Electron scattering experiment off proton at ultra-low Q^2

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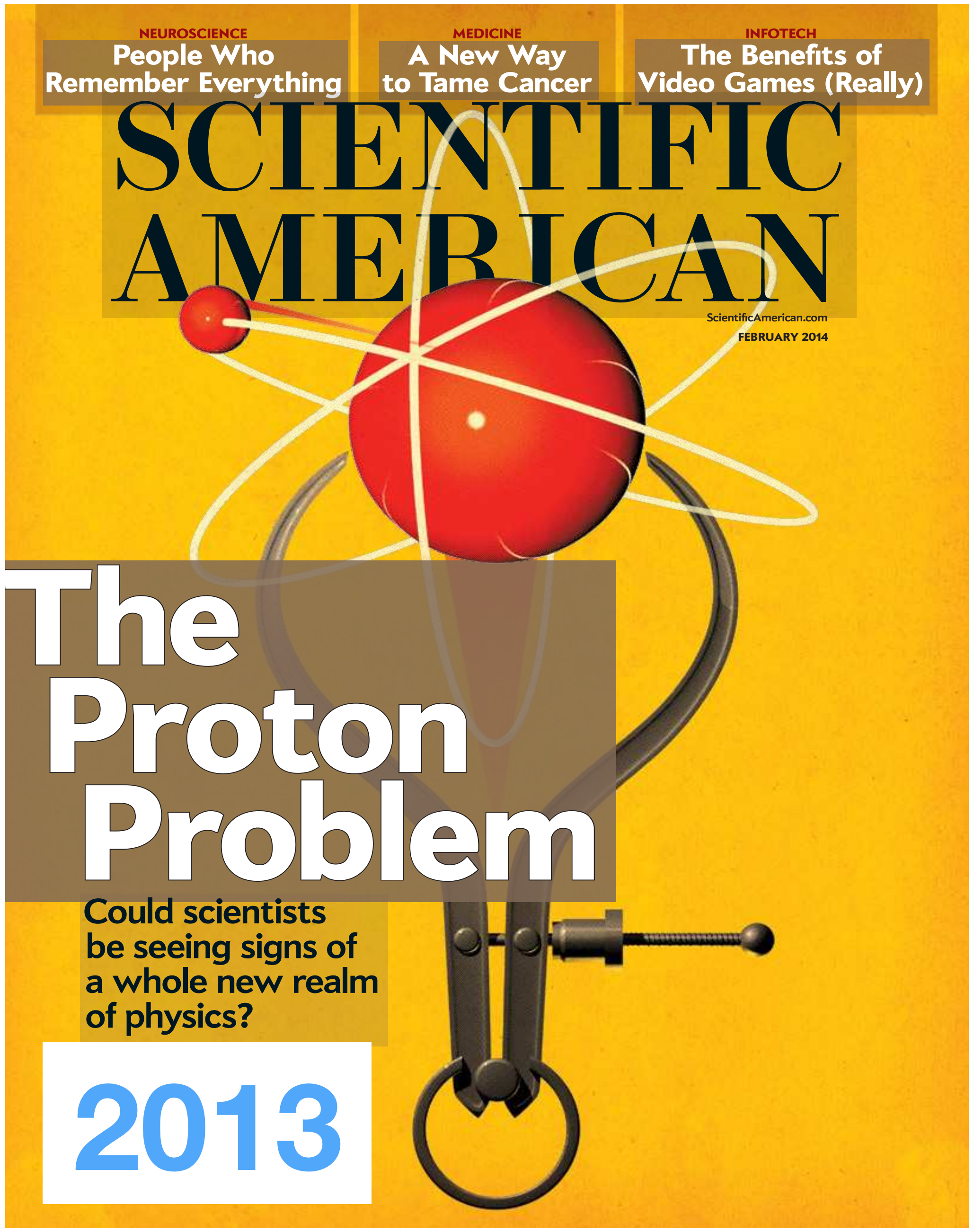
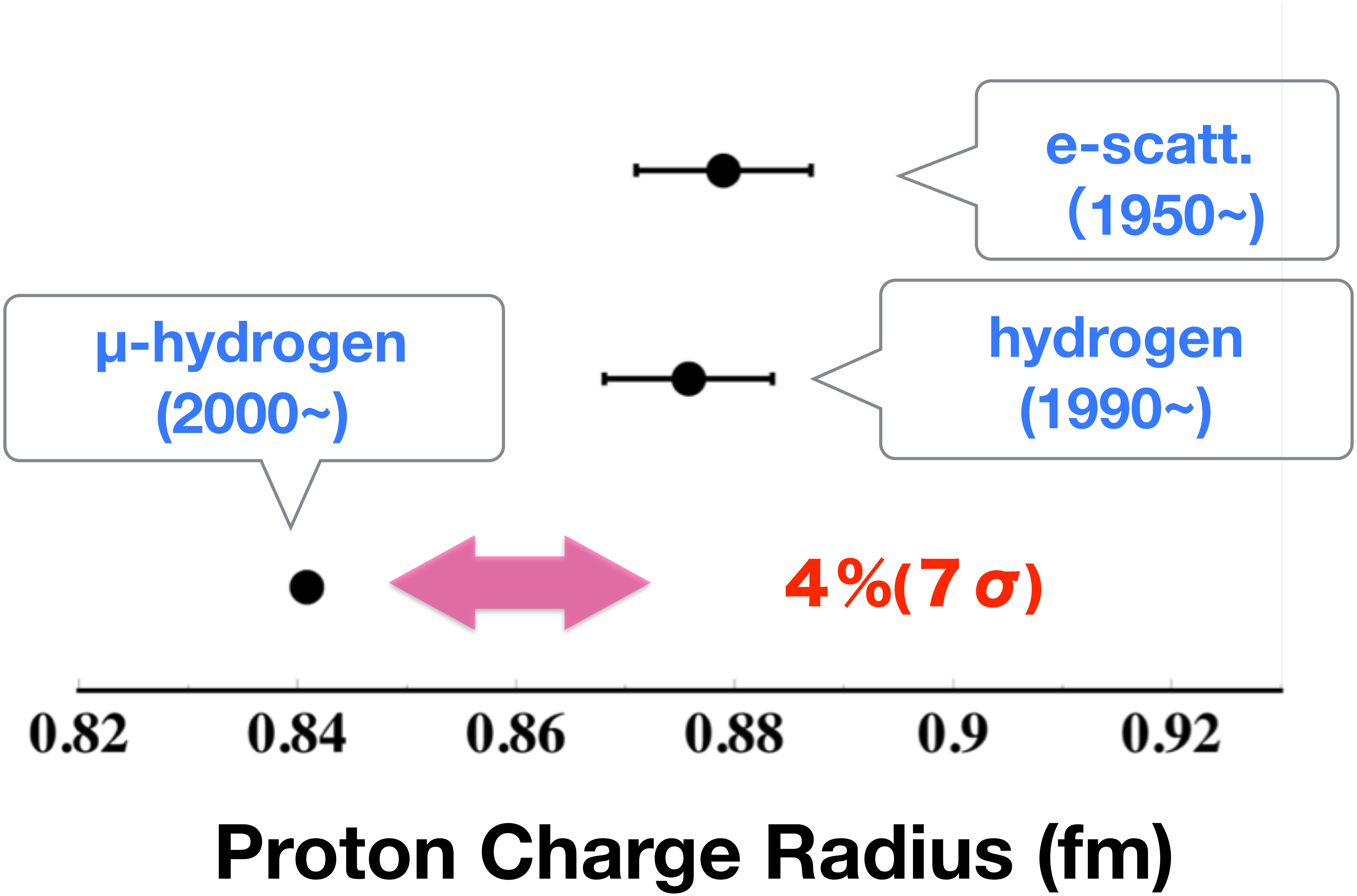
Proton Radius Puzzle



Proton charge radius puzzle



Proton charge radius puzzle

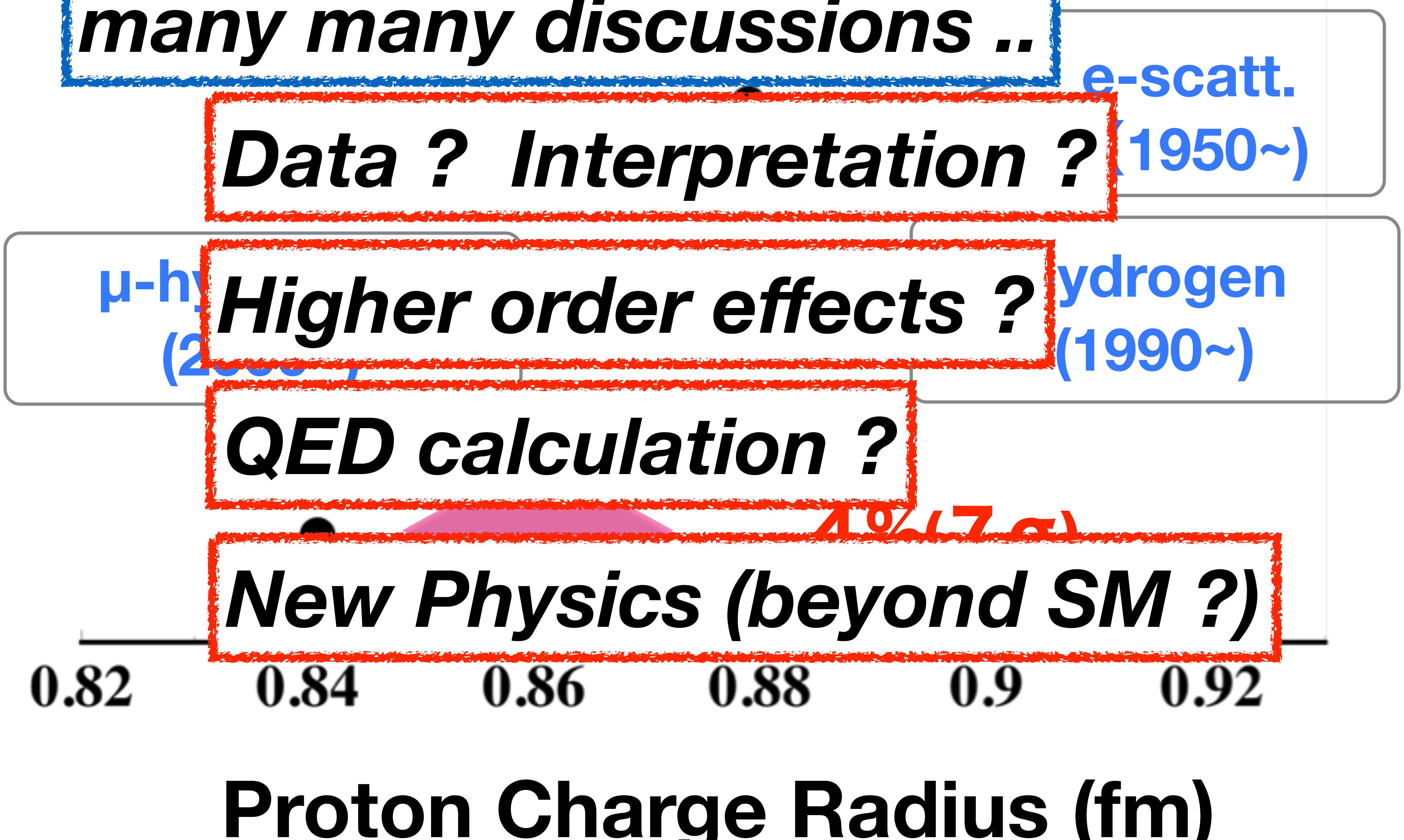
many many discussions ..

Data ? Interpretation ?

Higher order effects ?

QED calculation ?

New Physics (beyond SM ?)



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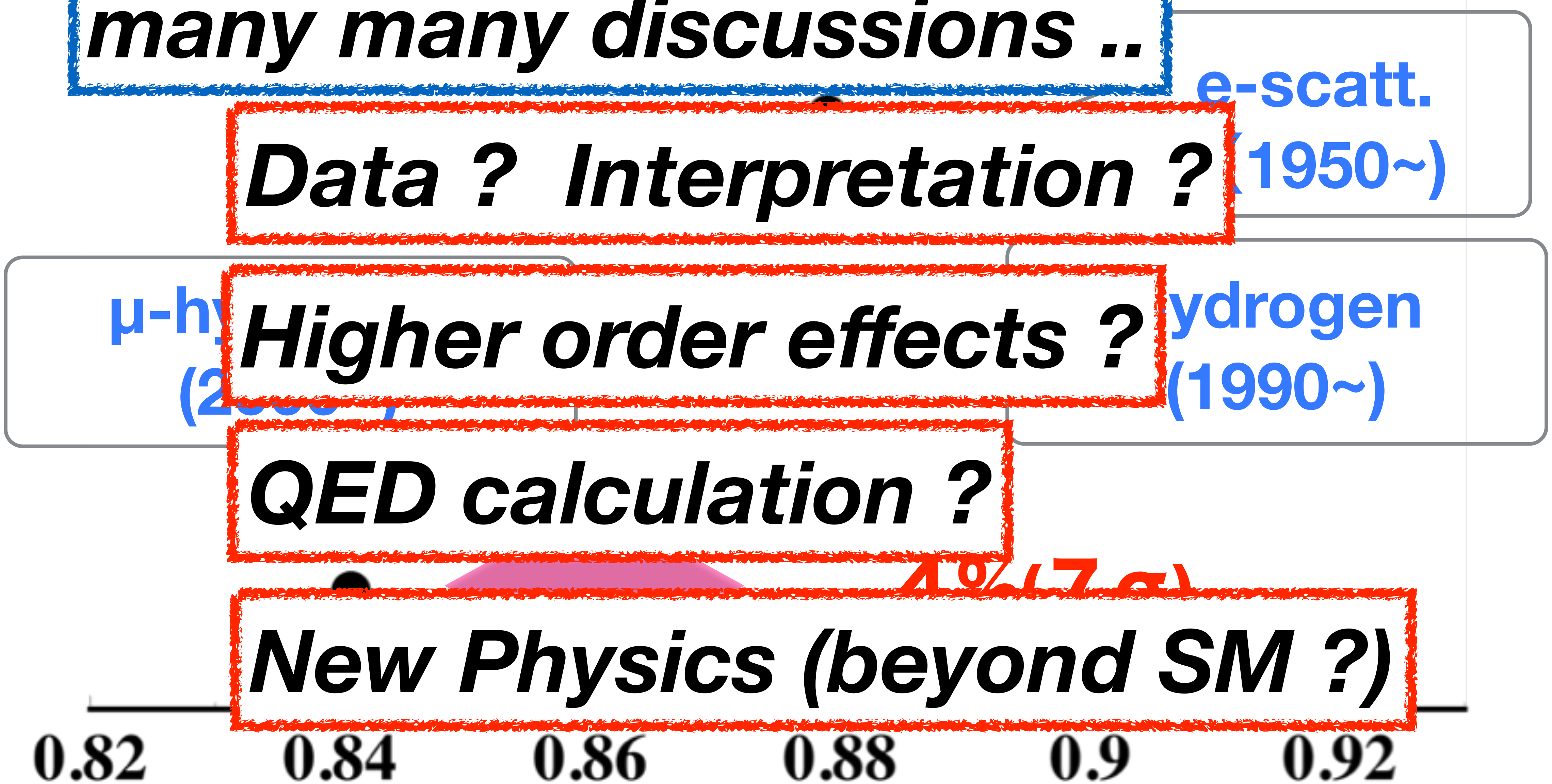

not yet settled

New experiments …

Who are we ?

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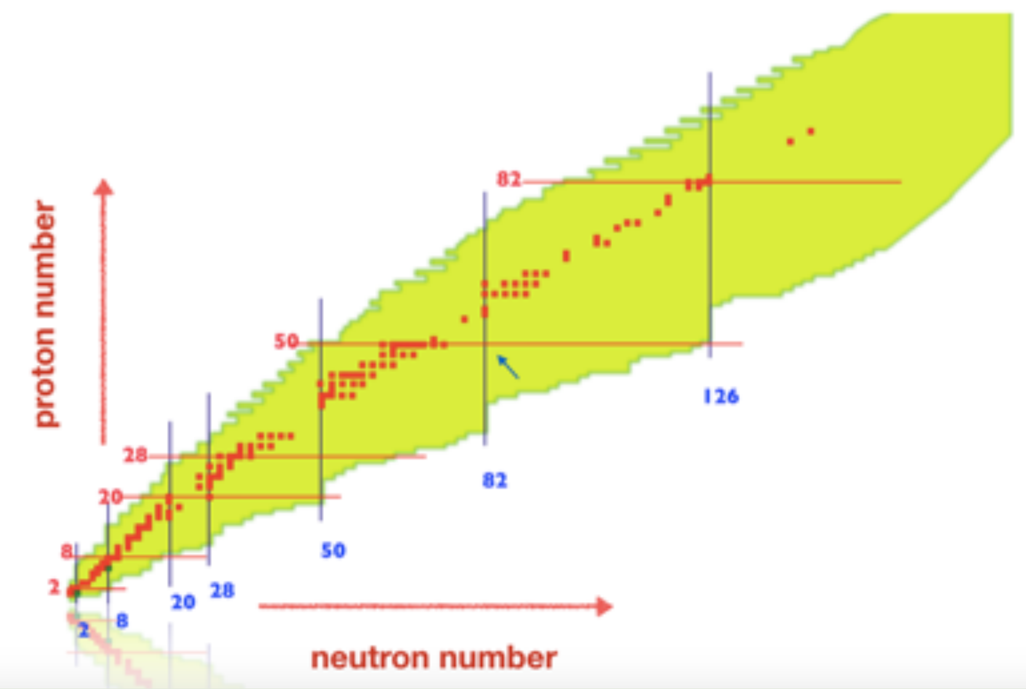
"classical" elastic electron scattering
to study the charge density distributions
pioneered by R. Hofstadter in 1950s !

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

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



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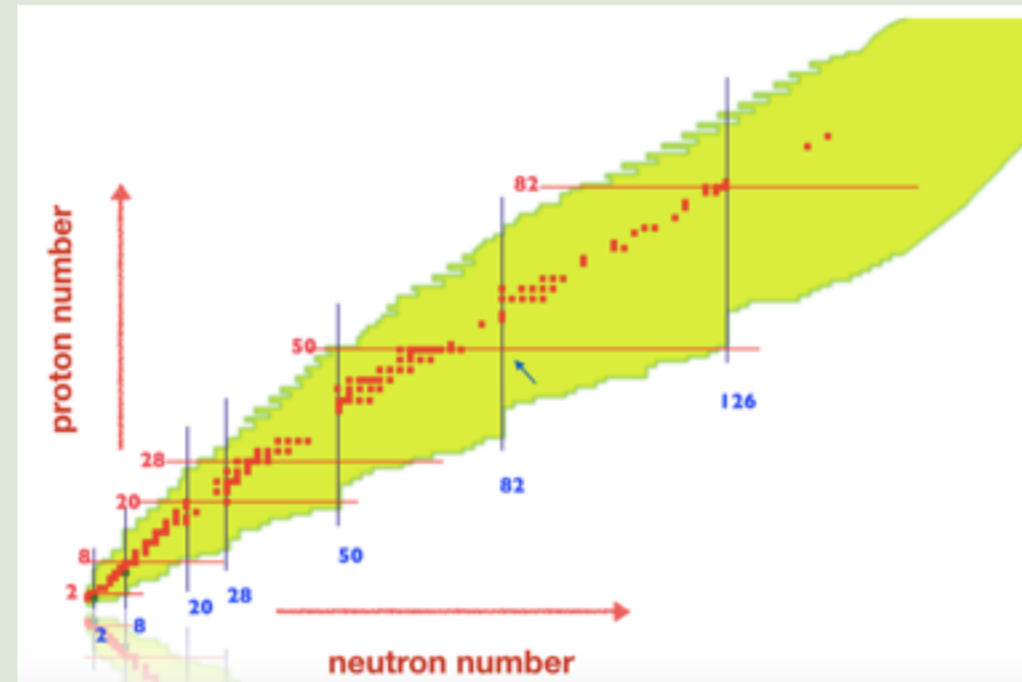

Not for stable nuclei,,,,,,

BUT never-yet-performed Short-Lived Exotic Nuclei !

➡ "Hofstadter's experiments" for exotic nuclei

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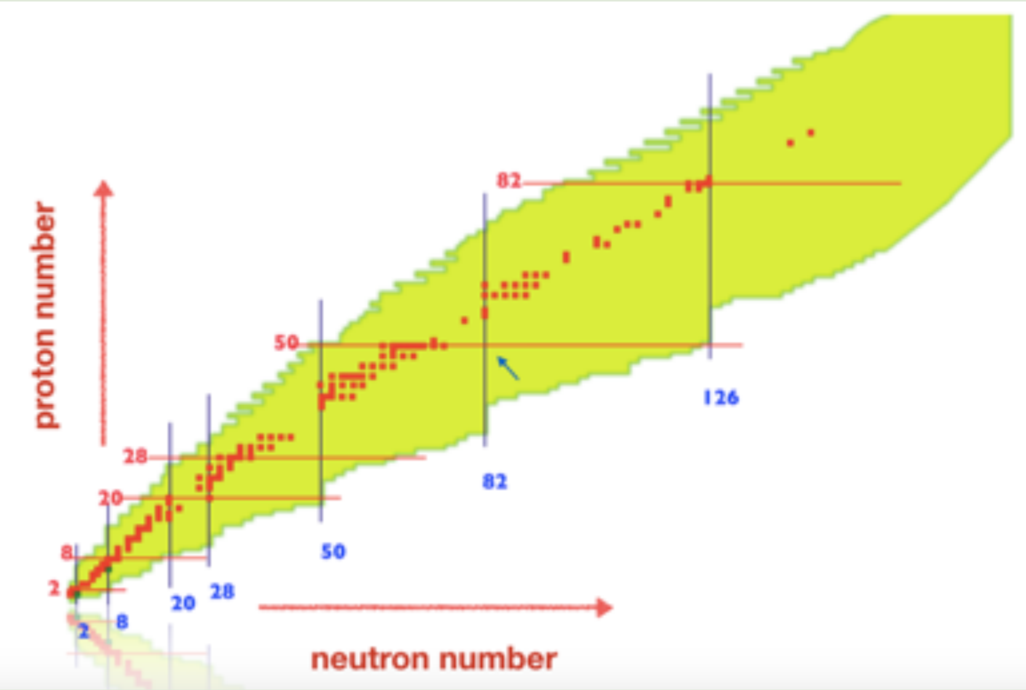

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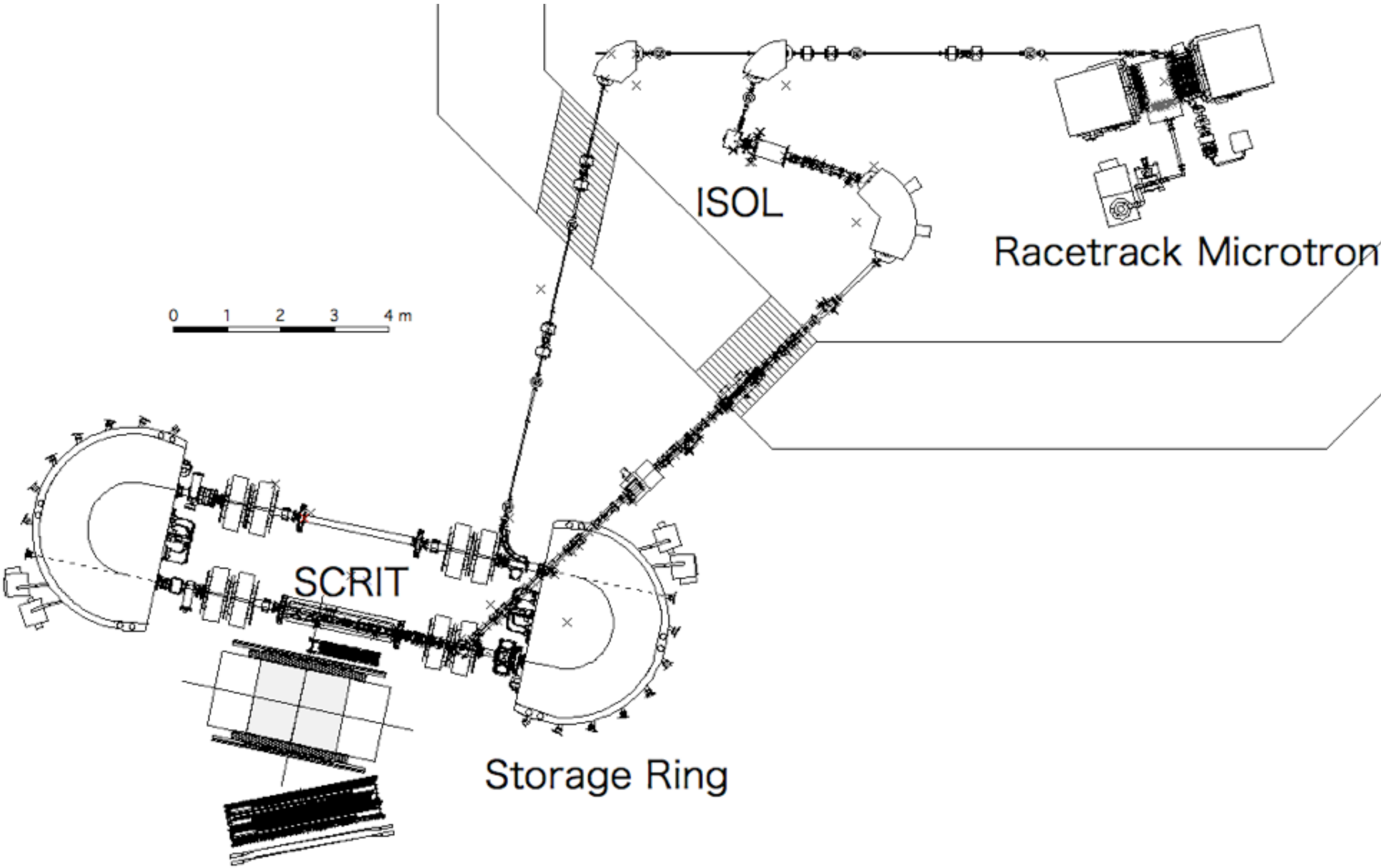
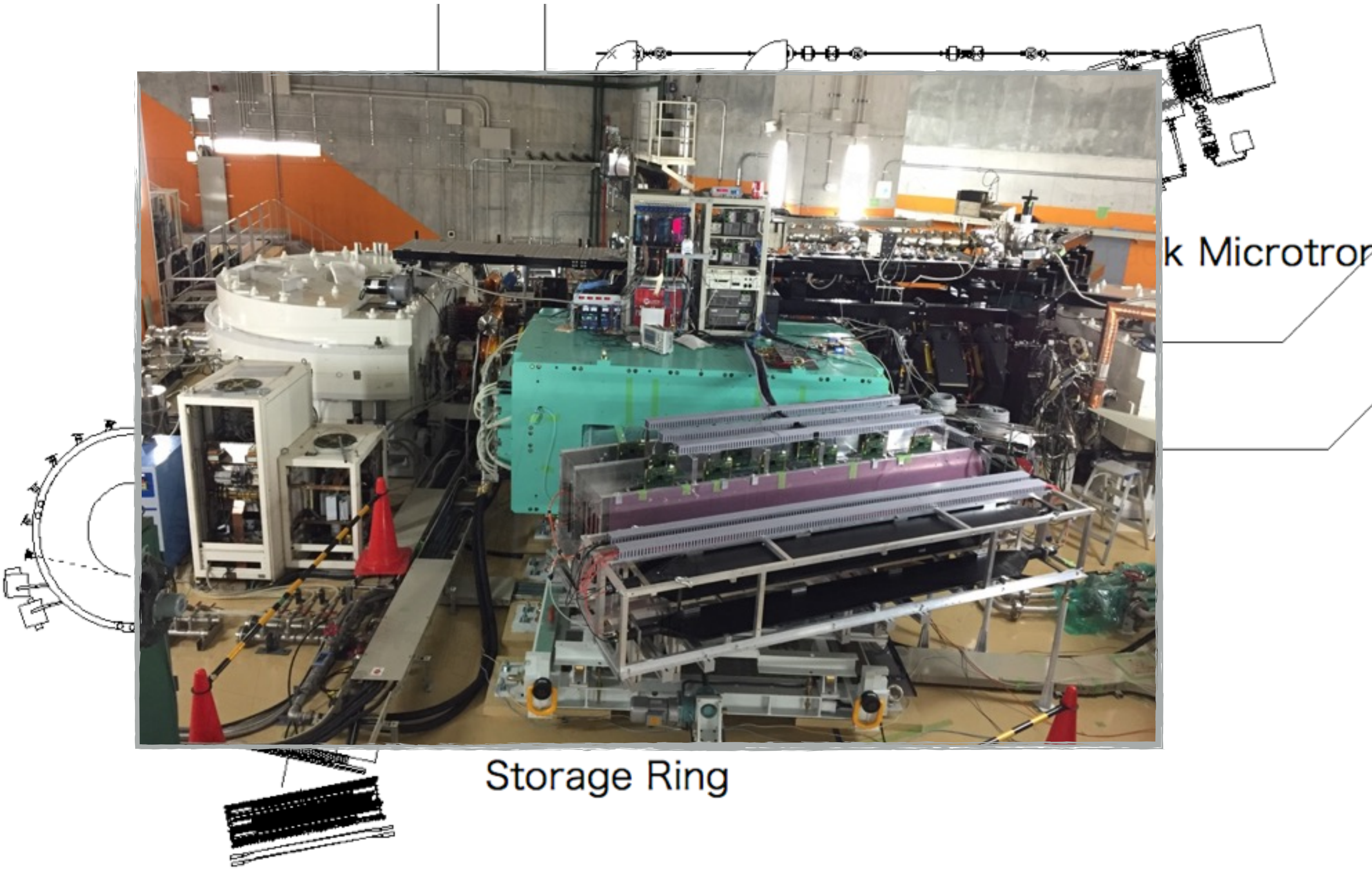
"Hofstadter's experiments" for exotic nuclei

we are currently operating
the World's first electron scattering facility
dedicated for exotic nuclei.

SCRIT electron scattering facility



SCRIT electron scattering facility



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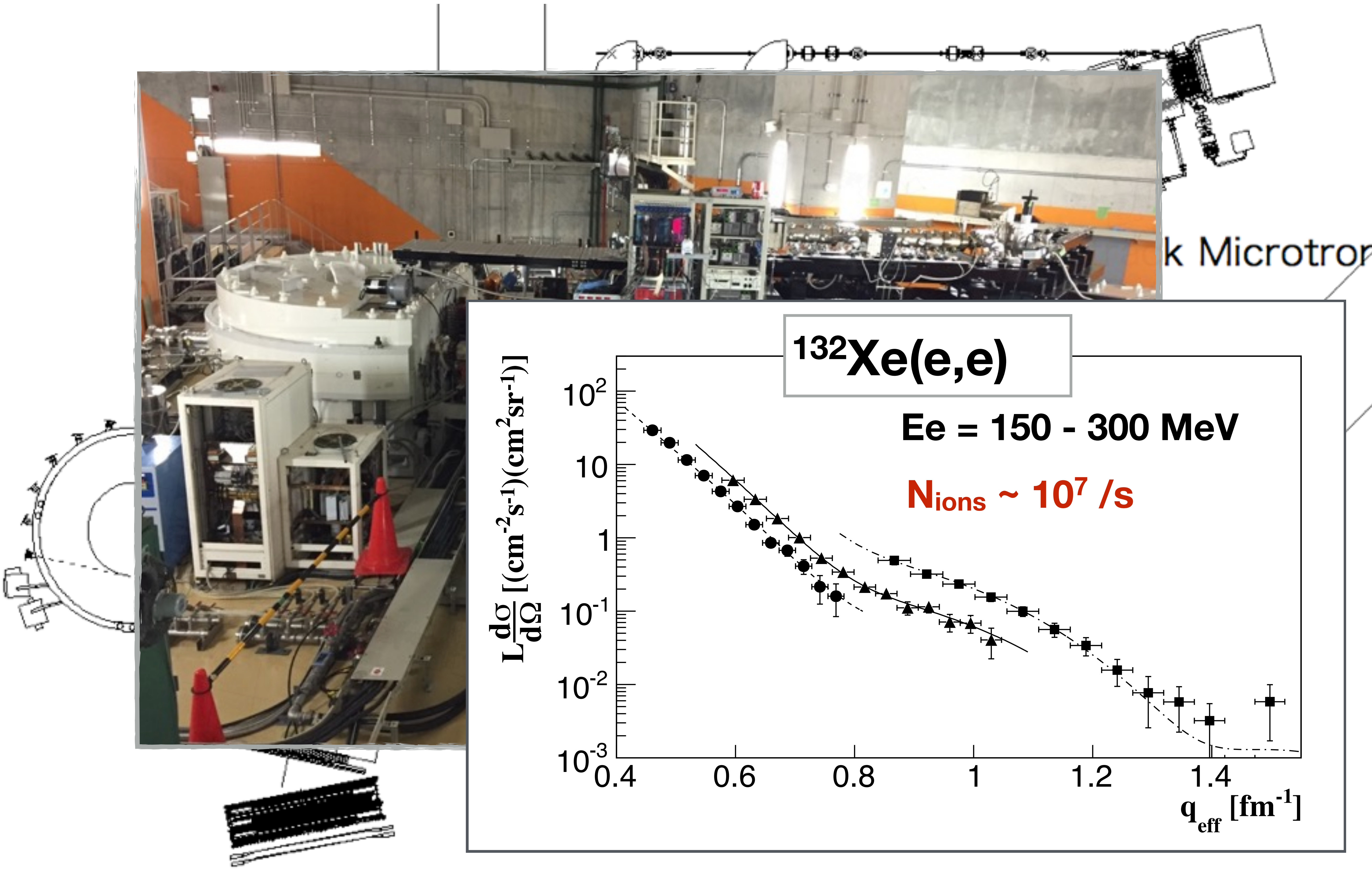


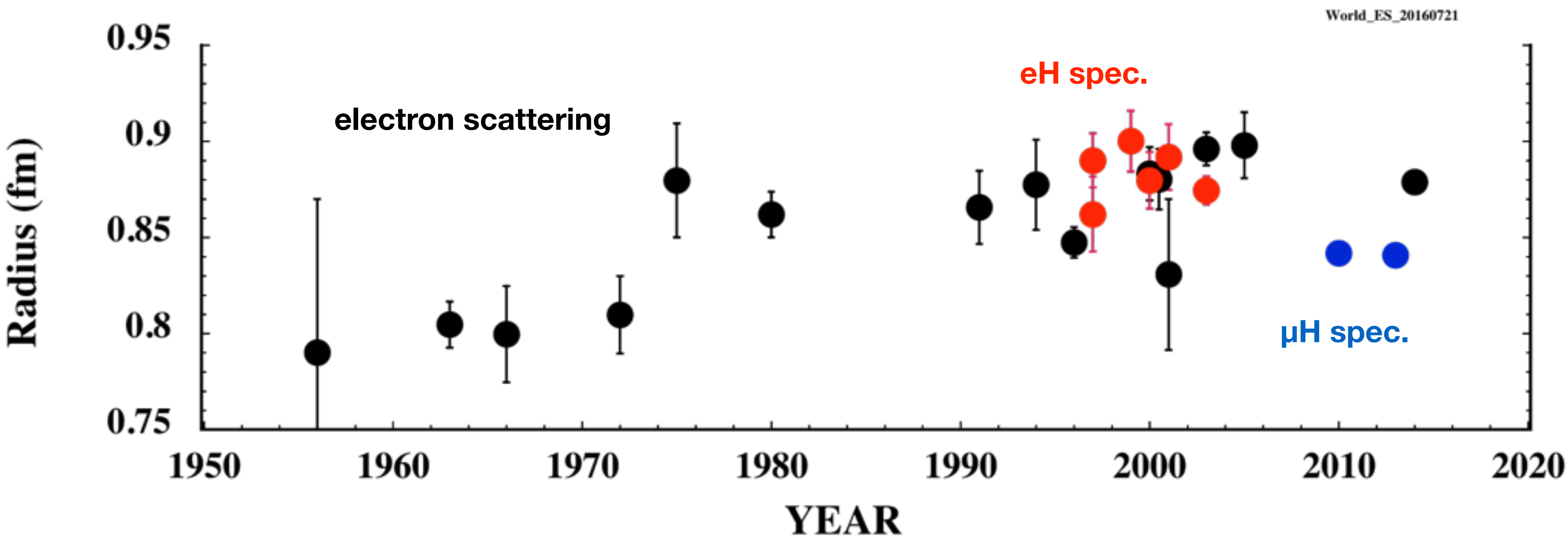
Electron scattering off proton

1960 1970 1980 1990 2000 2010

e+p, e+A elastic scattering
R. Hofstadter
(1961)



e+p deep inelastic scattering
J. Friedman, H. Kendall and R. Taylor
(1990)



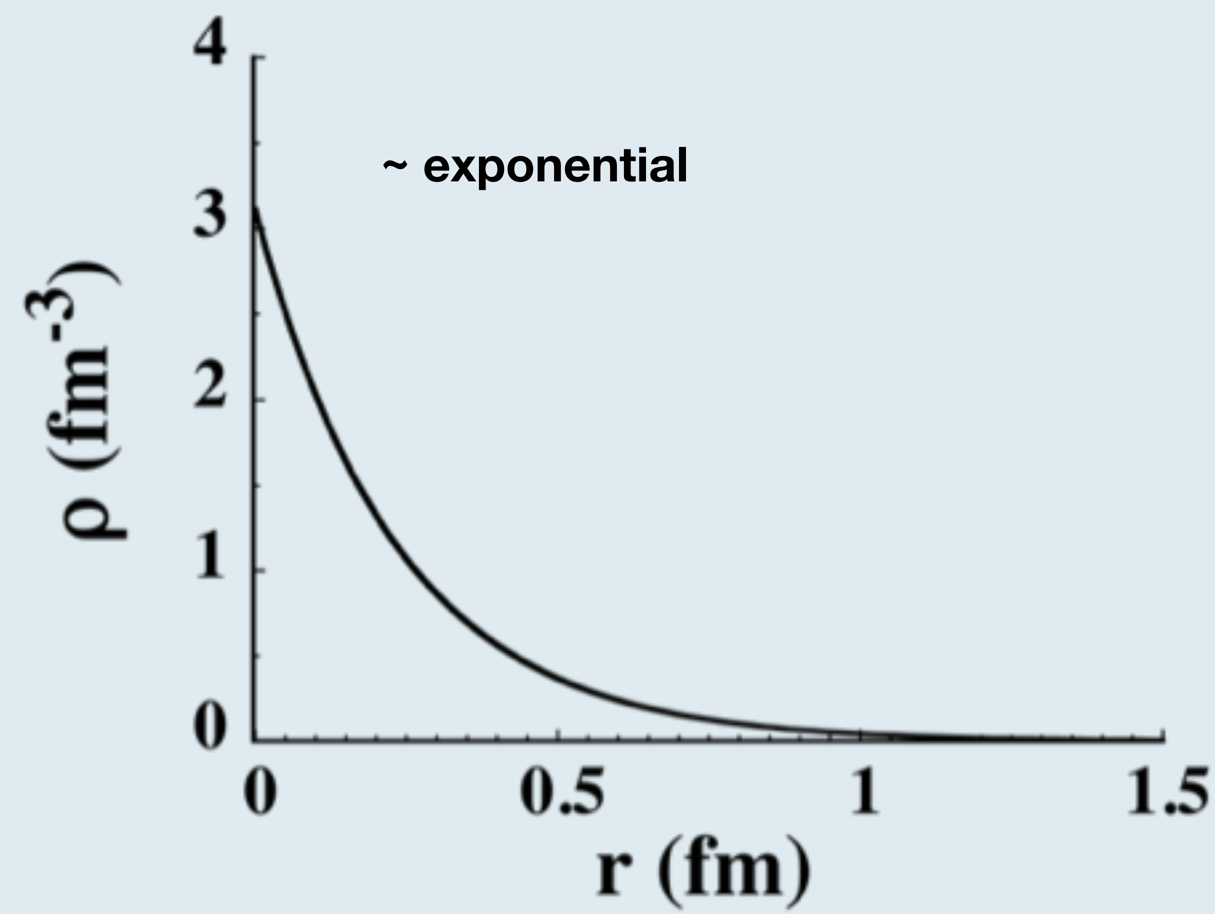
Proton charge radius

RMS radius

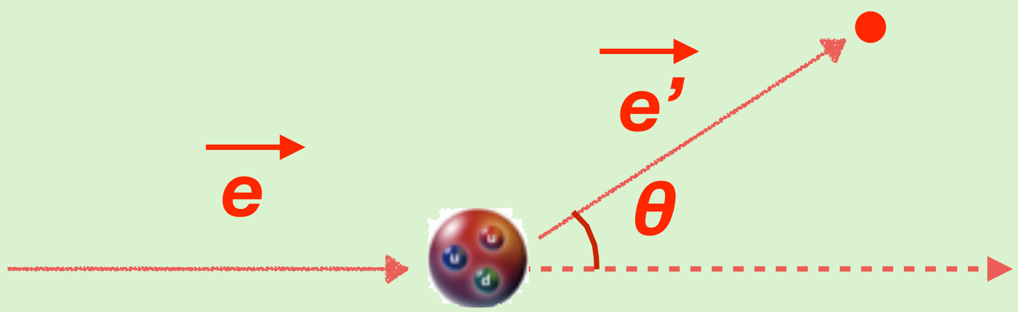
$$< r^2 >= \int r^2 \rho(\vec{r}) d\vec{r}$$

$$= 4\pi \int r^4 \rho(r)\ \mathrm{d}r$$

ρ(r)



Proton charge radius by e-scattering



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

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

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

$$\tau = \frac{Q^2}{4m_p^2}$$

momentum transfer $\vec{q} = \vec{e} - \vec{e'}$

energy transfer $\omega = e - e'$

4 momentum transfer $Q^2 = q^2 - \omega^2 = 4\, e\, e' \sin^2(\theta/2)$

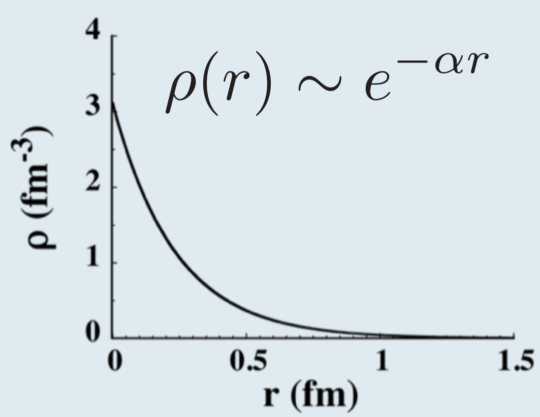
1） high Q^2: charge density ρ(r)

Electric Form FactorGE

⇕

ρ(r)

$$< r^2 >= \int r^2 \rho(\vec{r}) d\vec{r}$$



radius is sensitive to ρ(r) at large distance (even at r ~ 4 fm)

2） low Q^2

$$G_E(Q^2) \sim 1 - \frac{< r^2 >^{1/2}}{6} Q^2 + \frac{< r^4 >^{1/2}}{120} Q^4 - \ldots$$

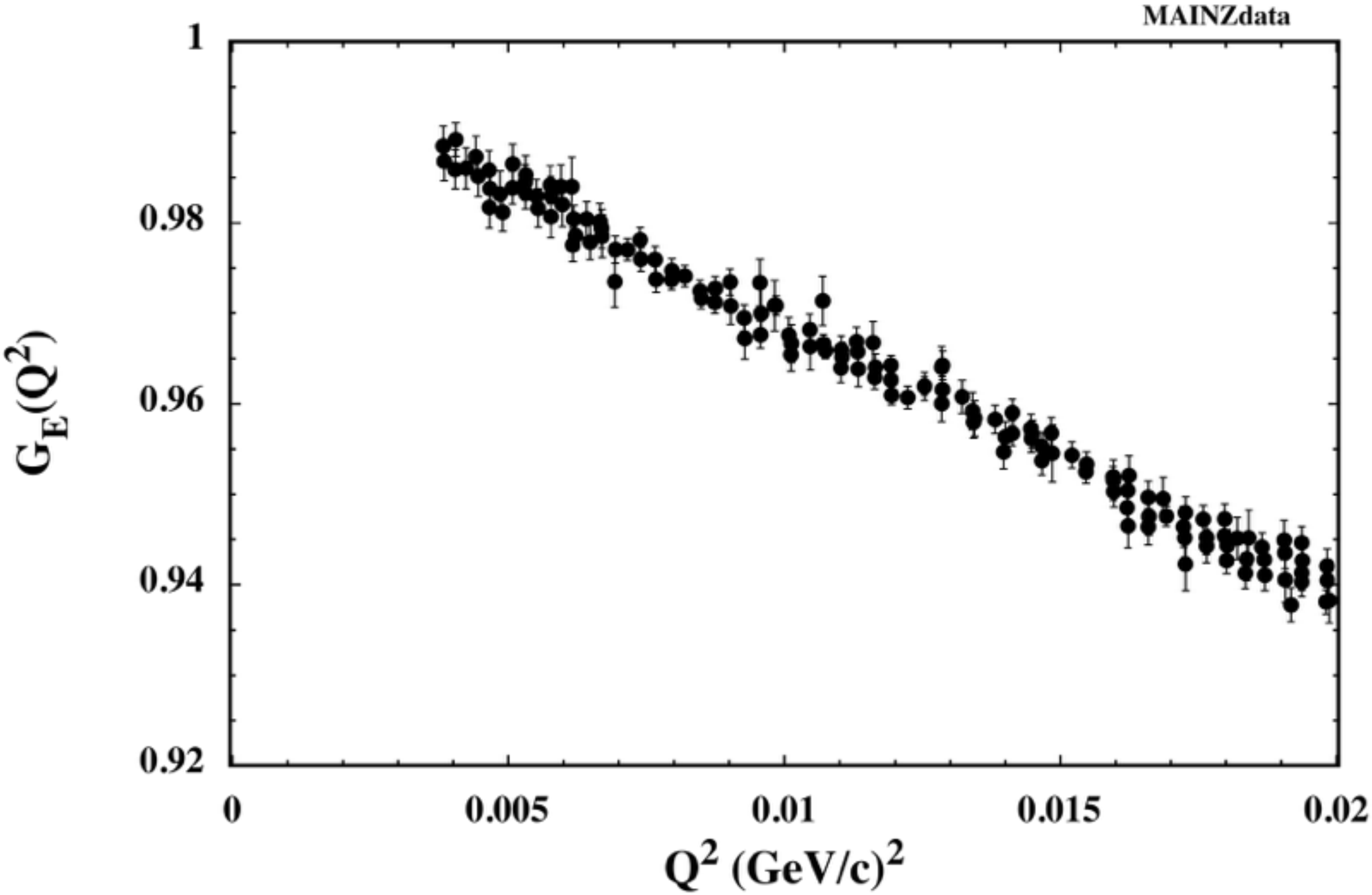
$$< r^2 > \equiv -6 \frac{dG_E(Q^2)}{dQ^2}\Big|_{Q^2 \to 0}$$

ill problem : higher order contribution

⇕

lower Q^2 as possible

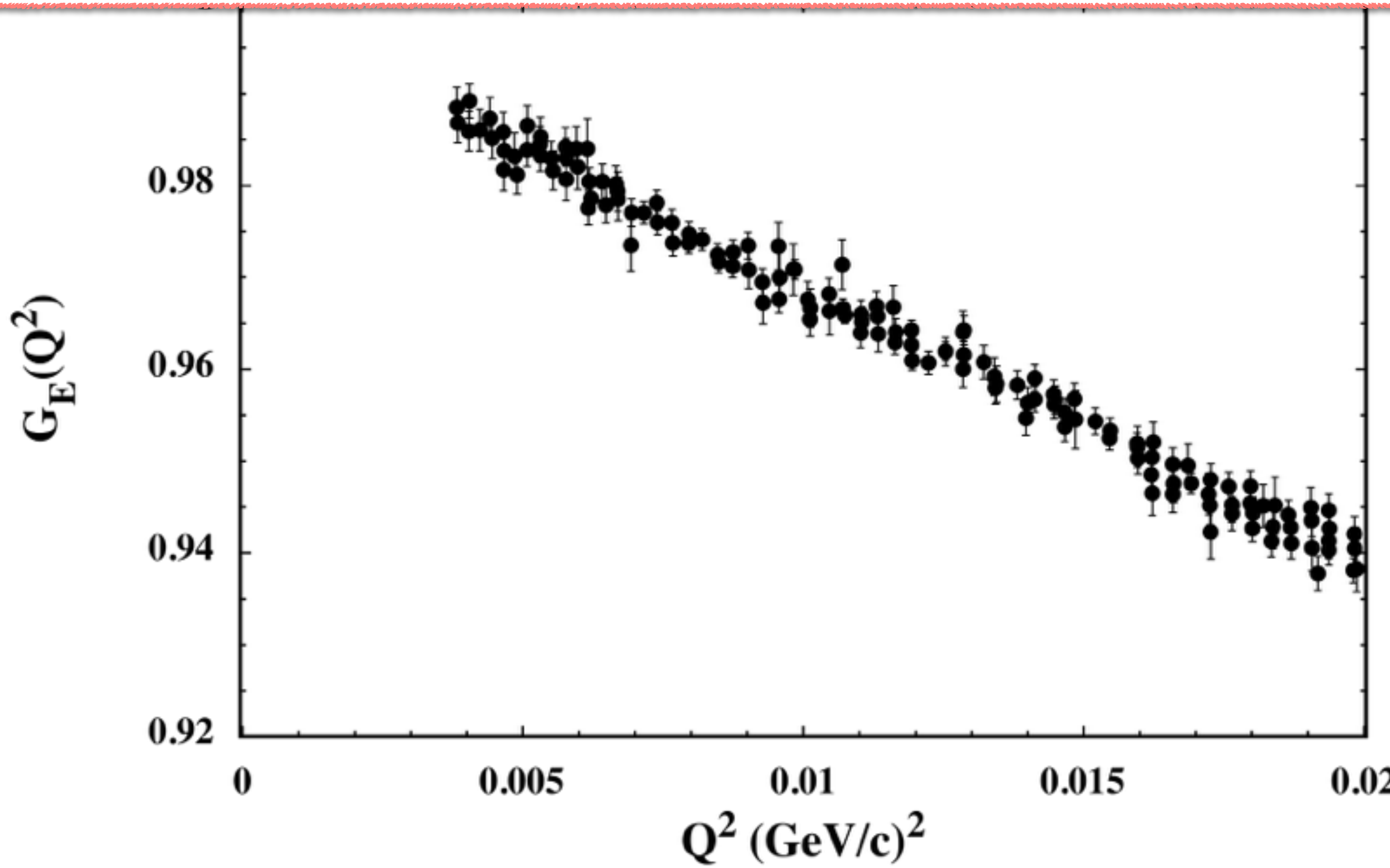
Electron scattering at Low Q^2



J. C. Bernauer et al., Phys. Rev. C90 (2014) 015206.

Electron scattering at Low Q^2

$$G_E(Q^2) \sim 1 - \frac{< r^2 >}{6} Q^2 + \frac{< r^4 >}{120} Q^4 - \frac{< r^6 >}{5040} Q^6 + \ldots$$



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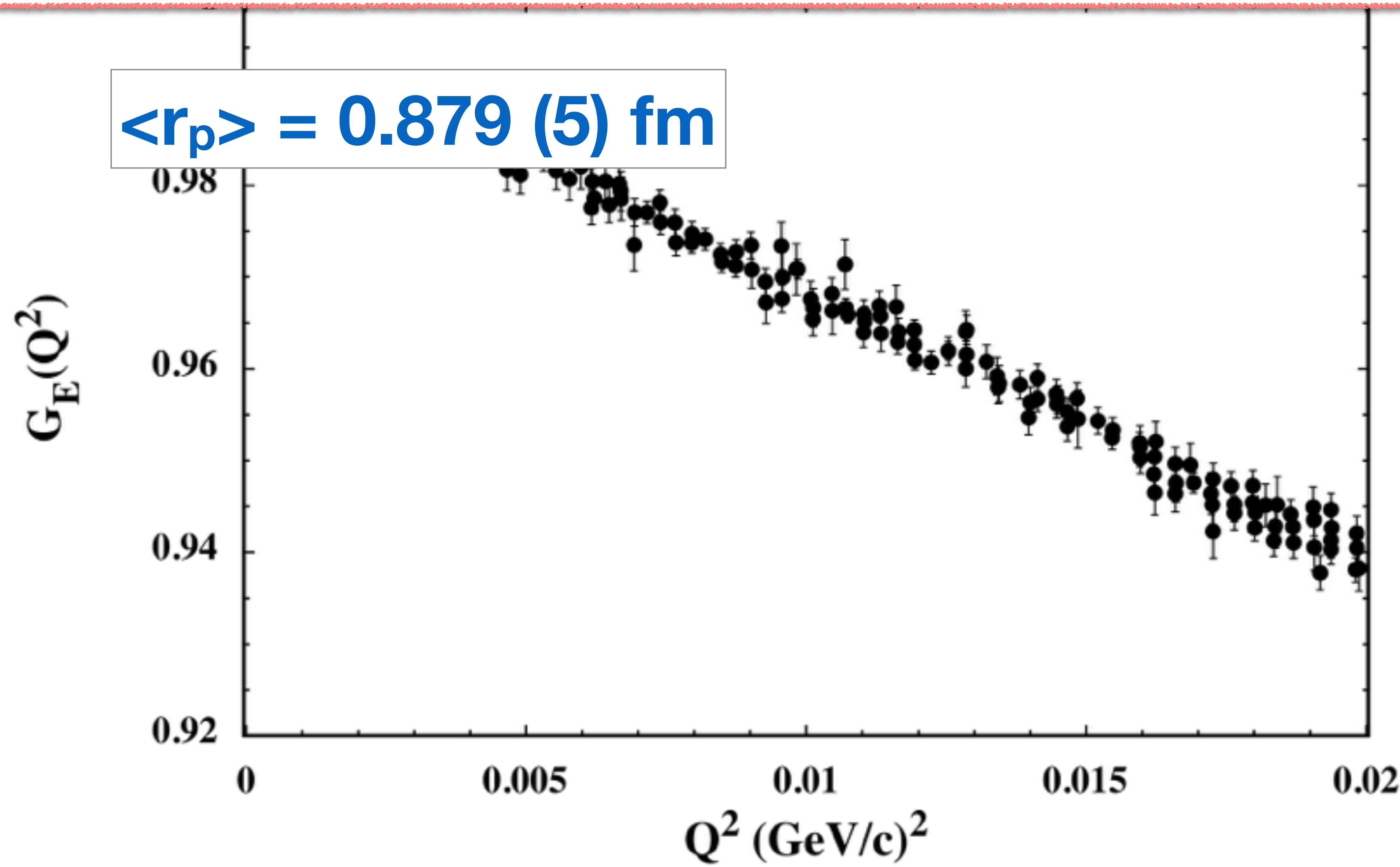

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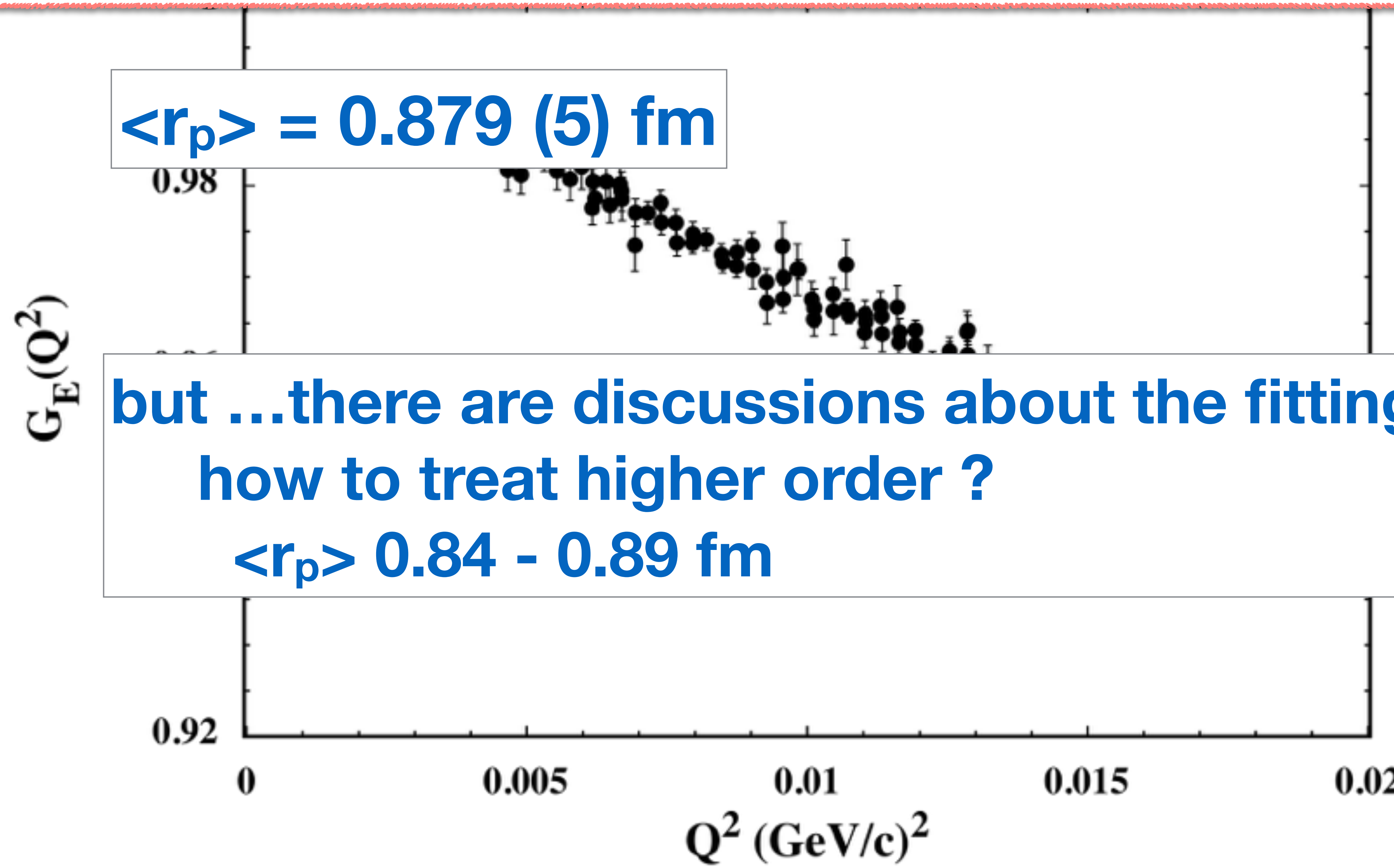
$<r_p> = 0.879\ (5)$ fm

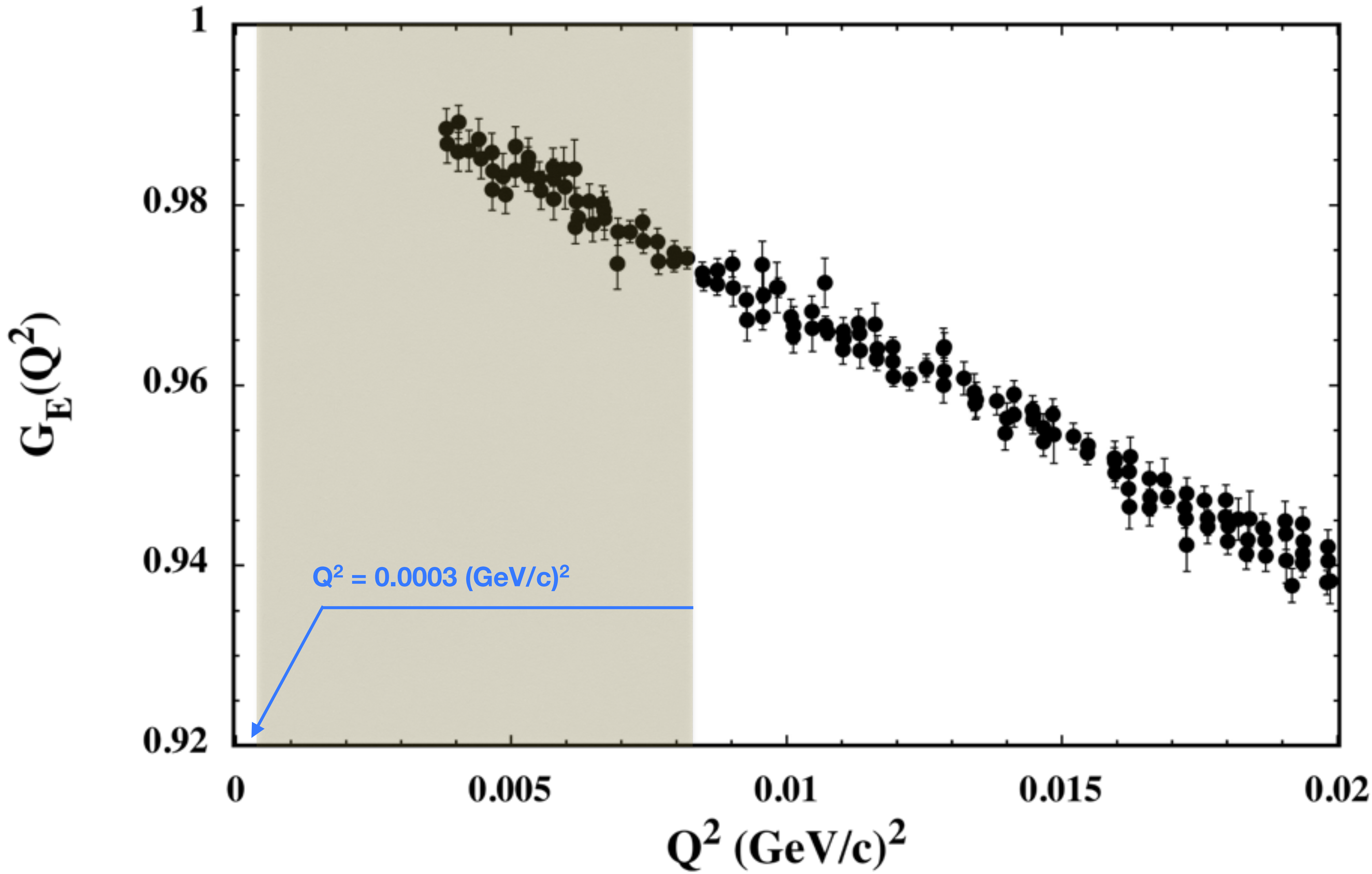


but …there are discussions about the fitting
how to treat higher order ?
$<r_p>$ 0.84 - 0.89 fm

J. C. Bernauer et al., Phys. Rev. C90 (2014) 015206.

What are we going to do ???

Reduction of the higher order contribution



What are we going to do ?

	Mainz	Tohoku
Q^2_{min} $(GeV/c)^2$	0.004	0.0003
Ee (MeV)	180 ~ 850	20 ~ 60
absolute $d\sigma/d\Omega$	x	○
G_E/G_M separation	x	○

Electron scattering at Lower Q^2

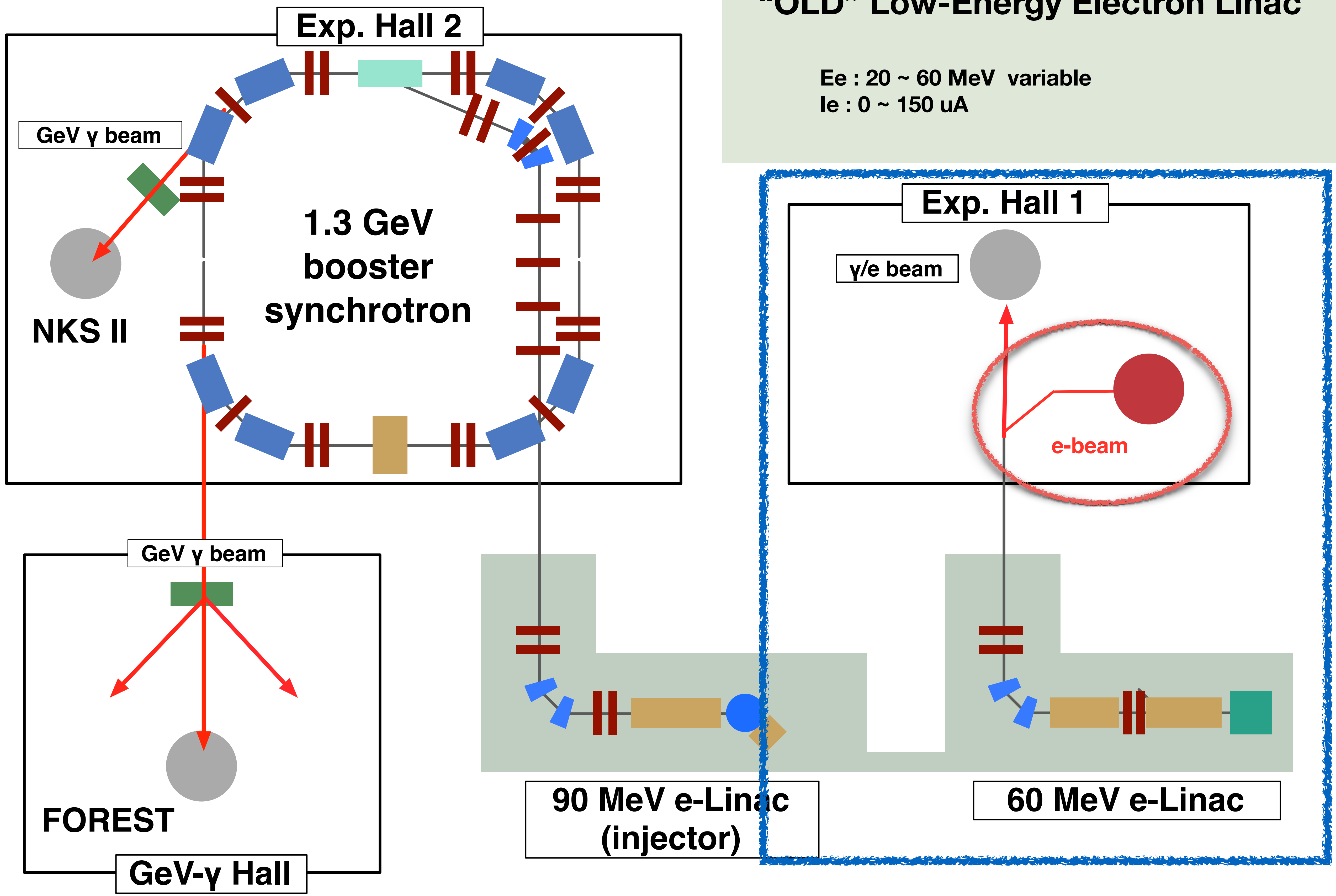
Lab.		Ee	θ	absolute $d\sigma/d\Omega$	G_E, G_M separation
JLAB (USA)	Ultra-forward	1.1 - 2.2 GeV	1 - 4 deg.	○	X
Mainz (Germany)	lower Ee by Bremsstrahlung	195, 330, 490 MeV		X	X
TOHOKU	low Ee	20 - 60 MeV	30 - 150 deg.	○	○

Research Center for Electron Photon Science

Tohoku Univ., Sendai, JAPAN

"OLD" Low-Energy Electron Linac

Ee : 20 ~ 60 MeV variable
Ie : 0 ~ 150 uA



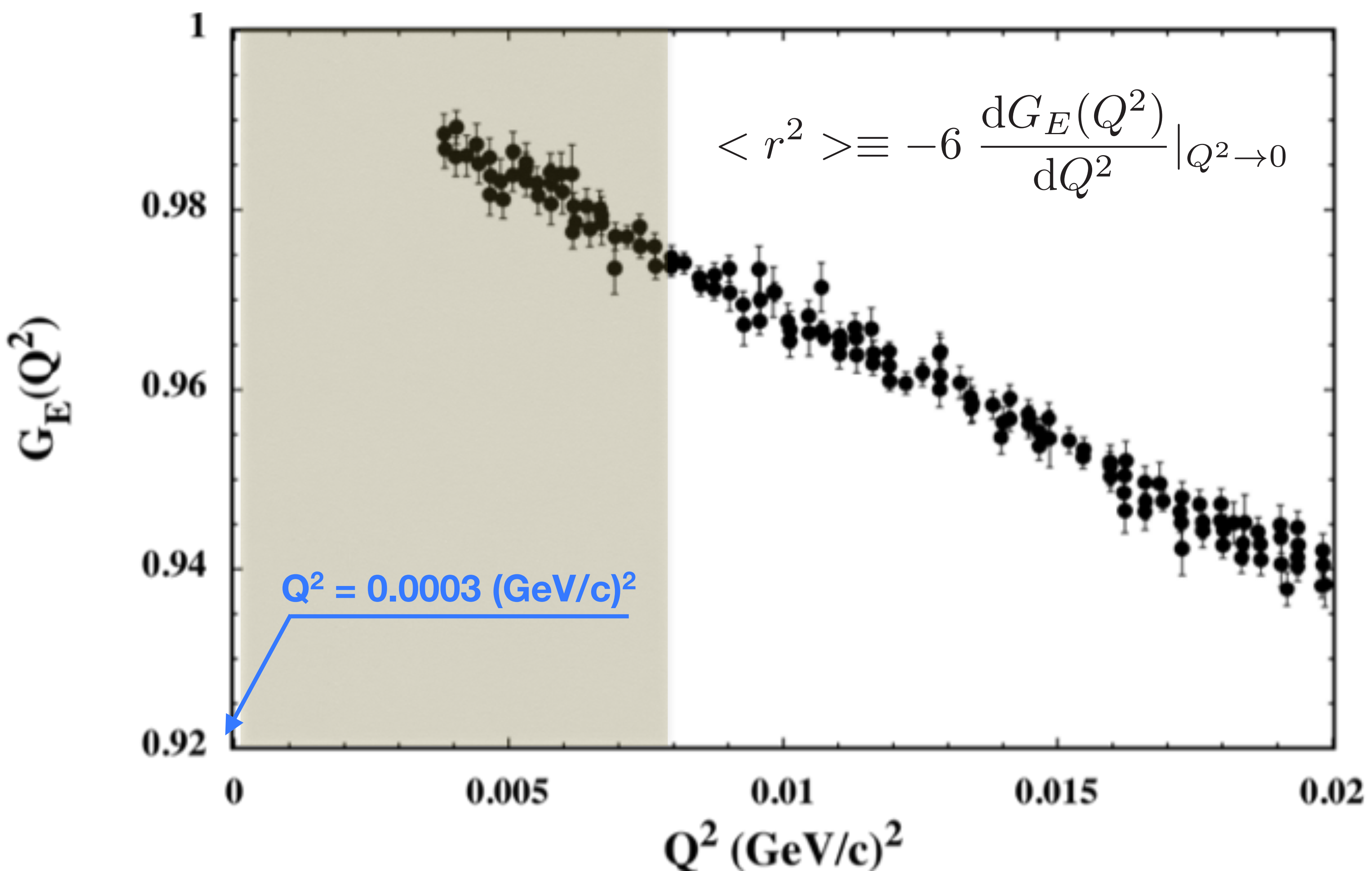
e-scattering off proton at ultra-low Q^2

Goal of our experiment

$G_E(Q^2)$ measurements in $0.0003 \leq Q^2 \leq 0.008$ (GeV/c)^2

Our experiments

Low energy electron beam ($20 \leq Ee \leq 60$ MeV)
Absolute cross section measurement
Rosenbluth separation ($G_E(Q^2)$, $G_M(Q^2)$ separation)



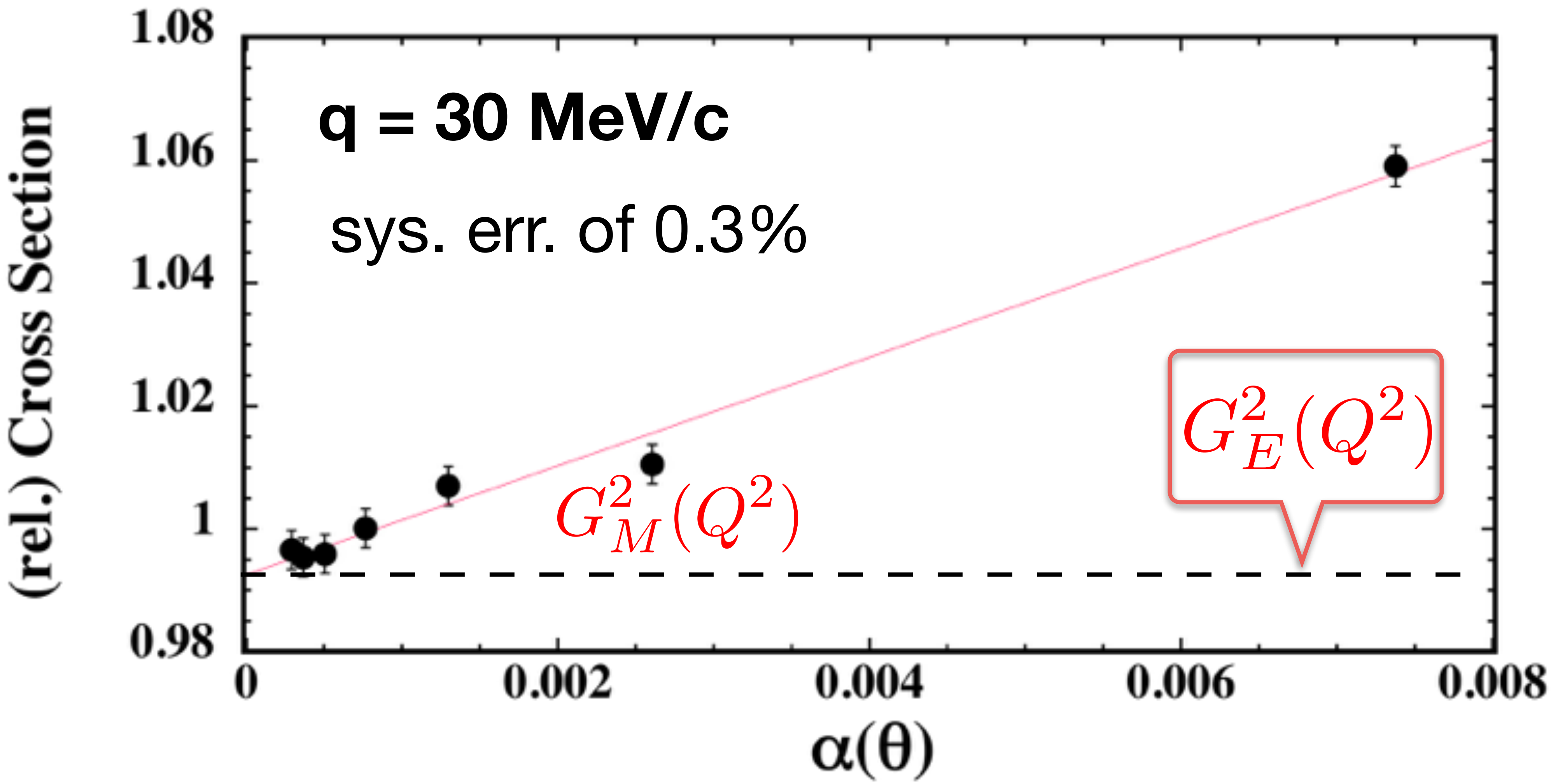
Rosenbluth separation (G_E/G_M)

Elastic cross section

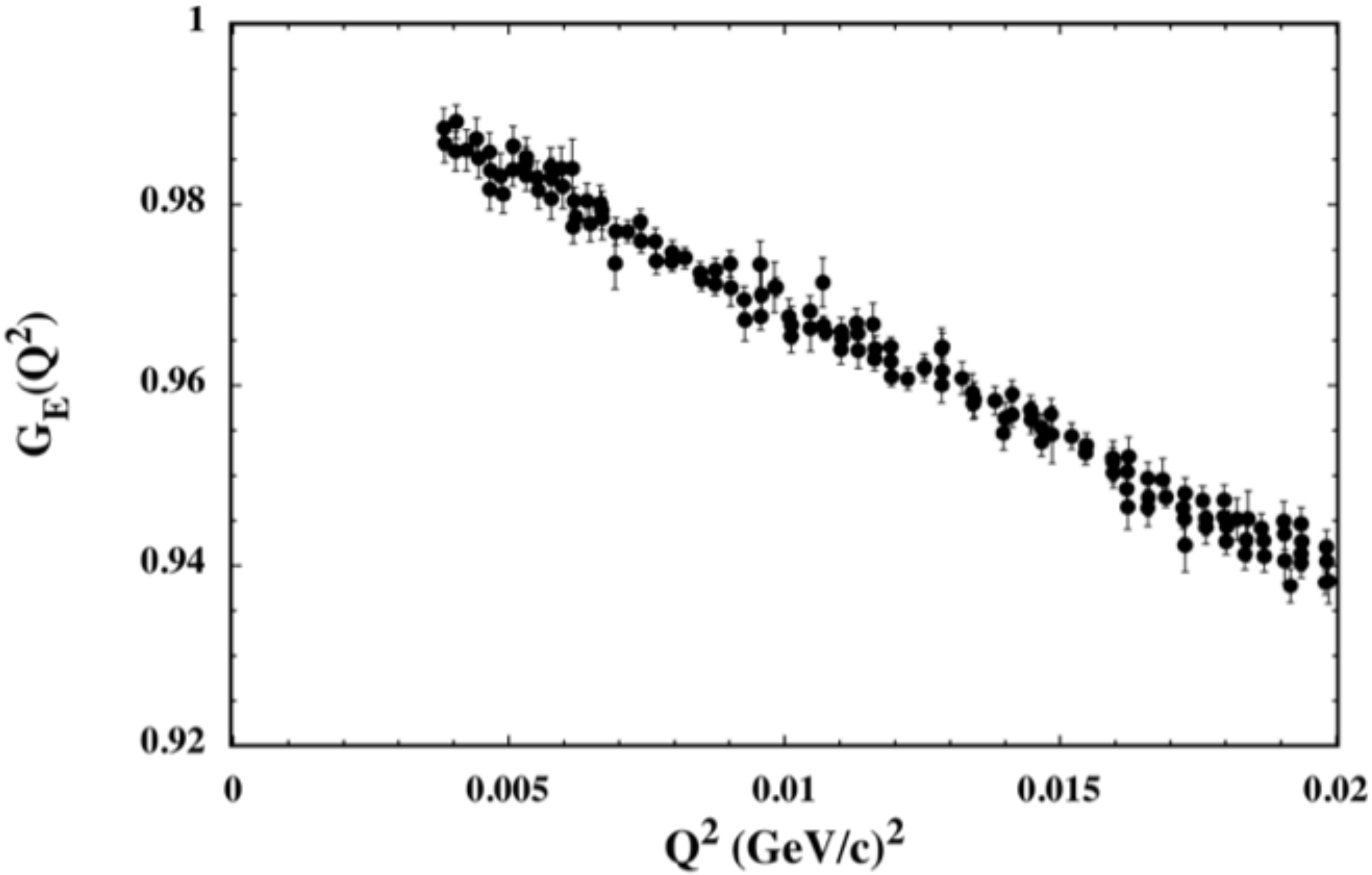
$$\frac{d\sigma}{d\Omega} \propto G_E^2(Q^2) + \alpha(\theta) G_M^2(Q^2) \qquad Q^2 = 4ee'\sin^2(\theta/2)$$

change $\alpha(\theta)$ under fixed Q^2 → different electron beam energies

Rosenbluth separation



A key of the e+p experiments at ULQ^2



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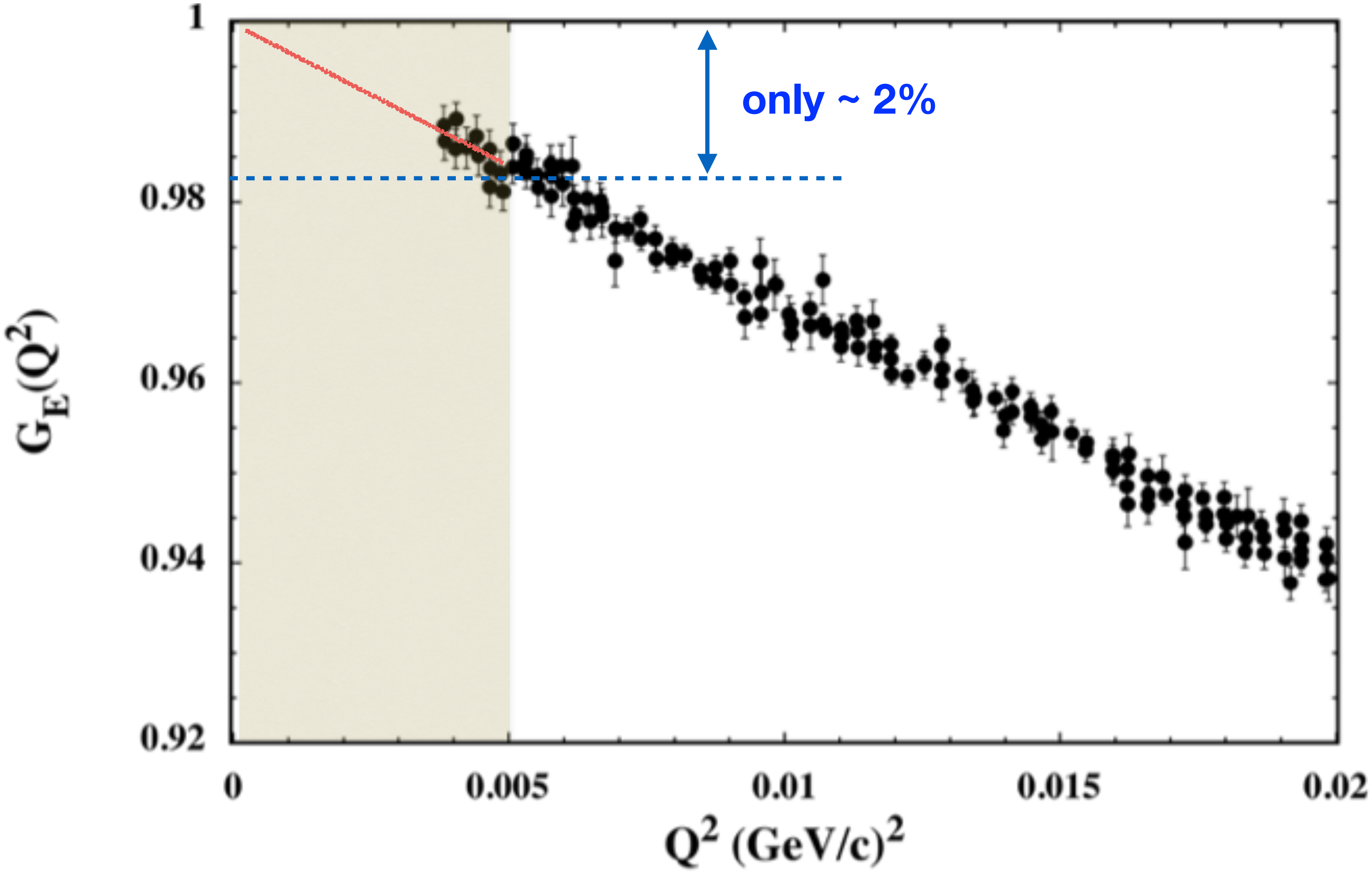

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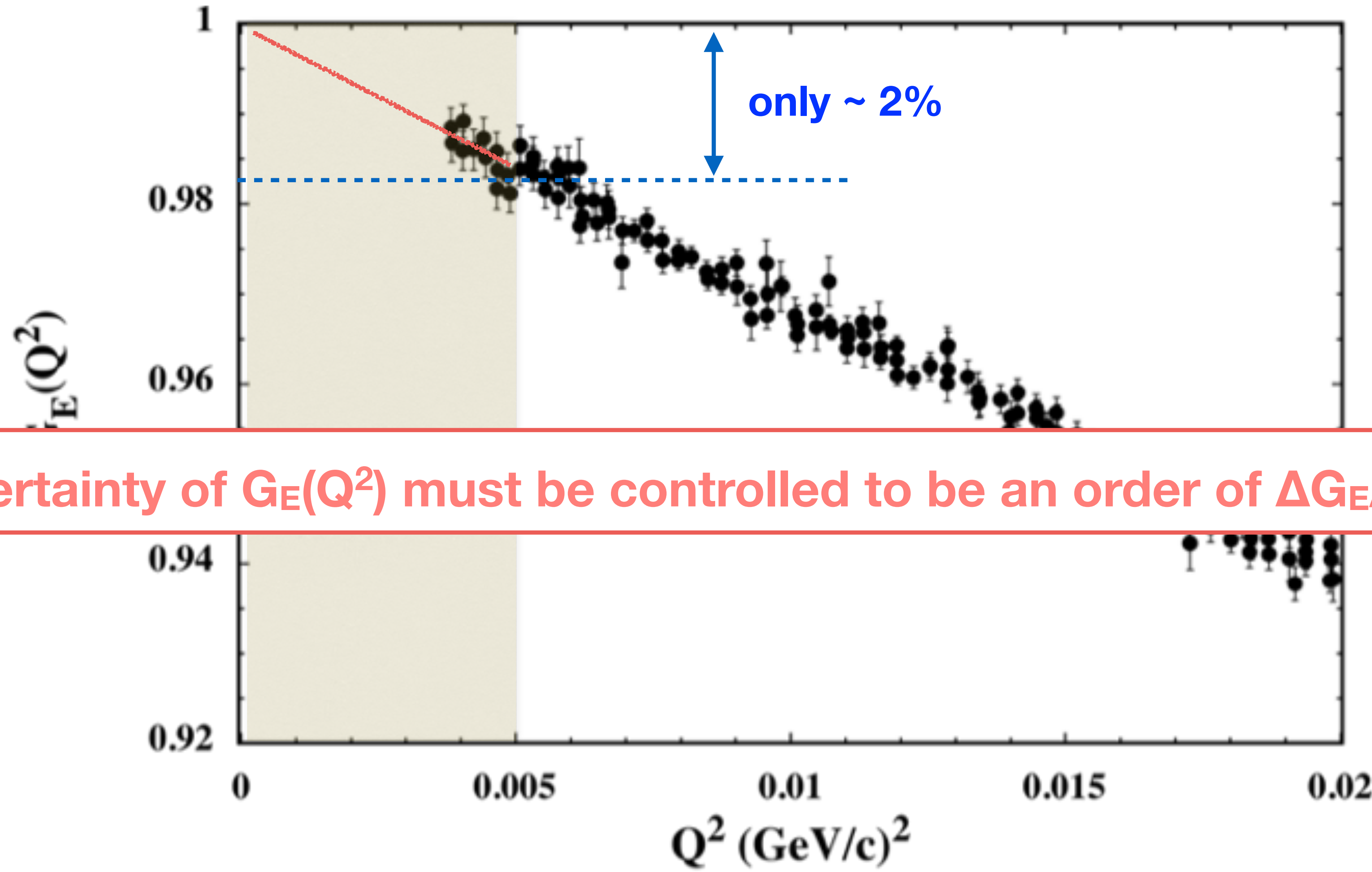

Uncertainty of $G_E(Q^2)$ must be controlled to be an order of $\Delta G_E/G_E \sim 10^{-3}$

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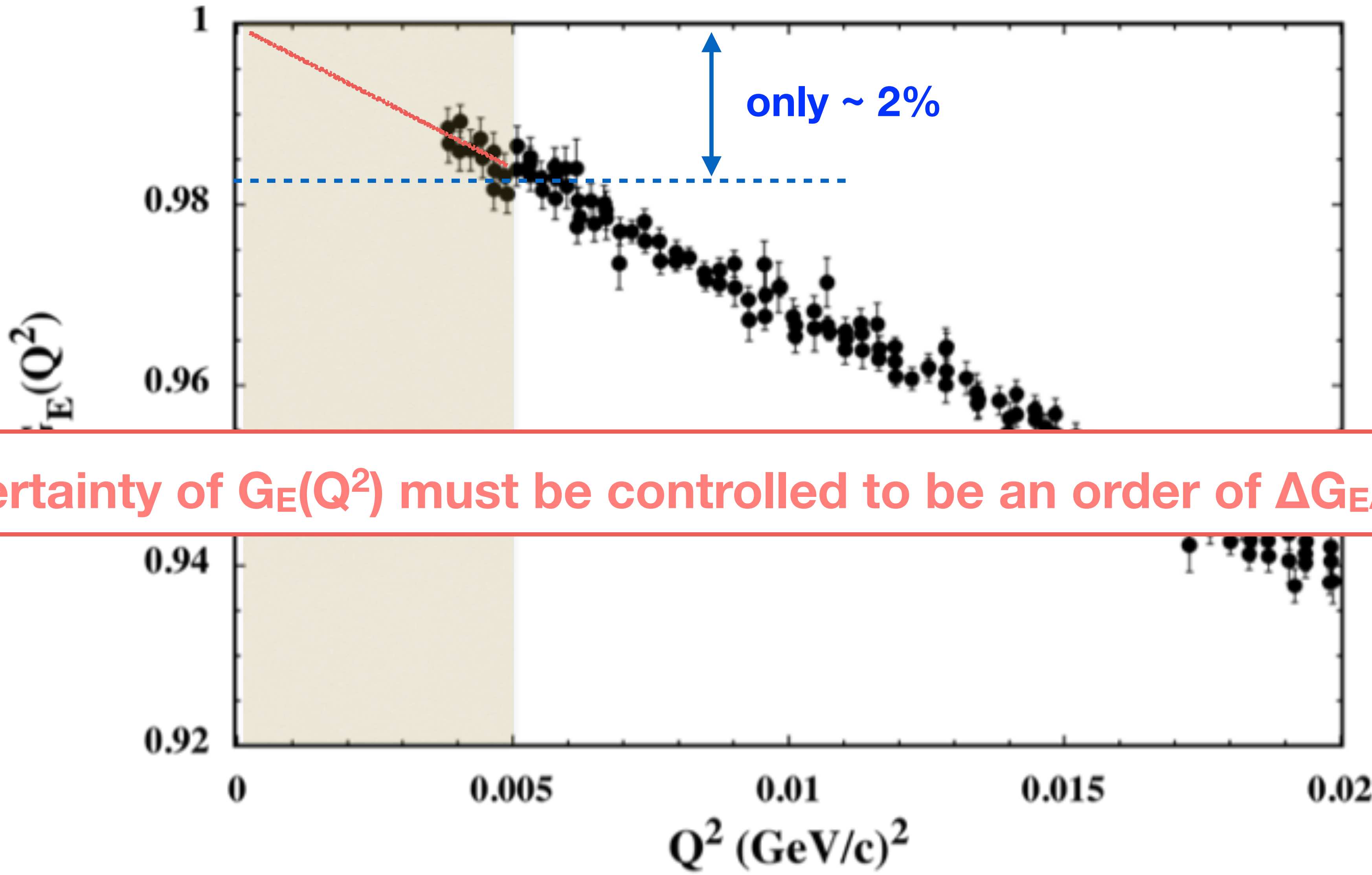

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$$\frac{dN_{evt}}{d\Omega} = \frac{d\sigma}{d\Omega} \boxed{N_{target}} \boxed{N_{beam}} \boxed{\Delta\Omega}$$

target thickens — beam dose — spectrometer acceptance

Statistics : at least > 10^6 for each (*Ee*,*θ*) measurements

Target thickness
Beam dose at various intensities
Acceptance at various scattering angle

⇨ accuracy of ~ 10^{-3} not obvious !

CH_2 target for absolute cross section measurement

Relative measurement for $^{12}C(e,e)^{12}C$ and p(e,e)p

$$\frac{\mathrm{d}N^{e^{12}C}/\mathrm{d}\Omega}{\mathrm{d}N^{ep}/\mathrm{d}\Omega} = \frac{\mathrm{d}\sigma^{e^{12}C}/\mathrm{d}\Omega}{\mathrm{d}\sigma^{ep}/\mathrm{d}\Omega} \cdot \frac{N_{target}^{^{12}C}}{N_{target}^{H}}$$

$$\frac{\mathrm{d}N_{evt}}{\mathrm{d}\Omega} = \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} N_{target} N_{beam}\ \Delta\Omega$$

Canceled out
in relative measurements

1) RMS charge radius (or ρ(r)) of ^{12}C ??

2) $^{12}C(e,e)^{12}C$, p(e,e)p by kinematics ??

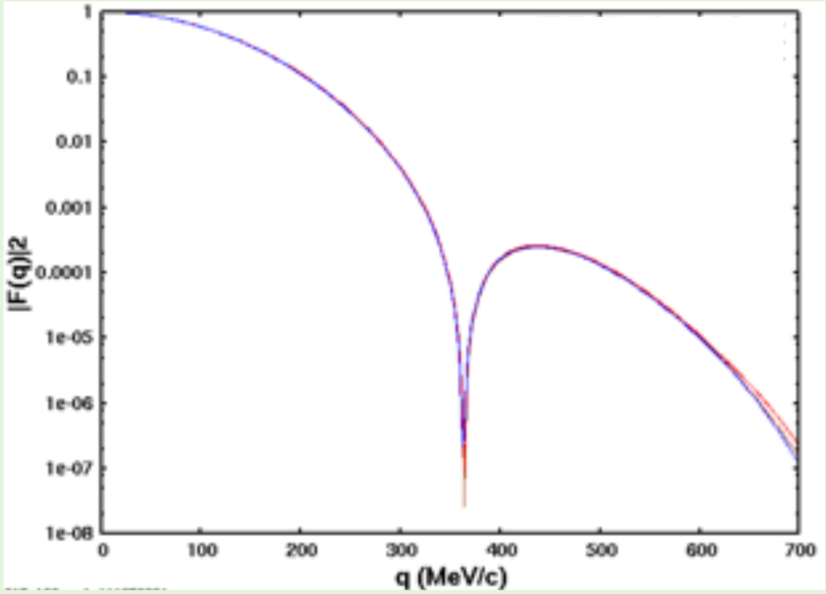
3) change of C/H ratio by beam irradiation ??

CH_2 (e,e') experiment

1) ^{12}C : "standard" nucleus for (e,e')

μ-Xray
electron scattering

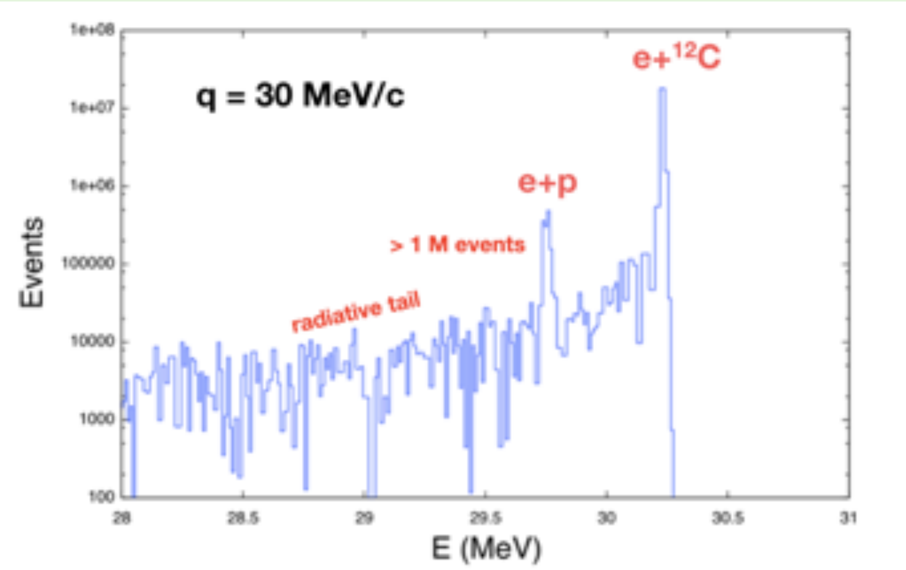
$$\frac{\Delta < r^2_{^{12}C} >^{1/2}}{< r^2_{^{12}C} >^{1/2}} \sim 3 \times 10^{-3}$$



2) $^{12}C(e,e)^{12}C$, p(e,e)p by kinematics

ΔE = 0.2 - 4 MeV
for q = 20 - 90 MeV/c

Δp/p ~ 10^{-3}

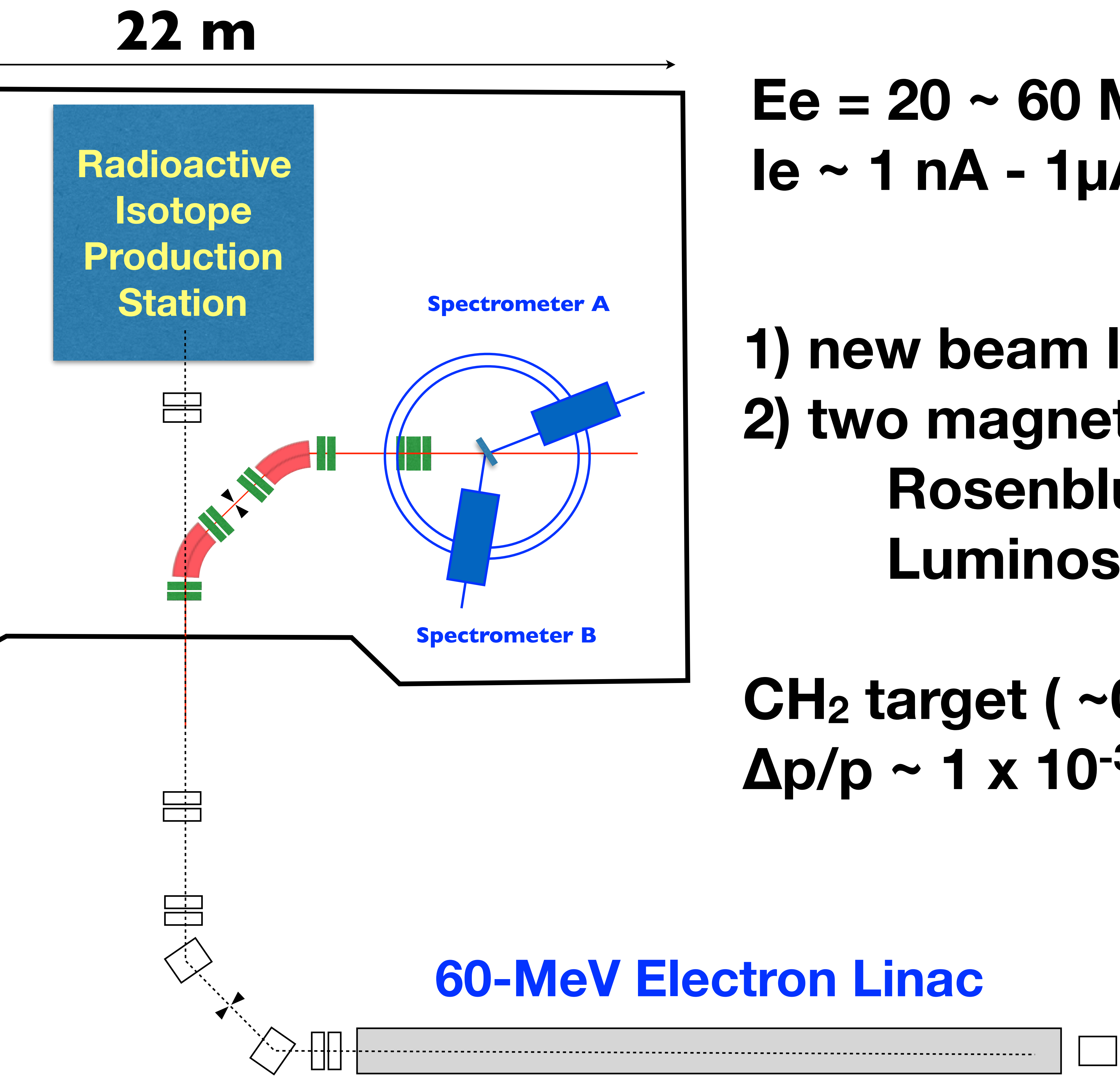


3) no severe damage of target is expected

large cross section : $\frac{d\sigma}{d\Omega} \propto 1/q^4$

Ie ~ 1 nA - 1 μA

Experimental setup at ULQ² exp.



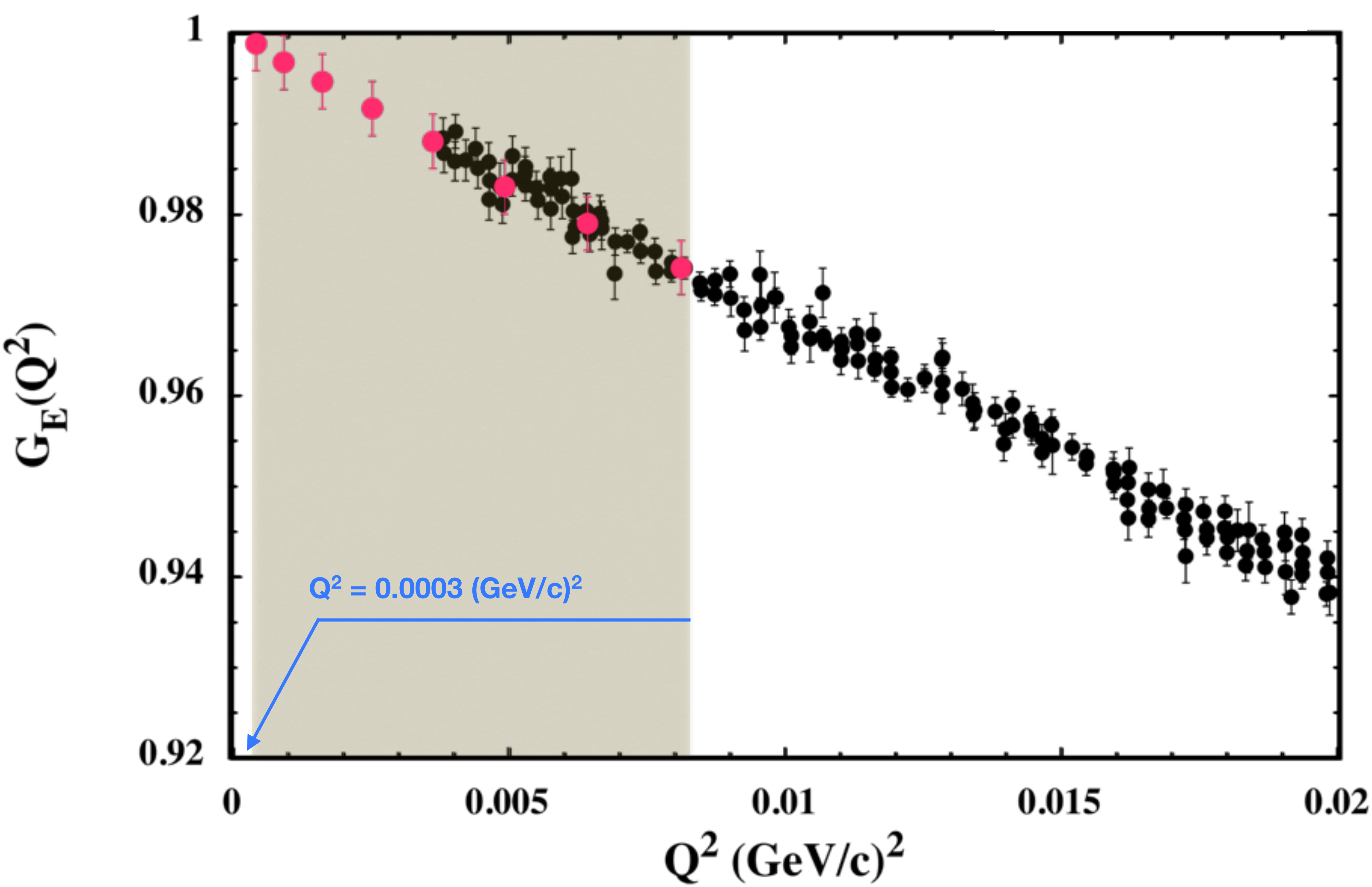
Ee = 20 ~ 60 MeV
Ie ~ 1 nA - 1μA

1) new beam line
2) two magnetic spectrometers
Rosenbluth measurements
Luminosity monitoring

CH_2 target (~0.1 mm t)
$\Delta p/p \sim 1 \times 10^{-3}$

Rosenbluth-Separated $G_E(Q^2)$ at ULQ^2

Absolute cross section
Rosenbluth separation ⇨ $G_E(Q^2)$



Summary

1) elastic e+p scattering at ultra-low Q^2 region

2) $G_E(Q^2)$ at $0.0003 \leq Q^2 \leq 0.008$ (GeV/c)^2

3) G_E is extracted by the Rosenbluth separation

4) absolute cross section measurement

relative to $^{12}C(e,e)^{12}C$: sys. err. ~3×10^{-3}

5) Ee = 20 - 60 MeV, θ = 30 - 150°

6) constructing of new beam line, and spectrometers

7) the experiments will start in 2019