Measurement of the Proton Form Factor Ratio at Low Momentum Transfer (GEp experiment)

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For the E08-007 collaboration

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The elastic Form Factors

point like particle:

$$\frac{d\sigma_R}{d\Omega}=\frac{\alpha^2}{Q^2}\left(\frac{E'}{E}\right)^2\frac{\cot^2(\theta_e/2)}{1+\tau}$$

spin 1/2 particle:

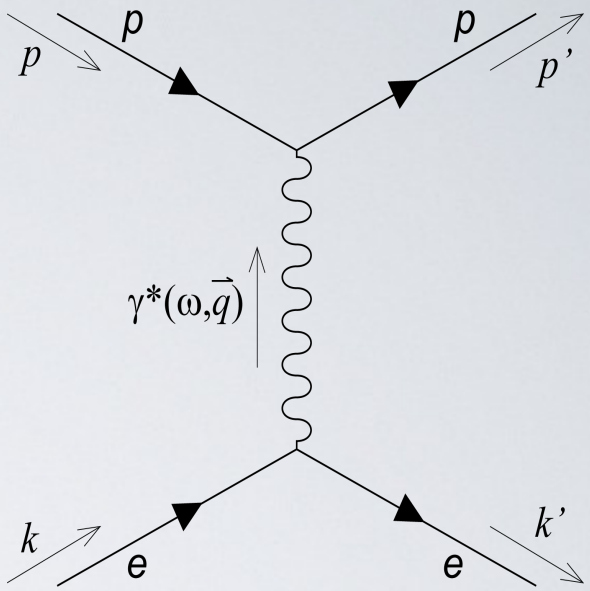
$$\frac{d\sigma_M}{d\Omega}=\frac{d\sigma_R}{d\Omega}\times[1+2\tau\tan^2(\theta_e/2)]$$

The proton is not structureless since:

$$\mu_p\neq\frac{q}{mc}|\vec{s}|$$

$$\frac{d\sigma_R}{d\Omega}=\frac{d\sigma_M}{d\Omega}\times(1+\tau)^{-1}\cdot[G_E^2(Q^2)+\frac{\tau}{\epsilon}G_M^2(Q^2)]$$

One Photon Exchange



$$\tau=\frac{Q^2}{4M^2};\epsilon=[1+2(1+\tau)\tan^2(\theta_e/2)]$$

Why we care?

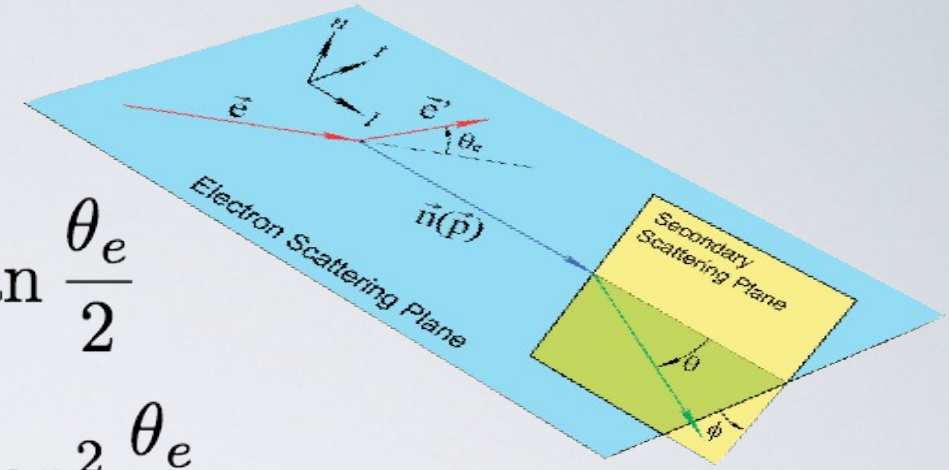
- FF are a basic property of the nucleon, related to the complex internal structure.
- Completely describe the EM structure of the nucleon ground state.
- Comparing G_E and G_M → difference between spatial distributions of charge and magnetization.
- Comparing proton and neutron FF → internal structure differences.
- Help to distinguish between different theoretical models.
- EM structure expected to change in the nuclear medium.
- FF related to the EM spatial distribution – the proton radius puzzle.

In the briet frame, in the non-relativistic limit:

$$G_{E,M}(Q^2) = \int \rho(\vec{r}) e^{i\vec{q}\vec{r}} d^3\vec{r} = \int \rho(\vec{r}) d^3\vec{r} - \frac{\vec{q}^2}{6} \int \rho(\vec{r}) \vec{r}^2 d^3\vec{r} + \ldots$$

Measurement Techniques

Recoil Polarization



$$I_0 P_t = -2\sqrt{\tau(1+\tau)}\, G_E G_M \tan\frac{\theta_e}{2}$$

$$I_0 P_l = \frac{E_e + E_{e'}}{M}\sqrt{\tau(1+\tau)}\, G_M^2 \tan^2\frac{\theta_e}{2}$$

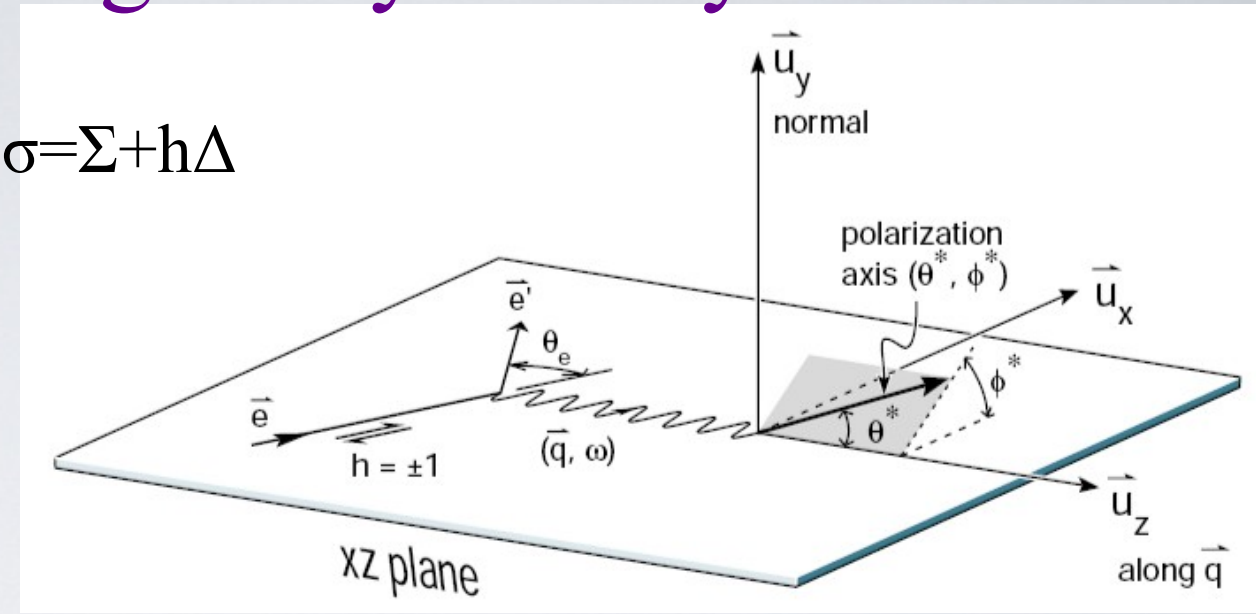
$$\mathcal{R} \equiv \mu_p \frac{G_E}{G_M} = -\mu_p \frac{P_t}{P_l}\frac{E_e + E_{e'}}{2M}\tan\frac{\theta_e}{2}$$

- A single measurement gives ratio of form factors.
- Allows measurement at (almost) all values of Q2.

Measurement Techniques
Beam-Target Asymmetry

Polarized Cross Section: $\sigma = \Sigma + h\Delta$

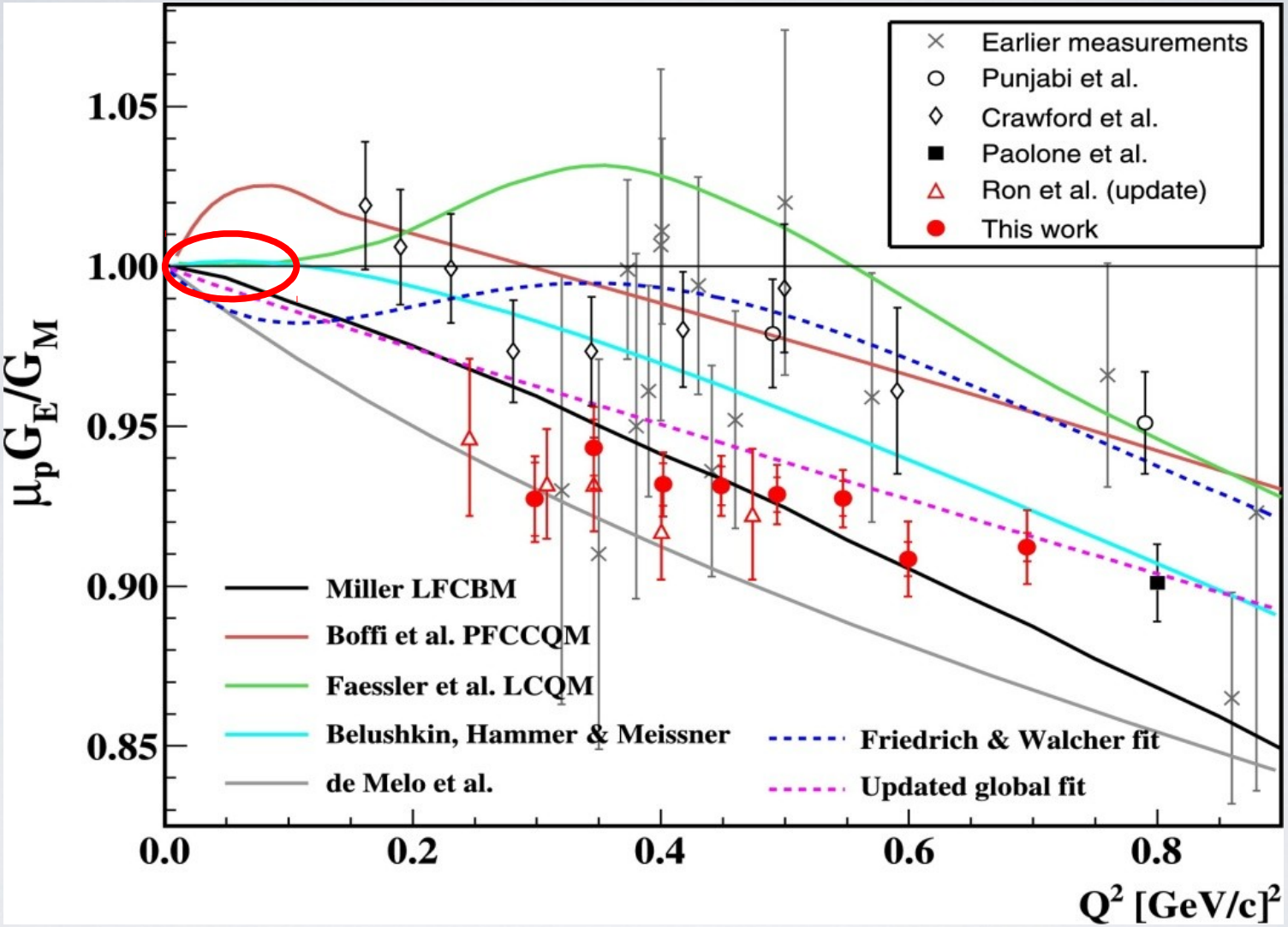
$$\mathcal{A} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$



$$\mathcal{A} = f P_b P_t \frac{\overbrace{a \cos\theta^* G_M^2}^{A_T} + \overbrace{b \sin\theta^* \cos\phi^* G_E G_M}^{A_{LT}}}{c G_M^2 + d G_E^2}$$

GEp: E_e = 1.1-2.2 GeV. $\theta = 5.6^\circ$.

available data status



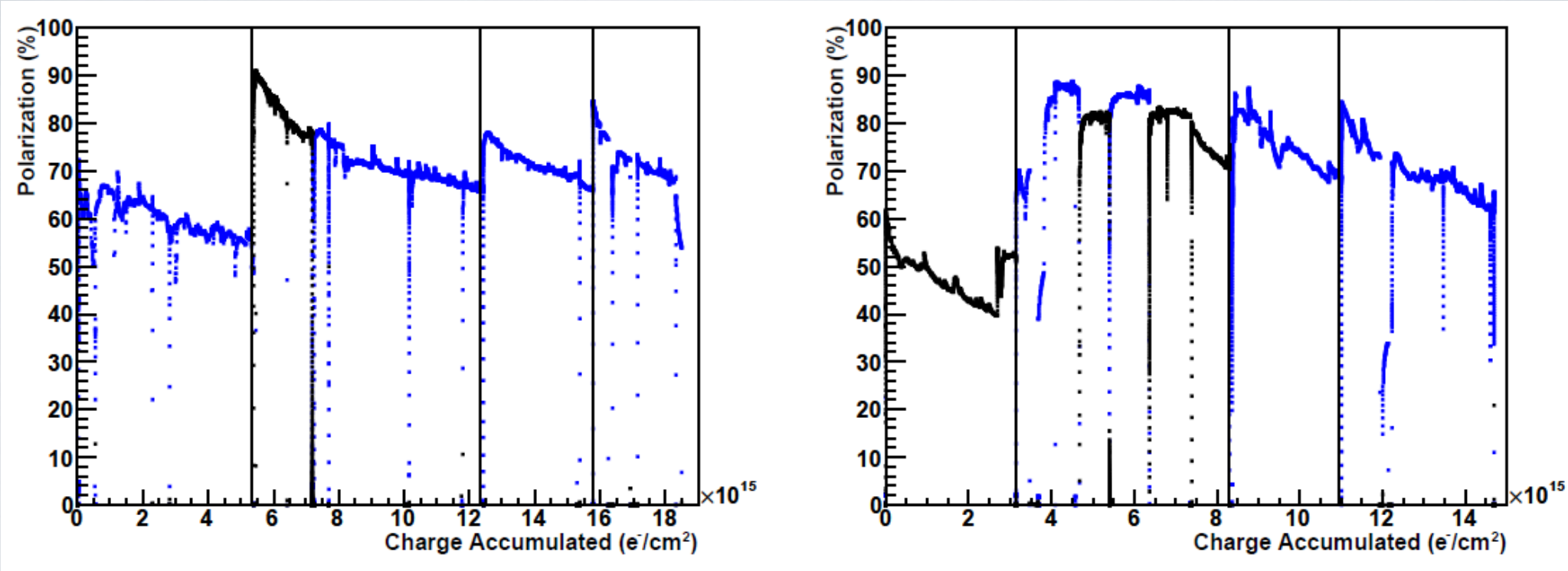
X. Zhan *et al.*, Phys. Lett. B 705 (2011) – GEp part I

The JLab low Q^2 program Proton FFs

- LEDEX - Single arm proton measurement
  - Recoil polarization measurement of the FF ratio.
  - 8 Q^2 data points (0.25 - 0.5 GeV^2) with ~ 1.5% uncertainty on best data points.
  - Led to the proposal of:
- E08-007 - Two arm experiment (proton + tagged electron for bck suppression)
  - A dedicated 2 part experiment to map the proton FF ratio at low Q^2.
  - First part used recoil polarization to achieve:
    - ~ 1% uncertainty (best ever achieved) at Q^2~ 0.3 - 0.7 GeV^2.
  - Second part used beam target asymmetry.
    - ~2% uncertainty at Q^2~ 0.01 - 0.08 GeV^2.

data analysis

polarization level (D. Keller)

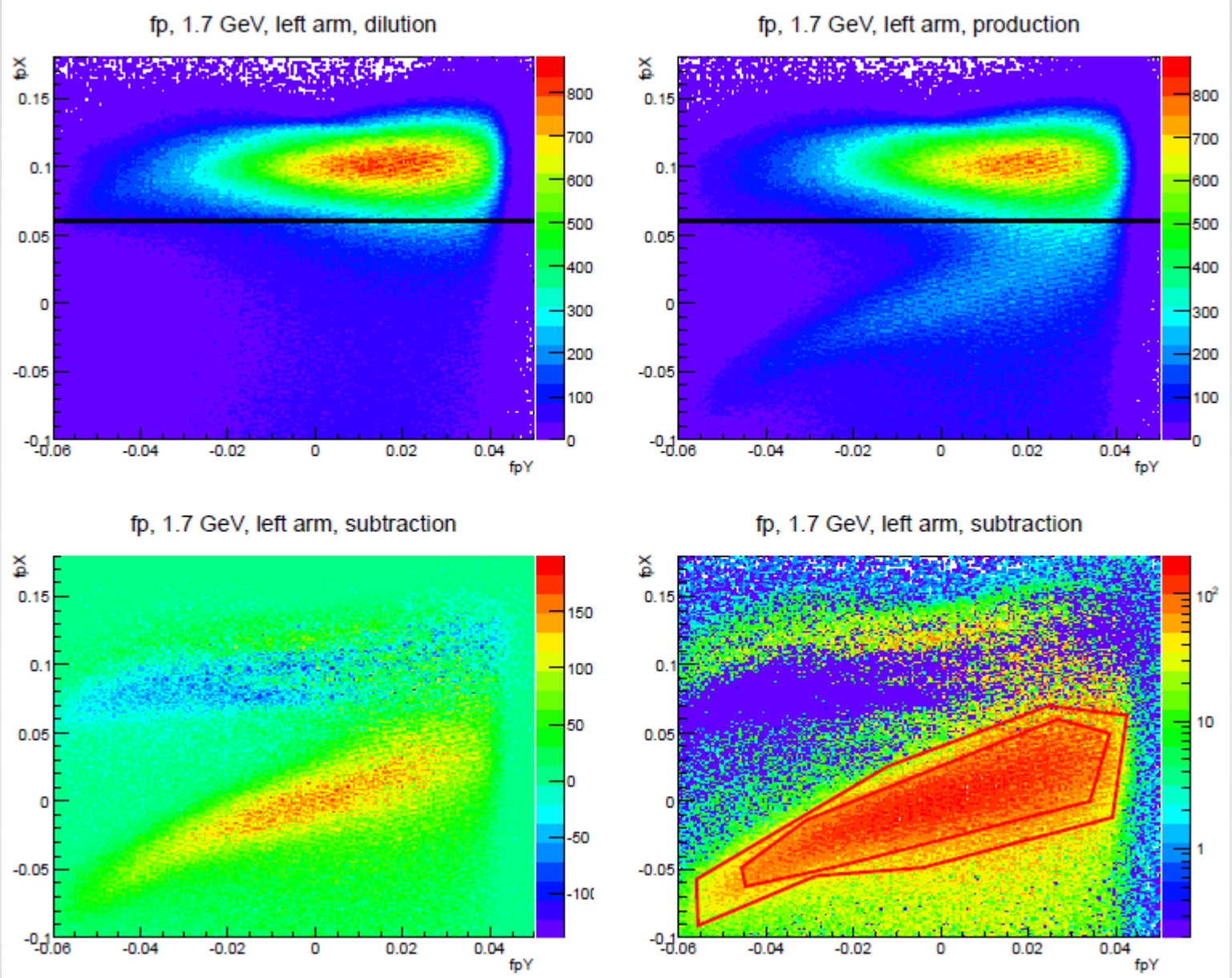


polarization level of 70%-90% for most of the data!

$\Delta P / P < 3.3\%$

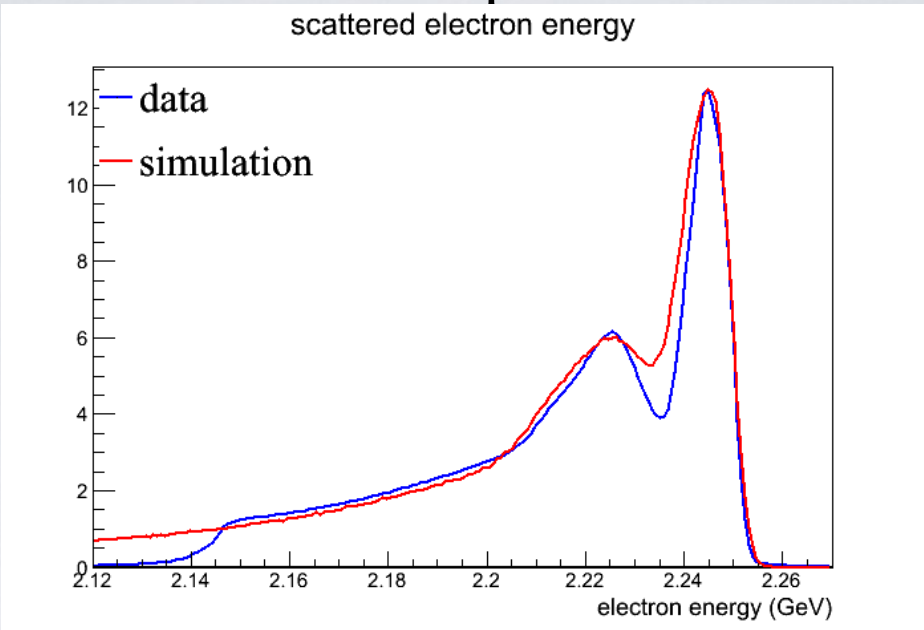
data analysis

event selection

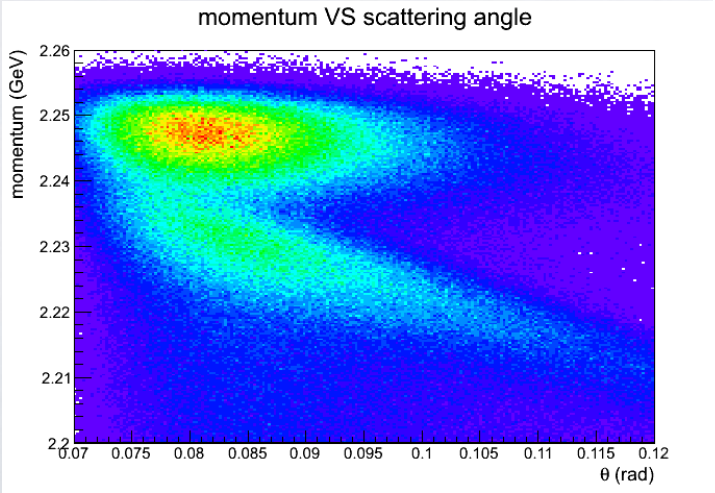


data analysis

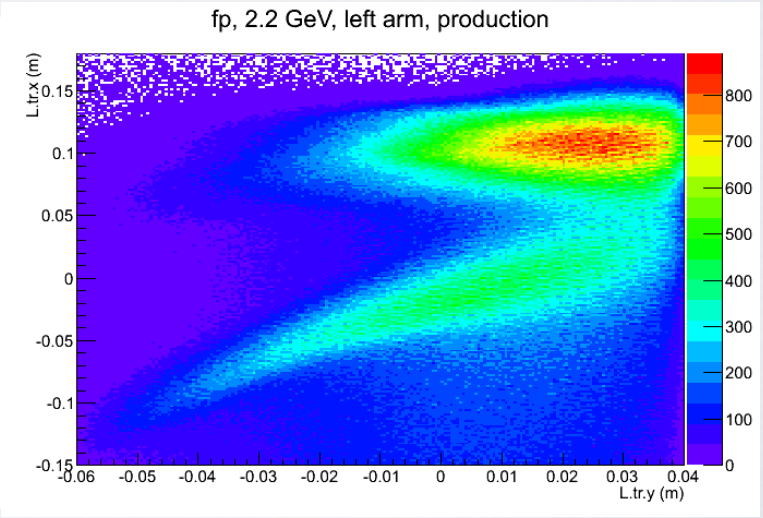
simulations – comparison with data



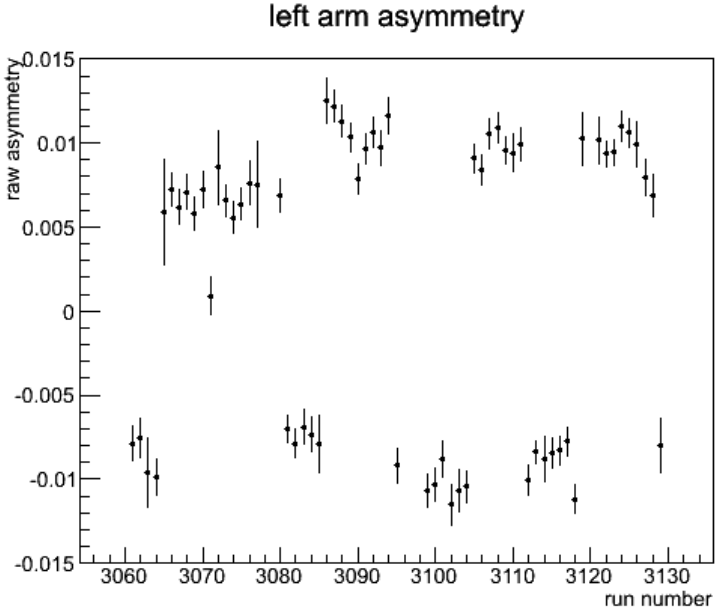
simulations – P VS θ

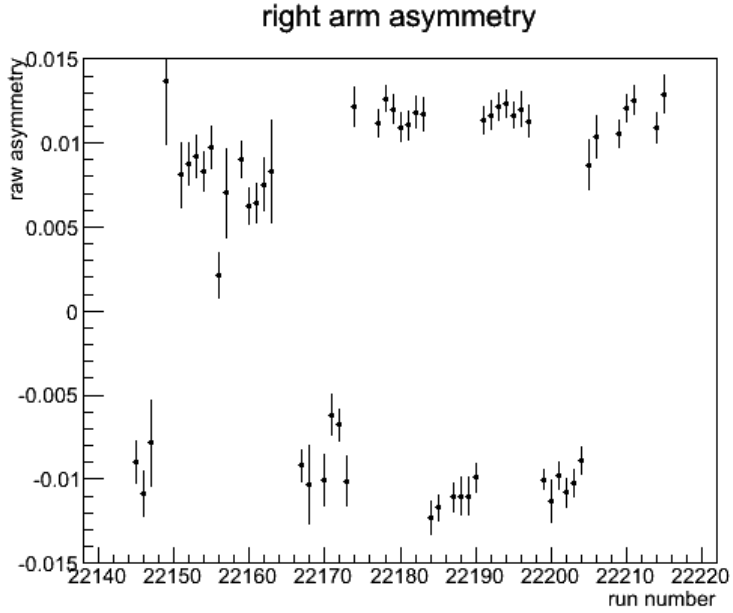


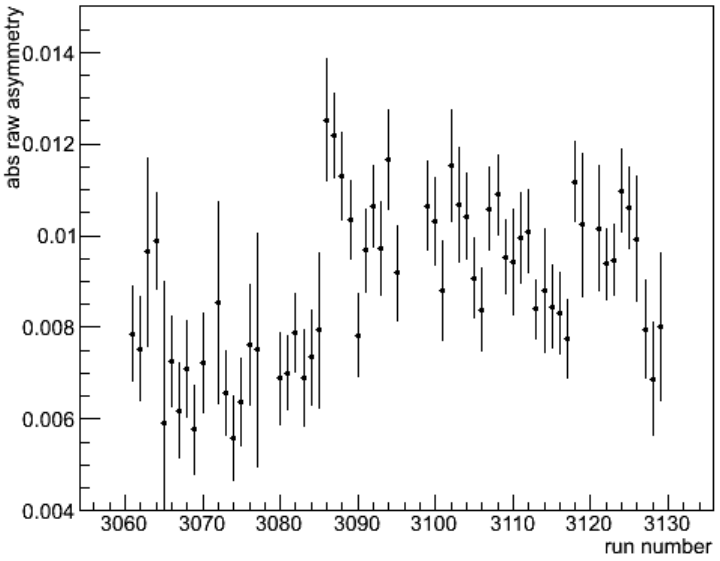
data – L.tr.x VS L.tr.y

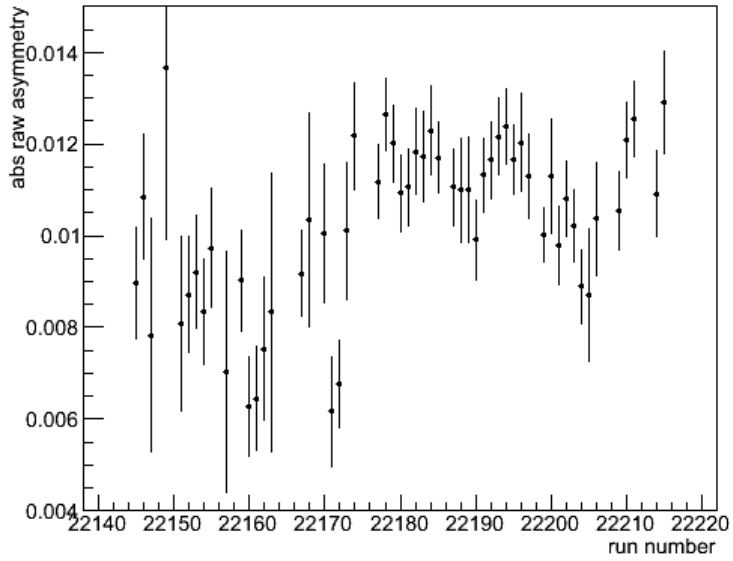


data analysis









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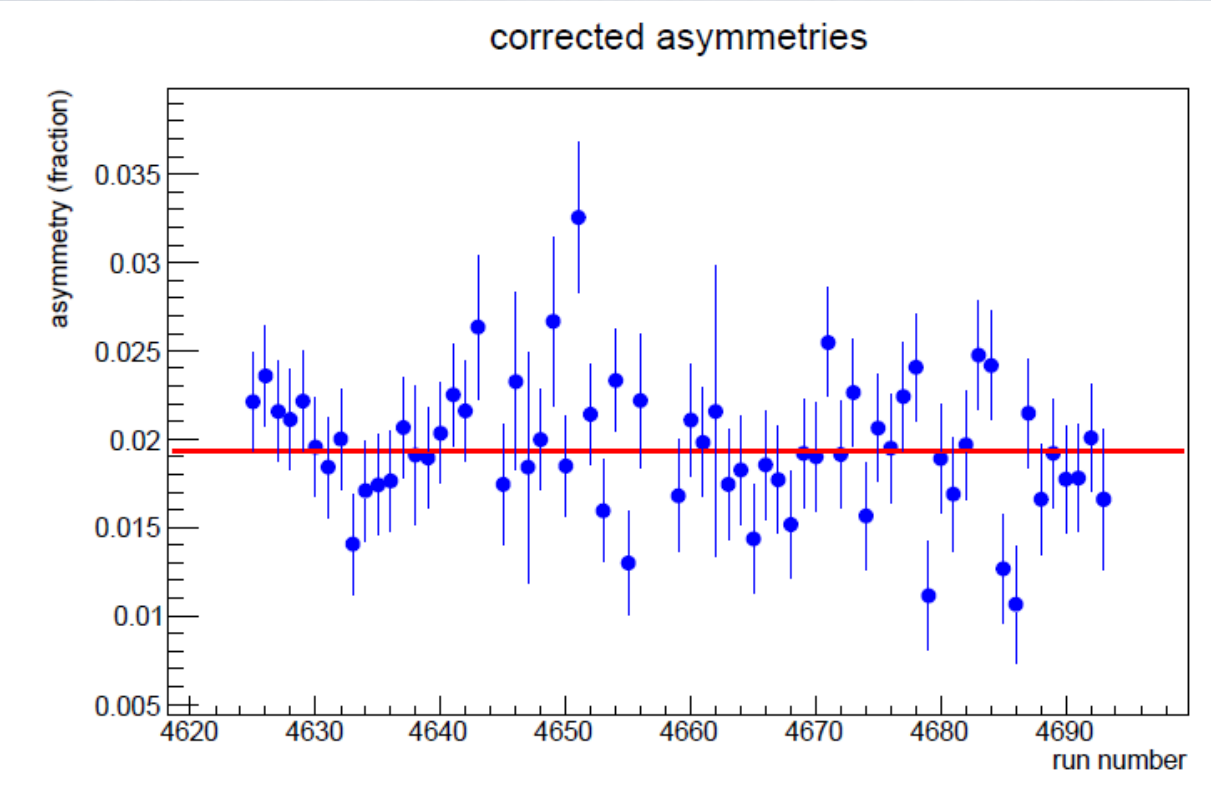

$$A = \frac{-2\sqrt{\frac{\tau}{1+tau}}\tan\frac{\theta}{2}\left[\sqrt{\tau\left(1+(1+\tau)\tan^2\frac{\theta}{2}\right)}\cos\theta^* G_M^2 + \sin\theta^*\cos\varphi^* G_M G_E\right]}{\frac{G_E^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2\tan^2\frac{\theta}{2}}$$

$$A \approx -2\sqrt{\tau}\tan\frac{\theta}{2}\sin\theta^*\cos\varphi^*\cdot\frac{G_M}{G_E}$$

main uncertainties

source	uncertainty (%)	comments
bin size	0.5-1	depends on bin size
beam polarization	1-1.5	
target polarization	1.5-3	Point-to-point uncertainties significantly lower
statistics	1-2	depends on bin size and cuts
dilution	?	depends on cuts

- There is a trade-off between bin size uncertainties and statistical uncertainties.
- There is a trade-off between dilution uncertainties and statistical uncertainties.
- Target polarization uncertainties are not final.
- Point-to-point uncertainty of the target polarization is significantly lower, and this is important for model testing.

preliminary results

bin				cut 1				cut 2			
arm	E_e (GeV)	Q^2 range (GeV^2)	Q^2 value (GeV^2)	dilution	A (%)	ΔA/A (%)	χ^2/ndf	dilution	A (%)	ΔA/A (%)	χ^2/ndf
left	2.2	0.045-0.080	0.057±0.008	0.74	3.03±0.046	1.52	1.57	0.68	2.96±0.042	1.42	1.53
right	2.2	0.056-0.082	0.065±0.005	0.67	3.39±0.059	1.74	0.85	0.59	3.41±0.058	1.70	1.21
left	2.2	0.028-0.050	0.037±0.006	0.75	1.56±0.021	1.35	1.20	0.70	1.48±0.021	1.42	1.34
right	2.2	0.038-0.064	0.047±0.006	0.71	1.93±0.029	1.50	1.60	0.66	1.74±0.029	1.67	1.39
left	1.7	0.020-0.045	0.028±0.006	0.71	1.93±0.038	1.97	1.25	0.66	1.95±0.035	1.79	0.96
right	1.7	0.031-0.050	0.037±0.004	0.78	2.17±0.071	3.27	0.79	0.73	2.20±0.055	2.50	0.87
left	1.7	0.017-0.027	0.020±0.003	0.54	1.24±0.071	5.87	0.90	0.48	1.18±0.066	5.59	0.82
right	1.7	0.023-0.033	0.027±0.003	0.67	1.68±0.056	3.33	1.23	0.64	1.53±0.047	3.07	1.38
left	1.1	0.009-0.020	0.012±0.0027	0.26	1.78±0.060	3.37	0.79	0.23	1.72±0.052	3.02	0.80
right	1.1	0.010-0.022	0.014±0.0026	0.18	2.33±0.120	5.15	0.74	0.15	2.78±0.097	3.49	0.70

- All uncertainties here are statistical.
- Combining data of two arms will reduce statistical uncertainties by $\sqrt{2}$
- Preliminary optics is used. Better optics may change Q2 ranges and uncertainties.
- Preliminary cuts are used.