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

Generation of Ultra Slow Muons

(Extraction and polarization)

Grants-in-Aid; Frontier of Materials, Life and Elementary Particle Science Explored by Ultra Slow Muon Microscope
Lead by Prof. E. Torikai

KEK-IMSS/J-PARC Center

Y. Miyake

Grants-in-Aid; Frontier of Materials, Life and Elementary Particle Science Explored by Ultra Slow Muon Microscope

Lead by Prof. E. Torikai

新学術領域研究：**超低速ミュオン**が拓く物質・生命・素粒子科学野フロンティア（鳥養映子代表）

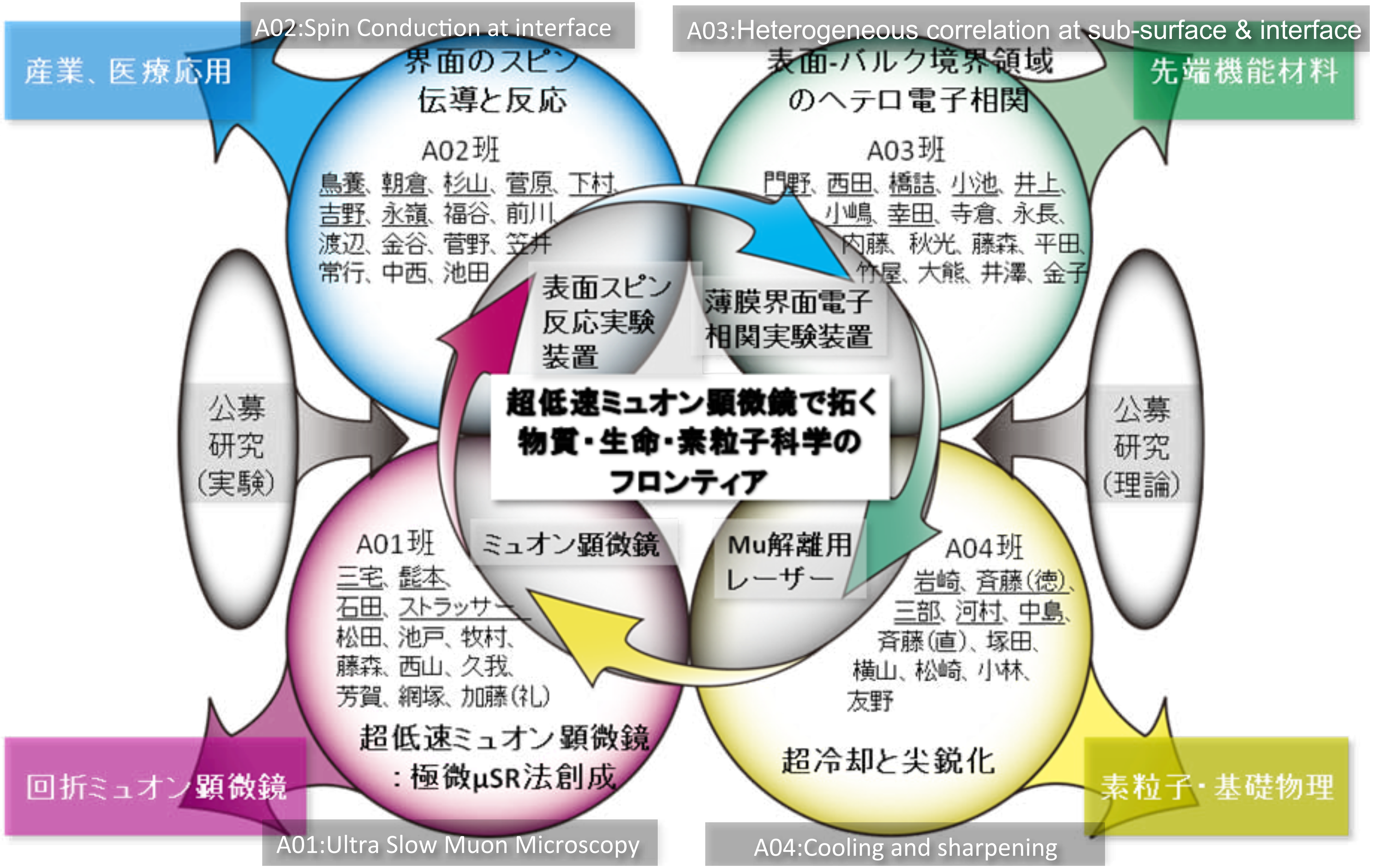
A01:Ultra Slow Muon Microscopy & Microbeam (Y. Miyake)

A02：Spin Transport and Reaction at Interface (E. Torikai)

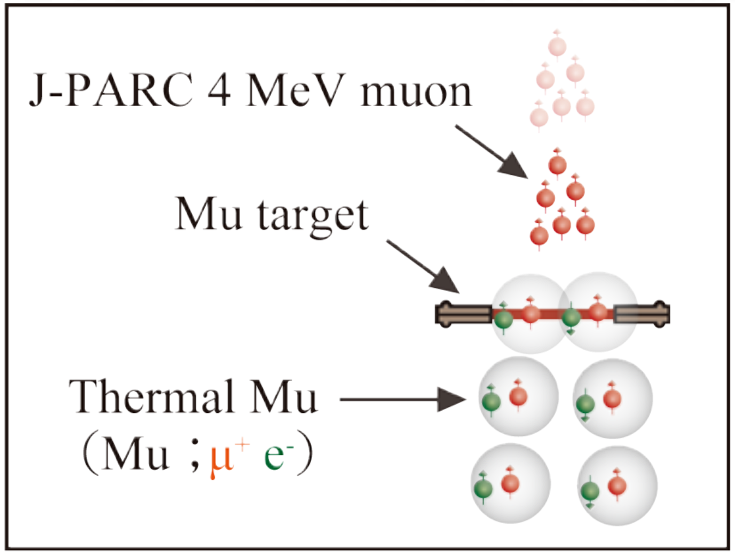
A03：Heterogeneous correlation of electrons over the boundary region between bulk and surface (R. Kadono)

A04:Ultra Cold Muon beam (M. Iwasaki)

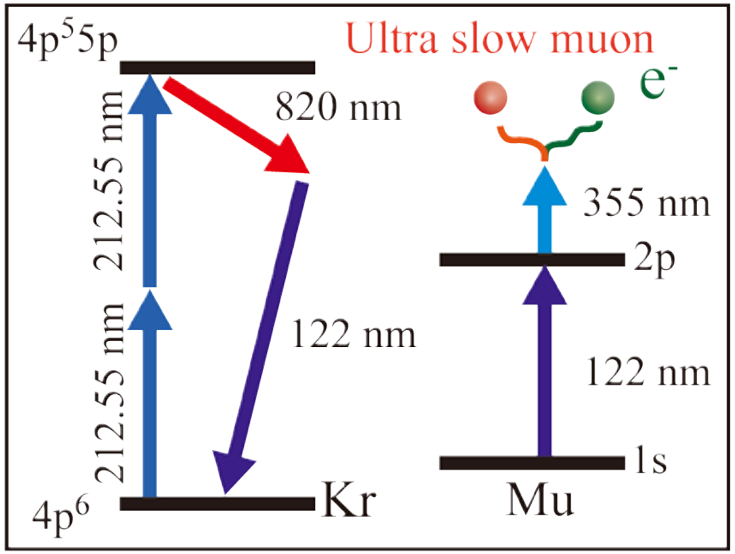
***Grants-in-Aid*; Frontier of Materials, Life and Elementary Particle Science Explored by Ultra Slow Muon Microscope Lead by Prof. E. Torikai**



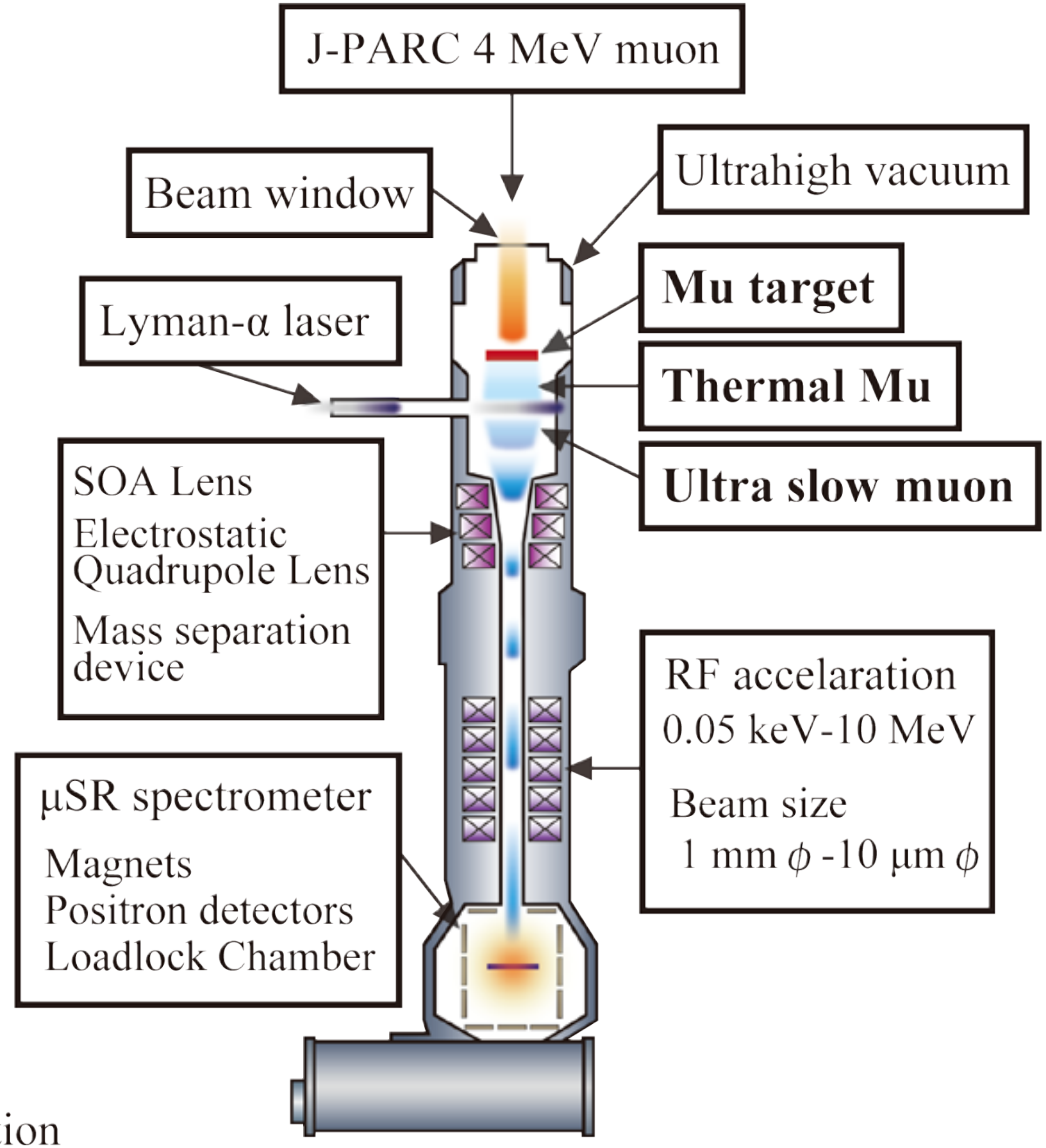
A01：Microbeam: Muon Microscopy



Mu generator



Lyman-α laser generation and Mu dissociation by laser resonant ionization method



A01：Microbeam: Muon Microscopy, requiring only μg to ng sample

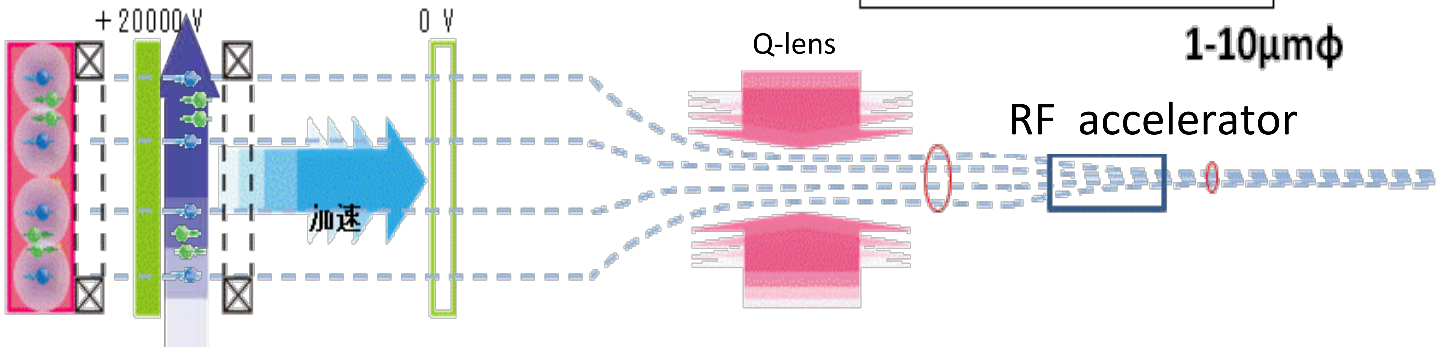
Ordinary muon beam

Beam is scraped away
by beam slit or collimeter.
Beam size >a few cm.
Beam intensity is reduced.

So far, requires 1 g sample

ultra-slow muon

Beam Focusing



Reduction of
beam size
without any
reduction of
beam intensity!

requiring only μg to ng sample

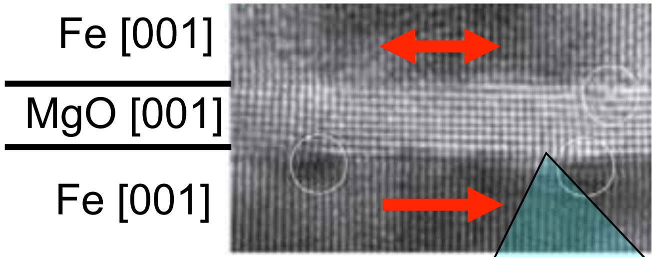
Beam size -> ~Φ70mm
Depth resolution -> a few nm

Minimum beam size -> ~Φ1μm
Depth resolution -> order of μm

Realization of muon microscope

A02 Spin Transport and Reaction at Interface

Spin direction of the Ultra Slow Muon can be easily controlled by Spin Rotator

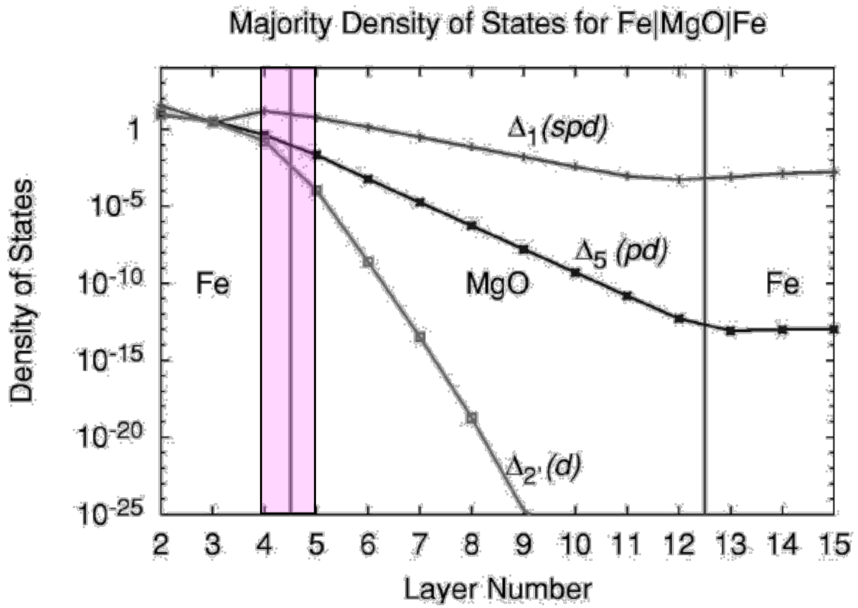


Spin implantation depends upon Atomic spin state on the boundary

磁気トンネル接合には絶縁体･強磁性体
界面のスピン状態の理解が重要

- ◆Extension towards half metal etc.
- ◆Spin Implantation to semiconductor

Observing spin state on the boundary between Ferro/insulator

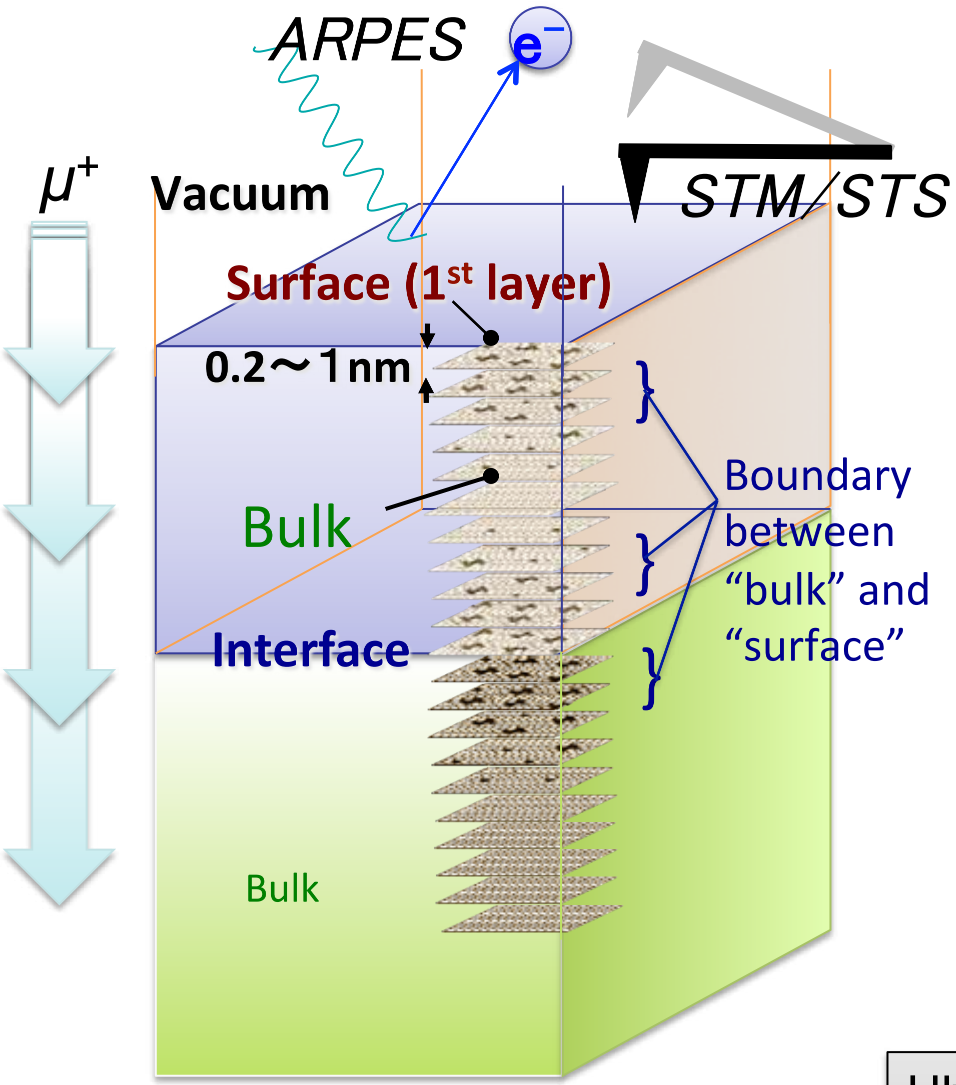


Butler et al. PRB 63, 056614 (2001).

μSR measurement in situ

According to Prof. Yoshino

A03: "Heterogeneous electronic correlation at sub-surface & interface"



Remarkable difference in the electronic property between surface and bulk

- Breakdown of inversion (mirror) symmetry at surface/interface → "Recovery of orbital angular momentum" near the surface
- Spatial constraint over the motion of electrons → "Enhancement of quasi-two-dimensional character and associated change in the electronic state

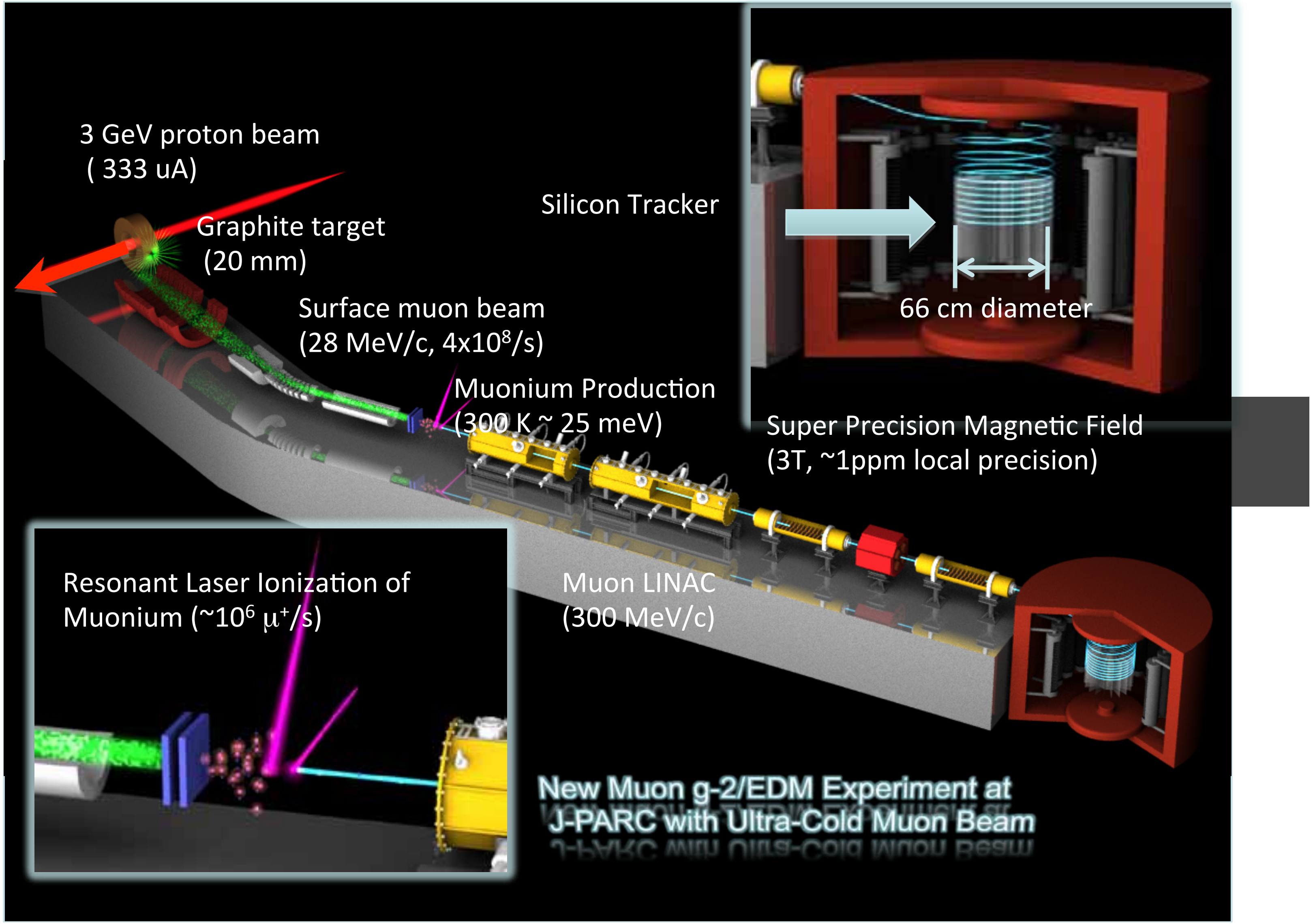
…Novel electronic property ("hetero-geneous electronic correlation") may be realized on the hetero-structure composed of transition metal compounds that are subject to strong electronic correlation.

Ultraslow muon serves as a unique tool to probe the electronic state of subsurface and interface in the real space.

A04 Ultra cold muon beam for muon g-2

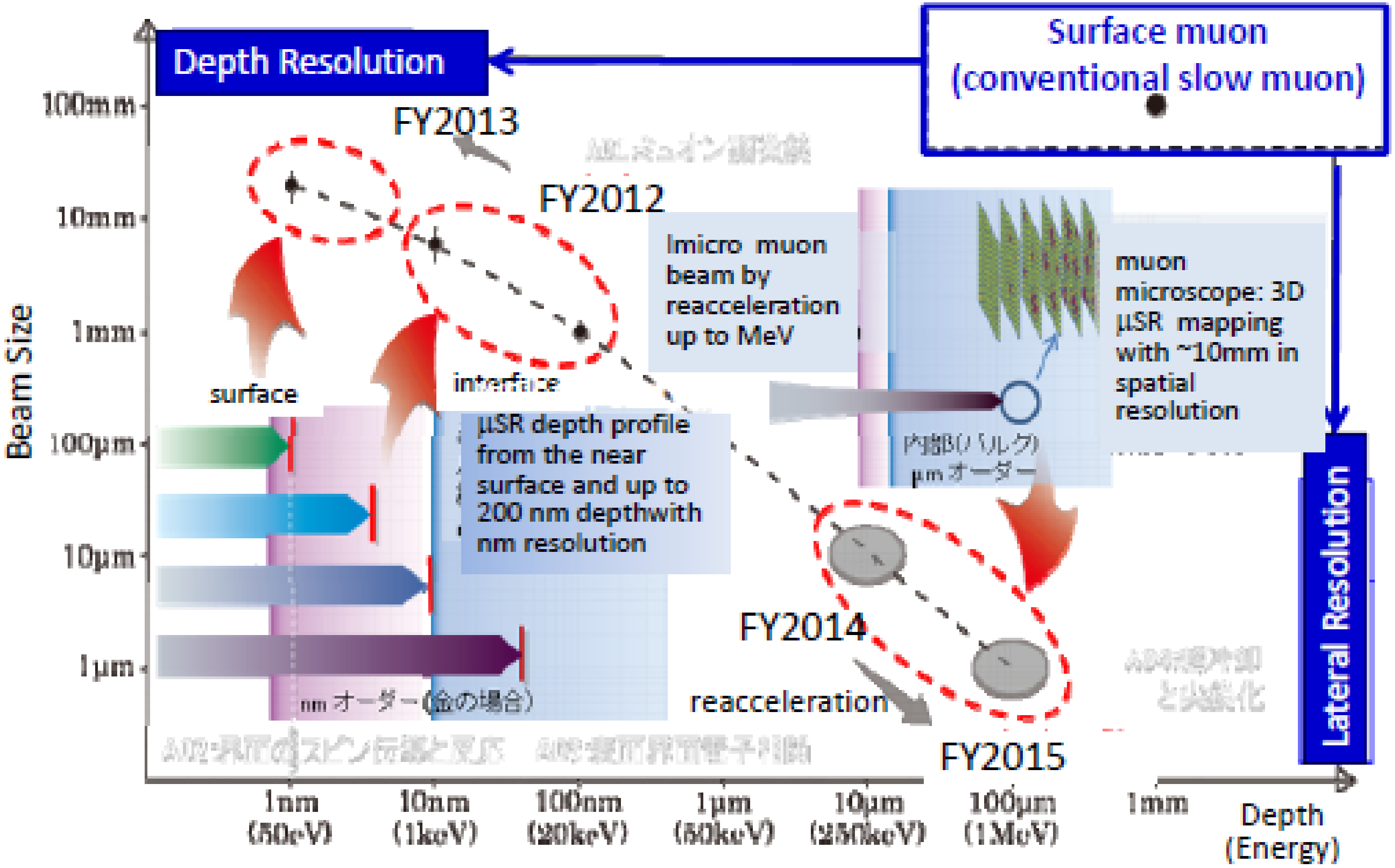
Laser Sytem!

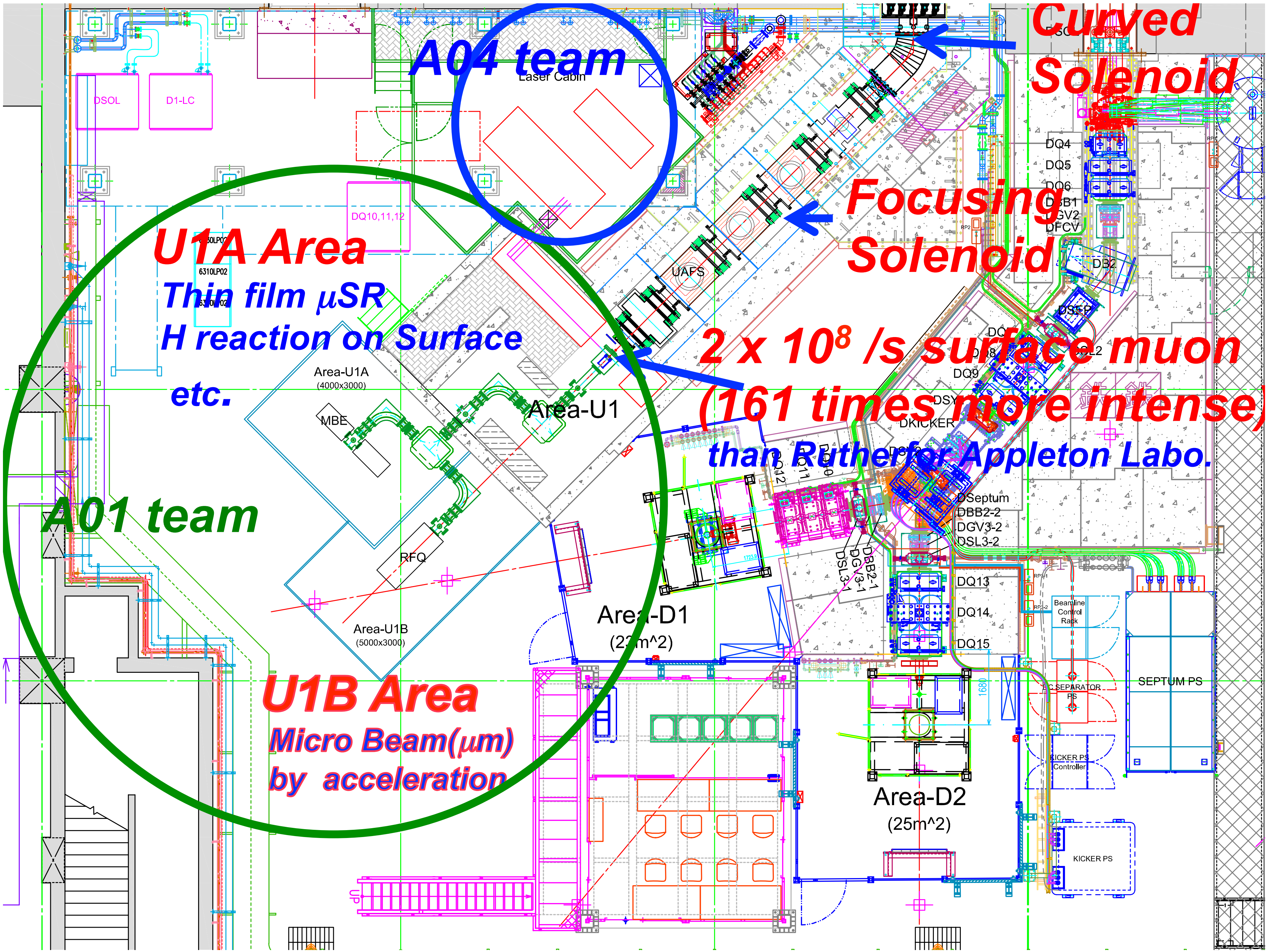
proposal P34 at J-PARC for precision study of muon g-2



Depth and Beam Size Scanned by Ultra Slow Muon Microscope

with Development Scenario





A04 team
Laser Cabin
Curved Solenoid
Focusing Solenoid
U1A Area
Thin film μSR
H reaction on Surface
etc.
2 x 10^8 /s surface muon
(161 times more intense)
than Rutherfor Appleton Labo.
A01 team
U1B Area
Micro Beam(μm)
by acceleration
DSOL
D1-LC
DQ10,11,12
Area-U1A
(4000x3000)
MBE
RFQ
Area-U1B
(5000x3000)
Area-U1
UAFS
DQ4
DQ5
DQ6
DB2
DQ9
DKICKER
DSeptum
DBB2-2
DGV3-2
DSL3-2
DBB2-1
DGV3-1
DSL3-1
DQ13
DQ14
DQ15
Beamline Control Rack
SEPARATOR PS
KICKER PS Controller
KICKER PS
SEPTUM PS
1680
Area-D2
(25m^2)

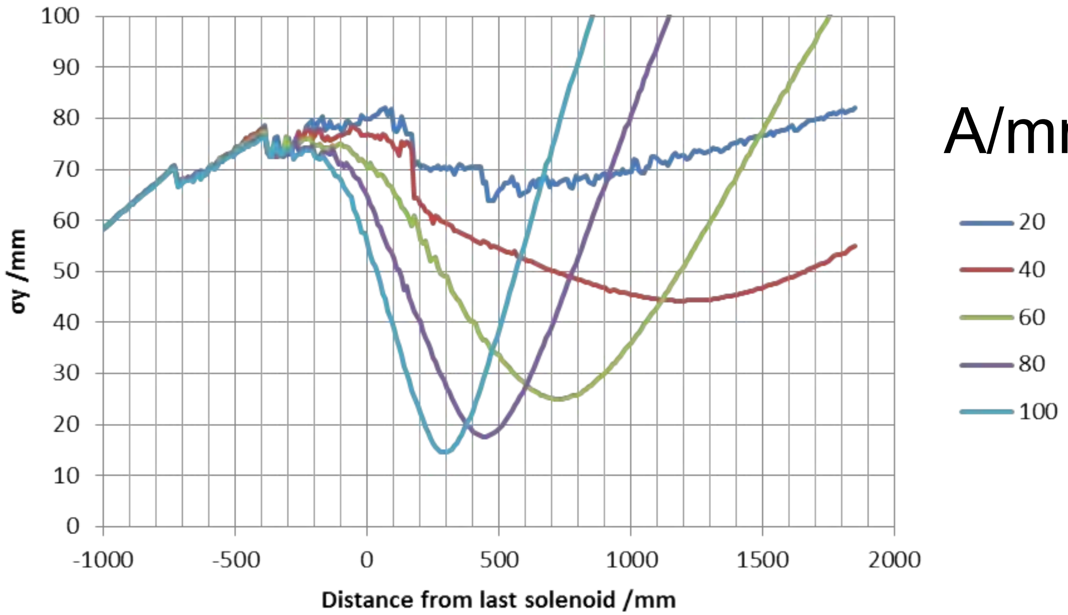
Mu Target

Surface μ^+ stopping on W

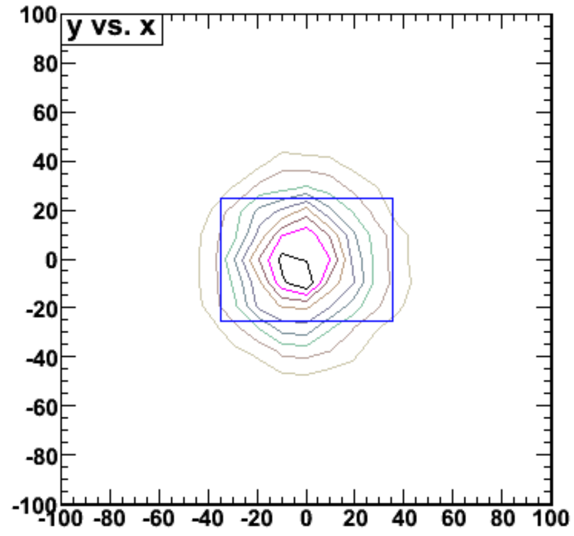
Beam size and focal length

Dependence of current density of the last coil

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



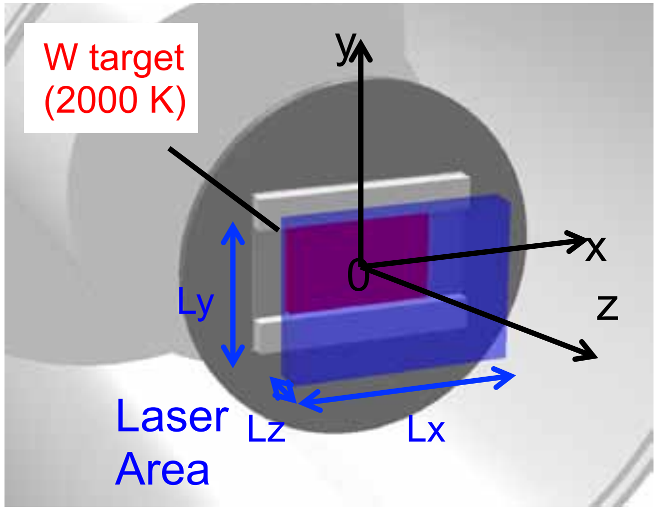
Beam profile at the final focusing point（700mm）



W Target (70 x 40 mm^2)

Intensity: **2 x 10^8 μ^+/s**, on **W** (70 x 40 mm^2)(@1 MW)
Intensity: **1.2 x10^6** (→0.5 x 10^6) **μ^+/s**, on **W** (40 x 35 mm^2)@RIKEN-RAL
1.2 x10^6/s is surface μ^+ arriving at Port3, could be less than 0.5 x 10^6/s stopping on W

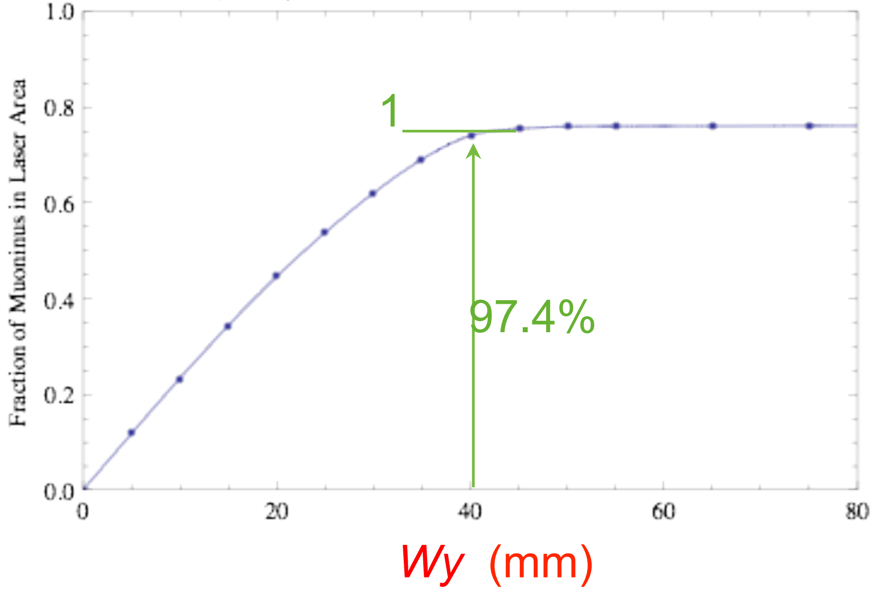
Hot Tungsten (**W**) Target Size **40** x **70** **mm²**



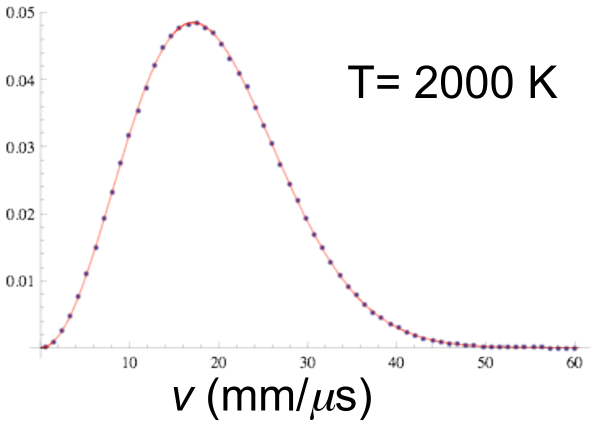
Surface muon Beam Size : 65 mmϕ (2σ)
Laser Area : Center = (0, 0, 3 mm)
*L*x 100 mm, *L*y 4 mm, *L*z 2 mm

Target Dimensions
*W*x 70mm, *Wy* : parameter

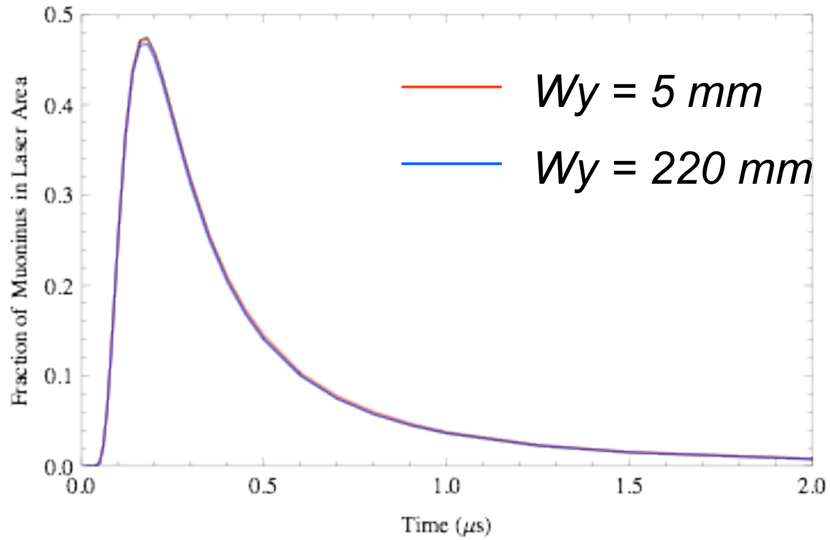
W target y-size dependene



Direction Distribution cos θ
Velocity Distribution Maxwell

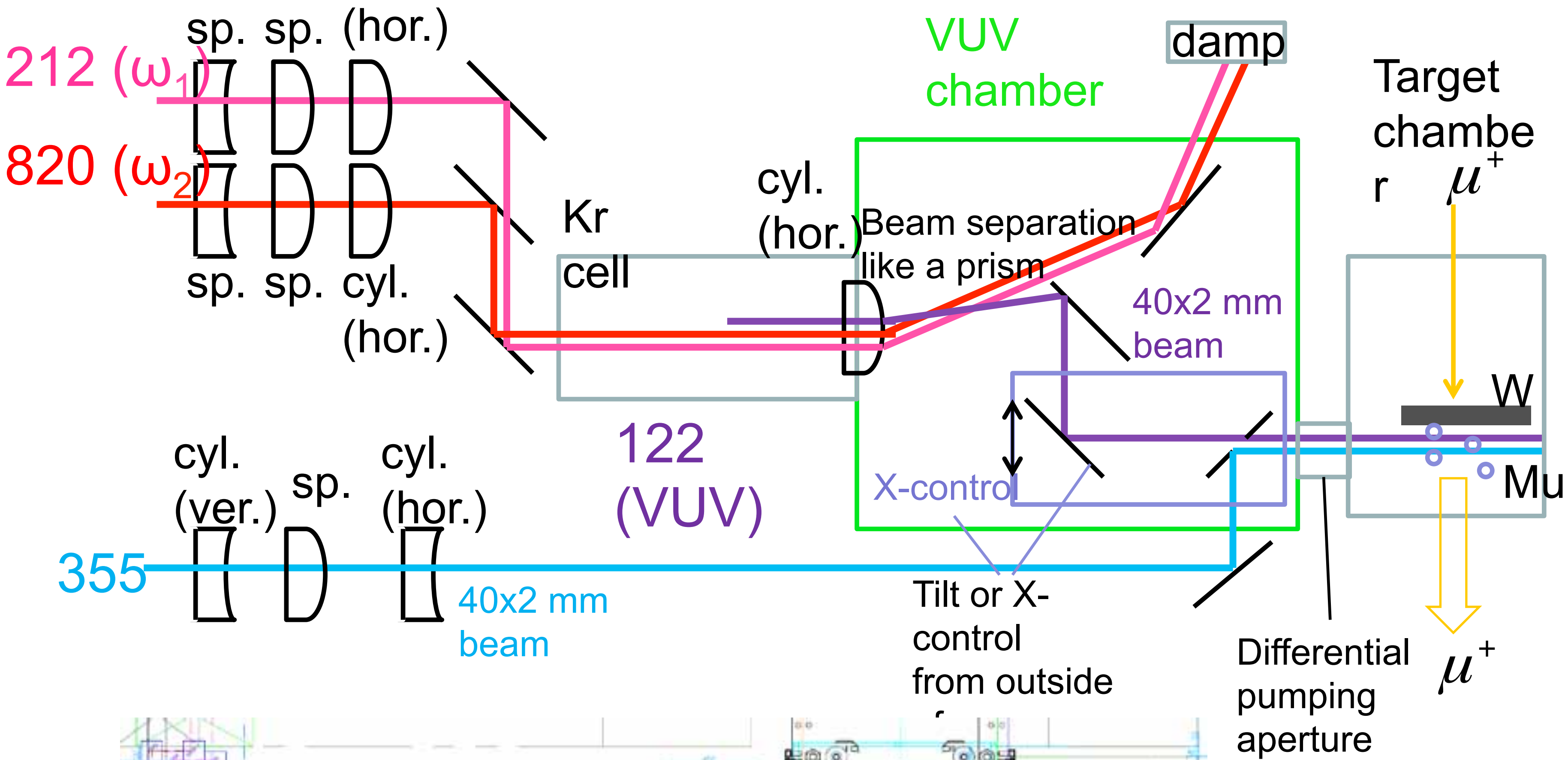


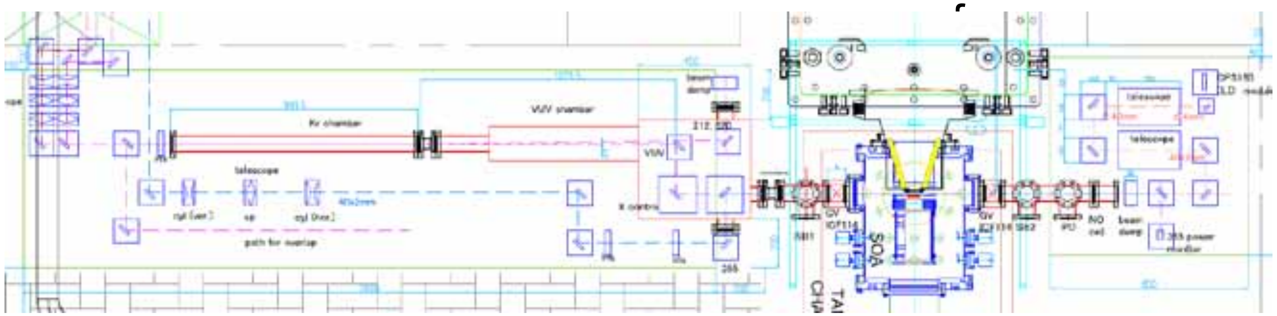
Time structure



Laser beam size designed to be 40 x 2 mm^2 on W

Schematic Diagram





Drawing

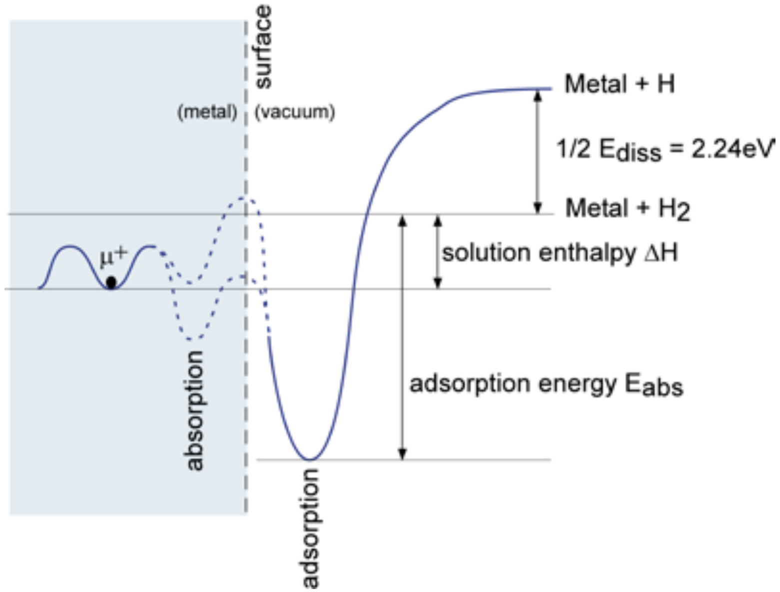
Target studies

Hydrogen solution in metals

- Extensive studies have been done for the solubility of hydrogen in metals.
- Large (positive) solution enthalpy means the work function for hydrogen (muonium) to escape from metal is small.
- But the depth of adsorption energy could play a role, as well as the height of surface barrier energy.

→ Needs experimental studies!

- Matsushita et al. studied muonium production from Iridium(Ir)[1], Platinum(Pt)[2] and Renium(Re)[3], and obtained a promising result for Iridium.
- Ruthenium(Ru) and Molybdenum(Mo) also seem promising.
- **Our system is a very sensitive muonium detector!**



	ΔH(eV/atom)	Melt point (C)
W	**0.22**	**3387**
Pt	0.20	1772
Ir	0.76	2457
Mo	0.53	2610
Ru	0.56	2250
Rh	0.28	1963
Ta	−0.37	2996
Nb	−0.37	2468
Ti	−0.47	1675
V	−0.32	1890

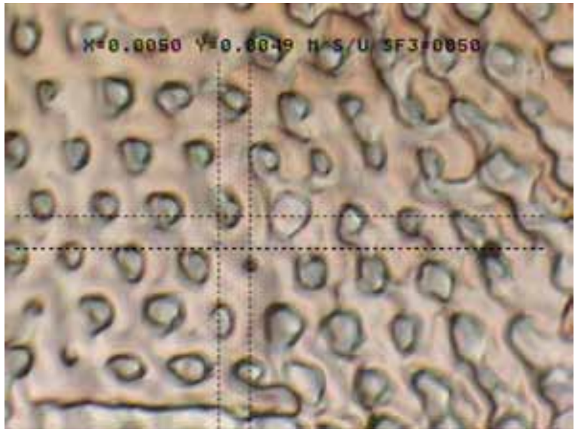
1) A. Matsushita et al. Hyp. Int. 106 (1997) 283
2) A. Matsushita et al. Phys. Lett. A 244 (1998) 174
3) A. Matsushita et al. unpublished

Target studies

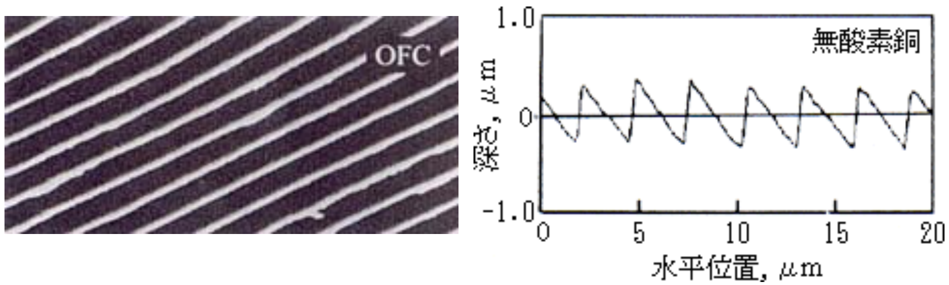
- Increasing conversion efficiency from incident muons to thermal muoniums is a straight-forward way to increase slow muon yield.
- **Micro-fabricating cryogenic moderator increased slow muon yield at PSI by 30%**

Increasing surface area...

- Etching by chemicals
- **Laser micro-fabrication : 20% increase of surface area expected.**
  (under discussion with * Ltd.)
- Micro-fabrication by a diamond cutter : 50% increase of surface area expected.
  (under discussion with * Lab.)



tungsten surface drilled by pulsed laser irradiation
(by Mr. David Wall, * Ltd.)



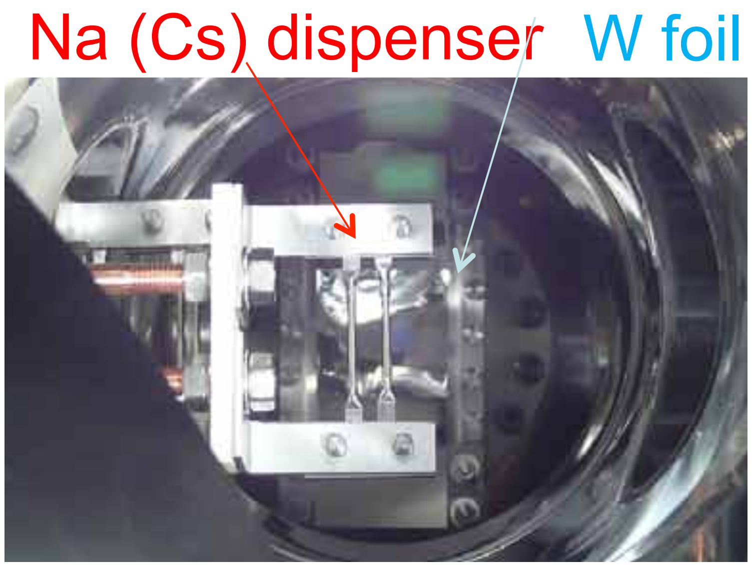
Example of micro-fabrication by a diamont cutter
(from pictures on *)

Mu$^-$ evaporation Experiments at J-PARC

Alkali Metal coating on W surface

- Lower the W-foil temperature of Mu production in vacuum
- Increase Mu production rate → **Mu evaporation at RT**

Vacuum chamber for investigating Mu production rate from W foil



Inserting Na dispenser in front of W foil

U-Line

Expected Yield of Ultra Slow Muon

20 slow muons/second at RIKEN-RAL→J-PARC, MUSE

1) Repetition Rate

25 Hz (At RIKEN-RAL *50 Hz*) factor **2 *times*** ***(1.5)***

2) Surface Muon Yield by **Super Omega Channel**

2.0 x 10^8 /s / 1.2 x 10^6 /s (RIKEN-RAL) = ***161*** *times (400)*

3) Lyman-α Intensity by **Laser Development**

71 μJ/p / <1 μJ/p (RIKEN-RAL) ~ ***100*** *times*

Our Goal of Ultra Slow Muon Yield is

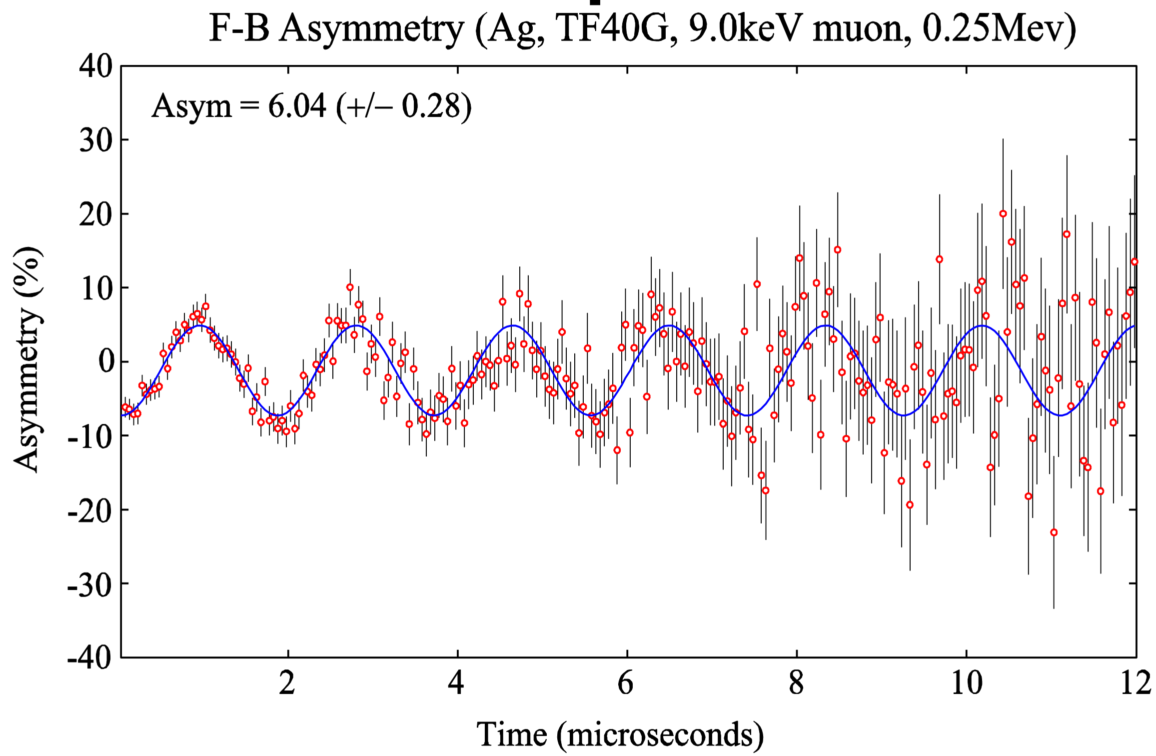
20 /s x 2 x 161 x 100 = 0.6 x 10^6/s (Maximum)

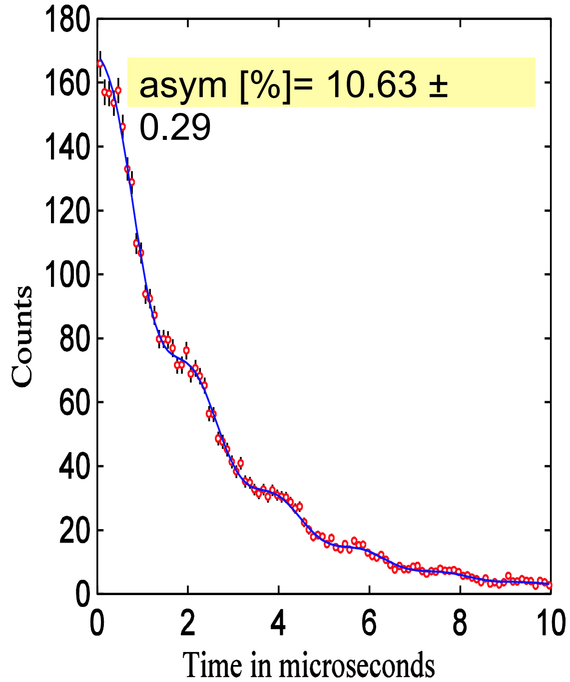
Riken-RAL Slow Muon Intensity

Started with realistically, $10^{3\text{-}5}$/s !

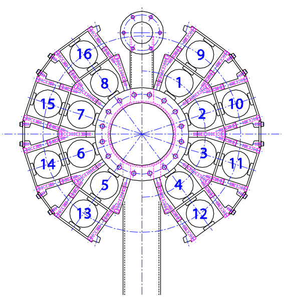
Polarization

Muon spin rotation signal

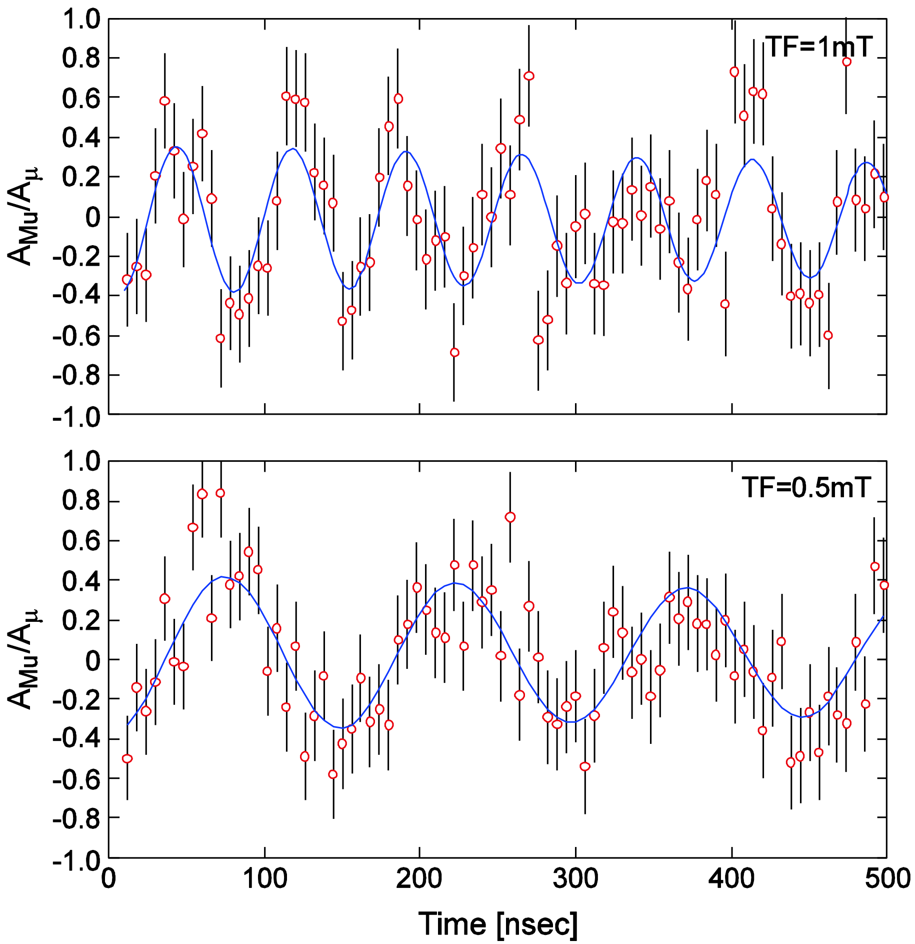




50 % polarization; only ^{T}Mu conserve its polarization!



Muonium spin precession signal in SiO_2



No observed change of asymmetry even at high frequency (14 MHz)

Recovery of muonium polarization

- Currently muonium are generated under no magnetic field, resulting loss of polarization due to triplet states are mixed up.

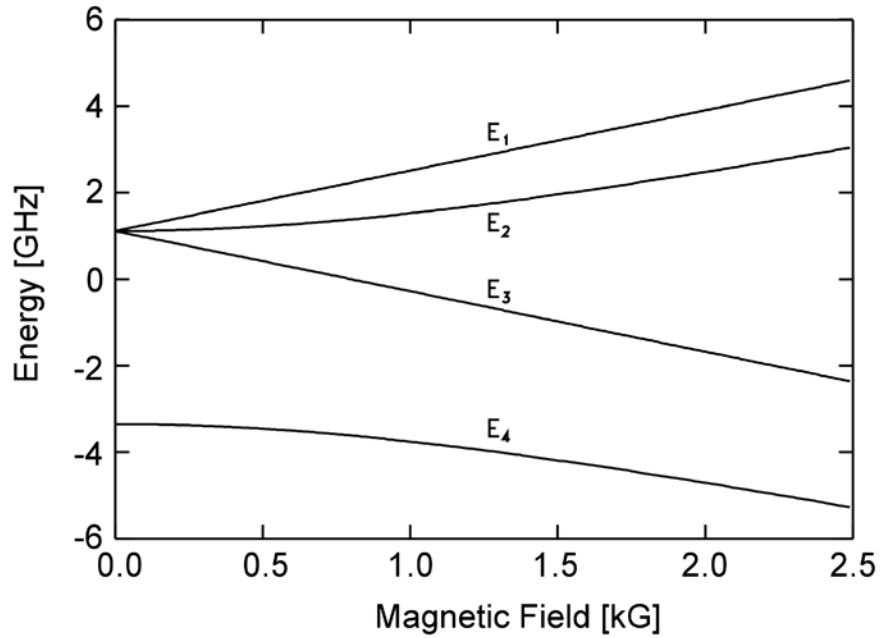
- Applying magnetic field to muonium would resolve degenerated levels.

→ less depolarization of muonium at triplet state

→ 100% polarization of muonium (Overcoming our weak side)

- Needs careful study for beam transportation, though.

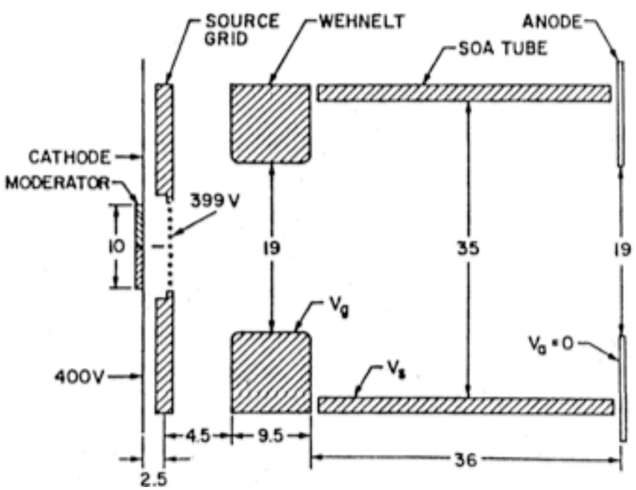
→ we have to cut a fringing field of 3kG in order to extract!

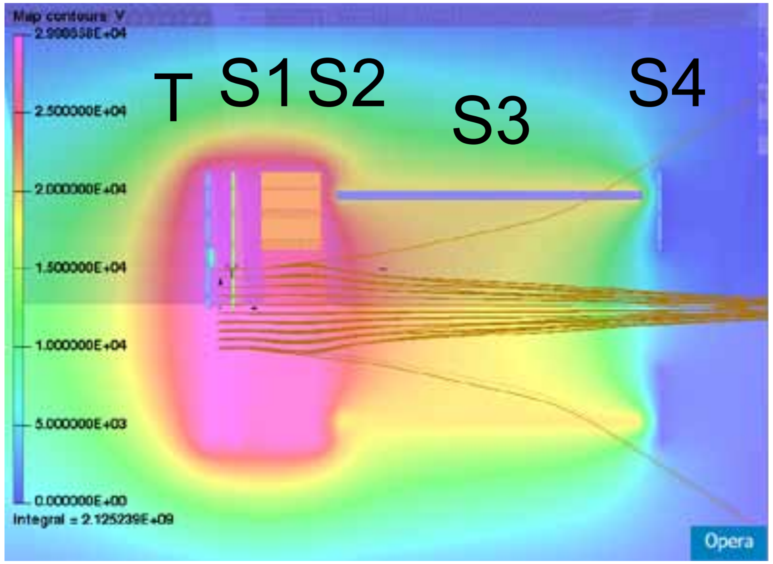


Extraction

Extraction and acceleration of ultra slow muon

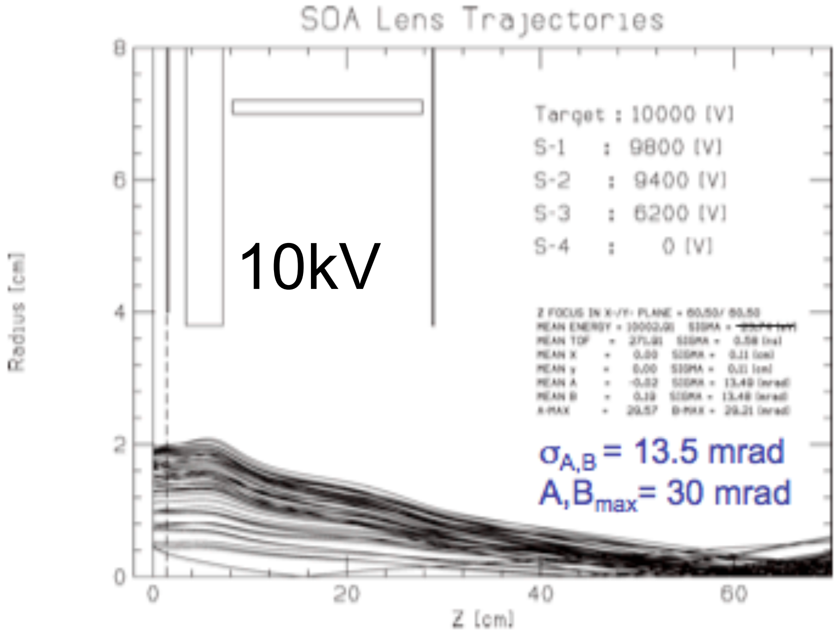
The SOA Lens



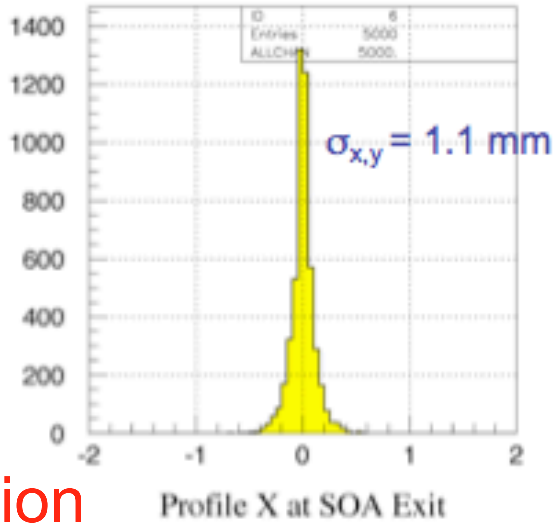


Electric Potential induced by electrodes of the present SOA Lens

T = 30.0kV
S1 = 29.8 kV
S2 = 28.5 kV
S3 = 18.8 kV
S4 = 0 V

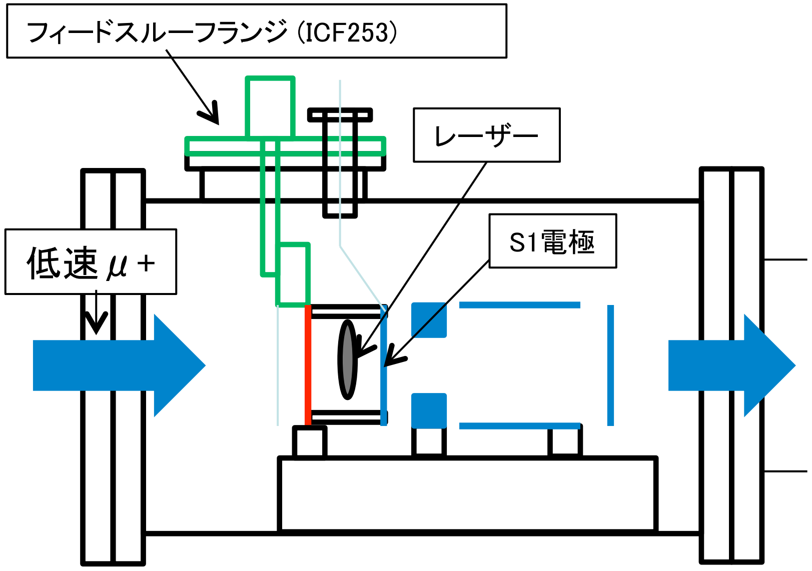


ε(3σ)=90mm•mrad

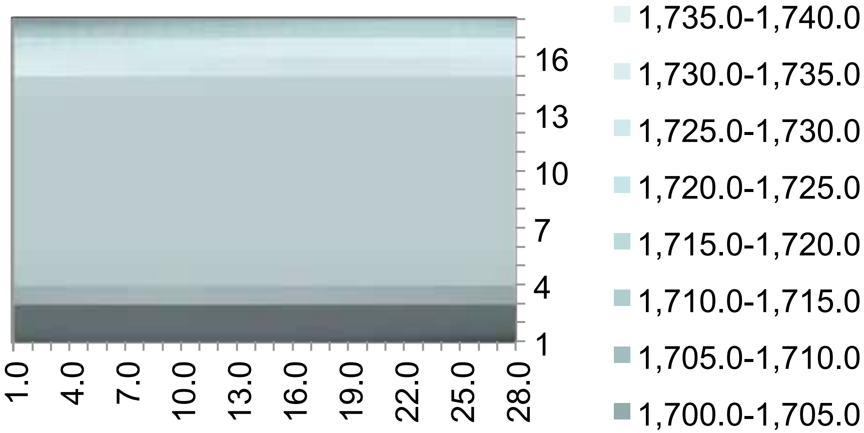


Need optimization in the case 30kV

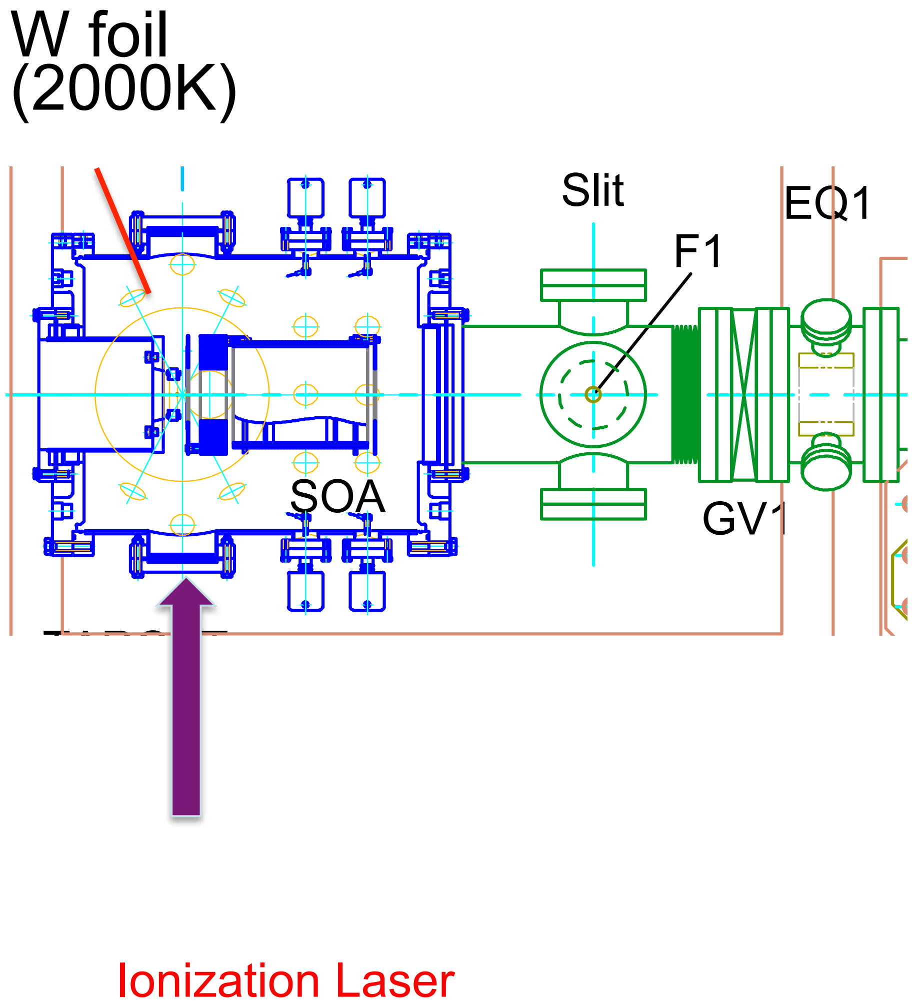
Design and Fabrication of Mu chamber, Slow Ion Optics



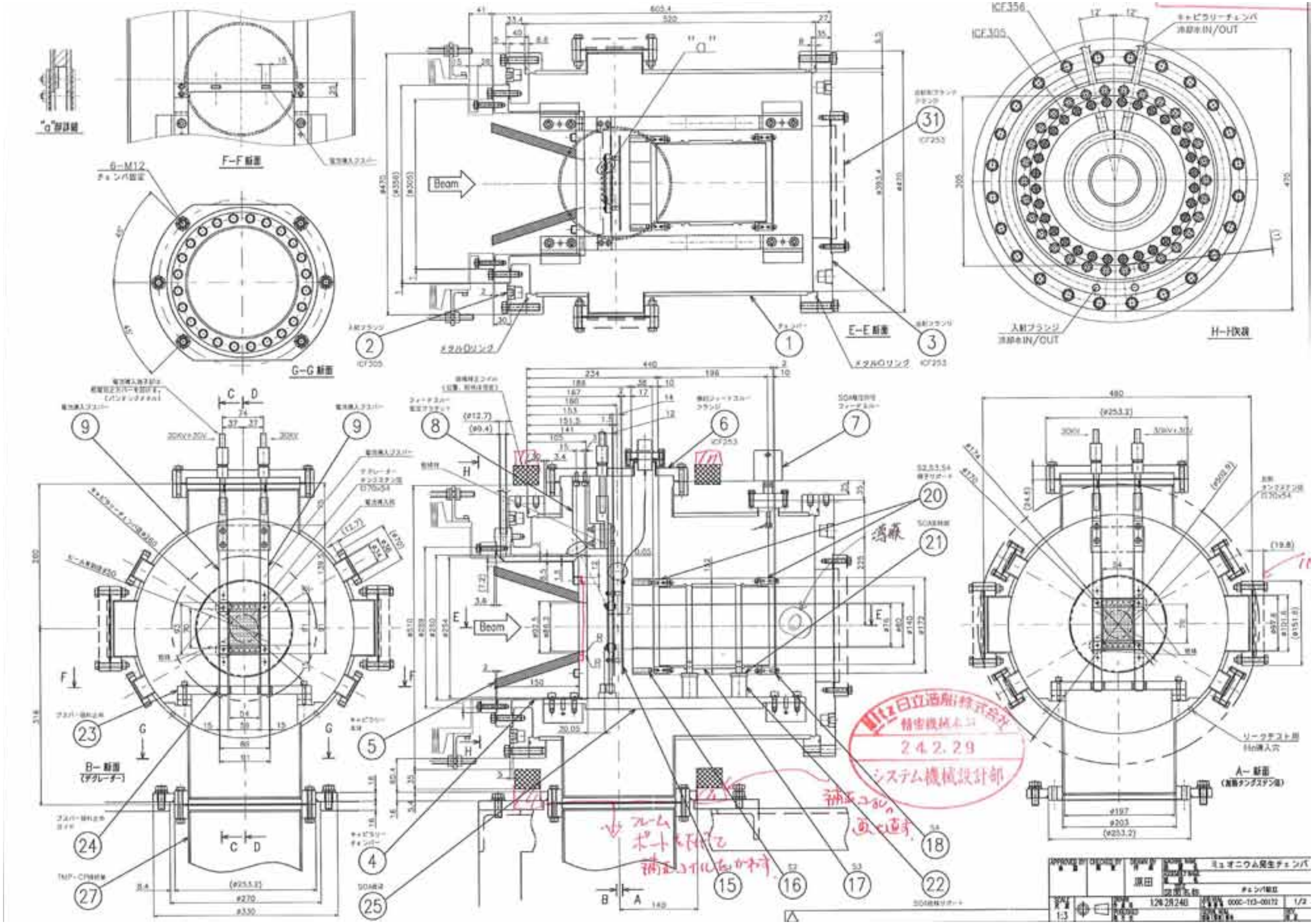
タングステン標的チェンバ側面図（今回の方式）



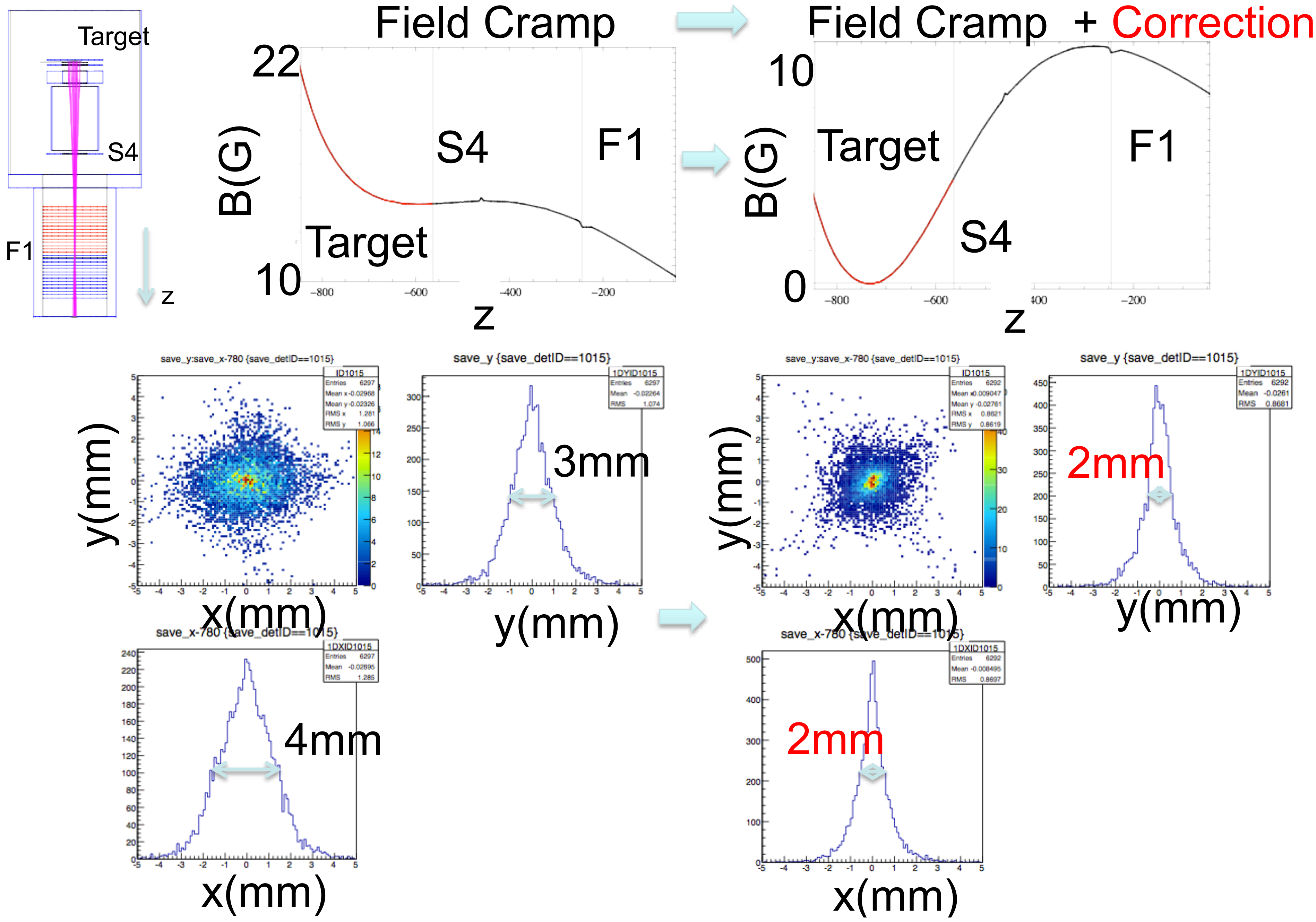
Temperature Distribution on W



Design and Fabrication of Mu chamber, Slow Ion Optics

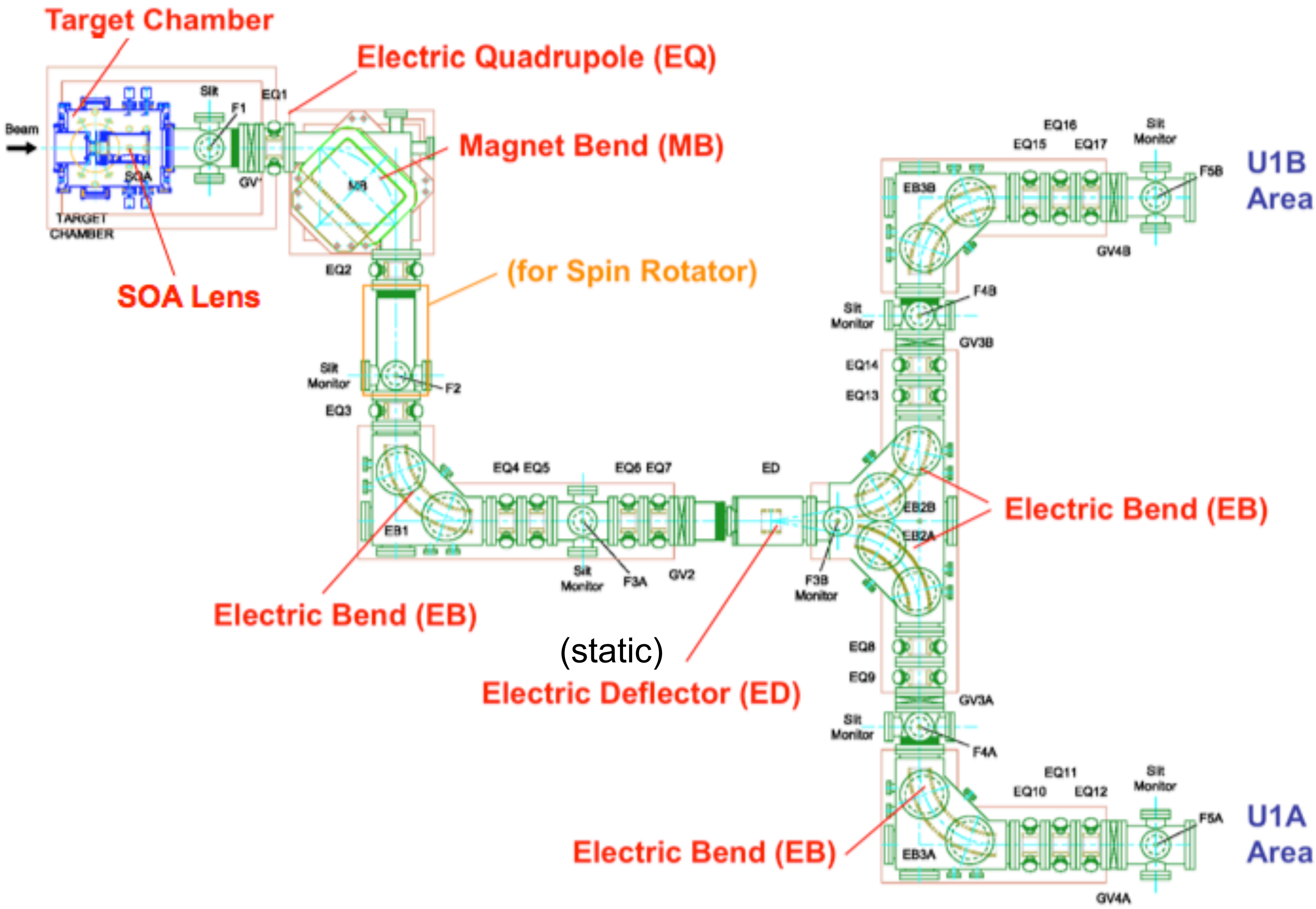


Effect of Fringe Field of Focusing solenoid (Beam Spot at F1)



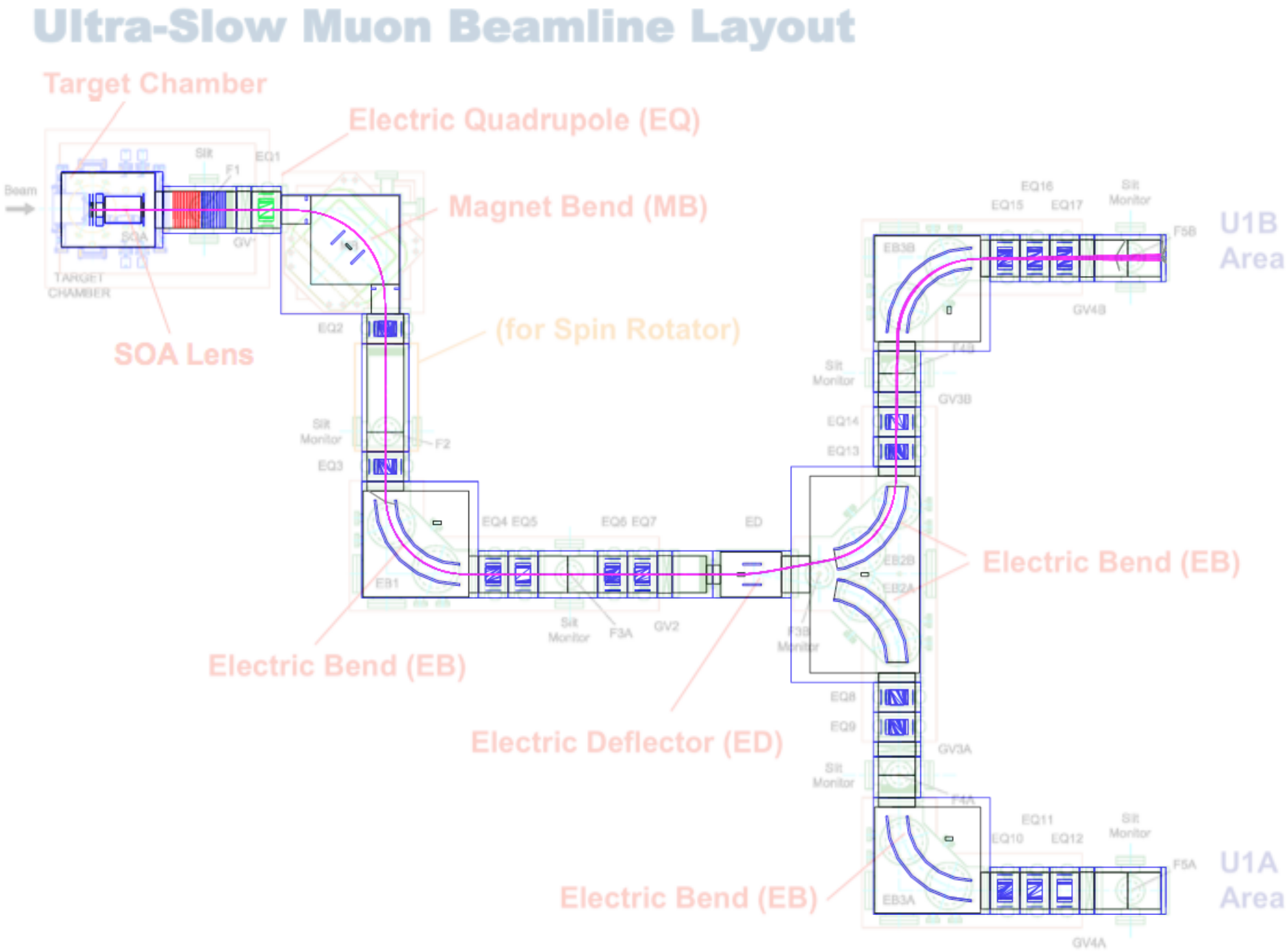
By Strasser

Ultra-Slow Muon Beamline Layout



Optics Calculation : musrSim* (based on GEANT4)

* developed by PSI group (K. Sedlak et al, http://lmu.web.psi.ch/simulation/)

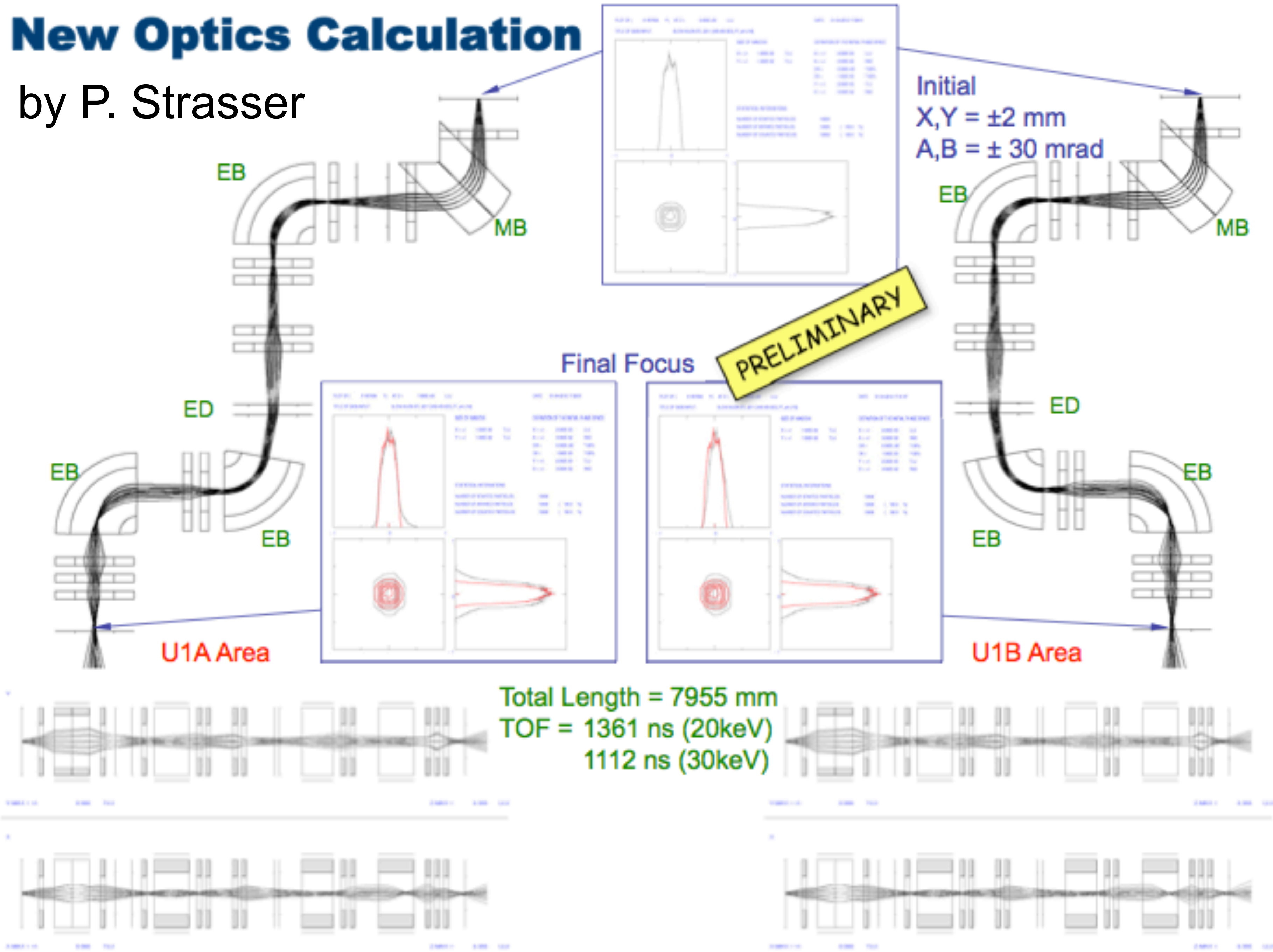


Transmission Efficiency ~100 %

(except for μ-e decays, r < 2 mm and θ< 30 mrad at F1)

New Optics Calculation

by P. Strasser



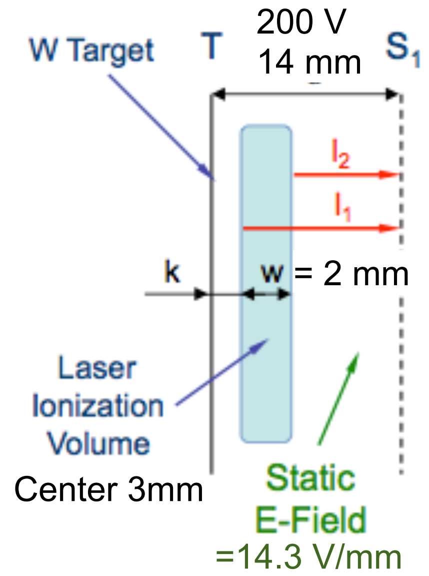
Ultra slow muon Beam Property

T - S1 of SOA

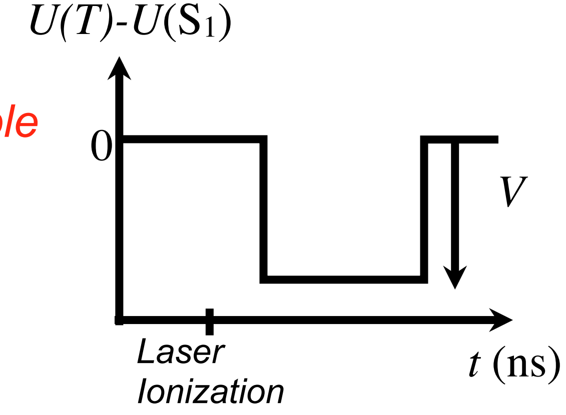
I : $6 \times 10^5 \mu^+/\text{s}$, Beam size : ~ mmφ

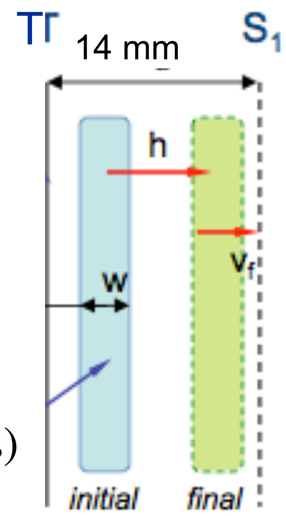
E = 30 keV ± 29 eV by static field extraction

	Static	Pulsed
V (V)	200	2000
E (V/mm)	14.3	143
duration t (ns)	static	8.2
vel. (mm/ns)	0.49 - 0.54	1.0
ΔE (eV)	± 29	0 *in principle*
Δt (eV)	3.9	2.0



Pulsed Voltage between T and S_1



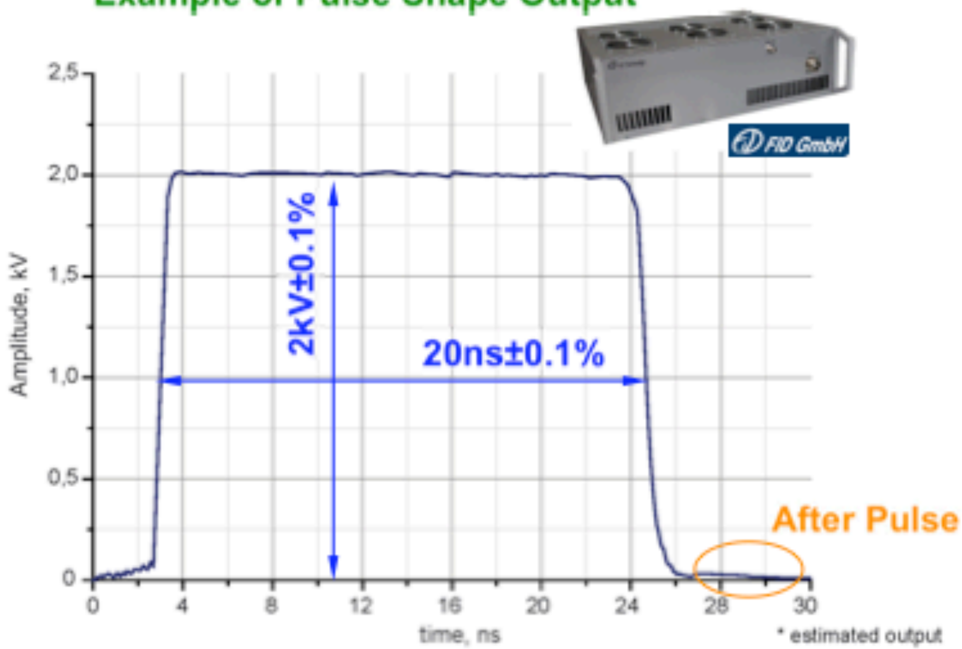


Development of Pulsed H.V. Extraction

Pulsed HV Power Supply

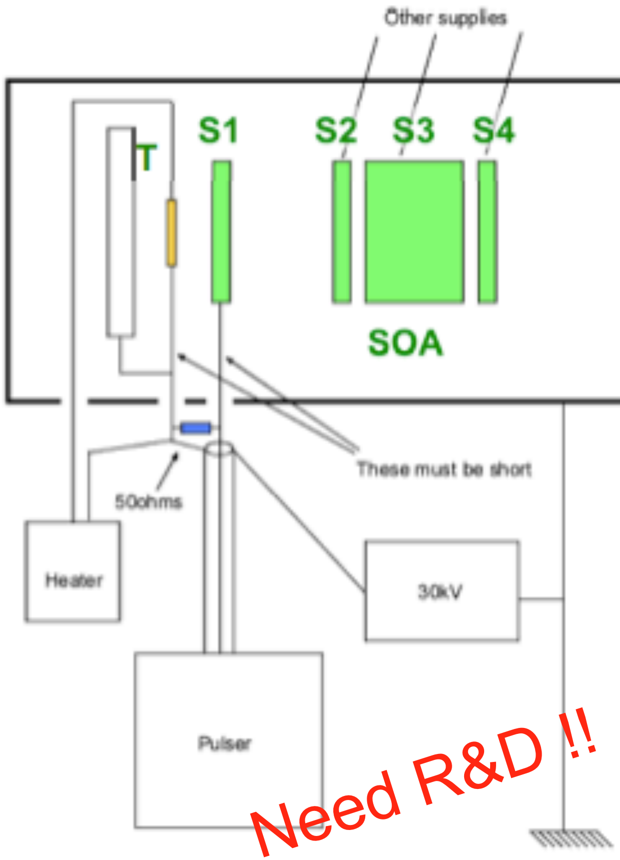
Amplitude:	0 – 2kV ± 0.1%
Pulse duration:	2 – 20ns ± 20ps
Rise Time (10-90%):	≤ 2ns
Fall Time:	≤ 2ns
After pulse:	≤ ±0.1% (±2 V)
Jitter:	≤ 0.5ns
Trigger Frequency:	25 Hz
Operation:	> 5000 hours

Example of Pulse Shape Output



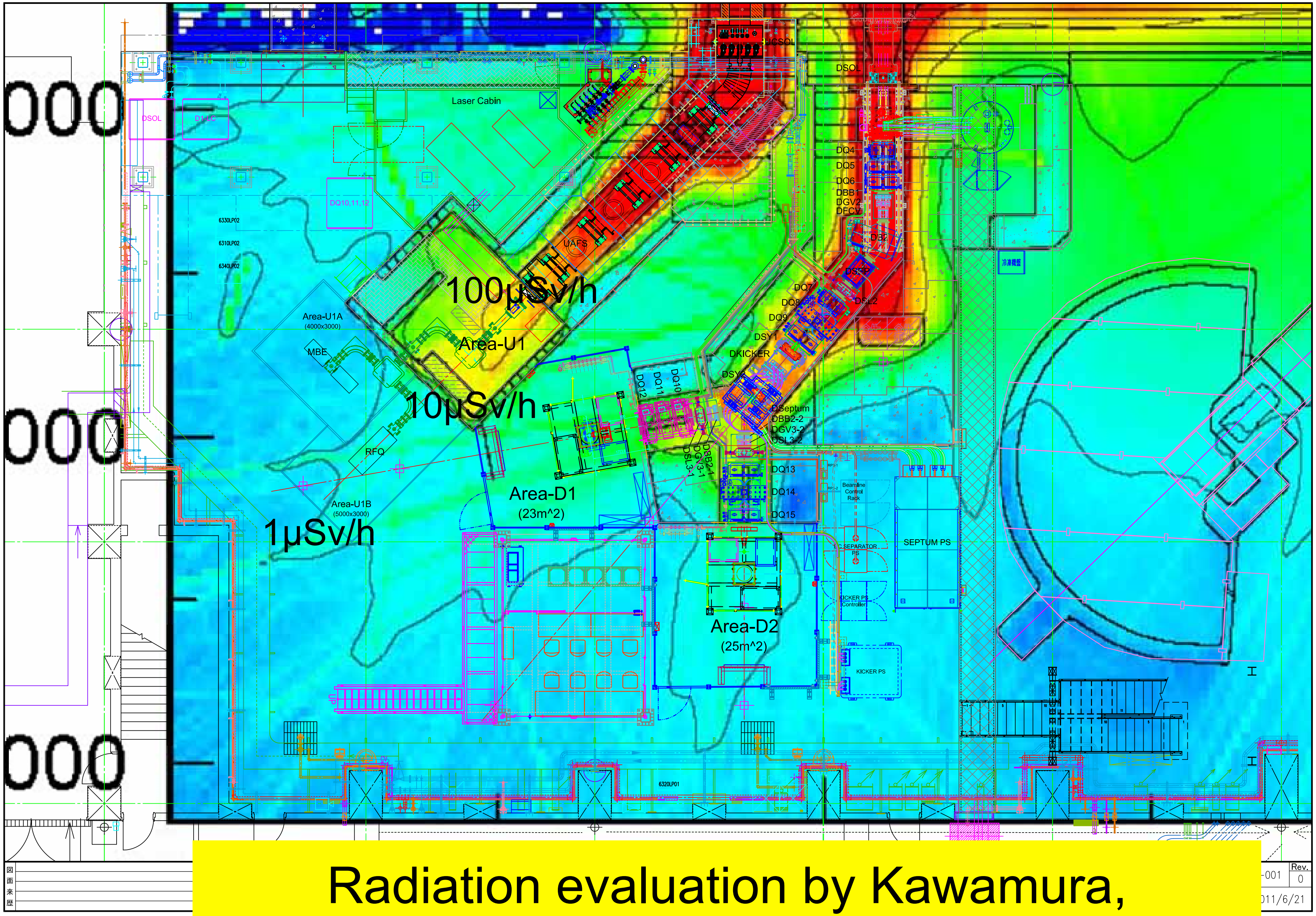
Error on the initial muon energy:

Pulse: 2kV, 8ns	⇒	~600 eV μ^+ (v = 1mm/ns)
Amplitude: ± 0.1%	⇒	dE ~ 1 eV
Duration: ± 0.1%	⇒	dE ~ 1 eV
After pulse: (±2V)	⇒	dE ~ 2 eV



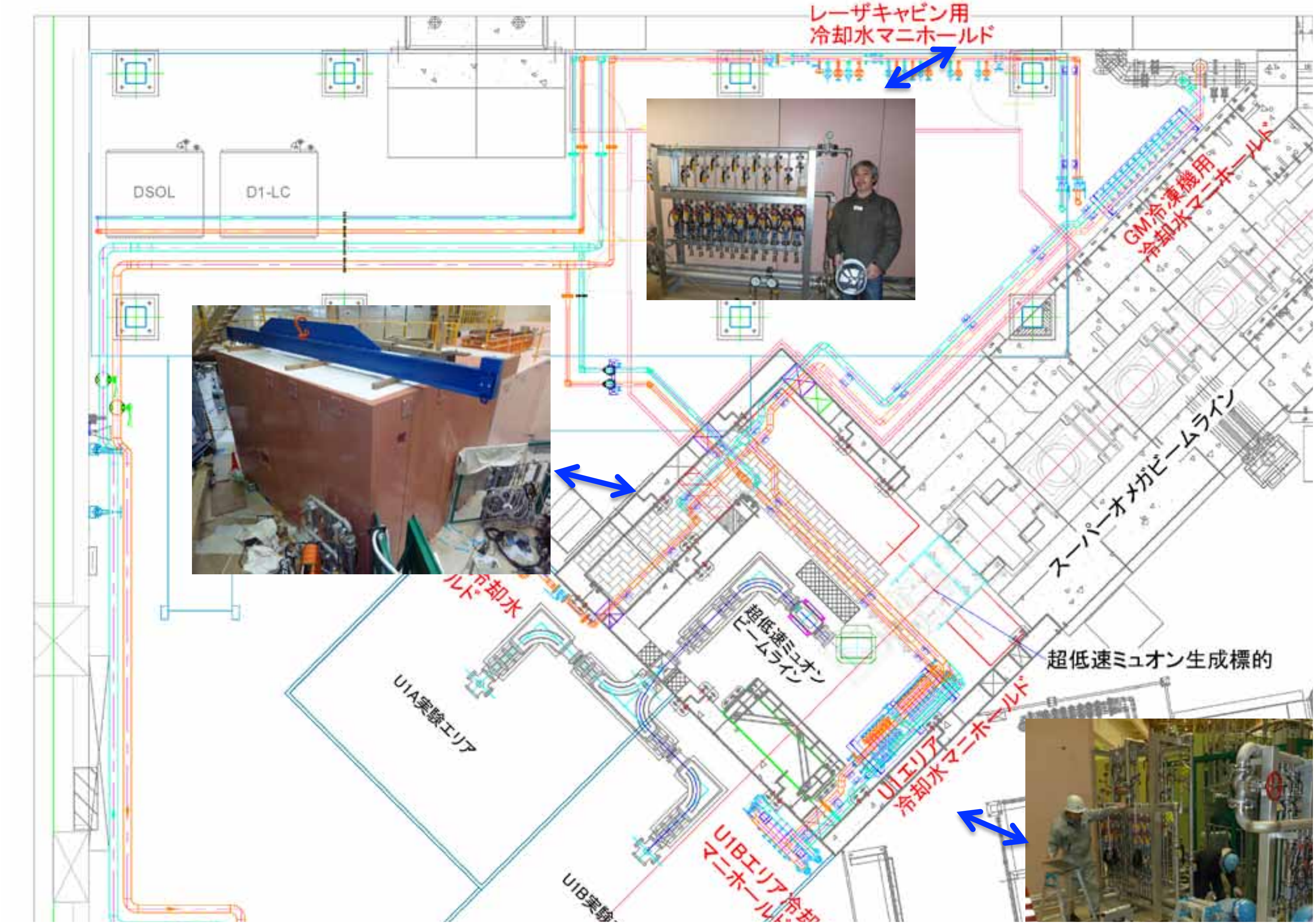
Need R&D !!

Related Facility and Items



Radiation evaluation by Kawamura,
requires 30cm thick concrete shielding area

Shielding area, and Water Manifolds were installed Feb., 2012



U-Cabin＋Cat's Walk Feb.―Mar.2102

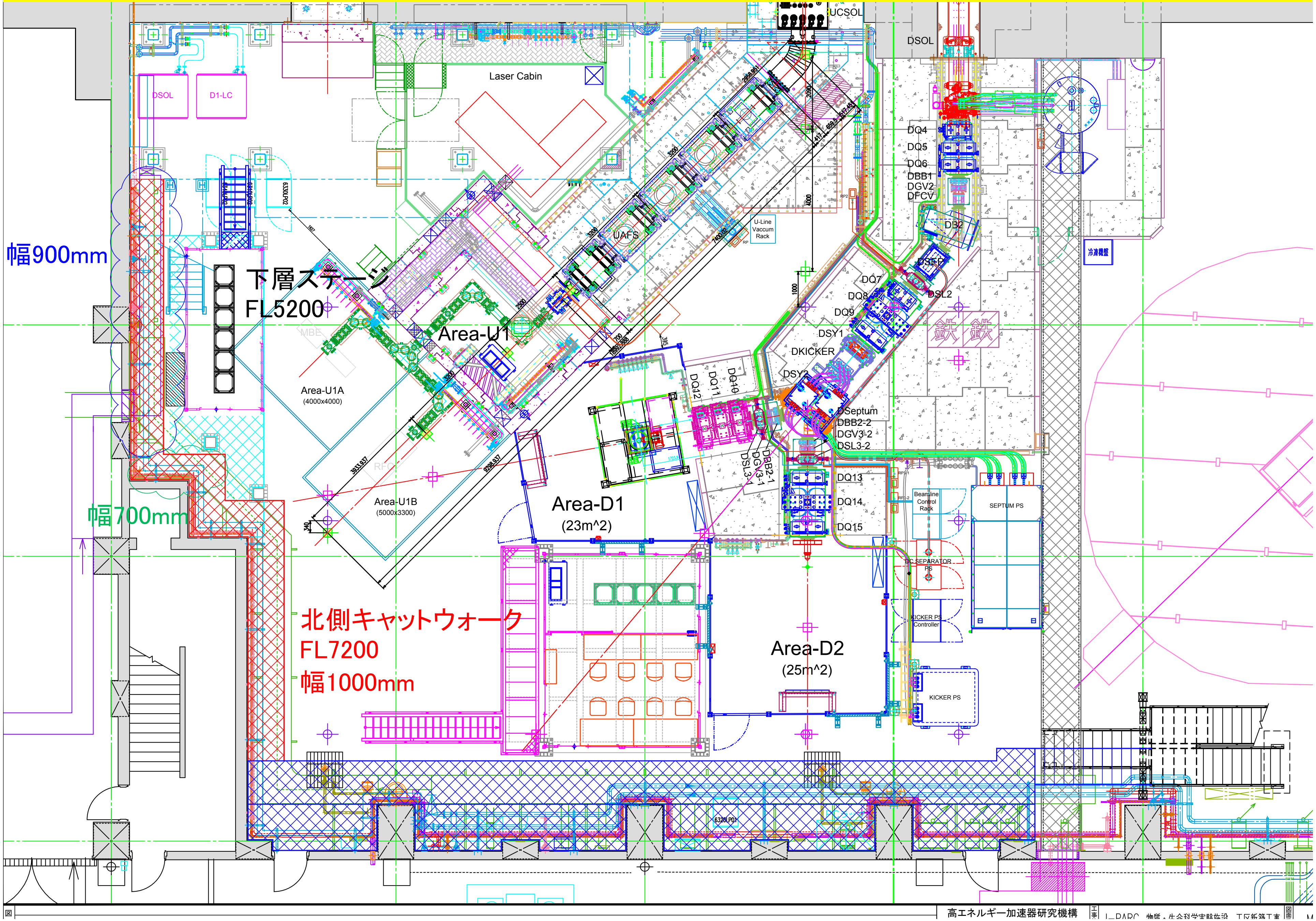


Photo of U-line 2012.2.13

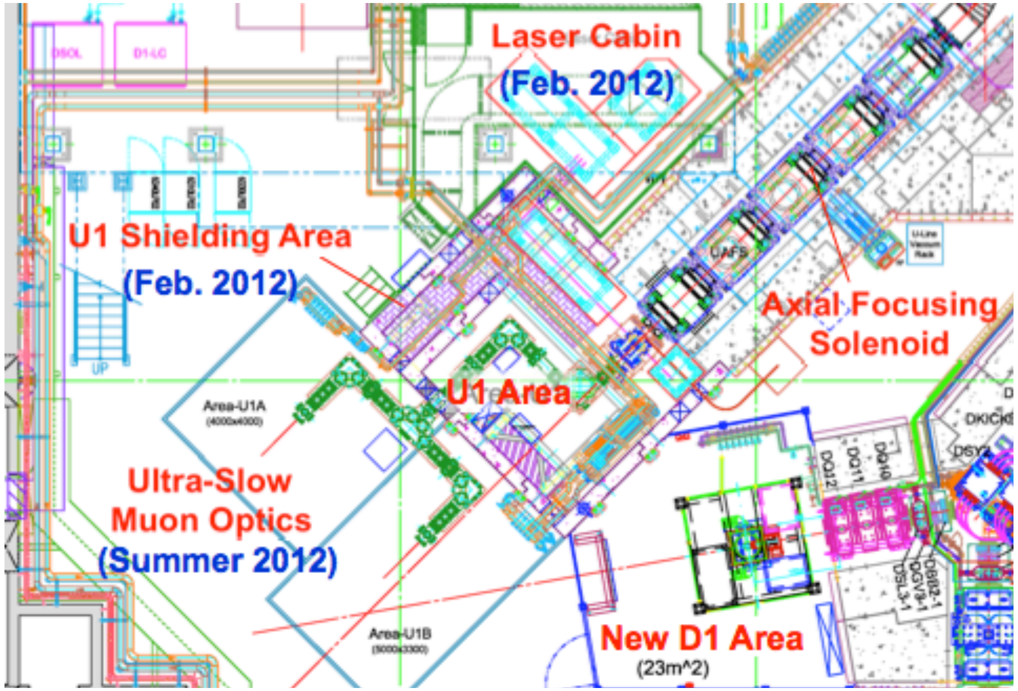
PS Yard

Proton beam

Graphite target

μ^+

Road Map of Construction

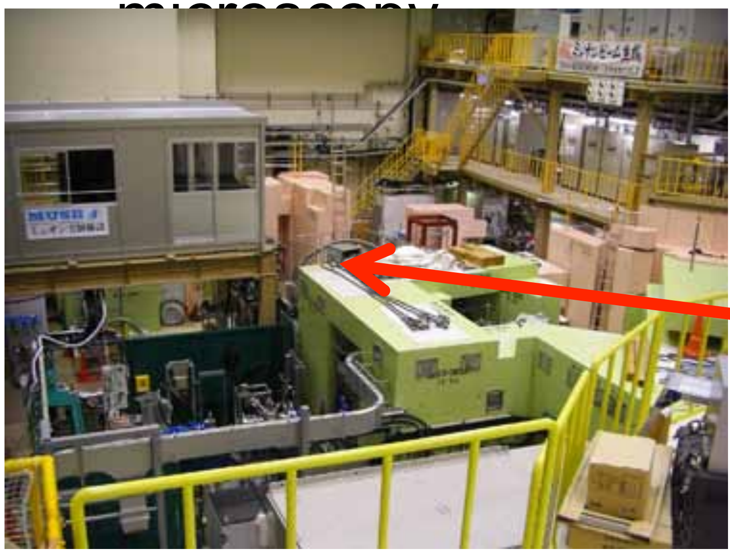


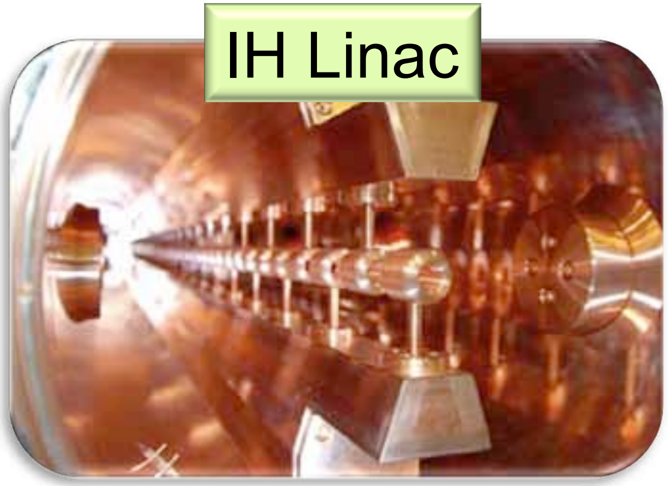
Ultra Slow Muon Beam Commissioning will start from Jan. 2013

End

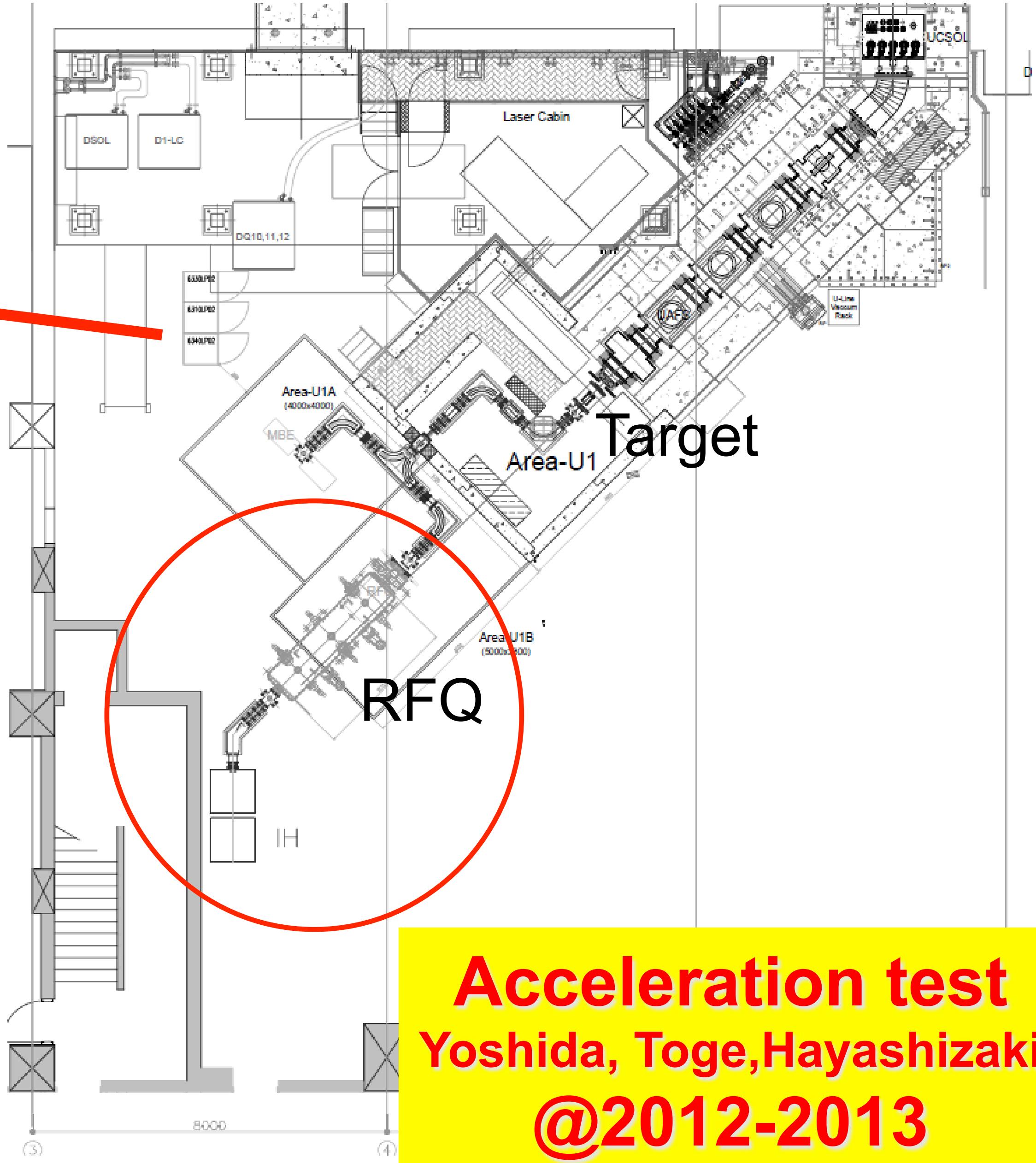
Test Plan for Muon Linac@ U-line

- A few MeV cold muon beam is required for muon microscopy





- Shunt Impedance is higher
- Construction is easier
  - comes in three pieces



Acceleration test

Yoshida, Toge,Hayashizaki

@2012-2013