DOUBLE SPIN ASYMMETRIES AND NUCLEON STRUCTURE AT CLAS

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Representing the CLAS Collaboration

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- Introduction
- Exclusive Data on Proton and Deuteron
- Inclusive Data on Proton and Deuteron
- Conclusions

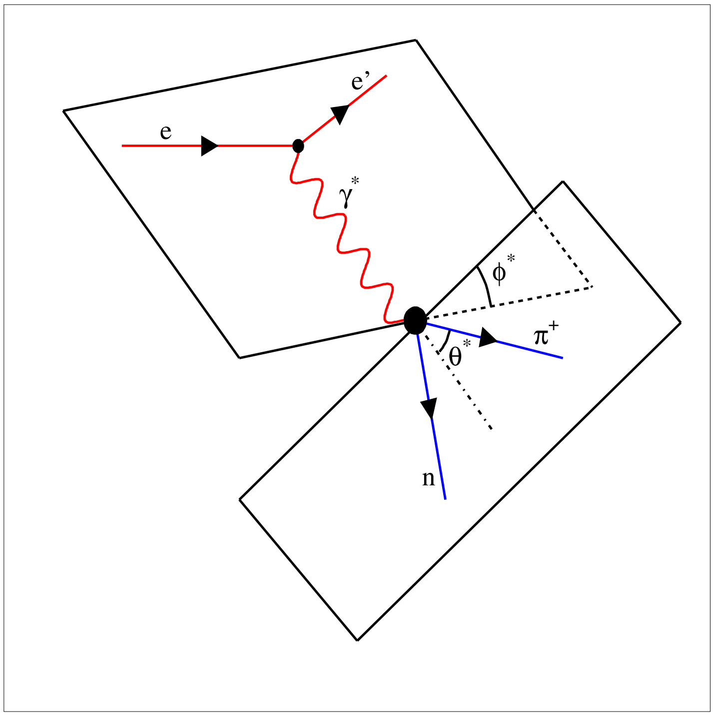
The CLAS Collaboration

- ≈ 200 physicists
- 37 institutions
- Arizona State University, Carnegie Mellon University, Christopher Newport University, Catholic University of America, Duke University, Edinburgh University, Florida International University, Florida State University, University of Glasgow, The George Washington University, Laboratori Nazionali di Frascatti, Sezione de Genova e Dipartmento di Fisica, Institute of Theoretical and Experimental Physics, Thomas Jefferson National Accelerator Laboratory, James Madison University, Kungpook National University, Massachusetts Institute of Technology, Norfolk State University, Old Dominion University, Ohio University, Institut de Physique Nucleaire ORSAY, University of Pittsburgh, Rice University, Rensselaer Polytechnic Institute, CEA Saclay Service de Physique Nucleaire, University of South Carolina, University of California at Los Angeles, University of Connecticut,University of Massachusetts, University of New Hampshire, University of Richmond, University of Texas at El Paso, University of Virginia, Virginia State University, Virginia Polytechnic Institute and State University, College of Willliam and Mary, Yerevan Physics Institute

The Experiments (eg1)

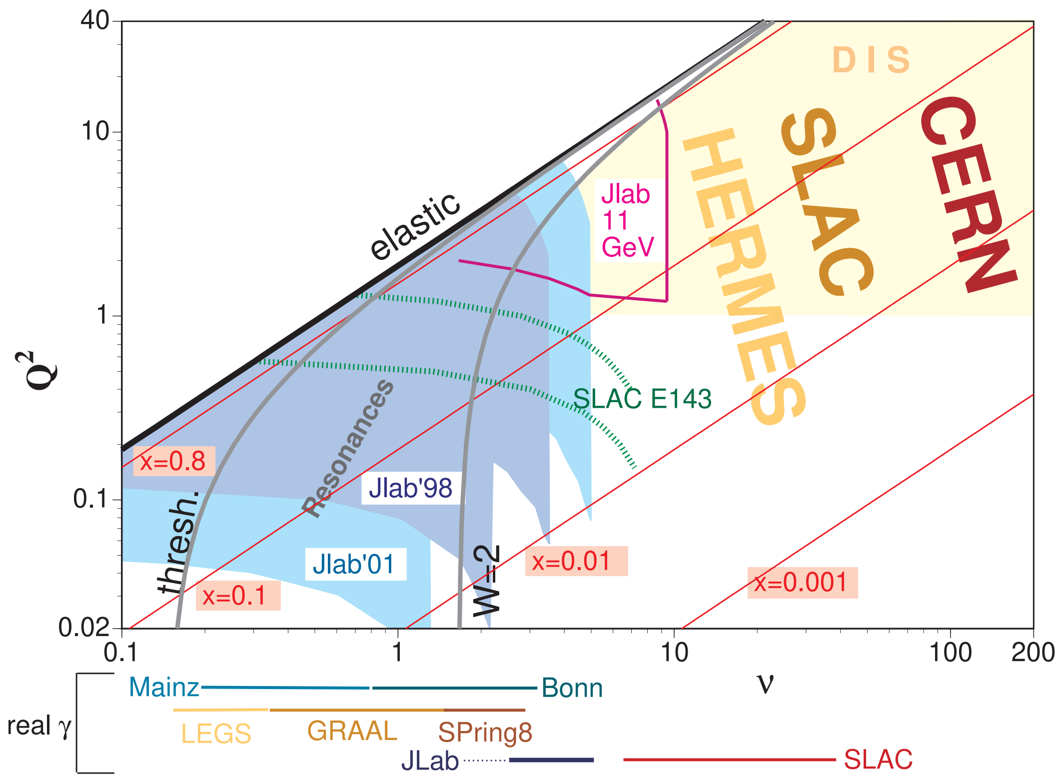
- Experiment 91-023: "Measurement of Polarized Structure Functions in Inelastic Electron Scattering using CLAS," V. Burkert, D. Crabb, and R. Minehart. (35% in first run)
- Experiment 93-009: "The Polarized Structure Function G_1^n and the Q^2 Dependence of the Gerasimov-Drell-Hearn Sum Rule for the Neutron," S. Kuhn, G. Dodge, and M. Taiuti. (10% in first run)
- Experiment 93-036: "Spin Asymmetries in Pion Electroproduction," M. Anghinolfi, R. Minehart, H. Weller. (35% in first run)
- First run period: Fall 1998
  - 2.5 and 4.2 GeV beams
  - $0.1 < Q^2 < 2.7$ GeV^2, $W < 2.5$ GeV
- Second run period: Fall/Winter 2000/2001
  - 1.6, 2.5, 4.2 and 5.7 GeV beams
  - $0.05 < Q^2 < 5$ GeV^2, $W < 3$ GeV
- Current analyses
  - g_1^p from asymmetries and cross section differences
  - g_1^d from asymmetries
  - $ep \rightarrow e'\pi^+ n$ double asymmetries
  - $ed \rightarrow e'pp\pi^-$ double asymmetries
  - $ep \rightarrow e'\pi^+ n$ or $e'\pi^0 p$ target symmetries

CLAS Kinematics



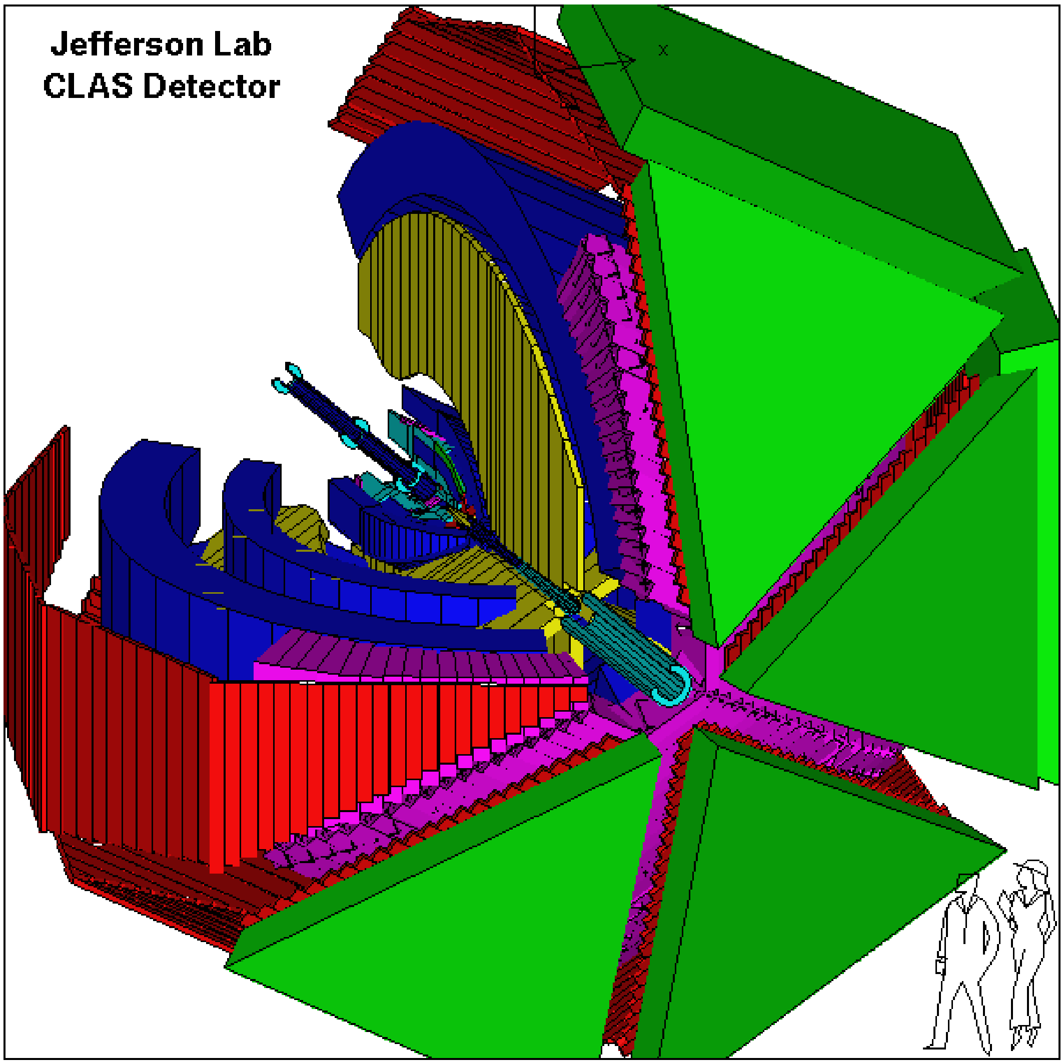
- Electron scattering angle θ
- Nucleon mass M
- Incident (E) and scattered (E') electron energies
- Energy transfer $\nu = E - E'$
- Bjorken $x = Q^2/2M\nu$; invariant mass W
- Azimuthal pion angle ϕ^*
- Polar pion angle θ^* (in lab or CM frames)

Kinematic Coverage



- $Q^2 = 4EE' \sin^2 \frac{\theta}{2}$, and $\nu = E - E'$.
- Jlab experiments cover the resonance region and reach into the deep-inelastic region.
- CLAS data exist for both dark and light blue regions.
- Results presented come from the dark blue region.

CLAS Spectrometer



Drift Chambers

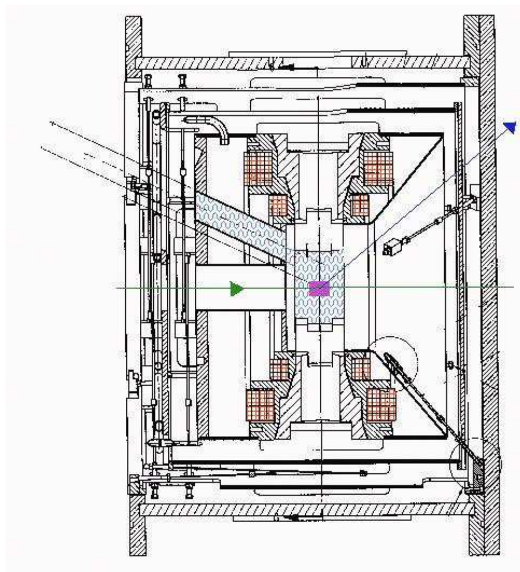
Cryostats for Superconducting Magnets

Cherenkov Counters

Time-of-Flight Counters

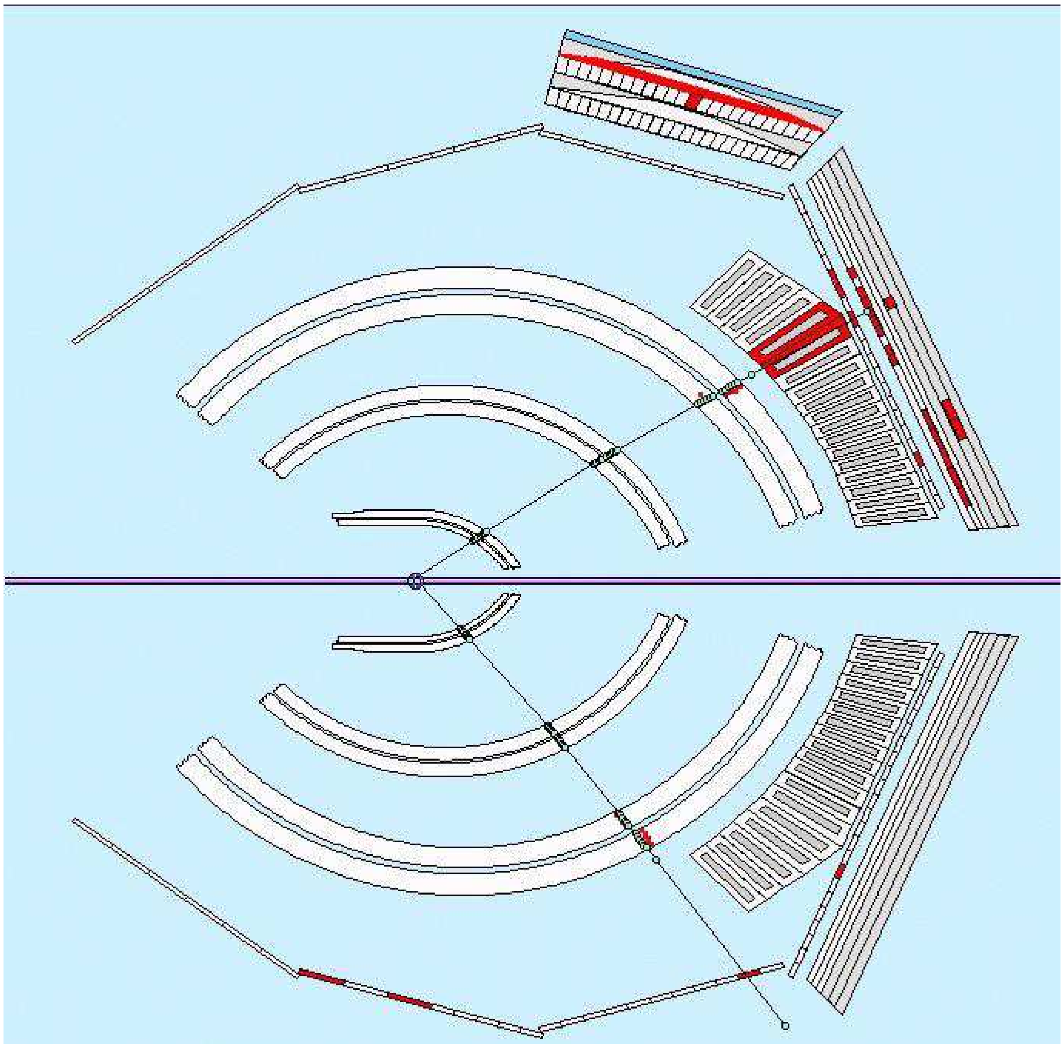
Sampling Calorimeter

CLAS Polarized Target



- Targets of $^{15}NH_3$ and $^{15}ND_3$, 1 cm long, 1.5 cm diameter; 1 K, 5 T field, dynamic nuclear polarization.
- $P_t \approx$ 50–80% for proton; $P_t \approx$ 10–35% for deuteron.

Representative CLAS Event

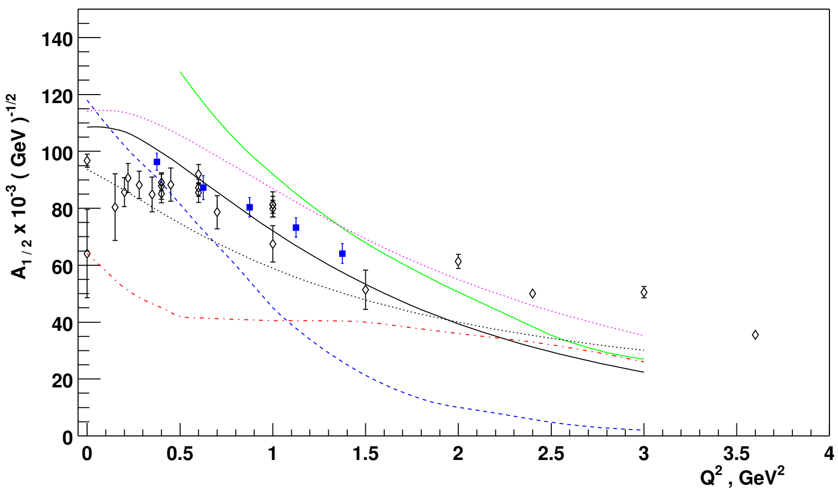


- Upper track bends inward (electron)
- Lower track bends outward (π^+)

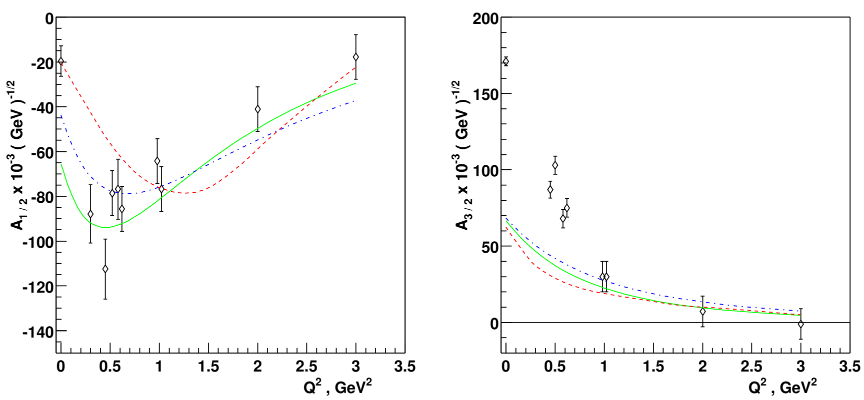
Exclusive Double Spin Asymmetries

- Target limits π acceptance to $\theta < 50°$ and $75° < \theta < 105°$.
- Cross section:
  - $\sigma = \sigma_0 + P_b\sigma_b + P_t\sigma_t + P_bP_t\sigma_{bt}$
  - σ_0 is the unpolarized cross section
  - P_b is the beam polarization
  - σ_t is the target single spin cross section difference
  - σ_{bt} is the double spin cross section difference
  - $A_{bt} = -\sigma_{bt}/\sigma_0$ is the double spin asymmetry
- Asymmetry:
  - $A_{bt} = \frac{1}{fP_bP_t}\frac{N^{\uparrow\downarrow}+N^{\downarrow\uparrow}-N^{\uparrow\uparrow}-N^{\downarrow\downarrow}}{N^{\uparrow\downarrow}+N^{\downarrow\uparrow}+N^{\uparrow\uparrow}+N^{\downarrow\downarrow}}$
  - Integration over ϕ^* yields $A_{bt} = \sqrt{1-\epsilon^2}\cos\theta_\gamma\frac{A_1+\eta A_2}{1+\epsilon R}$
  - θ_γ is the angle between the target spin and virtual photon directions
  - $A_1 + \eta A_2$ depends on W, Q^2 and $\cos\theta^*$
- Photon asymmetries:
  - $A_1 = \frac{\sigma^T_{1/2}-\sigma^T_{3/2}}{\sigma^T_{1/2}+\sigma^T_{3/2}} = \sigma_{TT}/\sigma_T = \frac{|A_{1/2}|^2-|A_{3/2}|^2}{|A_{1/2}|^2+|A_{3/2}|^2}$
  - $A_2 = \sigma_{LT}/\sigma_T$
  - $R = \sigma_L/\sigma_T$
  - $\epsilon^{-1} = 1 + 2(1+\gamma^{-2})\tan^2\frac{\theta}{2}$; $\gamma = 2Mx/Q$
  - $\eta = \epsilon Q/(E - E'\epsilon)$

S_{11} and D_{13} Amplitudes



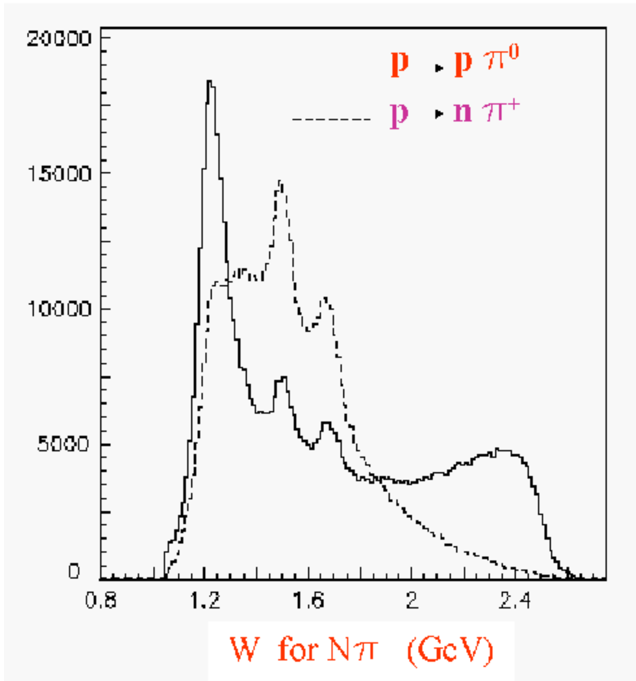
$A_{1/2}$ for the $S_{11}(1535)$ Resonance



$A_{1/2}$ and $A_{3/2}$ for the $D_{13}(1520)$ Resonance

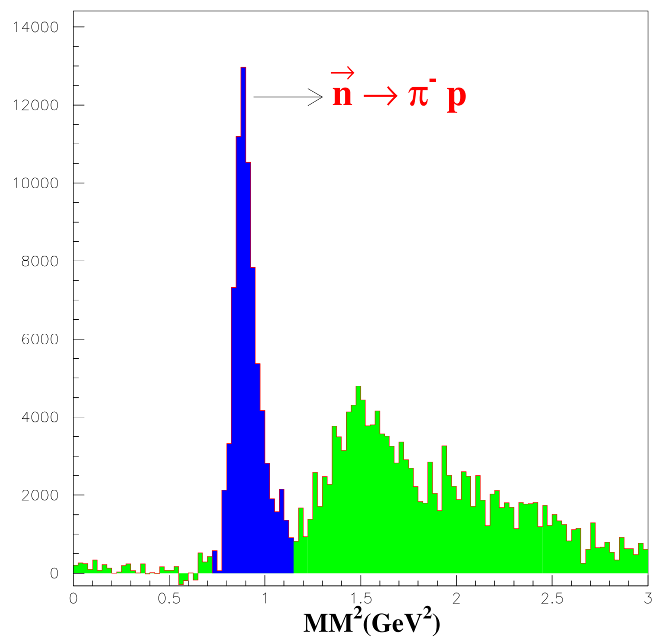
$$A_1 = \frac{|A_{1/2}|^2 - |A_{3/2}|^2}{|A_{1/2}|^2 + |A_{3/2}|^2}$$

Isospin Differences



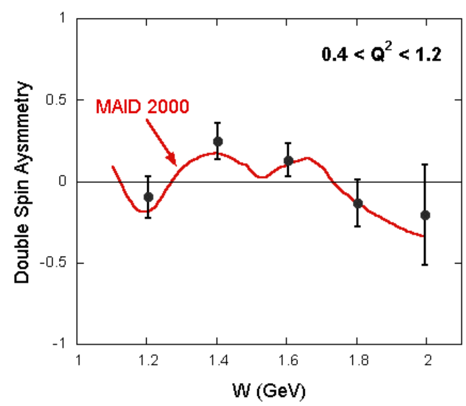
- Raw counts for $ep \to ep\pi^0$ and $ep \to en\pi^+$
- $$|\frac{3}{2}\frac{1}{2}\rangle = \sqrt{\frac{1}{3}}|n\pi^+\rangle + \sqrt{\frac{2}{3}}|p\pi^0\rangle$$
$$|\frac{1}{2}\frac{1}{2}\rangle = \sqrt{\frac{2}{3}}|n\pi^+\rangle - \sqrt{\frac{1}{3}}|p\pi^0\rangle$$
- $p\pi^0$ emphasizes isopin $T = \frac{3}{2}$ states
- $n\pi^+$ emphasizes isopin $T = \frac{1}{2}$ states

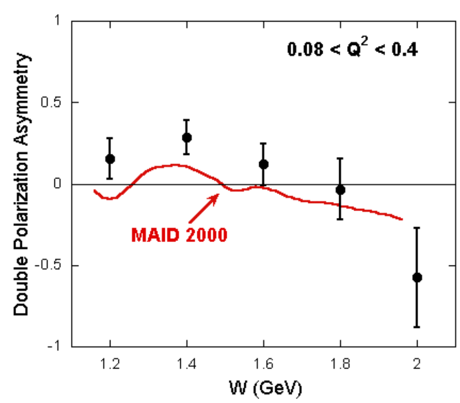
Missing Mass Spectrum for $ed \to e'pp\pi^-$



- Calculate missing mass for the $p\pi^-$ system
- Blue shaded region shows the cut that selects neutrons

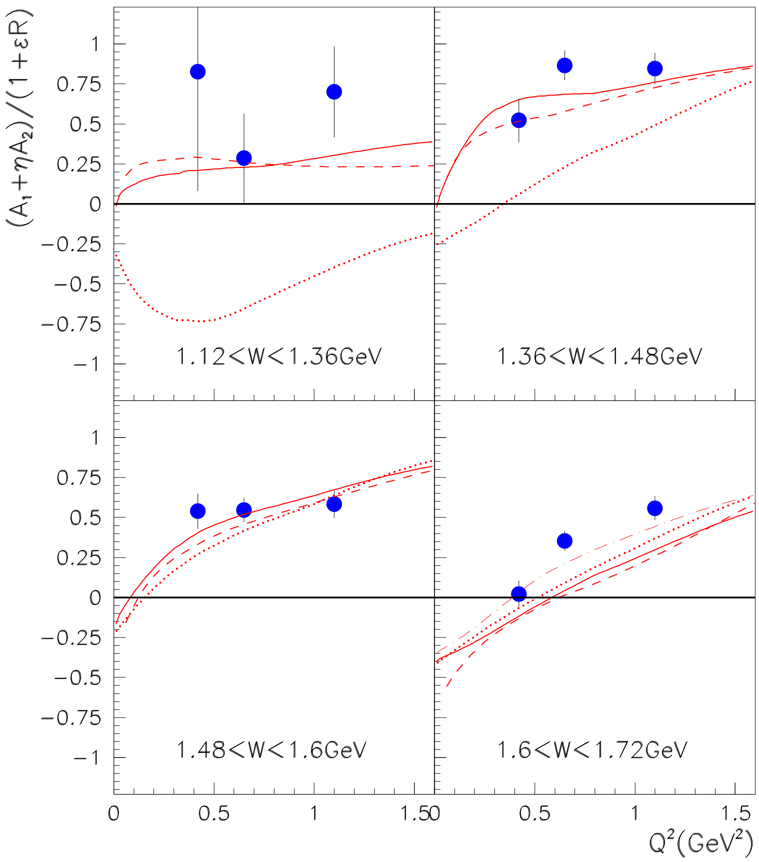
A_{bt} vs. W for $en \to e'p\pi^-$





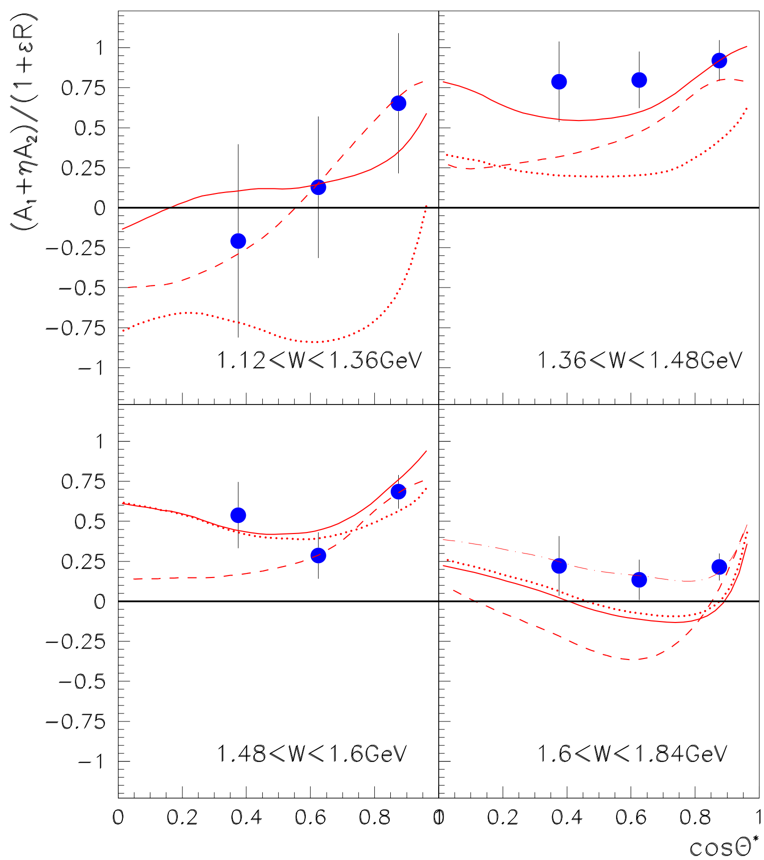
- top: inbending data $0.4 < Q^2 < 1.2$ GeV
- bottom: outbending data $0.08 < Q^2 < 0.4$ GeV

$A_1 + \eta A_2$ versus Q^2 from $\pi^+ n$



- Integrated over $\cos\theta^*$
- AO resonance (dotted) [PRD47(93)46]
- AO full (solid)
- AO with A_1^{F15} increased by 0.4 (dot-dashed)
- MAID2000 [NPA645(99)145]

$A_1 + \eta A_2$ versus $\cos\theta^*$ from $\pi^+ n$

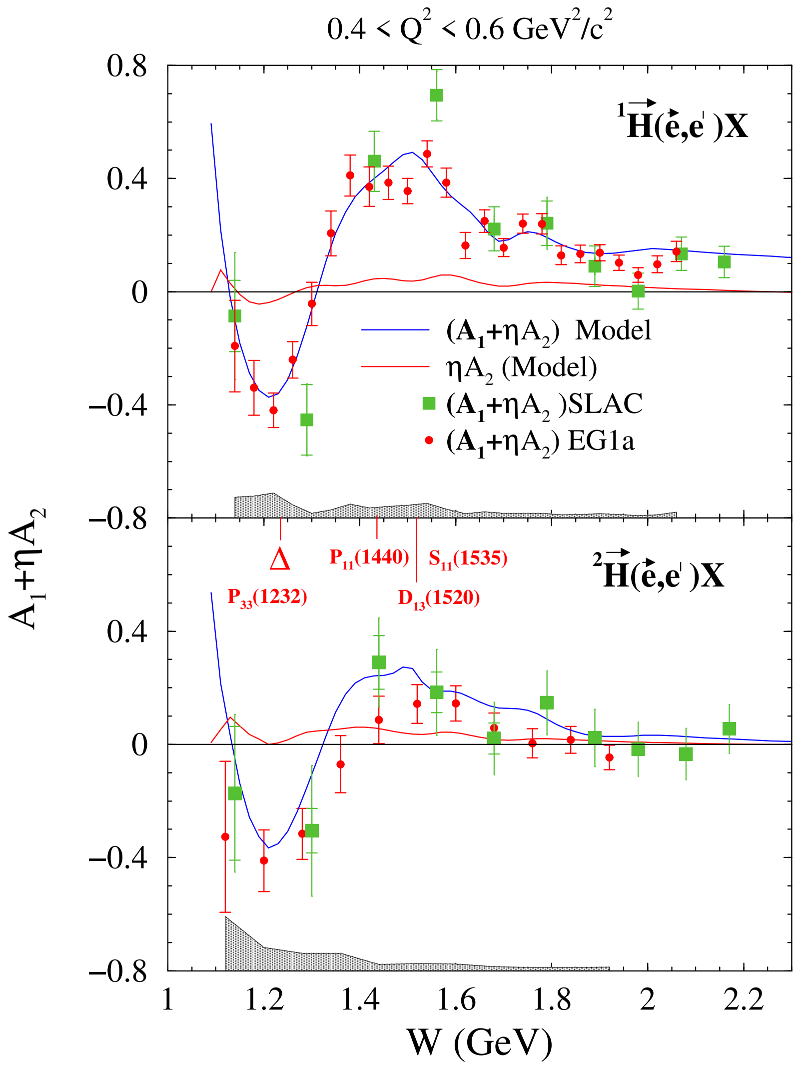


- $0.5 < Q^2 < 0.9$ GeV^2
- $A_1 = 1$ at $\theta^* = 0$ (ang. mom. conservation)
- For P_{33} background dominates at small θ^*
- For F_{15} models are systematically off

Inclusive Double Spin Asymmetries

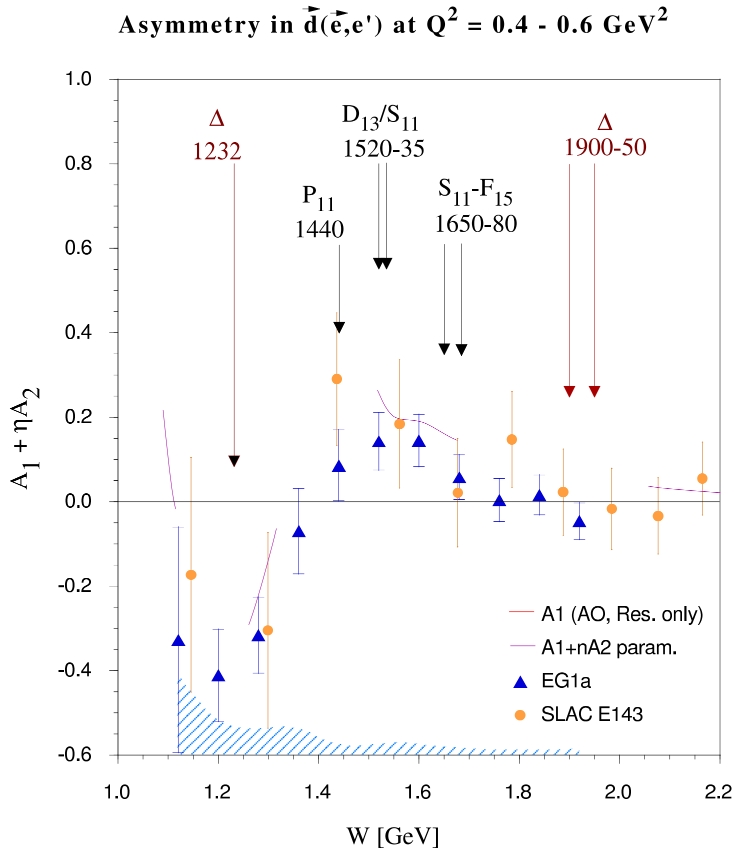
- Asymmetry:
  - $A^{\|} = \frac{1}{fP_bP_t}\frac{N^{\downarrow\uparrow}-N^{\uparrow\uparrow}}{N^{\downarrow\uparrow}+N^{\uparrow\uparrow}} = D(A_1 + \eta A_2)$
  - $A_1F_1 = g_1 - \gamma^2 g_2$
  - $A_2F_1 = \gamma(g_1 + g_2)$
  - Depolarization $D = (1 - E'\epsilon/E)/(1 + \epsilon R)$
  - $1 + R = (1 + \gamma^2)F_2/2xF_1$
  - g_1 and g_2 are the spin structure functions
- Isolated resonance:
  - $A_1 = (\sigma^T_{1/2} - \sigma^T_{3/2})/(\sigma^T_{1/2} + \sigma^T_{3/2})$
  - $\sigma^T_{1/2} = 2\pi\frac{M}{W}b|A_{1/2}|^2$
  - $\sigma^T_{3/2} = 2\pi\frac{M}{W}b|A_{3/2}|^2$
  - b is a unit-area resonance line shape
- Integrals:
  - $\Gamma_1 = \int_0^1 g_1(x, Q^2)dx$ (I exclude elastic)
  - Bjorken Sum Rule: $\Gamma_1^p - \Gamma_1^n = \frac{1}{6}g_AC_{ns}$
  - Leading twist: $g_2^{WW} = -g_1 + \int_x^1 \frac{g_1(y,Q^2)}{y}dy$
  - GDH Sum Rule: $\Gamma_1(Q^2) = -Q^2\kappa^2/8M^2$ as $Q^2 \to 0$.

$A_1 + \eta A_2$ **versus** W



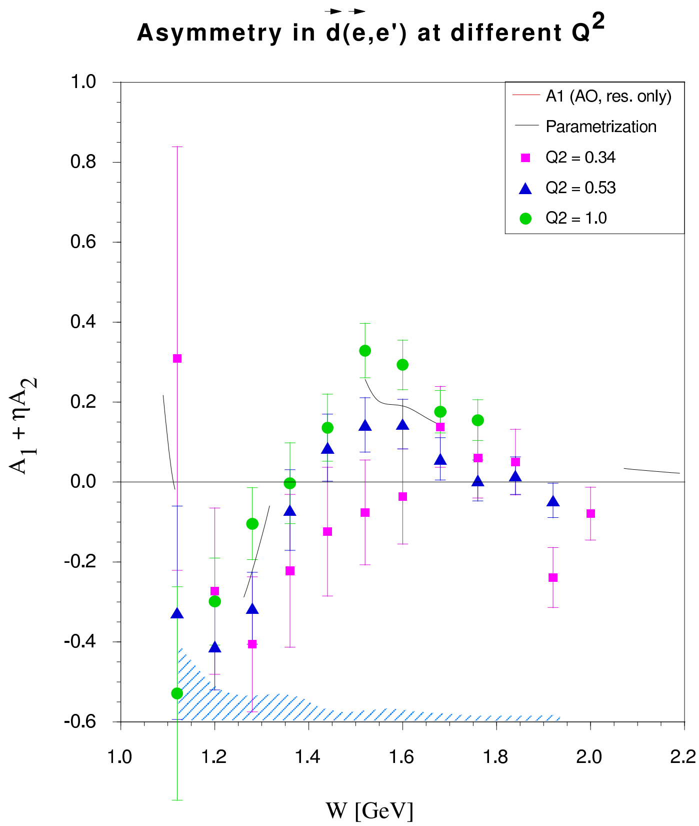
- Data for p and d are consistent with SLAC E143 at $Q^2 = 0.5$ GeV^2 [PRD **58**(1998)112003].
- $A_1^{\Delta} \approx -\frac{1}{2}$; $A_1^{S_{11}+D_{13}} > 0$.

Deuteron $A_1 + \eta A_2$ versus W



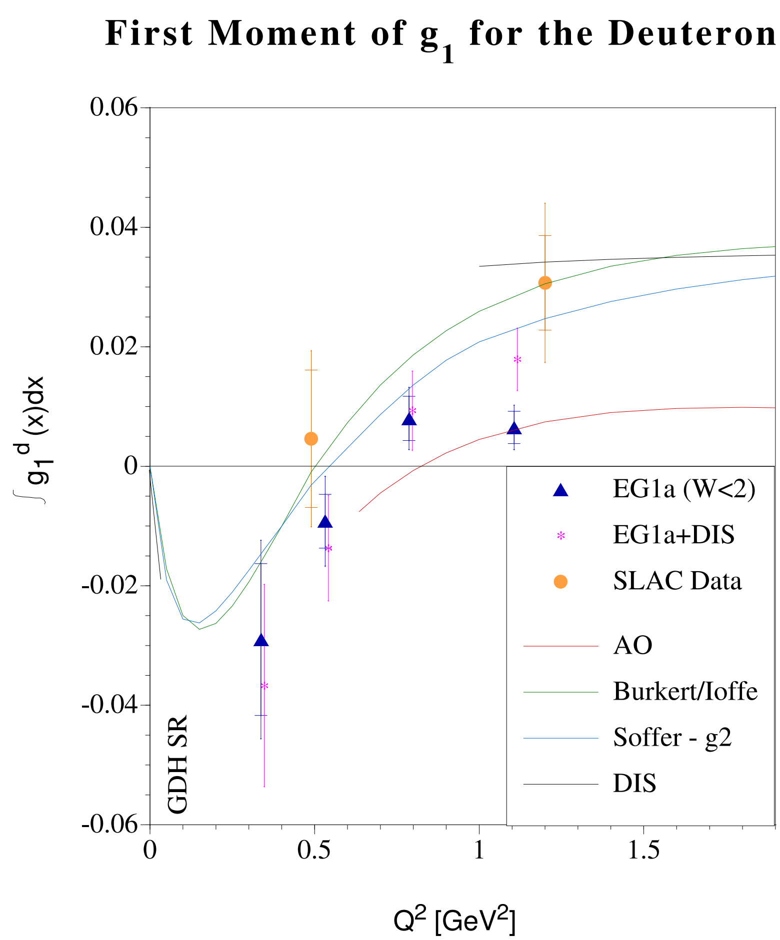
- $A_1^{\Delta} < 0$; $A_1^{S_{11}/D_{13}} > 0$
- Data agree with SLAC E143 at $Q^2 = 0.5\ \mathrm{GeV}^2$

Deuteron $A_1 + \eta A_2$ versus W



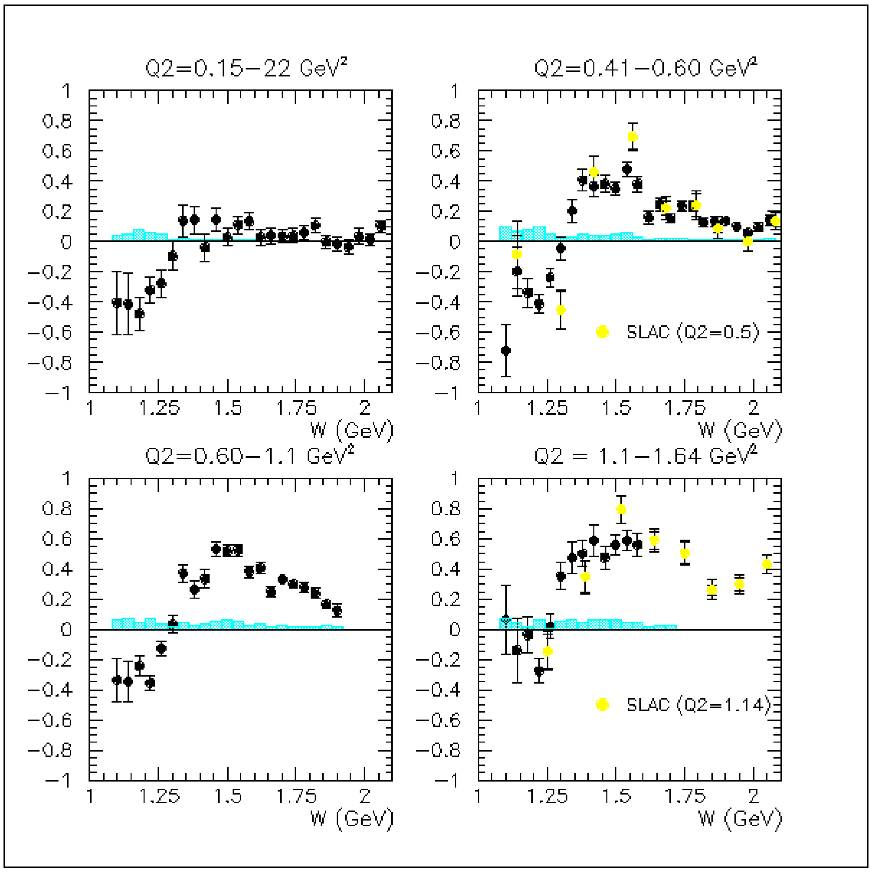
- Data show a marked Q^2 dependence
- $Q^2 = 0.34$ GeV^2 (magenta squares)
- $Q^2 = 0.53$ GeV^2 (blue triangles)
- $Q^2 = 1.0$ GeV^2 (green dots)

Γ_1^d versus Q^2



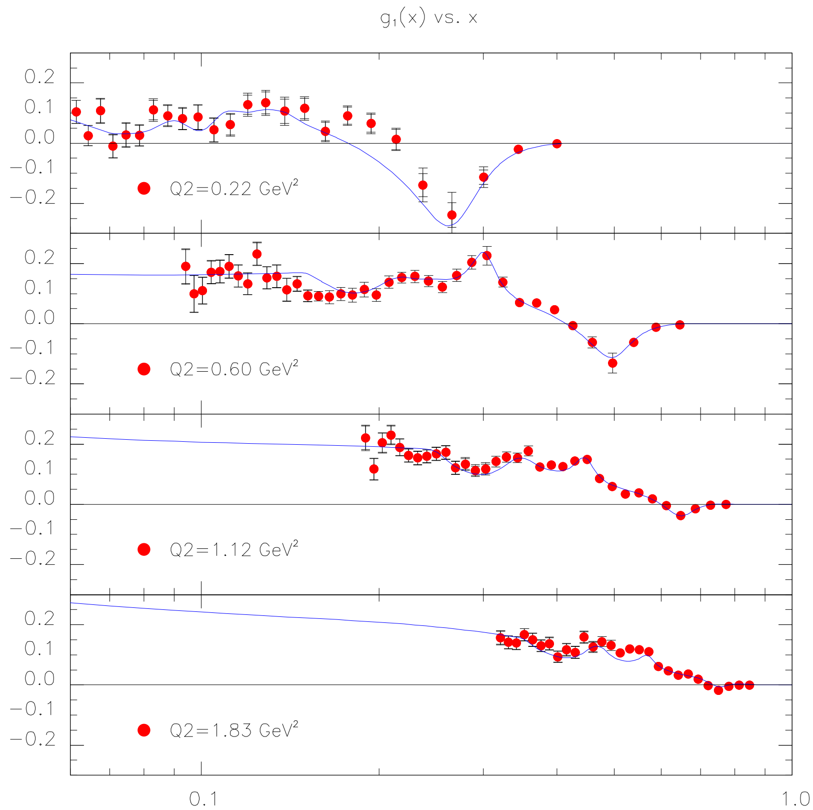
- Γ_1^d changes sign near $Q^2 = 0.5$ GeV^2
- Data are systematically below models

Proton $A_1 + \eta A_2$ versus W



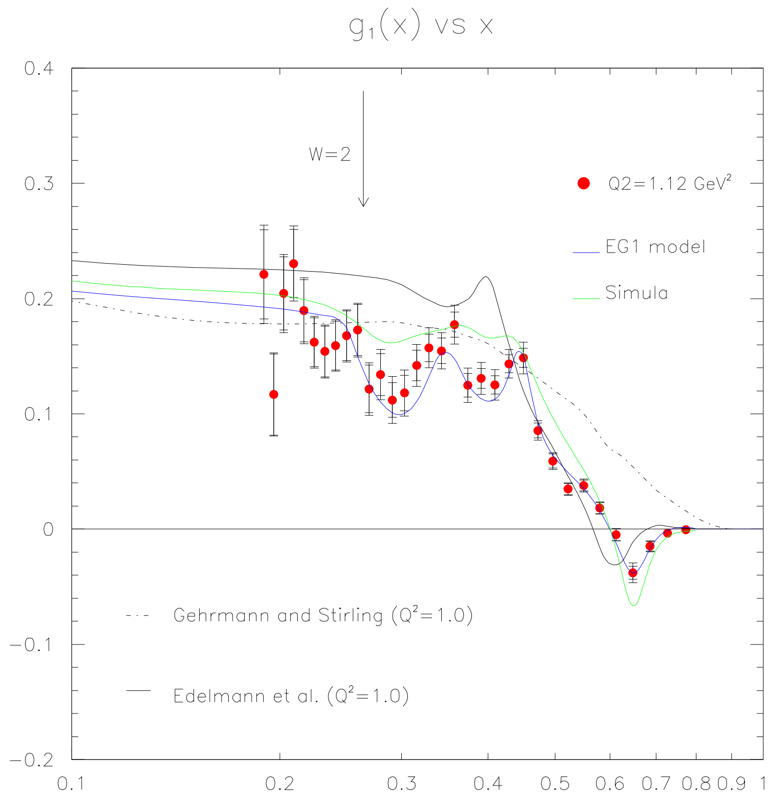
- Four representative Q^2's
- Comparison with SLAC (yellow) at $Q^2 = 0.5$ and 1.2 GeV^2
- Δ pulls A_1 negative at low Q^2

g_1 versus x



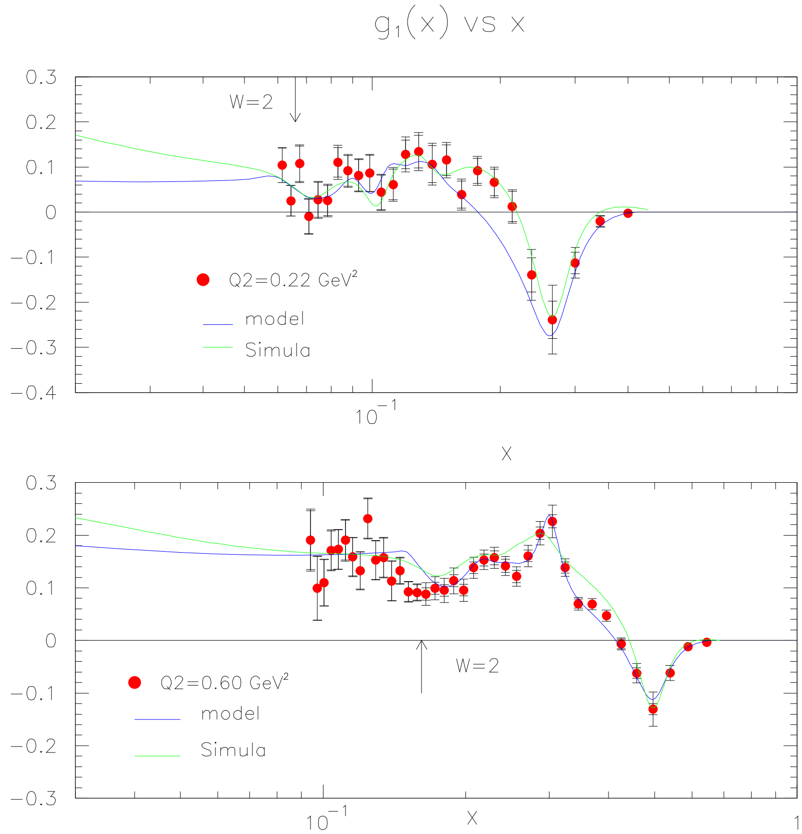
- $Q^2 = 0.22, 0.60, 1.12, 1.83$ GeV^2
- Blue curve is our model (MAID with tuning)
- Resonances move up in x with increasing Q^2

g_1 versus x



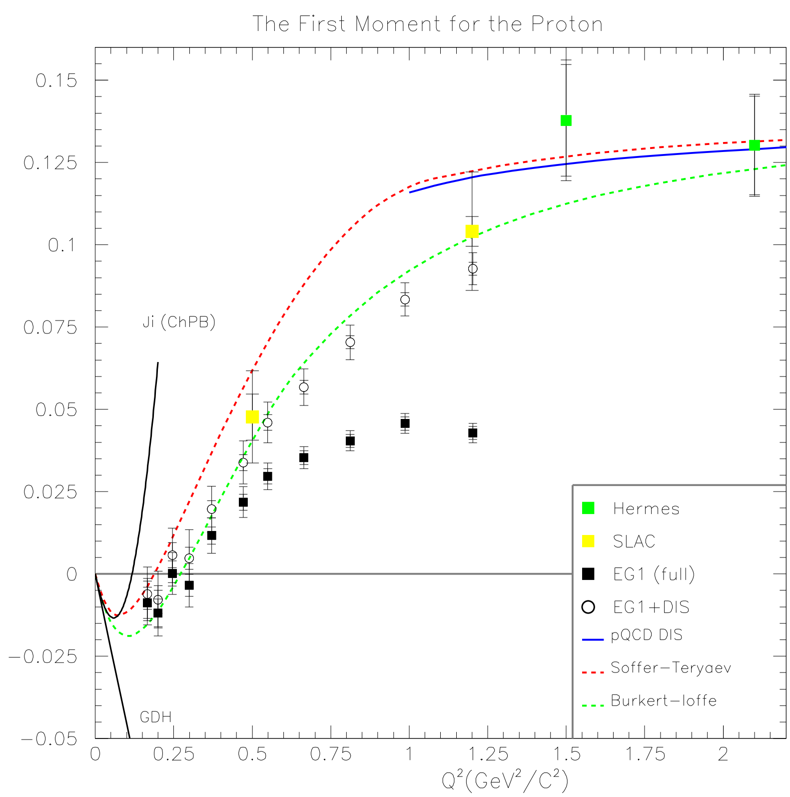
- $Q^2 = 1.12$ GeV^2 data with models
- Simula [hepph0107036]
- Gehrmann and Stirling [PRD53(96)6100]
- Edelmann [NPA665(00)125]

g_1 versus x



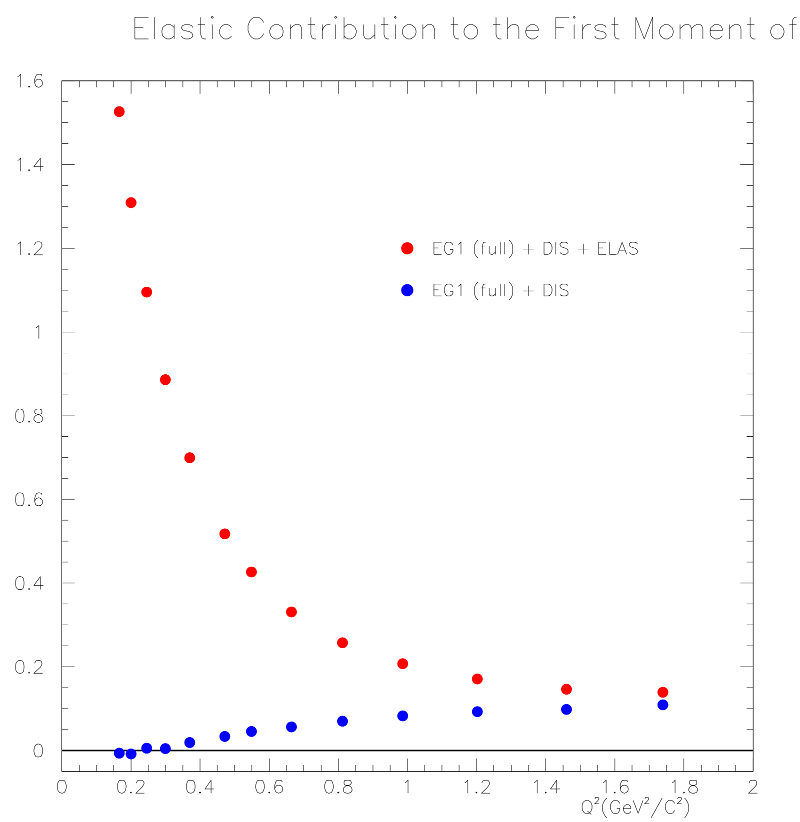
- Low Q^2 spectra
- Resonance structure is obvious in these plots

Γ_1^p versus Q^2



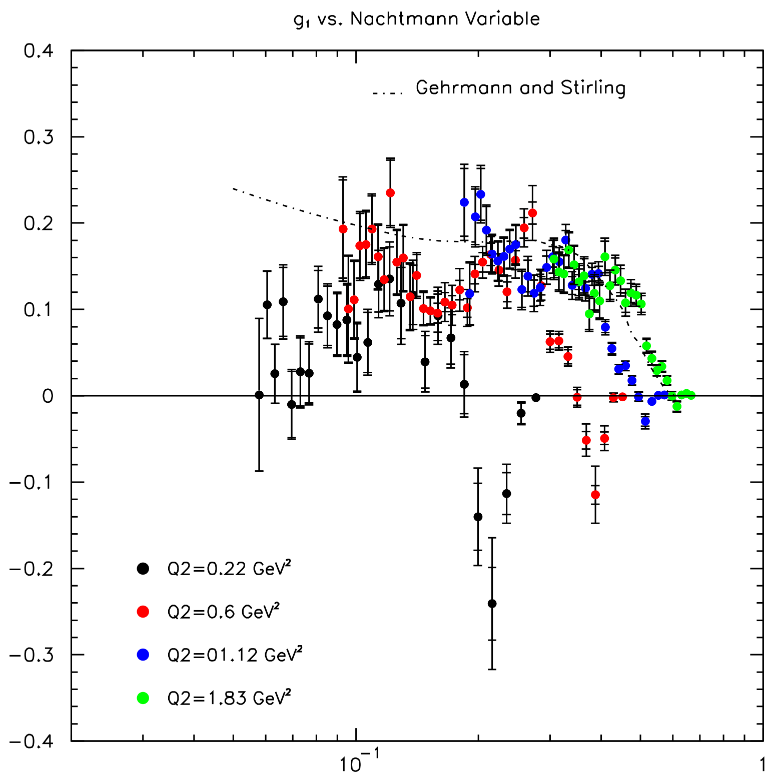
- Zero crossing near $Q^2 = 0.2$ GeV^2
- $W > 2$ contributes half at $Q^2 = 1$ GeV^2
- Chiral perturbation theory [PLB472(00)1] appears to break down above $Q^2 = 0.1$ GeV^2

Γ_1^p versus Q^2



- Γ_1^p for resonance and DIS (blue)
- Γ_1^p for resonance and DIS +elastic (red)
- $\Gamma_1^{\rm el} = \frac{1}{2}F_1(Q^2)[F_1(Q^2) + F_2(Q^2)]$

g_1 **versus** ξ



- Nachtmann variable $\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}}$
- Duality?

Representative CLAS Event

- CLAS has taken extensive data with longitudinally polarized electrons and polarized p and d targets.
- Structure functions g_1^p and g_1^d agree with SLAC and significantly extend the kinematic range.
- $\Gamma_1^{p(n)}$ becomes negative at $Q^2 \approx 0.2(0.5)$ GeV^2.
- Γ_1^p shows Q^2 limits of chiral perturbation theory.
- Exclusive reactions allow isospin selection of $A_{1/2}$ and $A_{3/2}$ amplitudes.
- Much more data ($\times 10$ for d, $\times 3$ for p) is presently being analyzed.