Oct. 18, 2023
@ PSI

Update from JP

Koichiro Shimomura
J-PARC, KEK

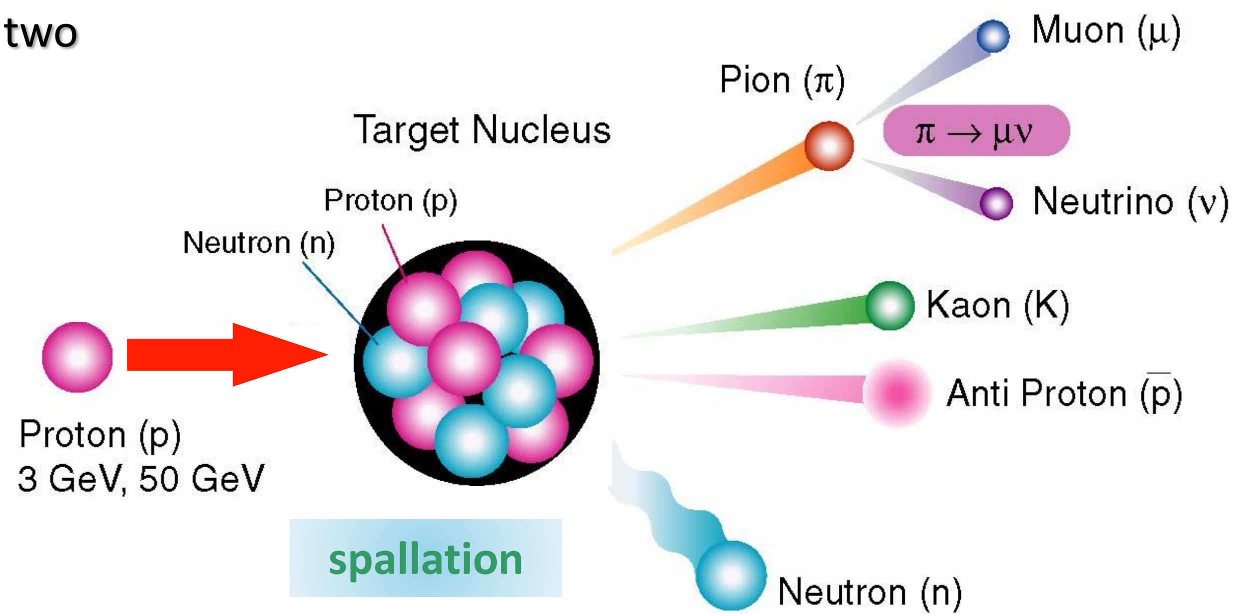
Versatile Quantum Beams for Microscopic World

J-PARC

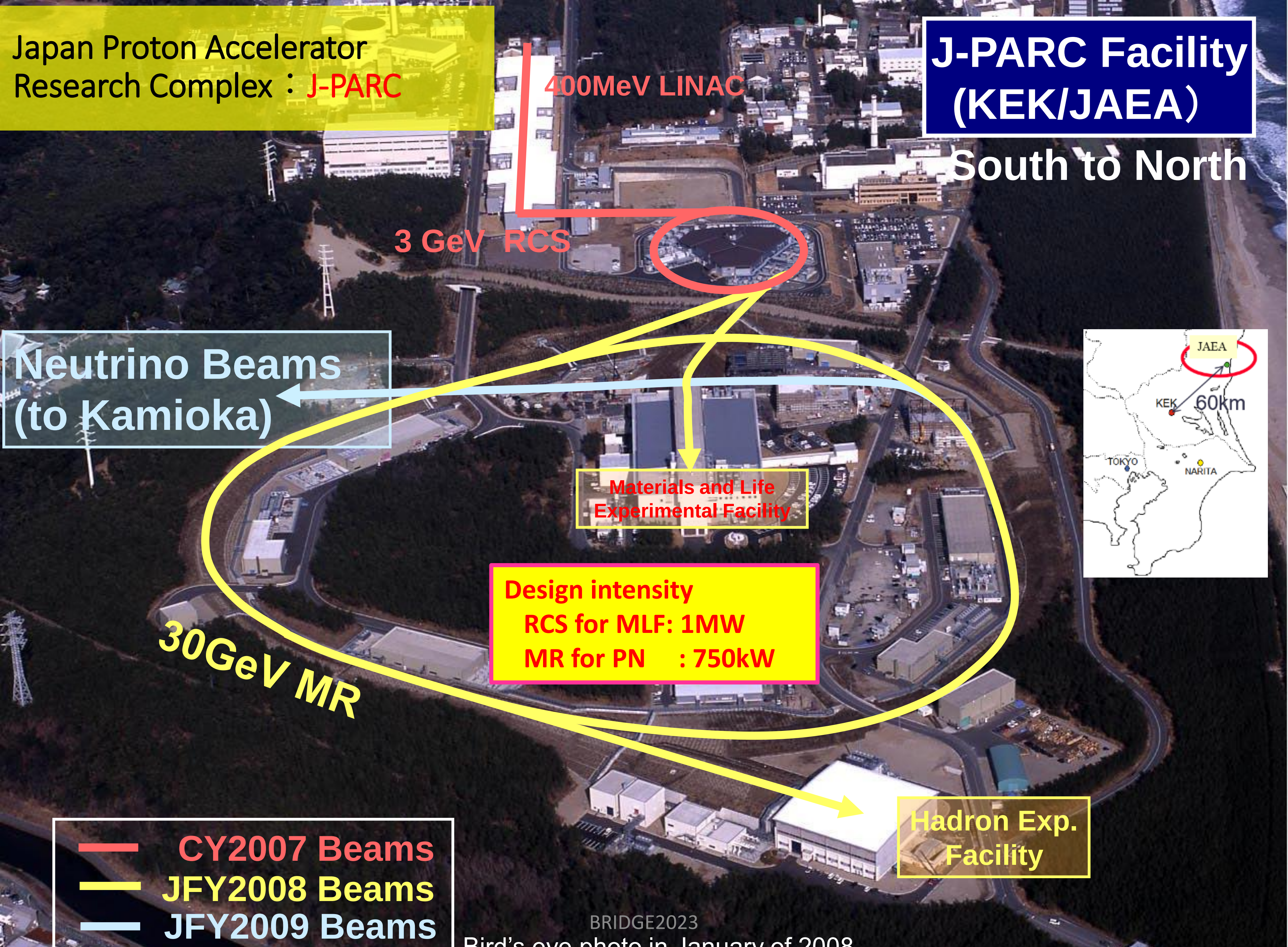
Japan Proton Accelerator Research Complex

Power-frontier accelerators and multi-purpose user facilities

Jointly operated by two organizations:
- KEK, and
- JAEA

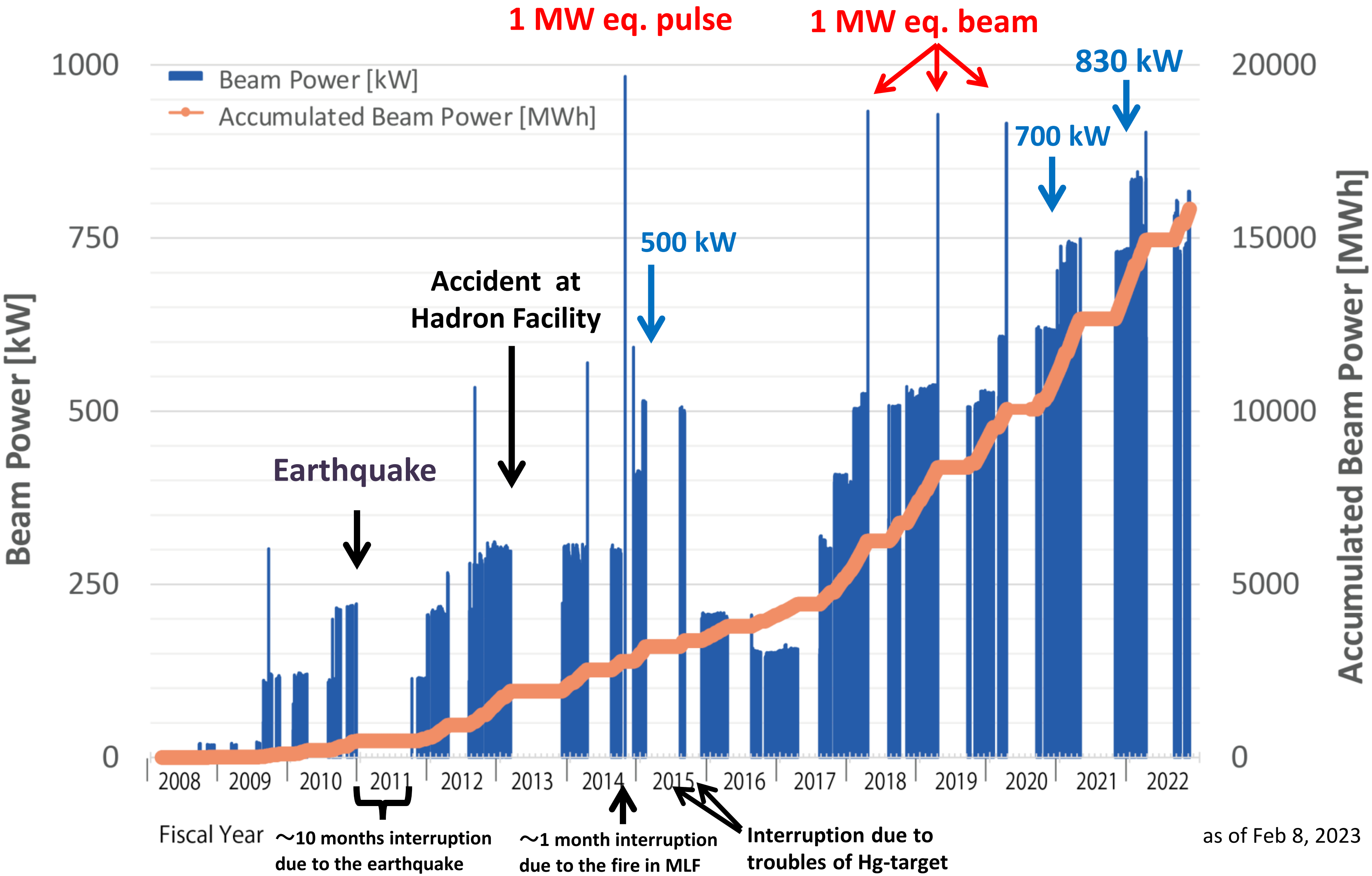


Variety of secondary particles generated with high-energy and high-intensity protons



Bird's eye photo in January of 2008

Beam Power History at MLF



BRIDGE2023

Main ring upgrade plan

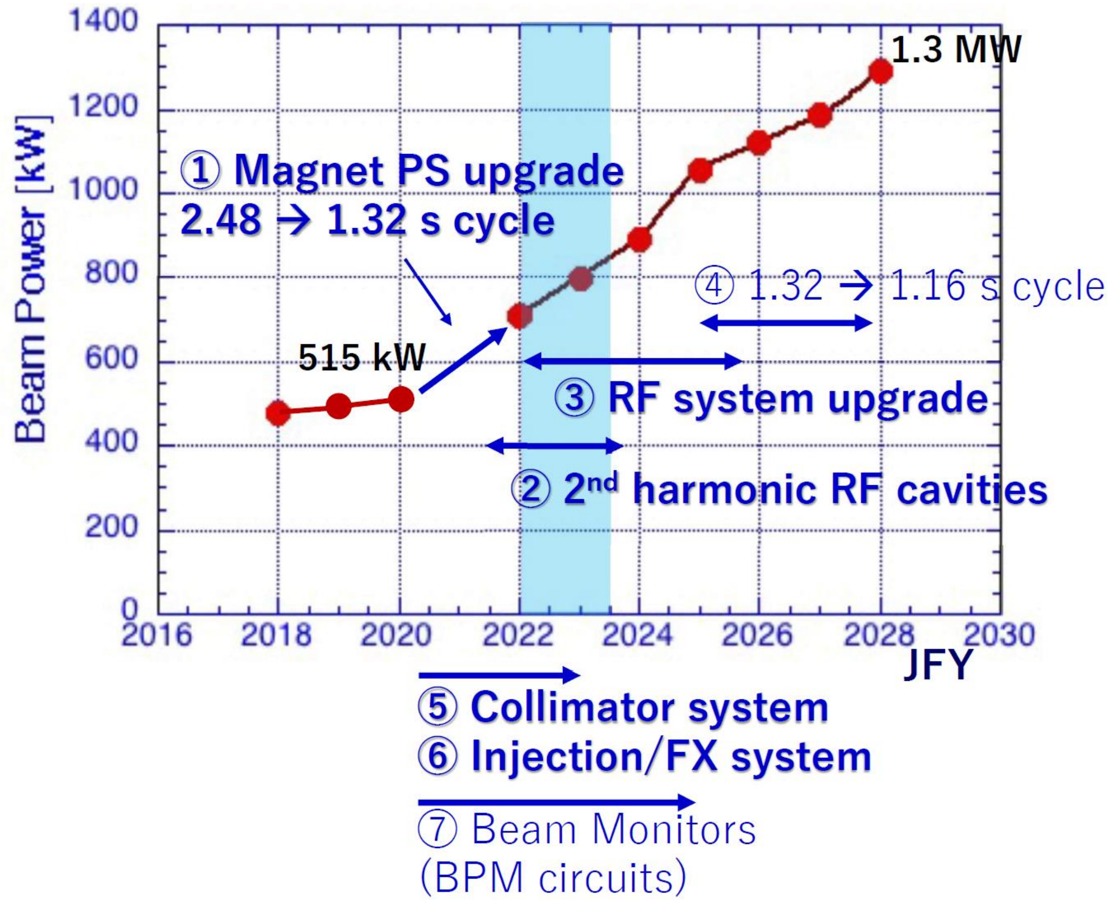
More Rapid Cycle:

2.48 s → 1.32 s → 1.16 s

- Main Power Supply to be renewed
- High gradient RF Cavity
- Improve Collimator
- Rapid cycle pulse magnet for injection/extraction

More Protons / Pulse：

- Improve RF Power
- More RF Systems
- Stabilize the beam with feedback



In April 2023
Successful demonstration of
MR-FX 30 GeV acceleration
766 kW eq. (2.17e14 ppp) in 1.36 s cycle

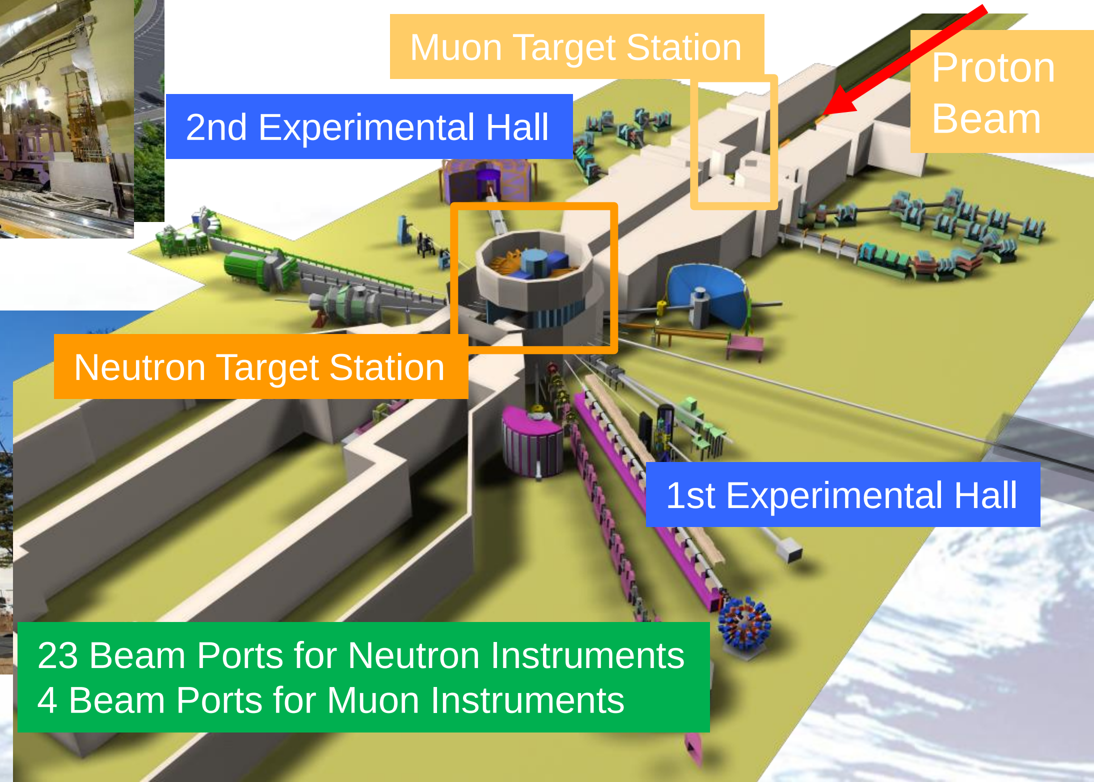
Materials & Life Science Experimental Facility

■ Neutron & Muon Beam Facility for Materials & Life S

The World Highest-Class Neutron & Muon Sources.

Neutron Source:

- 1MW
- Liq. Mercury Target
- Liq. H_2 Moderators

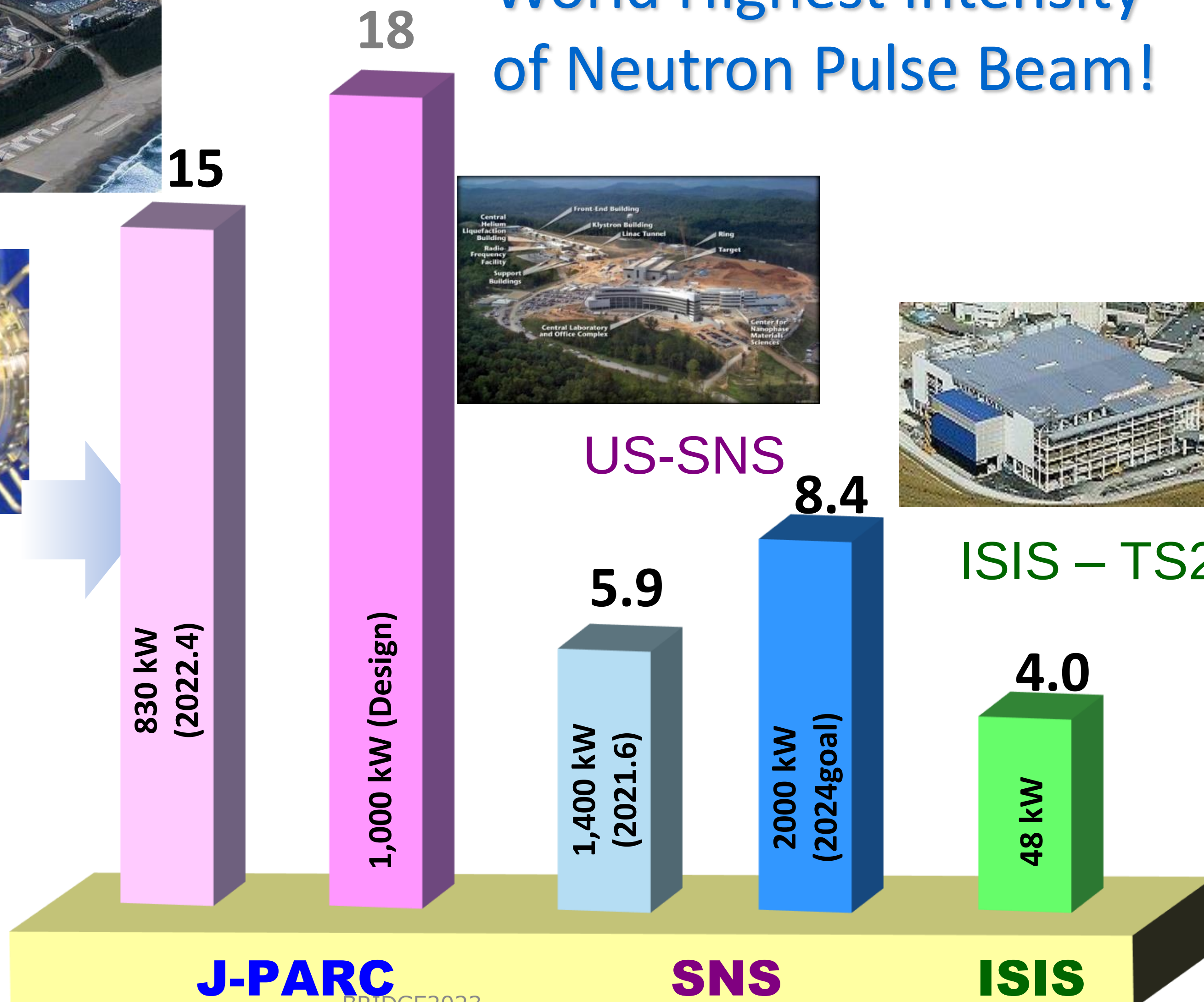


Materials and Life Science Facility（MLF）

World Highest Intensity of Neutron Pulse Beam!

JAEA's technologies

Coupled moderator

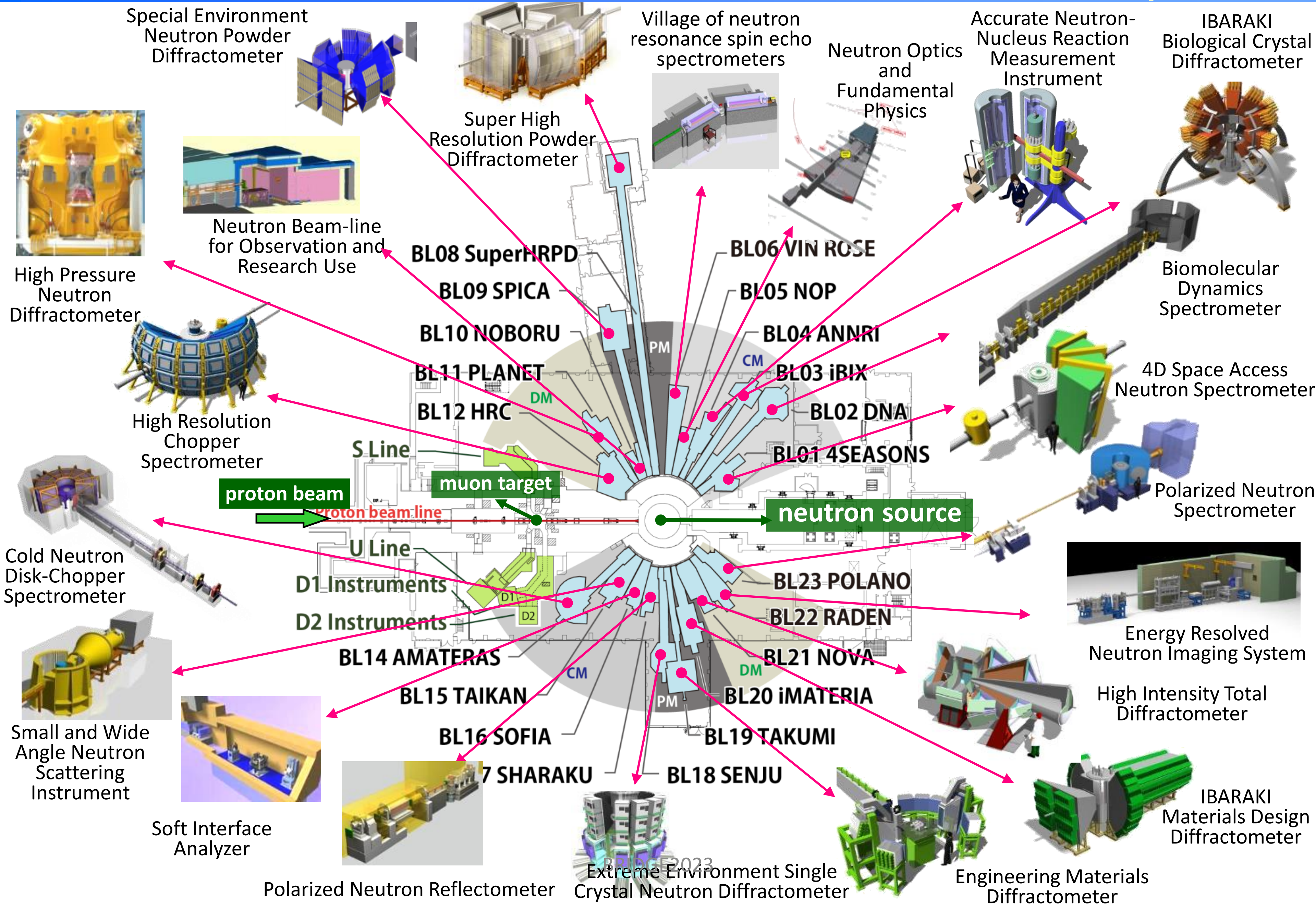


BRIDGE2023

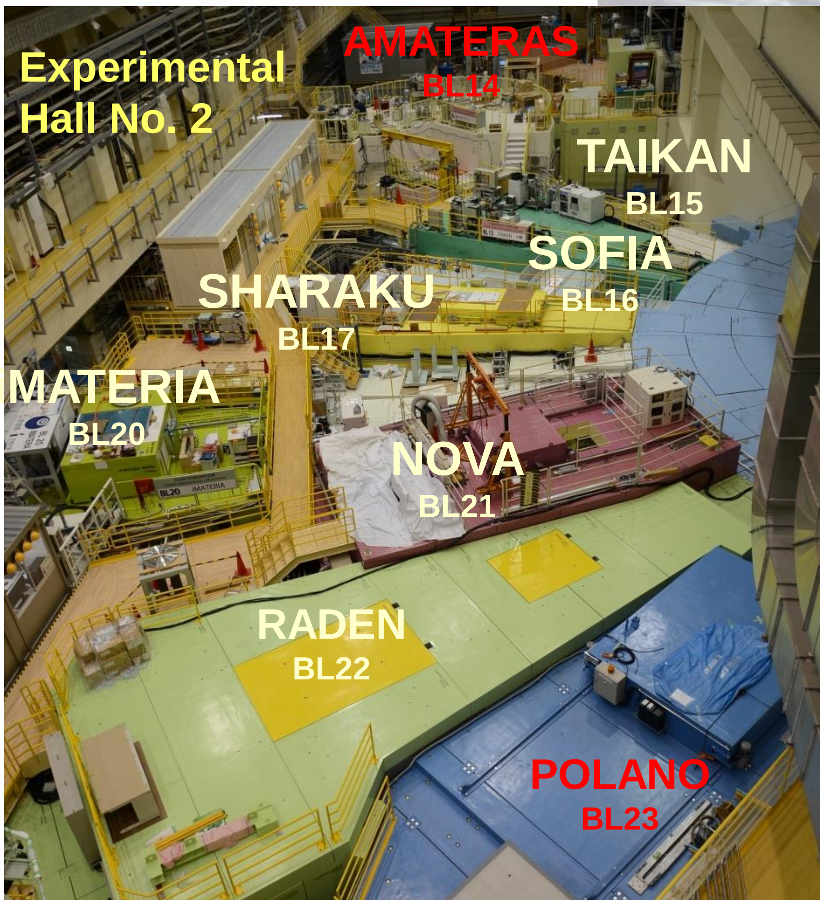
Unit：10^{12} n/(sr･pulse)

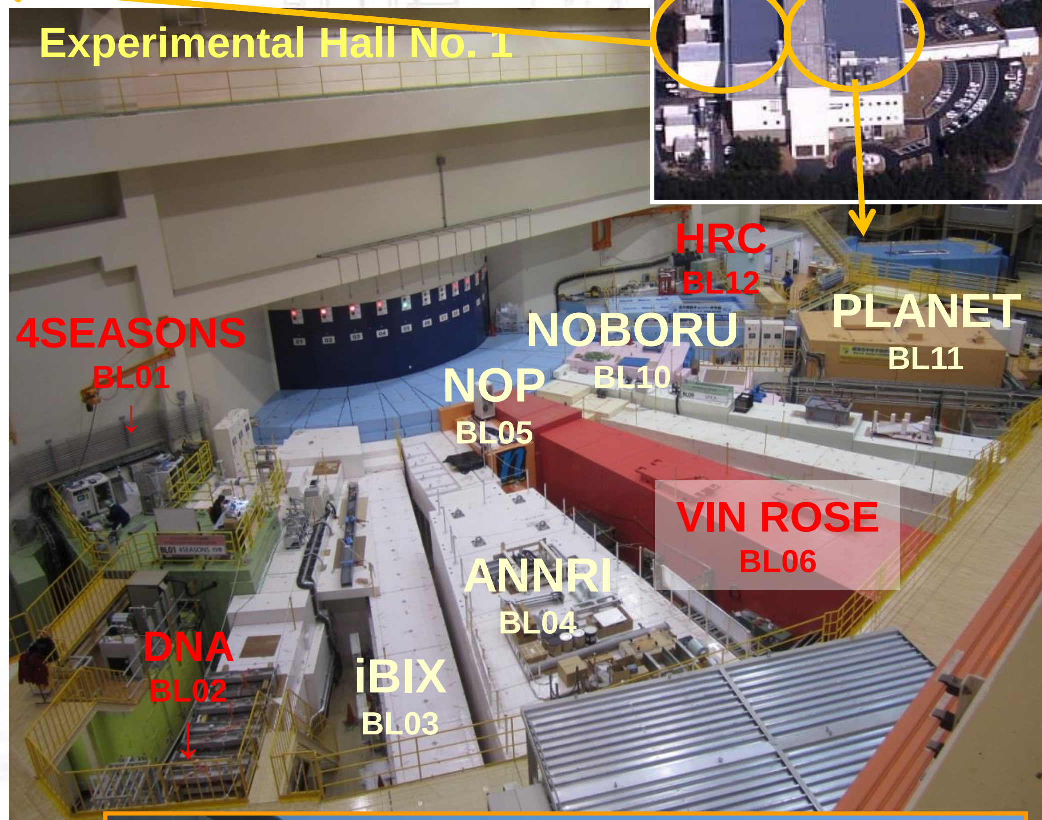
Neutron Instruments in MLF

23 beam ports
21 in operation

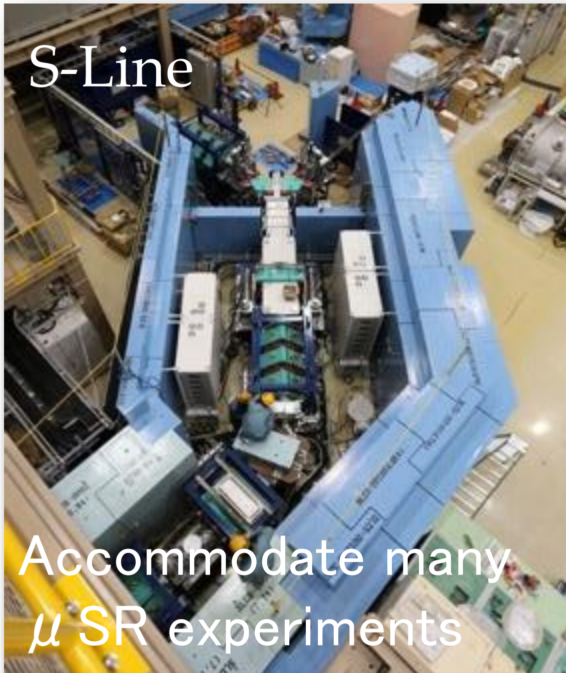


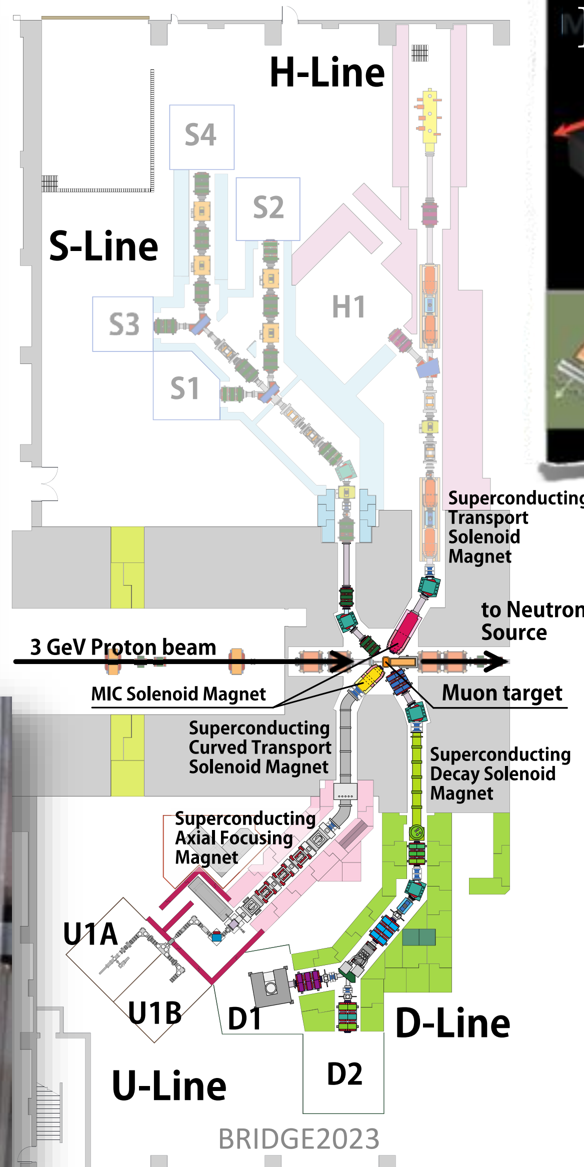
Neutron Instruments at MLF

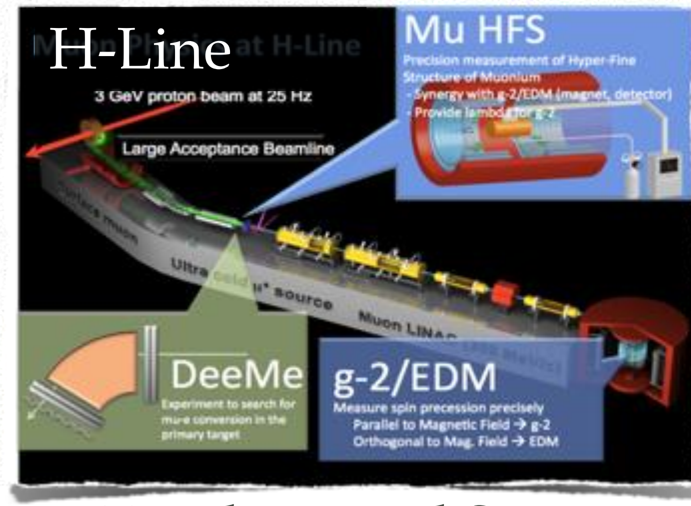




Muon Facility MUSE @ MLF





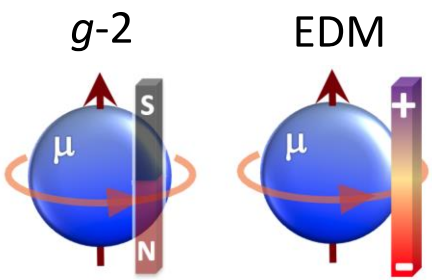


Fundamental Science with a large scale international coll.

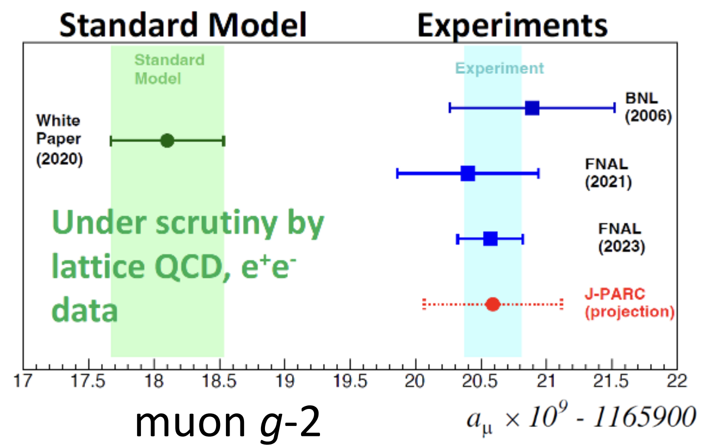
Particle and nuclear physics at J-PARC

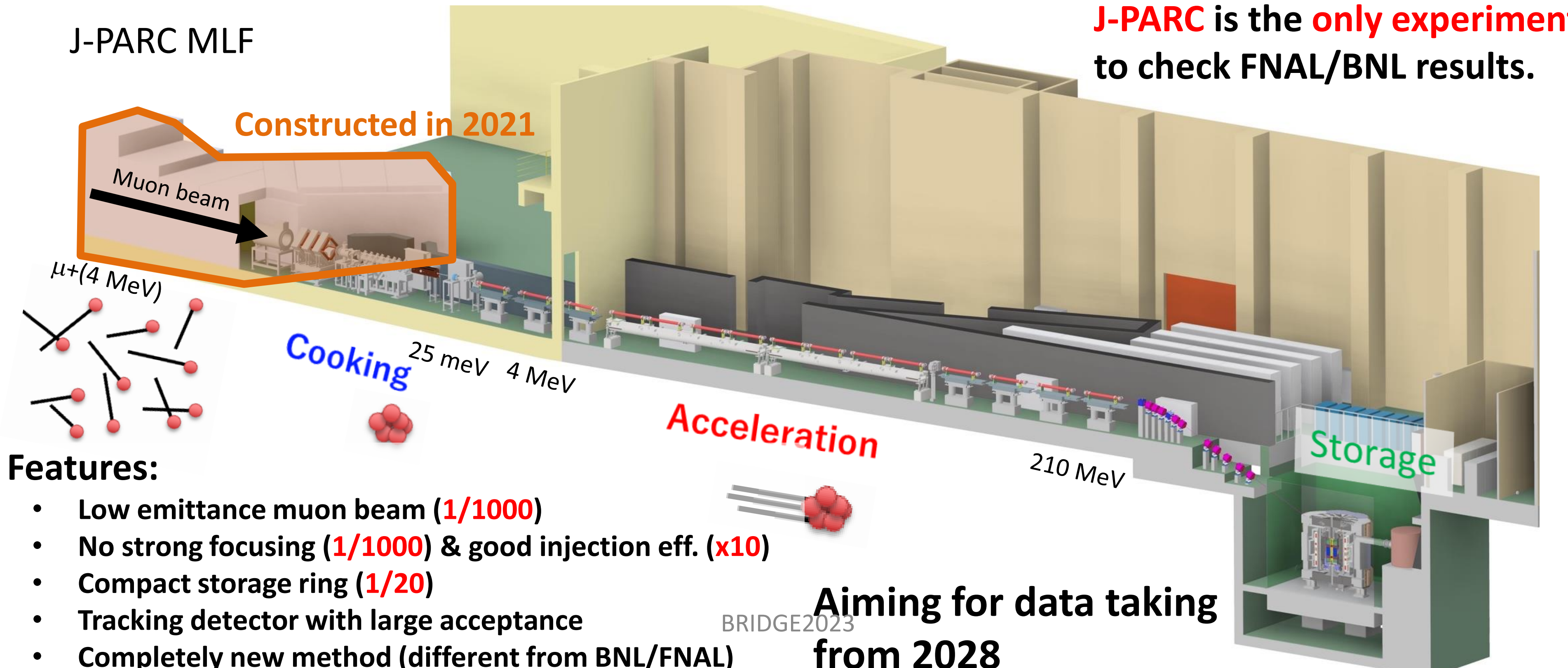
Experiments at MLF

J-PARC muon *g*-2/EDM experiment



- Aim to reach
  - μ g-2: 450ppb
  - μEDM: 1.5e-19





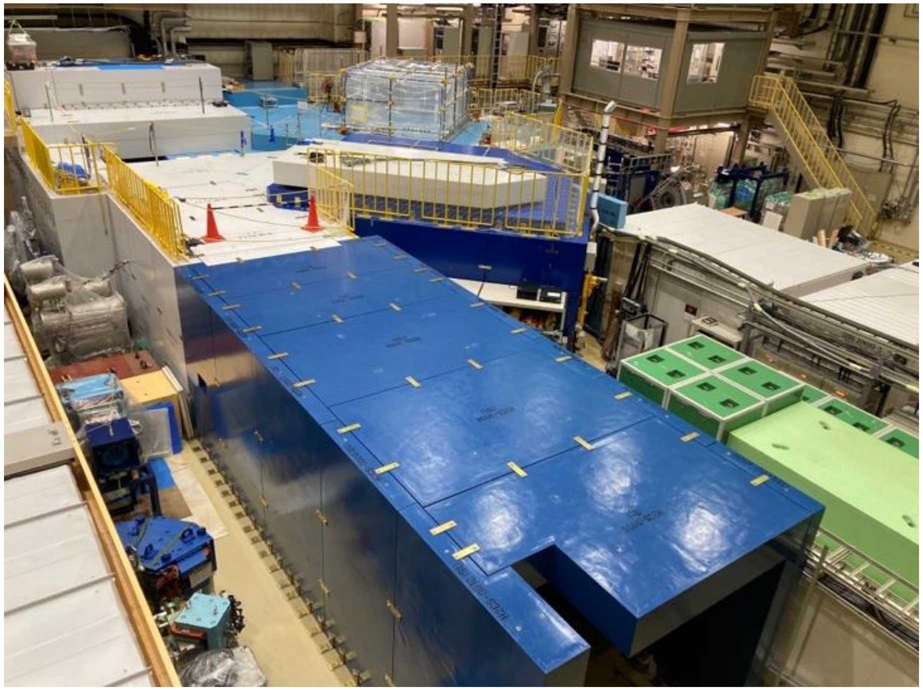
J-PARC is the only experiment to check FNAL/BNL results.

Features:
- **Low emittance muon beam (1/1000)**
- **No strong focusing (1/1000) & good injection eff. (x10)**
- **Compact storage ring (1/20)**
- **Tracking detector with large acceptance**
- **Completely new method (different from BNL/FNAL)**

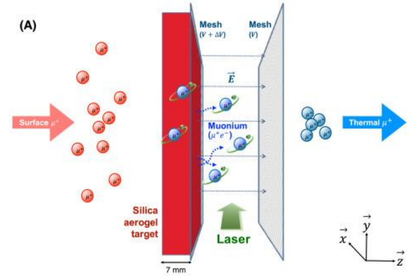
Aiming for data taking from 2028

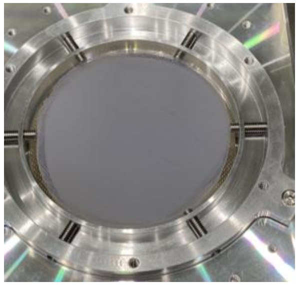
J-PARC muon *g*-2/EDM experiment

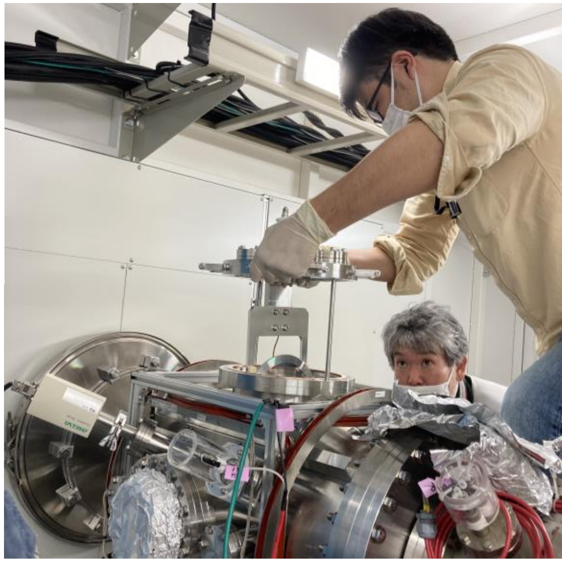
New radiation shields for beamline extension (2022)



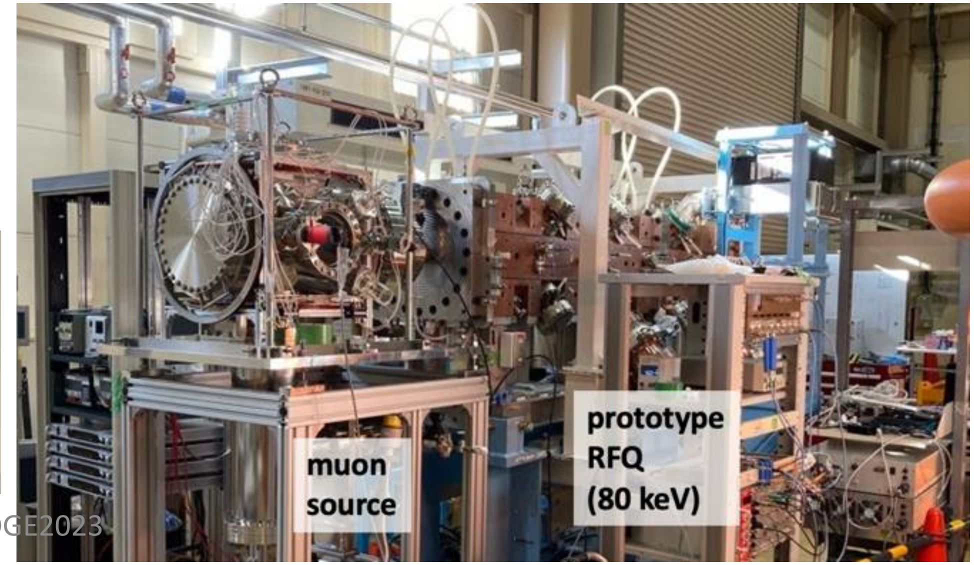
Muon cooling test (2022~)



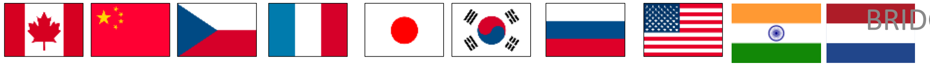




Muon cooling + acceleration test (2024~)



The collaboration (114 members fro 10 countries)



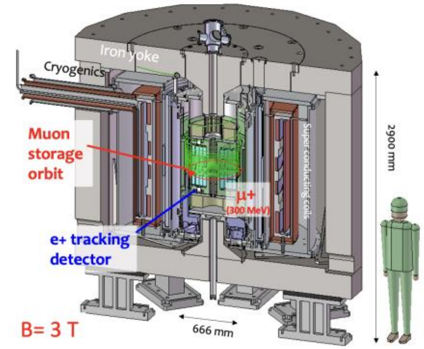
Muon *g*-2 and muonium

450 ppb

These three quantities are mutually correlated. **<u>Only J-PARC can close the triangle.</u>**

g-2

FNAL
J-PARC



μ_μ m_μ

$$a = \frac{g-2}{2} \quad \vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

J-PARC (MuSEUM)

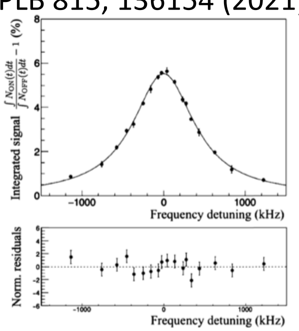
Mu HFS

J-PARC, PSI

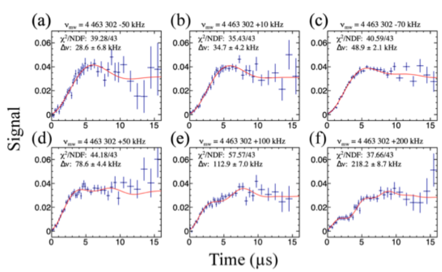
Mu 1S-2S

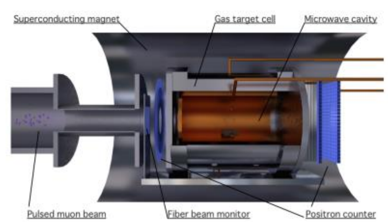
m_μ

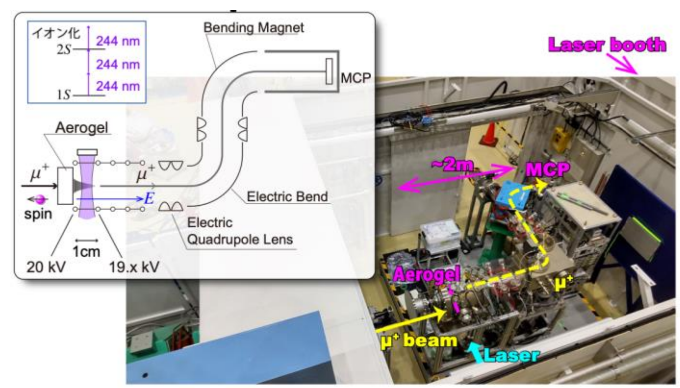
PLB 815, 136154 (2021)



PRA 104, 020801 (2021)





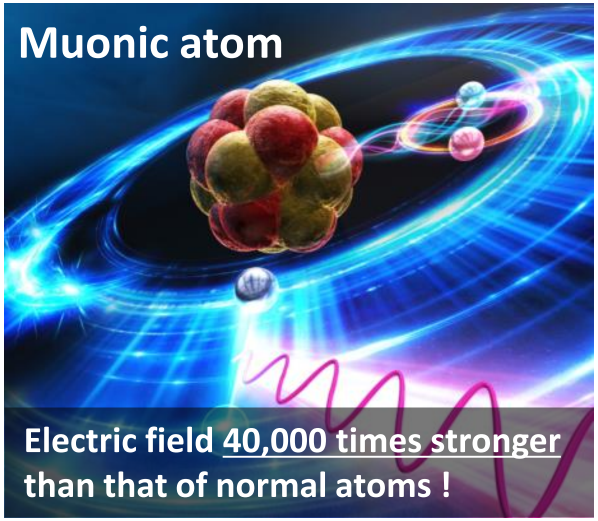


690 ppb$_{(2017)}$ → 160 ppb$_{(2018)}$ → 4 ppb

120 ppb → 1 ppb

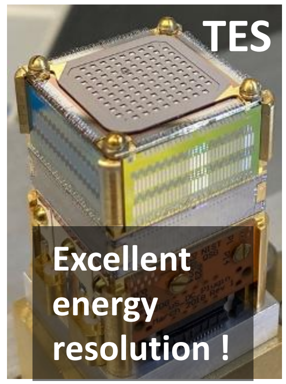
Muonic atom study @ J-PARC MLF

(1) QED verified with muonic Atoms [Phys. Rev. Lett. 130, 173001 (2023)]



Goal : **Verify strong-field QED** with spectroscopy of muonic atom X-rays

Key technology : **Superconducting TES microcalorimeters**



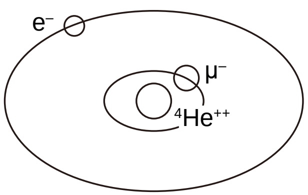
Result : Proof-of-principle experiment with μNe atom

Outlook : scheduling the main experiment (μAr atom) in next February, 2024.

towards QED test in ultra-strong electric fields **beyond the Schwinger limit**

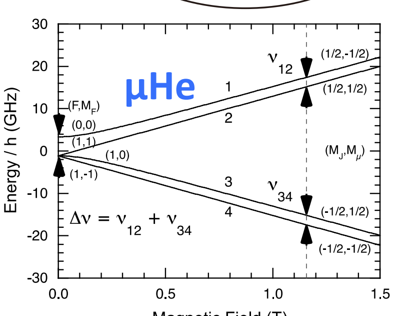
by introducing new TES detector for hard X-rays

(2) Muonic Helium Atom HFS



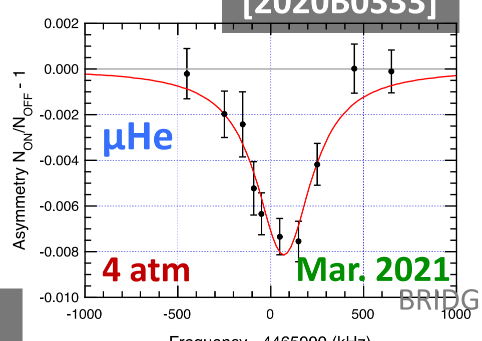
Muonic Helium

Hydrogen-like atom similar to muonium



Dn(μHe) = 4465.004(29) MHz

[2020B0333]



Goal : **Verify strong-field QED** with spectroscopy of muonic atom X-rays

Key technology : **Same technique as with Mu used to measure μHe HFS**

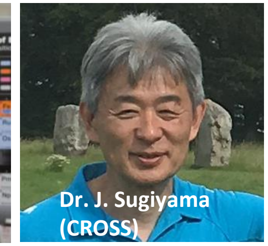
Result : **World record is achieved**

Previous date: 6.5 ppm → Our experiment: 4 ppm

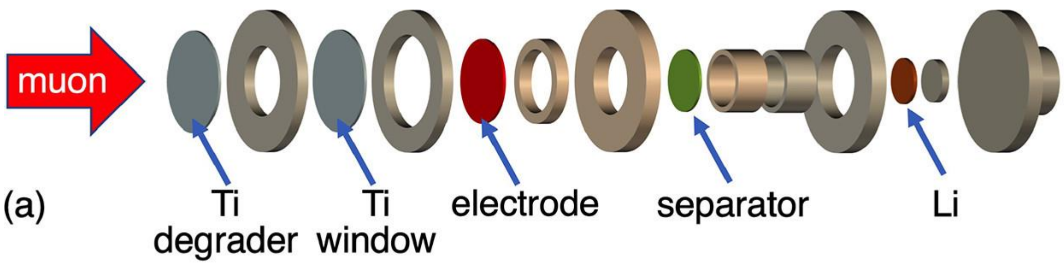
Outlook : Sensitive tool to test **3-body atomic system** and **bound-state QED** theory and determine fundamental constants of the **negative muon magnetic moment** and **mass** to test **CPT** with 2nd generation lepton

Operando μ^+SR on Li-ion battery

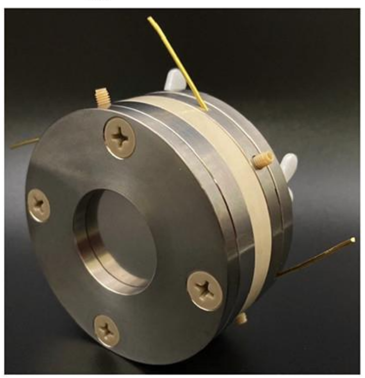
Research of Li ion diffusion in a Li-ion battery



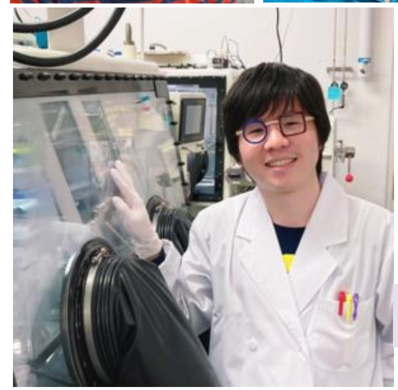
(a)



(b)



Self-diffusion coefficient of Li ions in Li_xCoO_2 has been measured with operando μ^+SR **during a charge and discharge process** (0.2<x<0.9).



D. Igarashi
Ph.D student in Department of Applied Chemistry, Tokyo Univ. of Science

PRESS

Nikkan Kogyo Shimbun
(日刊工業新聞)

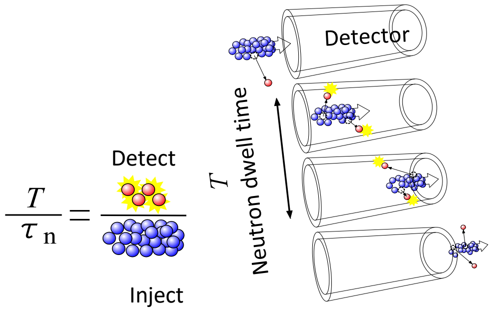
Operando Muon Spin Rotation and Relaxation Measurement on $LiCoO_2$Half-Cell
K.Ohishi *et al., ACS Appl. Energy Mater.* **5**, 12538 (2022).

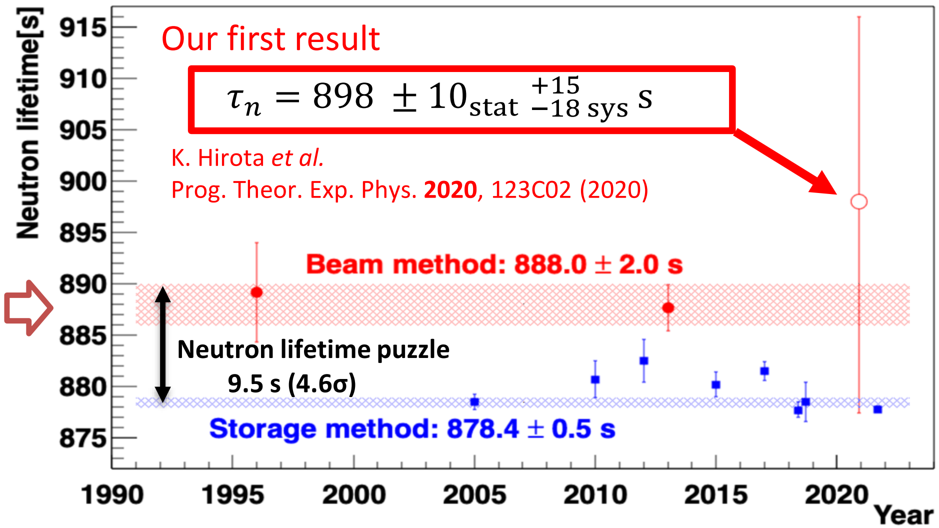
Neutron lifetime experiment

The neutron lifetime differs significantly between measurement of decay and disappearance. This discrepancy is known as the "**neutron lifetime puzzle**". It is still an open question, whether some errors of experiment, or indicating new physics.

Decay

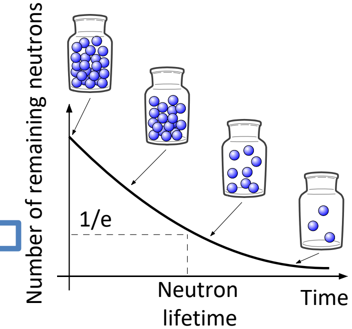
Beam method

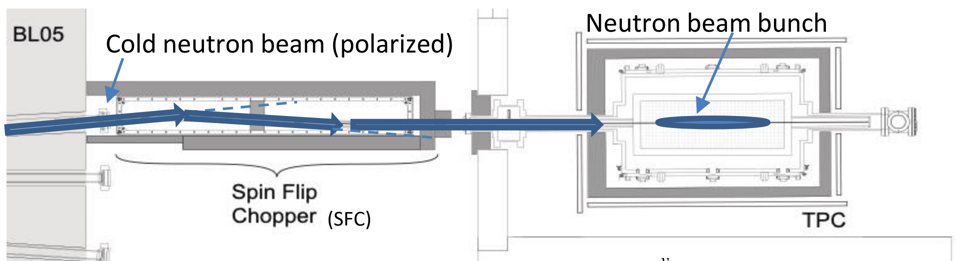


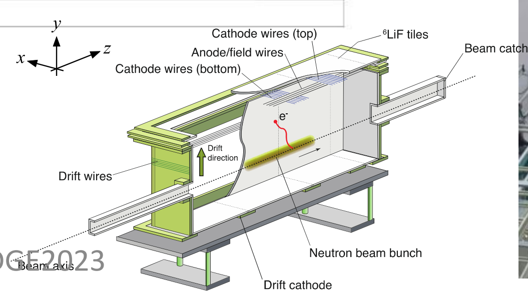


Disappearance

Storage method







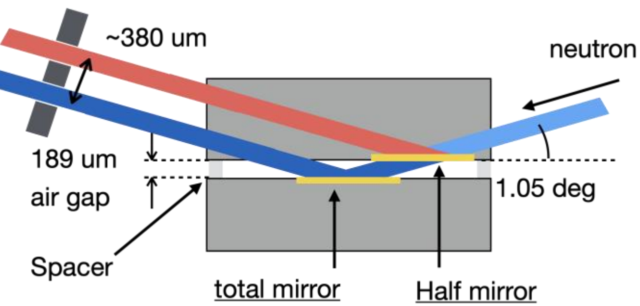
- To solve the neutron lifetime puzzle, a new type of experiment is on-going at a neutron beam line in J-PARC.

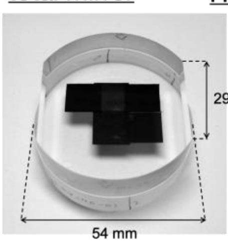
  <u>Goal: measurement with ~1 s accuracy</u>

Neutron Interferometer

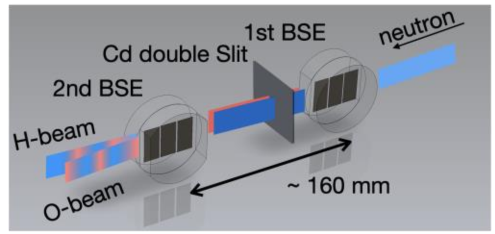
Neutron interferometers can precisely measure interactions with neutron as phase differences. The newly developed multilayer interferometer with a pulsed neutron source can use wide wavelength, simultaneously.

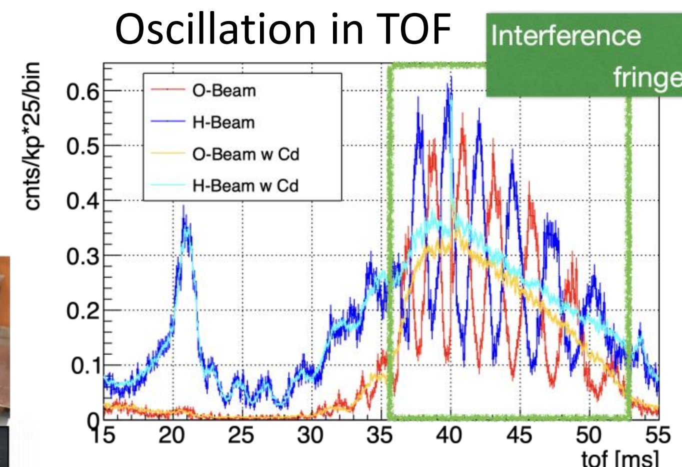
$$\Delta\phi = 2\pi \frac{m_n \lambda L}{h^2} \Delta E \propto \mathrm{TOF}$$

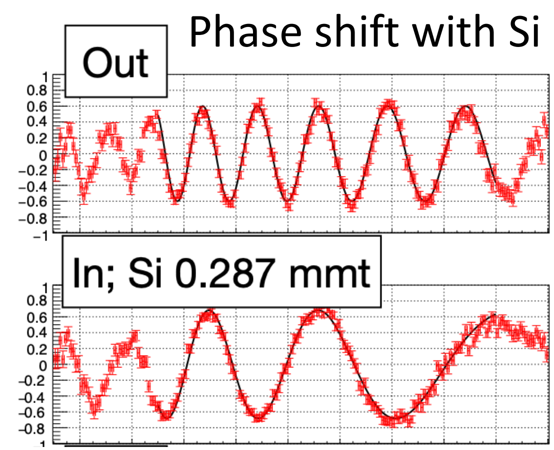




Beam Splitting Etalon (BSE)







- Oscillation by interference of neutrons were clearly observed (visibility ~70%).
- Phase shift by inserting sample in a path was measured.
  → successfully measured scattering length.
- Further wavelength extension is planned to increase statistics by a factor of 20.

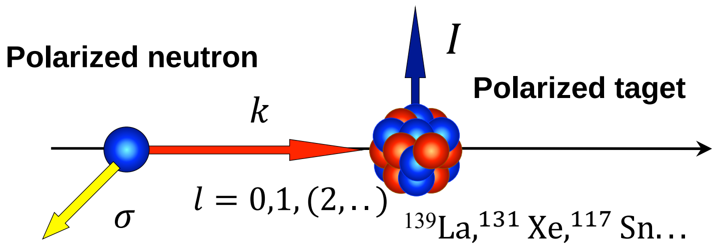
T. Fujiie et al., arXiv:2308.01922

T-violation search using compound nuclei

NOPTREX
Neutron Optical Parity and Time-Reversal EXperiment

P-odd and T-odd interactions can be largely enhanced in neutron induced compound nuclei
New T-violation search experiment based on optical behavior of neutron can be performed without final state interaction. The fundamental study and development of polarized target and neutron polarization device are ongoing.

T-odd cross section: $\sigma \cdot (k \times I)$

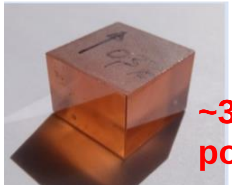


1. Optical Test — final-state interaction free

2. Enhancement — 10^6 times enhancement

3. New Type of New Physics Search — chromo-EDM

Development



~30% ^{139}La polarization

Polarized target : $LaAlO_3$

K. Ishizaki *et al.* NIM A1020, 165845 (2021)

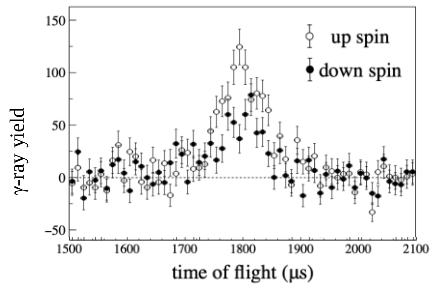
~40% neutron polarization

^{3}He neutron polarizer

T. Okudaira *et. al.* , NIM A 977, 164301 (2020)

Enhancement mechanism

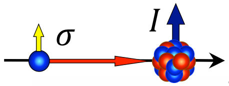
Neutron spin dependent asymmetry



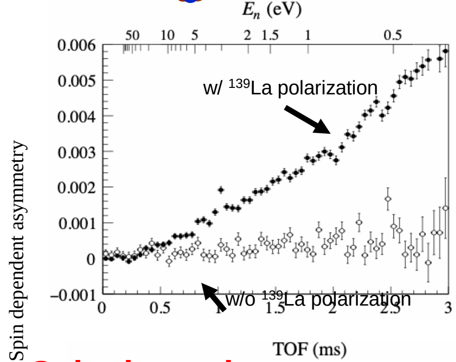
T. Yamamoto *et al.* Phys. Rev. C. 101, 064624 (2020)

Enhancement factor was determined using (n,γ) reaction
→T-violation enhancement in ^{139}La+n : 10^6 times!

Experiment with polarized target + neutron



T-even spin dependent cross section: $\sigma \cdot I$



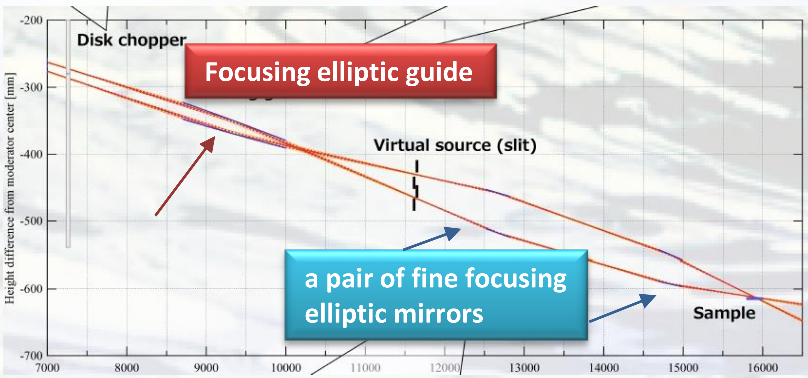
Spin dependent cross section of ^{139}La+n was successfully observed !

T. Okudaira *et al*, arXiv:2309.08905 (2023)

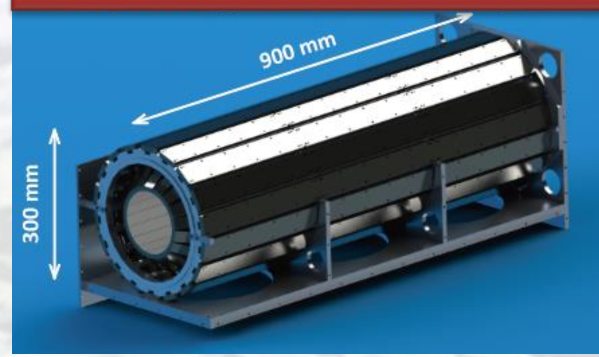
Advanced instrumentations with neutron optical devices at J-PARC

- Dr. Masako Yamada @KEK/ MLF, J-PARC Center

"*A time-slicing measurement* with *Multi-Incident-angle Neutron Reflectometry*"@SOFIA(BL!6) using a pair of focusing elliptic supermirrors

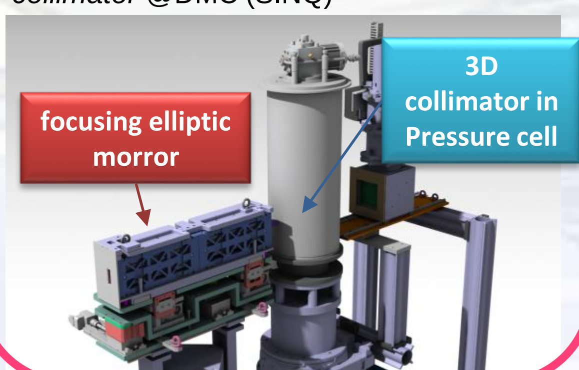


"*A high-resolution* Neutron Resonance Spin Echo spectrometer" @VIN-ROSE(BL06) using a large ellipsoidal neutron-focusing super-mirror in a full figure of revolution

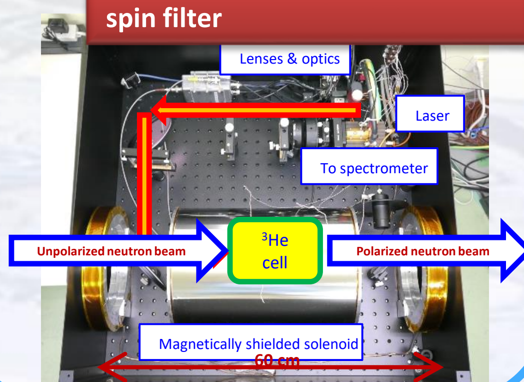


"*High-S/N* setup for a Small Sample in Pressure Cell" @DMC (SINQ)

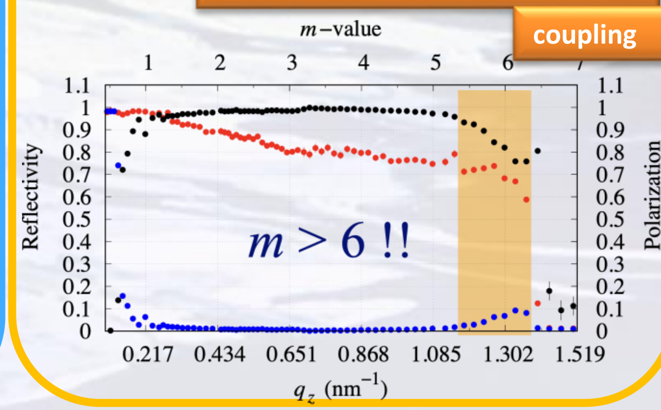
using a focusing elliptic mirror +3D-printed collimator @DMC (SINQ)



"*Polarizing high energy neutrons*@POLANO(BL23)" using a in-situ polarized 3He neutron spin filter



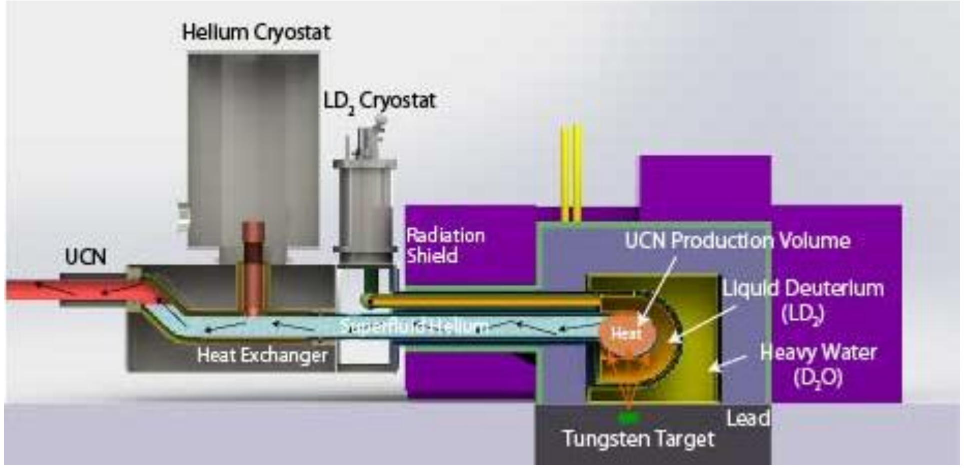
"*Improved performance* of *wide bandwidth neutron-spin polarizer* due to ferromagnetic interlayer exchange coupling



TUCAN Project

TRIUMF Ultra-Cold Advanced Neutron
Japan-Canada Collaborative Research

Goal of TUCAN
- Construct the world-leading Ultra Cold Neutron source
- To search the neutron EDM with the precision of $10^{-27}\ e{\cdot}cm$



TUCAN Source Overview
Combination of a spallation neutron source and superfluid helium UCN converter

Expected performance
UCN Source
- Production rate 1.4×10^{7} UCN/sec
- Source storage lifetime 28 sec
- UCN density in the source 3×10^{3} UCN/cc
- Total number in the source 3×10^{8} UCN

EDM measurement
- Initial density in EDM cel 200 Pol. UCN/cc
- To reach statistical sensitivity of $\sigma_d = 10^{-27}$ ecm **400 MT day**

Helium Cryostat System
- Cooling Power 9.6 W
- liquid 3He temperature 0.8 K
- He-II temperature
  - 1.0 K @ HEX
  - 1.1 K @ production volume

First UCN production is scheduled in 2024!!

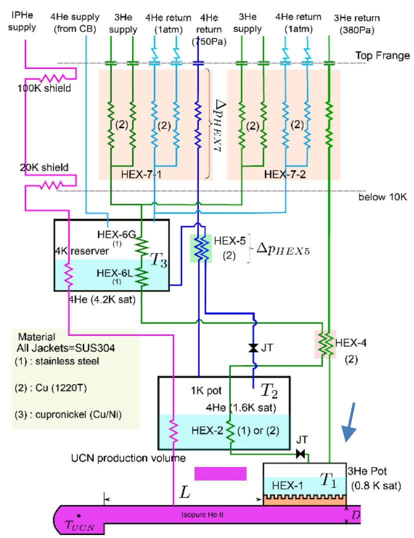
Cryogenic System Development at KEK

KEK is responsible for the superfluid helium cooling

- To suppress UCN loss by phonon up-scattering, superfluid helium needs to be kept around 1.0 K

Helium-3 cryostat

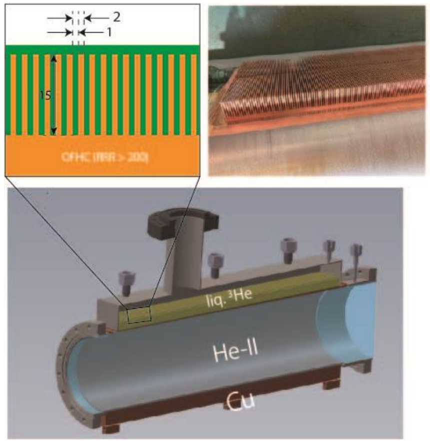
Cooling power: 10 W @ 0.8 K



Flow diagram

Main Heat Exchanger

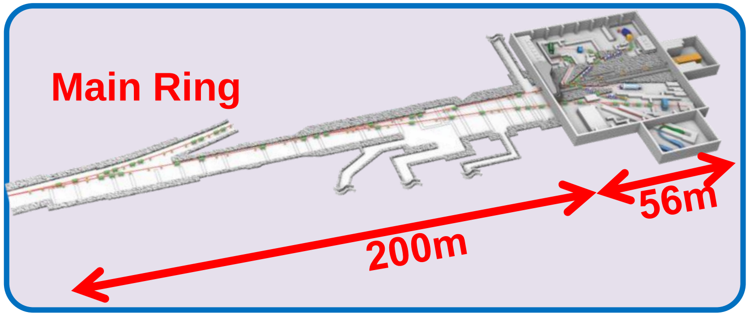
Cooldown superfluid helium by the liquid ^{3}He



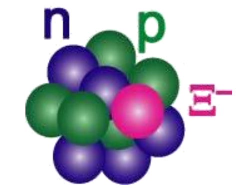
Details are presented in poster session!!

Experiments at Hadron Experimental Facility

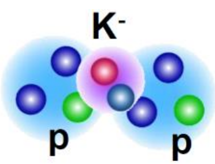
Hadron Experimental Facility



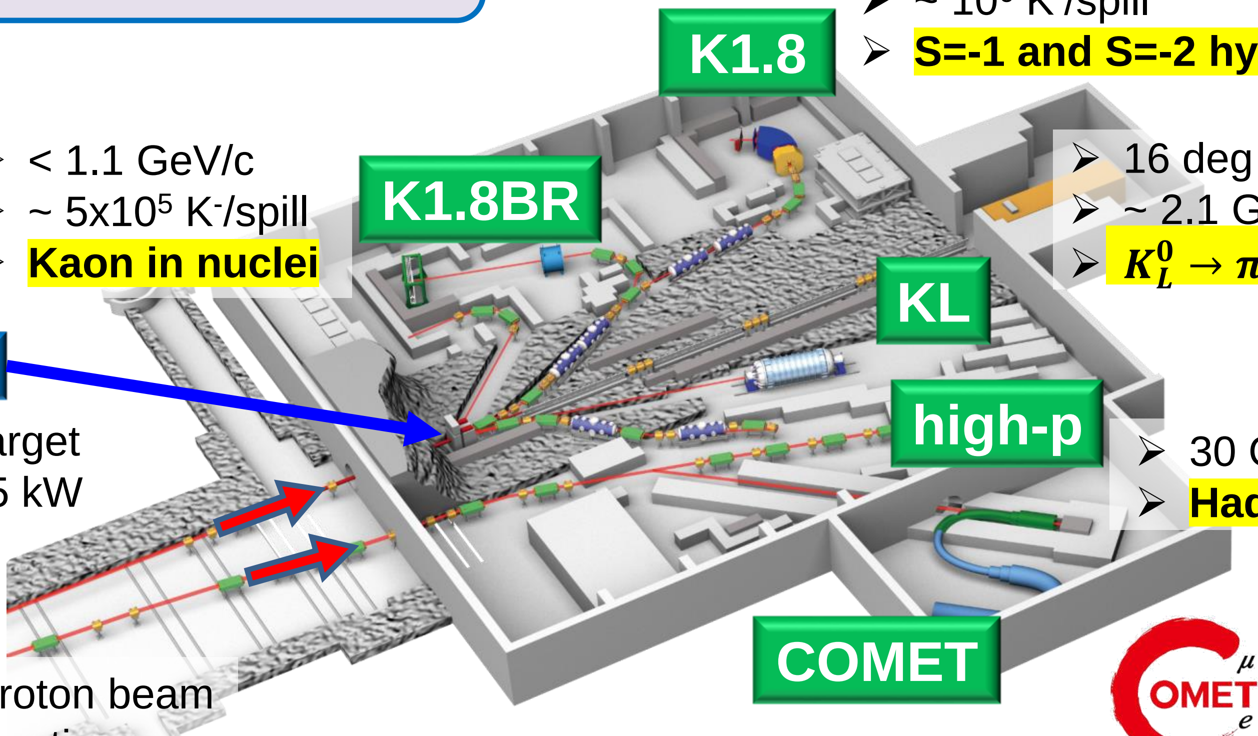
➡ Overview: Poster No.5 by S.Sawada



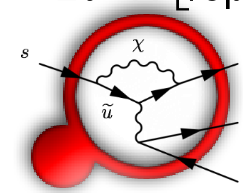
- < 2.0 GeV/c
- ~ 10^6 K^-/spill
- **S=-1 and S=-2 hypernuclei**



- < 1.1 GeV/c
- ~ 5×10^5 K^-/spill
- **Kaon in nuclei**



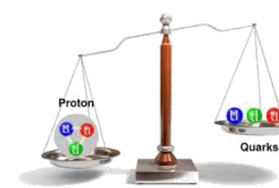
- 16 deg extraction
- ~ 2.1 GeV/c ~ 10^7 K^0_L/spill
- $K_L^0 \to \pi^0 \nu \bar{\nu}$



T1 target

- Gold target
- max 95 kW

- 30 GeV proton ~ 10^{10}
- **Hadron physics**

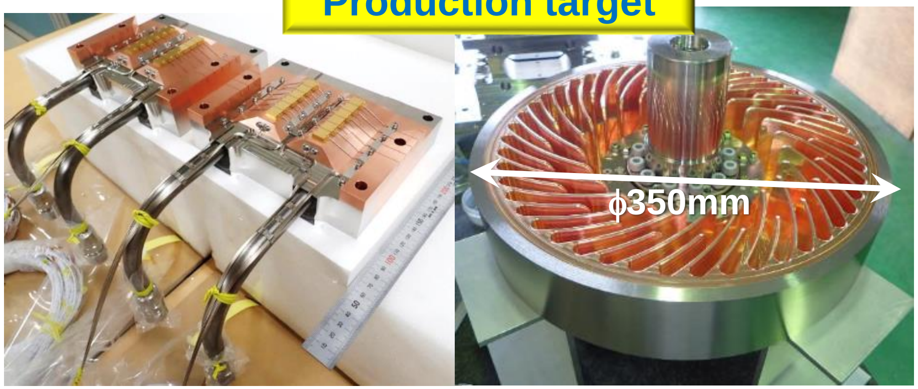


- 30GeV proton beam
- Slow extraction
- 65kW achieved

- μ^- beam
- **μ-e conversion**

Development of Beam Line Components

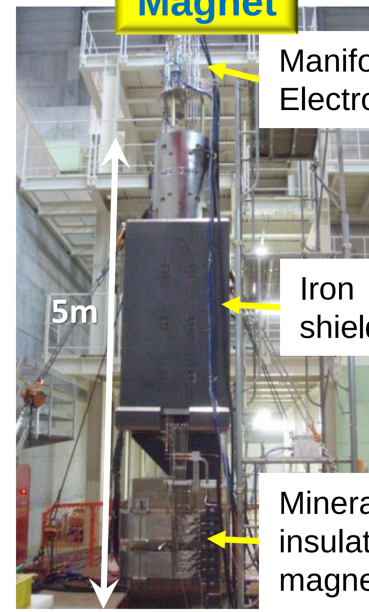
Production target



Development of rotating target: Poster No.3 by H.Takahashi
Development of displacement sensor: Poster No.9 by F.Muto

Vacuum devices

Magnet



Manifolds, Electrodes

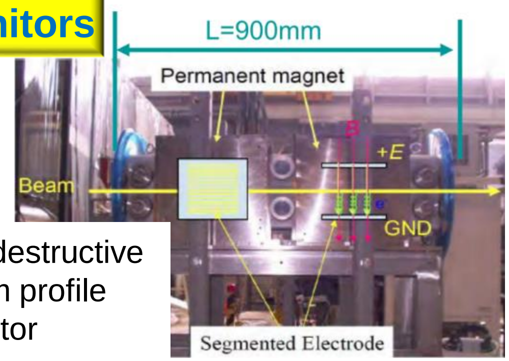
Iron shield

Mineral insulation magnet

Beam dump

Status of beam dump: Poster No.7 by K.Agari

Beam monitors



Nondestructive beam profile monitor

Beam control & Safety interlocks

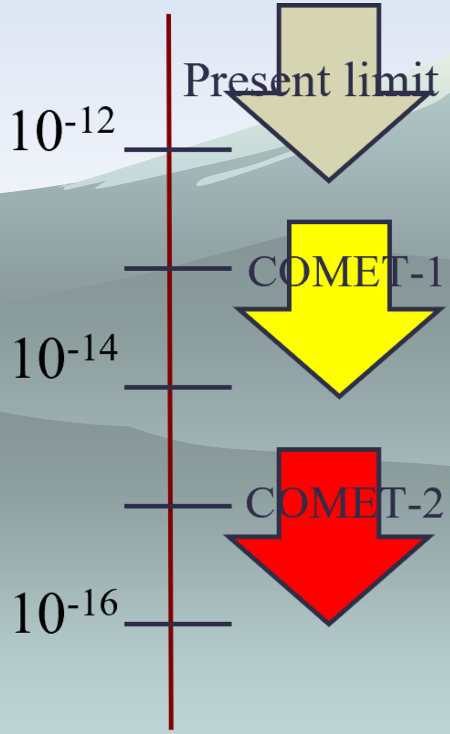
EPICS

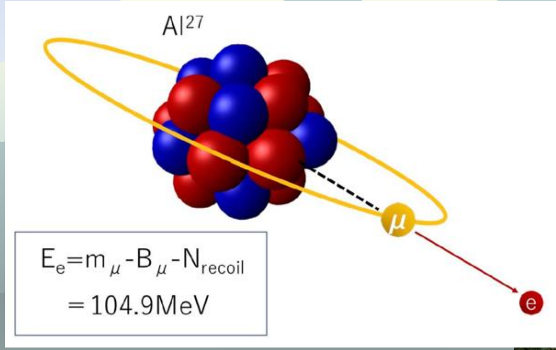
Main control system is based on EPICS

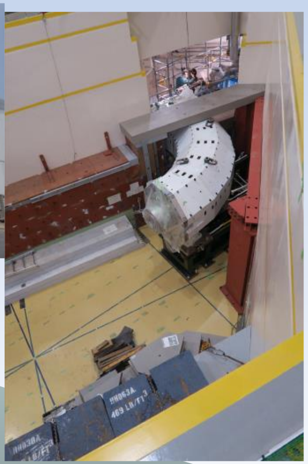
COMET experiment

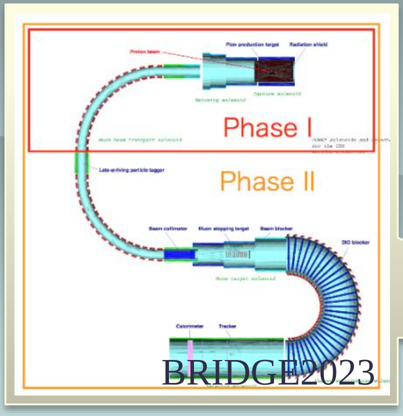
- μ→e conversion search
  $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - Very small $O(10^{-54})$ in SM
  - **Discovery = New Physics!**
- First commissioning in FY2022

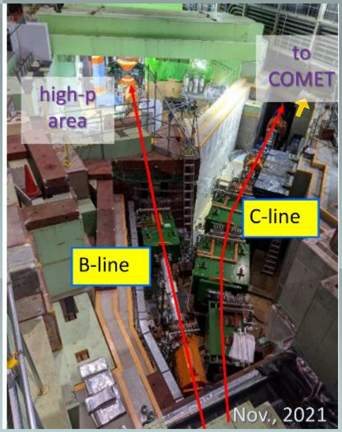
COMET Hall



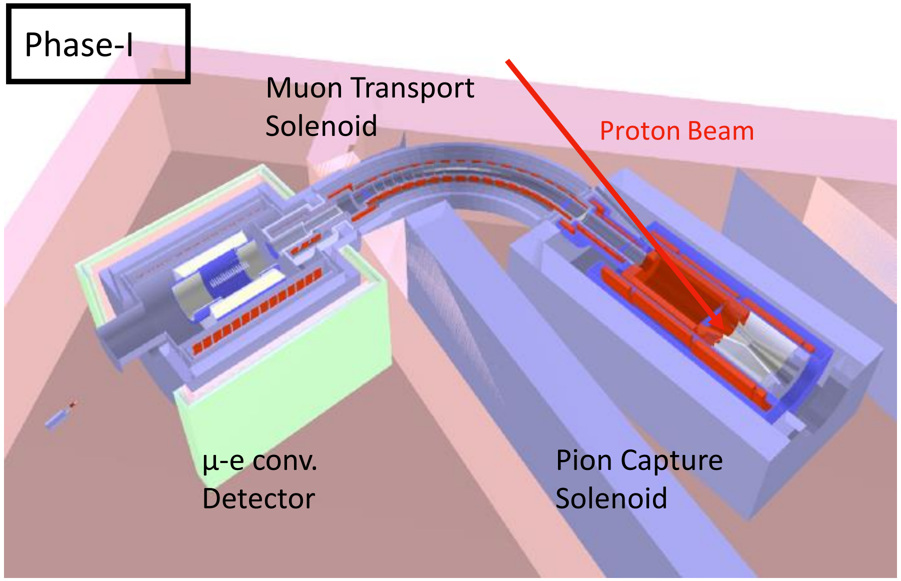








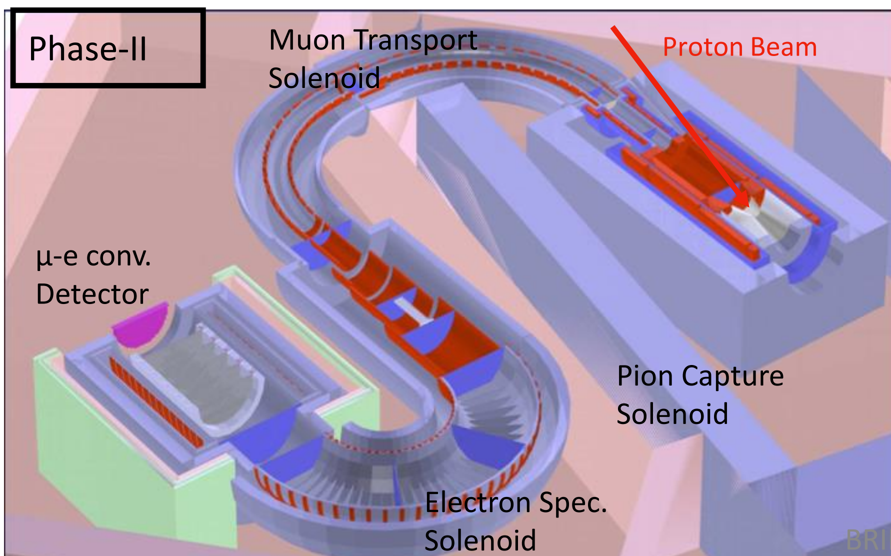
COMET Phase I & II



Target Sensitivity $<10^{-14}$ with 3.2kW beam

- **Proton beam line** construction completed in **FY2021**
- **Graphite** as a pion production target
- Pion Capture Solenoid construction is in the 4th year of multi-year construction contract (FY2020-2023)
- Physics Detector
  - CDC and hodoscope in a solenoid
  - Muon stopping target (Al) at the center of the solenoid

Beam engineering run in FY2022 and physics in FY2024-.

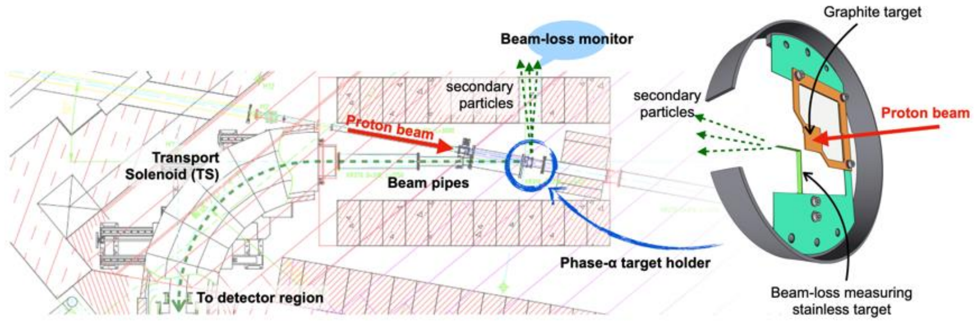


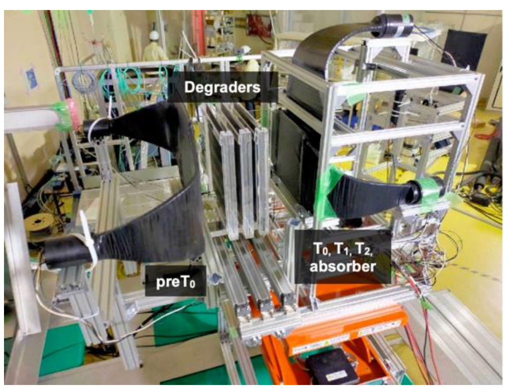
Target Sensitivity $<10^{-16}$ with 56 kW beam

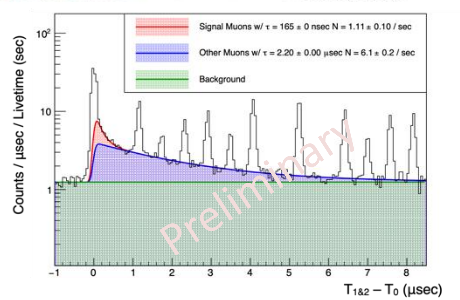
- **Extension of muon transport solenoid** to **cope with higher proton beam power**
  - More efficient beam background suppression
  - Pions decay to muons in longer transport
- **Tungsten alloy** as a pion production target
- **Electron spectrometer solenoid** to suppress the detector counting rate
- Physics detector
  - Straw-tube tracker and LYSO calorimeter
  - Muon stopping target (Al + others) in a gradient magnetic field for the purpose of signal electron collection with a magnetic lens

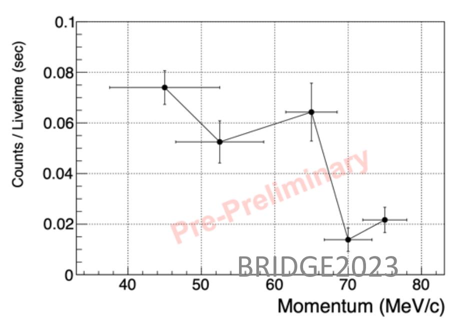
COMET Engineering Run

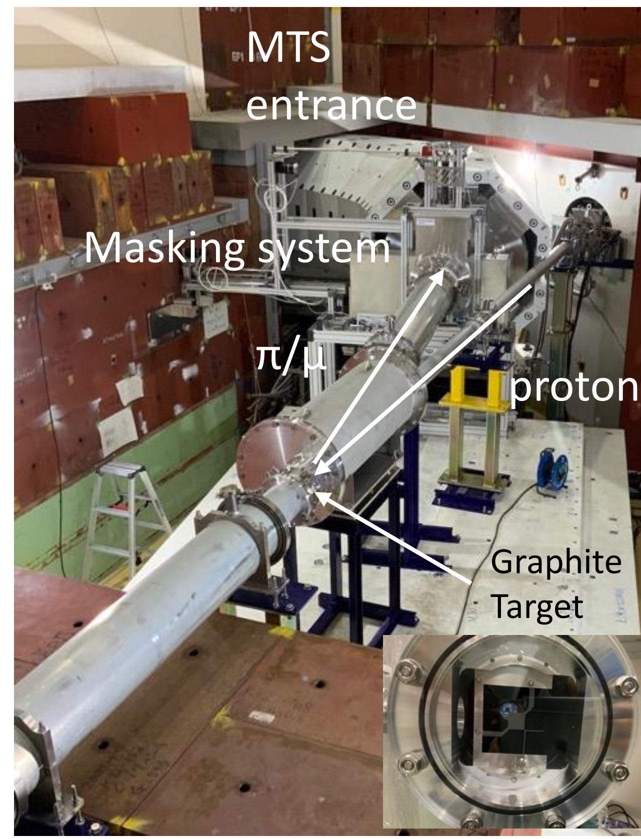
- Engineering run in Feb.-Mar. 2022 to study,
  - New C-Line proton beam property
  - Pion/muon production by 8GeV proton beam injection on graphite
  - Charged particle transport through Muon Transport Solenoid (MTS)











Range Counter in the Exp. area for

- secondary particle timing
- Momentum measurements, and
- Particle ID

Summary

- J-PARC is the world leading intensity frontier proton accelerator research complex
  - 3GeV RCS/MLF: reached at 700kW stable operation
  - 30GeV MR
    - 515kW for neutrino
    - 64kW for hadron
- J-PARC is unique facility covering wide range of research fields
  - Particle, nuclear physics, material and life sciences and industrial applications, Archeology, planetary science
- J-PARC is open to world community for discovery and innovation
- Continue to achieve world leading scientific outcome