Measurement of the Parity Violating Asymmetry in the $N \rightarrow \Delta$ Transition

(E04-101)

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for the

G0 Collaboration

Overview

- Purpose:
  - Precise measurement of $G^A_{N\Delta}$ and M_A
- Data:
  - Runs concurrently with G^0 Backward Angle:
    - Elastically scattered e's: ***G^0***
    - Inelastically scattered e's: $N \rightarrow \Delta$
- Status:
  - Taking data:
    - LD2 @ 362MeV currently, 687MeV in March
  - Preliminary data analysis:
    - LH2 @ 362MeV & 687MeV
    - LD2 @ 687MeV

Motivation

- Measuring $G^A_{N\Delta}$
  - General axial form factor for N
    - How is the spin distributed?
  - Axial form factor for $N \rightarrow \Delta^+$
    - How is the spin redistributed during transition?

- $A_{N\Delta}$ gives *direct access* to $G^A_{N\Delta}$
  - Directly measure the axial (intrinsic spin) response during $N \rightarrow \Delta^+$

- Axial mass M_A:
  - Describe Q^2 dependence of $G^A_{N\Delta}$

Motivation

- Reaction Mechanism (CQM)
  - G^0 N-Δ Measurement: Z^0 exchange (Neutral Current)
    - $ep \rightarrow e\Delta^+$
      - Z^0 induces quark spin flip
      - c.f. *M1* from γ induced quark spin flip
  - Previous Measurements: W^+ exchange (Charged Current)
    - $\nu p \rightarrow \mu^- \Delta^{++}$, $ep \rightarrow \pi^- \Delta^{++}$
      - Quark flavor change and spin flip
        - » different reaction mechanism

$\rightarrow$ *First measurement in neutral current process*

Theory

$$A_{inel} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[\Delta^{\pi}_{(1)} + \Delta^{\pi}_{(2)} + \Delta^{\pi}_{(3)}\right]$$

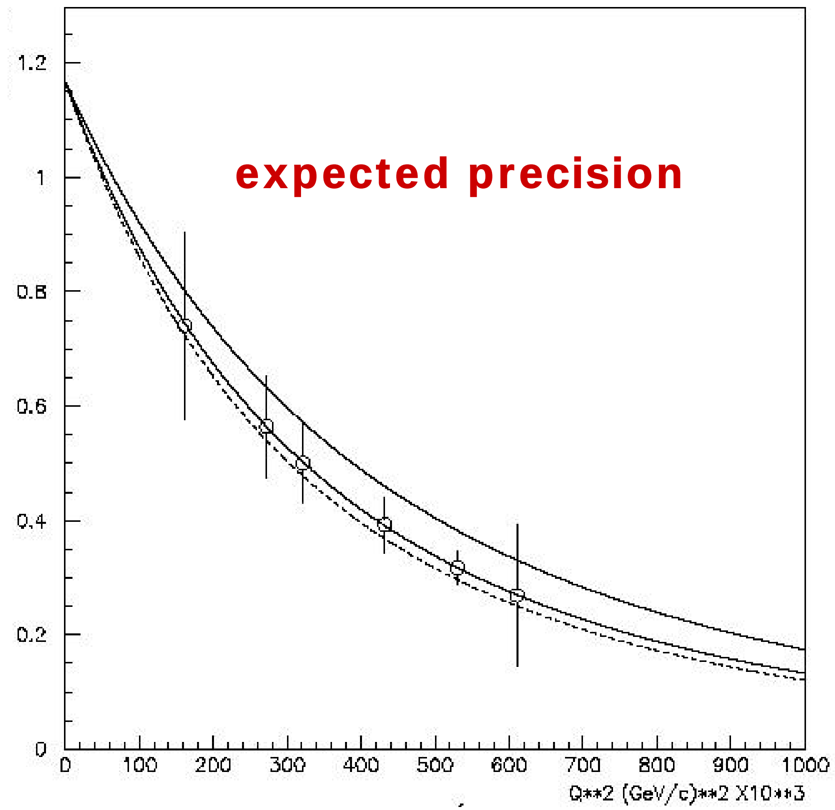
$\Delta_{(1)} = 2(1-\sin^2\theta_W) = 1$ (Standard Model)
$\Delta_{(2)} =$ non-resonant contrib. (small)
$\Delta_{(3)} = 2(1-4\sin^2\theta_W)$ *$F(Q^2,s)$* → *(N-Δ resonance)*

At tree-level:

$$F(Q^2, s) \rightarrow G^A_{N\Delta}(Q^2)$$

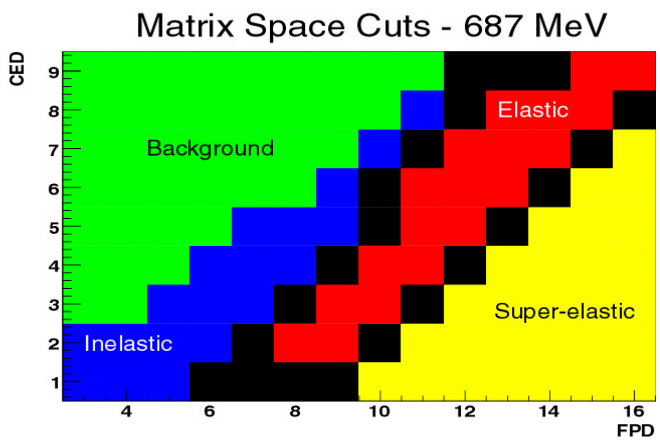
- *F* contains kinematic information & all weak transition form factors
  →Extract $G^A_{N\Delta}$ from *F*

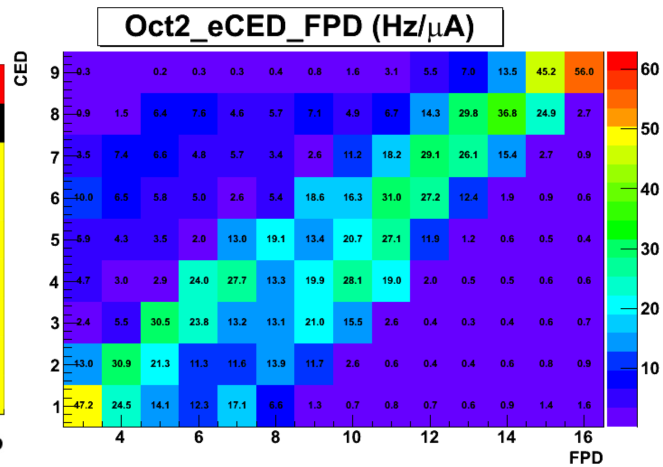
$G^A_{N\Delta}(Q^2)$ vs Q^2



Coincidence Rates: LH_2

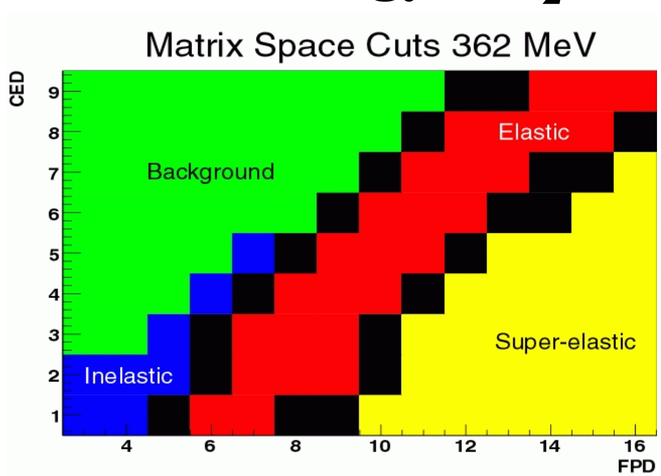
- **High Energy LH_2**

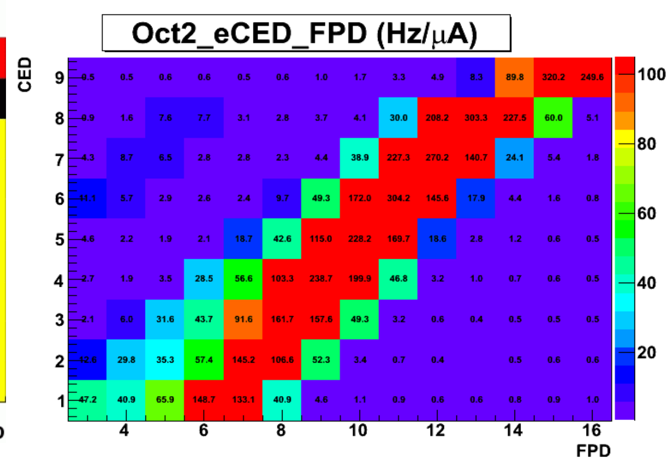




Total Charge Accumulated: ~ 100C

- **Low Energy LH_2**

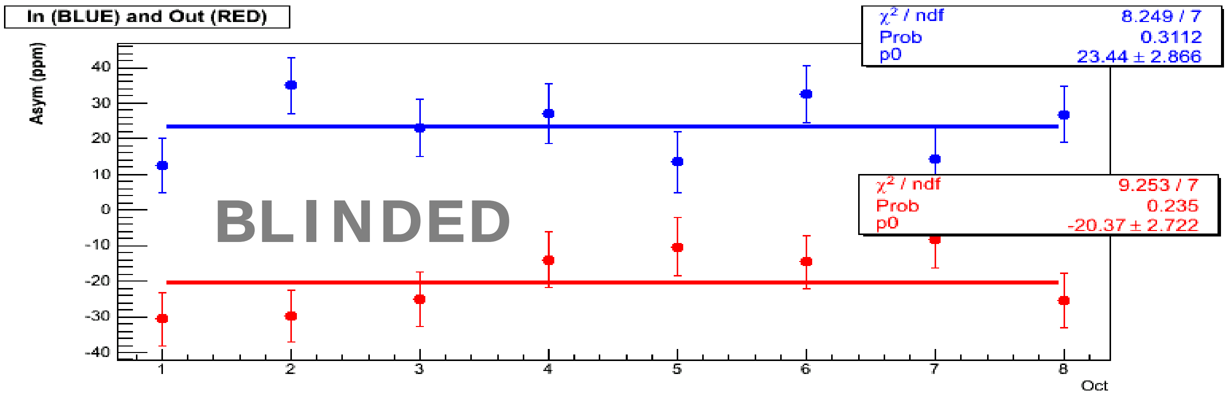




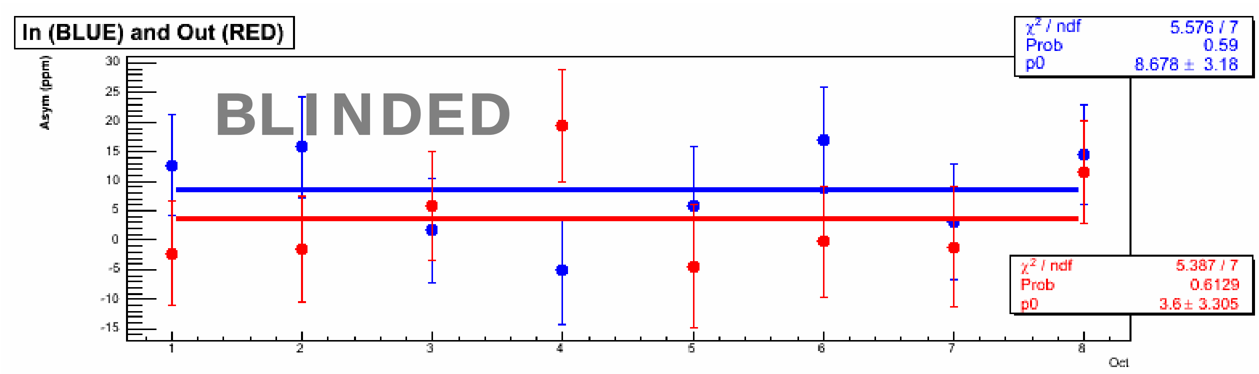
Total Charge Accumulated: ~ 90C

Asymmetries: LH_2

- High Energy LH_2: Average Along Inelastic Locus



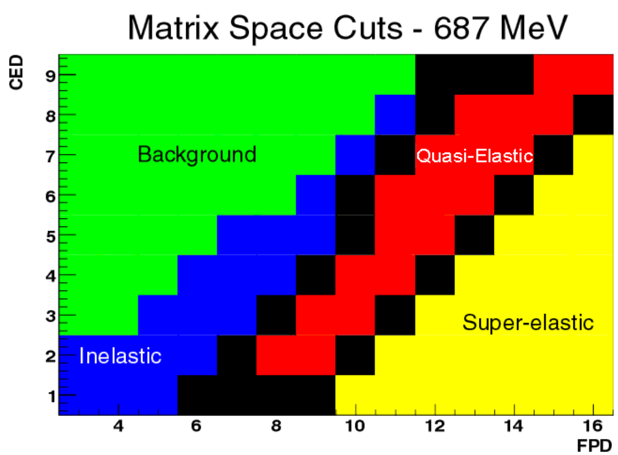
- Low Energy LH_2: Average Along Inelastic Locus

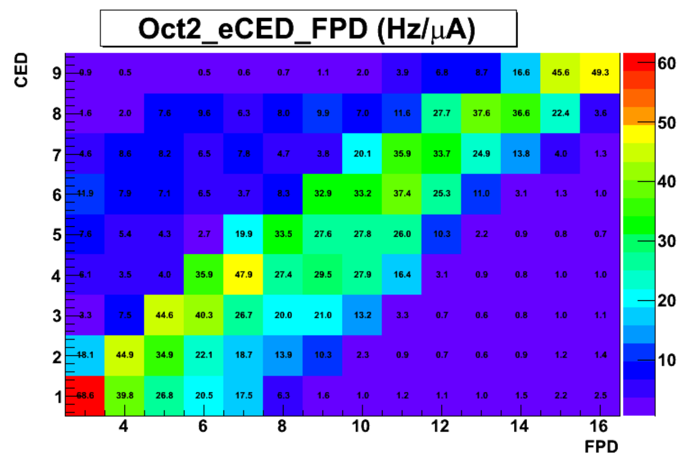


→**Raw Asymmetries – no corrections!**

Coincidence Rates: LD_2

- **High Energy LD_2**

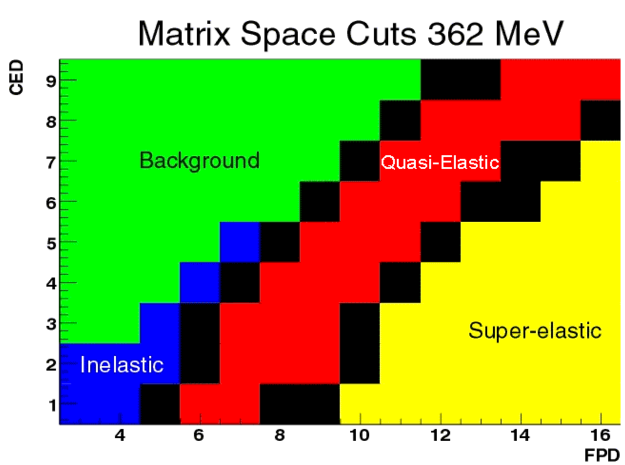


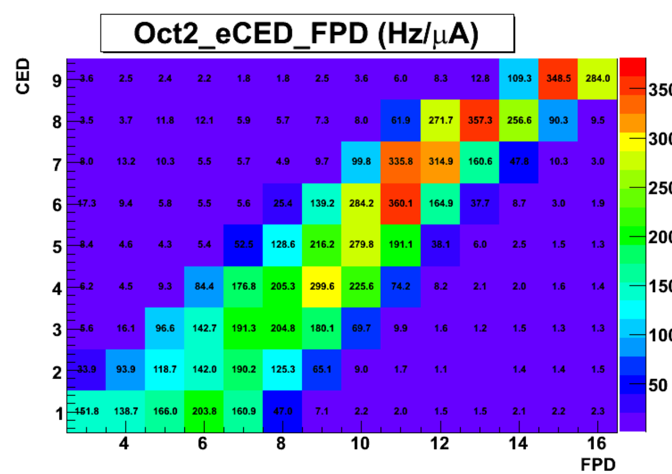


Total Charge Accumulated: ~ 37C

(more to come)

- **Low Energy LD_2**



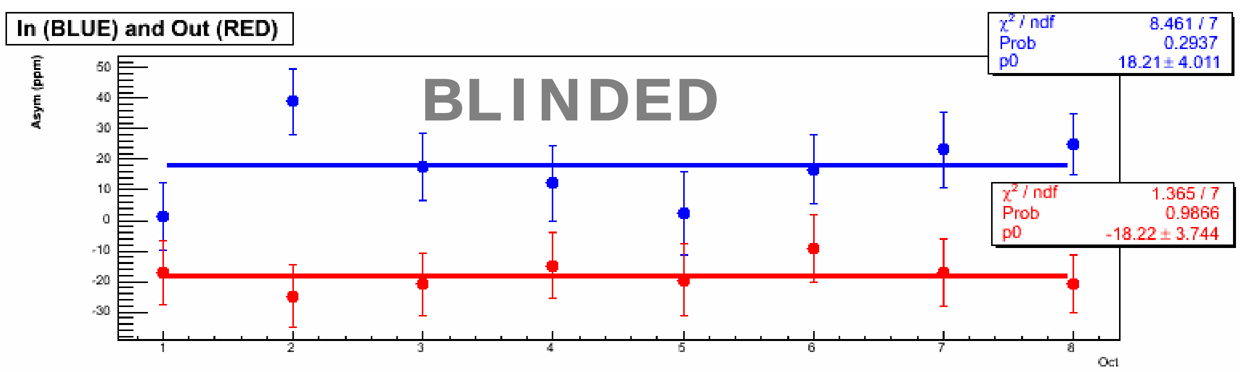


Total Charge Accumulated: ~ 26C

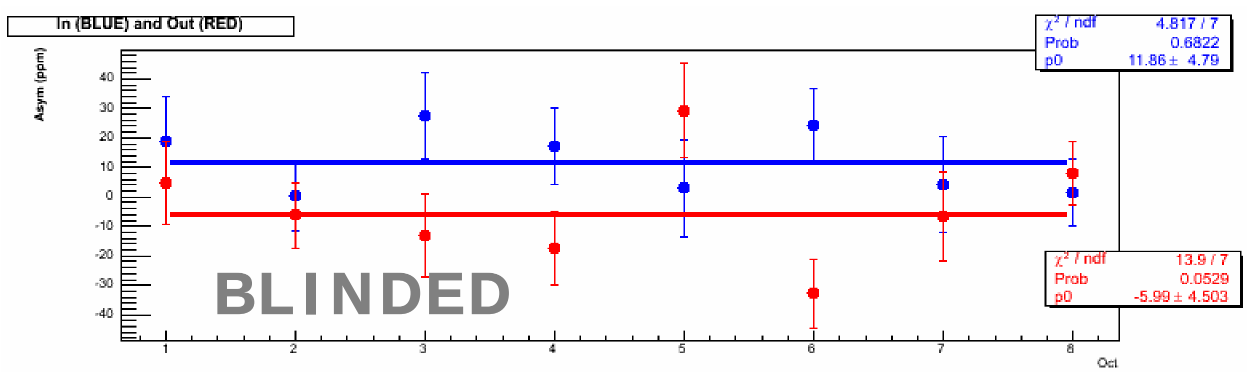
(more to come)

Asymmetries: LD_2

- High Energy LD_2: Average Across Inelastic Locus



- Low Energy LD_2: Average Across Inelastic Locus



→Raw Asymmetries – no corrections!

A work in progress…

Analysis Strategy

- General Corrections: Same process as G^0
  - Beam/Instrument related
    - Dead time/Randoms
    - Helicity correlated beam properties
    - Beam polarization
  - Background
    - Dilution factors
    - Background from target
    - Pion contamination

Currently ongoing…

Analysis Strategy

- Specific to $N \rightarrow \Delta^+$
  - Find Q^2 "bins"
    - Use simulation results to find evolution of Q^2 along locus
      - 2 or 3 bins for 687 MeV
      - 1 bin for 362 MeV
  - From here can find $G^A{}_{N\Delta}(Q^2)$ and $M_A(Q^2)$
- Note on LD_2:
  - Apply same process as LH_2
    - Treat as an incoherent process
  - No dedicated calculation exists
    - Expect theoretical interest in such a measurement

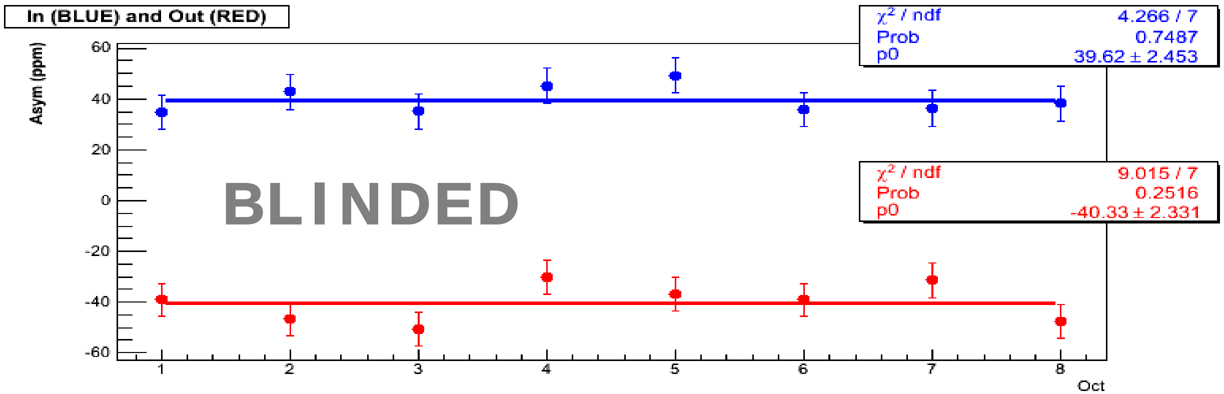
Summary

- Measurement of $G^{A}_{N\Delta}$
  - First time measurement in neutral current reaction
- Data Progress
  - G^0 Backward taking data until late March
- Analysis Progress
  - Working on corrections
    - Beam related
    - Backgrounds
  - Working with simulation
    - Finding the appropriate Q^2 bins

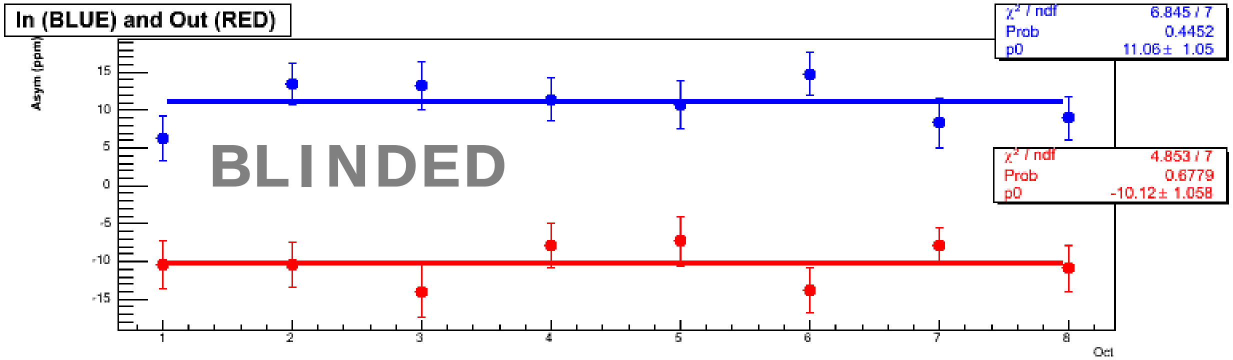
The end... let the backups begin!!

Asymmetries: LH2

- High Energy LH2: Average Along Elastic Locus



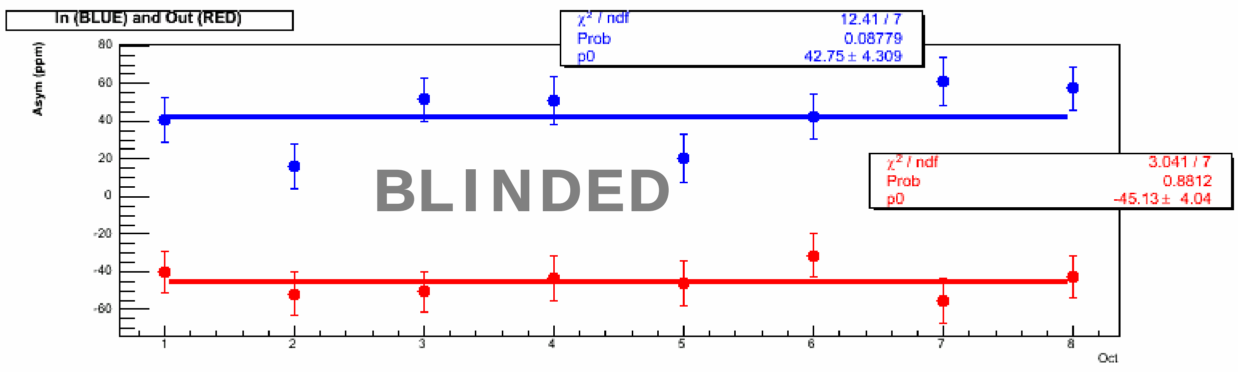
- Low Energy LH2: Average Along Elastic Locus



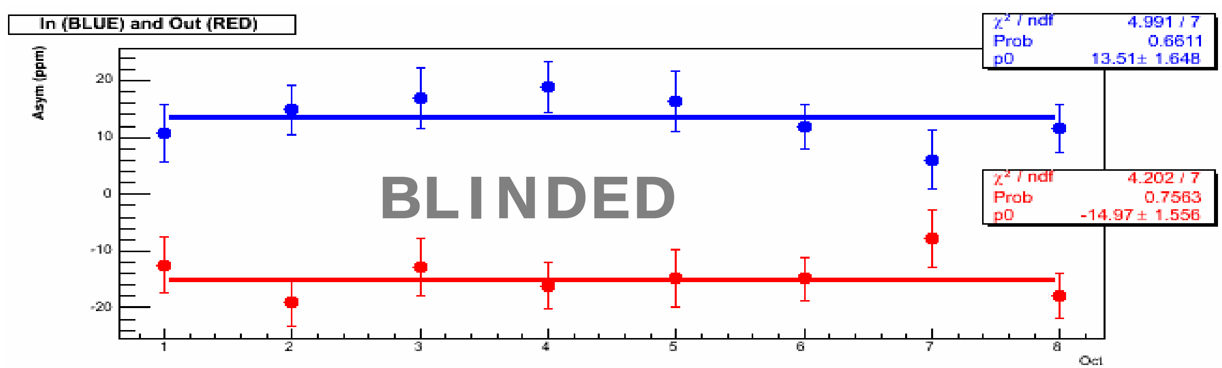
→**Raw Asymmetries – no corrections!**

Asymmetries: LD2

- High Energy LD2: Average Across Elastic Locus



- Low Energy LD2: Average Across Elastic Locus



A work in progress…

→Raw Asymmetries – no corrections!

Non-resonant Contributions

Nimai C. Mukhopadhyay et al., Nucl. Phys. ***A633****,481 (1998)*

$E(GeV)$	$\theta_{lab}(^o)$	$Q^2((GeV/c)^2)$	$\Delta^{\pi}_{(2)}/\Delta^{\pi}_{(3)}$
0.4	90	0.035	0.06
0.5	90	0.106	0.16
0.6	90	0.192	0.27
0.7	90	0.291	0.39

$\Delta^{\pi}_{(2)}(E_{0+}^{1/2,0,3/2}, S_{0+}^{1/2,0,3/2}, E_{1+}^{1/2,0,3/2}, M_{1+}^{1/2,0,3/2}, \text{etc.})$

CLAS(ep, ed, etc. single π production w/polarization)

H. Schmieden, Eur. Phys. J. ***A1****:427-433,1998*

The end again….

I told you this was the end, why are you still looking?

Are you calling me a liar?!

Ok, you got me… there are more… but they don't count!

Unused…… fun and games

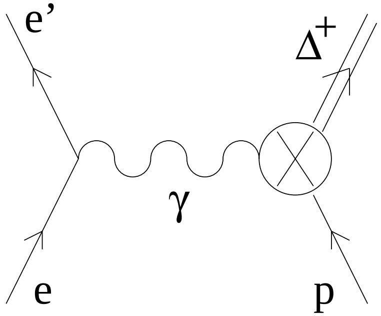
Beam time, resource request

* *0 days*

* *0 additional resources*

* *Simultaneous running w/ G0 backward angle*

Siegert Contribution



$$A_{PV}^{\gamma} \sim \frac{G_F}{\alpha} Q^2 \left[a \frac{\omega}{Q^2} \quad + \quad Anapole \right]$$

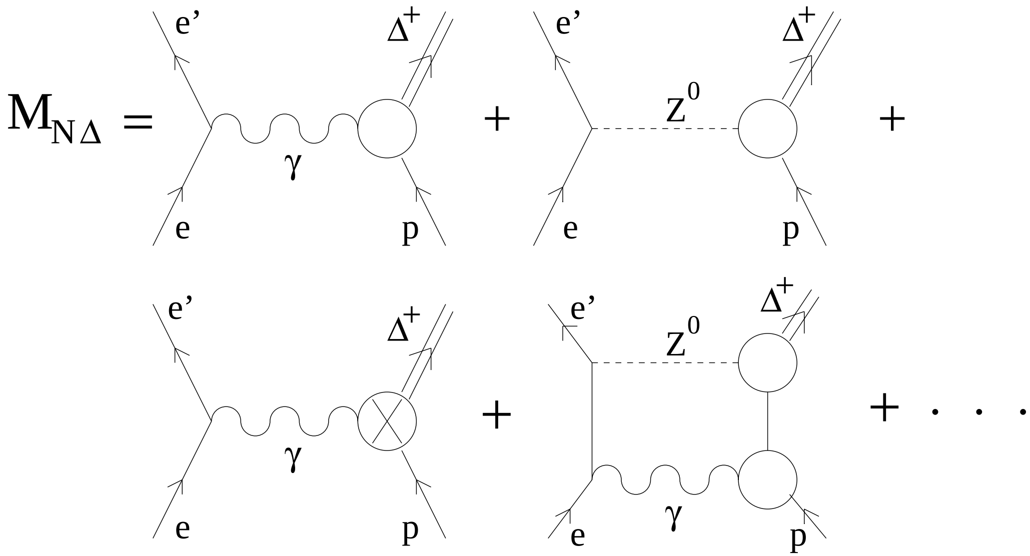
$\uparrow$

PV $\gamma N \Delta$ E1 *amplitude (Siegert's Theorem)* $\longrightarrow$ $\mathbf{d_\Delta}\,(\sim g_\pi)$

$$\rightarrow A_{PV}^{\gamma}\left(Q^2 = 0\right) \neq 0\,!$$

Same **M.E.** *driving Weak Hyperon Decay (e.g.* $\Sigma^+ \rightarrow p\gamma$*)*

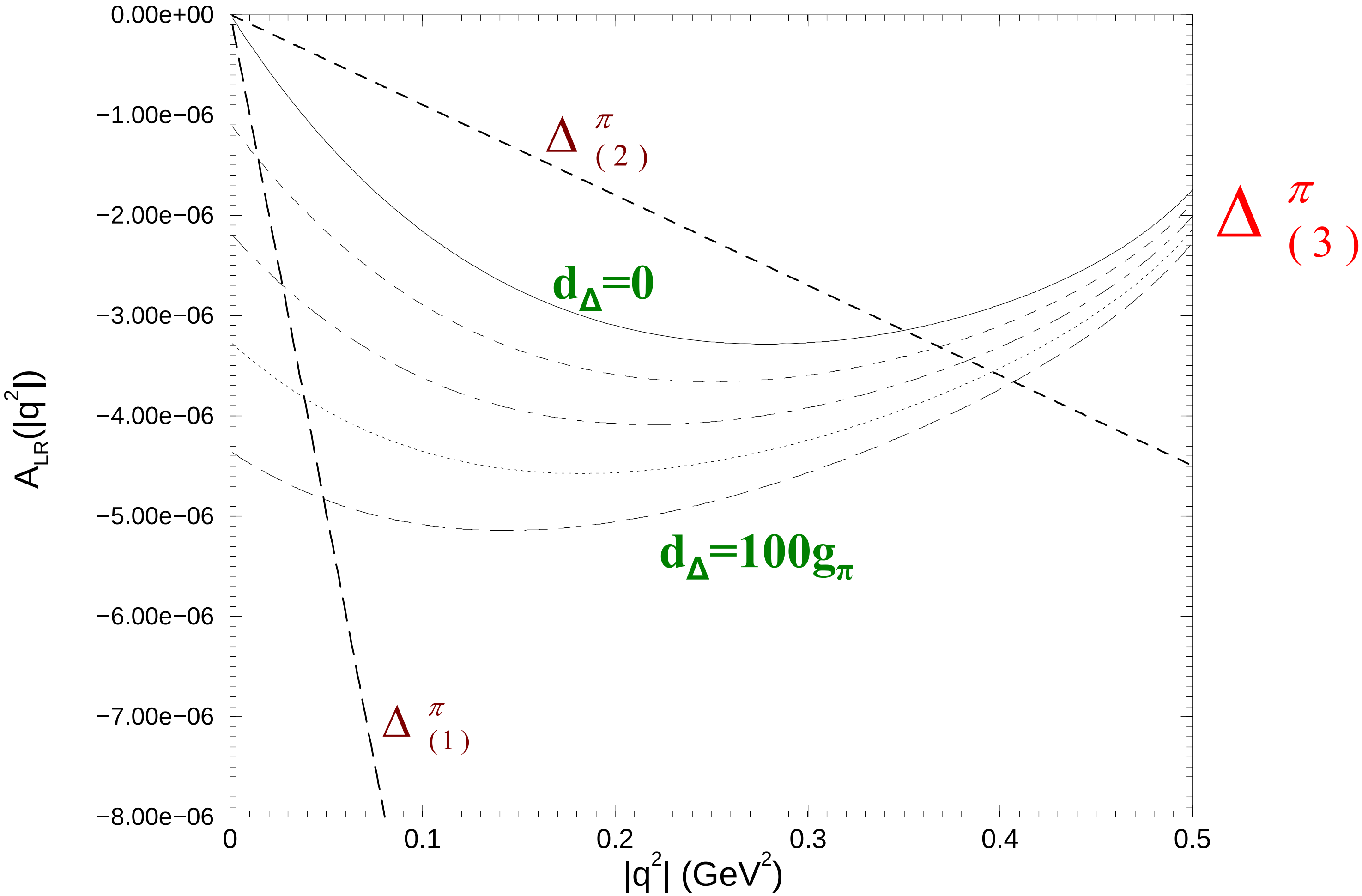
Radiative Corrections



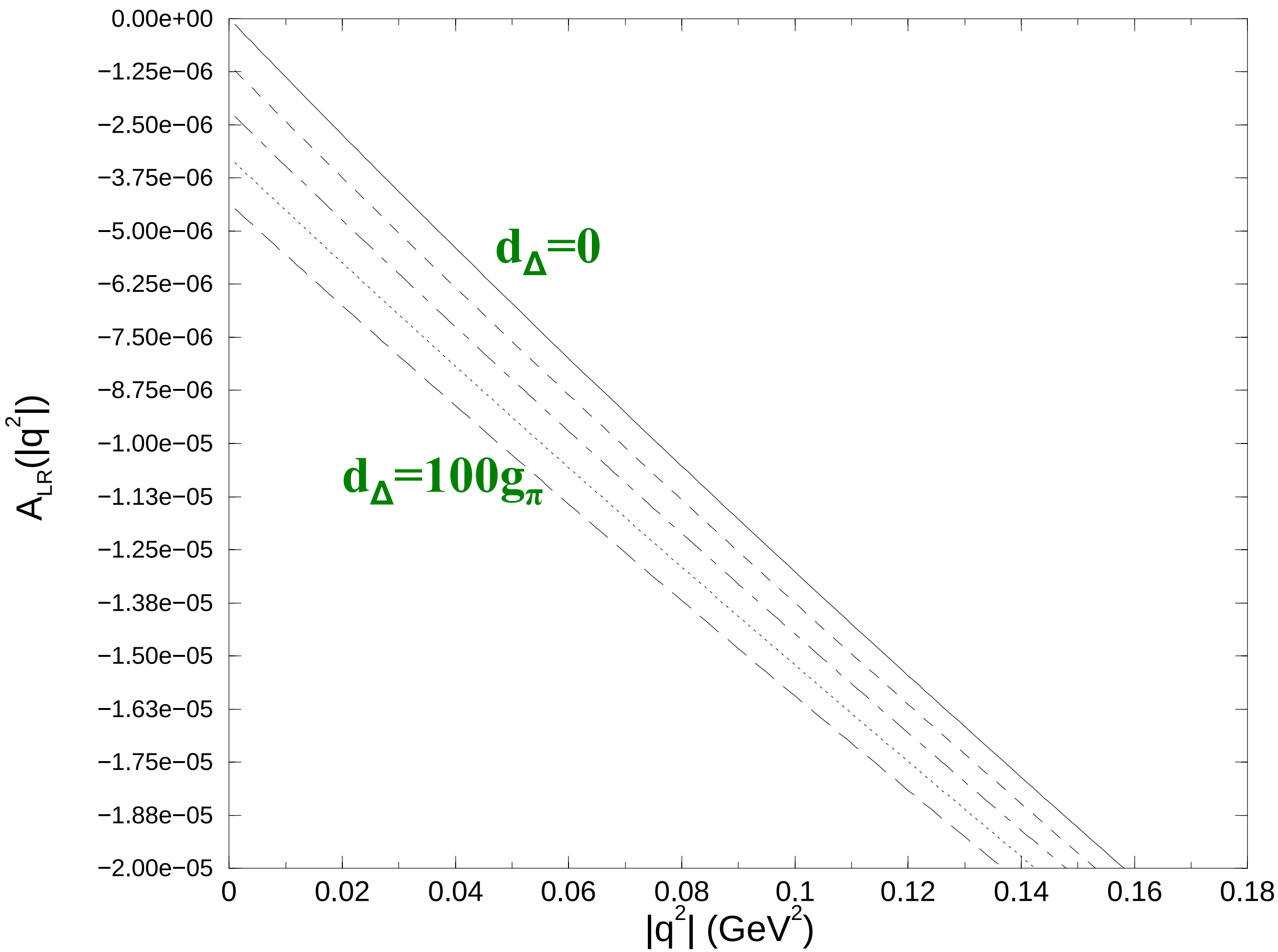
$$\Delta^{\pi}_{(3)} \propto \left(1 + R_A^{\Delta}\right) G^{A}_{N\Delta}$$

$$R_A^{\Delta} = R_A^{ewk} + R_A^{Siegert} + R_A^{Anapole} + R_A^{Box} + \cdots$$

S.-L. Zhu et al., hep-ph/0107076 (July 2001)

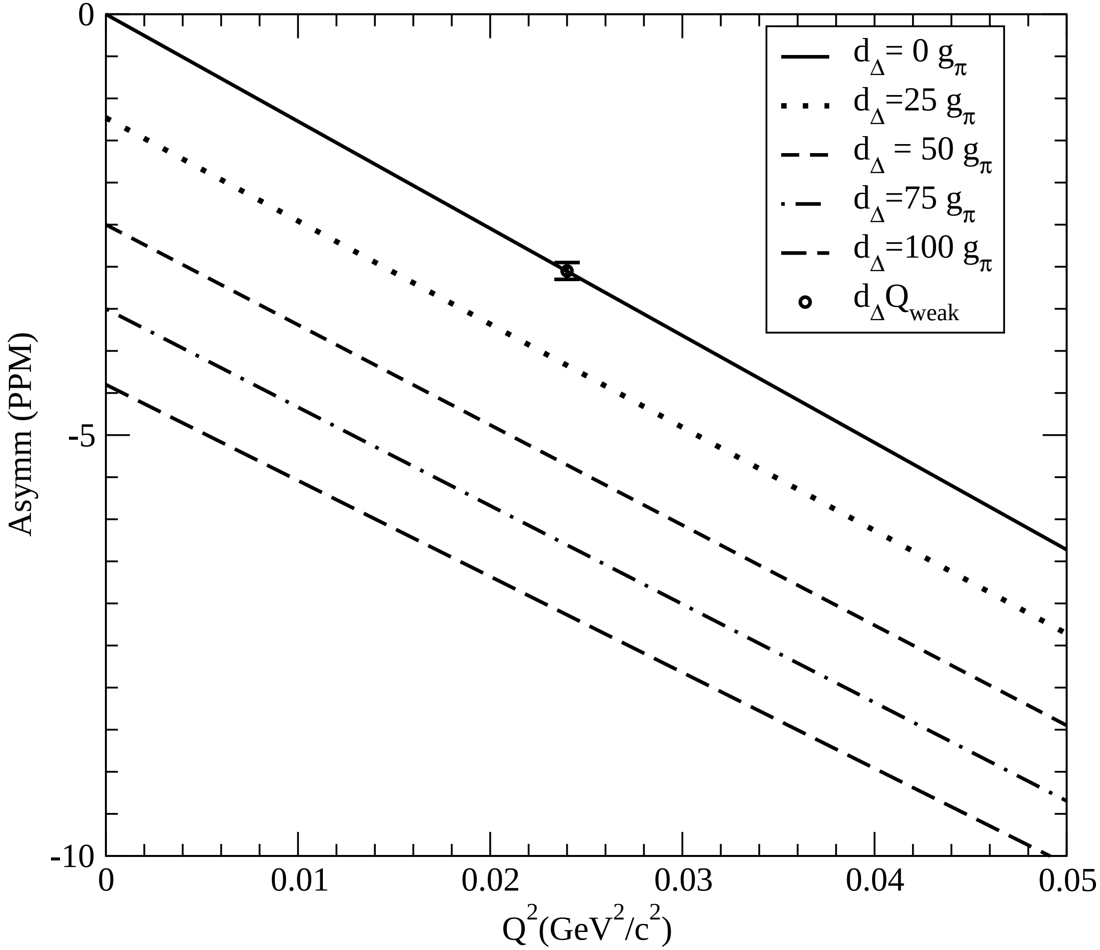


0.00e+00
−1.00e−06
−2.00e−06
−3.00e−06
−4.00e−06
−5.00e−06
−6.00e−06
−7.00e−06
−8.00e−06
0
0.1
0.2
0.3
0.4
0.5
$A_{LR}(|q^2|)$
$|q^2|$ (GeV^2)
$\Delta^{\pi}_{(1)}$
$\Delta^{\pi}_{(2)}$
$\Delta^{\pi}_{(3)}$
$d_\Delta=0$
$d_\Delta=100g_\pi$



0.00e+00
−1.25e−06
−2.50e−06
−3.75e−06
−5.00e−06
−6.25e−06
−7.50e−06
−8.75e−06
−1.00e−05
−1.13e−05
−1.25e−05
−1.38e−05
−1.50e−05
−1.63e−05
−1.75e−05
−1.88e−05
−2.00e−05
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
$A_{LR}(|q^2|)$
$|q^2|$ (GeV^2)
$d_\Delta=0$
$d_\Delta=100g_\pi$

Q



PAC24 LOI

LaTech

1 week beam time

Asymmetries: LD2 @ 362MeV

- Inelastic Locus w/o Randoms Correction

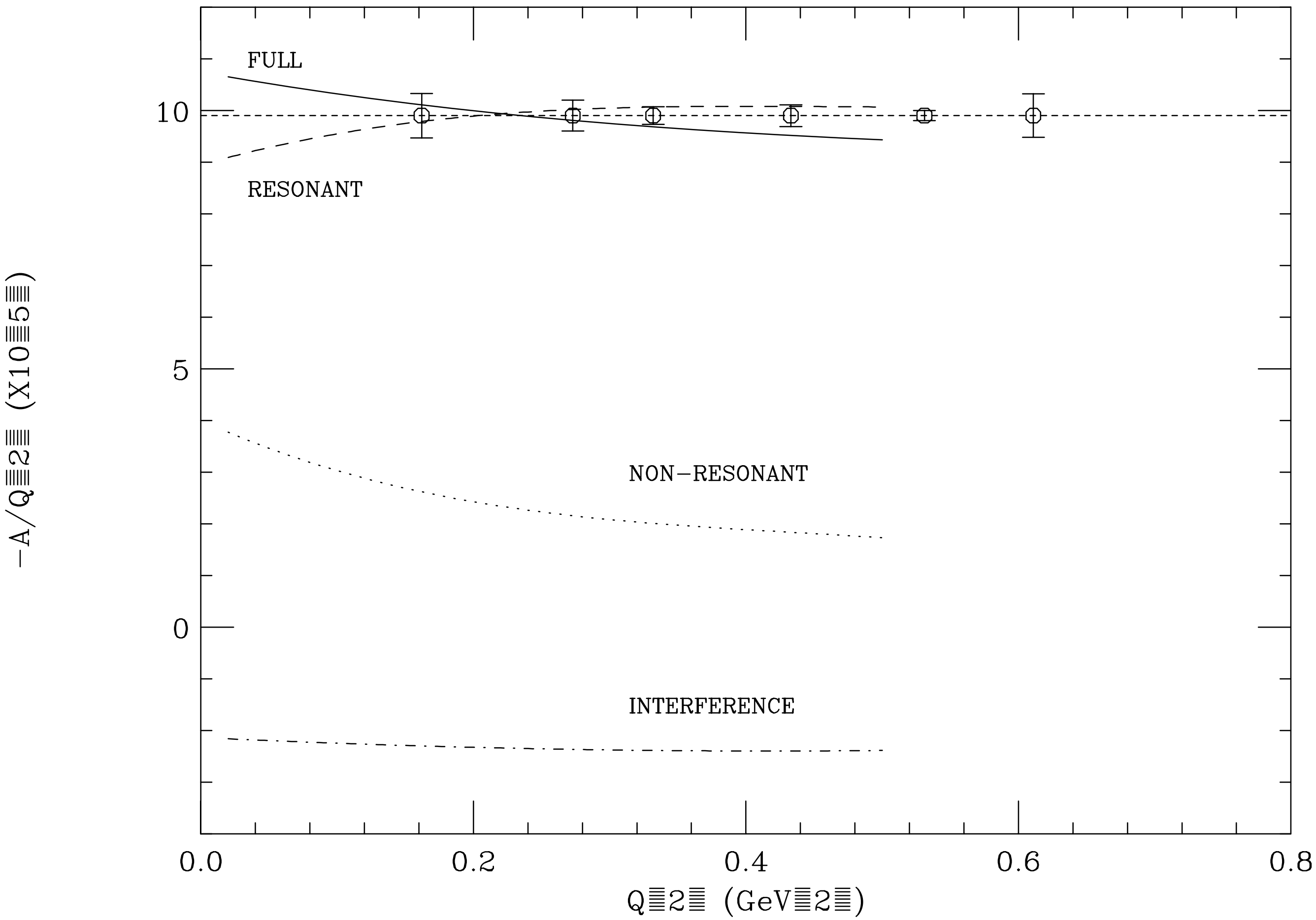
BLINDED

- Inelastic Locus w/ Randoms Correction

BLINDED

A work in progress…

Effective Lagrangian Model



E=424,585,799 MeV

700 hours each

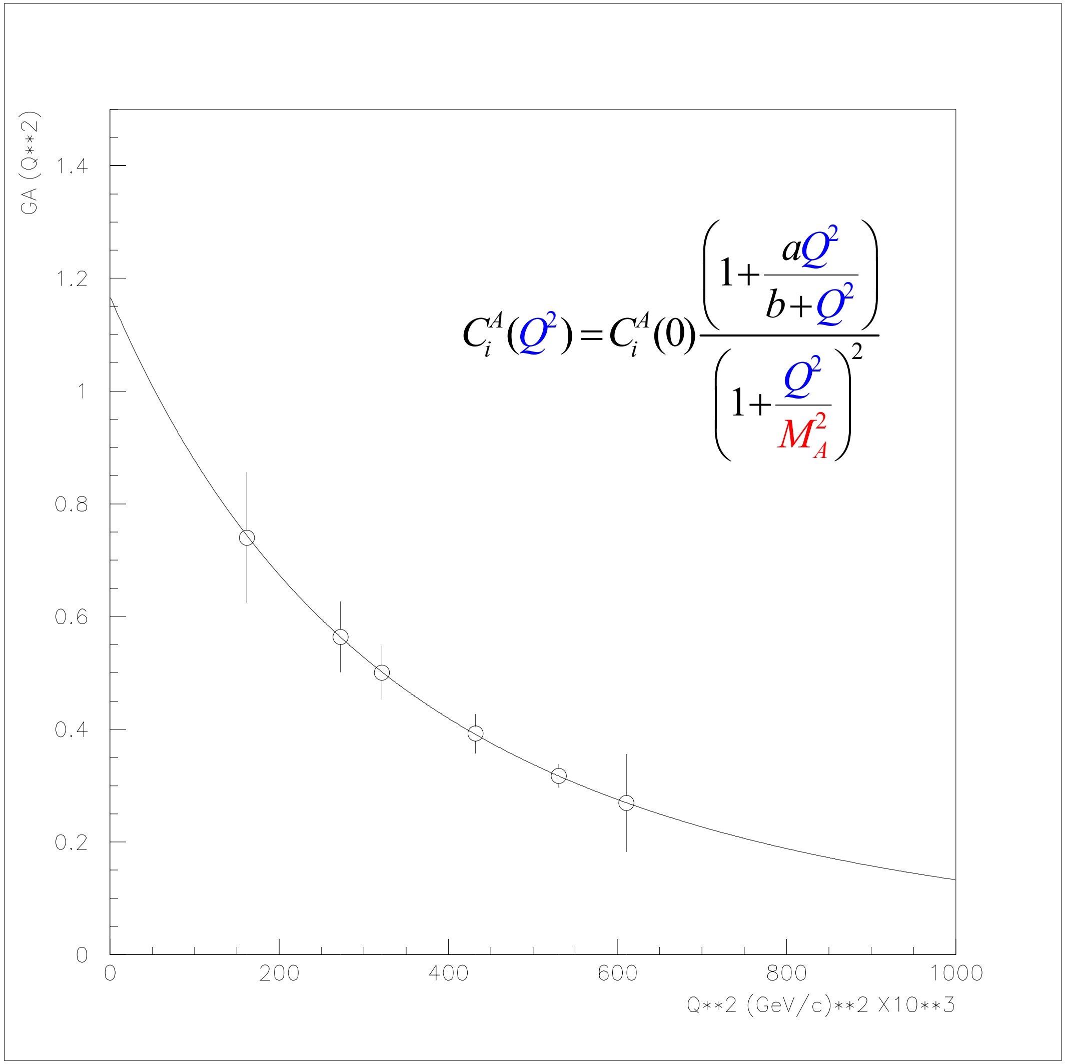
P=70%

I=80 μA

20 cm LH_2

H.-W. Hammer and D. Drechsel, Z. Phys. ***A353****, 321 (1995)*

Adler Model (modified dipole form)



$$C_i^A(Q^2) = C_i^A(0)\frac{\left(1+\frac{aQ^2}{b+Q^2}\right)}{\left(1+\frac{Q^2}{M_A^2}\right)^2}$$

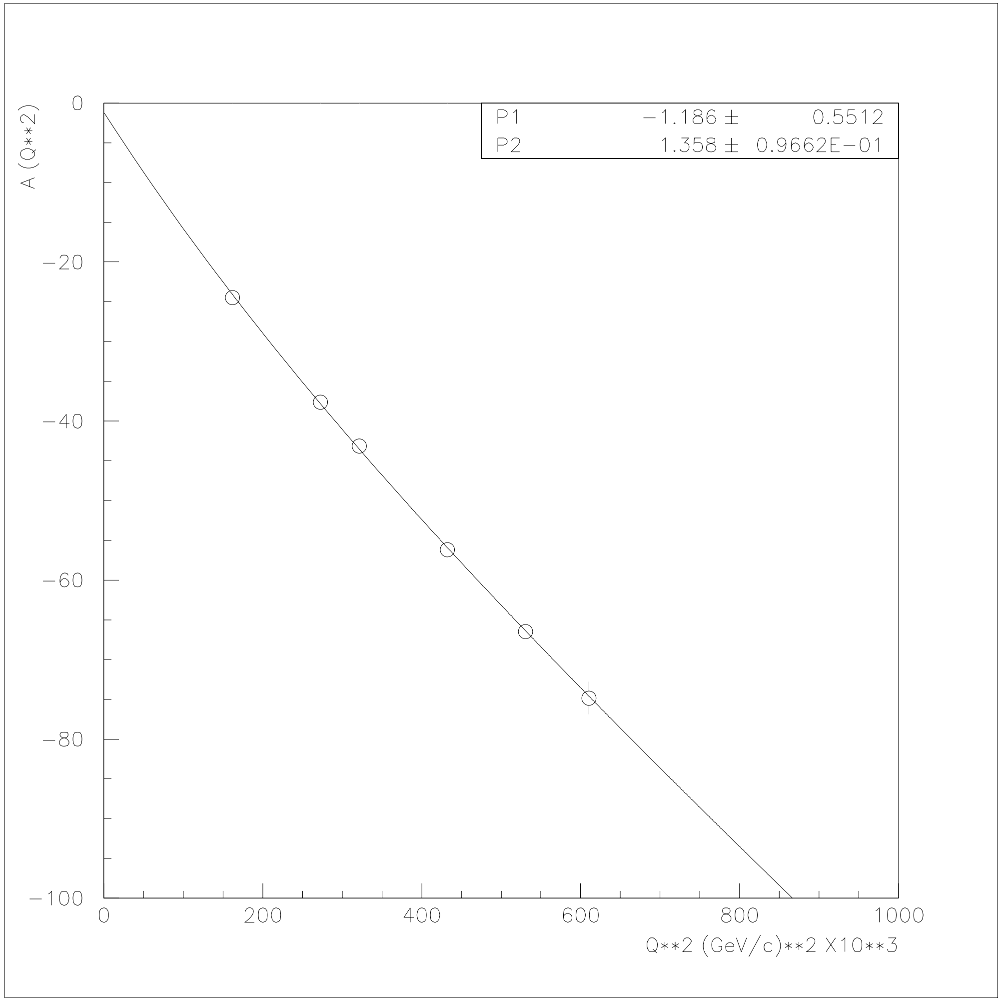
$\delta M_A = 0.031\ GeV$

vs.

$\delta M_A{}^{\nu} = 0.090\ GeV$

S.L. Adler, Ann. Phys. ***50****, 189 (1968)*

Effect on δM_A

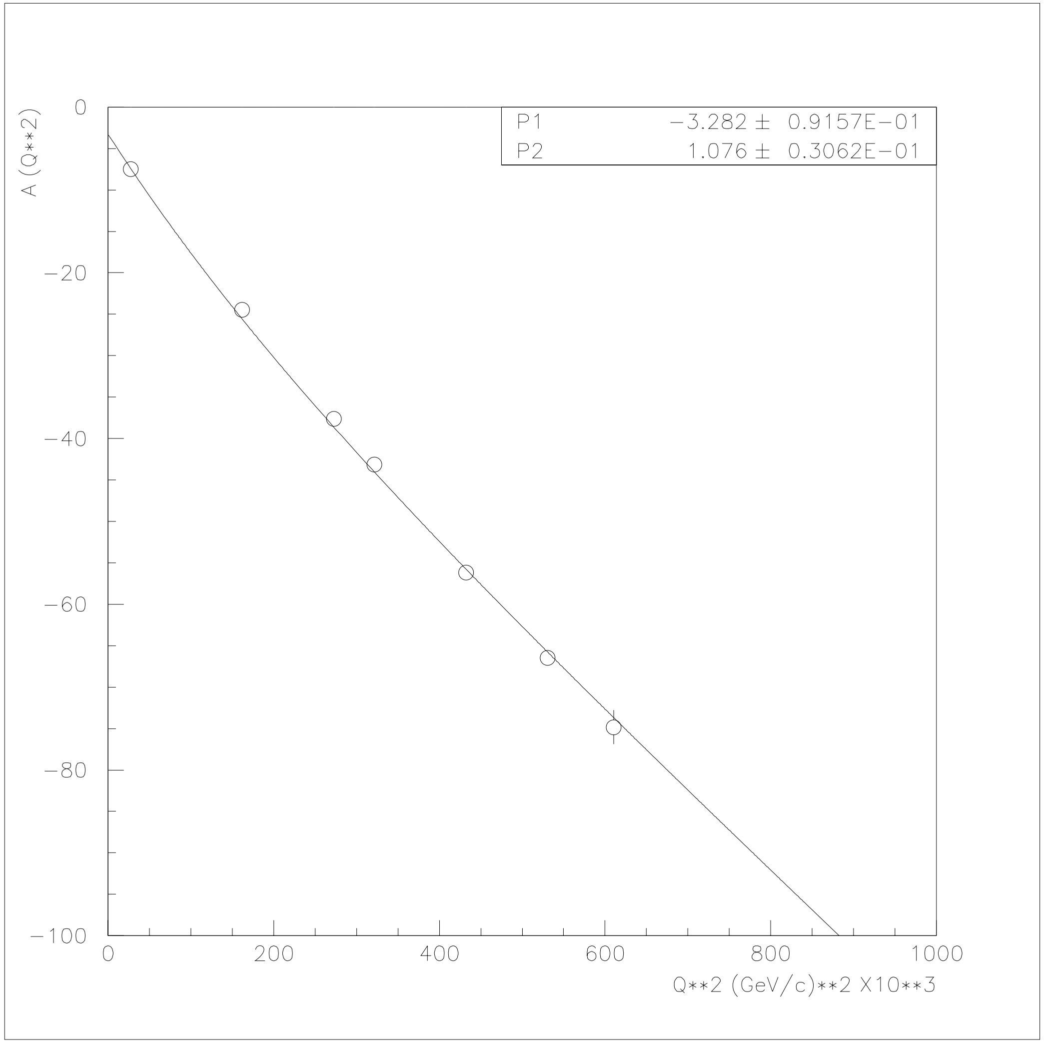


$\delta \mathbf{d}_{\Delta}$=*0.55 ppm*

$\sim 14 g_{\pi}$

δM_A=*0.097 GeV*

$\delta M_A, \delta d_\Delta$ w/ G0 & Q_{weak} $N \rightarrow \Delta$

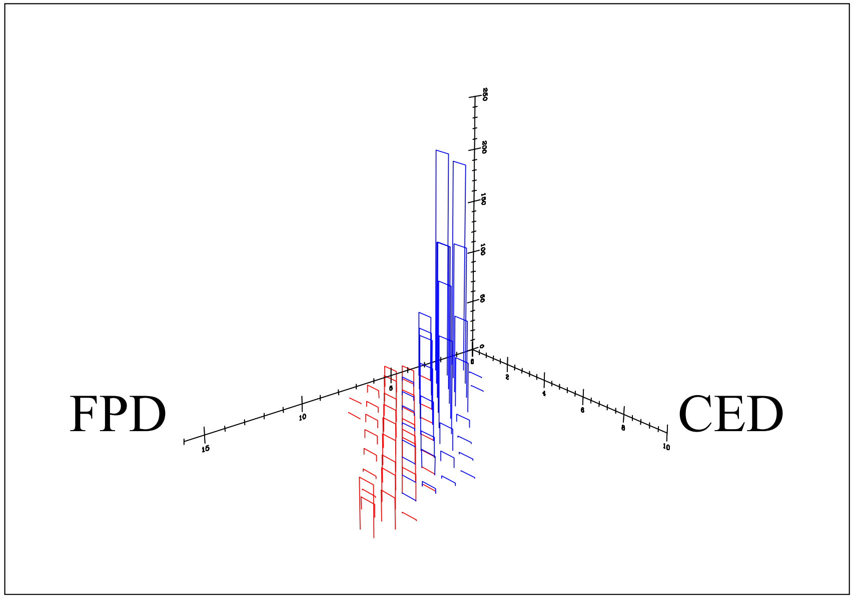


$\delta d_\Delta = 0.091\ ppm$

$\sim 2.3 g_\pi$

$\delta M_A = 0.031\ GeV$

Elastics, Inelastics, and Contamination



- Elastics

- Inelastics

Phenomenological approach:

* *Fit* A_{inel} *vs. CED-FPD (or* Q^2 *and* W*)*

$$A_{inel} = a + bQ^2 + cW\left[+ d\left(Q^2\right)^2 + eW^2 + fQ^2W + \square\square\square\right]$$

* *Extrapolate under elastic locus*

* *Error on* A_{inel} *from fit uncertainty*

$$\delta A_{inel} = \delta A_{inel}\left(\delta a, \delta b, \delta c, \ldots, \delta Q^2, \delta W\right)$$

Theory: Steve Wells

$$A_{N\Delta}^{PV} = \frac{G_F}{\sqrt{2}} \frac{Q^2}{2\pi\alpha} \left[\Delta_{(1)}^{\pi} + \Delta_{(2)}^{\pi} + \Delta_{(3)}^{\pi} \right]$$

$\Delta_{(1)}^{\pi}$: $T=1$, standard model coupling $\left(1 - 2\sin^2\theta_W\right)$

$\Delta_{(2)}^{\pi}$: Non-resonant contributions (small)

$\Delta_{(3)}^{\pi}$: $T=1$, axial vector nucleon response

$\propto G_{N\Delta}^{A}$

In elastic-inelastic overlap region:

$$A_{meas} = \frac{\sigma_{el} A_{el} + \sigma_{inel} A_{inel}}{\sigma_{el} + \sigma_{inel}}$$

$$A_{el} = \left(1 + \frac{\sigma_{inel}}{\sigma_{el}}\right) A_{meas} - \frac{\sigma_{inel}}{\sigma_{el}} A_{inel} \quad or \quad A_{inel} = \left(1 + \frac{\sigma_{el}}{\sigma_{inel}}\right) A_{meas} - \frac{\sigma_{el}}{\sigma_{inel}} A_{el}$$

Elastics:

$$\delta A_{el} = \sqrt{\left(1 + \frac{\sigma_{inel}}{\sigma_{el}}\right)^2 \delta A_{meas}^2 + \left[\delta \frac{\sigma_{inel}}{\sigma_{el}}\right]^2 A_{meas}^2 + \left(\frac{\sigma_{inel}}{\sigma_{el}}\right)^2 \delta A_{inel}^2 + \left[\delta \frac{\sigma_{inel}}{\sigma_{el}}\right]^2 + A_{inel}^2}$$

What is A_{inel}, δA_{inel} *?*

Inelastics:

$$A_{inel} = \frac{\sigma_\Delta A_\Delta + \sigma_{Al} A_{Al}}{\sigma_\Delta + \sigma_{Al}}$$

$$A_\Delta = \left(1 + \frac{\sigma_{Al}}{\sigma_\Delta}\right) A_{inel} - \frac{\sigma_{Al}}{\sigma_\Delta} A_{Al}$$

$$\delta A_\Delta = \sqrt{\left(1 + \frac{\sigma_{Al}}{\sigma_\Delta}\right)^2 \delta A_{inel}^2 + \left[\delta \frac{\sigma_{Al}}{\sigma_\Delta}\right]^2 A_{inel}^2 + \left(\frac{\sigma_{Al}}{\sigma_\Delta}\right)^2 \delta A_{Al}^2 + \left[\delta \frac{\sigma_{Al}}{\sigma_\Delta}\right]^2 A_{Al}^2}$$

* *Measure* A_{Al} , δA_{Al} *with dedicated "frame", "empty target" runs*

Data Summary: LH2

- **High Energy LH2:**
  - → $Q^2 = 0.62\ (\text{GeV/c})^2$

Total accumulated charge ~ 100C