Present status and perspective of the SCRIT electron scattering facility

ISNS-24, Sofia, Bulgaria, Sep. 9, 2024

RIKEN Nishina Center
Tetsuya Ohnishi
and
SCRIT collaboration

Phys. Rev. Lett. 131 (2023) 092502

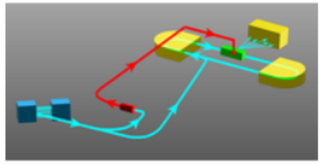
Featured in Physics | Editors' Suggestion

First Observation of Electron Scattering from Online-Produced Radioactive Target

K. Tsukada, Y. Abe, A. Enokizono, T. Goke, M. Hara, Y. Honda, T. Hori, S. Ichikawa, Y. Ito, K. Kurita, C. Legris, Y. Maehara, T. Ohnishi, R. Ogawara, T. Suda, T. Tamae, M. Wakasugi, M. Watanabe, and H. Wauke

Phys. Rev. Lett. **131**, 092502 (2023) – Published 30 August 2023

Physics Viewpoint: What Do Unstable Atomic Nuclei Look Like?



The first electron-scattering experiment off unstable radioisotopes marks a milestone for understanding the shape of exotic atomic nuclei.

Show Abstract +

1. Introduction
2. SCRIT Facility
3. Recent results
4. Perspective of SCRIT
5. Summary

1. Introduction

Electron scattering

Powerful tool to study the internal structure of nuclei

Well known interaction (Coulomb interaction)

Structure-less probe

No serious modification of nucleus

Electron – nucleus scattering

Elastic electron scattering

= Mott scattering × Form factor

Inelastic electron scattering

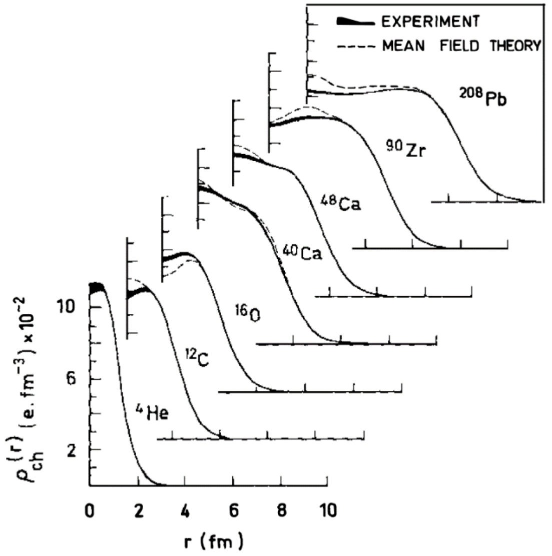
= deformation etc....

Electron – nucleon scattering

Proton radius

→ Next speaker's talk

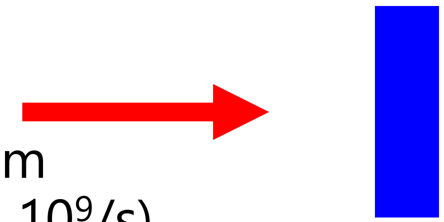
Charge density distribution



B. Frois and C. N. Papanicolas, Ann.Rev.Nucl.Part.Sci. 37 (1987) 133.

Electron scattering with unstable nuclei

Conventional way (Stable nuclei)



e-beam
($\sim$ 1nA = 10^9/s)

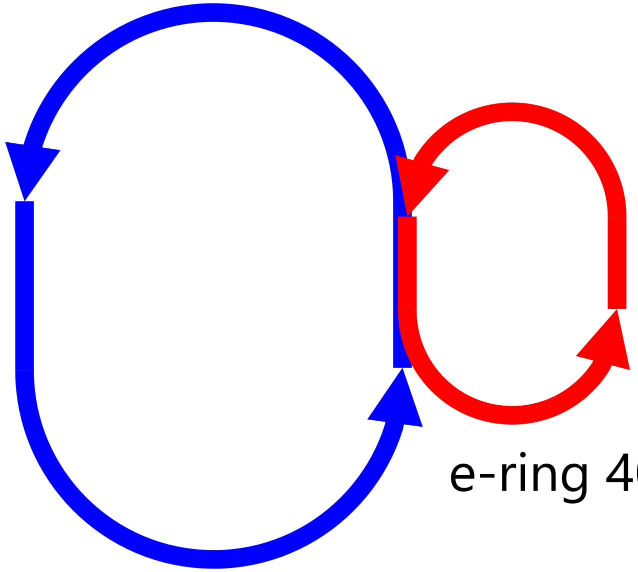
Target
($\sim 10^{19}$/cm^2)

Luminosity $\sim 10^{27\sim28}$/cm^2/s

➔ Difficulty of the preparation of RI target

Collider

ELISe at FAIR
DREICA at Dubna



e-ring 400mA (10^{18}/s)

RI-ring 10^7/bunch($\sim$5.5MHz)

Luminosity $\sim 10^{28}$/cm^2/s

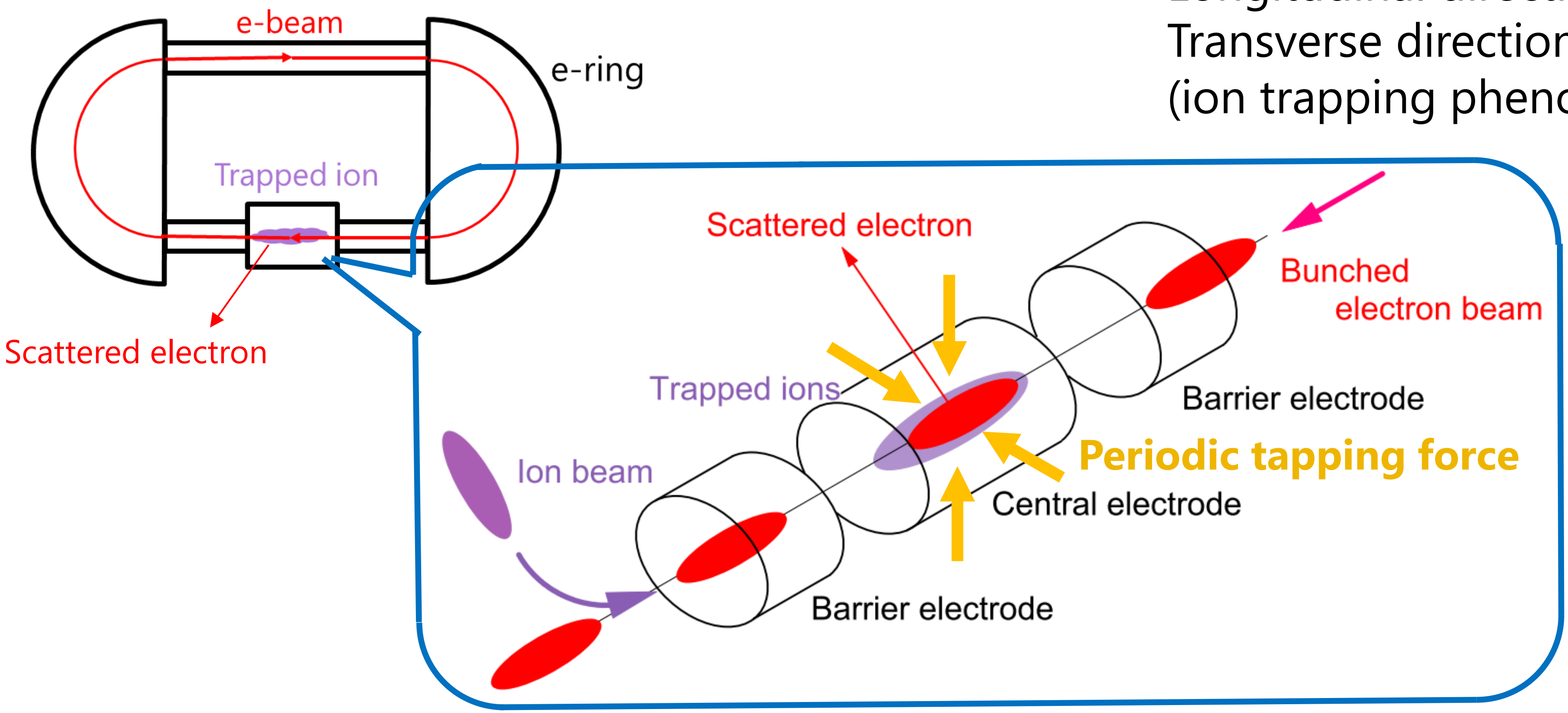
➔ High costs

New target forming technique : SCRIT

SCRIT(Self Confining RI Ion Target) method

M. Wakasugi et al., Phys. Rev. Lett. 100 (2008) 164801.

Longitudinal direction: Electric static potential
Transverse direction: Trapping force by e-beam
(ion trapping phenomena)

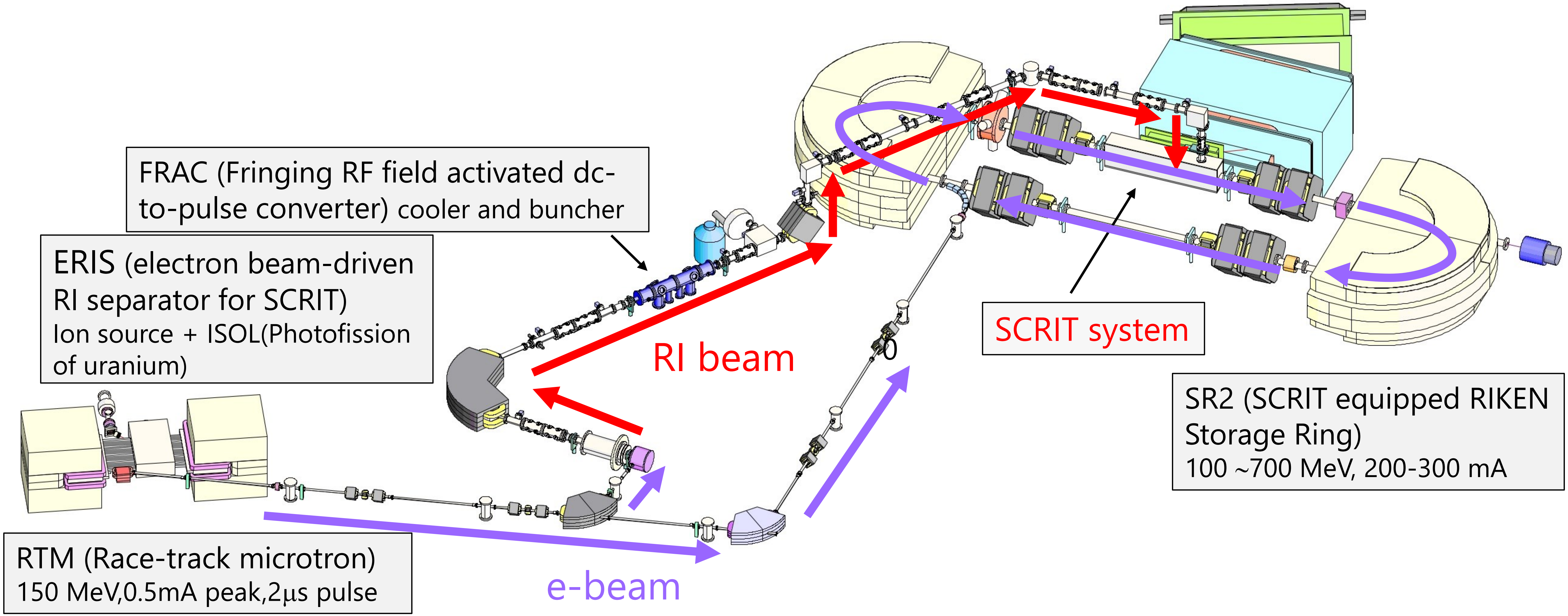


Typical values
Luminosity 10^{27} cm^{-2}s^{-1}
e-beam
current～200 mA
size ～mm^2
10^8 ions

Automatic electron scattering with trapped ions

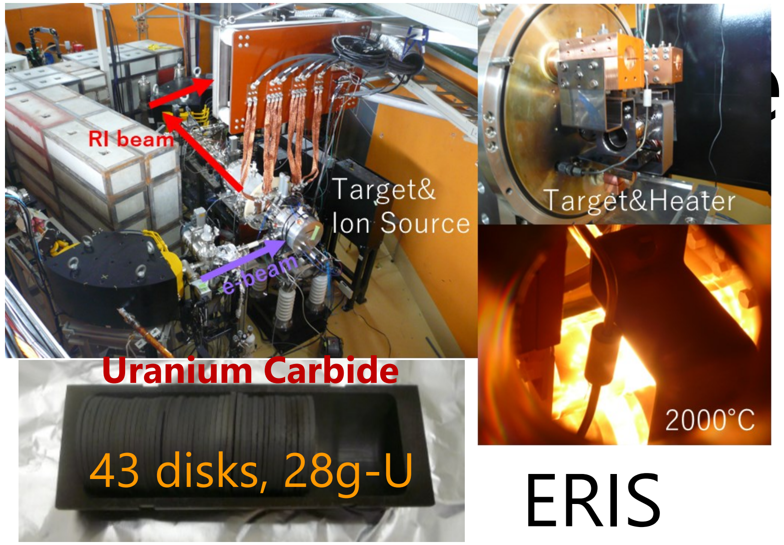
2. SCRIT electron scattering facility

M. Wakasugi et al., NIMB 317 (2013) 668.
T. Ohnishi et al., NIMB 541 (2023) 380.



electron scattering facility

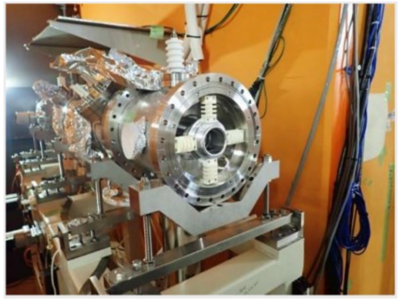
M. Wakasugi et al., NIMB 317 (2013) 668.
T. Ohnishi et al., NIMB 541 (2023) 380.



φ 18 mm, t 0.8 mm disks

ERIS

FRAC

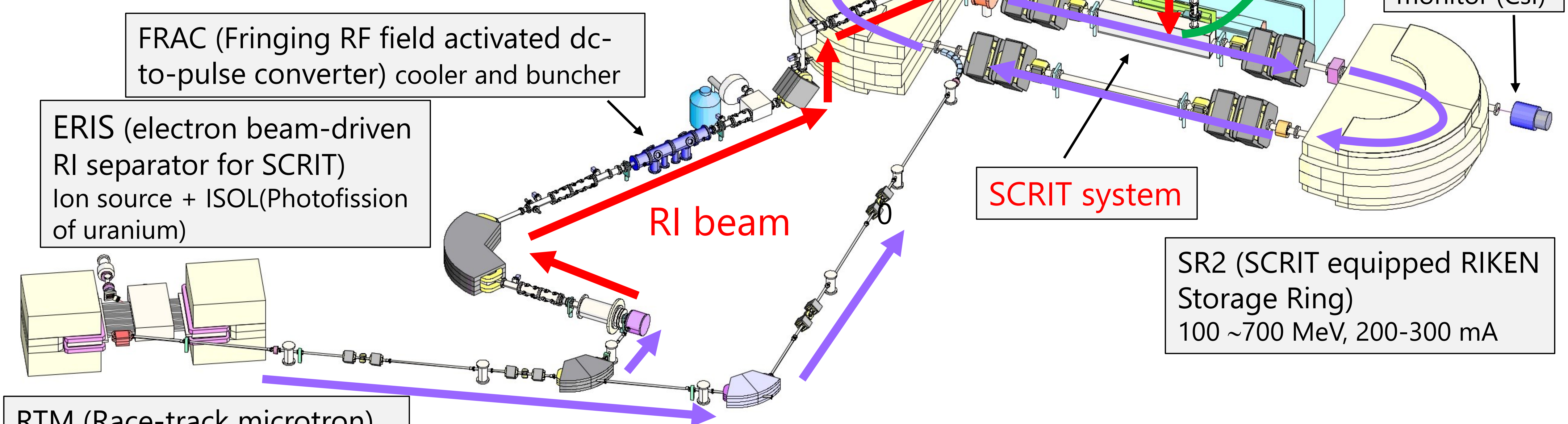


WiSES (Window-frame spectrometer for electron scattering) Magnetic spectrometer, 2×Drift Chambers, Trigger Scinti.

LMon: Luminosity monitor (CsI)

FRAC (Fringing RF field activated dc-to-pulse converter) cooler and buncher

ERIS (electron beam-driven RI separator for SCRIT)
Ion source + ISOL(Photofission of uranium)



SR2 (SCRIT equipped RIKEN Storage Ring)
100 ~700 MeV, 200-300 mA

RTM (Race-track microtron)
150 MeV,0.5mA peak,2μs pulse

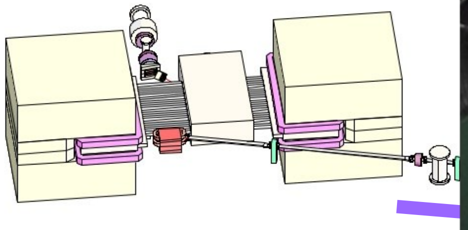
electron scattering facility

M. Wakasugi et al., NIMB 317 (2013) 668.
T. Ohnishi et al., NIMB 541 (2023) 380.

φ 18 mm, t 0.8 mm disk

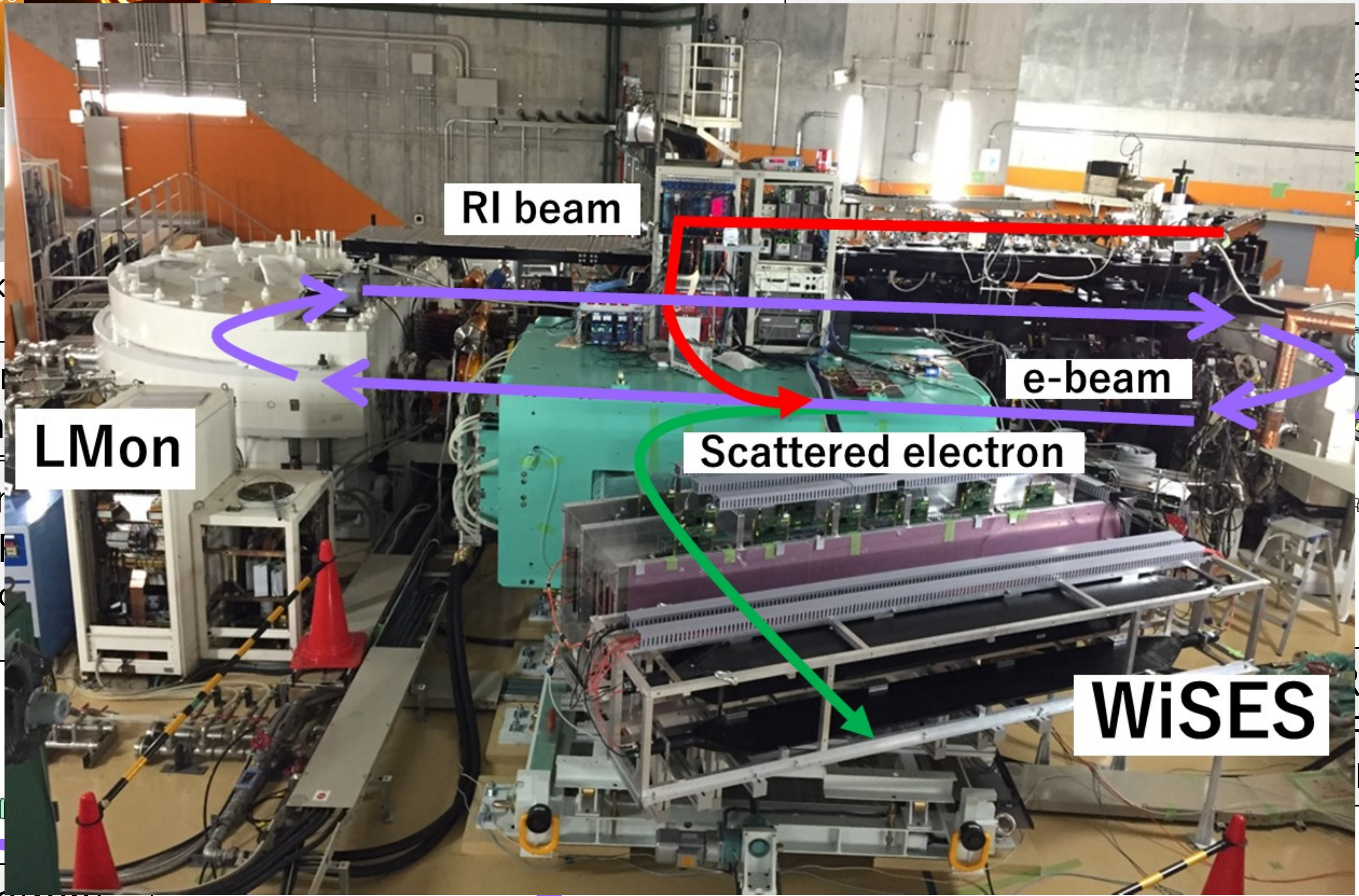
FRAC (Fringi
to-pulse con

ERIS (electron bea
RI separator for SC
Ion source + ISOL(Ph
of uranium)



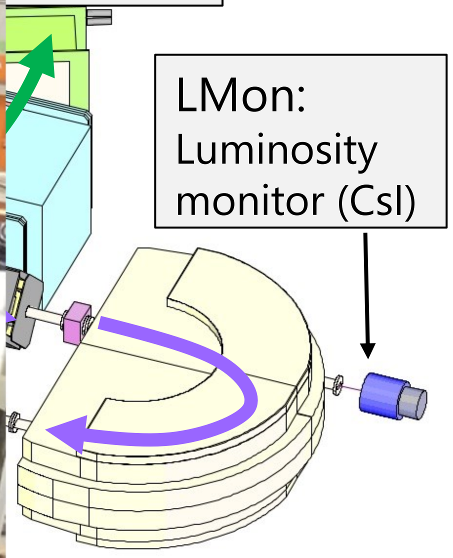
RTM (Race-track microtron)
150 MeV,0.5mA peak,2μs pulse

e-beam



meter for
ectrometer,

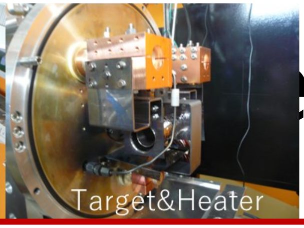
LMon:
Luminosity
monitor (CsI)



IT equipped RIKEN
Ring)
MeV, 200-300 mA

…lectron scattering facility

M. Wakasugi et al., NIMB 317 (2013) 668.
T. Ohnishi et al., NIMB 541 (2023) 380.

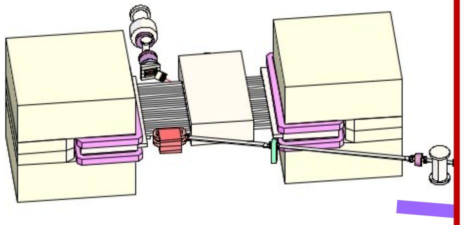


Uranium Carbide

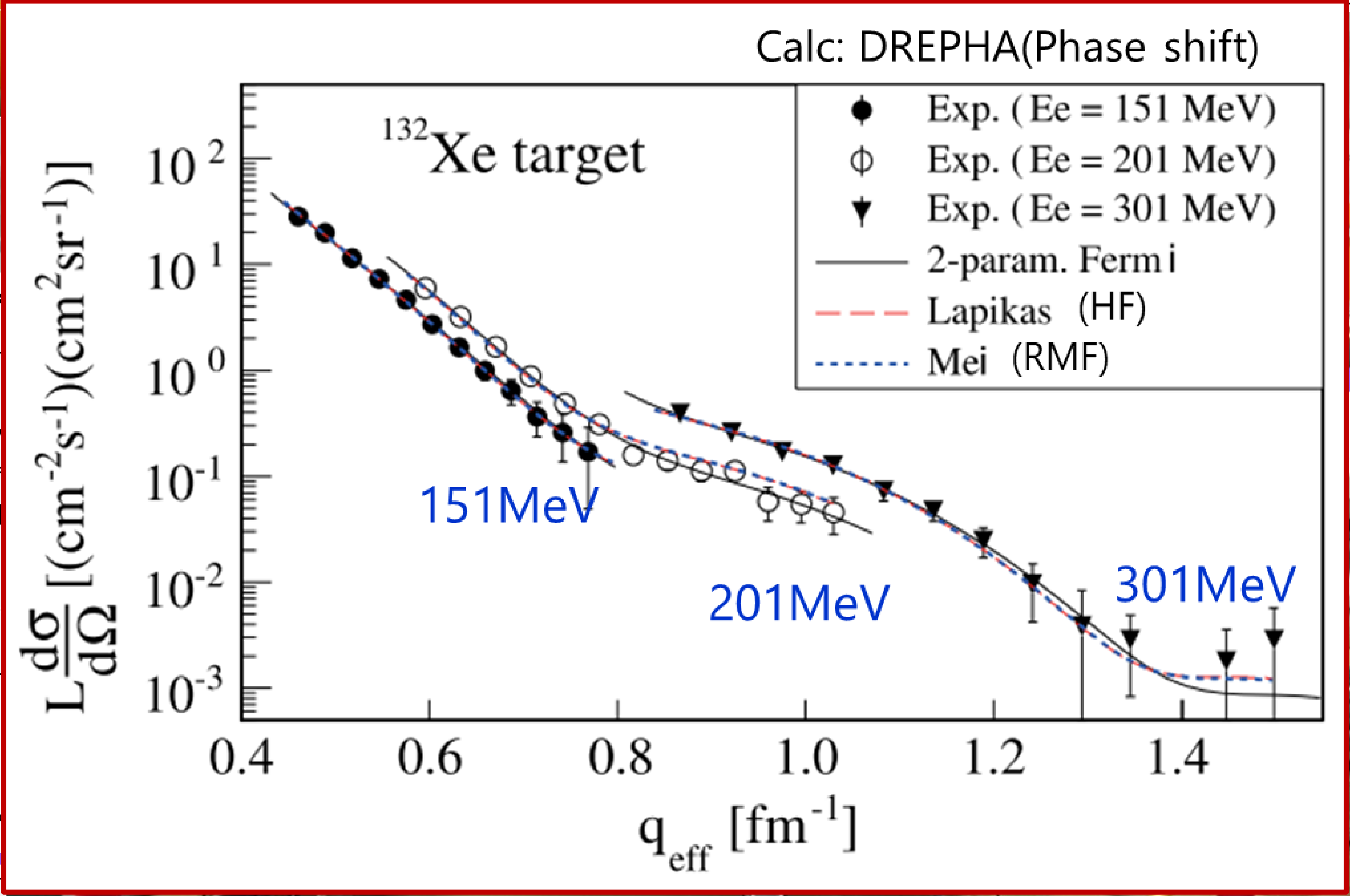
φ 18 mm, t 0.8 mm disk

FRAC (Fringi…
to-pulse con…

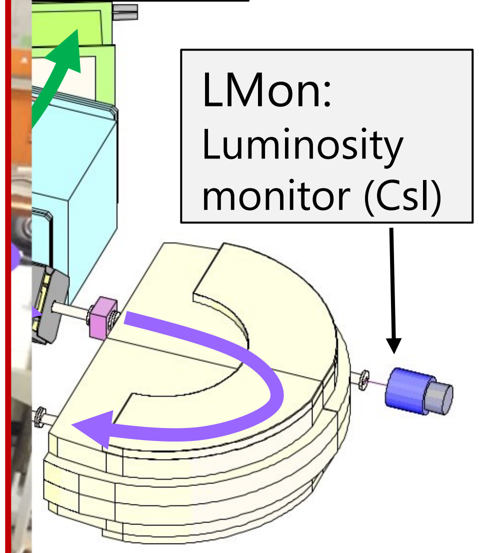
ERIS (electron bea…
RI separator for SC…
Ion source + ISOL(Ph…
of uranium)



RTM (Race-track microtron)
150 MeV,0.5mA peak,2μs pulse



…meter for
…ectrometer,

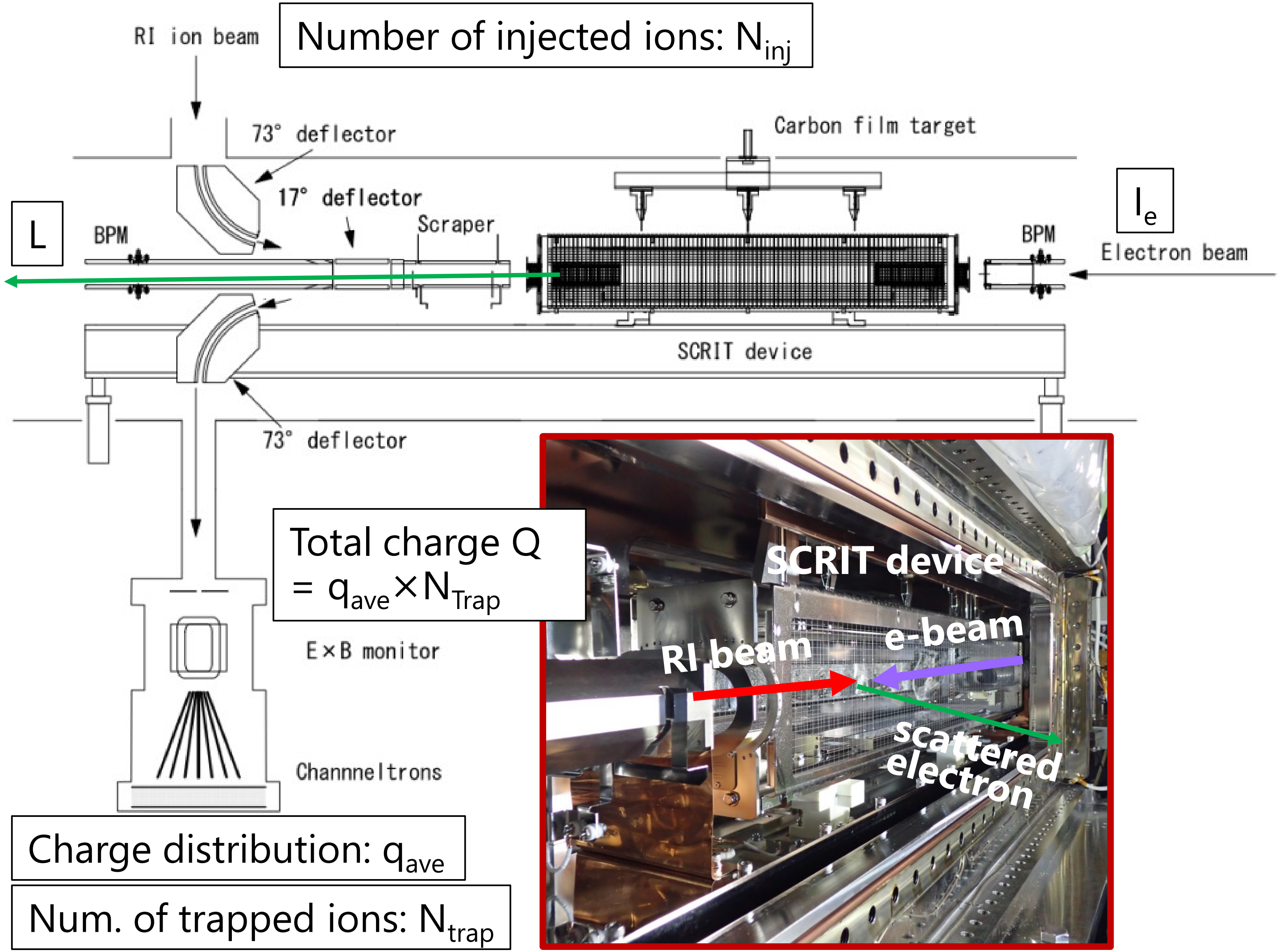


LMon:
Luminosity
monitor (CsI)

…IT equipped RIKEN
…Ring)
…MeV, 200-300 mA

e-beam

Ion trap property at SCRIT

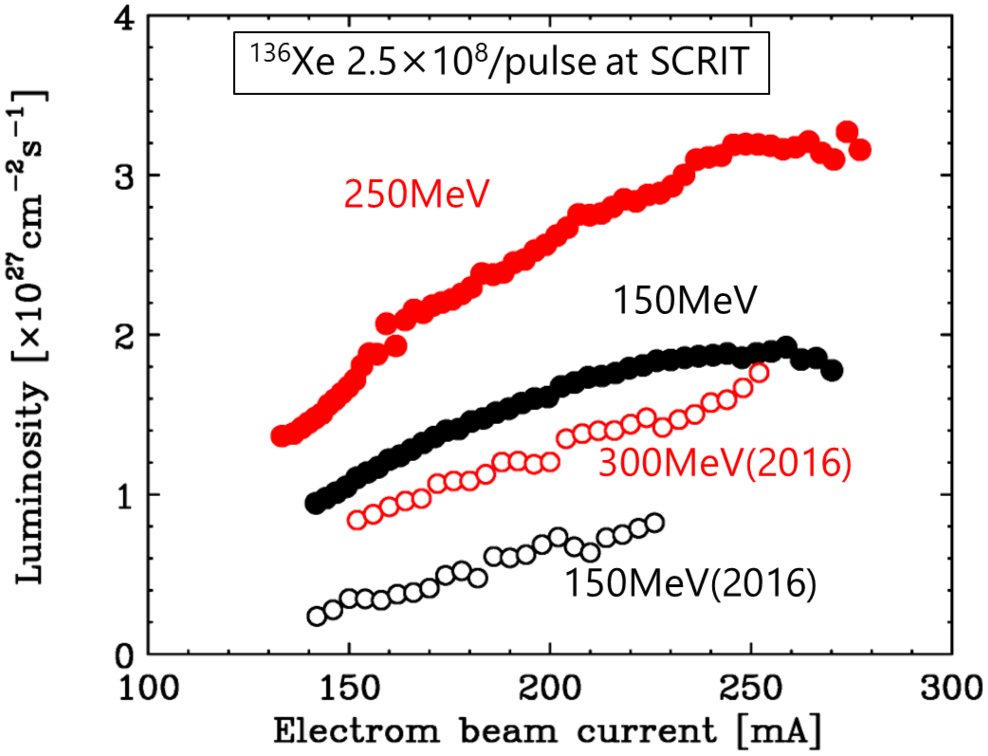


Charge distribution: q_{ave}

Num. of trapped ions: N_{trap}

Luminosity $L \sim \frac{I_e/e \cdot N_T}{\sigma}$ $[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$

Achived luminosity



3. Recent results

^{137}Cs(e,e') experiment

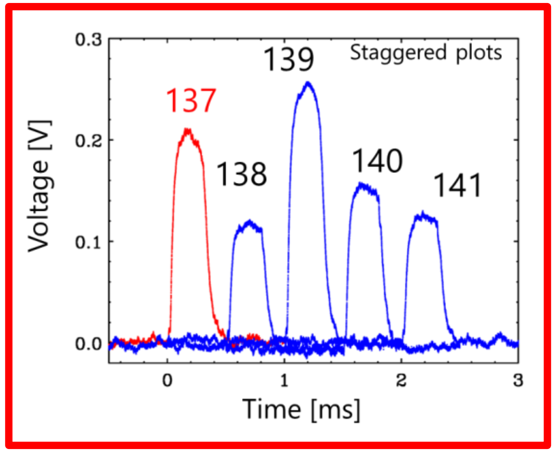
-first experiment of electron scattering with online-produced RI-

K. Tsukada et al., Phys. Rev. Lett. 131, 092502 (2023)

Why ^{137}Cs?

- Relatively high production rate
- Good ion beam emittance by surface ionization
- Long lifetime of nucleus (~30 years)
- N=82 isotone

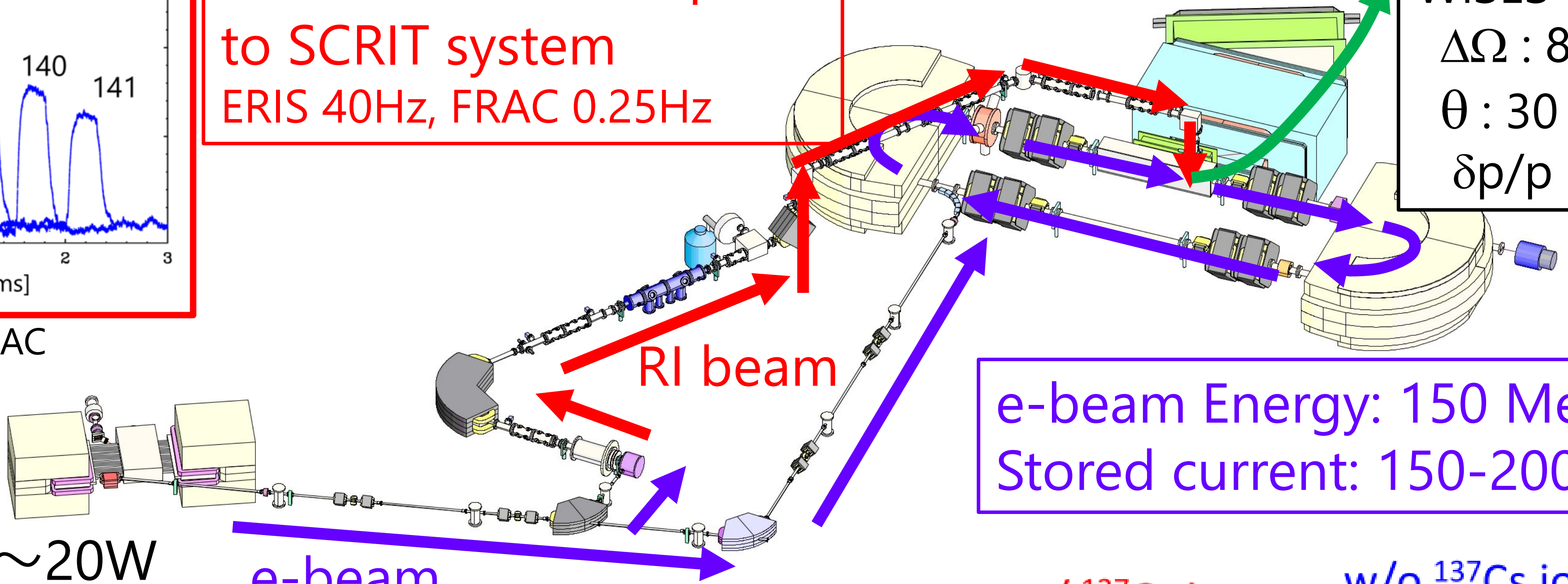
Electron scattering with online-produced RI, ^{137}Cs



Cooling gas at FRAC
Ne gas (10^{-3} Pa)

^{137}Cs ~2×10^{7} ions/pulse
to SCRIT system
ERIS 40Hz, FRAC 0.25Hz

WiSES condition
$\Delta\Omega$: 80 mSr
θ : 30 – 60 deg
$\delta p/p$: 1 – 4×10^{-3}

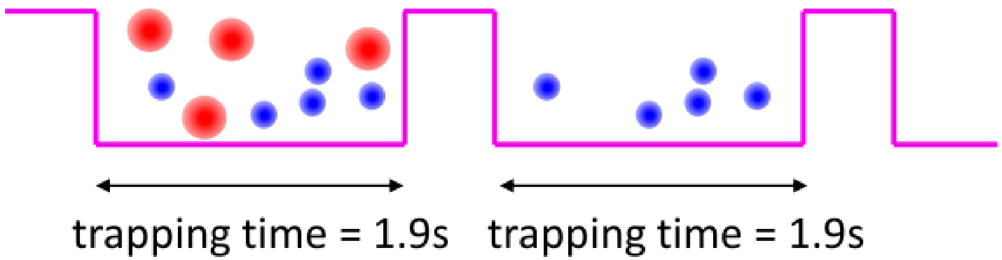


e-beam 15～20W

e-beam Energy: 150 MeV
Stored current: 150-200 mA

w/ ^{137}Cs ions

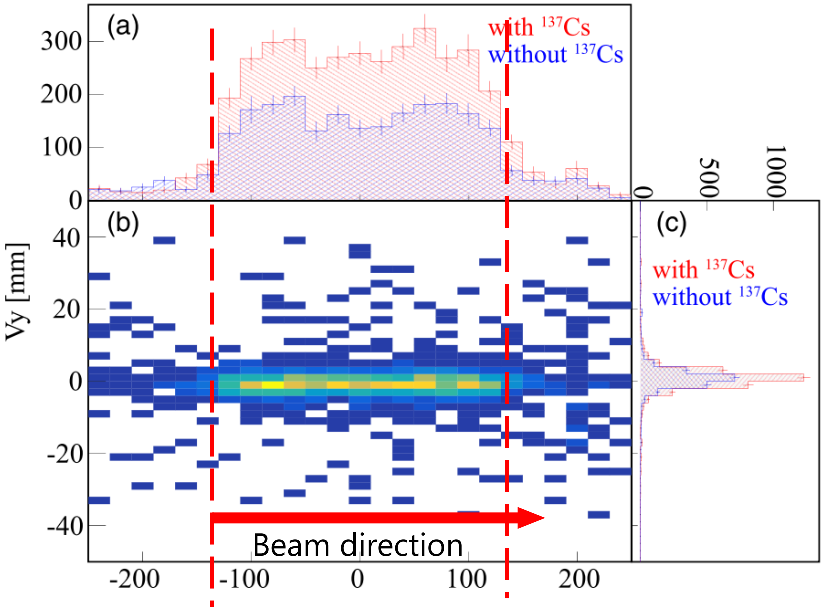
w/o ^{137}Cs ions
(only residual gas ions)

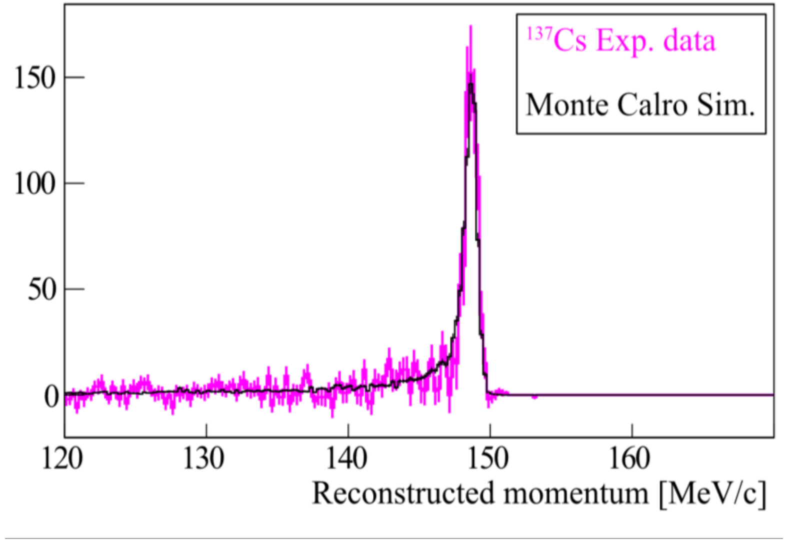


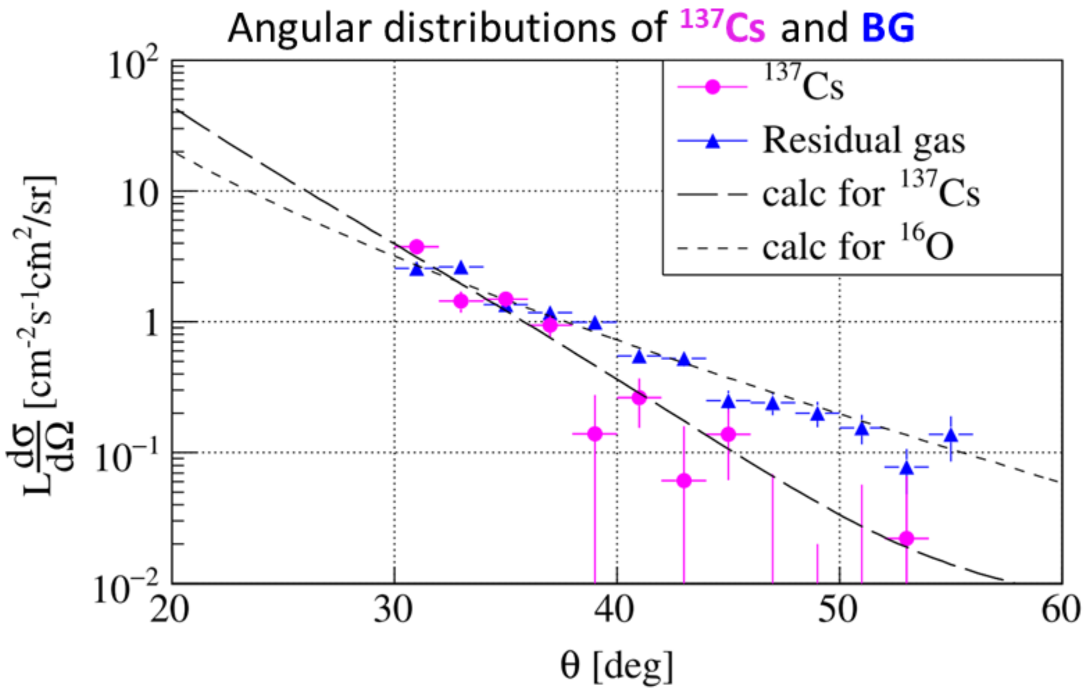
Luminosities: 0.9×10^{26} cm^{-2}s^{-1} for ^{137}Cs
1.5×10^{27} cm^{-2}s^{-1} for BG

Total measurement time: 3 days

Results





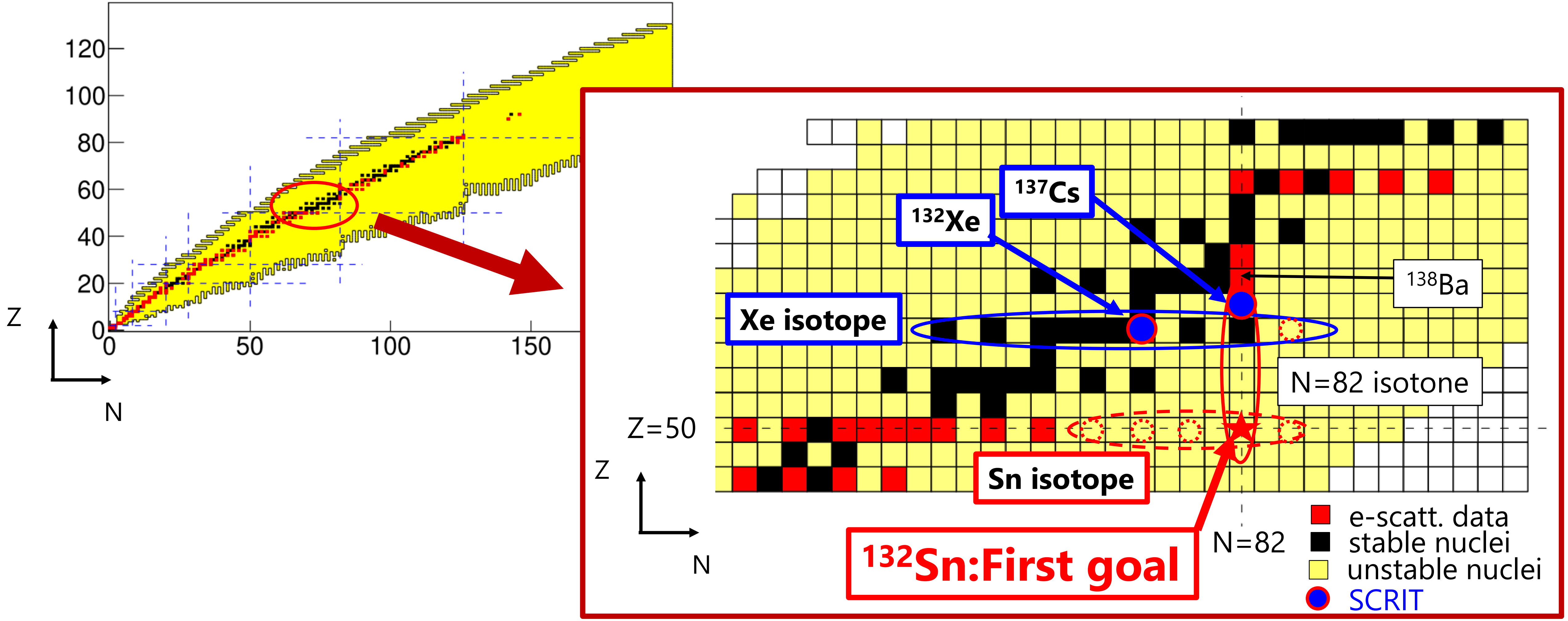


- ✓ Phase shift calculation, DREPHA, with 2-param Fermi dist.
- ✓ Assuming $<r^2>$ of 4.813 fm from isotope shift and t=2.3 fm
- ✓ ^{137}Cs : $I^P=7/2^+$, multipoles contrib. are negligible in this region

Elastic events with ^{137}Cs are clearly observed.

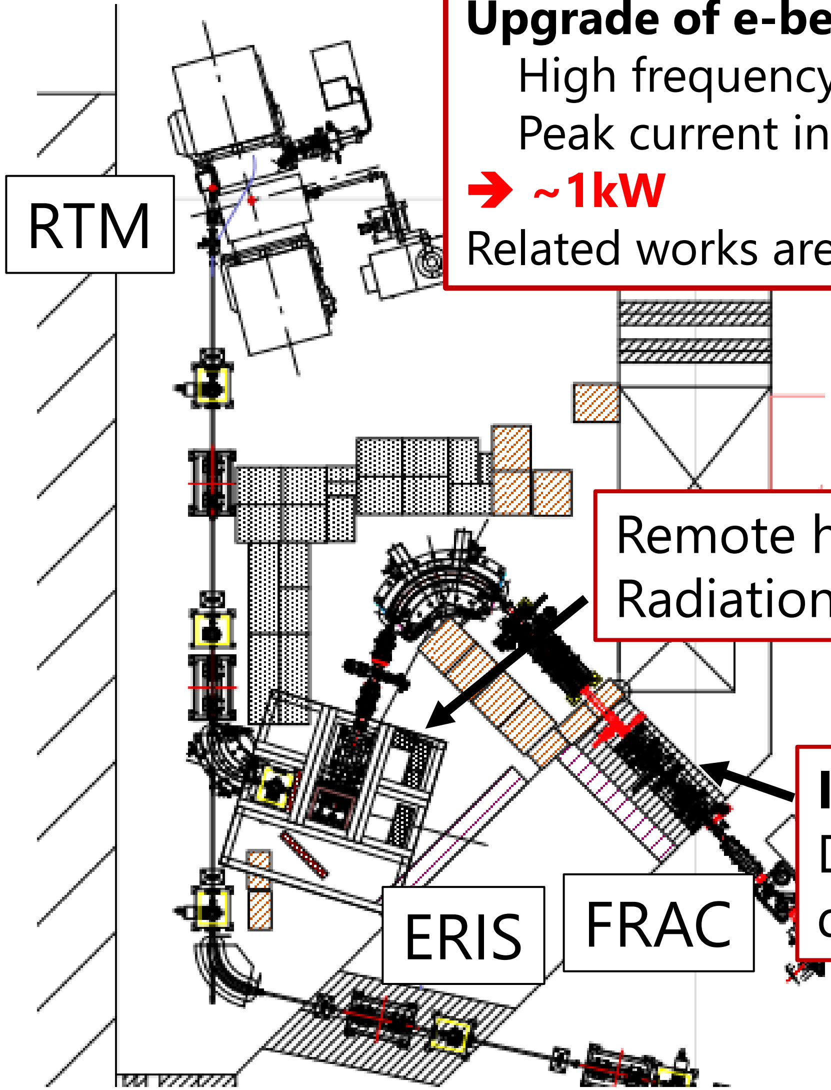
4. Perspective of SCRIT facility

Electron scattering around ^{132}Sn region



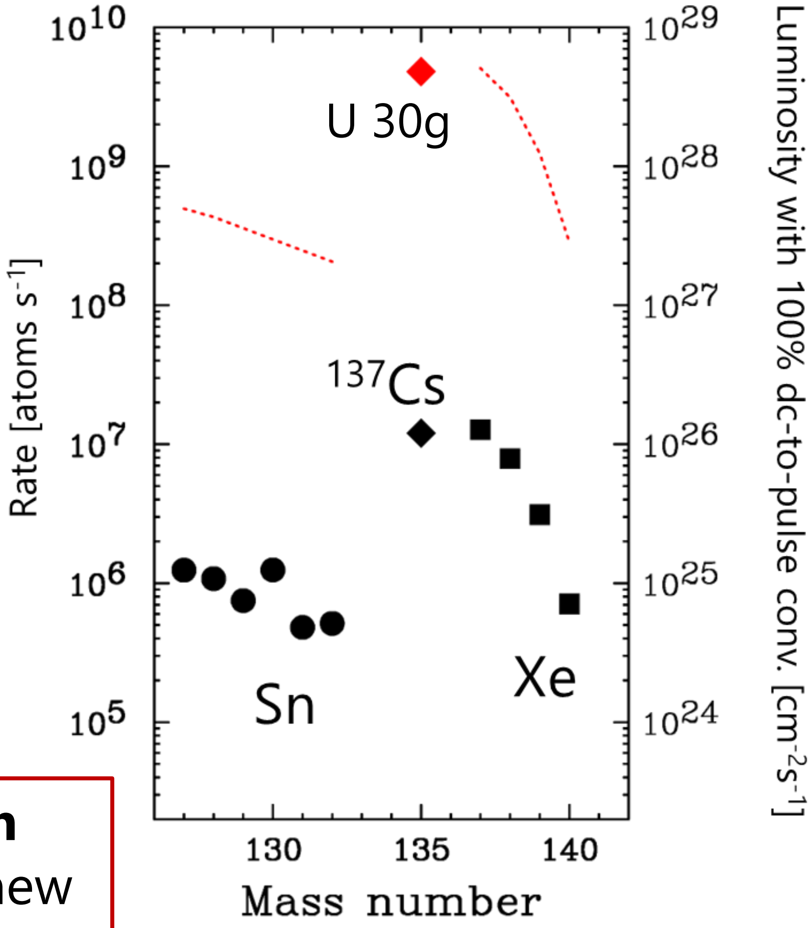
Upgrade towards short-lived nuclei

Upgrade of e-beam driver
High frequency (2Hz → 100 Hz)
Peak current increasing
➔ ~1kW
Related works are ongoing.



Remote handling system
Radiation shield

Isobar separation
Development of new devices is going on.



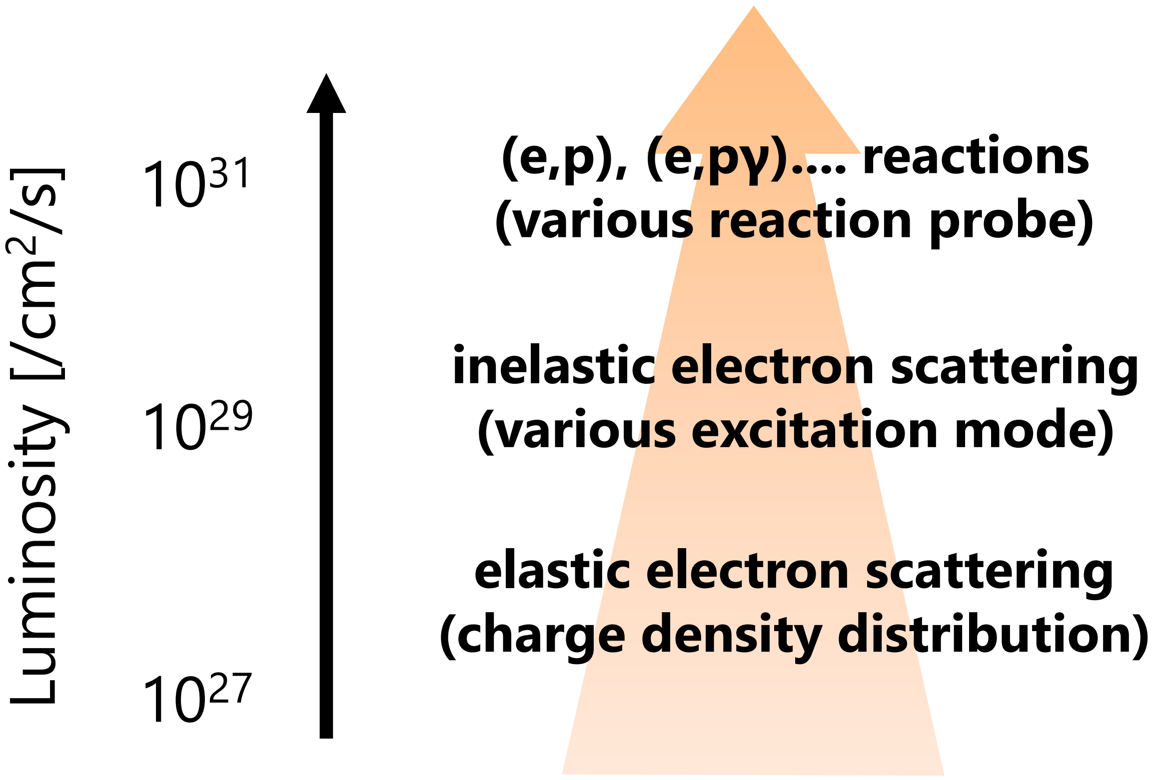
1 kW beam
ERIS Eff. × 4

10W beam
ERIS Eff.
5.5%(^{138}Xe)
2.0%(^{132}Sn)
5.5% (^{137}Cs)

Electron scattering with ^{132}Sn will be performed in near future.

Future plan

Precise Nuclear Spectroscopy



- Photo-absorption measurement
- Xe isotope dependence (on going)
- 4th-order moment measurement

to study neutron distribution

Future plan

Precise Nuclear Spectroscopy

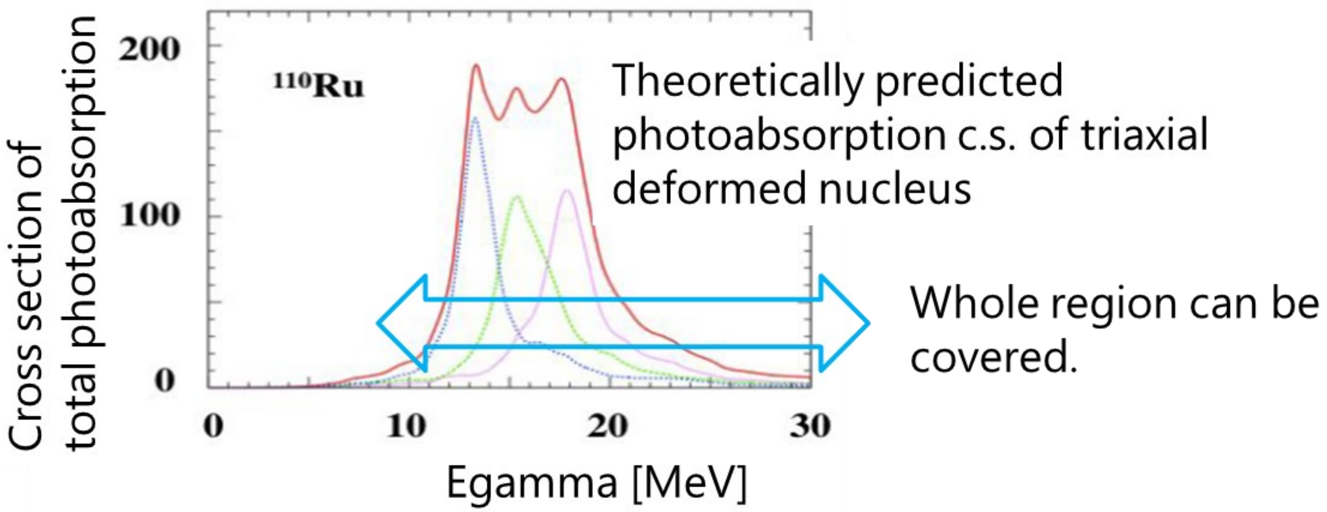
Luminosity [/cm^2/s]

10^{31} — **(e,p), (e,pγ)…. reactions (various reaction probe)**

10^{29} — **inelastic electron scatteri (various excitation mode**

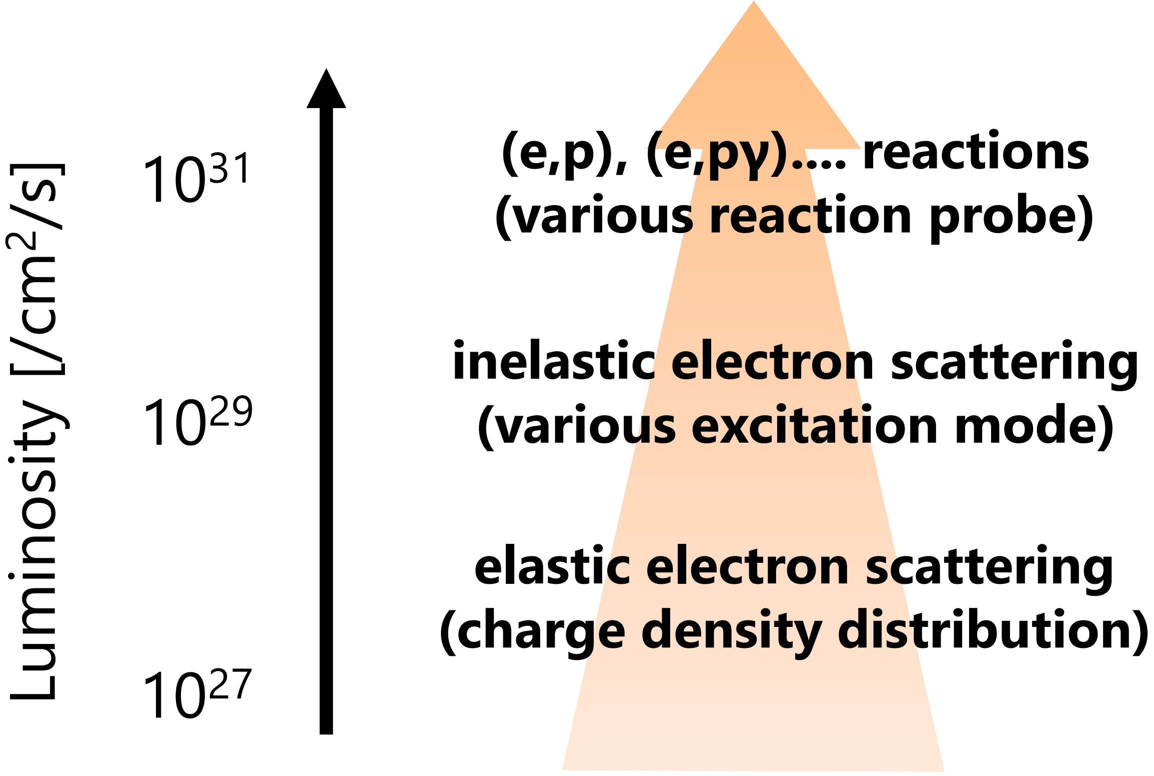
10^{27} — **elastic electron scattering (charge density distributio**

Zero-degree scattering



Future plan

Precise Nuclear Spectroscopy



- Next generation SCRIT
- Photo-absorption measurement
- Xe isotope dependence (on going)
- 4th-order moment measurement to study neutron distribution

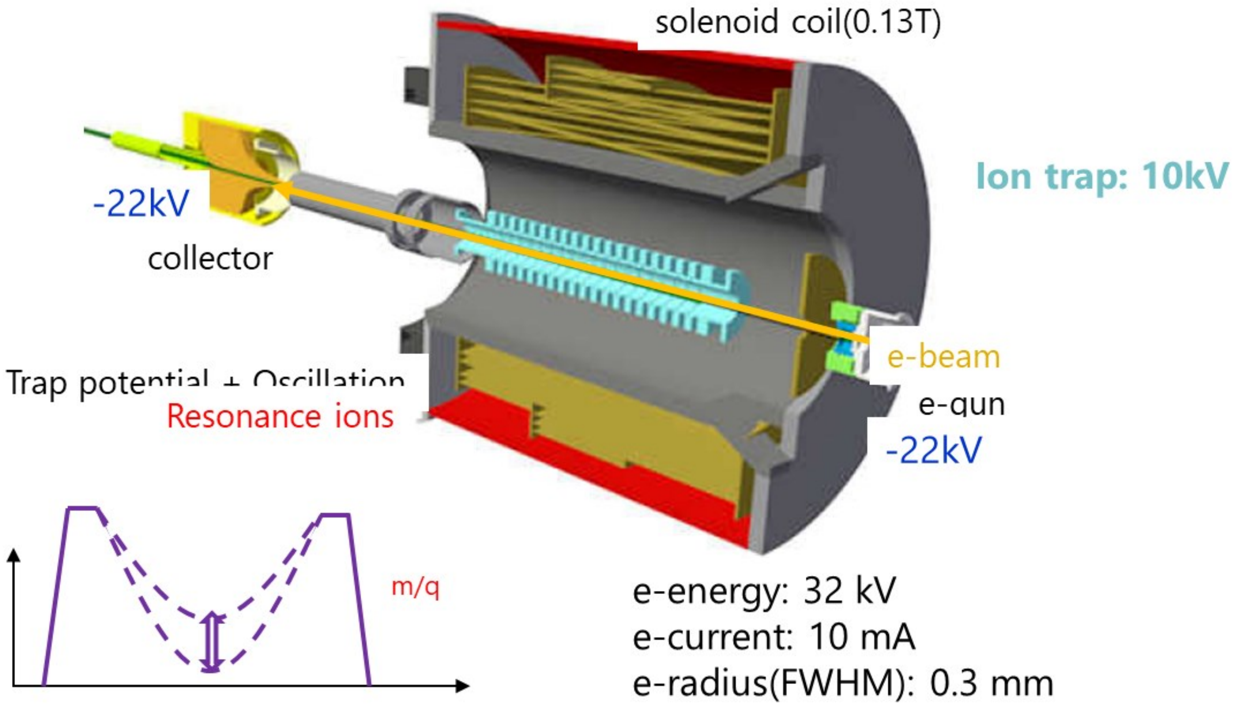
Future plan

Precise Nuclear Spectroscopy

Luminosity [/cm²/s]

Luminosity	
10^{31}	**(e,p), (e,pγ).... reactions (various reaction probe)**
10^{29}	**inelastic electron scattering (various excitation mode)**
10^{27}	**elastic electron scattering (charge density distribution)**

Prototype device (Charge breeder)
developed at ICR, Kyoto University



e-energy: 32 kV
e-current: 10 mA
e-radius(FWHM): 0.3 mm

• 4th-order moment measurement to study neutron distribution

H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys. 2019, 113D01.

Precise measurement at low momentum transfer region

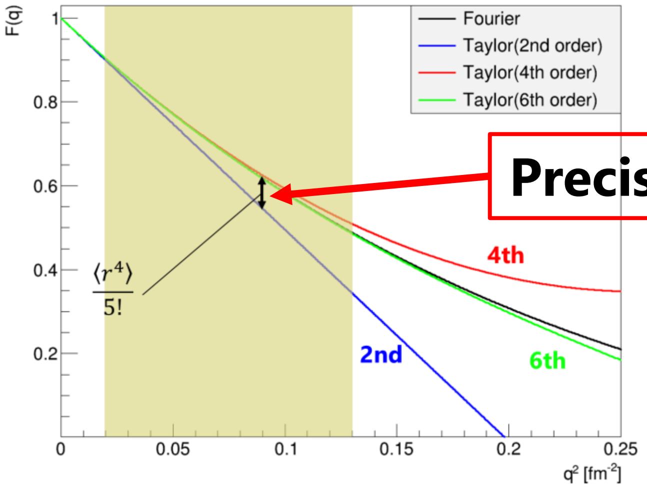
$$\langle r_C^4 \rangle = \int r^4 \rho_C(r)\, dr^3 = \langle r^4_{p(point)} \rangle + \frac{10}{3}\langle r^2_{p(point)} \rangle \langle r_p^2 \rangle + \frac{10}{3}\langle r^2_{n(point)} \rangle \langle r_n^2 \rangle \frac{N}{Z} + \text{relativistic corr.}$$

proton radius — neutron radius

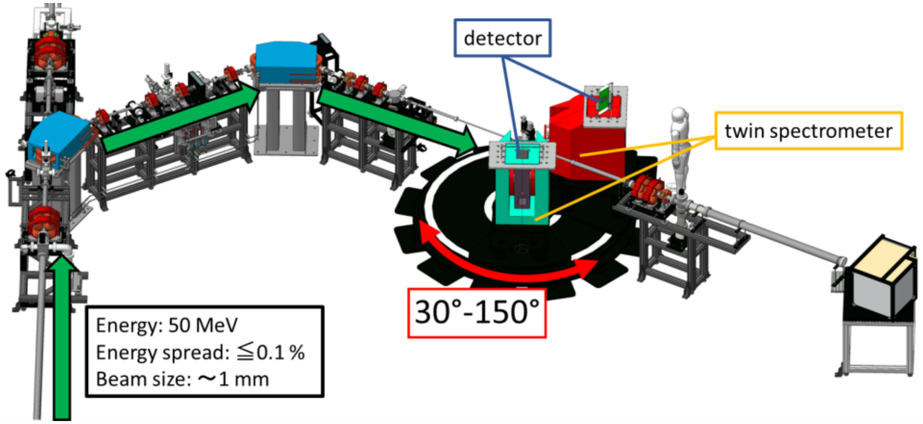
Point proton radius — Point neutron radius

Low-q region

$$\sim 1 - \frac{\langle r_C^2 \rangle}{3!} q^2 + \frac{\langle r_C^4 \rangle}{5!} q^4 - \frac{\langle r_C^6 \rangle}{7!} q^6 + \cdots \text{ (PWIA)}$$



LEEP (Low Energy Electron scattering with ^{208}Pb) experiment at RARiS



Establishment of new method

large cross section ($1/q^4$)

➔ Application to unstable nuclei at SCRIT

5. Summary

・The SCRIT electron scattering facility was constructed and many development have performed.

・World's first experiment of electron scattering with online-produced unstable nuclei was successfully performed.

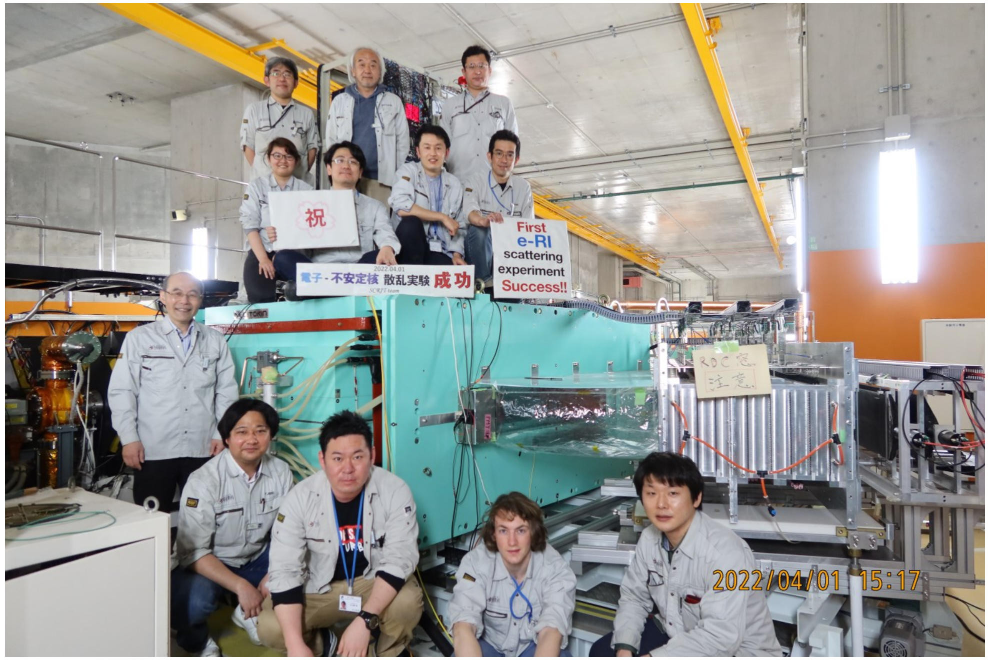
・Upgrade of RI beam production is already started.
The electron scattering with ^{132}Sn will be performed in near future.

The way to new and long-awaited research method,
electron scattering with unstable nuclei, is opened.

SCRIT collaboration

D. Abe[1], Y. Abe[2], R. Danjyo[1], A. Enokizono[2] , T. Goke[1], M. Hara[2] ,Y. Honda[1], T. Hori[2] , S. Iimura[3], S. Ichikawa[2] , Y. Ishikura[1], K. Ishizaki[1], Y. Ito[4], K. Kurita[3], C. Legris[1], Y. Maeda[4], Y. Maehara[4], R. Obara[1], R. Ogawara[2] , T. Ohnishi[2], T. Suda[1,2] , M. Tachibana[4], T. Tamae[1], K. Tsukada[2,4], M. Wakasugi[2,4], M. Watanabe[2], H. Wauke[1,2] , T. Yamano[3], S. Yoshida[4]

[1]ELPH Tohoku University, [2]RIKEN, Nishina Center, [3]Rikkyo University, [4]ICR Kyoto University



Thank you for your attention!