Past and future TPE experiments

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Cross section for elastic scattering

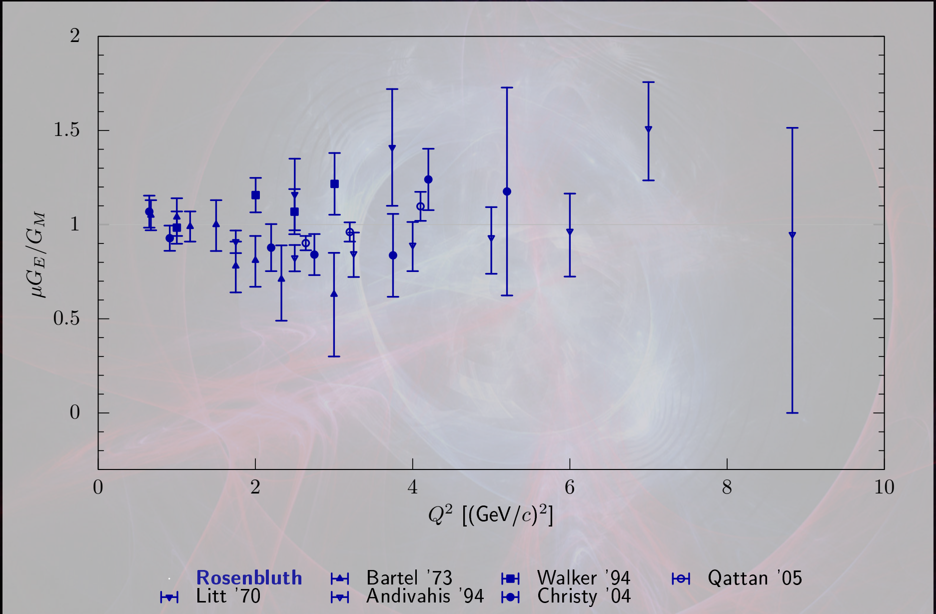
$$\frac{\left(\frac{d\sigma}{d\Omega}\right)}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}}} = \frac{1}{\varepsilon\,(1+\tau)}\left[\varepsilon G_E^2\left(Q^2\right) + \tau G_M^2\left(Q^2\right)\right]$$

with:

$$\tau = \frac{Q^2}{4m_p^2}, \quad \varepsilon = \left(1 + 2\,(1+\tau)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

- Rosenbluth formula
- Electric and magnetic form factor encode the shape of the proton
- Is shape of G_E and G_M similar? $\Leftrightarrow$ Are distributions similar?

Values for $\mu G_E/G_M$ from Rosenbluth experiments

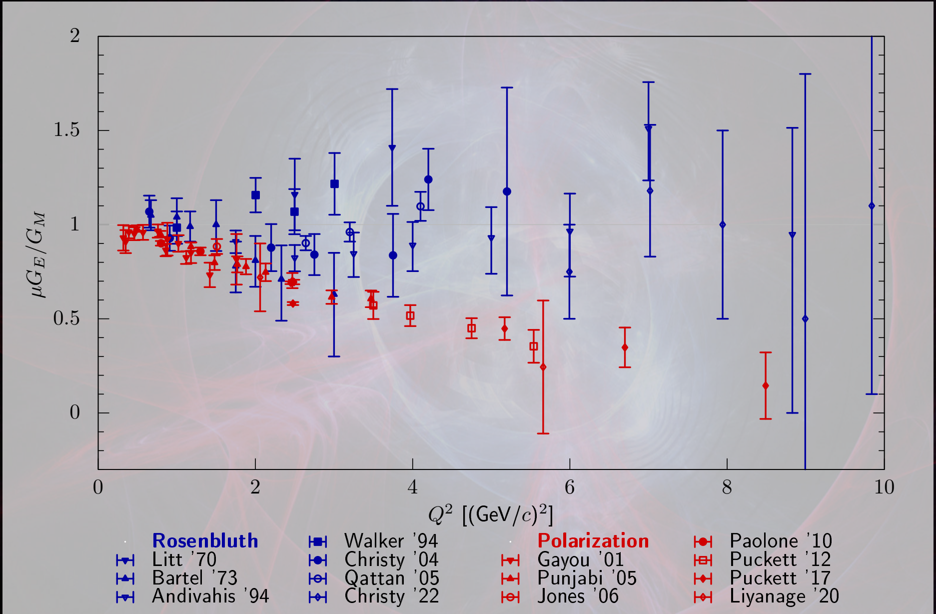


Polarization can help

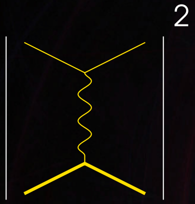
$$\left(\frac{d\sigma}{d\Omega}\right) \propto \varepsilon G_E^2\left(Q^2\right) + \frac{Q^2}{4M^2} G_M^2\left(Q^2\right)$$

- At large Q^2, G_M part dominant $\Longrightarrow$ G_E hard to extract
- Polarization transfer or beam-targer asymmetry: Access $\frac{G_E}{G_M}$ (only)

The (other) puzzle



Expected explanation: Two Photon Exchange



$$\sigma_{exp} \propto \left| M_{1\gamma} \right|^2$$

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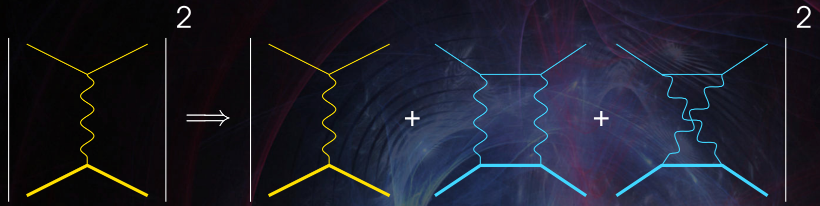
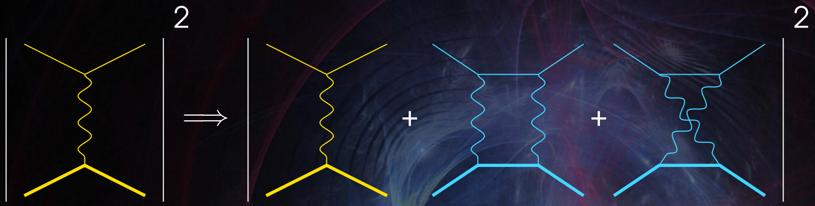


$$\sigma_{exp} \propto \left|M_{1\gamma}\right|^2 \pm 2\Re\left\{M_{1\gamma}^{\dagger} M_{2\gamma}\right\} + \cancel{\left|M_{2\gamma}\right|^2}$$

Expected explanation: Two Photon Exchange



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

Rosenbluth:

$$\sigma_{exp} = \sigma_{1\gamma}\left(1 \pm \delta_{TPE}\right)$$

(Negligible correction for polarization data)

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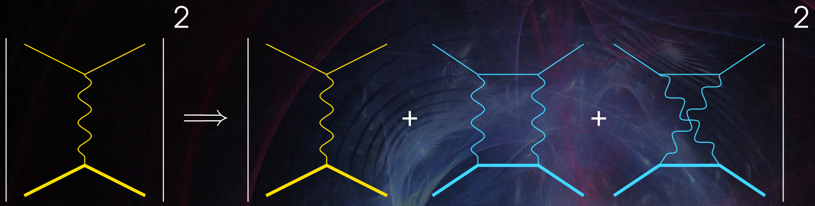

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Rosenbluth:

$$\sigma_{exp} = \sigma_{1\gamma}\left(1 \pm \delta_{TPE}\right)$$

(Negligible correction for polarization data)

Can measure:

$$R_{2\gamma} = \frac{1+\delta_{TPE}}{1-\delta_{TPE}} \propto \frac{\sigma(e^{+}p)}{\sigma(e^{-}p)}$$

Direct measurements: Three modern experiments

CLAS

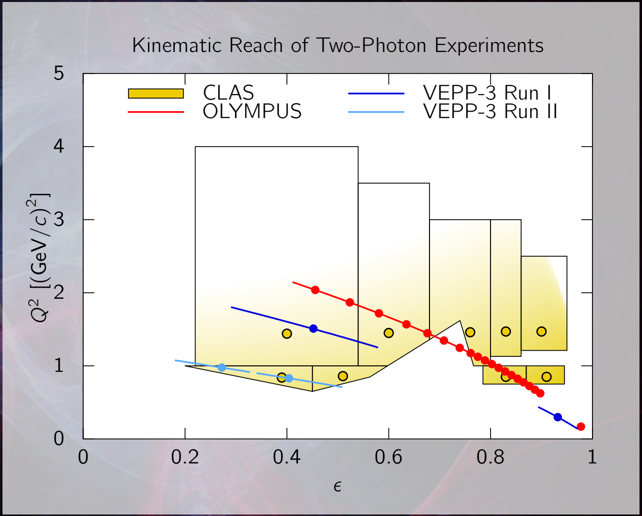
- e^- to γ to $e^{+/-}$ -beam
- Phys. Rev. C 95, 065201 (2017)
- PRL 114, 062003

VEPP-3

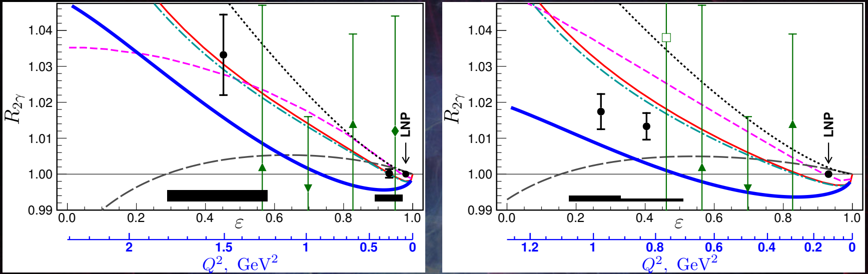
- 1.6/1 GeV beam
- no field
- Phys. Rev. Lett. 114, 062005 (2015)

OLYMPUS

- DORIS @ DESY
- 2 GeV beam
- Phys. Rev. Lett. 118, 092501 (2017)

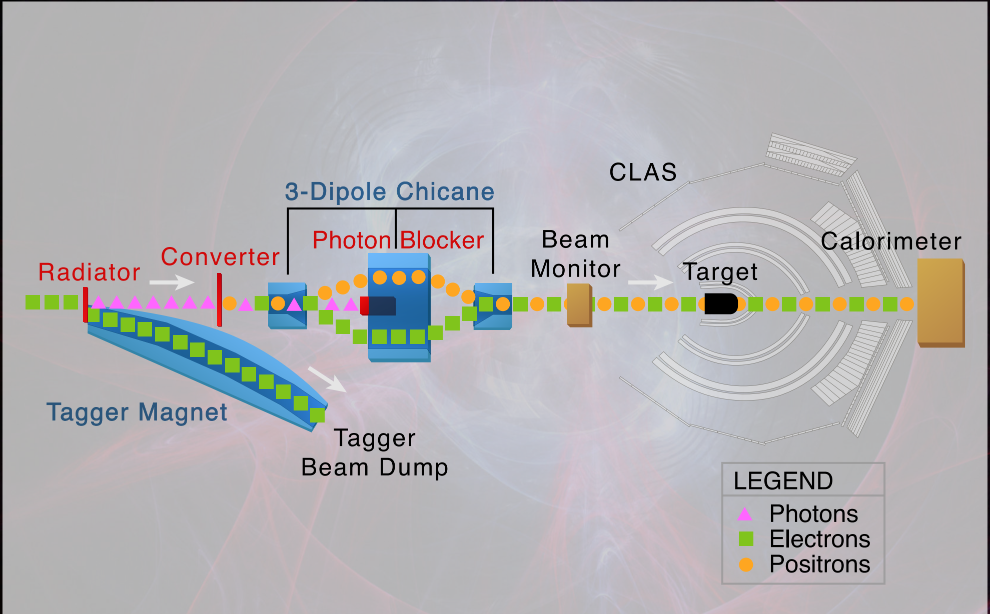


VEPP-3 results (I. A. Rachek et al., Phys. Rev. Lett 114, 062005)

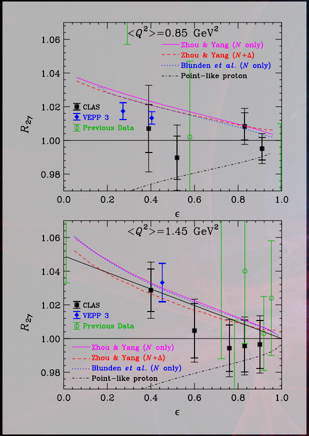


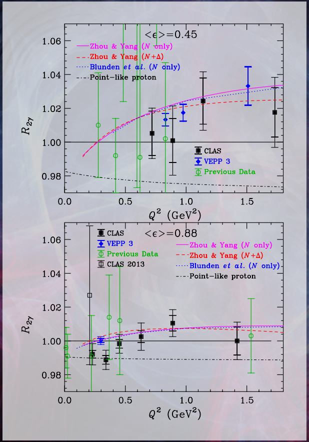
	$R_{2\gamma}^{\mathrm{LNP}}$	$\frac{\chi^2}{n_{\mathrm{d.f.}}}$	$R_{2\gamma}^{\mathrm{LNP}}$ Run-I	Run-II	$\frac{\chi^2}{n_{\mathrm{d.f.}}}$
Borisyuk and Kobushkin	1	2.14	0.998	0.997	3.80
Blunden, et al.	1	2.94	0.998	0.997	4.75
Bernauer, et al.	1	4.19	0.997	0.995	1.00
Tomasi-Gustafsson, et al.	1	5.09	1.001	1.001	5.97
Arrington and Sick	1	7.72	1.000	1.000	8.18
Qattan, et al.	1	25.0	1.000	1.002	22.0
No hard TPE ($R_{2\gamma} \equiv 1$)	1	7.97	1	1	7.97

CLAS (D. Rimal et al., arXiv:1603.00315 , D. Adikaram et al., Phys. Rev. Lett 114, 062003)



CLAS (D. Rimal et al., arXiv:1603.00315 , D. Adikaram et al., Phys. Rev. Lett 114, 062003) (color adjusted)



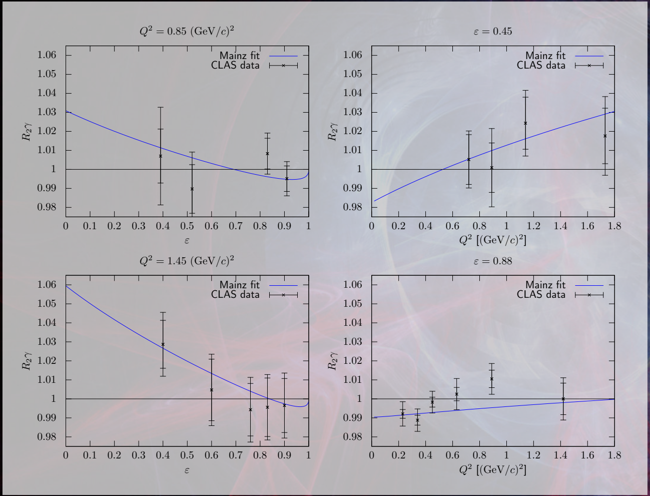


Fit to world data set:

- 12 non-overlapping points from CLAS
- 4 Vepp-3 points

	$\frac{\chi^2}{n_{d.f.}}$
Z & Y (N)	1.09
Z & Y (N+Δ)	1.03
Blunden (N)	1.06
No TPE	2.10
Point-proton	6.96

CLAS data + Mainz prediction

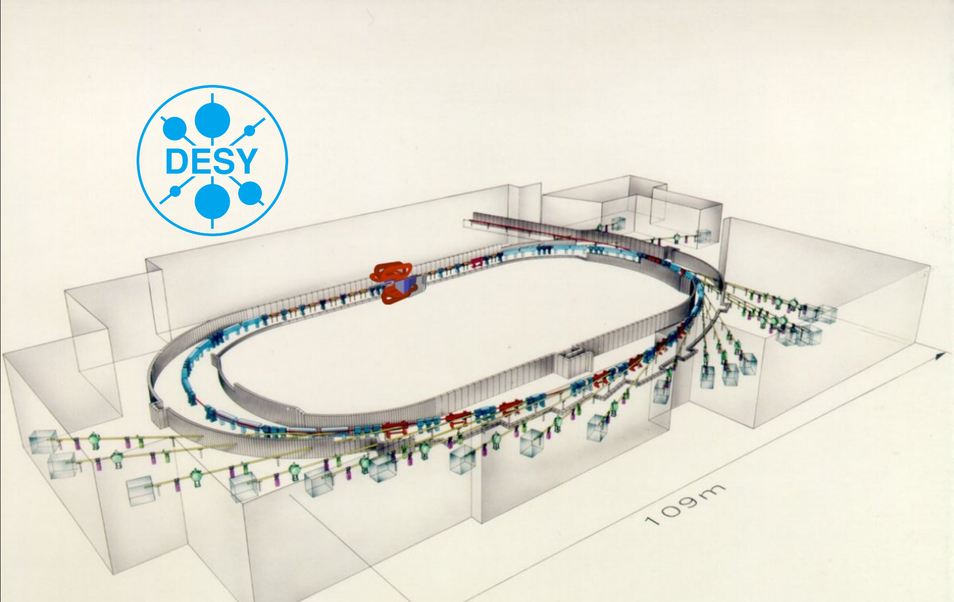


Comparison with predictions:

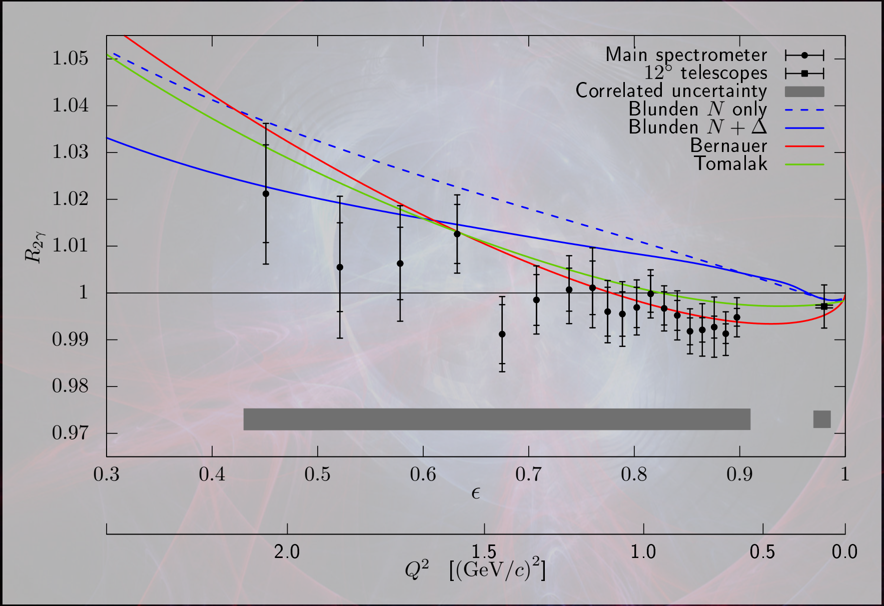
- 12 non-overlapping points from CLAS
- 4 Vepp-3 points

	$\frac{\chi^2}{n_{d.f.}}$
Z & Y (N)	1.09
Z & Y (N+Δ)	1.03
Blunden (N)	1.06
No TPE	2.10
Point-proton	6.96
Mainz	0.666

OLYMPUS at DESY/DORIS



OLYMPUS $R_{2\gamma}$ result (B. Henderson et al., PRL. 118, 092501 (2017))



Can we squeeze more out of OLYMPUS?

If

$$\sigma_{e^+} = \sigma_{1\gamma}\left(1 + \delta_{TPE}\right)$$

and

$$\sigma_{e^-} = \sigma_{1\gamma}\left(1 - \delta_{TPE}\right)$$

Then:

$$\sigma_{1\gamma} = \frac{\sigma_{e^+} + \sigma_{e^-}}{2}$$

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Then:

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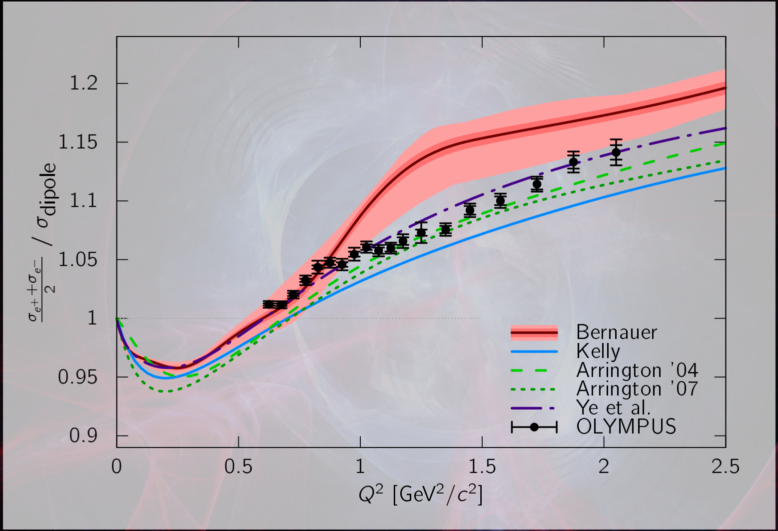
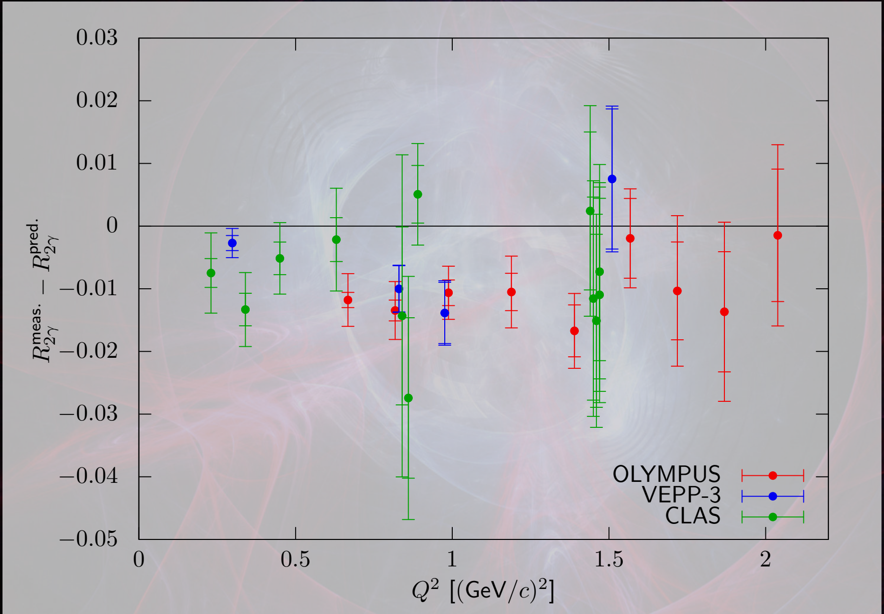
We can get an approximately non-TPE affected cross section from the charge-average!

Result (10.1103/PhysRevLett.126.162501)

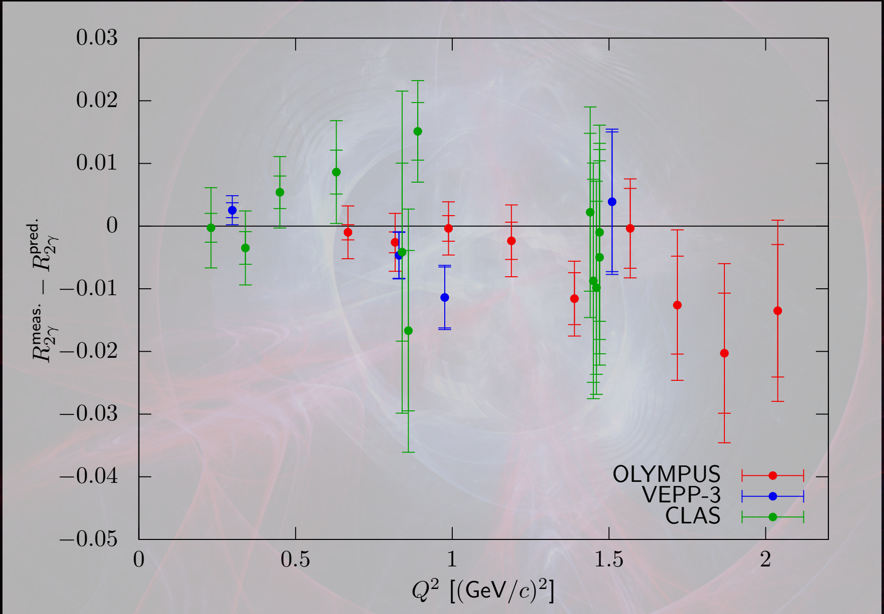


» First precision data set without TPE assumptions.

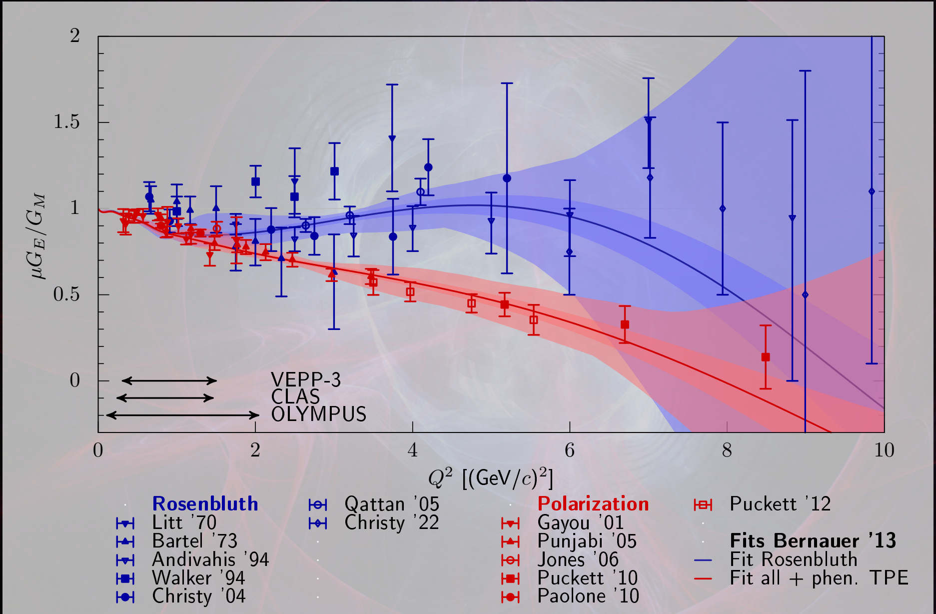
Comparison with theory



...Mainz prediction



Is that a surprise?



Next gen experiments

- At small Q^2 : MUSE (some range in ε), AMBER ($\varepsilon \sim 1$)
- At larget Q^2: Where measure?
  - 3-5 GeV beam energy
  - need e^+ and e^- beam of similar quality
  - preferably external beam: thick target to get enough luminosity
  - At least 10s of nA.

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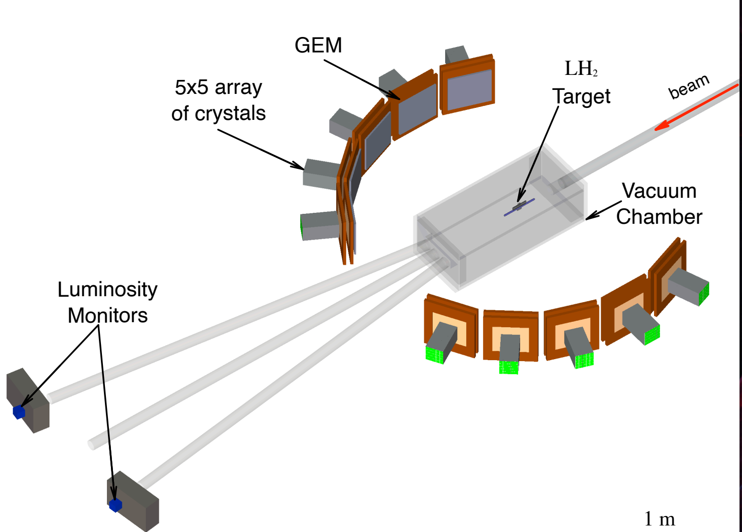
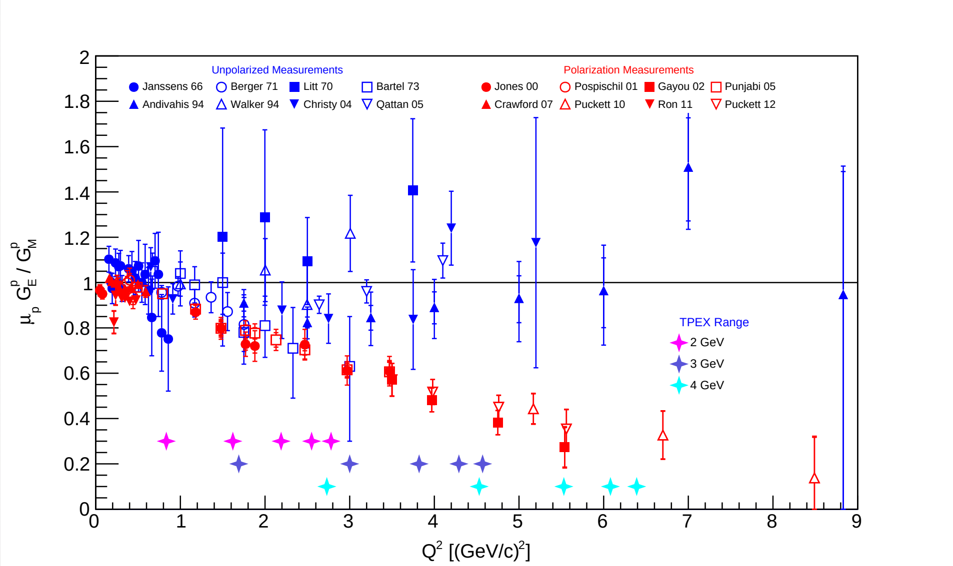
  - At least 10s of nA.
- Two options: DESY, JLAB (future)

TPEX (arxiv 2301.04708)

- DESY has $e^{\pm}$ from DESY ring (feeder for PETRA, test beam)
- Could mount experiment, but needs extracted beam line



TPEX reach

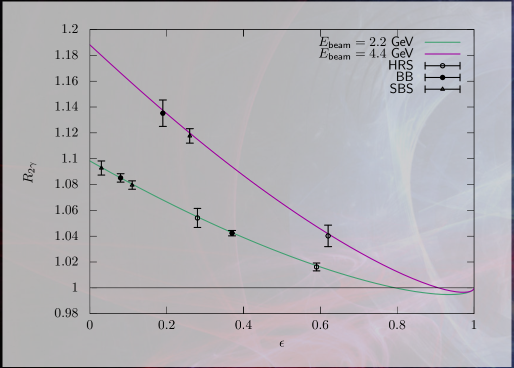


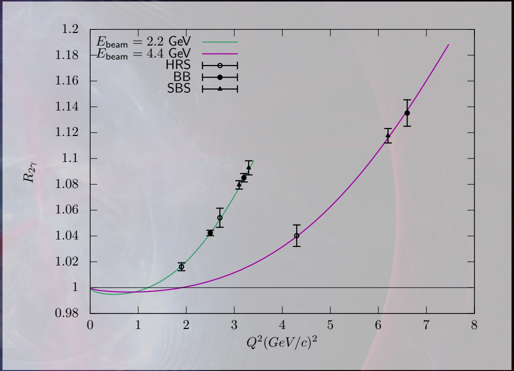
Unpolarized Measurements
Janssens 66
Berger 71
Litt 70
Bartel 73
Andivahis 94
Walker 94
Christy 04
Qattan 05
Polarization Measurements
Jones 00
Pospischil 01
Gayou 02
Punjabi 05
Crawford 07
Puckett 10
Ron 11
Puckett 12
TPEX Range
2 GeV
3 GeV
4 GeV
$\mu_p G_E^p / G_M^p$
Q^2 [(GeV/c)^2]

Positrons@JLAB

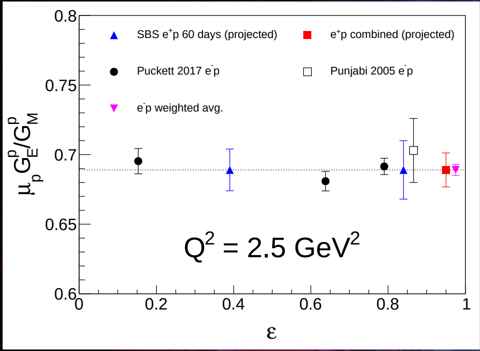
- Future facility, not funded!
- Timeline: 2030-2033 for first beam
- Polarized beam, JLAB 12 energies, significant current

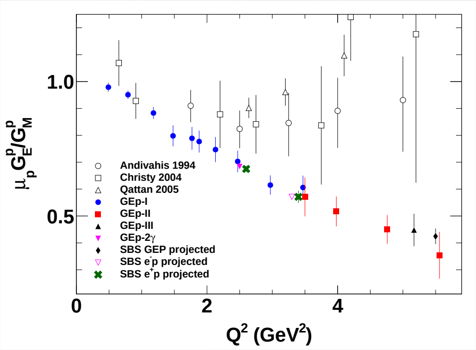
Hall A TPE (Eur.Phys.J.A 57 (2021) 10, 290)





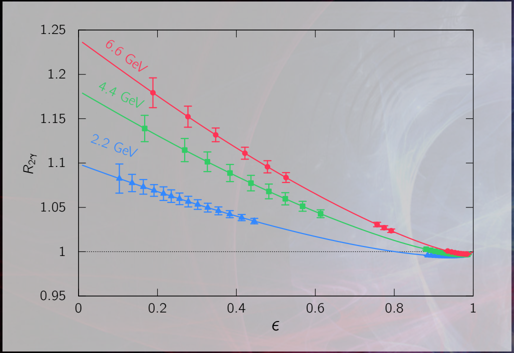
Hall A Polarization transfer (Eur.Phys.J.A 57 (2021) 6, 188)

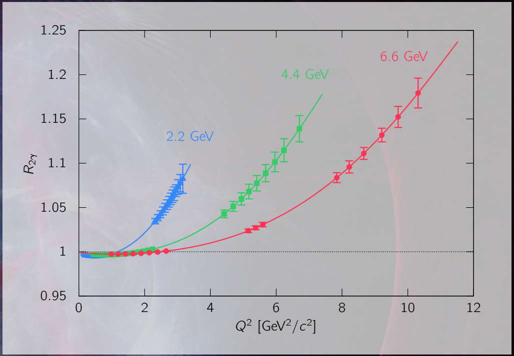




» LOI submitted to PAC51

CLAS 12 (Eur.Phys.J.A 57 (2021) 4, 144)





- Updated proposal submitted to PAC51
- Endorsed by Positron working group and CLAS collaboration

Timeline

- MUSE/AMBER: next couple of years
- TPEX@DESY: unknown, unlikely. If greenlit, experiment could be performed in <3 years
- JLAB program: Unfunded, future plan. Positrons seen as a step towards energy upgrade.
  - Timeline depends on Moller + Solid, likely 2030-2033 for first positron beam

Conclusions

- Tested kinematics show good agreement with phenomenological predictions, mediocre agreement with theory.
- Theory valid for higher Q^2 completely untested
- Experimental opportunities scarce:
  - MUSE+AMBER will test low-Q, on the "surprise" level
  - DESY unlikely
  - JLAB only hope?
- Fixed target experiment comparatively easy