First result from **SCRIT** electron scattering facility : Charge density distribution of ^{132}Xe

Kyo Tsukada

Tohoku University

SCRIT collaboration

Tohoku Univ.	K. Kasama, K. Namba, T. Suda, T. Tamae
RIKEN	M. Hara, T. Hori, S. Ichikawa, T. Ohnishi, M. Wakasugi, M. Watanabe
Rikkyo Univ.	K. Adachi, A. Enokizono, T. Fujita, M. Hori, K. Kurita, S. Sasamura, M. Togasaki, N. Uchida, K. Yamada
Shandong Univ.	W. Shuo

Contents

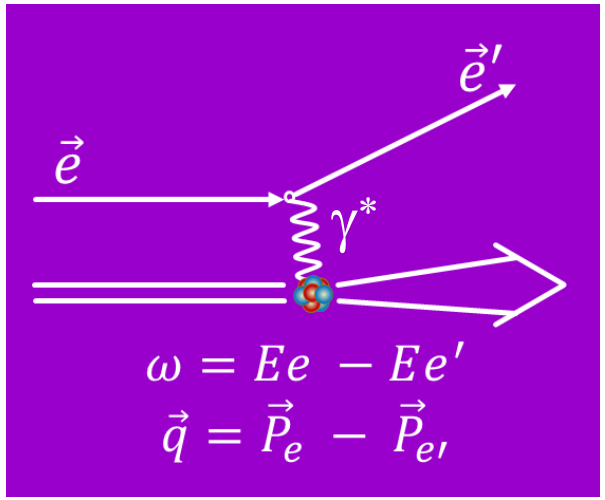
- Introduction
- Apparatus
- Experiment and Data analysis
- Summary and Outlooks

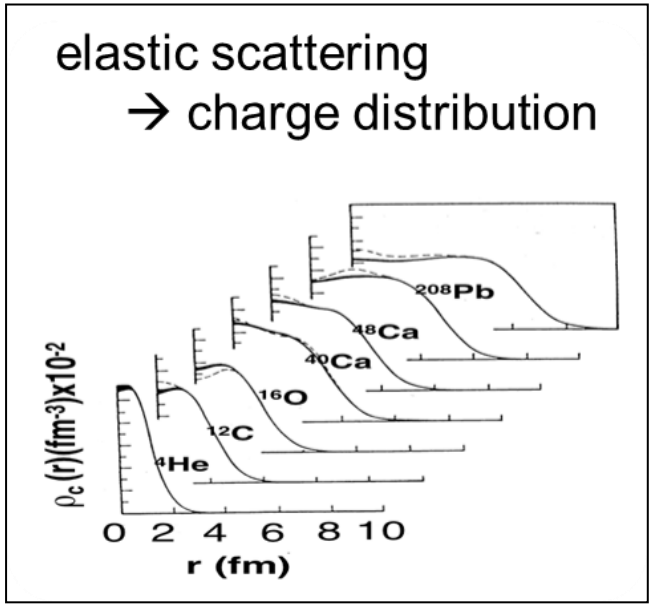
Contents

Electron scattering

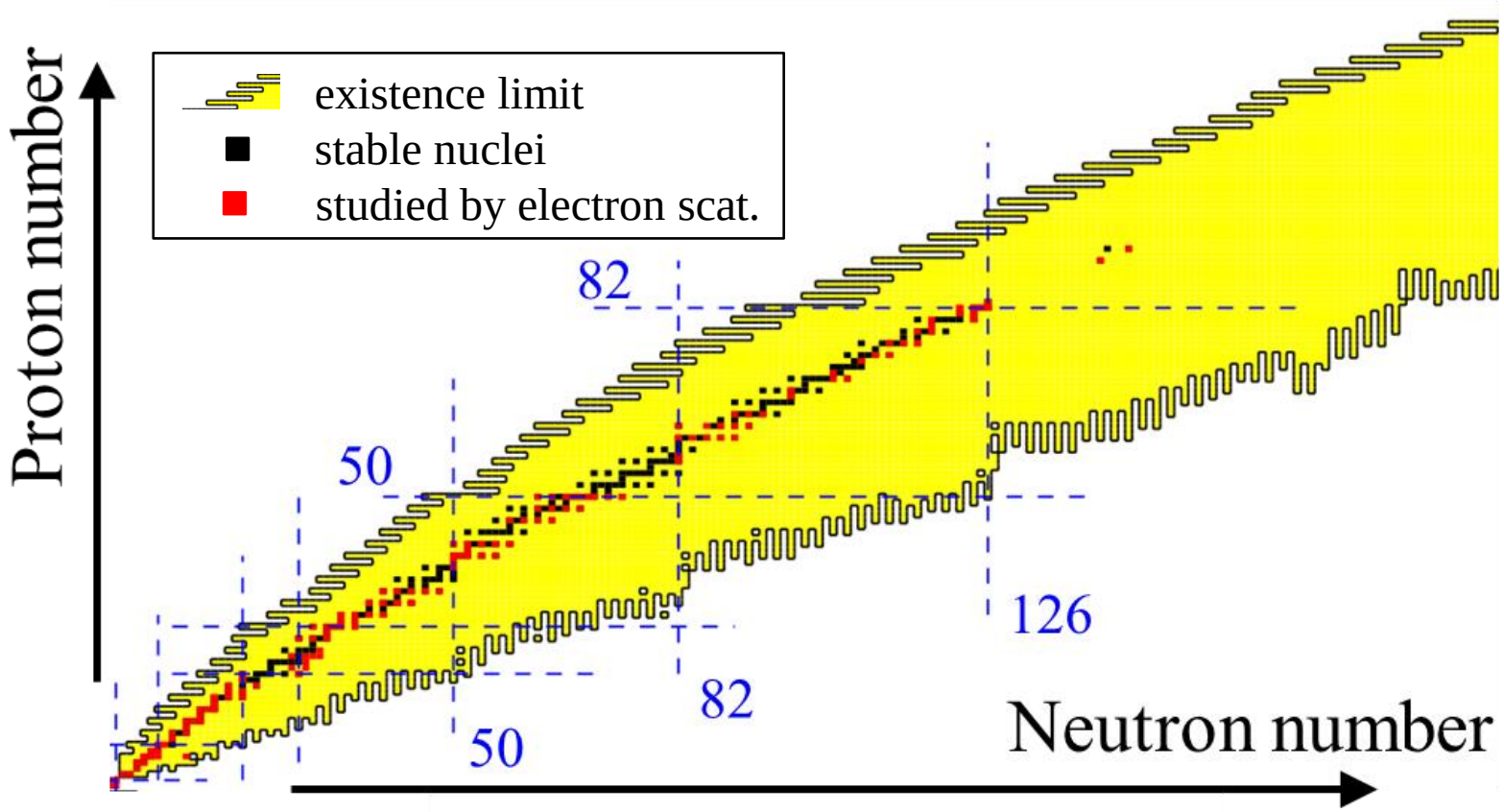
Direct and **unambiguous** structure information of atomic nuclei

- Probe particle : electron, structureless particle
- Reaction mechanism : well known electromagnetic interaction
  - Charge and current coupling → EM structure
  - Weak coupling → probing whole volume without serious modification
    valid for perturbation theory





Nuclei studied by electron scattering



Electron scattering is so powerful to investigate the nuclear structure information.
But,

- Strictly limited to stable nuclei
- Almost no data of unstable nuclei (a few exceptions: ^{3}H, ^{14}C, …)

Elastic electron scattering

- Relatively large cross section
- Doorway to various electron scattering experiments

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \cdot |Fc(q)|^2$$

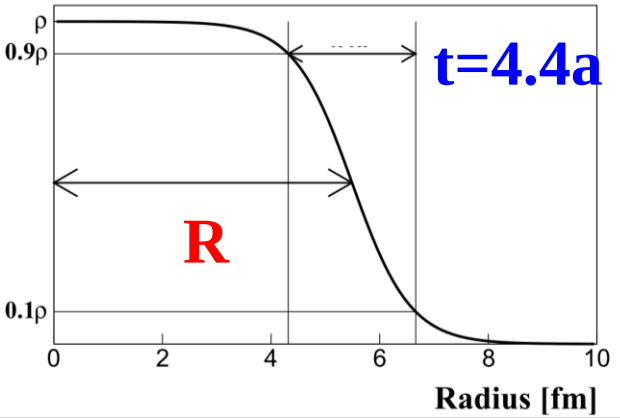
Cross section of Mott scattering

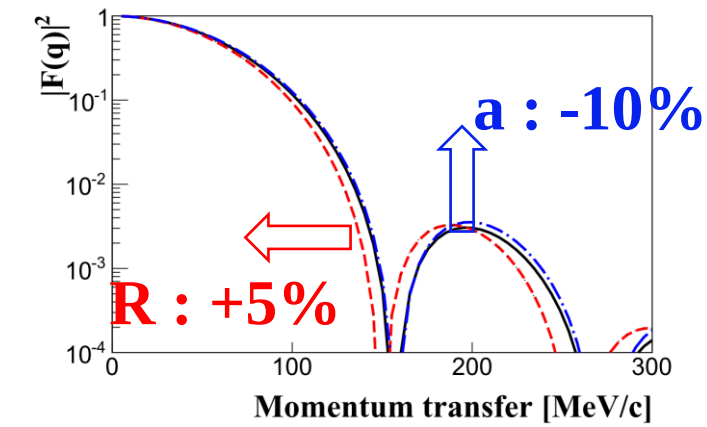
Form factor

$$Fc(q) = \int \rho_C(\vec{r}) e^{i\vec{q}\vec{r}} d\vec{r}$$

Charge density distribution

$$\rho_C = \rho/(1 + e^{(r-R)/a})$$



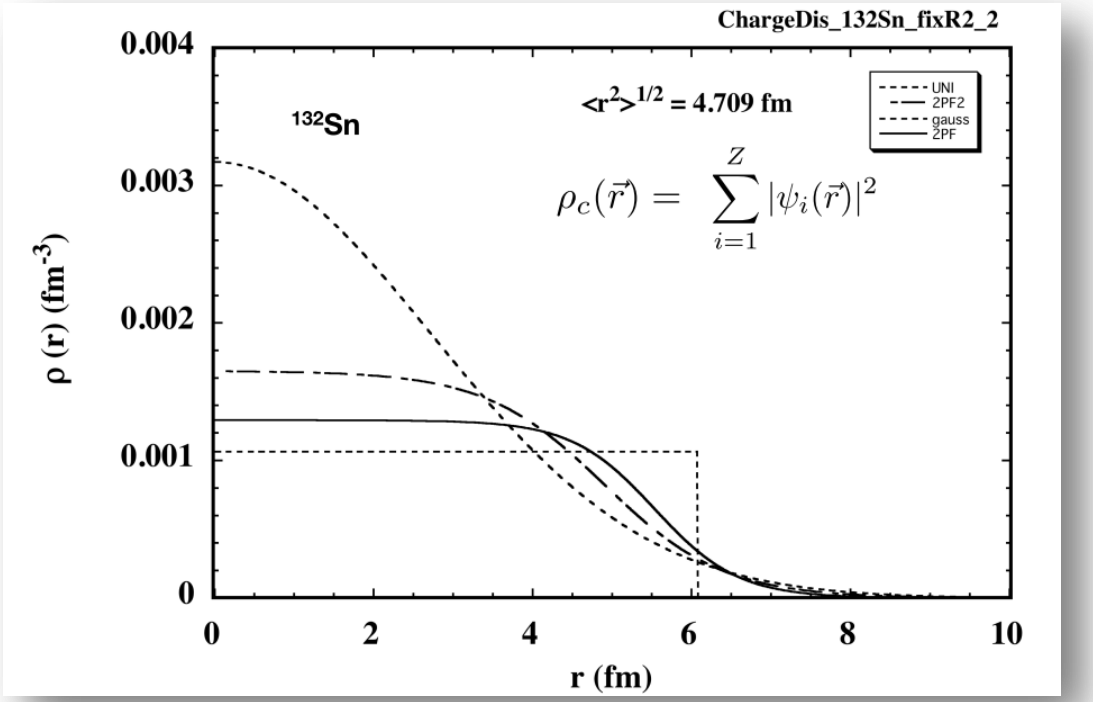


Nuclear size with EM probe

- X-ray from muonic atom (2P-1S)
  - Measurement : $\langle r^2 \rangle^{1/2}$ with assumption of the nuclear shape
  - Target : Only stable nuclei
- Isotope shift of optical transition
  - Measurement : Relative shift of charge radius : $\delta\langle r^2 \rangle^{1/2}$
  - Target : Stable and unstable nuclei
- Electron scattering
  - Measurement : Form Factor
  - Target : Only stable nuclei, so far

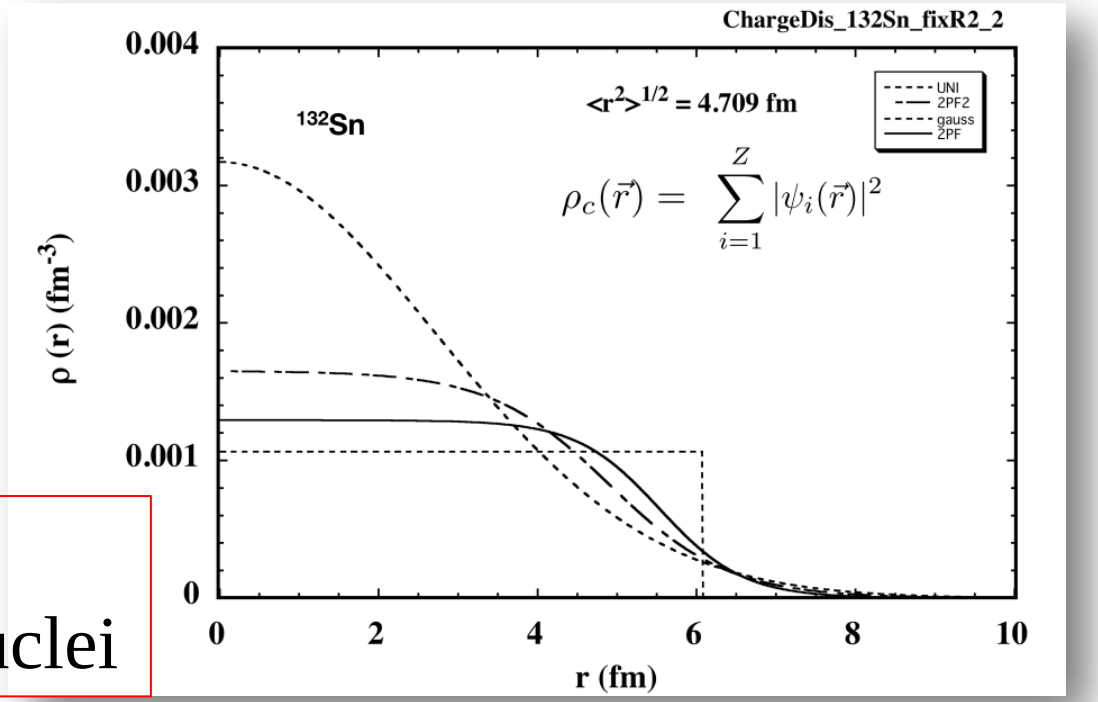
Nuclear size with EM probe

- X-ray from muonic atom (2P-1S)
  - Measurement : $\langle r^2 \rangle^{1/2}$ with assumption of the nuclear shape
  - Target : Only stable nuclei
- Isotope shift of optical transition
  - Measurement : Relative shift of charge radius : $\delta\langle r^2 \rangle^{1/2}$
  - Target : Stable and unstable nuclei
- Electron scattering
  - Measurement : Form Factor
  - Target : Only stable nuclei, so far



Nuclear size with EM probe

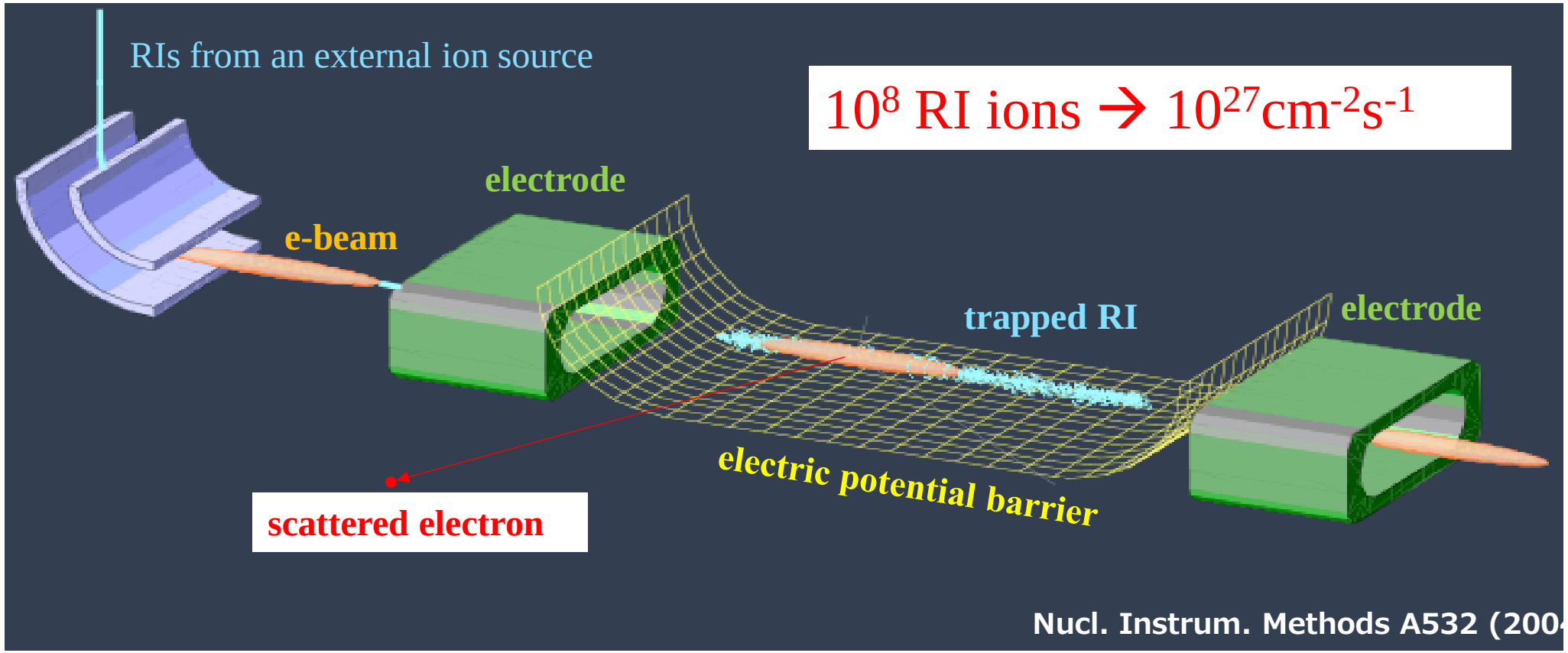
- X-ray from muonic atom (2P-1S)
  - Measurement : $\langle r^2 \rangle^{1/2}$ with assumption of the nuclear shape
  - Target : Only stable nuclei
- Isotope shift of optical transition
  - Measurement : Relative shift of charge radius : $\delta\langle r^2 \rangle^{1/2}$
  - Target : Stable and unstable nuclei
- Electron scattering
  - Measurement : Form Factor
  - Target : Only stable nuclei, so far



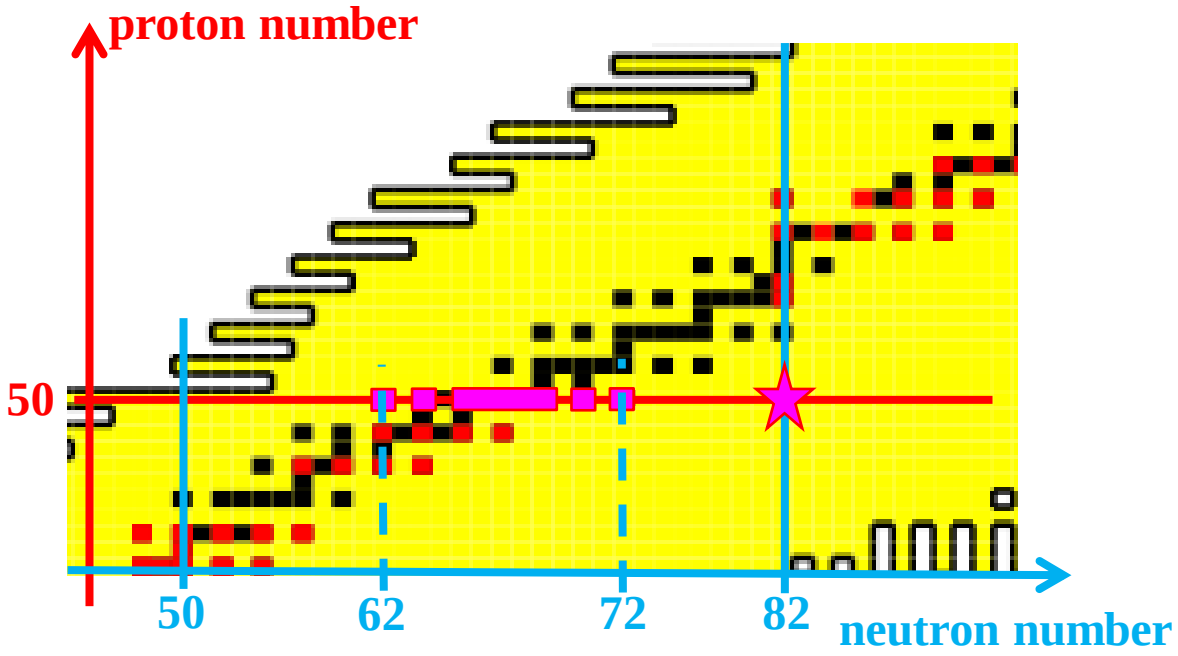
SCRIT system
realizing electron scattering for unstable nuclei

Concept of **SCRIT**

Ion trapping phenomena : Transverse trap
known as a serious problem of electron storage ring
+
Electric potential barrier : Longitudinal trap



First goal of SCRIT project



Isotope chain of Sn

$^{112\text{-}124}$Sn : stable

$^{126\text{-}132}$Sn : unstable

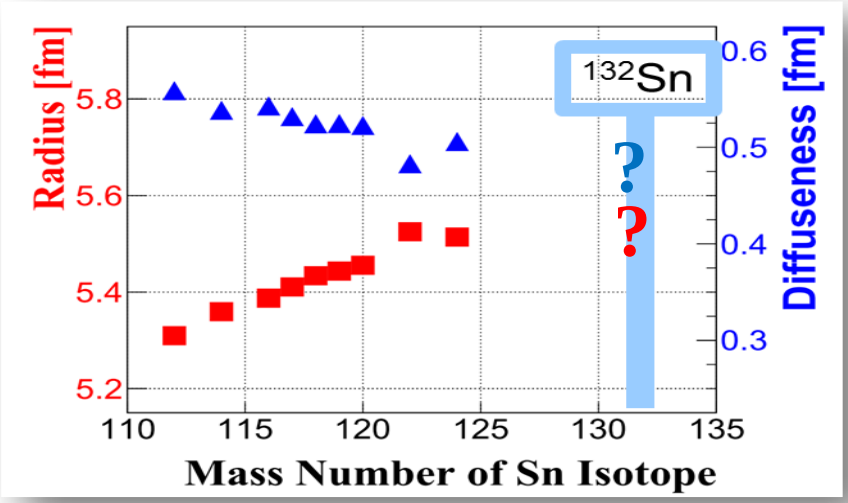
^{126}Sn : 10^5 year

^{128}Sn : 59 msec

^{130}Sn : 3.7 msec

^{132}Sn : 39 sec

^{134}Sn : 1.2 sec

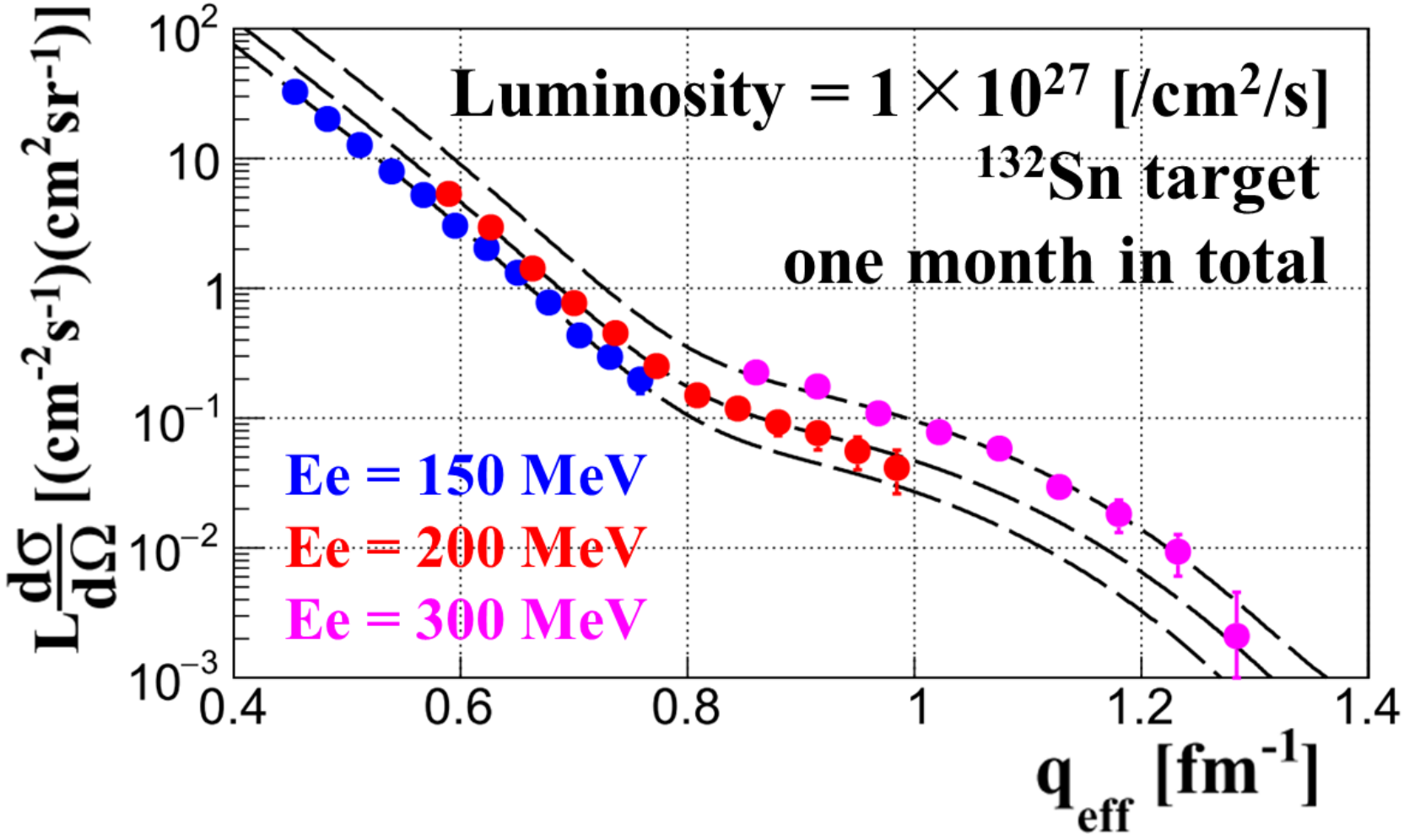


^{132}Sn

- unstable
- double magic (50+82)
- important roles for nuclear structure study

Luminosity requirement

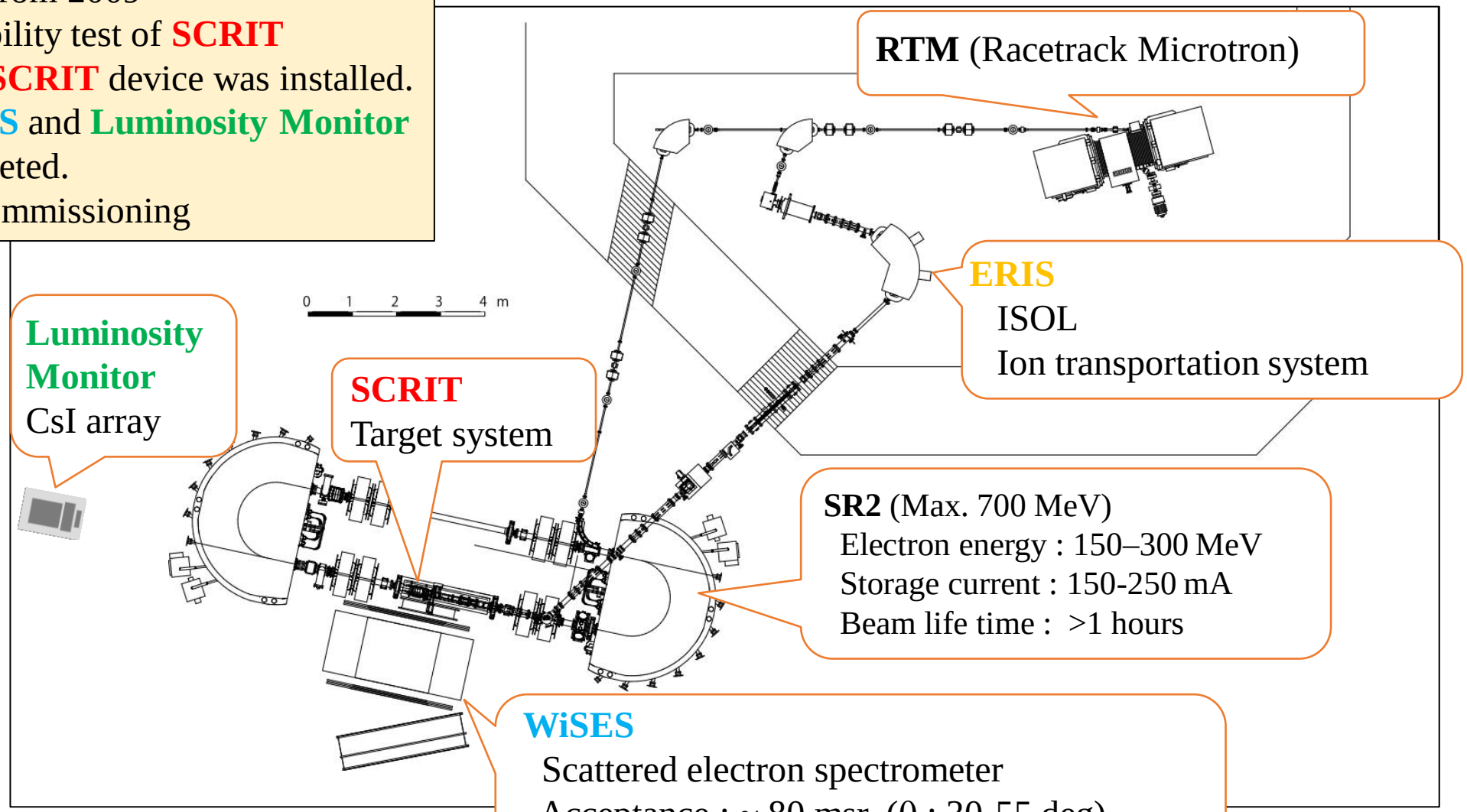
Assumptions: Spectrometer acceptance (dΩ~80 msr, dθ:30-55 deg)
Cross section calculated by DREPHA code
BG is assumed to be ^{16}O



Contents

SCRIT electron scattering facility

Construction from 2009 –
2011: Feasibility test of **SCRIT**
2014: New **SCRIT** device was installed.
WiSES and **Luminosity Monitor** completed.
2015-2016: commissioning



RTM (Racetrack Microtron)

ERIS
ISOL
Ion transportation system

Luminosity Monitor
CsI array

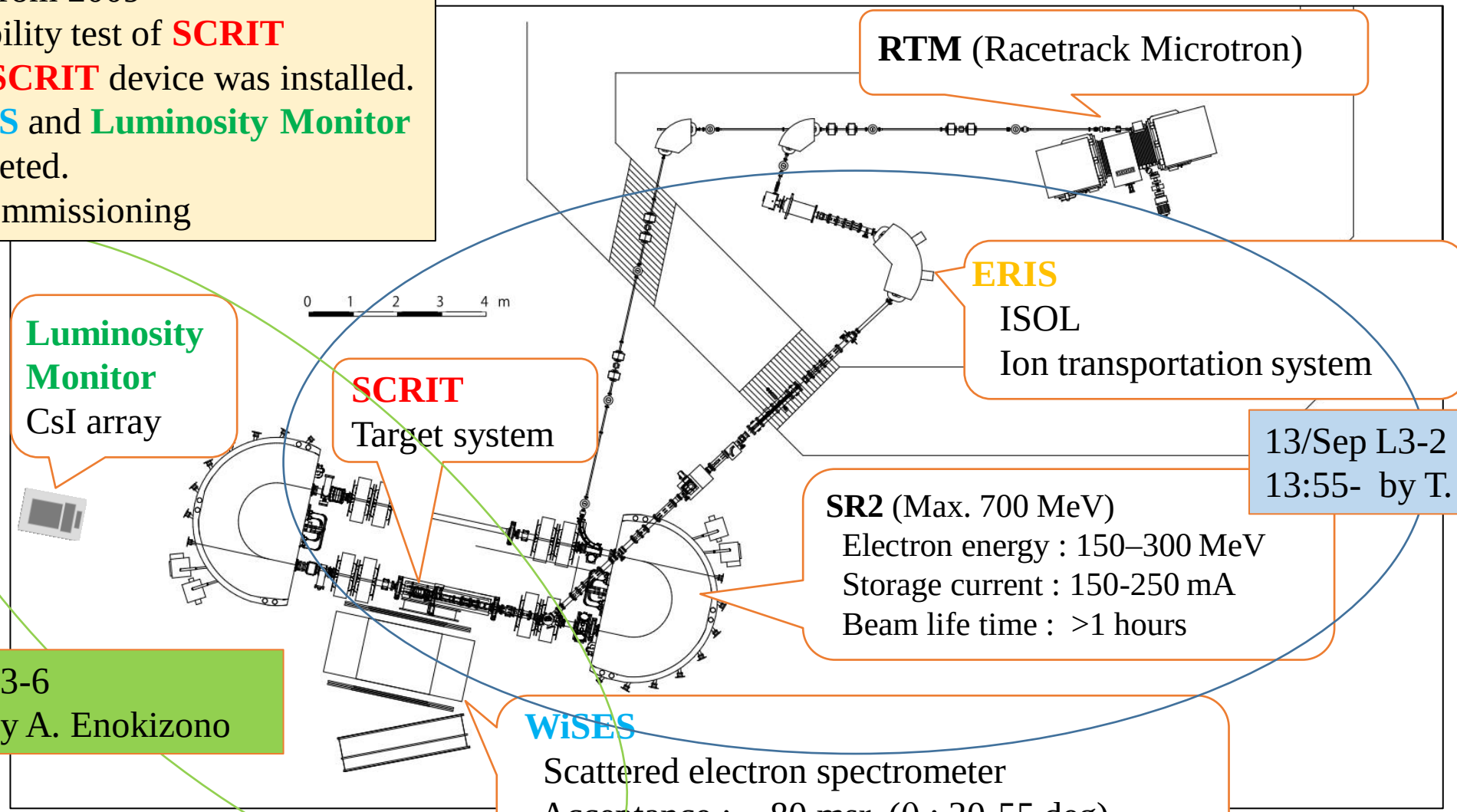
SCRIT
Target system

SR2 (Max. 700 MeV)
Electron energy : 150–300 MeV
Storage current : 150-250 mA
Beam life time : >1 hours

WiSES
Scattered electron spectrometer
Acceptance : ~ 80 msr, (θ : 30-55 deg)
dp/p : ~ 10^{-3} (Ee=300MeV)

SCRIT electron scattering facility

Construction from 2009 –
2011: Feasibility test of **SCRIT**
2014: New **SCRIT** device was installed.
WiSES and **Luminosity Monitor** completed.
2015-2016: commissioning



RTM (Racetrack Microtron)

ERIS
ISOL
Ion transportation system

Luminosity Monitor
CsI array

SCRIT
Target system

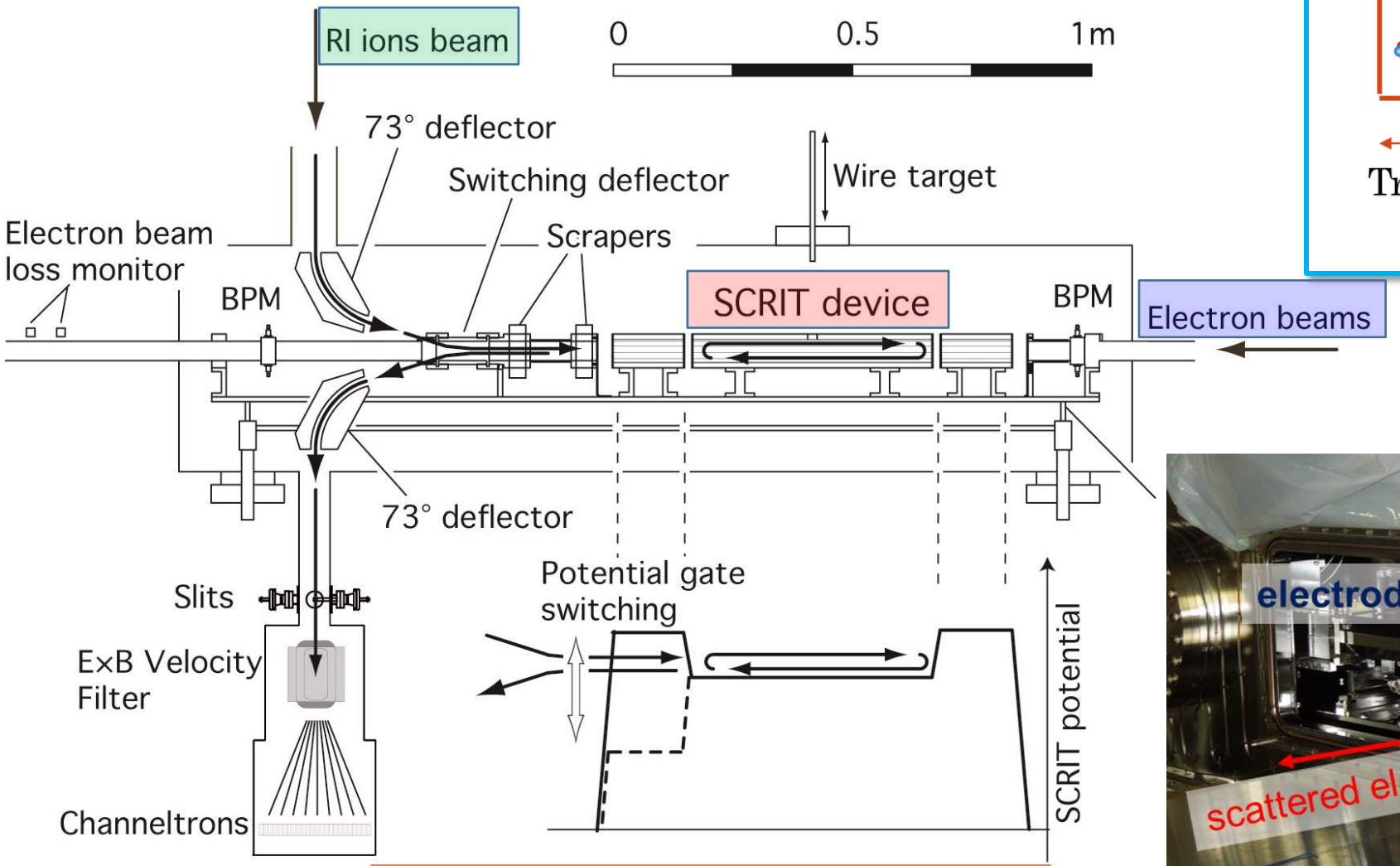
13/Sep L3-2
13:55- by T. Ohnishi

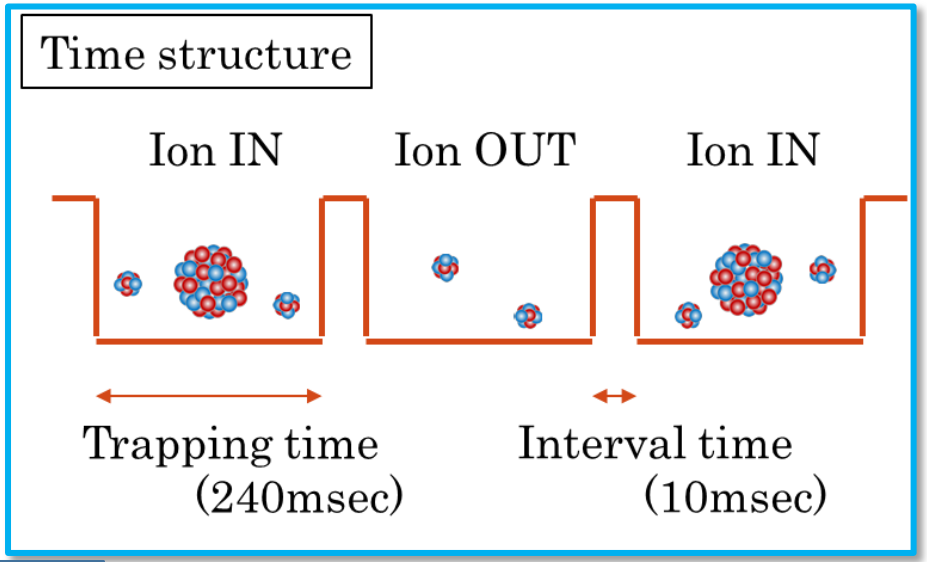
SR2 (Max. 700 MeV)
Electron energy : 150–300 MeV
Storage current : 150-250 mA
Beam life time : >1 hours

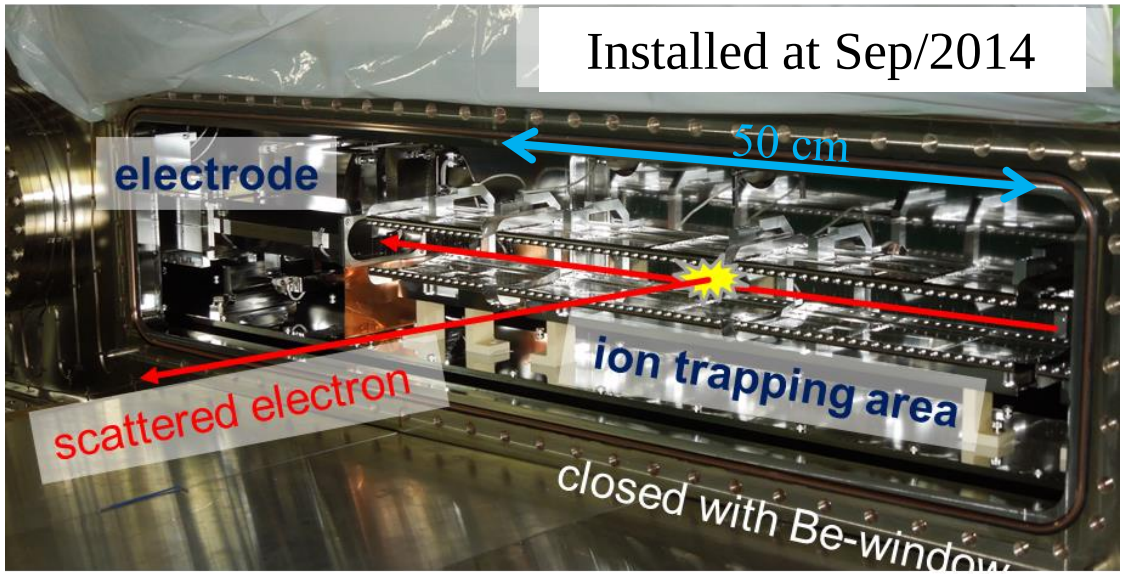
13/Sep L3-6
14:55- by A. Enokizono

WiSES
Scattered electron spectrometer
Acceptance : ~ 80 msr, (θ : 30-55 deg)
dp/p : ~ 10^{-3} (Ee=300MeV)

Schematic of **SCRIT** system

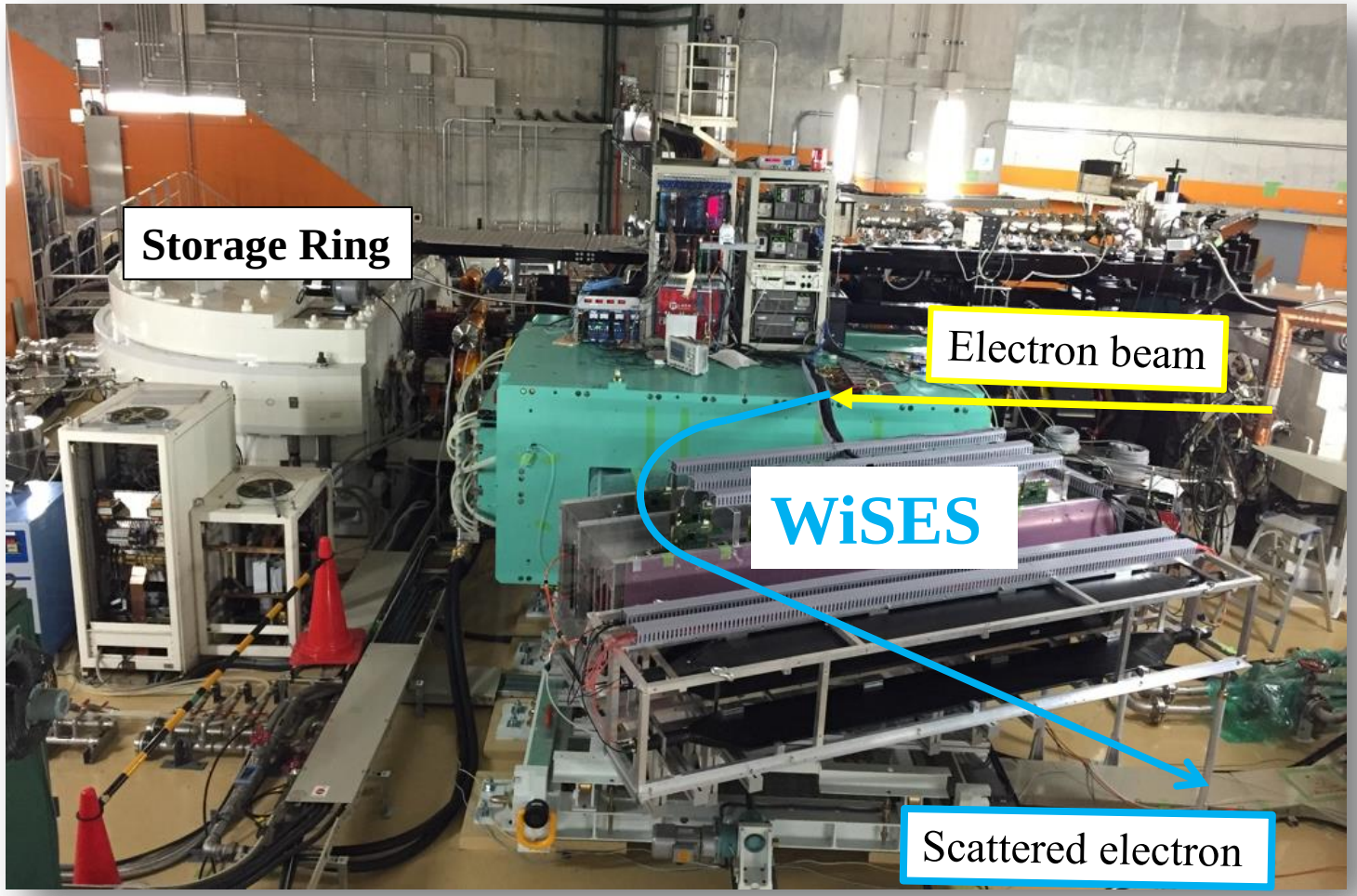


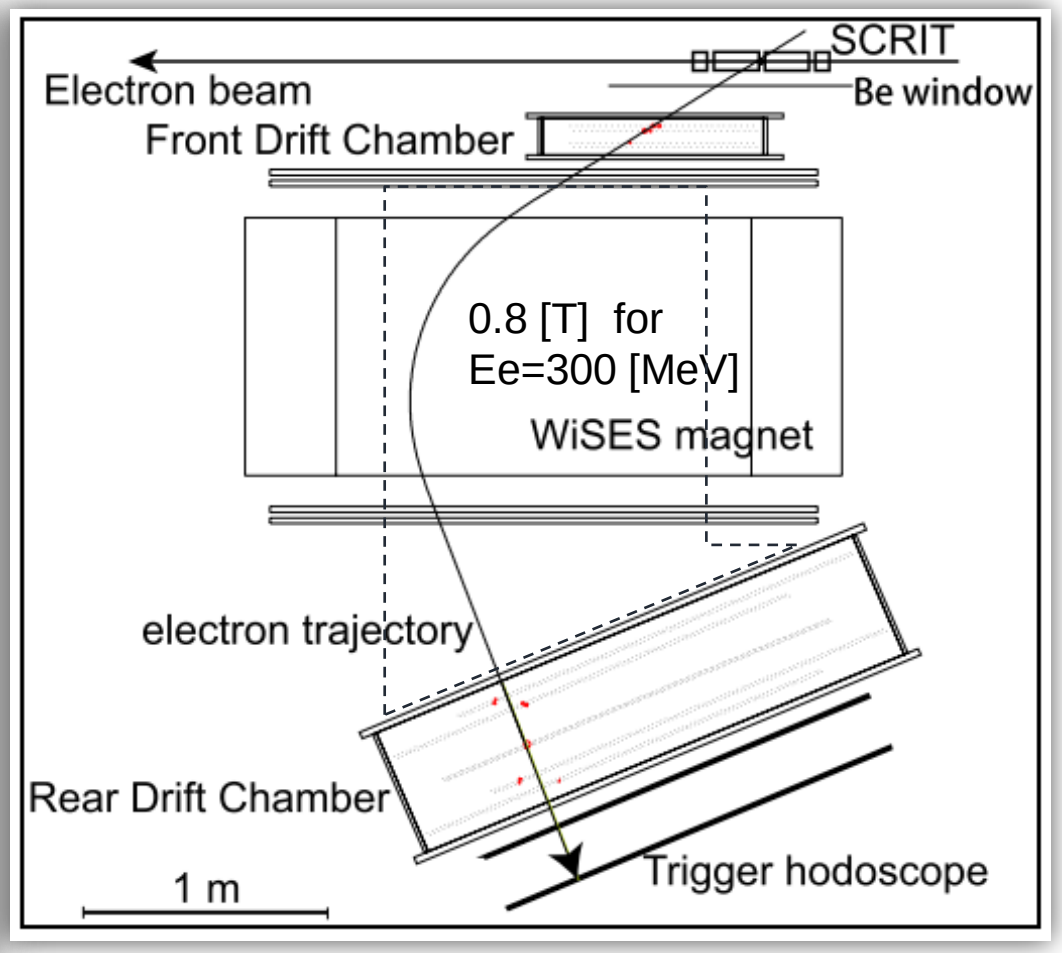




Details will be presented at 13/Sep L3-2 13:55- by T. Ohnishi

WiSES (Window-frame Spectrometer for Electron Scattering)





Details will be presented at 13/Sep L3-6
14:55- by A. Enokizono

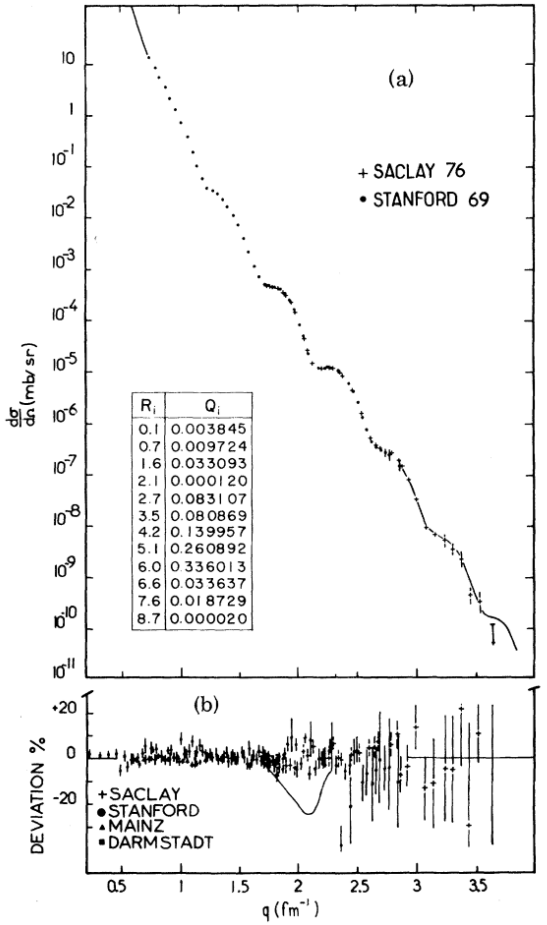
Contents

Experiments with stable nuclei

- ^{132}Xe
  - Stable nucleus (natural abundance : 26.9%)
  - Separated from a standard xenon gas
  - $\langle r^2 \rangle^{1/2}$ =4.787 [fm] by X-ray from muonic atom
  - No electron scattering
  - First physics data from SCRIT project
- ^{208}Pb
  - Stable nucleus (natural abundance : 52.4%)
  - Evaporated from a lead wire by heating
  - precise charge density distribution by electron scattering
  - Commissioning data for SCRIT project

G. Fricke *et al.*,
Atom.Nucl.Data Tables **60**, 177 (1995

B. Frois *et. al.*,
Phys.Rev.Lett.38,152 (1977)



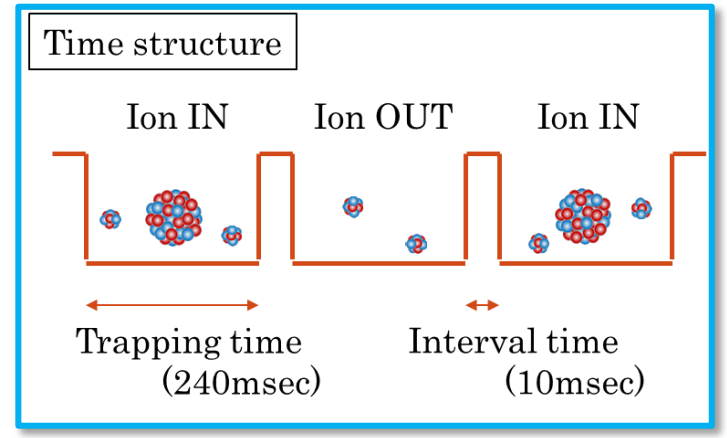
Both target ions were separated from natural materials by the mass-spectrometer of the **ERIS**.

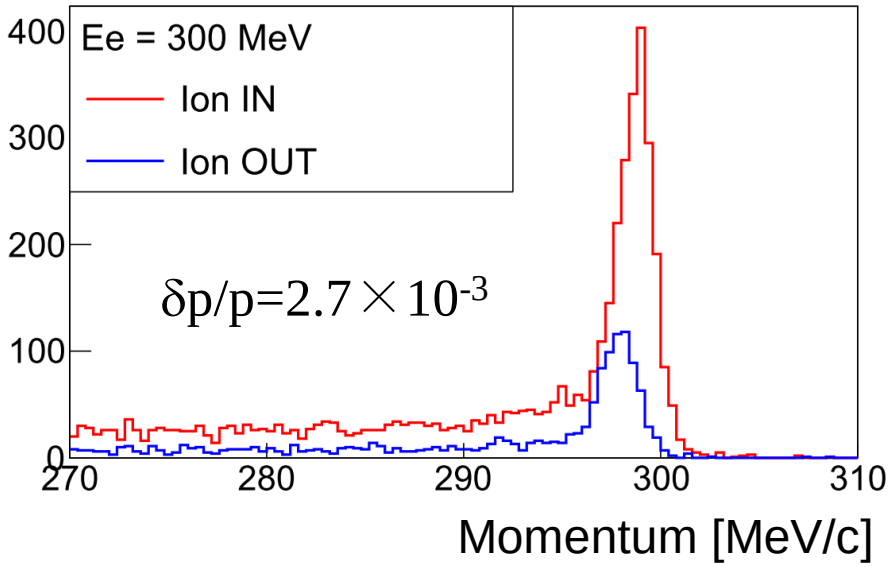
Experimental conditions

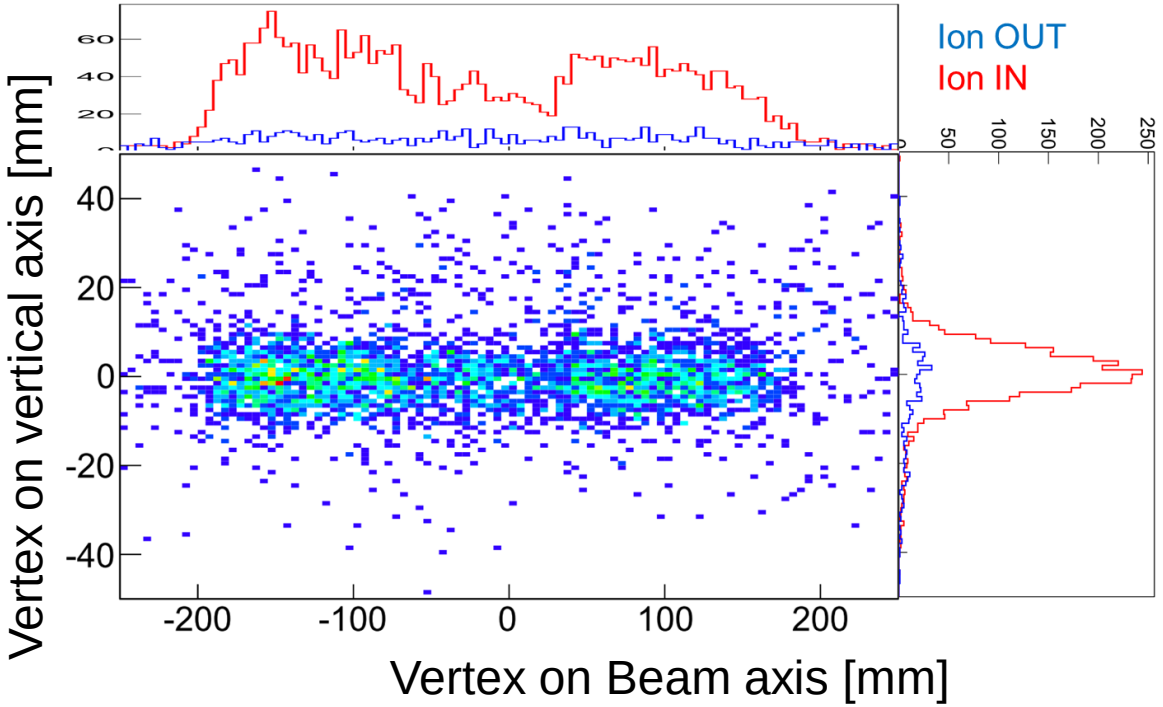
- ^{132}Xe
  - Beam energy : 150, 200, 300 [MeV]
  - Beam current : 250 [mA] → 150 [mA] (typically)
  - Vacuum pressure in SCRIT : ~5×10^{-8} [Pa]
  - #ions injected into SCRIT : ~2×10^{8} particles/pulse
  - Exp. Period :
    - 5 days for 150 [MeV]
    - 8 days for 200 [MeV]
    - 11 days for 300 [MeV]
  - Duty : 15~25 [%] ← including IonIN/OUT switching and the beam injection sequence
- ^{208}Pb
  - Almost similar to ^{132}Xe.

Data analysis

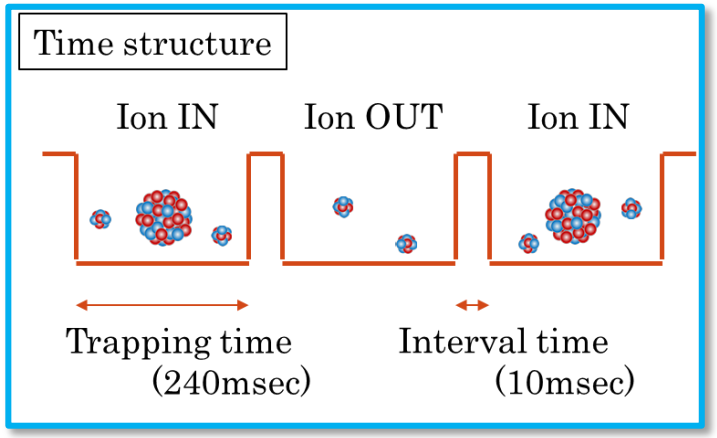
- Momentum distribution
  - Clear elastic peak from
    targets (IonIN) and residual gas (IonOUT)
- Vertex point distribution
  - Events from SCRIT inside



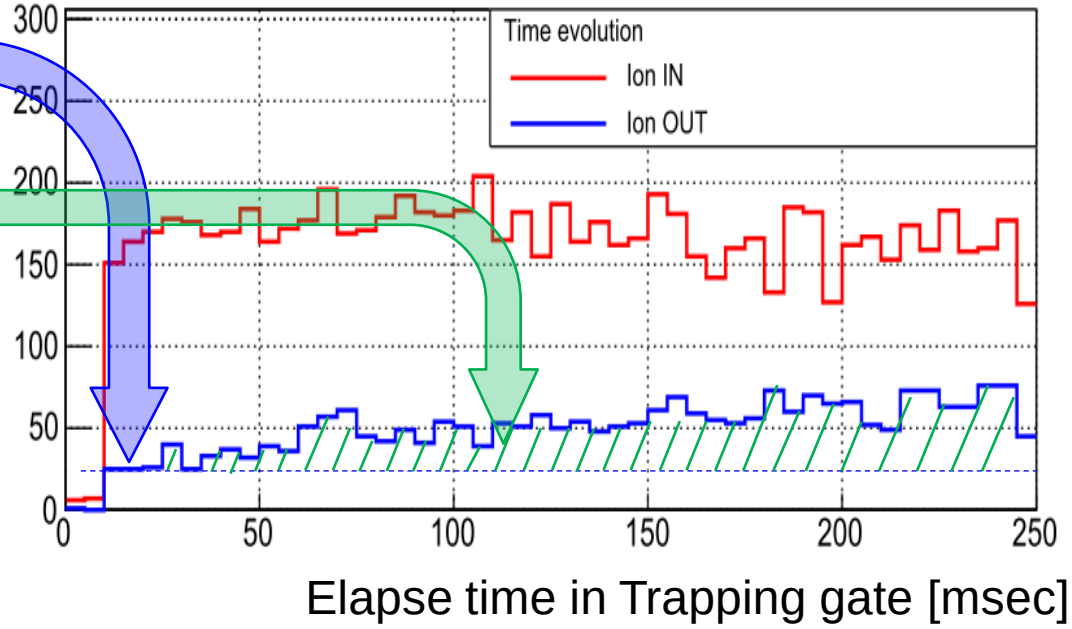




Background contribution

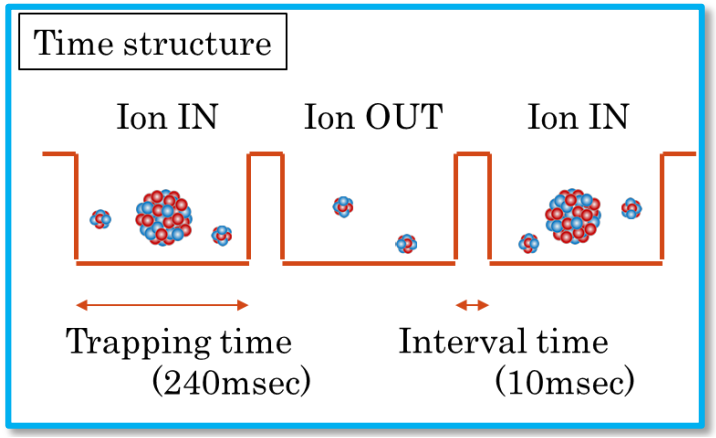


- Beam current : ~200 mA → 10^{18} [e^-/s]
- Residual gases in the SCRIT : ~5x10^{-8} Pa
  → 6x10^{8} [particles/cm^2]
  → L ~ 0.6x10^{27} [/cm^2/s]
  for neutral gas
- Residual gases are ionized by the beam and trapped.
  - Amount is similar to the neutral ones.

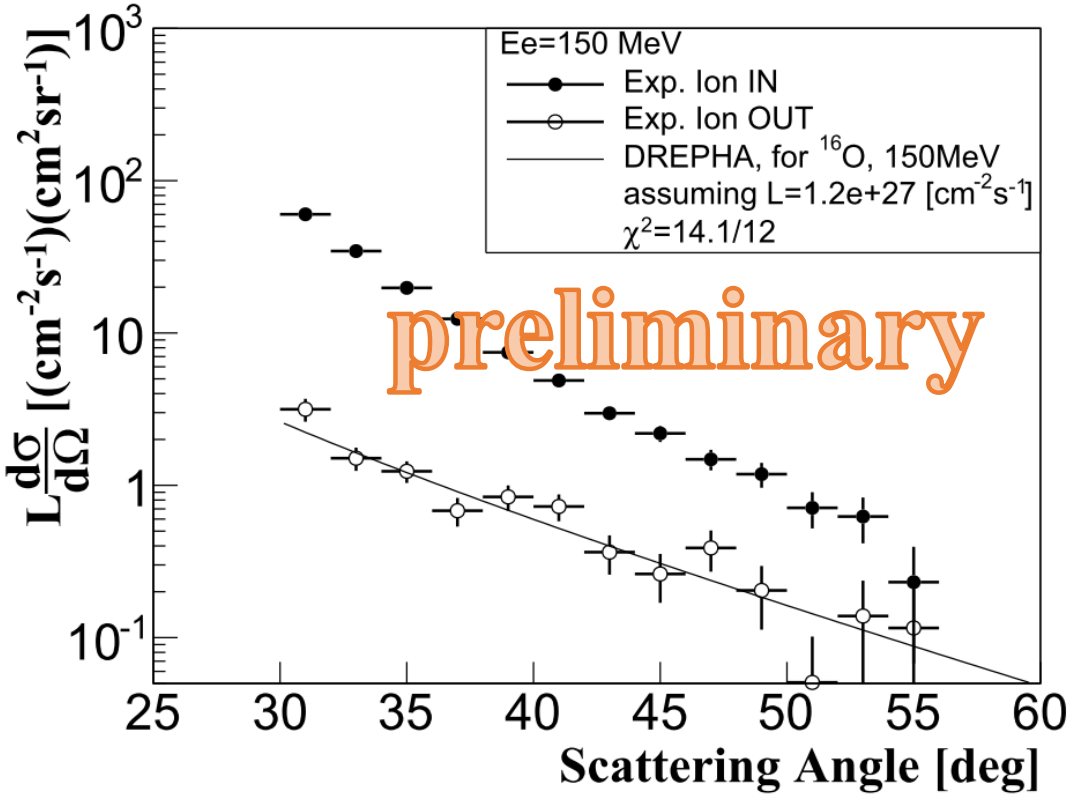


- Luminosity of residual gas can exceed 1×10^{27} [/cm^2/s].
  - It is not small, and should be subtracted.

Background contribution



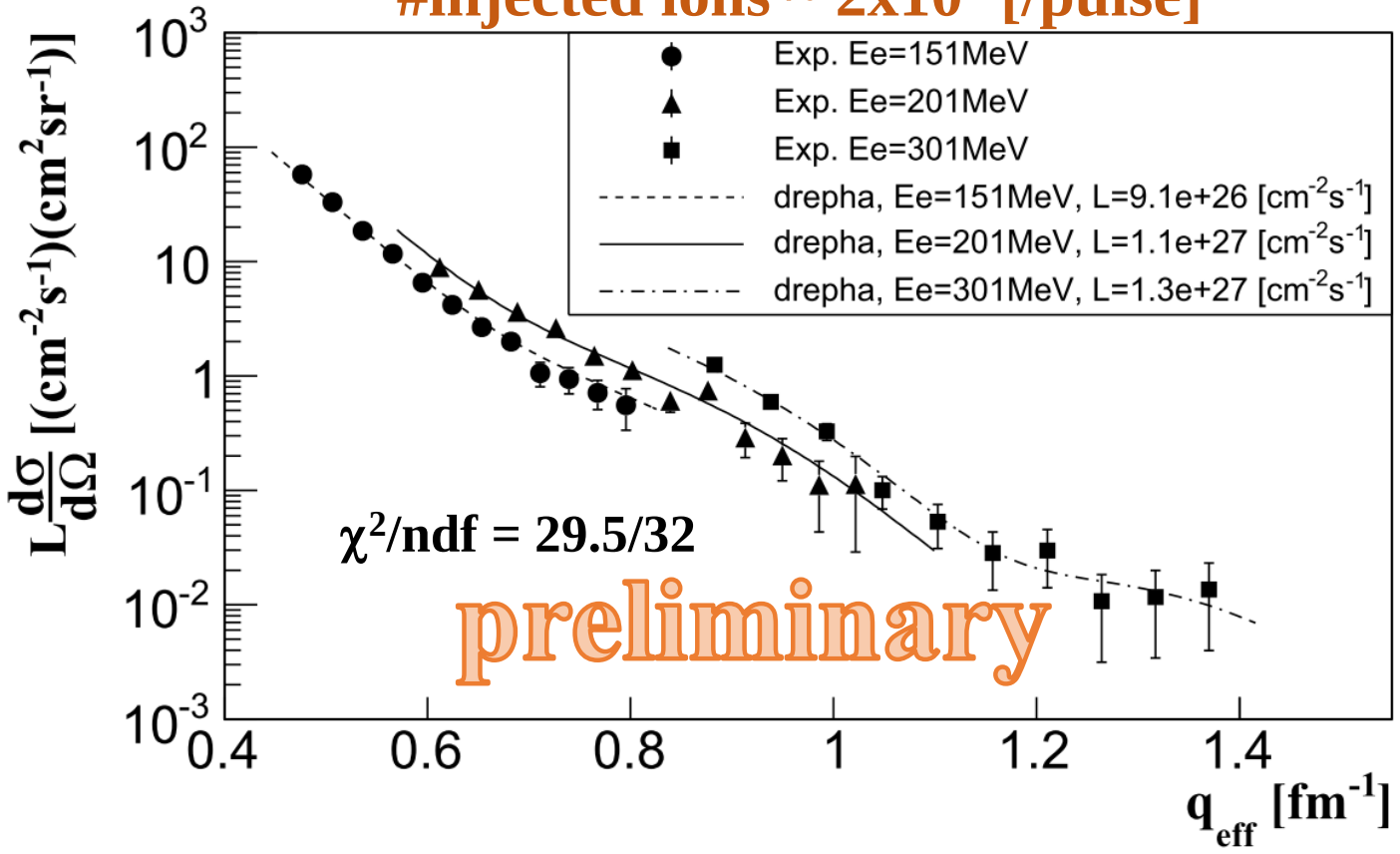
- Beam current : ~200 mA → 10^{18} [e^-/s]
- Residual gases in the SCRIT : ~5×10^{-8} Pa
  → 6×10^{8} [particles/cm^2]
  → L ~ 0.6×10^{27} [/cm^2/s]
  for neutral gas
- Residual gases are ionized by the beam and trapped.
  - Amount is similar to the neutral ones.
- Luminosity of residual gas can exceed 1×10^{27} [/cm^2/s].
  - It is not small, and should be subtracted.

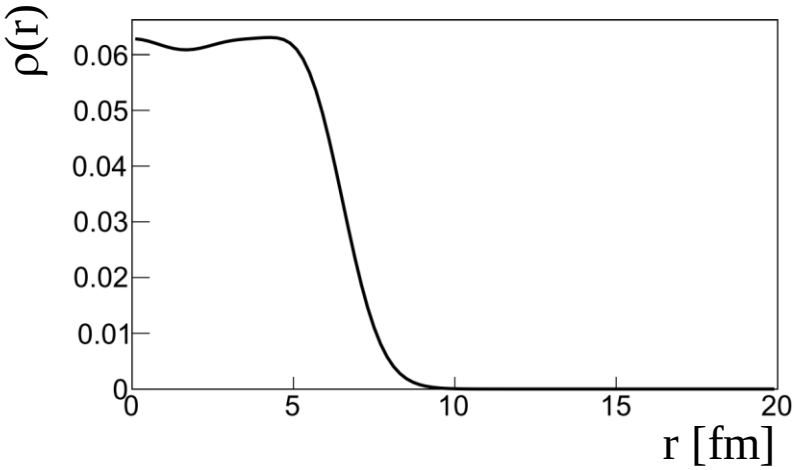


Angular distributions of ^{208}Pb

- The cross sections are calculated by a DWBA code (DREPHA).
- The charge density distribution is expressed by the Sum Of Gaussian.
- The luminosity is considered as free parameter.

#injected ions ~ 2x10^8 [/pulse]





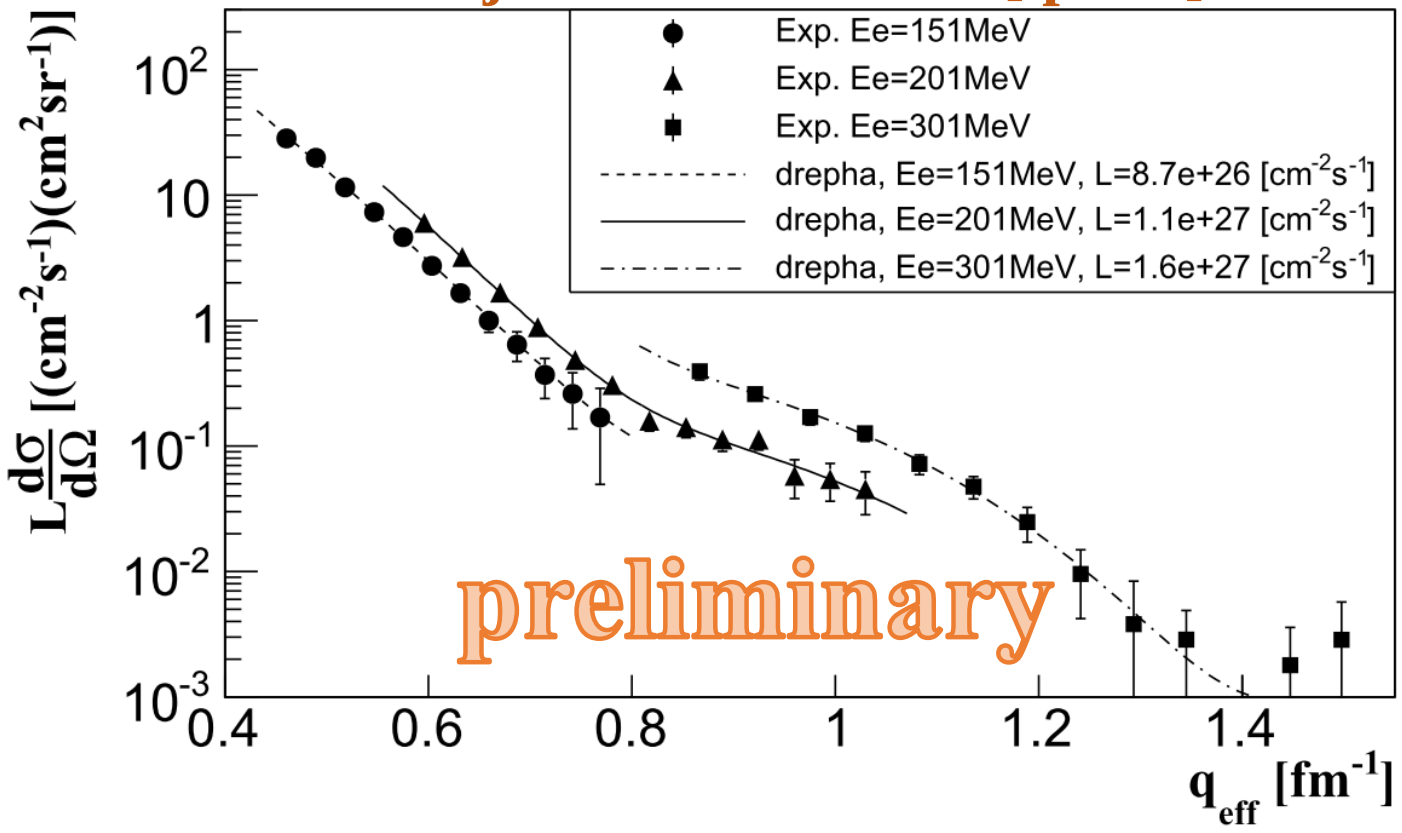
$$\rho(r) = \frac{Ze}{2\pi^{\frac{3}{2}}\gamma^3}\sum_{i=1}^{N}\frac{Q_i}{1+2R_i^2/\gamma^2}\left(e^{-(r-R_i)^2/\gamma^2}+e^{-(r+R_i)^2/\gamma^2}\right).$$

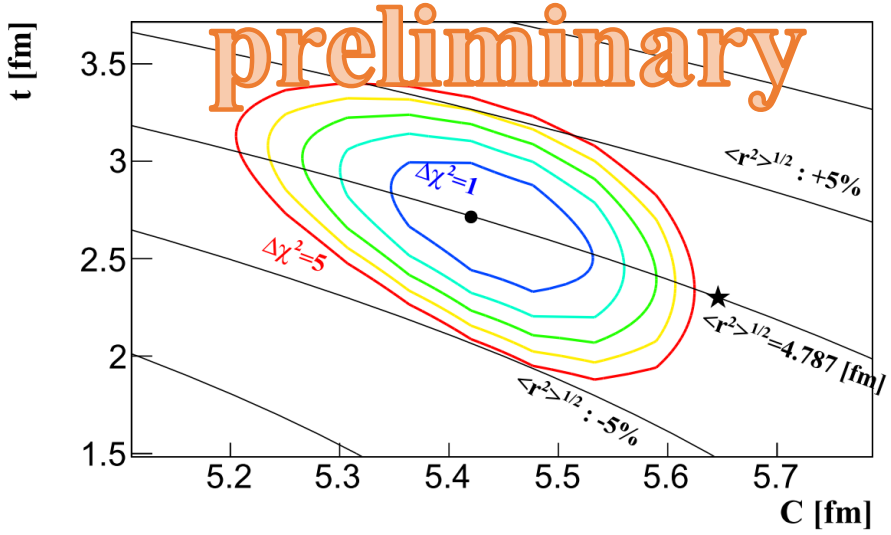
B. Frois *et. al.*,
Phys.Rev.Lett.38,152 (1977)

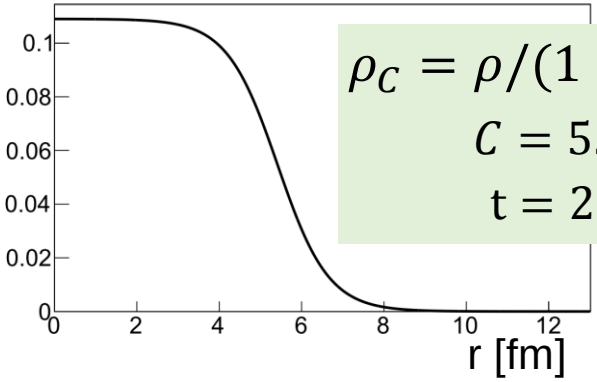
Angular distribution of ^{132}Xe

- The cross sections aree calculated by a DWBA code (DREPHA).
- The charge density distribution is expressed by the 2-parameter Fermi.
- The luminosity and C, t are considered as free parameter.

#injected ions ~ 2x10^8 [/pulse]







$$\rho_C = \rho/(1 + e^{4.4(r-C)/t})$$

$$C = 5.42^{+2.0\%}_{-1.4\%}$$

$$t = 2.71^{+10\%}_{-14\%}$$

Summary and outlook

Summary

- We have constructed **SCRIT** electron scattering facility.
- The commissioning experiment with stable nuclei successfully carried out.
  - The angular distribution of ^{208}Pb
  - The angular distribution of ^{132}Xe and nuclear size parameters (C and t)
- The facility is almost ready to start electron scattering with unstable nucleus target.

Outlook

- First experiment of e-RI scattering will be performed.
  - ^{138}Xe : demonstration, soon,
  - ^{132}Sn : the first goal, in one year.

Contribution of inelastic scattering for ^{132}Xe

- Transition density of the first 2^+ state is calculated by a relativistic mean field theory. **Private communication**
- Cross section of the inela. scatt. is calculated by a phase shift code (MEFCAL). **Private communication**
- The contribution is **negligible** in our kinematical region.