The SCRIT Facility at RIKEN

M. Wakasugi and SCRIT collaborations

Work shop on e-Ion collision at CEA Saclay
(25-27 Apr. 2016)

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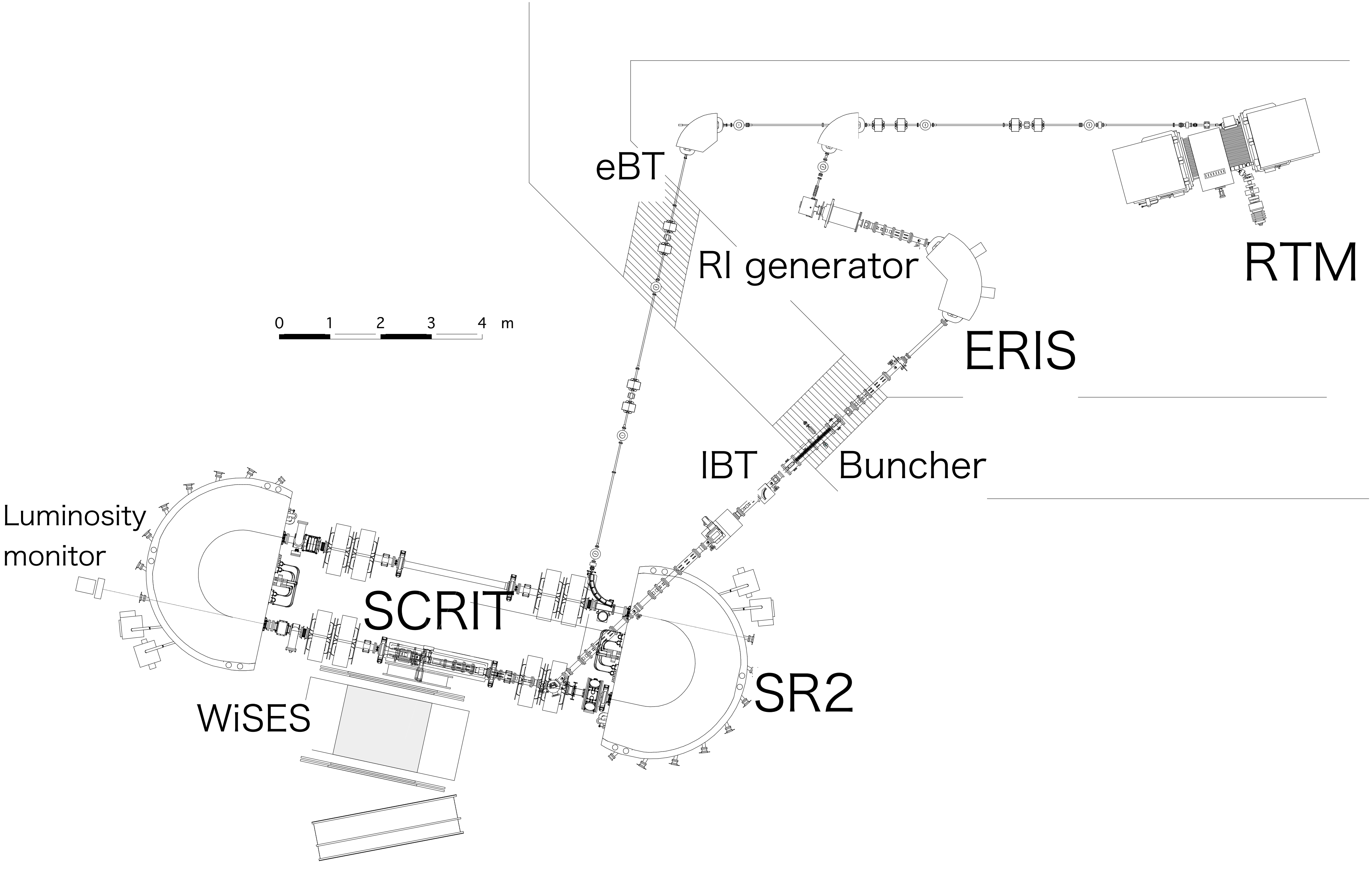
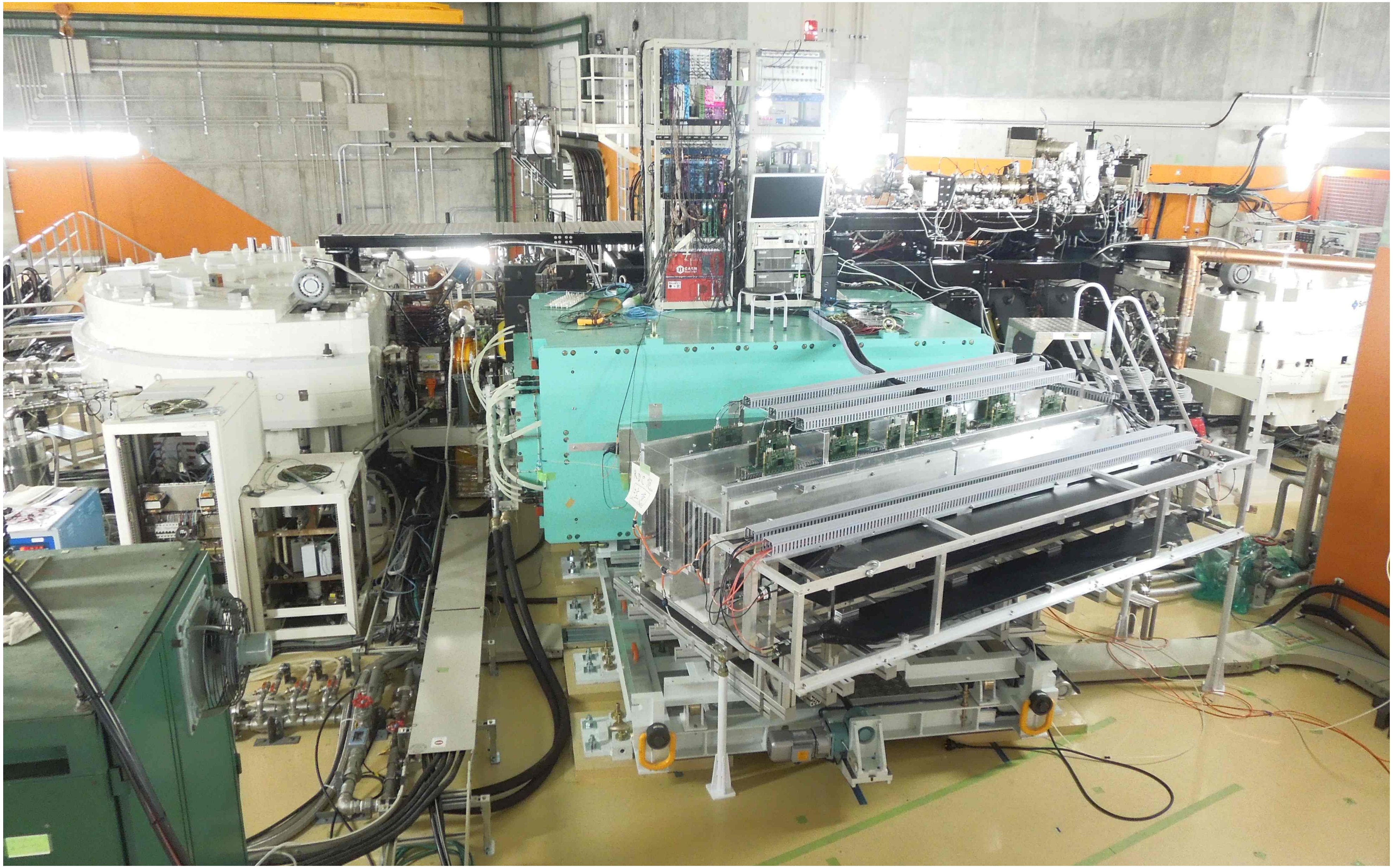
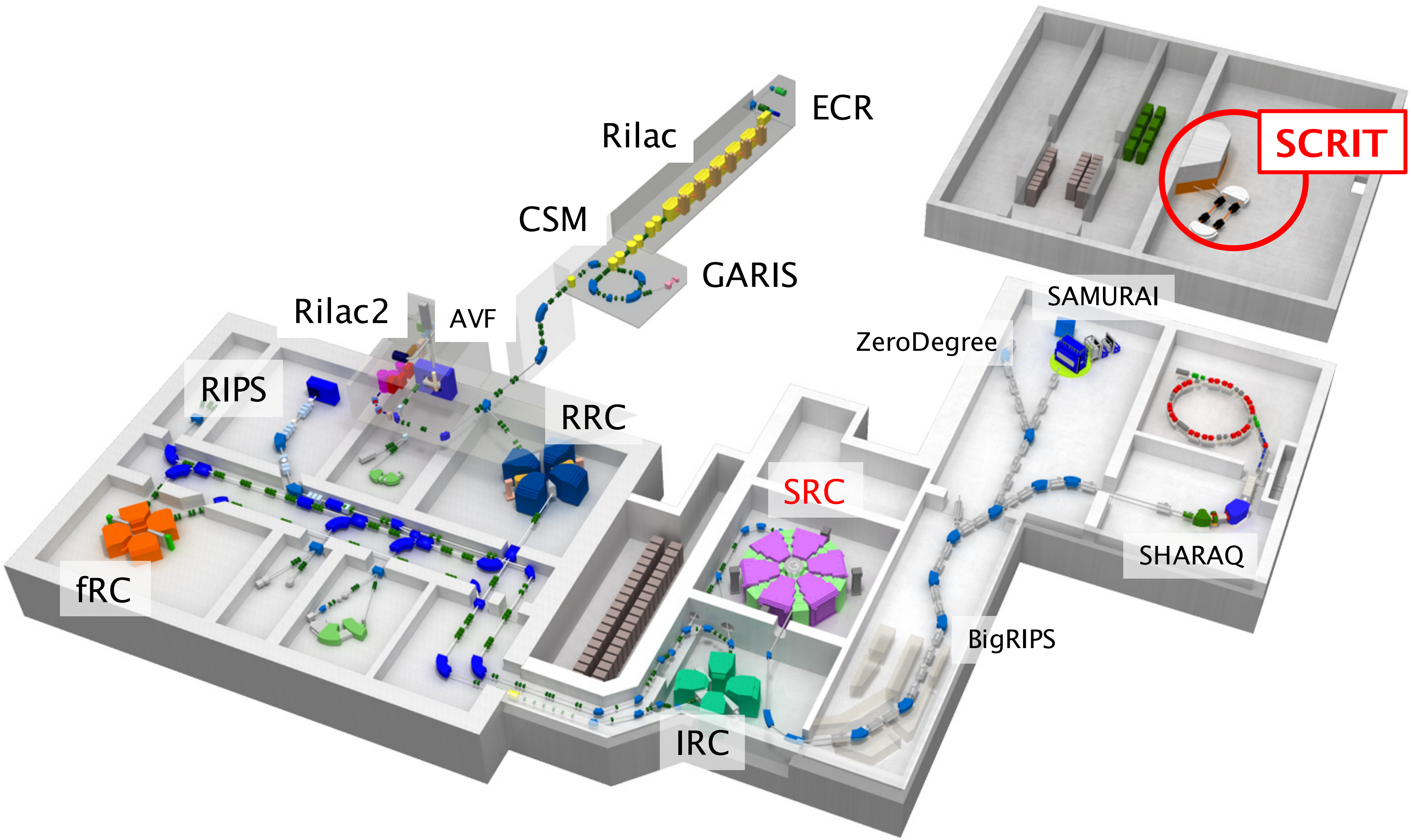
The SCRIT Electron Scattering Facility



The SCRIT Electron Scattering Facility



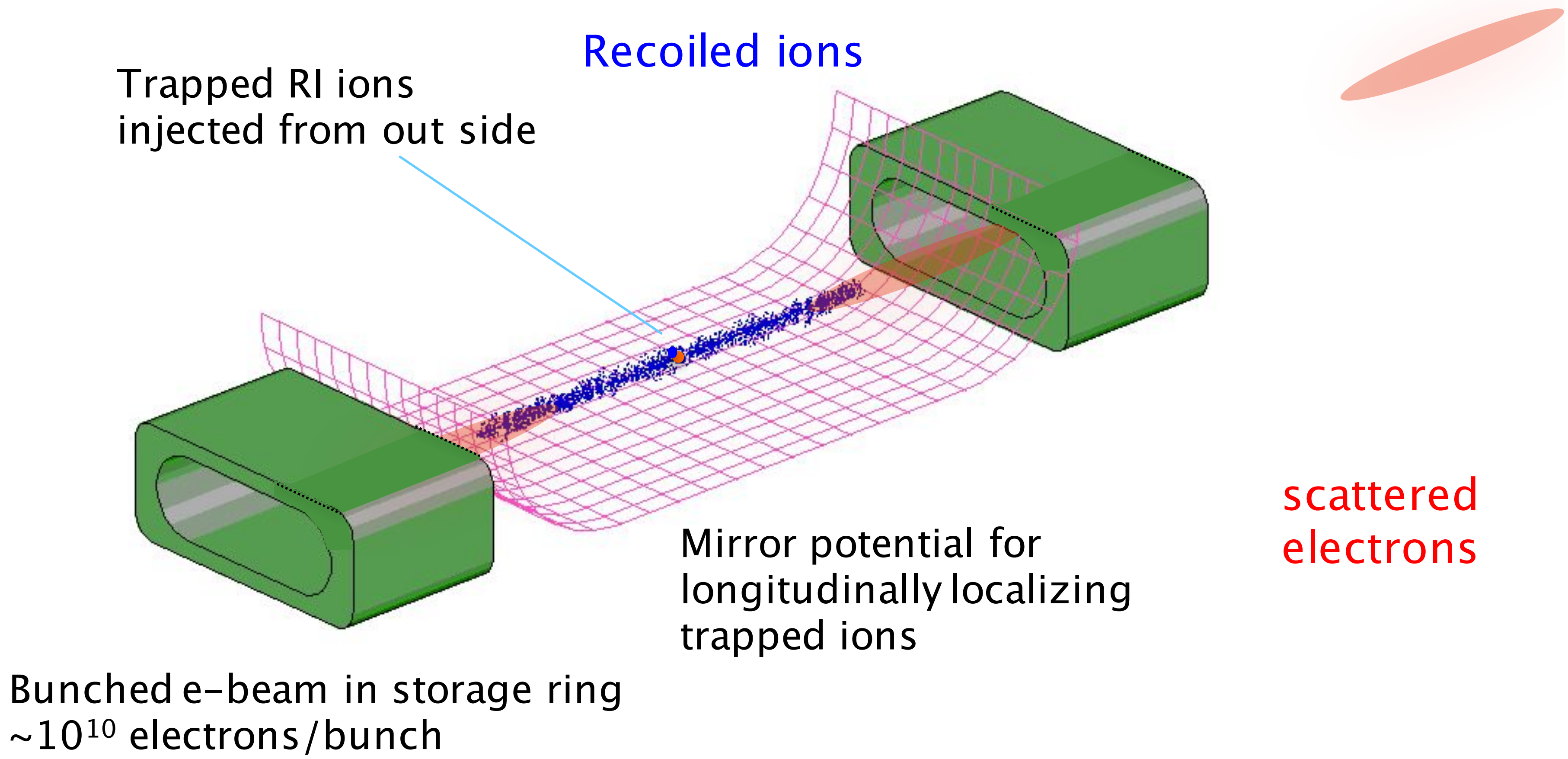
Location of the SCRIT Facility in the RIKEN RI Beam Factory



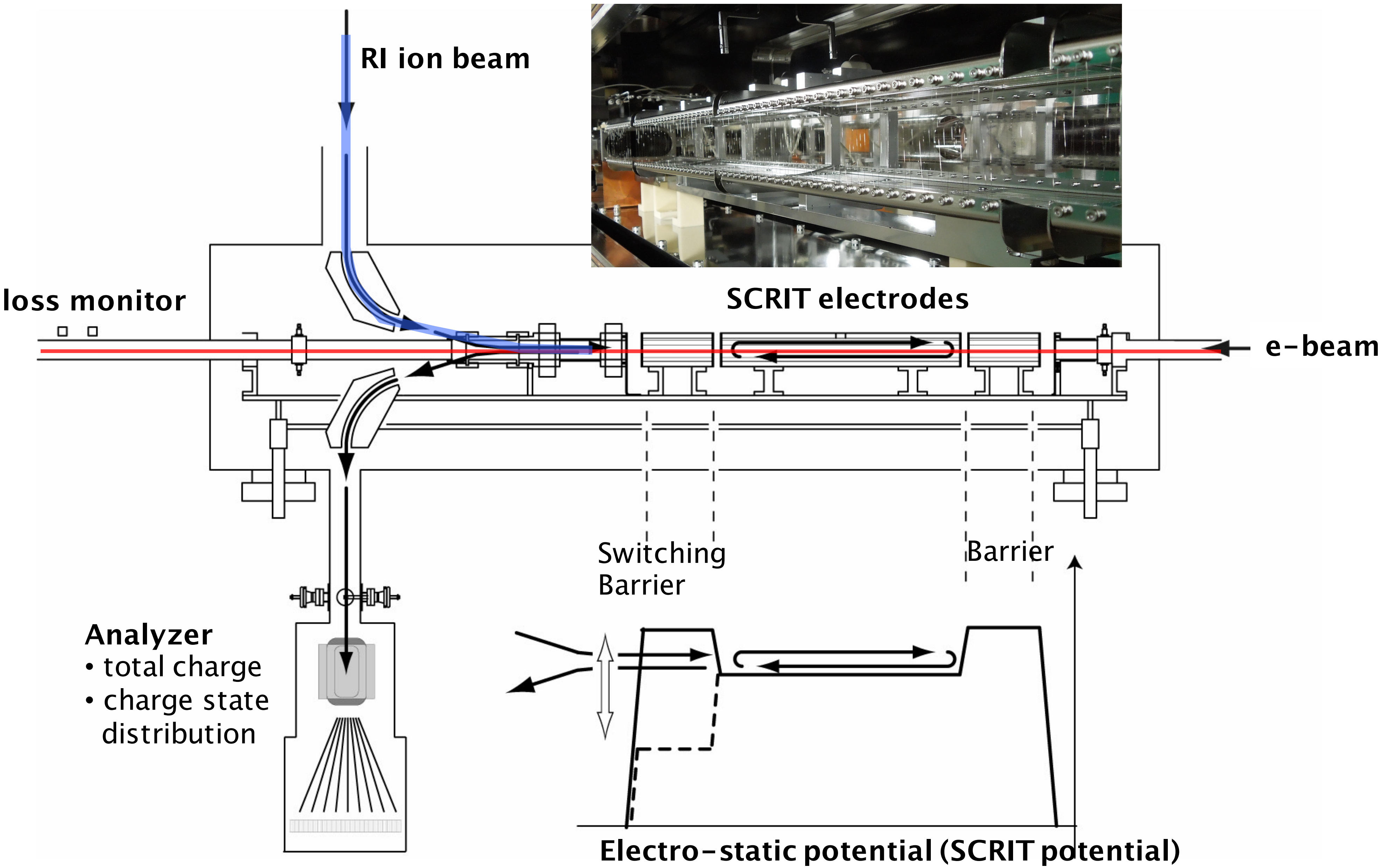
SCRIT (Self-Confining RI Ion Target)

SCRIT is internal-target-forming technique in an electron storage ring.

Target ions are confined in the beam orbit by periodic focusing force.

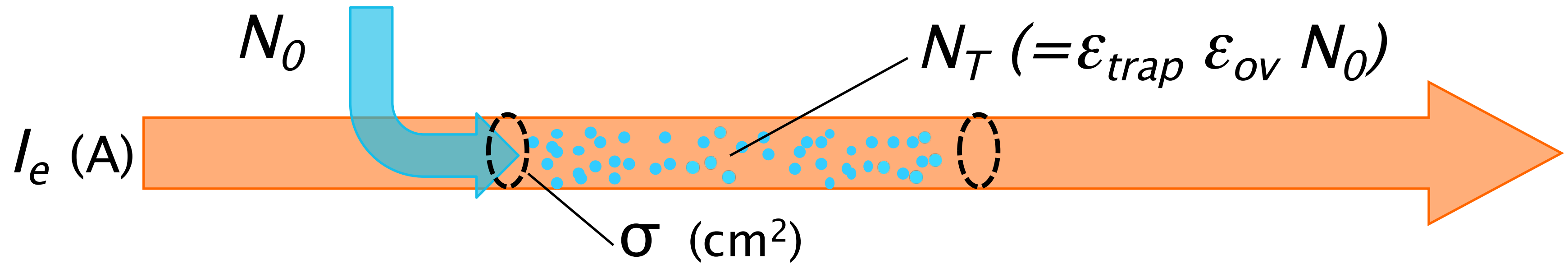


The SCRIT device



Luminosity and related properties of e-beam and target ion trapping

Achievable luminosity



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

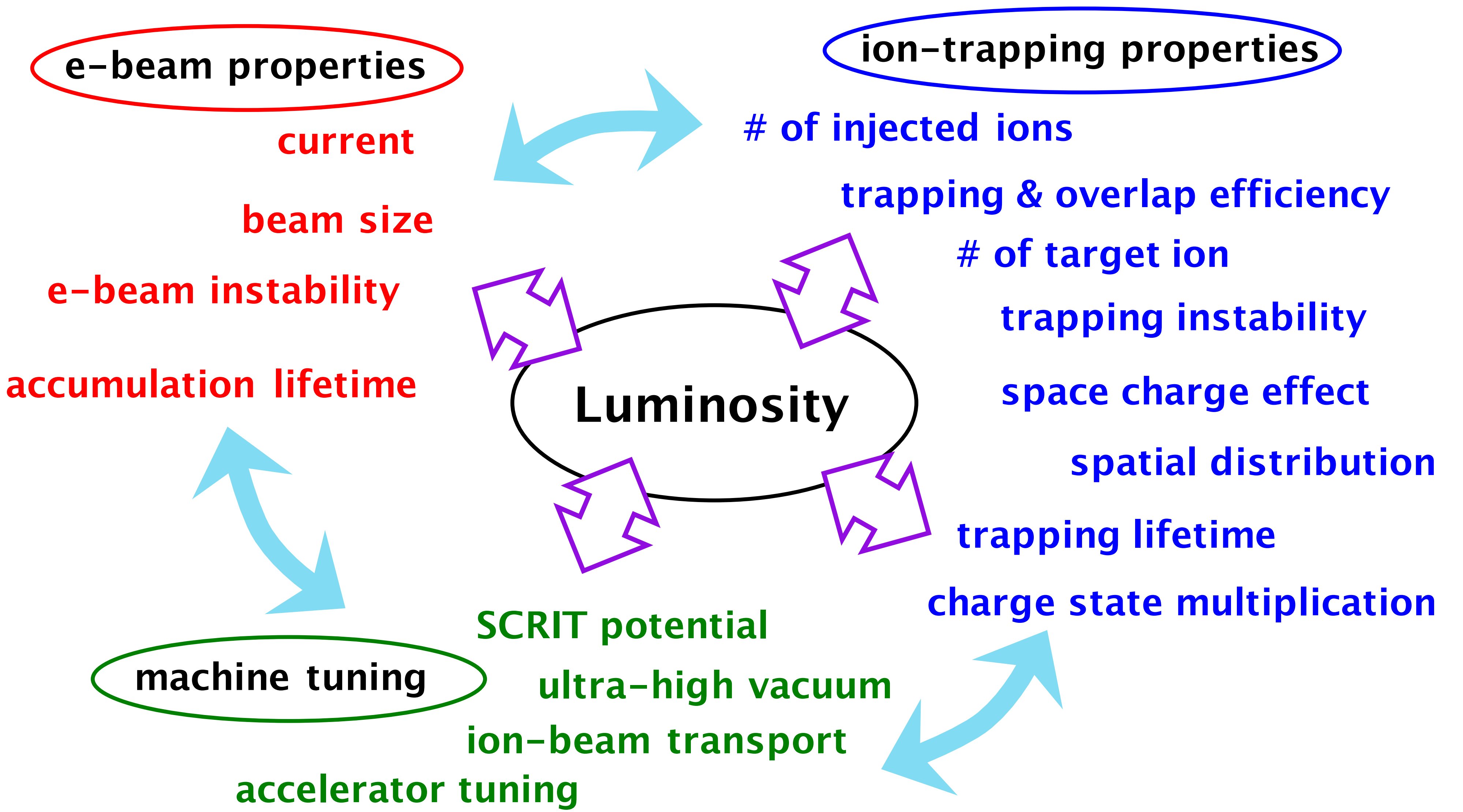
Current performance (typical)

at I_e ~ 220mA, σ ~ 3.5mm^2, N_0 ~ 2x10^8 ⇨ L ~ 10^{27} /(cm^{2}s)

Number of target ions $N_T \sim 2.6\text{x}10^7$

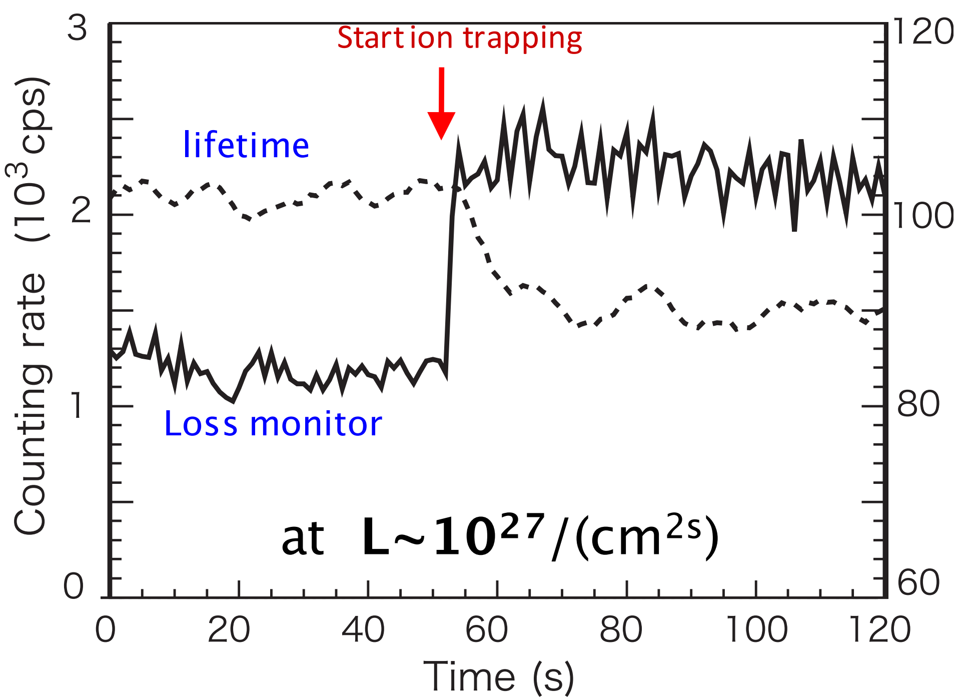
Total efficiency $\varepsilon_{trap}\,\varepsilon_{ov} = N_T/N_0 \sim 13\ \%$

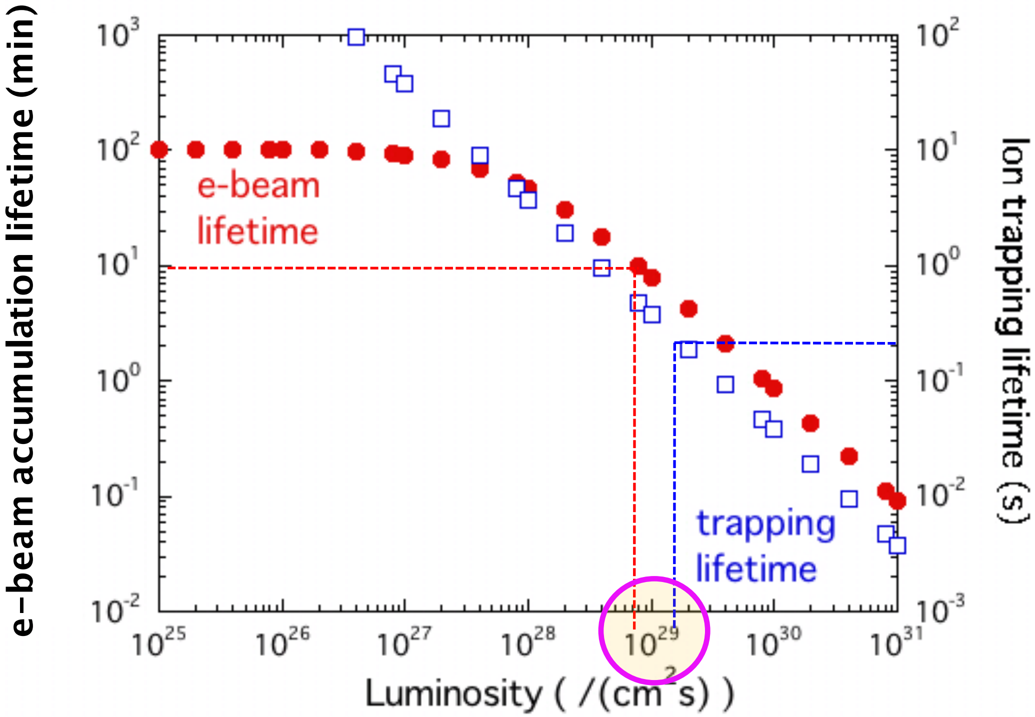
luminosity is strongly related to e-beam & ion-trapping properties



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.**

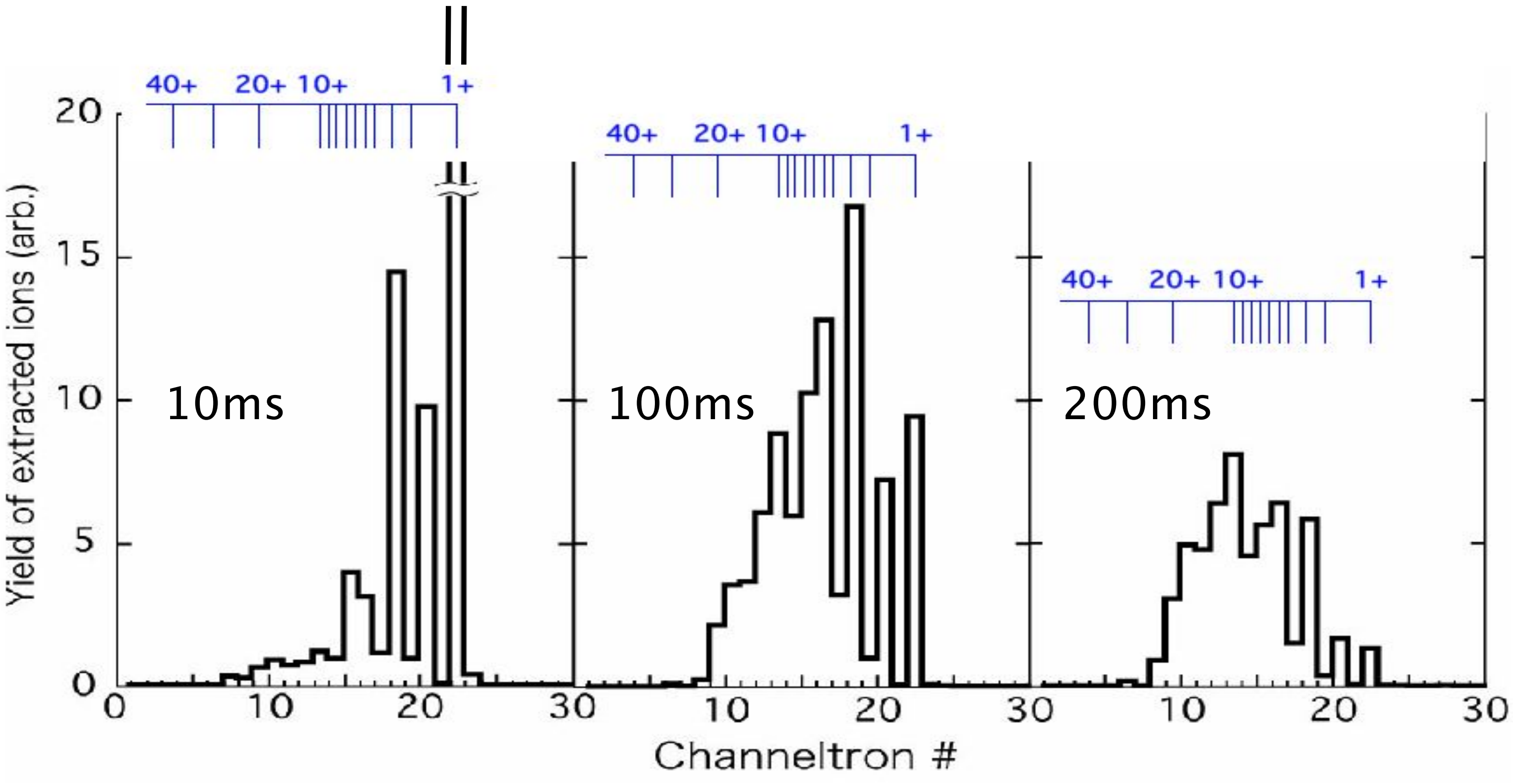
ion trapping lifetime limit = **200 ms**

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.

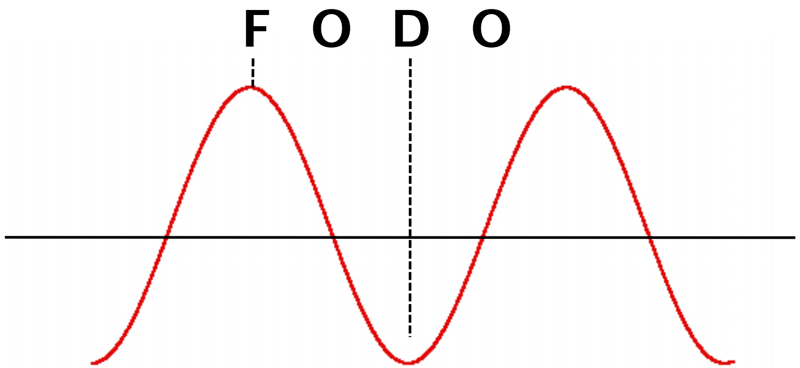
  → Dropout of higher charge state ions

- 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)

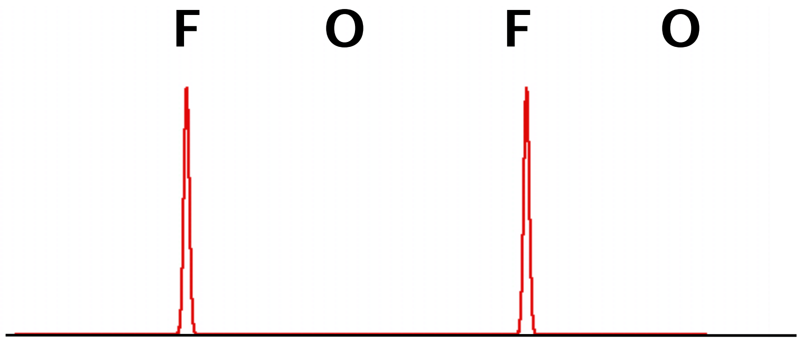
SCIRT ion trapping is in principal the same with RFQ

RFQ

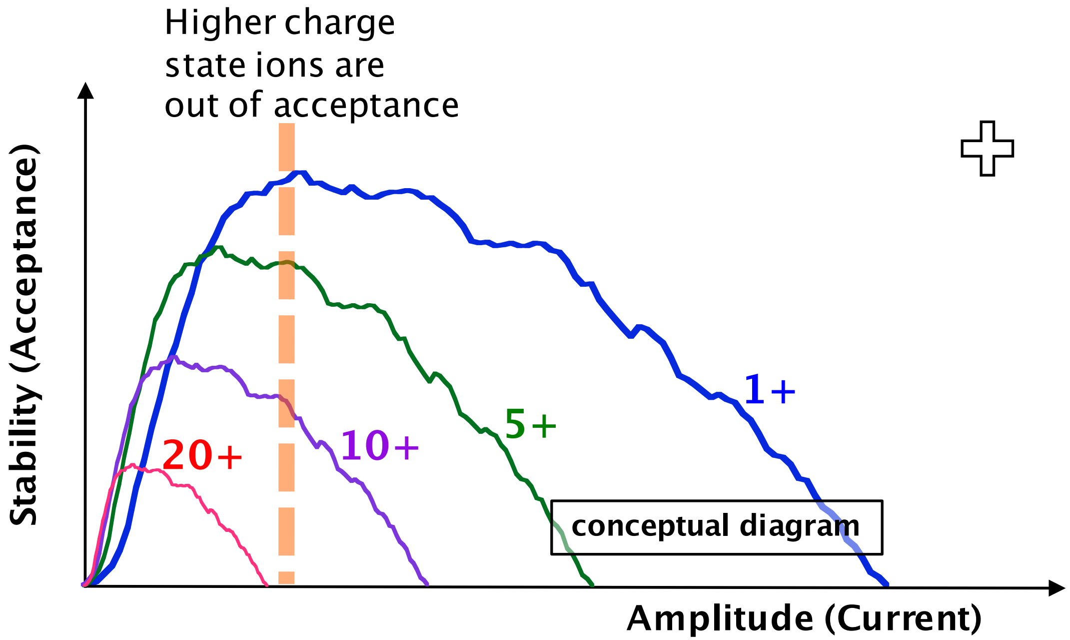


$A\cos(2\pi f_0 t)$

e-beam



$\Sigma_n A_n \cos(2\pi\, n\, f_0 t)$



+

Non-periodic term :

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

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

Non-periodic term induces shorter trapping lifetime.

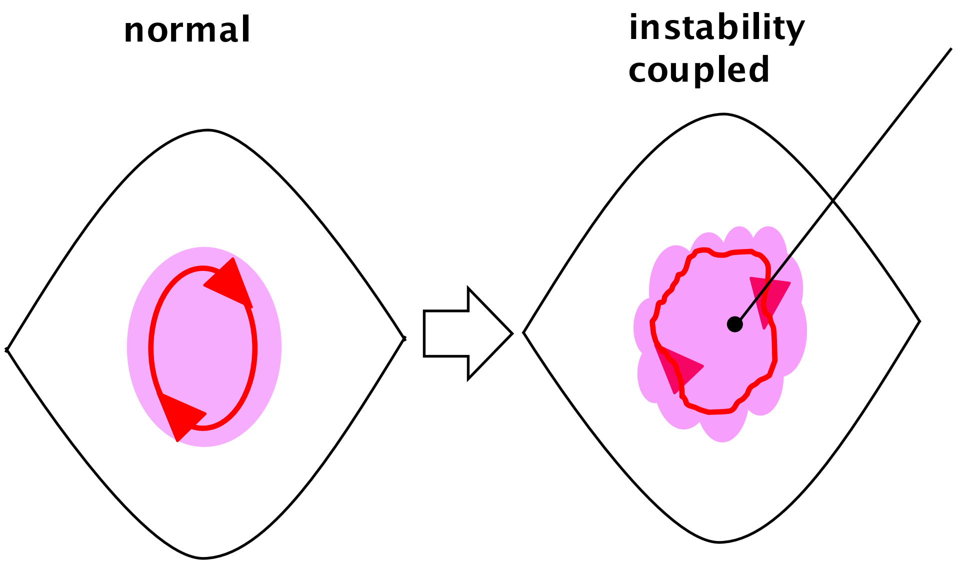
Electron beam instability

(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

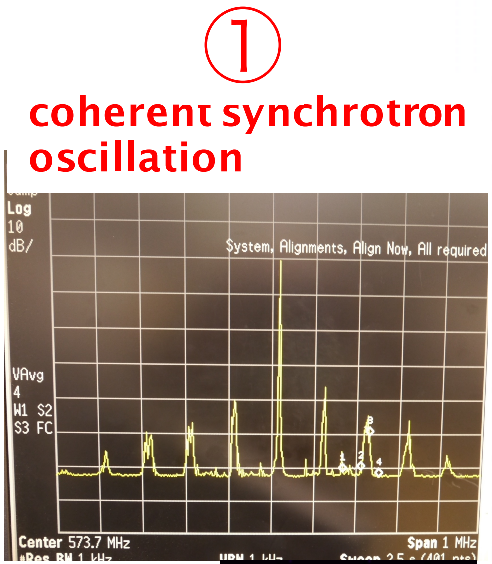
Dipole → **B**eam axis oscillation at dispersive section
Periodicity oscillation

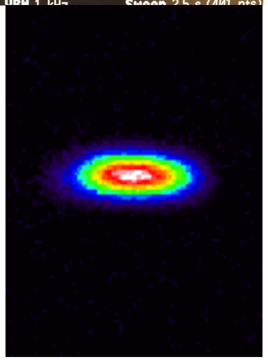
Quadrupole → **B**eam size oscillation at dispersive section
Bunch length oscillation

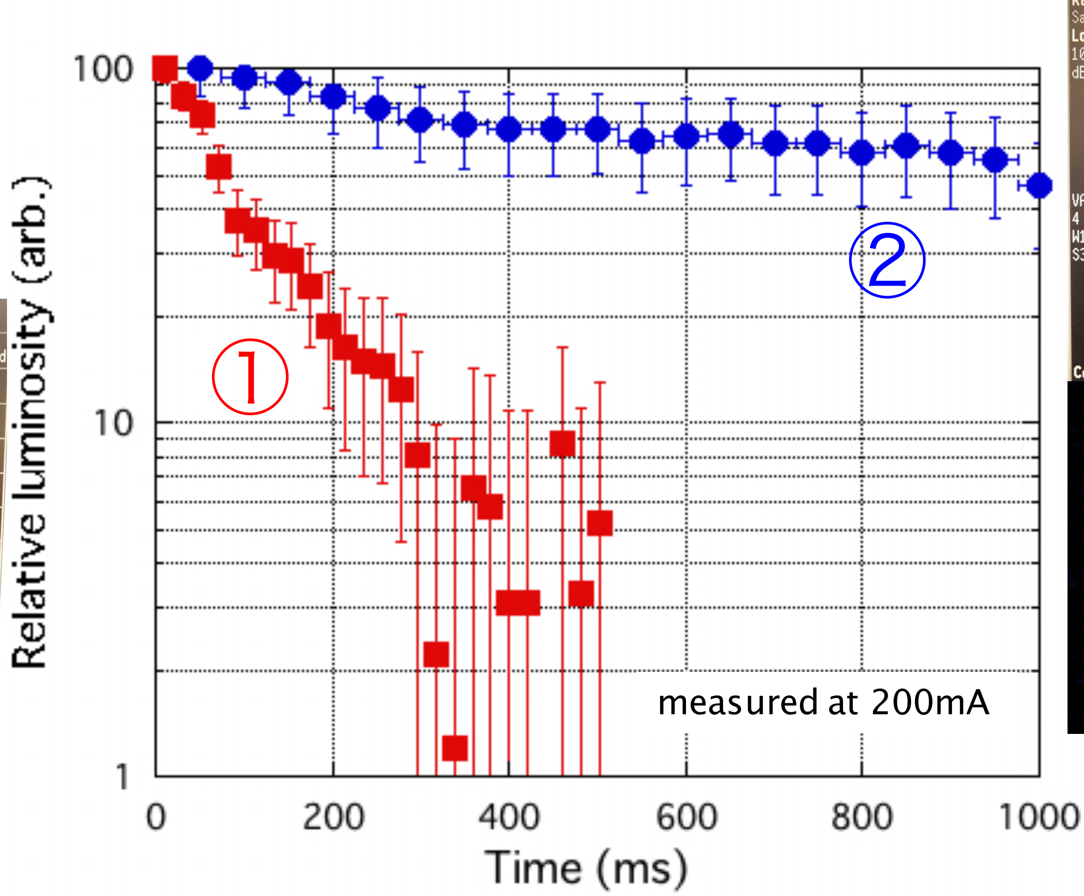
Octapole → ……

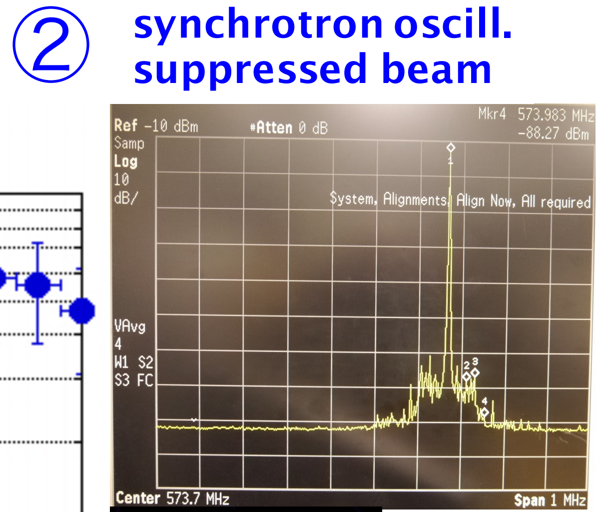
……

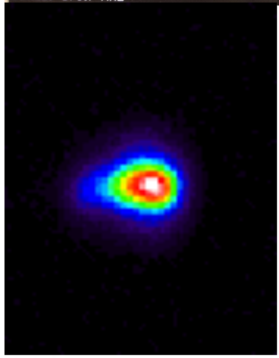
Trapping lifetime reduction due to e-beam instability









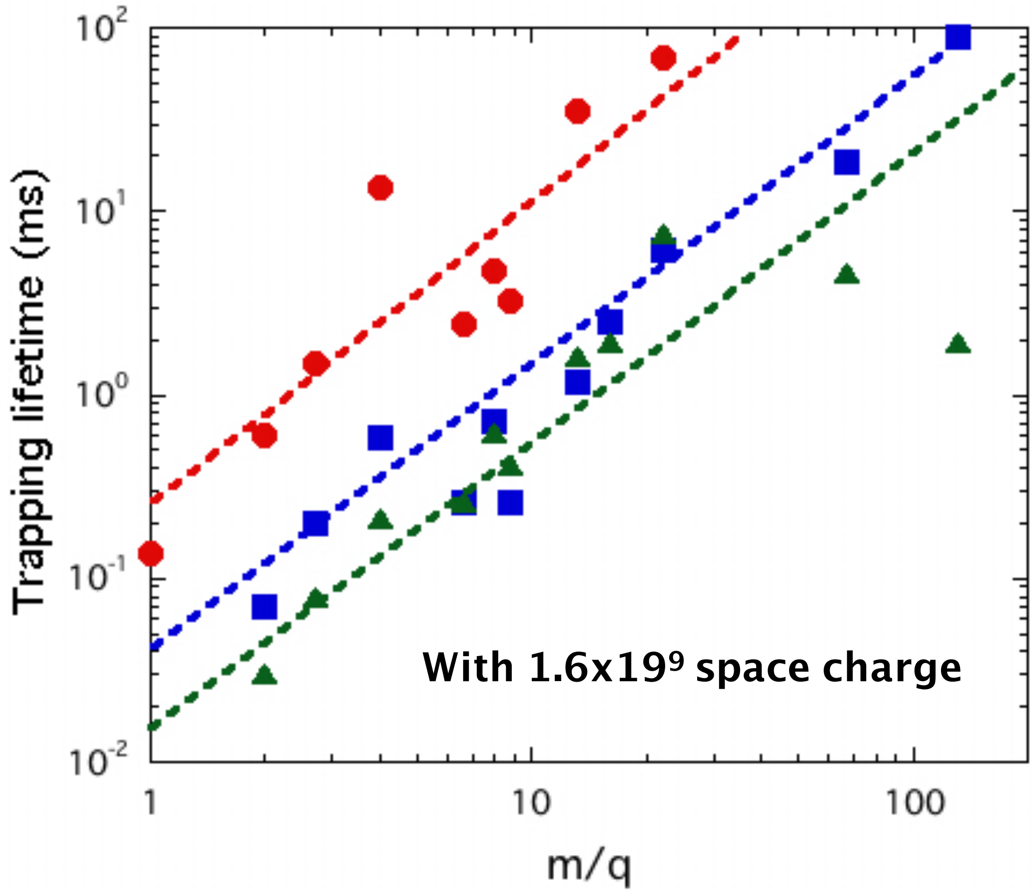


The e-beam instability dominates the ion trapping properties

Influence of e-beam instability and space charge

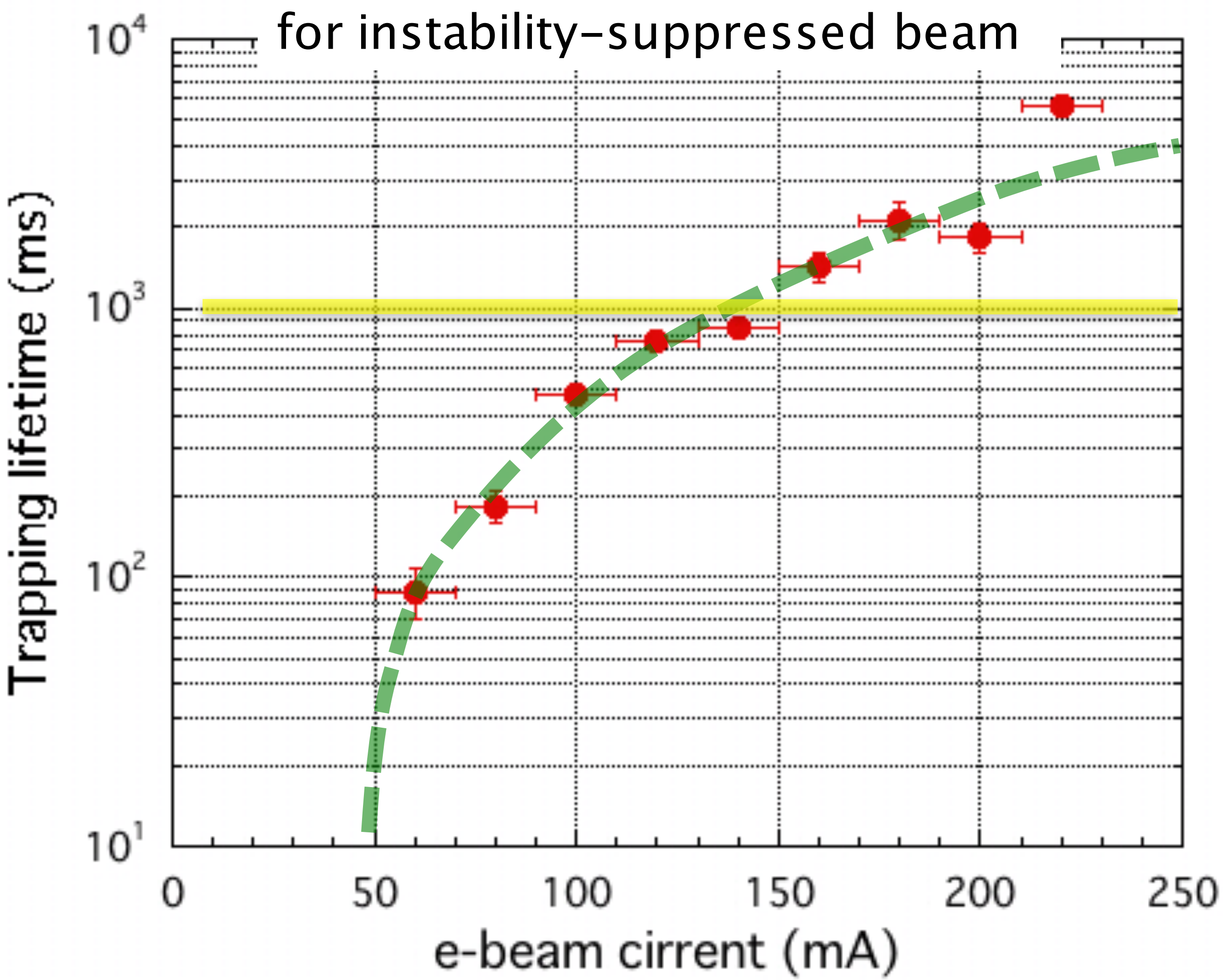
Ion trapping lifetime with coherent synchrotron oscillation
(simulation)

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



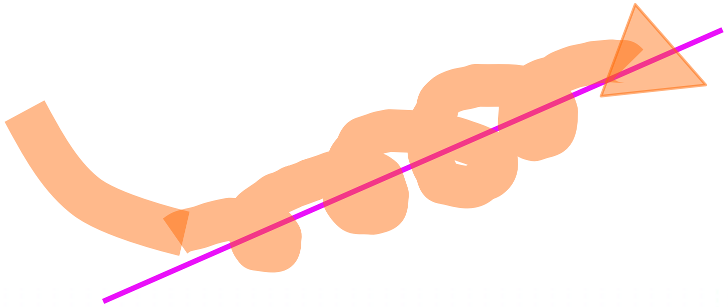
Necessary lifetime is **~1s** for practical use

Prerequisite for e-beam

I_e > 150mA

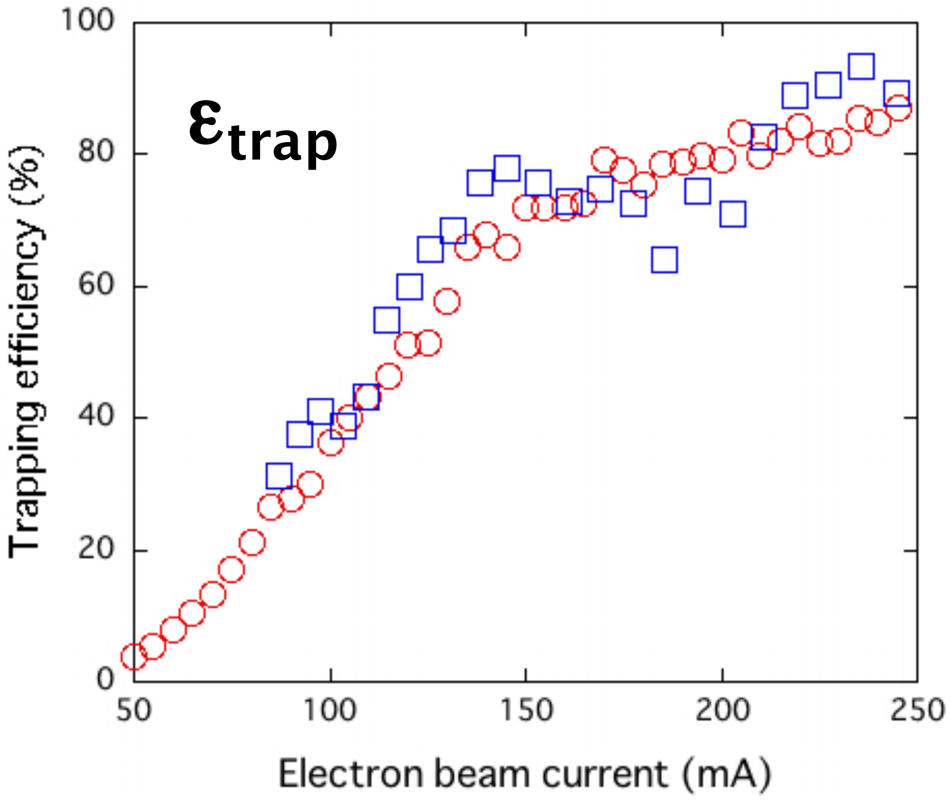
without instability

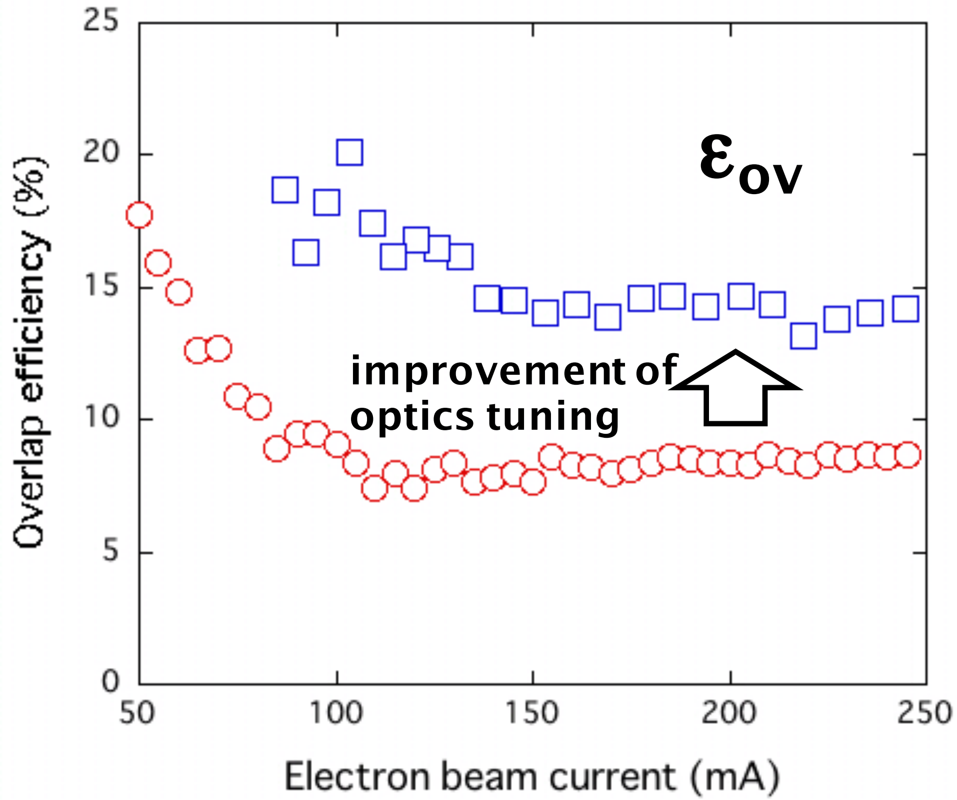
Trapping efficiency ε_{trap} and overlap efficiency ε_{ov}



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

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



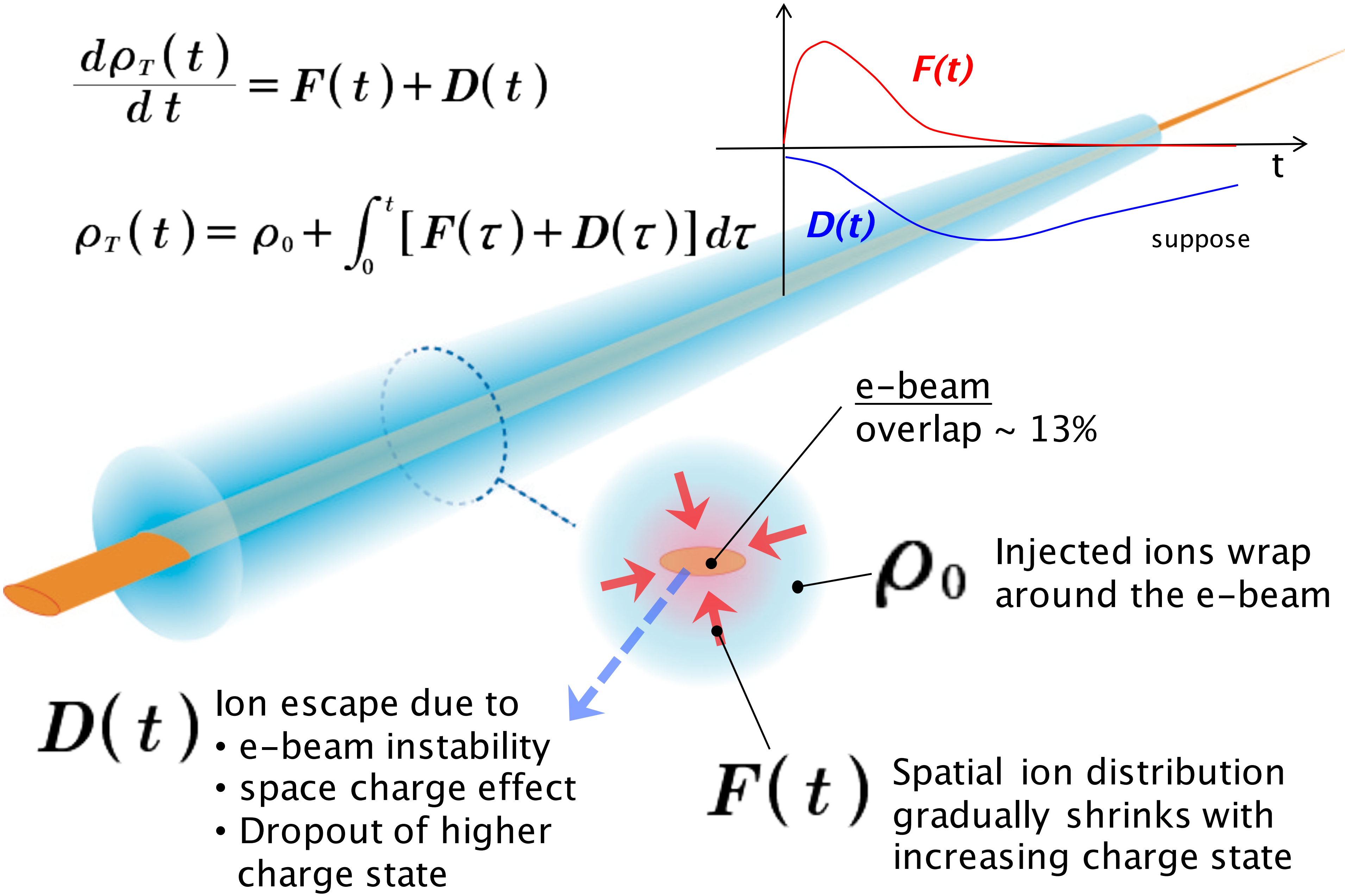


larger ε_{ov} → higher luminosity → shorter trapping lifetime

Ion trapping imagined from our measurements

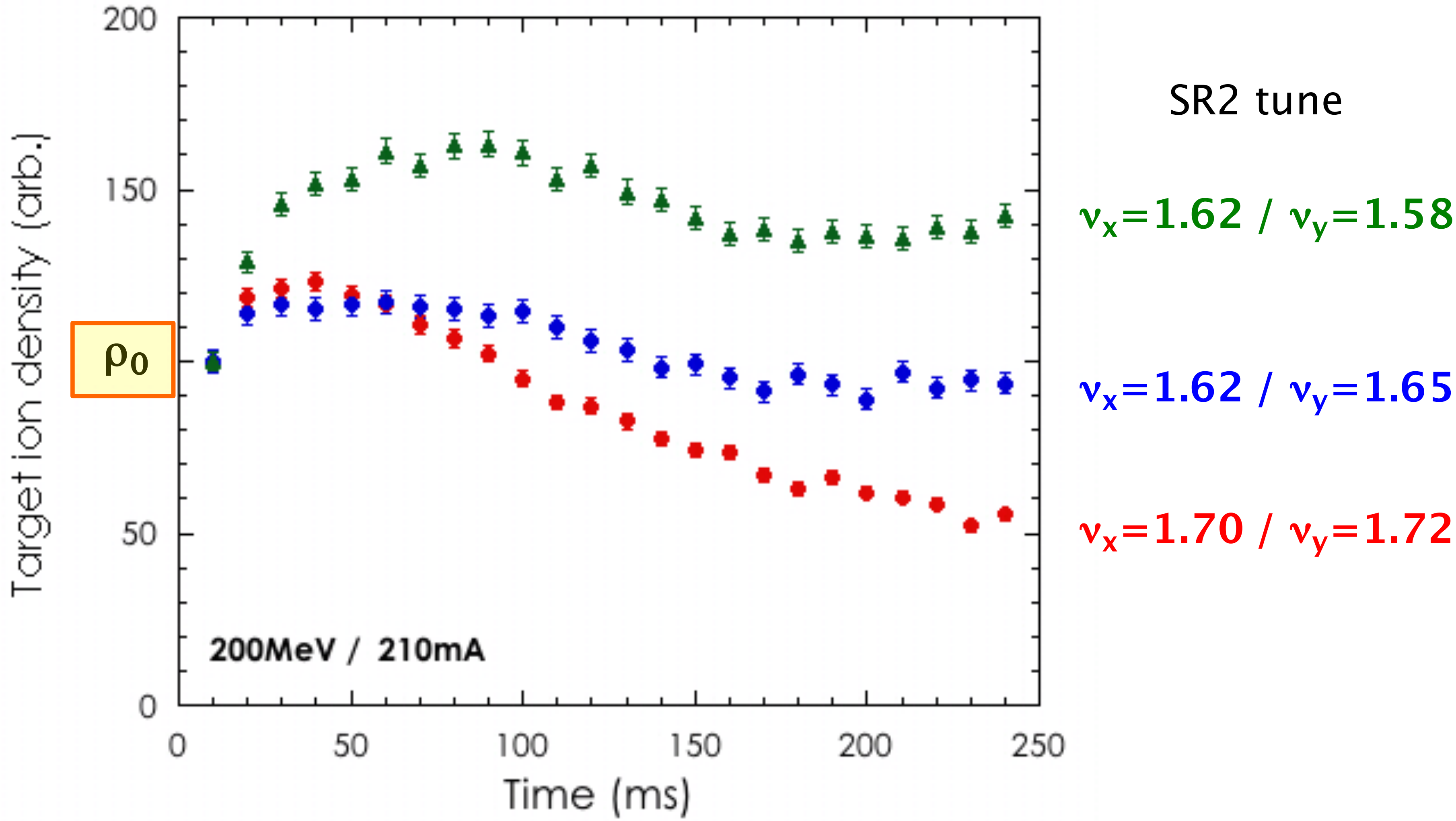
$$\frac{d\rho_T(t)}{dt} = F(t) + D(t)$$

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



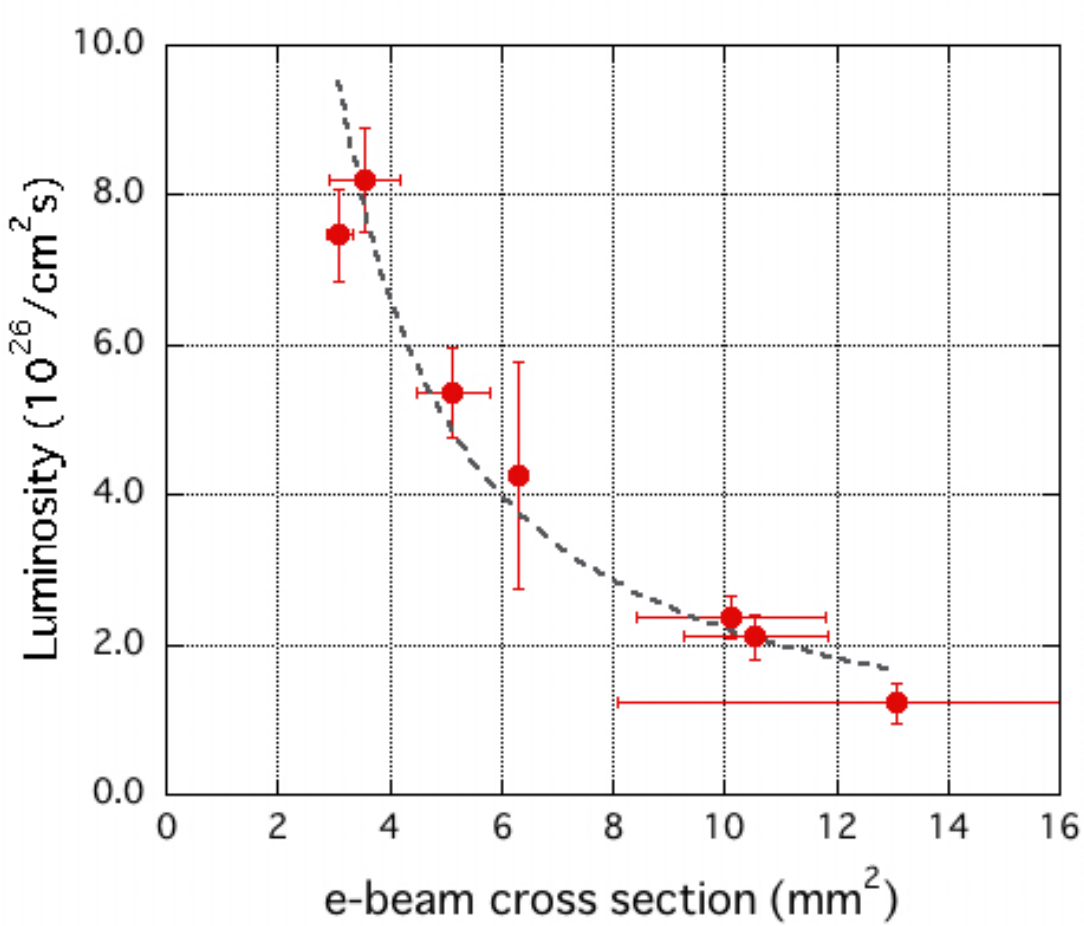
Time evolution of $\rho_t(t)$ ($\propto L$) in trap duration

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



Luminosity depending on e-beam size

at the beginning of trap (proportional to ρ_0)



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

$$L \propto \frac{1}{a}$$

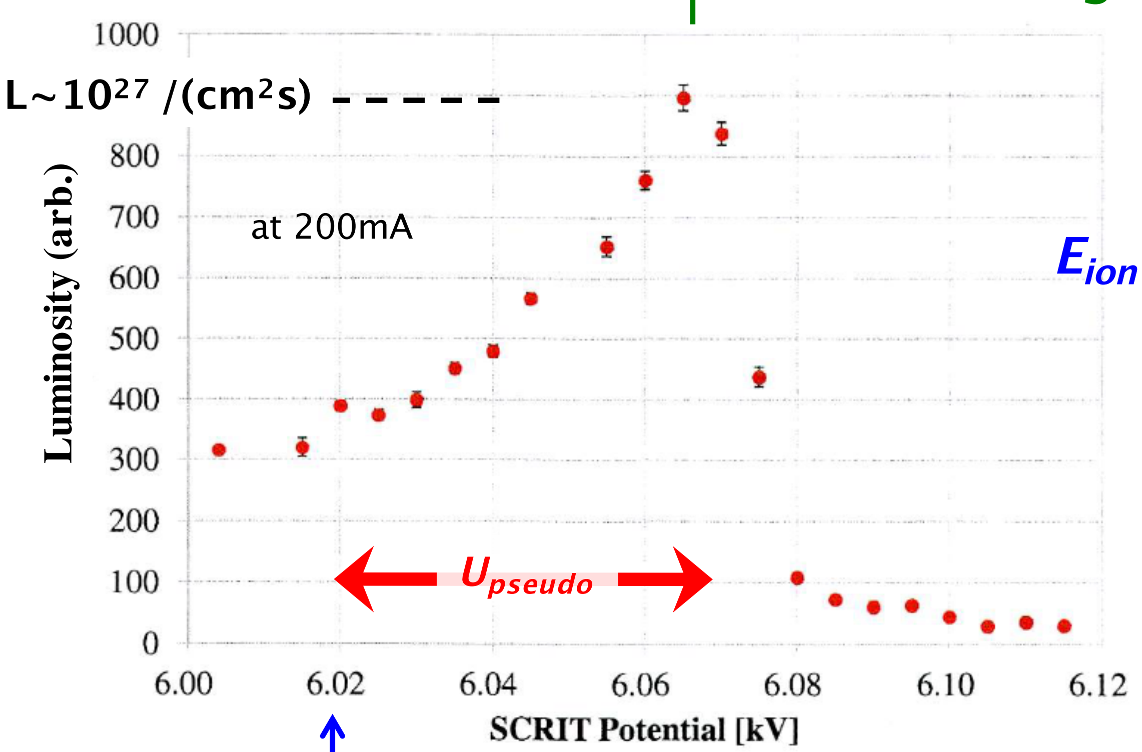
$$N_t \approx constant$$

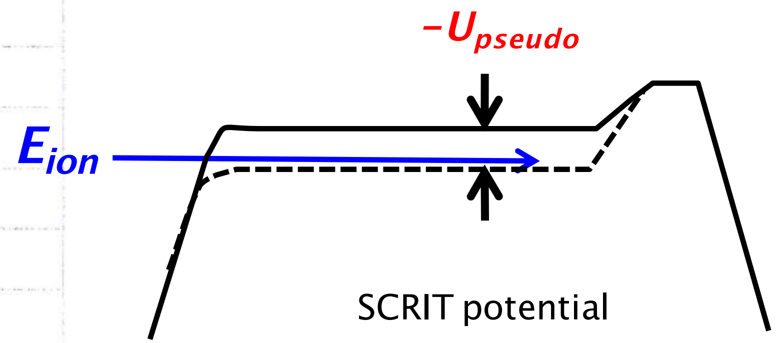
$$\rho_0 \propto \frac{1}{a}$$

Luminosity depending on the SCRIT electrostatic potential

6.07kV

optimum position is shifted according to the current and the size

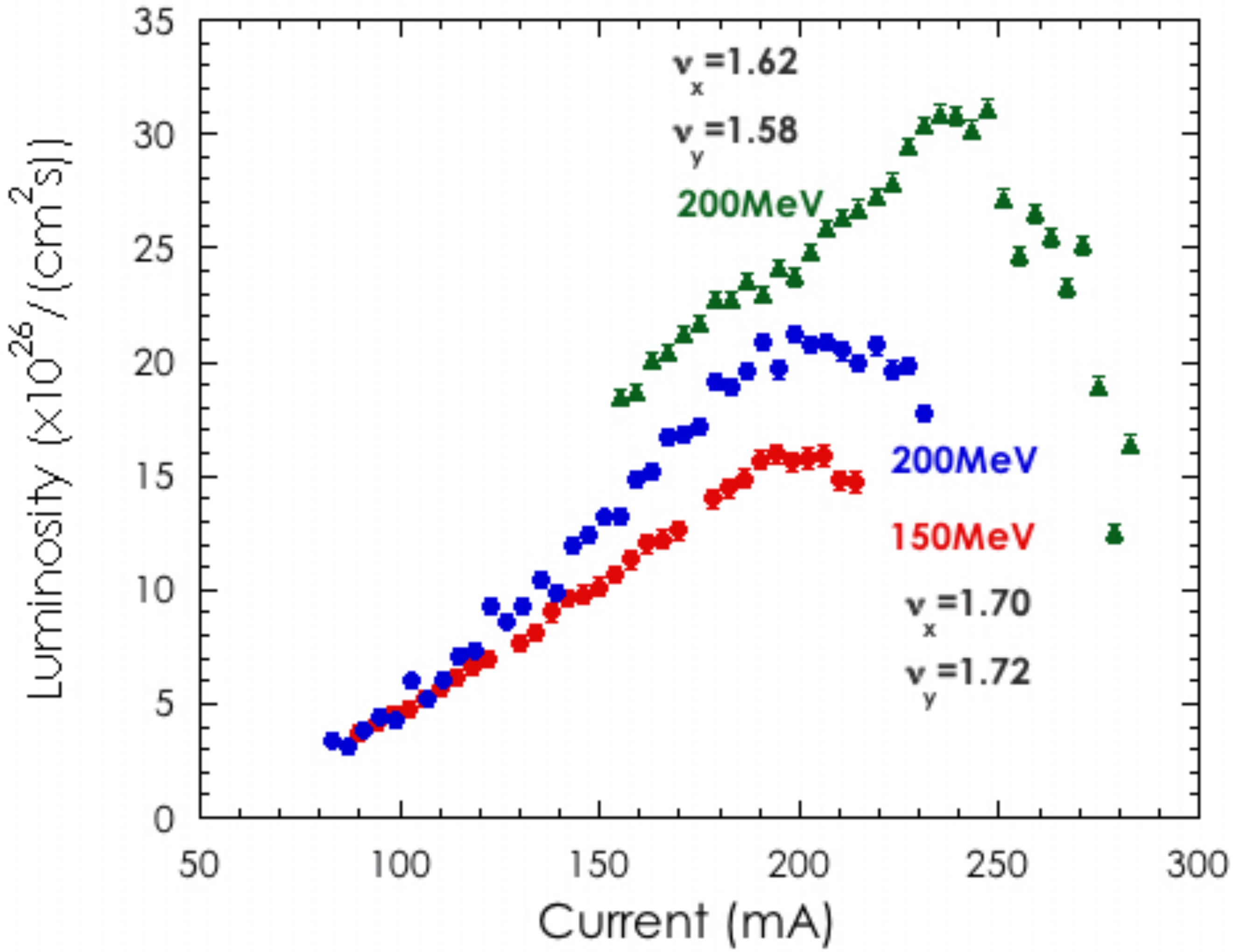




Injected ion beam energy = 6.02keV

Ion energy should be thermalized in the SCRIT

Achieved luminosity as a function of current



- Maximum luminosity was **3×10^{27} /(cm^2s)**
- Number of injected ions was **3×10^8**.
- Trapping time was 240ms.
- Instability was happen in large current region.
- Luminosity for 200MeV is lager than that for 150MeV, because of smaller beam size.

Preparation of target RI ions

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

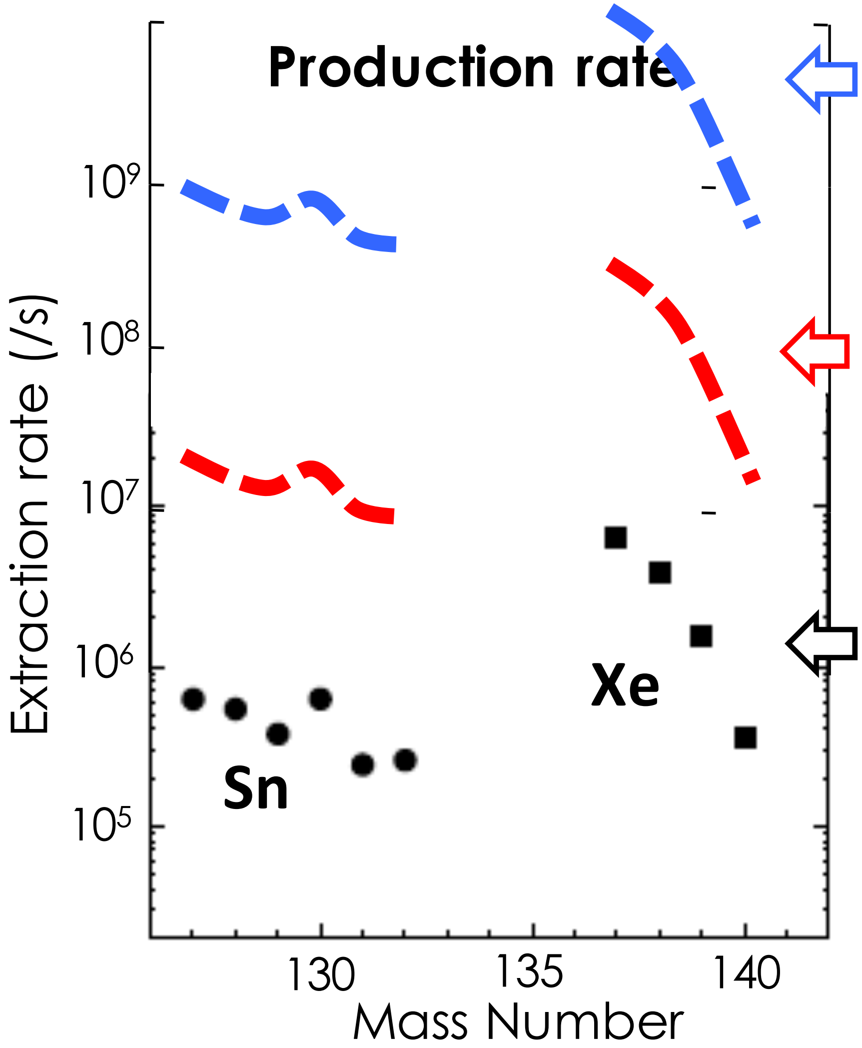
Performances

mass resolution M/ΔM 1660

overall efficiency 21 %

(record values for stable Xe isotopes)

RI ion beam from ERIS



Planed

Expected
U **30g**
P_{eb} **50W**
Effi. **x 4**

Achieved
U **15g**
P_{eb} **10W**
Effi. **5.5% ^{138}Xe**
2.0% ^{132}Sn

Improvements are currently going on

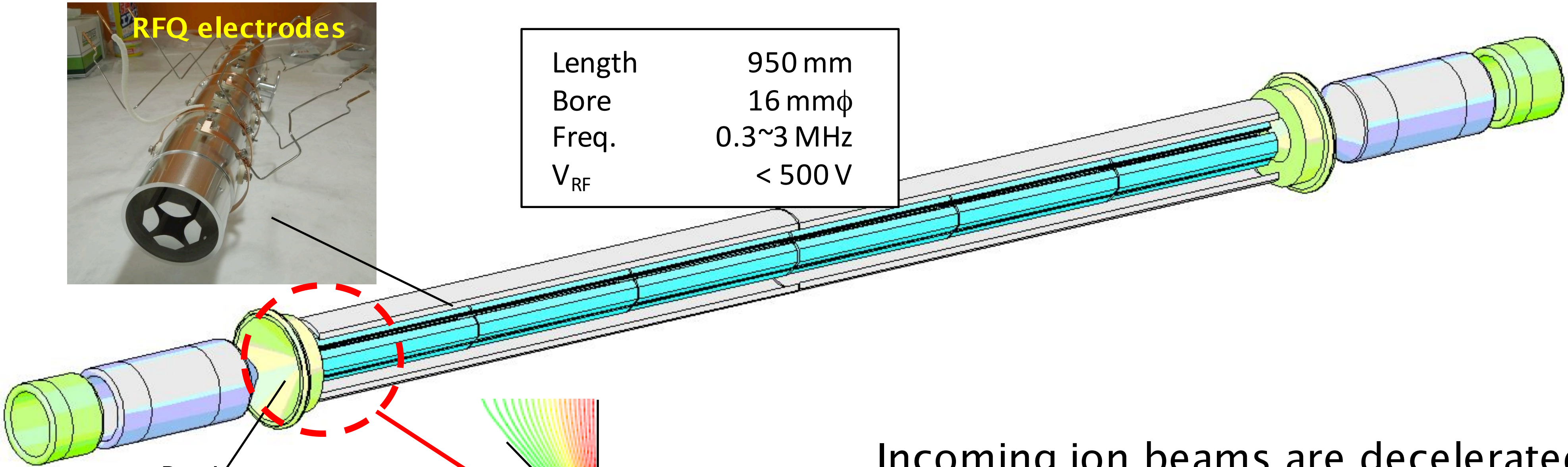
1. Increase the amount of U
2. Extraction efficiency improvement
3. Upgrade e-beam power

First experiment of e-RI scattering

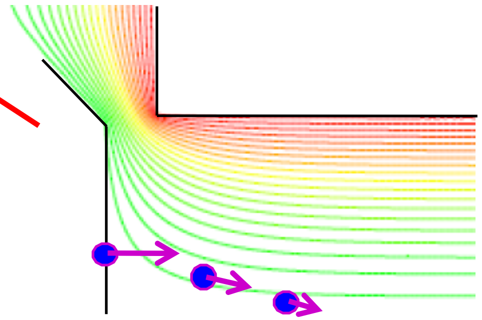
Further upgrade of e-beam power to 2~3kW

Buncher Device for Ion Injection to SCRIT

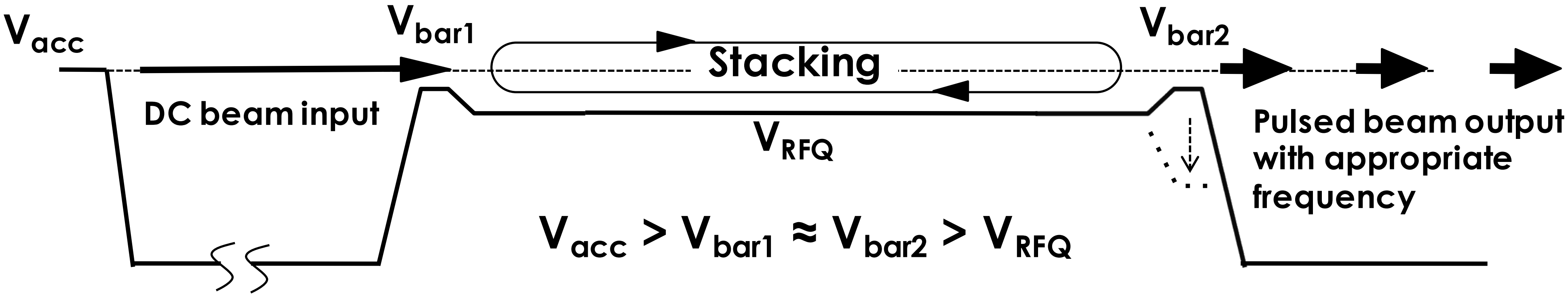
Buncher based on RFQ linear trap converts 1-s DC beam into 500μs pulsed beam



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

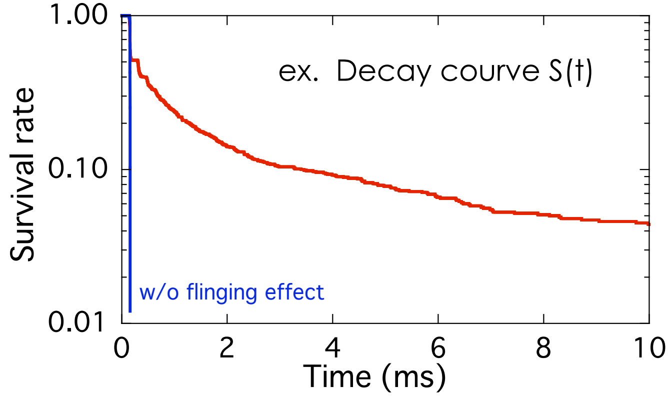


Incoming ion beams are decelerated and stacked in RFQ by **flinging RF field effect** at the entrance



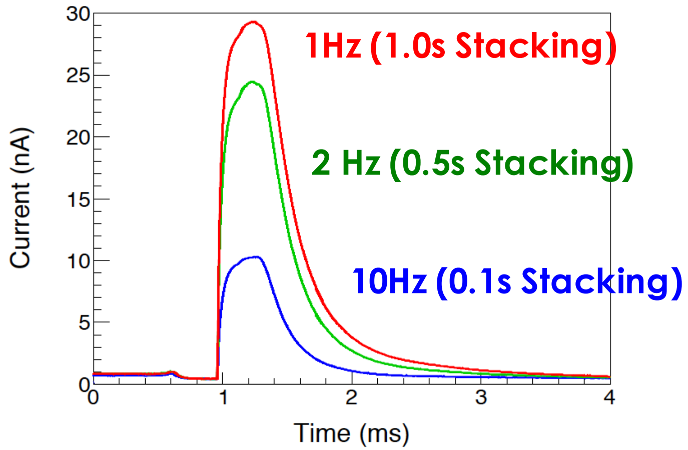
Ion stacking using flinging field and conversion efficiency

Stacked ions slowly decay

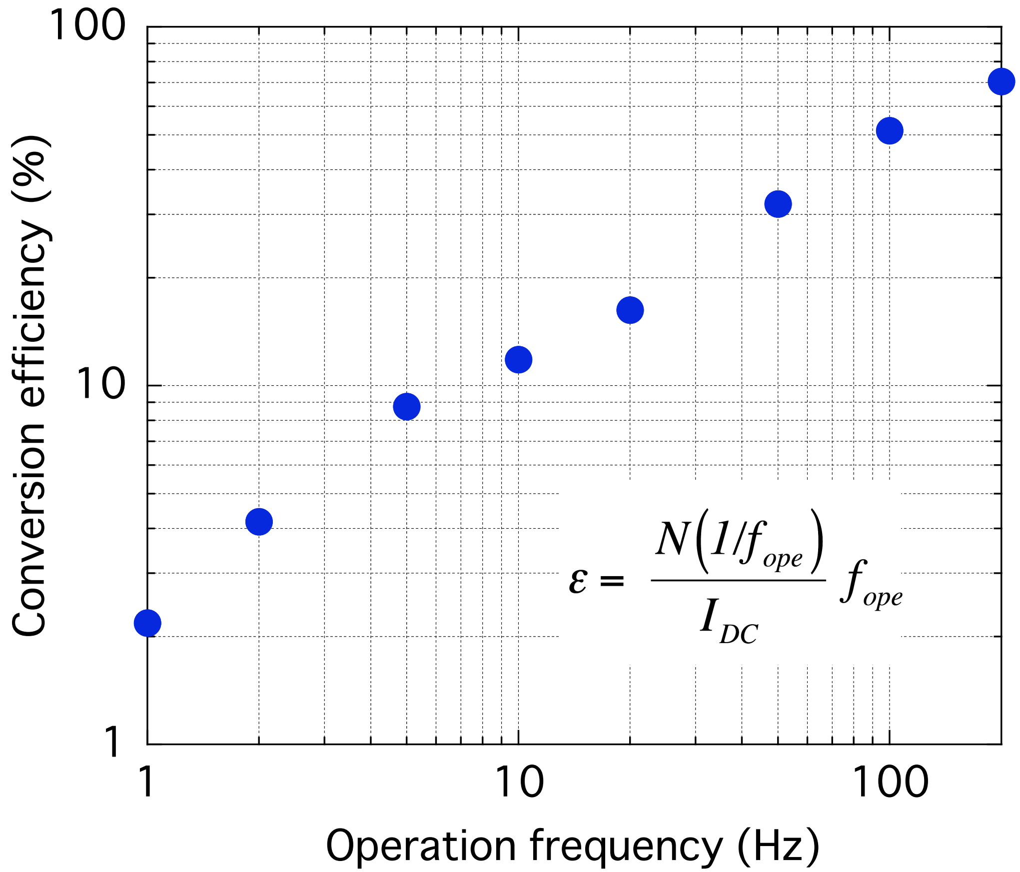


Number of stacked ions *N(t)* :

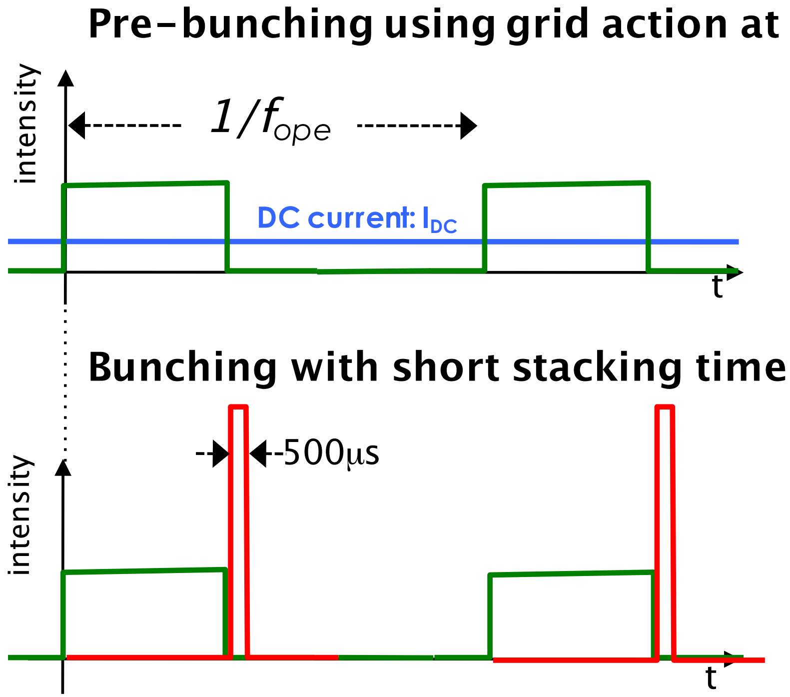
$$N(t) = I_{DC} \int_0^t S(t - t')\, dt'$$

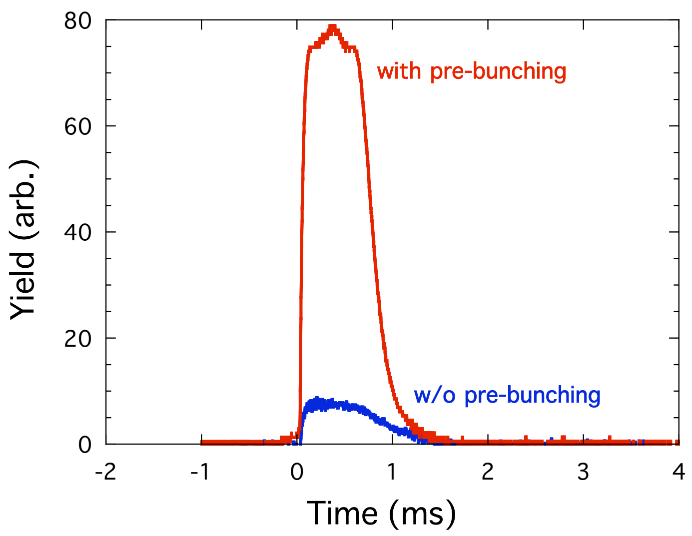


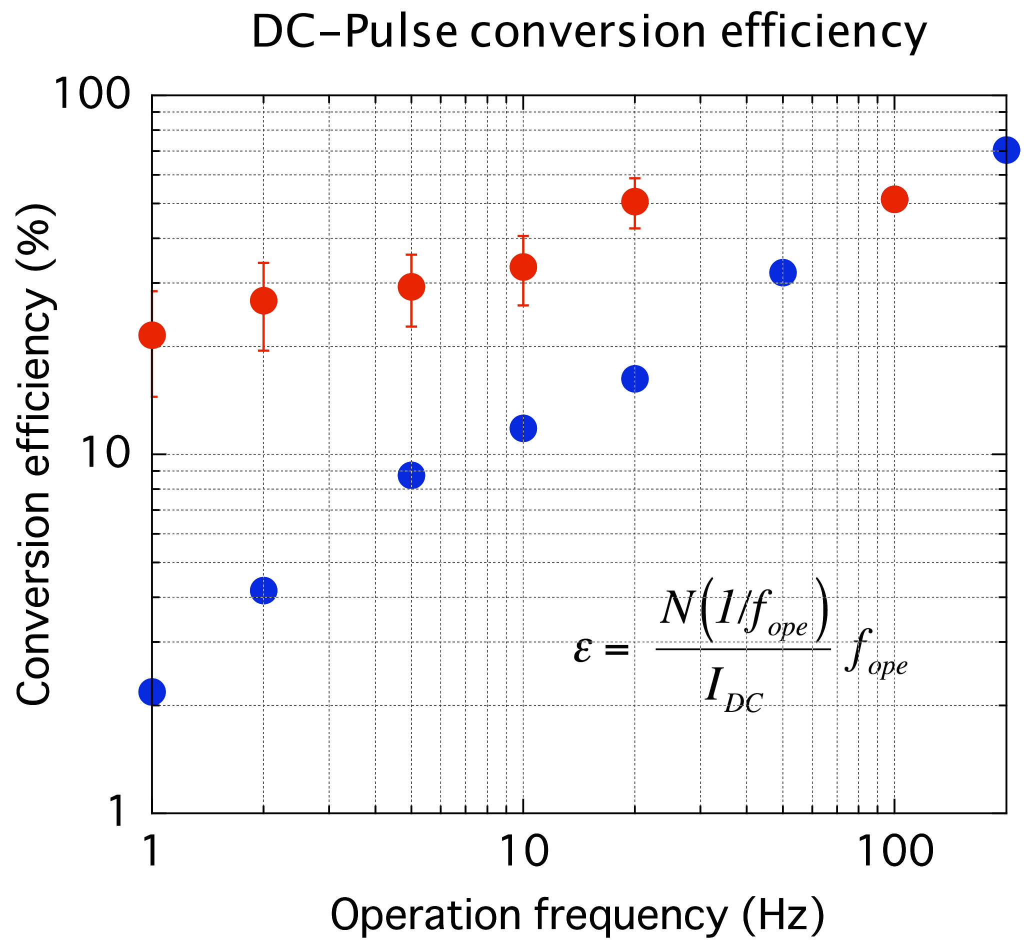
DC-Pulse conversion efficiency



More efficient conversion using two-step bunching







Summary

1. The SCRIT facility has been constructed and is now in test experiment phase.

2. Achieved luminosity is $\sim 3 \times 10^{27}$ /(cm^{2}s).

3. Upper limit of achievable luminosity in our SCRIT system is $\sim 10^{29}$ /(cm^{2}s).

4. Electron-beam-instability suppression is the most important issue to get higher luminosity.

5. It is essential to understand relationship between electron-beam properties and ion-trapping properties.

6. We will be able to move to the experiments for unstable isotopes as soon as possible.

Thank you for your attention