May 12, 2021

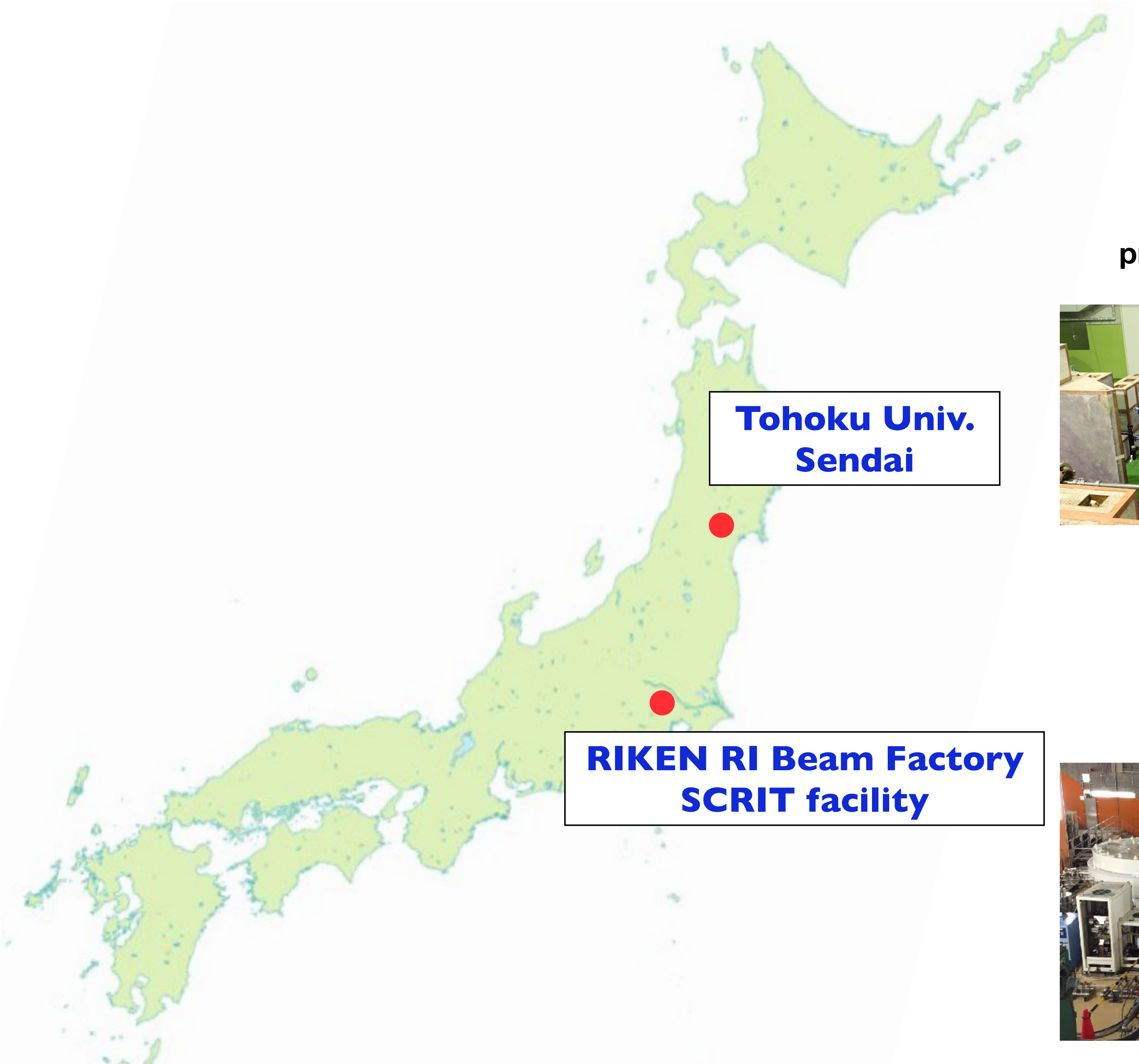
For discussion with the ETIC group

Toshimi Suda

ELPH, Tohoku Univ.

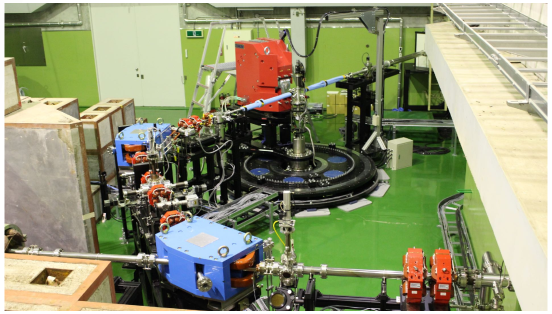
Sendai, JAPAN

1) general remarks
2) new researches
   - a) photonuclear response
   - b) neutron



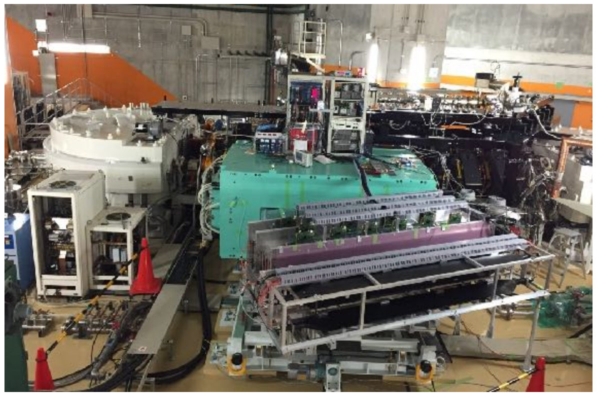
ULQ2

proton charge radius



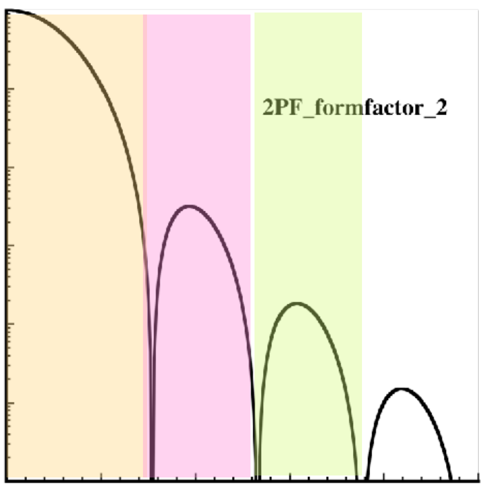
SCRIT

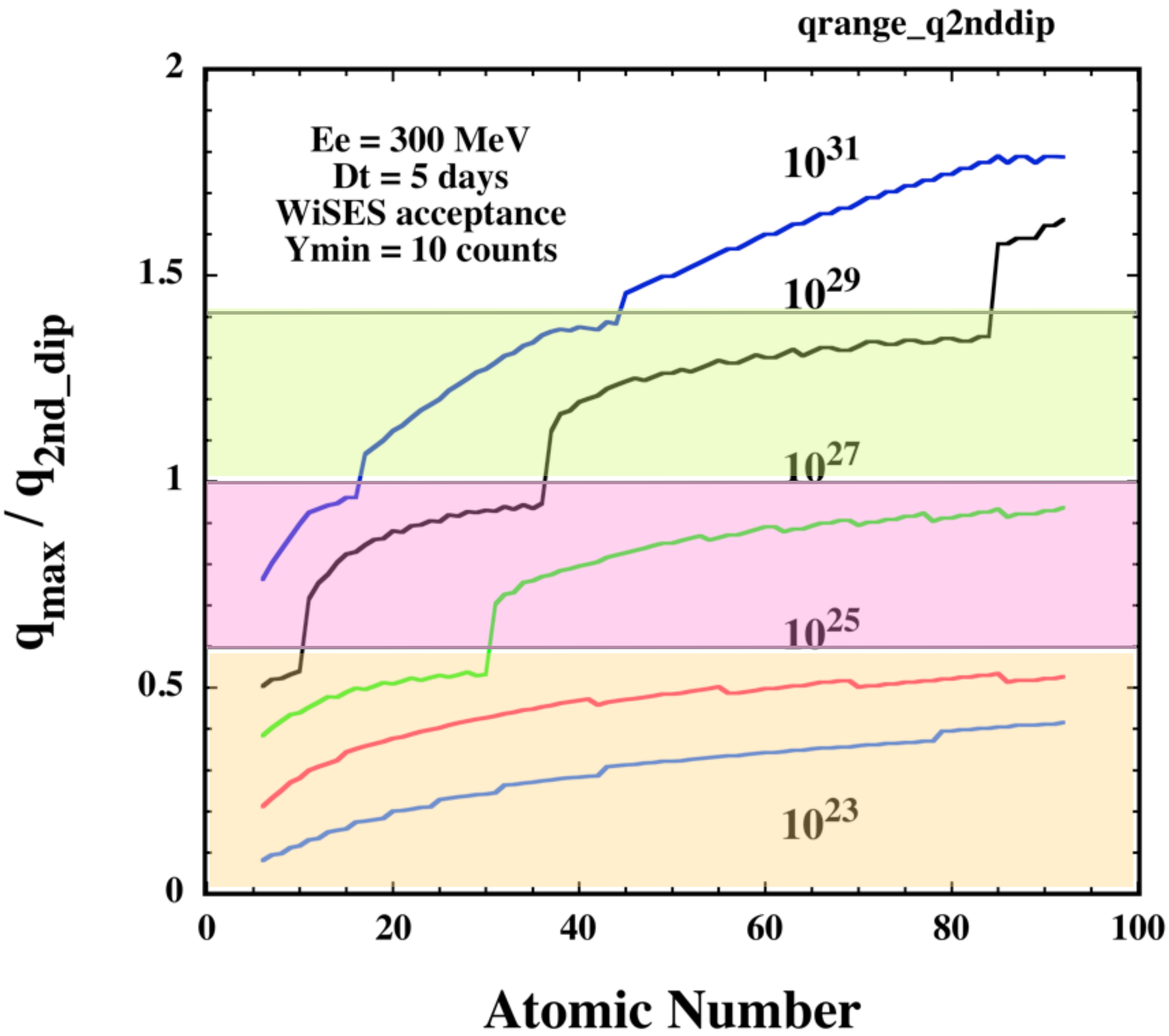
e-RI scattering



Elastic scattering : Accessible q-range for *L* and *Z*

$$\frac{d\sigma_0}{d\Omega} \propto z^2 \frac{E^2}{q^4}$$





T.S. and Haik Simon.
Prog. Part. Nucl. Phys. 96 (2017) 1-31.

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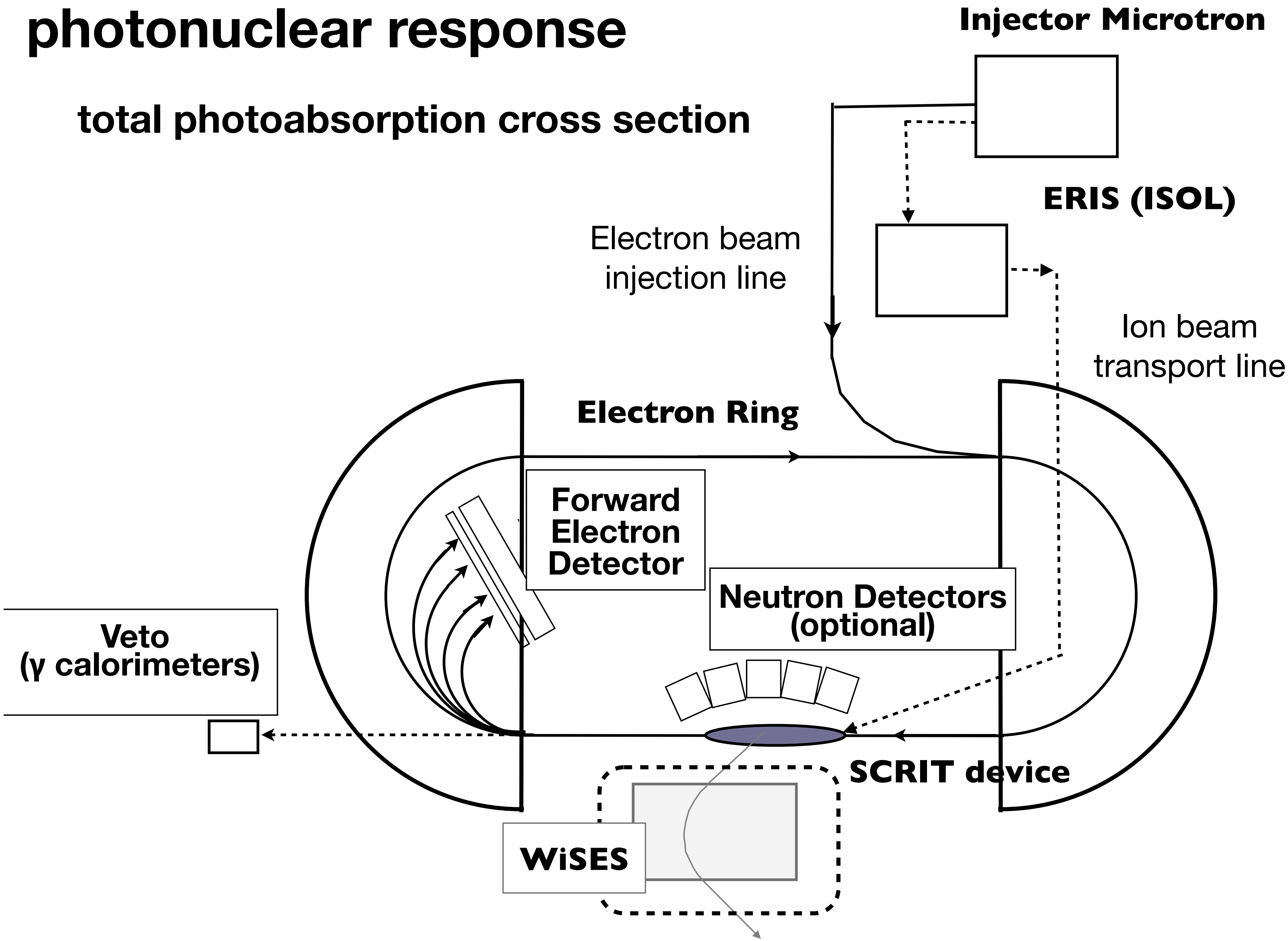
additional research opportunity at e-RI facility

photonuclear response

total photoabsorption cross section



Total Photoabsorption Cross Section

Sum Rules

TRK sum rule

$$\int_0^{\infty} \sigma(E_\gamma) dE_\gamma = \frac{2\pi^2 e^2 \hbar}{M} \frac{NZ}{A}(1+\kappa) = 60 \frac{NZ}{A}(1+\kappa) MeV \cdot mb$$

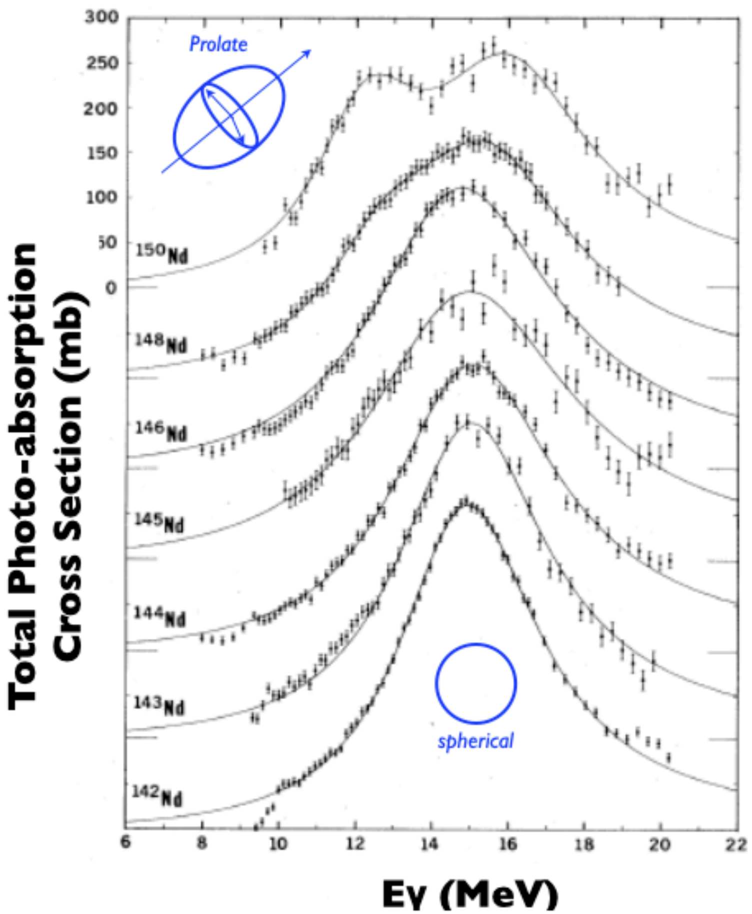
Bremmstrahlung sum rule

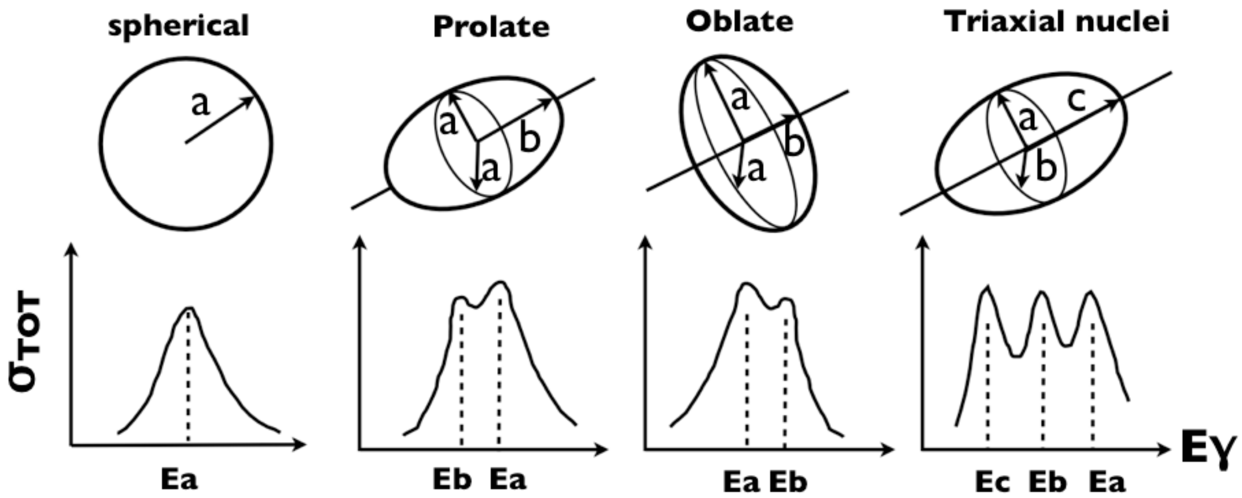
$$\int_0^{\infty} \frac{\sigma(E_\gamma)}{E_\gamma} dE_\gamma = \frac{4\pi^2 e^2}{3\hbar} \frac{NZ}{A-1} < r^2 >$$

Migdal sum rule

$$\int_0^{\infty} \frac{\sigma(E_\gamma)}{E_\gamma^2} dE_\gamma = \frac{2\pi^2}{\hbar} P$$

P : polarizability



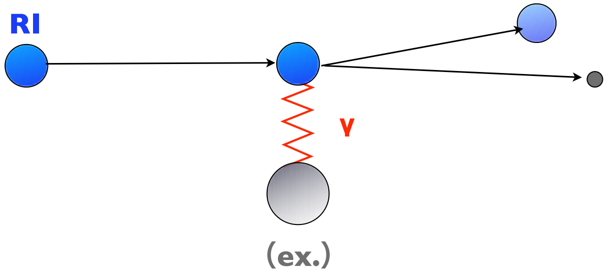


R. Bergere :Lecture Note in Physics, 61 (1971) 84

photonuclear reaction for exotic nuclei

so far $\gamma \sim 1$

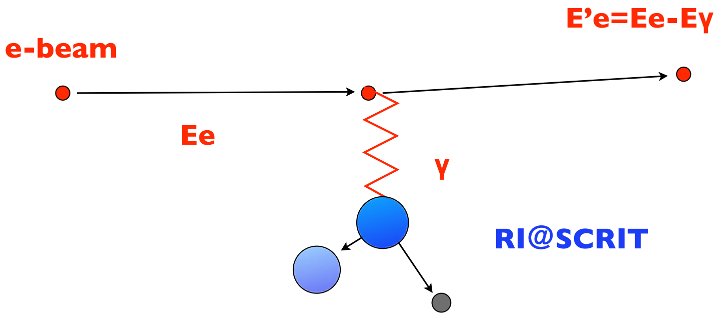
only way : Coulomb excitation in heavy ion reaction

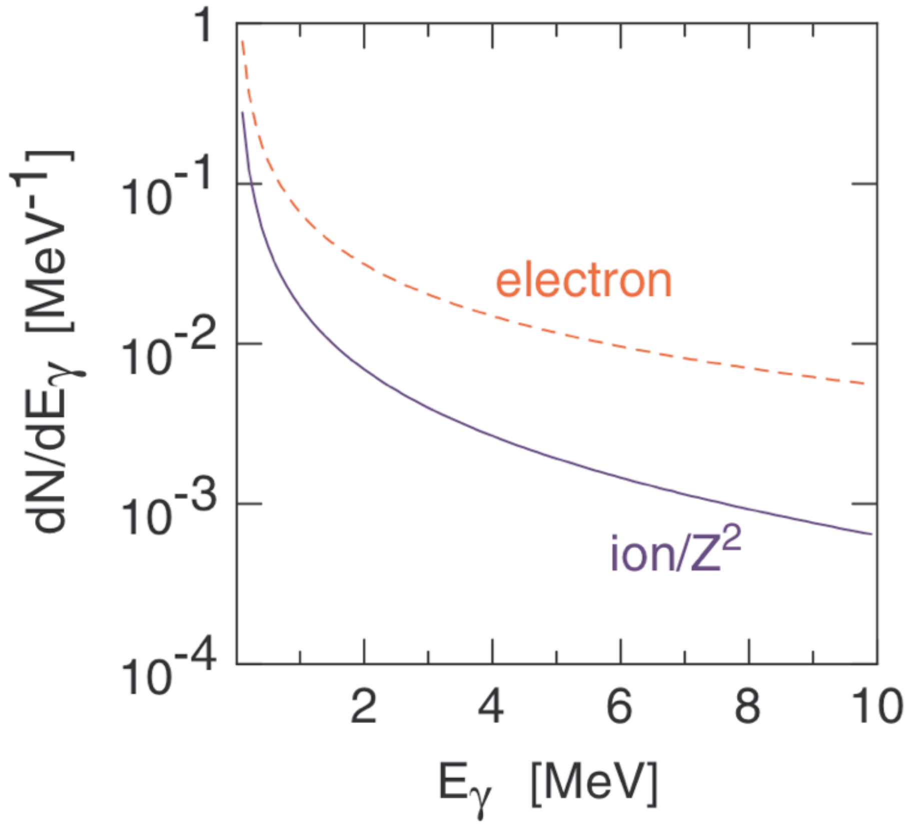


Virtual Photon flux

$$\frac{d^2\sigma}{dE_e d\Omega} = \sum \frac{d^2 N_e^{EL}(E, E_\gamma, \theta)}{dE_\gamma d\Omega} \cdot \sigma_\gamma^{EL}(E_\gamma)$$

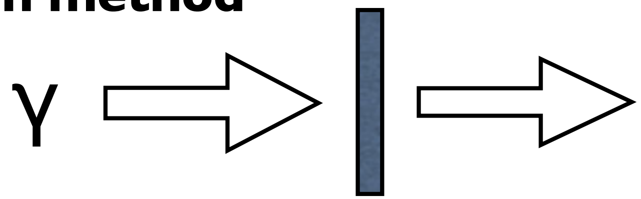
SCRIT facility $\gamma \sim 300 - 600$





Total Photoabsorption Cross Section

1. Attenuation method

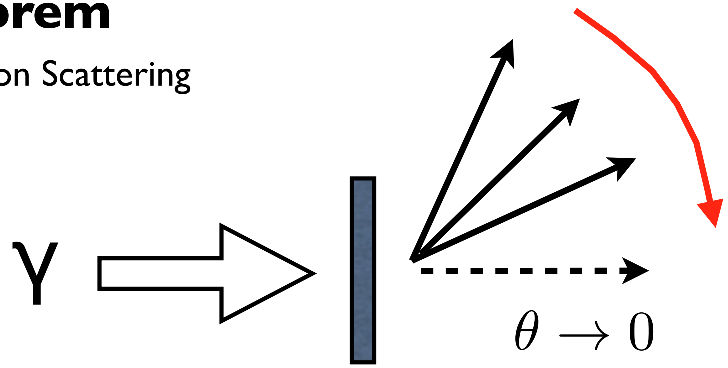


$$N(E_\gamma) = N_0(E_\gamma)e^{-n\sigma_{tot}(E_\gamma)}$$

$$\sigma_{tot}(E_\gamma) = \sigma_{tot}^{nucl}(E_\gamma) + \sigma_{tot}^{atomic}(E_\gamma)$$

2. Optical theorem

(elastic) Compton Scattering



$$\frac{d\sigma}{d\Omega}(E_\gamma, \theta) = |R(E_\gamma, \theta)|^2$$

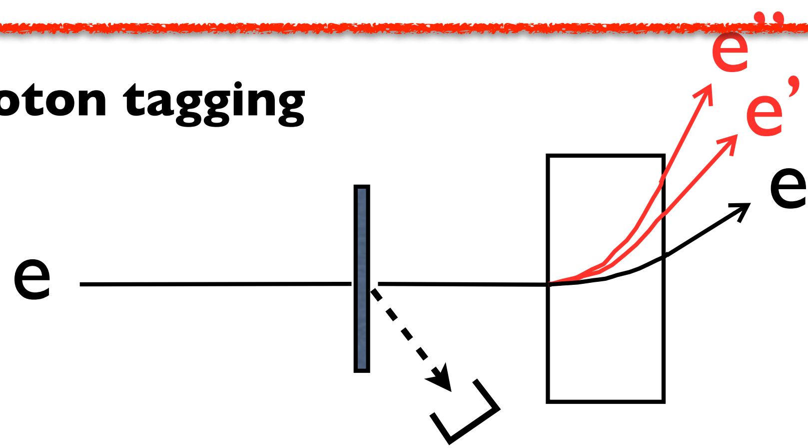
$$\sigma_{tot}(E_\gamma) = 4\pi \frac{\lambda}{2\pi} \cdot ImR(E_\gamma, 0)$$

3. detecting all final states

few nucleon system, heavy nucleis (γ,xn)

$$\sigma_{tot}(E_\gamma) = \sigma_{tot}^{A}(E_\gamma) + \sigma_{tot}^{B}(E_\gamma) + \sigma_{tot}^{c}(E_\gamma) + \ldots$$

4. virtual photon tagging



electro-excitation
+ virtual photon theory

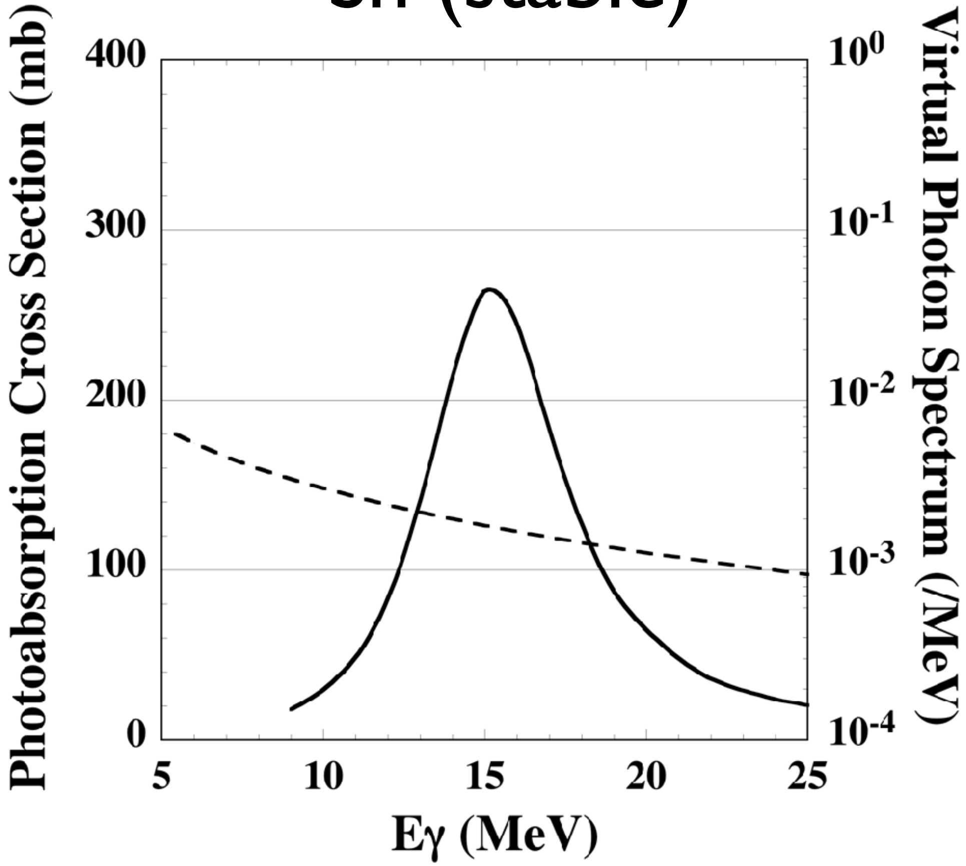
photo-reaction cross section

Expected reaction rate for $L = 10^{27}$ /cm²/s

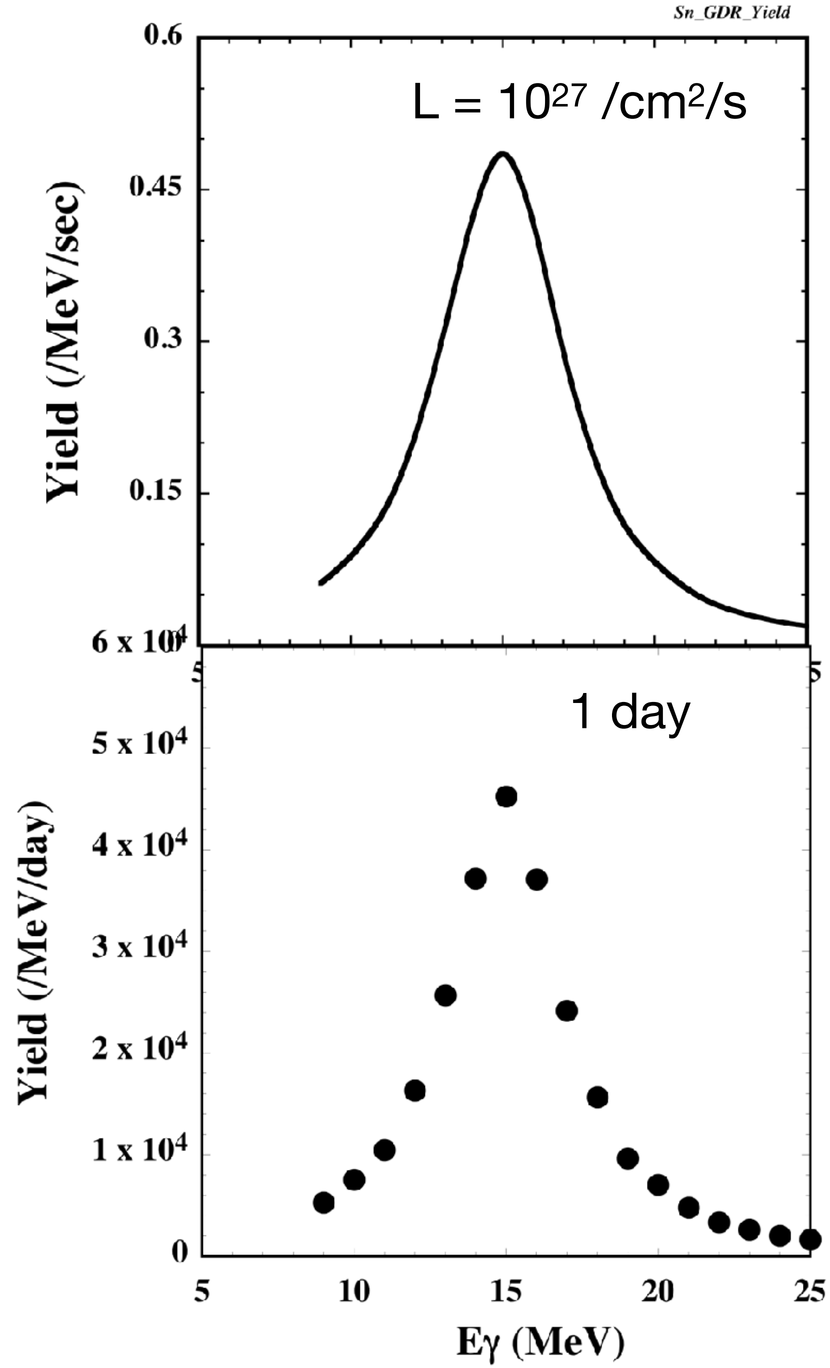
virtual photon theory

$$\frac{dN}{dE_\gamma} = L \cdot \int d\Omega \frac{d^2 N_e^{E1}(E, E_\gamma, \theta)}{dE_\gamma d\Omega} \cdot \sigma_\gamma^{E1}(E_\gamma)$$

^{120}Sn (stable)



P. Durgapal and D.S. Onley
Comp. Phys. Comm. 32 (1984) 291



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A novel way to access neutrons by “traditional”electron scattering

“The n-th order moment of the nuclear charge density and contribution from the neutrons”

H. Kurasawa and T. Suzuki
Prog. Theor. Exp. Pays. (2019) 113D01.

“The mean square radius of the neutron distribution and the skin thickness derived from electron scattering”

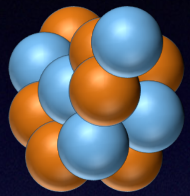
H. Kurasawa, T. Suda and T. Suzuki
Prog. Theor. Exp. Pays. (2021) 013D02.

and more to come …

n-th moments of the charge density

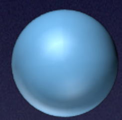
$$< r_c^n > = \int r^n \rho_c(r)\, \mathrm{d}^3 r$$

elastic e-scattering



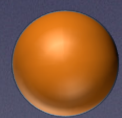
$$\rho_c(r) = \rho_c^p(r) + \rho_c^n(r)$$

Proton



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

Neutron

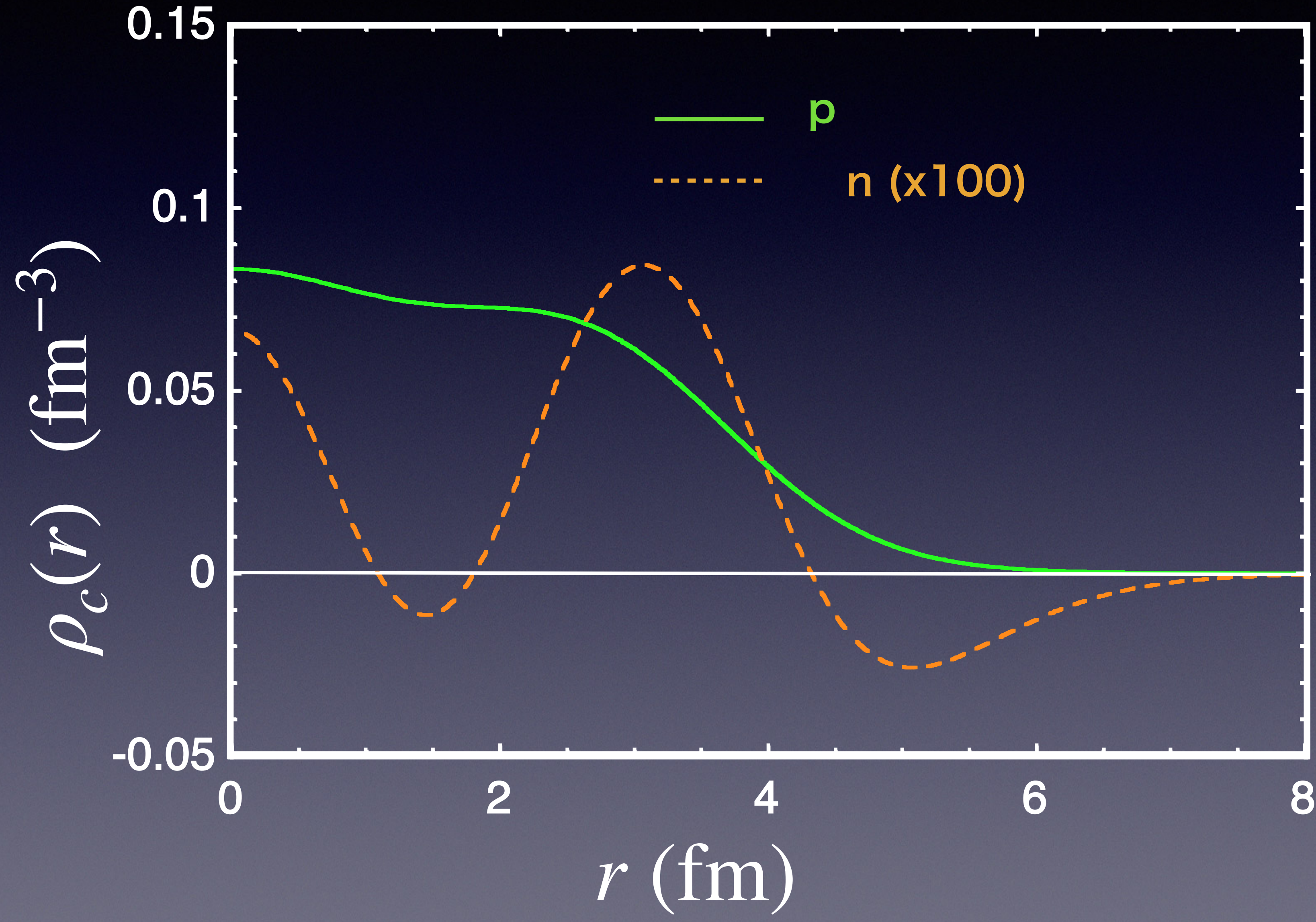


$$\rho_c^n(r) = \int \rho_n(r)\, \rho_{n(point)}(r - r')\, \mathrm{d}^3 r'$$

structure theory

Courtesy : H. Kurasawa and T. Suzuki

^{48}Ca Charge density distribution



4-th moment

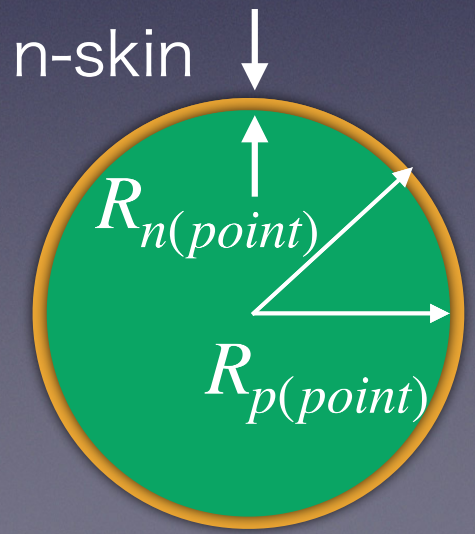
$$\langle r_c^4 \rangle = \int r^4 \rho_c(r)\, d^3 r$$

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

Proton

Neutron

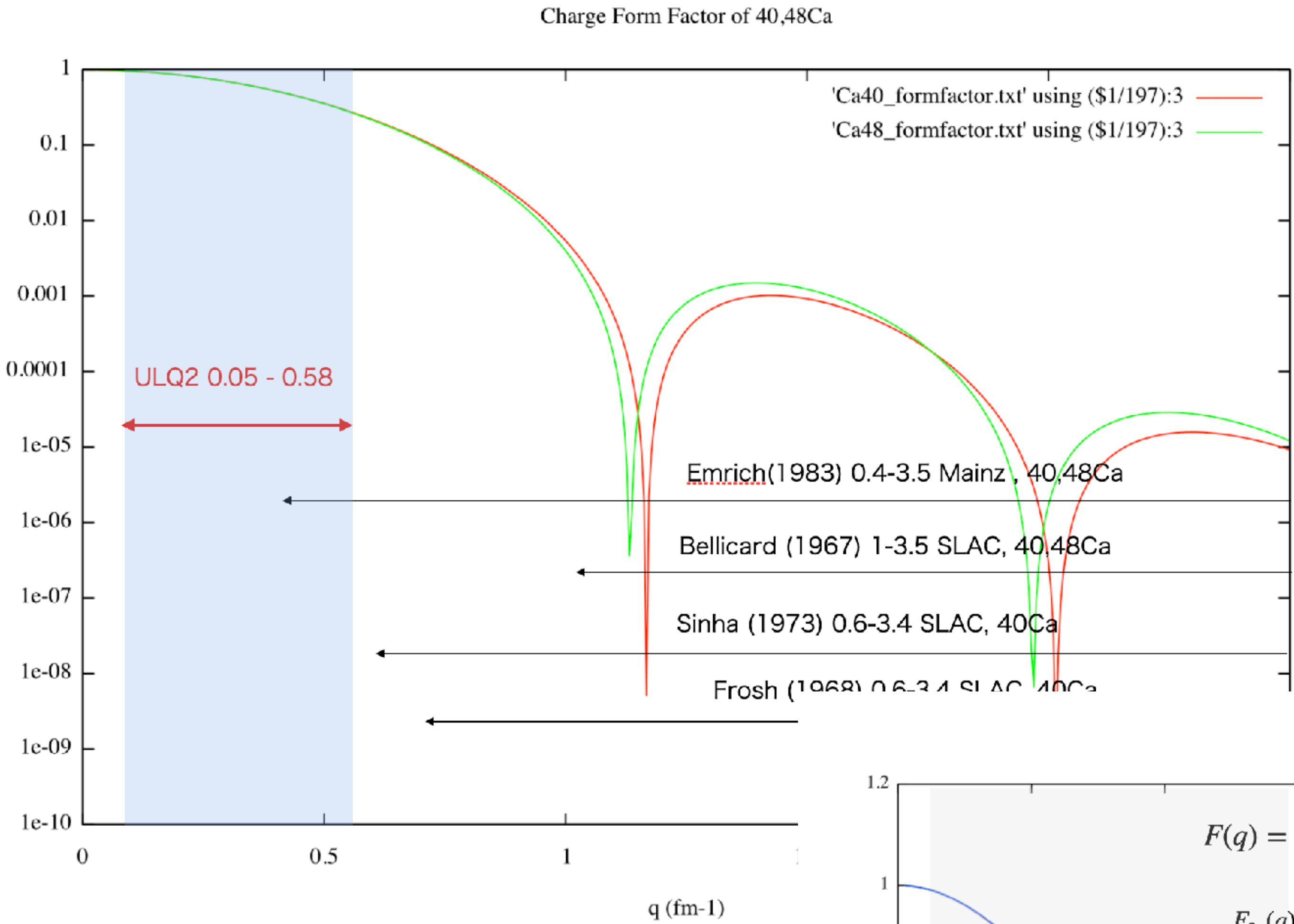
neutron (point) radius



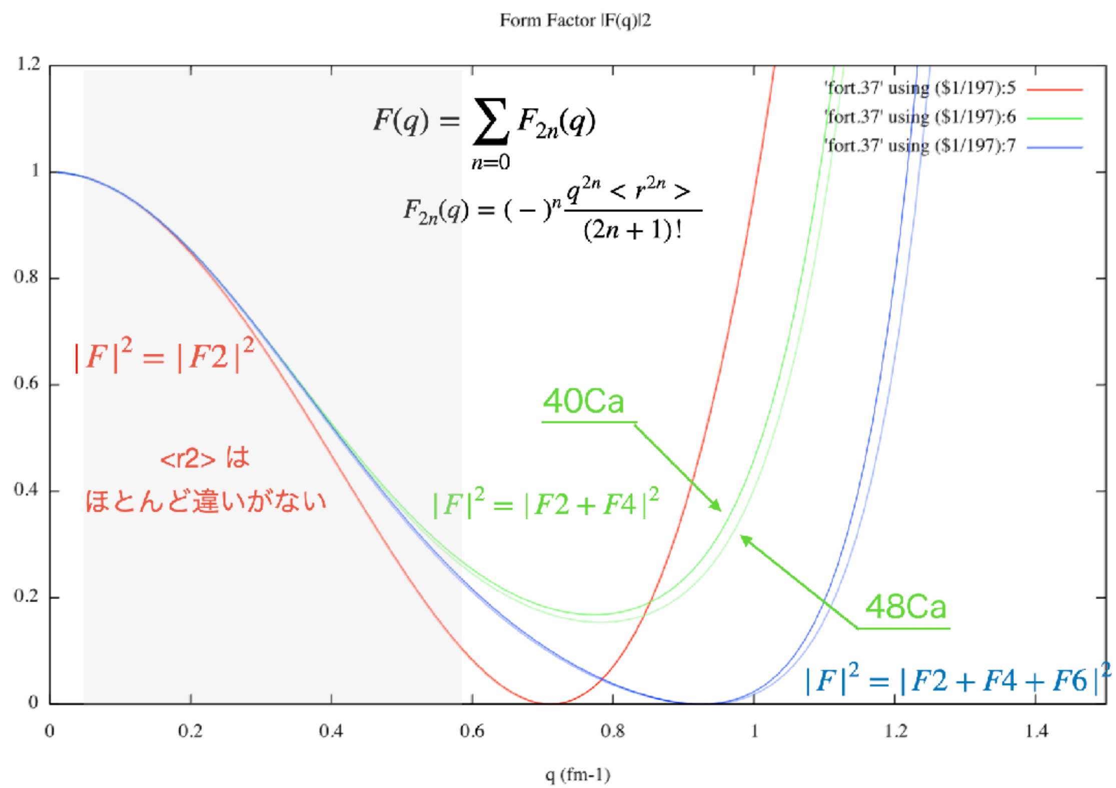
Full rel. calculation (NL3)

H. Kurasawa and T. Suzuki (arXiv : 1907.09071)

	Exp	$\langle r^4_c \rangle$	n-cont.	Rp(point)	Rn(point)	n-skin
^{48}Ca	194.7	191.7	6.9%	3.38	3.44	0.23
^{208}Pb	1171.6	1156.8	2.9%	5.46	5.74	0.28



Charge Form Factor of 40,48Ca
'Ca40_formfactor.txt' using ($1/197):3
'Ca48_formfactor.txt' using ($1/197):3
ULQ2 0.05 - 0.58
Emrich(1983) 0.4-3.5 Mainz , 40,48Ca
Bellicard (1967) 1-3.5 SLAC, 40,48Ca
Sinha (1973) 0.6-3.4 SLAC, 40Ca
Frosh (1968) 0.6-3.4 SLAC, 40Ca
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
0
0.5
1
q (fm-1)



Form Factor |F(q)|2
'fort.37' using ($1/197):5
'fort.37' using ($1/197):6
'fort.37' using ($1/197):7
$F(q) = \sum_{n=0} F_{2n}(q)$
$F_{2n}(q) = (-)^n \frac{q^{2n} < r^{2n} >}{(2n+1)!}$
$|F|^2 = |F2|^2$
<r2> は
ほとんど違いがない
$|F|^2 = |F2 + F4|^2$
40Ca
48Ca
$|F|^2 = |F2 + F4 + F6|^2$
1.2
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
q (fm-1)

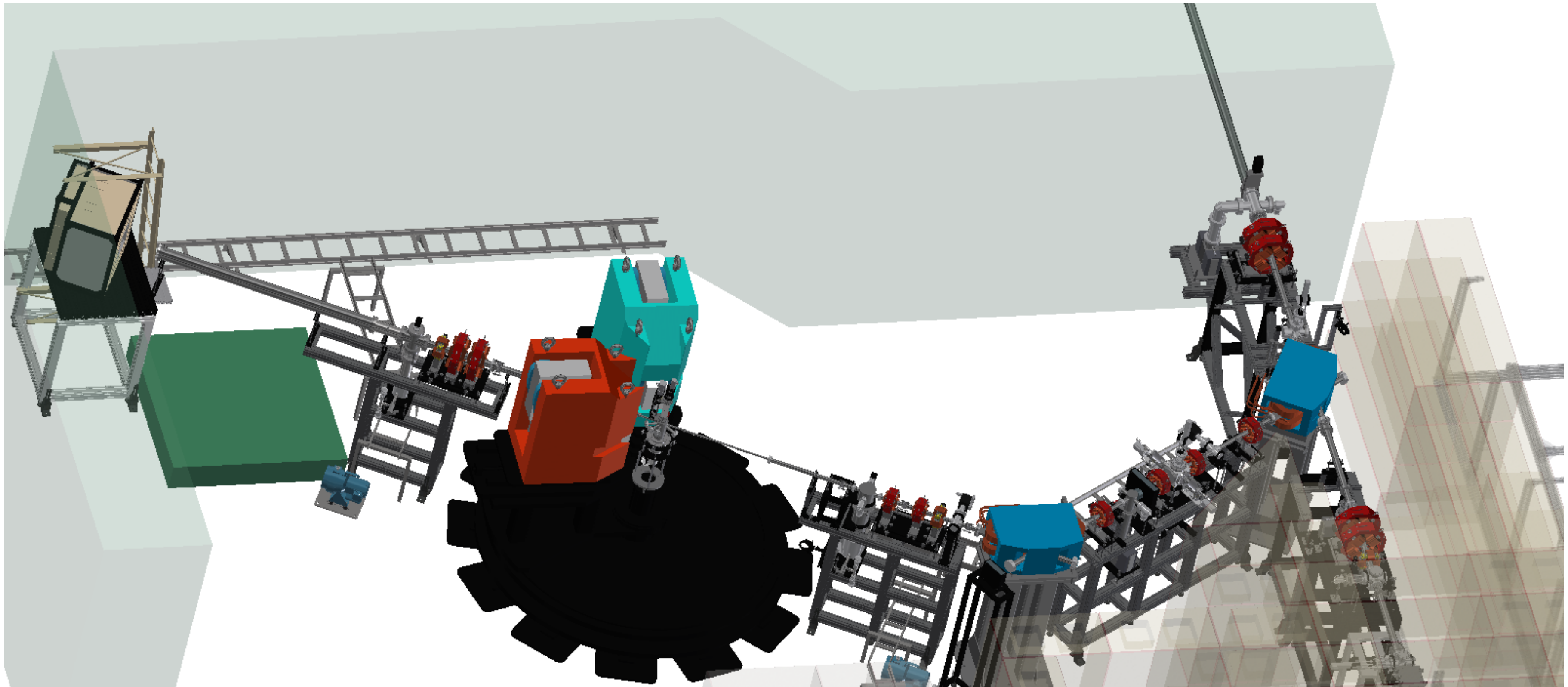
new beam line + double spectrometers
for
proton charge radius

40, 48Ca(e,e') using Ee = 20 - 60 MeV

absolute cross section

Spec A : luminosity monitor at a fixed scattering angle

Spec B : "accurate" q-dependence of Xsection by varying angle



Sendai ULQ2 (Ultra-Low Q2) for proton radius

A new low-energy electron beam line + spectrometers

Ee = 20 - 60 MeV
θ = 30 - 150 MeV