Precision measurement of the electron-proton elastic scattering cross-section at High Q^2 (The GMp experiment)

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GMp experiment: E12-07-108

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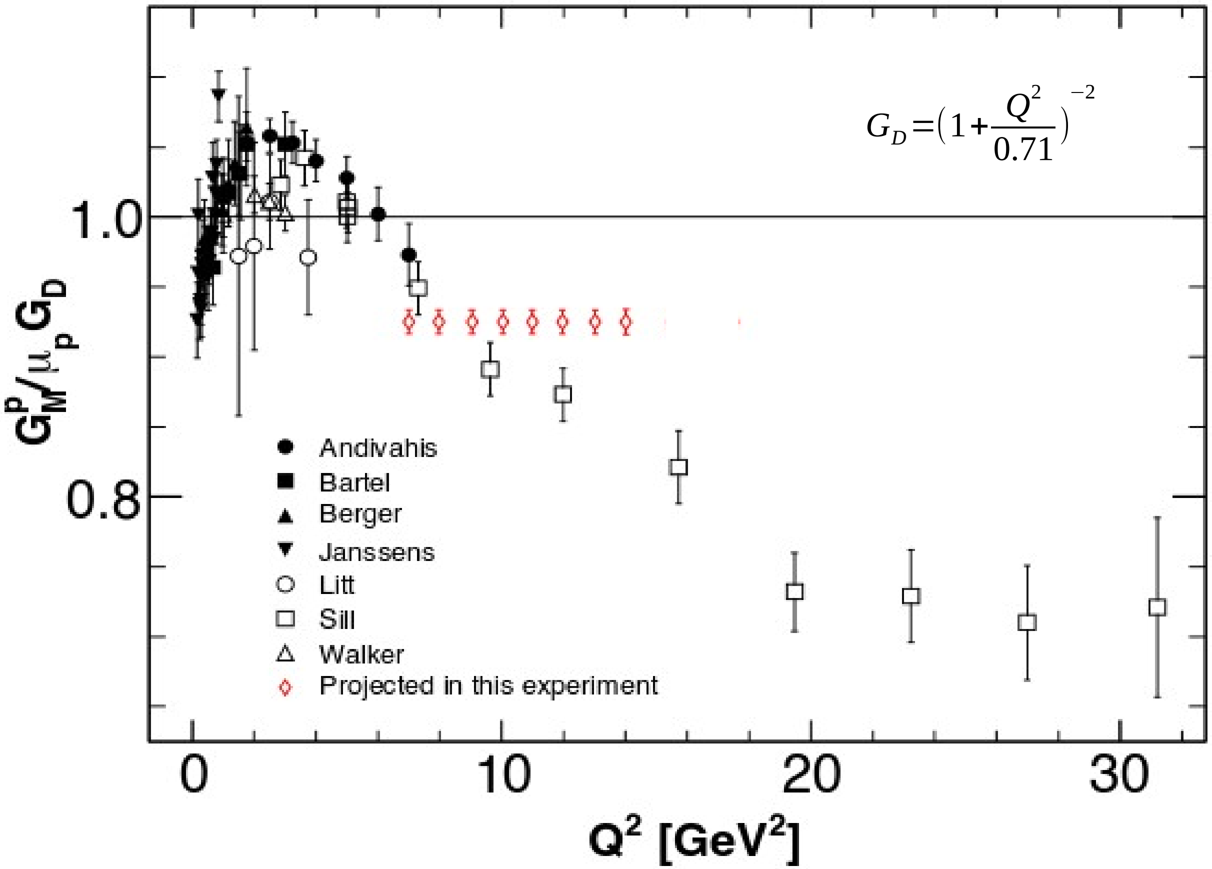


Proton magnetic form factor

- Form factors encode electric and magnetic structure of the target

→ At low Q^2, form factors characterize the spatial distribution of electric charge and magnetization current in the nucleon

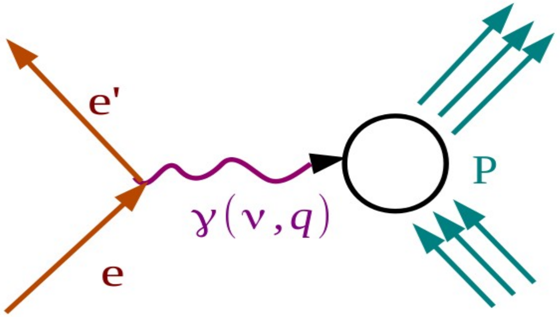
$$|\text{Form Factor}|^2 = \frac{\sigma(\text{Structured object})}{\sigma(\text{Point like object})}$$

$$\mathcal{J}_{\text{proton}} = e\bar{N}(p')\left[\gamma^\mu F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(Q^2)\right]N(p)$$

$$G_E = F_1 - \tau F_2 \qquad G_M = F_1 + F_2$$

- In one photon exchange approximation the cross-section in *ep* scattering when written in terms of G_M^p and G_E^p takes the following form:

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\frac{\epsilon(G_E^p)^2 + \tau(G_M^p)^2}{\epsilon(1+\tau)}, \quad \sigma_{Mott} = \frac{\alpha^2\cos^2\frac{\theta}{2}}{4E^2\sin^4\frac{\theta}{2}}\frac{E'}{E}$$



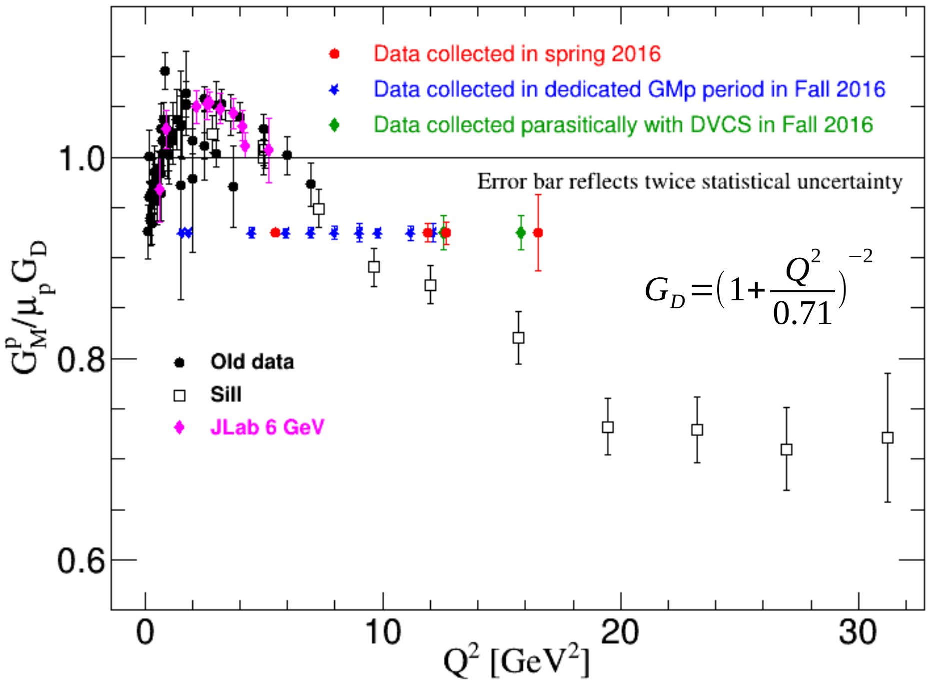
Where, $\tau = \frac{Q^2}{4M^2}, \quad \epsilon = \left[1 + 2(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]^{-1}$

Overview of GMp experiment

- Precision measurement of the elastic *ep* cross-section over the wide range of the Q^2 and extraction of proton magnetic form factors
  - To improve the precision of cross section at high Q^2 by a factor of 3 or better
  - To provide insight into scaling behavior of the form factors at high Q^2

Statistical: Better than 2%

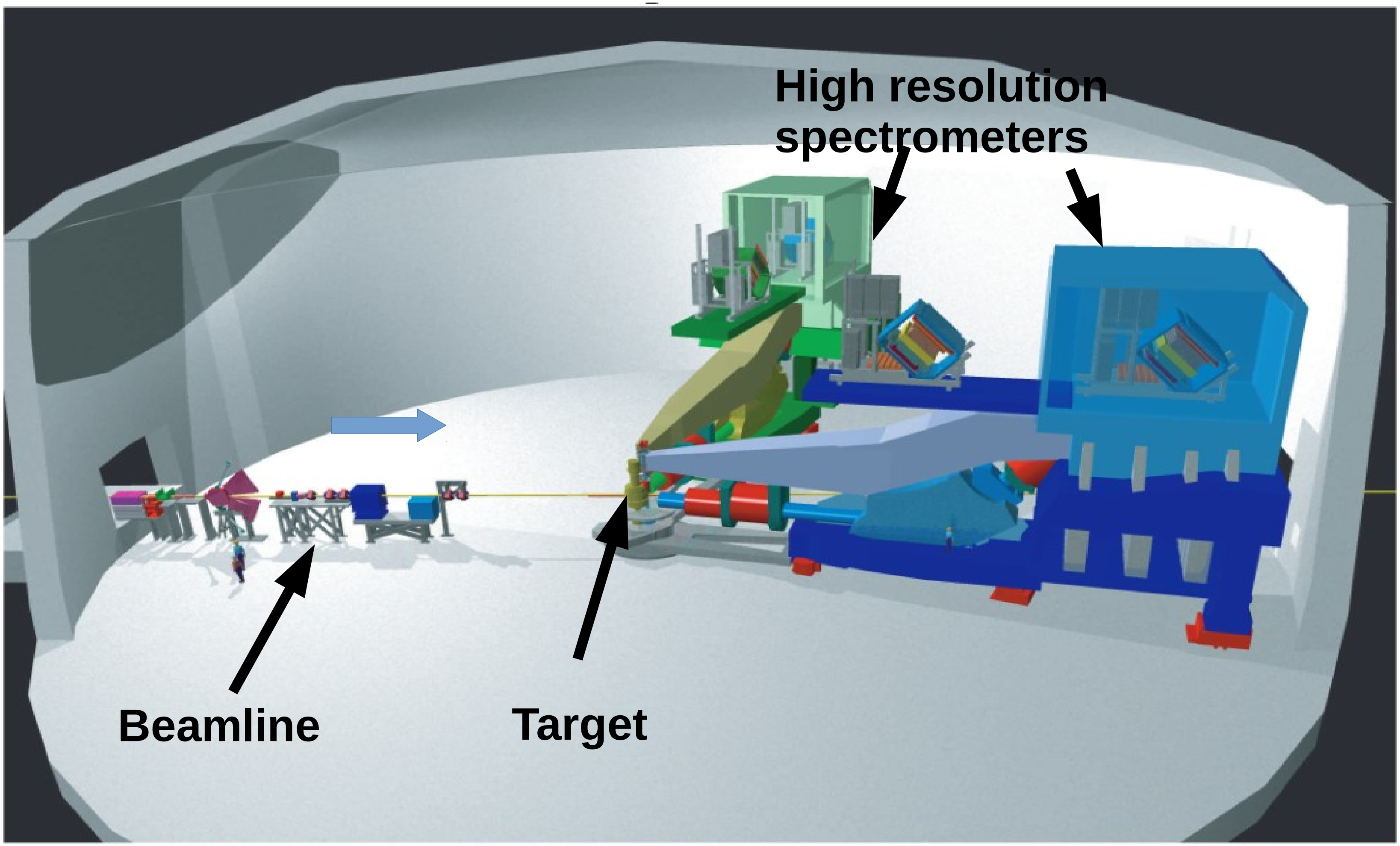
Systematic:
Point to point: 0.8-1.1%
Normalization: 1.0-1.3%
Total Error Budget: 1.2-2.6%



Need a good control on:

- Beam charge
- Beam position
- Scattering angle, target density, ...

Hall A configuration



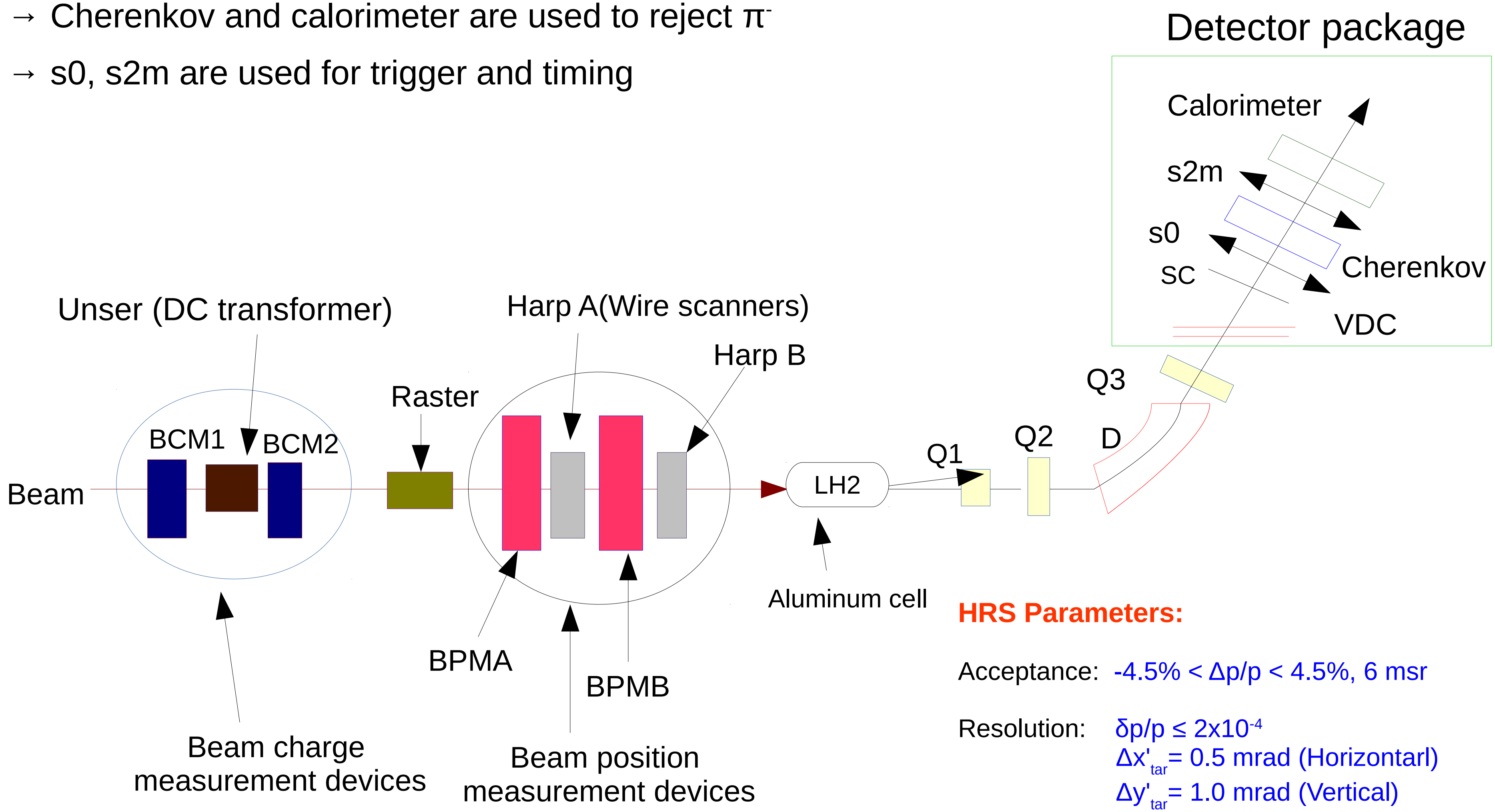
Hall A beamline, spectrometer and detectors

→ VDC is used for tracking information

→ Straw Chamber(SC) is used to reduce systematic on VDC tracking efficiency

→ Cherenkov and calorimeter are used to reject π^-

→ s0, s2m are used for trigger and timing



HRS Parameters:

Acceptance: $-4.5\% < \Delta p/p < 4.5\%$, 6 msr

Resolution: $\delta p/p \leq 2\times10^{-4}$
$\Delta x'_{tar} = 0.5$ mrad (Horizontarl)
$\Delta y'_{tar} = 1.0$ mrad (Vertical)

GMp analysis status

System Calibration:

→ Beamline component Calibration (done)
→ PID detector calibration (done)
→ Tracking detector(VDC, Straw chamber) calibration (done)
→ Timing (s0, s2m) calibration (done)
→ Optics calibration first iteration (first pass done)

Data Analysis:

→ Target boiling analysis (done)
→ HRS acceptance studies (ongoing)
→ Tracking, trigger, PID efficiencies, DAQ livetime (done)
→ First pass cross section analysis (done)
→ Second pass analysis with a goal of 3% measurement (done)
→ Detailed aperture checks in the simulation model (ongoing)

Elastic cross section extraction procedure

- Cross section

$$\frac{d\sigma}{d\Omega}^{data}(\theta) = \int dE' \frac{N^{data}(E',\theta) - N_{BG}(E',\theta)}{\mathcal{L}^{data}.\epsilon.LT} \cdot \frac{RC^{data}}{A^{data}(E',\theta)} \quad (1)$$

- Parameters:

- N_{data} : Number of scattered electrons detected
- N_{BG} : Events from background processes
- $\mathcal{L}$: Integrated luminosity
- ϵ : Correction for efficiencies (raw detector tracking and PID cut)

- LT : Live time correction
- A(E',θ) : Spectrometer acceptance
- RC : Radiative correction factor
- E : Beam energy
- θ : Scattering angle

$$\mathcal{L} = \frac{n_e n_p}{a} = \frac{Q}{e} \rho l \frac{Z}{A} N_A$$

a : Target area
n_e : Number of electron beam
n_p : Number of target atoms
A : Atomic mass of target
l : Length of the target

Elastic cross section (Monte carlo ratio method)

$$\frac{d\sigma}{d\Omega}^{mod}(\theta) = \int dE' \frac{N^{MC}(E',\theta)}{\mathcal{L}^{MC}} \cdot \frac{RC^{MC}}{A^{MC}(E',\theta)} \longrightarrow (2)$$

→ Monte Carlo is a COSY transport model use to transport events through the magnetic fields

→ Scattering events are generated at the target and weighted by the physics cross section model

→ Compare MC yield to data yield for same normalized luminosity

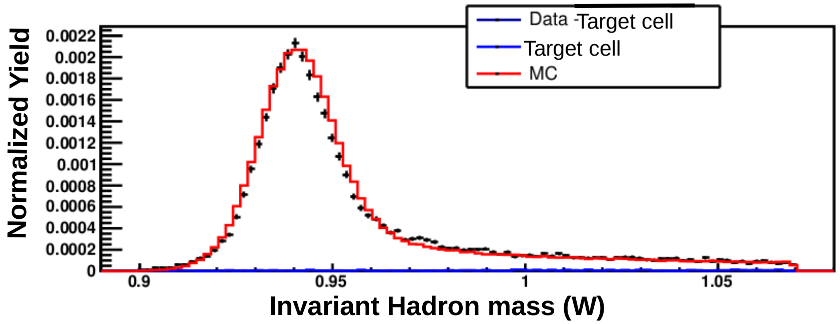
$$\frac{d\sigma}{d\Omega}^{data}(\theta) / \frac{d\sigma}{d\Omega}^{mod}(\theta) = \frac{\int^{E_{max}} (N^{data}(E',\theta) - N_{BG}(E',\theta))dE'}{\int^{E_{max}} N^{MC} dE'} \cdot \frac{A^{MC}(E',\theta)}{A^{data}(E',\theta)} \cdot \frac{RC^{data}}{RC^{MC}} \longrightarrow (3)$$

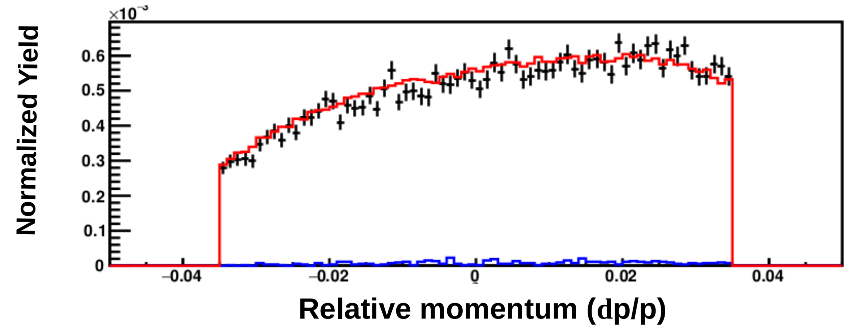
Assuming acceptance and radiative contributions are correctly modeled:

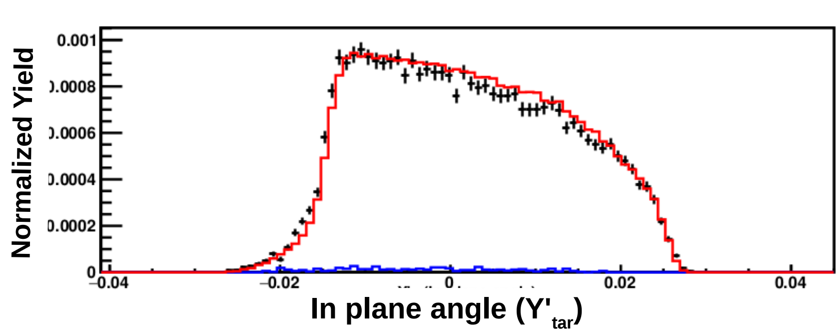
$$\frac{d\sigma}{d\Omega}^{data}(\theta) = \frac{d\sigma}{d\Omega}^{mod}(\theta) . \frac{Y^{data}}{Y^{MC}} \longrightarrow (4)$$

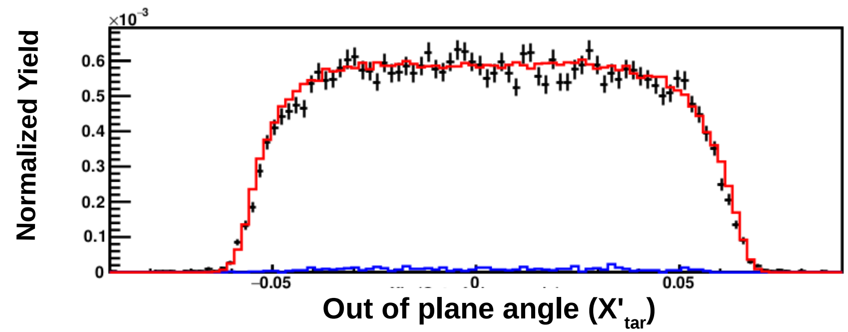
Elastic ep Cross Section Extraction

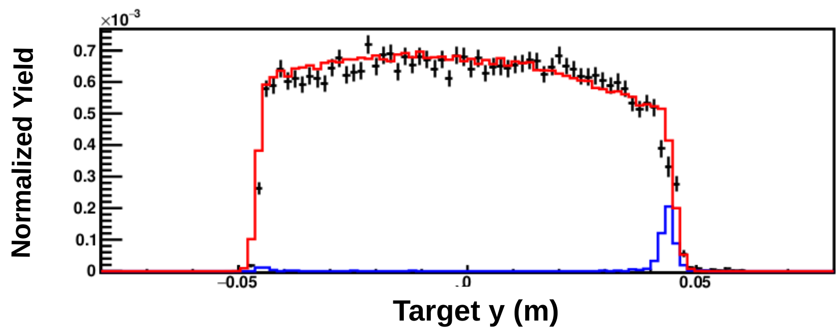
E = 6.427 GeV, θ = 37.0°, p_0 = 2.672 GeV











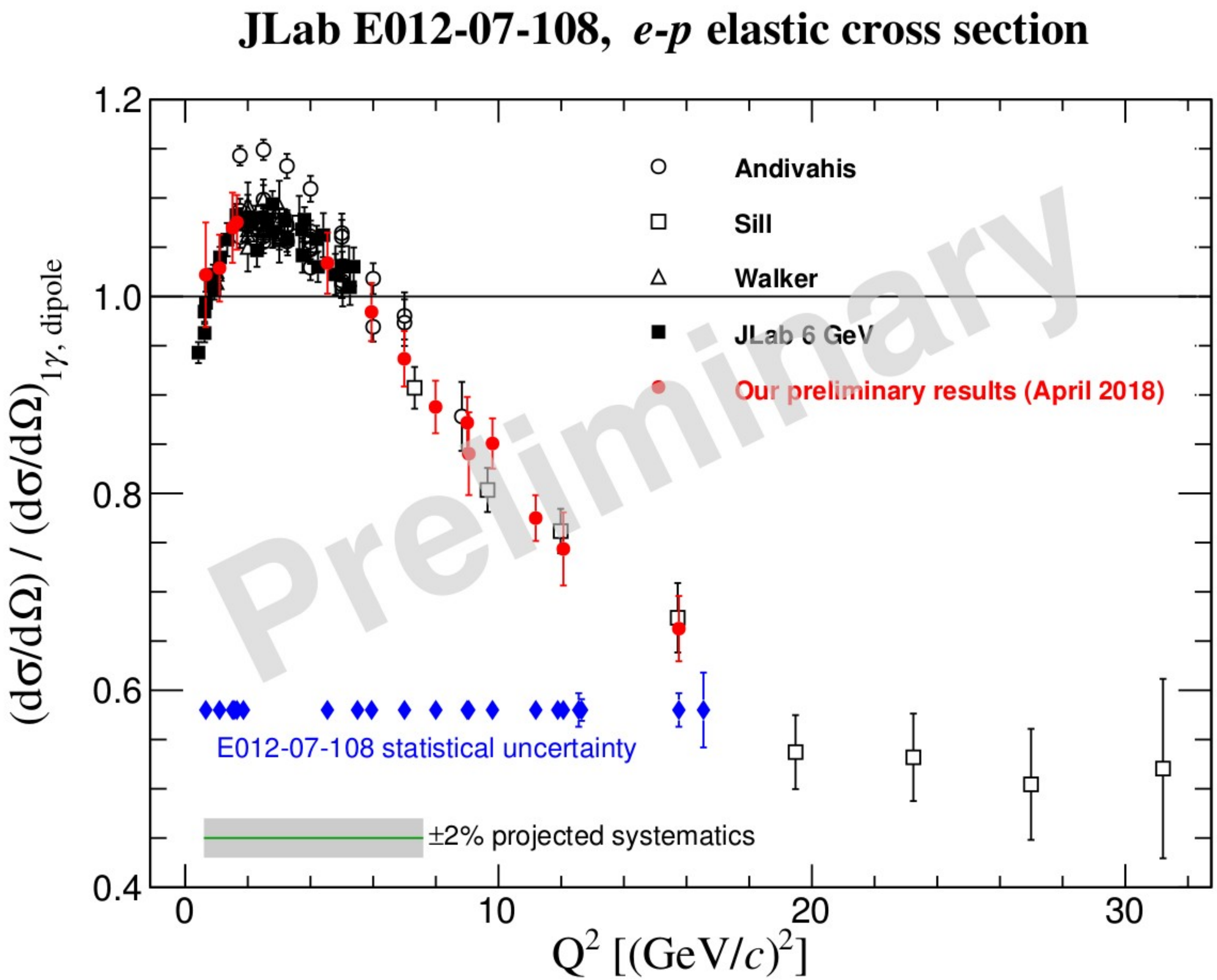
Y^{data}/Y^{MC} = 0.980 ± 0.005

→ Model cross sections multiplied by Data/SIMC ratio gives an estimate of the cross section

→ Independent check of this will be done by the method of software collimator at the sieve slit

Preliminary results (Data/MC method)

- Preliminary cross-section results presented below with 3% systematic uncertainty



Summary

- 12 GeV era GMp experiment data taking with high statistics at Q^2 up to 17 GeV^2 completed successfully
- Detector calibrations are completed and significant progress has been made in the analysis of systematic and spectrometer acceptance study
- Preliminary cross section results with a precision of 3% were extracted
- Projected milestones:

  → Final ~2% cross section results expected in summer 2018

GMp collaboration

- Hall A collaboration, physics staff, technical staff, accelerator team and shift takers
- Spokesperson: J. Arrington, E. Christy, S. Gilad, V. Sulkosky, B. Wojtsekhowski (contact)
- Postdoc: Kalyan Allada (MIT)
- Graduate students: Thir Gautam (Hampton U.), Longwu Ou (MIT), Barak Schmookler (MIT), Bashar Aljawrneh (NCA&T Uni.), Yang Wang (W&M)

Thank you everybody!