Low-Energy Electron Scattering Facilities in Japan

SCRIT : exotic nuclei

ULQ2 : proton (+ stable nuclei)

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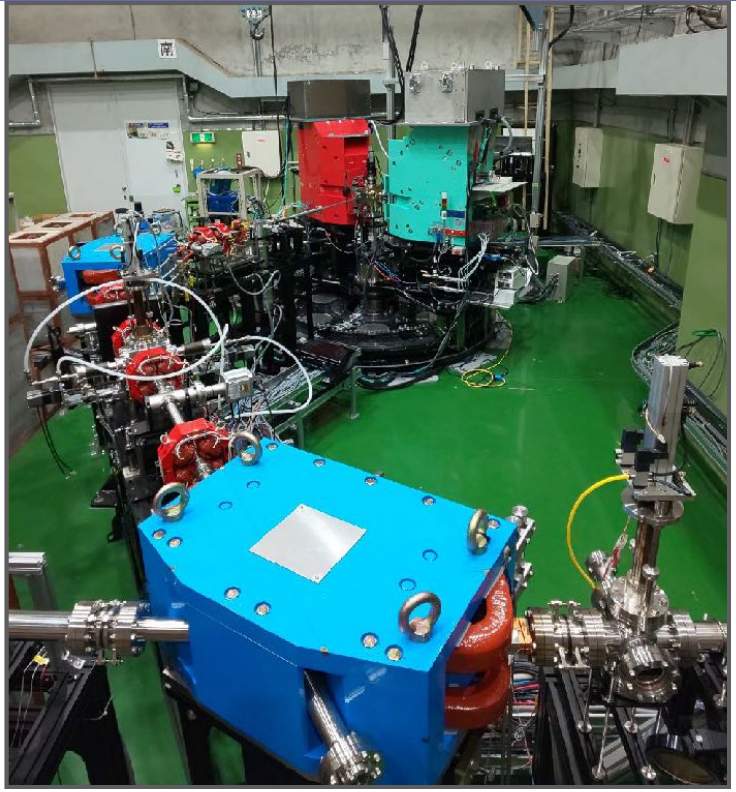
Low-energy electron-scattering facilities

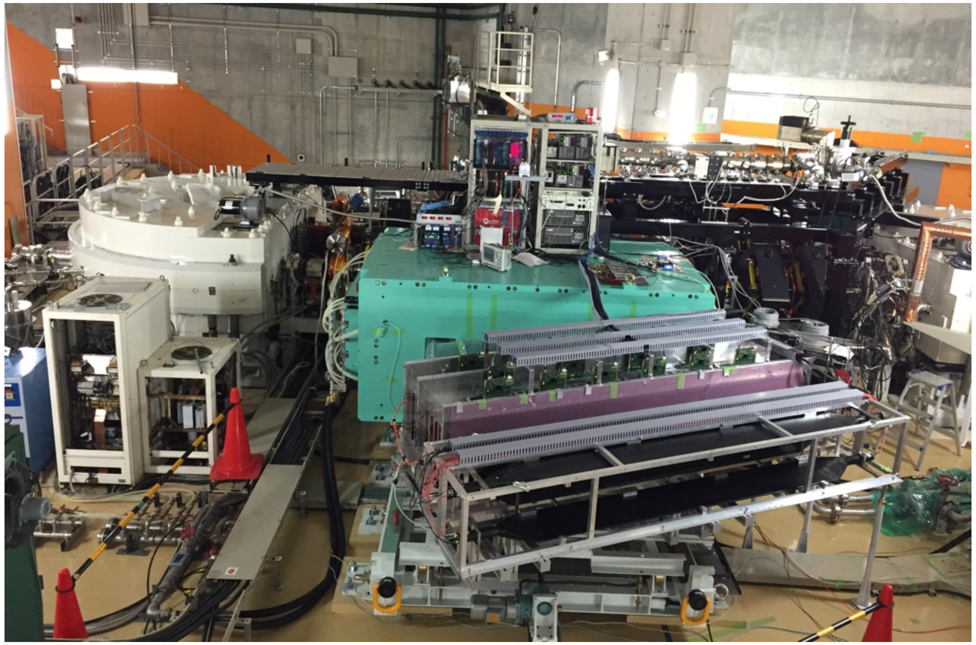
ULQ2 @Tohoku



ULQ2 : Ultra-Low Q2
Proton Charge Radius

Ee = 10 - 60 MeV
θ = 30 - 150 deg.
q = 5 - 116 MeV/c
Twin spectrometers

SCRIT @ RIKEN/RIBF



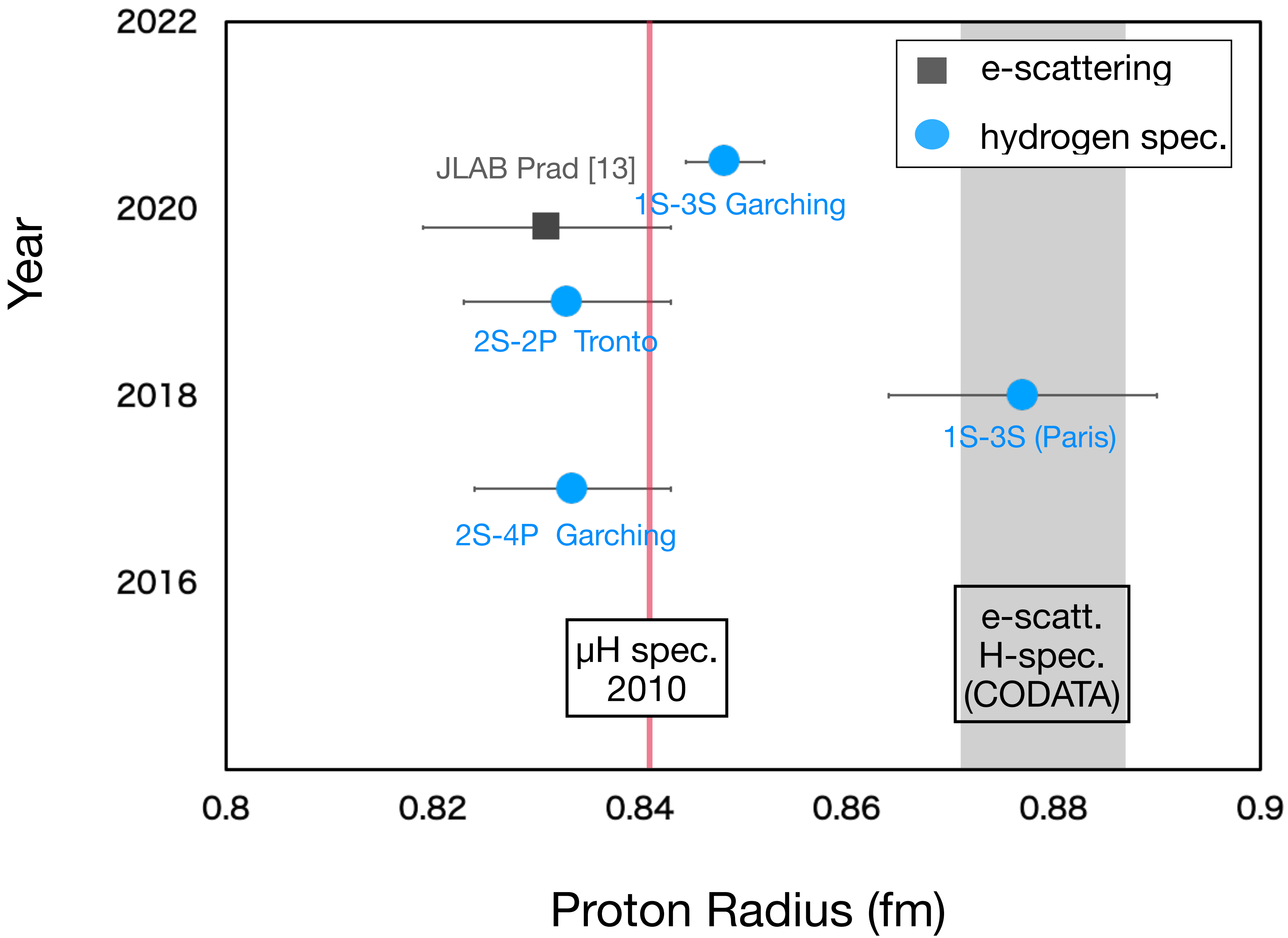
SCRIT : Self-Confining RI-Ion Target
e-scattering off exotic nuclei

Ee = 150 - 300 MeV
θ = 30 - 60 deg.
q = 78 - 300 MeV/c

ULQ2 @Tohoku

(Ultra-Low Q^2)

Proton Charge Radius as of today

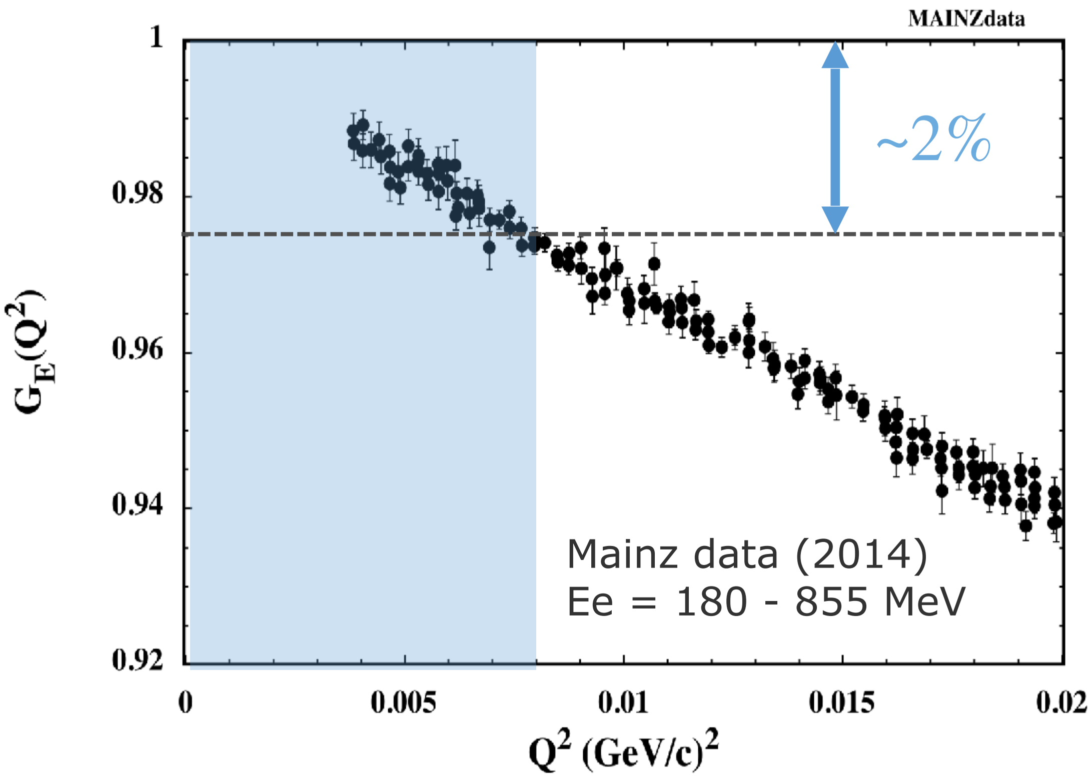


The ULQ2 project at Tohoku

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

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

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



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

② e+p absolute cross section with $\sim 10^{-3}$ accuracy.

→ relative measurement of e+C and e+H with CH_2 target

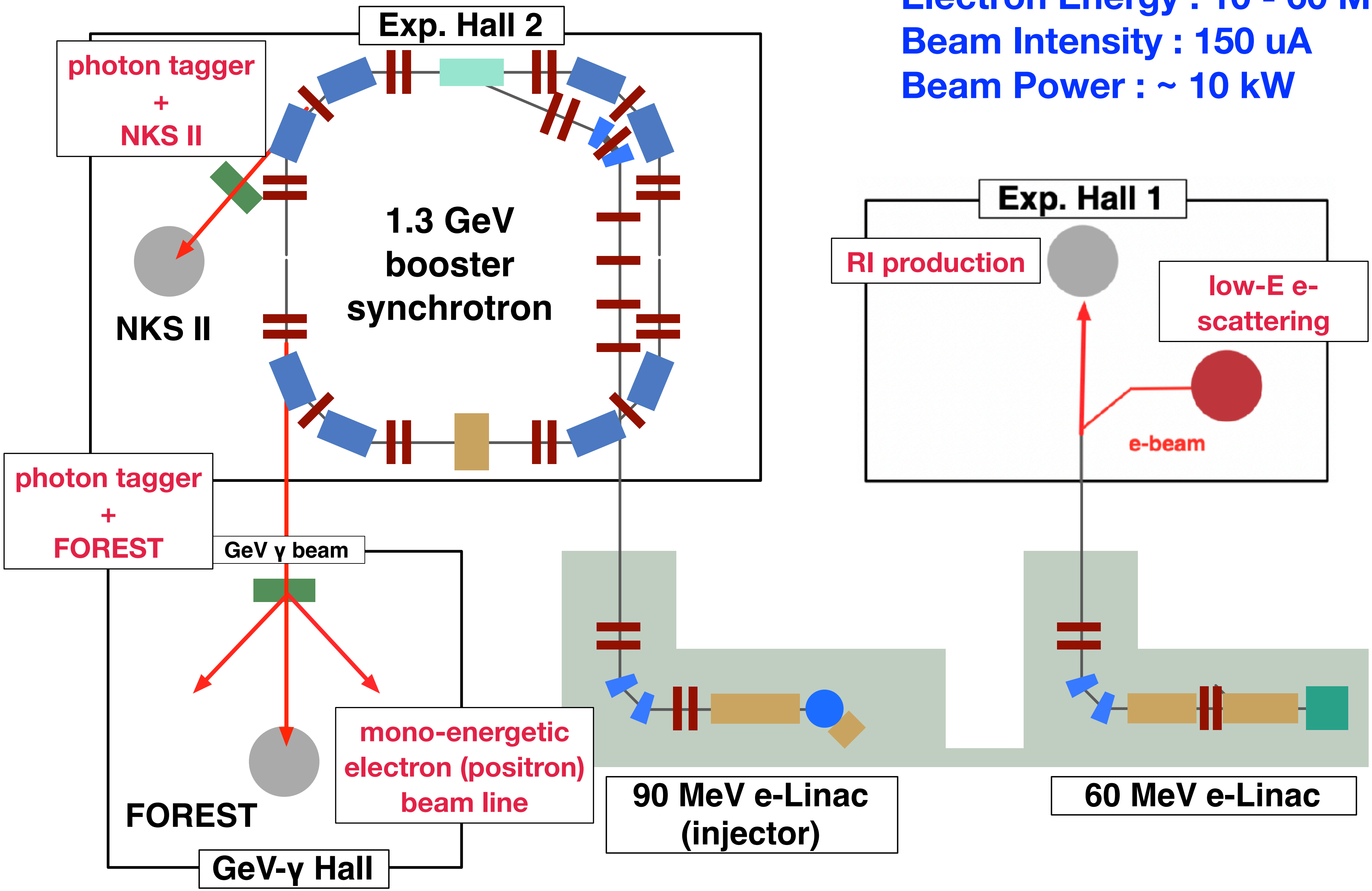
③ Rosenbluth separated $G_E(Q^2)$ and $G_M(Q^2)$.

$\Rightarrow$ $Ee = 10 - 60$ MeV, $\theta = 30 - 150°$

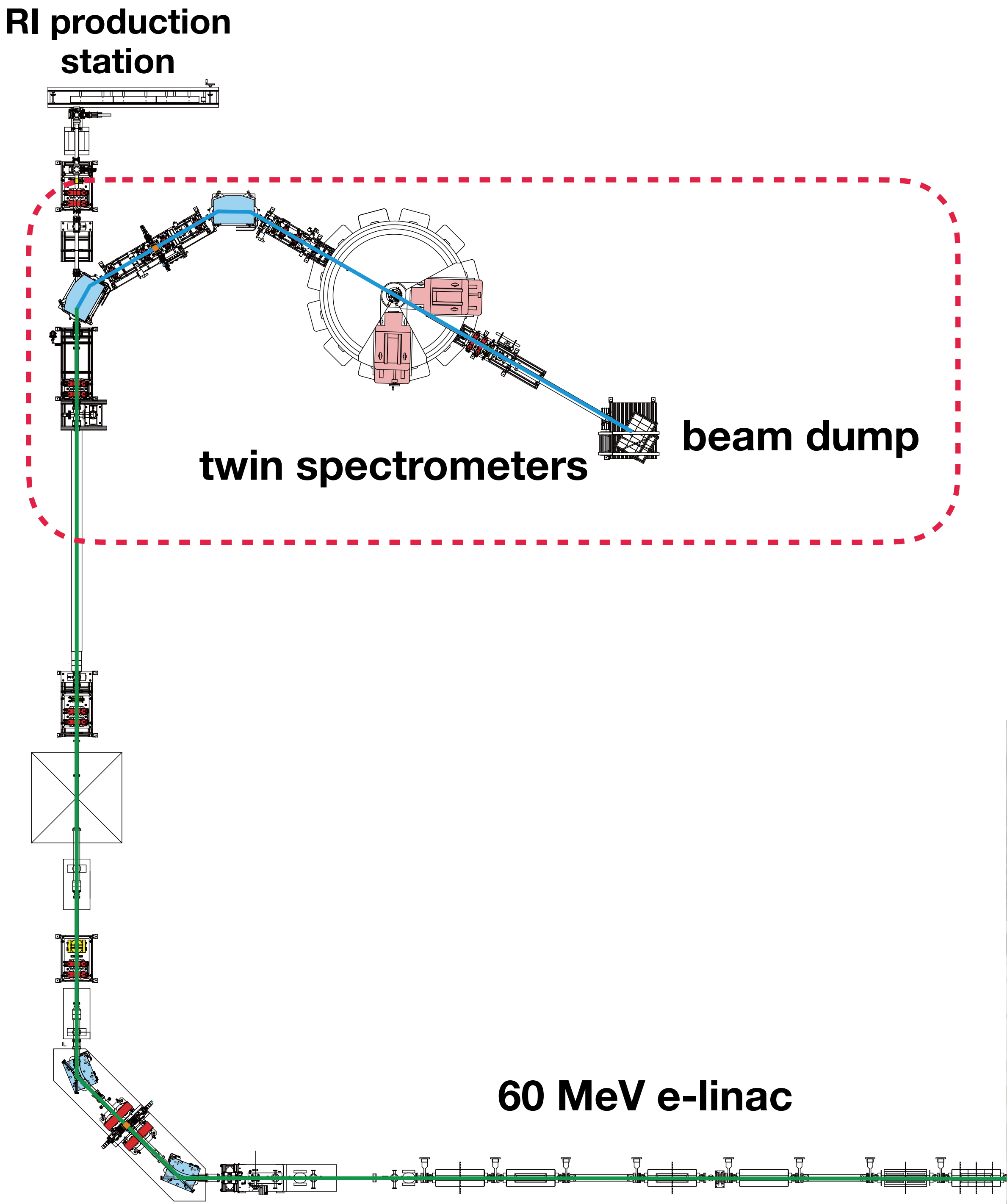

電子光理学研究センター
三神峯キャンパス

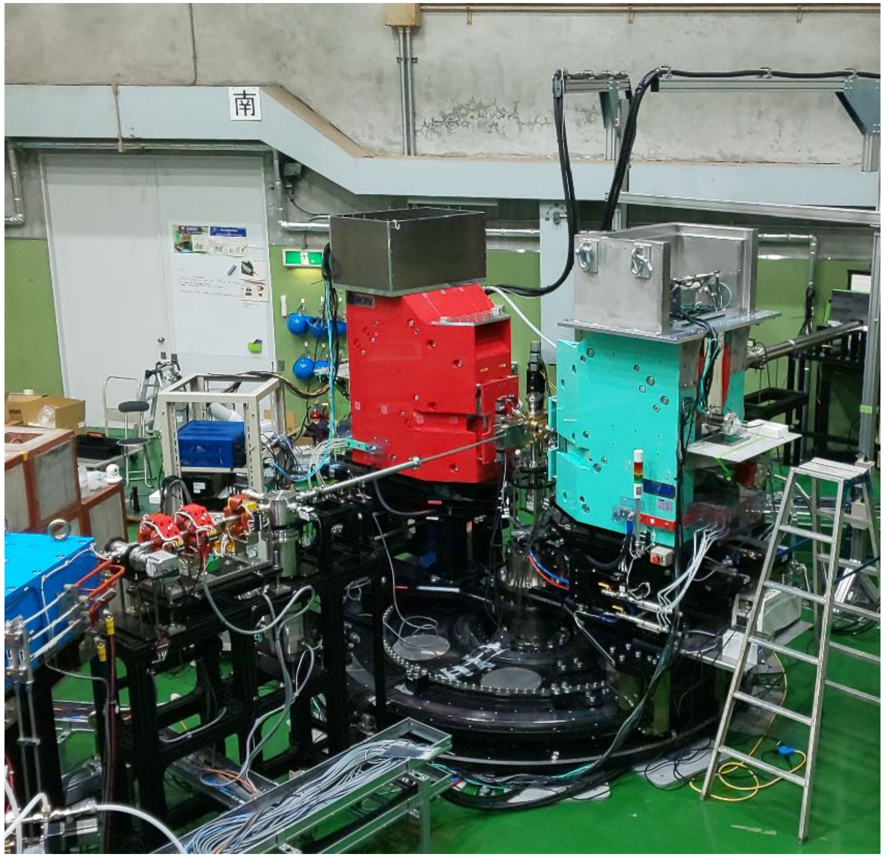
Tagged Photon Energy: 0.8 – 1.27 GeV
Intensity: ~ 2 MHz

Electron Energy : 10 - 60 MeV
Beam Intensity : 150 uA
Beam Power : ~ 10 kW

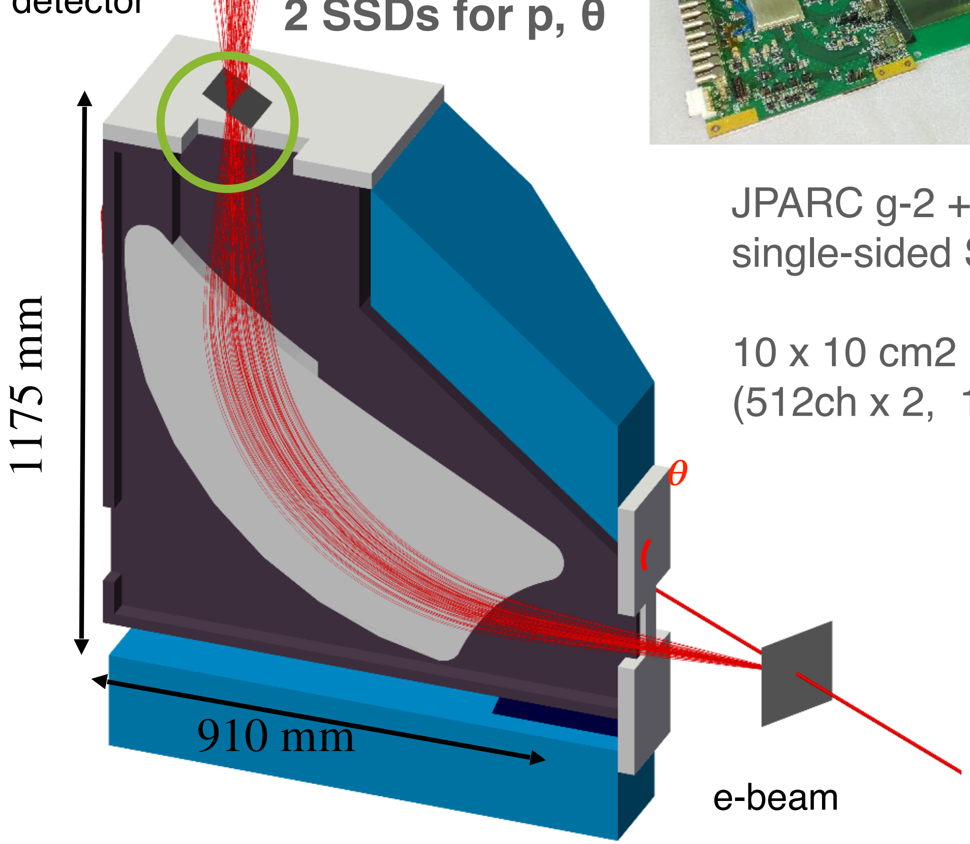


ULQ2 setup at ELPH, Tohoku Univ.



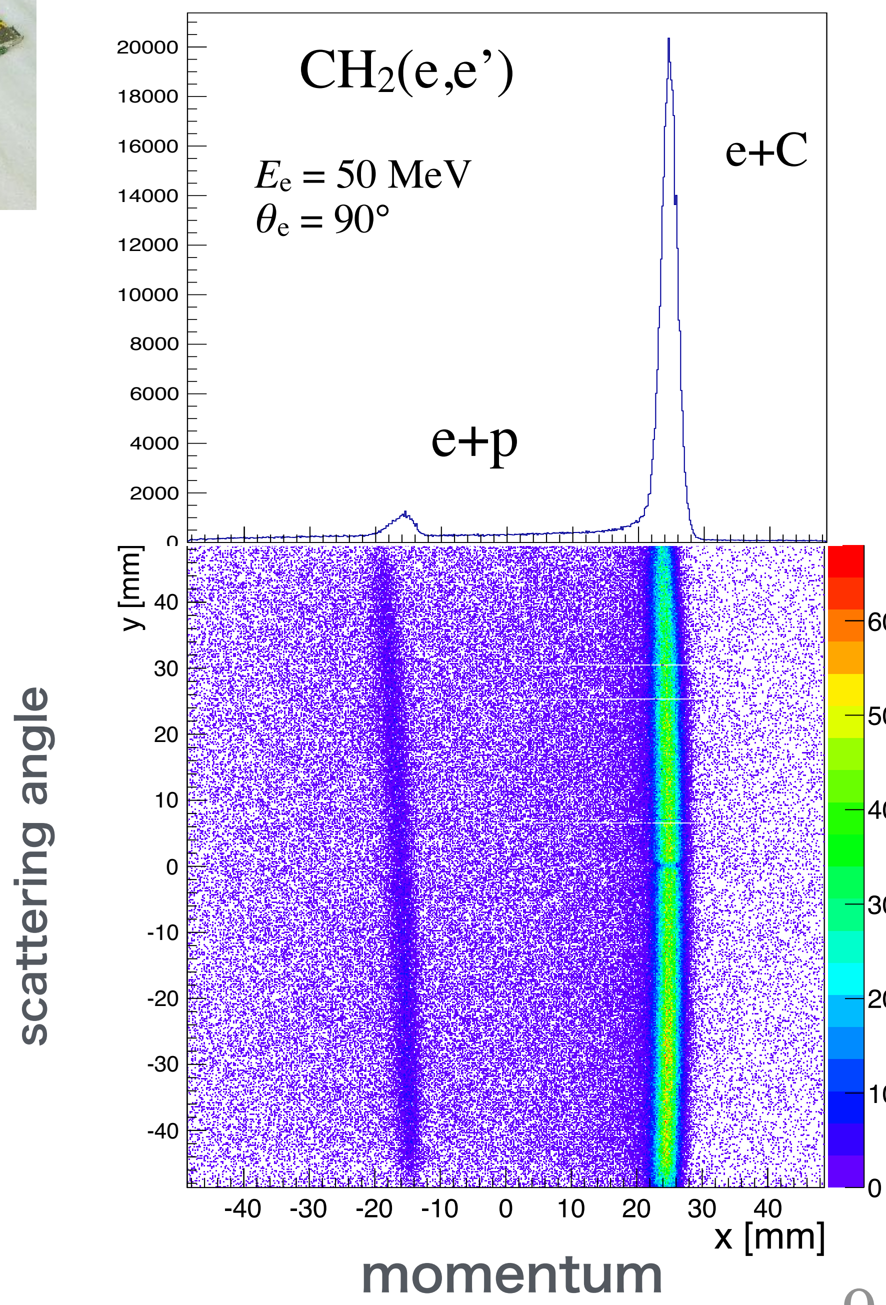


Twin spectrometers



JPARC g-2 + ULQ2
single-sided SSD

10 x 10 cm2
(512ch x 2, 190 um)

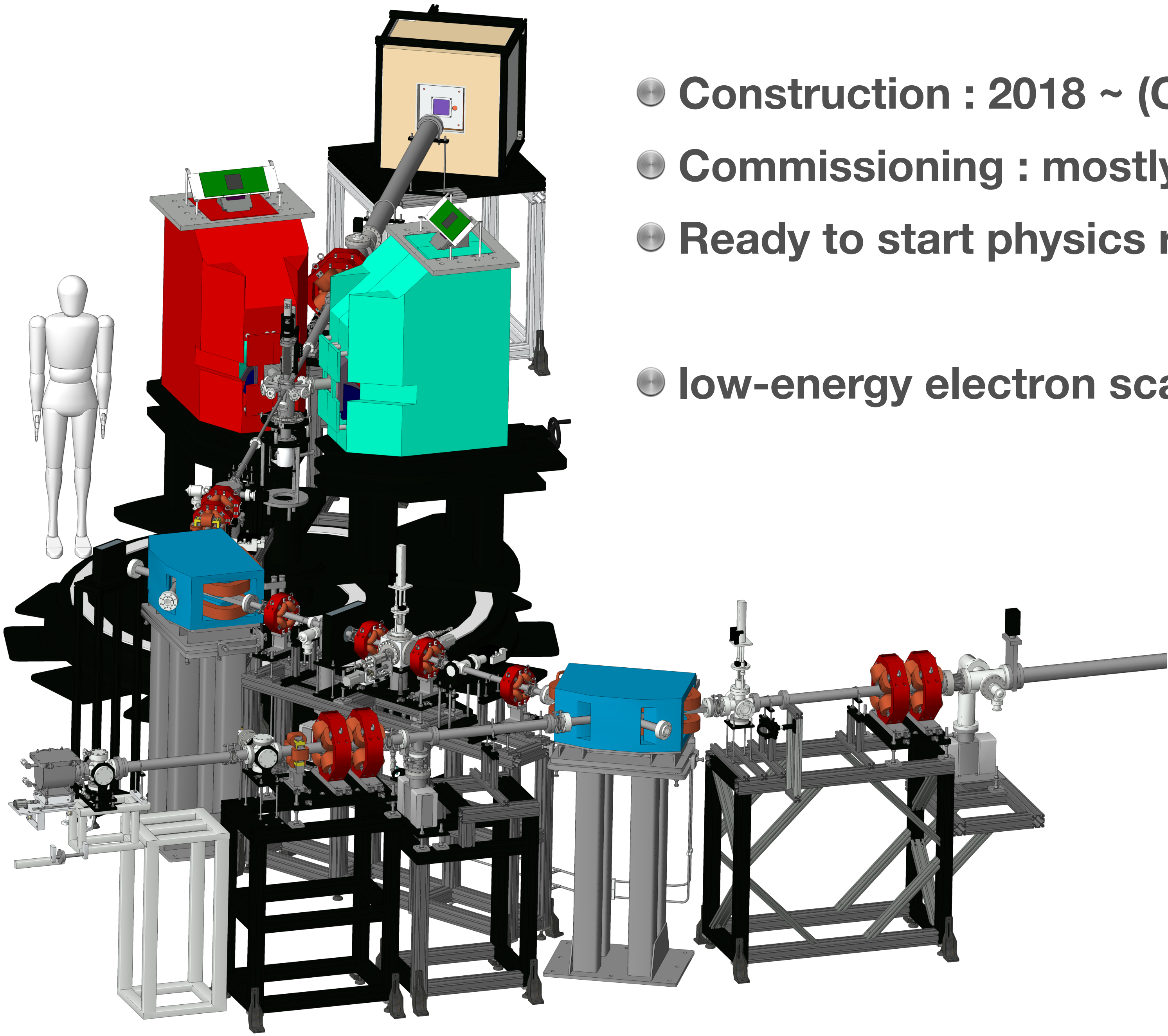


	Simulation	Measured
Dispersion (mm)	854.9	855.8 ± 1.1
Mom. resolution	5.1×10^{-4}	5.6×10^{-4}
Momentum bite	11%	
θ resolution	5 mad	
solid angle	5 mSr	

Twin spectrometers

$$\begin{cases} x_d = x_0 + (x_d|\delta)\delta + (x|\delta^2)\delta^2 + (x_d|\Delta\theta^2)[\Delta\theta - \theta_0]^2 + (x_d|x_b)x_b \\ y_d = [(y_d|\Delta\theta) + \delta(y_d|\delta\Delta\theta)]\Delta\theta + (y_d|y_b)y_b \end{cases}$$

Parameters	Spectrometer 1	Spectrometer 2
x_0 [mm]	4.9	-1.8
$(x_d\|\delta)$ [mm]	866.1(7)	862.4(7)
$(x_d^2\|\delta)$ [mm]	-174(26)	-164(26)
$(x_d\|\Delta\theta^2)$ [10^{-4} mm/mrad^2]	-4.1(2)	-3.6(2)
θ_0 [mrad]	-2.9(5)	6.8(6)
$(y_d\|\Delta\theta)$ [mm/mrad]	0.999(4)	0.997(3)
$(y_d\|\delta\Delta\theta)$ [mm/mrad]	2.01(14)	1.92(11)
$(x_d\|x_b)$, $(y_d\|y_b)$ [mm/mm]	~ 0.5 , 1.8	



- Construction : 2018 ~ (Corona + earthquake)
- Commissioning : mostly completed.
- Ready to start physics run from this year

- low-energy electron scattering for ^{208}Pb etc..

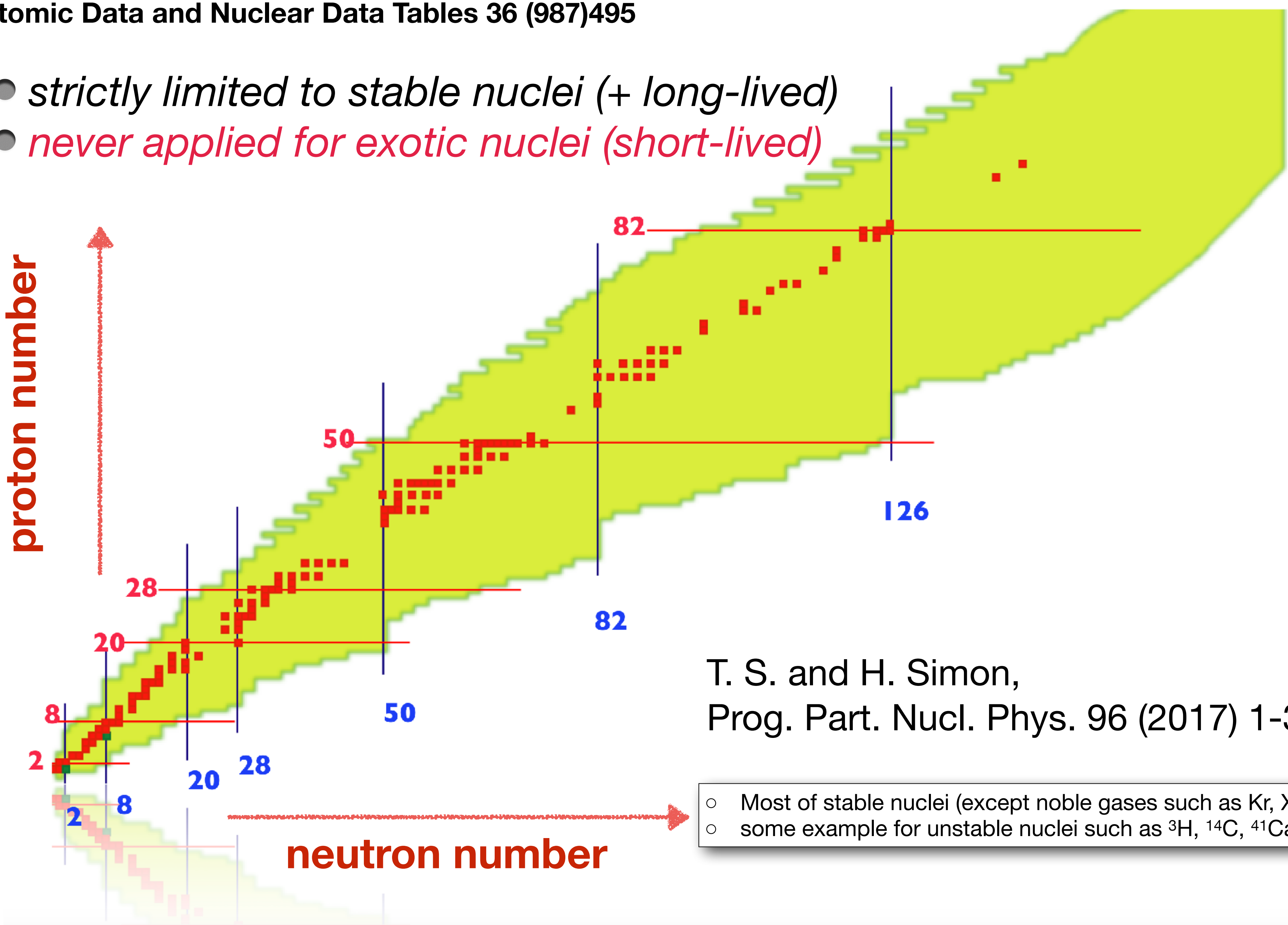
SCRIT @ RIKEN/RIBF

(Self-Confining RI Ion Target)

Nuclei ever studied by electron scattering

H.deVries, C. deJager and C. deVries
Atomic Data and Nuclear Data Tables 36 (987)495

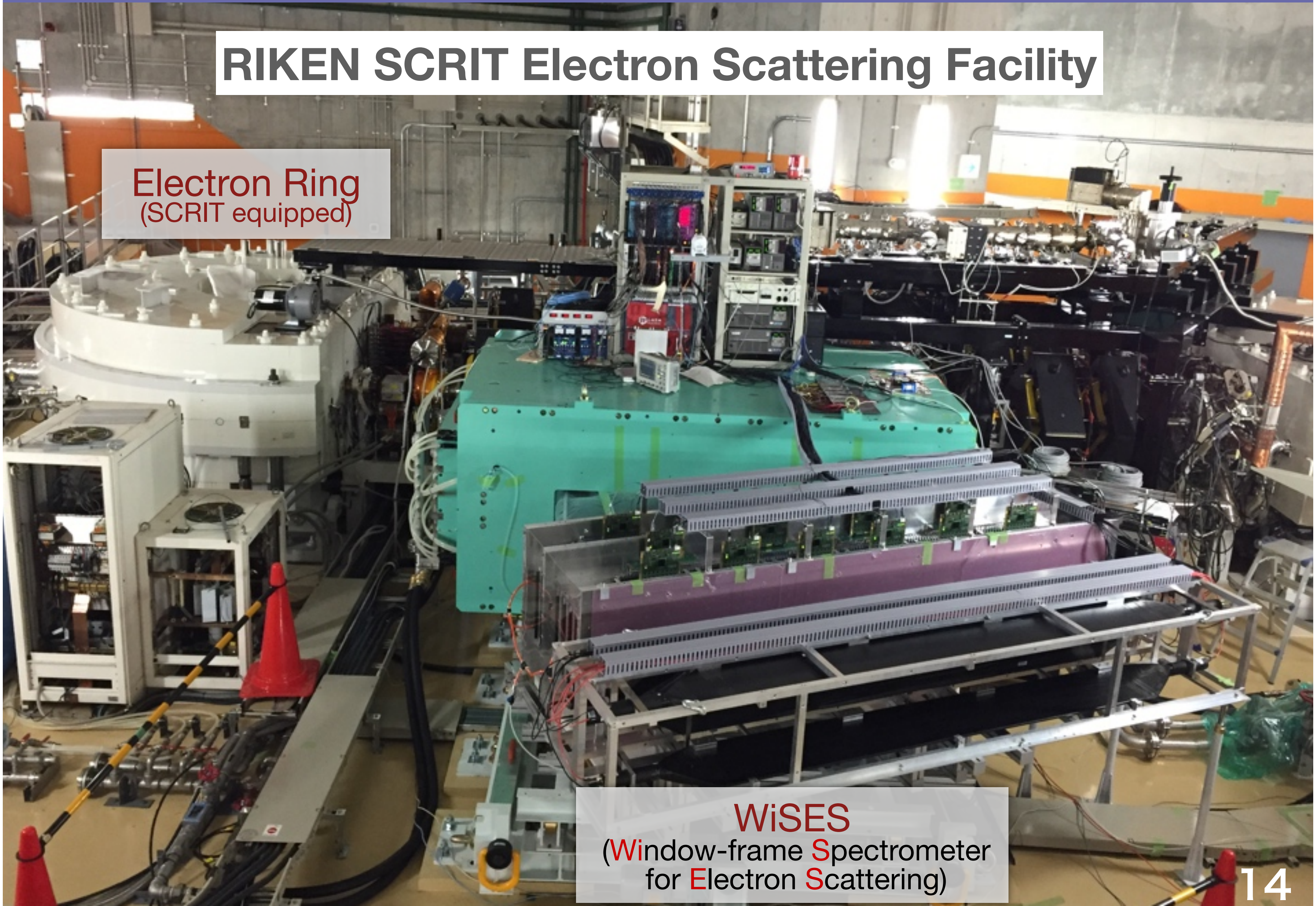
- *strictly limited to stable nuclei (+ long-lived)*
- *never applied for exotic nuclei (short-lived)*



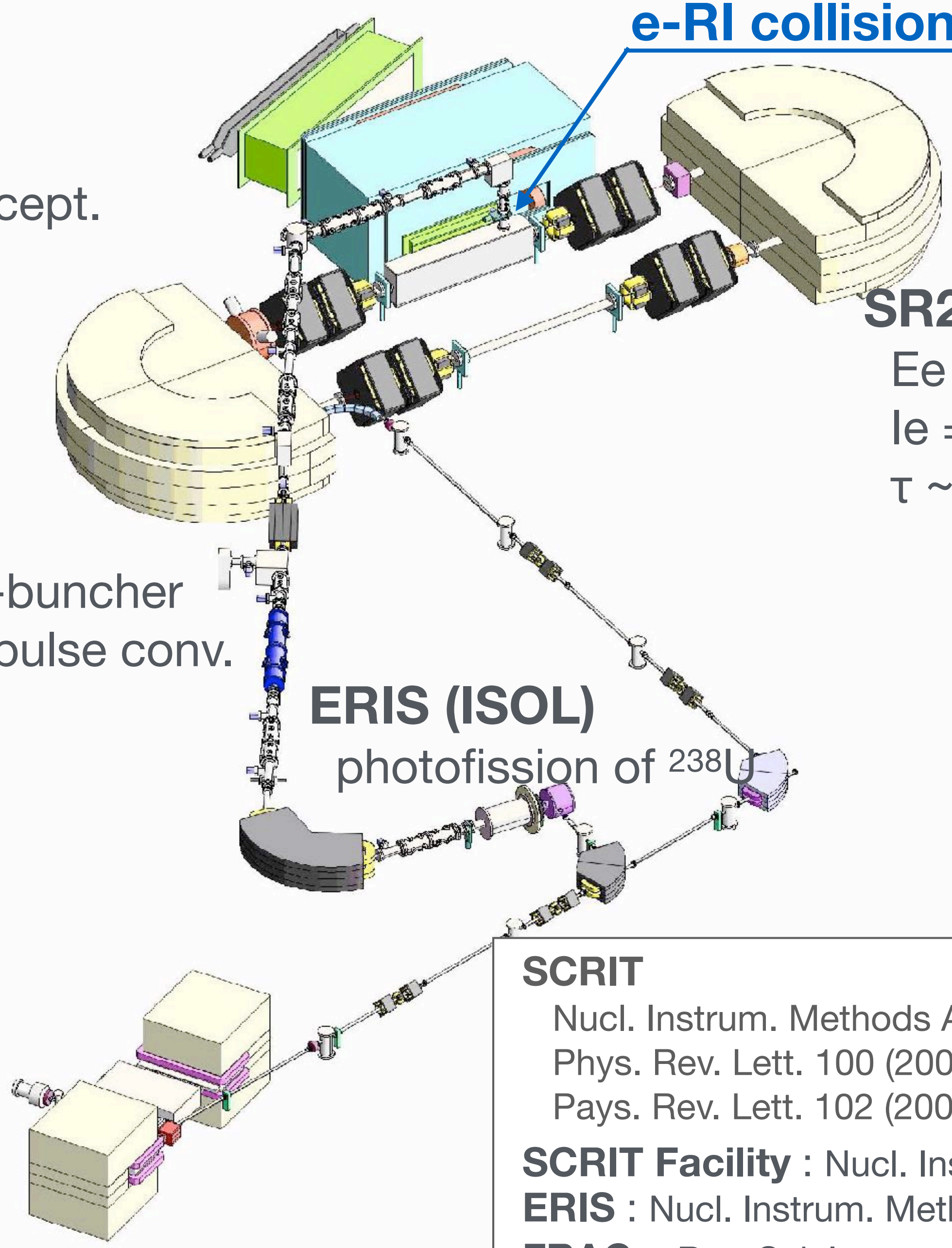
T. S. and H. Simon,
Prog. Part. Nucl. Phys. 96 (2017) 1-31.

- Most of stable nuclei (except noble gases such as Kr, Xe)
- some example for unstable nuclei such as ^{3}H, ^{14}C, ^{41}Ca etc...

world’s first e-facility for exotic nuclei



RIKEN SCRIT Electron Scattering Facility



WiSES spectrometer

ΔΩ ~ 90 mSr
θ = 30 - 60°
Δp/p ~ 10^{-3}
long target accept.

e-RI collisions

SR2 storage ring

Ee =150-700 MeV
Ie = 300 mA
τ ~ 2 hours

FRAC

cooler-buncher
dc-to-pulse conv.

ERIS (ISOL)

photofission of ^{238}U

Injector + ISOL driver

150 MeV Microtron

SCRIT

Nucl. Instrum. Methods A532 (2004) 216.
Phys. Rev. Lett. 100 (2008) 164801.
Pays. Rev. Lett. 102 (2009) 102501.

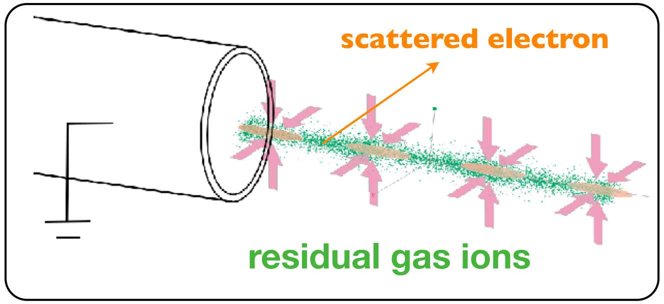
SCRIT Facility : Nucl. Instrum. Method B317 (2013) 668.
ERIS : Nucl. Instrum. Method B317 (2013) 357.
FRAC : Rev. Sci. Instrum. 89 (2018) 095107.

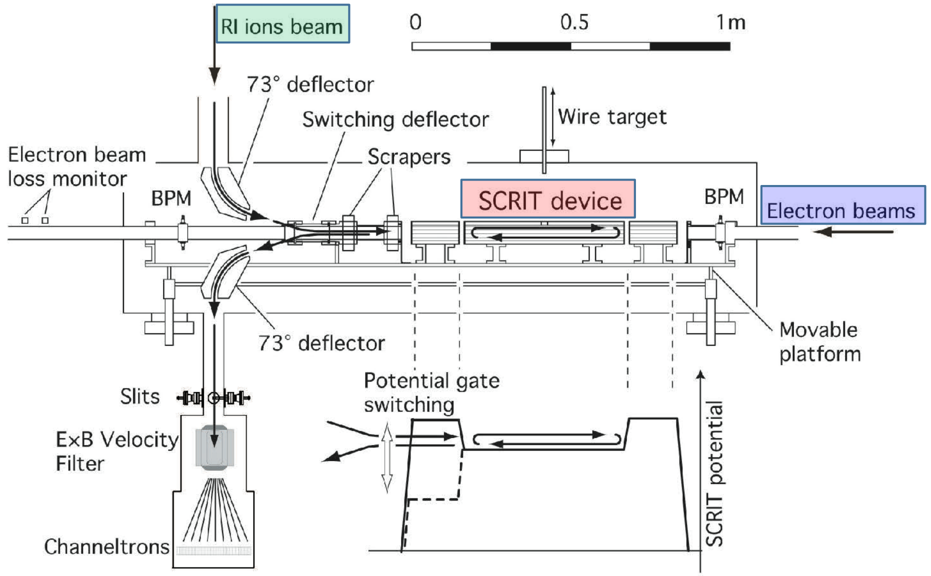
SCRIT (Self-Confining RI Ion Target)

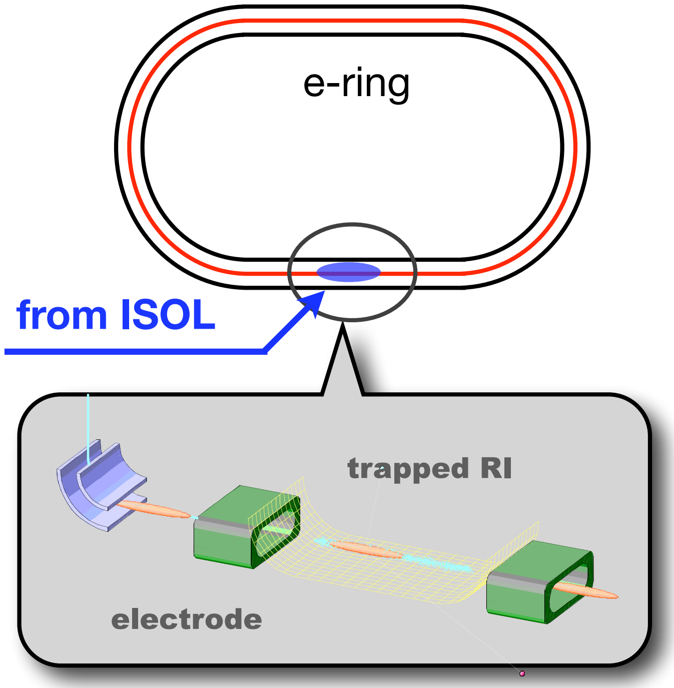
Idea : "ion trapping" at SR facilities.

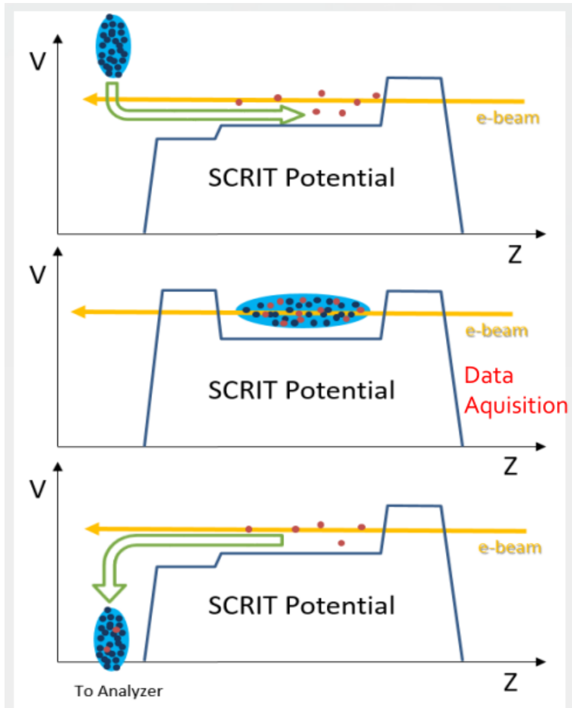
ionized residual gases are trapped by the circulating electron beam

ill problem of e-storage rings

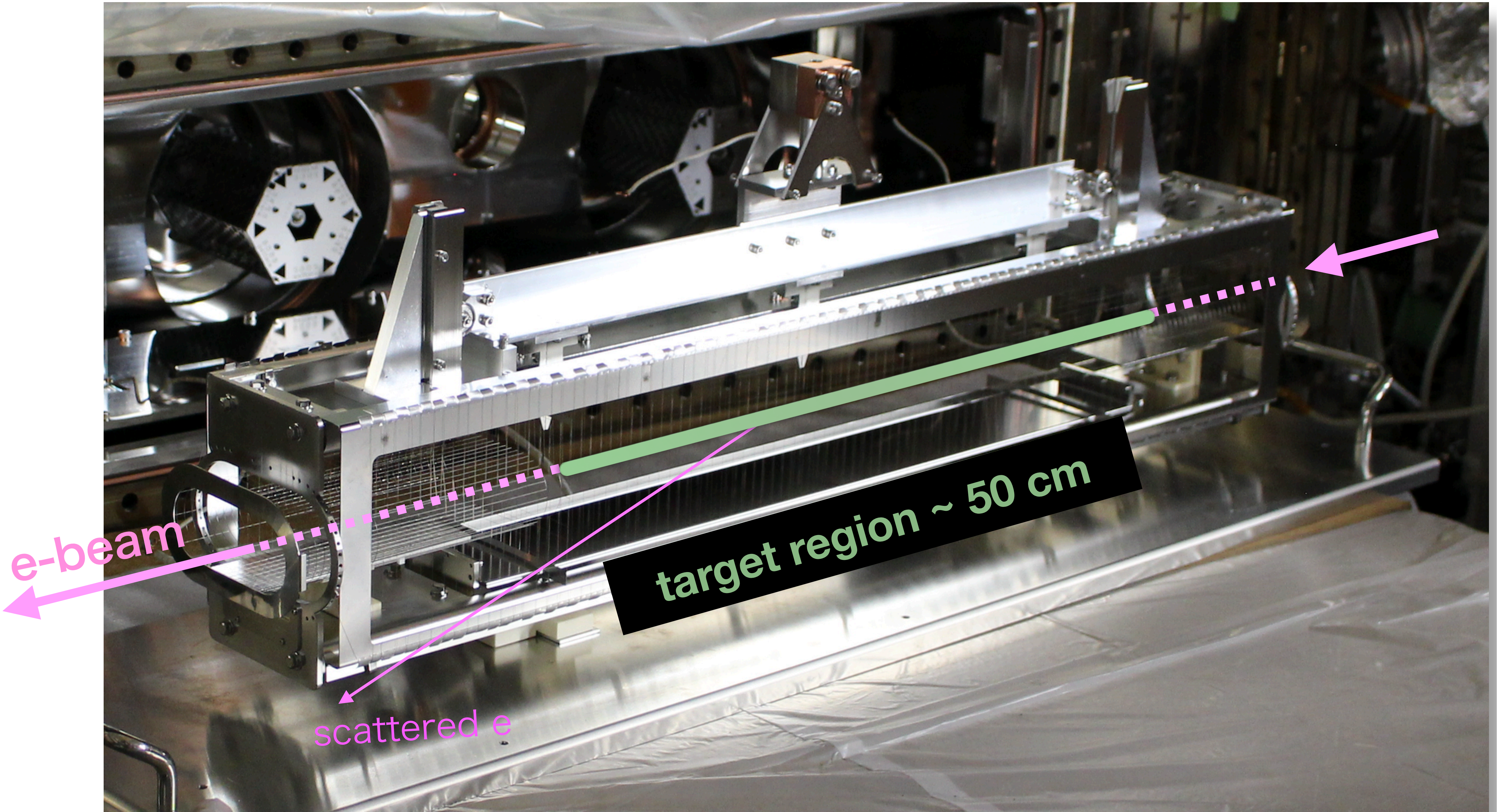




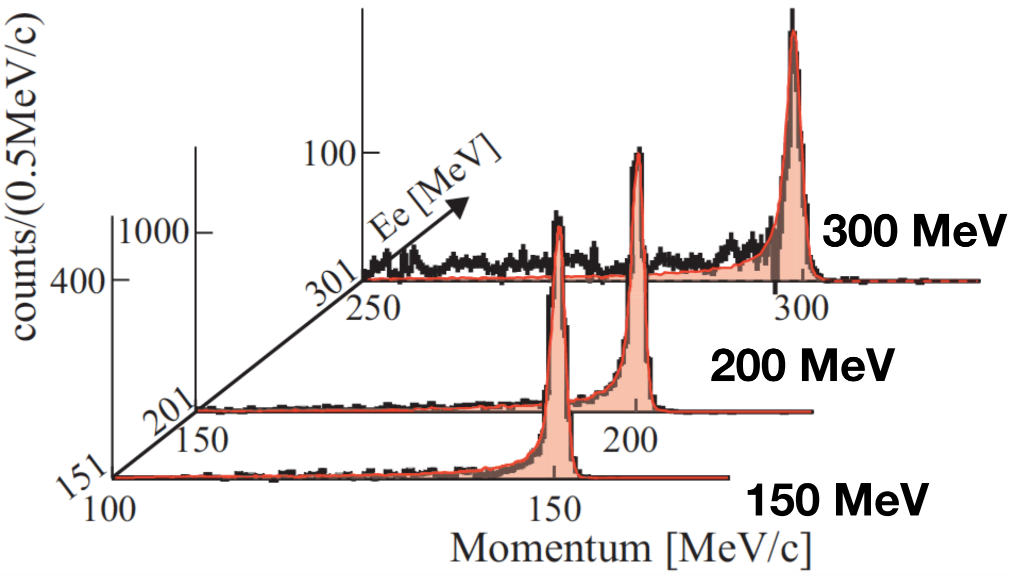




SCRIT electrodes

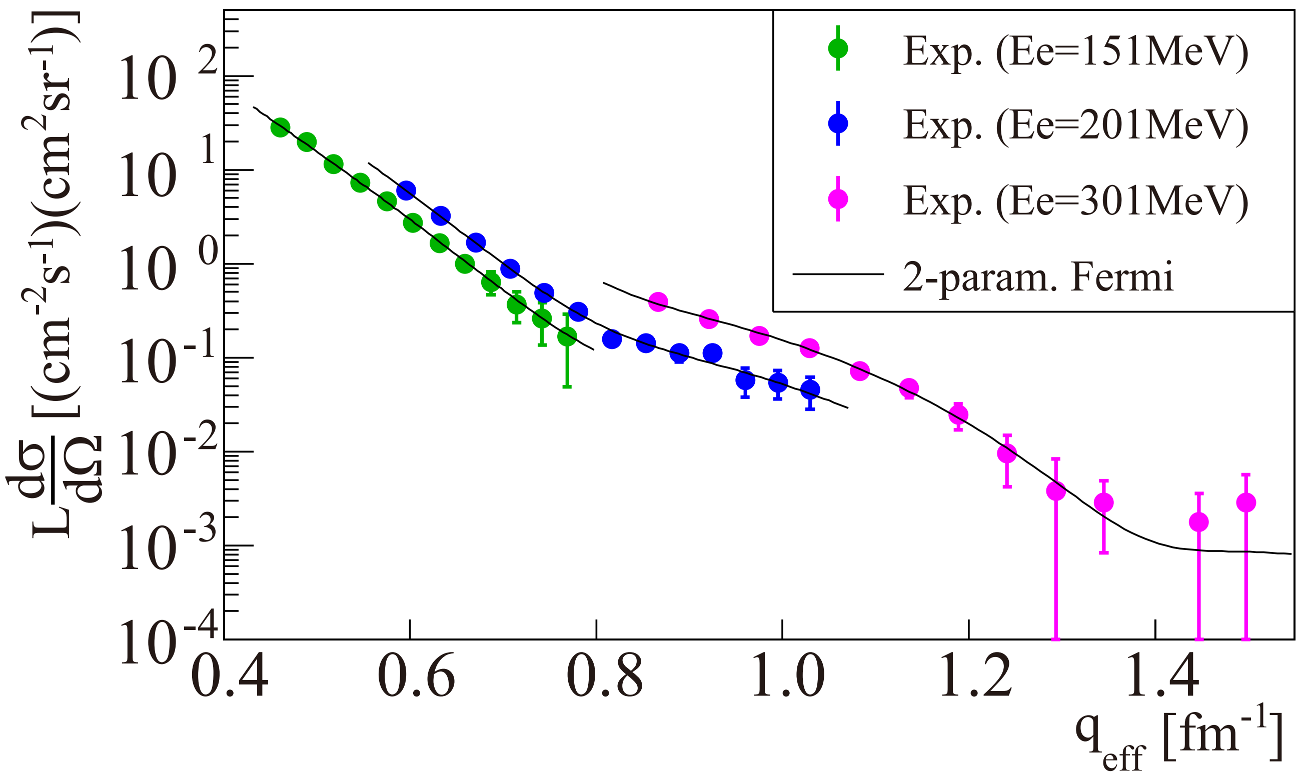


Commissioning : $^{132}Xe(e,e')$



K. Tsukada et al.,
PRL 118 (2017) 262501.

$N_{trapped}$ ~ 10^8 @ Ie = 250 mA
=> L ~ 10^{27} /cm²/s



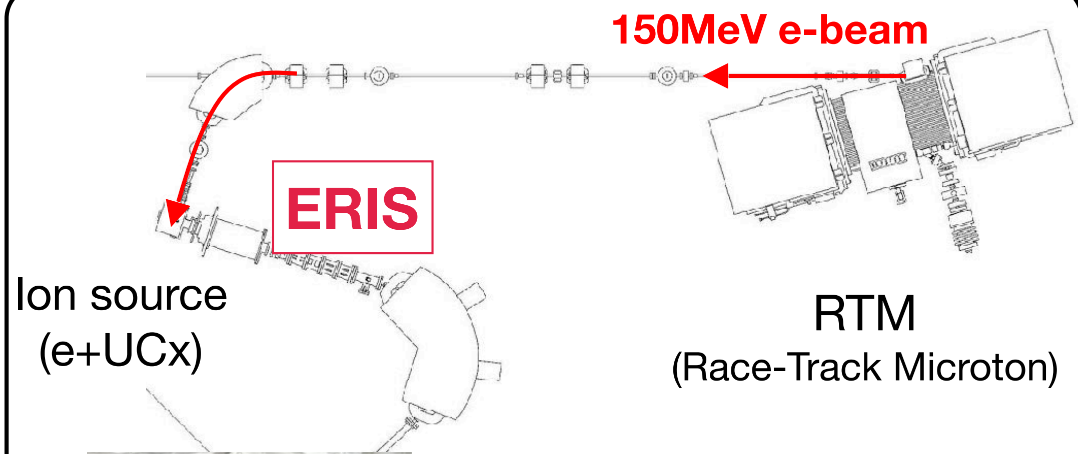
SCRIT facility

	Ee	N_{beam}	target thickness	L
Hofstadter's era (1950s)	150 MeV	~ 1nA (~10^9 /s)	~10^{19} /cm^2	~10^{28} /cm^2/s
JLAB	12 GeV	~100µA (~10^{14} /s)	~10^{22} /cm2	~10^{36} /cm^2/s
SCRIT	150-300 MeV	300 mA (~10^{18} /s)	~10^9 /cm^2	~10^{27} /cm^2/s

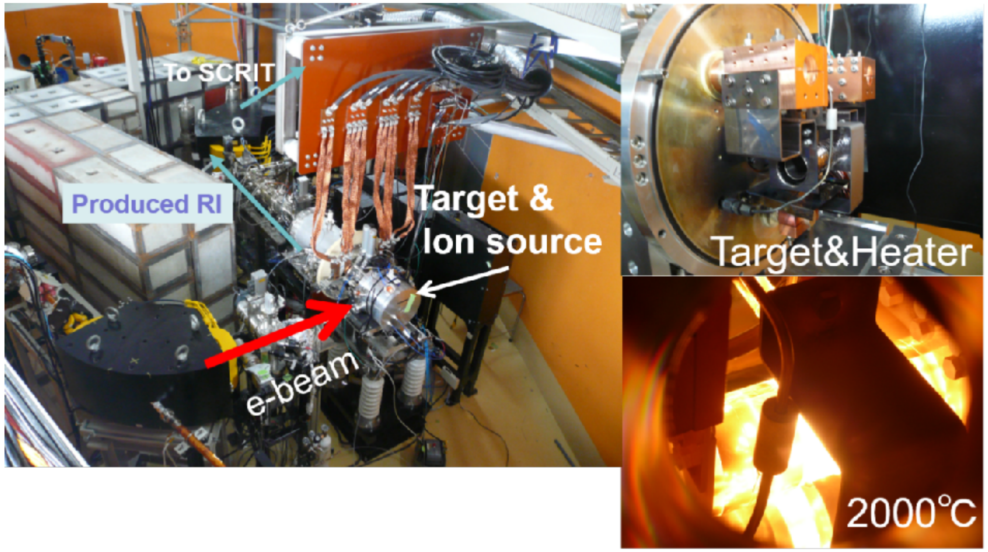
~10^7 trapped ions in e-beam of ~1 mm^2

required target thickness ~ 10^{-10} !!

ERIS (Electron-beam-driven RI separator for SCRIT)



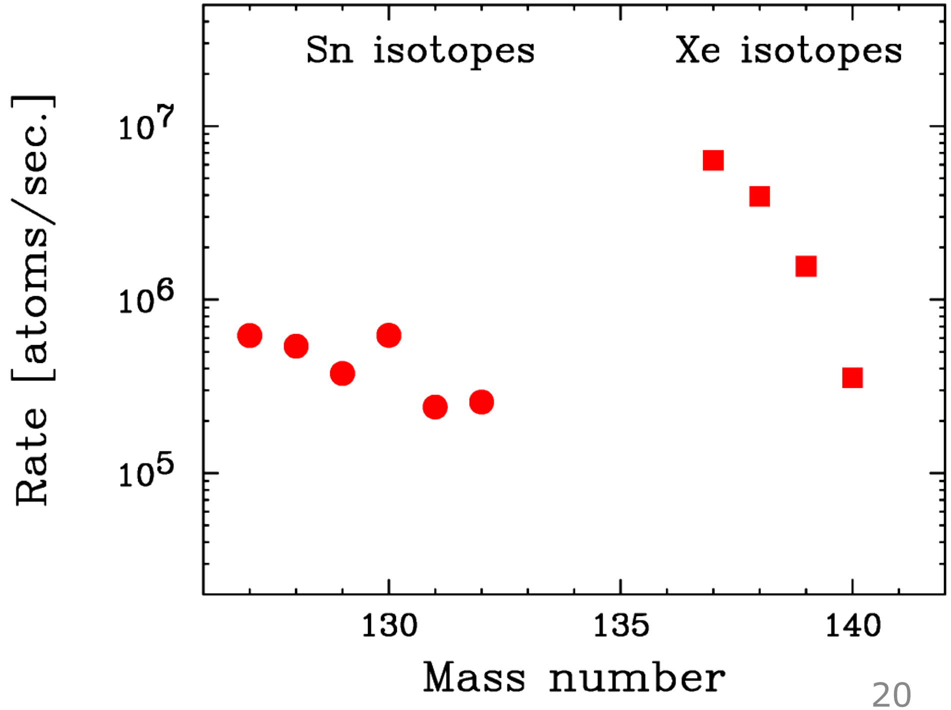
home-made UC_x disks
40 disks (φ 18 mm, t=0.8 mm)



- Photo fission of uranium
- Ion source: FEBIAD& Surface ionization
- RI production:

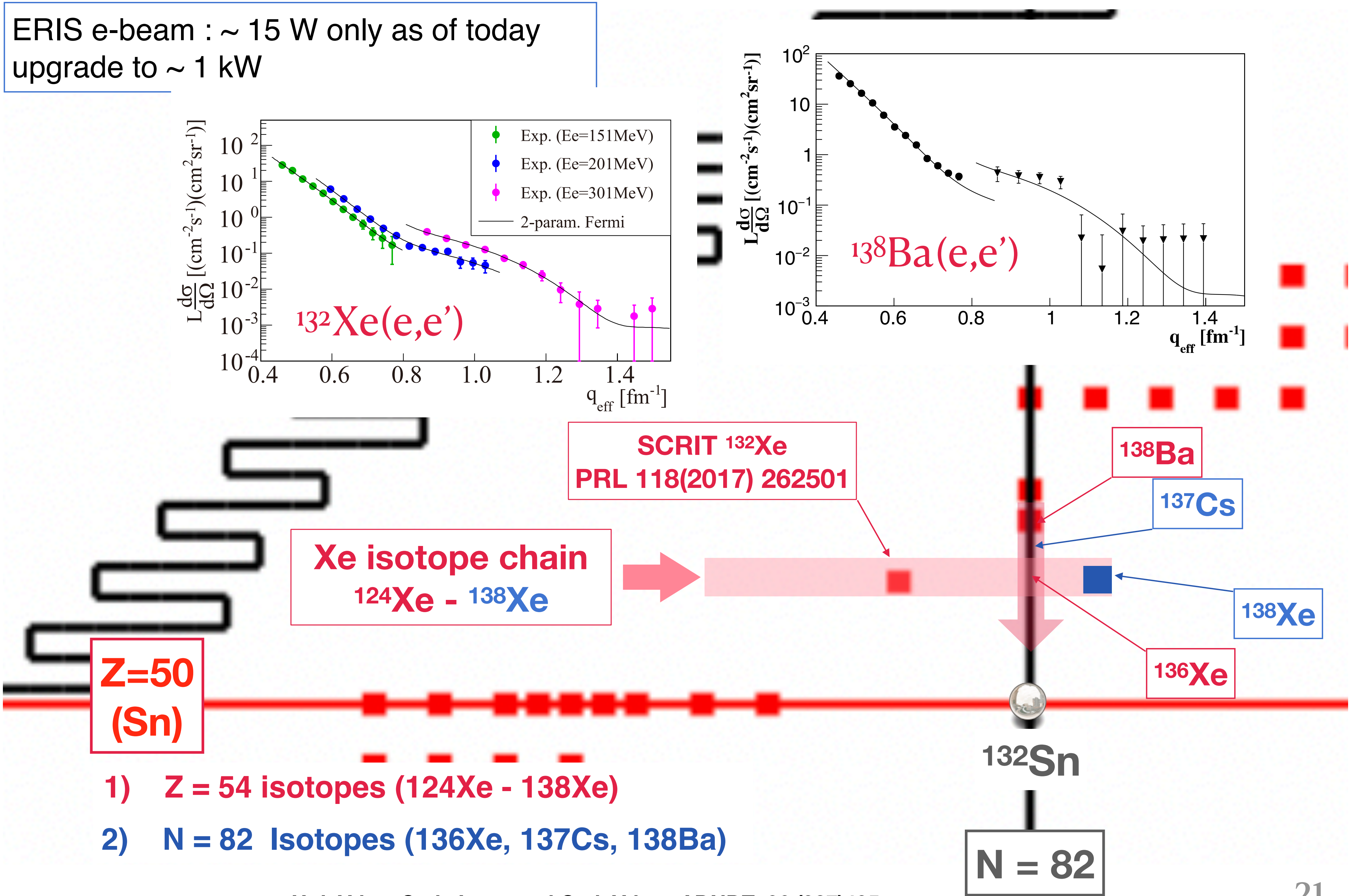
  e-beam: 150MeV, ~ 10W
  Total U: 15g (~21 disks + Ta conv. 5mm)
  Target temperature: ~ 2000 degree

  ^{138}Xe: 3.9×10^6 cps
  ^{132}Sn: 2.6×10^5 cps



On-going Physics Program

ERIS e-beam : ~ 15 W only as of today
upgrade to ~ 1 kW



1) Z = 54 isotopes (124Xe - 138Xe)

2) N = 82 Isotopes (136Xe, 137Cs, 138Ba)

H.deVries, C. deJager and C. deVries : ADNDT 36 (987)495

new physics opportunity for low-E e-scattering

n-th moments of charge distribution and neutron distribution

H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys., 2019, 113D01
H. Kurasawa, T. Suda and T, Suzuki, Prog. Theor. Exp. Phys., 2021, 013D02
H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys. 2022 023D03

PTEP

Prog. Theor. Exp. Phys. **2021**, 013D02 (40 pages)
DOI: 10.1093/ptep/ptaa177

The mean square radius of the ne distribution and the skin thickne electron scattering

Haruki Kurasawa[1], Toshimi Suda[2,3], and Toshio Suzuki[2,*]
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PTEP

Prog. Theor. Exp. Phys. **2019**, 113D01 (15 pages)
DOI: 10.1093/ptep/ptz121

The *n*th-order moment of the nuclear ch density and contribution from the neutr

Haruki Kurasawa[1,*] and Toshio Suzuki[2]
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PTEP

Prog. Theor. Exp. I

The mean-square radius of the neutron the relativistic and non-relativistic mea

Haruki Kurasawa[1] and Toshio Suzuki[2,*]

Charge density and its moments

1) charge density

$$\rho_c(r) = \rho_c^p(r) + \rho_c^n(r)$$

$$\rho_c^p(r) = \int \rho_p(r)\, \rho_{p(point)}(r - r')\, \mathrm{d}^3 r'$$

$$\rho_c^n(r) = \int \rho_n(r)\, \rho_{n(point)}(r - r')\, \mathrm{d}^3 r'$$

2) 2nd moment

structure theories   Proton   Neutron

$$< r_c^2 > = \int r^2 \rho_c(r)\, \mathrm{d}^3 r \;= < r_{p(point)}^2 > + < r_p^2 > + \frac{N}{Z} < r_n^2 > + \mathrm{rel.corr.}$$

3) 4th moment

$$< r_c^4 > = \int r^4 \rho_c(r)\, \mathrm{d}^3 r$$

$$= < r_{p(point)}^4 > + \frac{10}{3} < r_{p(point)}^2 > < r_p^2 >$$ ← proton

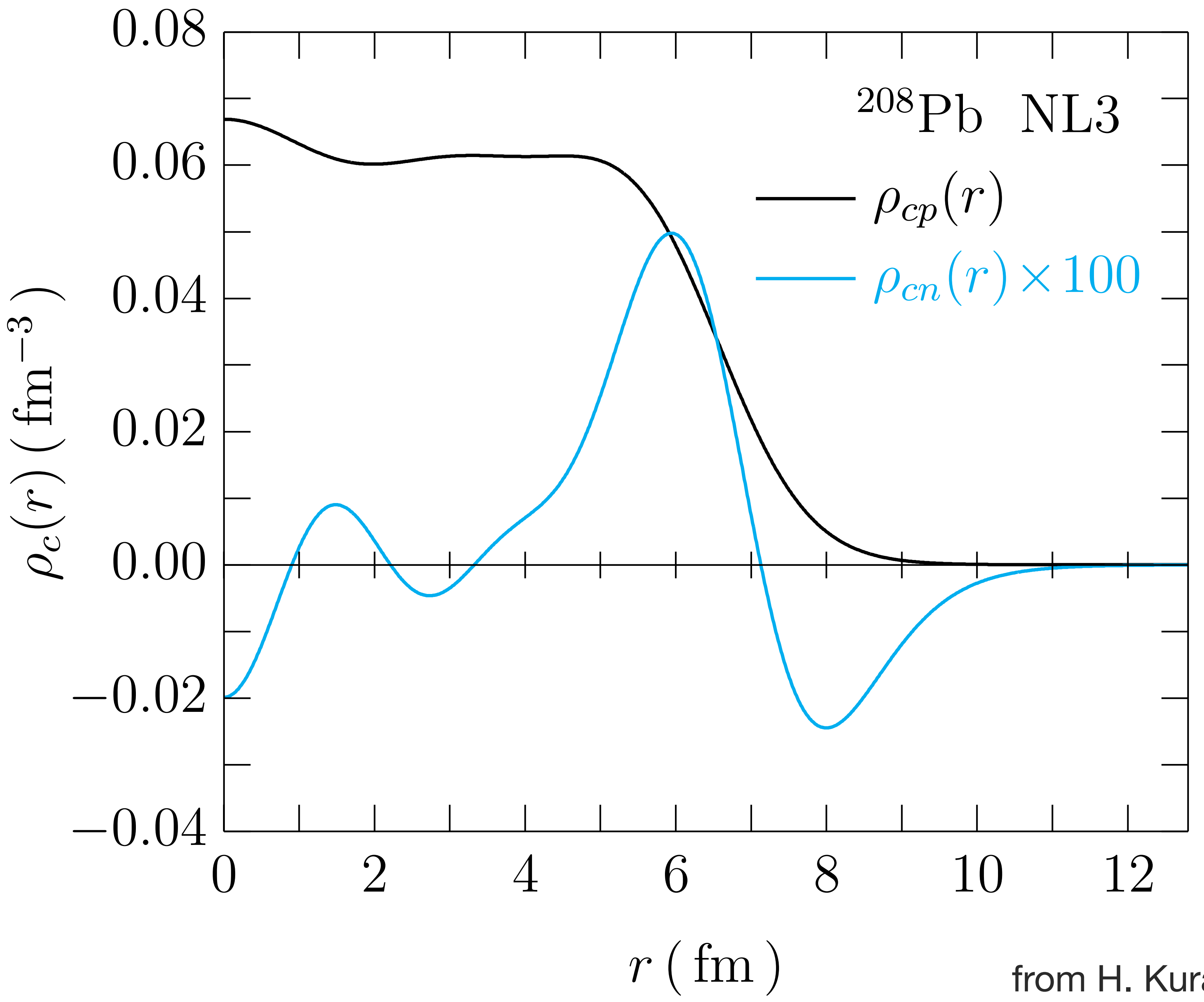
$$+ \frac{10}{3} < r_{n(point)}^2 > < r_n^2 > \frac{N}{Z}$$ ← neutron

RMS n-radius

$$+\mathrm{rel.corr.}$$

H. Kurasawa and T. Suzuki, PTEP 2019, 113D01

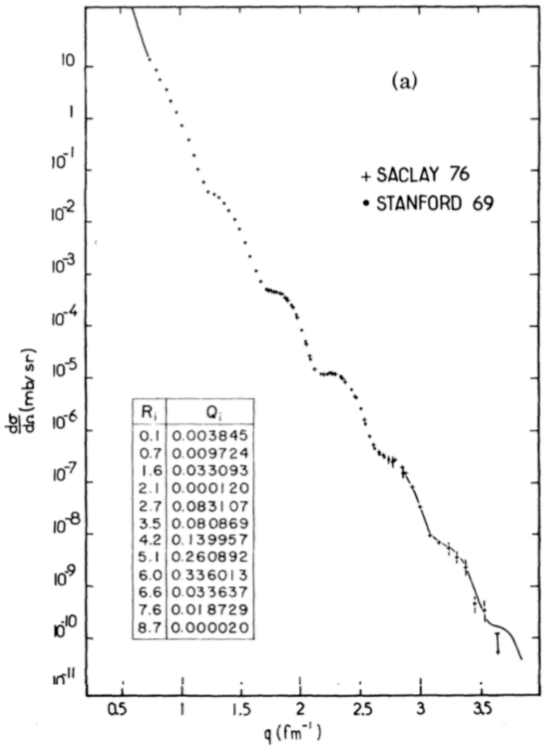
Charge density distribution of ^{208}Pb



from H. Kurasawa

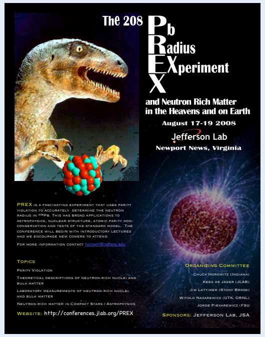
<r4> moments of ^{48}Ca, ^{208}Pb

^{208}Pb



H. Kurasawa, T. S. and T, Suzuki, PTEP, 2021, 013D02

		R_p	R_n	δR
^{208}Pb	Rel.	5.454(0.013)	5.728(0.057)	0.275(0.070)
	Non.	5.447(0.014)	5.609(0.054)	0.162(0.068)
	Exp.	$R_c = 5.503(0.014)$		

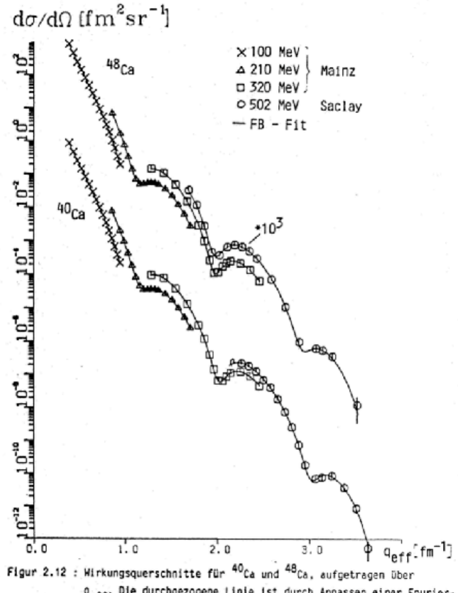


JLab : PREX I,II (parity-violating e-scattering)

$$\Delta r_{np} \equiv R_n - R_p = 0.283 \pm 0.071 \text{ fm}$$

PRL 126, 172502 (2021)

^{48}Ca



H. Kurasawa, T. S. and T, Suzuki, PTEP, 2021, 013D02

		R_p	R_n	δR
^{48}Ca	Rel.	3.378(0.005)	3.597(0.021)	0.220(0.026)
	Non.	3.372(0.009)	3.492(0.028)	0.121(0.036)
	Exp.	$R_c = 3.451(0.009)$		

<r4> moments of exotic nuclei ?

$$< r_c^4 > = \int r^4 \rho_c(r)\, \mathrm{d}^3 r$$

- **no hope to determine $\rho_c(r)$ precisely for low *L* e-RI facility**

$$\frac{\mathrm{d}\sigma_{\mathrm{Mott}}}{\mathrm{d}\Omega} \propto 1/q^4$$

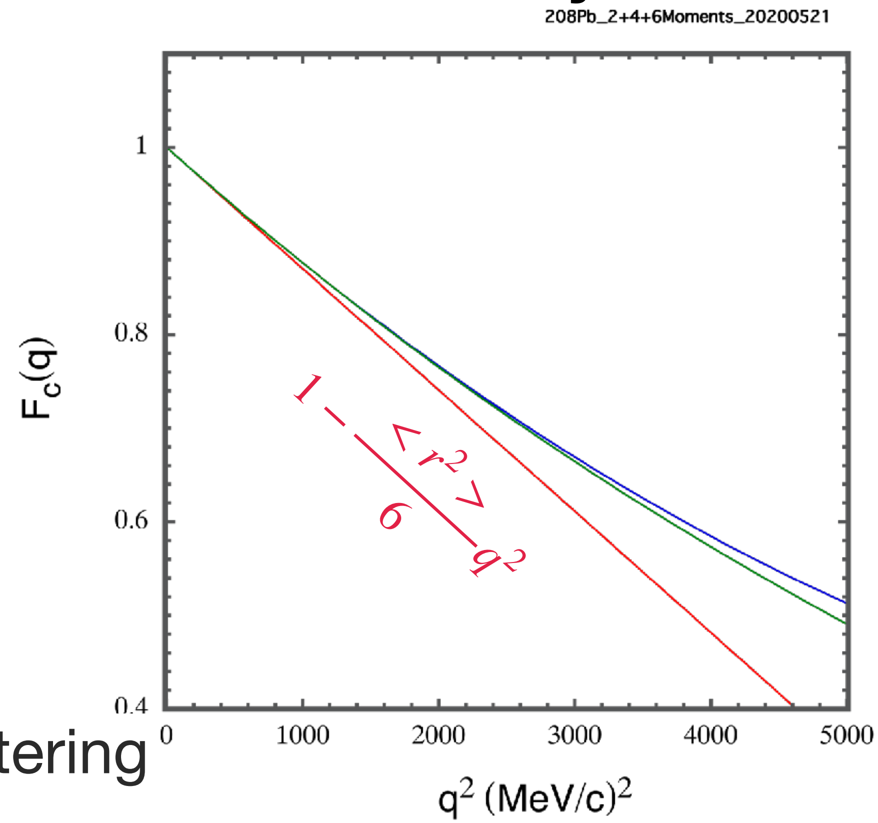
- **charge form factor at low q**

$$F_c(q) \sim 1 - \frac{< r^2 >_c}{6} q^2 + \frac{< r^4 >_c}{120} q^4 + \ldots$$

IS

elastic cross section : huge

➡ Low-luminosity e-RI scattering



- **Coulomb distortion**

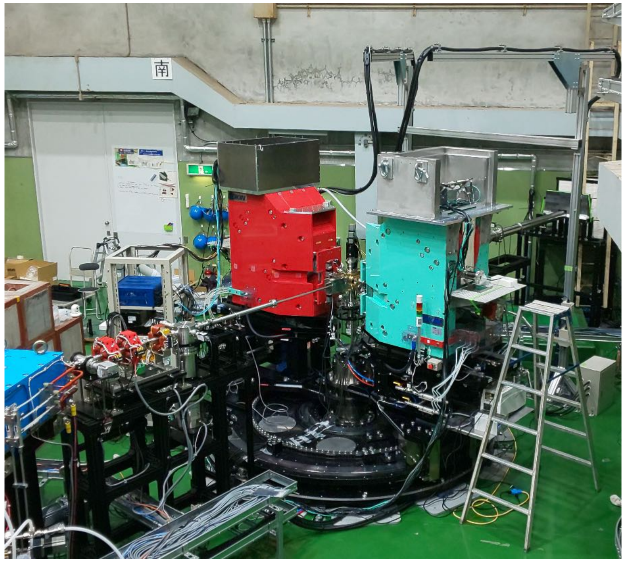
phase shift calculation for cross section essential

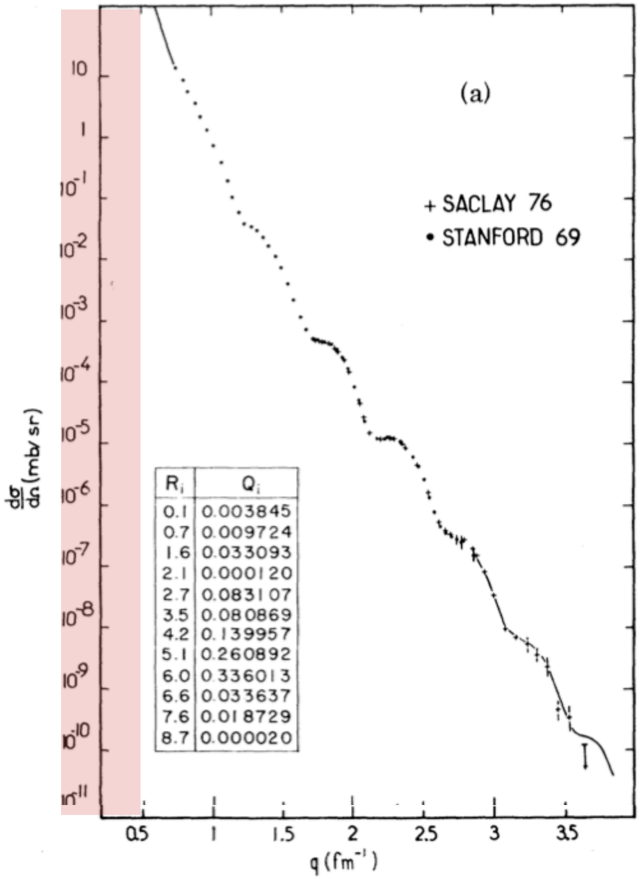
➡ no discussion based on charge form factors

Rn determination at extremely low-q (e,e') ?

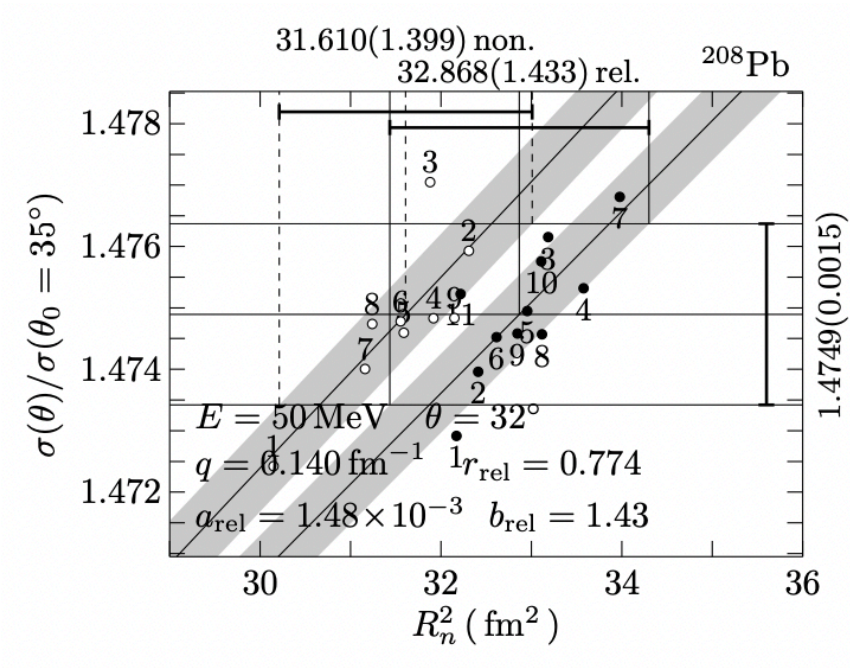
- ^{208}Pb(e,e') at the ULQ2 beam line

Ee ~ 10 - 50 MeV
θ = 30 - 150°
q = 2.5 - 100 MeV/c





$\sigma(\theta)/\sigma(\theta_0)$ vs R_n^2



courtesy of H. Kurasawa

- precise $\sigma(\theta)/\sigma(\theta_0)$ with the twin spectrometers
- phase-shift calculations are underway
- short beam time for feasibility test this fall

- if we find it works, apply to exotic nuclei at SCRIT !!

Conclusions

Low-energy electron-scattering facilities in Japan

	ULQ2 (Tohoku University)	SCRIT (RI Beam Factory/RIKEN)
Ee	10 - 50 MeV	150 - 300 MeV
θe	30 - 150°	30 - 60°
Ie	≤ 1 μA	~ 300 mA
	twin spec. (10 mSr)	WiSES (100mSr)
Physics	proton radius (+stable nuclei)	exotic nuclei
Status	ready to go	in operation
next step	R_n of stable nuclei (^{208}Pb...)	Rn, photo-nuclear response...