Current Status of ULQ2 Experiment:
Proton Radius Measurement with Low-energy Electron Scattering

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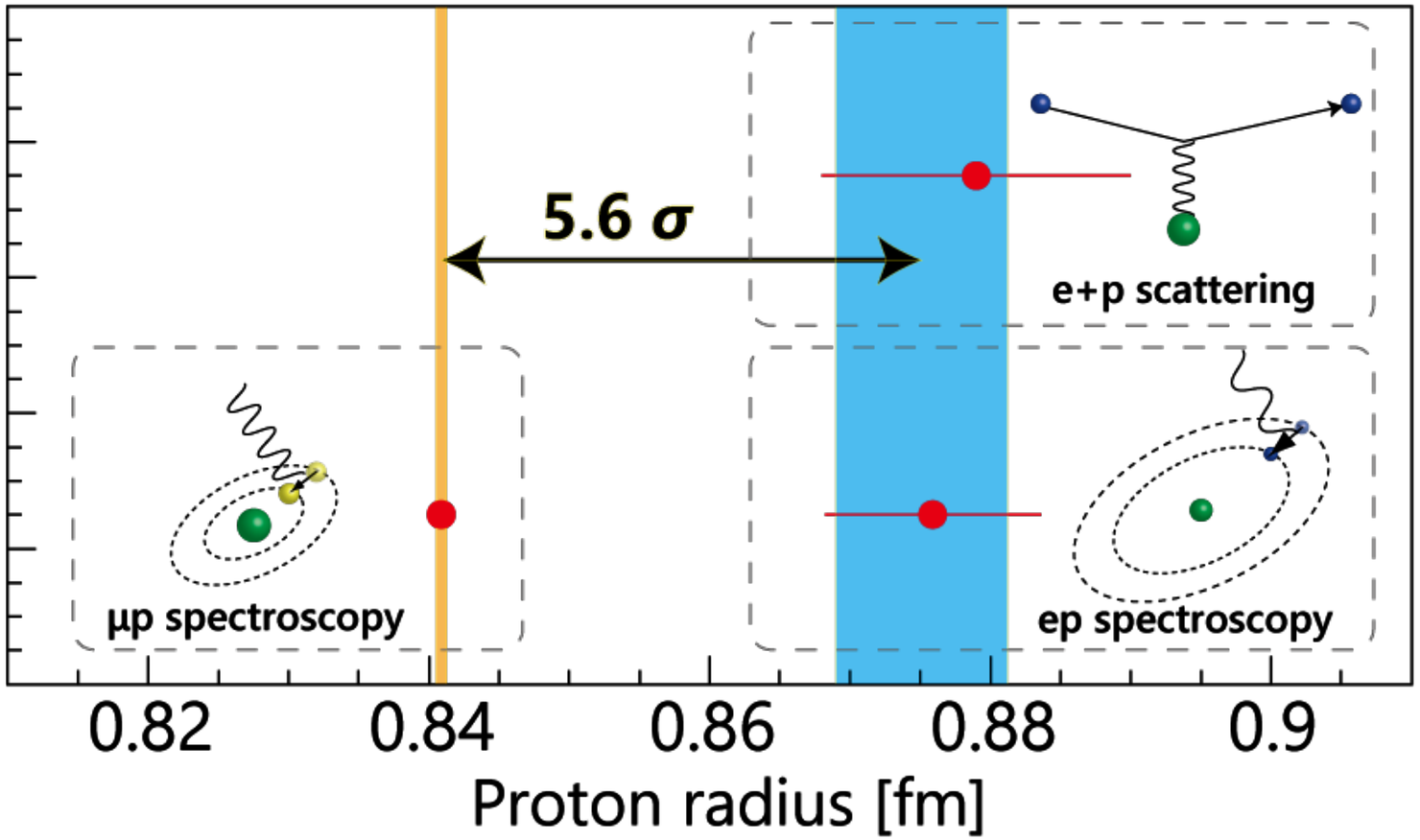
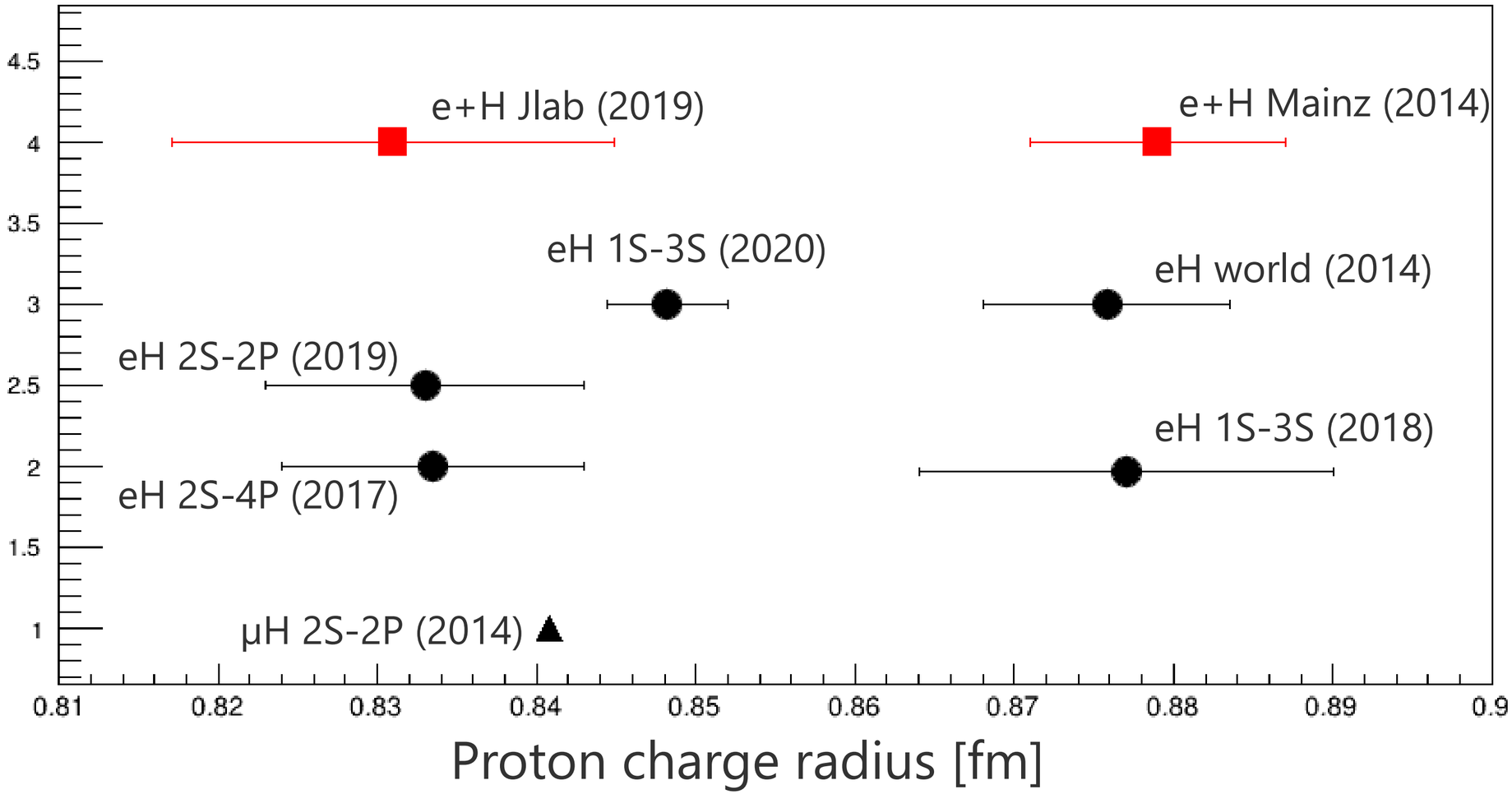
1. Proton radius puzzle
2. ULQ2 experiment
3. Commissioning
4. Summary

Proton radius puzzle

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



Present status of the proton radius puzzle



electron scattering
hydrogen spec.
μ-hydrogen spec.

What makes the difference?

QED calculation?
Undiscovered systematic effects?
Model dependencies?

Ultra Low Q^2 (ULQ2) experiment

ULQ2 experiment

- Proton radius measurement with electron scattering
- Removing model dependencies as much as possible

characteristics

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

② Absolute cross section with $\sim\mathbf{10^{-3}}$ accuracy.

③ Rosenbluth separated $\boldsymbol{G_E(Q^2)}$ and $\boldsymbol{G_M(Q^2)}$.

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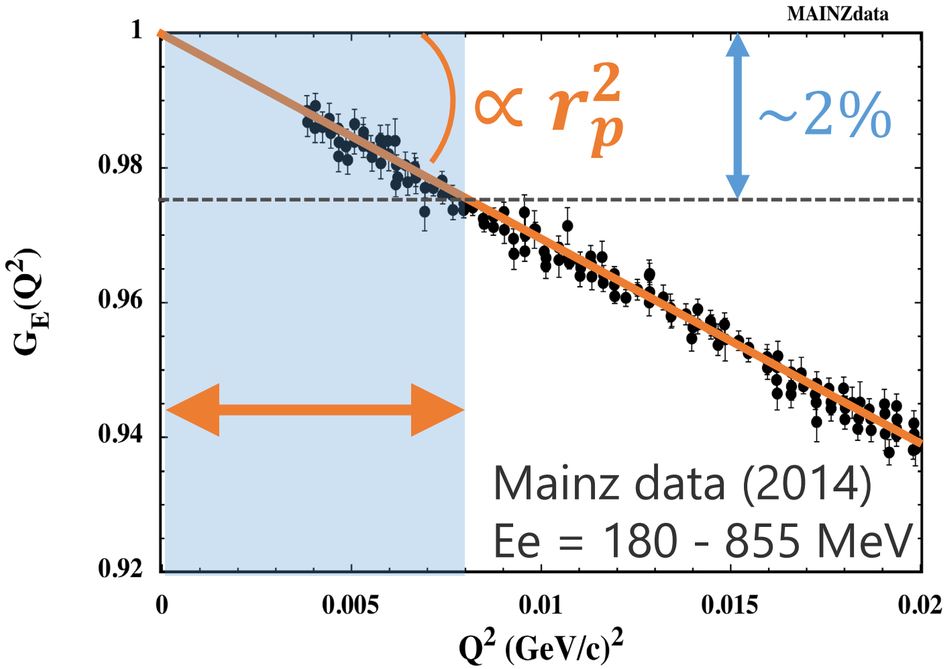
$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right) \propto (G_E^2(Q^2) + \alpha(\theta) G_M^2(Q^2))$$

$$Q^2 \sim 4E_e E_e' \sin^2(\theta/2)$$



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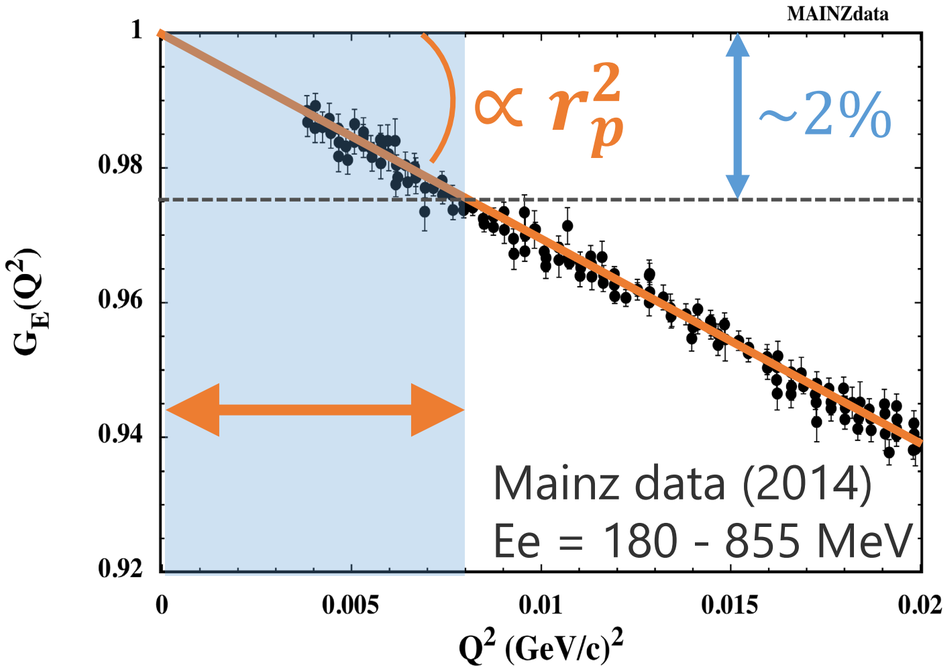

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- Relative measurement to well-known cross section.
  e+p / e+C scattering → **CH_2 target**

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

N_p: p target number; N_e: Beam dose; $\Delta\Omega$: Solid angle

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

N_p/N_C: Ratio of p and C; $\left(\frac{d\sigma}{d\Omega}\right)_{e+C}$: Well known

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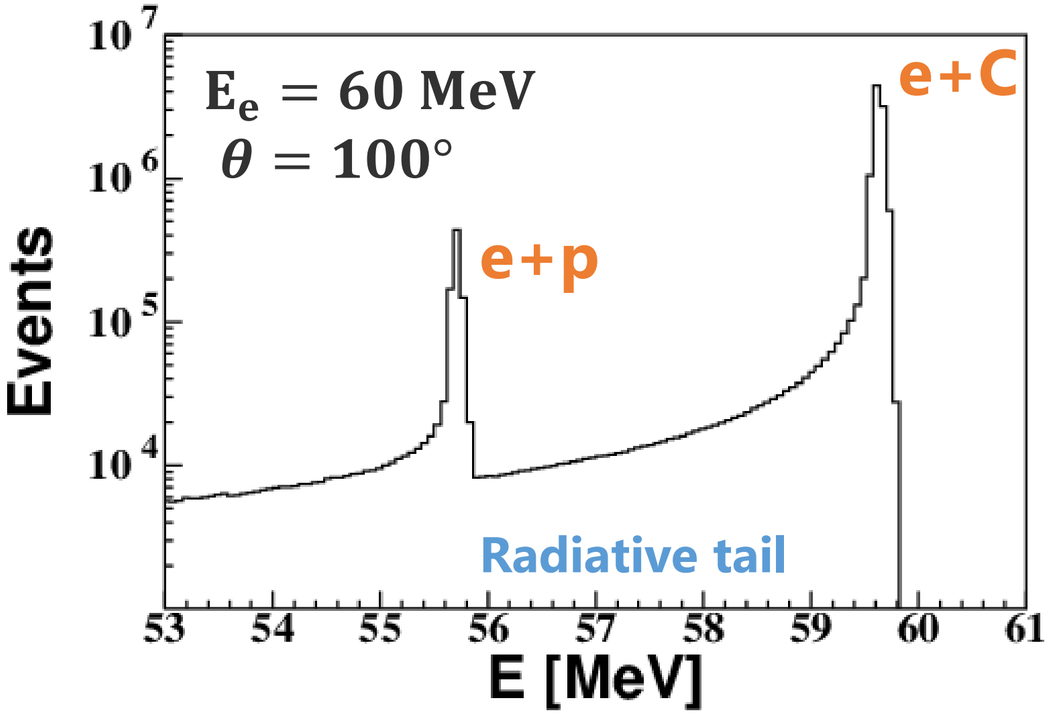

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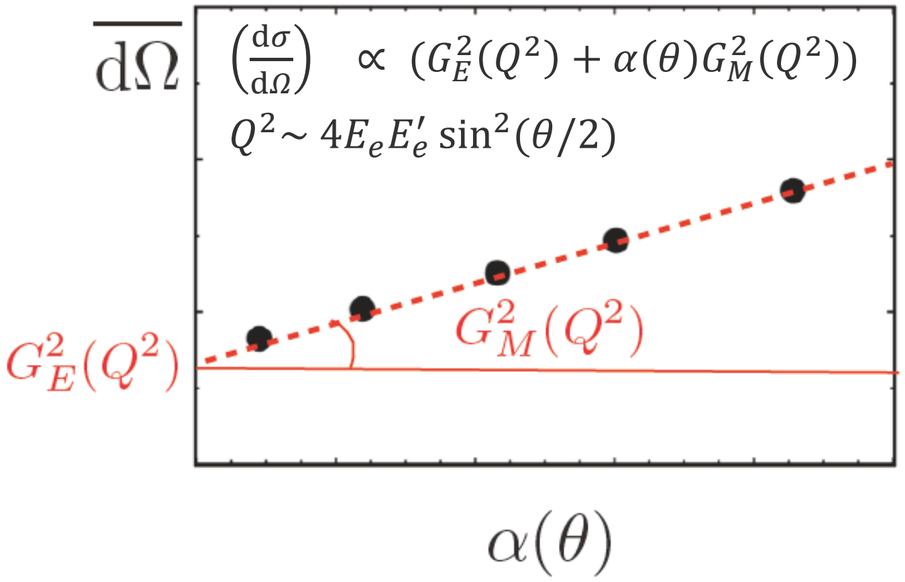
Rosenbluth separation



- Rosenbluth separation requires frequently change of E_e and θ

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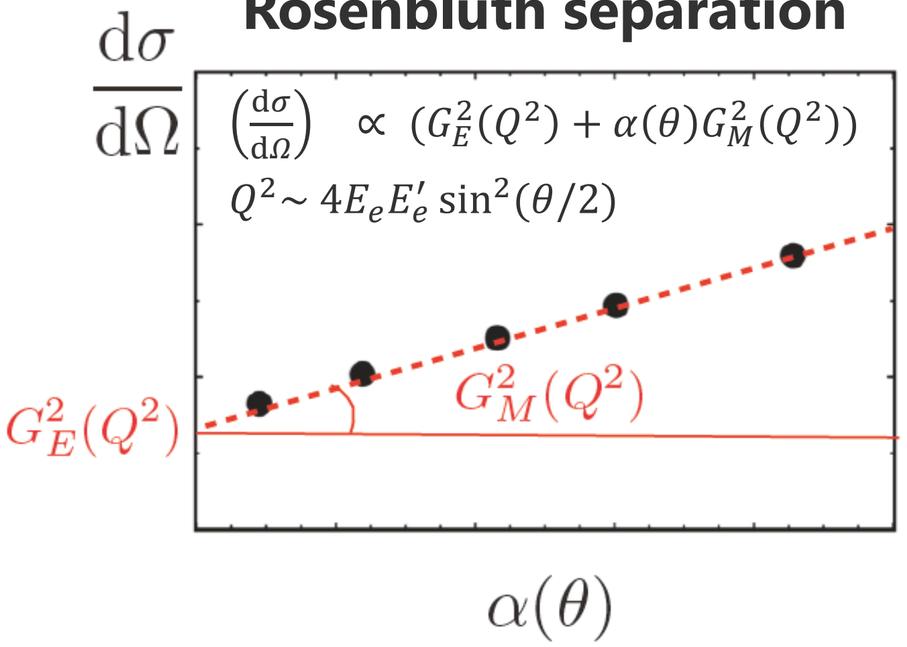
$\Rightarrow E_e = \underline{\mathbf{20-60\ MeV}},\ \theta = 30-150°$

Lowest-ever beam energy !!

Rosenbluth separation



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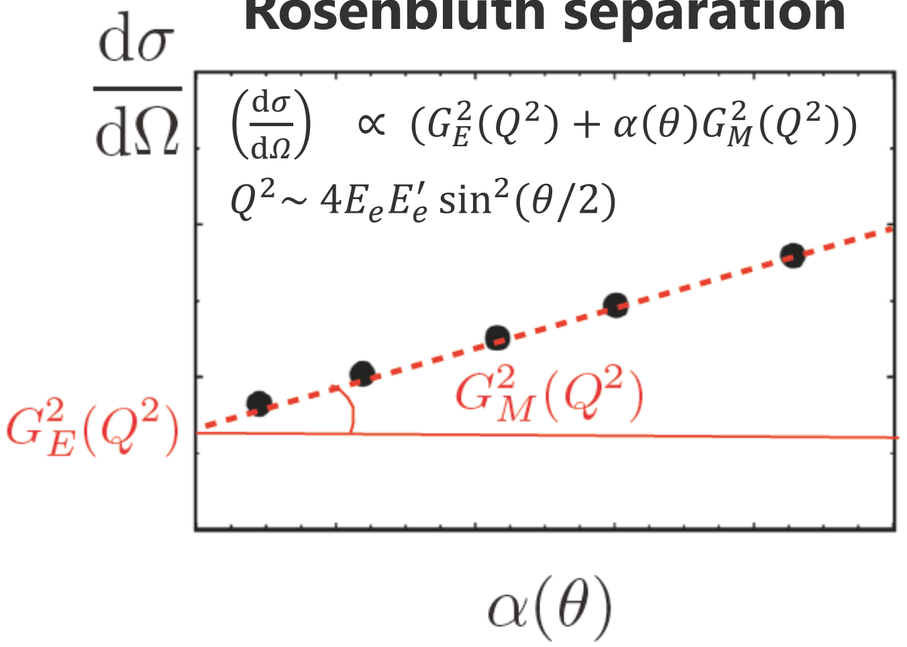

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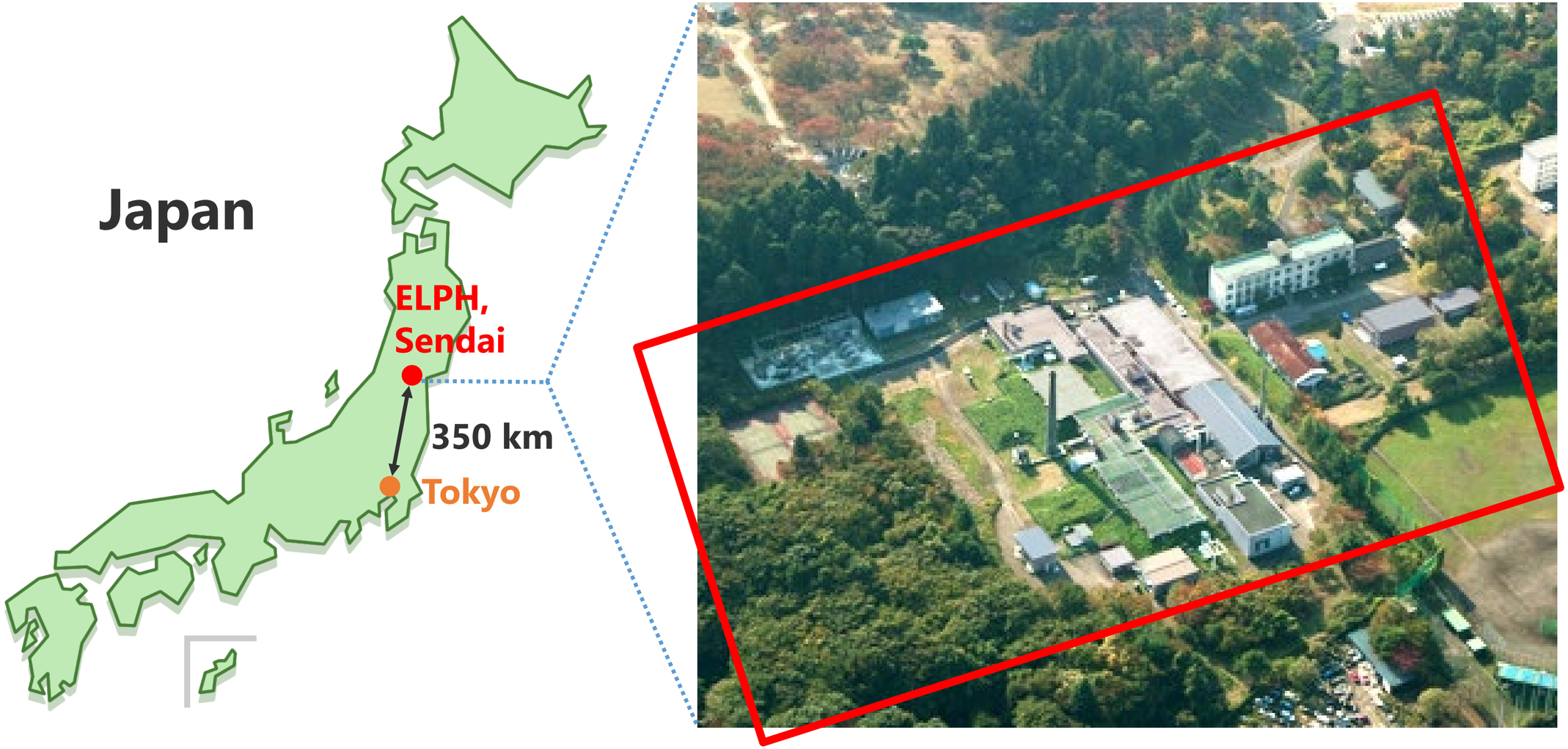

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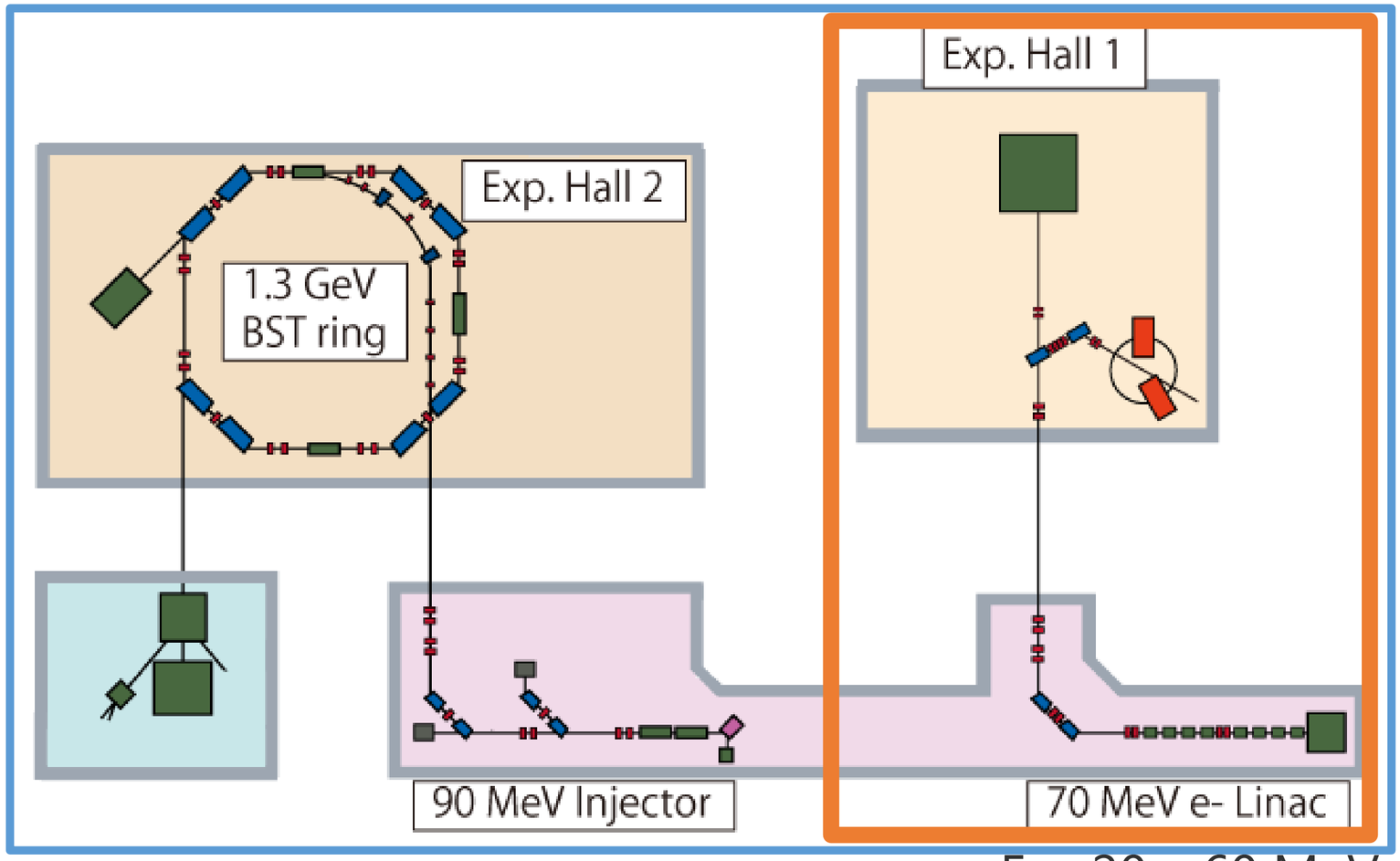
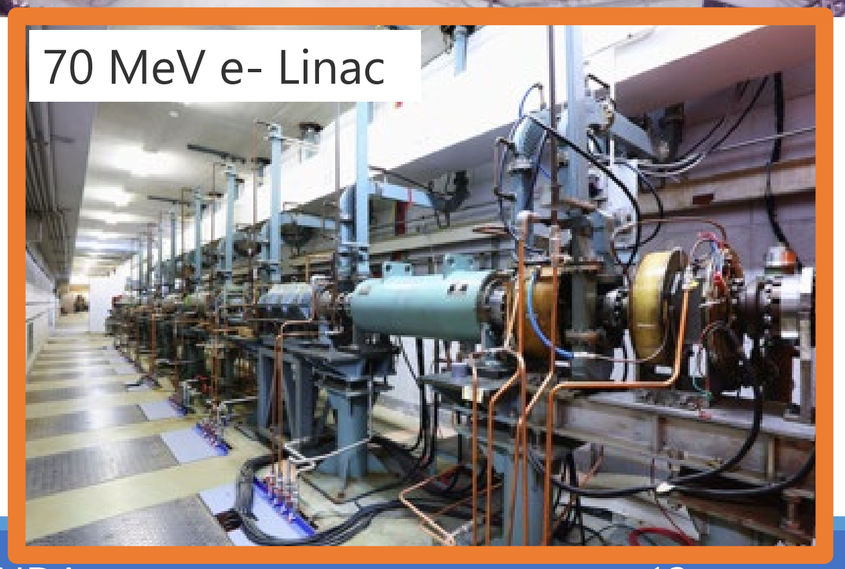




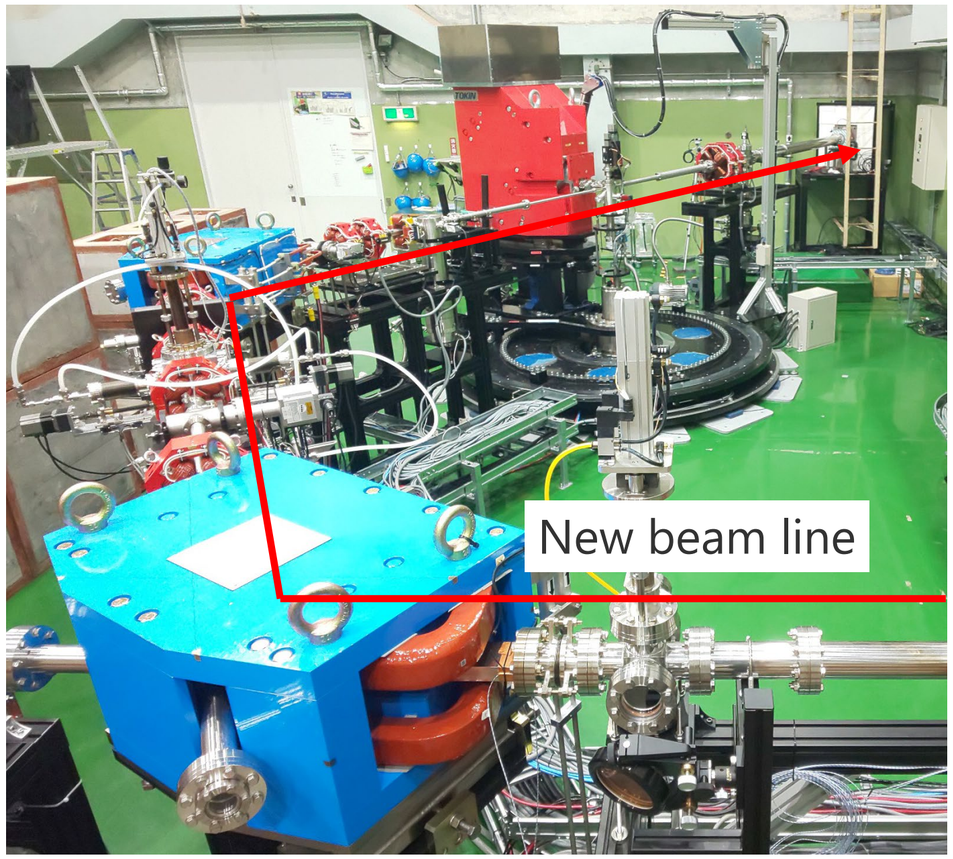
E = 20 – 60 MeV

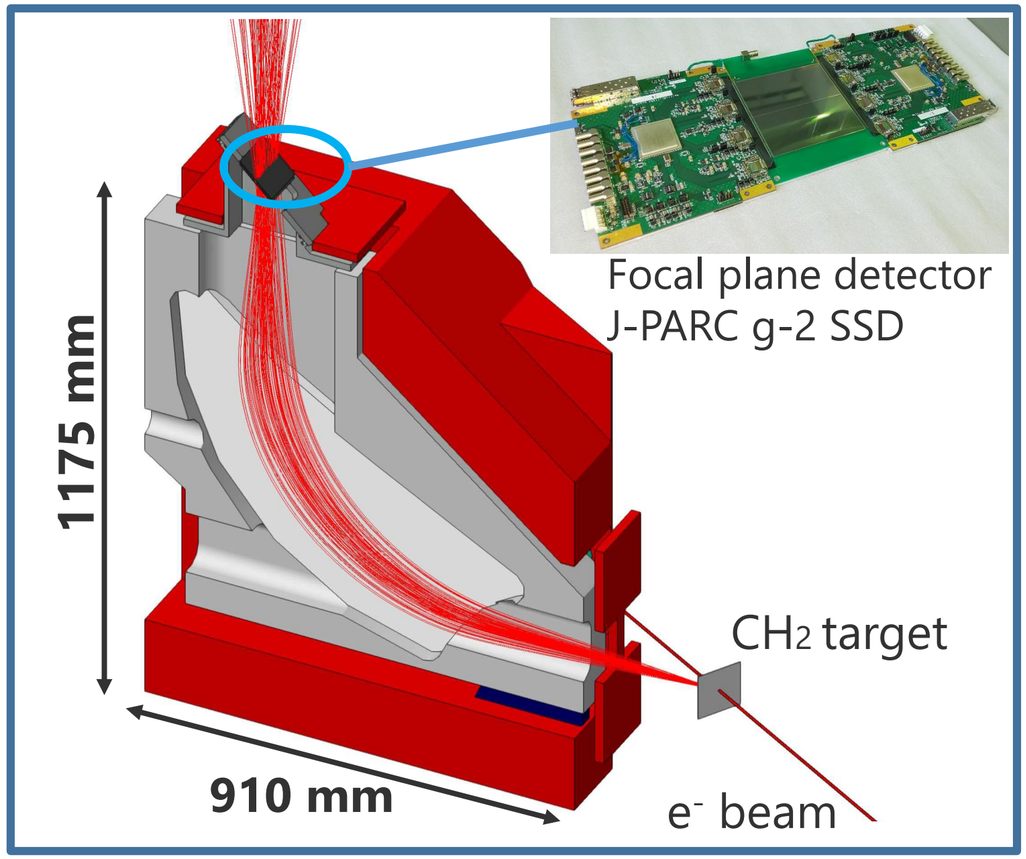
$I_e = 180\ \mu A$

ULQ2 : Commissioning

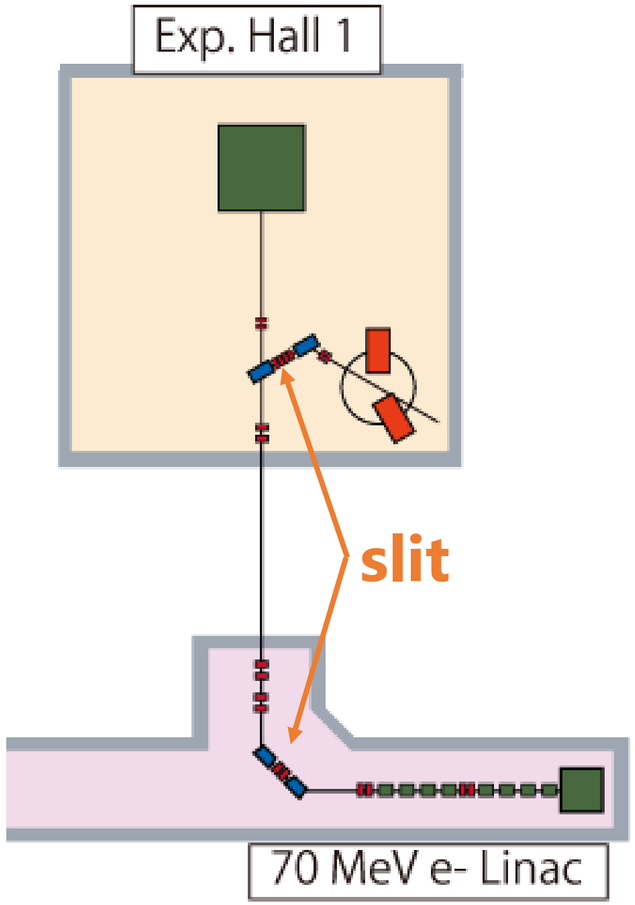
First beam Sep. 11, 2020

Commissioning Sep., Oct., Nov. 2020, May, June, July 2021





ULQ2 beam line

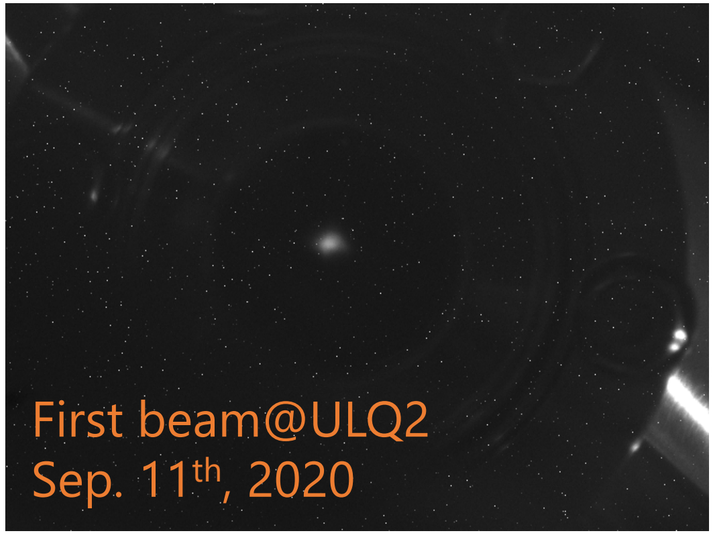


■ Previous status

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

■ Requirement : ULQ2 exp.

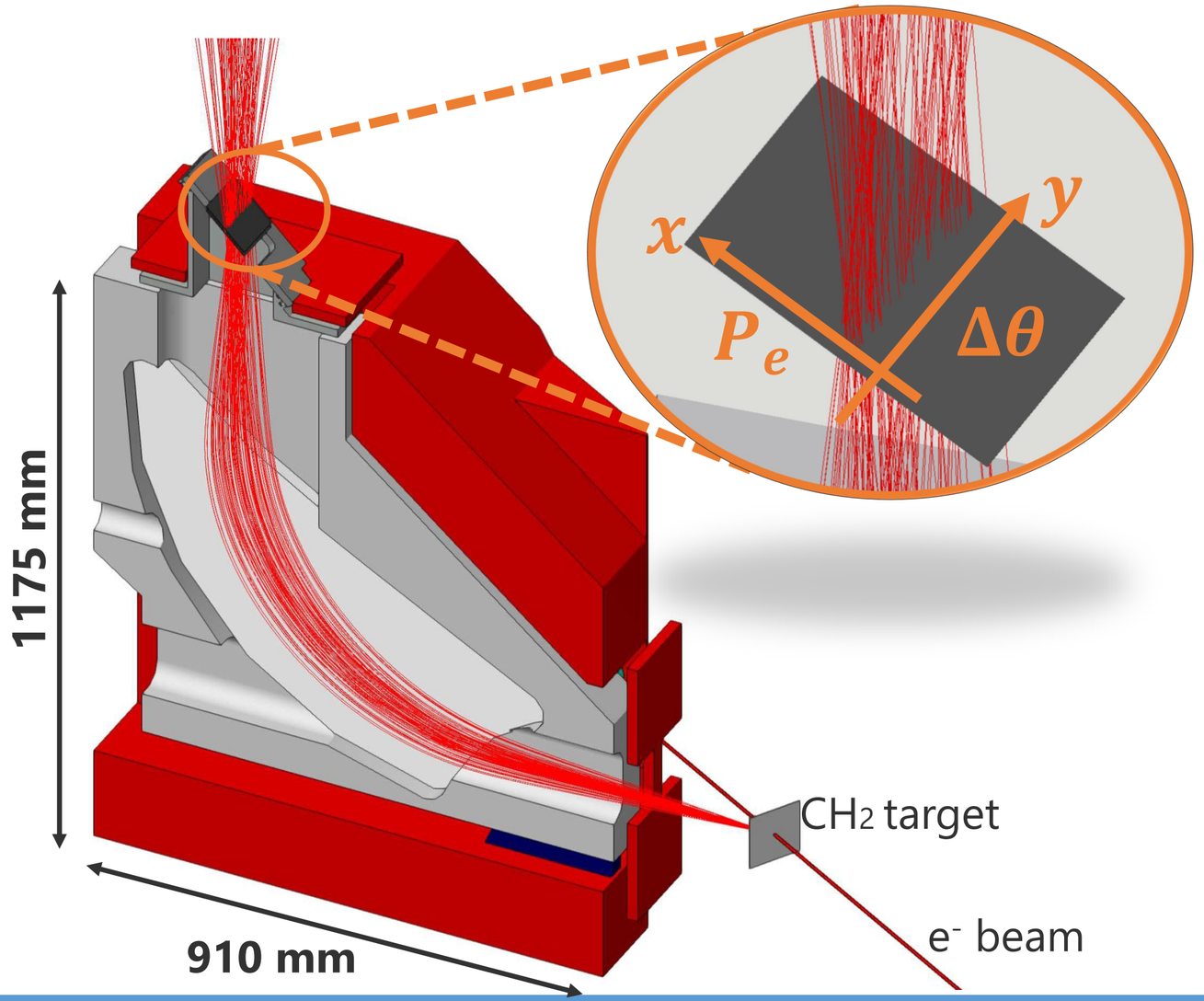
- $E_e = 20\ -60$ MeV
- $\sigma_E/E_e \leq 0.1$ %
- $\sigma_{x,y} \leq 1$ mm
- $I_{\max} \sim 1$ μA



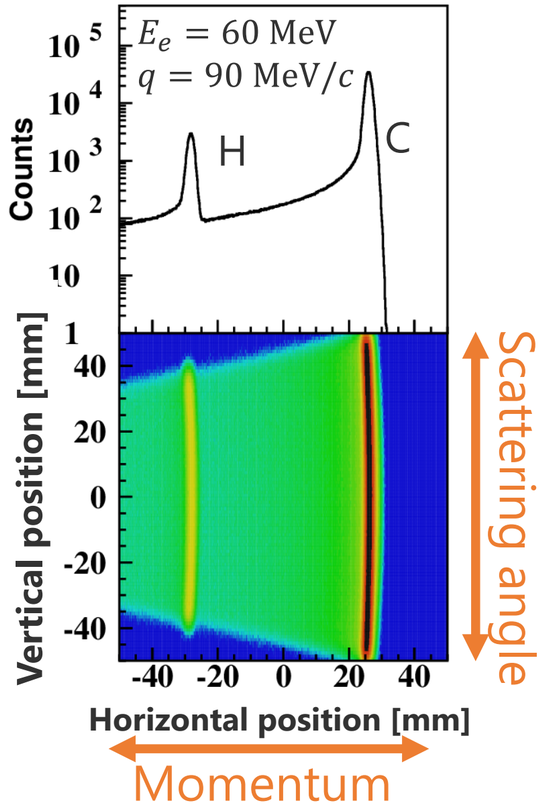
■ Commissioning

- $E_e = 50$ MeV
- $\sigma_E/E_e = 0.06$ %
- $\sigma_{x,y} \sim 0.6$ mm
- $I \sim 50$ nA (not max)

Spectrometer



Hitmap on detector



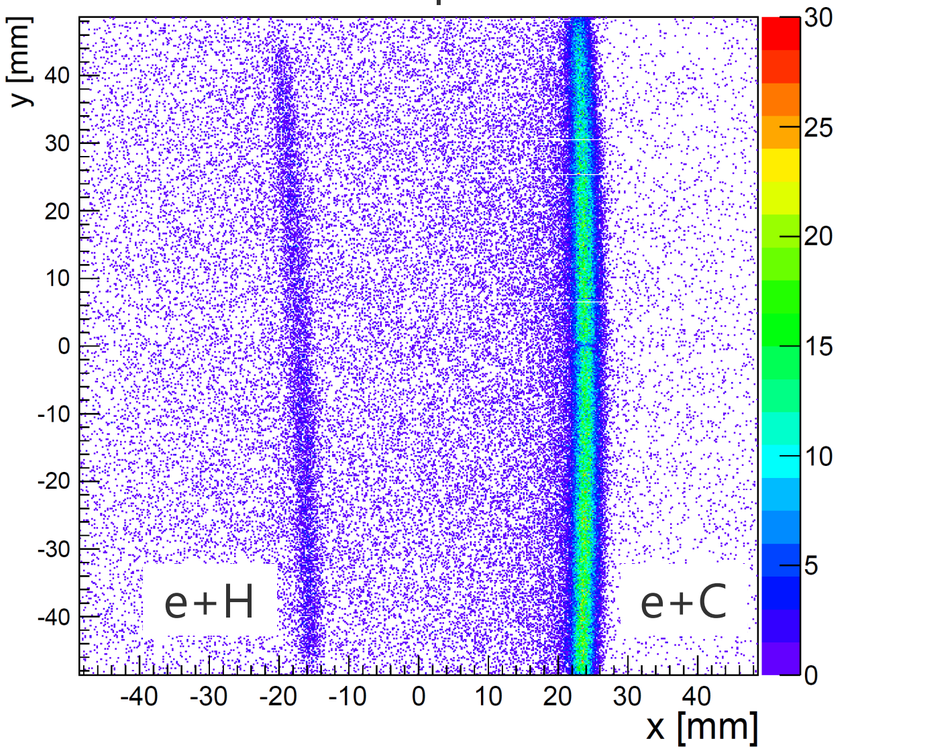
Spectrometer property

radius	50 cm
bending angle	90°
B_{Max}	0.4 T @ 60 MeV
gap	70 mm
dispersion	855 mm
σ_p/p	8×10^{-4}
momentum bite	11 %
σ_θ	5 mrad
solid angle	10 mSr

Spectrometer performance study

- e+H elastic peak was observed.
- Reproduced simulation well
  - Momentum resolution (Req. : 10^{-3})
    Exp. $7.0(4) \times 10^{-4}$
    Sim. 6.8×10^{-4}
  - Transition matrix
    $(x|\delta), (x|x)$
- Unevaluated : Angle resolution

Hitmap on SSD 2021/7/28



$E_e = 50\ \mathrm{MeV/c},\ \ \theta = 90°$
CH_2 target

Basically, it was confirmed that there are no serious problems with the spectrometer design.

Summary

- Proton radius has a serious inconsistency.
- ULQ2 experiment aims to determine the proton radius removing model dependencies as much as possible.
- Commissioning of the new beamline and spectrometer has been performed, and it is confirmed there are no serious problems.