Recent results and prospects of the SCRIT electron scattering facility

ICR, Kyoto University

Kyo Tsukada

Contents

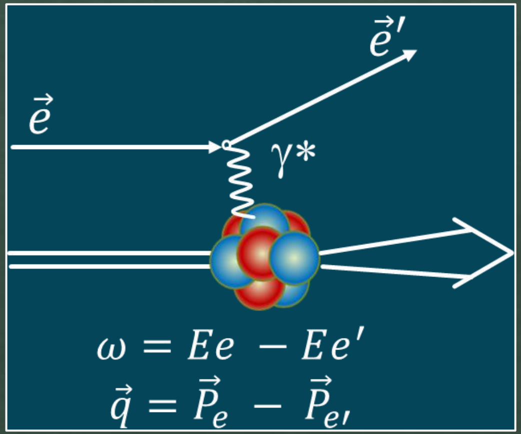
- Introduction
- SCRIT facility
- Recent results of (e,e)
  - ^{137}Cs as world's first online-produced RI target
  - Xe isotopes for study of isotope dependence
- Summary
- Advertisement of a workshop (if time allows)

Motivation

Electron scattering off unstable nuclei

Direct and unambiguous information for structure study of atomic nuclei:

- Elementary point particle probe
- Well known electromagnetic interaction
  - EM structure of nucleus
  - probing the whole volume of nucleus
  - one photon exchange approximation
- Independent variable q and ω

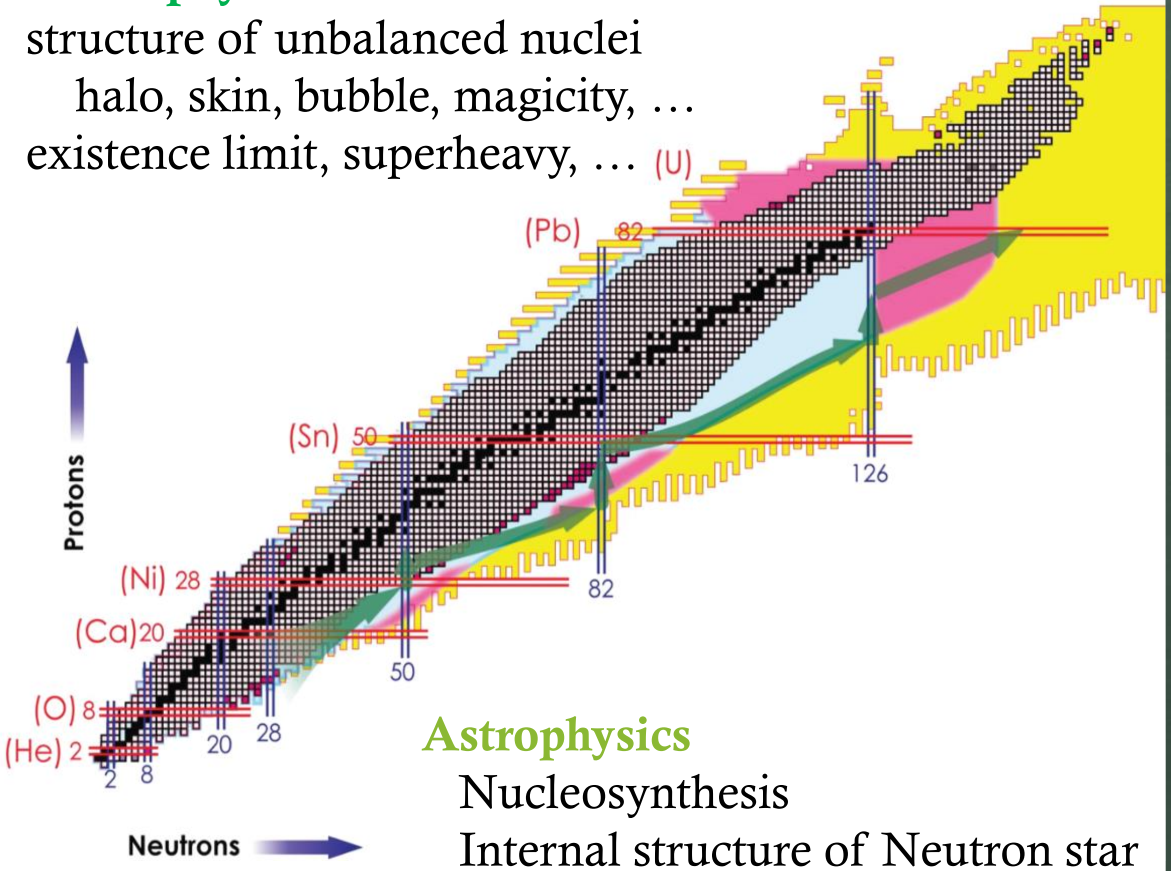


Nuclear physics

structure of unbalanced nuclei

halo, skin, bubble, magicity, …

existence limit, superheavy, …



Astrophysics

Nucleosynthesis

Internal structure of Neutron star

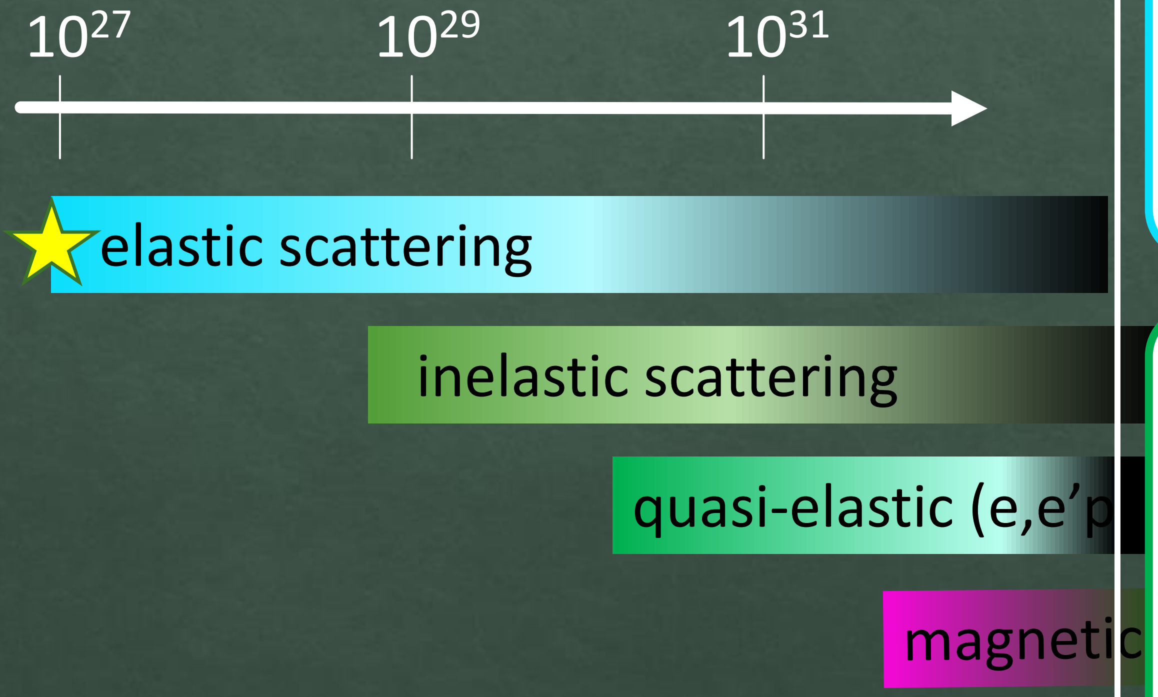
…

Electron scattering for nuclear structure studies

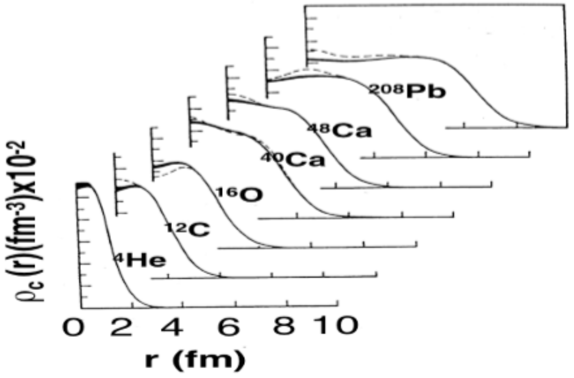
Yield ≈ CrossSection($\propto Z^2$) × Luminosity × dΩ

Luminosity : overlap between beam and target

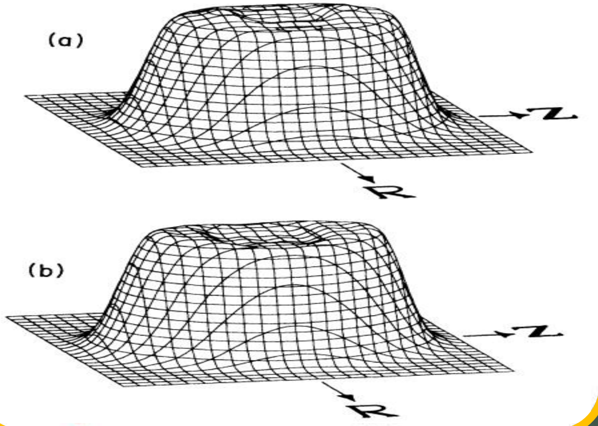
Rough idea of Required Luminosity [/cm²/s]



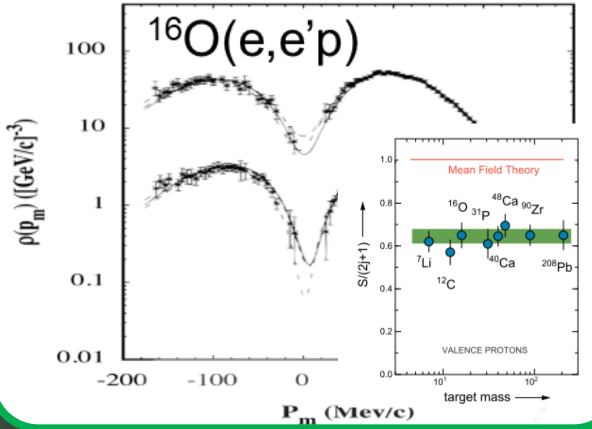
elastic scattering
→ charge distribution



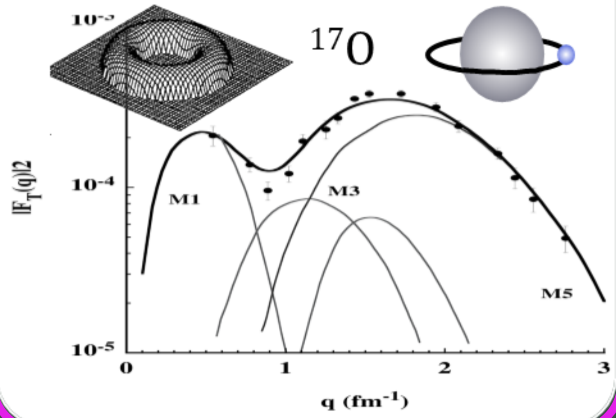
elastic + inelasticscattering
→ deformation



quasi-elastic (e,e'p)
→ S-factor



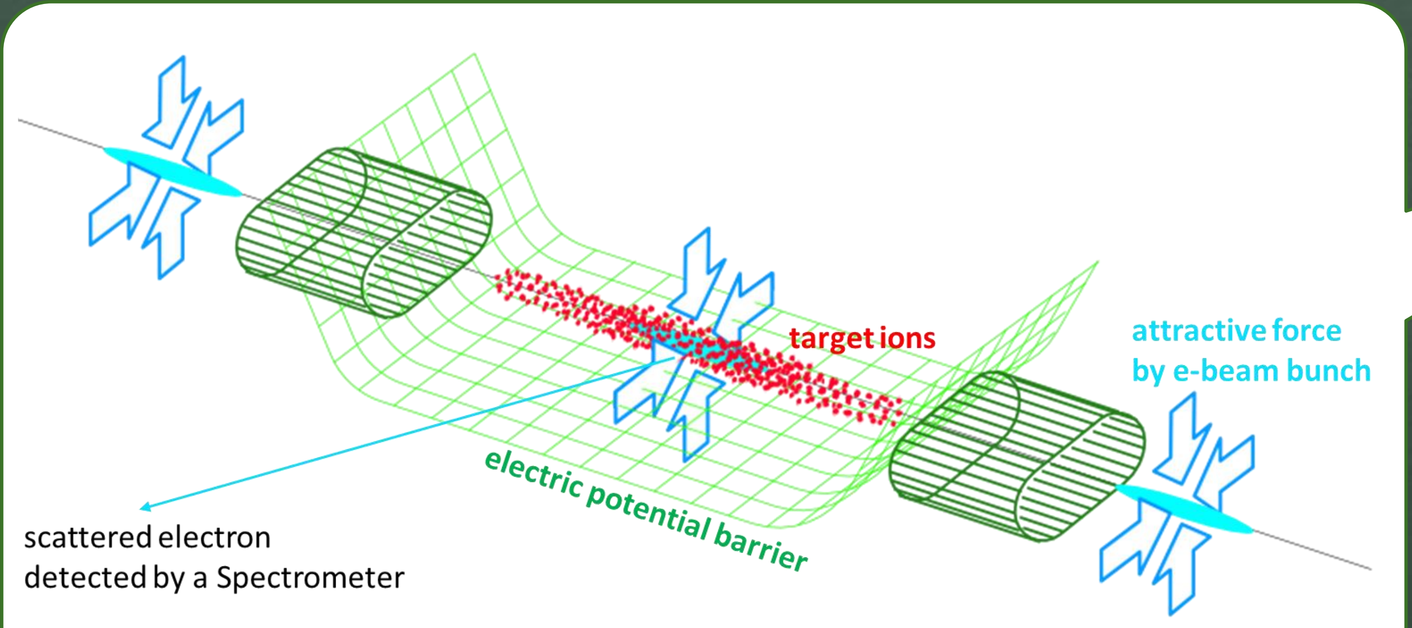
magnetic scattering
→valence neutron



SCRIT (Self-Confining Radioactive isotope Ion Target)

Ion trapping phenomena : Transverse trapping
(known as a serious problem of e-storage ring)
+
Electric potential barrier : Longitudinal trapping

Electron storage ring

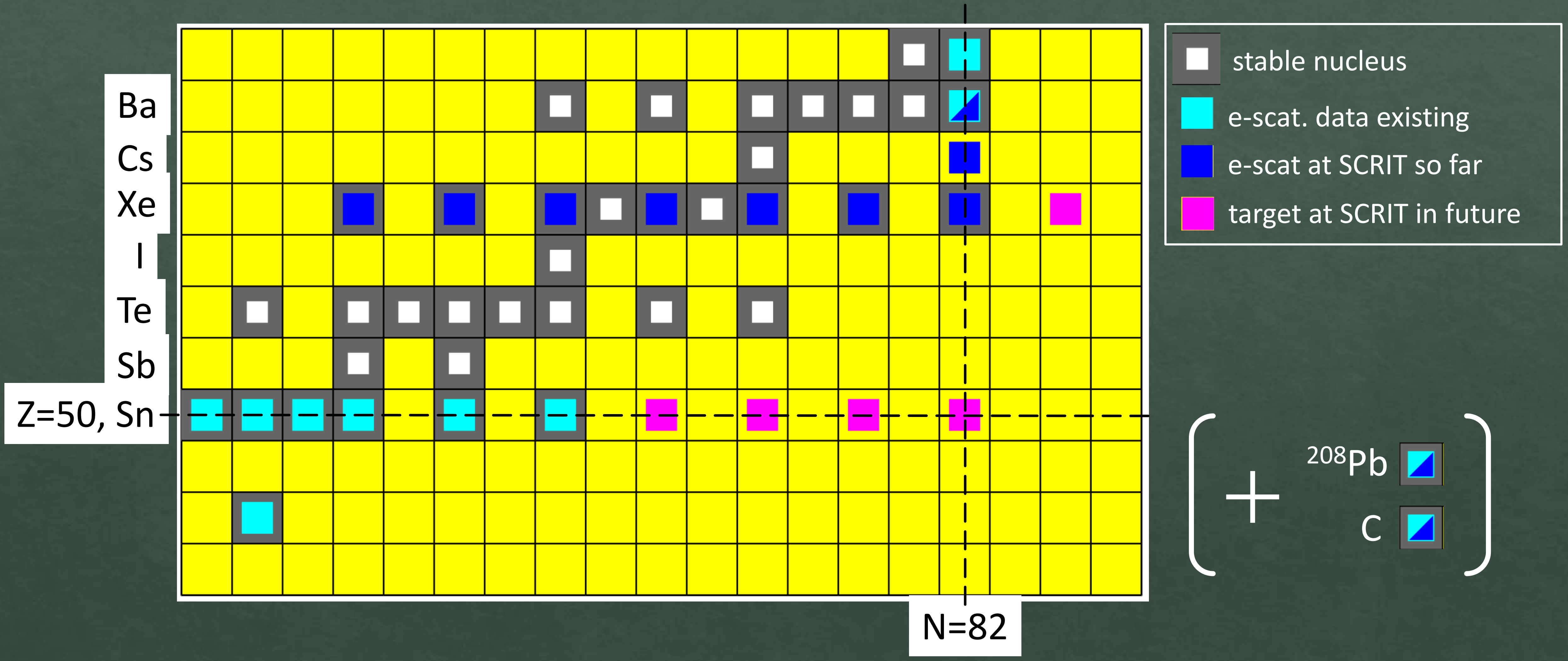


Electron scattering with trapped ions automatically occur!

Beam : Ie ≈ 200 mA, size ≈ mm^2
10^8 RI ions introduced
→ Target thickness ≈ 10^9 cm^{-2}

$L \sim 10^{27}$ $cm^{-2}s^{-1}$

e-scat. target at the SCRIT facility



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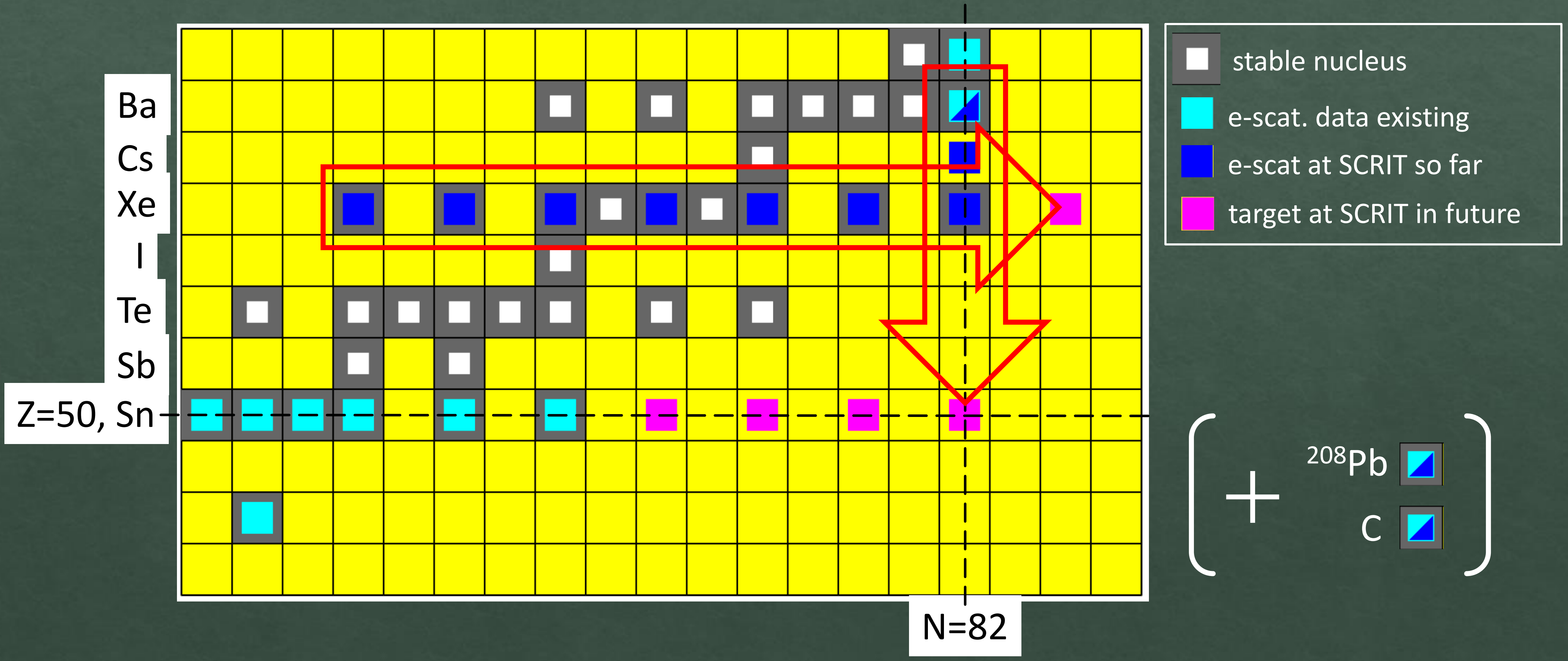

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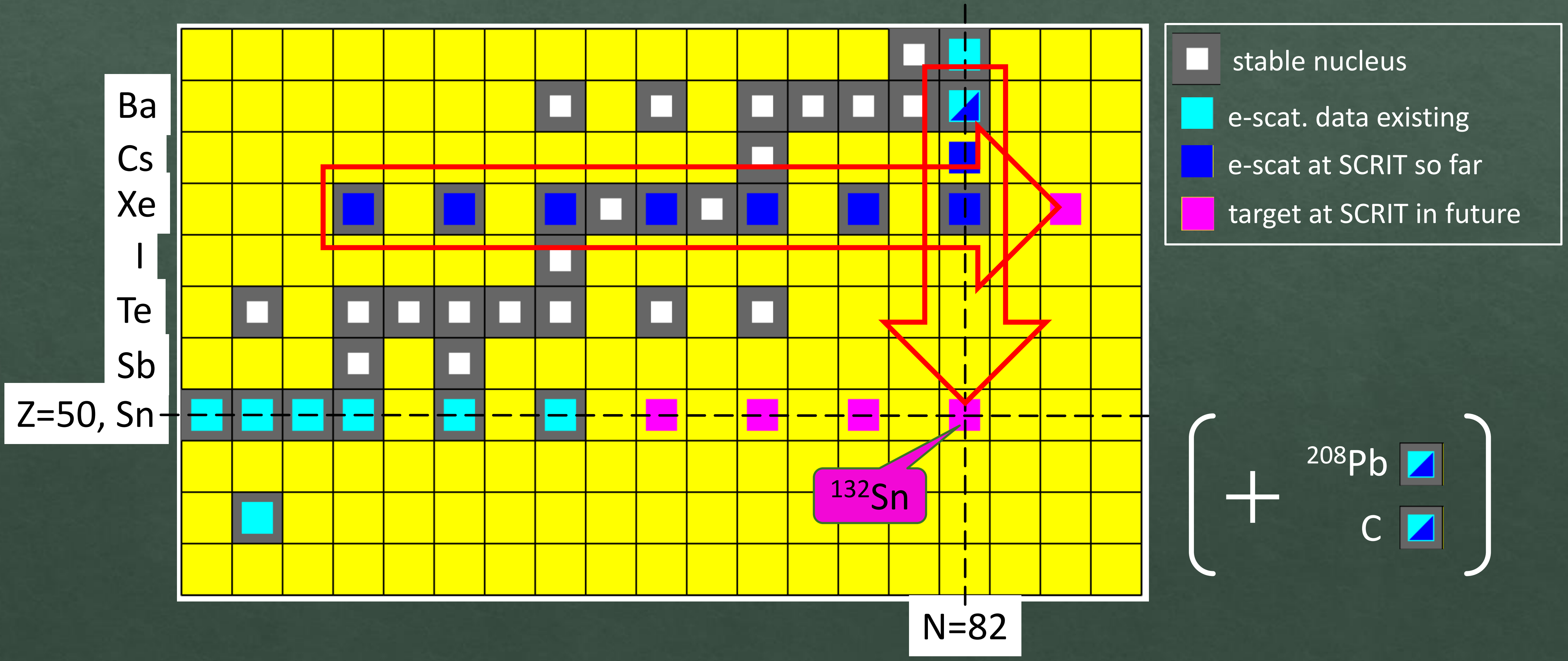

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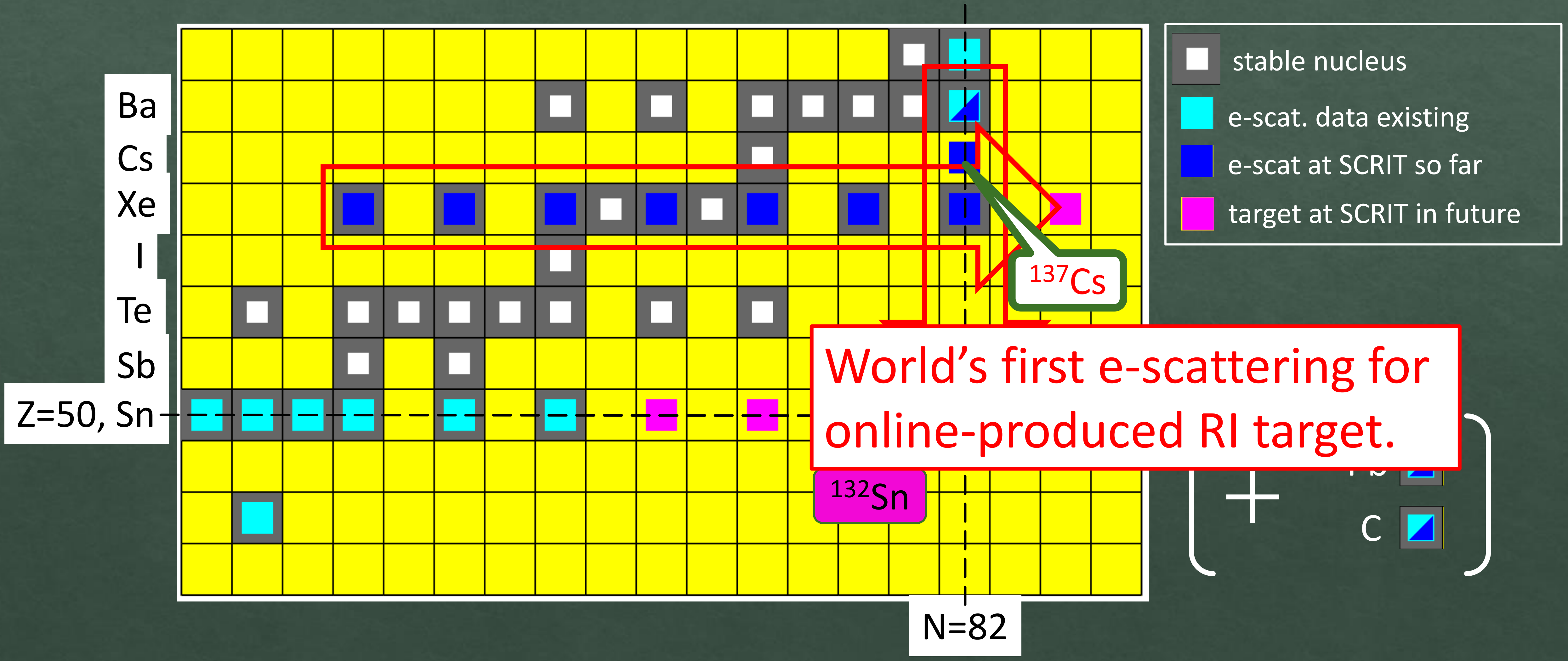


World's first e-scattering for online-produced RI target.

World's first electron scattering from online-produced RI target

Phys. Rev. Lett. 131 (2023) 092502

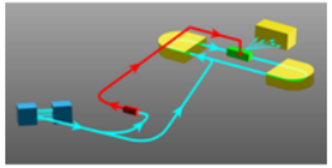
Featured in Physics | Editors' Suggestion

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 +

Johanna L. Miller, Physics Today 76(11) 14, 2023

SEARCH & DISCOVERY

Electron scattering provides a long-awaited view of unstable nuclei

Nuclear reactions produce a plethora of short-lived artificial isotopes. Figuring out what they look like has been a challenge.

The cartoon picture of an atomic nucleus looks kind of like the inside of a gumball machine that dispenses only two flavors: protons and neutrons, evenly mixed in a compact, spherical cluster.

That's not generally what real nuclei stranger the structures it can adopt. Short-lived nuclei might form bubble structures with depleted central density, or they might have a valence nucleon or two that form a halo around a compact central core. (See the article by Filomena Nunes, Physics Today, May and colleagues, working at RIKEN's Radioactive Isotope Beam Factory (RIBF) in Wako, Japan, have performed the first electron-scattering experiment on unstable nuclei produced on the fly in a nuclear reaction.[1] Their isotope of choice, cesium-137, has a half-life of 30 years. It's not so exotic that the researchers expected—or found—anything unusual about its structure. But the technique they used is applicable to shorter-

Patrick Achenbach, Physics 16, 144

Physics — VIEWPOINT

What Do Unstable Atomic Nuclei Look Like?

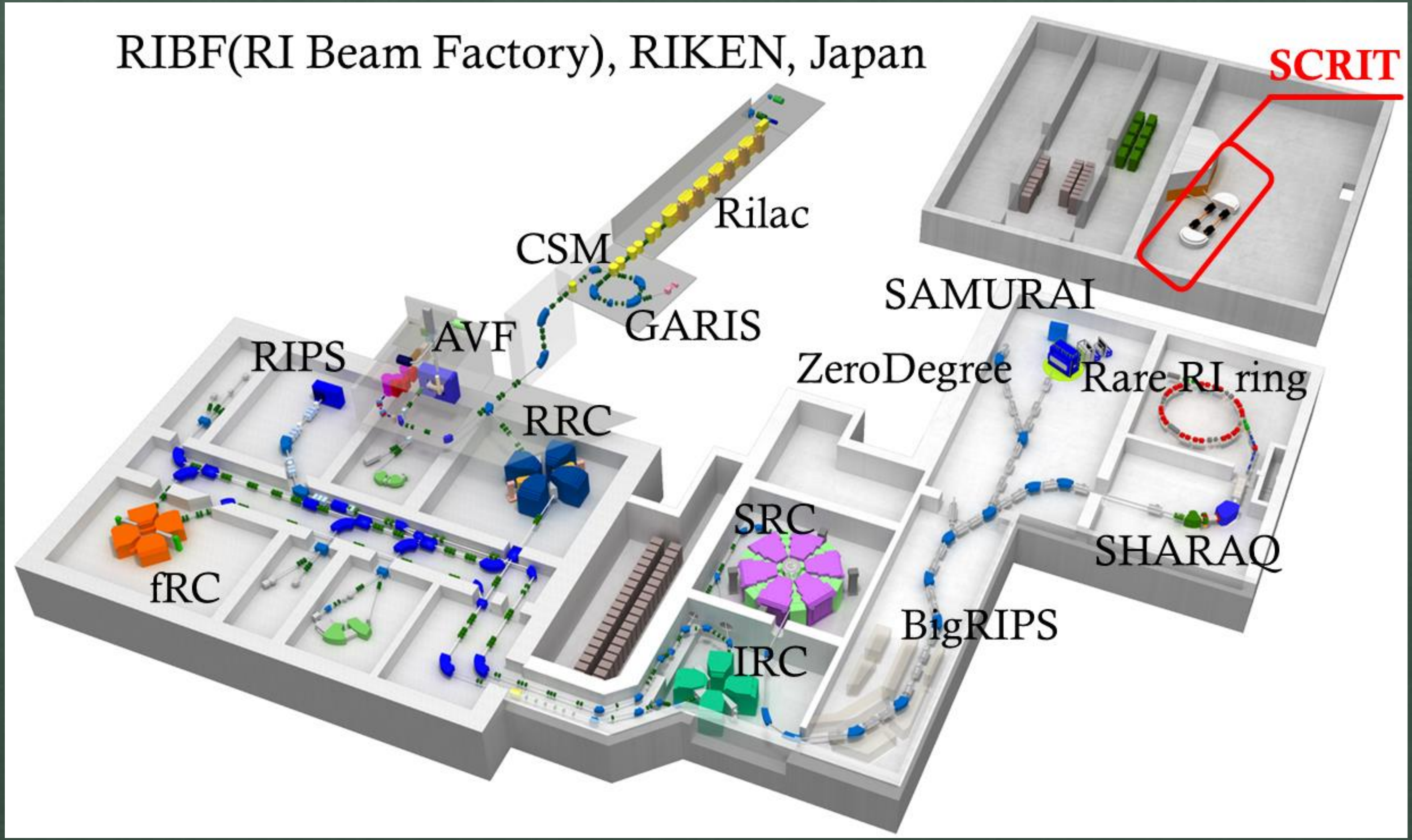
The first electron-scattering experiment off unstable radioisotopes marks a milestone for understanding the shape of exotic atomic nuclei.

By Patrick Achenbach

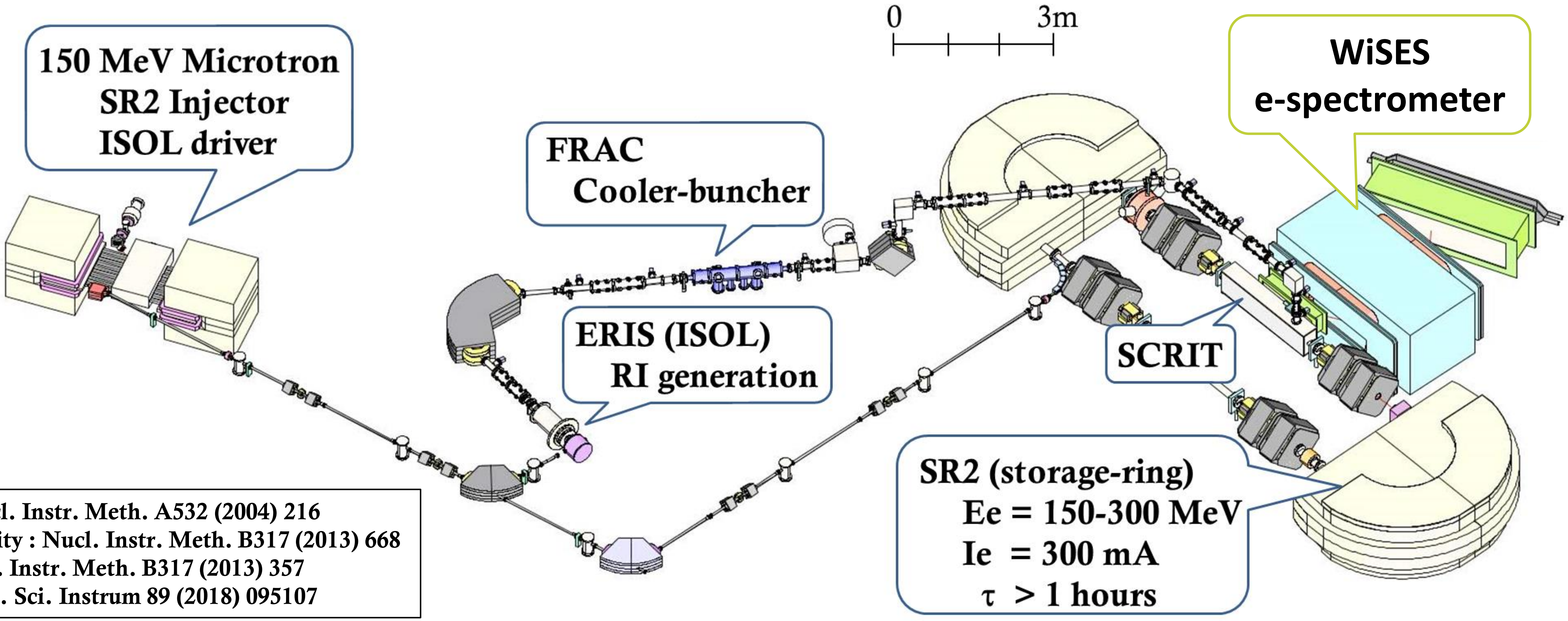
Since the pioneering measurements of Robert Hofstadter and co-workers in the 1950s, it has been known that atomic nuclei are not point-like particles but have a finite size on the femtometer scale—about 10,000 times smaller than naturally [2]. The physicists achieved this long-awaited result through successive advances in accelerator technology and novel methods in producing and trapping ions. Their success marks the realization of the anticipated "femtoscope"—a

SCRIT electron scattering facility

The world's first and unique facility dedicated to electron scattering off unstable nuclei.



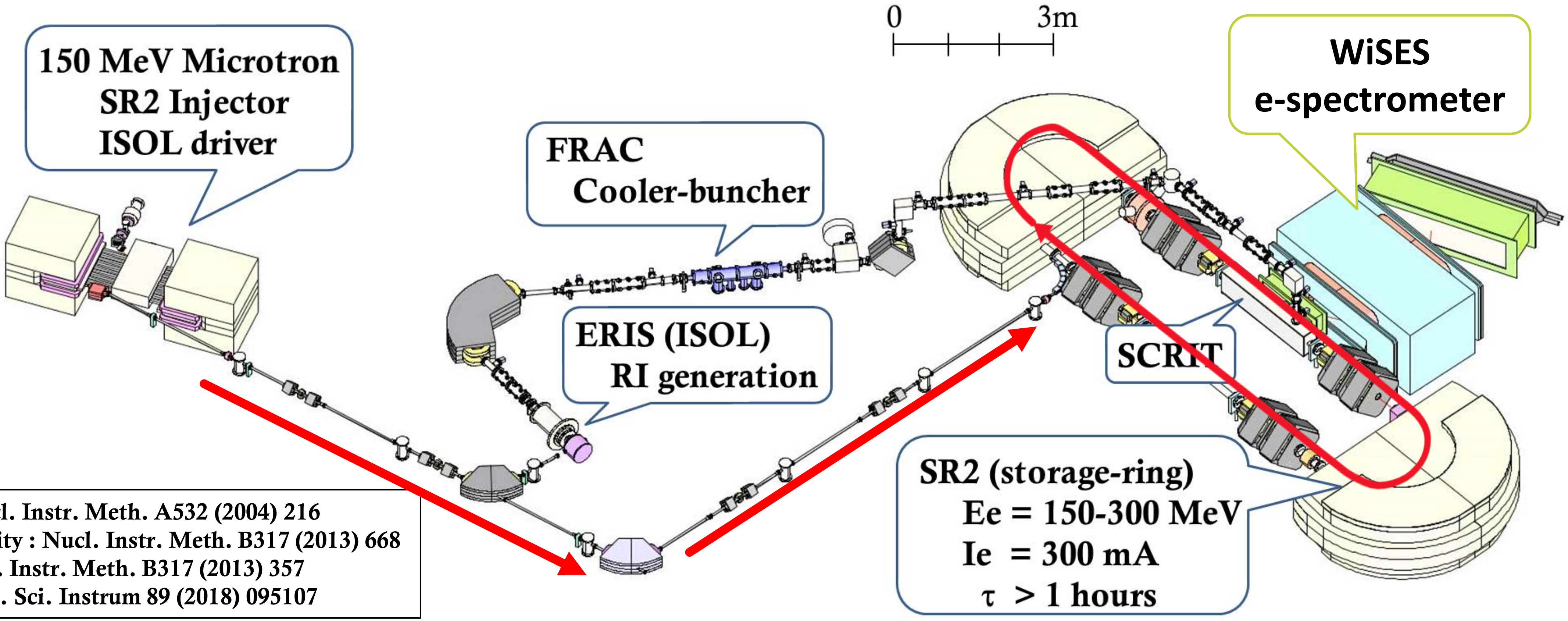
Overview of SCRIT electron scattering facility



SCRIT: Nucl. Instr. Meth. A532 (2004) 216
SCRIT facility : Nucl. Instr. Meth. B317 (2013) 668
ERIS : Nucl. Instr. Meth. B317 (2013) 357
FRAC : Rev. Sci. Instrum 89 (2018) 095107

Injection to SR2 Ee=150-300MeV Ie=250mA → RI generation via Uranium photo-fission → Transportation and trapping → Measuring scattered electrons

Overview of SCRIT electron scattering facility



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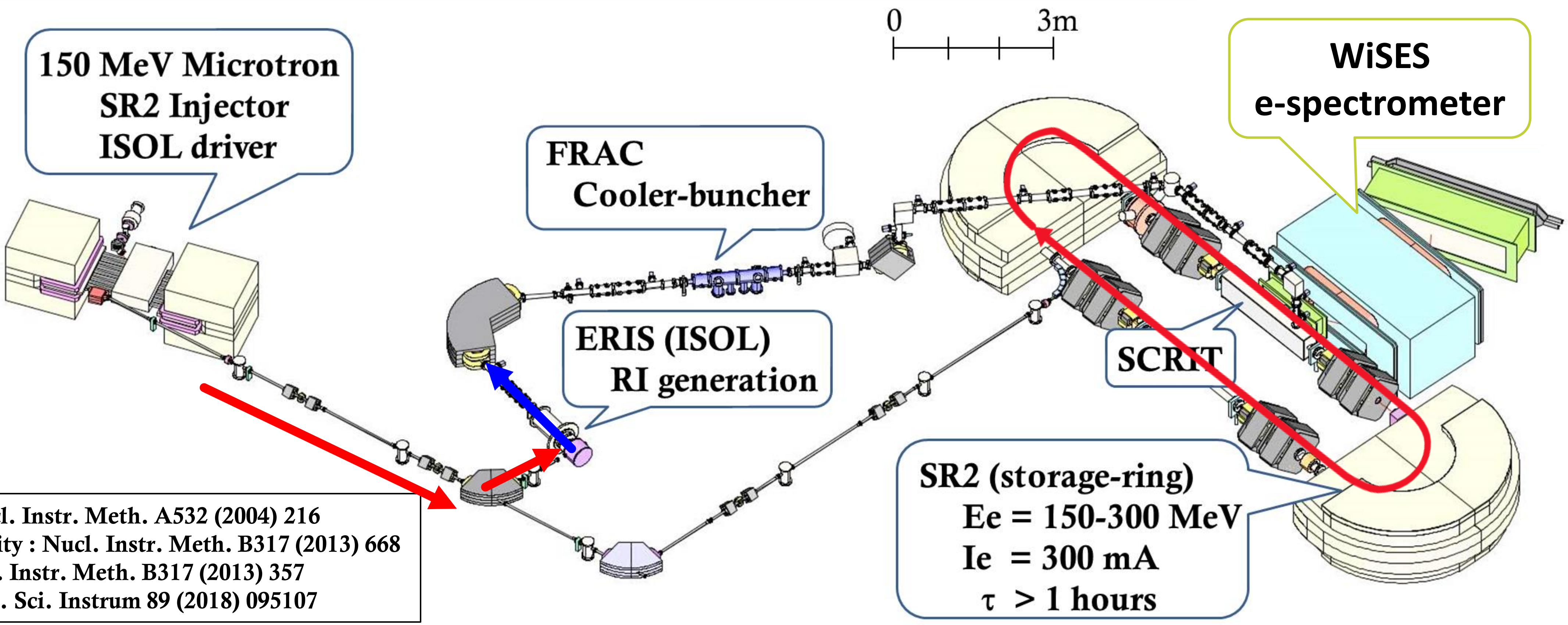

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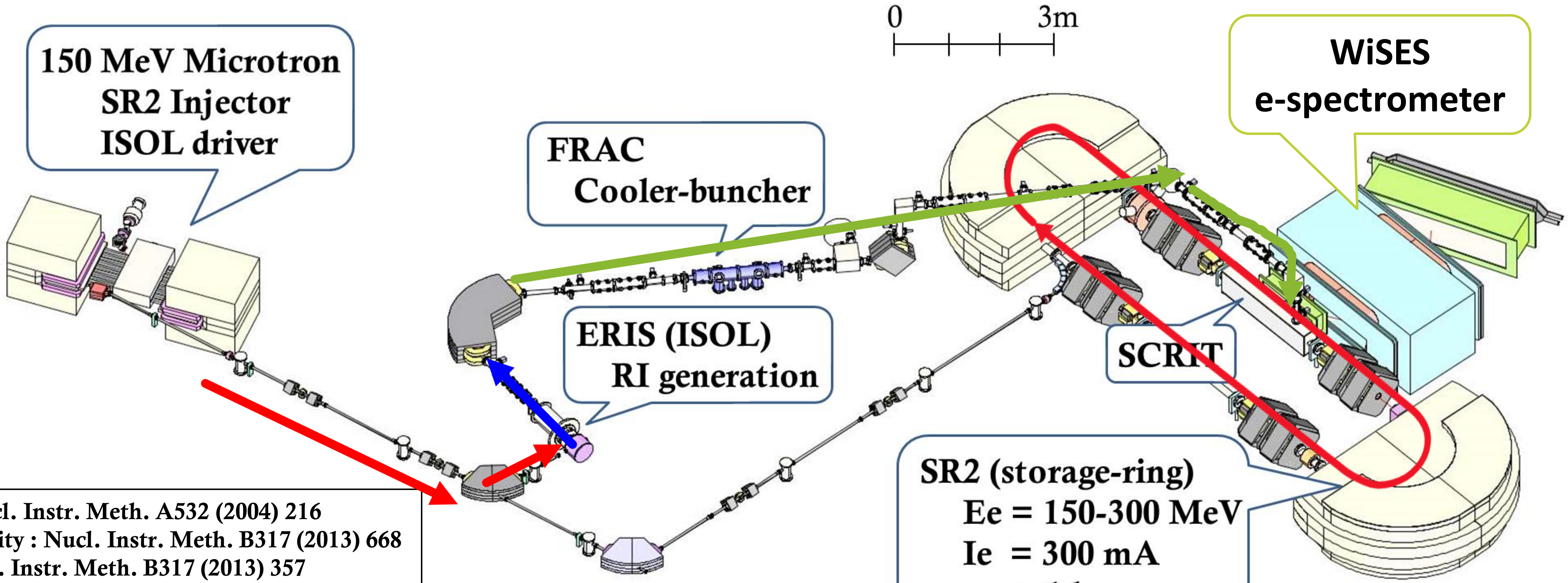

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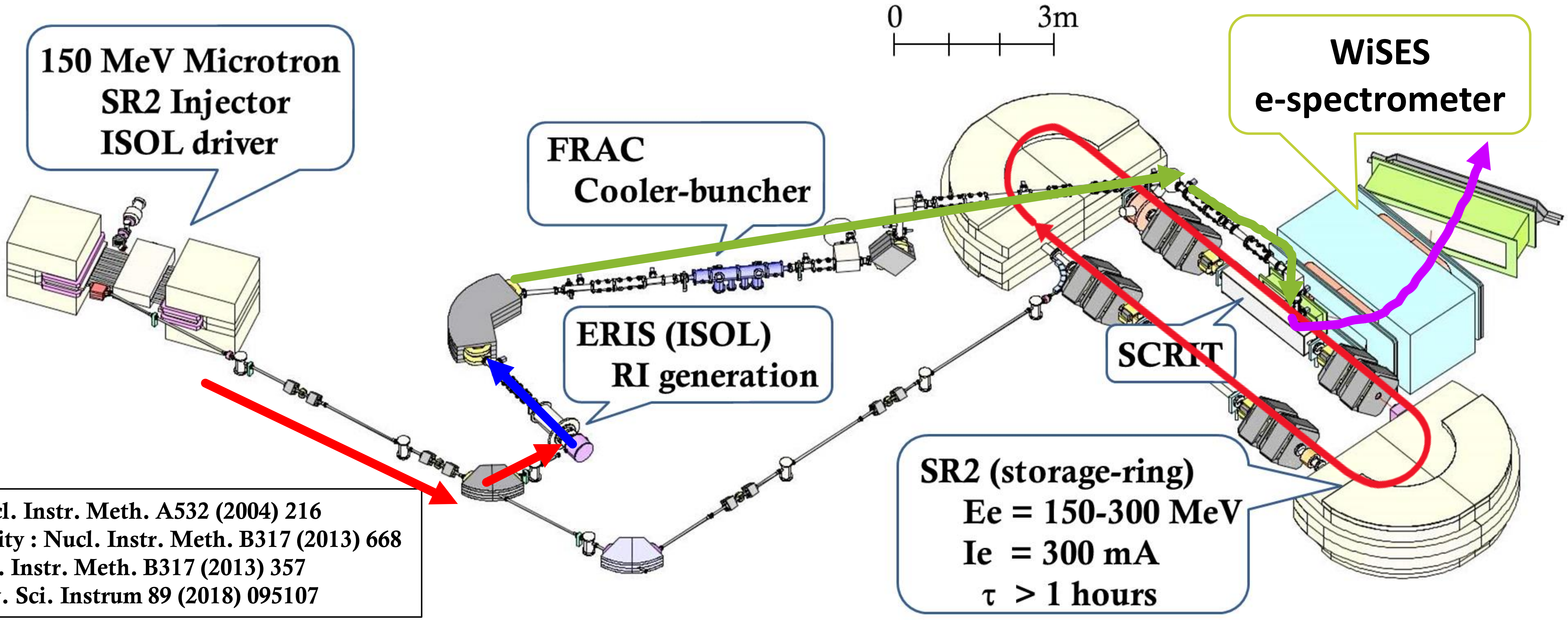

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Injection to SR2
Ee=150-300MeV
Ie=250mA

RI generation
via Uranium
photo-fission

Transporta
tion and
trapping

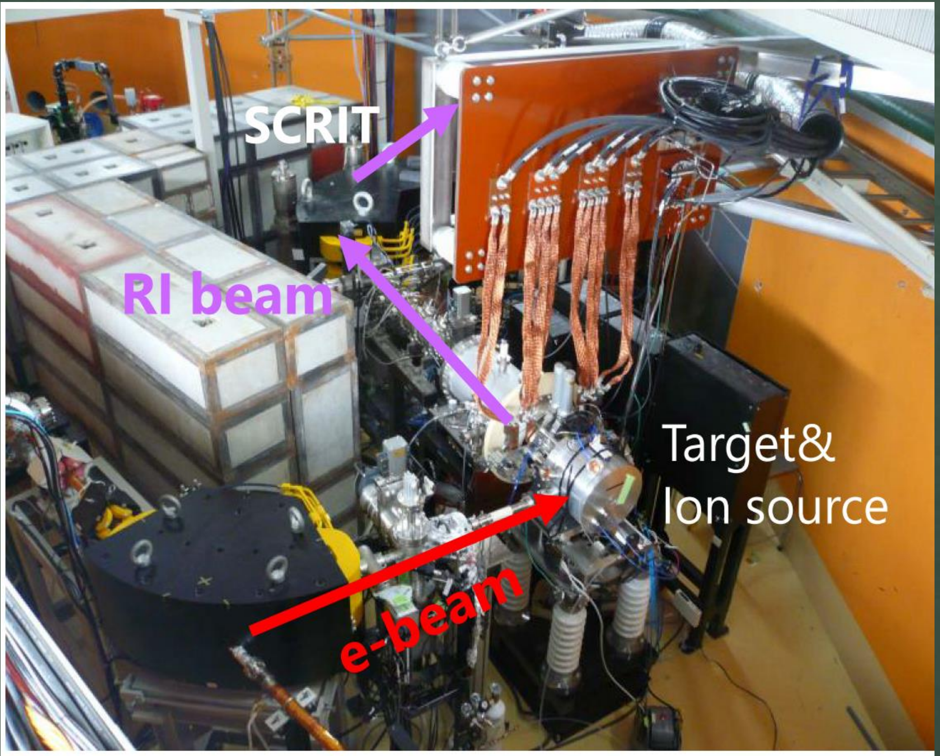
Measuring
scattered
electrons

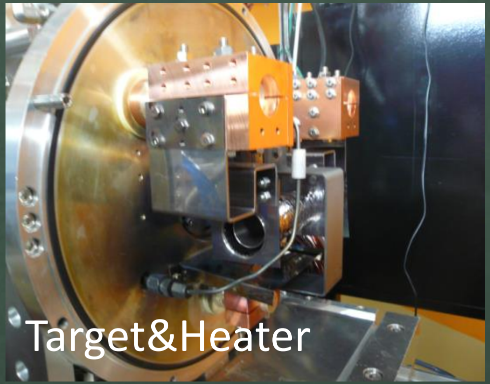
ERIS (Electron-beam-driven RI separator for SCRIT)

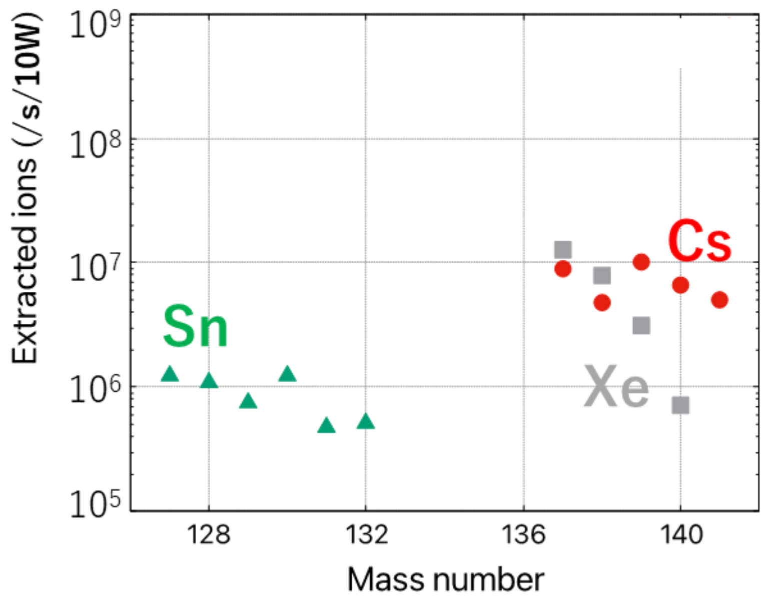
- RI Production : photo-fission of uranium
- Two ionization methods are available:
  - FEBIAD (Sn, Xe, etc.)
  - Surface Ionization (Cs, Ba, etc.)
- Nfission : 10^8/W with 20W e-beam (today)

house-made Uranium carbide (UCx) disks

φ 18 mm, t 0.8 mm disks





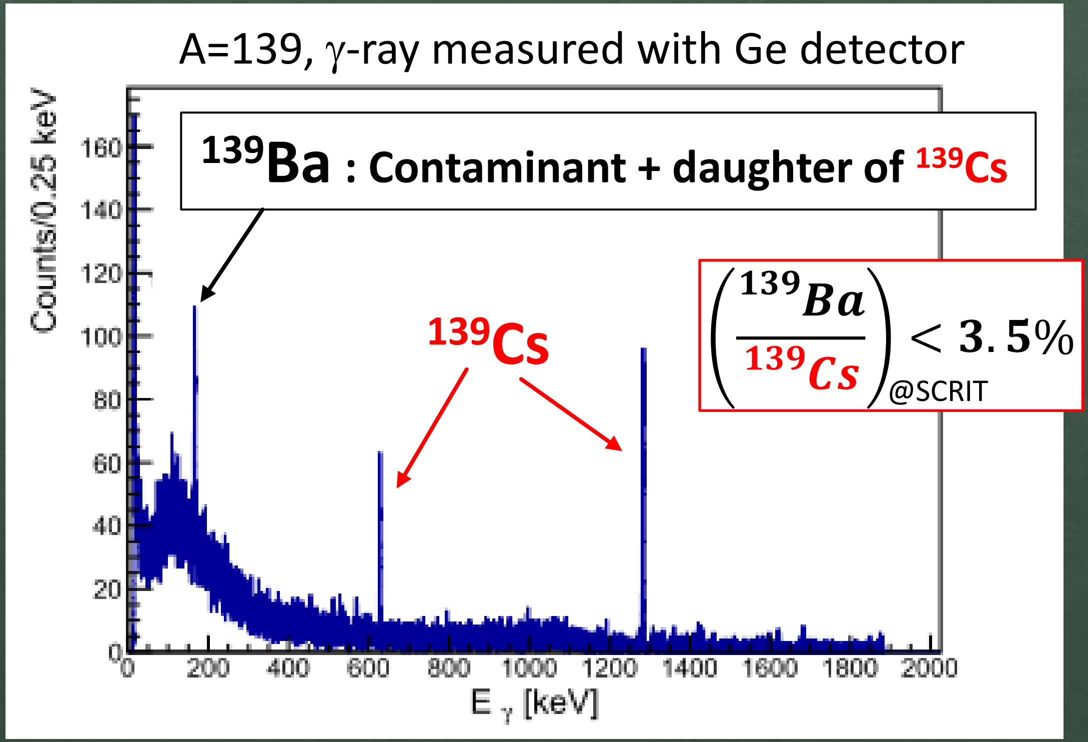


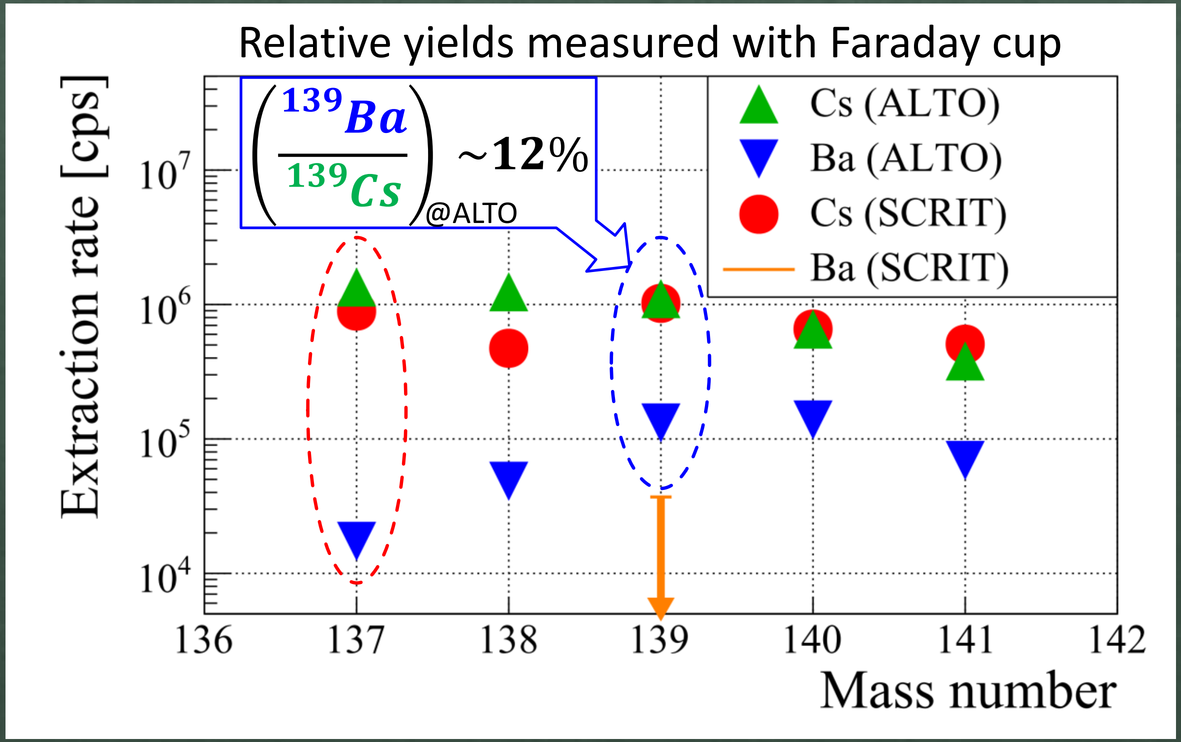
^{138}Xe : 3.9 x 10^6 cps
^{132}Sn : 2.6 x 10^5 cps
^{137}Cs : 8.0 x 10^6 cps (28-g U)

Purity of ^{137}Cs beam

- Ionization eff. of possible elements at Surface Ionization chamber (~1300ºC):
  - 0.90 for Cs >> 5.4x10^{-4} for Ba >> 4.3x10^{-5} for La >> …
  - → The largest contamination in the Cs beam was Ba.

NIMB317(2013)218-222



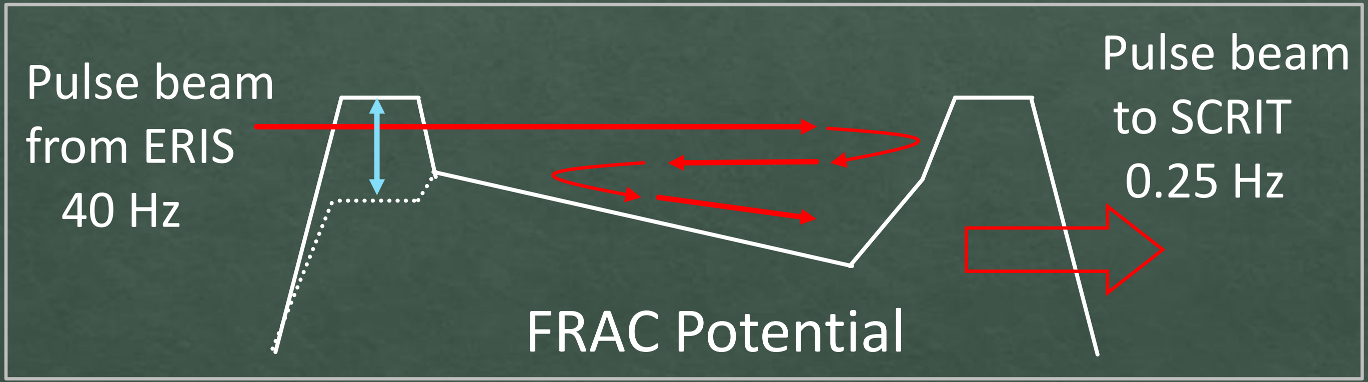


By assuming that isotope dependences are the same, $\left(\frac{^{137}Ba}{^{137}Cs}\right)_{@SCRIT} < 0.5\%$ is obtained.

FRAC (Fringing-RF-field-Activated dc-to-pulse Converter)

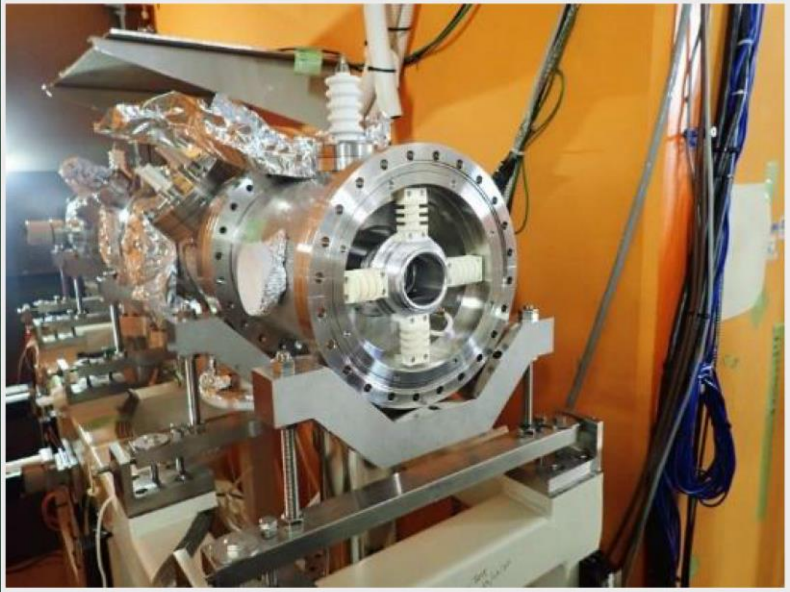
Ion beams were stacked in the FRAC for:

- ✓ Cooling by collision with Ne buffer gas
- ✓ Increasing #RI-ions in a pulse



- ⟐ Vacuum pressure : 10^{-3} Pa
- ⟐ Extracted pulse beam width : 300 us

FRAC : RFQ-based trap



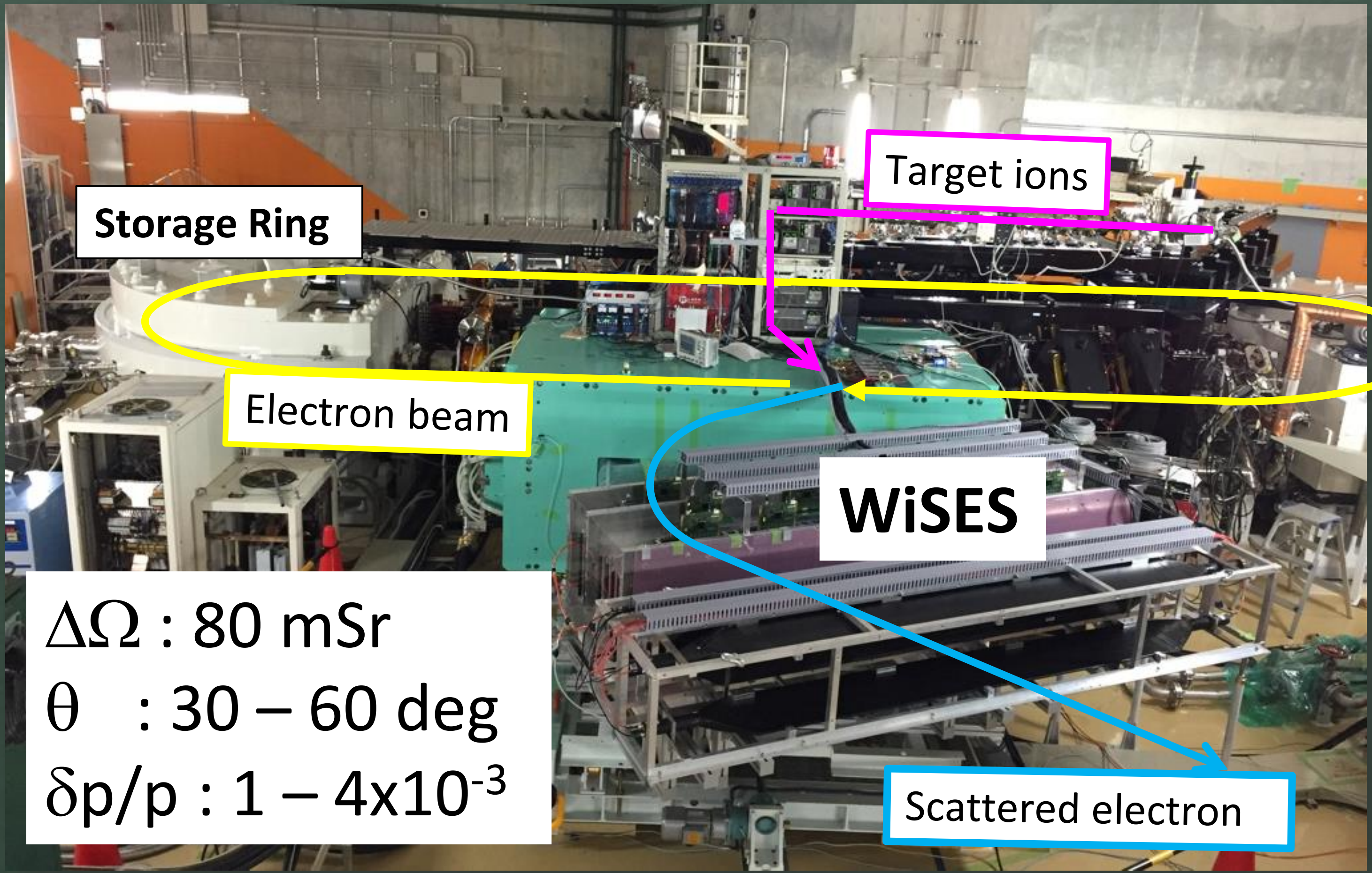
M. Wakasugi, Rev. Sci. Instrum. 89 (2018) 095107

Total dc-to-pulse conversion eff. ~ 80 %

→ #^{137}Cs ions injected into SCRIT reached 2×10^7 ions/pulse

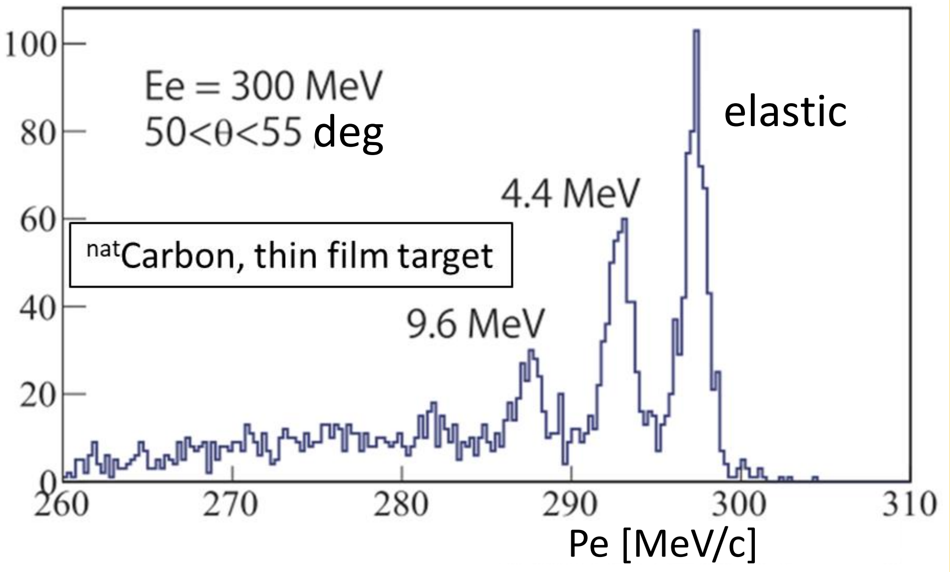
H. Ohnishi, Nucl.Instr.Meth.B541(2023)380-384

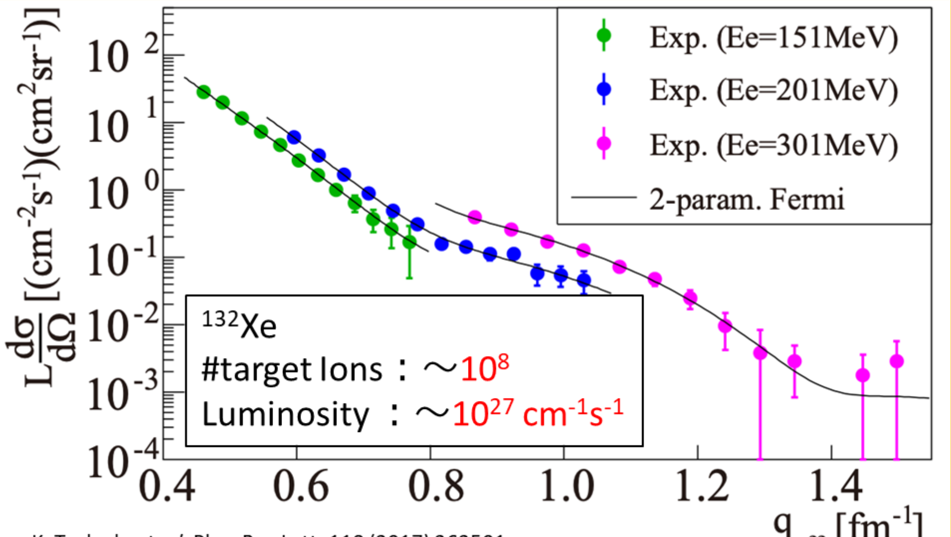
WiSES (Window-frame Spectrometer for Electron Scattering)



$\Delta\Omega$: 80 mSr
θ : 30 – 60 deg
$\delta p/p$: 1 – 4x10^{-3}

Commissioning exp. with stable nuclei

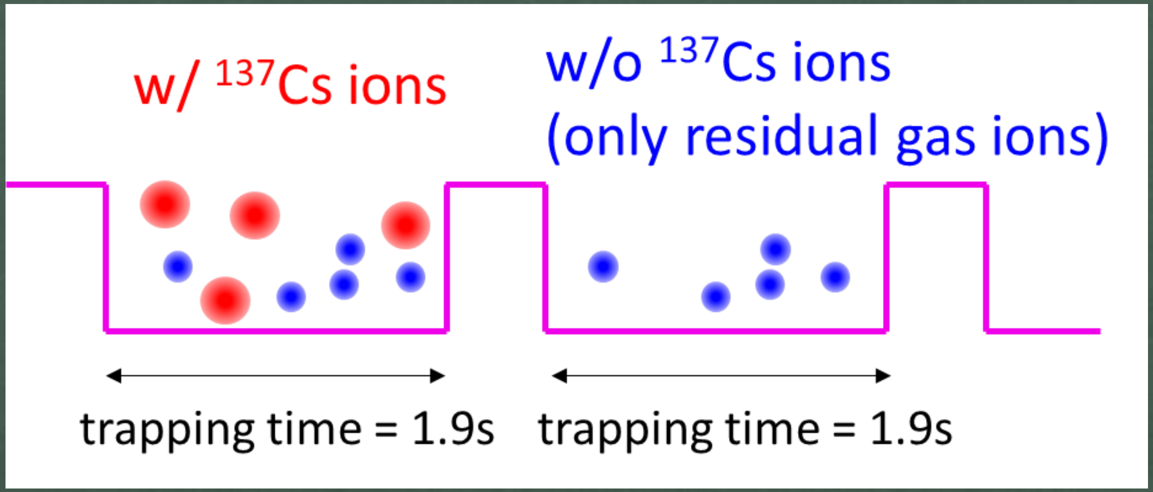


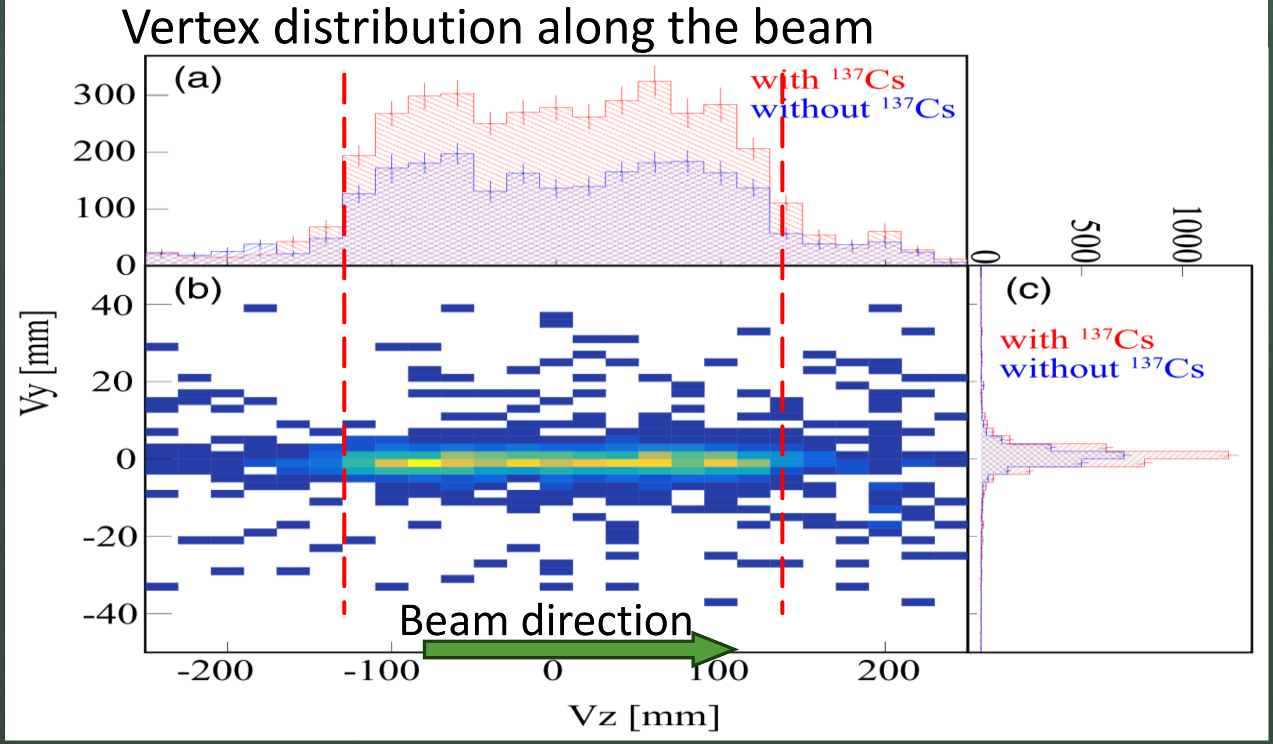


K. Tsukada *et. al*, Phys.Rev.Lett. 118 (2017) 262501

Analysis results for ^{137}Cs exp.

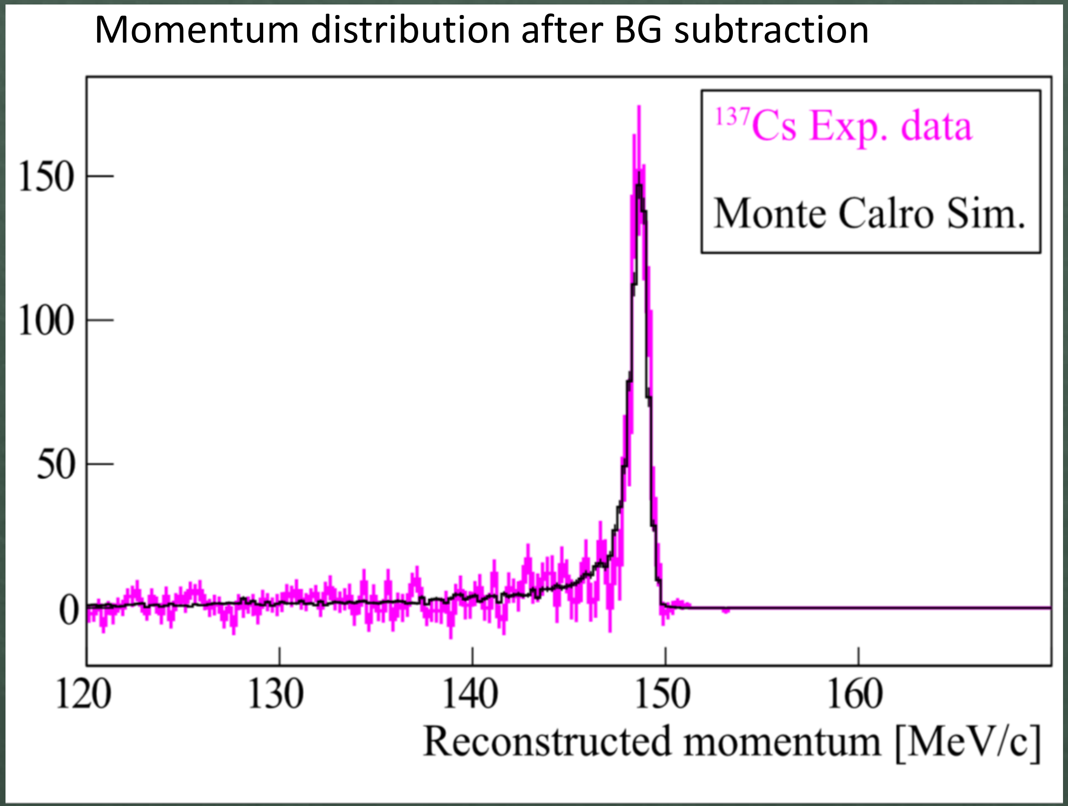
- Ee : 150 MeV
- Ie : 150-250 mA
- Luminosities on average :
  - **0.9 x 10^{26} cm^{-2}s^{-1} for ^{137}Cs**
  - **1.5 x 10^{27} cm^{-2}s^{-1} for BG (^{16}O,^{12}C,…)**

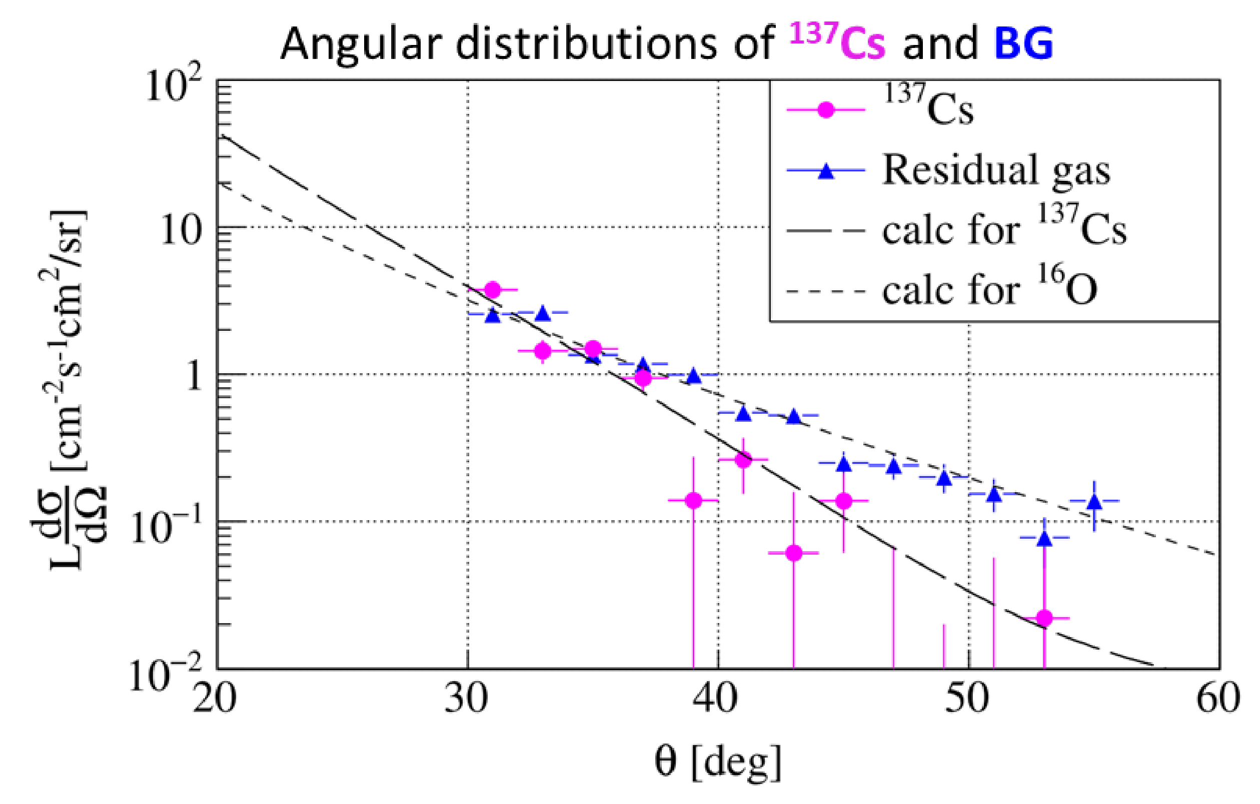




Both ^{137}Cs and BG ions are trapped in +-120mm.
Both yields are comparable.

Momentum and Angular distributions



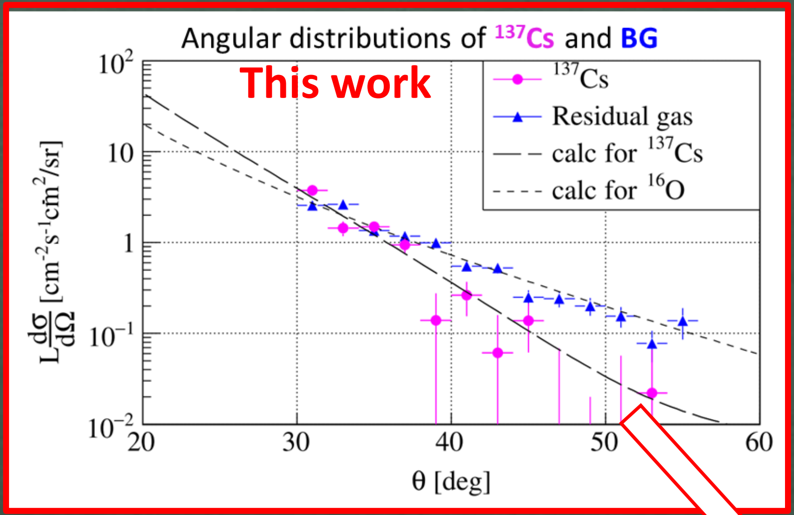


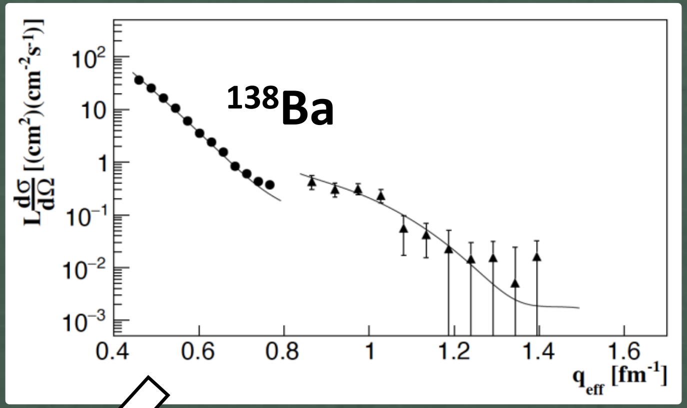
- ✓ Phase shift calculation, DREPHA, with 2-param Fermi dist.
- ✓ Assuming $\langle r^2 \rangle$ of 4.813 fm from isotope shift and t=2.3 fm
- ✓ ^{137}Cs : $I^P=7/2^+$, multipoles contrib. are negligible in this region

We succeeded to demonstrate electron scattering from online-produced RI for the first time!

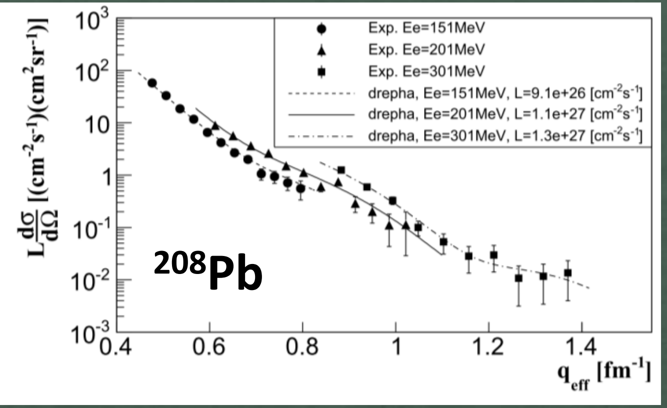
Nuclei examined at SCRIT facility so far

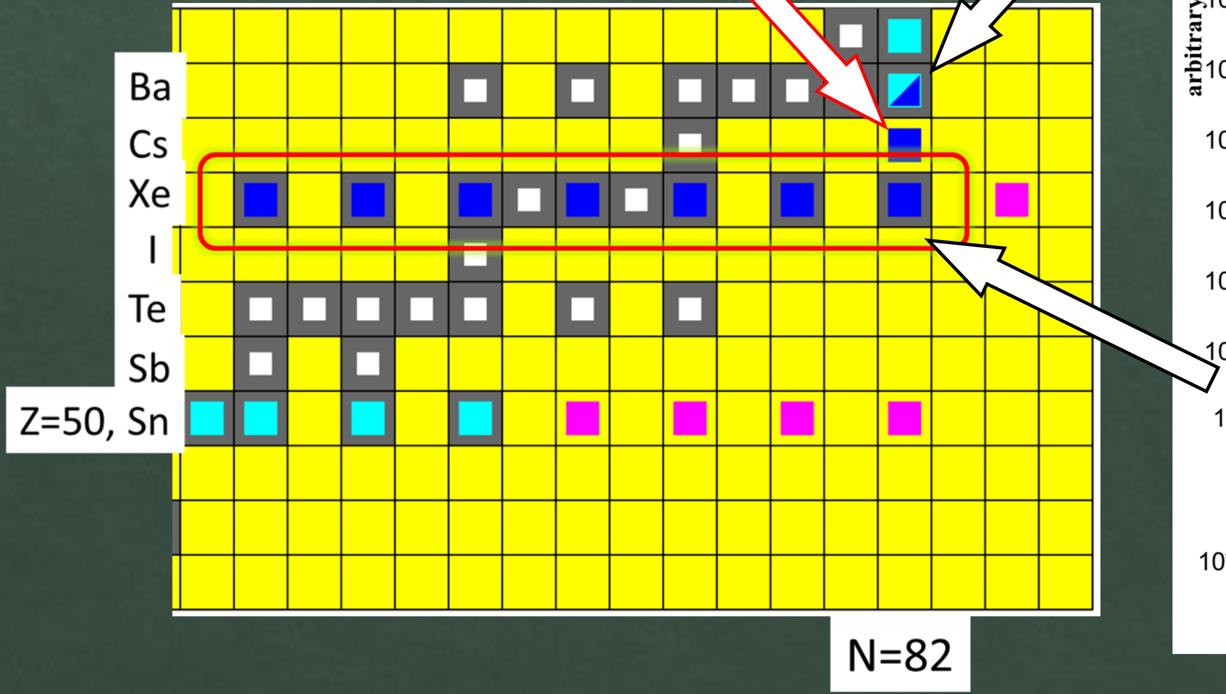
Phys.Rev.Lett. 131 (2023) 092502

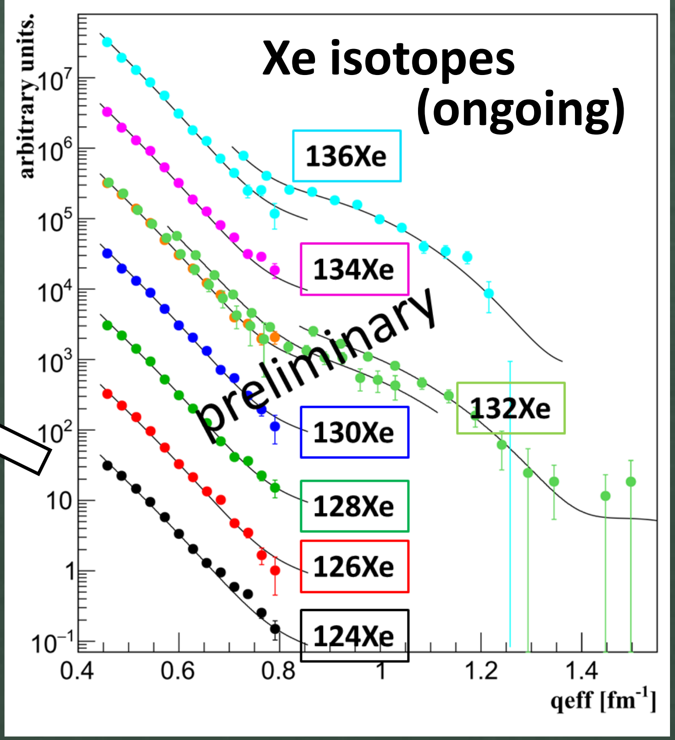


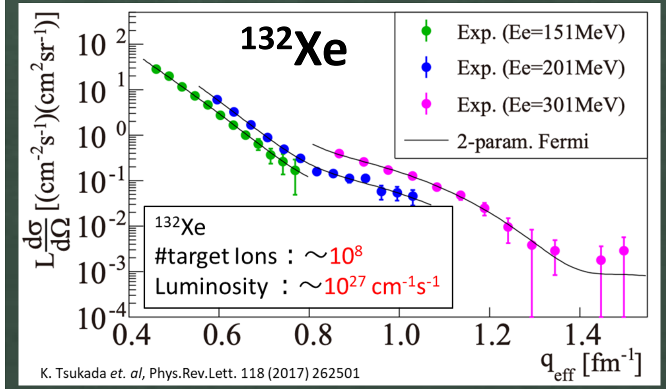


Hyperfine Interact 240, 102 (2019)









Phys.Rev.Lett. 118 (2017) 262502

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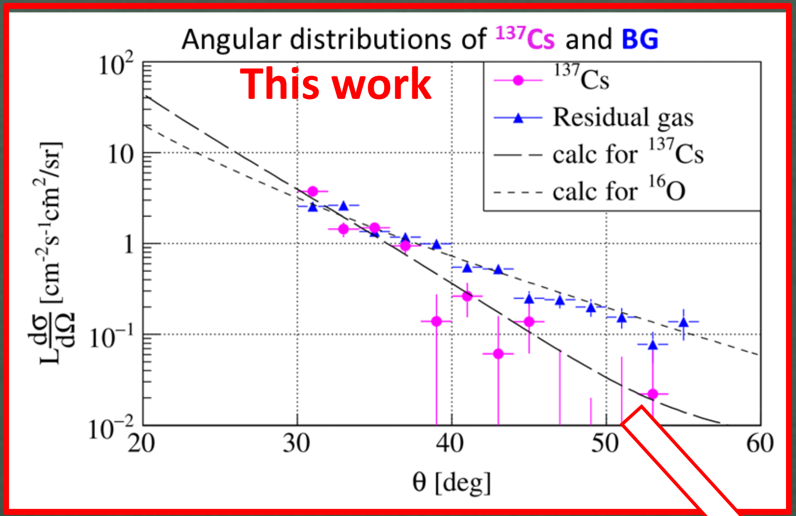

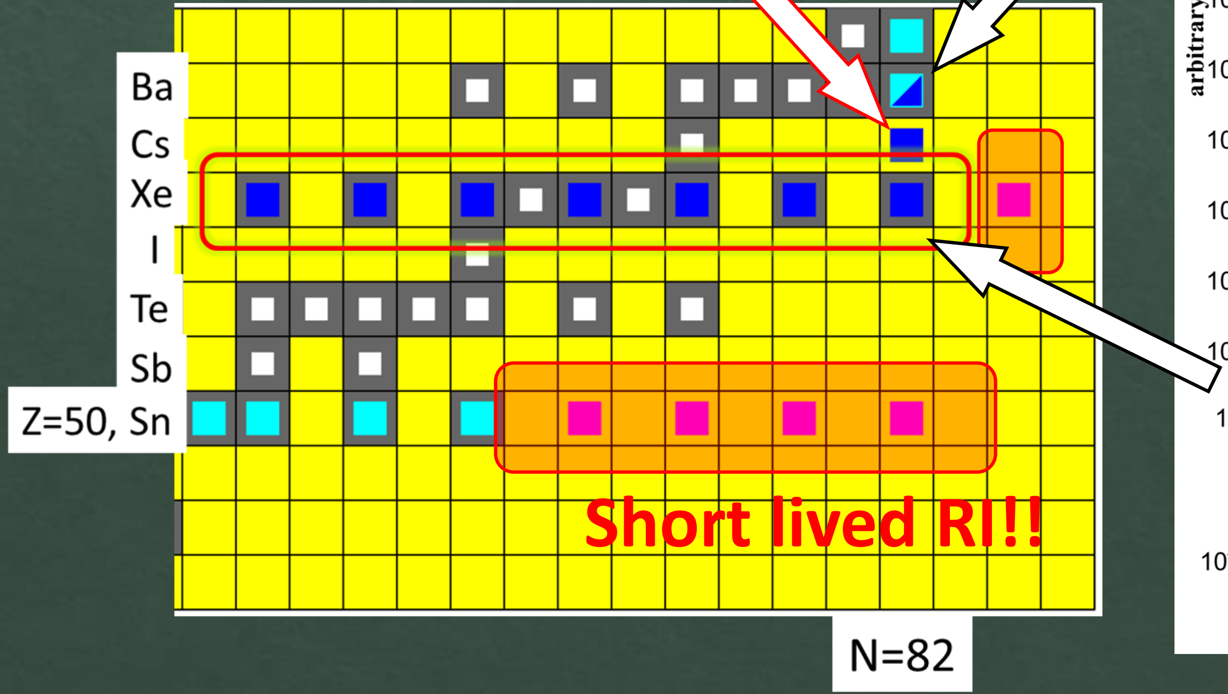

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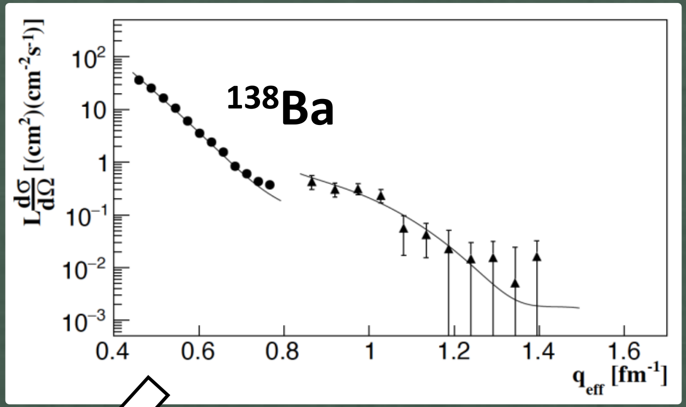
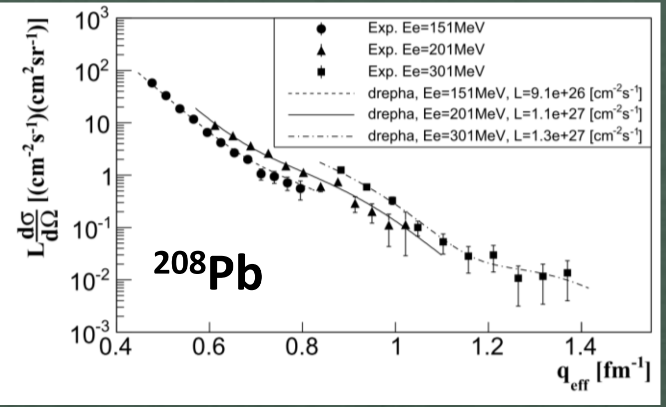
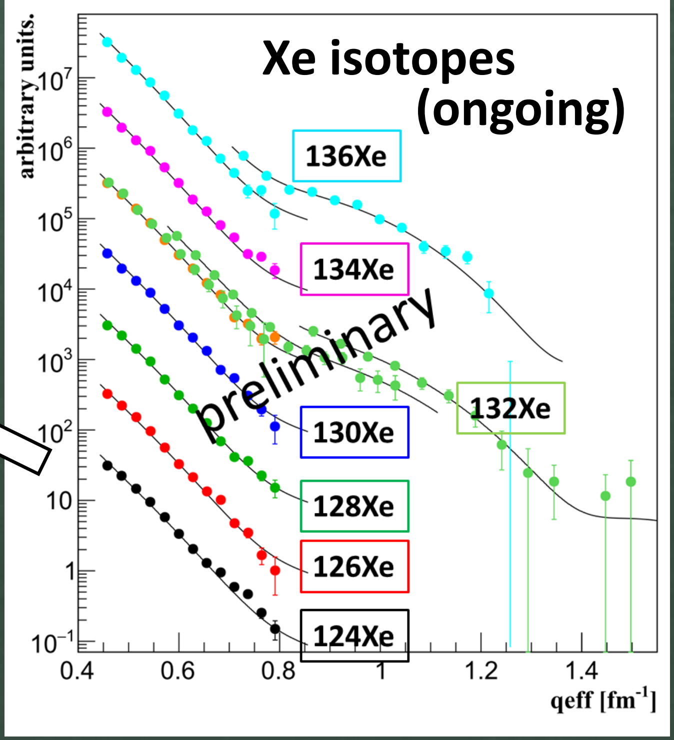
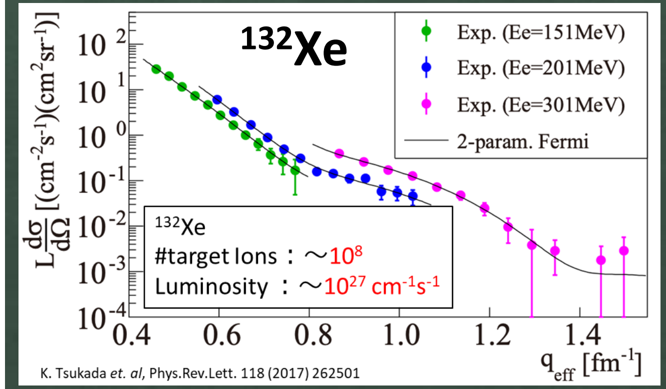




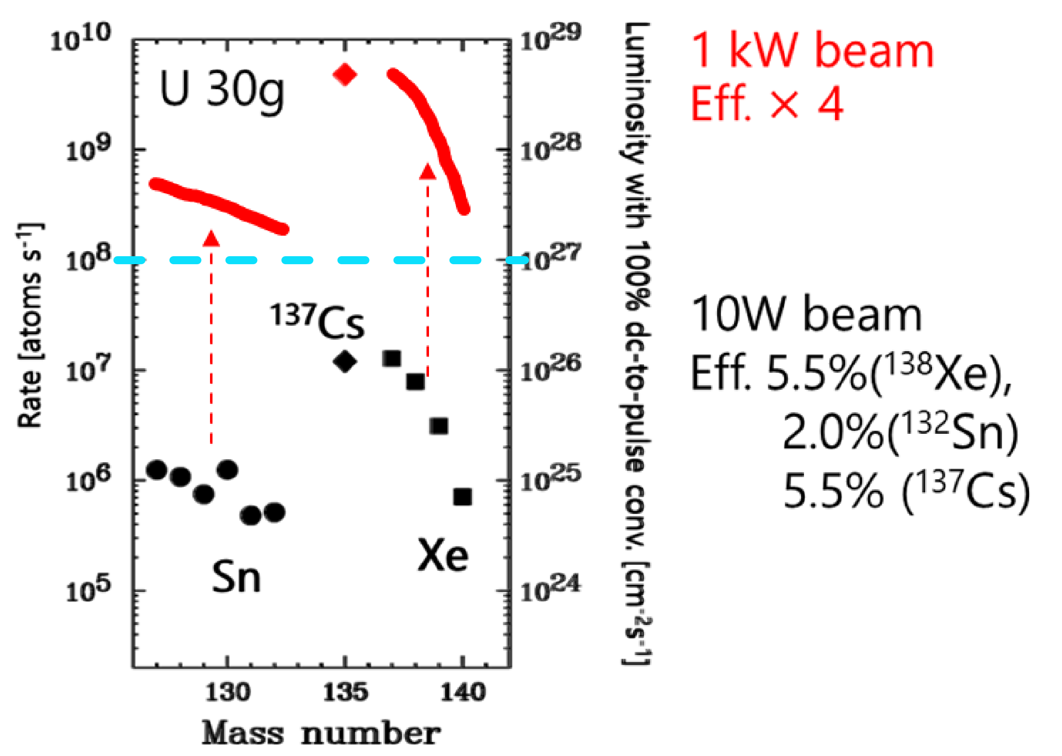




Phys.Rev.Lett. 118 (2017) 262502

Towards short-lived unstable nuclei

- Upgrade of the power of ISOL driver
  - Higher frequency and peak current : 10W → 1kW e-beam
  - Related works are ongoing
    - Radiation control
    - Remote handling systems
    - BG suppression for spectrometers
- Isobar separation system
  - R&D of new devices are ongoing.

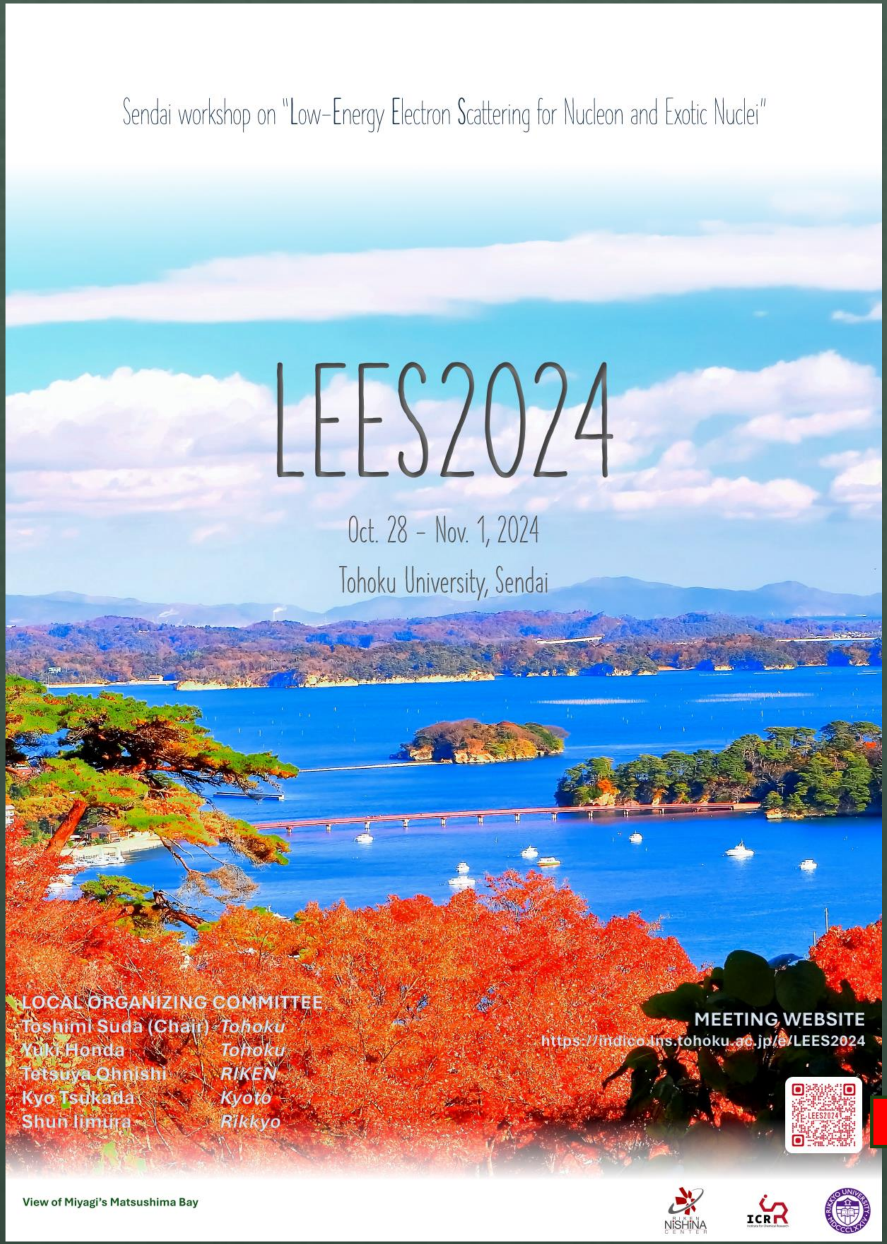


We will conduct e-RI experiment for various RI, such as Sn isotopes, in a few years.

Summary

- We are aiming to perform electron scattering off short-lived unstable nuclei.
- SCRIT electron scattering facility is the world's first facility dedicated for exotic nuclear target.
- The first experiment with unstable nucleus, ^{137}Cs, was successfully carried out after years of developments.
- The luminosity for ^{132}Sn will reach 10^{27} $cm^{-2}s^{-1}$ to investigate $\rho(r)$ in a few years.
  - The upgrade of the power of ISOL driver and related work are ongoing.
  - R&D of new technique for isobar separation are also ongoing.

Advertisement for Workshop : LEES2024



LEES2024 : Low-Energy Electron Scattering for Nucleon and Exotic Nuclei

Place : Tohoku Univ. in Japan

Date : Oct.28 – Nov.1

Key topics:

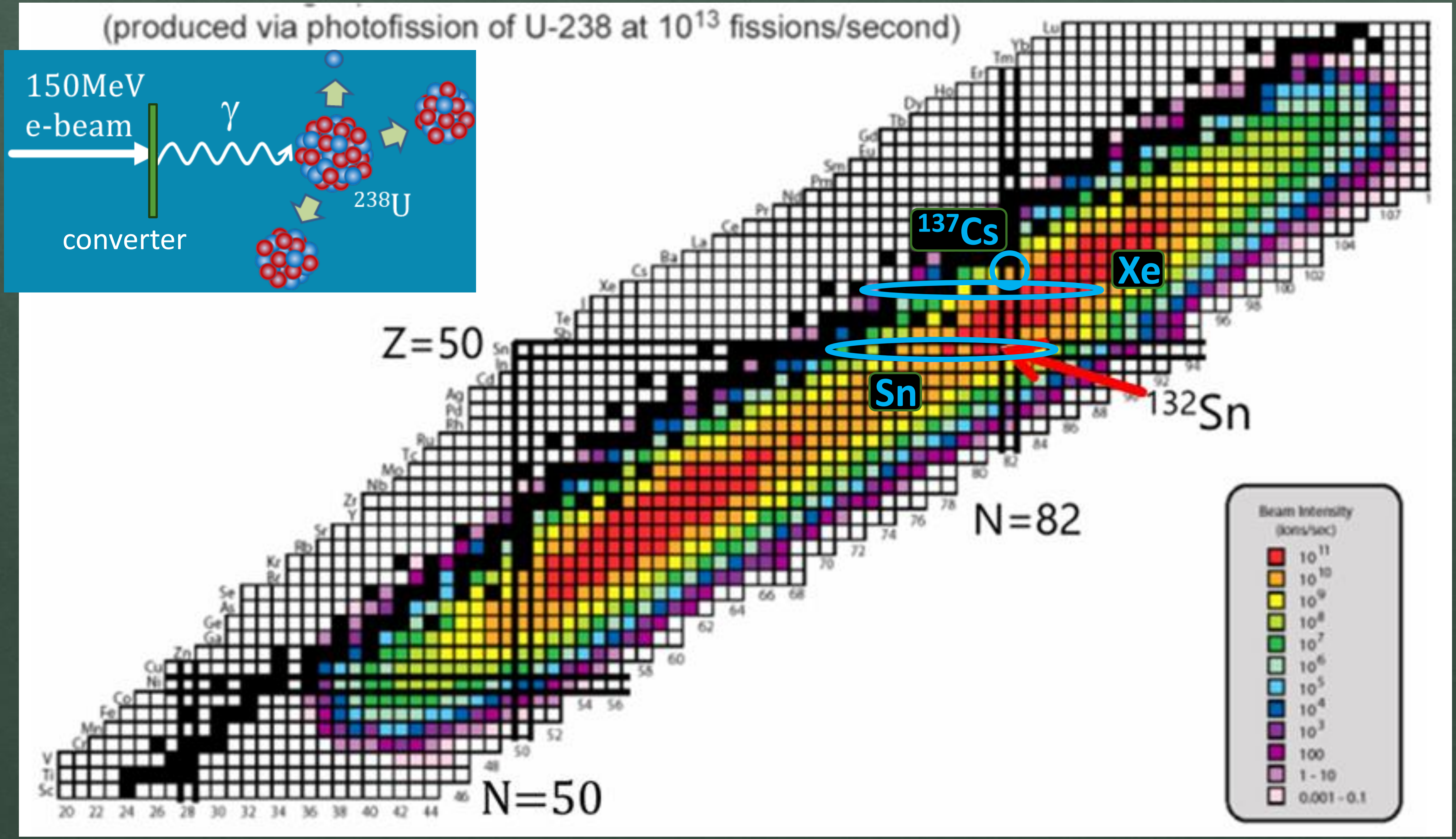
- Experimental and theoretical studies on
  - e-scat. for nucleons and nuclei including exotic ones
  - Size and structure of nucleons and nuclei including exotic ones
  - Photo-nuclear reaction
- New physics with high-intensity low-energy electron beams

Registration is now open.

LEES2024

https://indico.lns.tohoku.ac.jp/e/LEES2024 backup

Unstable nuclei produced via photo-fission of ^{238}U



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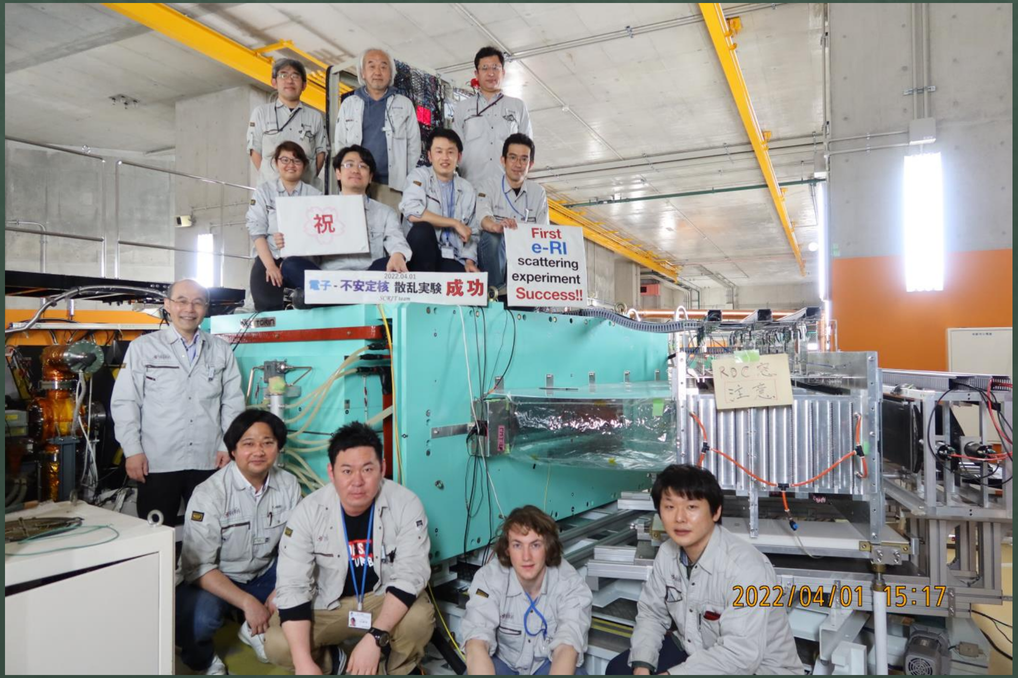

Thank you for your attention!