GEP (E08027-II) Analysis Update

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For the GEP Collaboration

Hall A Collaboration Meeting, June 2013

E08-007 part 1: polarization transfer, 2008
E08-007 part 2: polarized beam + polarized target asymmetry, 2012

Motivation

Goal:

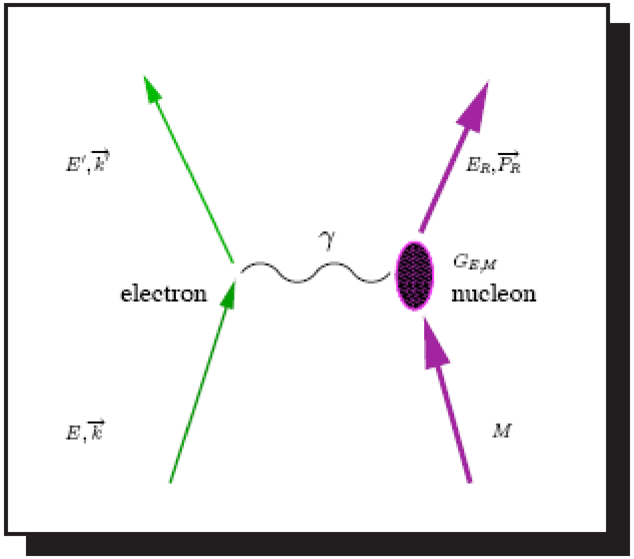
- Measure the Proton Form Factor Ratio $\mu G_E/G_M$ at low Q^2

Impacts:

- nucleon EM structure,
- determination of proton radius,
- hyperfine splitting,
- muonic hydrogen Lamb shift corrections ...

What Are G_E and G_M?

$$\frac{d\sigma}{d\Omega} = \sigma_{\text{Mott}} \frac{E'}{E_0} \left\{ (F_1)^2 + \tau \left[2\,(F_1 + F_2)^2 \tan^2(\theta_e) + (F_2)^2 \right] \right\} ; F_{1,2} = F_{1,2}(Q^2)$$



$Q^2 = 4EE' \sin^2(\theta/2)$	$\tau = \frac{Q^2}{4M^2}$
$F_1^p(0) = 1$	$F_1^n(0) = 0$
$F_2^p(0) = 1.79$	$F_2^n(0) = -1.91$

In Breit frame F_1 and F_2 related to charge and spatial curent densities:

$$\rho = J_0 = 2eM[F_1 - \tau F_2]$$

$$J_i = e\bar{u}\gamma_i u[F_1 + F_2]_{i=1,2,3}$$

$$G_E(Q^2) = F_1(Q^2) - \tau F_2(Q^2) \qquad G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$$

✓ For a point like probe G_E and G_M are the FT of the charge and magnetizations distributions in the nucleon, with the following normalizations

$Q^2 = 0$ limit: $G_E^p = 1$ $G_E^n = 0$ $G_M^p = 2.79$ $G_M^n = -1.91$

one-photon approx.

Alternative to Rosenbluth Separation

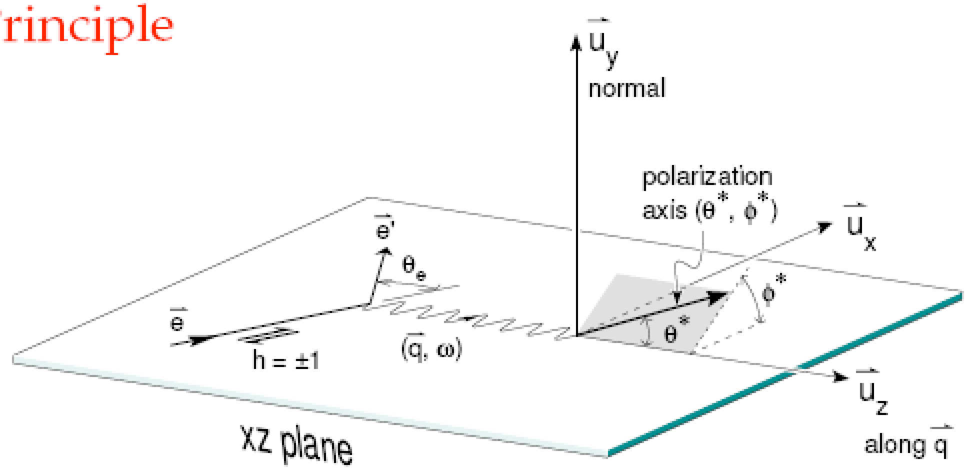
Beam–Target Asymmetry - Principle

Polarized Cross Section:

$\sigma = \Sigma + h\Delta$

Beam Helicity $h \pm 1$

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{\Delta}{\Sigma}$$



$$A = \frac{\overbrace{a\cos\Theta^\star (G_M)^2}^{A_T} + \overbrace{b\sin\Theta^\star\cos\Phi^\star G_E G_M}^{A_{TL}}}{c\,(G_M)^2 + d\,(G_E)^2}; \quad \varepsilon = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} = P_B \cdot P_T \cdot f \cdot A$$

$\Theta^\star = 90^\circ \quad \Phi^\star = 0^\circ$

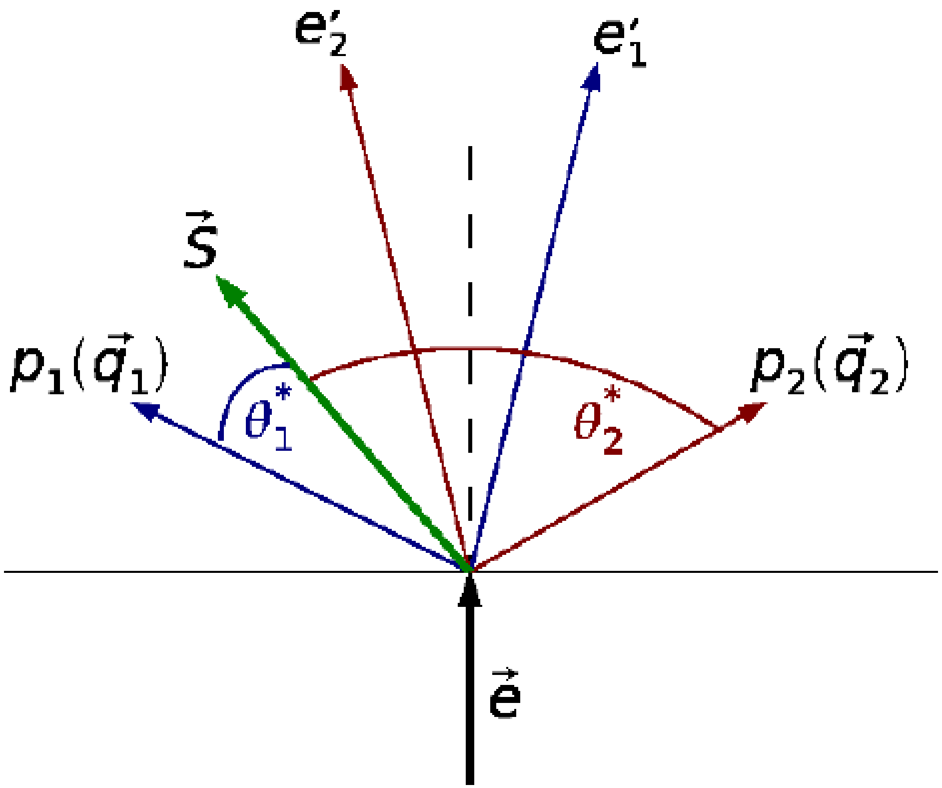
$$\Longrightarrow A_{TL} = \frac{b G_E G_M}{c\,(G_M)^2 + d\,(G_E)^2}$$

$\Theta^\star = 0^\circ \quad \Phi^\star = 0^\circ$

$$\Longrightarrow A_T = \frac{a G_M^2}{c\,(G_M)^2 + d\,(G_E)^2}$$

Strategy

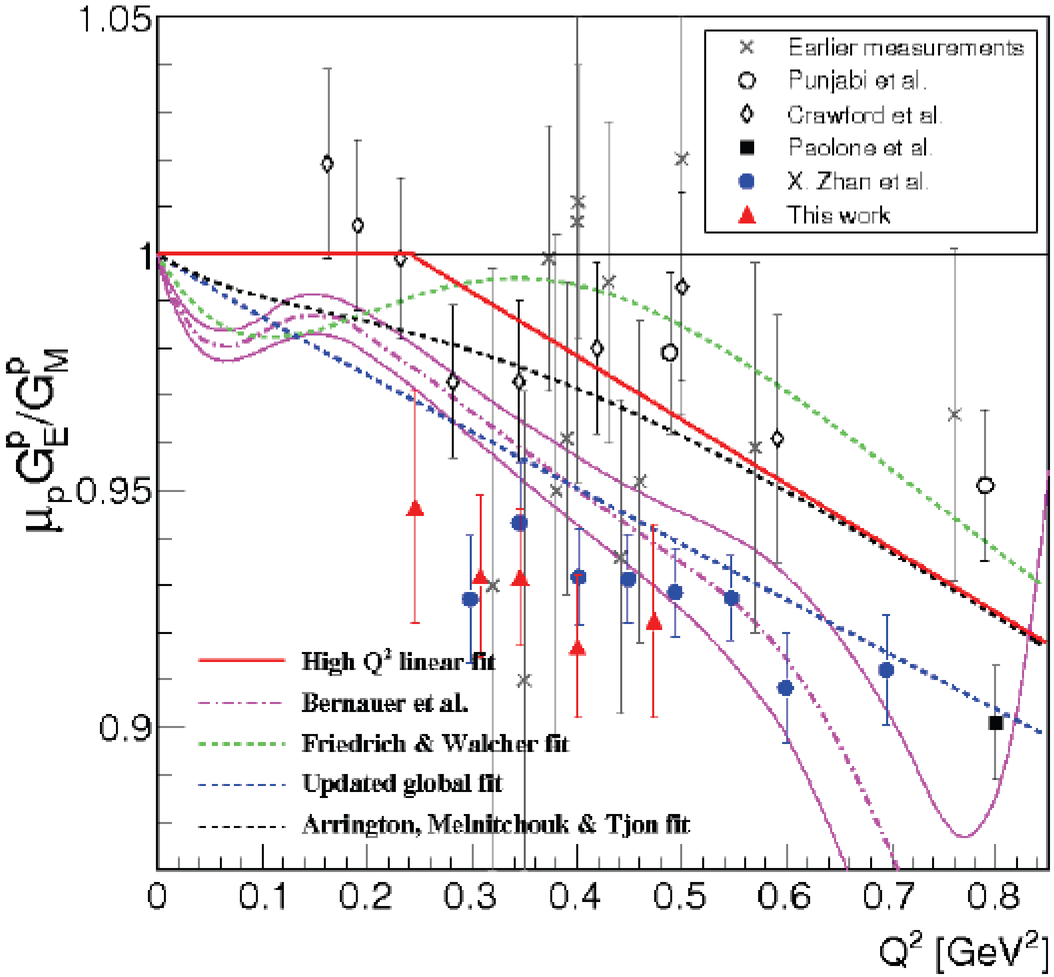
- High precision (≈1%)
- Beam-target asymmetry measurement by electron scattering from polarized NH3 target.
- Electrons detected in two matched spectrometers.
- Ratio of asymmetries cancels systematic errors → only one target setting to get FF ratio.



$$\mu_P \frac{G_E^P}{G_M^P} = -\mu_P \frac{a(\tau,\theta) cos\theta_1^* - \frac{f_2}{f_1}\Gamma a(\tau,\theta)\cos\theta_2^*}{\cos\phi_1^*\sin\theta_1^* - \frac{f_2}{f_1}\Gamma\cos\phi_2^*\sin\theta_2^*}$$

Where $\Gamma = \frac{A_1}{A_2}$, the ratio of the asysmetries measured by left and right HRS

Proton Form Factors



Zhan et al., PLB705, 59 (2011), E08007-I

Ron et al., PRC84, 055204 (2011), LEDEX

- •Existing data from 1960s to 2010s. Data from Jlab do not agree with others
- •Low Q^2 (<0.2) data is scare
- •Models do not agree with each other, especially in low Q^2 region
- •GEP(E08027-II) experiment measured this ratio at Q^2 from 0.01 to 0.16

Proton Size

Two ways to measure:

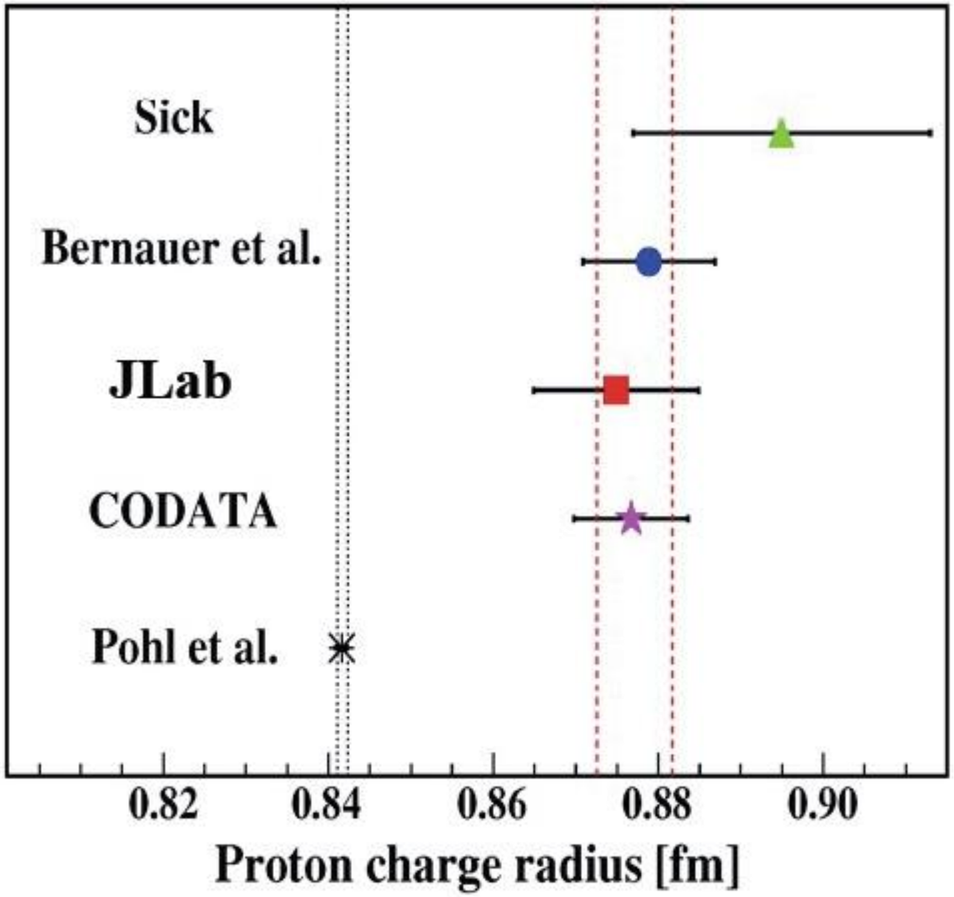
1. Atomic physics: energy splitting of the $2S_{1/2}$-$2P_{1/2}$ level (Lamb shift).
   The result from Lamb shift in muonic hydrogen is much more precise than normal hydrogen.
   R. Pohl *et.al.*, *Nature*, *July 2010*

2. Nuclear physics: e-p scattering experiment.
   $dG_{E,M} / dQ^2$ at Q^2=0 defines the radii.
   By SICK, *Mainz*, *CODATA*, *Jlab* ...

Results from these 2 methods do not agree with each other, see next slice for details.
The main uncertainties originates from the proton polarizability and different values of the Zemach radius. G2P and GEP could help.

Proton Radius Puzzle

Results from Lamb shift measurement with muonic hydrogen disagrees with electron scattering

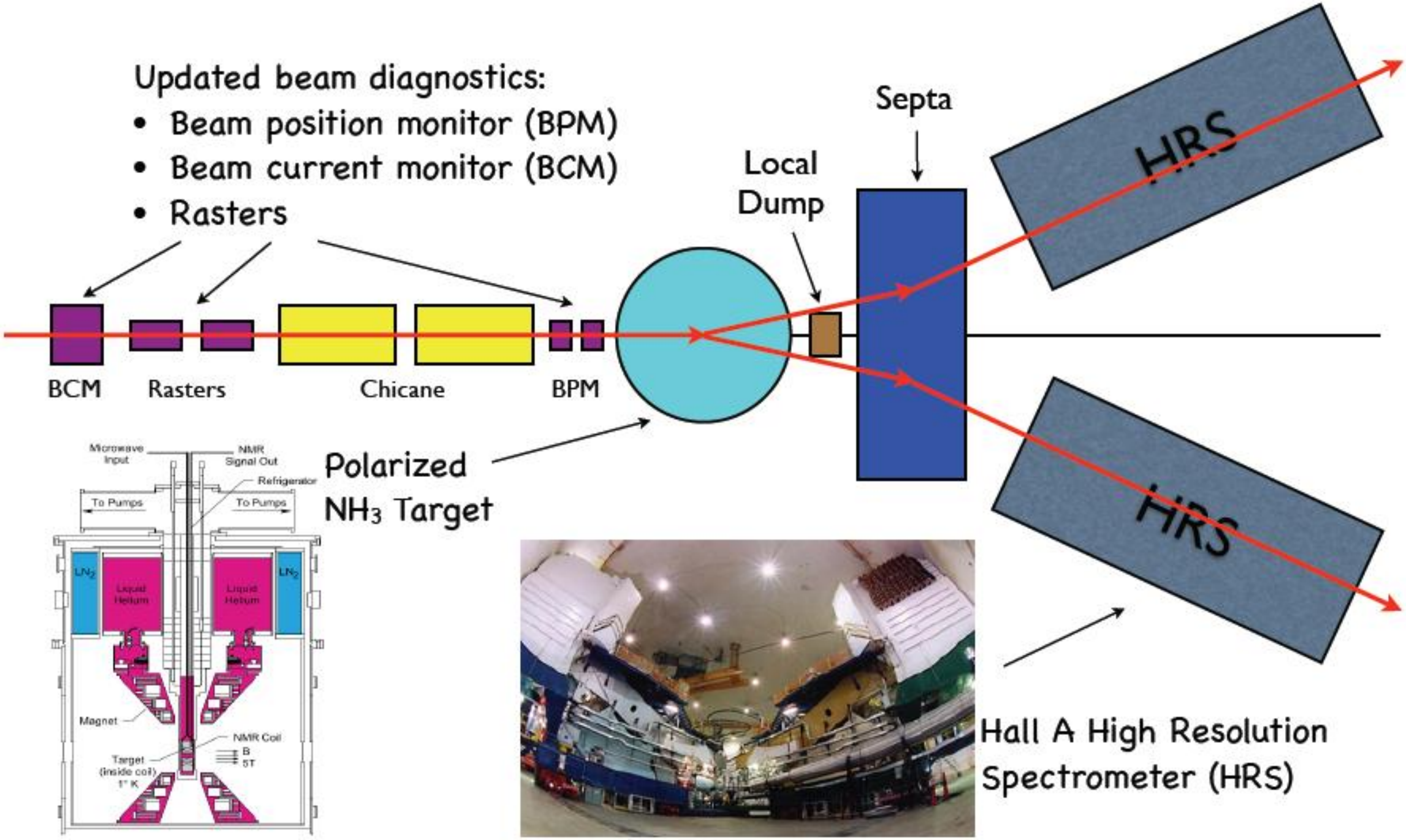


#	Extraction	$<R_E>^2$ [fm]
1	Sick	0.8950(180)
2	Mainz	0.8790(80)
3	JLab	0.8750(100)
4	CODATA'06	0.8768(69)
5	Combined 2-4	0.8772(46)
6	Muonic Hydrogen	0.8418(7)

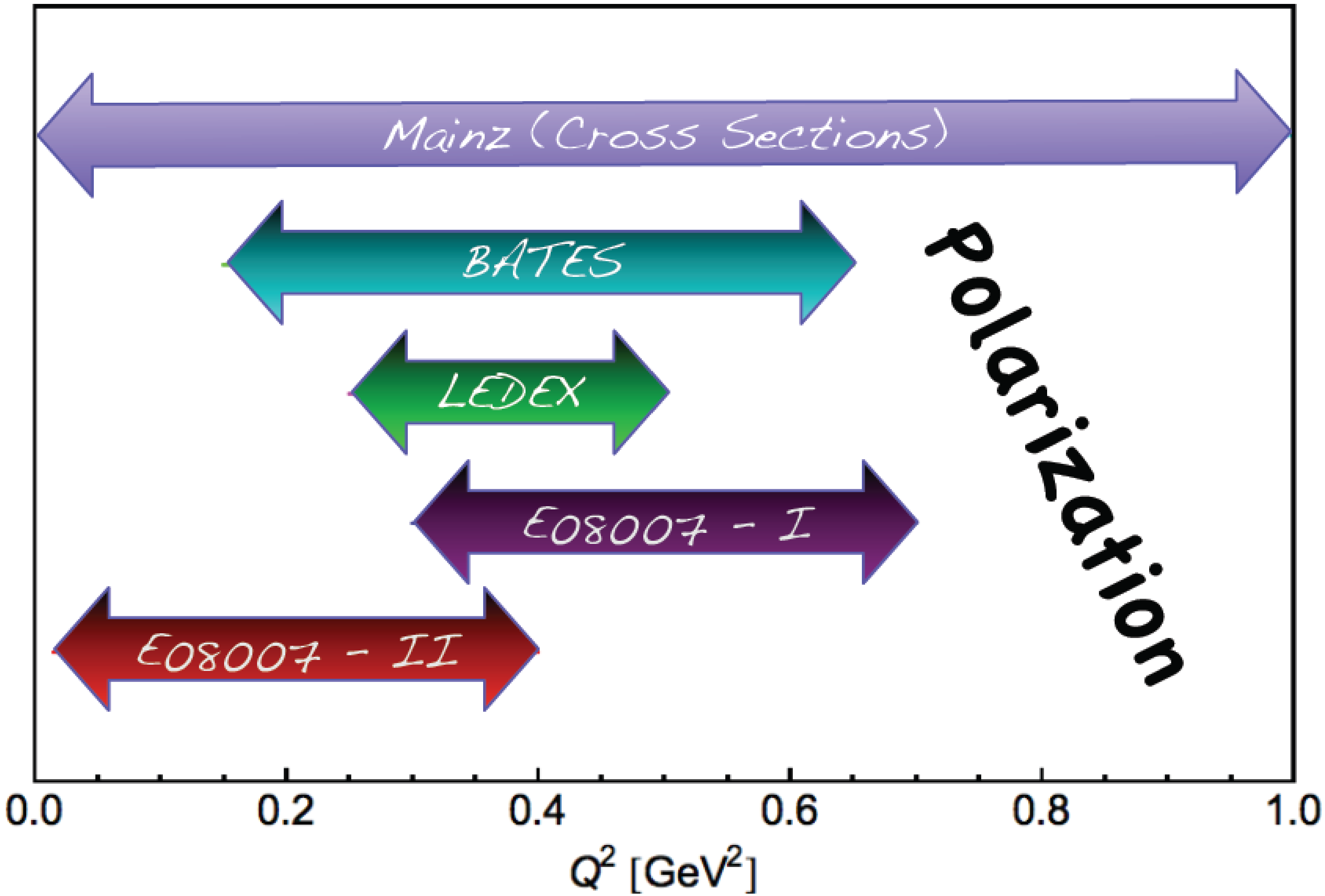
The Experiment

- Use polarized proton target (NH_3) under 5T target field at about 6^o
- HRS located at 5.7^o
- Took elastic data with 1.1, 1.7, 2.2 GeV beam energies
- Q^2 ranged from 0.01 to 0.16 GeV^2, high Q^2 points missed due to 12.5^o HRS setting was not able to run
- Measure elastic electron from both arms
- Ran in 2012 March to May, together with G2P

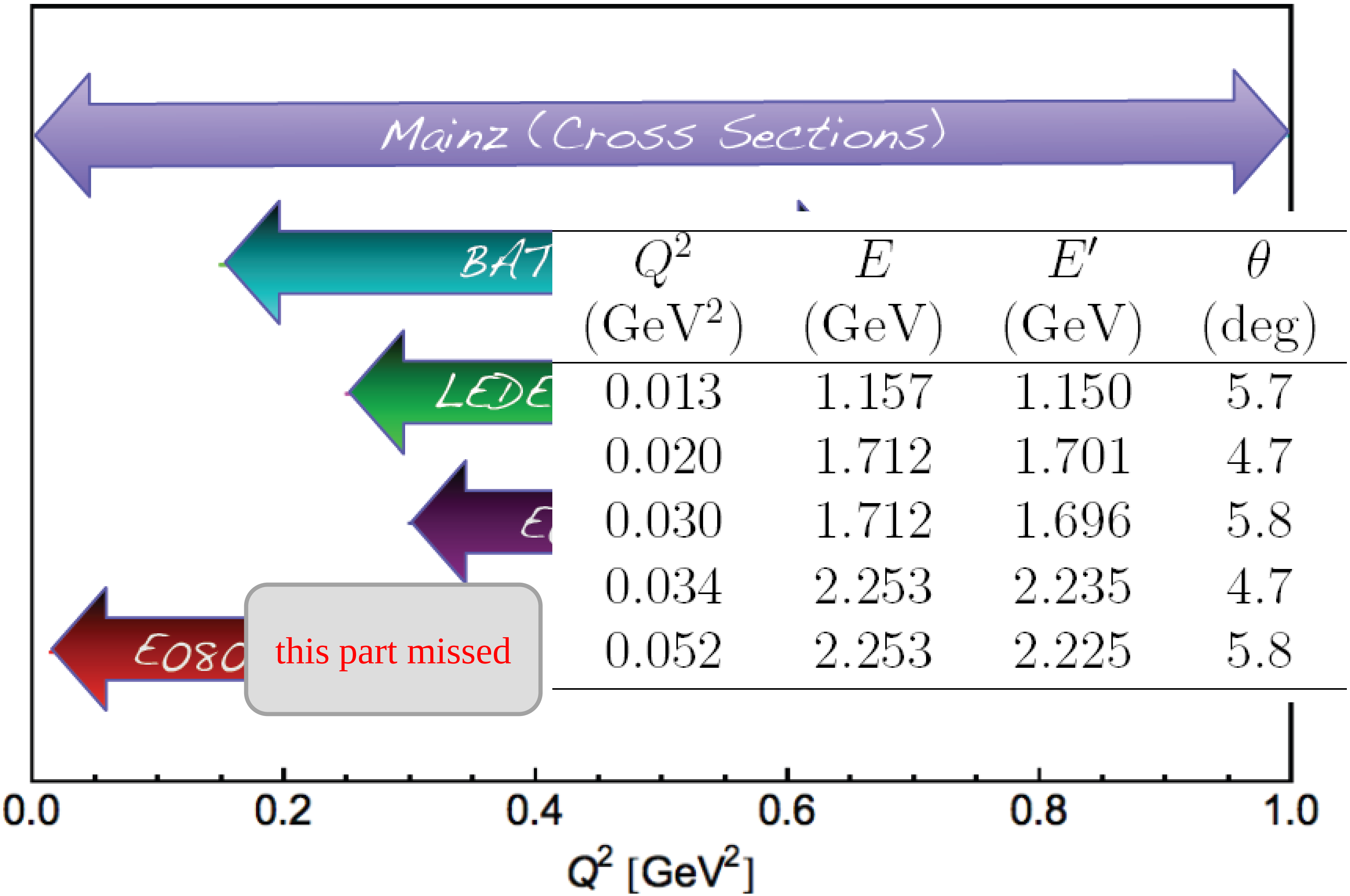
Experiment Setup



Kinematic Coverage

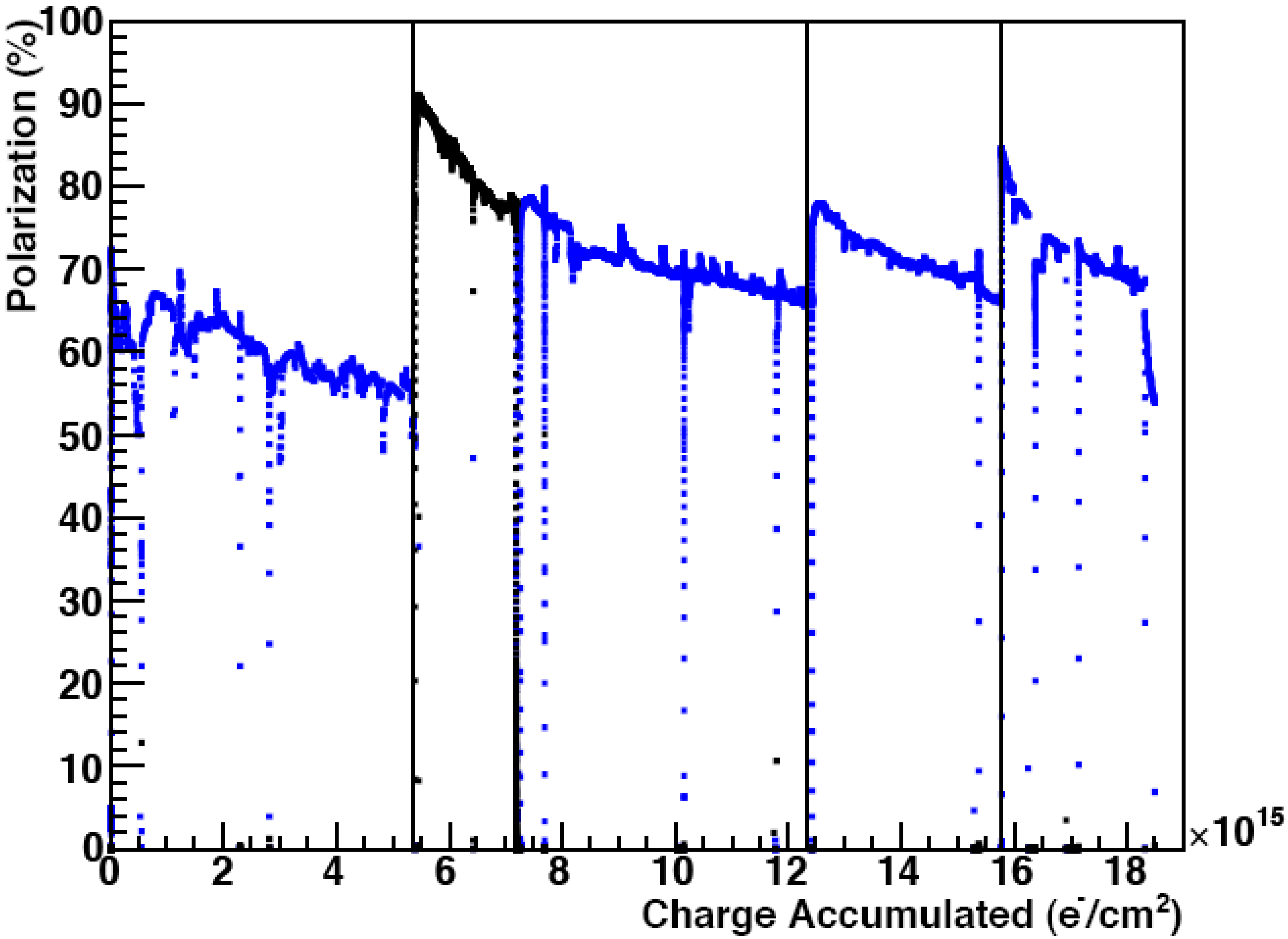


Kinematic Coverage



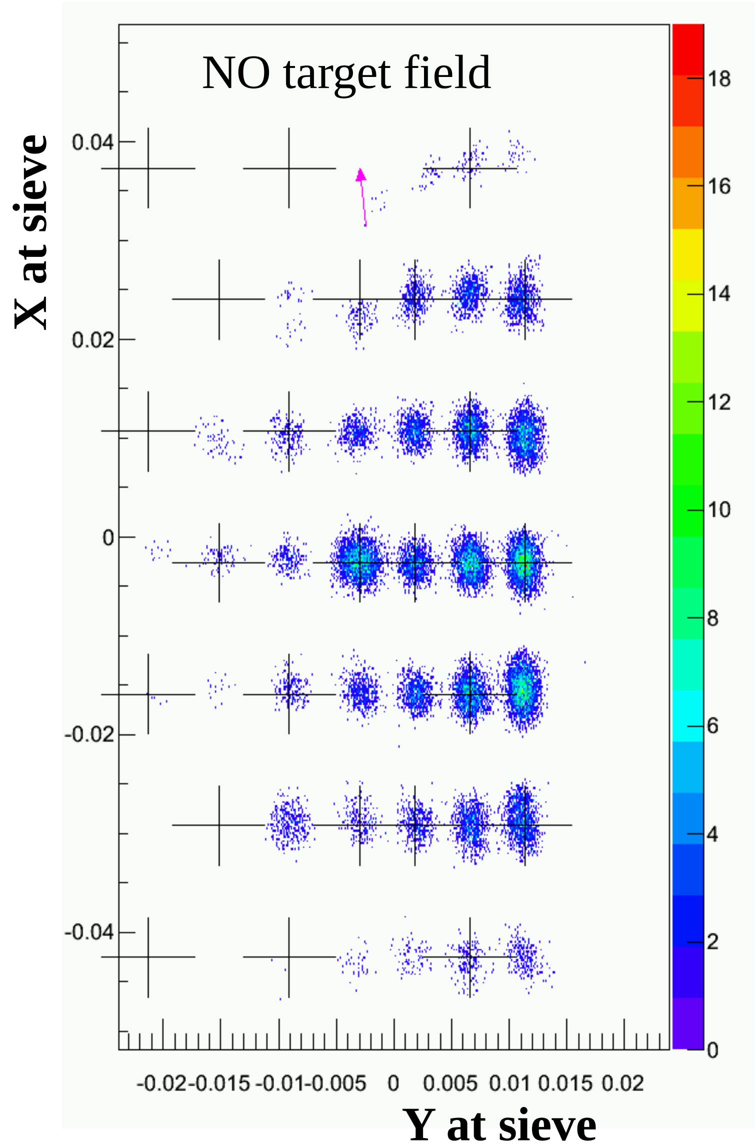
Q^2 (GeV^2)	E (GeV)	E' (GeV)	θ (deg)
0.013	1.157	1.150	5.7
0.020	1.712	1.701	4.7
0.030	1.712	1.696	5.8
0.034	2.253	2.235	4.7
0.052	2.253	2.225	5.8

Target Polarization



Polarization uncertainty about 3%

Optics



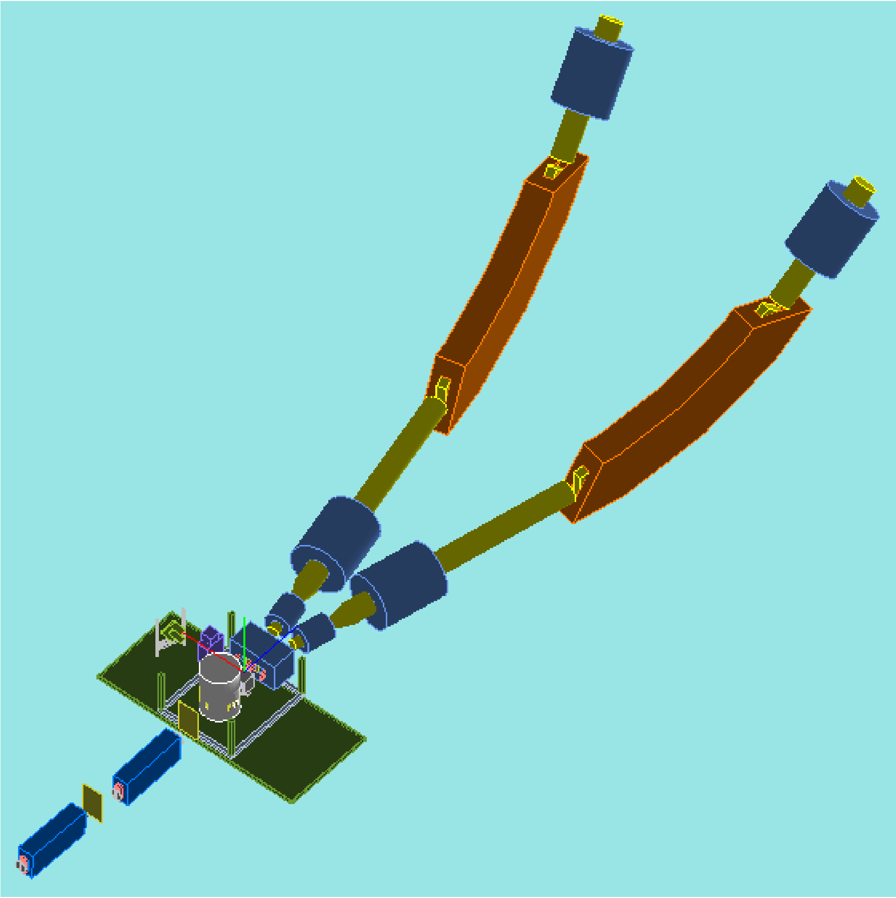
In progress ...
Depends on BPM calibration
Need to implement latest BPM calibaration result

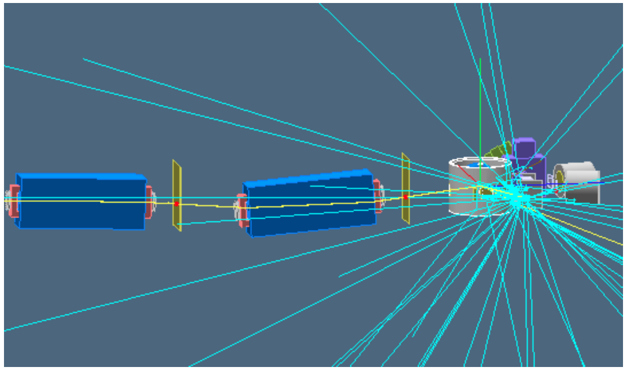
By Jixie, Min, Chao and Ryan

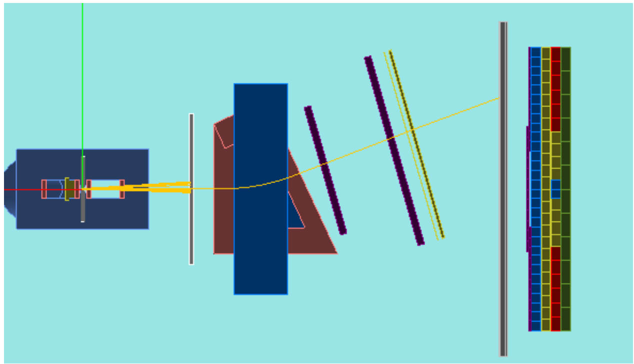
Two steps for optics with target field: (5T target field contribute only 1.6% of its total BdL from the sieve to further away)

1) Using NO field data → Focal plan to Sieve plane reconstruction
2) Ray chase electron from Sieve plane to target plane

Geant4 Simulation, HRSMC

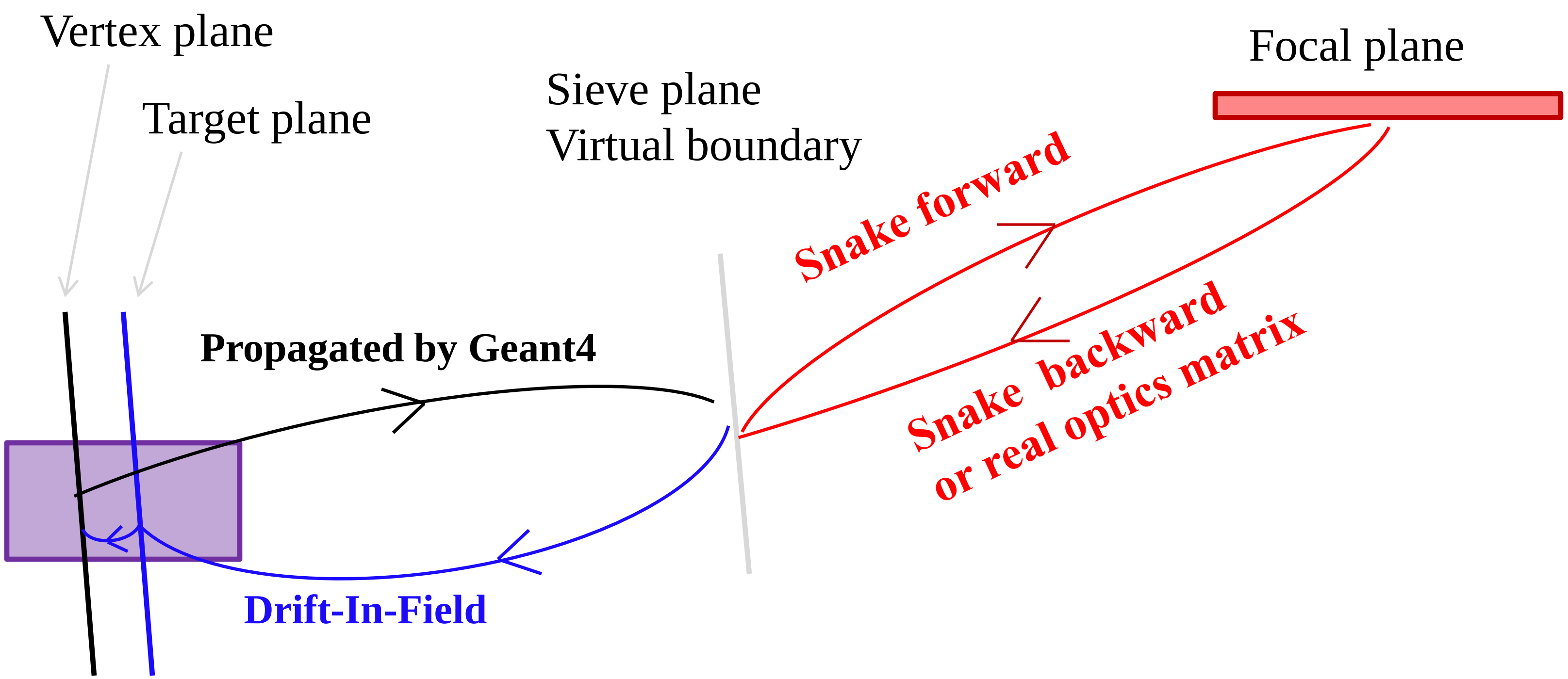






- Designed to support all Hall HRS experiment
- BitBite and HAND included
- Use SANKE transport packages. HRS QQDQ field not include
- Easy to modify for any other experiment. Used by G2P, GEP. tested for CREX

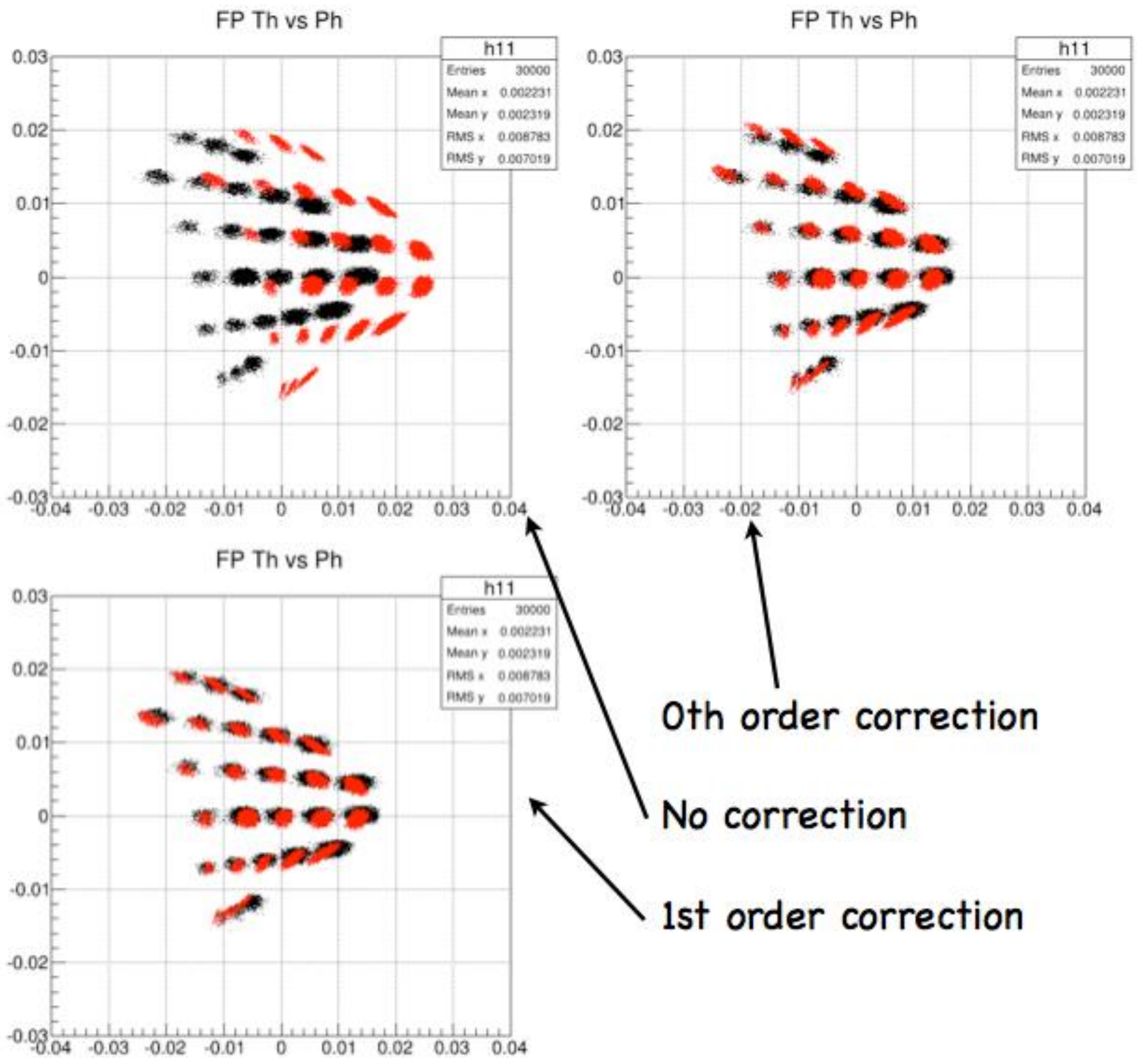
Reconstruction Strategy



Two steps for reconstraction with target field:

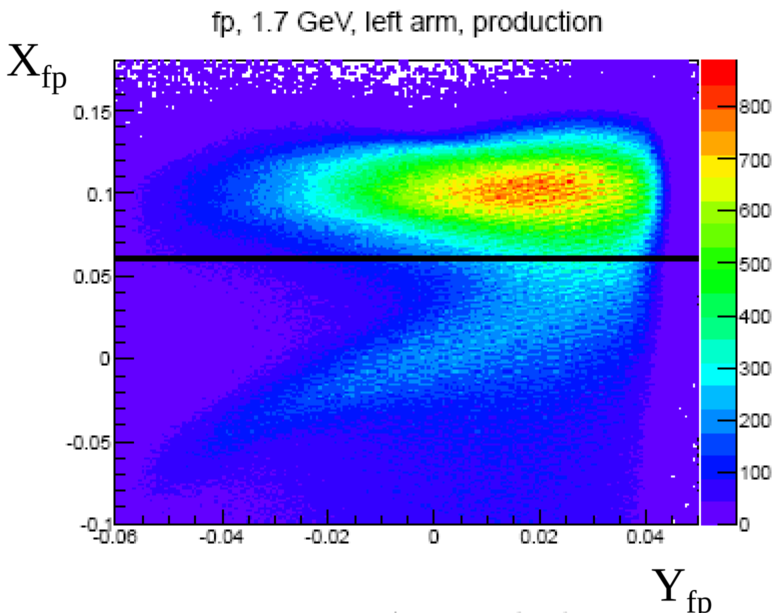
1) Using NO field real optics matrix or snake backward function to reconstruct electron from Focal plane to Sieve plane
2) Ray chase electron from Sieve plane to target plane in the target field

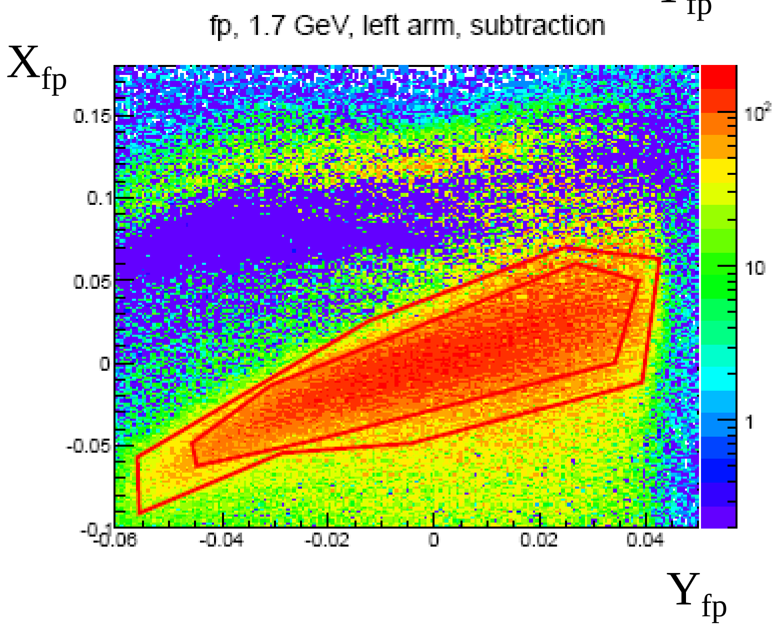
Match Simulation to Real Data



Courtesy of Chao Gu and Min Huang.

Event Slection





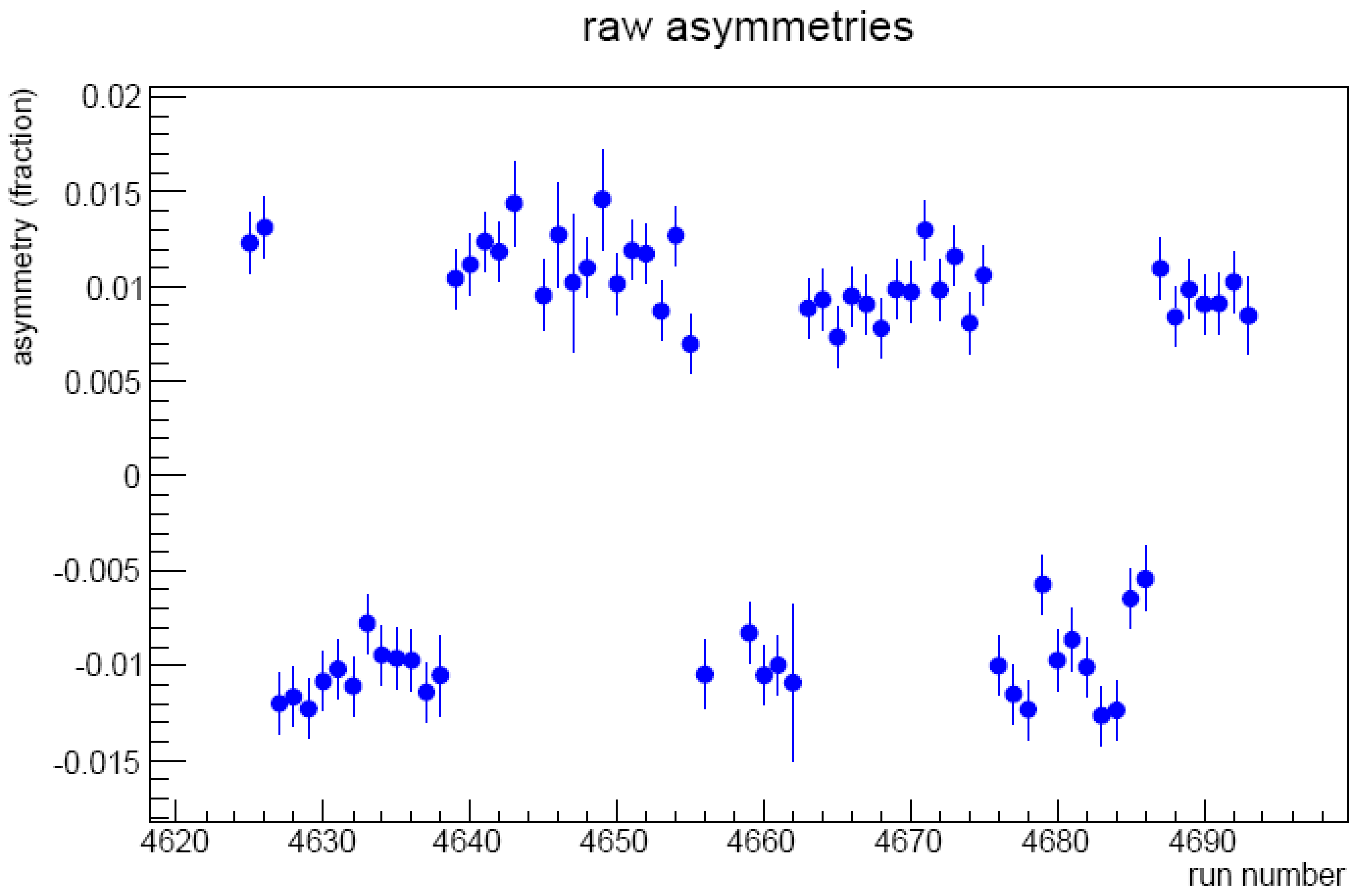
Cut on focal plan variable Xfp and Yfp

Remove Nitrogen and ^{4}He atoms elastic peak to view the H elastic peak clearly

Select e-H elastic events

Make 2 graph cuts on the e-H elastic peak to study the stability of the cuts

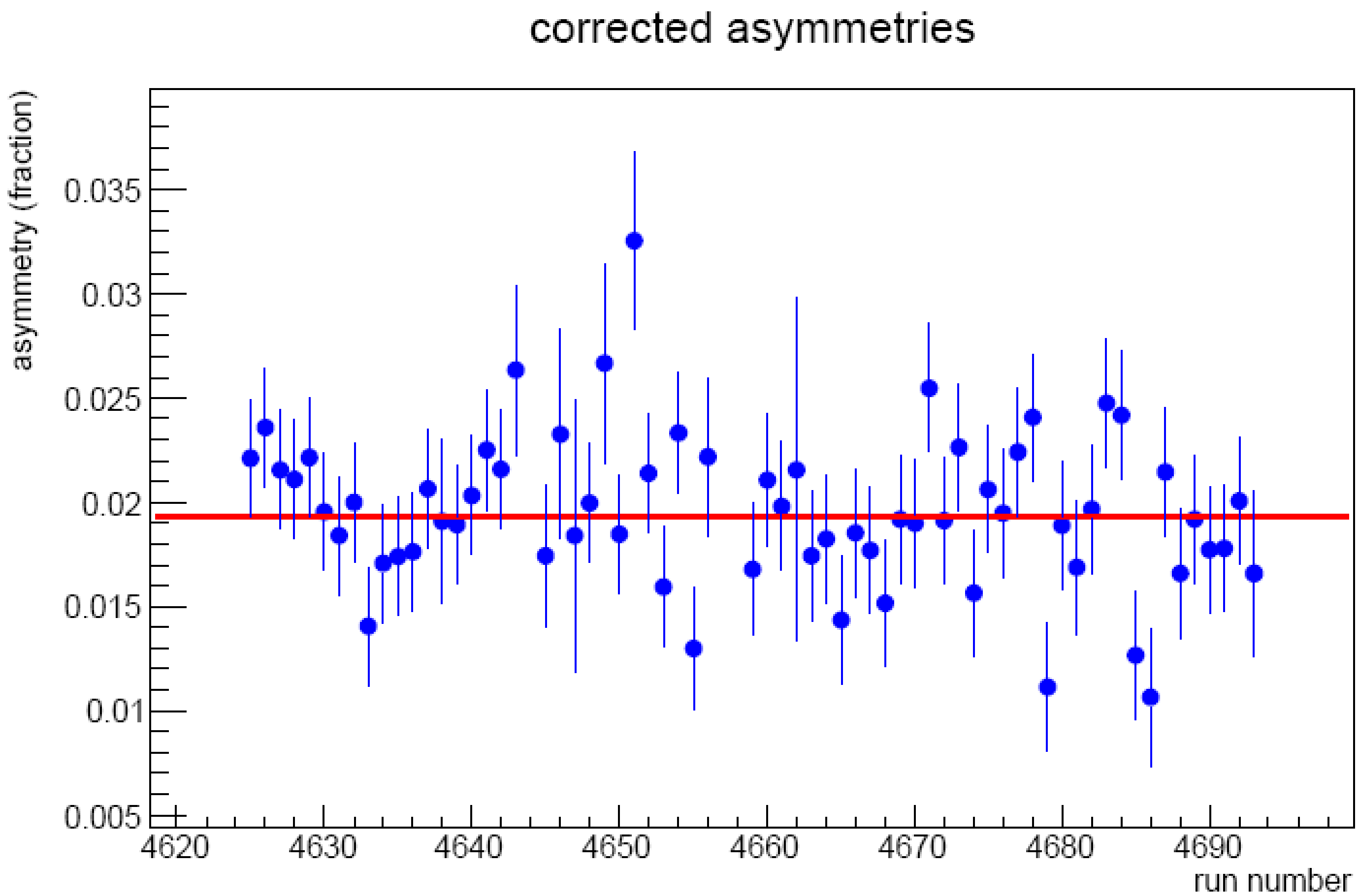
Raw Asysmetry



Uncorrect for beam and charge asymmetries yet

By Moshe

Extracted Asymmtries



Very very preliminary, using a roughly estimated dilution factor.
Uncorrect for beam and charge asymmetries yet

By Moshe

Summary

- Data was taken to cover Q^2 from 0.01 to 0.16 with both left and right HRS
- New instruments, i.e, BCM and BPM works
- The first round and asysmmetry analysis (without apply detector calibrations) was performed
- Target polarization analysis is almost ready
- Will work on simulation to determine the dilution factor
- Will apply detector calibration and use new optics

How G_E Relate to Radius

Slope of GE,M at Q^2=0 defines the radii

$$
\begin{aligned}
G_E^{p(n)}(Q^2) &= \frac{1}{(2\pi)^3}\int d^3r\rho(\vec{r})e^{(-i\vec{q}\cdot\vec{r})} \\
&= \int d^3r\rho(r) - \frac{q^2}{6}\int d^3r\rho(r)r^2 + \cdots \\
&= 1(0) - \frac{q^2}{6}\langle r^2\rangle_{p(n)} + \cdots
\end{aligned}
$$

$$
\langle r_E^{p(n)}\rangle = -6\left(\frac{dG_E^{p(n)}(Q^2)}{dQ^2}\right)_{Q^2=0}
$$

More Results

bin				cut 1				cut 2			
arm	E_e (GeV)	Q^2 range (GeV^2)	Q^2 value (GeV^2)	dilution	A (%)	$\Delta A/A$ (%)	χ^2/ndf	dilution	A (%)	$\Delta A/A$ (%)	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

Table 1: Preliminary asymmetries for the GEp experiment. All numbers should be taken with caution. See text for details.

Nitrogen polarization

Nitrogen is polarized and contributes to the asymmetry

Should be small.

Nuclear Instruments and Methods in Physics Research A 437 (1999) 23}67