Single Nucleon spin experiments

A. Deur
Thomas Jefferson National Accelerator Facility

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- Single nucleon (neutron or proton)
- Single particle detection (lepton detection, inclusive experiments)
- Single spin direction for each type of particle (doubly polarized experiments)
- Single Lab (focus on the role of Jefferson Lab)

Context (why should we care about the nucleon spin structure at low Q^2 ?)

Four forces in nature:

- Gravity
- Electromagnetic
- Weak
- Strong

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Adequate description (within experimentally accessible range) — Gravity, Electromagnetic, Weak

Analytical fundamental description only in a small fraction of the experimentally accessible range — Strong

We need to know the strong force better for a complete understanding of nature.

The nucleus is a natural laboratory for such study because its structure is governed by the strong force.

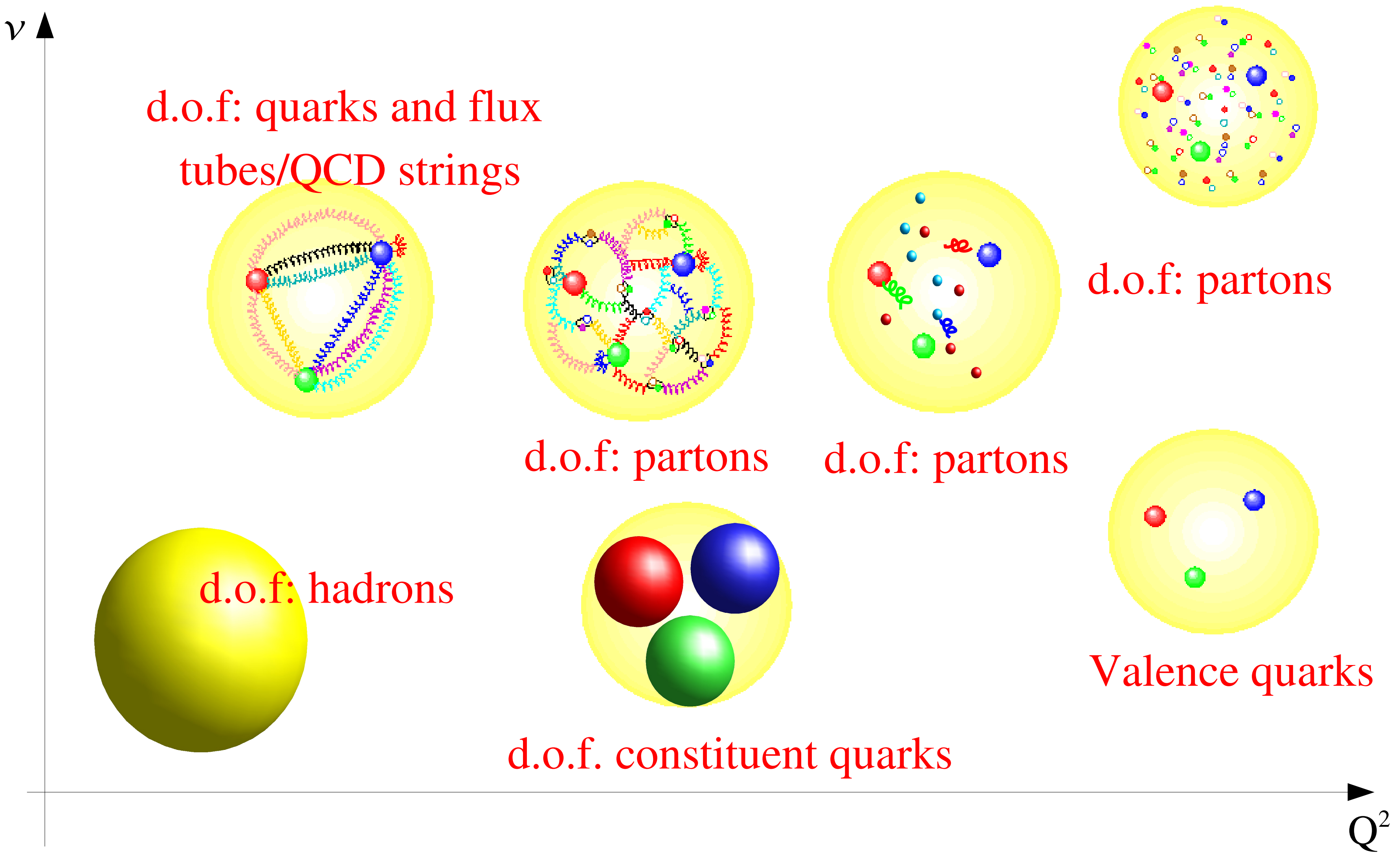
1st step:

Test:

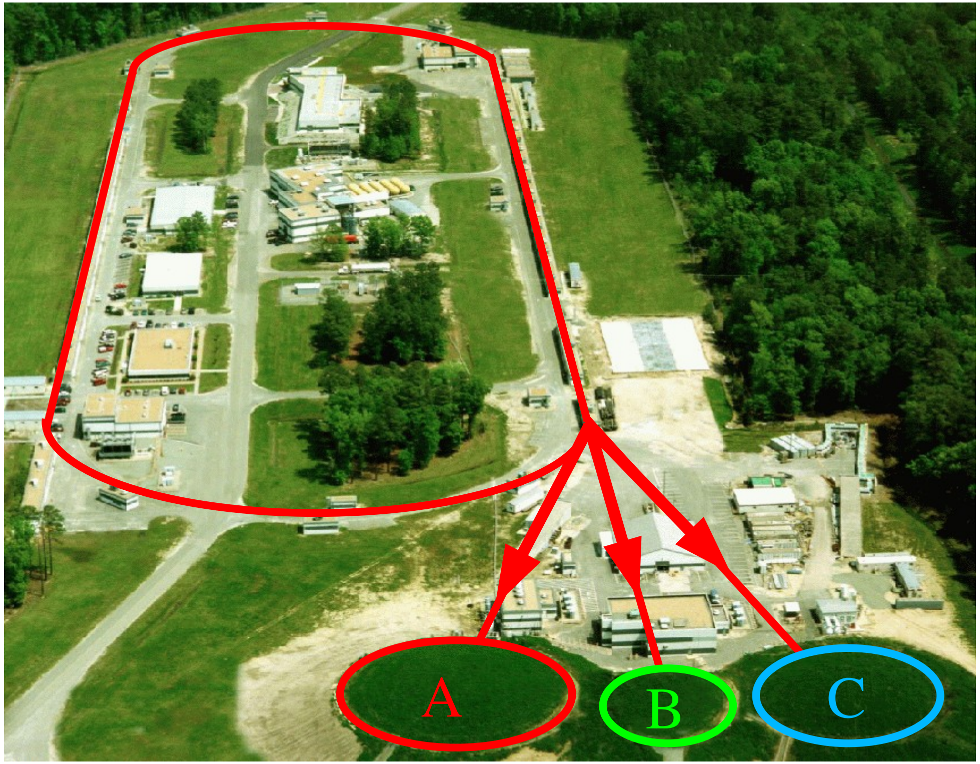
- Gauge theory of strong force (QCD) in calculable domain (perturbative domain, pQCD).
- Effective descriptions in non perturbative domain (e.g. χpT).

2nd step:

Connection between fundamental description (QCD) and effective descriptions.


ν
d.o.f: quarks and flux
tubes/QCD strings
d.o.f: partons
d.o.f: partons
d.o.f: partons
d.o.f: hadrons
Valence quarks
d.o.f. constituent quarks
Q^2

Jefferson Lab



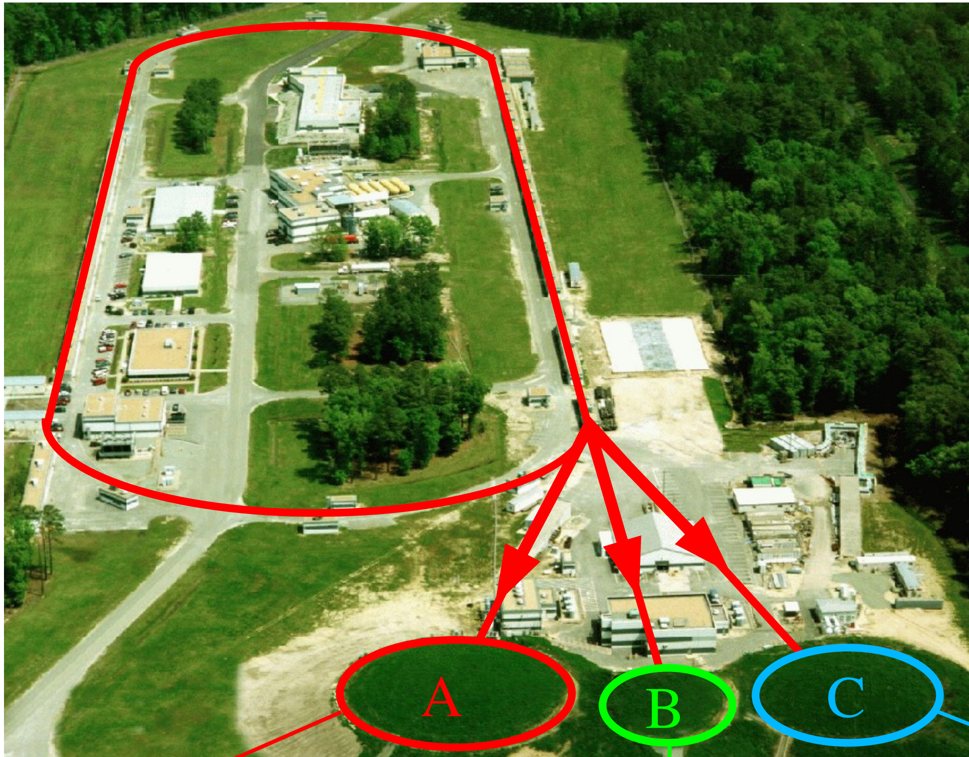
Continuous e^- beam.

1 to 6 GeV.

Polarization: ~85%

Up to 200 μA.

Jefferson Lab



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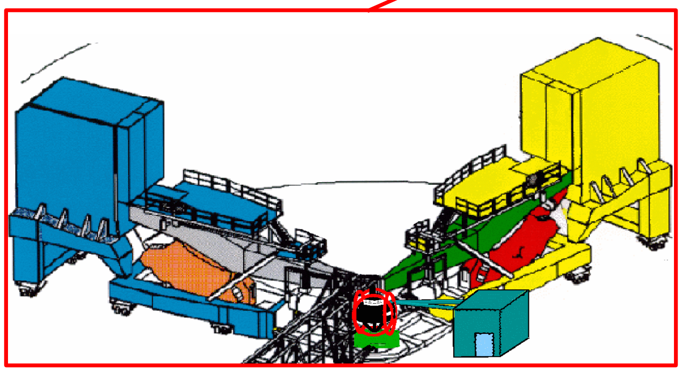
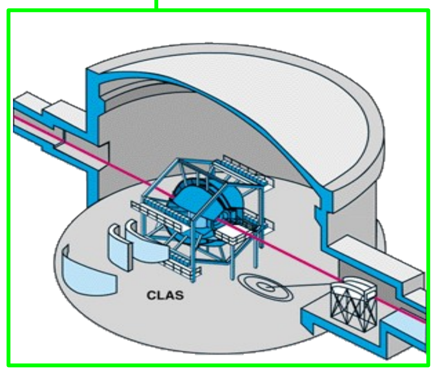
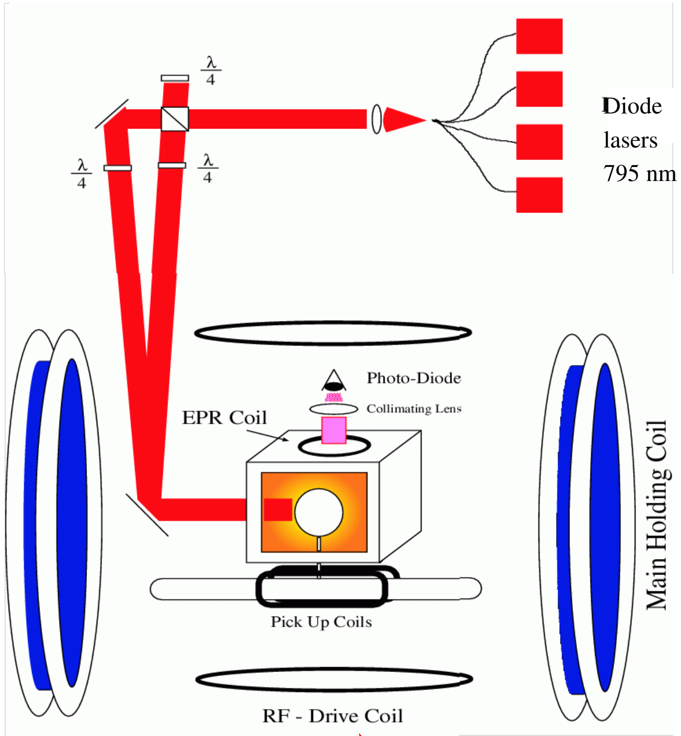




Polarized targets

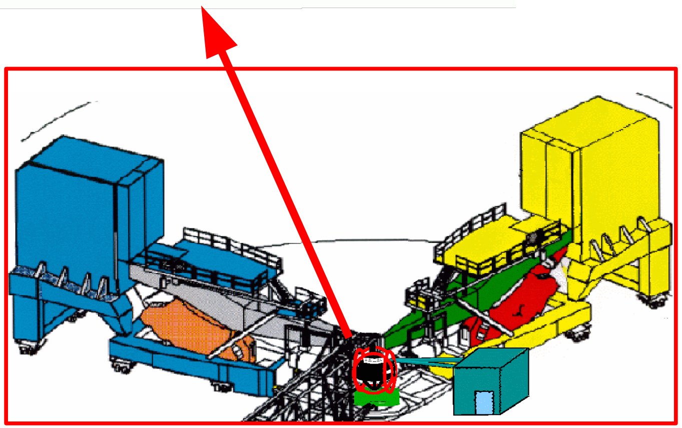


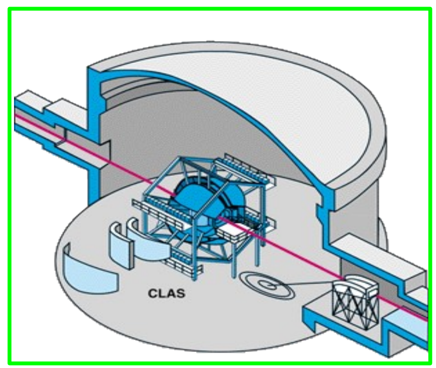
^{3}He target:

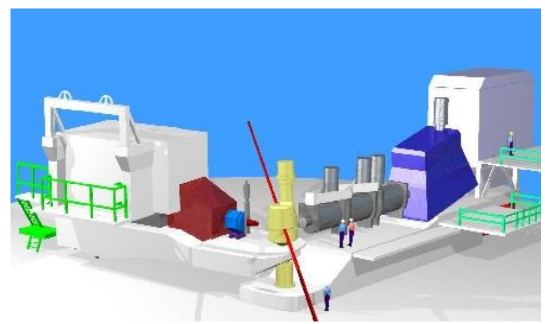
- Effective polarized neutron target
- High luminosity: 10^{36} $s^{-1}cm^{-2}$
- Low dilution: ~30%
- Excellent polarization: ~60-70%
- Any polarization directions

Results on ^{3}He structure available as well.

See K. Slifer's talk today.







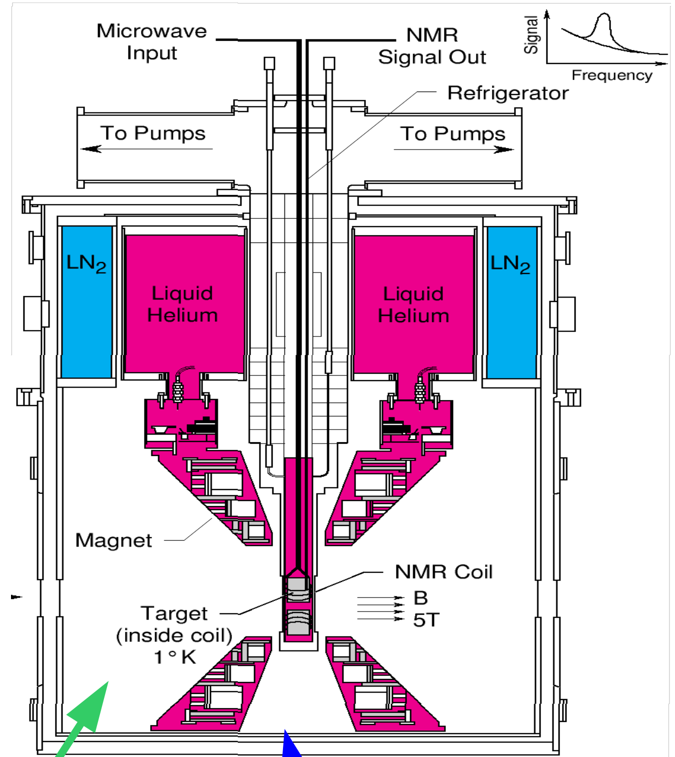
Polarized targets

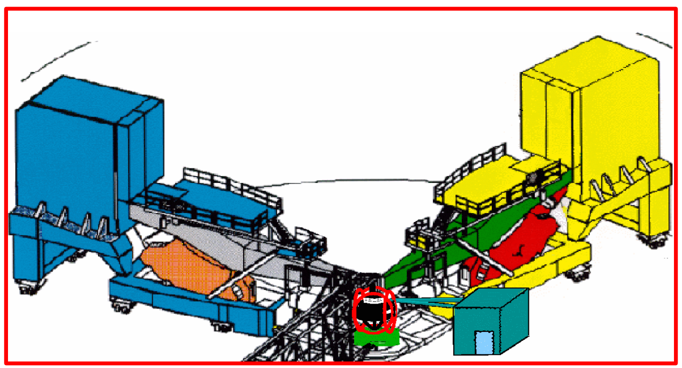
Ammonia targets:

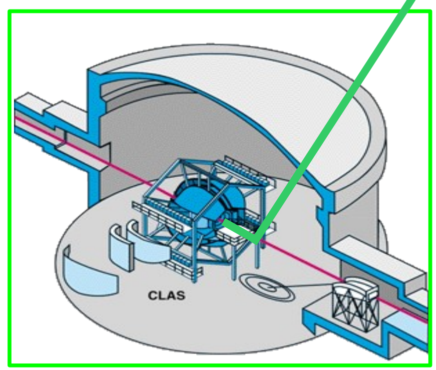
- Polarized proton & deuteron
- Good luminosity: 10^{34} (B) & 10^{35} (C) $s^{-1}cm^{-2}$
- High dilution: ~15%
- High polarization: ~80% (p)

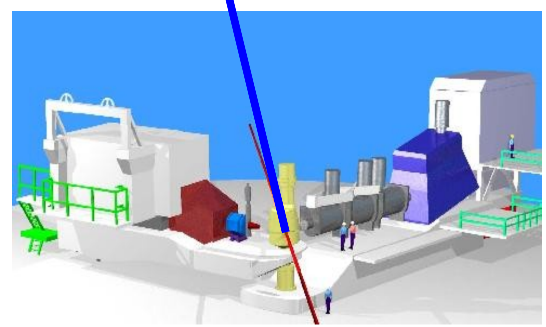
  ~40% (d)
- Longitudinal polarization (B)

  Longitudinal and transverse polarization (C)

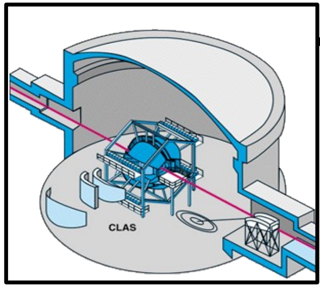


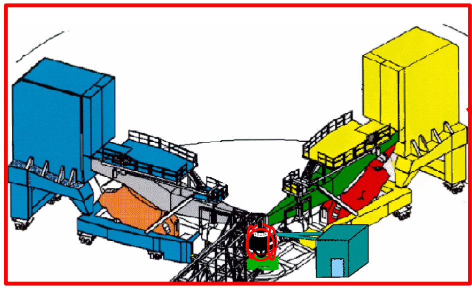


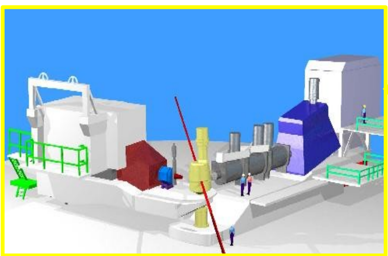


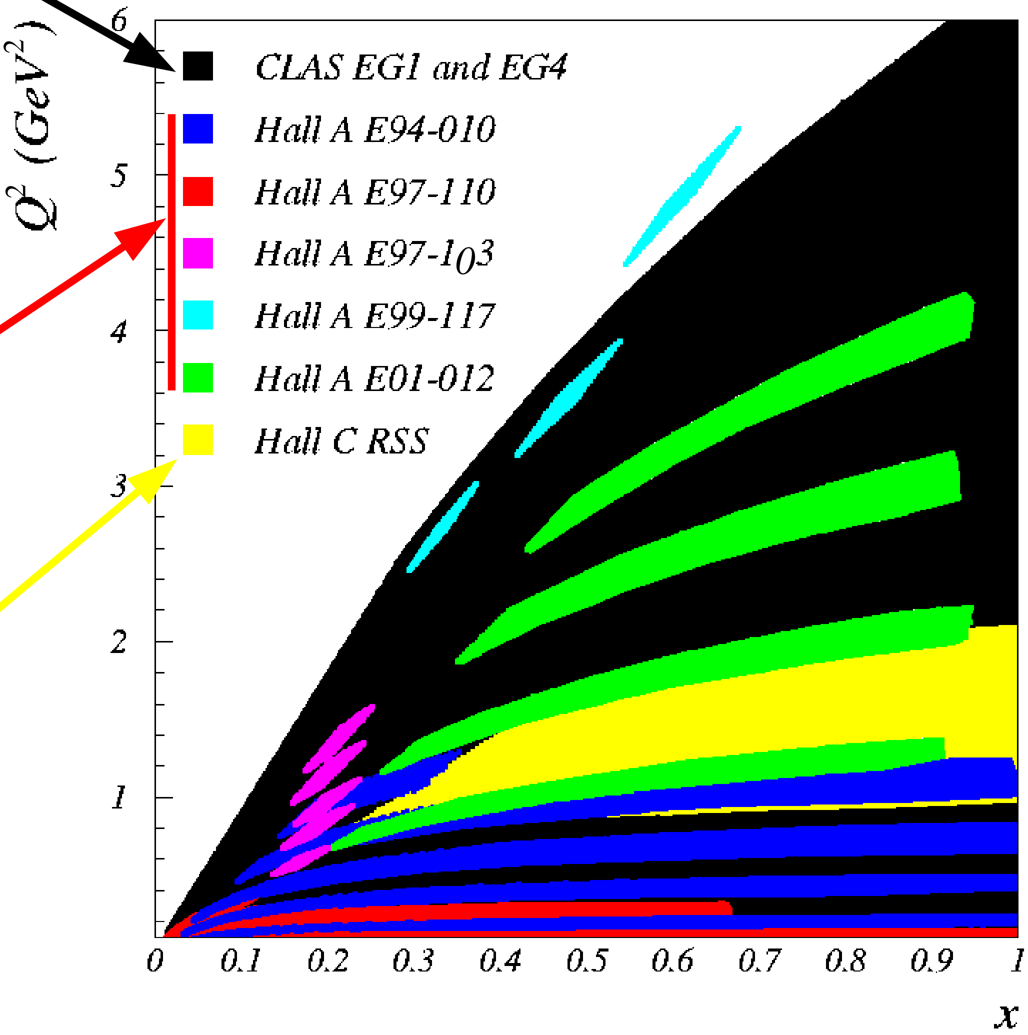


Kinematic coverage









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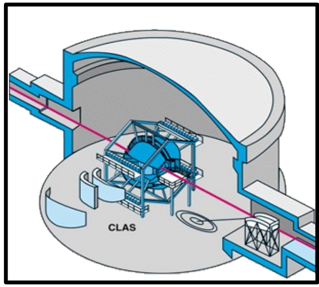
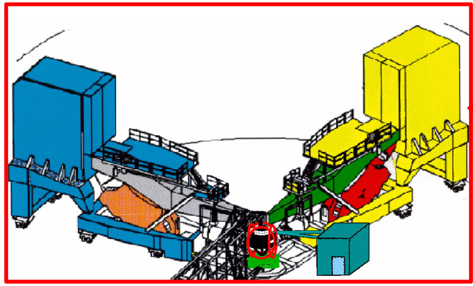
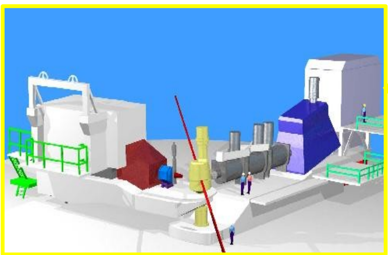
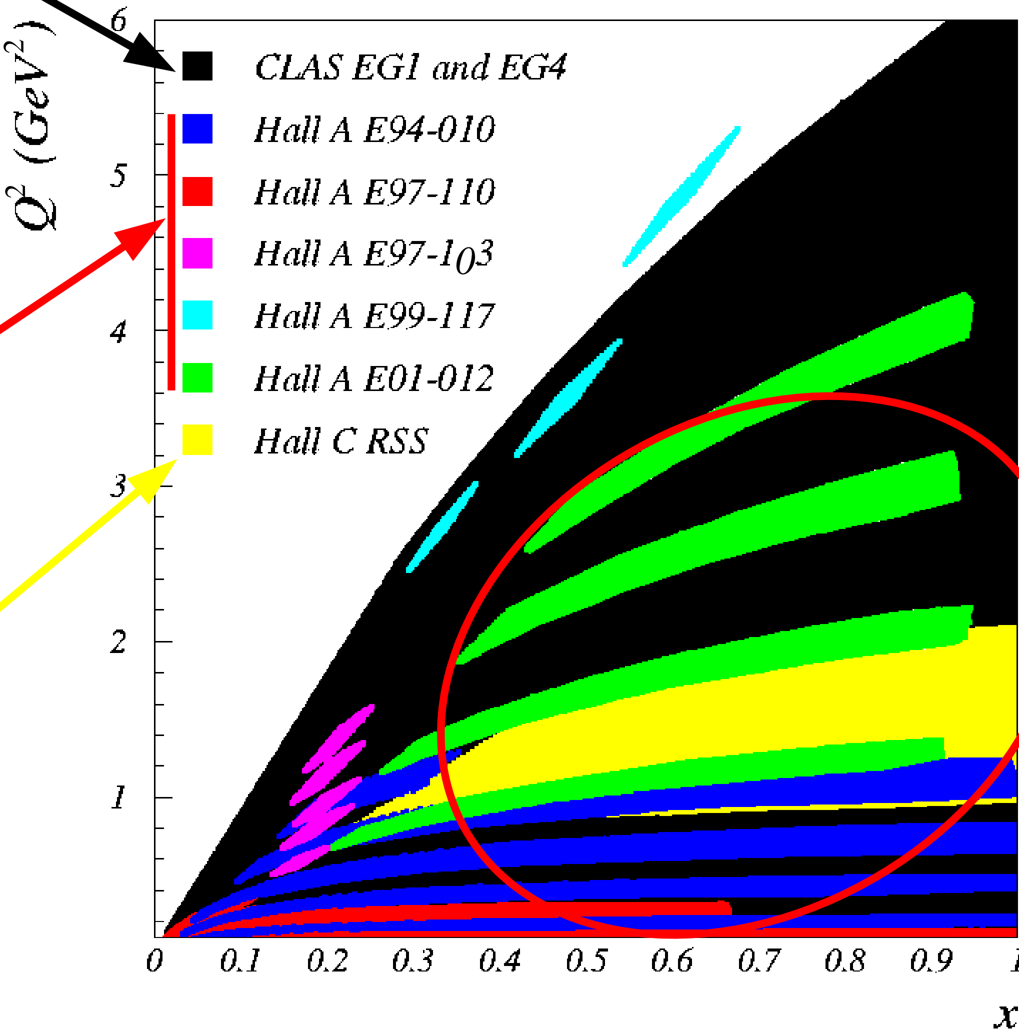


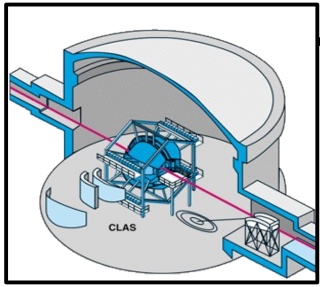


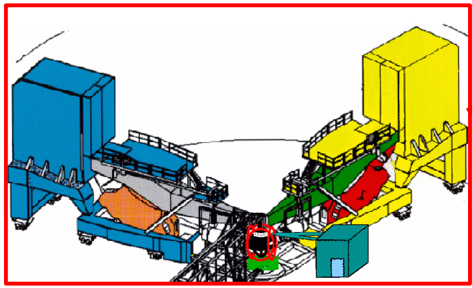


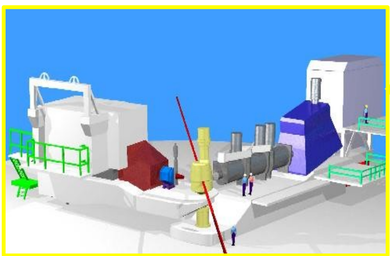


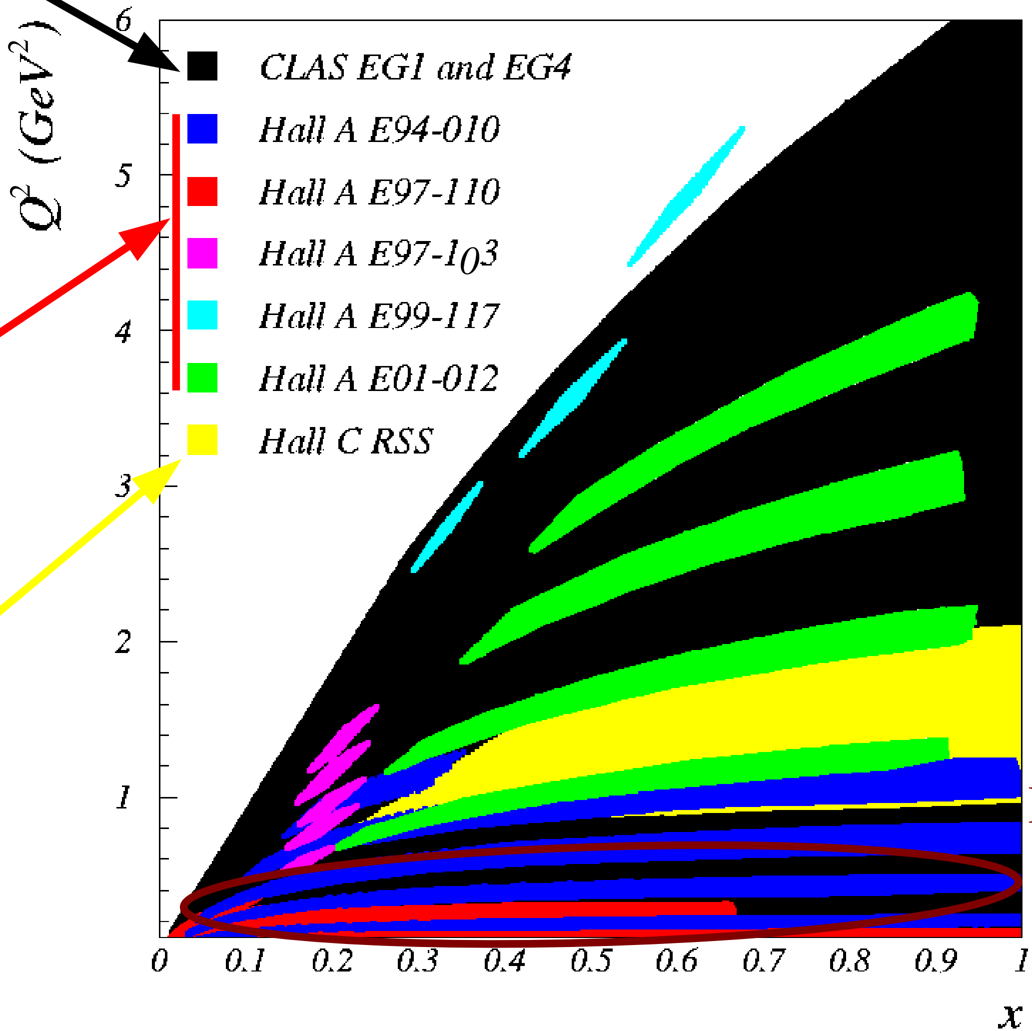
Transition from short scales (pQCD) to large scales

Kinematic coverage









Effective theories of strong interaction at large distances

Moments of spin structure functions

N^{th}-moments: $\left\{ \begin{array}{l} \int g_1 x^{n-1} dx \\ \int g_2 x^{n-1} dx \end{array} \right.$ First moments: Γ_1, Γ_2

- Γ_1^N: Ellis-Jaffe sum rule (large Q^2); Gerasimov-Drell-Hearn (GDH) sum rule (Q^2=0)
- Γ_1^{p-n}: Bjorken sum rule (large Q^2)
- Γ_2^N: Burkhardt–Cottingham (BC) sum rule (any Q^2)

- d_2
- Spin polarizability

} No low-x extrapolation issue

In this talk, I will focus on moments. Structure Functions are (obviously) available too.

Transition from short to large scales: results on $\int g_1^p - g_1^n \, dx$

At large Q^2, proportional to axial charge of the nucleon g_a (**Bjorken sum rule**):

$$\int g_1^p - g_1^n \, dx = \frac{1}{6} g_a (1 + f(Q^2))$$

$f(Q^2)$: series in α_s fully calculable within pQCD.

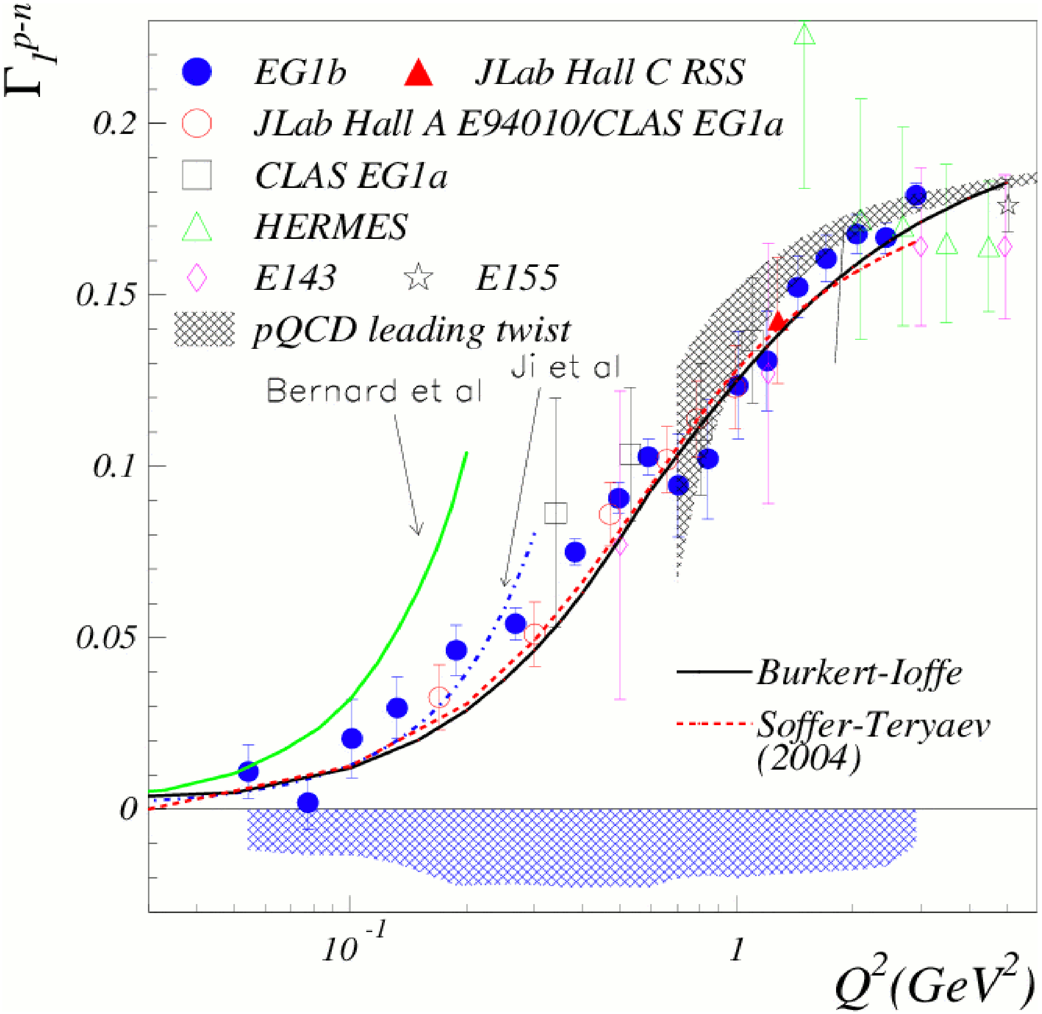
At intermediate Q^2, (lattice QCD) proportional to spin-dependent Compton amplitude.

At small Q^2, (χpT) proportional to spin-dependent Compton amplitude.

At $Q^2 \rightarrow 0$, proportional to anomalous magnetic moments squared of the nucleons (**Gerasimov-Drell-Hearn sum rule**, applies also to individual nucleons):

$$\int g_1^p - g_1^n \, dx = \frac{-Q^2}{8} \left(\frac{\kappa_p^2}{M_p^2} - \frac{\kappa_n^2}{M_n^2} \right)$$

Transition from short to large scales: results on $\int g_1^p - g_1^n \, dx$



Δ contribution suppressed

$\Rightarrow$Easier check of χpT.

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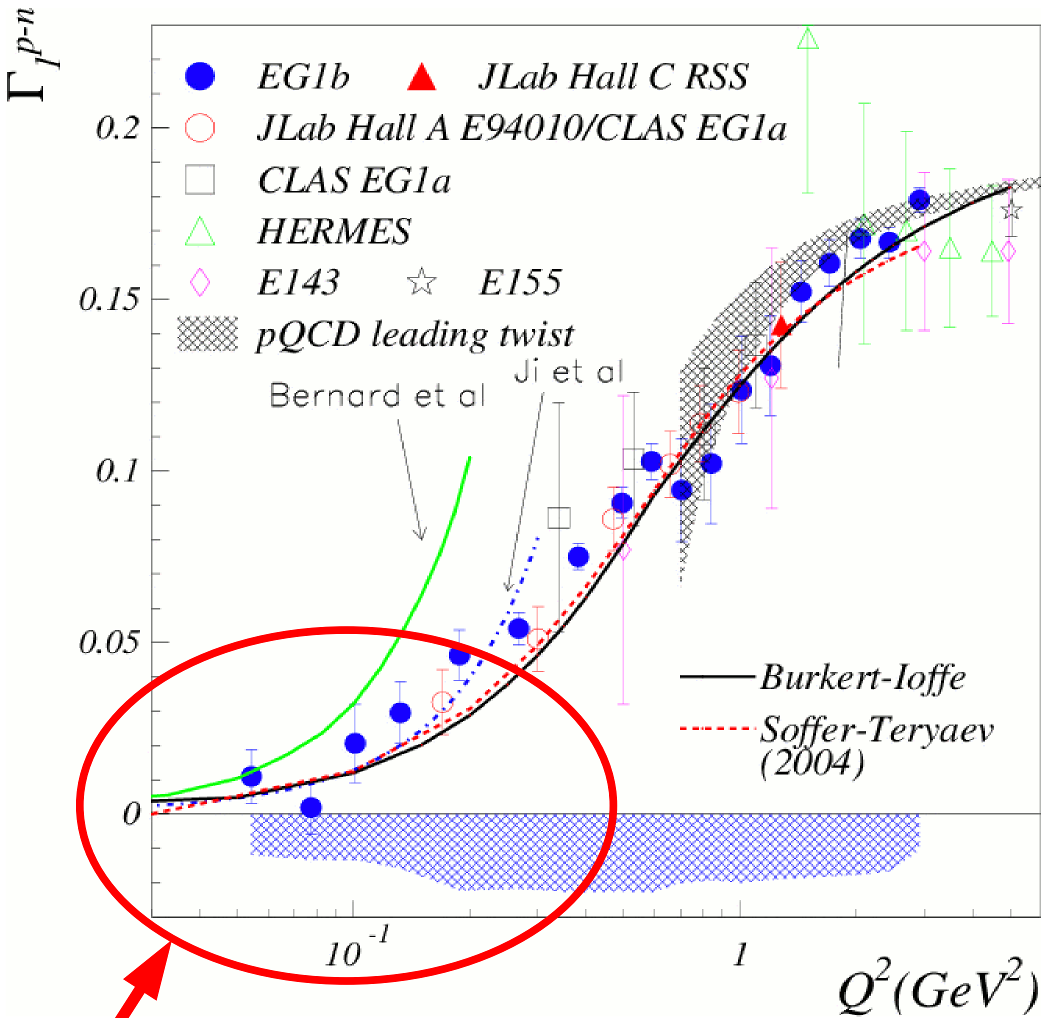

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Nice agreement with χpT (Δ suppressed?)

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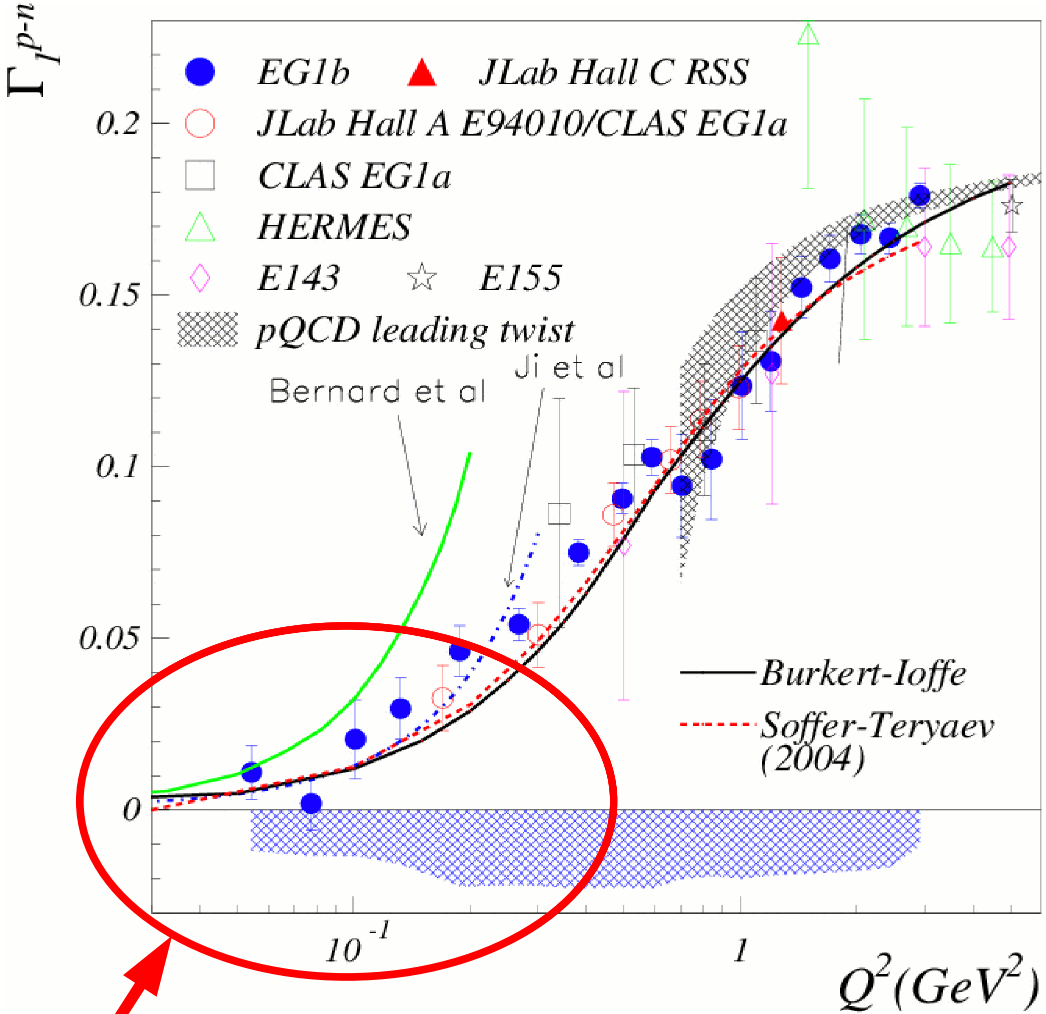

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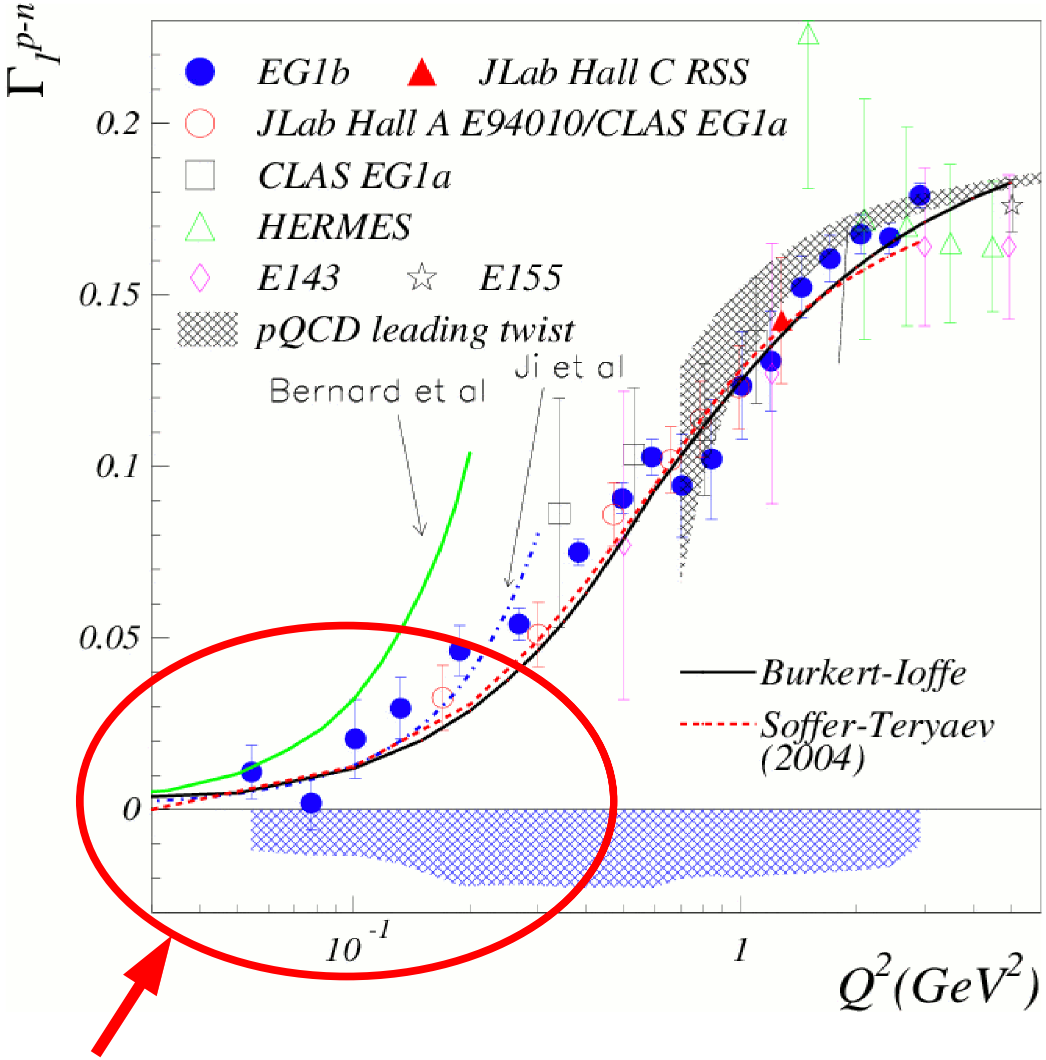
Low Q^2 fit:

$$\Gamma_1^{p-n} = \frac{\kappa_n^2 - \kappa_p^2}{8M^2} Q^2 + aQ^4 + bQ^6$$

a=0.80±0.07±0.23, b=-1.13±0.16±0.39

$a^{\chi pT,Ji}$=0.74, $a^{\chi pT,B.}$=2.4

Transition from short to large scales: results on $\int g_1^p - g_1^n \, dx$



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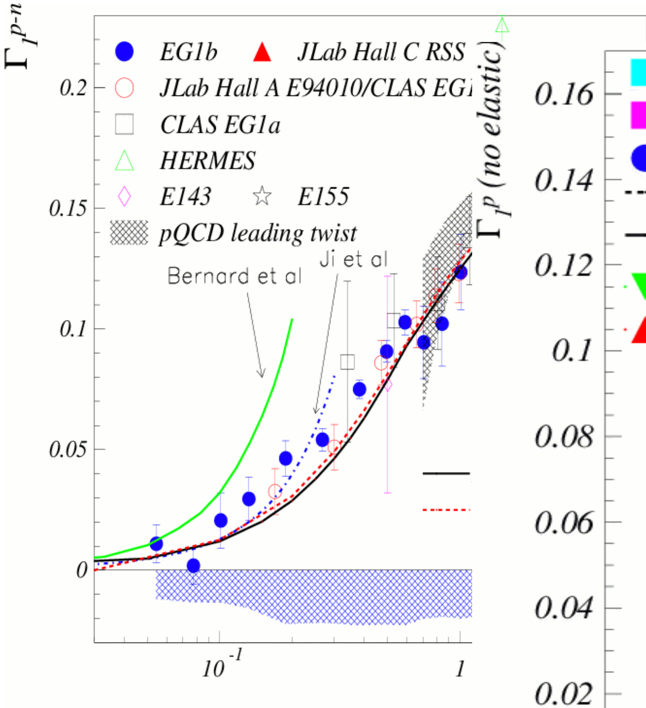
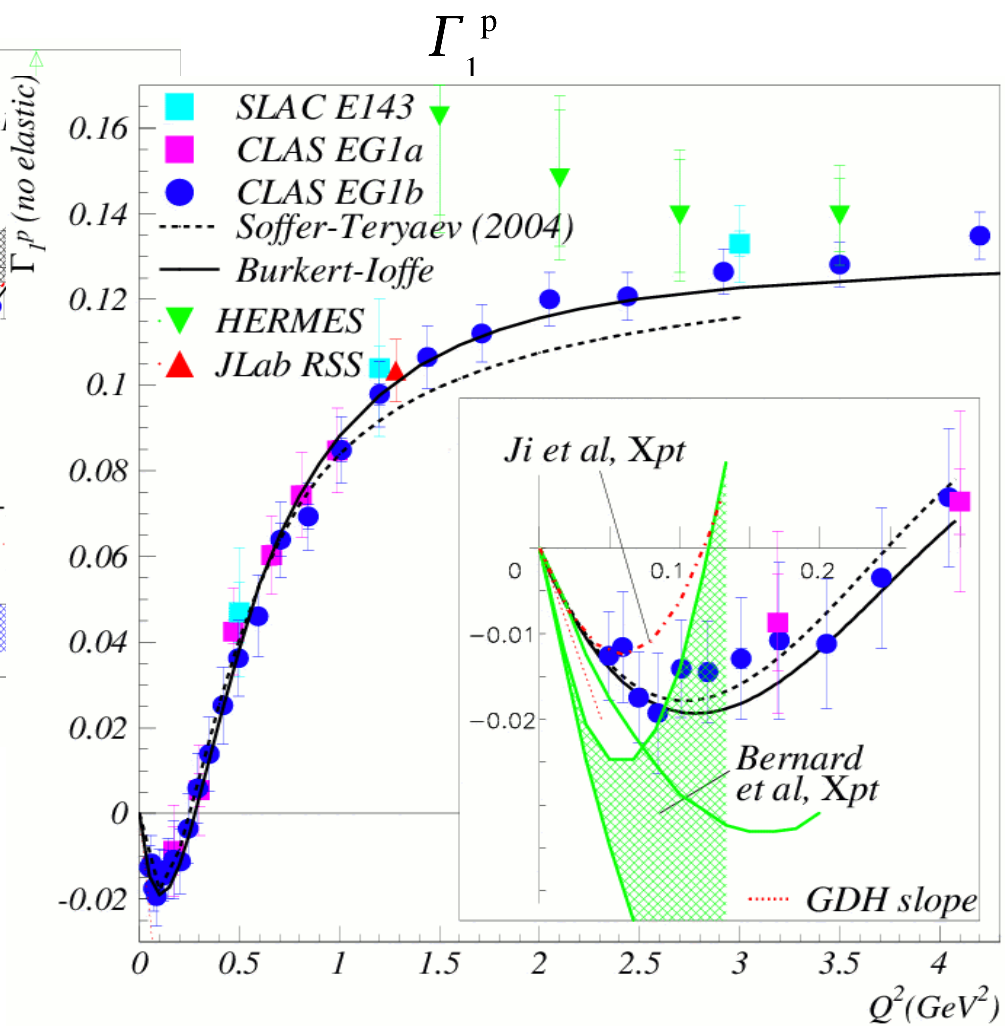
Transition from short to large scales: results on $\int g_1 dx$





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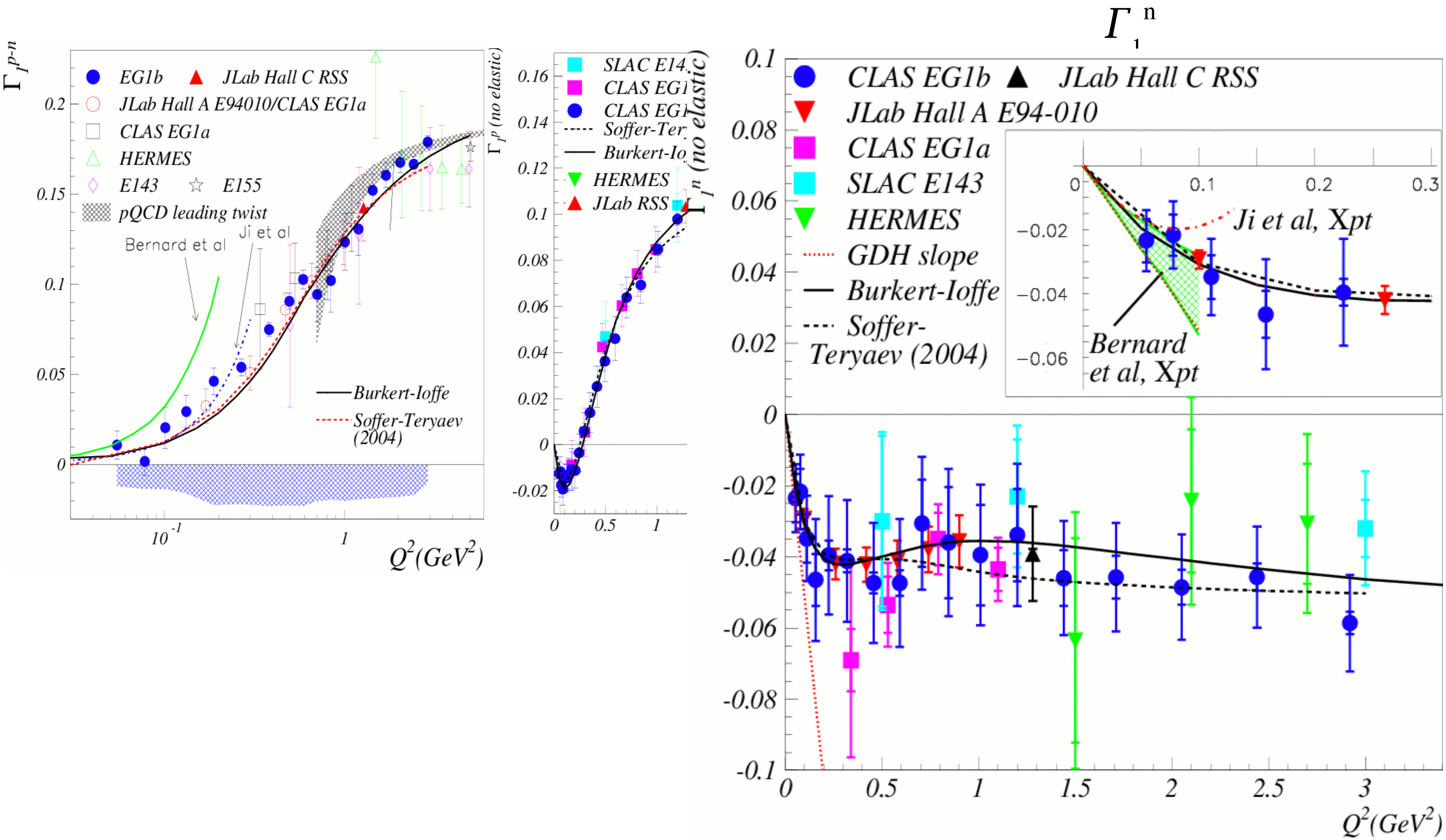

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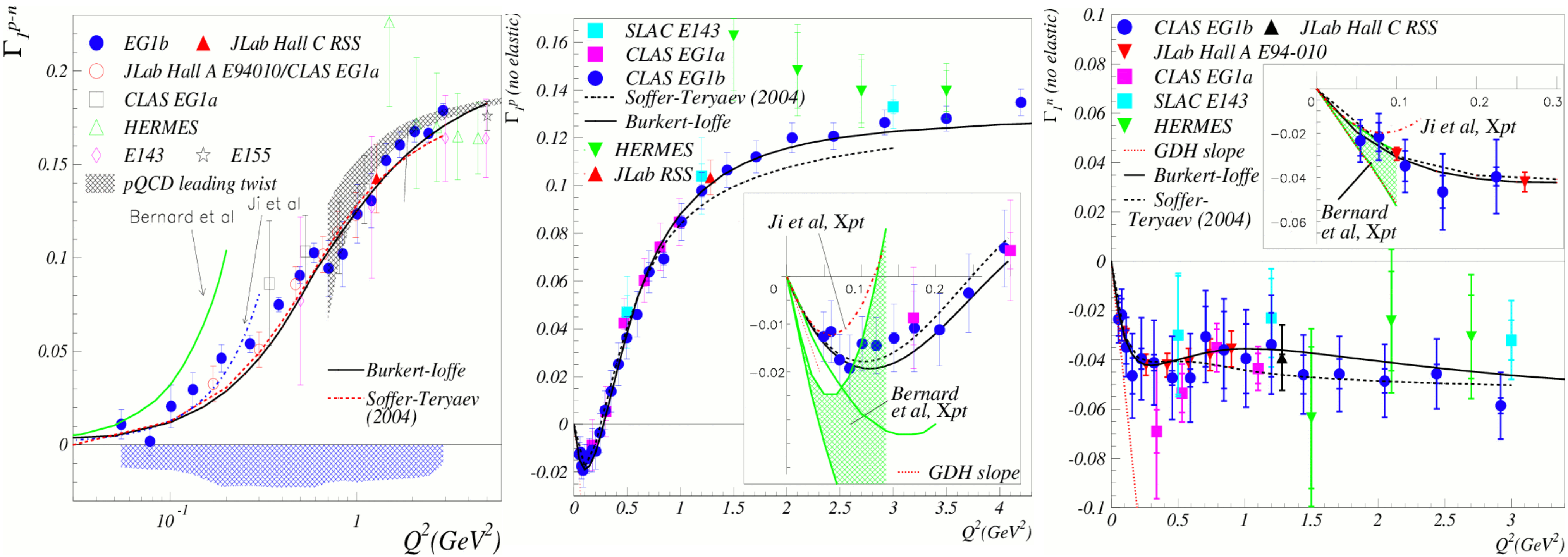


Results on sum rules (higher moments)

Generalized forward spin polarizability:

$$\gamma_0 = \frac{4e^2M^2}{\pi Q^6} \int x^2\left(g_1 - \frac{4M^2}{Q^2}\ x^2 g_2\right)dx$$

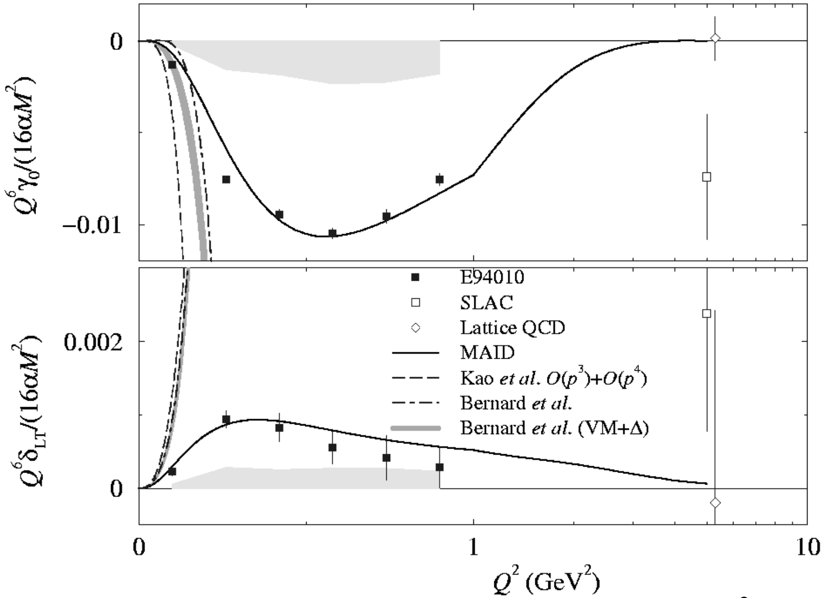
For Neutron

Longitudinal-Transverse polarizability:

$$\delta_{LT} = \frac{4e^2M^2}{\pi Q^6} \int x^2(g_1 + g_2)dx$$

Δ contribution suppressed

⇒Easier check of χpT.



Q^2

Results on sum rules (higher moments)

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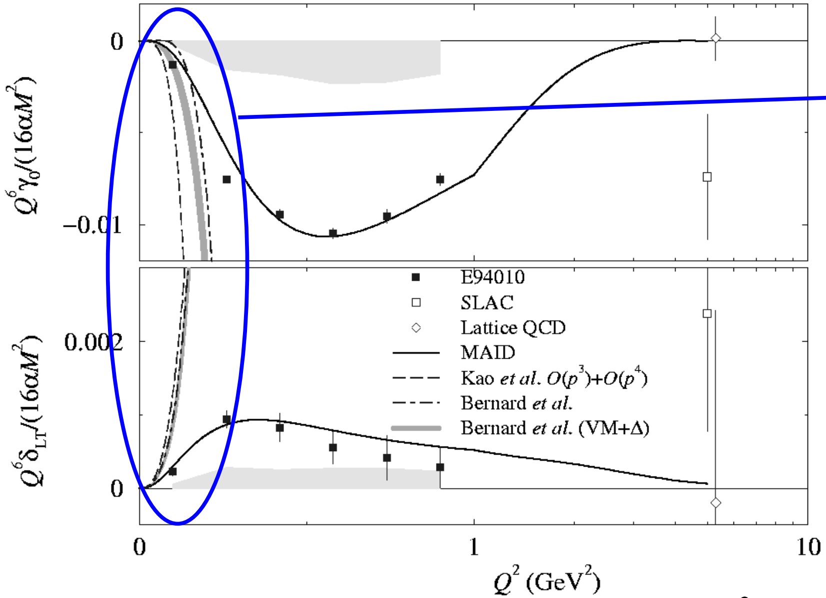
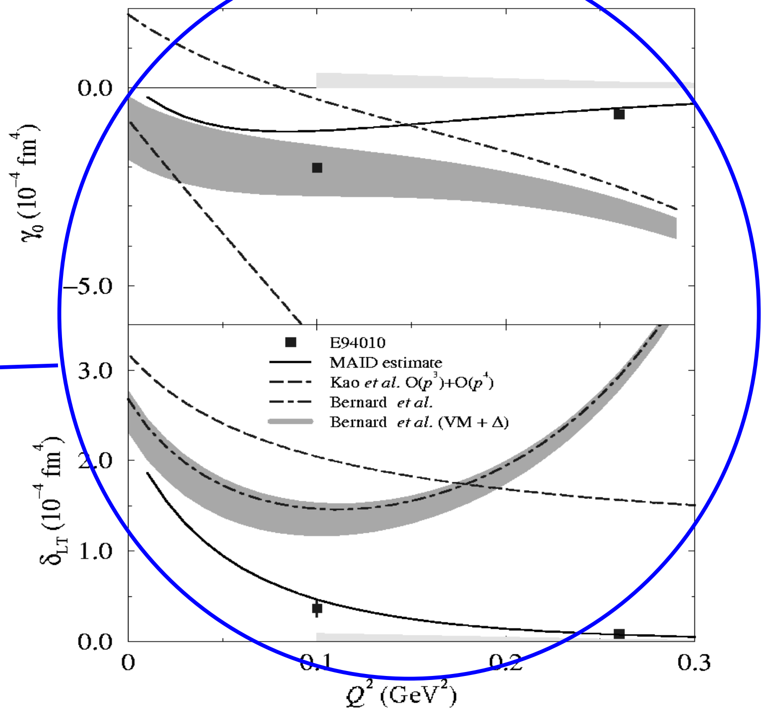


Q²

For Neutron



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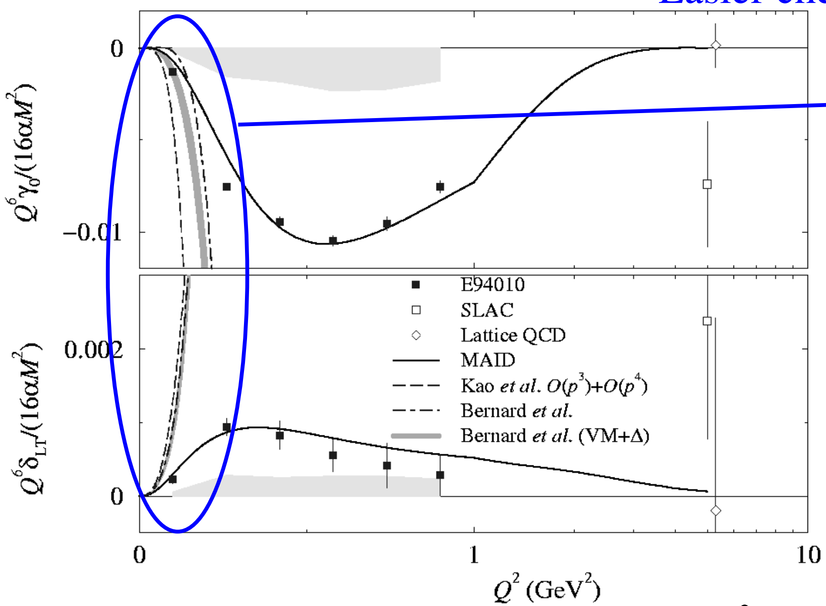
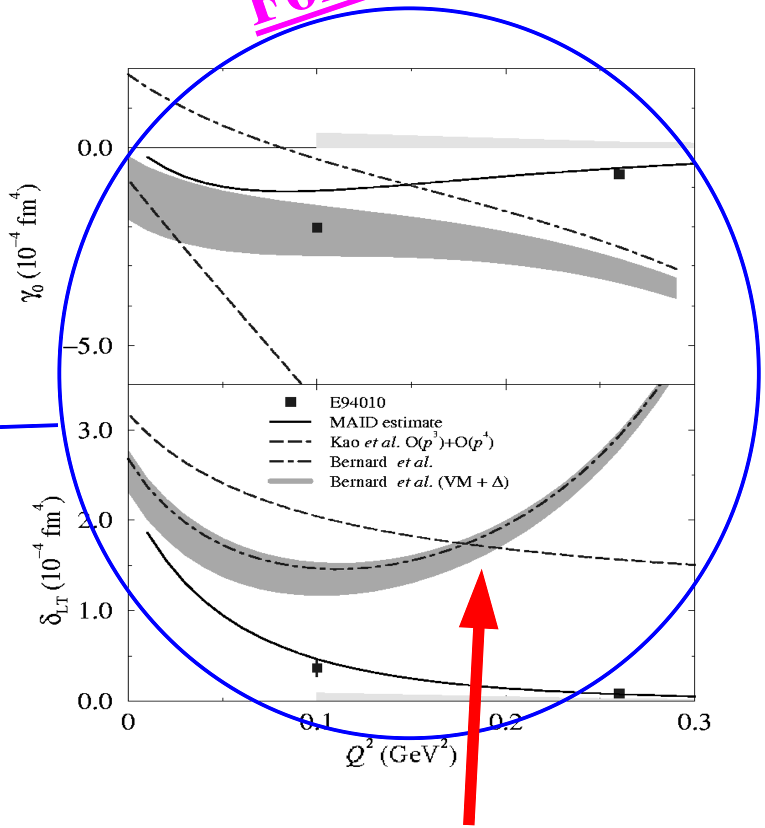


Q^2

For Neutron

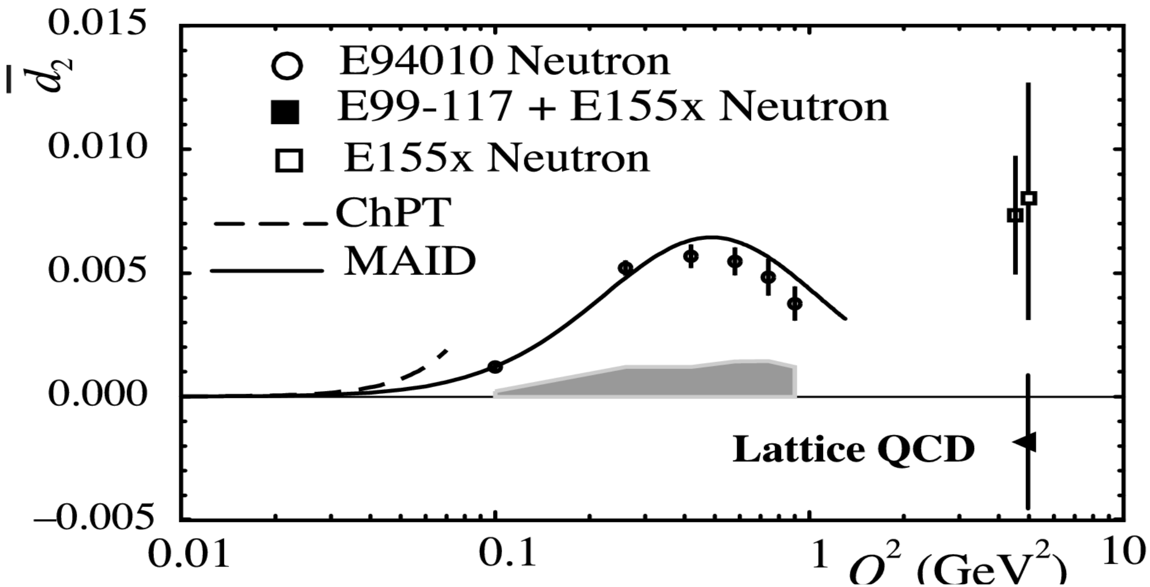


Failure of calculations in spite of Δ suppression.

Results on sum rules (higher moments)

$$d_2 = \int x^2(2g_1+3g_2)dx$$

For Neutron



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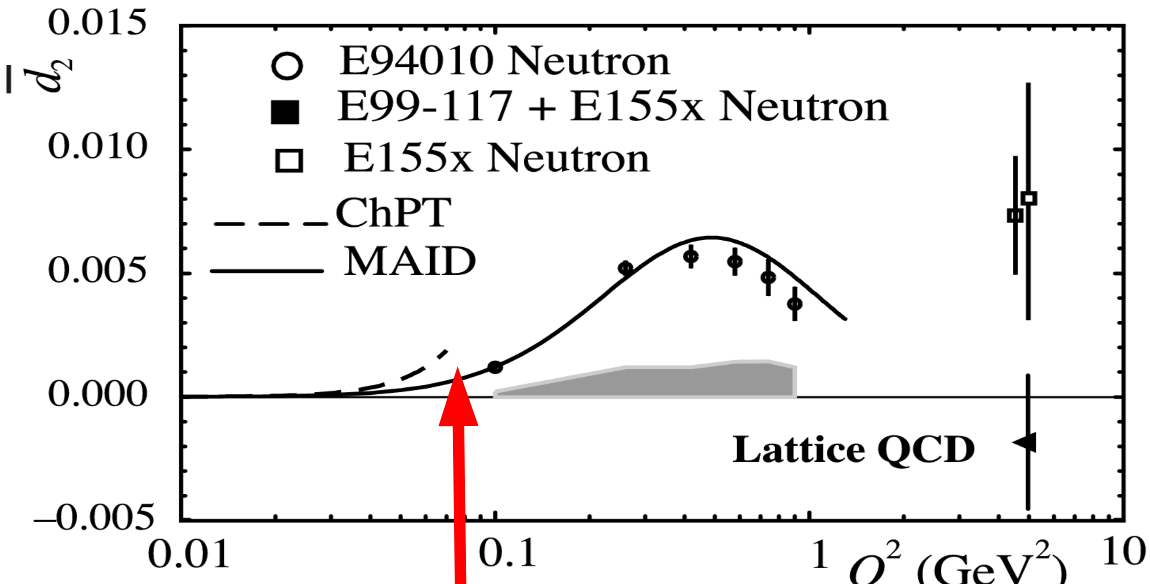

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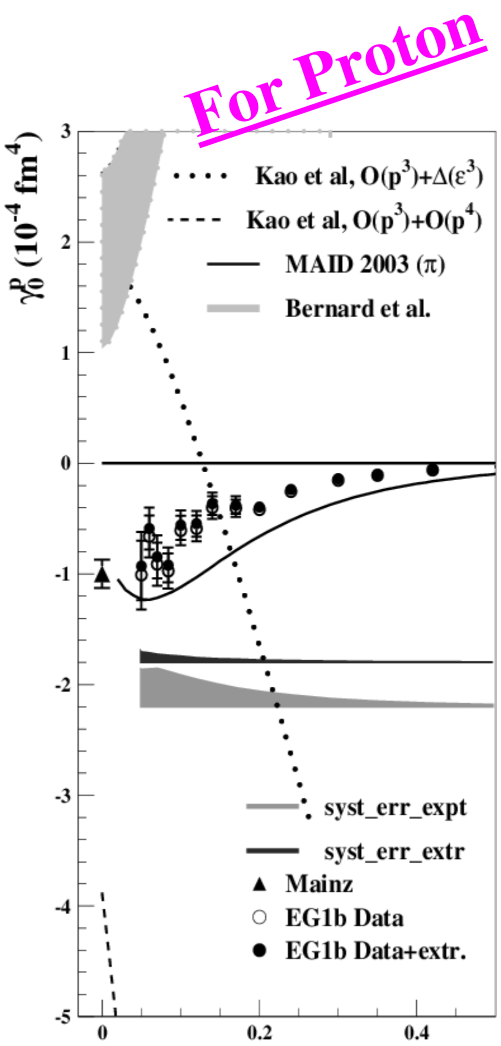

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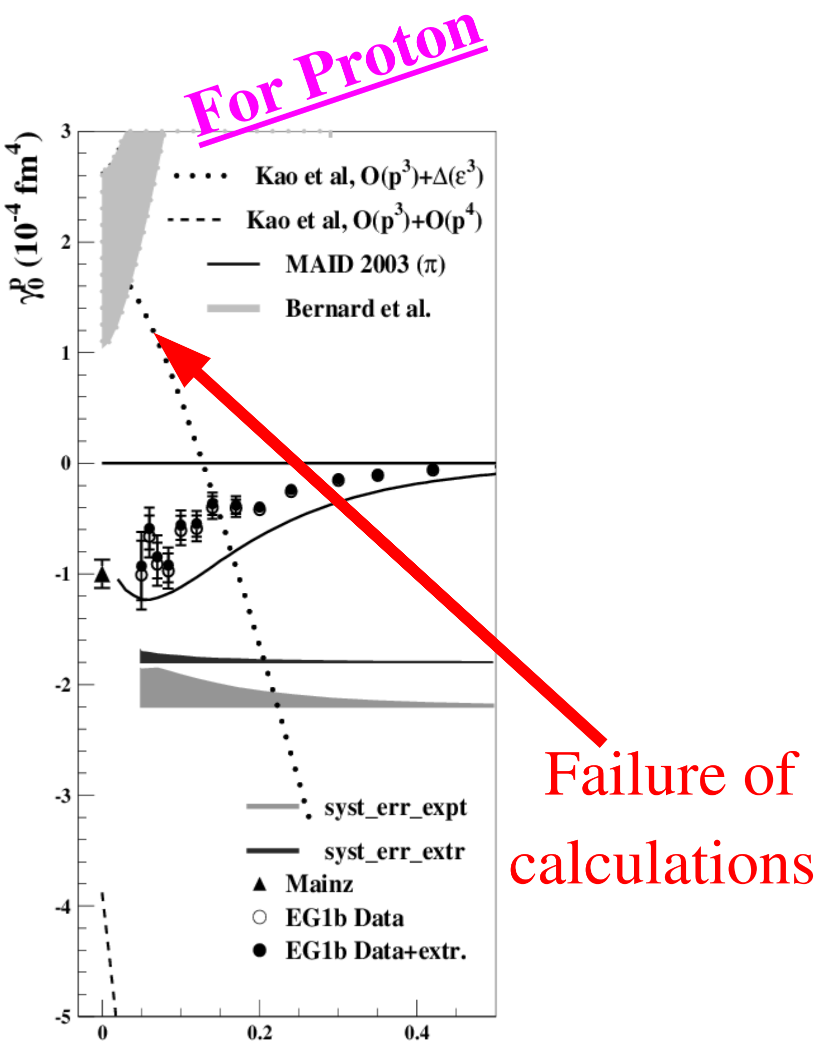

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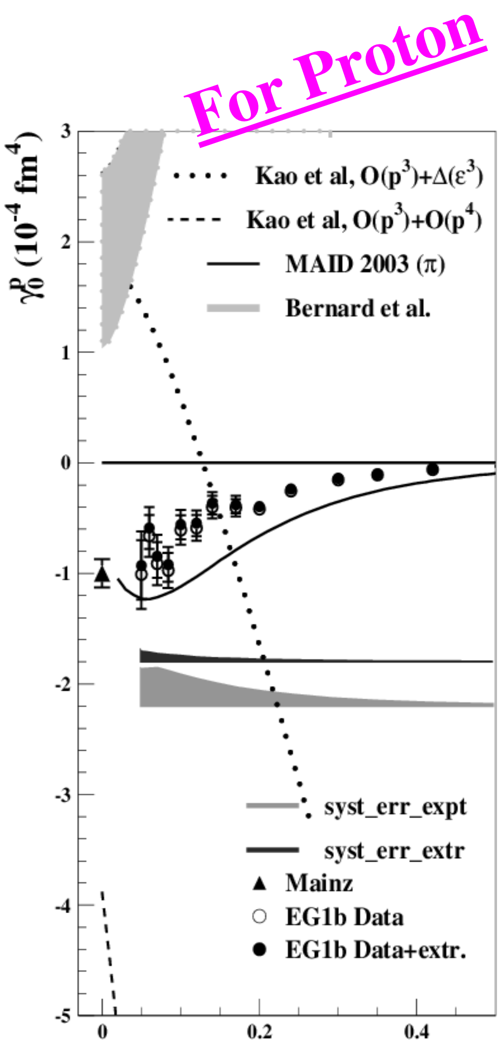
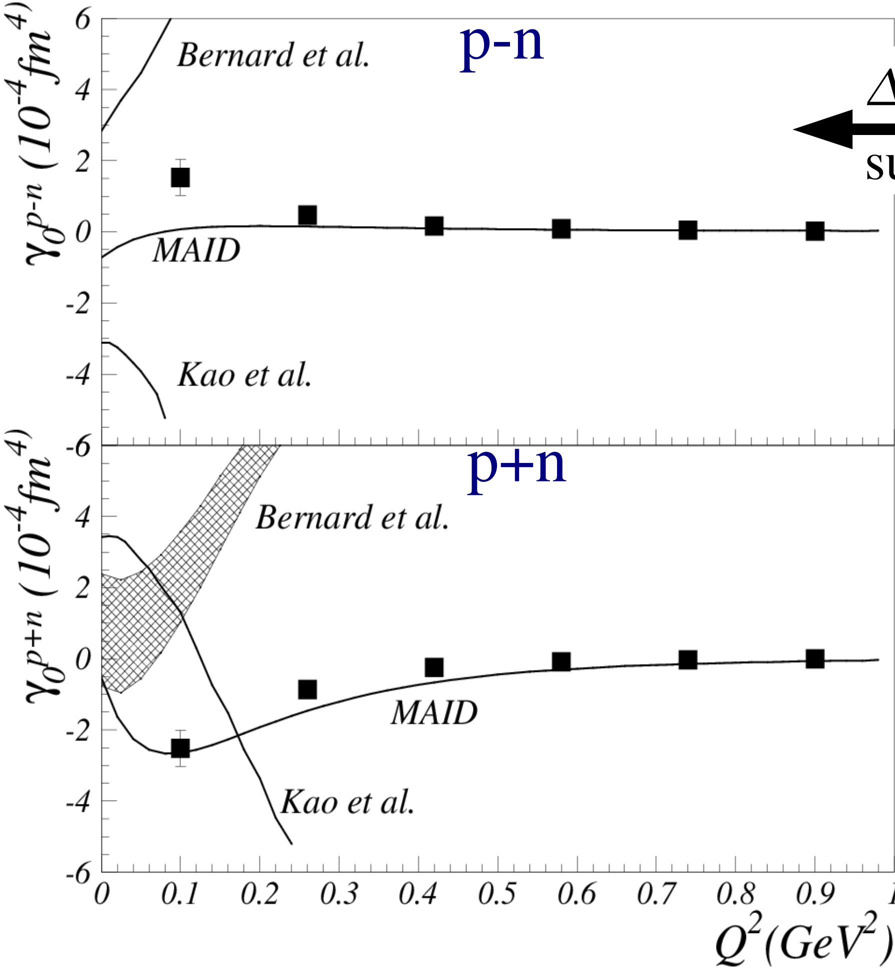


To study the influence of the Δ: Isospin decomposition of γ_0 using the Hall A and B data.



Δ contribution suppressed

Results on sum rules (higher moments)

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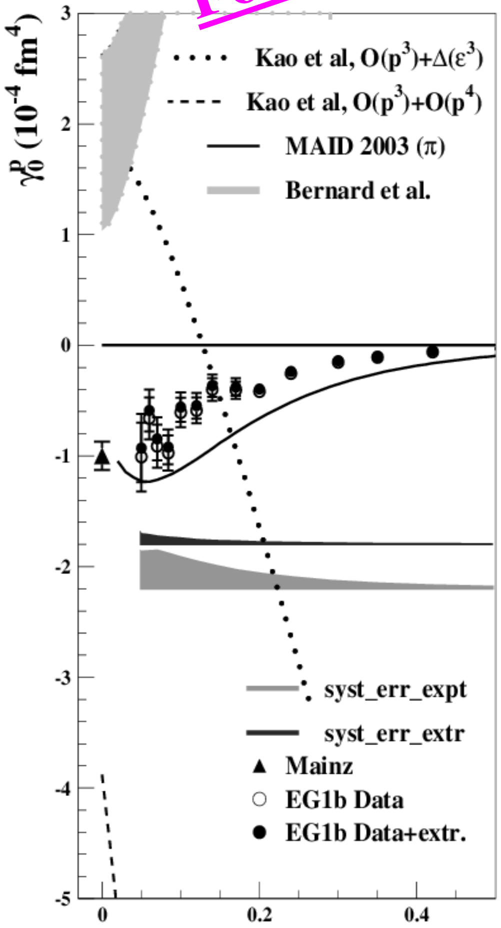
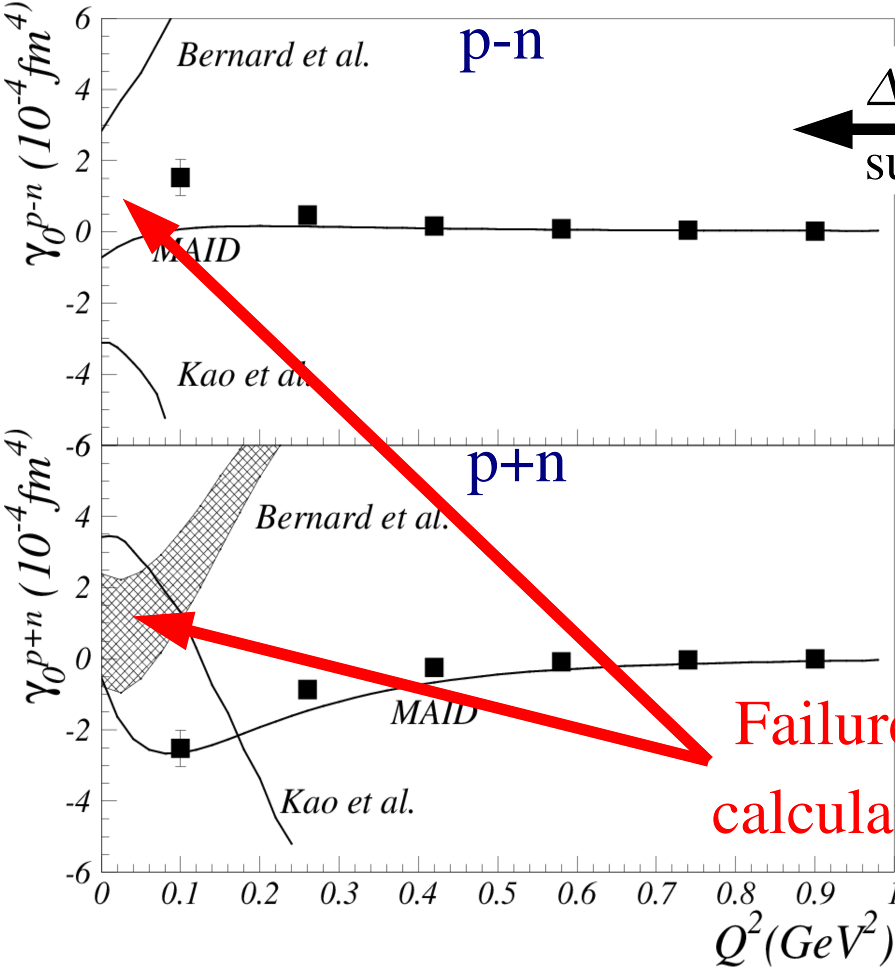
For Proton





Δ contribution suppressed

Failures of calculations

Results on sum rules (higher moments)

For Proton

$\delta_{LT}{}^{p}$ is yet unmeasured. Desirable to measure it in order for isospin study of the **"$\boldsymbol{\delta_{LT}}$ puzzle"**

Summary:

χpT:

No low-x (→ γ_0); No low-x, No Δ (→ δ_{LT}); No low-x (→ d_2)

	Γ_1	γ_0	δ_{LT}	d_2
Proton	a^{exp}=4.31±0.31±1.36 a^{Ji}=3.89 Up to Q^2~0.08 GeV^2		*No low Q^2 data*	*No low Q^2 data*
Neutron		Up to Q^2~0.1 GeV^2 (Bernard *et al.* only)		
P-N	a^{exp}=0.80±0.07±0.23 a^{Ji}=0.74, $a^{B.}$=2.4 Up to Q^2~0..3 GeV^2		*No low Q^2 data*	*No low Q^2 data*
P+N	a^{exp}=6.97±0.96±1.48 a^{Ji}=7.11 Up to Q^2~0.1 GeV^2		*No low Q^2 data*	*No low Q^2 data*

No Δ → P-N

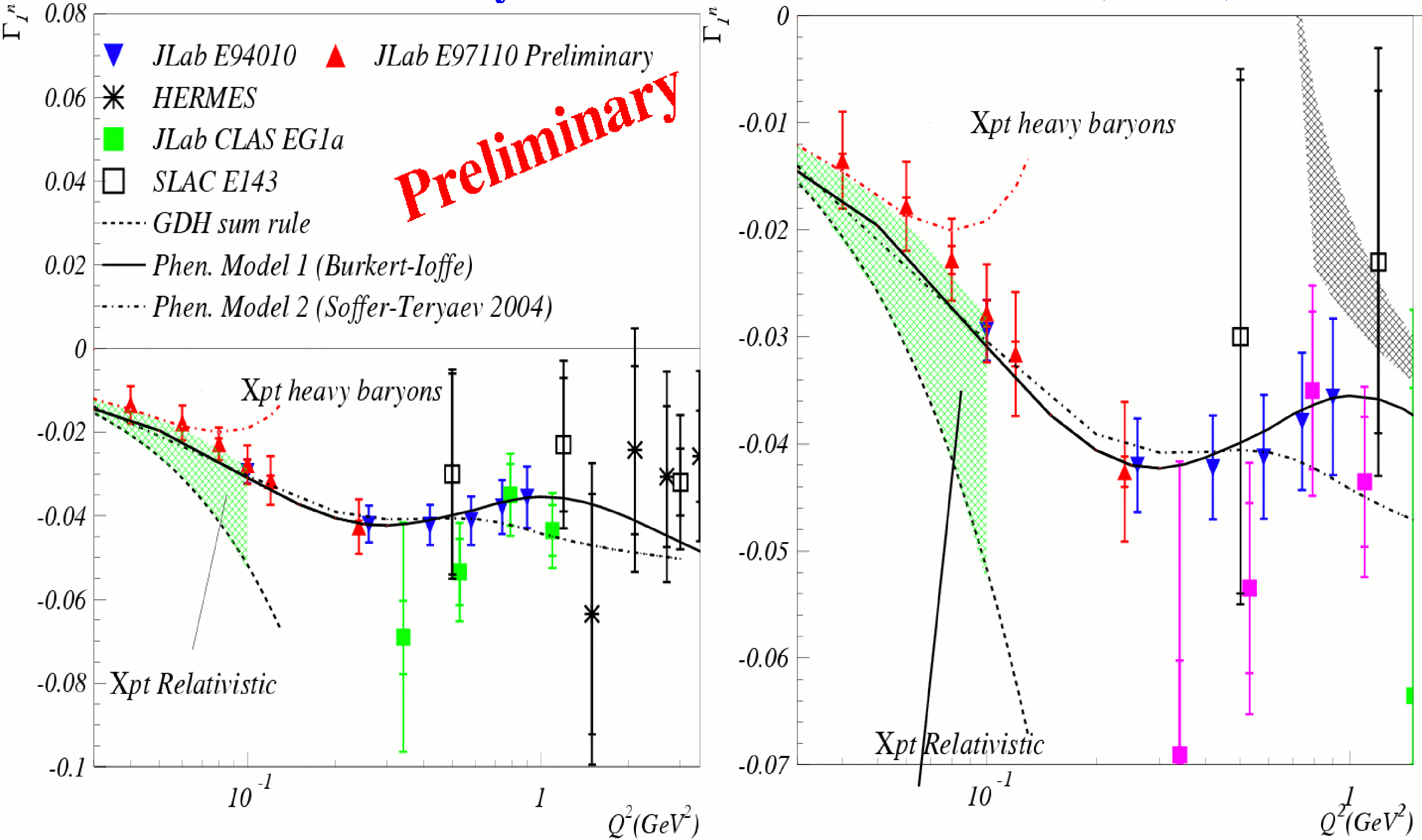
Preliminary Neutron Results from Hall A (E97110)

Experiment specially designed to access low Q^2:

- $\parallel$ and $\perp$ data on neutron (ran in 2003)
- New magnet added to high resolution spectrometer
- ^{3}He target redesigned for low angles.
- Target moved upstream.

(See V. Sulkosky's Talk)

Preliminary Neutron Results from Hall A (E97110)



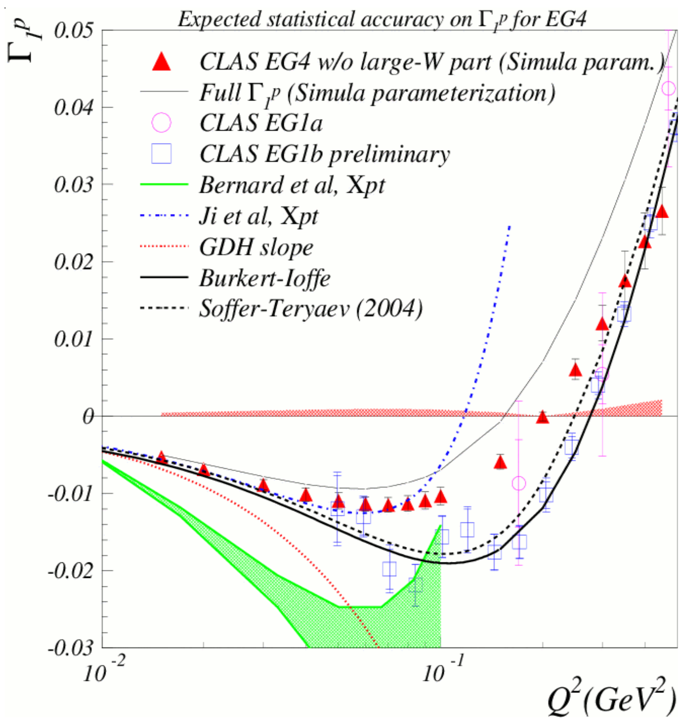
Preliminary Proton Results from Hall B (EG4)

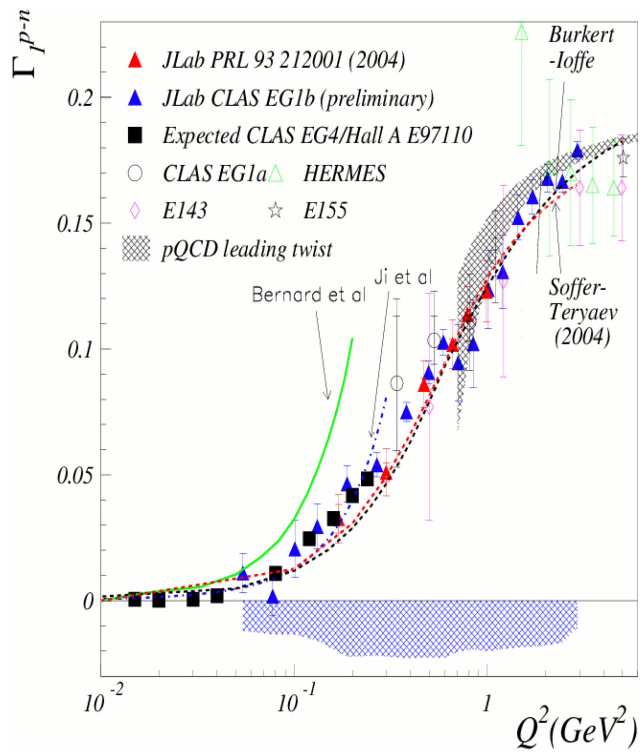
Experiment specially designed to access low Q^2:

- || data on proton and deuteron (ran in 2006)
- New detector added to large acceptance spectrometer
- NH^3 & ND^3 targets moved upstream.

(See S. Phillips' Talk)

Inclusive results not available yet.

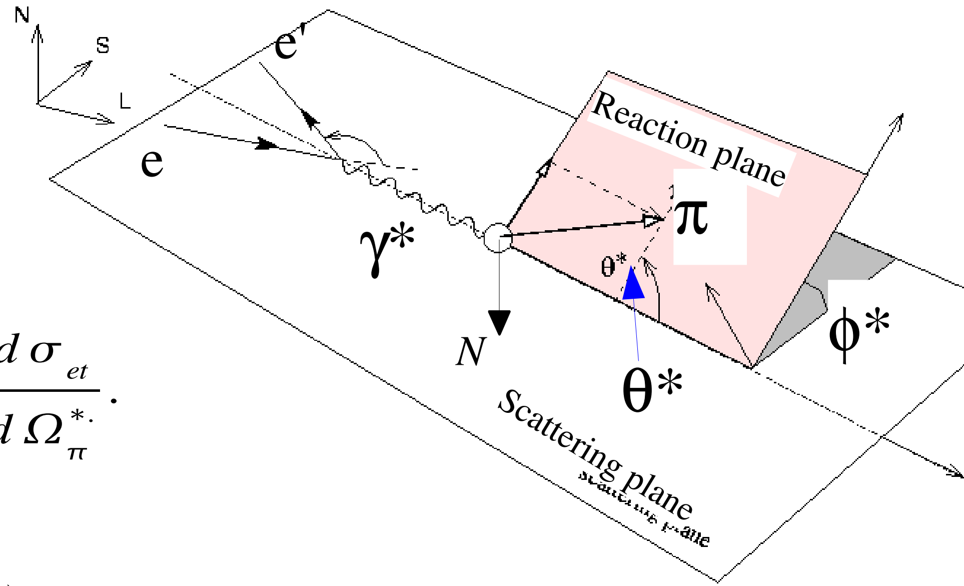




Preliminary results on pion production asymmetries available (Xiaochao Zheng).

Observables in Pion Electroproduction

- NH3: $\vec{e}\,\vec{p} \rightarrow e'\pi^{+}n$ and $\vec{e}\,\vec{p} \rightarrow e'\pi^{0}p$
- ND3: $\vec{e}\,\vec{n} \rightarrow e'\pi^{-}p$ and $\vec{e}\,\vec{p} \rightarrow e'\pi^{+}n$



- Cross section:

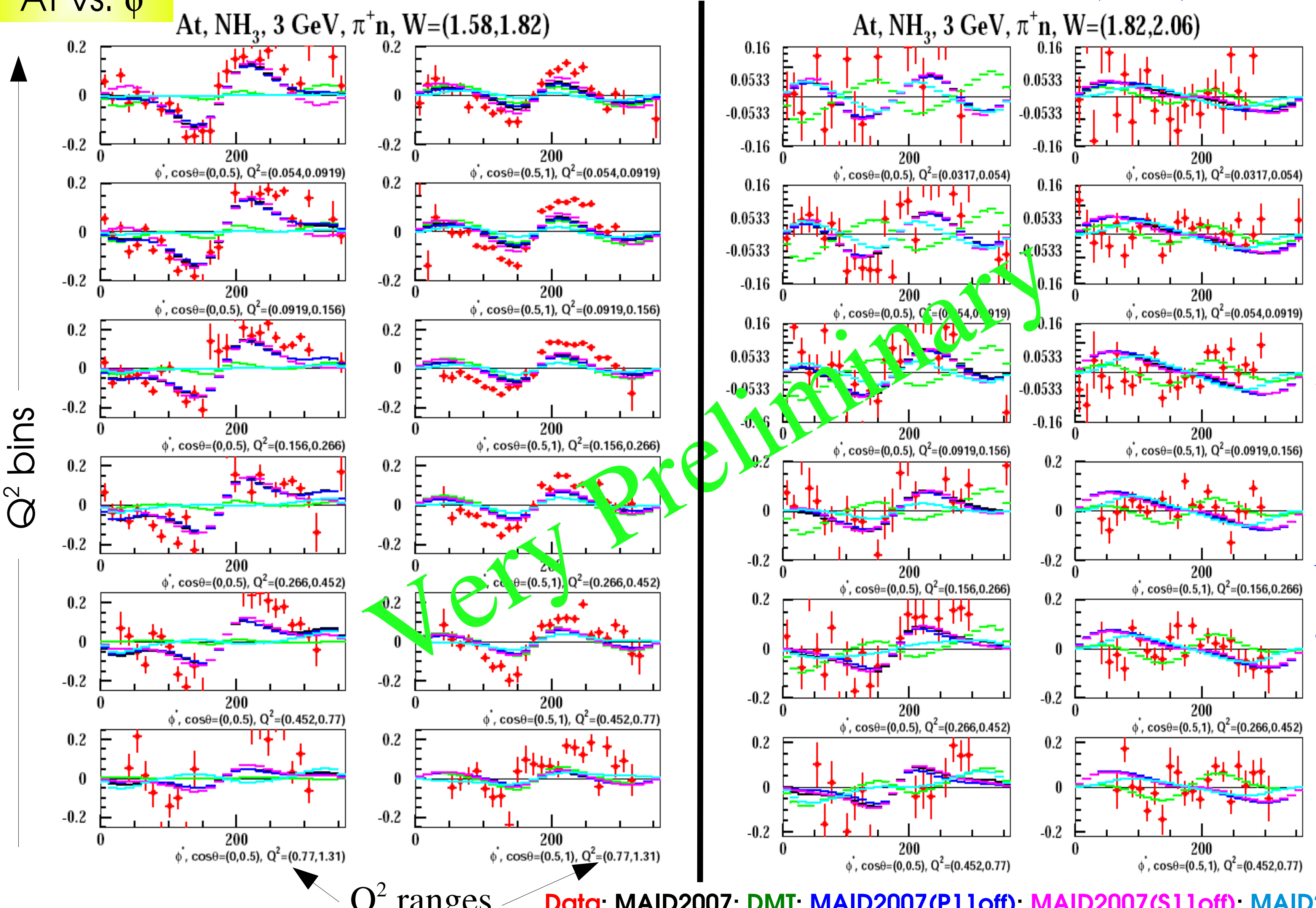
$$\frac{d\sigma}{d\Omega_\pi^*} \sim \frac{d\sigma_{unp}}{d\Omega_\pi^*} + P_e\frac{d\sigma_e}{d\Omega_\pi^*} + P_t\frac{d\sigma_t}{d\Omega_\pi^*} + P_e P_t\frac{d\sigma_{et}}{d\Omega_\pi^*}.$$

- Three independent asymmetries:
  - Single-beam $$A_e = \frac{d\sigma_e}{d\sigma_{unp}} = \frac{\sigma(+h_e)-\sigma(-h_e)}{\sigma(+h_e)+\sigma(-h_e)}$$ ← accessible from unpolarized target data
  - Single-target $$A_t = \frac{d\sigma_t}{d\sigma_{unp}} = \frac{\sigma(+h_N)-\sigma(-h_N)}{\sigma(+h_N)+\sigma(-h_N)}$$ ← only accessible from polarized target data
  - Double beam-target

$$A_{et} = \frac{d\sigma_{et}}{d\sigma_{unp}} = \frac{\sigma(+h_e,+h_N)+\sigma(-h_e,-h_N)-\sigma(+h_e,-h_N)-\sigma(-h_e,+h_N)}{\sigma(+h_e,+h_N)+\sigma(-h_e,-h_N)+\sigma(+h_e,-h_N)+\sigma(-h_e,+h_N)}$$

Preliminary Results from Hall B (EG4)

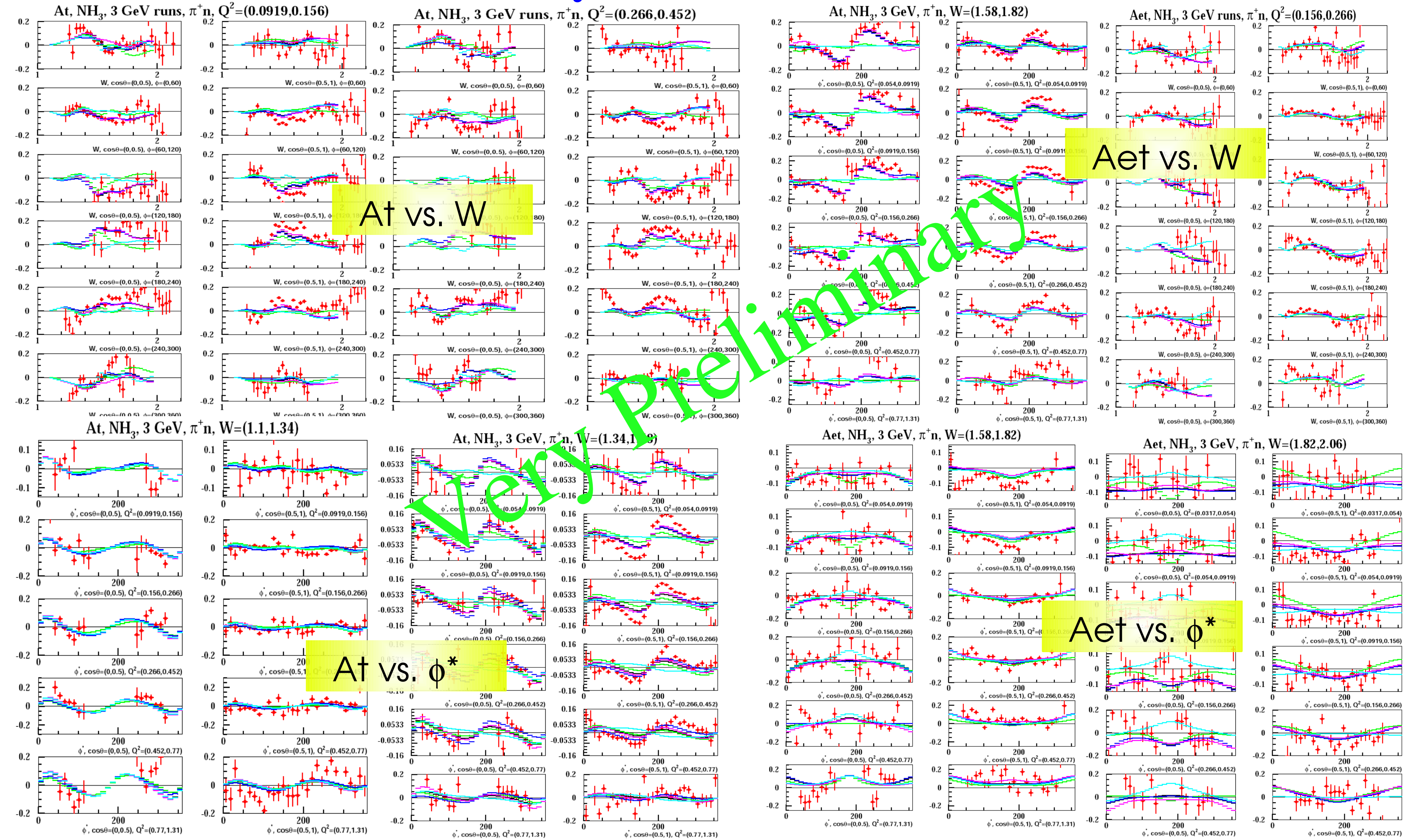
At vs. φ*



3 GeV
(2 GeV, 1.3 GeV and 1.0 GeV beam energies available too)

Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

Preliminary Results from Hall B (EG4)



A. Deur, Chiral Workshop, Bern 2009

Perspectives

E08027 (A. Camsonne, J.P. Chen and K. Slifer spokespersons)

- $\parallel$ **and $\perp$** data on proton (approved to run in Hall A).
- Use of new forward angle detection of Hall A.
- Import the NH_3 (& ND_3) target from Hall C.
- Dedicated to measure the missing $\delta_{LT}{}^{p}$.

Possibility for $\perp$ data on proton and deuteron in Hall B is opening (HDice target).

- Target imported from BNL (LEGS, A. Sandorfi spokesperson and HD target group leader).
- Low dilution target.
- Used only with photons so far.
- Scheduled to be tested with electrons at end of 2010.
- If successful, open possibilities for transverse target polarization studies in Hall B.

Perspectives

No low-x (↓ γ_0) — No low-x, No Δ (↓ δ_{LT}) — No low-x (↓ d_2)

	Γ_1	γ_0	δ_{LT}	d_2
Proton	a^{exp}=4.31±0.31±1.36 a^{Ji}=3.89 Up to Q^2~0.08 GeV^2			
Neutron		Up to Q^2~0.1 GeV^2 (Bernard *et al.* only)		
P-N	a^{exp}=0.80±0.07±0.23 a^{Ji}=0.74, $a^{B.}$=2.4 Up to Q^2~0..3 GeV^2			
P+N	a^{exp}=6.97±0.96±1.48 a^{Ji}=7.11 Up to Q^2~0.1 GeV^2			

No Δ → (P-N)

Conclusions

- Data on SSF moments at low Q^2 and χpT do not consistently agree (or disagree).
- (Implication of these discrepancies to χpT extrapolation for lattice results?)
- Δ cannot be the explanation for some disagreements.
- Low-Q^2 fits provide quantitative comparisons. Importance of Q^6 terms.
- Exclusive data on pion-electroproduction at Low-Q^2. What can χpT tells us?
- Need high precision data at lower Q^2. Transverse data on proton is especially missing. New experiments are fulfilling these needs:

    E97110: $\parallel$ and $\perp$ on neutron (ran in 2003 in Hall A)

    EG4: $\parallel$ on proton and deuteron (ran in 2006 in Hall B)

  Longer term:

    E08027: $\parallel$ and $\perp$ on proton (approved for Hall A)

  Possibility:

    $\perp$ data on P and D in Hall B (HDice target)