

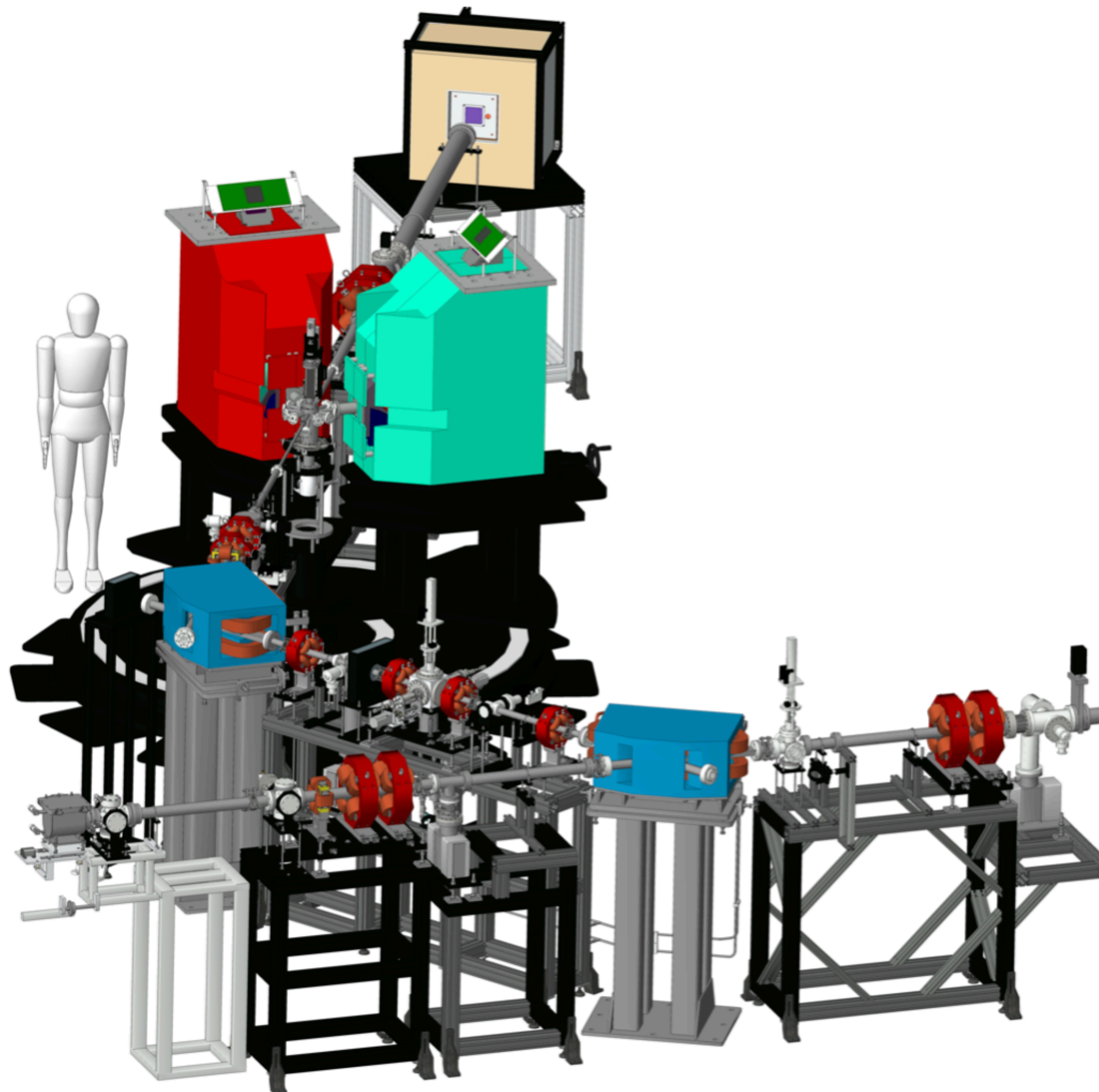
Low-Energy Electron scattering for Exotic Nuclei and Nucleons

Toshimi SUDA

**Research Center for Electron-Photon Science,
Tohoku University
Sendai**

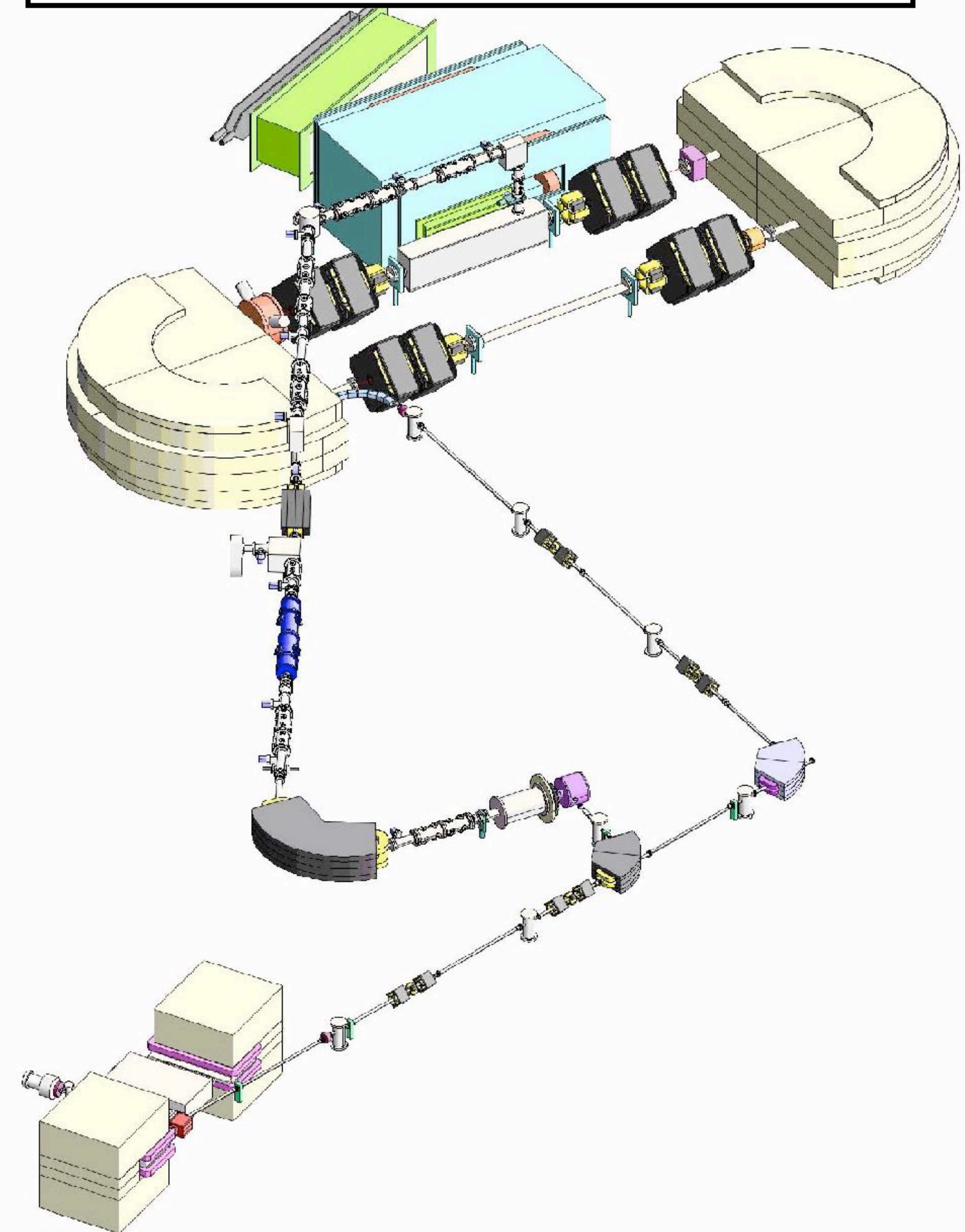
Tohoku ULQ2

$E_e = 10 - 60 \text{ MeV}$



RIKEN SCRIT

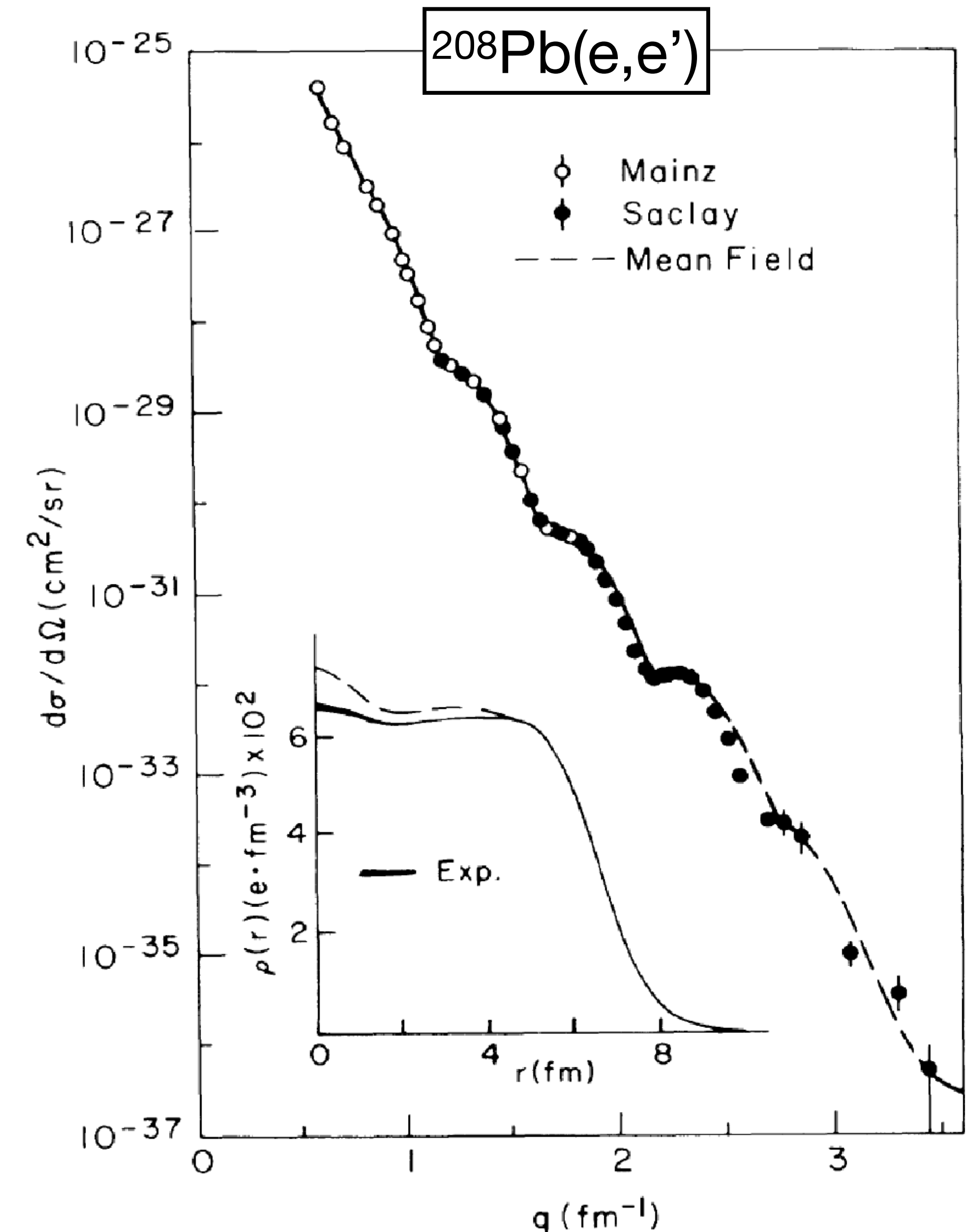
$E_e = 150 - 300 \text{ MeV}$



Low-energy (elastic) electron scattering

NuSRAP2026
2026.07.13-07.15

$$\frac{dN}{dt} = L \times \left(\frac{d\sigma_{\text{Mott}}}{d\Omega} |F_c(q)|^2 \right)$$
$$\frac{d\sigma_{\text{Mott}}}{d\Omega} \propto \frac{e^2}{q^4} \quad q = 2E \sin(\theta/2)$$

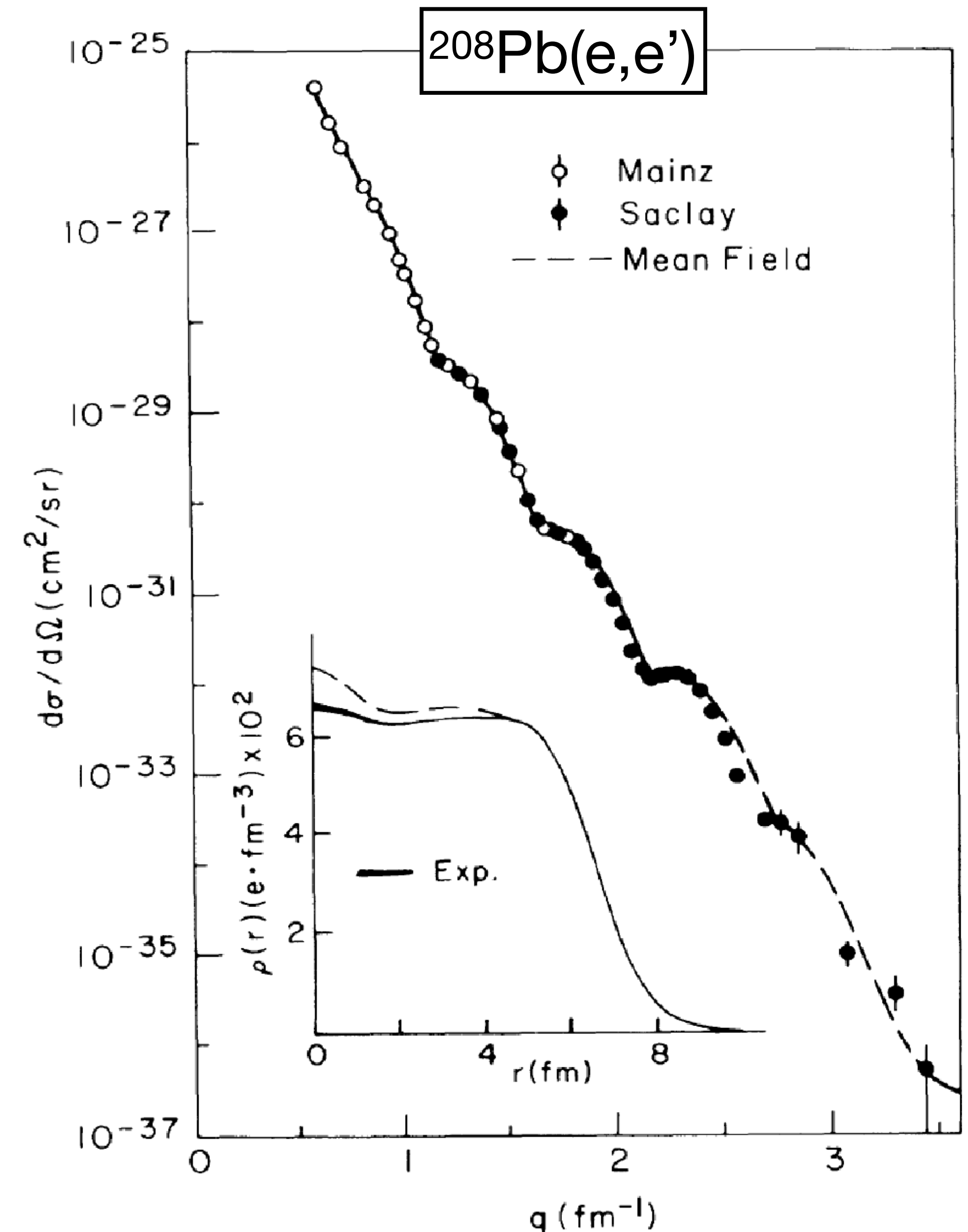


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electron scattering covering **low-q region**



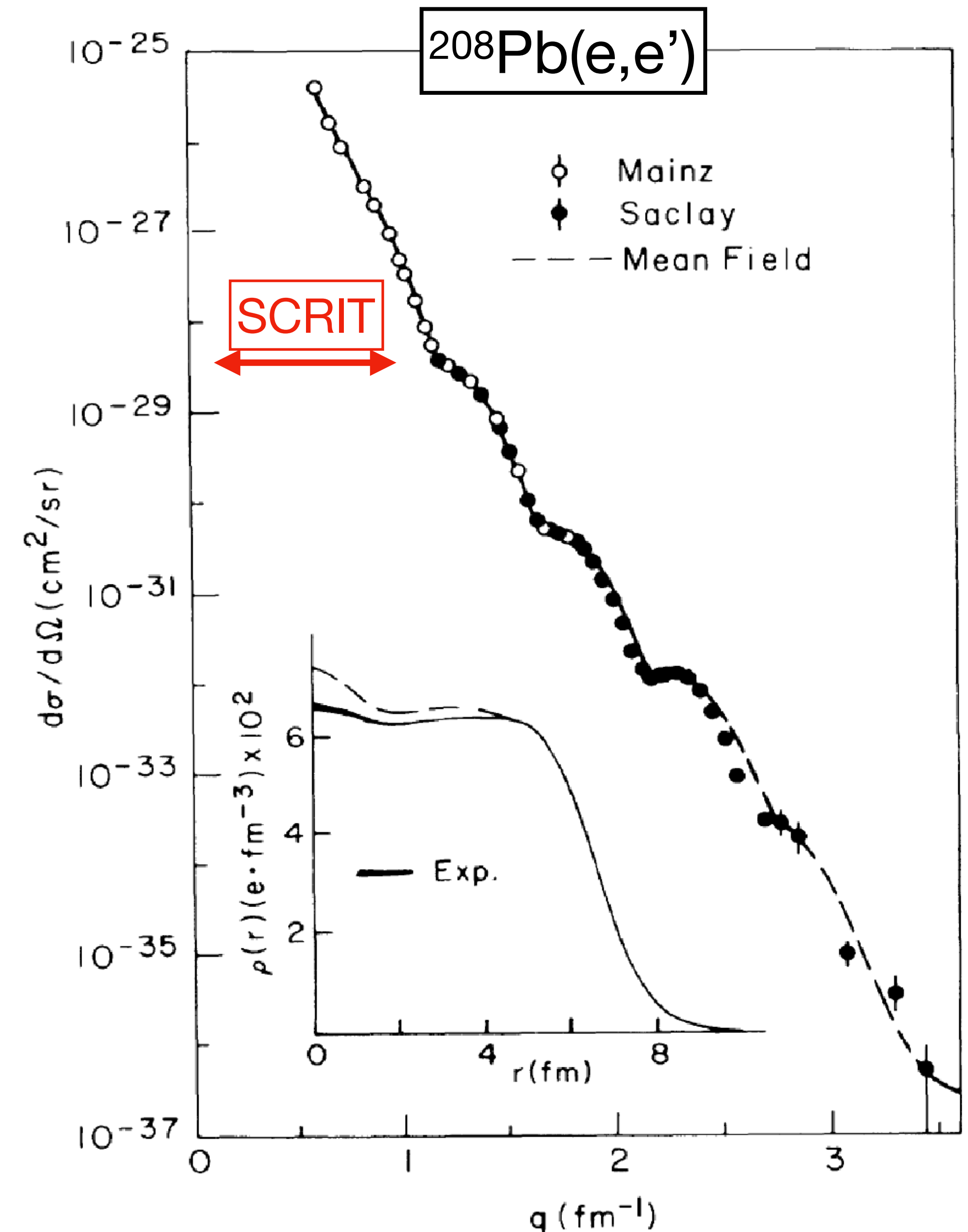
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➔ e-RI scattering at the RIKEN SCRIT facility
($E_e = 150 - 300 \text{ MeV}$)
beyond $\langle r_c^2 \rangle \Rightarrow \rho(r)$



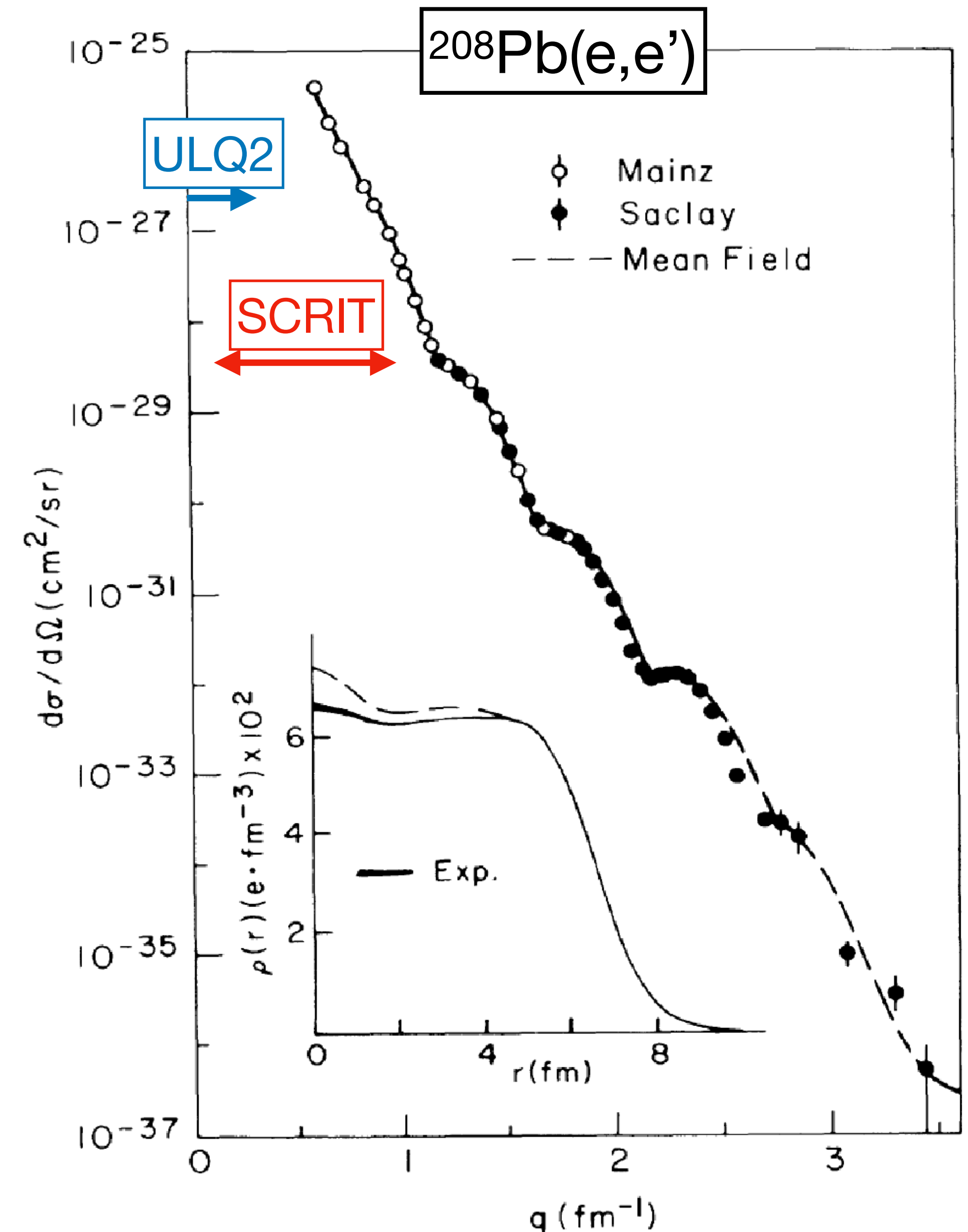
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- ➔ new opportunities at Tohoku ULQ2 facility
($E_e = 10 - 60 \text{ MeV}$)
*higher moments $\Leftrightarrow$ neutron distribution
proton (and neutron) charge radius*



Low-energy (elastic) electron scattering

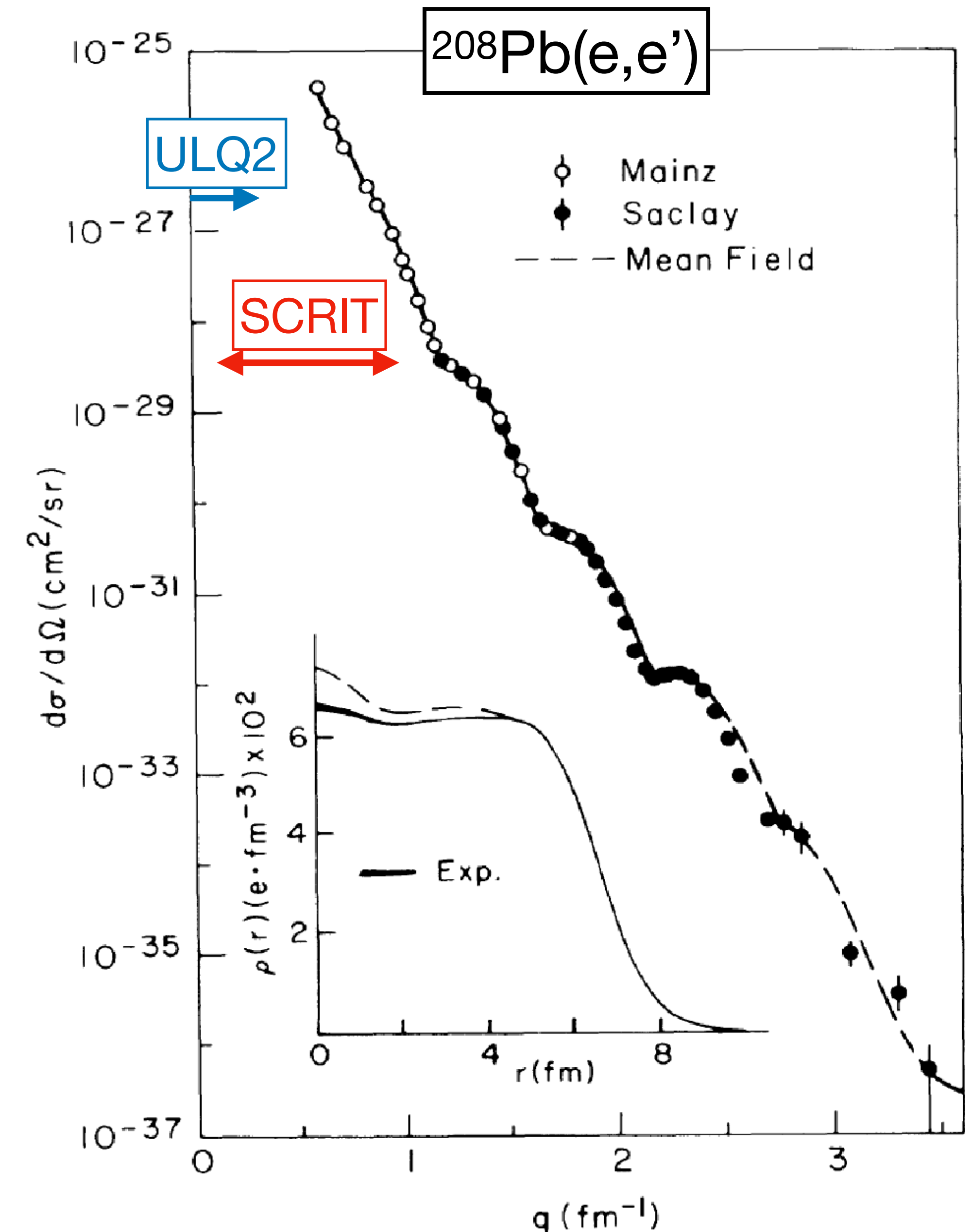
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RIKEN SCRIT facility

*dedicated for never-yet-performed
electron scattering for short-lived nuclei*

Electron Ring
(SCRIT equipped)

WiSES
(Window-frame Spectrometer
for Electron Scattering)

PHYSICAL REVIEW LETTERS 131, 092502 (2023)

Editors' Suggestion

Featured in Physics

First Observation of Electron Scattering from Online-Produced Radioactive Target

K. Tsukada^{1,2}, Y. Abe², A. Enokizono^{2,3}, T. Goke⁴, M. Hara², Y. Honda^{2,4}, T. Hori², S. Ichikawa^{2,*},
Y. Ito¹, K. Kurita³, C. Legris⁴, Y. Maehara¹, T. Ohnishi², R. Ogawara^{1,2}, T. Suda^{2,4},
T. Tamae⁴, M. Wakasugi^{1,2}, M. Watanabe², and H. Wauke^{2,4}

¹Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan

²Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan

³Department of Physics, Rikkyo University, Toshima, Tokyo 171-8501, Japan

⁴Research Center for Electron Photon Science, Tohoku University, Sendai, Miyagi 982-0826, Japan

 (Received 7 March 2023; accepted 21 June 2023; published 30 August 2023)

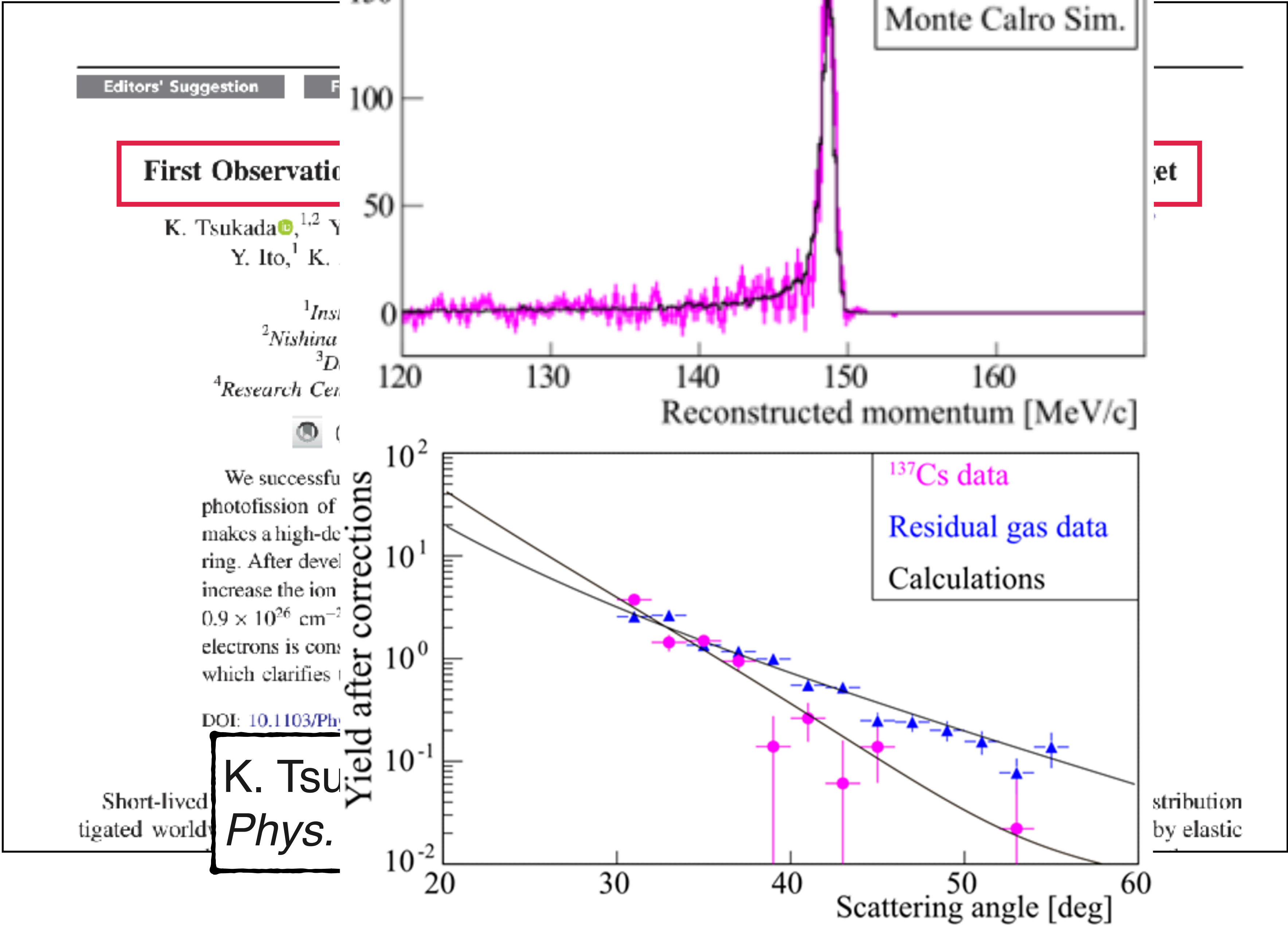
We successfully performed electron scattering off unstable nuclei which were produced online from the photofission of uranium. The target ¹³⁷Cs ions were trapped with a new target-forming technique that makes a high-density stationary target from a small number of ions by confining them in an electron storage ring. After developments of target generation and transportation systems and the beam stacking method to increase the ion beam intensity up to approximately 2×10^7 ions per pulse beam, an average luminosity of $0.9 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$ was achieved for ¹³⁷Cs. The obtained angular distribution of elastically scattered electrons is consistent with a calculation. This success marks the realization of the anticipated femtoscope which clarifies the structures of exotic and short-lived unstable nuclei.

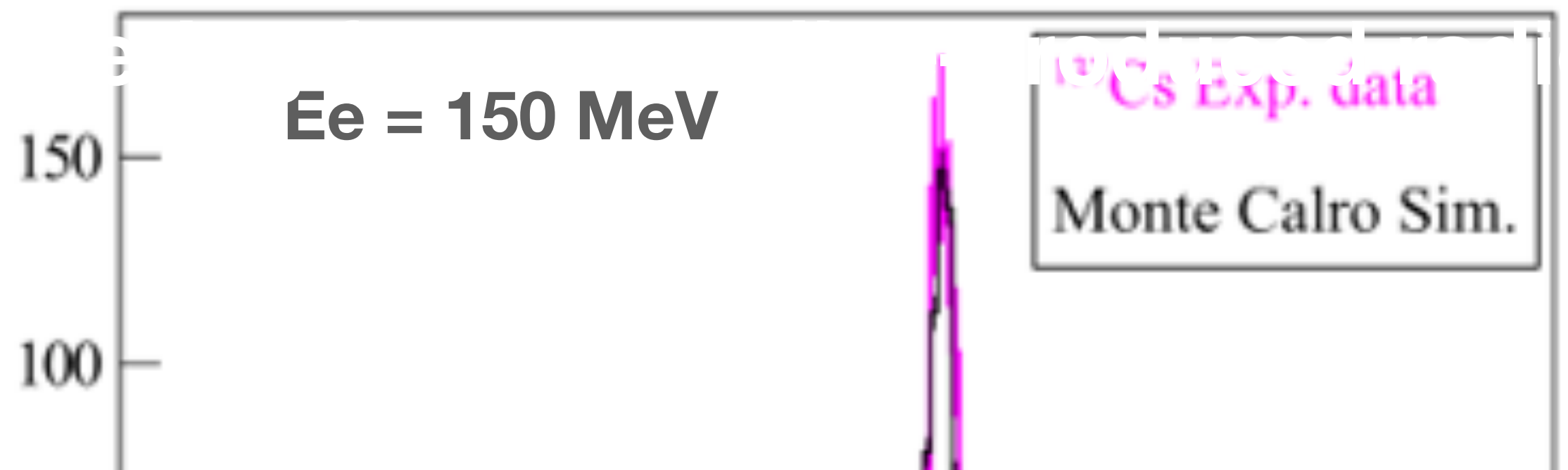
DOI: [10.1103/PhysRevLett.131.092502](https://doi.org/10.1103/PhysRevLett.131.092502)

Short-lived
tigated world

K. Tsukada et al.,
Phys. Rev. Lett. 131 (2023) 092502.

charge density distribution
ture determined by elastic





Viewpoint in Physics Magazine

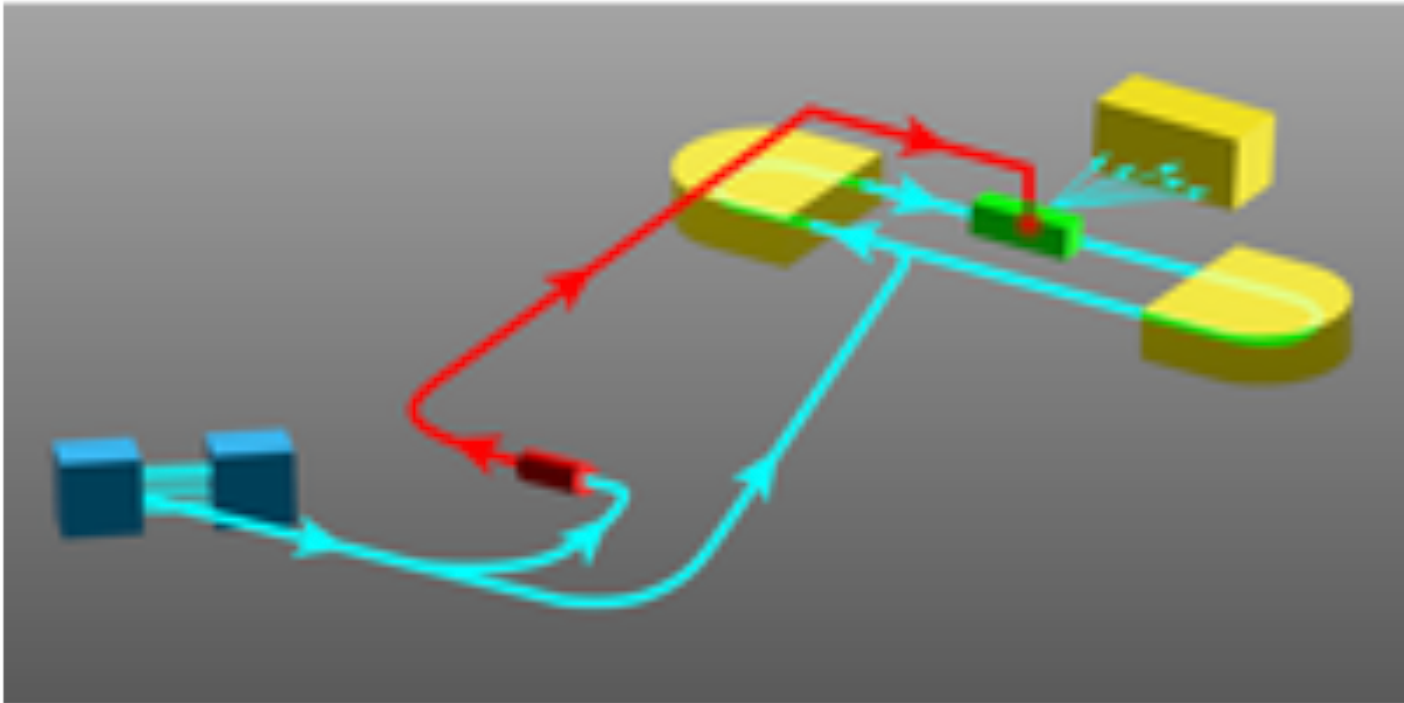
“What Do Unstable Atomic Nuclei Look Like?”
by Patrick Achenbach

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Phys. Rev. Lett. **131**, 092502 (2023) – Published 30 August 2023

Physics Viewpoint: [What Do Unstable Atomic Nuclei Look Like?](#)



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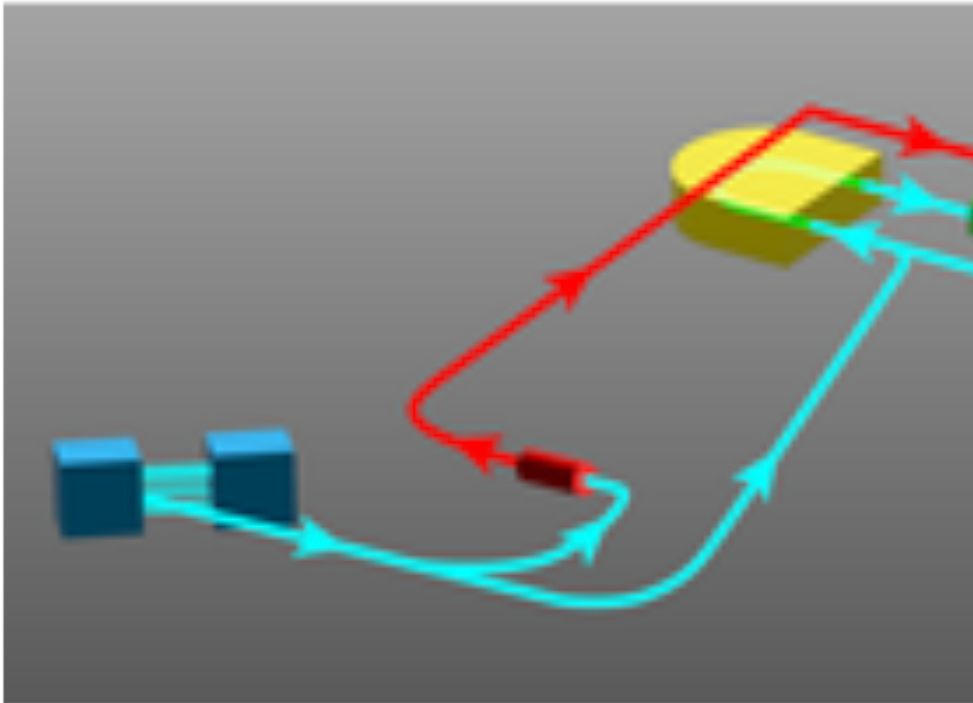
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Physics Viewpoint: What Do Unstable Atomic Nuclei Look Like?



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 look like. Neutron-rich lead-208, for example, has a thick skin of neutrons encasing its proton-endowed core (see *Physics Today*, July 2021, page 12). Some nuclei are flattened, and some are elongated. Some are even pear shaped.

The more unstable a nucleus, the

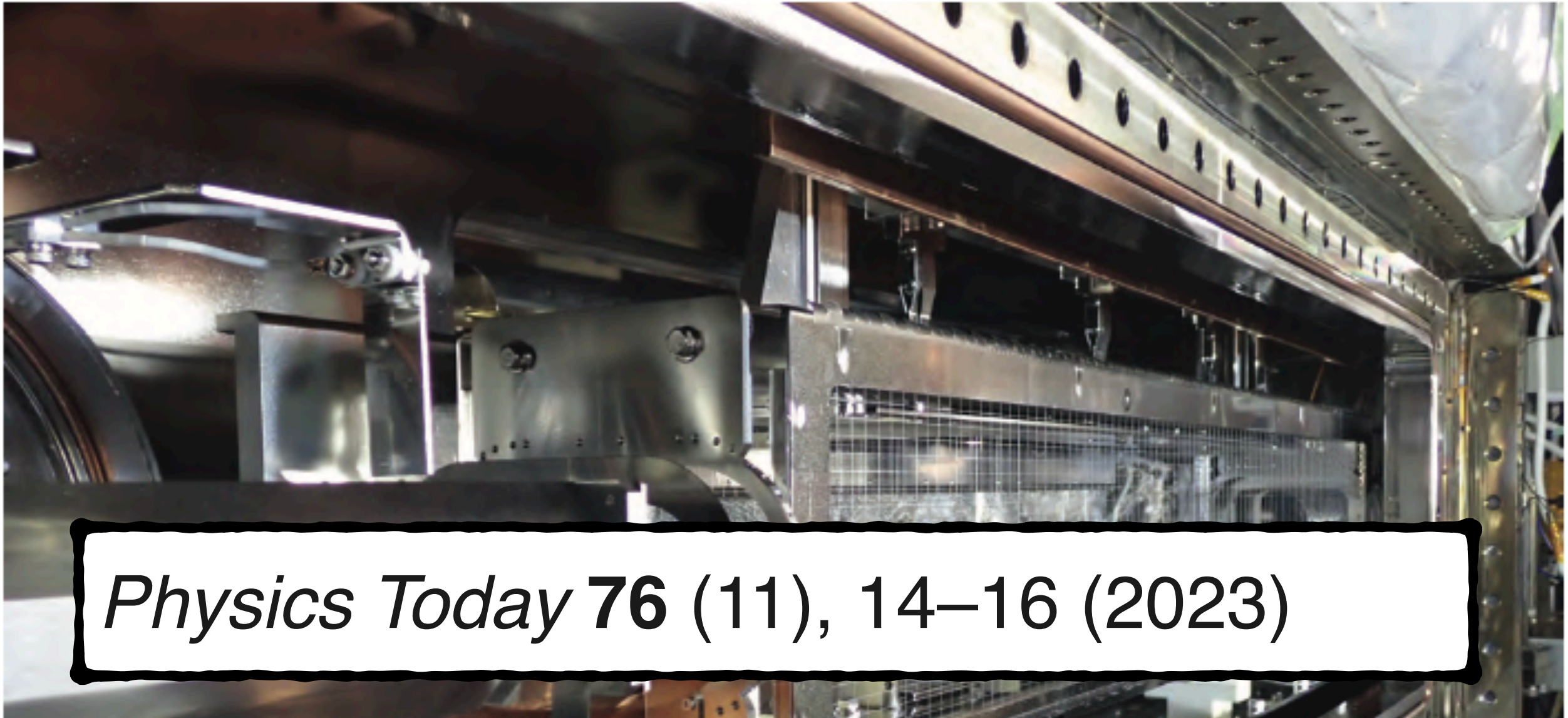
stranger the structures it can adopt. Short-lived nuclei might form bubble structures with depleted central density, or they might have a valence nucleon or two that form a halo around a compact central core. (See the article by Filomena Nunes, *Physics Today*, May 2021, page 34.) Frustratingly, though, these exotic structures are hard to experimentally confirm, because the gold standard for probing nuclear structure—electron scattering—has been off limits to short-lived nuclei.

That could change soon. Kyo Tsukada

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-lived nuclei, so more experiments are on the way.

Backscatter

Probing nuclei through particle scattering dates back to the discovery of the nucleus itself, in 1911, when Ernest



Physics Today 76 (11), 14–16 (2023)

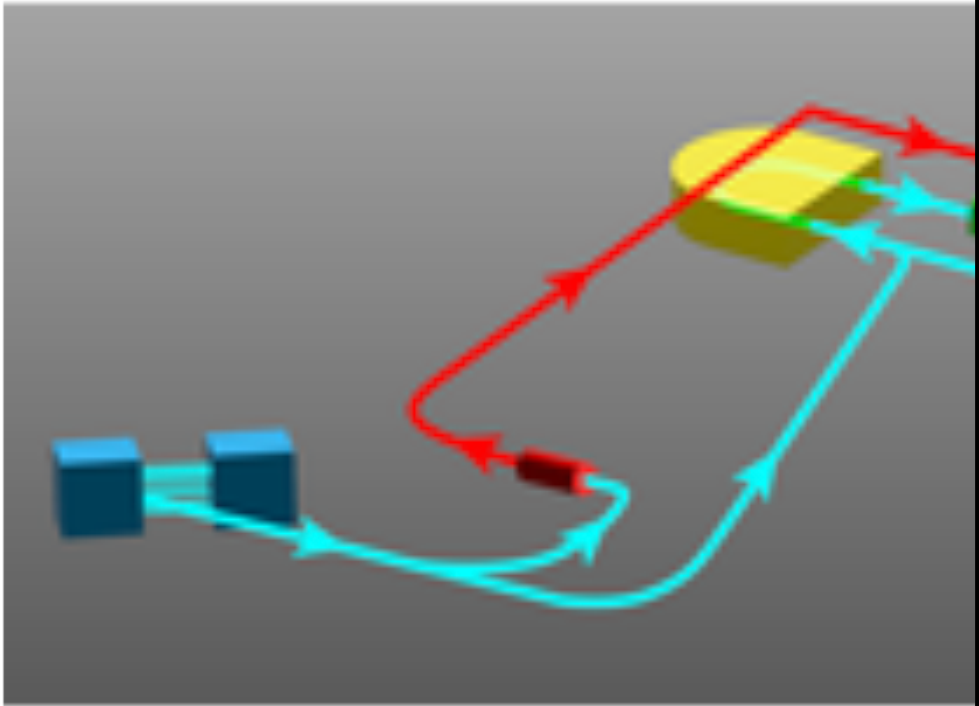
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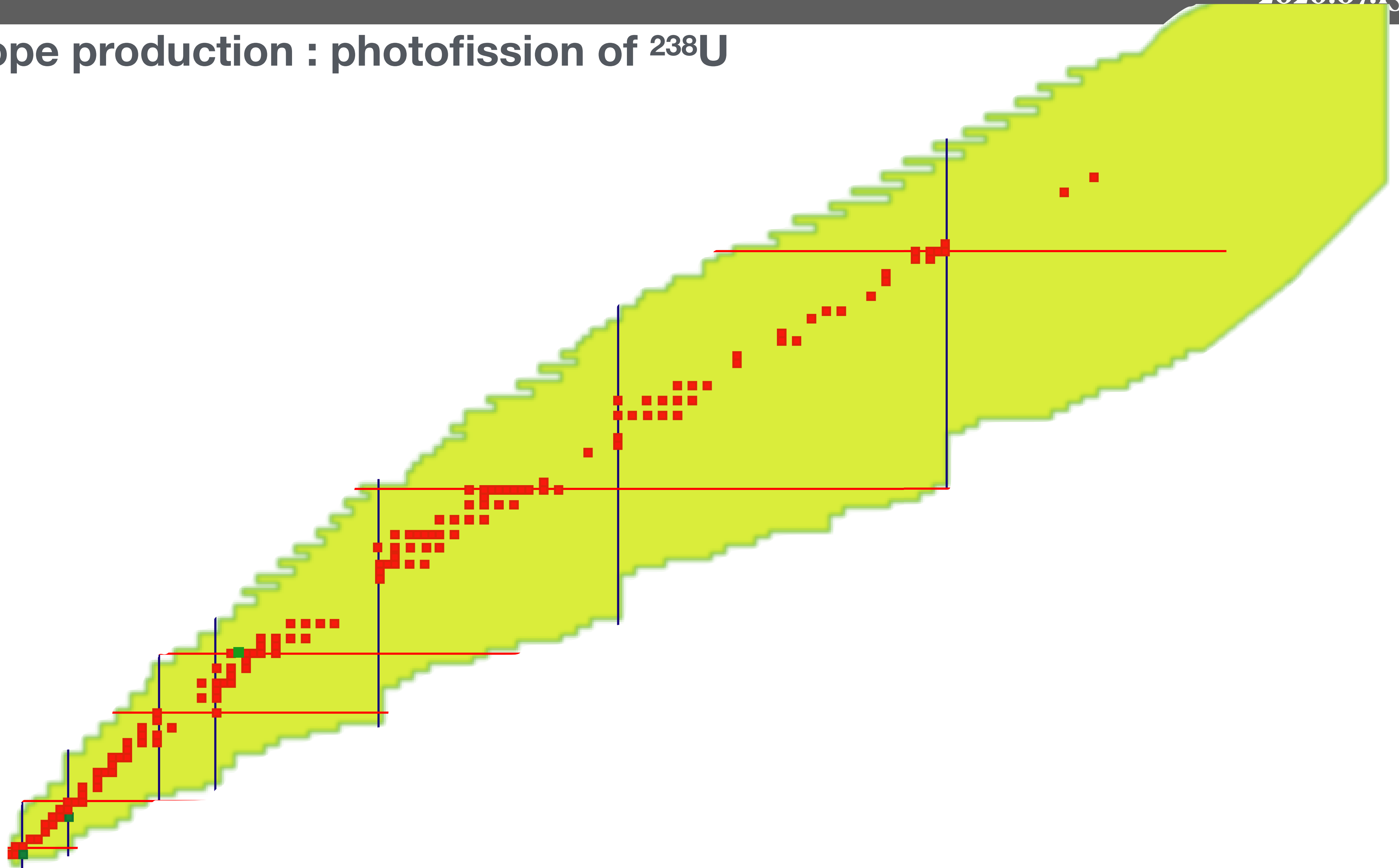
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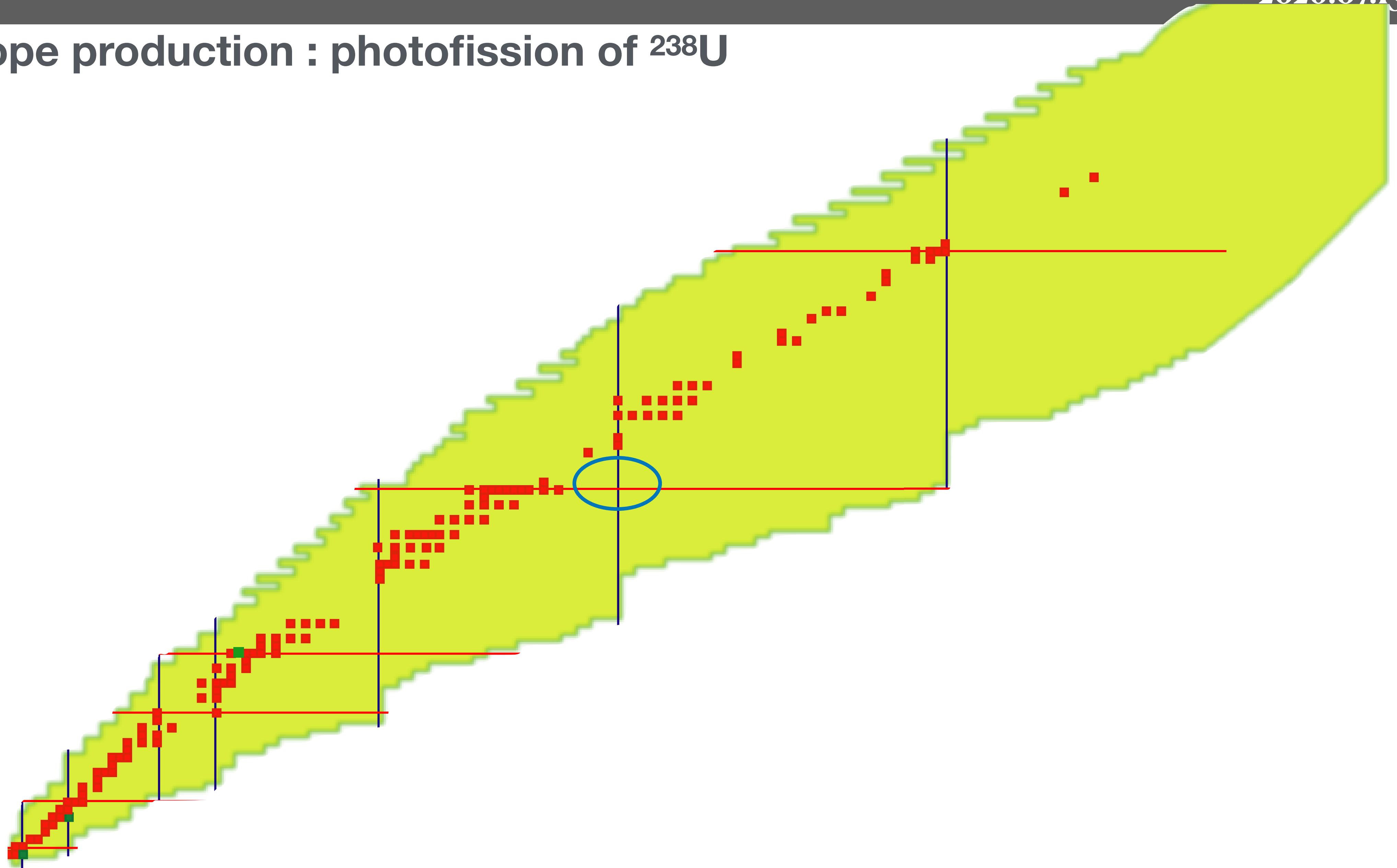
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Physics Today 76 (11), 14–16 (2023)

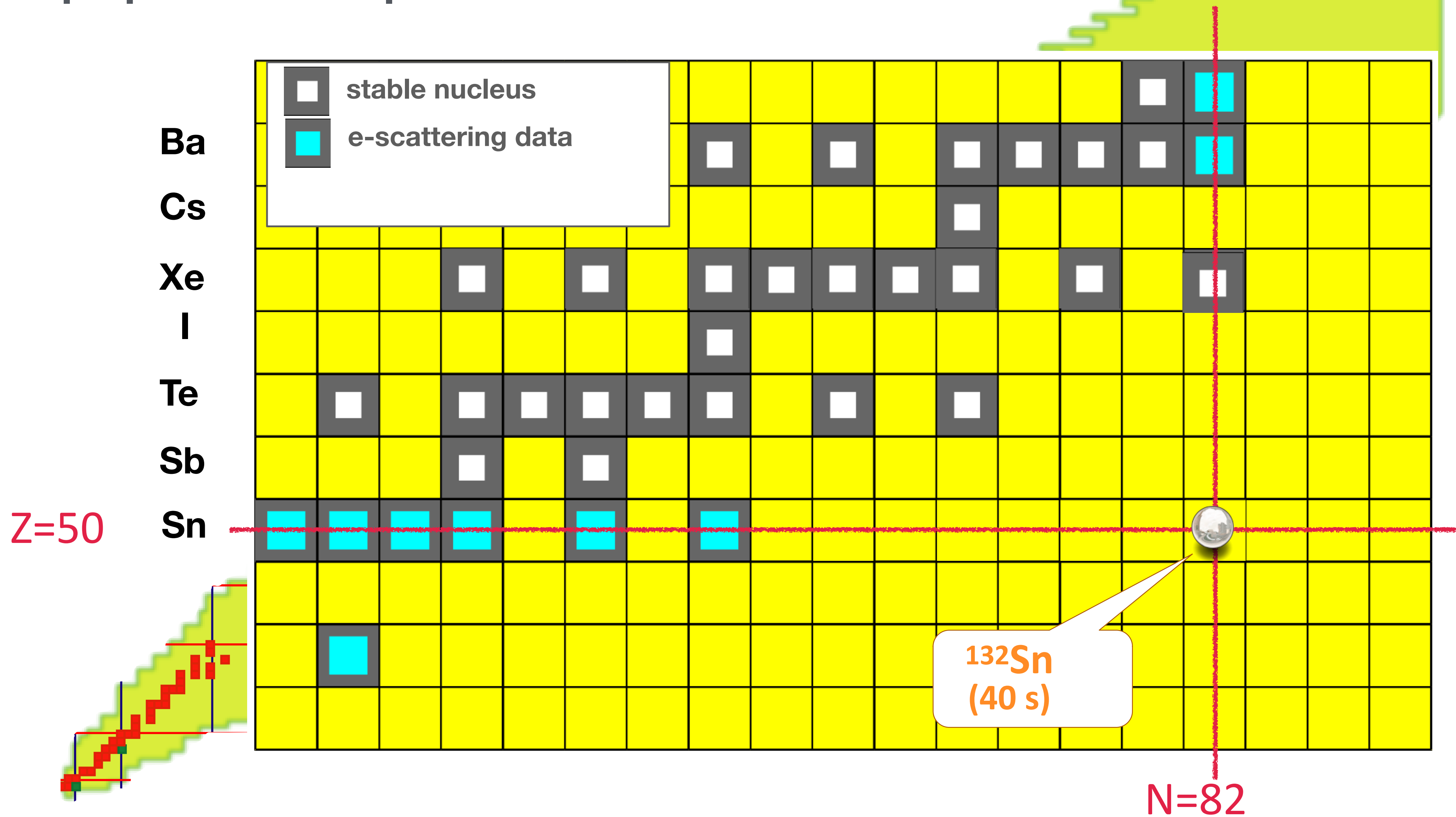
Isotope production : photofission of ^{238}U



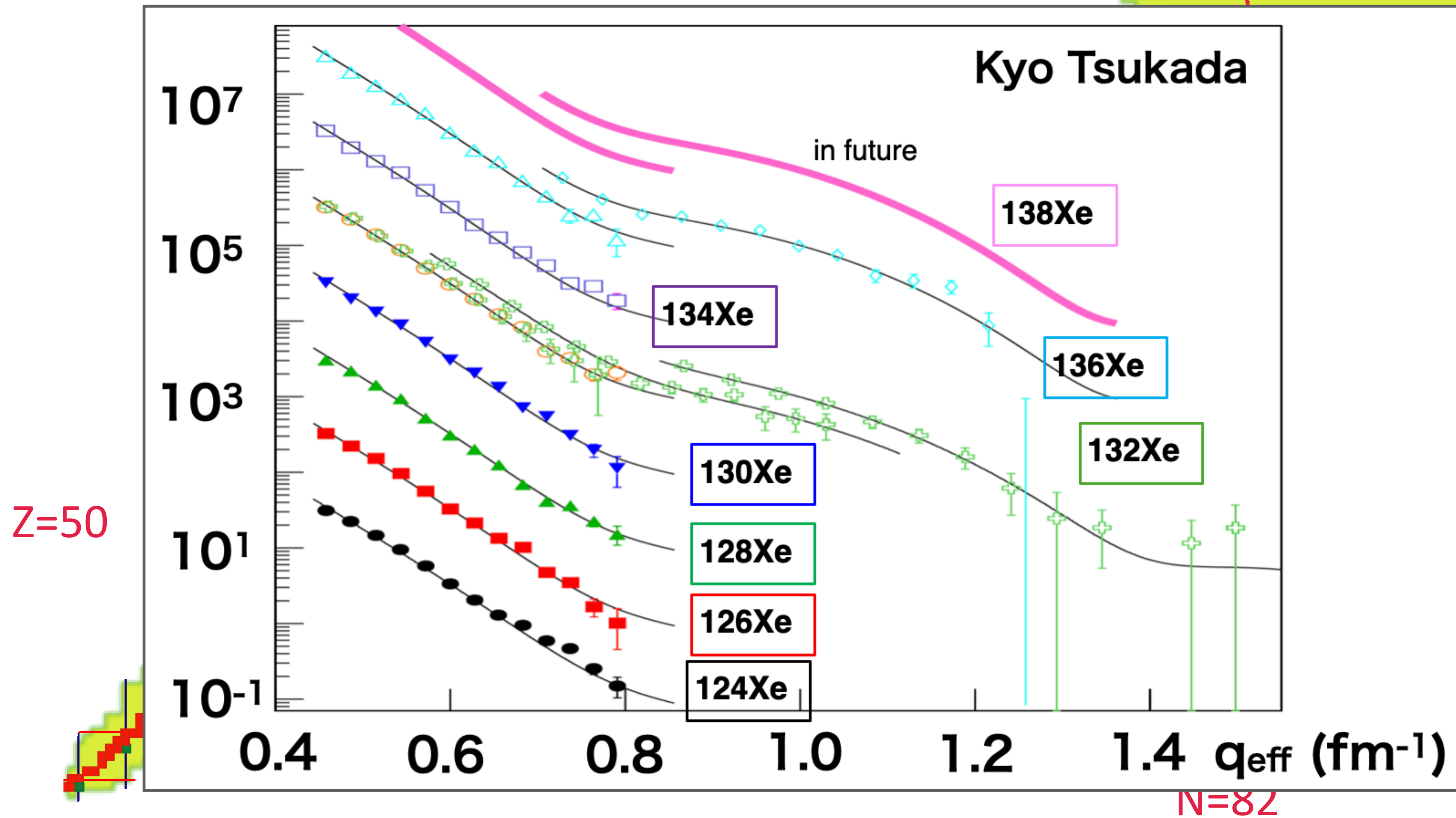
Isotope production : photofission of ^{238}U



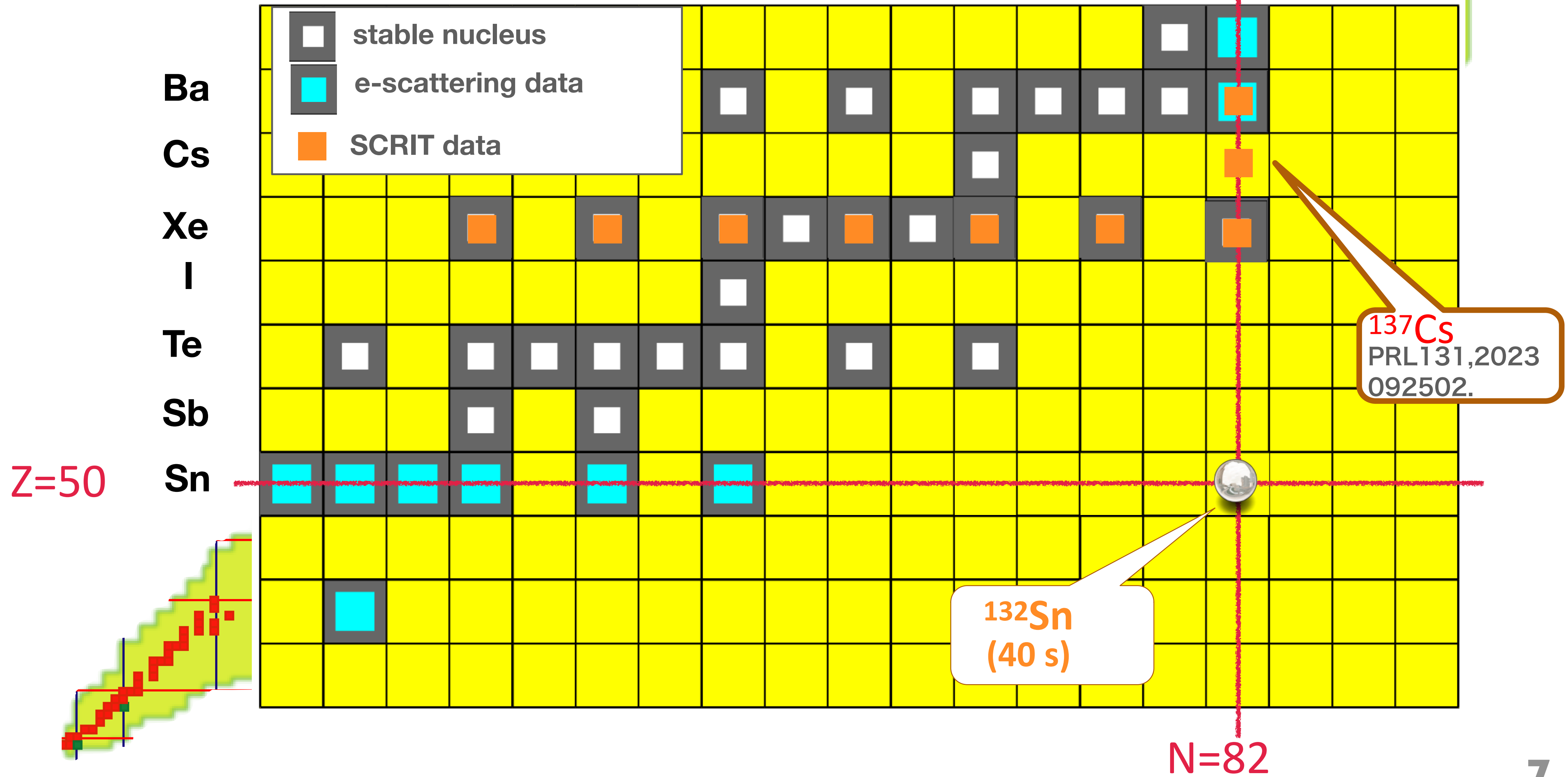
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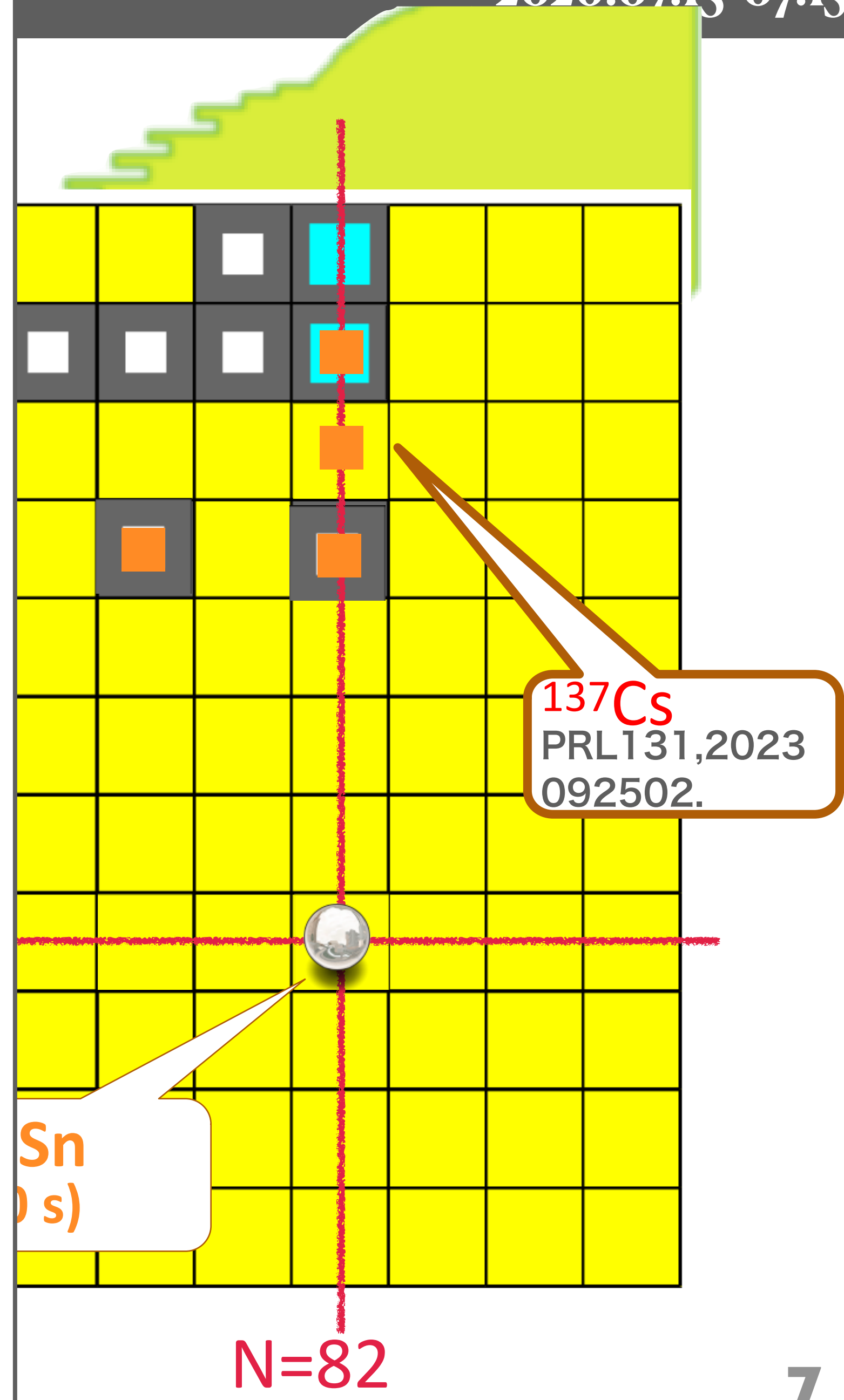
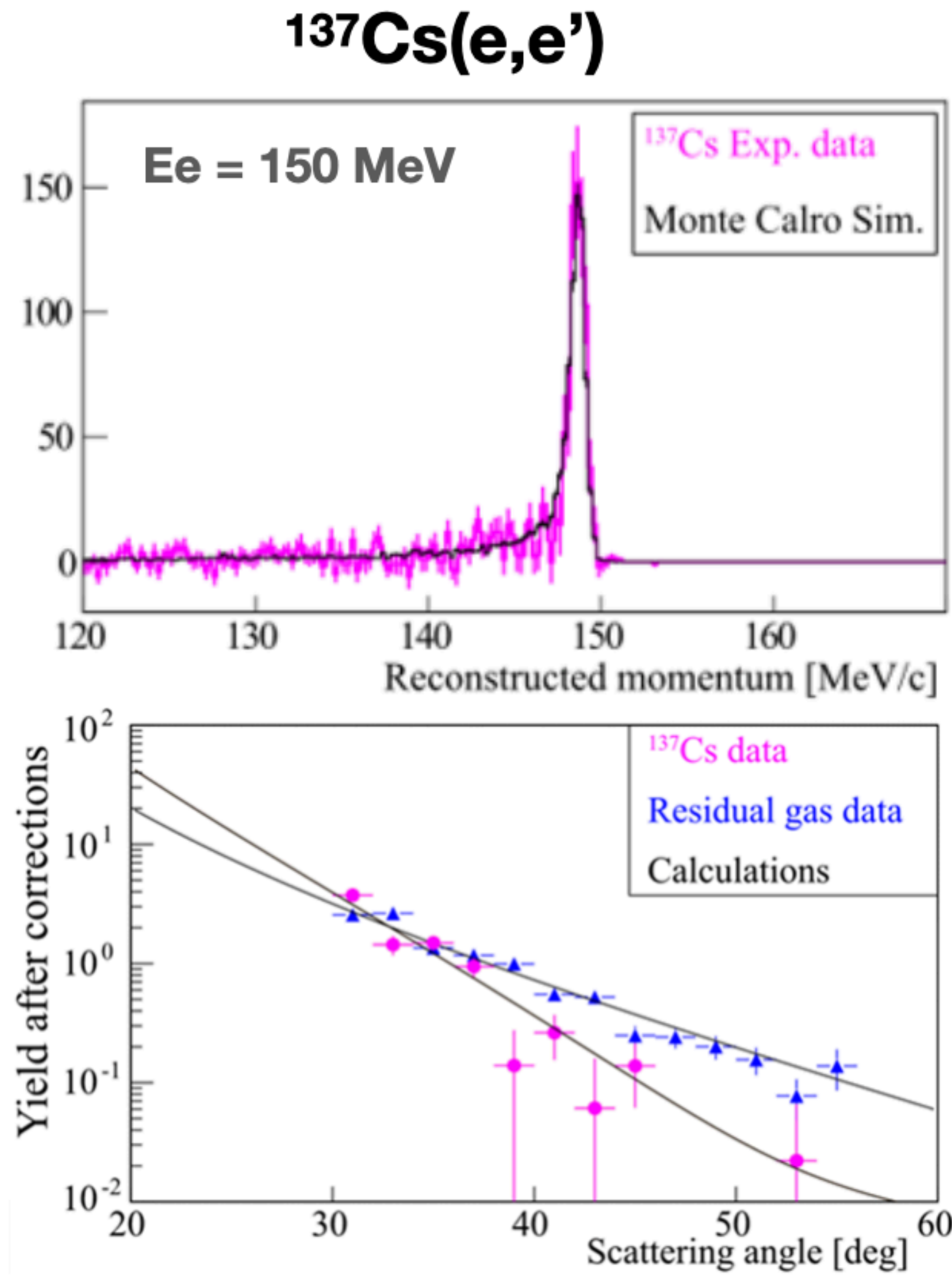
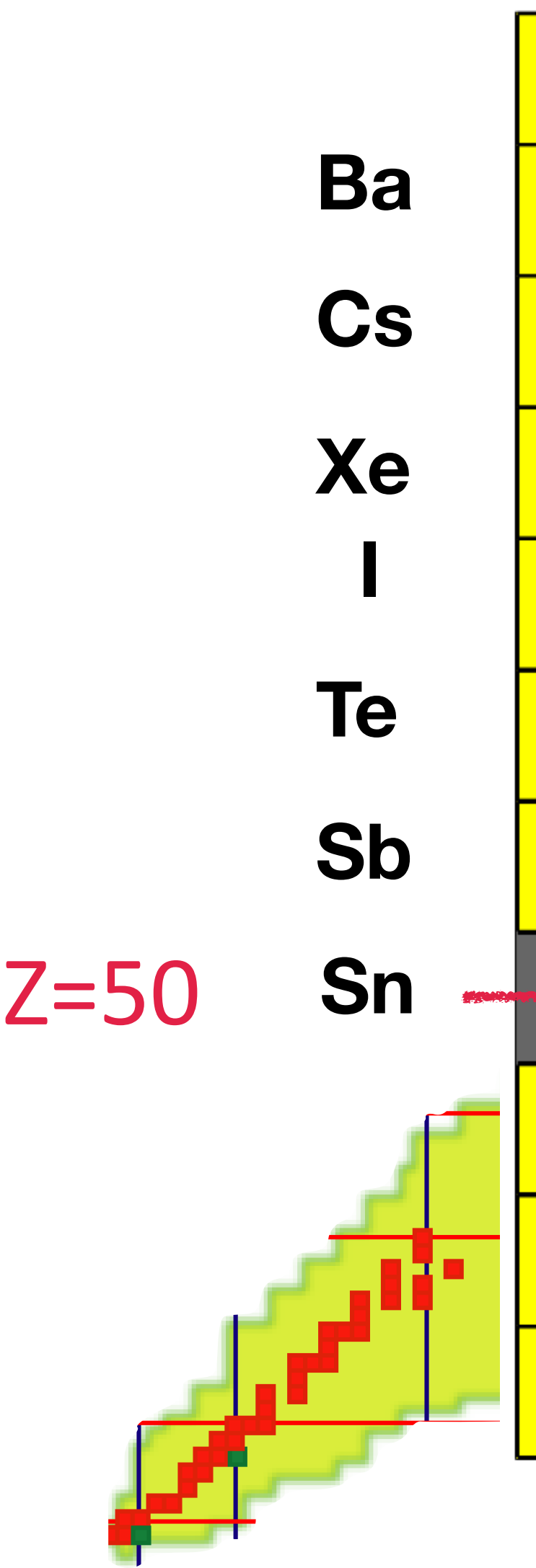


Isotope production : photofission of ^{238}U



Towards the doubly magic nucleus ^{132}Sn (40 s)

Isotope production

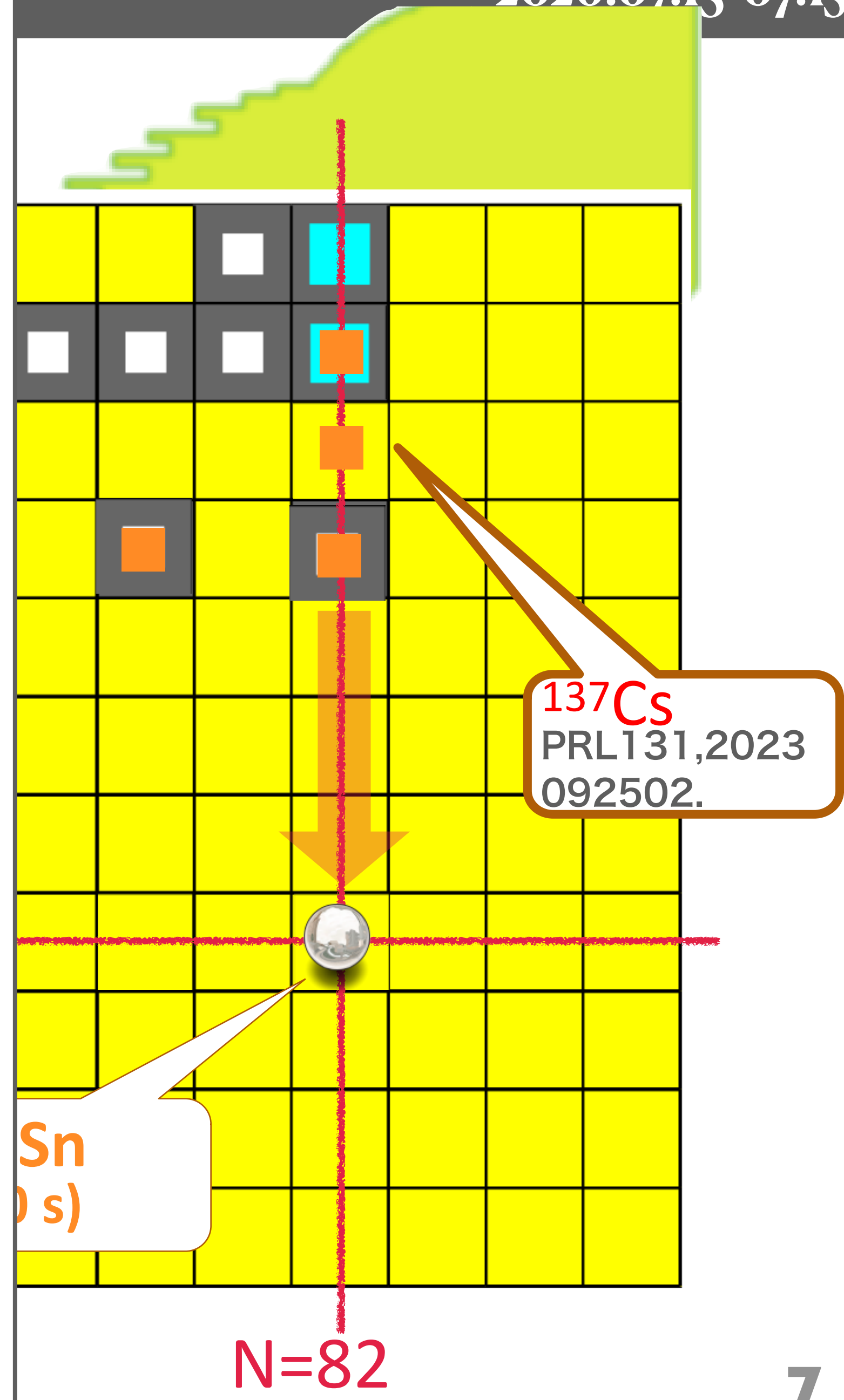
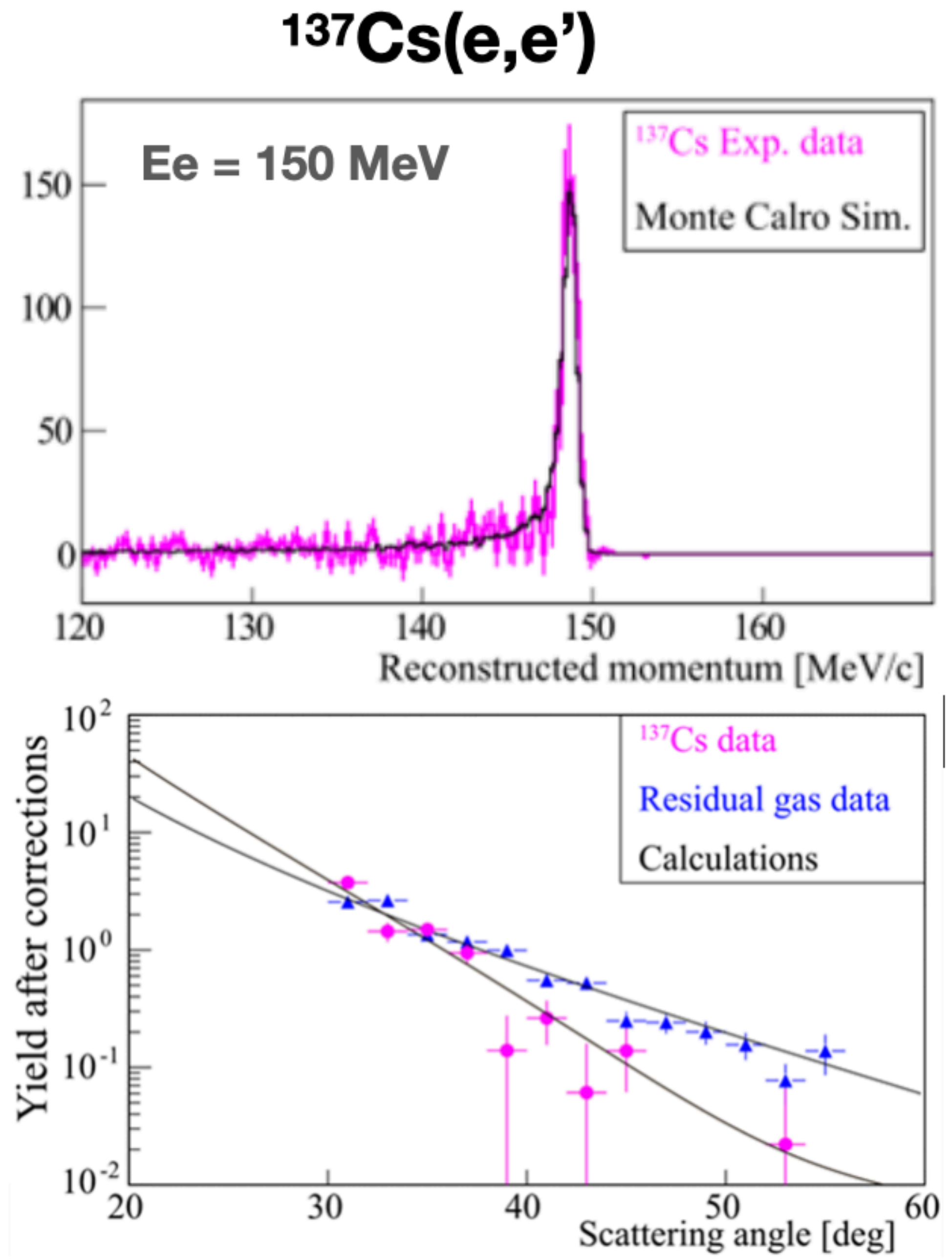
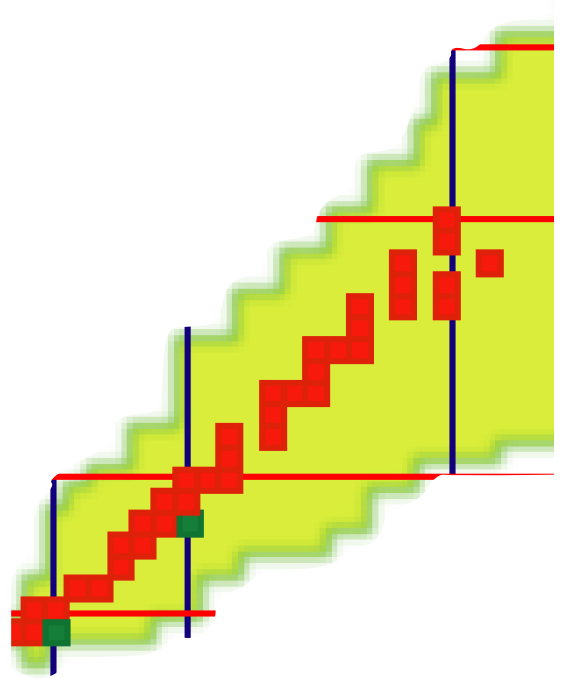


Towards the doubly magic nucleus ^{132}Sn (40 s)

Isotope production

Ba
Cs
Xe
I
Te
Sb
Sn

Z=50



ISOL upgrade: towards ^{132}Sn (40s)

NuSRAP2026
2026.07.13-07.15

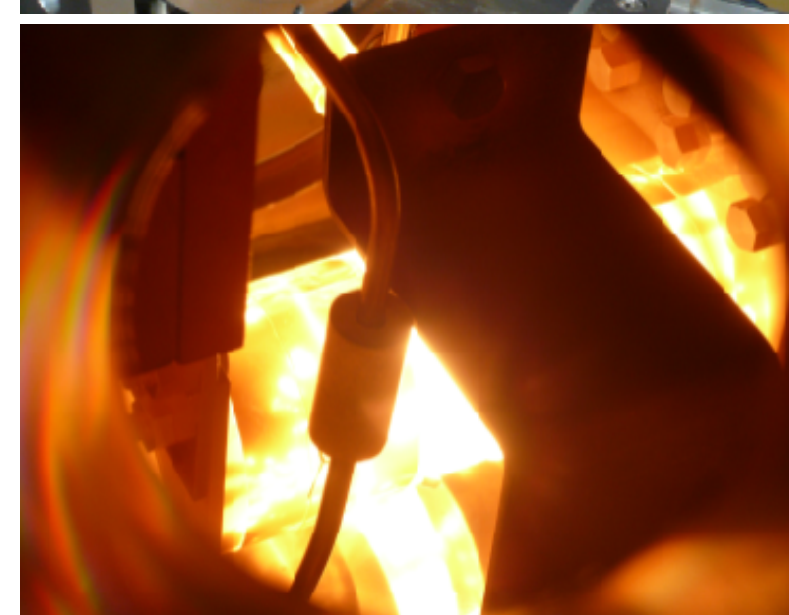
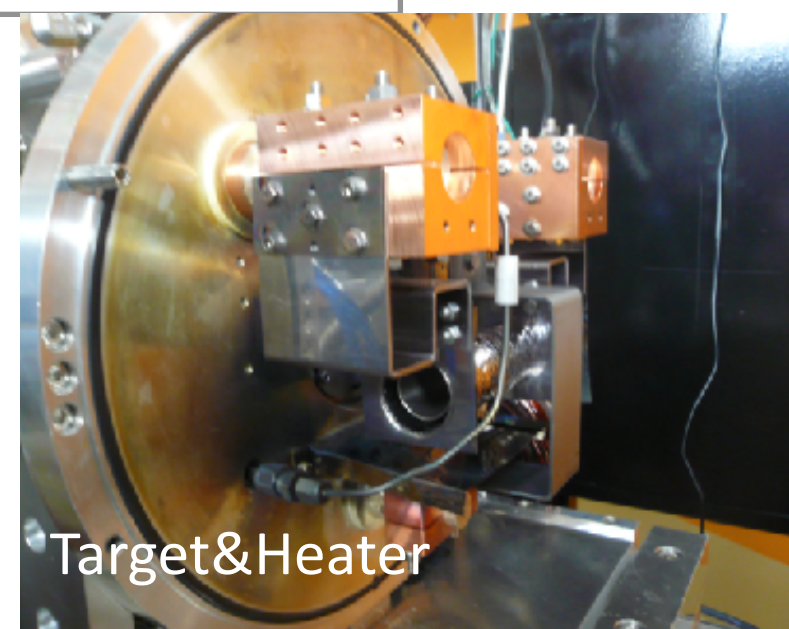
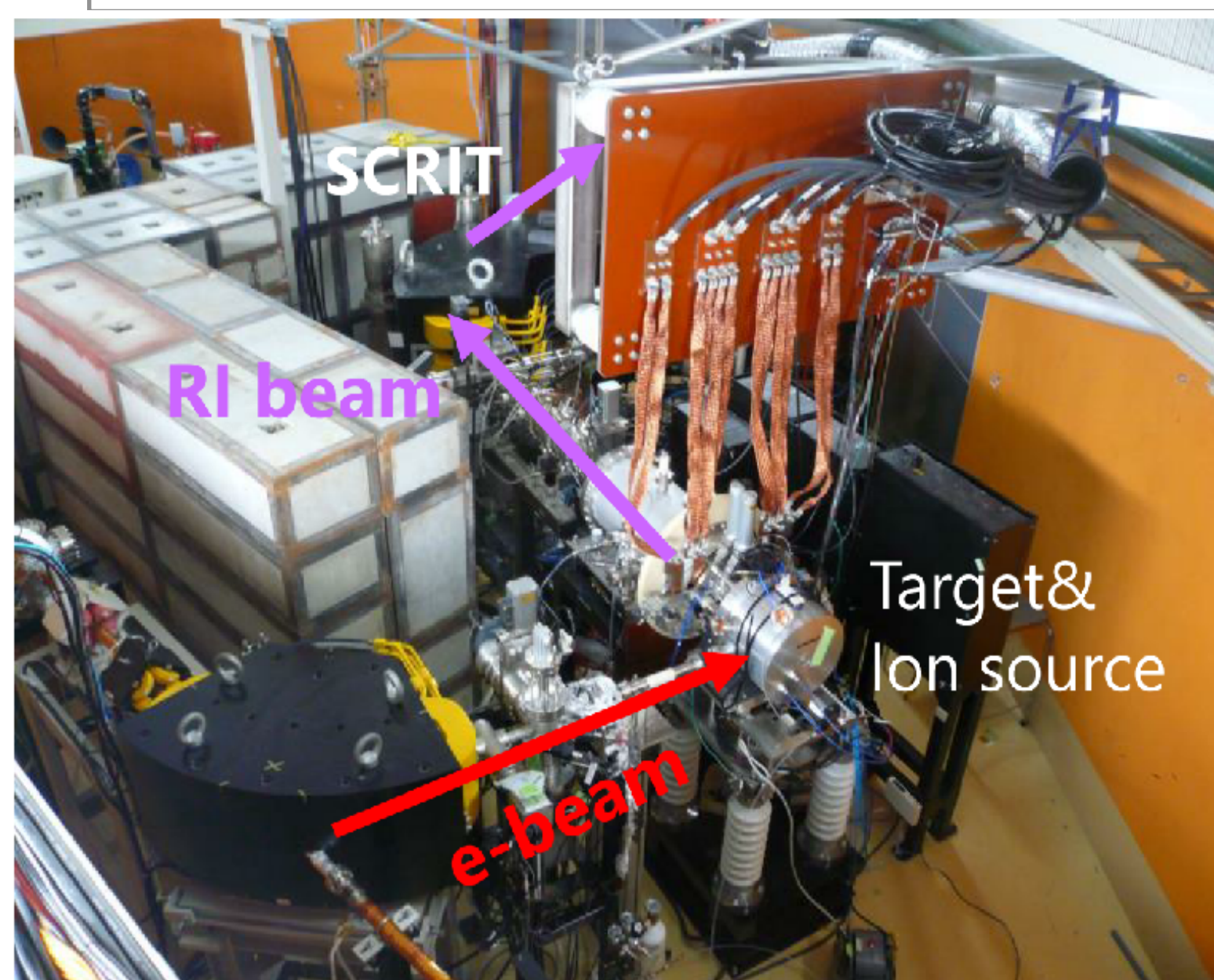
Production Rate

$N_{\text{fission}} \sim 10^8$ /watt

$N^{132}\text{Sn} \sim 10^6$ /watt * 1% ($\epsilon_{\text{trans.}}$)

beam power : $\sim 20\text{W}$ (today)

$\sim 2\text{ kW}$ (underway)



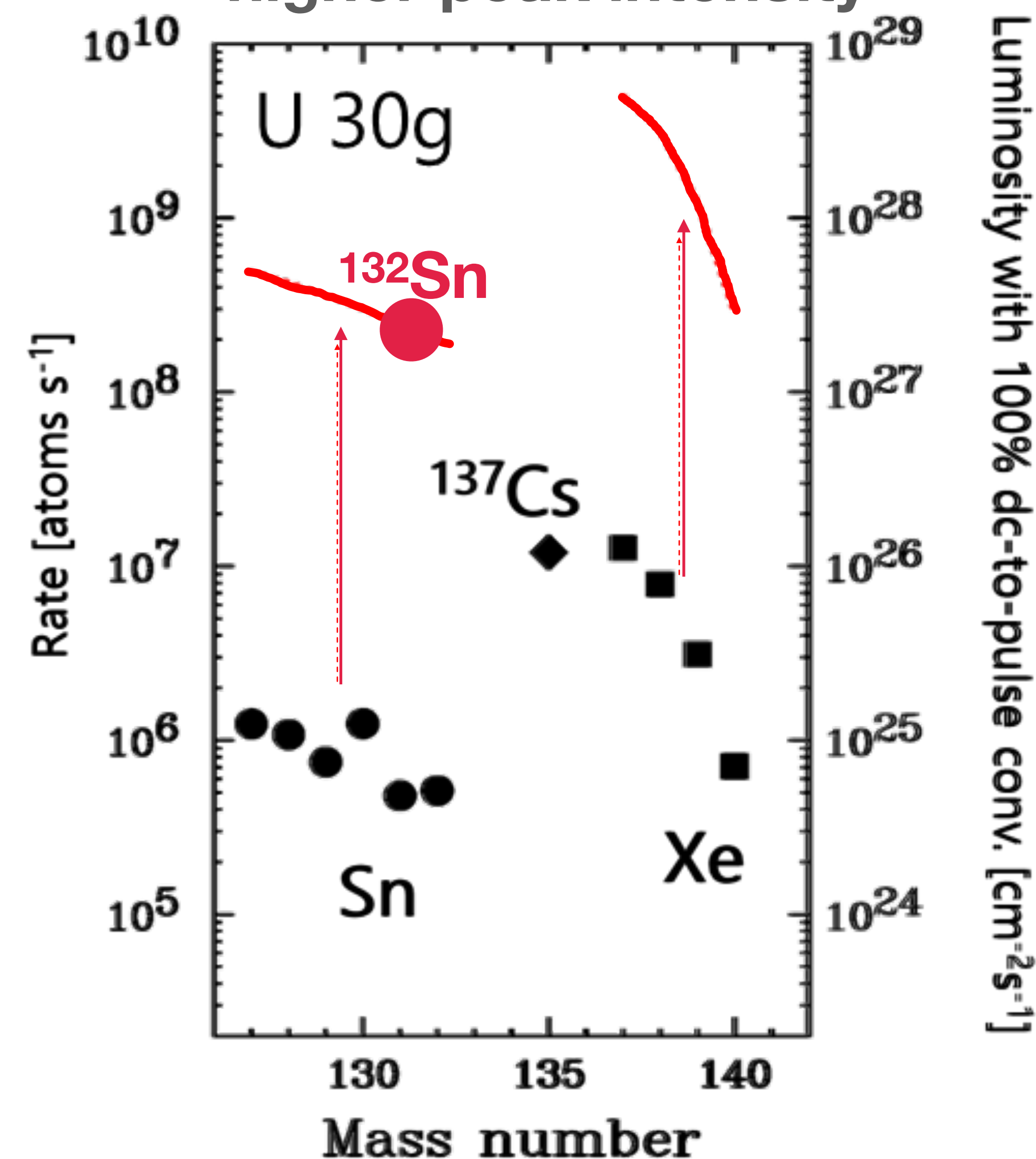
House-made
Uranium carbide (UCx)

T. Ohnishi et al. NIM B317 (2013) 357.

towards 2 kW e-beam

higher repetition

higher peak intensity



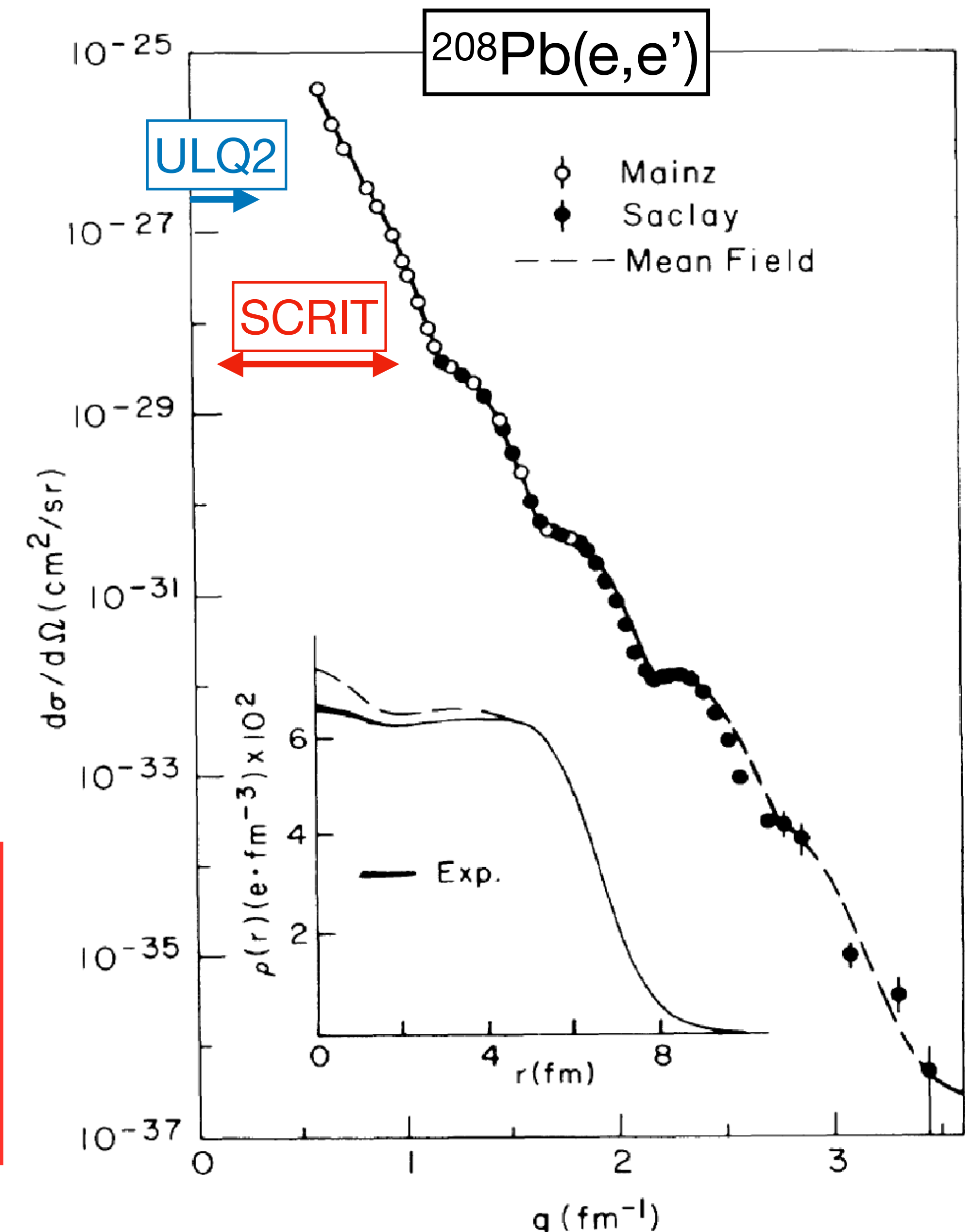
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electron scattering covering **low-q region**

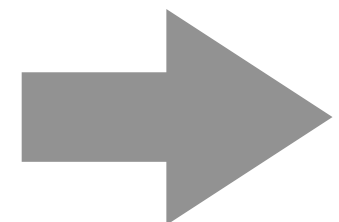
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*higher moments $\Leftrightarrow$ neutron distribution
proton (and neutron) charge radius*



higher moments of the nuclear charge distribution

$$\langle r_c^n \rangle = \int \rho_c(r) r^n d^3r$$

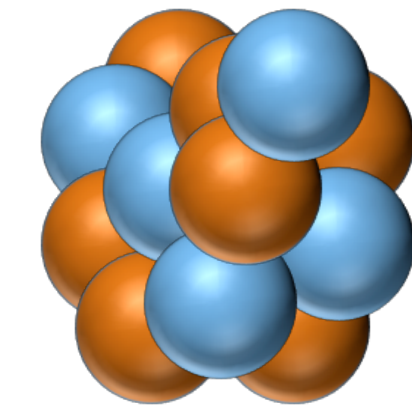
 **neutron distribution (by e-scattering)**

- 1) H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys. 2019, 113D01
- 2) H. Kurasawa, T. S. and T. Suzuki, Prog. Theor. Exp. Phys. 2021, 013D02
- 3) H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys. 2022, 023D03
- 4) T. Suzuki, Prog. Theor. Exp. Phys. 2023, 013D02

1) charge density

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$
$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3r'$$

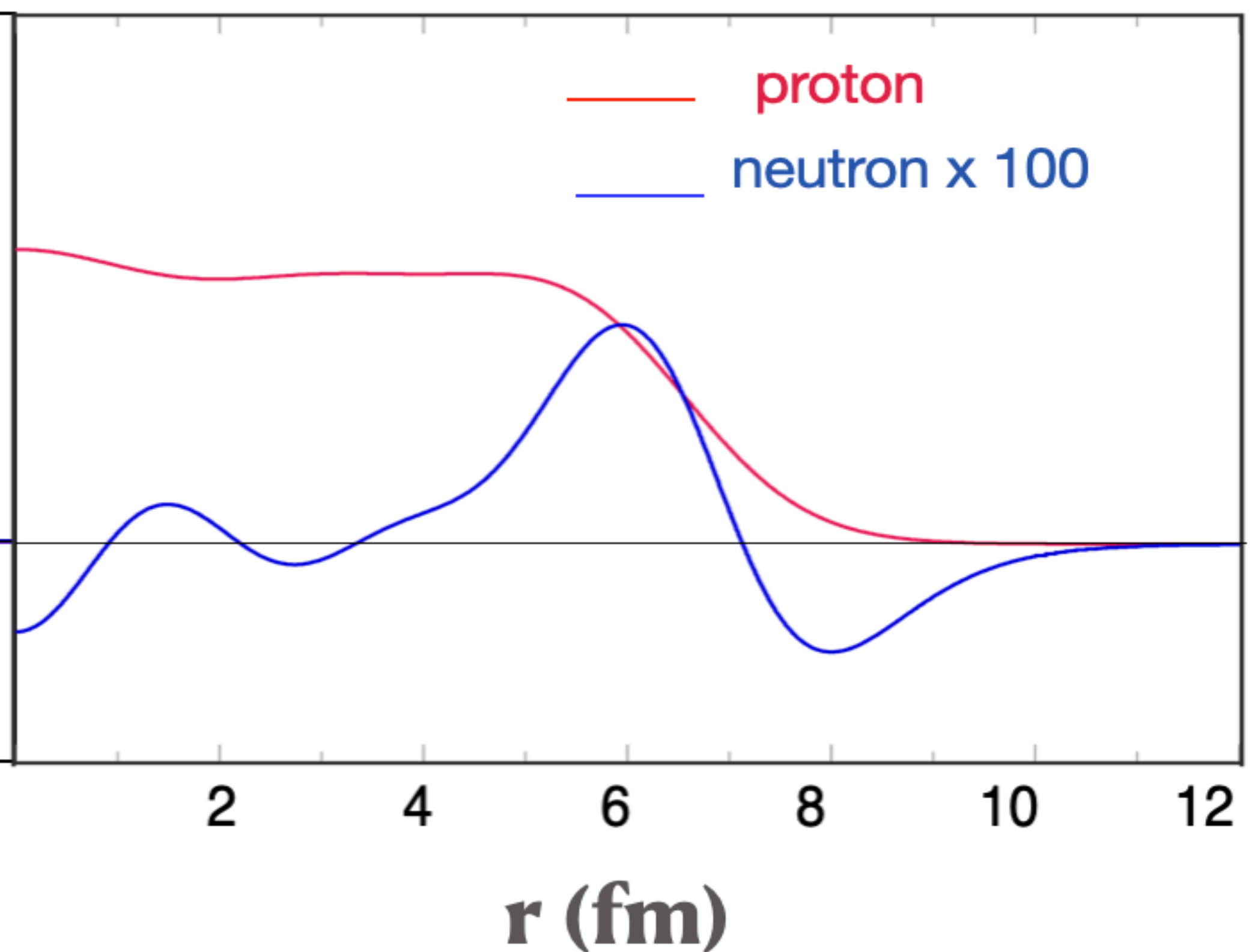
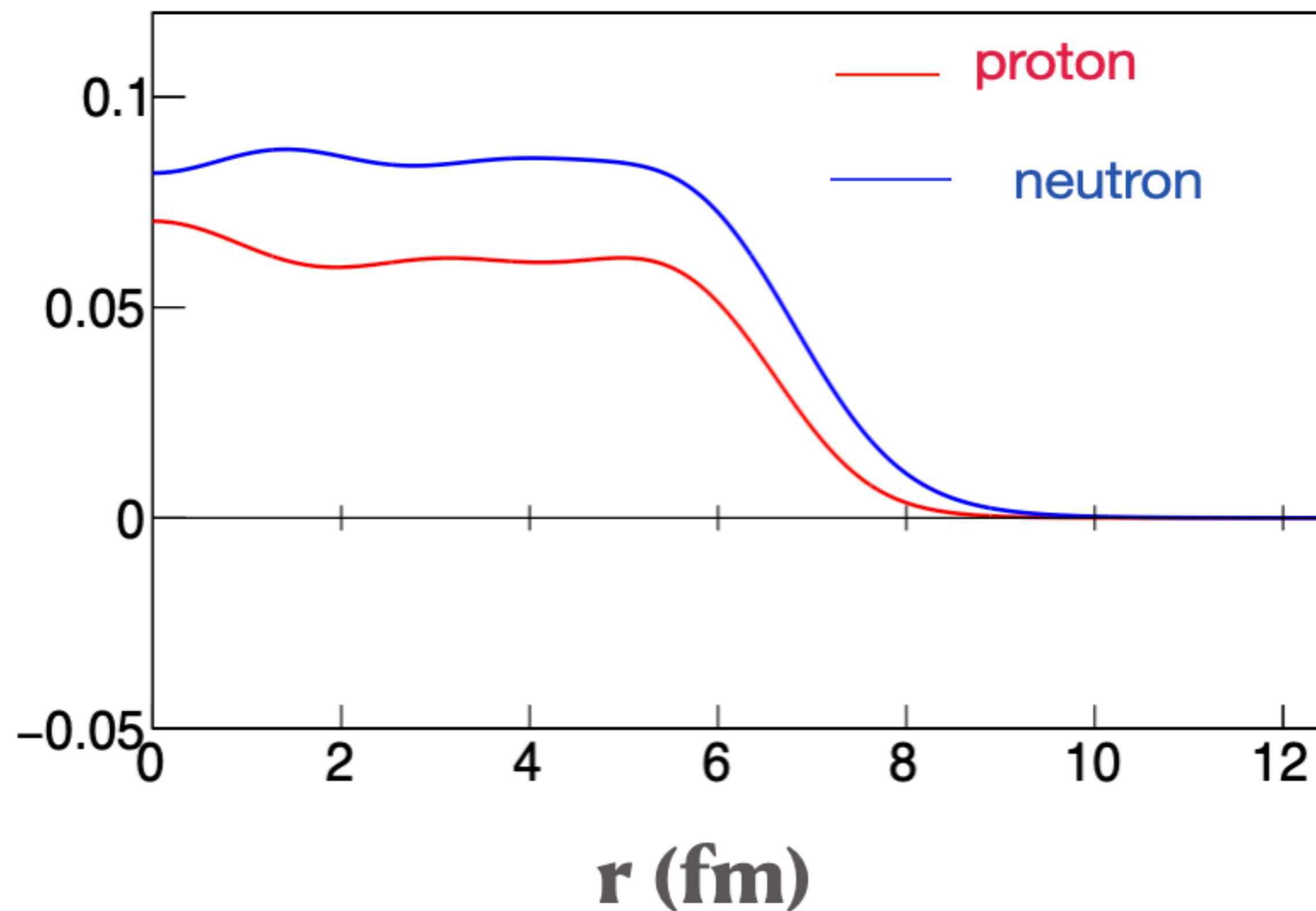
$$\rho_c(r) = \rho_c^p(r) + \rho_c^n(r)$$



Proton

Neutron

RMF NL3 (H. Kurasawa)

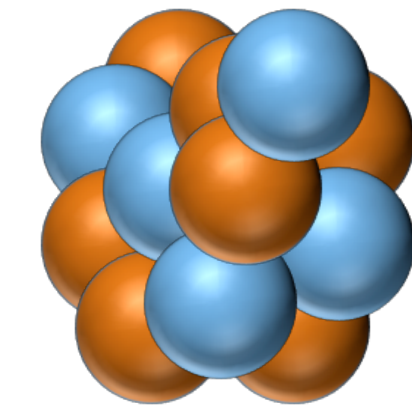
(point) nucleon density**charge density distributions**

1) charge density

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3 r'$$

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

$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3 r'$$



Proton

Neutron

2) 2nd moment

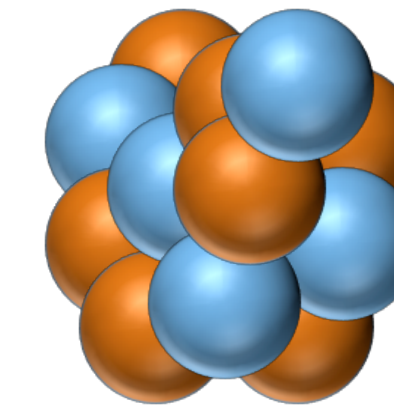
$$\begin{aligned} \langle r_c^2 \rangle &= \int r^2 \rho_c(r) d^3 r \\ &= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \langle r_{n(point)}^2 \rangle + \frac{N}{Z} \langle r_n^2 \rangle + \text{rel. corr.} \end{aligned}$$

1) charge density

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$

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

$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3r'$$



Proton

Neutron

2) 2nd moment

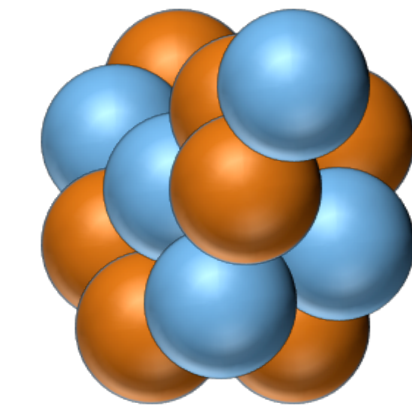
$$\begin{aligned} \langle r_c^2 \rangle &= \int r^2 \rho_c(r) d^3r \\ &= \underbrace{\langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle}_{\text{Proton}} + \underbrace{\langle r_{n(point)}^2 \rangle + \frac{N}{Z} \langle r_n^2 \rangle}_{\text{Neutron}} + \text{rel. corr.} \end{aligned}$$

1) charge density

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$

$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3r'$$

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



Proton

Neutron

2) 2nd moment

$$\langle r_c^2 \rangle = \int r^2 \rho_c(r) d^3r$$

$$= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \overset{\text{Proton}}{\text{blue sphere}} \quad \overset{\text{Neutron}}{\text{orange sphere}} \quad \text{e}_n=0$$

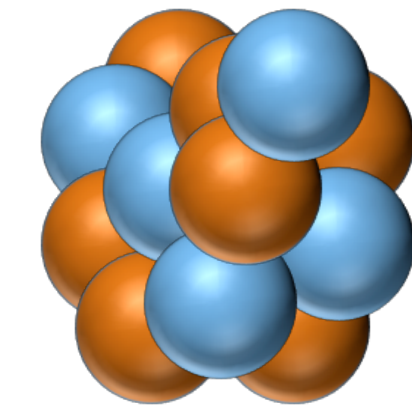
$$= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \cancel{\langle r_{n(point)}^2 \rangle} + \frac{N}{Z} \langle r_n^2 \rangle + \text{rel. corr.}$$

1) charge density

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

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$

$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3r'$$



Proton

Neutron

2) 2nd moment

$$\begin{aligned} \langle r_c^2 \rangle &= \int r^2 \rho_c(r) d^3r \\ &= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \cancel{\langle r_{n(point)}^2 \rangle} + \frac{N}{Z} \langle r_n^2 \rangle + \text{rel. corr.} \end{aligned}$$

Proton e_n=0 Neutron

3) 4th moment

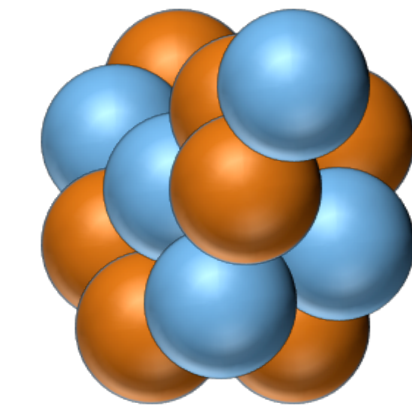
$$\begin{aligned} \langle r_c^4 \rangle &= \int r^4 \rho_c(r) d^3r \\ &= \langle r_{p(point)}^4 \rangle + \frac{10}{3} \langle r_{p(point)}^2 \rangle \langle r_p^2 \rangle + \langle r_{n(point)}^4 \rangle + \frac{10}{3} \langle r_{n(point)}^2 \rangle \langle r_n^2 \rangle + \text{rel. corr.} \end{aligned}$$

1) charge density

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

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$

$$\rho_c^n(r) = \int \rho_n(r) \rho_{n(point)}(r - r') d^3r'$$



Proton

Neutron

2) 2nd moment

$$\begin{aligned} \langle r_c^2 \rangle &= \int r^2 \rho_c(r) d^3r \\ &= \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \cancel{\langle r_{n(point)}^2 \rangle} + \frac{N}{Z} \langle r_n^2 \rangle + \text{rel. corr.} \end{aligned}$$

Proton e_n=0 Neutron

3) 4th moment

$$\begin{aligned} \langle r_c^4 \rangle &= \int r^4 \rho_c(r) d^3r \\ &= \langle r_{p(point)}^4 \rangle + \frac{10}{3} \langle r_{p(point)}^2 \rangle \langle r_p^2 \rangle + \langle r_{n(point)}^4 \rangle + \frac{10}{3} \langle r_{n(point)}^2 \rangle \langle r_n^2 \rangle + \frac{N}{Z} + \text{rel. corr.} \end{aligned}$$

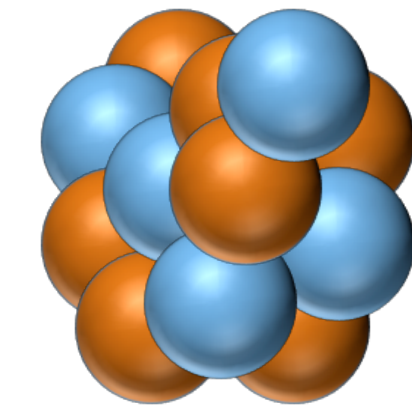
Proton Neutron

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Proton

Neutron

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Proton e_n=0 Neutron

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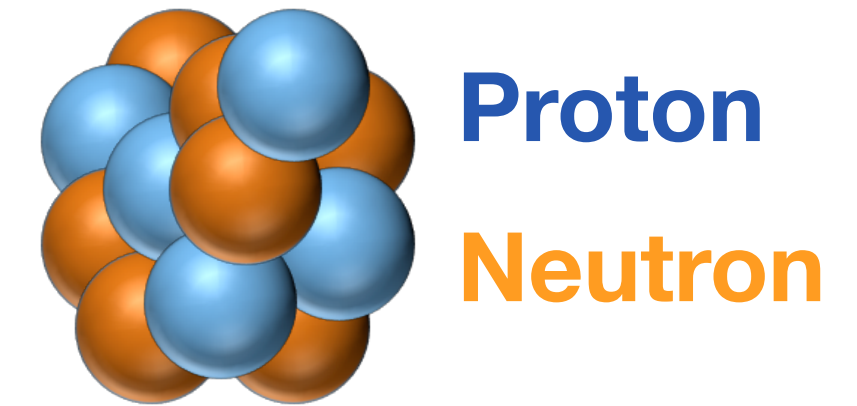
Proton e_n=0 Neutron

1) charge density

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') d^3r'$$

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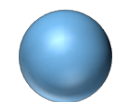
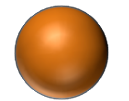
$$\rho_c(r) = \rho_c^p(r) + \rho_c^n(r)$$



2) 2nd moment

$$\langle r_c^2 \rangle = \int r^2 \rho_c(r) d^3r$$

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

Proton  Neutron 

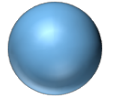
$e_n=0$

RMS n-radius

3) 4th moment

$$\langle r_c^4 \rangle = \int r^4 \rho_c(r) d^3r$$

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

Proton  Neutron 

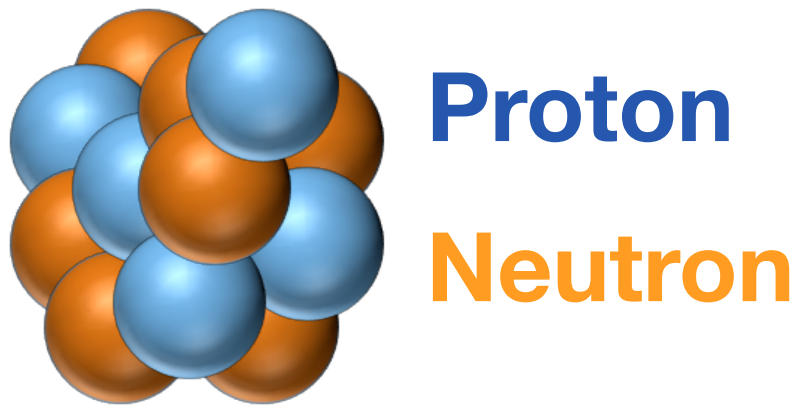
$e_n=0$

1) charge density

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

$$\rho_c^p(r) = \int \rho_p(r) \rho_{p(point)}(r - r') \, d^3r'$$

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2) 2nd moment

$$\langle r_c^2 \rangle = \int r^2 \rho_c(r) \, d^3r$$

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Proton

Neutron

$e_n=0$

RMS n-radius

3) 4th moment

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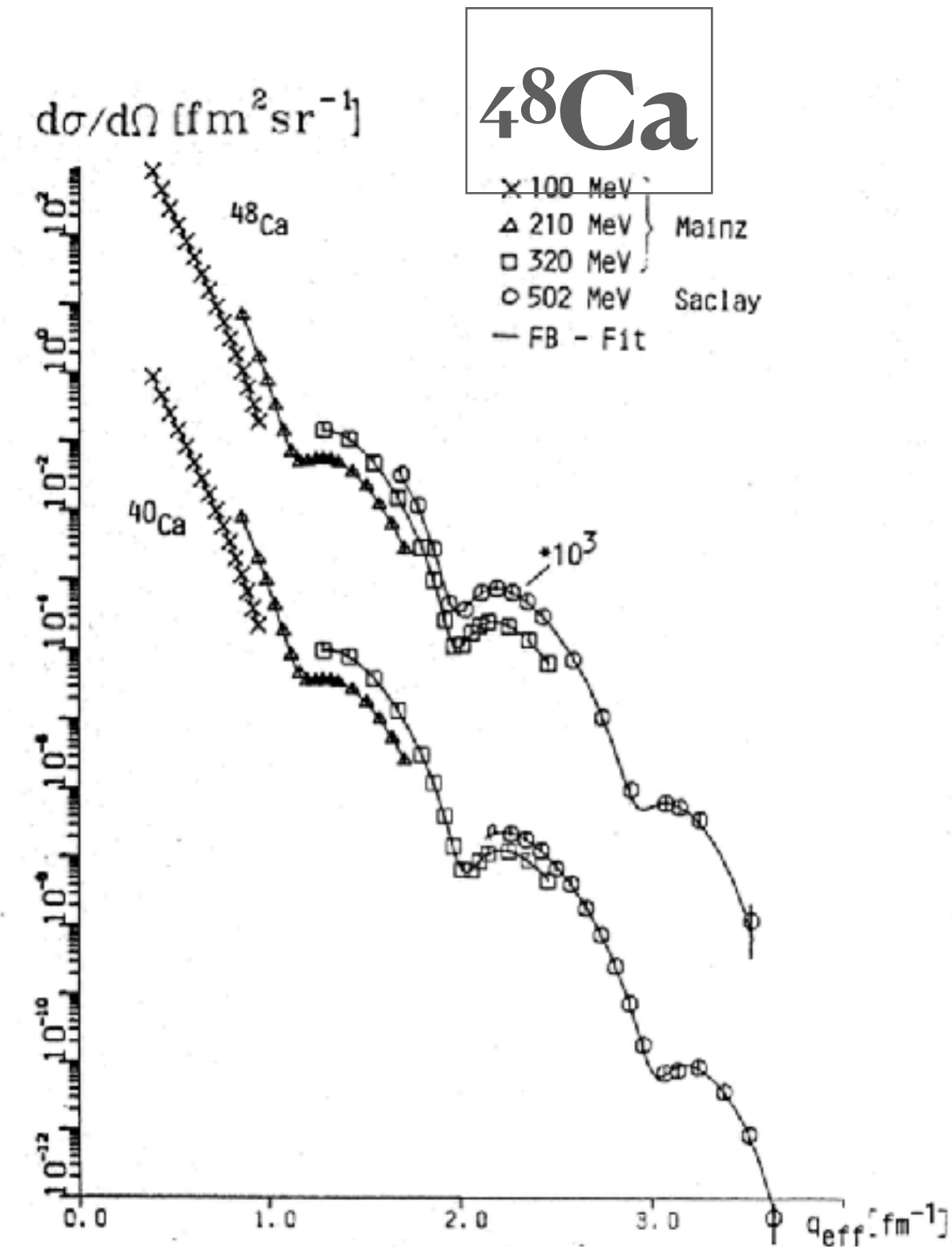
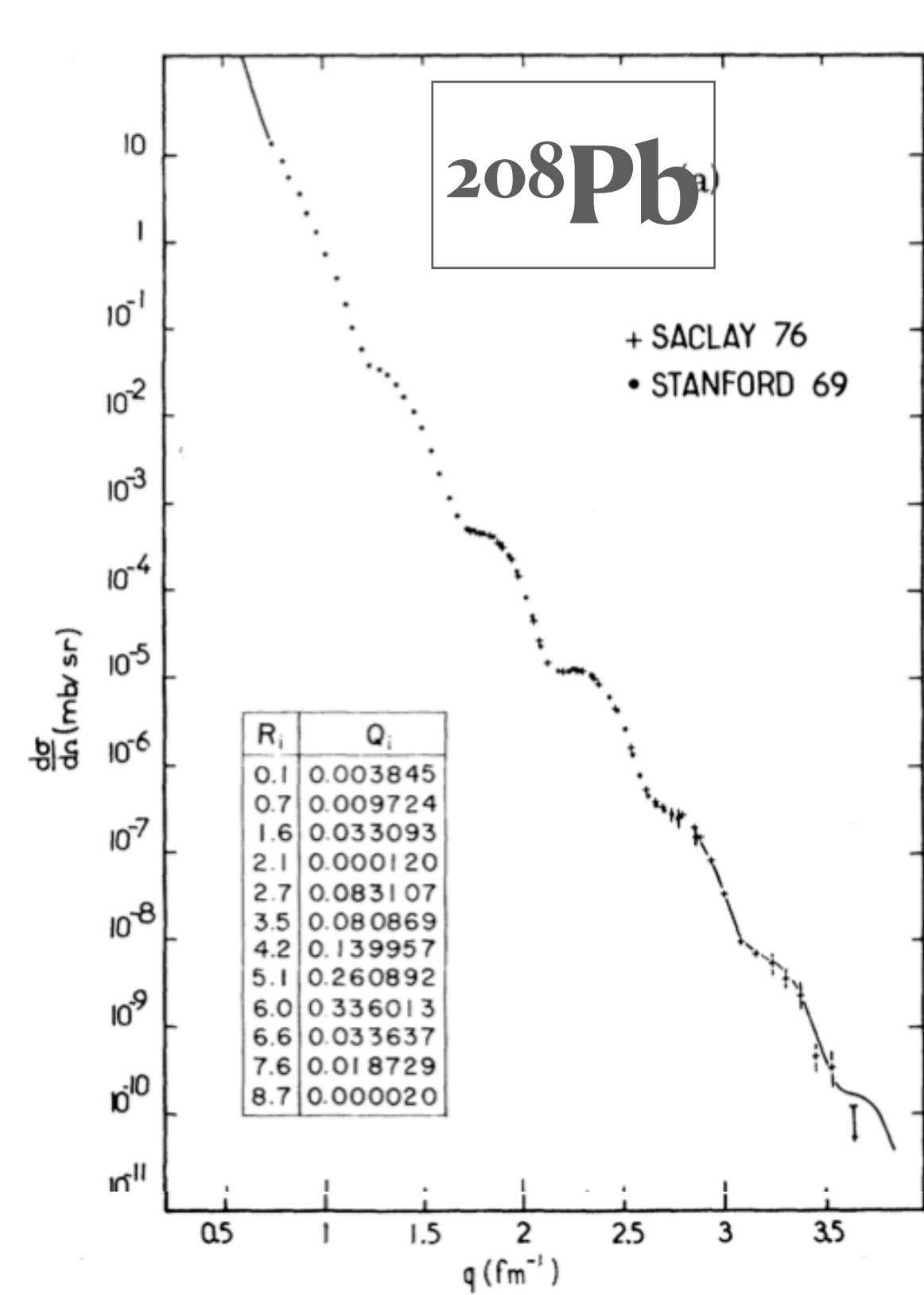
Proton

Neutron

$e_n=0$

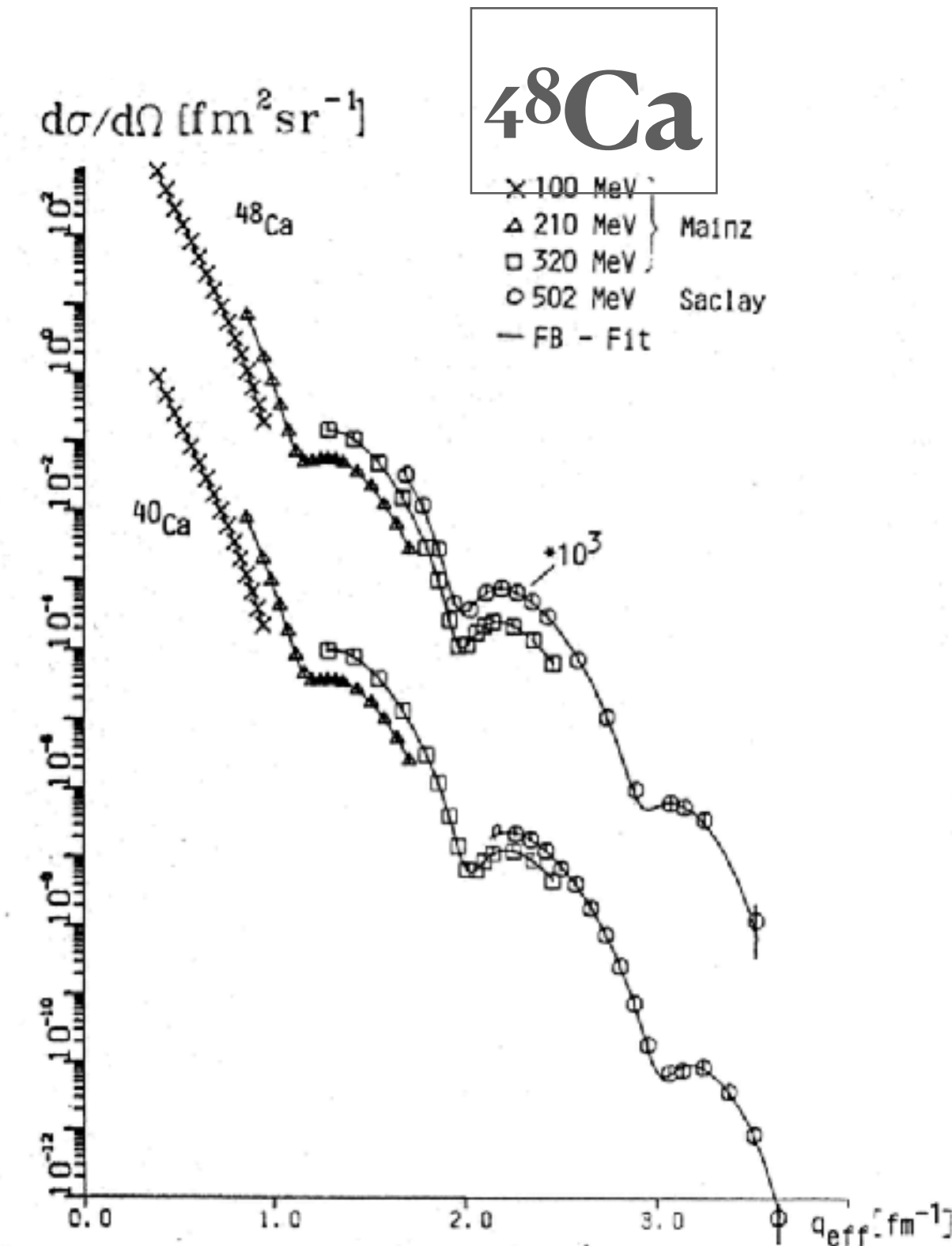
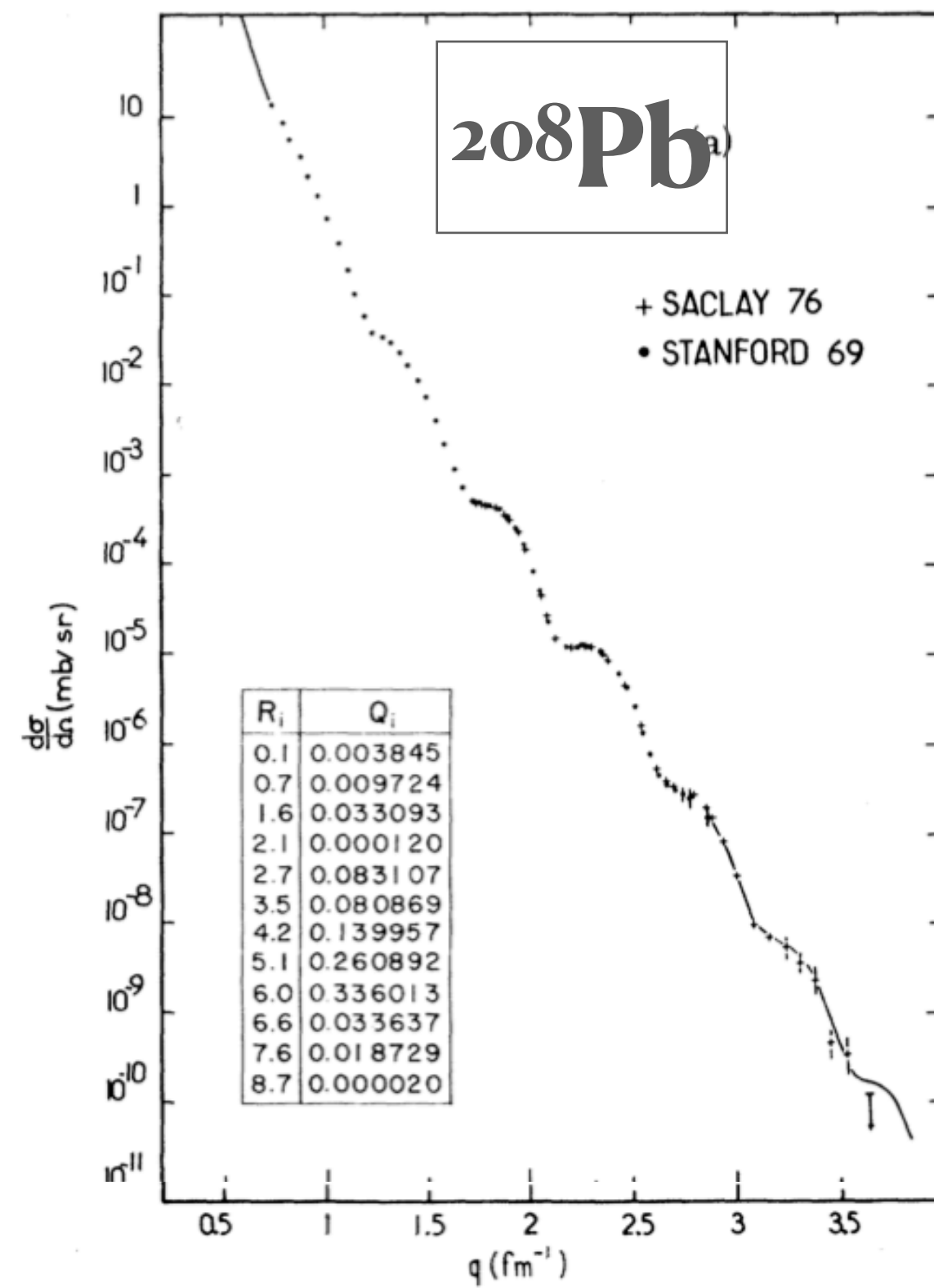
	$\langle r^4 \rangle \text{ (fm}^4\text{)}$	n-cont.
⁴⁸ Ca	194.7	6.9%
²⁰⁸ Pb	1171.6	2.9%

RMS radii of (point) proton and neutron of ^{48}Ca ^{208}Pb



RMS radii of (point) proton and neutron of ^{48}Ca ^{208}Pb

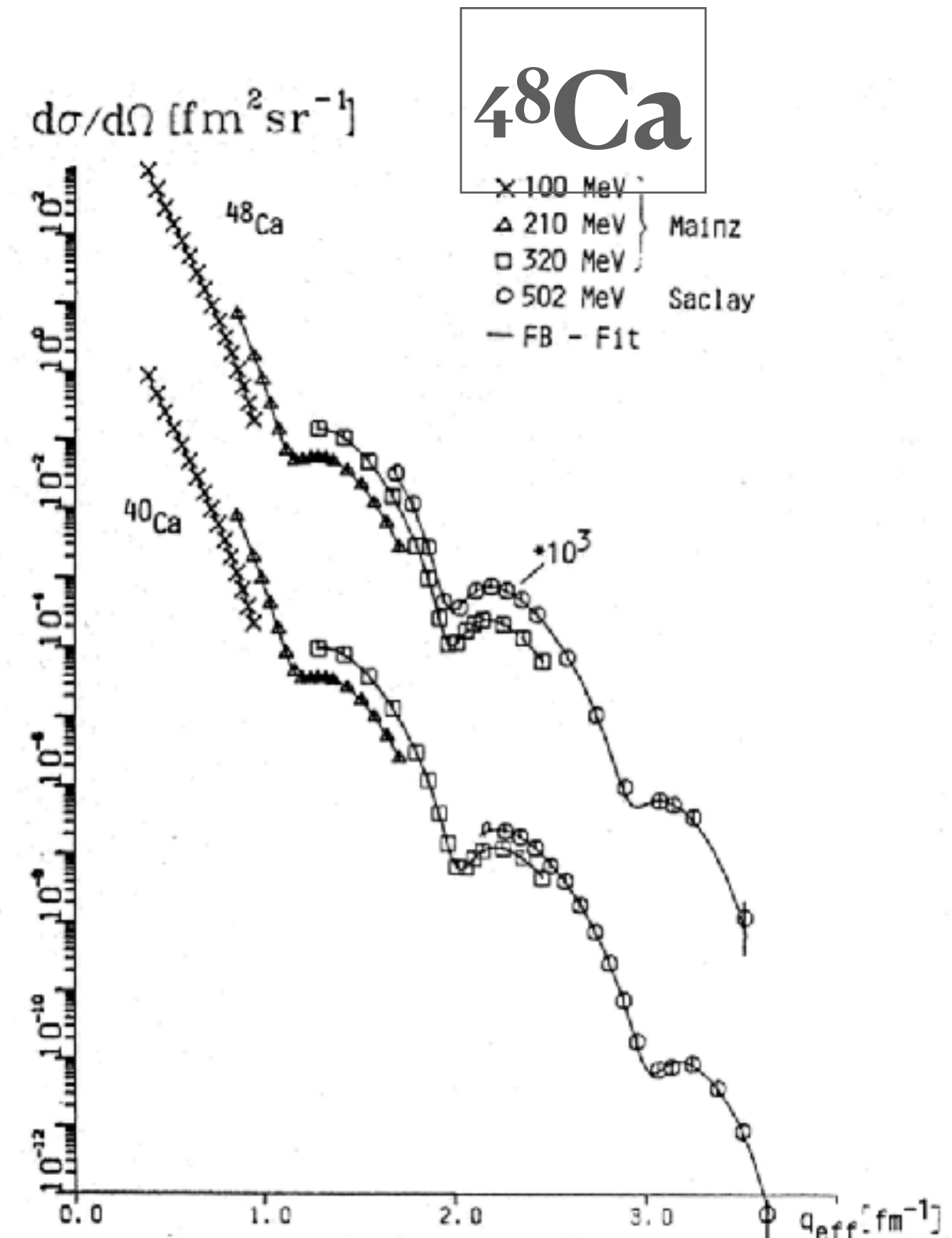
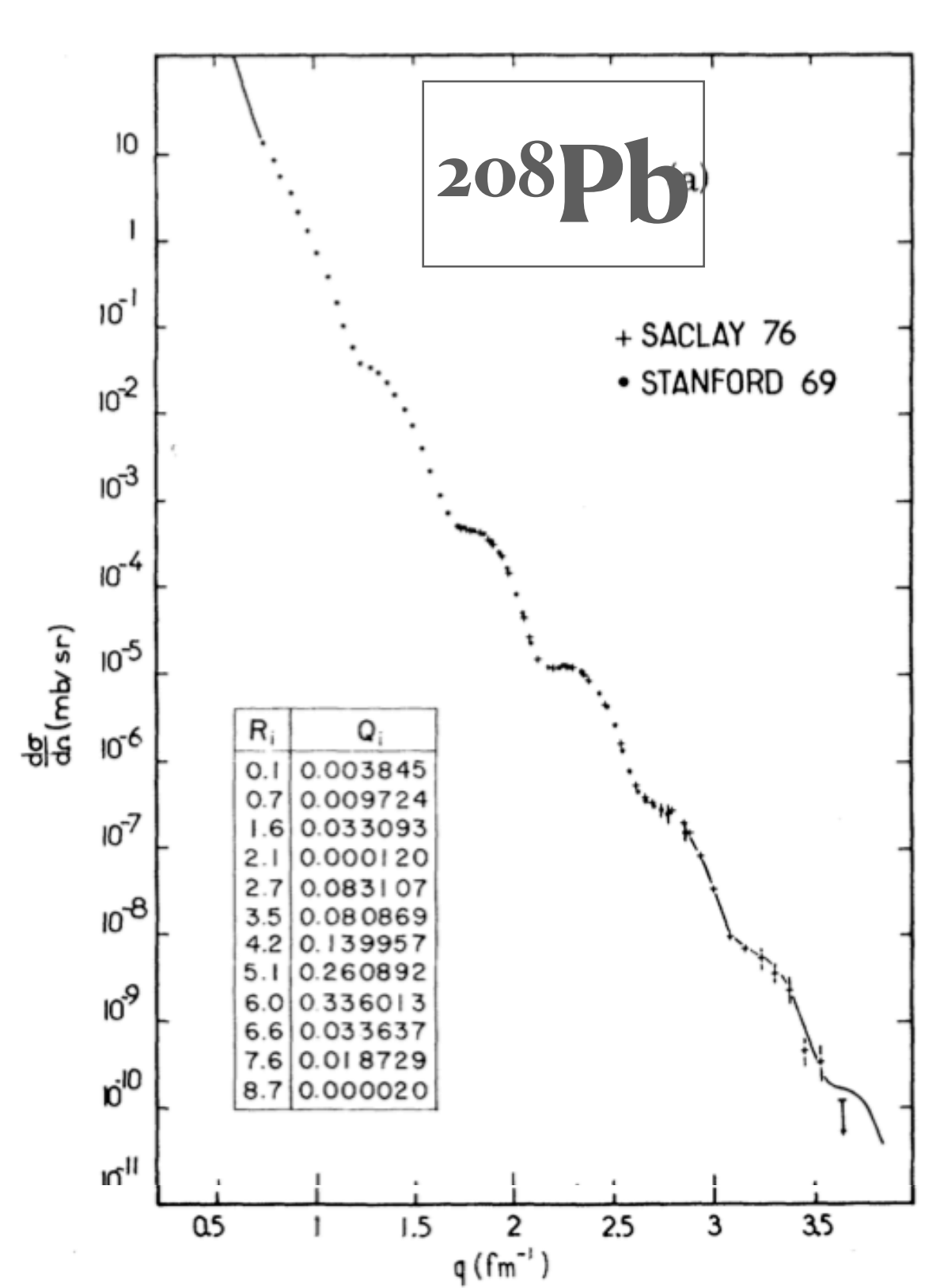
NuSRAP2026
2026.07.13-07.15



$$\rho_c(r) \rightarrow \langle r_c^4 \rangle = \int r^4 \rho_c(r) d^3r \rightarrow \langle r_{n(point)}^2 \rangle$$

RMS radii of (point) proton and neutron of ^{48}Ca ^{208}Pb

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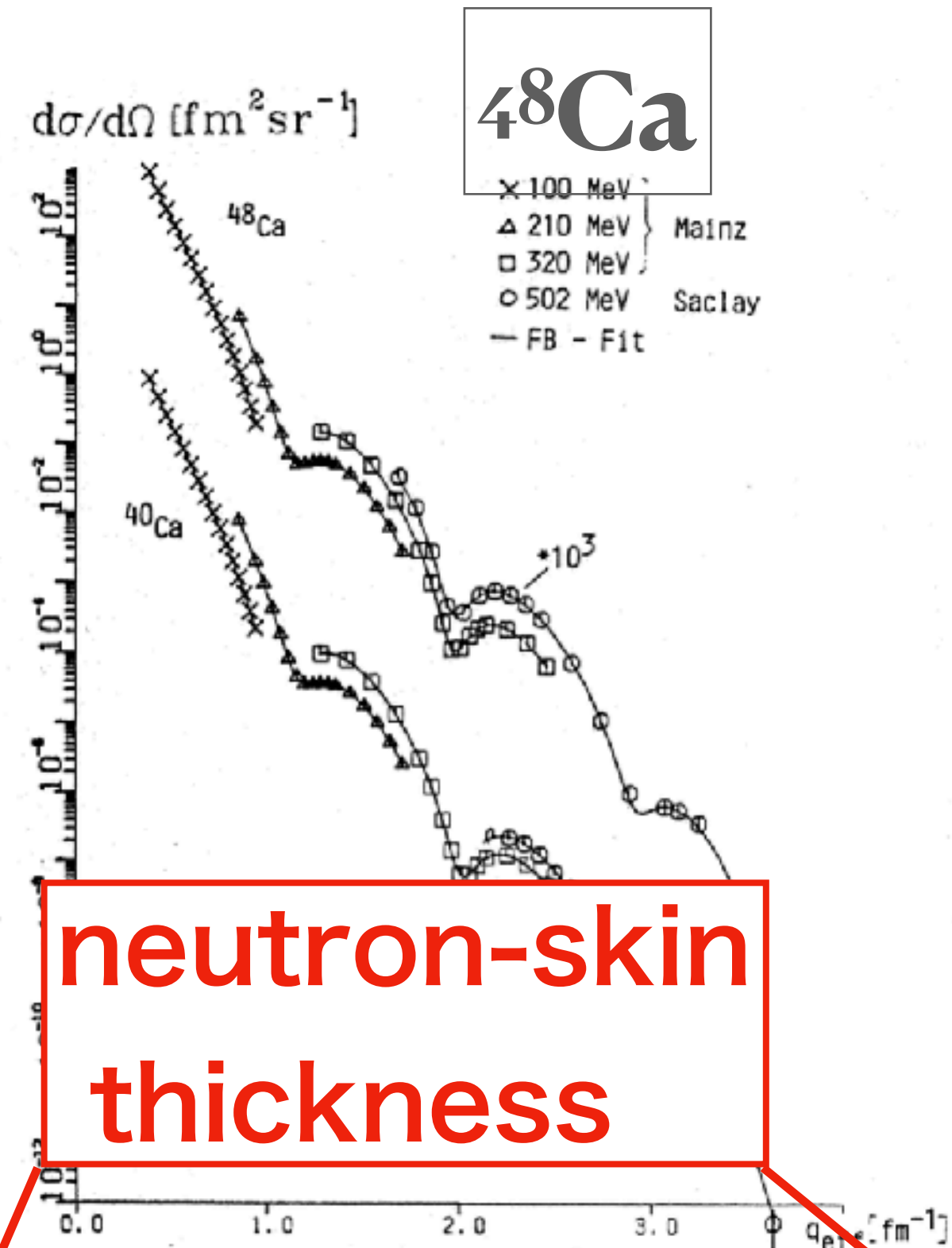
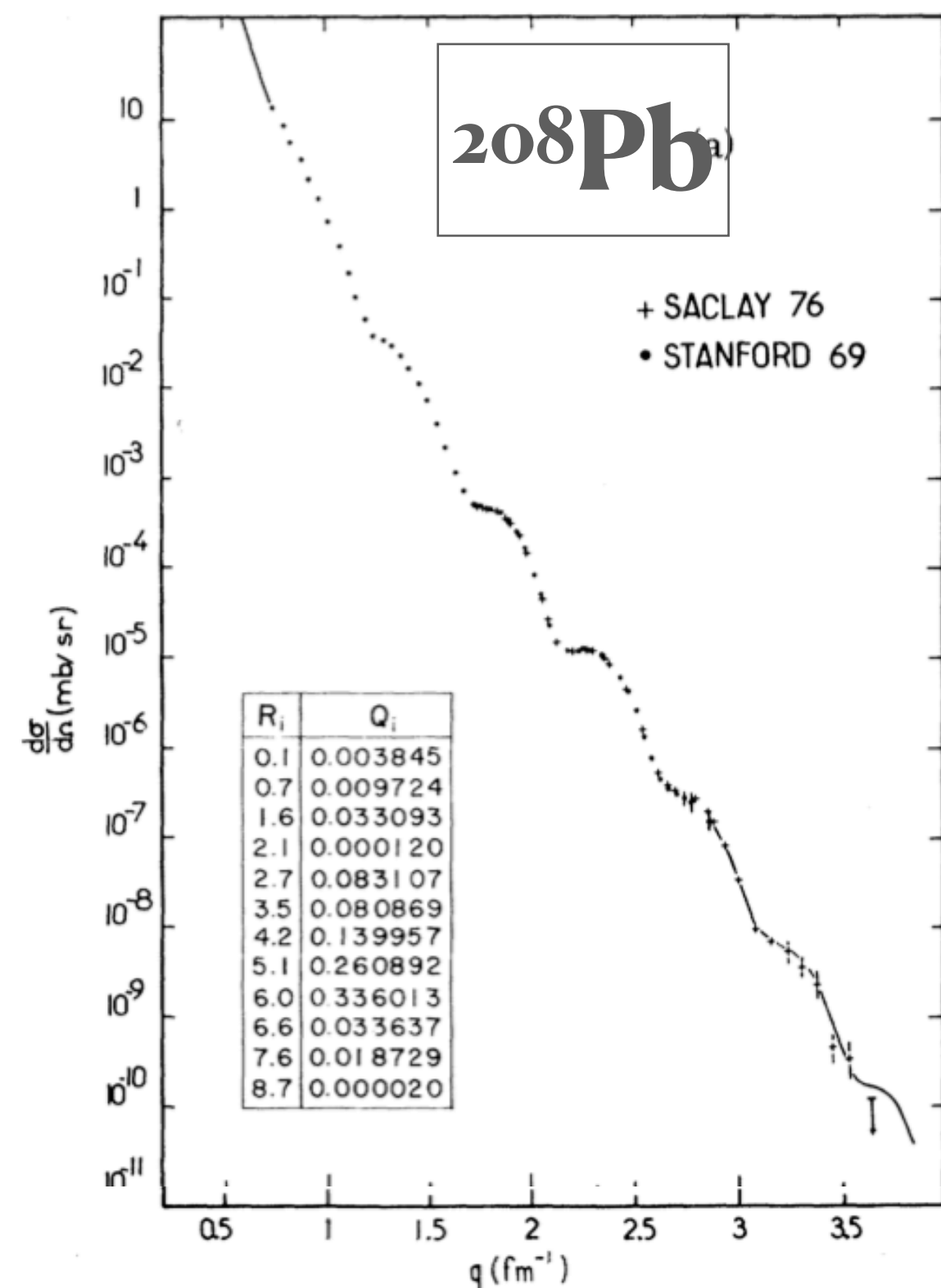


$$\rho_c(r) \longrightarrow \langle r_c^4 \rangle = \int r^4 \rho_c(r) d^3r \longrightarrow \langle r_{n(point)}^2 \rangle$$

R_p		R_n	δR	
^{208}Pb	Rel.	5.454(0.013)	5.728(0.057)	0.275(0.070)
	Non.	5.447(0.014)	5.609(0.054)	0.162(0.068)
	Exp.	$R_c = 5.503(0.014)$		

R_p		R_n	δR	
^{48}Ca	Rel.	3.378(0.005)	3.597(0.021)	0.220(0.026)
	Non.	3.372(0.009)	3.492(0.028)	0.121(0.036)
	Exp.	$R_c = 3.451(0.009)$		

RMS radii of (point) proton and neutron of ^{48}Ca ^{208}Pb



$$\rho_c(r) \rightarrow \langle r_c^4 \rangle = \int r^4 \rho_c(r) d^3r \rightarrow \langle r_{n(point)}^2 \rangle$$

		R_p	R_n	δR
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Determination of $\langle r^4 \rangle$ by low-q measurement

NuSRAP2026
2026.07.13-07.15

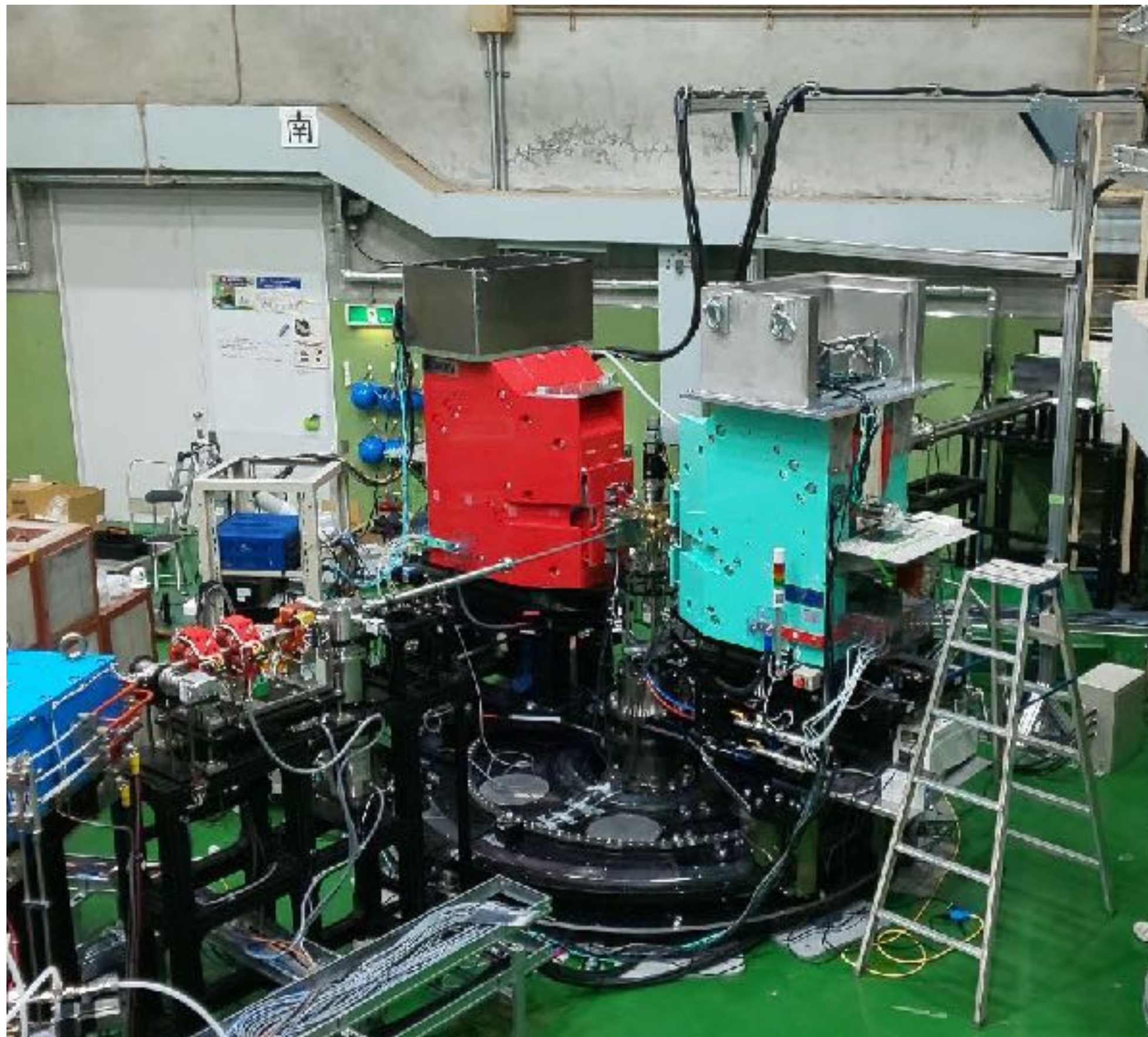
ULQ2 facility, Tohoku Univ.

proton and deuteron charge radii

$E_e \sim 10 - 50 \text{ MeV}$

$\theta = 30 - 150^\circ$

$q = 5 - 50 \text{ MeV}/c$



Determination of $\langle r^4 \rangle$ by low-q measurement

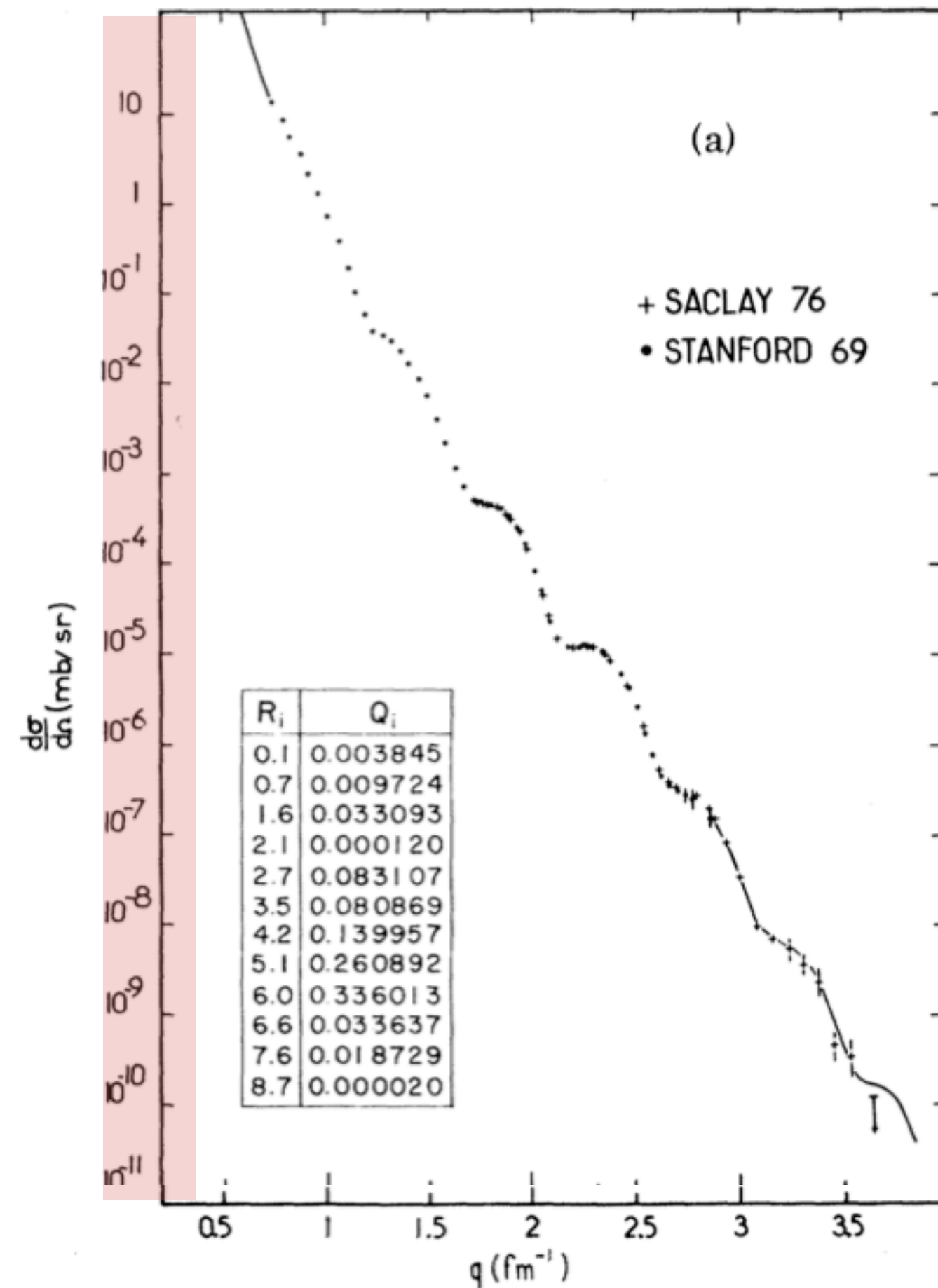
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2026.07.13-07.15

ULQ2 facility
proton and

$E_e \sim 10 - 15$ MeV

$\theta = 30 - 130^\circ$

$q = 5 - 50$ fm $^{-1}$



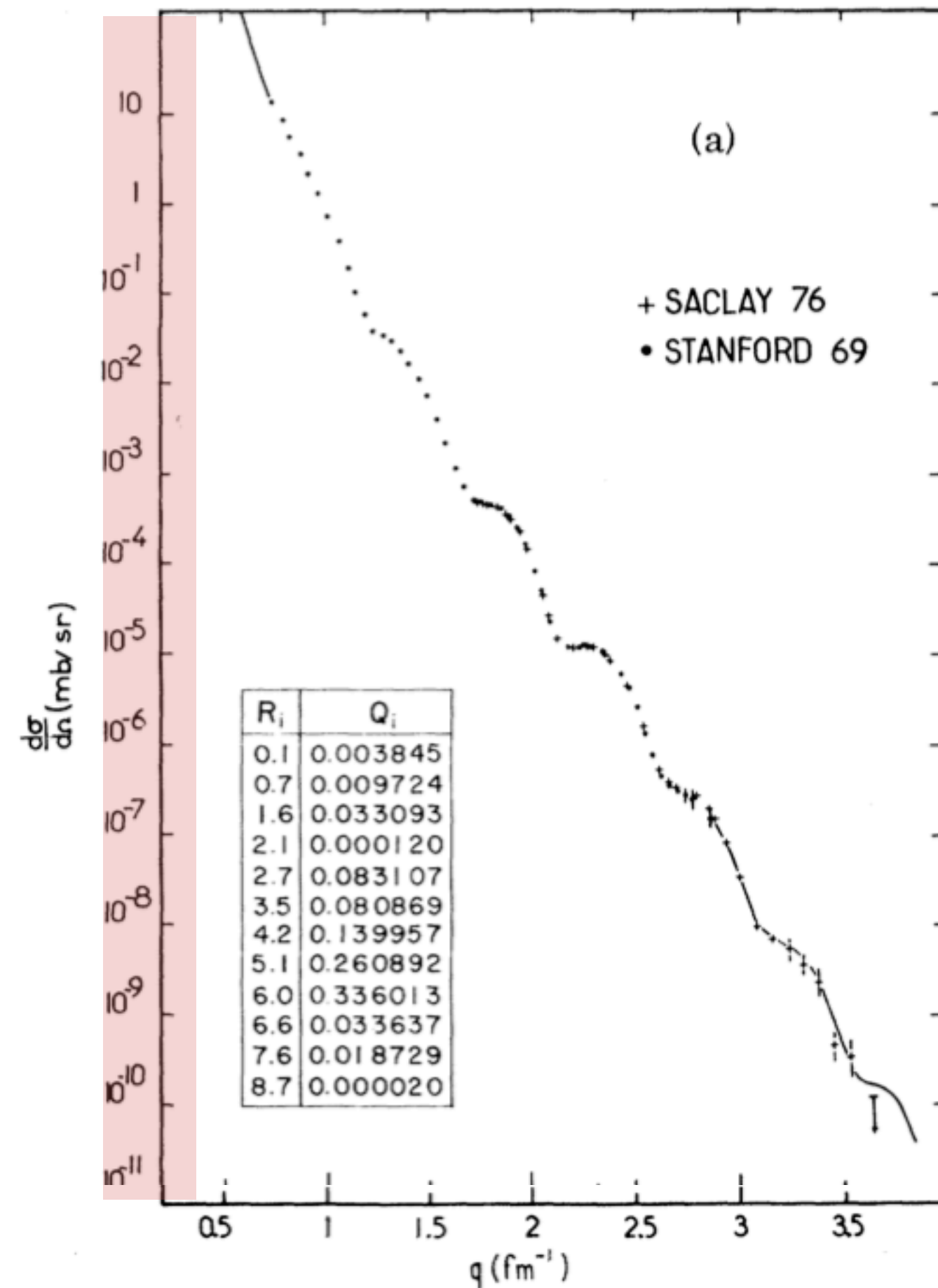
$$F_c(q) \sim 1 - \frac{\langle r_c^2 \rangle}{3!} q^2 + \frac{\langle r_c^4 \rangle}{5!} q^4 + \frac{\langle r_c^6 \rangle}{6!} q^6 + \dots$$

Determination of $\langle r^4 \rangle$ by low- q measurement

NuSRAP2026
2026.07.13-07.15

ULQ2 facility
proton and

$E_e \sim 10 - 100$ MeV
 $\theta = 30 - 130^\circ$
 $q = 5 - 50$ fm $^{-1}$

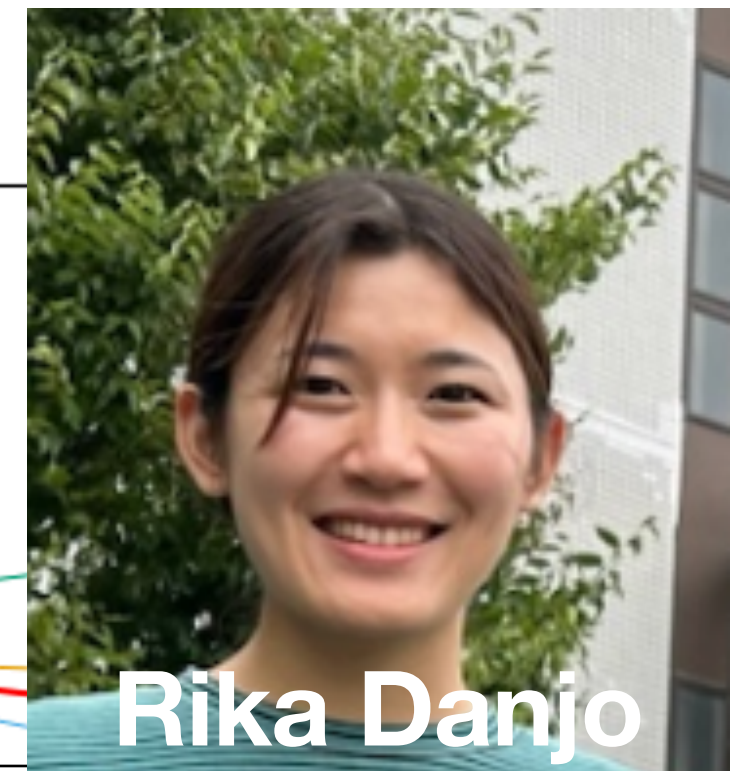
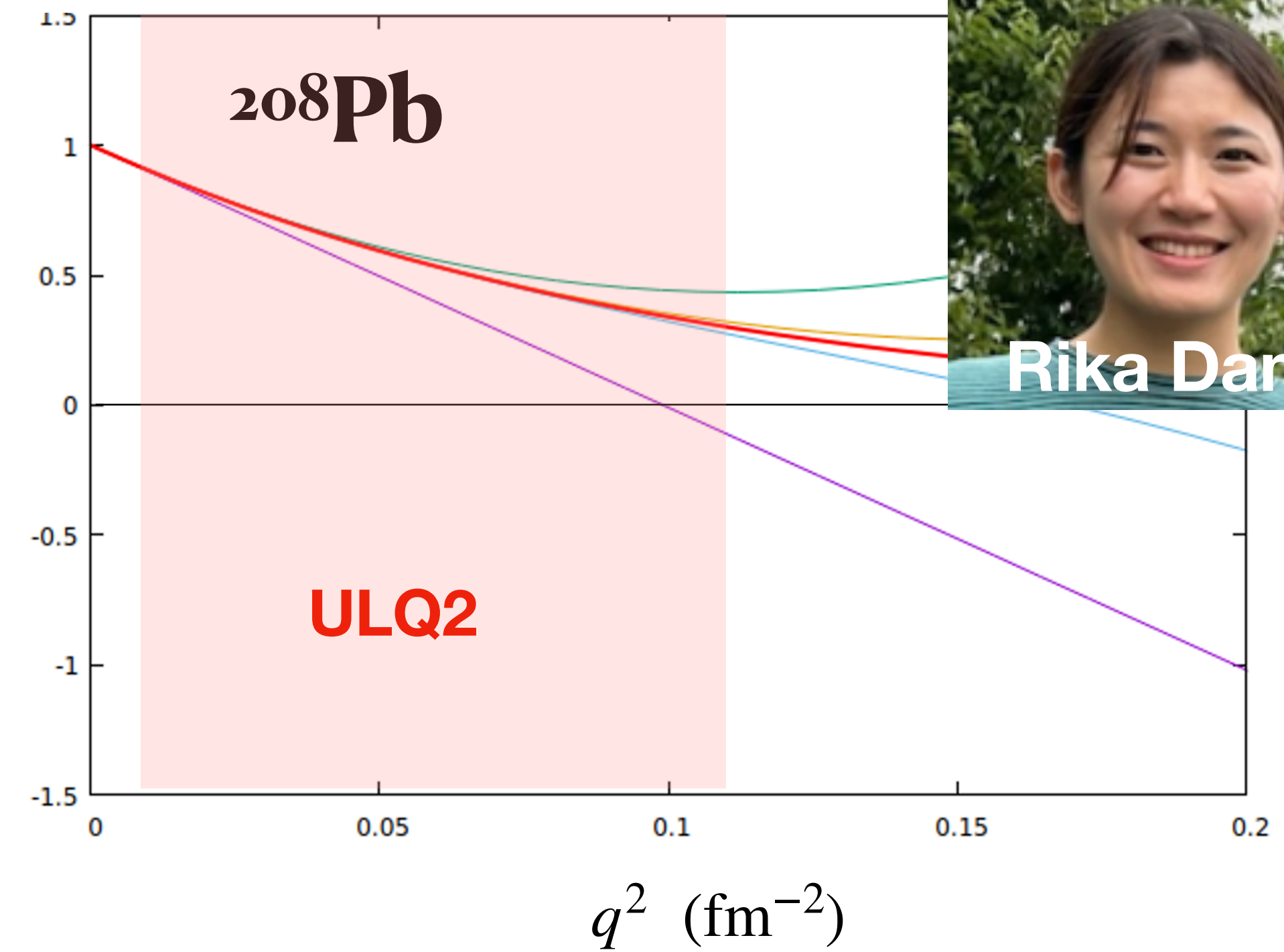


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$^{208}\text{Pb}(e,e')$

- $^{208}\text{Pb}(e,e')$ at the **lowest-ever q** region
- **known $\rho(r)$** $\Rightarrow \langle r_c^4 \rangle$
- high precision measurement (10^{-3}) required

$|F(q)|^2$



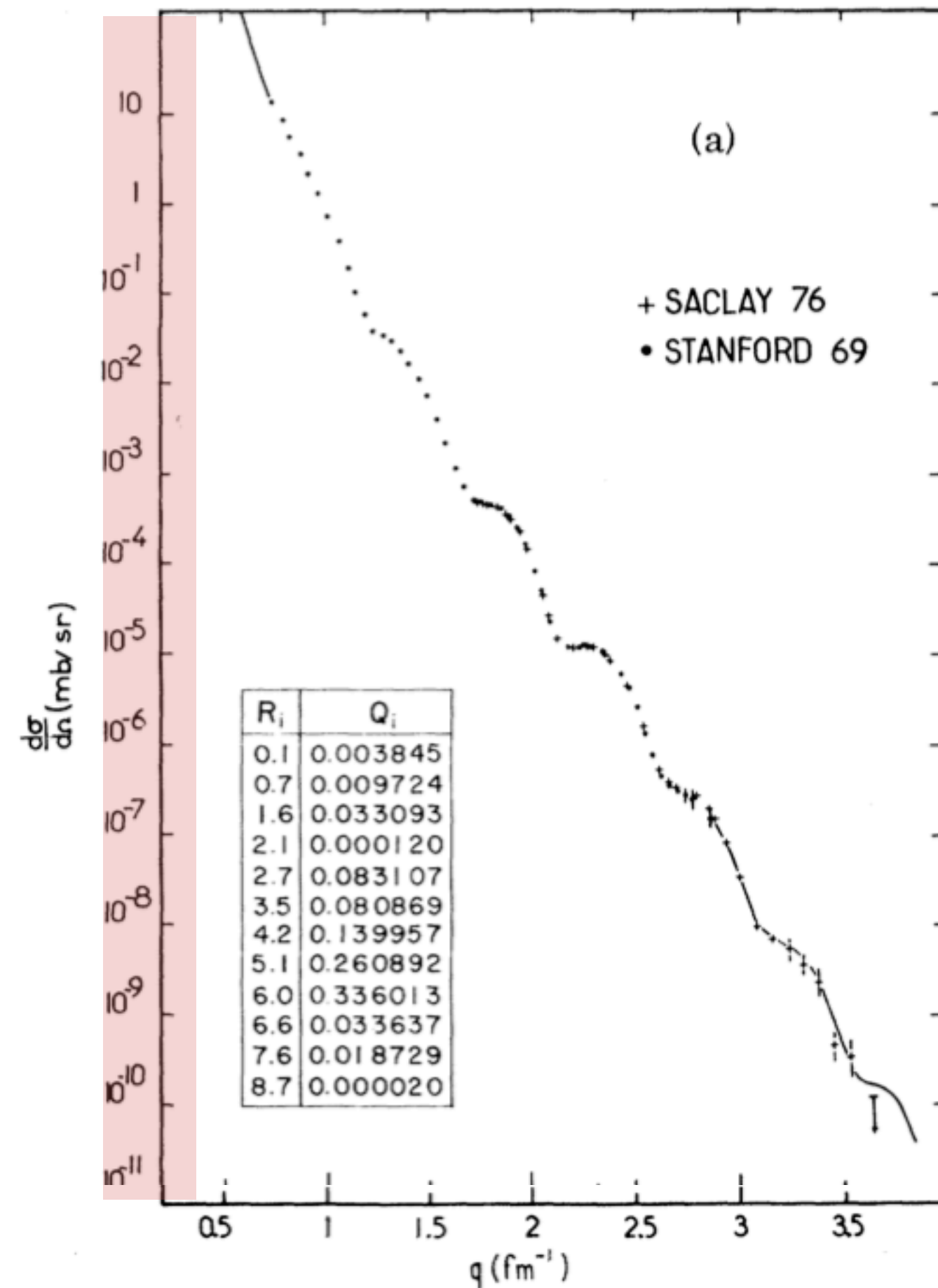
Rika Danjo

Determination of $\langle r^4 \rangle$ by low- q measurement

NuSRAP2026
2026.07.13-07.15

ULQ2 facility
proton and

$E_e \sim 10 - 100$ MeV
 $\theta = 30 - 130^\circ$
 $q = 5 - 50$ fm $^{-1}$

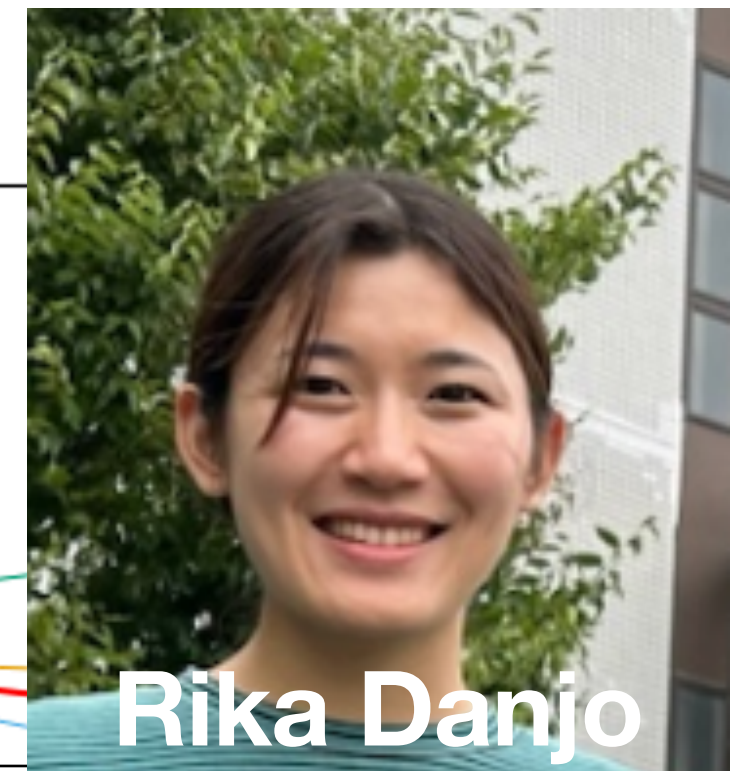
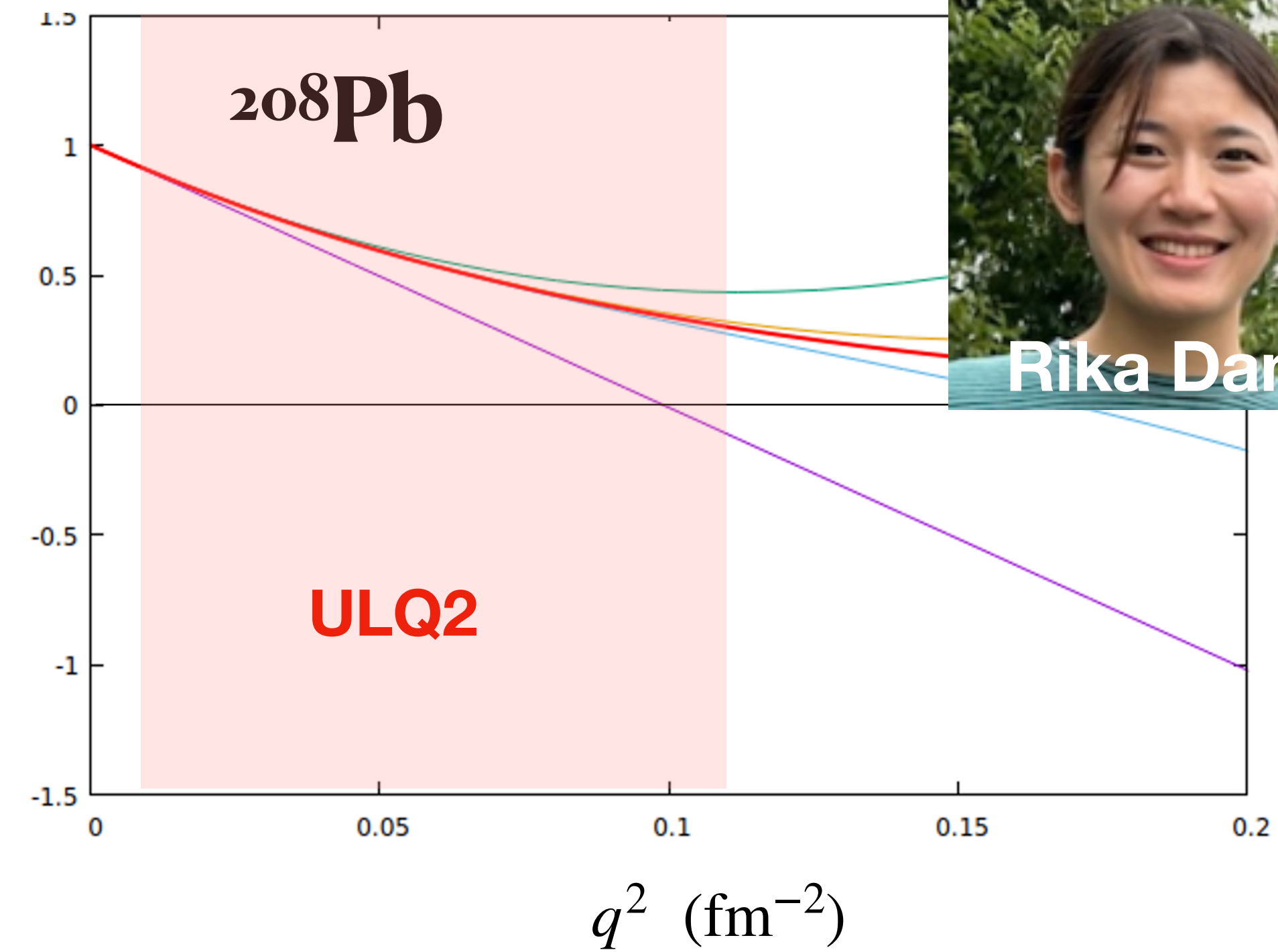


$$F_c(q) \sim 1 - \frac{\langle r_c^2 \rangle}{3!} q^2 + \frac{\langle r_c^4 \rangle}{5!} q^4 + \frac{\langle r_c^6 \rangle}{6!} q^6 + \dots$$

$^{208}\text{Pb}(e,e')$

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$|F(q)|^2$



Rika Danjo

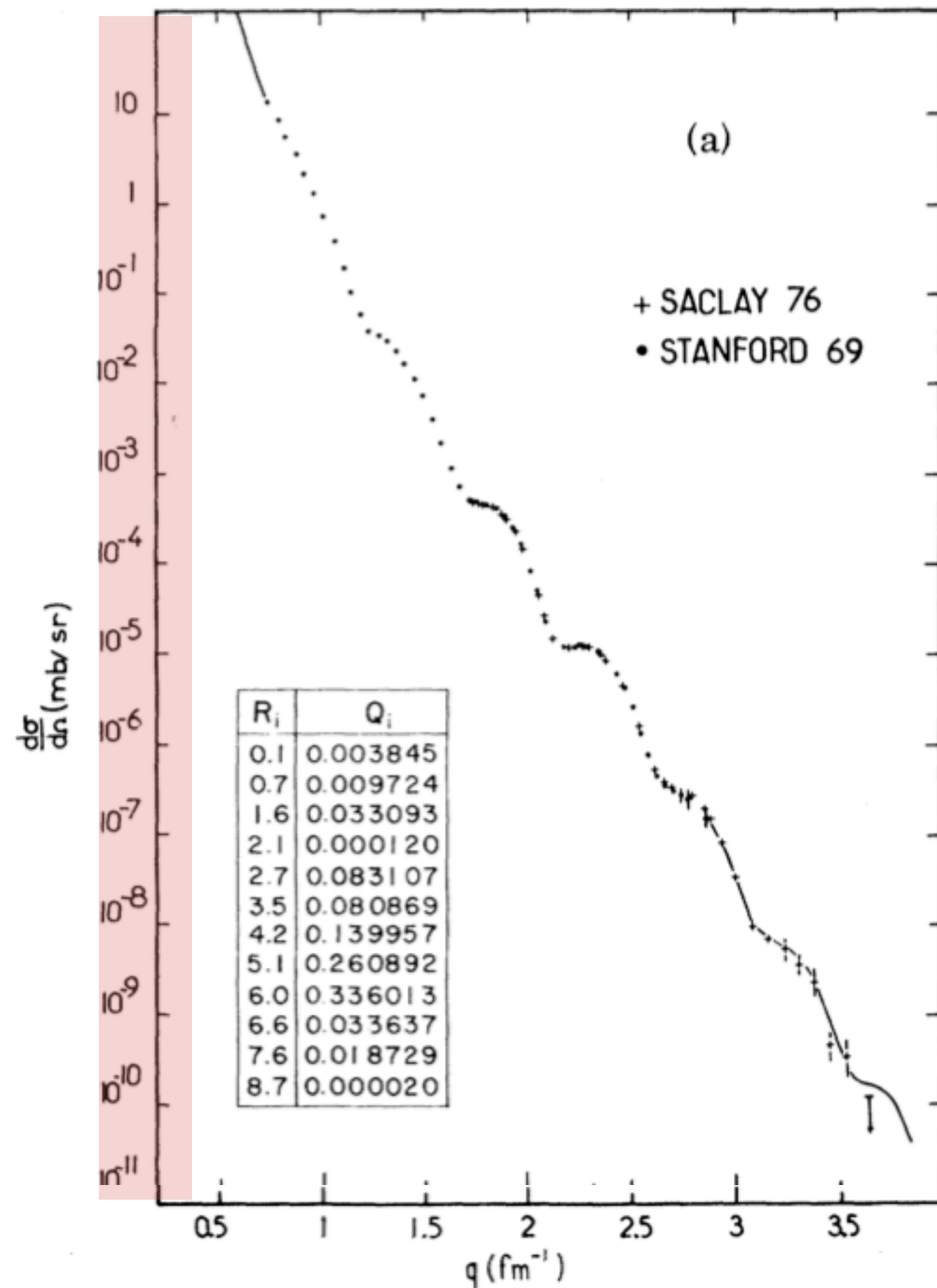
$\Rightarrow$ successfully conducted at Tohoku in the last May

Determination of $\langle r^4 \rangle$ by low- q measurement

NuSRAP2026
2026.07.13-07.15

ULQ2 facility
proton and

$E_e \sim 10 - 100$ MeV
 $\theta = 30 - 130^\circ$
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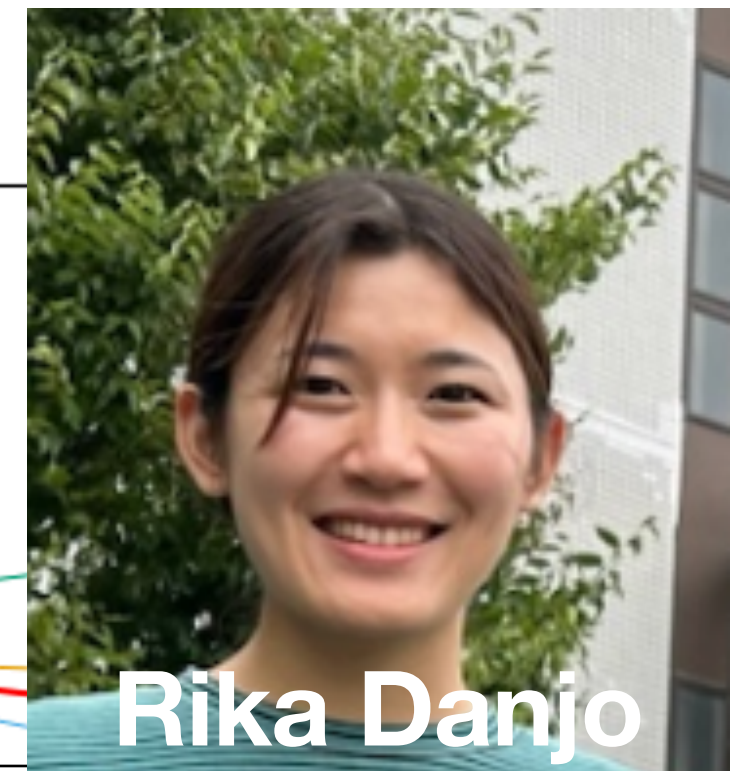
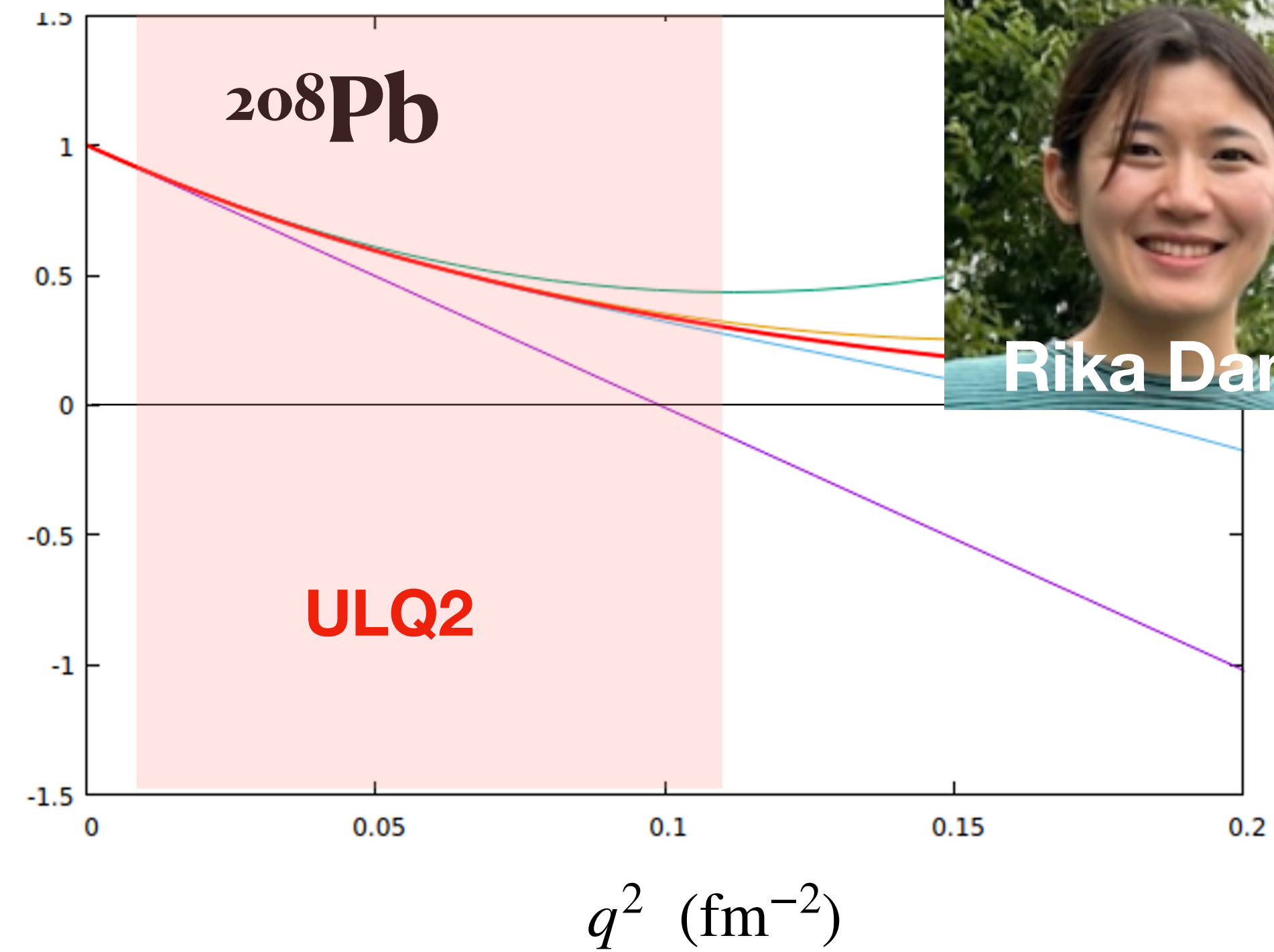


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$^{208}\text{Pb}(e,e')$

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$|F(q)|^2$



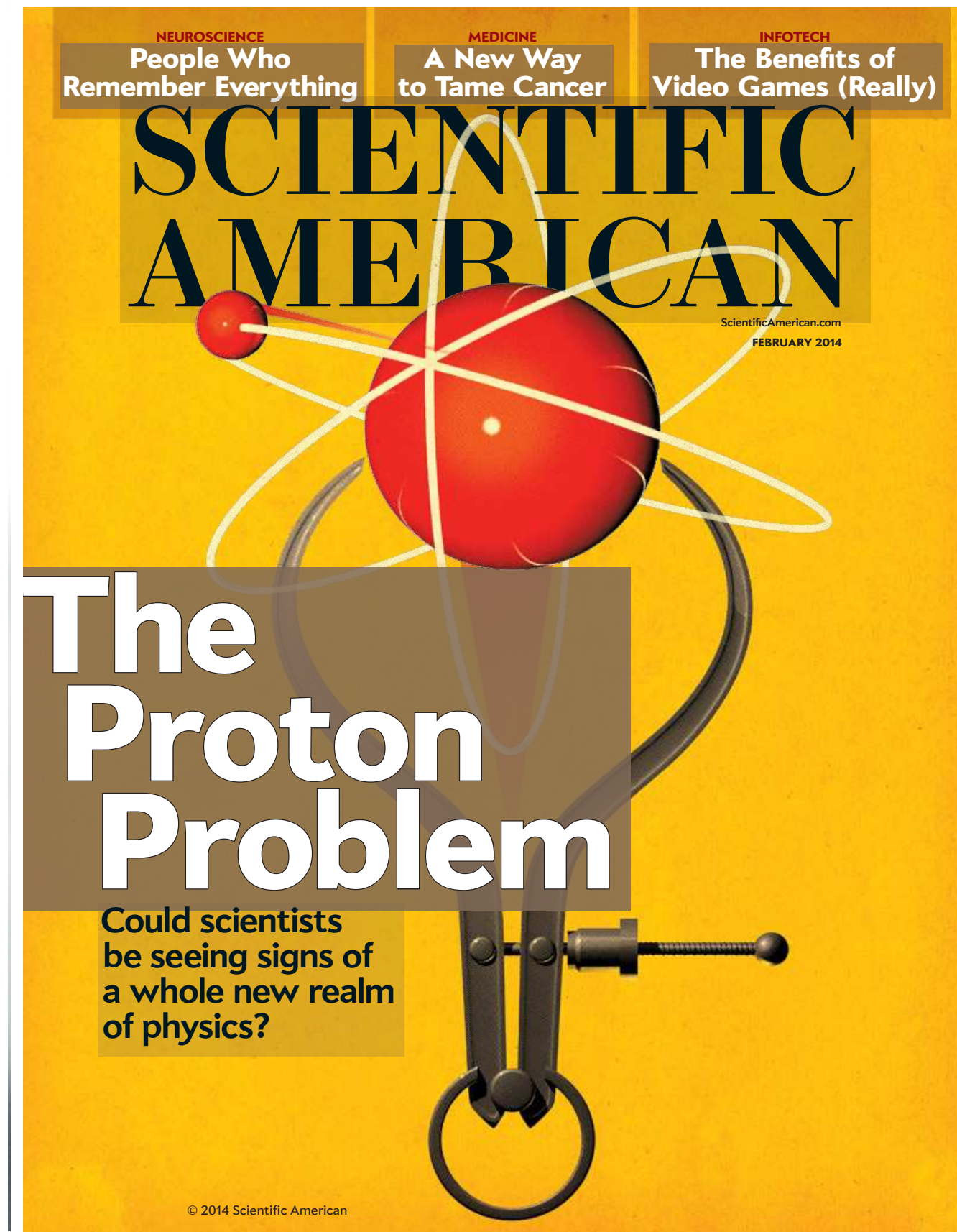
Rika Danjo

$\Rightarrow$ successfully conducted at Tohoku in the last May

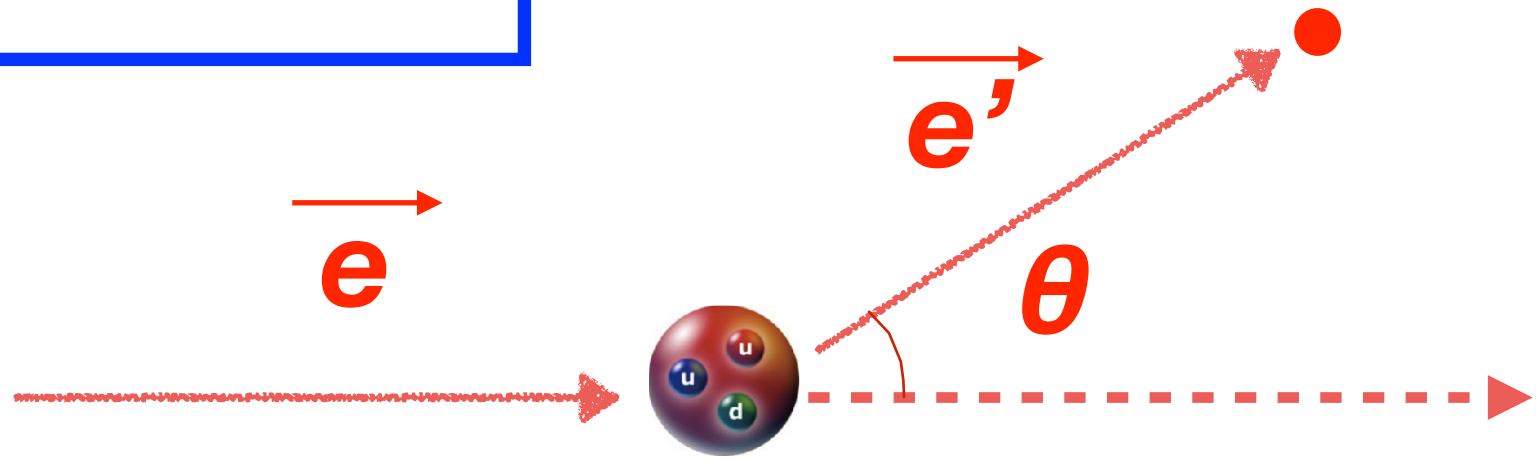
$\Rightarrow$ **future application to neutron-rich nuclei at SCRIT**

**elastic electron-proton scattering
covering the lowest-ever q region**

**elastic electron-proton scattering
covering the lowest-ever q region**



Kinematics



momentum transfer $\vec{q} = \vec{e} - \vec{e}'$
 energy transfer $\omega = e - e'$
 4 momentum transfer $Q^2 = q^2 - \omega^2$
 $= 4 e e' \sin^2(\theta/2)$

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{G_E^2(Q^2) + \frac{\tau}{\epsilon} G_M^2(Q^2)}{1 + \tau}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{z^2 \alpha^2 \cos^2(\theta/2)}{4e^2 \sin^4(\theta/2)} \propto \frac{e^2}{q^4}$$

$$\epsilon = \frac{1}{1 + 2(1 + \tau) \tan^2 \frac{\theta}{2}} \quad \tau = \frac{Q^2}{4m_p^2}$$

Proton charge radius

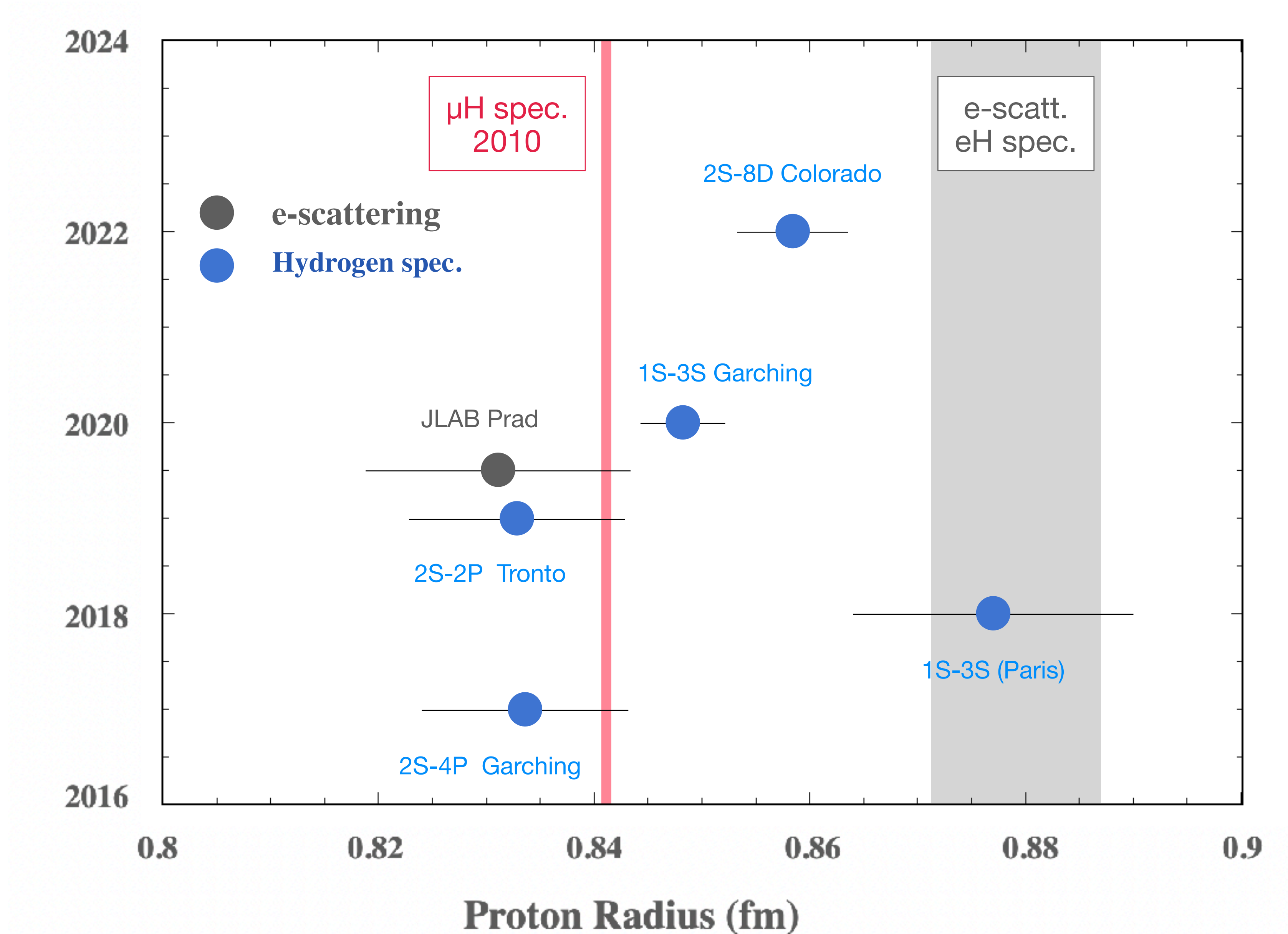
$$\langle r^2 \rangle \equiv -6 \frac{dG_E(Q^2)}{dQ^2} \Big|_{Q^2 \rightarrow 0}$$

no measurement is possible at $Q^2 = 0$

➡ $G_E(Q^2)$ at low Q^2 as possible

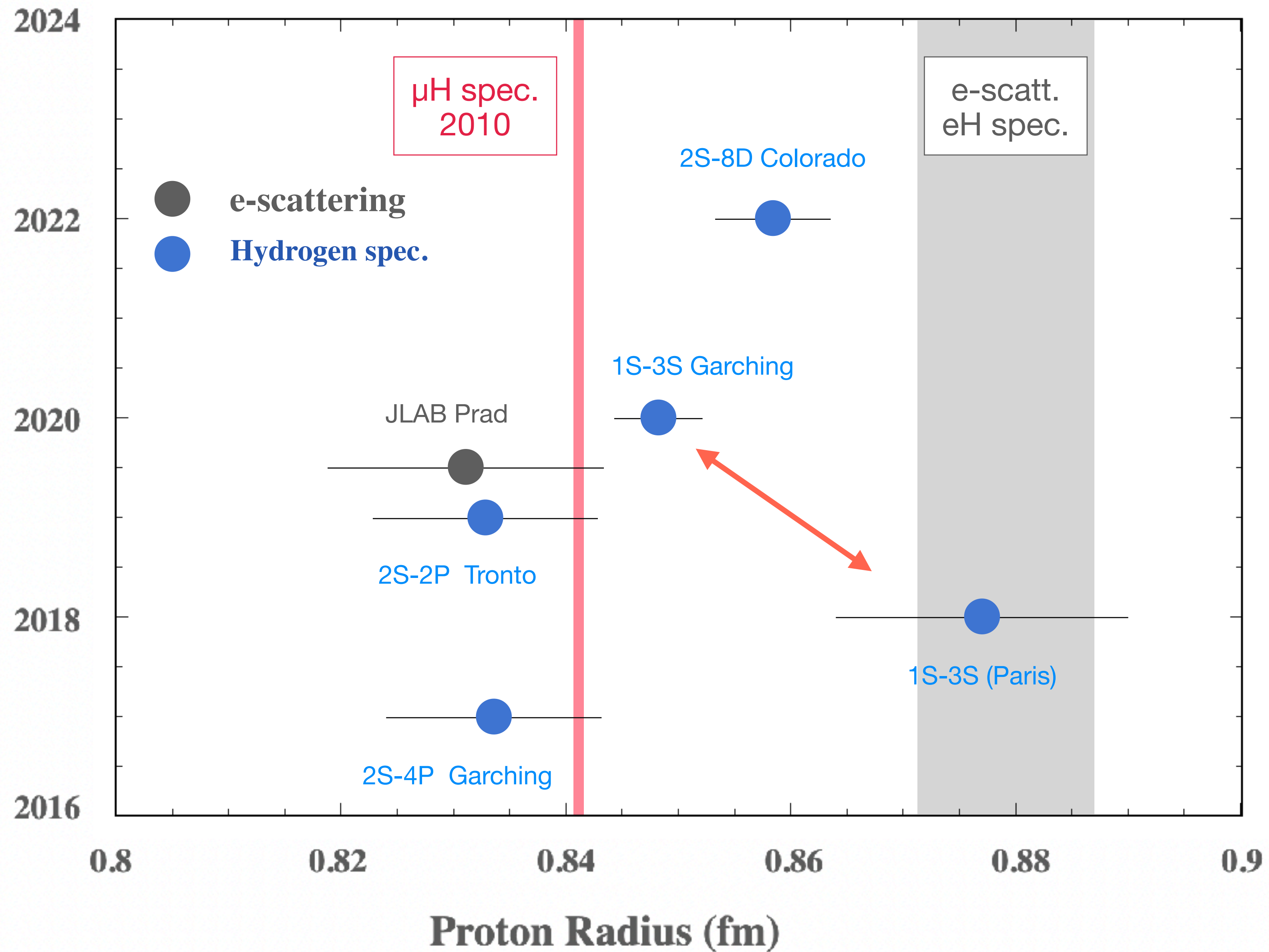
proton charge radius as of today

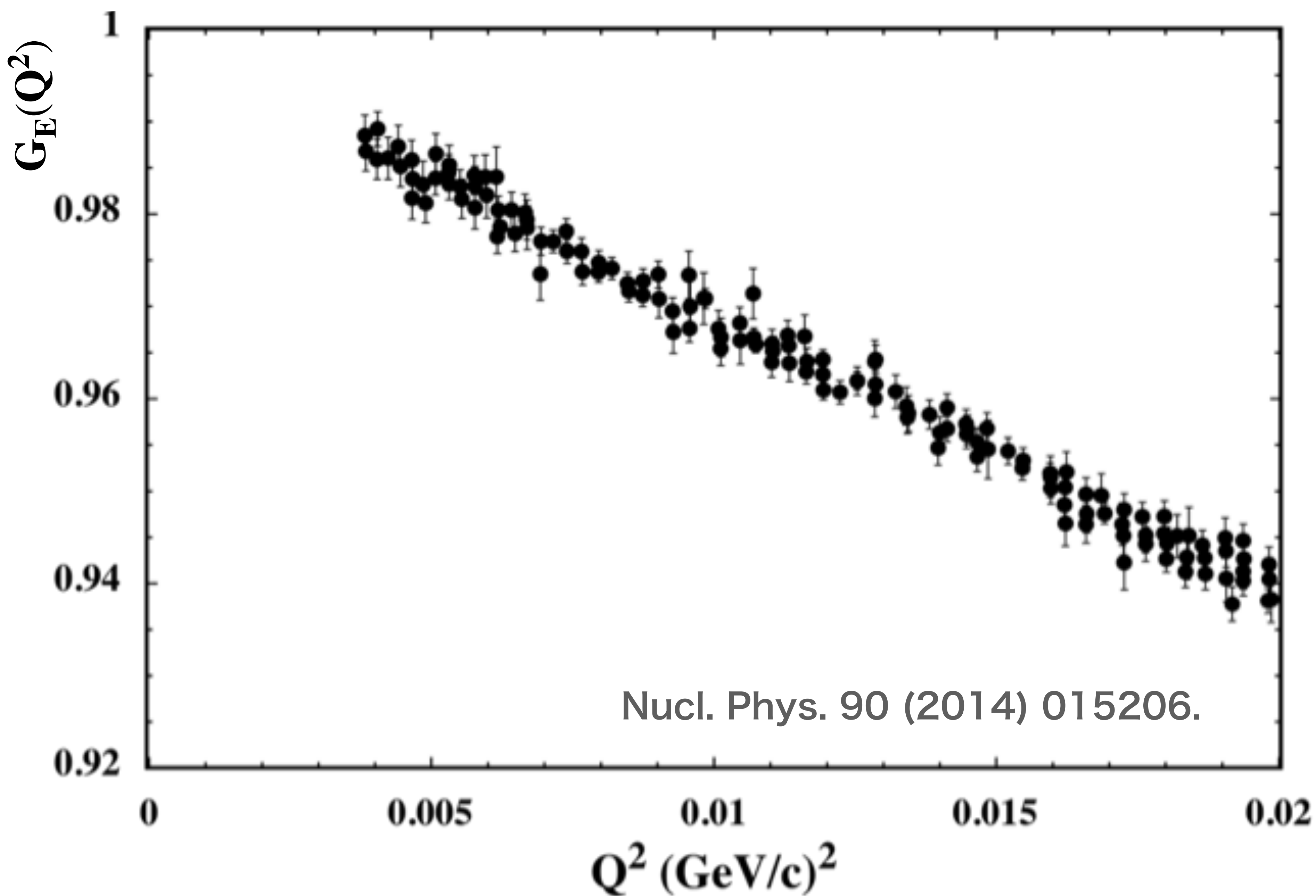
NuSRAP2026
2026.07.13-07.15

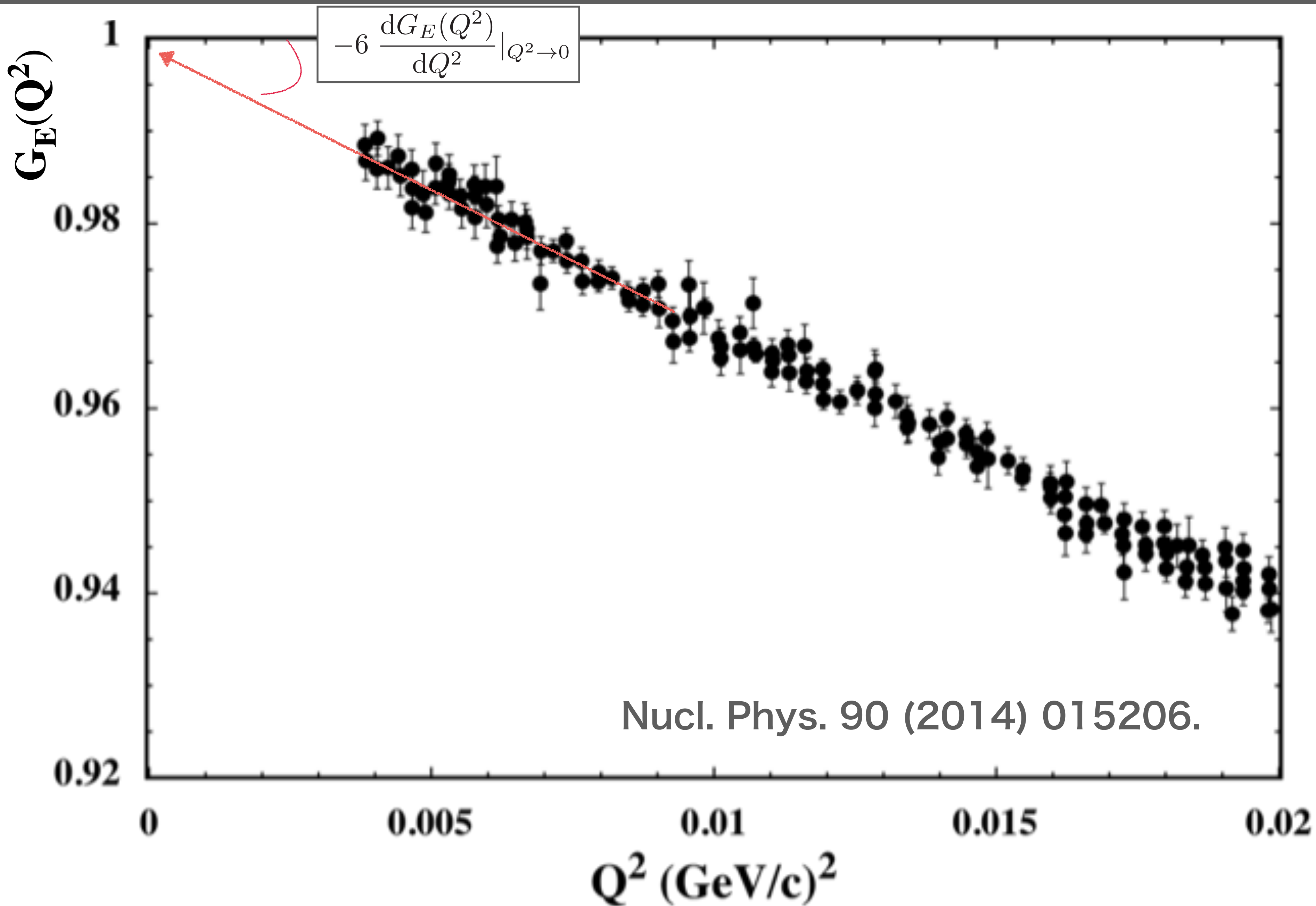


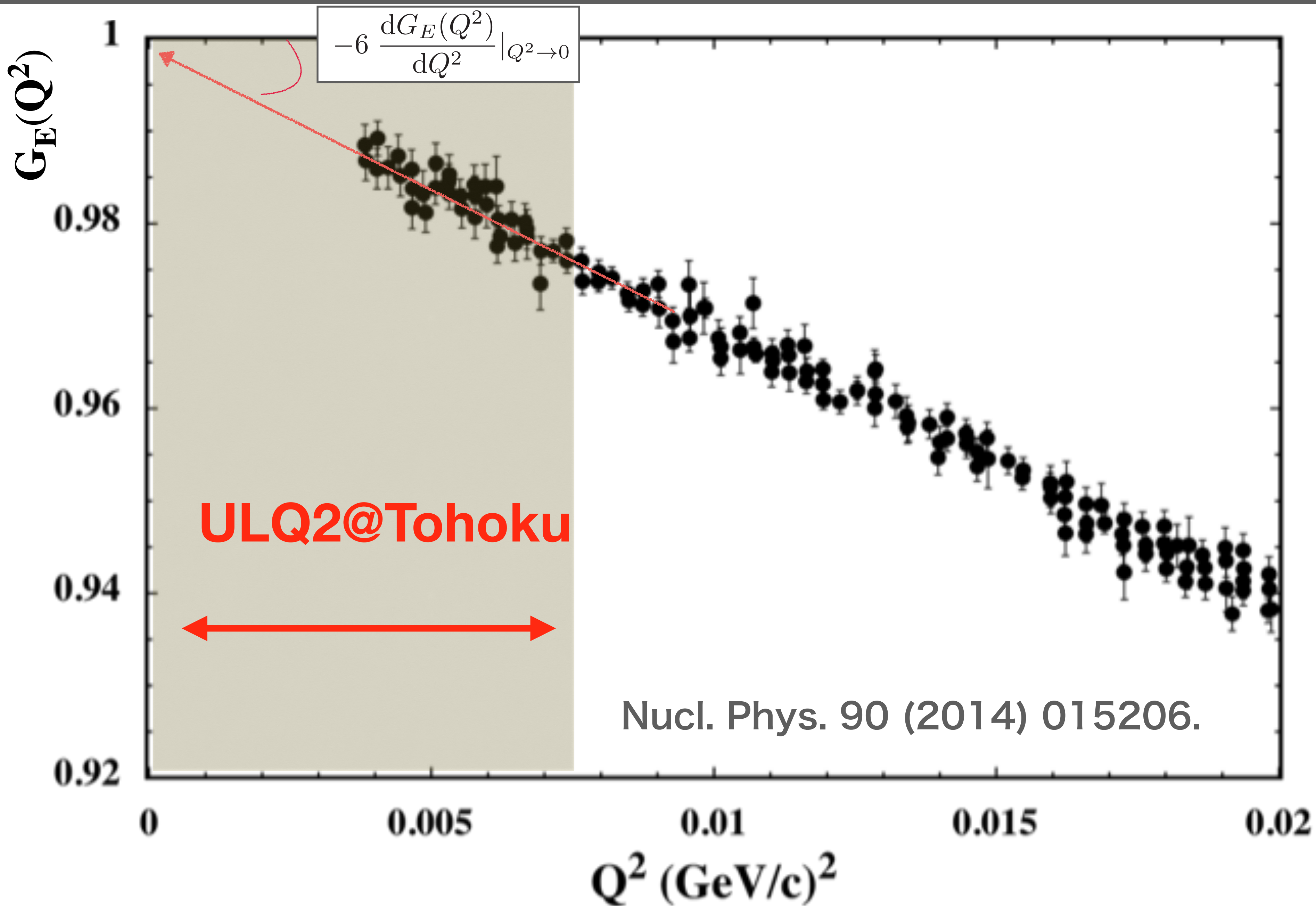
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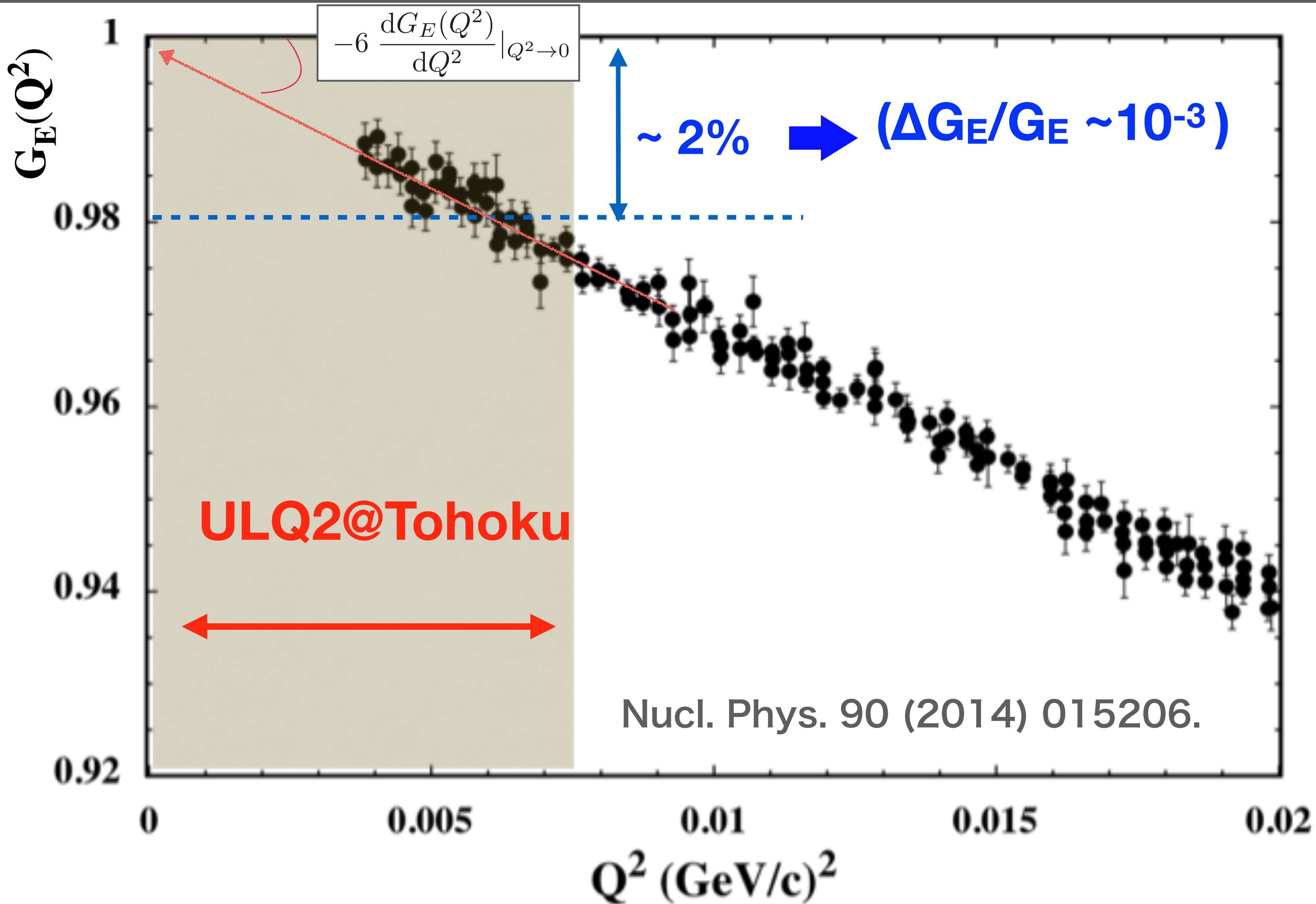
NuSRAP2026
2026.07.13-07.15

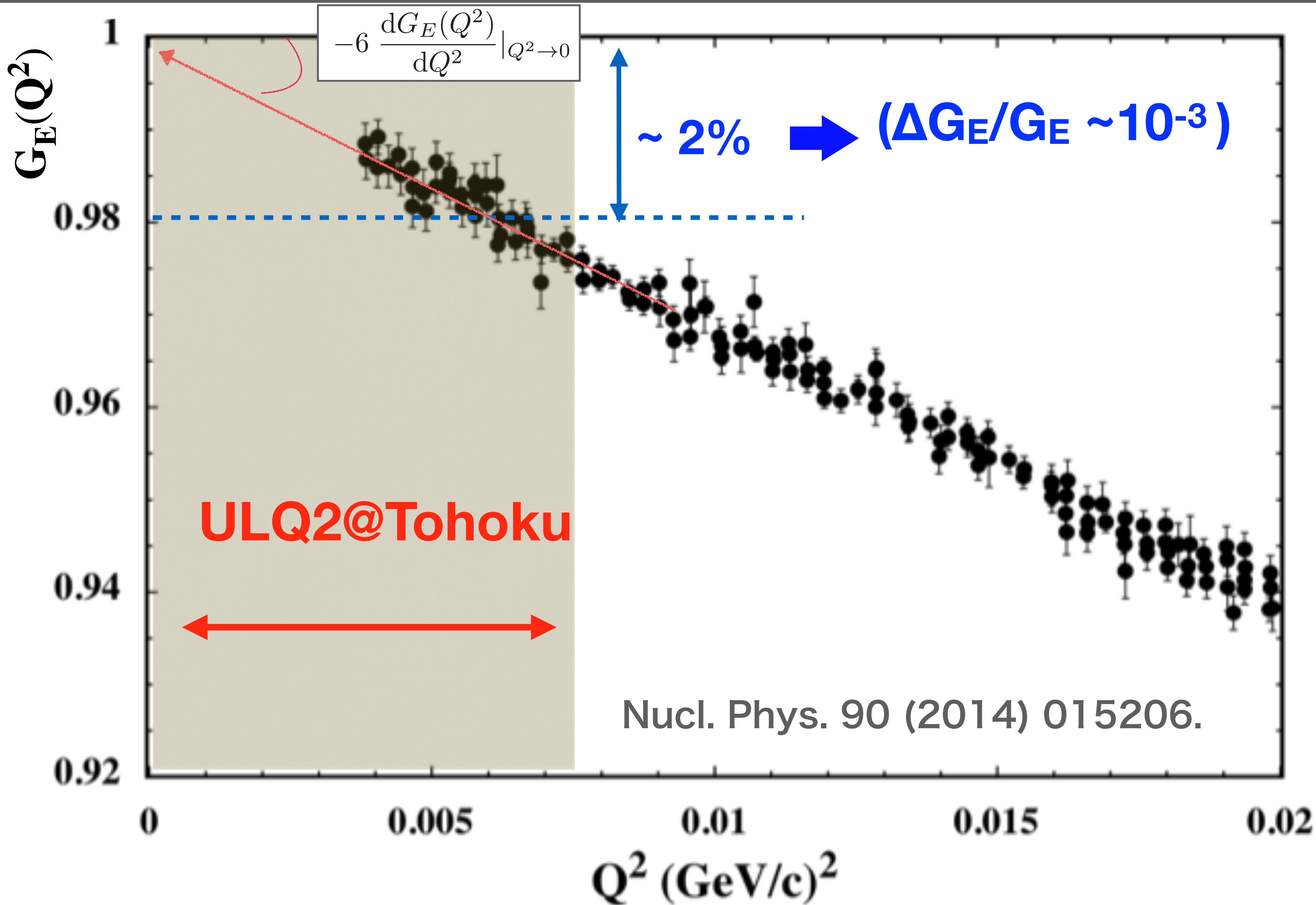












Known problems

1. need lower Q^2
2. no absolute σ
($\Delta \sigma / \sigma \sim 10^{-3}$)
3. GE, GM separation

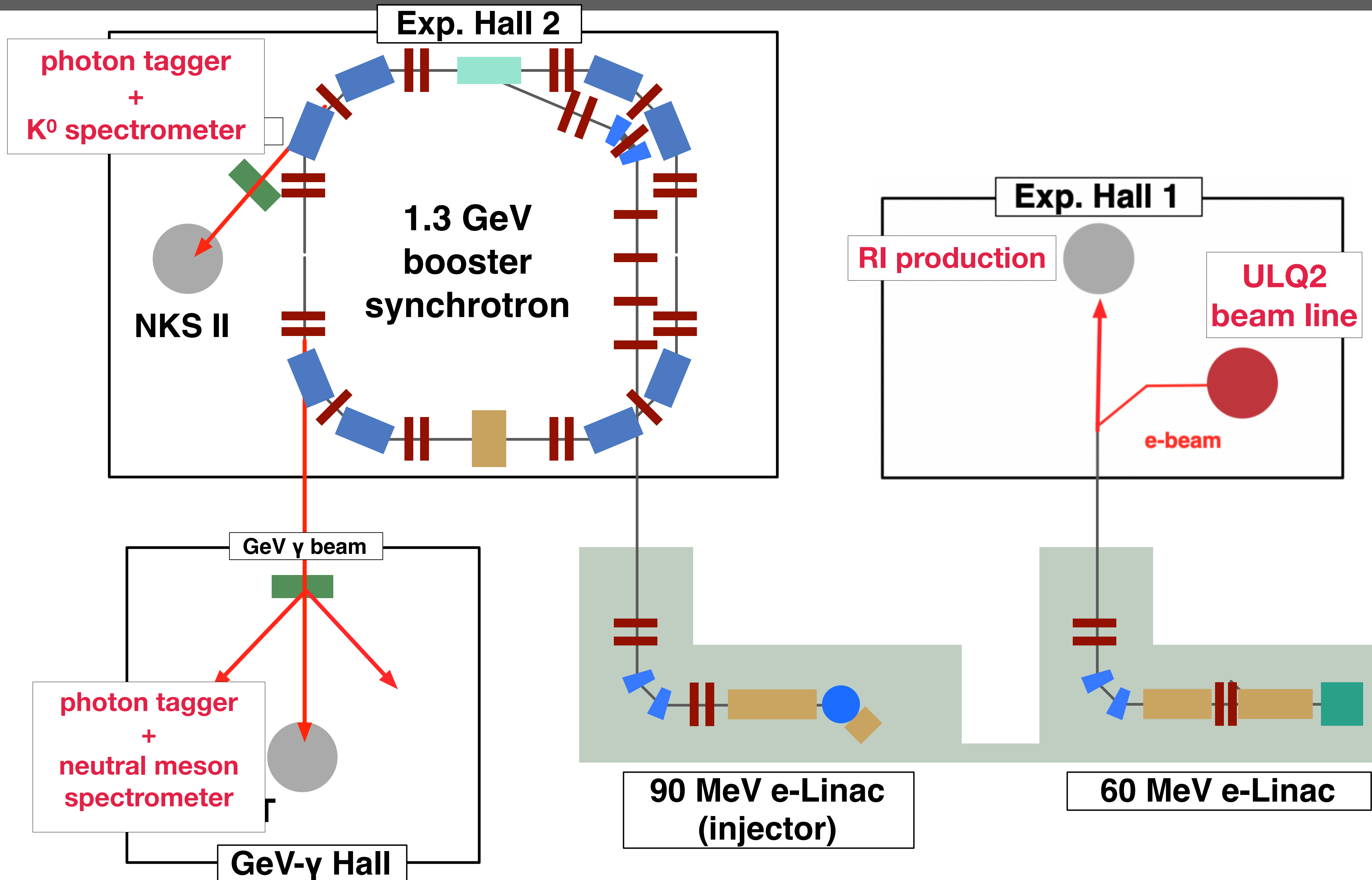
ULQ2 @ Tohoku

$\text{CH}_2(e, e')$

ρ of ^{12}C best know
Rosenbluth sep.

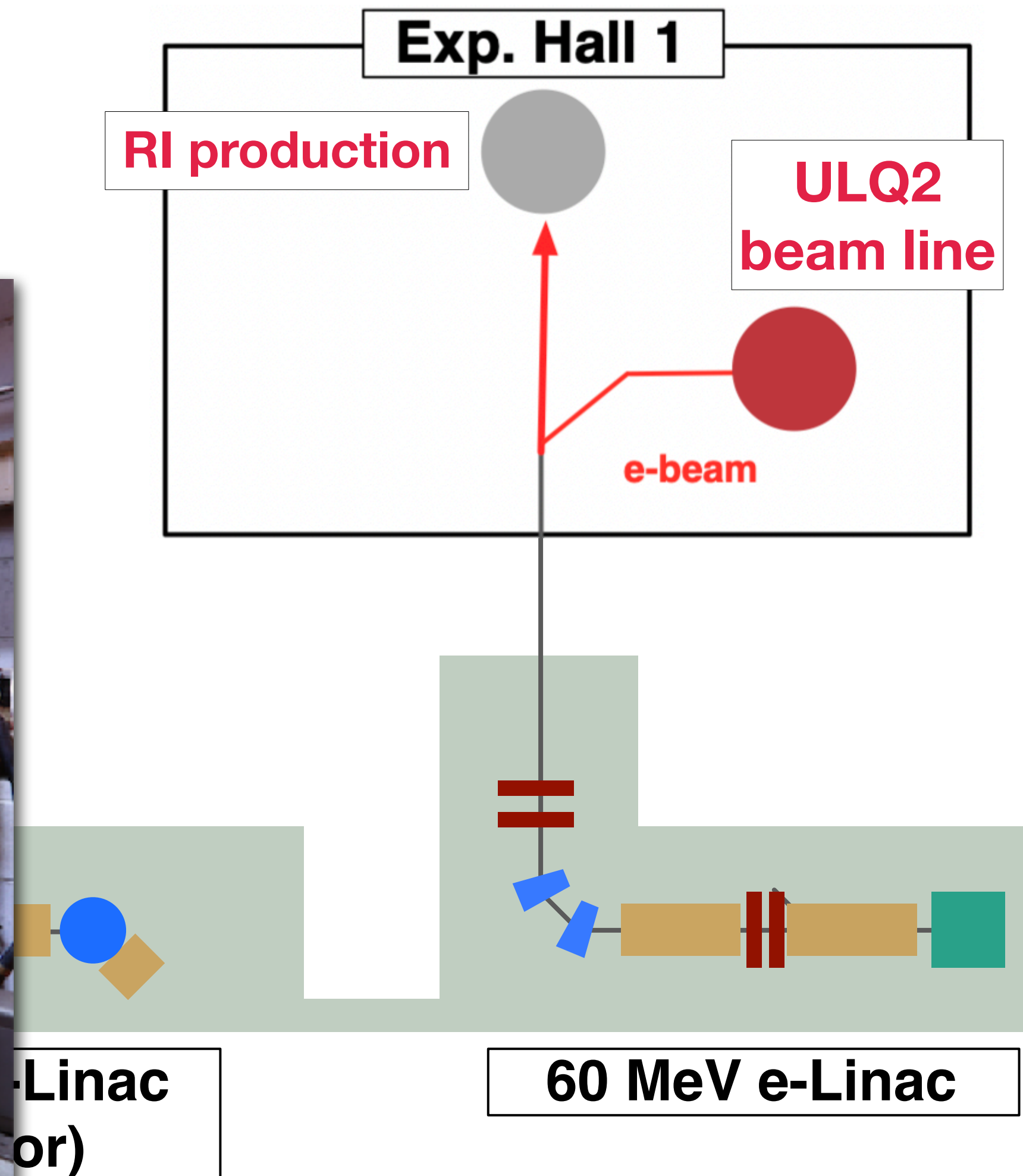
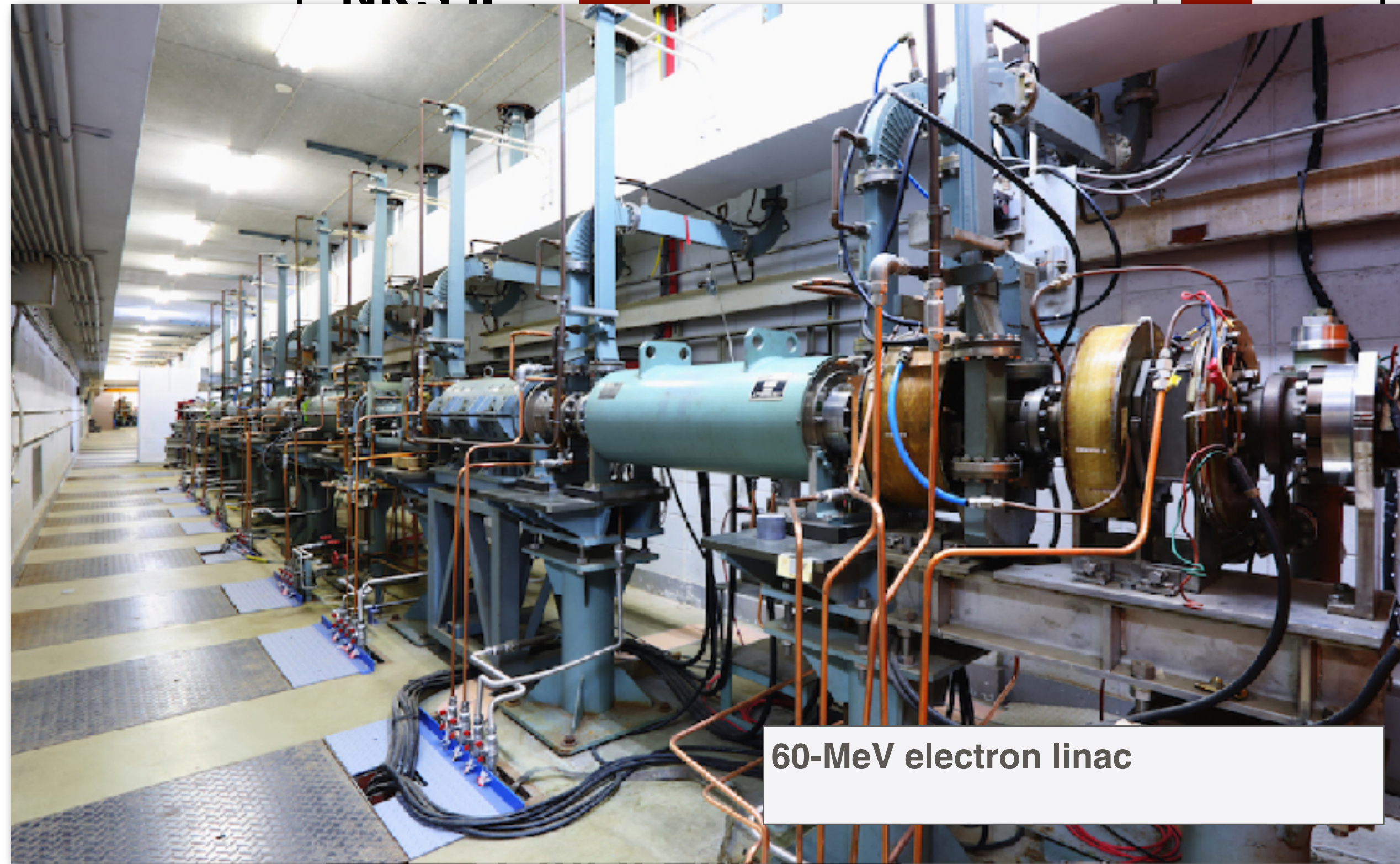
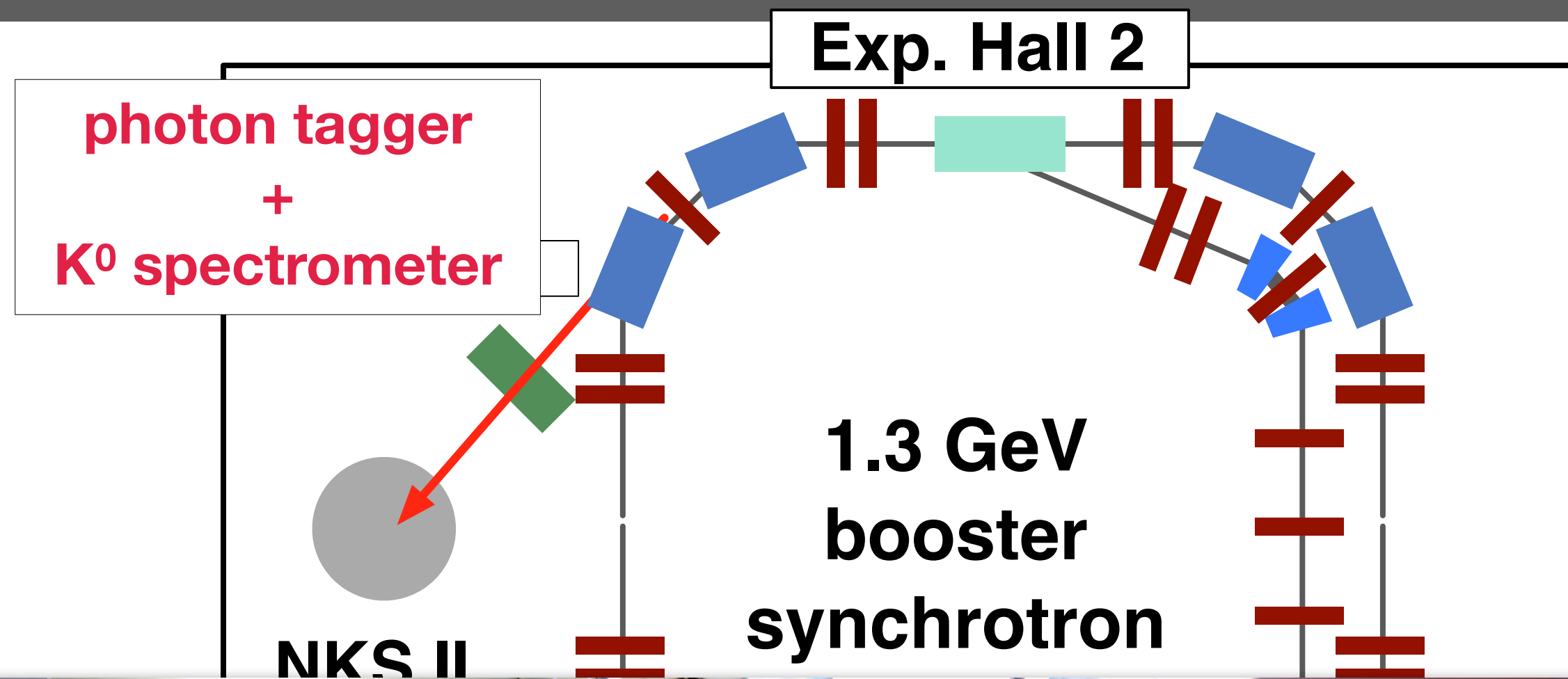
ULQ2 (Ultra-Low Q^2) at Tohoku

NuSRAP2026
2026.07.13-07.15



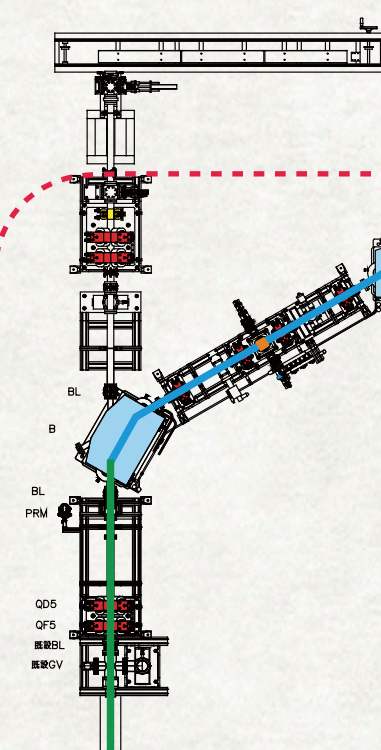
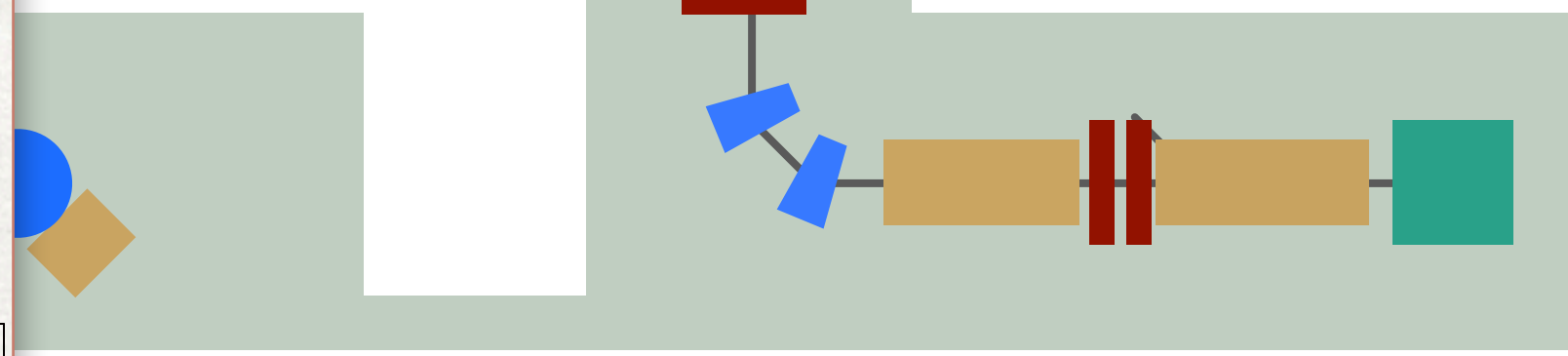
ULQ2 (Ultra-Low Q^2) at Tohoku

NuSRAP2026
2026.07.13-07.15



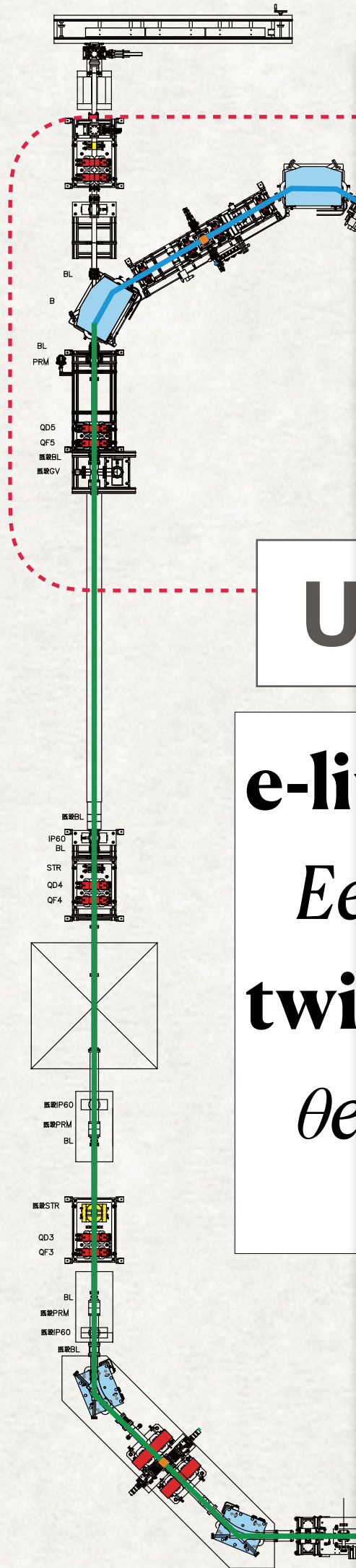
GeV- γ Hall

Ge v-γ παλ

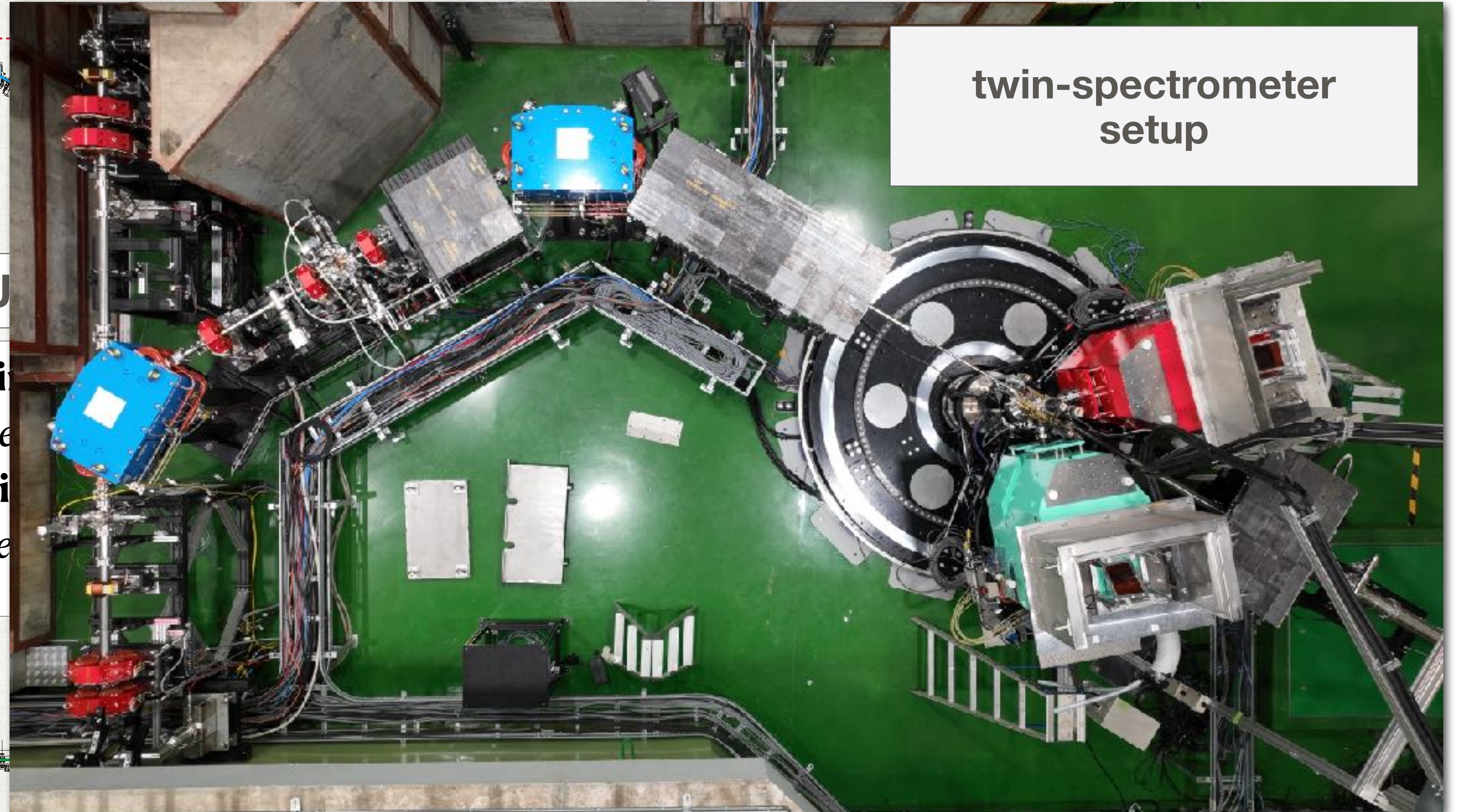
[illegible]

ULQ2 (Ultra-Low Q^2) at Tohoku

NuSRAP2026
2026.07.13-07.15



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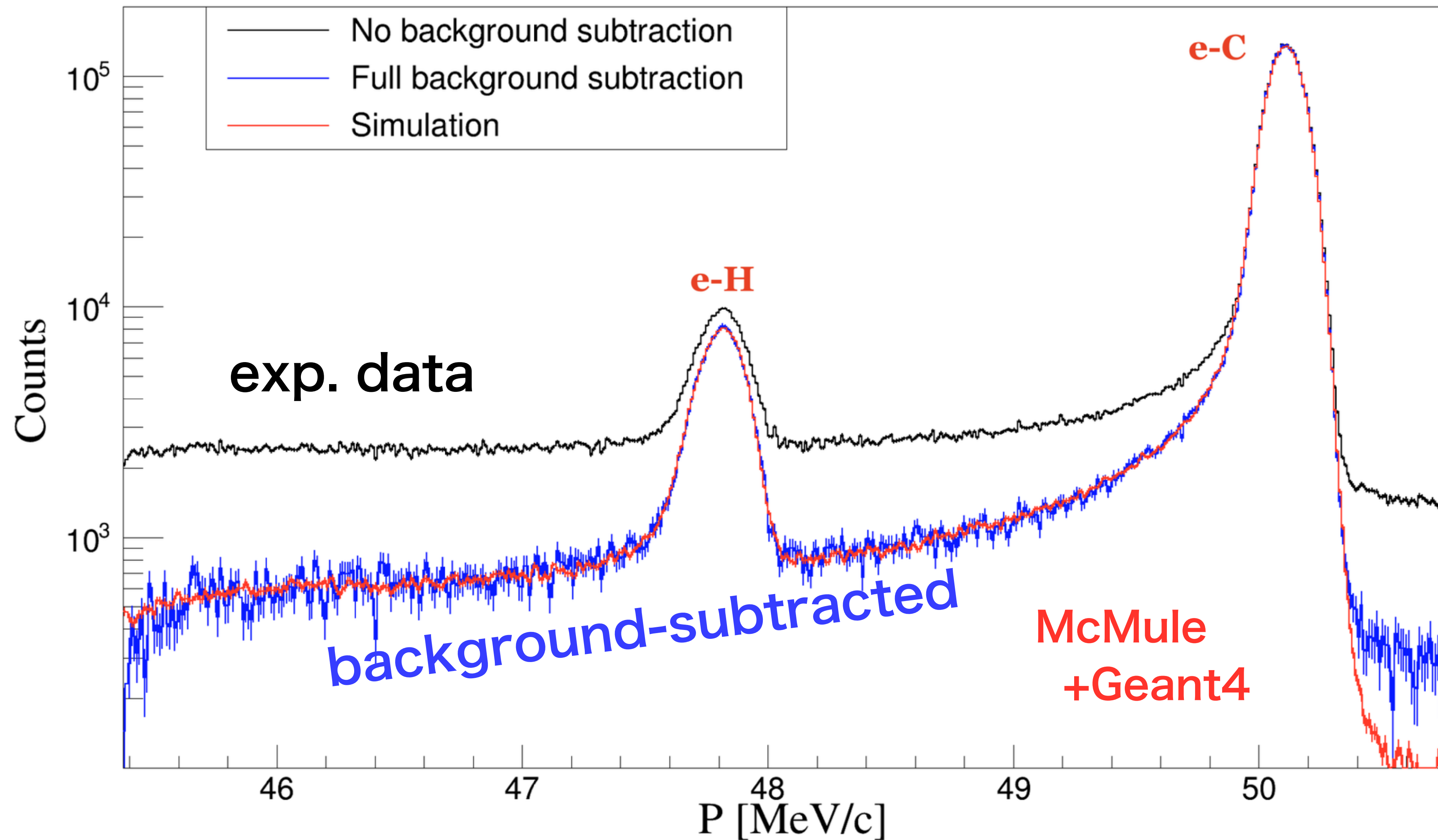


twin-spectrometer
setup

GeV-γ hall

CH2(e,e') at ULQ2 (Ee=20-60 MeV)

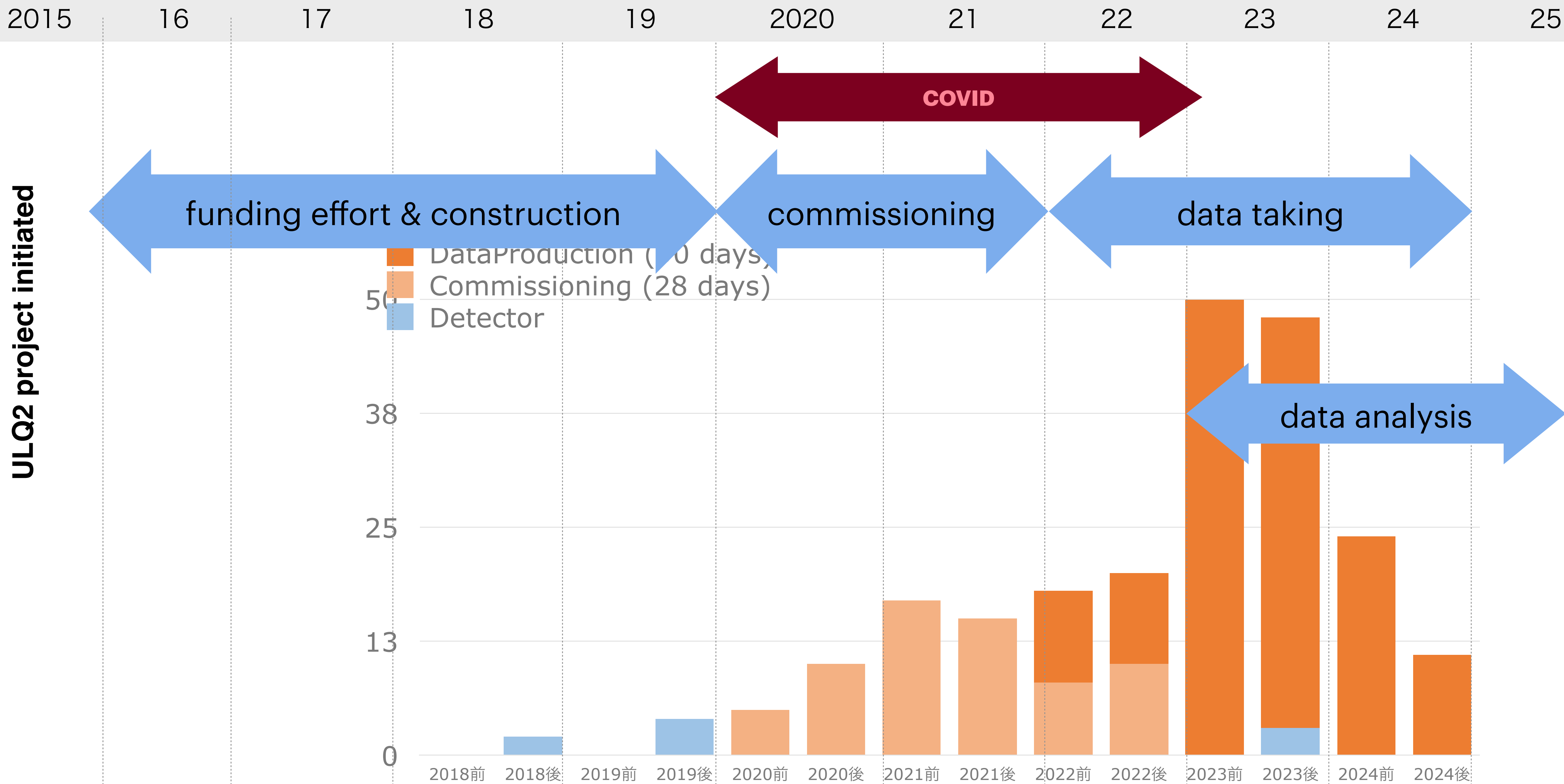
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2026.07.13-07.15



McMule (PSI):
rad. processes
upto NNLO

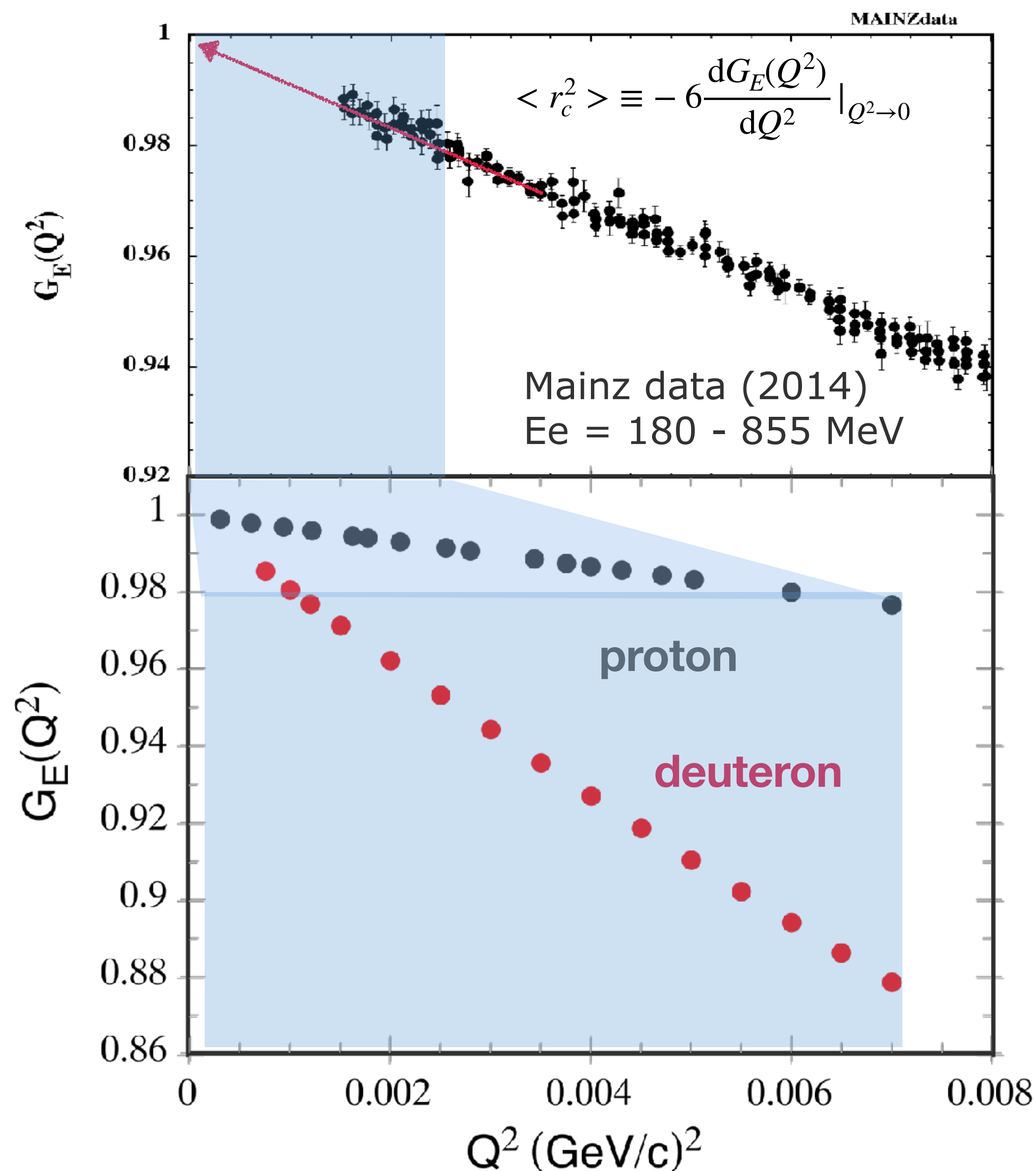
ULQ2-project time line

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ULQ2 measurements for e+p and e+d

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2026.07.13-07.15



three-year data-collection completed(2024, Oct.)



Yuki Honda



Yukie Maeda



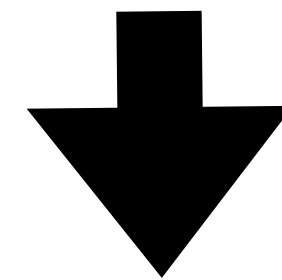
- 1) **proton**
charge radius
magnetic radius (next step)

- 2) **deuteron**
deuteron charge radius
=> neutron charge radius

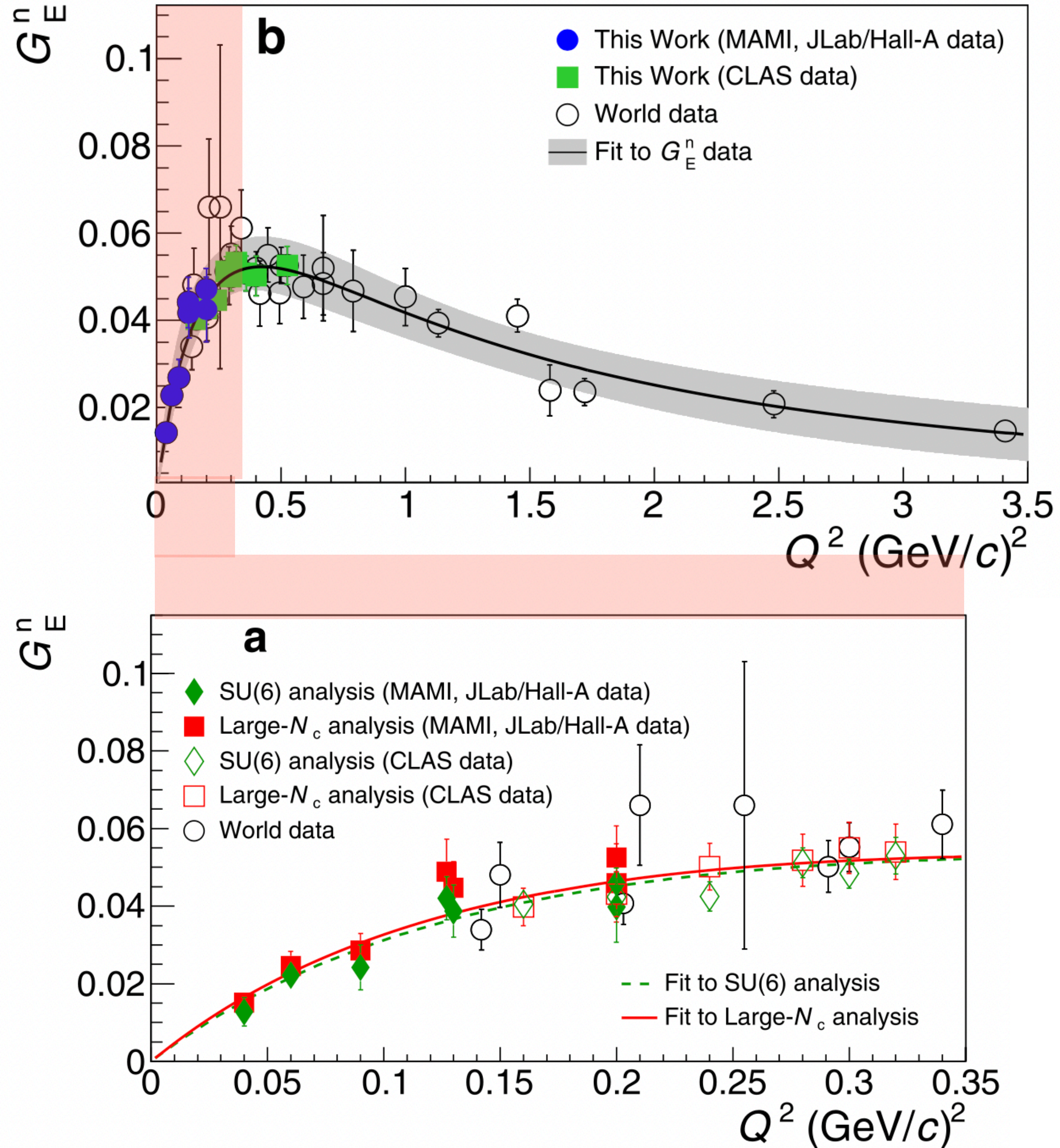


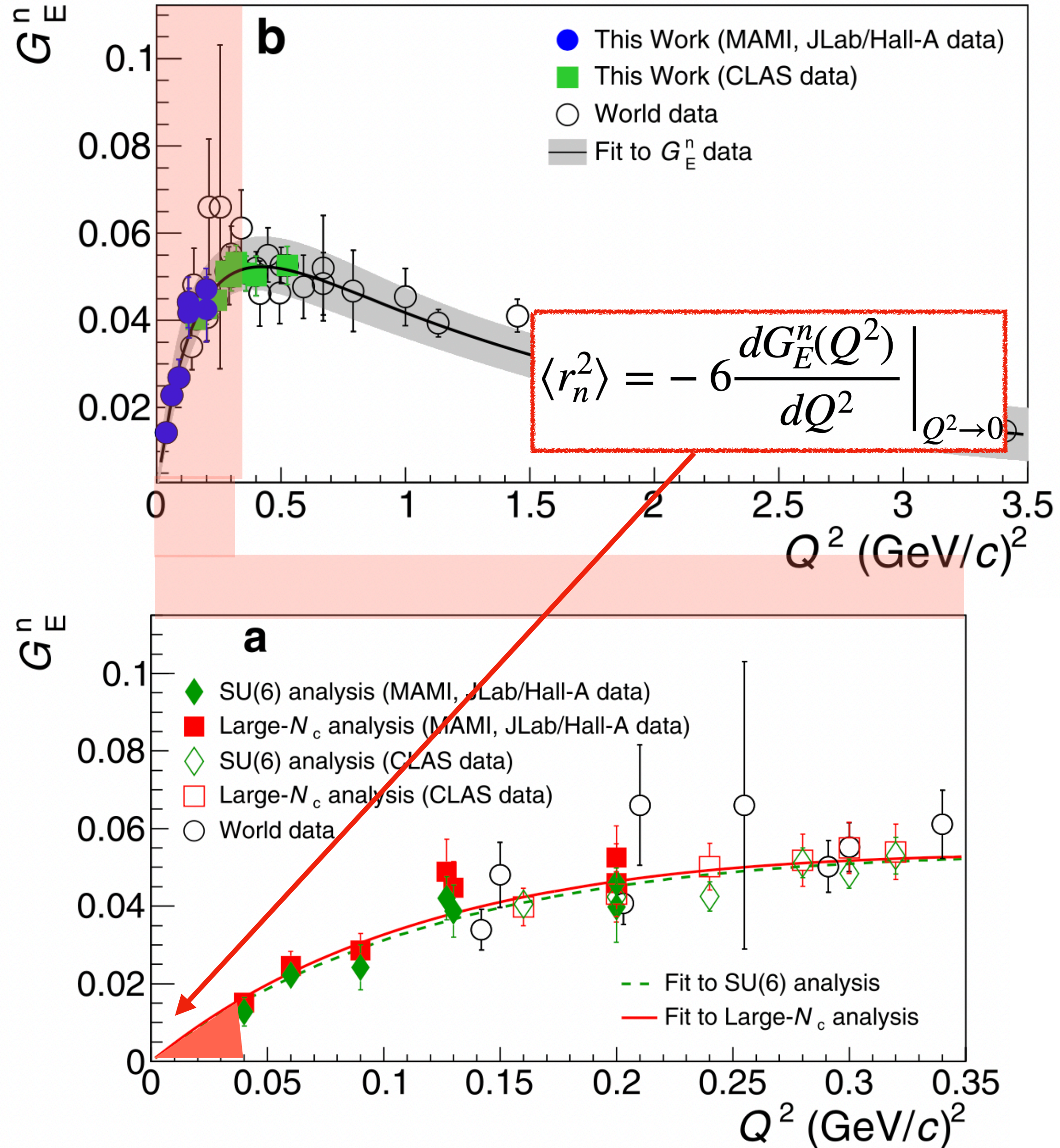
e+D scattering at ULQ2 (lowest-ever Q2 data)

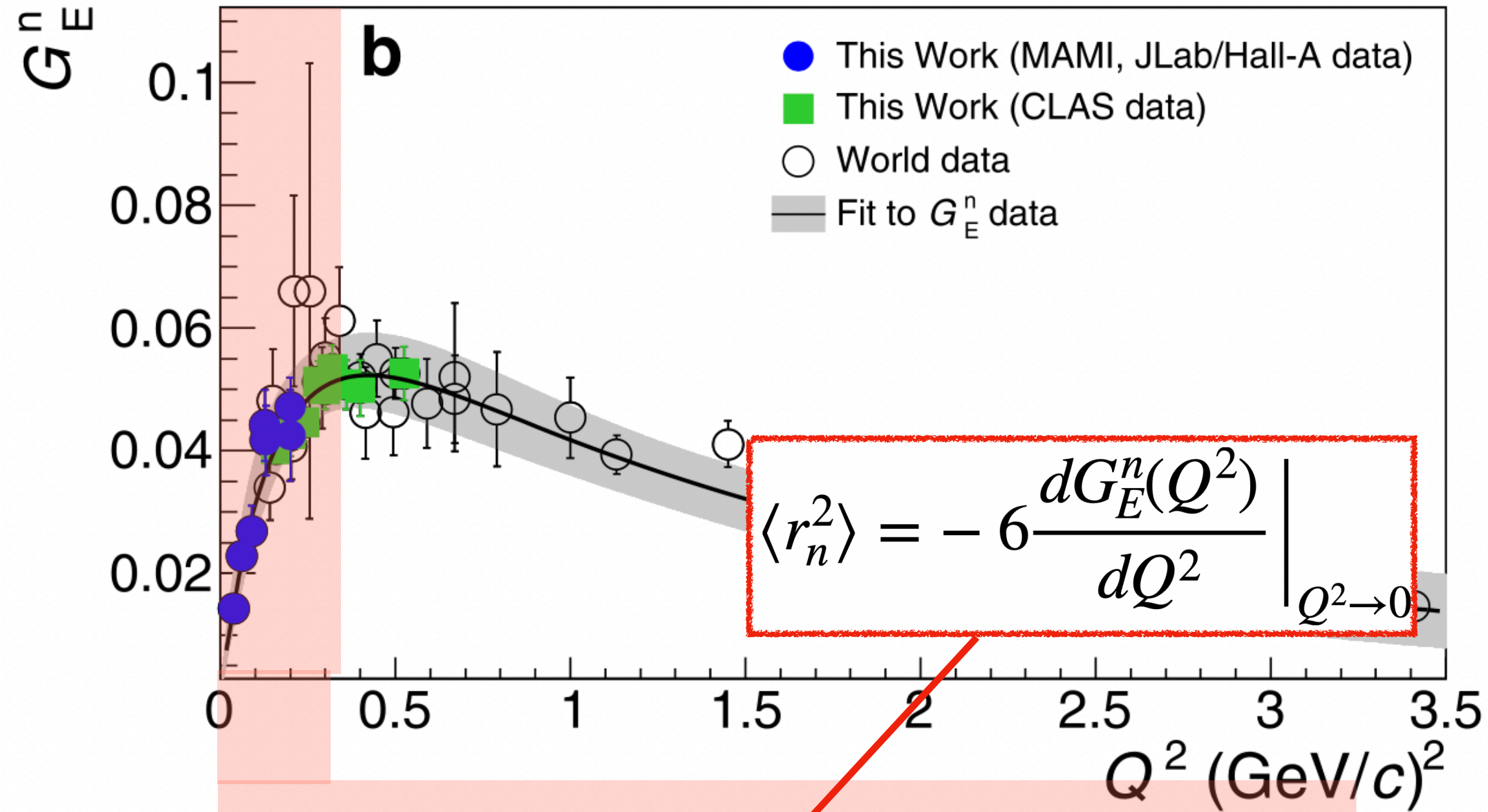
**e+D scattering at ULQ2
(lowest-ever Q^2 data)**



Neutron Charge radius

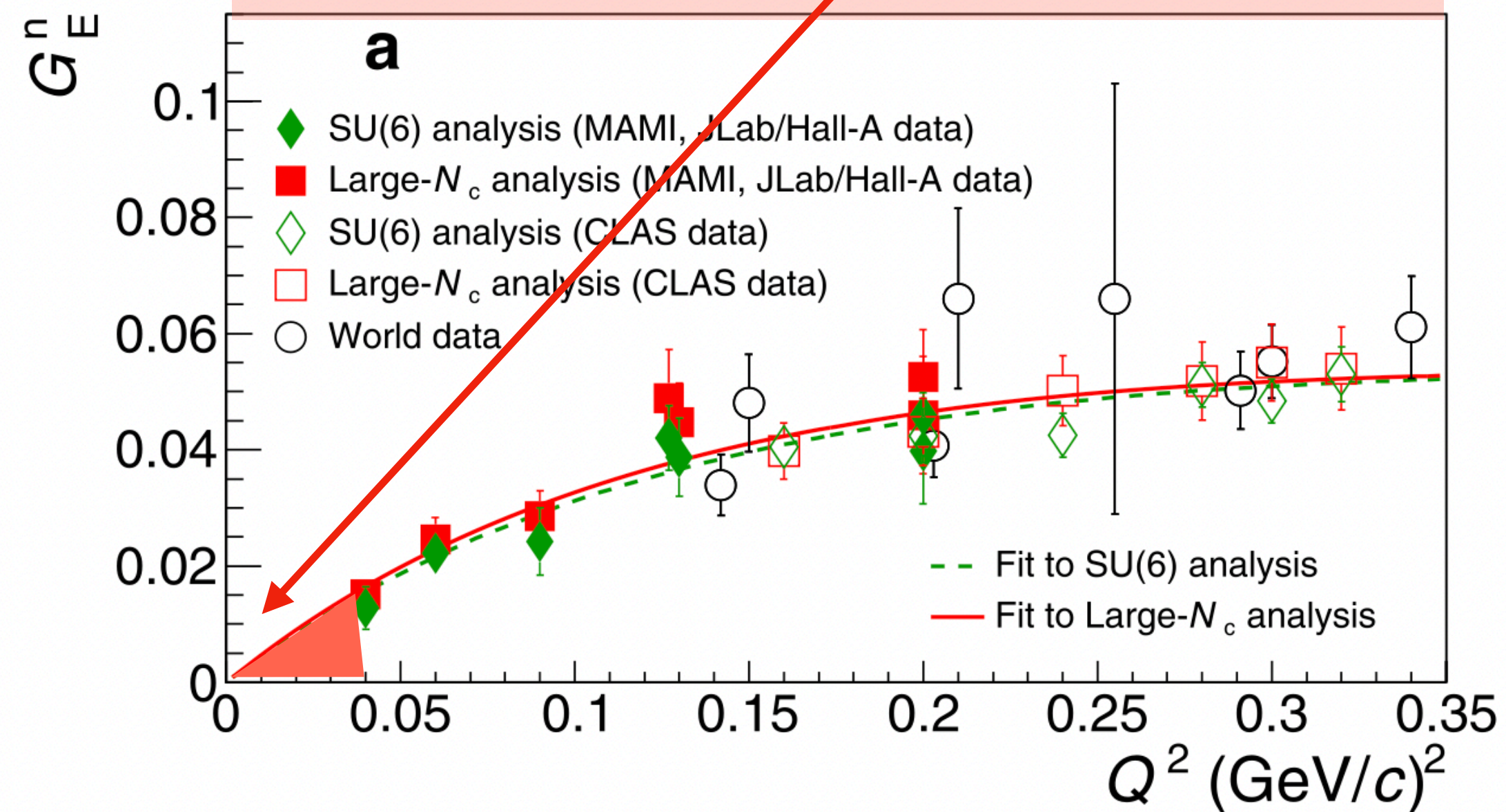






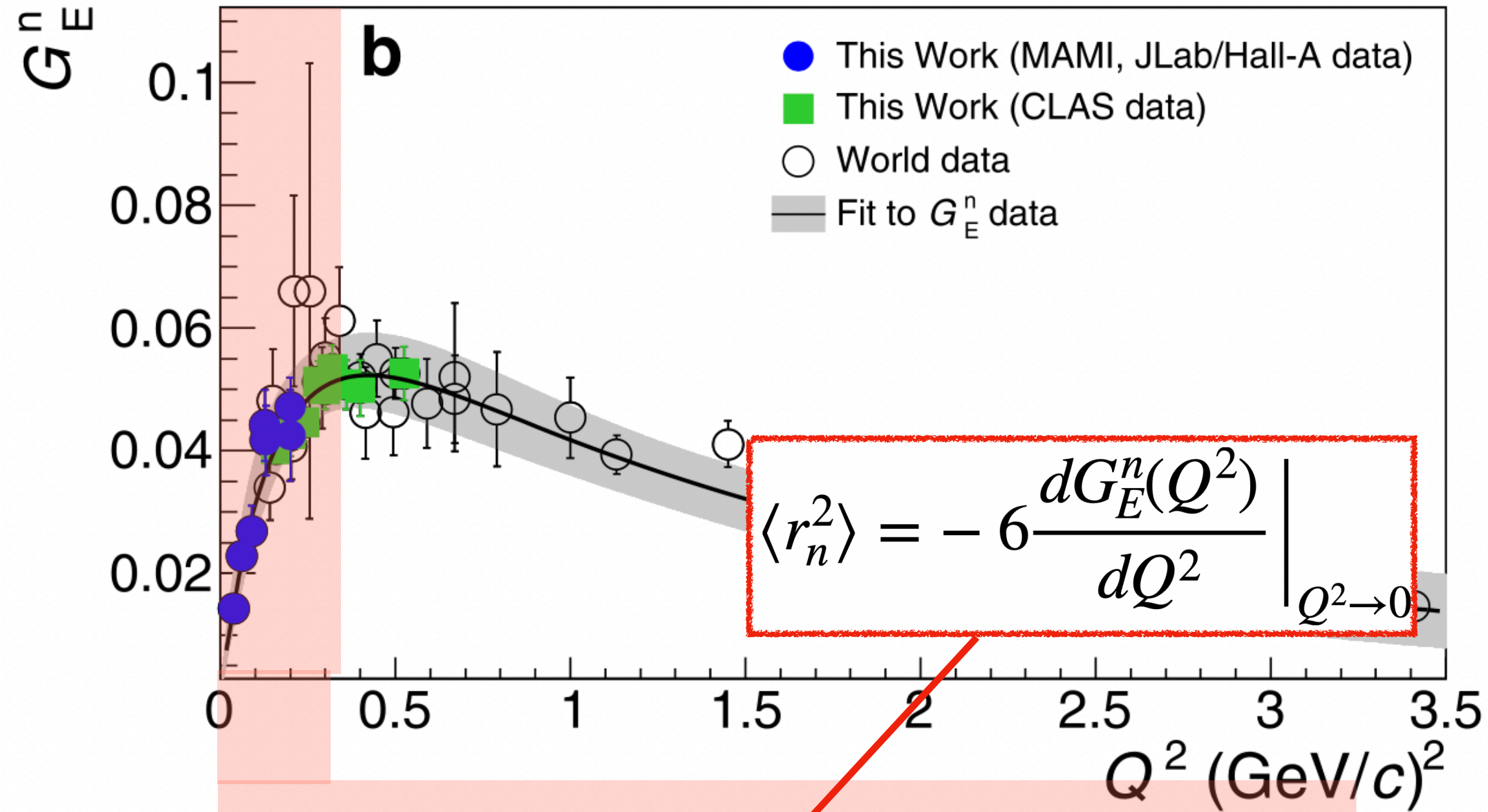
2nd moment

$$\langle r_c^2 \rangle = \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \langle r_n^2 \rangle + \text{rel. corr.}$$



4th moment

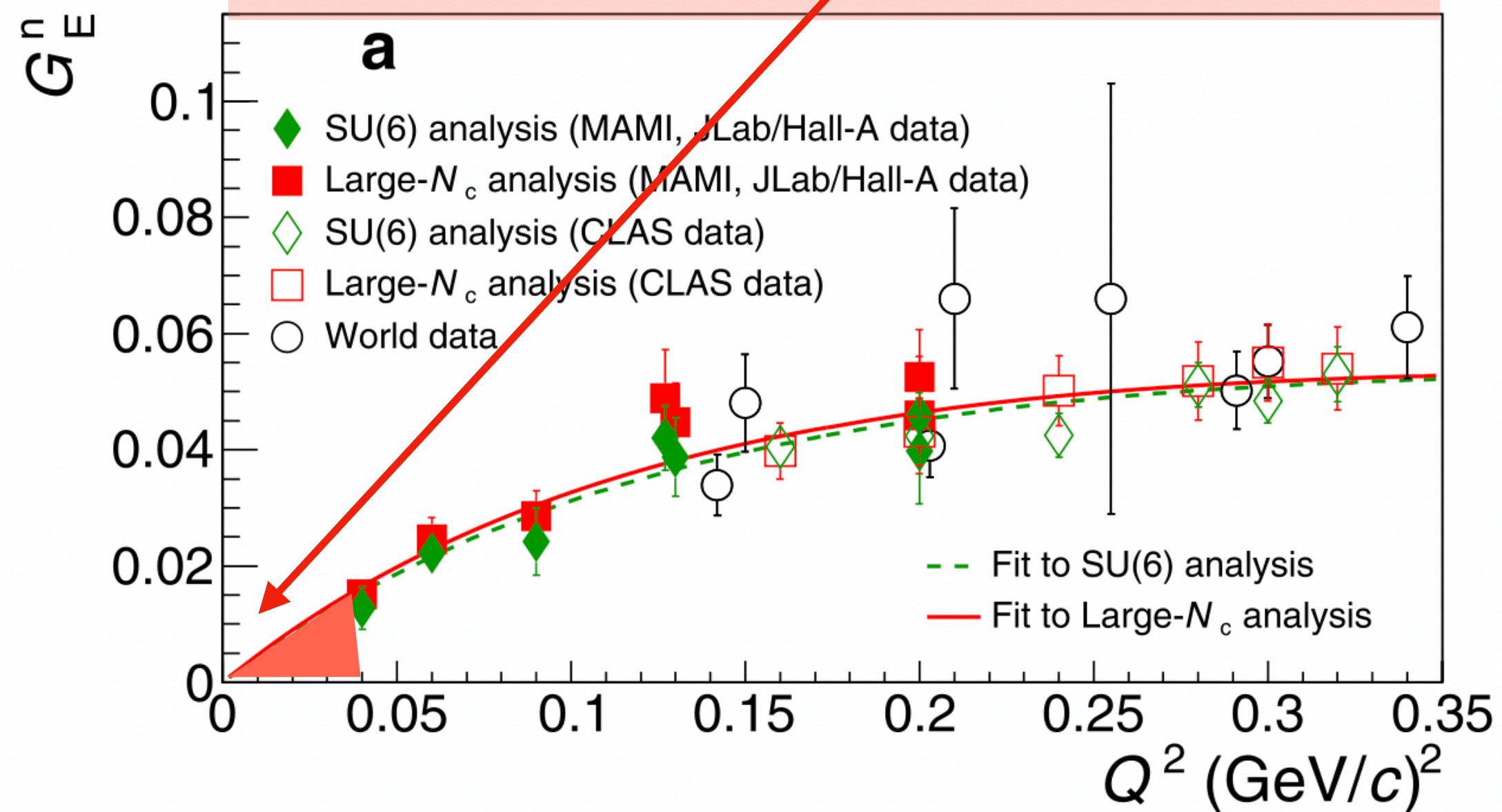
$$\langle r_c^4 \rangle = \langle r_{p(point)}^4 \rangle + \frac{10}{3} \langle r_{p(point)}^2 \rangle (\langle r_p^2 \rangle + \langle r_n^2 \rangle) + \text{rel. corr.}$$



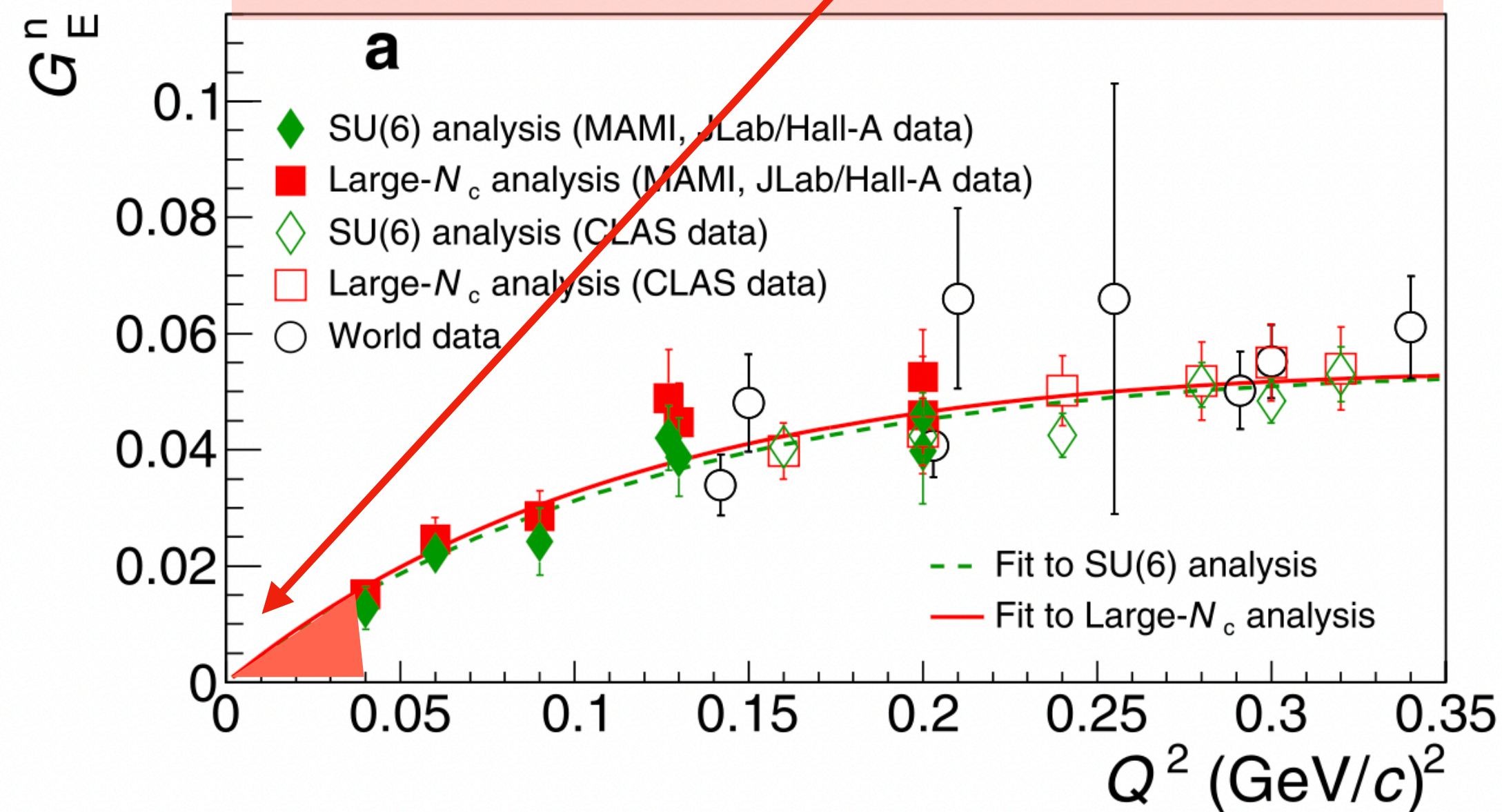
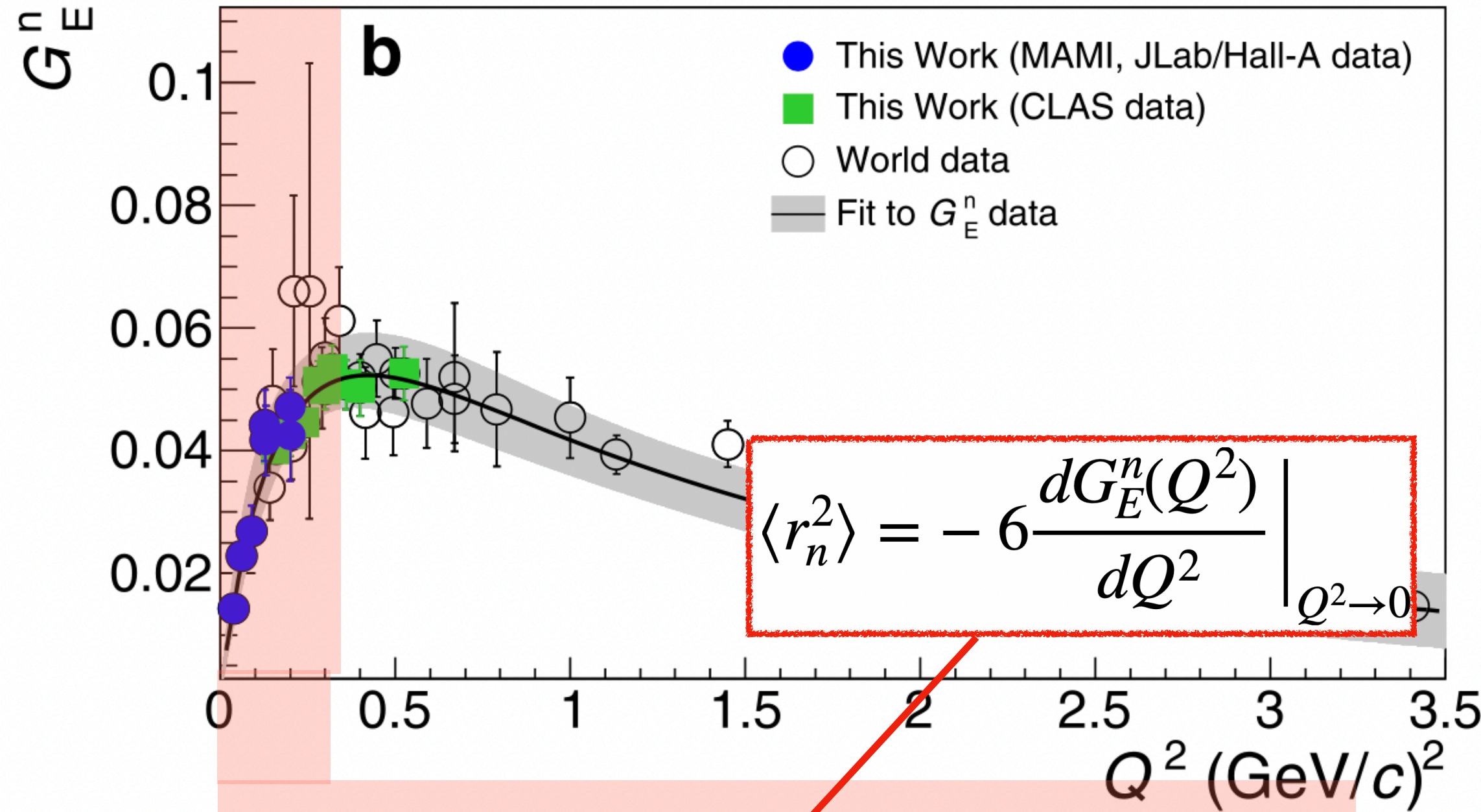
2nd moment

$$\langle r_c^2 \rangle = \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \langle r_n^2 \rangle + \text{rel. corr.}$$

4th moment



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



2nd moment

$$\langle r_c^2 \rangle = \langle r_{p(point)}^2 \rangle + \langle r_p^2 \rangle + \langle r_n^2 \rangle + \text{rel. corr.}$$

4th moment

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

ULQ2-d

ULQ2-p

- Low-energy electron scattering activities in Japan
 - ULQ2 : 1) e+p, e+D scattering (data collection completed)
=> charge radii of the proton and neutron
2) $^{208}\text{Pb}(e,e')$ at the lowest-ever momentum transfer (data collection completed)
 - SCRIT : 1) charge distributions and higher moments of short-lived exotic nuclei
=> neutron-distribution radius through $\langle r_c^4 \rangle$
2) ISOL upgrade to 2 kW is underway towards $^{132}\text{Sn}(e,e')$

in addition

- study of possible triaxiality of ^{154}Sm (Otsuka-san's proposal)
 - at q maximizing the transition form factor ($0^+ \rightarrow 2^+$) (data collection completed)

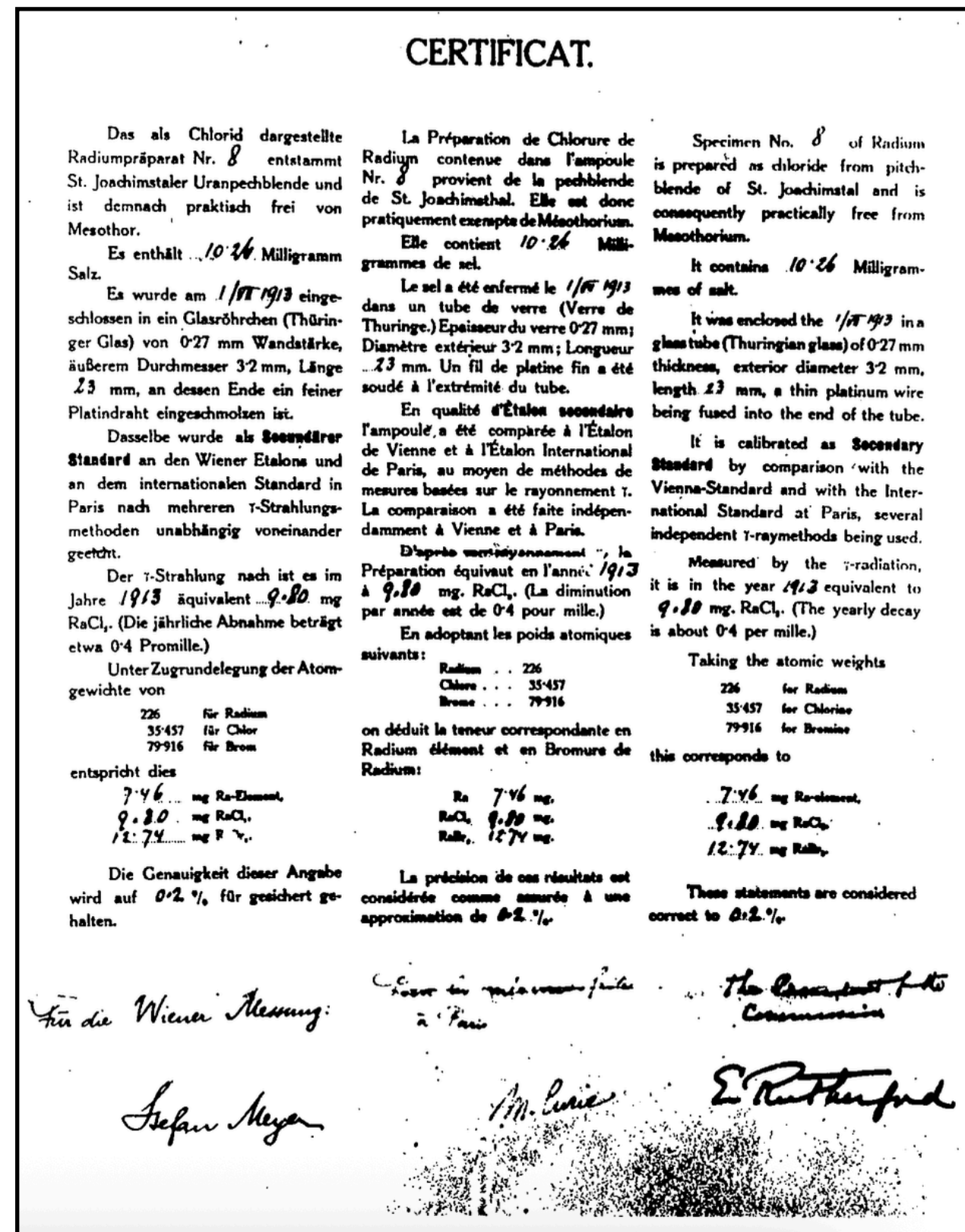
Marie Curie's Radium Standard No. 8 preserved at Tohoku Univ.

Currently under review for recognition as the first “Physical Heritage” by the Physical Society of Japan

Paris Certificate (1913)

Radium source

"Fingerprint" on the case



Brought to Tohoku University in 1914.



Prof. Hélène Langevin-Joliot viewed her grandmother's legacy during her Sendai visit in 2009.

Prepared and measured directly by Marie Curie to establish the international standard. There are signatures of **E. Rutherford**, **M. Curie**, and **S. Meyer**. The document displayed here is a preserved copy.

Autoradiography of the wooden case for the source revealed α -radiation contamination. These marks may possibly correspond to **fingerprints left by Marie Curie herself**. We hope to explore this possibility further in collaboration with French institutes.