Low-energy electron scattering facility at RARiS

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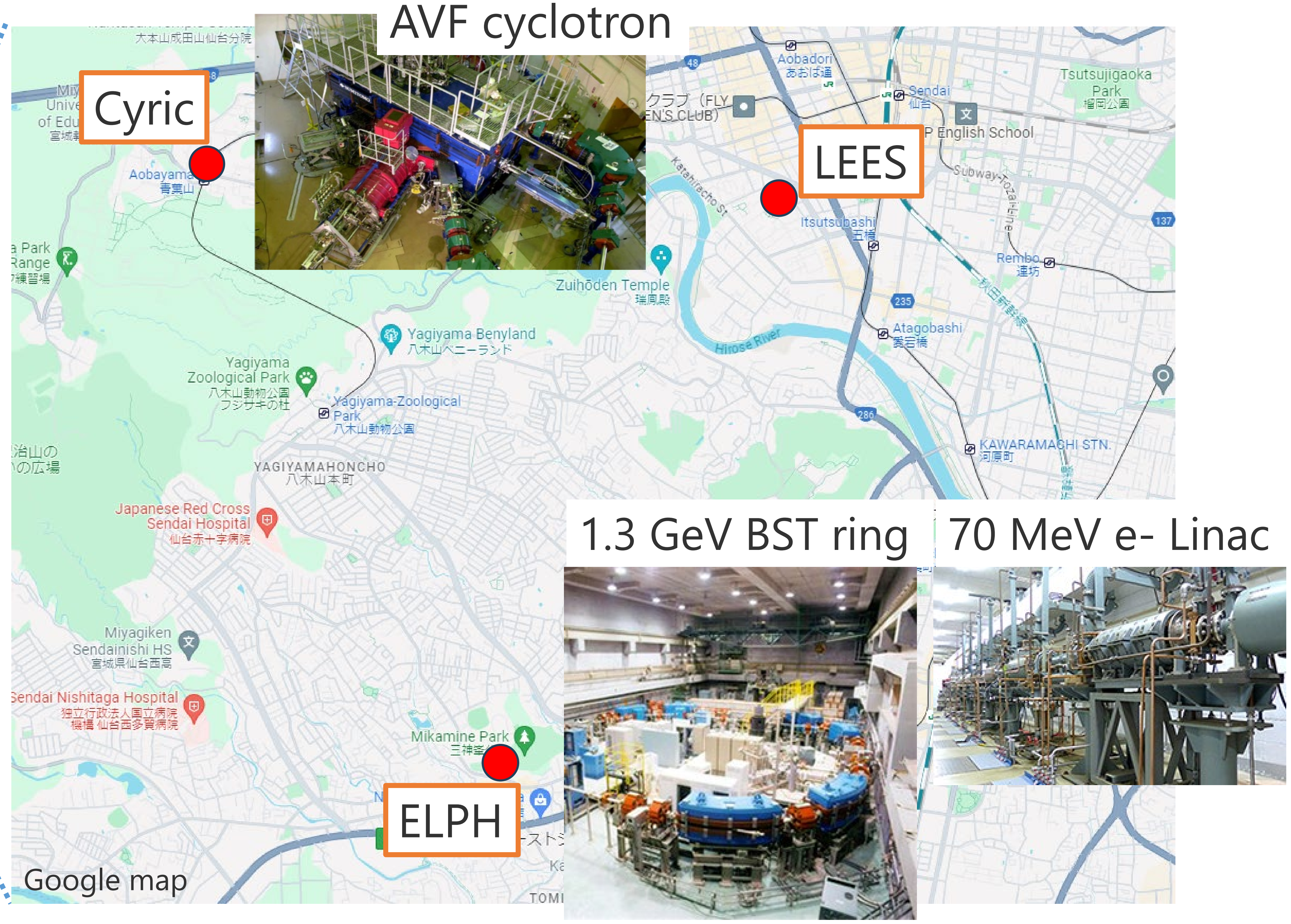
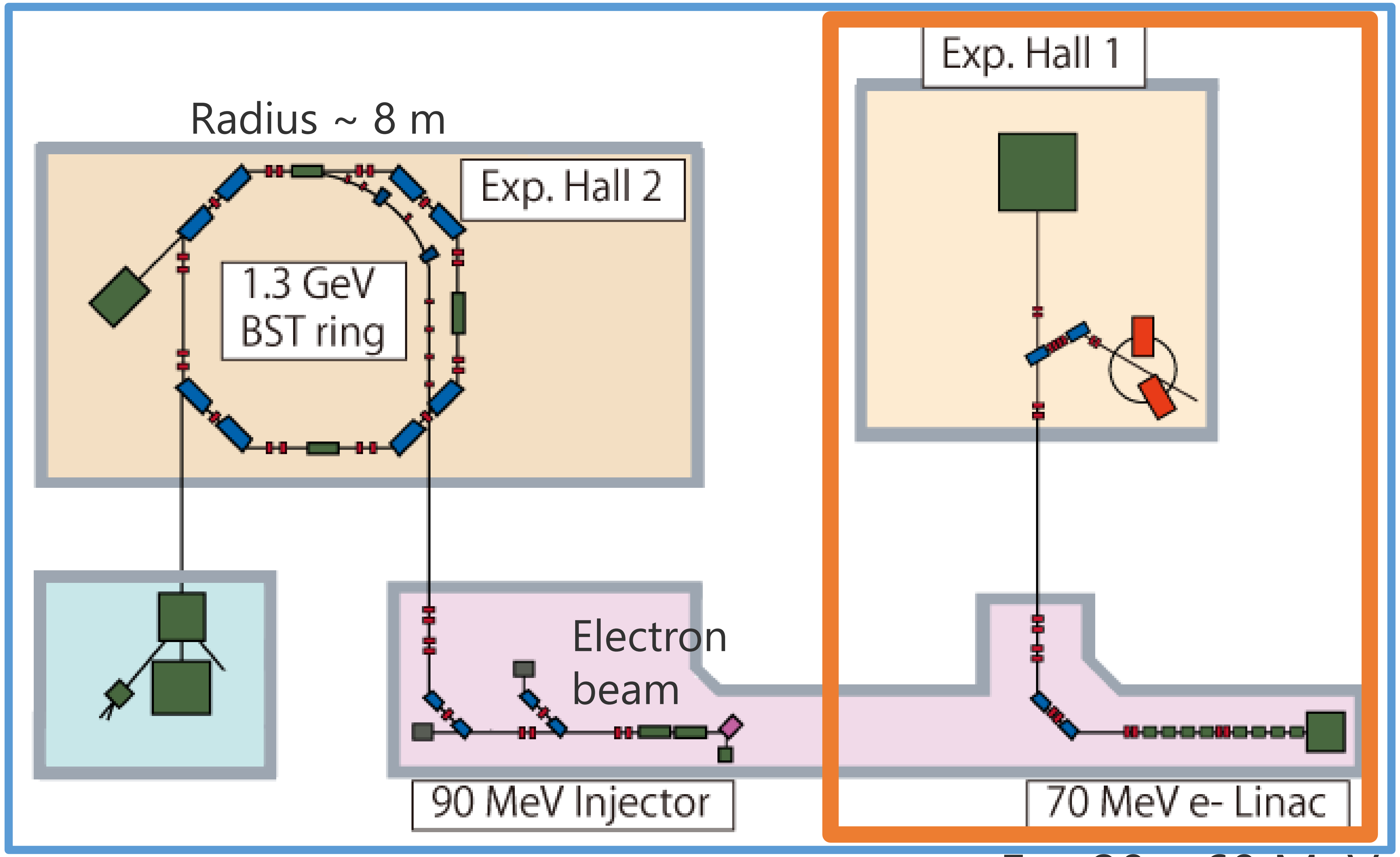
for the ULQ2 collaboration.

Research Center for Accelerator and Radioisotope Science (RARiS)



Accelerators in RARIS Mikamine cite (old ELPH)

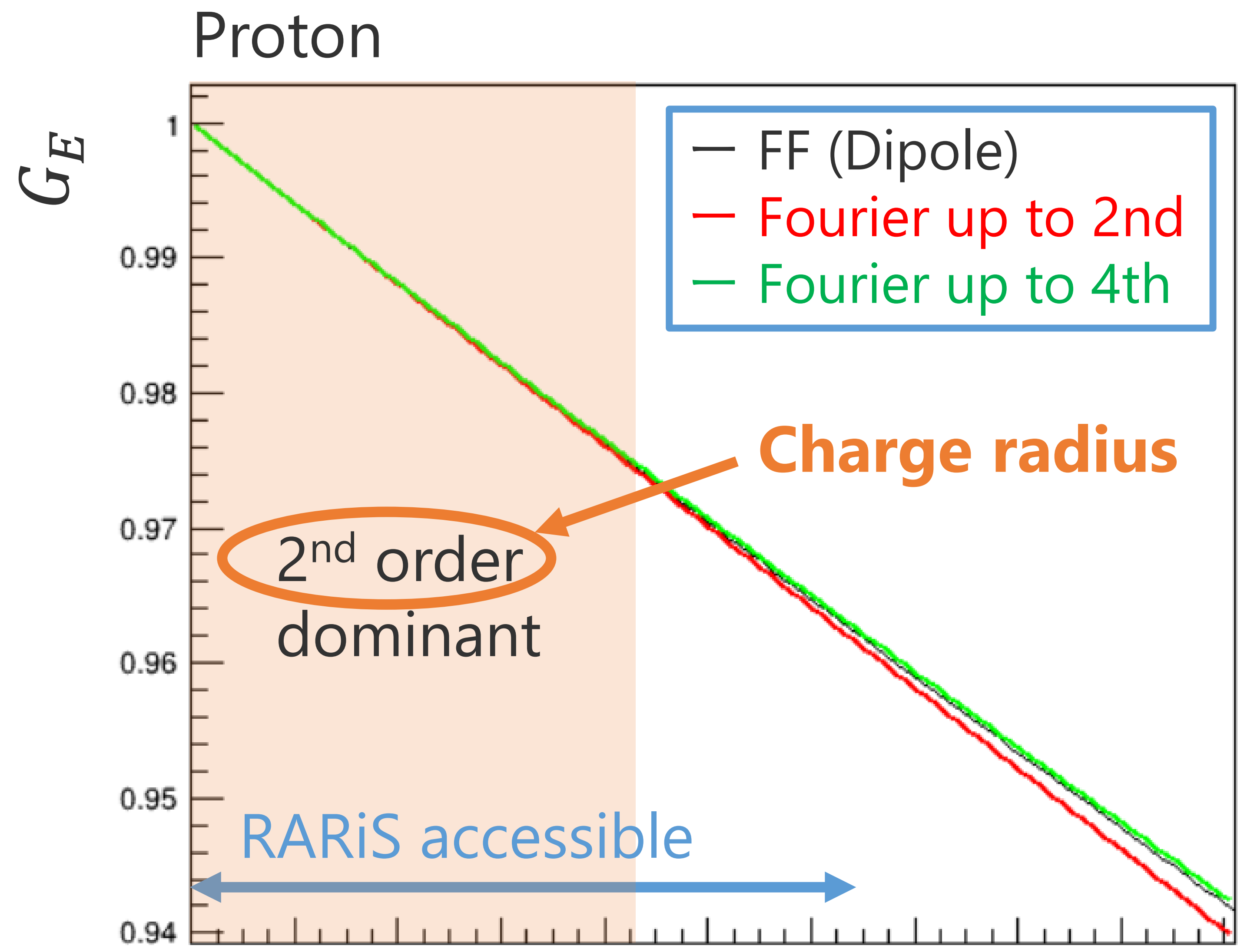


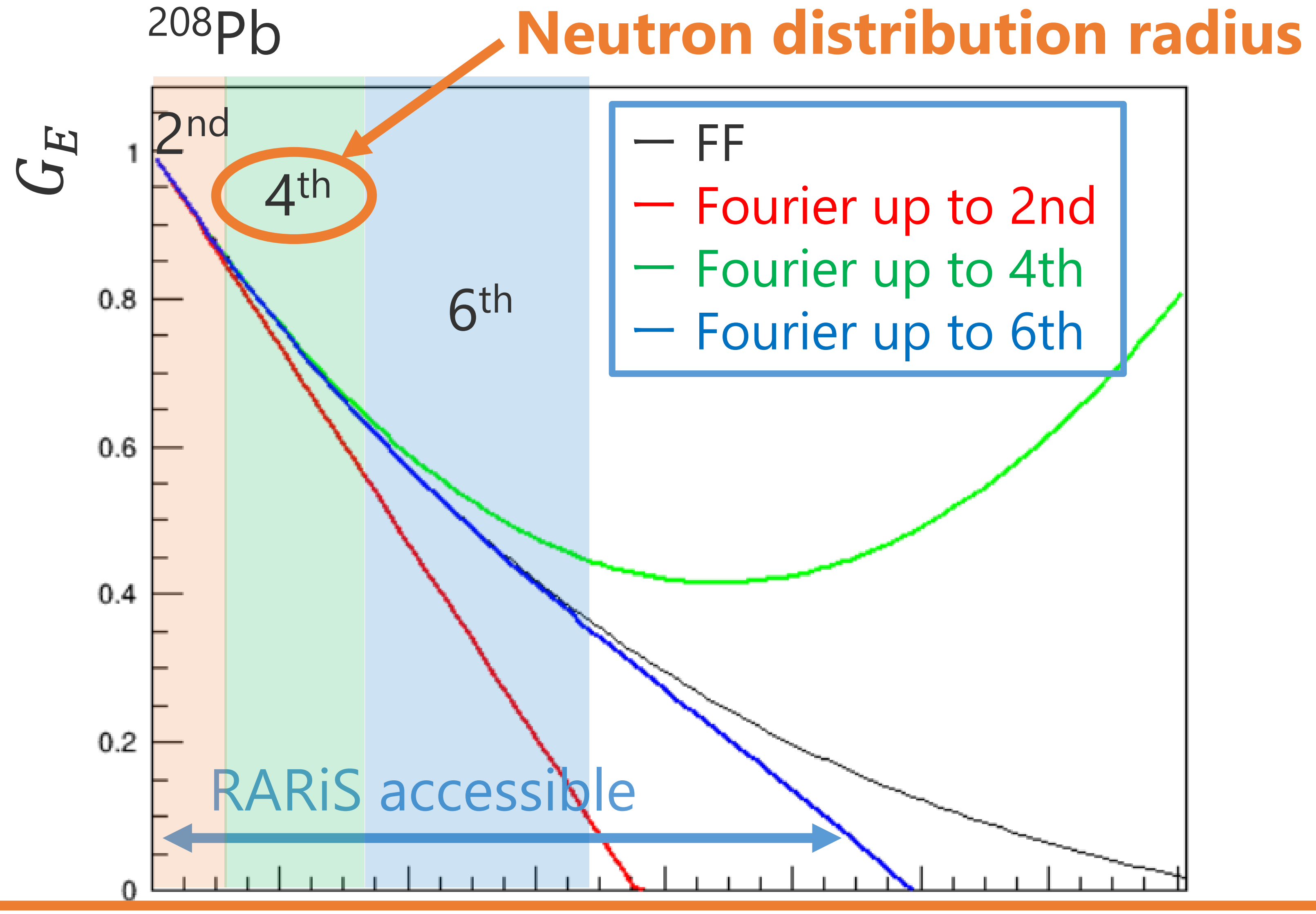
E = 20 – 60 MeV

$I_e = 180\ \mu A$

70 MeV electron linac

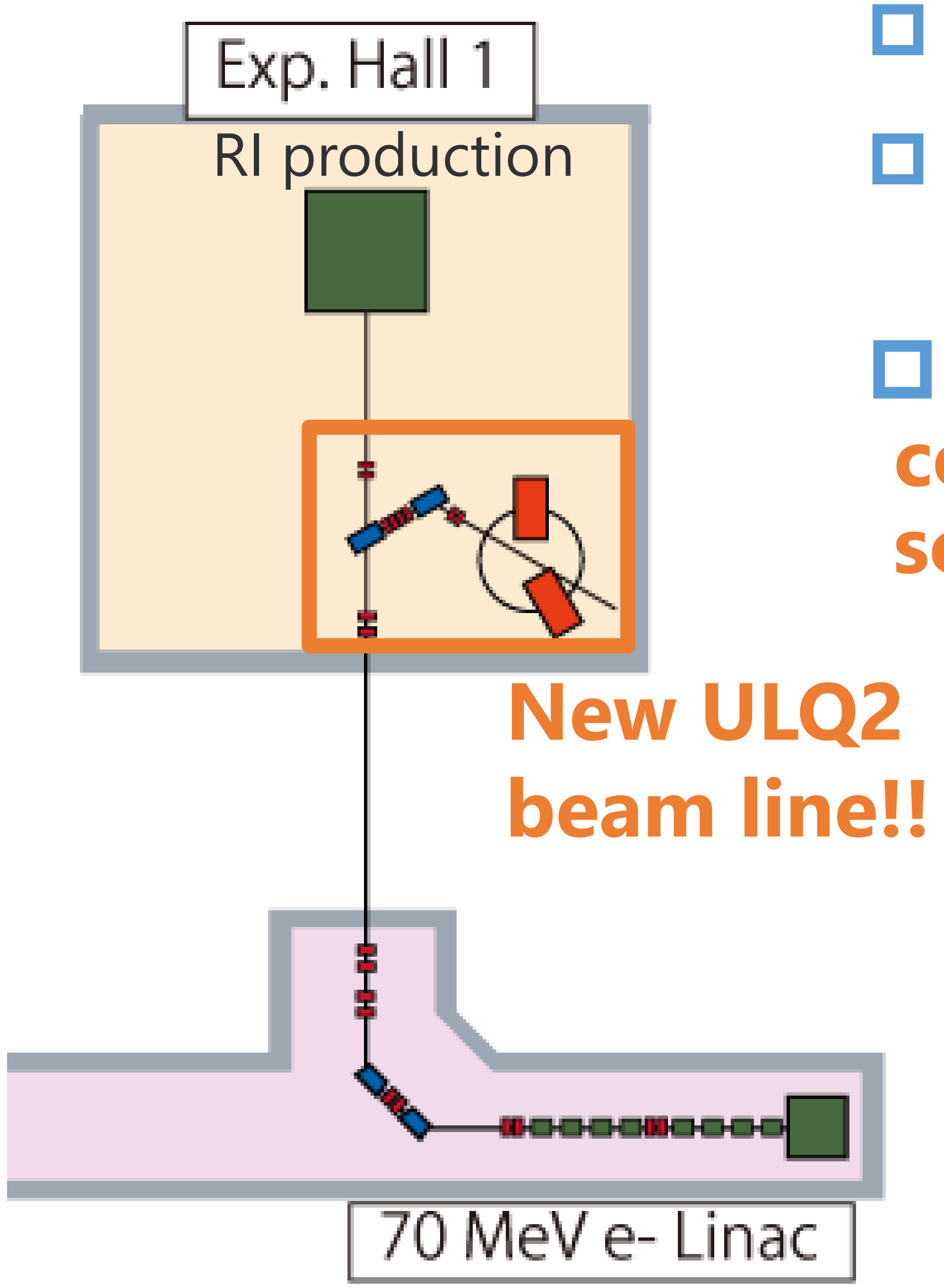
RARiS's linac energy is very suitable to measure the 2nd order for the light nuclei, and 4th or 6th order for the heavy nuclei.





Low energy electron scattering facility have been developed at RARiS

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.**

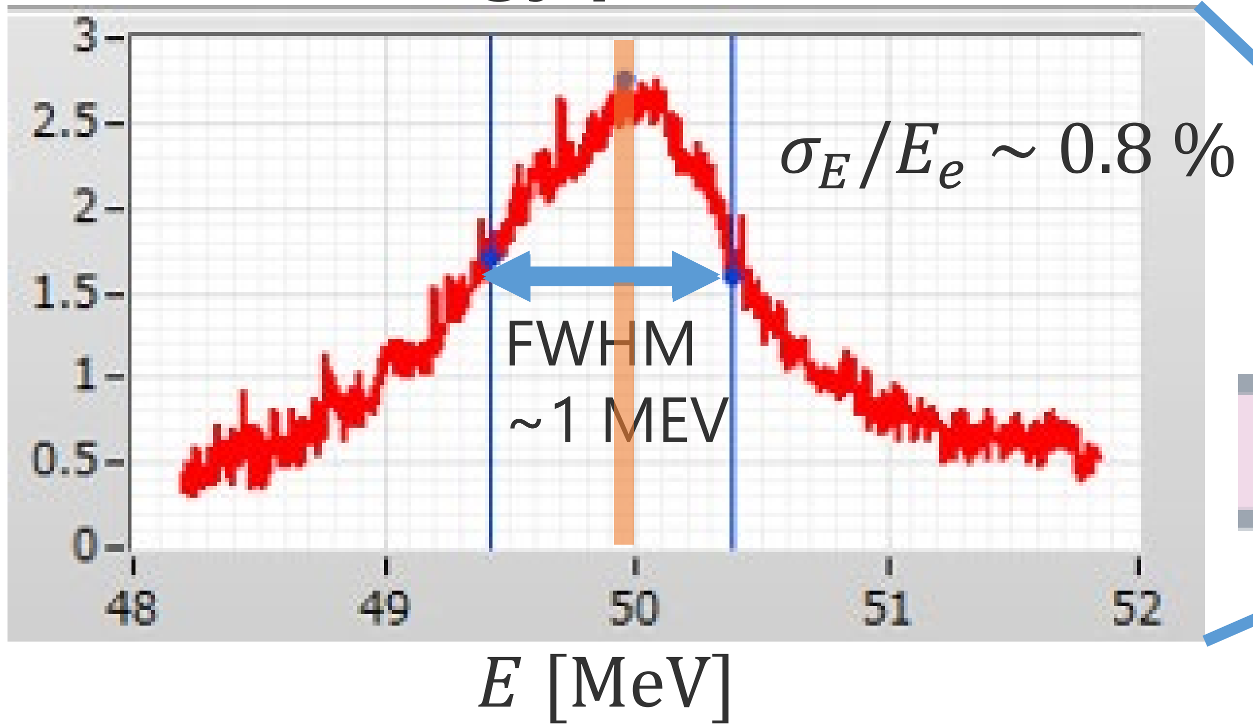
- Beam status
  - $E_e = 20 - 60$ MeV
  - $\sigma_E/E_e \sim 0.8\ \%$
  - $\sigma_{x,y} \sim 3$ mm
  - $I_{\max} \sim 180\ \mu$A

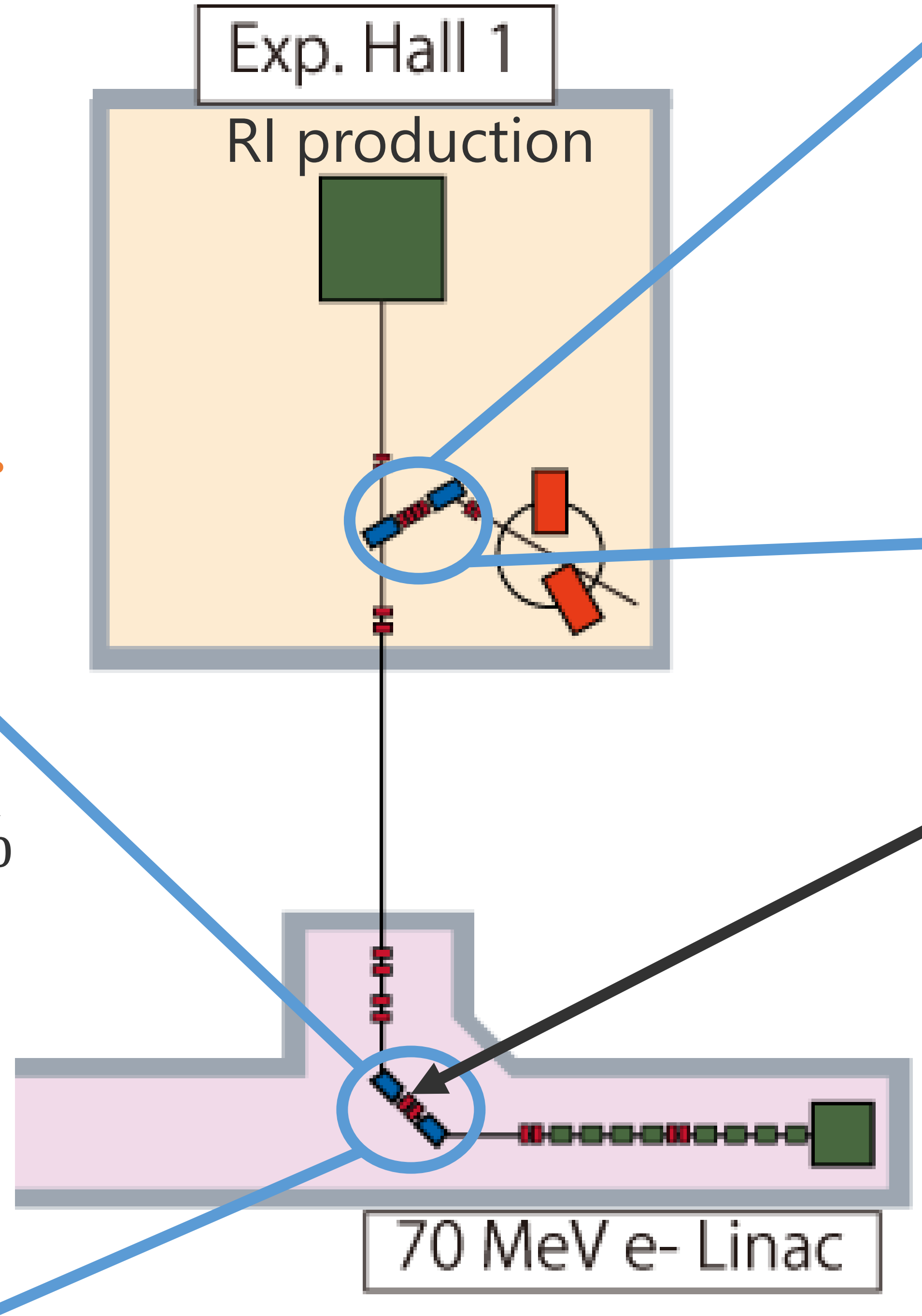
Unfortunately, beam energy spread and beam size was too wide for the electron scattering.

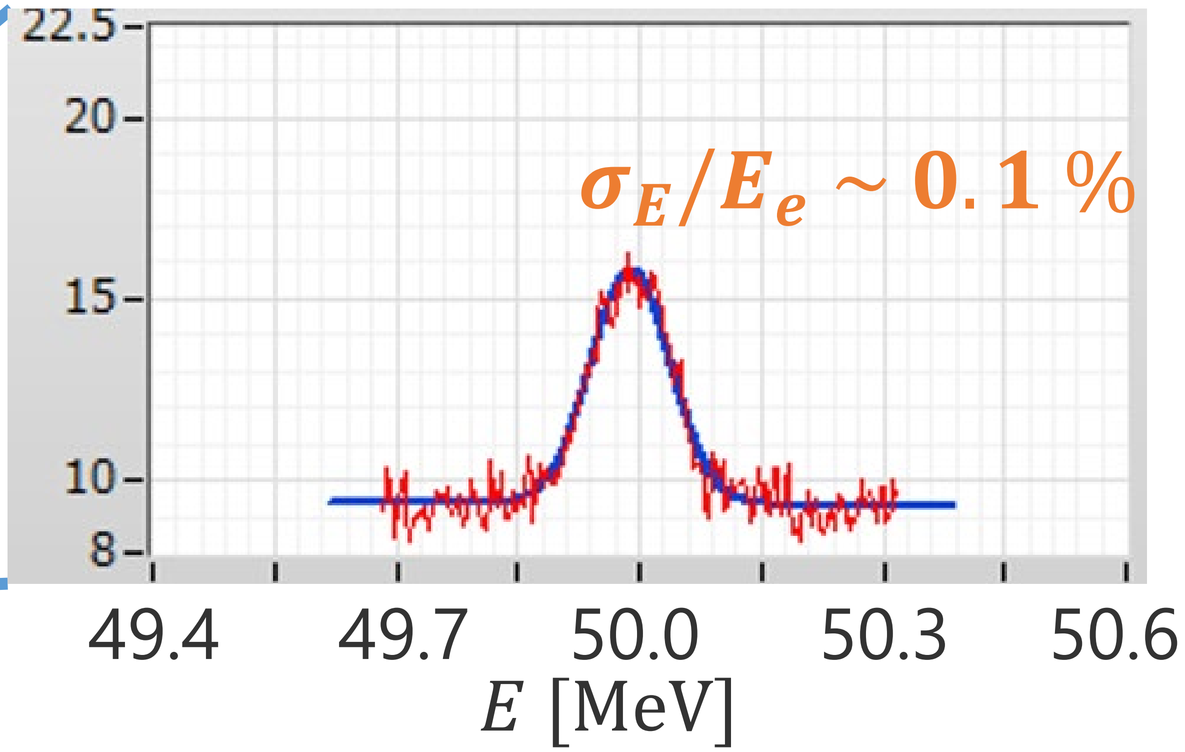
70 MeV electron linac

- Beam energy spread was too wide for the electron scattering.
- Installed beam slit to reduce energy spread.
- **0.1 % energy spread was achieved.**

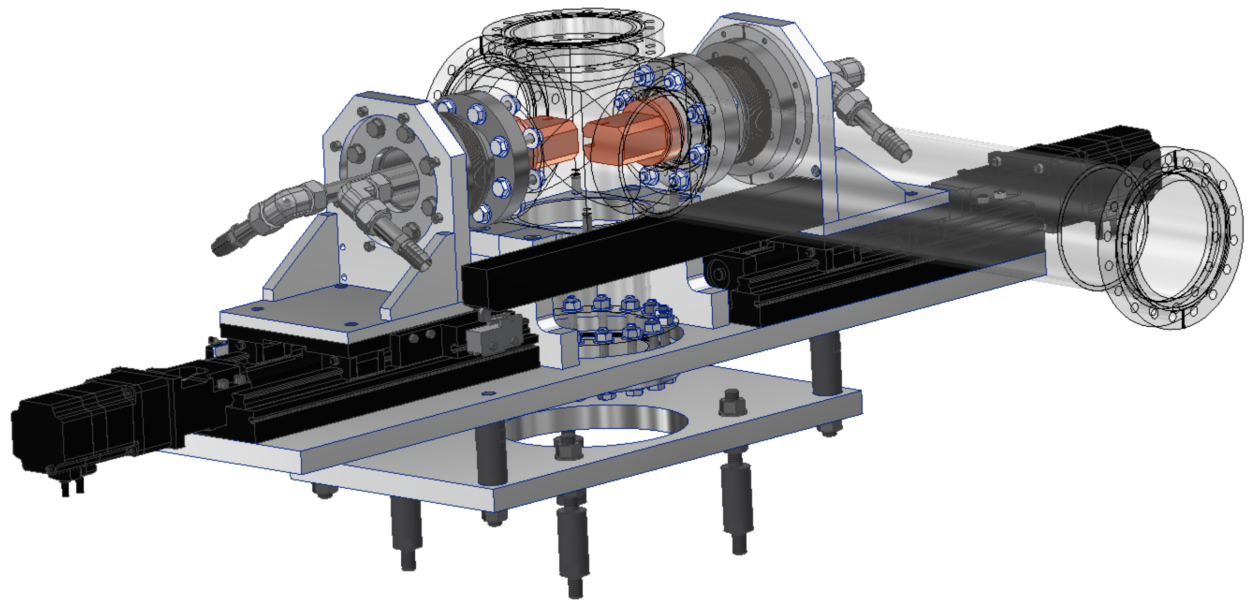
Beam energy profile w/o slit



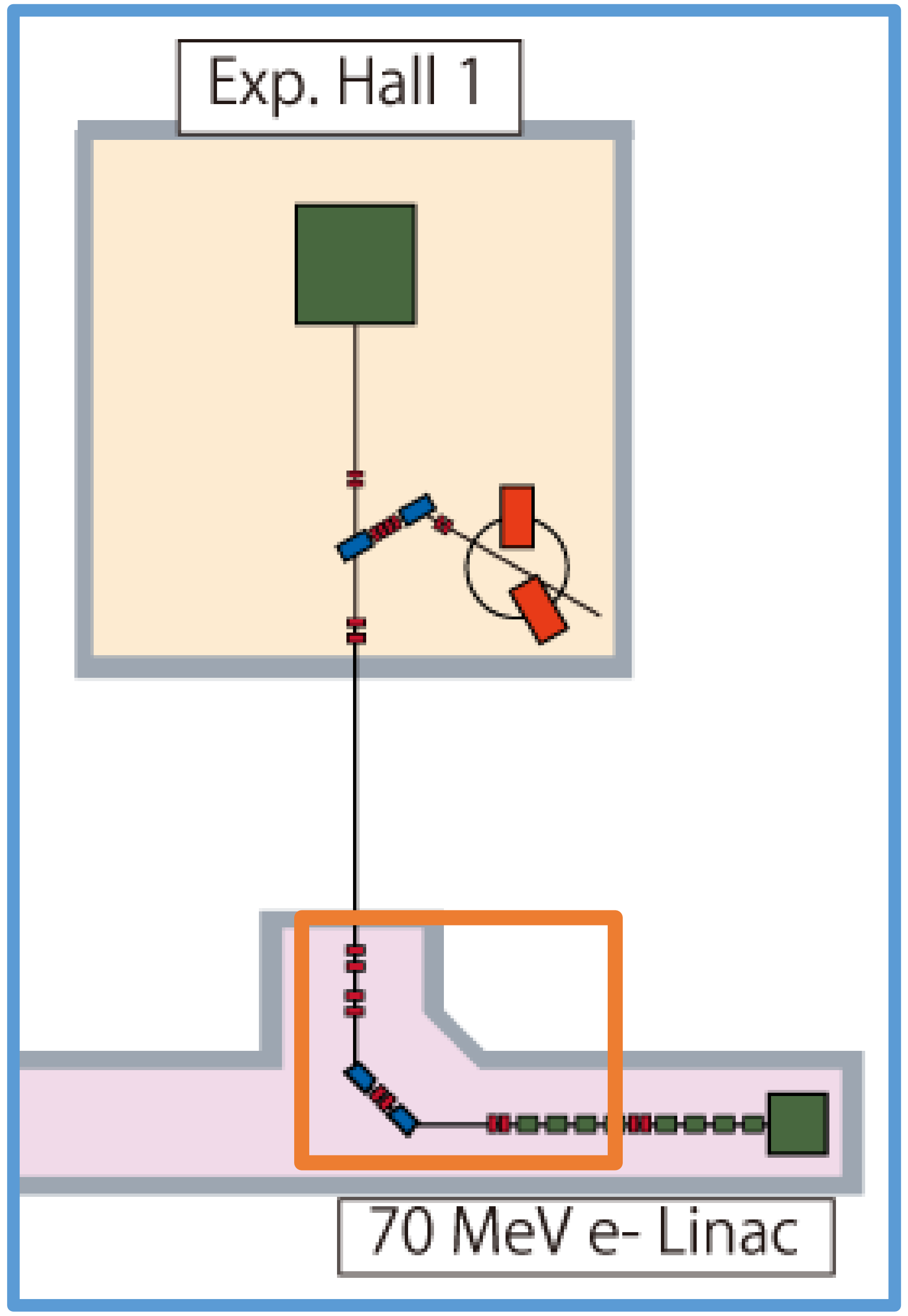




Installed beam slit



Beamline upgrade



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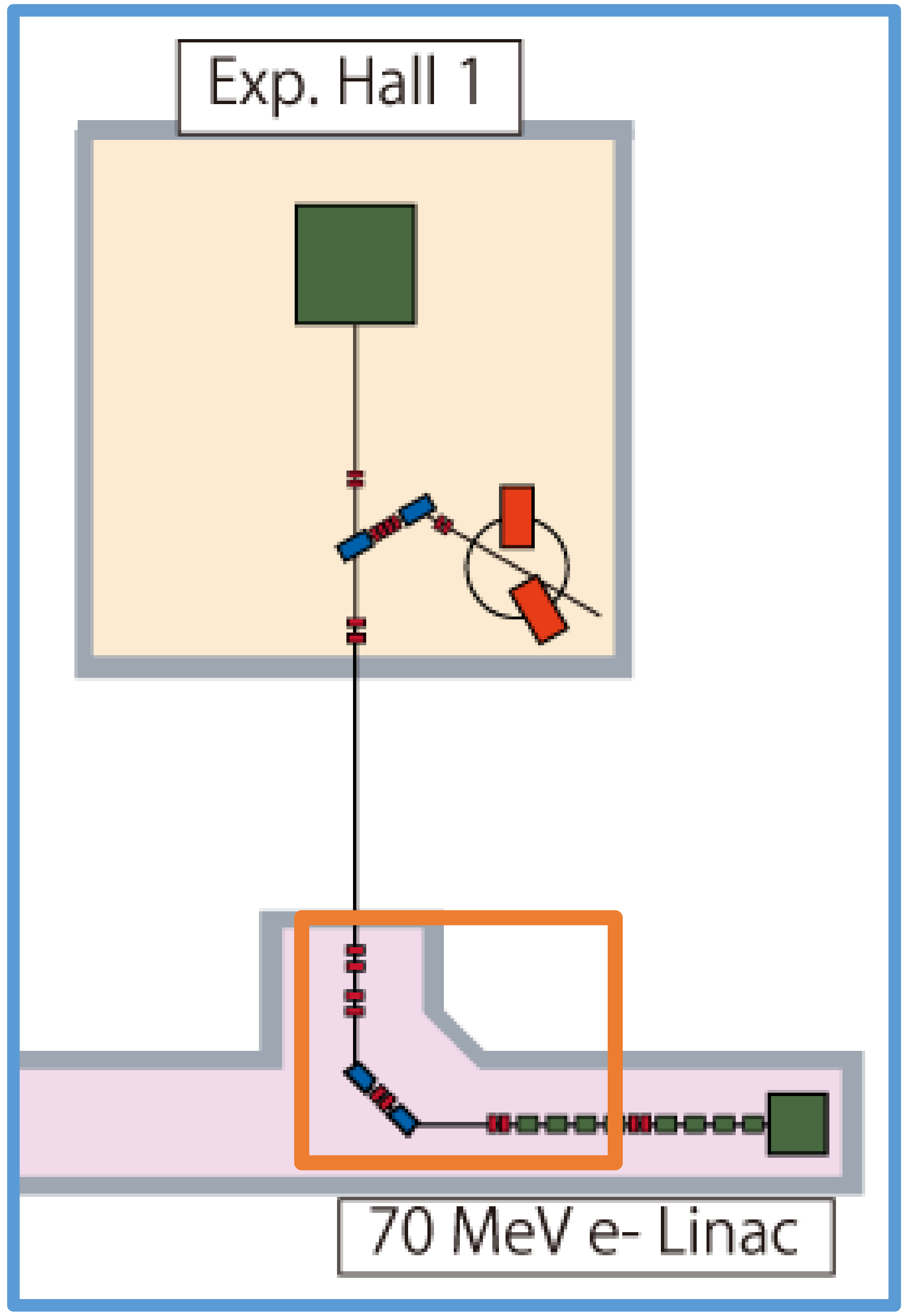
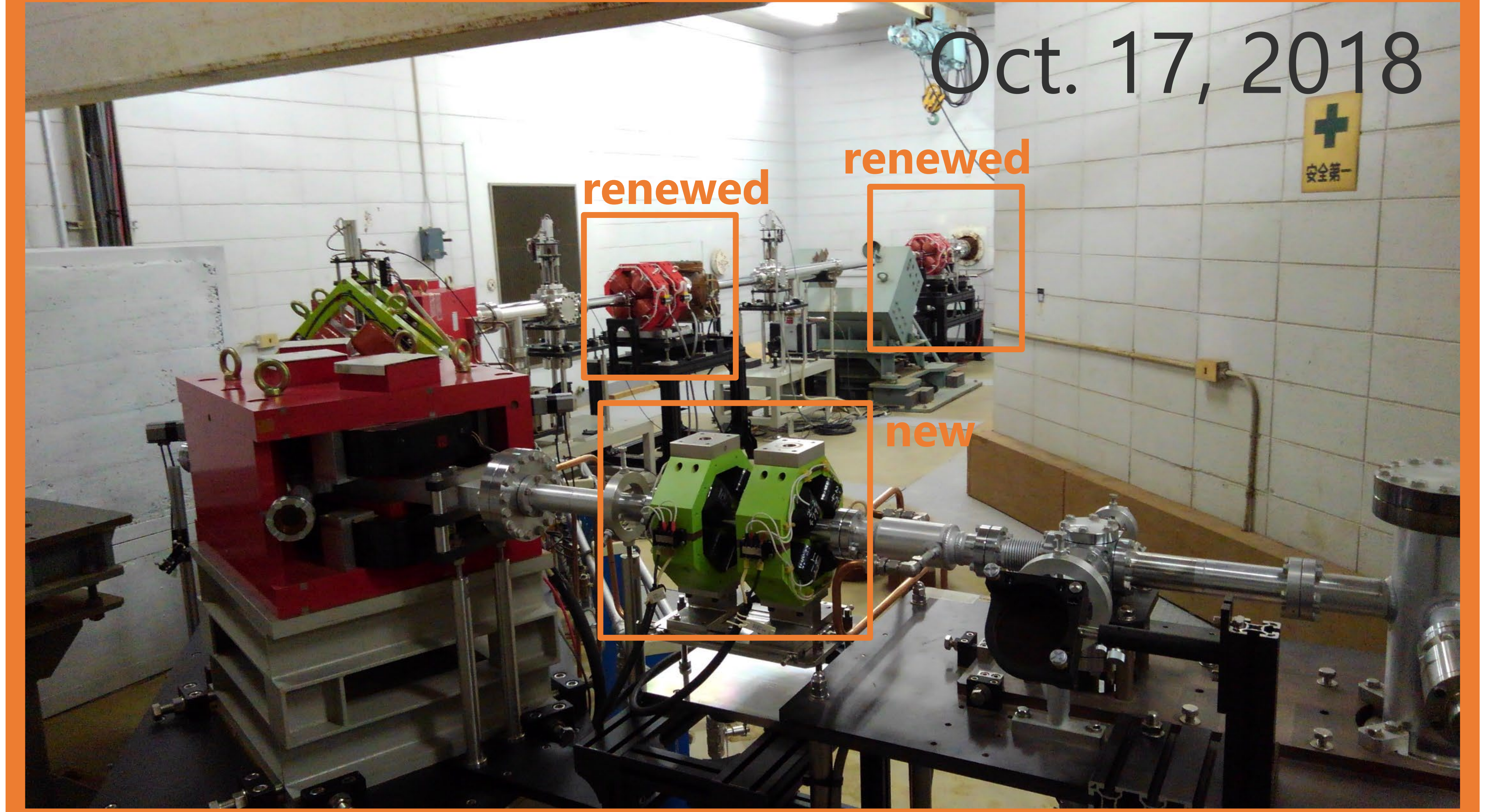


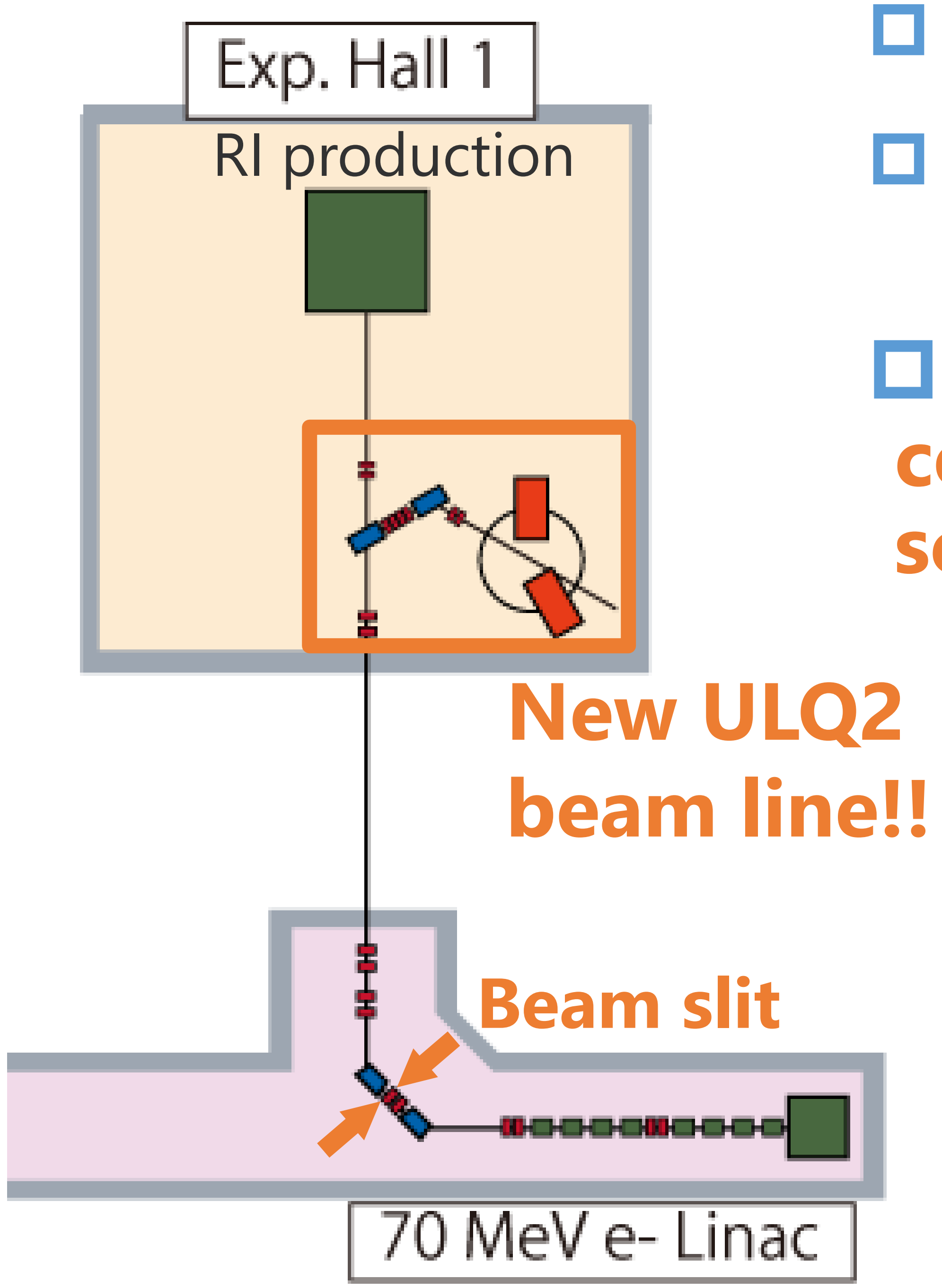
Beamline upgrade

Old

New!!



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.**

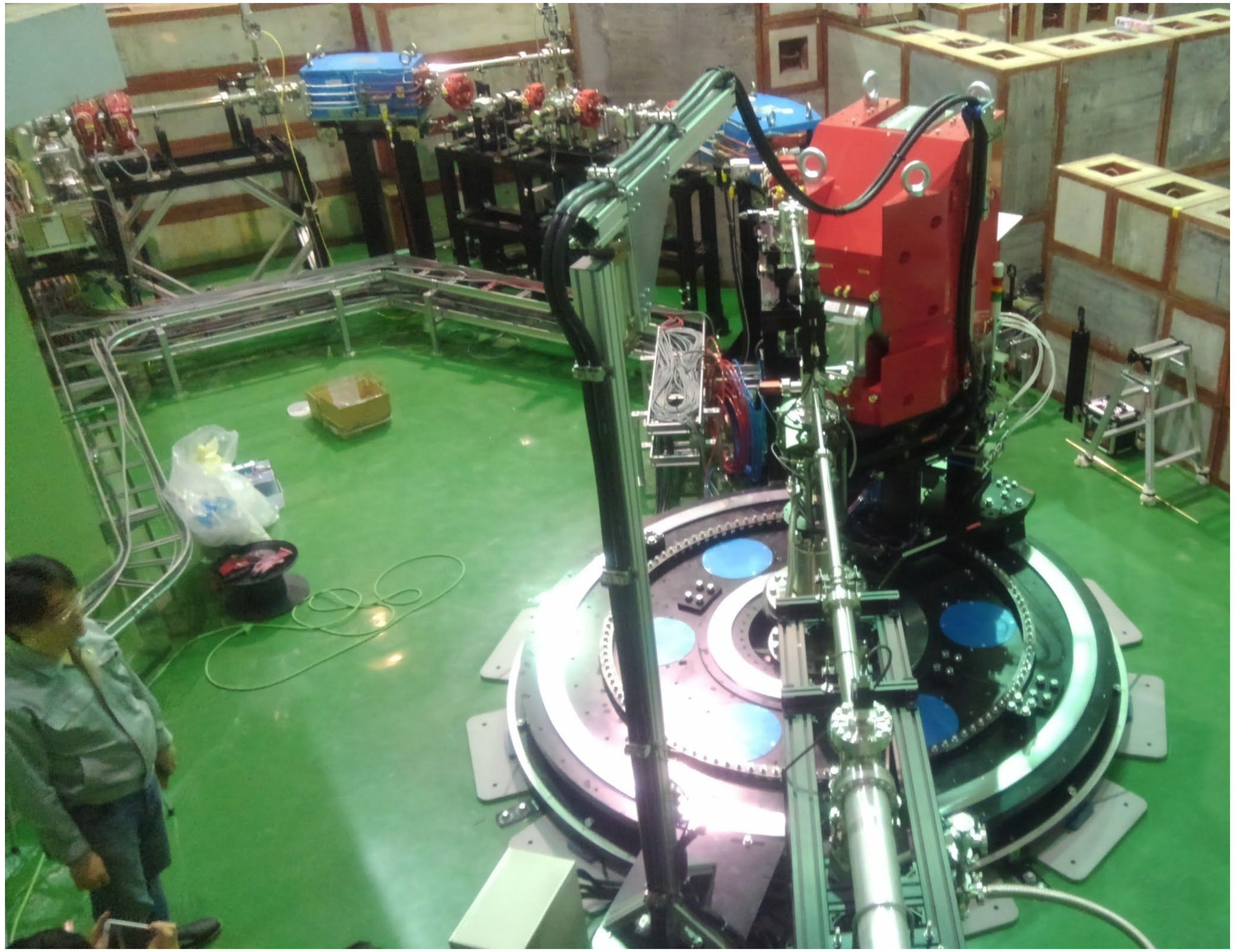
- Previous status
  - $E_e = 20 - 60$ MeV
  - $\sigma_E/E_e \sim 0.8\ \%$
  - $\sigma_{x,y} \sim 3$ mm
  - $I_{\mathrm{max}} \sim 180\ \mu\mathrm{A}$

- ULQ2 beamline
  - $E_e = 10 - 65$ MeV
  - $\sigma_E/E_e \leq 0.1\ \%$
  - $\sigma_{x,y} \leq 1$ mm
  - $I_{\mathrm{max}} \sim 1\ \mu\mathrm{A}$

Spectrometer & beamline construction

In 2017

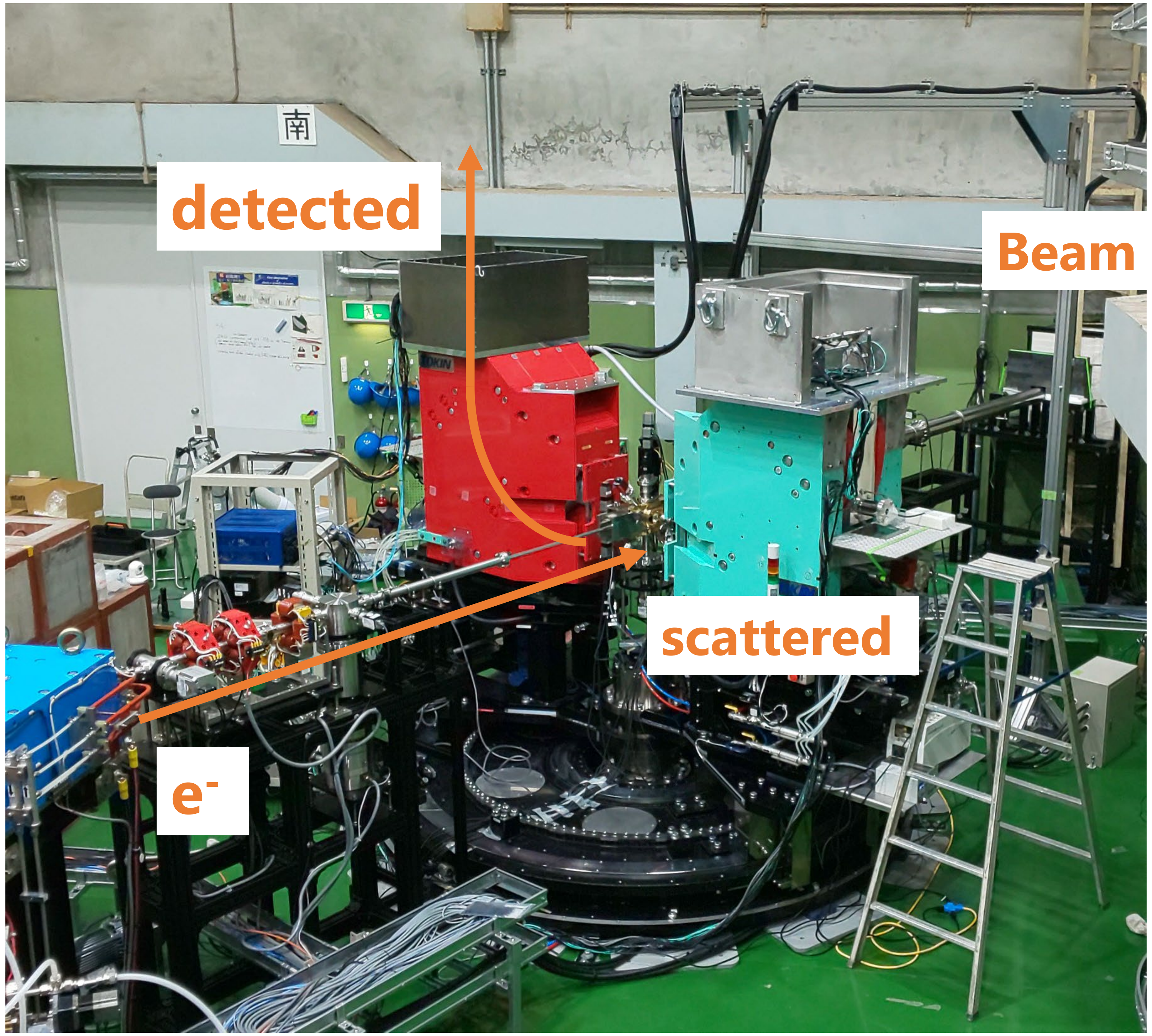
Since 2019



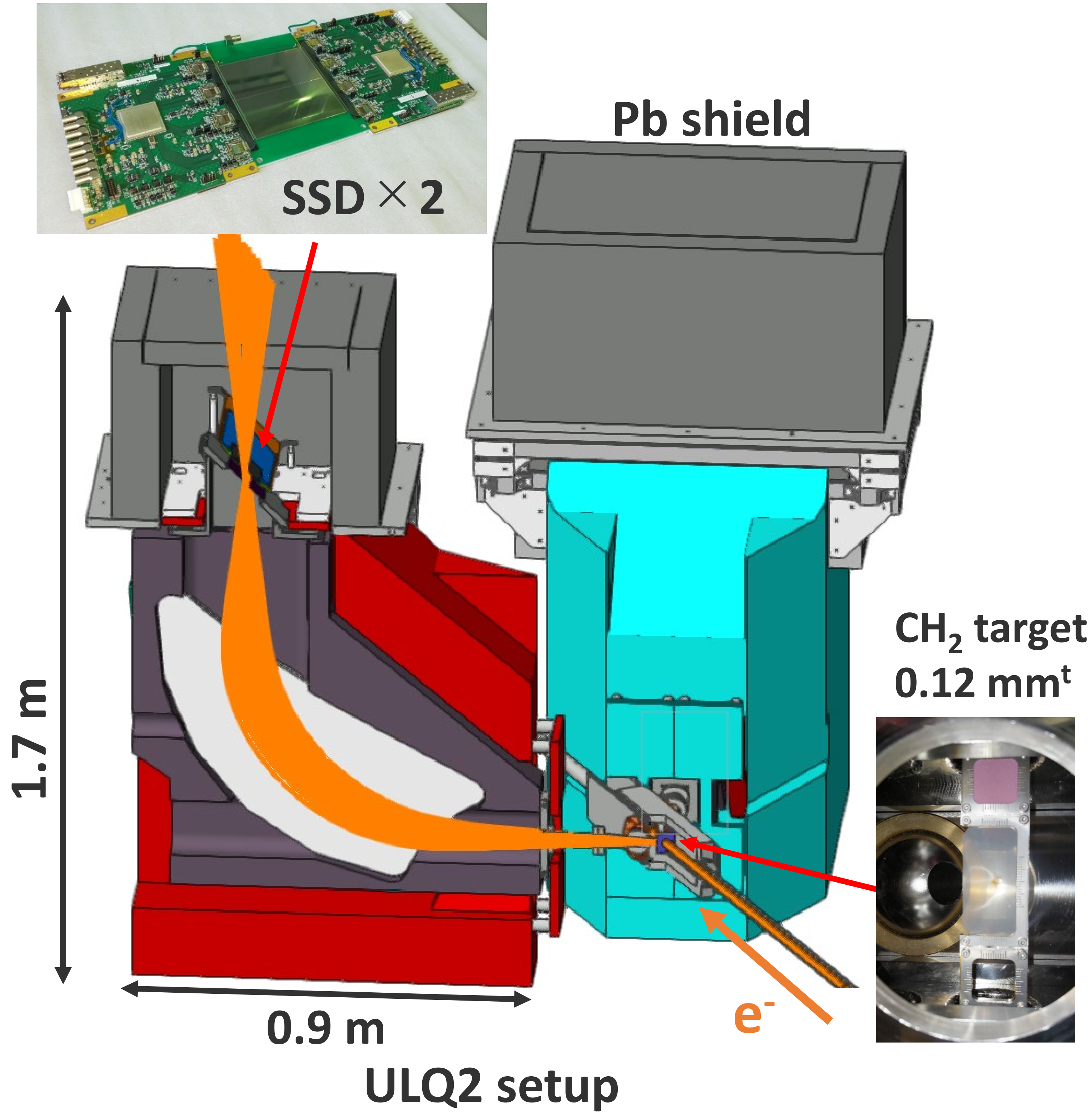
Spectrometer & beamline construction

In 2017

Since 2021



Spectrometer for low-energy electron



- Twin electro-magnetic spectrometer
  ① Foreground measurement
  ② Luminosity monitor, CH/CD ratio monitor

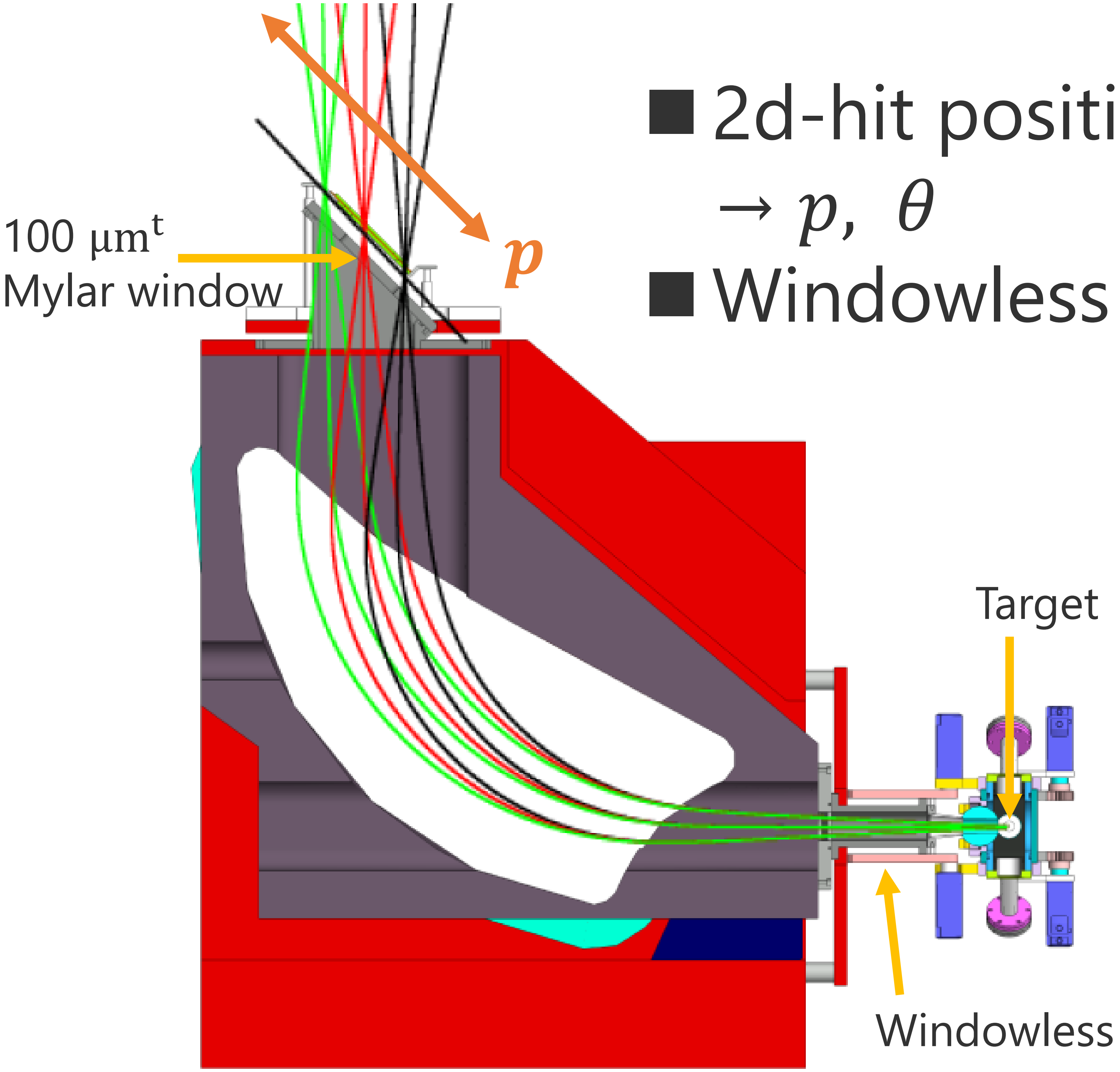
  $\theta = 30° - 150°$

- Specialized for low-energy electron
  ① Windowless
  ② Tracking less

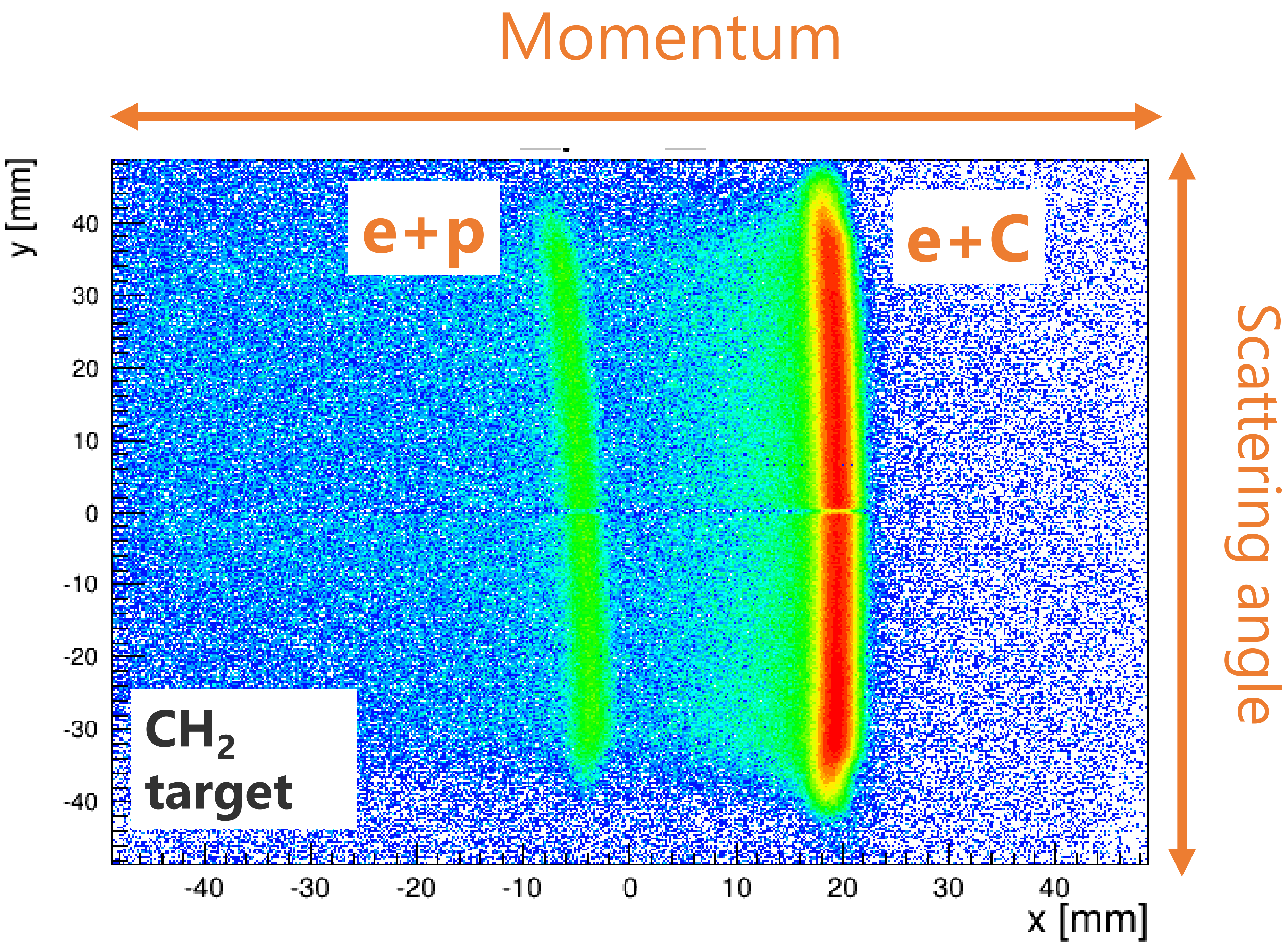
  $E_e = 10 - 65$ MeV

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

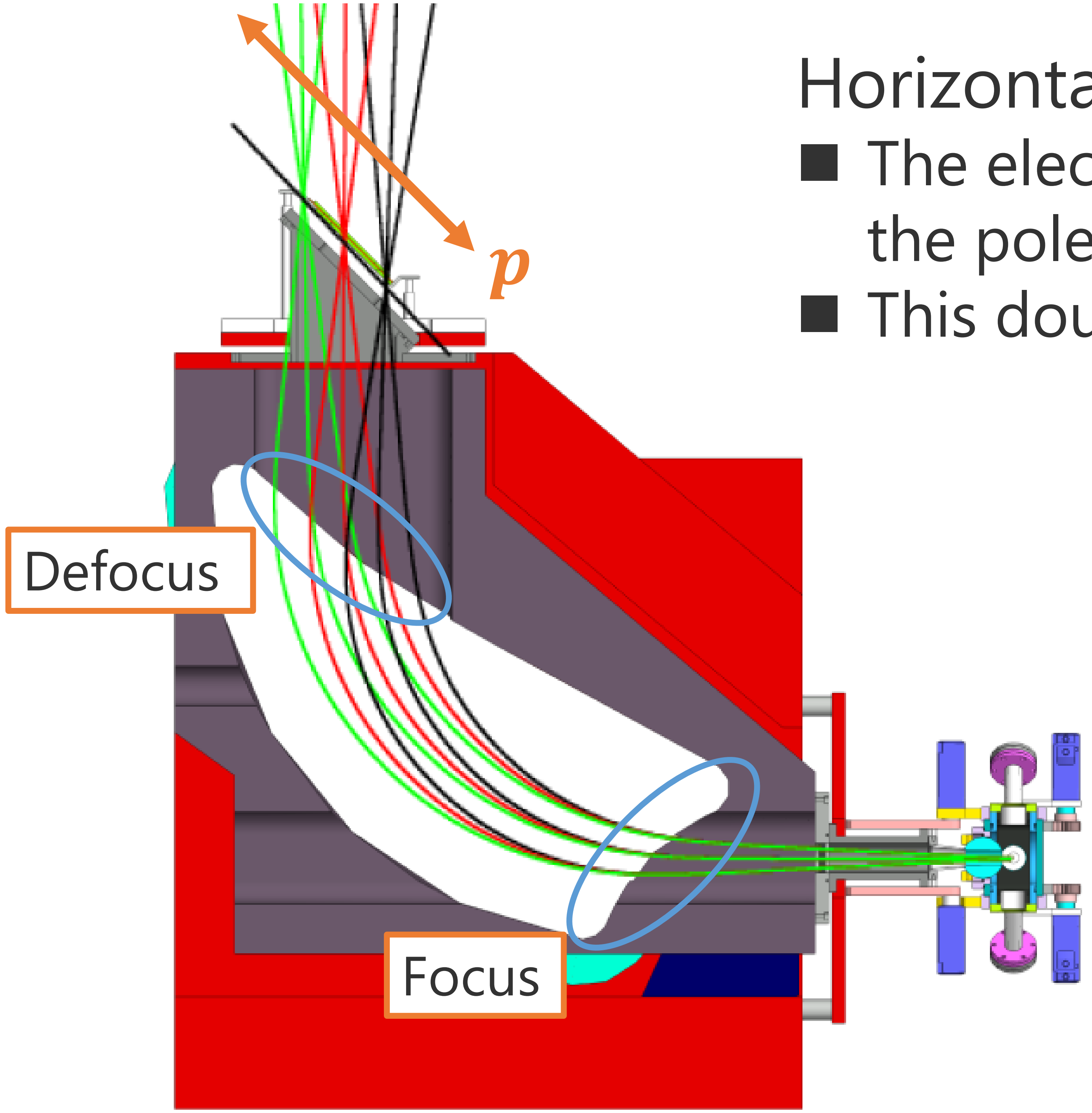
Spectrometer design



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

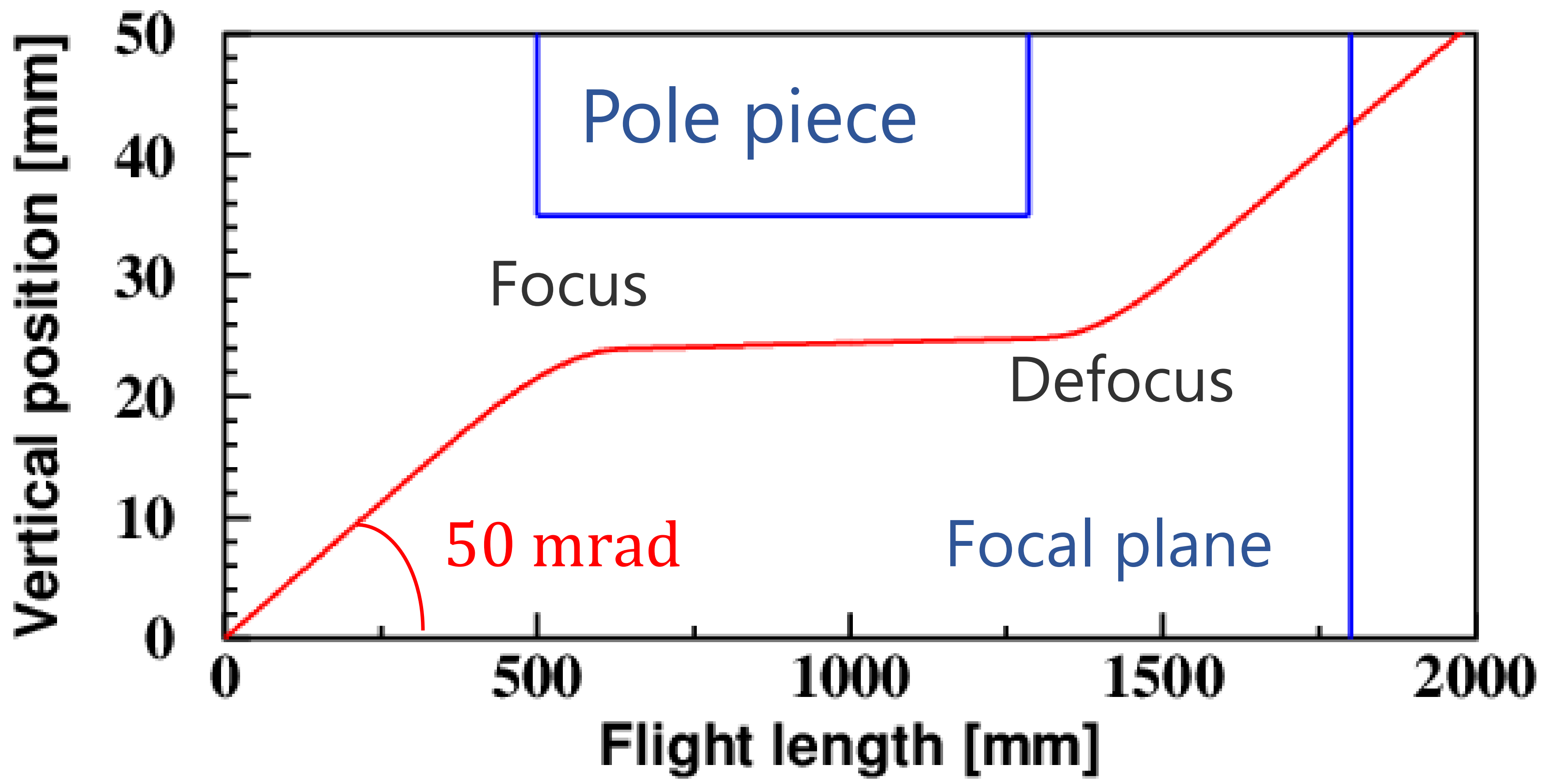


Spectrometer design

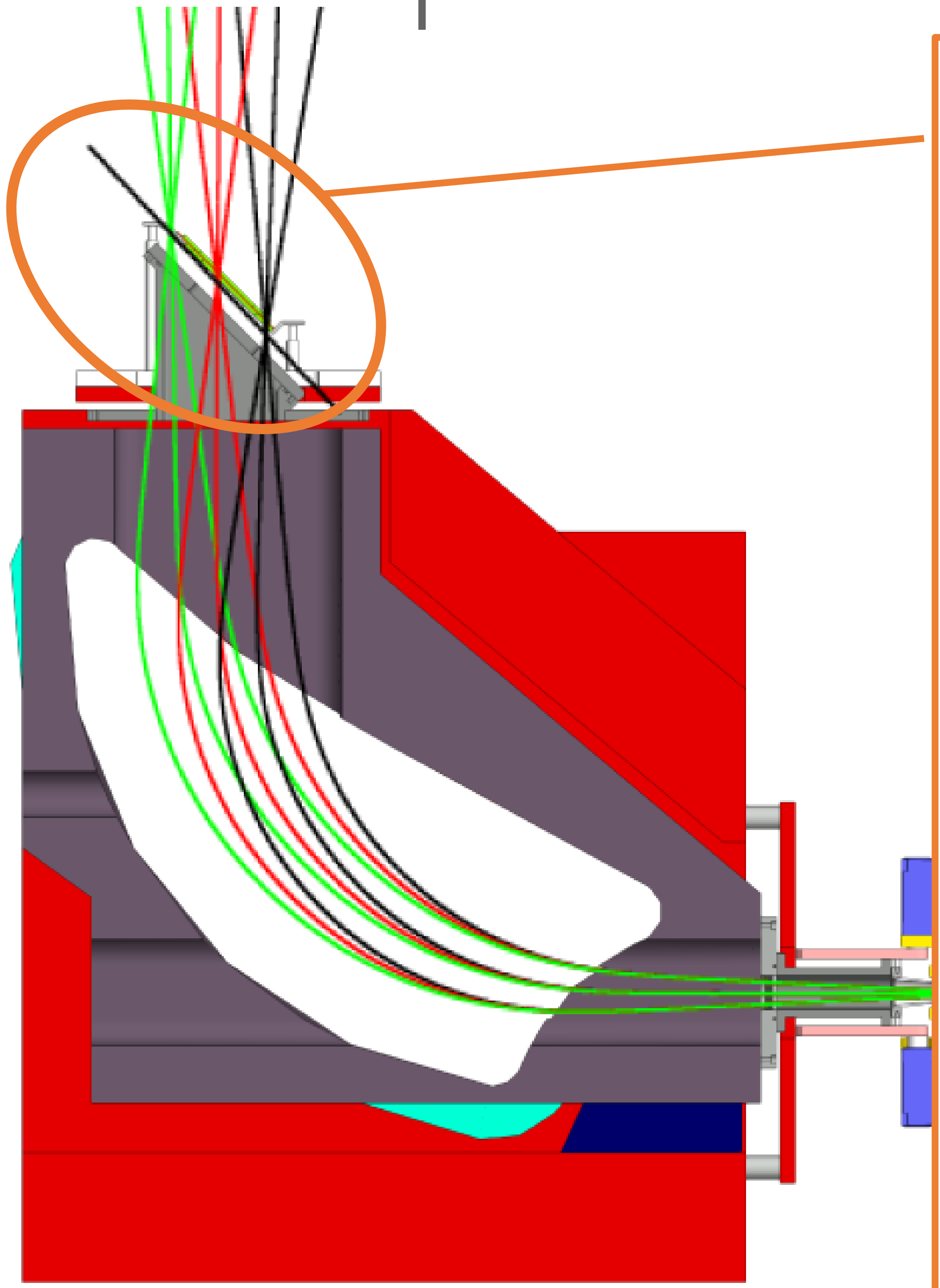


Horizontal trajectory

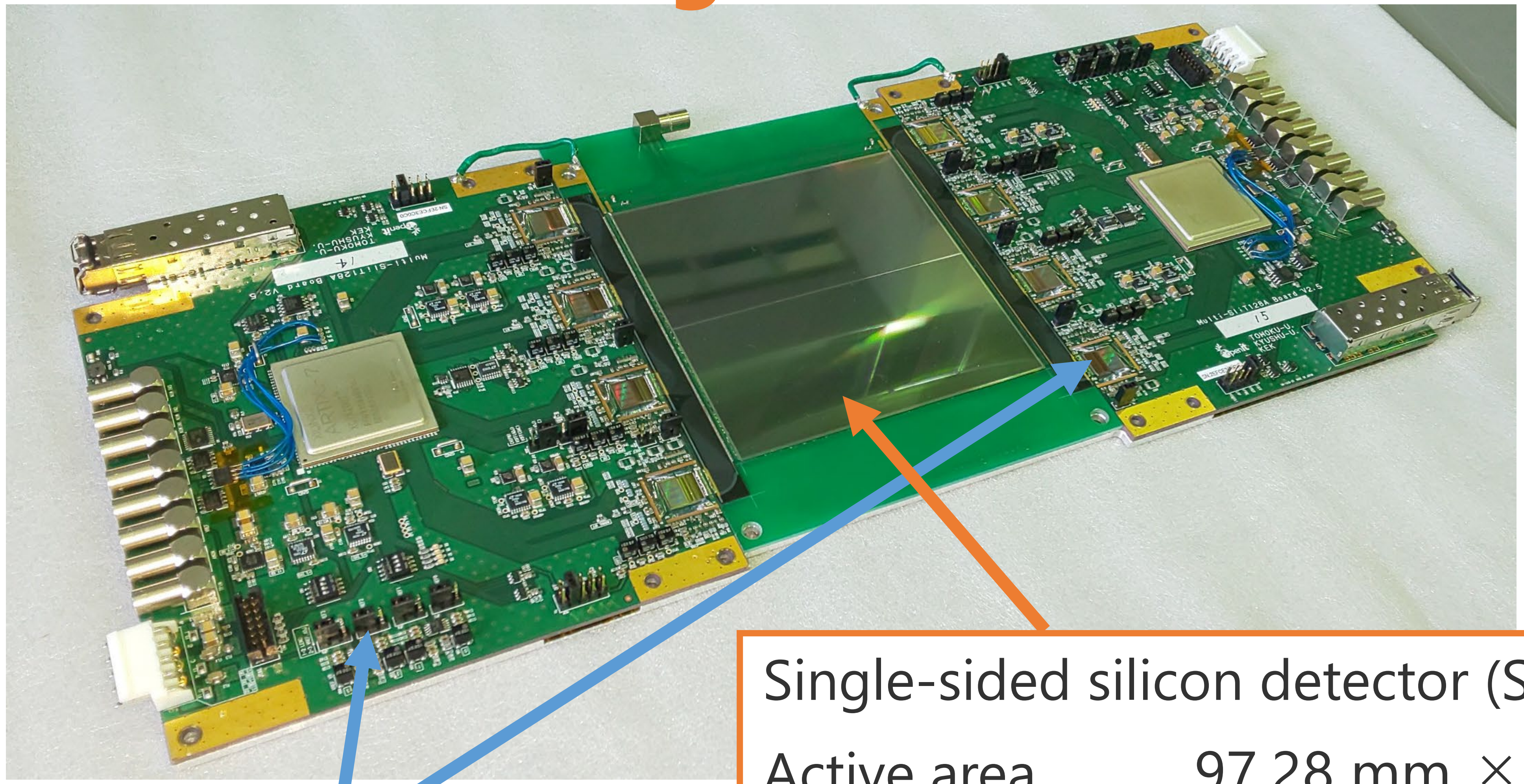
- The electrons are focused/defocused at the entrance/exit of the pole piece by the fringing field.
- This doubles the acceptance.



Focal plane detector



J-PARC muon g-2/EDM Test module2



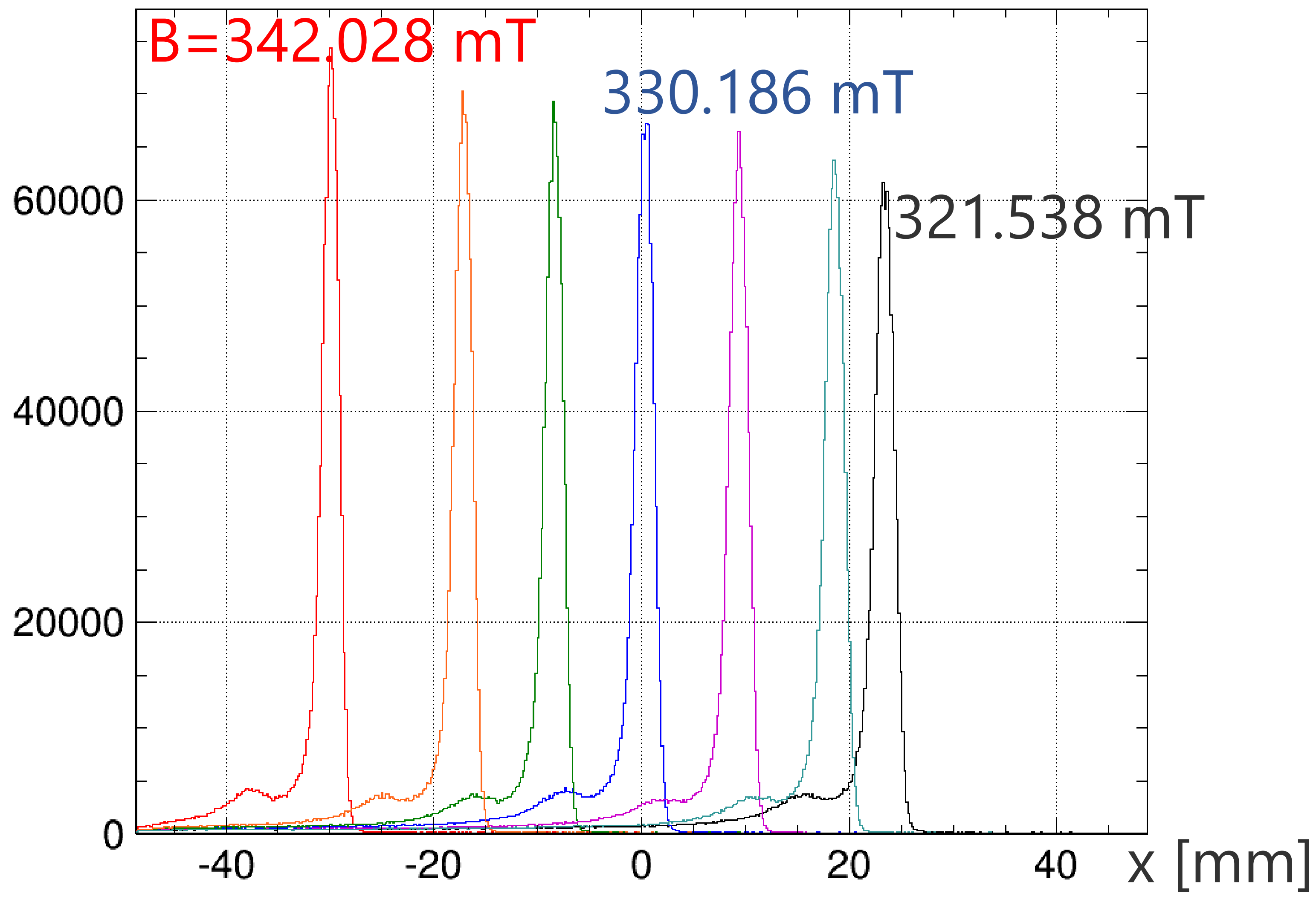
Readout boards
"Multi-Slit128A board"
Four ASICs "Slit128A"
(128 ch/chip)

Single-sided silicon detector (SSSD)

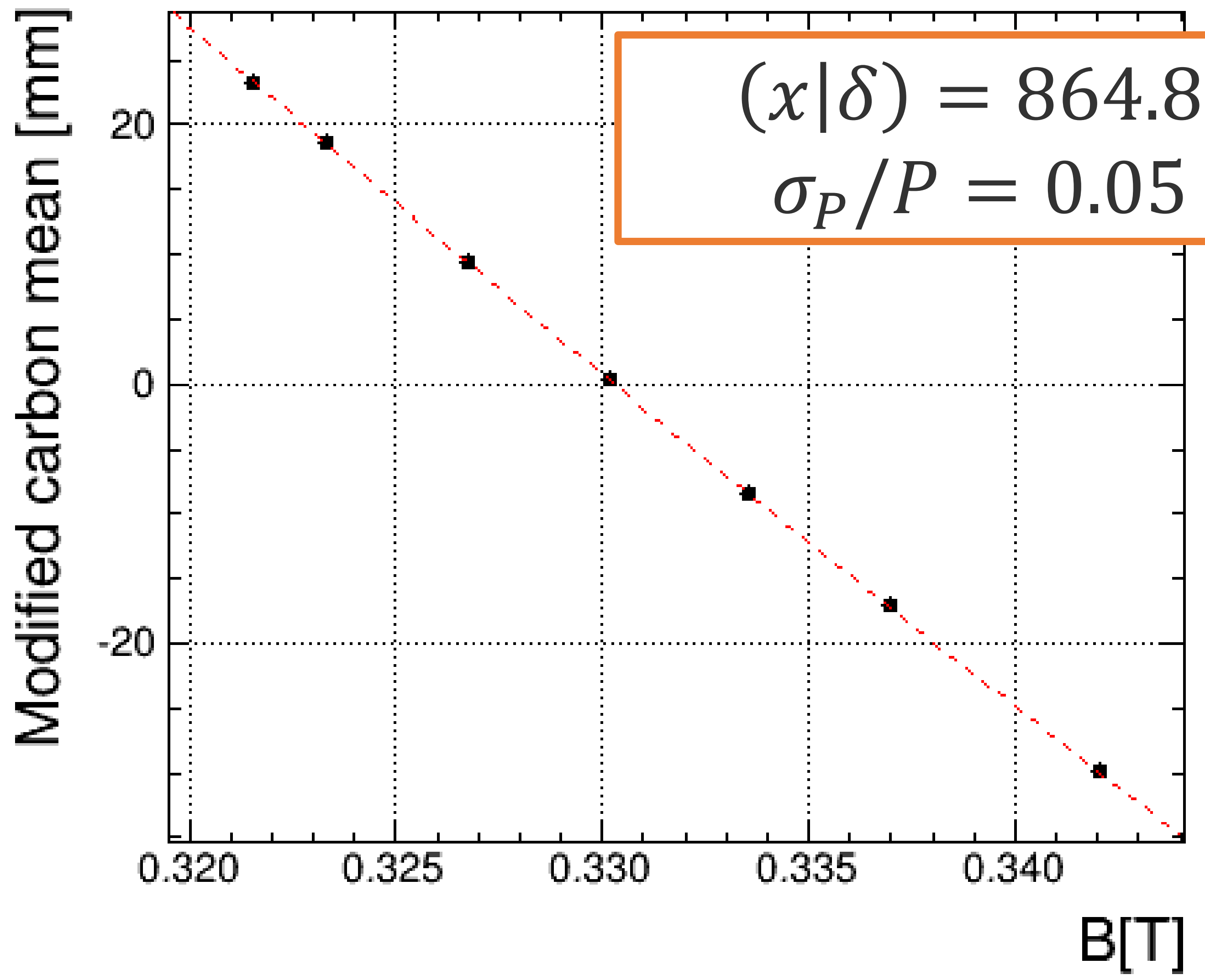
Active area	97.28 mm × 97.28 mm
Thickness	0.32 mm
Strip pitch	0.19 mm
Strip length	48.575 mm
No. of strips	512 ch × 2

Spectrometer optics : $(x|\delta)$

- Relation between (x,y) and (p, θ)
  - Momentum dispersion : $x = (x|\delta)\delta + \cdots$
  - We changed the magnetic field (B) of the spectrometer instead of the beam momentum.



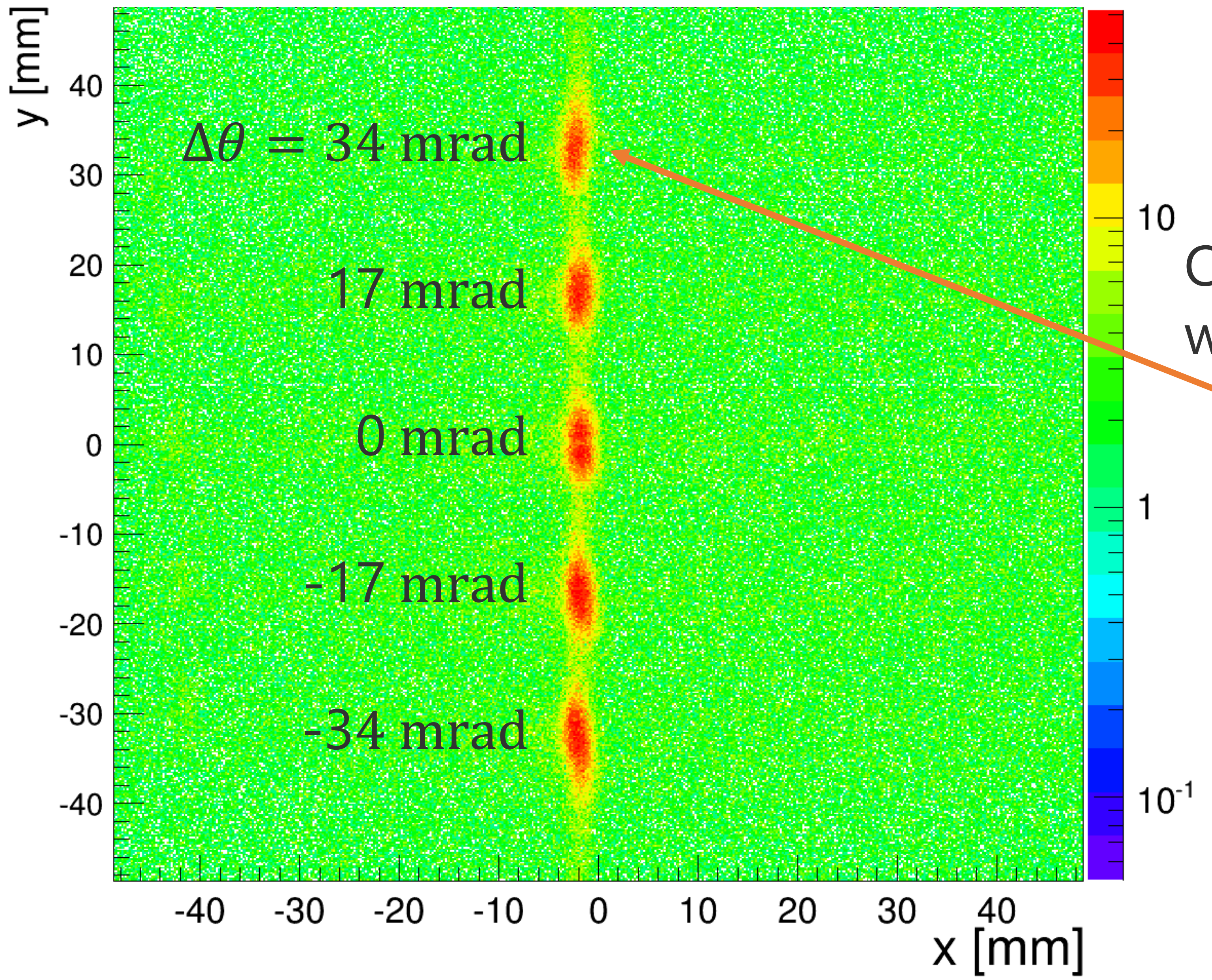
δ ~-0.05 δ = 0 δ ~0.05



$(x|\delta) = 864.8(3)$
$\sigma_P/P = 0.05$ %

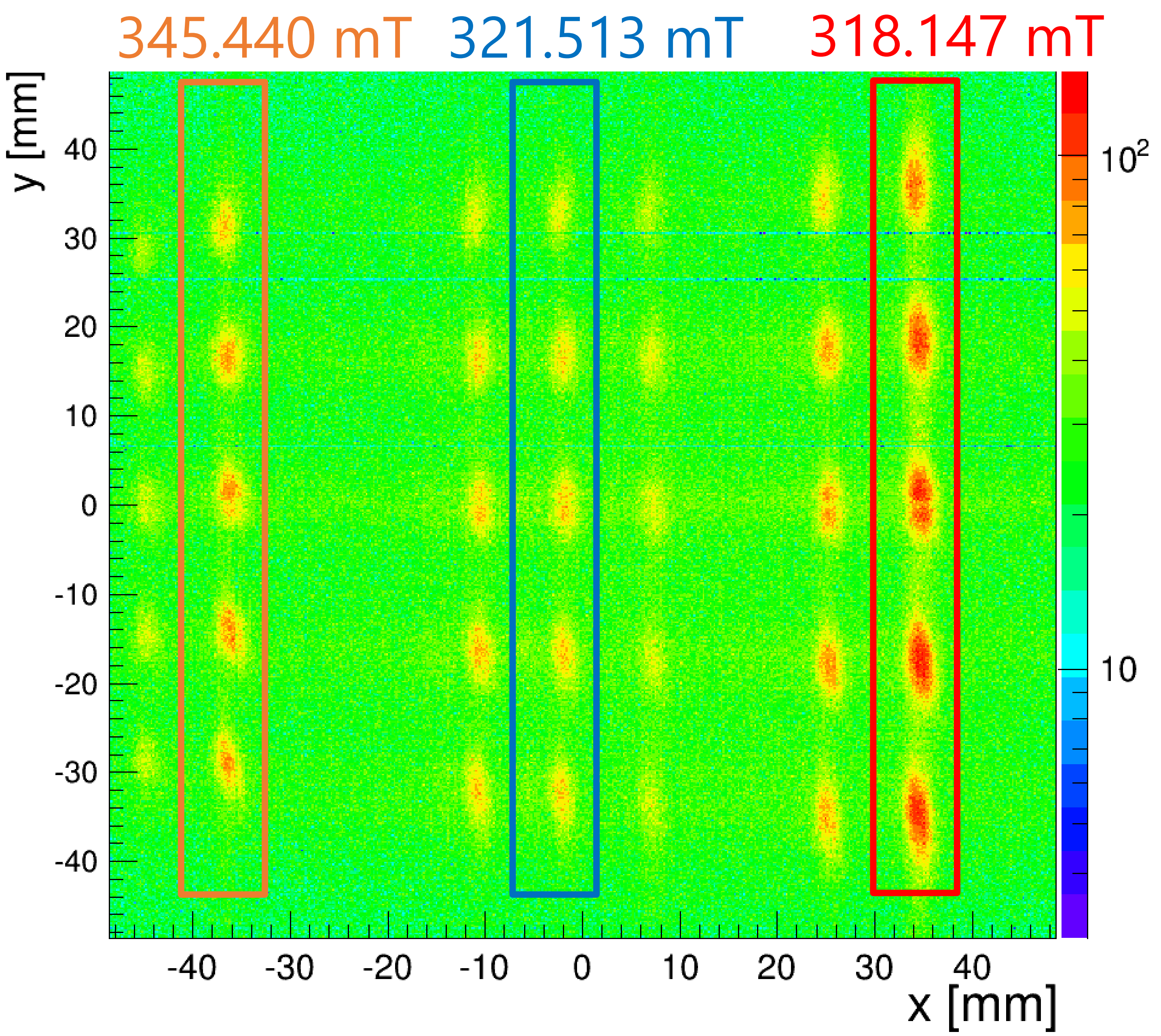
Spectrometer optics : $(y|\theta), (y|\theta\delta)$

- Relation between (x,y) and (p, θ)
  - Angle dispersion : $y = (y|\theta)\Delta\theta + (y|\theta\delta)\Delta\theta\delta + \cdots$



Overlaying data with different B

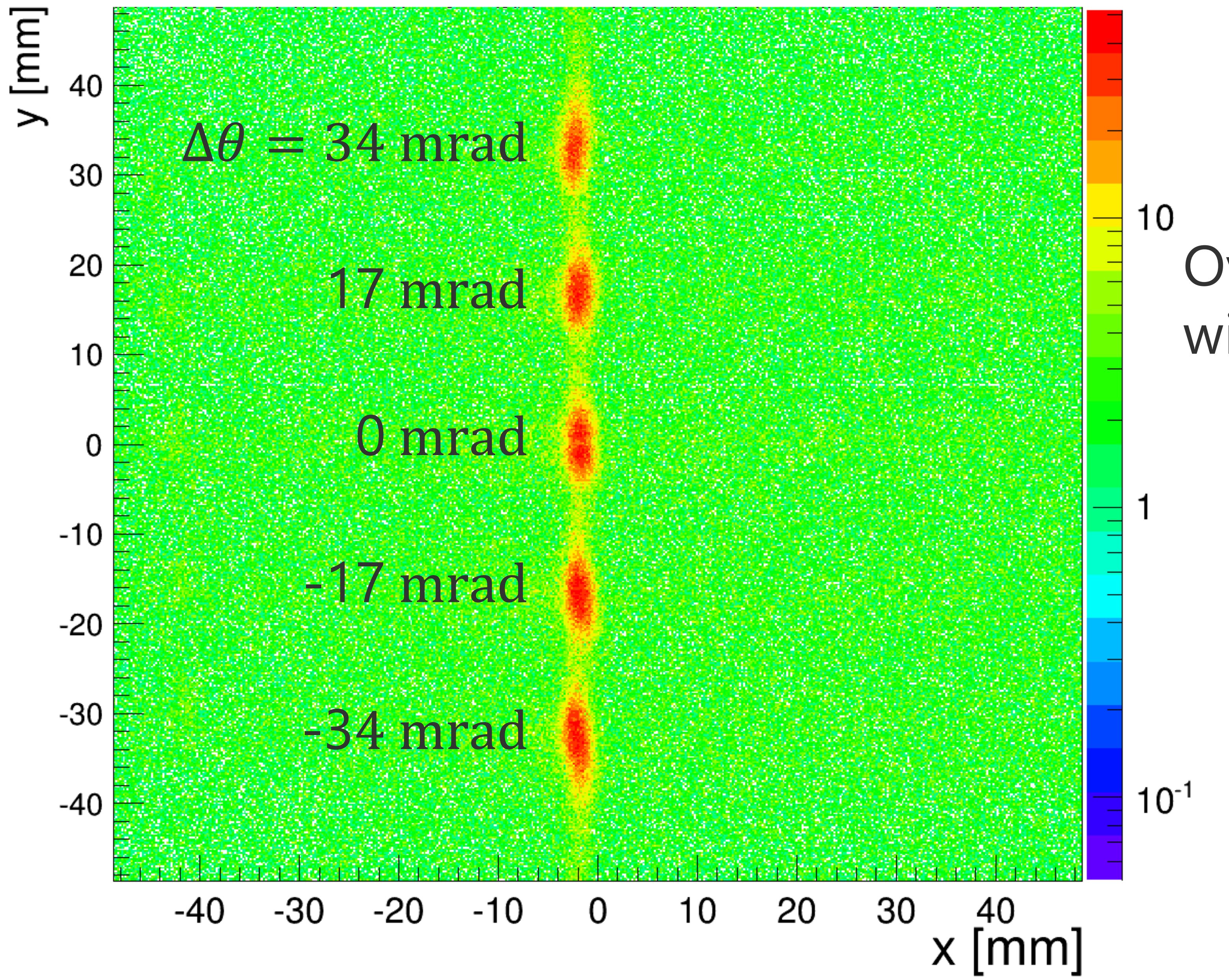
5×



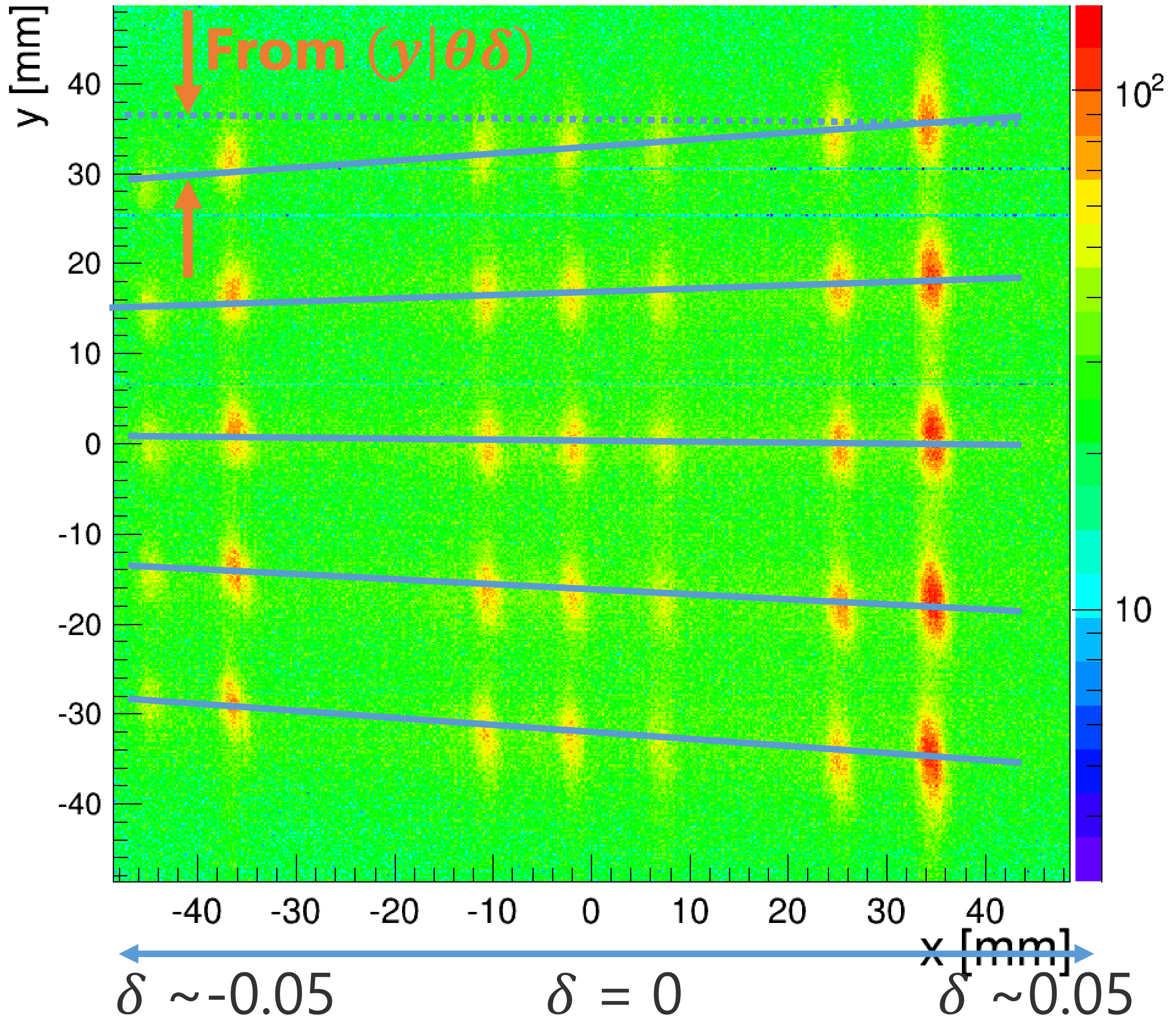
Spectrometer optics : $(y|\theta), (y|\theta\delta)$

- Relation between (x,y) and (p, θ)
  - Angle dispersion : $y = (y|\theta)\Delta\theta + (y|\theta\delta)\Delta\theta\delta + \cdots$

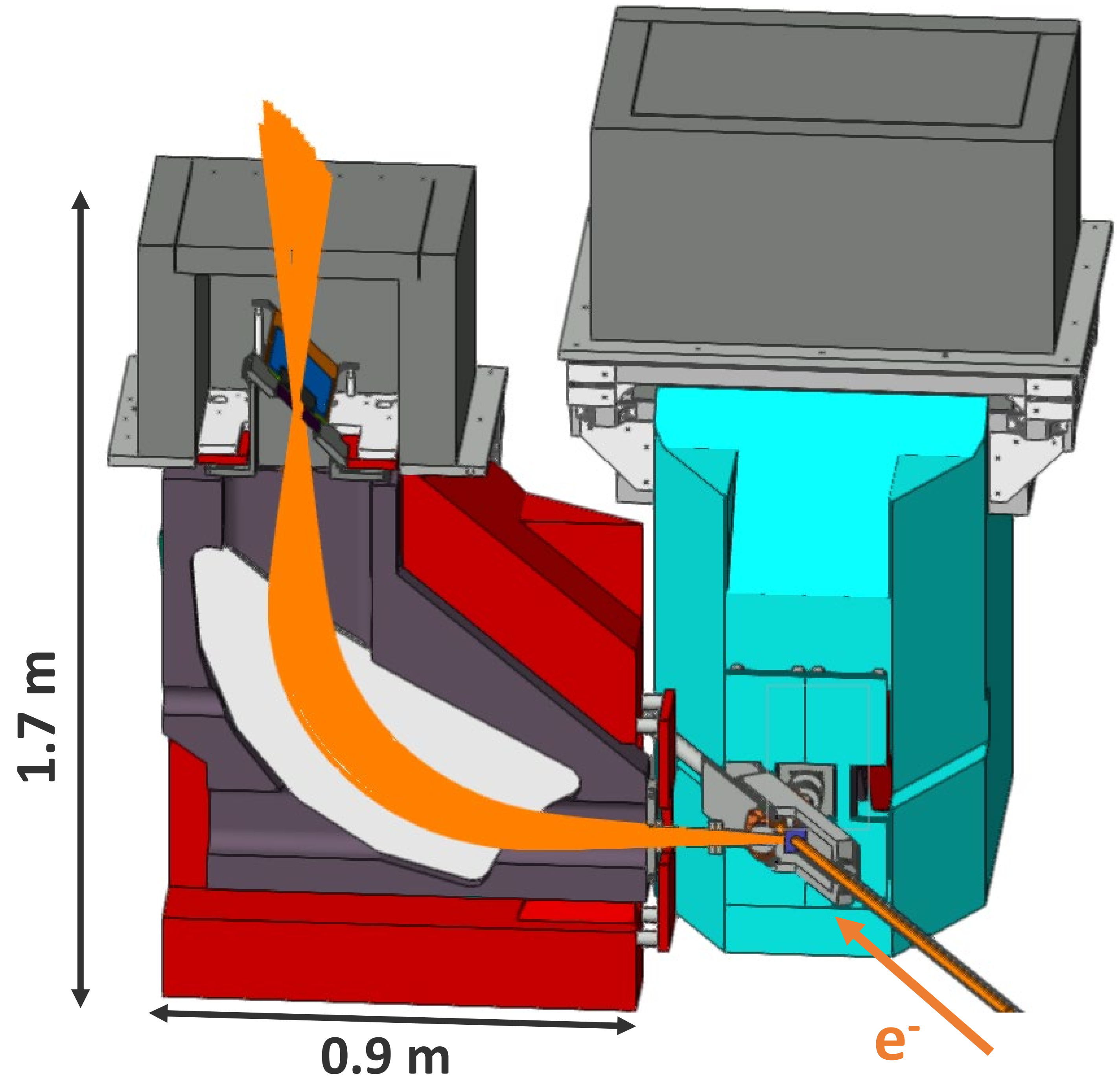
$(y|\theta) = 1.000(4)$
$(y|\theta\delta) = 2.01(14)$
$\sigma_\theta \leq 5$ mrad



Overlaying data with different B



Spectrometer optics : summary



radius	50 cm
bending angle	90°
B_{Max}	0.4 T @ 60 MeV
gap	70 mm
$(x\|\delta)$	864.8(3) mm
σ_p/p	5×10^{-4}
p bite	11 %
$(y\|\theta)$	$1.000(4)$
σ_θ	5 mrad
solid angle	10 mSr

Beam momentum determination

Unfortunately, we can't obtain the exact beam momentum from the accelerator setting.
We obtained it from the momentum ratio of the scattered electrons from H and C.

From kinematics,

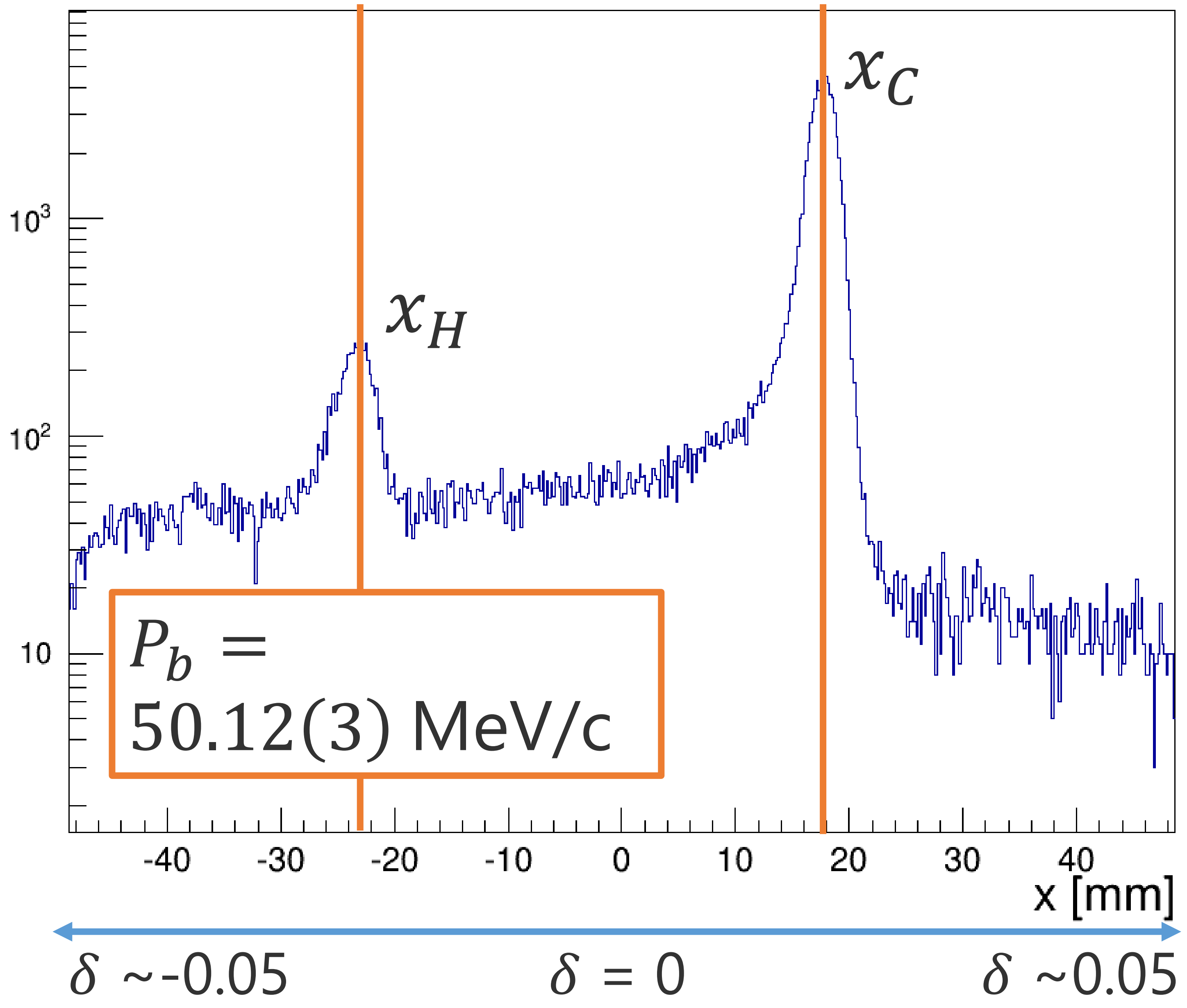
$$p_{H(C)} \sim \frac{\boldsymbol{P_b}}{1+\frac{2\boldsymbol{P_b}\sin^2\theta/2}{M_{H(C)}}} \Rightarrow E_b = \frac{\frac{P_C}{P_H}-1}{2\sin^2\theta/2\left(\frac{1}{M_H^2}+\frac{1}{M_C^2}\right)}$$

$P_{H(C)}$	Electron momentum scattered by H(C)
P_b	Beam momentum
$M_{H(C)}$	H (or C) mass

From experiment,

$$P_{H(C)} = P_0(1+\delta_{H(C)})$$
$$\delta_{H(C)} \sim x_{H(C)}/(x|\delta) \Rightarrow \frac{P_C}{P_H} = \frac{1+\delta_C}{1+\delta_H}$$

P_0 : Center momentum
$(x|\delta)$: Momentum dispersion



Physics projects in RARIS

Four projects by low-energy electron scattering are ongoing.

- ULQ2 by Legris Clement, this session.
  - Proton radius measurement
- ULQ2-D by Taiga Goke, this session.
  - Deuteron radius measurement
- LEEP by Rika Danjo, poster session, Toshio Suzuki, Tuesday morning session.
  - Technical development of neutron distribution radius measurement with low-energy electron scattering off ^{208}Pb
- 2^+ (~2.7 MeV) state search of ^{154}Sm by Kengo Hotta, poster session. by Takaharu Otsuka, yesterday.
  - Reveal triaxial asymmetry of nuclei.

Summary

- A low-energy electron scattering facility has been developed at RARiS, Tohoku University.
- The beam energy region is very suitable for measuring 2^{nd} and 4^{th} moments of the nuclei.
- Twin spectrometers are developed the low energy electron scattering.
- Four physics projects are ongoing.
  - Proton charge radius measurement
  - Deuteron charge radius measurement
  - Neutron distribution radius measurement for ^{208}Pb
  - 2^{+} state search of ^{154}Sm