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

PAC32 12 GeV Proposal : PR-07-1NN

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Motivation

Electron – Nucleon Scattering

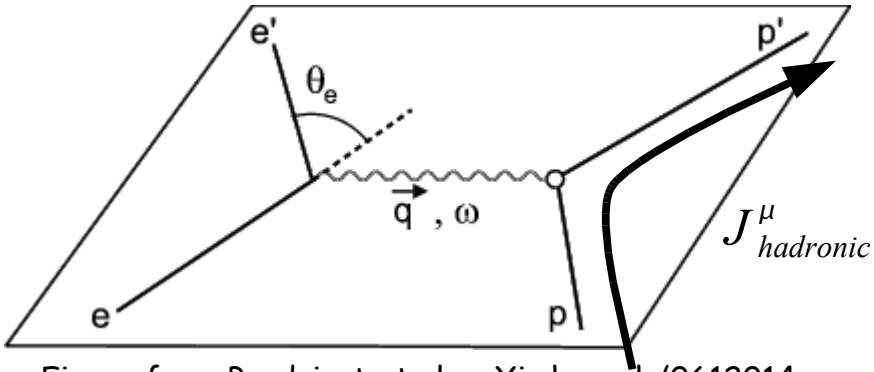


Figure from Perdrisat et al. arXiv:hep-ph/0612014

Hadronic Current with internal structure

$$J^{\mu}_{hadronic} = ie\,\bar{N}(p')\left[\gamma^{\mu} F_1(Q^2) + \frac{i\sigma^{\mu\nu}}{2M} F_2(Q^2)\right] N(p)$$

Electric and Magnetic Form Factors

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

Fits well to Dipole form:

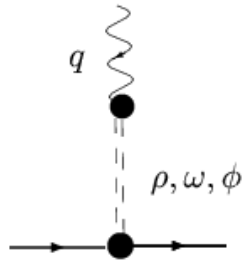
$$G_D = \frac{1}{(1 + Q^2/0.71)^2}$$

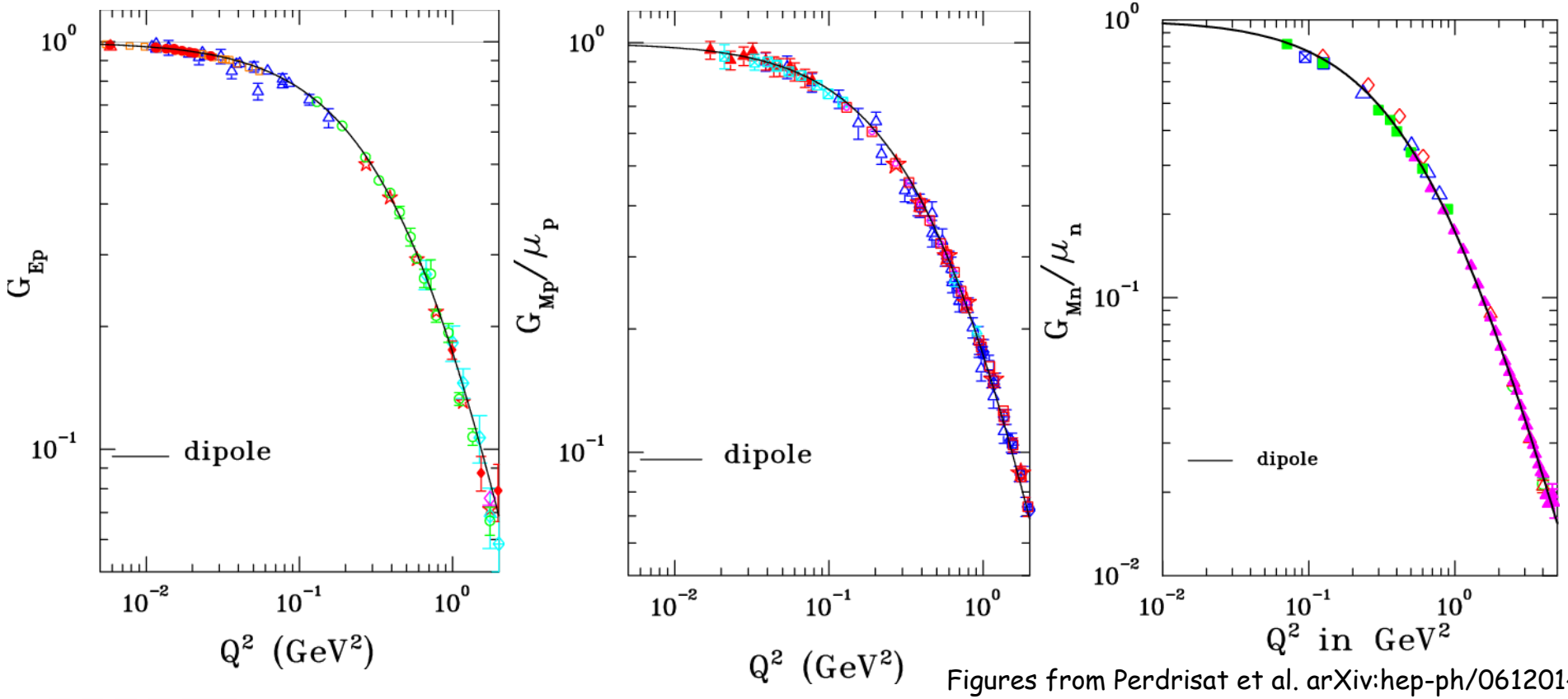
$$G_E^p = G_D, \quad G_M^p = \mu_p G_D, \quad G_M^n = \mu_n G_D$$

Dipole Form Factor

Vector Meson Dominance to Dispersion Relations

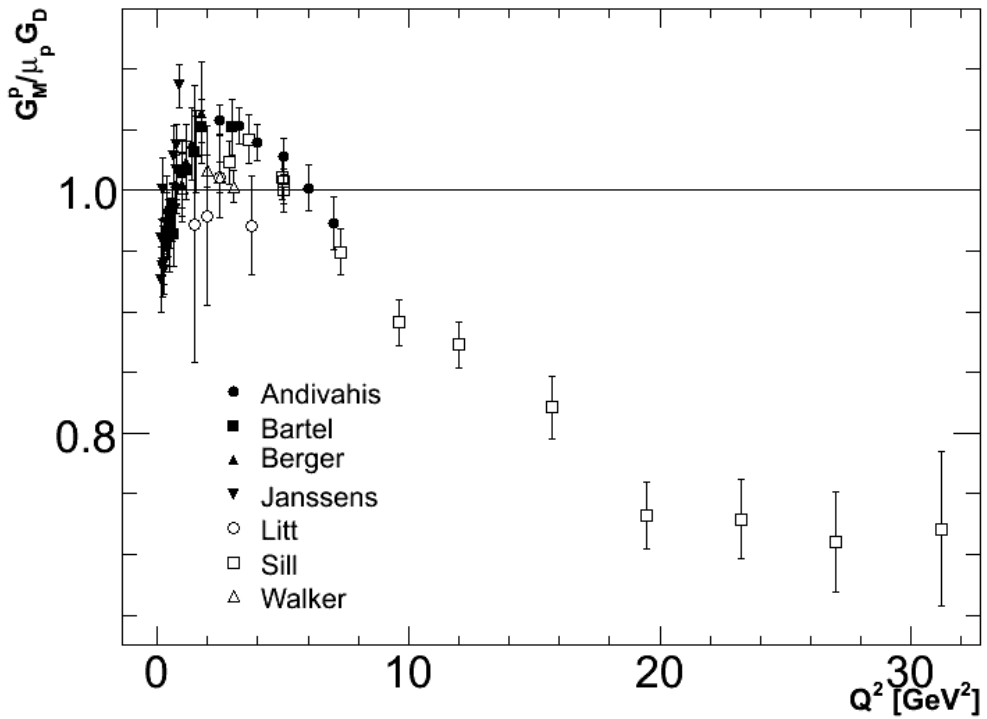
$$F(q^2) \sim \frac{a}{q^2 - m_{V1}^2} + \frac{(-a)}{q^2 - m_{V2}^2}$$





Figures from Perdrisat et al. arXiv:hep-ph/0612014

More Models – Higher Q^2



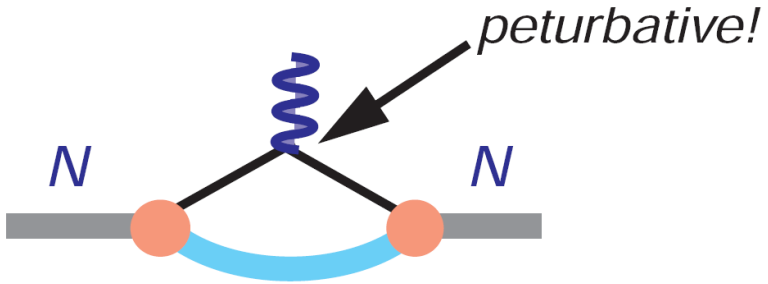


Figure from 12 GeV Upgrade pCDR

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?

$$F_1(t) = \int_{-1}^{+1} \sum_q dx\, H^q(x,0;t)\, dx$$

$$F_2(t) = \int_{-1}^{+1} \sum_q dx\, E^q(x,0;t)\, dx$$

Form Factor Scaling

At high values of Q^2,
asymptotic freedom [small $\alpha_s(Q2)$] allows for pQCD calculations.

How high is that?

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

n = participating valence quarks

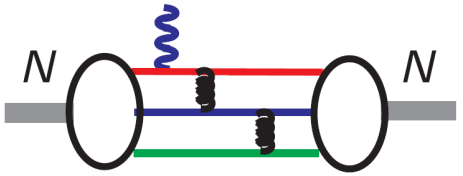
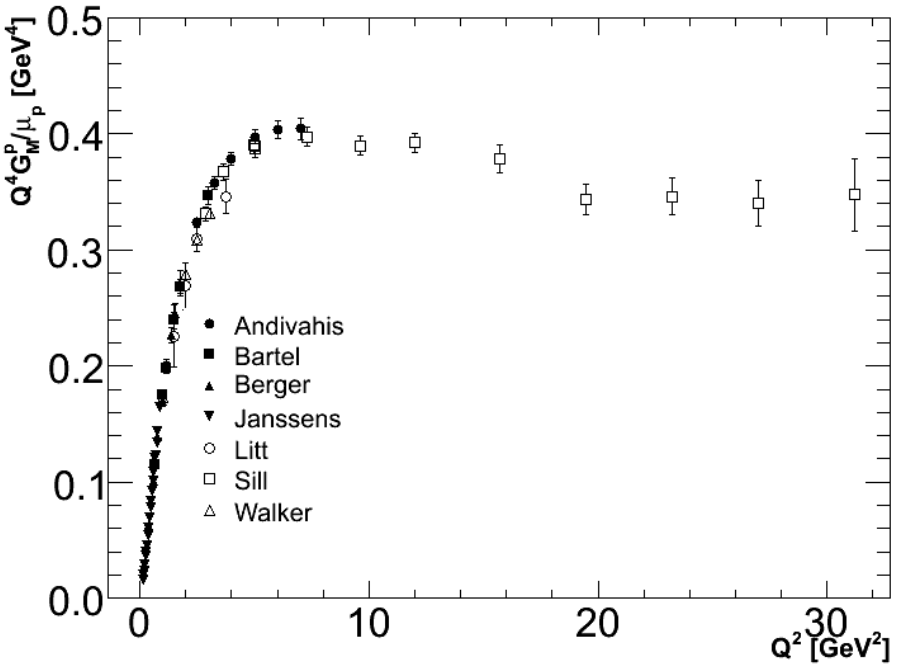


Figure from 12 GeV Upgrade pCDR



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

pQCD -> logarithmic departures from Q^2 dependence

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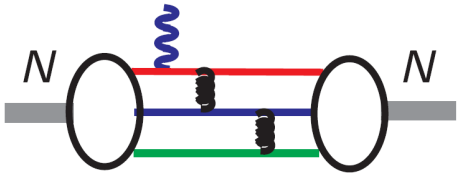

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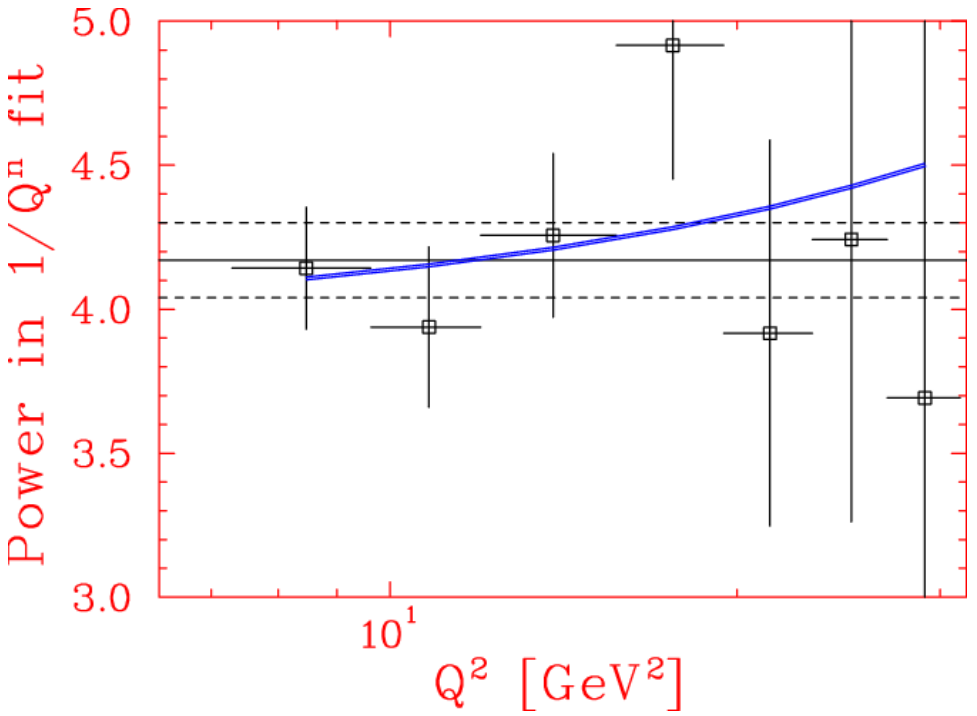


$$Q^4 G_M^p \propto Q^4 F_1^p \sim constant$$

pQCD -> logarithmic departures from Q^2 dependence

Rosenbluth Separation

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

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

Form Factor Extraction (Method 1):

- Rosenbluth Separation
  - Measure Cross Section at same Q^2 but different E and θ (varying ϵ)

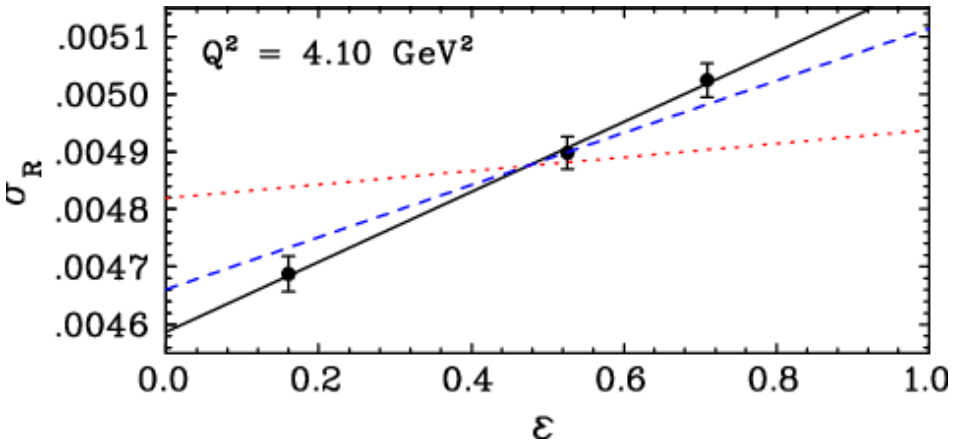


Figure from Qattan et al. **PRL** 94 (2005) 142301

Polarization Transfer

$$\frac{G_E^p}{G_M^p} = \frac{P_x}{P_z}\frac{(E_e + E_{e'})}{2M}\tan(\theta_e/2)$$

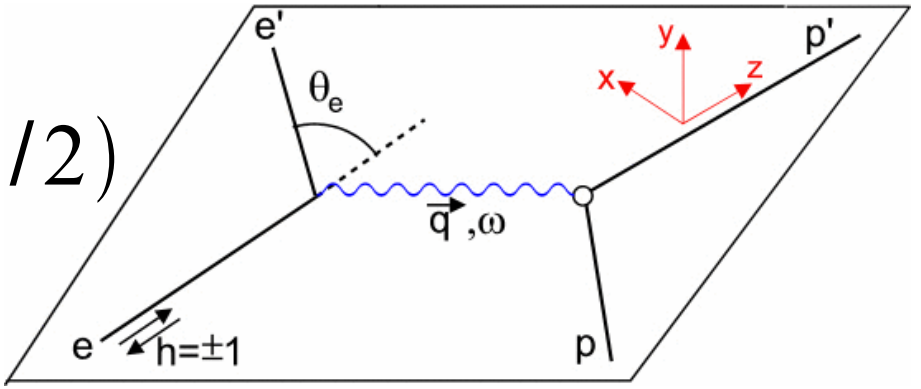


Figure from Perdrisat et al. arXiv:hep-ph/0612014

Form Factor Extraction (Method 2):

- Polarization Transfer
  - Measure components of the scattered proton polarization transferred from polarized electron

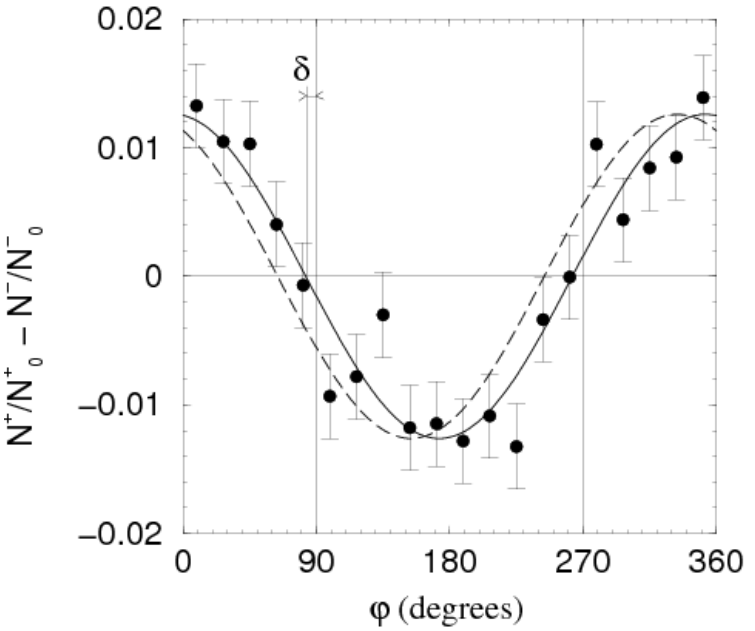


Figure from Gayou et al. **PRL** 88 (2002) 092301

Measured G_E/G_M Ratio

(e,e')

Rosenbluth Separation

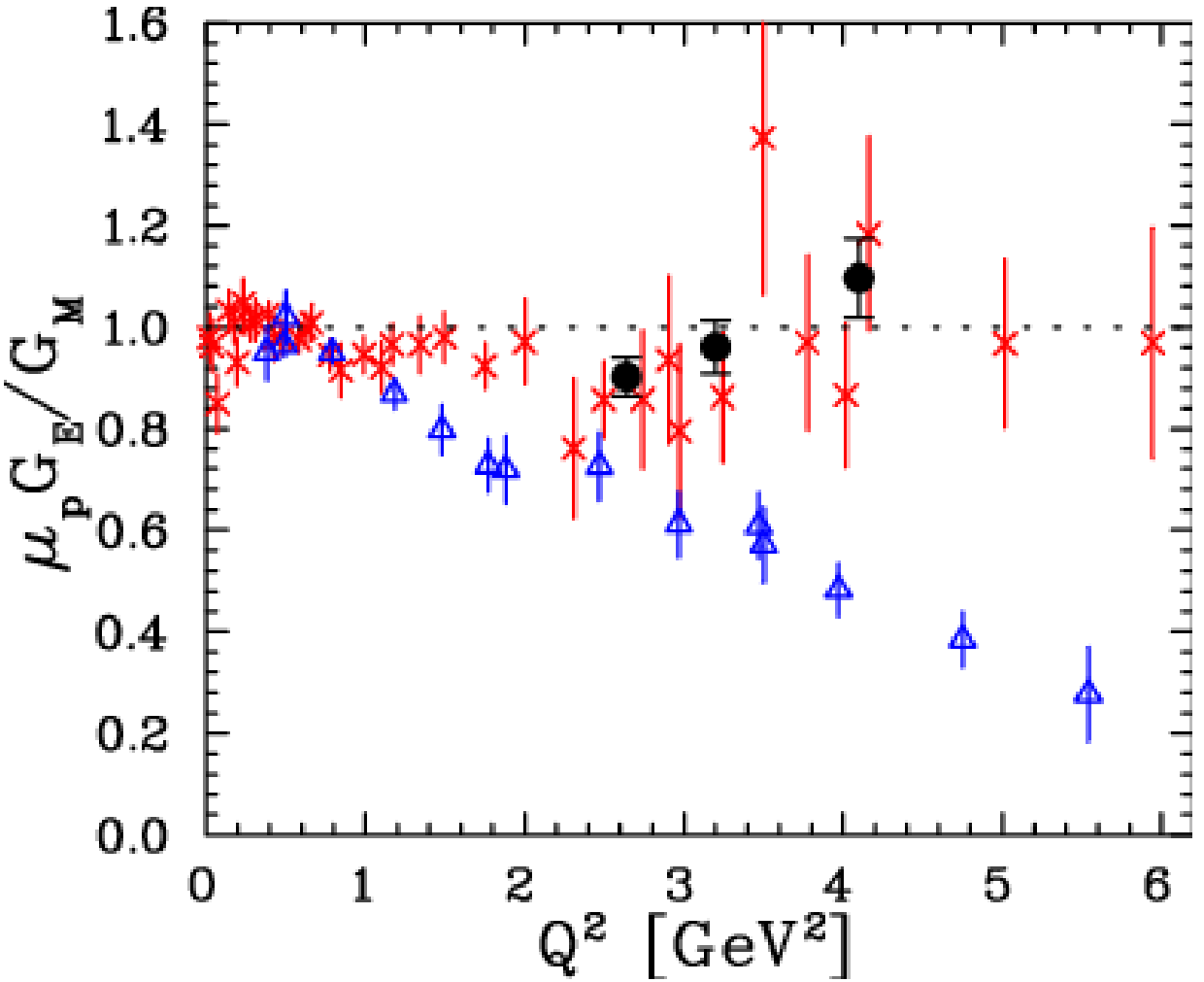
(e,p)

Super-Rosenbluth

$\vec{e}\,p \Rightarrow e\,\vec{p}$

Polarization Transfer

Discrepancy explained by Two-Photon Exchange?



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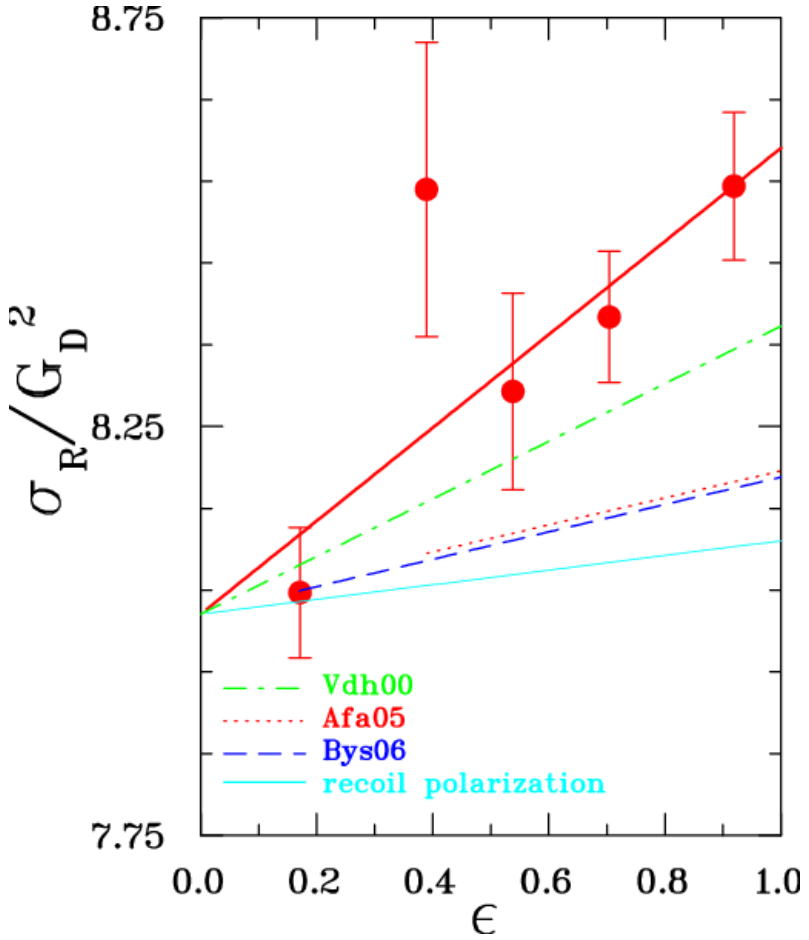
Two-Photon Exchange



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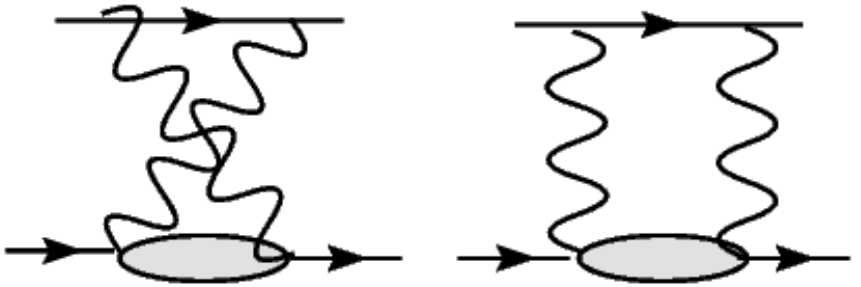
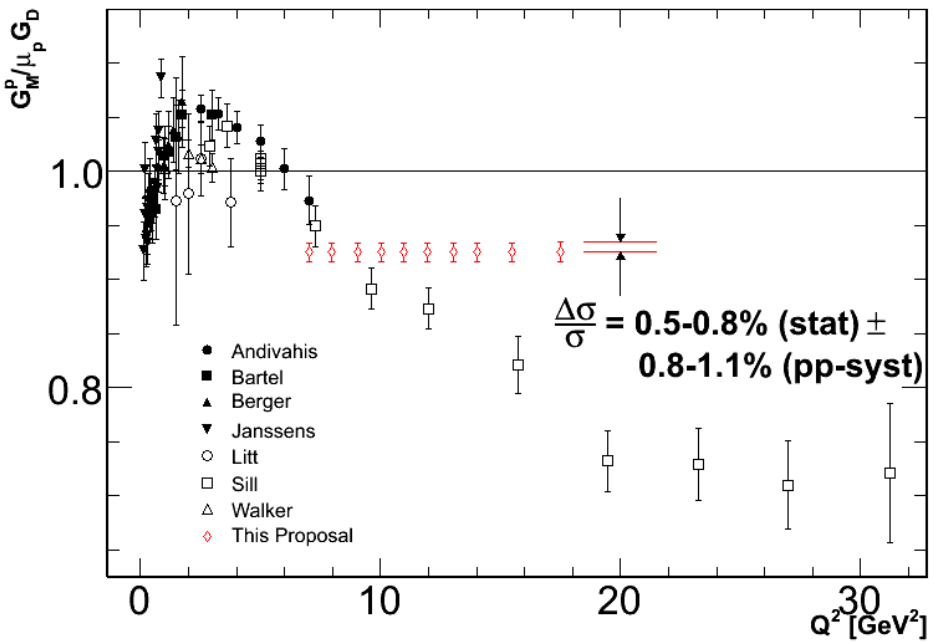


TPE Corrections

- Significant ϵ dependence
- Difficult to extrapolate from SLAC to JLab kinematics

- Does not impact $\sigma_{e\text{-}p}$ for other experiments at JLab kinematics
- Only important for G_M^P extraction

This Proposal



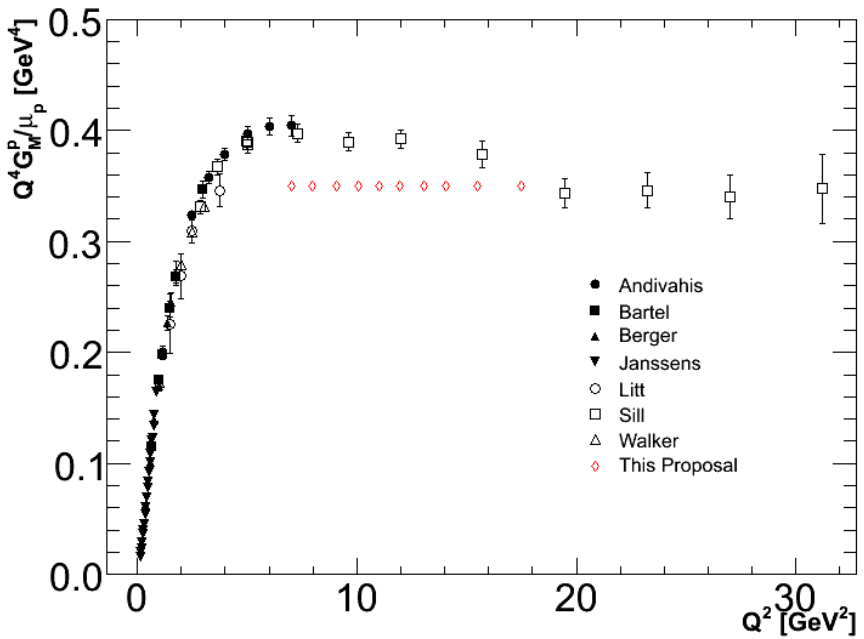
Measure Proton Elastic Cross Section at High Q^2 to high precision.

Improved G_M^P allows for better extraction of G_E^P from future Polarization Transfer Experiments

High Precision Cross Section important for extraction of **neutron** FFs:

- QE measurements from the deuteron
- Asymmetry measurements on ^{3}He

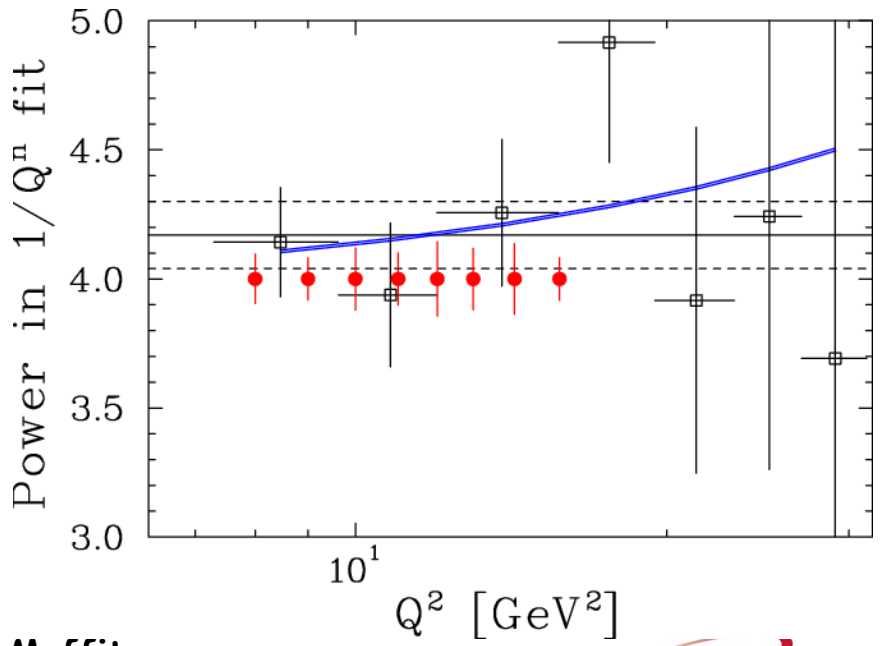
Precision Test of FF Scaling



What is the power of the Q2 dependence?

How does GMP approach the pQCD limit?

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

HRS Detector Package

Additional VDC layer
- Spare and on-site components

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

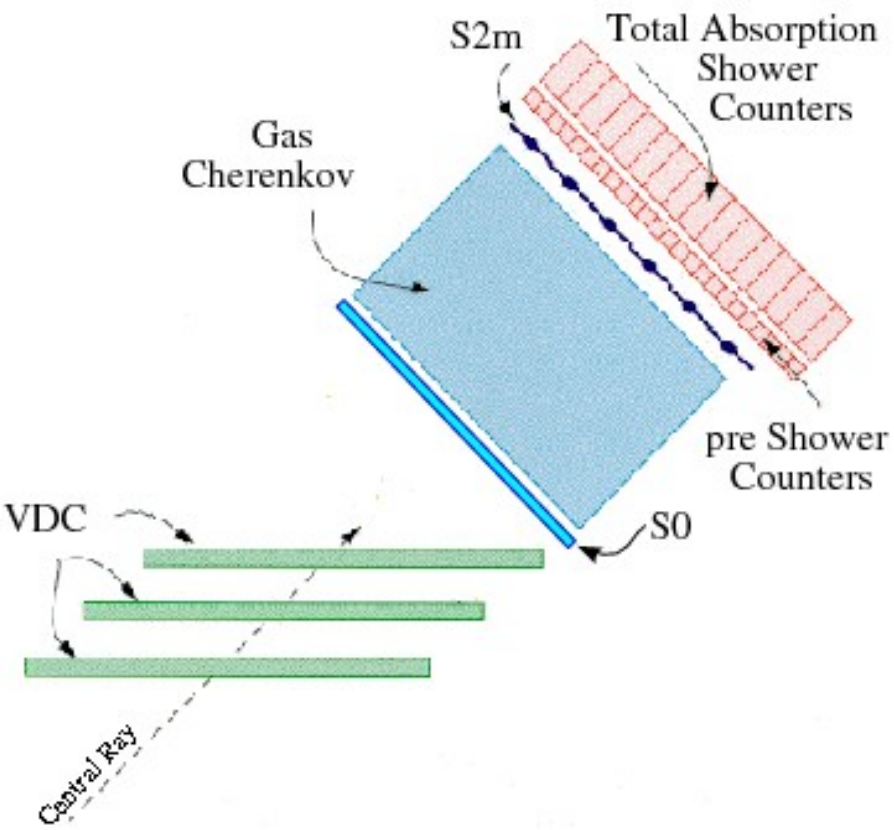


Figure from Hall A Webpage (modified)

Beam Energy

Upgrade of eP and 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)

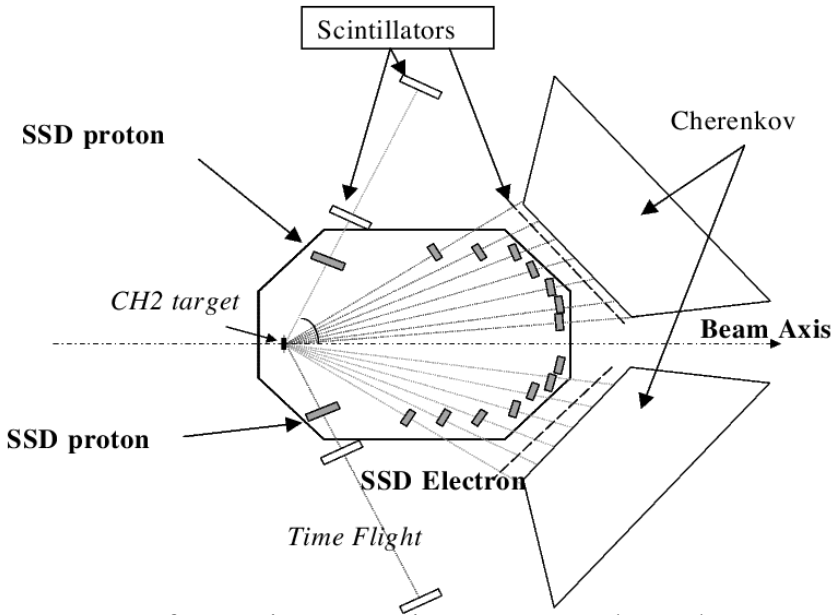


Figure from Alcorn et al. NIM A522 (2004)

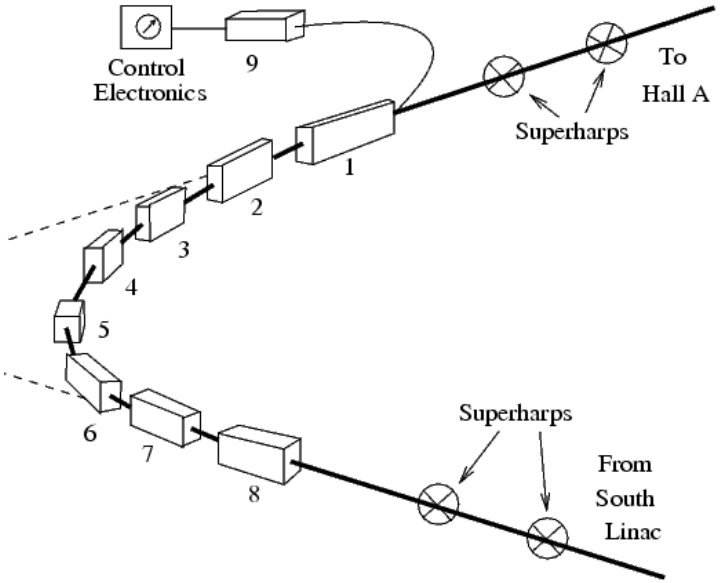


Figure from Kevin Kramer Ph.D. Thesis (2003)

Target Configuration

LH^2 : 20 cm Racetrack

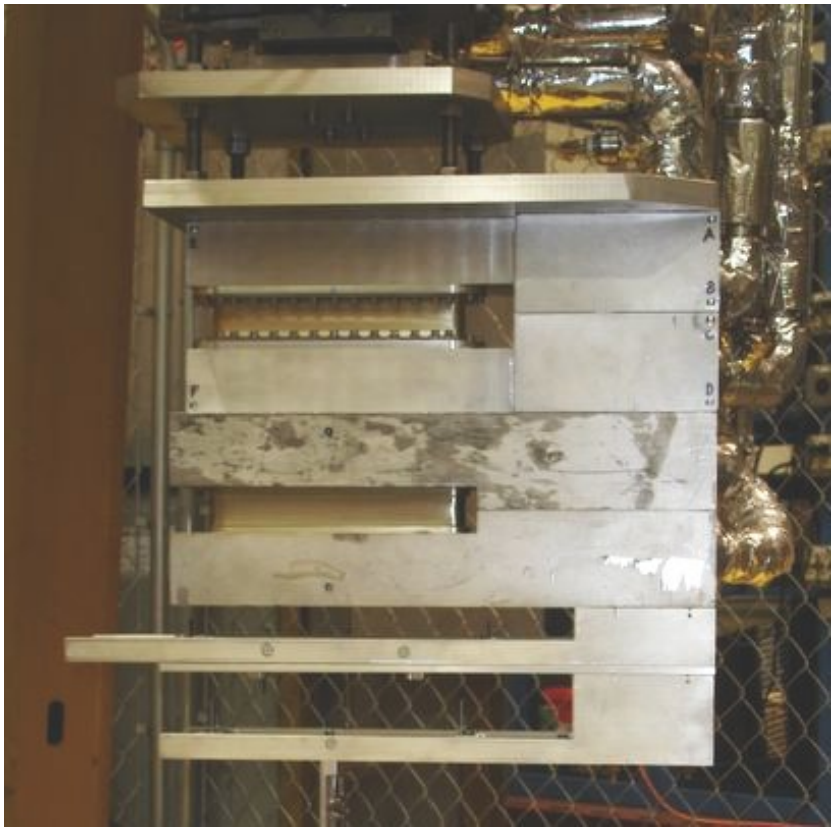
- Vertical Flow Design
- Dedicated Studies of density fluctuations
- Luminosity Monitor in datastream

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

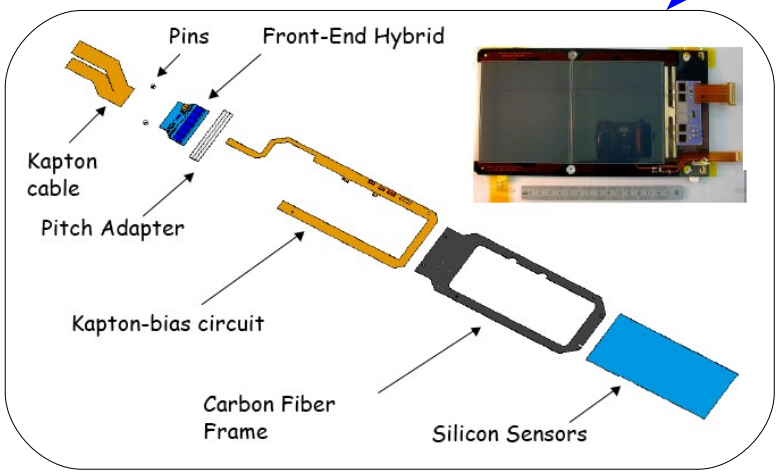
Solid Target / Racetrack Endcaps measured with X-ray attenuation

Precision Angle Measurement (PAM)

All targets and detectors mounted to an aluminum frame
- Accurate placement (~ few μm)

Wire Scanners
- Measure/Calibration of incoming beam angle

Micro Strip Detector (MSD)
- Accurate measure of scattering angle and improved HRS optics/acceptance studies



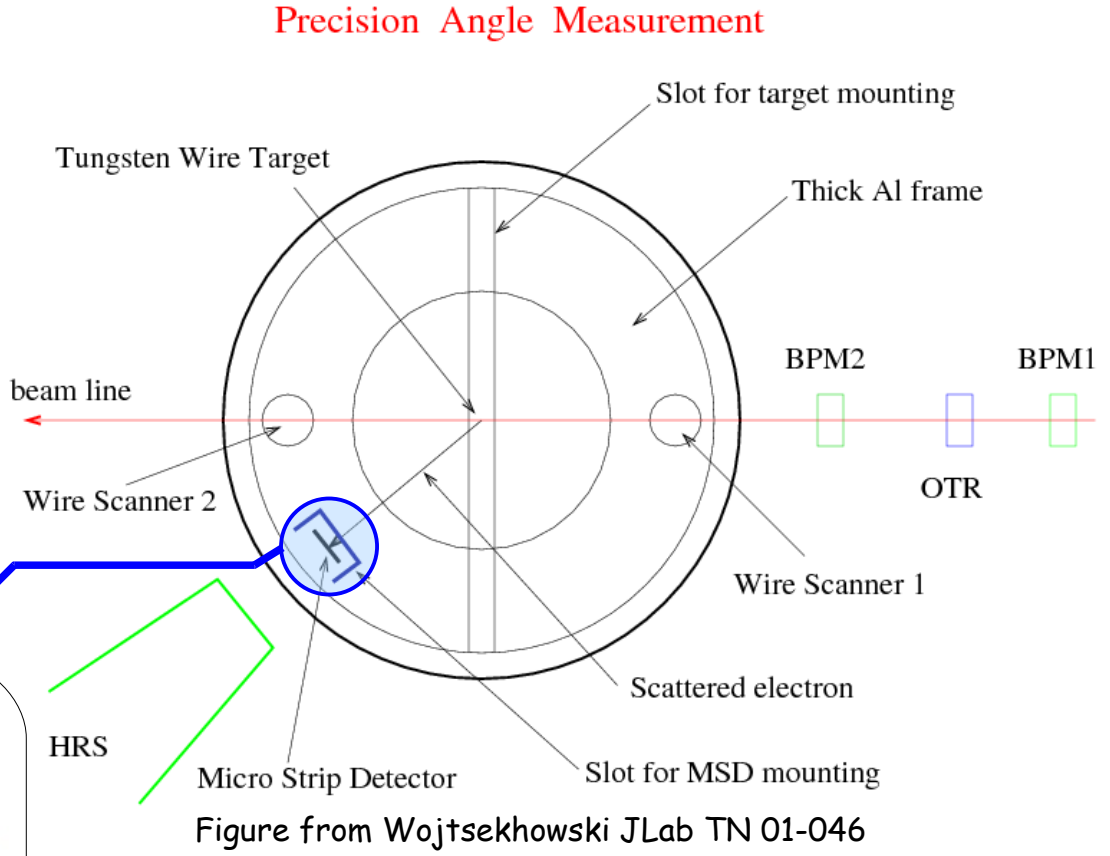


Figure from Wojtsekhowski JLab TN 01-046

MSD from CMS (LHC)
Electronics adaptation being evaluated by JLab DAQ group.

Systematic Uncertainties

Point to Point

Source	Δσ/σ (%)
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

Source	Δσ/σ (%)
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**

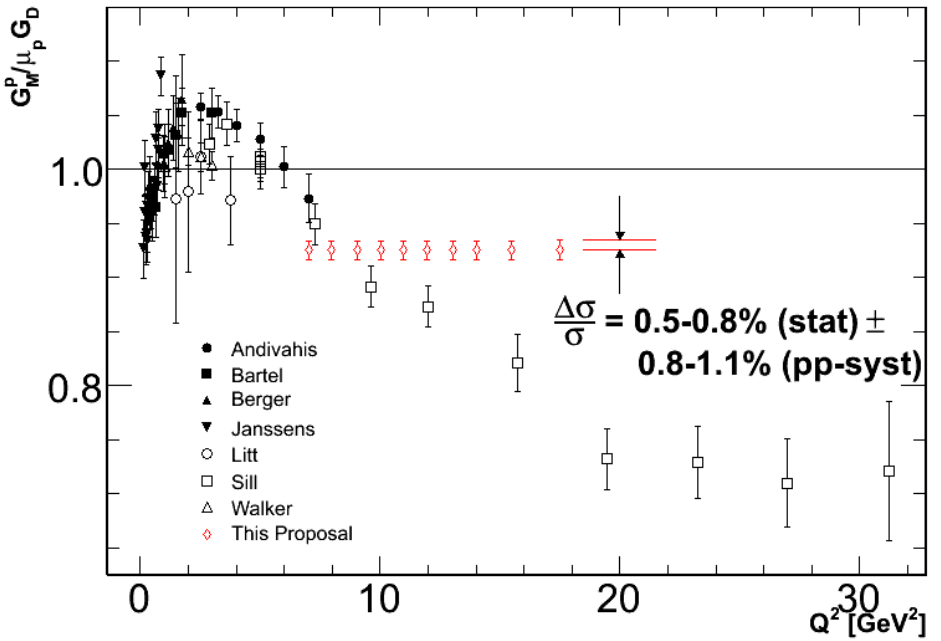
Statistics: 0.5 – 0.8%

TOTAL (Scale + Rand. + Stat.) : 1.2 – 1.7 %

Summary

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

- Provide additional experimental constraints for GPD and pQCD calculations
  - Test $1/Q^4$ scaling behavior and approach to pQCD limit
- Precision of σ_{ep} and G_M^P will allow
  - Better extraction of all other nucleon Form Factors G_E^P, G_E^N, G_M^N



We request **31 days** to perform this measurement.

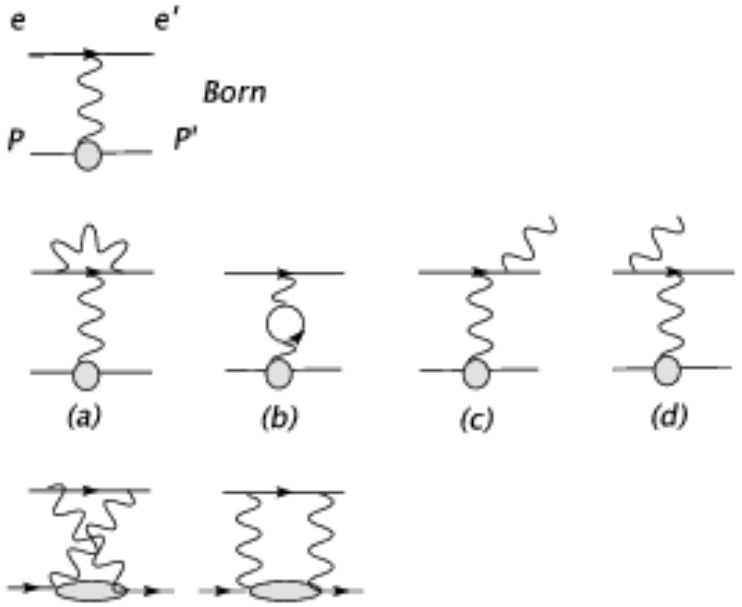
THANKS!

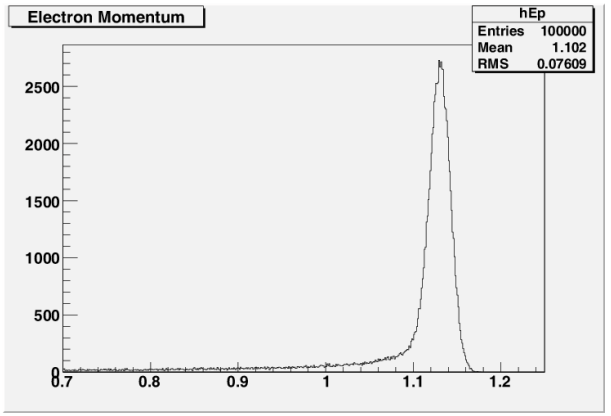
Bryan Moffit
Hall A Collaboration Meeting

Jefferson Lab

Start of backup slides

Radiative Corrections





Standard Corrections large,
but well understood

High Statistics ->
Better Confirmation of
Radiative Tail Calculations

Two-Photon Corrections
still quite uncertain.

Large progress in calculations
and experimental input to verify
them.

Not relevant for G_E^P or **neutron**
FF extraction at JLab kinematics