Proton scalar polarizabilities at MAMI

EINN 2019

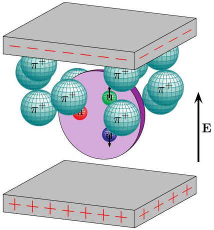
Edoardo Mornacchi

on behalf of the A2 collaboration

Institute for Nuclear Physics
Johannes Gutenberg University of Mainz

Pafos, October 30th 2019

Proton scalar polarizabilities



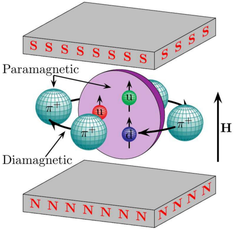
Describes the response of a proton to an applied electric field:

- Electric dipole moment:

$$\vec{p} = \boxed{\alpha_{E1}} \times \vec{E}$$

Electric polarizability

- "Stretchability" of the proton



Describes the response of a proton to an applied magnetic field:

- Magnetic dipole moment:

$$\vec{m} = \boxed{\beta_{M1}} \times \vec{H}$$

Magnetic polarizability

- "Alignability" of the proton

Measure proton scalar polarizabilities

Why measure them?

- Fundamental properties related to nucleon internal structure
- Limit precision to different area of physics:
  - two-photon exchange contribution to the Lamb shift and hyperfine structure in atomic physics
  - determination of the EM contribution to n-p mass difference
  - neutron star susceptibility
- Fertile meeting ground between theory and experiment

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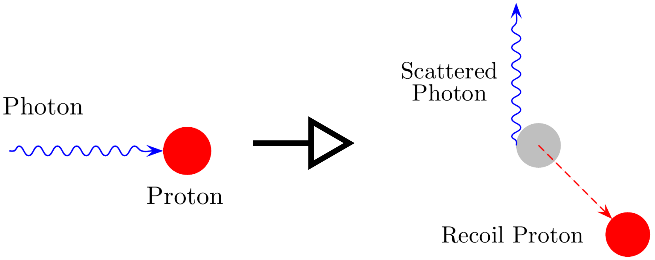
OK!! But how?

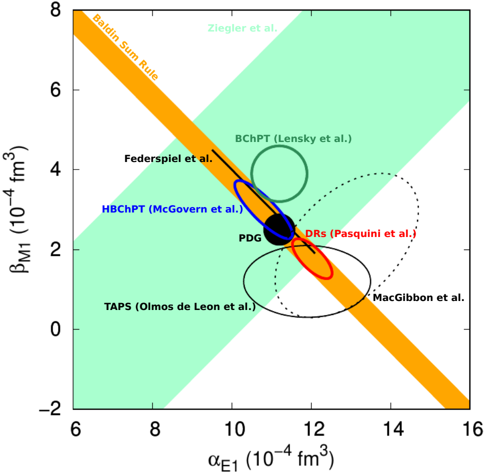
Nuclear Compton scattering



$$\gamma(\mathbf{k}) + \mathbf{P}(\mathbf{p}) \rightarrow \gamma(\mathbf{k'}) + \mathbf{P}(\mathbf{p'})$$

Internal structure of the proton can be accessed by measuring unpolarized cross-section and polarization observables for Compton scattering

Existing data on scalar polarizabilities



B. Pasquini, P. Pedroni and S. Sconfietti, J. Phys. G **46**, no. 10, 104001 (2019).

PDG (2012) values:

$$\alpha_{E1} = (12.0 \pm 0.6)\ 10^{-4}\ \mathrm{fm}^3$$
$$\beta_{M1} = (1.9 \pm 0.5)\ 10^{-4}\ \mathrm{fm}^3$$

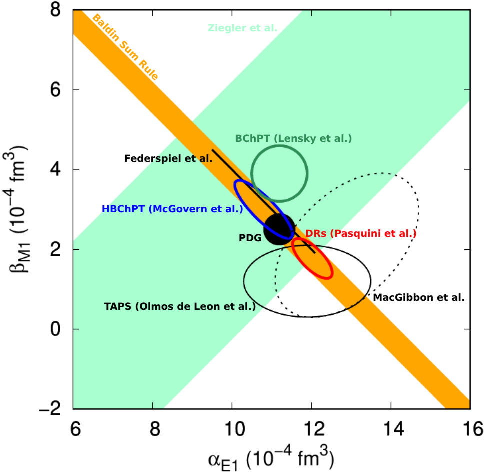
Current PDG values:

$$\alpha_{E1} = (11.2 \pm 0.4)\ 10^{-4}\ \mathrm{fm}^3$$
$$\beta_{M1} = (2.5 \pm 0.4)\ 10^{-4}\ \mathrm{fm}^3$$

Significant change between reviews without new experimental data

⇒ Dataset not fully consistent!

Existing data on scalar polarizabilities



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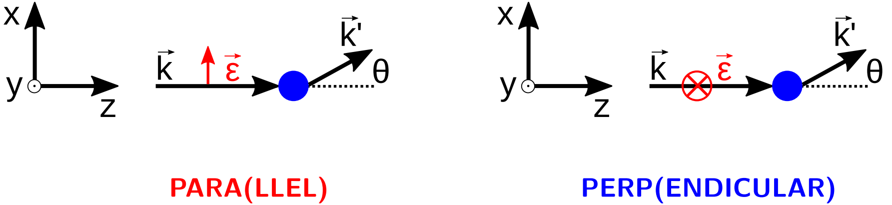
Significant change between reviews without new experimental data

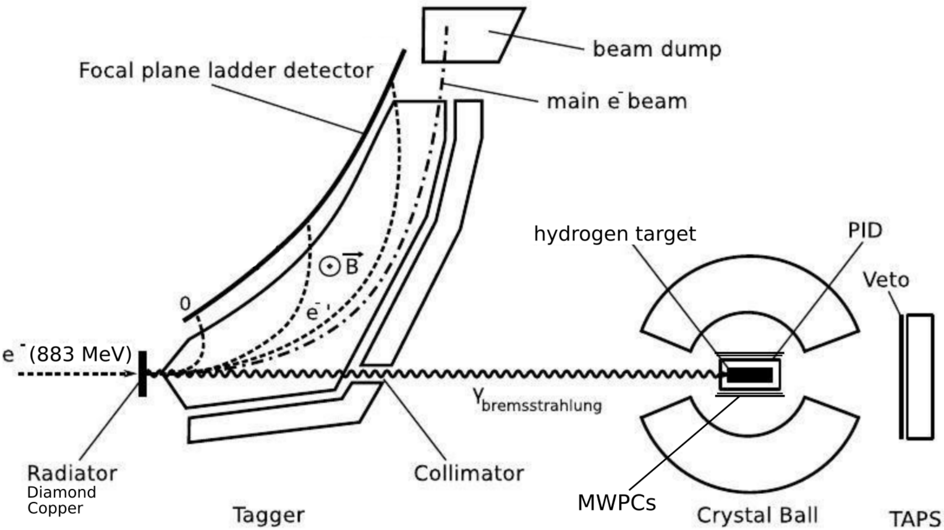
$\Rightarrow$ Dataset not fully consistent!

$\Rightarrow$ New high-precision dataset is needed!

- World existing dataset was previously obtained using only unpolarized cross-section for Compton scattering
- At low energy, below the pion photoproduction threshold, the measurement of the beam asymmetry Σ_3 provides an alternative way to extract β_{M1}

$$\Sigma_3 = \frac{d\sigma_{\parallel} - d\sigma_{\perp}}{d\sigma_{\parallel} + d\sigma_{\perp}}$$





beam dump
Focal plane ladder detector
main e⁻ beam
hydrogen target
PID
⊙B
Veto
0
e⁻'
e⁻(883 MeV)
γ bremsstrahlung
Radiator
Diamond
Copper
Collimator
MWPCs
Tagger
Crystal Ball
TAPS

Data collection:

- Pilot experiment: data collected in June 2013
- New high precision experiment: data collected in the first half of 2018

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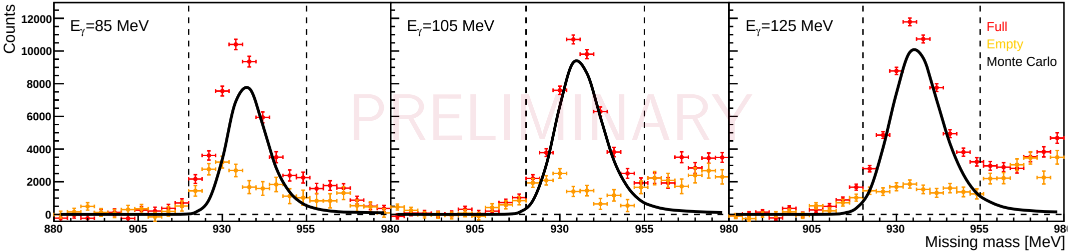
We are selecting Compton scattering $\vec{\gamma}p \rightarrow \gamma p$ events with:

$\Rightarrow E_{\gamma_{beam}} = 80$ - 140 MeV and $\theta_{\gamma_{out}} = 30^\circ$ - 155°

- Subtraction of random coincidences in the tagger
- 1 γ in the final state
- Subtraction of the empty target contribution
- Missing mass cut
- Linear polarization degree extraction event by event
- Constant flux monitoring using a pair spectrometer

Missing mass distribution — PARALLEL dataset

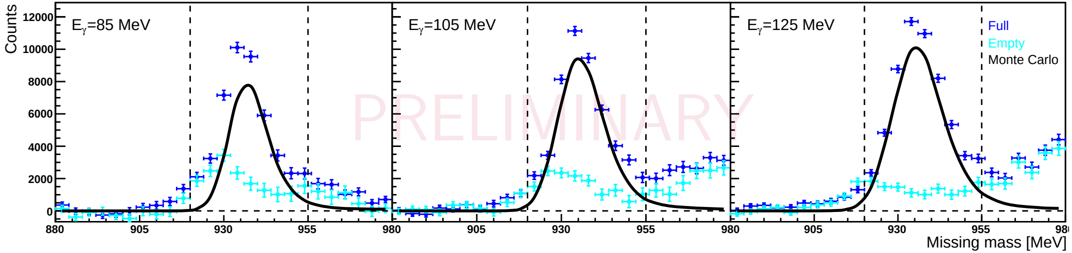
The LH_2 target requires separate data taking with the empty target to determine the contribution of the target cell itself



$$m_{miss} = \sqrt{(E_{\gamma_i} + m_p - E_{\gamma_f})^2 - (\vec{p_{\gamma_i}} - \vec{p_{\gamma_f}})^2} = m_p$$

Missing mass distribution — PERPENDICULAR dataset

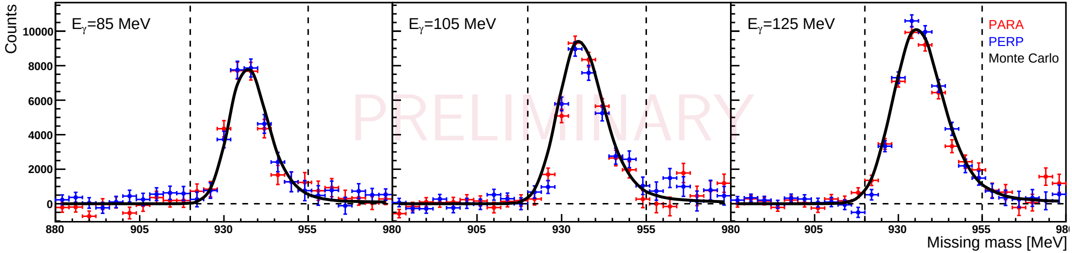
The LH_2 target requires separate data taking with the empty target to determine the contribution of the target cell itself



$$m_{miss} = \sqrt{(E_{\gamma_i} + m_p - E_{\gamma_f})^2 - (\vec{p_{\gamma_i}} - \vec{p_{\gamma_f}})^2} = m_p$$

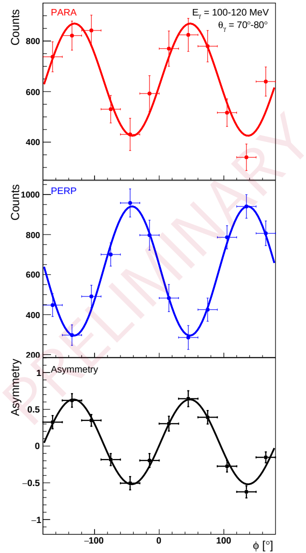
Missing mass distribution — after empty target subtraction

Good agreement between PARA, PERP and Monte Carlo simulation.
Very good statistics with low background!



$$m_{miss} = \sqrt{(E_{\gamma_i} + m_p - E_{\gamma_f})^2 - (\vec{p_{\gamma_i}} - \vec{p_{\gamma_f}})^2} = m_p$$

New measurement - ϕ distributions



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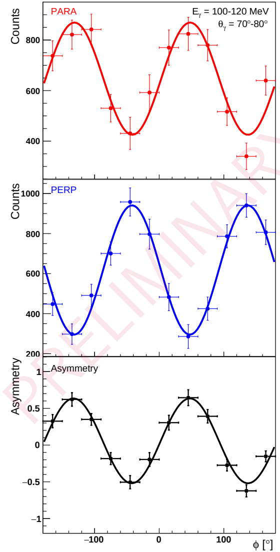
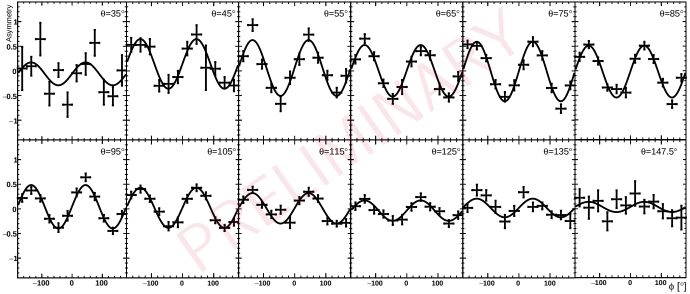
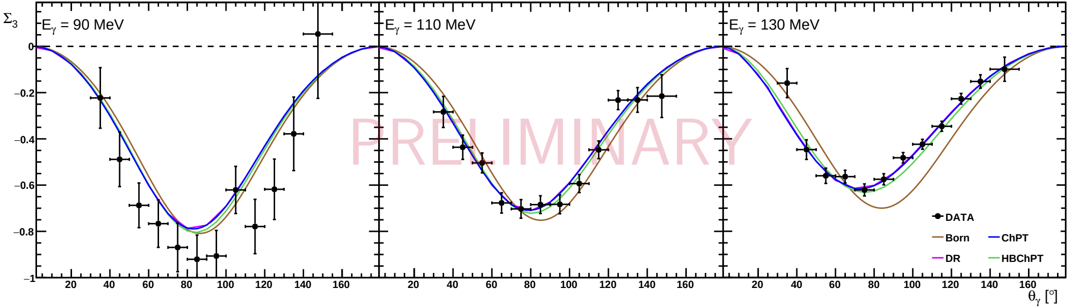


$E_{\gamma_i} = 130$ MeV



New measurement - Beam asymmetry Σ_3



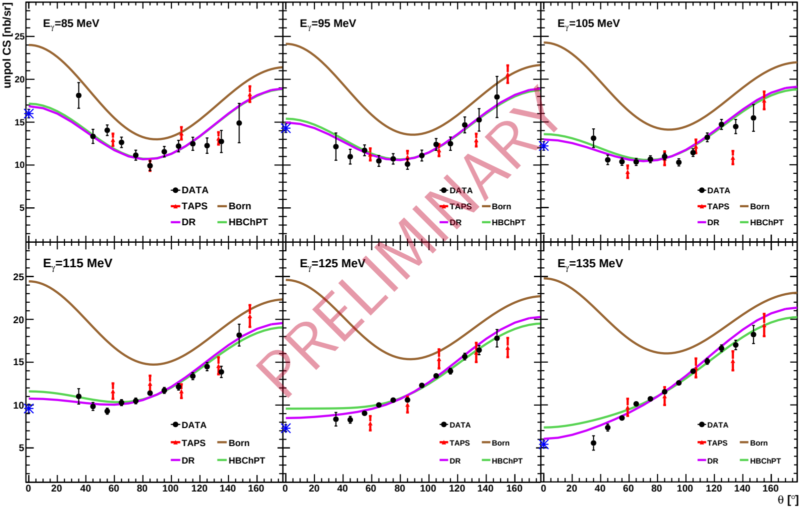
Big improvement in statistics compared to the pilot experiment!

Lensky, V. & Pascalutsa, V., Eur. Phys. J. C (2010) 65:195

McGovern, J.A., Phillips, D.R. & Grießhammer, H.W., Eur. Phys. J. A (2013) 49:12

B. Pasquini, D. Drechsel, & M. Vanderhaeghen, Phys. Rev. C 76

New measurement - Unpolarized cross-section



Good agreement with theoretical predictions and improvement in statistics compared to TAPS dataset!

V. Olmos de Leon, et al., Eur. Phys. J. A 10 (2001)

McGovern, J.A., Phillips, D.R. & Grießhammer, H.W., Eur. Phys. J. A (2013) 49: 12

B. Pasquini, D. Drechsel, and M. Vanderhaeghen, Phys. Rev. C 76

Conclusions

- 1.2 million good Compton scattering events in the relevant energy range
- Simultaneous high precision measurement of unpolarized cross-section and Σ_3
- Preliminary results are definitively very promising!
- Preliminary checks showed a small systematic error
- Preliminary fits for the extraction of the scalar polarizabilities showed a significant improvement compared to the biggest data-set currently published
- Analysis is almost finalized and a publication is expected soon

THANKS!

Special thanks to all the A2 collaboration members!

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and in particular...

THANKS TO YOU FOR YOUR ATTENTION!