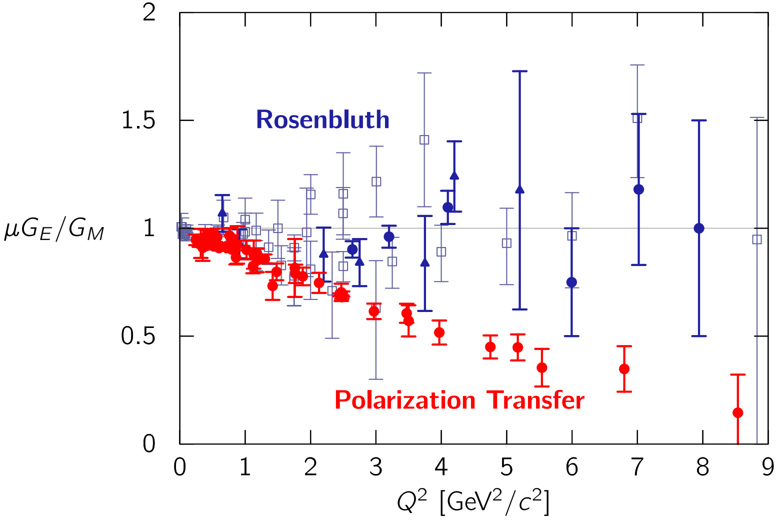
A direct measurement of hard Two-Photon Exchange with positrons at CLAS12

Axel Schmidt

Positron Working Group Meeting

March 7, 2022

Measurements of the proton's form factors are discrepant.



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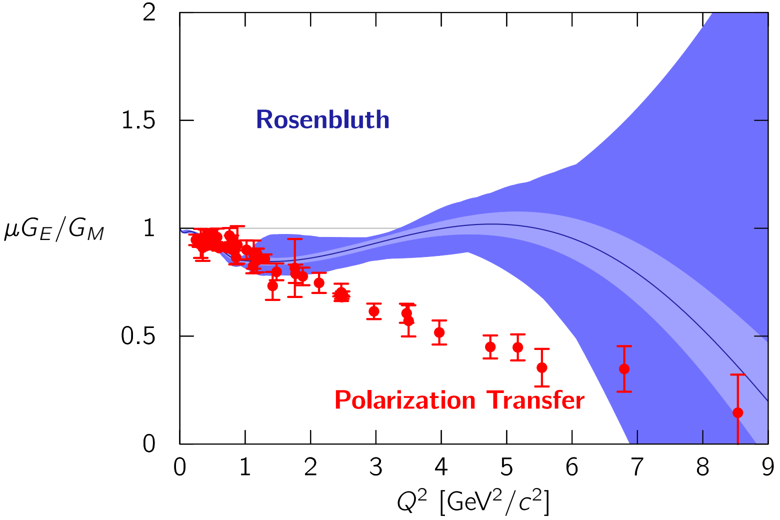
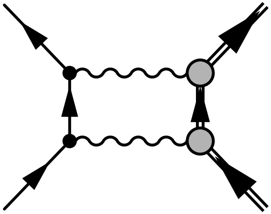


The current status of two-photon exchange is uncomfortable.



- Difficulties in calculations
- Recent experiments inconclusive
- Positron facilities world-wide are turning off

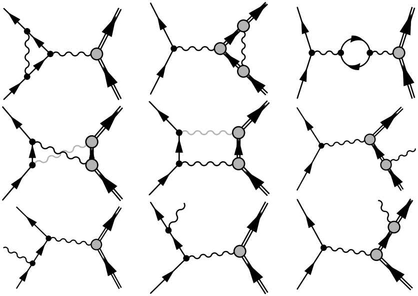
- *Field is embarking on 3d imaging campaign of the nucleon.*

Goal of producing a PAC proposal to measure two-photon exchange at CLAS12 with positrons

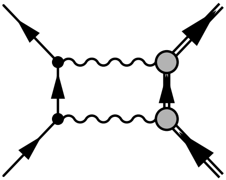
- Spokespeople: J. C. Bernauer, V. D. Burkert, E. Cline, **A. Schmidt**, N. Santiesteban, T. Kutz
- Based on PWG White paper article:
  "Determination of two-photon exchange via e^+p/e^-p scattering with CLAS12"
  J. C. Bernauer et al., EPJA 57:144 (2021)
- Experimental details:
  - e^+, e^- beams at 2.2., 3.3, 4.4, 6.6 GeV, unpolarized, $\approx$ 60 nA
  - Unpolarized H_2 target
  - $\approx$ 55 PAC days

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

The standard set



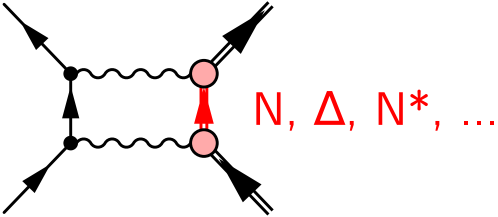
Hard two-photon exchange



Calculations of two-photon exchange come with model dependency.

Hadronic Approaches

- Treat off-shell propagator as collection of hadronic states.
- e.g. Ahmed, Blunden, Melnitchouk, PRC 102, 045205 (2020)



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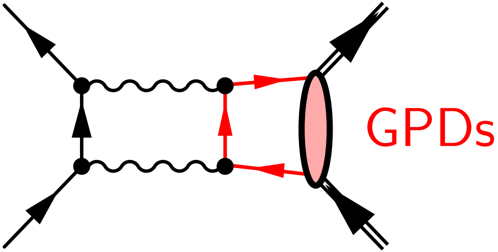
- Treat interaction of $\gamma\gamma$ with quarks, distributed by GPDs.
- e.g. A. Afanasev et al., PRD 72, 013008 (2005)



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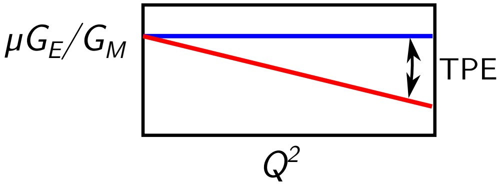
- Assume the discrepancy is caused by TPE, estimate the effect.
- e.g. A. Schmidt, JPG 47, 055109 (2020)



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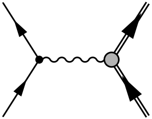
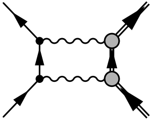
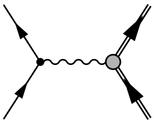
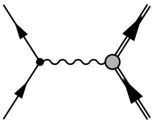
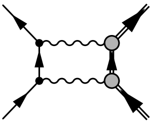
Alternate Approaches

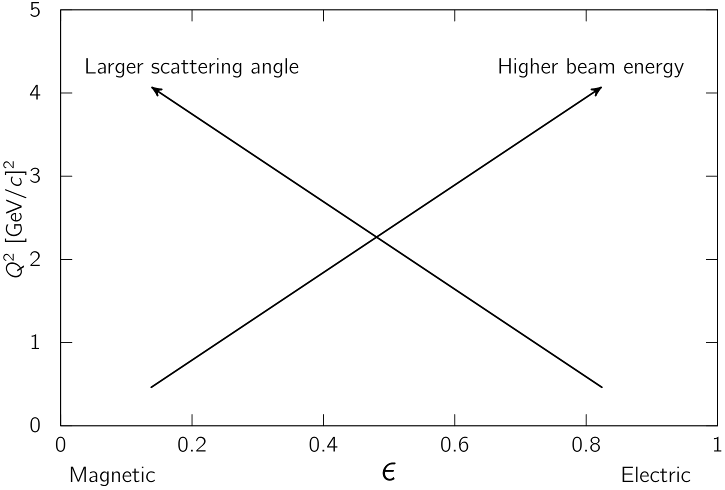
- e.g., E. A. Kuraev et al., Phys. Rev. C 78, 015205 (2008)

TPE produces an asymmetry between electron and positron scattering.

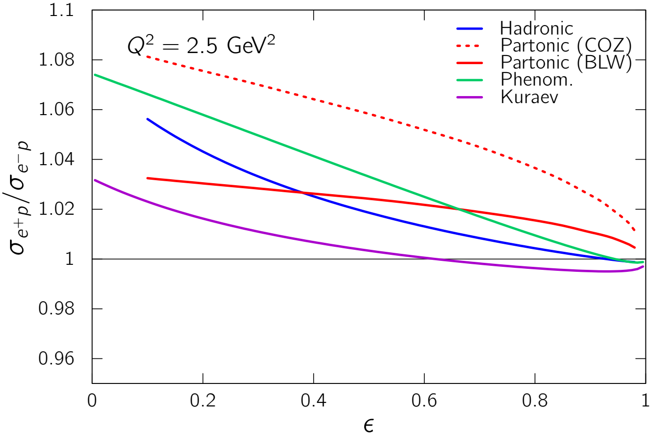
$\mathcal{M} =$  $+$  $+\,\mathcal{O}(\alpha^3)$

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

Elastic scattering is a 2D space



Theory predictions for $\sigma_{e^+p}/\sigma_{e^-p}$ are not in agreement.



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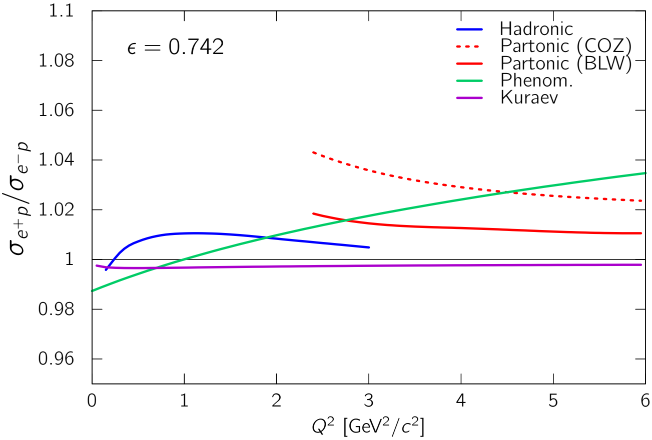


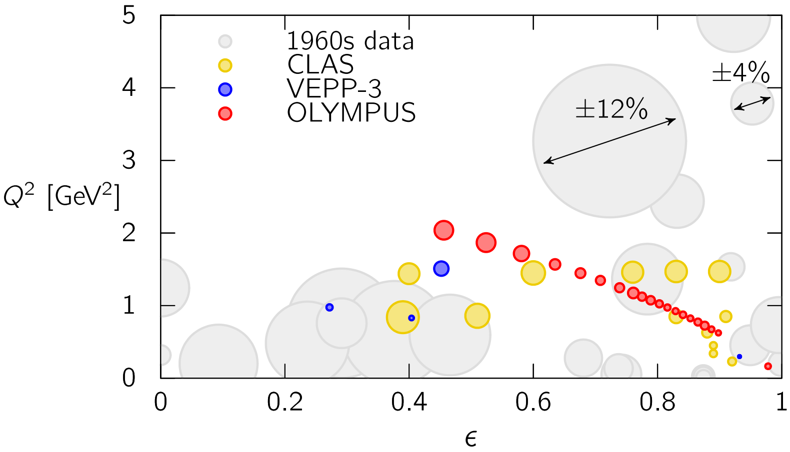
The polarization transfer results are not necessarily correct.

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

$$\frac{P_t}{P_l} = \sqrt{\frac{2\epsilon}{\tau(1+\epsilon)}}\frac{G_E}{G_M} \times [1 + \dots$$
$$+\mathrm{Re}\left(\frac{\delta\tilde{G_M}}{G_M}\right) + \frac{1}{G_E}\mathrm{Re}\left(\delta\tilde{G_E} + \frac{\nu}{m^2}\tilde{F}_3\right) - \frac{2}{G_M}\mathrm{Re}\left(\delta\tilde{G_M} + \frac{\epsilon\nu}{(1+\epsilon)m^2}\tilde{F}_3\right)$$
$$+ \mathcal{O}(\alpha^4) + \dots]$$

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

Three recent experiments measured hard TPE.



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OLYMPUS

CLAS **VEPP-3**

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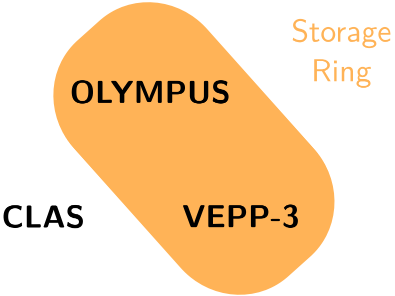

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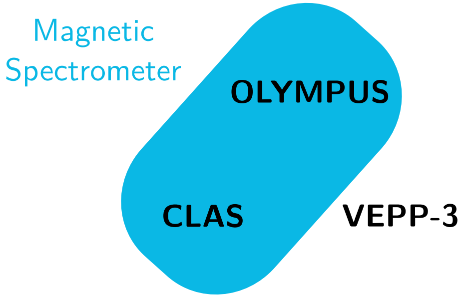
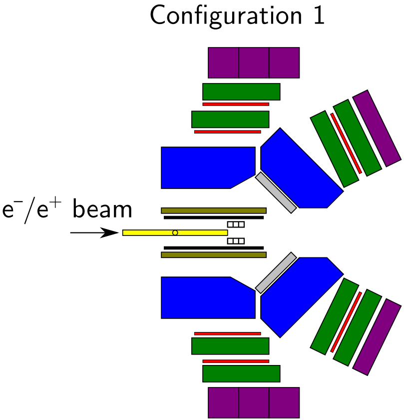
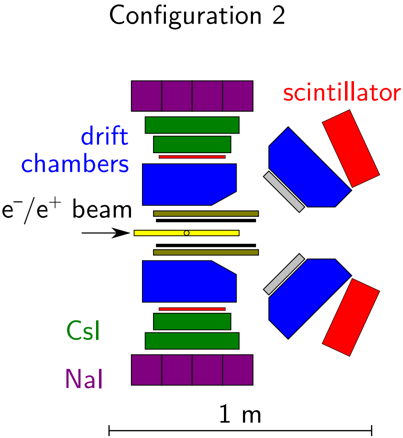
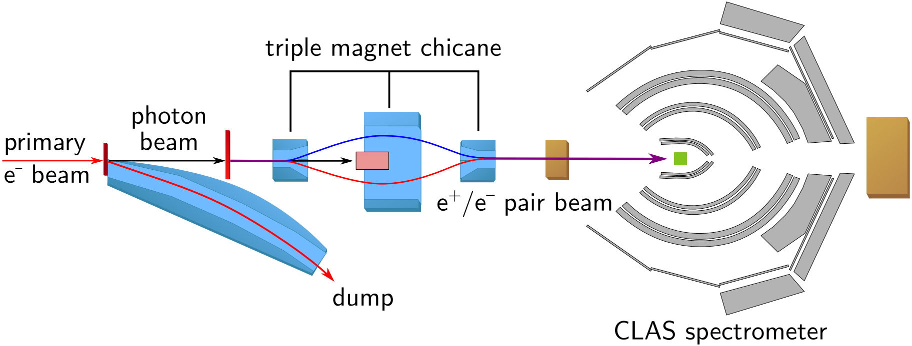


VEPP-3, Novosibirsk, Russia

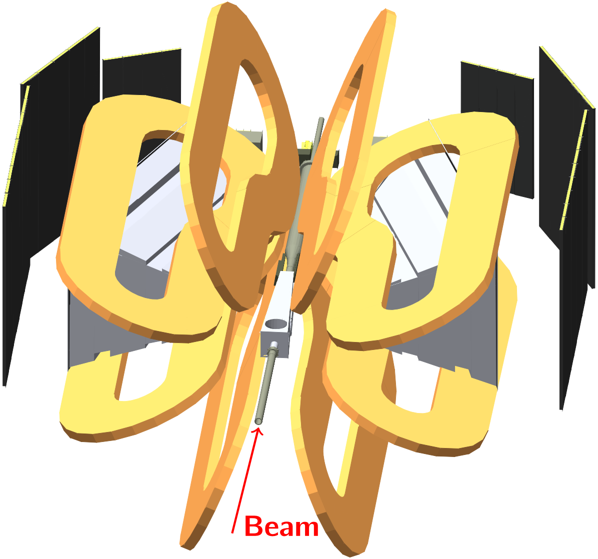




CLAS, Jefferson Lab, USA



OLYMPUS, DESY, Germany



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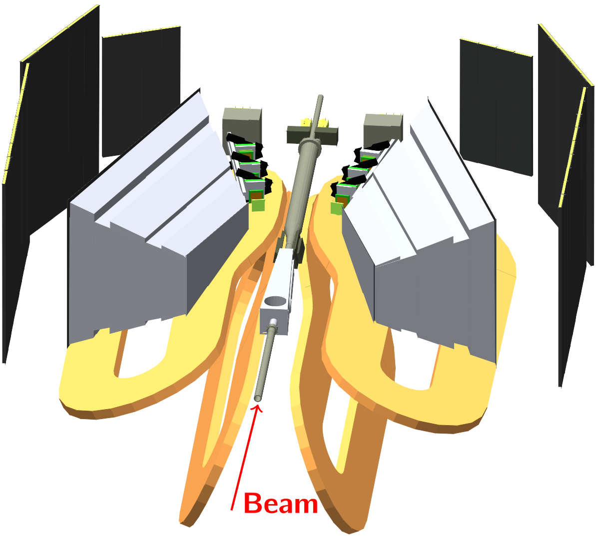

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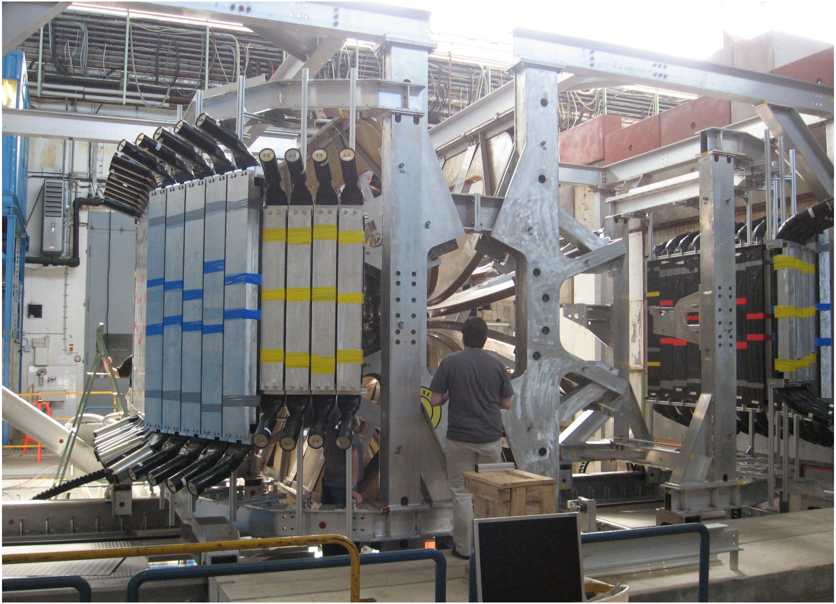
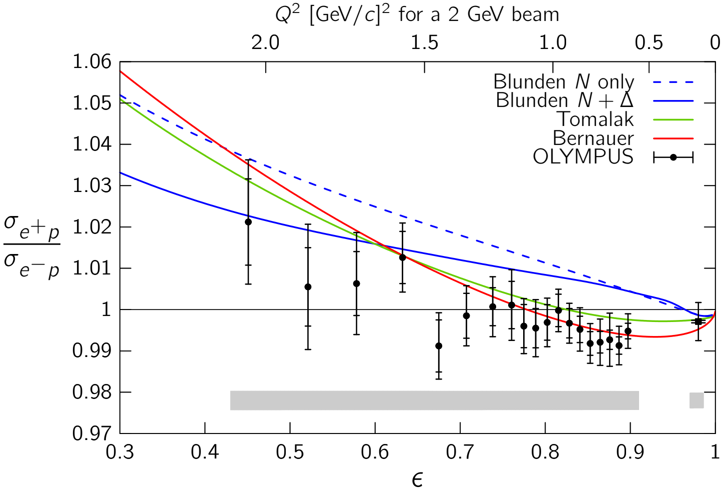
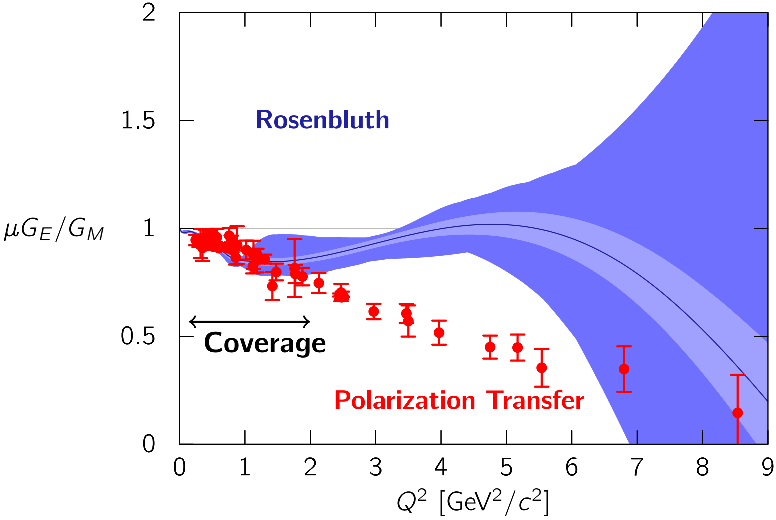


OLYMPUS observed a small TPE effect.



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

Recent measurements lacked the kinematic reach to be decisive.



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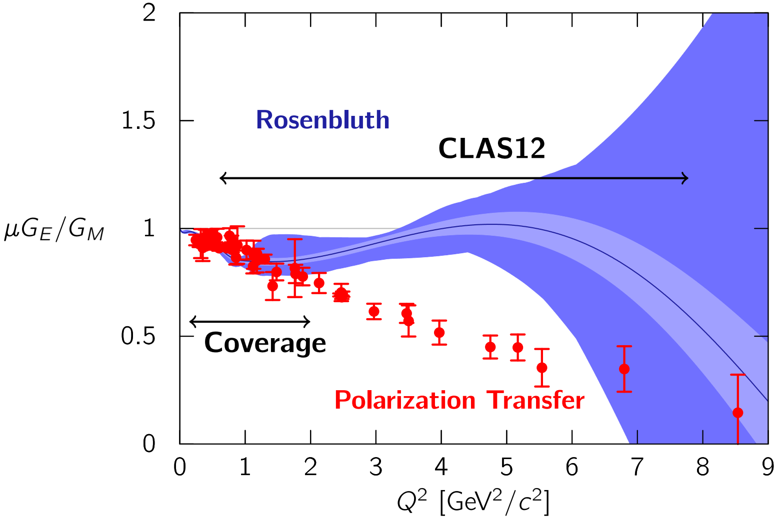


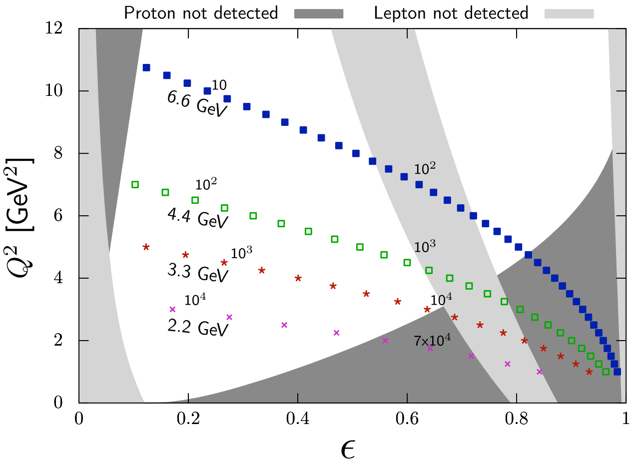
CLAS12 TPE experiment, as drawn up in the white paper

- 100 nA (unpolarized) e^+ beam
  - 2.2, 3.3, 4.4, 6.6 GeV
- 10^{35} cm^{-2} s^{-1} luminosity
  - Standard CLAS liquid H_2 target
- 55 PAC days
  - Collect data with both e^- and e^+ to reduce systematics.
- Coincident detection of $e^\pm$ and p
  - Over-constrainted kinematics
  - Need to modify trigger

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	10 GeV

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



J. C. Bernauer et al., Eur.Phys.J.A 57, p. 144 (2021)

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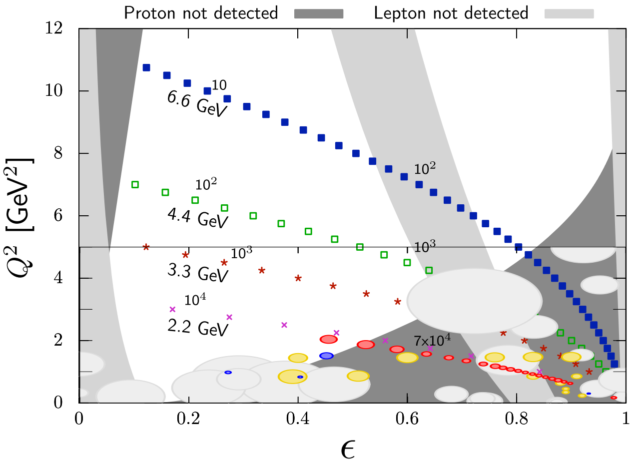

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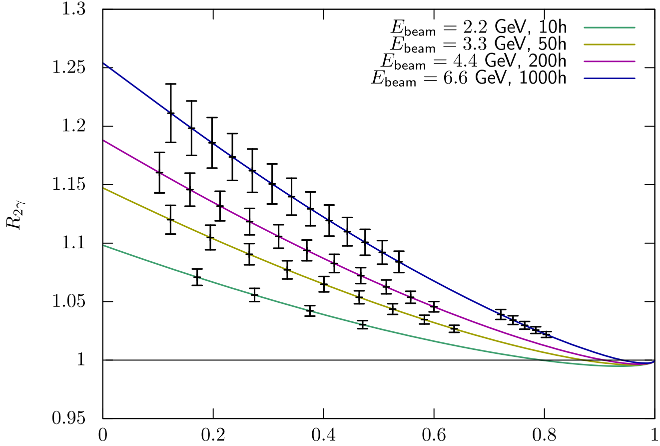
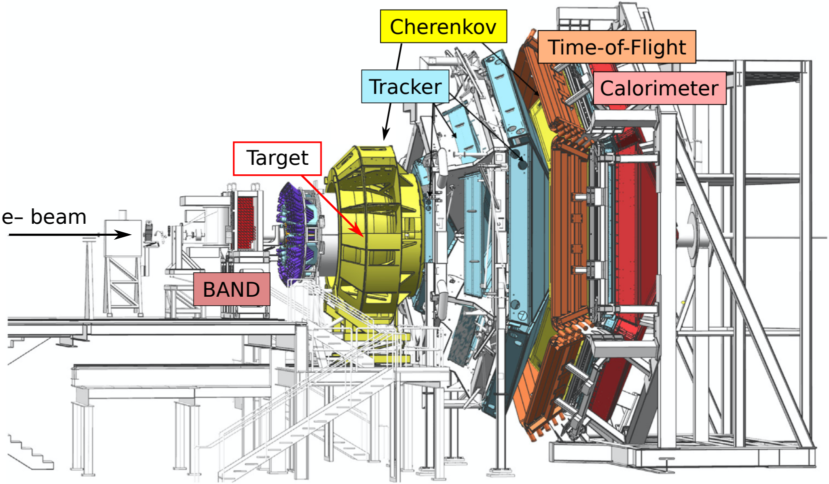


J. C. Bernauer et al., Eur.Phys.J.A 57, p. 144 (2021)

An elastic scattering event in CLAS12



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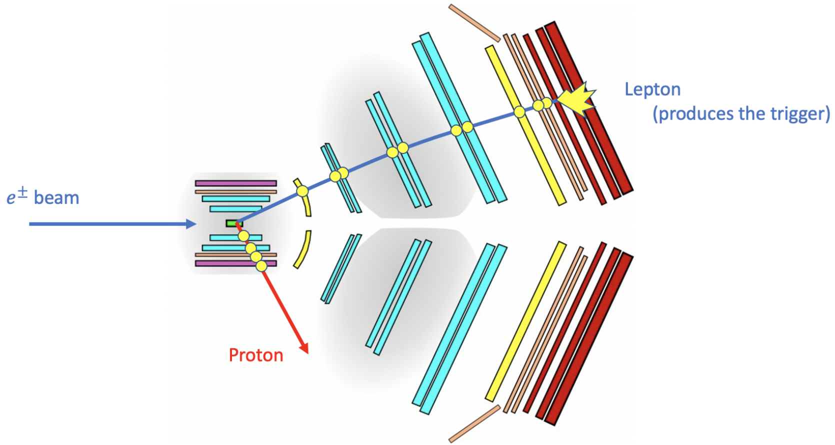
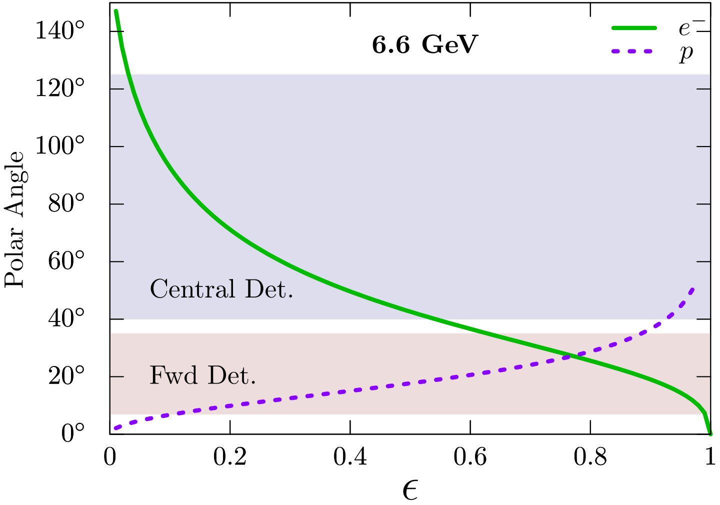


Current CLAS12 equipment lack the means to trigger on a central $e^{\pm}$.



Proposed solution: run with streaming read-out

- Already a long-term goal for CLAS12
  - Streaming test of forward tagger
    F. Ameli et al., EPJ Web of Conferences (2021)
- Key R&D stepping stone to EIC
- Expertise within our collaboration

Work underway

- Analyzing CLAS12 data on tape
  - Run Group M, 6 GeV on H_2
  - Study backgrounds, rates, resolutions

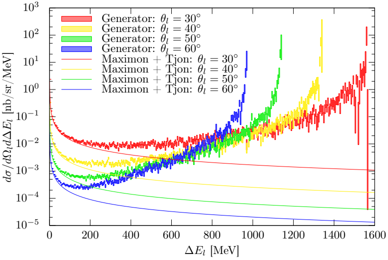
- Simulations
  - How do our events look outside of normal “triggered” kinematics?

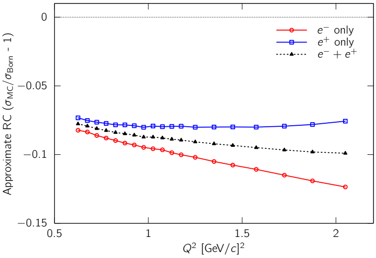
- Developing streaming plan
  - Clock trigger data can tell us about expected data rates
  - What resources will be needed to reduce data to manageable rate?

Limiting Systematics

- Over-all Scale: Relative e^+/e^- luminosity
  - Typical absolute accuracy of 2–5% in Hall B
  - Relative luminosity should be better, $\approx 1\%$
  - Compare to OLYMPUS, high-ϵ data as a cross check
- Point-to-Point: Local efficiency
  - Magnetic fields bend e^+, e^- to different parts of the detector for equivalent Q^2, ϵ.
  - Need heavy-duty Monte Carlo
    - OLYMPUS had efficiency, gain, resolution mapped for individual drift chamber wires
  - Fast-switching of $e^+ \leftrightarrow e^-$ can reduce time-dependent effects.

Radiative corrections will be critical.

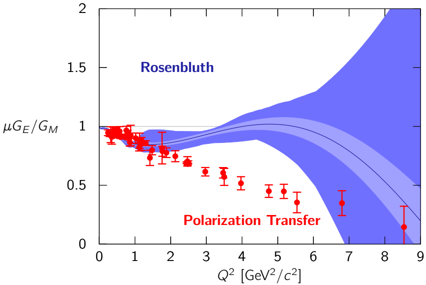




- OLYMPUS tested several RC prescriptions, built custom radiative event generator.
- Significant charge-odd corrections that are not hard TPE
- See recent (2022) ECT Workshop, as well as 2020 CFNS Workshop White Paper.

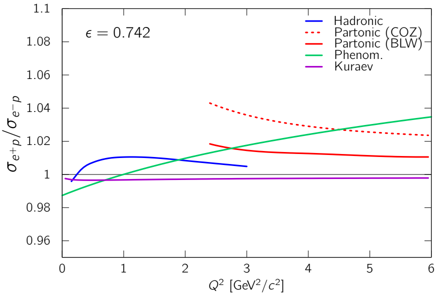
Recap:

- TPE is still a problem.



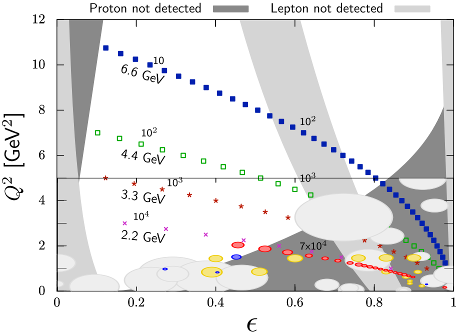
Recap:

- TPE is still a problem.
- Key region is $3 < Q^2 < 5$



Recap:

- TPE is still a problem.
- Key region is $3 < Q^2 < 5$
- CLAS12 e^+ proposal in preparation



After this proposal

- White paper proposed several alternative TPE observables.
  - How do rank priorities?
  - Polarization transfer, TPE on nuclei, **Beam-normal SSAs**

Single-spin asymmetries with positrons

Eur. Phys. J. A (2021) 57:213
https://doi.org/10.1140/epja/s10050-021-00531-7

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Regular Article - Experimental Physics

Target-normal single spin asymmetries measured with positrons

G. N. Grauvogel[1], **T. Kutz**[1,2], **A. Schmidt**[1,a]

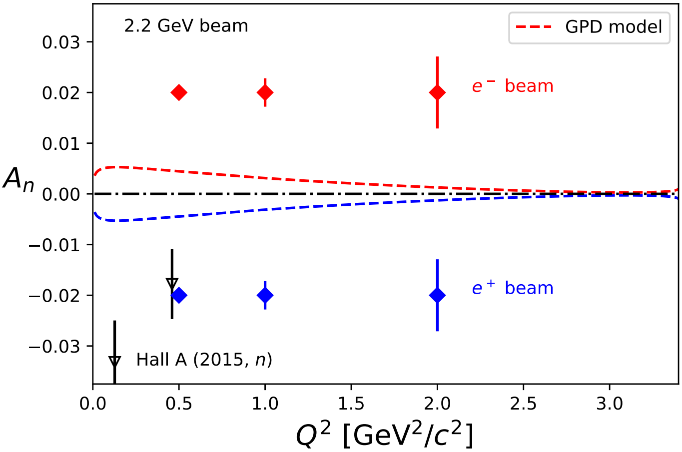
[1] George Washington University, Washington, DC 20052, USA
[2] Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Eur.Phys.J.A 57, p. 213 (2021)

- Sensitive to imaginary part of TPE amplitude
- Separate TPE from T-violation
- First measurement on protons at JLab

Gabe Grauvogel

A measurement at JLab would cover new ground.



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- Consider a CLAS12 positron run group
  - Obvious reactions: SIDIS, DVCS, π electroproduction
  - Need to consider within streaming plan
  - Polarized e^+ can't hurt

Back Up

Proposed solution: replace CLAS CND with new "Central Electron Calorimeter"

- Design based on previous CLAS12 CEC concept
  - Some proof-of-concept work done by group in Paris-Saclay
- Tungsten powder calorimeter
- Light collected by fiber, sent to SiPMs