Charge and neutron distribution radius measurement using low energy electron scattering

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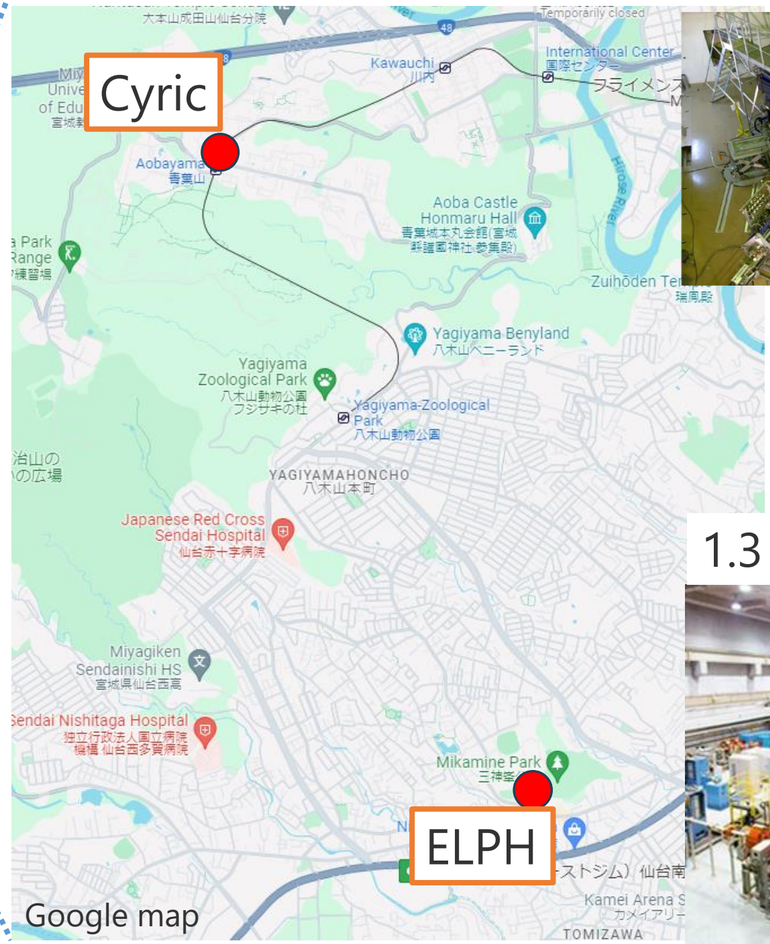
Outline

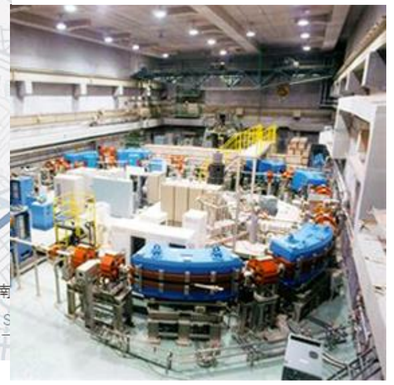
- ULQ2 : Low energy electron scattering facility
  - Beam line
  - Spectrometer
- Three projects in RARIS
  - Proton radius
  - Deuteron radius
  - Neutron distribution radius of ^{208}Pb
- Summary

Research Center for Accelerator and Radioisotope Science (RARIS)



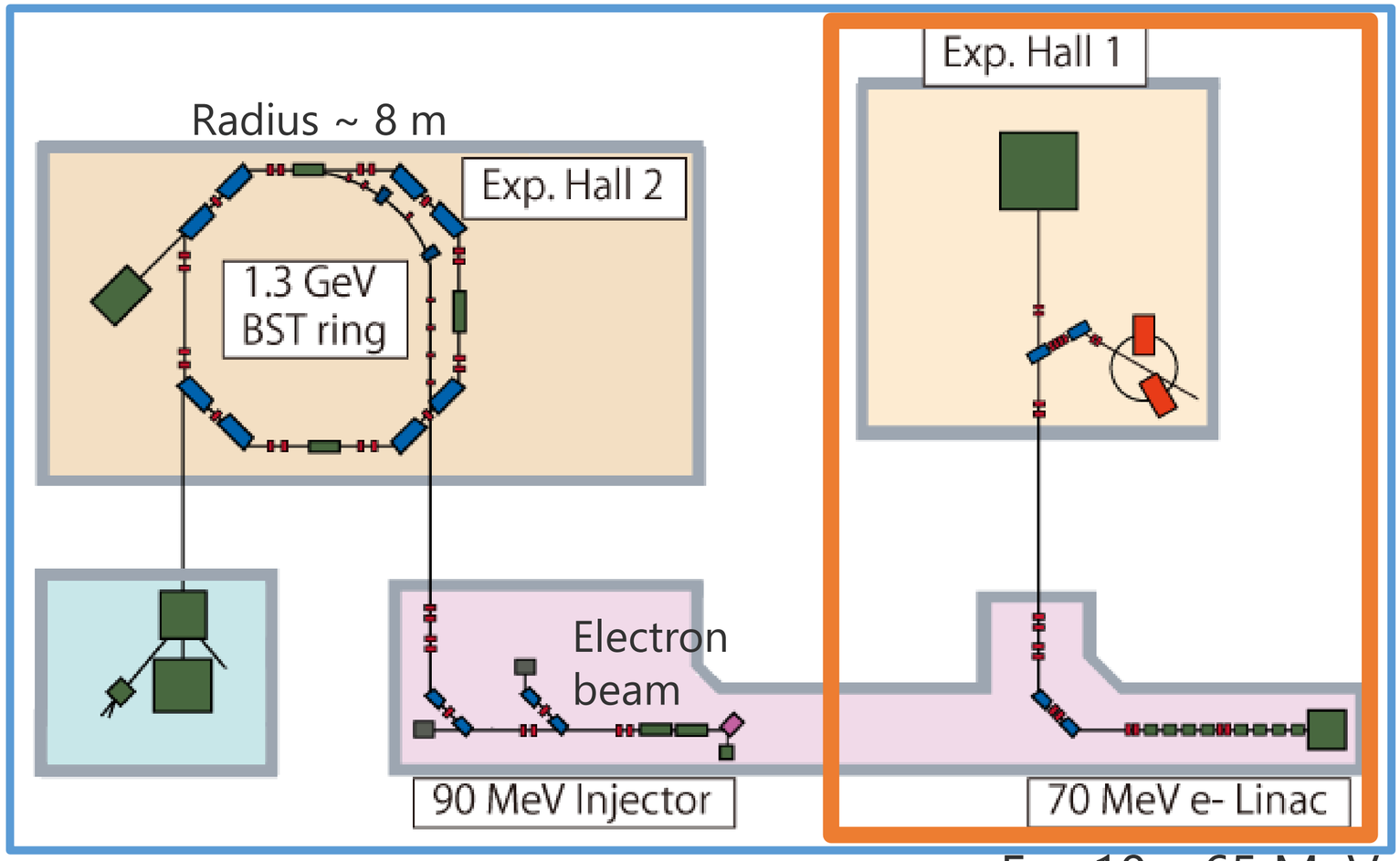
AVF cyclotron

1.3 GeV BST ring



70 MeV e- Linac

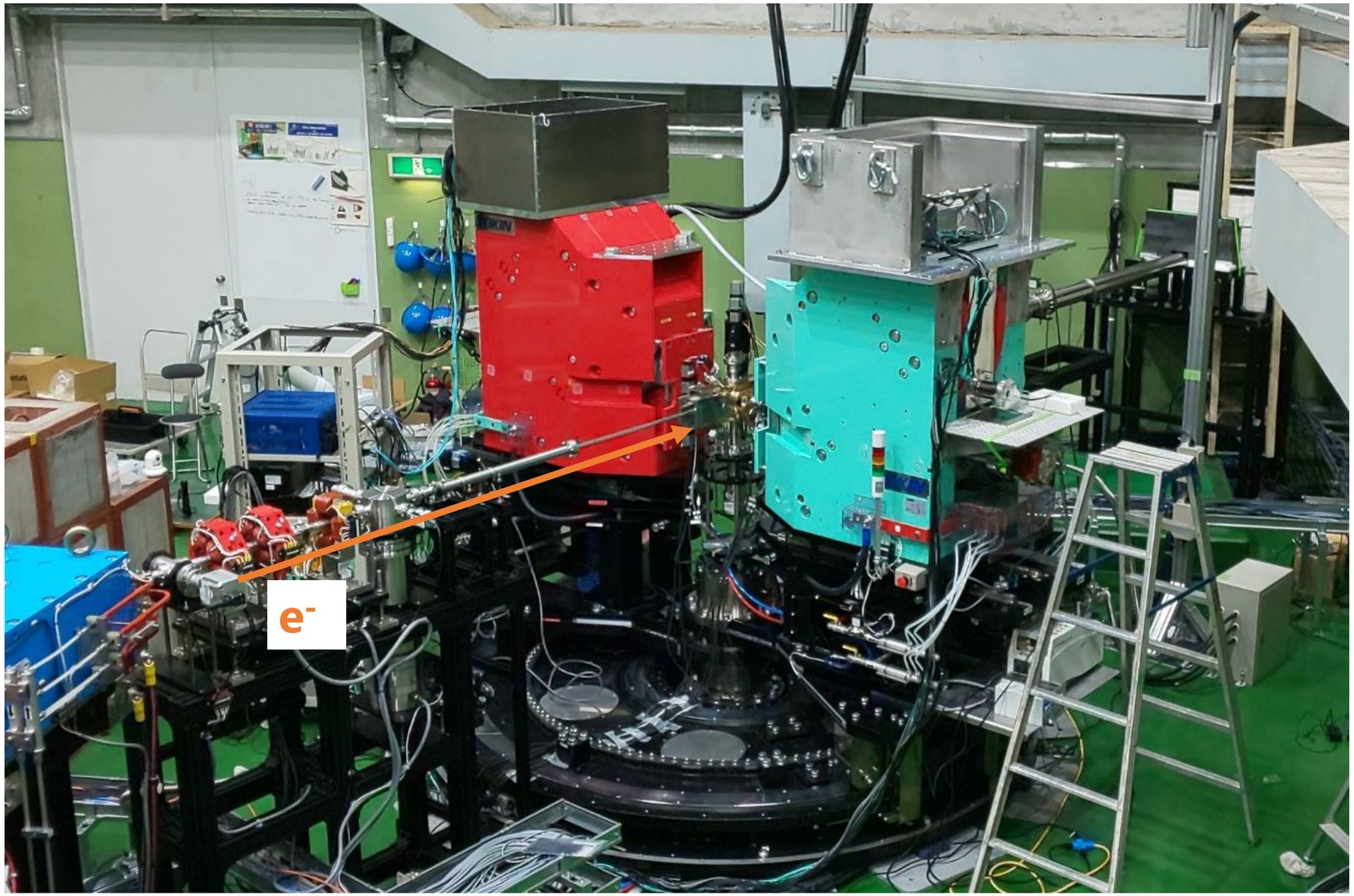
Accelerators in RARIS Mikamine cite (old ELPH)



E = 10 – 65 MeV

$I_e = 180\ \mu A$

ULQ2 equipment

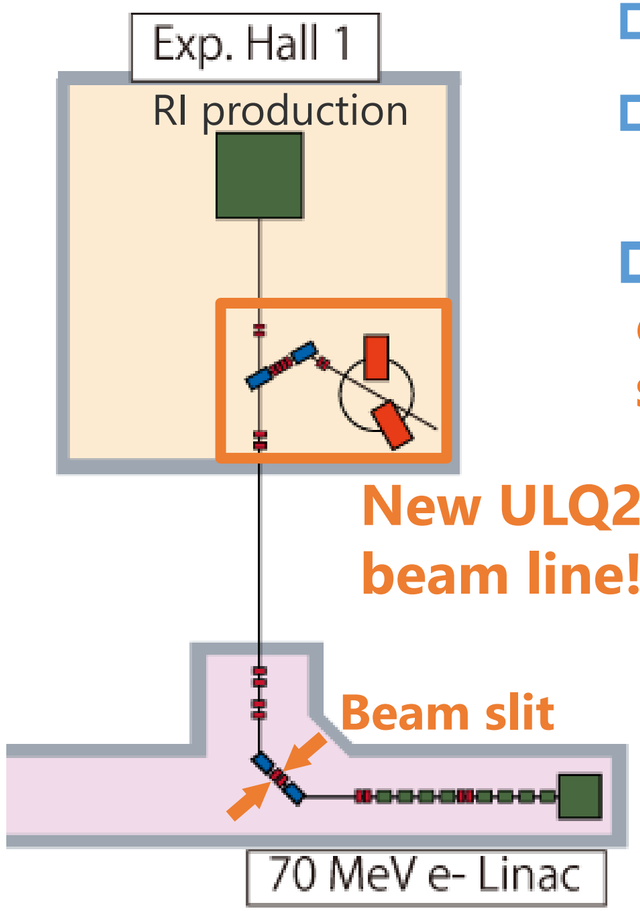


Developed for low-energy electron scattering

① ULQ2 beam line

② Twin spectrometers

70 MeV electron linac



- Used for radio-isotope production
- Beam duty is ~ 0.1%
  (3 us bunch, 300 pps).
- **ULQ2 beam line was constructed for the electron scattering.**

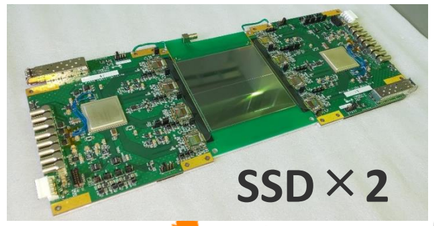
■ Previous status

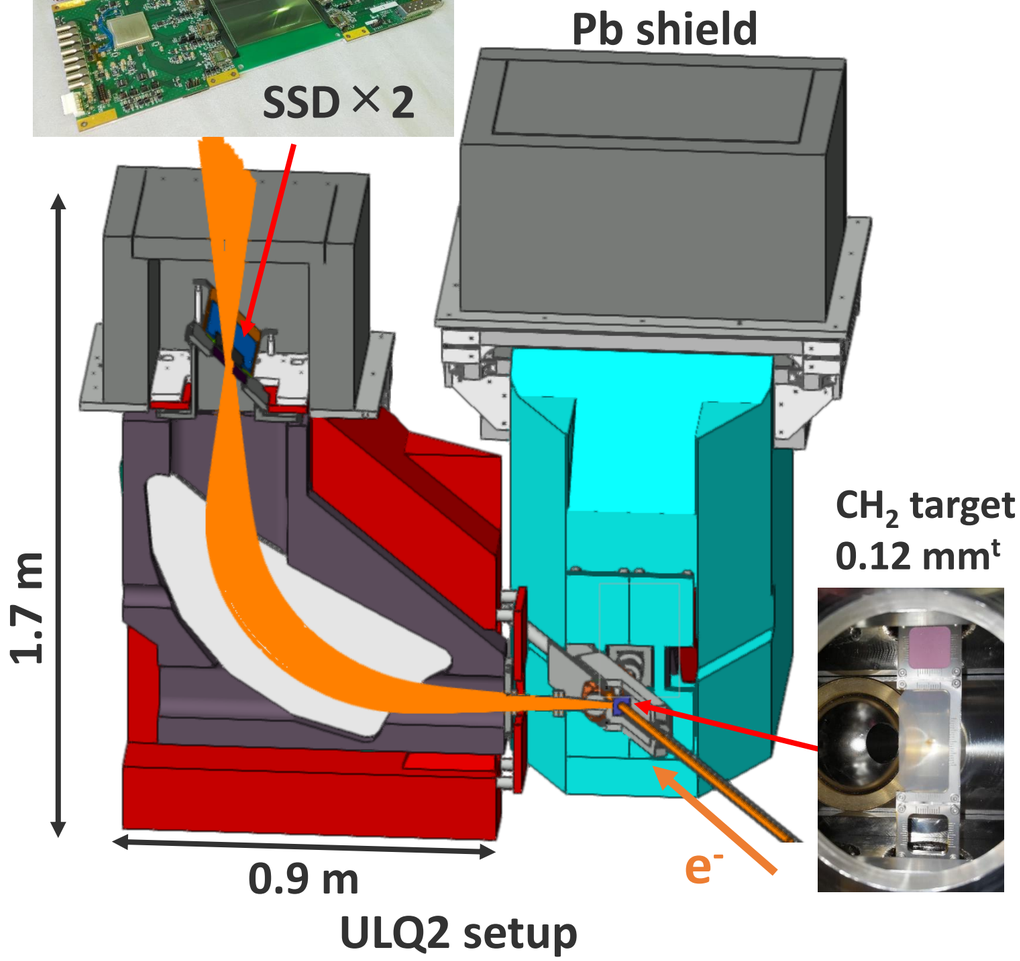
- $E_e = 20\ -60$ MeV
- $\sigma_E/E_e \sim 0.5$ %
- $\sigma_{x,y} \sim 3$ mm
- $I_{\max} \sim 180$ μA

■ ULQ2 beamline

- $E_e = 10\ -65$ MeV
- $\sigma_E/E_e \leq 0.1$ %
- $\sigma_{x,y} \leq 1$ mm
- $I_{\max} \sim 1$ μA

Spectrometer for low-energy electron





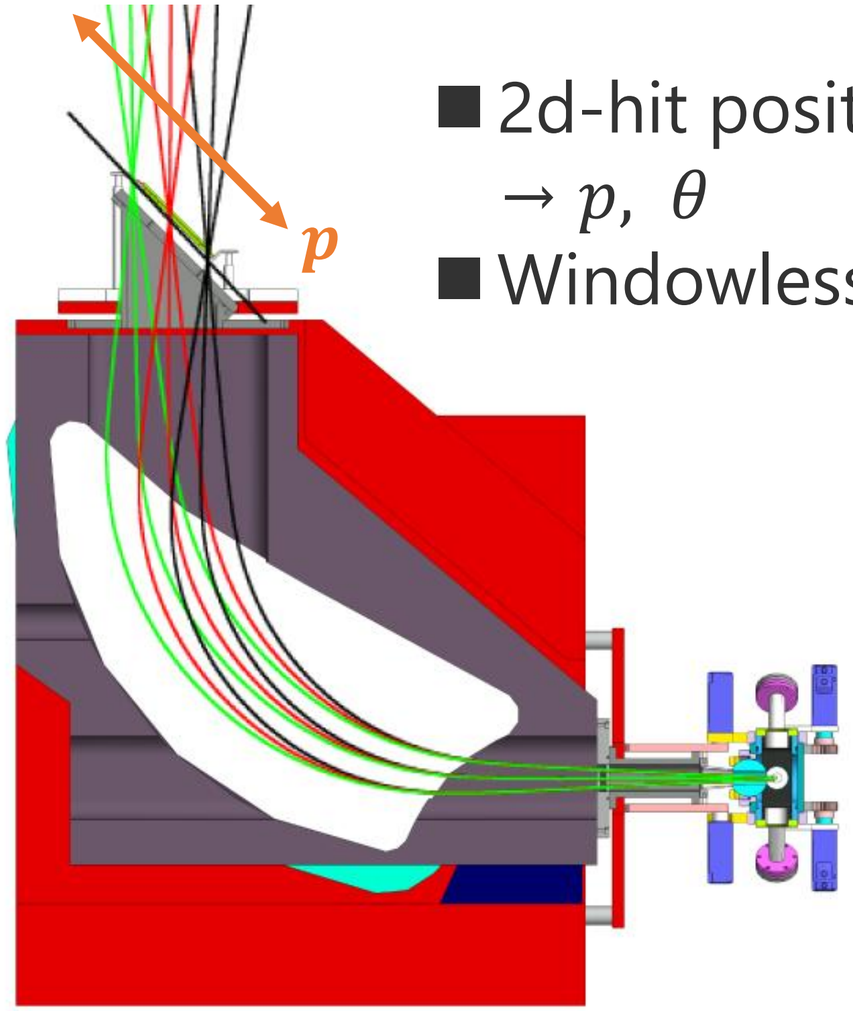
ULQ2 setup

- Twin electro-magnetic spectrometer
  - ① Foreground measurement
  - ② Luminosity monitor, CH ratio monitor
- Specialized for low-energy electron
  - ① Windowless
  - ② Tracking less

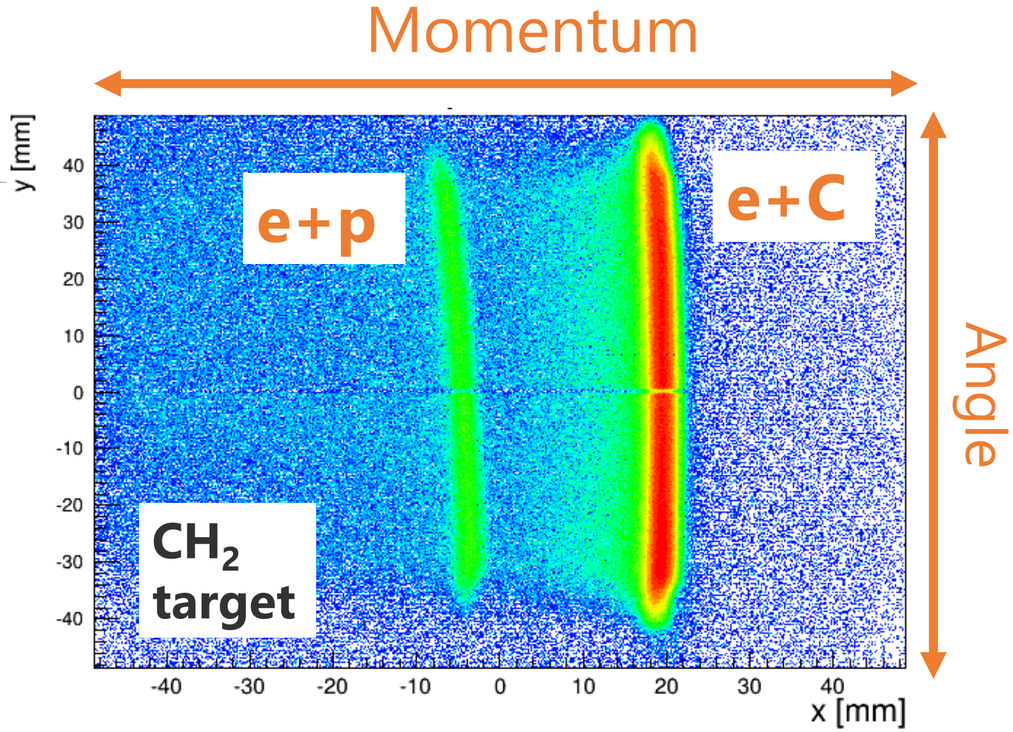
$E_e = 10 - 65$ MeV

- Consist of
  - ① Dipole magnet
  - ② Focal plane detector
  - ③ Target chamber

Spectrometer

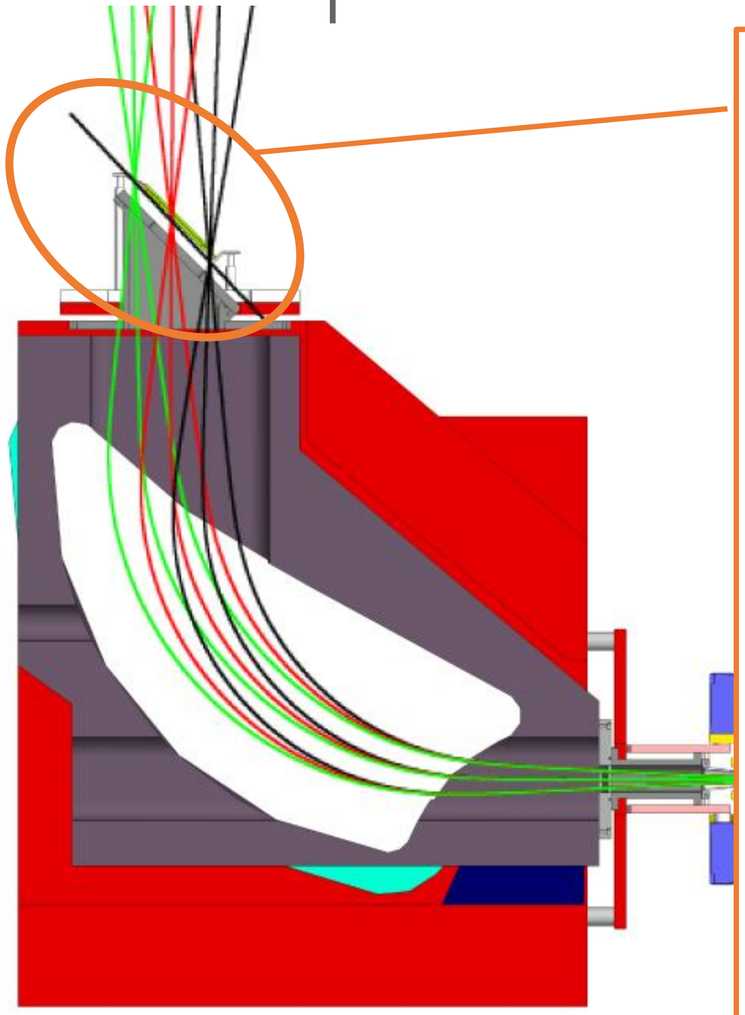


- 2d-hit position
  $\rightarrow p,\ \theta$
- Windowless

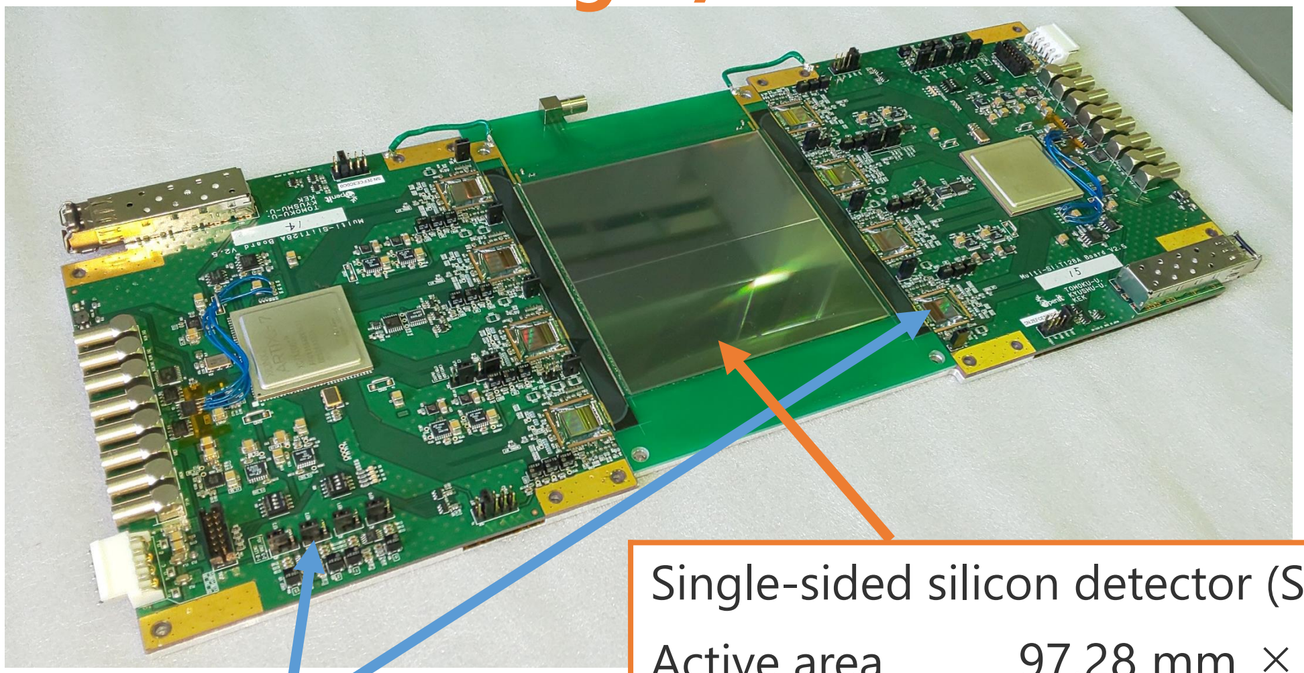


σ_p/p	0.05%
$\Delta p/p$	11%
σ_θ	5 mrad
$\Delta\Omega$	7 mSr (10 mSr)
θ	$30° - 150°$

Focal plane detector



J-PARC muon g-2/EDM Test module2

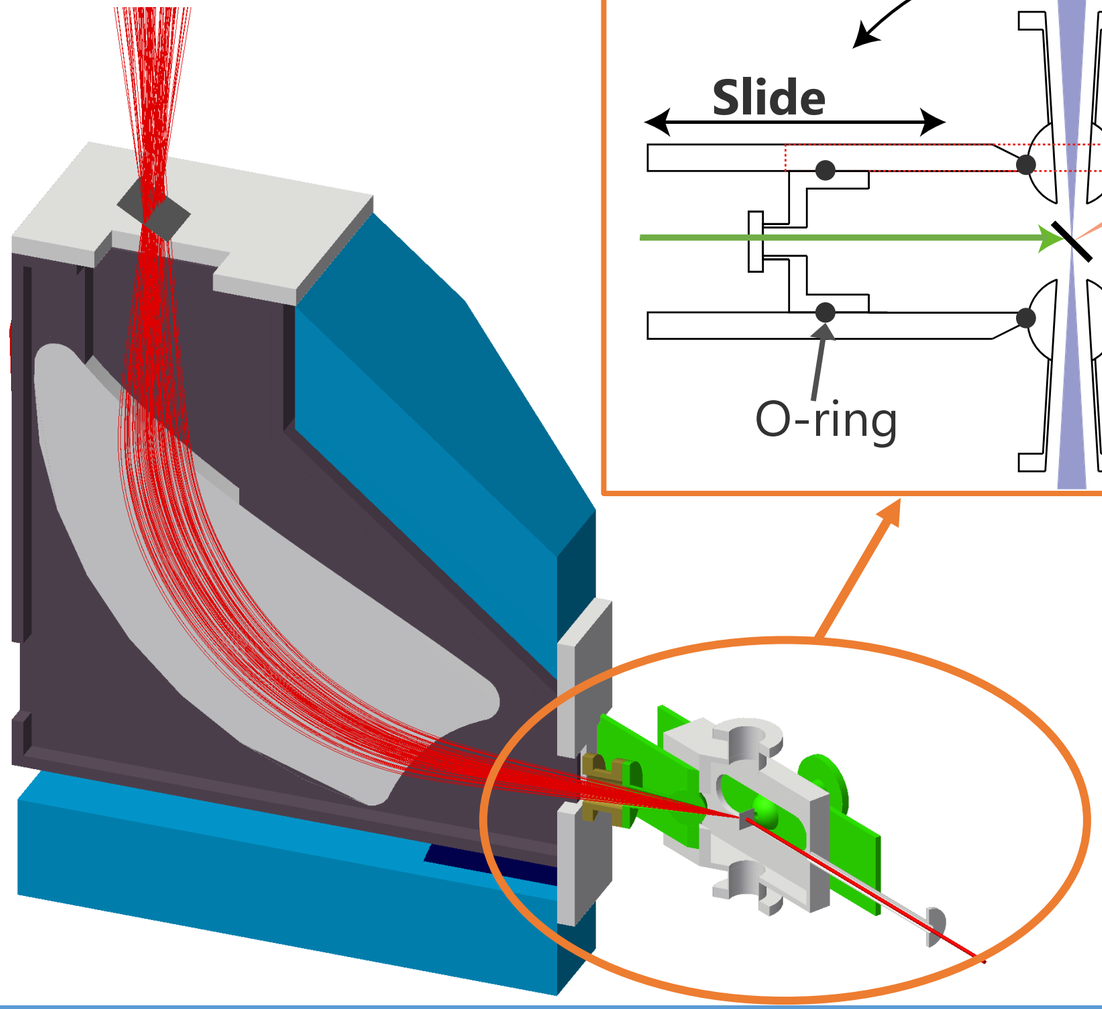


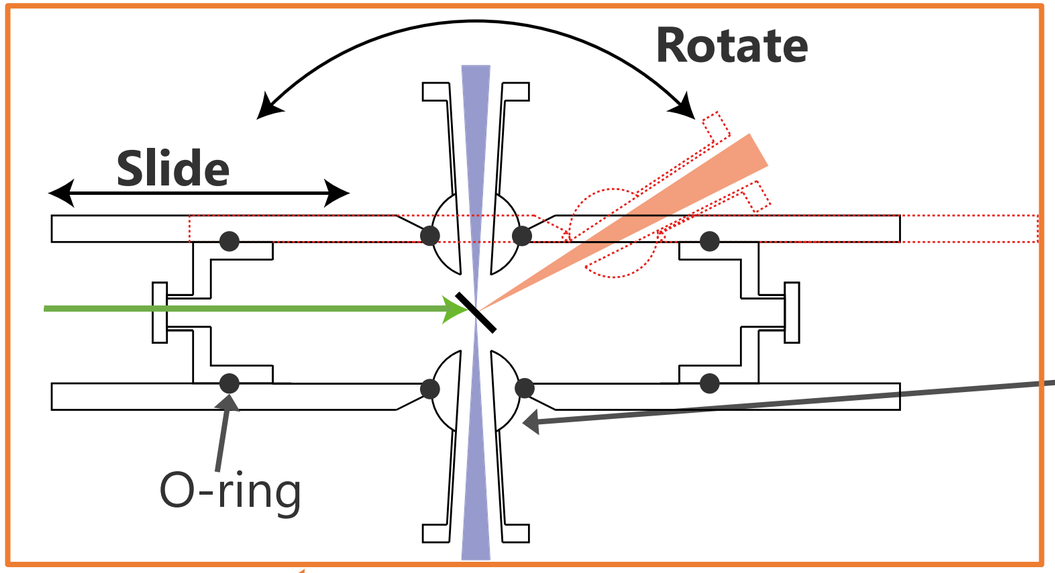
Readout boards
"Multi-Slit128A board"
Four ASICs "Slit128A"
(128 ch/chip)

Single-sided silicon detector (SSSD)

Active area	97.28 mm × 97.28 mm
Thickness	0.32 mm
Strip pitch	0.19 mm
Strip length	48.575 mm
No. of strips	512 ch × 2

Variable-angle target chamber





Ball flange

Vacuum seal	O-ring
Size	$390\ \mathrm{mm} \times 50\ \mathrm{mm}$
Acceptance	$\Delta\Omega \sim 24\ \mathrm{mSr}$
Angle	$30° \leq \theta \leq 150°$

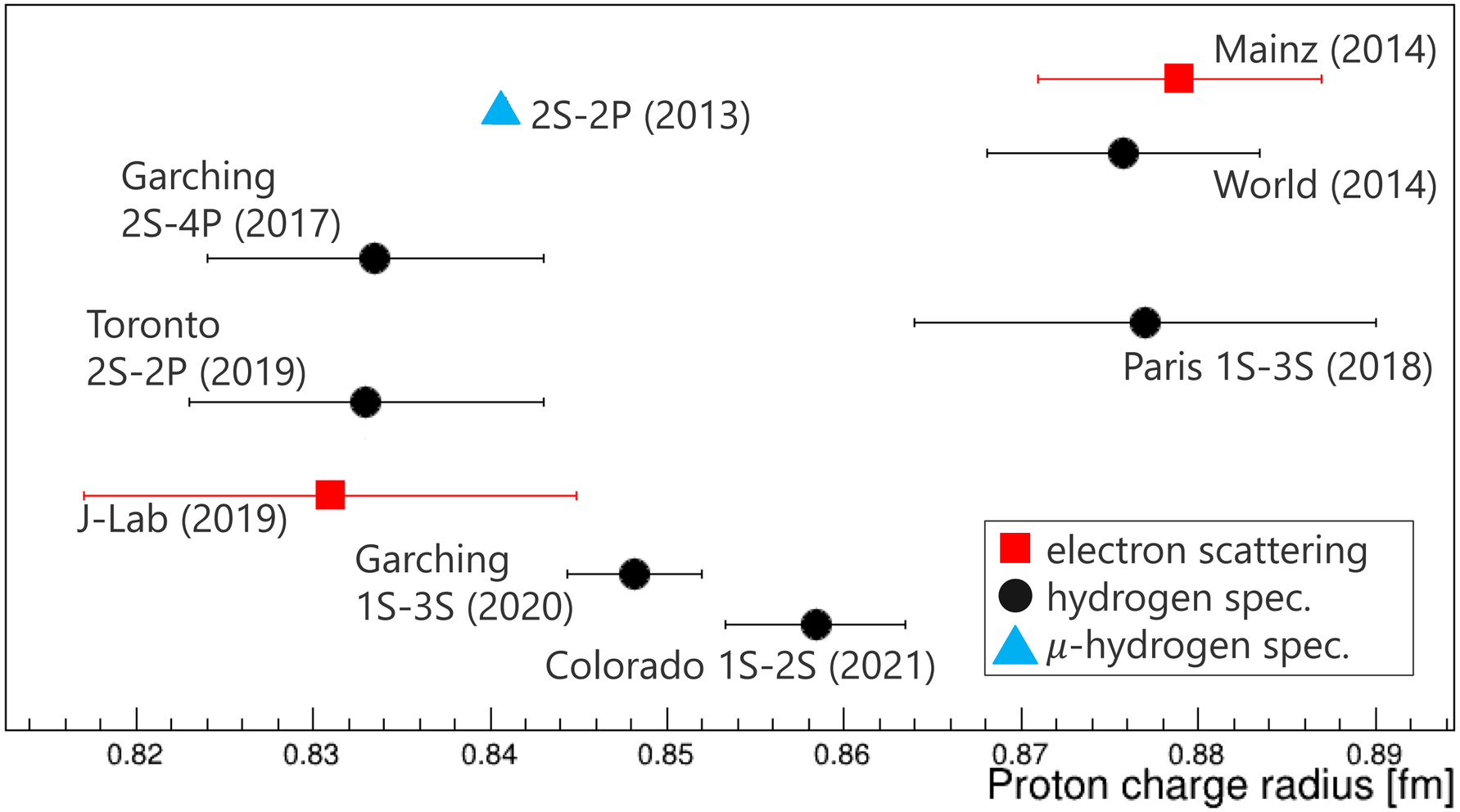
Keep 10^{-4} Pa during the rotation.

Physics projects in RARIS

Three projects by low-energy electron scattering are ongoing.

- ULQ2
  - Proton radius measurement
- ULQ2-D
  - Deuteron radius measurement
- LEEP (Low-Energy Electron scattering for ^{208}Pb)
  - Technical development of neutron distribution radius measurement with low-energy electron scattering off ^{208}Pb

Proton radius puzzle



Ultra Low Q^2 (ULQ2) experiment

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} |F(Q^2)|^2$$

$$|F(Q^2)|^2 \propto G_E^2(Q^2) + \alpha(\theta) G_M^2(Q^2)$$

$$< r_p^2 > \equiv -6 \frac{dG_E(Q^2)}{dQ^2}\Big|_{Q^2 \to 0}$$

ULQ2 experiment

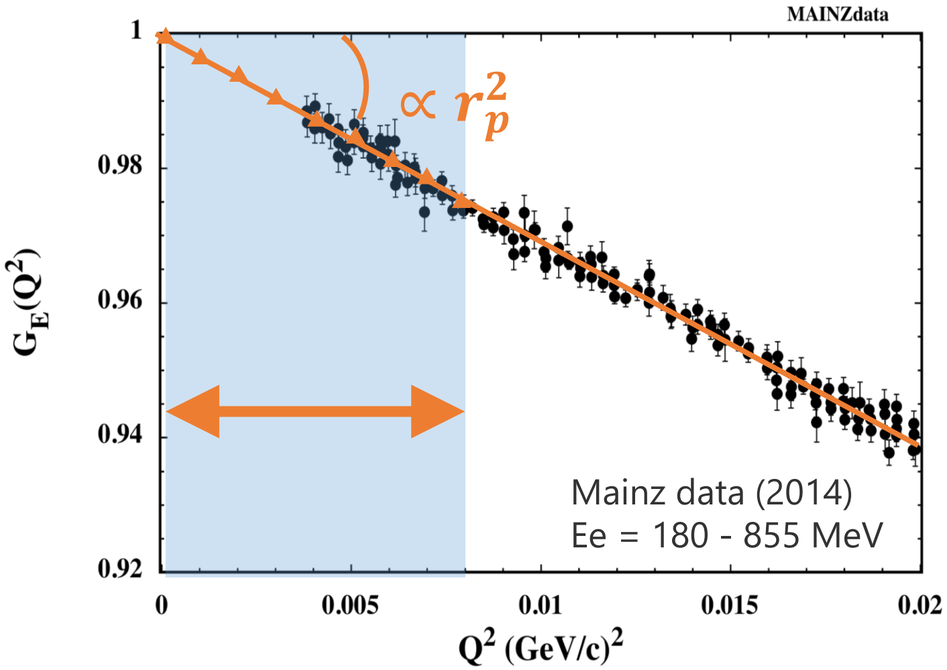
- Determine the proton radius with 1% accuracy by electron scattering

to achieve

① Extreme low Q^2 : $\mathbf{0.0003 \leq Q^2 \leq 0.008}$ $(\mathrm{GeV}/c)^2$.

② Rosenbluth separated $\boldsymbol{G_E(Q^2)}$ and $\boldsymbol{G_M(Q^2)}$.

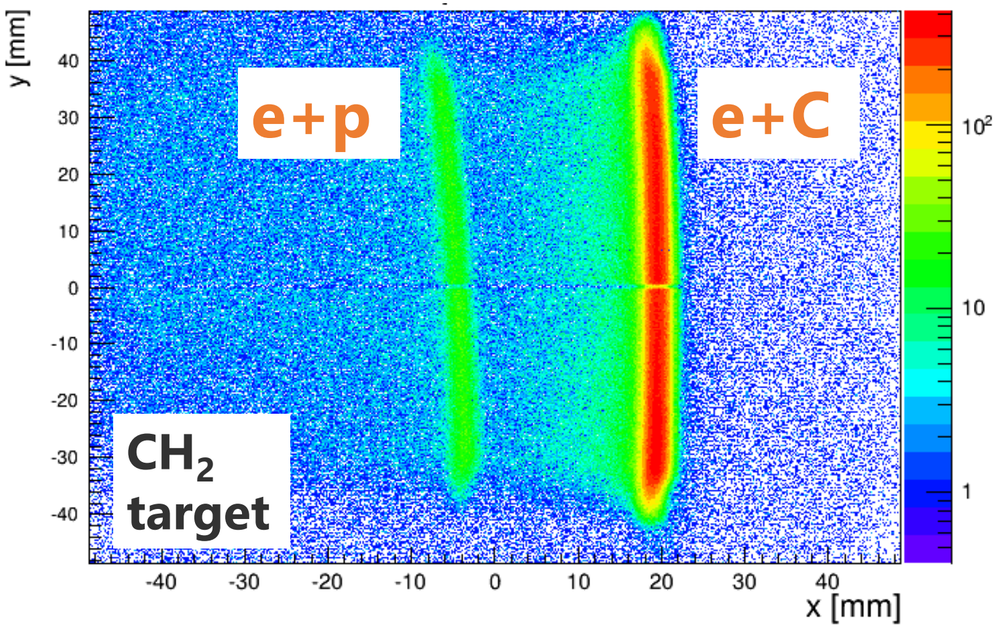
③ Absolute cross section measurement with $\sim \mathbf{10^{-3}}$ accuracy with simultaneous measurement of e+H and e+C with CH_2 target.



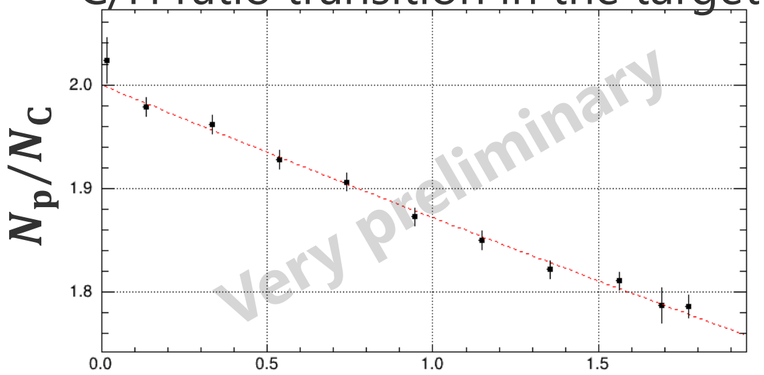
Physics run

$$\left(\frac{d\sigma}{d\Omega}\right)_{e+p} = \frac{N_{e+p}(\Delta\Omega)/N_{e+C}(\Delta\Omega)}{N_p/N_C}\left(\frac{d\sigma}{d\Omega}\right)_{e+C}$$

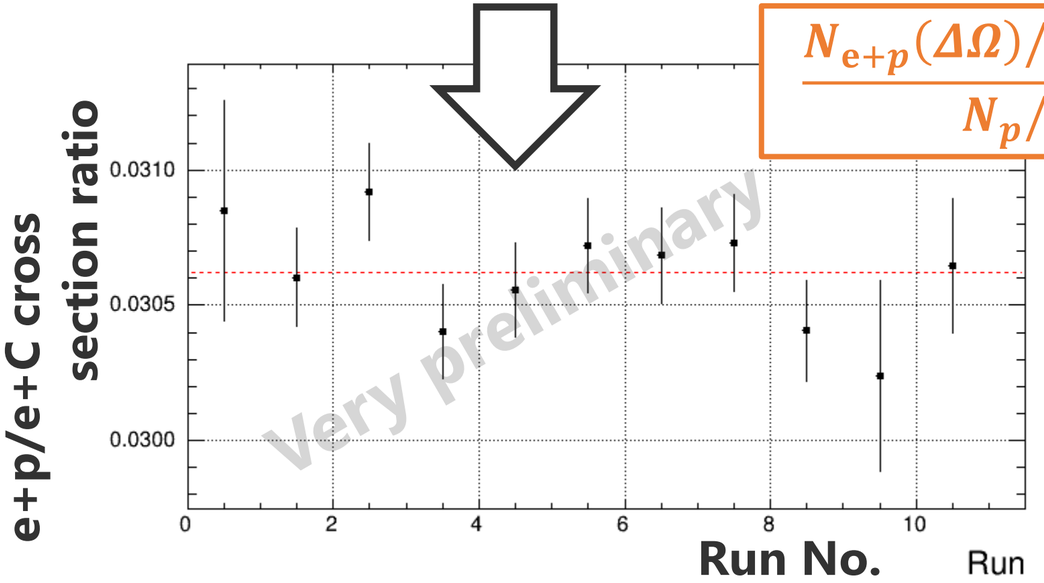
Precisely calculatable



C/H ratio transition in the target from 2nd spectrometer



N_p/N_C

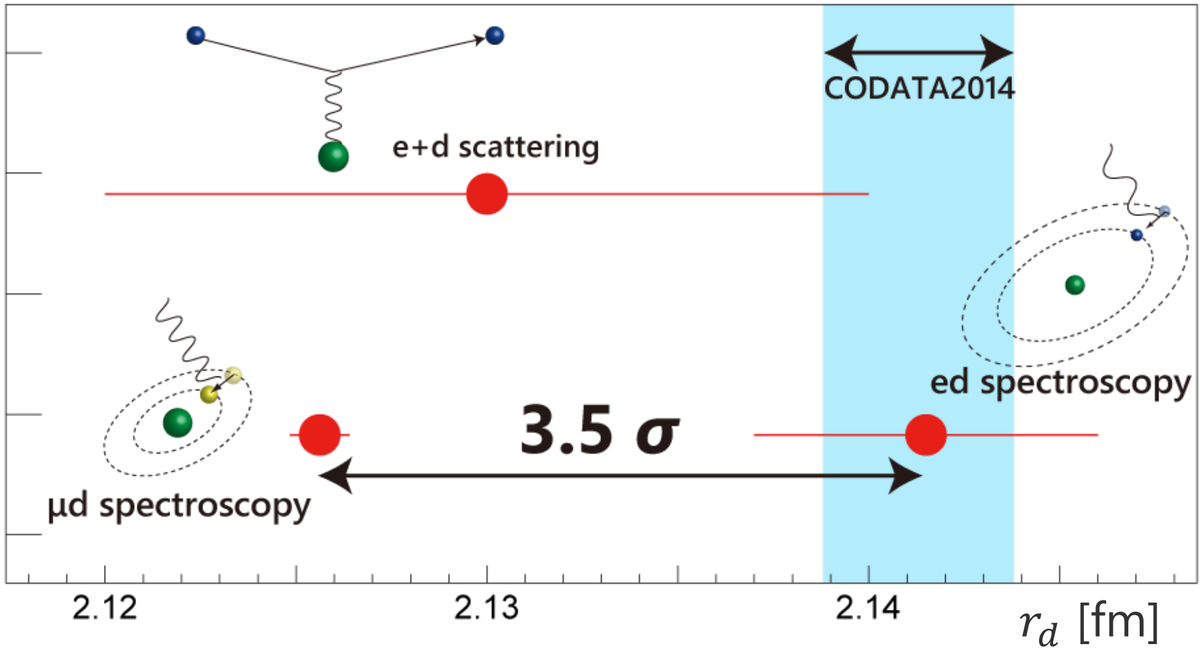


$$\frac{N_{e+p}(\Delta\Omega)/N_{e+C}(\Delta\Omega)}{N_p/N_C}$$

- Data taking is almost finished, and will be completed this FY.
- Radiative collection study is ongoing.
- The result will be published in 2024.

ULQ2-D

Deuteron radius puzzle



$$r_d^2 = r_{\mathrm{str}}^2 + r_n^2 + r_p^2 + \frac{3}{4m_p^2}$$

r_d : deuteron charge radius
r_{str}: deuteron structure radius
r_n : neutron charge radius
r_p : proton charge radius

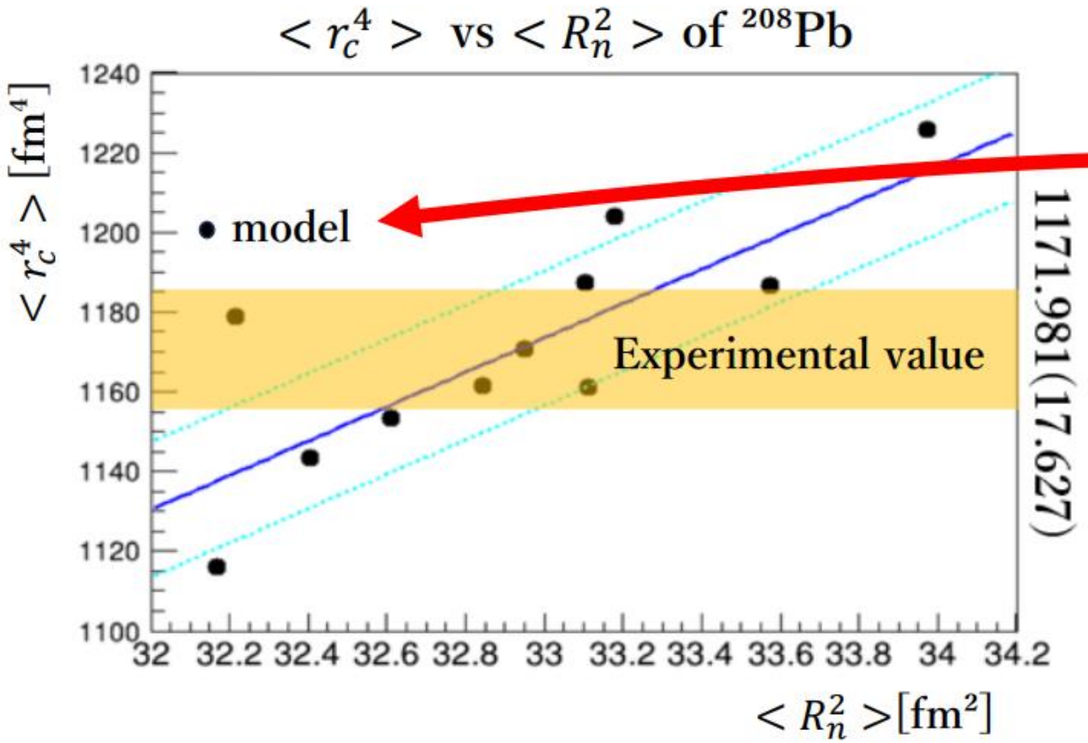
- The deuteron charge radius is also a puzzle.
- The deuteron is the simplest nuclear compound and the radius related to the neutron charge radius.
- Unfortunately, the e+d scattering did not contribute to the puzzle due to the large error.
- We will measure the radius with CD2 target with same technique as the proton.
- The first target accuracy is 0.5%, and the result will be obtained in this year.

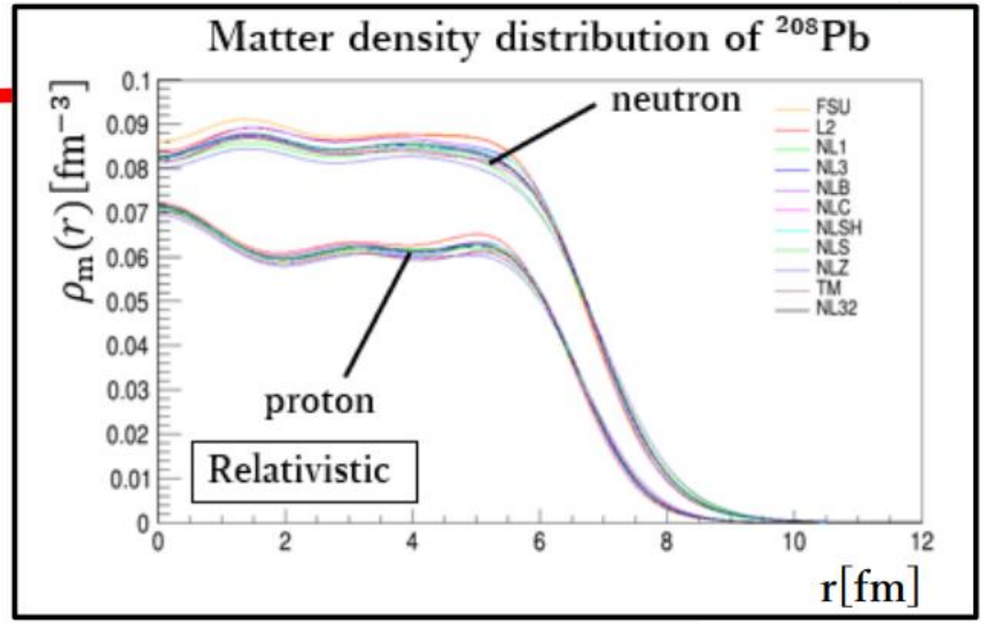
LEEP (Low-Energy Electron scattering for ^{208}Pb)

$$< r_c^4 > = \int r^4 \rho(\vec{r}) d\vec{r}$$

$$= \underset{\text{calc.}}{< R_p^4 >} + \frac{10}{3} \underset{\text{calc.}}{< R_p^2 >} \underset{\text{known}}{< r_p^2 >} + \frac{10}{3} < \boldsymbol{R_n^2} > \underset{\text{known}}{< r_n^2 >} \frac{N}{Z} + rel.corr.$$

[1] H. Kurasawa, T. Suda and T. Suzuki, PTEP **2021** 013D02





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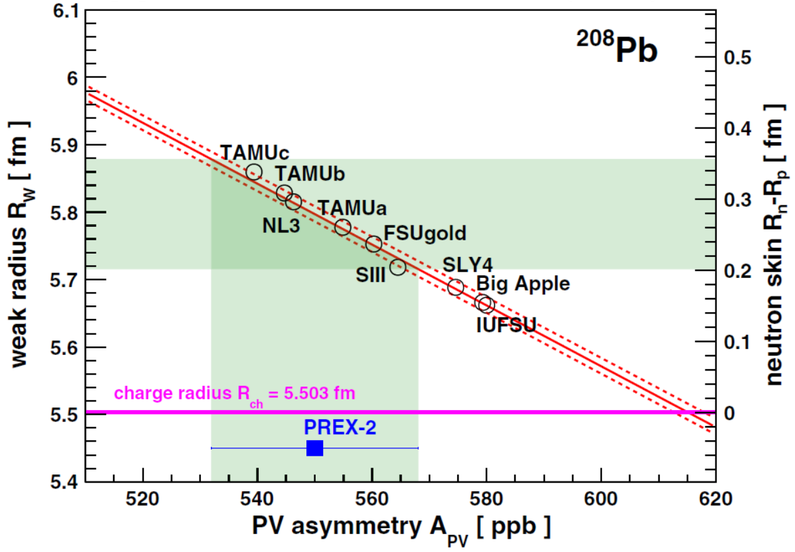
[1] H. Kurasawa, T. Suda and T. Suzuki, PTEP **2021** 013D02

R_n from weak interaction by PREX-2

[2] D. Adhikari *et. al.* PRL **126**(2021) 172502.



$$R_n - R_p$$

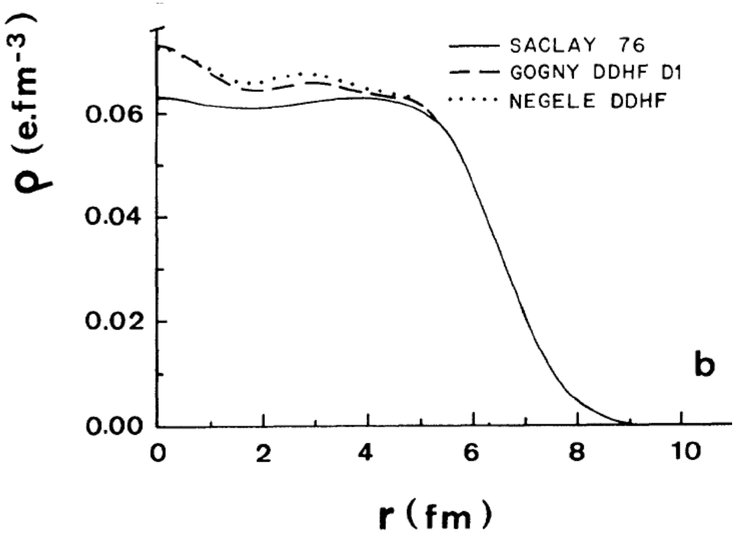
$$||$$

0.283(71)[2] ⟷ **0.275(70)**[1]

Consistent results!!

Charge distribution of ^{208}Pb

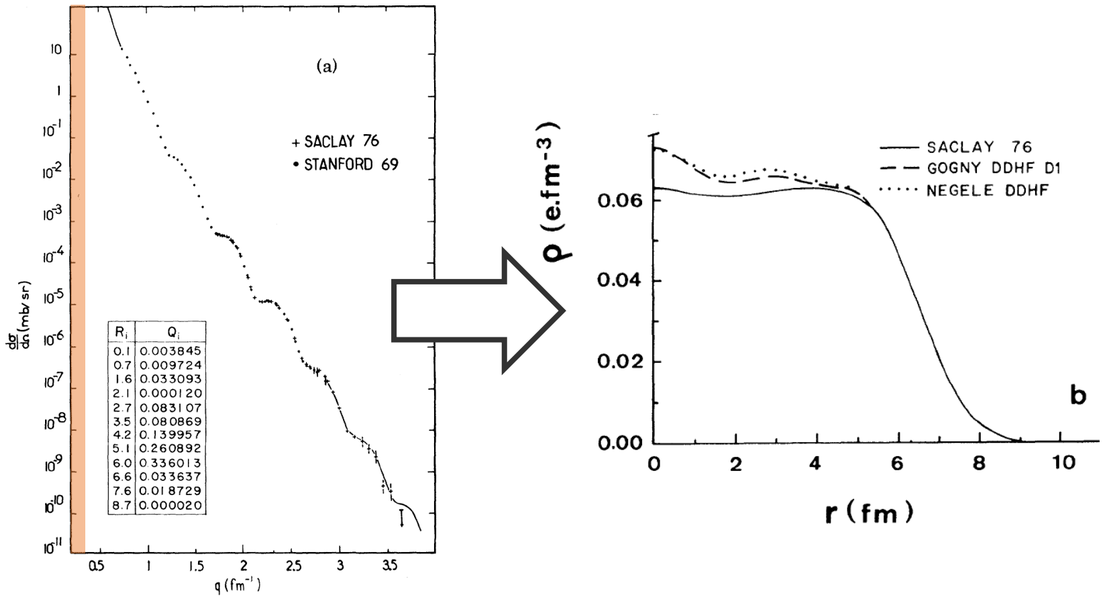
B. Frois *et. al.* PRL **38**(1977) 152.



☐ New approach to access the neutron distribution

LEEP (Low-Energy Electron scattering for ^{208}Pb)

$$< r^4 > = \int r^4 \rho(\vec{r}) d\vec{r}$$

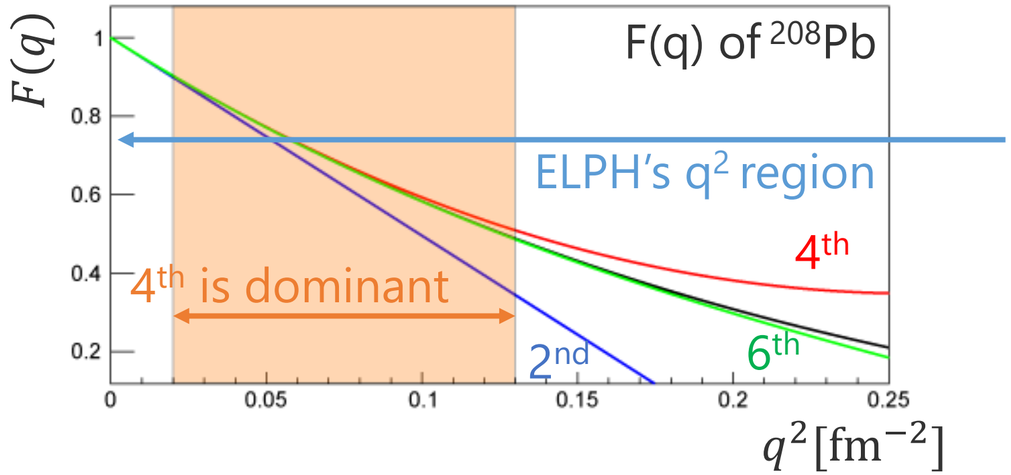


D. Adhikari *et. al.* PRL **58**(1987) 195.

Wide q region data is necessary.

It include data at very small cross section.

$$F(q) \sim 1 - \frac{< r^2 >}{6} q^2 + \frac{< \boldsymbol{r^4} >}{120} q^4 + \cdots$$



- Cross section is very large (~ barn)
  → Expandable to unstable nuclei at SCRIT
  → Suda-san's talk
- We have started to develop this approach by measuring the e+^{208}Pb cross section.

Summary

- A low-energy electron scattering facility has been developed at RARIS, Tohoku University.
- The commissioning has been completed and the physics experiments are beginning.
- Three physics projects are ongoing.
  - Proton charge radius measurement
  - Deuteron charge radius measurement
  - Neutron distribution radius measurement for ^{208}Pb
- The results will start to be published in this year.

Advertisement

- We will organize a workshop in Sendai, Japan during October 28 - November 1, 2024.

" Low-Energy Electron Scattering for Nucleon and Exotic Nuclei (LEES2024)"

- Key topics
  - Electron scattering on nucleon and exotic nuclei
  - Nucleon and nuclear radius
  - Nuclear density distribution
  - Nuclear photo reaction
  - Nuclear structure
- Web site and registration will be opened middle of June.
- We look forward to your participation.