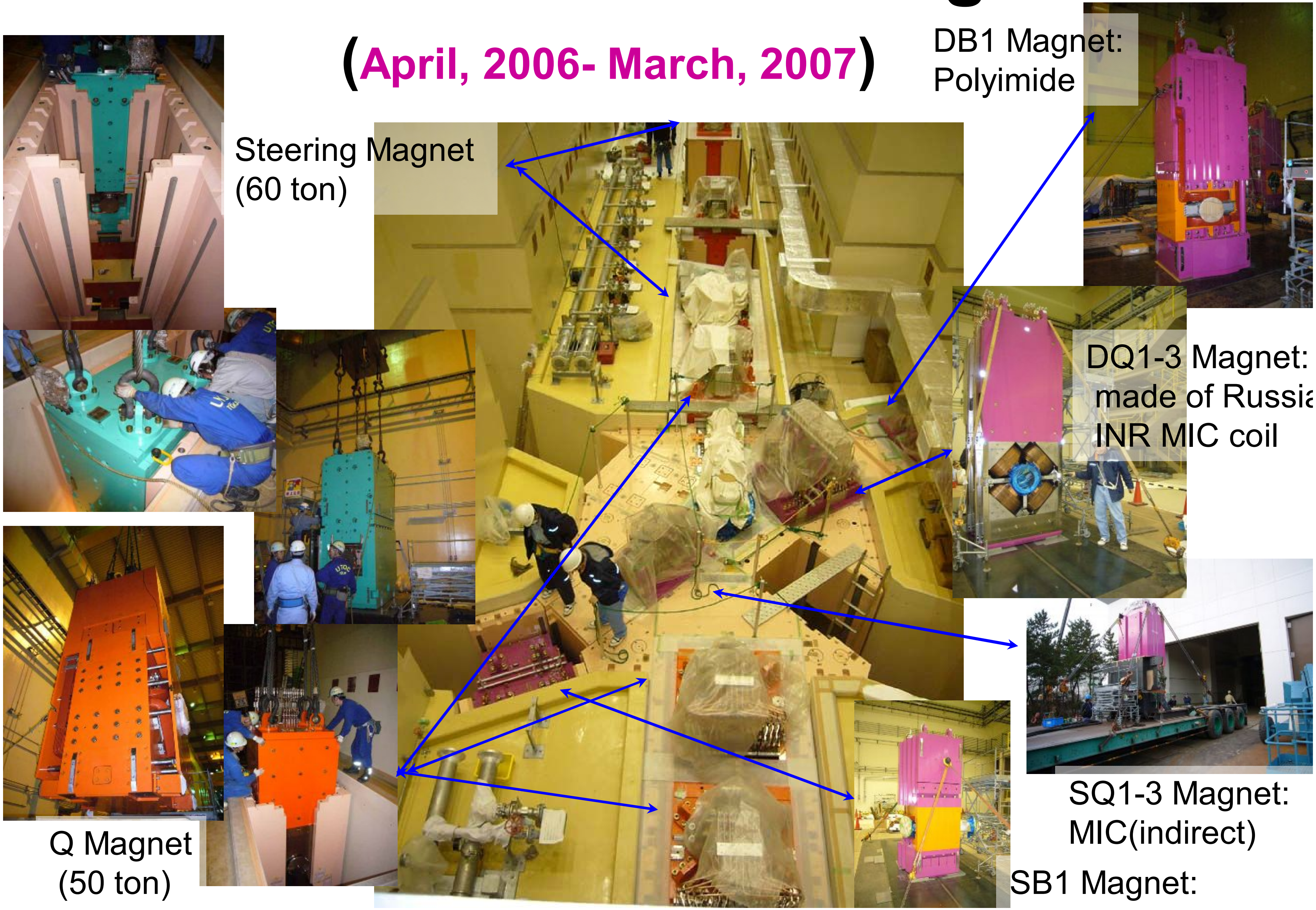
Guide Shied for M2-line

Guide Shied for DB1

Guide Shied for SB1

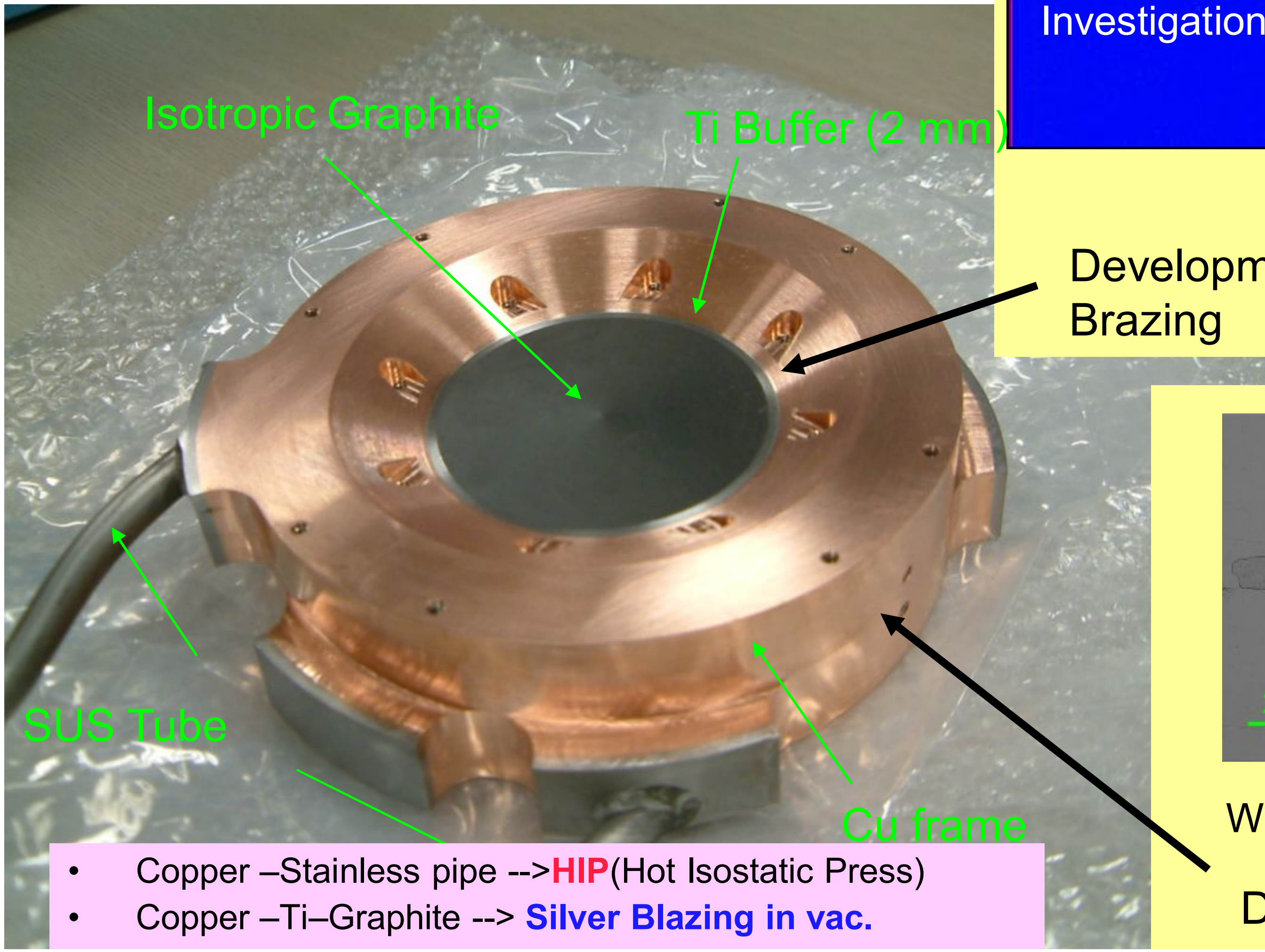
Installation of M2 line magnets

(April, 2006- March, 2007)

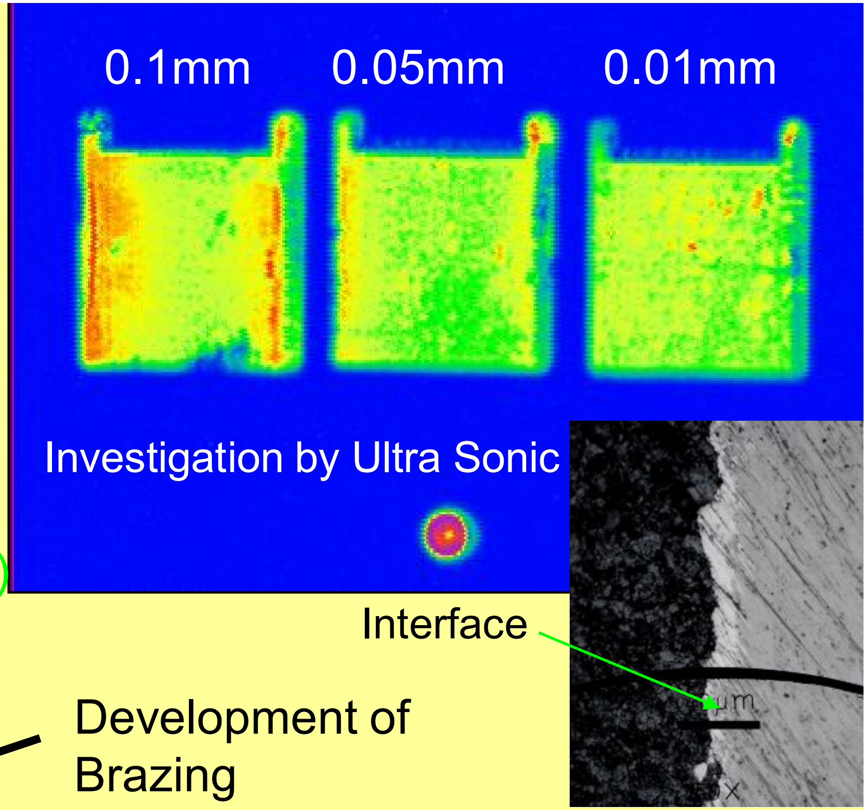


Muon Target

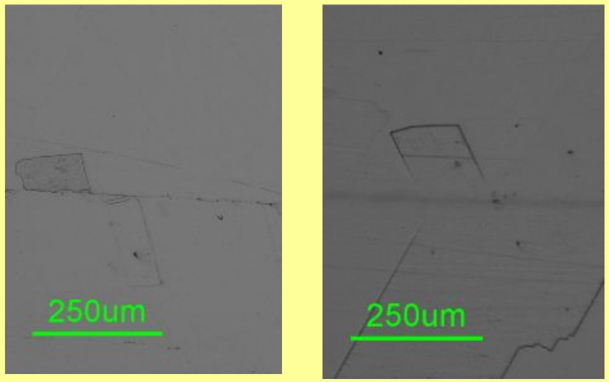
In the beginning up to 0.6 MW,
We use an edge cooled graphite Target.



- Copper –Stainless pipe -->**HIP**(Hot Isostatic Press)
- Copper –Ti–Graphite --> **Silver Blazing in vac.**



Development of Brazing

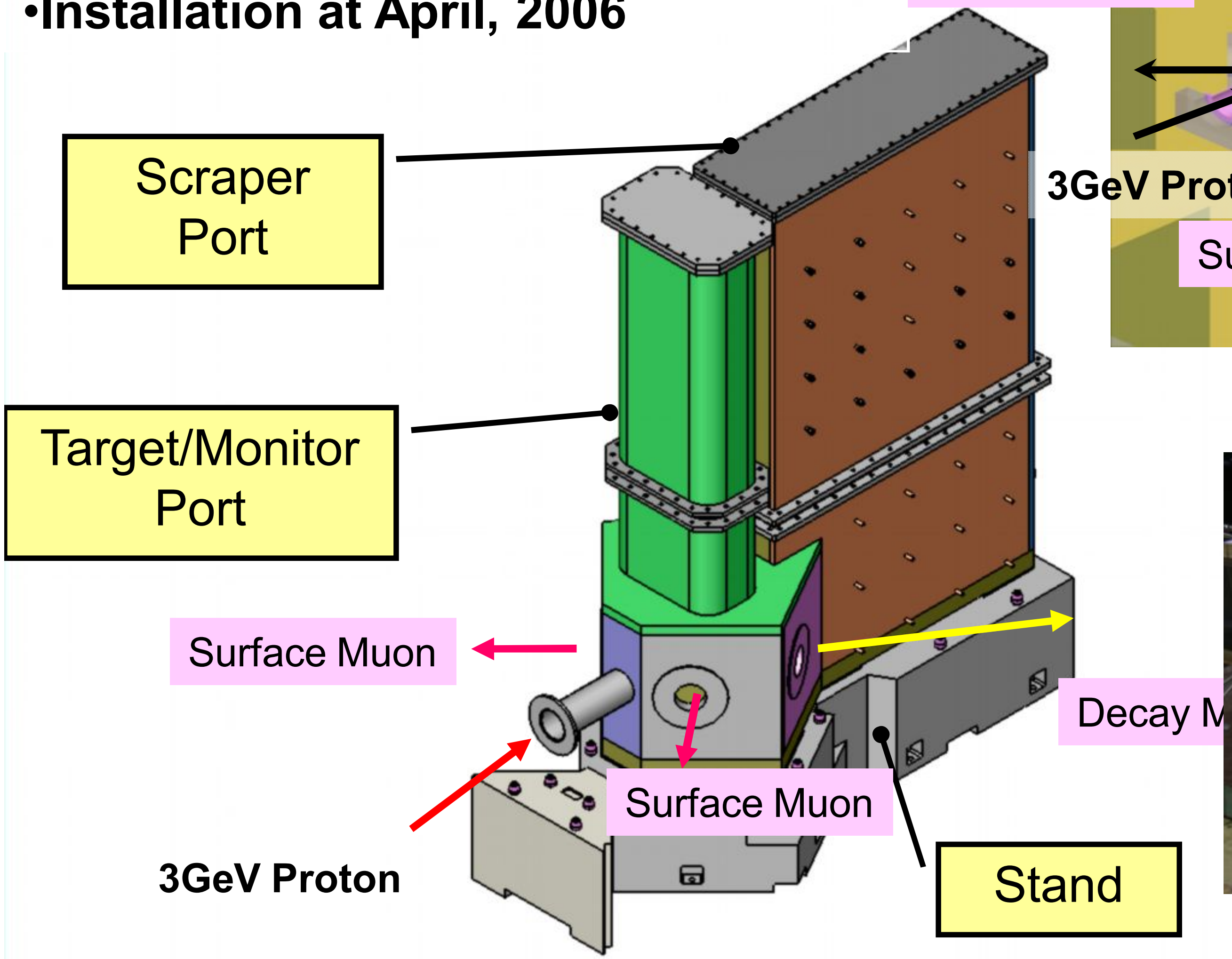


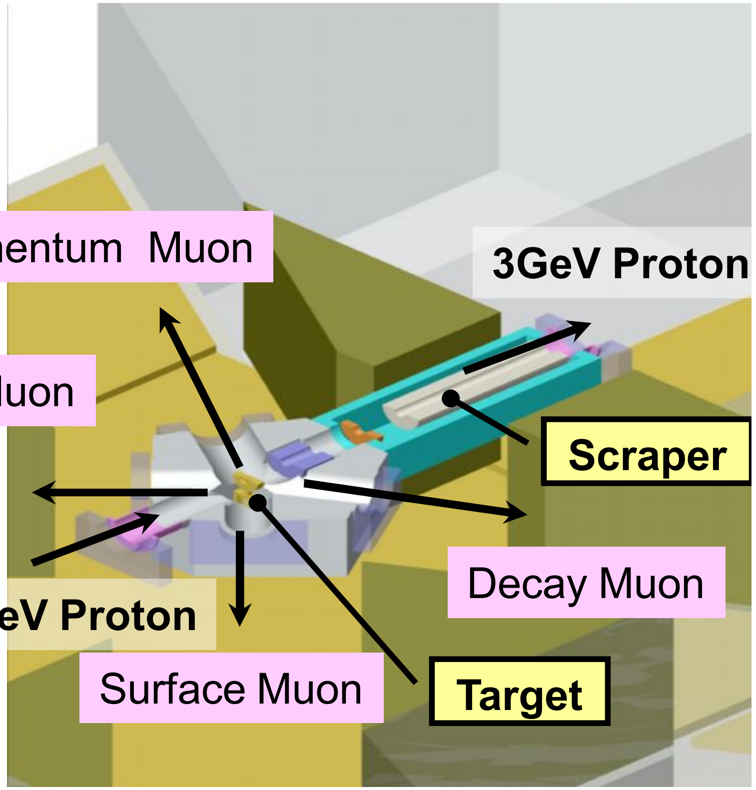
Without Insert Ni coated

Development of HIP

Target chamber

- •Design by 2004, December
- •Ordering at April, 2005
- •Installation at April, 2006





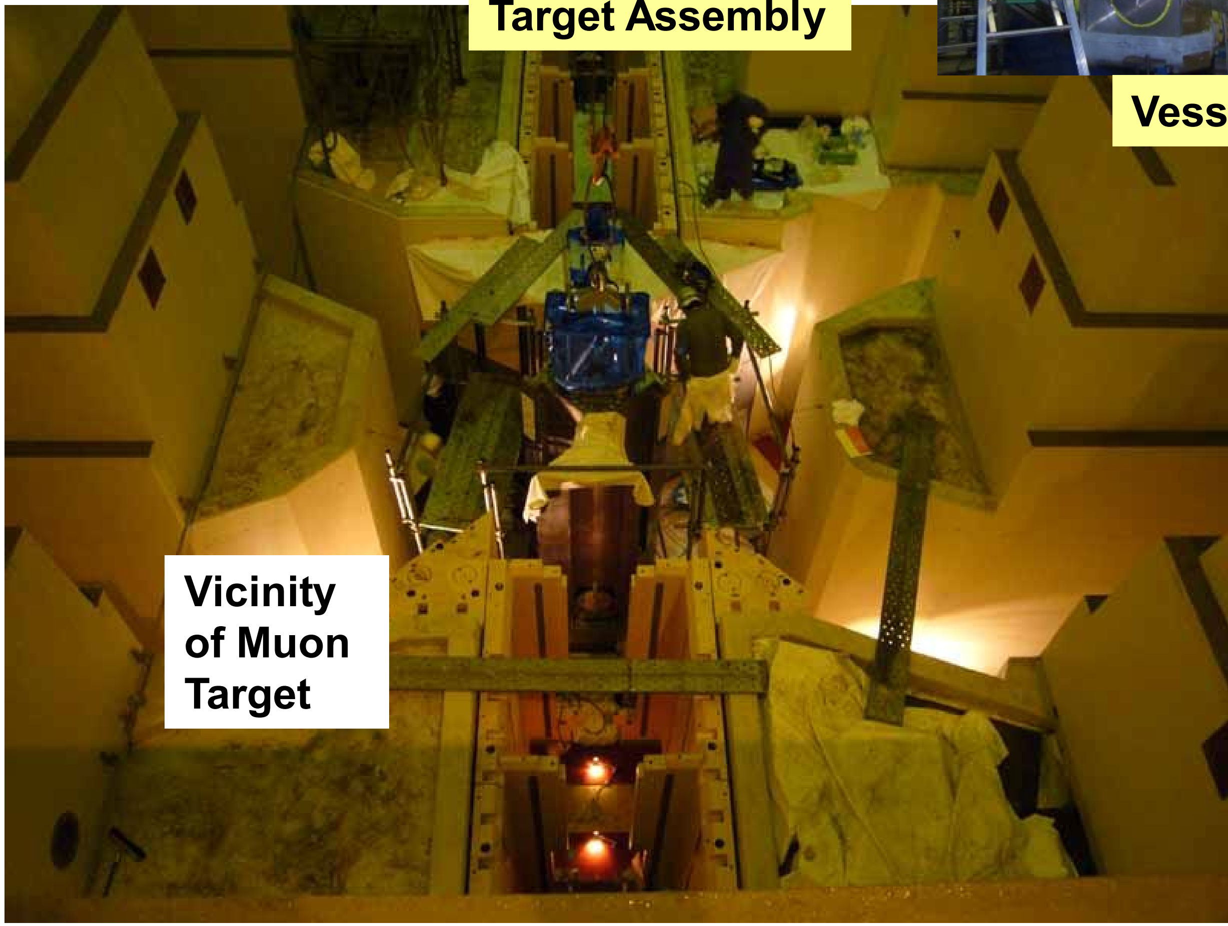
Under Fabrication

Installation of Muon Target Chamber (April- December 2006)

Target Assembly

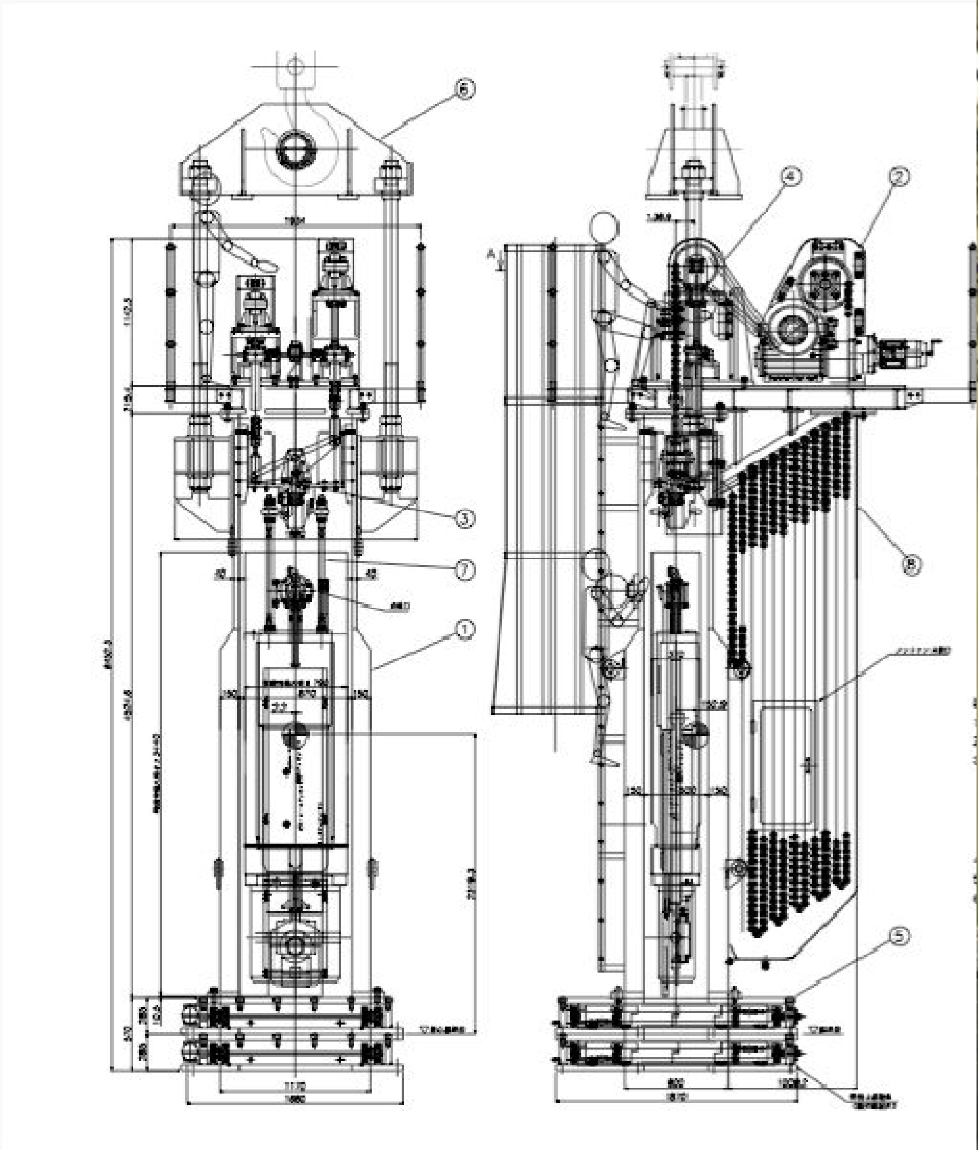
Vessel

Scraper Assembly

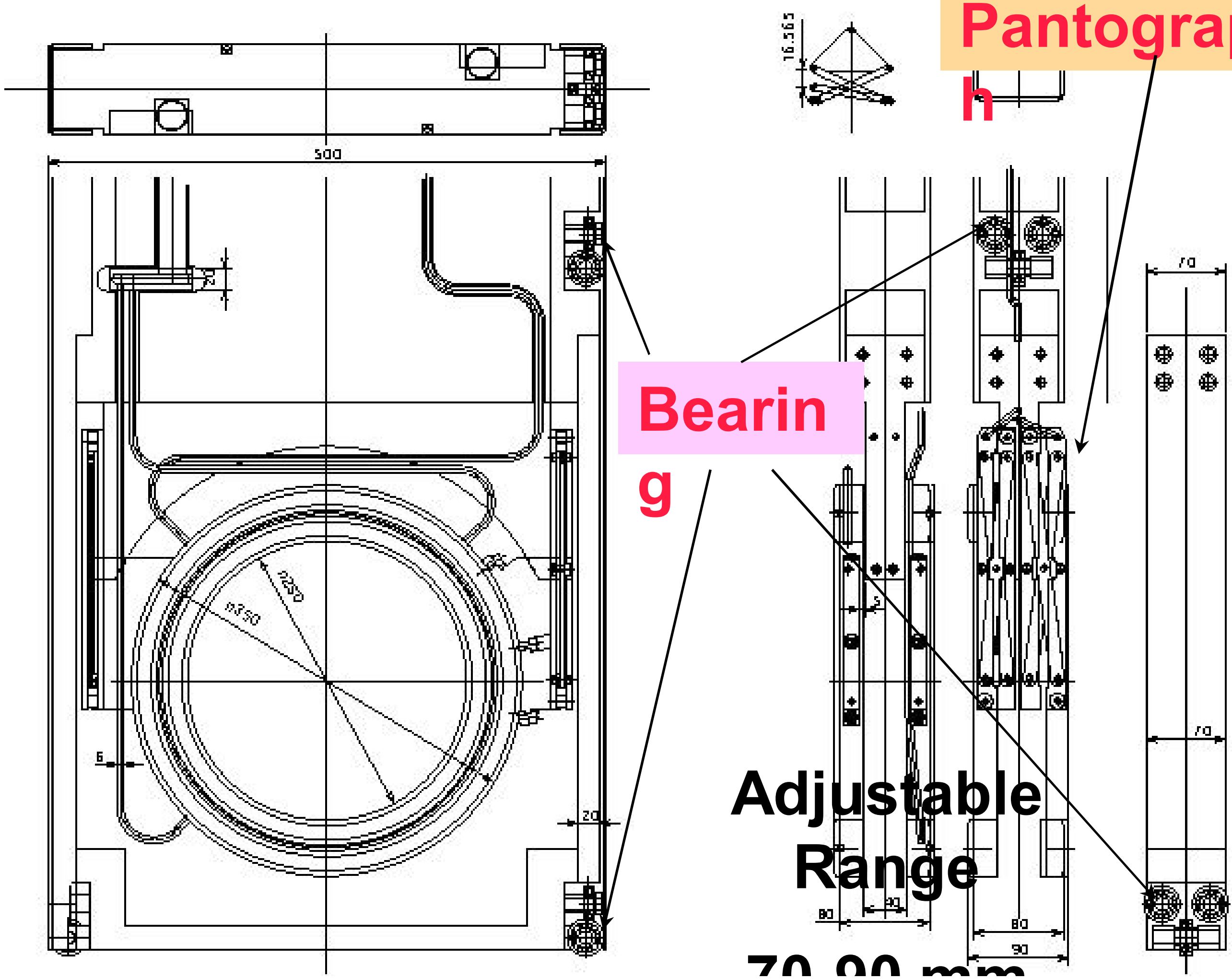


Vicinity of Muon Target

Muon CASK for the maintenance of Muon Target, Scrapers, pillow seal, & profile monitor ! (June 2007)



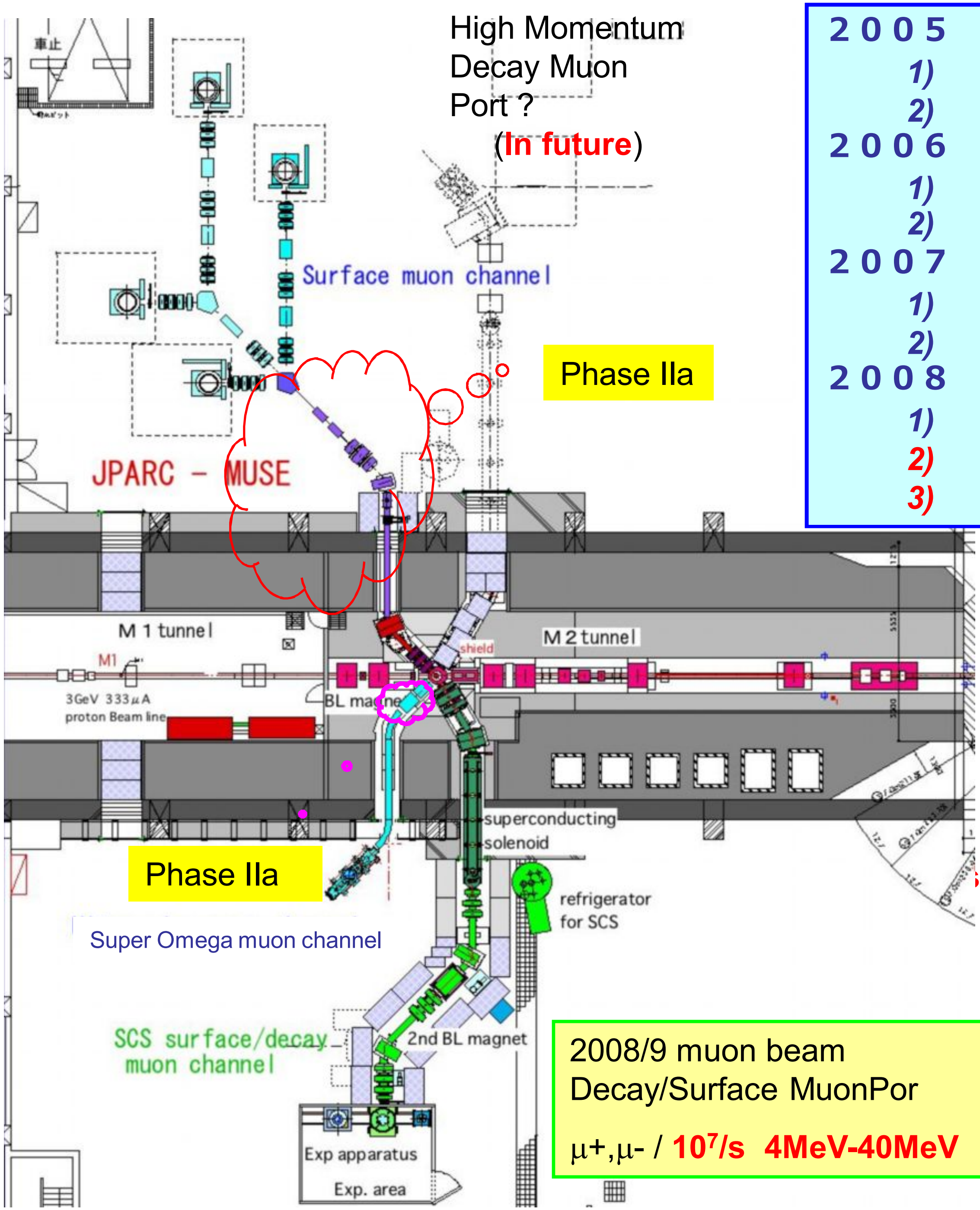
Pillow Seal for the Vacuum Connection



Leak Rate:

1.0 x 10^{-8} Pa・m^3/s

Secondary Muon Channel



2008/9 muon beam
Decay/Surface MuonPor
μ+,μ- / **10^7/s 4MeV-40MeV**

2005
1) *Building construction*
2) *M2 tunnel BL component manufacture*

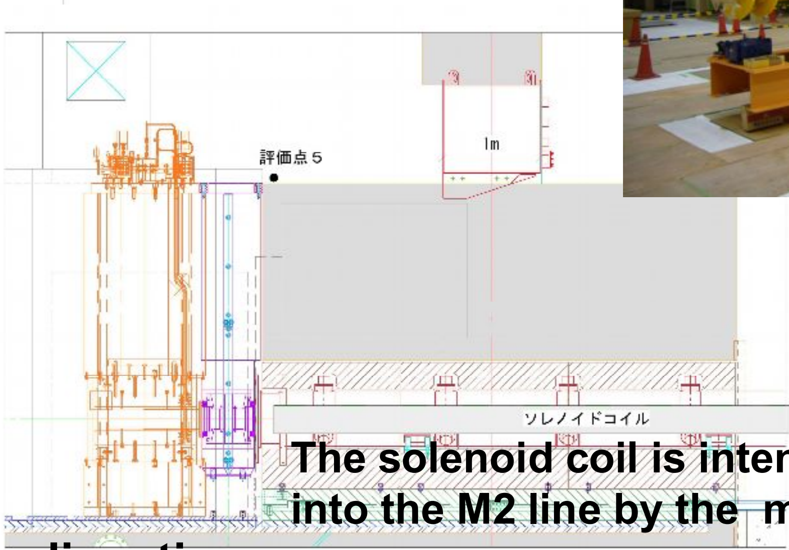
2006
1) *M2 tunnel BL component install*
2) *Air Cooling system、Electricity*

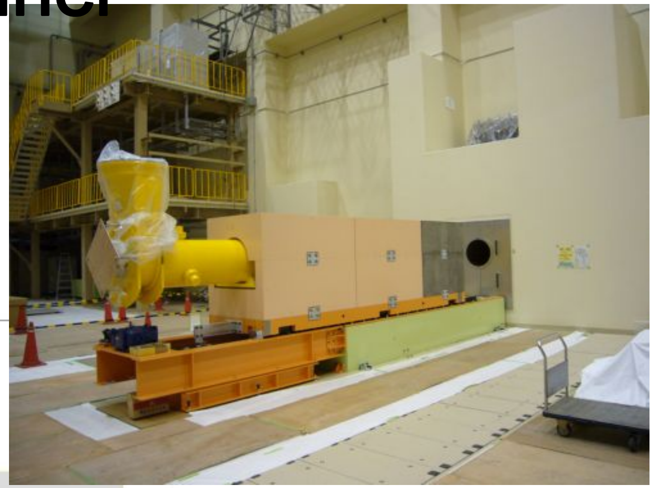
2007
1) *M2 tunnel BL commissioning*
2) *SCS channel install*

2008
1) *Exp apparatus for general user*
2) *Surface muon channel (tunnel-B3)*
3) *Front magnet for slow muon*

J-PARC
Plan for FY 2007-8
07.6 ceiling shield
07.9 solenoid install
07.12 radiation safety
08.3-9 proton beam
Project budget
(2005−8)
Special budget for PS-experim.
(2005−8)
Phase II budget
(2008-2011)

Decay-Surface Muon Channel





The solenoid coil is intended to be carried into the M2 line by the movable slide table.

We are going to bring the radioactive superconducting solenoid coil from KEK this September, 2007!

(June 2007)

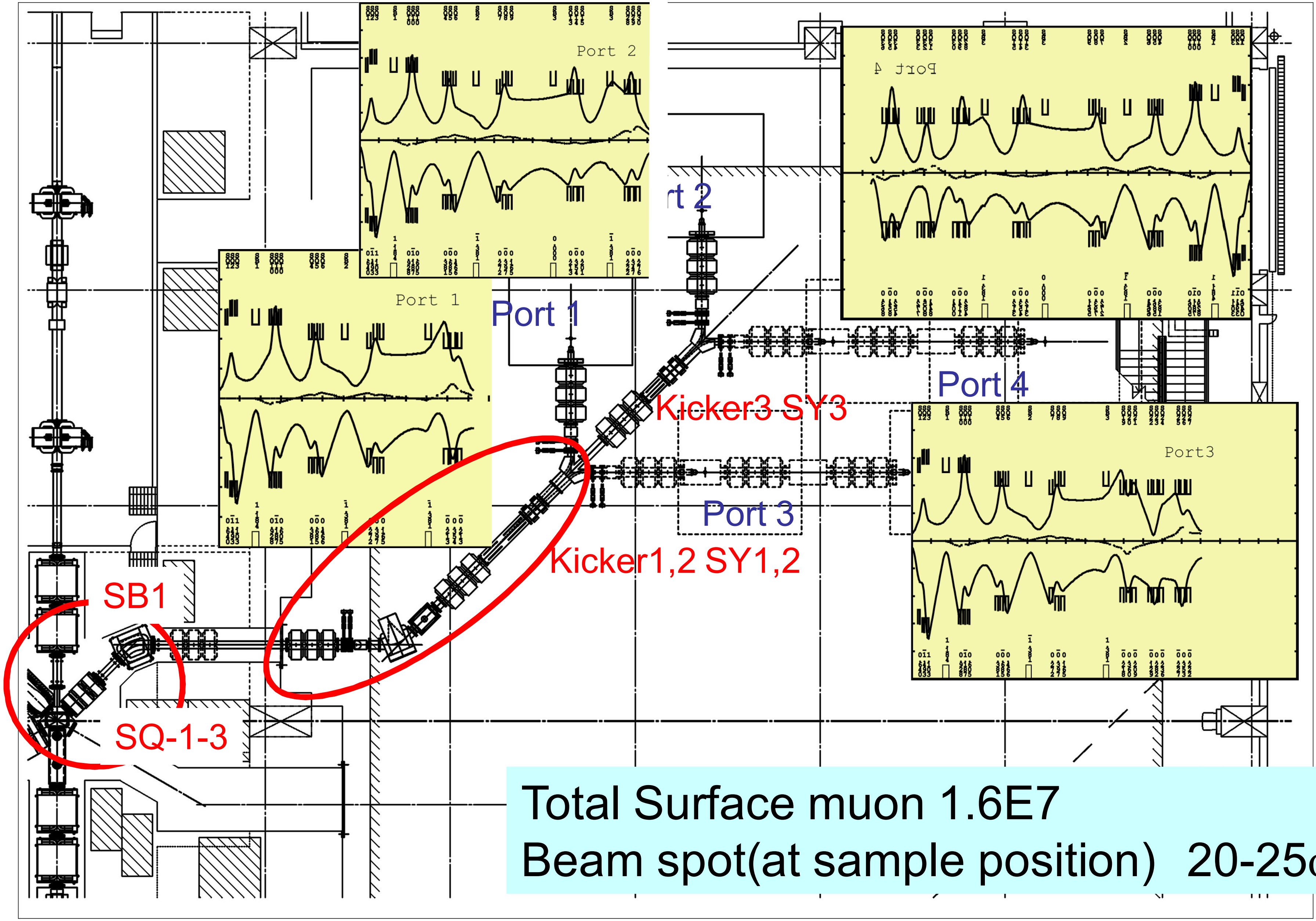
Expecting a first beam on May, 2008

Surface muon 30MeV/c (Δp/p=4%) 3.0×10^{7}/s

Decay positive muon 60MeV/c (Δp/p=10%) 4.8×10^{6}/s

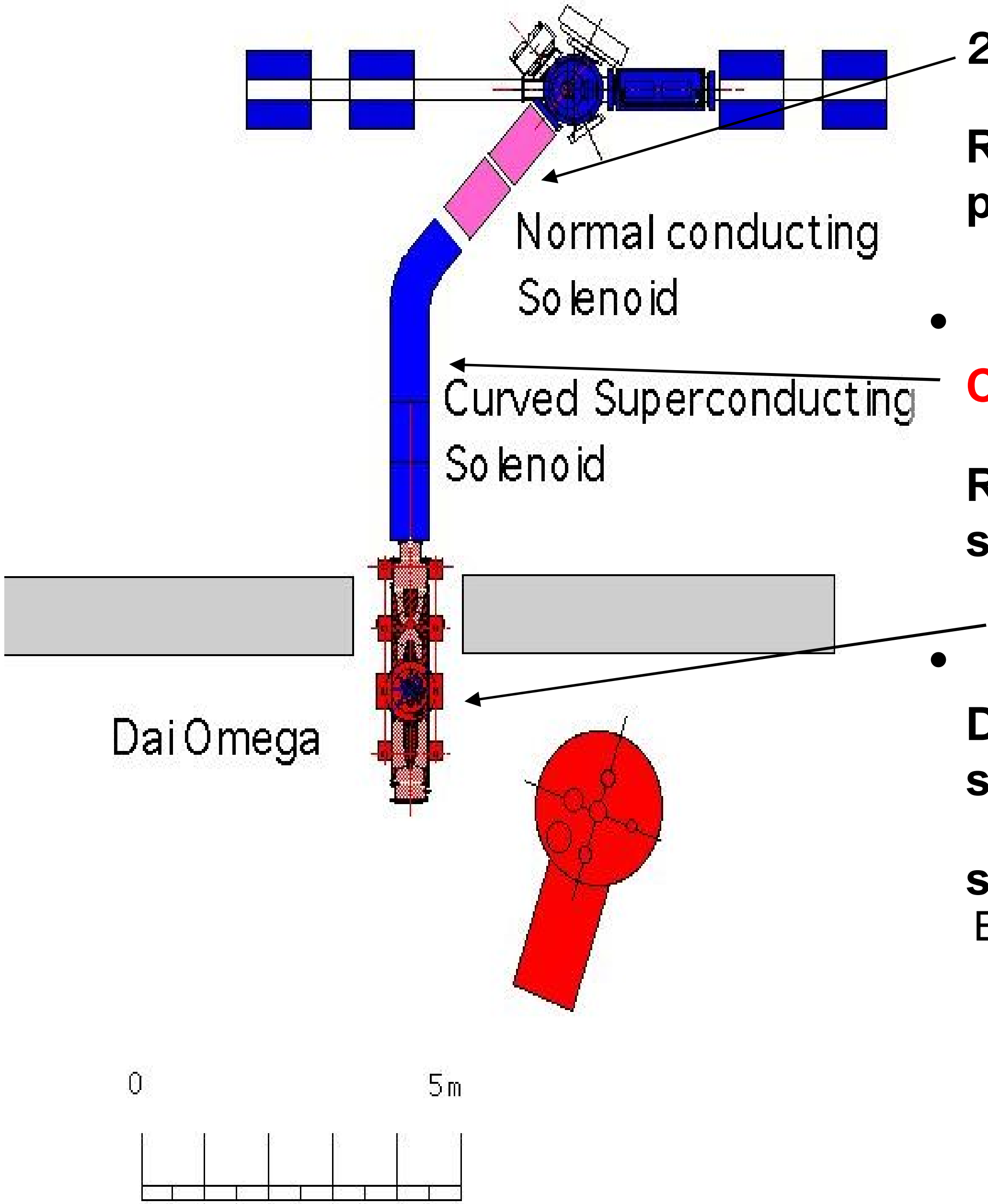
Decay positive muon 120MeV/c(Δp/p=10%) 2.1×10^{7}/s

Surface Muon Channel



Total Surface muon 1.6E7
Beam spot(at sample position)   20-25ϕ

Super Omega Muon Line at J-PARC, Details by Nakahara



- **Injection part**

  2 normal solenoid ~ 400mSr (typical magnetic field 0.3T)

  Residual magnetic field on the proton beam line ~ 10G

- **Transport part**

  Curved superconducting solenoid (~2T)

  Reduction of neutral background

  selection of charged particle

- **Extraction part**

  Dai Omega type axial focusing channel

  strong focusing at the experimental position

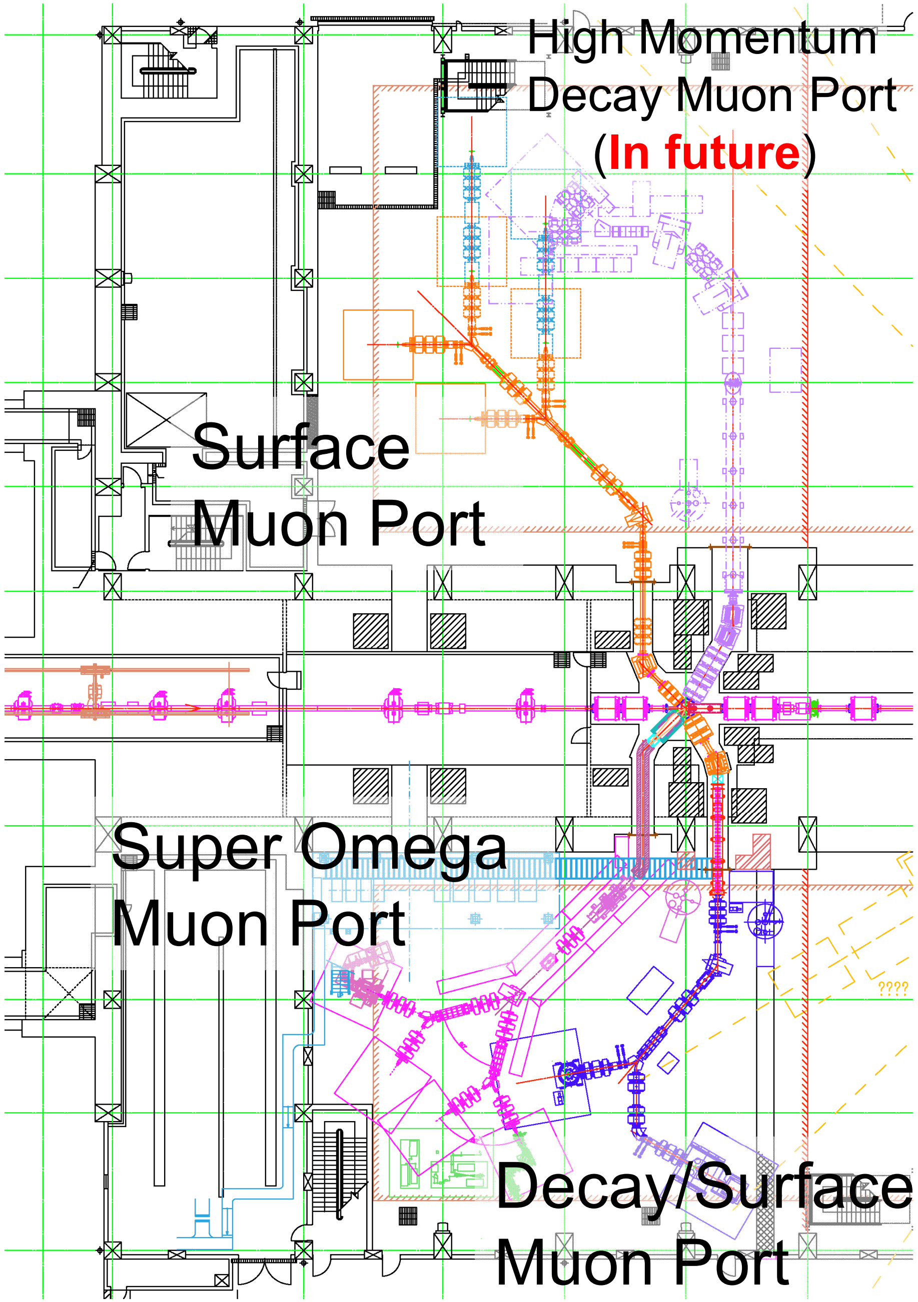
  selection of muon and positron by electric separator

Beam shift along path calculated by Ishida

surface μ^+
~5×10^8/s

cloud μ^- (30MeV/c) ~

Muon Beam available at J-PARC Muon



1)Decay/Surface Muon Port (Phase 1 with PS movement budget)

	Surface Muon (μ^+)	Decay Muon (μ^+,μ^-)
Beam EnergyÅ@	4.1MeV	5-50 MeV
Å@Implantation Depth	~ 0.2 mm	1 mm - ~ cm
Energy Distribution	~15%	~15%
Pulse Width	~100 ns	~100 ns
Beam Size	30 mm x 40 mm	70 mm x 70 mm
Intensity	3 x 10^7/s	$10^{6\text{-}7}$/s
Beam Port	2	2

2)Surface Muon Port (Phase 1')

	Surface Muon (μ^+)
Beam EnergyÅ@	4.1MeV
Å@Implantation Depth	~ 0.2 mm
Energy Distribution	~15%
Pulse Width	~100 ns
Beam Size	30 mm x 40 mm
Intensity	$10^{6\text{-}7}$/s
Beam Port	4

3) Super Omega Muon Port (Phase2)

	Ultra Slow Muon (μ^+)	Cloud Muon (μ^-)
Beam EnergyÅ@	0-30 keV	4 MeV
Å@Implantation Depth	0 nm - 200 nm	?
Energy Distribution	<< 1 %	?
Pulse Width	8.3 ns(present) --> ps	~100 ns
Beam Size	3x4mm(present) --> 1 ϕ	?
Intensity	2-5 x 10^5/s	10^7/s
Beam Port	2	2

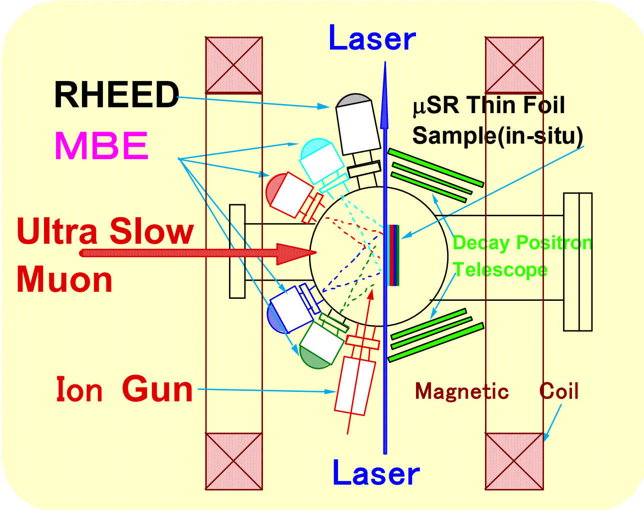
Planned Experiments

Unique Features of Pulsed Muon

(1) **Long-time range measurements** can be realized for muon - associated events, such as muon decay or μSR.

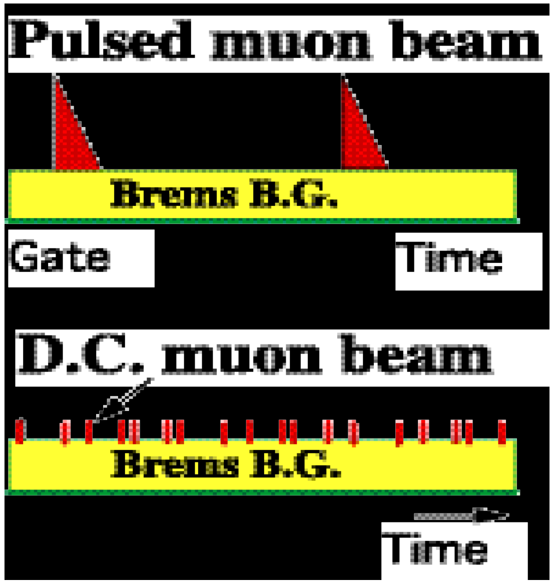
(2) **Coupled with extreme experimental conditions**, such as muon spin RF resonance and laser resonance etc., in the **pulsed** mode.

(3) **Phase-sensitive detection** of weak muon-associated signals can be achieved **under a large white-noise background**.



Complementary to Continuous Beams

(PSI, TRUMF)



Variety of Scientific Research Subjects

with use of the World ***strongest pulsed*** μ^{+-} ***Beam***

1) Extending to the tiny volume like small crystals or gaseous samples

2) Observe dynamics every one minute

Proposal and LOI etc.

MuSAC1,II,III,IV(2003,2004,2005)
LoI (2006.1.31)

Muon fundamental physics

(MuSAC1;Nakamura TOHOKU,Nagamine）

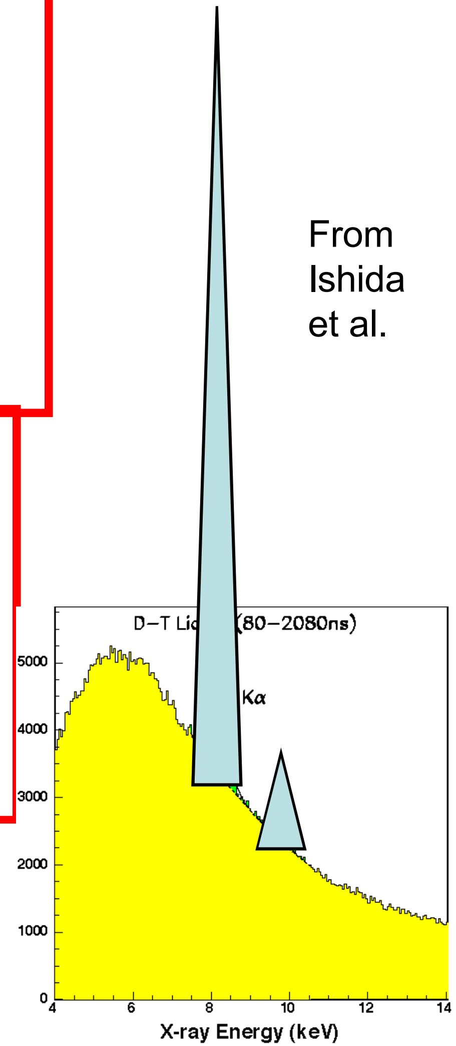
- Hydrogen μ-Capture
  - μ- life, ortho-para transition rate in ($p\mu p$)
- Mu-$\overline{\text{Mu}}$ Conversion
- High Precision Spectroscopy of Mu
  - （1s−2s transition）

Negative muon

μCF（RIKEN、KEK：Ishida, Matsuzaki, Kawamura)
1）UNDER High temperature, High Pressure
2）$d\mu^-$、$t\mu^-$—muonic Xray Kα,Kβ,Kγ precise measurement
3）α–capture precise measurement
4）$(\alpha\mu^-)^+$ Beam extraction
5）Laser resonance

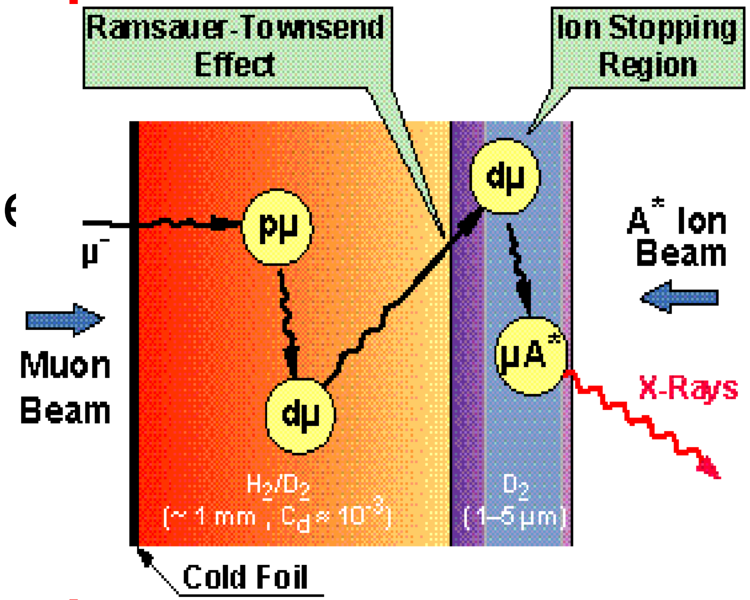
Muonic atom chemistry、chemical reaction、electric state (Osaka ：Shinohara）
1）X-ray measurement Z−1
2）Chemical reaction□Difference between μ^-Ar, Cl
3）Laser resonance

Application Nondestructive 3-dimensional analysis（ICU:Kubo et al.）



Negative muon

Radioactive muonic atom
（KEK:Strasser）
1）muonic X-ray
2）charge distribution of Radioactive nucle
　　nuclear structure（direct measure of Quadrupole momentum）
　　Radioactive nuclei in solid hydrogen target（anormalous diffusion dμ）



μSR with negative muon （KEK:Shimomura）
1）local hyperfine field at Oxygen site
2）Z−1 impurity electric state and effect in semiconductor Nitrogen atom in ZnO（ using laser）

Positive muon

◎High temperature superconductivity cuprate (Tohoku Koike)
◎ μSR study of organic conductor under high pressure(Riken Ohira)
◎ μSR study on 4f, 5f electron system（JAEA:Hefner,Higemoto）
——— Development and methodology———
◎ μSR study under High pressure,/ ◎ Internal field distribution by RF-resonance High Time resolution by RF (KEK:Kadono)
◎ GHZ resonance (RIKEN:Watanabe)

◎ Application to industrial study(Thermo-electrics, Proton conductor, Li battery materials, H storage materials)

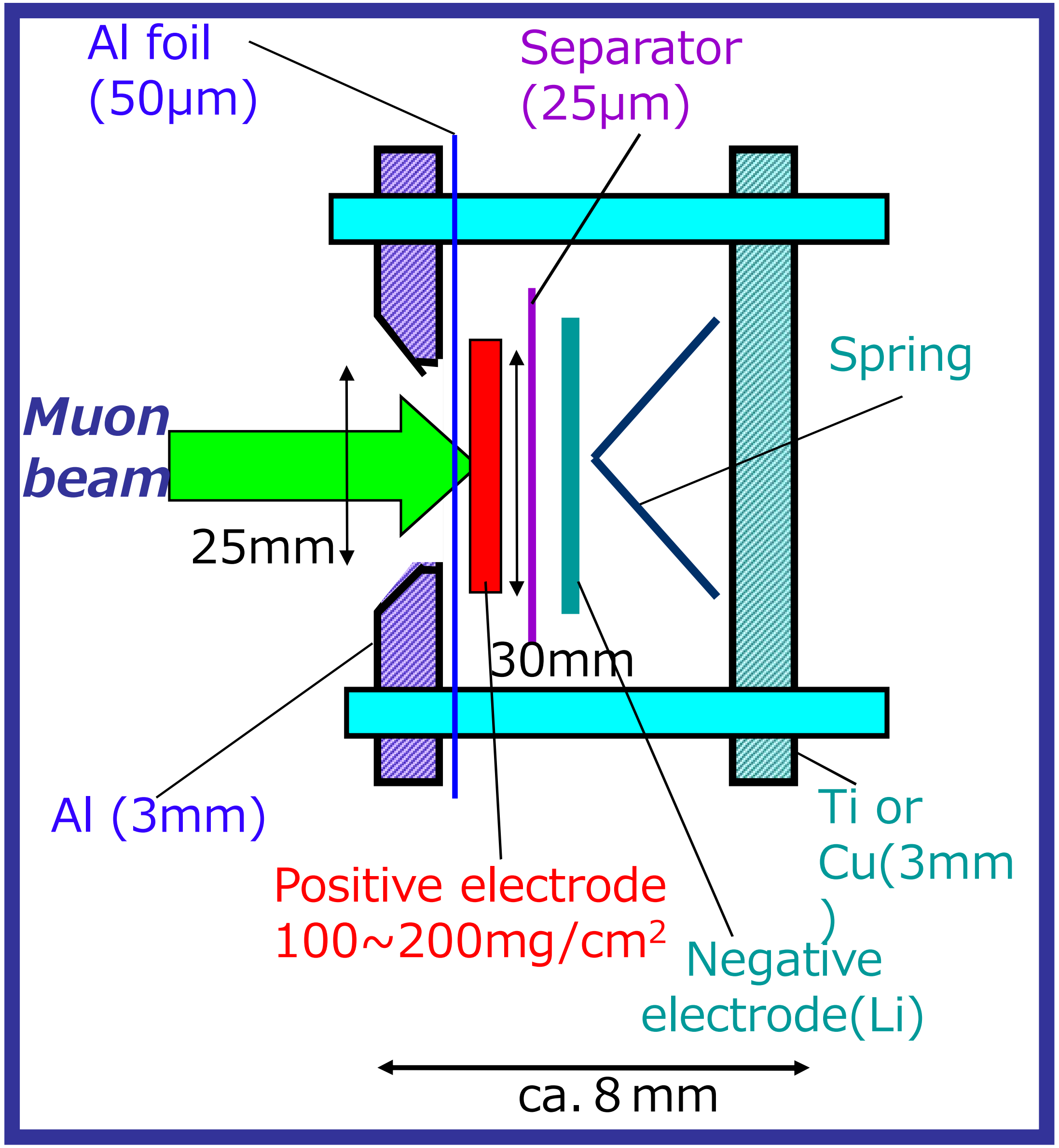
Li battery materials; current & future

- Li_xCoO_2
- Li_xNiO_2
- $Li_xMn_2O_4$

In-situ μSR

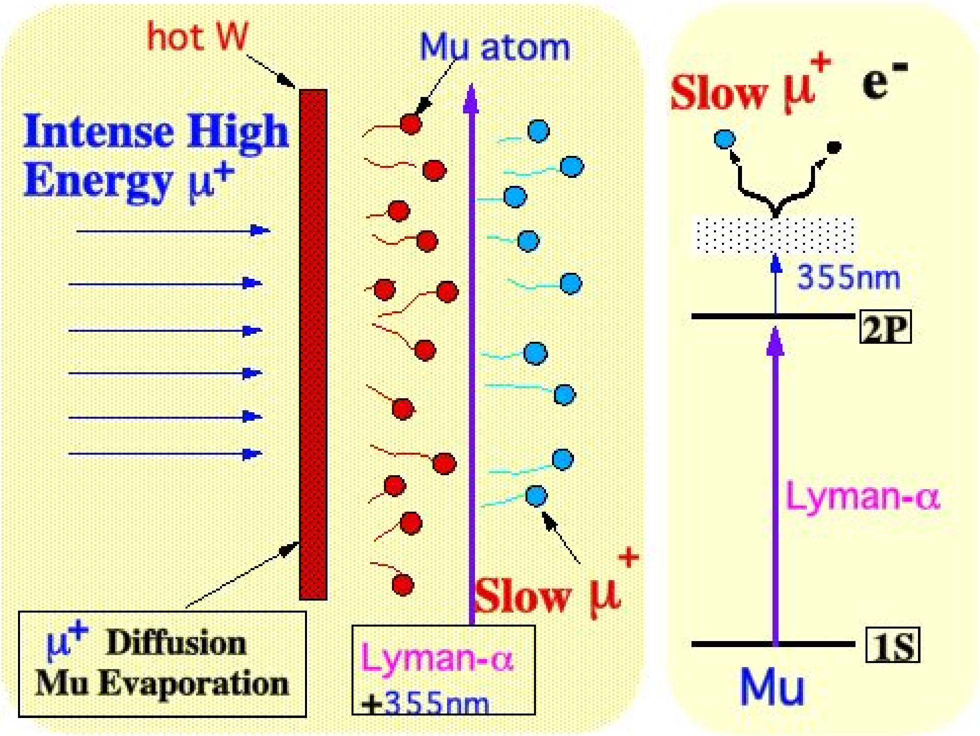
TF-, ZF-, LF-

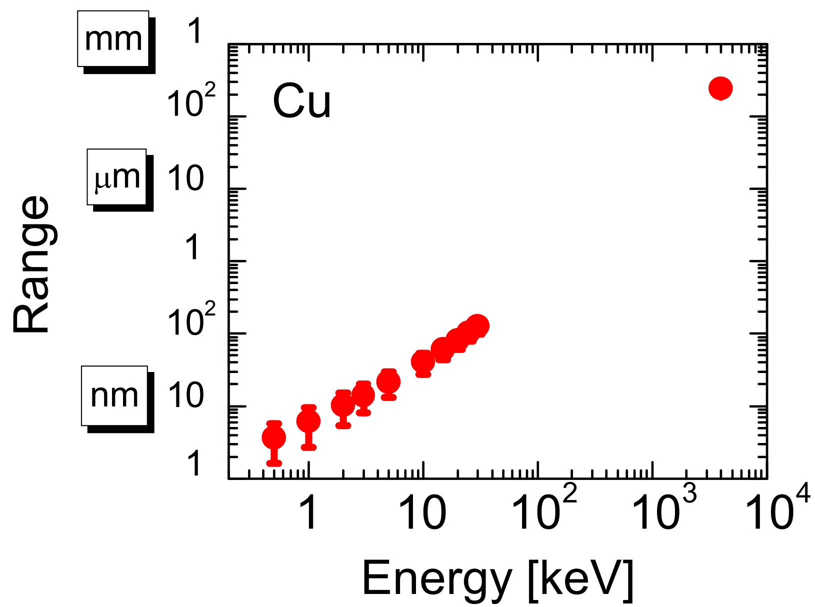
We expect that J-PARC μSR provides really in-situ information on Li batteries.



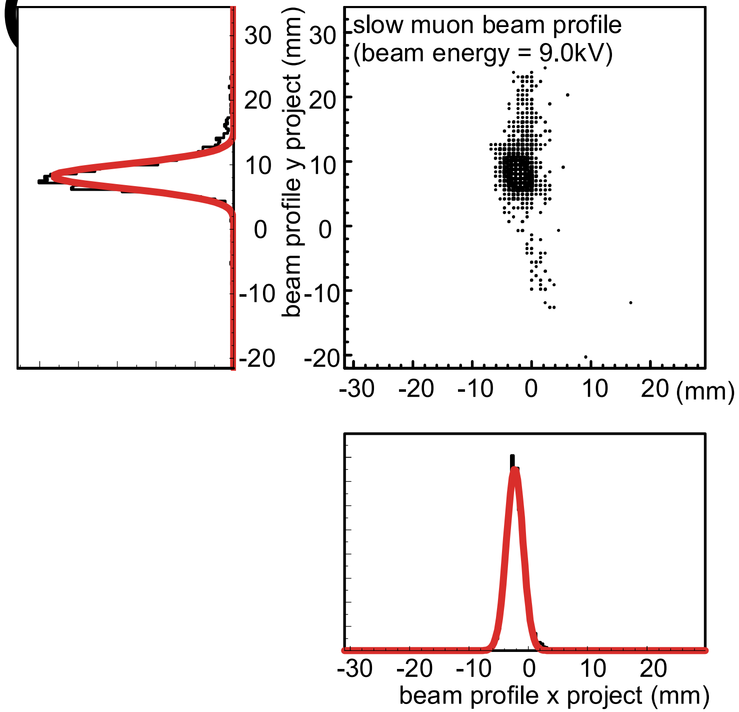
Ultra Slow muon *developed at KEK & RIKEN-RAL*

◎ μSR study on nano-structure（Osaka：Nozue，MuSAC3)
◎ Surface and interface studies of superconductors and magnetic materials with ultra slow muon （TIT, Nishida）
◎ Study on Magnetic multilayer with ultra slow muon（Riken：Matsuda, KEK Miyake）





Super Omega Muon Line at J-PARC



Yield Estimation (Expected)

Solid Angle	400mSr
Momentum Width	4~10%

surface μ^+	**~5×10^8/s**
cloud μ^- (30MeV/c)	**~1×10^7/s**

Science

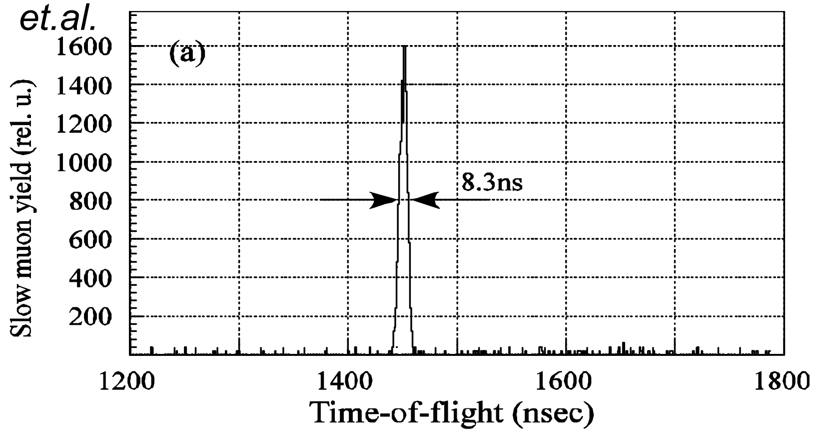
Ultra Slow Muon with laser > **2×10^5/s**

Muon micro beam

Muonium spectroscopy

Application to neutrino factory

The beam width was **4.4mm (x-axis)** and **3.2mm (y-axis)** with 9.0keV beam energy.
Demonstrated at RIKEN-RAL by Matsuda et.al.

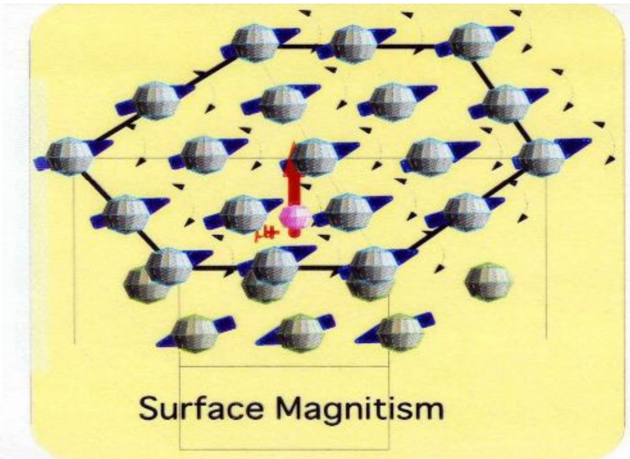


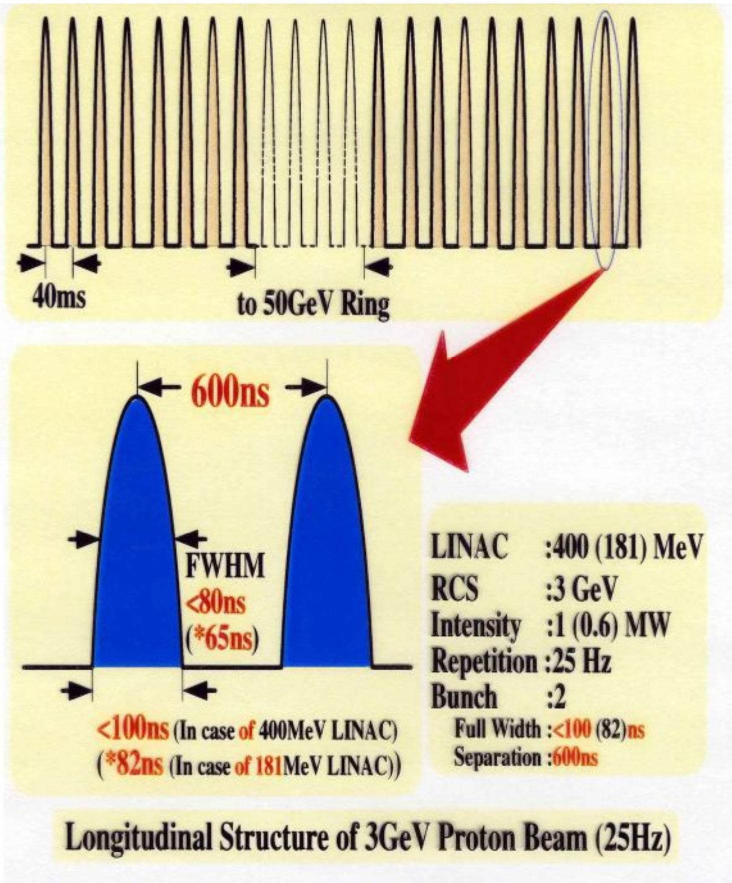
Ultra Muon Source at J-PARC (Phase 2)

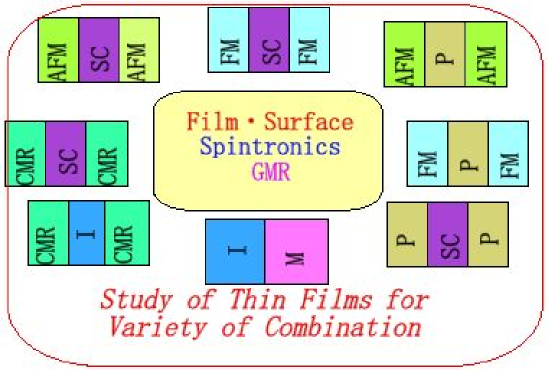
	Surface Muon	Ultra Slow Muon
Energy	4.1MeV	0-30 keV
Å@Implatation depth	aboutÅ@ 0.2 Å@μm	0 nm - 200 nm
Å@Energy Distribution	about 15%	<< 1 %
Temporal Width	> 100 ns	8.3 ns --> ps
Beam Size /Sample Size	30 mm x 40 mm	3mm x 4mm --> 1 ϕ

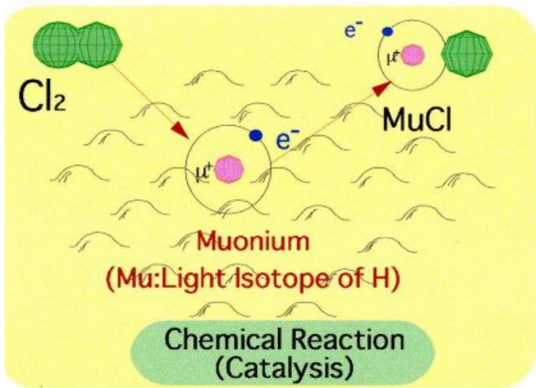
Intense Slow μ^+ source

> 200000 μ^+ /s (@ Phase2)

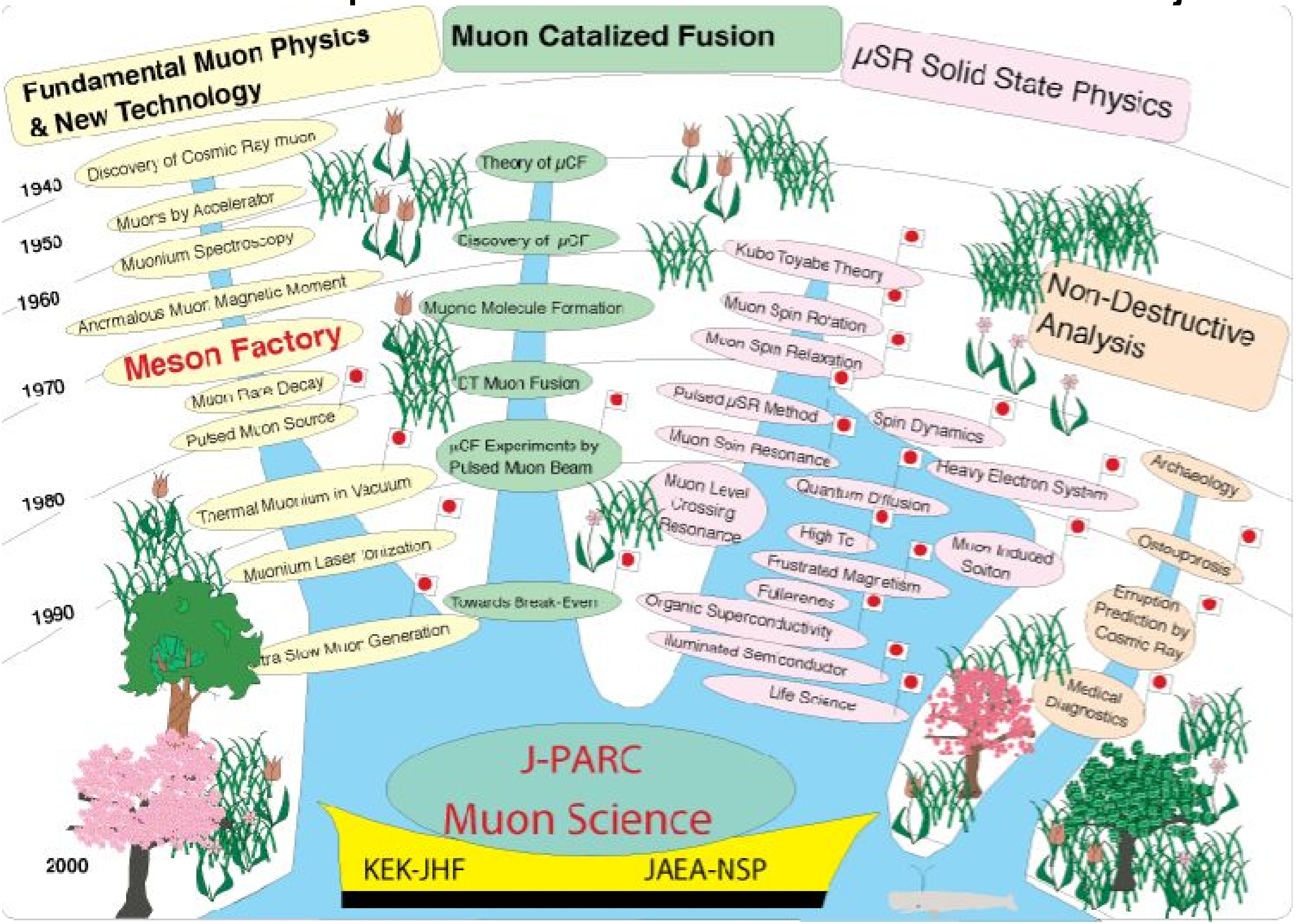








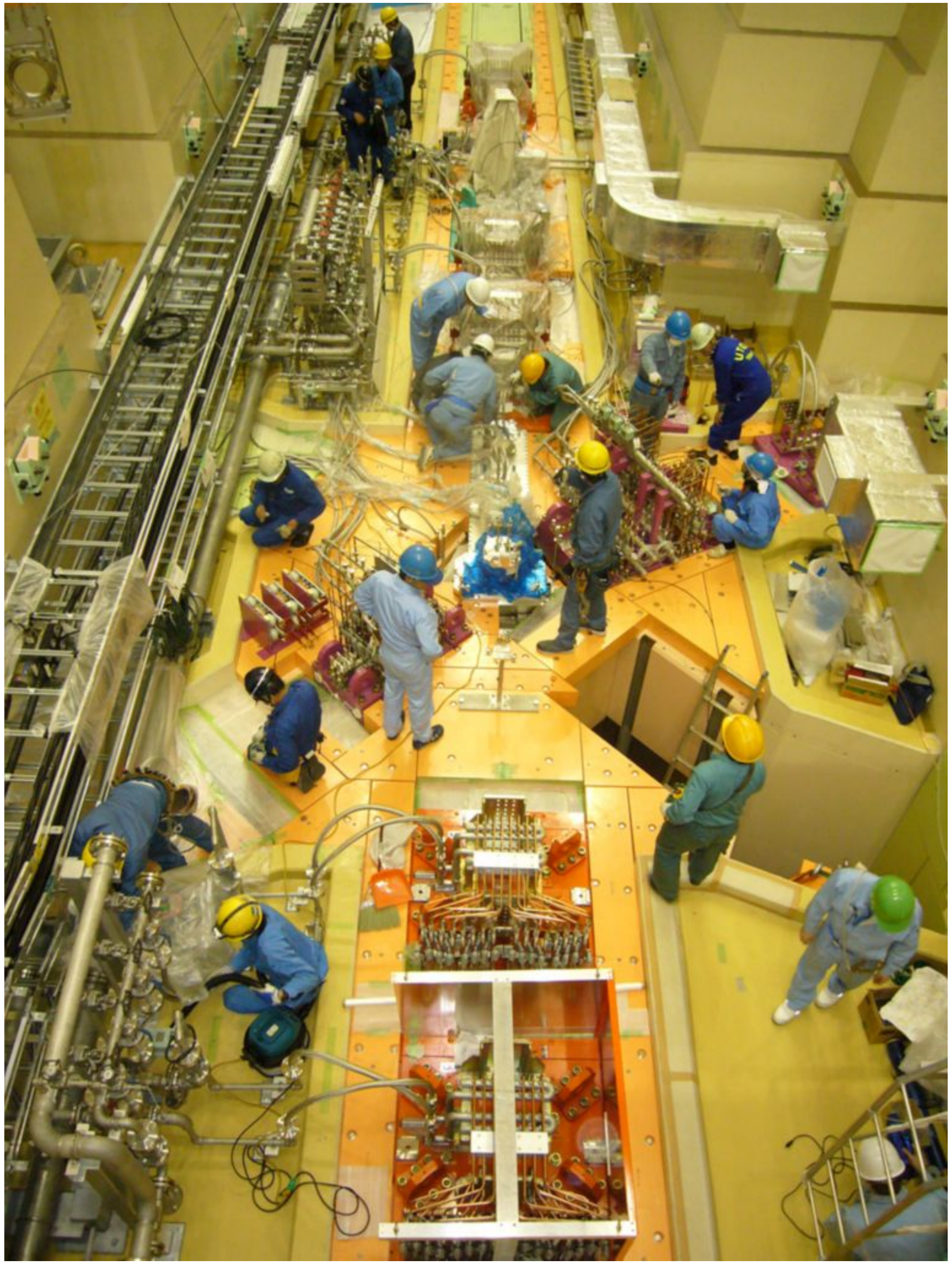
Historical Development of Muon Science towards the J-PARC Project



Summary

- Installation of the proton beamline components were almost completed.
- Decay/Surface Muon Beams will be available at May, 2008.
- Ultra Slow Muon Beam Channel and Surface Muon Channel; we are preparing!
- Welcome to J-PARC muon,

  for your participation !




Hadron Experimental Hall
Materials & Life Experimental Hall
50 GeV Synchrotron
Neutrino Experimental Area
3 GeV Synchrotron
ADS Area
Linac
November, 2006