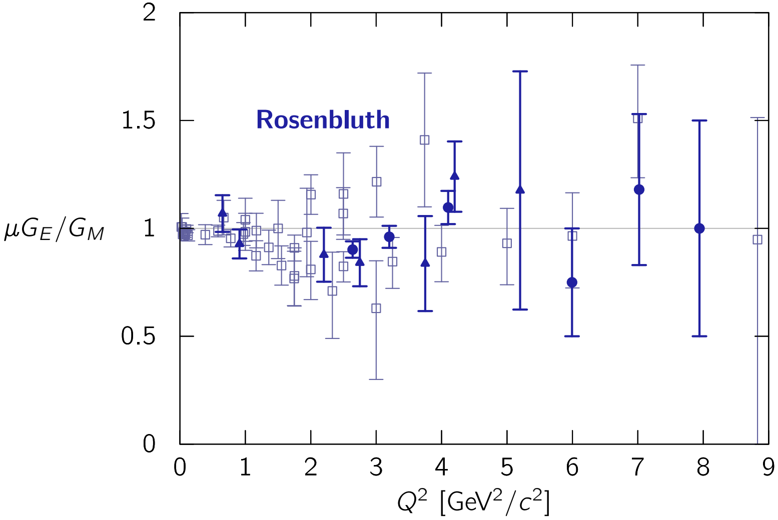
A Direct Measurement of Two-Photon Exchange Using Positrons with CLAS12 (PR12+23-008)

Spokespeople:
J. C. Bernauer, V. Burkert, E. Cline, I. Korover, T. Kutz,
N. Santiesteban, **Axel Schmidt**

Presentation to PAC51

July 25, 2022

Measurements of the proton's form factors are discrepant.



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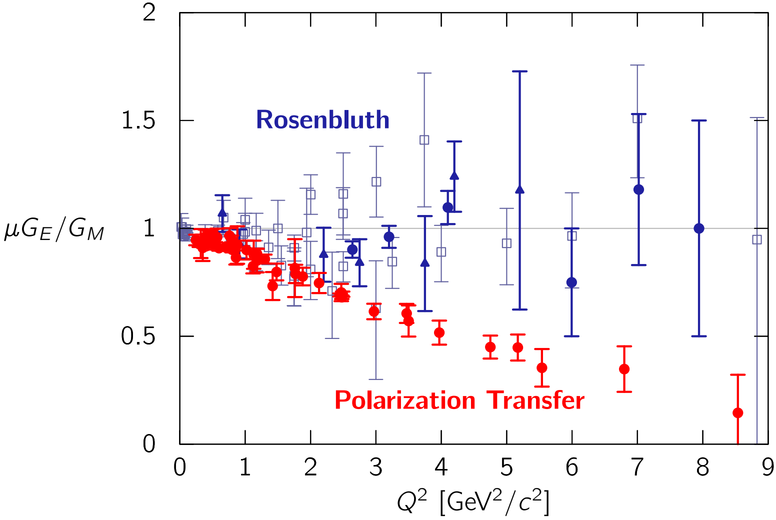

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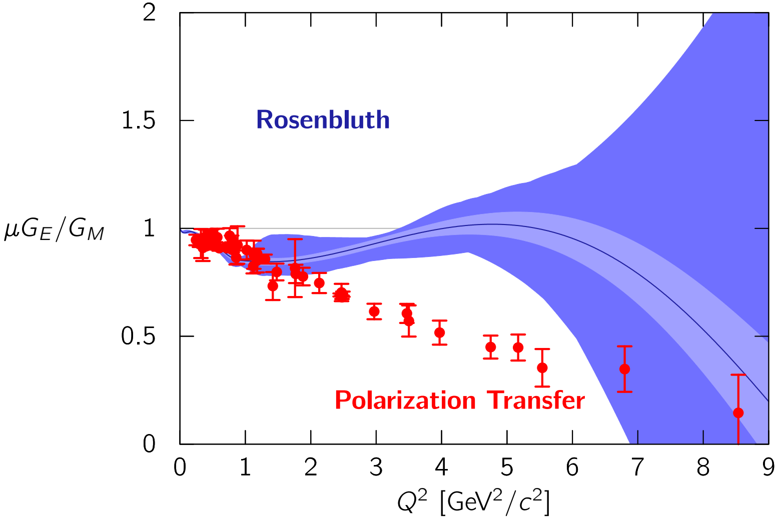
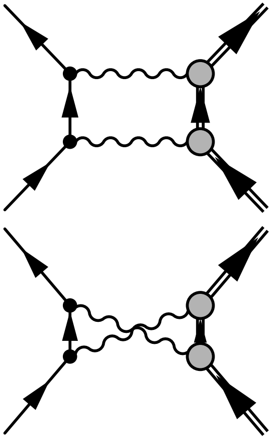


The current status is uncomfortable.

Two-photon exchange



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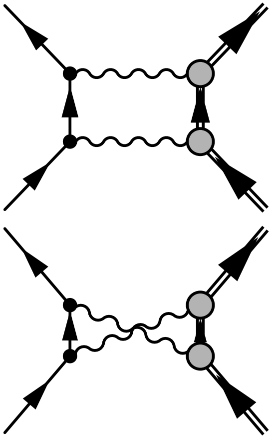


- Proton FFs are ambiguous.
- TPE is hard to calculate.
- Recent experiments inconclusive

- *Field is embarking on 3d imaging campaign of the nucleon.*

Proposal to PAC51: measuring two-photon exchange at CLAS12 with positrons.

- Spokespeople: J. C. Bernauer, V. D. Burkert, E. Cline, I. Korover, **A. Schmidt**, N. Santiesteban, T. Kutz

- Experimental details:
  - 55 days in Hall B with CLAS12
  - e^+, e^- beams at 2.2., 4.4, 6.6 GeV, unpolarized, $\approx$ 75 nA
  - Unpolarized H_2 target
  - Measure e^+p/e^-p elastic cross section ratio: $R_{2\gamma}$

- Developed from LOI12-18-004

  "Determination of two-photon exchange via e^+p/e^-p scattering with CLAS12"

  J. C. Bernauer et al., EPJA 57:144 (2021)

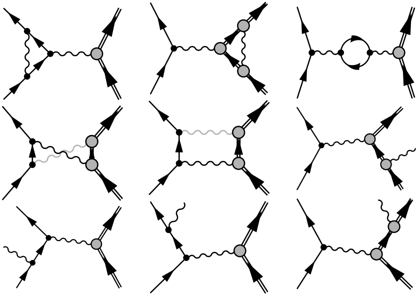
- Endorsed by CLAS and the PWG

Proposal to PAC51: measuring two-photon exchange at CLAS12 with positrons.

- **The field needs this experiment.**
  - The proton form factor discrepancy is still not solved.
  - Theory needs data at higher Q^2.
- **Positrons at CLAS12 is the way to do it.**
  - Huge acceptance, wide kinematic coverage
  - Big advantages over previous measurements
- **Our team has experience to do it.**
  - Veterans of the CLAS, OLYMPUS measurements
  - Expertise with radiative corrections

The one “missing” radiative correction is hard two-photon exchange.

The standard set



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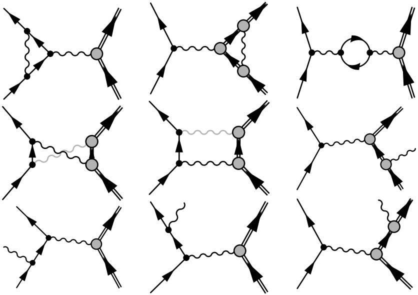
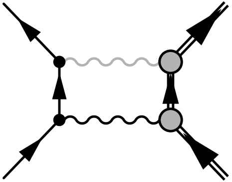


Soft two-photon exchange



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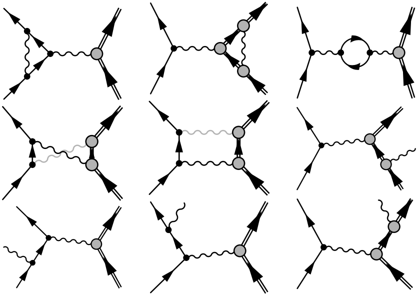

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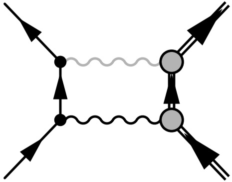

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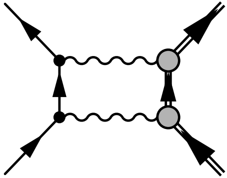
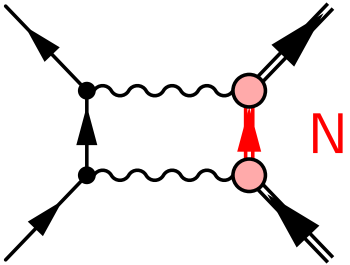


Calculations of two-photon exchange come with model dependency.



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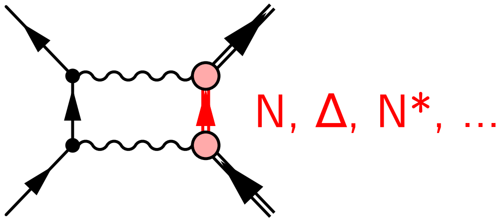
- Treat off-shell propagator as collection of hadronic states.
- e.g. Blunden, Melnitchouk, PRC '17, Ahmed et al., PRC '20



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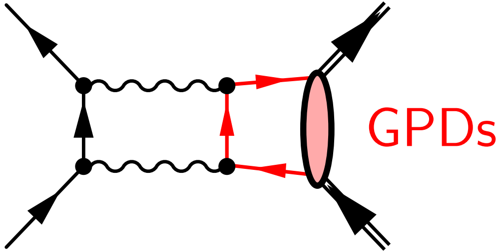

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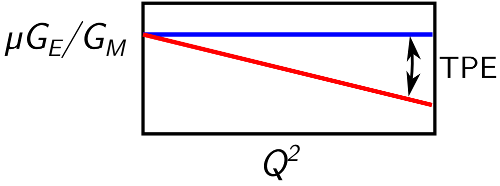
- Assume the discrepancy is caused by TPE, estimate the effect.
- e.g. Bernauer et al., PRC '14 A. Schmidt, JPG '20



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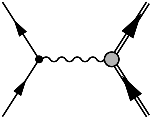
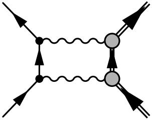
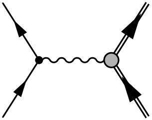
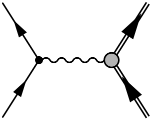
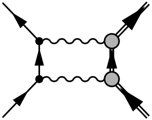
Alternate Approaches

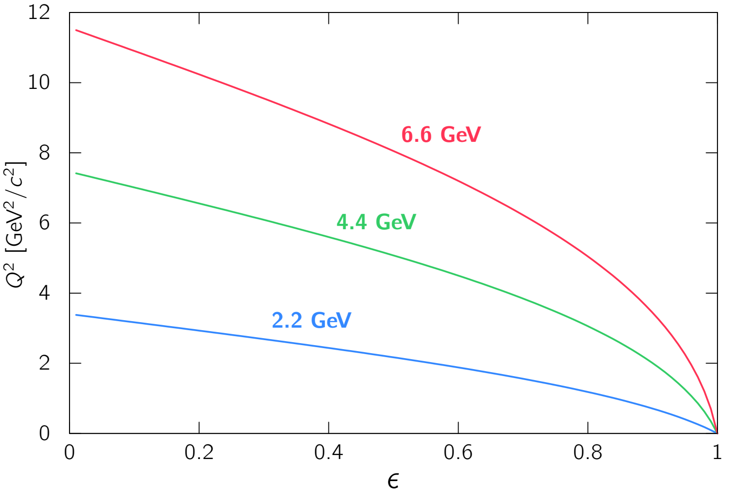
- e.g., Kuraev et al., PRC '08

TPE produces an asymmetry between electron and positron scattering.

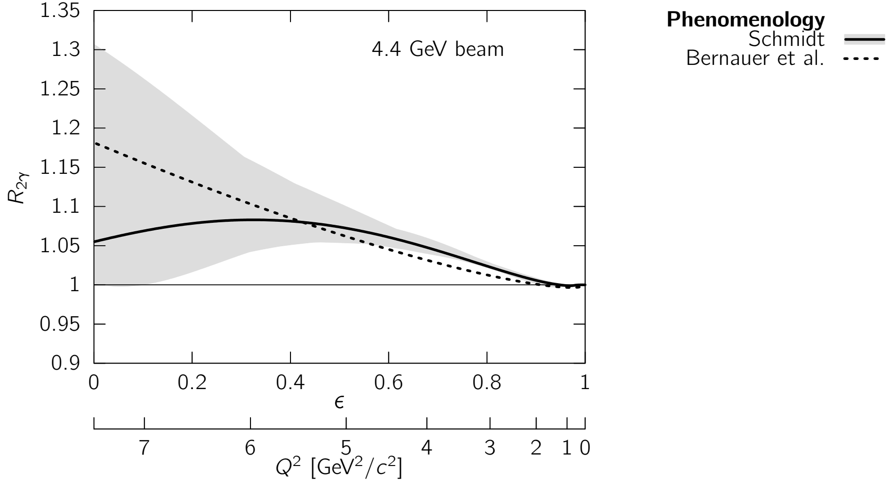
$\mathcal{M} =$  $+$  $+\, \mathcal{O}(\alpha^3)$

$\sigma \approx |\mathcal{M}|^2 =$ |  $|^2$ $\pm\, 2\mathrm{Re}$ [ ] $+\, \mathcal{O}(\alpha^4)$

Elastic scattering is a 2D space



Predictions for $R_{2\gamma} = \sigma_{e^+p}/\sigma_{e^-p}$



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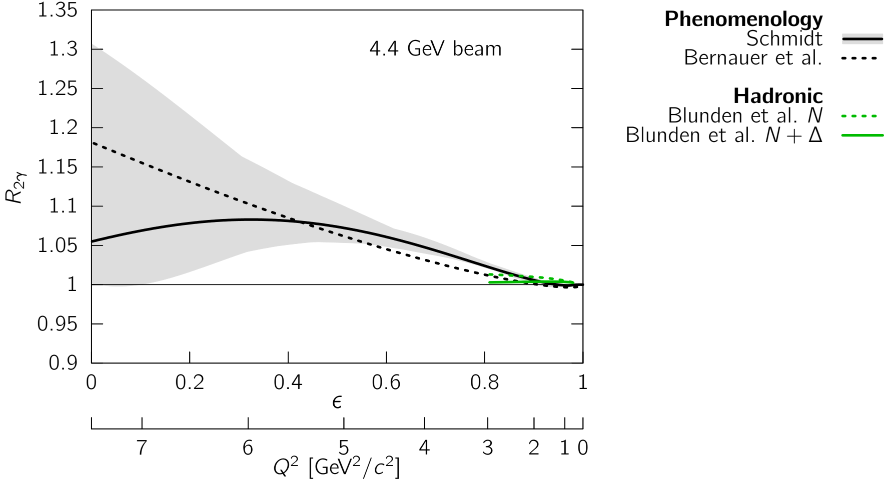

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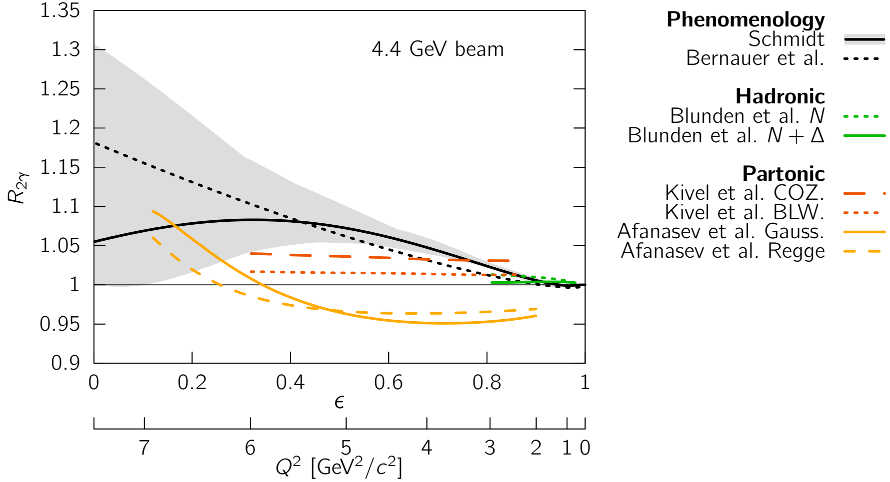

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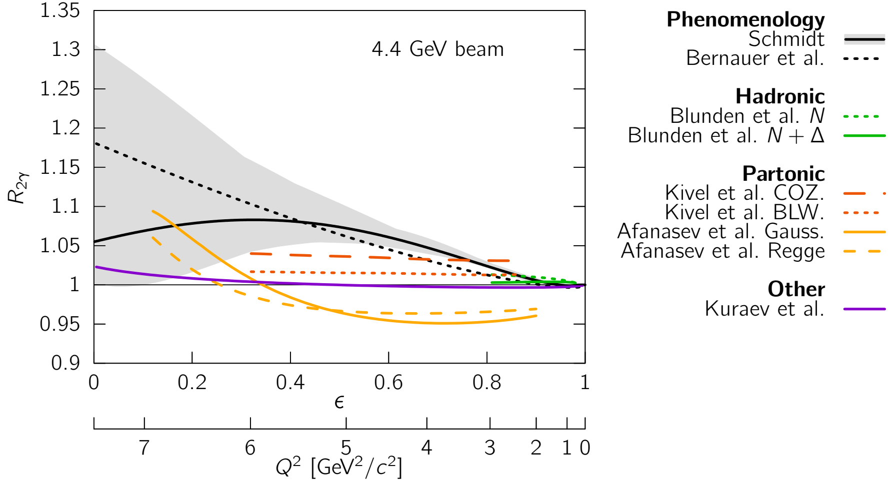
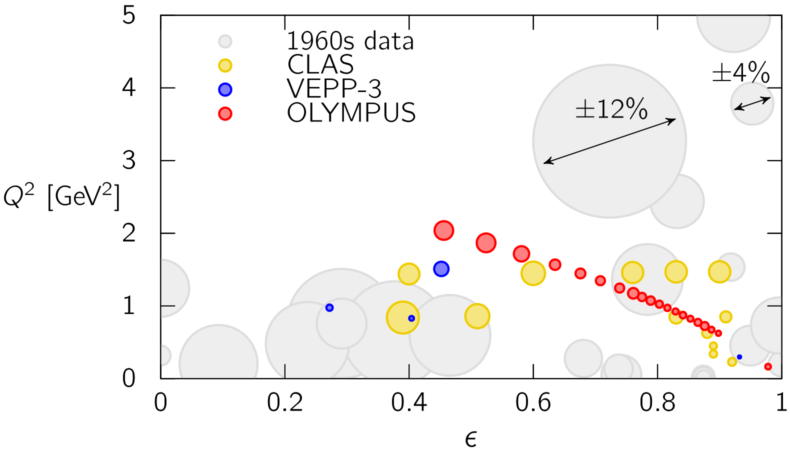
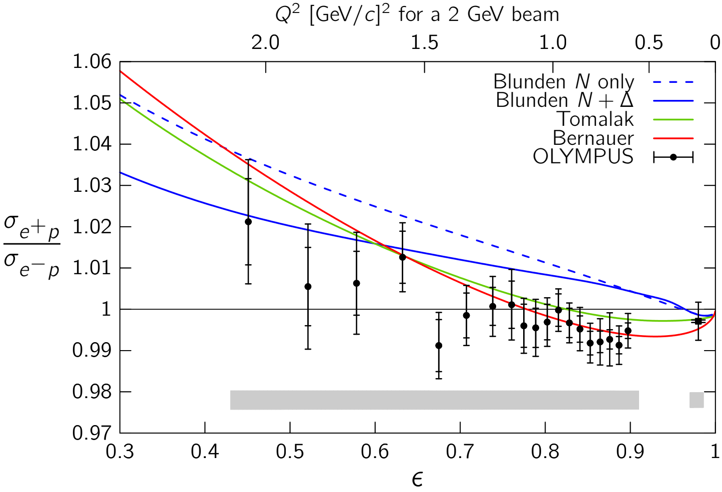


Three recent experiments measured hard TPE.

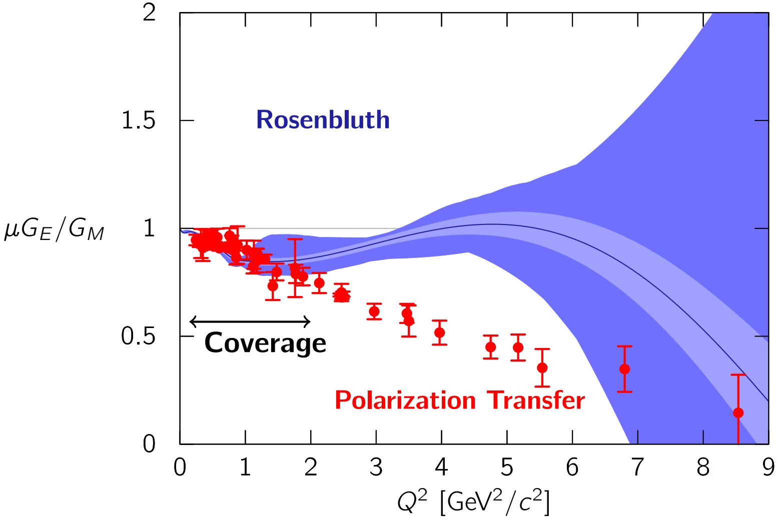


OLYMPUS observed a small TPE effect.



Henderson et al., PRL 118, 092501 (2017)

Recent measurements lacked the kinematic reach to be decisive.



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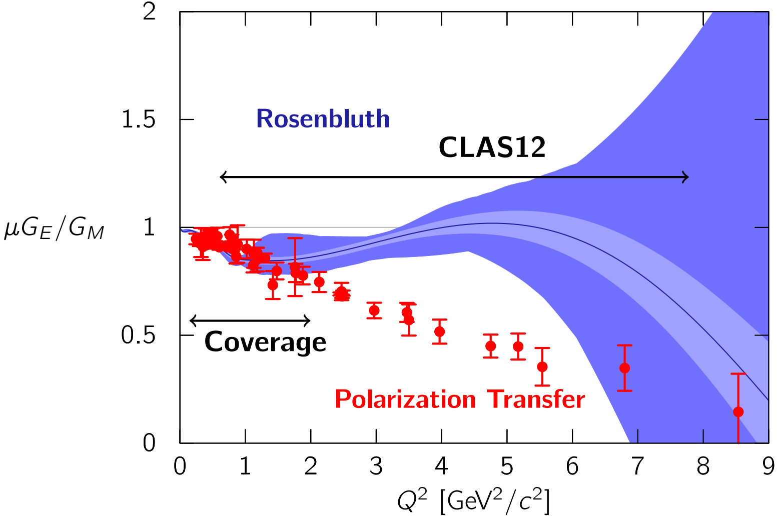
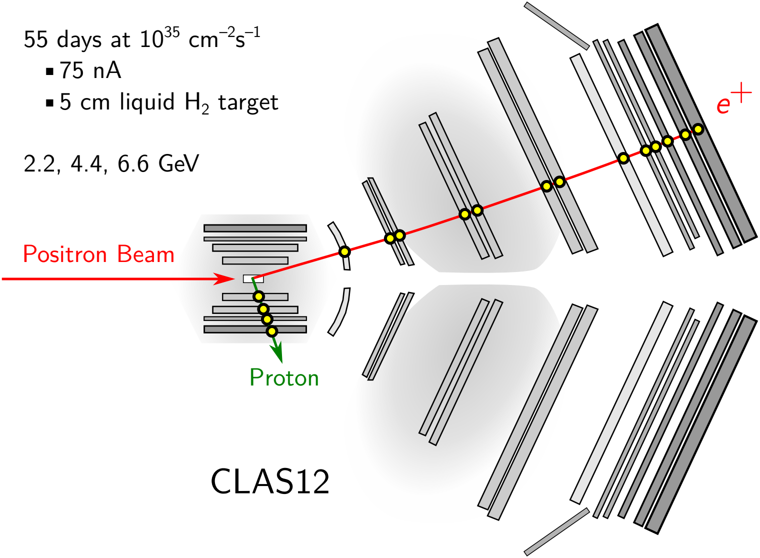


Our proposed experiment

55 days at 10^{35} cm^{-2}s^{-1}

- 75 nA
- 5 cm liquid H_2 target

2.2, 4.4, 6.6 GeV



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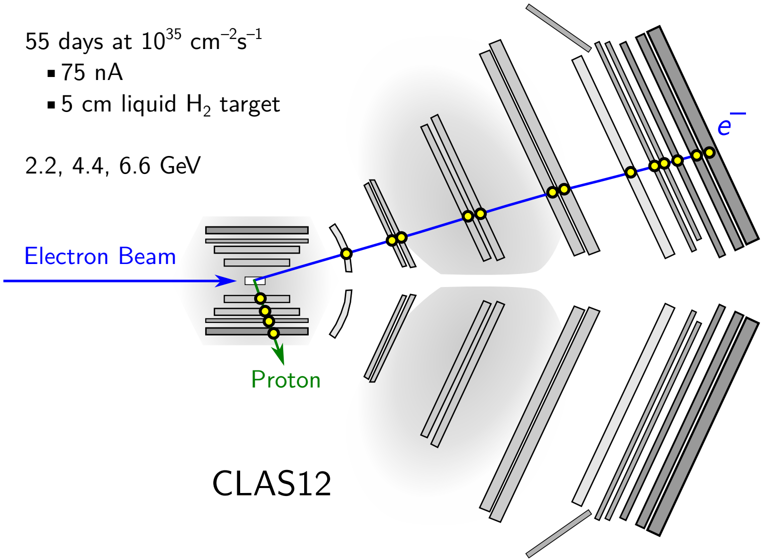
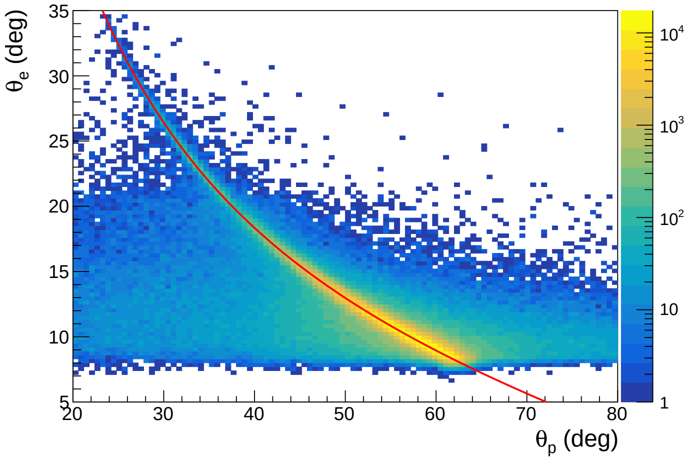


CLAS12 holds several key advantages over OLYMPUS

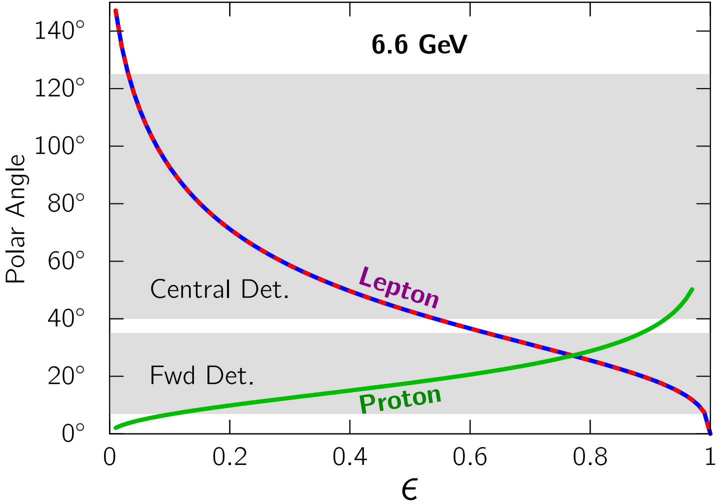
	OLYMPUS	**CLAS12**
Azimuthal acceptance	$\pi/4$	2π
Luminosity	$2 \cdot 10^{33}$	10^{35}
Beam energy	2 GeV	6.6 GeV

Elastic scattering is easy to identify in CLAS12.

2021 Run Group M data (6 GeV e^- on hydrogen)



We want to trigger on events with a lepton in the CLAS12 central detector.



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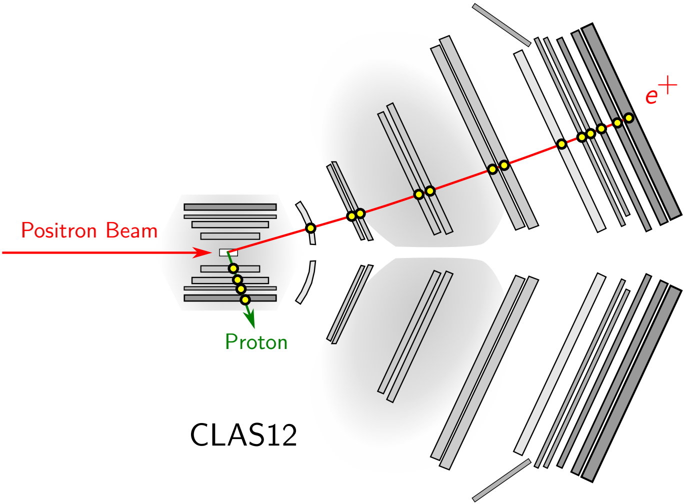

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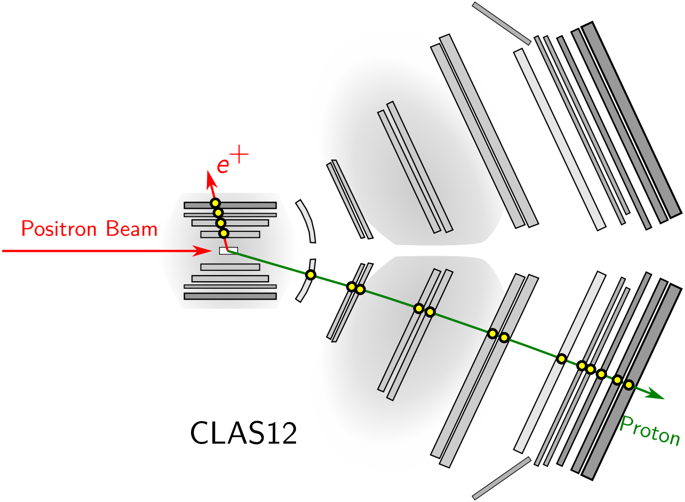
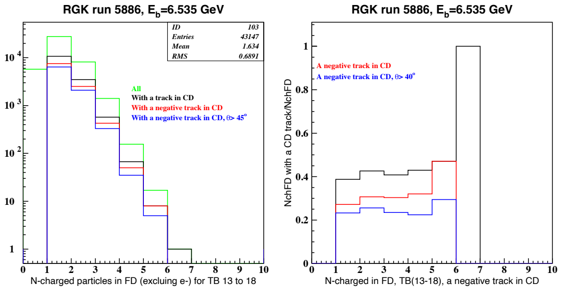


Triggering our experiment

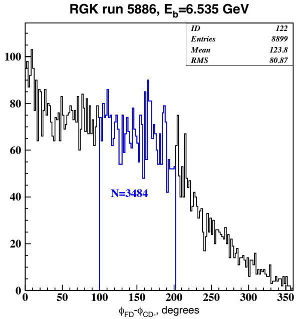
- Recent data with similar conditions
  - Forward hadron trigger rate of **420 kHz**
  - Planned rate after high luminosity upgrade: **100 kHz**
  - Need a 5$\times$ reduction

- Possible trigger additions
  - CTOF/CND Coincidence
  - CVT Coincidence, including "roads"
  - Kinematic Correlations between forward and central hits
  - Cherenkov veto

Run Group K data shows this will not be hard.



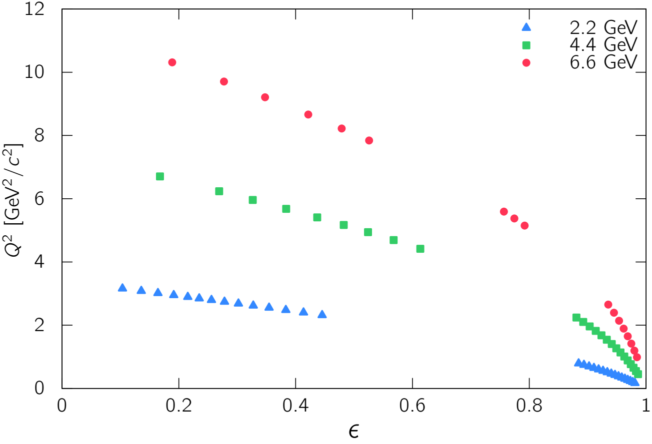
Coincident neg. central track
5x reduction



Loose coplanarity requirement
10x reduction

Study by S. Stepanyan

CLAS12 is ideal for mapping TPE over a wide phase space.



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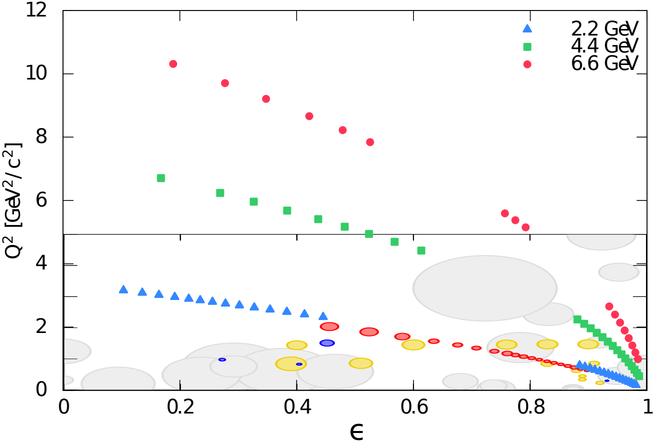

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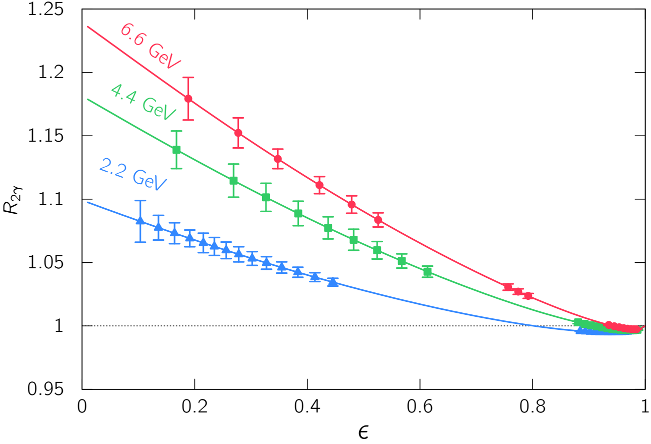

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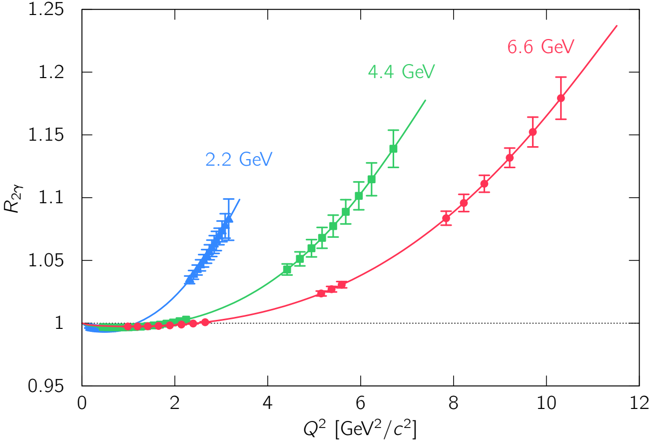

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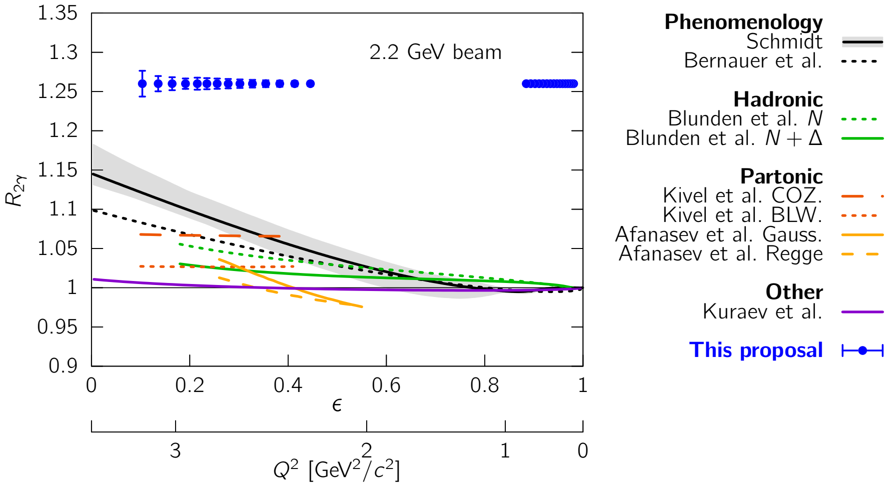

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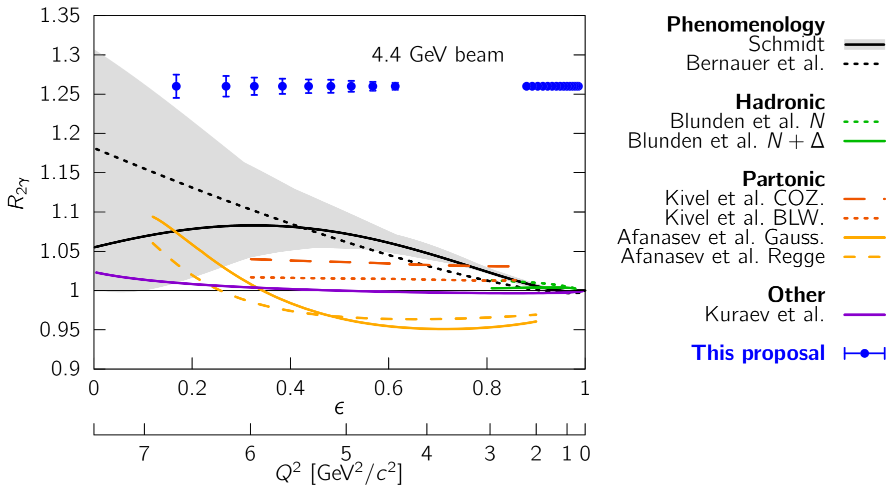

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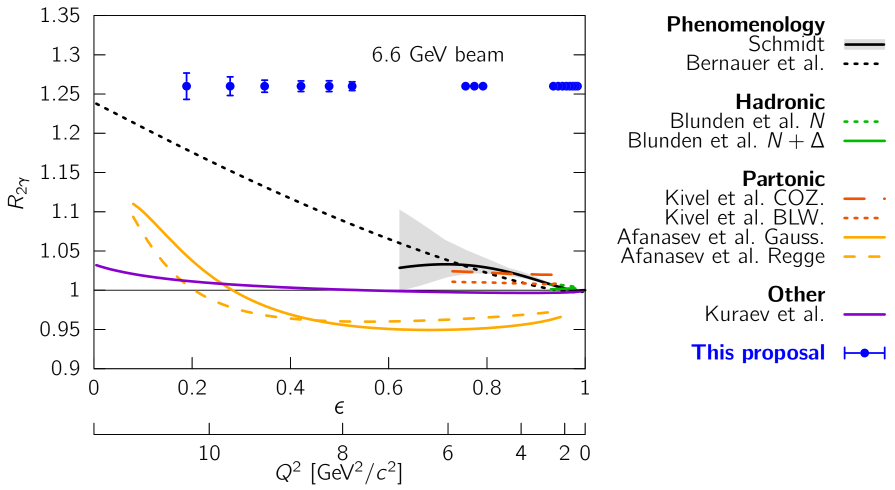

Limiting Systematics

- Over-all Scale: Relative e^+/e^- luminosity
  - Typical Hall B abs. accuracy: 2–5%
  - Relative should be much better: $< 1\%$
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- Point-to-Point: Local efficiency
  - Magnetic fields bend e^+, e^- to different parts of the detector.
    - Polarity switching of solenoid and torus

$$R_{2\gamma} = \left[\left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\uparrow\uparrow} \cdot \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\uparrow\downarrow} \cdot \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\downarrow\uparrow} \cdot \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\downarrow\downarrow} \right]^{1/4}$$

  - Need heavy-duty Monte Carlo
  - Fast-switching $e^+ \leftrightarrow e^-$ helps

Issues raised in TAC/Theory Reports

Theory: "Overall ... this is a must-do experiment..."

Issues raised in TAC/Theory Reports

Theory: "Overall . . . this is a must-do experiment. . ."

TAC:

- CLAS12 can perform under proposed conditions.
- Systematic impact of $e^+ \leftrightarrow e^-$ rate.
- New trigger needs to be developed
- Common issues for all positron experiments

Our team

CLAS

Jan Bernauer

Axel Schmidt

Volker Burkert

Igor Korover

OLYMPUS

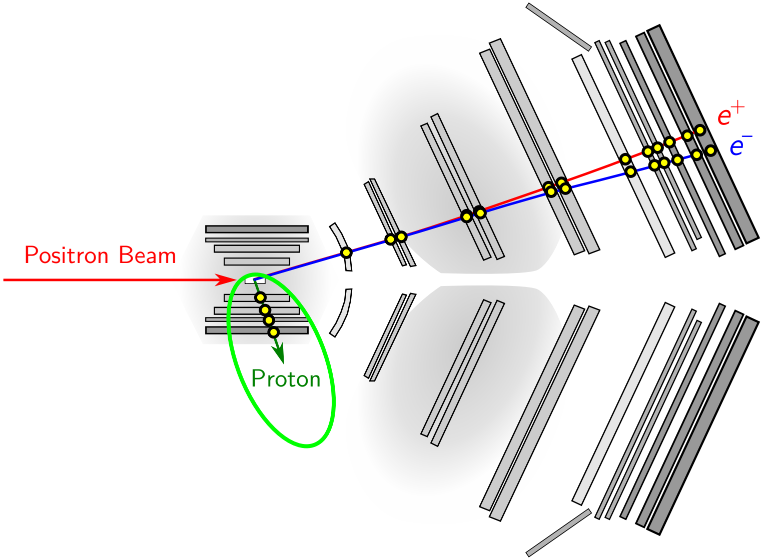
Ethan Cline

Nathaly Santiesteban

Tyler Kutz

Precision Form Factors

Lesson 1: Define kinematics based on the proton



Lesson 2: Compare CLAS12 sectors to make unbiased checks.

$$r_{i,j} = \{N_{\text{exp}}/N_{\text{MC}}\}_i / \{N_{\text{exp}}/N_{\text{MC}}\}_j$$

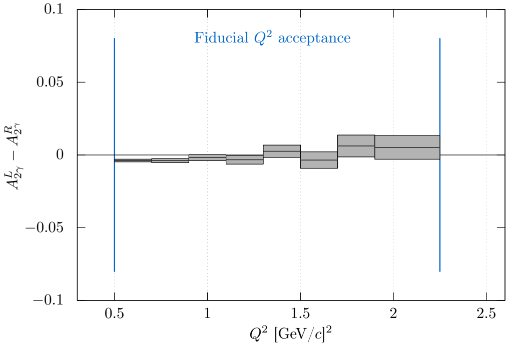
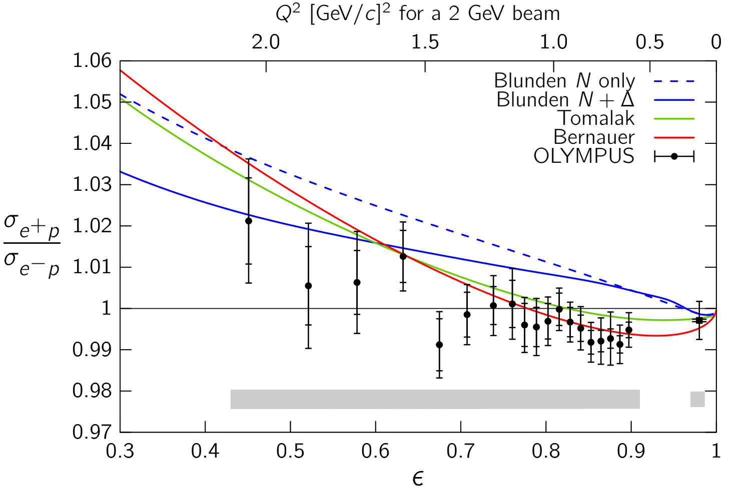
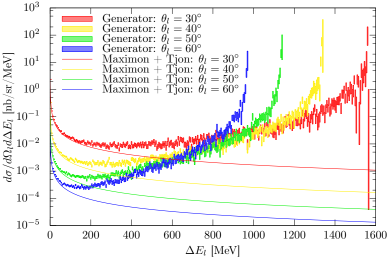


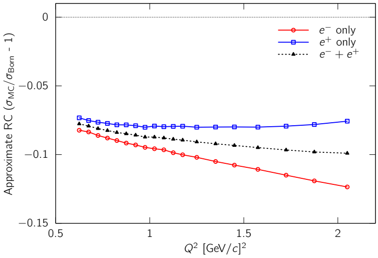
Fig. 9-2 from my thesis

Lesson 3: Independent normalization is valuable.



Lesson 4: Radiative corrections will be critical.

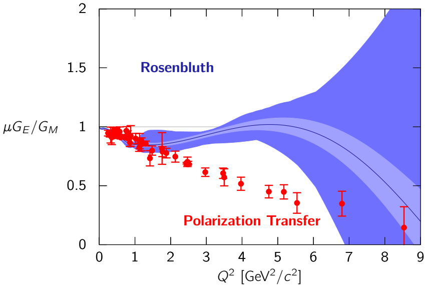




- Significant charge-odd corrections that are not hard TPE
- OLYMPUS tested several RC prescriptions, built custom radiative event generator.
- See white paper (`https://arxiv.org/abs/2306.14578`) from the recent ECT Workshop, as well as 2020 CFNS Workshop.

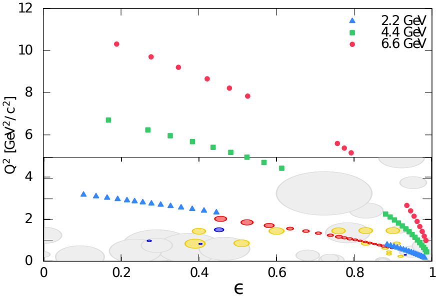
Recap:

- TPE is still a problem.



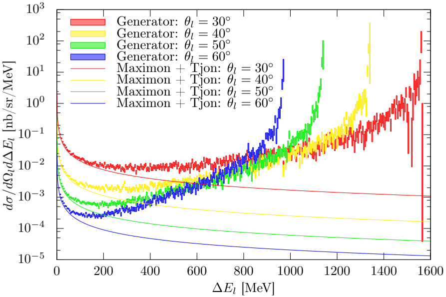
Recap:

- TPE is still a problem.
- CLAS12 can make a definitive measurement



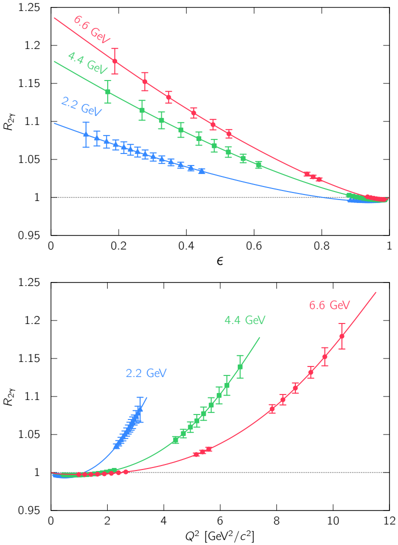
Recap:

- TPE is still a problem.
- CLAS12 can make a definitive measurement
- We have experience!
  - with two-photon exchange
  - with radiative corrections
  - with precision measurements



We request 55 PAC days.

Setting	PAC Days
2.2 GeV production	1.333
4.4 GeV production	4
6.6 GeV production	44
Calibrations	0.5
Configuration Changes	5.167
Totals	55

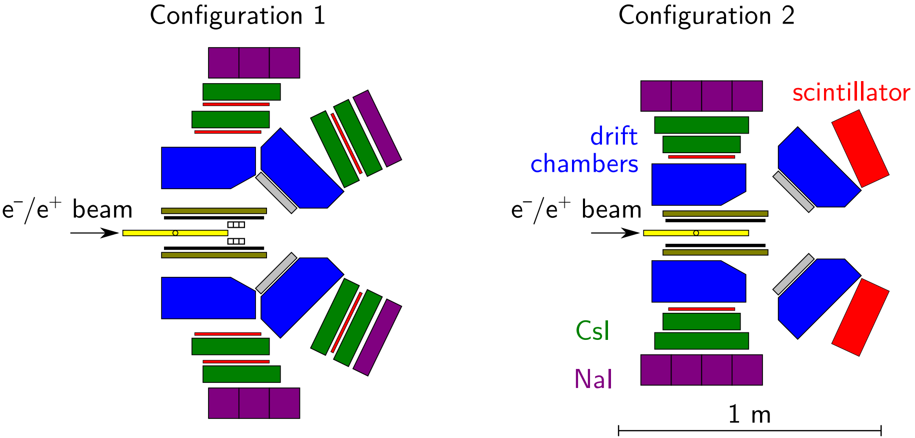


Back Up

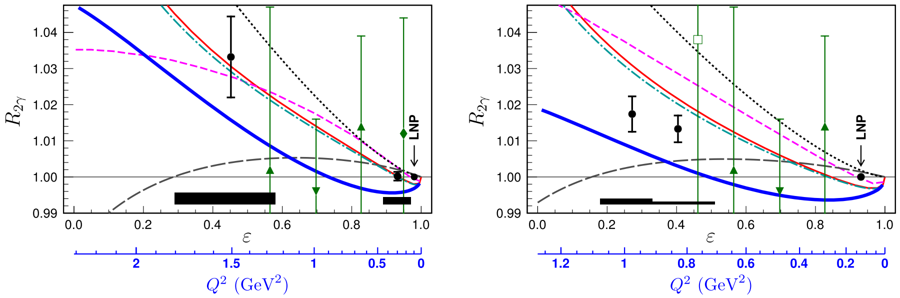
Jefferson Lab Positron Working Group

- Web: `https://wiki.jlab.org/pwgwiki/index.php/Main_Page`
- Join the mailing list: `mailto:pwg-request@jlab.org`
- Link to our recent White Paper

VEPP-3, Novosibirsk, Russia



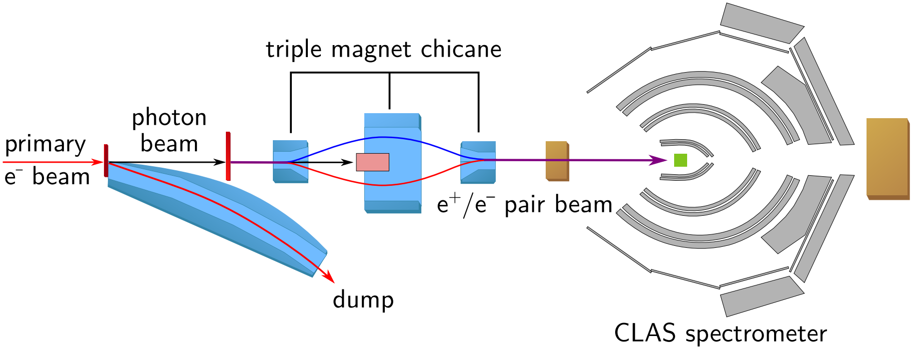
VEPP-3, Novosibirsk, Russia



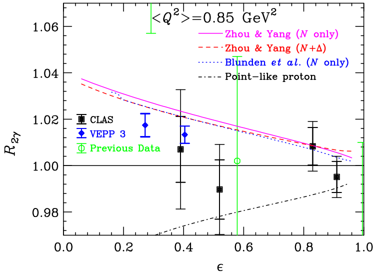
I. A. Rachek et al., PRL 114, 062005 (2015)

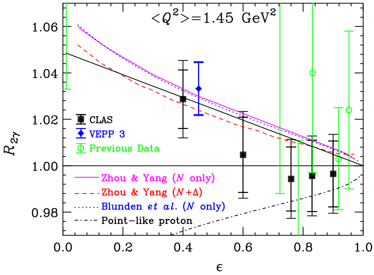
CLAS, Jefferson Lab, USA

TPE/eg5 run period



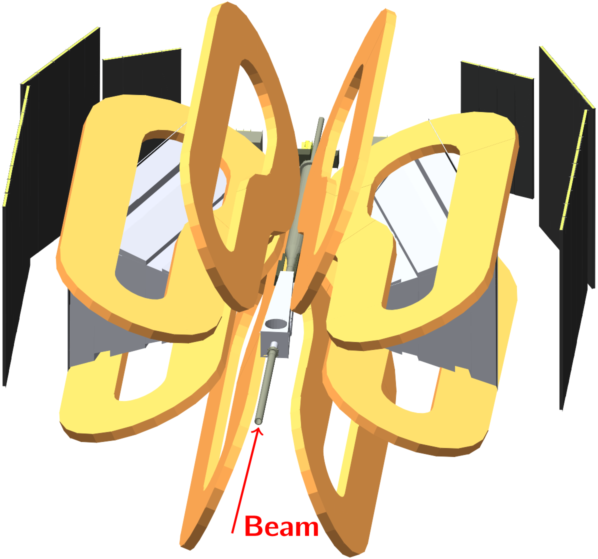
CLAS, Jefferson Lab, USA



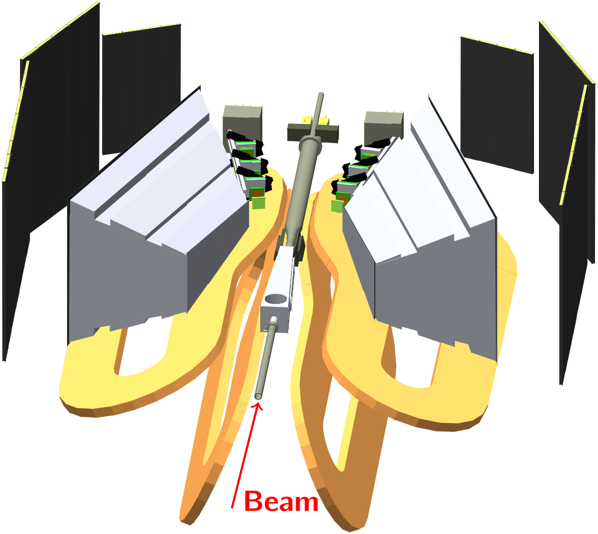


D. Adikaram et al., PRL 114, 062003 (2015)
D. Rimal et al., PRC 95, 065201 (2017)

OLYMPUS, DESY, Germany



OLYMPUS, DESY, Germany



The polarization transfer results are not necessarily correct.

$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 - 4G_M \mathrm{Re}\left(\delta\tilde{G}_M + \frac{\epsilon\nu}{M^2}\tilde{F}_3\right) - \frac{4\epsilon}{\tau}G_E \mathrm{Re}\left(\delta\tilde{G}_E + \frac{\nu}{M^2}\tilde{F}_3\right) + \mathcal{O}(\alpha^4)$$

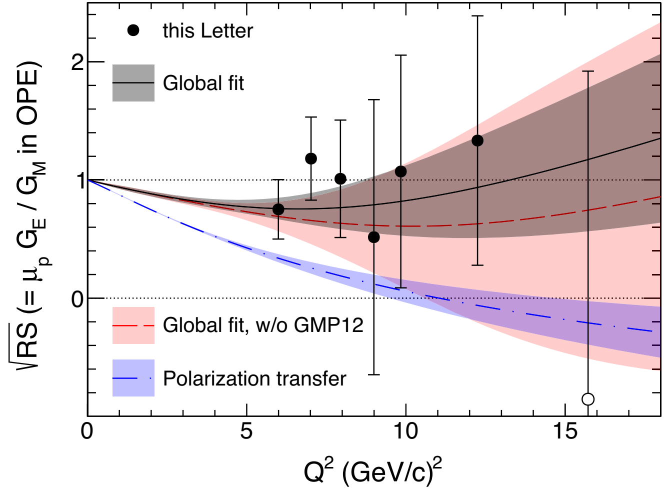
$$\frac{P_t}{P_l} = \sqrt{\frac{2\epsilon}{\tau(1+\epsilon)}}\frac{G_E}{G_M} \times [1 + \dots$$

$$+ \mathrm{Re}\left(\frac{\delta\tilde{G_M}}{G_M}\right) + \frac{1}{G_E}\mathrm{Re}\left(\delta\tilde{G_E} + \frac{\nu}{m^2}\tilde{F}_3\right) - \frac{2}{G_M}\mathrm{Re}\left(\delta\tilde{G_M} + \frac{\epsilon\nu}{(1+\epsilon)m^2}\tilde{F}_3\right)$$

$$+ \mathcal{O}(\alpha^4) + \dots]$$

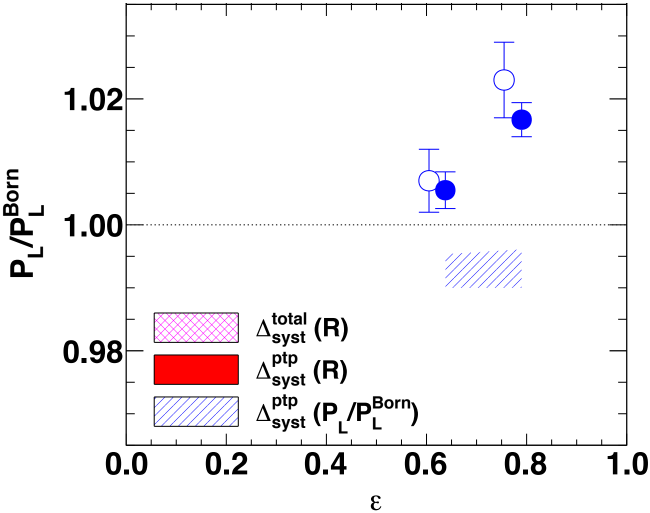
Formalism of Carlson, Vanderhaeghen, Annu. Rev. Nucl. Part. Sci., 2007

Hall A G_M^p Experiment confirms FF discrepancy to $Q^2 = 10$.



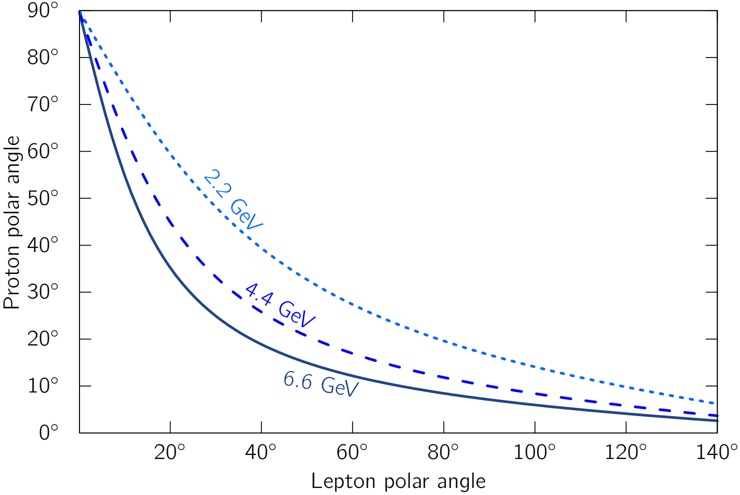
M. E. Christy et al., PRL 128, 102002 (2022)

GEP-2γ finds ϵ-dependence in P_l.

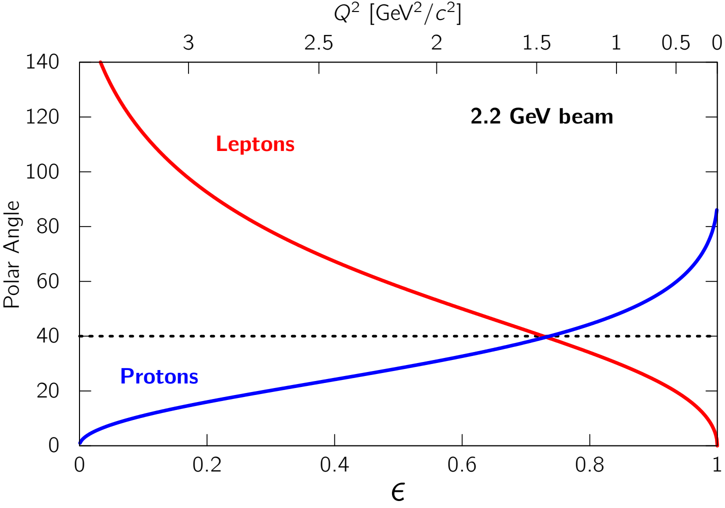


A. J. R. Puckett et al., PRC 98 019907 (2018)

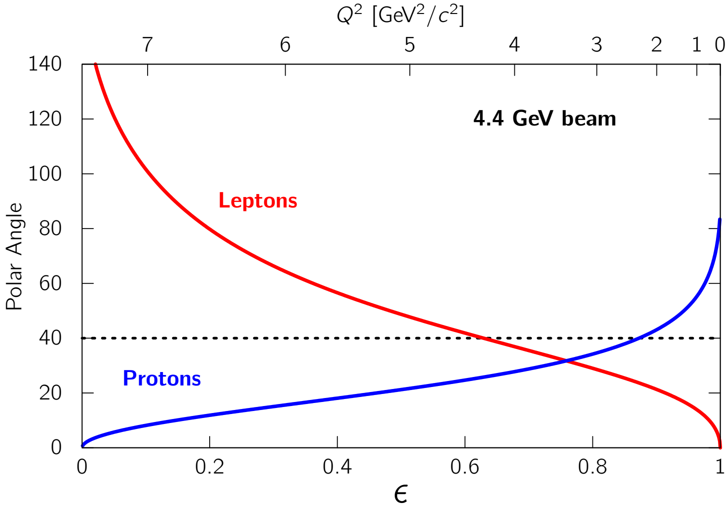
Kinematics: Lepton Angle vs. Proton Angle



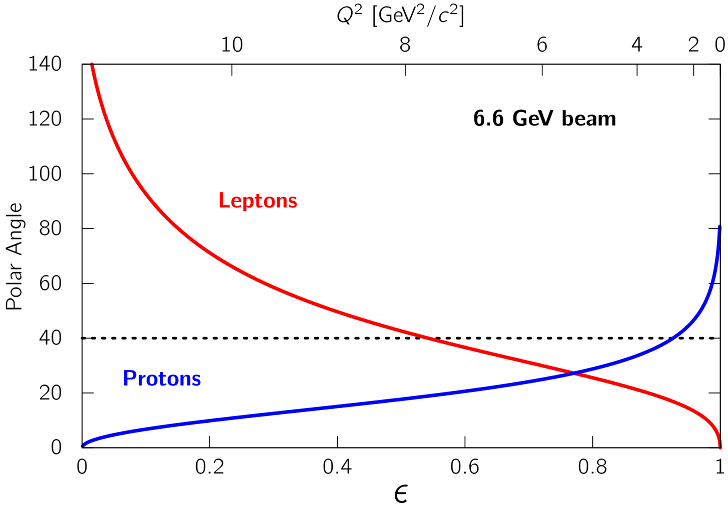
Kinematics: Angles at 2.2 GeV



Kinematics: Angles at 4.4 GeV



Kinematics: Angles at 6.6 GeV



Kinematics: Momenta vs. Angles