Low Q^2 Measurement of g_2^p
(A Test of χPT)

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A New Proposal to Jefferson Lab PAC-31

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Collaboration

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(and The Hall A Collaboration)

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Polarizabilities

Fundamental observables that characterize nucleon structure.

Electric and Magnetic polarizabilities measure the nucleon's response to EM field.

Measured using real photon scattering since they are linked to forward Compton Scattering Amplitudes.

Generalized polarizabilities : extension to virtual photon scattering at finite Q^2.

1. Optical Theorem (Unitarity).

2. Unsubtracted dispersion relation (Causality).

3. Low energy expansion (Lorentz and guage invariance).

(Note: *Same assumptions as for the GDH Sum Rule.*)

allows us to relate polarizabilities to the VVCS.

Dispersion Relation

$$\mathrm{Re}[\tilde{g}_{\mathrm{TT}}(\nu, Q^2)] = (\frac{\nu}{2\pi^2})\mathcal{P}\int_{\nu_0}^{\infty} \frac{K(\nu', Q^2)\sigma_{TT}(\nu', Q^2)}{\nu'^2 - \nu^2} d\nu',$$

$\tilde{g}_{\mathrm{TT}}(\nu, Q^2)$: Spin-flip doubly virtual Compton Scattering Amplitude.

$\sigma_{TT}(\nu', Q^2)$: Transverse-Transverse interference cross section.

and similar relation for σ_{LT}, g_{LT}

Low Energy Expansion

$$\gamma_0(Q^2) = (\frac{1}{2\pi^2}) \int_{\nu_0}^{\infty} \frac{K(\nu, Q^2)}{\nu} \frac{\sigma_{TT}(\nu, Q^2)}{\nu^3} d\nu$$

$$\delta_{LT}(Q^2) = (\frac{1}{2\pi^2}) \int_{\nu_0}^{\infty} \frac{K(\nu, Q^2)}{\nu} \frac{\sigma_{LT}(\nu, Q^2)}{Q\nu^2} d\nu$$

Spin Polarizabilities

Or in more familiar terms:

$$\gamma_0(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\Big[g_1(x,Q^2) - \frac{4M^2}{Q^2}x^2 g_2(x,Q^2)\Big]dx.$$

$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\Big[g_1(x,Q^2) + g_2(x,Q^2)\Big]dx.$$

1. Polarizabilities are a natural testing ground for χPT.

2. x^2-weighting leads to a fast convergence.

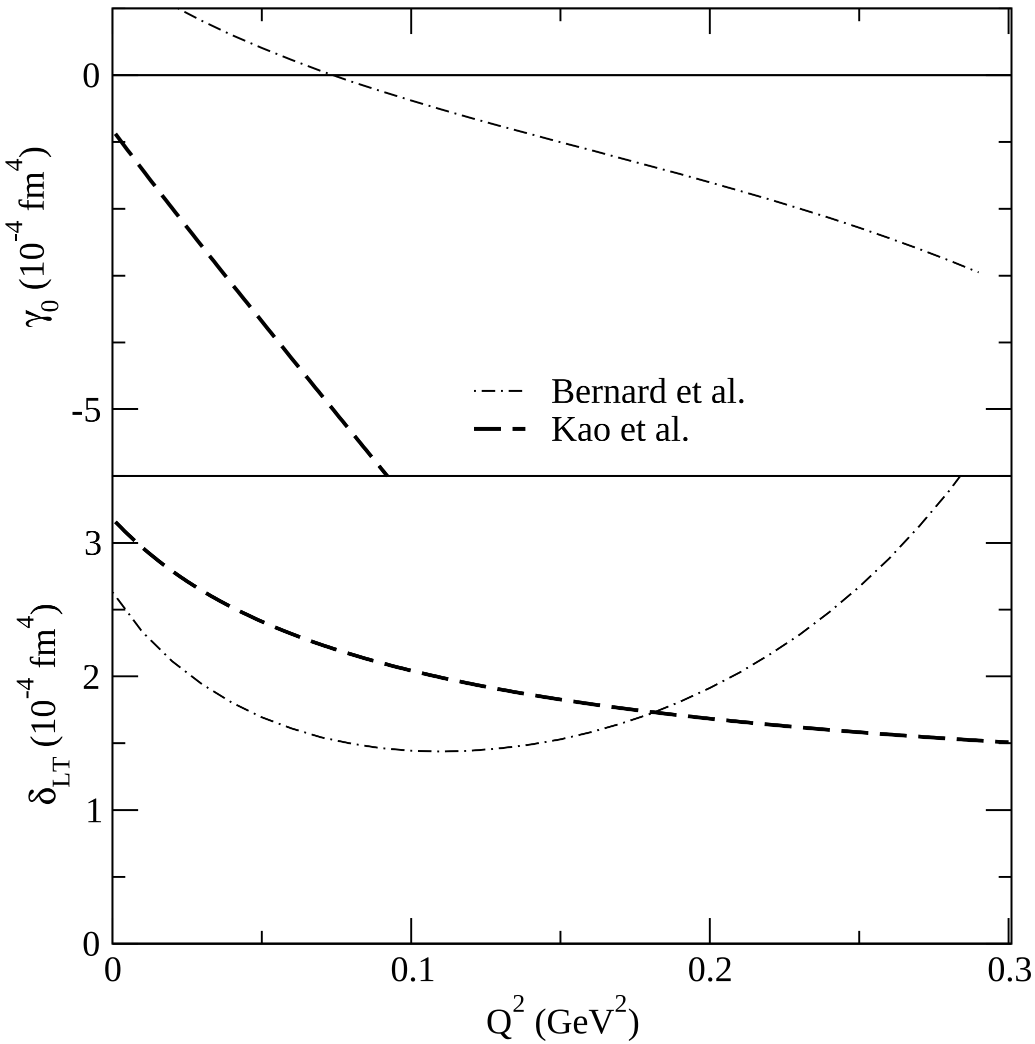
   Also implies the resonances will dominate.

3. Δ(1232) contribution is largest uncertainty in χPT calculations:

   δ_{LT} much less sensitive to Δ than γ_0

Expected that δ_{LT} would be good place to test χPT...

Neutron Polarizabilities

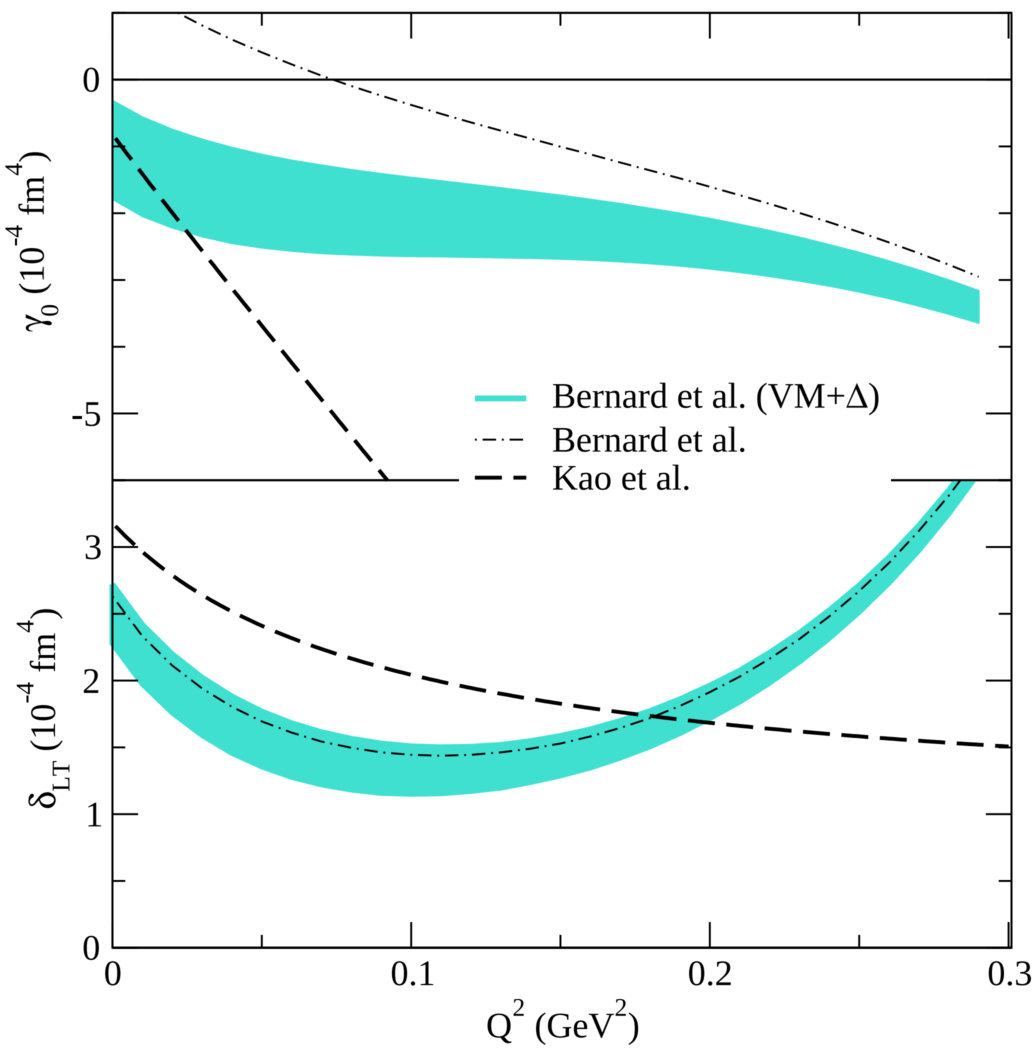


NLO χPT calculations

Kao *et. al* PRD 67:016001(2003)

Bernard PRD 67:076008(2003)

Neutron Polarizabilities



NLO χPT calculations

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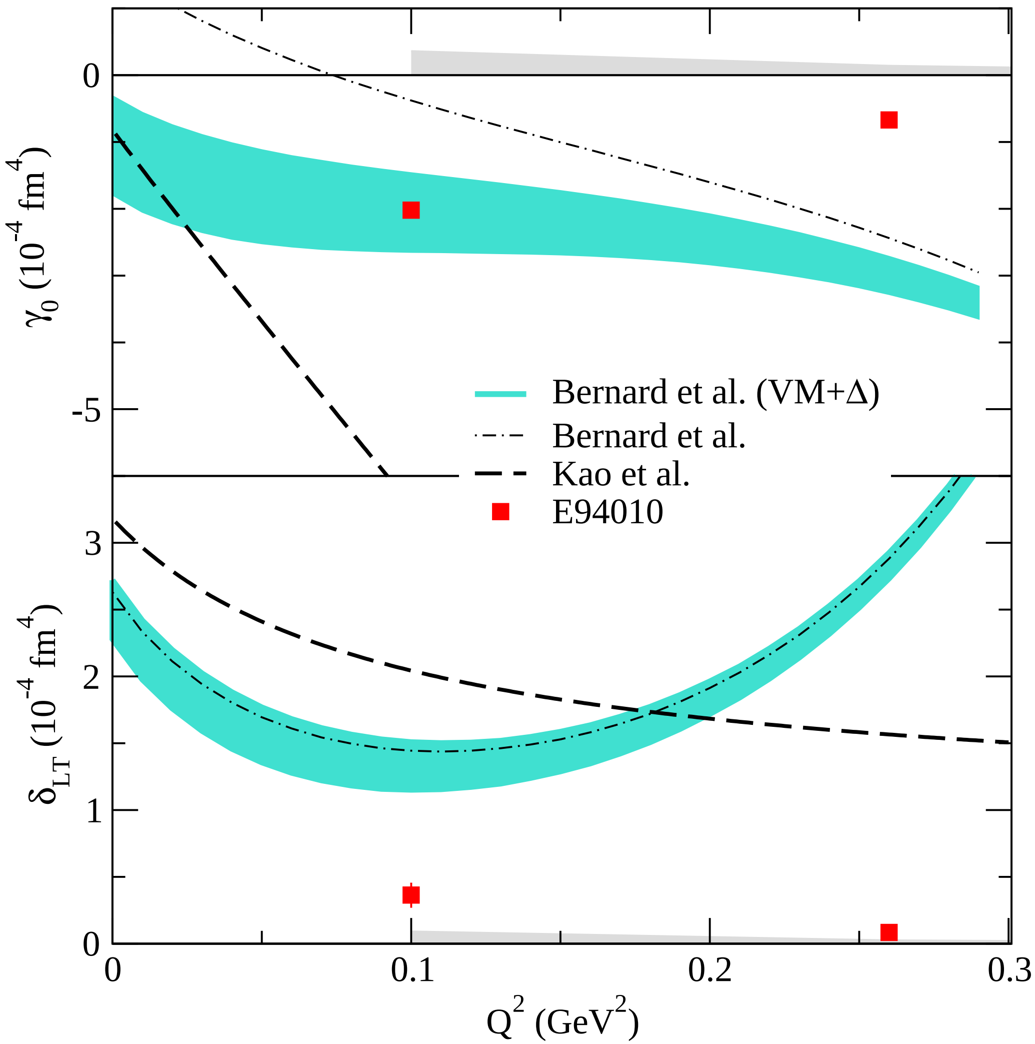
Include Δ(1232)

Neutron Polarizabilities



NLO χPT calculations

Kao *et. al* PRD 67:016001(2003)

Bernard PRD 67:076008(2003)

Include Δ(1232)

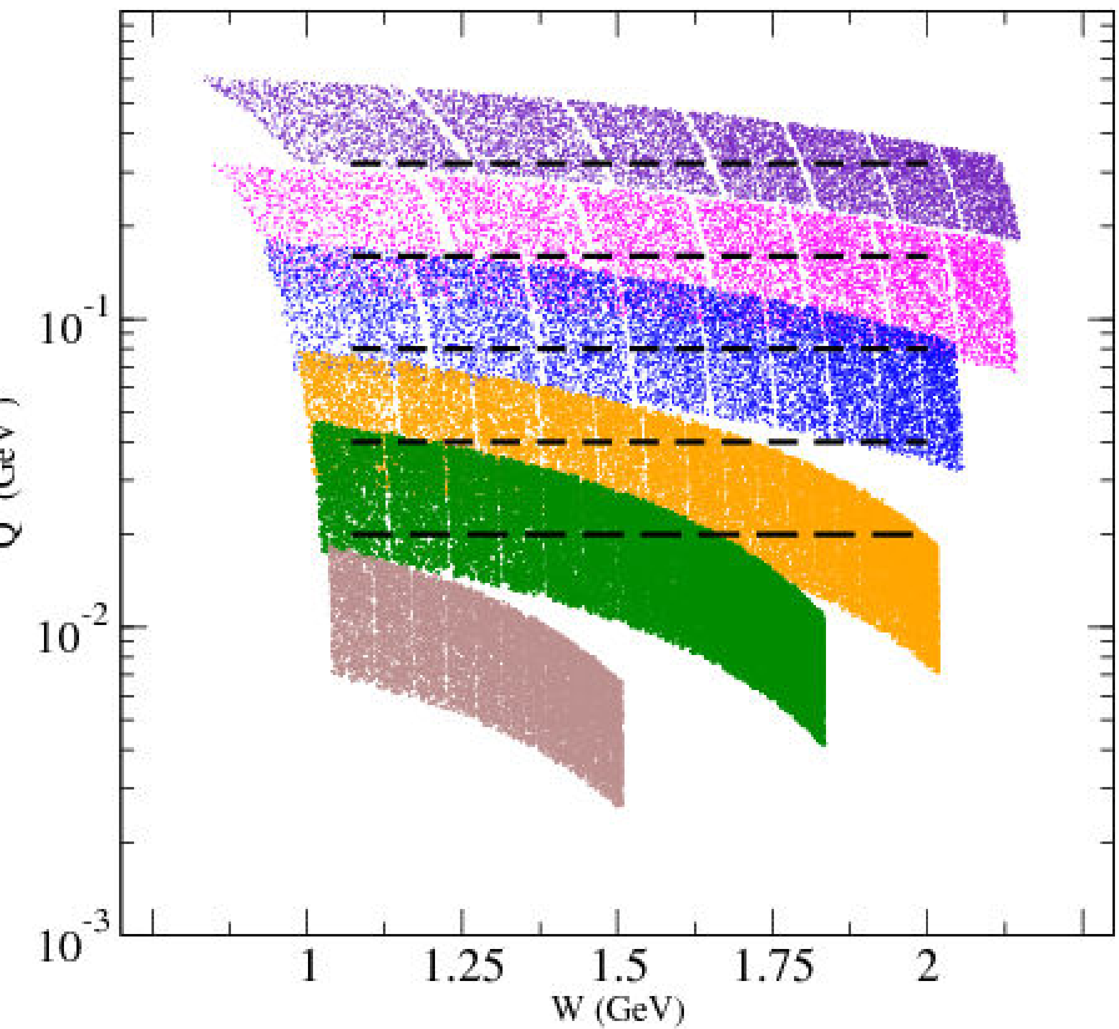
PRL 93:152301 (2004)

Theorists

1. B. Holstein: *A real challenge to (χPT) theorists!*
2. Ulf-G. Meissner: *Don't know now, Need to work on it.*
3. T. Hemmert: *Short range effects beyond πN?*
4. Kochelev/Vanderhaghen: *t-channel axial vector meson exchange? Isoscalar in nature?*
5. C. Weiss: *An efffect of QCD vacuum structure?*

To solve the puzzle and to understand the nature of the problem, need isospin separation.

The Experiment



$$\vec{e} + \vec{P} \rightarrow e' + X$$

$0.02 < Q^2 < 0.32$

$W_\pi < W < 2$ GeV

1. Polarized UVA/JLab target.
2. Septa Magnets.

Major Installation

1. Installation of the UVA/JLab 5 T Polarized Target.
2. Installation of an upstream Chicane and supports.

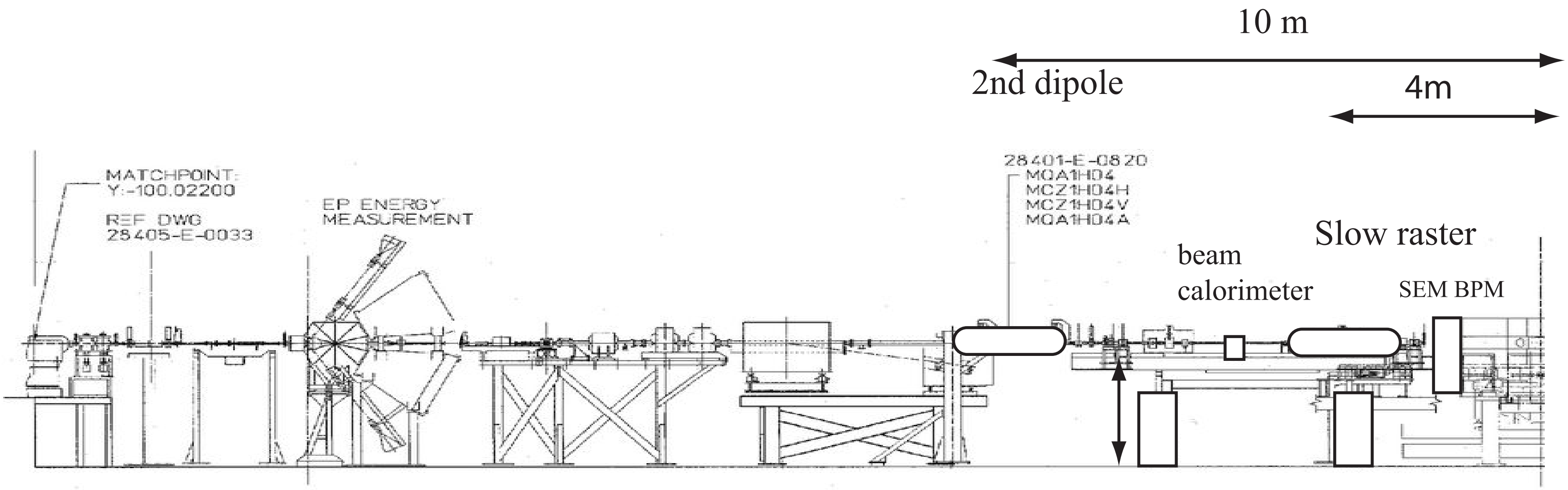
A. Installation of the Hall A septa.

B. Installation of a local beam dump.

C. Installation of the slow raster, and Basel SEM.

D. Beamline instrumentation for 50-100 nA beam.

Chicane



Preliminary analysis by Jay Benesch.

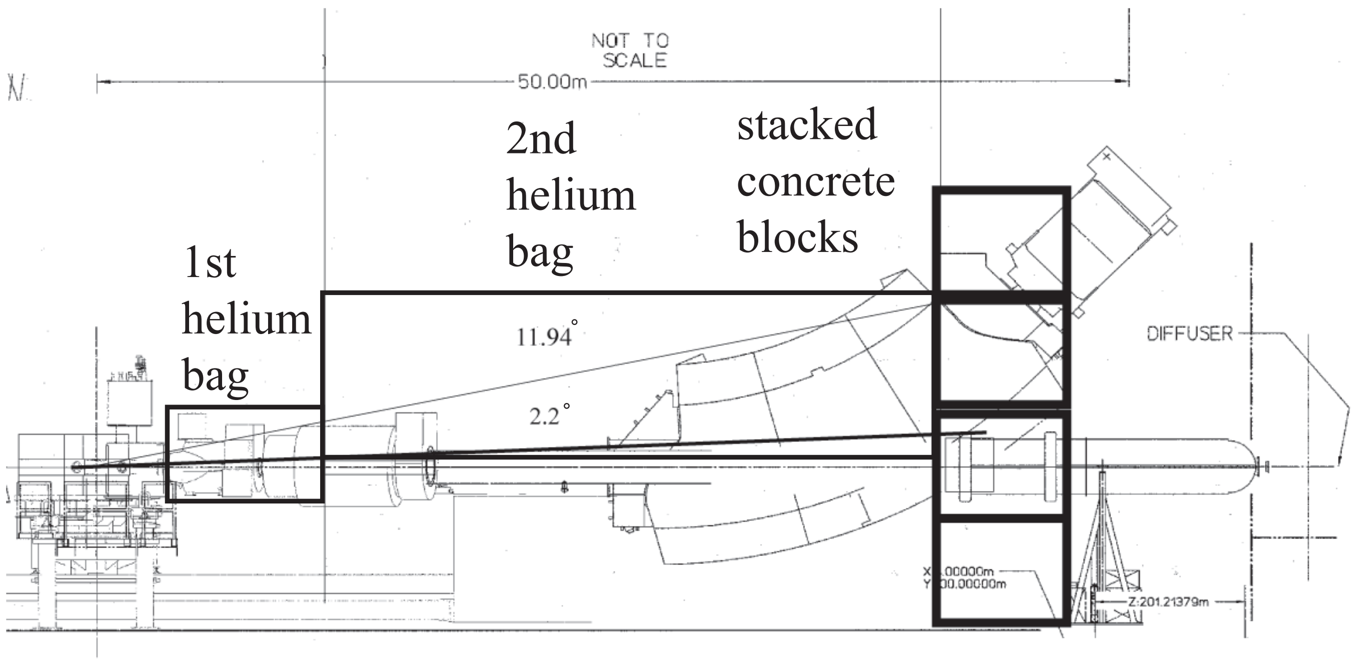
First dipole used to kick the beam out of plane.

Second dipole with variable vertical height.

Hall C HKS magnets could be used.

Vacuum chambers would need to be modified.

Local Beam Dump



1. 1^{st} helium bag up to existing beam pipe to allow vertical exit of beam.
2. 2^{nd} helium bag to dump for deflected beam to reach the dump.
3. External dump made of concrete.

Beamline Instrumentation

Beam Current Monitor

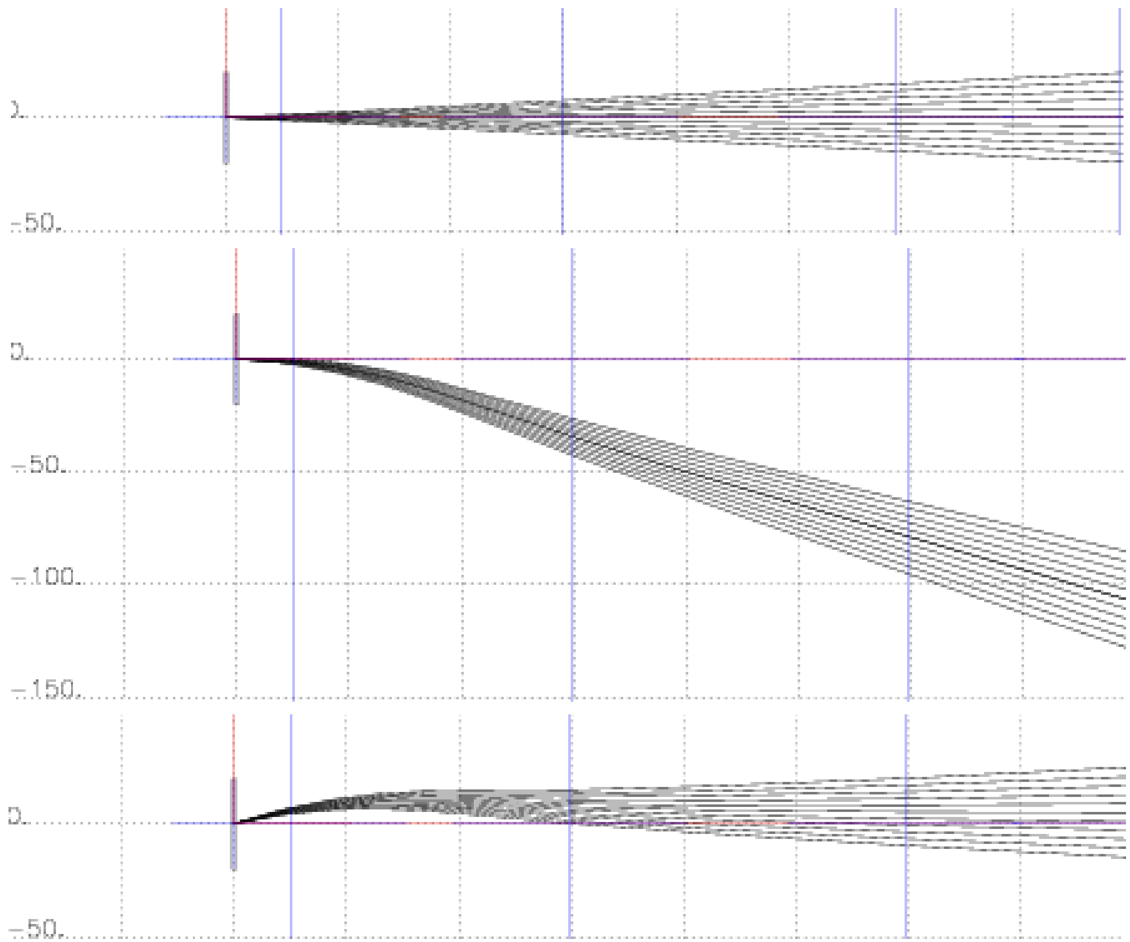
1. Low current BCM will be commissionned for Parity exp. in 2009 (50-100 nA)
2. Those BCM will be able to be well calibrated using the Beam calorimeter designed for LEDEX which would allow 1% of BCM at low current.

Beam Position Monitor

1. BPM cavities from Happex.
2. Basel SEM : used in Hall C to determine beam position after rastering.

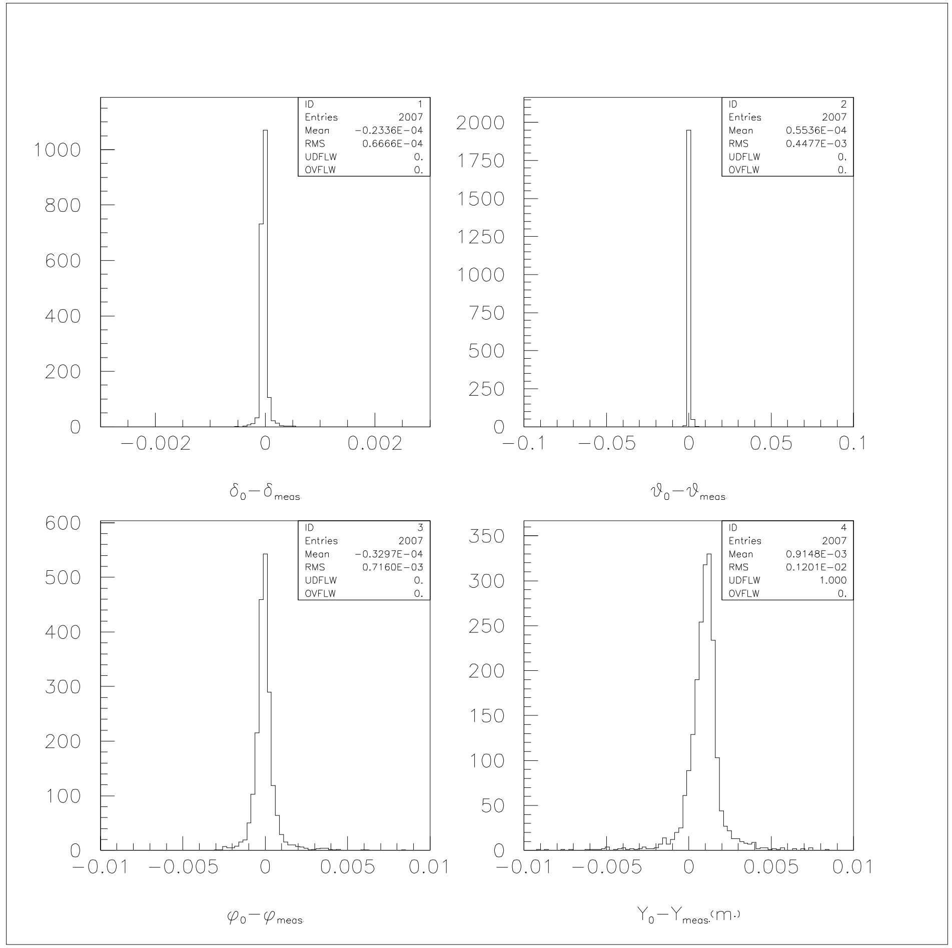
Slow raster : needed to spread heat load on target.

Effect of Target Field on Acceptance

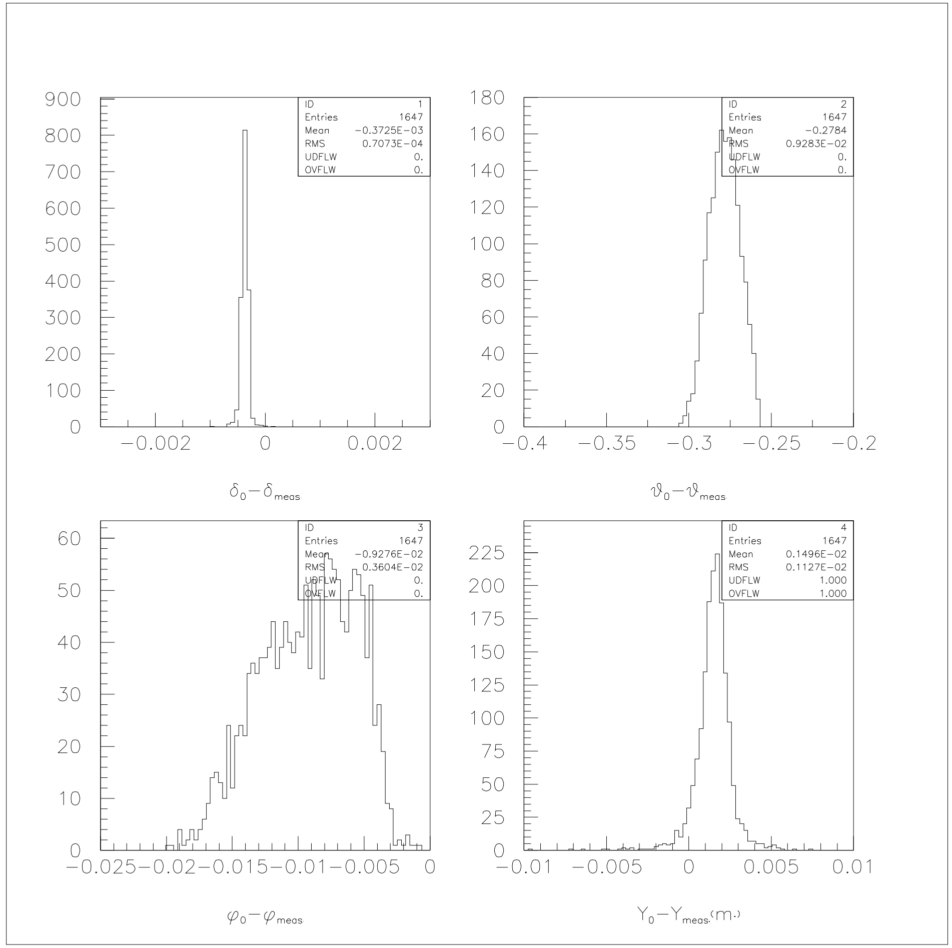


Net effect : $\approx$ 5mm vertical offset (J. Lerose)

Resolution


ID 1
Entries 2007
Mean −0.2336E−04
RMS 0.6666E−04
UDFLW 0.
OVFLW 0.
δ0−δmeas
ID 2
Entries 2007
Mean 0.5536E−04
RMS 0.4477E−03
UDFLW 0.
OVFLW 0.
ϑ0−ϑmeas
ID 3
Entries 2007
Mean −0.3297E−04
RMS 0.7160E−03
UDFLW 0.
OVFLW 0.
φ0−φmeas
ID 4
Entries 2007
Mean 0.9148E−03
RMS 0.1201E−02
UDFLW 1.000
OVFLW 0.
Y0−Ymeas (m.)

Resolution



Worst case : resolution degrades by factor of 2.

Analysis

$$g_1 = \frac{MQ^2}{4\alpha_e^2}\frac{y}{(1-y)(2-y)}\left[\Delta\sigma_\parallel + \tan\frac{\theta}{2}\Delta\sigma_\perp\right]$$

$$g_2 = \frac{MQ^2}{4\alpha_e^2}\frac{y^2}{2(1-y)(2-y)}\left[-\Delta\sigma_\parallel + \frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}\Delta\sigma_\perp\right]$$

1. We will measure $\Delta\sigma_\perp$
2. Rely on Hall B EG4 for g_1, except for one energy where we will also measure g_1.

Cross Section Systematic

Source	(%)
Acceptance	4-6
Packing fraction	3.0
Charge determination	1.0
VDC efficiency	1.0
PID detector efficiencies	$\leq$1.0
Software cut efficiency	$\leq$1.0
Energy	0.5
Deadtime	0.0
Total	5-7

Total Systematic

Source	(%)
Cross section	5-7
Target Polarization	3
Beam Polarization	3
Radiative Corrections	3
Parallel Contribution	< 1
^{15}N asymmetry	< 1
Total	7-9

Beam Time Request

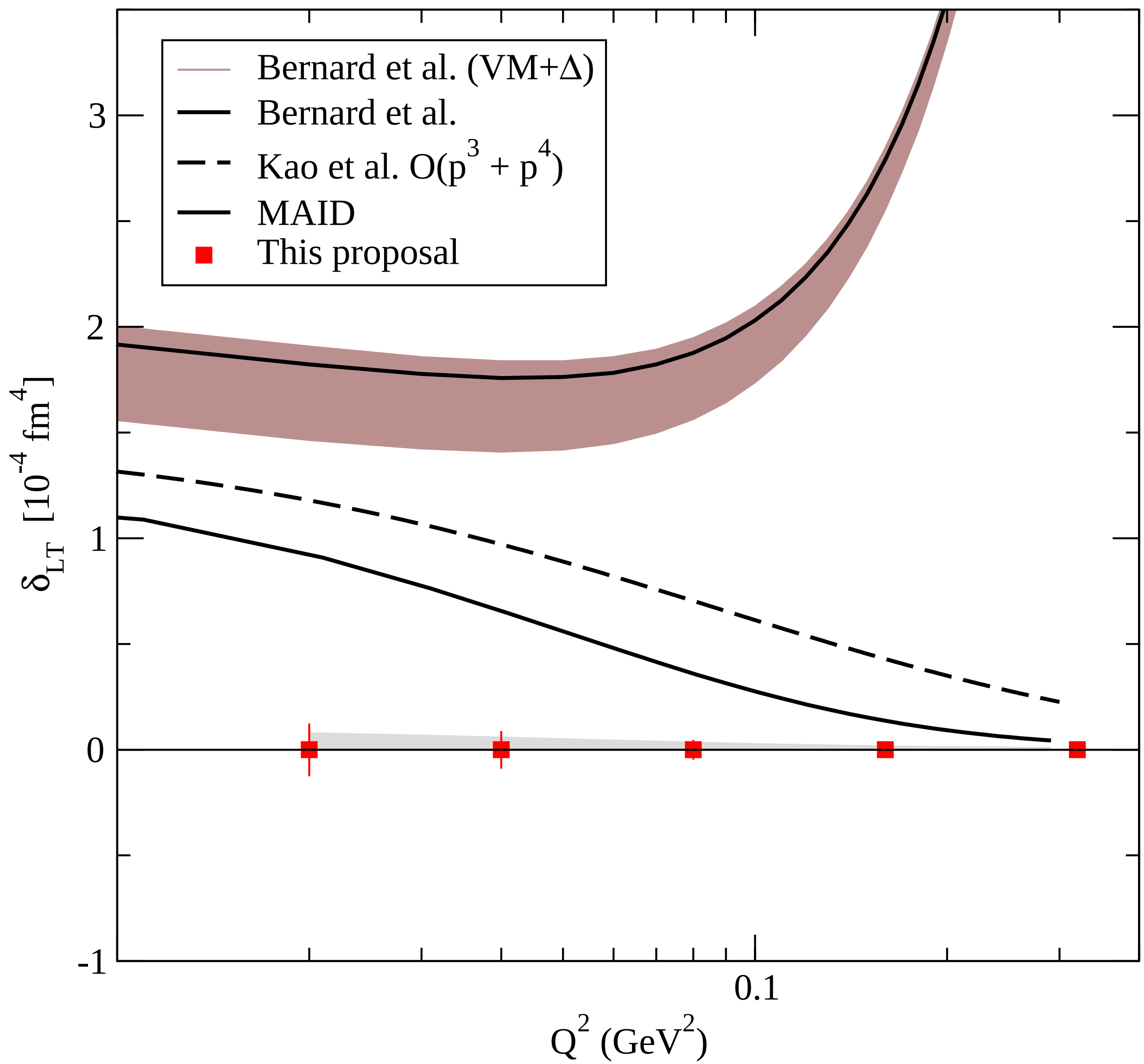
E_0 (GeV)	θ	Time(days)
1.1	6°	1.0
1.7	6°	1.5
2.2	6°	1.6
3.3	6°	2.9
4.4	6°	2.7
4.4	9°	6.0

Physics	15.7
Overhead	8.4

Overhead

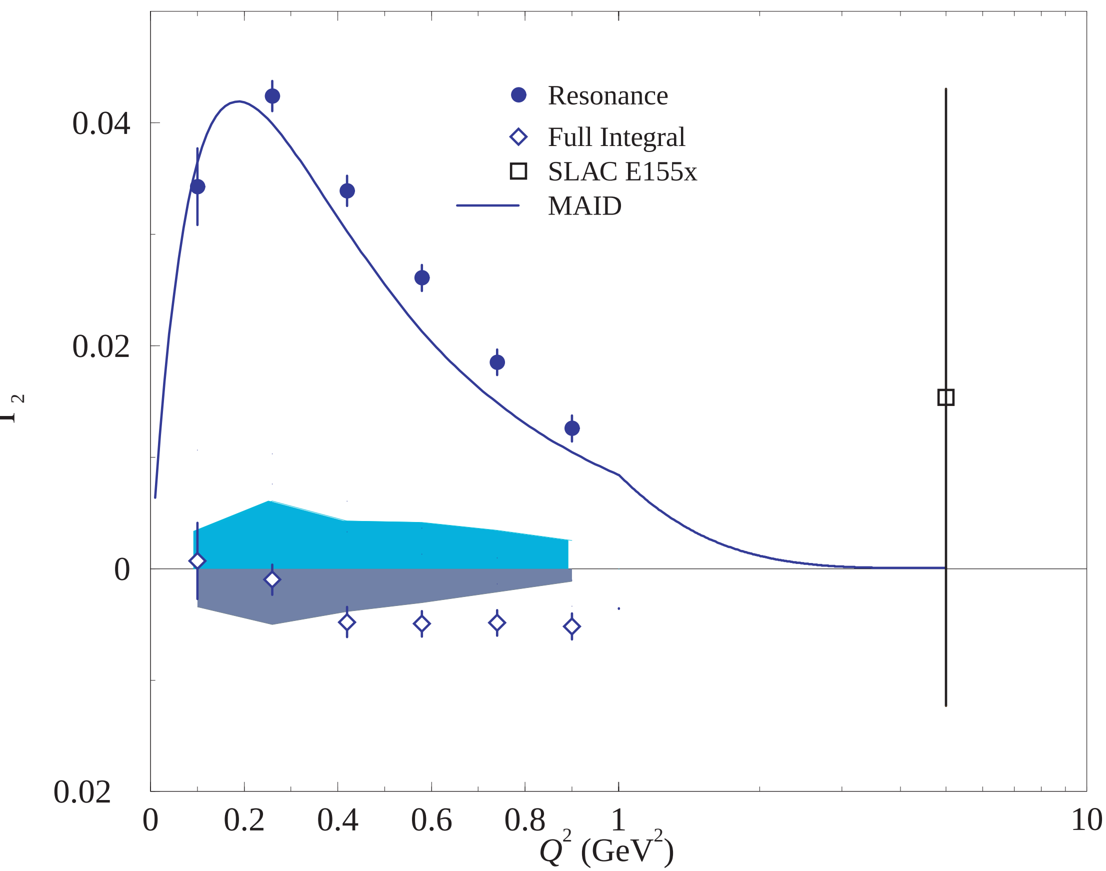
Overhead	Number	Time Per (hr)	(hr)
Target anneal	27	2.5	67.5
Target rotation	2	16.0	32.0
Target swap	2	8.0	16.0
Pass change	6	4.0	24.0
Packing Fraction	34	0.50	17.0
Linac change	0	8.0	0.0
Momentum change	69	0.25	17.2
Moller measurement	6	2.0	12.0
Septum angle change	1	8.0	8.0
Elastic calibration	2	4.0	8.0
			201.8

Projected Results



Other Physics

B.C. Sum Rule (Neutron)

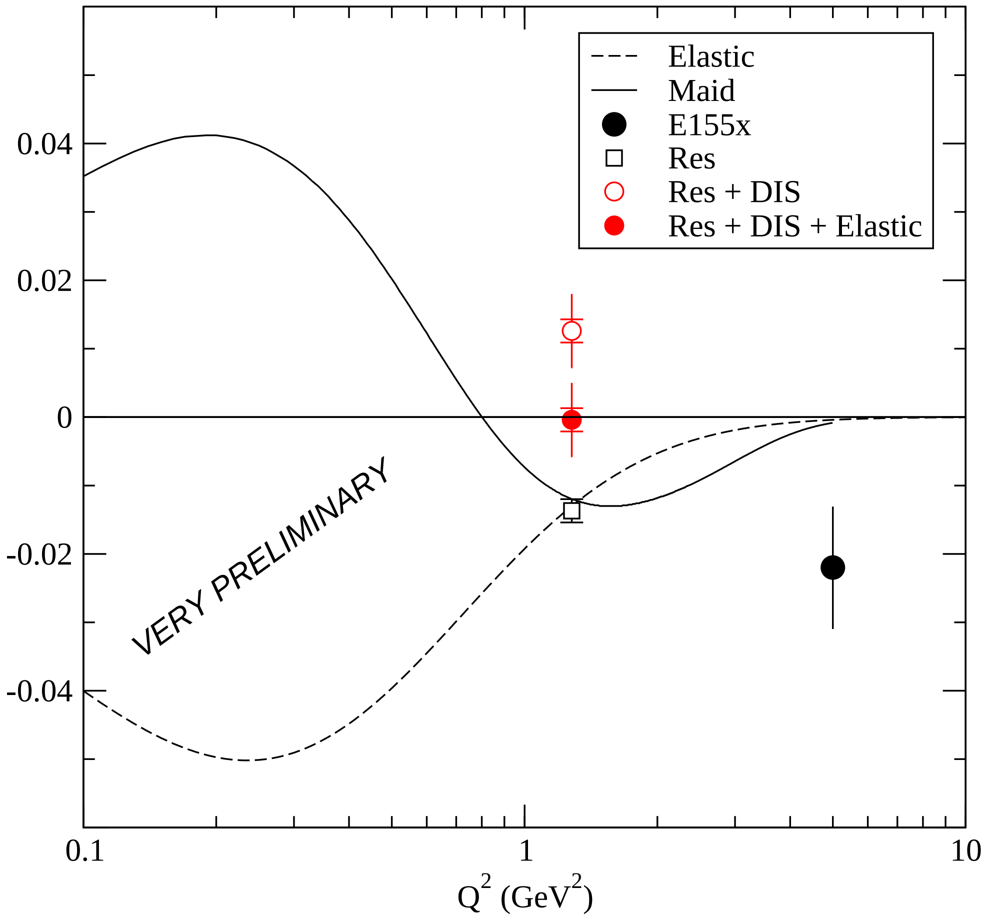


$$\int g_2(x, Q^2)dx = 0$$

Also from dispersion relation

Appears to hold for neutron.

B.C. Sum Rule (Proton)



$$\int g_2(x, Q^2)dx = 0$$

3 σ violation at $Q^2 = 5$.

Appears to hold at $Q^2 = 1.3$

RSS Collab: M. Jones, O. Rondon Spokesman.

Summary

δ_{LT} Puzzle: δ_{LT} is insensitive to $\Delta(1232)$. So it should be one of the best quantities to test χPT. Instead the data disagrees with available calculations by several hundred %.

Lots of interest from the theory community.

With 24 days, we can provide an unambiguos test of the available χPT calcuations.

Also get lots of nice (rare) transverse data for more traditional physics: BC, d_2, GDH, etc.

Though quantum chromodynamics (QCD) is generally accepted as underlying theory of the strong interactions, a numerical check of the theory in the confinement region is difficult due to the strong coupling constant. A plethora of models has been inspired by QCD, but none of these models can be quantitatively derived from QCD. Only two descriptions are, in principle, exact realizations of QCD, namely chiral perturbation theory (ChPT) and lattice gauge theory (LGT).

D. Drechsel (GDH 2000), Mainz, Germany, 14-17 Jun 2000.

Work in Progress...

Preliminary analysis by Jay Benesch indicates that the input beam angles required at the target may be obtained by installing two of the magnets used in the HKS chicane as vertical bends in the space now occupied by the 7m girder before the target chamber. New vacuum chambers would be required.