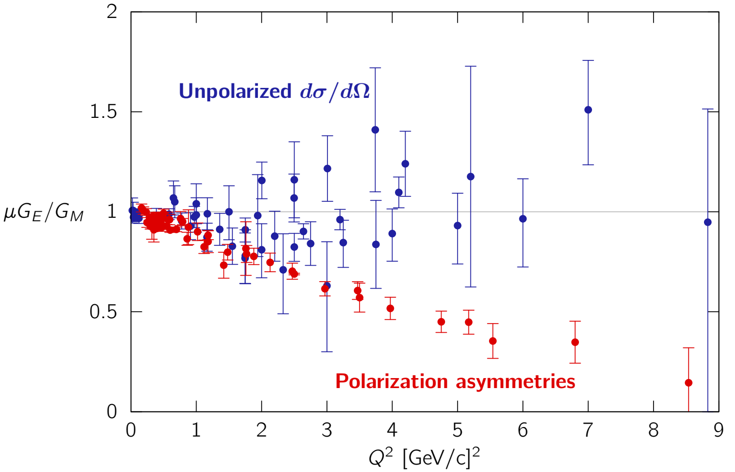
Polarization Observables using Positron Beams

Axel Schmidt

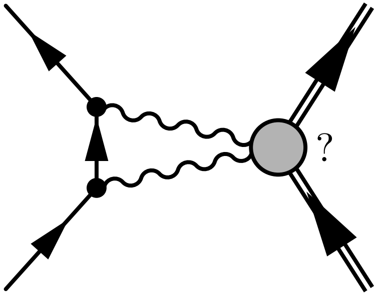
MIT

JPos17, September 12, 2017

There is a large discrepancy in proton form factor data.



Two-photon exchange might be the cause.



$$G_E(Q^2), G_M(Q^2) \longrightarrow G_E(Q^2), G_M(Q^2),$$
$$\delta\tilde{G}_E(Q^2,\epsilon), \delta\tilde{G}_M(Q^2,\epsilon), \tilde{F}_3(Q^2,\epsilon), \tilde{F}_4(Q^2,\epsilon), \tilde{F}_5(Q^2,\epsilon), \tilde{F}_6(Q^2,\epsilon)$$

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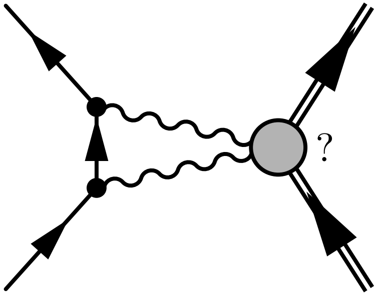

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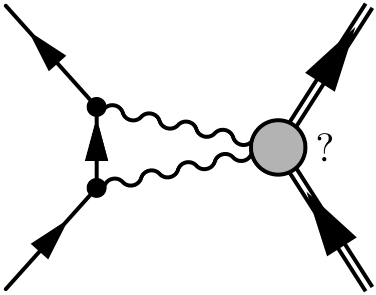

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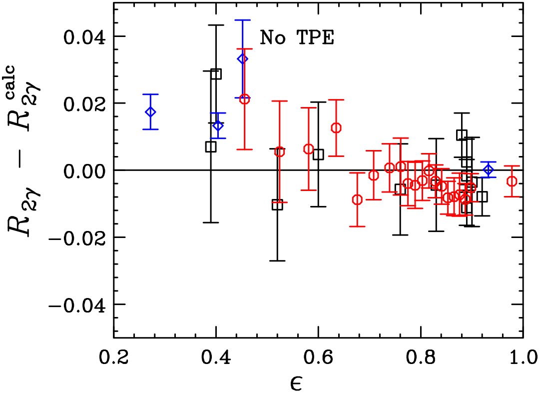
$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 - 4G_M \mathrm{Re}\left(\delta\tilde{G}_M + \frac{\epsilon\nu}{M^2}\tilde{F}_3\right) - \frac{4\epsilon}{\tau}G_E \mathrm{Re}\left(\delta\tilde{G}_E + \frac{\nu}{M^2}\tilde{F}_3\right) + \mathcal{O}(\alpha^4)$$

Recent $\sigma_{e^+p}/\sigma_{e^-p}$ measurements were not a slam dunk.



Afanasev, Blunden, Hasell, and Raue, Prog. Nucl. Part. Phys. (2017)

- TPE is there.
- . . . but it's small.
- Higher Q^2?

The experimental goal should be to validate theory from multiple angles.

- A precise experimental determination of TPE will be a challenge.
- We need to validate theories that allow interpolation/extrapolation.
- Constraints should come from multiple channels.

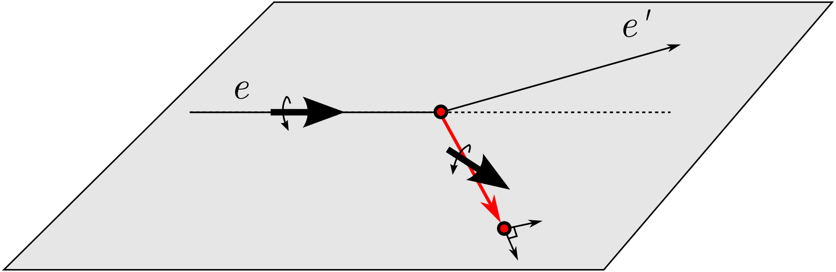
Constraining TPE using Polarization

1. Polarization transfer with e^+
   - Systematically clean
   - Statistics prohibitive
2. Beam-normal single-spin asymmetry
   - Really statistics prohibitive
3. Target-normal single-spin asymmetry
   - Feasible

Polarization transfer is a better way to measure the proton form factor ratio.

- Measurements are performed at one kinematic setting.
- Radiative corrections are small.
- Measure a ratio rather than a cross section.

What polarization is transfered to the proton?



$$P_t = -hP_e\sqrt{\frac{2\epsilon(1-\epsilon)}{\tau}}\frac{G_E G_M}{G_M^2+\frac{\epsilon}{\tau}G_E^2}$$

$$P_l = hP_e\sqrt{1-\epsilon^2}\frac{G_M^2}{G_M^2+\frac{\epsilon}{\tau}G_E^2}$$

$$P_t/P_l = \sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}}\frac{G_E}{G_M}$$

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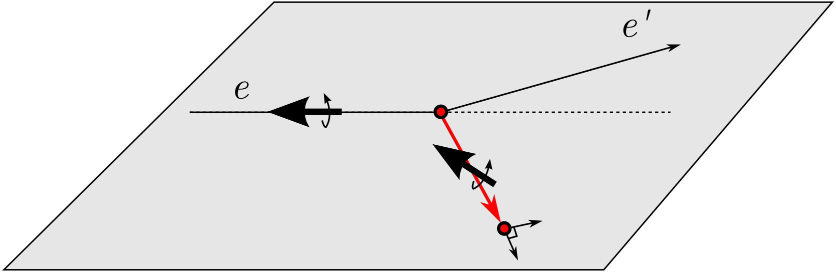

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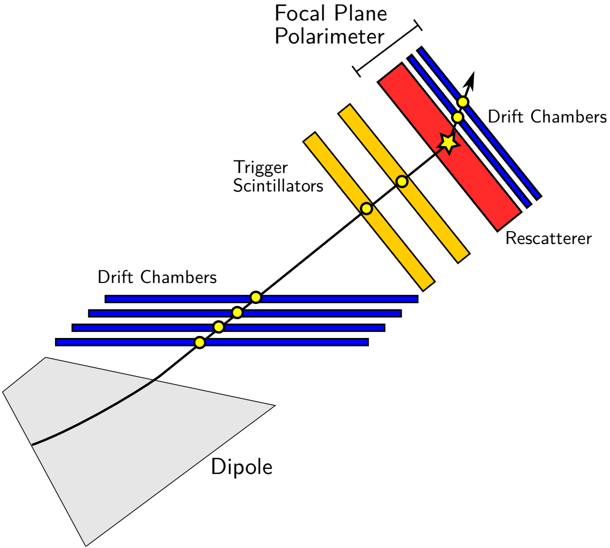
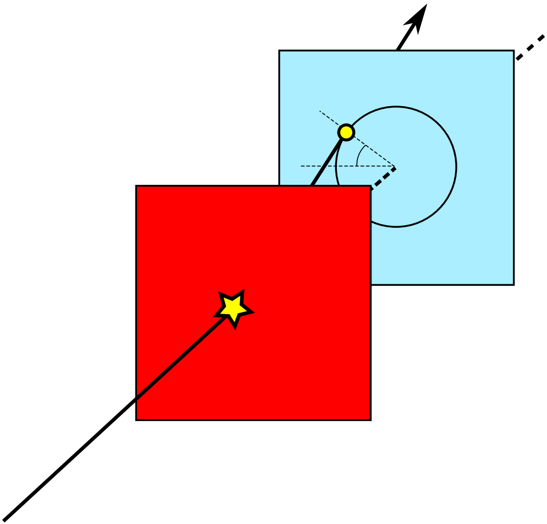
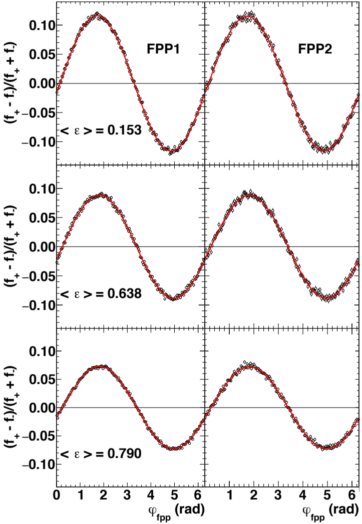
Polarization can be measured with a focal plane polarimeter.

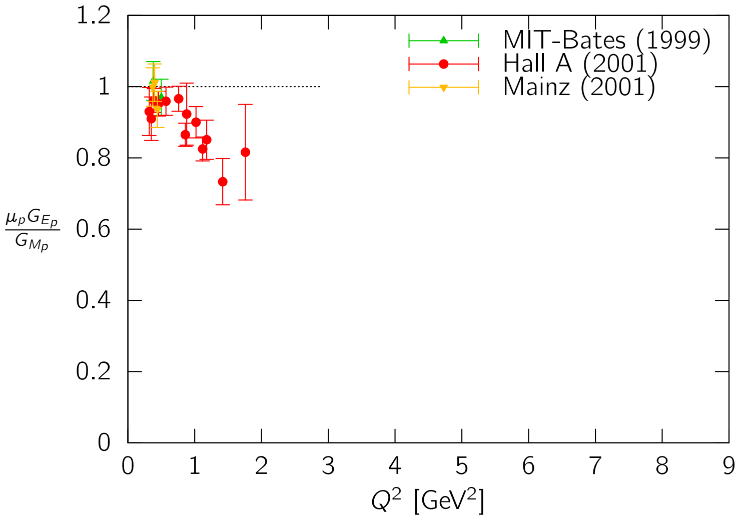


The FPP converts transverse polarization into an azimuthal distribution.





History of PT measurements



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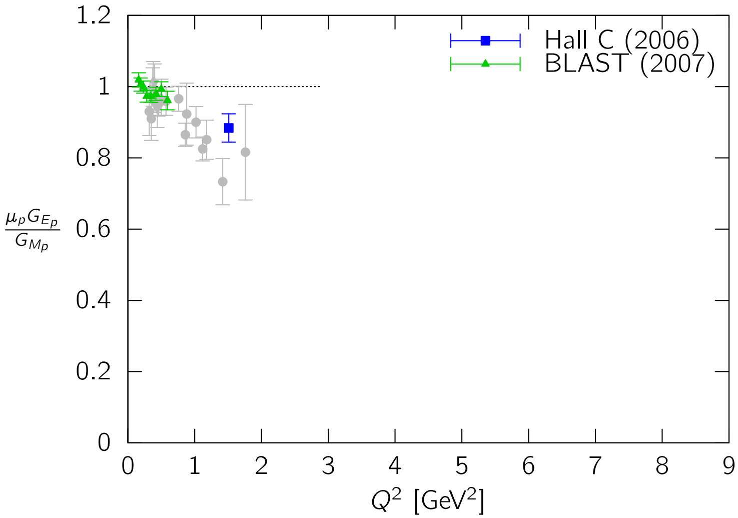

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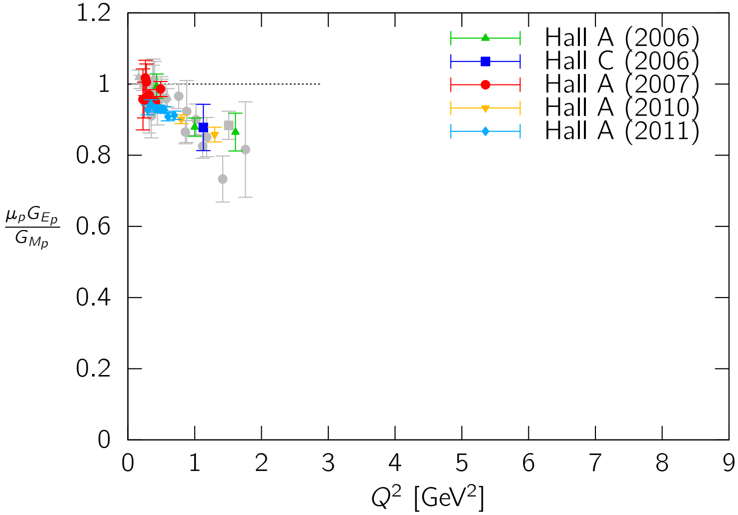

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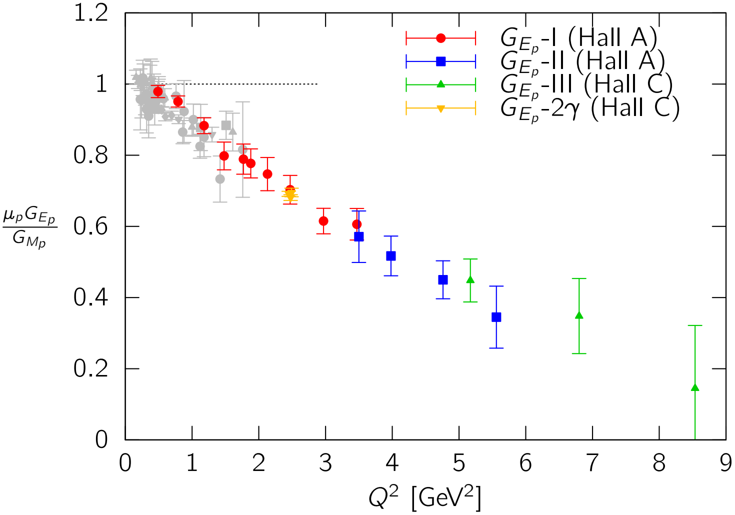

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Different dependence from $\sigma(e^+p)/\sigma(e^-p)$!

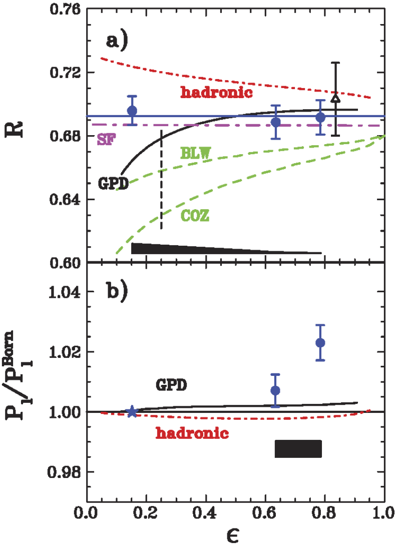
Without TPE, $\frac{G_E}{G_M}$ should be constant with ϵ.

$$\frac{G_E}{G_M} = \sqrt{\frac{\tau(1+\epsilon)}{2\epsilon}}\frac{P_t}{P_l} \times [1 + \ldots ?$$

Any ϵ dependence is a signature of TPE.

The GEp-2γ experiment looked for TPE.

- 40 days, data taken in 2007–08, Hall C
- $Q^2 = 2.5\ \text{GeV}^2/c^2$
- Meziane et al., PRL 106, 132501 (2011)
- A. J. R. Puckett et al., arXiv:1707.08587v1 [nucl-ex] (2017)



What do positrons get you?

Largest systematics in PT:

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Positrons can't help you get the form factors (biases have the same sign).

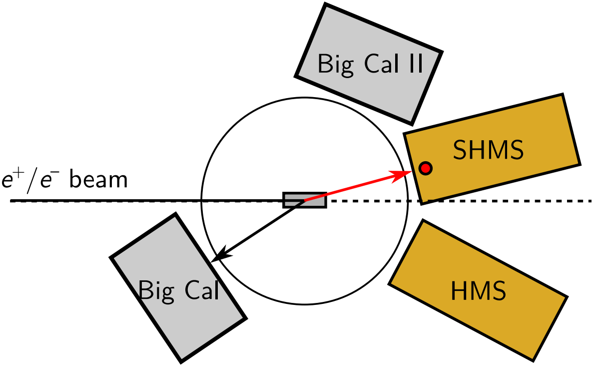
Figure-of-merit

$$\text{F.o.M.} \propto A P_e \sqrt{\frac{d\sigma}{d\Omega} \Omega \mathcal{L} T \varepsilon}$$

- A: polarimeter analyzing power $\longrightarrow$ same
- P_e: beam polarization $\approx 80\% \longrightarrow \approx 60\%$
- $\mathcal{L}$: luminosity $\approx 80\ \mu$A $\longrightarrow \approx 100$ nA
- T: run time ???
- ε: polarimeter efficiency $\longrightarrow$ same

Factor 38 increase in uncertainty!

Imagined set-up



BigCal from GEp-III, GEp-2γ

- Protons in SHMS/HMS
- Non-magnetic lepton detector (BigCal)
- SHMS for low-ϵ, in parallel with other kinematics in HMS

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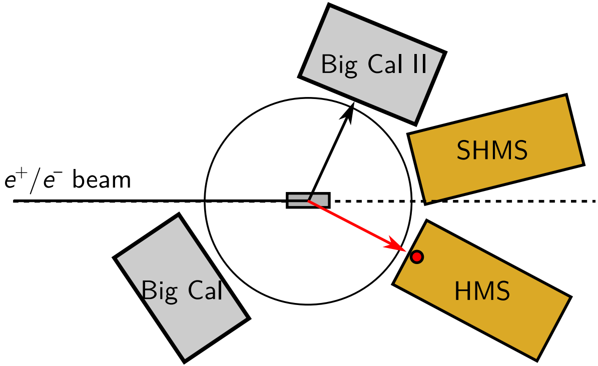

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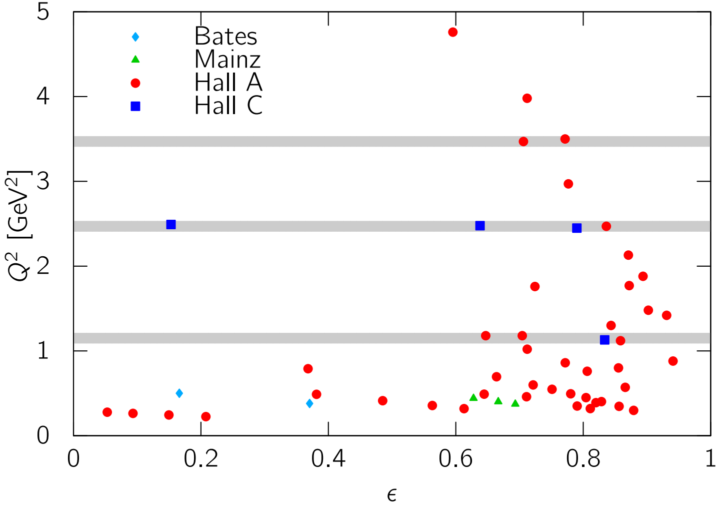
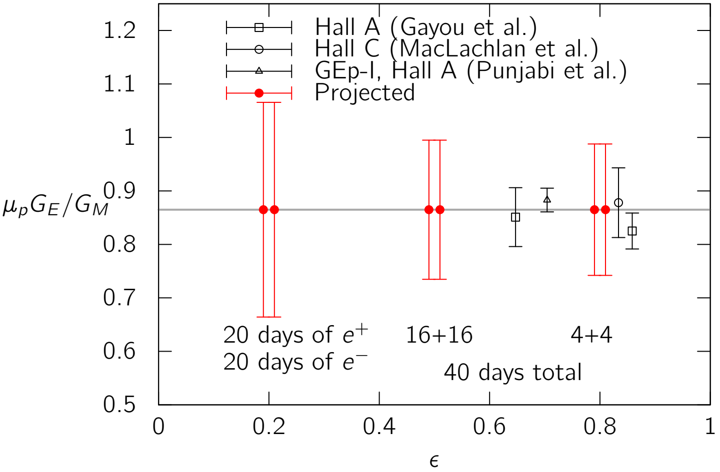
Kinematics



$Q^2 = 1.15\ \text{GeV}^2$



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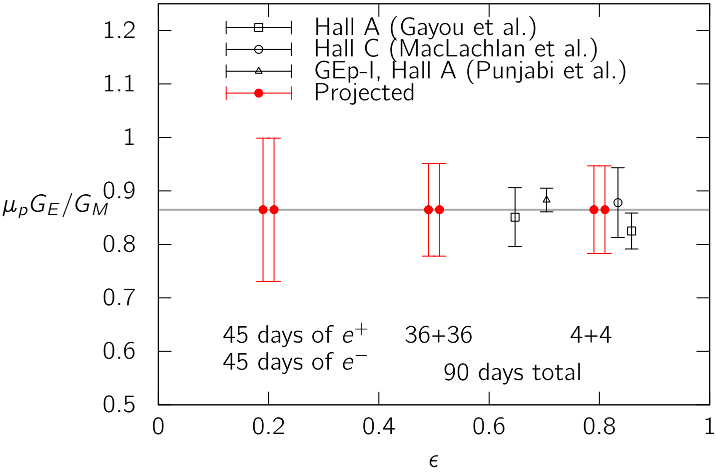

Hall A (Gayou et al.)
Hall C (MacLachlan et al.)
GEp-I, Hall A (Punjabi et al.)
Projected
$\mu_p G_E / G_M$
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
45 days of e^+
45 days of e^-
36+36
4+4
90 days total
0
0.2
0.4
0.6
0.8
1
ϵ

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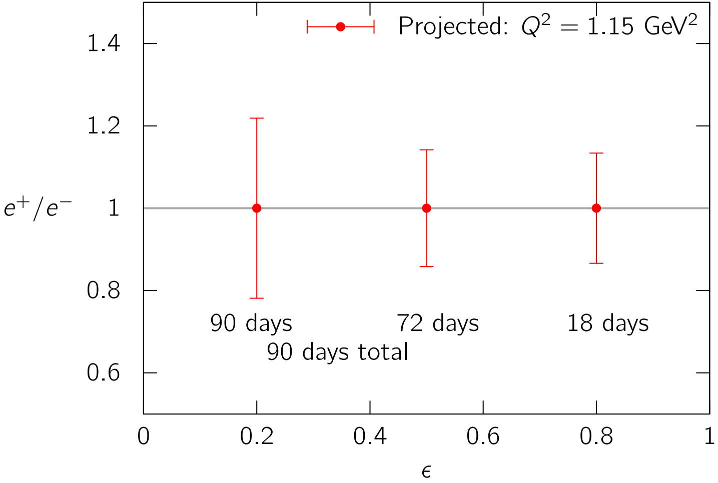


To summarize:

- TPE can show up in polarization transfer.
- e^+/e^- is a clean way to measure it.
  - Systematics are on the proton side.
  - Non-magnetic lepton detection
- **Getting enough stats is the hard part.**

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

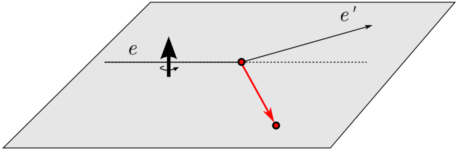
Target-normal:

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

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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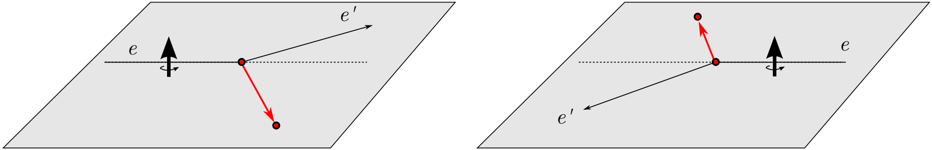

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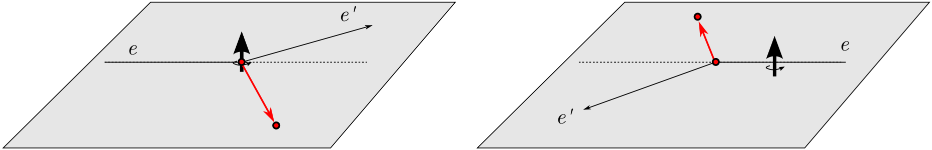

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Beam-normal

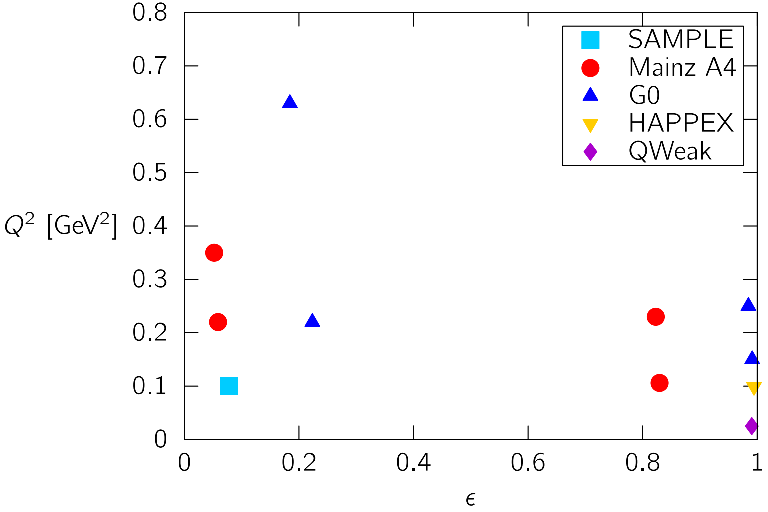
- Suppressed by m_e/Q
- $\approx 10^{-4}$–10^{-6}
- False asym. in PV
- Previously measured by:
  - SAMPLE
  - G0
  - Mainz A4
  - HAPPEX/PREX
  - QWeak (prelim)

Target-normal

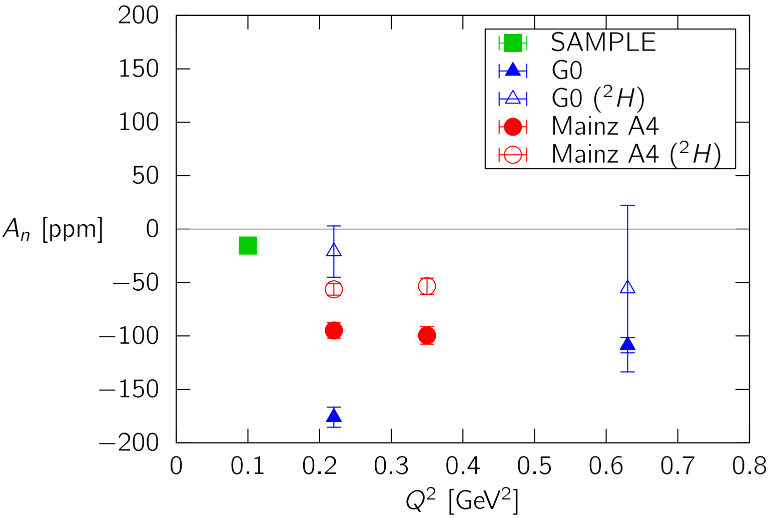
- $\approx 10^{-3}$
- Previously measured
  - 1970's, looking for T-violation
  - HERMES (including with e^+)
  - ^{3}He, Hall A

$$\text{F.o.M} = P\sqrt{\frac{d\sigma}{d\Omega}\Omega\mathcal{L}T}$$

Previous beam-normal asymmetry data



Low-ϵ beam-normal asymmetry data



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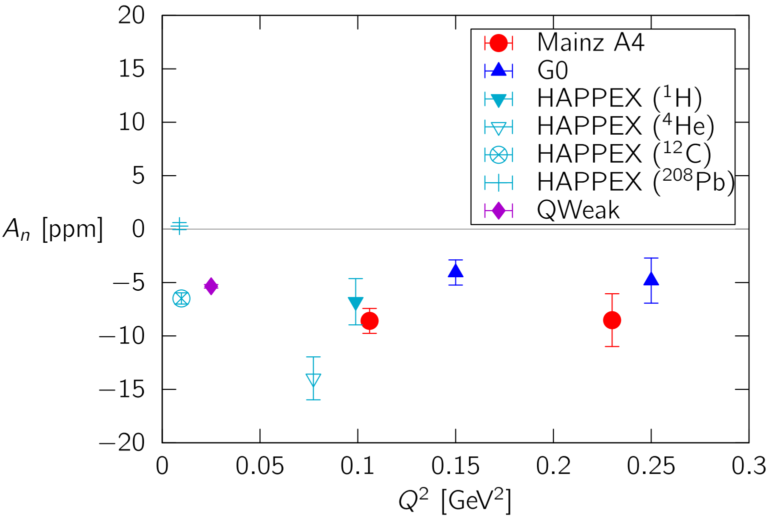


Challenges with beam-normal asymmetries and positrons

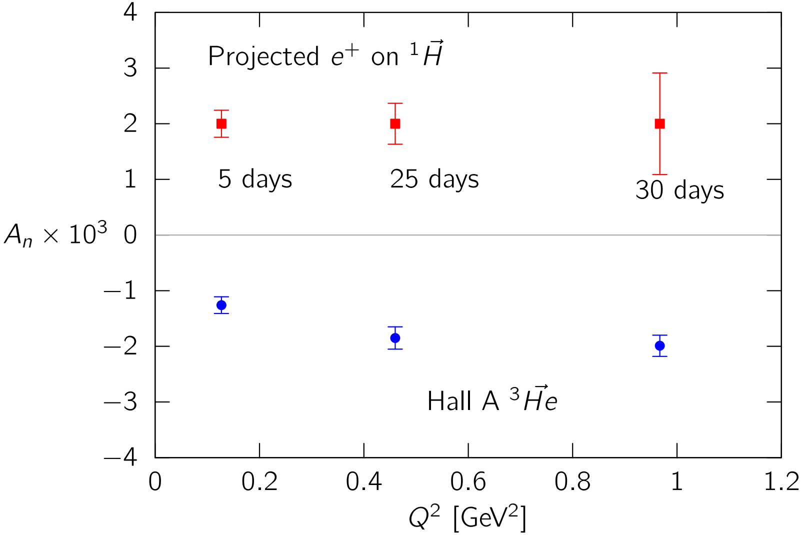
- Making *transversely* polarized beam
- Need high luminosity
- Resolve ppm asymmetries
- Positrons don't help with systematics
  - Beam polarimetry
  - False asymmetries

Target-Normal Asymmetry Estimate

Assumptions

- $\mathcal{L} = 10^{35}\ \text{cm}^{-2}\text{s}^{-1}$
  - Limited by target
  - ≈ 100 nA
- 12% target polarization (including NH_3 dilution factor)
- Both Hall A HRSs at 17°
- 50% live time

Target-Normal Asymmetry Estimate



Target-Normal Asymmetry Estimate

- e^+ measurement is feasible
- Adequate statistics
- Problems are systematic
  - Luminosity
  - e^+/e^- switching time
  - Target polarization
  - Target flip time
  - Positrons do not help.

Summary

- Polarization transfer is clean, but statistics limited.
- Beam-normal asymmetries are statistics limited.
- Target-normal asymmetries might be feasible

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Getting TPE data in multiple channels is important for validating theory!