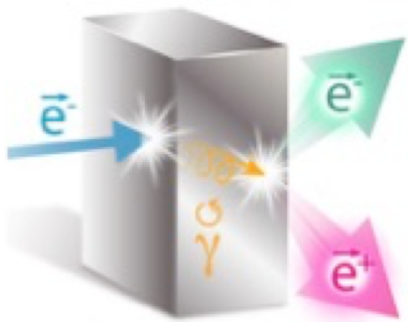
A direct measurement of hard Two-Photon Exchange with positrons at CLAS12

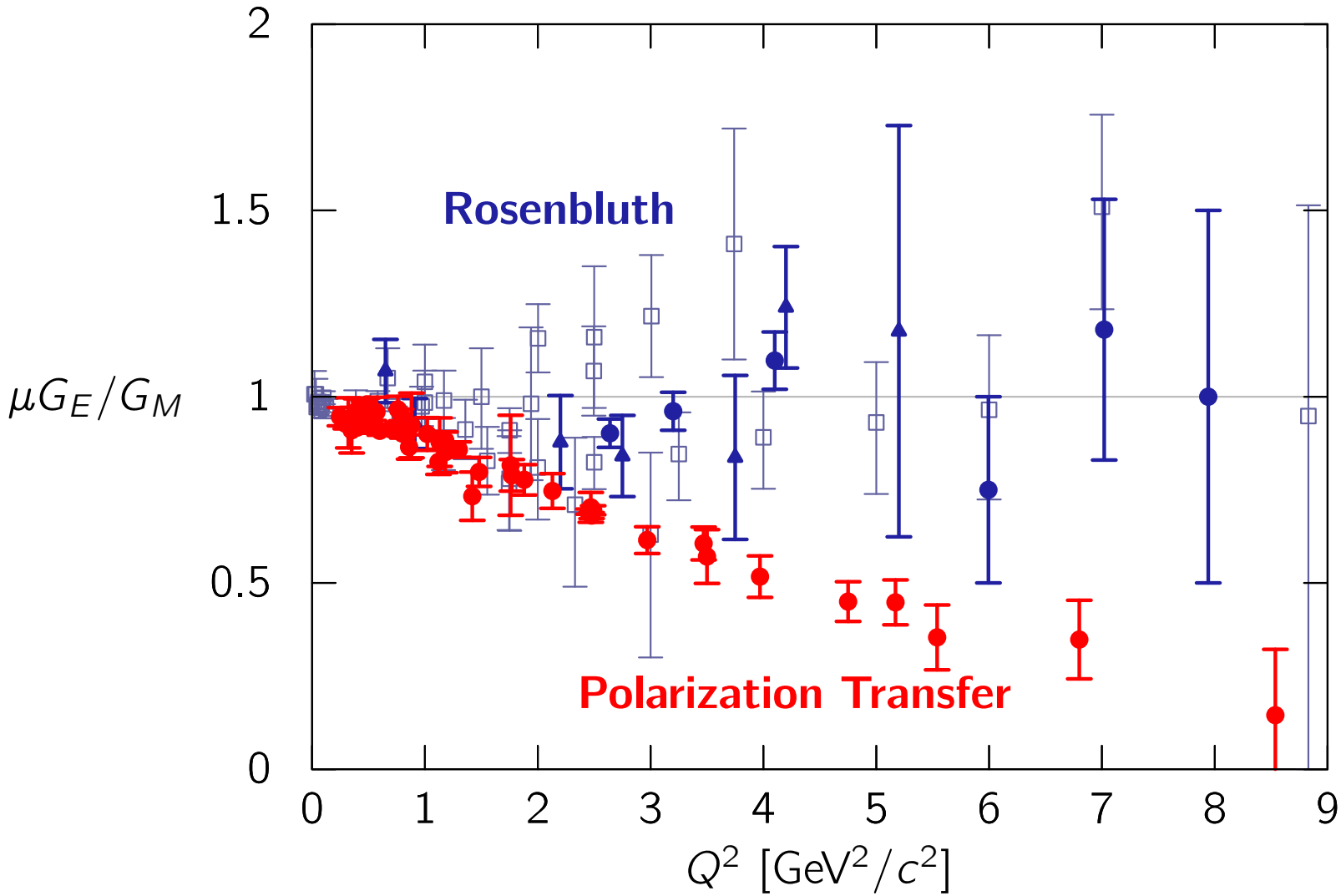
Axel Schmidt

International Workshop on CLAS12 Physics and Future Perspectives at JLab

March 21, 2022



Measurements of the proton's form factors are discrepant.



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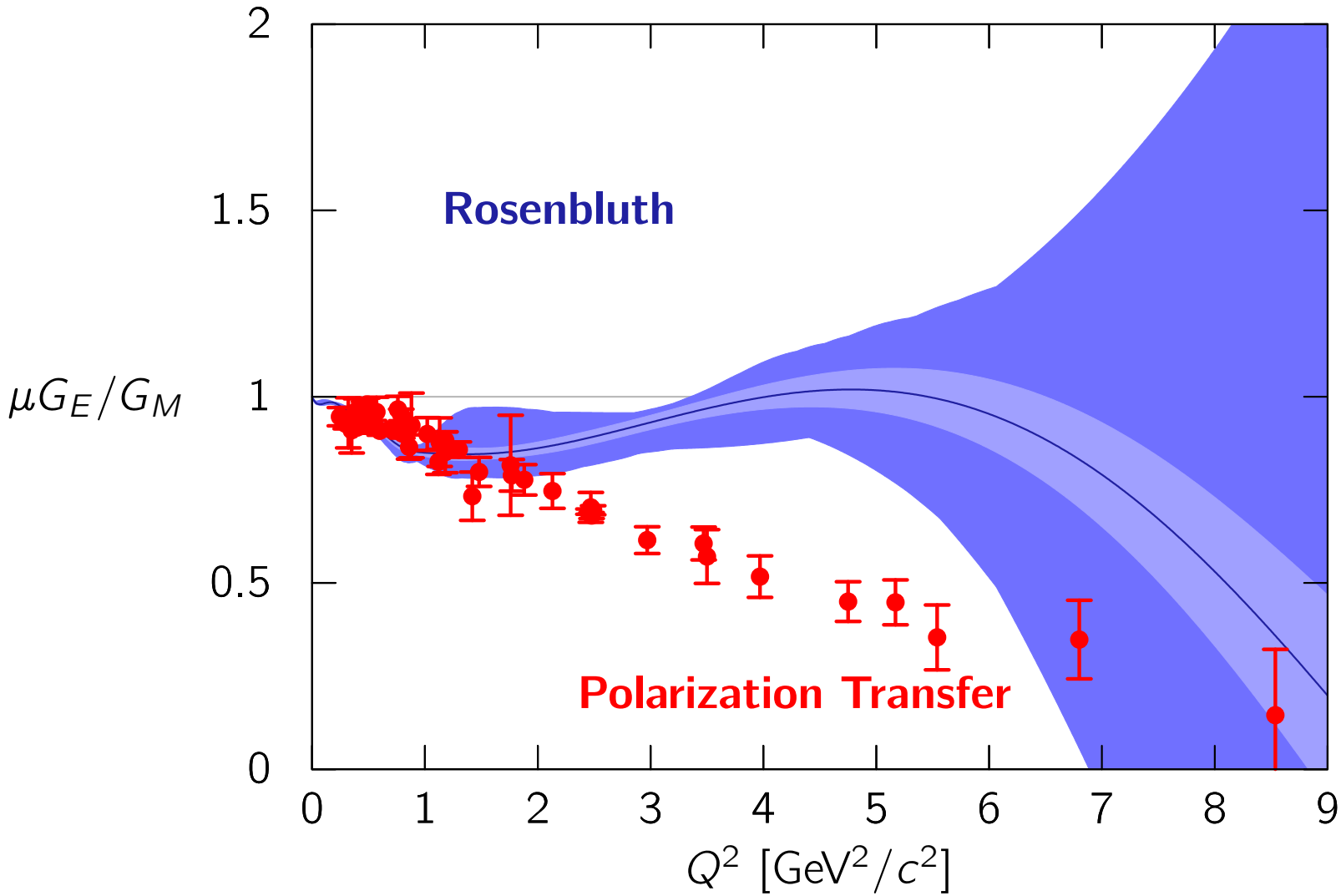
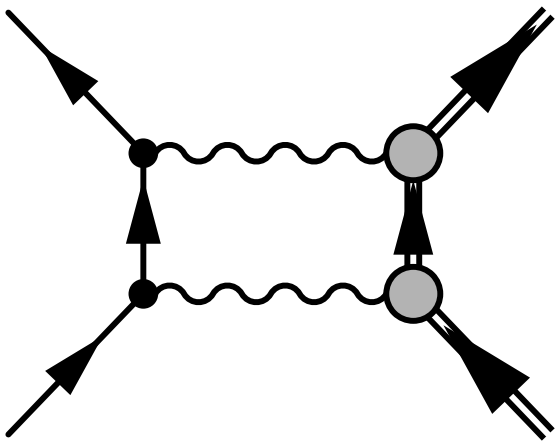


The current status of two-photon exchange is uncomfortable.



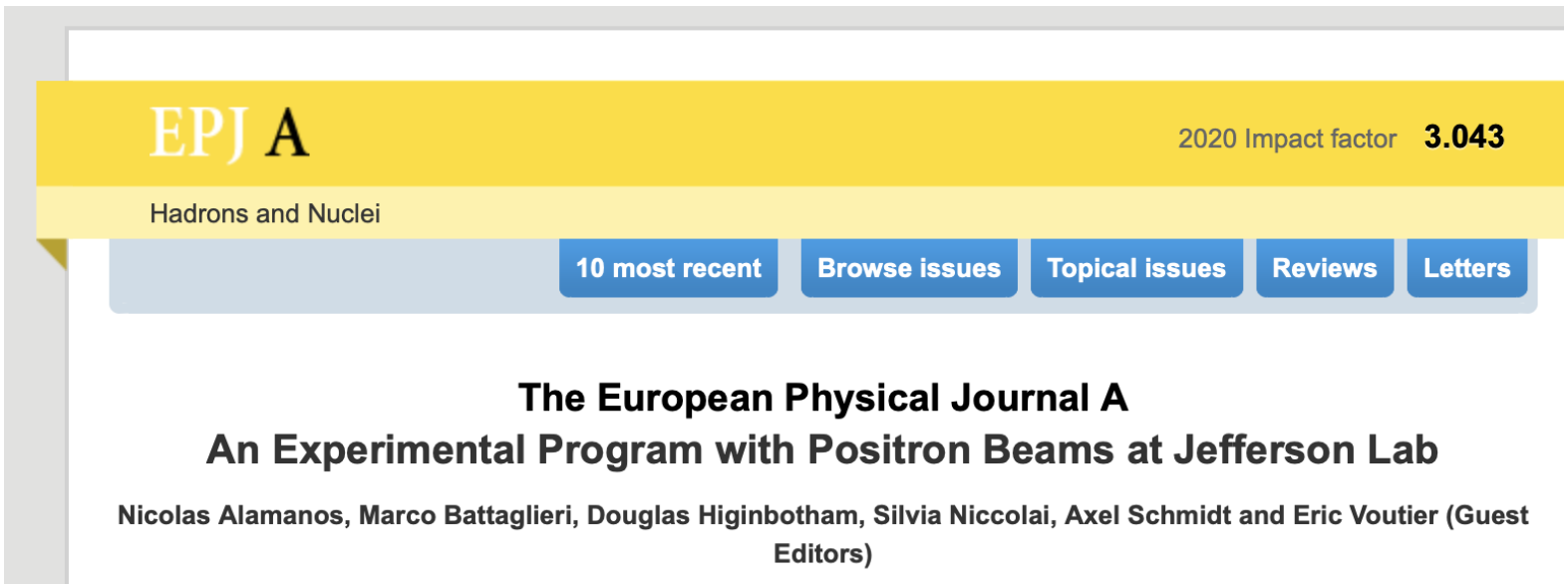
- Difficulties in calculations
- Recent experiments inconclusive
- Positron facilities world-wide are turning off
- *Field is embarking on 3d imaging campaign of the nucleon.*

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 Positron Working Group 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, ≈ 60 nA
  - Unpolarized H_2 target
  - Compare σ_{e^+p} and σ_{e^-p} in elastic scattering
  - ≈ 55 PAC days

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



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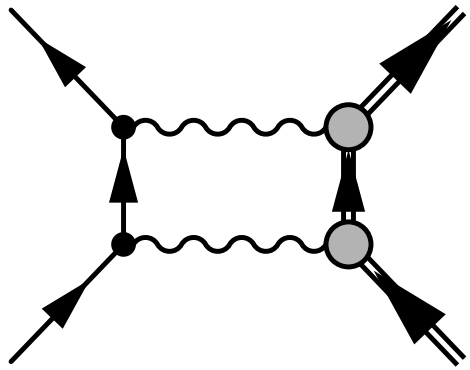
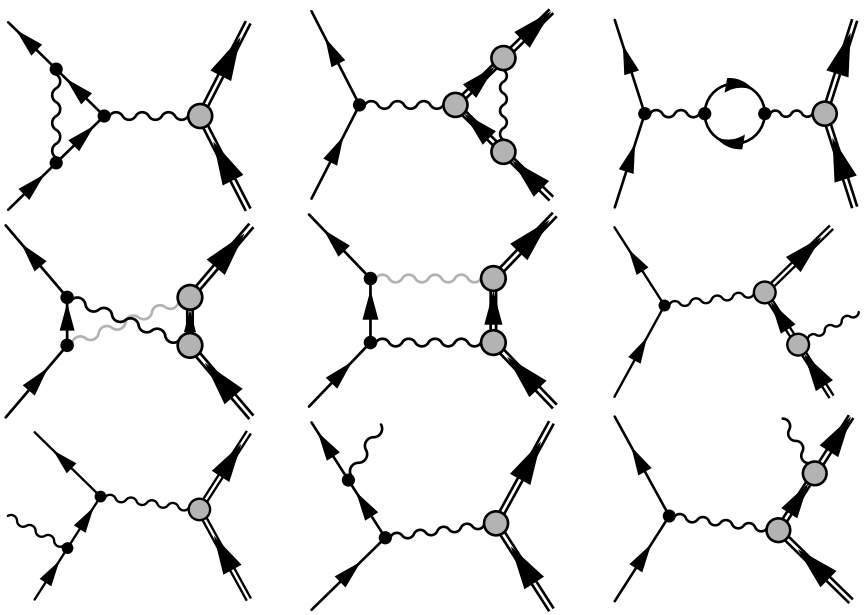
Hard two-photon exchange



The standard set



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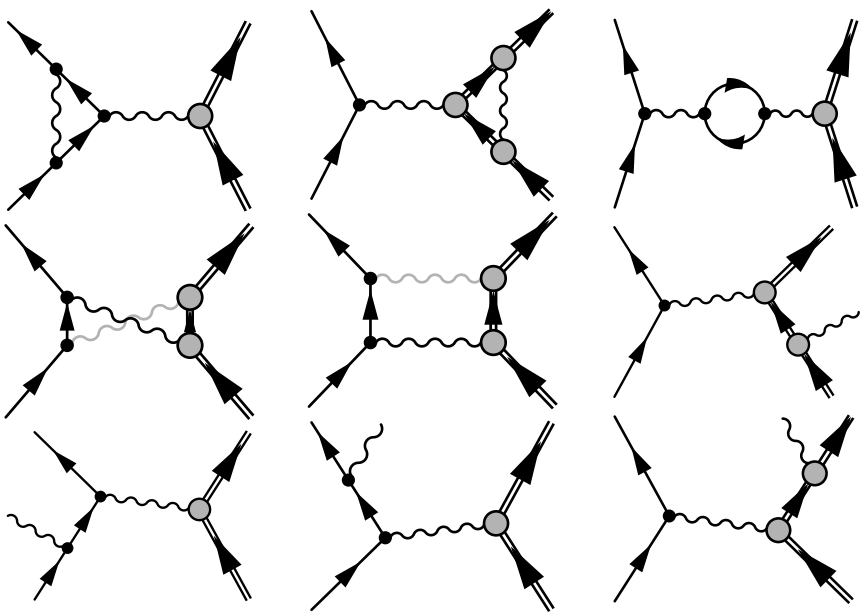

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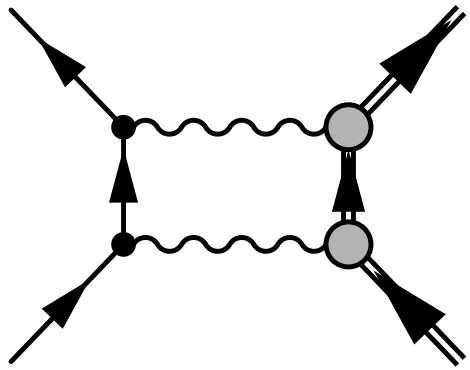
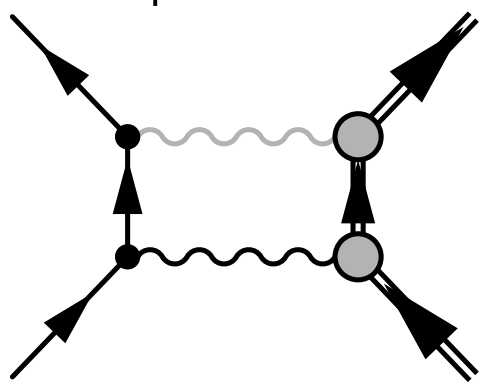


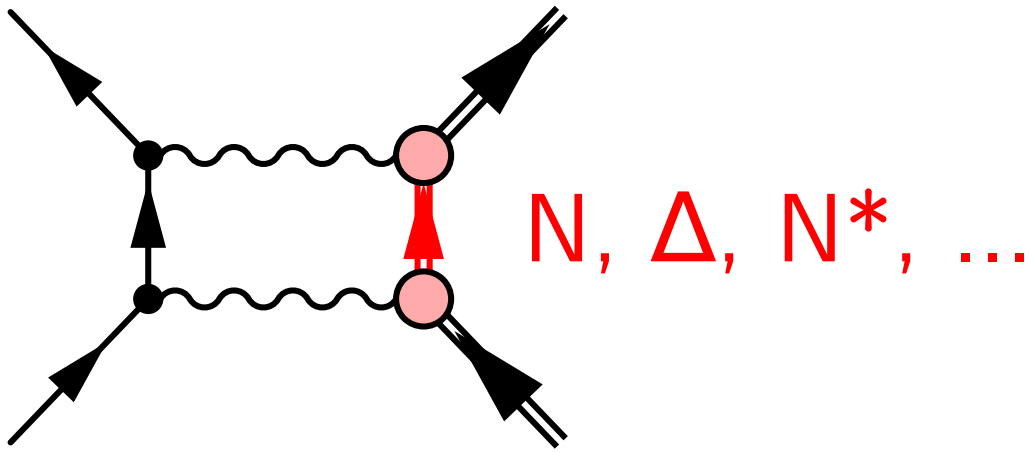
Soft two-photon exchange



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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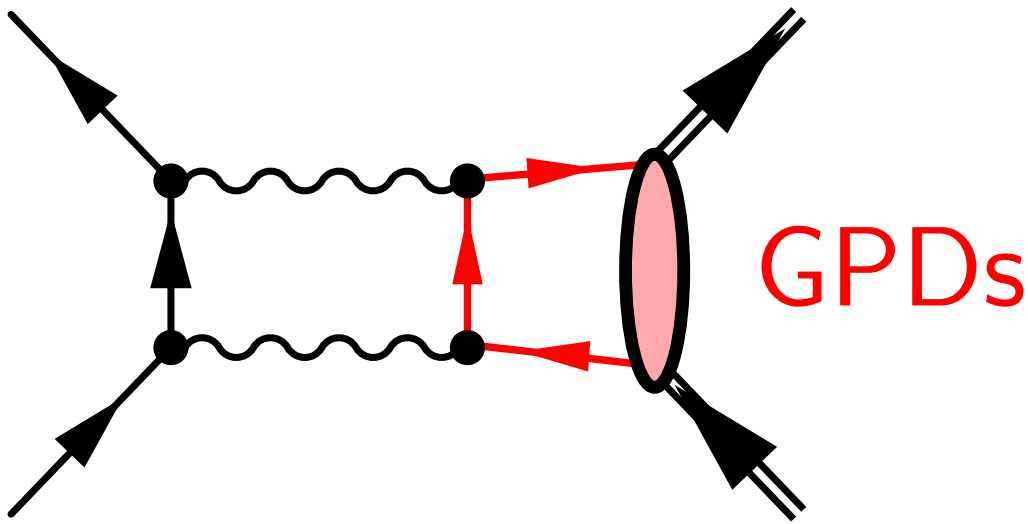

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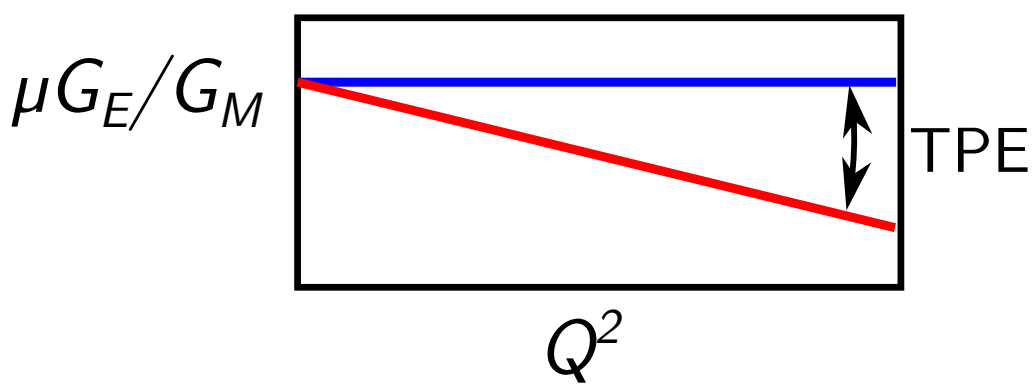
- Assume the discrepancy is caused by TPE, estimate the effect.
- e.g. A. Schmidt, JPG 47, 055109 (2020)



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Alternate Approaches

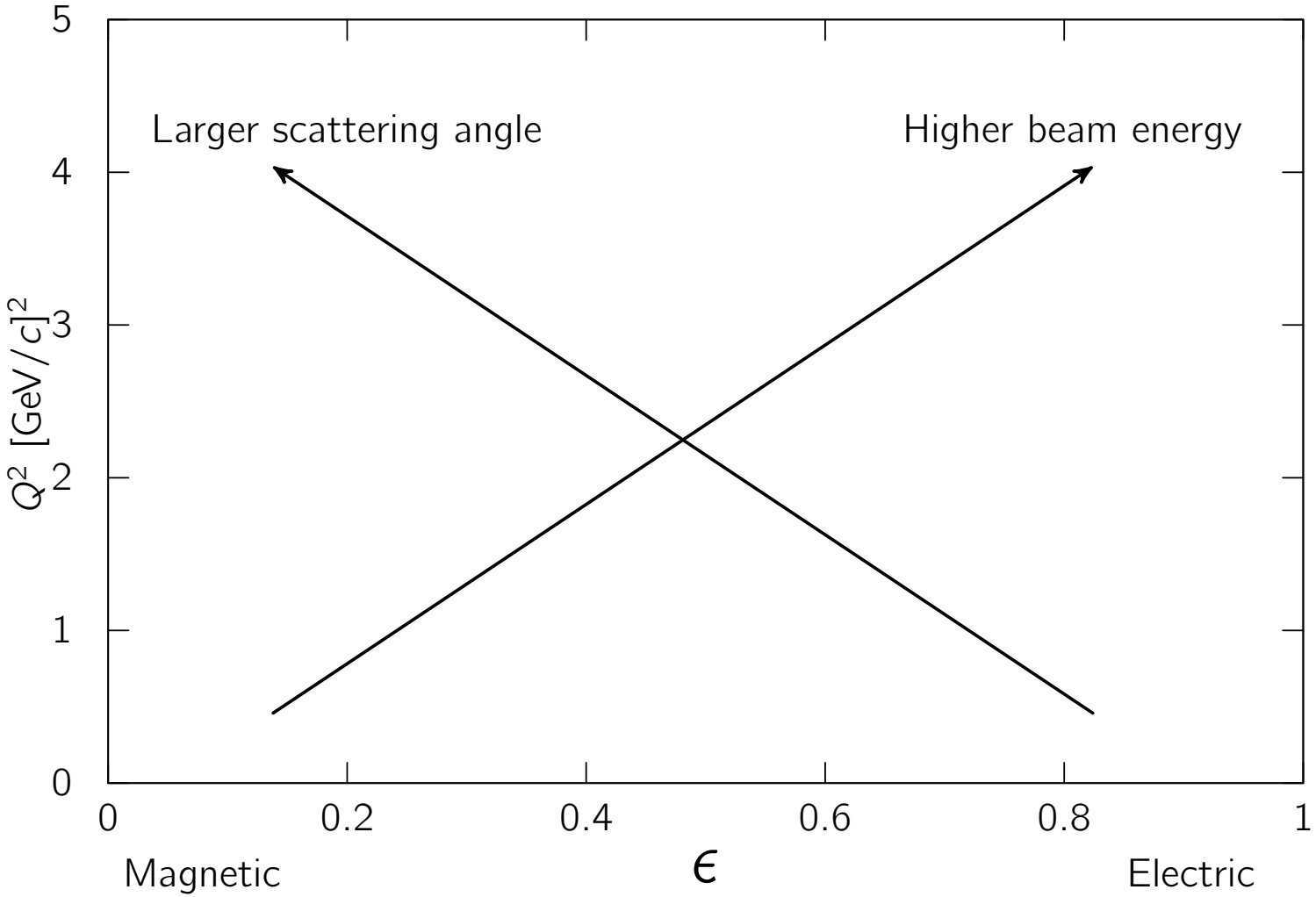
- e.g., E. A. Kuraev et al., Phys. Rev. C 78, 015205 (2008)

TPE produces an asymmetry between electron and positron scattering.

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

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

Elastic scattering is a 2D space



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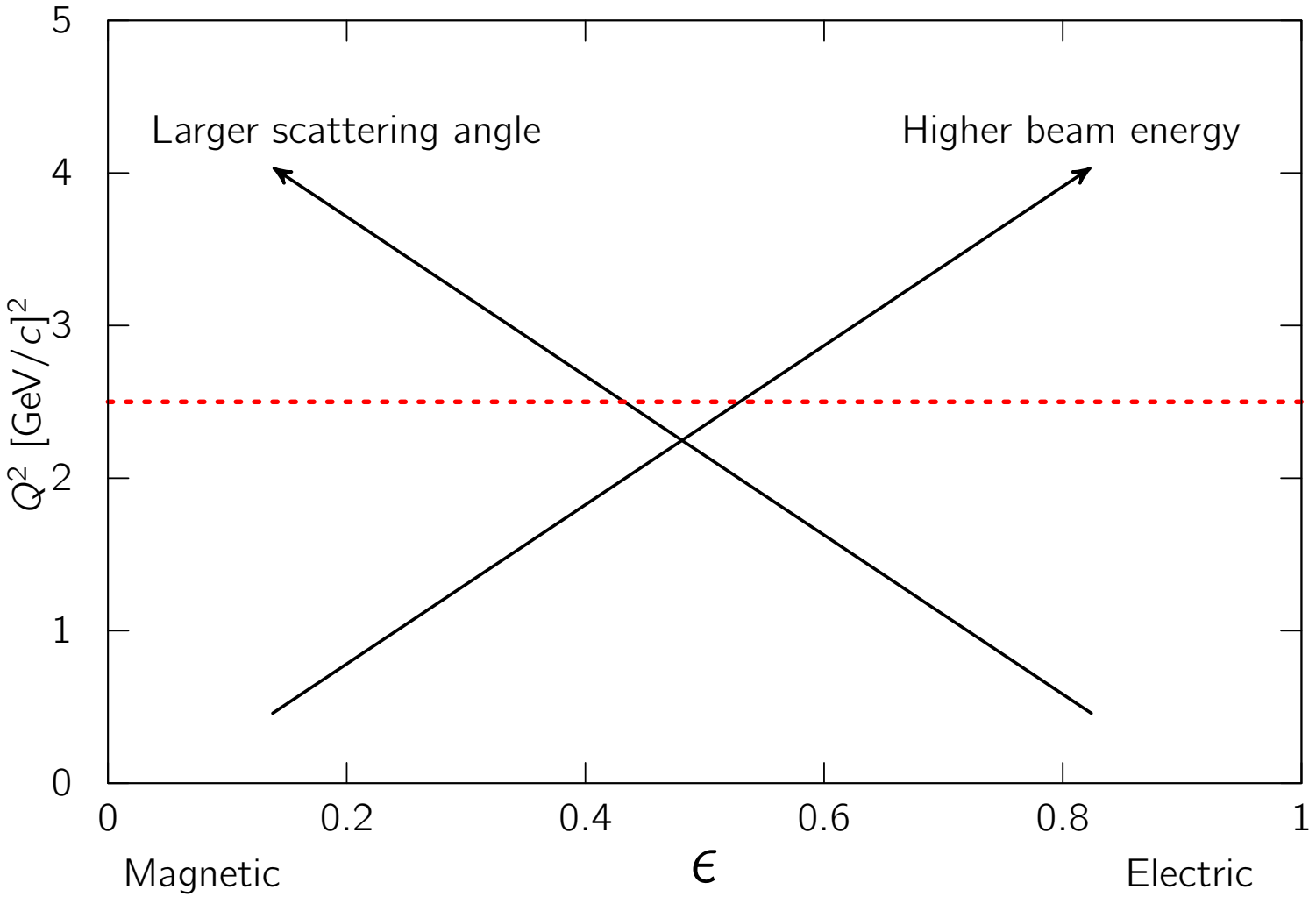
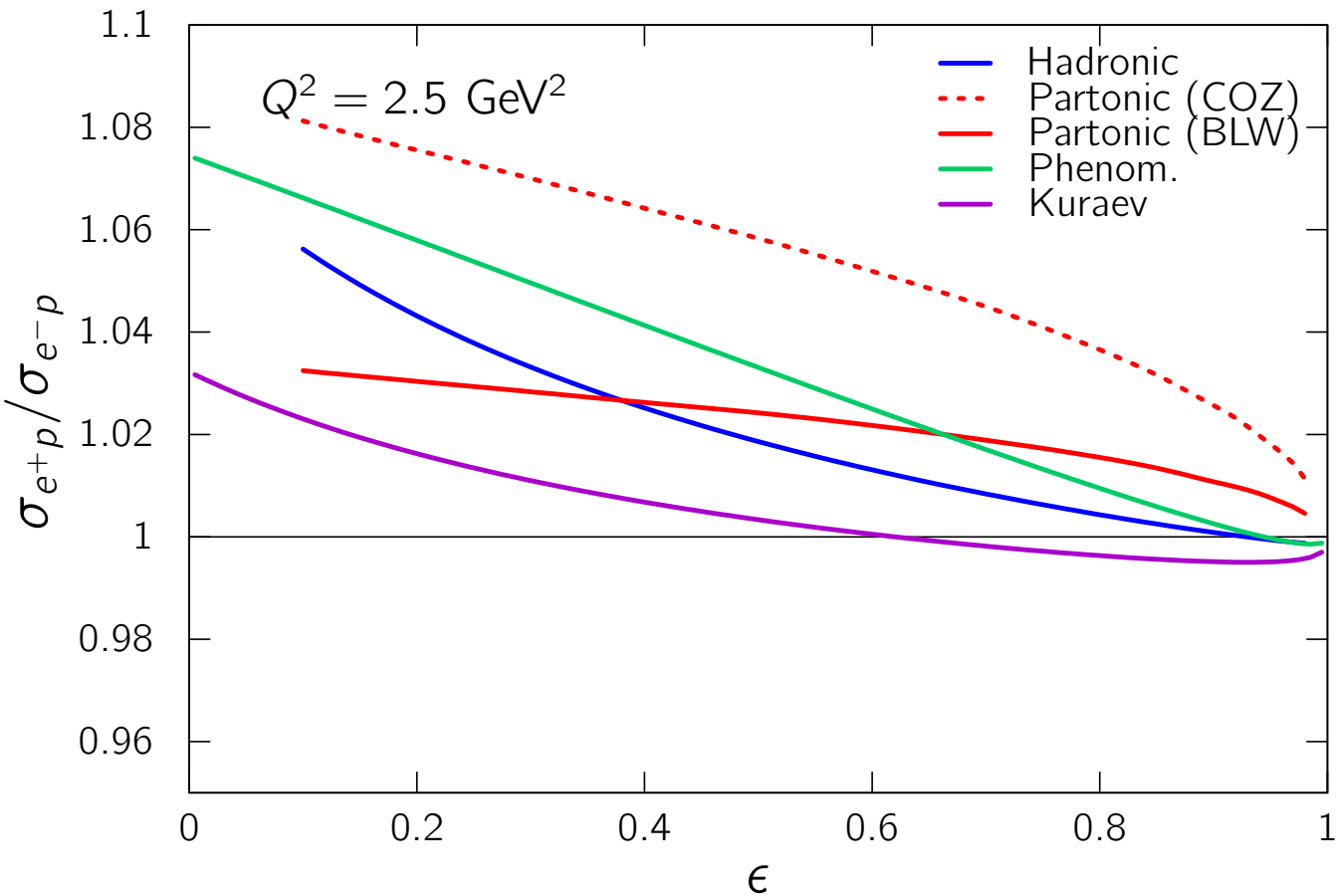


Theory predictions for $\sigma_{e^+p}/\sigma_{e^-p}$ are not in agreement.



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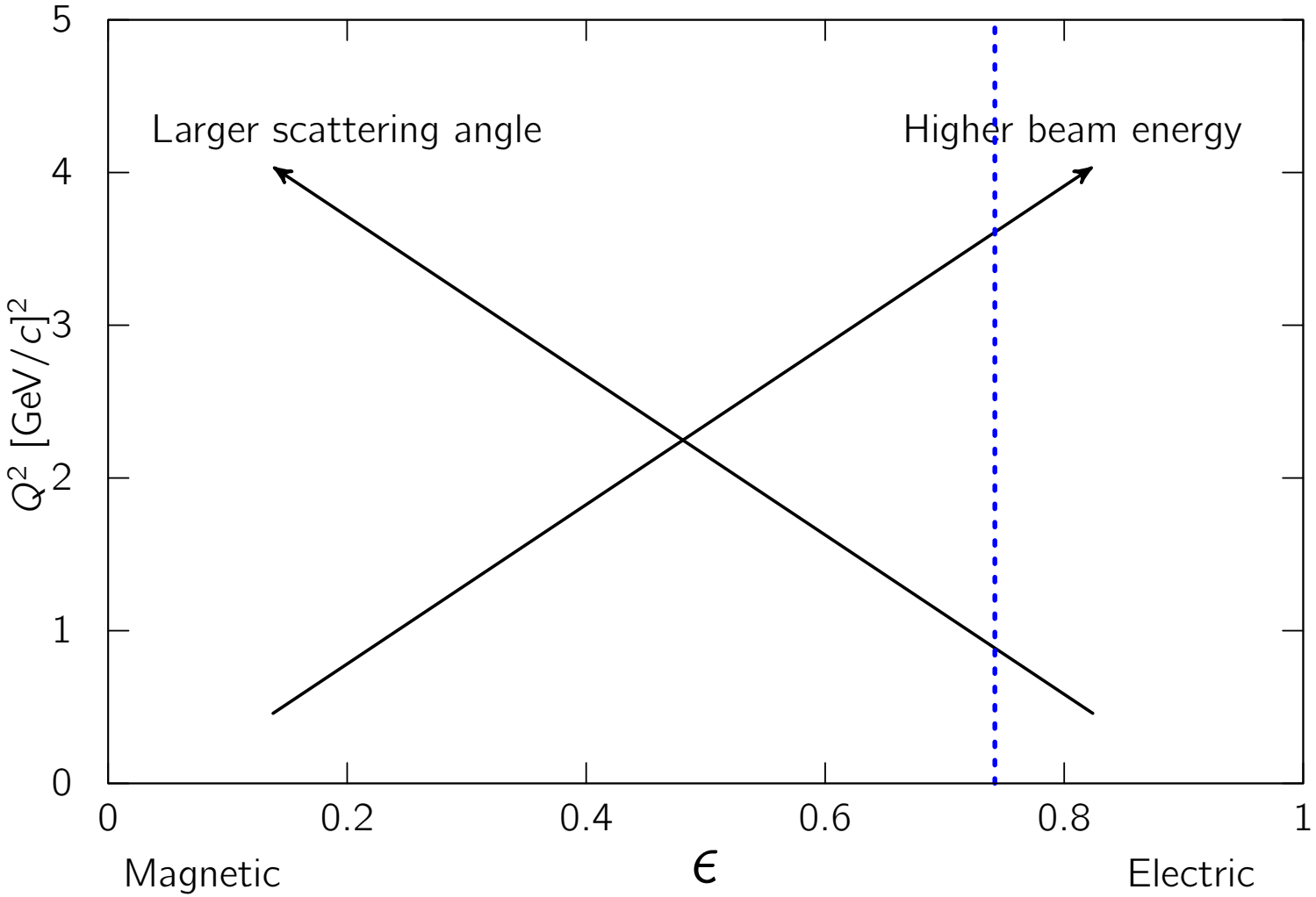

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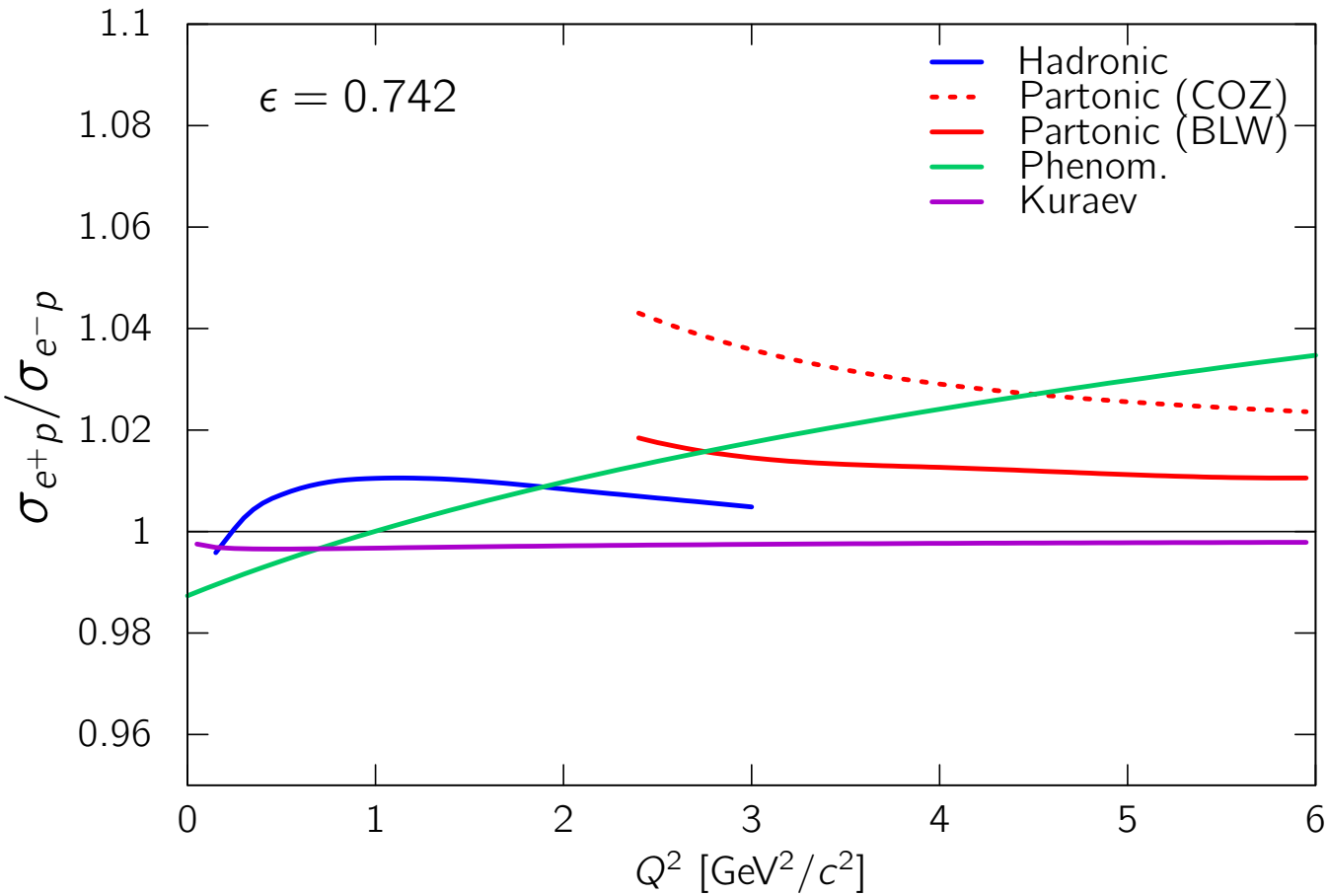


The polarization transfer results are not necessarily correct.

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

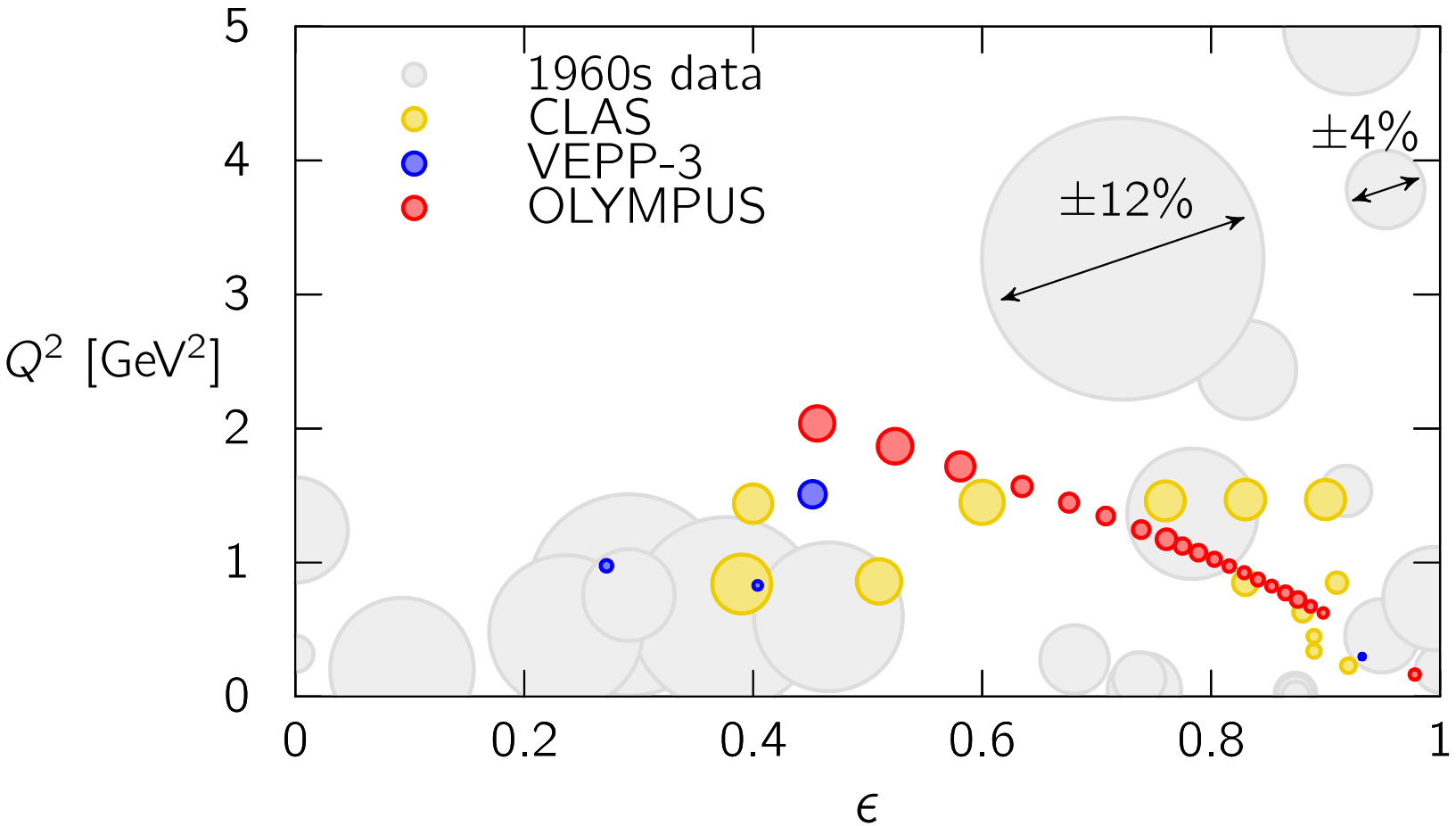
$$\frac{P_t}{P_l} = \sqrt{\frac{2\epsilon}{\tau(1+\epsilon)}}\frac{G_E}{G_M} \times [1 + \ldots$$

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

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

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

Three recent experiments measured hard TPE.



Three new experiments have measured $R_{2\gamma}$.

OLYMPUS

CLAS **VEPP-3**

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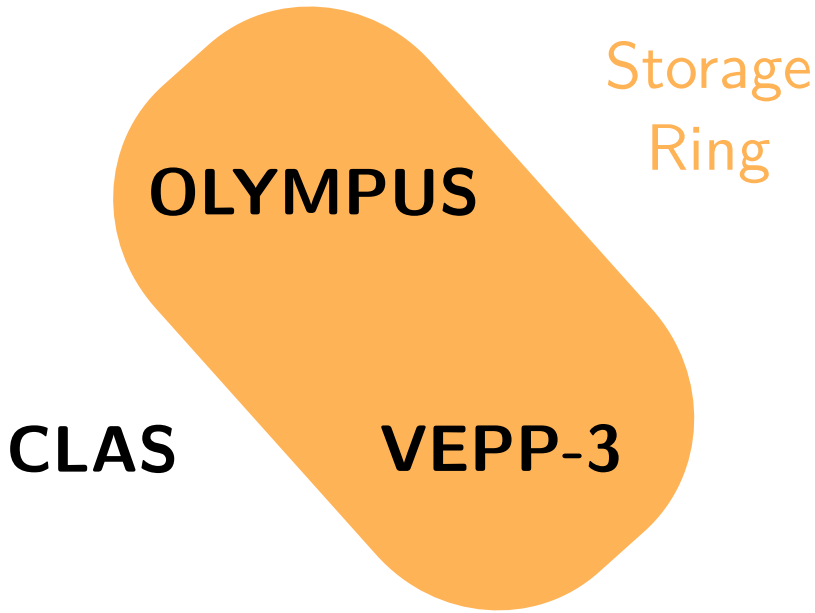

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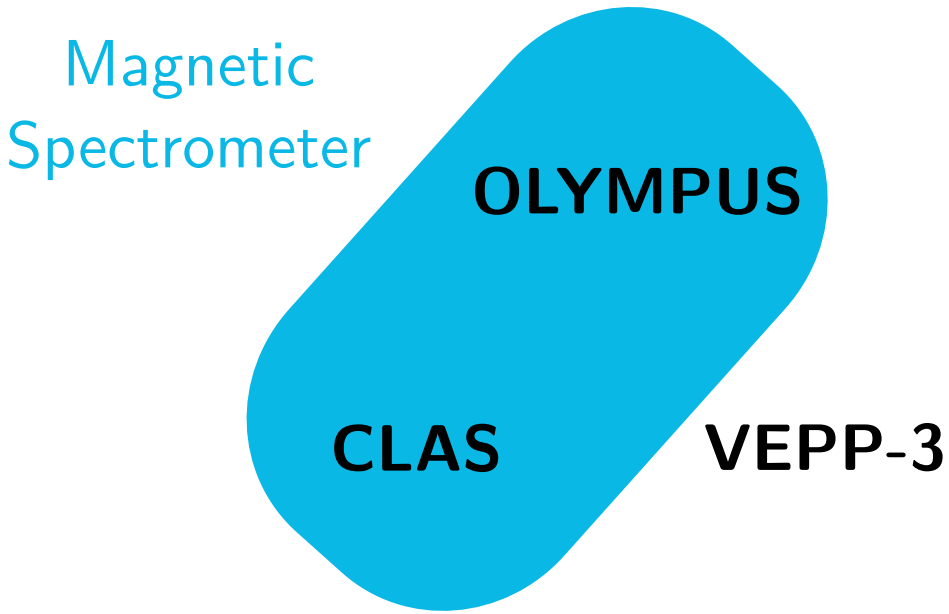
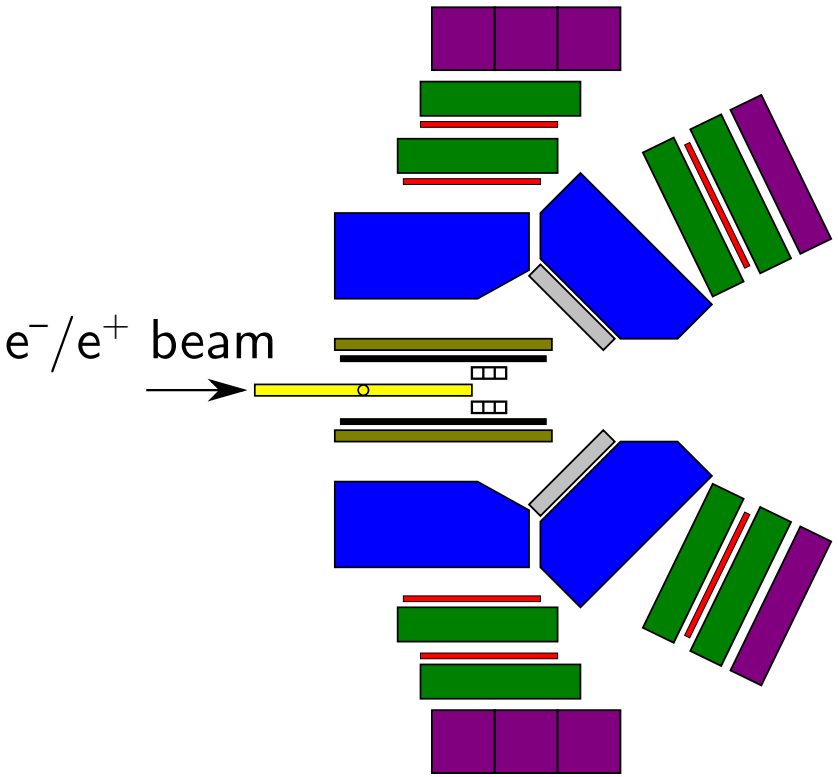


VEPP-3, Novosibirsk, Russia

Configuration 1



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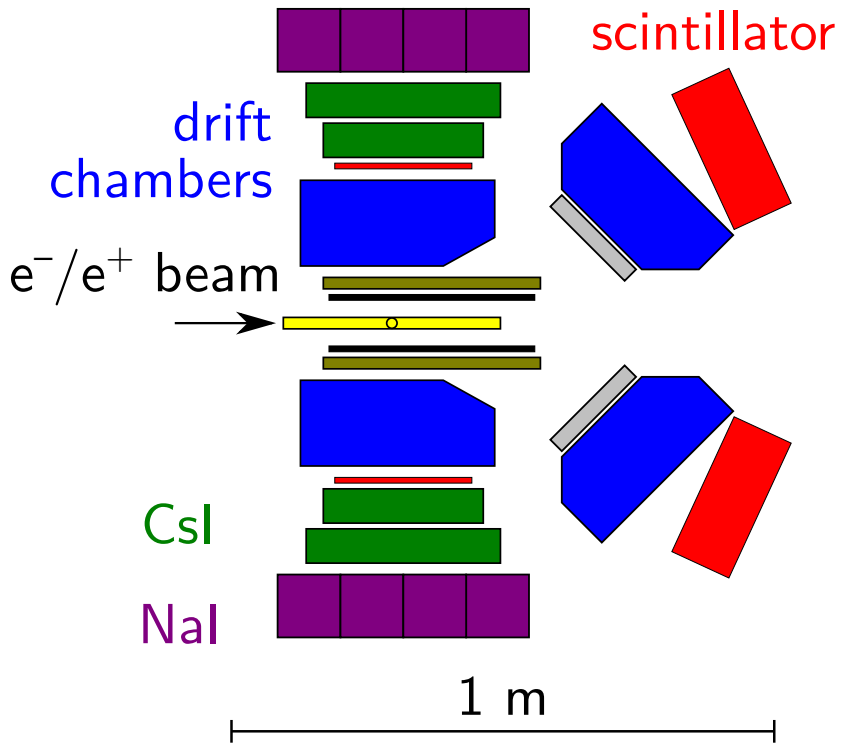
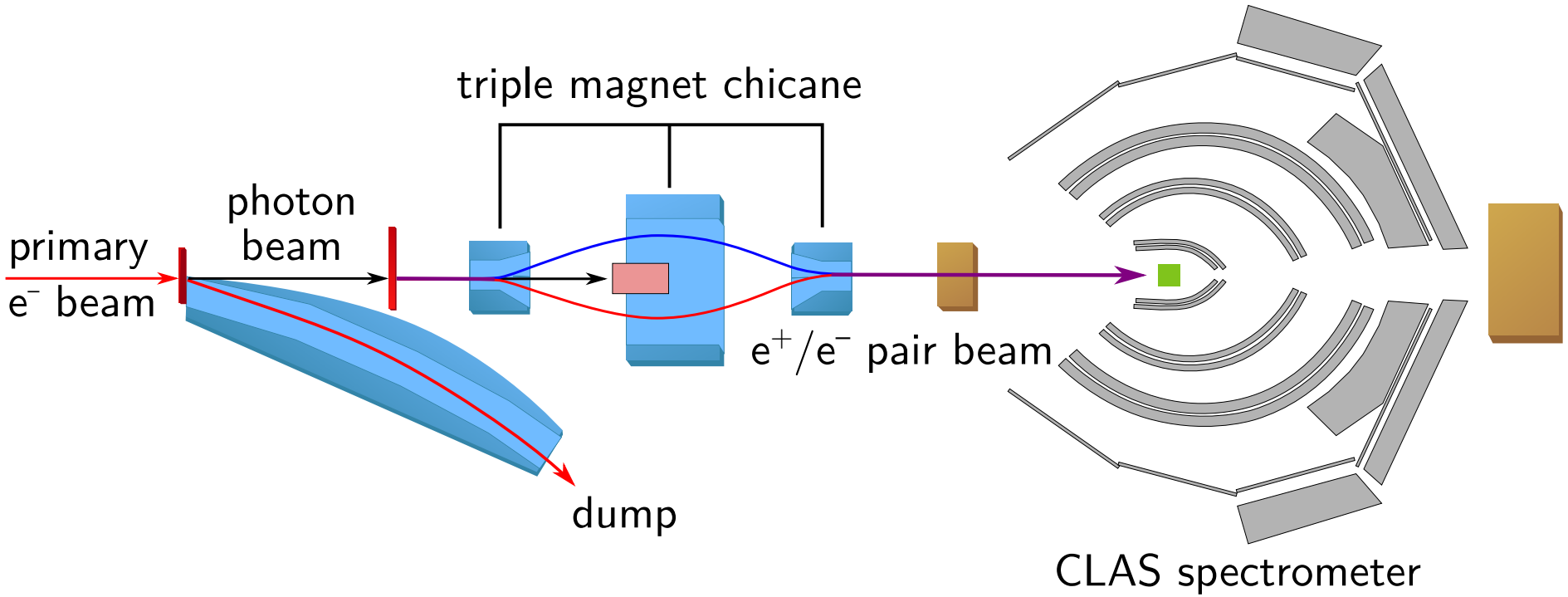
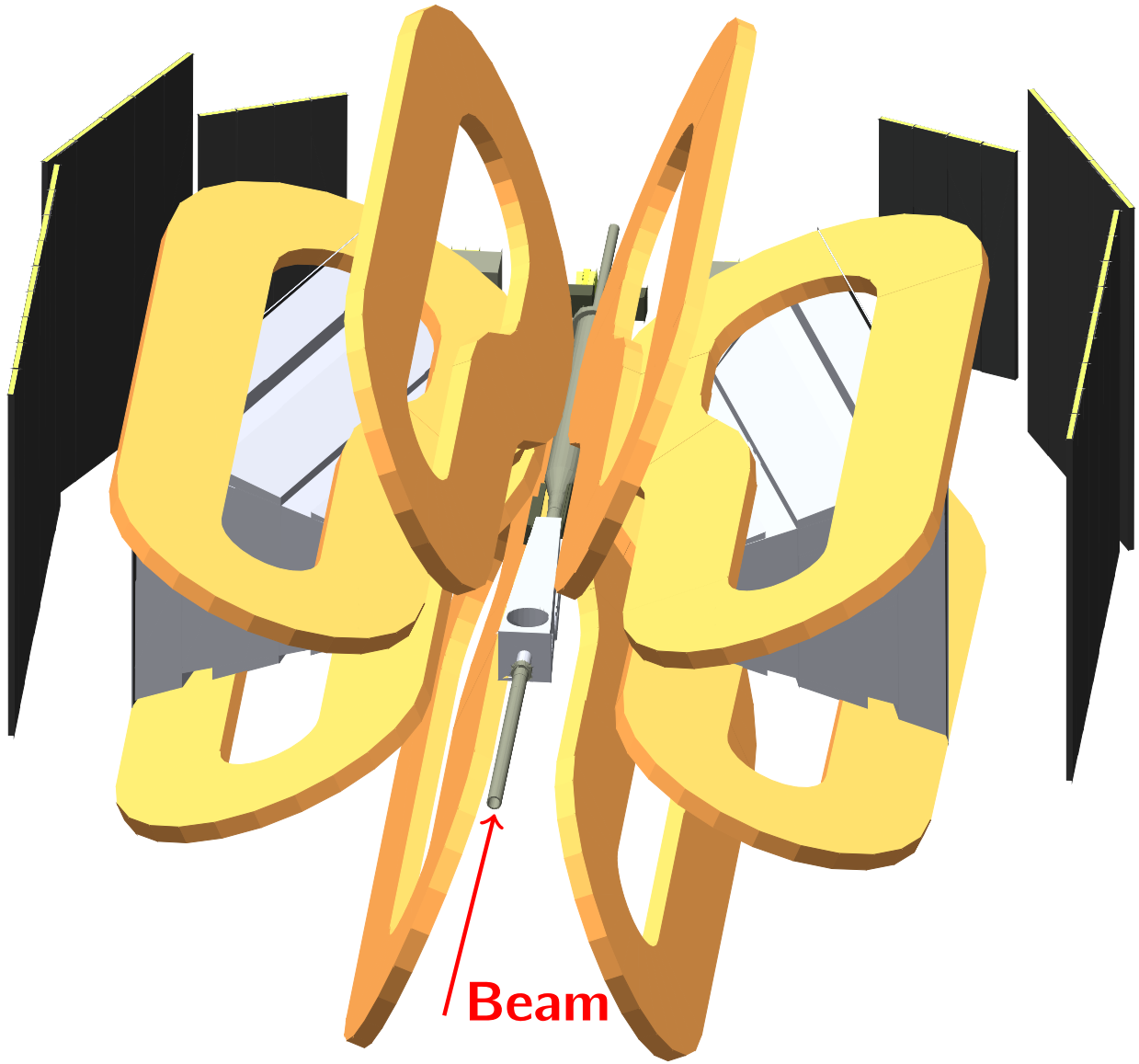


CLAS, Jefferson Lab, USA

TPE/eg5 run period



OLYMPUS, DESY, Germany



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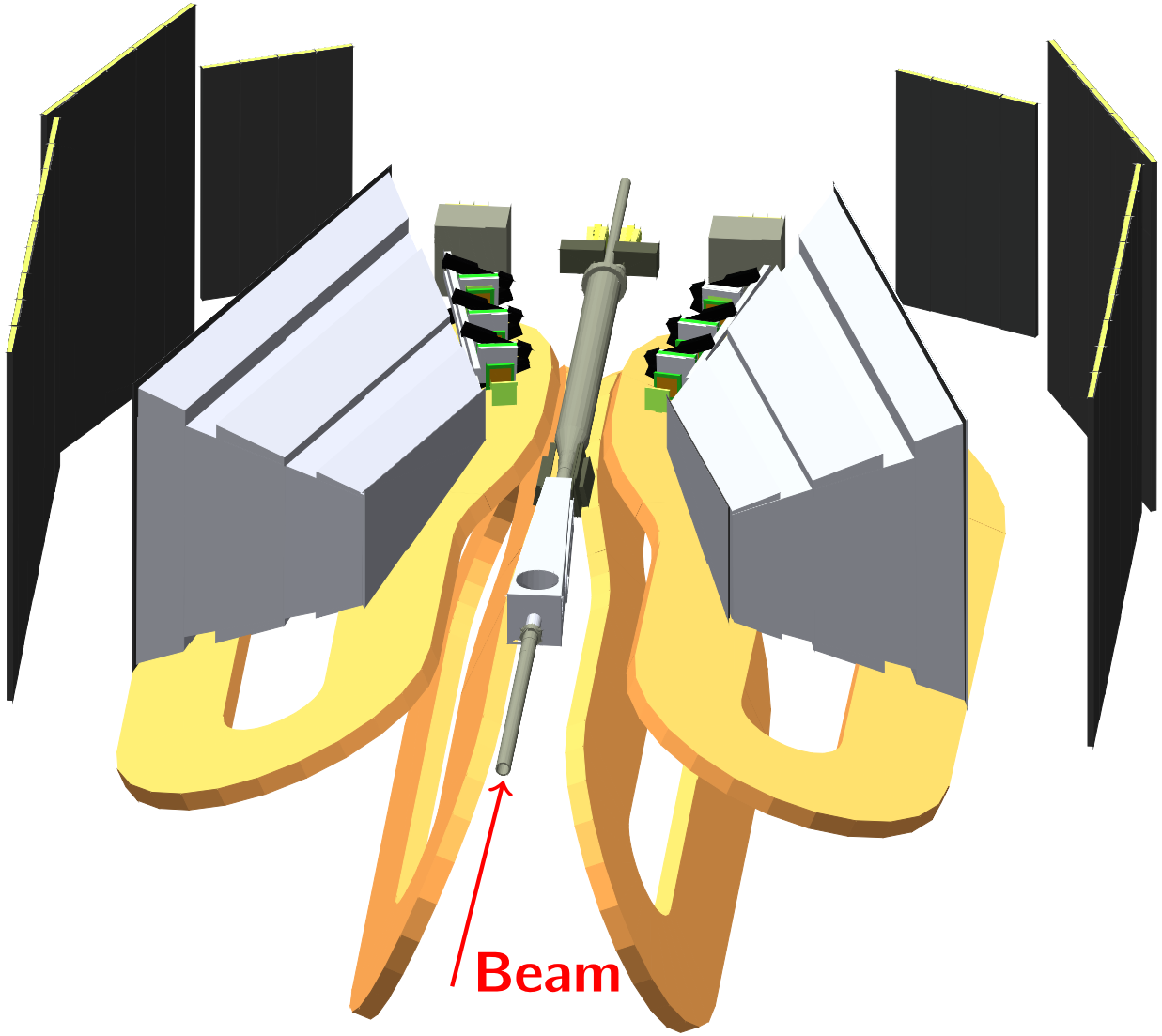

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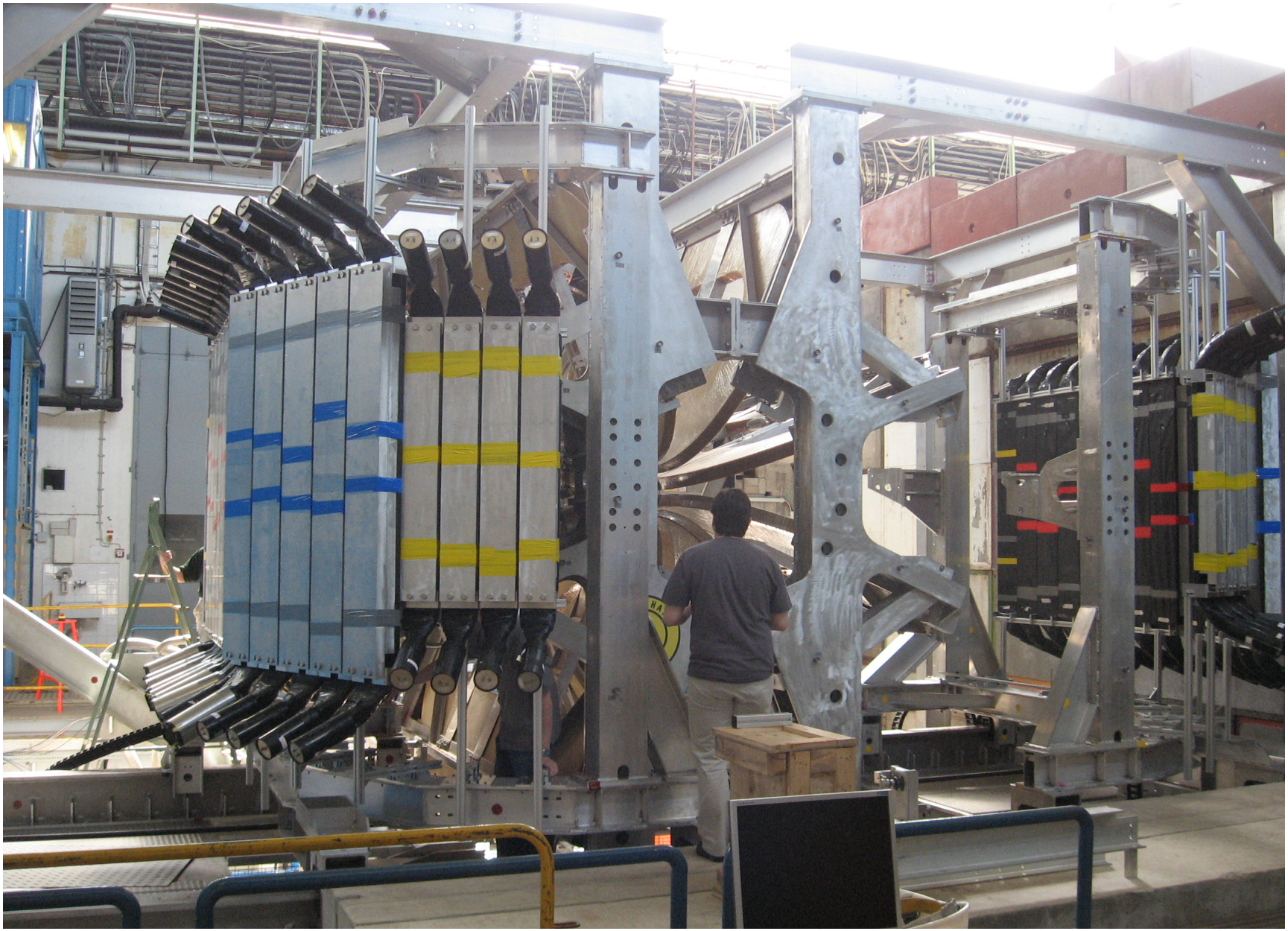
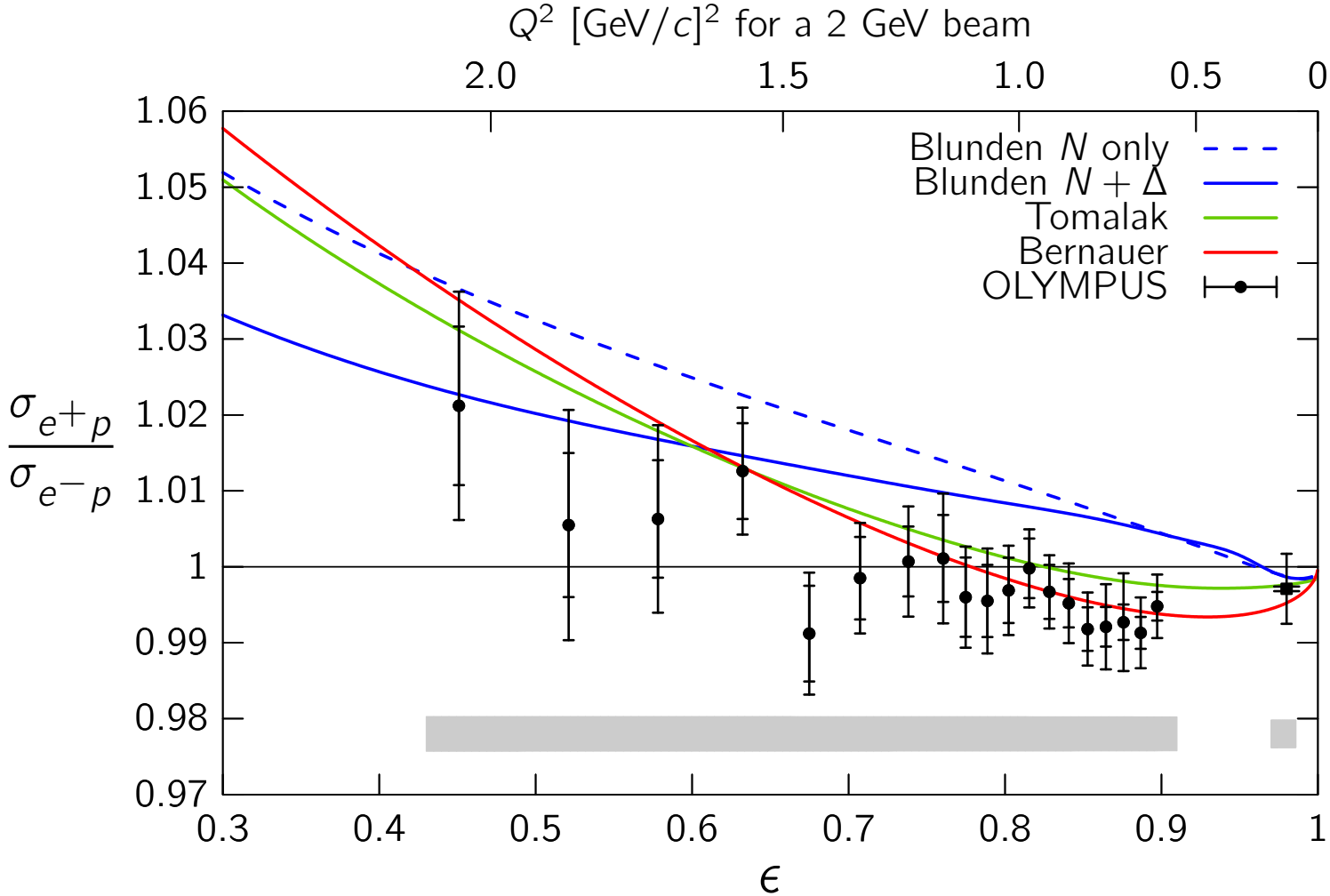
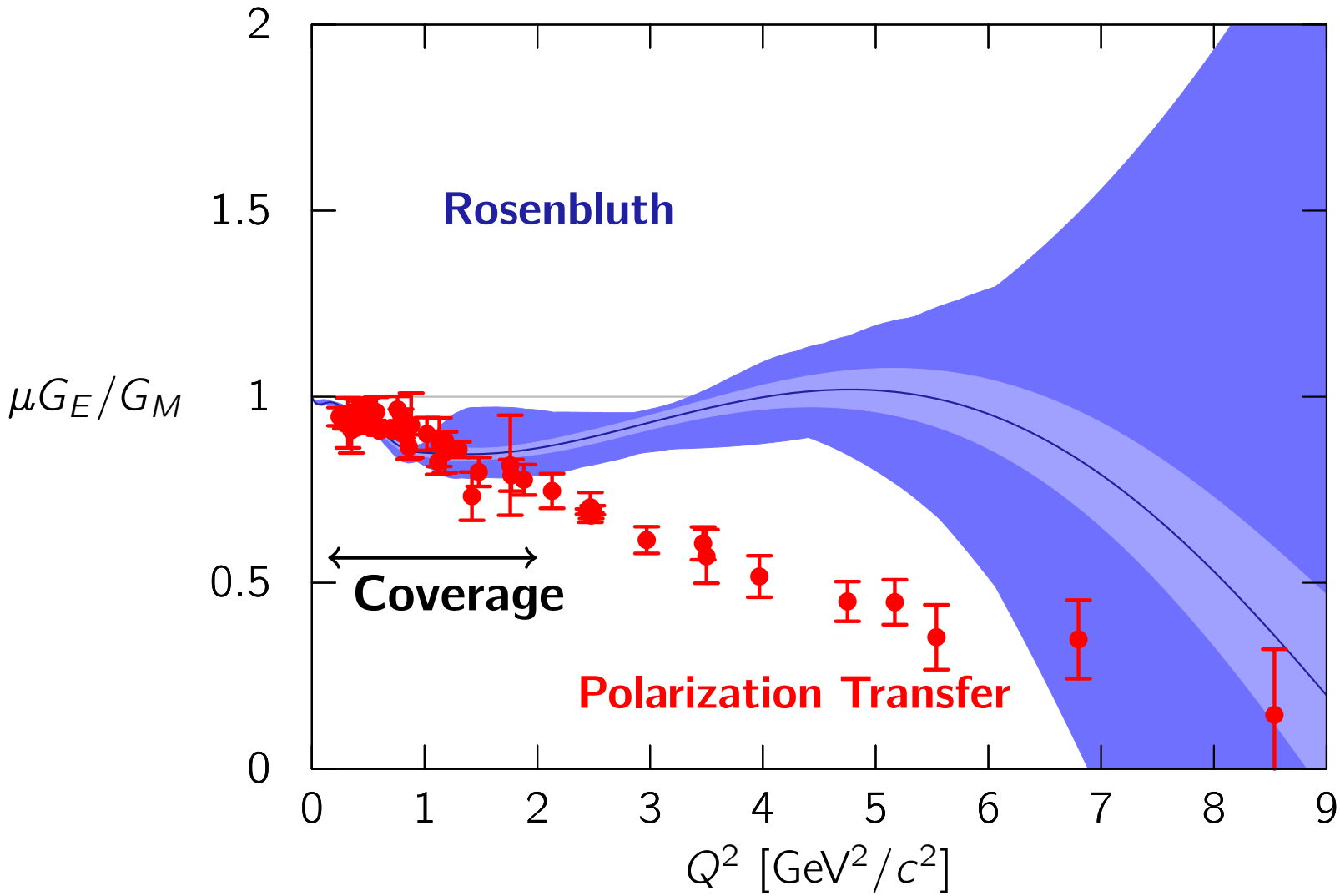


OLYMPUS observed a small TPE effect.



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

Recent measurements lacked the kinematic reach to be decisive.



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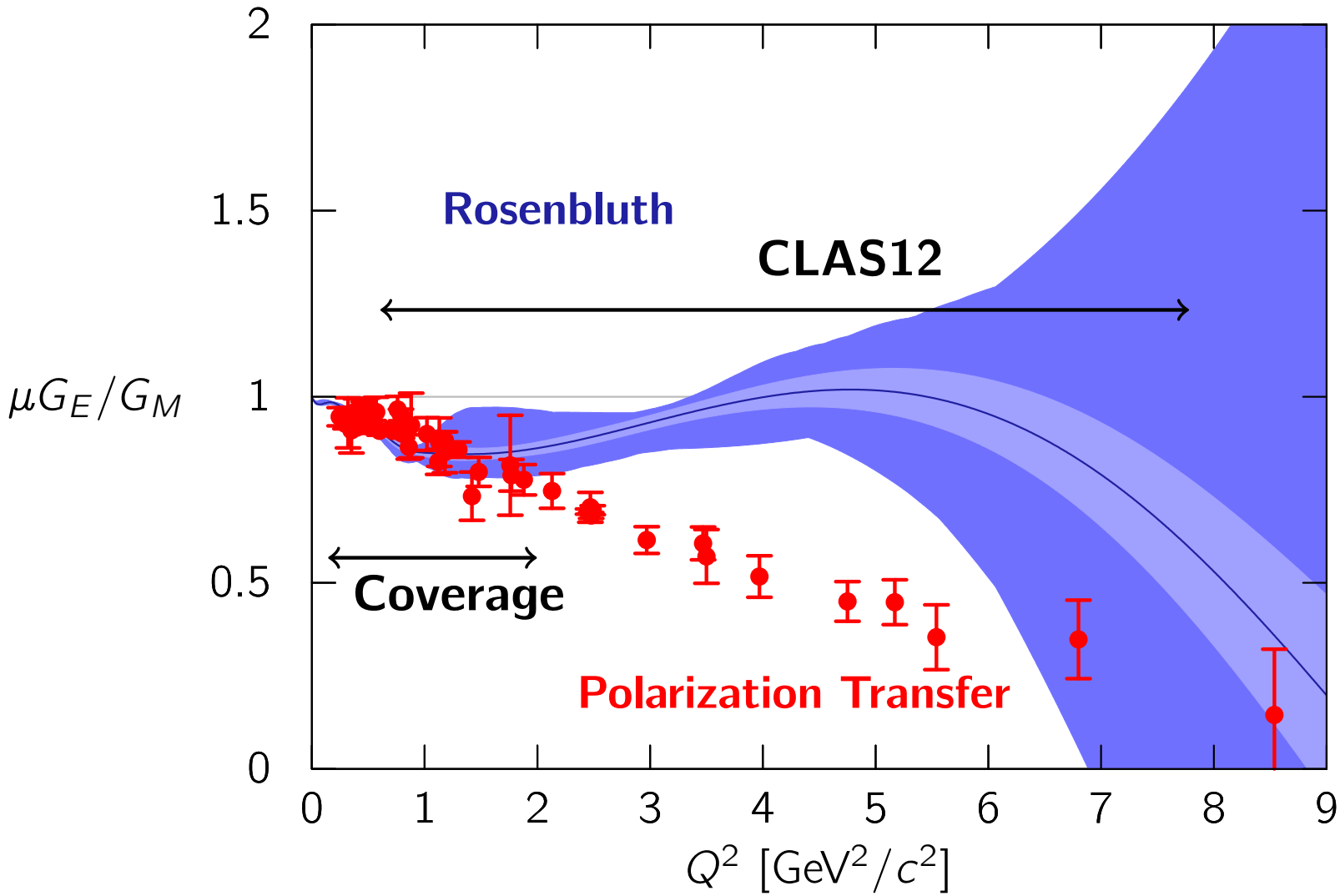


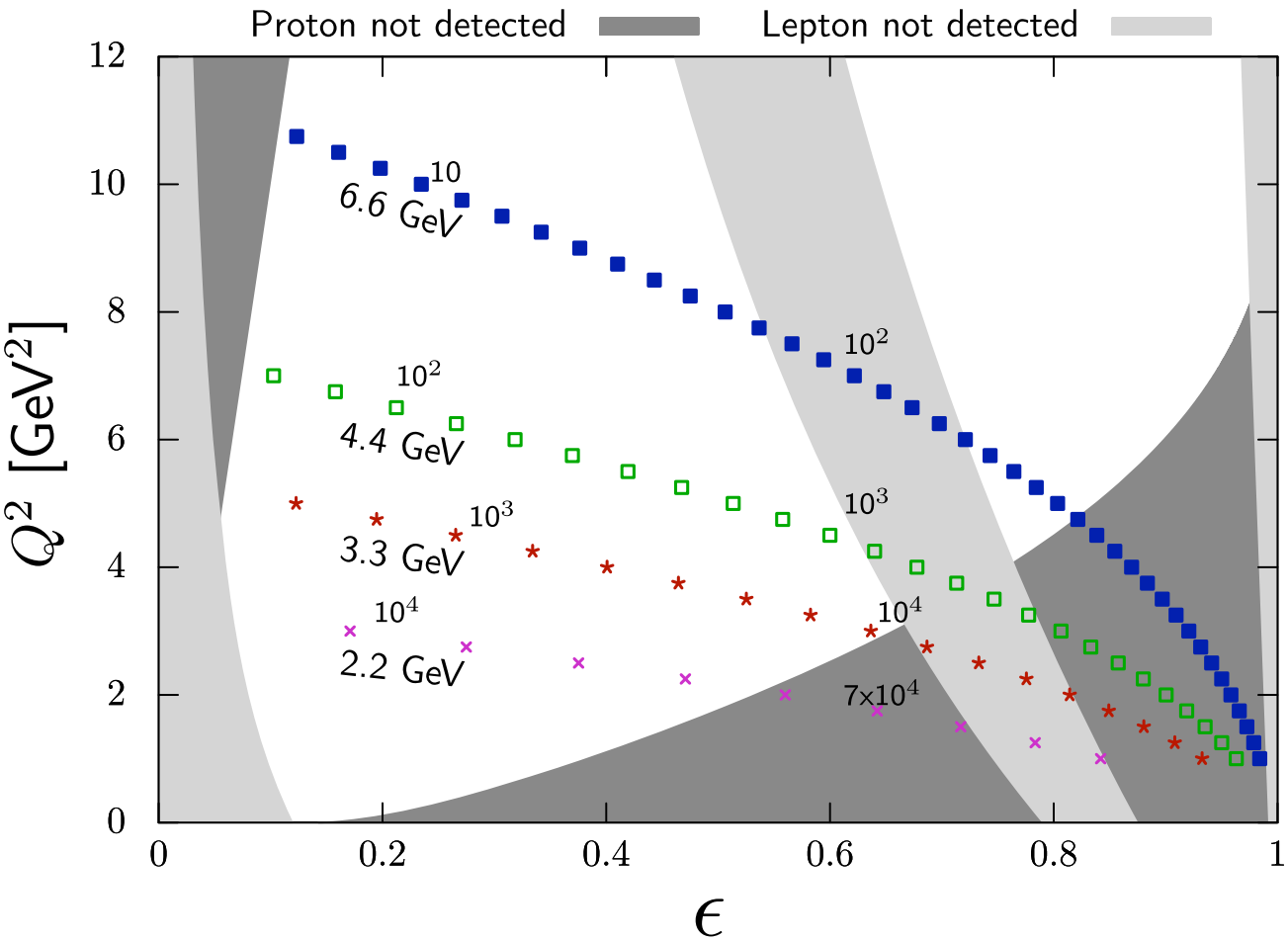
CLAS12 TPE experiment, as drawn up in the white paper

- 60 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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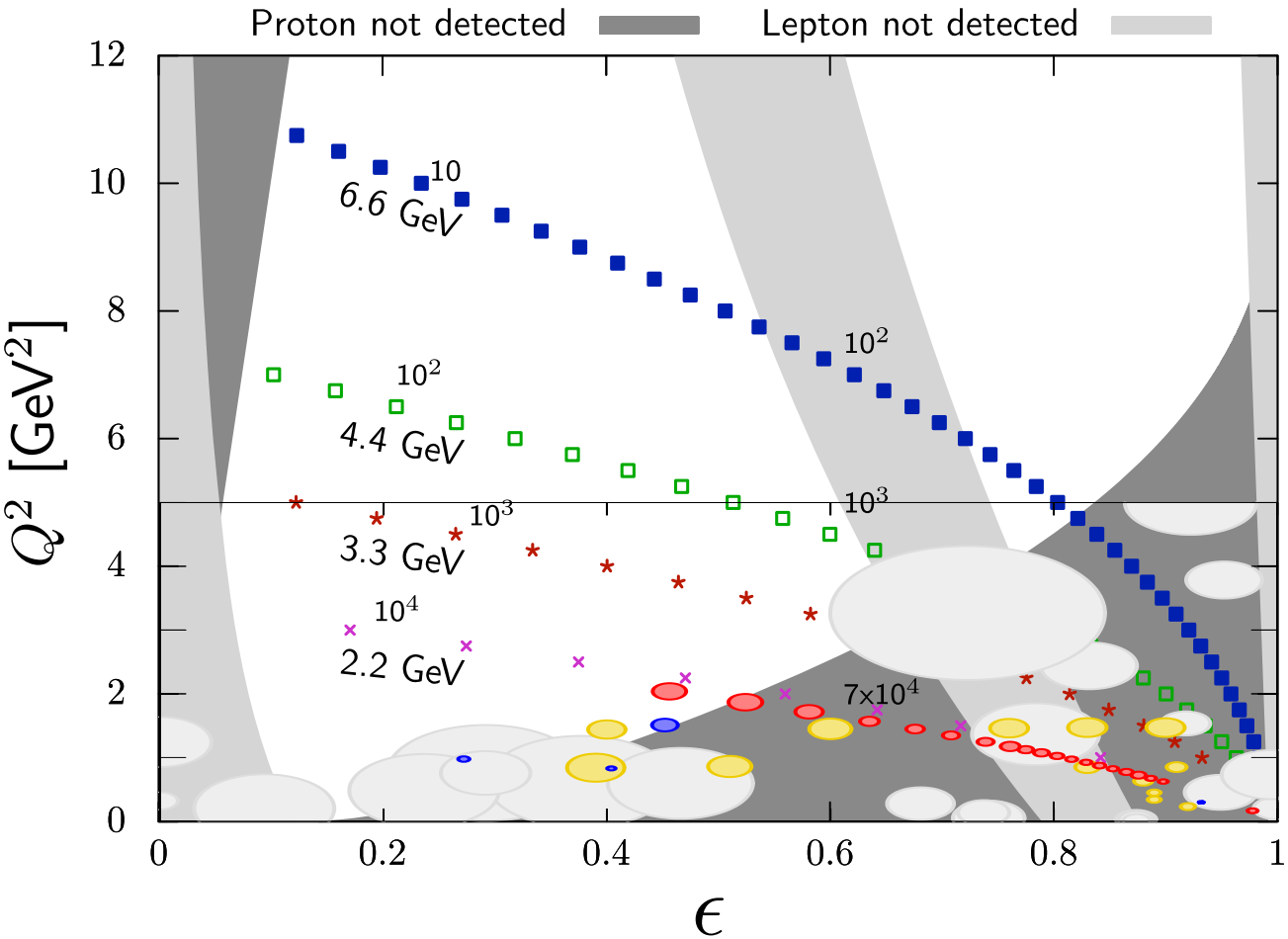

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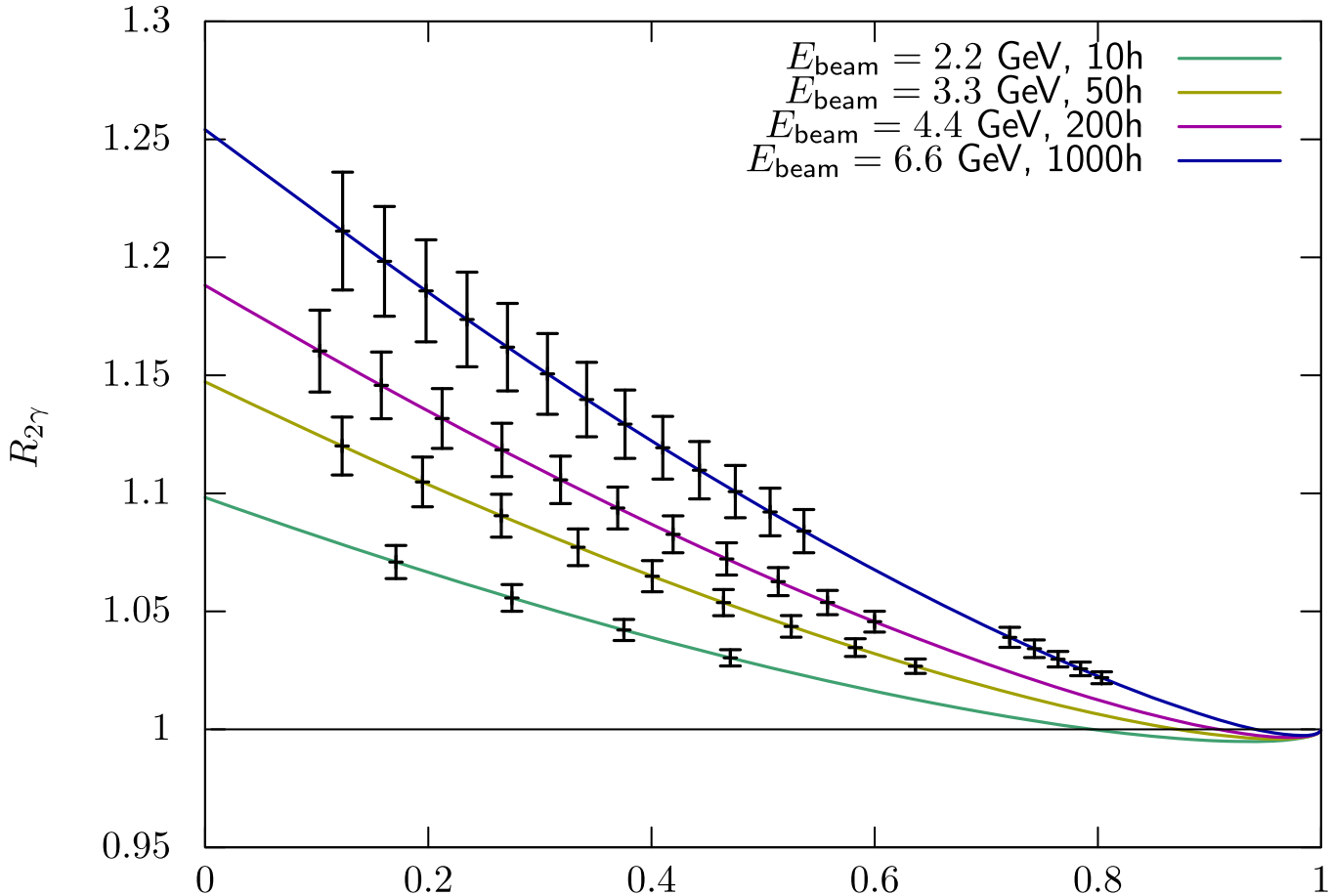

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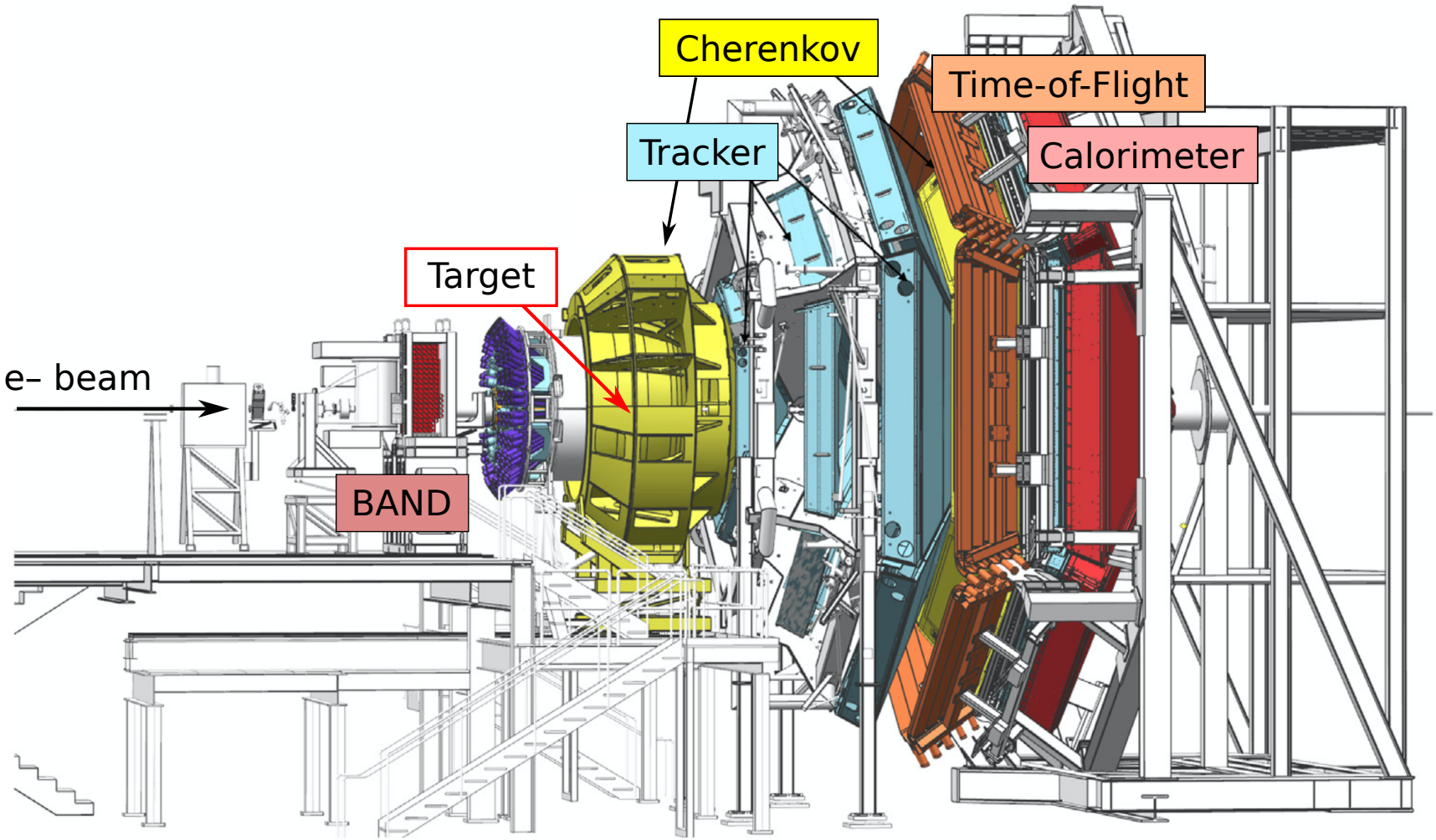
An elastic scattering event in CLAS12



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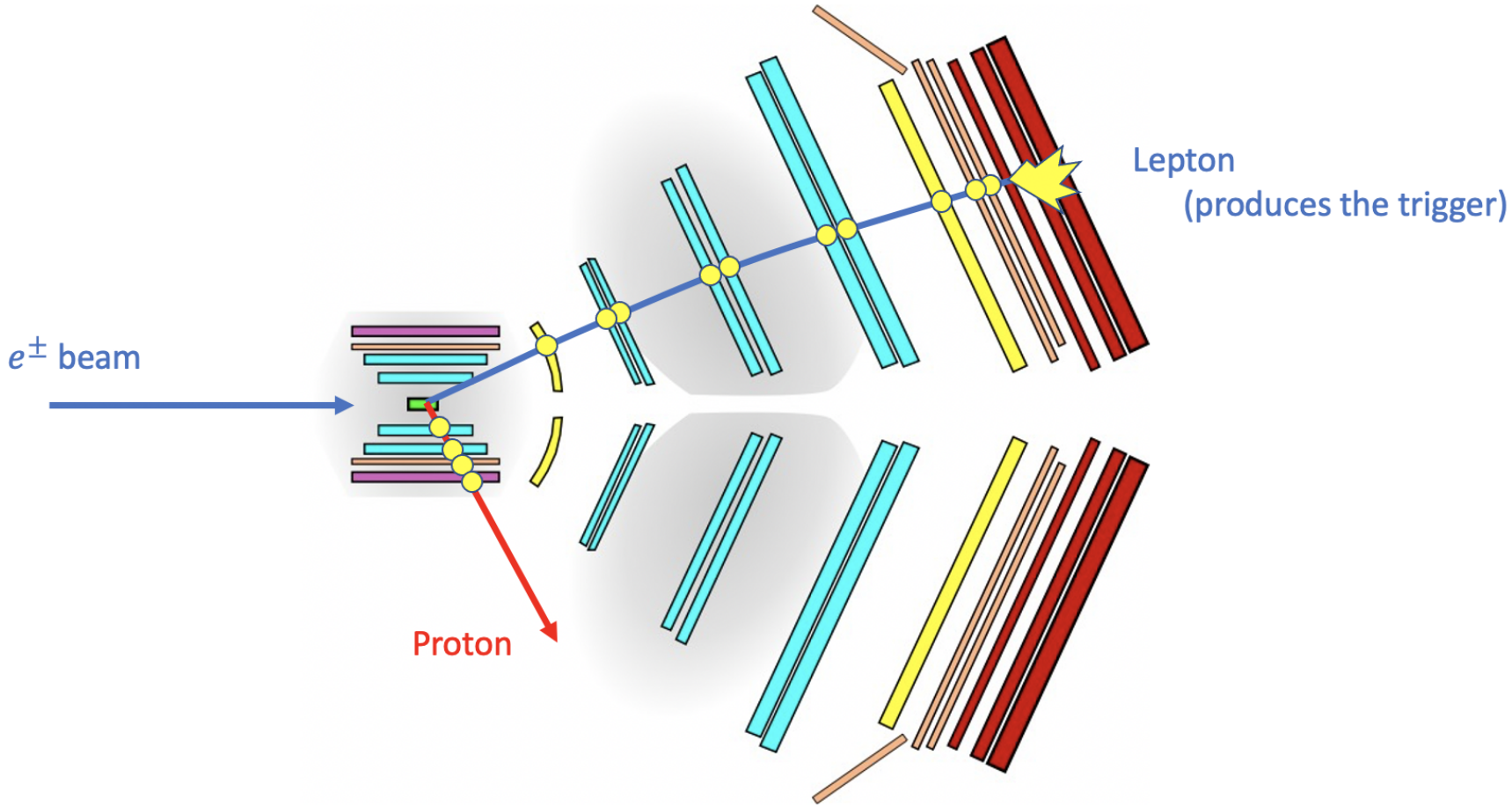
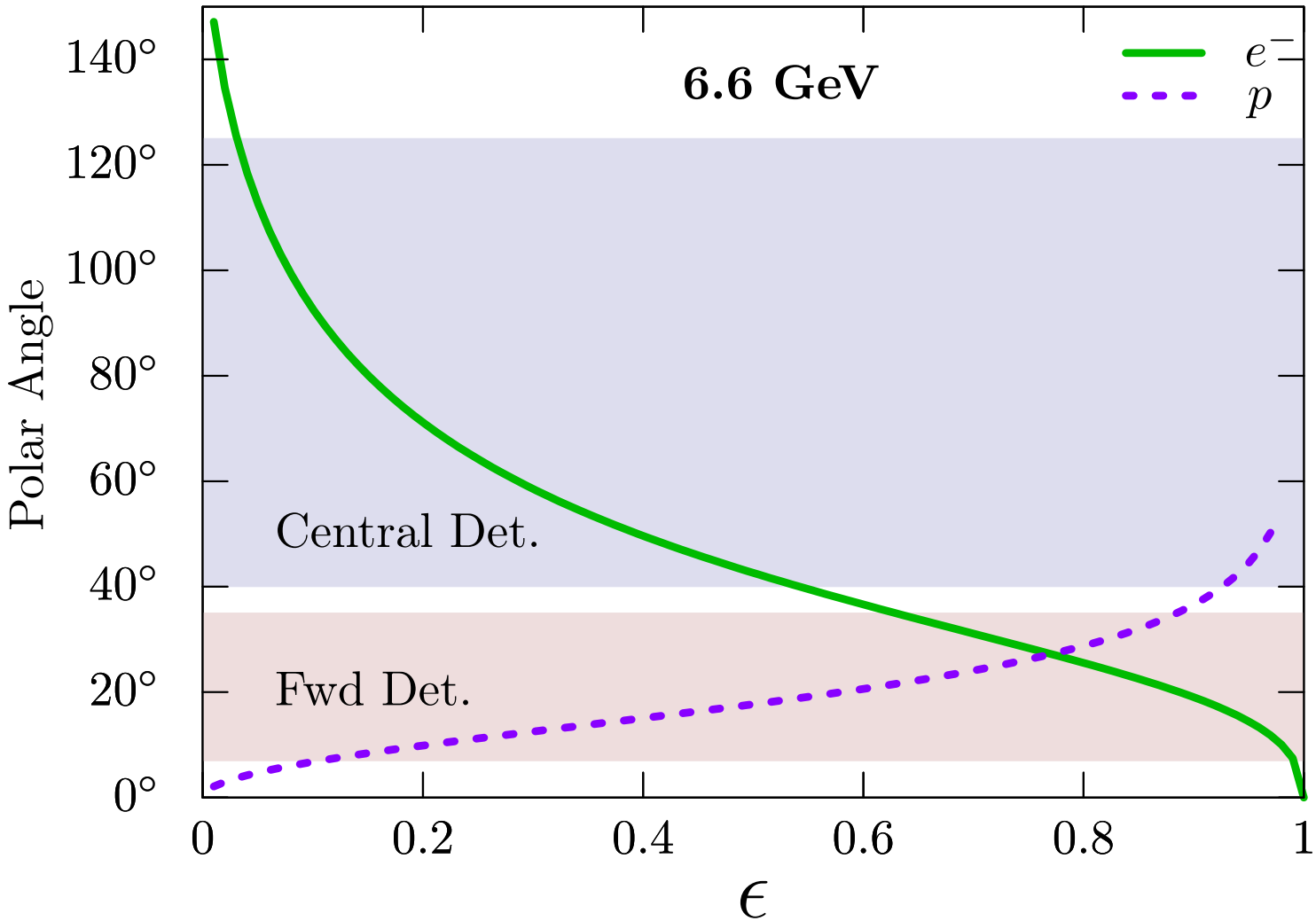


Current CLAS12 equipment lack the means to trigger on a central $e^{\pm}$.



Possible solutions to the triggering problem

- Modified trigger based on elastic kinematics
  - Trigger based on angular correlations between hits
  - Possibility of adding forward and central “roads”
  - Feasibility being studied using clock trigger data
  - High-luminosity upgrade is a major asset.

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- Streaming read-out
  - If CLAS12 were streamed, this would be a non-issue
  - Streaming test of forward tagger
    F. Ameli et al., EPJ Web of Conferences (2021)

Work underway

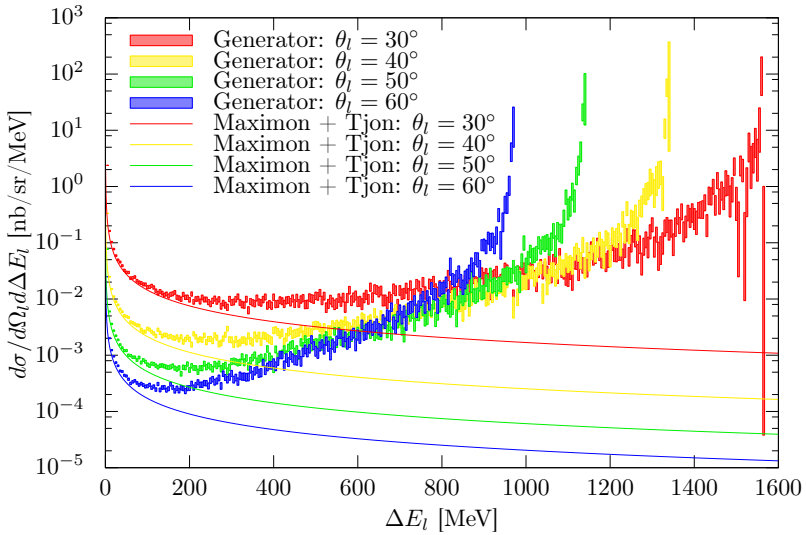
- Analyzing CLAS12 data on tape
  - Run Group M, 6 GeV on H_2
  - Study backgrounds, rates, resolutions
- Simulations
  - How do our events look outside of normal "triggered" kinematics?
- Developing read-out plan
  - Clock trigger data can tell us about expected data rates
  - What will be needed to reduce data to manageable rate?

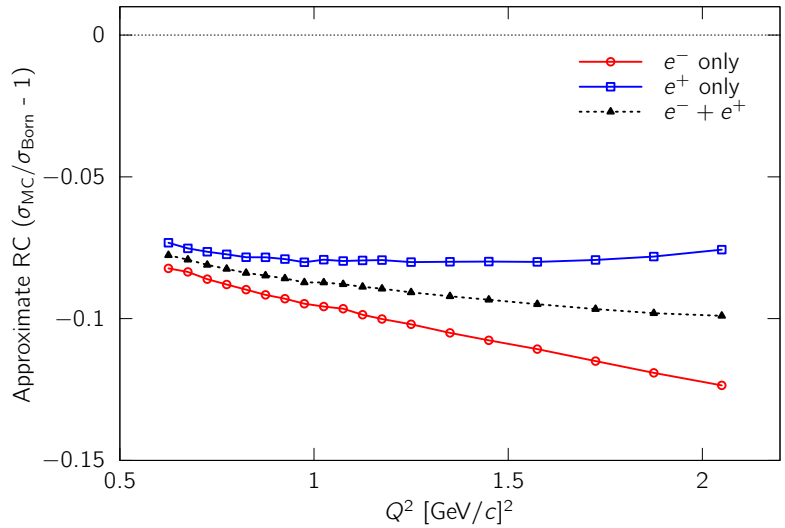
Limiting Systematics

- 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.
    - Polarity switching of solenoid and torus
  - 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.

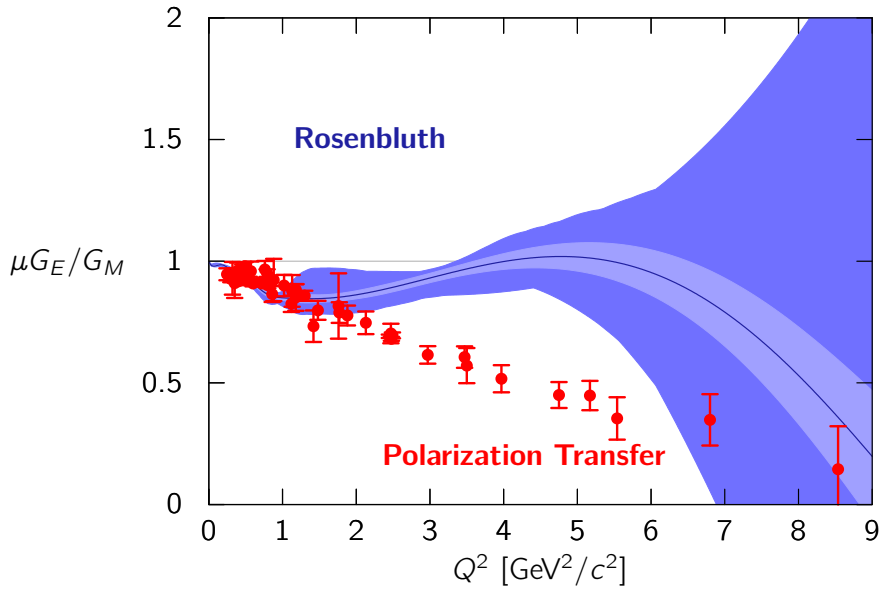




- OLYMPUS tested several RC prescriptions, built custom radiative event generator.
- Significant charge-odd corrections that are not hard TPE
- See recent (2022) ECT Workshop, as well as 2020 CFNS Workshop White Paper.

Recap:

- TPE is still a problem.



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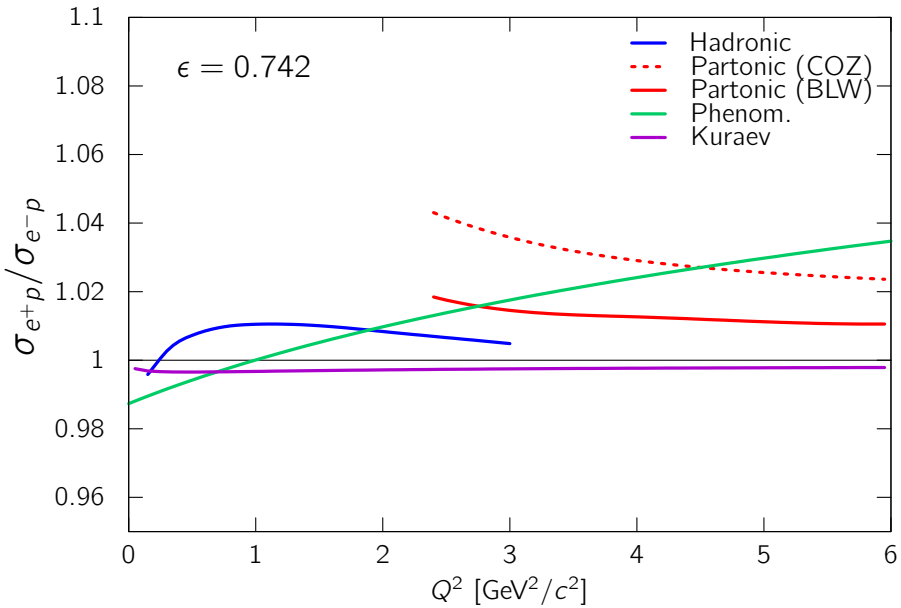
- TPE is still a problem.
- Key region is $3 < Q^2 < 5$



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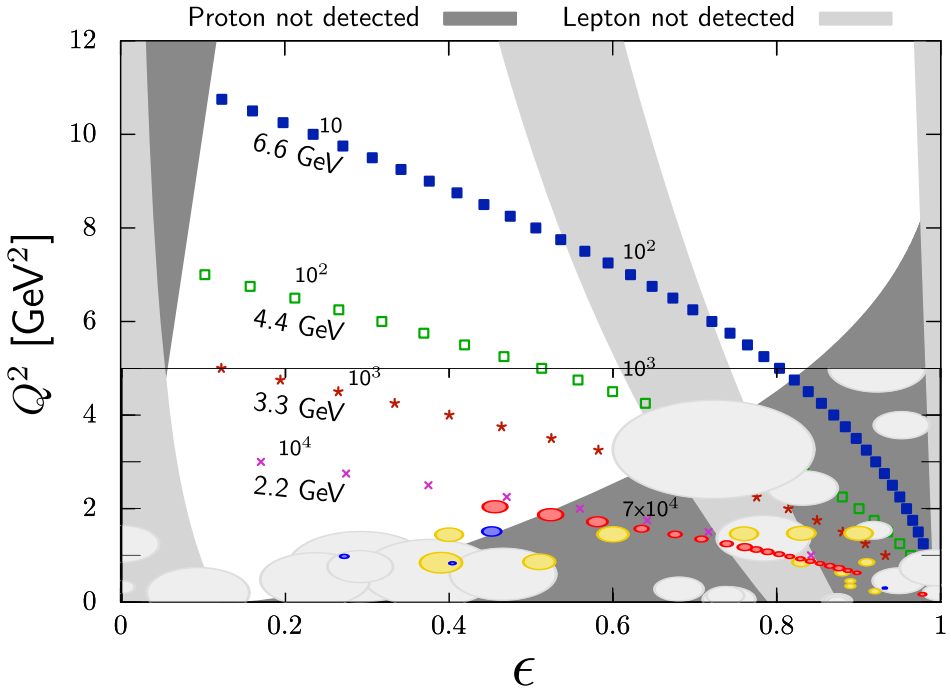
- CLAS12 e^+ proposal in preparation



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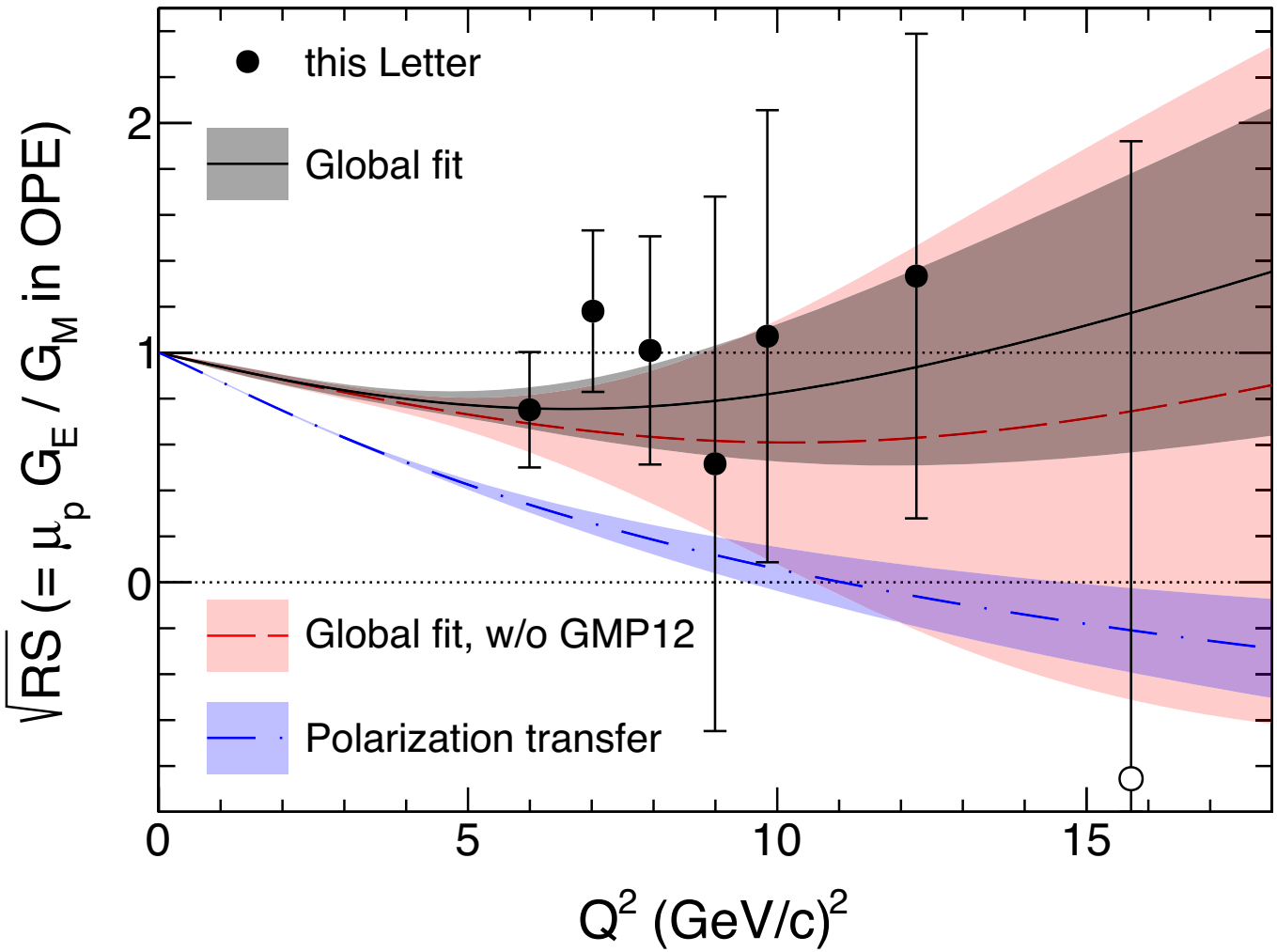
- Longer term: consider a CLAS12 positron run group
  - Obvious reactions: SIDIS, DVCS, π electroproduction
  - Need to consider within triggering/streaming plan
  - Polarized e^+ can't hurt, given luminosity

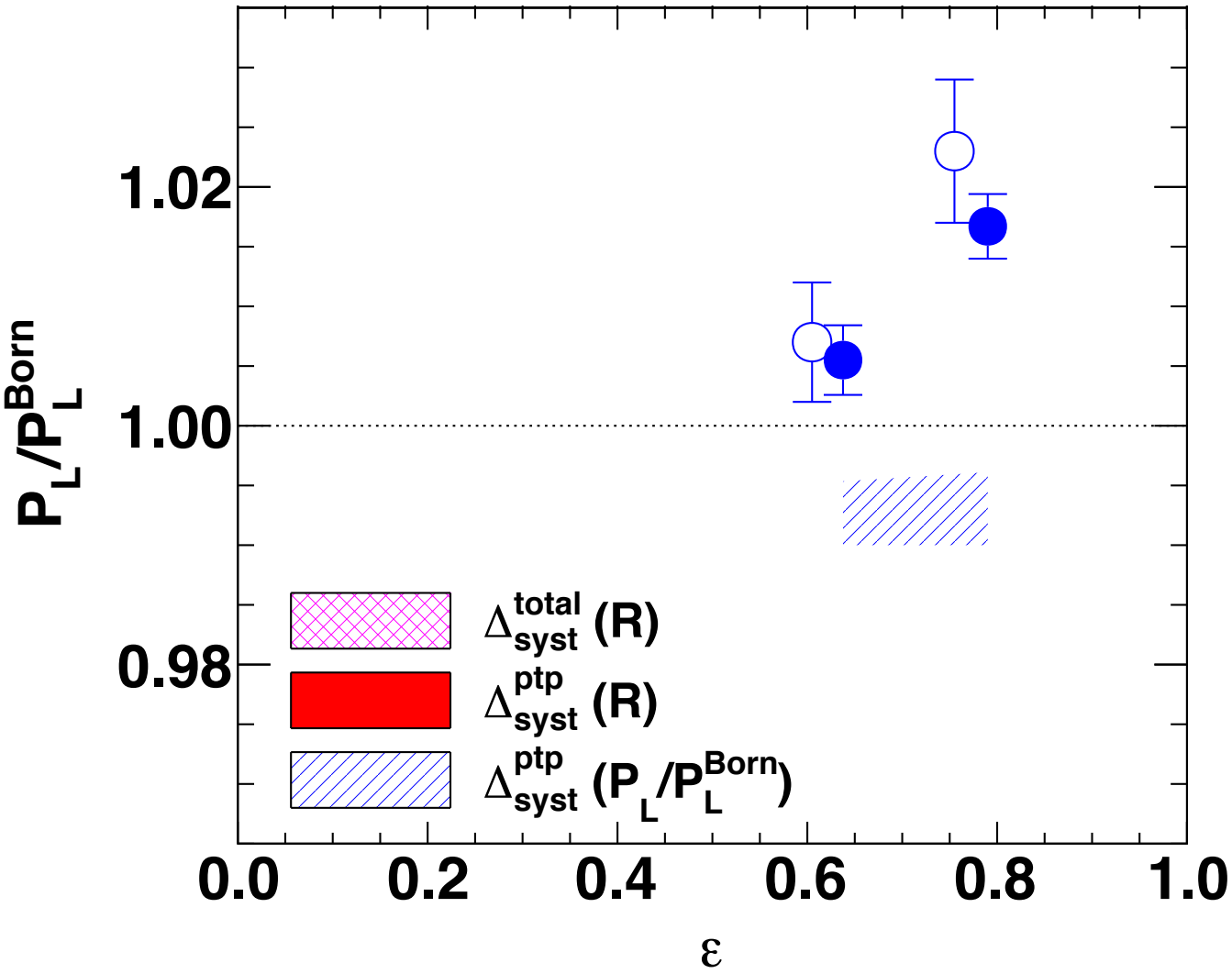
Back Up

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)