Overview of the muon facility in MLF J-PARC

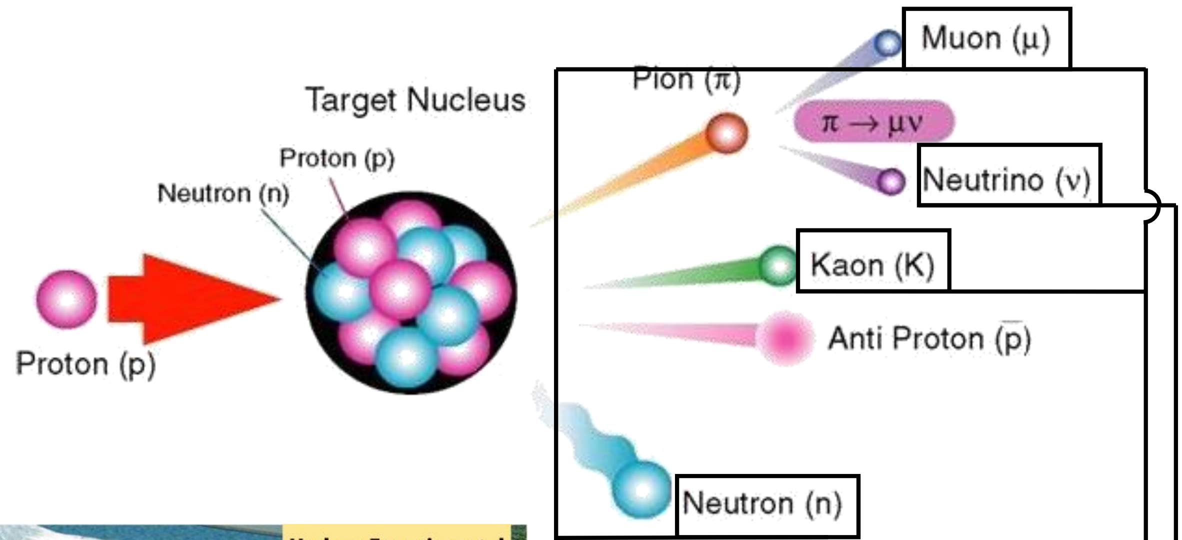
BRIDGE2023, 19/Oct/’23

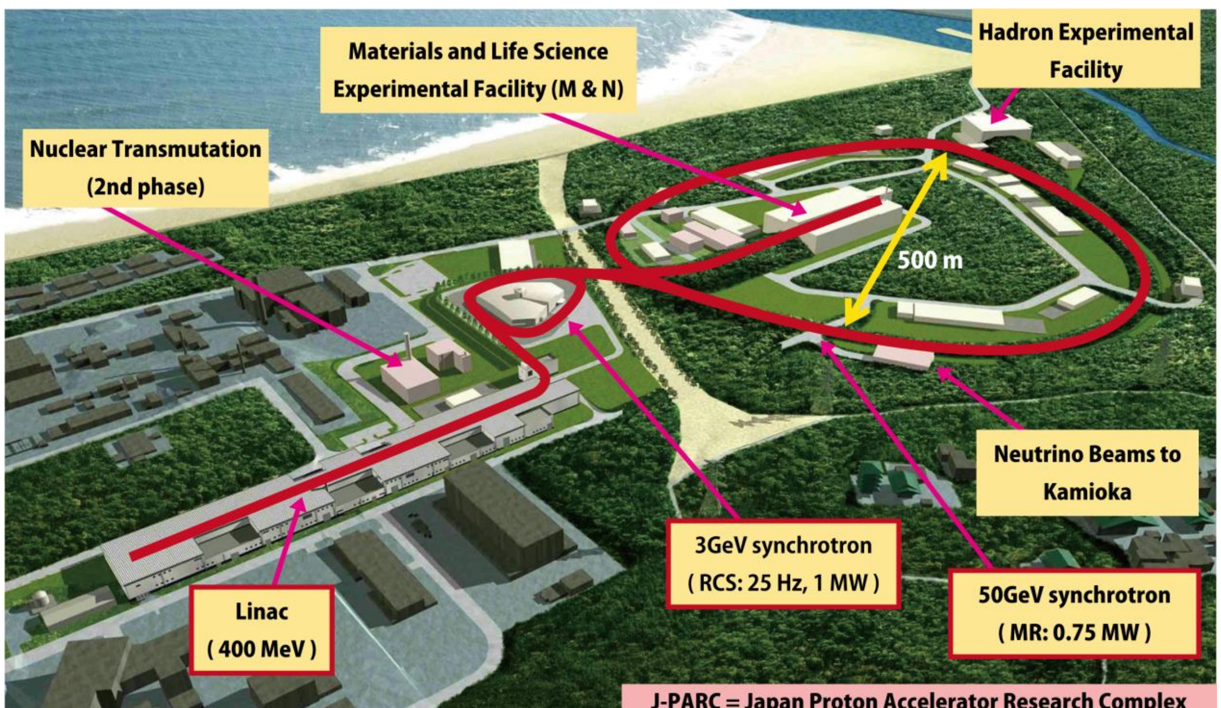
J-PARC, MLF Div., Muon Sec. Naritoshi Kawamura

J－PARC

3 accelerators

400 MeV linac
3GeV synchrotron (RCS)
30GeV synchrotron (MR)





Materials and Life Science Facility

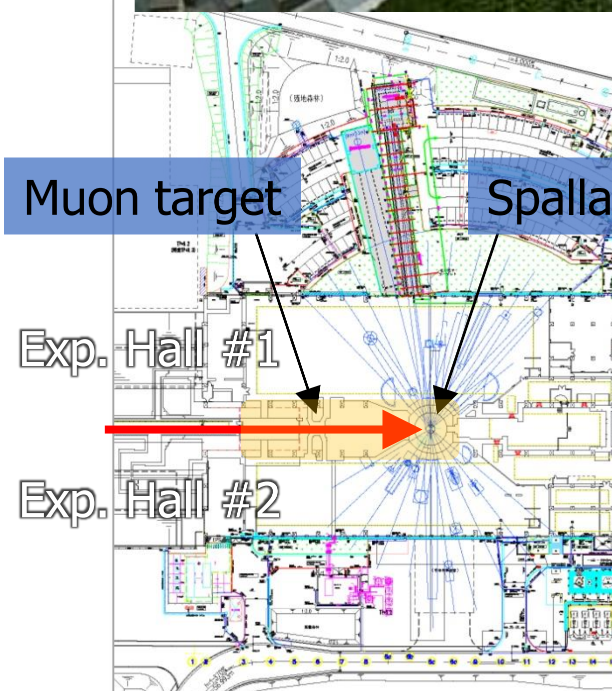
Hadron facility

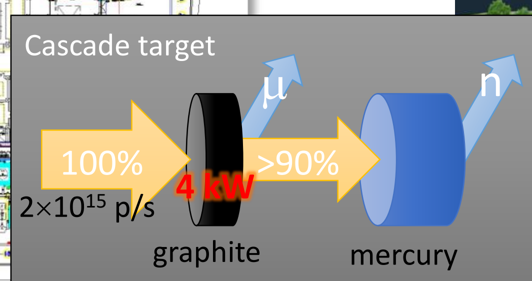
Neutrino facility

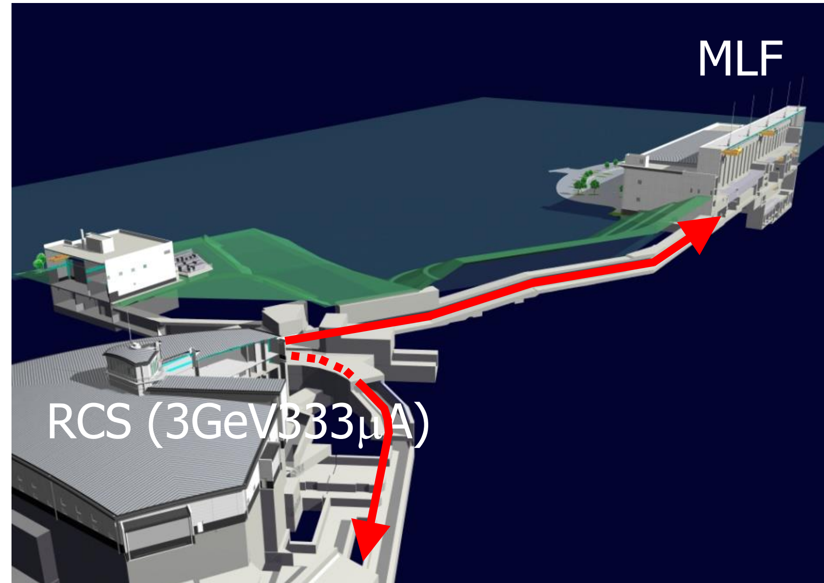
Nuclear transmutation research (under design)

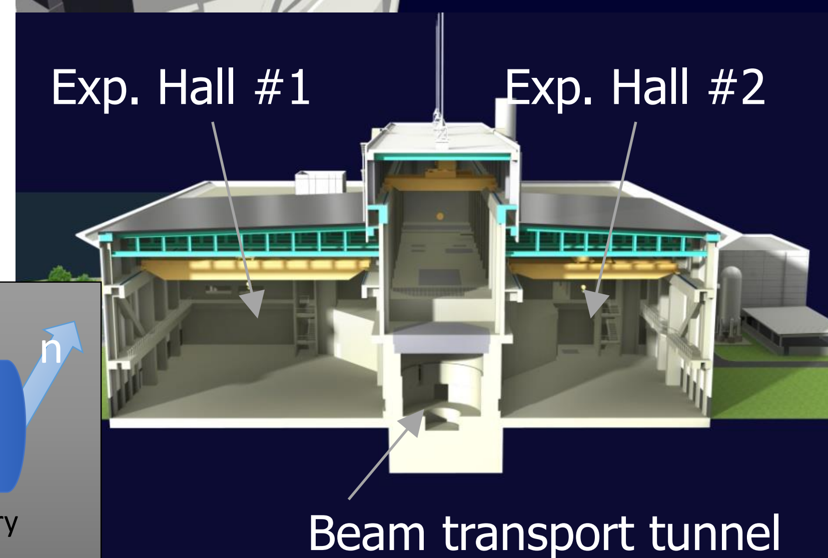
4 facilities

Materials and Life Science Facility









Muon Facility in MLF, MUSE

S-line μ^+

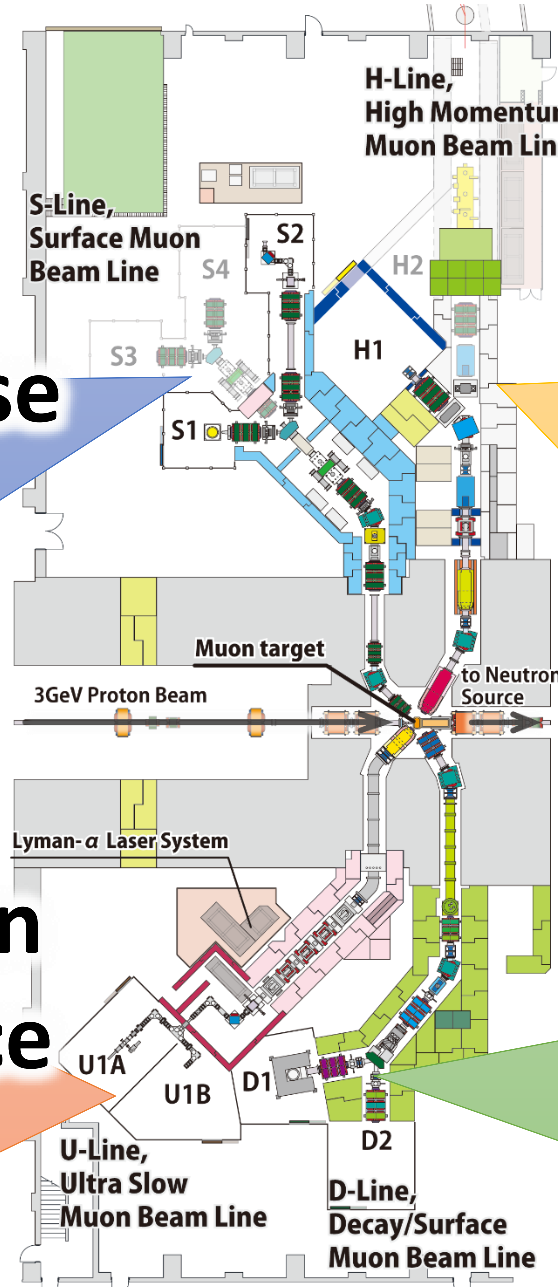
Surface muon (4 MeV) dedicated to bulk μSR in 4 experimental areas

4 areas

Simultaneous use

w/ various sample env.

- ultra-low temperature
- high magnetic field
- pulsed excitations *etc.*



H-line μ^+/μ^-

High-intensity surface

High Intensity

muon (<4 - 50 MeV)

General Use

"fundamental physics"

requiring high precision,
high sensitivity

U-line μ^+

Ultra Slow Muon

(0.1 - 30 keV)

Surface/Interface

/interface sciences (U1A)

Test-bench for TμM (U1B)

D-line μ^+/μ^-

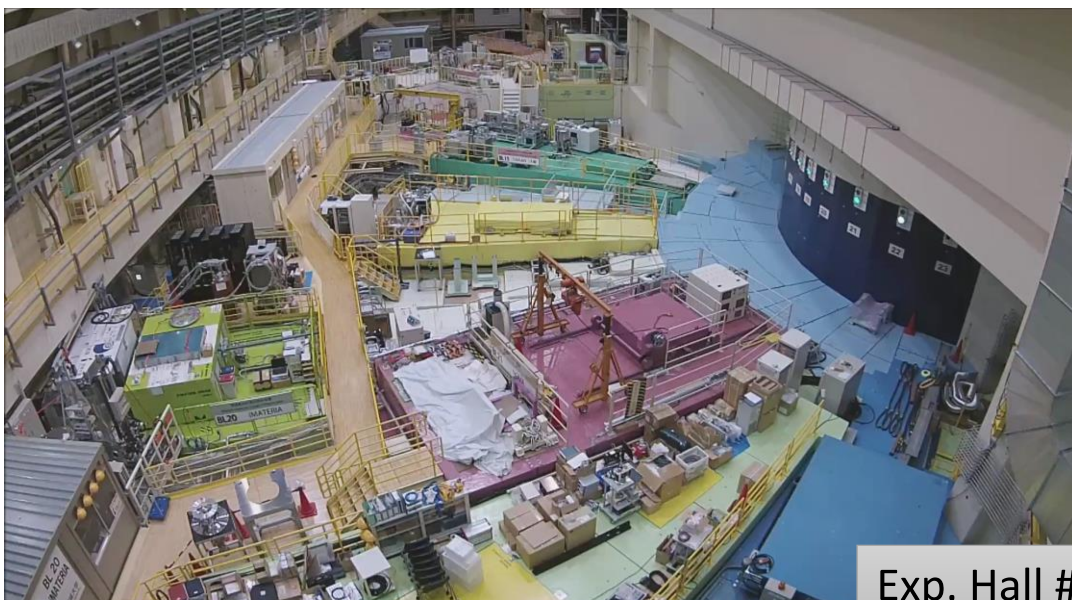
Decay and surface muon

General Use

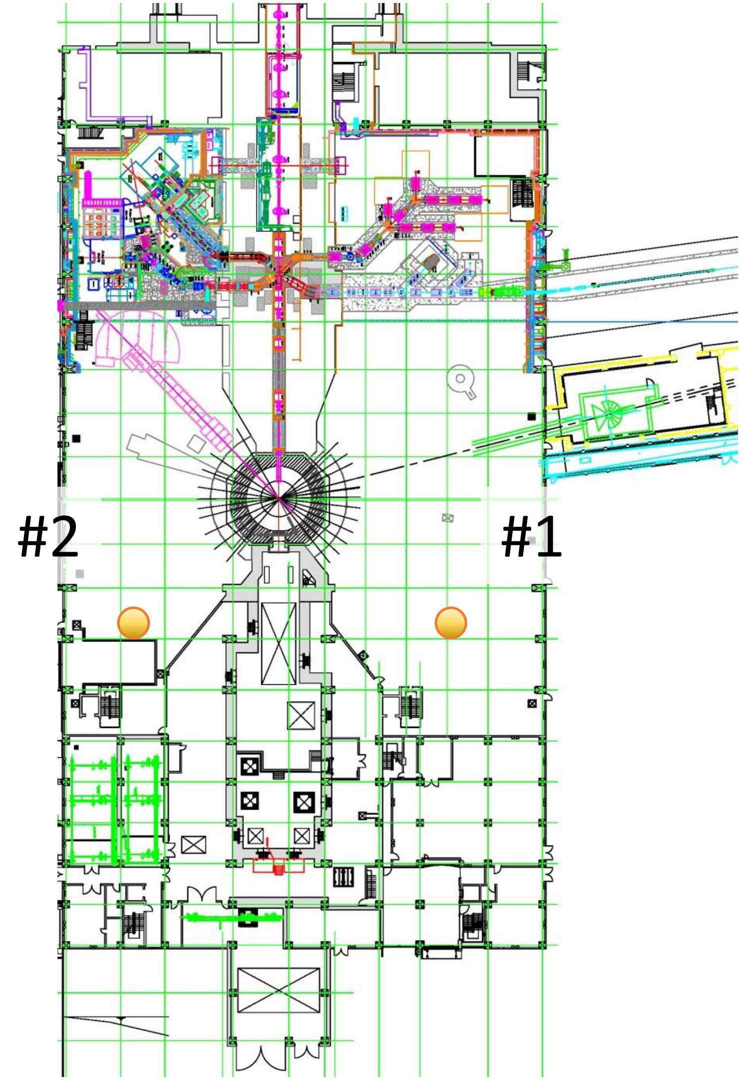
to answer a variety of users' demands with μSR spectrometer (D1) general purpose (D2)

MLF tour

Exp. Hall #1

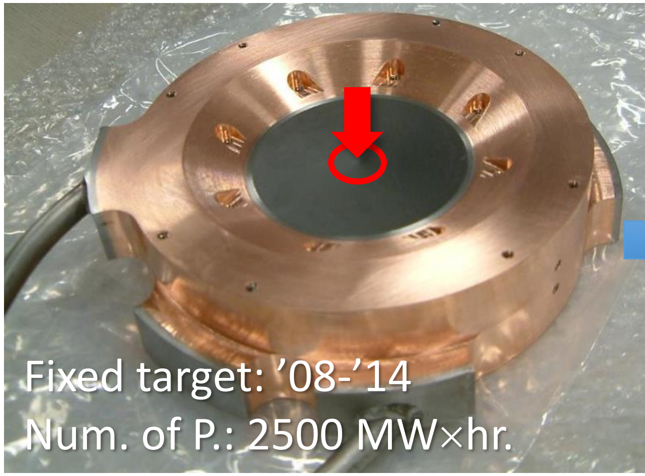


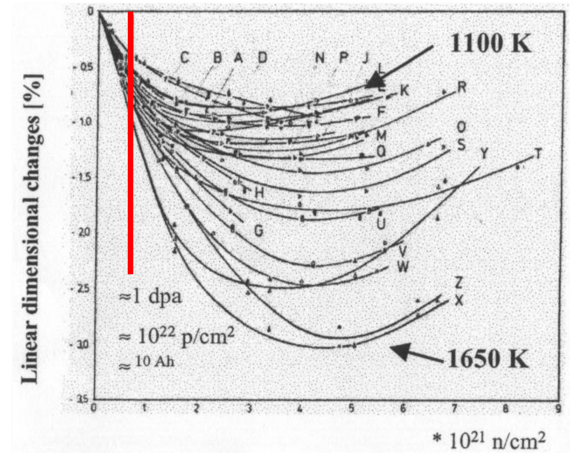
Exp. Hall #2



Muon Production Target

S. Matoba’s poster

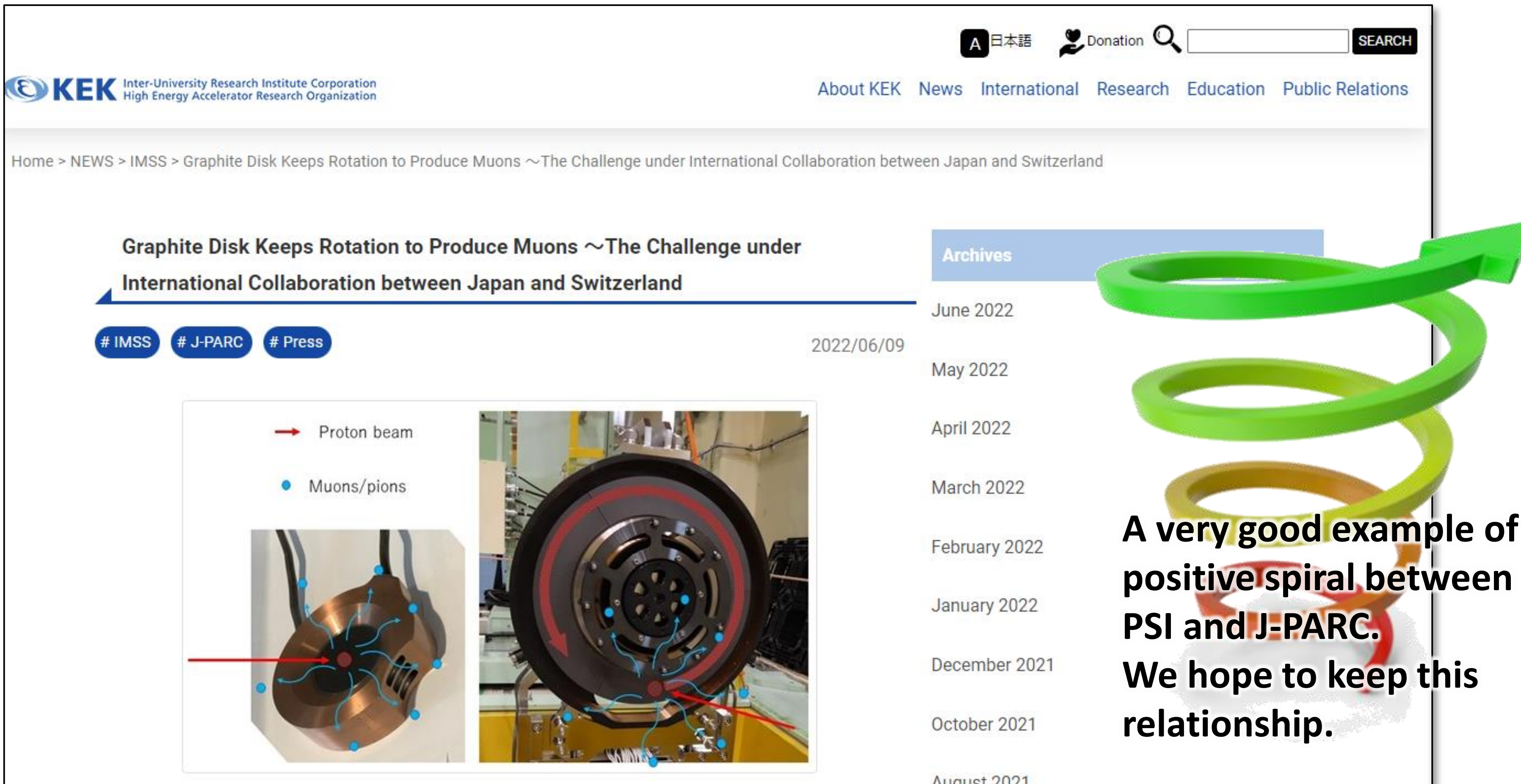




- To disperse the radiation damage, 1% shrinkage / 1DPA (~0.5-year irradiation under 1 MW), and to prolong the lifetime, a rotating system has been applied since 2014.
- Common property
  - 2-cm thick IG-430U from Toyo Tanso Inc., consuming 5% of protons
- Different property
  - direct water cooling (fixed) vs. radiation cooling (rotating)
  - Max temp.: 1500 deg C (fixed) vs. 700 deg C (rotating)

Target: Collaboration between PSI and MUSE

The rotating muon production target was developed in a collaboration with PSI, which had developed the rotating target in advance. In PSI, they replaced the bearings with a new one developed in J-PARC, and one year of stable operation was achieved the last December, which is the best after a long period of several bearing failures.
To commemorate it, PSI, KEK, and J-PARC jointly released the press.

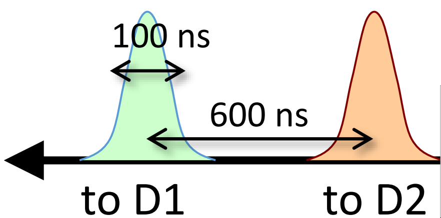


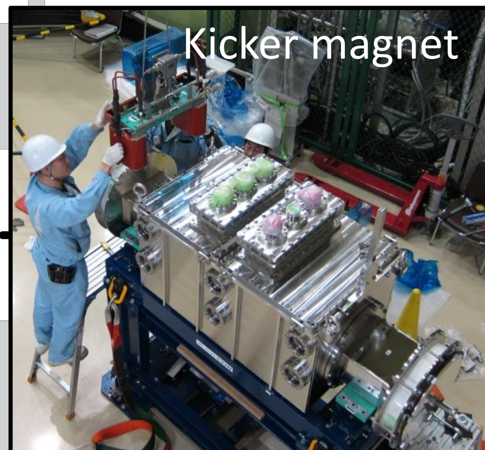
A very good example of positive spiral between PSI and J-PARC.
We hope to keep this relationship.

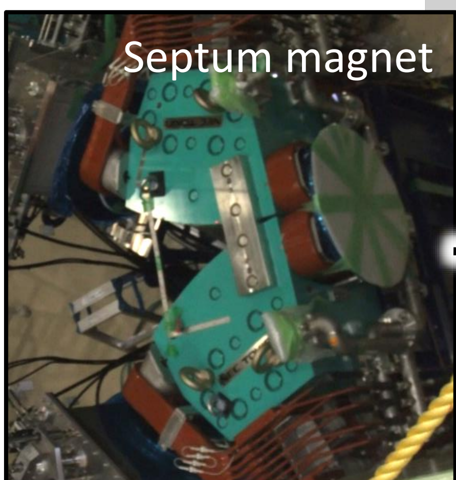
D-line: A decay/surface muon beamline

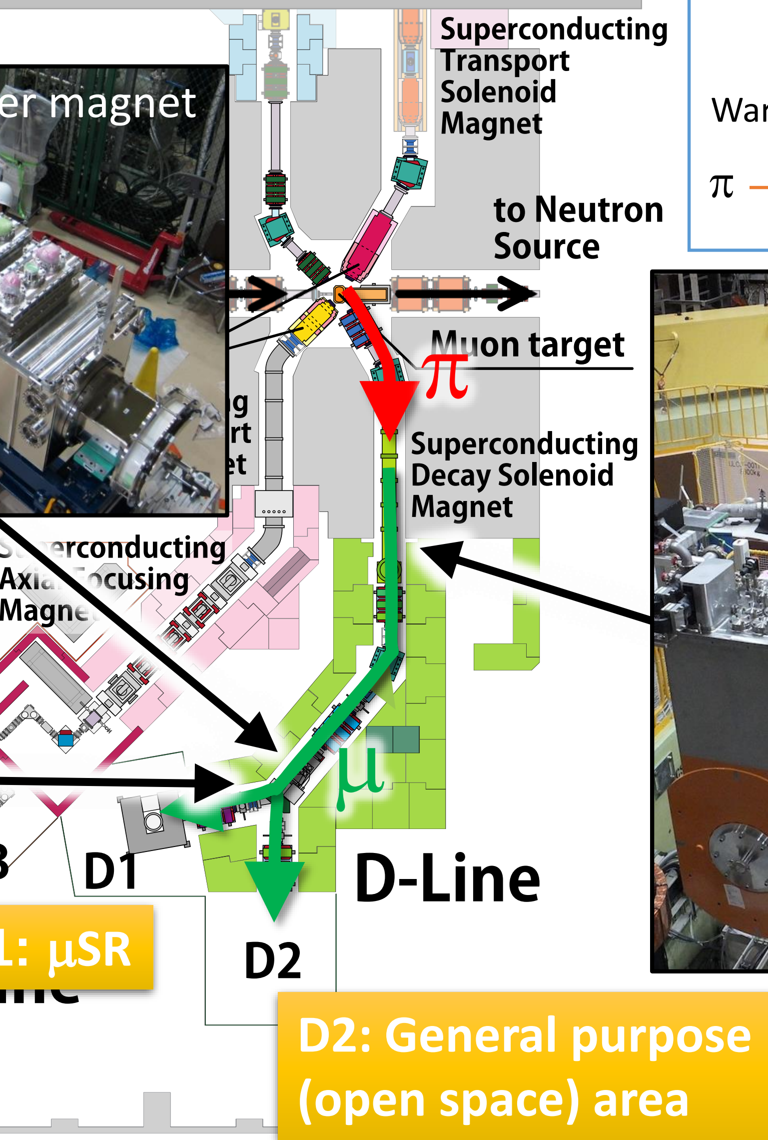
Improved performance with a new superconducting solenoid.
Larger warm bore (ϕ12cm → ϕ24cm) without window foils

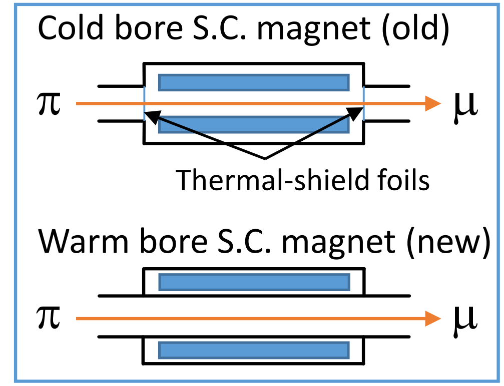
Double pulse structure due to accelerator bunch
Each pulse is distributed to D1 and D2 areas with a kicker magnet.

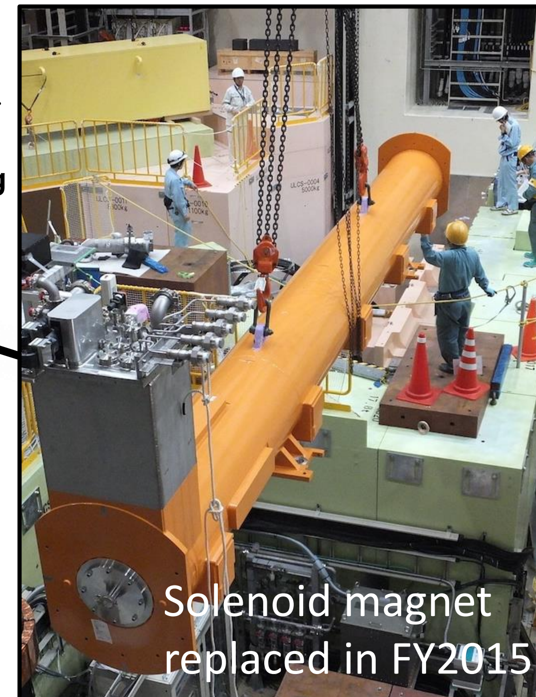












D-line: The new S.C. solenoid magnet

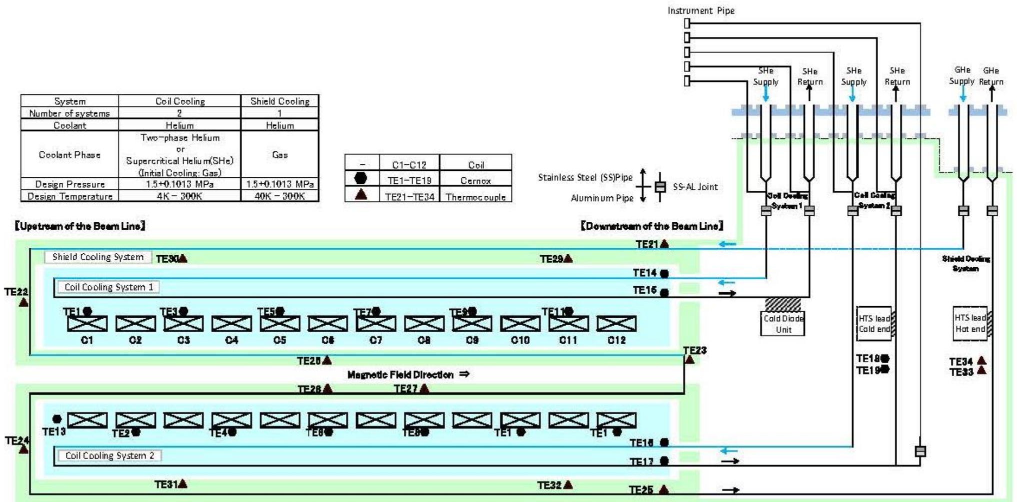


Figure 2: Schematic diagram of the superconducting solenoid cooling system.

Table 1: The Solenoid Specifications

Magnetic Field	3.5 T
Diameter of Warm Bore	0.2 m
Length of Solenoid	6 m
Coil Shape	Solenoid
Wire of Coil	NbTi/Cu
Number of Coils	12
Total Weight	4.7 t

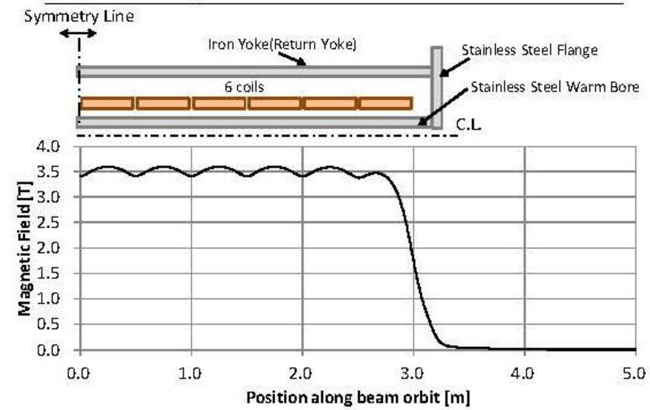
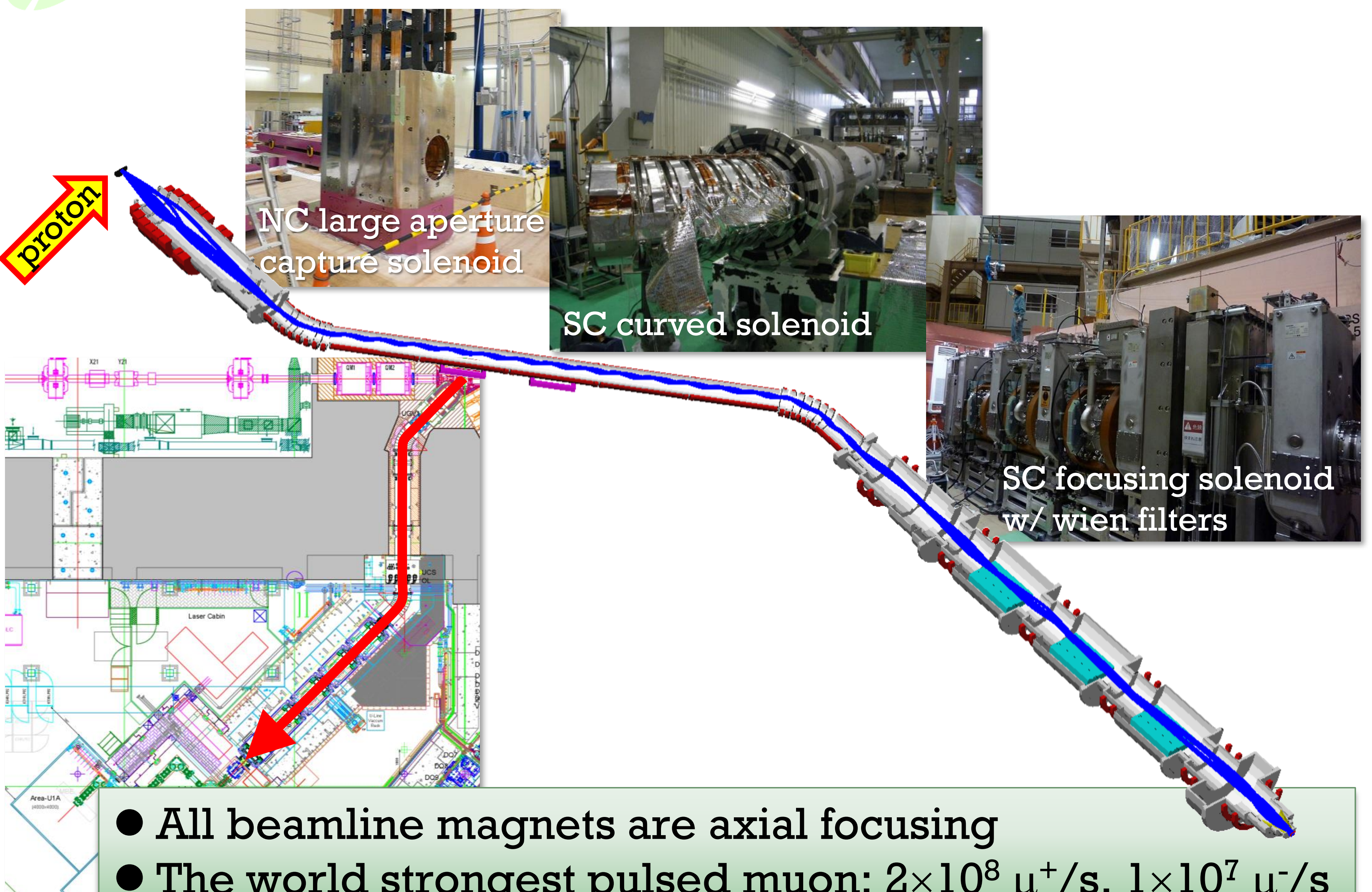


Figure 1: Schematic Diagram of Solenoid Design and Result of Magnetic Field Calculation.

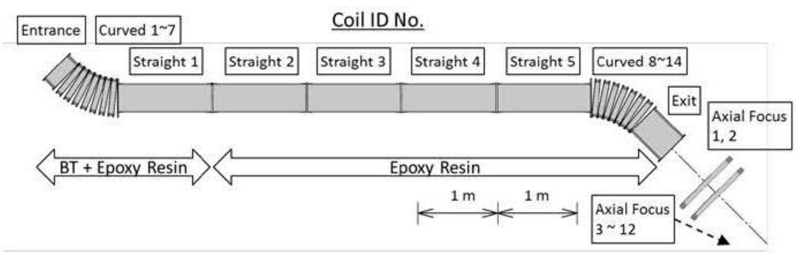
Y. Tanaka *et al.*, Proc. 13th annual Meeting of Part. Accl. Soc. Jap. (in Japanese)

U-line: The highest intensity beamline for USM

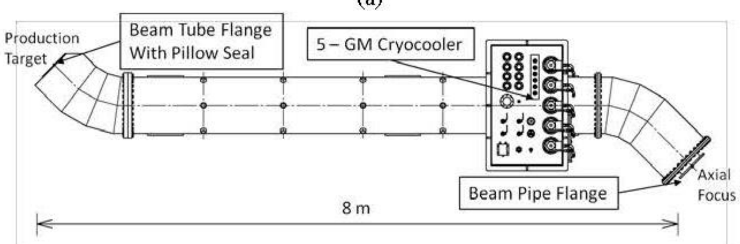


- All beamline magnets are axial focusing
- The world strongest pulsed muon: 2×10^{8} μ^{+}/s, 1×10^{7} μ^{-}/s

U-line: The S.C. curved solenoid magnet



(a)



(b)

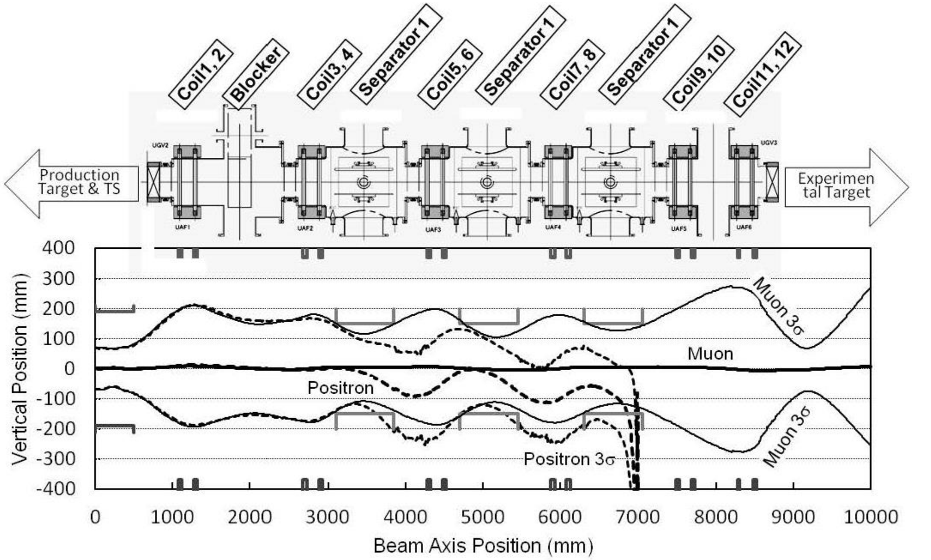
TABLE 1 TS magnet parameters.

Individual Solenoid Coil Dimensions and Induced Field:					
Coil ID	Length mm	Inner Diameter mm	Outer Diameter mm	Central Field T	Max. Field T
Entrance	149.6	380	426	1.224	2.7
Curved 1-7	46.4	380	440	0.536	3.1
Straight 1-5	1172	320	346	2.053	2.4
Curved 8-14	46.4	380	440	0.536	3.1
Exit	490.9	380	414	2.07	2.5

Coil Assembly:	unit	Parameter
Total Length	m	8
Current	A	83
Turns		~164000
Inductance	H	406
Stored Energy	MJ	1.4
Superconductor:		
Type		NbTi Multifilament Round Wire
Material		Nb-47Ti / Cupper Matrix
Cupper Ratio		~4.2
Cupper RRR		170
Outer Diameter with Insulator	mm	0.860 +/- 0.01
Outer Diameter w/o Insulator	mm	0.785
Critical Current @ 5 T and 4.2 K	A	>220
Insulation for Entrance, Curved 1-7 and Straight 1		Polyamide-Imide
Insulation for Straight 2-5, Curved 8-14 and Exit		Polyvinyl Formal
Elastic Stress	MPa	>180

Y. Makida *et al.*, CEC/ICMC2013 proceedings
DOI:10.1063/1.4860734

U-line: The S.C. focusing solenoid magnet



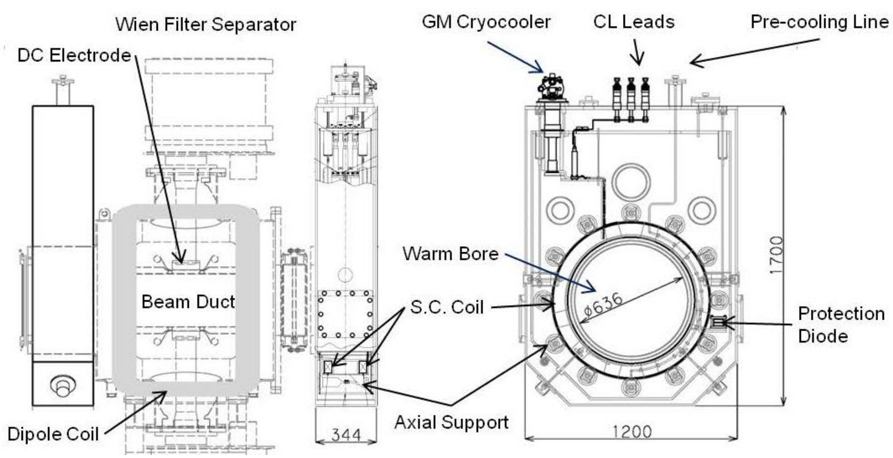
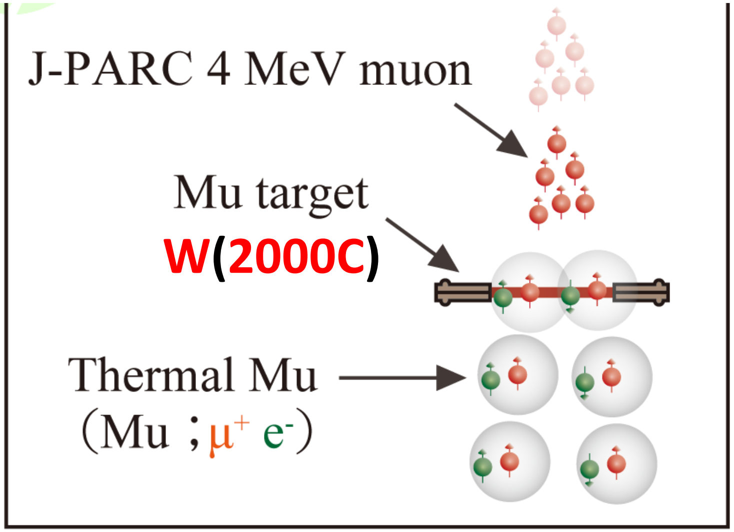


TABLE 2 FS magnet parameters.

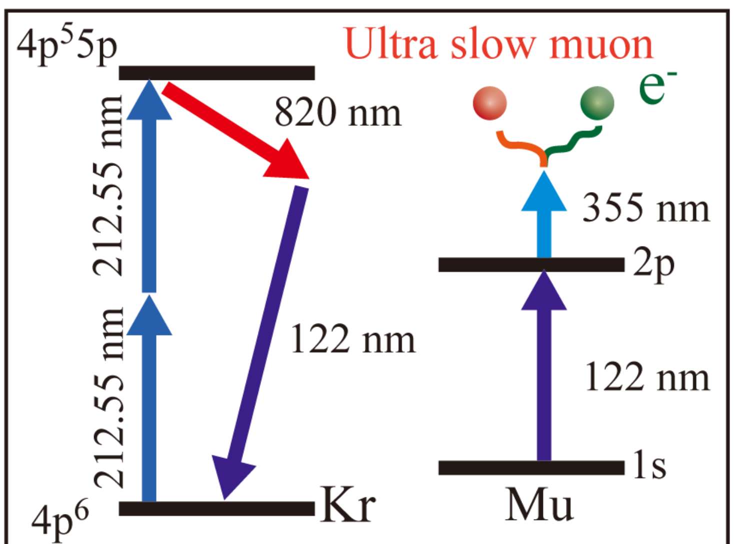
Items	Unit	Specification
Superconducting Coil and Coil Assembly:		
Inner Diameter	mm	741
Outer Diameter	mm	882.6
Length	mm	48
Turn		5355
Nominal Current	A	82.5
Central Field	T	1.2 (0.66 by individual coil)
Maximum Field in Coil	T	3.4
Number of Coils in a Cryostat		2
Distance b/w Two Coil Center Planes	mm	200
Inductance (Two Coils)	H	102
Stored Energy (Two Coils)	kJ	347
Superconductor:		
Type		NbTi Multifilament Round Wire
Material		Nb-47Ti / Cupper Matrix
Cupper Ratio		~4.2
Cupper RRR		170
Outer Diameter with Insulator	mm	0.860
Outer Diameter w/o Insulator	mm	0.785
Critical Current @ 5 T and 4.2 K	A	270
Insulation		Polyvinyl Formal
Elastic Stress	MPa	211
Electric-magnetic Forces		
Axial Force on Coil 1, 2	kN	15.6
Axial Force on Coil 3, 4	kN	1.3
Axial Force on Coil 5, 6	kN	1.4
Axial Force on Coil 7, 8	kN	1.9
Axial Force on Coil 9, 10	kN	116
Axial Force on Coil 11, 12	kN	-135
Cooling Scheme and Cryostat		
Cooling Scheme		Direct Conductive Cooling by GM Cryocooler
GM Cryocooler		SHI Cryo. / RDK-415D
Cooling Capacity of Cryocooler @ 4.2 K	W	1.5
Thermal Load onto 1st Stage	W	33
Thermal Load onto 2nd Stage	W	1.2
Pre-cooling time (measured)	hours	168
Cooled Temperature of Cold Mass (measured)	K	4.0
Cooled Temperature of Shield	K	75

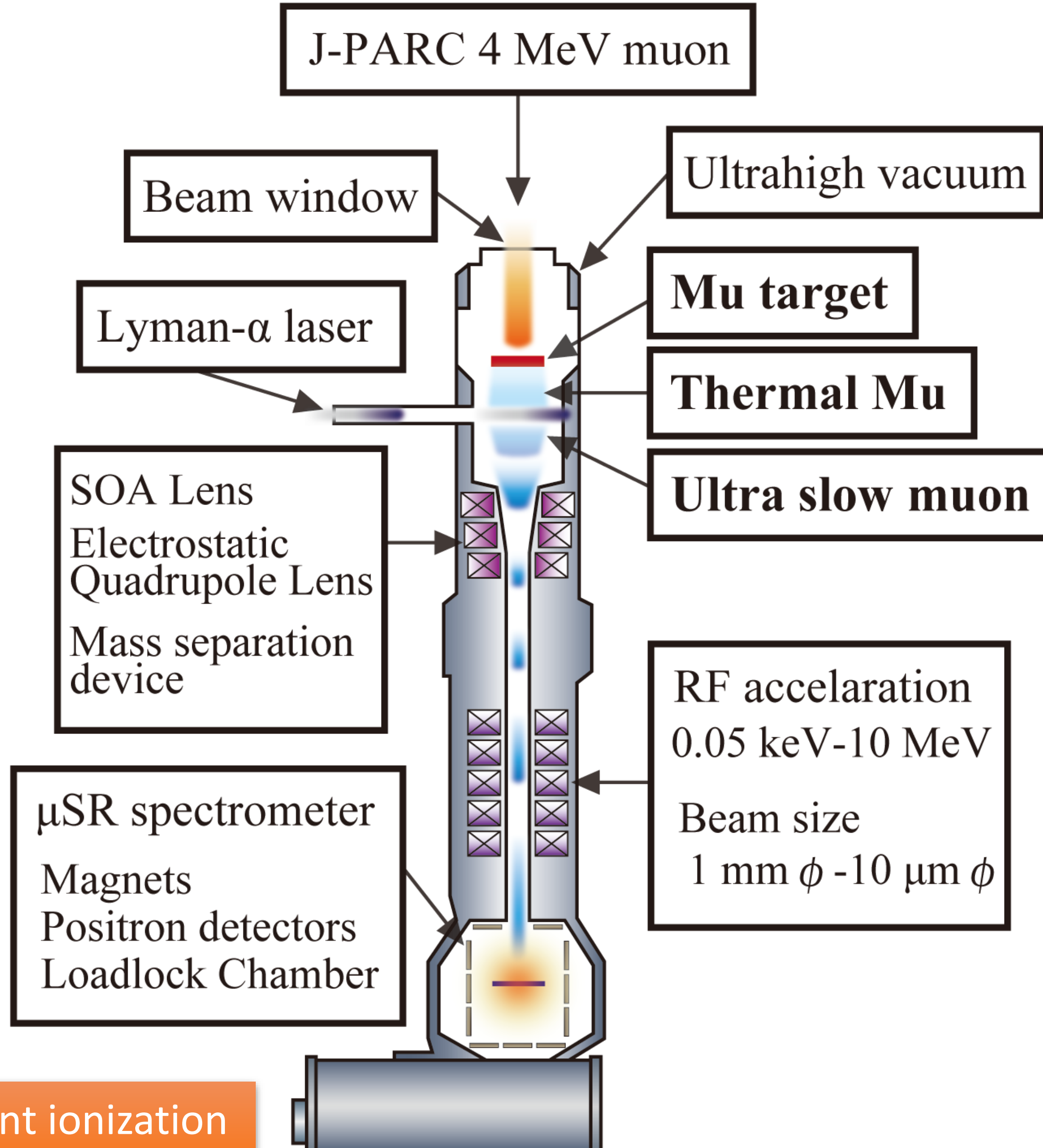
Y. Makida *et al.*, CEC/ICMC2013 proceedings
DOI:10.1063/1.4860734

U-line: Generation of Ultra slow muon (USM)



Mu generator



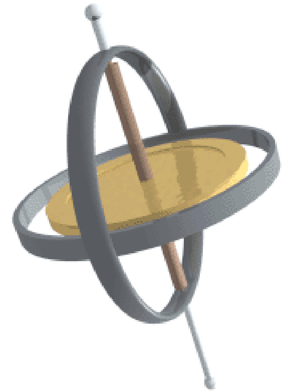


USM is generated by the laser resonant ionization method synchronized with the muon beam pulse.

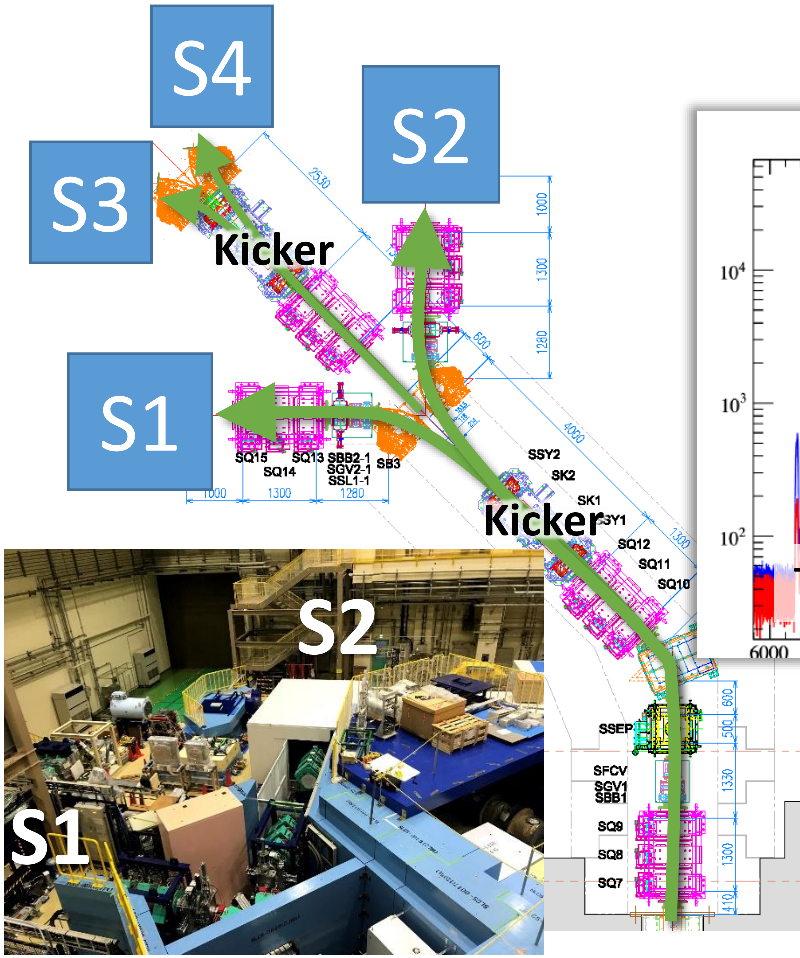
S. Kanda's poster

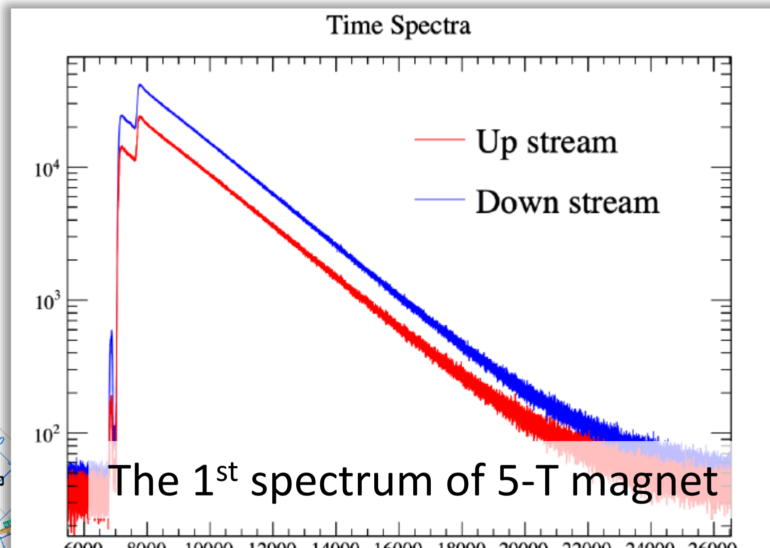
S-line: A surface muon beamline

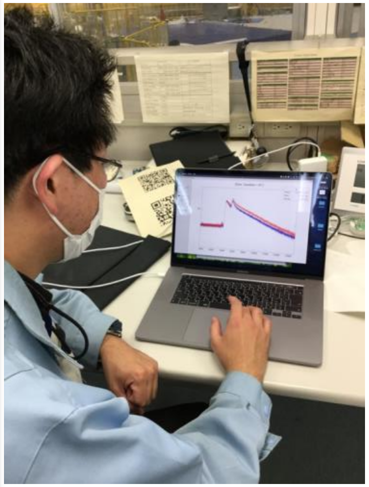
S line is dedicated to transport surface muon beam.
By using two kicker system, S line provides muon beams to all 4 areas simultaneously.
At present two experimental areas, S1 and S2, were completed.



In the S1 area, a μSR spectrometer was placed. The S1 area is one of the busiest ones, and users are switching every few days. The S2 area is partially funded by Okayama-univ. group to perform high rescission measurement of the Mu 1s-2s level.





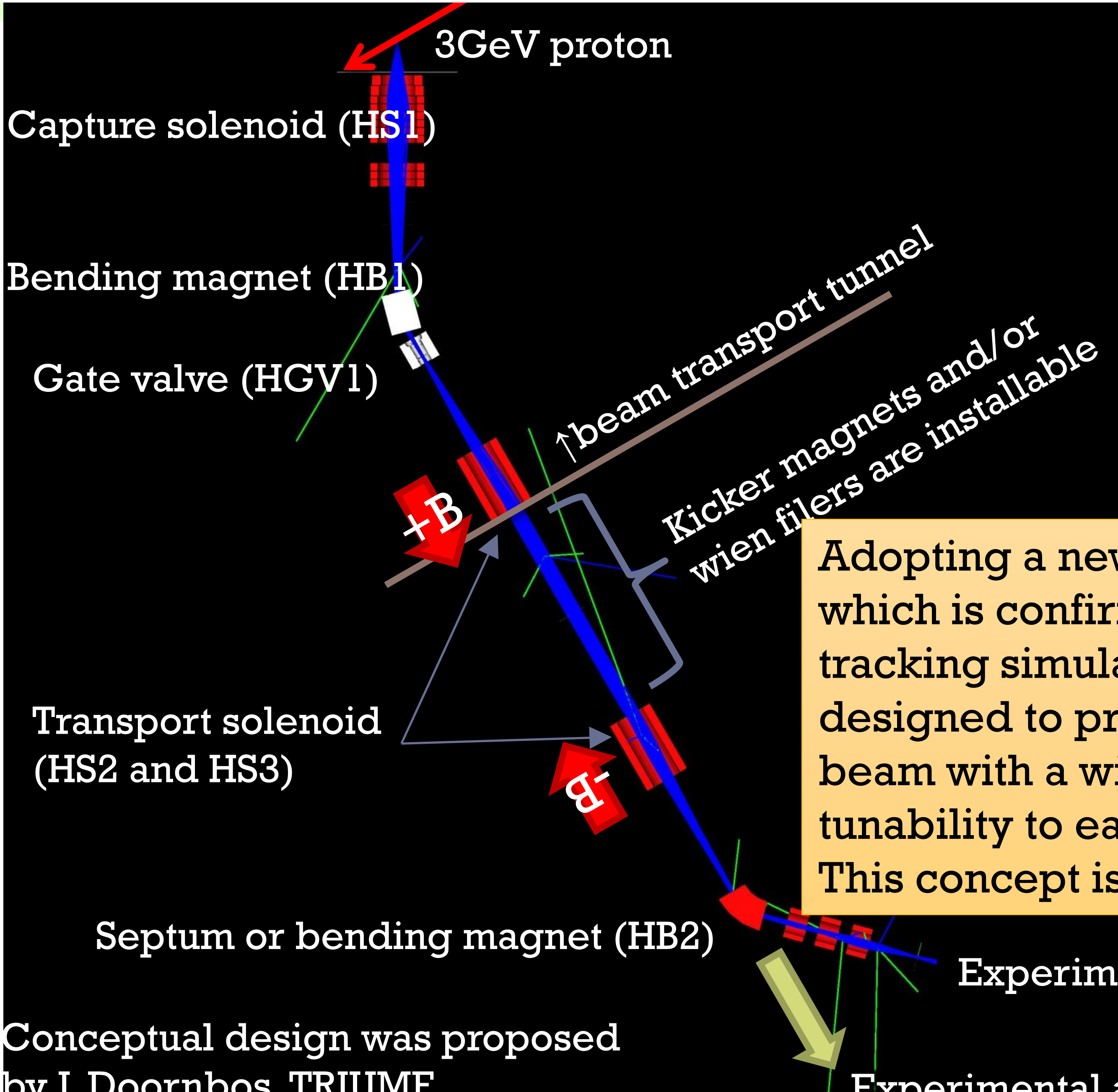


Pulse μSR: Highly segmented spectrometer is necessary to avoid the distortion of time spectrum due to pileup.
Cf. 5-T magnet needs 3008-ch

P. Strasser's poster

H-line: Generic-purpose High-intensity beamline

T. Yamazaki's poster



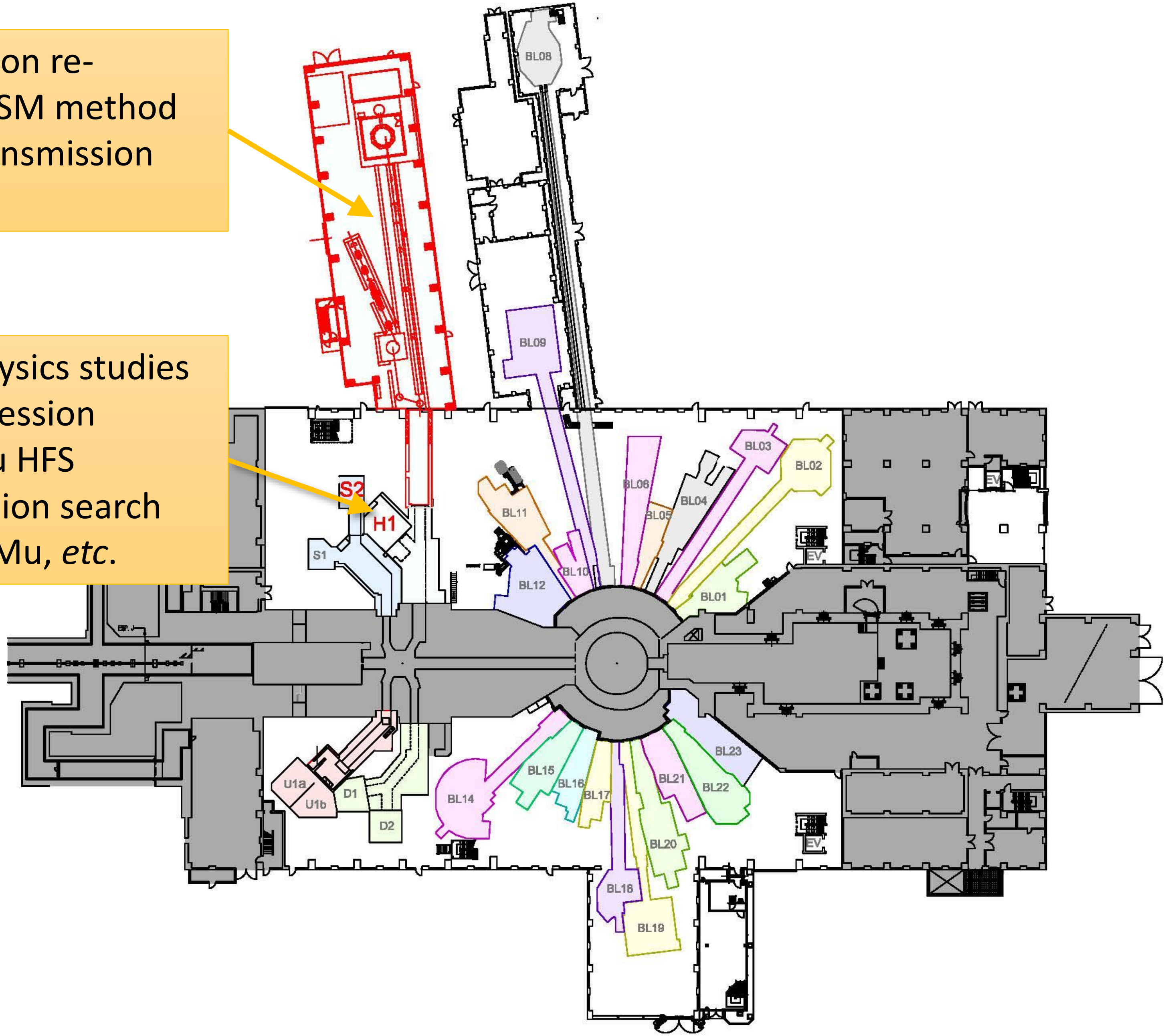
Adopting a new beamline concept which is confirmed by a particle tracking simulation, H line is designed to provide a high intensity beam with a wide-range momentum tunability to each of several areas. This concept is inherited to 2^{nd} TS.

Conceptual design was proposed by J. Doornbos, TRIUMF.

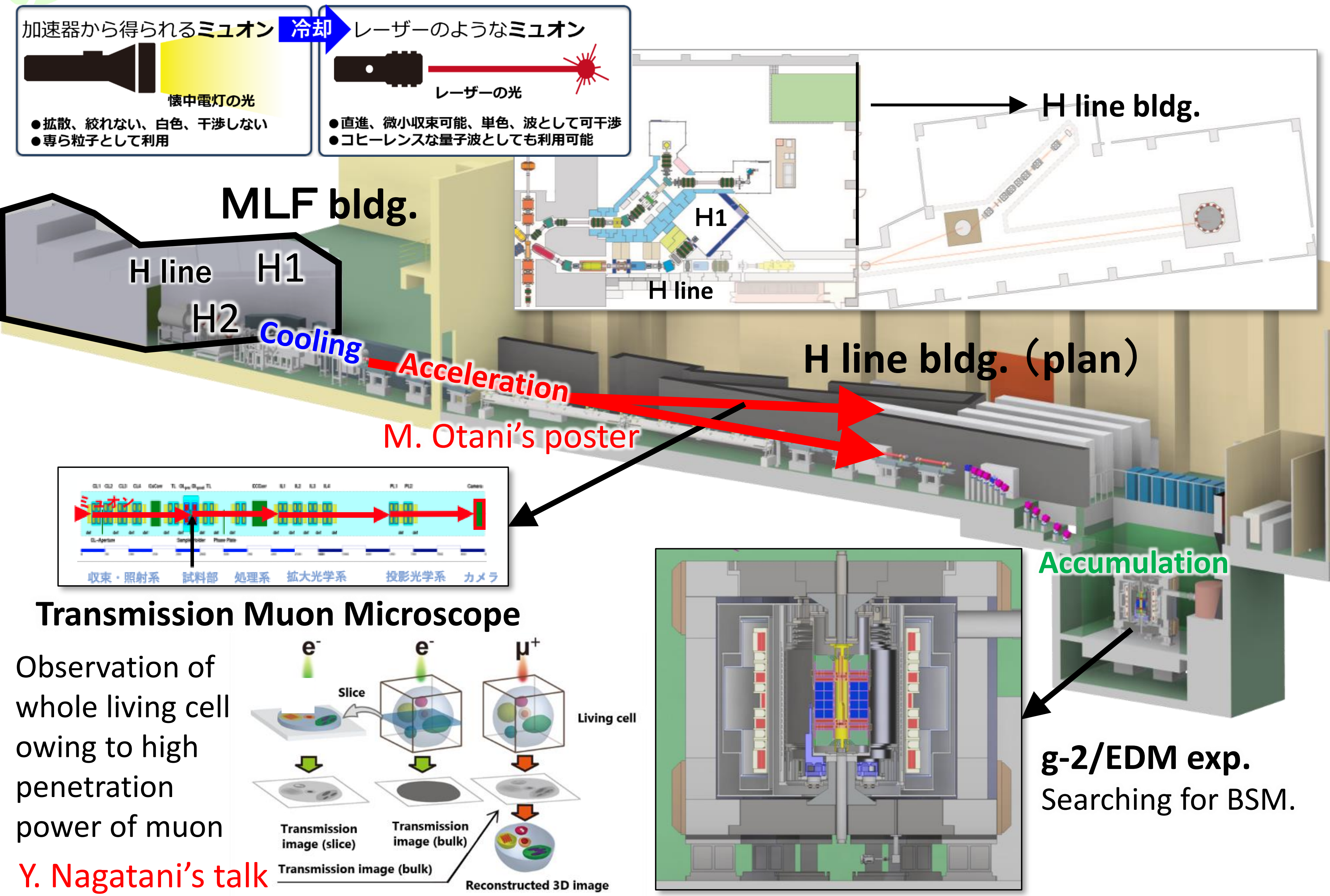
H-line: feature prospects

H2: realizing the muon re-acceleration from USM method for g-2/EDM and transmission muon microscope

H1: fundamental physics studies
MuSEUM: high precession measurement of Mu HFS
DeeMe: μ-e conversion search
…Mu1s-2s, Mu-antiMu, *etc.*



H-line: feature prospects

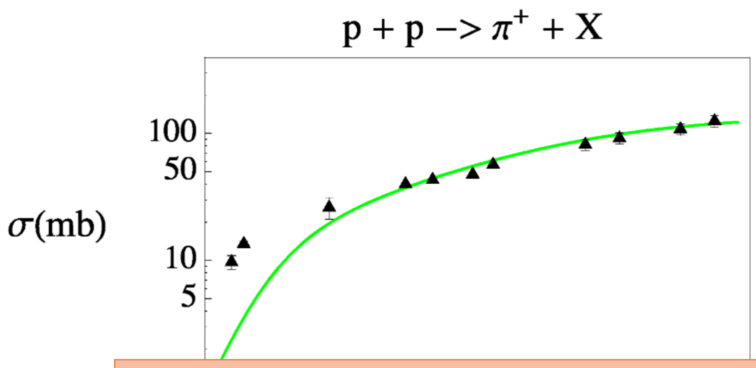


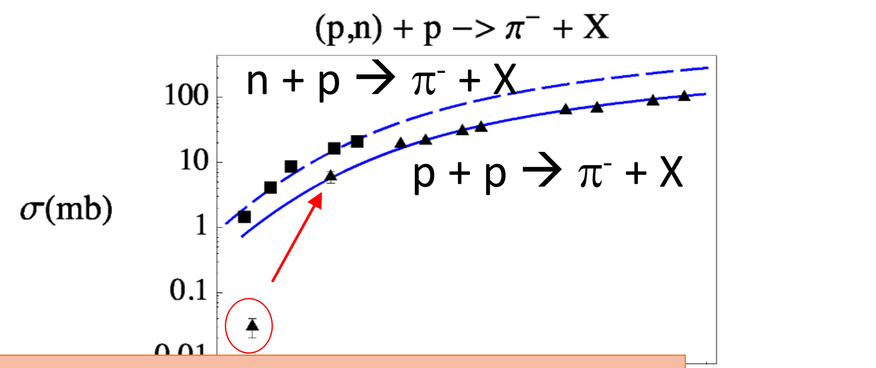
“Specialties” of MUSE

- High-intensity pulsed beam
  → beam distribution by kicker systems (S line)
  → devices synchronizing the pulse
    → flashlight *etc*. for μSR spectroscopy (SE)
    → ultra slow muon generation by pulse-laser
      → g-2/EDM exp., transmission muon microscope

- pion generation by 3-GeV proton beam
  → relatively high yield of π^- and thus μ^-
    → promotion of non-destructive elemental analysis
      → application to archeological artifacts *etc*.

D-line





MUSE utilizes 3GeV proton, and the π^- yield is higher than the other meson factories.

Figure 5: Log - ... solid line) of equ... 6, 7, 9, 14].

... (blue, solid line) o... (triangle symbols ... solid squares) fron... meterization (blue

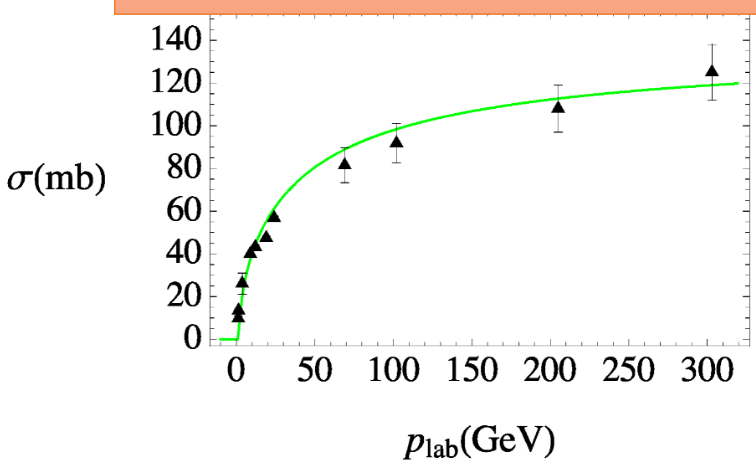


Figure 6: Same as figure 5, except for use of linear axes.

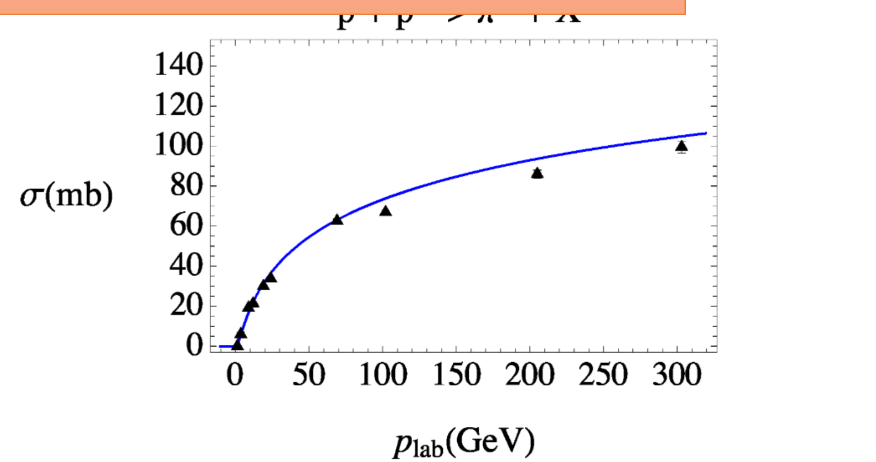
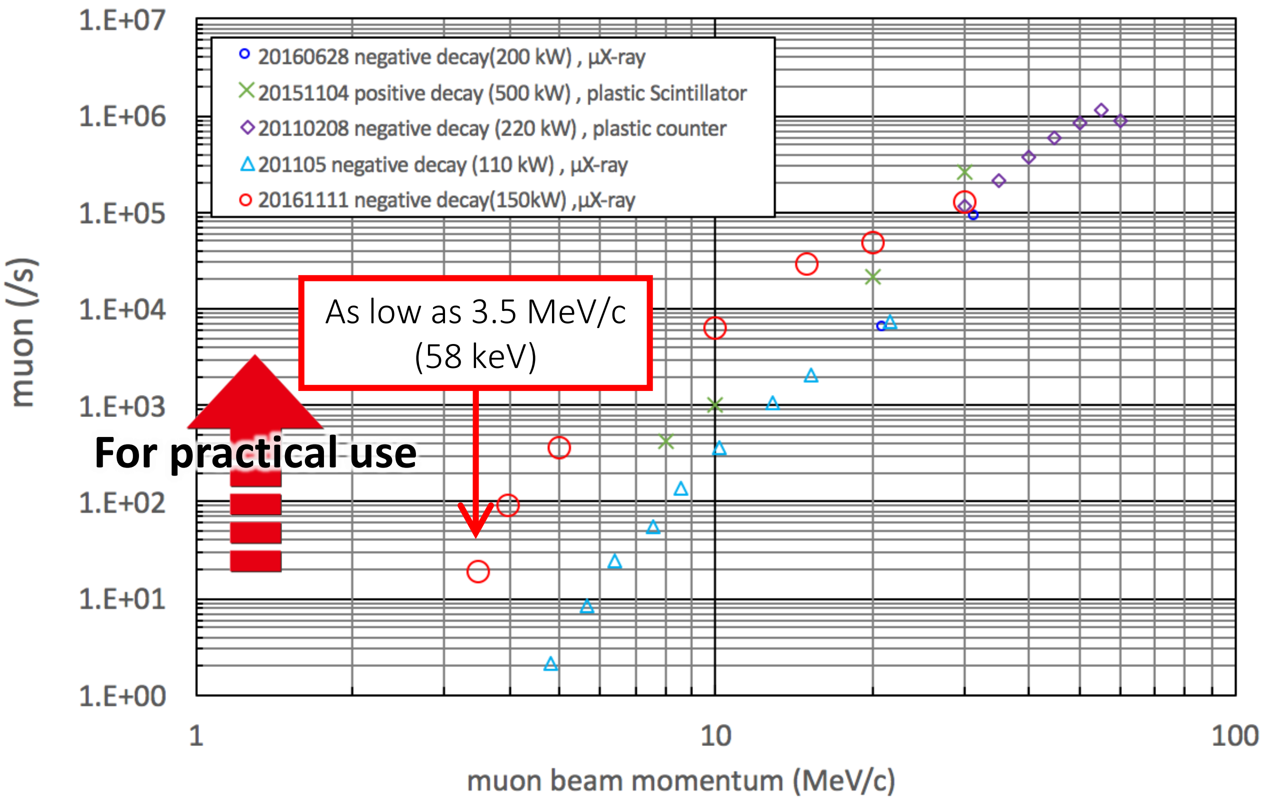


Figure 8: Same as Figure 7, except for use of linear axes and n+p reaction is not shown

Negative muon yield in MLF J-PARC

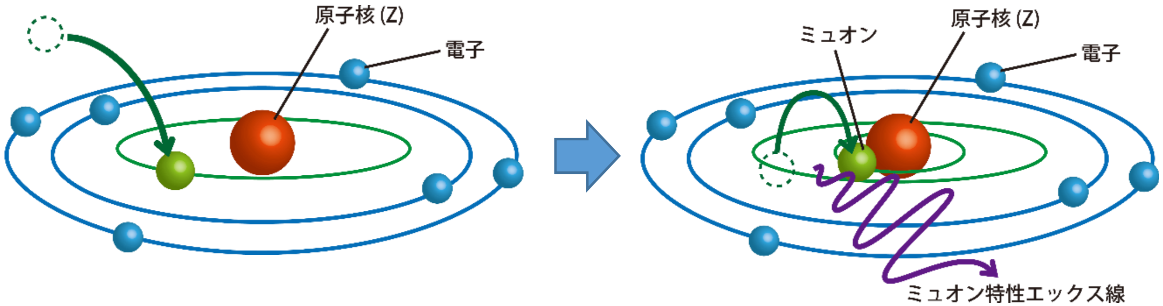
High negative muon yield owing to

- Beam transport with a window-less super-conducting solenoid
- Relatively high negative muon yield by 3 GeV proton



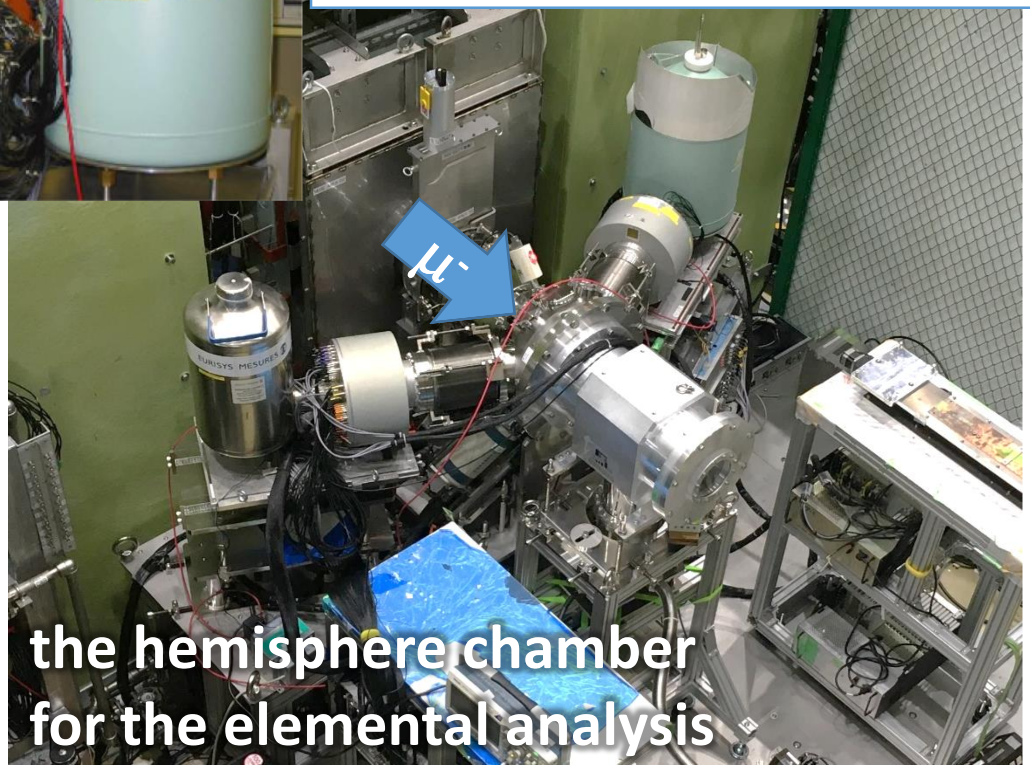
"The world's strongest pulse" and "high negative muon yield" are our specialties that differentiate the other meson factories in the world.

D-line: D2 area



In recent years, applying to archeological artifacts, *etc*, the fraction of the elemental analysis studies by μ^- has been getting increased in the D2 area.

To answer such demands, the apparatus for the elemental analysis study has been developed.



HAYABUSA2 return sample, rocks of the asteroid RYUGU was analyzed in 2021.

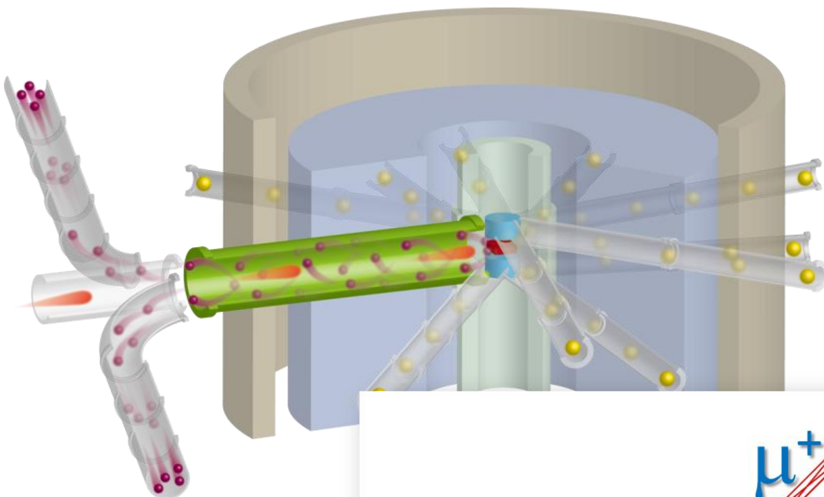
M. Tampo's talk

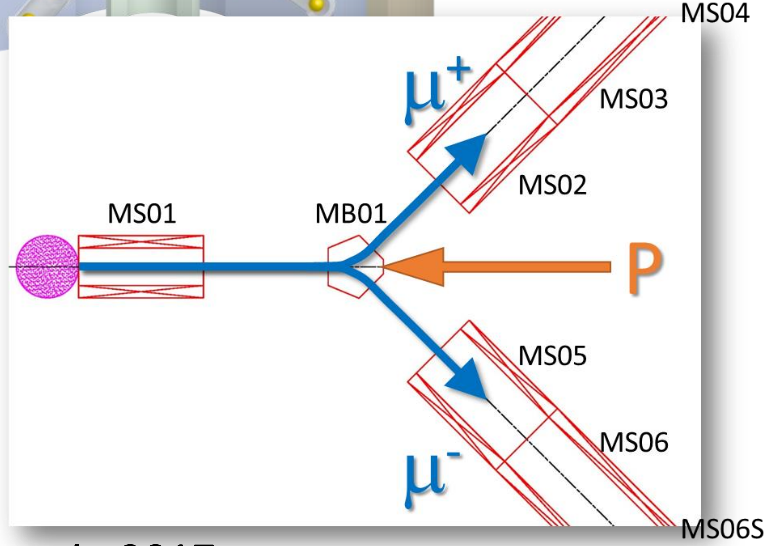
Four secondary beamlines

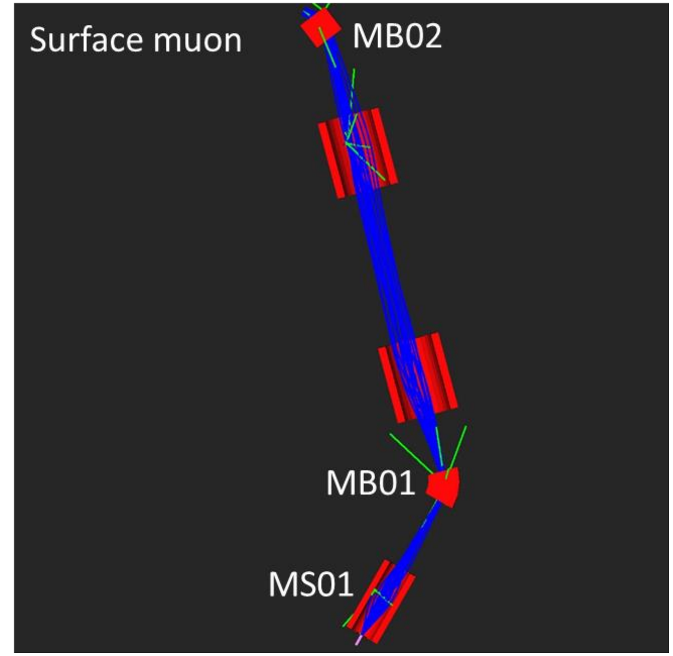
- D line since 2008
  - A decay muon beamline with a 6-m solenoid magnet for the π-μ decay section, 2 experimental areas
- U line since 2014
  - Composed of only axial focusing magnets
    The highest-intensity surface muon beamline in MUSE dedicated to the Ultra Slow Muon beam
- S line since 2014(S1) and 2021(S2)
  - A surface muon beamline, 4 experimental areas (plan) answering a lot of users' demands
- H line since 2022(H1) and 2023(H2)
  - A newly constructed beamline with a new concept realizing high intensity and high versatility

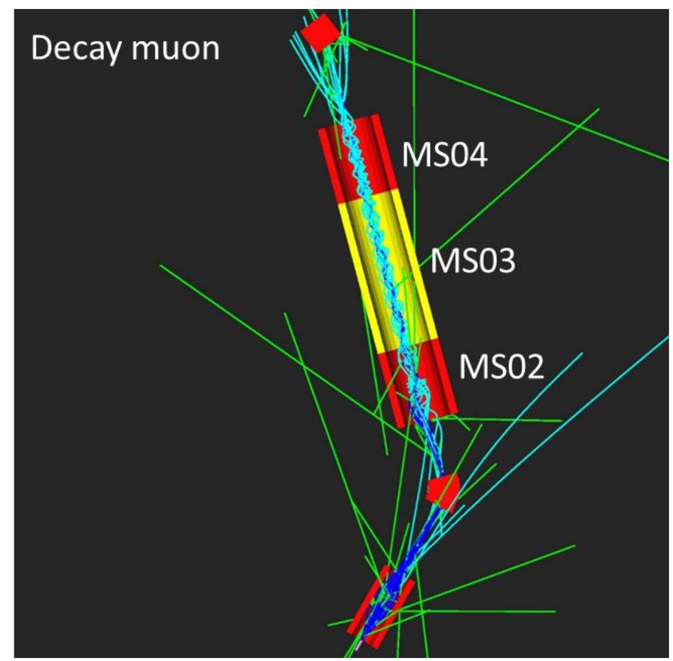
Feature prospects

MLF 2nd target station
Combination of muon and neutron target
inspired by F. Berg *et al.*, PRAB 19, 024701 (2016)
“Target studies for surface muon production”



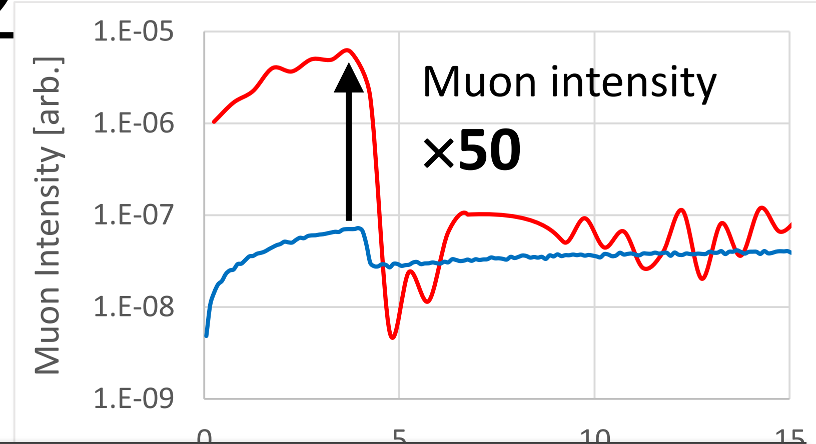




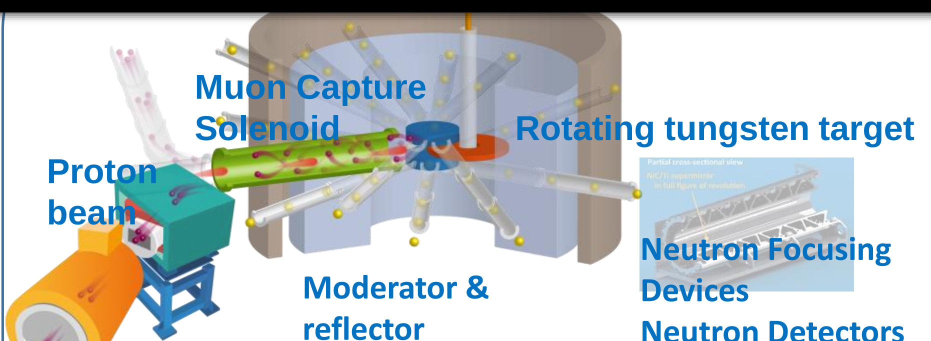


The first proposal was in 2017…

MLF Target Station2

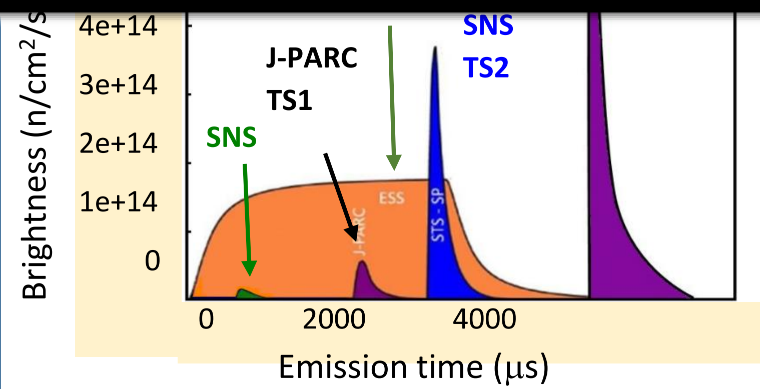


This project was selected as one of "The Medium- to the Long Term Academic Research Strategy" by the Science Council of Japan although the budget has not been guaranteed yet.



Neutron:
10 (target) x 2 (device) → 20 times gain of brightness

Muon: :
10 (target) x 5~10 (Muon capture solenoid) → 50 ~100 times gain of flux



Brightness of MLF TS2 will be the world's highest compared to the next plan of overseas facilities

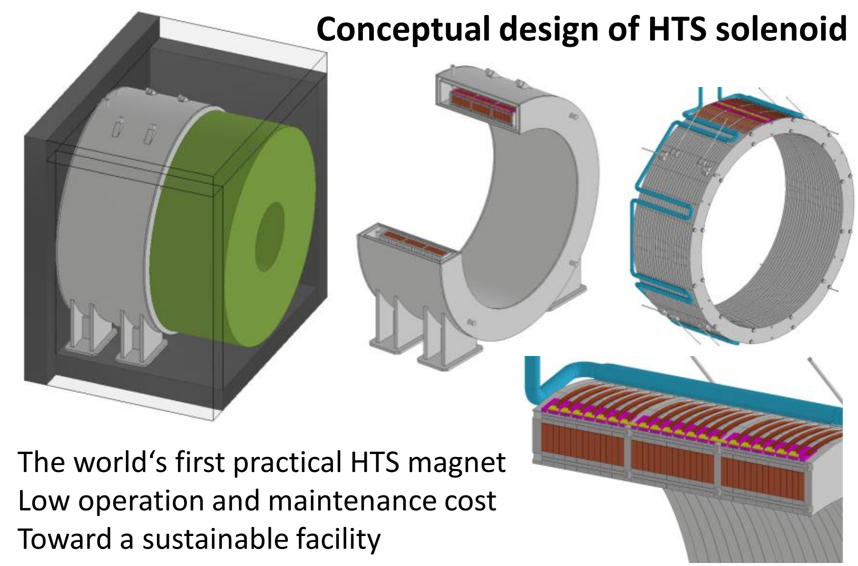
R&D for TS2

The requirement to TS2 Capture solenoid

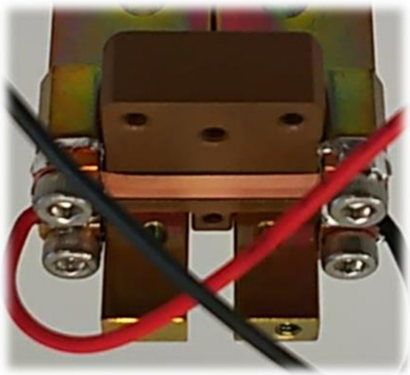
- Heat deposit: 650 W
- Neutron flux: 7.7×10^{21} n/m^2 for 10 yr.
- Absorbed dose: 130 MGy

c.f. COMET-PCS (NbTi): 1~3MGy, 250W

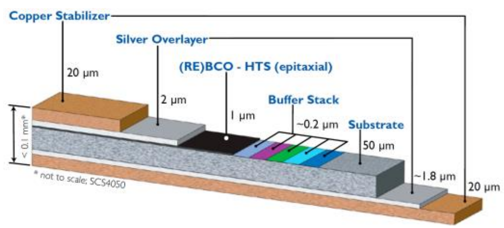
HTS S.C. magnet must be realized.



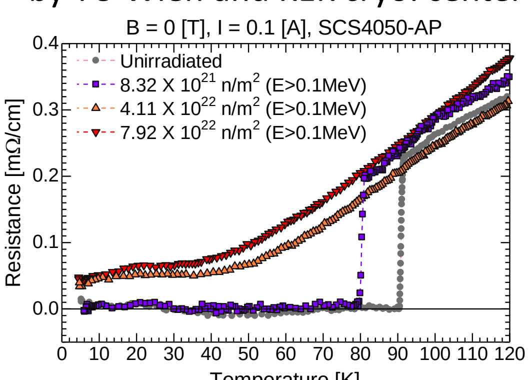
The world's first practical HTS magnet
Low operation and maintenance cost
Toward a sustainable facility

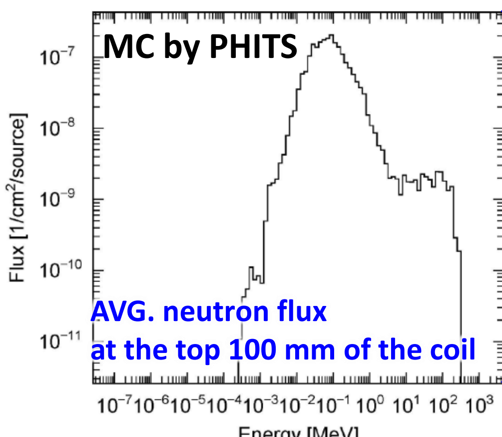


REBCO (Copper oxide S.C.)

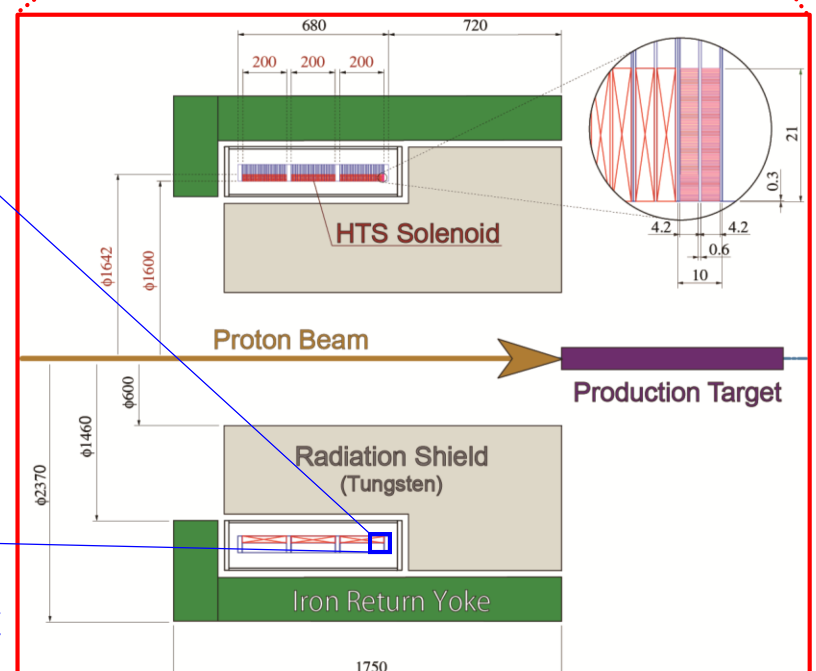


Irradiation test
by TU Wien and KEK cryo. center





Integrated flux : 7.7×10^{20} n/m^2/y (@1 MW)



Summary

- So far, I hope my talk could be just a trigger to stimulate further discussions.
- I am not confident in answering your questions correctly. But I am sure that I can introduce the responsible/suitable personnel.
- Even if we can not answer at present, we can keep discussing it after this workshop.