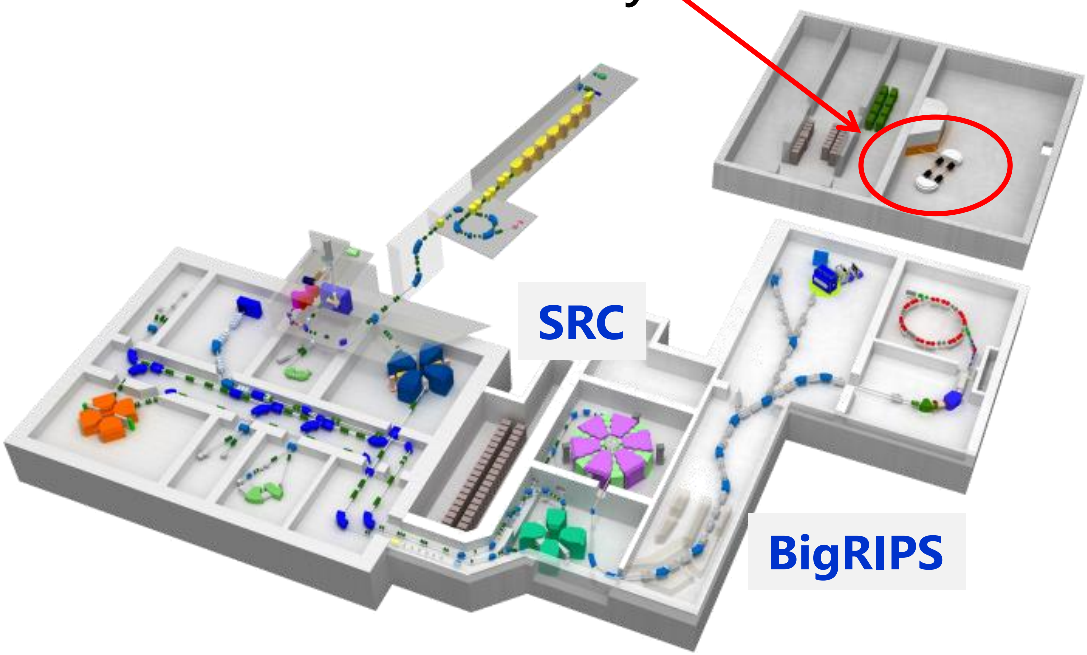
The SCRIT project at RIKEN

NUSTAR Annual Meeting 2020, GSI, Mar. 5, 2020

SCRIT facility



RIKEN RI Beam Factory

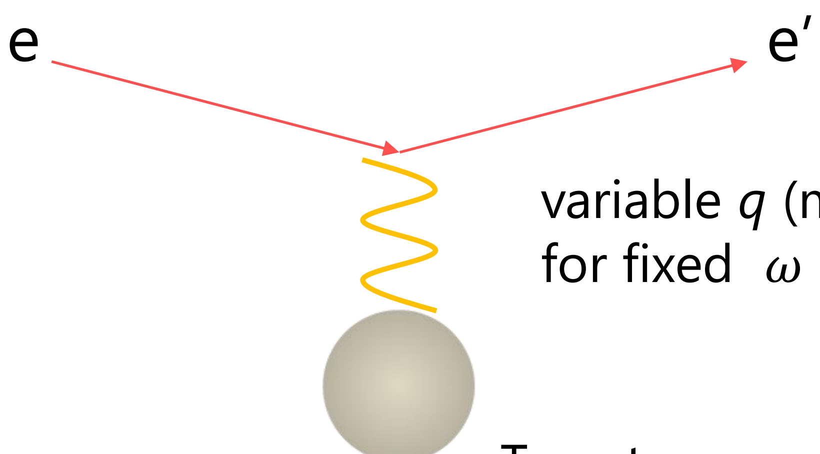
RIKEN Nishina center
Tetsuya Ohnishi
and
SCRIT collaboration

1. Introduction
2. SCRIT facility
3. First physics run
4. Recent developments
5. Future plans
6. Summary

Electron scattering on nuclei

Electron scattering :
Precise information of internal structure of nuclei

Coulomb interaction	Well known and model independent
Structure-less particle	Point-like probe
Weak interaction	Probing whole volume of nucleus without any serious modification



variable q (momentum transfer)
for fixed ω (energy transfer)

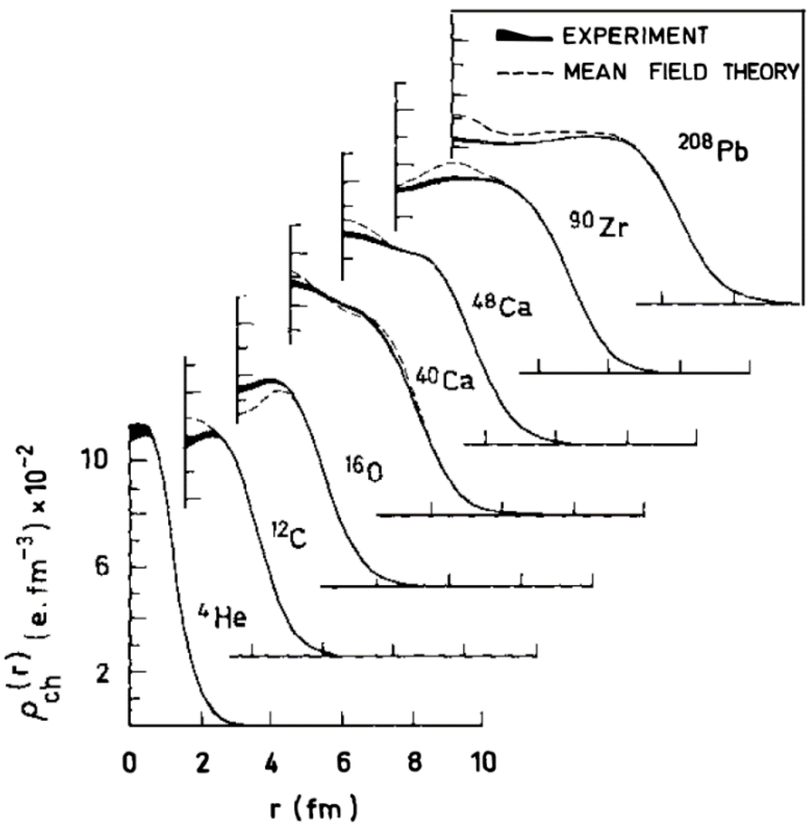
Target

Electron scattering on nuclei

Elastic electron scattering

= Mott scattering × Form factor

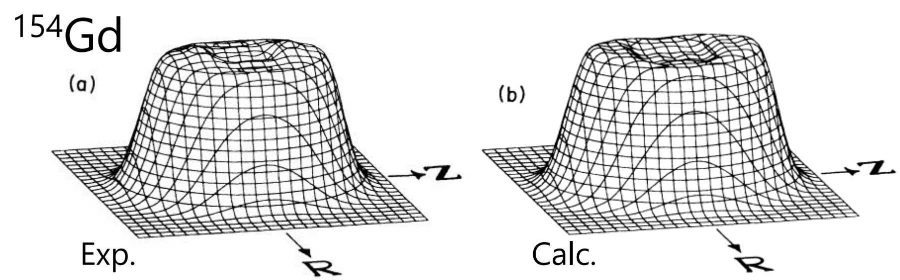
➔ Charge density distribution



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

Various subjects

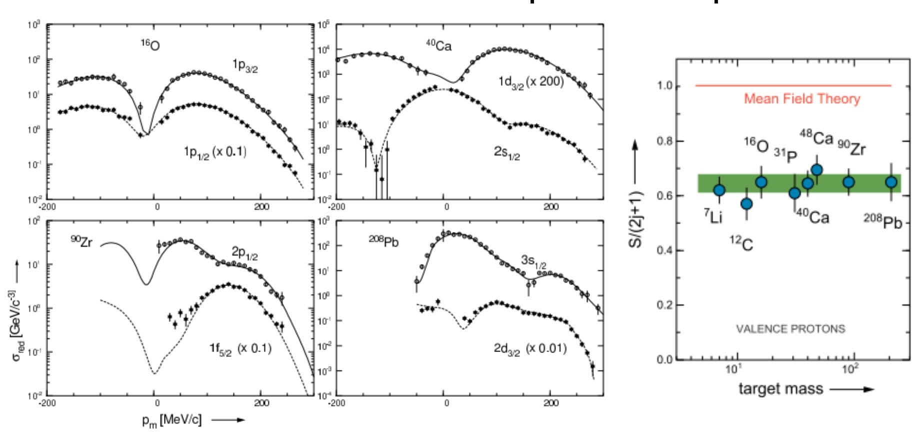
Deformation



F. W. Hersman et al., Phys. Rev. C33 (1986) 1905.

quasi-elastic scattering (e,e'p)

→ Spectroscopic factor



H. Dickhoff, C. Barbieri, Prog. Part. Nucl. Phys. 52 (2004) 377.

Electron scattering on short-lived unstable nuclei

Unstable nuclei: Exotic structure (halo, skin, new magic number..)

→ Electron scattering can provide

"Direct and unambiguous structure information".

No electron scattering experiment on short-lived unstable nuclei at present

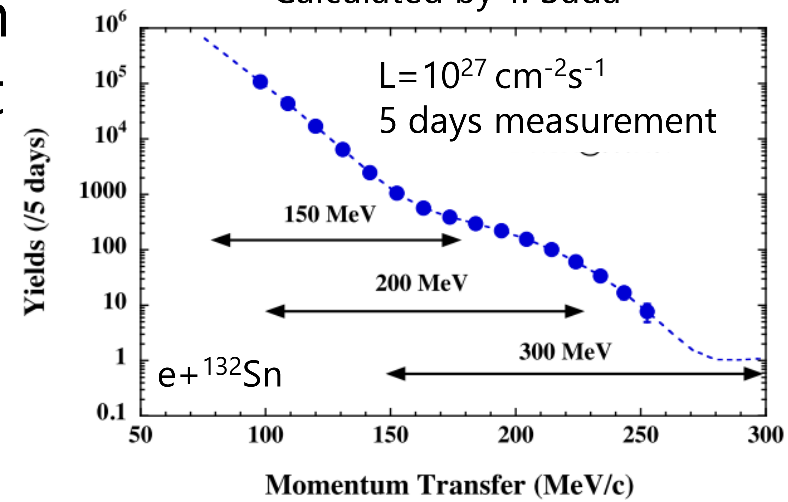
→ Main difficulty: **Luminosity**

L = Beam [atoms/s] × Target [atoms/cm^2]

Elastic scattering (largest σ)

Required luminosity 10^{27} $cm^{-2}s^{-1}$

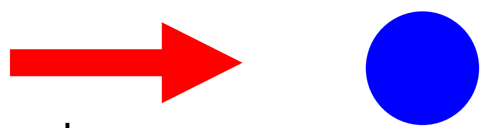
Calculated by T. Suda



How realize electron scattering with unstable nuclei?

Ways to realize electron scattering with unstable nuclei

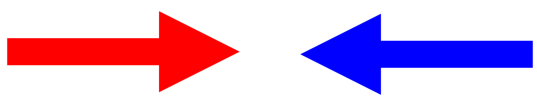
1) RI target



Low production rate of RI ➔
Electron storage ring
+ new target forming technique

SCRIT

2) Collider



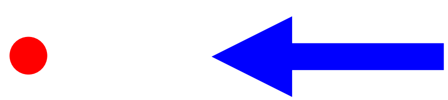
ELISe at FAIR

A.N. Antonov et al., Nucl. Instrum. and Meth. A637(2011)60.

DREICA at Dubna

L. V. Grigorenko et al., Phys. Part. Nucl. Lett 15 (2018) 997.

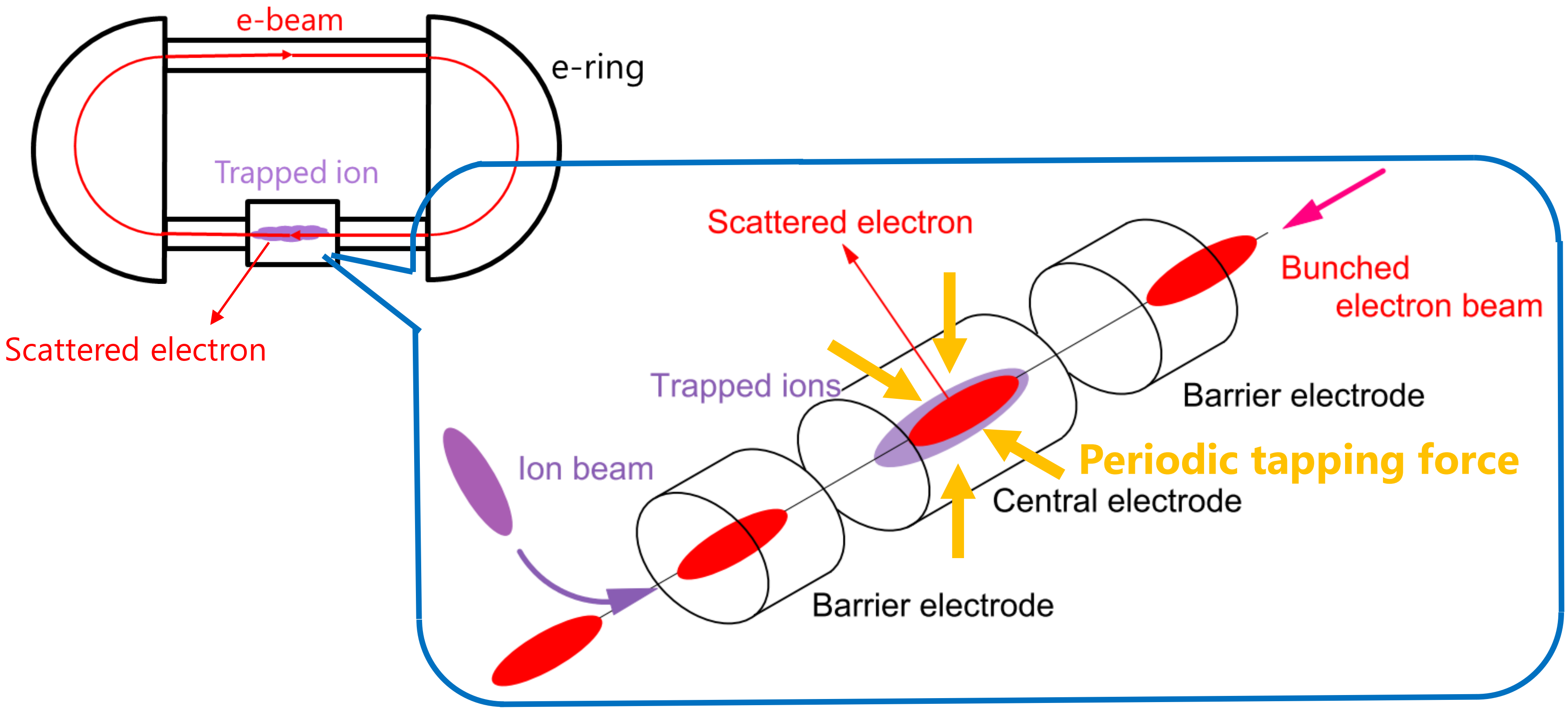
3) Electron at reset



RI beam energy
~ 600 GeV/A (γ_A~600) (E_e 300MeV)

SCRIT (Self Confining RI Ion Target)

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



Longitudinal direction: Electric potential
Transverse direction: Trapping force by e-beam
→ known as ion trapping phenomena in e-ring

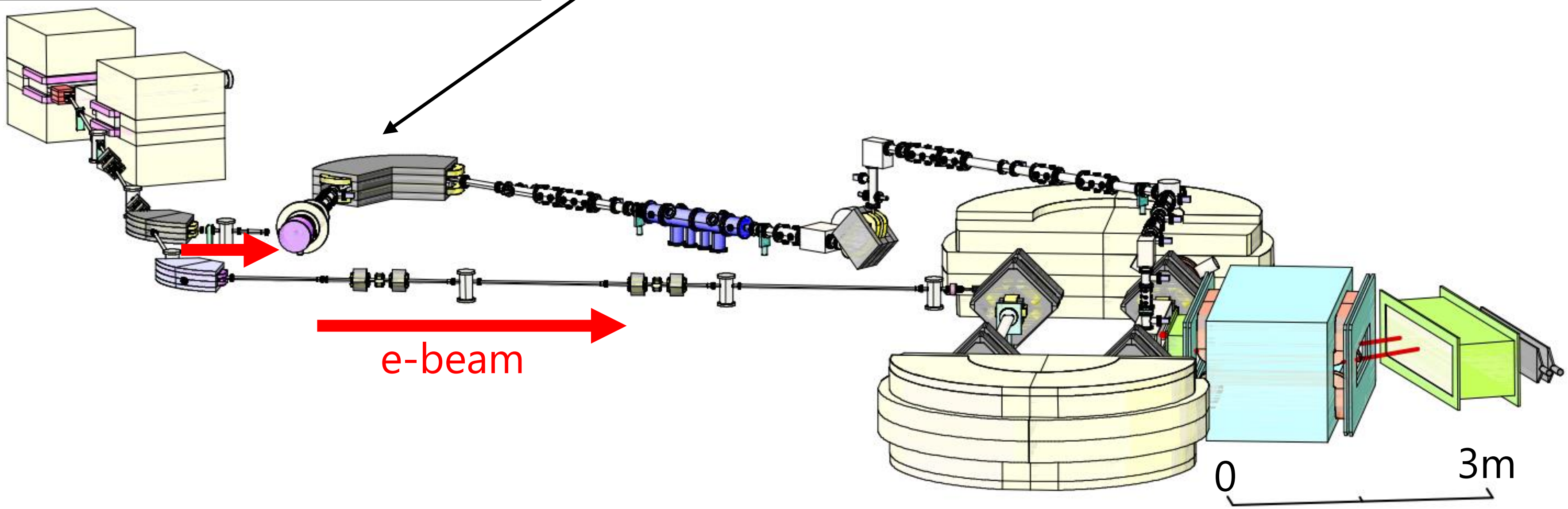
Automatic electron scattering with trapped ions

2. SCRIT electron scattering facility

M. Wakasugi et al., NIMB 317 (2013) 668.

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

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



SR2 (SCRIT equipped RIKEN Storage Ring)100 ~700 MeV

SCRIT: M. Wakasugi et al., NIMB 317 (2013) 668.
ERIS: T. Ohnishi et al., NIMB 317 (2013) 357.
FRAC: M. Wakasugi et al., Rev. Sci. Instrum. 89 (2018) 095107.
WiSES: A. Enokizono et al., PoS (INPC2016) 092.

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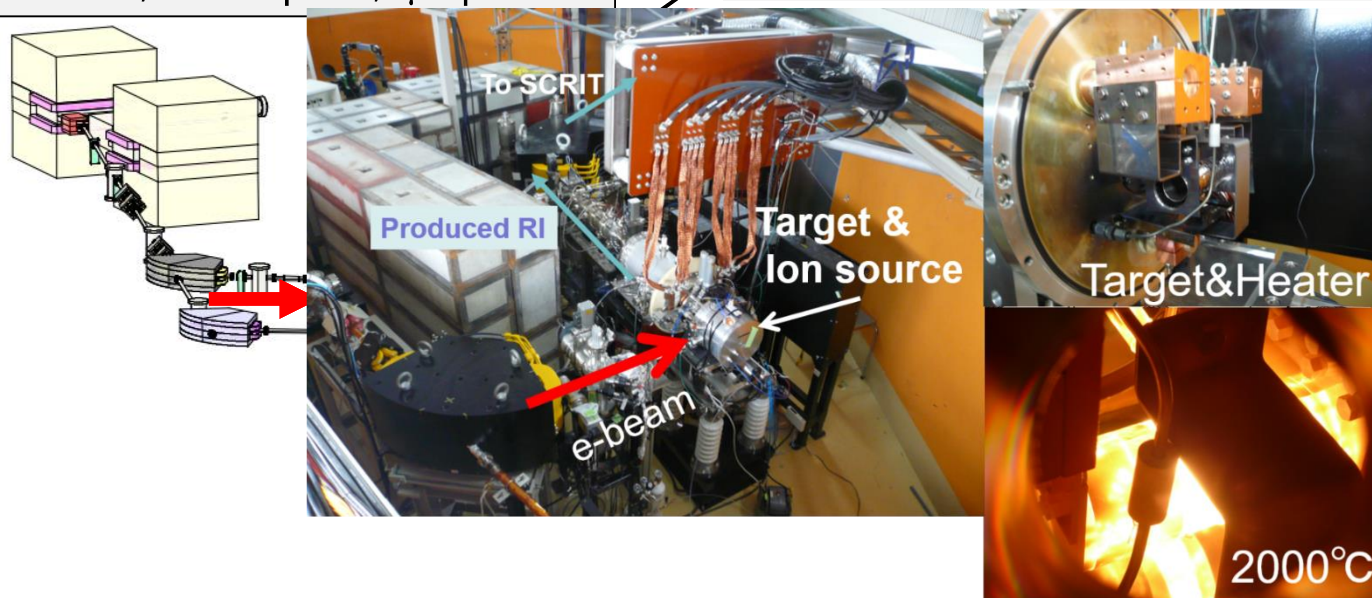
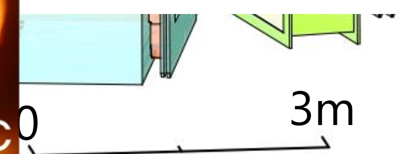


House-made uranium carbide disks
φ18 mm, 0.8 mm^t
U density 3.4 g/cm^3
C/U ~6



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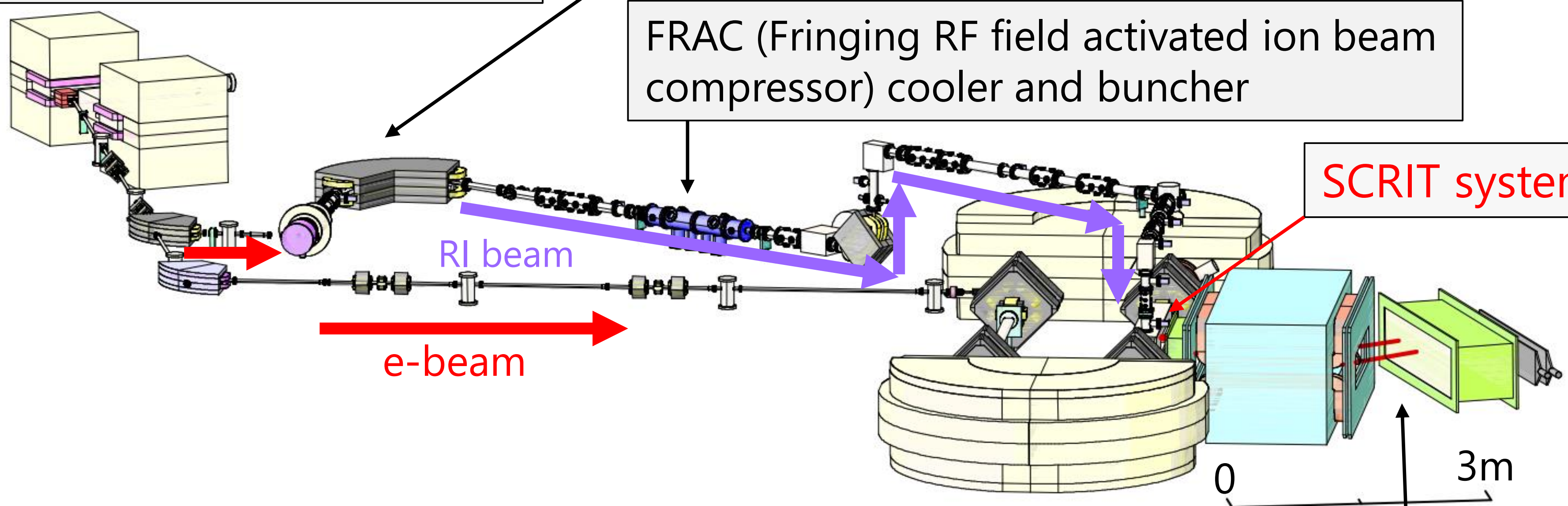
FRAC (Fringing RF field activated ion beam compressor) cooler and buncher

SCRIT system



SR2 (SCRIT equipped RIKEN Storage Ring)100 ~700 MeV

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

LMon: Luminosity monitor (CsI+Fiber Scinti.)

SCRIT: M. Wakasugi et al., NIMB 317 (2013) 668.
ERIS: T. Ohnishi et al., NIMB 317 (2013) 357.
FRAC: M. Wakasugi et al., Rev. Sci. Instrum. 89 (2018) 095107.
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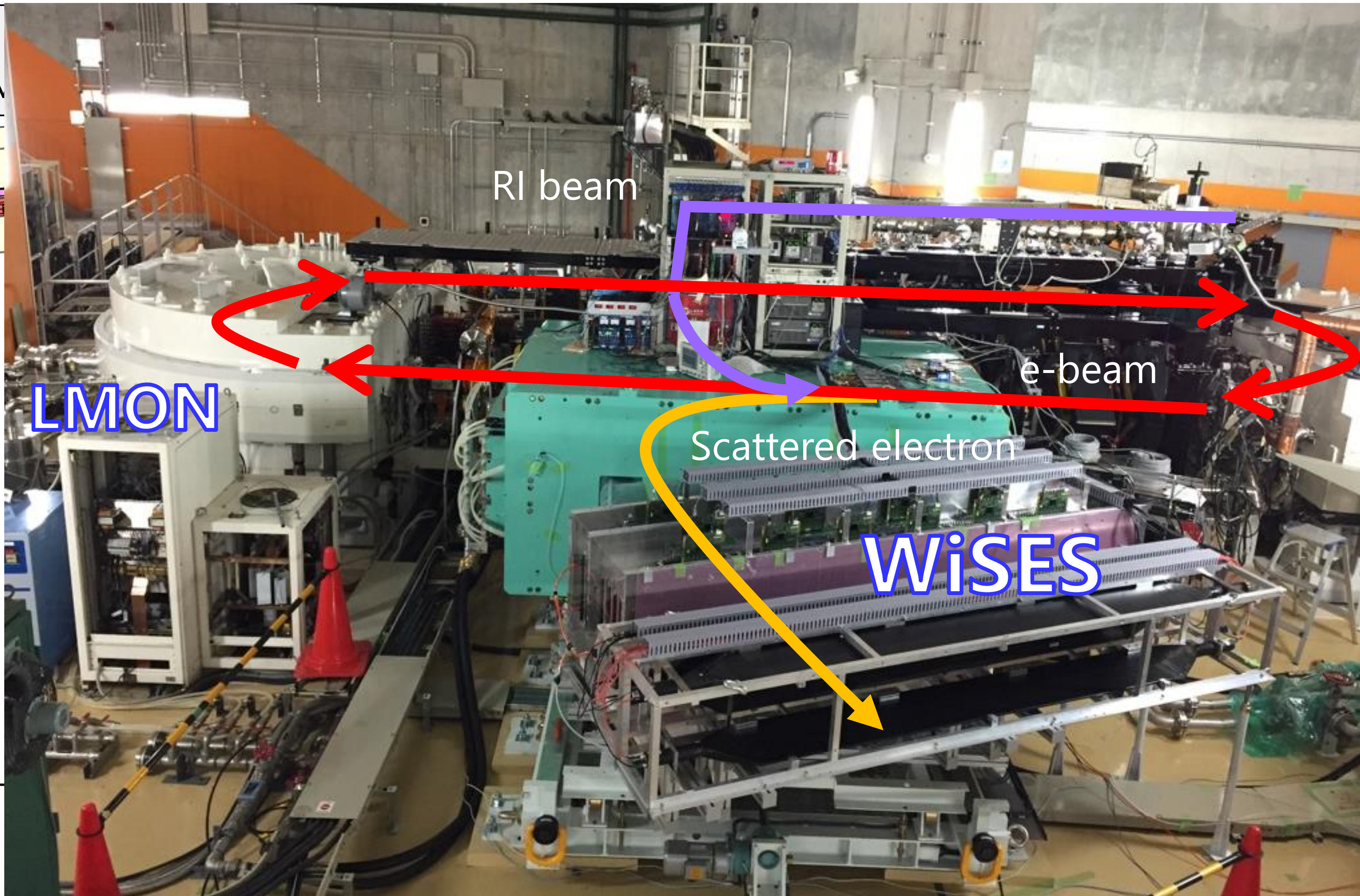
2. SCRIT electron scattering facility

M. Wakasugi et al., NIMB 317 (2013) 668.

RTM
150 M

)

ystem



m

SCRIT:
ERIS: T
FRAC:
(2018)
WiSES: A. Enokizono et al., PoS (INPC2016) 092.

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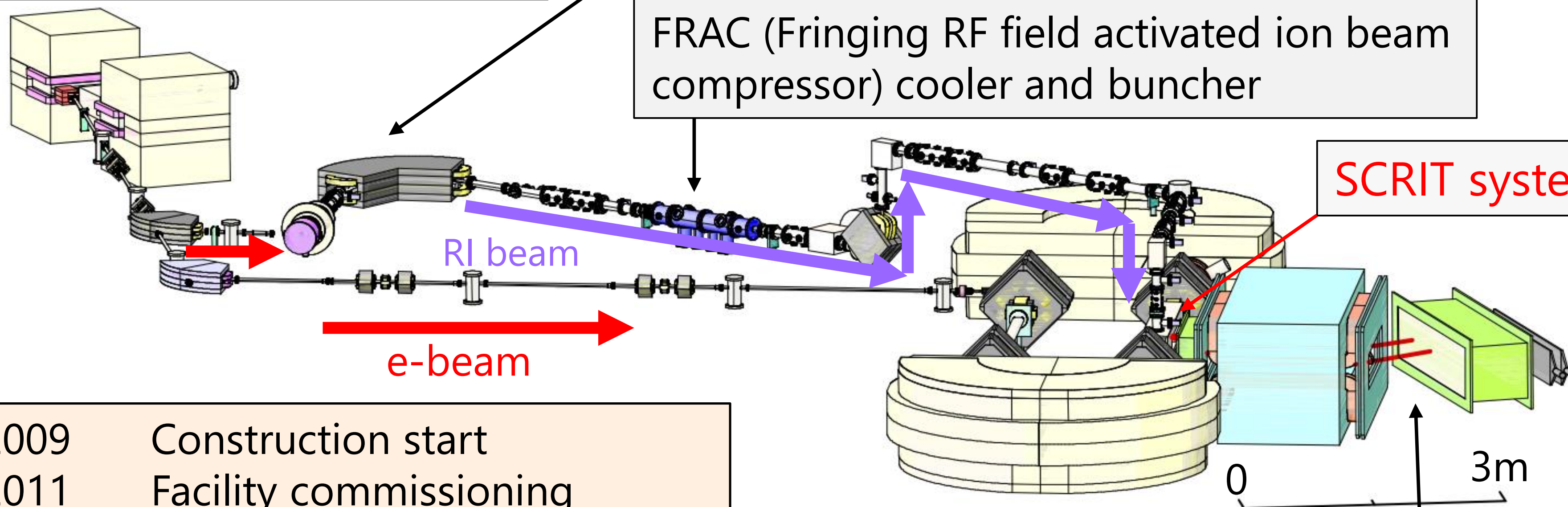

2009	Construction start
2011	Facility commissioning
2013	RI production start
2014	Spectrometer installation
2015 ~ 2016	Experiment with stable nuclei
2016 ~	Development of ion beam cooling & pulsing

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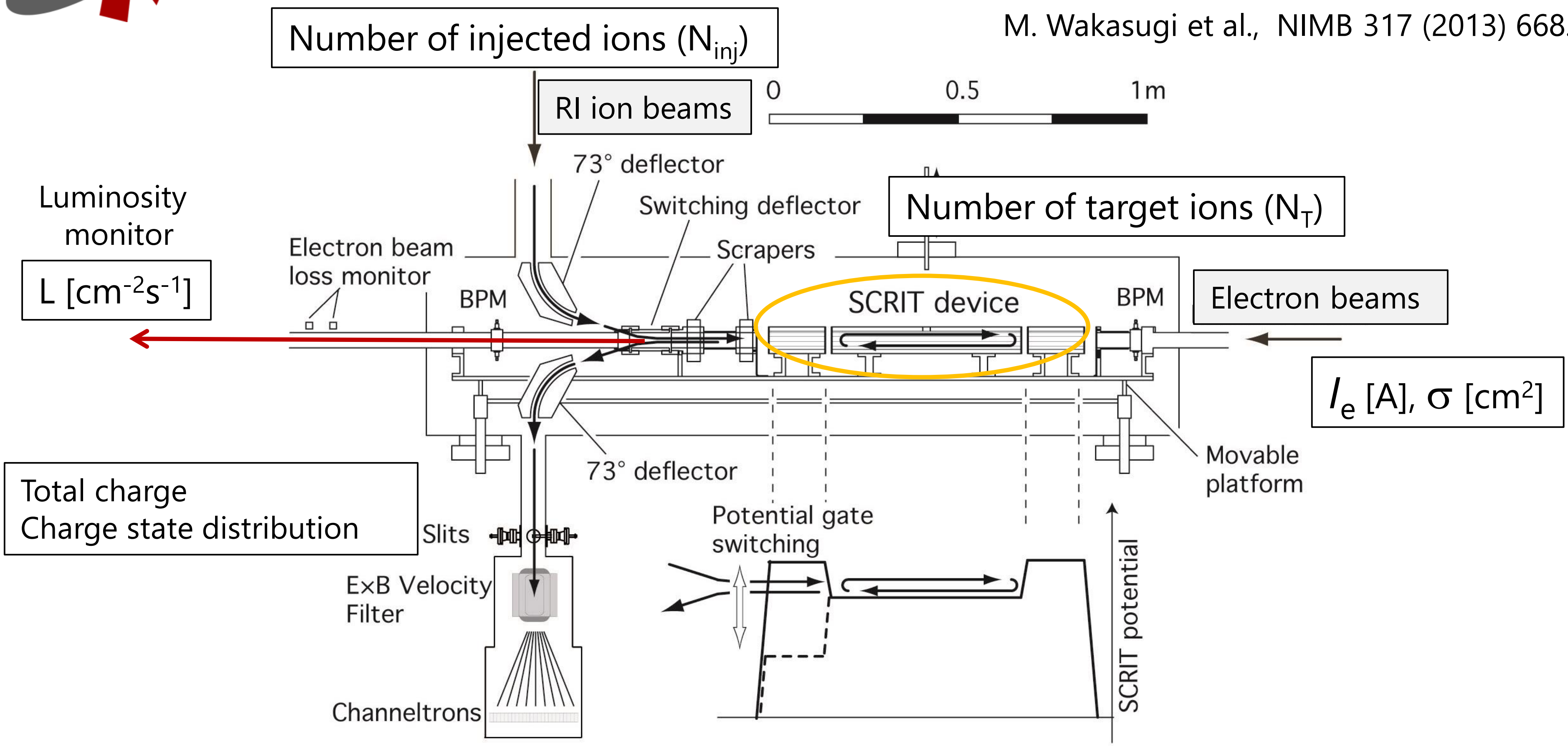


Luminosity $L \sim \dfrac{I_e/e \cdot N_T}{\sigma}$ [cm^{-2}s^{-1}]

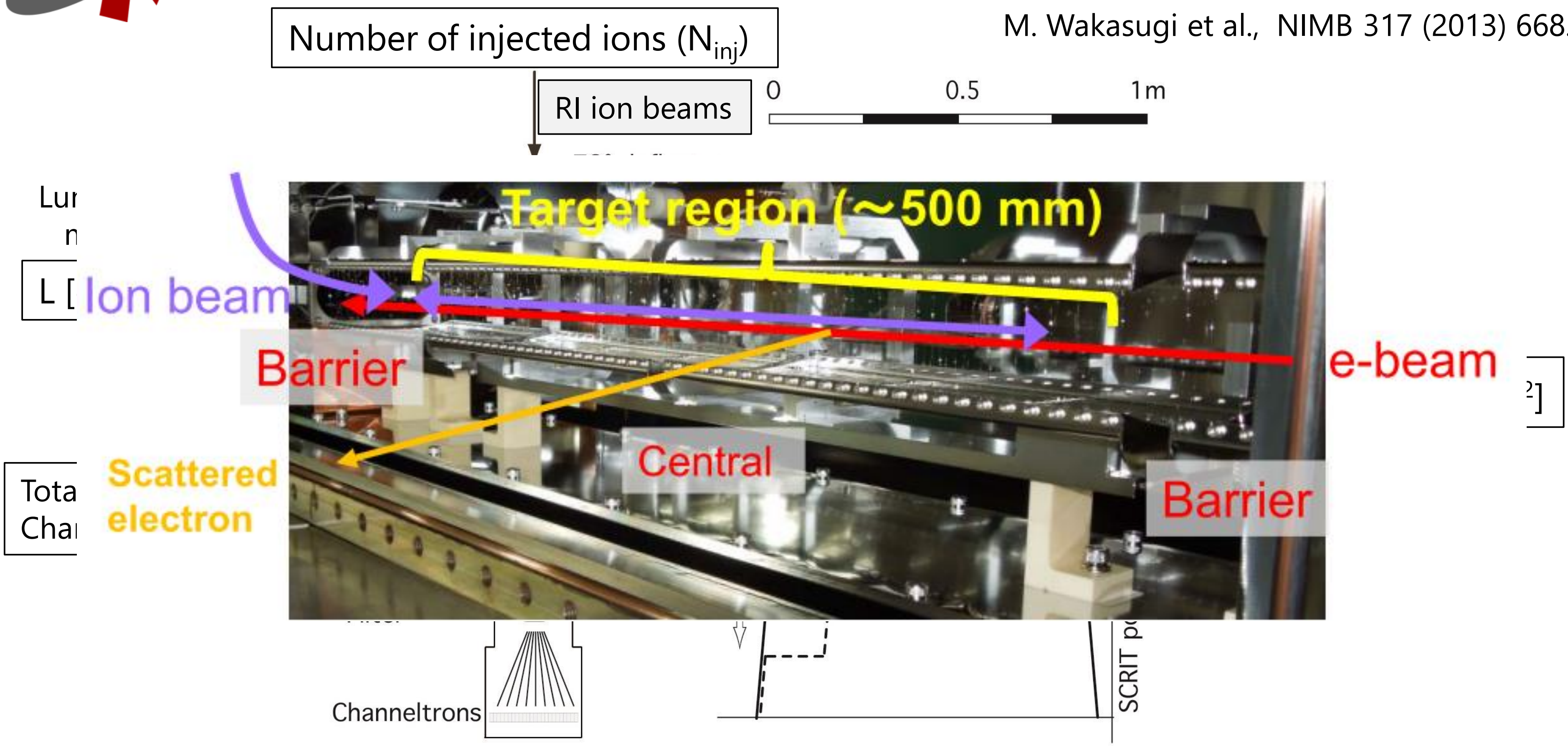
$$N_T = \varepsilon_{trap}\varepsilon_{overlap}N_{inj}$$

Typical value

- $L \sim 1.4\times10^{27}$ cm^{-2}s^{-1}
- $I_e \sim 175$ mA, $\sigma \sim 3.6$ mm^2
- $N_{inj} \sim 2.3\times10^{8}$ /pulse, $N_T \sim 4.6\times10^{7}$ /pulse
- $\varepsilon_{trap}\varepsilon_{overlap} \sim 19.8\%$

SCRIT system

M. Wakasugi et al., NIMB 317 (2013) 668.



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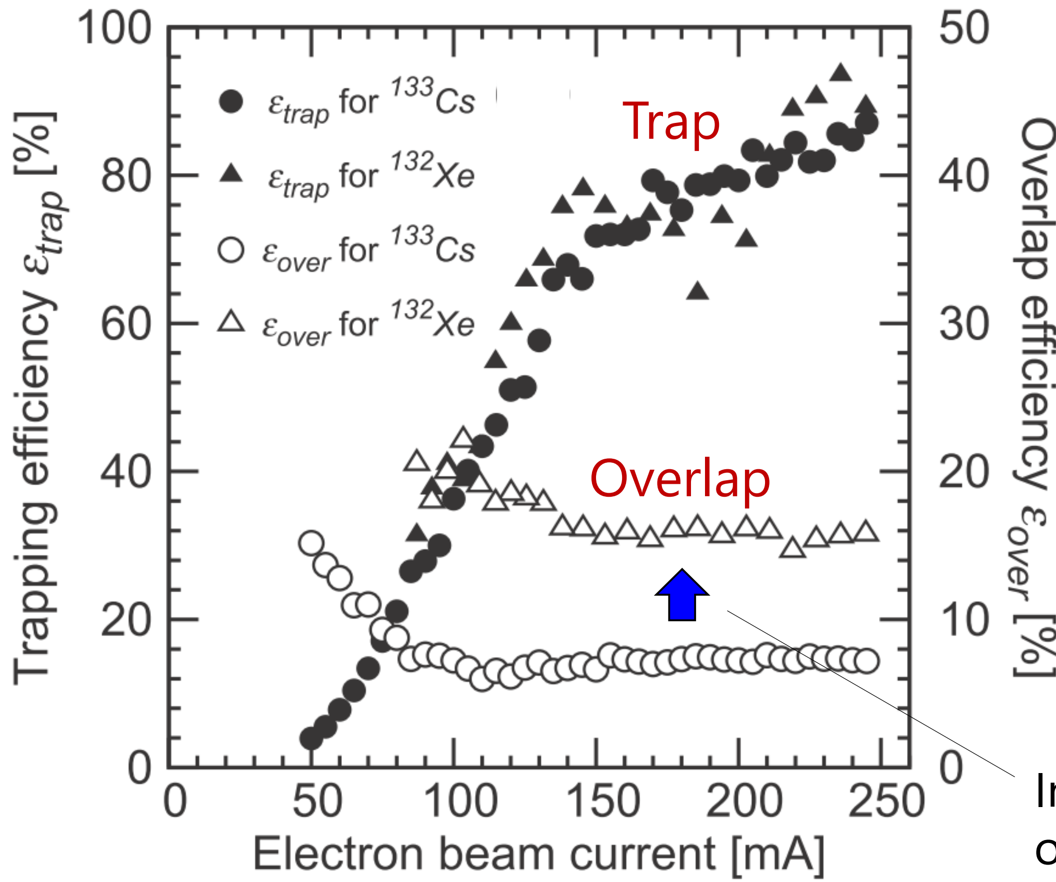
Trap and overlap efficiency

R. Ogawara et al., NIMB 317 (2013) 674.

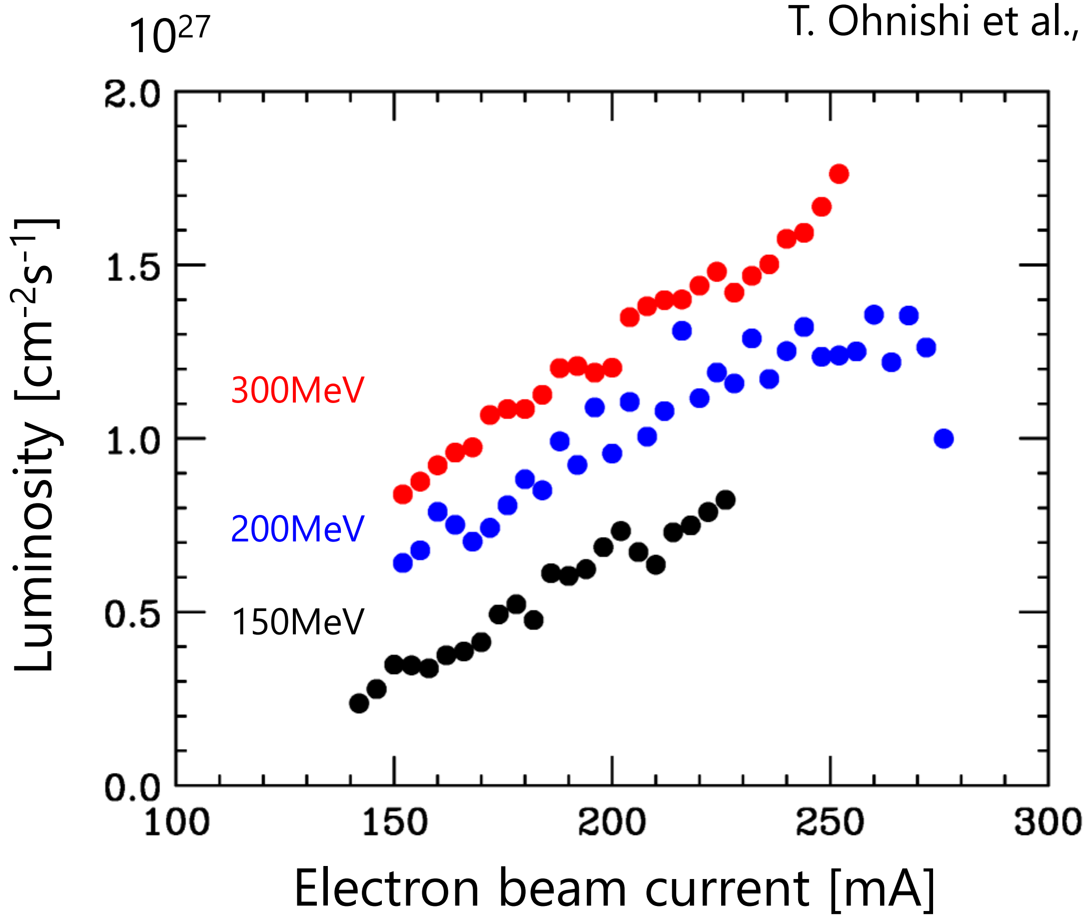


E_e: 150MeV
Trap: 45 ms

Improvement of Ion optics

Achieved Luminosity

T. Ohnishi et al., PoS (INPC2016) 088.



Injection ion (^{132}Xe) ~2×10^{8} particles/pulse

L ~ 1.8×10^{27} $cm^{-2}s^{-1}$ at e-beam 250 mA

Experimental conditions

	E_e	I_e	N_{target}	Luminosity
e-beam (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}/cm^2	~10^{36}/cm^2/s
Collider* (ELISe)	740MeV(Ion) 500 MeV(e^-)	400 mA (10^{18}/s)	10^7 /bunch	10^{28}/cm^2/s
SCRIT	150-300 MeV	300 mA (~10^{18}/s)	~10^9/cm^2	~10^{27} /cm^2/s

~10^7 target, ~mm^2

*A.N. Antonov et al., Nucl. Instrum. and Meth. A637(2011)60.

$$L = F_e n_e \frac{N_e N_A}{4\pi\sigma_x\sigma_y}$$

F_e=5.5MHz, n_e=8, N_e=5×10^{10}, N_A=0.86×10^7, σ_x=0.21mm, σ_y=0.09 mm

3. First physics run

- Elastic electron scattering with ^{132}Xe -

Elastic electron scattering

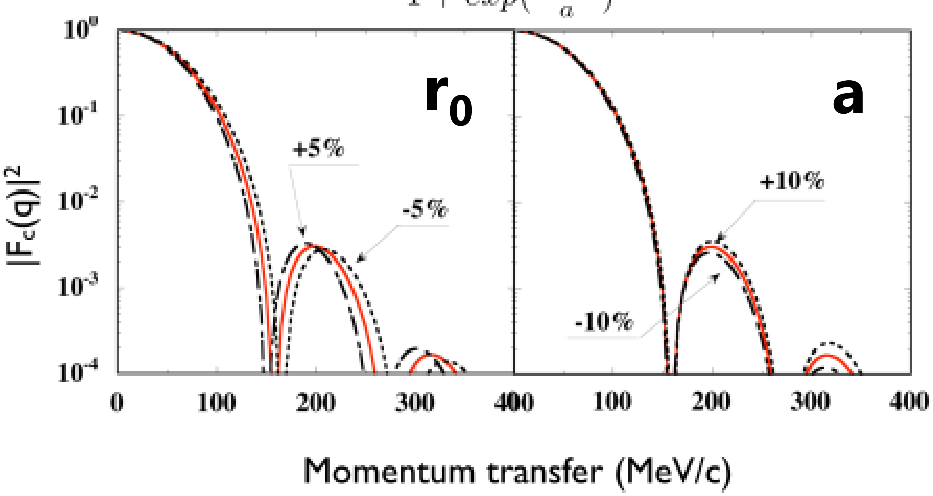
for (spin-less) nuclei

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} |F_c(q)|^2 \quad \propto \frac{1}{q^4}$$

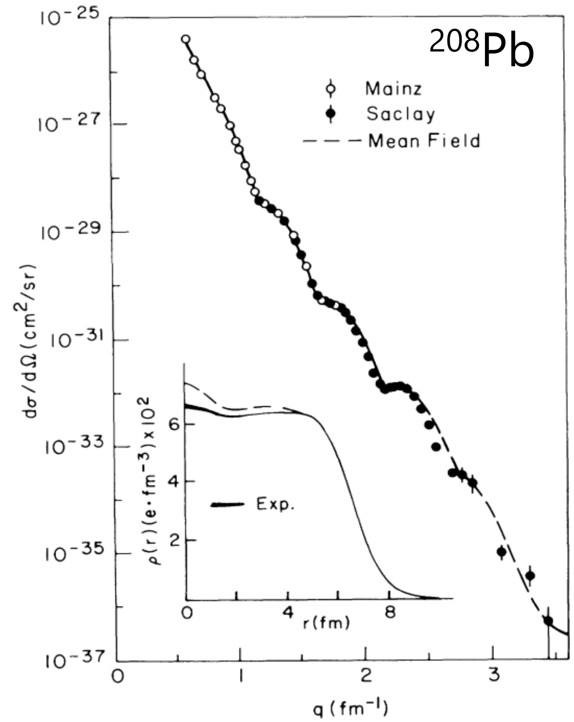
$$F_c(q) = \int \rho_c(r) e^{iqr} d^3r$$

low luminosity ➔ <u>moderate *q* range</u>

$$\rho(r) = \frac{\rho_0}{1 + exp(\frac{r - r_0}{a})}.$$



e+^{132}Sn
Calculated by T. Suda



J. M. Cavedon et al., PRL 58 (1987) 195.

Elastic electron scattering of ^{132}Xe

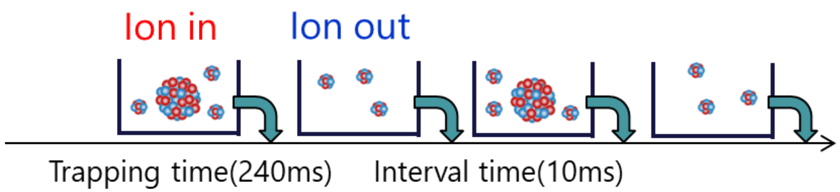
K. Tsukada et al., Phys. Rev. Lett. 118 (2017) 262501.

- Conditions

e-Energy	151, 201, 301 MeV
Trapping time	240 ms
Ave. current	200 mA
Inj. ions	2×10^{8} ions/injection

- Measurement scheme

IonIN(Target ion +Residual gas) – IonOUT(Residual gas)

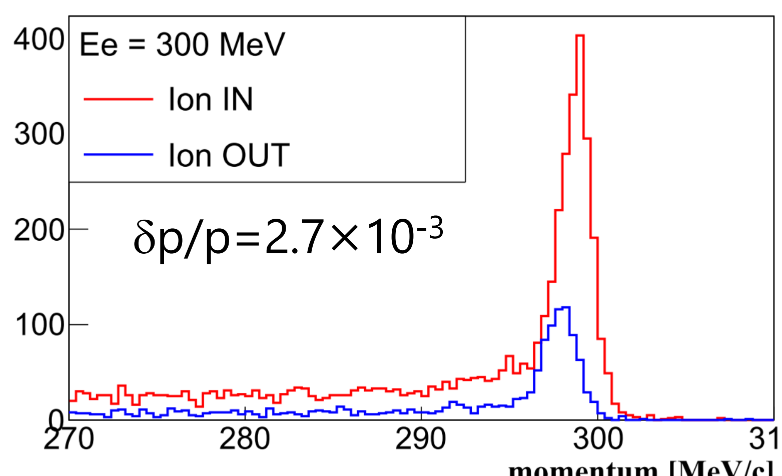


- Momentum spectrum

  Clear elastic peak from

  Targets (IonIN),

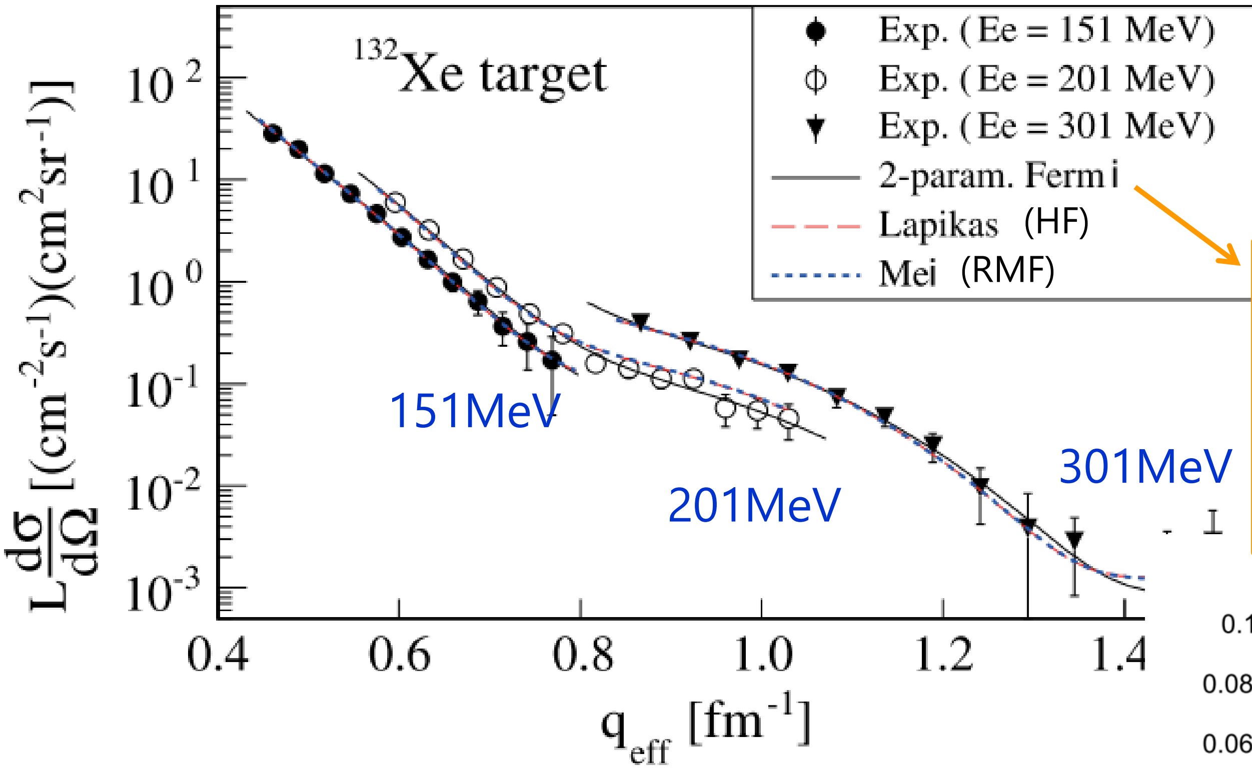
  Residual gas (IonOUT)



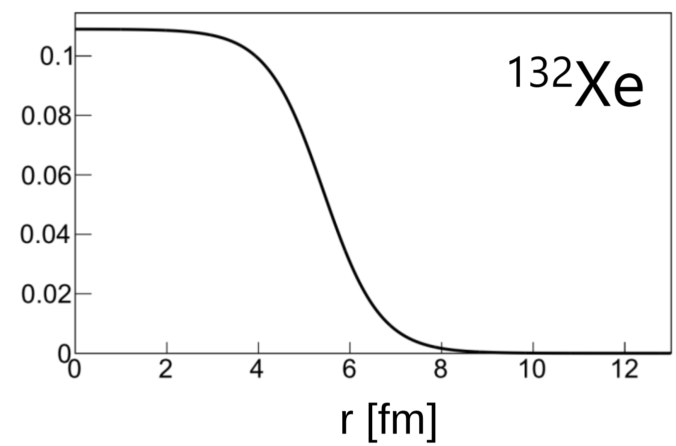
Elastic electron scattering of ^{132}Xe

K. Tsukada et al., Phys. Rev. Lett. 118 (2017) 262501.

Calc: DREPHA(Phase shift)

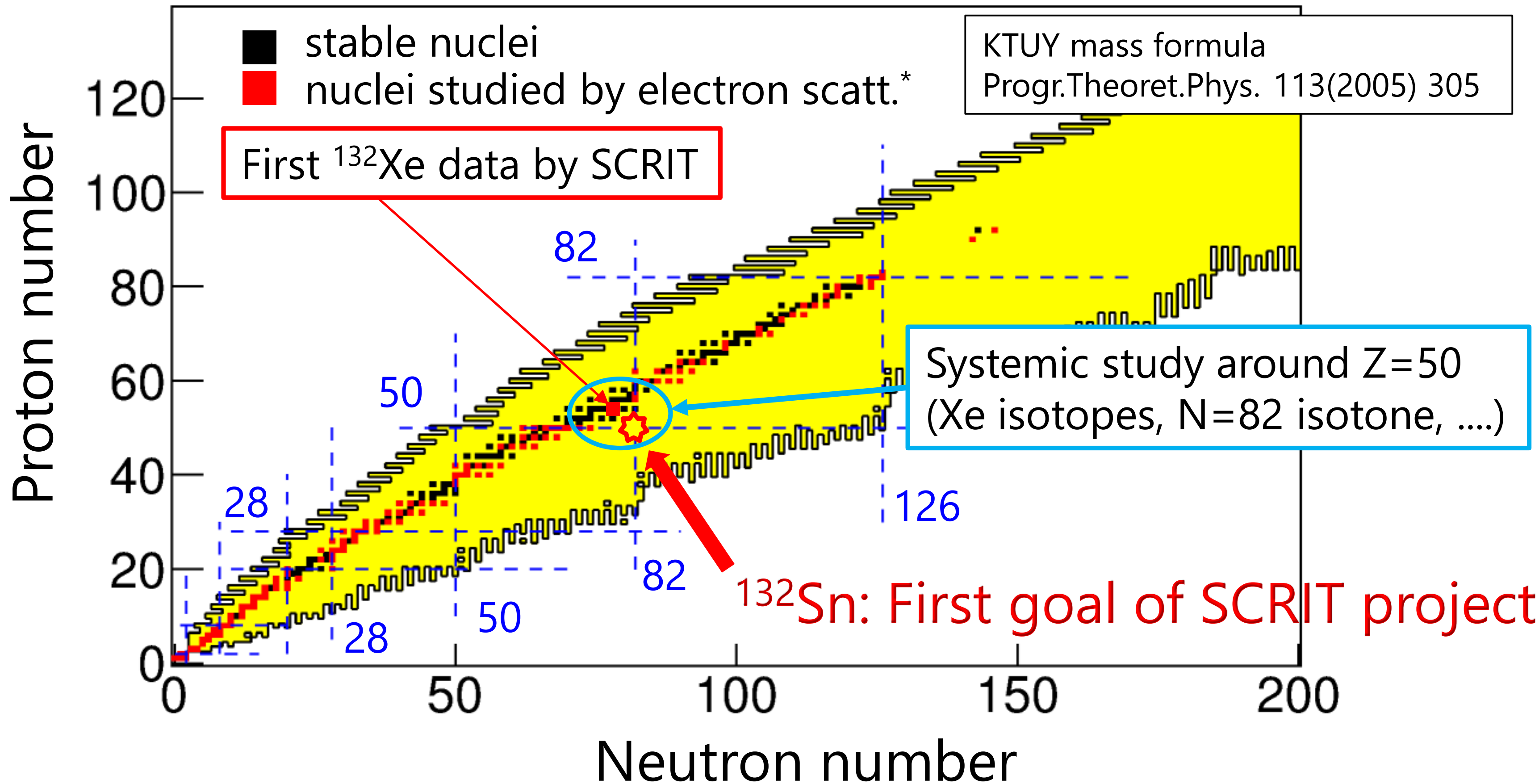


$$\rho_C = \rho/(1 + e^{4.4(r-C)/t})$$
$$C = 5.42^{+0.11}_{-0.08}$$
$$t = 2.71^{+0.29}_{-0.38}$$
$$\langle r \rangle^{1/2} = 4.79^{+0.12}_{-0.10}$$



Electron scattering on Nuclear chart

* H. deVries et al., At. Data Nucl. Data Tables 36, 495 (1987)
G. Fricke et al., At. Data Nucl. Data Tables 60, 177 (1995)

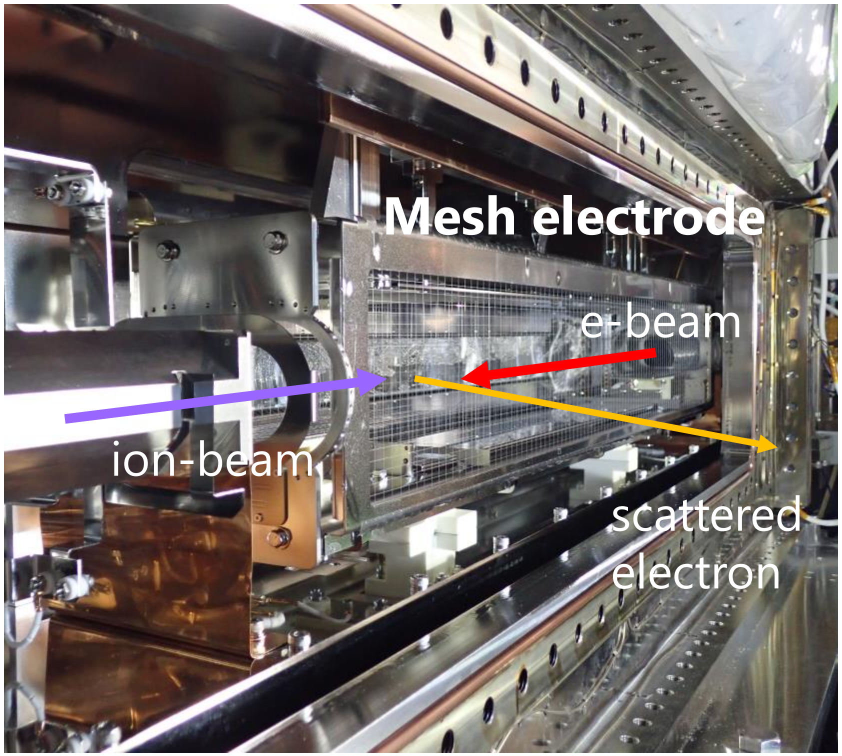


SCRIT method expands the research field of electron scattering!

4. Recent developments

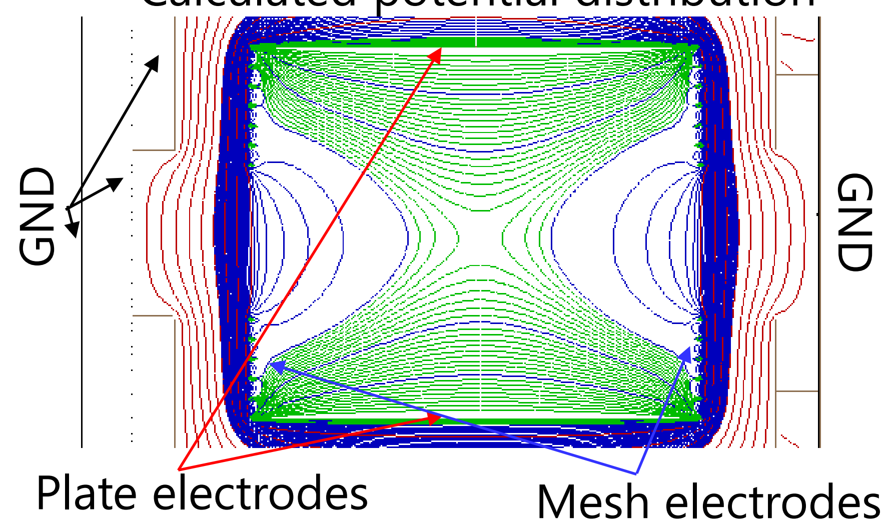
Towards electron scattering with unstable nuclei

1) New SCRIT electrodes



Fewer materials
→ Reduction of background events
Improvement of uniformity and center position of electric potential
→ Improvement of trap and overlap efficiency

Calculated potential distribution

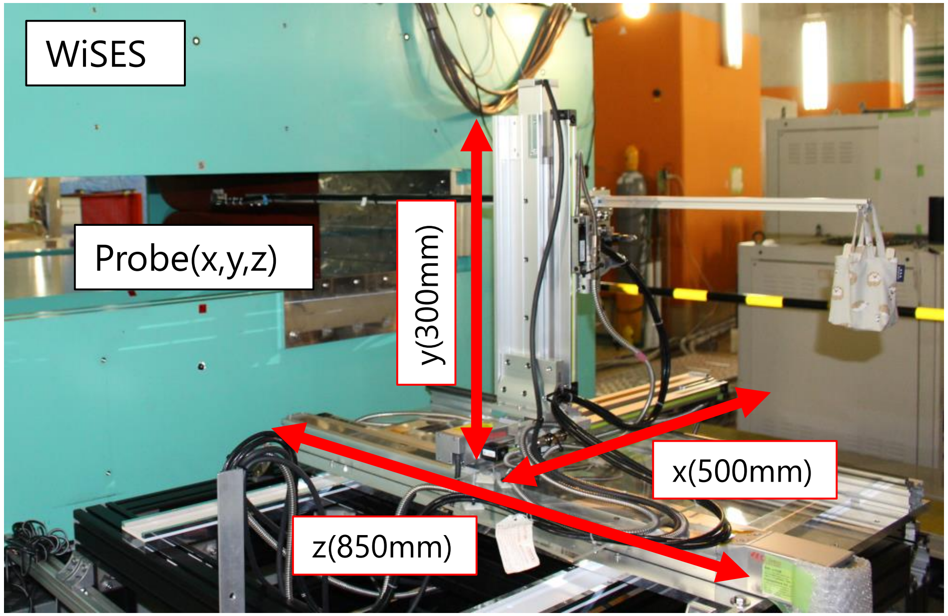


Center of SCRIT device, Potential 10kV

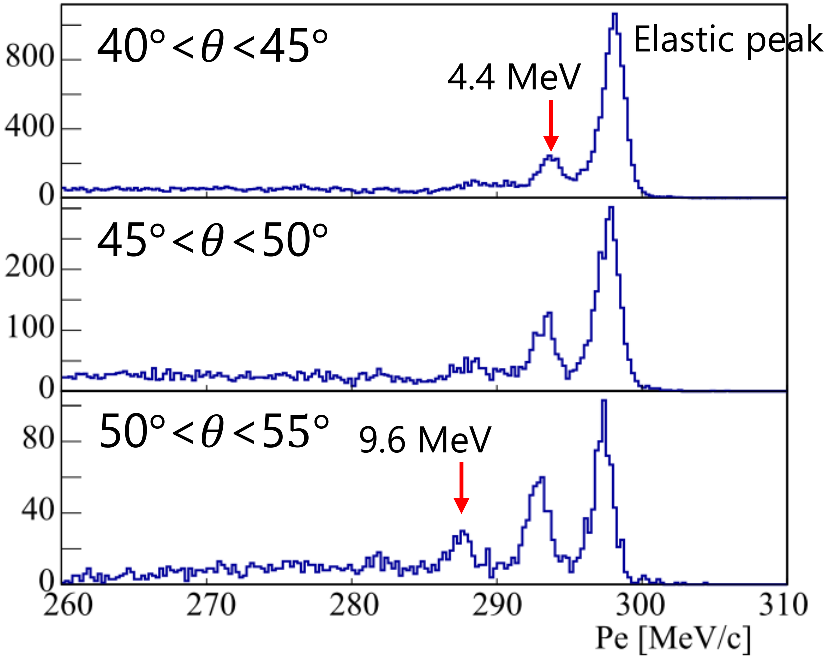
2) Improvement of WiSES

- New front drift chamber
- Precise 3D magnetic-field map measurement
- Re-commissioning experiment with C targets

3D magnetic-field measurement device



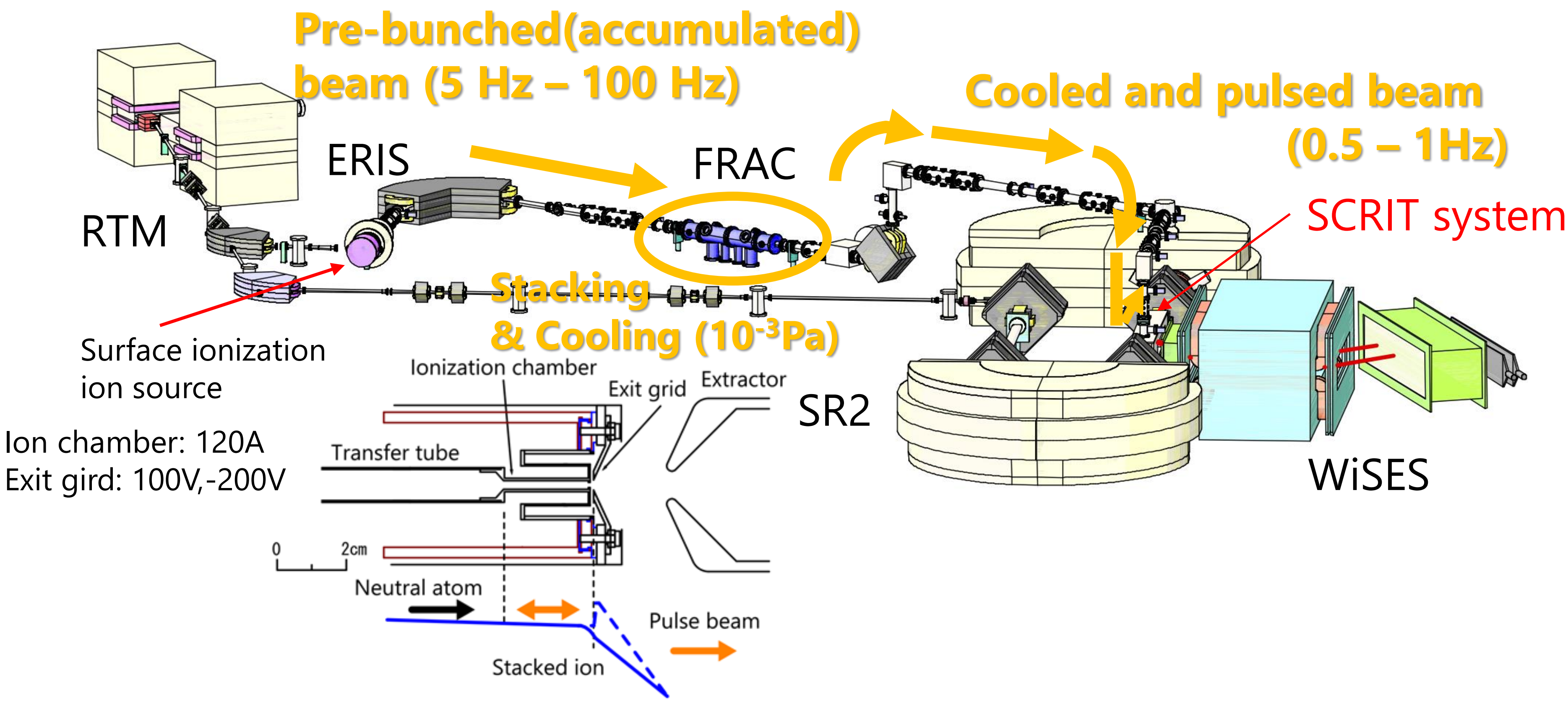
E_e = 300 MeV



3) Two-step bunching using ERIS and FRAC

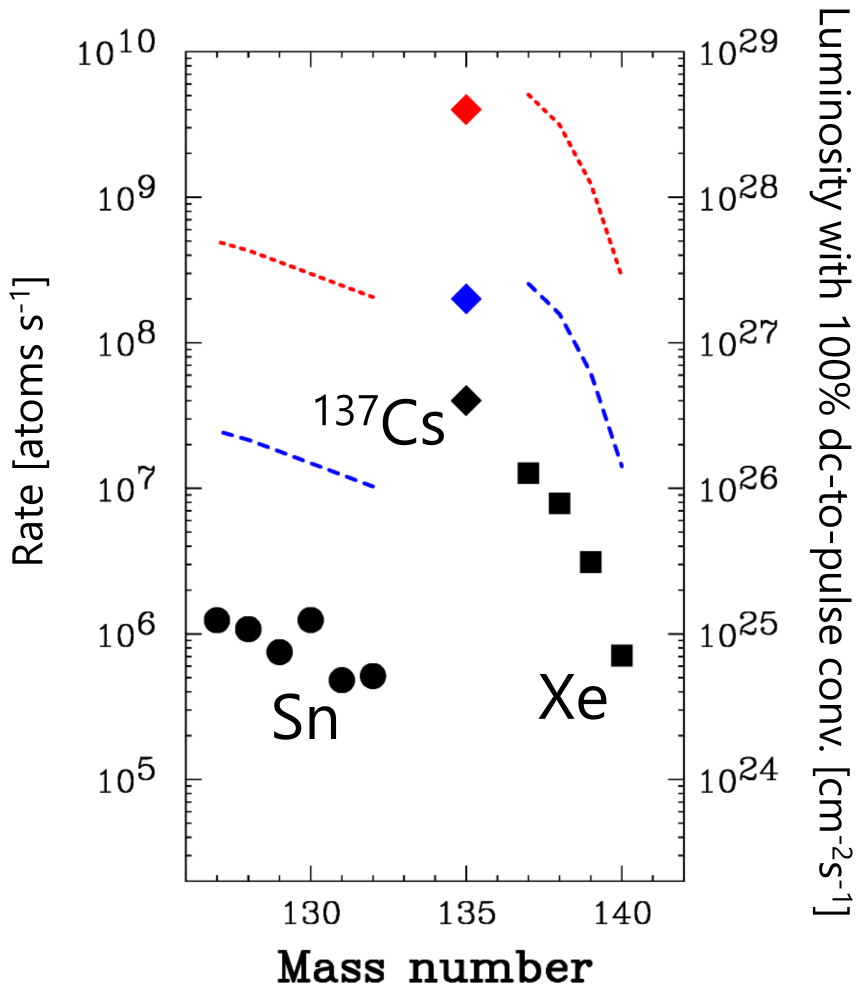
Pulse injection to the SCRIT system with low production rate of unstable nuclei, $\sim 10^8$ ions in 500 μs

→ Lossless dc-to-pulse conversion



5. Future plans

1) Elastic electron scattering with unstable nuclei



Planed
U 30g, 1 kW beam

Developing
U 30g, 50W beam
Effi. (Sn,Xe)×4

Present U 30g, 10W beam
Eff. 5.5%(^{138}Xe), 2.0%(^{132}Sn)
22% (^{137}Cs)

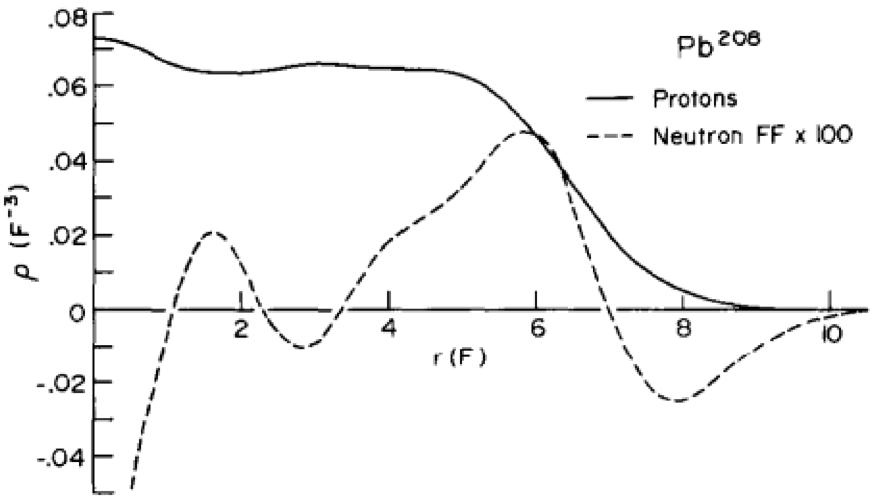
^{137}Cs → First elastic electron scattering with unstable nuclei

2) Neutron skin by electron elastic scattering

"The nth-order moment of the nuclear charge density and contribution from the neutrons"

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

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



W. Bertozzi et al., Phys. Lett. B41 (1972) 408.

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

$$\langle r_C^2 \rangle = \int r^2 \rho_C(r)\, dr^3$$

$$= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \langle r_n^2 \rangle \frac{N}{Z} + \text{relativistic corr.(spin-orbit terms and ....)}$$

Point proton radius

proton radius

neutron radius

$$\langle r_{p(point)}^2 \rangle = \int r^2 \rho_{point}^p(r)\, dr^3$$

$$\langle r_{n(point)}^2 \rangle = \int r^2 \rho_{point}^n(r)\, dr^3$$

$$\langle r_C^4 \rangle = \int r^4 \rho_C(r)\, dr^3$$

$$= \langle r_{p(point)}^4 \rangle + \frac{10}{3} \langle r_{p(point)}^2 \rangle \langle r_p^2 \rangle + \frac{10}{3} \langle r_{n(point)}^2 \rangle \langle r_n^2 \rangle \frac{N}{Z} + \text{relativistic corr.}$$

Point neutron radius

	$\langle r_C^4 \rangle_{exp}$	$\langle r_C^4 \rangle_{calc}$ (Full rel. calc NL3)	n-cont.(3rd term) (calc)	n-skin (calc)
^{48}Ca	194.7 fm^4	191.7 fm^4	7.3 fm^4 (6.9%)	0.06 fm
^{208}Pb	1171.58 fm^4	1156.81 fm^4	20.254 fm^4 (1.8%)	0.28 fm

How to measure $\langle r_C^4 \rangle$

1. Measurement of the charge distribution with wide q range
   → High luminosity
2. Precise measurement of the charge distribution in the low-q region
   → low luminosity (large cross section ($1/q^4$))

Low-q region

$$F_C(q) = \int \rho_C(\vec{r})\, e^{-i\vec{q}\cdot\vec{r}} d^3r$$

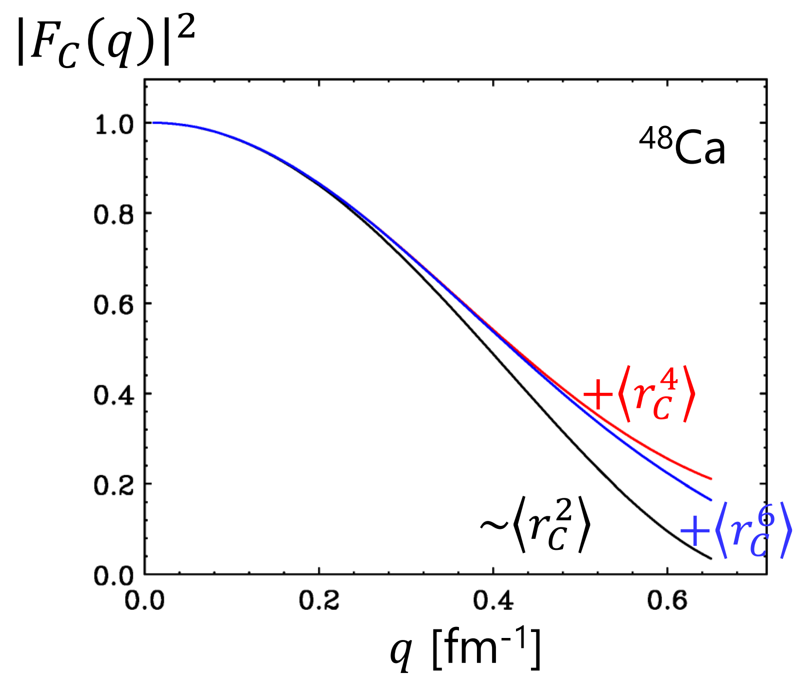
$$\sim 1 - \frac{\langle r_C^2 \rangle}{3!} q^2 + \frac{\langle r_C^4 \rangle}{5!} q^4 - \frac{\langle r_C^6 \rangle}{7!} q^6 + \cdots$$

(PWIA)

Calculated values

	$\langle r_C^2 \rangle$	$\langle r_C^4 \rangle$	$\langle r_C^6 \rangle$
^{48}Ca	11.91	194.7	3913

H. De Vries et al., Atomic data and nuclear data tables 36 (1987) 495.



under discussion....

6. Summary

- SCRIT electron scattering facility was constructed.
- Successful experiment with stable nucleus, ^{132}Xe, was performed.
- For electron scattering with unstable nuclei, various developments are going on.
- Possible determination of neutron skin by elastic electron scattering.

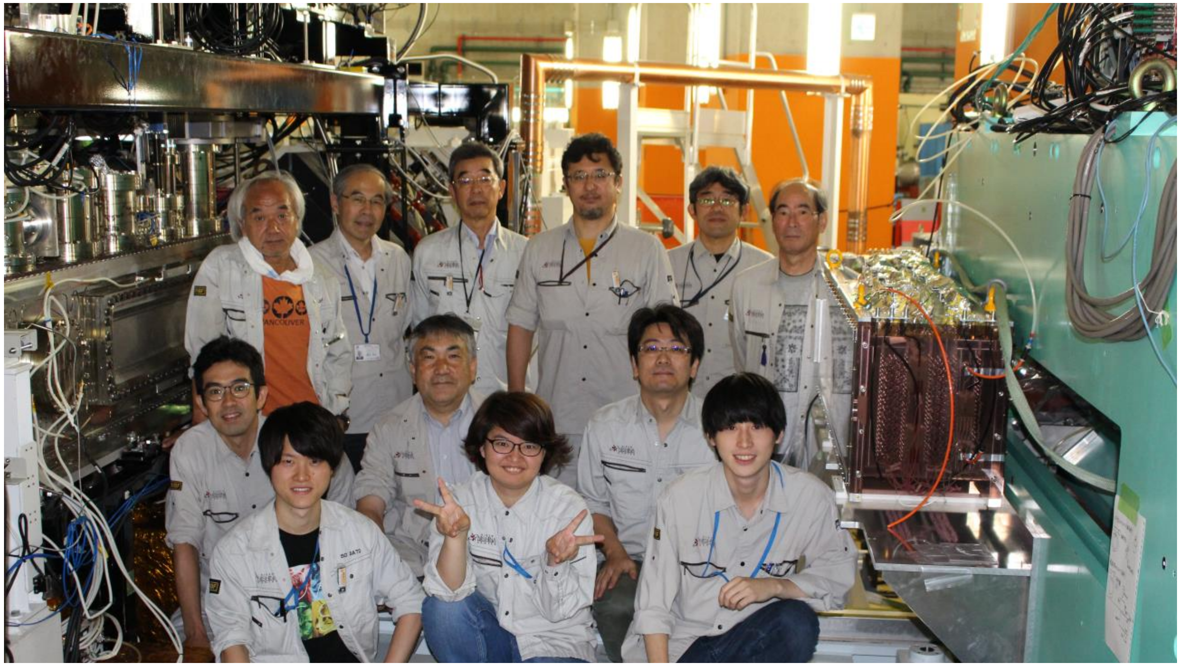
  $\langle r_C^4 \rangle$ includes the information of the neutron distribution.

First experiment of elastic electron scattering with unstable nuclei will be performed soon.

SCRIT Collaboration

A. Enokizono[1] , M. Hara[1] , T. Hori[1] , S. Ichikawa[1] , K. Kurita[2] , R. Ogawara[1,3] , T. Ohnishi[1] , S. Sato[2] , T. Suda[1,4] , S. Takayama[4], D. Taki[4] , S. Takagi[3], T. Tamae[4] , K. Tsukada[1,4], M. Wakasugi[1,3], M. Watanabe[1], H. Wauke[4]

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



Thank you for your attention!