E12-07-108 (GMp)

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

PAC32 12 GeV Proposal : PR12-07-108

Spokespersons: Bryan Moffit (MIT)
Shalev Gilad (MIT)
Bogdan Wojtsekhowski (JLab)
John Arrington (ANL)

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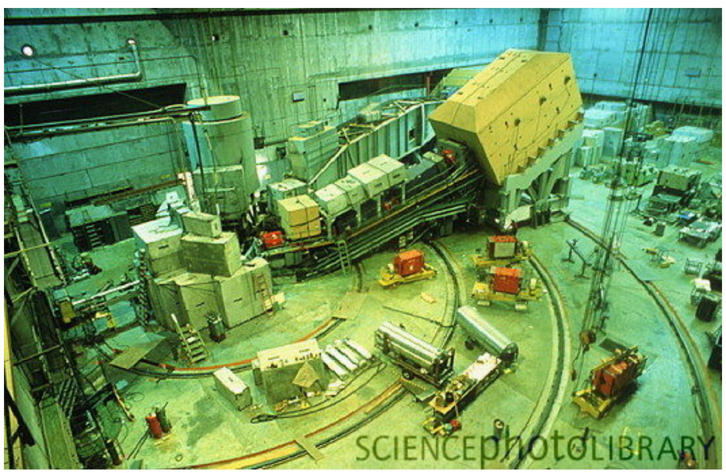
Grading and beam time were considered by PAC35:

PR12-07-108: The PAC recommends a beam time assignment of 24 days, compared with the request for 31 days, by asking the experimentalists not to pursue a measurement at the highest Q^2 point.

SLAC first measurement



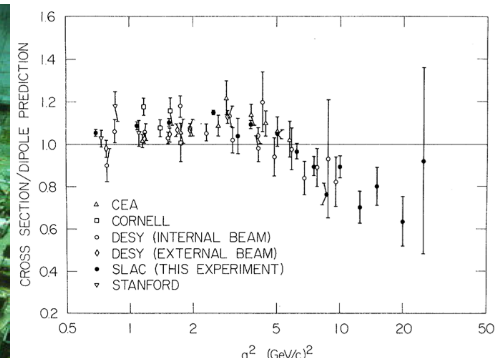


FIG. 1. Compilation of electron-proton elastic-scattering cross sections for q^2 greater than 0.7 (GeV/c)^2. The cross sections are normalized to the Rosenbluth formula and the dipole relation. Systematic errors in the SLAC data are not shown, but would be up to 6%.

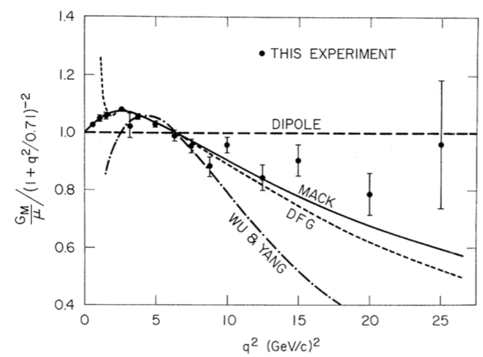


FIG. 2. Comparison of several theoretical expressions for G_M/μ and the SLAC data from Table I. Details of the fits are given in the text.

SLAC results in 1968

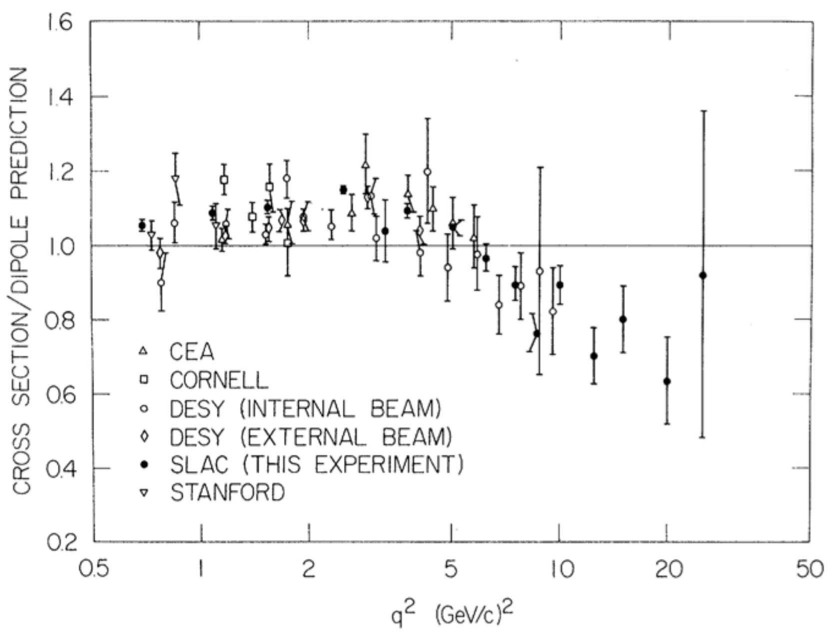


FIG. 1. Compilation of electron-proton elastic-scattering cross sections for q^2 greater than 0.7 $(\mathrm{GeV}/c)^2$. The cross sections are normalized to the Rosenbluth formula and the dipole relation. Systematic errors in the SLAC data are not shown, but would be up to 6%.

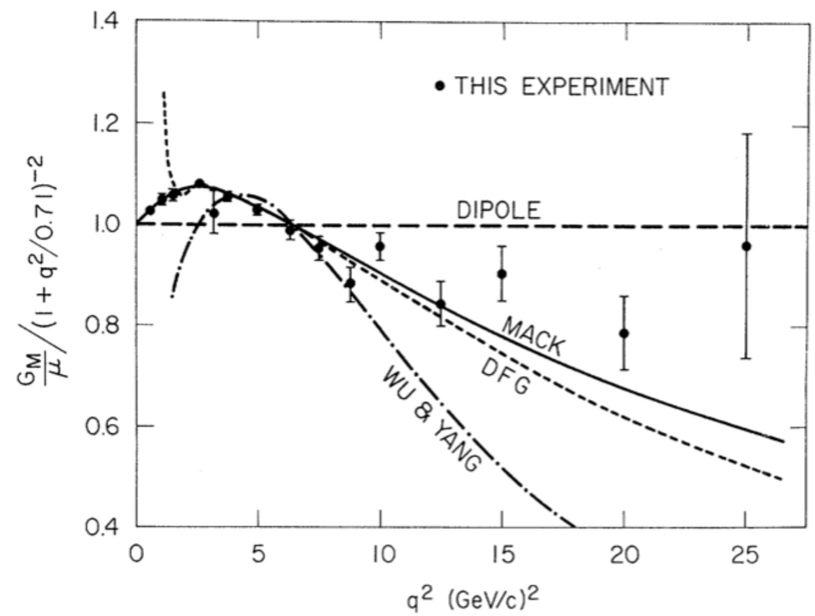


FIG. 2. Comparison of several theoretical expressions for G_M/μ and the SLAC data from Table I. Details of the fits are given in the text.

PRL 20, 292 (1968), GMp scales to $G_D = 1/(1+Q^2/0.71)^2$

SLAC results for the proton Form Factors

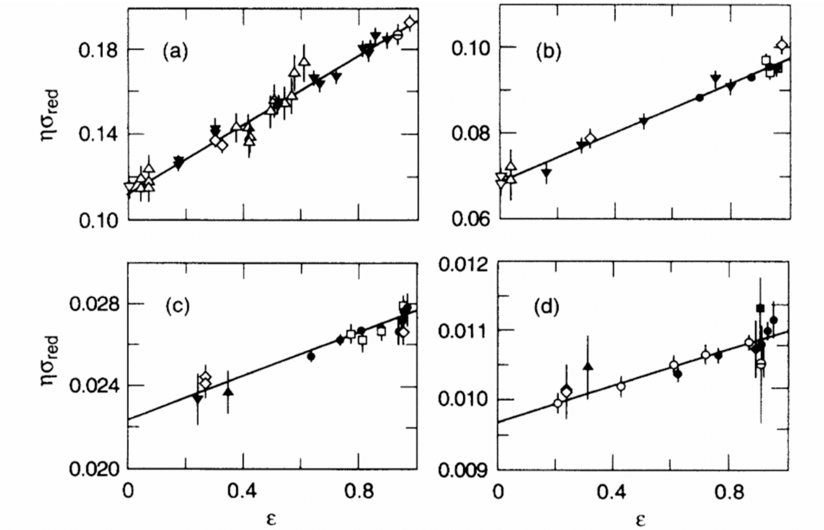
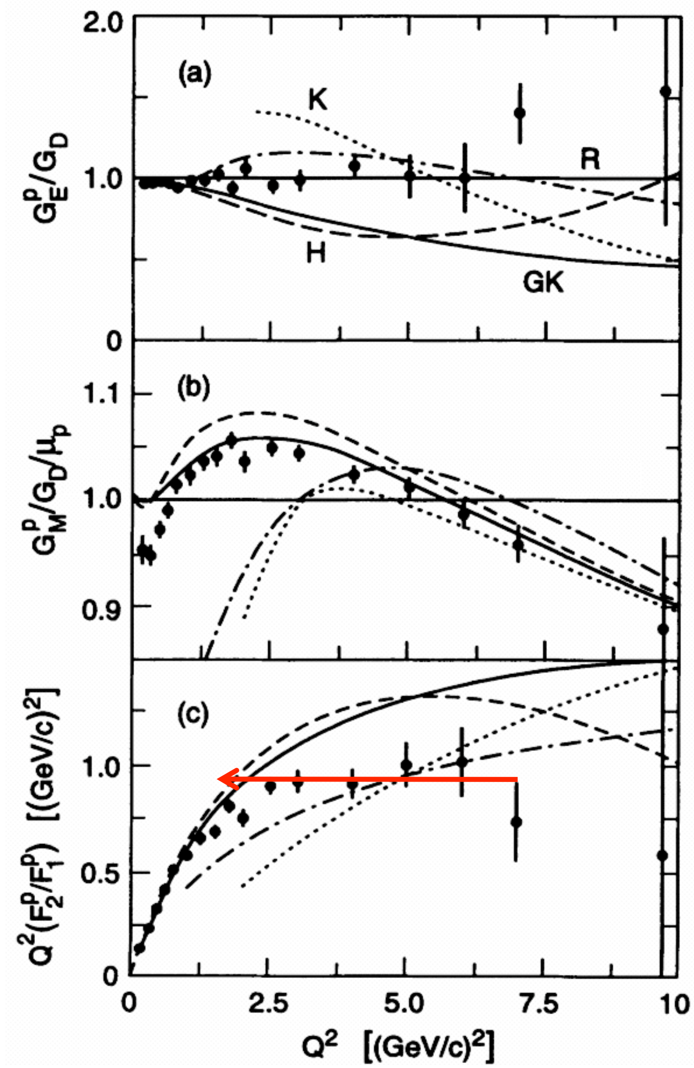
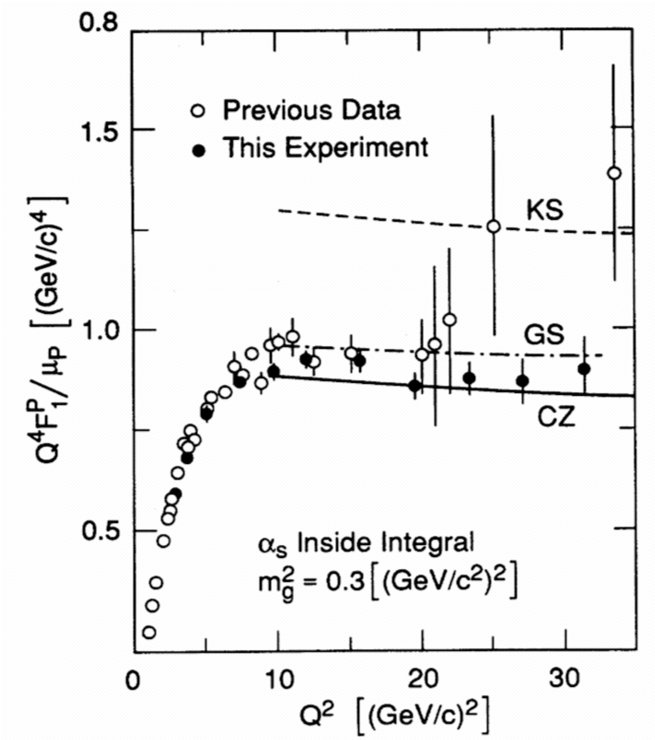


FIG. 9. Four typical Rosenbluth fits for the form factor extraction from the global data set at (a) $Q^2 = 0.6$, (b) $Q^2 = 1.0$, (c) $Q^2 = 2.0$, and (d) $Q^2 = 3.0$ $(\mathrm{GeV}/c)^2$.



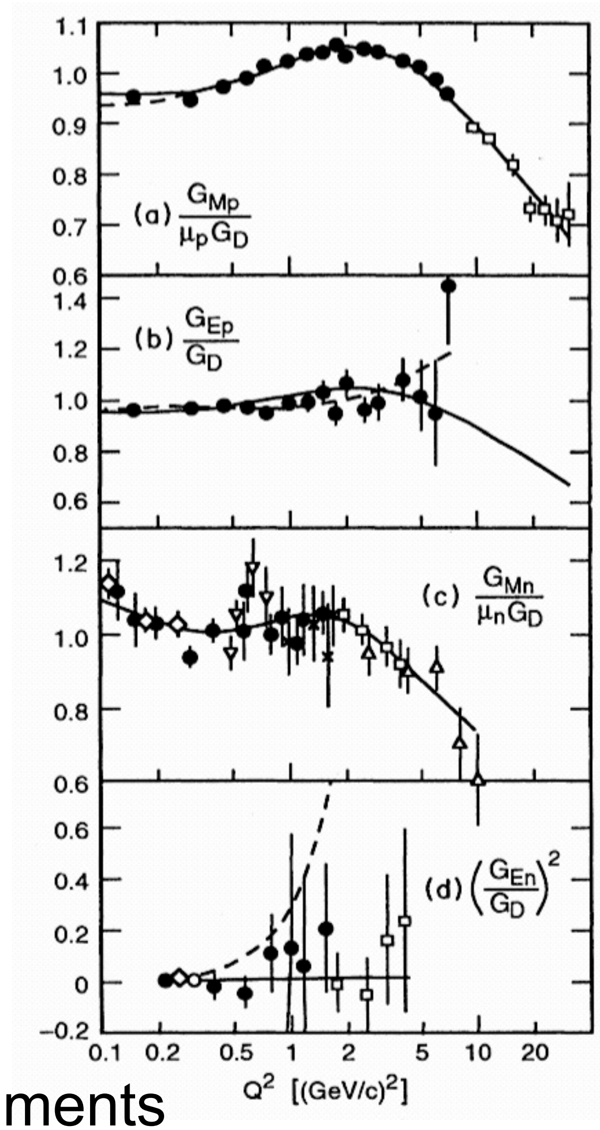
Walker et al
(1993)

SLAC results for the Form Factors



Sill et al (1993)

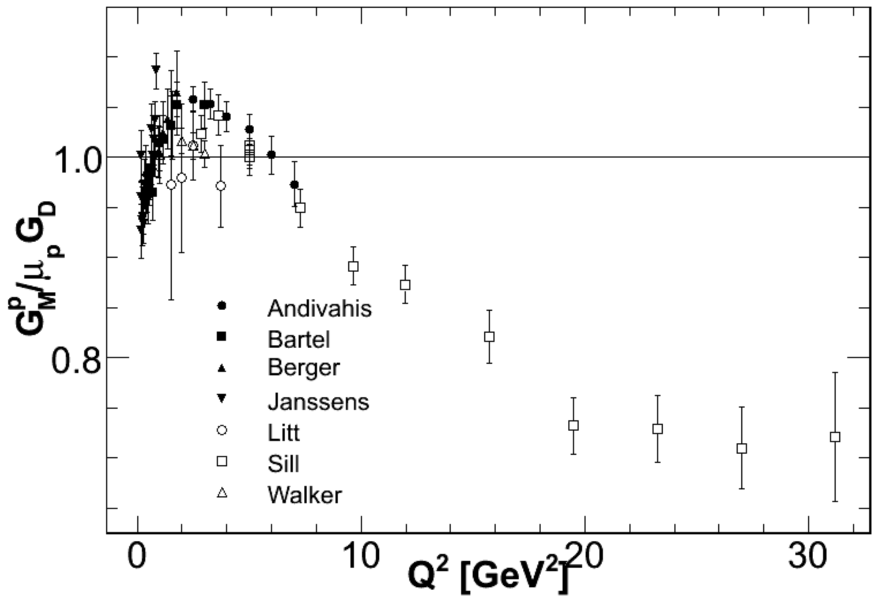
Bosted (1995)



What does it mean?

These are the (e,e') single arm measurements

Form Factors - High Q^2



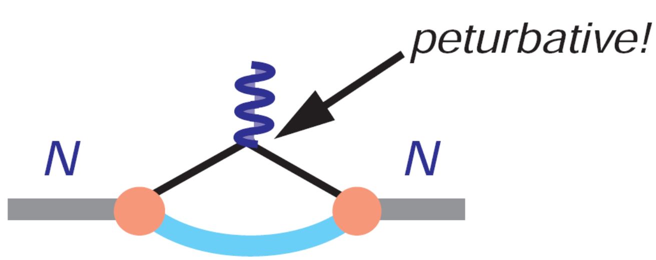


Figure from 12 GeV Upgrade pCDR

Predictions from QCD?

QCD Lagrangian:

- Nucleon Structure in terms of quark and gluon degrees of freedom

GPDs:

- How does the active quark couple to the proton?

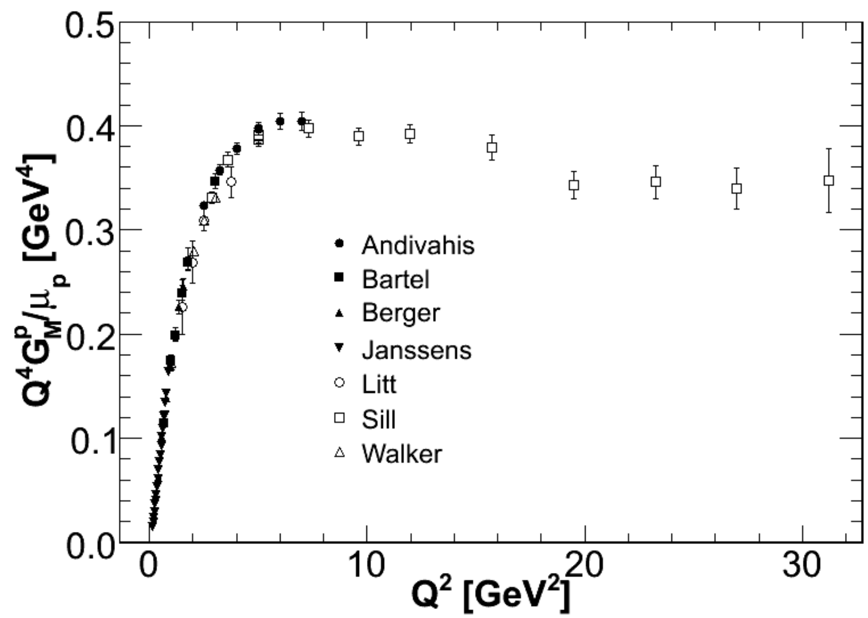
$$F_1(t) = \int_{-1}^{+1} \sum_q dx\, H^q(x, \xi, t)\, dx$$

$$F_2(t) = \int_{-1}^{+1} \sum_q dx\, E^q(x, \xi, t)\, dx$$

Form Factor Scaling

At high values of Q^2,
asymptotic freedom [small $\alpha_s(Q^2)$] allows for pQCD calculations.

How high is that?



Dimensional Scaling:

Form Factors scale asymptotically as $(Q^2)^{-(n-1)}$

n = participating valence quarks

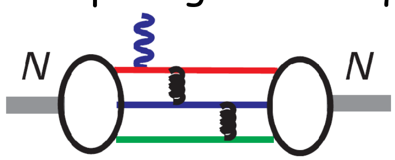


Figure from 12 GeV Upgrade pCDR

$$Q^4 G_M^p \propto Q^4 F_1^p \sim constant$$

pQCD -> logarithmic departures from Q^2 dependence

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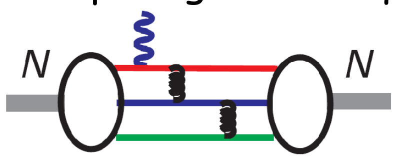
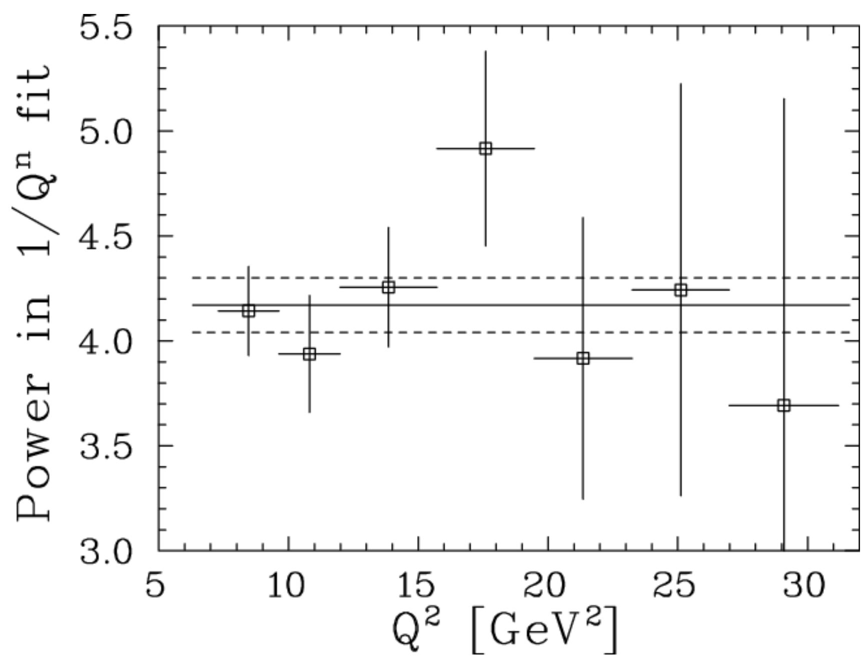


Figure from 12 GeV Upgrade pCDR

$$Q^4 G_M^p \propto Q^4 F_1^p \sim constant$$



pQCD -> logarithmic departures from Q^2 dependence

Cross Section -> Form Factors

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott} \frac{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}{\epsilon (1+\tau)} \qquad \tau = \frac{Q^2}{4 M_p^2}$$

$$\epsilon = [1 + 2(1+\tau)\tan^2(\theta/2)]^{-1}$$

Rosenbluth Separation

- Measure Cross Section at same Q^2 but different E and θ (varying ϵ)
- At sufficiently high Q^2, G_M^P dominates.

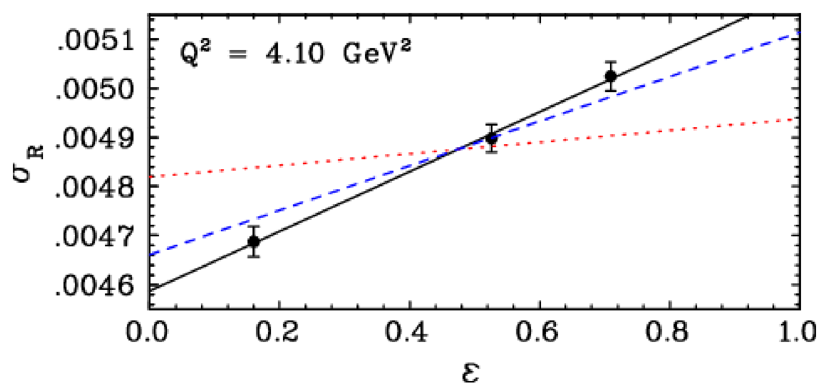


Figure from Qattan et al. **PRL** 94 (2005) 142301

Cross Section -> Form Factors

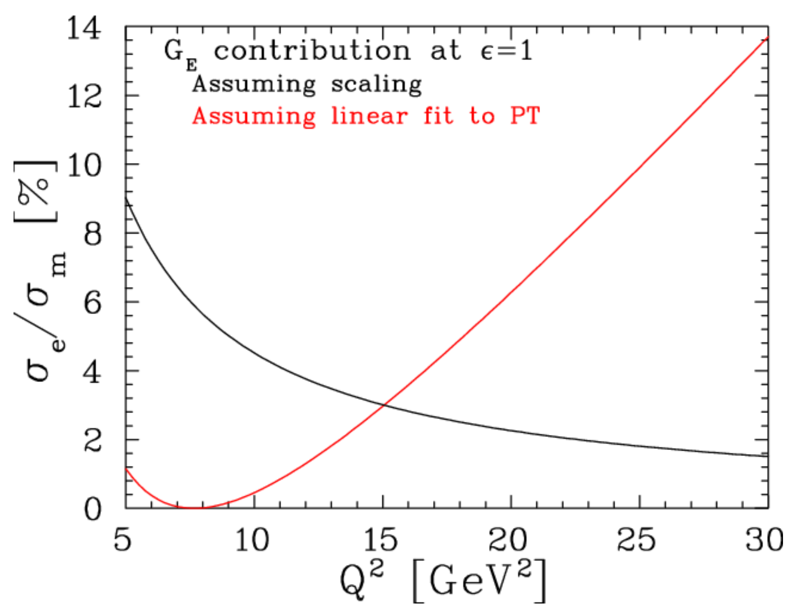
$$\frac{d\sigma}{d\Omega} = \sigma_{Mott} \frac{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}{\epsilon (1+\tau)}$$

$$\tau = \frac{Q^2}{4 M_p^2}$$

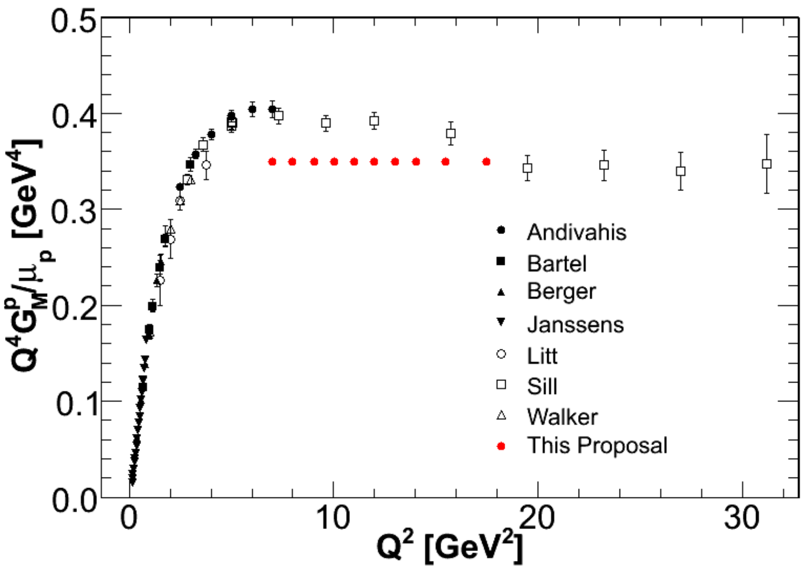
$$\epsilon = [1 + 2(1+\tau)\tan^2(\theta/2)]^{-1}$$

Rosenbluth Separation

- *Measure Cross Section at same Q^2 but different E and θ (varying ϵ)*
- *At sufficiently high Q^2, G_M^P dominates.*



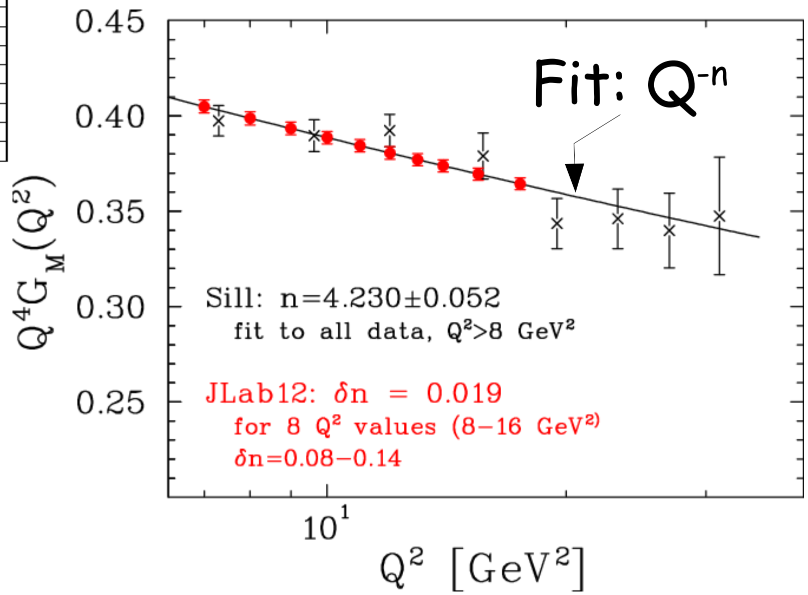
Precision Study of Q^2 Dependence



What is the power of the Q^2 dependence?

How does G_M^p approach the pQCD limit?

Onset of Scaling Behavior at Q^2 ~ 7-8 GeV^2?



Kinematics

- 3 Beam Energies
  - I = 80μA
- Both HRSs in symmetric configuration*
- 3 Redundant Q^2
  - Different ε
- 21.5 days for LH_2
- 31 days requested

E_{beam}	Q^2	θ	E'	ε	Hours	Events
6.6	7.0	35	2.87	0.62	1	40k
	8.0	42	2.35	0.51	3	40k
	9.0	52	1.78	0.37	12	40k
	10.0	67	1.25	0.23	38	40k
8.8	9.0	29	4.00*	0.67	3	40k
	10.0	33	3.47*	0.59	9	40k
	11.0	38	2.95	0.51	11	40k
	12.0	44	2.42	0.41	27	40k
	13.0	53	1.86	0.30	67	28k
11	13.0	31	4.07*	0.58	21	28k
	14.0	35	3.53*	0.50	39	24k
	15.5	42	2.74	0.39	53	20k
	17.5	58	1.69	0.21	271	16k

Kinematics

Update for the PAC35 presentation

- 3 Beam Energies
  I = 80μA
- Both HRSs in symmetric configuration*
- 3 Redundant Q^2
  - Different ε
- 21.5 days for LH_2
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E_e (GeV)	Q^2 $(GeV)^2$	θ_e (deg)	E' (GeV)	ϵ	Rate (Hz)	Time (hours)	Events
4.8**	7.0	71.0	1.08	0.25	0.60	9.3	40k
6.6	7.0	35.4	2.87	0.62	7.45	0.7	40k
6.6	8.0	42.0	2.35	0.51	2.29	2.4	40k
5.8**	9.0	77.0	1.00	0.18	0.15	36.3	40k
6.6	9.0	52.0	1.78	0.37	0.48	11.6	40k
8.8	9.0	29.3	4.00*	0.67	3.38	3.3	40k
6.6	10.0	67.0	1.25	0.23	0.15	38.3	40k
8.8	10.0	33.3	3.47*	0.59	1.31	8.5	40k
8.8	11.0	38.0	2.95	0.51	0.53	10.5	40k
8.8	12.0	44.0	2.42	0.41	0.21	26.7	40k
8.8	13.0	53.0	1.86	0.30	0.06	67.4	28k
11.0	13.0	31.3	4.07*	0.58	0.36	21.2	28k
11.0	14.0	35.0	3.54*	0.50	0.17	39.0	24k
11.0	15.5	42.0	2.74	0.39	0.053	52.8	20k
11.0	17.0	53.0	1.94	0.26	0.013	175.2	16k
						503.3	

Kinematics

Update for the PAC35 presentation

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11.0	14.0	35.0	3.54*	0.50	0.17	39.0	24k

24 days

Systematic Uncertainties

Point to Point

Source	$\Delta\sigma/\sigma$ [%]
Incident Energy	0.3
Scattering Angle	0.1 (0.5)
Incident Beam Angle	0.1 (0.5)
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 (1.2)**

Normalization

Source	$\Delta\sigma/\sigma$ [%]
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)**

$\Delta E/E=1\times10^{-3}$ => ~0.70% in $\Delta\sigma$

$\Delta\theta$=1mrad => ~0.75% in $\Delta\sigma$

Lower numbers indicate values estimated if PAM device functions as well as desired

Statistics: 0.5 – 0.8%

TOTAL (Scale + Rand. + Stat.) : 1.3 (1.8) % Goal: 2% or better

Beam Energy

Require use of eP and Upgrade of Arc energy methods for JLab 12 GeV

Precision ~ 3-4 x 10^{-4}

Monitor stability and energy spread with

- OTR
- Tiefenback
- Synchotron Light Interferometer (SLI)

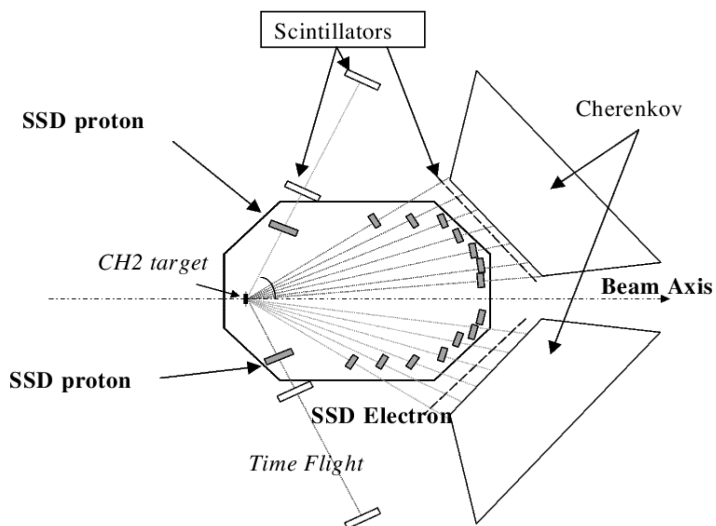


Figure from Alcorn et al. NIM A522 (2004)

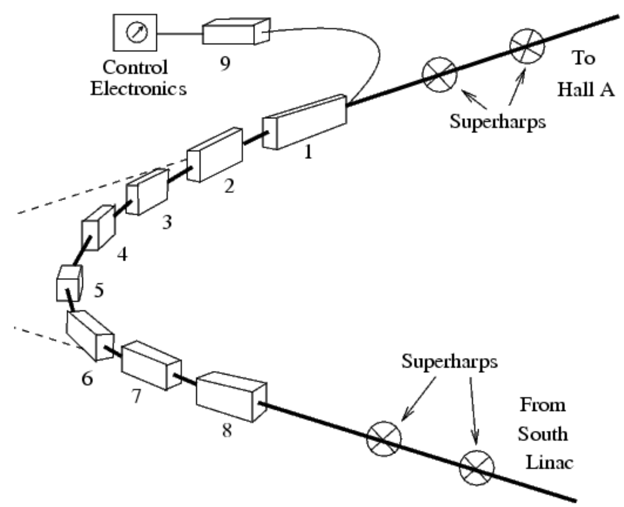


Figure from Kevin Kramer Ph.D. Thesis (2003)

Target Configuration

LH_2 : 20 cm Racetrack

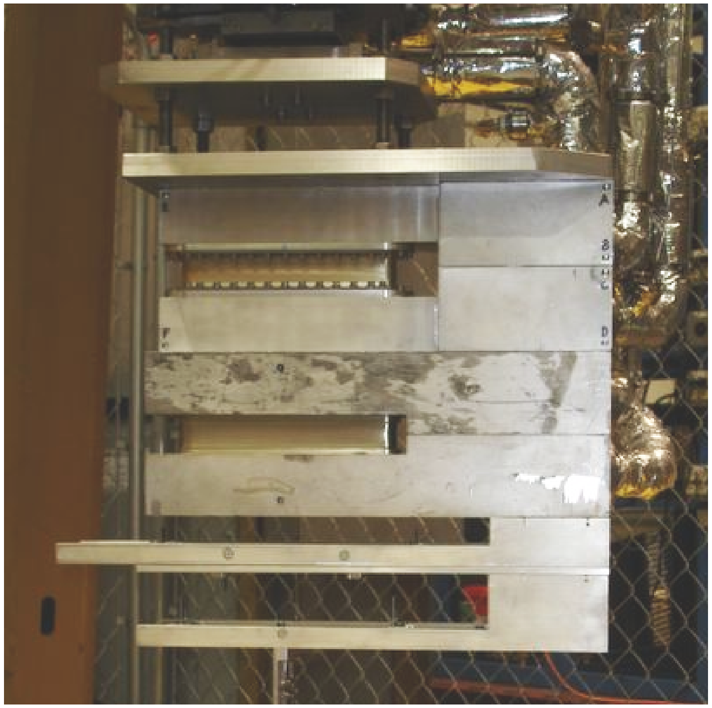
- Vertical Flow Design
- Dedicated Studies of density stability
- Luminosity Monitor in datastream

Solid Aluminum Foils (Dummy)

- Endcap subtraction

Carbon Optics Targets

- 1-2 cm spacing along z_{lab} for extended target optics/acceptance



Picture from 2005 HAPPEX-II

Solid Target / Racetrack Endcaps measured with X-ray attenuation

HRS Detector Package

Main Trigger (electrons)

- S2m AND Gas Cherenkov

Secondary Triggers

- S0 AND Gas Cherenkov
- S0 AND S2m

Gas Cherenkov with Lead Glass Counters

- 10^4 pion rejection ?
- 99.5% electron efficiency

Additional VDC layer

- Improvement in tracking efficiency
- Reduction of non-statistical tails

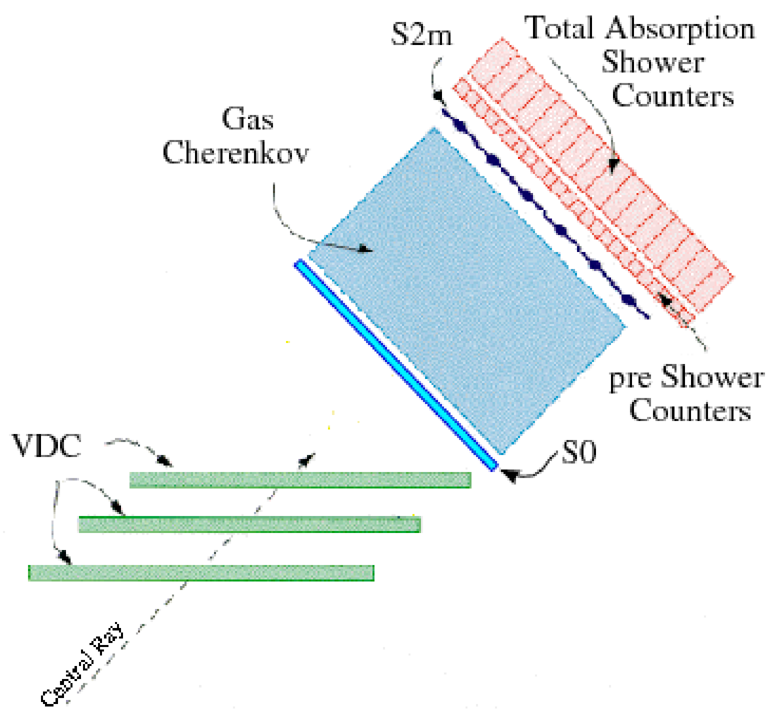
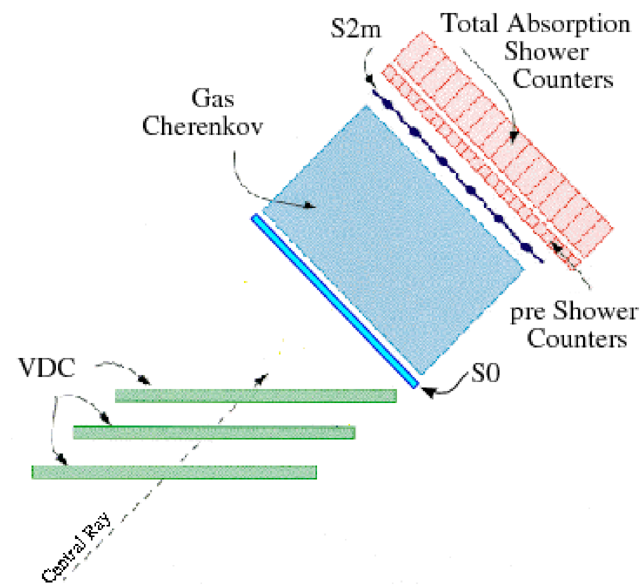


Figure from Hall A Webpage (modified)

Additional Wire Chamber

Current usage:
- Tight cuts on # hits/chamber
- Correct for lost events
- 0.5% correction on σ_{ep} for E01-001



One additional Wire Chamber for each spectrometer
- Added redundancy to account of multiple hit clusters per event.
- → Higher tracking efficiency

Additional Wire Chamber Options:
- ✯ Use "Spare" and build another "spare" from on-site components
- ✯ Use Multi-Wire Drift Chambers from BigBite Spectrometer
- ✯ Use front drift chambers from Focal Plane Polarimeter

Spectra from the Super Ratio experiment

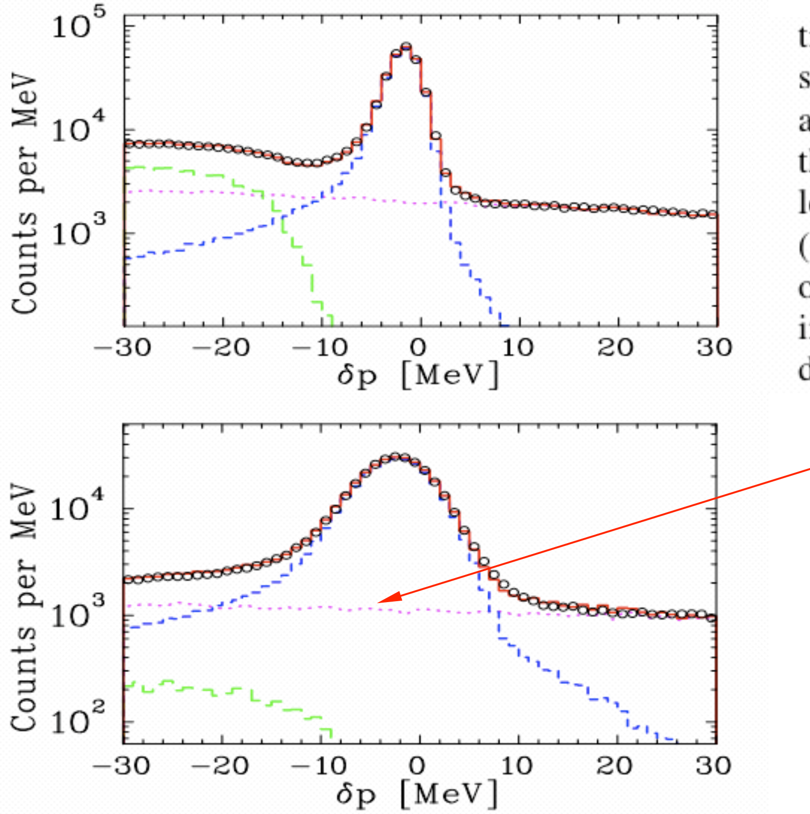


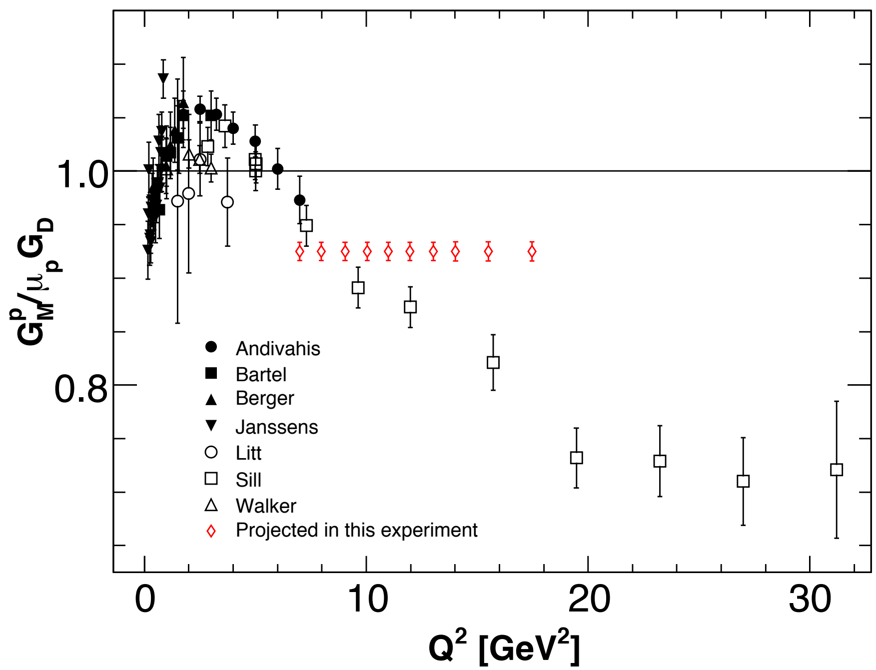
FIG. 1 (color online). The measured δp spectrum for the low (top) and high (bottom) ε points at $Q^2 = 3.2$ GeV^2 (circles). The dotted magenta line is the background from the target walls, the long-dash green line is the simulated background from $\gamma p \to \pi^0 p$ and $\gamma p \to \gamma p$ reactions, the short-dash blue line is the simulated elastic spectrum, and the solid red line (largely obscured by the data points) is the sum of the target wall, elastic, and background contributions.

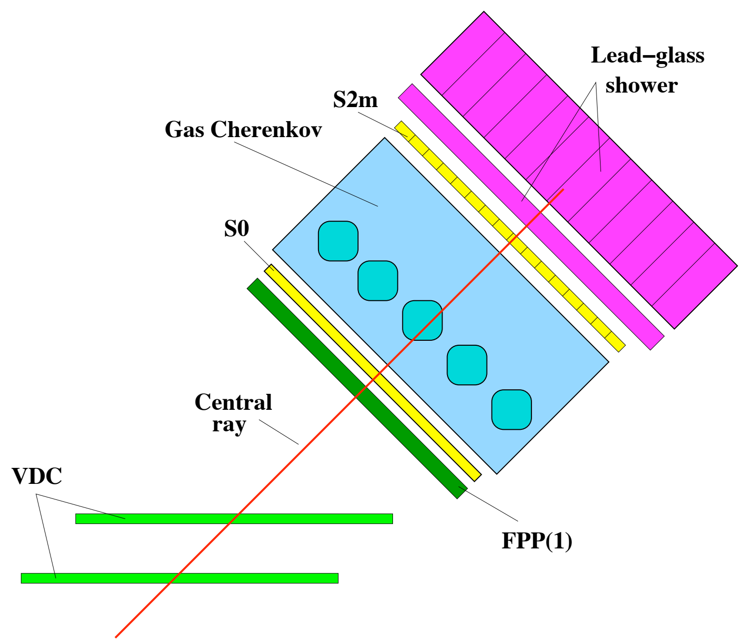
tions where the electron was detected. We also require a single clean cluster of hits in each drift chamber plane to avoid events where the resolution is worsened by noise in the chambers. This reduces the non-Gaussian tails, but leads to an inefficiency of roughly 7%, with a small (0.25%) ε dependence, possibly related to the variation of rate with ε. We correct the yield for the observed inefficiency and apply a 100% uncertainty on the ε dependence of the correction.

background

E12-07-108 (GMp)

- It is the only one measurement of the cross section – key input to all form factors and many other experiments
- It was proposed in 2007 after the GEp(5) was formulated
- It is based on the 15-years success of HRS

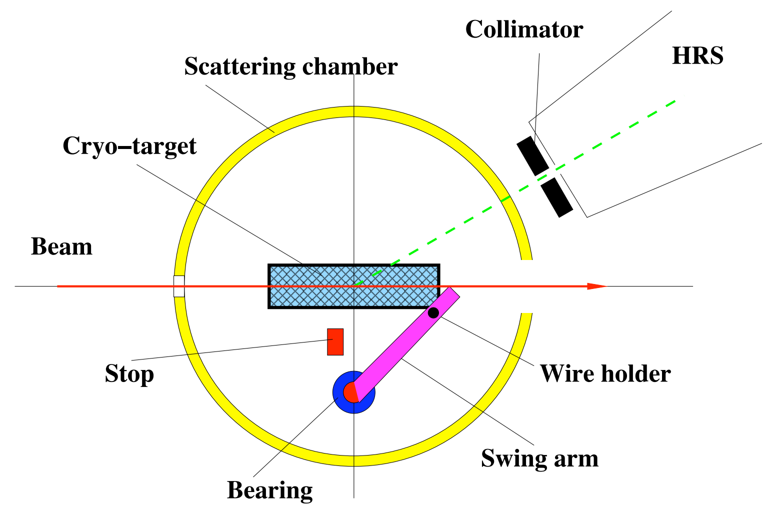




E12-07-108 (GMp)

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*
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**

Several parameters need serious work on systematic, among them: the scattering angle, detector/DAQ efficiency, HRS solid angle, the target density, the beam charge



GMp and DVCS

Q^2 (GeV^2)	k (GeV)	x_{Bj}	$q'(0°)$ (GeV)	D (m)	θ_q (deg)	θ_{calo}^{min} (deg)	t_{min} (GeV^2)	t_{max} (GeV^2)	$\sigma(M_X^2)$ (GeV^2)	$\mathcal{L}/10^{38}$ (cm^{-2}/s)	HRS (Hz)	DVCS (Hz)	Time (days)
3.0	6.6	0.36	4.35	1.5	11.7	7.1	-0.16	-0.42	0.23	0.75	479	1.16	3
4.0	8.8	0.36	5.83	2.0	10.3	7.0	-0.17	-0.42	0.26	1.3	842	1.74	2
4.55	11.0	0.36	6.65	2.5	10.8	7.0	-0.17	-0.42	0.27	2	2460	4.63	1
3.1	6.6	0.5	3.11	1.5	18.5	11.0	-0.37	-0.64	0.17	0.75	873	0.77	5
4.8	8.8	0.5	4.91	2.0	14.5	8.9	-0.39	-0.70	0.20	1.3	716	0.82	4
6.3	11.0	0.5	6.50	2.5	12.4	7.9	-0.40	-0.72	0.20	2.	778	0.99	4
7.2	11.0	0.5	7.46	2.5	10.2	7.0	-0.40	-0.75	0.25	2.	331	0.53	7
5.1	8.8	0.6	4.18	1.5	17.8	10.4	-0.65	-1.06	0.16	0.75	338	0.27	13
6.0	8.8	0.6	4.97	2.0	14.8	9.2	-0.67	-1.05	0.18	1.3	227	0.22	16
7.7	11.0	0.6	6.47	2.5	13.1	8.6	-0.69	-1.10	0.20	2.	274	0.28	13
9.0	11.0	0.6	7.62	3.0	10.2	7.3	-0.71	-1.14	0.22	3.	117	0.17	20

GMp: 20 cm x 80 μA

L = 4.3 x 10^{38} Hz/cm^2

both HRSs x 24 days
~ 200 HRS-day x 10^{38}

E_e (GeV)	Q^2 (GeV)^2	θ_e (deg)	E' (GeV)	ϵ	Rate (Hz)	T (hours)	
4.8**	7.0	71.0	1.08	0.25	0.60	9.3	40k
6.6	7.0	35.4	2.87	0.62	7.45	0.7	40k
6.6	8.0	42.0	2.35	0.51	2.29	2.4	40k
5.8**	9.0	77.0	1.00	0.18	0.15	36.3	40k
6.6	9.0	52.0	1.78	0.37	0.48	11.6	40k
8.8	9.0	29.3	4.00*	0.67	3.38	3.3	40k
6.6	10.0	67.0	1.25	0.23	0.15	38.3	40k
8.8	10.0	33.3	3.47*	0.59	1.31	8.5	40k
8.8	11.0	38.0	2.95	0.51	0.53	10.5	40k
8.8	12.0	44.0	2.42	0.41	0.21	26.7	40k
8.8	13.0	53.0	1.86	0.30	0.06	67.4	28k
11.0	13.0	31.3	4.07*	0.58	0.36	21.2	28k
11.0	14.0	35.0	3.54*	0.50	0.17	39.0	24k

8.8 GeV ~ 5 days; 11 GeV ~ 2.5 days

DVCS in E03-106: L = 4. x 10^{37} Hz/cm^2

DVCS: L = 15 cm x J μA
0.75-3 x 10^{38} Hz/cm^2

L/L_{GMP} x T at 6.6 GeV ~ 1.4 days

L/L_{GMP} x T at 8.8 GeV ~ 8.6 days

L/L_{GMP} x T at 11 GeV ~ 21 days

Threshold inelastic electron scattering from the proton at high momentum transfers

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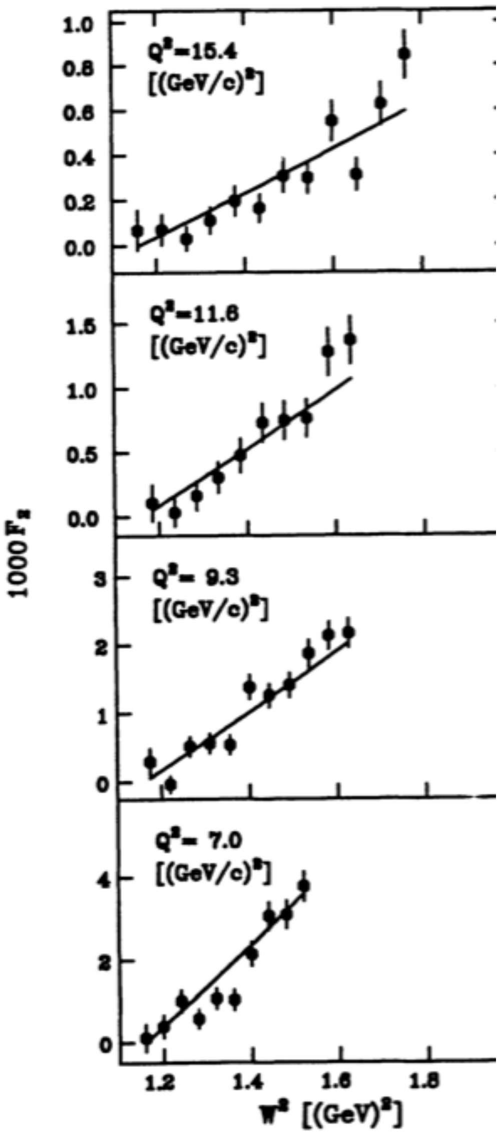
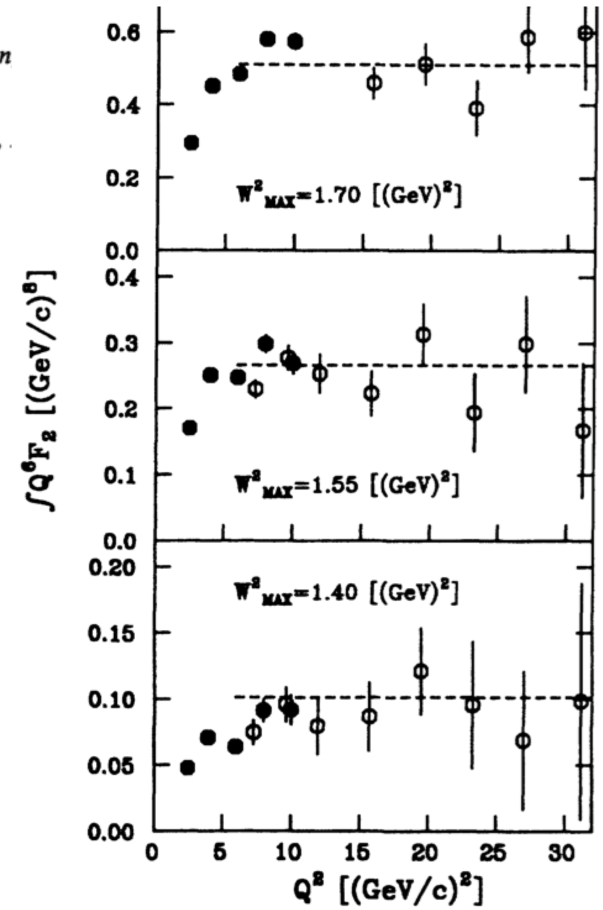


QCD firm prediction for the threshold pion electro-production:

$$Q^6F_2 = \text{const}$$



The integrated values of $Q^6F_2(x,Q^2)$ from t
.6 $(GeV)^2$] to the maximum values indicated in
panels, as a function of Q^2. The open circles