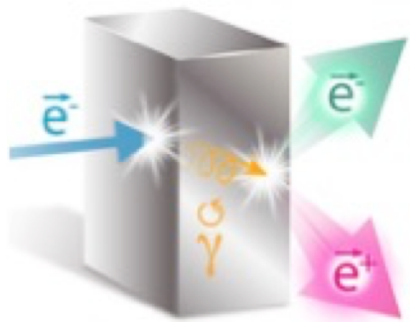
Positrons at Jefferson Lab and the Goal of Understanding Two Photon Exchange

Axel Schmidt

J-FUTURE Workshop

March 30, 2022



Jefferson Lab Positron Working Group

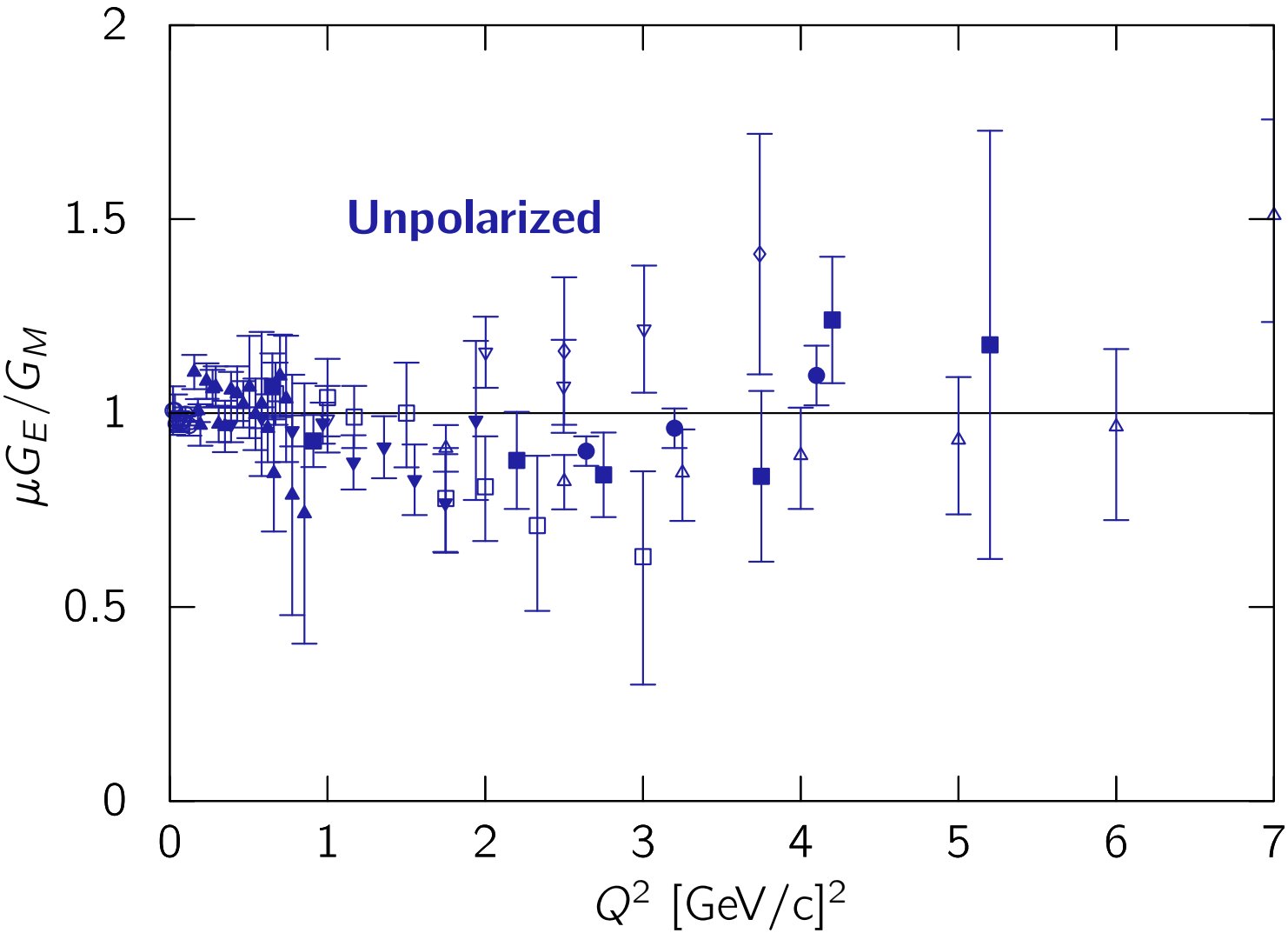
- Website:
  `https://wiki.jlab.org/pwgwiki/index.php/Main_Page`
- Join the mailing list: `mailto:pwg-request@jlab.org`
- Recent White Paper:
  `https://epja.epj.org/component/toc/?task=topic&id=1430`

In my talk today:

1. Current state of two-photon exchange

2. How a positron beam at JLab can move us beyond this state

Proton form factors measurements show a striking discrepancy.



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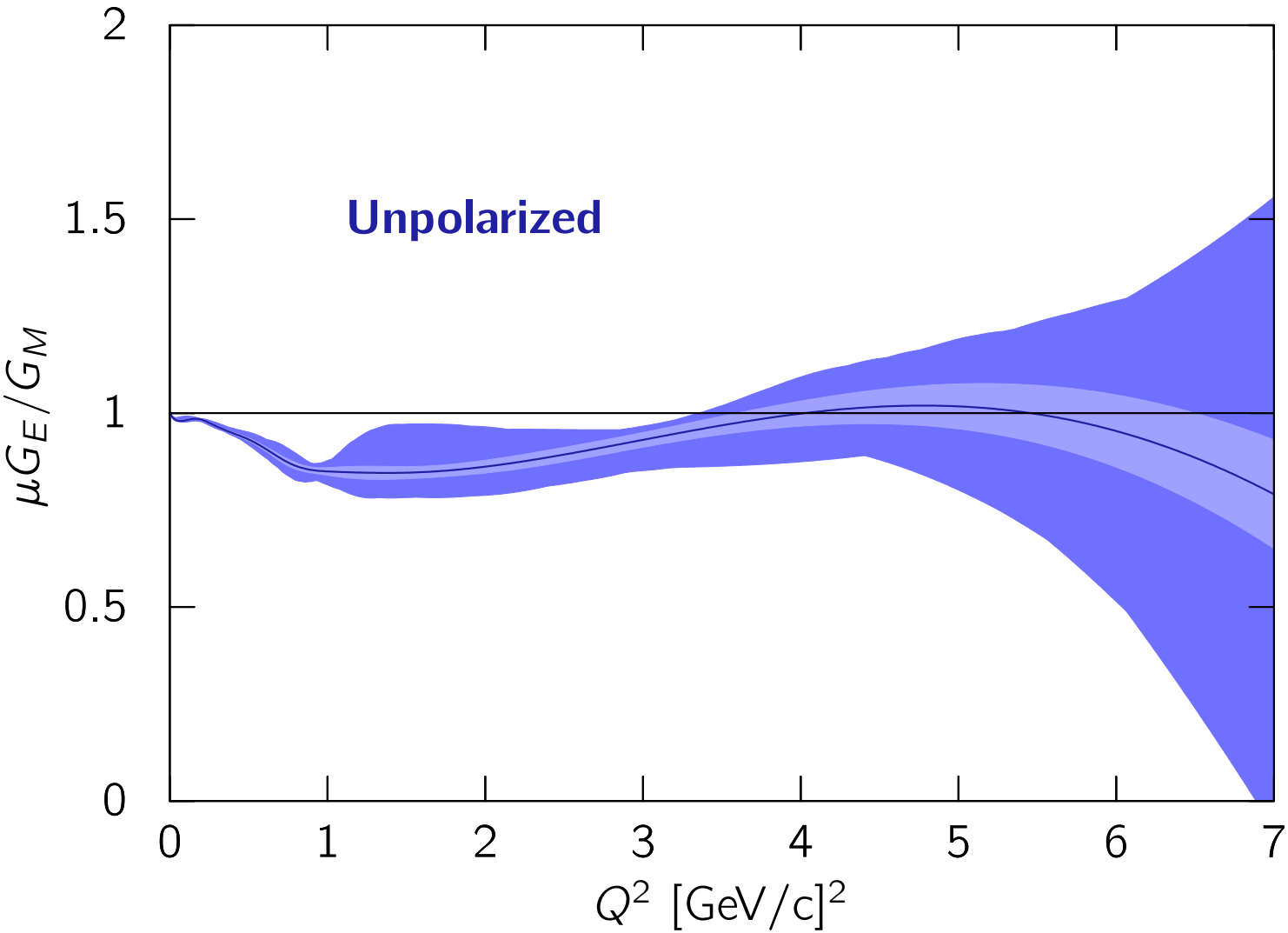

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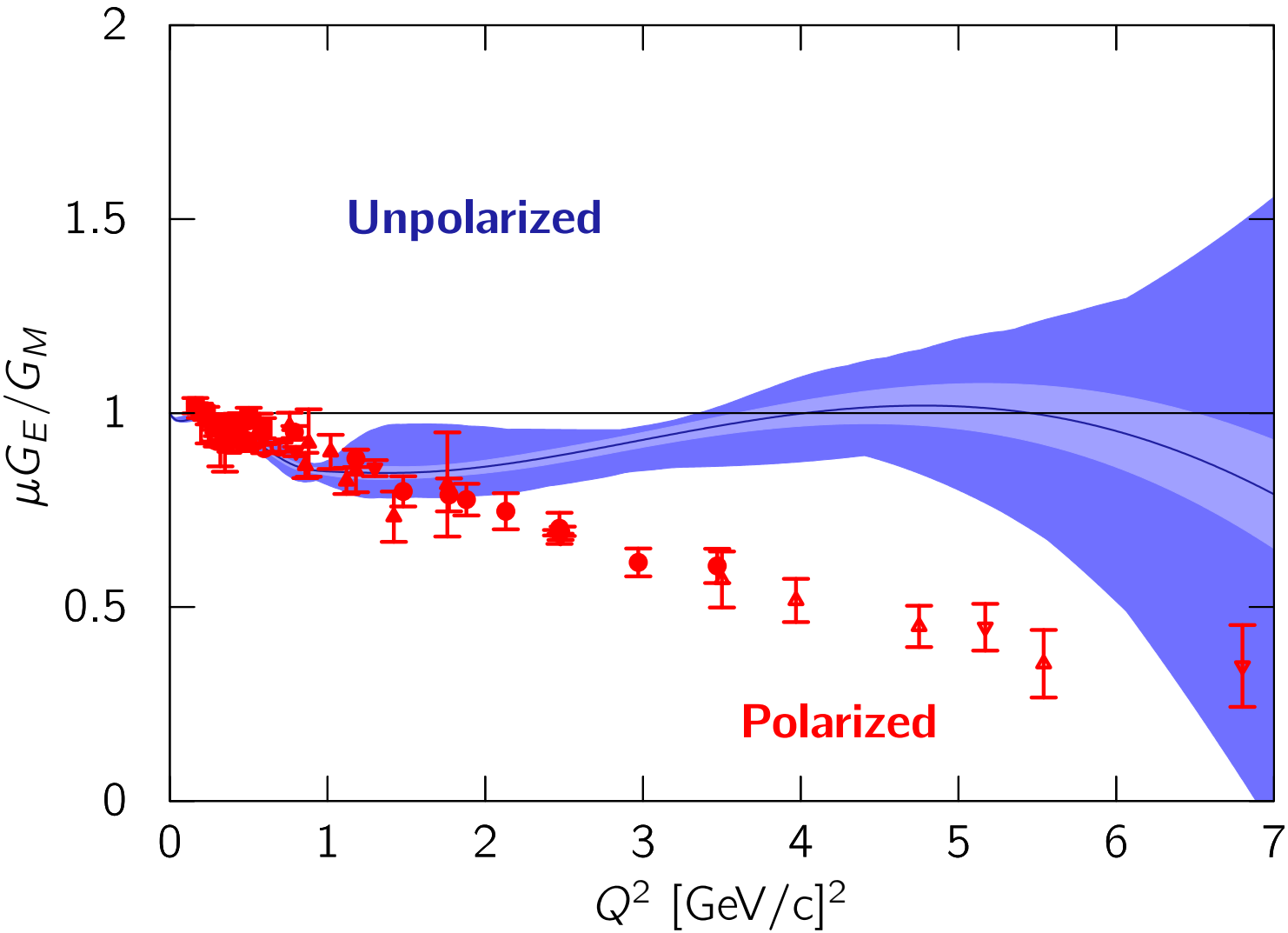
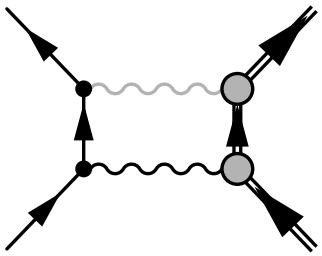
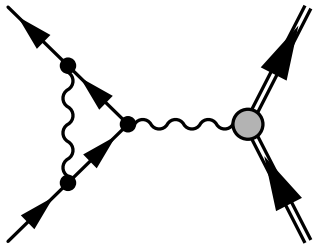


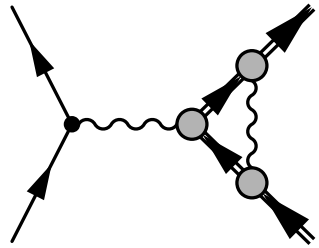
Hard two-photon exchange is the missing radiative correction.



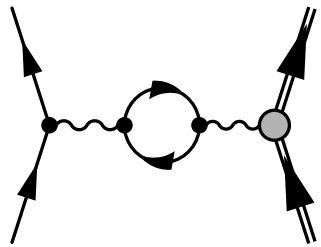
Soft TPE



e-vertex correction

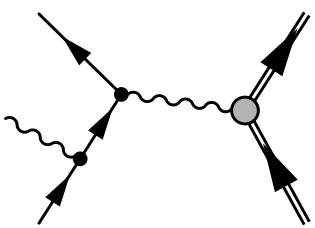


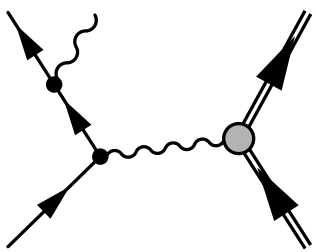
p-vertex correction

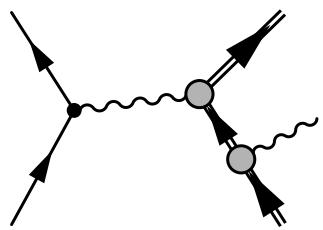


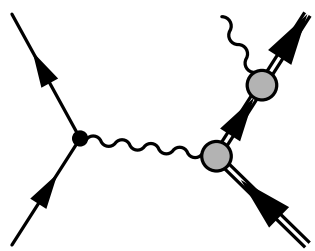
Vacuum polarization

Soft Bremsstrahlung





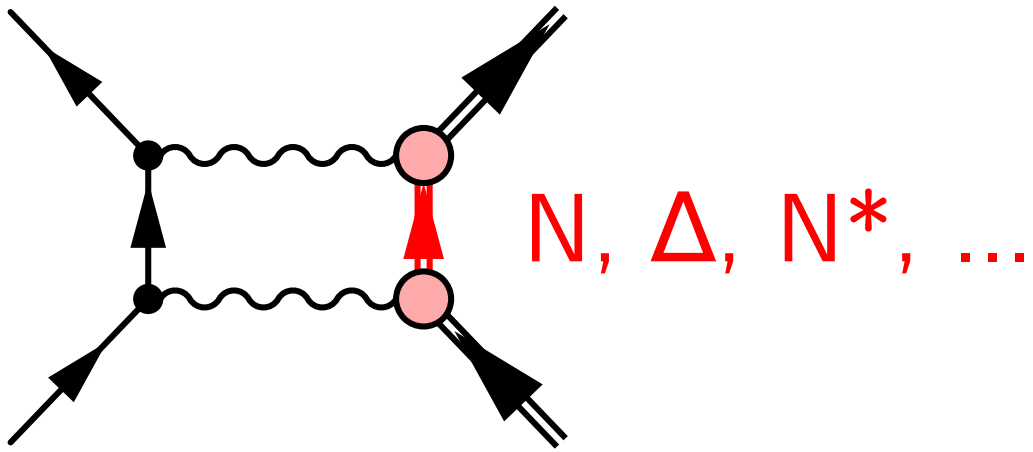




Calculations of two-photon exchange come with model dependency.

Hadronic Approaches

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



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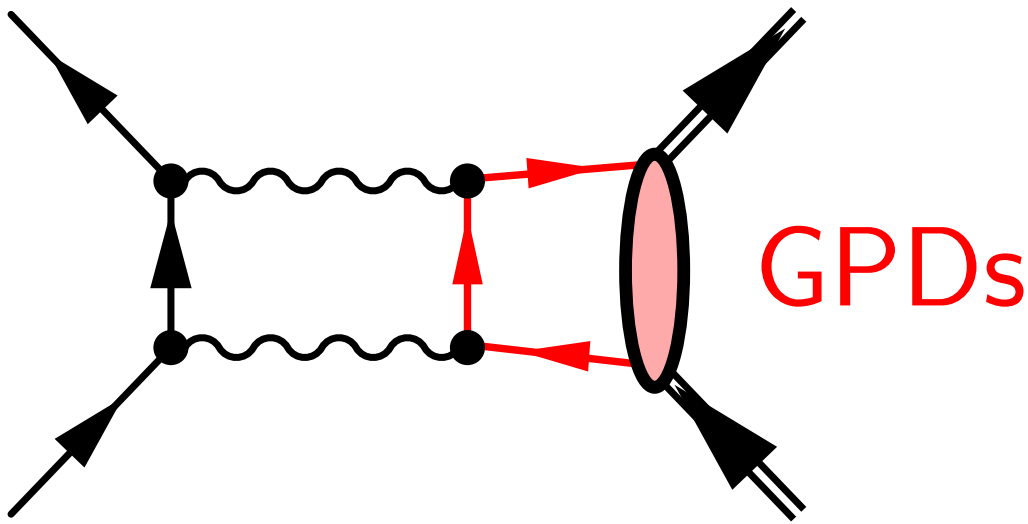

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- Assume the discrepancy is caused by TPE, estimate the effect.
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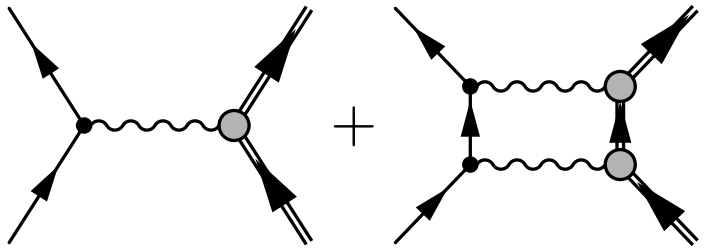
Alternate Approaches

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

TPE can be measured through an asymmetry between e^+p and e^-p scattering.

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



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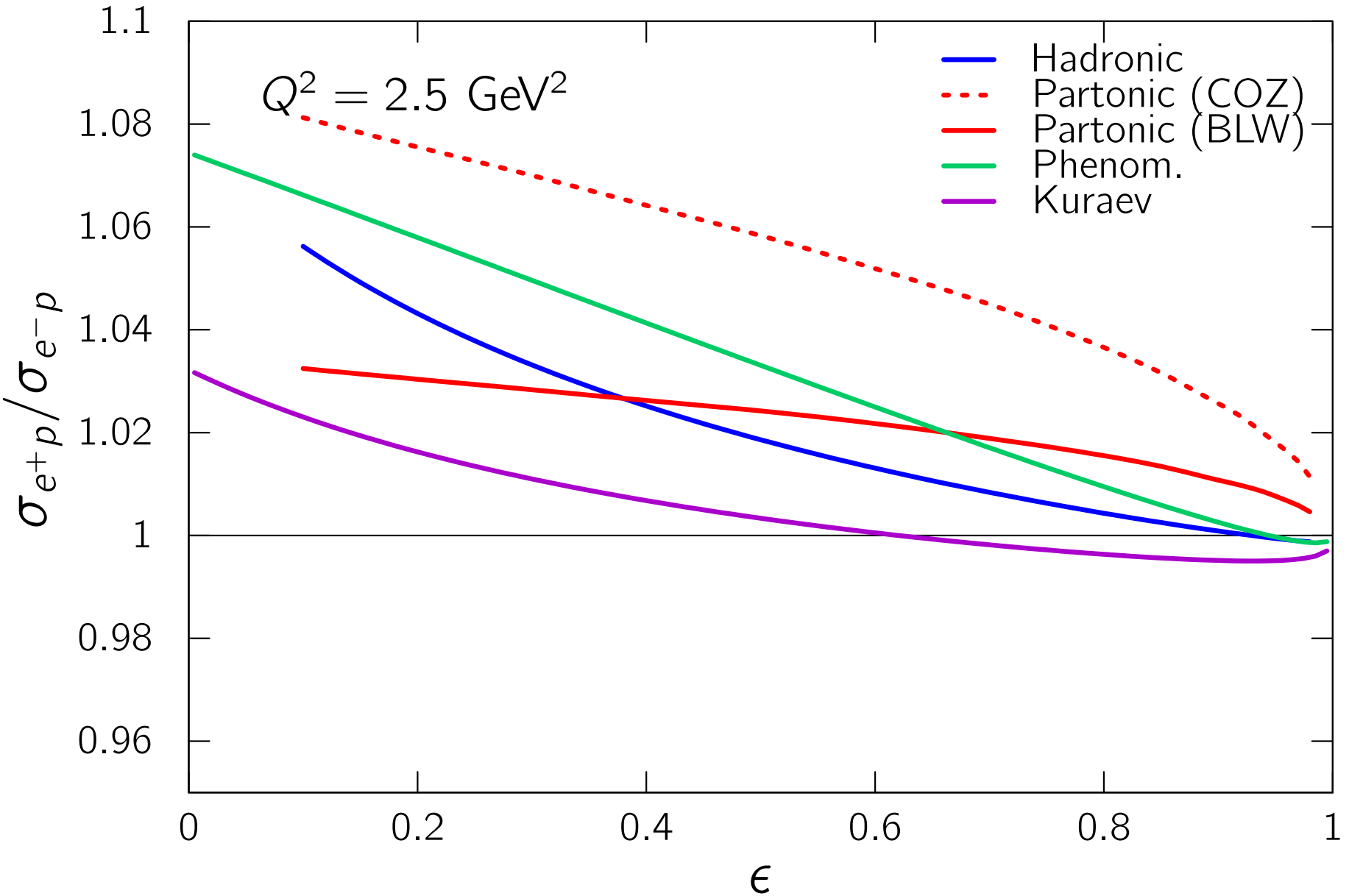
$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \approx 1 + \frac{4\mathrm{Re}\{\mathcal{M}_{2\gamma}\mathcal{M}_{1\gamma}\}}{|\mathcal{M}_{1\gamma}|^2}$$

Theory predictions for $\sigma_{e^+p}/\sigma_{e^-p}$



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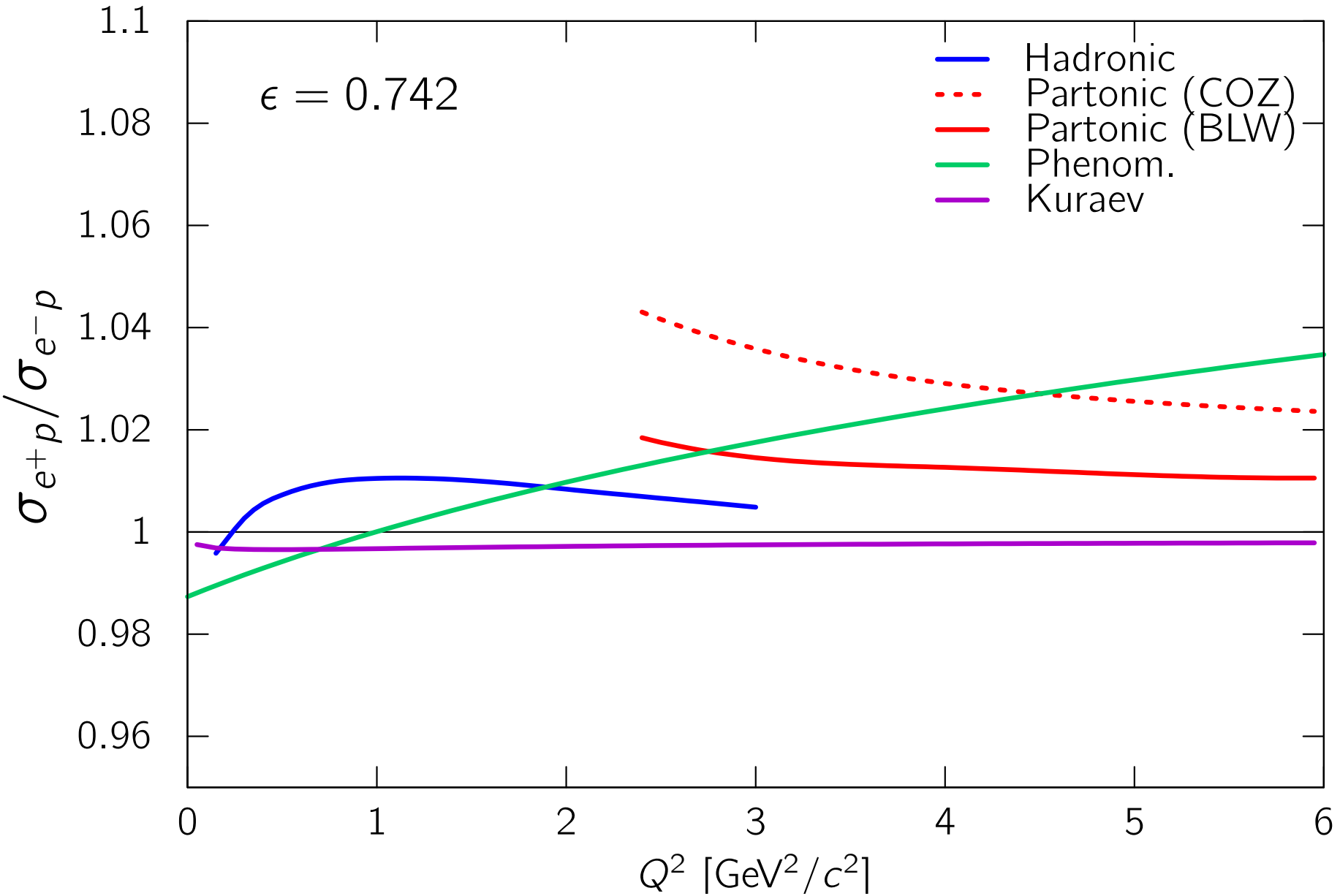
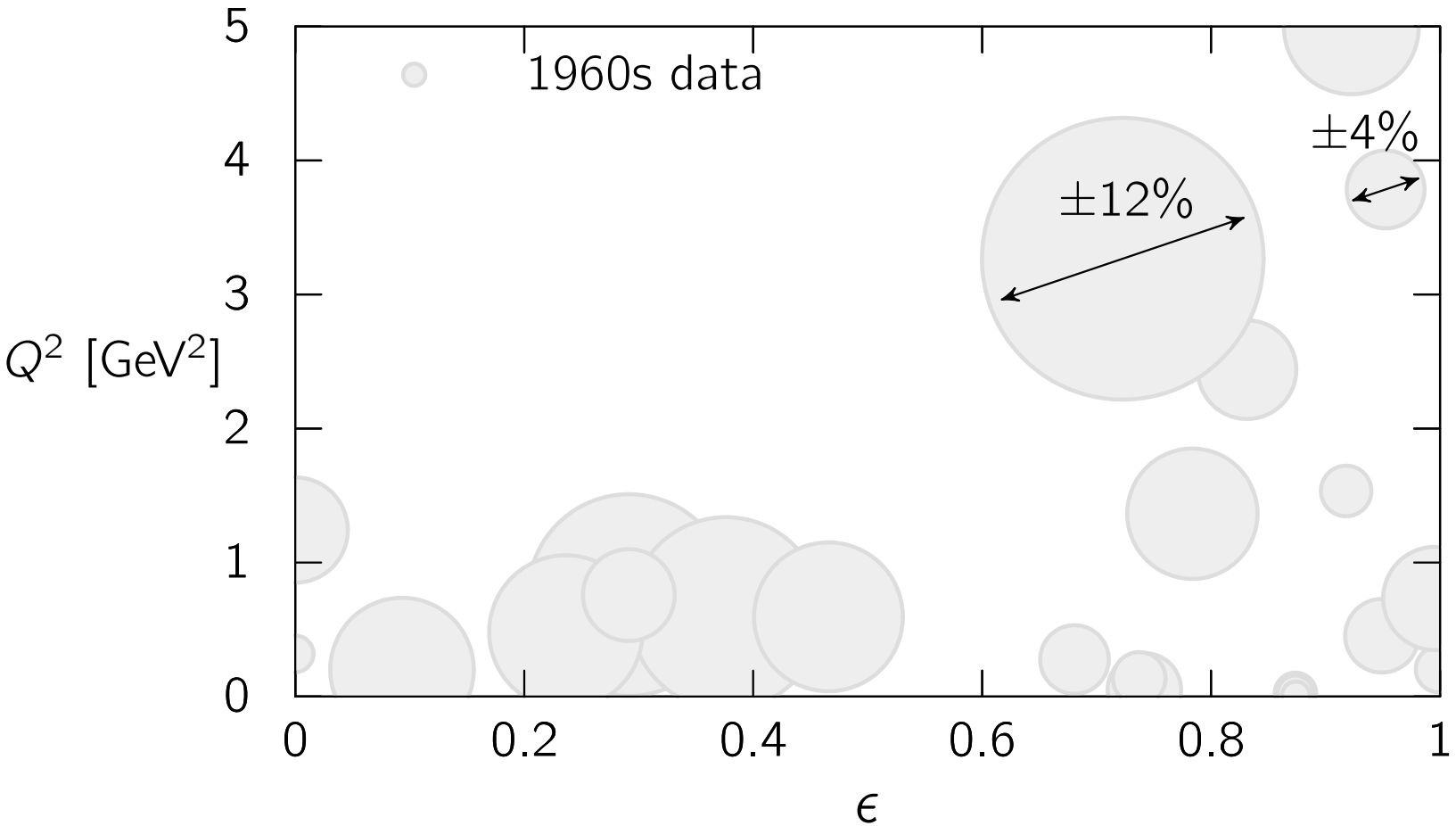


Three recent experiments measured hard TPE.



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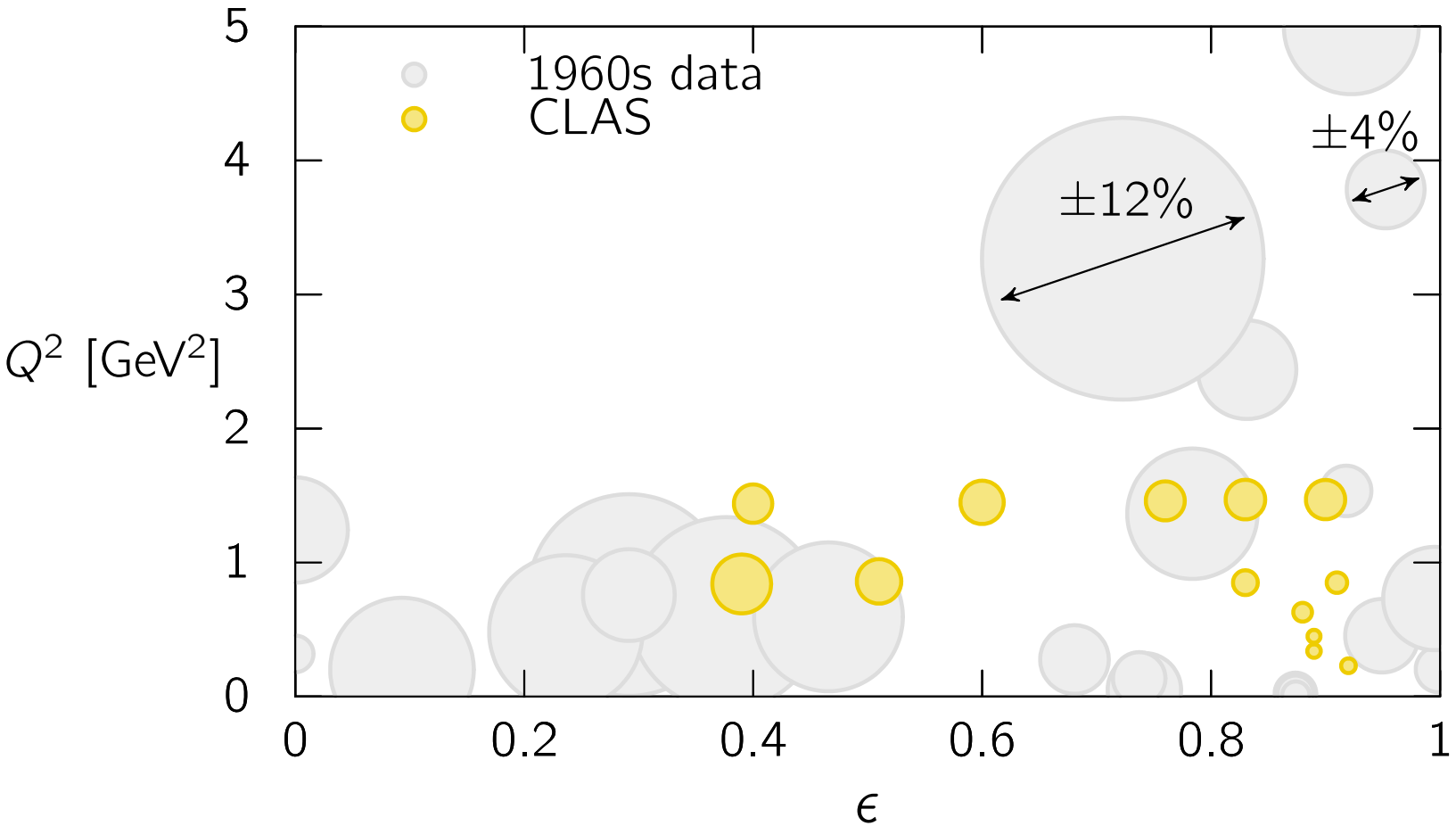

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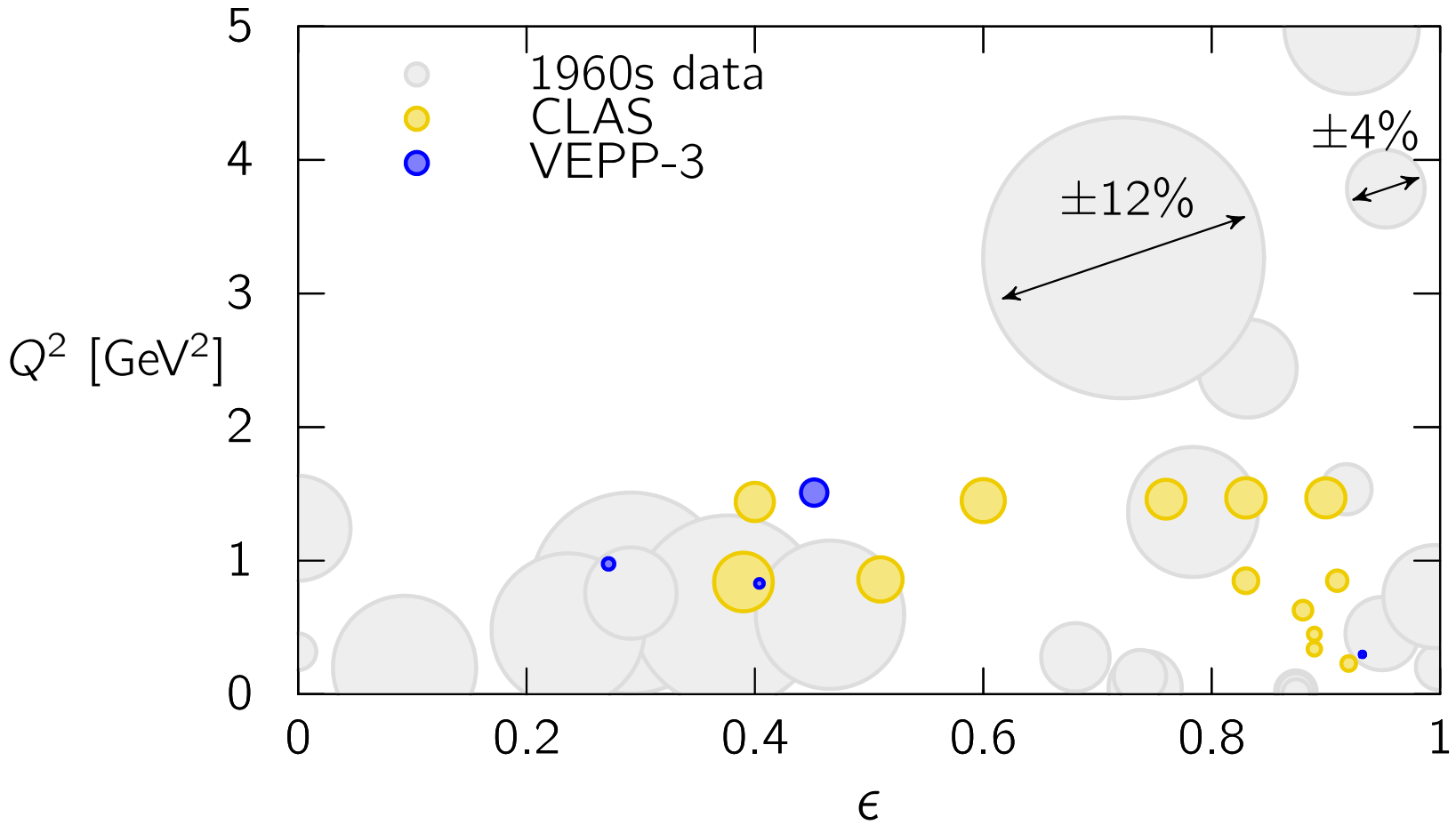

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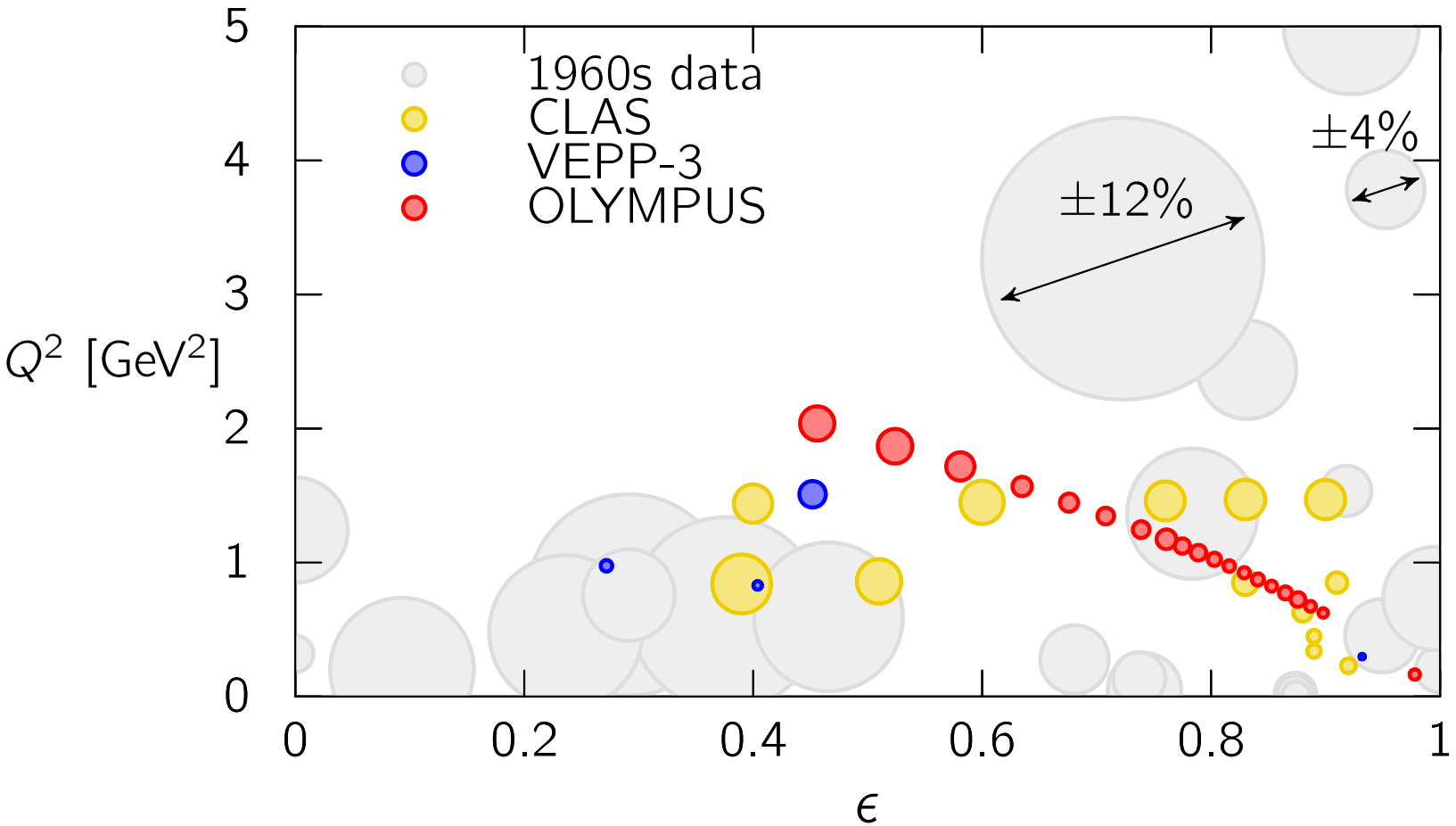
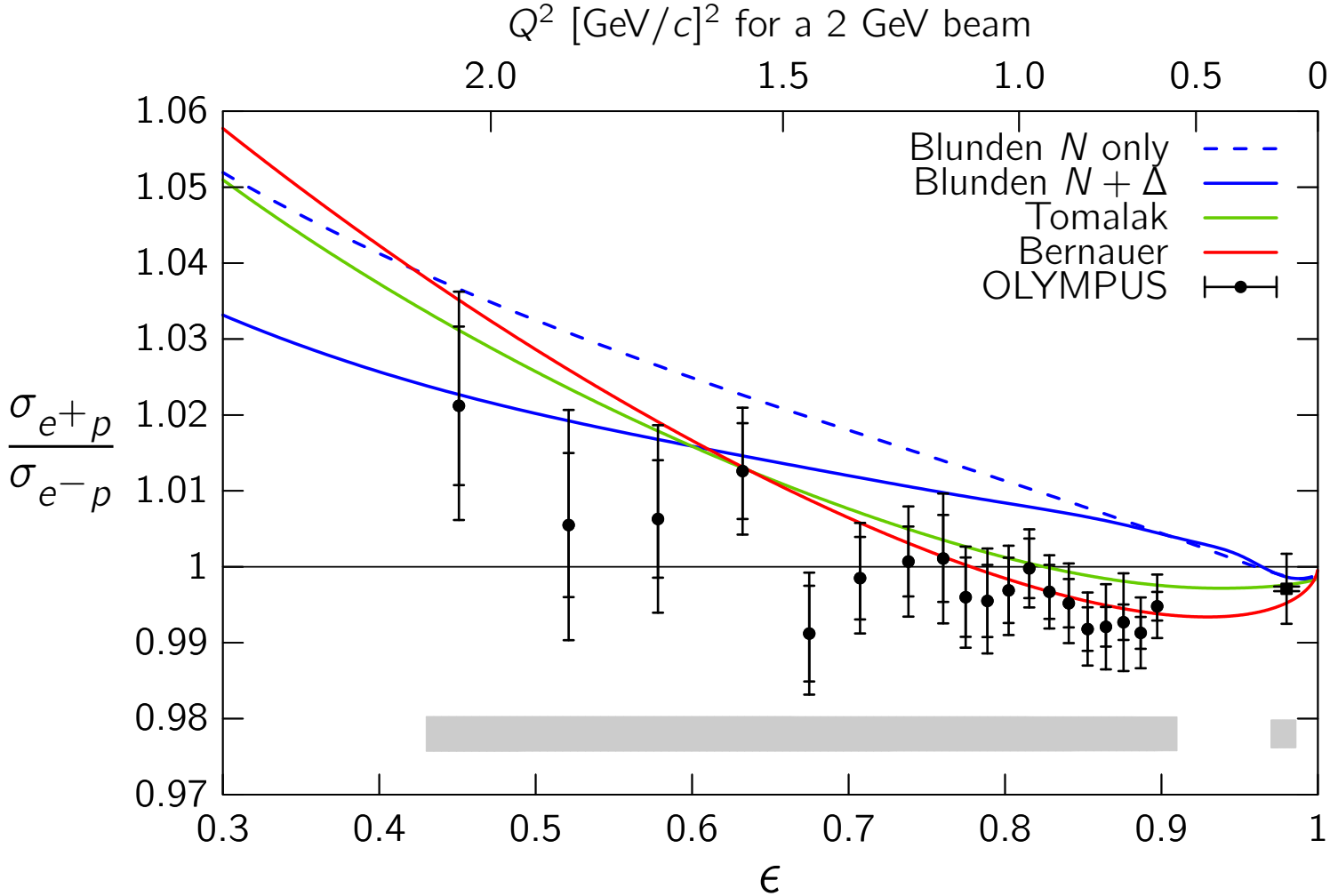


OLYMPUS observed a small TPE effect.



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

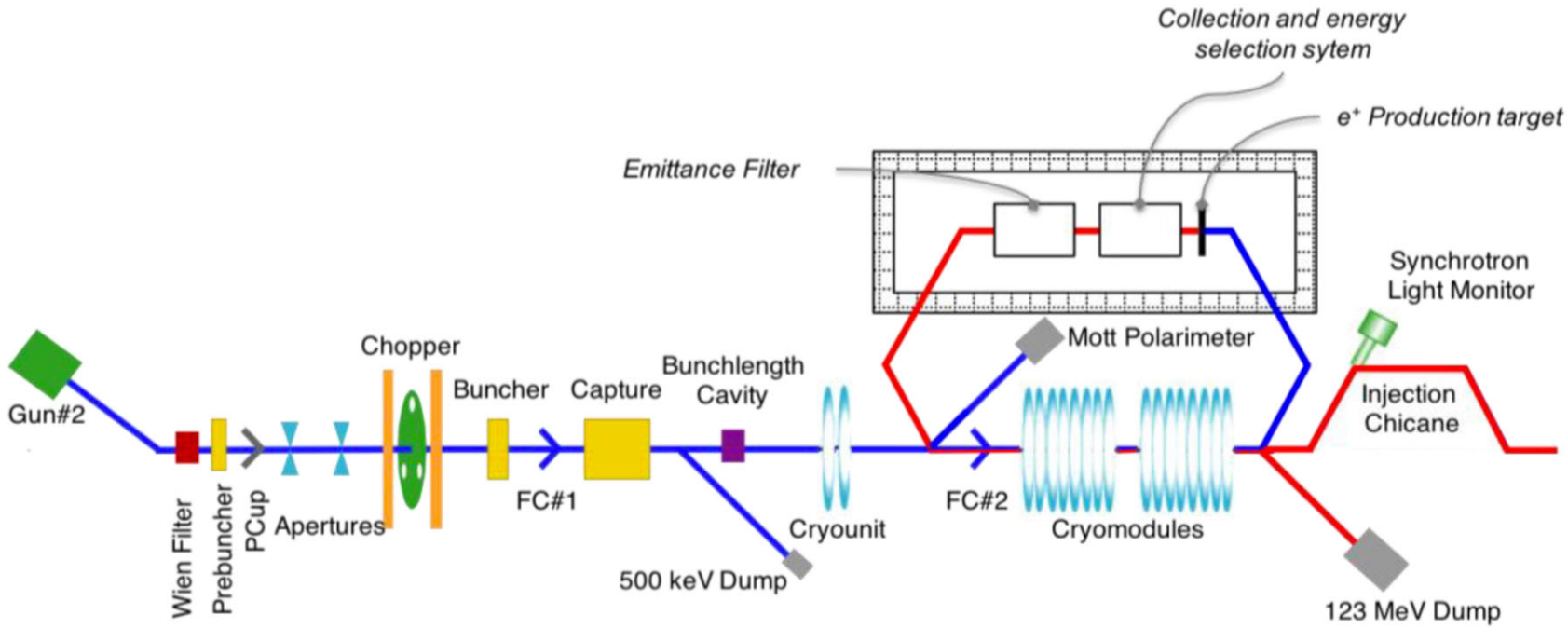
Summary of current state

- We lack measurements where FF discrepancy is large.
- We don't have any measurements where partonic and hadronic calculations interface.
- We have no facility with a positron beam and state of the art detectors.
- We are at the cusp of a major campaign to look at 3D nucleon structure.

In my talk today:

1. Current state of two-photon exchange
2. **How a positron beam at JLab can move us beyond this state**

Positron beam at CEBAF with PEPPo



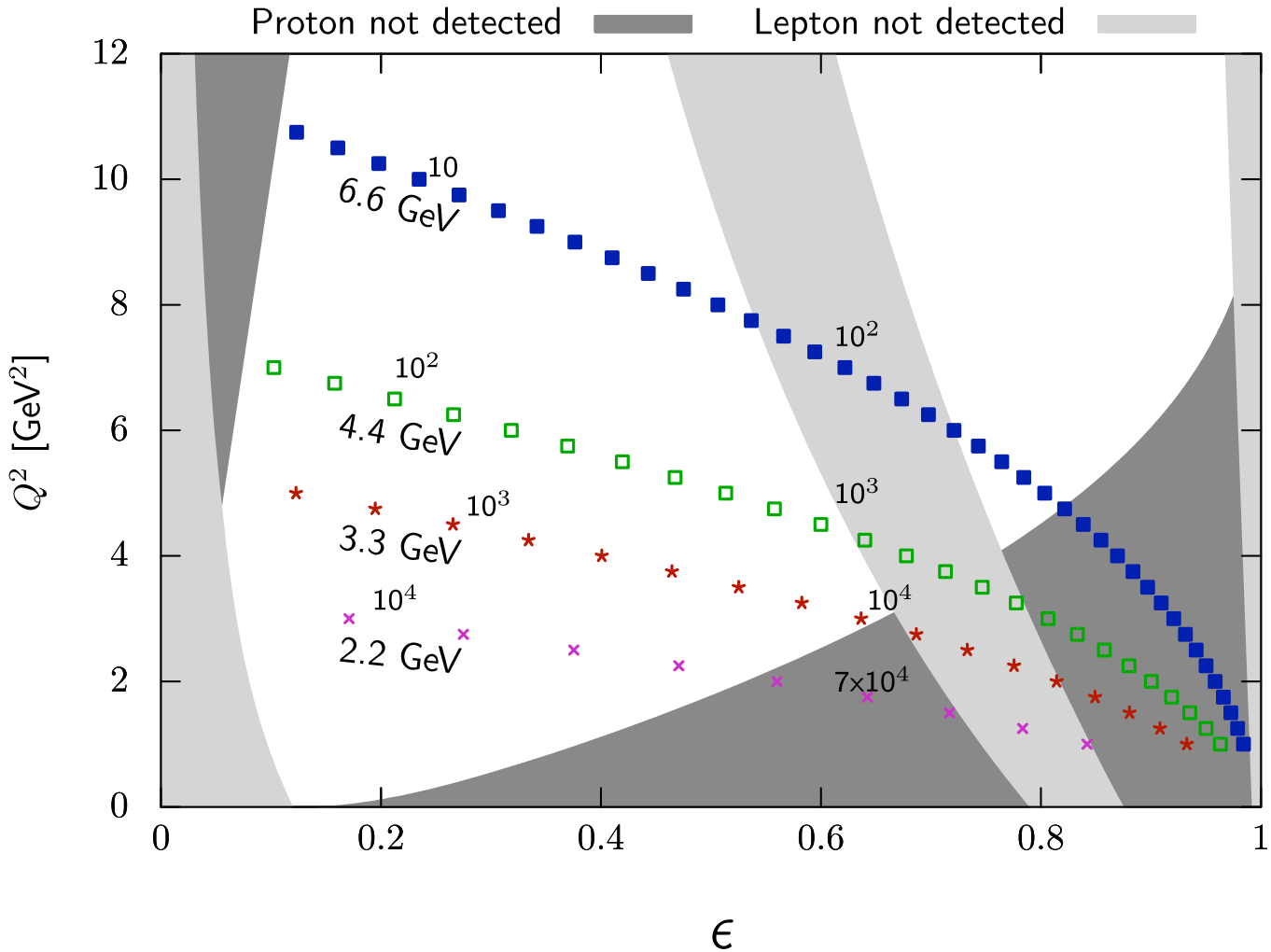
Design goal:

- 100 nA with $\approx 60\%$ polarization
- Up to 1 μA unpolarized

Two-photon exchange concepts at Jefferson Lab

- e^+p/e^-p at CLAS12
  - J. C. Bernauer et al.
  - Campaign to map out TPE once and for all
- e^+p/e^-p at SBS
  - E. Cline et al.
  - Quick, targeted measurement at low-ϵ
- e^+p super-Rosenbluth, Hall C
  - J. Arrington, M. Yurov
  - Demonstrate opposite bias in G_E/G_M
- e^+A/e^-A in Hall C
  - T. Kutz et al.
  - First measurement of TPE on nuclei
- e^+ polarization transfer at SBS
  - A. J. R. Puckett et al.
  - Show ϵ-dependence comes from TPE
- Target-normal single spin asymmetry at SBS
  - G. N. Grauvogel et al.
  - Imaginary part of TPE amplitude

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



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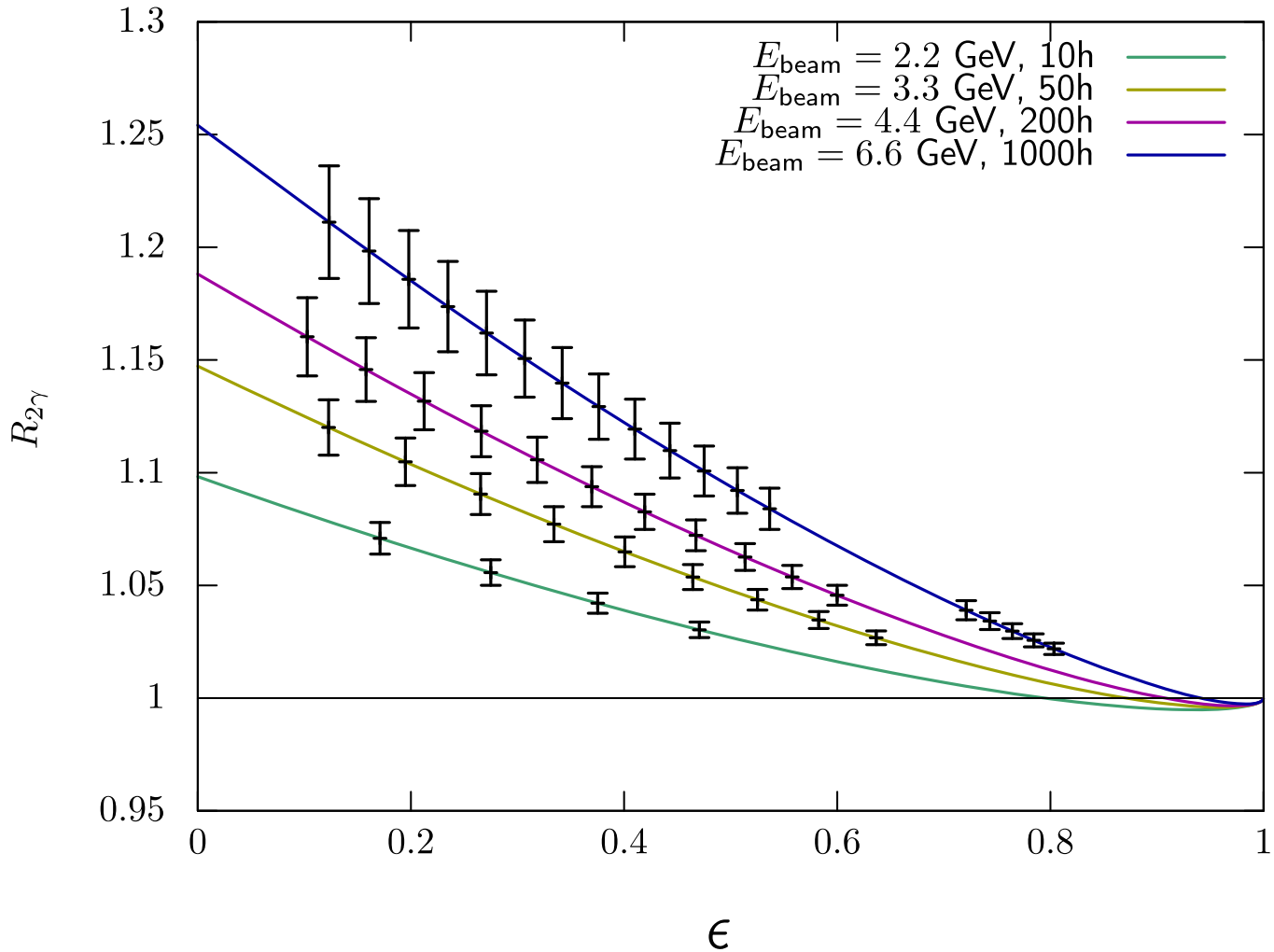
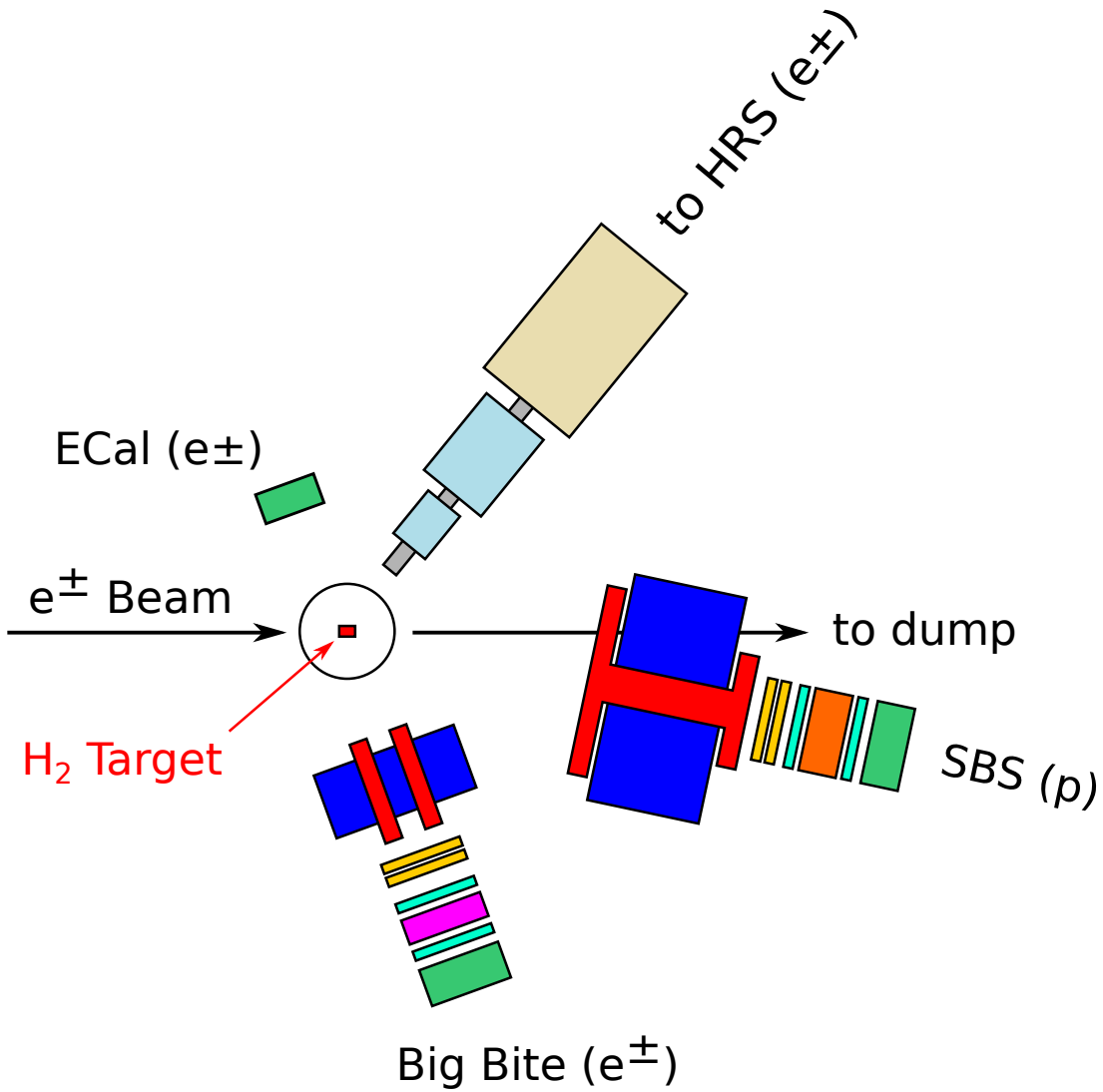


Super BigBite would allow quicker measurement at the expense of coverage.



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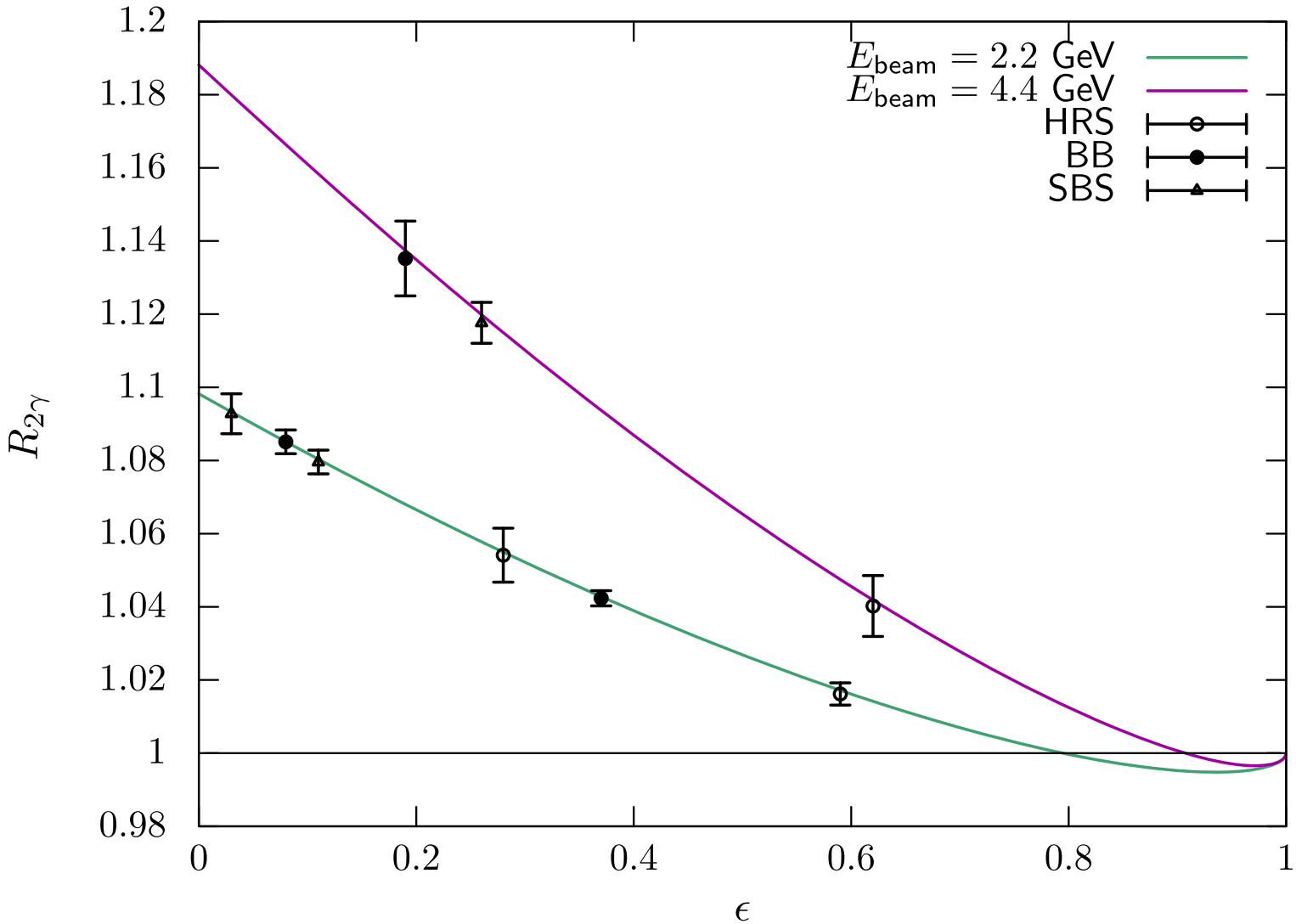
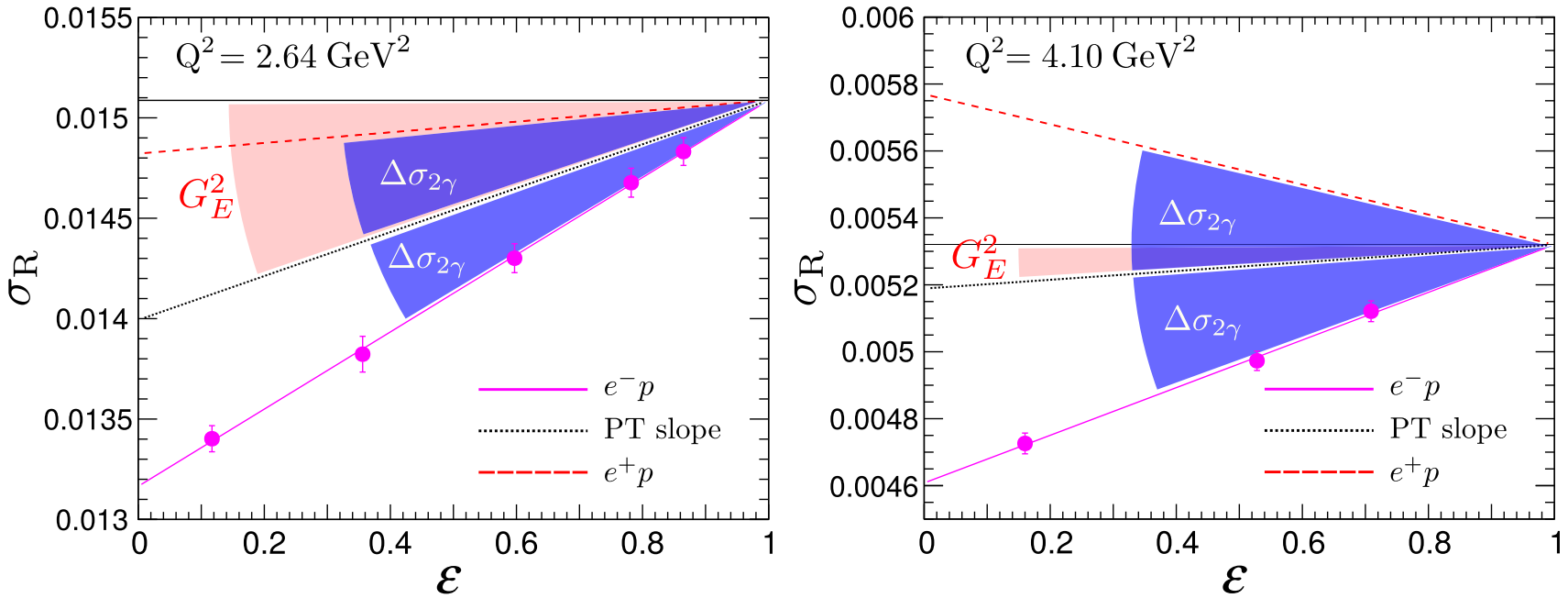


A super-Rosenbluth measurement with e^+ would clearly show the bias caused by TPE.



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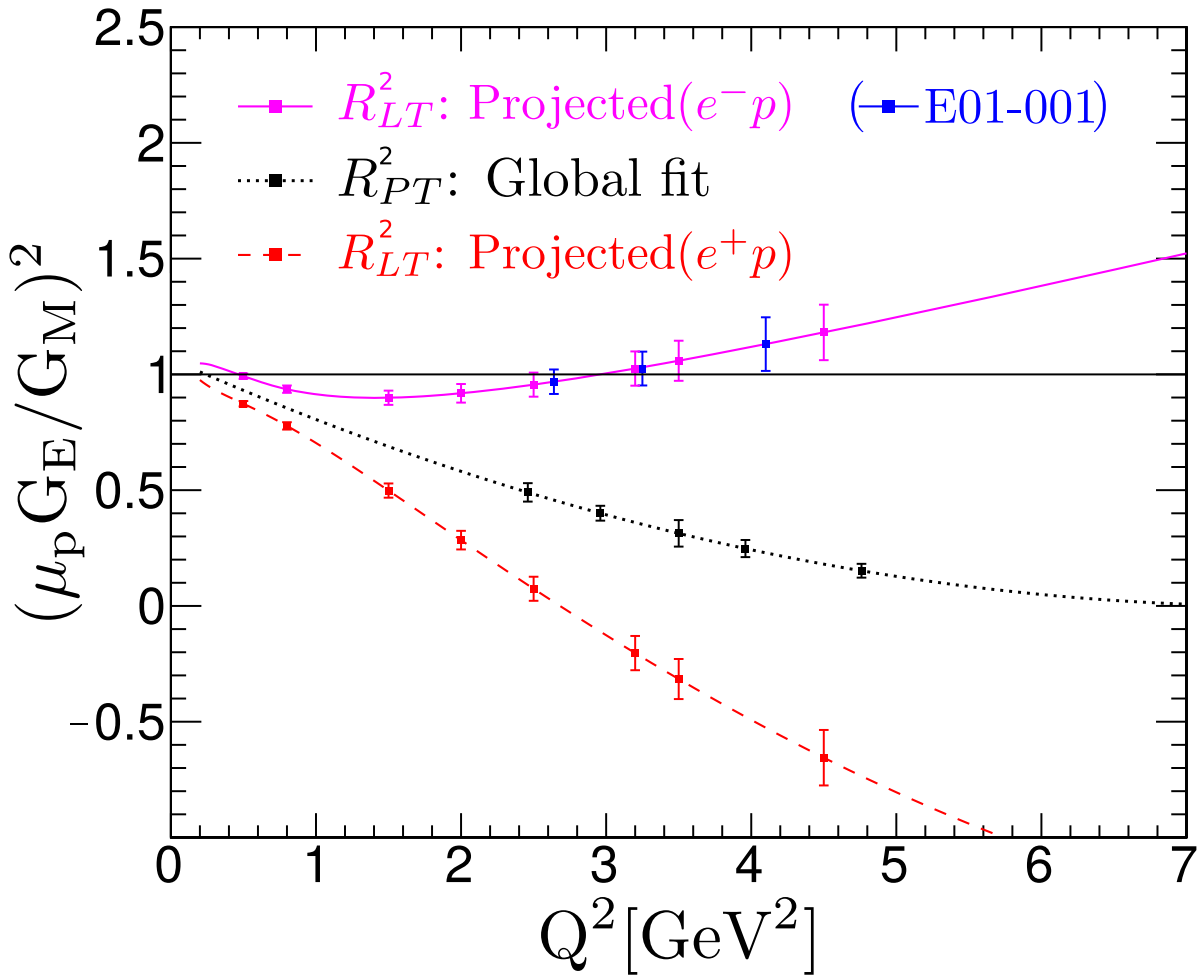
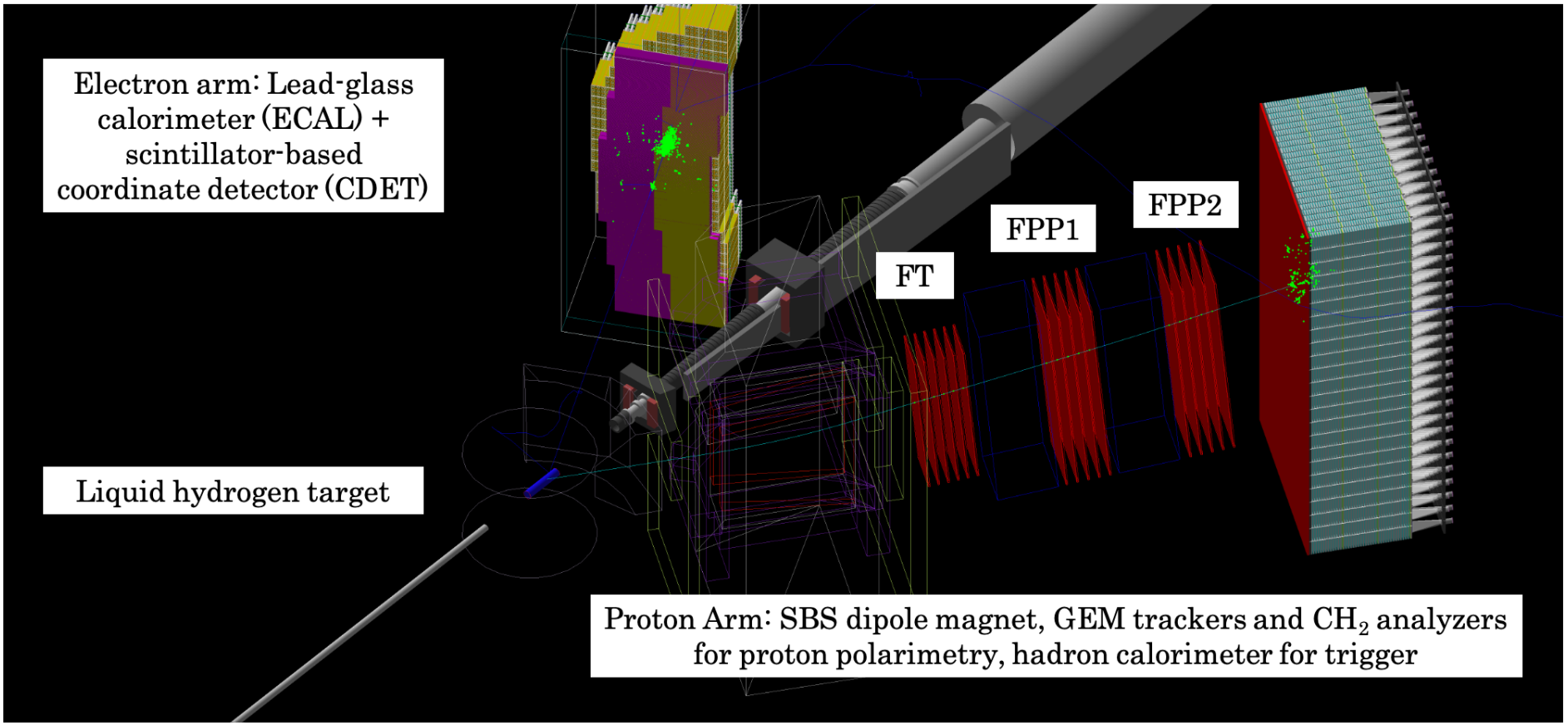
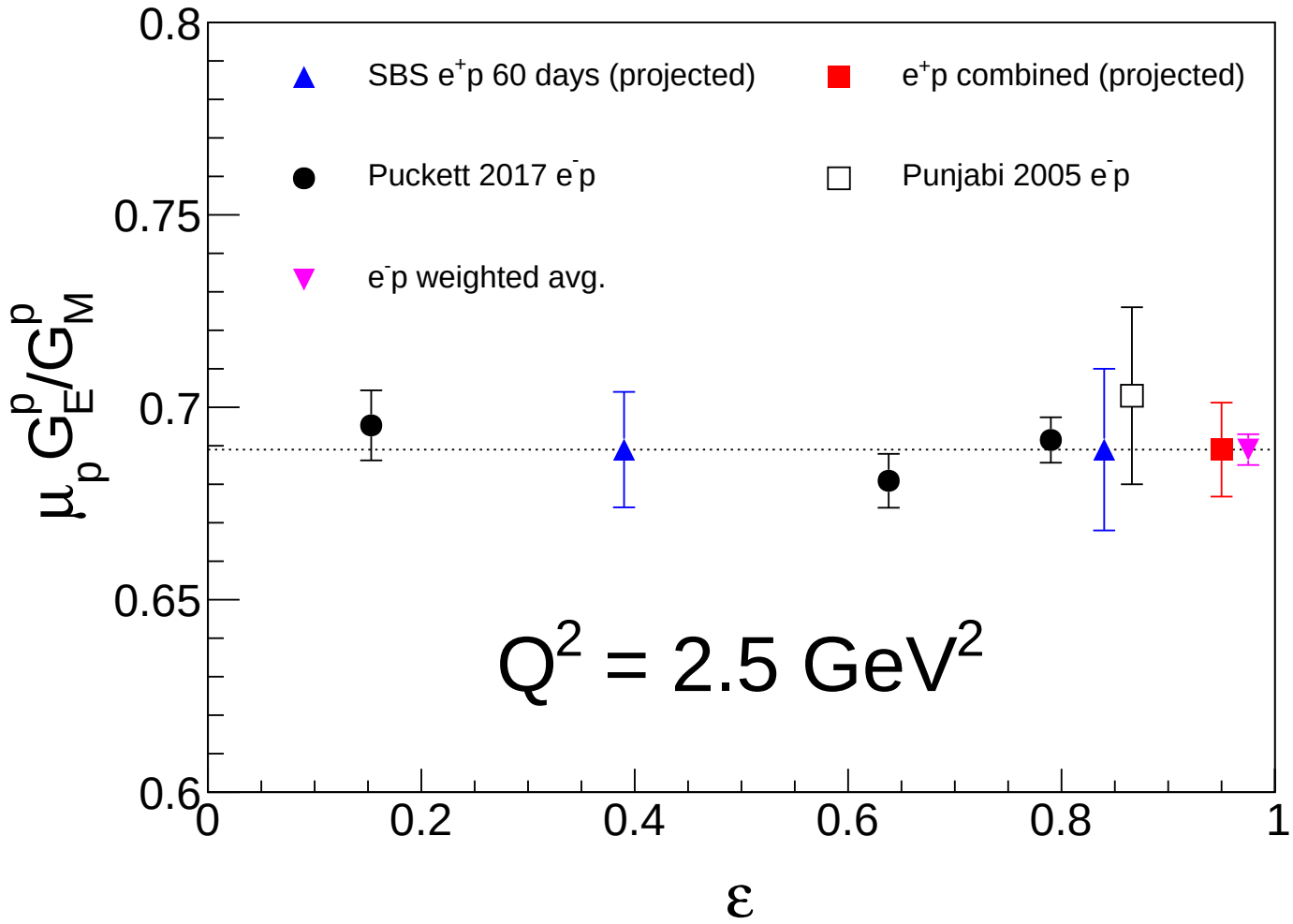


With Super BigBite, even e^+ polarization transfer would be feasible.



e^+ and e^- measurements can prove if ϵ-dependence comes from TPE.



Single-spin asymmetries with positrons

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

THE EUROPEAN PHYSICAL JOURNAL A

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

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

Gabe Grauvogel

Single-spin transverse asymmetries are sensitive to the imaginary part of TPE.

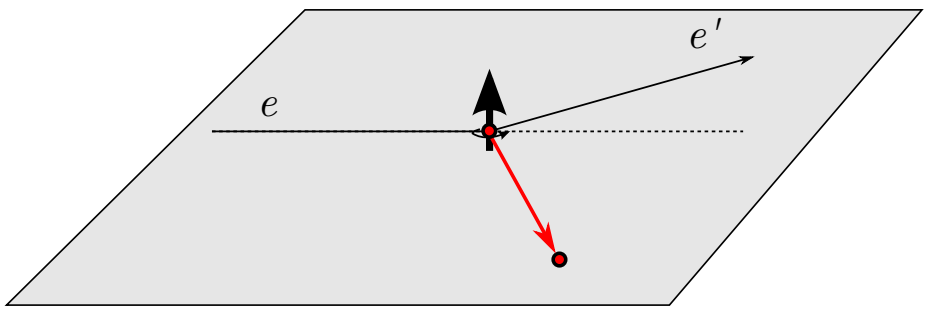
Target-normal:

$$A_n = \frac{\sqrt{2\epsilon(1+\epsilon)}}{\sqrt{\tau}\left(G_M^2 + \frac{\epsilon}{\tau}G_E^2\right)} \times$$
$$\left[-G_M \mathrm{Im}\left(\delta\tilde{G}_E + \frac{\nu}{M^2}\tilde{F}_3\right) + G_E \mathrm{Im}\left(\delta\tilde{G}_M + \frac{2\epsilon\nu}{M^2(1+\epsilon)}\tilde{F}_3\right)\right] + \mathcal{O}(\alpha^4)$$

Beam Normal:

$$B_n = \frac{4mM\sqrt{2\epsilon(1-\epsilon)(1+\tau)}}{Q^2\left(G_M^2 + \frac{\epsilon}{\tau}G_E^2\right)} \times$$
$$\left[-\tau G_M \mathrm{Im}\left(\tilde{F}_3 + \frac{\nu}{M^2(1+\tau)}\tilde{F}_5\right) - G_E \mathrm{Im}\left(\tilde{F}_4 + \frac{\nu}{M^2(1+\tau)}\tilde{F}_5\right)\right] + \mathcal{O}(\alpha^4)$$

Transverse asymmetries do not violate parity.



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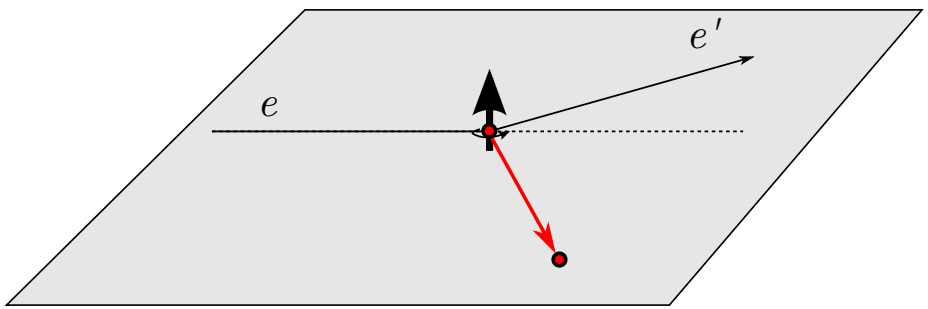
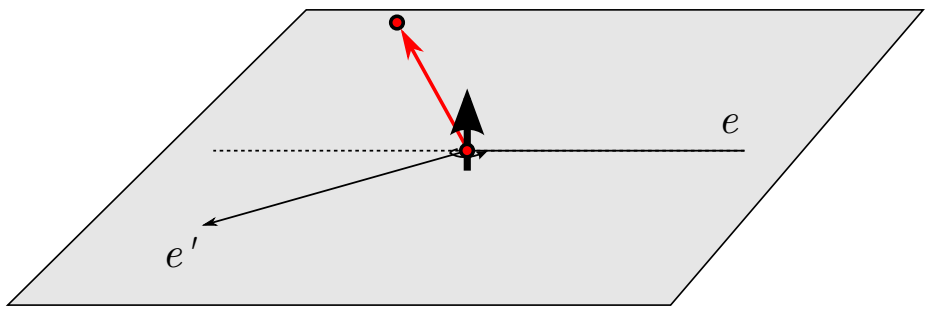
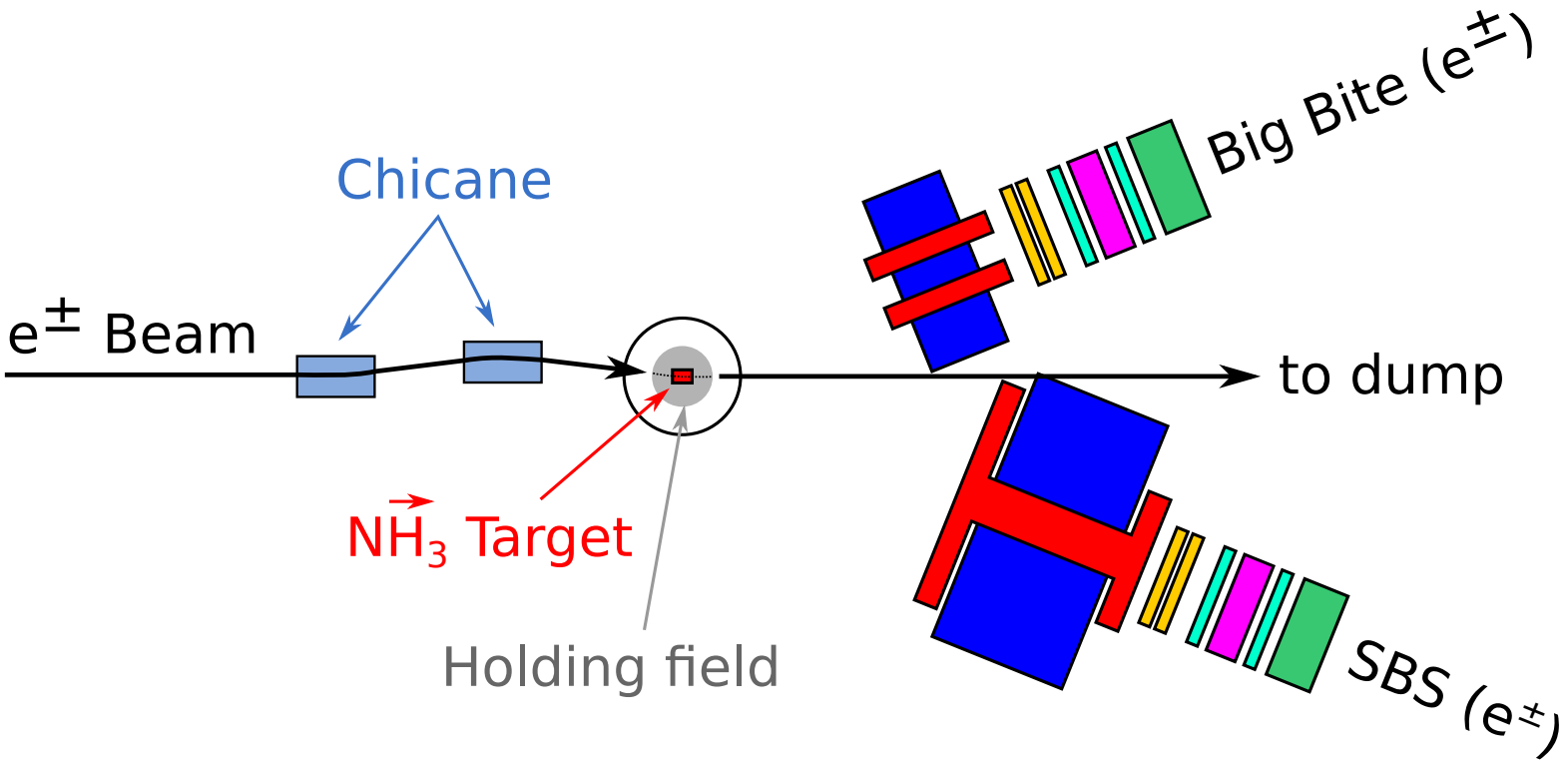




A transversely polarized proton target will require a strong holding field.



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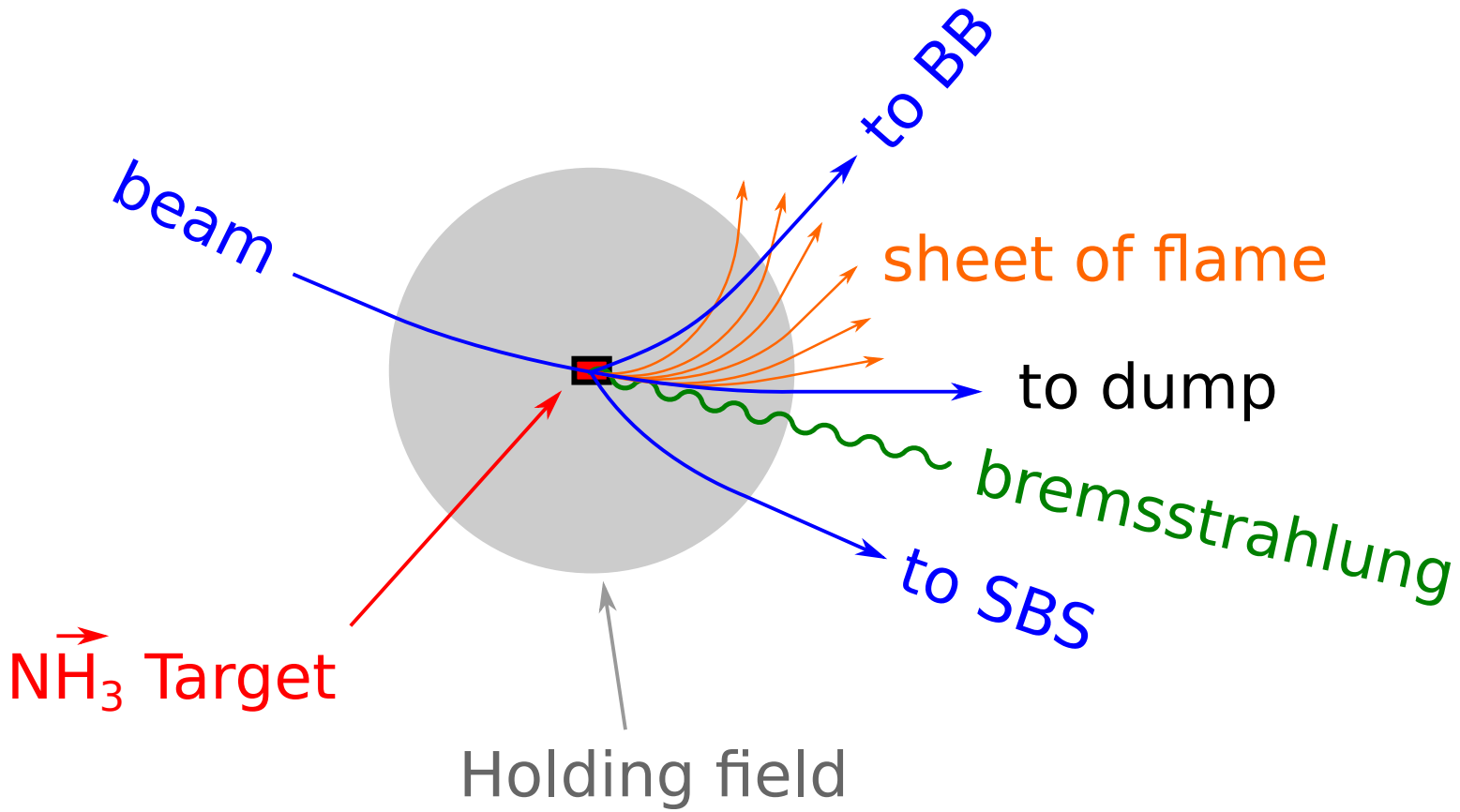
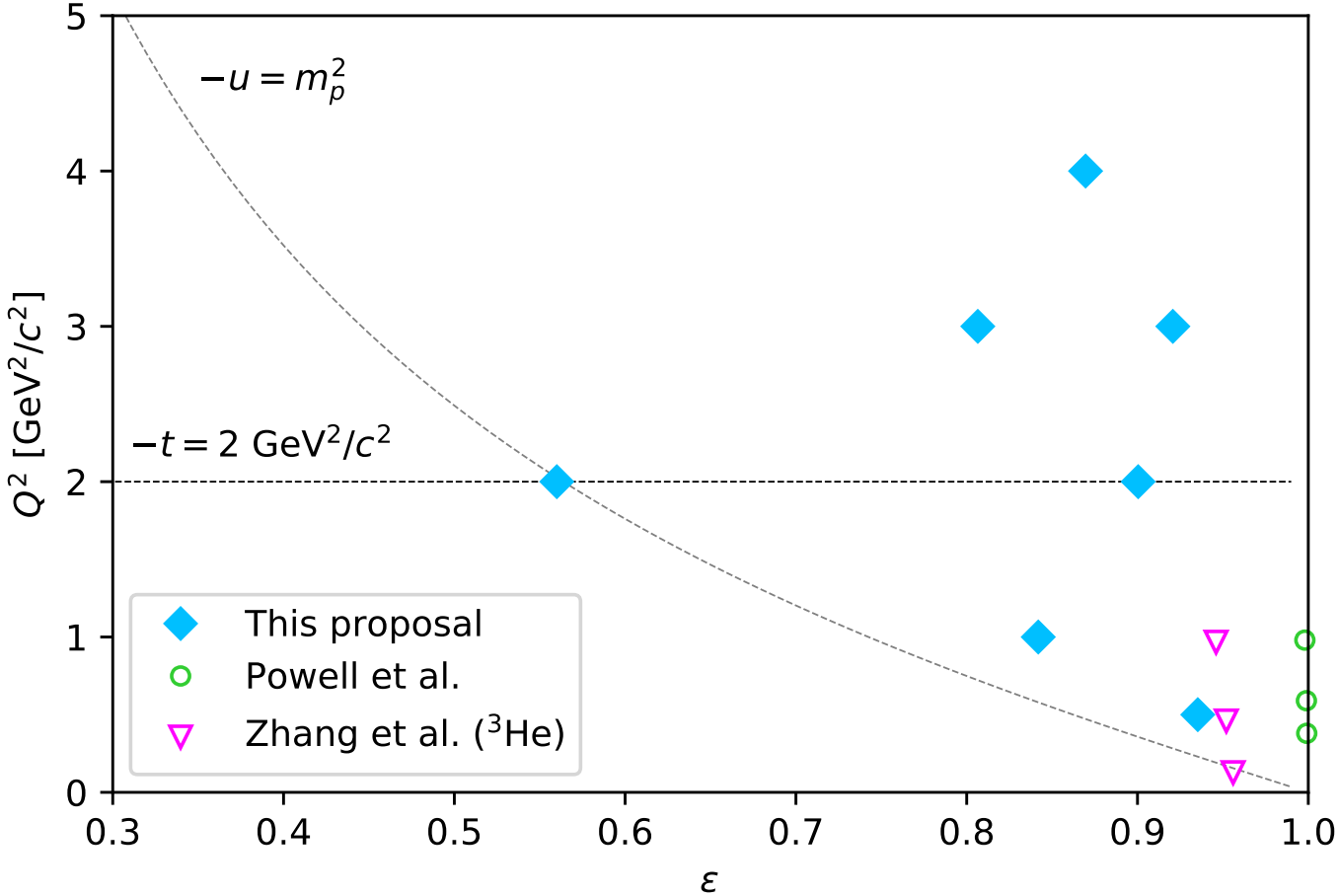


A measurement at JLab would cover new ground.



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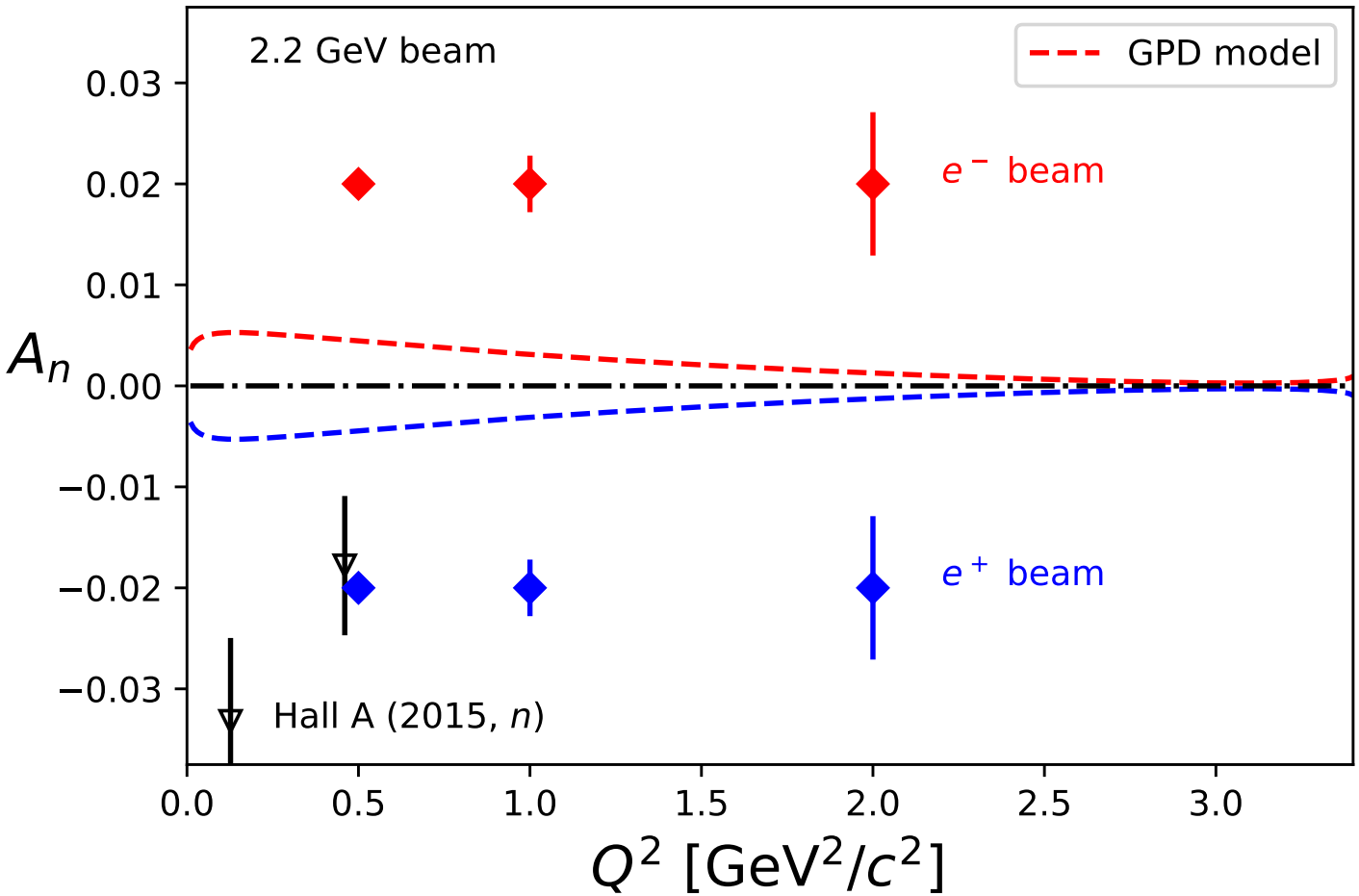

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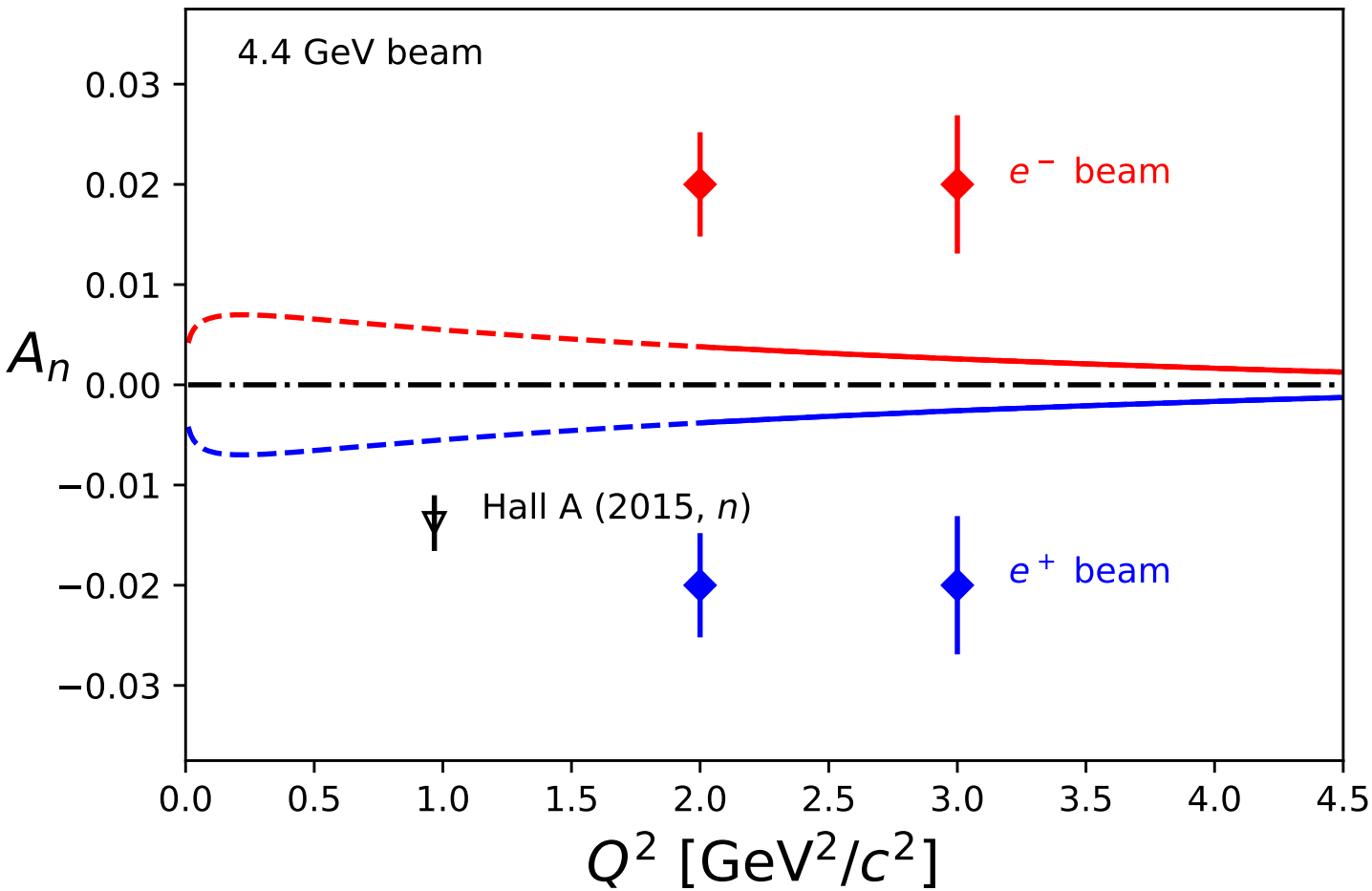

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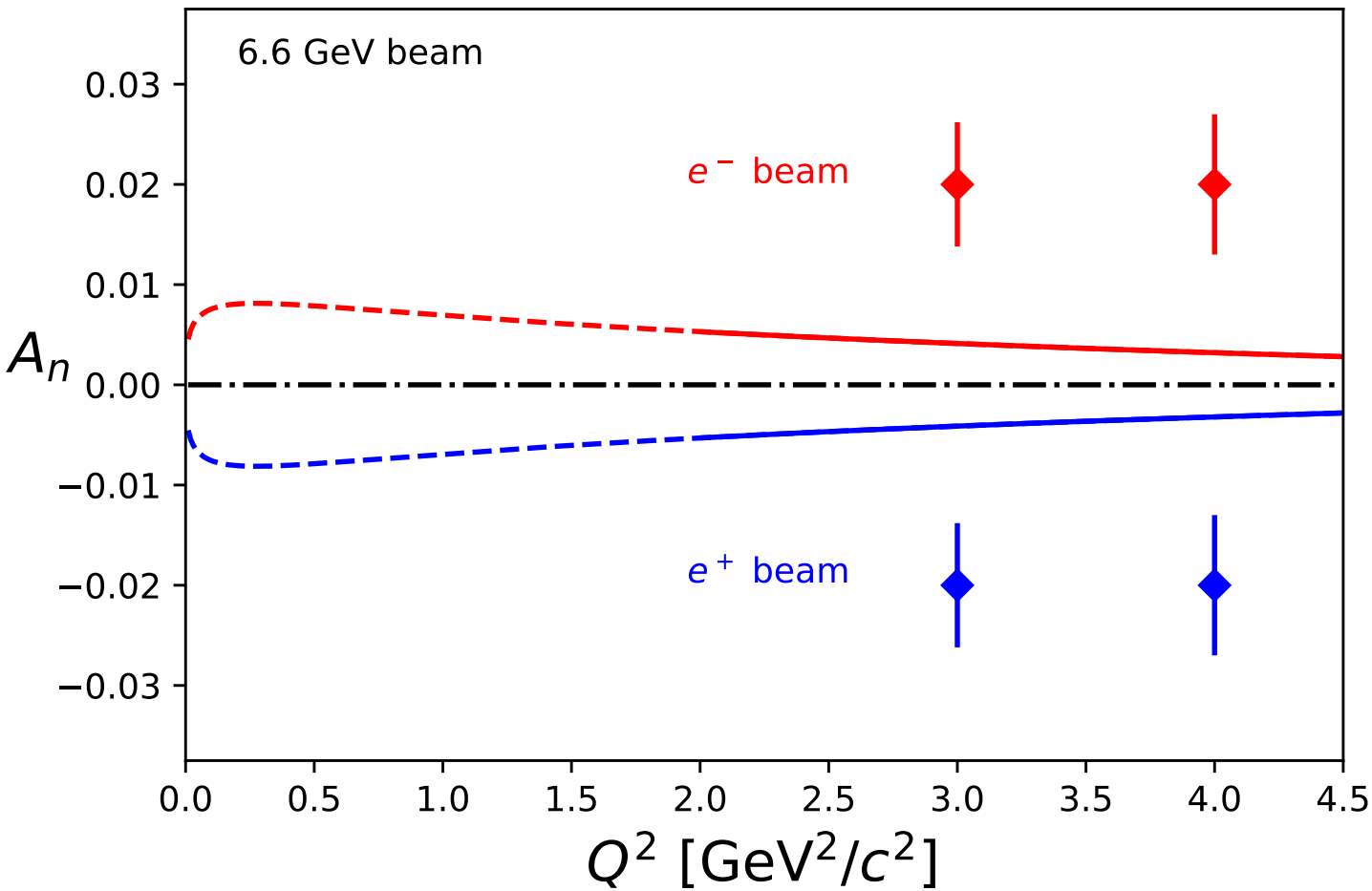

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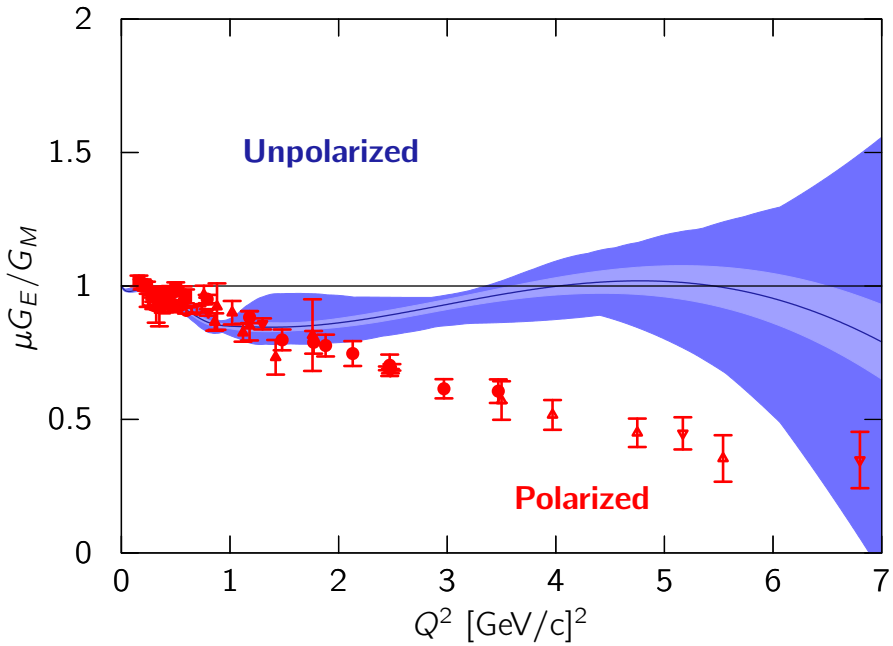
- Discrepancy in proton FFs may be cause by TPE.



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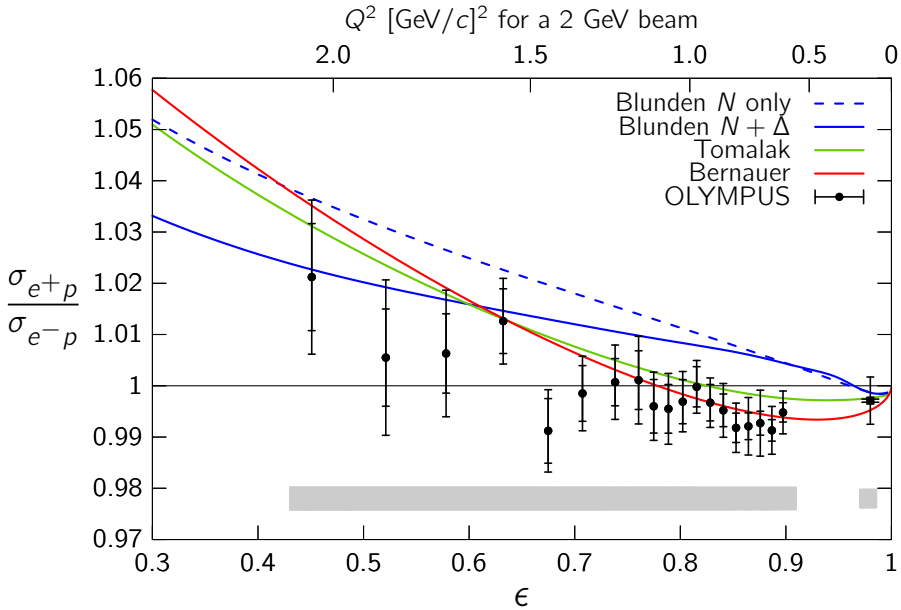

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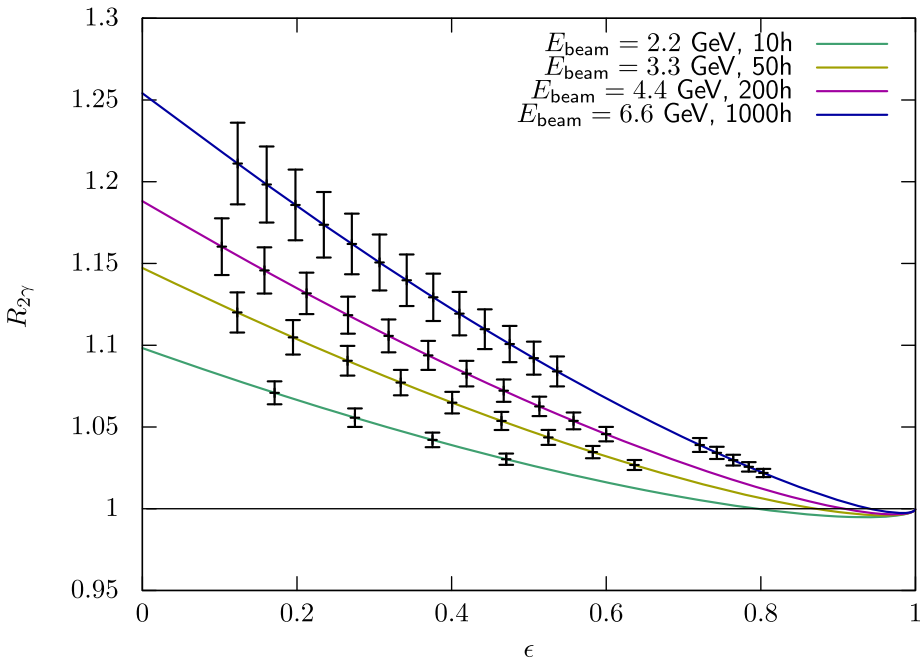

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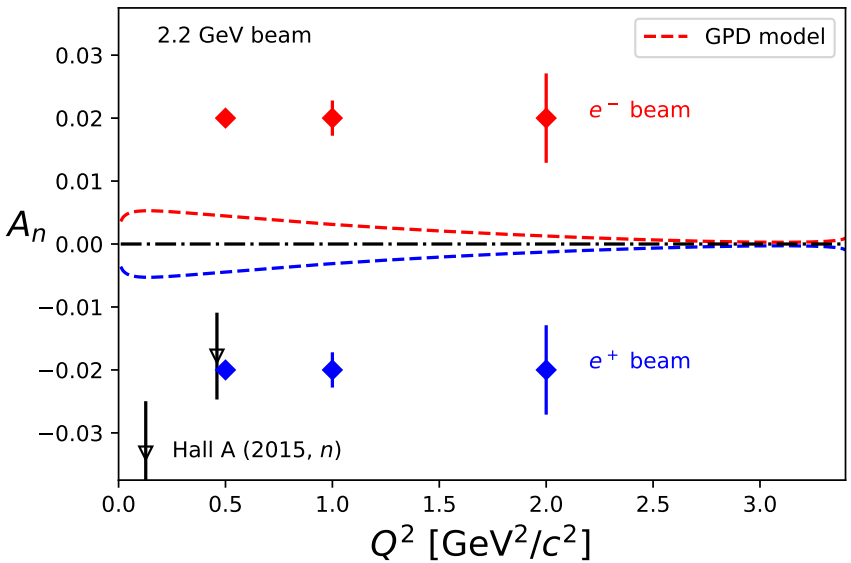

Conclusions:

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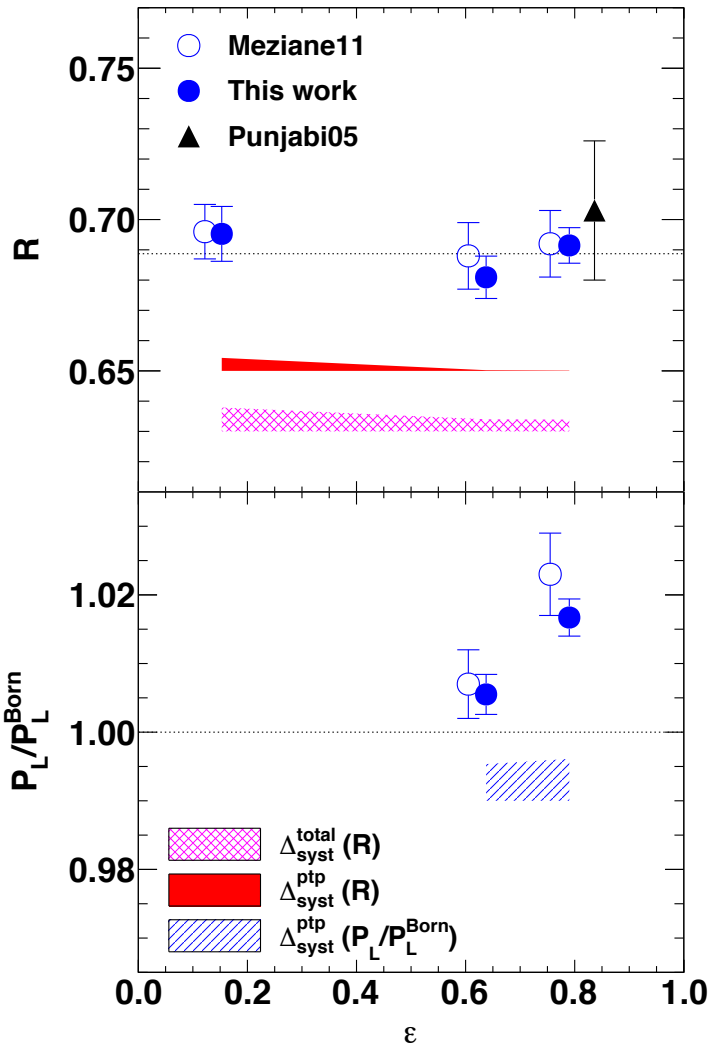
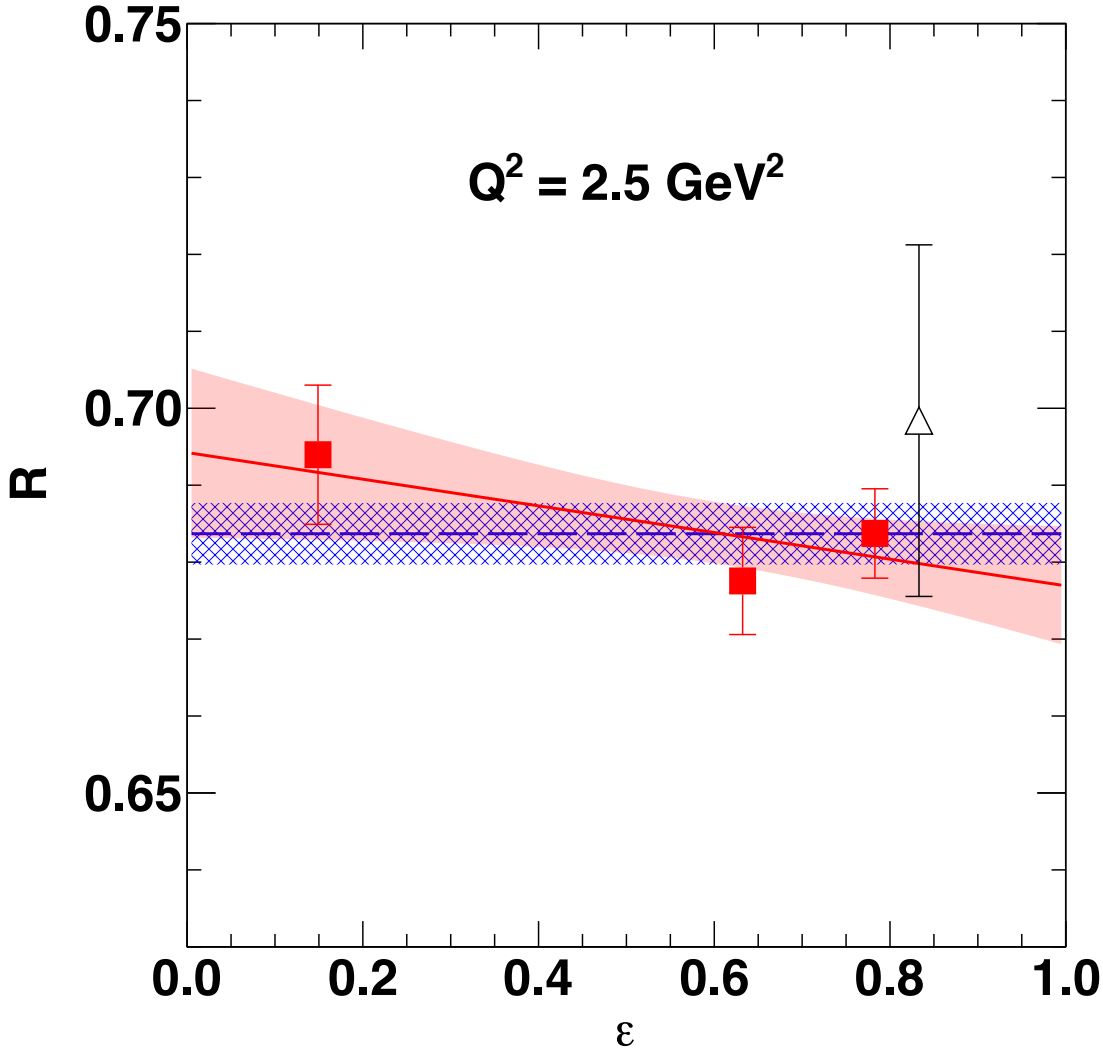
Check out our white paper:
`https://epja.epj.org/component/toc/?task=topic&id=1430`

Back Up

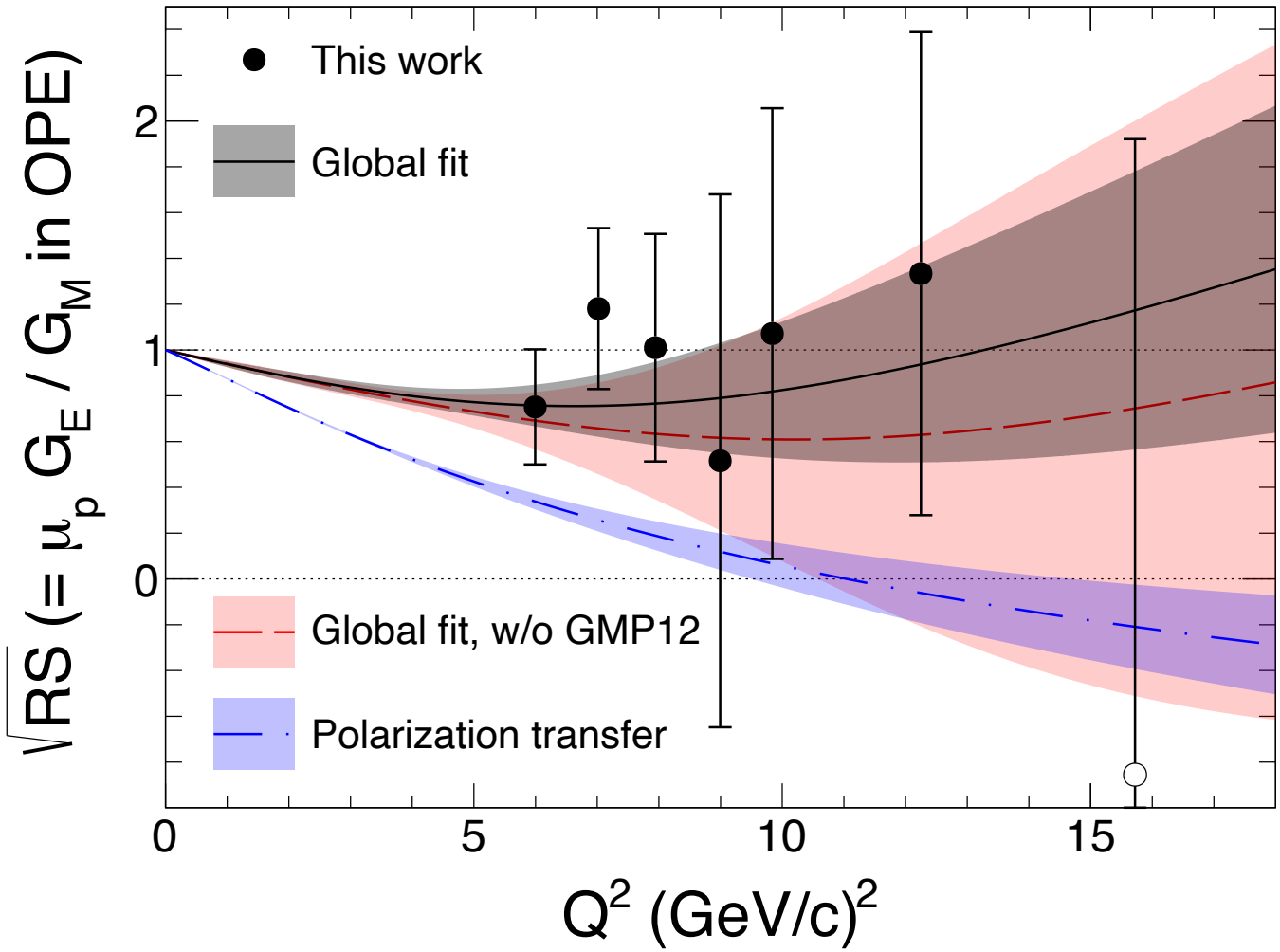
GEp-2γ showed surprising ϵ-dependence of P_l.





A. J. R. Puckett et al., Phys. Rev. C 96, 055203 (2017)

GMp results show that the FF discrepancy persists at high Q^2.



M. E. Christy et al., Phys. Rev. Lett. 128, 102002 (2021)