Thinking inside the box (diagram):

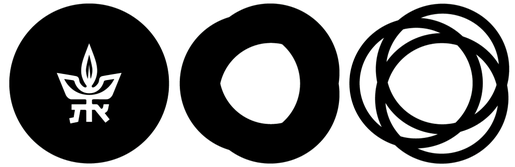
Two photon exchange at Jefferson Lab

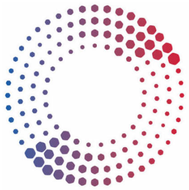
Tyler Kutz

PREN2022 Convention

Paris, France

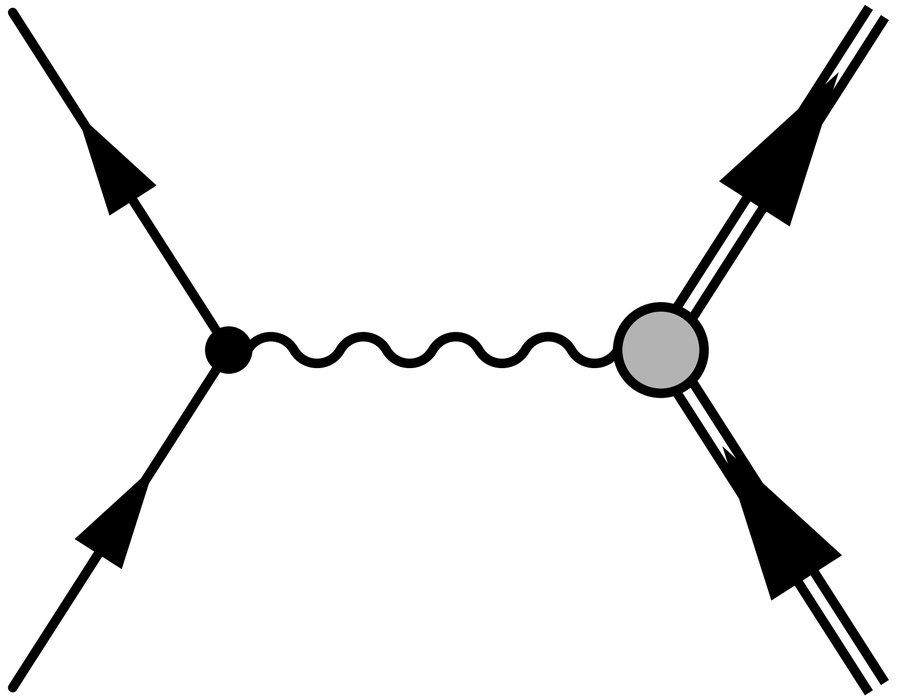
June 23, 2022



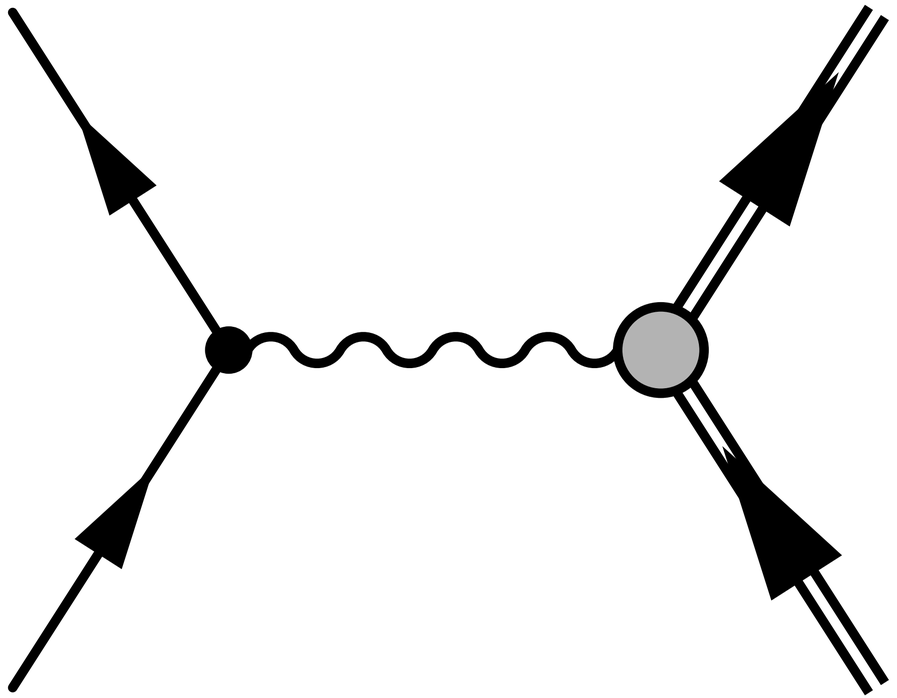


MORTIMER B.
ZUCKERMAN
STEM LEADERSHIP
PROGRAM

Scattering experiments are interpreted in the Born approximation



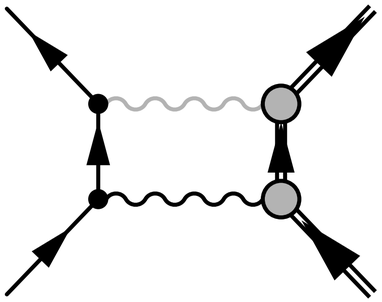
Scattering experiments are interpreted in the Born approximation



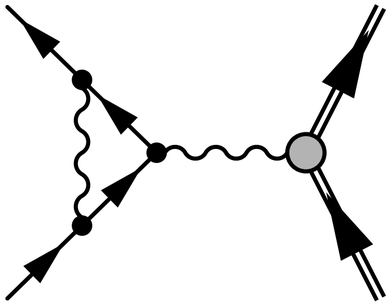
But the probability of OPE occurring is zero!

Hard TPE neglected in standard radiative corrections

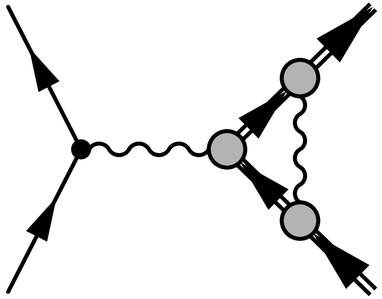
Soft TPE



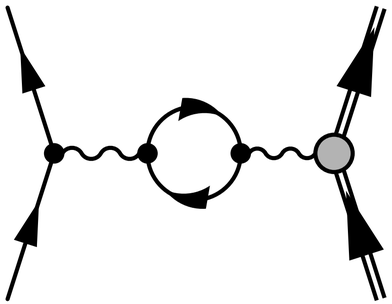
e vertex



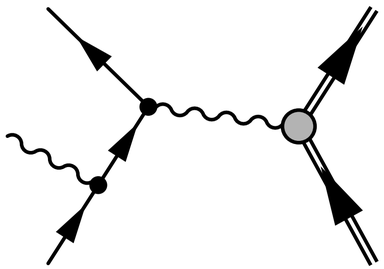
p vertex

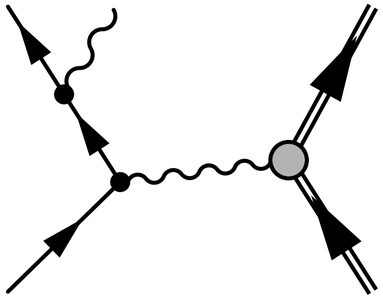


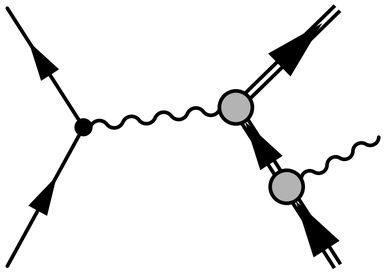
Vacuum polarization

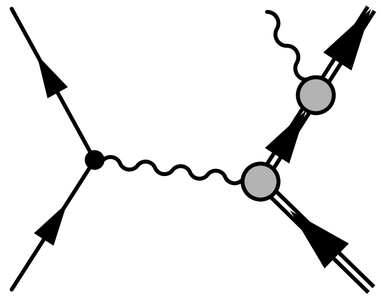


Bremsstrahlung

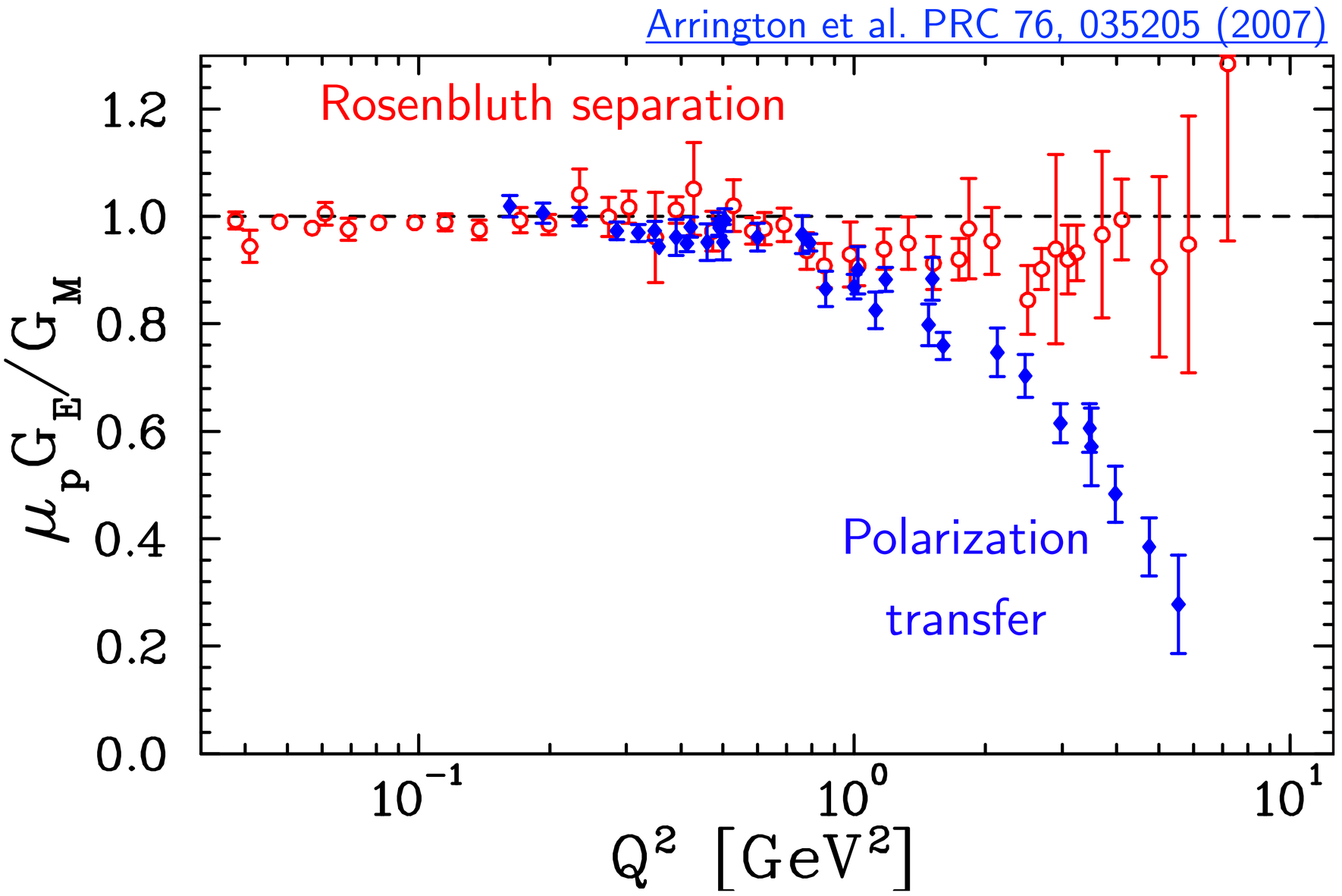






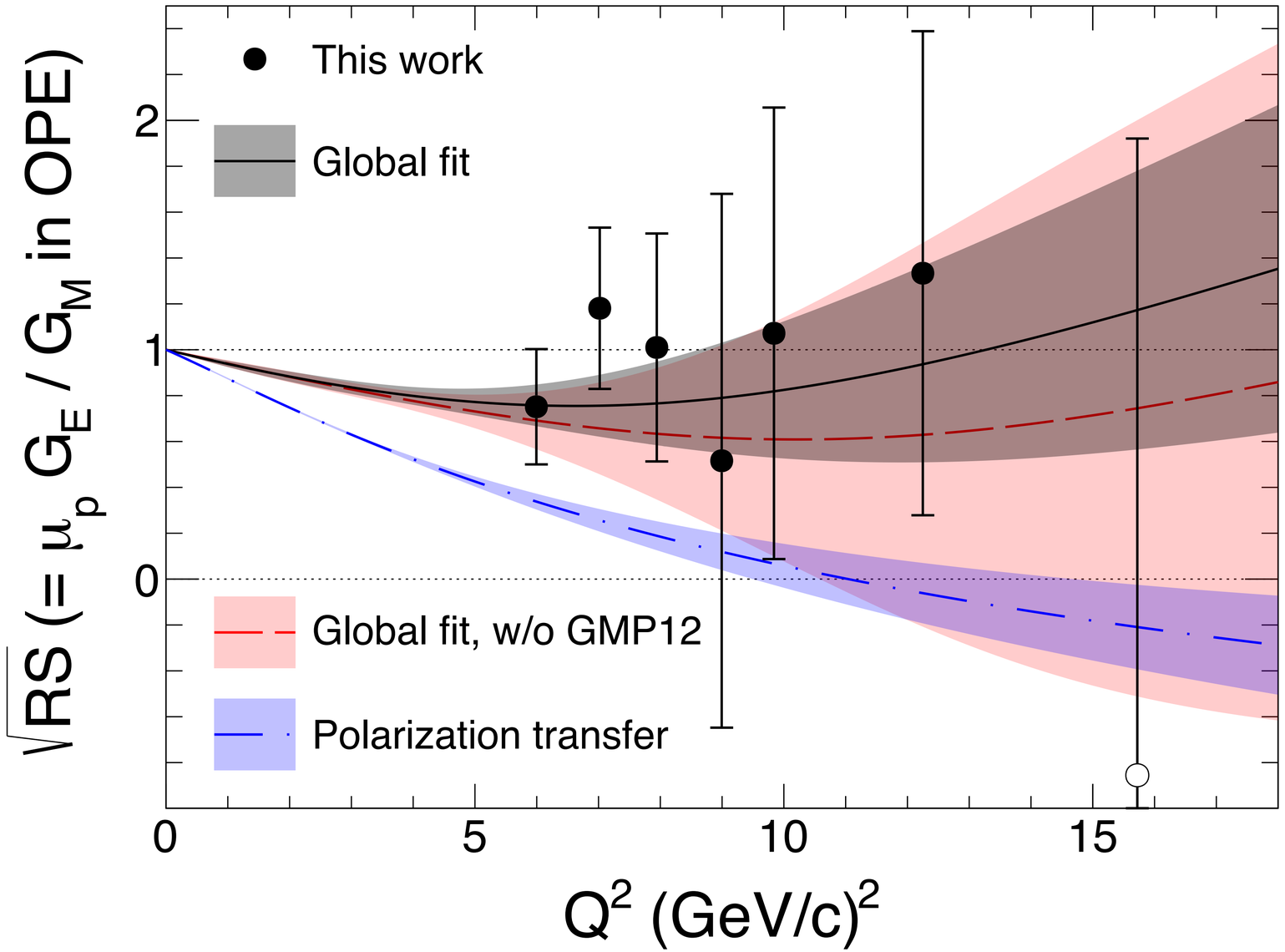


TPE could explain proton form factor discrepancy



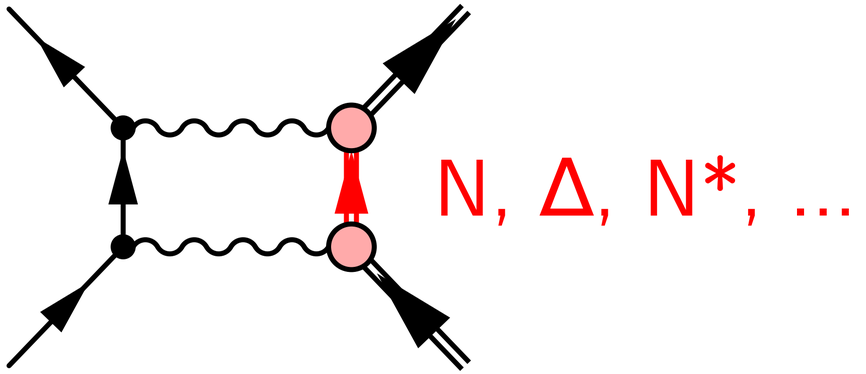
Recent results from JLab consistent with discrepancy

Christy et al. PRL 128, 102002 (2022)

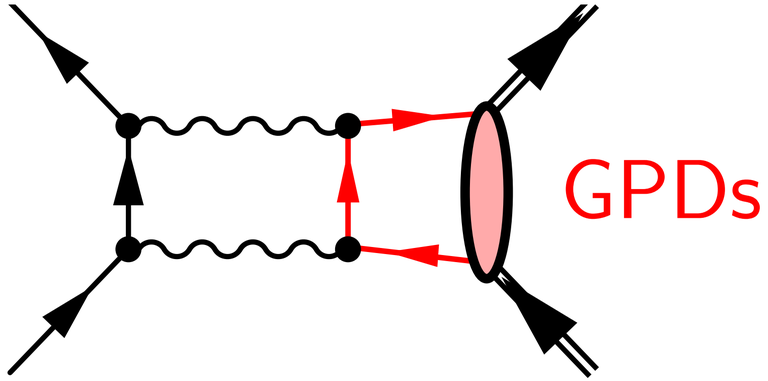


Calculation of hard TPE is model-dependent

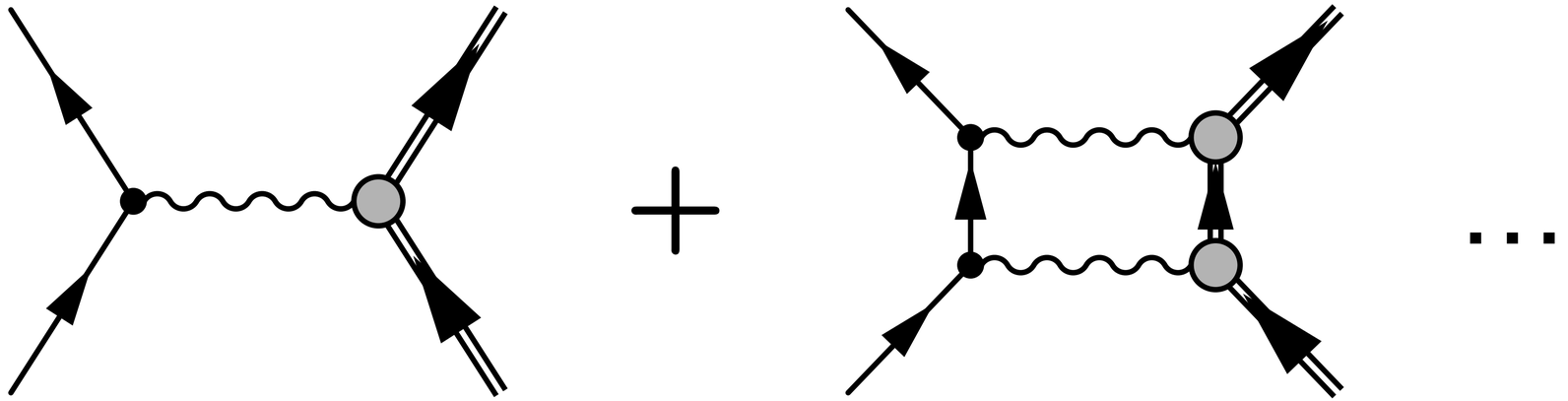
- Sum over intermediate *hadronic* states
  e.g. Ahmed, Blunden, Melnitchouk
  PRC 102, 045205 (2020)



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

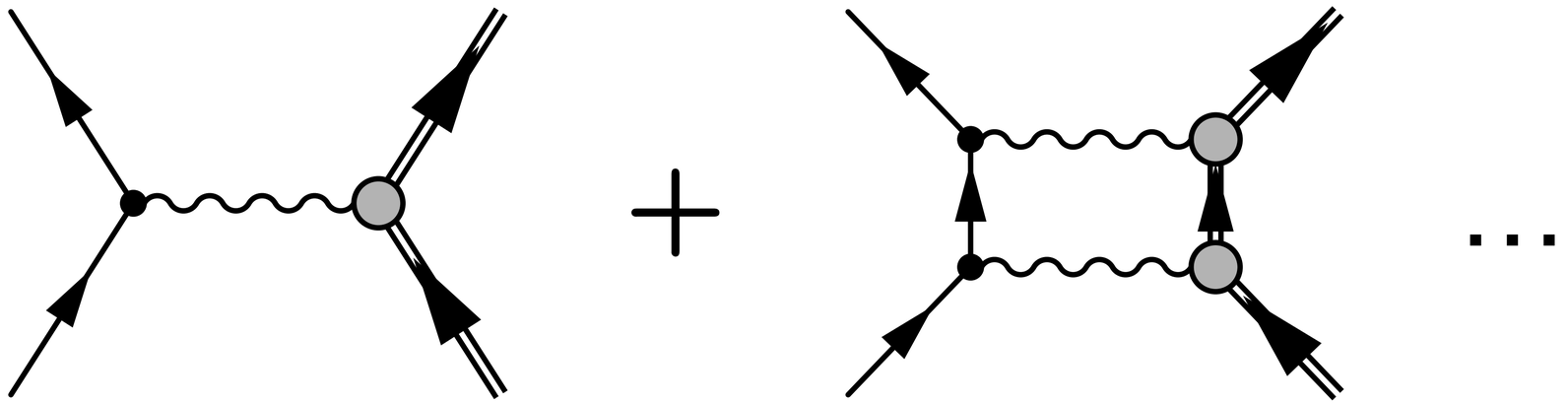


Can observe interference term between one and two photon exchange

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

- Single-spin asymmetries A_n
  - Imaginary part of OPE/TPE interference
- e^+/e^- cross section ratio
  - Real part of OPE/TPE interference

Can observe interference term between one and two photon exchange

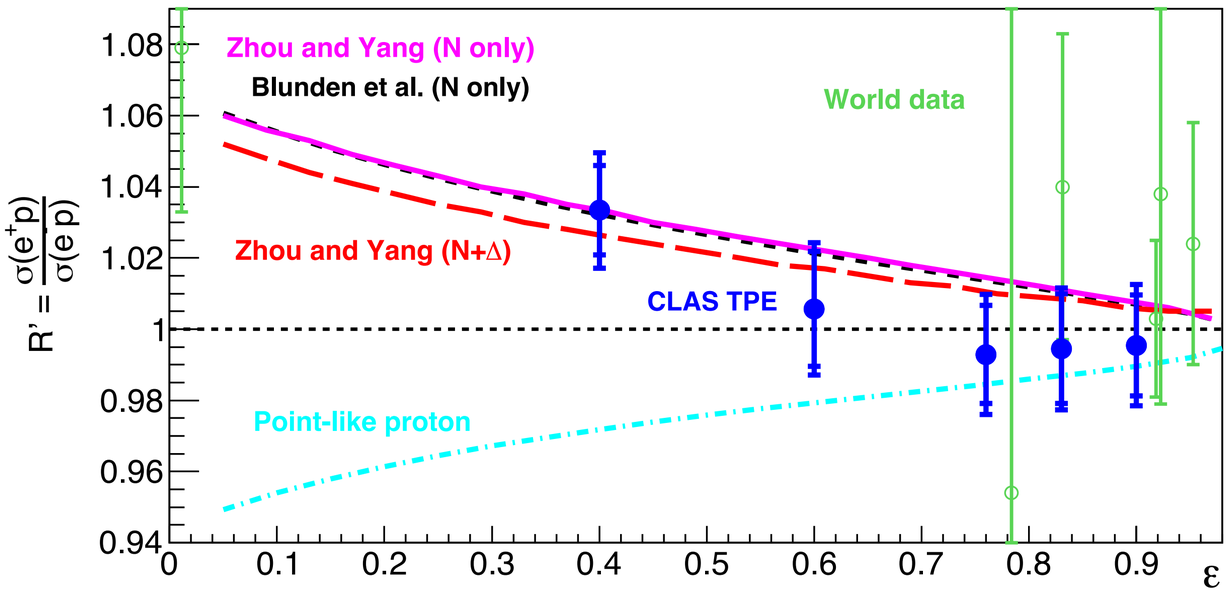
$\mathcal{M} =$  $+$ $\ldots$

- Single-spin asymmetries A_n
  - Imaginary part of OPE/TPE interference
- e^+/e^- cross section ratio
  - Real part of OPE/TPE interference

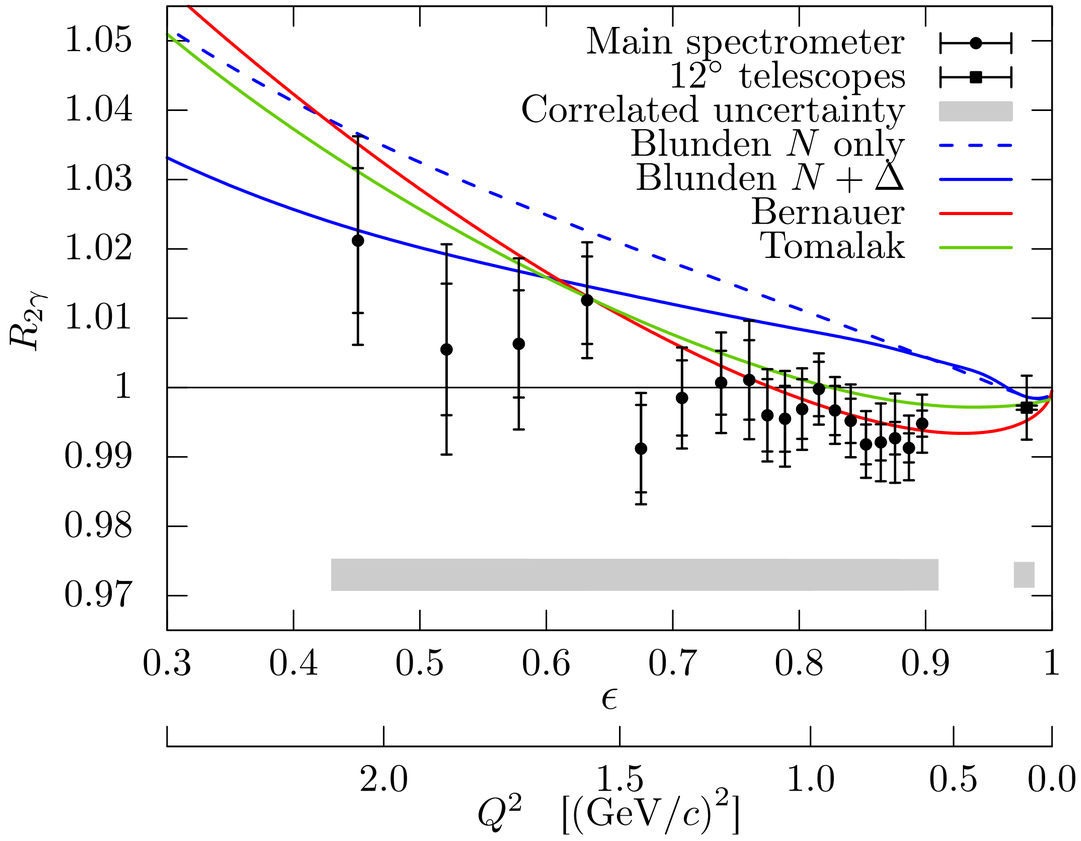
Relative sign change for e^+ and e^- scattering

Most recent e^+p/e^-p measurements unable to resolve $\mu G_E/G_M$ discrepancy

CLAS, PRL 114, 062003 (2015)



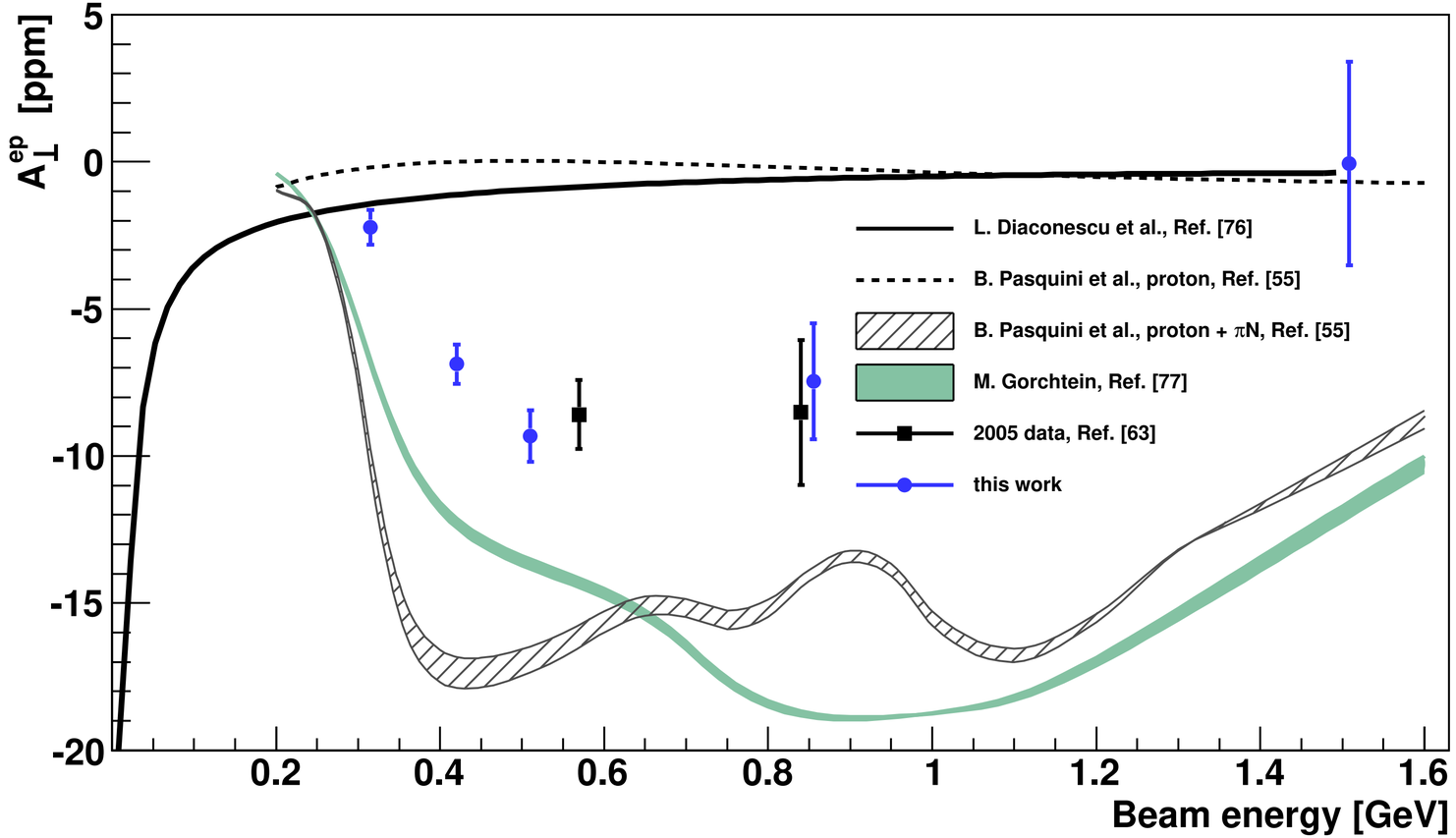
OLYMPUS, PRL 118, 092501 (2017)



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

Theory unable to reproduce recent proton A_n results from MAMI...

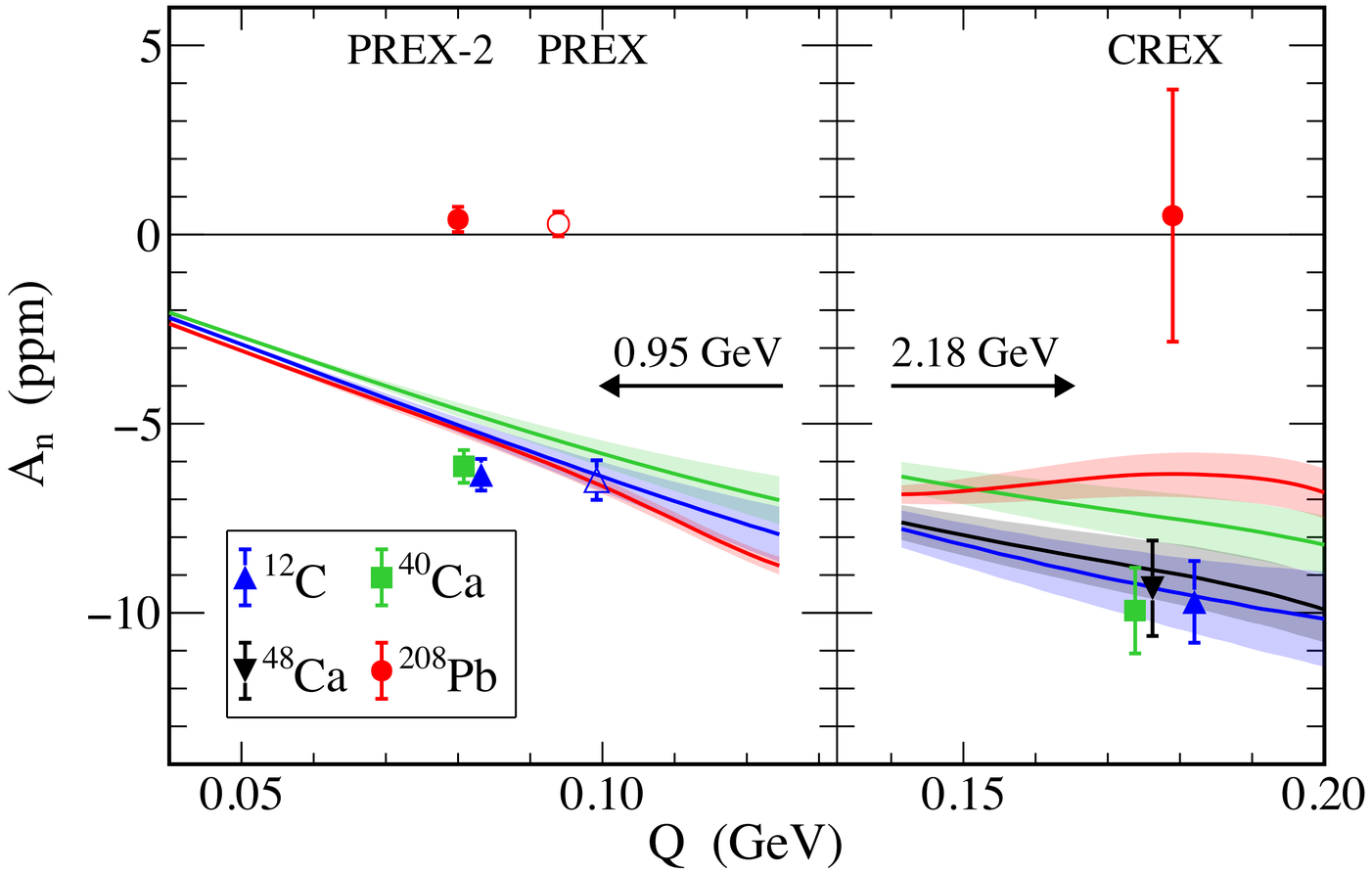
Gou et al. PRL 124, 122003 (2020)



- Calculations only account for elastic and πN inelastic intermediate states

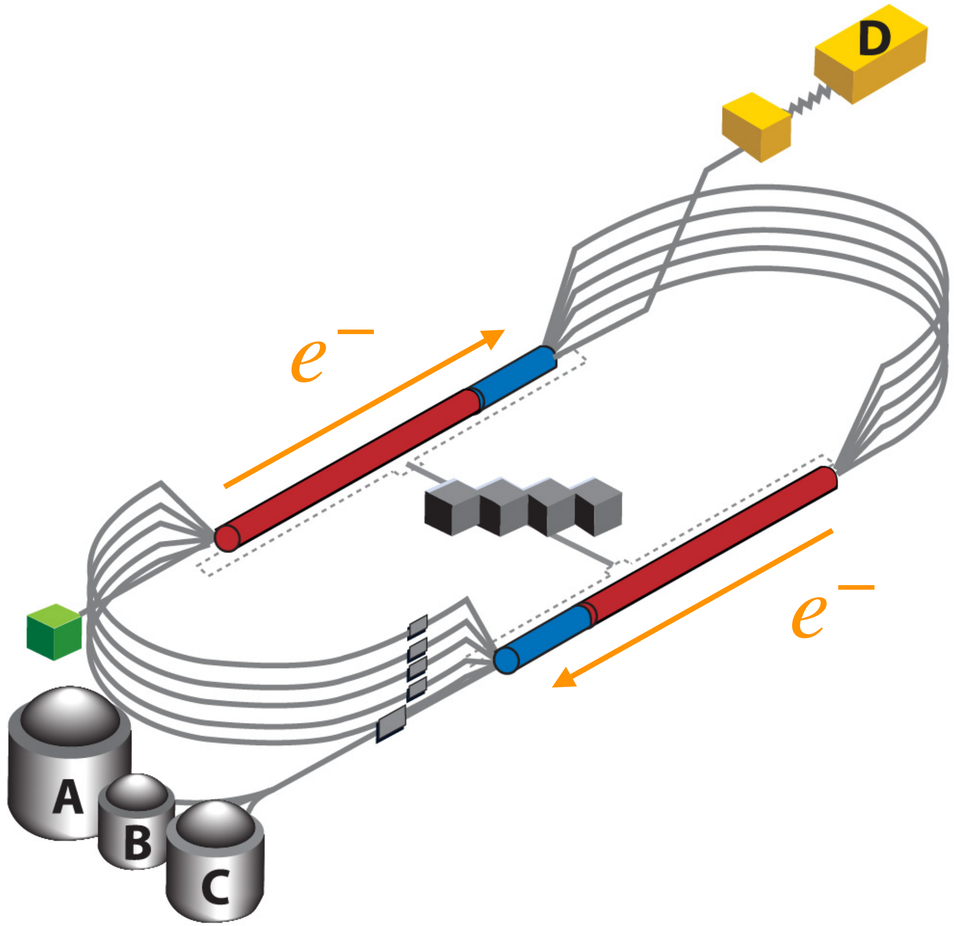
...or recent nuclear A_n results from PREX/CREX

PREX/CREX, PRL 128, 142501 (2022)

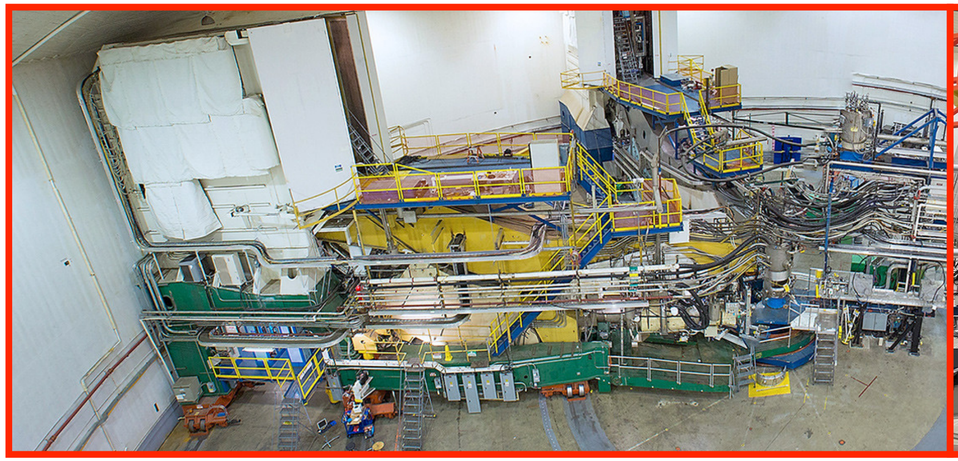


- Exchange of many soft photons (Coulomb distortion) grows with Z
- Coulomb distortion + inelastic states included in recent calculation (shown):
  - Koshchii, et al. PRC 103, 064316 (2021)

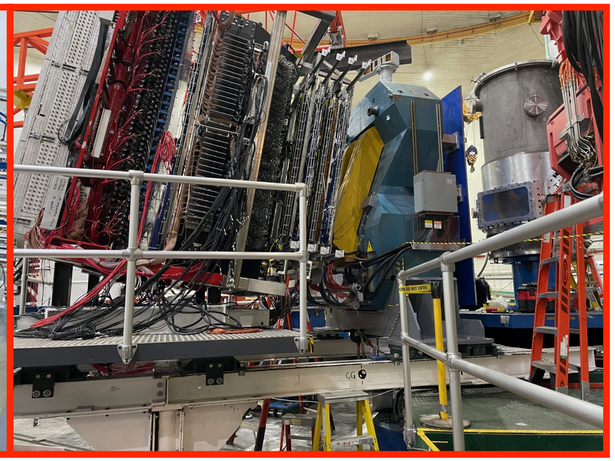
Jefferson Lab



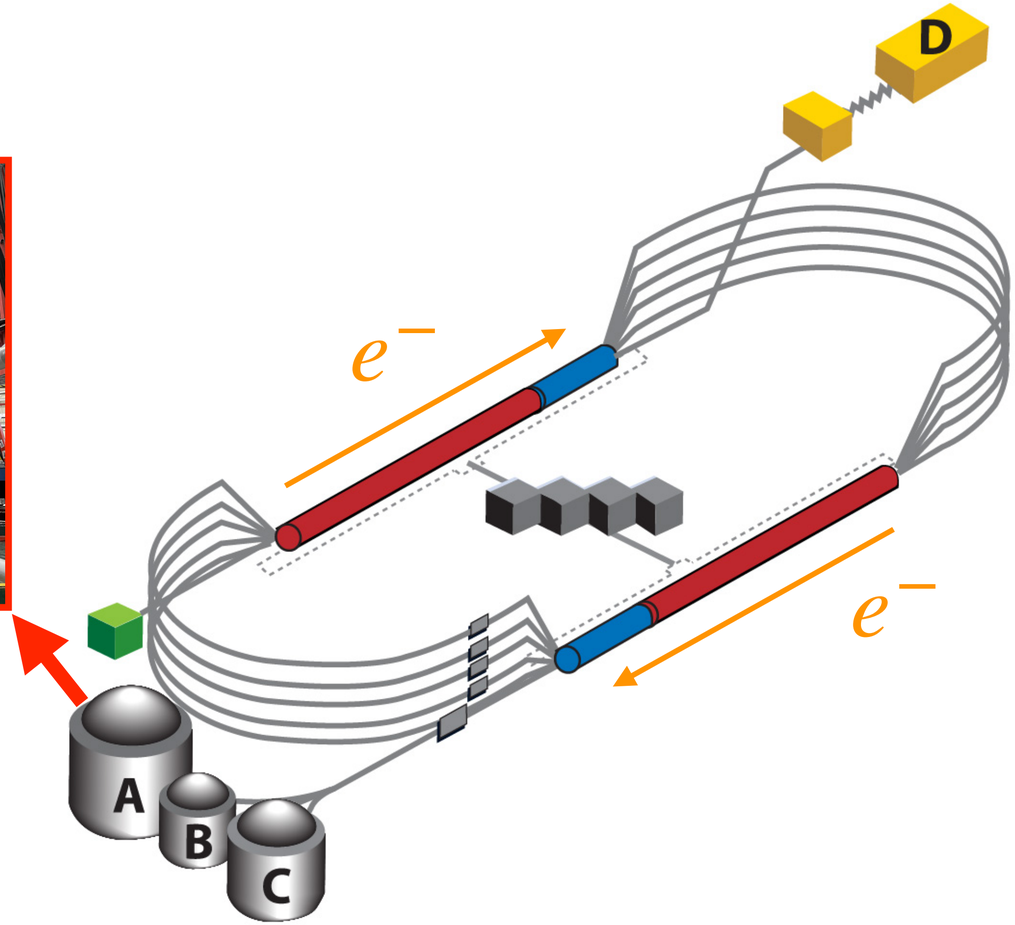
Jefferson Lab



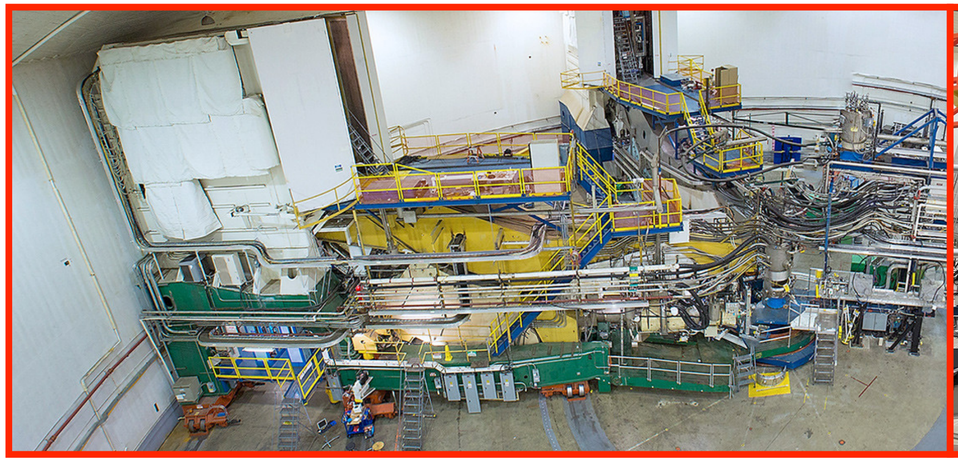
High resolution spectrometers



BigBite/SuperBigBite spectromters



Jefferson Lab



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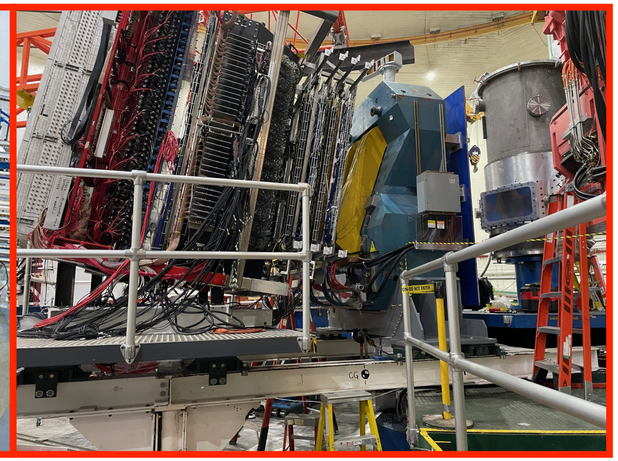

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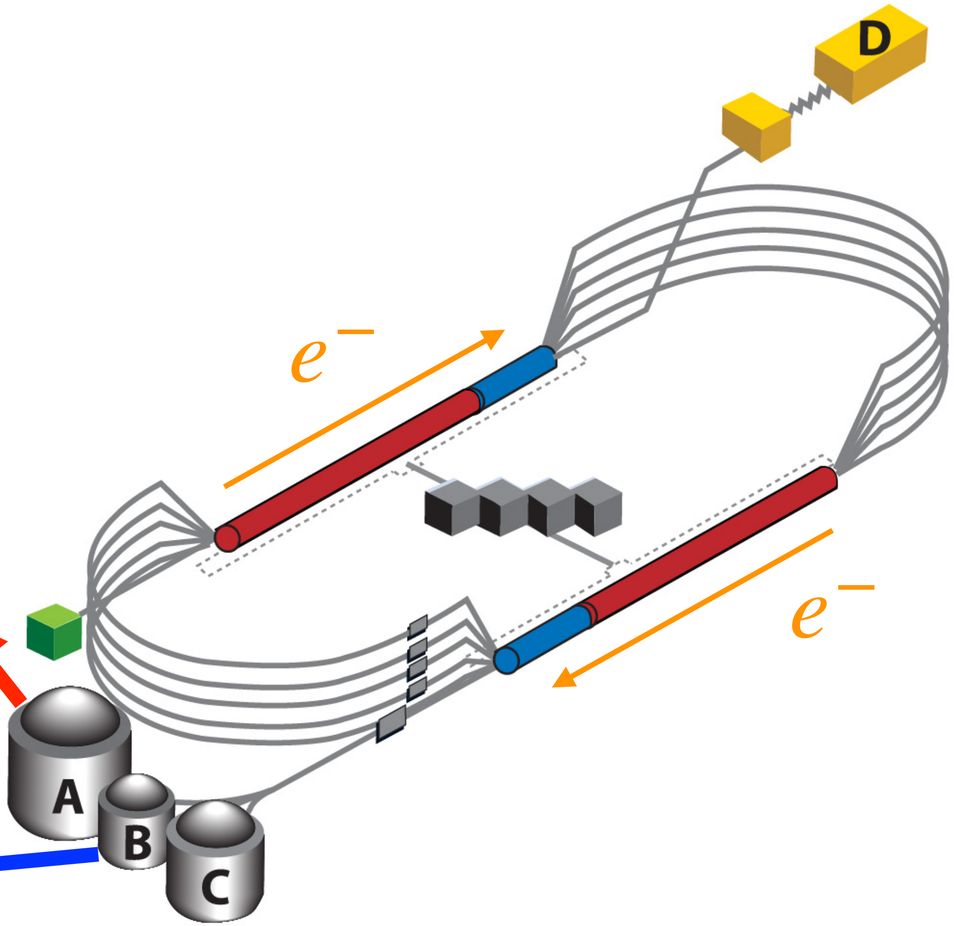
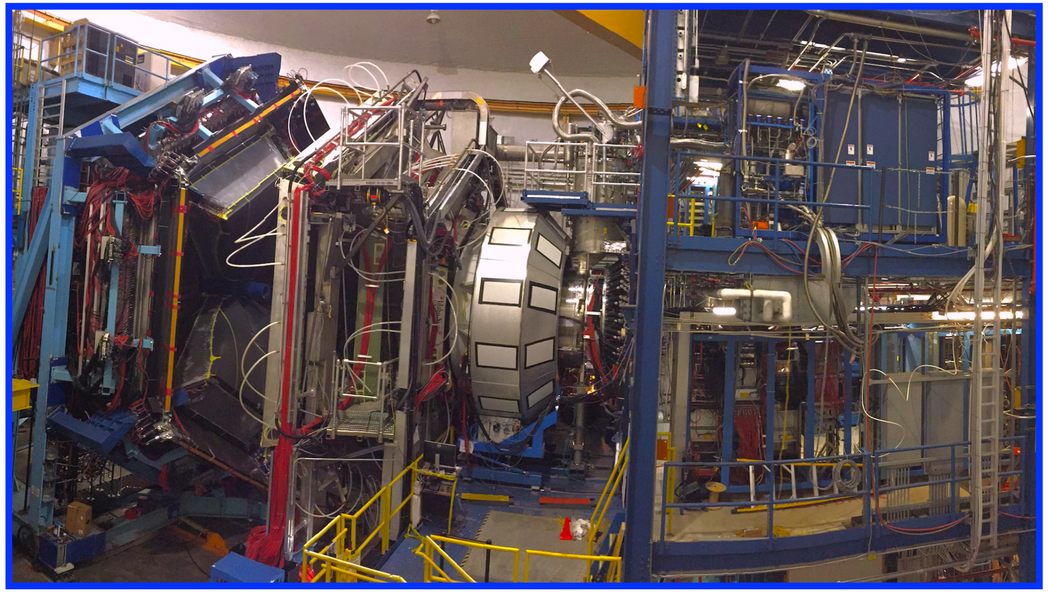
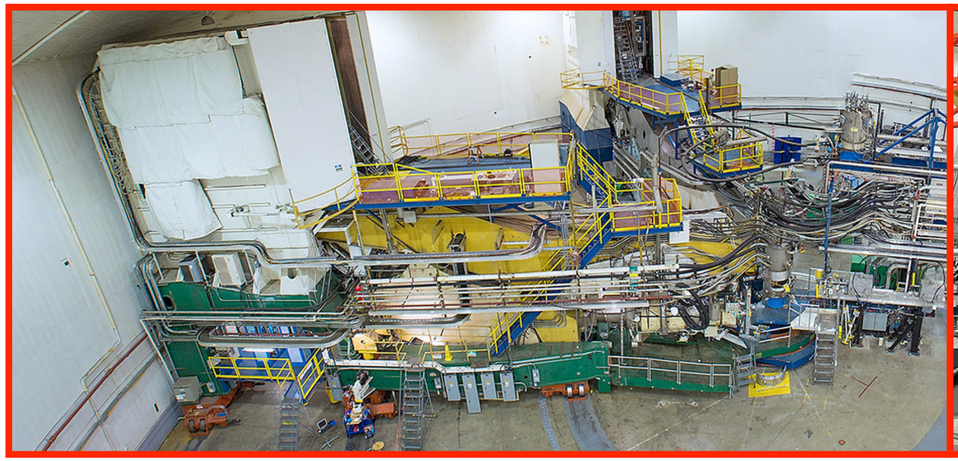


CLAS12



Jefferson Lab



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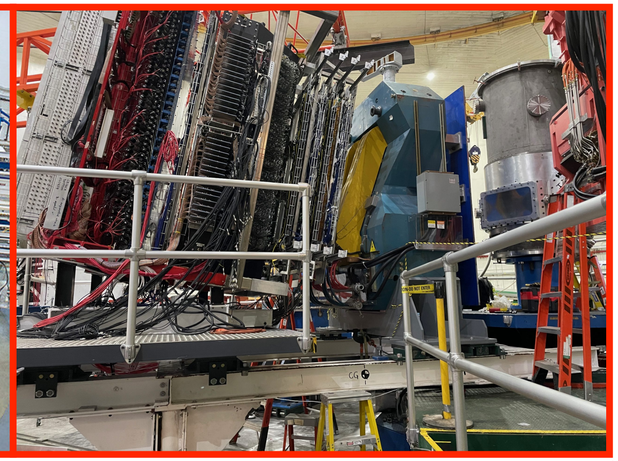

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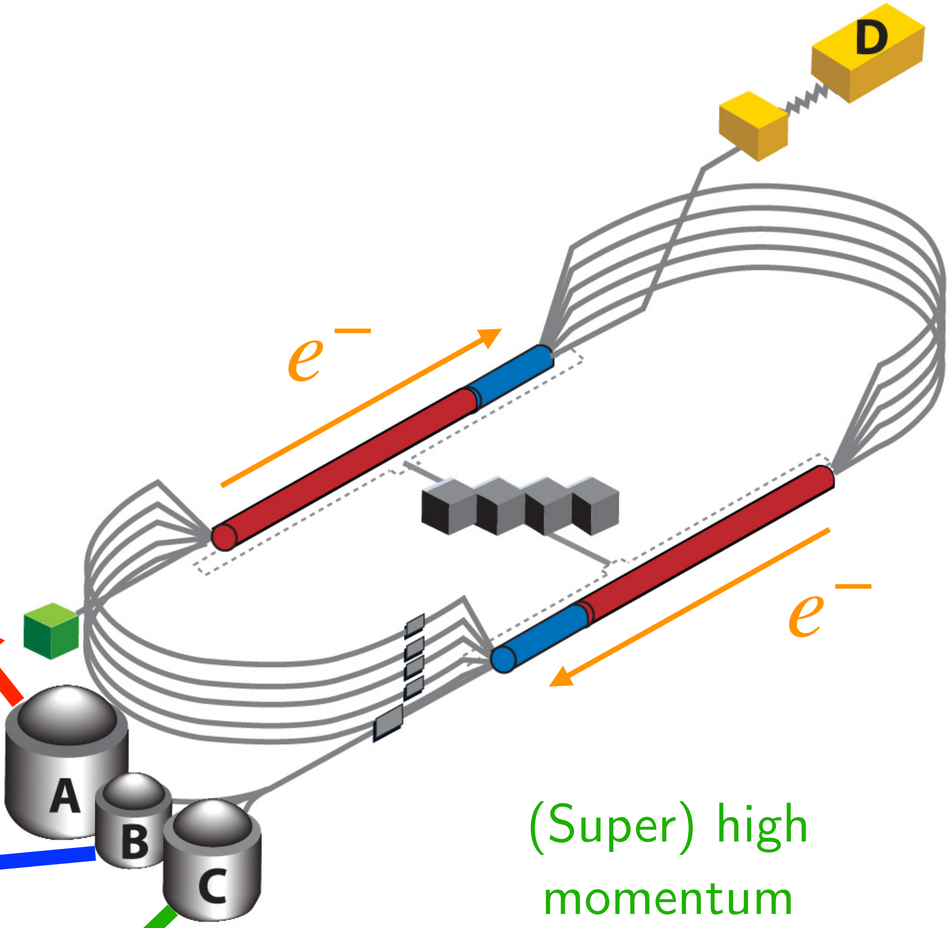
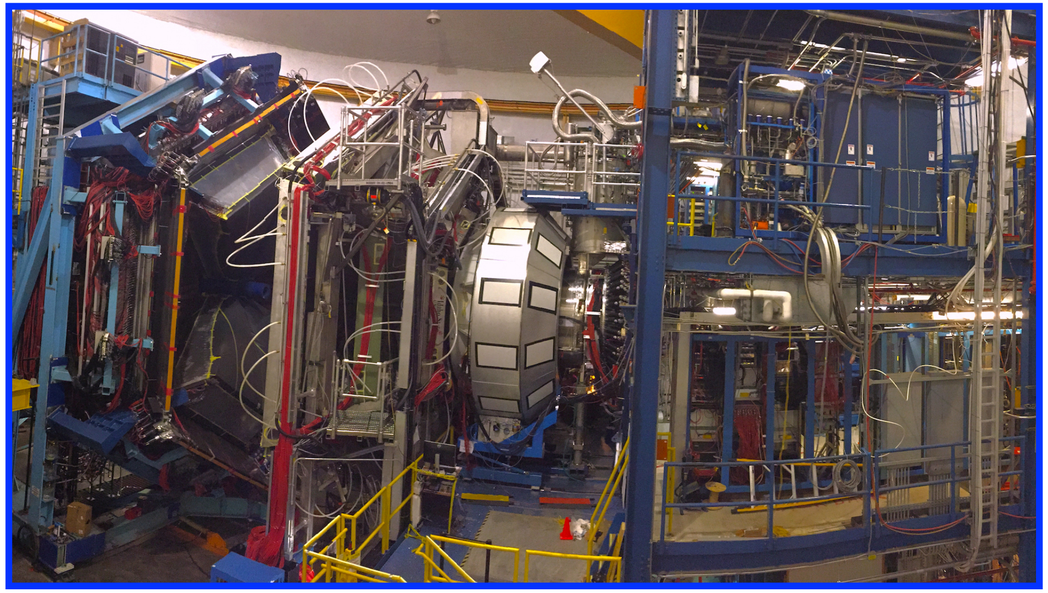
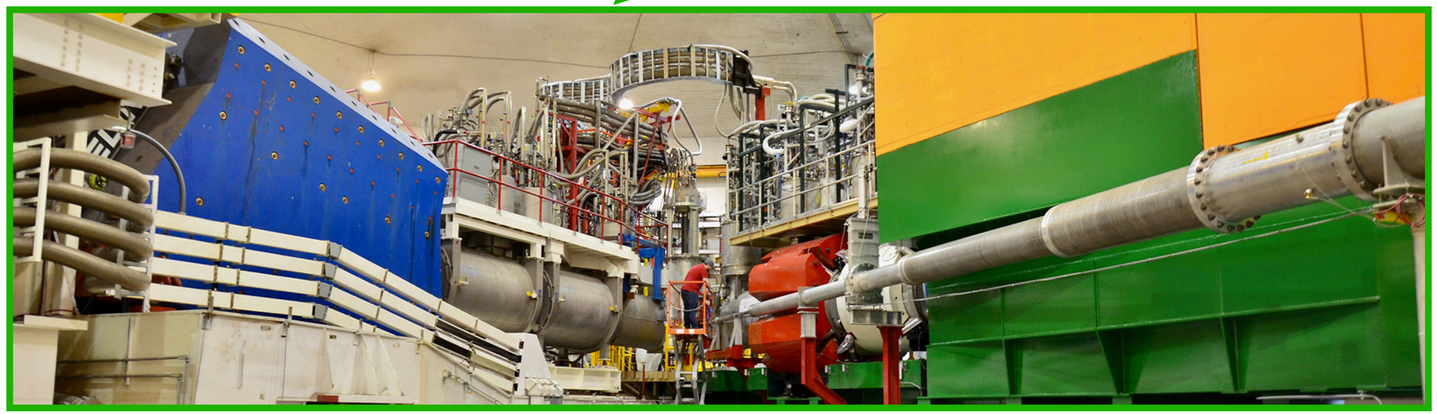


CLAS12



(Super) high momentum spectrometers



Jefferson Lab positron working group

- Website:
  https://wiki.jlab.org/pwgwiki/index.php/Main_Page
- Recent White Paper:
  https://epja.epj.org/component/toc/?task=topic&id=1430

TPE with positrons at Jefferson Lab

Proposed measurements

- Polarized:
  - Single-spin asymmetry
  - $\mu_p G_E/G_M$ (polarization transfer)
- Unpolarized:
  - e^+/e^- cross section ratios
  - $\mu_p G_E/G_M$ ("Super-Rosenbluth")

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- Unpolarized:
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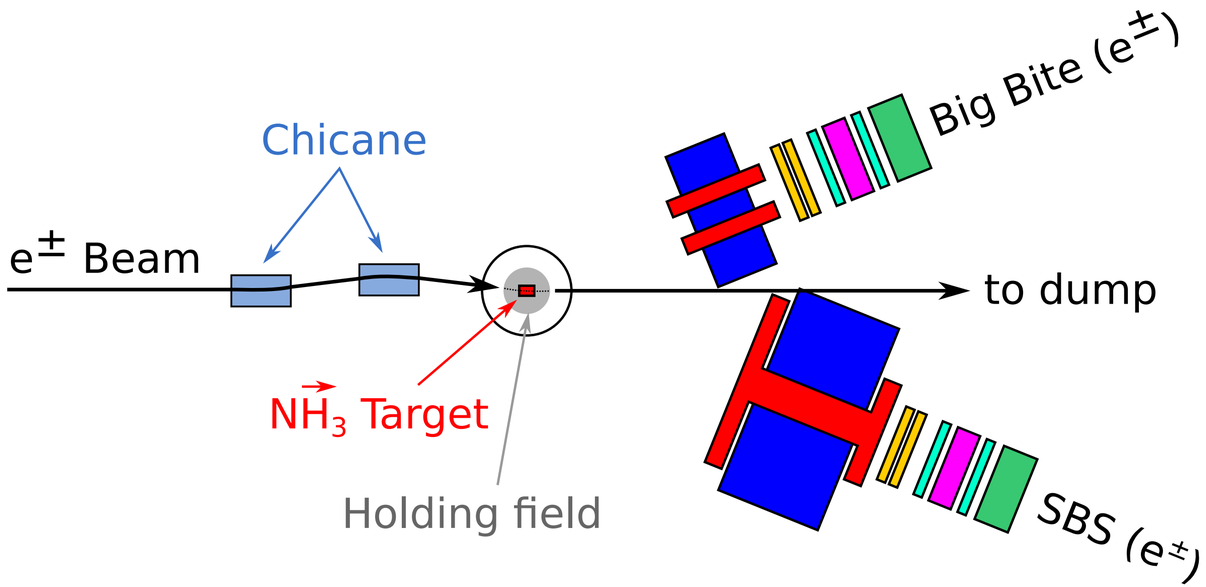
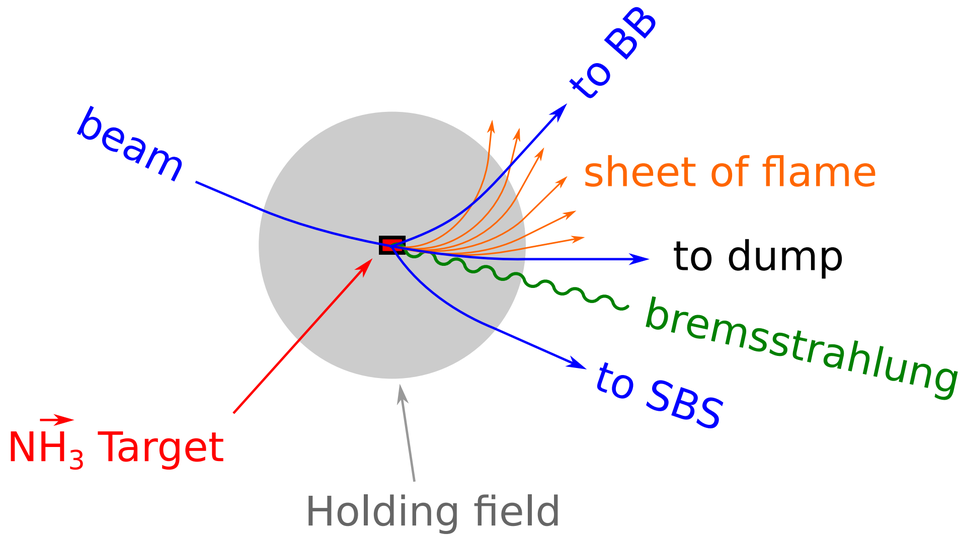
Technical considerations

- Assumed maximum e^+ beam current of 1-2 μA (unpolarized), 100-200 nA (polarized)
- Assumed e^+ beam polarization of 60%
- Switching between e^- and e^+ beams may be limiting

Target normal single-spin asymmetry in $e^{\pm}p$ scattering

- Unpolarized $e^{\pm}$ beams on vertically polarized ammonia target
- Technical challenges:
  - Beam deflection in holding field
  - "Sheet of flame"

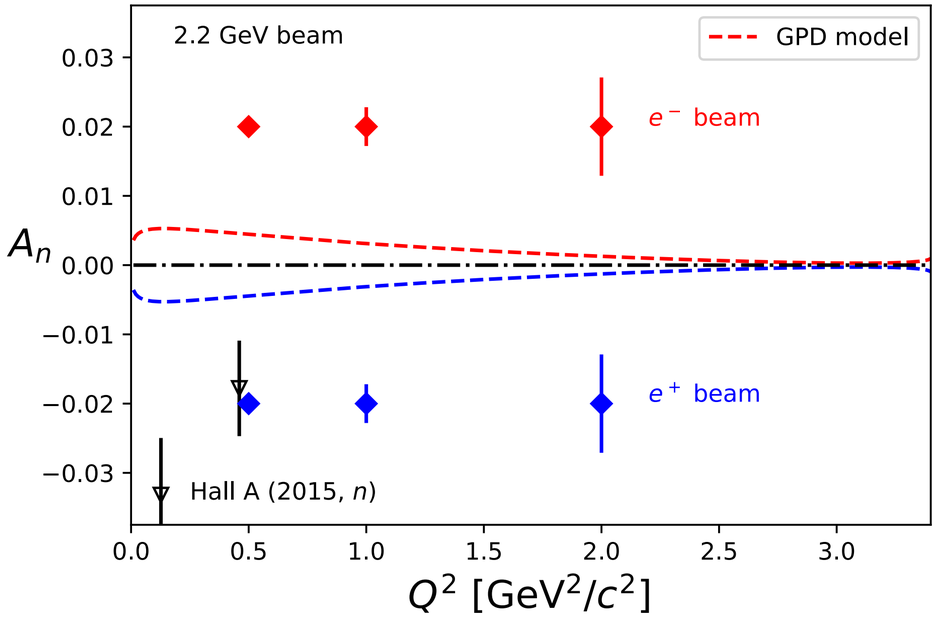


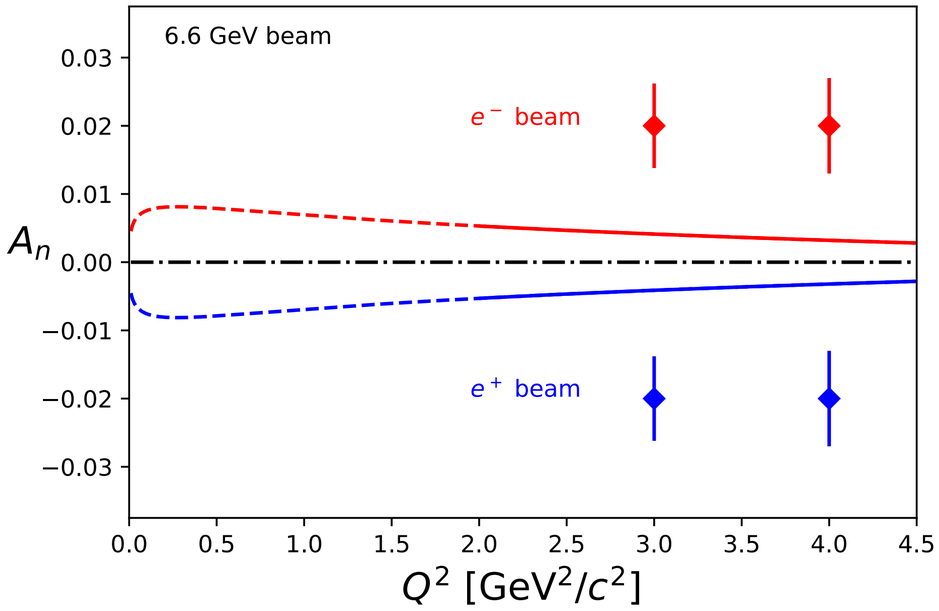


[Grauvogel et al. EPJA 57, 213 (2021)]

Target normal single-spin asymmetry in $e^{\pm}p$ scattering

- Unpolarized $e^{\pm}$ beams on vertically polarized ammonia target
- Technical challenges:
  - Beam deflection in holding field
  - "Sheet of flame"
- 20 day runplan at 3 beam energies (2.2, 4.4, 6.6 GeV)
- Measurement with both $e^{\pm}$ can distinguish TPE from T-violation

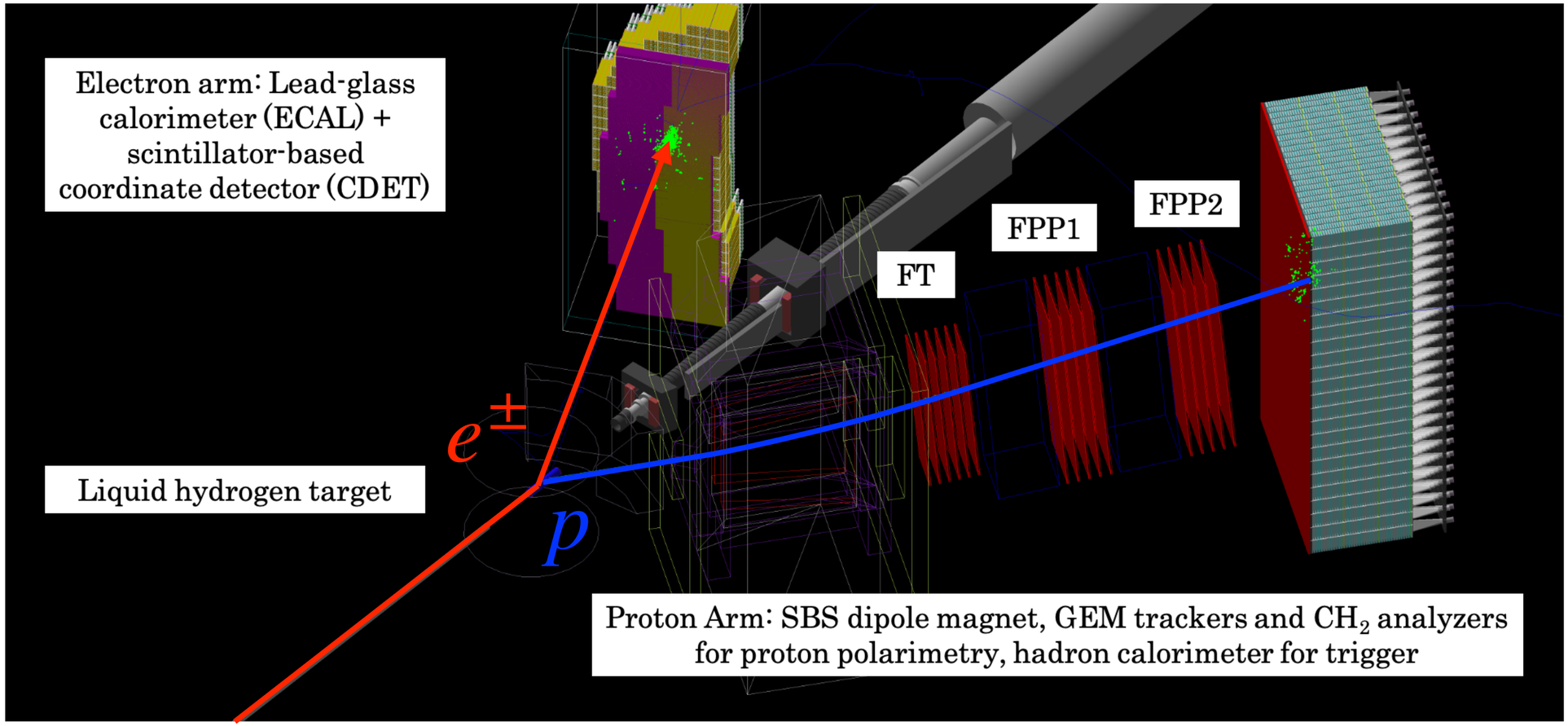




Grauvogel et al. EPJA 57, 213 (2021)

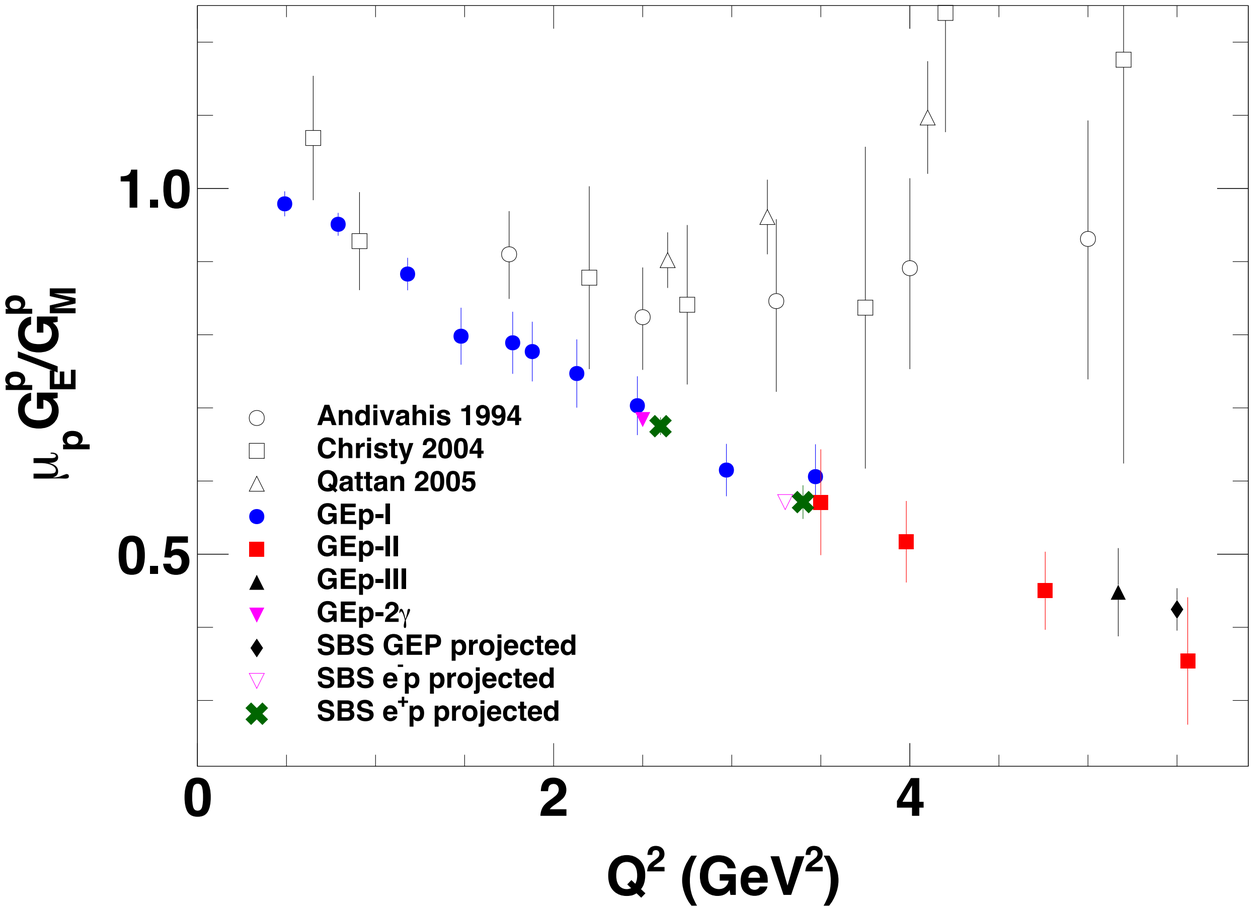
Polarization transfer with $e^{\pm}p$ scattering

- Polarized $e^{\pm}$ beams on unpolarized hydrogen target



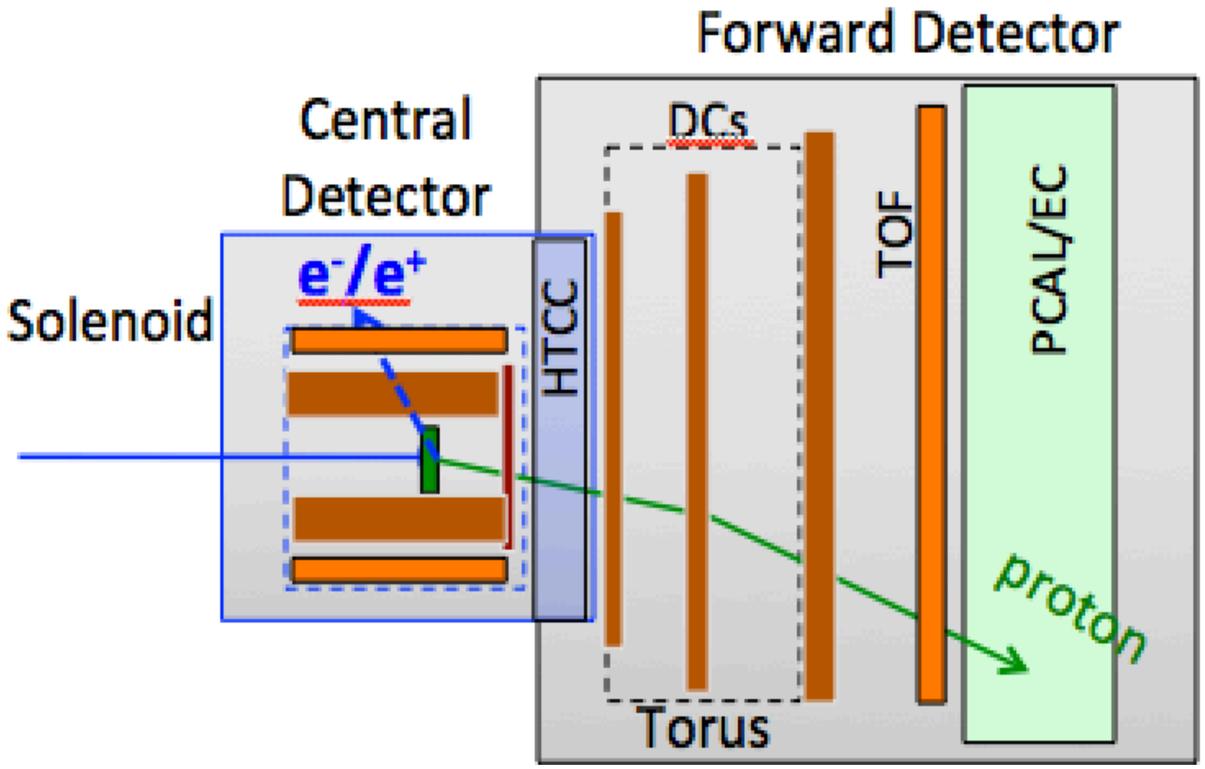
Polarization transfer with $e^{\pm}p$ scattering

- Polarized $e^{\pm}$ beams on unpolarized hydrogen target
- Requires 120 days of running
- Simultaneous positron and electron measurements could identify systematic difference



e^+/e^- cross section ratios

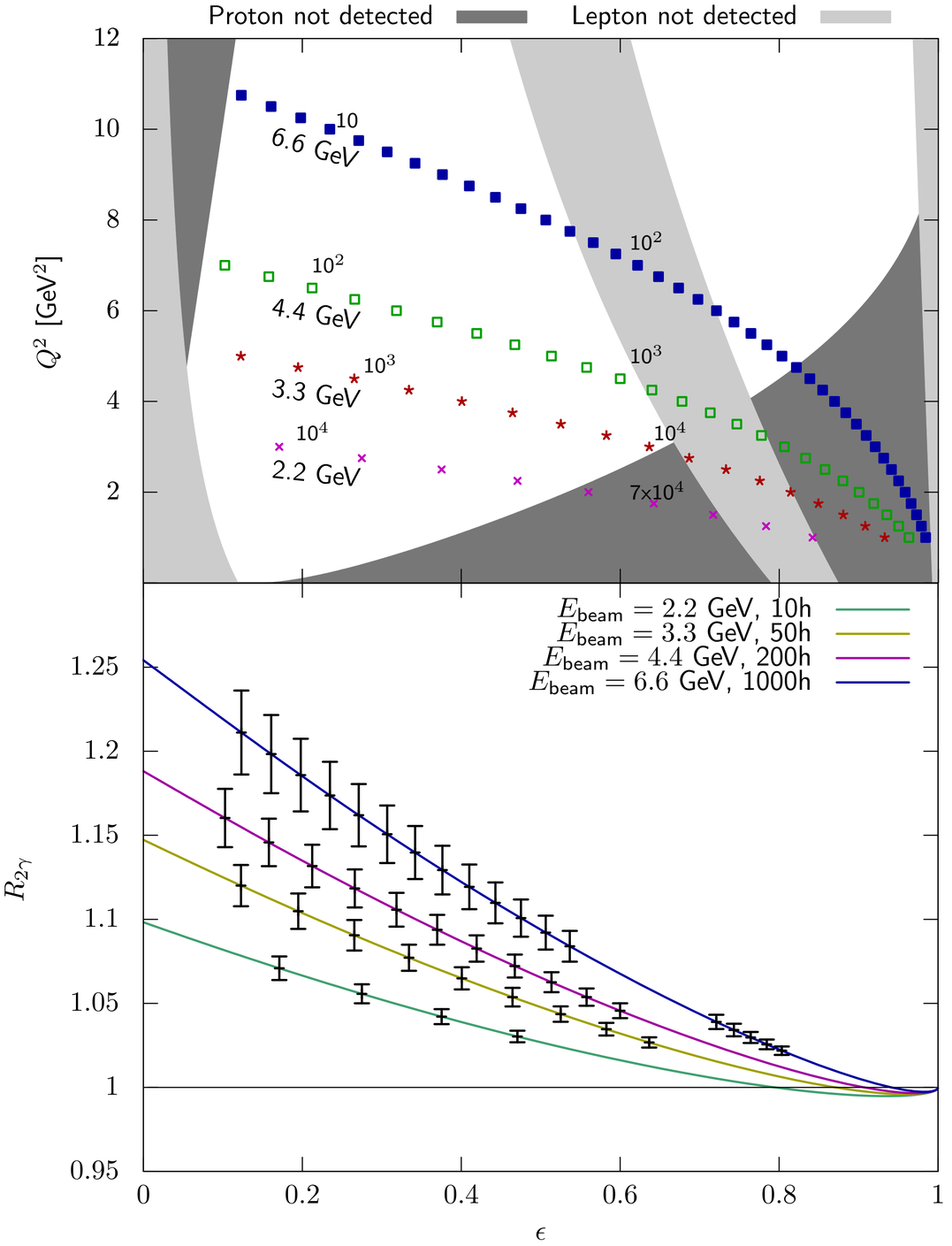
- Unpolarized $e^\pm$ beams on unpolarized hydrogen target
- Measurement with CLAS12



Bernauer et al. EPJA 57, 144 (2021)

e^+/e^- cross section ratios

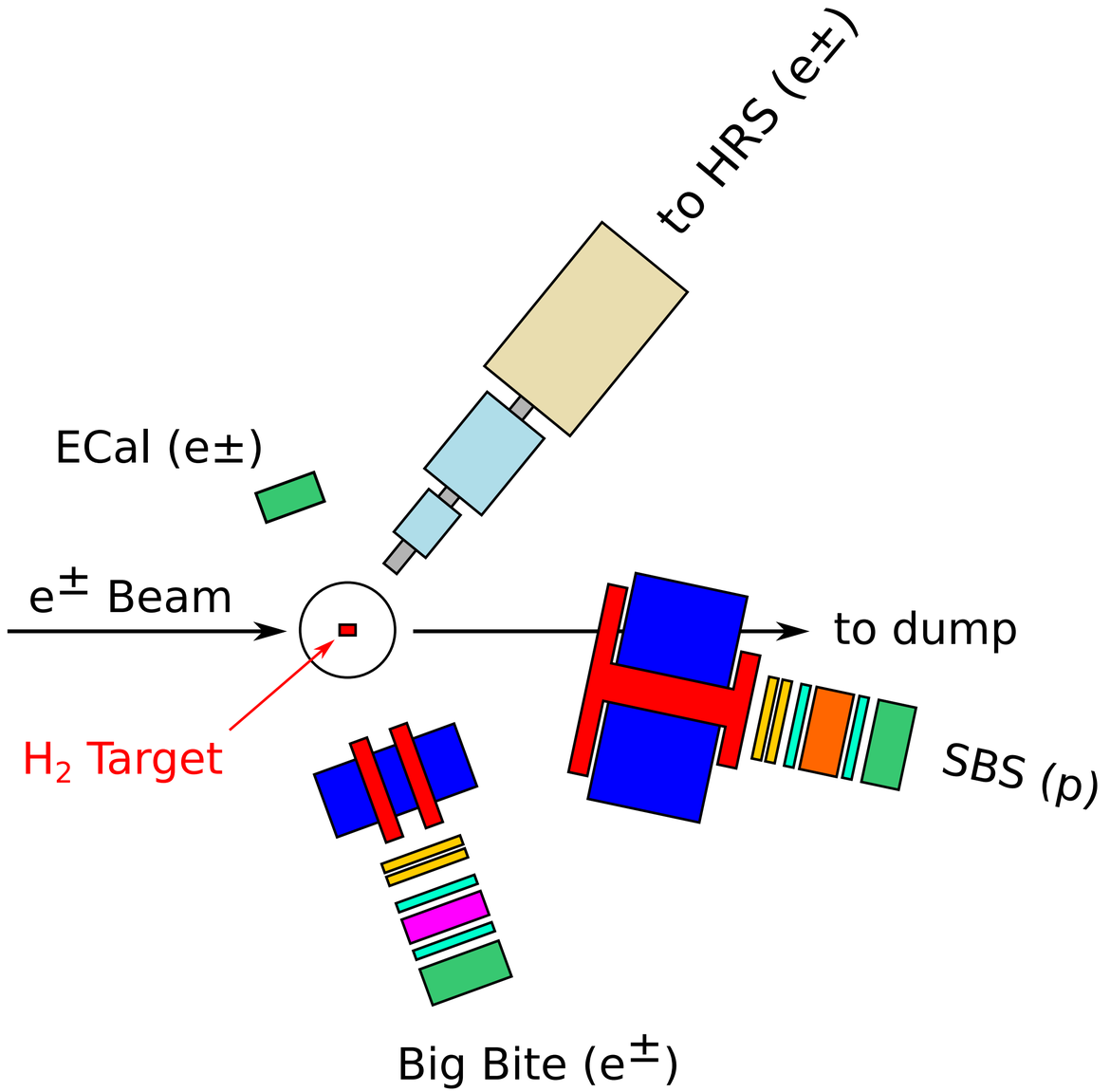
- Unpolarized $e^{\pm}$ beams on unpolarized hydrogen target
- Measurement with CLAS12
  - Simultaneous coverage of wide kinematic phase space
  - Not limited by positron current compared to standard electron running
  - Requires 50 days of running



Bernauer et al. EPJA 57, 144 (2021)

e^+/e^- cross section ratios

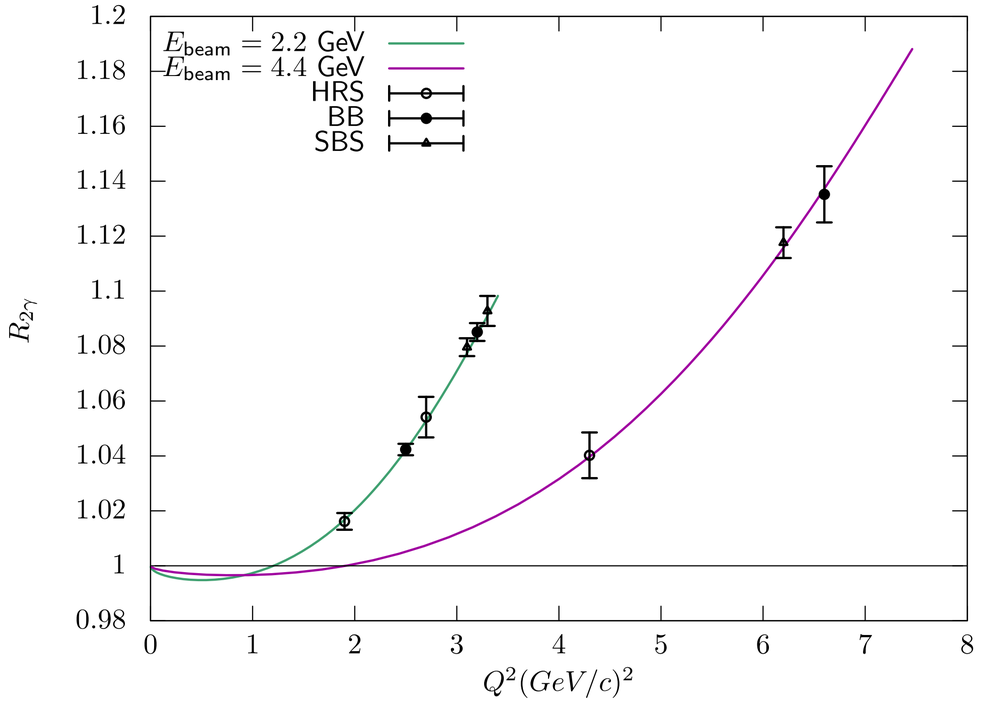
- Unpolarized $e^\pm$ beams on unpolarized hydrogen target
- Measurement in Hall A

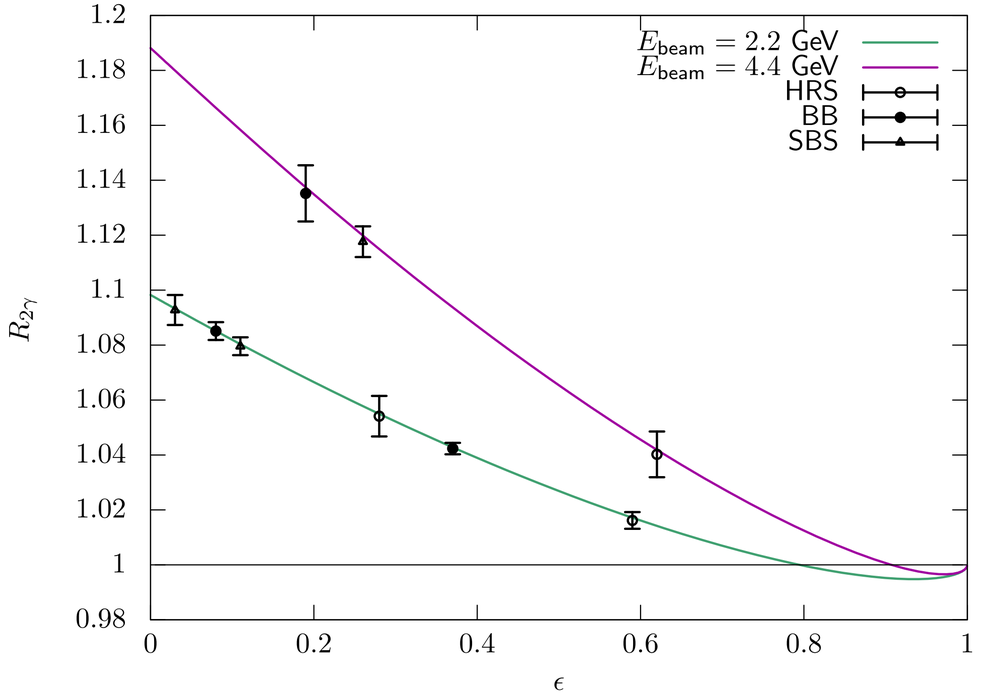


Cline et al. EPJA 57, 290 (2021)

e^+/e^- cross section ratios

- Unpolarized $e^{\pm}$ beams on unpolarized hydrogen target
- Measurement in Hall A
  - Shorter run time (14 days) at expense of kinematic coverage

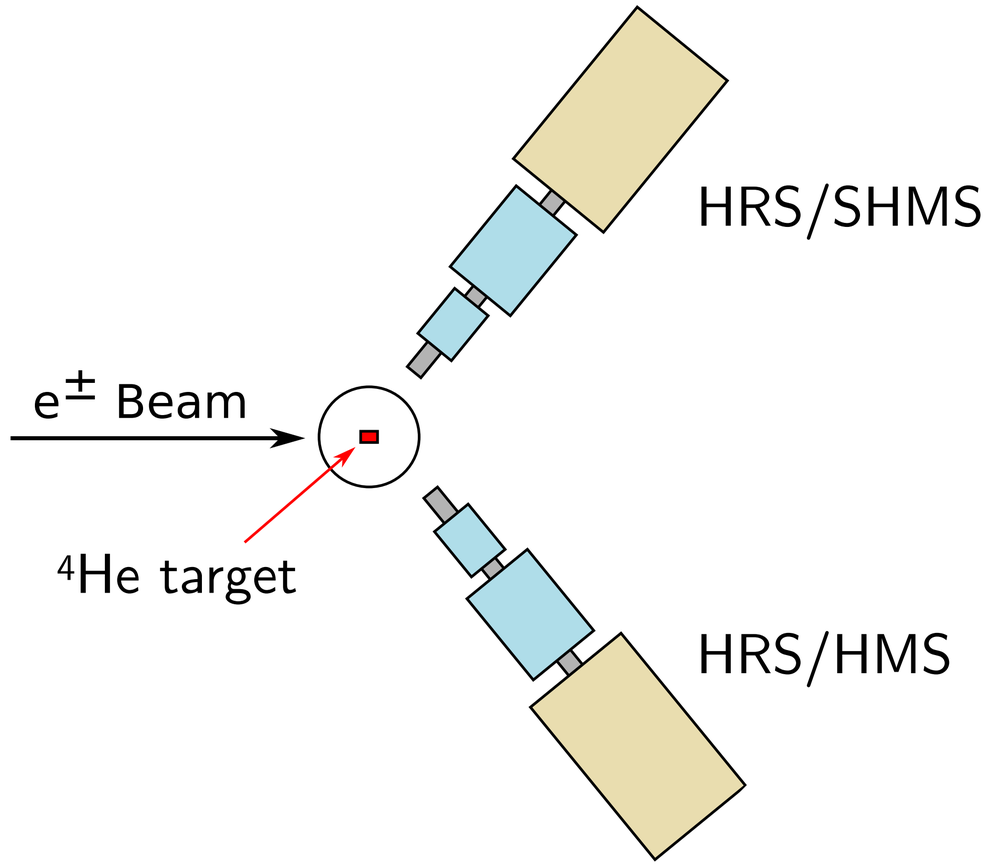




Cline et al. EPJA 57, 290 (2021)

First measurement of e^+/e^- ratio from complex nucleus

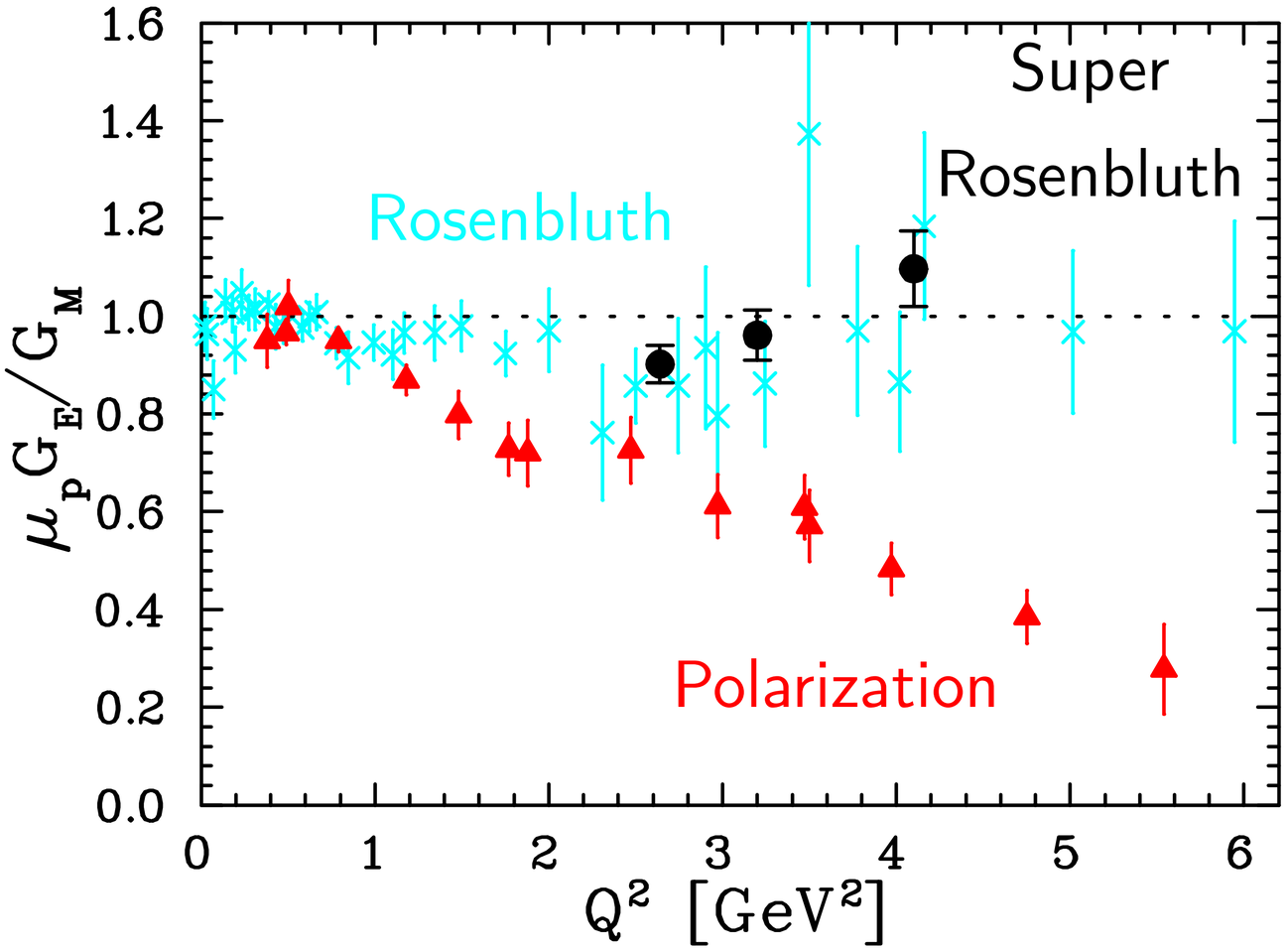
- Unpolarized $e^{\pm}$ beams on nuclear target
- Coulomb distortion limits choice of Z
  - Helium-4 is low Z and standard target
- Requires high momentum resolution to resolve elastic peak
- Complementary to measurements of A_n from nuclei



Kutz & Schmidt EPJA 58, 36 (2022)

Super-Rosenbluth separation with $e^{\pm}p$ scattering

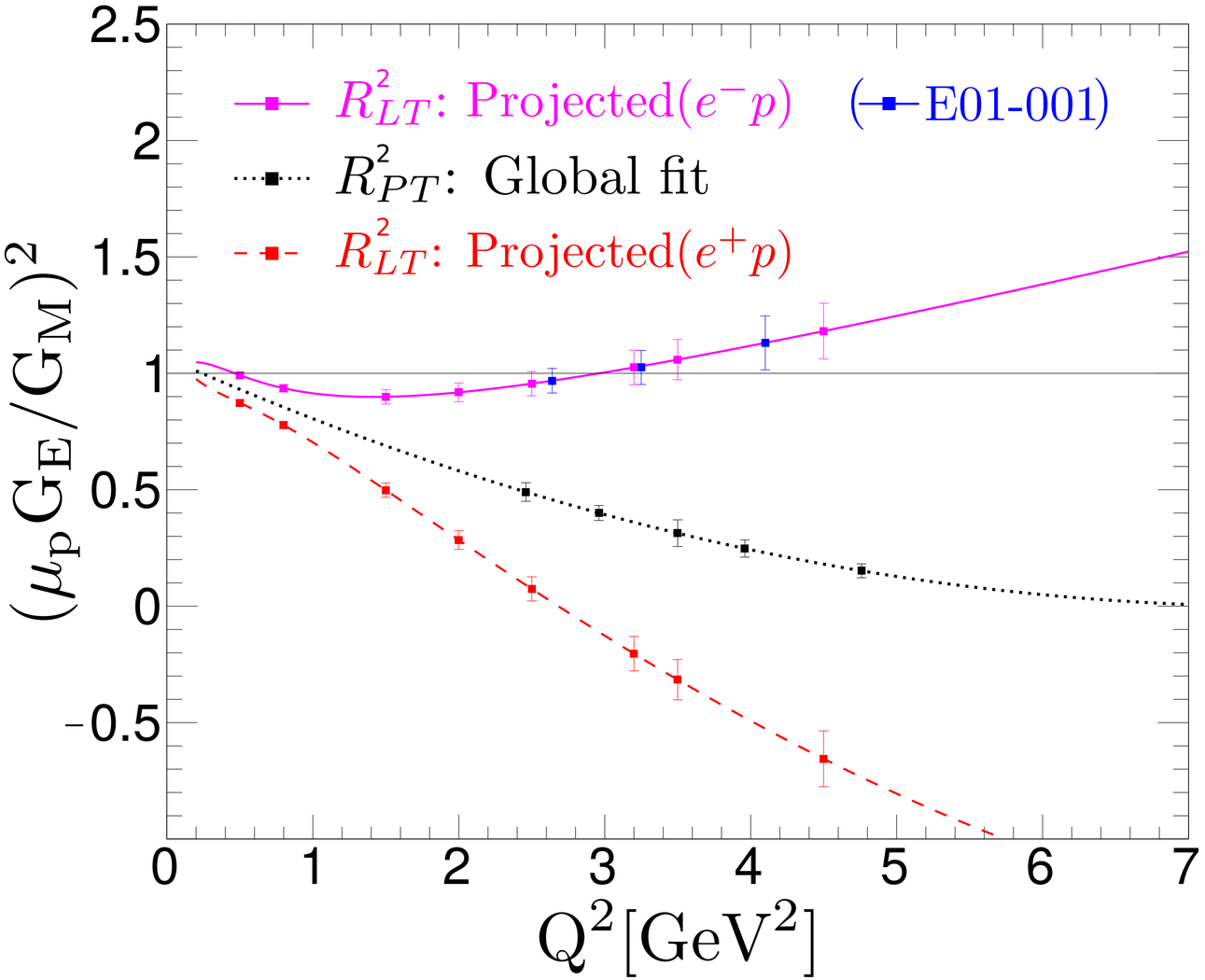
- Unpolarized $e^{\pm}$ beams on unpolarized hydrogen target
- Super Rosenbluth: detect proton instead of scattered lepton



Arrington & Yurov, EPJA 57, 319 (2021)

Super-Rosenbluth separation with $e^{\pm}p$ scattering

- Unpolarized $e^{\pm}$ beams on unpolarized hydrogen target
- Super Rosenbluth: detect proton instead of scattered lepton
- Requires 35 days of running
- Simultaneous positron and electron measurements would show bias caused by TPE



Arrington & Yurov, EPJA 57, 319 (2021)

Summary and outlook

- TPE could explain discrepancy in measurements of $\mu_p G_E/G_M$
- Current theory seems inadequate to fully explain existing TPE measurements
- A positron source at Jefferson Lab would allow a variety of new TPE measurements
- Select measurement[s] from White Paper to evolve into official proposal