Opportunities for unpolarized Two-Photon Exchange measurements at Jefferson Lab

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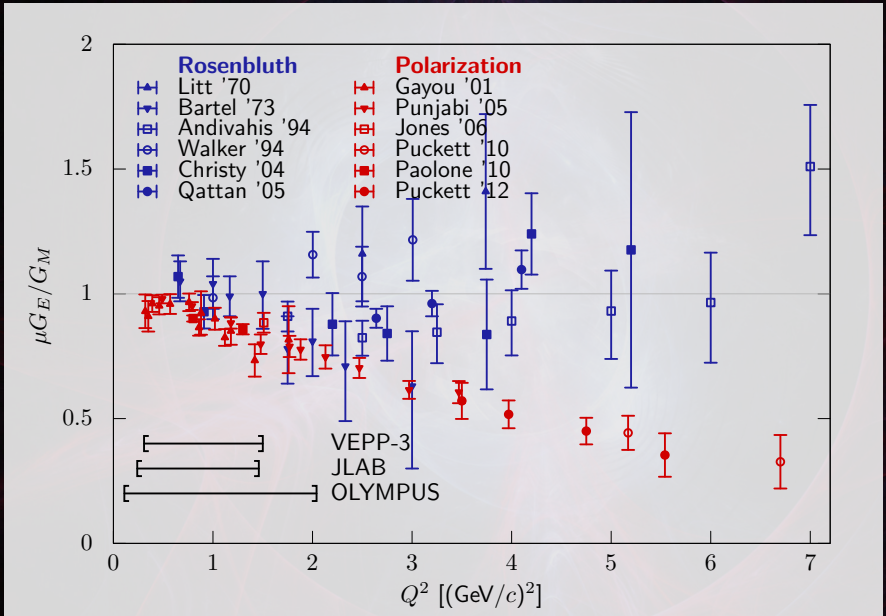
Measure twice, cut once

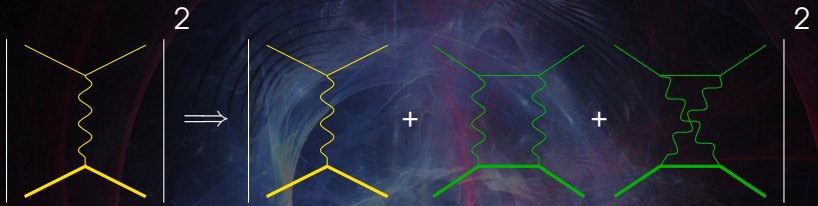
$$\frac{\left(\frac{d\sigma}{d\Omega}\right)}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}}} = \frac{1}{\varepsilon(1+\tau)}\left[\varepsilon G_E^2\left(Q^2\right) + \tau G_M^2\left(Q^2\right)\right]$$

- Problem: G_E suppressed at large Q^2
- Solution: measure ratio with polarization experiments
  - polarization transfer
  - beam-target asymmetries
- Better measure the same!

We don't measure the same



Probable cause: Two-Photon Exchange

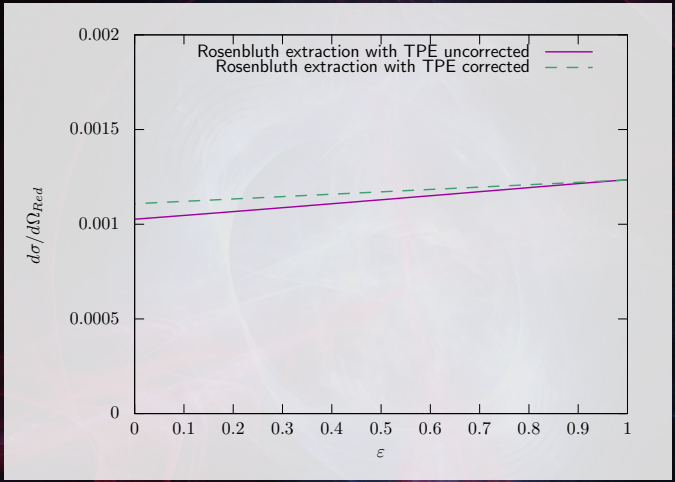


$$\sigma_{exp} \propto |M_{1\gamma}|^2 \pm 2\Re\left\{M_{1\gamma}^{\dagger} M_{2\gamma}\right\} + \cancel{|M_{2\gamma}|^2}$$

$$R = \frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 - 2\delta_{TPE}$$

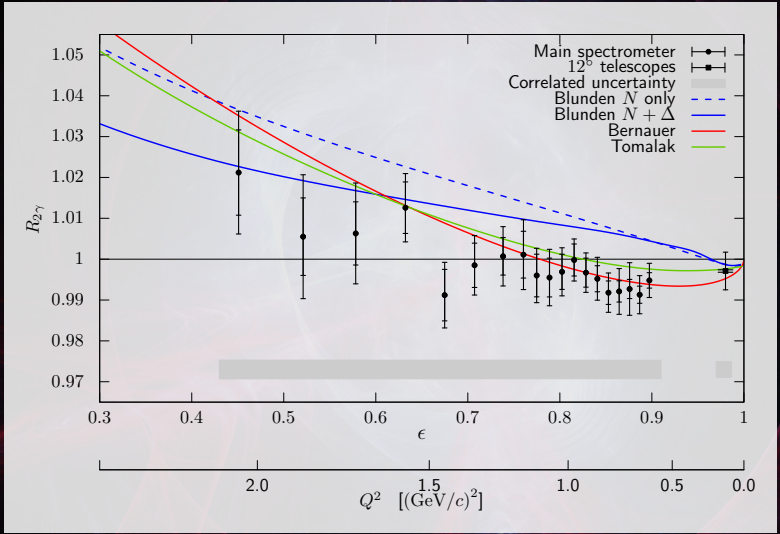
Measured at Vepp-3, JLab, and DESY (OLYMPUS)

Impact on Rosenbluth fit ($Q^2 = 6(\mathrm{GeV}/c)^2$)

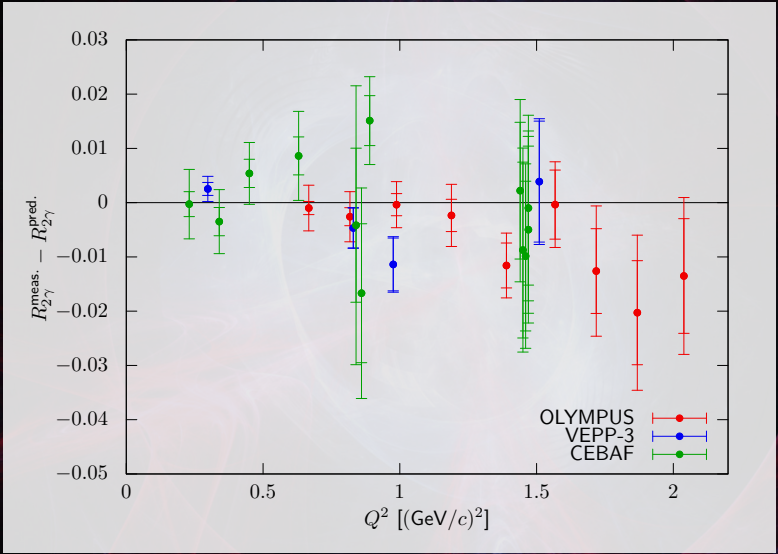


- G_M from intercept: Almost unaffected
- G_E from slope: big effect

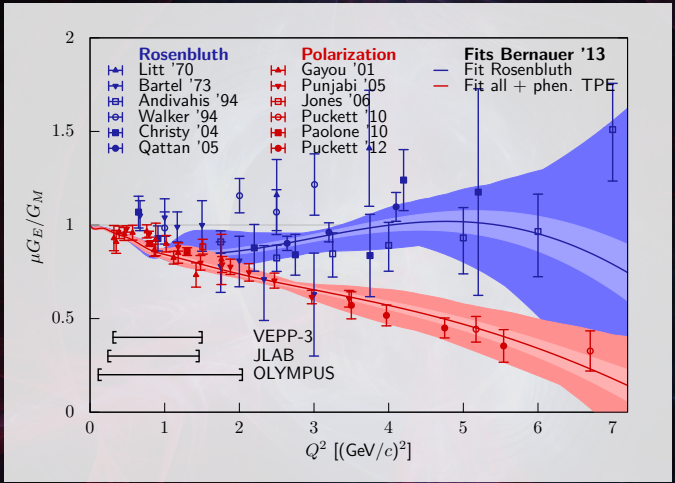
OLYMPUS results (B. Henderson et al., Phys. Rev. Lett. 118, 092501 (2017))



Difference of data to prediction

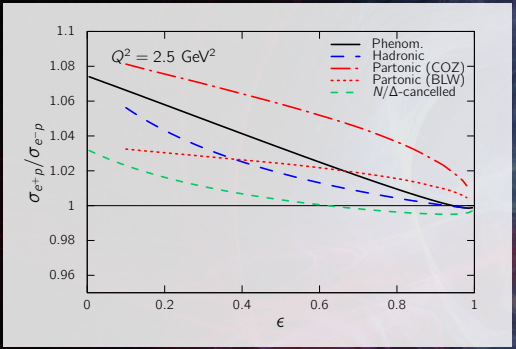


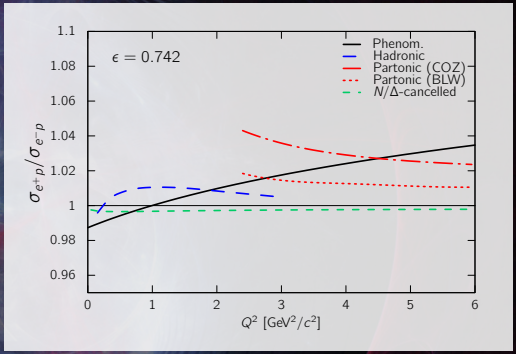
Where did we measure?



Too low in Q^2 to really test. No good agreement with theory!

Some predictions





What can JLAB do about it

A lot!

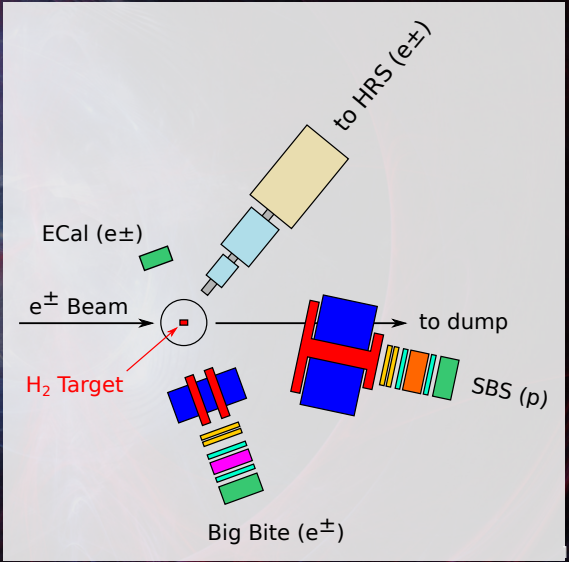
Measure cross section:

- Hall A (ratio)
- Hall B (ratio)
- Hall C (Rosenbluth separation)

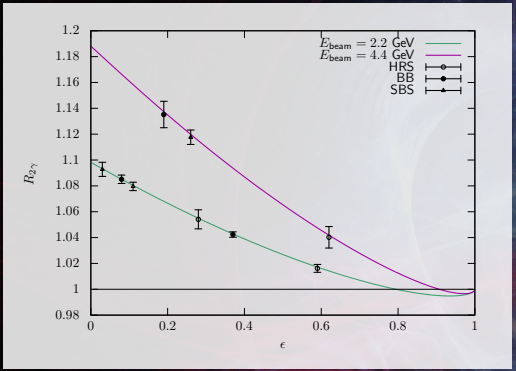
Measure polarization observables: See next talk.

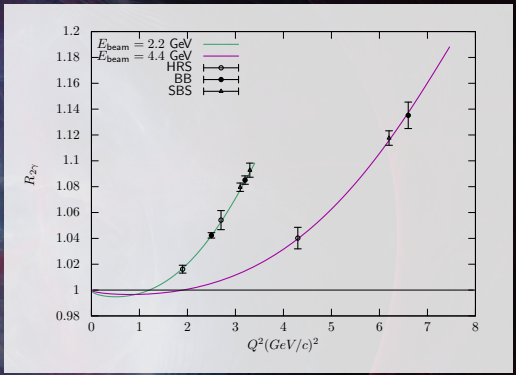
Hall A

- Cline et al.,Eur. Phys. J. A 57, 290 (2021)
- Two measurements at the same time:
  - Single arm measurement: HRS, BigBite for leptons
  - Coincidence SBS for protons + ECal for lepton
- 2 weeks beamtime at 1μA:
  - 2.2 GeV, 2 settings, 1 day+ 2 days per species
  - 4.4 GeV, 1 setting, 3 days per species



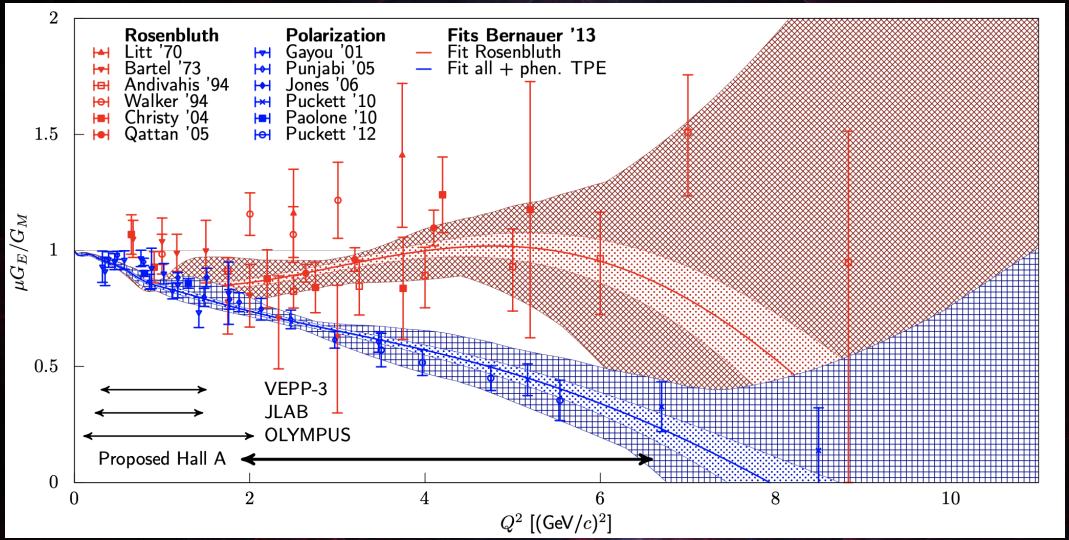
Predicted impact





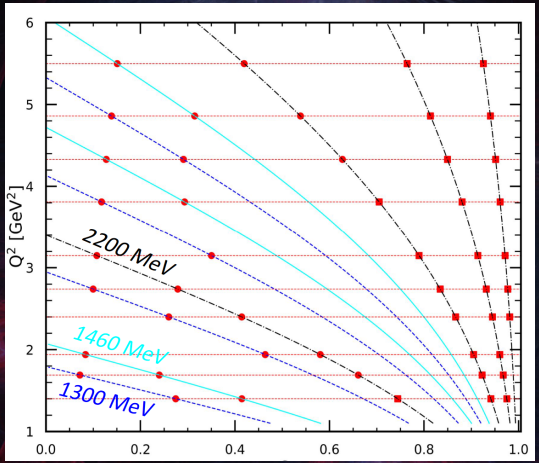
(statistical errors only)

In context


Rosenbluth
Litt '70
Bartel '73
Andivahis '94
Walker '94
Christy '04
Qattan '05
Polarization
Gayou '01
Punjabi '05
Jones '06
Puckett '10
Paolone '10
Puckett '12
Fits Bernauer '13
Fit Rosenbluth
Fit all + phen. TPE
VEPP-3
JLAB
OLYMPUS
Proposed Hall A
$\mu G_E/G_M$
Q^2 [(GeV/c)^2]
0
0.5
1
1.5
2
0
2
4
6
8
10

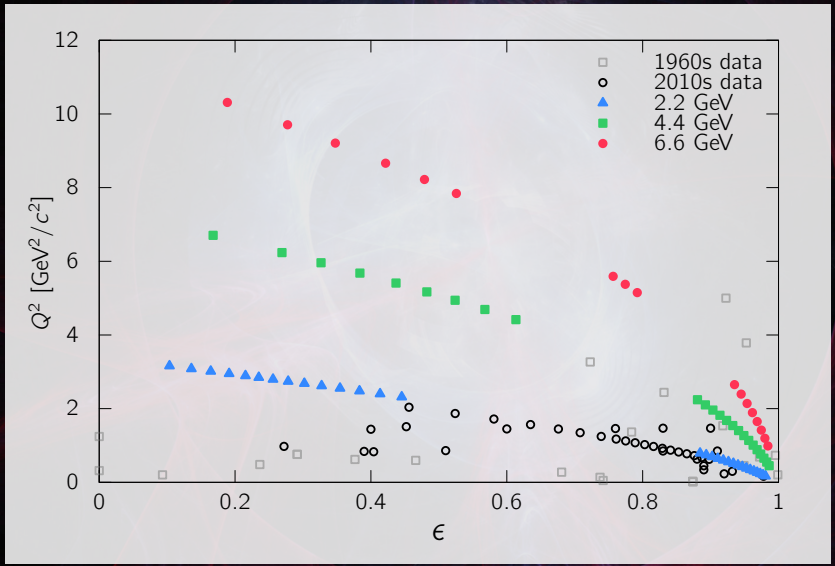
Hall C (PR12+23-012)

» See talk from Michael Nycz from 10/28

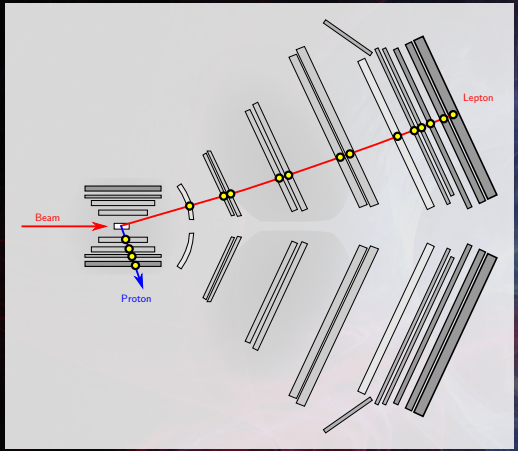


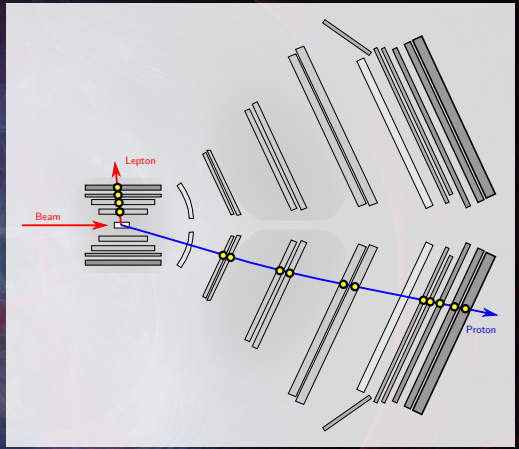
CLAS12 (arXiv:2308.08777 + 2103.03948)

» Approved (C1) by PAC51, A rating, 55 PAC days



Challenges: Topology





Trigger for small ε: >400 kHz. Too much even for CLAS12 HL

- » Streaming readout
- » CTOF/CND coinc., CVT coinc., etc.

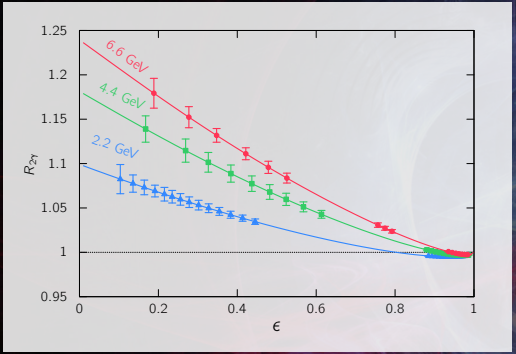
Challenges: Systematics

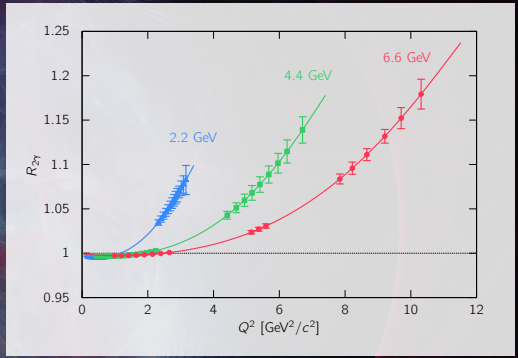
Different bending direction for e^+/e^-. Risk of false asymmetries from detector effects.

- » Swap field
- » Two magnetic fields: Solenoid/Toroid $\rightarrow$ Four combinations

$$R_{2\gamma} = \left[\left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\uparrow\uparrow} \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\uparrow\downarrow} \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\downarrow\uparrow} \left(\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \right)_{\downarrow\downarrow} \right]^{\frac{1}{4}}$$

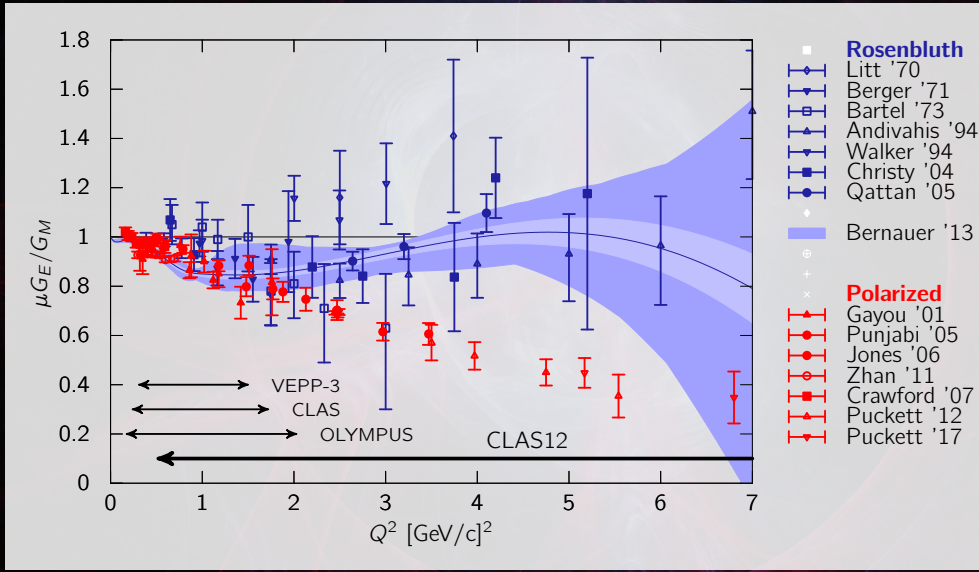
Predicted impact





(statistical errors only)

In context

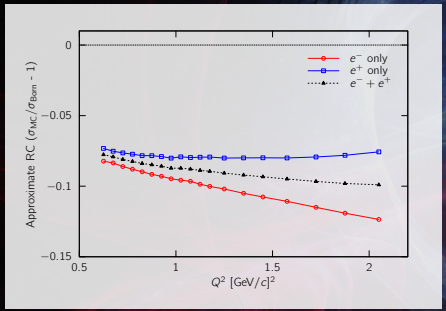

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
$\mu G_E/G_M$
0
1
2
3
4
5
6
7
Q^2 [GeV/c]^2
VEPP-3
CLAS
OLYMPUS
CLAS12
Rosenbluth
Litt '70
Berger '71
Bartel '73
Andivahis '94
Walker '94
Christy '04
Qattan '05
Bernauer '13
Polarized
Gayou '01
Punjabi '05
Jones '06
Zhan '11
Crawford '07
Puckett '12
Puckett '17

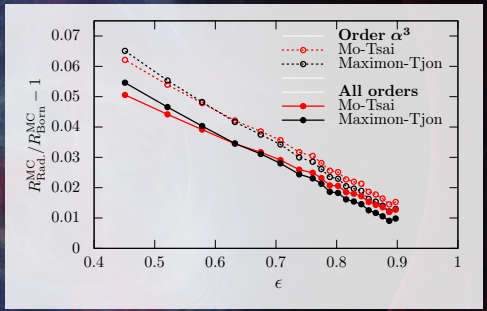
How to beat systematics

- Ratio measurement: Many systematics cancel!
- "Quick" species switching to minimize effect of drifts.
  - Once a week or more often?
- Better same beam than best beam: Use e^- from positron source to match beam parameters!
- Blinded analysis (see e.g. arXiv:2310.11469)

Data conservation

- We want to measure the hard TPE effect
- Definition of hard depends on applied soft corrections!





Provide info that RC can be updated!

Conclusions

- Two-photon exchange is likely but unconfirmed reason for FF ratio discrepancy
- Many models with percent-level differences
- JLAB with positrons perfectly equipped to provide impactful data!