The Case for a Positron Beam at Jefferson Lab

Axel Schmidt

Photonuclear Reactions and Frontiers & Careers Workshop

August 9, 2024

This work is supported by the US DOE Office of Science, Office of Nuclear Physics, under contract no. DE-SC0016583.

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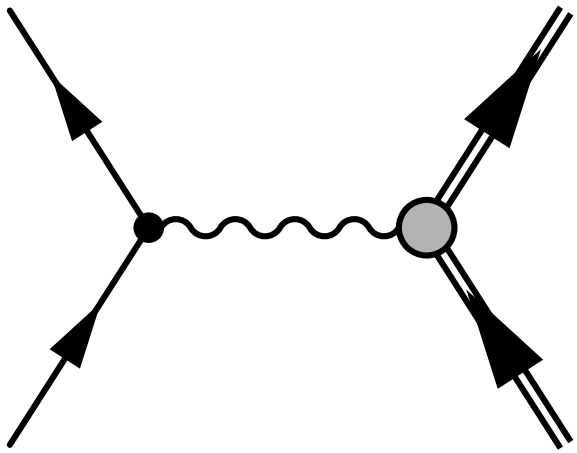

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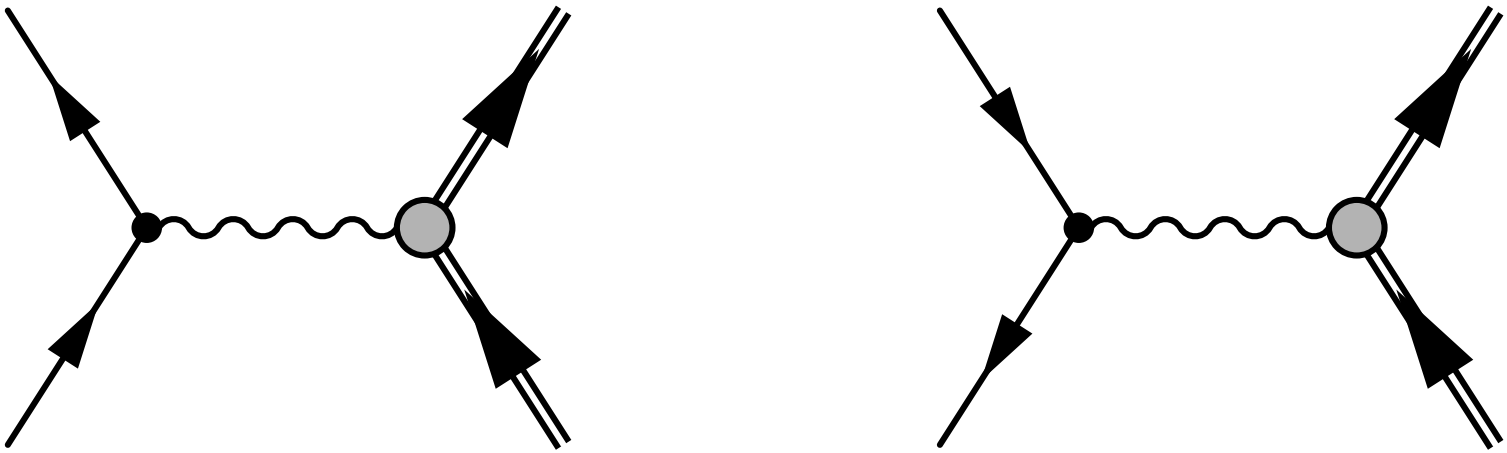

Positrons add new information beyond what electrons can provide.

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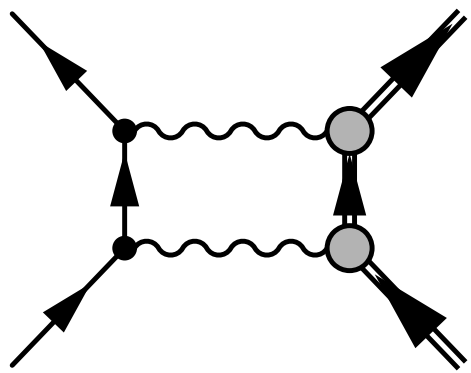
   - Two-photon exchange
   - DVCS / Bethe-Heitler
   - Coulomb effects



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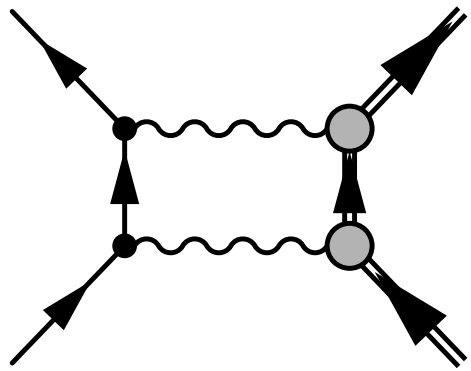

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   - Annihilation search for dark matter
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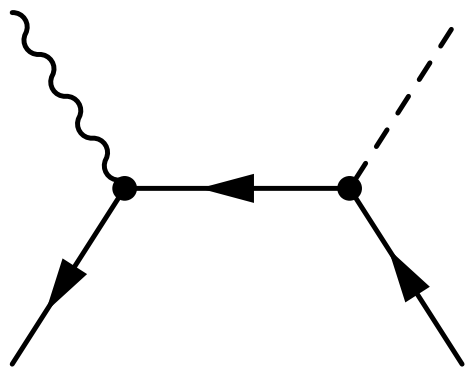
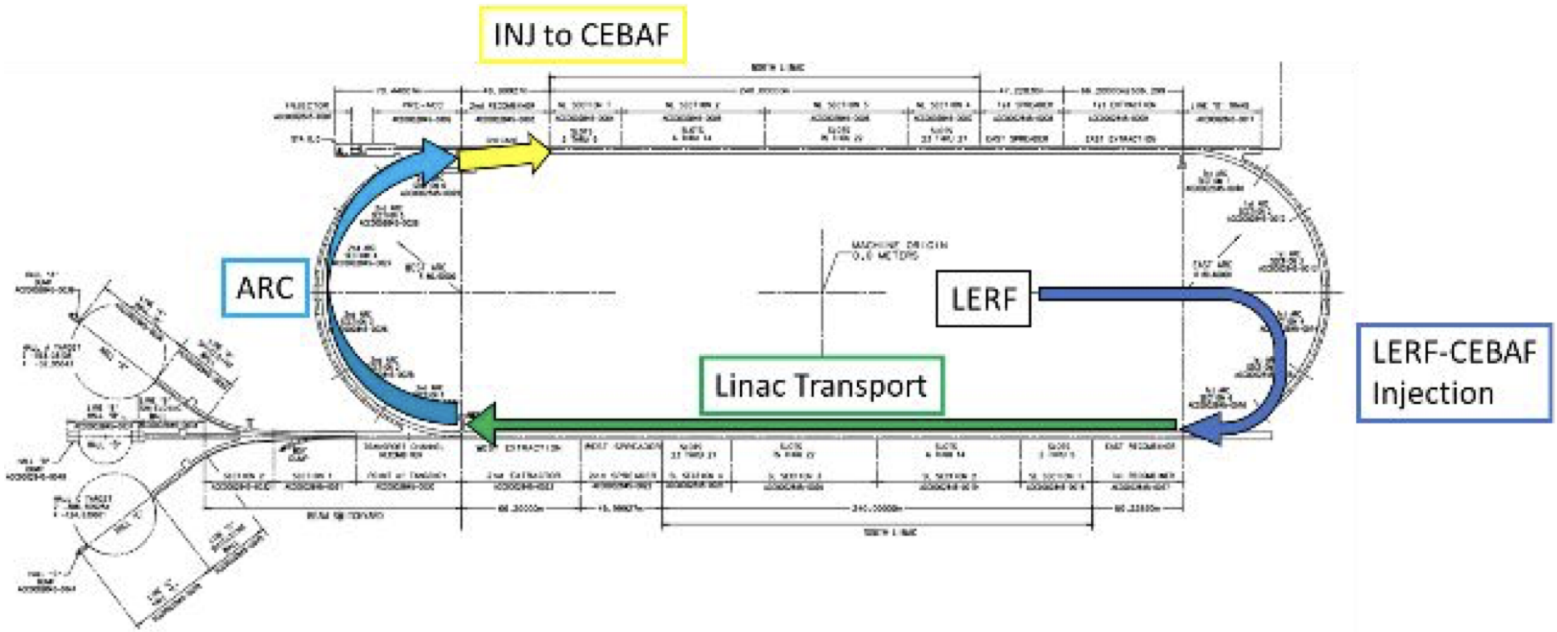


Jefferson Lab Positron Working Group

Read our white paper: EPJA 2022

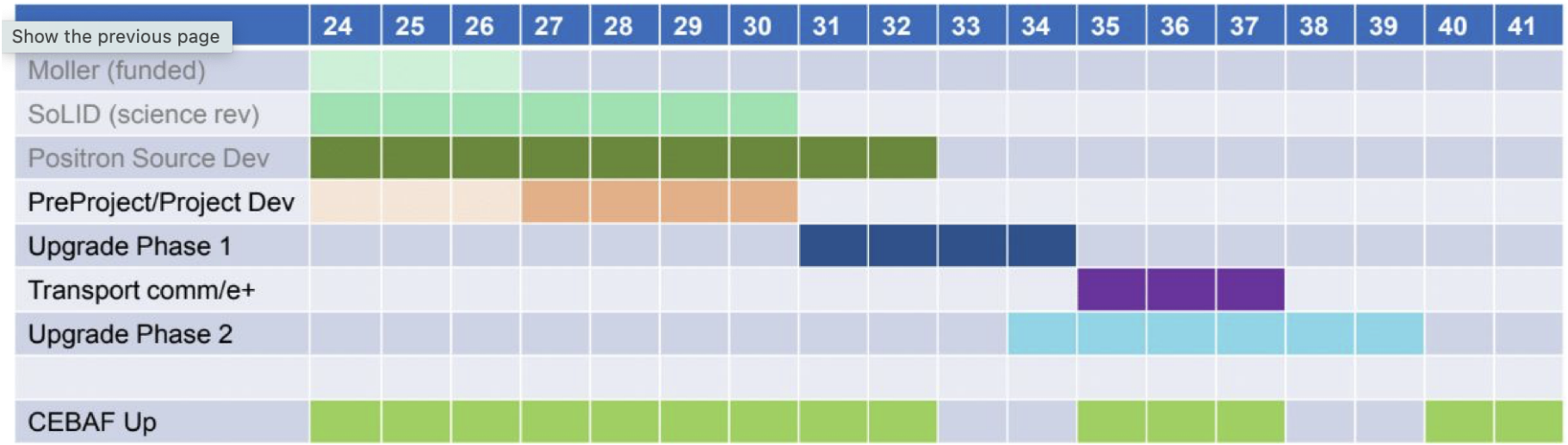
Join our mailing list:
pwg-request@jlab.org

Plan: build new positron source in the LERF vault.



- Minimize civil construction, reduce cost
- Pre-cursor to 22 GeV upgrade

This will not be soon.



- FY23 $$
- Phase 1: tie LERF to CEBAF & injector for e+ $101M ($78M – $152M)
- Phase 2: High Energy Upgrade (includes FFAs) $244M ($188M – $366M)
- Total cost (Class 4 estimate) $345M ($265M – $517M)
- Pre-R&D (FY25 – FY27) $3.0M/year (+$0.5M/year in LDRD)

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Jefferson Lab

- We are working to produce pre-CDR document.

The PAC has solicited positron proposals.

Positron experiments / concepts:

Multi-photon Exchange

- PR12+23-003: Coulomb Effects in DIS
- PR12+23-008: Two-Photon Exchange at CLAS
- PR12+23-012: Two-Photon Exchange in Hall C
- LOI12+24-008: Two-Photon Exchange in neutrons

Dark Photon Searches

- PR12+24-005: Annihilation Search
- LOI12+23-005: Bhabha Search

Other BSM

- WP: charged-lepton flavor violation search

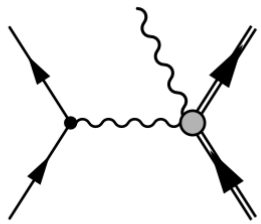
Virtual Compton Scattering

- PR12+23-002: DVCS asymmetries at CLAS12
- PR12+23-006: DVCS cross section in Hall C
- LOI12+23-001: Generalized Polarizabilities
- WP: DVCS on neutrons, He-4
- DDVCS at SOLID

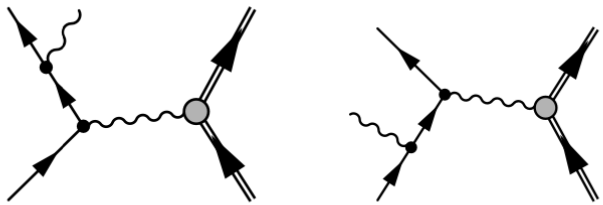
Charged-Current Physics

- LOI12+23-002: Axial Form Factor
- WP: Strangeness via Charm Tag

Positrons can disentangle DVCS from the Bethe-Heitler process.



DVCS: Probe GPDs



Bethe-Heitler Process

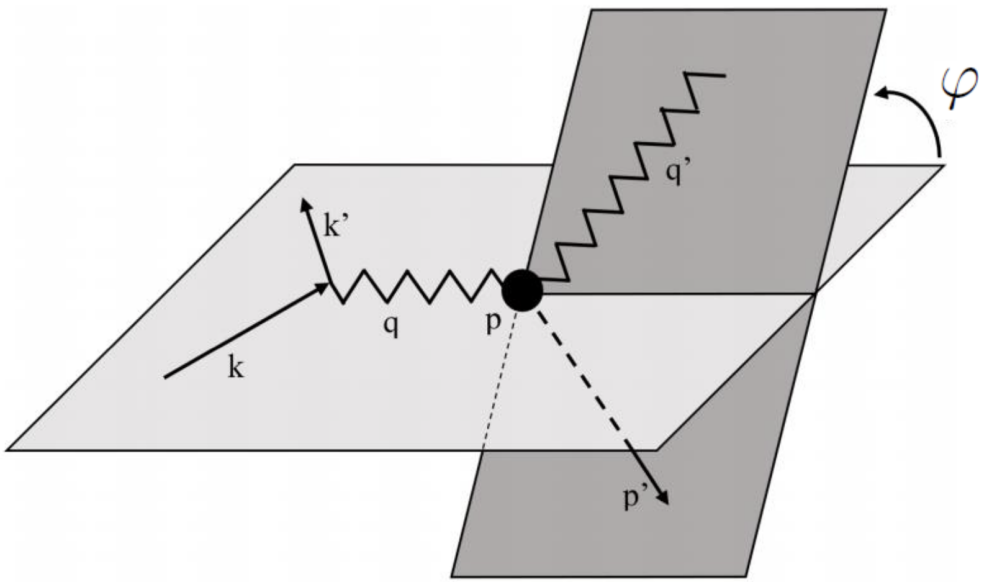
$$\sigma \sim \left| \quad \right|^2 + \left| \quad \right|^2 \pm 2Re \left\{ \quad \right\}$$

Bi-linear combination of GPDs

QED: Known to ≈1%

Linear Combination of GPDs
Beam charge-dependent

Kinematics of DVCS



ϕ-dependence contains 5 observables:

$\sim 1, \cos\phi, \sin\phi, \cos 2\phi, \sin 2\phi$

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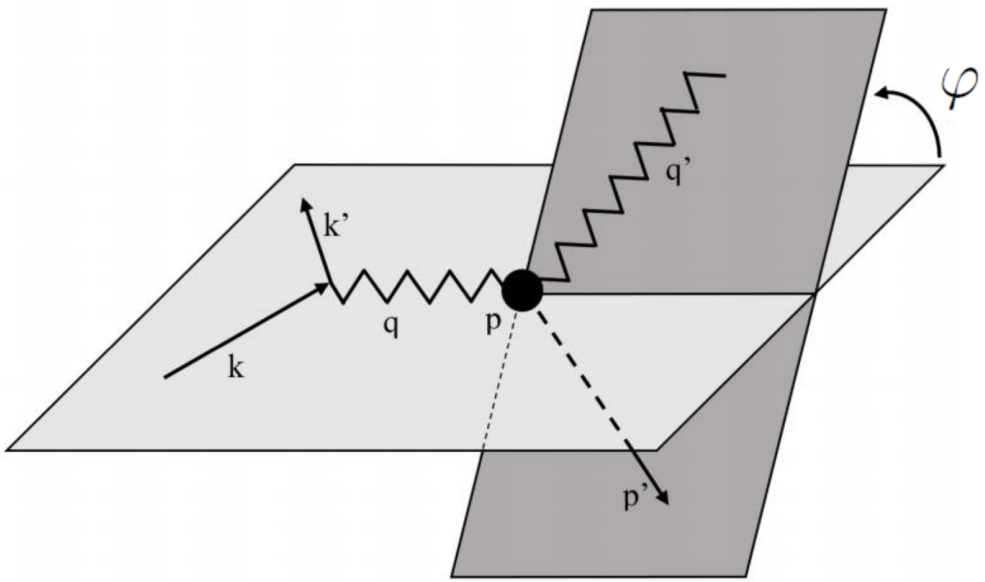

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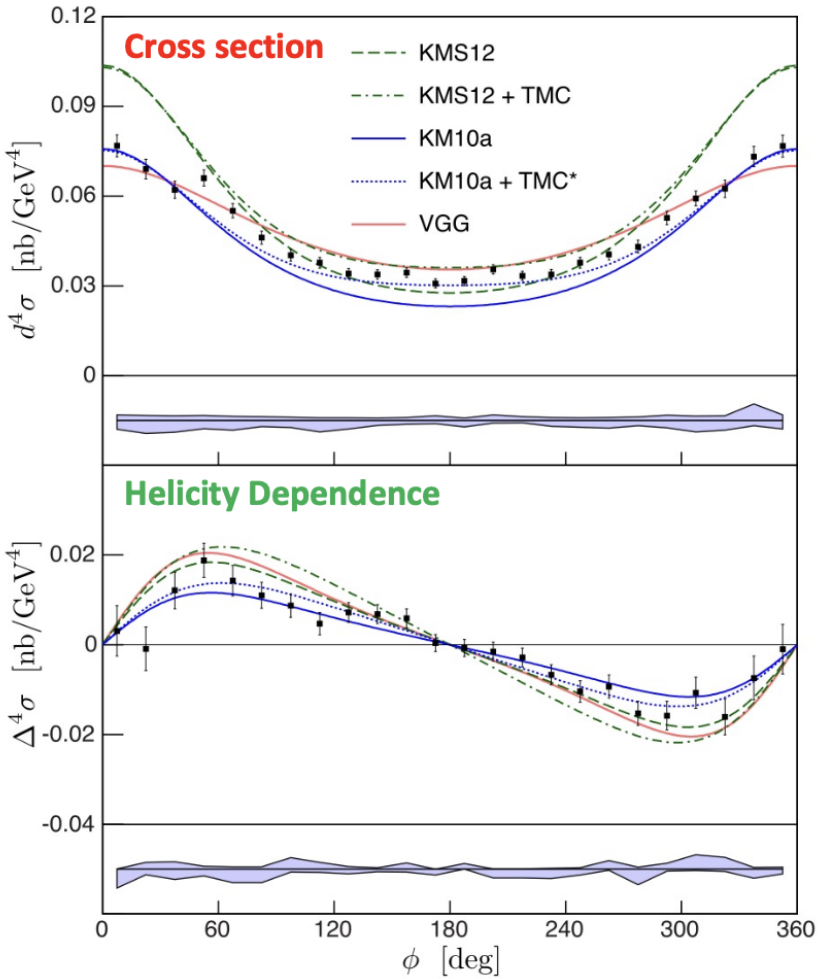


M. Duferne et al., PRC 92, 055202 (2015)

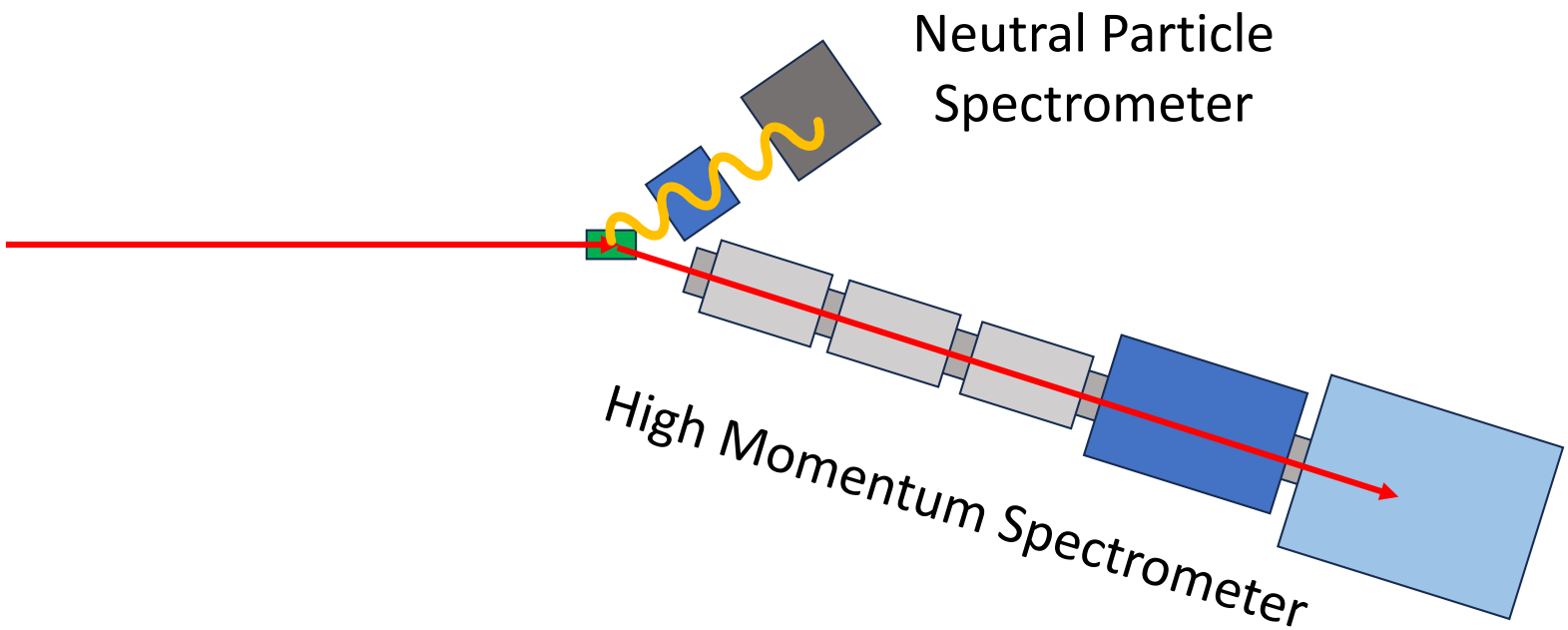
Proposed DVCS Experiments

- Precision Measurements in Select Kinematics (Hall C)
  - PR12+23-006
  - High Momentum Spectrometer (HMS) + Neutral Particle Spec. (NPS)
- Survey over a Wide Phase Space (CLAS12, Hall B)
  - PR12+23-002
  - CLAS12

E12+23-006 in Hall C

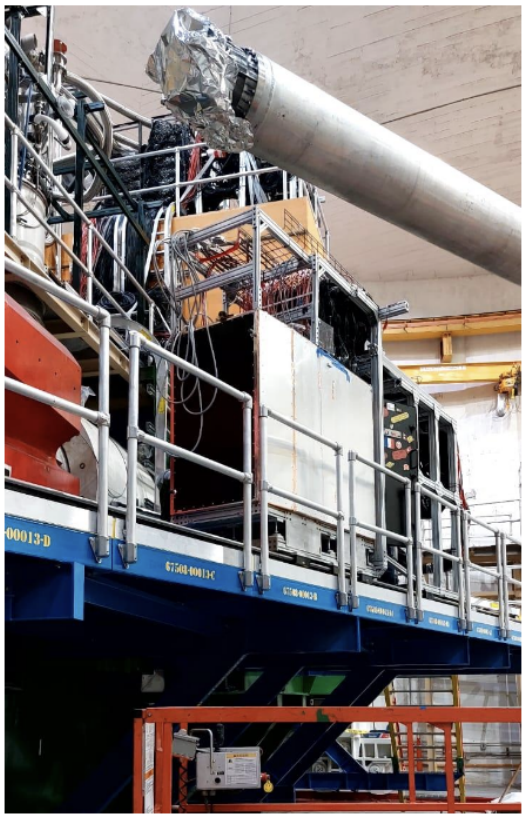
Goal: high-precision cross sections overlapping electron data

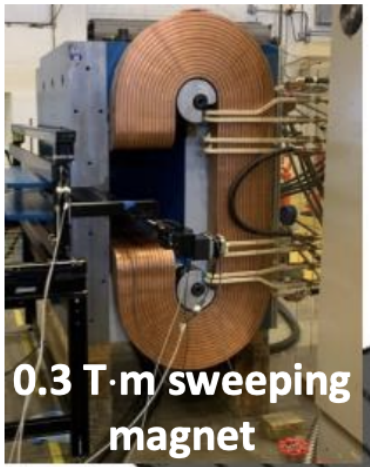
- Match $x_B = 0.36$ settings from E12-13-010
  - 6 kinematic settings over three beam energies
- 135 days, 1 μA of unpolarized e^+

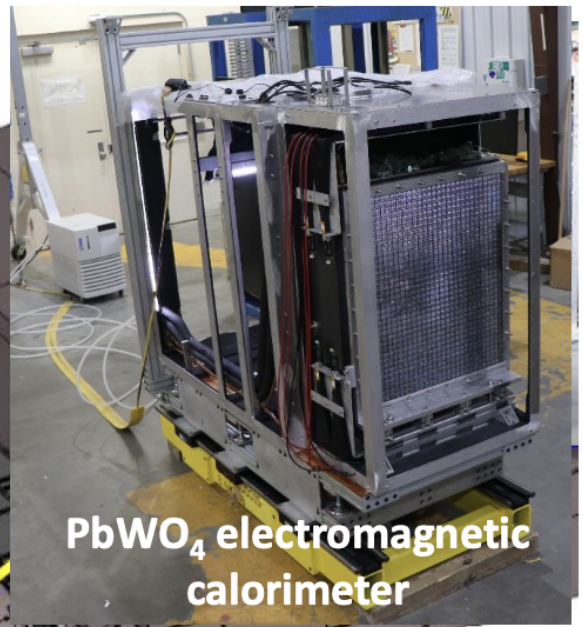


Spokespeople: C. Munoz-Camacho, M. Mazouz

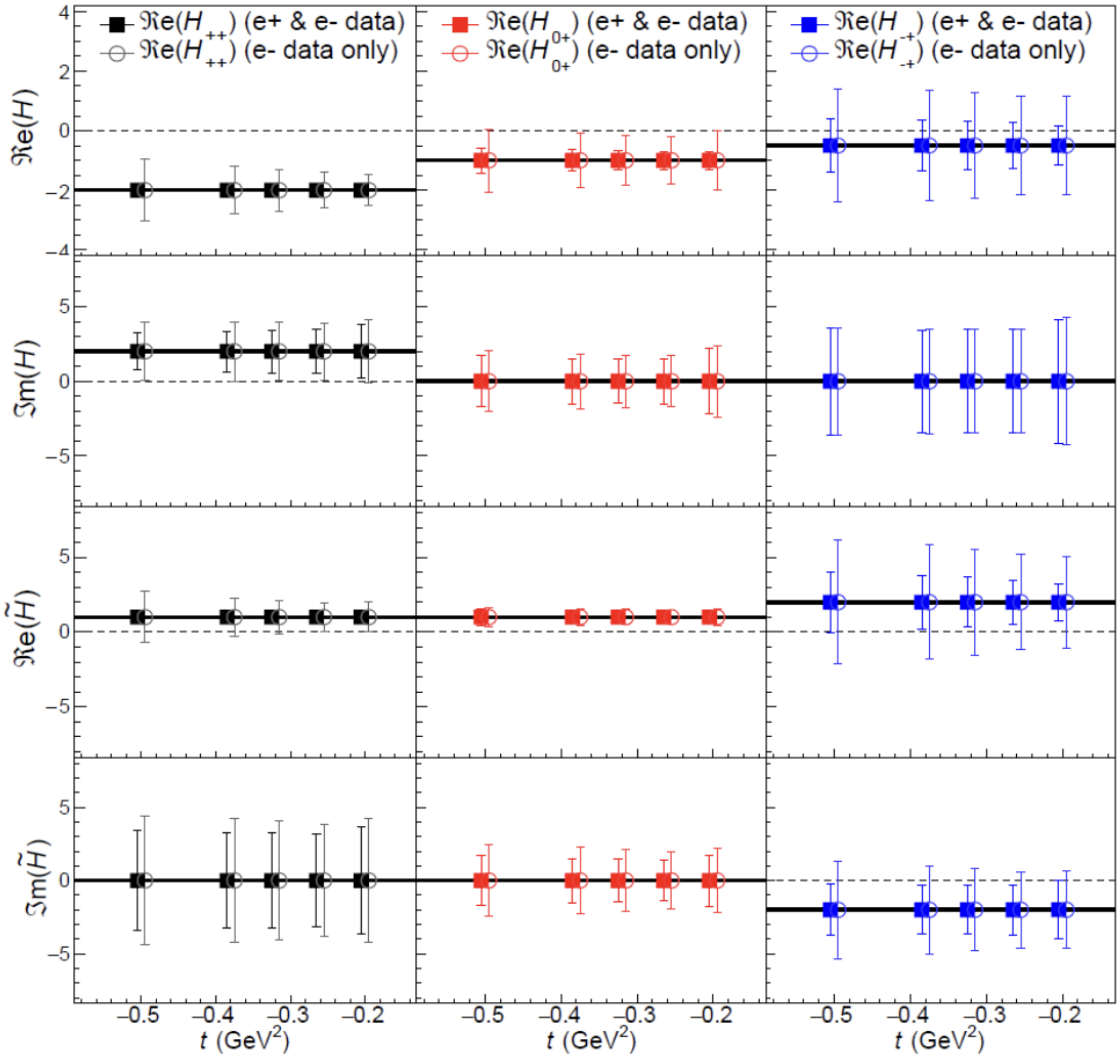
Neutral Particle Spectrometer

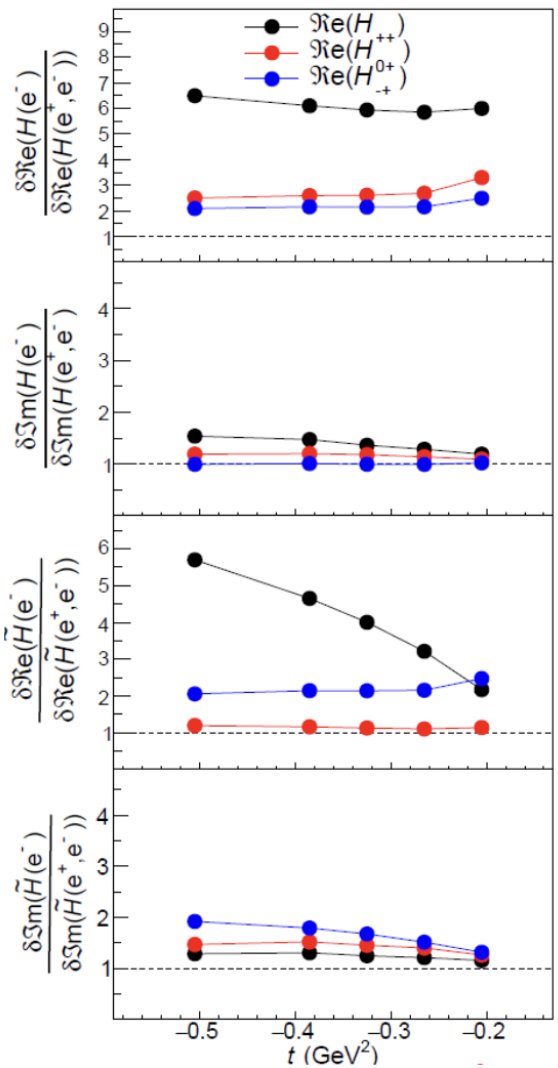






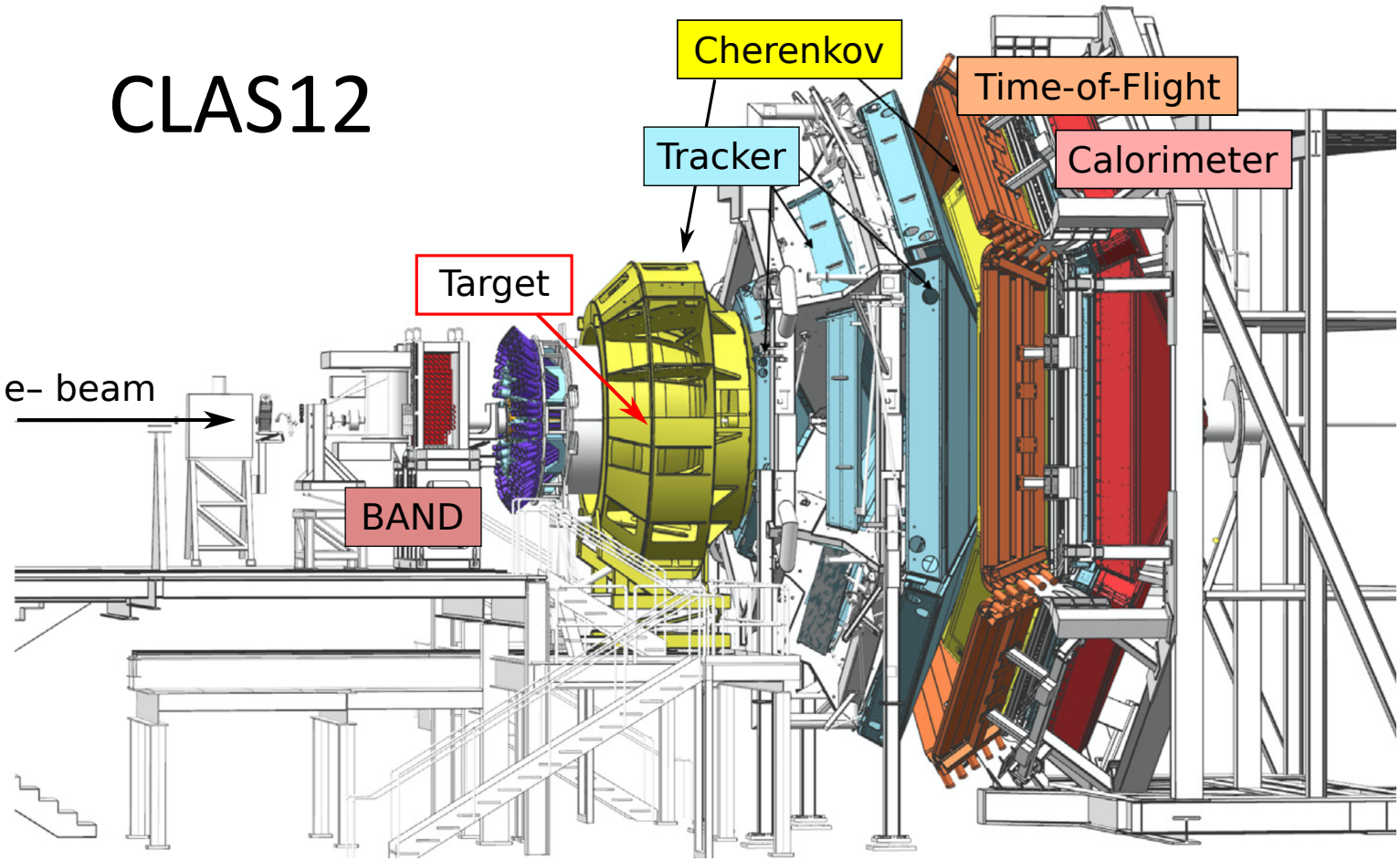
Positrons will greatly improve Compton Form Factor extraction.





E12+23-002 in Hall B

Goal: determination of helicity and charge asymmetries over a wide phase space.



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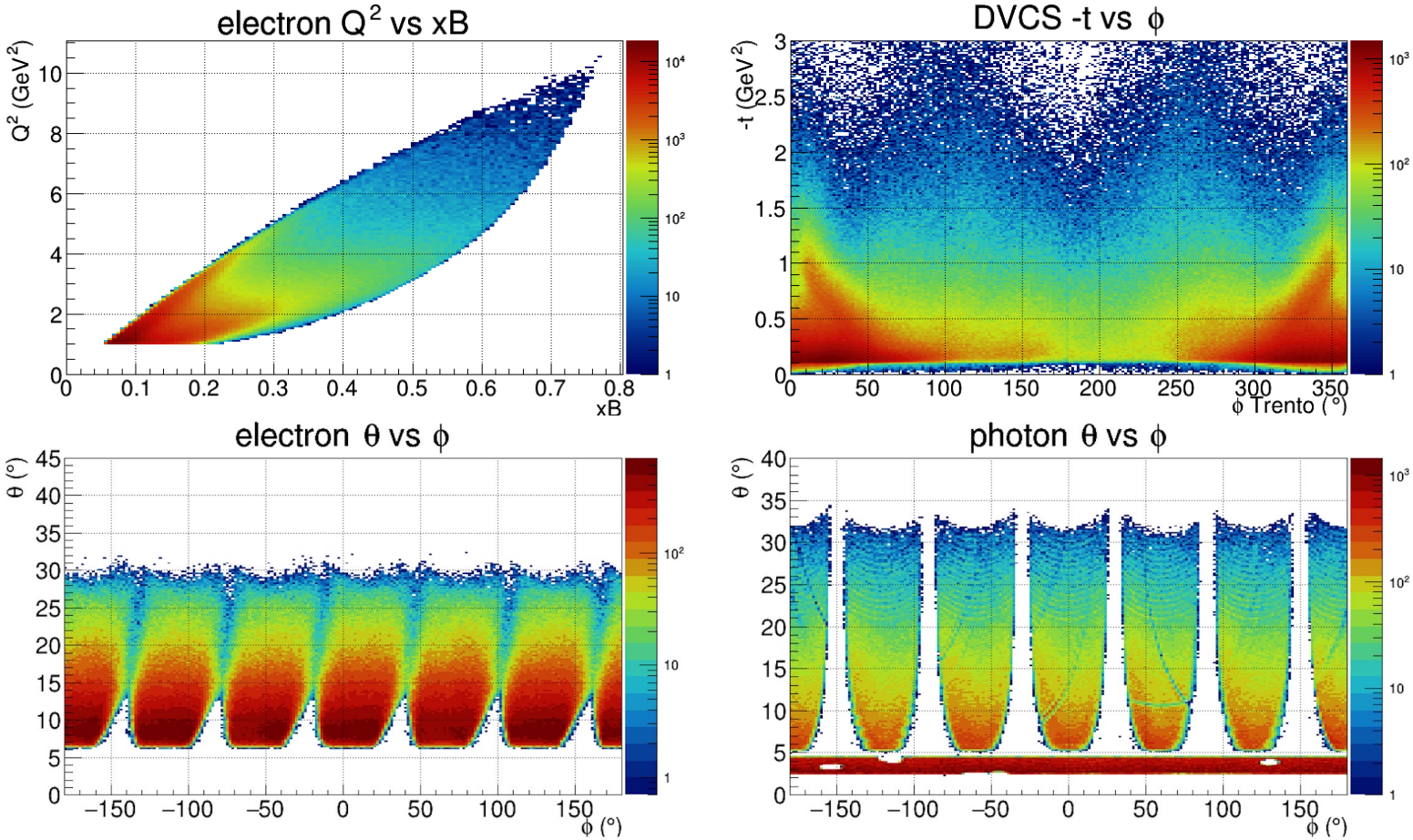

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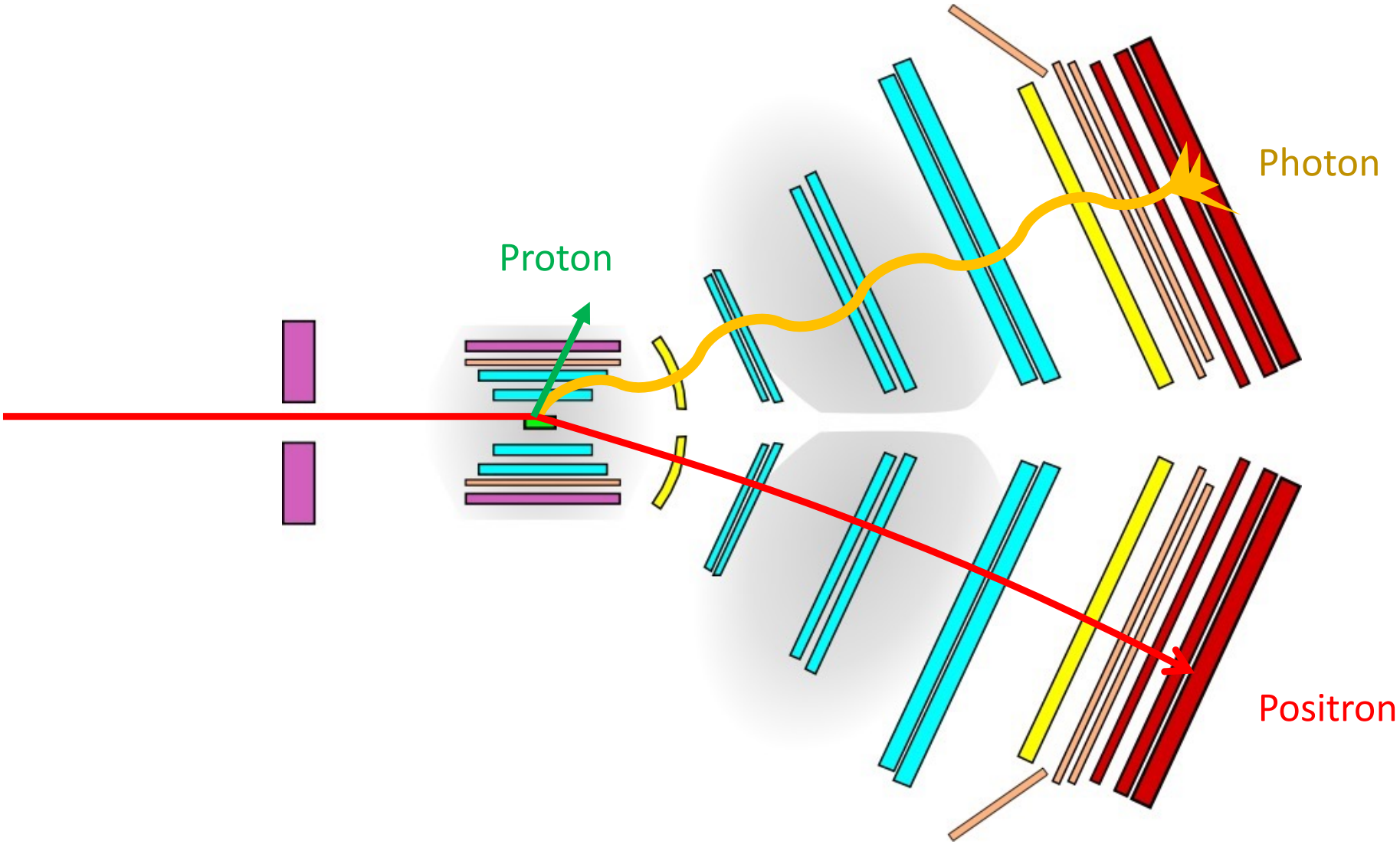

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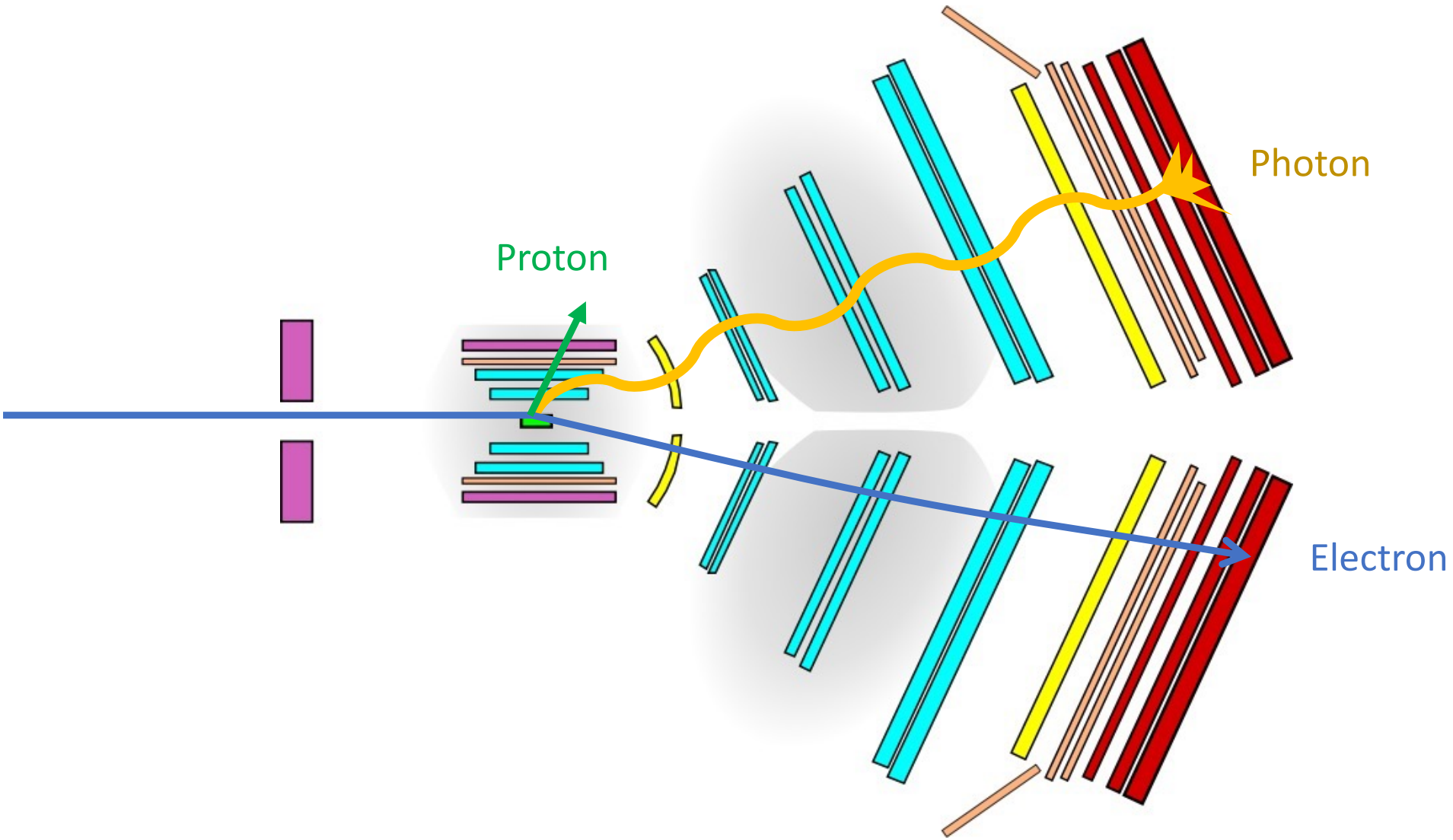
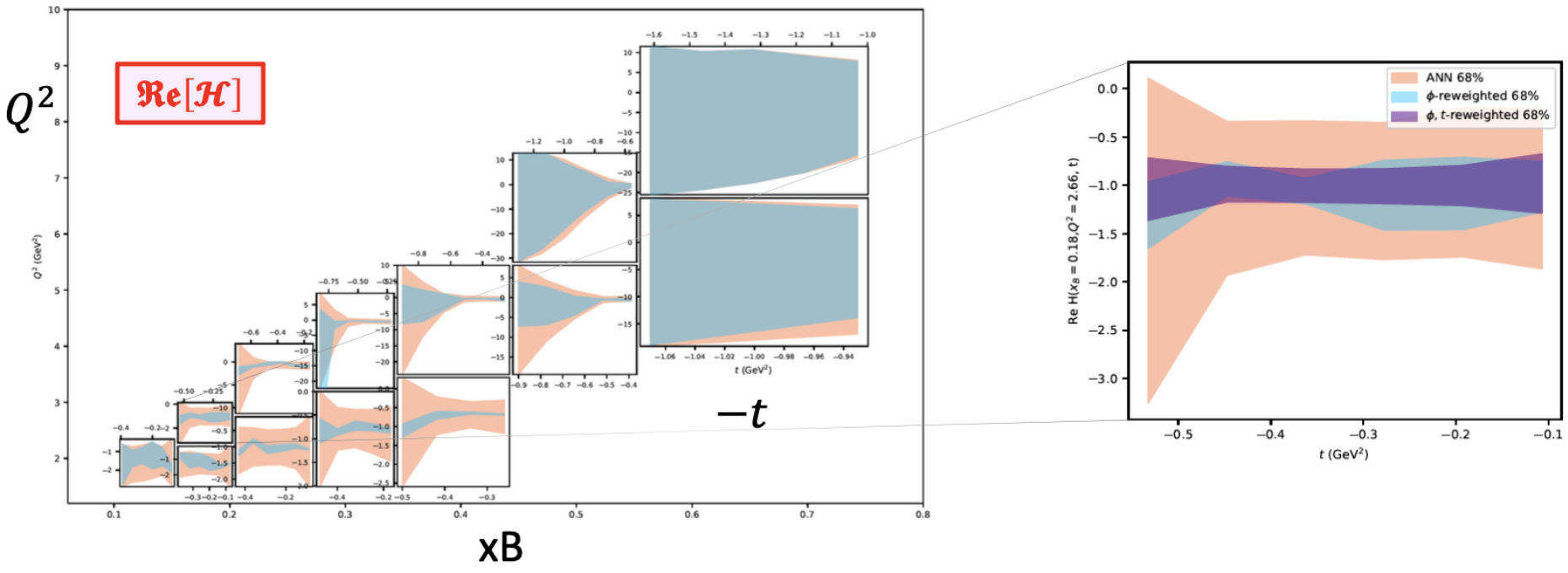


Positrons significantly improve constraints on GPDs.



H. Dutrieux, V. Bertone, H. Moutarde, P. Sznajder, EPJ A 57:250 (2021)

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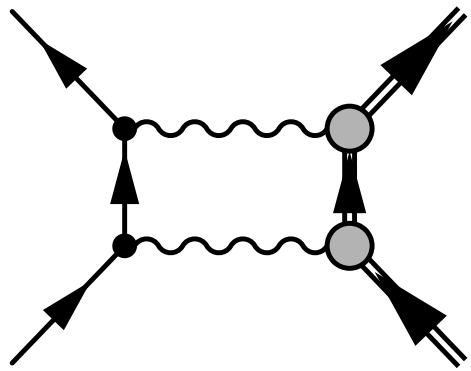

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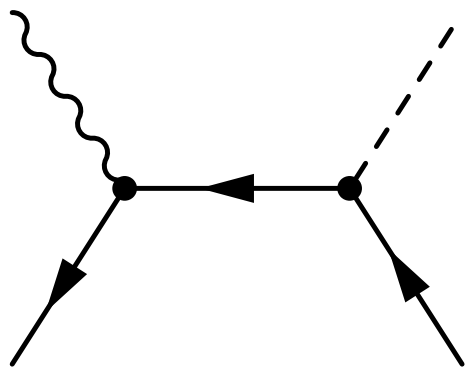

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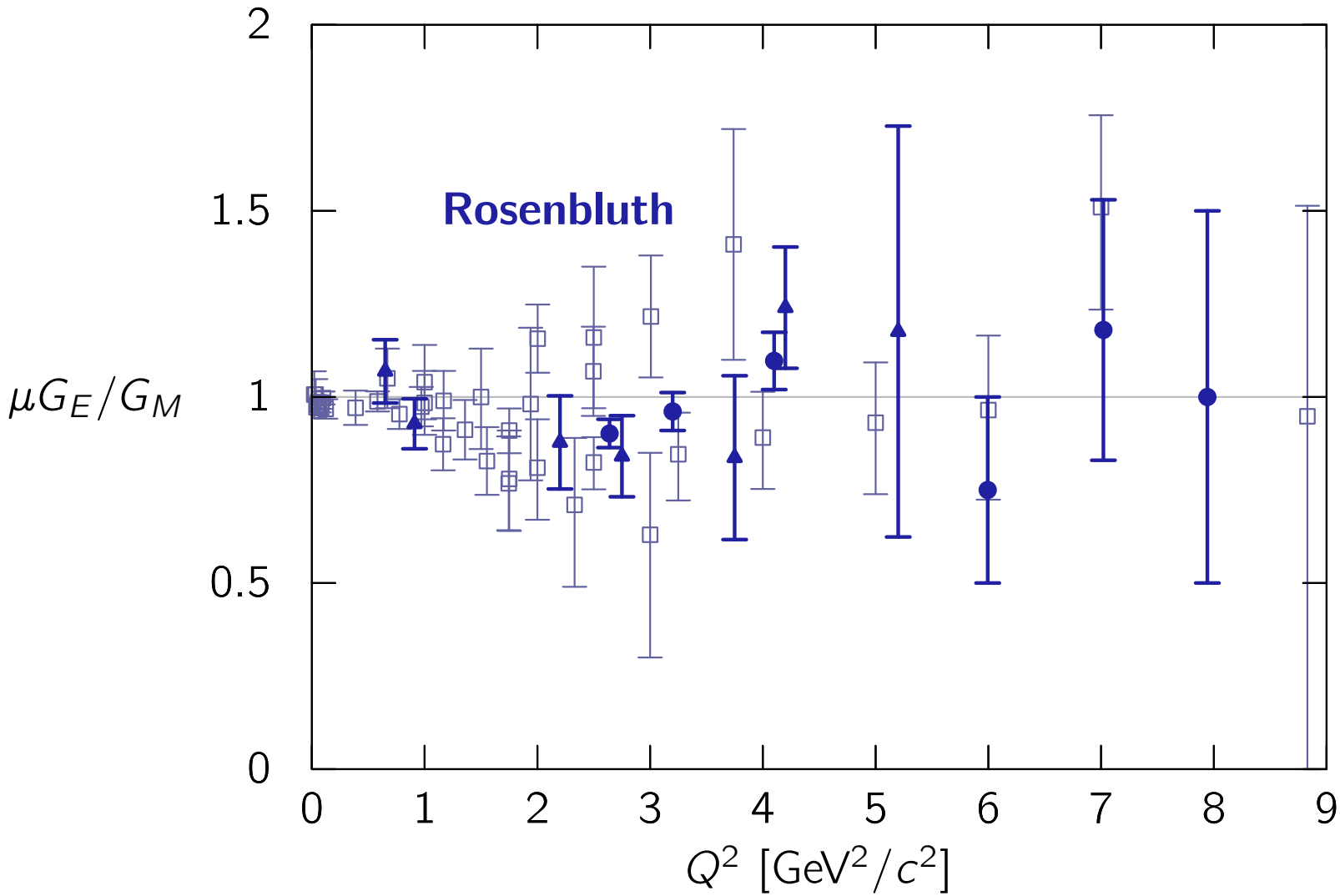

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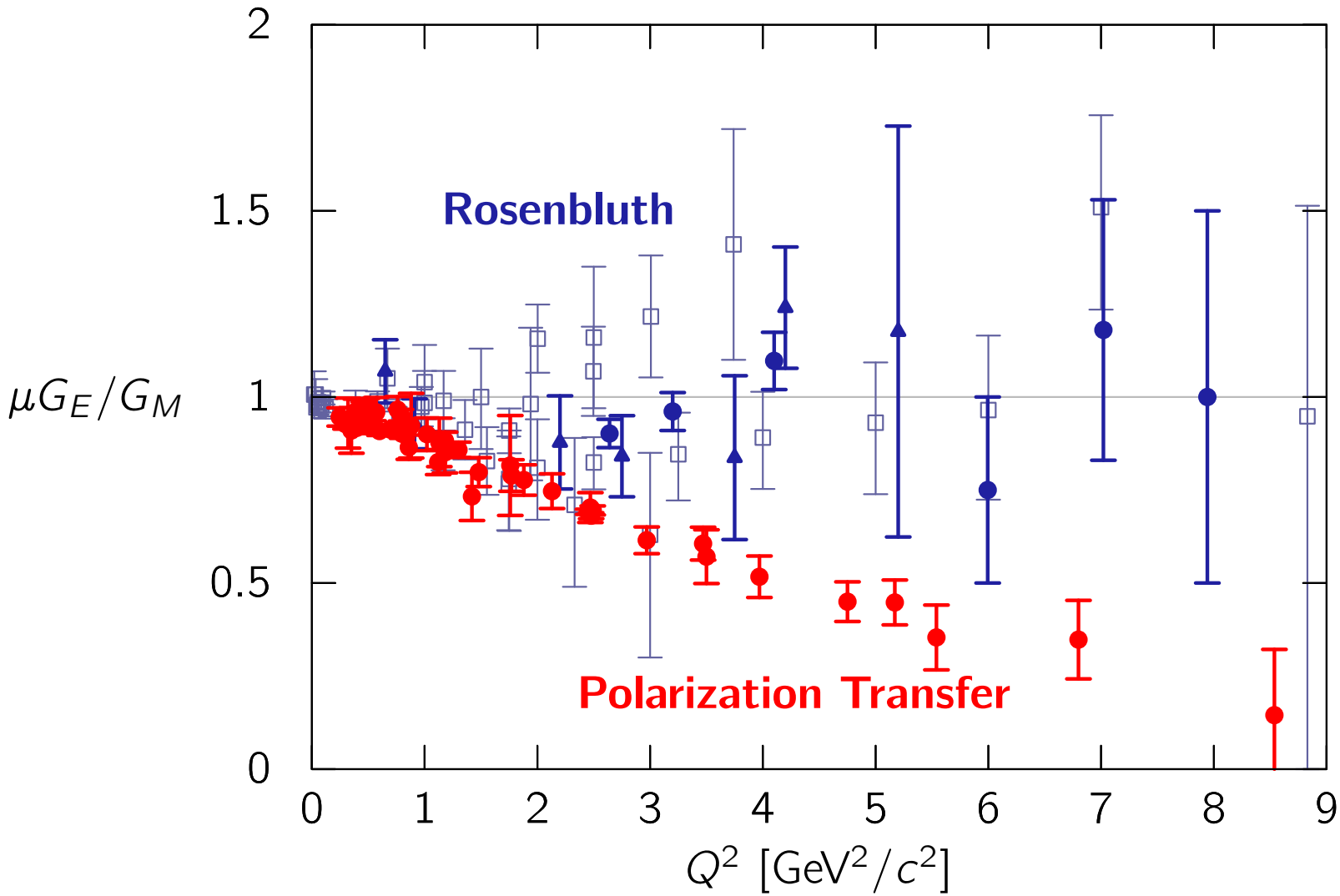

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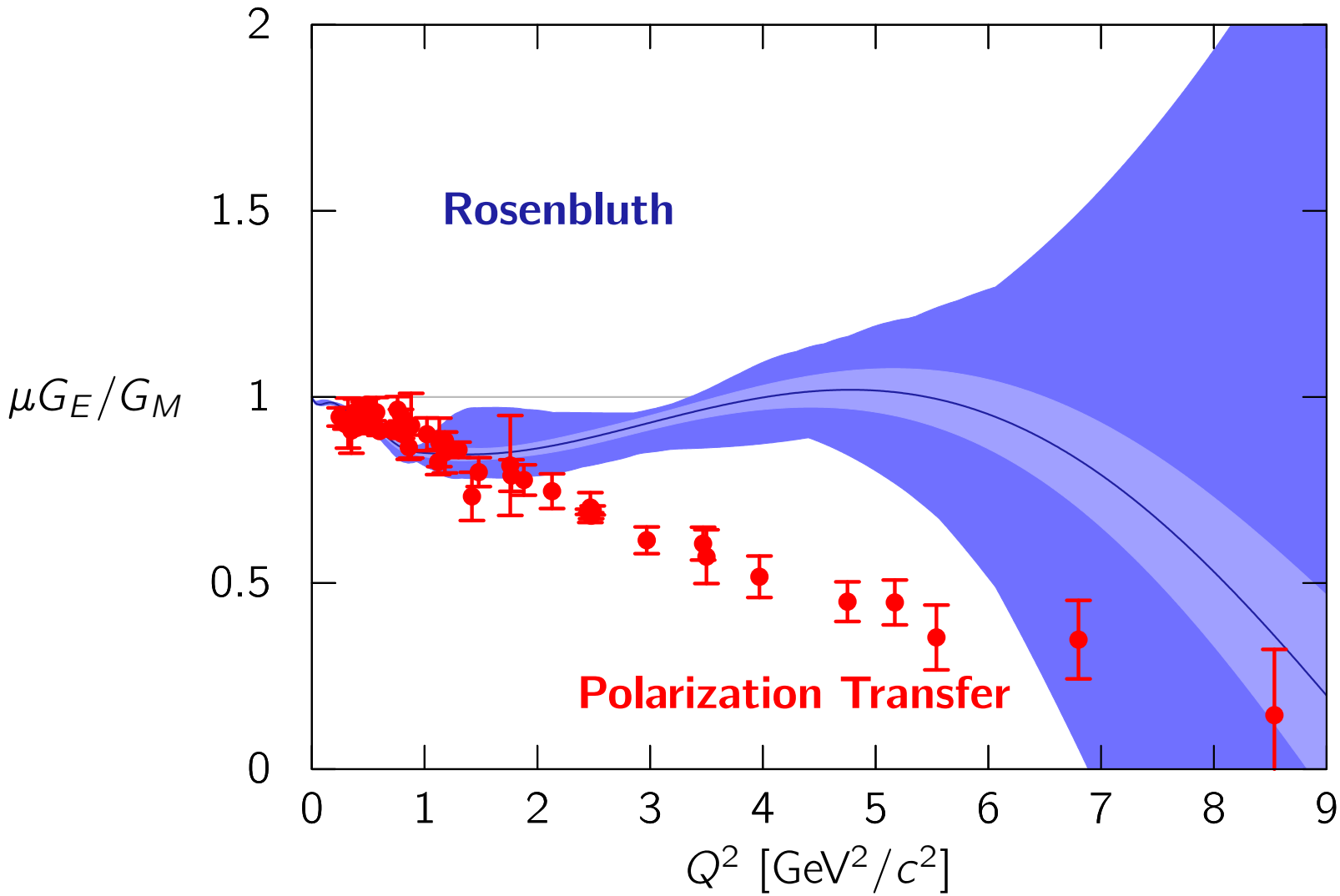

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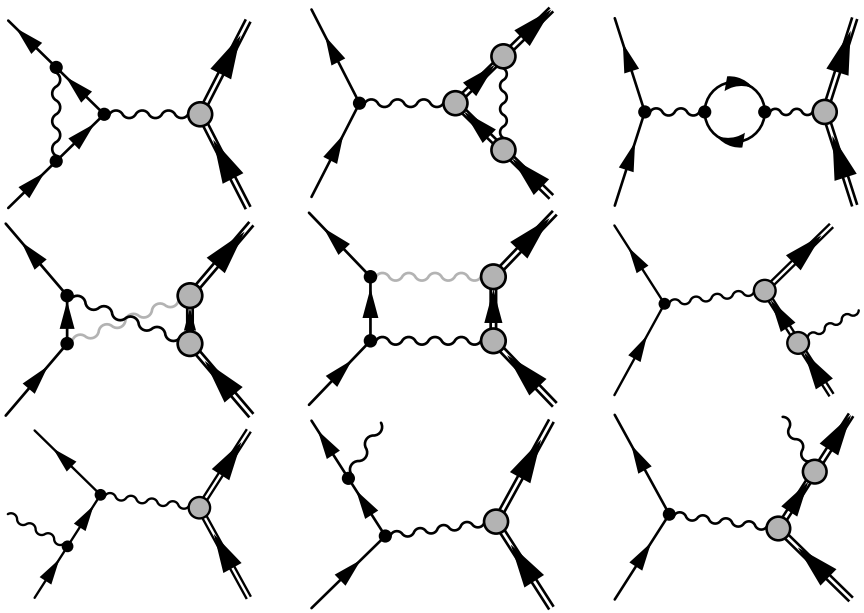
The standard set



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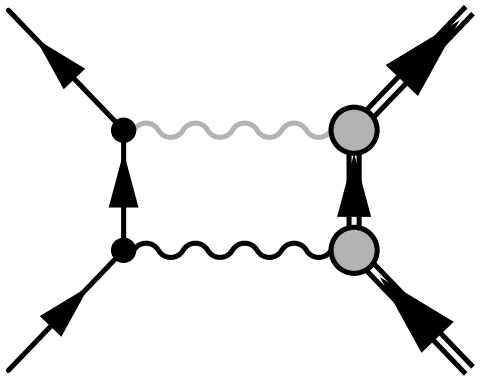

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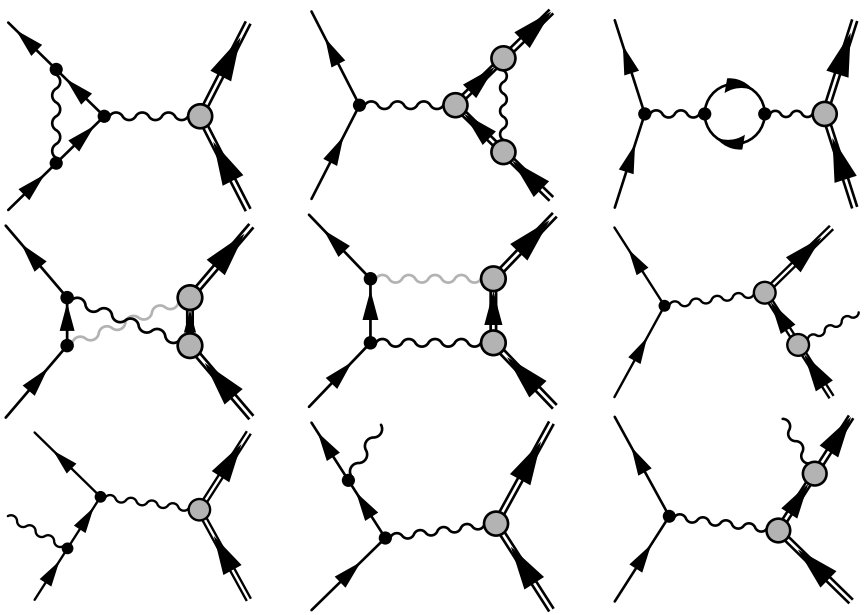

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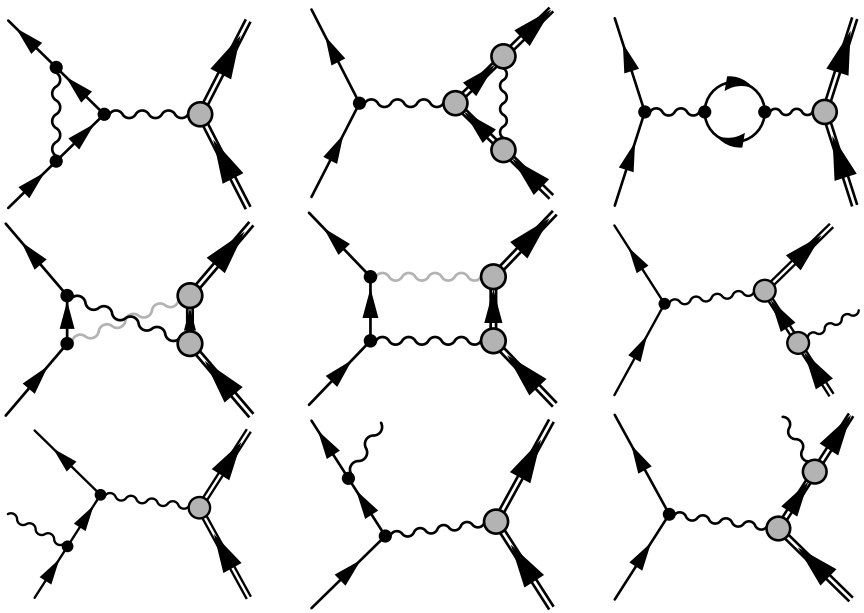

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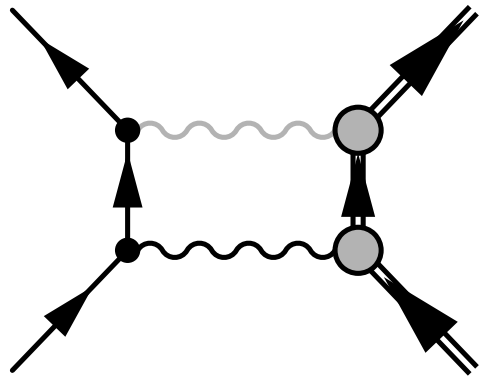
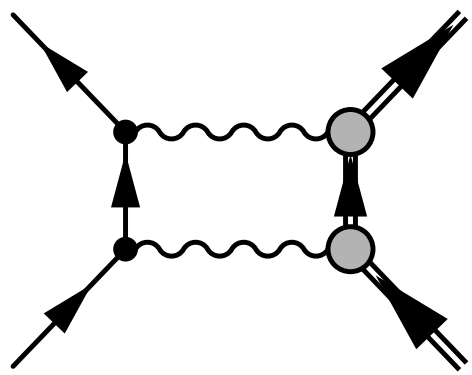


Hard TPE (*not included!*)



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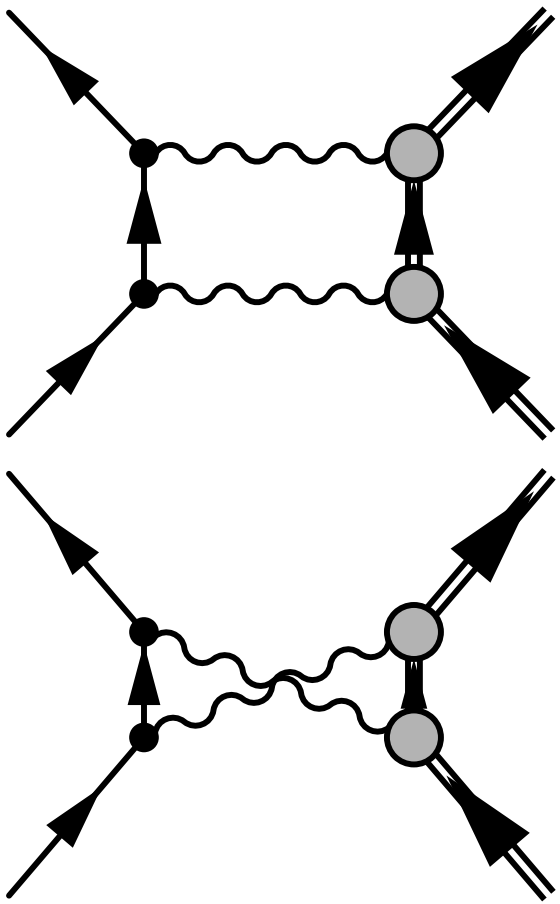

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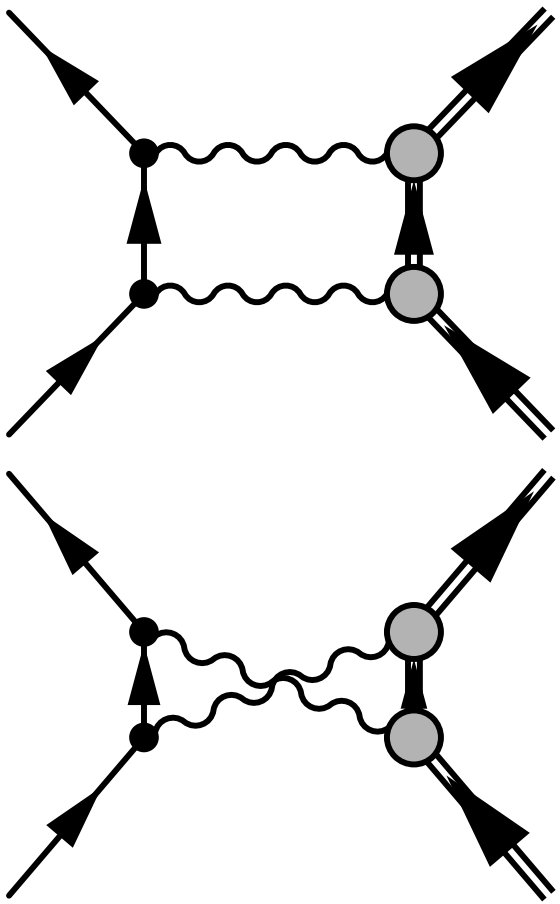
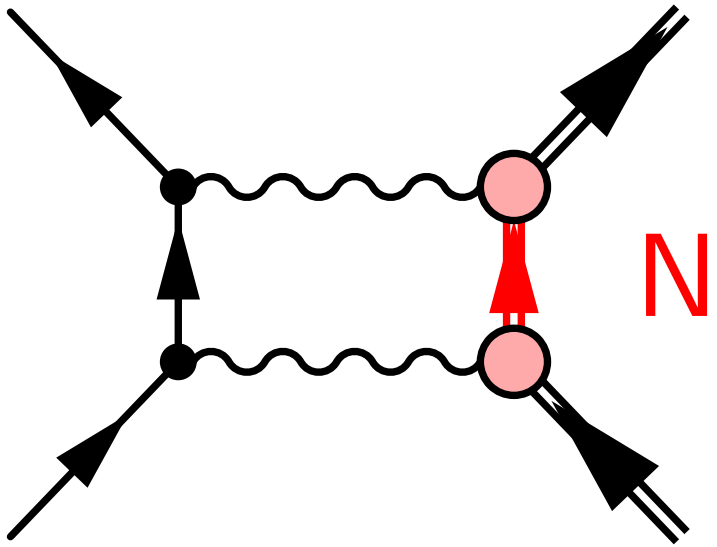


- Proton FFs are ambiguous.
- TPE is hard to calculate.
- Recent experiments inconclusive
- *Field is embarking on 3d imaging campaign of the nucleon.*

Calculations of two-photon exchange come with model dependency.



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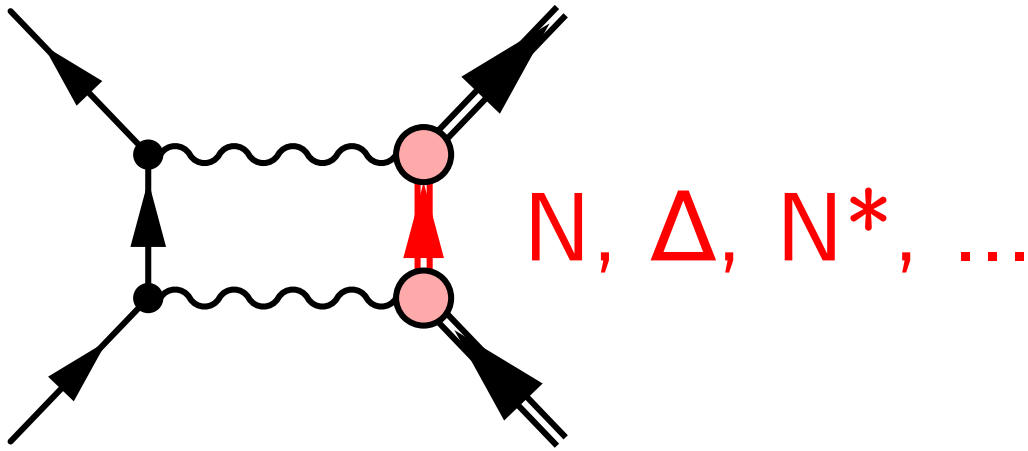
- Treat off-shell propagator as collection of hadronic states.
- e.g. Blunden, Melnitchouk, PRC '17, Ahmed et al., PRC '20, '23



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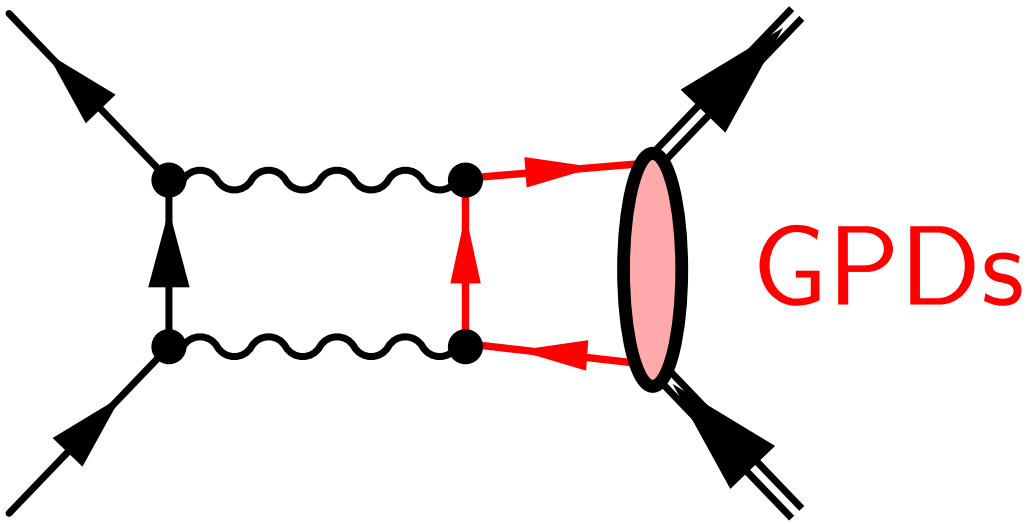

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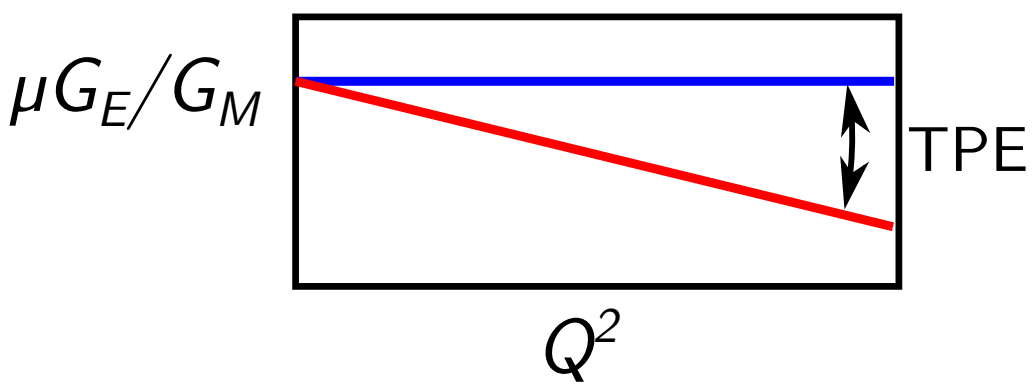

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Alternate Approaches

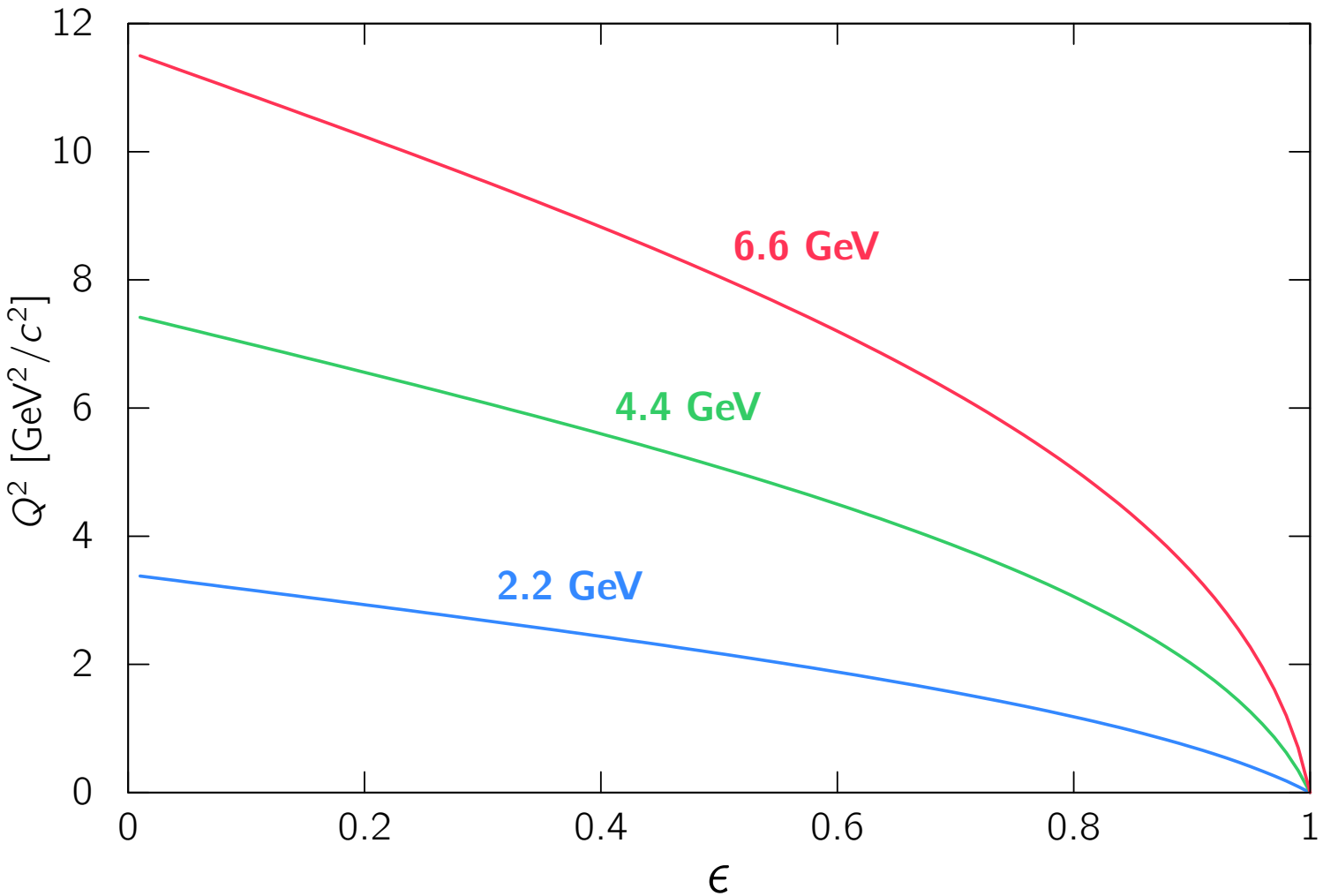
- e.g., Kuraev et al., PRC '08

TPE produces an asymmetry between electron and positron scattering.

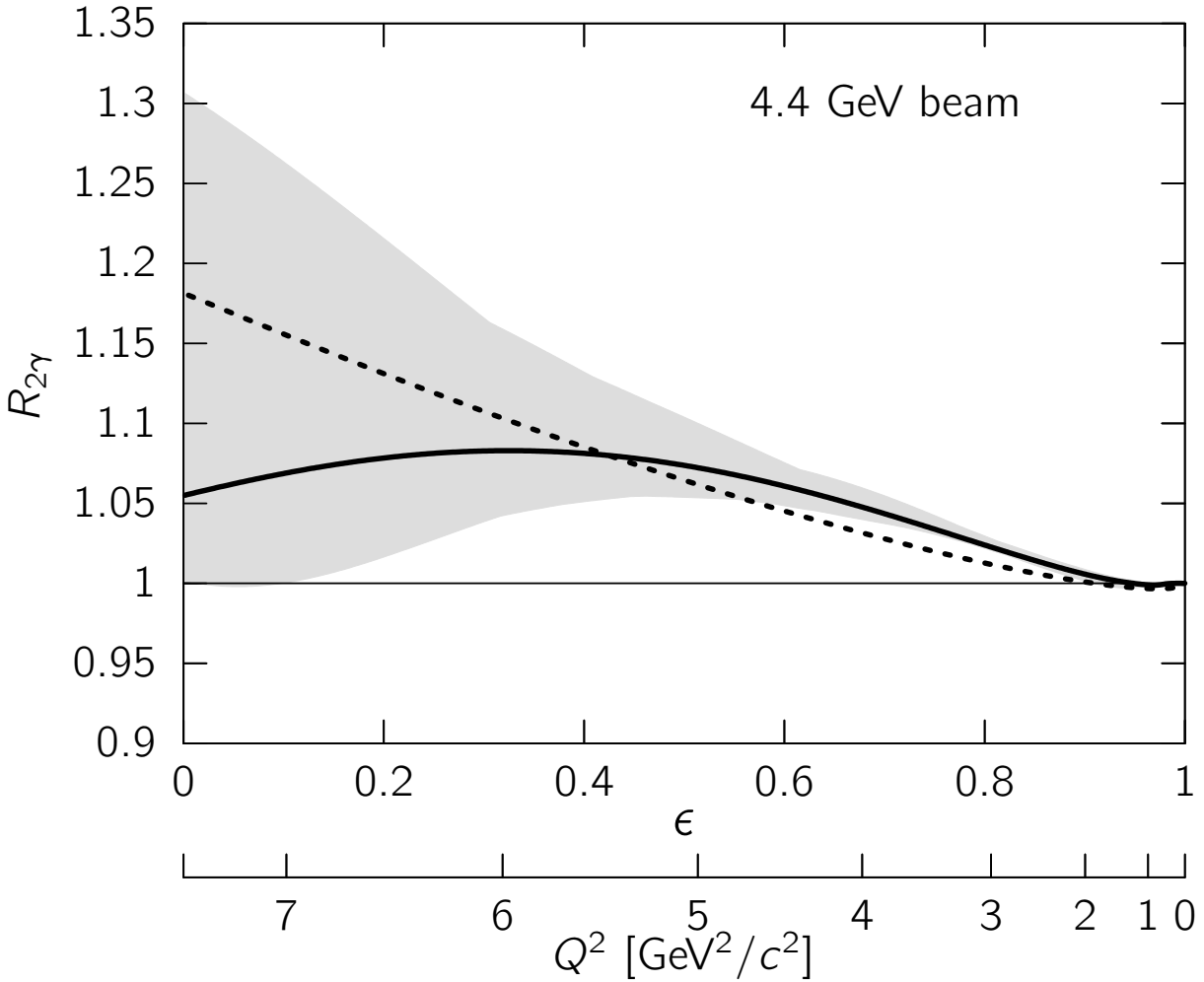
$$\mathcal{M} = \quad + \quad + \mathcal{O}(\alpha^3)$$

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

Elastic scattering is a 2D space



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



Phenomenology
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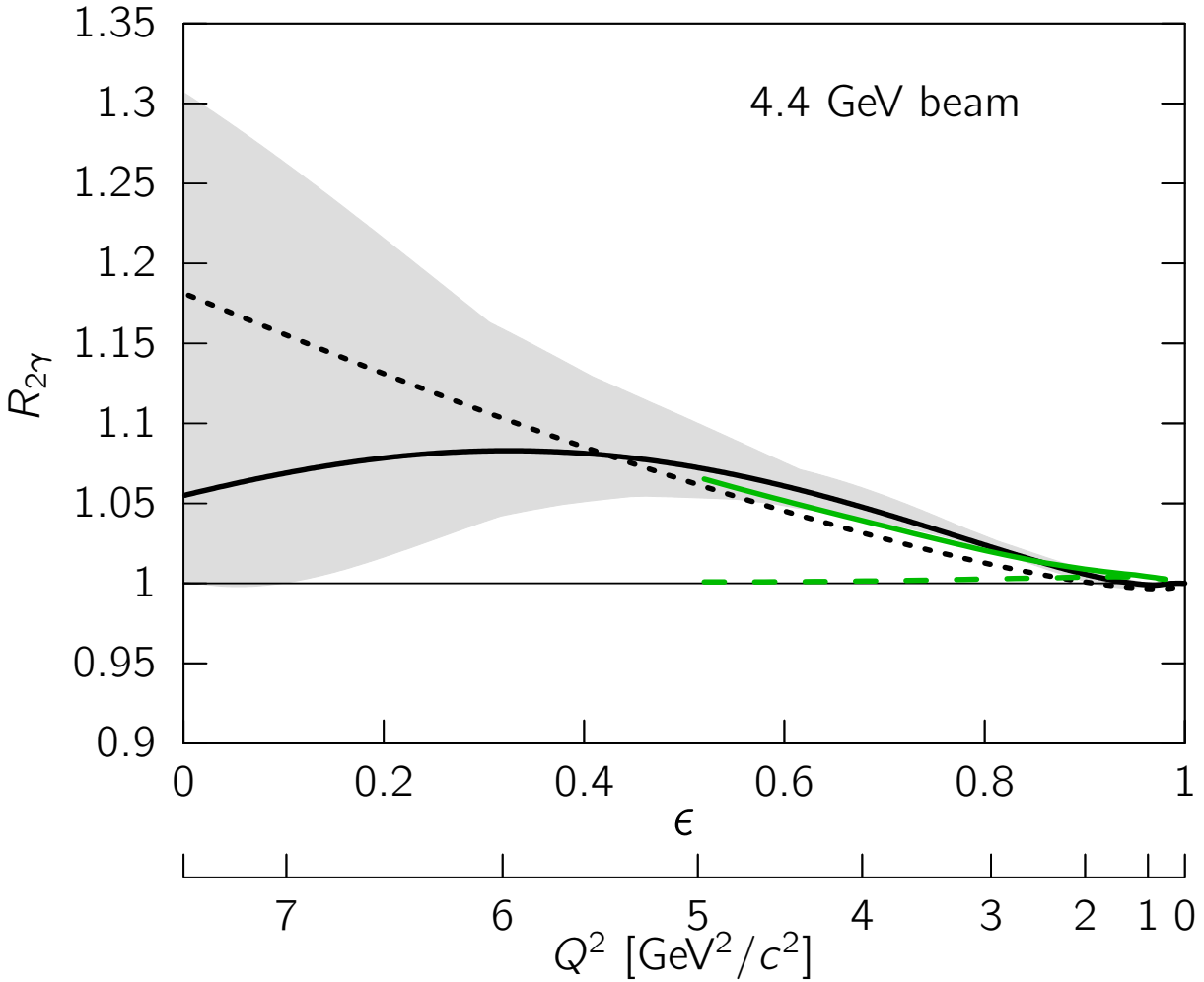

Phenomenology
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Hadronic
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Blunden et al. (full)

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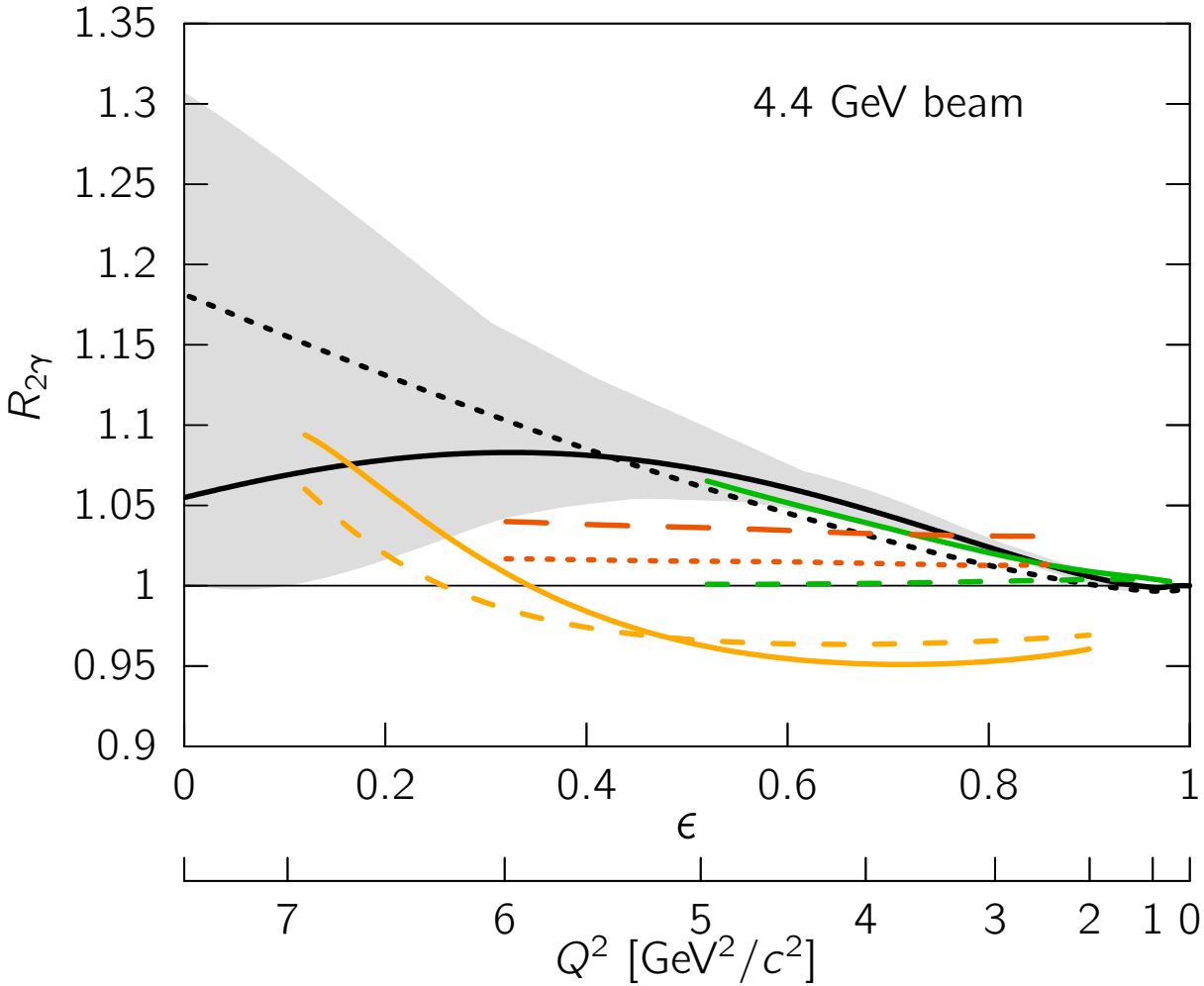

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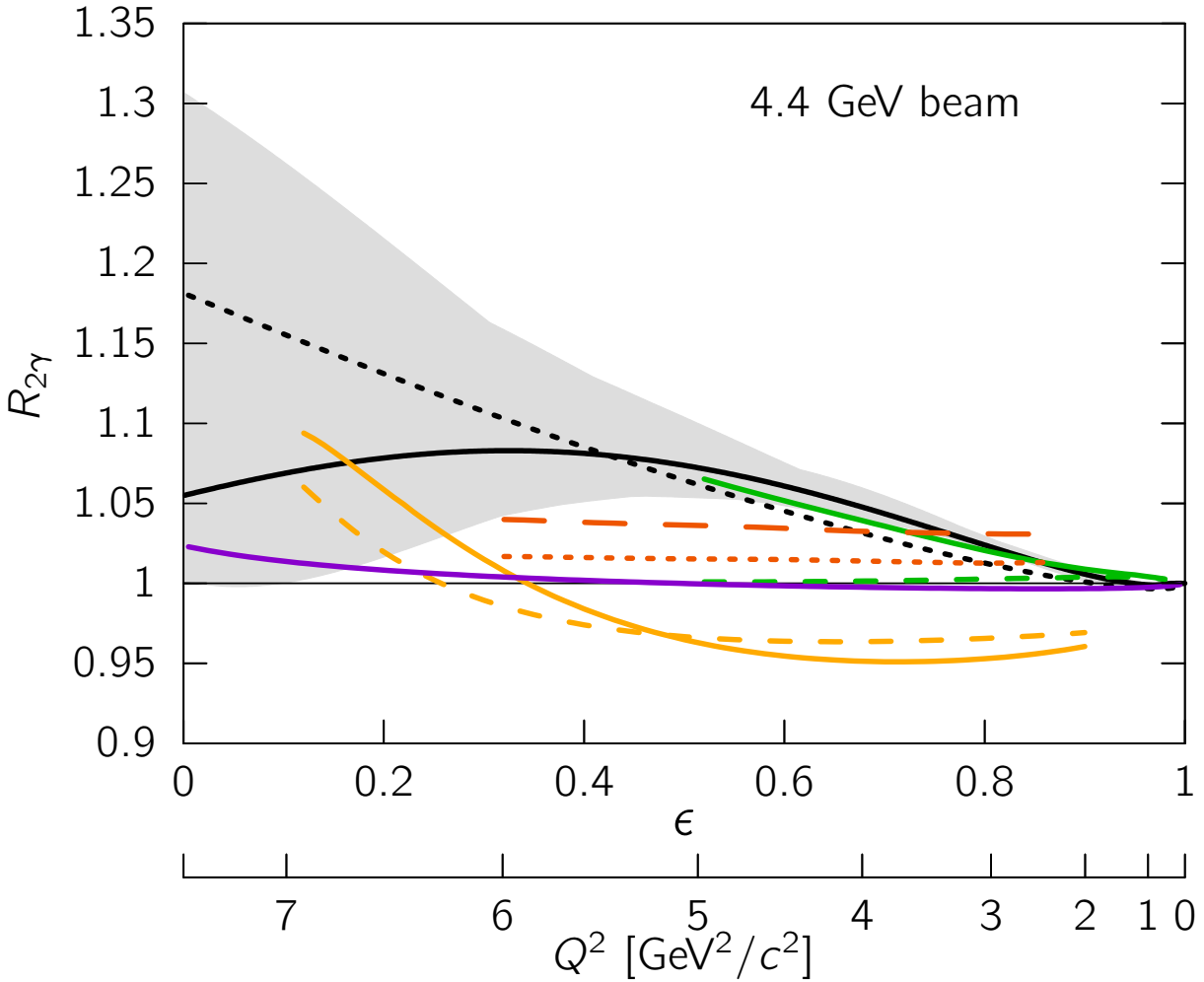
Kivel et al. BLW.
Afanasev et al. Gauss.
Afanasev et al. Regge

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



Phenomenology
Schmidt
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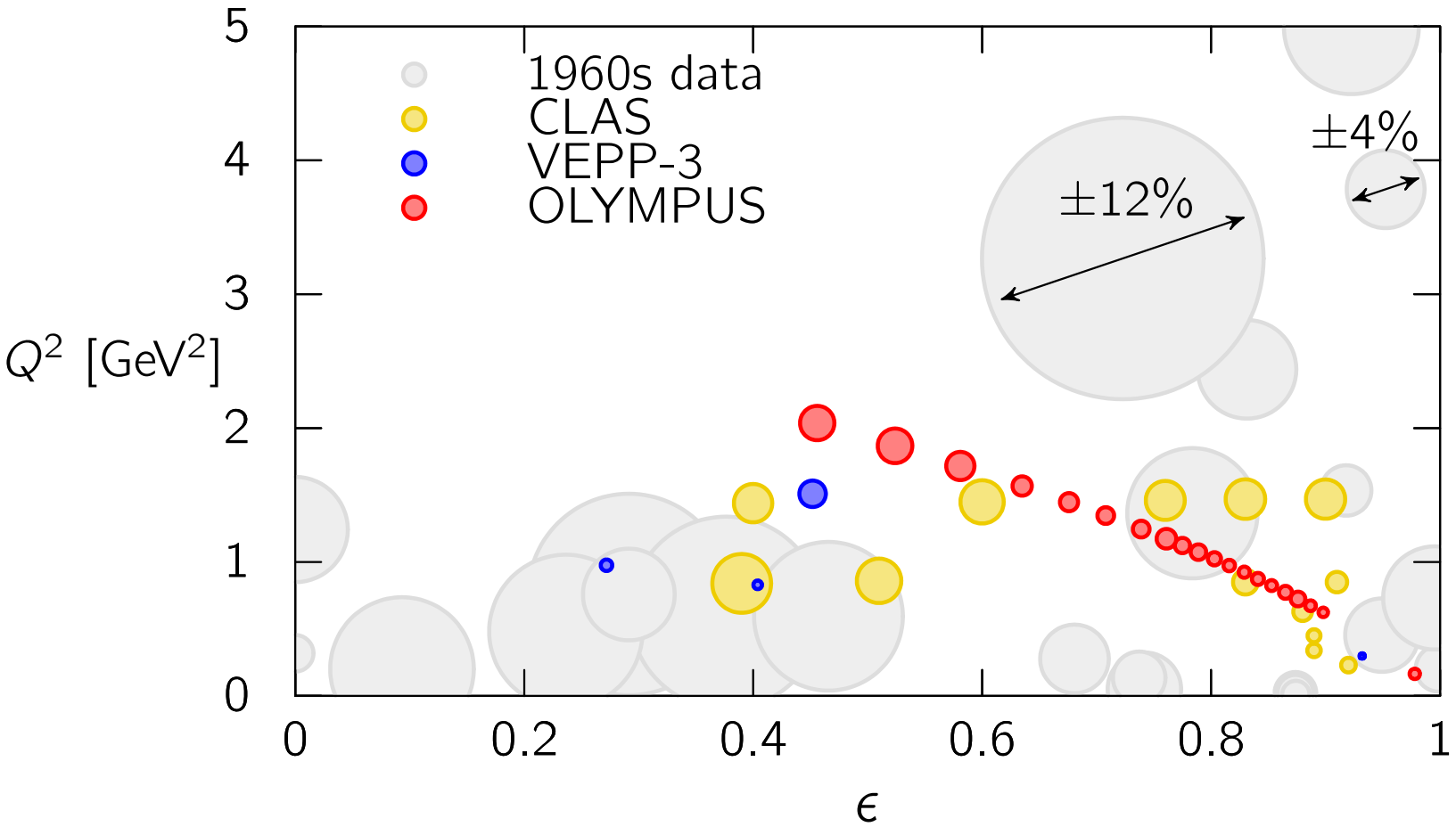
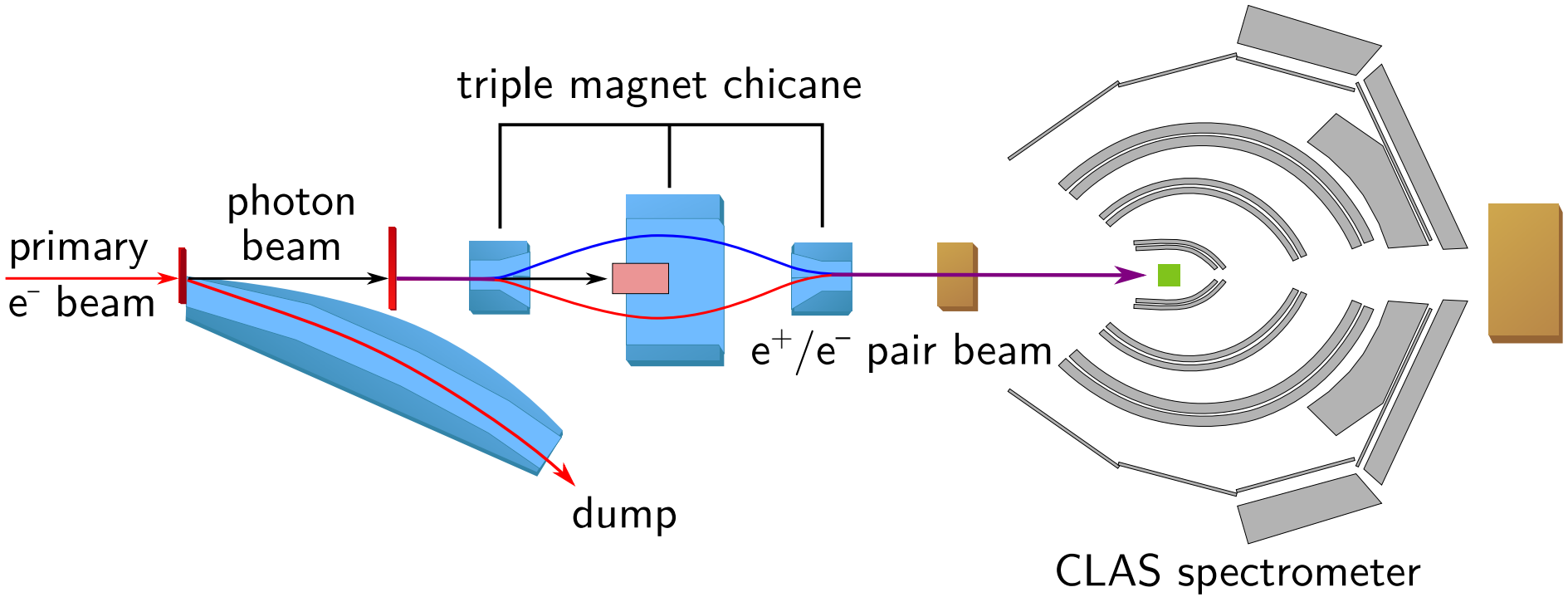
Other
Kuraev et al.

Three recent experiments measured hard TPE.

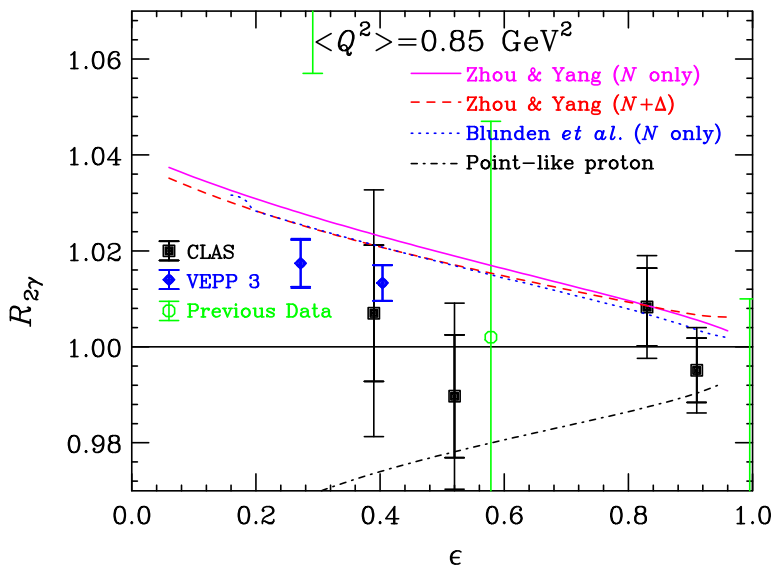


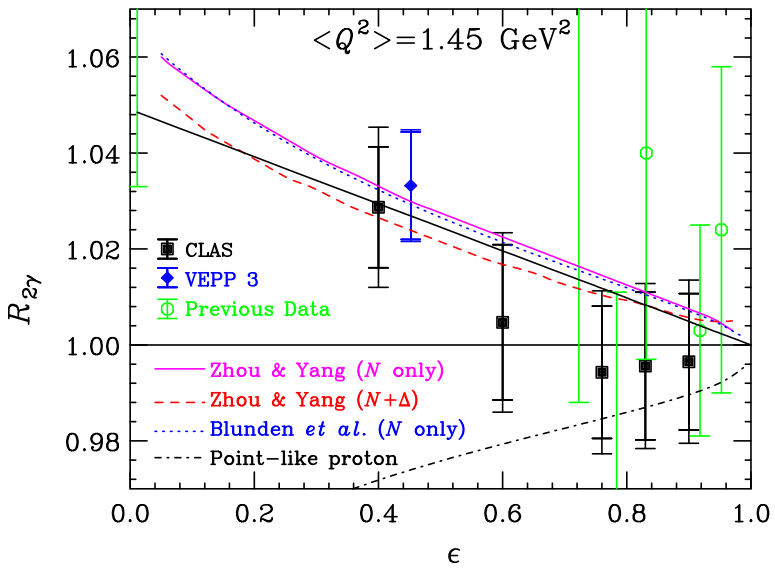
CLAS Two-Photon Exchange Experiment

TPE/eg5 run period (2010–11)



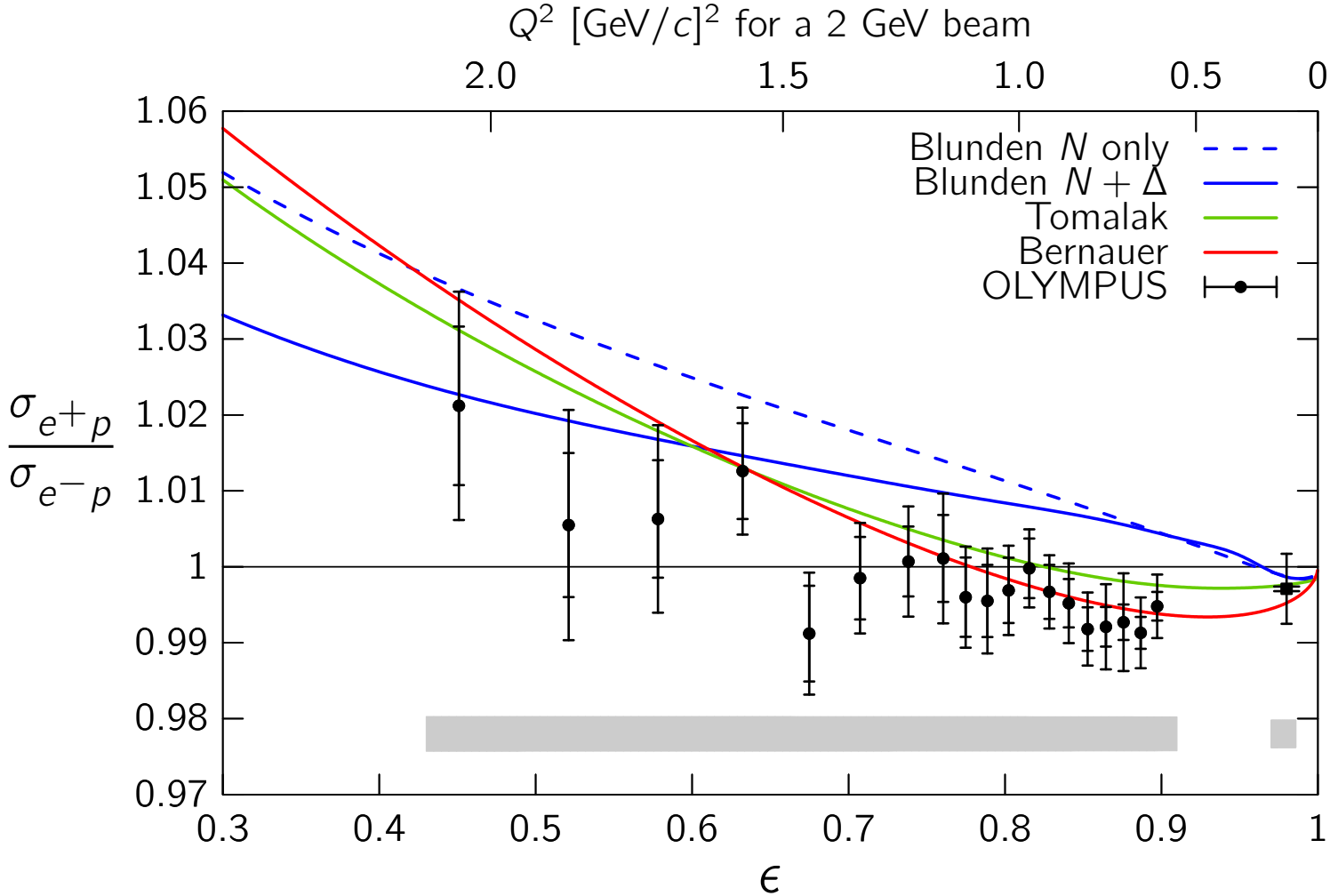
CLAS Two-Photon Exchange Experiment





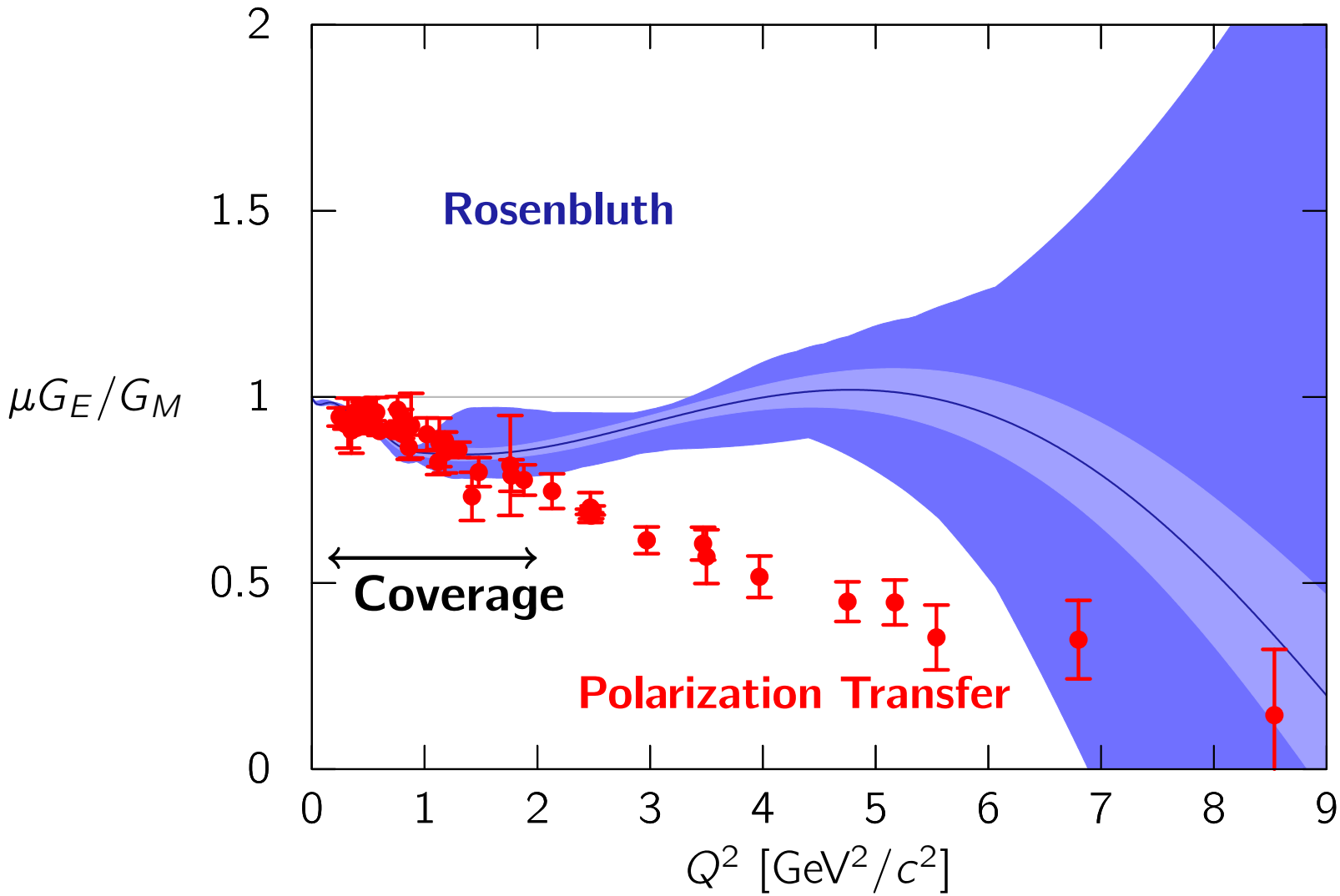
D. Adikaram et al., PRL 114, 062003 (2015)
D. Rimal et al., PRC 95, 065201 (2017)

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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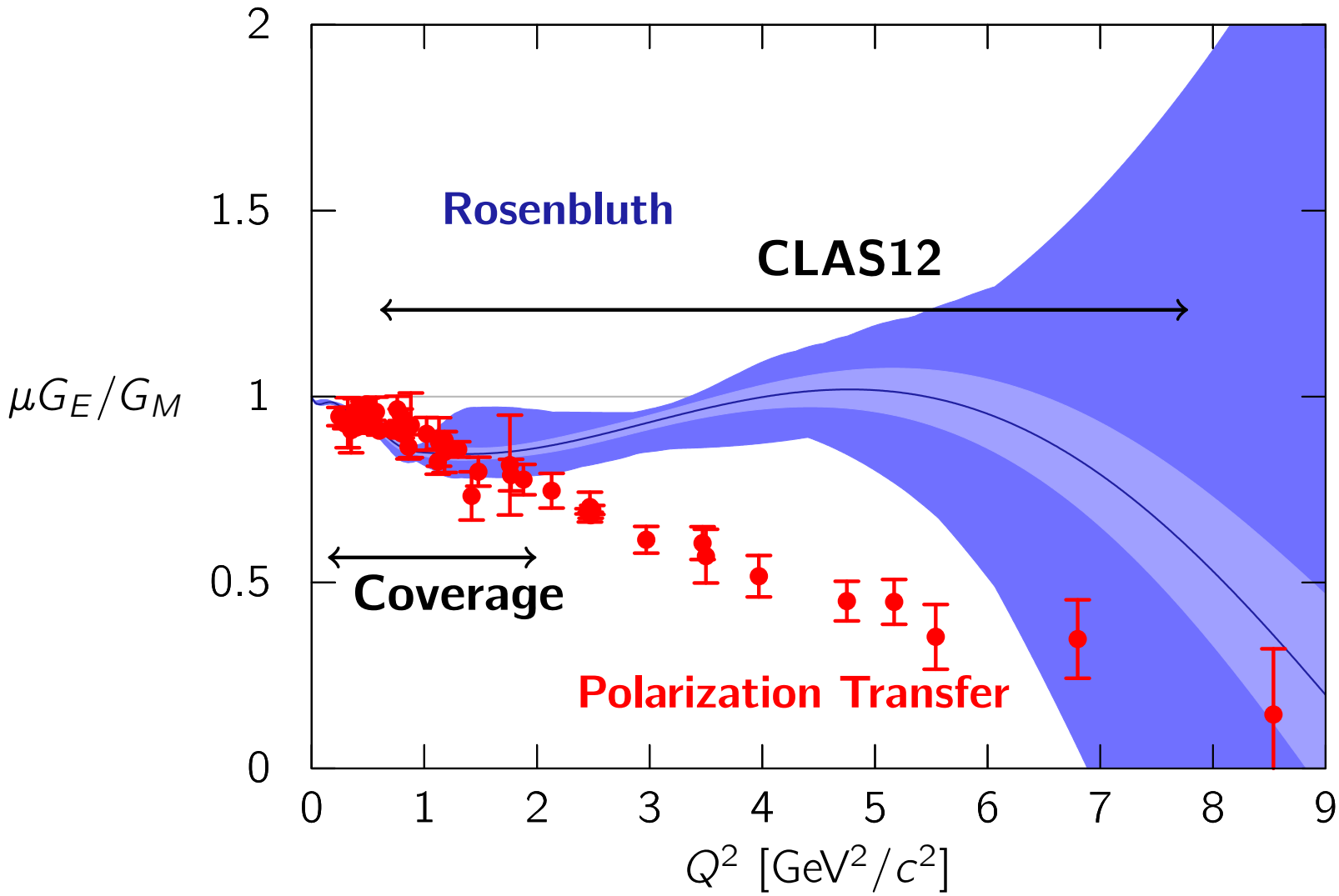


CLAS12 holds several key advantages over OLYMPUS

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

E12+23-08: 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, ≈ 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)

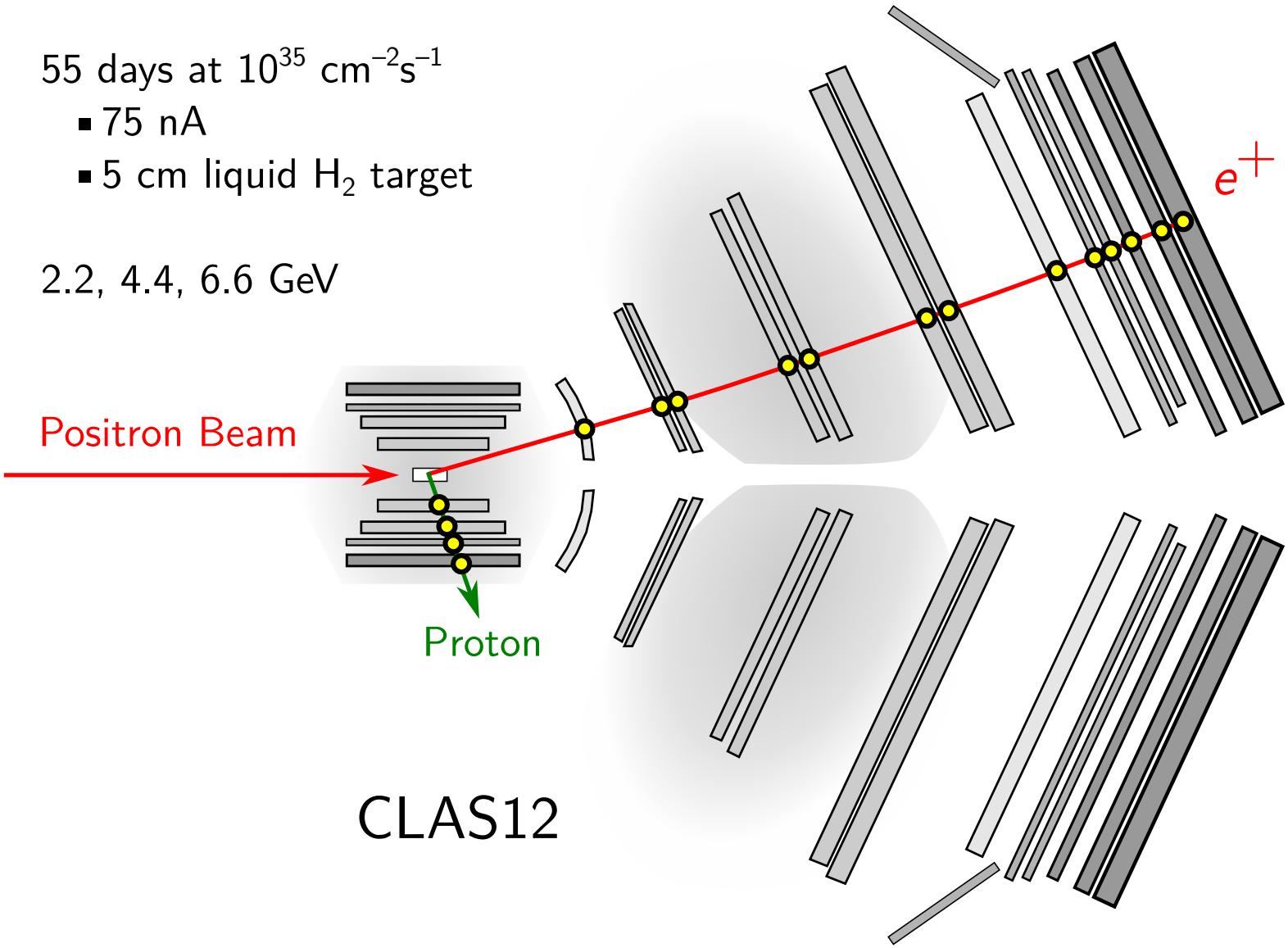
- Conditionally approved by PAC51 (2023) with an 'A' rating.

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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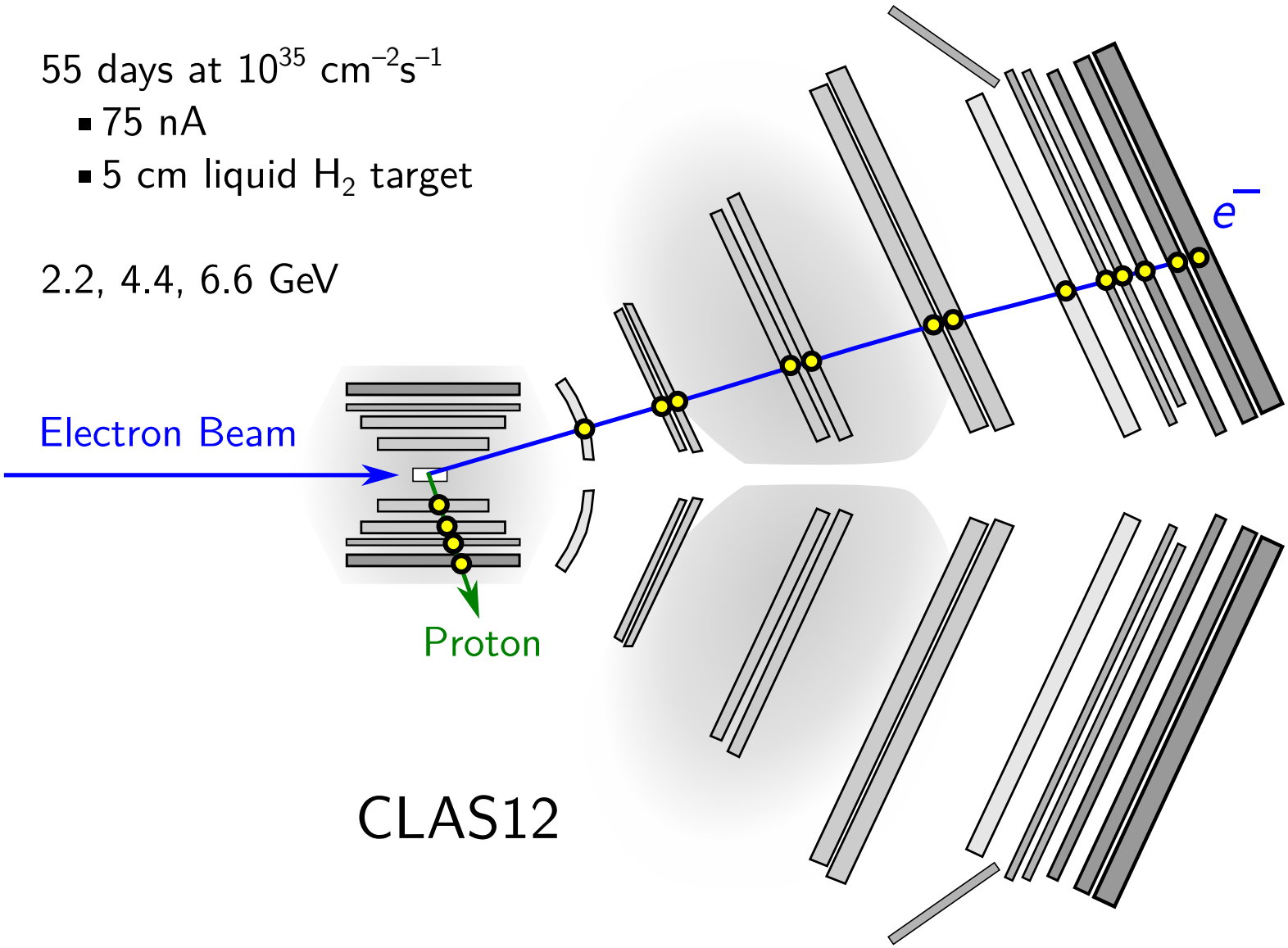
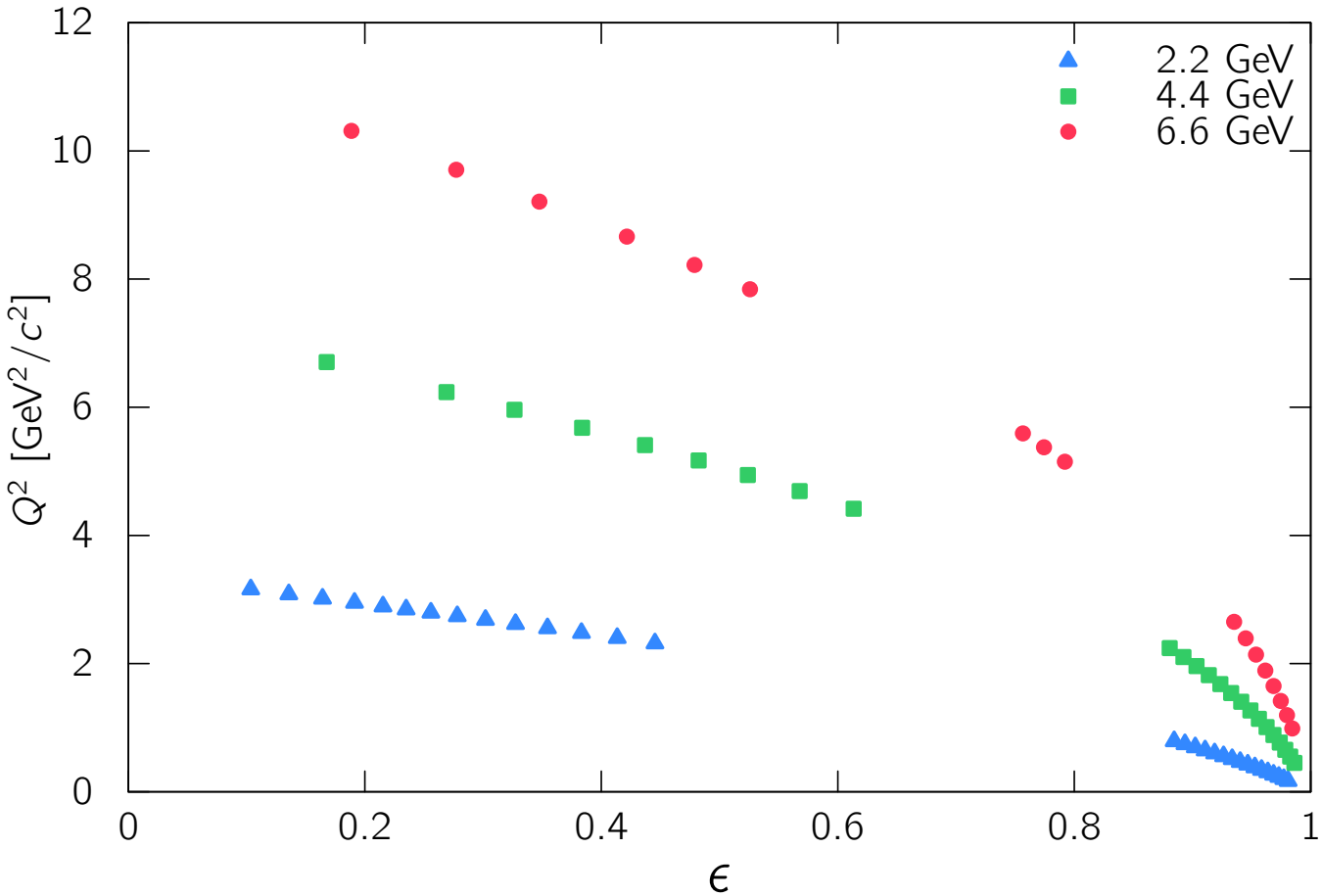


CLAS12 is ideal for mapping TPE over a wide phase space.



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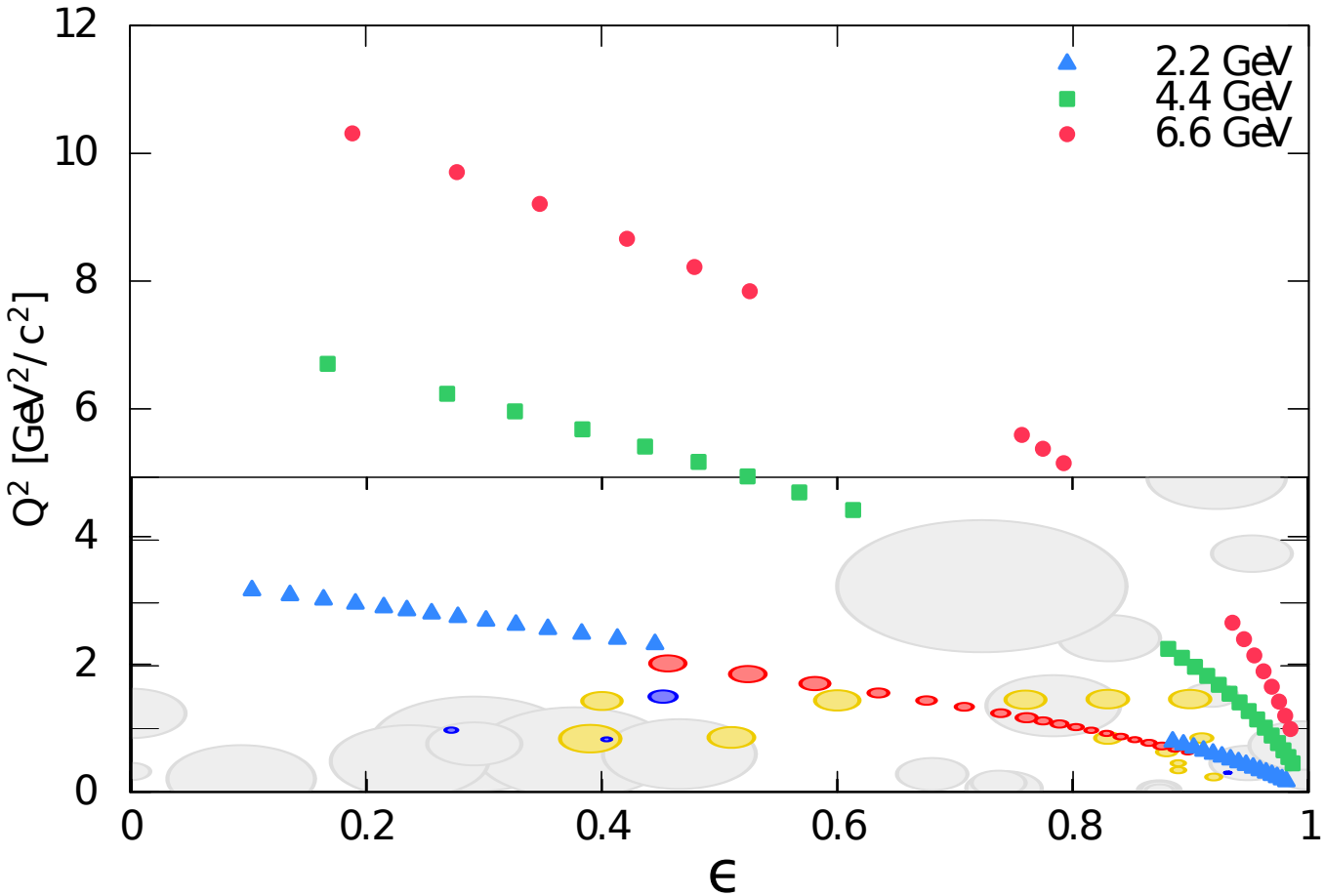

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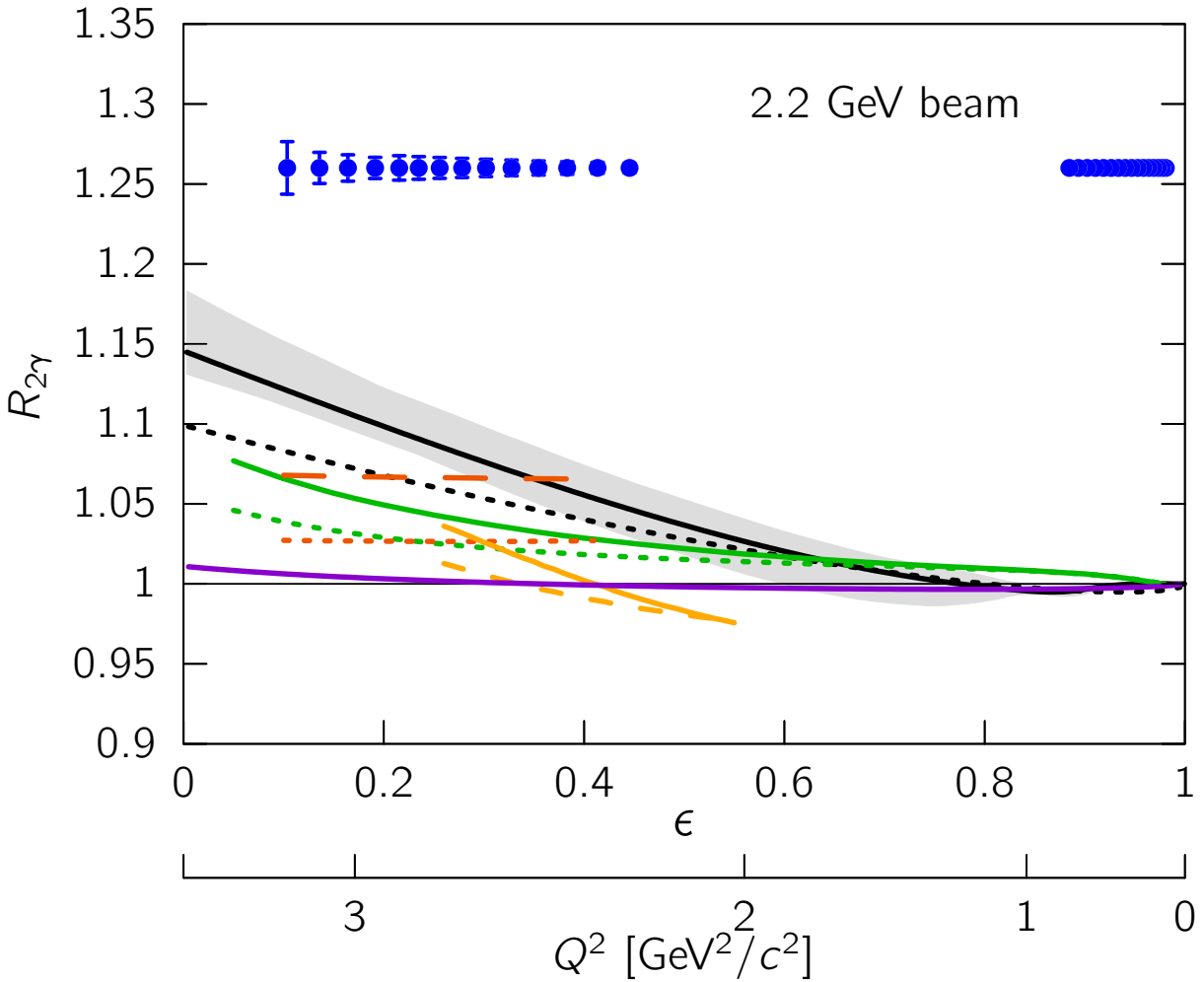

Phenomenology
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Other
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This proposal

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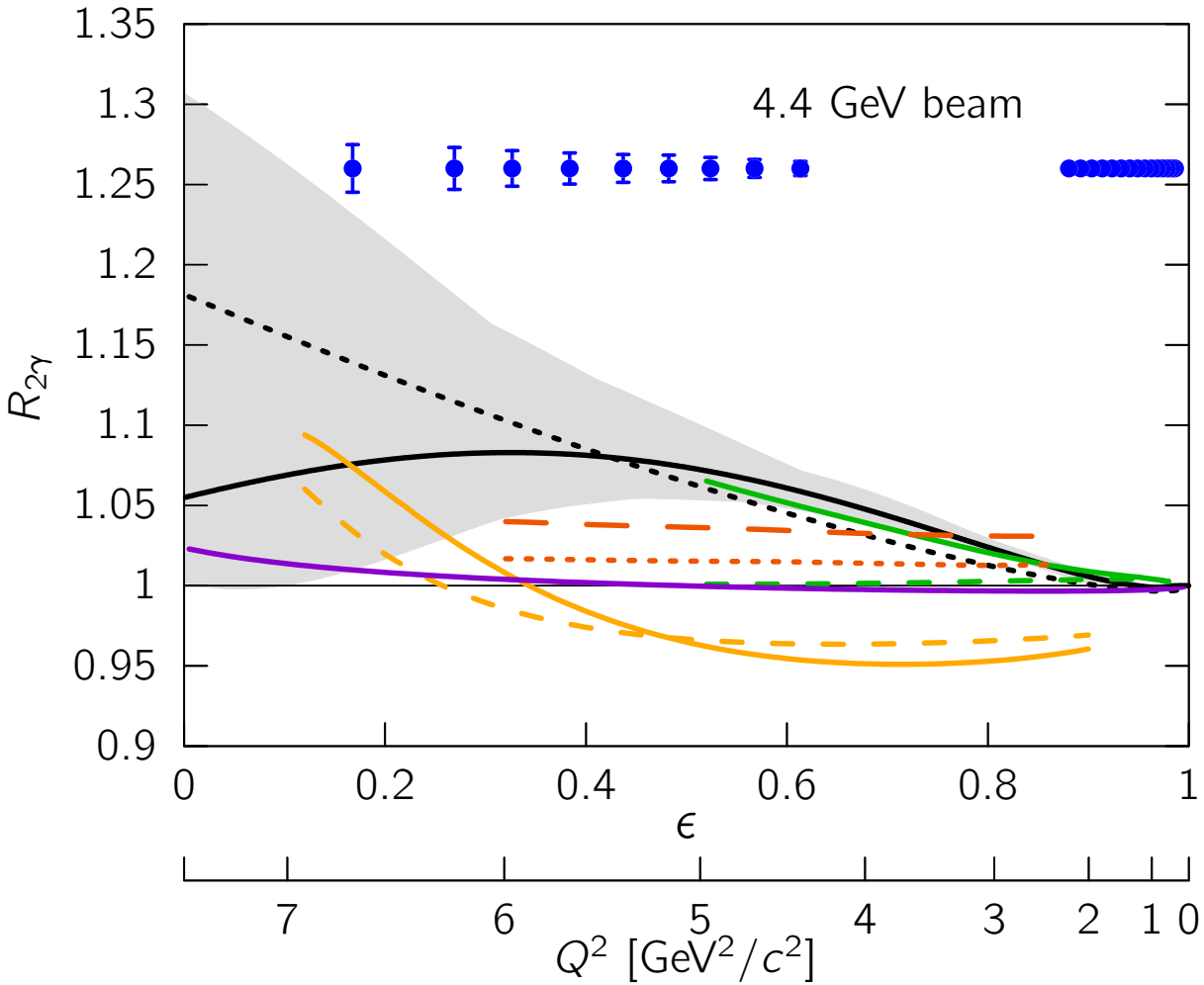

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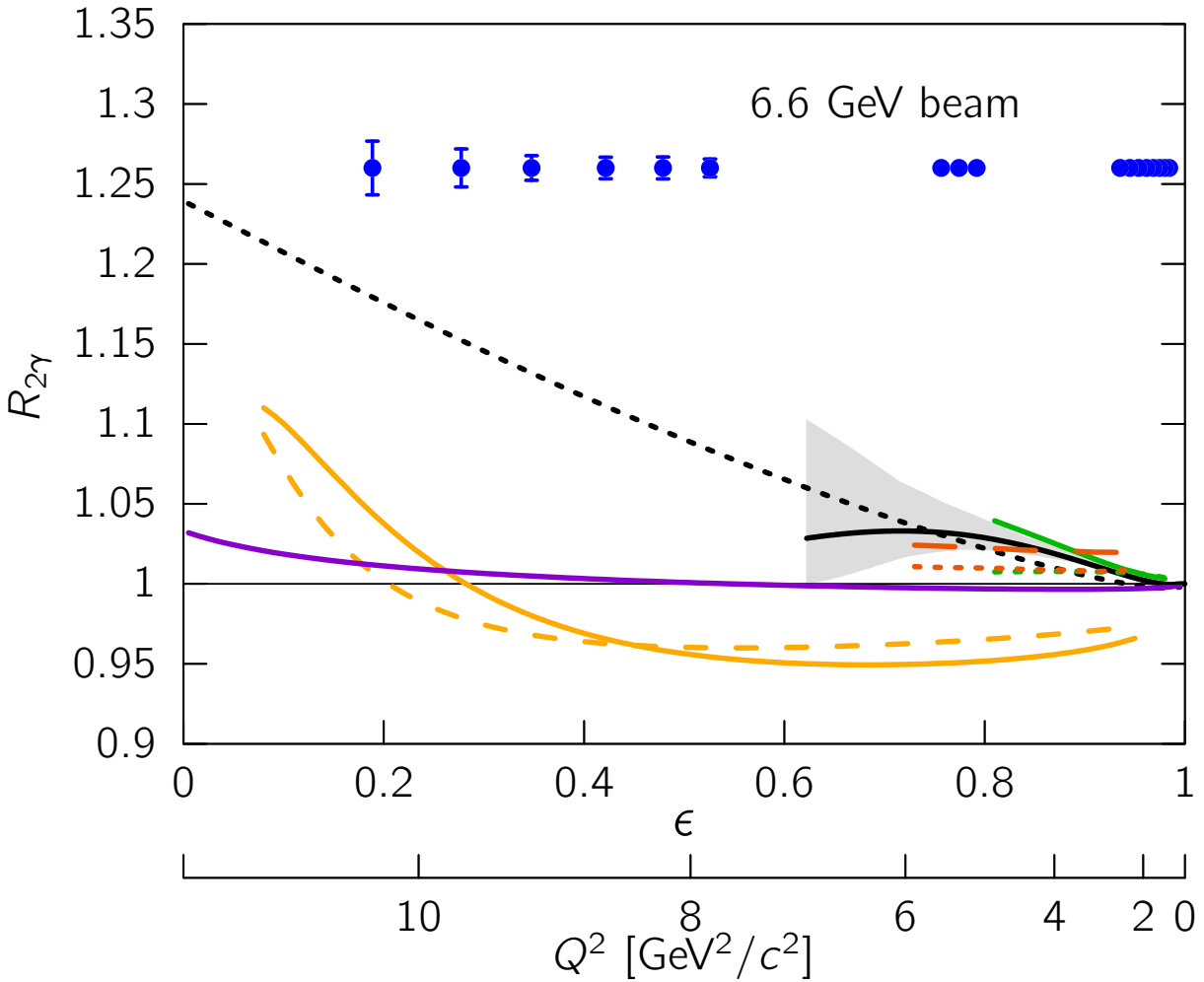

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Kuraev et al.

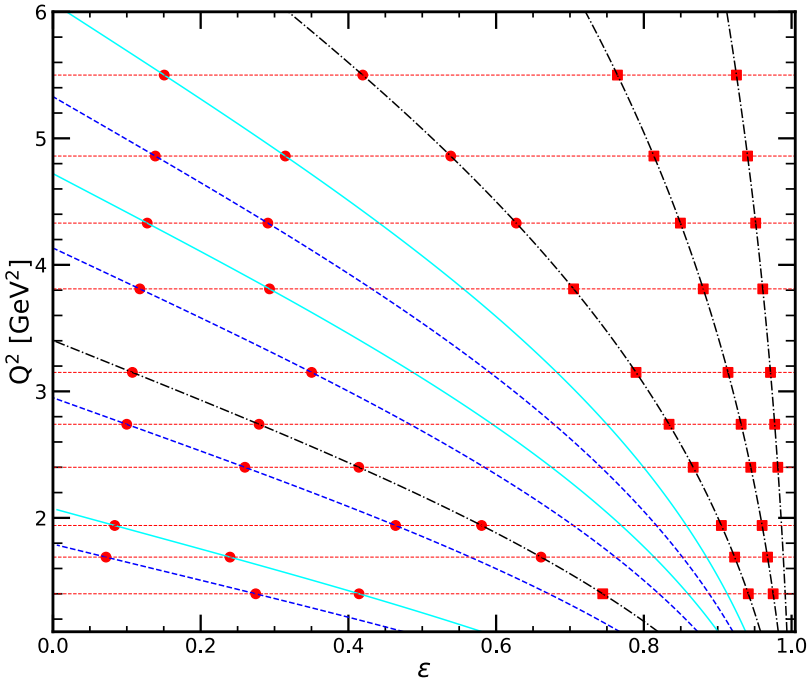
This proposal

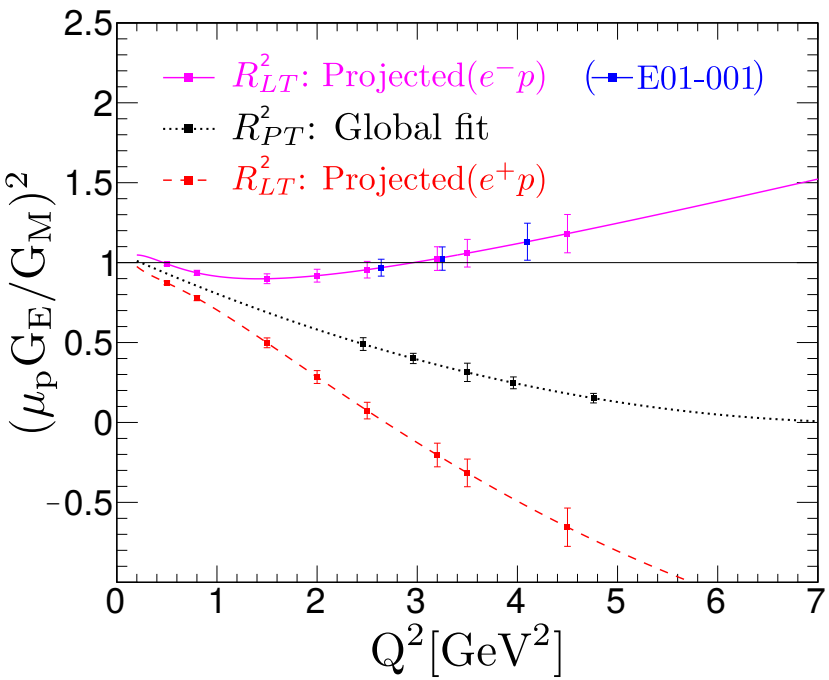
Positron Super-Rosenbluth Experiment (Hall C) E12+23-012

Spokespeople: M. Nycz, J. Arrington, N. Santiesteban, M. Yurov

Only detect recoiling proton

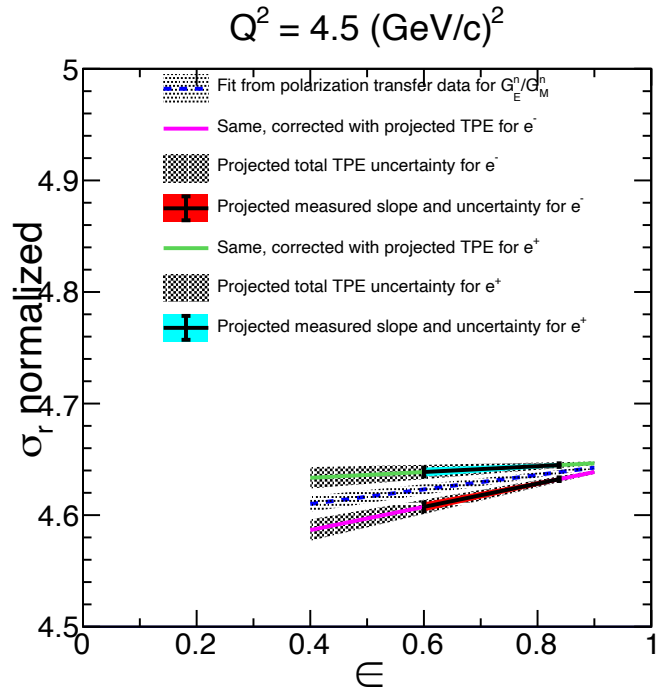
- Fixed $Q^2 \longrightarrow$ fixed spectrometer setting

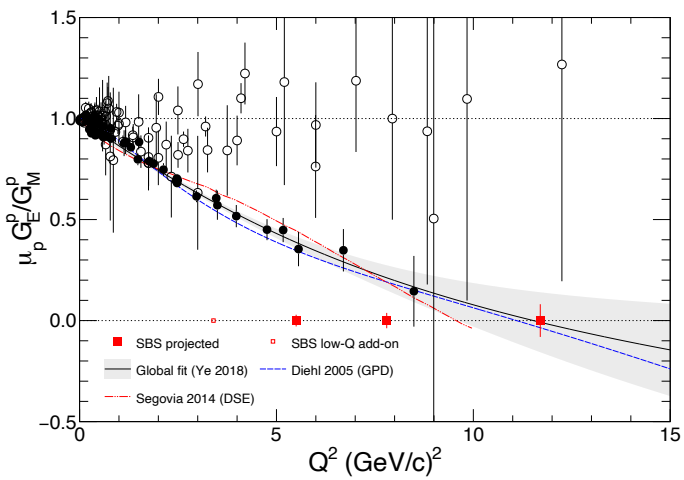




Super Big Bite nucleon form factor program

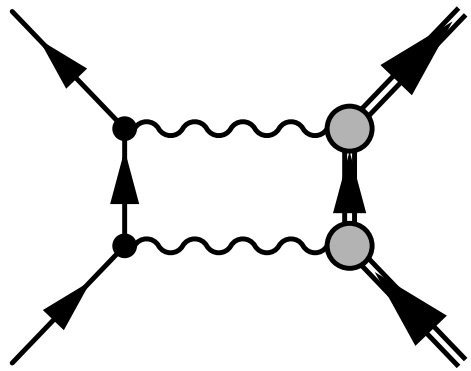
- Rosenbluth separation of G_E^n, G_M^n
  - E12-20-010 (E. Fuchey et al.)
  - 2024 Positron LOI
- Polarization transfer
  - LOI12+23-008, Puckett, Bernauer, Schmidt
  - 2024 Proposal: 2 days (e^-) at $Q^2 = 3.7$



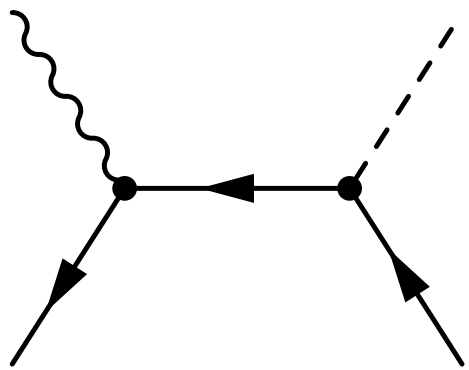


Positrons add new information beyond what electrons can provide.

1. Multi-photon interferences
   - Two-photon exchange
   - DVCS / Bethe-Heitler
   - Coulomb effects

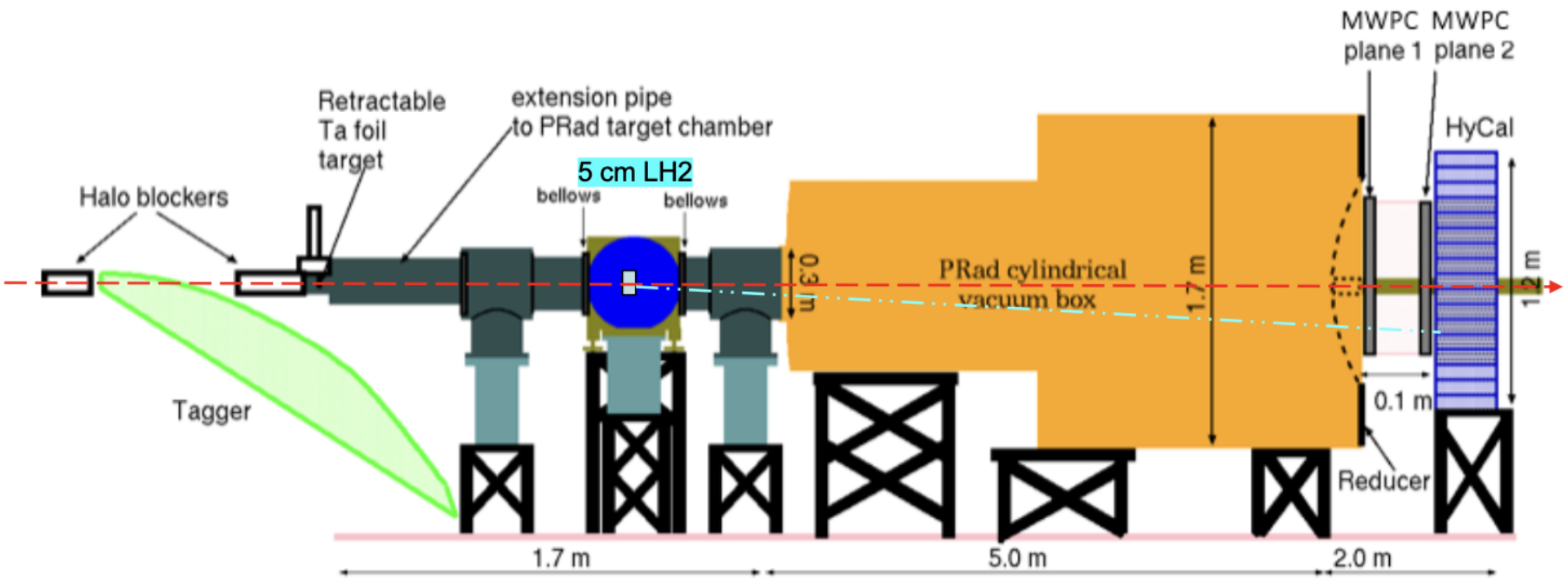


2. Our world is made of matter
   - **Annihilation search for dark matter**
   - Axial form factors
   - Strangeness via charm tagging



PR12+24-005: Search for Dark Photons with Positron Annihilation

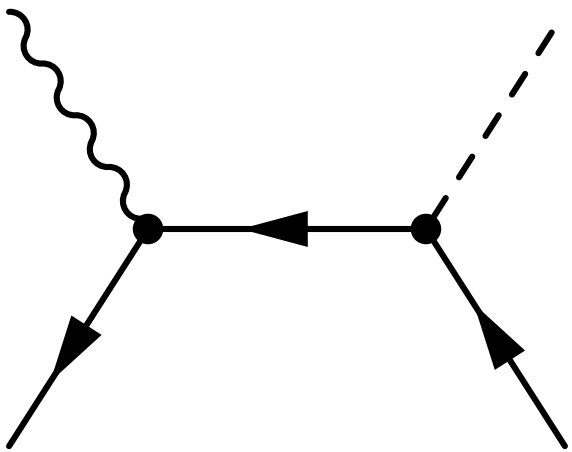
PRAD set-up to search for $e^+e^- \to \gamma A'$

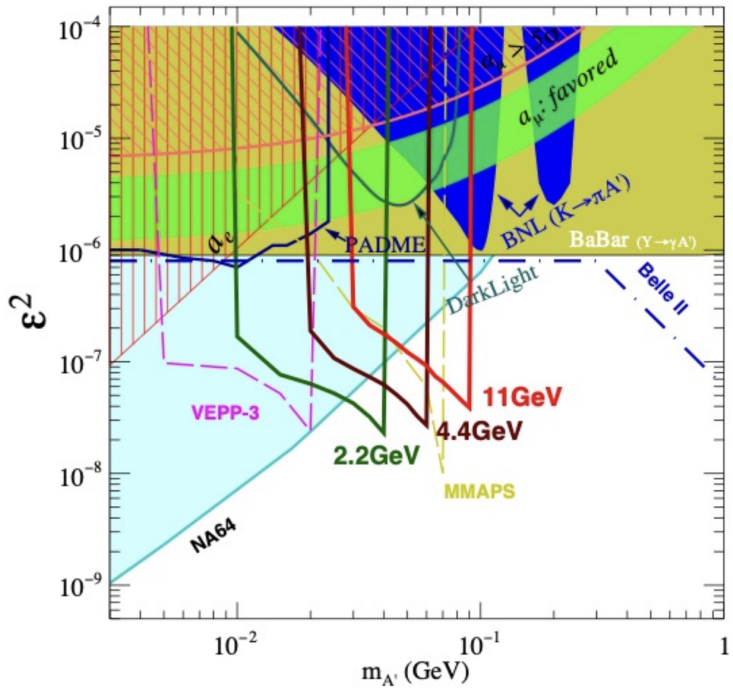


Spokespersons: A. Gasparian, N. Liyanage, B. Raydo, B. Wojtsekhowski

PR12+24-005: Search for Dark Photons with Positron Annihilation

PRAD set-up to search for $e^+e^- \to \gamma A'$





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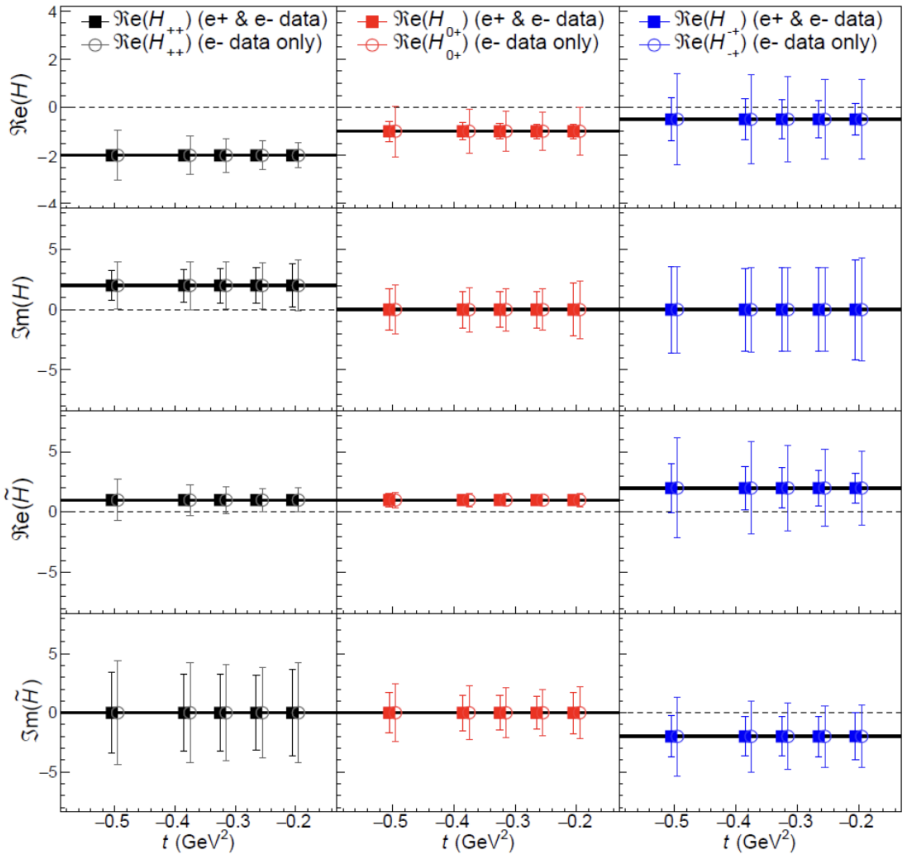
Recap

Positrons add new information!

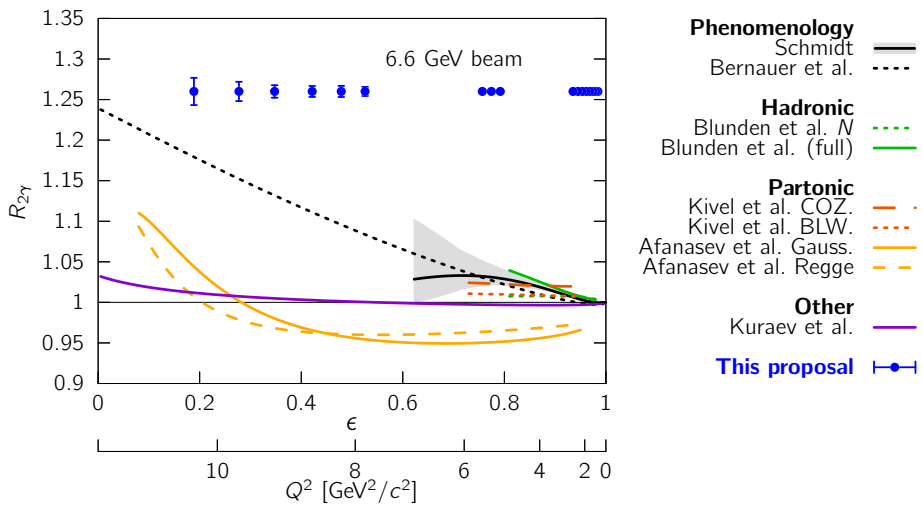
- Isolating DVCS



Recap

Positrons add new information!

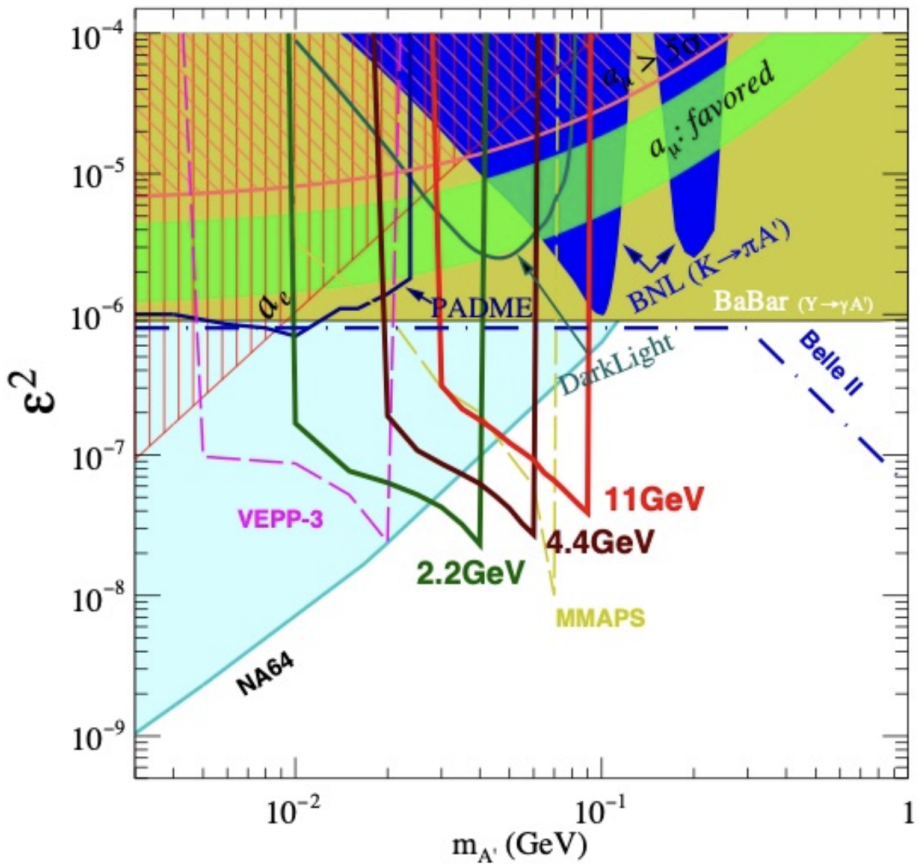
- Isolating DVCS
- Measuring TPE



Recap

Positrons add new information!

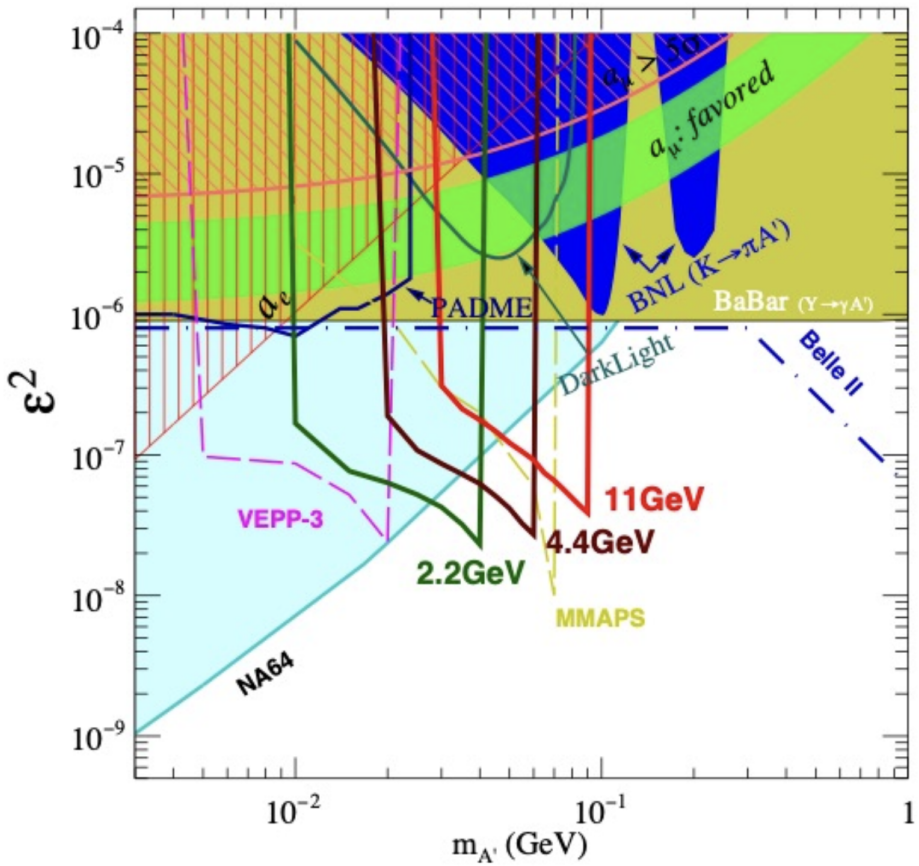
- Isolating DVCS
- Measuring TPE
- Dark Photons



Recap

Positrons add new information!

- Isolating DVCS
- Measuring TPE
- Dark Photons
- **Much much more!**
  Let's make positrons happen!



Jefferson Lab Positron Working Group

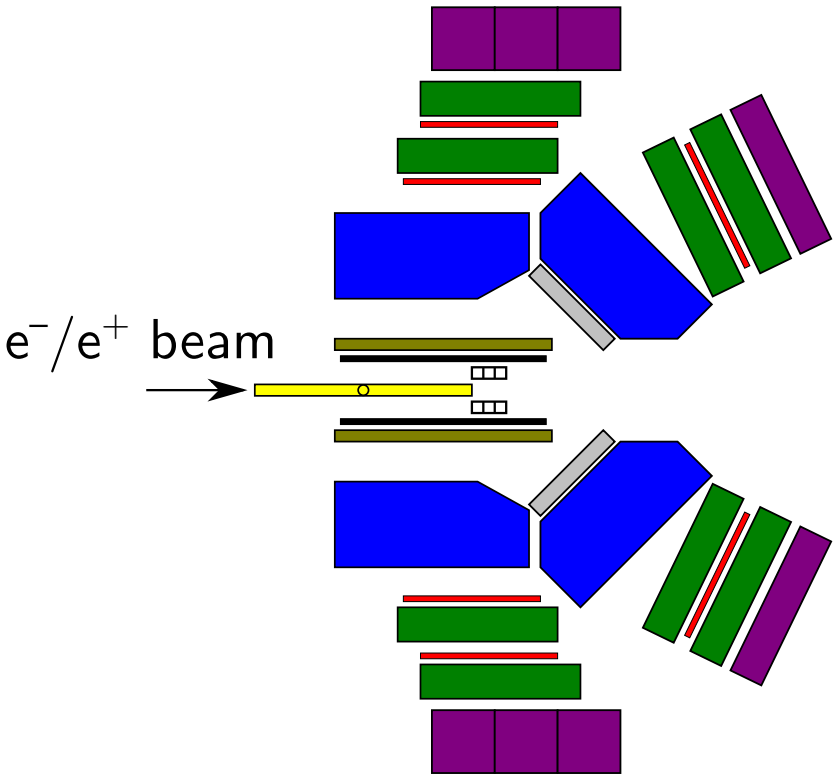
Read our white paper: EPJA 2022

Join our mailing list:
pwg-request@jlab.org

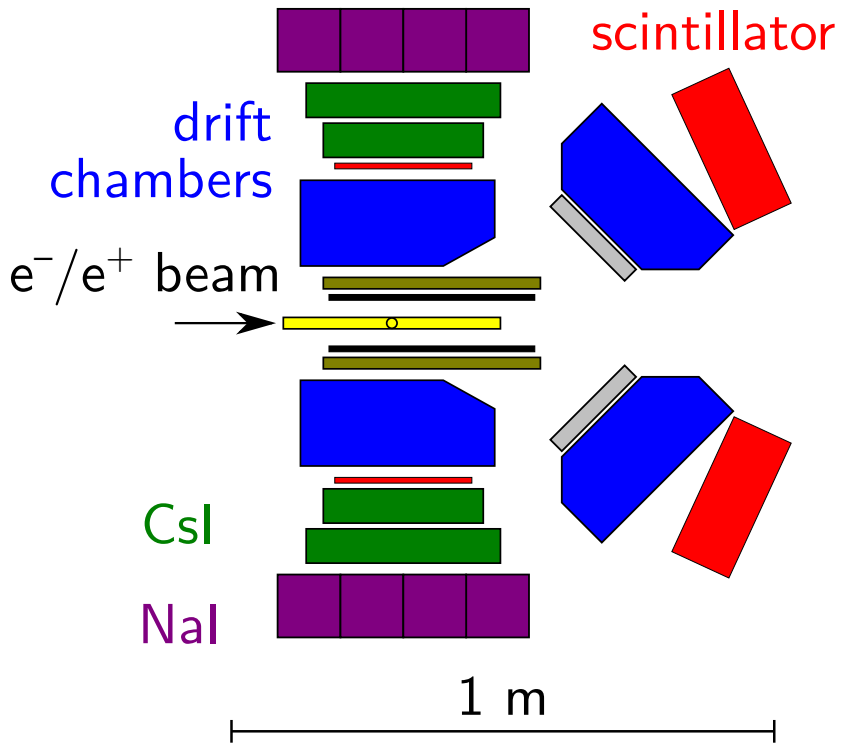
Back Up

VEPP-3, Novosibirsk, Russia

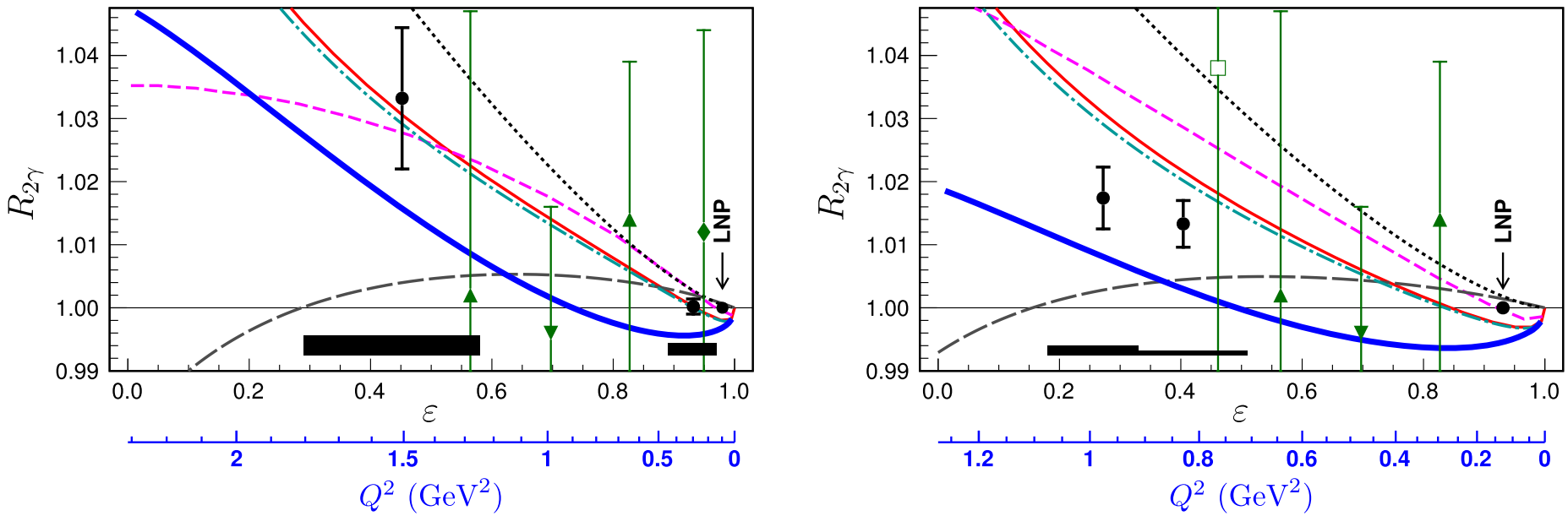
Configuration 1



Configuration 2

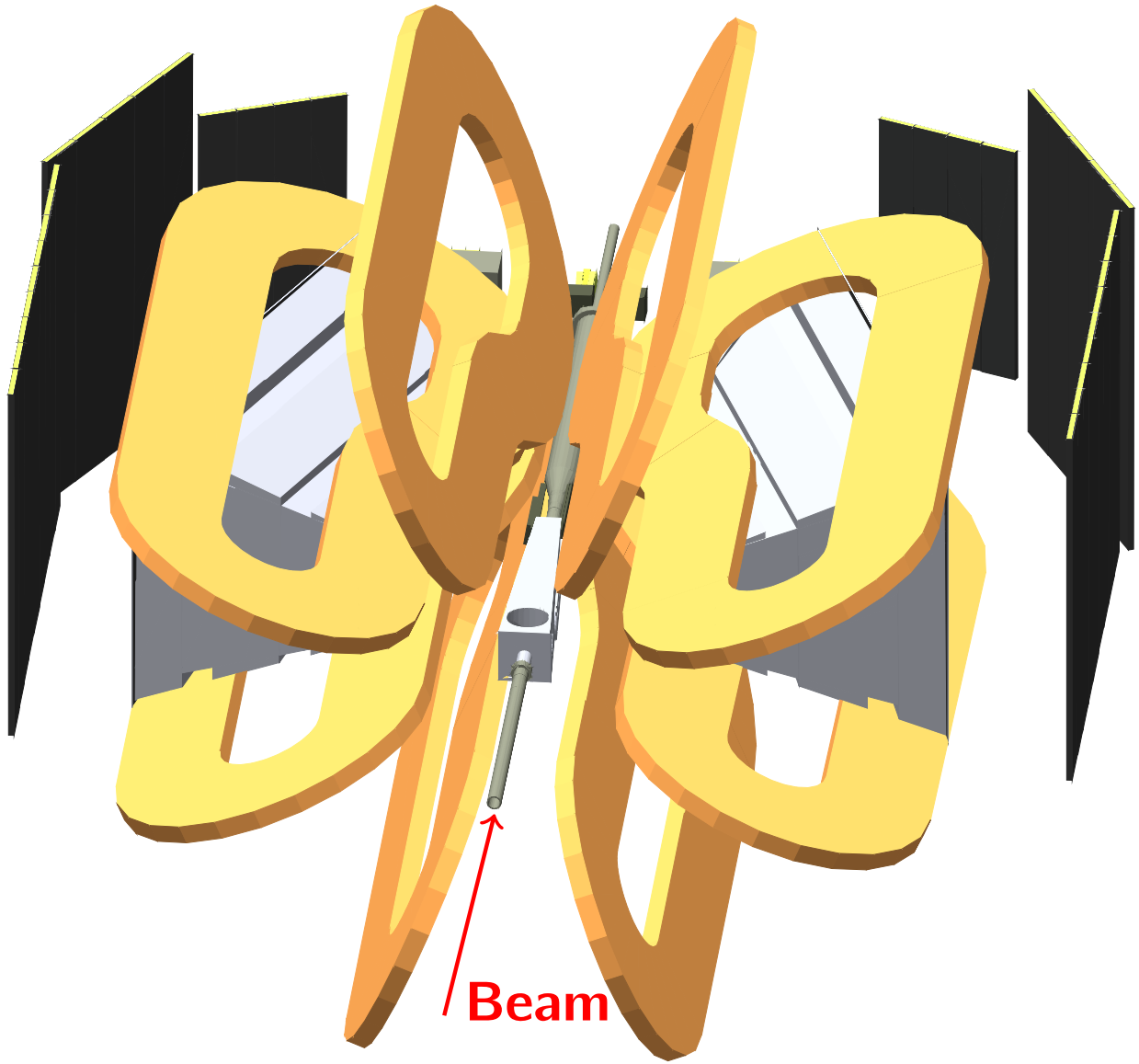


VEPP-3, Novosibirsk, Russia



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

OLYMPUS, DESY, Germany



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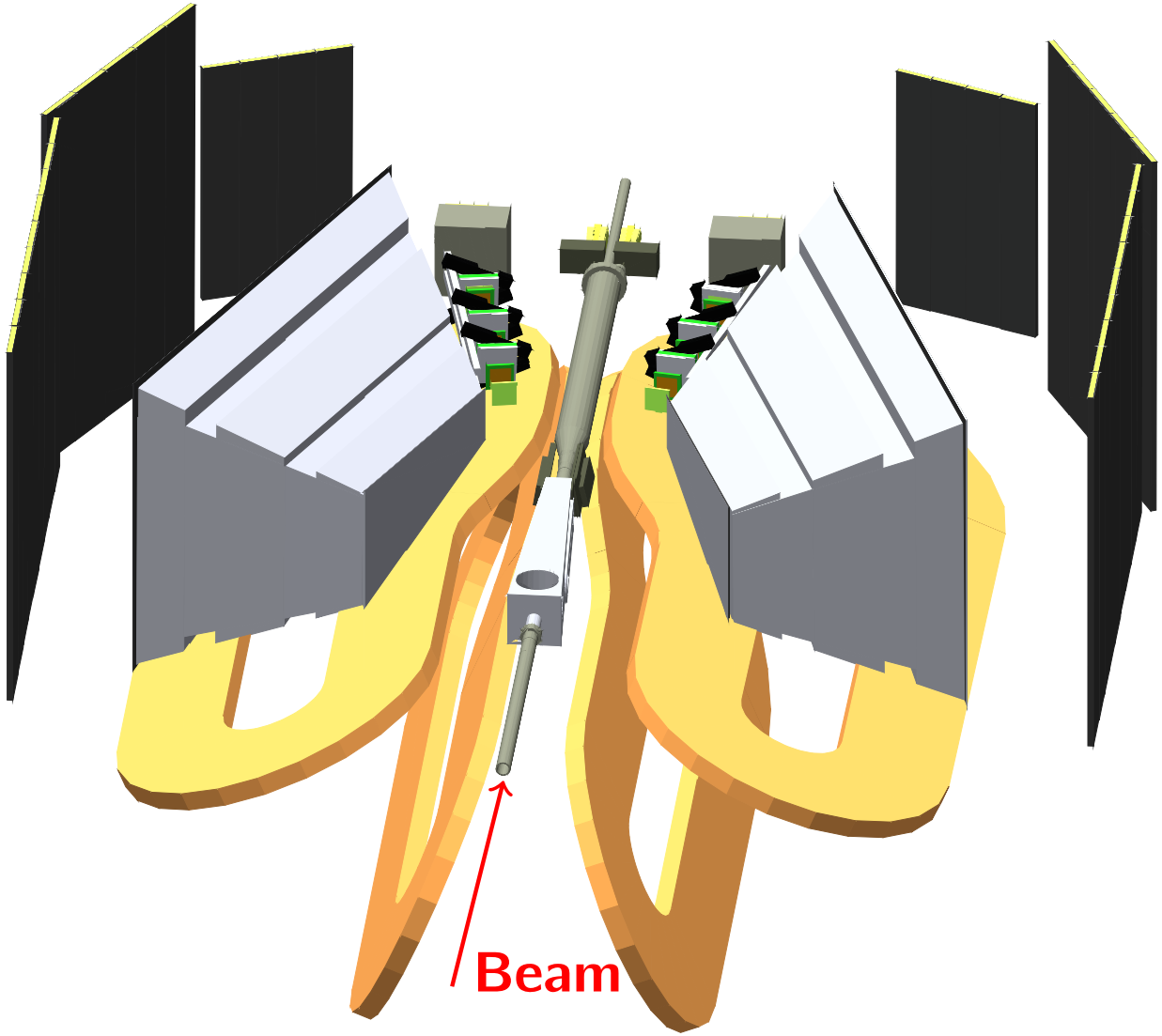


The polarization transfer results are not necessarily correct.

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

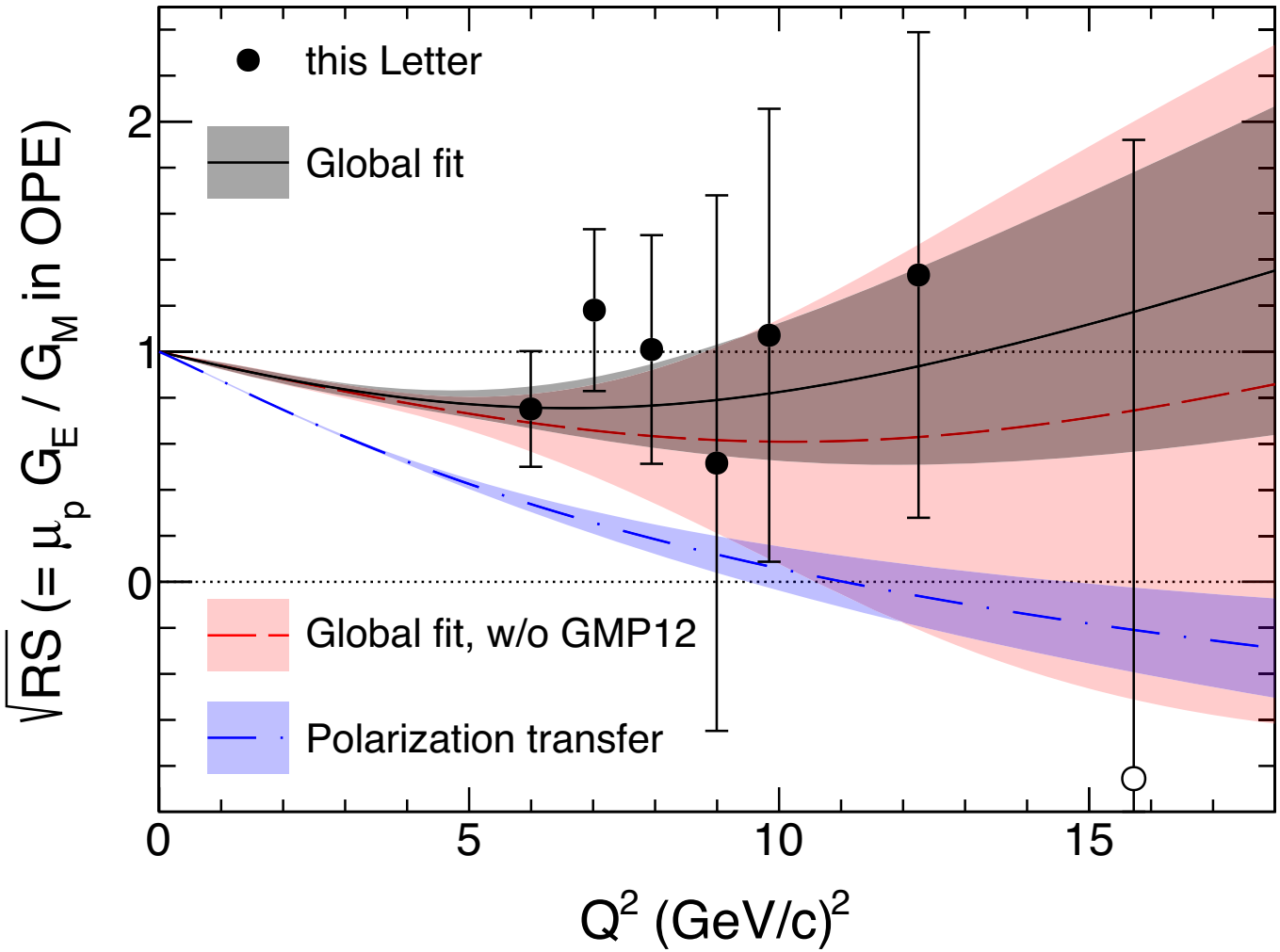
$$\frac{P_t}{P_l} = \sqrt{\frac{2\epsilon}{\tau(1+\epsilon)}}\frac{G_E}{G_M} \times [1 + \ldots$$

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

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

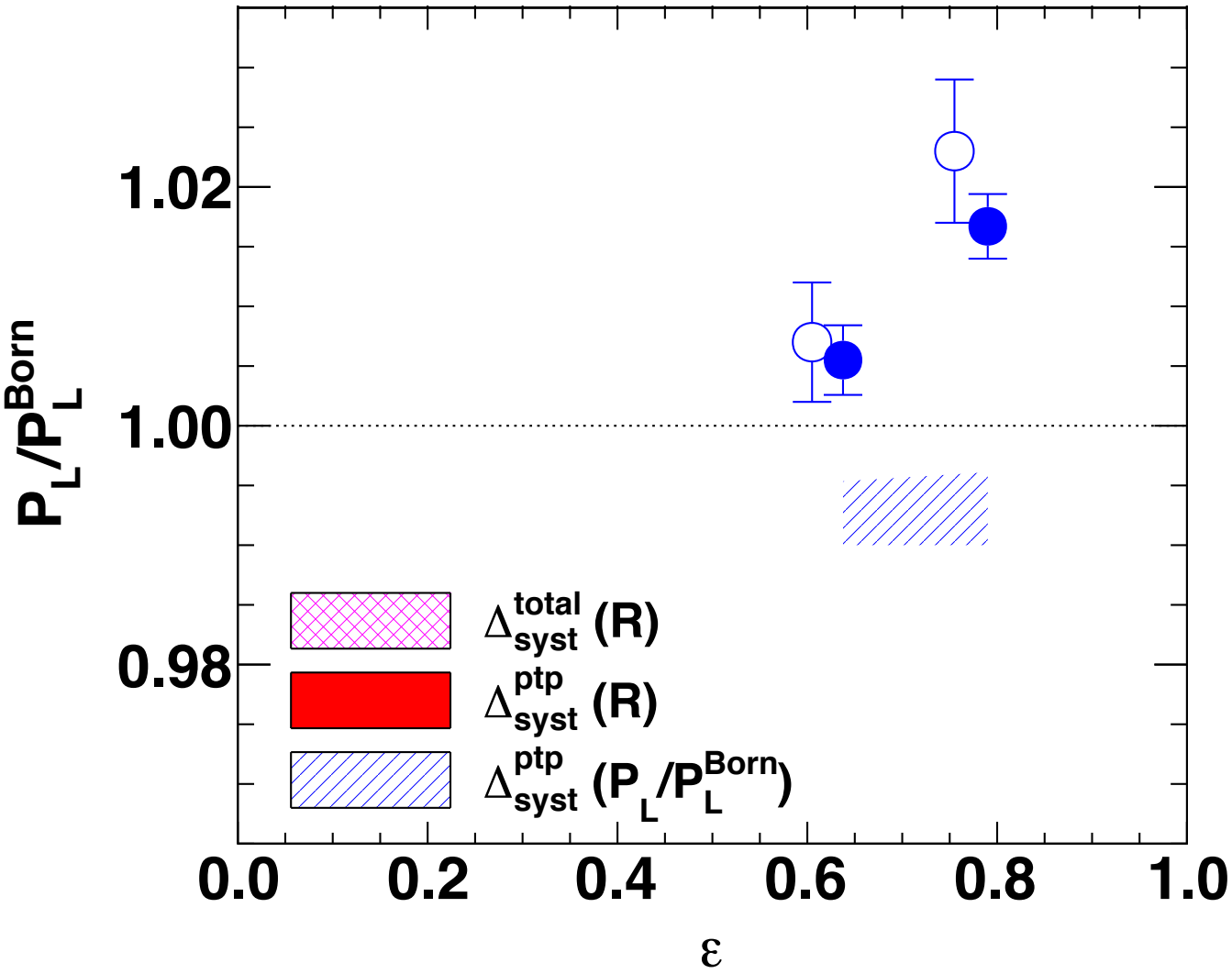
Formalism of Carlson, Vanderhaeghen, Annu. Rev. Nucl. Part. Sci., 2007

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



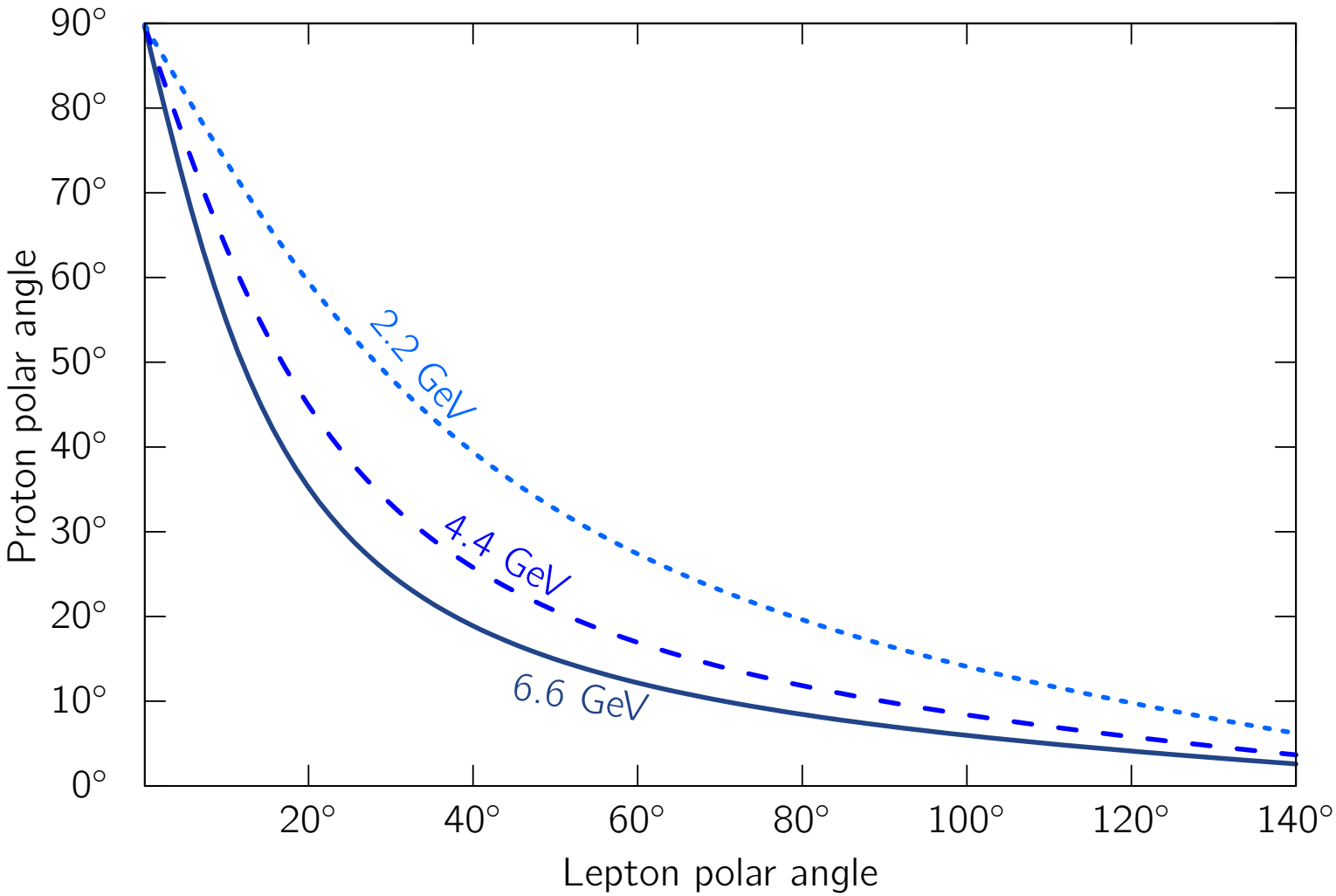
M. E. Christy et al., PRL 128, 102002 (2022)

GEP-2γ finds ϵ-dependence in P_l.

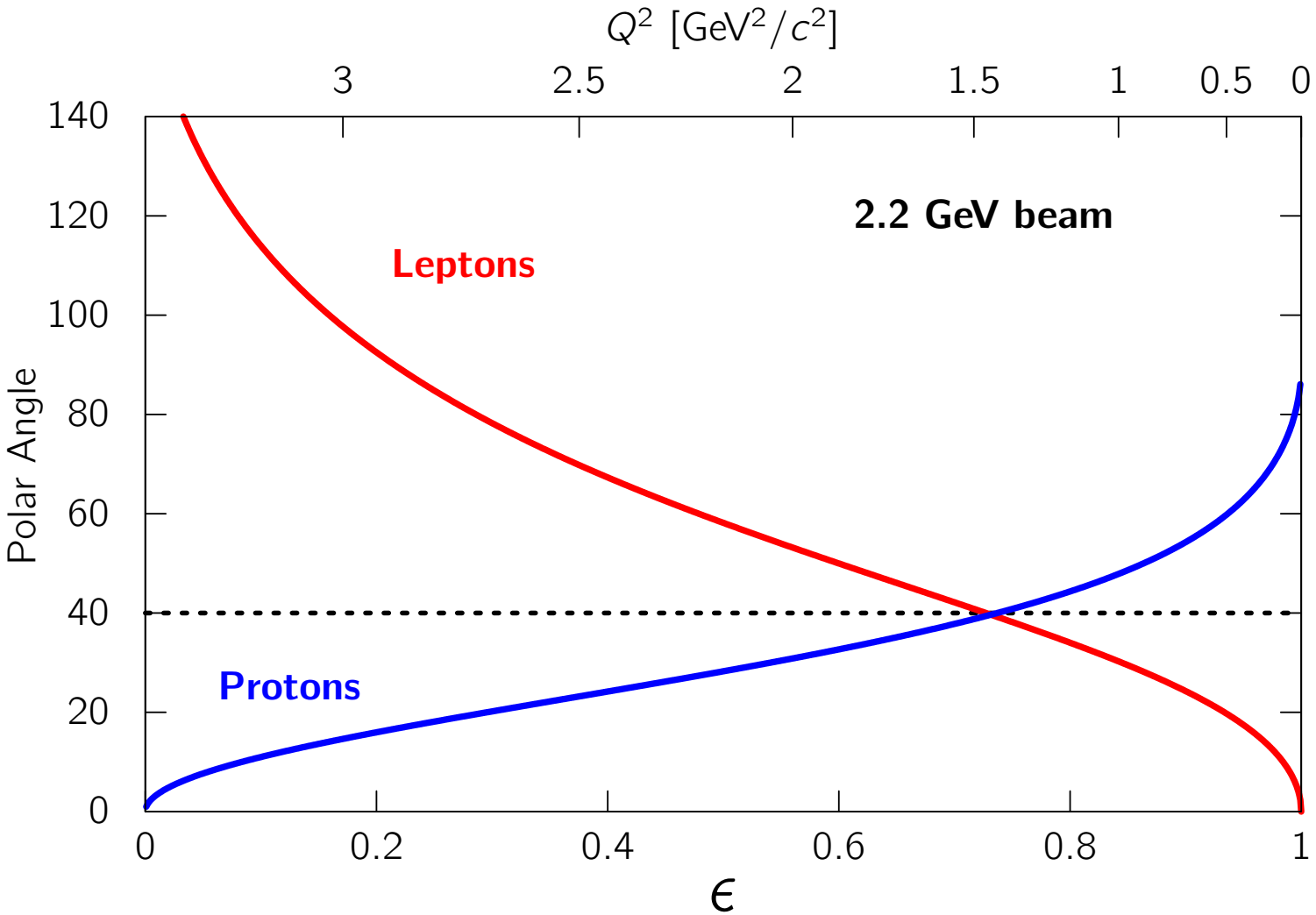


A. J. R. Puckett et al., PRC 98 019907 (2018)

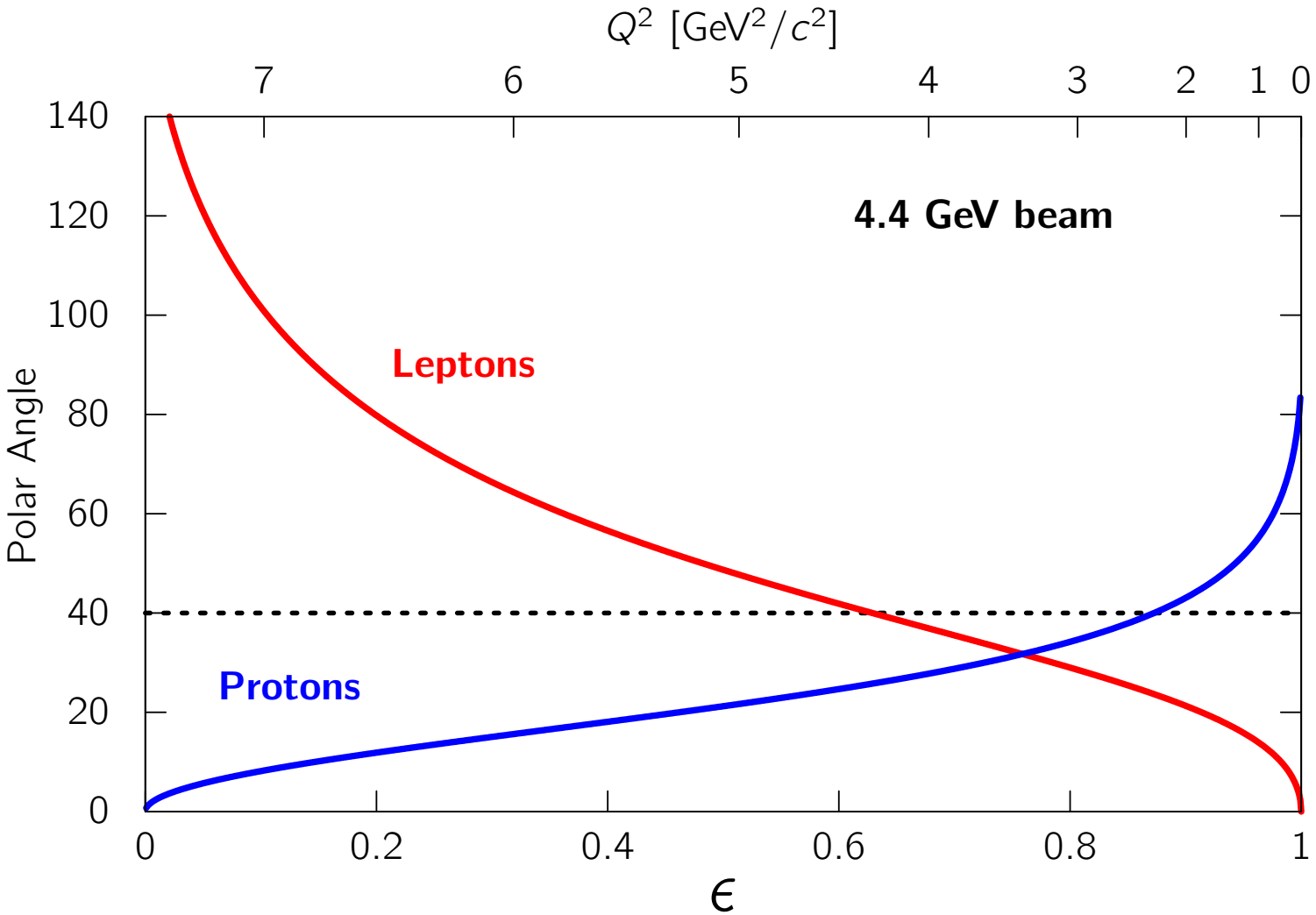
Kinematics: Lepton Angle vs. Proton Angle



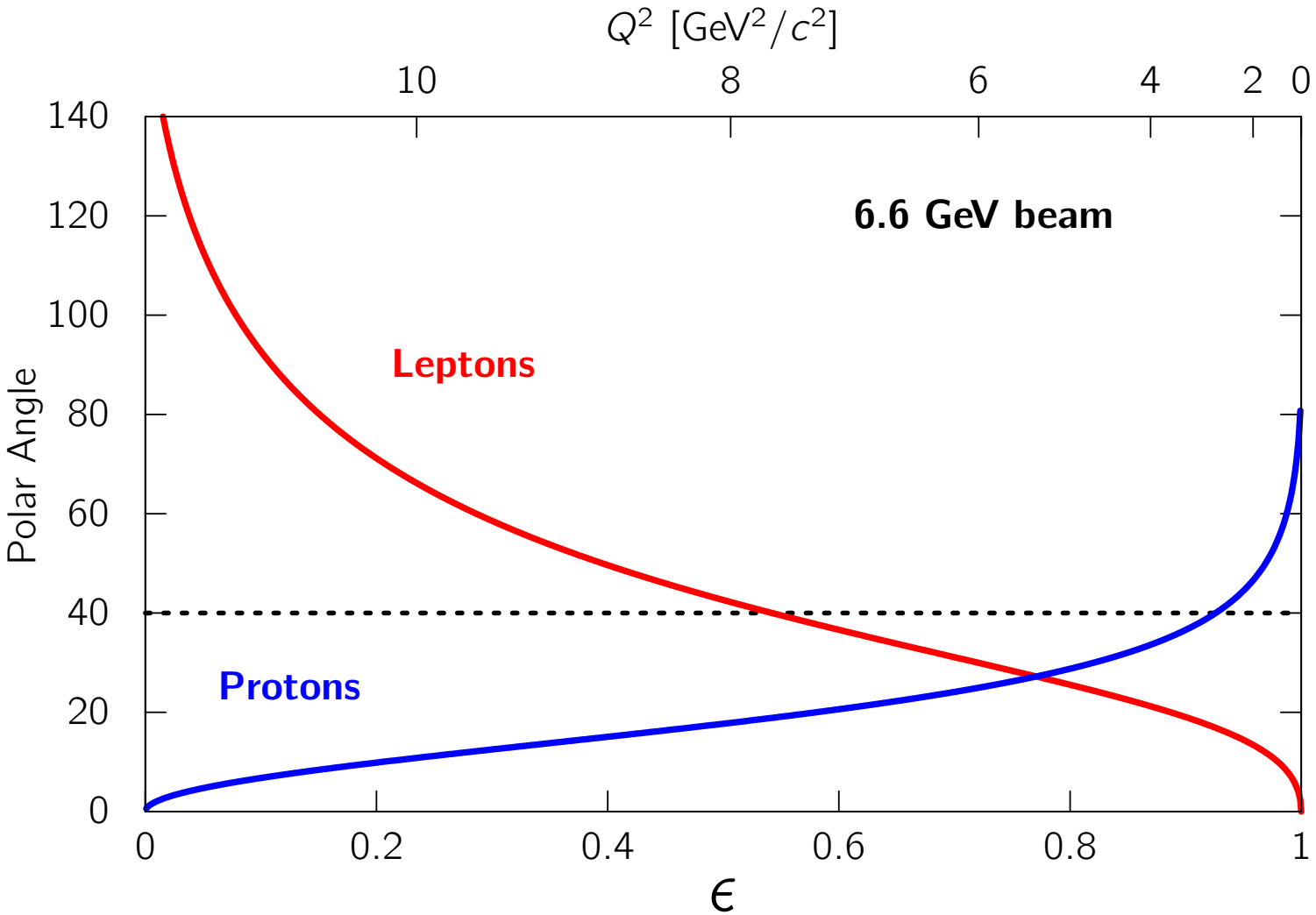
Kinematics: Angles at 2.2 GeV



Kinematics: Angles at 4.4 GeV



Kinematics: Angles at 6.6 GeV



Kinematics: Momenta vs. Angles