The SCRIT electron scattering facility at RIKEN RI Beam Factory

RIKEN Nishina Center
T. Ohnishi
INPC2016, Adelaide

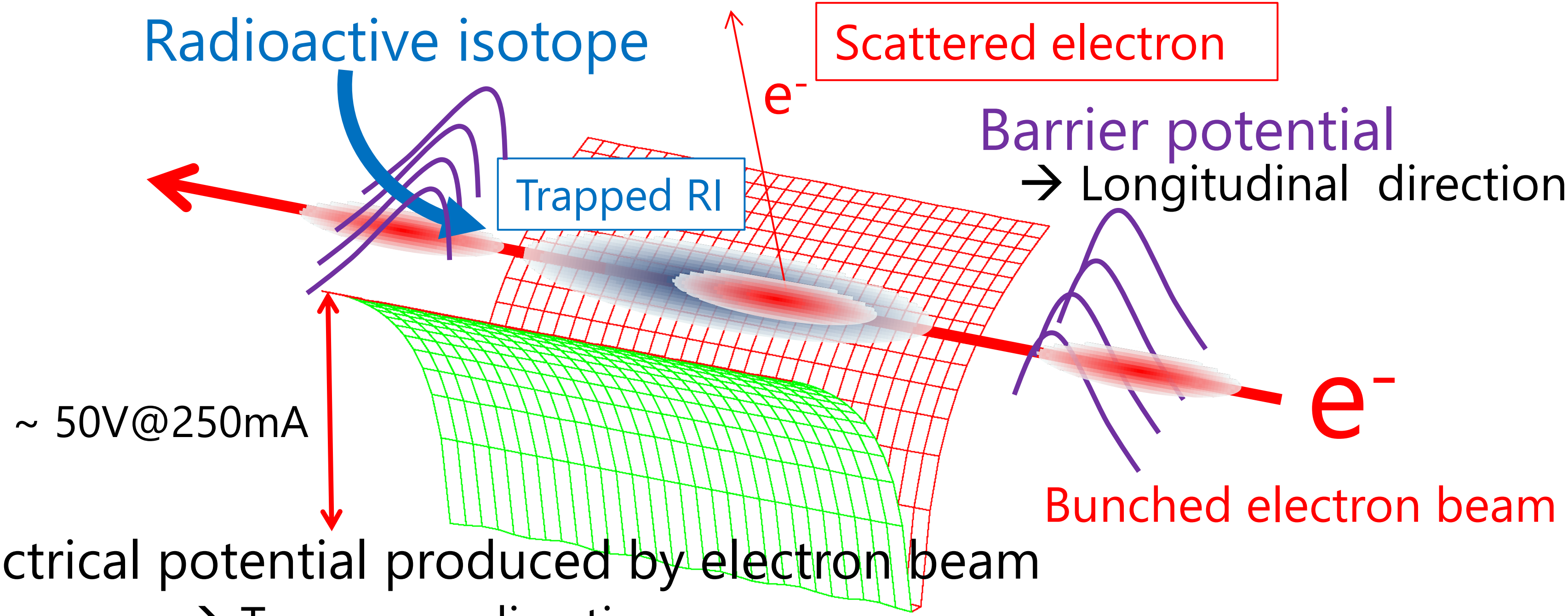
SCRIT = Self Confining RI Ion Target

Electron scattering with unstable nuclei

First goal : Charge distribution/radius for ^{132}Sn

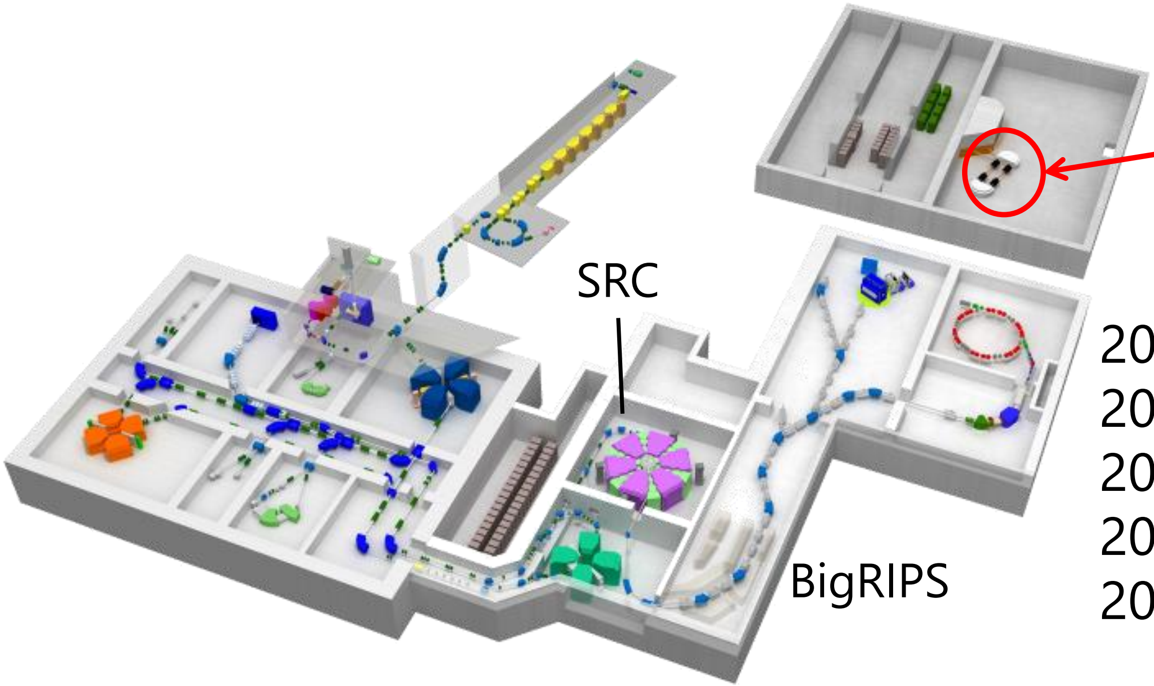
SCRIT (Self-Confining RI Ion Target)

M. Wakasugi et al., Nucl. Inst. Meth. A532 (2004) 216.
M. Wakasugi et al., Phys. Rev. Lett. 100 (2008) 164801.



Electrical potential produced by electron beam
→ Transverse direction

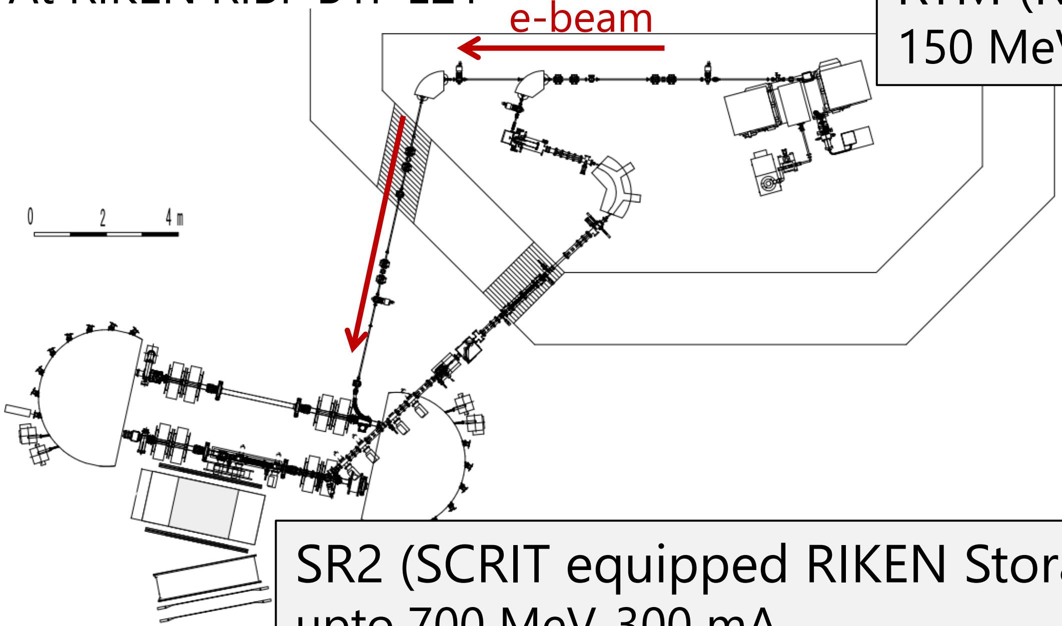
RIKEN RI Beam Factory



2009 Construction start
2011 Facility commissioning
2013 RI production start
2014 Spectrometer installation
2015 ~ 2016
Experiment with stable nuclei
2016 ~ Luminosity improvements

SCRIT electron scattering facility

At RIKEN RIBF B1F E21

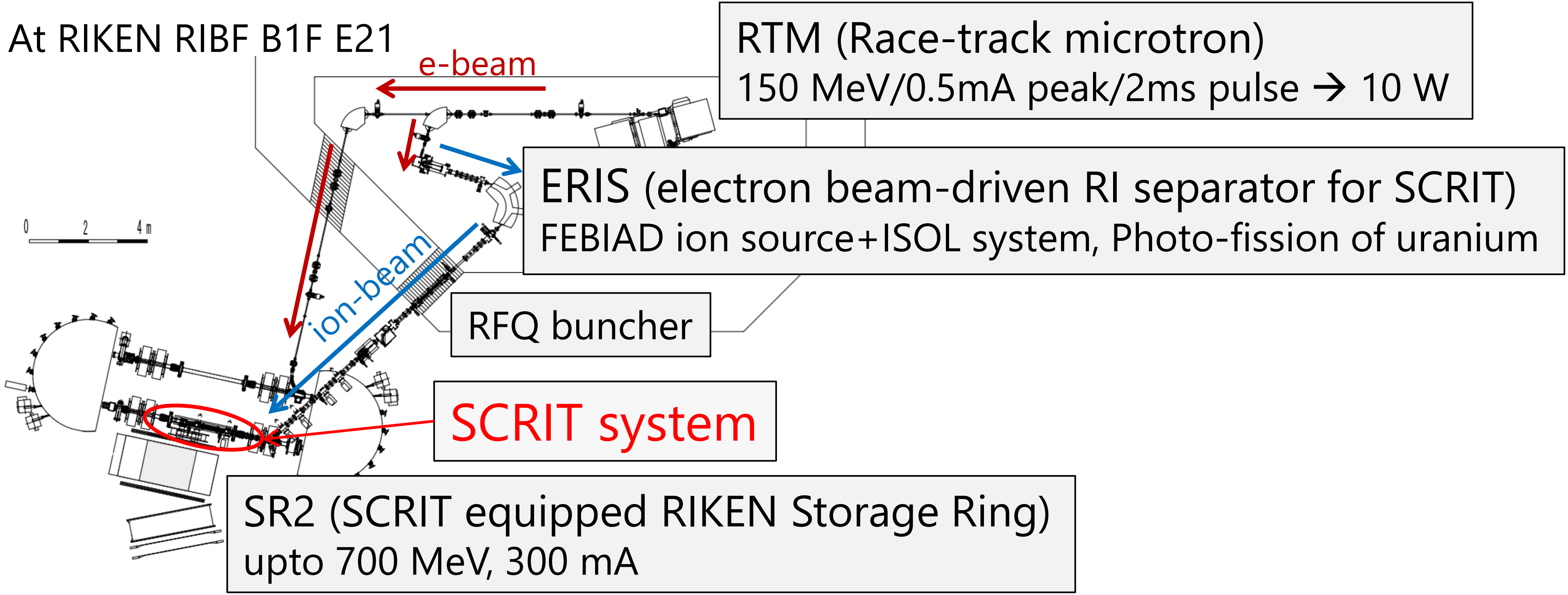


RTM (Race-track microtron)
150 MeV/0.5mA peak/2ms pulse → 10 W

SR2 (SCRIT equipped RIKEN Storage Ring)
upto 700 MeV, 300 mA

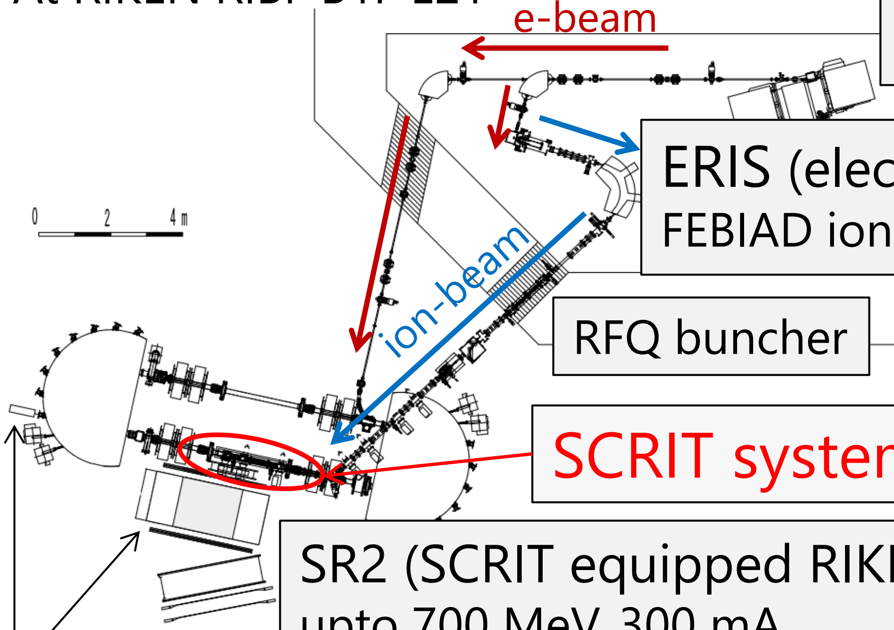
SCRIT electron scattering facility

At RIKEN RIBF B1F E21



SCRIT electron scattering facility

At RIKEN RIBF B1F E21



RTM (Race-track microtron)
150 MeV/0.5mA peak/2ms pulse → 10 W

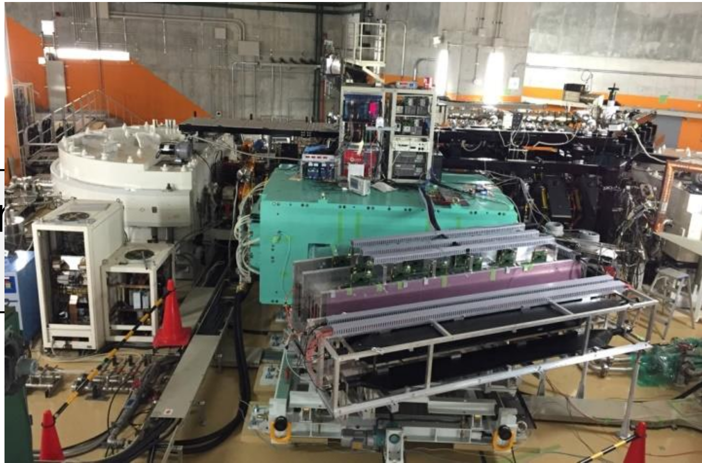
ERIS (electron beam-driven RI separator for SCRIT)
FEBIAD ion source+ISOL system, Photo-fission of uranium

RFQ buncher

SCRIT system

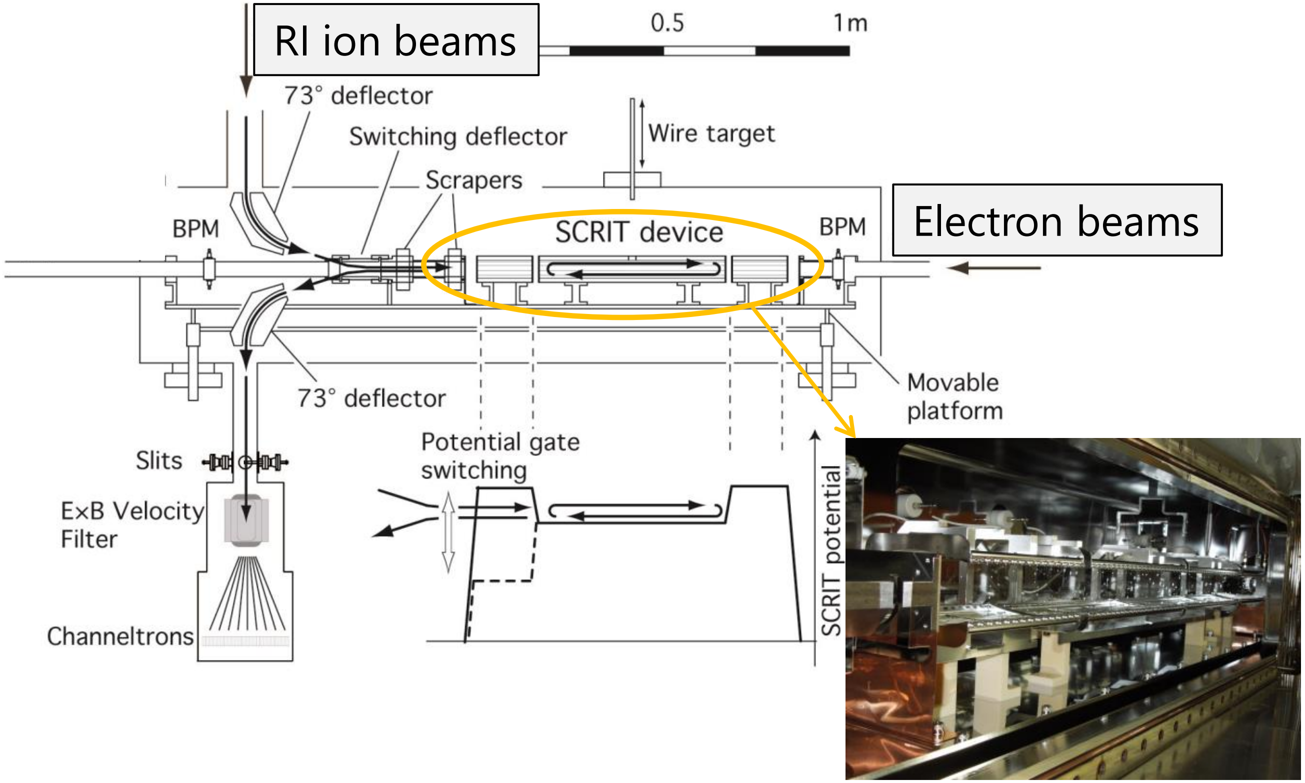
SR2 (SCRIT equipped RIKEN Storage Ri
upto 700 MeV, 300 mA

WiSES (electron spectrometer) & Luminosity monitor
→ Dr. Enokizono's talk in this session



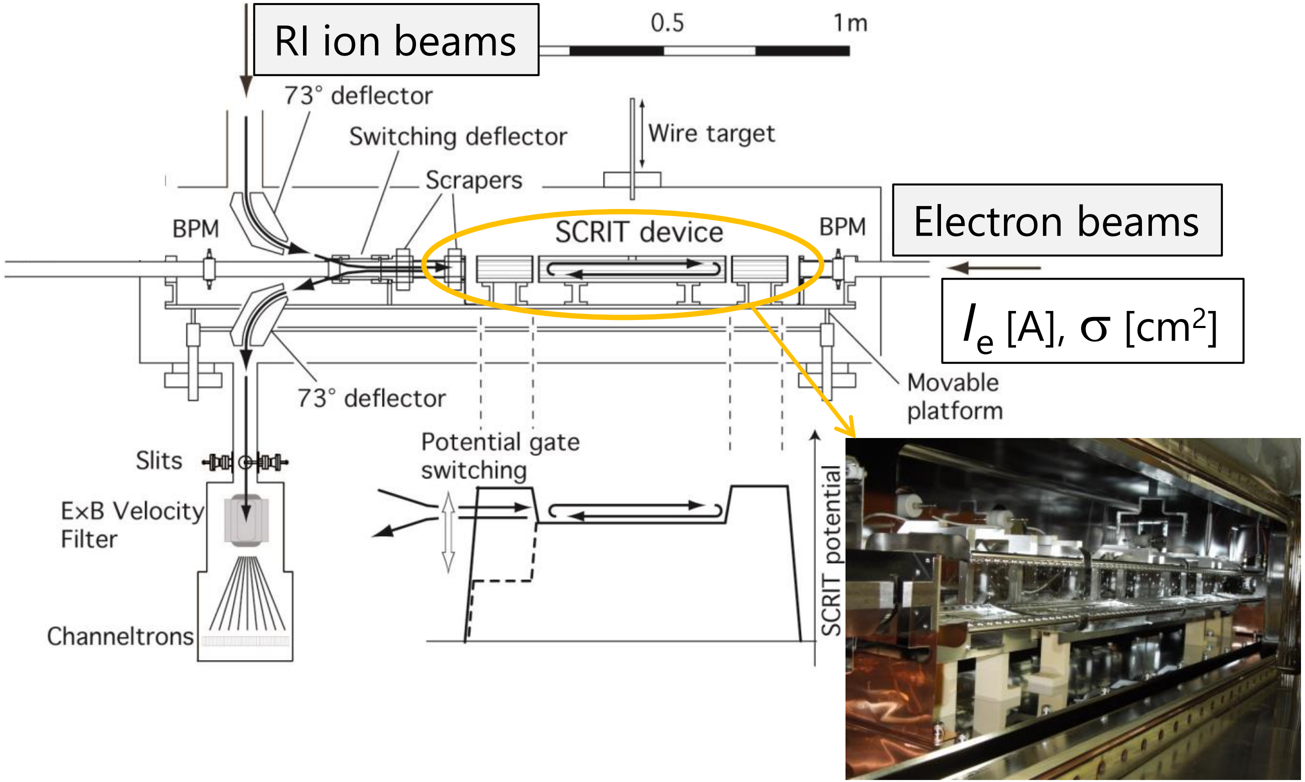
SCRIT system

M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.



SCRIT system

M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.



SCRIT system

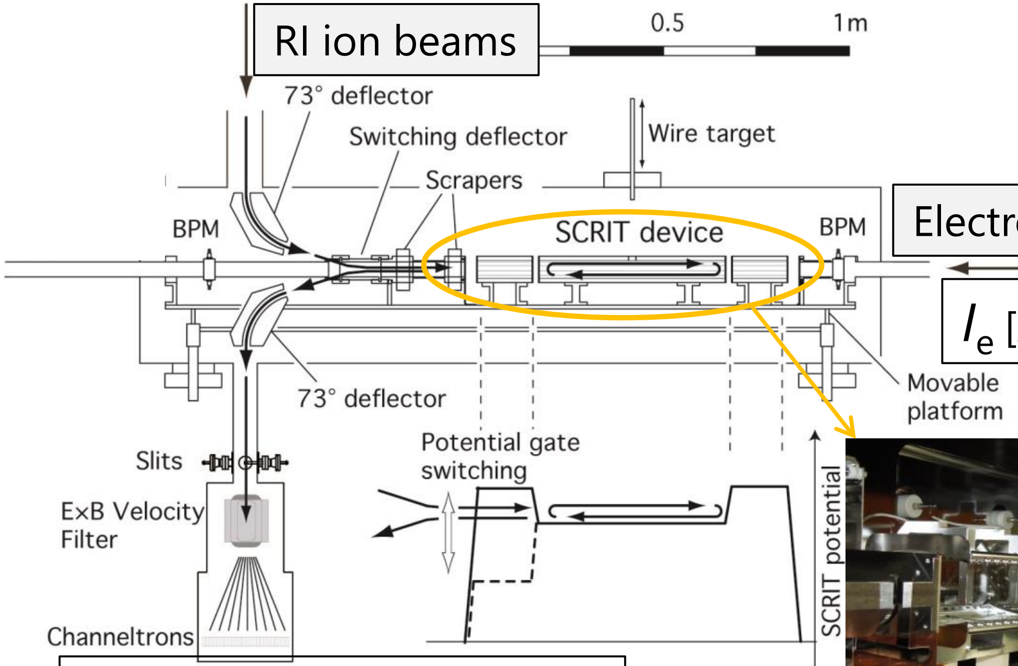
M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.

Number of injected ions (N_{inj})

RI ion beams

Electron beams

I_e [A], σ [cm^2]

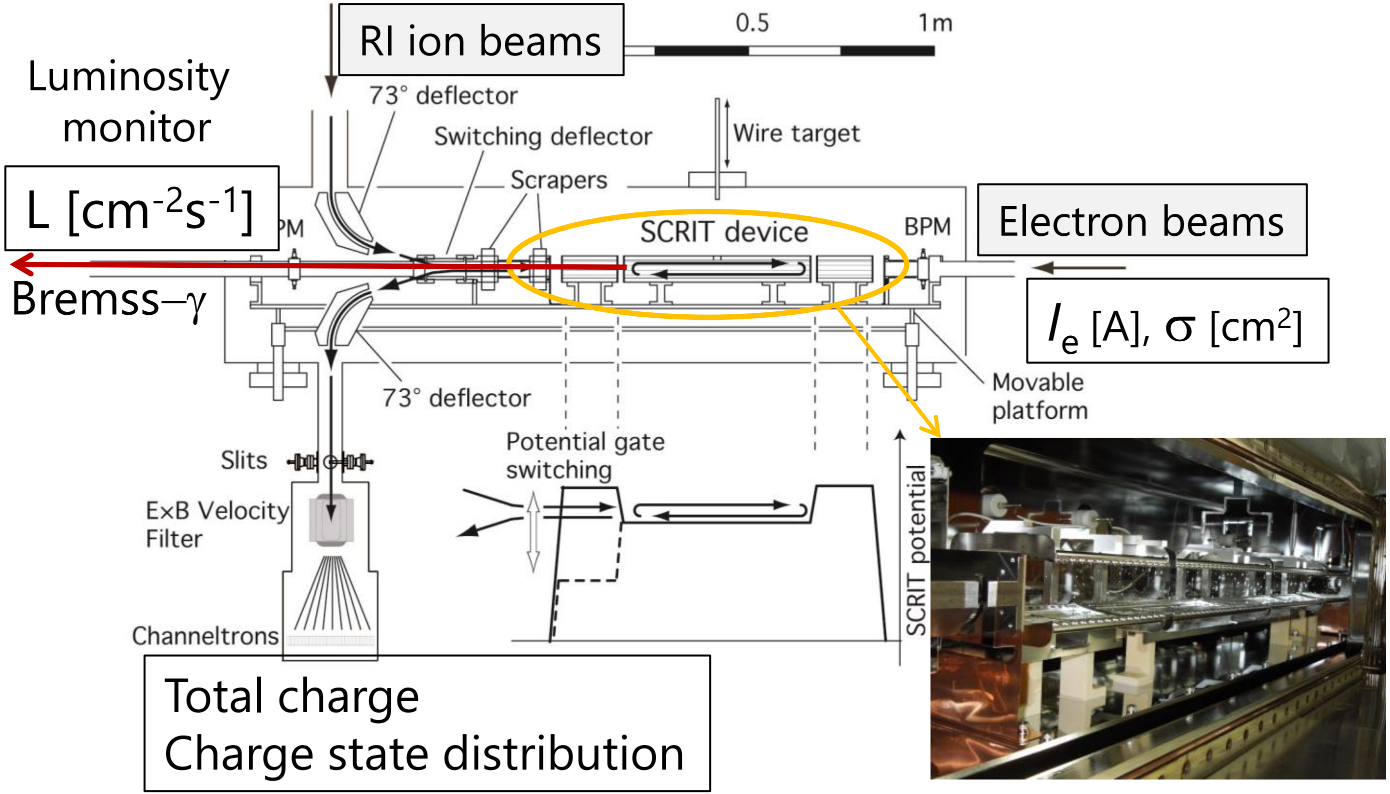


Total charge
Charge state distribution

SCRIT system

M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.

Number of injected ions (N_{inj})



Total charge
Charge state distribution

SCRIT system

M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.

Number of injected ions (N_{inj})

RI ion beams

Luminosity monitor

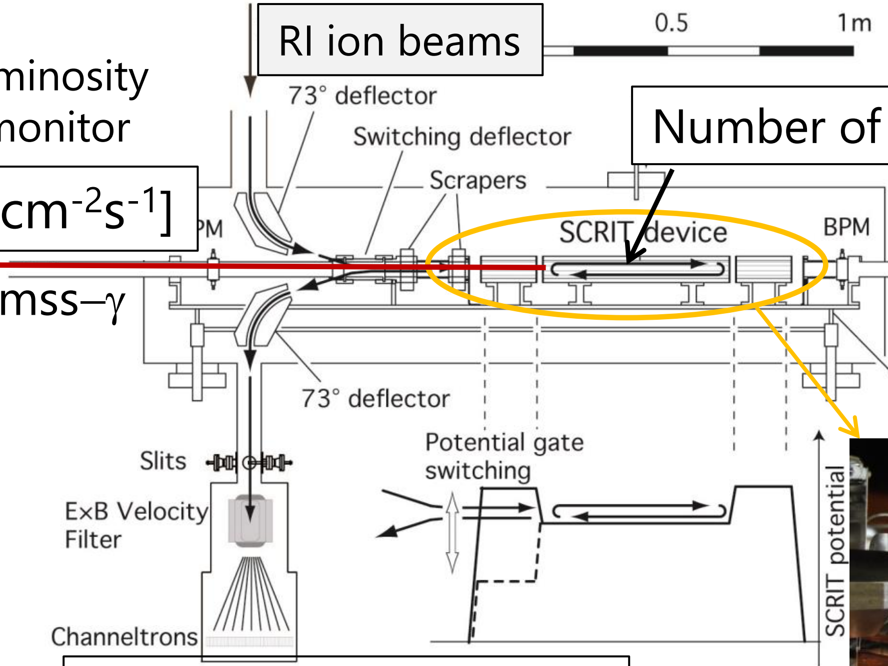
L [$cm^{-2}s^{-1}$]

Bremss–γ

Number of target ions (N_T)

Electron beams

I_e [A], σ [cm^2]



Total charge
Charge state distribution

Luminosity

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

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

SCRIT system

M. Wakasugi et al., Nucl. Inst. Meth. B317 (2013) 668.

Number of injected ions (N_{inj})

RI ion beams

Luminosity monitor

L [$cm^{-2}s^{-1}$]

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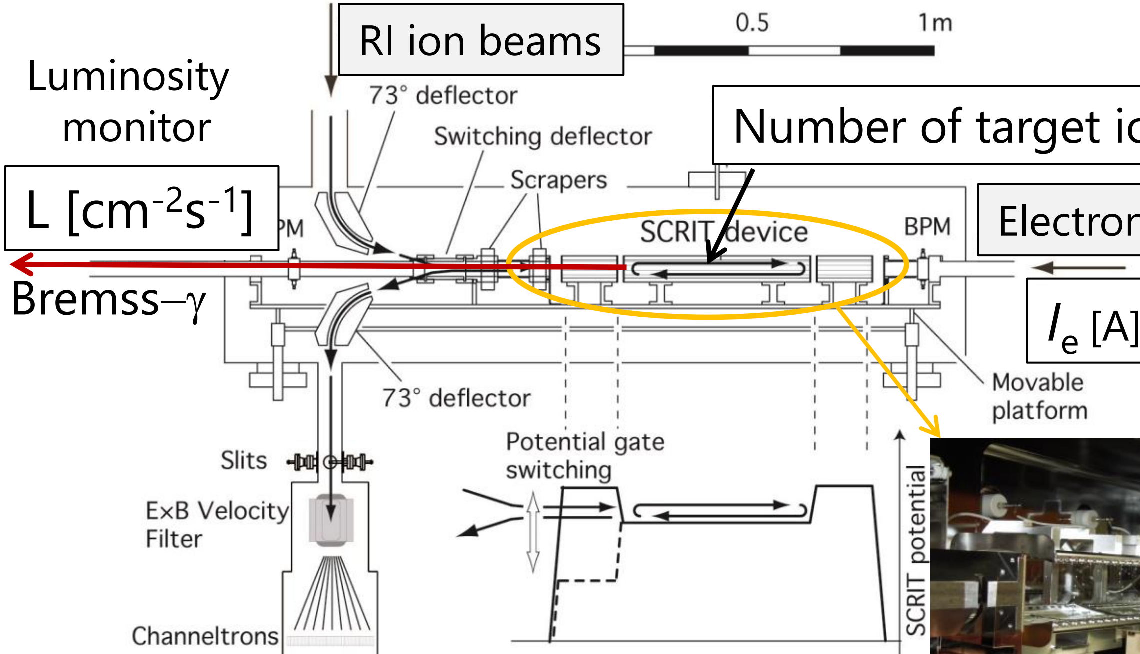


Total charge
Charge state distribution

Luminosity

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

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

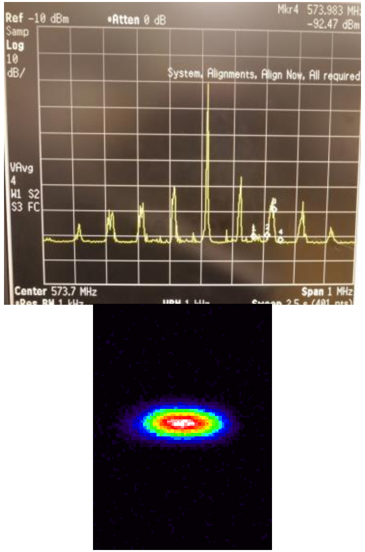
Typical value (1sec trap)

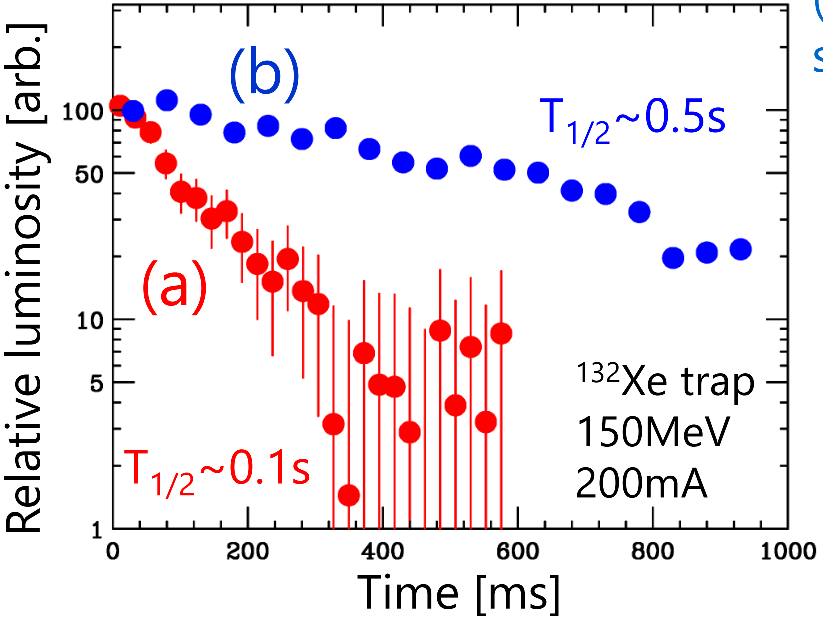
- $L \sim 1.4\times10^{27}$
- $I_e \sim 175$ mA
- $\sigma \sim 3.6$ mm^2
- $N_{inj} \sim 2.3\times10^{8}$ /pulse
- $N_T \sim 4.6\times10^{7}$ /pulse
- $\varepsilon_{trap}\varepsilon_{overlap} \sim 19.8\%$

Effect of electron beam property

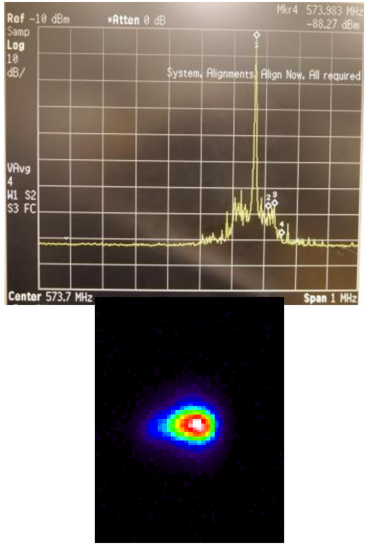
Electron beam instability reduces ion trapping lifetime.

(a) Coherent synchrotron oscillation





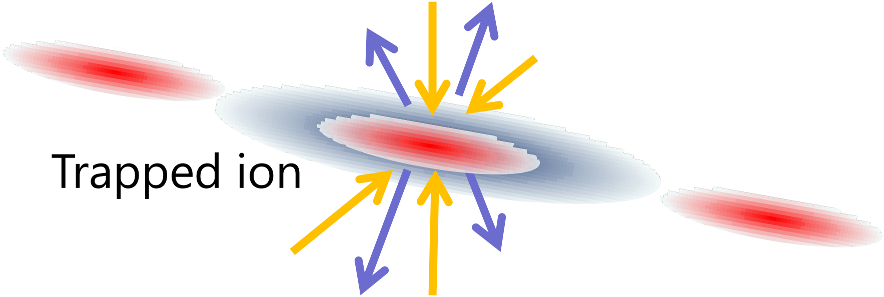
(b) Suppressed synchrotron oscillation



Ion trapping time evolution

Ion confinement (Luminosity increasing)

- e-beam potential
- Ion distribution shrinking due to increasing charge state

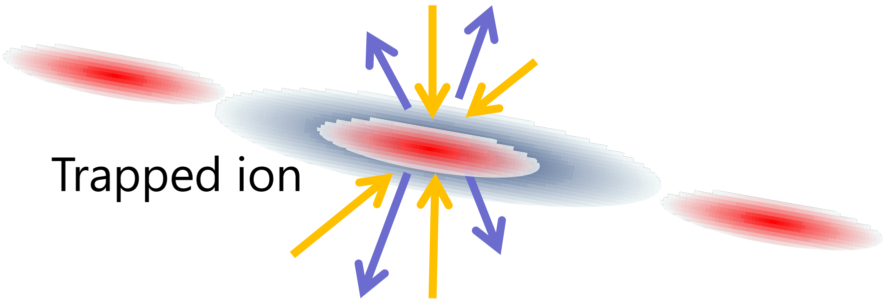


Ion escape (Luminosity decreasing)

- e-beam instability
- Space charge effect
- Dropout of higher charge state

Ion trapping time evolution

Ion confinement (Luminosity increasing)
- e-beam potential
- Ion distribution shrinking due to increasing charge state



Ion escape (Luminosity decreasing)
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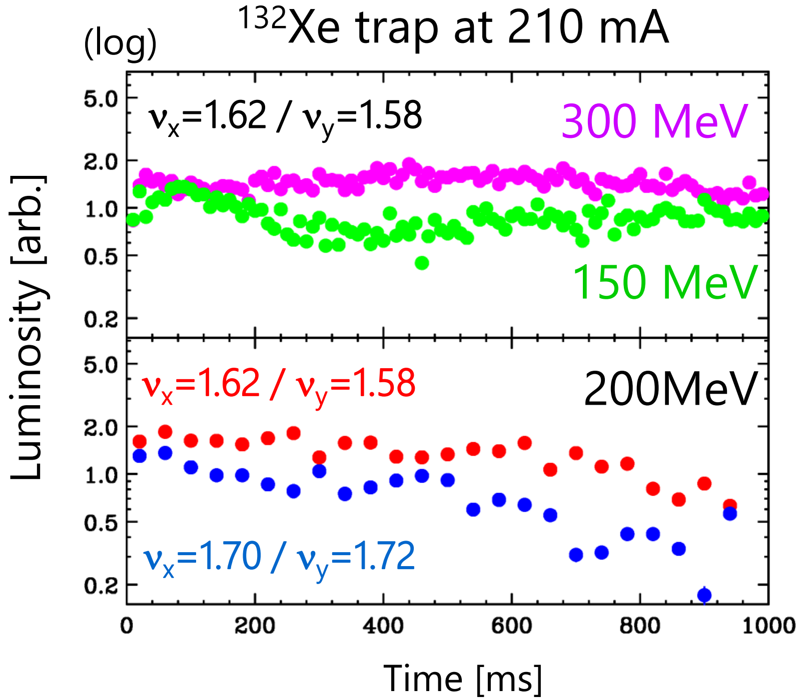
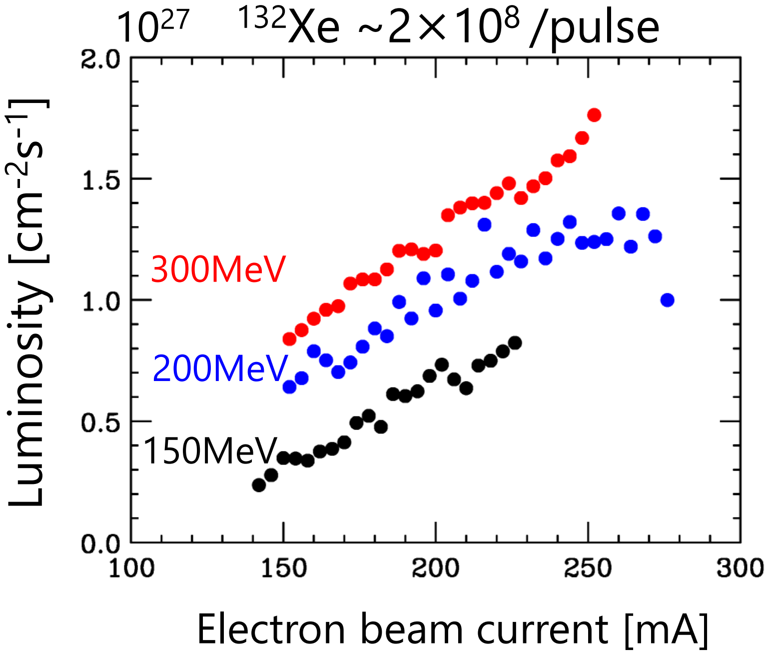


The ion trapping time evolution can be changed by adjusting beam parameter.

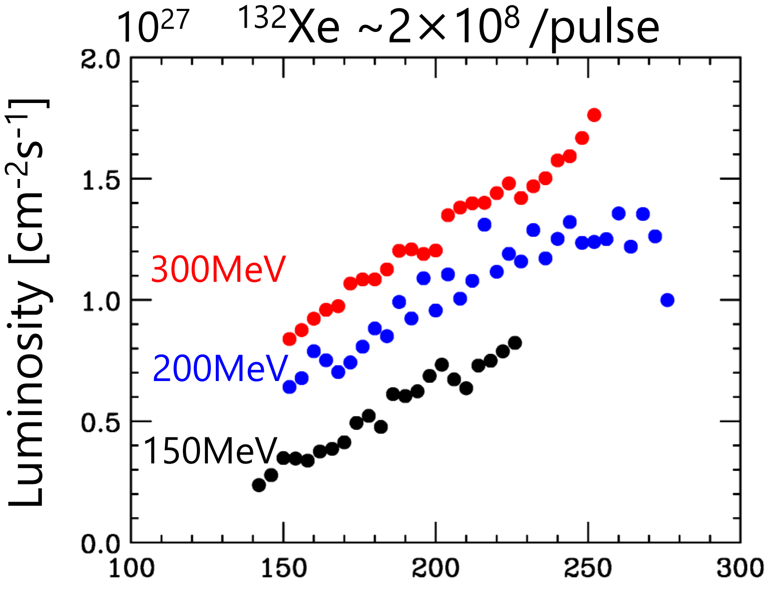
Achieved Luminosity

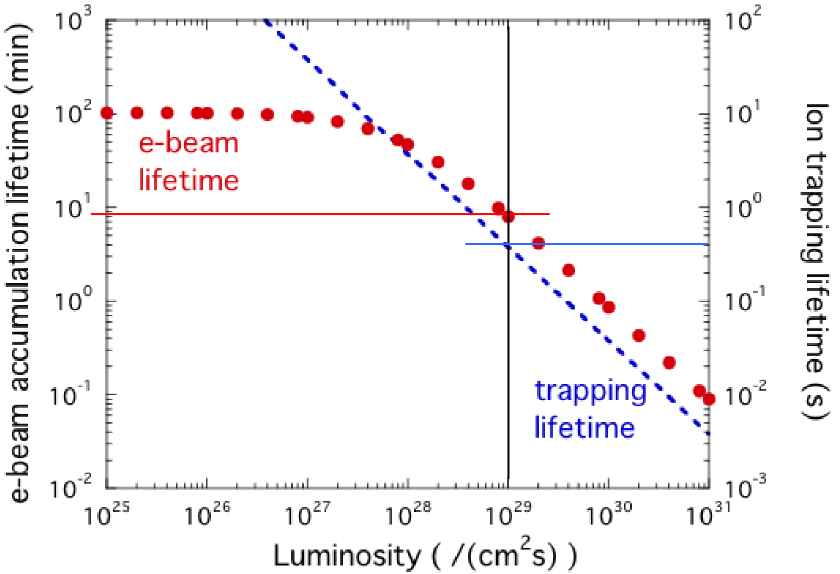


$L \sim 1.8\times10^{27}\ cm^{-2}s^{-1}$

at e-beam 250 mA

Achieved Luminosity





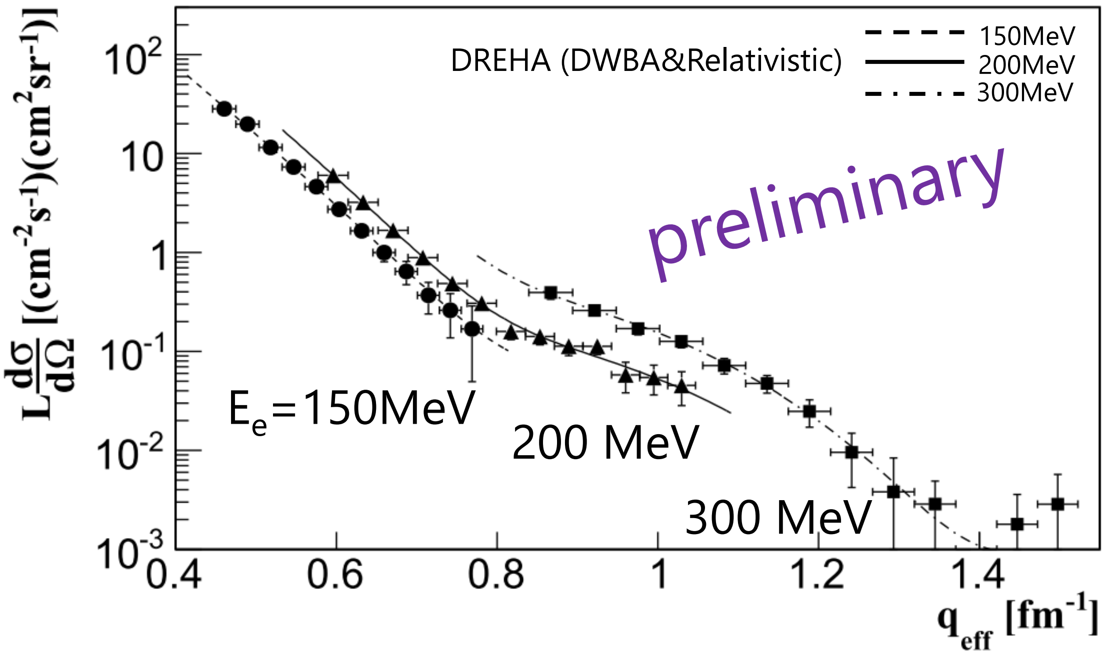
Lost: Scattered electron >3mrad
Recoiled ion >10eV

$L \sim 1.8\times10^{27}\ cm^{-2}s^{-1}$
at e-beam 250 mA

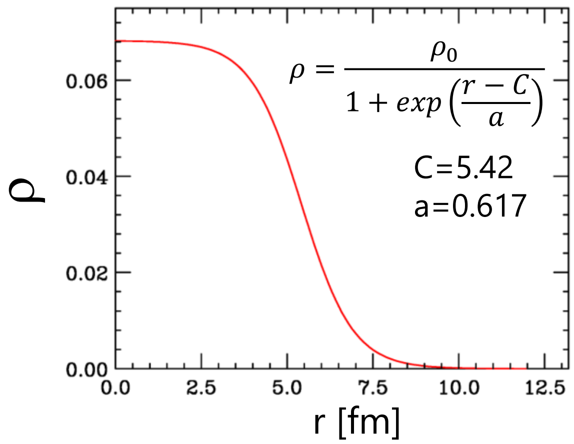
At 10^{29} $cm^{-2}s^{-1}$ luminosity
e-beam life ～ 10 min Trap-ion life ～ 0.4 sec
→ Upper limit

Electron elastic scattering of ^{132}Xe

First data of Xe in the world!



Charge distribution of ^{132}Xe

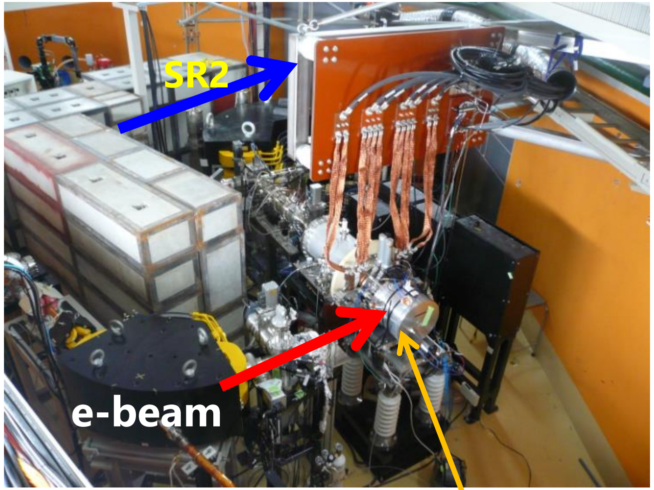


Dr. K. Tsukada's talk at yesterday

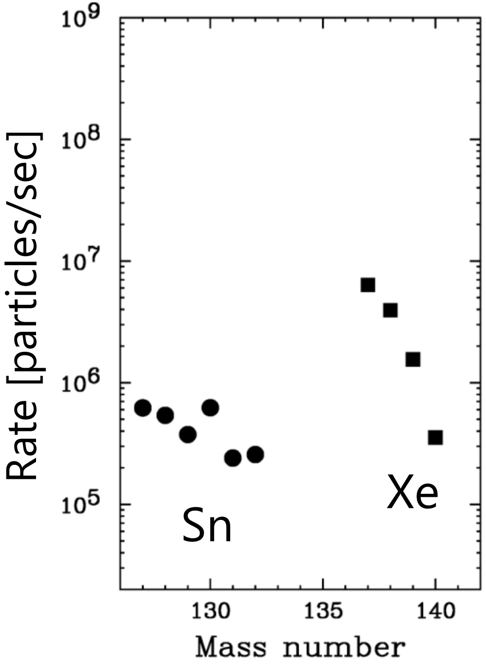
15:40	*Nuclear radii and nuclear skin*
	Chairperson: Prof Isao Tanihata (Professor, RCNP, Osaka University)
15:40	First Result from Scrit Electron Scattering Facility : Charge Density Distribution Of ^{132}Xe **Dr Kyo TSUKADA (Assistant professor, Physical Society of Japan), Dr Akitomo ENOKIZONO**

RI production at ERIS

Photo fission of uranium + FEBIAD ion source



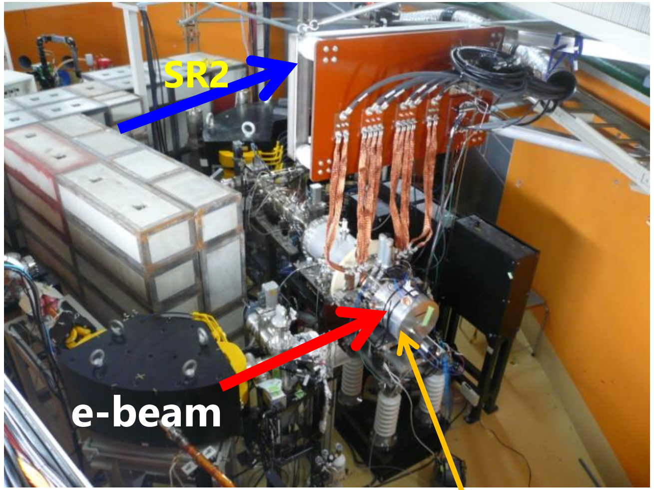
Uranium carbide target
FEBIAD ion source
at HV stage



Present
U 15g(Φ20mm,1mm^t×20)
10W at 150MeV
Effi. 5.5 % ^{138}Xe

RI production at ERIS

Photo fission of uranium + FEBIAD ion source



Uranium carbide target
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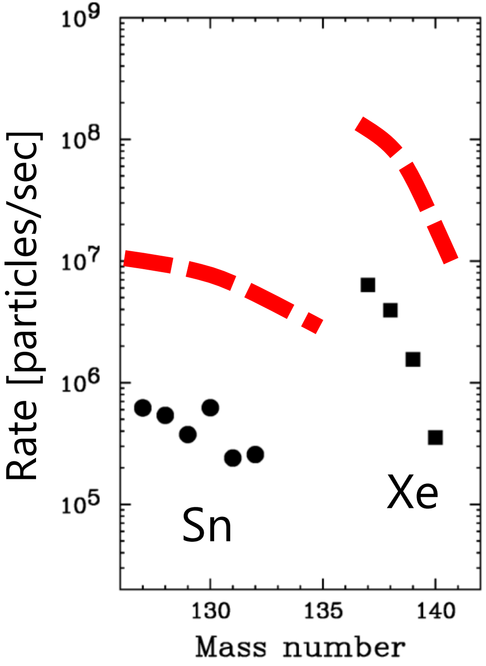
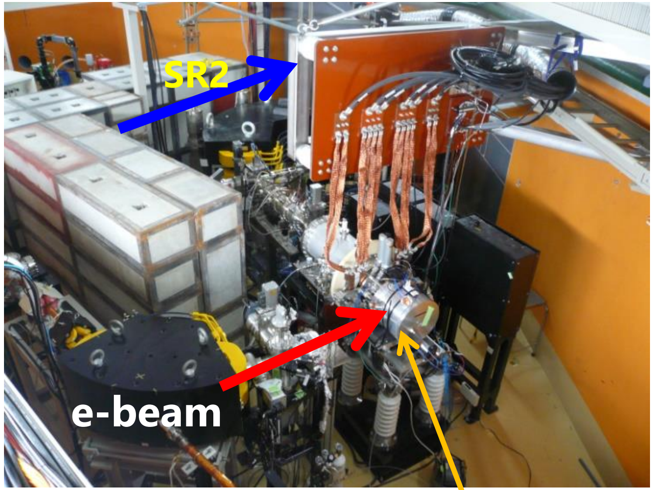


Developing
U 30g, 50W beam
Effi. ×4

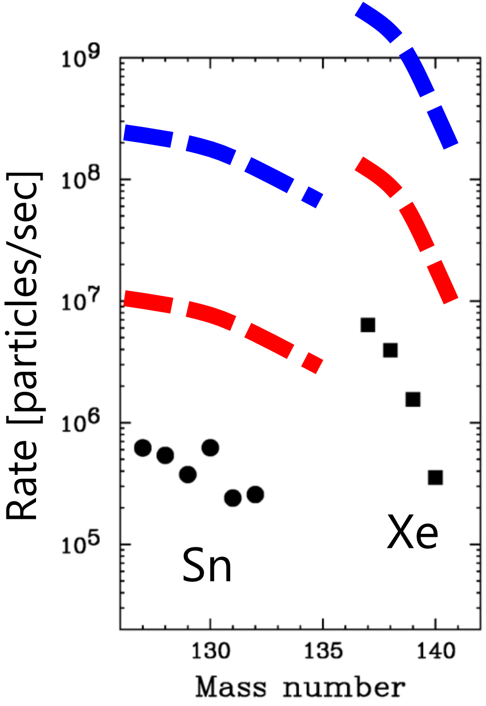
Present
U 15g(Φ20mm,1mm^t×20)
10W at 150MeV
Effi. 5.5 % ^{138}Xe

RI production at ERIS

Photo fission of uranium + FEBIAD ion source



Uranium carbide target
FEBIAD ion source
at HV stage



Planed
U 30g, 1 kW beam

Developing
U 30g, 50W beam
Effi. ×4

Present
U 15g(Φ20mm,1mm^t×20)
10W at 150MeV
Effi. 5.5 % ^{138}Xe

Summary

- The SCRIT facility has been constructed.
- The ion trapping properties are investigated.
- Luminosity is achieved as about 2×10^{27} $cm^{-2}s^{-1}$.
- The experiment using stable nuclei has been performed.
- RI production was started and the development is going on.

First experiment of e-RI scattering
will be performed as soon as possible.

SCRIT Collaboration

RIKEN Nishina Center for Accelerator Based Science
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K. Tsukada, T. Tamae, K. Yanagi, S. Yoneyama, T. Suda
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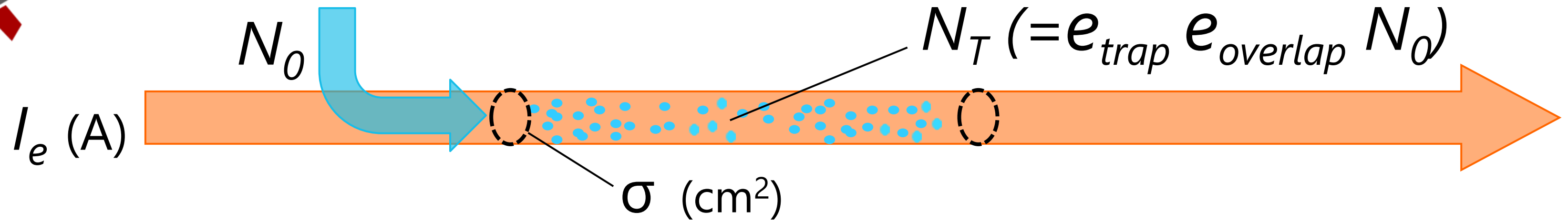
A. Enomoto, T. Yamaguchi
School of space science and physics, Shandong University
S. Wang
Department of Electrical Engineering, Nagaoka University of Technology
Y. Haraguchi, H. Takehara, R. Toba, T. Kikuchi

Thank you for your attention!

Backups

Achievable luminosity



$$L \sim \frac{I_e/e \quad N_T}{\sigma} \ /(\mathrm{cm}^2\mathrm{s})$$

Current performance (typical)

I_e ~ 175 mA

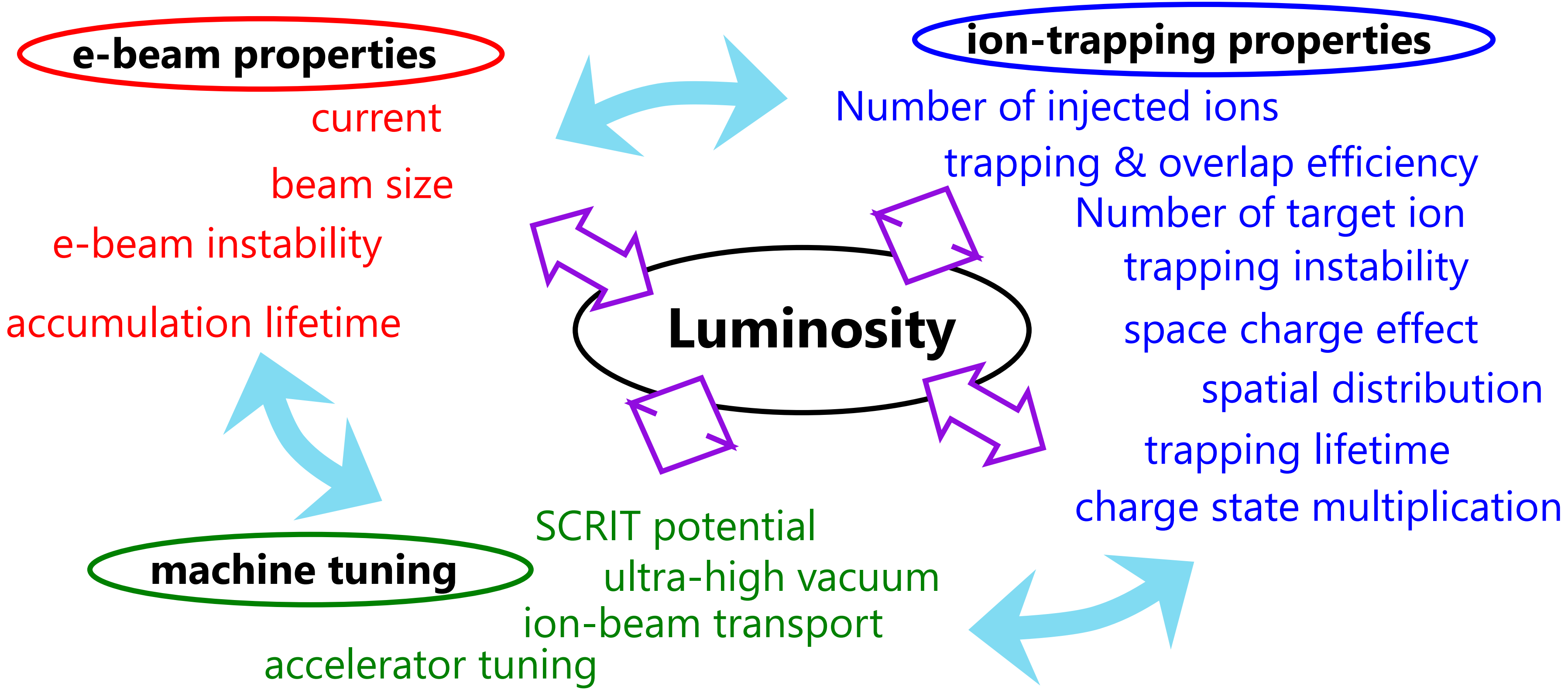
at σ ~ 3.6 mm^2 ⇨ L ~ **1.4 × 10^{27} /(cm^{2}s)**

N_0 ~ 2.3 × 10^8

Number of target ions **N_T ~ 4.6 × 10^7**

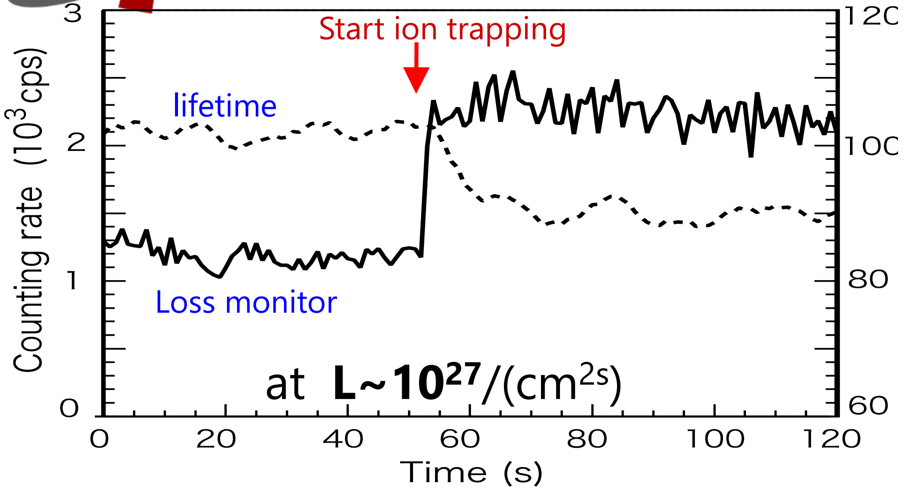
Total efficiency **e_{trap} $e_{overlap}$ = N_T/N_0 ~ 20 %**

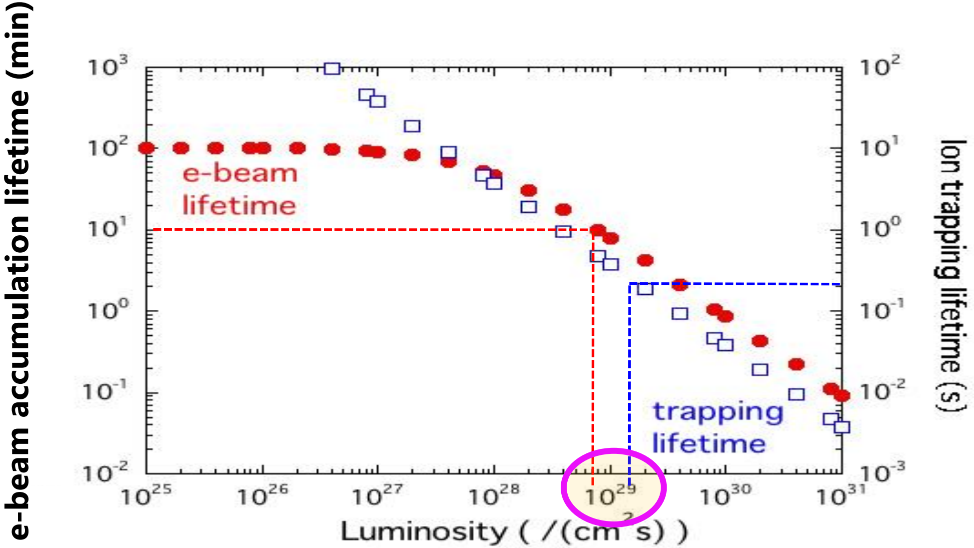
luminosity is strongly related to e-beam & ion-trapping properties



Luminosity results from achieving a practical balance between these properties

Luminosity limit in the SCRIT system





- **Scattered electrons** with the angle over **3 mrad** are lost.
- **Recoiled ions** with kinetic energy over **10eV** are lost.

Assuming:

e-beam lifetime limit = **10 min.**

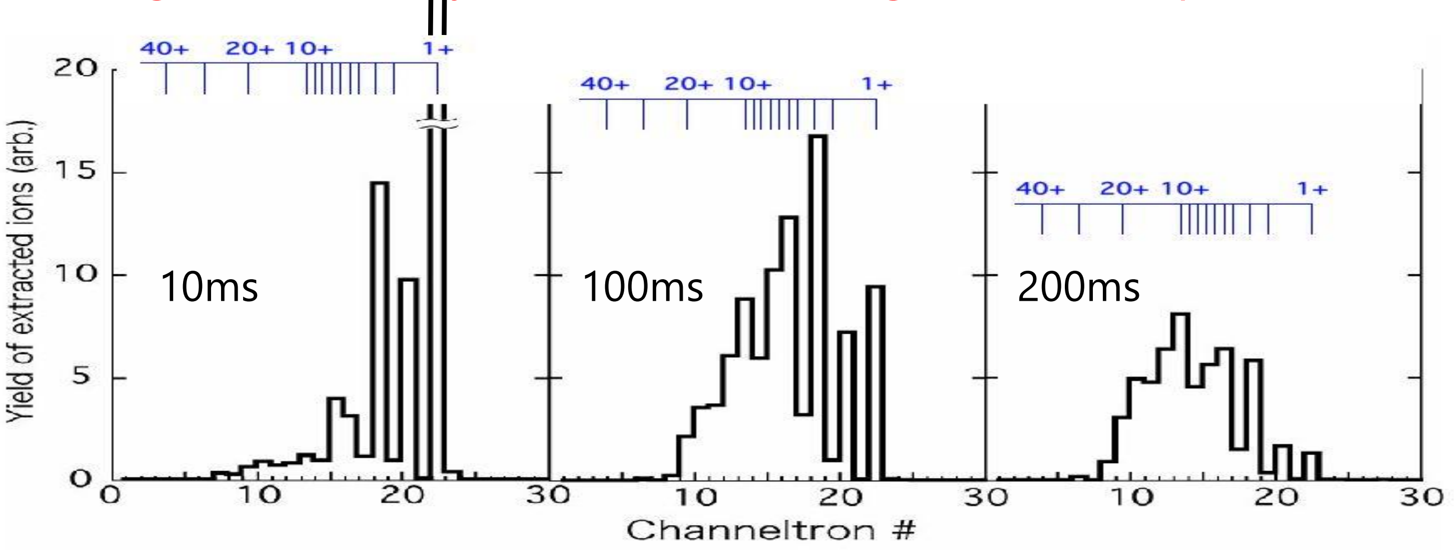
ion trapping lifetime limit = **200 ms**

Upper limit of luminosity:

⇨ **$\sim 10^{29}$ /(cm^{2}s)**

Charge state multiplication in SCRIT

(Higher luminosity induces faster charge-state multiplication)



- Maximum charge state is ~20+, and higher charge states (>20+) do not exist in the SCRIT.

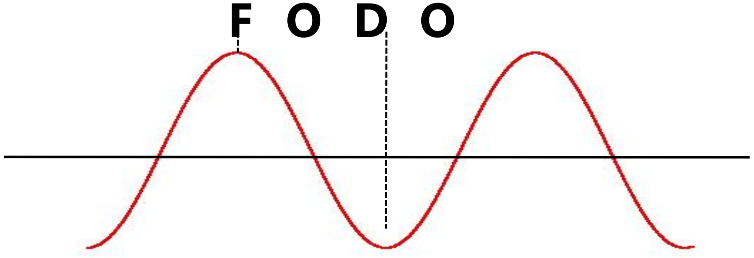
  → Dropout of higher charge state ions

- Rapid increase of total charge (target ions + residual gas ions)

  → Space charge effect (Neutralization limit : ***f*** x 2×10^9 (***f*** **:** 0.2~0.5) at 200mA)

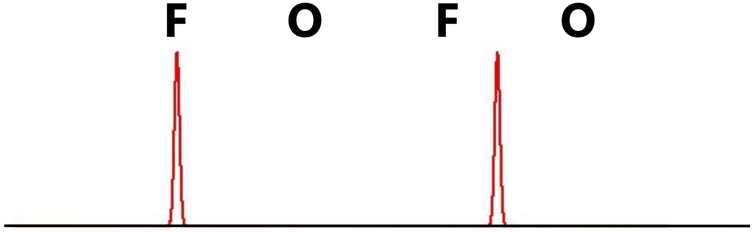
SCRIT ion trapping is in principal the same with RFQ

RFQ

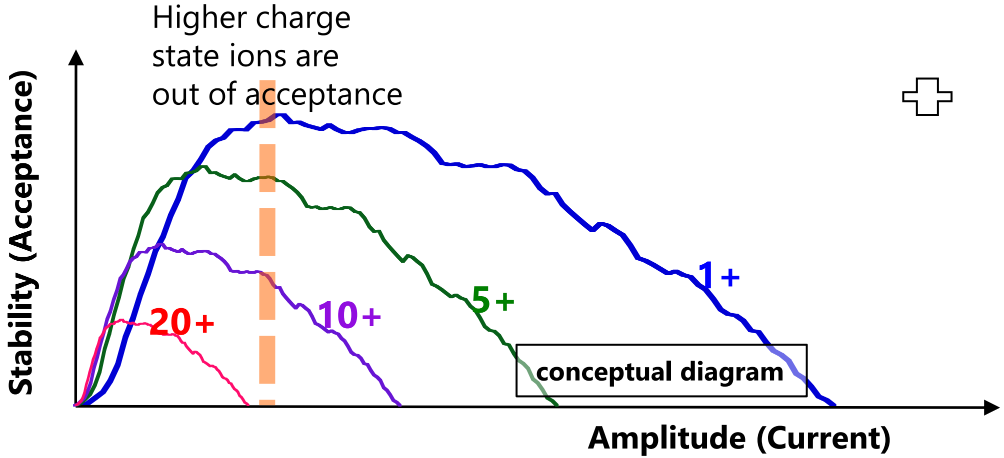


$$A \cos(2p\, f_0\, t)$$

e-beam



$$S_n\, A_n \cos(2p\, n\, f_0\, t)$$



Non-periodic term :

$$S_n\, \underline{A_n(x,t)} \cos(2p\, n\, f_0\, t) + \underline{C(x,t)}$$

due to

- **e-beam instability**
- **space charge effect**
- etc.

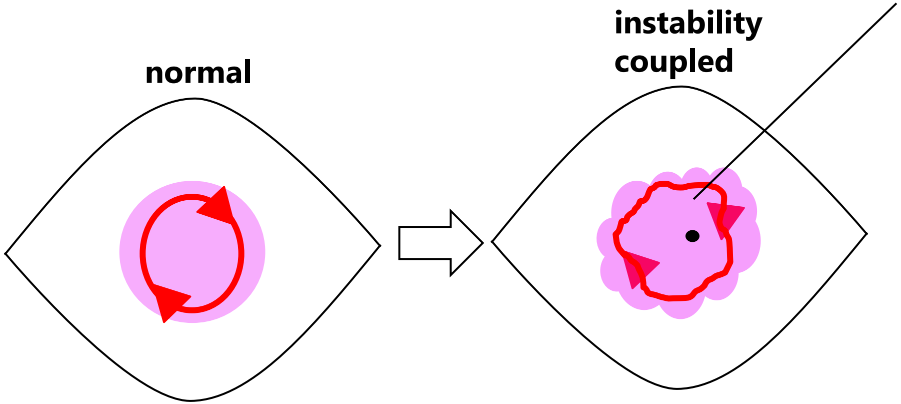
Non-periodic term induces shorter trapping lifetime.

Electron beam instability

(We should take it seriously)

- Microwave instability
- Coupled bunch instability
- HOM excited in cavity
- Intra-beam scattering
- Tune shift and spread
- etc.

} coupled to
- Synchrotron oscillation
- Betatron oscillation



Beam motion in longitudinal phase space

Induced multi-pole coherent motion

Dipole → **B**eam axis oscillation
at dispersive section
Periodicity oscillation

Quadrupole → **B**eam size oscillation
at dispersive section
Bunch length oscillation

Octapole → ……

Influence of e-beam instability and space charge

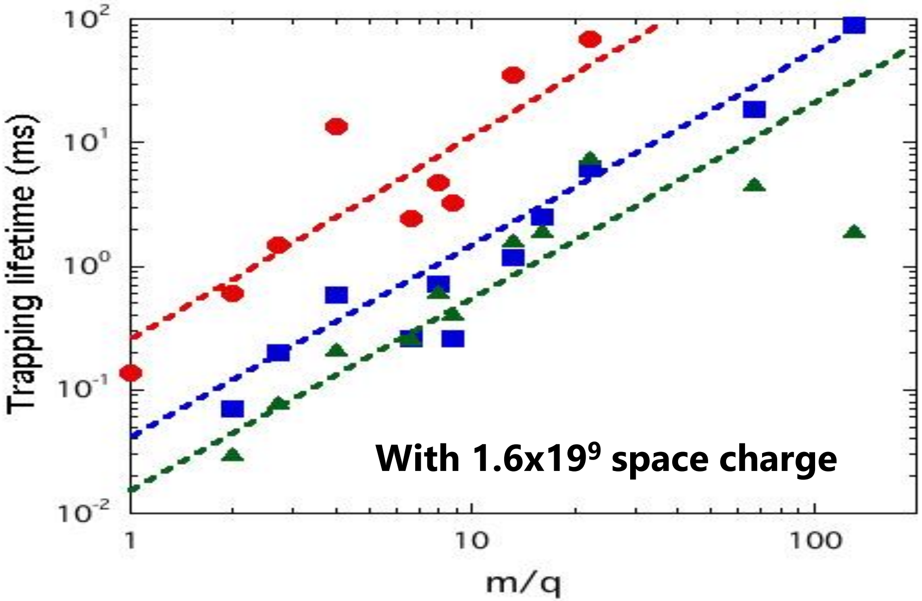
Ion trapping lifetime with coherent synchrotron oscillation (simulation)

Synchrotron oscillation amplitude in real space

0.1 mm

0.5 mm

1.0 mm

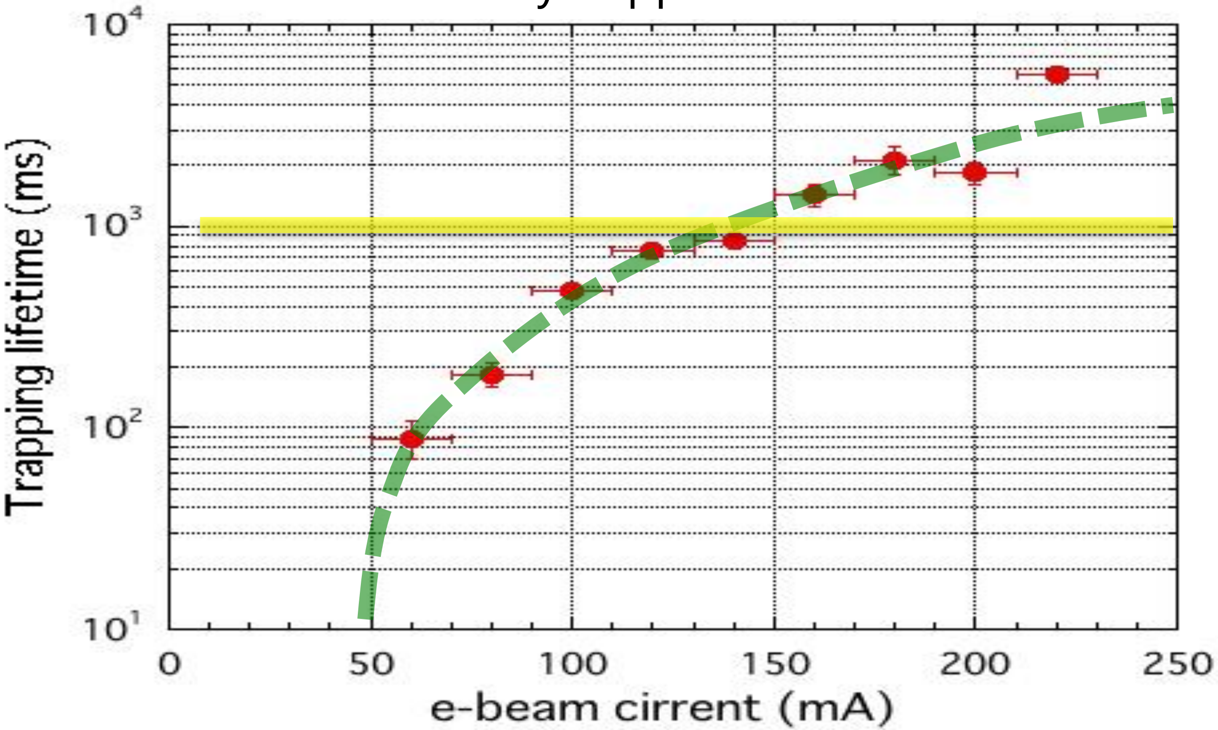


e-beam instability extremely reduces the trapping lifetime especially for highly charged ions.

Space charge enhances the trapping instability

Current dependence of trapping lifetime

for instability-suppressed beam



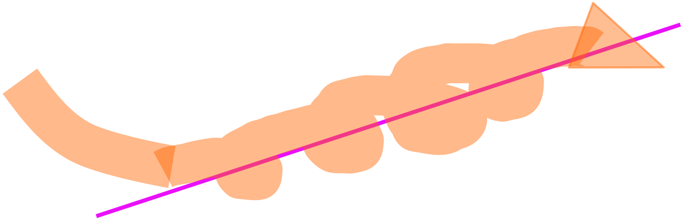
Necessary lifetime is **~1s** for practical use

Prerequisite for e-beam

I_e > 150mA

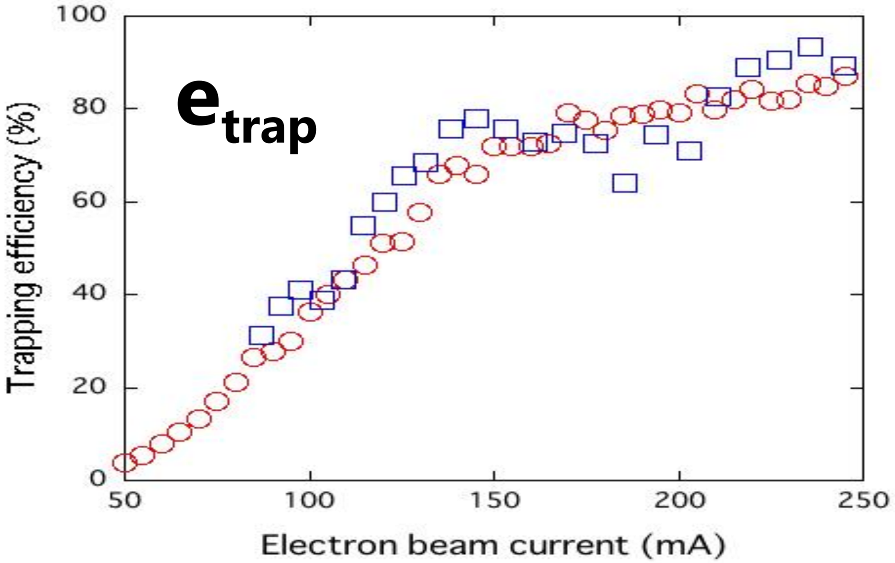
without instability

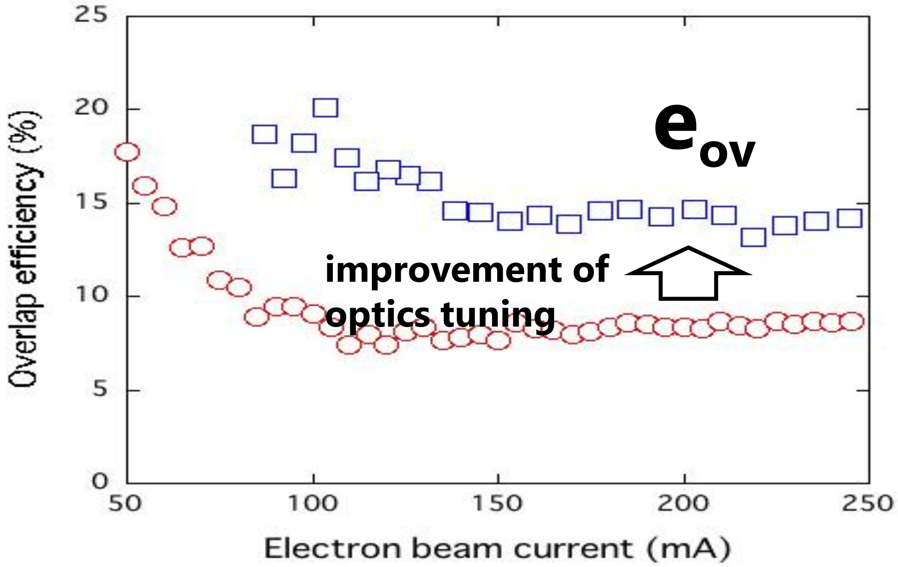
Trapping efficiency e_{trap} and overlap efficiency e_{ov}



$$N_T = e_{trap}\, e_{ov}\, N_0$$

At merging section, ion beam may **wrap around** electron beam axis due to **strong focusing force**.



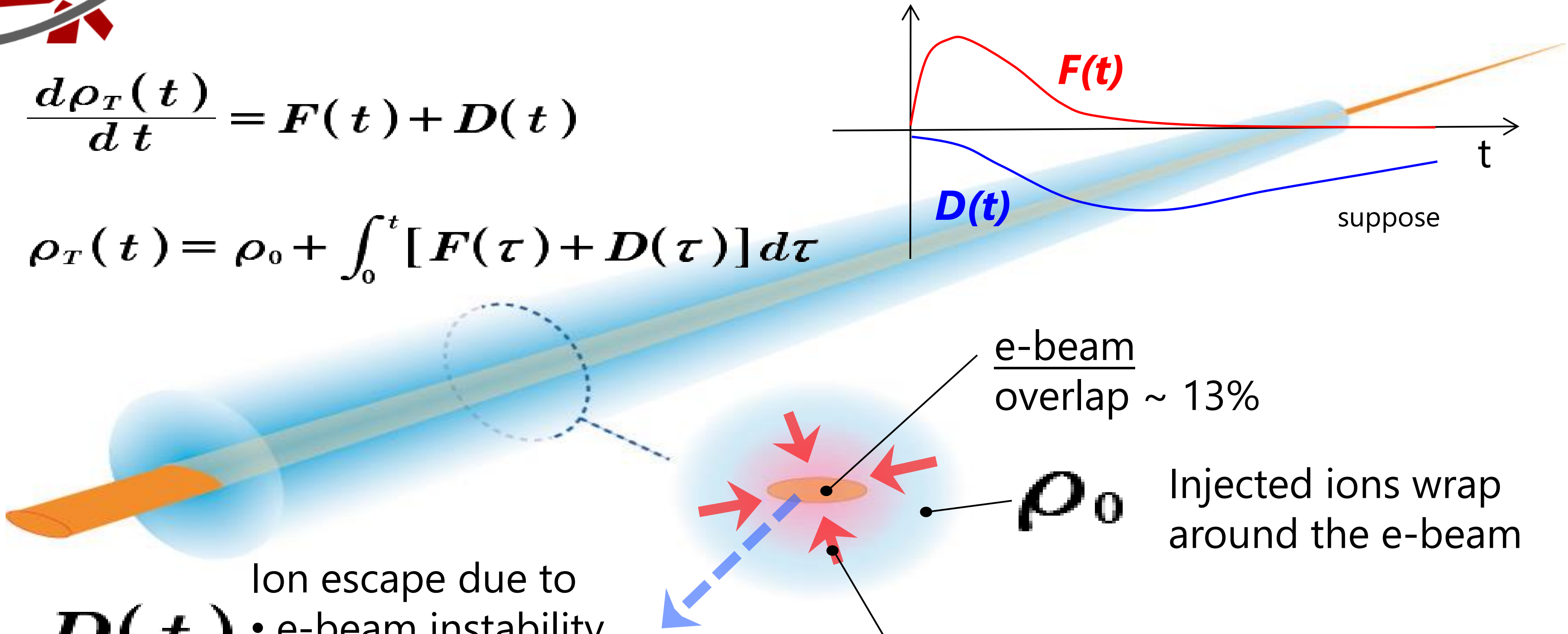


larger e_{ov} → higher luminosity → shorter trapping lifetime

Ion trapping imagined from our measurements

$$\frac{d\rho_T(t)}{dt} = F(t) + D(t)$$

$$\rho_T(t) = \rho_0 + \int_0^t [F(\tau) + D(\tau)]\,d\tau$$



ρ_0 Injected ions wrap around the e-beam

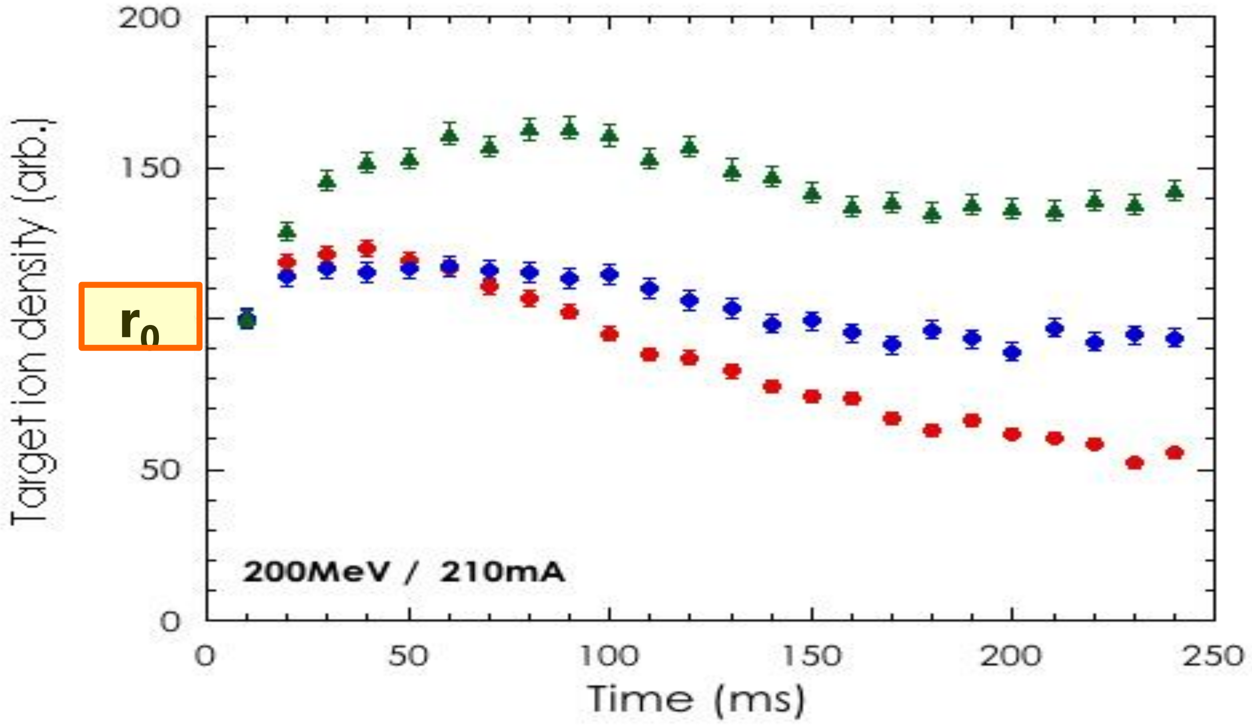
$D(t)$ Ion escape due to

- e-beam instability
- space charge effect
- Dropout of higher charge state

$F(t)$ Spatial ion distribution gradually shrinks with increasing charge state

Time evolution of $r_t(t)$ ($\propto L$) in trap duration

There is a possibility to control ***F(t)*** and ***D(t)*** functions by adjusting e-beam parameters.



SR2 tune

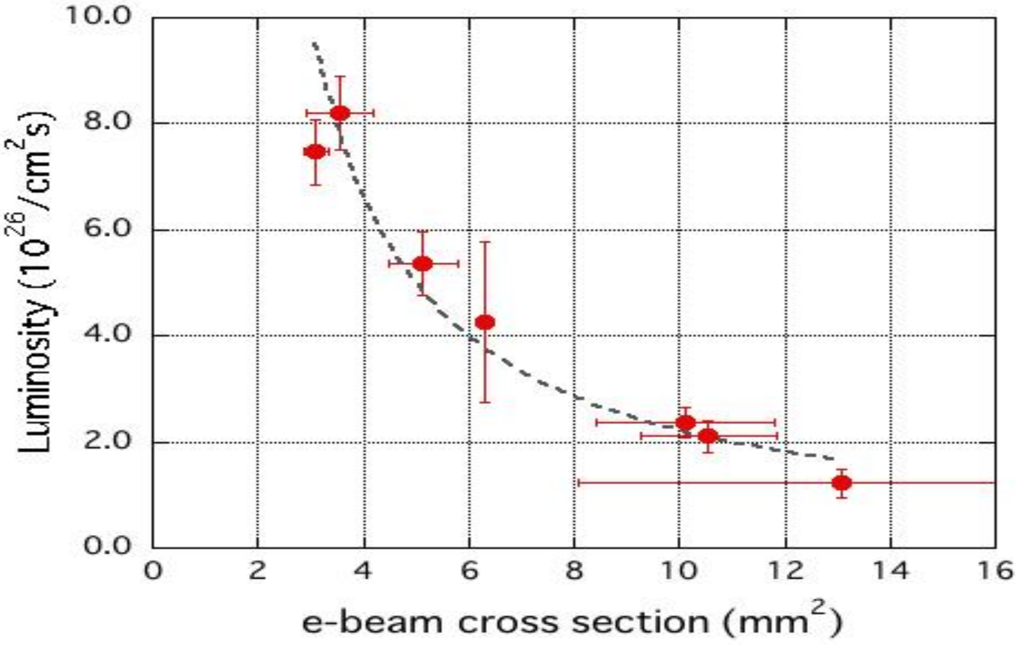
n_x=1.62 / n_y=1.58

n_x=1.62 / n_y=1.65

n_x=1.70 / n_y=1.72

Luminosity depending on e-beam size

at the beginning of trap (proportional to r_0)



Luminosity is expressed by a linear fractional function of the beam cross section.

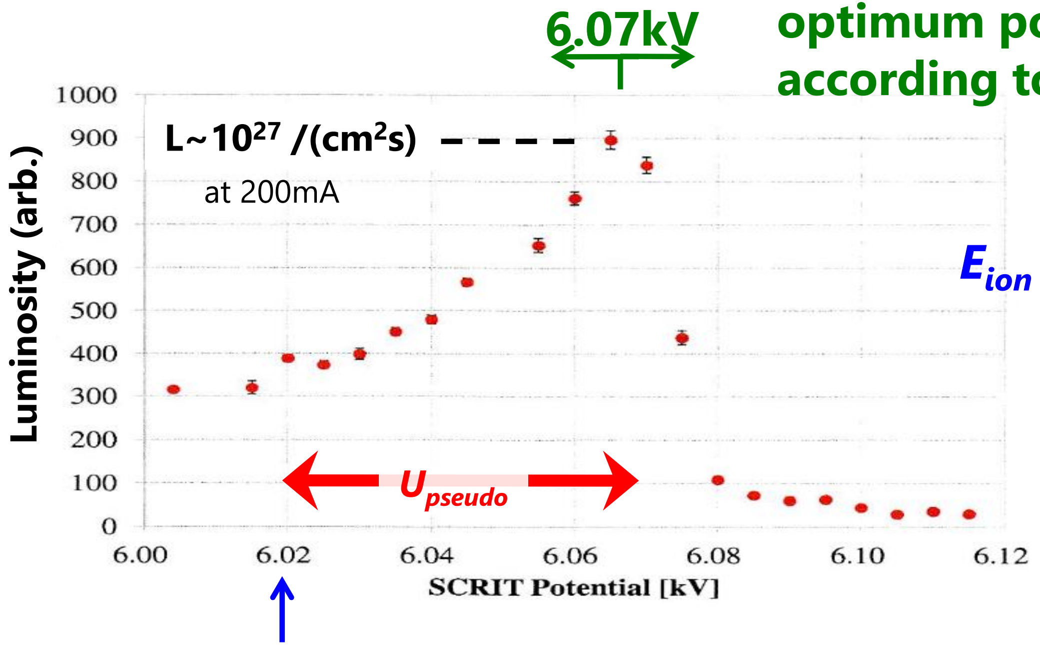
$$L \propto {}^{1}\!/\!_{a}$$

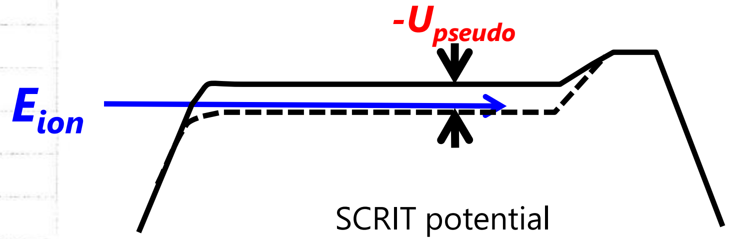
$$N_t \approx constant$$

$$\rho_0 \propto {}^{1}\!/\!_{a}$$

Luminosity depending on the SCRIT electrostatic potential

optimum position is shifted according to the current and the size

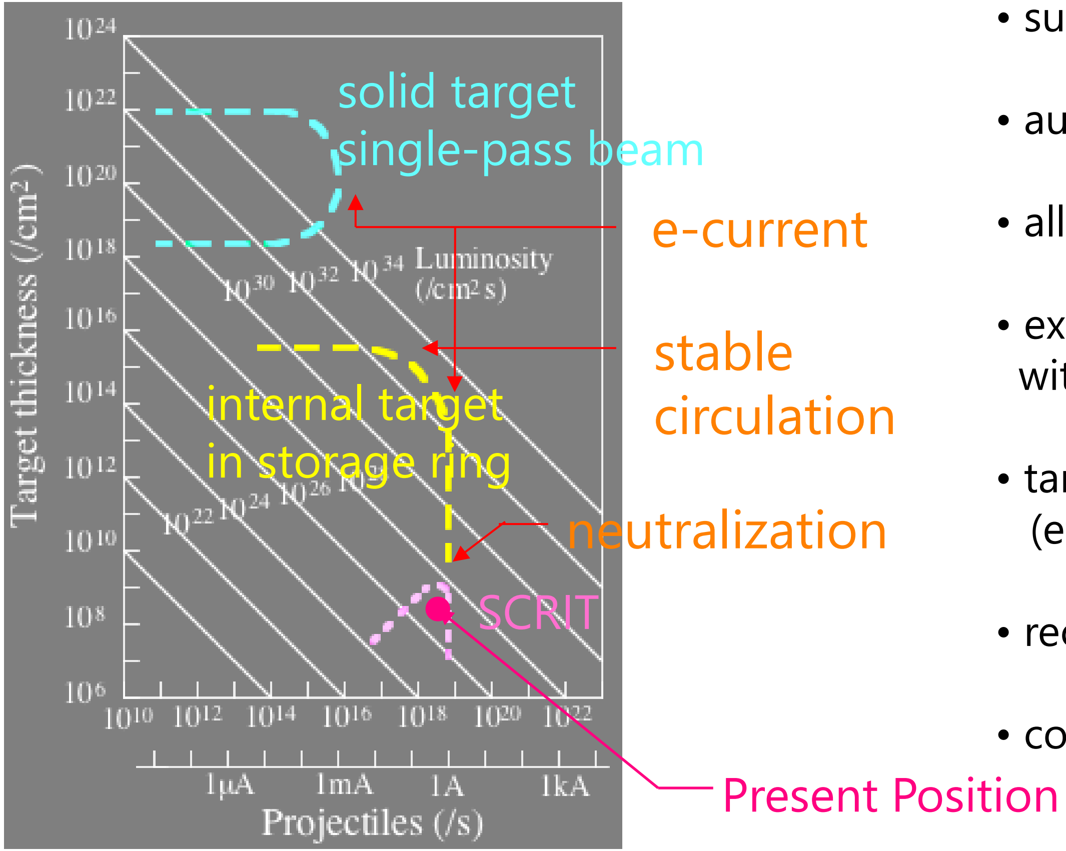




Injected ion beam energy = 6.02keV

Ion energy should be thermalized in the SCRIT

Capability of the SCRIT as a target

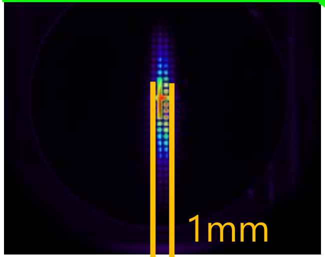


- support-free and floated thin-target
- automatic collision
- all trapped ions participate collision
- expected luminosity ~10^{28} /cm^{2}s with 10^7~10^8 nuclei
- target ions are fully controllable (efficient use of rear nuclei)
- recoiled ions are detectable
- compact experimental system

RI production at ERIS

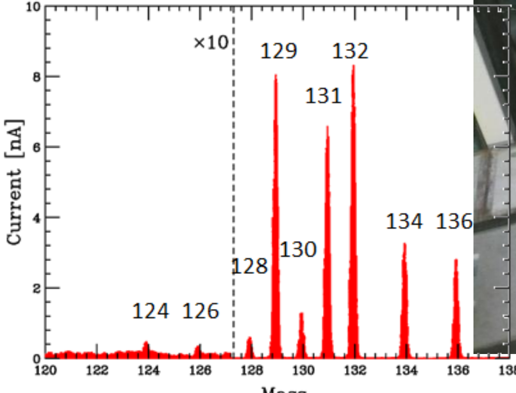
Photofission of uranium

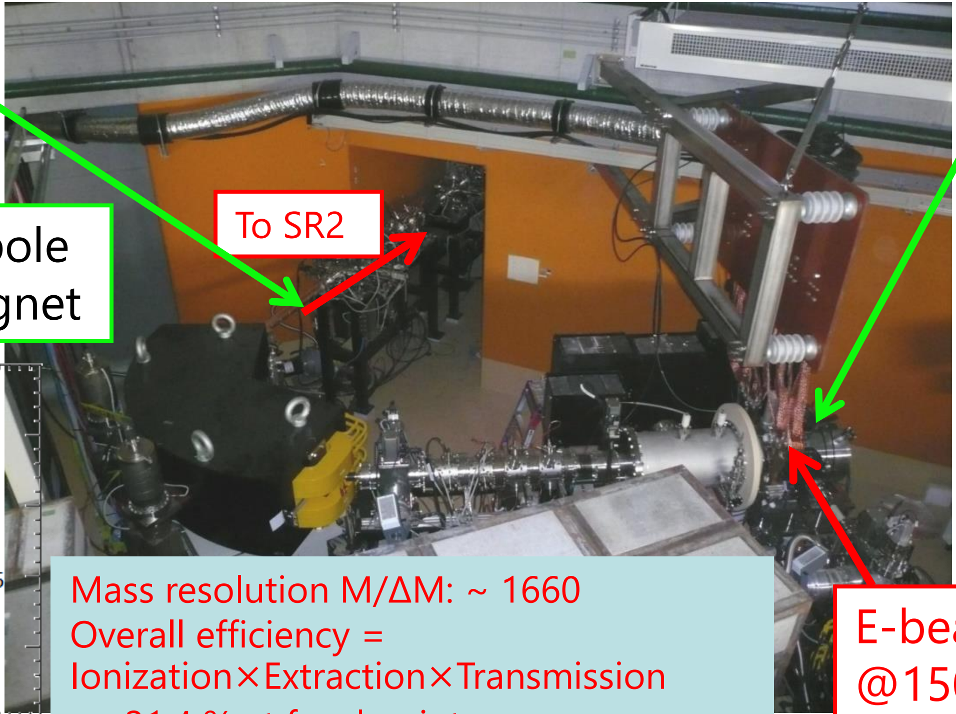
Beam diagnostic system(FC+CCD)



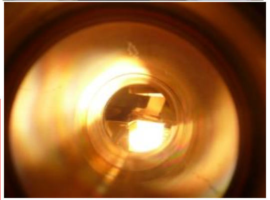
$^{129}Xe^{+}$

Dipole magnet





Production target & FEBIAD type ion source @ 20 kV HV stage

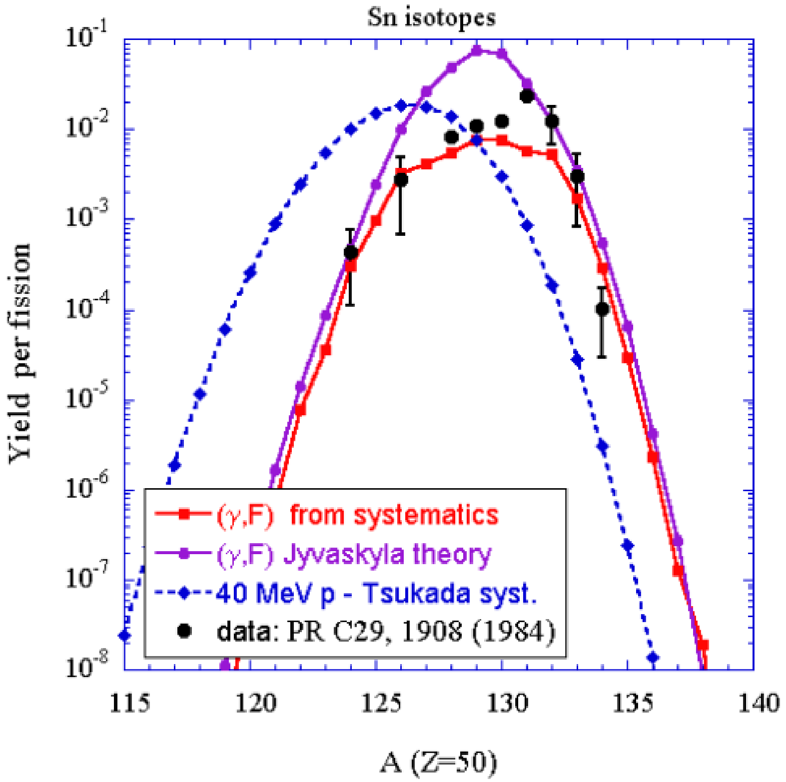


~ 2000 °C

E-beam @150MeV

Mass resolution M/ΔM: ~ 1660
Overall efficiency = Ionization×Extraction×Transmission : ~ 21.4 % at focal point

A sample comparison with data: Sn isotopes



taken from eRIB's07 workshop
Reported by Jim Beene

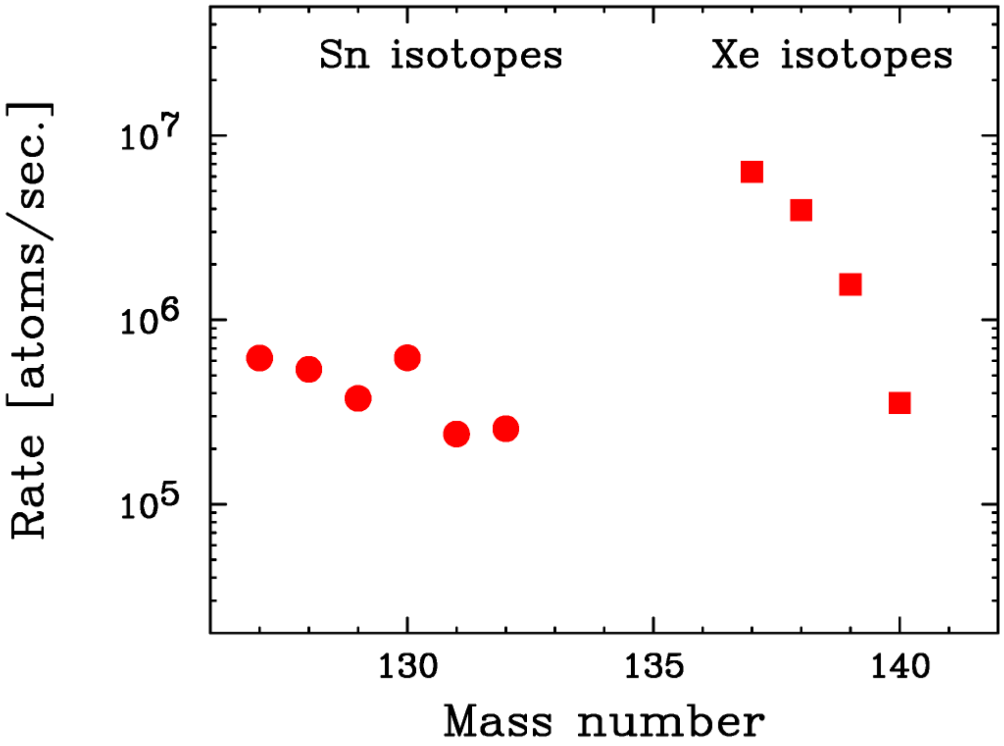
Target preparation

Uranyl nitrate solution mixed with graphite powder (20μm)
→ Oxidization around 500 °C
→ 180 MPa compression with no binder

Uranium-oxide-coated carbon disk
Φ20 mm, 1 mm thickness, U 0.7 g, C 0.35 g

Carbothermic reaction at 1100-1600 °C

Uranium carbide disk
Φ18 mm, 0.8 mm thickness
U density ~3.4 g/cm^3



U 15g, 10W e-beam

^{138}Xe: 3.9×10^{6} cps

^{132}Sn: 2.6×10^{5} cps

Release efficiency

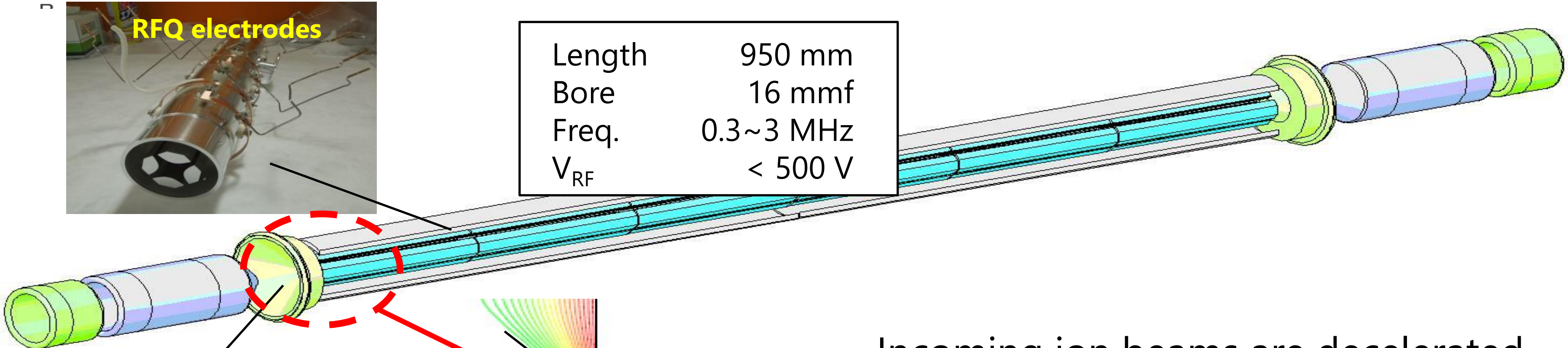
Overall efficiency = Release × Ionization × Transport

Exp./Calc. | Target～Ionization | from ^{129}Xe gas (14～15%)

	Rate at 10W (atoms/s)	Calc at 10W (atoms/s)	Overall	Release
^{138}Xe	3.9×10^6	7.1×10^7	5.5 %	40 %
^{132}Sn	2.6×10^5	1.3×10^7	2.0 %	14 %

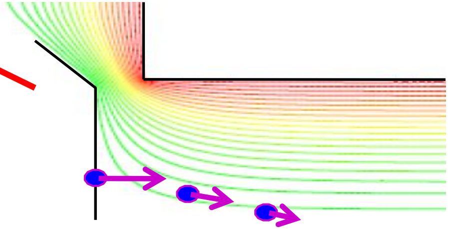
Buncher Device for Ion Injection to SCRIT

Buncher based on RFQ linear trap converts 1-s DC beam into 500ms pulsed beam

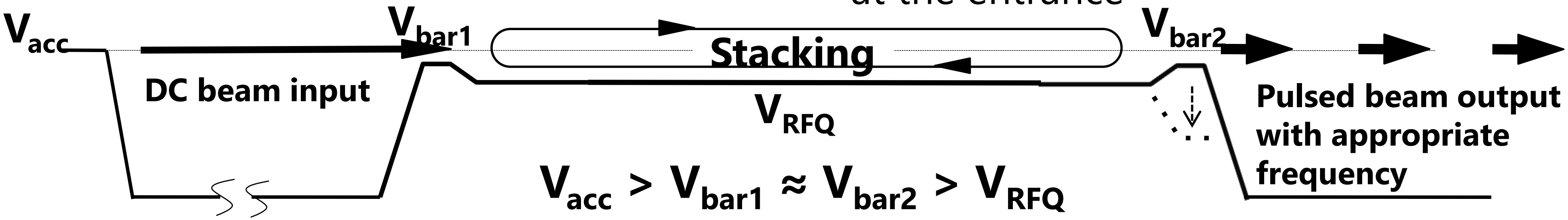


Barrier electrodes

Length	950 mm
Bore	16 mmf
Freq.	0.3~3 MHz
V_{RF}	< 500 V

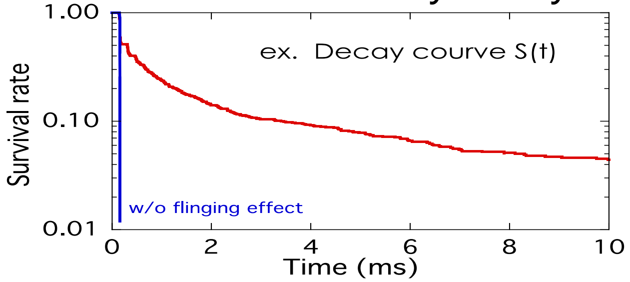


Incoming ion beams are decelerated and stacked in RFQ by **flinging RF field effect** at the entrance



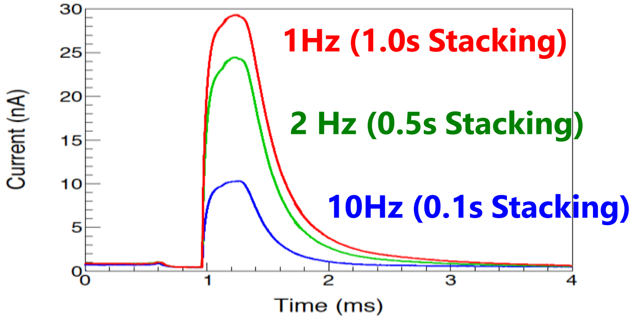
Ion stacking using flinging field and conversion efficiency

Stacked ions slowly decay



Number of stacked ions *N(t)* :

$$N(t) = I_{DC} \int_0^t S(t - t')\, dt'$$



DC-Pulse conversion efficiency