Nucleon polarizabilities from Compton scattering

Nadiia Krupina

in collaboration with Vladimir Pascalutsa

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

International School of Nuclear Physics

Sept. 20, 2015, Erice

Outline

1) Inelastic structure, polarizabilities, and how they matter for the *proton size*

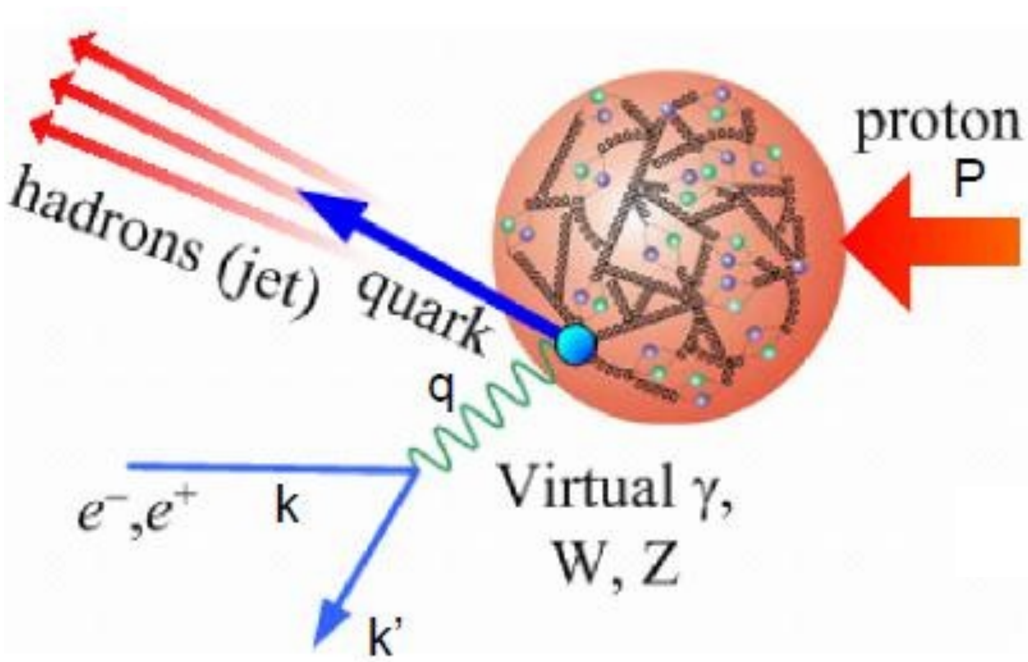
2) Status of dipole scalar polarizabilities

3) Disentangling the magnetic polarizability by beam asymmetry of Compton scattering

4) Multipole analysis - in progress..

5) Summary

Electron-proton scattering

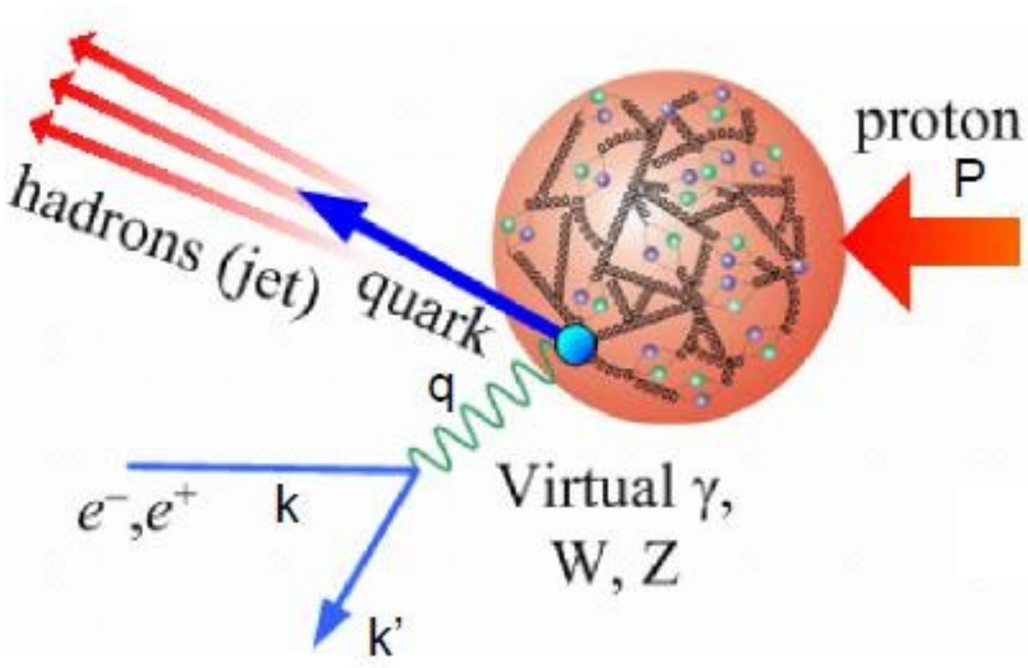


$$Q^2 = -(k' - k)$$
$$x = Q^2/(2M_N\nu)$$

Yields 4 Structure functions:

$$f_1(\nu, Q^2),\ f_2(\nu, Q^2),\ g_1(\nu, Q^2),\ g_2(\nu, Q^2).$$

Electron-proton scattering



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(i) Elastic part given by form factors

$$\begin{aligned}
f_1^{\rm el}(\nu,Q^2) &= \tfrac{1}{2}G_M^2(Q^2)\,\delta(1-x),\\
f_2^{\rm el}(\nu,Q^2) &= \frac{1}{1+\tau}\left[G_E^2(Q^2)+\tau G_M^2(Q^2)\right]\delta(1-x),\\
g_1^{\rm el}(\nu,Q^2) &= \tfrac{1}{2}F_1(Q^2)G_M(Q^2)\,\delta(1-x),\\
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\end{aligned}$$

where $\tau = Q^2/4M^2$ and $G_E(Q^2),\, G_M(Q^2)$ are the Sachs FFs

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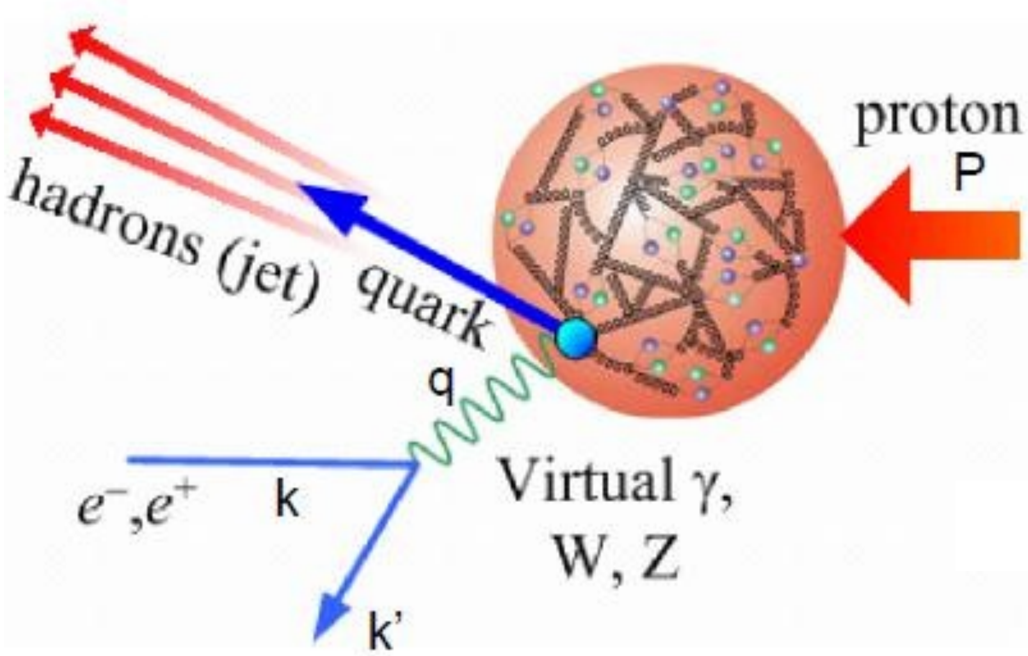

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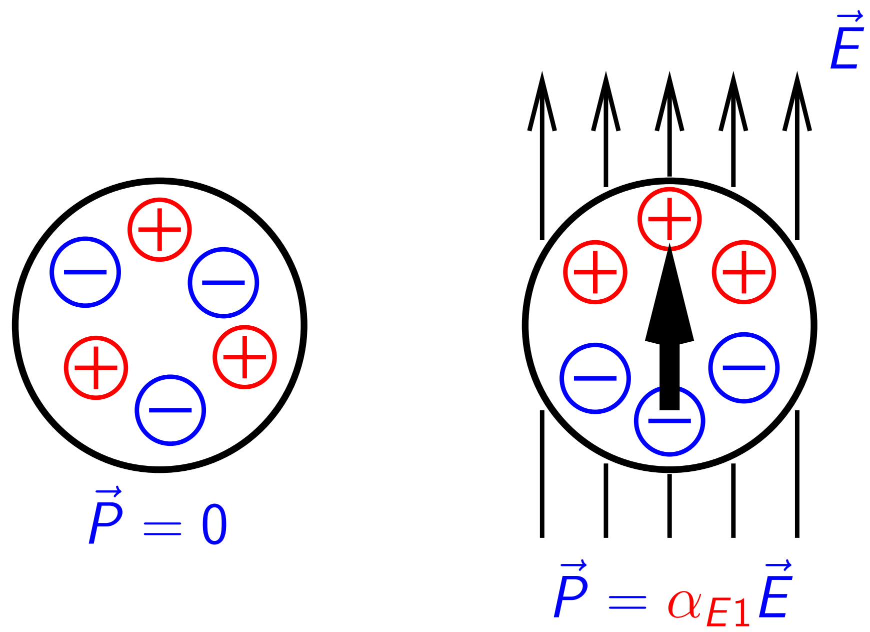
(ii) Moments of the inelastic structure functions are related to polarizabilities, e.g.

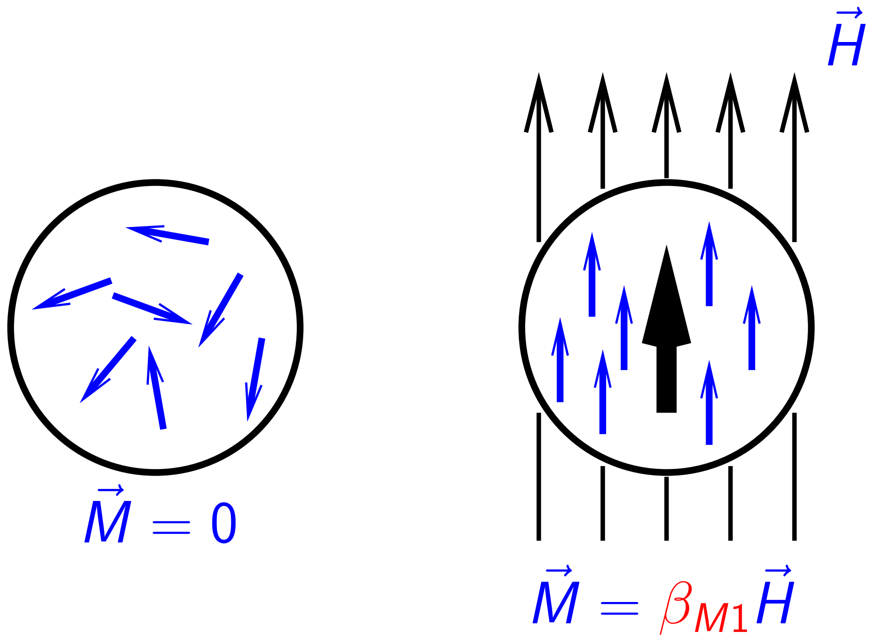
$$\alpha_{E1}(Q^2) + \beta_{M1}(Q^2) = \frac{8\alpha M_N}{Q^4}\int_0^{x_0} {\rm d}x\, x f_1(x, Q^2).$$

(i) Describe the response of internal structure to applied external field

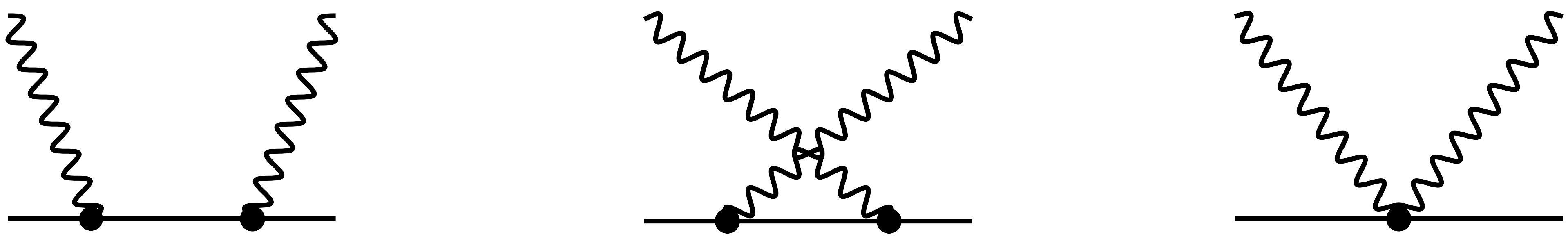
Electric dipole polarizability



Magnetic dipole polarizability



(ii) Accessed experimentally in Compton scattering



Born (elastic) contributions

non-Born contribution, given by polarizabilities

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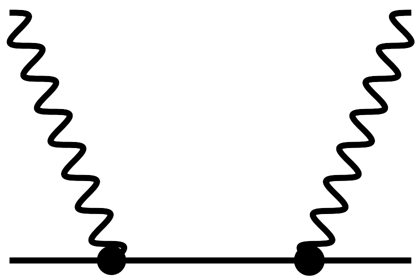
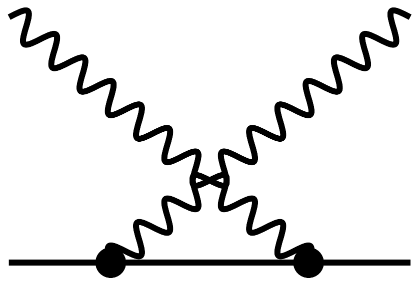
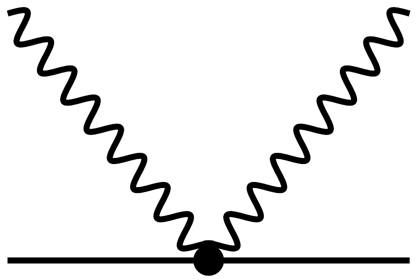






Born (elastic) contributions

non-Born contribution, given by polarizabilities

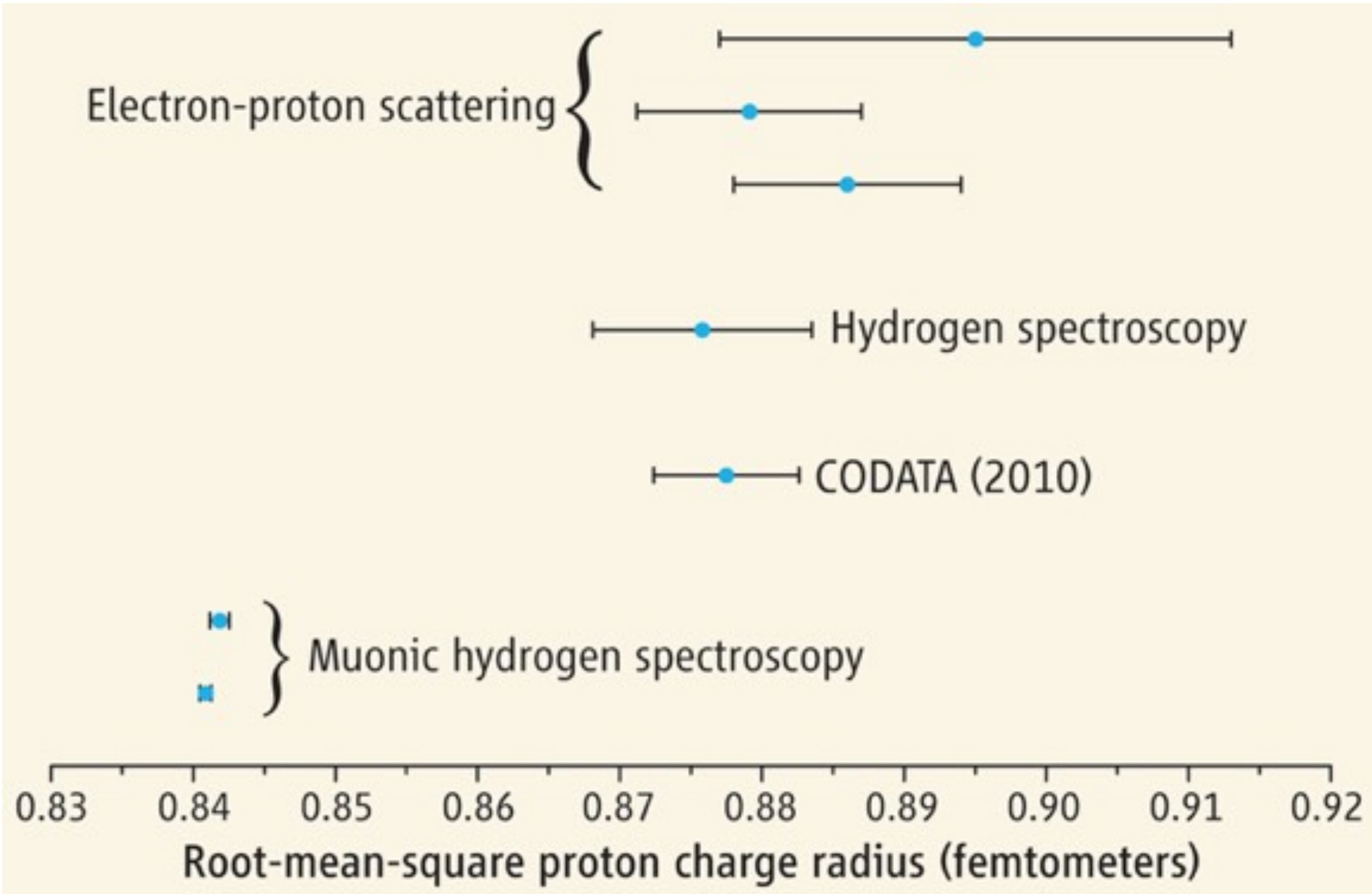
(iii) Theoretical approaches:

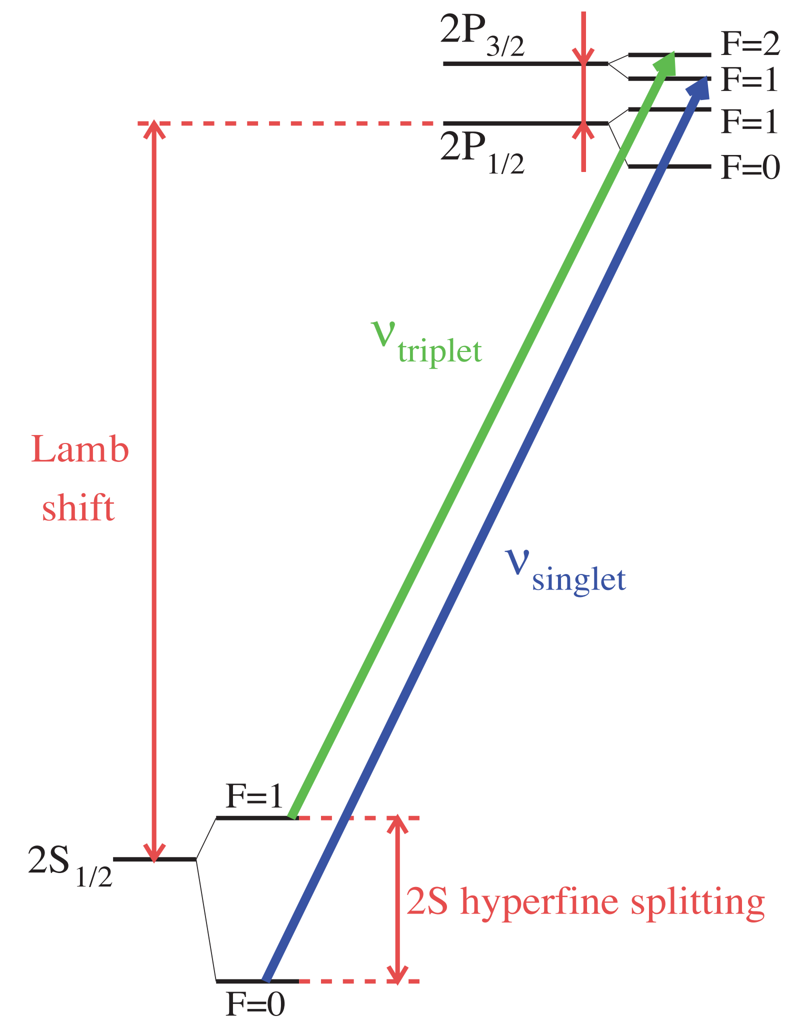
Effective field theory

Dispersion relations

Lattice QCD

Proton radius puzzle





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

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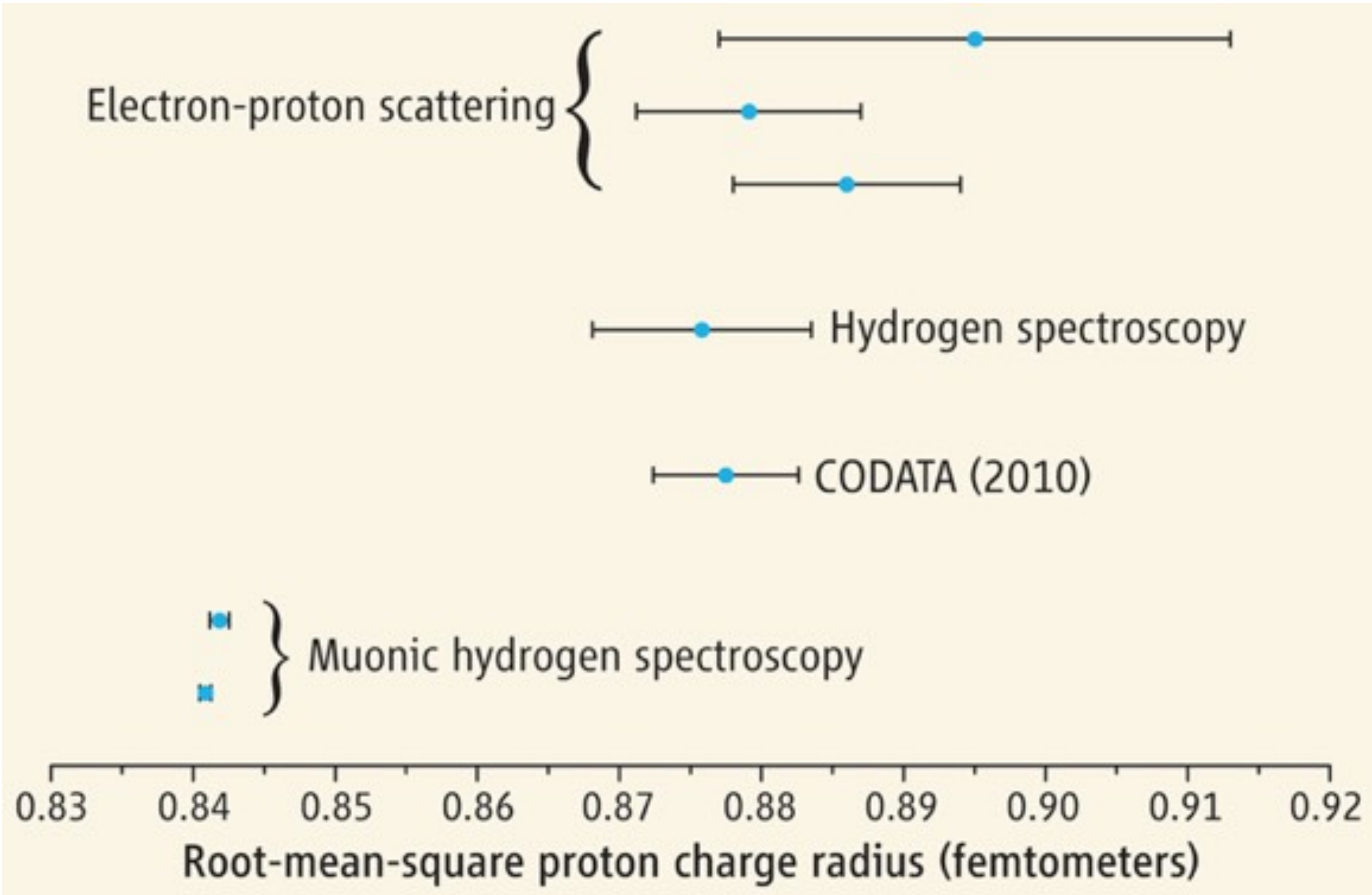

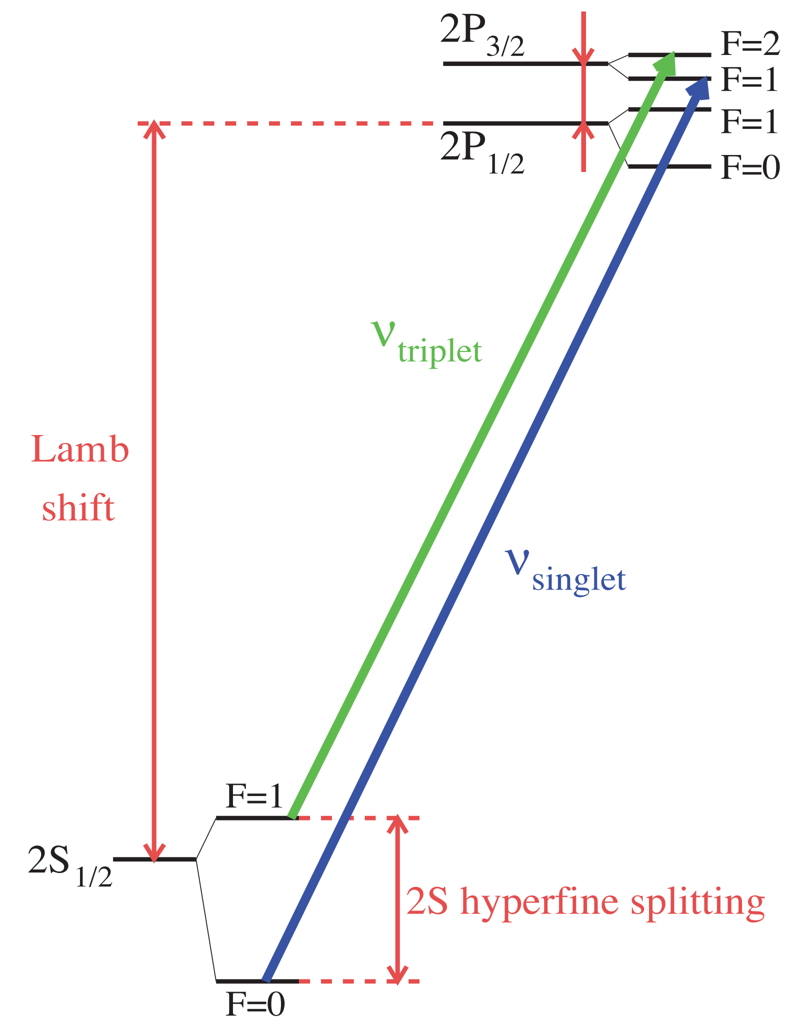

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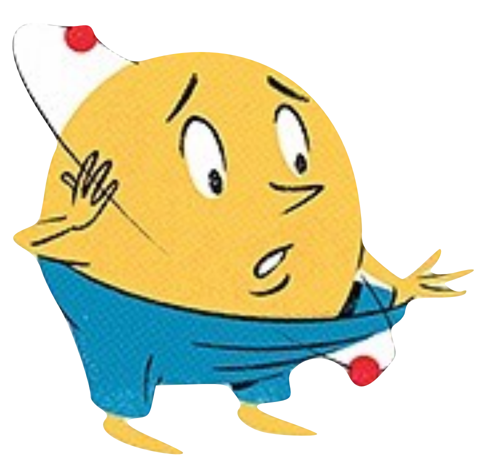
$$[R_E^{\mu\mathrm{H}} = 0.84087(39)\,\mathrm{fm}]$$

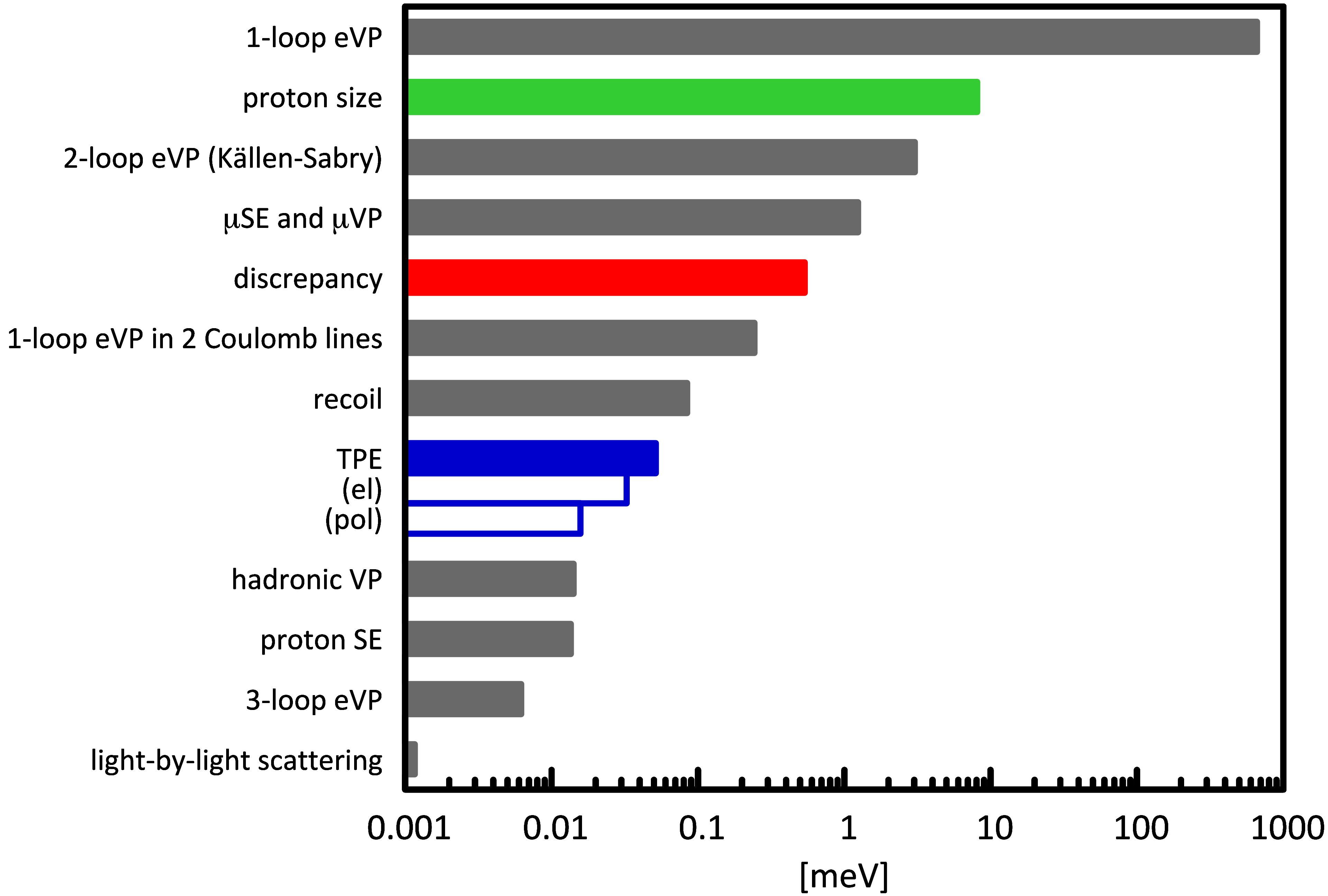


$$[R_E^{\mathrm{CODATA}\ 2010} = 0.8775(51)\,\mathrm{fm}]$$

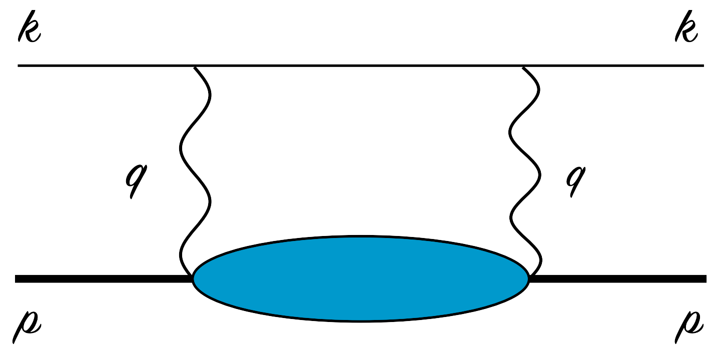
Muonic Hydrogen Lamb shift

$$\Delta E_{\rm LS}^{\rm th} = 206.0668(25) - 5.2275(10)\,(R_E/{\rm fm})^2$$

theory uncertainty:
0.0025 meV

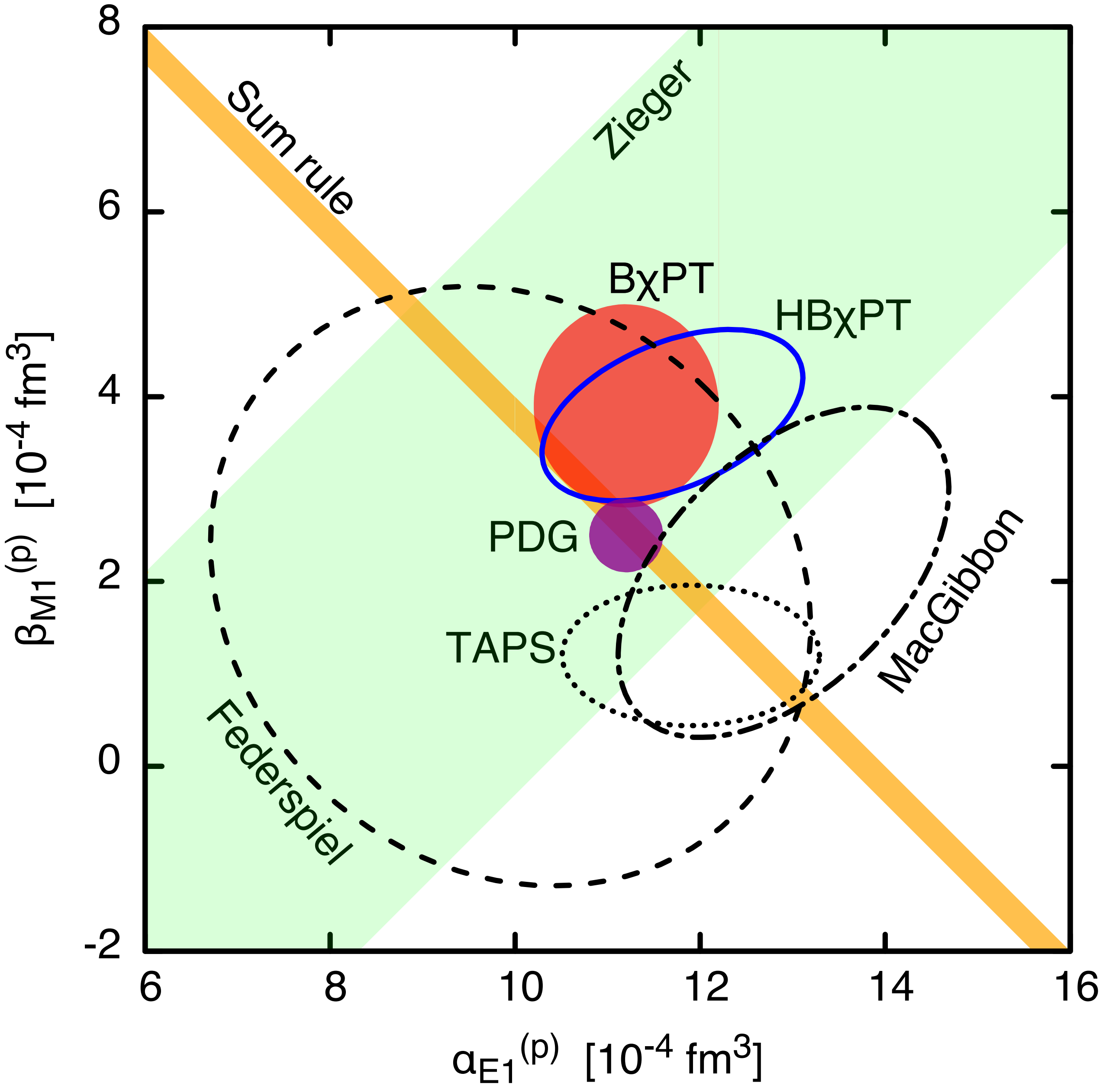


Two photon exchange (TPE)



$$\delta V^{(2\gamma)} = \delta V^{(2\gamma)}_{\rm elastic} + \delta V^{(2\gamma)}_{\rm polariz.}$$

Proton dipole polarizabilities

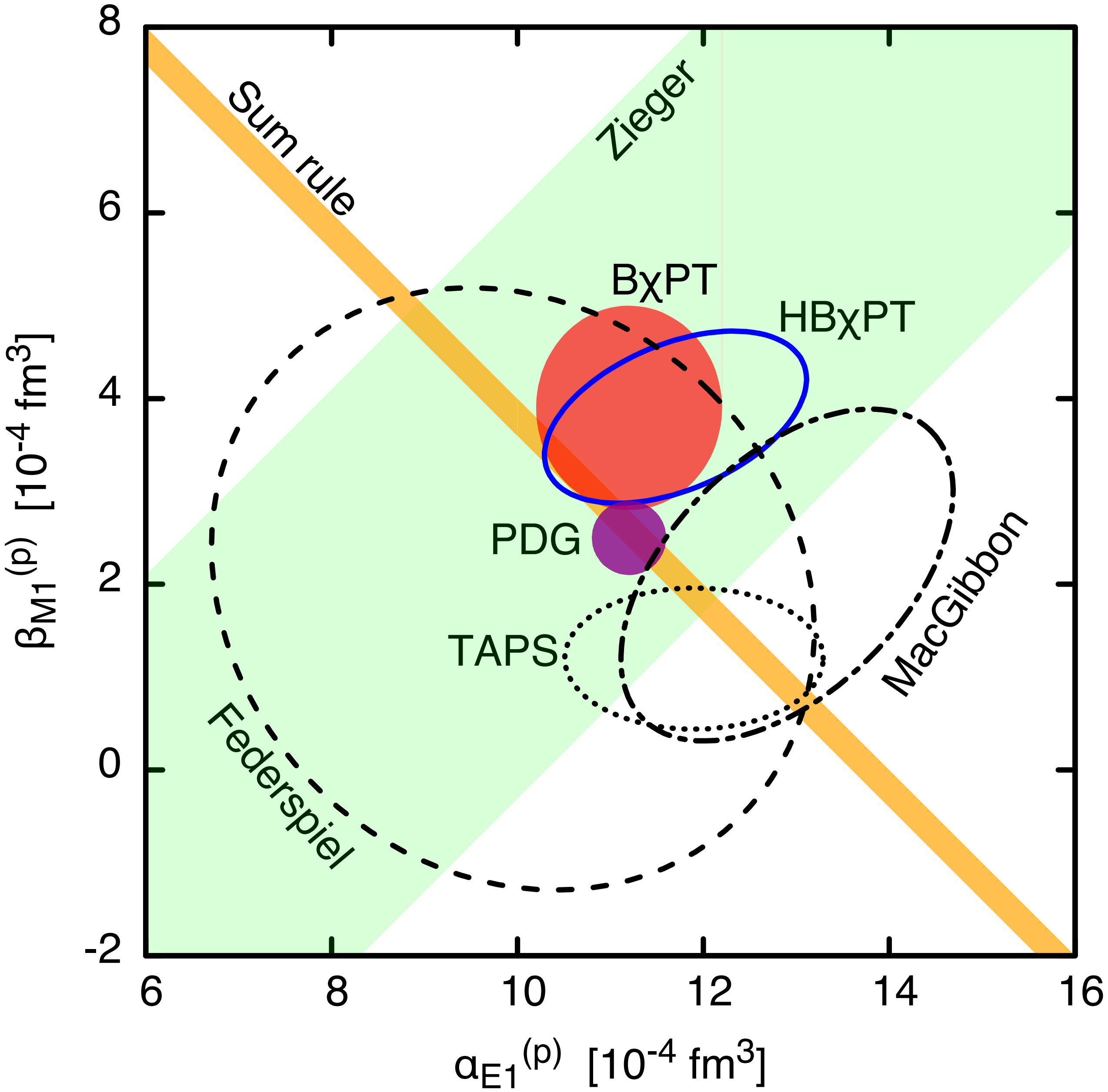


Theory:

BChPT - Lensky & Pascalutsa, EPJC (2010)

HBChPT - McGovern, Phillips & Griesshammer, EPJA (2013)

Proton dipole polarizabilities



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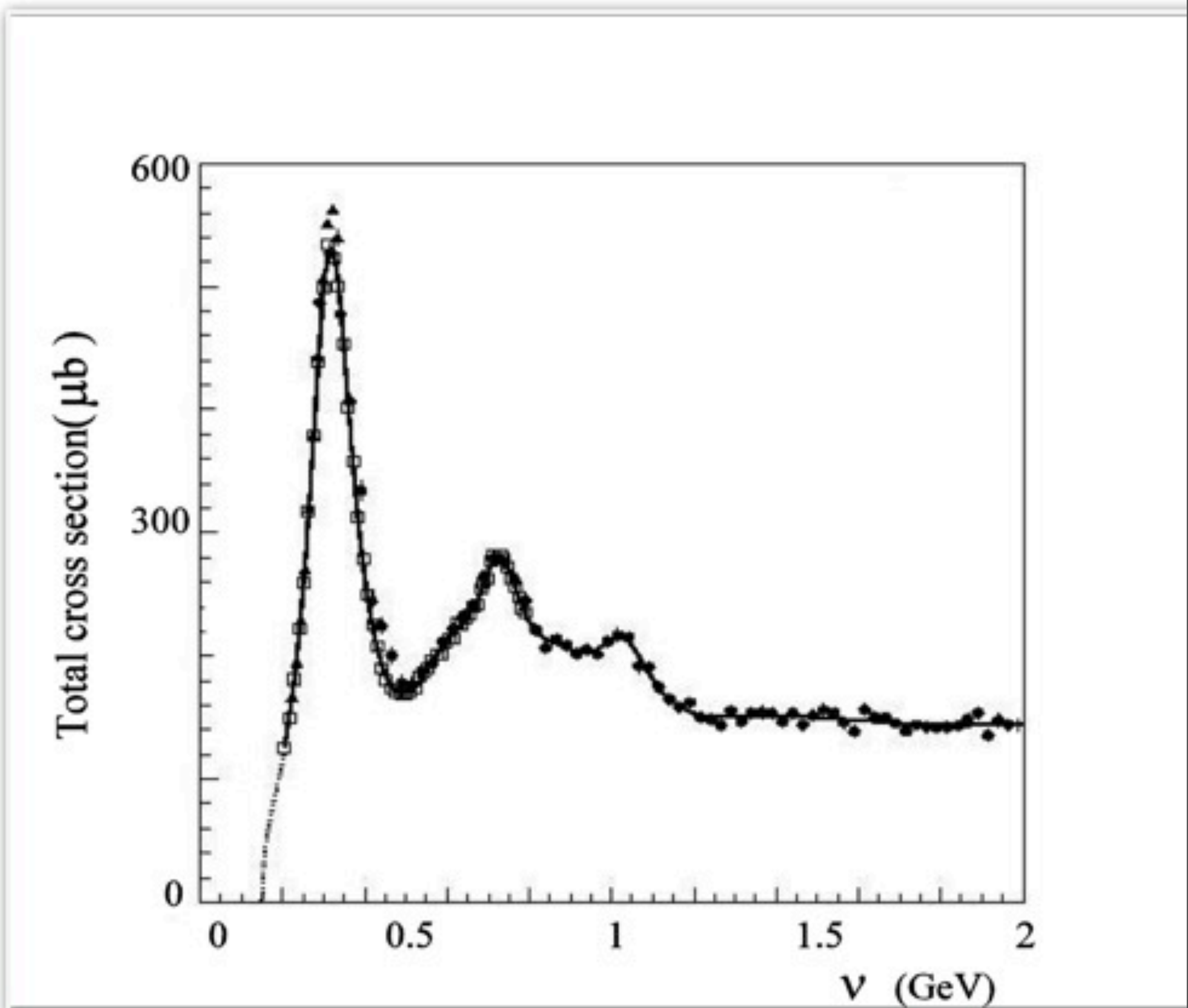
Baldin sum rule

$$\alpha_{E1} + \beta_{M1} = \frac{1}{2\pi^2} \int_{\nu_{thr}}^{\infty} d\nu' \frac{\sigma_{tot}(\nu')}{\nu'^2} \simeq 14 \times 10^{-4} \mathrm{fm}^3$$



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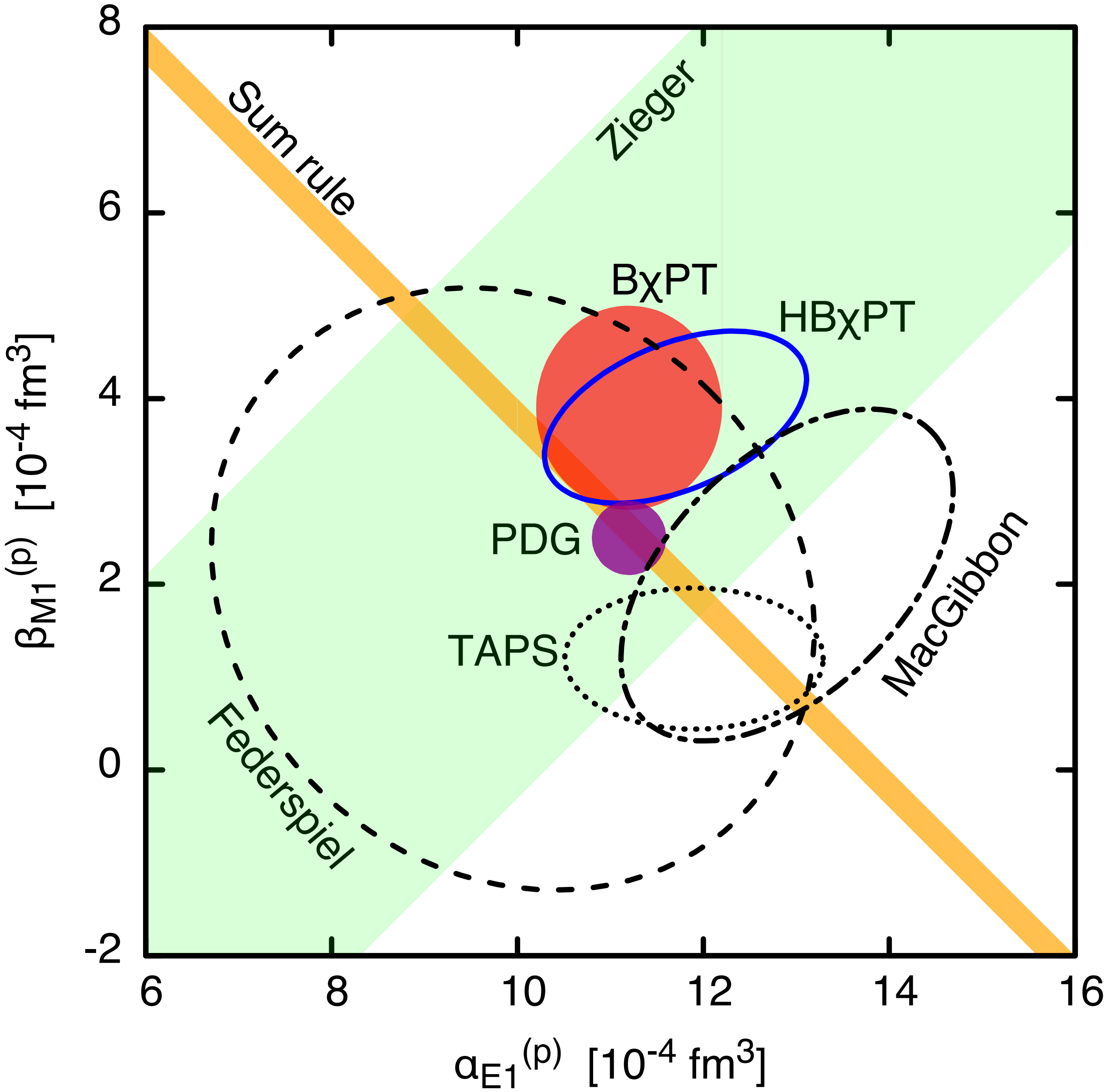
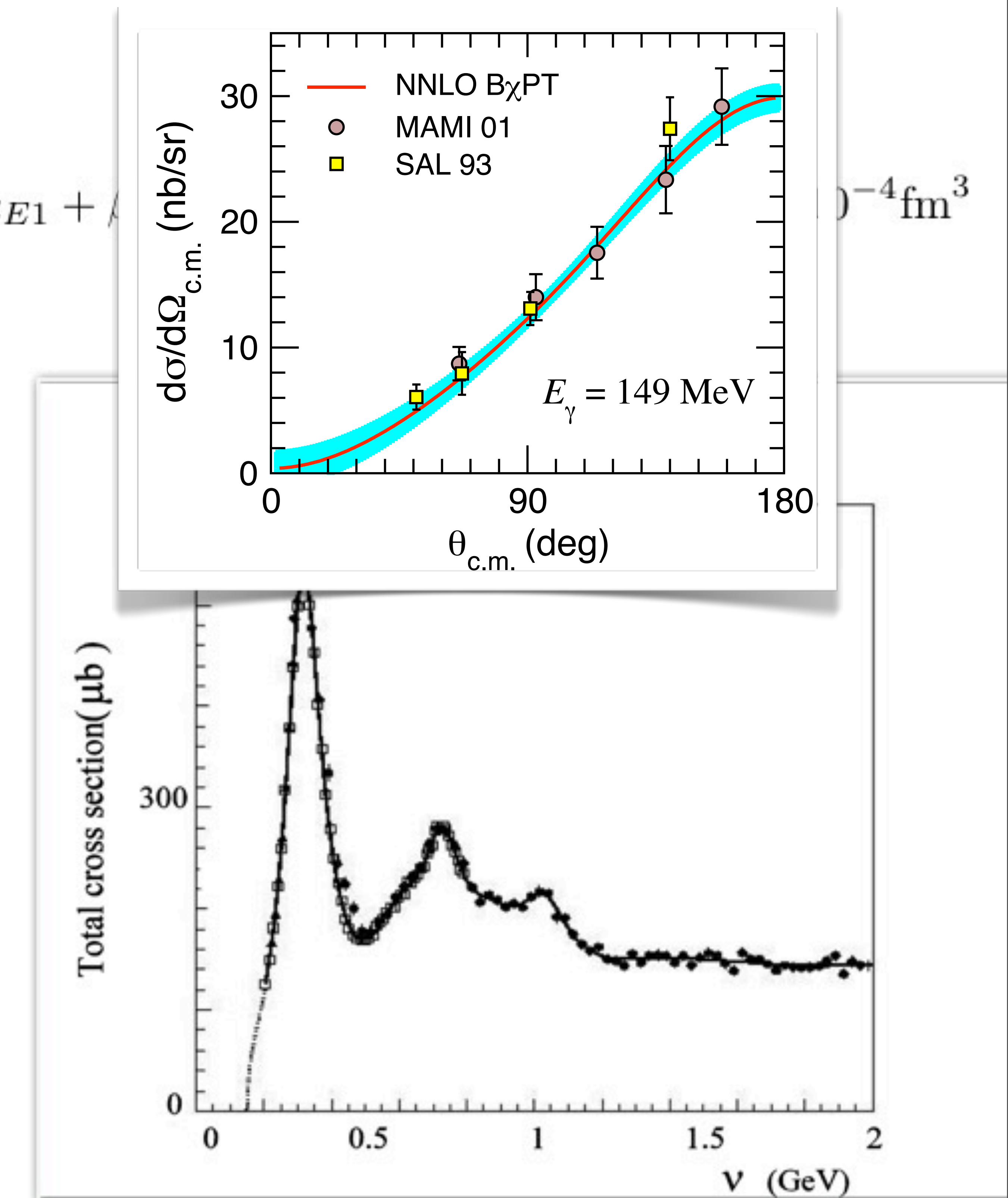


$\alpha_{E1} + \ldots \, 0^{-4}\mathrm{fm}^3$



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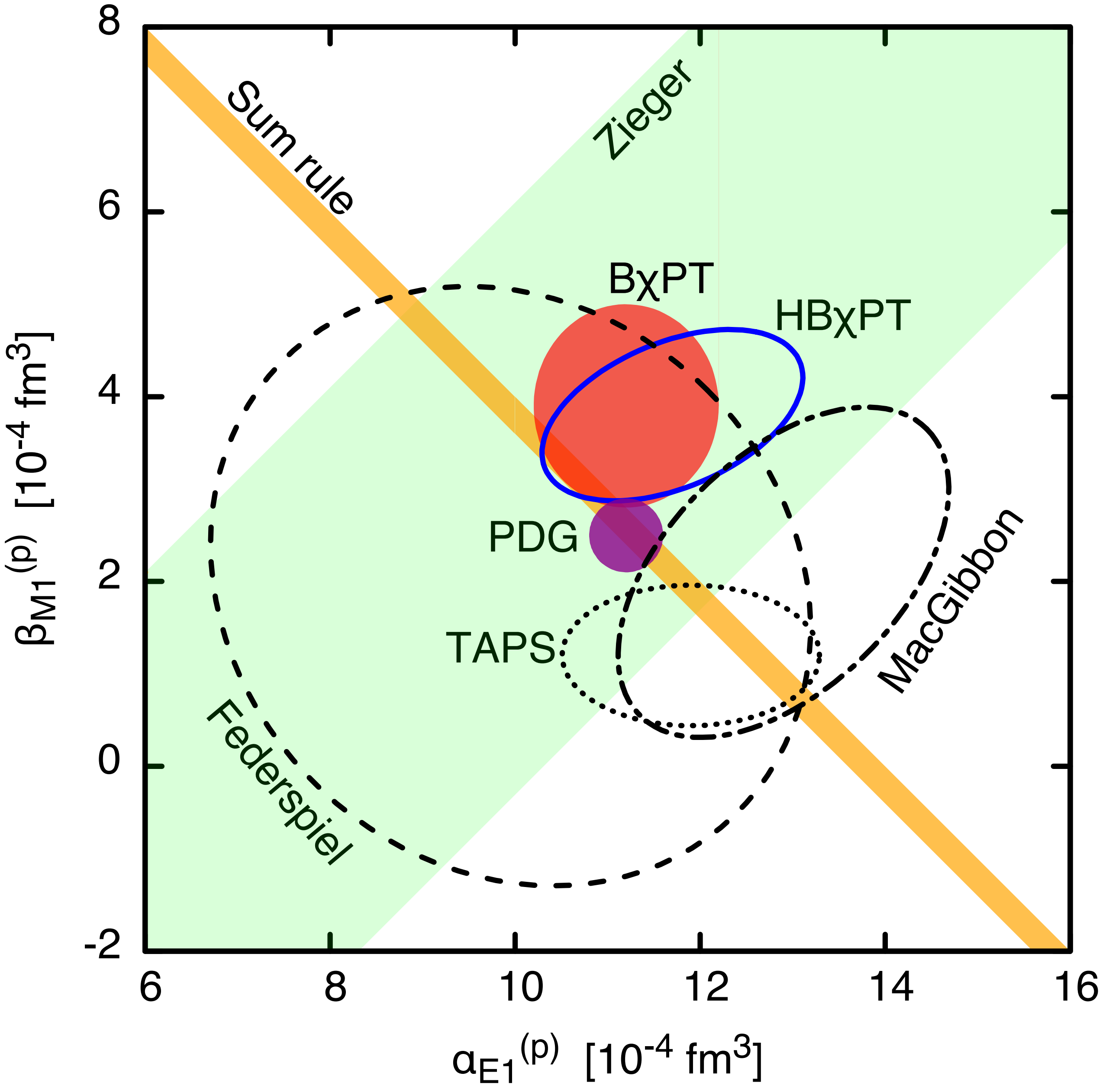

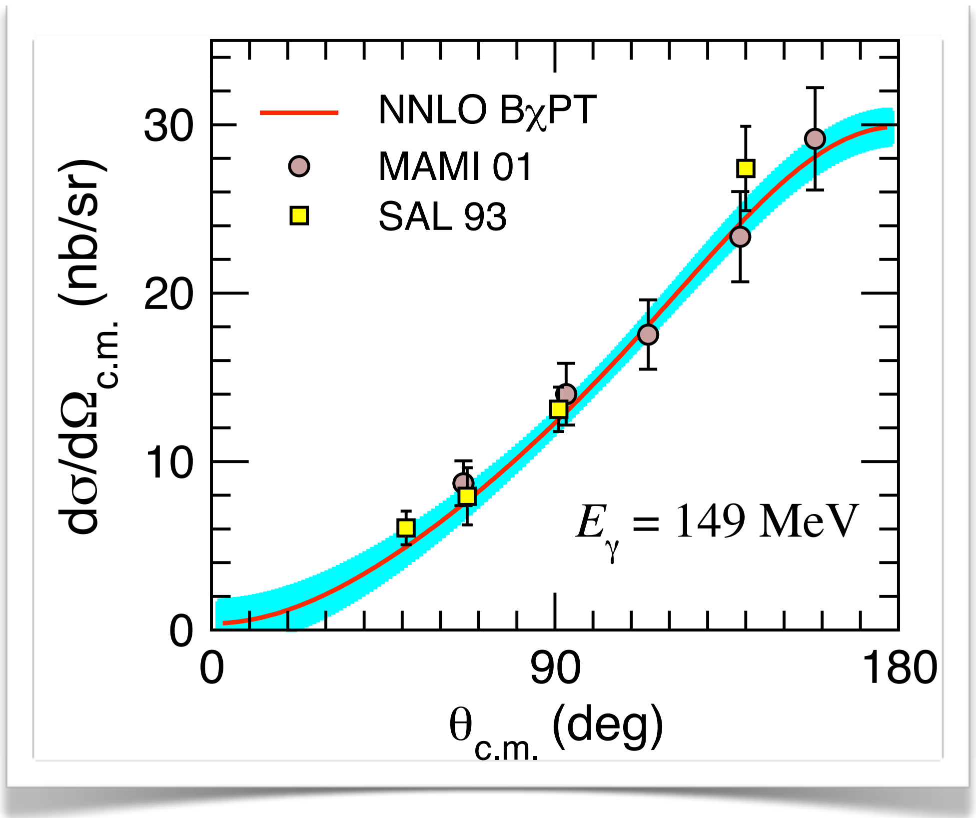

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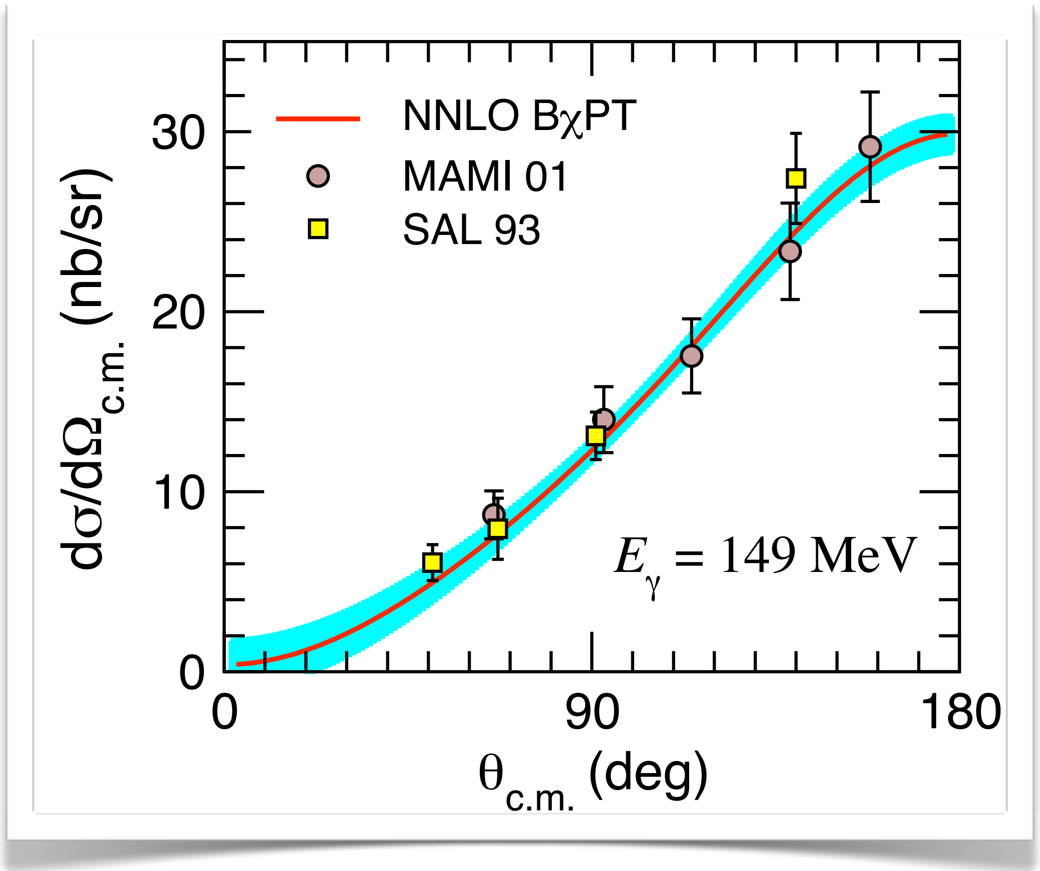
<u>Past experiments</u>: measured unpolarized cross sections of Compton scattering to extract alpha and beta from the angular dependence.
(a la Rothenbluth separation of GE, GM)

LEX: $$\frac{d\sigma^{(\mathrm{NB})}}{d\Omega} = -2\pi Z^2 \frac{\alpha}{M}\left(\frac{\nu'}{\nu}\right)^2 \nu\nu' \left[2\alpha_{E1}\left(1+\cos^2\theta\right) + 4\beta_{M1}\cos\theta\right] + O(\nu^4)$$



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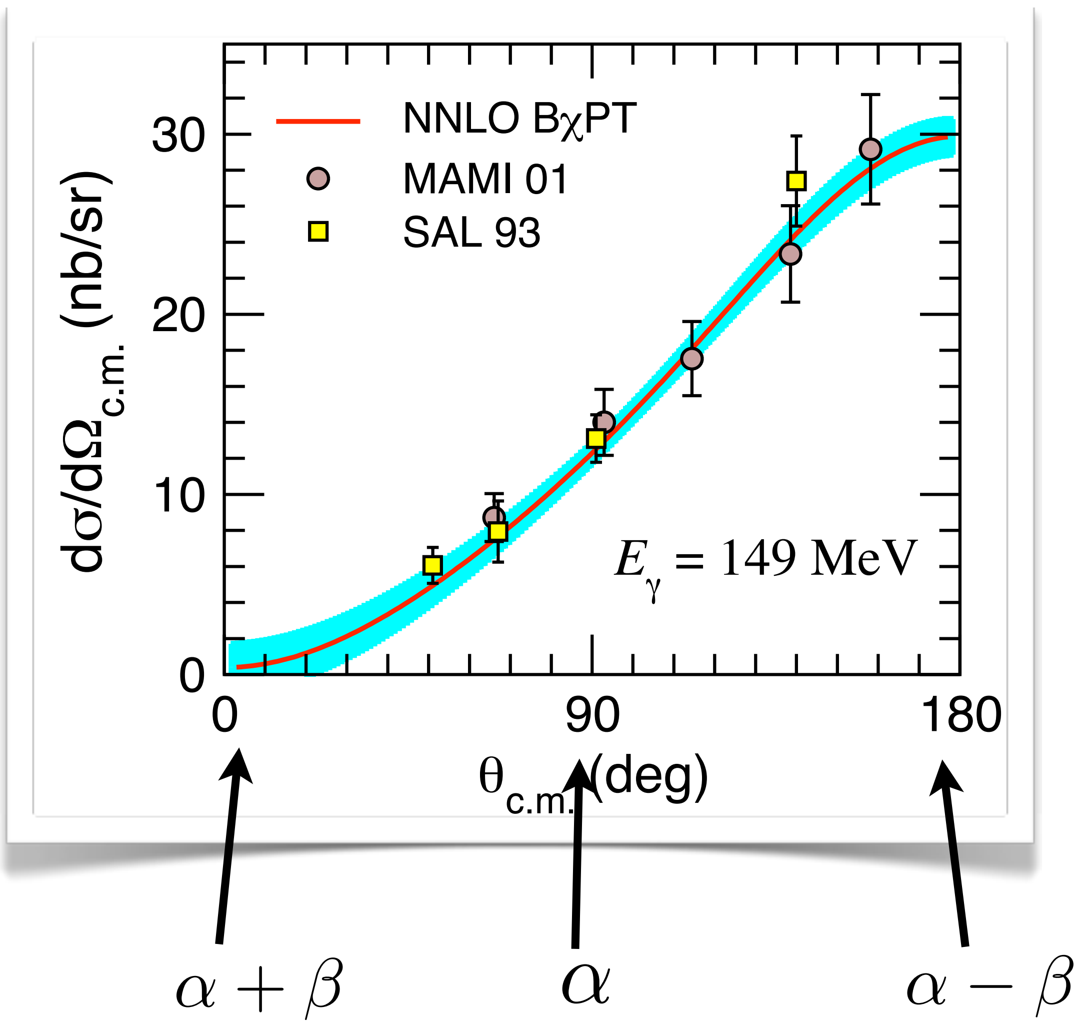

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Extraction of beta from beam asymmetry

PRL 110, 262001 (2013) PHYSICAL REVIEW LETTERS week ending 28 JUNE 2013

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PRISMA Cluster of Excellence Institut für Kernphysik, Johannes Gutenberg–Universität Mainz, 55128 Mainz, Germany
(Received 3 April 2013; published 25 June 2013)

We propose to determine the magnetic dipole polarizability of the proton from the beam asymmetry of low-energy Compton scattering based on the fact that the leading non-Born contribution to the asymmetry is given by the magnetic polarizability alone; the electric polarizability cancels out. The beam asymmetry thus provides a simple and clean separation of the magnetic polarizability from the electric one. Introducing polarizabilities in a Lorentz-invariant fashion, we compute the higher-order (recoil) effects of polarizabilities on beam asymmetry and show that these effects are suppressed in forward kinematics. With the prospects of precision Compton experiments at the Mainz Microtron and High Intensity Gamma Source facilities in mind, we argue why the beam asymmetry could be the best way to measure the elusive magnetic polarizability of the proton.

DOI: 10.1103/PhysRevLett.110.262001 PACS numbers: 13.60.Fz, 14.20.Dh, 25.20.Dc

Definition: $$\Sigma_3 \equiv \frac{d\sigma_{||} - d\sigma_{\perp}}{d\sigma_{||} + d\sigma_{\perp}}$$

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(applicability region Energy<100 MeV)

Low energy measurement of beam asymmetry can be used to extract magnetic polarizability independently of electric one

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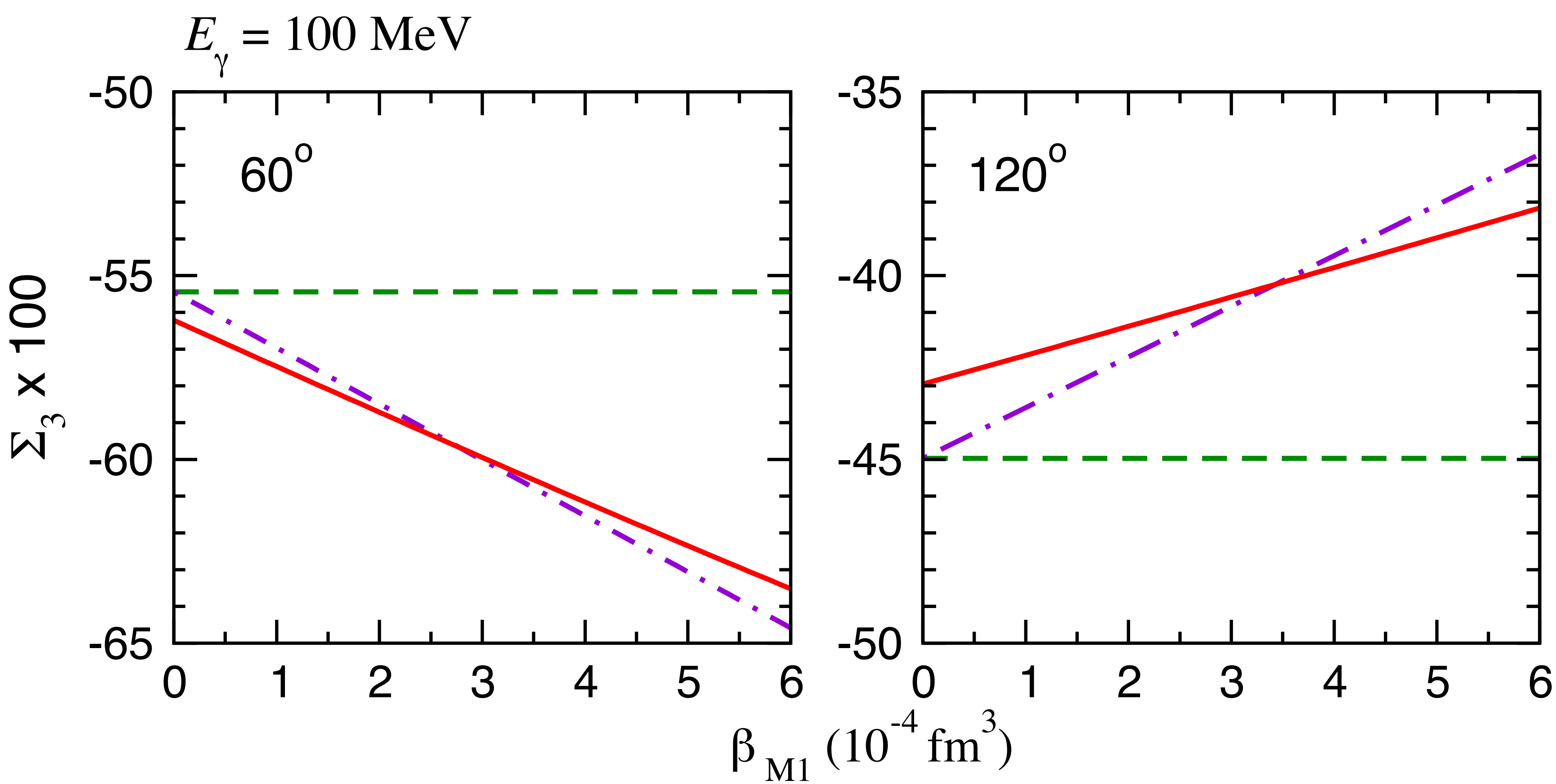
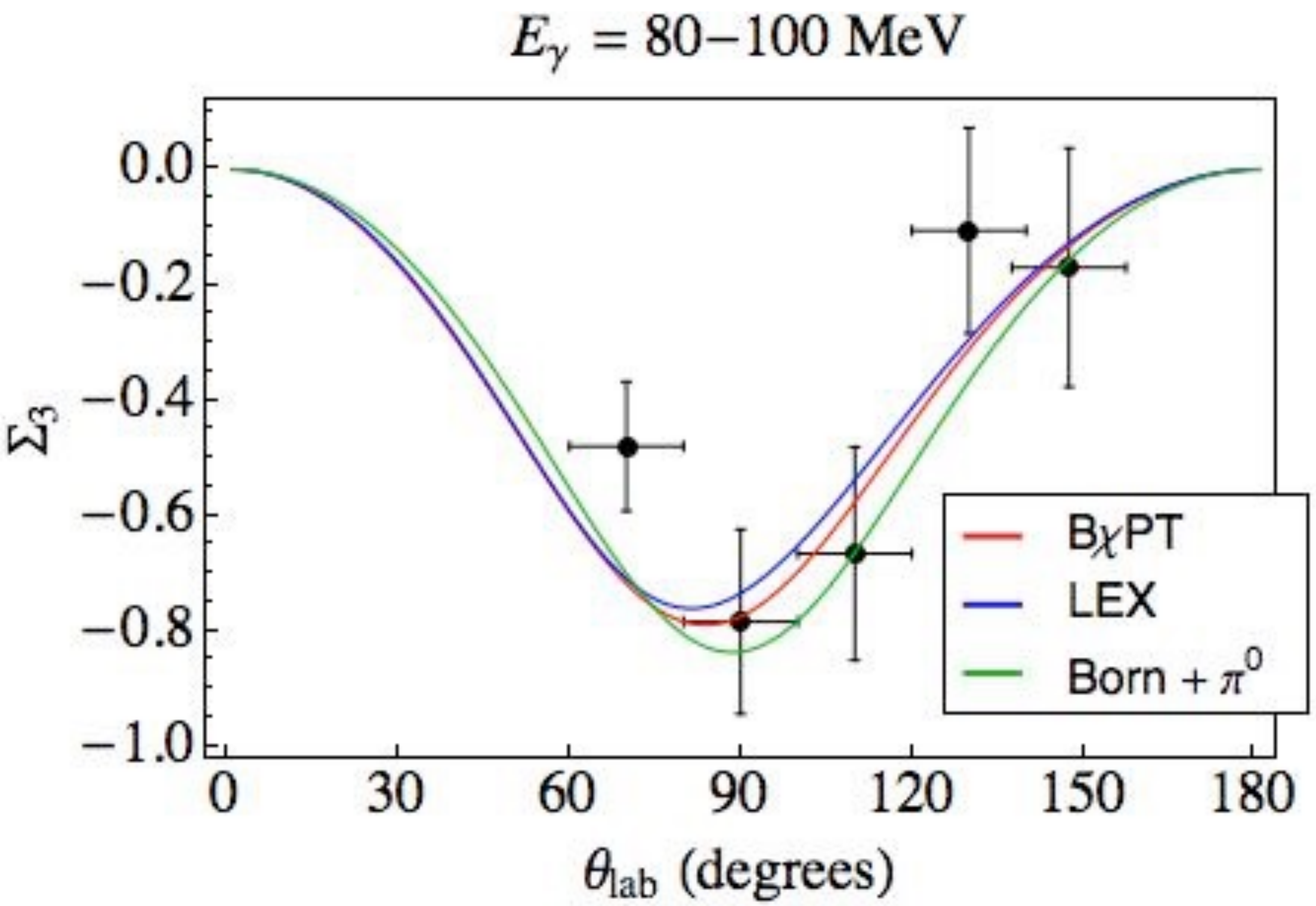
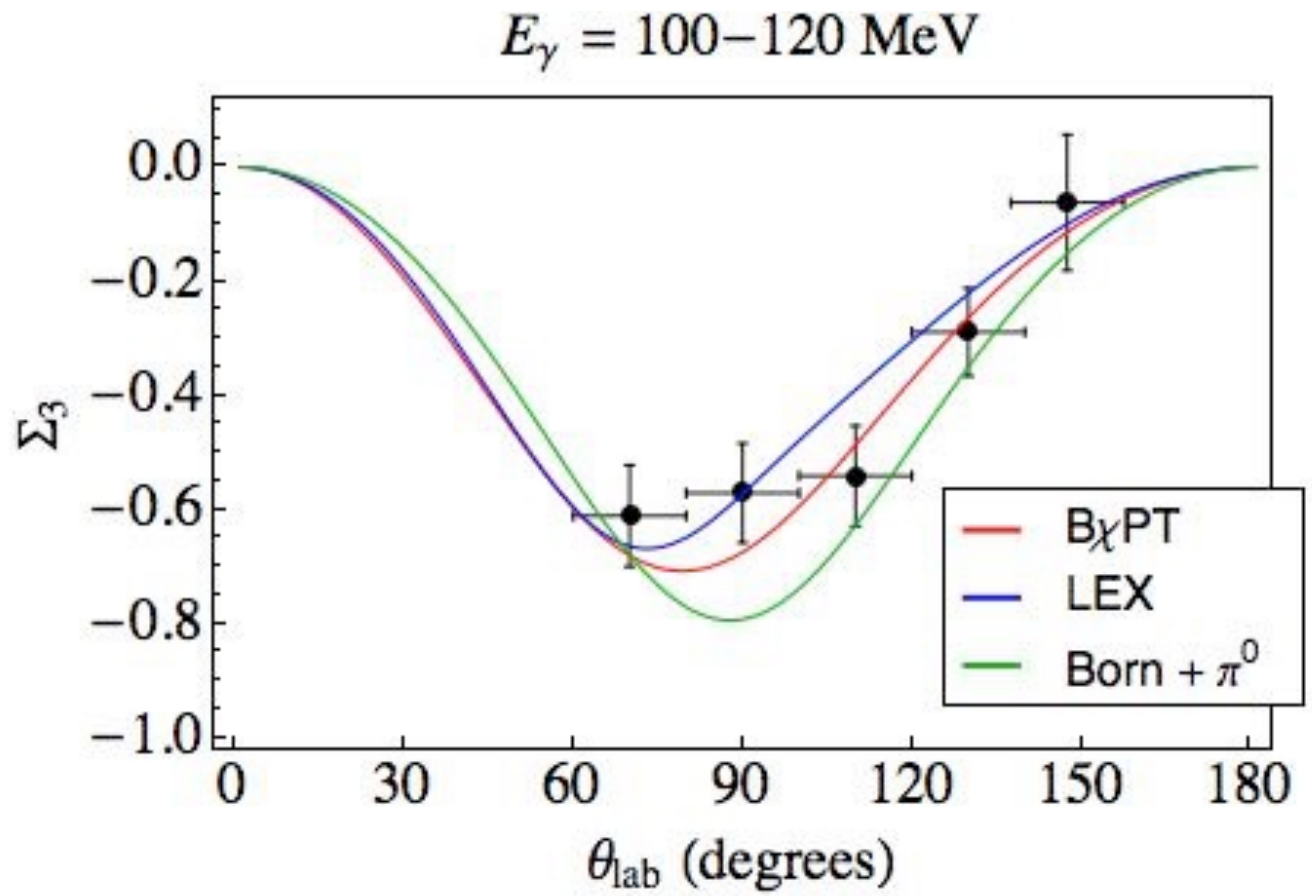
Applicability of LEX

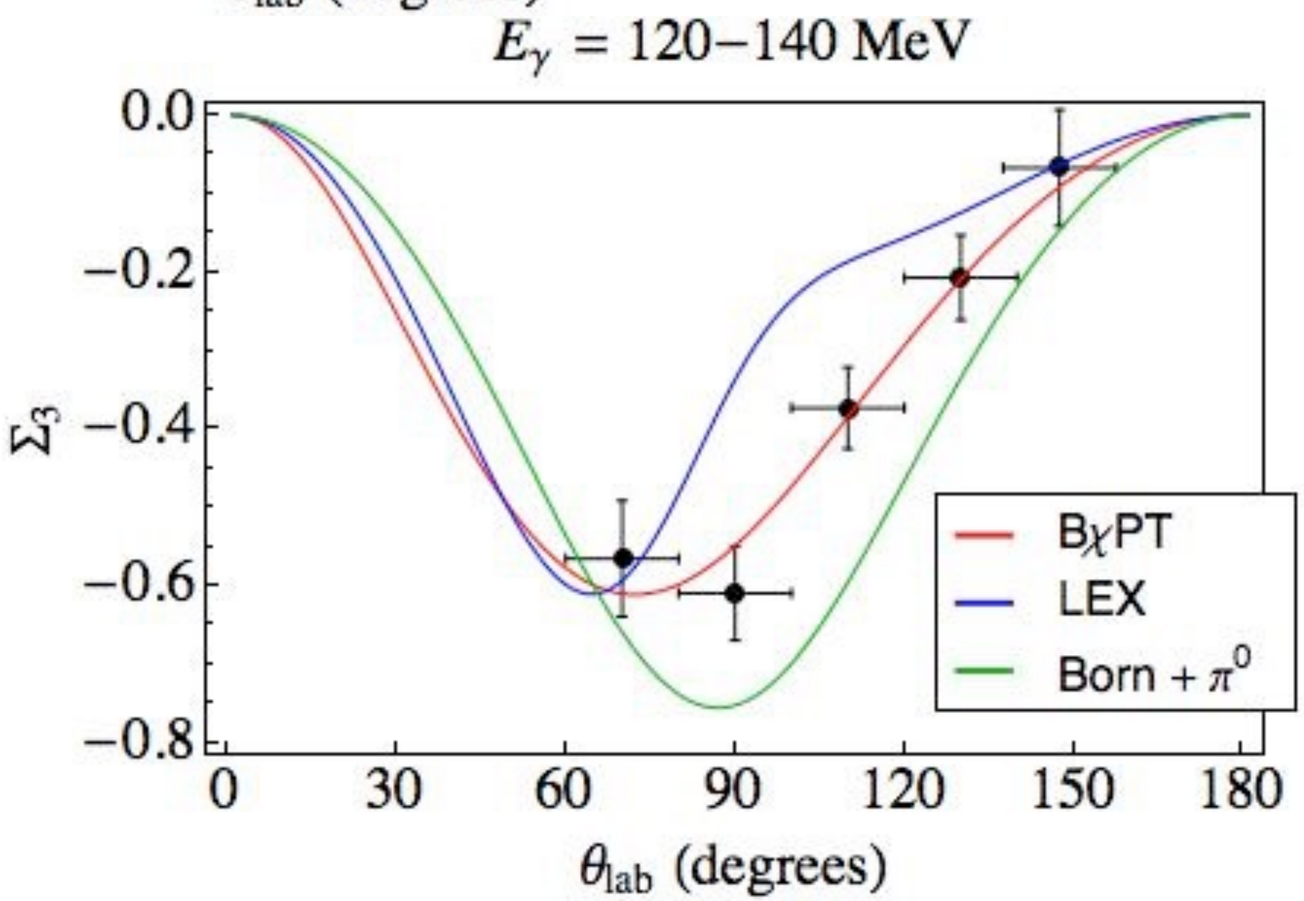


At 100 MeV *NNLO BChPT and LEX curves coincide* for forward angles - ‘LEX regime’

Preliminary results from MAMI







More data is needed to extract the values of polarizabilities

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Multipole expansion

Dynamical polarizabilities:

$$\alpha_{E1}(\omega_{cm}) = \omega_{cm}^{-2}(2f_{EE}^{1+} + f_{EE}^{1-}),$$

$$\beta_{M1}(\omega_{cm}) = \omega_{cm}^{-2}(2f_{MM}^{1+} + f_{MM}^{1-})$$

→ $\alpha_{E1}(0)$ and $\beta_{M1}(0)$ are the scalar polarizabilities

where f_{EE}^{L+} denotes the multipole with the angular momentum of the initial photon *L* and the initial and final photons are both in an electrical mode.

The values of scalar polarizabilities can be obtained by extrapolation of dynamical polarizabilities to zero energy.

Summary

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Thank you for listening