Electron scattering and neutrino-less double-β decay

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electrons for neutrinos?

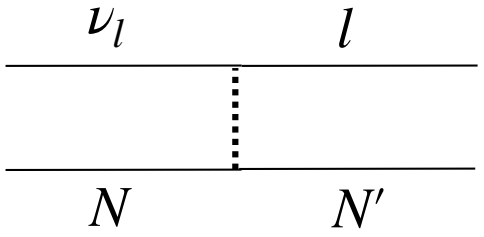
electron as a simulator?

as a simulator of neutrino-related nuclear reactions??

similar interaction (single boson exchange)

weak current (vector + axial)

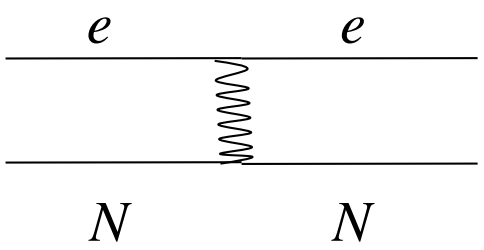
$$J_\mu = g_w \bar{u} \gamma_\mu (1 - \gamma_5) u$$



$$\propto \frac{1}{M_W^2}$$

e.m. current (vector only)

$$J_\mu^{em} = e \bar{u} \gamma_\mu u$$



$$\propto \frac{1}{Q^2}$$

similarity of nuclear physics cases (structures)

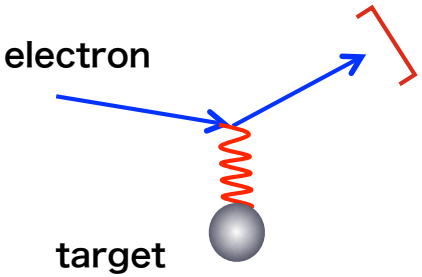
GT transitions
M1 transitions …..

electron beam

well-controlled beam parameters : energy, current etc..

high intensity ~ 10^{15} /s (~100 uA)

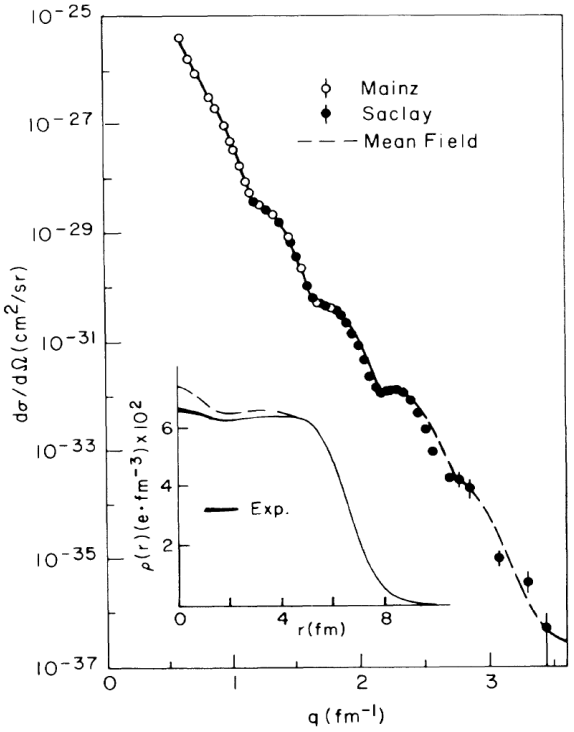
electron scattering



1. elementary particle - structure-less -
2. electro-weak interaction - best understood -
3. “relatively” weak - probing whole volume -

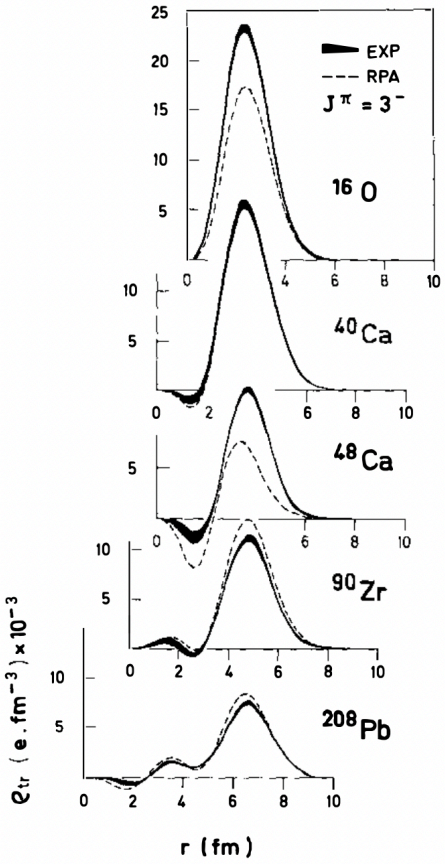
elastic -> charge densities

ground-state w.f.



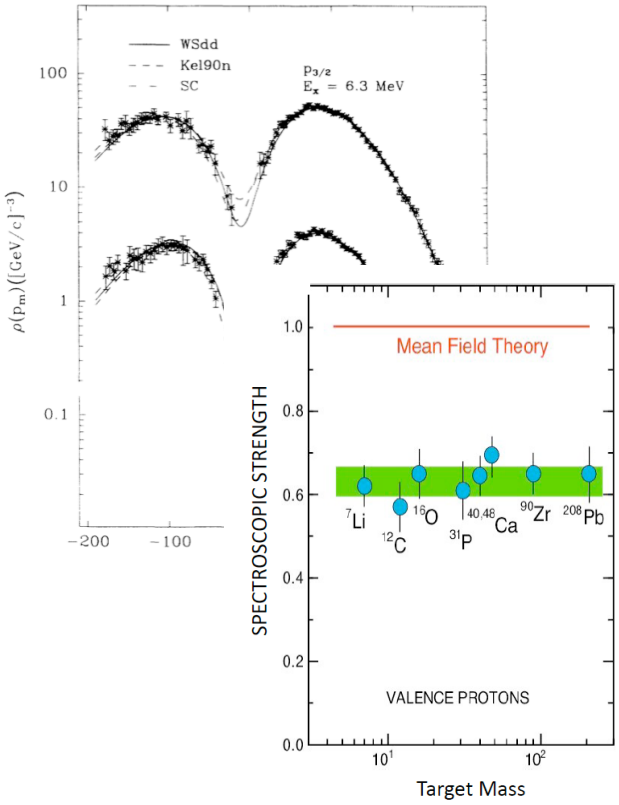
inelastic-> transition densities

excited-state w.f.



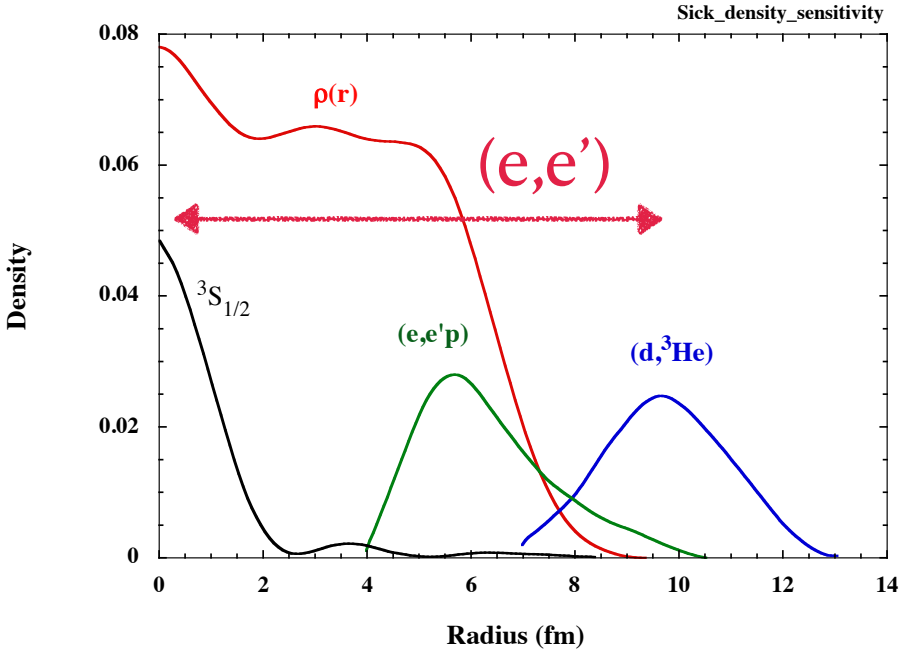
quasifree -> single particle

single particle w.f.
S factor



Spectroscopic factor　by (e,e'), (e,e'p)

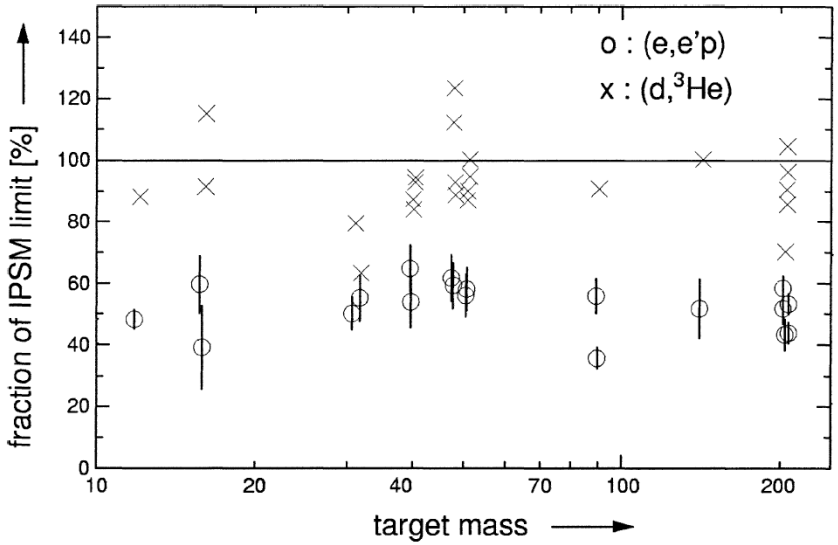
1)　elastic (e,e')
2) quasi elastic (e,e'p)
3) (d, ^{3}He) etc.

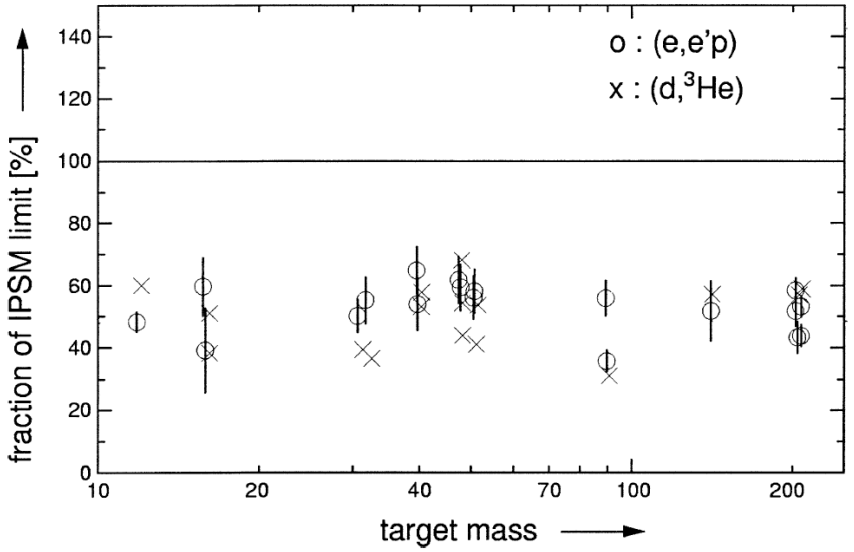


(d,^{3}He)反応: 核表面のみに感度

電子散乱: 波動関数 =>　(d,^{3}He)反応測定結果を再解析

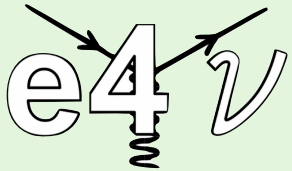
Nucl. Phys. A679(2001)267.

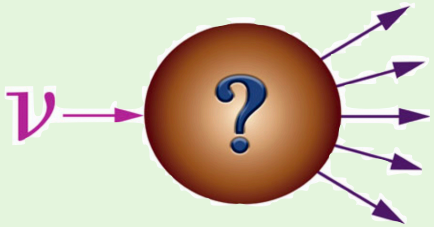




electrons for neutrinos?

GeV electrons for neutrinos @ JLab



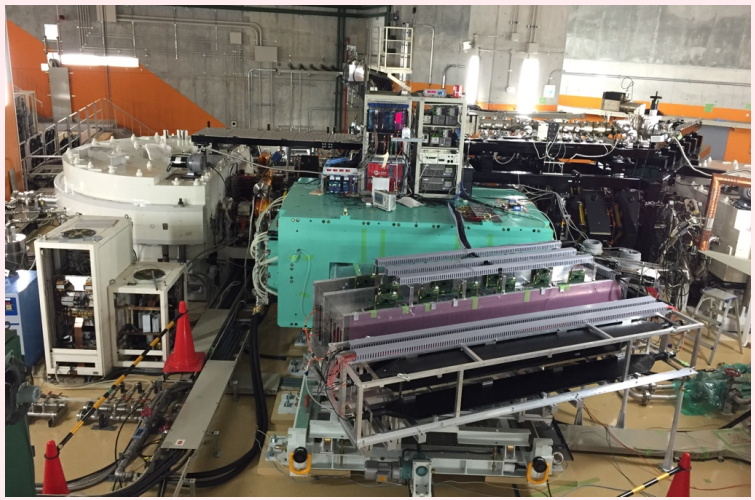


Low-energy electrons for neutrinos??

SCRIT facility@RIKEN

Ee = 150 - 300 MeV

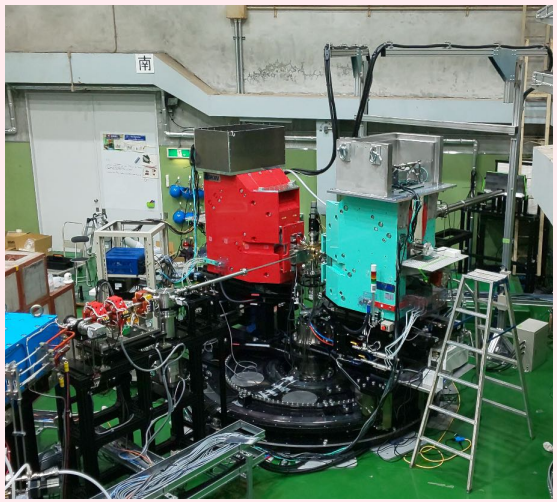
world's first for exotic nuclei



ULQ2 facility@Tohoku

Ee = 10 - 60 MeV

lowest-ever Ee



new SC linac ?

Ee ~ 100 MeV

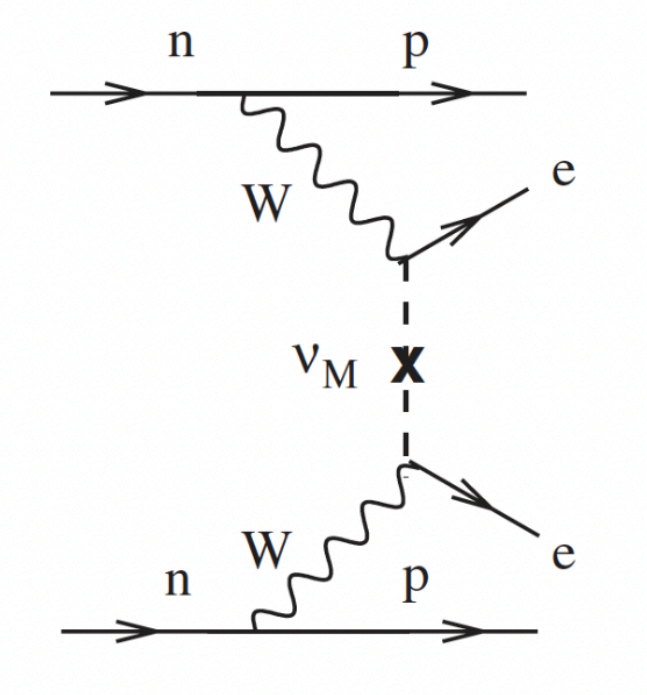
良質な低エネルギー電子ビーム
基礎研究、応用研究

独：*MESA*　*Ee = 155 MeV*

high-Tc SC (Nb3Sn) 加速管

開発競争：
日本、中国、米国、欧州

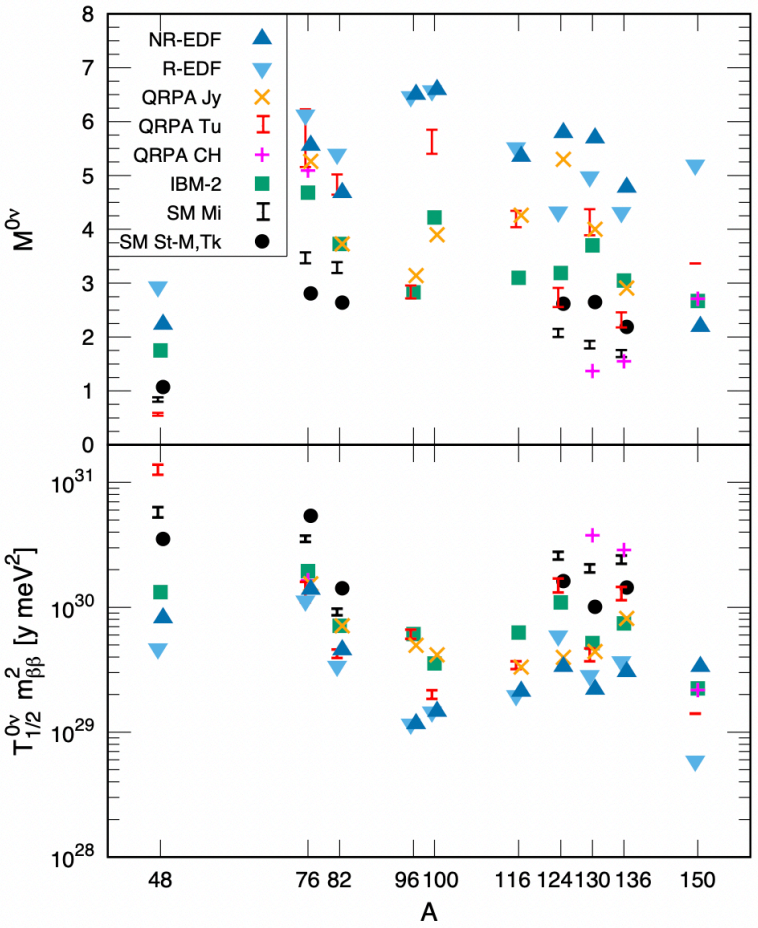
neutrino-less double β decay



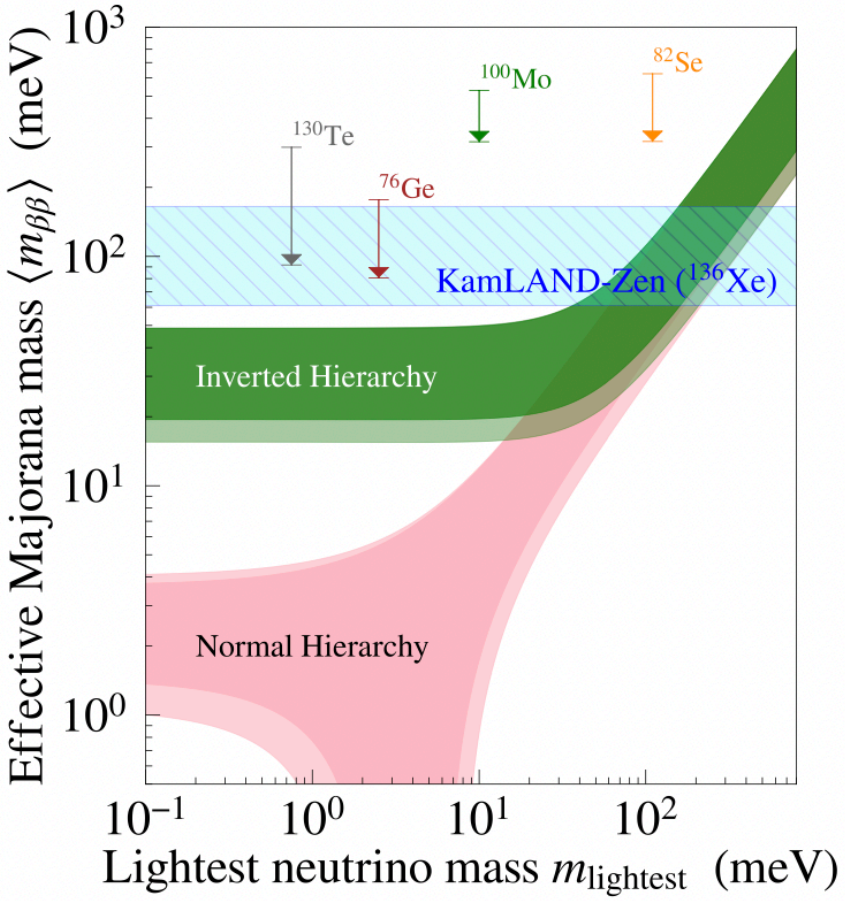
0ν2β decay process

- Majorana nature of neutrino
- neutrino mass hierarchy

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2\,<m_{\beta\beta}>^2$$



J. Engel and J. Menendez,
Reports on Progress in Physics 80 (4) (2017) 046301.



竹内 敦人 博士論文（東北大学 2021年度）

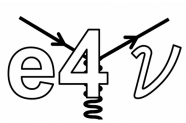
electrons for neutrinos?

possible contribution of e-scattering

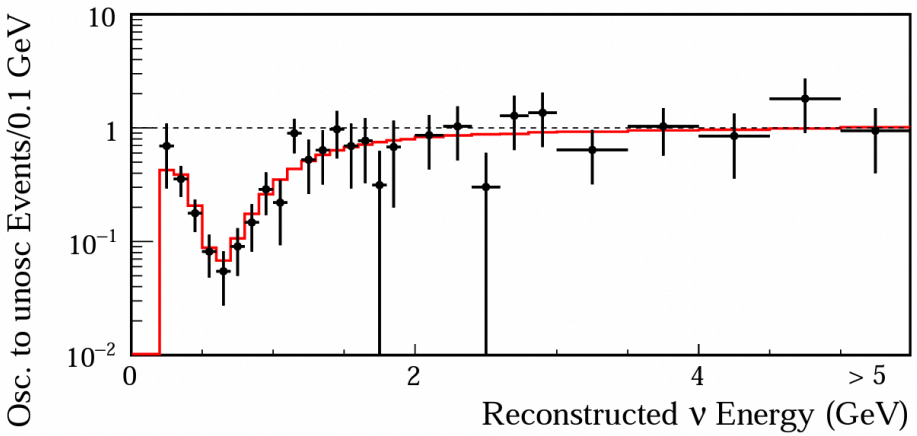
JLab

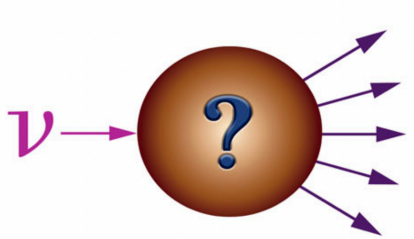
nuclear responses for GeV ν

Lawrence Weinstein (Old Dominion Univ.)



$$P(\nu_\mu \to \nu_\mu) = \sin^2(2\theta_{23}) \times \sin^2(\frac{\Delta m^2_{32} L}{4E_\nu})$$





T2K : Phys. Rev. D91 072010 (2015)

Low-Ee

a new low-energy electron scattering facility at ELPH, Tohoku : lowest-ever Ee
a new e-scattering facility for exotic nuclei at RIKEN : world's first

nuclear physics studies using low-energy electrons for neutrino-related study

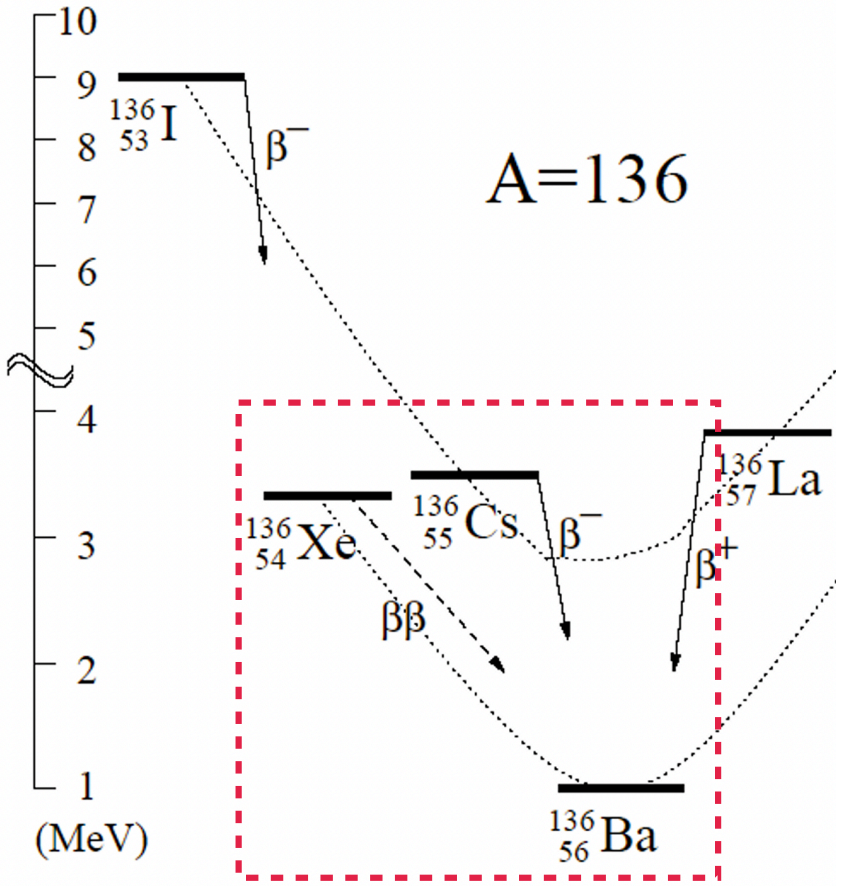
nuclear matrix element of 0ν2β decay
low-neutrino induced nuclear reaction such as $\nu + {}^{16}O \to X$

nuclear matrix elements

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\ |M_{0\nu}|^2\ < m_{\beta\beta} >^2$$

$$M_{0\nu} \propto \sum_n \left[\frac{< f | J^{\mu}_L(x) | n >< n | J^{\nu}_L(x) | i >}{\text{energy denominator}} + \frac{< f | J^{\nu}_L(x) | n >< n | J^{\mu}_L(x) | i >}{\text{energy denominator}} \right]$$

J : charge changing hadronic current $\propto \sigma \cdot \tau$



NME and electron scattering

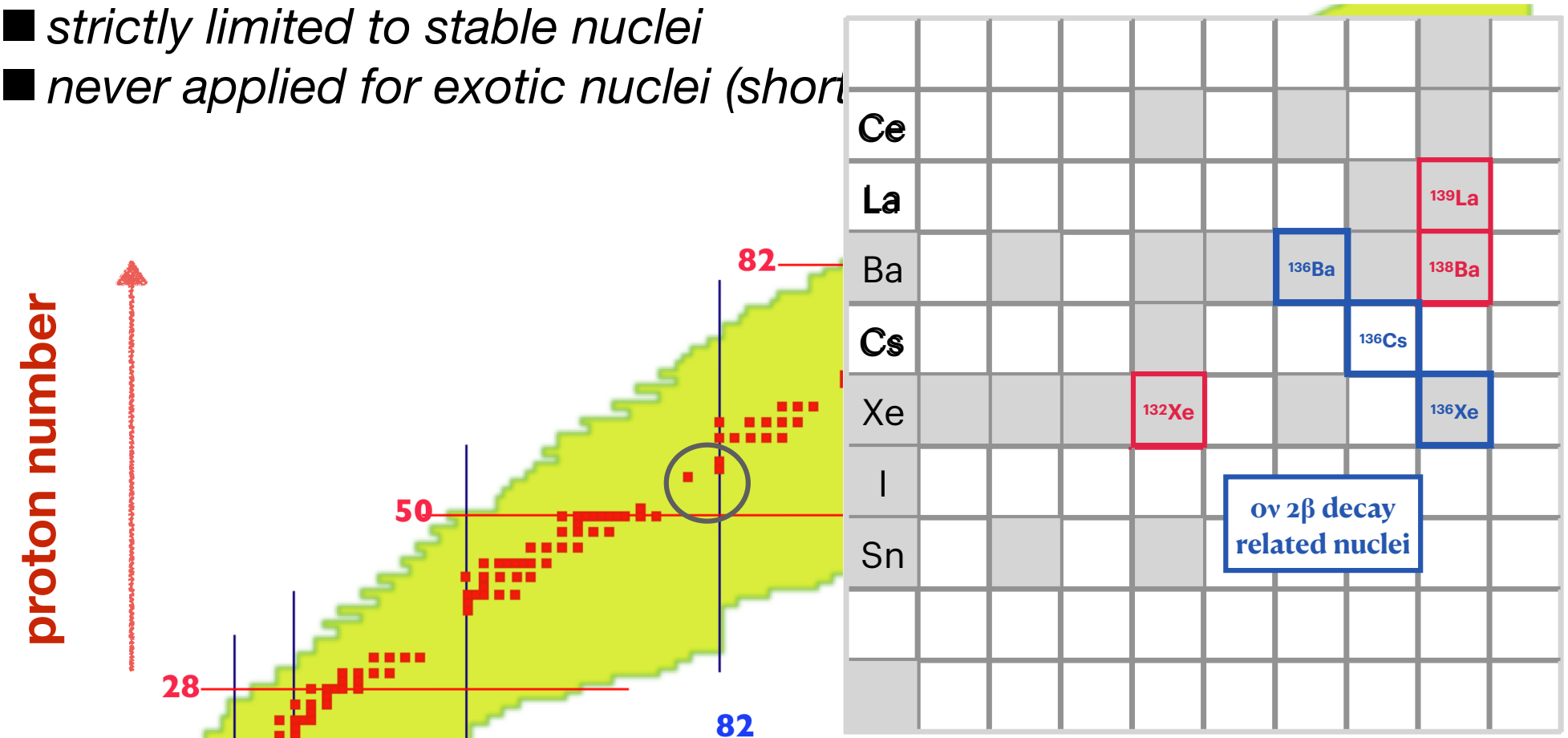
^{136}Xe -> ^{136}Cs -> ^{136}Ba

1. *their charge density distributions*
2. *transition densities*
3. *M1 transition strength*

nuclei ever studied by electron scattering

H.deVries, C. deJager and C. deVries
Atomic Data and Nuclear Data Tables 36 (987)495

- *strictly limited to stable nuclei*
- *never applied for exotic nuclei (short*



- Most of stable nuclei (except noble gases such as Kr, Xe)
- some example for unstable nuclei such as ^{3}H, ^{14}C, ^{41}Ca etc...

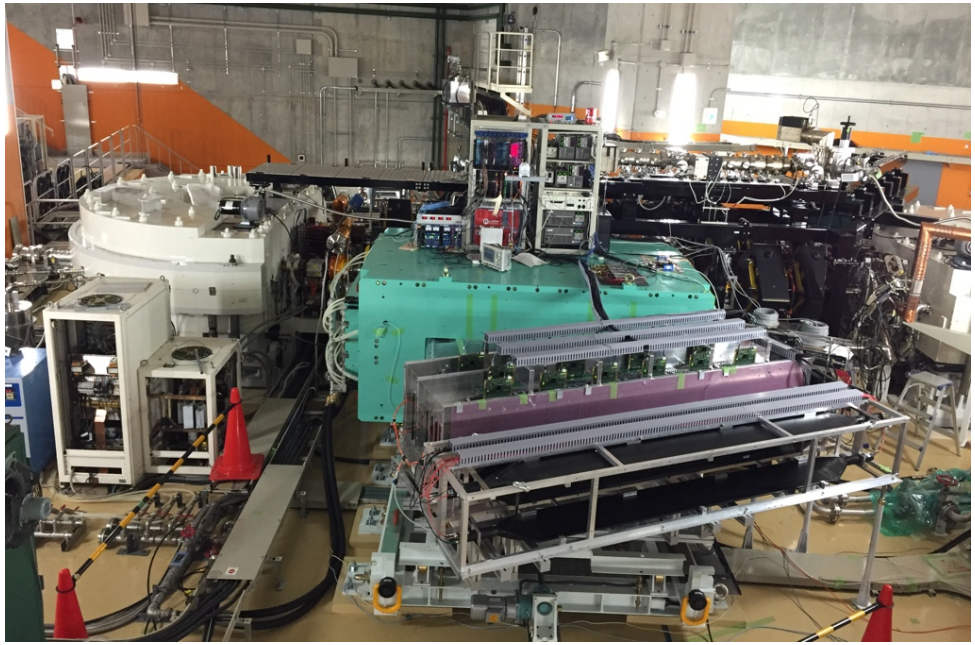
Low-energy electron-scattering facilities

SCRIT @ RIKEN/RIBF

world's first for exotic nuclei

SCRIT : Self-Confining RI-Ion Target
e-scattering off exotic nuclei

Ee = 150 - 300 MeV
θ = 30 - 60 deg.
q = 78 - 300 MeV/c



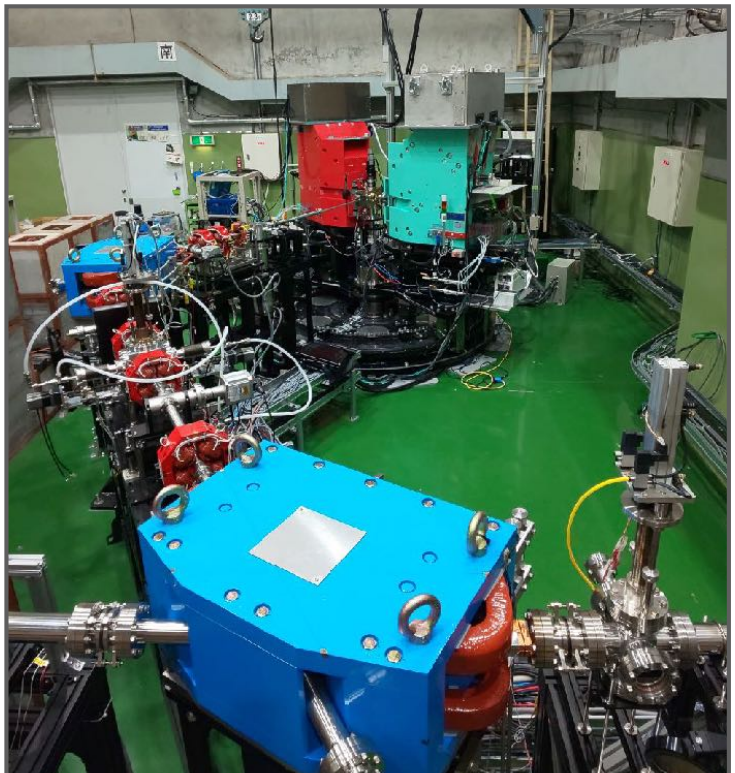
ULQ2 @Tohoku

lowest-ever Ee

ULQ2 : Ultra-Low Q2

Proton Charge Radius
neutron-distribution radius of nuclei

Ee = 10 - 60 MeV
θ = 30 - 150 deg.
q = 5 - 116 MeV/c
Twin spectrometers



Low-energy electron-scattering facilities

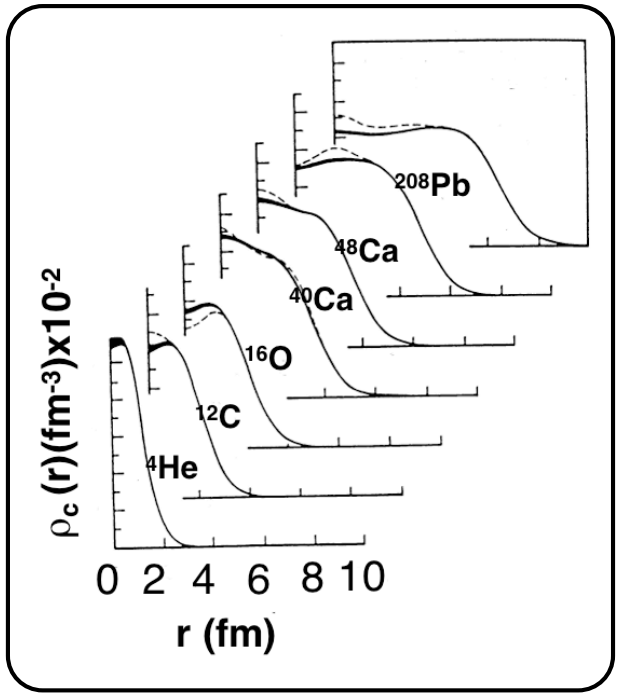
1) charge densities of short-lived nuclei

world's first !

SCRIT facility

e-scattering facility (Ee = 150 - 300 MeV)

dedicated for short-lived exotic nuclei



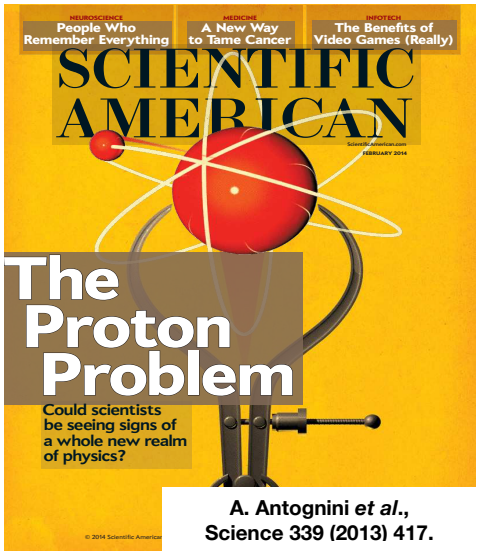
2) proton charge radius

lowest-ever Q^2

low-energy electron scattering

Ee = 10 - 60 MeV

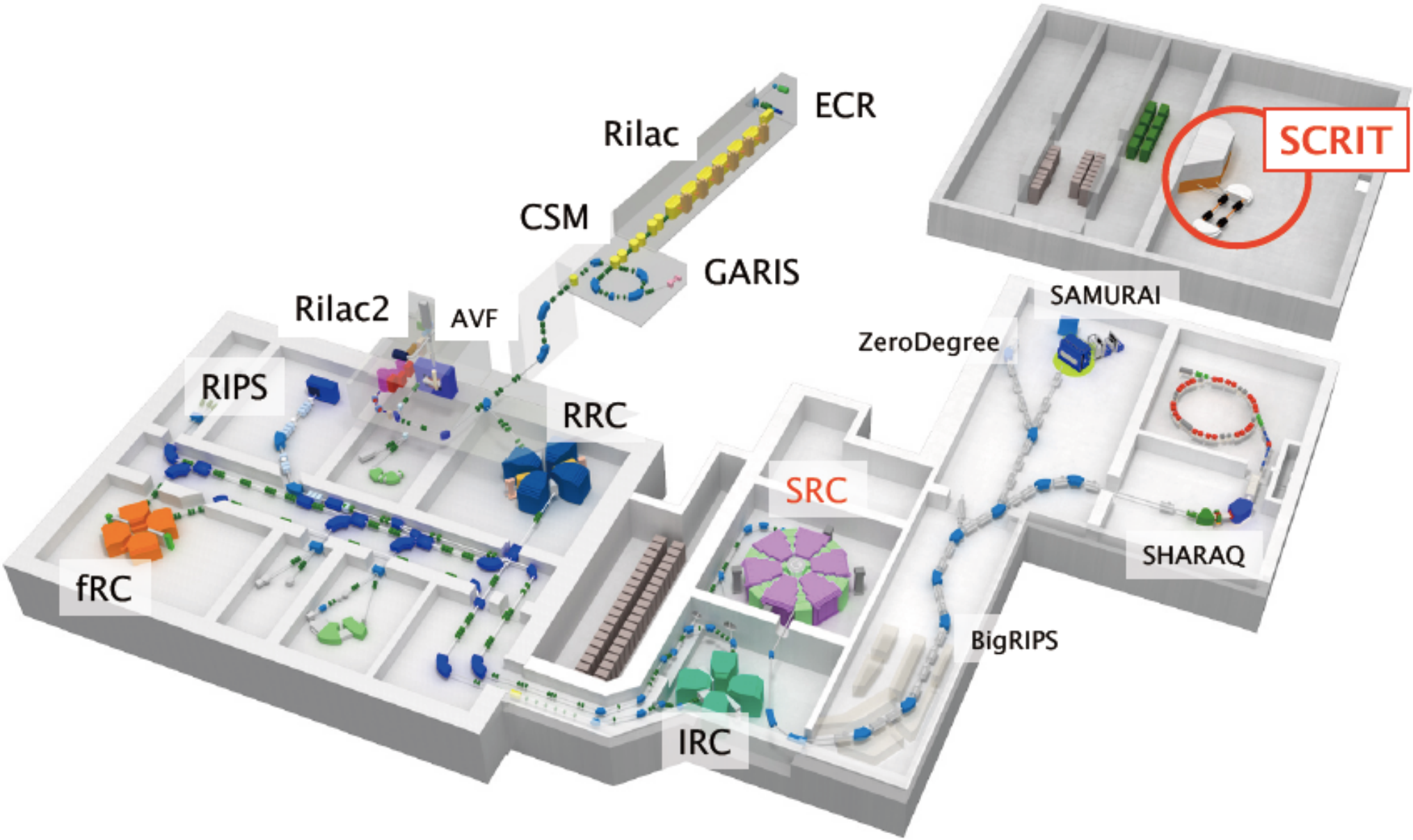
R. Pohl *et al.*,
Nature 466 (2010) 213.



A. Antognini *et al.*,
Science 339 (2013) 417.

SCRIT @ RIKEN/RIBF

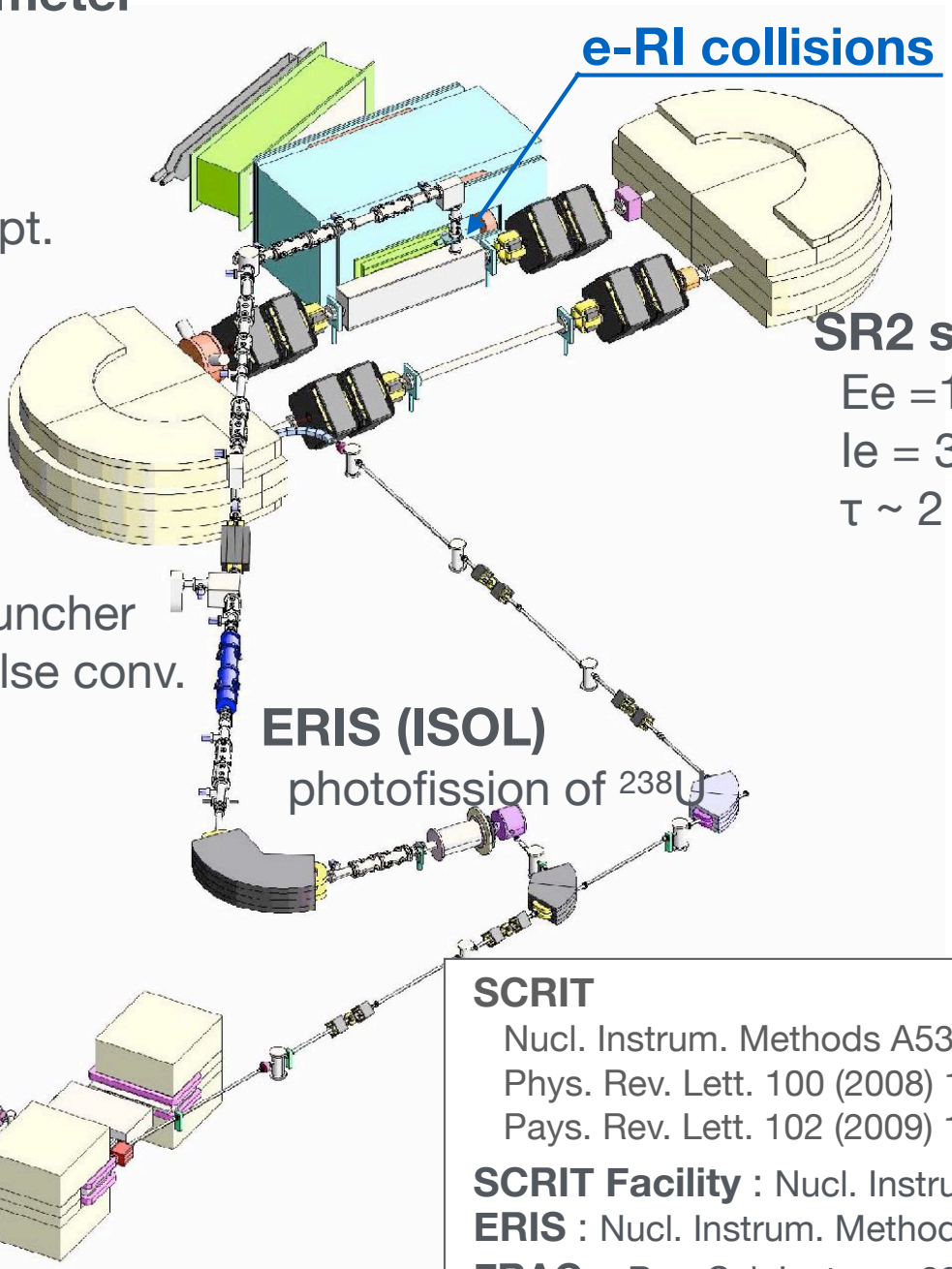
RIKEN RI Beam Factory (RIBF)



RIKEN SCRIT Electron Scattering Facility

WiSES spectrometer

$\Delta\Omega$ ~ 90 mSr
θ = 30 - 60°
$\Delta p/p \sim 10^{-3}$
long target accept.



SR2 storage ring

Ee =150-700 MeV
Ie = 300 mA
τ ~ 2 hours

FRAC

cooler-buncher
dc-to-pulse conv.

ERIS (ISOL)

photofission of ^{238}U

Injector + ISOL driver

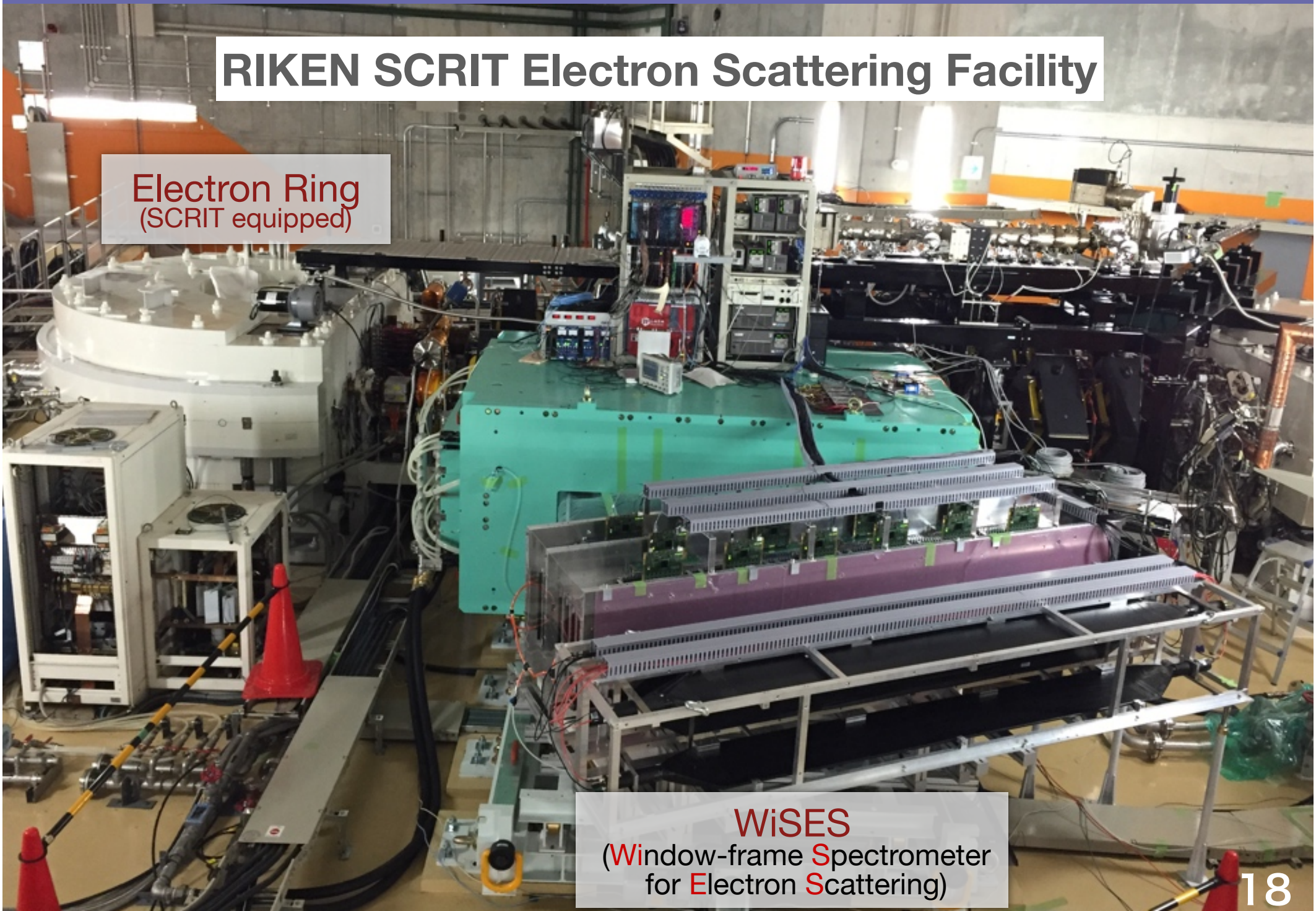
150 MeV Microtron

SCRIT

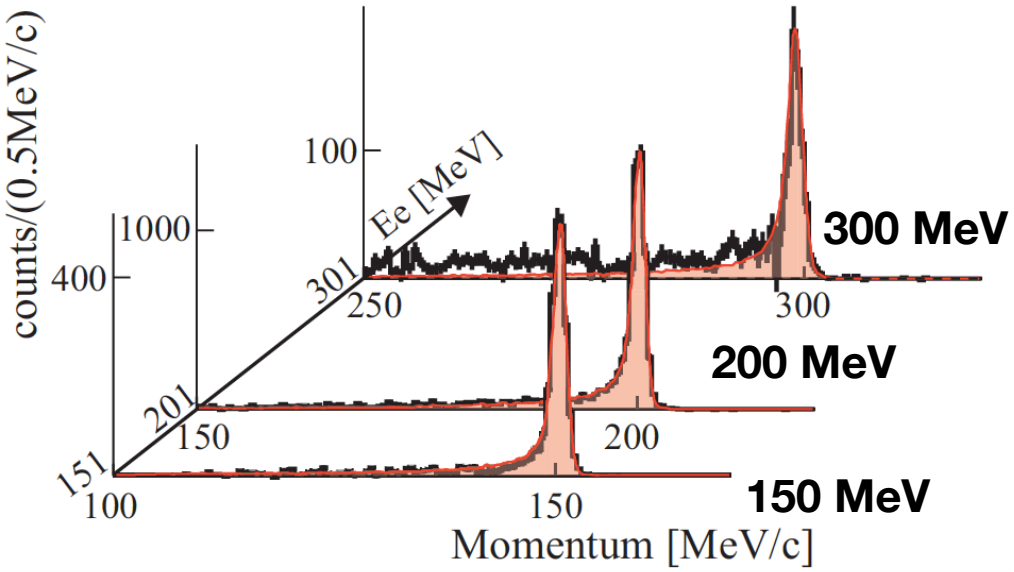
Nucl. Instrum. Methods A532 (2004) 216.
Phys. Rev. Lett. 100 (2008) 164801.
Pays. Rev. Lett. 102 (2009) 102501.

SCRIT Facility : Nucl. Instrum. Method B317 (2013) 668.
ERIS : Nucl. Instrum. Method B317 (2013) 357.
FRAC : Rev. Sci. Instrum. 89 (2018) 095107.

RIKEN SCRIT Electron Scattering Facility

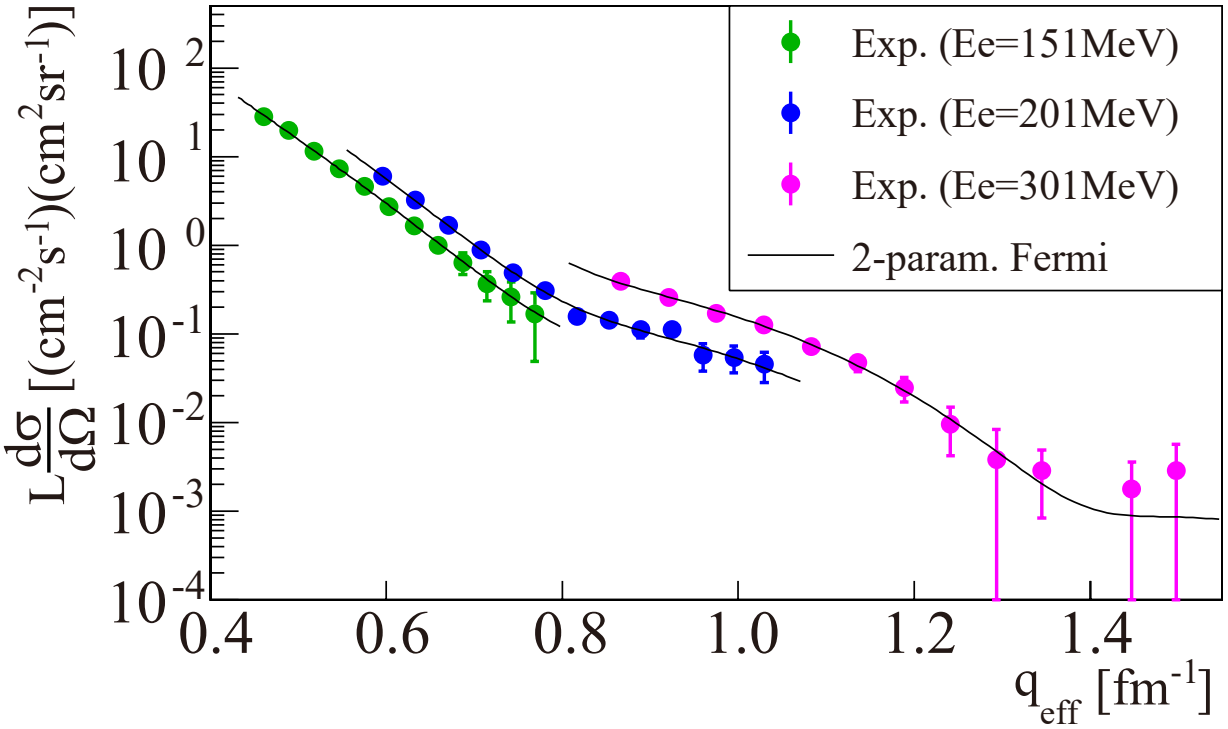


Example : ^{132}Xe(e,e')



K. Tsukada et al.,
PRL 118 (2017) 262501.

$N_{trapped}$ ~ 10^8 @ Ie = 250 mA
=> L ~ 10^{27} /cm^2/s



$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_{Mott}}{d\Omega}|F_c(q)|^2$$

$$F_c(\vec{q}) = \int \rho(\vec{r}) e^{-i\vec{q}\cdot\vec{r}} d\vec{r}$$

$$\rho(r) = \sum_{i=1}^{Z} |\phi_i(r)|^2$$

Luminosity of the SCRIT facility

	Ee	N_{beam}	target thickness	L
Hofstadter's era (1950s)	150 MeV	~ 1nA (~10^9 /s)	~10^{19} /cm^2	~10^{28} /cm^2/s
JLAB	12 GeV	~100μA (~10^{14} /s)	~10^{22} /cm2	~10^{36} /cm^2/s
SCRIT	150-300 MeV	300 mA (~10^{18} /s)	~10^9 /cm^2	~10^{27} /cm^2/s

~10^7 trapped ions in e-beam of ~1 mm^2

required target thickness ~ 10^{-10} !!

nuclei ever studied by electron scattering

H.deVries, C. deJager and C. deVries
Atomic Data and Nuclear Data Tables 36 (987)495

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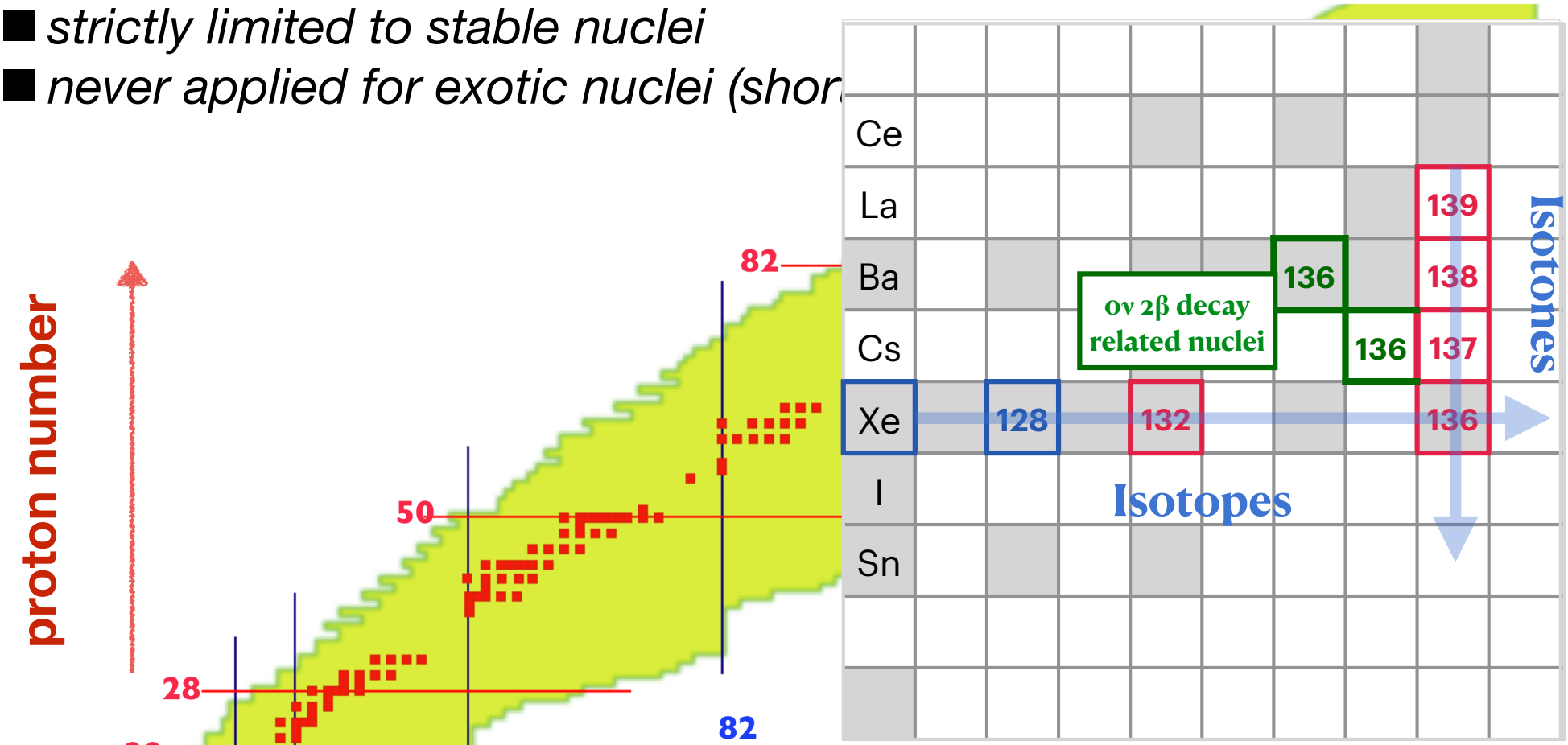

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