E12-07-108: (GMp)

Precision Measurement of the Proton Elastic Cross Section at High Q^2

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(for the GMp collaboration)

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Manpower

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Introduction

- 1917: Discovery of the "proton" (E.Rutherford) – hydrogen nucleus is contained in other nuclei, $^{14}N + \alpha \rightarrow ^{17}O + p$
- 1933: Proton magnetic moment $\mu_p = 2 - 3\mu_N, \mu_N = e\hbar/(2m_p)$ (Otto Stern)

  Proton is not elementary (Dirac) particle, must have a substructure.
- 1961: finite size of the proton through e-p elastic scattering (Robert Hofstadter), $R_P \sim 0.8\, fm$
- The proton's electromagnetic form factors describe the spatial distributions of electric charge and current inside the proton.

$$|Form\ \ factors|^2 = \frac{\sigma(structured\ object)}{\sigma(po\mathrm{int}\,like\ object)}$$

Introduction

- In terms of the Sachs electromagnetic form factors G_E and G_M , the differential cross section for elastic scattering is written compactly as

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott} \frac{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}{\varepsilon (1+\tau)},$$

where the structure-less cross section σ_{Mott} is given by

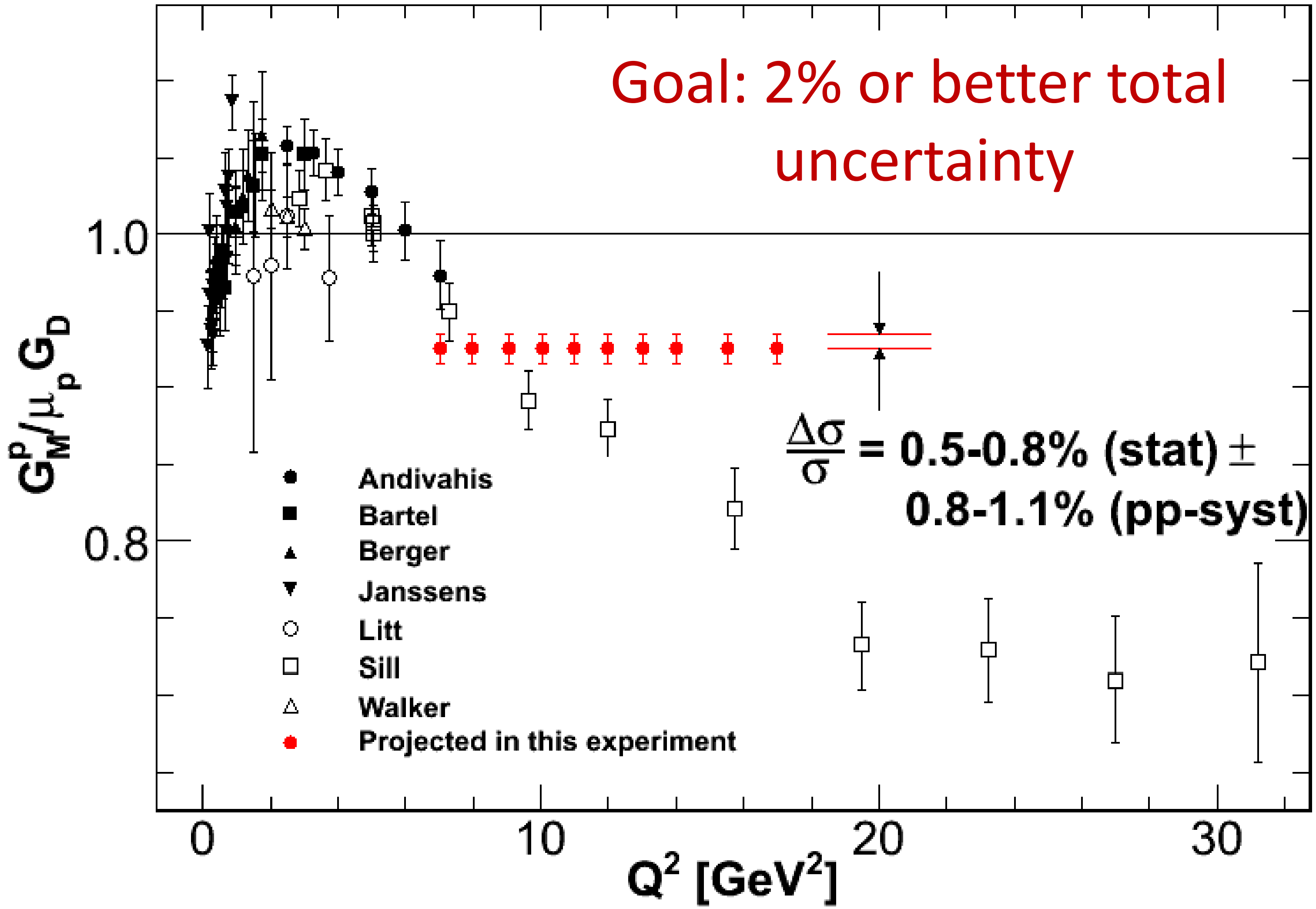
$$\sigma_{Mott} = \left(\frac{\alpha}{2E} \frac{\cos(\theta/2)}{\sin^2(\theta/2)}\right)^2 \frac{E'}{E},$$

with $\tau = Q^2 / 4M_p$, and $\varepsilon = \left[1 + 2(1+\tau)\tan^2\left(\frac{\theta_e}{2}\right)\right]^{-1}$.

Motivations

- Accurately measure e-p elastic cross section in kinematics similar to other JLab form factor measurements ($Q^2 = 7 - 14 GeV^2$).
- Aim to improve the accuracy of the cross section to less than 2%.
- Useful input to all form factor experiments, and many of other experiments where elastic scattering is used for normalization.

Expected Precision



Detailed Kinematics for the Measurement

- We plan to measure the e-p elastic cross section at beam energies of 6.6 GeV, 8.8 GeV and 11 Gev, with both HRSs in a symmetric configuration in electron detector mode.

E_e (GeV)	Q^2 $(\mathrm{GeV})^2$	θ_e (deg)	E' (GeV)	ϵ	Rate (Hz)	Time (hours)	Events
6.6	7.0	35.4	2.869	0.62	7.45	0.7	40k
6.6	8.0	42.0	2.351	0.51	2.29	2.4	40k
6.6	9.0	52.0	1.782	0.37	0.48	11.6	40k
6.6	10.0	67.0	1.249	0.23	0.15	38.3	40k
8.8	9.0	29.3	4.000*	0.67	3.38	3.3	40k
8.8	10.0	33.3	3.465*	0.59	1.31	8.5	40k
8.8	11.0	38.0	2.945	0.51	0.53	10.5	40k
8.8	12.0	44.0	2.423	0.41	0.21	26.7	40k
8.8	13.0	53.0	1.859	0.30	0.06	67.4	28k
11.0	13.0	31.3	4.065*	0.58	0.36	21.2	28k
11.0	14.0	35.0	3.525*	0.50	0.17	39.0	24k
11.0	15.5	42.0	2.742	0.39	0.05	52.8	20k
11.0	17.5	58.0	1.689	0.21	0.01	271.4	16k
						517.8	

Kinematics with scattered electron energy (E') with an asterisk indicate measurements that will only be done with the Left HRS.

Systematic uncertainties

We plan to be aggressive in minimizing the systematic uncertainties:

- **Incident Energy**:

  --Arc method to calibrate the absolute energy ⇒ $(3-4)\times 10^{-4}$ precision

  --beam energy spread will be monitored ⇒ 6×10^{-5} (FWHM)

- **Target density**: The newly designed 15cm long LH_2 cell will be used.

  -- new design ⇒ reduce the effects of density fluctuations.

  -- we will characterize the beam-related density changes.

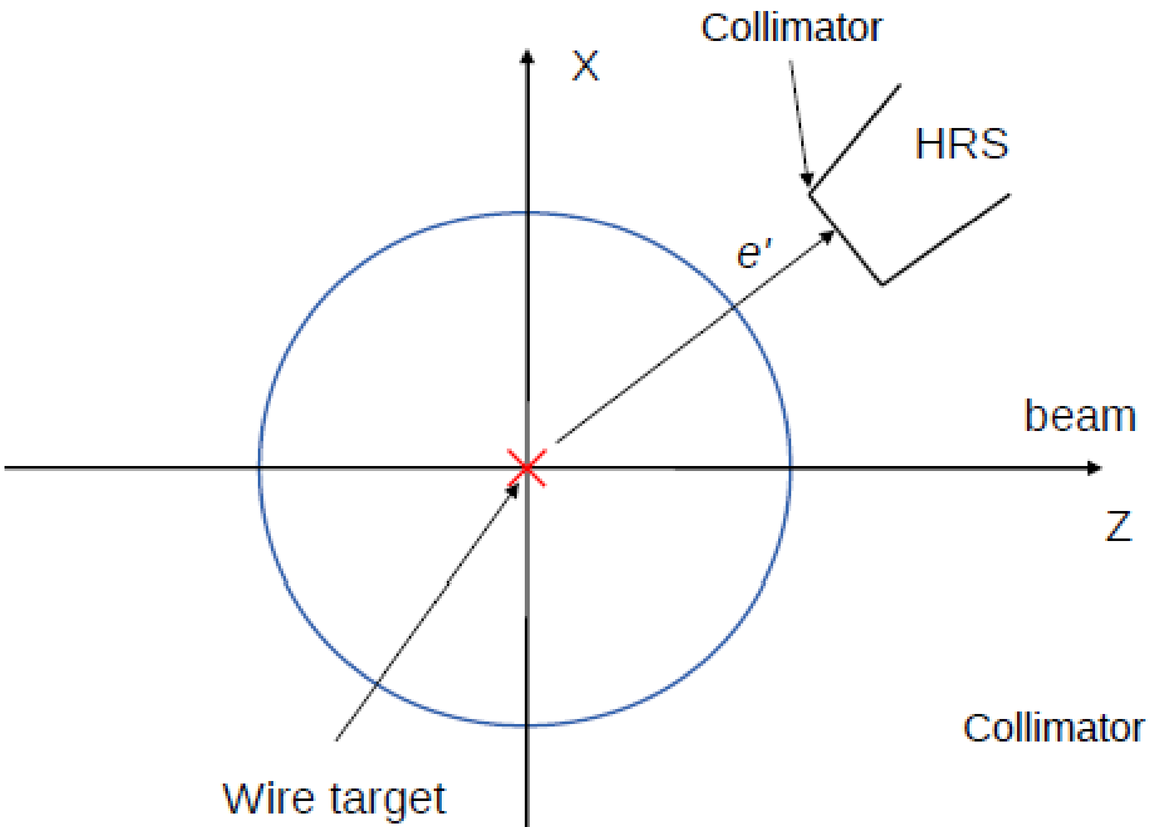
- **Scattering angle**: two independent methods to cross check the angle.

  -- floor marks ⇒ ±0.4mrad precision.

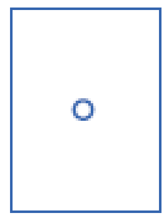
  -- PAM (Precision Angle Measurement) ⇒ less than 0.5mrad precision

continue →

Angle measurement

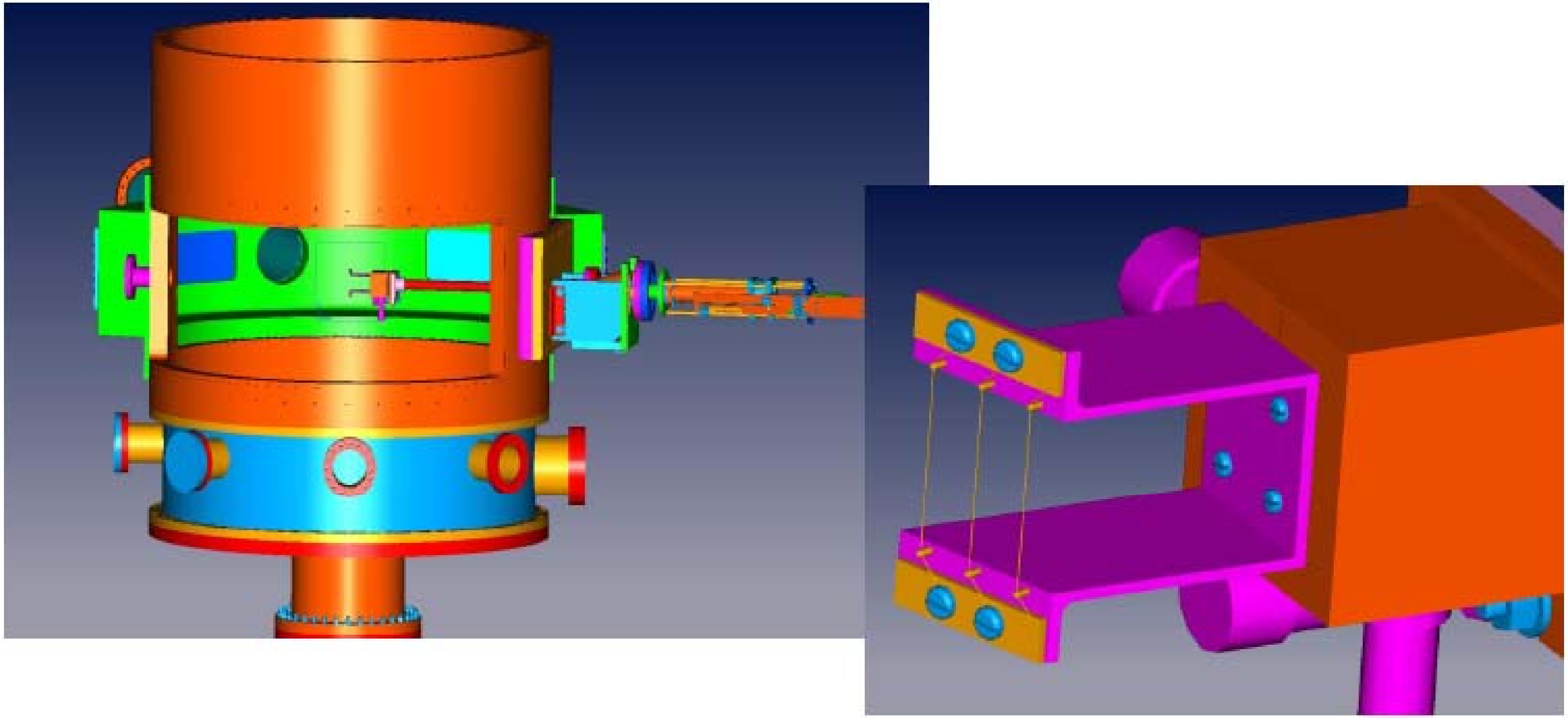


Collimator hole: 0.6 mm diameter



Not to scale

Wire Target for pointing measurement



New design will have cross-hair instead of three wires

Systematic uncertainties

- **Incident beam angle**:
  --the Beam Position Monitors (BPMs) ⇒ 0.1mrad precision
- **Radiative corrections**:
  -- standard corrections large, but well understood.
  -- TPE corrections still uncertain, but does not impact σ_{e-p} for other experiments at JLab kinematics.
- **Optics and spectrometer acceptance**:
  The major issues: the loss of events at apertures within that magnetic elements & the target length acceptance.
  -- Careful studies with taking data with optics target.
  -- Narrower collimator to obtain flatter target length acceptance.
  -- Improve optics optimization analysis code.
- **Detector efficiencies and CPU/Electronic Dead time**:
  -- generally high for the HRS.
  -- EDTM pulser for dead time measurement will be improved.
  -- A straw chamber is installed in each arm ⇒ reduce uncertainties associated with the track reconstruction efficiency

Expected systematic uncertainties

Source	$\Delta\sigma/\sigma$ (%)
Point to point uncertainties	
Incident Energy	<0.3
Scattering Angle	0.1–0.3
Incident Beam Angle	0.1–0.2
Radiative Corrections*	0.3
Beam Charge	0.3
Target Density Fluctuations	0.2
Spectrometer Acceptance	0.4–0.8
Endcap Subtraction	0.1
Detector efficiencies and dead time	0.3
Sum in quadrature	*0.8–1.1*

* Not including TPE

The lower numbers indicate the values we hope to achieve if the new PAM device functions as well as desired.

Expected systematic uncertainties

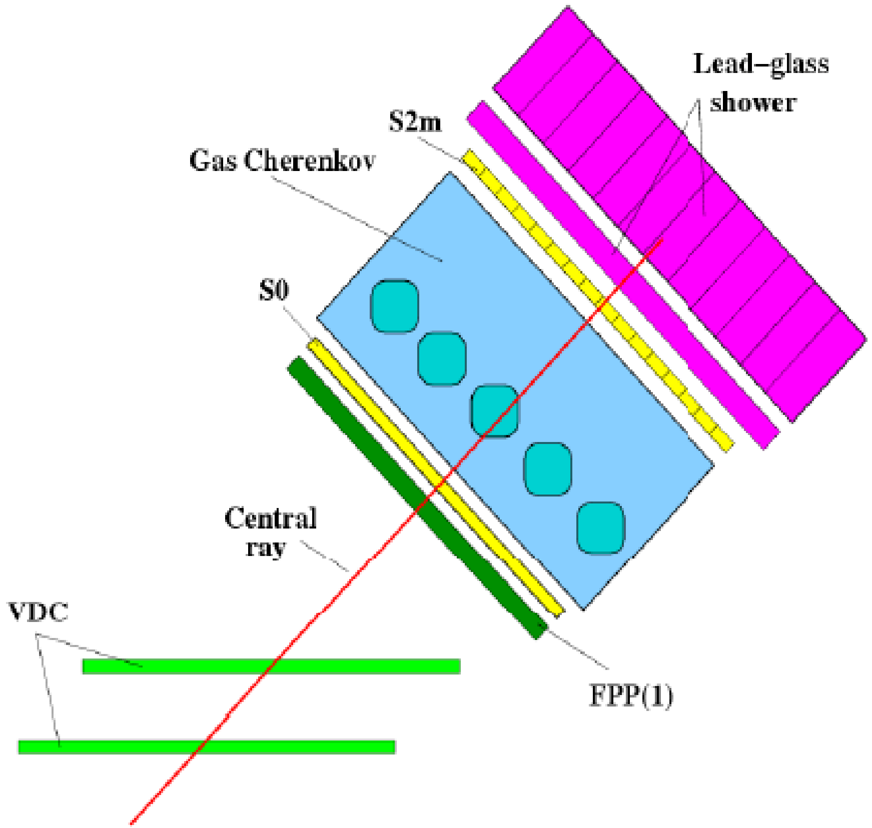
Source	$\Delta\sigma/\sigma$ (%)
Normalization uncertainties	
Beam Charge	0.4
Target Thickness/Density	0.5
Radiative Corrections*	0.4
Spectrometer Acceptance	0.6–1.0
Endcap Subtraction	0.1
Detector efficiencies and dead time	0.4
Sum in quadrature	*1.0–1.3*
Statistics	*0.5–0.8*
Total (Scale+Rand.+Stat.)	**1.2–1.7**

* Not including TPE

The lower numbers indicate the values we hope to achieve if the new PAM device functions as well as desired.

HRS Detector Stack

- One FPP straw chamber is installed in each spectrometer.
- Old VDC disc. cards were replaced with new MAD cards.
- Replace aging PMTs in Gas Cerenkov with new 5” Tubes.
- Modify straw chamber gas distribution system.
- Use wavelength shifter (WLS) for Gas Cerenkov PMTs.
- Fix numerous problems in electronics.
- March 2014 checkout run was successful, and 50+% gain of Cherenkov signal was observed with WLS.



Summary

- Precise e-p elastic cross-section measurement at Q^2 up to $14GeV^2$
- Control systematic uncertainties:

  -- additional instrumentation to Hall A baseline equipment.

  -- improve analysis techniques (such as optics optimization analysis code and tracking reconstruction code).
- First production data in Fall 2014!