Parity Violating Asymmetry in the $N \rightarrow \Delta$ Transition and Axial Transition Form Factors

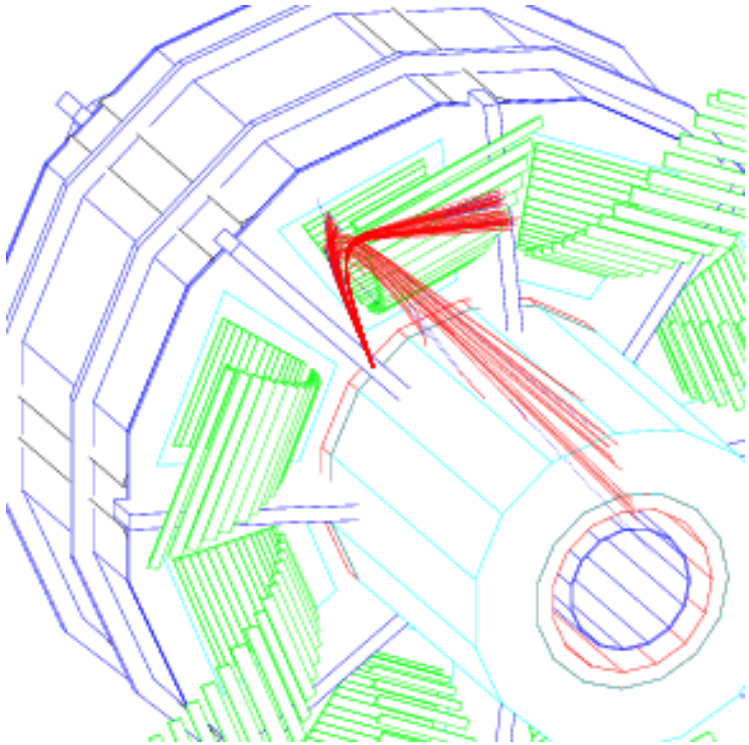
N. Simicevic

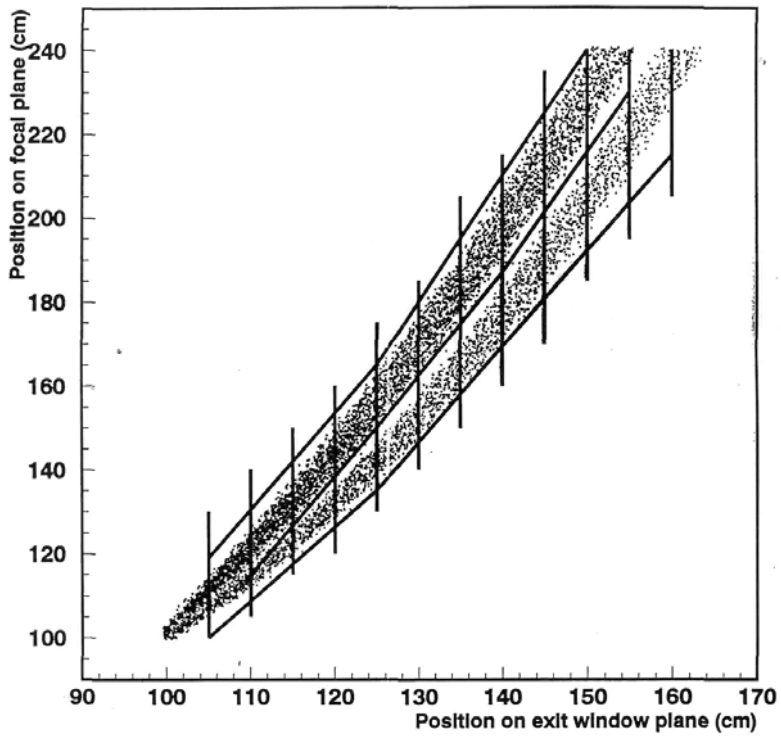
Louisiana Tech University

Ruston, LA

History: Elastic/Inelastic Electron Separation for the G0 Backward Measurement (I)

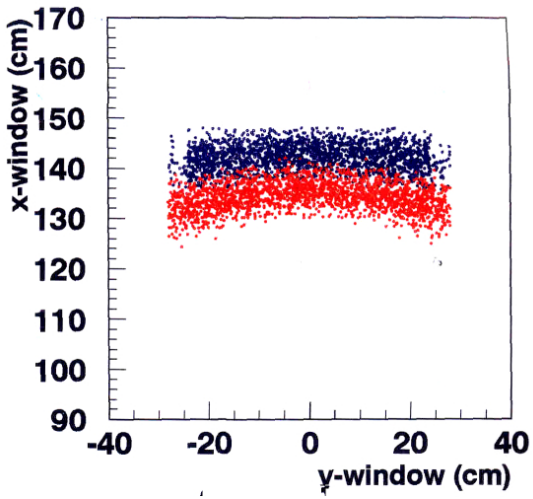
- **Separation of the reaction channels requires two sets of detectors (left figure).**
- **In the process of separation the reaction channels are labeled (right figure).**
- **Method of measuring asymmetries is the same for both channels.**





History: Elastic/Inelastic Electron Separation for the G0 Backward Measurement (II)

- **Separation of the reaction channels is not perfect – overlap region:**



- **In overlap region measured asymmetry is a function of both, elastic and inelastic asymmetries:**

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

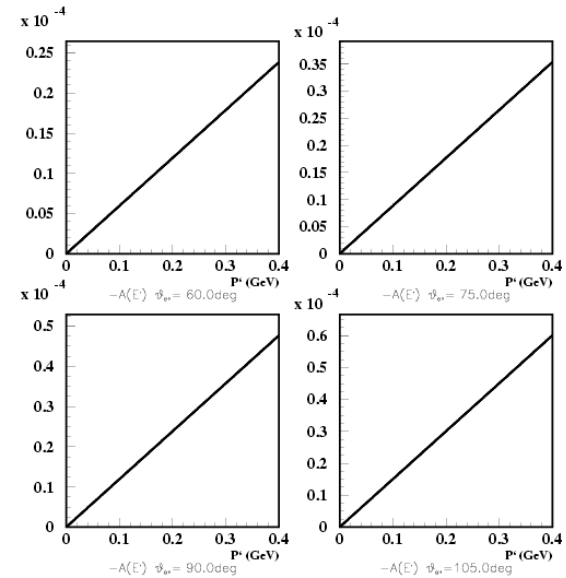
- **Inelastic asymmetries has to be measured.**

Inelastic Asymmetry: Is the measurement feasible?

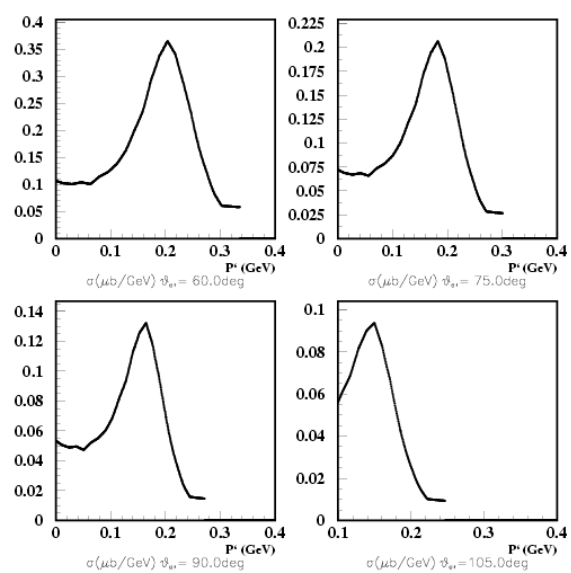
- **Function of the asymmetry of $N \rightarrow \Delta^+$ transition and the asymmetry of the background, which will be measured separately:**

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

- **Values of the $A_{N\Delta}$ large compared to elastic asymmetry:**



- **Cross section for $N \rightarrow \Delta^+$:**



Inelastic Asymmetry – Theory (I)

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

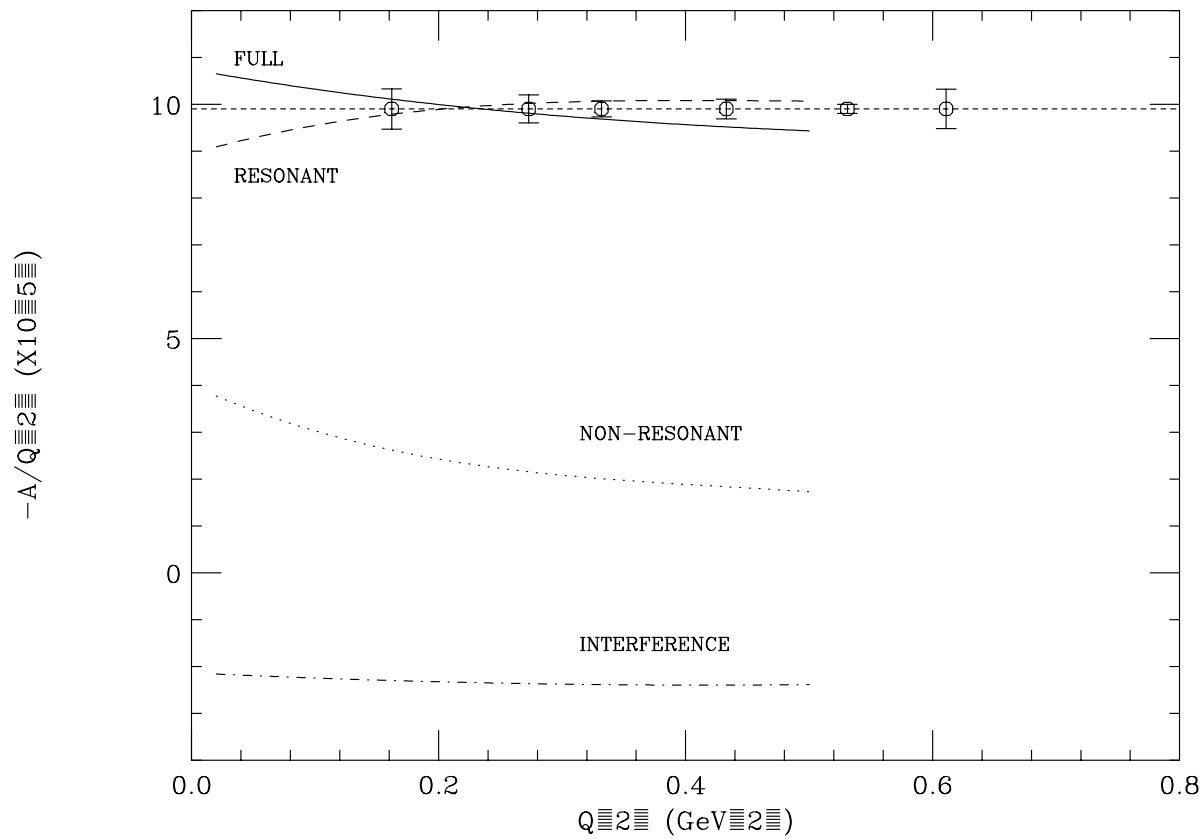
$\Delta_{(1)}^{\pi}$: T=1, standard model coupling: $\left(1 - 2\sin^2\theta_W\right)$

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

$\Delta_{(3)}^{\pi}$: T=1, axial vector nucleon response: $\propto G_{N\Delta}^{A}$

Inelastic Asymmetry – Theory (II)

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



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

Inelastic Asymmetry: Non-Resonant Contribution

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

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

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

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

Inelastic Asymmetry: Neglecting Non-Resonant Contribution

- **For purely isovector $N \to \Delta^+$ transition:**

$$A_{N\Delta} = \frac{G_F}{\sqrt{2}} \frac{Q^2}{2\pi\alpha} [\tilde{\alpha} + \tilde{\beta} F(Q^2, E, E', \theta_e)]$$

$$\tilde{\alpha} = -(1 - 2\sin^2\theta_W)$$

$$\tilde{\beta} = -(1 - 4\sin^2\theta_W)$$

- **All the weak $N \to \Delta^+$ transition form factors are contained in:**

$$F(Q^2, E, E', \theta_e) = \frac{(E + E')}{M} H^{EM}(Q^2, \theta_e) G^A_{N\Delta}(Q^2),$$

Axial Transition Form Factors

- **All the weak $N \rightarrow \Delta^+$ transition form factors are contained in:**

$$F(Q^2, E, E', \theta_e) \;=\; \frac{(E+E')}{M} H^{EM}(Q^2, \theta_e) G^A_{N\Delta}(Q^2),$$

- **where:**

$$H^{EM}(Q^2, \theta_e) = \frac{h_3(Q^2, \theta_e) C_3^\gamma(Q^2) + h_4(Q^2, \theta_e) C_4^\gamma(Q^2)}{h_{33}(Q^2, \theta_e)[C_3^\gamma(Q^2)]^2 + h_{34}(Q^2, \theta_e) C_3^\gamma(Q^2) C_4^\gamma(Q^2) + h_{44}(Q^2, \theta_e)[C_4^\gamma(Q^2)]^2}$$

$$G^A_{N\Delta}(Q^2) = g_3(Q^2) C_3^A(Q^2) + g_4(Q^2) C_4^A(Q^2) + g_5(Q^2) C_5^A(Q^2)$$

- **h_i and g_i are kinematical factors, C_i^γ are electroproduction form factors, and C_i^A are the axial transition form factors.**

Axial Transition Form Factors -Motivation

- **Axial (intrinsic spin) response during $N \rightarrow \Delta^+$**

- **Reaction Mechanism (CQM)**

  - **Z^0 induces "quark spin flip" (Neutral Current)**
    $\rightarrow$ c.f. M1 from γ induced quark spin flip
  - **c.f. $\nu p \rightarrow \mu^- \Delta^{++}$, $ep \rightarrow \pi^- \Delta^{++}$**
    $\rightarrow$ W^+ exchange (Charged Current)
    $\rightarrow$ Flavor change (different reaction mechanism)

Axial Transition Form Factors – Physics Community Interest

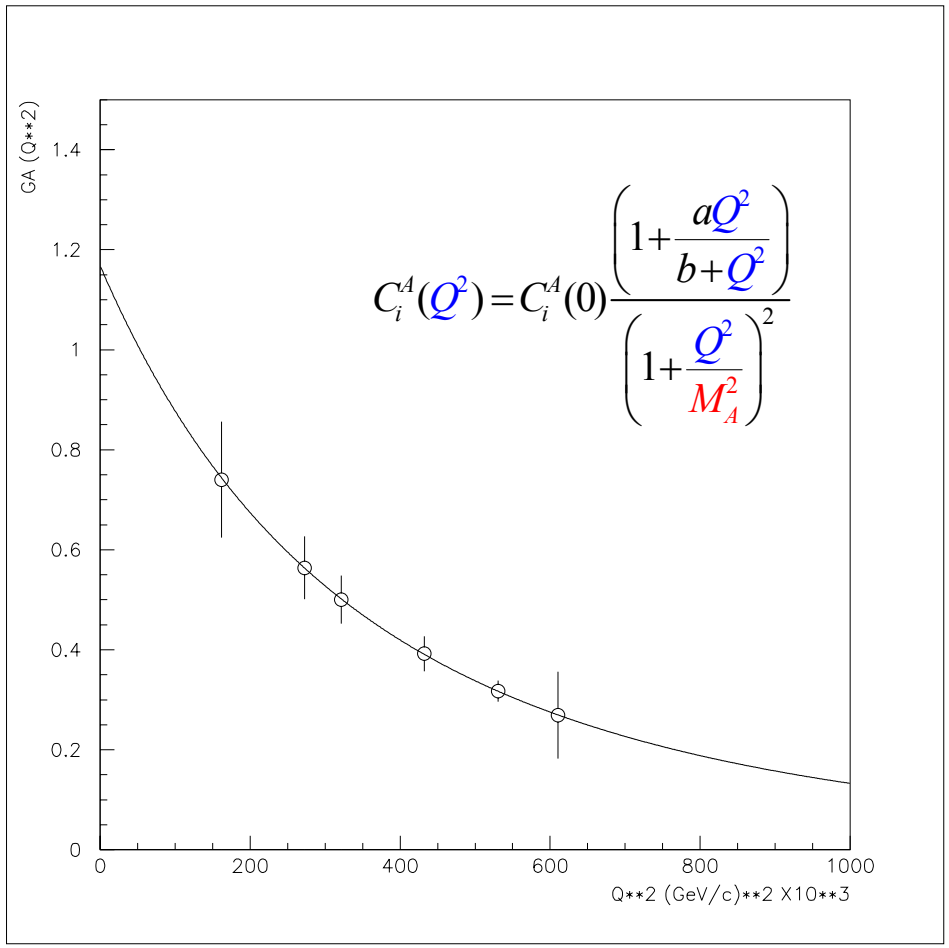
- **Before 1998 - from Mukhopadhyay et al, Nucl. Phys. A633, 481 (1998):**

	C_3^V	C_4^V	C_5^V	C_6^V	C_3^A	C_4^A	C_5^A	$C^A_{6,non-pole}$
Salin [66]	2.0	0	0	0	0	−2.7	0	–
Adler [23,10]	1.85	−0.89	0	0	0	−0.3	1.2	–
Bijtebiar [67]	2.0	0	0	0	0	$-2.9 \sim -3.6$	1.2	–
Zucker [25]	–	–	–	0	1.8	−1.8	1.9	–
Nath *et al.* [68]	1.85	−0.89	0	0	0	−0.35	1.2	–
Ravndal [69]	1.70	−1.30	0	0	0	−0.65	0.97	–
Orsay *et al.* [70]	1.54	−1.17	0	0	0	−0.20	0.83	–
Körner *et al.* [71]	1.70	−1.30	0	0	0	−0.32	0.97	–
Jones and Petcov [13]	2.05	−1.56	0	0	0	−0.3	1.2	–
HHM [16]	1.39	−1.06	0	0	0	-0.29 ± 0.006	0.87 ± 0.03	–
SU(6) [29]	1.48	−1.13	0	0	0	−0.38	1.17	–
IK [29]	1.32	−0.79	−0.36	0.014	−0.0013	−0.66	1.16	0.032
IK2 [29]	1.37	−0.66	−0.59	−0.015	0.0008	−0.657	1.20	0.042
D-mixing [29]	1.29	0.78	−1.9	−0.15	0.052	0.052	0.813	−0.17

TABLE I. Values of Adler form factors at $Q^2 = 0$ in various empirical and theoretical approaches. "–" means the reference does not provide a prediction. As discussed in the text, C_6^A is a pseudoscalar response, and effectively does not contribute to the PV asymmetry. "Non-pole" indicates that the pion pole contributions to C_6^A have not been included in the predictions cited (see Ref. [73]).

Axial Transition Form Factors – Measurements with G0 Backward Angle Set-Up: Q^2 Dependence

- **Adler Model: - modified dipole form [S.L. Adler, Ann. Phys. 50, 189 (1968)]**



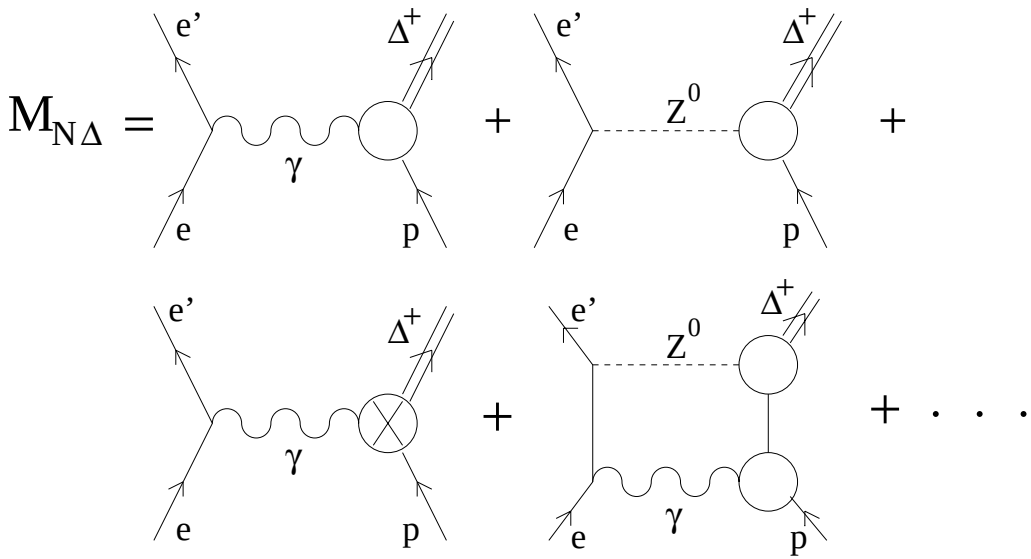
$$C_i^A(Q^2) = C_i^A(0)\frac{\left(1+\frac{aQ^2}{b+Q^2}\right)}{\left(1+\frac{Q^2}{M_A^2}\right)^2}$$

$\delta M_A = 0.031$ GeV

vs.

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

Axial Transition Form Factors – Radiative Corrections

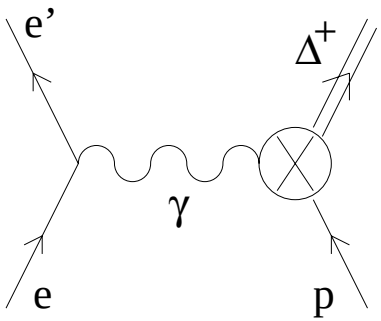


$$\Delta^{\pi}_{(3)} \propto \left(1 + R_A^{\Delta}\right) G^{A}_{N\Delta}$$

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

S.-L. Zhu** et al.**, Phys. Rev. D 65, 033001 (2002)

Radiative Corrections - Siegert Term



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

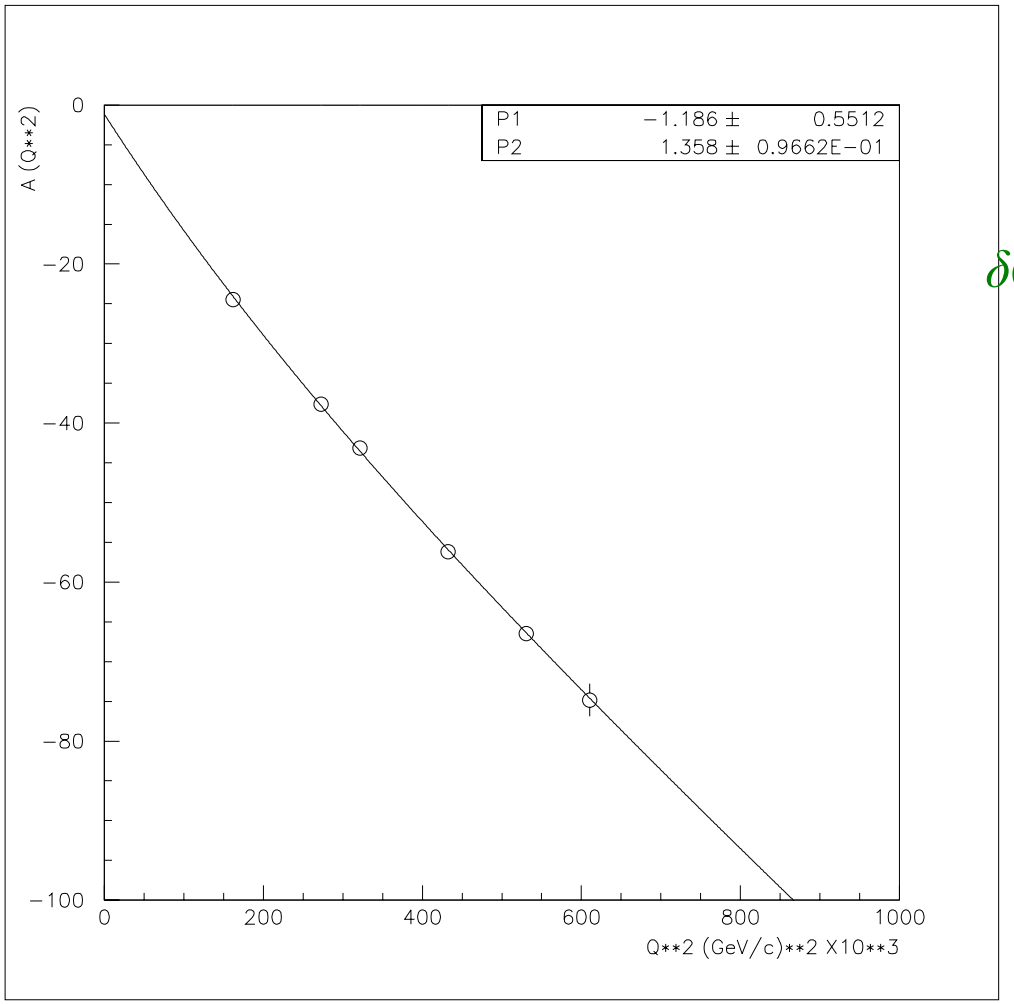
$$A_{LR}\left[\Delta_{(3)}^{\pi}(\text{Siegert})\right] = -\frac{2d_{\Delta}}{C_3^V}\frac{\delta}{\Lambda_{\chi}}P(Q^2, s)$$

PV *γNΔ* E1 *amplitude (Siegert's Theorem)*

→ **d_{Δ} (~ g_{π}), a low-energy constant characterizing the PV γNΔ coupling**

→ **potentially large asymmetry, may be related to SU(3)-violating effects seen in hyperon decays *(e.g. $\Sigma^+ \rightarrow p\gamma$)***

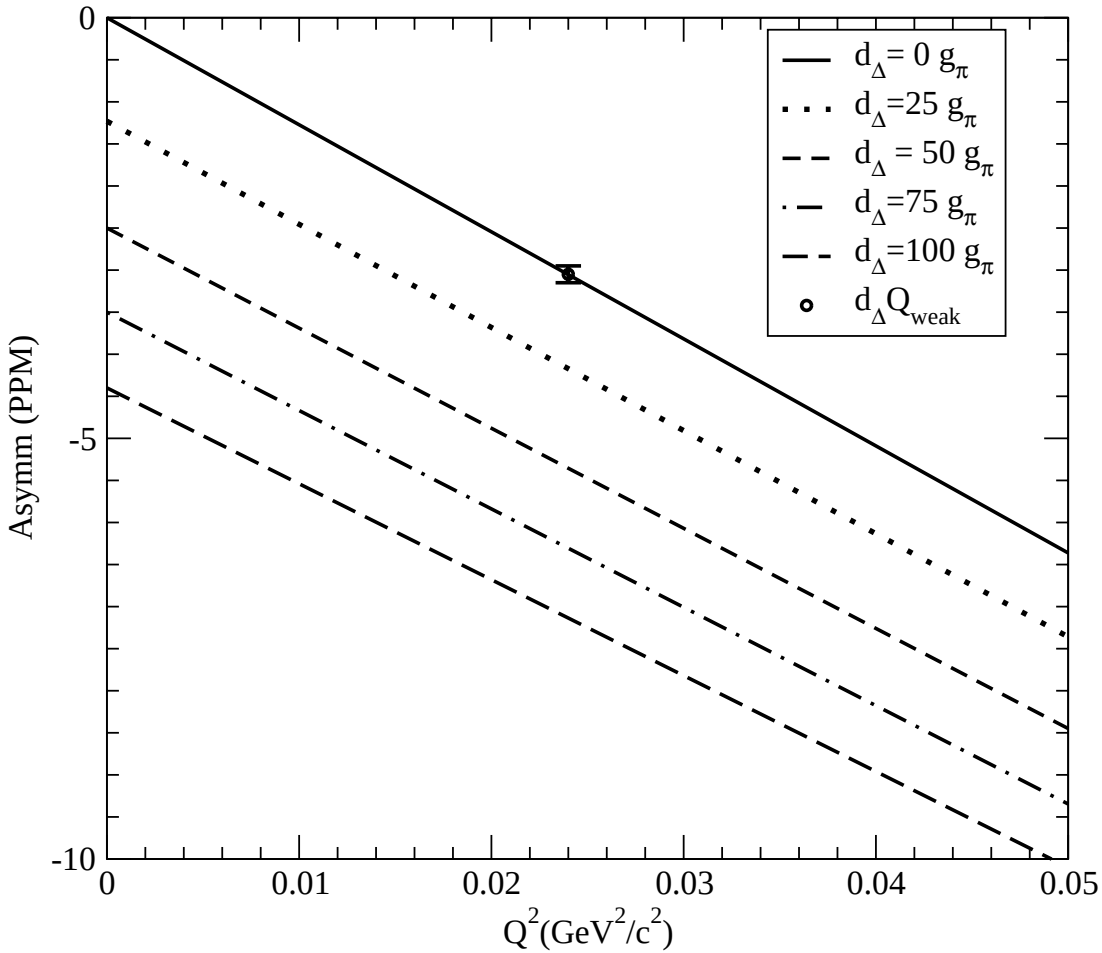
Radiative Corrections - Effect on δM_A



$\delta d_\Delta = 0.55$ ppm $\sim 14 g_\pi$

$\delta M_A = 0.097$ GeV

1 Program

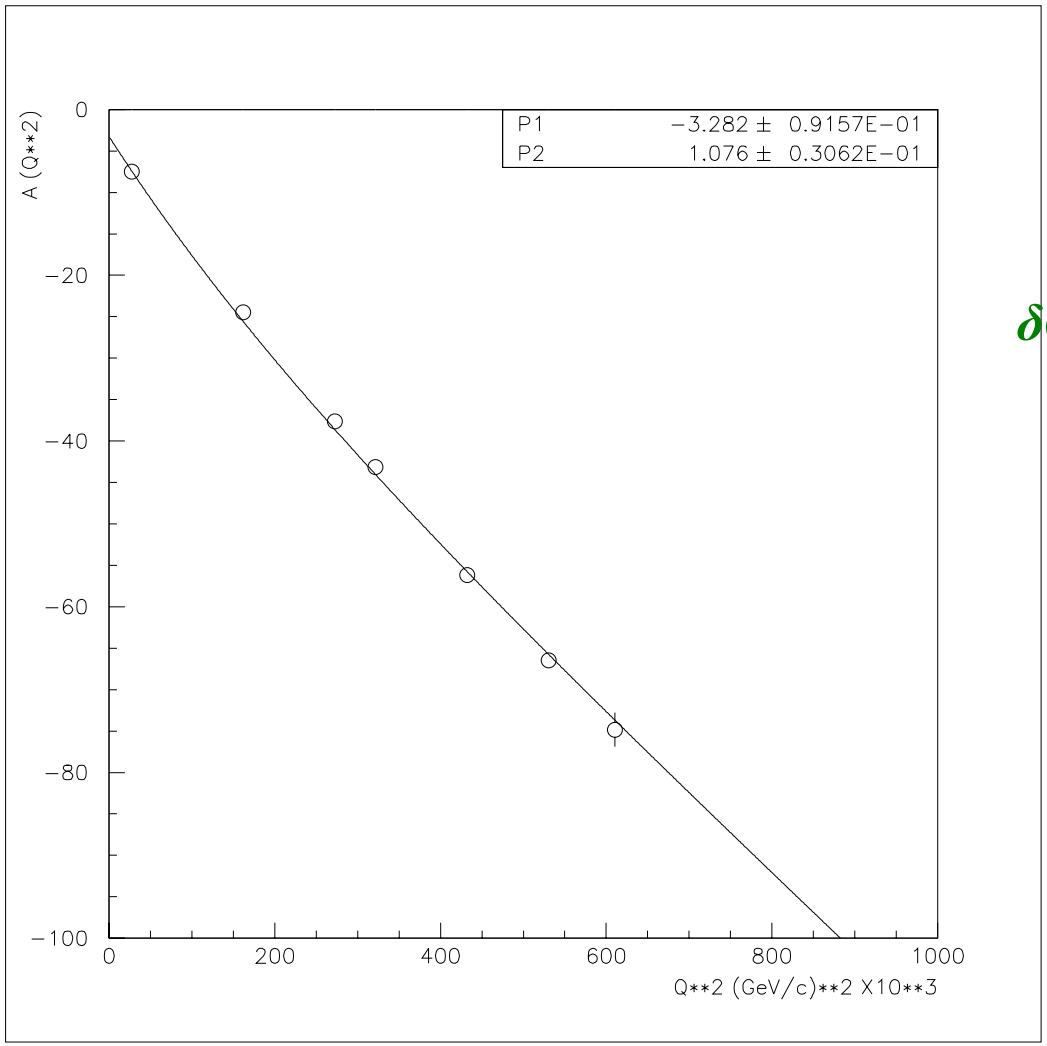


LaTech

PAC24 LOI

1 week beam time

Finally: δM_A and δd_Δ with G0 & Q_{weak} $N \rightarrow \Delta$



δd_Δ = *0.091 ppm* ~ *2.3*g_π

δM_A=*0.031 GeV*

Conclusion

- **Parity violating asymmetry in the N →Δ transition will be measured simultaneously with the G0 backward angle parity violating elastic electron-proton scattering.**

- **From N →Δ transition asymmetry one can extract Q^2 dependence of the axial transition form factors.**

- **This experimental program can be easily extended by using Q_{weak} setup to measure radiative corrections of the asymmetry, particularly the Siegert term which may be related to SU(3)-violating effects seen in hyperon decays.**

- **Interest for such a program is constantly increasing in physics community.**