
Arizona State University


UNIVERSITY OF MASSACHUSETTS
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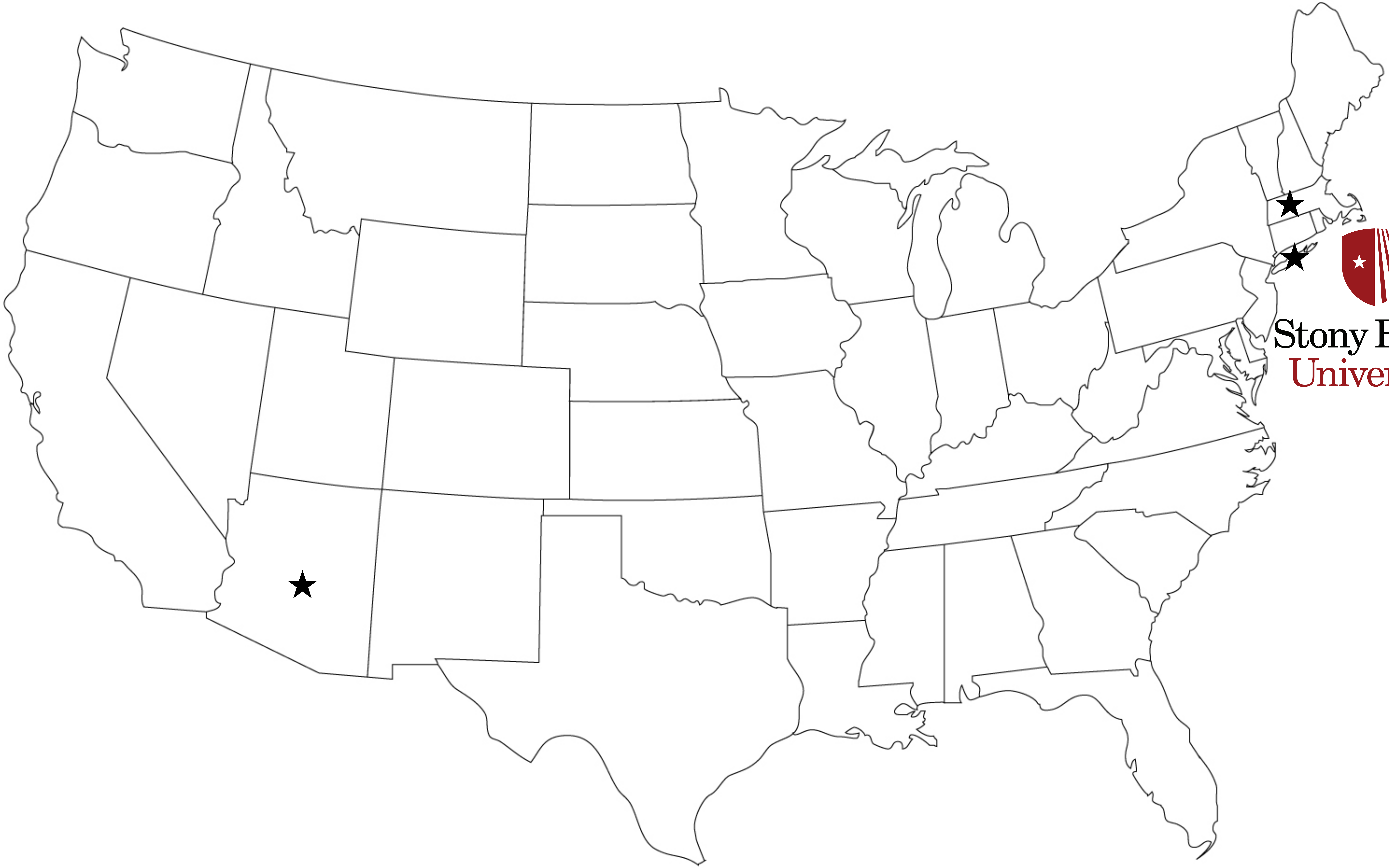

Stony Brook
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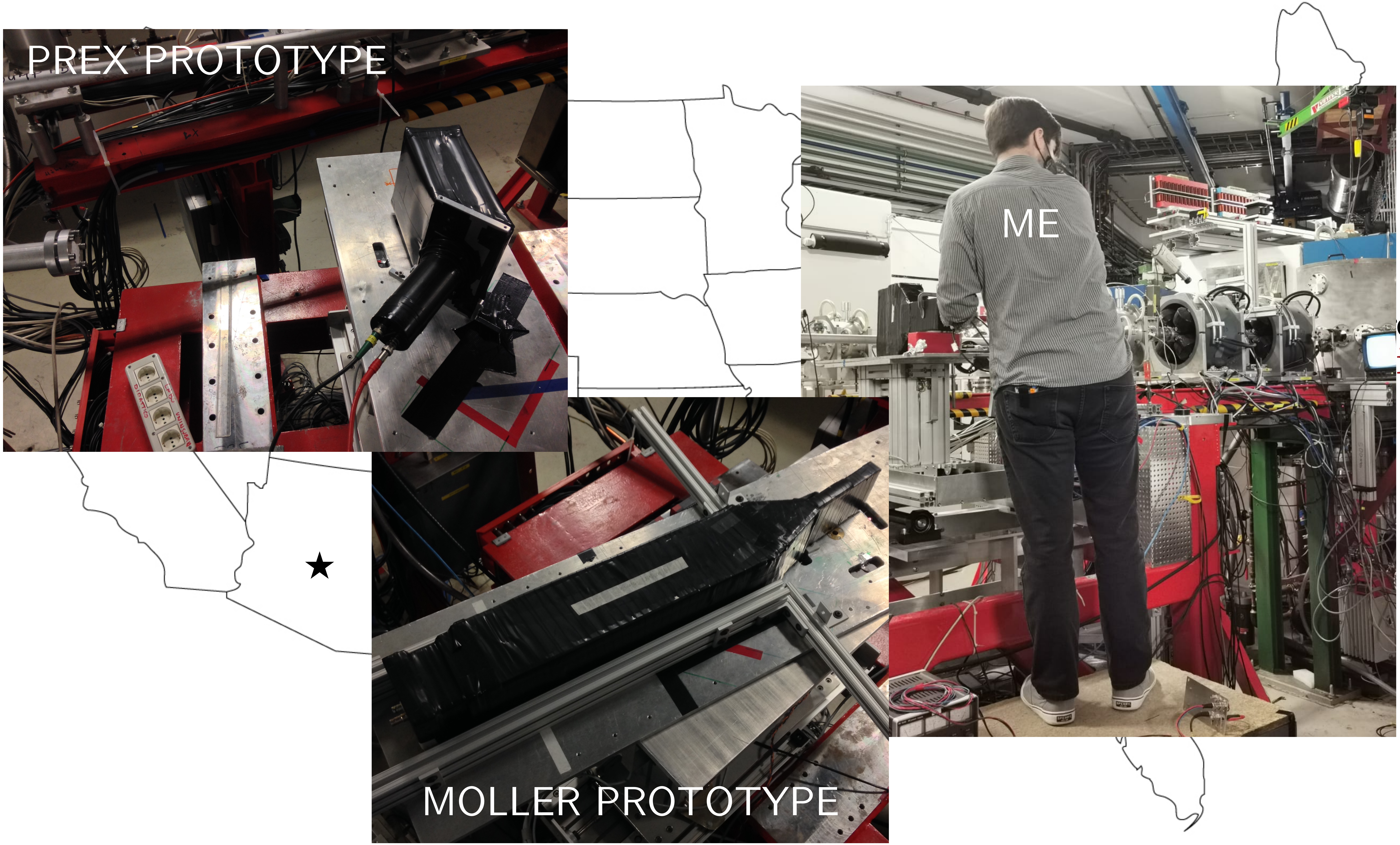

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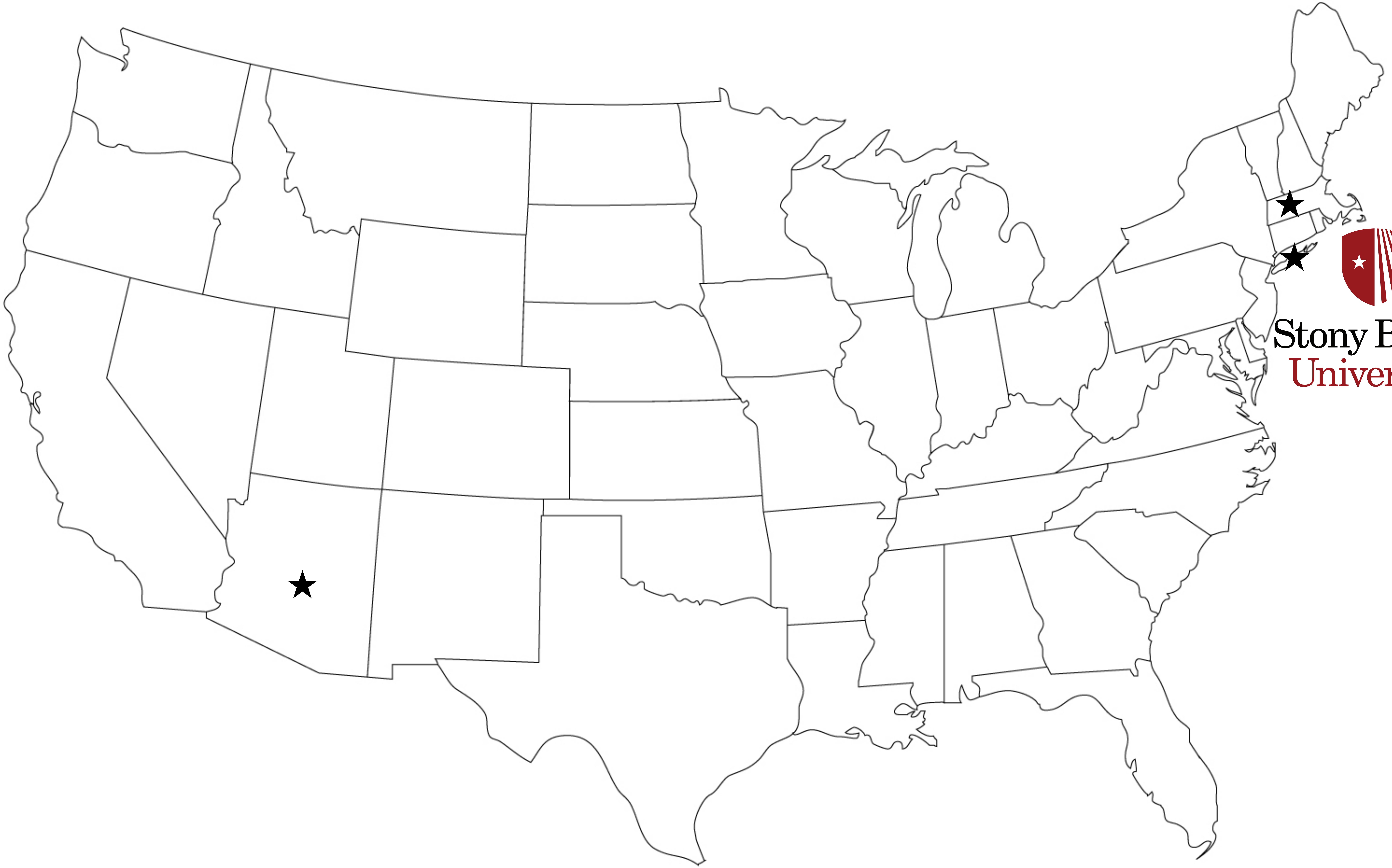
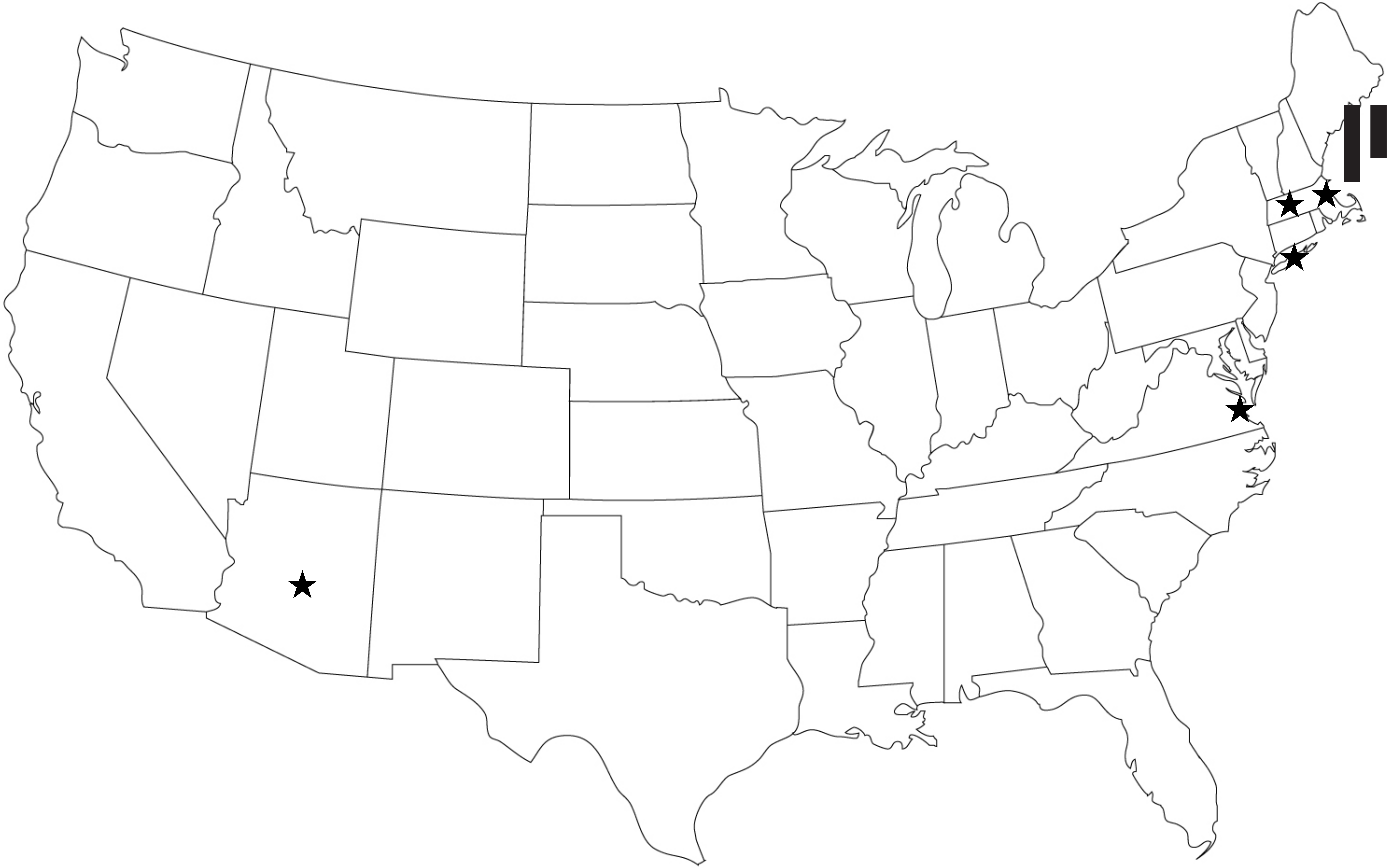


Stony Brook
University


Jefferson Lab
Stony Brook
University



Thinking outside the box (diagram): Probing two-photon exchange in lepton scattering

Tyler Kutz
JGU Mainz

CRC1660 Kick-Off Meeting
December 9, 2024

Proton form factor ratio can be determined by two independent methods

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_{\mathrm{Mott}} \frac{\epsilon G_E^2 + \tau G_M^2}{1 + \tau}$$

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Rosenbluth separation
determines G_E, G_M

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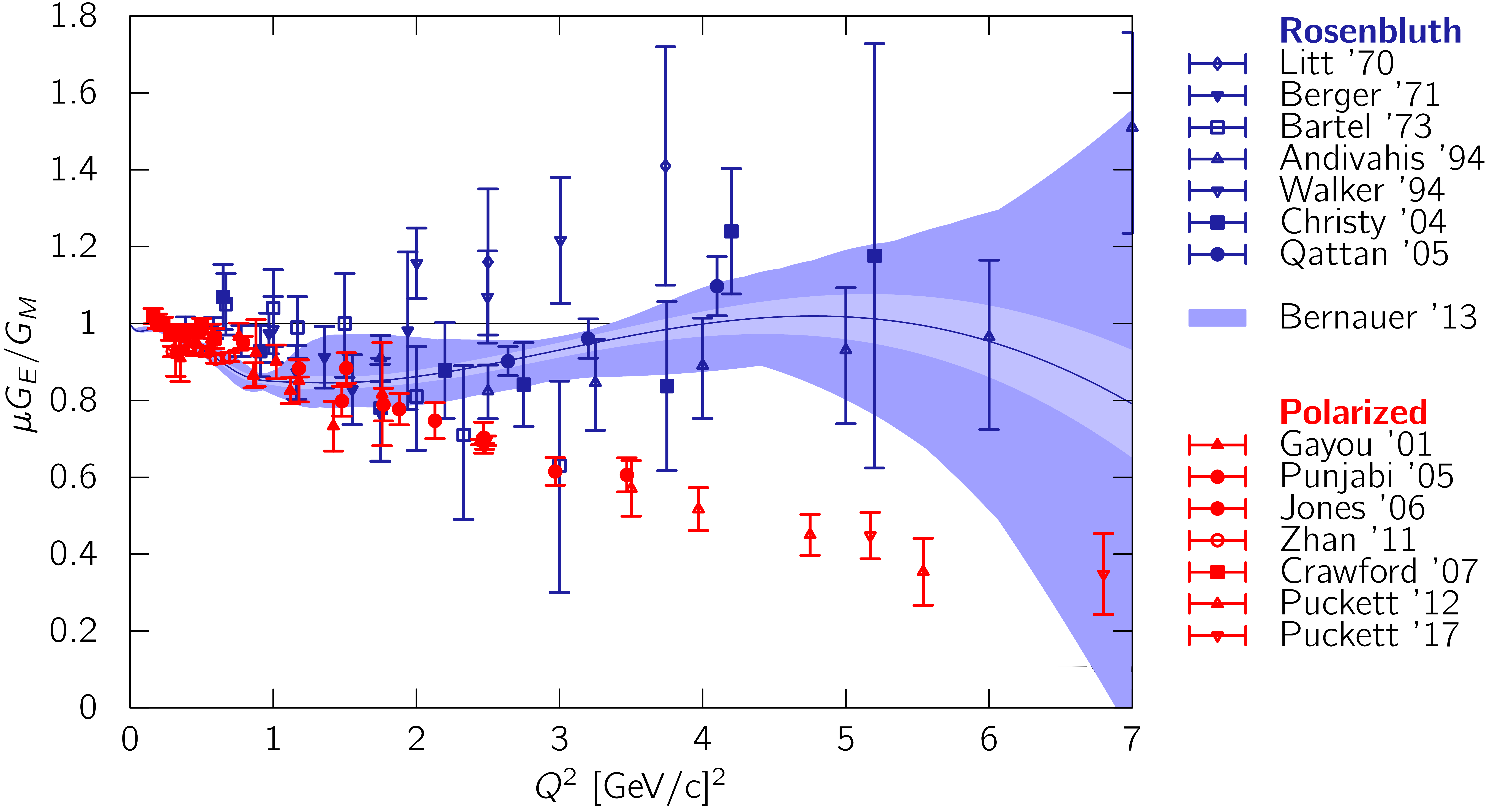
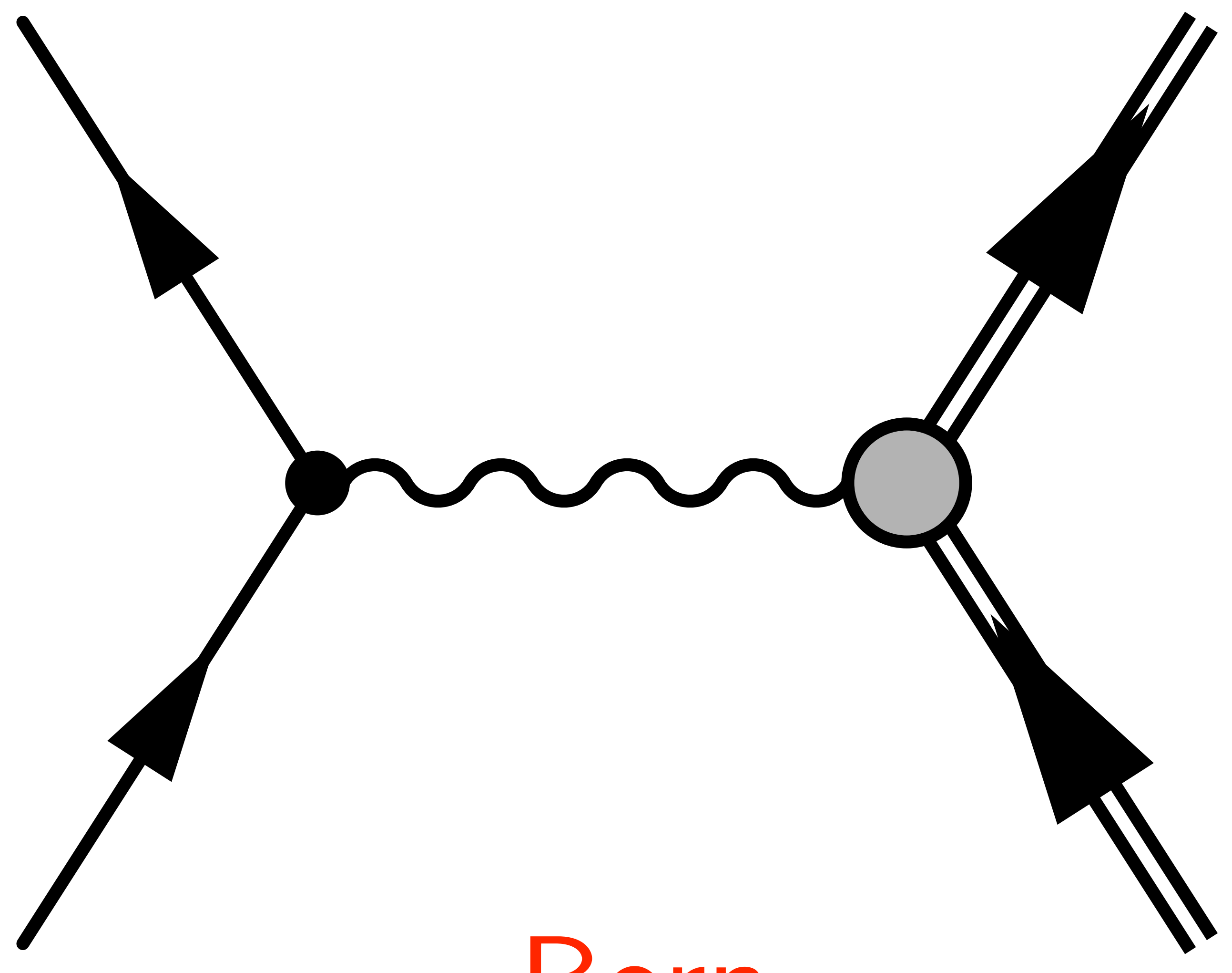
Rosenbluth separation determines G_E, G_M

Polarization transfer determines G_E/G_M

But they disagree!



Electron scattering interpreted in Born approximation



Born
approximation

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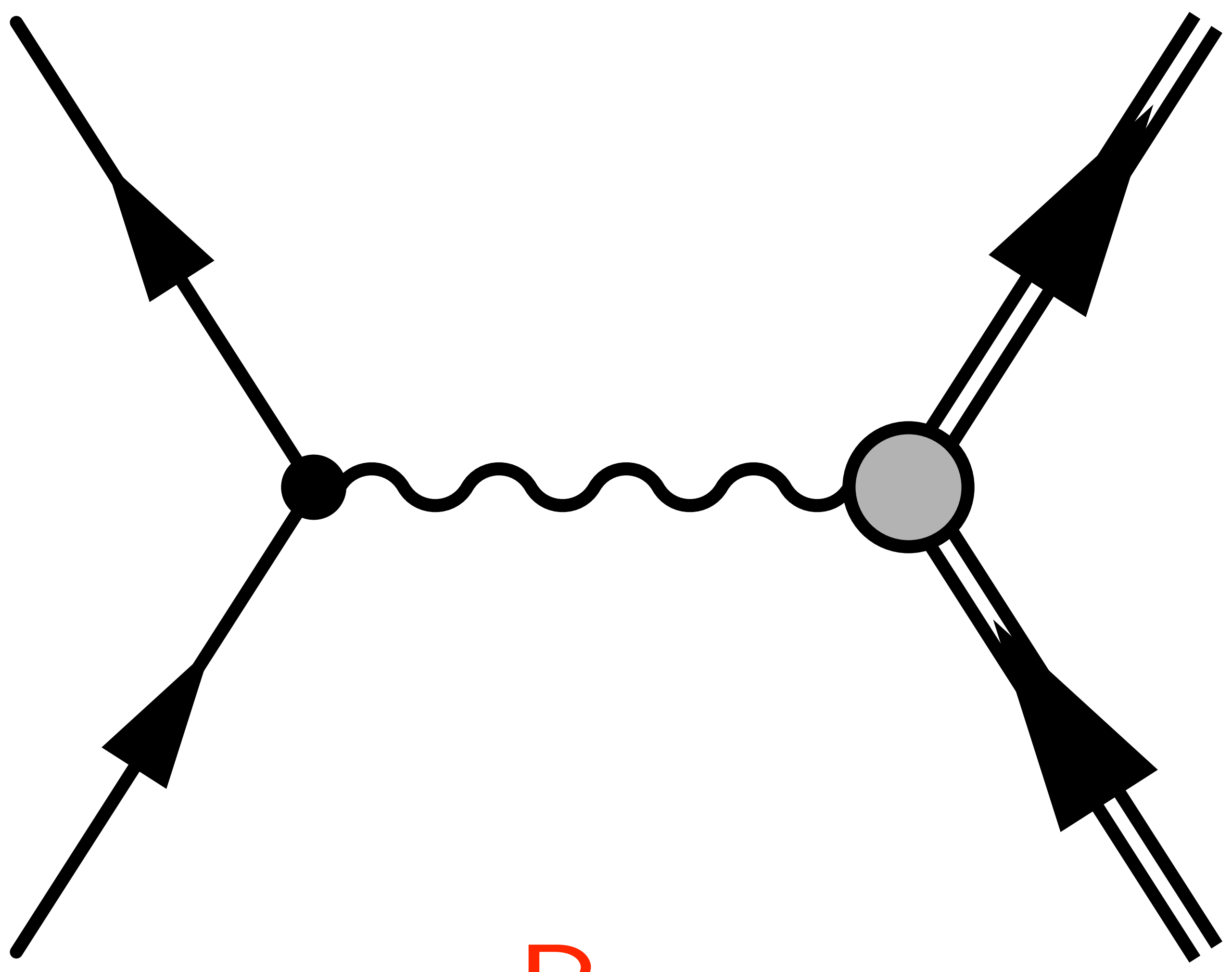
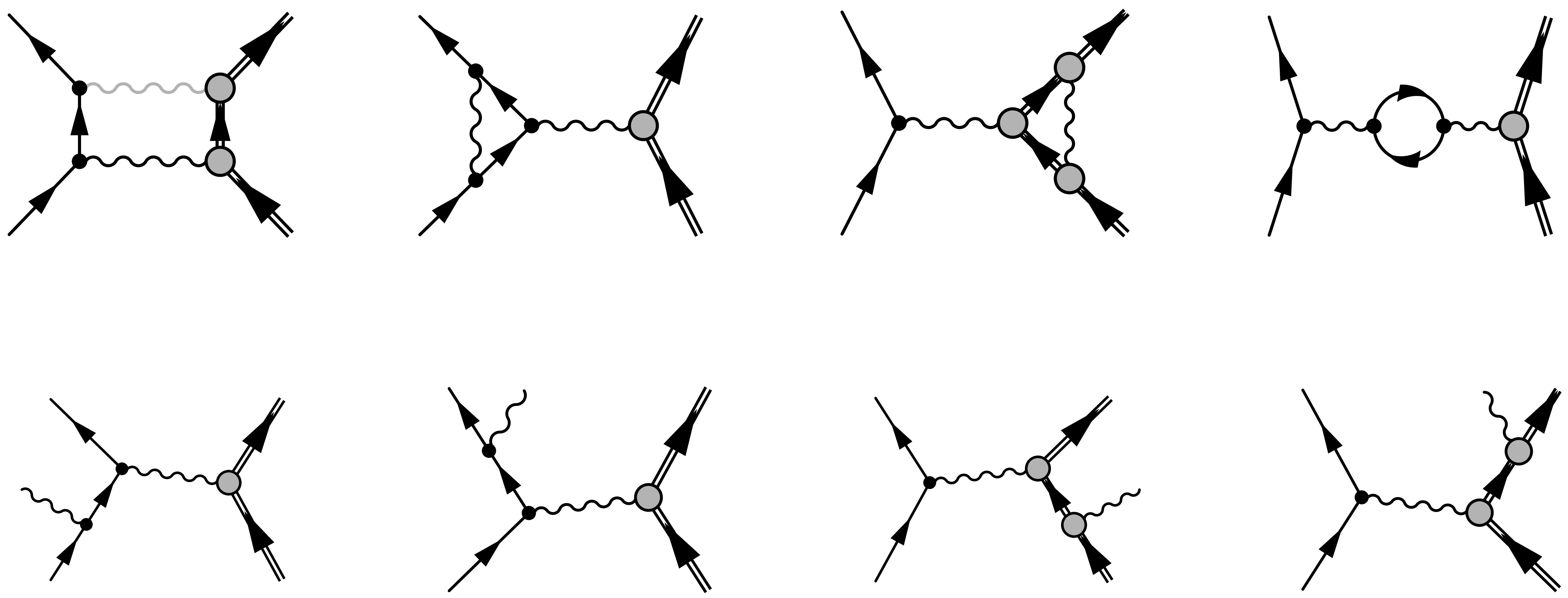
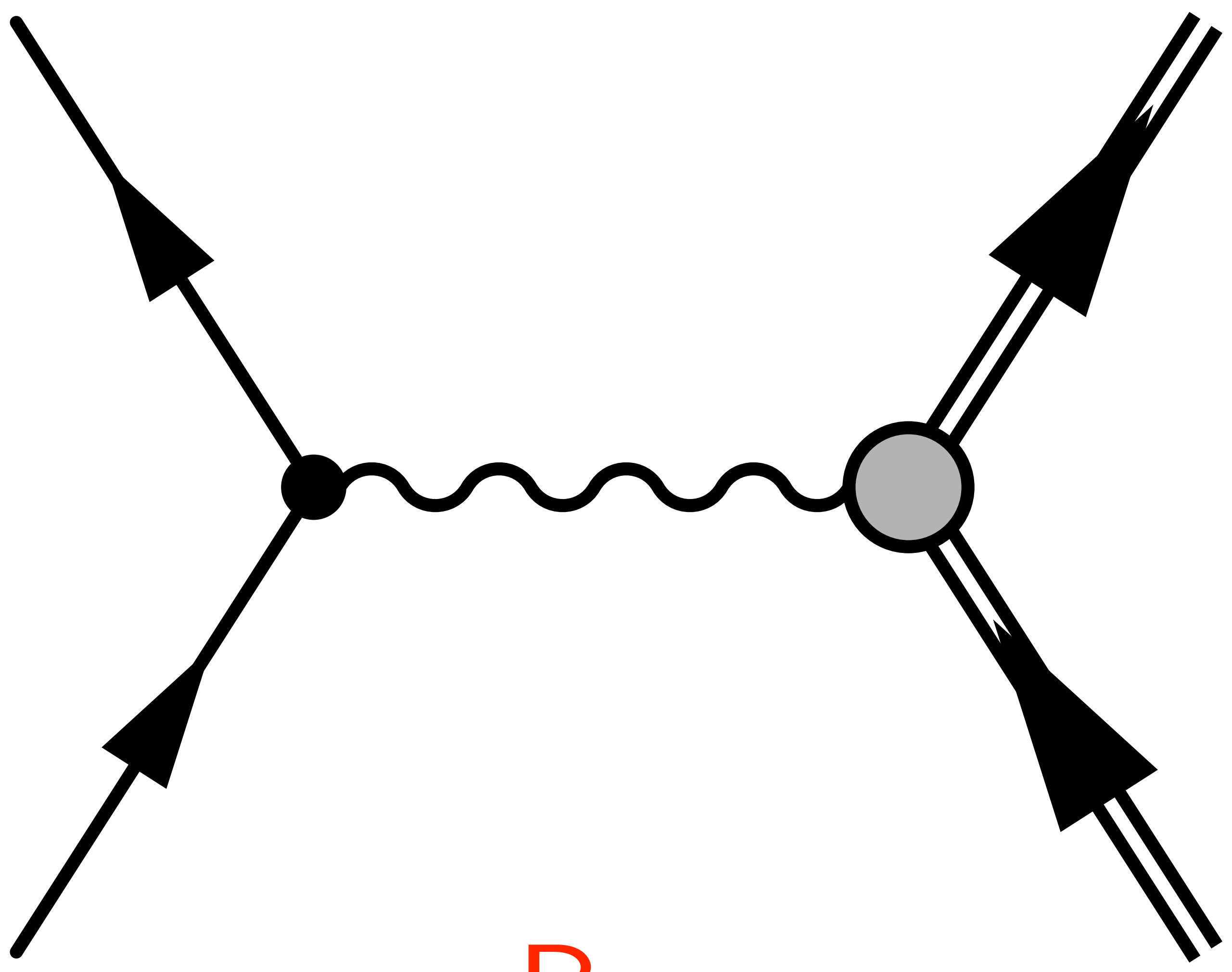


Born approximation

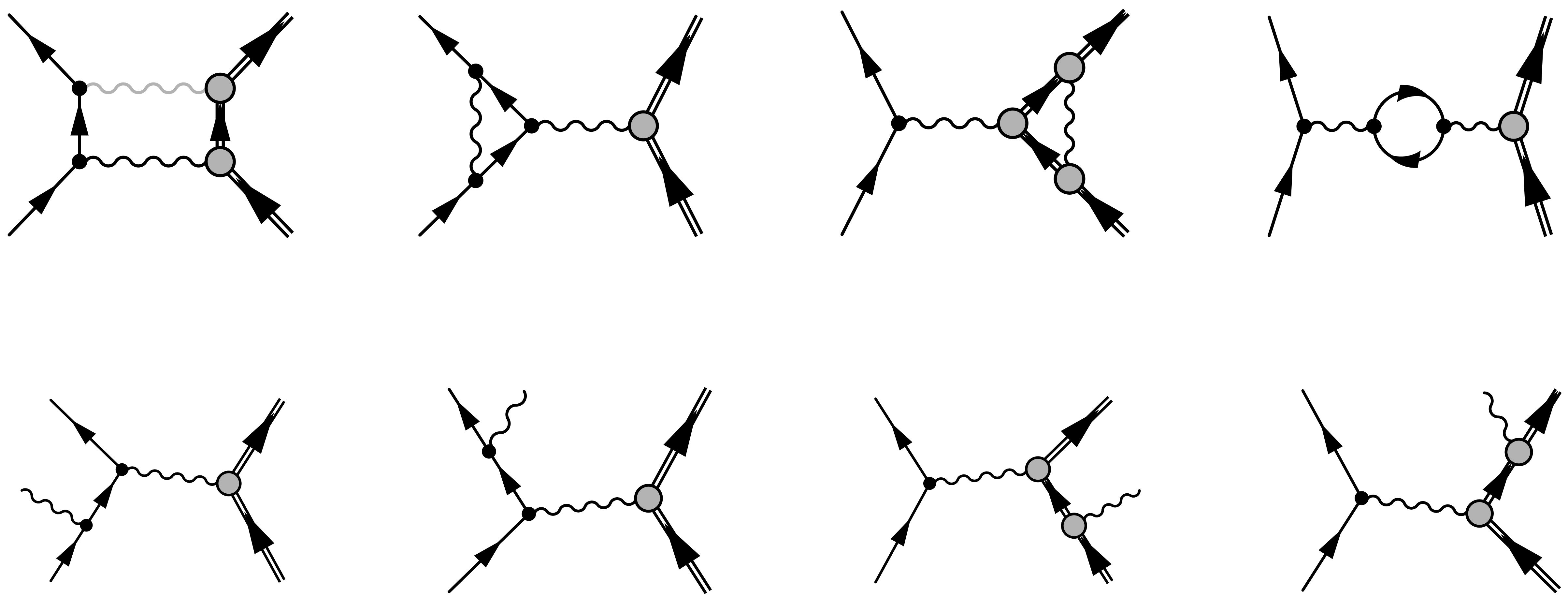


“Standard” radiative corrections

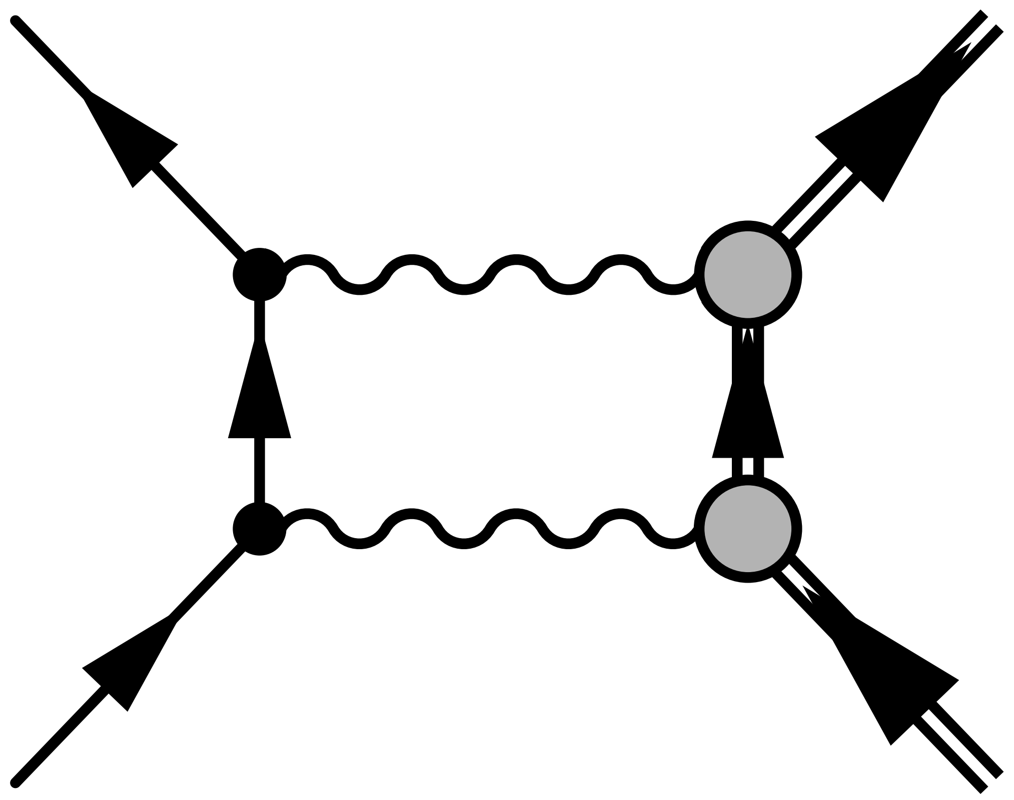
Electron scattering interpreted in Born approximation



Born approximation



"Standard" radiative corrections



Hard two-photon exchange is neglected!

Calculation of hard TPE highly model-dependent

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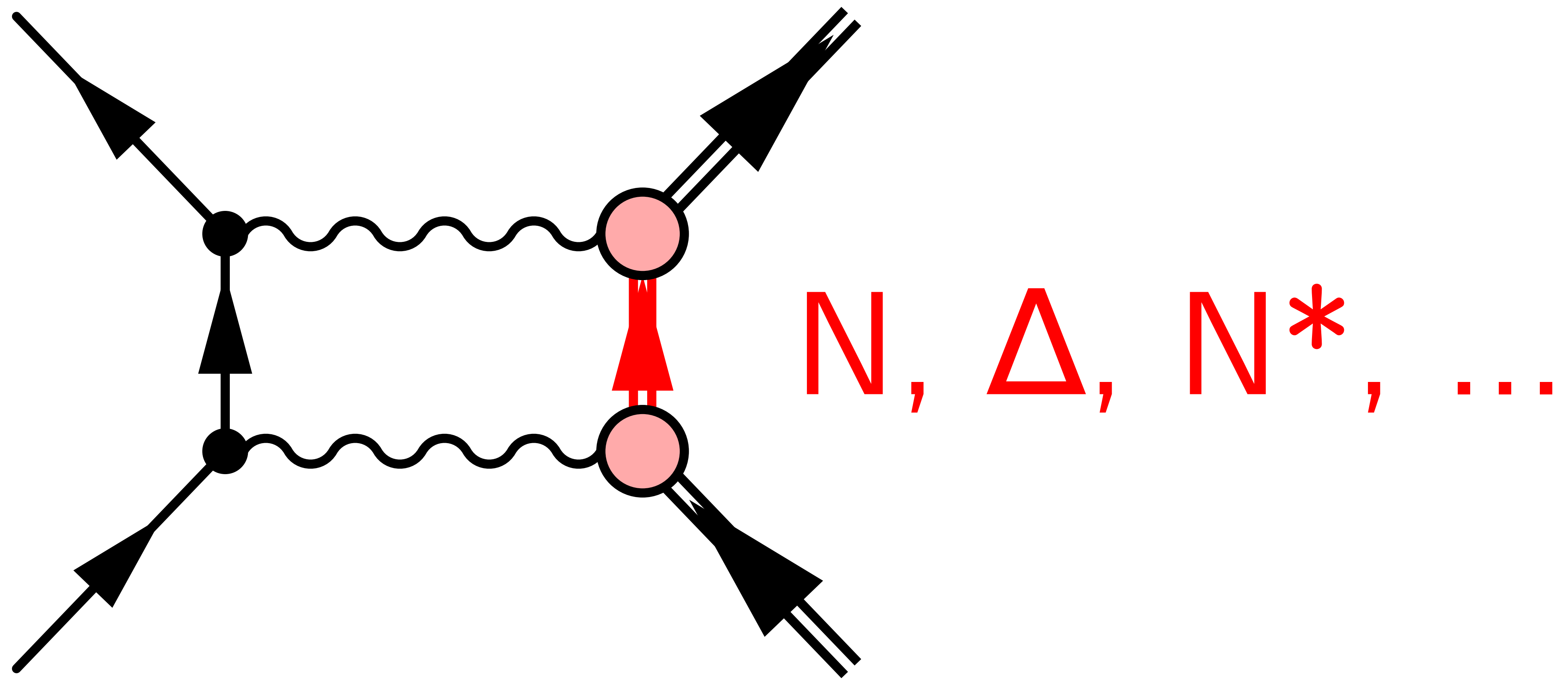
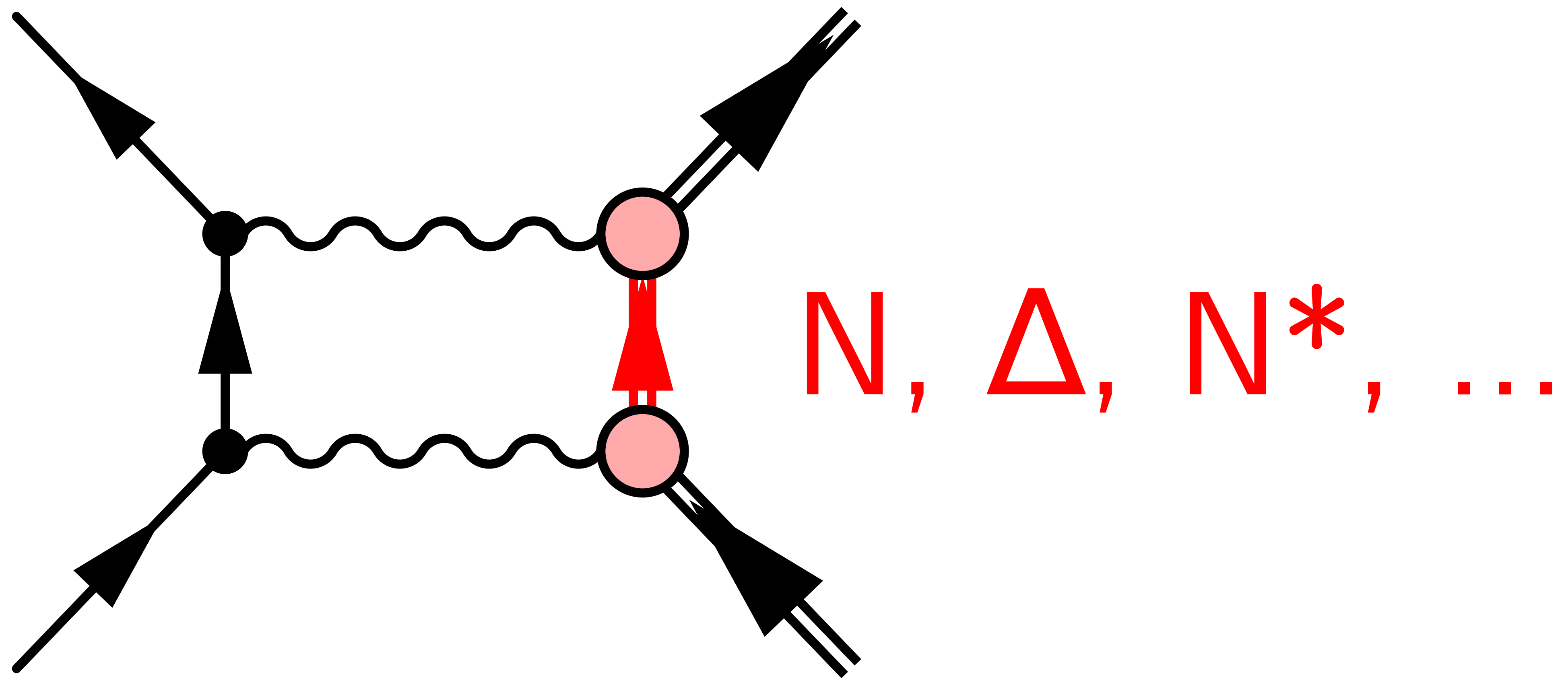


- Sum over intermediate hadronic states e.g. Ahmed, Blunden, Melnitchouk PRC 102, 045205 (2020)
- $Q^2 \lesssim 3$ GeV^2.

Calculation of hard TPE highly model-dependent



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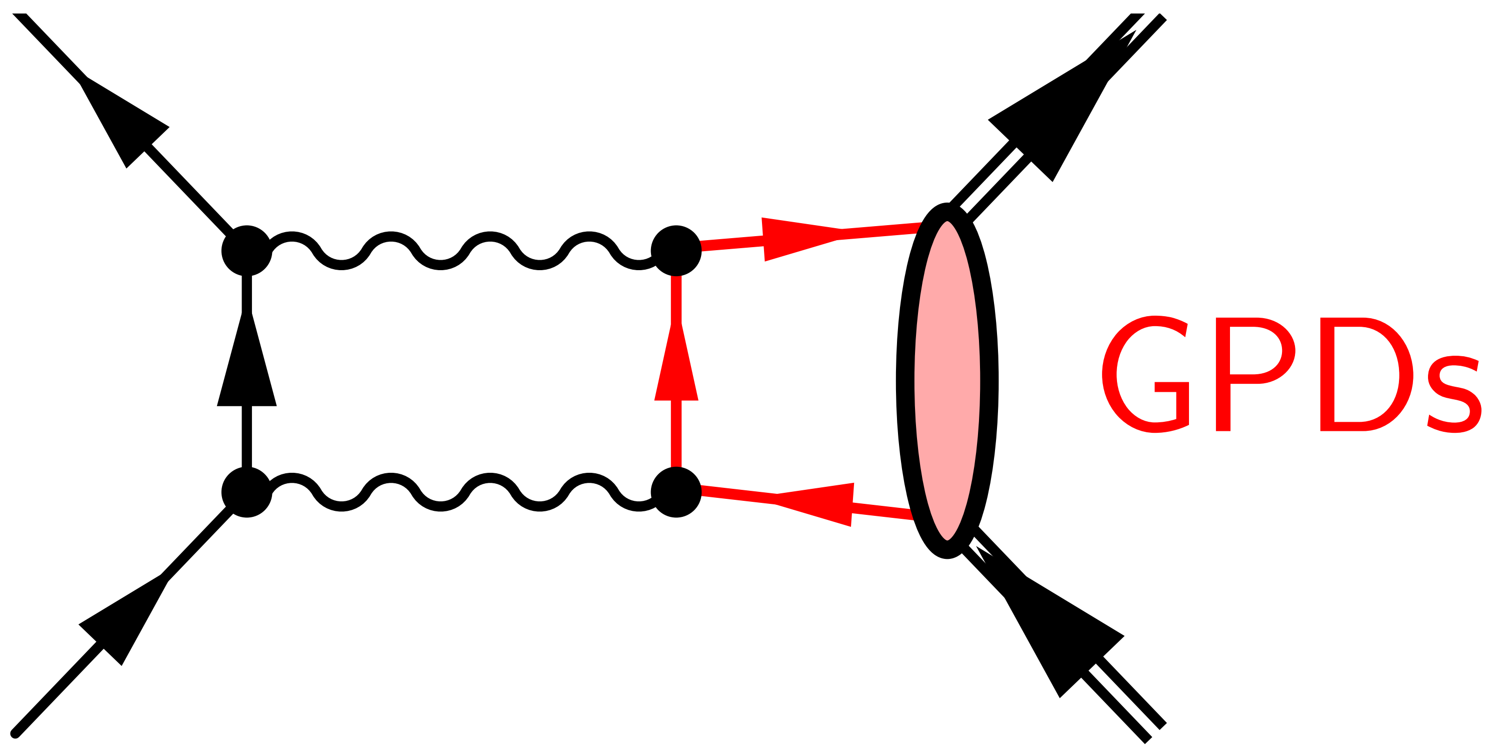

- Treat as $\gamma\gamma$ interaction with quarks, distributed by GPDs e.g. Afanasev et al. PRD 72, 013008 (2005)
- $Q^2 \gtrsim 5$ GeV^2.

TPE could resolve $\mu G_E/G_M$ discrepancy

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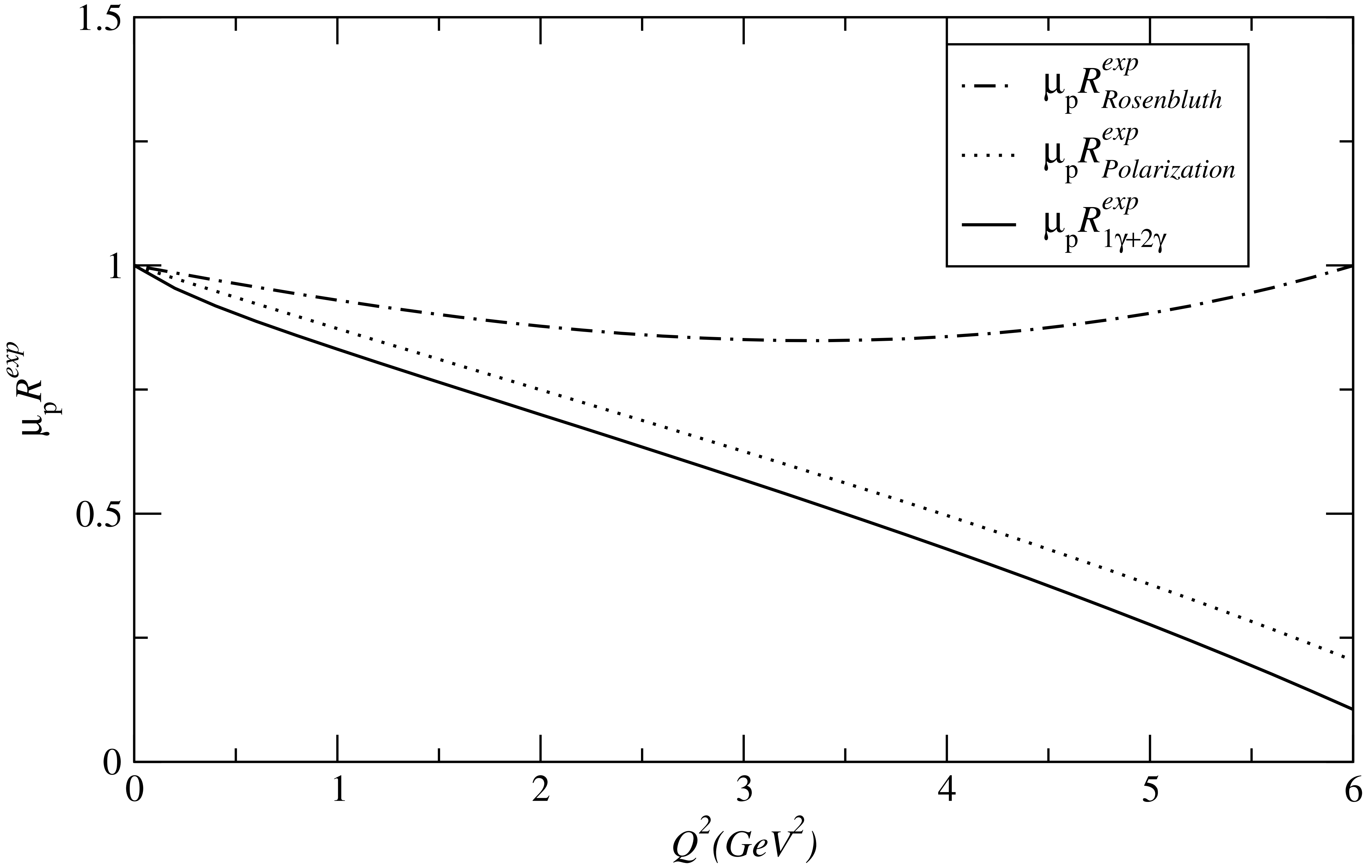
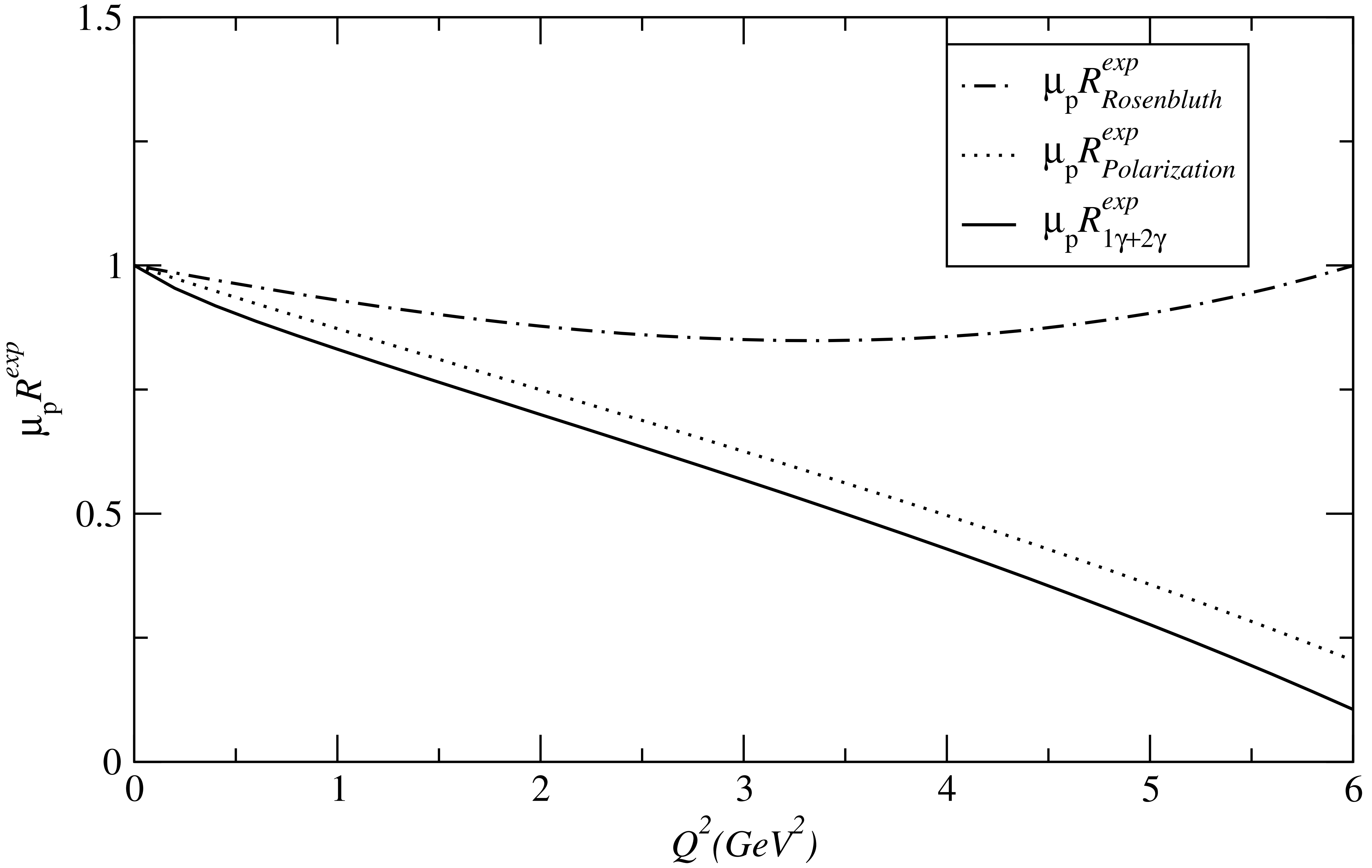
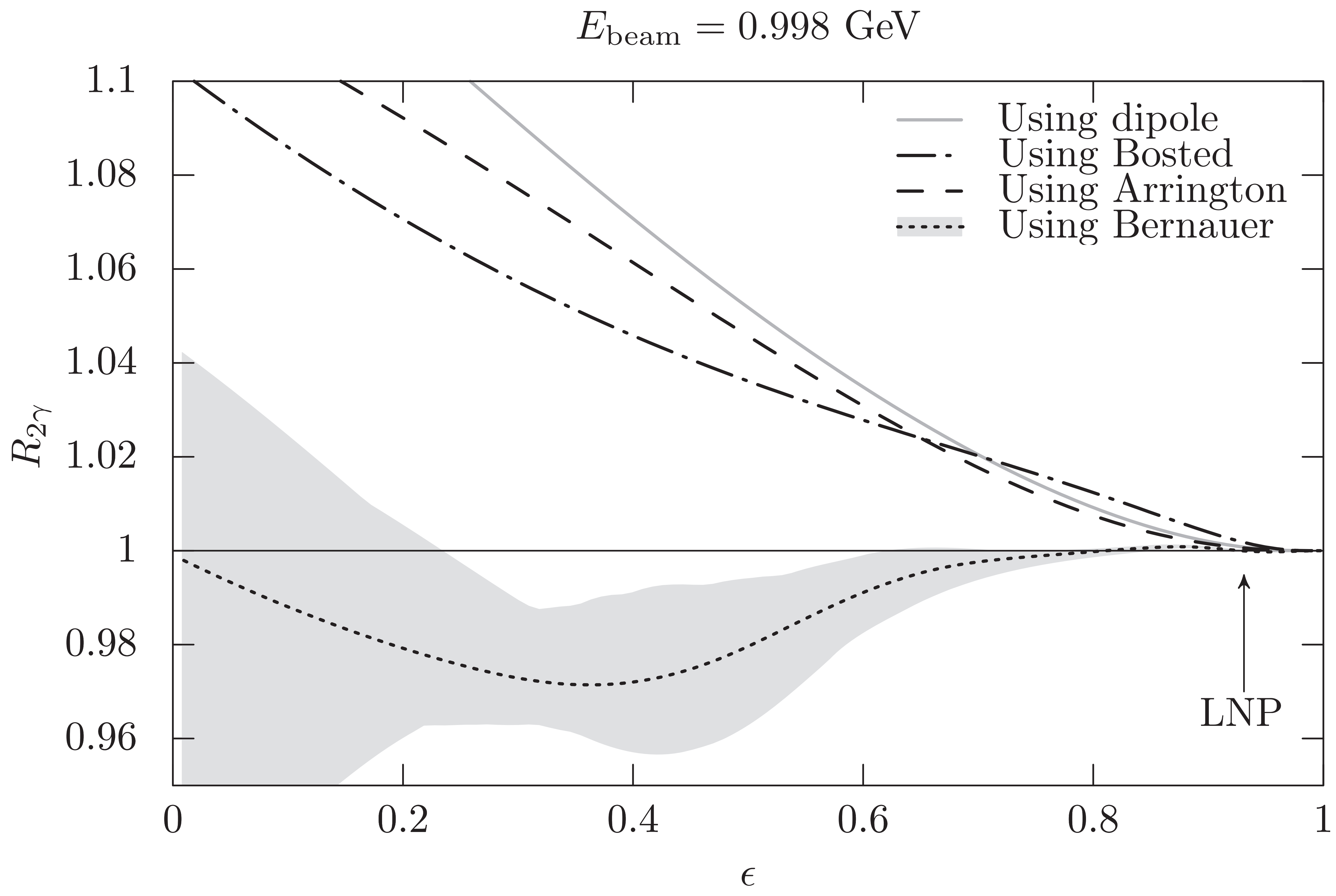
- TPE would have enhanced impact on Rosenbluth separation vs. polarization transfer e.g. [Guichon & Vanderhaeghen, PRL 91, 142303 (2003)]



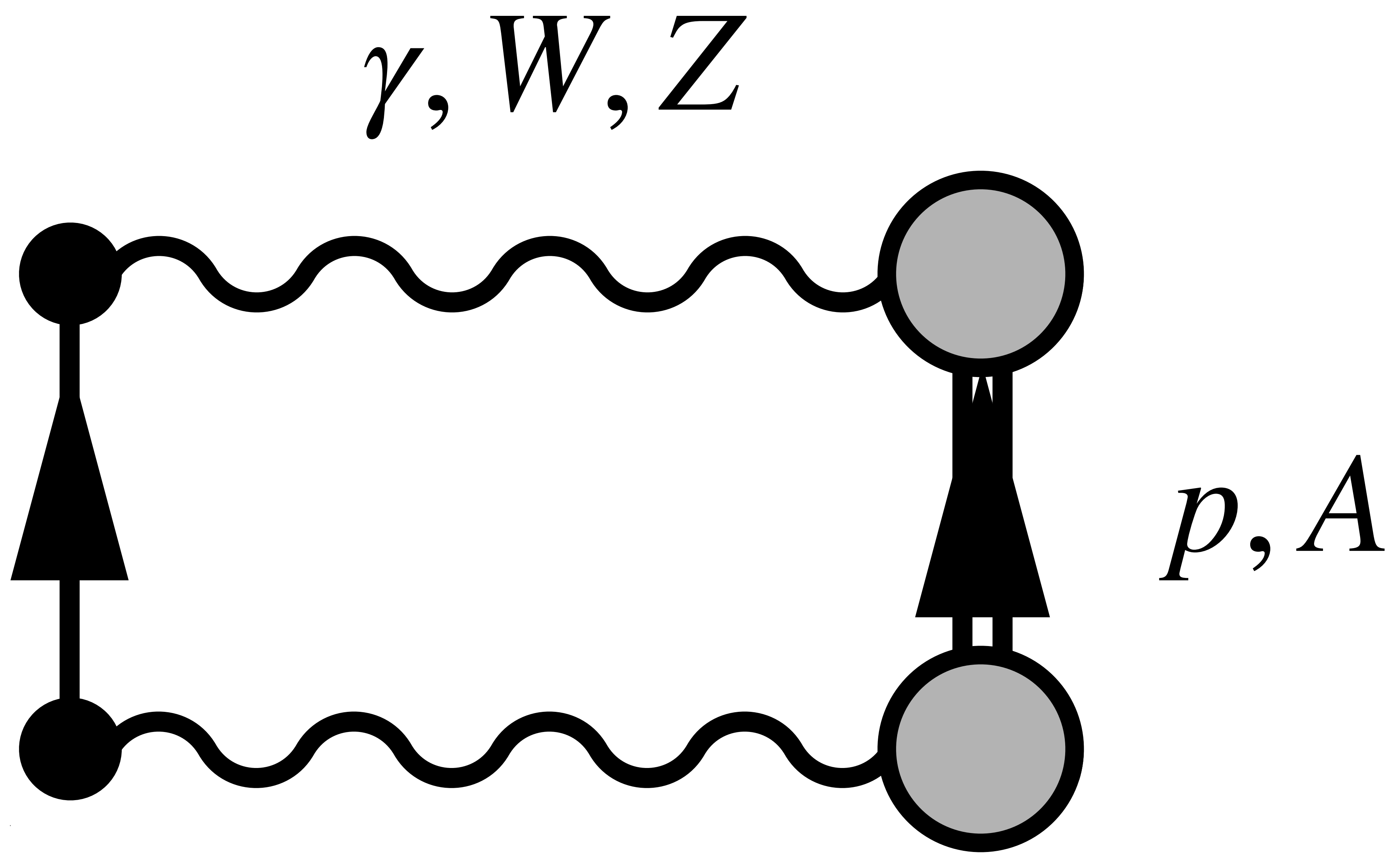
TPE could resolve $\mu G_E/G_M$ discrepancy

- TPE would have enhanced impact on Rosenbluth separation vs. polarization transfer
  e.g. Guichon & Vanderhaeghen, PRL 91, 142303 (2003)
- Phenomenological approach: predict size of TPE needed to resolve discrepancy
  e.g. Schmidt, JPG 47, 055109 (2020)





Hadronic box diagrams a more general challenge as radiative correction to electro(weak) measurements



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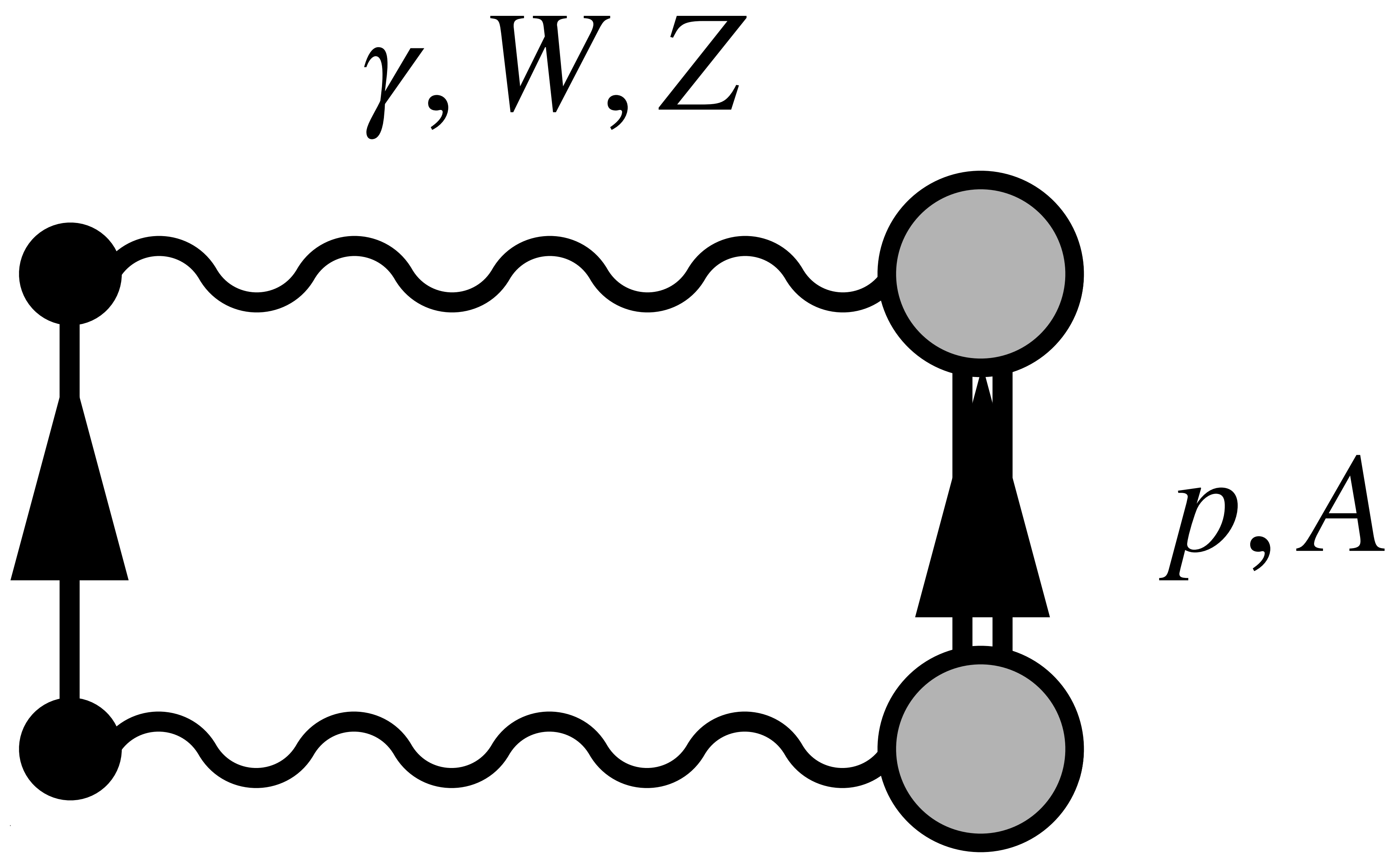
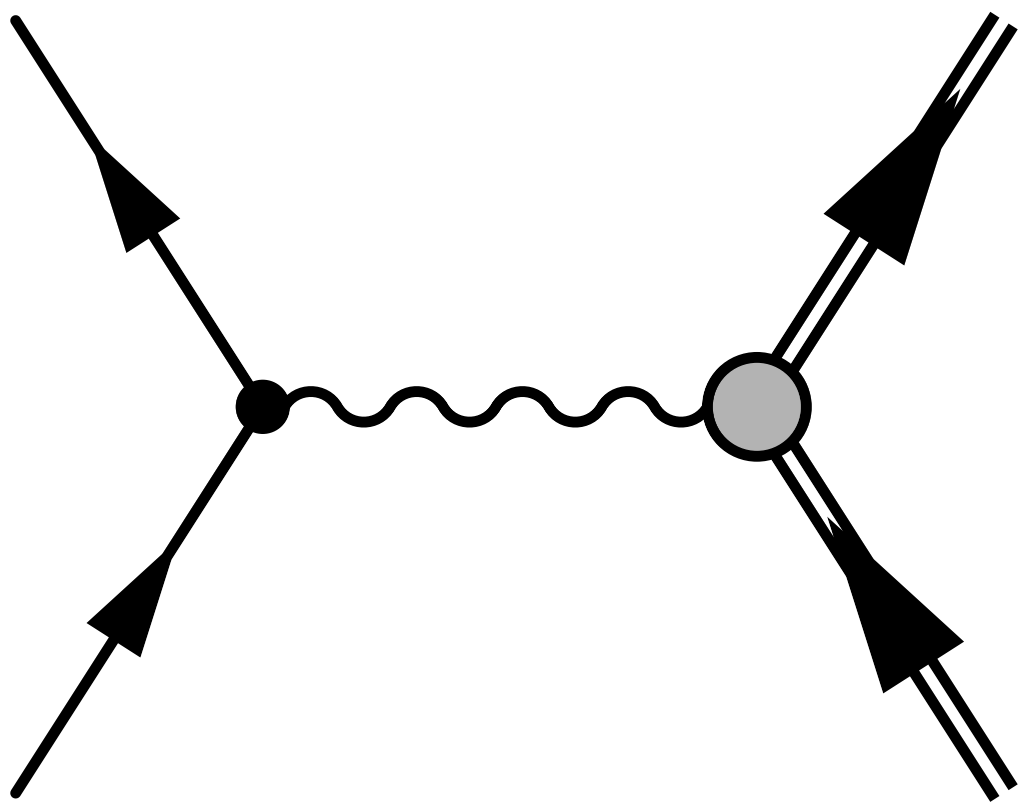
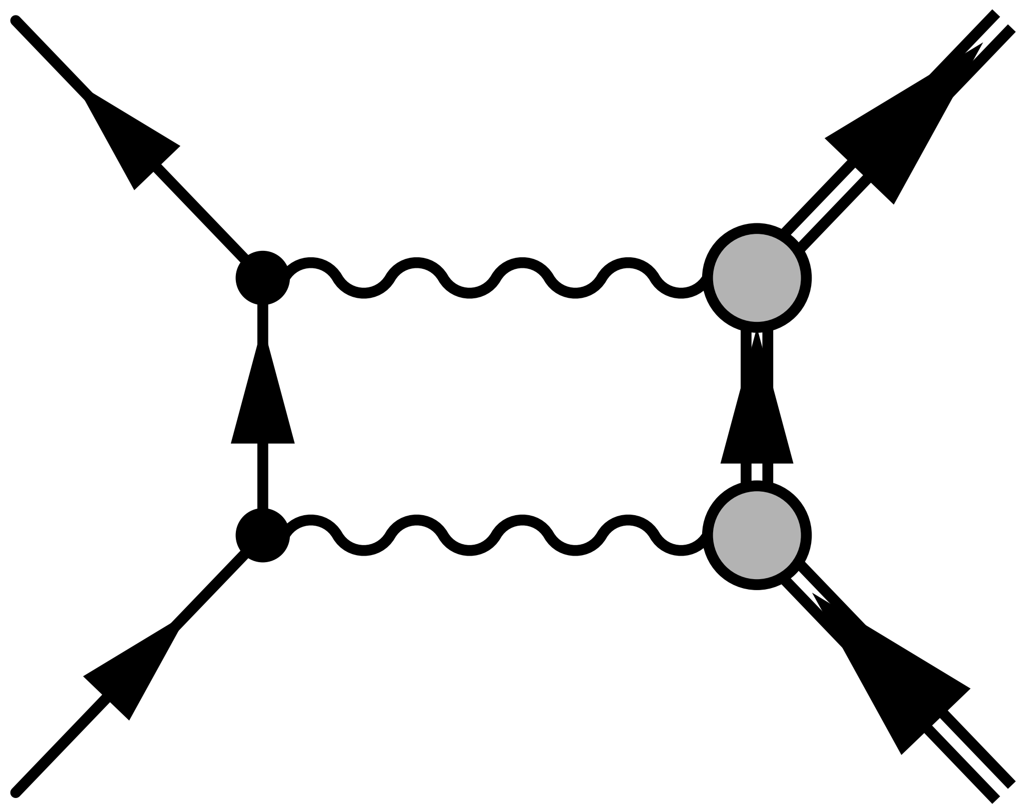


- $\Box_{\gamma\gamma}$: background to PVES
- $\Box_{\gamma Z}$: weak mixing angle extractions from PVES
- $\Box_{\gamma W}$: CKM matrix elements from β-decay

Can observe interference between one- and two-photon exchange

$\mathcal{M} =$  $+$  $\dots$

Can observe interference between one- and two-photon exchange

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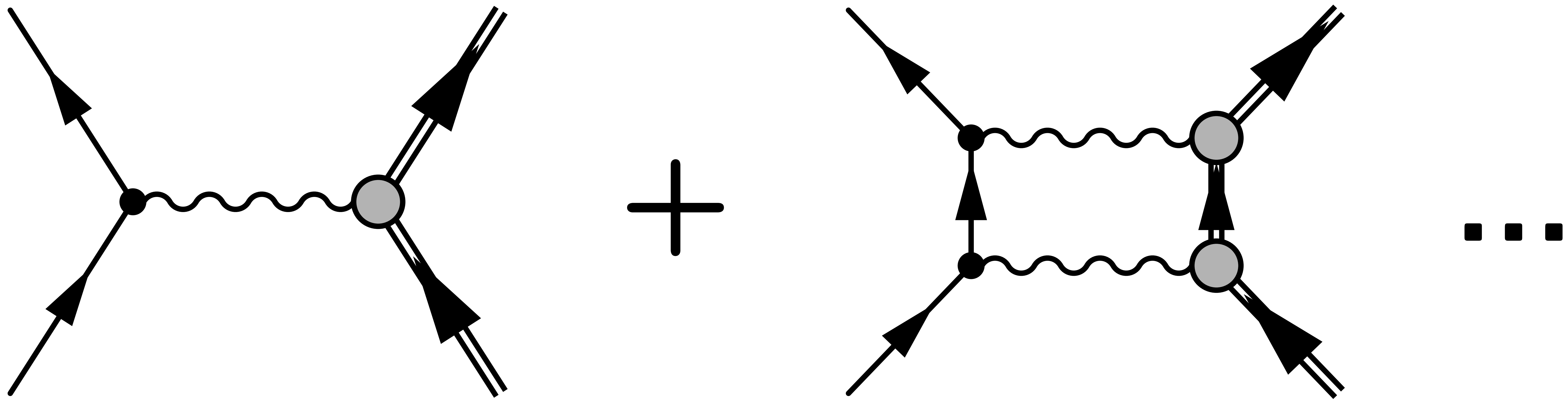

- Normal single-spin asymmetries

$$A_n = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = \frac{2\mathcal{I}(\mathcal{M}_{1\gamma}\mathcal{M}_{2\gamma}^{*})}{|\mathcal{M}_{1\gamma}|^2}$$

  - Background to PVES

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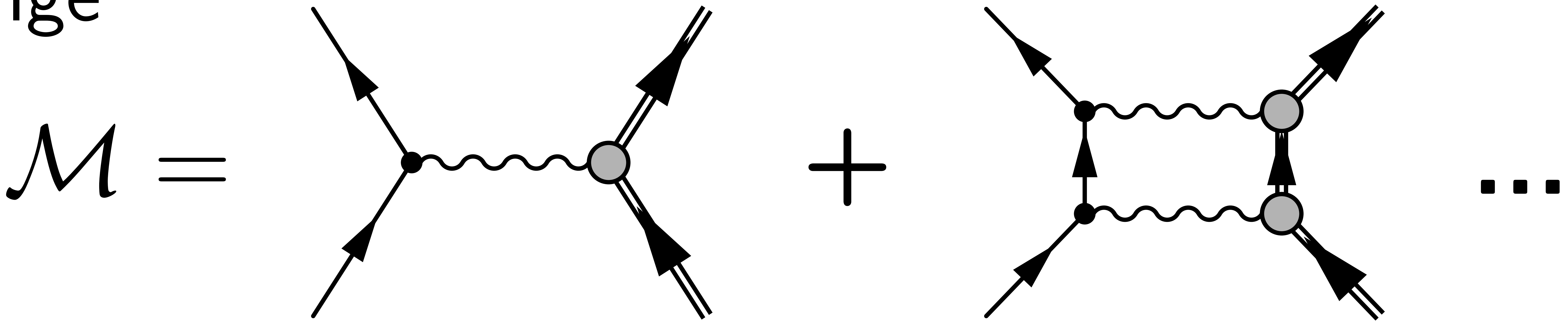

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  - Background to PVES

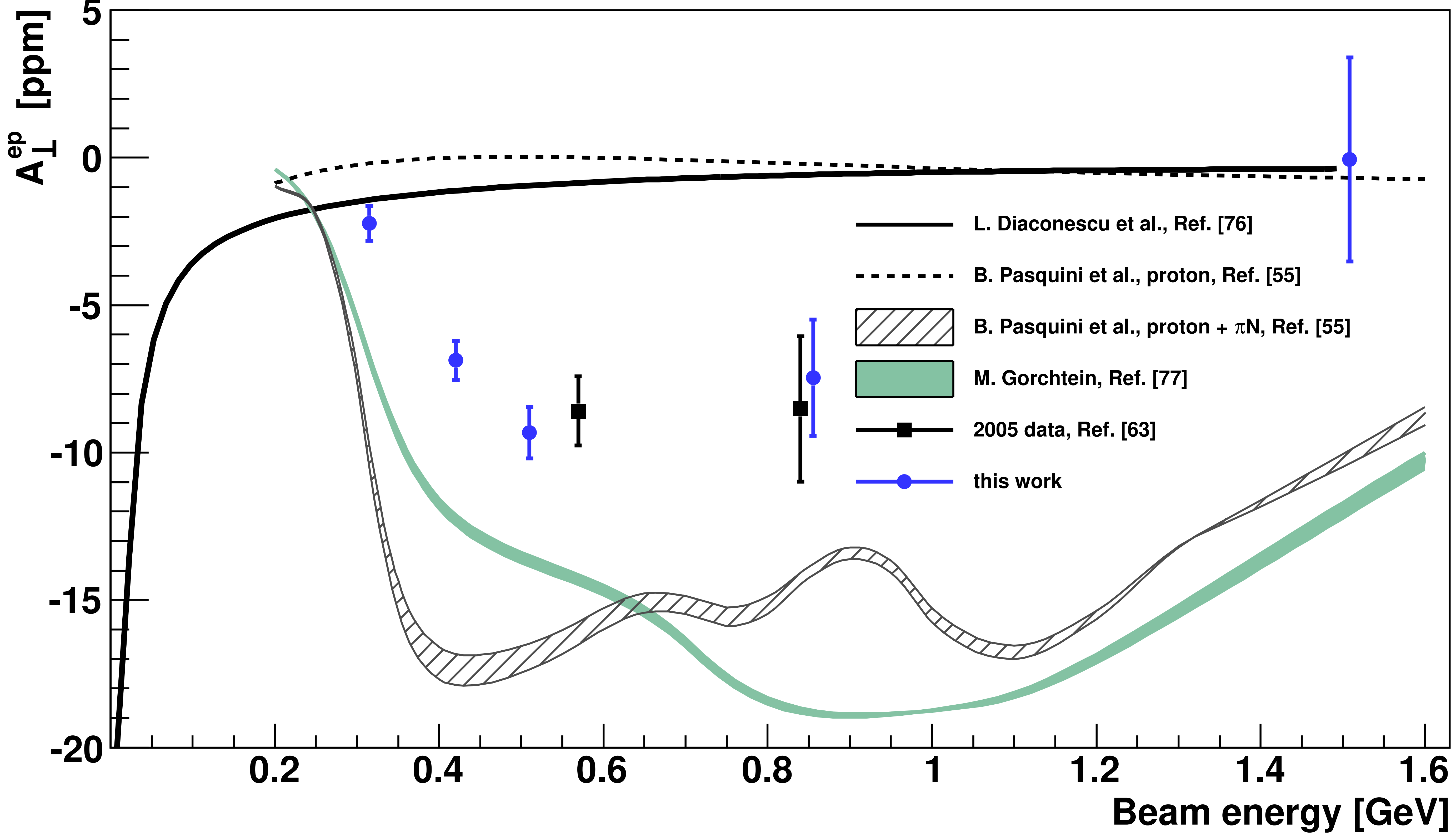
- Positron to electron ratio:

$$R_{2\gamma} = \frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 + \frac{4\mathcal{R}(\mathcal{M}_{1\gamma}\mathcal{M}_{2\gamma}^{*})}{|\mathcal{M}_{1\gamma}|^2} + \ldots$$

  - Leading TPE correction to unpolarized *ep* scattering

Existing SSA measurements suggest tension with theory

Gou et al. PRL 124, 122003 (2020)



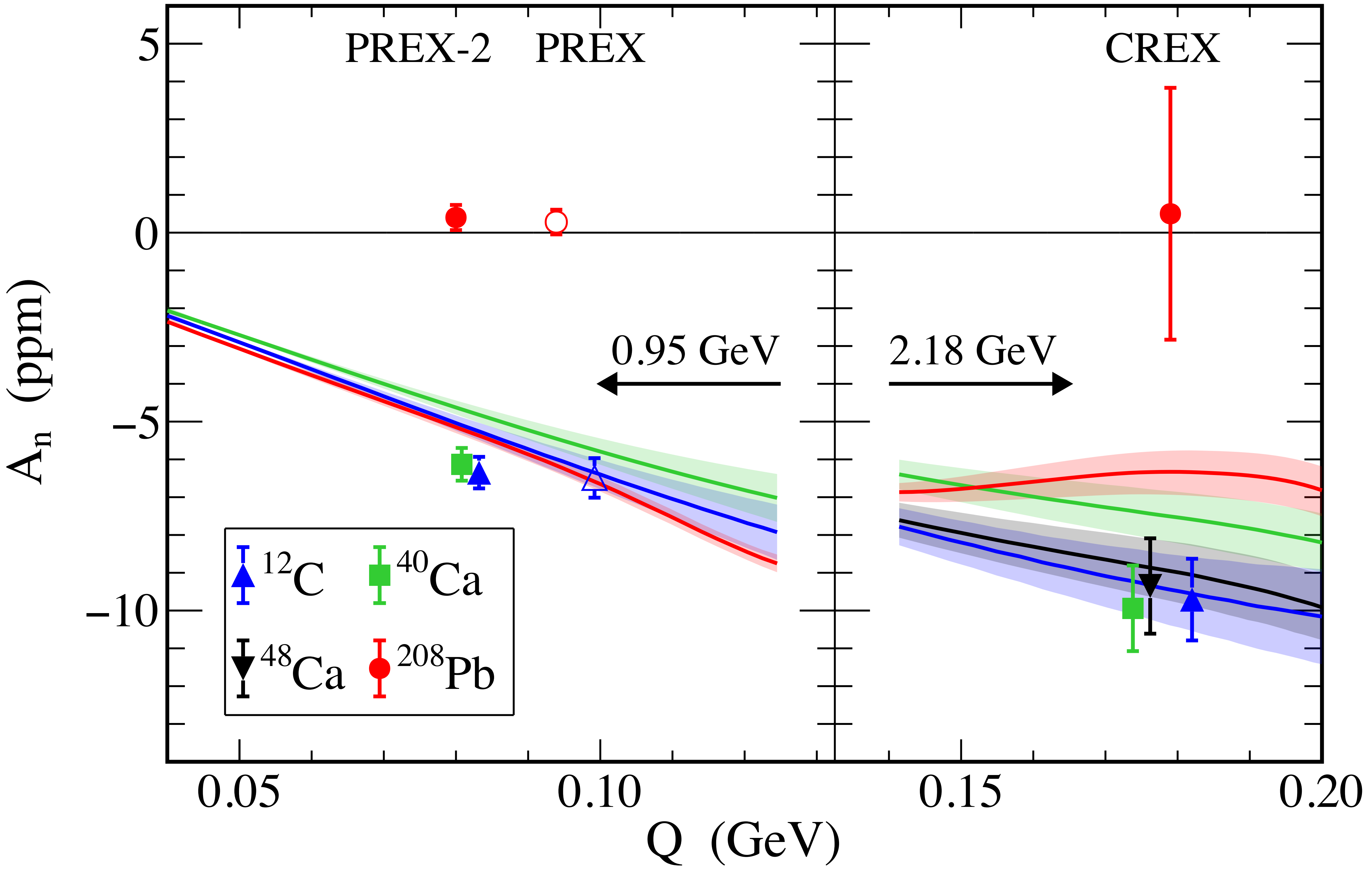
- Calculations account for elastic and πN inelastic intermediate states

  Gorchtein, PRC 73, 055201 (2006)

  Pasquini & Vanderhaeghen, PRC 70, 045206 (2004)

Existing SSA measurements suggest tension with theory

PREX/CREX, PRL 128, 142501 (2022)



- Coulomb distortion + inelastic states included in recent calculation
  Koshchii, et al. PRC 103, 064316 (2021)

Existing SSA measurements suggest tension with theory

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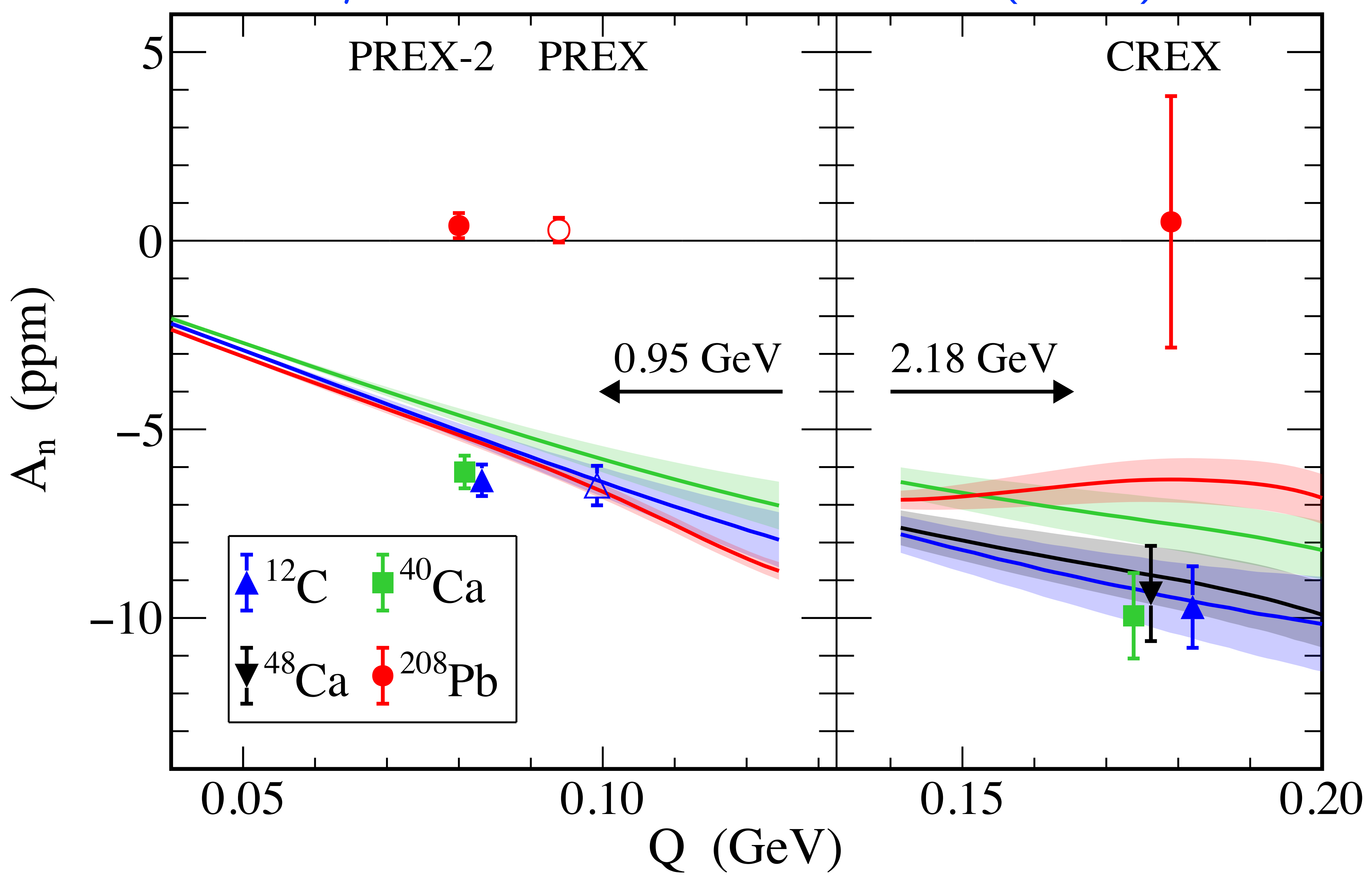
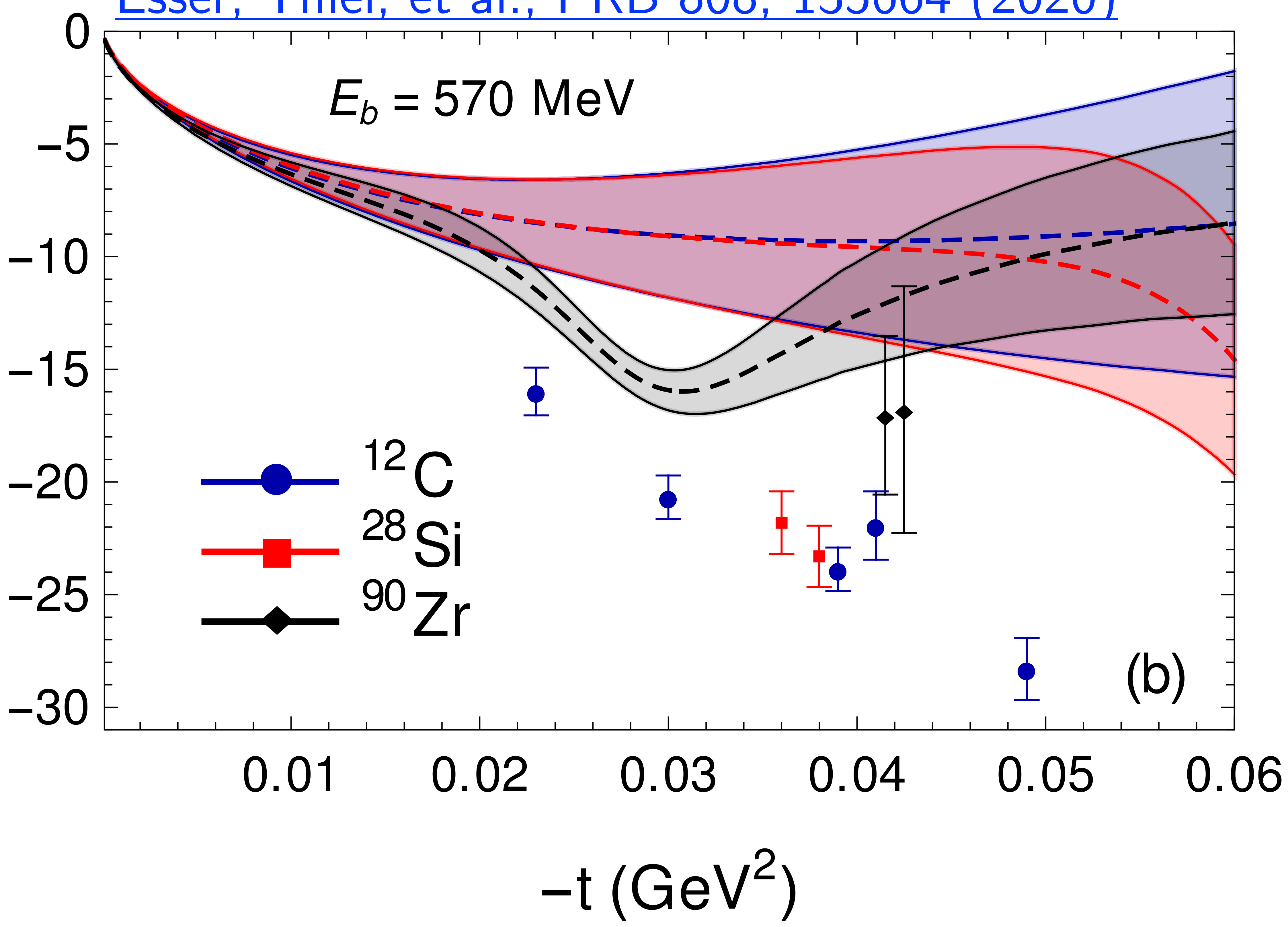


Esser, Thiel, et al., PRL 121, 022503 (2018)

Esser, Thiel, et al., PRB 808, 135664 (2020)



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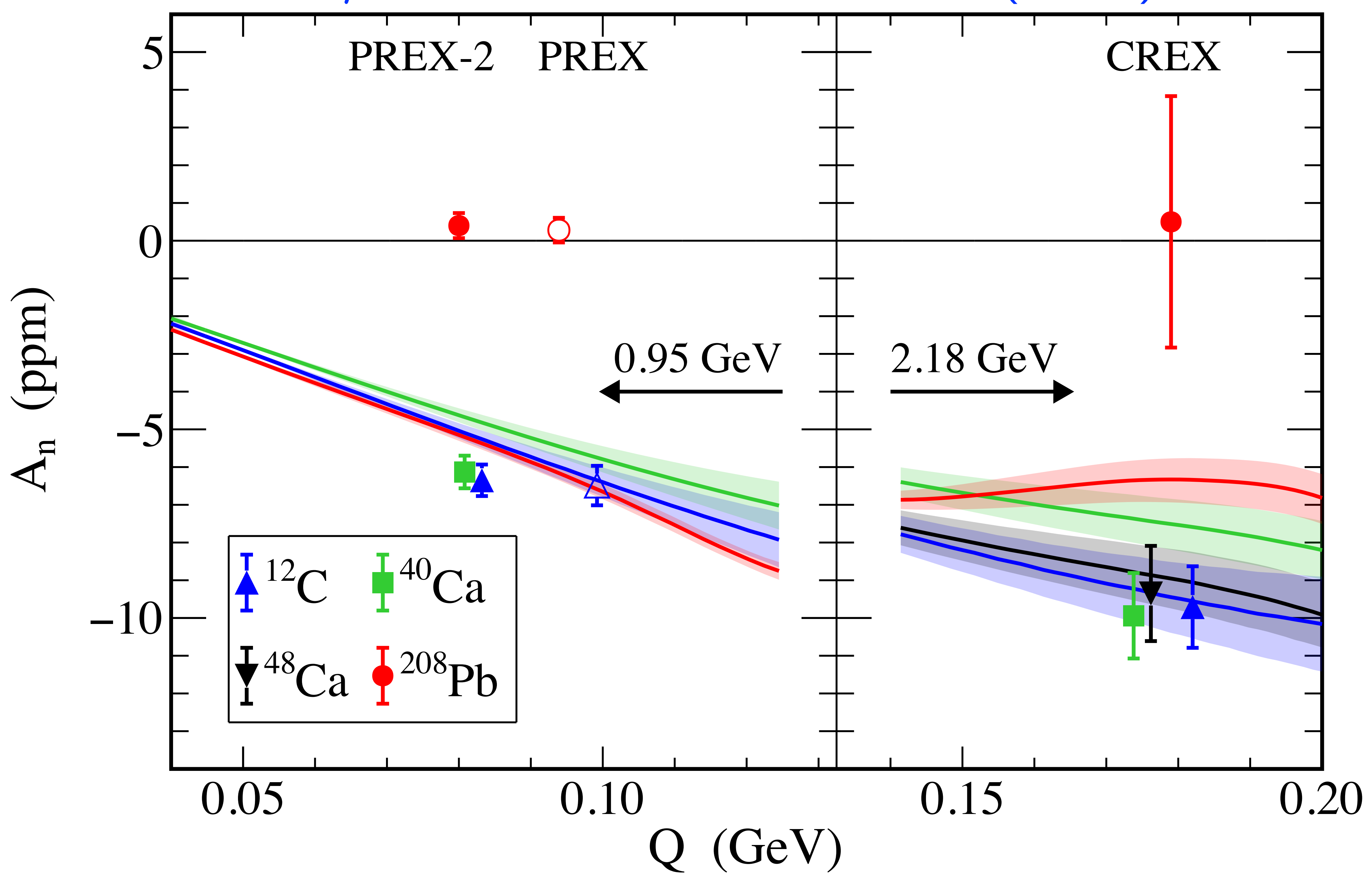

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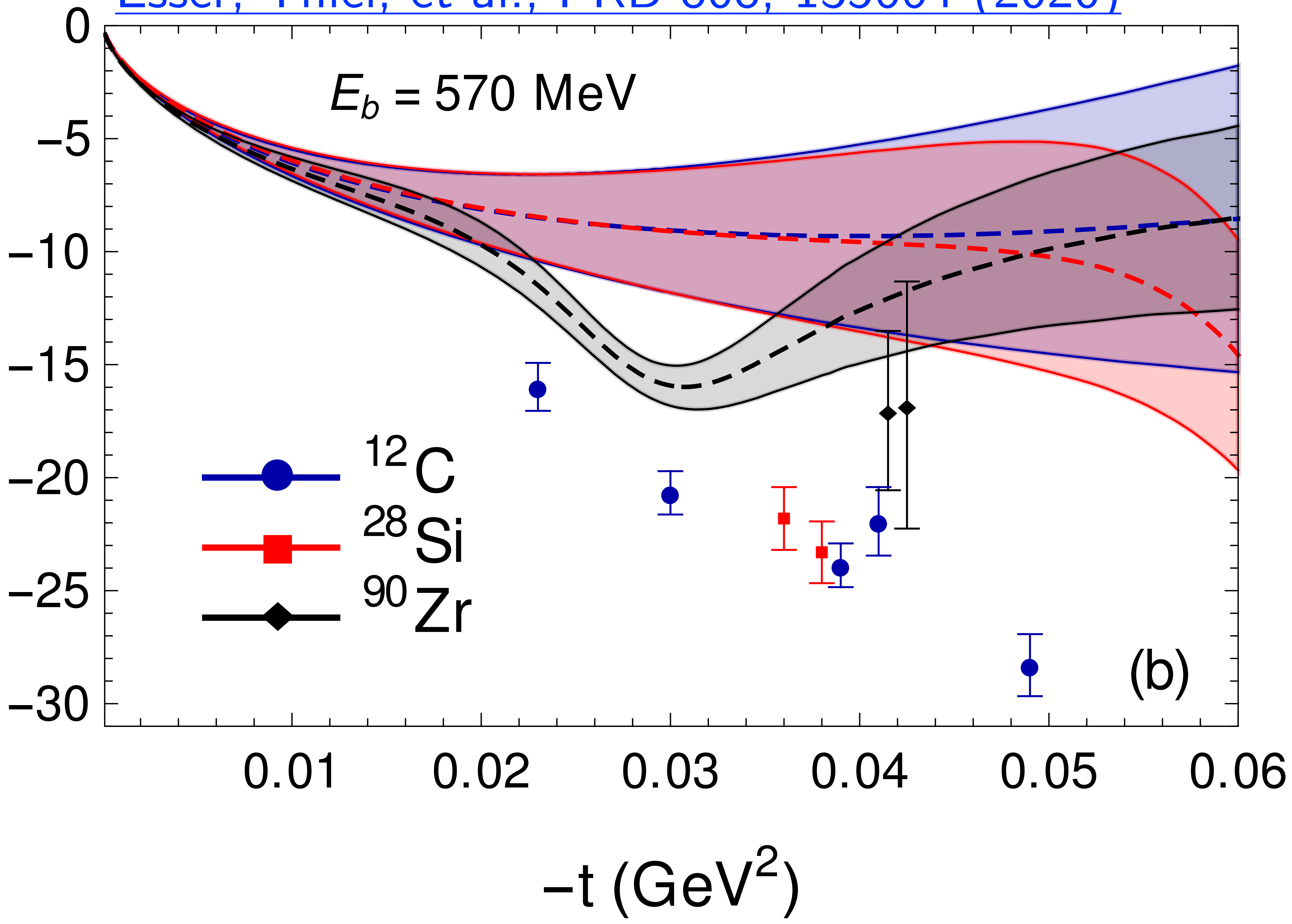
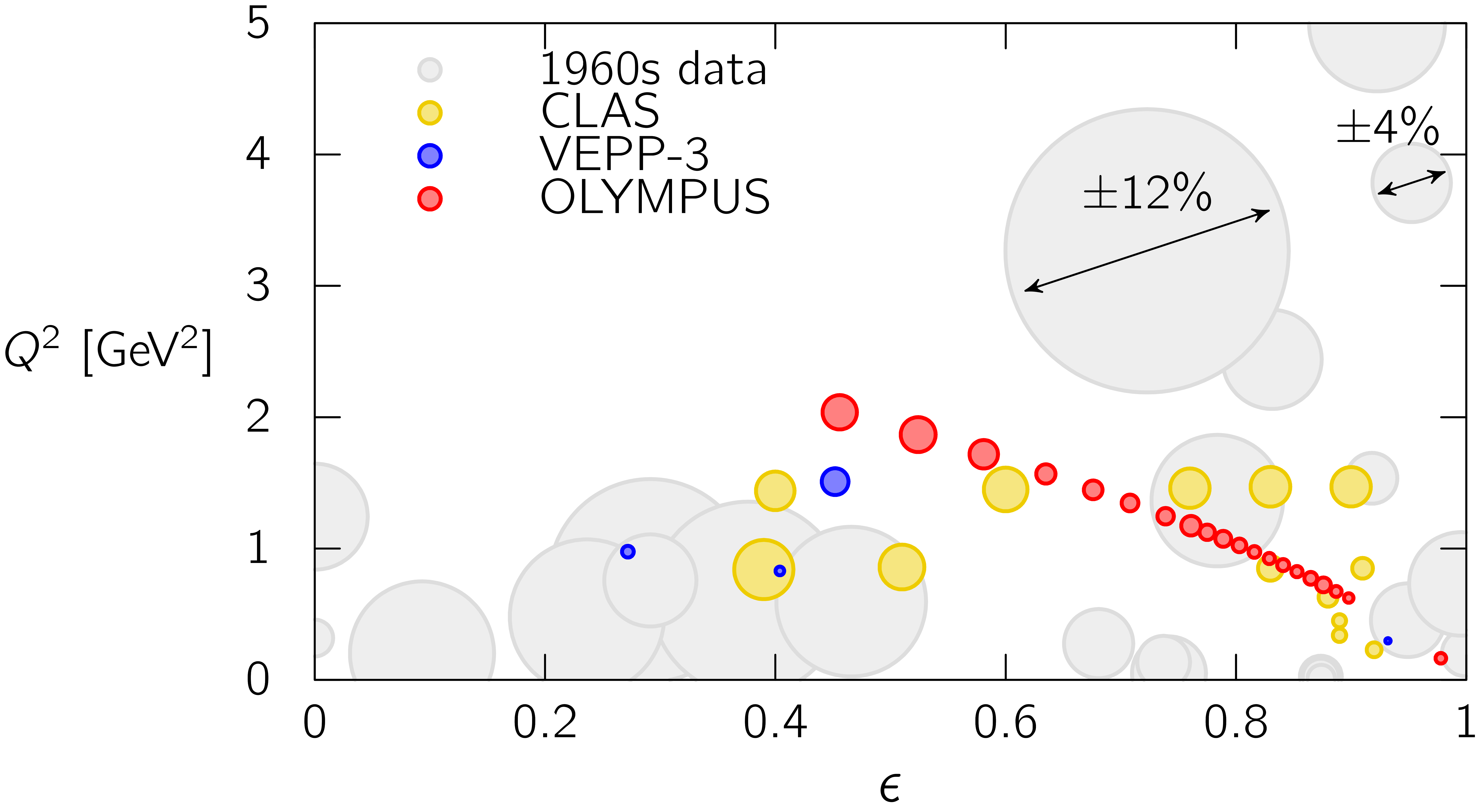


- Coulomb distortion + inelastic states included in recent calculation
  Koshchii, et al. PRC 103, 064316 (2021)

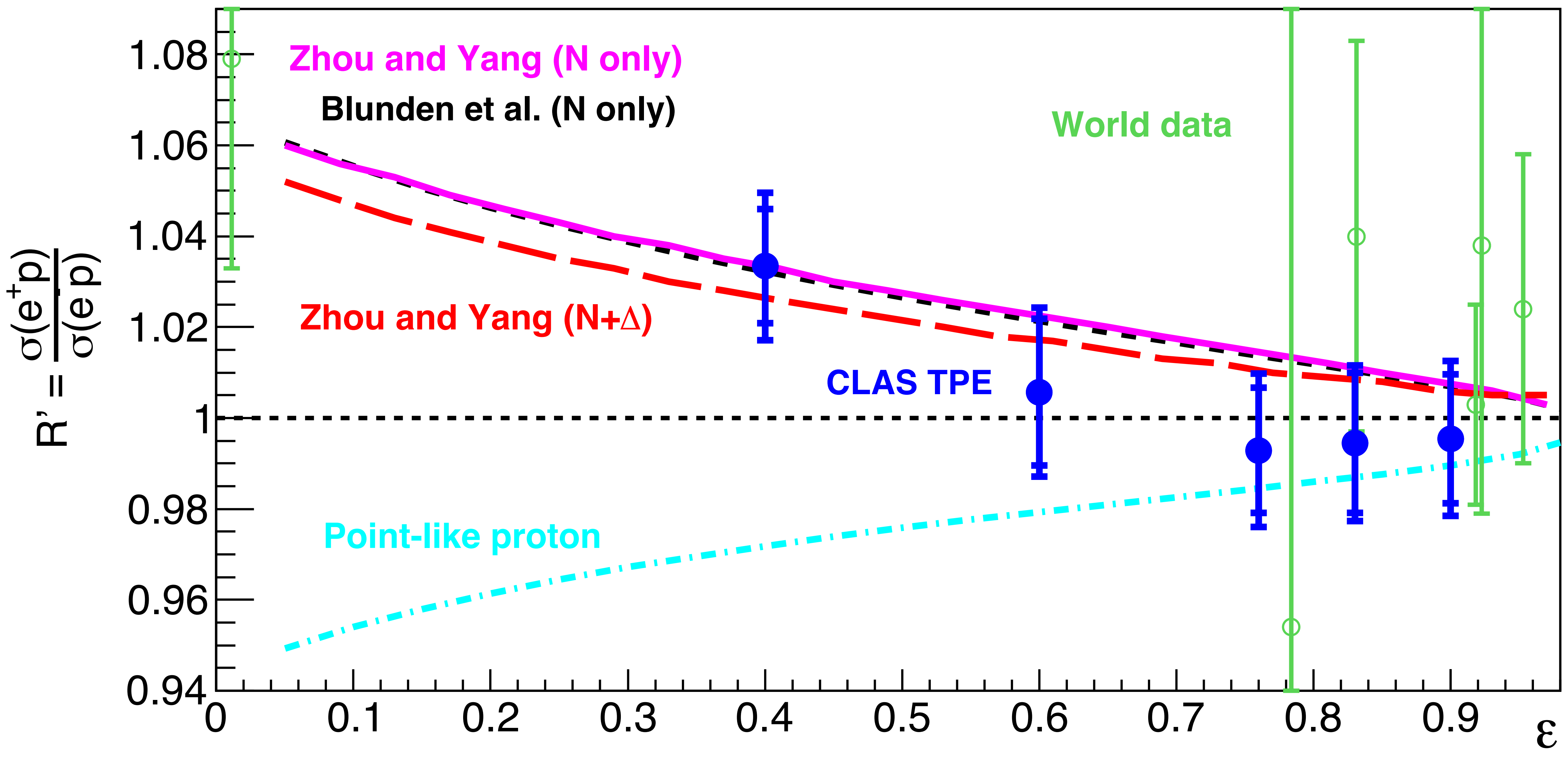
Pending: new ^{208}Pb results from MAMI!

Existing positron measurements inconclusive on $\mu G_E/G_M$ discrepancy

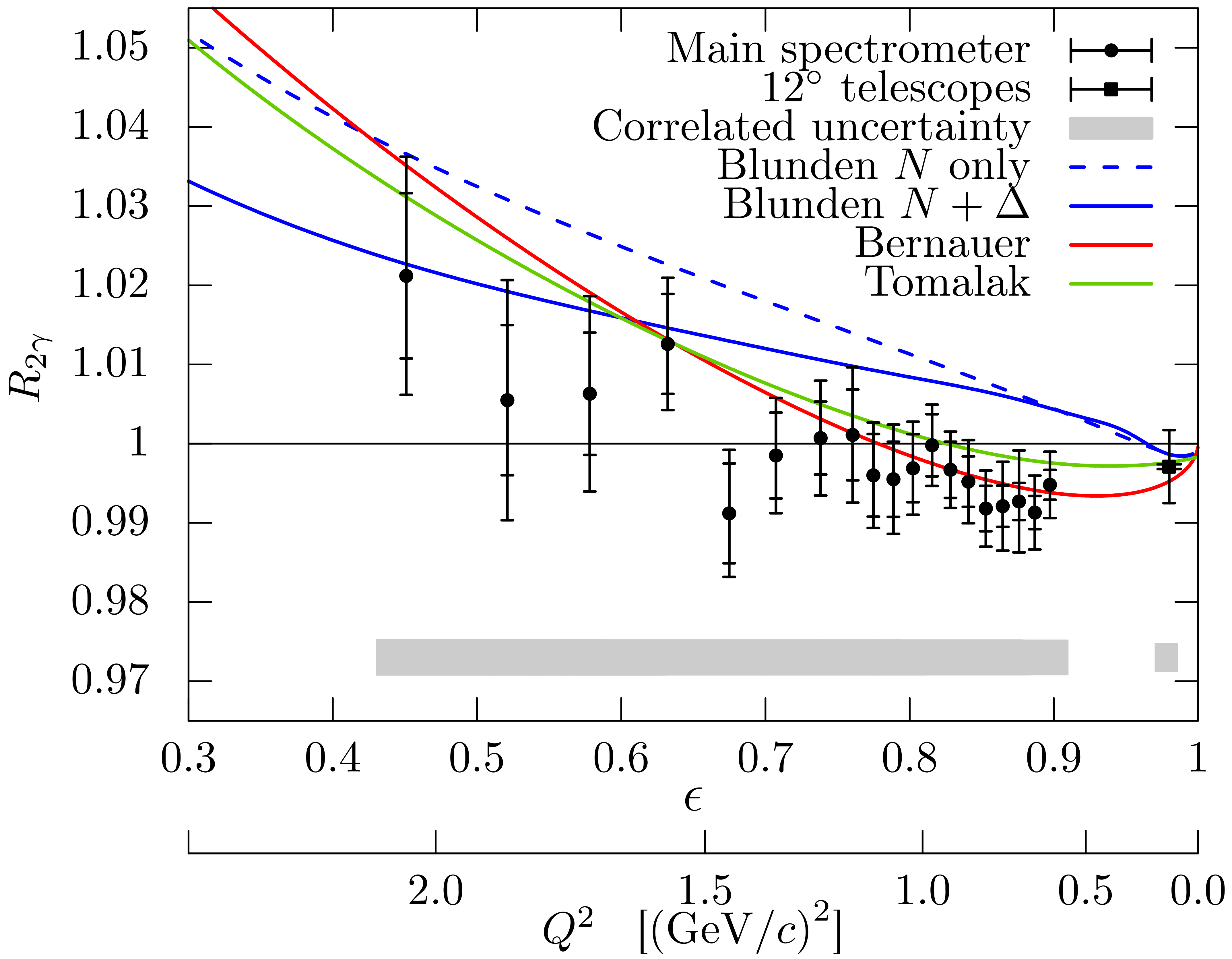


Existing positron measurements inconclusive on $\mu G_E/G_M$ discrepancy

CLAS, PRL 114, 062003 (2015)



OLYMPUS, PRL 118, 092501 (2017)

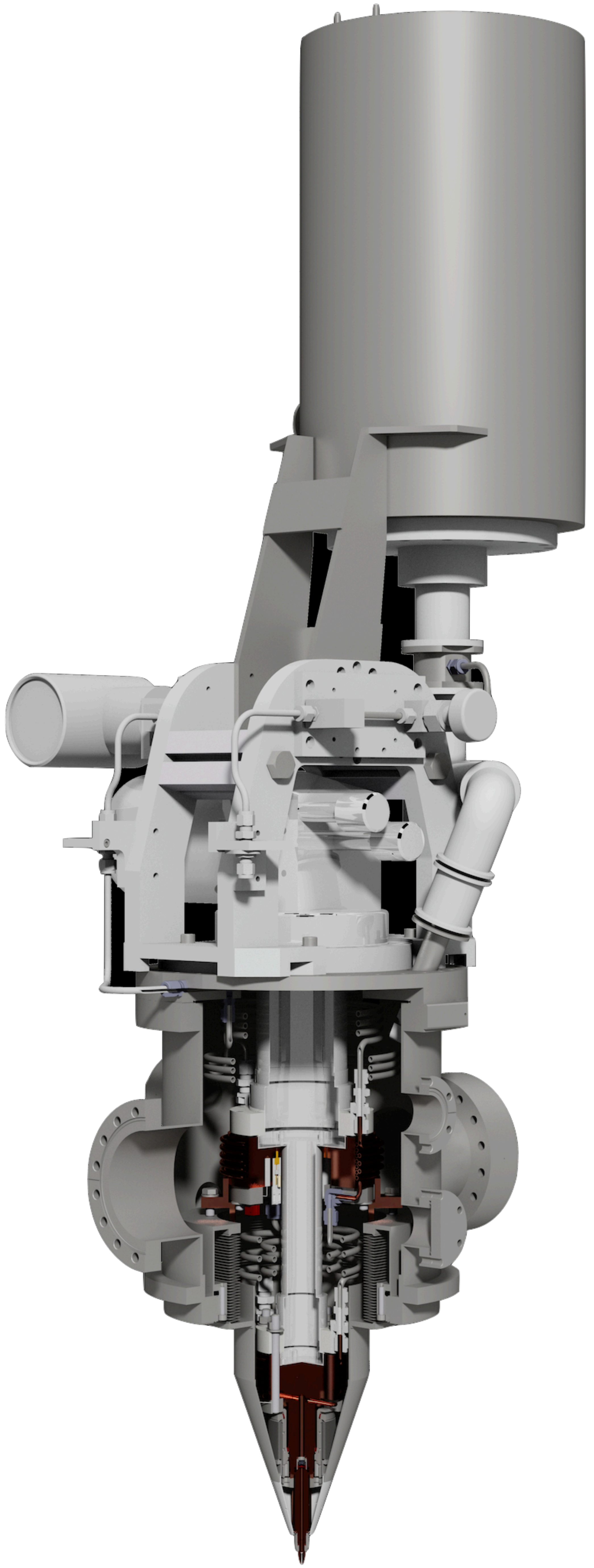


See also: Rachek et al. PRL 114, 062005 (2015)


I GOT A FEVER…
AND THE ONLY PRESCRIPTION
…IS MORE ~~COWBELL~~
DATA!

SSA measurements at MAGIX

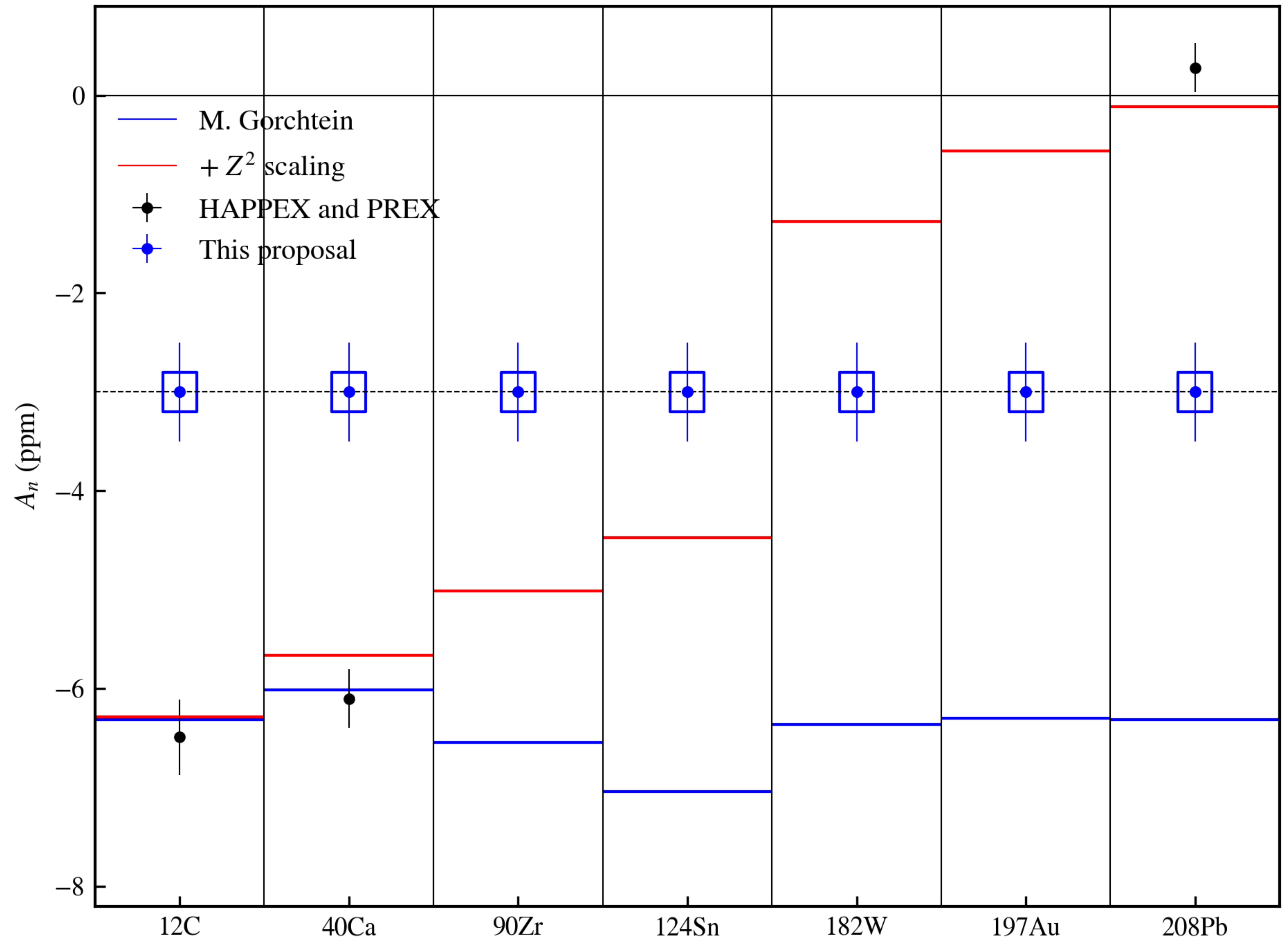
- Existing and planned SSA measurements use traditional liquid/solid targets
- Opportunity to measure SSAs in uniquely clean environment with MAGIX
- Challenges:
  - Beam dump limitations (extracted beam) vs. source lifetime (ERL)
  - Beam/polarization monitoring
- Working on rate estimates for proton, heavier nuclei
- Long term: polarized target possible?



SSAs at JLab

Nuclear SSA scan (PR12-24-007)

- Measure 7 nuclei, ranging from ^{12}C to ^{208}Pb
- Carry out measurement with Hall C HMS/SHMS, PREX detectors
- Proposal for 9 days approved with A rating by JLab PAC 52



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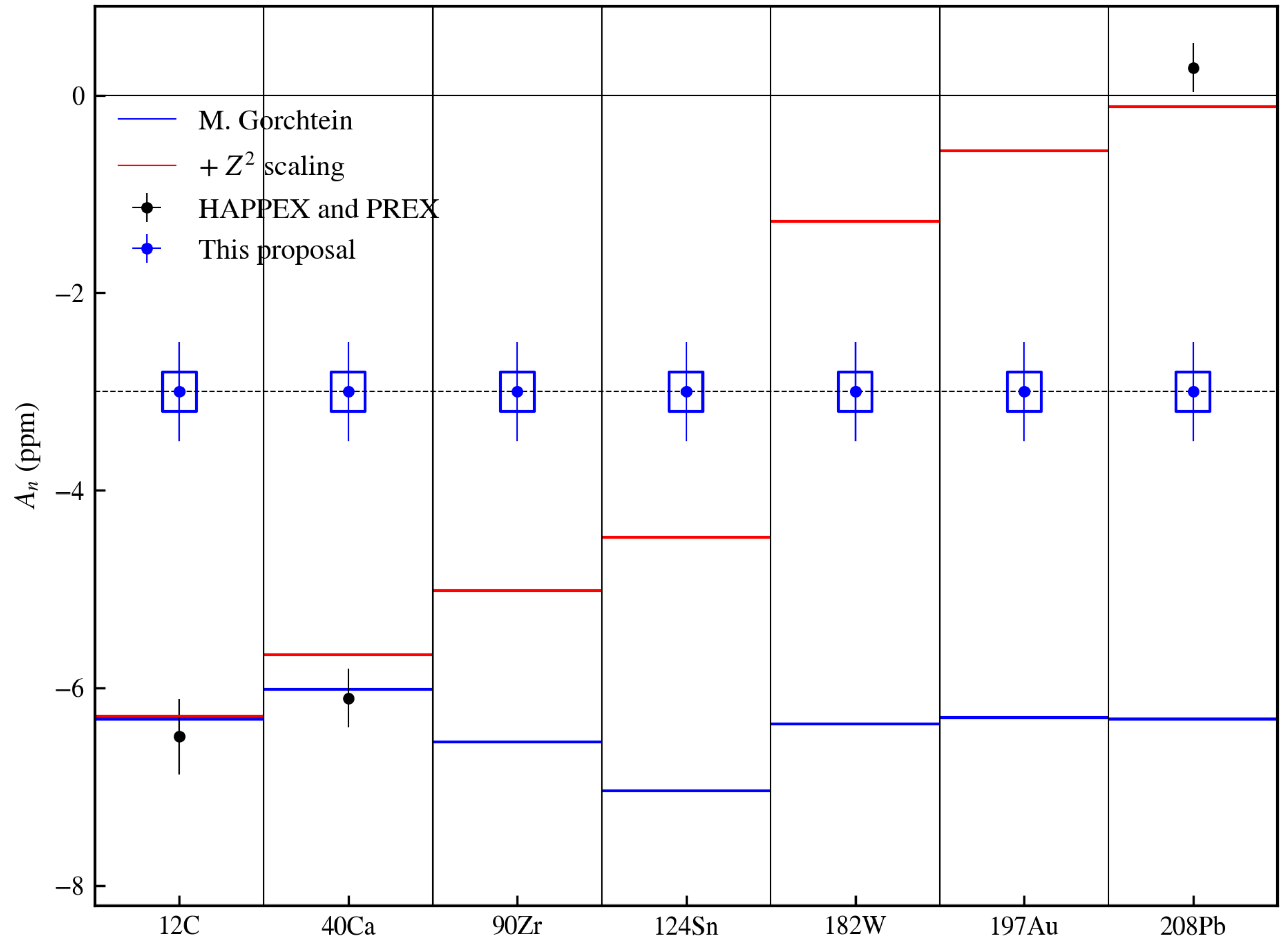
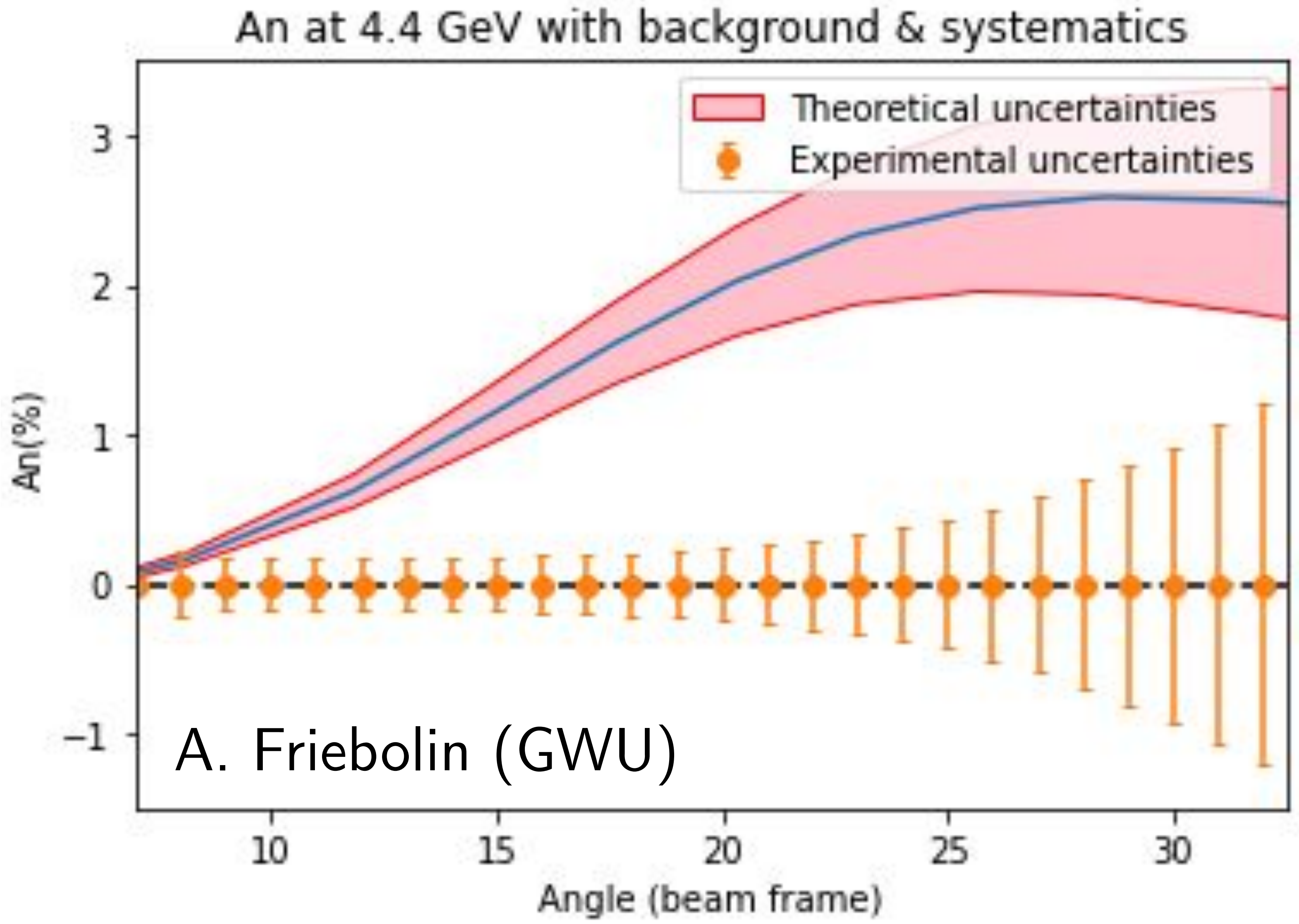


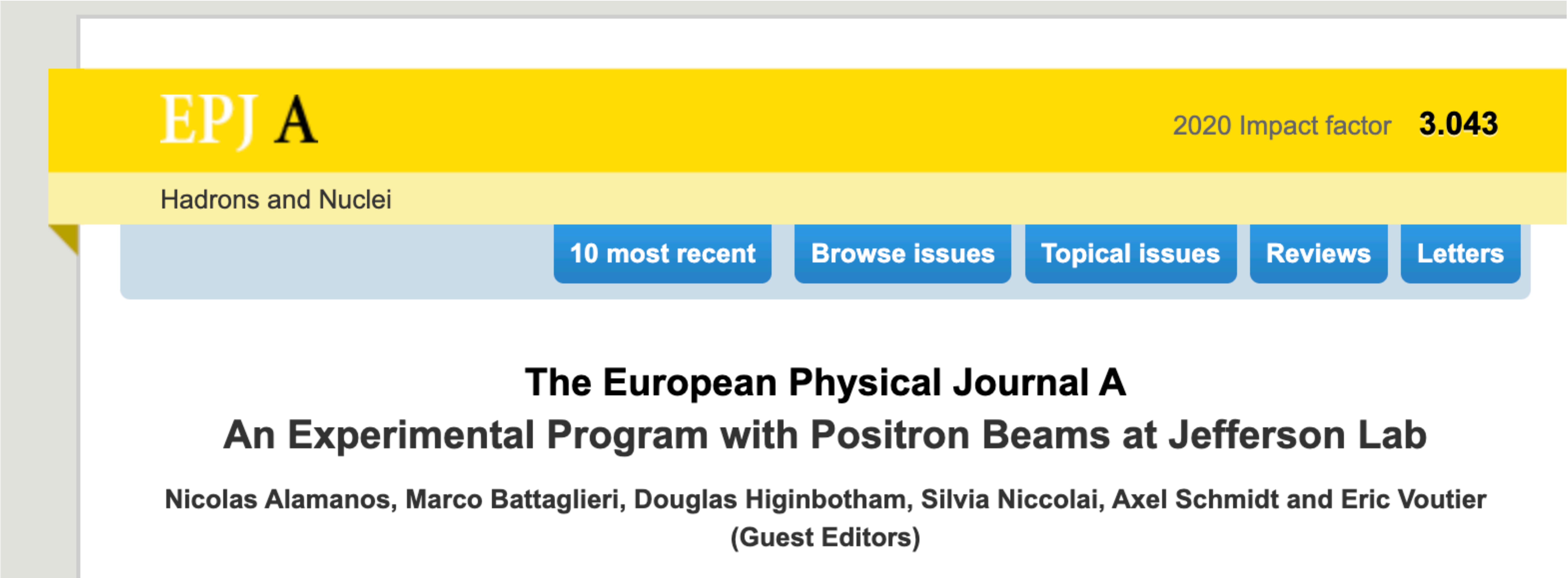
Potential proton target-normal SSA

- CLAS12 Run Group H plans to run with transversely polarized proton target
- Propose run group addition at lower beam energy for SSA (LOI next year)



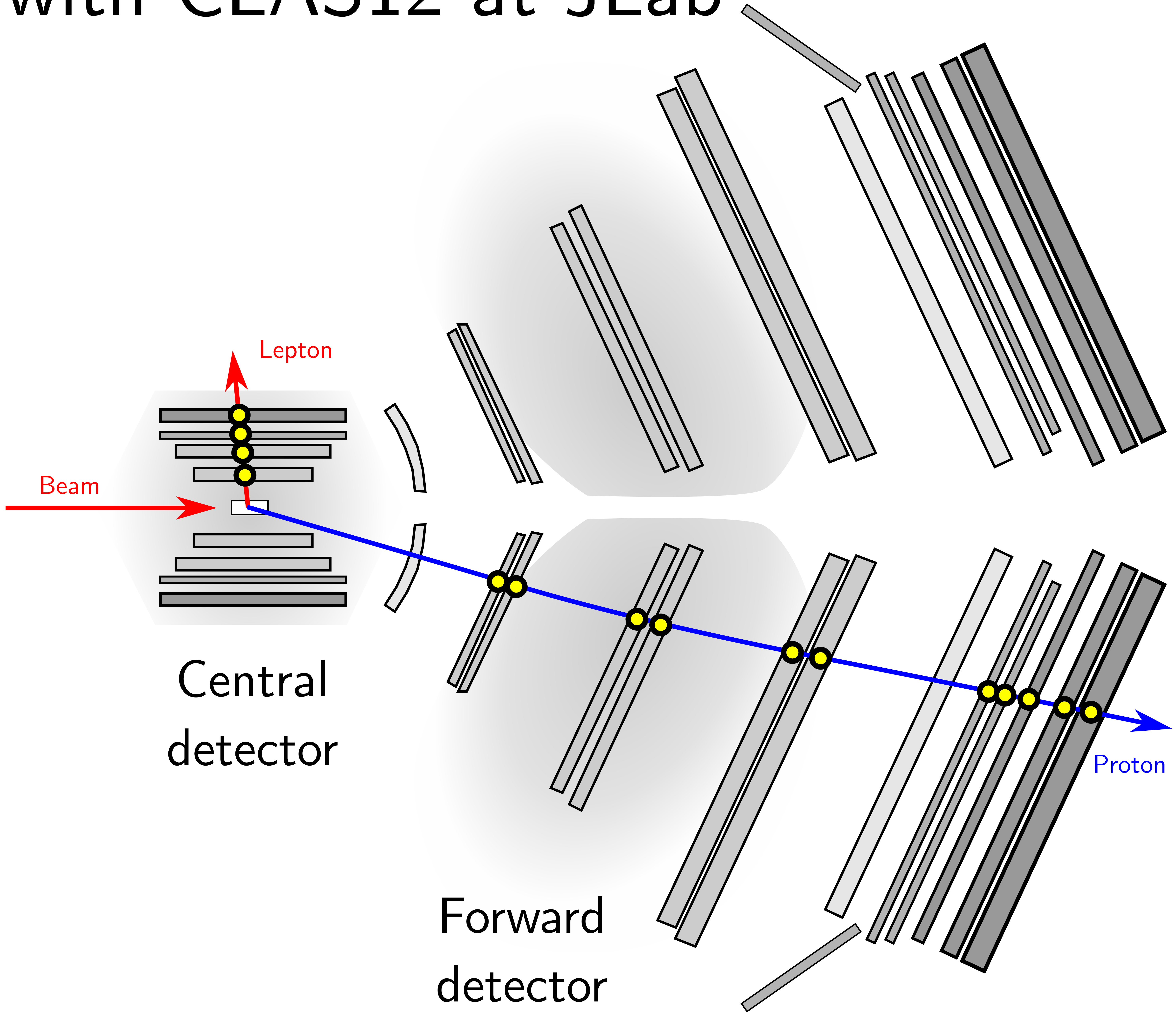
Jefferson Lab positron working group

- "Explore and develop the capabilities for positron beam physics at Jefferson Lab"
- Website: https://wiki.jlab.org/pwgwiki/index.php/Main_Page
- 2022 White Paper: https://epja.epj.org/component/toc/?task=topic&id=1430

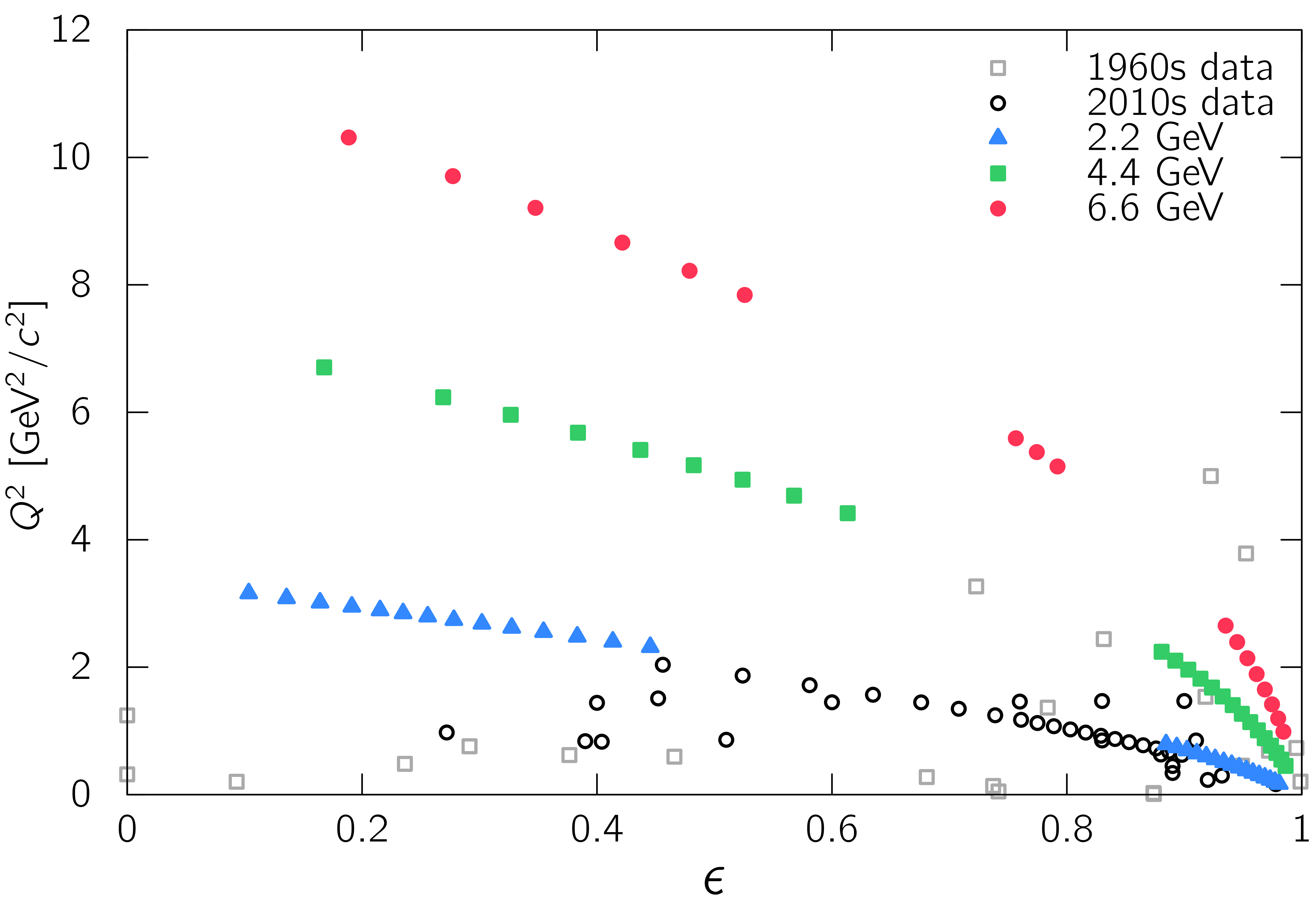


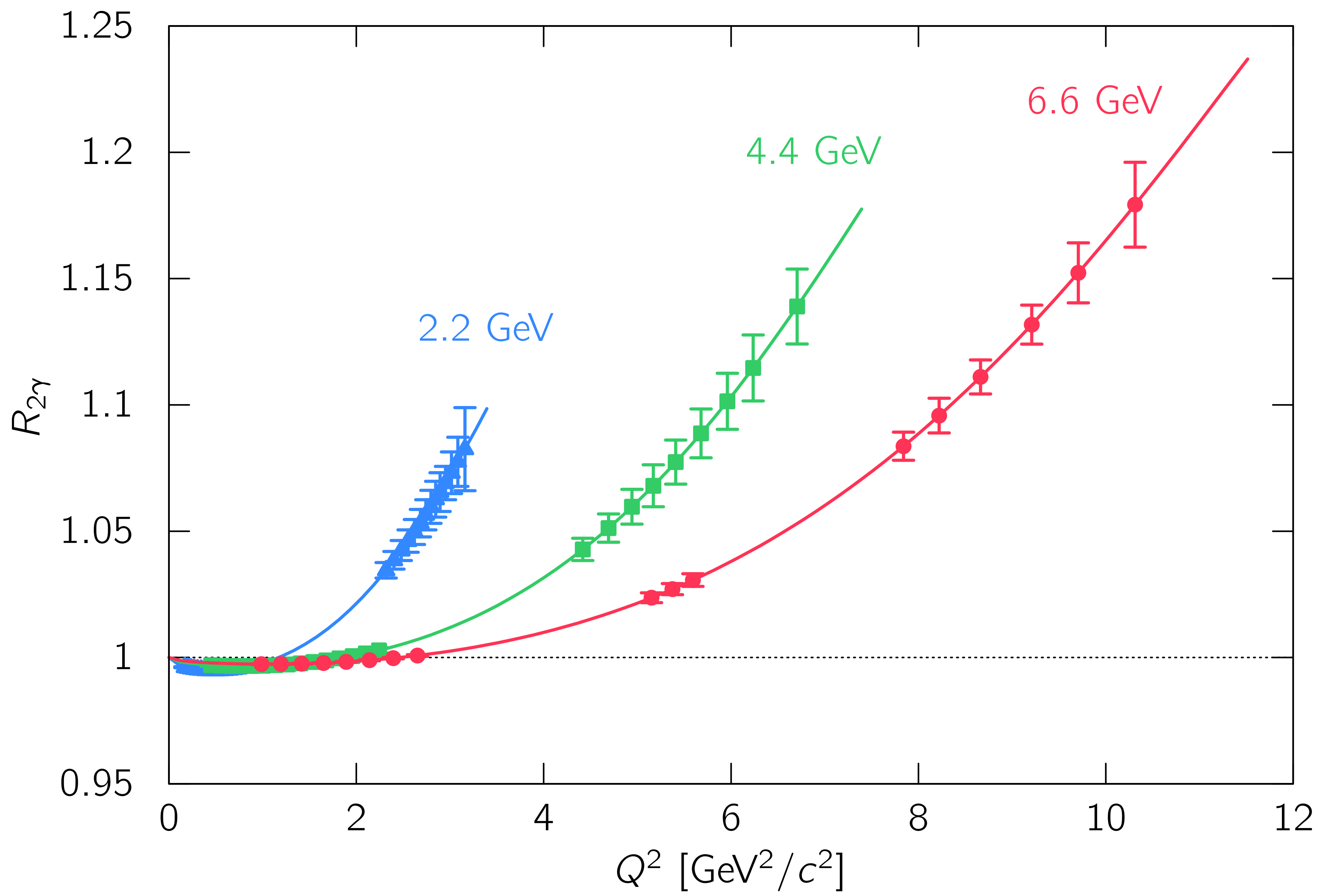
Proposed measurement with CLAS12 at JLab

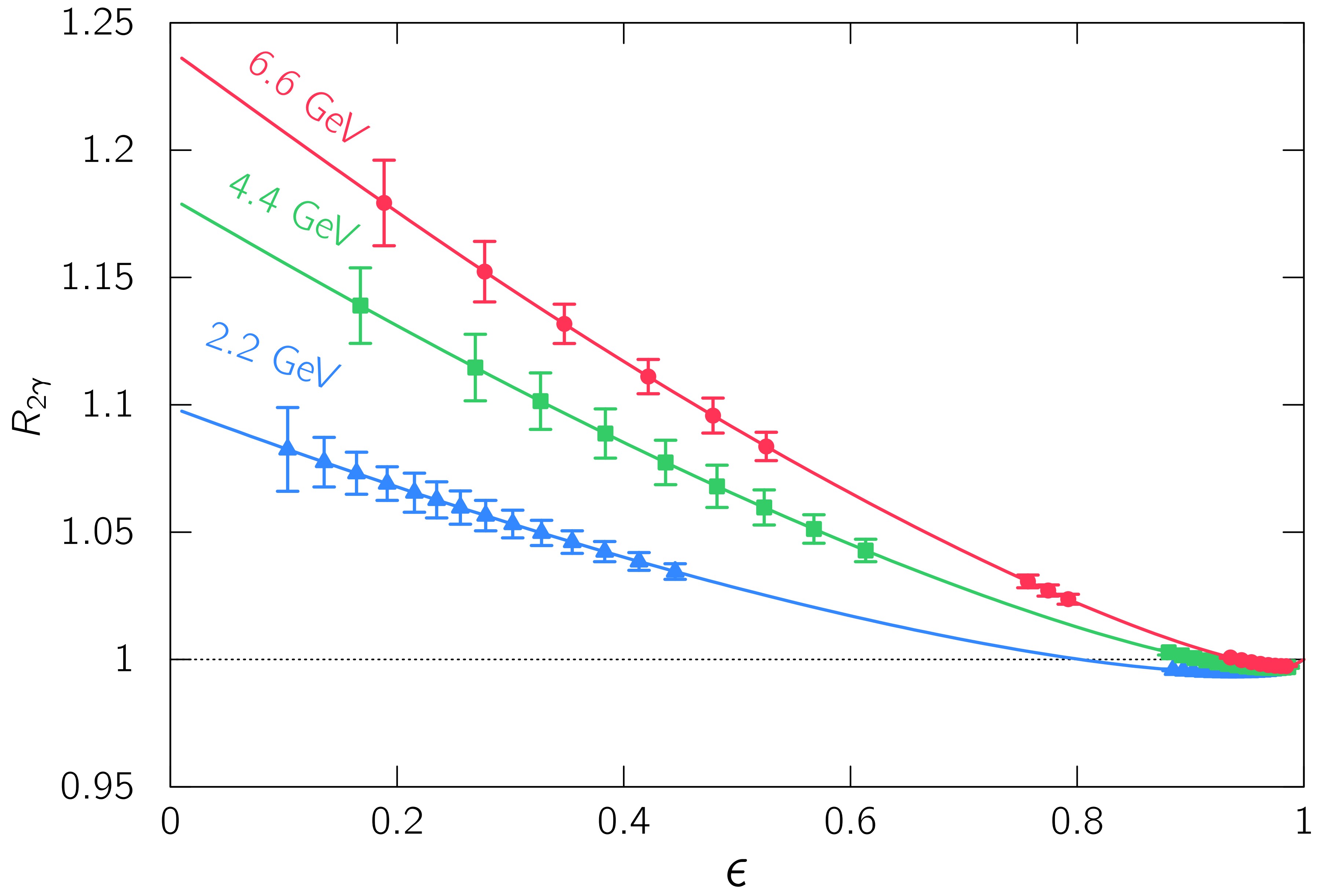
- Measure e^+p/e^-p ratio in Hall B
- 55 days at 10^{35} cm^{-2} s^{-1}:
  - 75 nA
  - 5 cm LH_2 target
  - Ideally switch lepton species weekly
- $E_{beam} = 2.2, 4.4, 6.6$ GeV
- Accessing high Q^2, low ϵ requires forward proton, central lepton



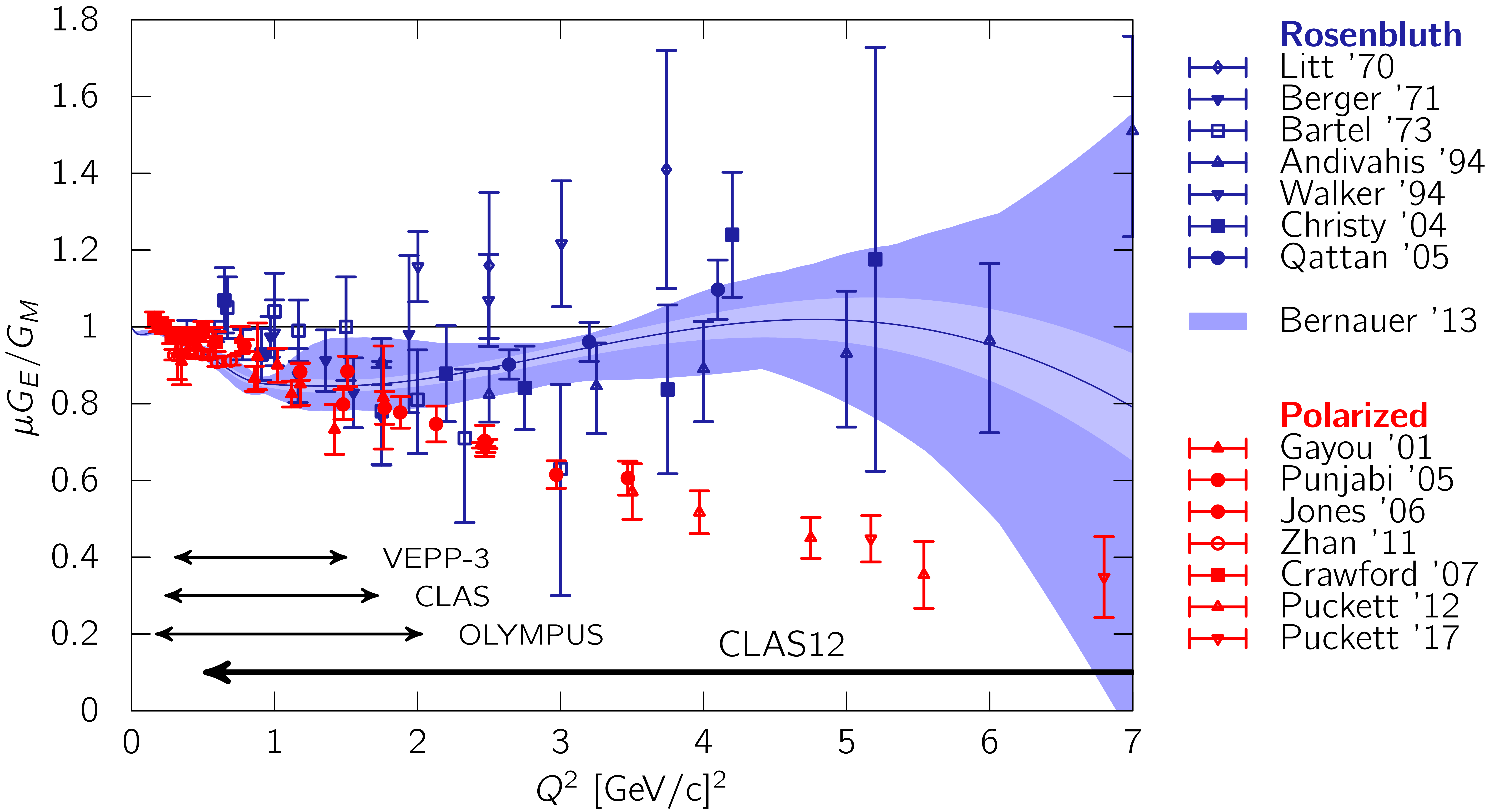
CLAS12 well-suited for mapping TPE over wide phase space







Definitive answer to whether TPE causes discrepancy



In-progress CRC1660 follow-up application

- Focus primarily on SSA measurements at MAGIX
  - Identify reasonable deliverables for FP1
- Maintain participation in near-term experiments at JLab (good opportunity for PhD thesis data)
- Mention long term aspirations for positrons at JLab (unfortunately, likely beyond FP3)

Summary

- TPE (and hadronic box diagrams) are a significant source radiative corrections in electromagnetic (and electroweak) measurements...
- ...however, the effect remains largely unconstrained both theoretically and experimentally
- Additional lepton scattering measurements can:
    - Provide additional benchmarks for theory
    - Definitively test TPE hypothesis for $\mu G_E/G_M$ discrepancy
- In-progress CRC1660 follow-up application will focus on SSA measurements at MAGIX