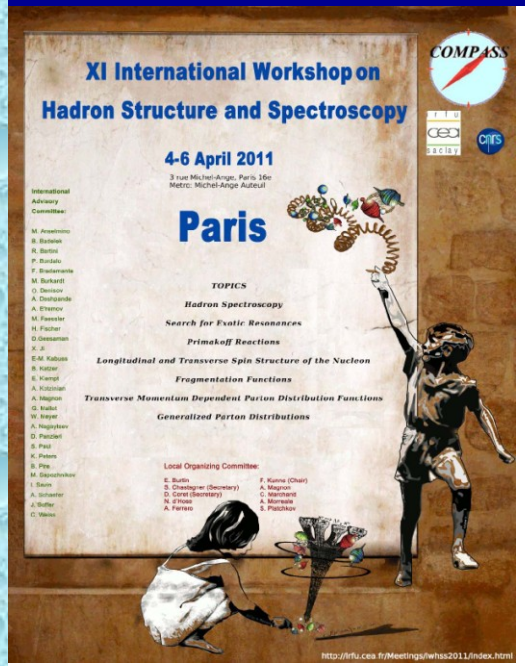
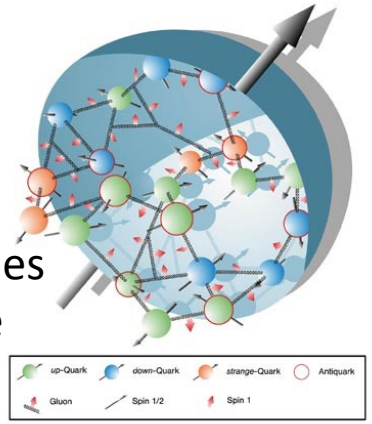
Recent JLab Nucleon Spin Experiments/Results



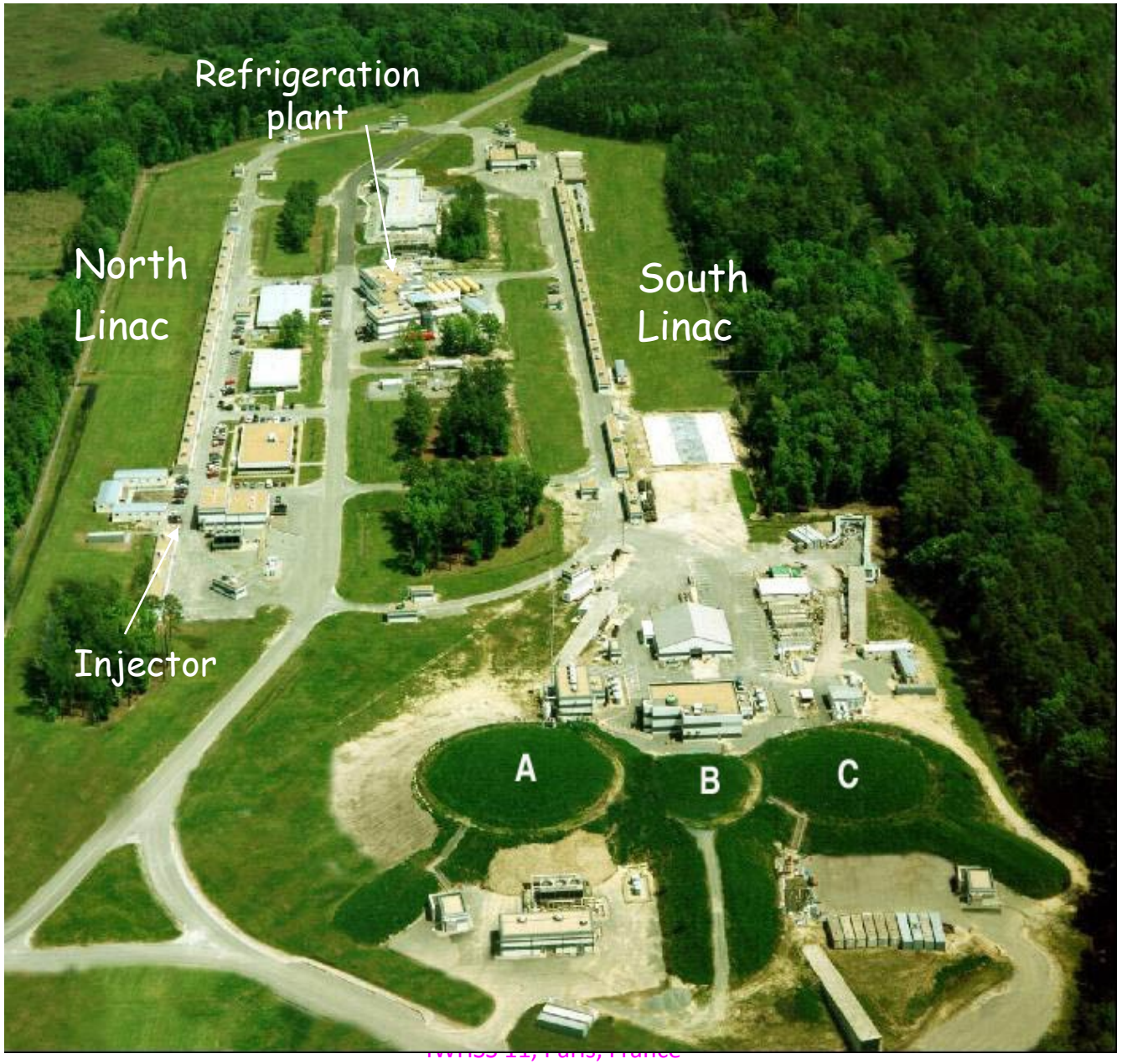
Zein-Eddine Meziani
Temple University

- Transverse structure of the nucleon and dynamical effetcs
  - Semi-inclusive
    - ✓Collins, Sivers, etc…
  - Inclusive
    - ✓Small angle GDH an polarizabilities
    - ✓g_2 and d_2 and Lorentz color force



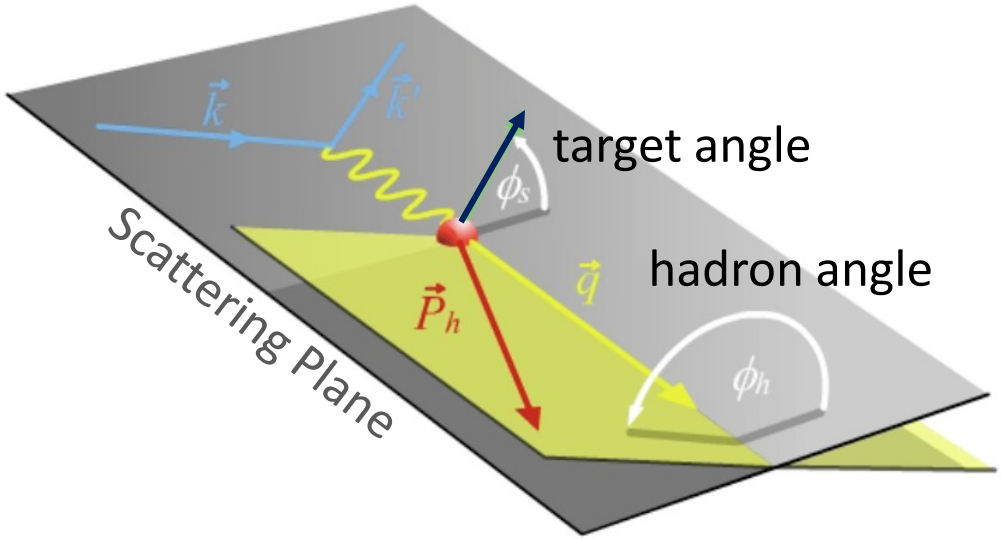
IWHSS'11
International Workshop on Hadron Structure and Spectroscopy

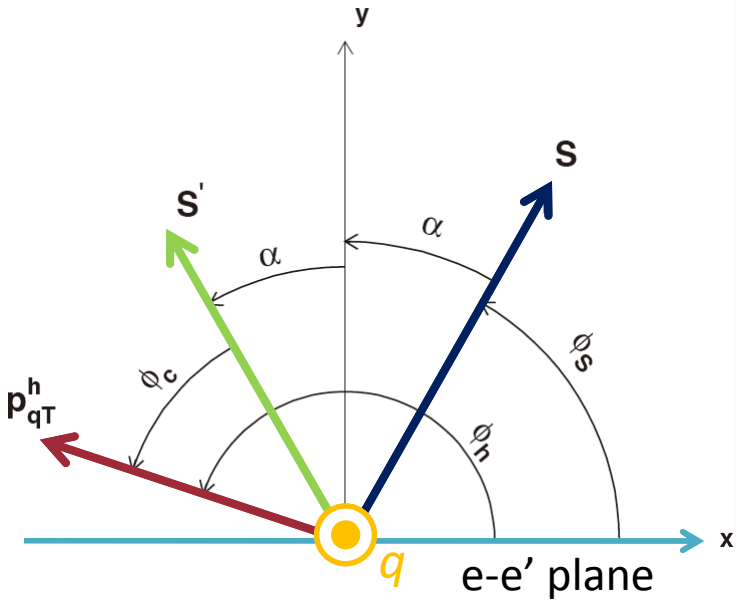
Jefferson Lab



SIDIS electroproduction of pions

- With spin one can separate Sivers and Collins effetcs



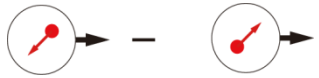


- **Sivers** angle, effect in distribution function:
  - $(\Pi_h - \Pi_s)$ = angle of hadron relative to ***initial*** quark spin
- **Collins** angle, effect in fragmentation function:
  - $(\Pi_h + \Pi_s) = \square + (\Pi_h - \Pi_{s'})$ = angle of hadron relative to ***final*** quark spin

Transverse Spin Structure: Leading Twist TMDs

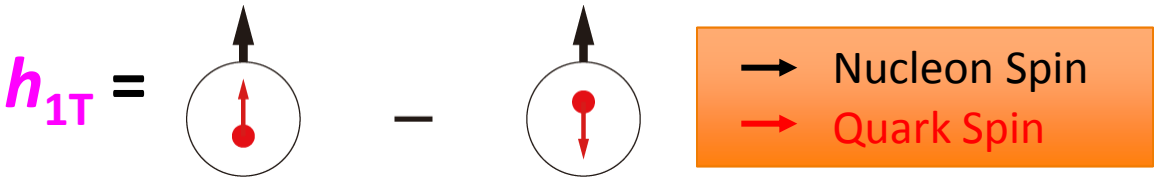
Nucleon Spin

Quark Spin

Quark /Nucleon		Quark polarization: Un-Polarized	Quark polarization: Longitudinally Polarized	Quark polarization: Transversely Polarized
Nucleon Polarization	U	f_1 = 		$h_1^{\perp}$=  Boer-Mulder
	L		g_1 =  Helicity	$h_{1L}^{\perp}$= 
	T	$f_{1T}^{\perp}$=  Sivers	$g_{1T}^{\perp}$= 	h_{1T} =  Transversity $h_{1T}^{\perp}$=  Pretzelosity

Transversity distribution

- Quark transverse polarization in a transversely polarized nucleon:



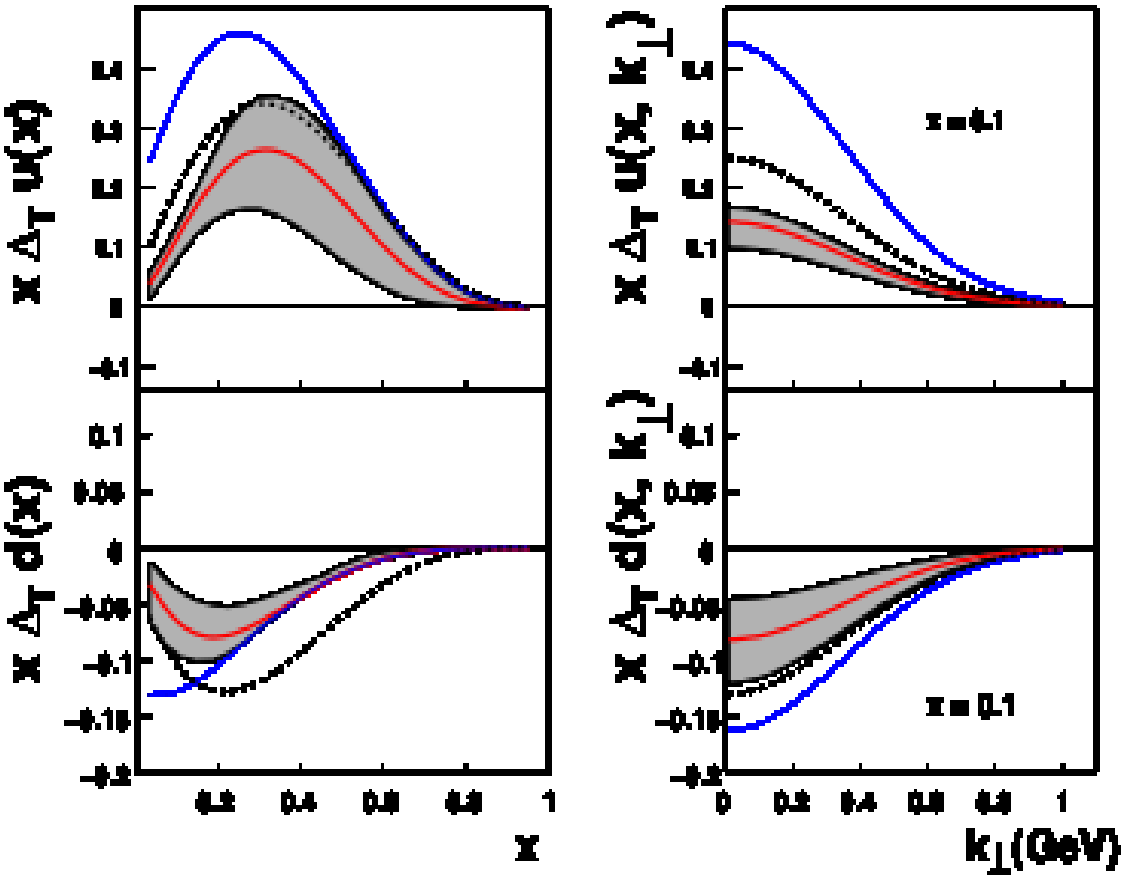
  - Can be probed in Semi-Inclusive DIS, Drell-Yan processes.
  - Does not mix with gluons, has valence like behavior.
  - Nucleon tensor charge can be extracted from the lowest moment of h_1 and compared to LQCD calculation:

$$\sigma_{UT} : \sin(\phi_h - \phi_s) f_{1T}^{\perp} \otimes D_1, \qquad \cos(\phi_h + \phi_s) h_1 \otimes H_1^{\perp}$$

$$\langle PS\bar{\psi}\sigma^{\mu\nu}\psi PS\rangle = \int_0^1 dx\,[\delta q(x) - \delta\bar{q}(x)]$$

Transversity using COMPASS and HERMES SIDIS data $eN^{\uparrow} \to eHX$ and the Belle data $e^+e^- \to H_1 H_2 X$

- A good start, good agreement with models
- Soffer bound imposed in the extraction
- What happens if it is not imposed. Is the Soffer bound violated?
- Soft gluon emission should reduce the extracted quantity by a factor of 2 ?! (Boer, 2008)



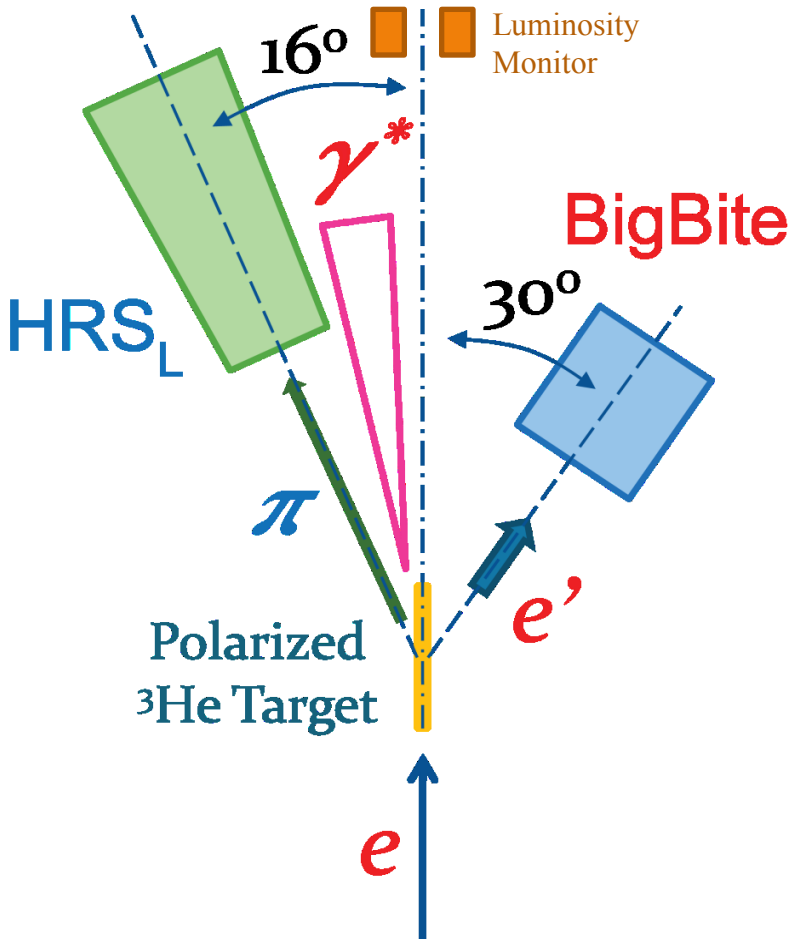
Anselmino et al. 2008

E06-010 Experiment to access the neutron

Spokespeople: X. Jiang (Los Alamos), J.-P. Chen (JLab), H. Gao (Duke), J.C. Peng (UIUC),

Students: XinQian (Duke), ChiranjibDutta (Kentucky), and KalyanAllada (Kentucky)

- Polarized ^{3}He Target
- Polarized Electron Beam
  - ~80% Polarization
  - Fast Flipping at 30Hz
  - PPMlevel charge Asymmetry controlled by online feed back
- BigBite at 30° as Electron Arm
  - P_e = 0.7 ~ 2.2 GeV/c
- HRS_L at 16° as Hadron Arm
  - P_h = 2.35 GeV/c

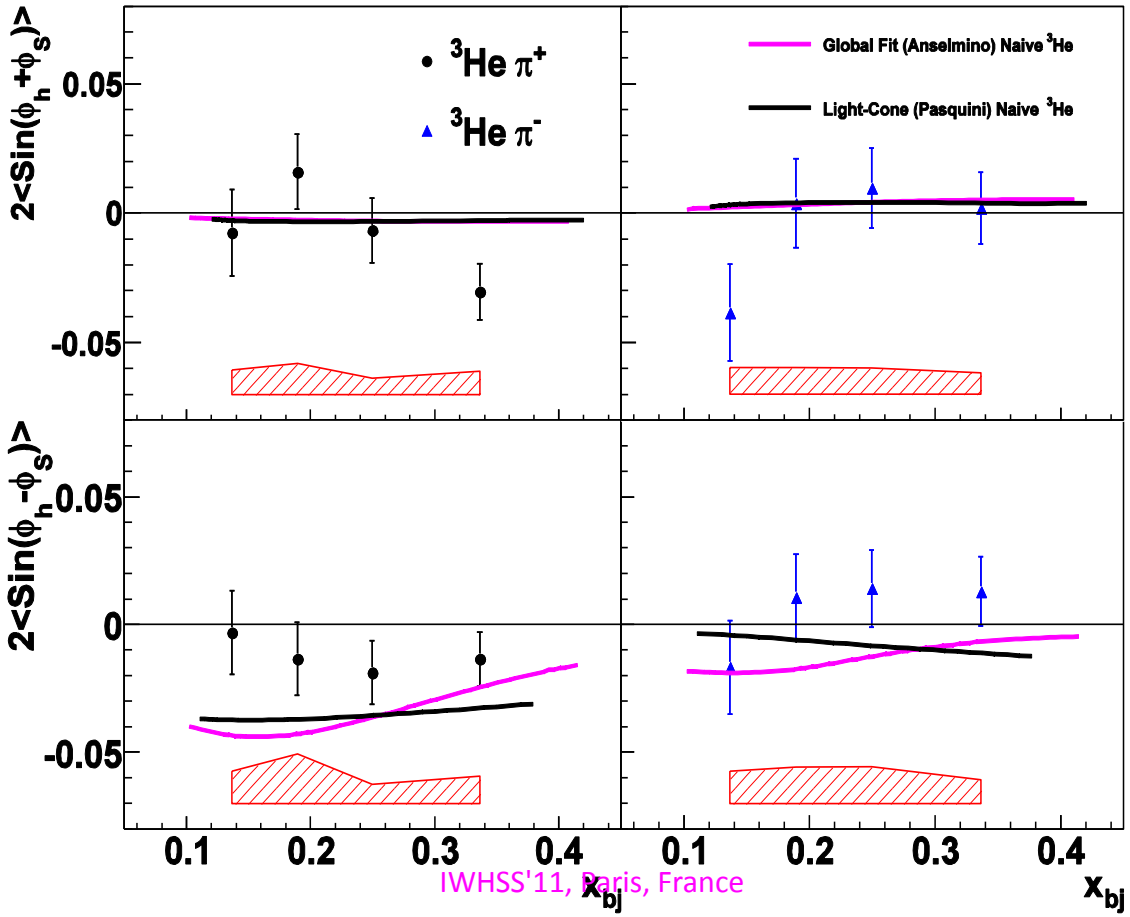


Preliminary ^{3}He Collin/Sivers Asymmetries

At leading twist: Collins: $2 < \cos(\phi_h + \phi_s) > \propto h_{1T}^q \otimes H_{1q}^h$

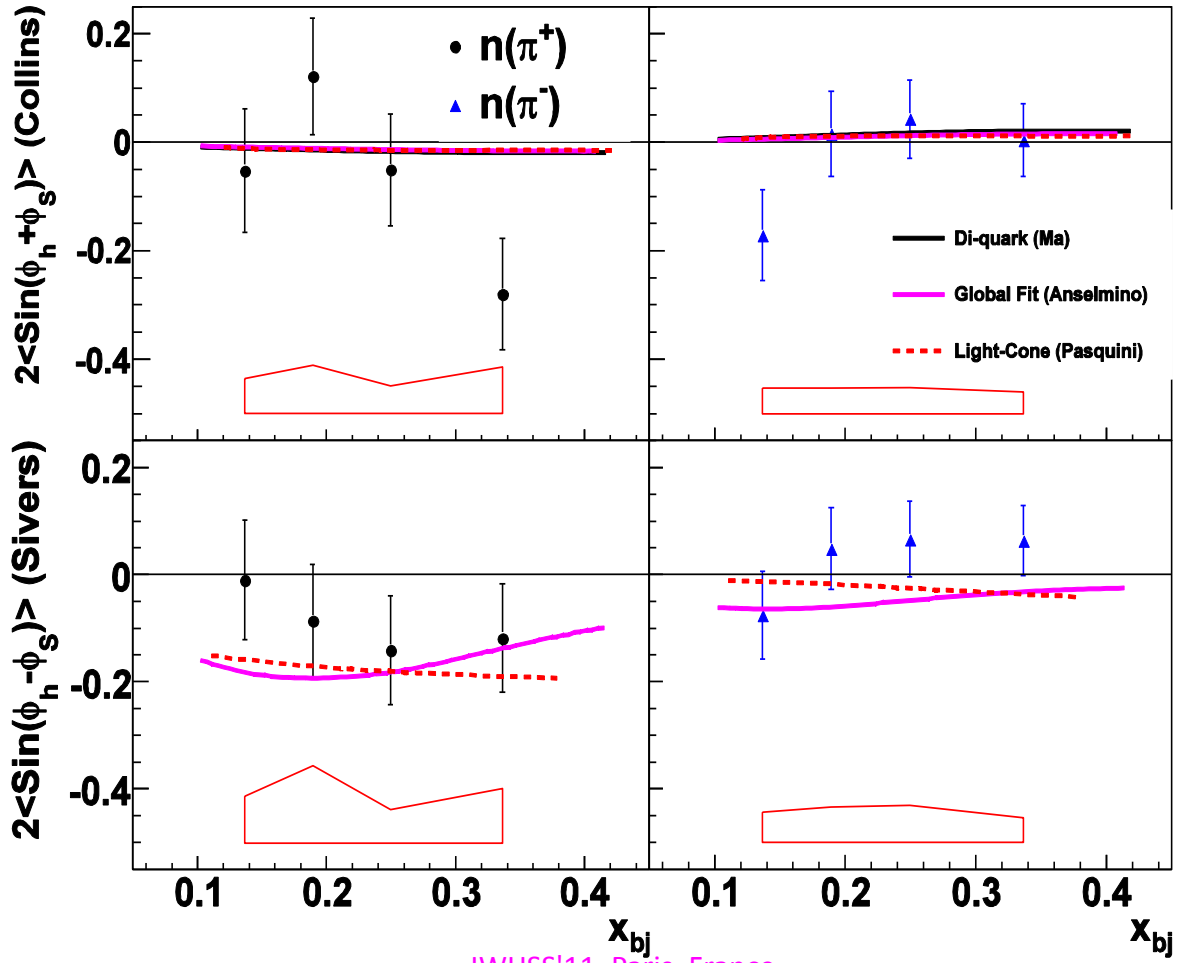
Sivers: $2 < \cos(\phi_h - \phi_s) > \propto f_{1T}^q \otimes D_{1q}^h$

- Systematic uncertainty is still under study
- Curves are Naïve ^{3}He (n +2p with effective polarizations)



Preliminary Neutron Collin/Sivers Asymmetries

- Systematic uncertainty is still under study
- Curves: Diquark-quark Model (Ma), Global Fit (Anselmino), Light-Cone quark model (Pasquini)



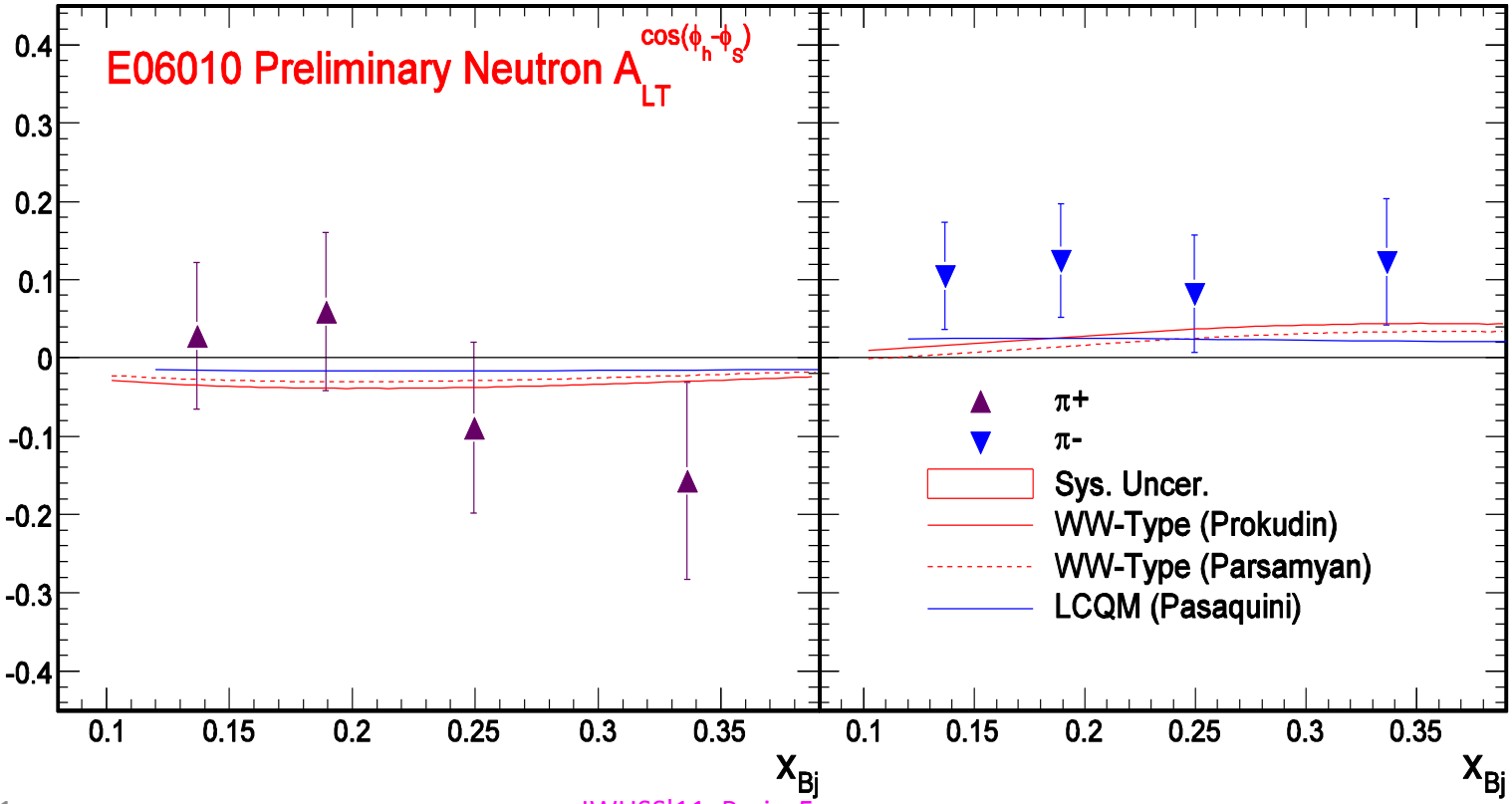
Collins

Sivers

Preliminary Neutron A_{LT}

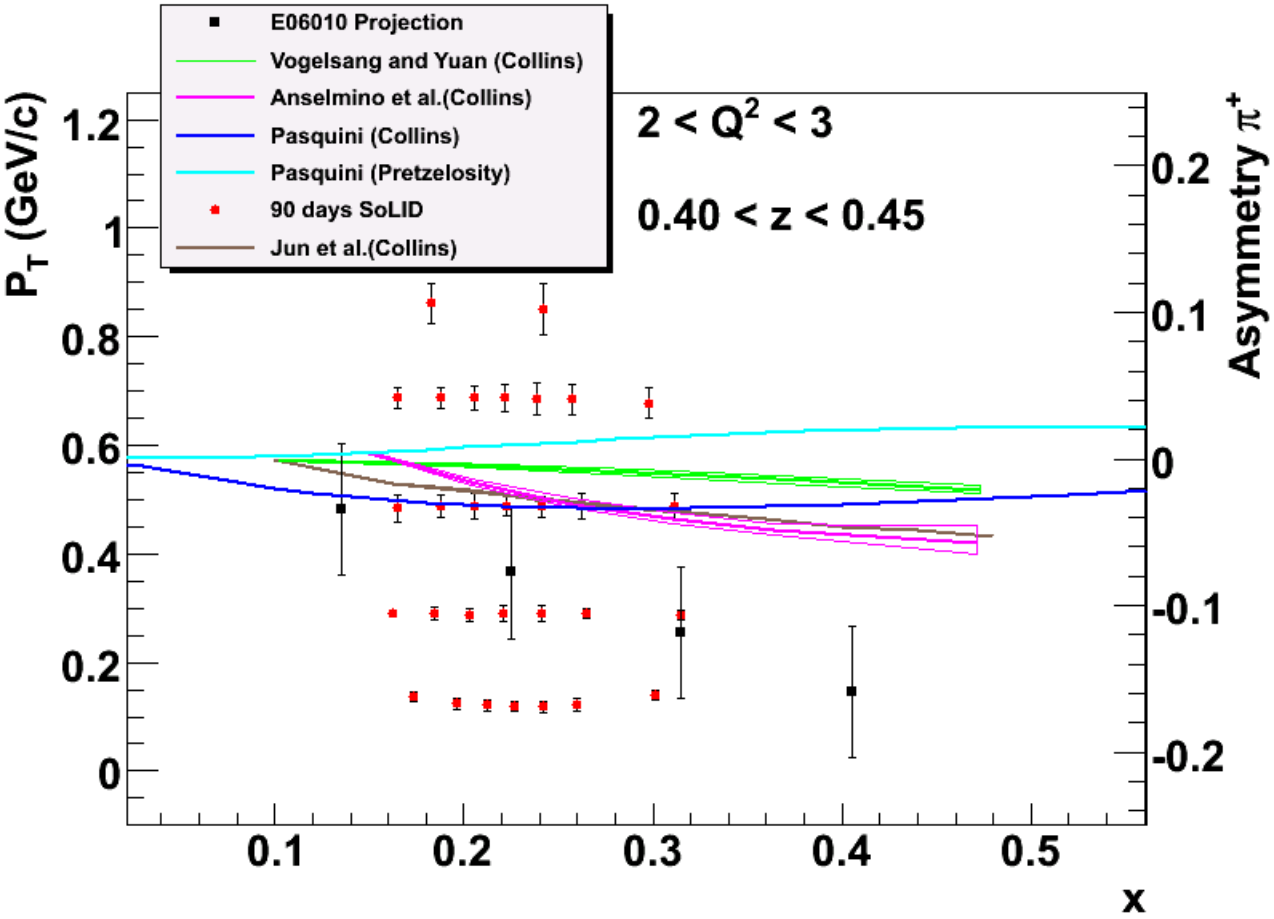
At leading twist: $A_{\mathrm{LT}}^{\cos(\phi_h - \phi_s)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$

- Preliminary neutron A_{LT} (results also available for ^{3}He)
- Systematic uncertainty is still under work



Hall A Transversity Projected Data Using SOLID

- Total 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam.
- z ranges from 0.3 ~ 0.7, only one z and Q^2 bin of 11/8.8 GeV is shown here. π^+ projections are shown, similar to the π^- .



TMDs program @ 12 GeV in Hall B

PAC approved experiments & LoI

E12-06-112: **Pion** SIDIS
E12-09-008: **Kaon**SIDIS

E12-07-107: **Pion** SIDIS
E12-09-009: **Kaon**SIDIS

LOI12-06-108: **Pion** SIDIS
LOI12-09-004: **Kaon**SIDIS

N \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

- Complete program of TMDs studies for pions and kaons
- Kaon measurements crucial for a better understanding of the TMDs "kaon puzzle"
- Kaon SIDIS program requires an upgrade of the CLAS12 detector
  PIDRICH detector to replace LTCC
  Project under development

Courtesy of H. Avakian

Inclusive Polarized Scattering

$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2}{MQ^2}\frac{E'}{\nu E}\left[(E + E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)\right] = \Delta\sigma_{\parallel}$$

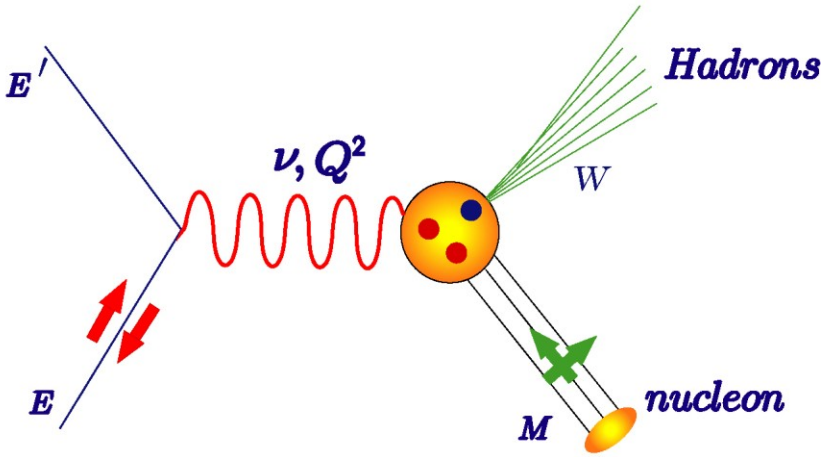
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right] = \Delta\sigma_{\perp}$$

Q^2 = 4-momentum transfer squared of the virtual photon.

ν = energy transfer.

θ = scattering angle.

$x = \frac{Q^2}{2M\nu}$ fraction of nucleon momentum carried by the struck quark.



Generalized Spin Polarizabilities of the Neutron

$$T(\nu,Q^2) = \varepsilon'^{*}\cdot\varepsilon f_T(\nu,Q^2) + f_L(\nu,Q^2) + i\sigma\cdot(\varepsilon'^{*}\times\varepsilon)g_{TT}(\nu,Q^2) - i\sigma\cdot[(\varepsilon'^{*}-\varepsilon)\times\hat{q}]g_{LT}(\nu,Q^2)$$

$$\mathrm{Re}\, g_{TT}{}^{\mathrm{nonpole}}(\nu,Q^2) = \frac{2\alpha_{\mathrm{em}}}{M^2}I_A(Q^2)\nu + \gamma_0(Q^2)\nu^3 + \mathcal{O}(\nu^5)$$

$$\mathrm{Re}\, g_{LT}{}^{\mathrm{nonpole}}(\nu,Q^2) = \frac{2\alpha_{\mathrm{em}}}{M^2}QI_3(Q^2) + Q\delta_{LT}(Q^2)\nu^2 + \mathcal{O}(\nu^4)$$

$$\gamma_0(Q^2) = \frac{16M^2\alpha_{\mathrm{em}}}{Q^6}\int_0^{x_0} x^2\left\{g_1(x,Q^2) - \frac{Q^2}{\nu^2}g_2(x,Q^2)\right\}dx$$

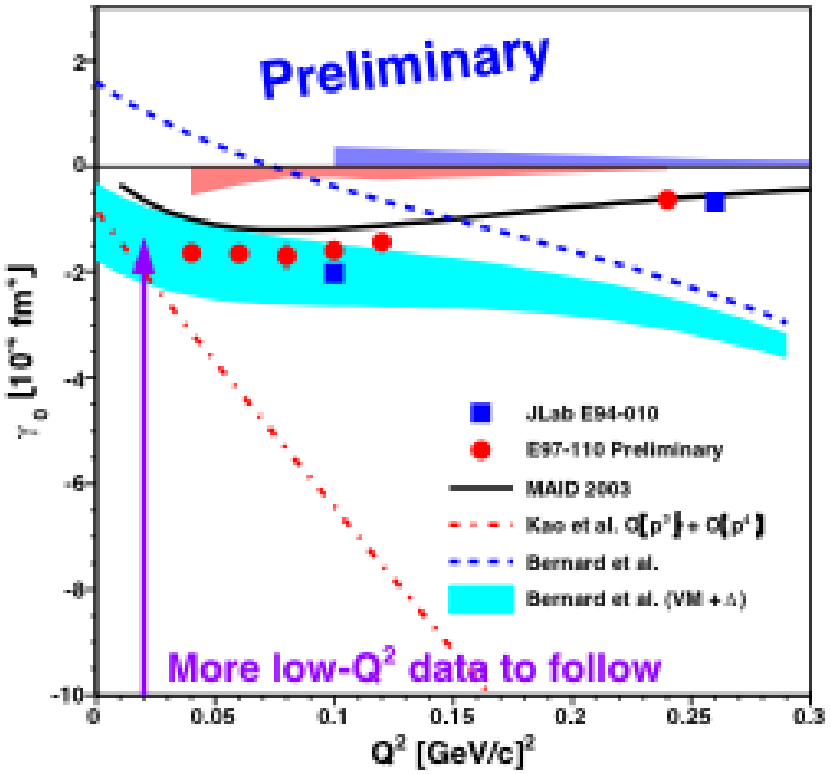
$$\delta_{LT}(Q^2) = \frac{16M^2\alpha_{\mathrm{em}}}{Q^6}\int_0^{x_0} x^2\left\{g_1(x,Q^2) + g_2(x,Q^2)\right\}dx$$

$$\delta_{LT}(Q^2)\to\frac{1}{3}\gamma_0(Q^2),\quad Q^2\to\infty$$

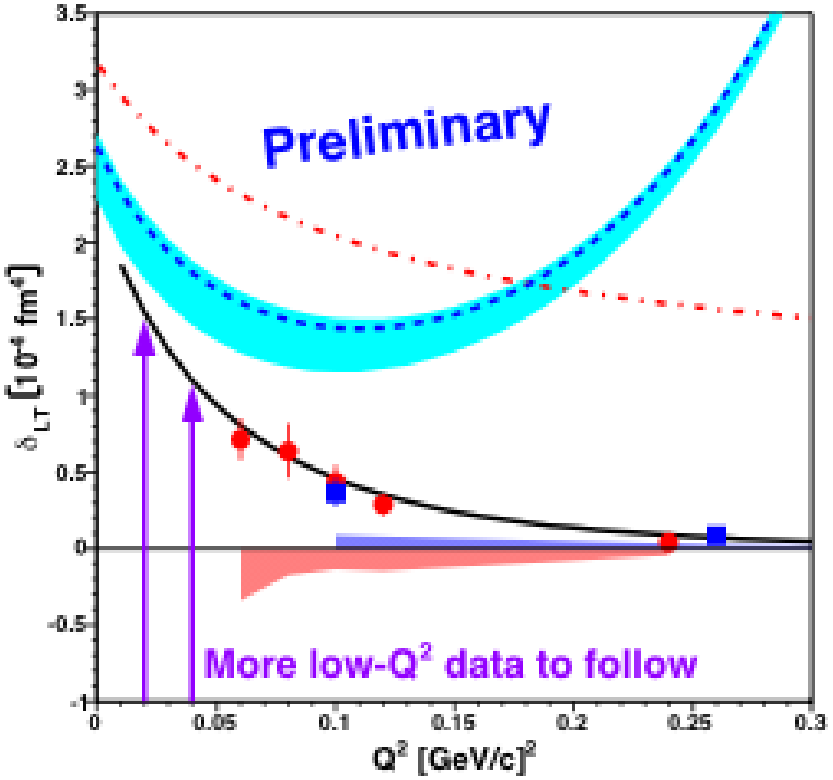
E97-110 Small angle GDH experiment

γ_0

Vince Sulkosky et al.



δ_{LT}



E08-027 : Proton g_2 Structure Function

Fundamental spin observable has never been measured at low or moderate Q^2

Spokesmen: Camsonne, Crabb, Chen, Slifer(contact) **A⁻ rating by PAC33**

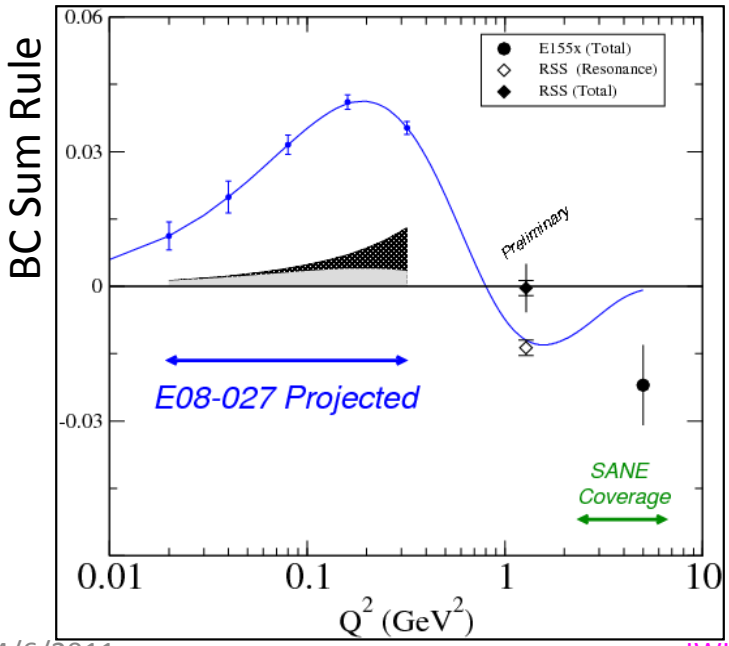
BC Sum Rule : violation suggested for proton at large Q^2,but found satisfied for the neutron &^{3}He.

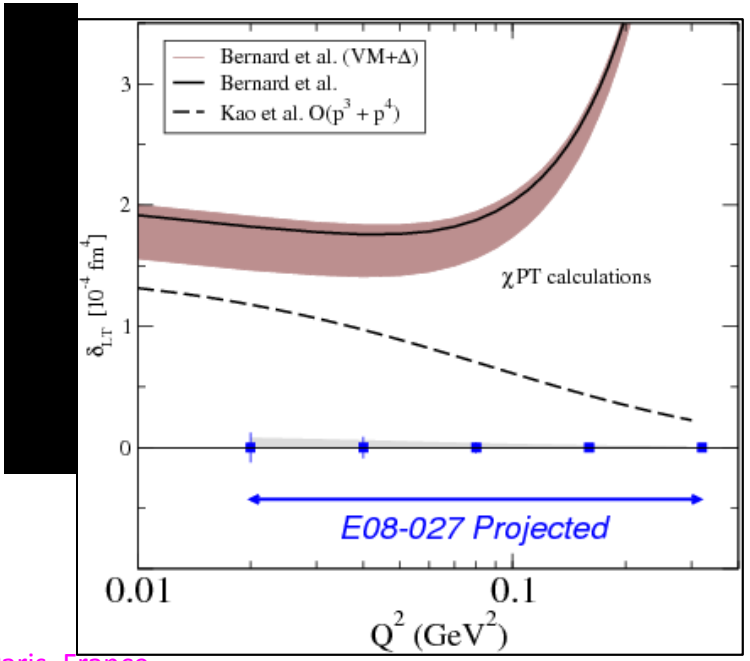
Spin Polarizability: Major failure (>8 ∫)of |PT for neutron™$_{LT}$. Need $g_2$isospinseparation to solve.

Hydrogen Hyperfine Splitting : Lack of knowledge of g_2 at low Q^2 is one of the leading uncertainties.

Proton Charge Radius : also one of the leading uncertainties in extraction of $<R_p>$ from ∫–H Lamb shift.

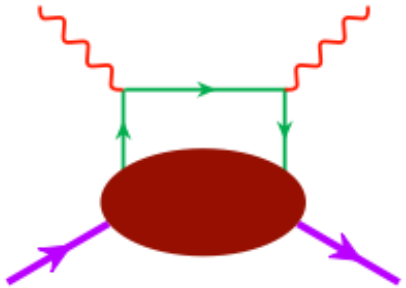
g_2 data strongly anticipated by theorists



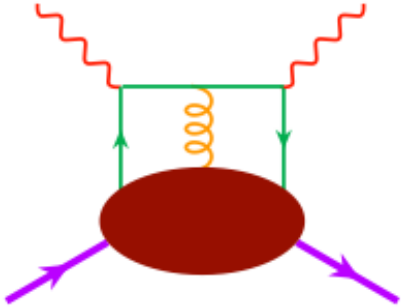


g_2 and Quark-Gluon Correlations

Twist -2



Twist -3



$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

- a twist-2 term (Wandzura & Wilczek, 1977):

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(x,Q^2)\frac{dy}{y}$$

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 1992):

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}h_T(y,Q^2) + \xi(y,Q^2)\right]\frac{dy}{y}$$

Transversity

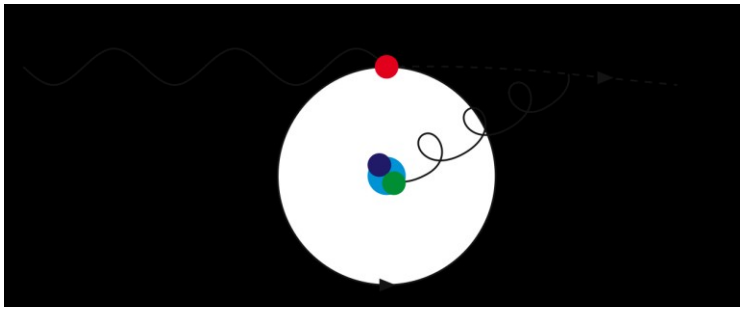
q-g correlations

Moments of Structure Functions

$$d_2(Q^2) = 3\int_0^1 x^2 \left(g_2(x,Q^2) - g_2^{WW}(x,Q^2)\right) dx$$

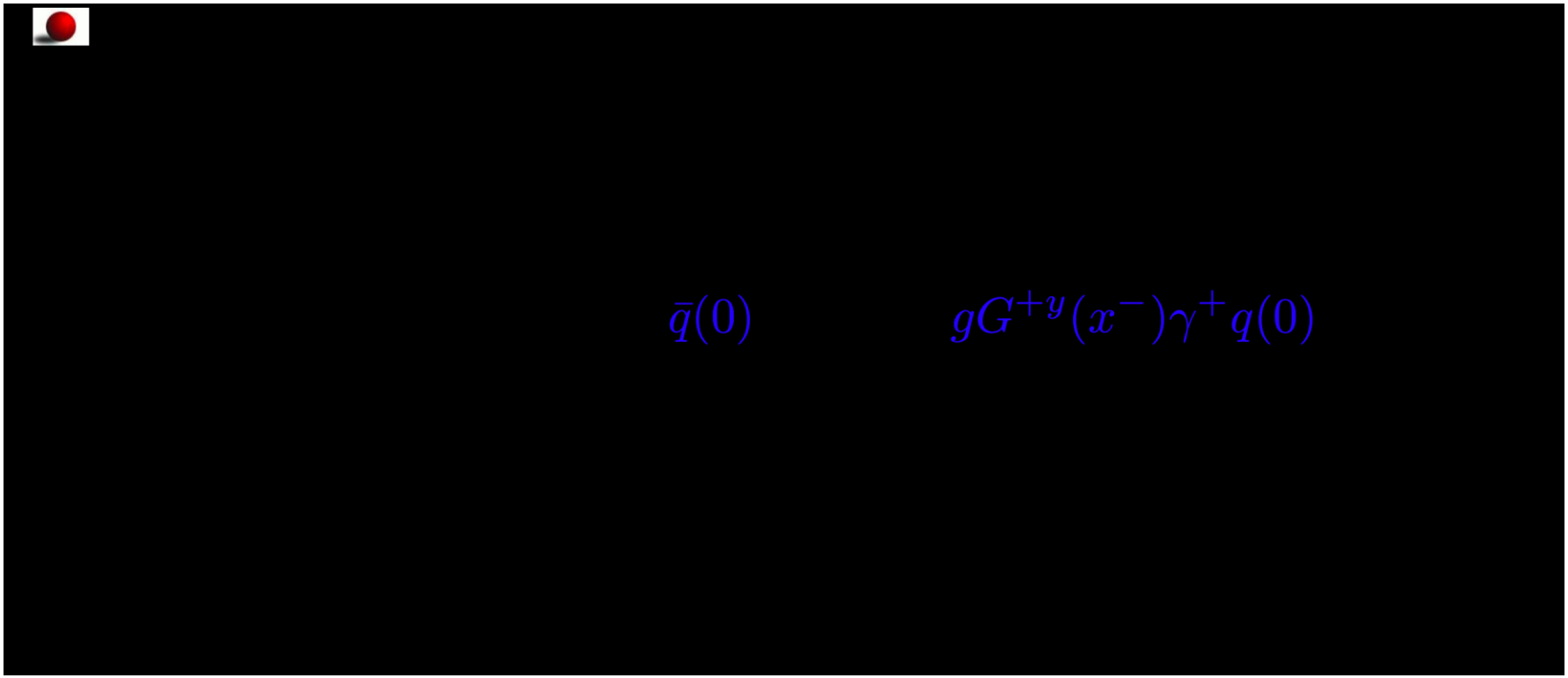
Average Color Lorentz Force (M. Burkardt)

$$\int dx x^2 \bar{g}_2(x) = \frac{1}{3} d_2 = \frac{1}{6MP^{+2}S^x} \left\langle P,S \left| \bar{q}(0) g G^{+y}(0) \gamma^+ q(0) \right| P,S \right\rangle$$



↪ d_2 a measure for the **color Lorentz force** acting on the struck quark in SIDIS in the instant **after being hit by the virtual photon**

$$\langle F^y(0) \rangle = -M^2 d_2 \qquad \text{(rest frame; } S^x = 1\text{)}$$


$\bar{q}(0)$
$gG^{+y}(x^-)\gamma^+ q(0)$

Hall A d_2^n and Hall C SANE experiments

Neutron and Proton

Spokespeople:
B. Sawatzky, S. Choi, X. Jiang and Z.-E.M

Students:
D. Flay, D. Parno, M. Posik

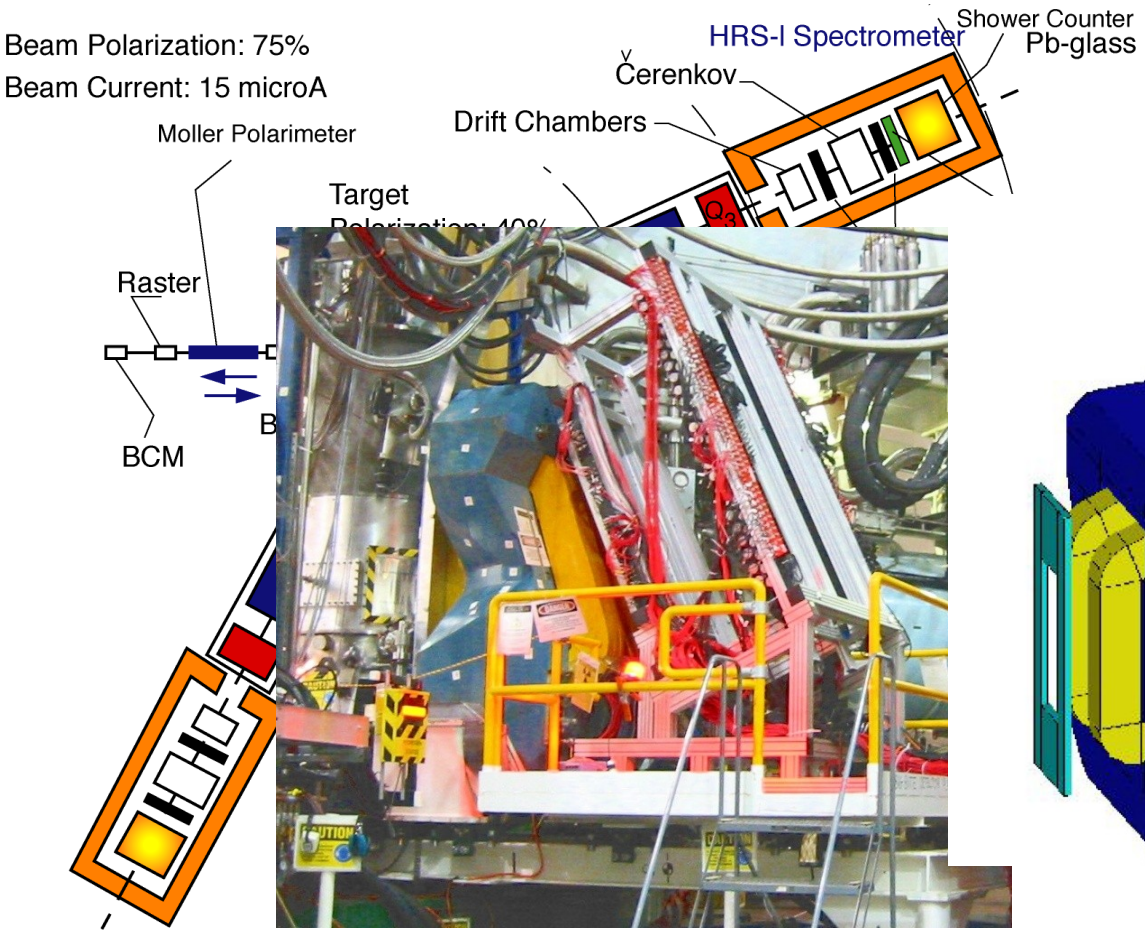
and the Hall A collaboration

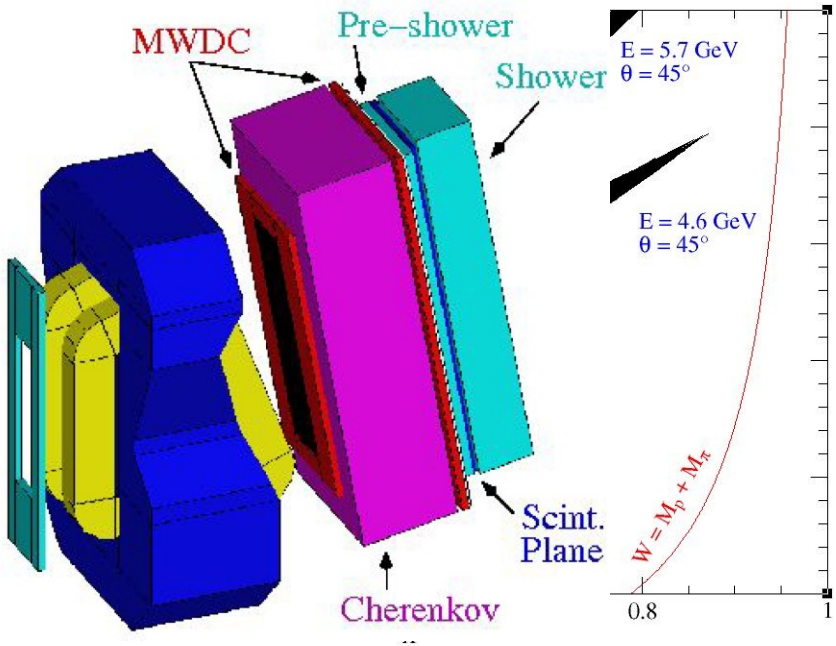
Spokespeople:
O. Rondon, S. Choi, M. Jones,, Z.-E. M

Students:
W. Armstrong, H. Kang, A. Liyanage, J. Maxwell, J. Mulholland

and the Hall C collaboration

Experiment E06-114 (d_2^n) in Hall A





Two beam energies 4.6 and 5.7 GeV
(4 pass, 5 pass)

Experiment ran Jan.-Mar. 09

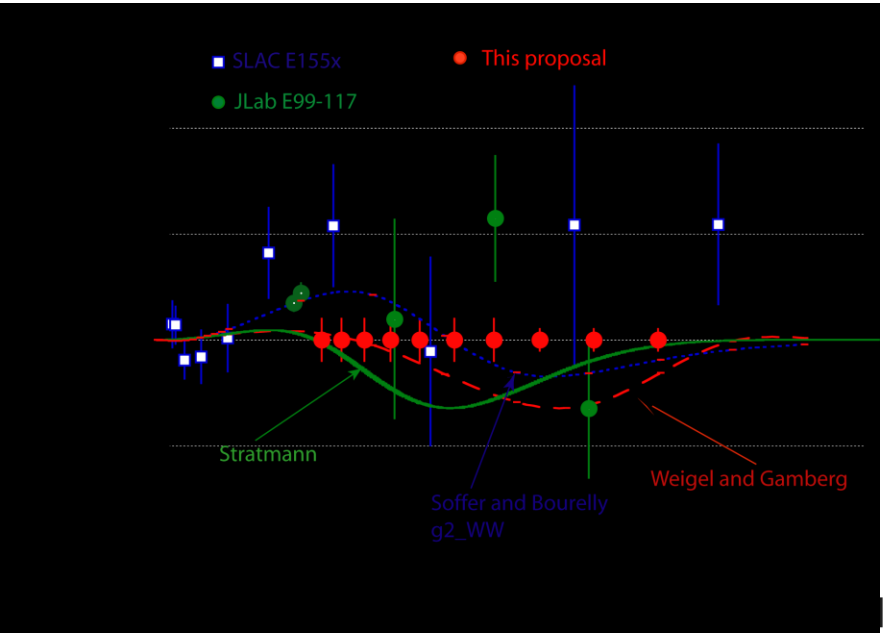
BigBite fixed at single scattering angle (θ=45°)
(data divided into 10 bins during analysis)

A_1 He3 at 4.7 GeV beam energy

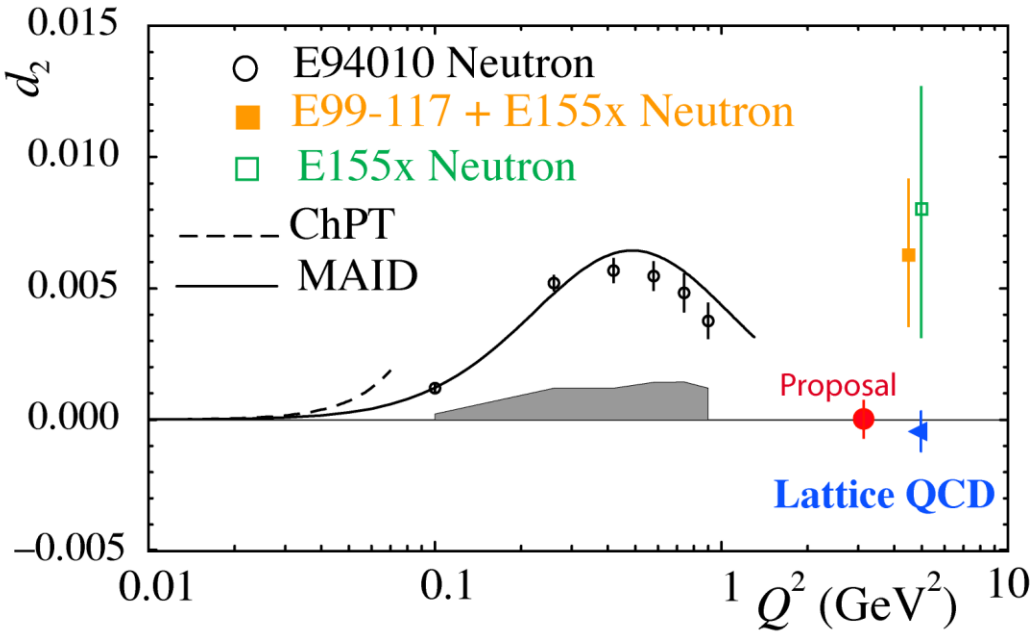
Very preliminary

A_2 He3 at 4.7 GeV beam energy

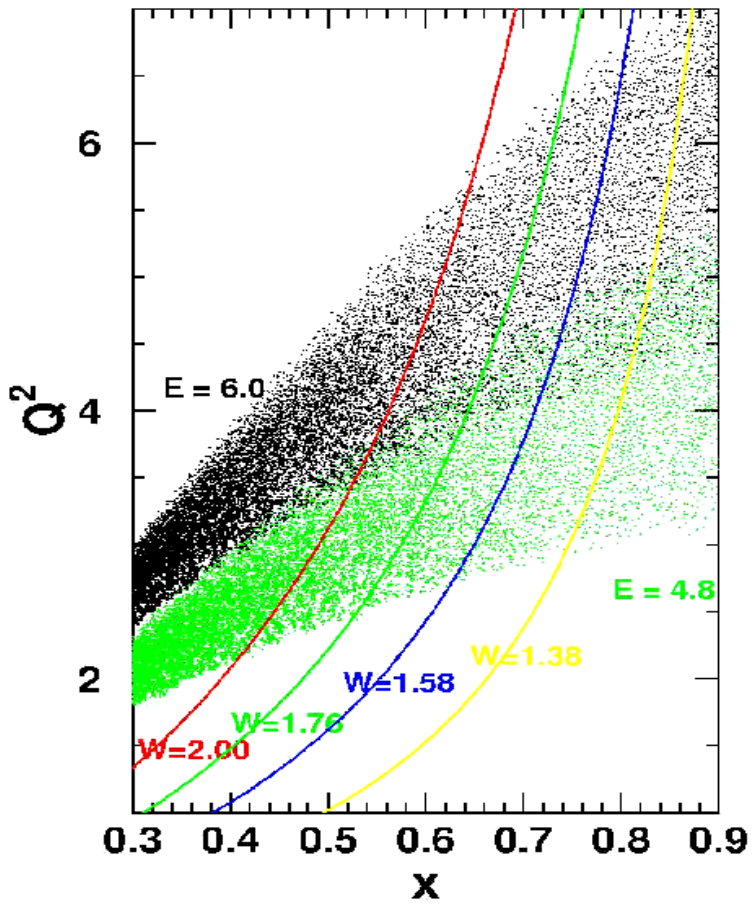
Expected precision in Experiment E06-114

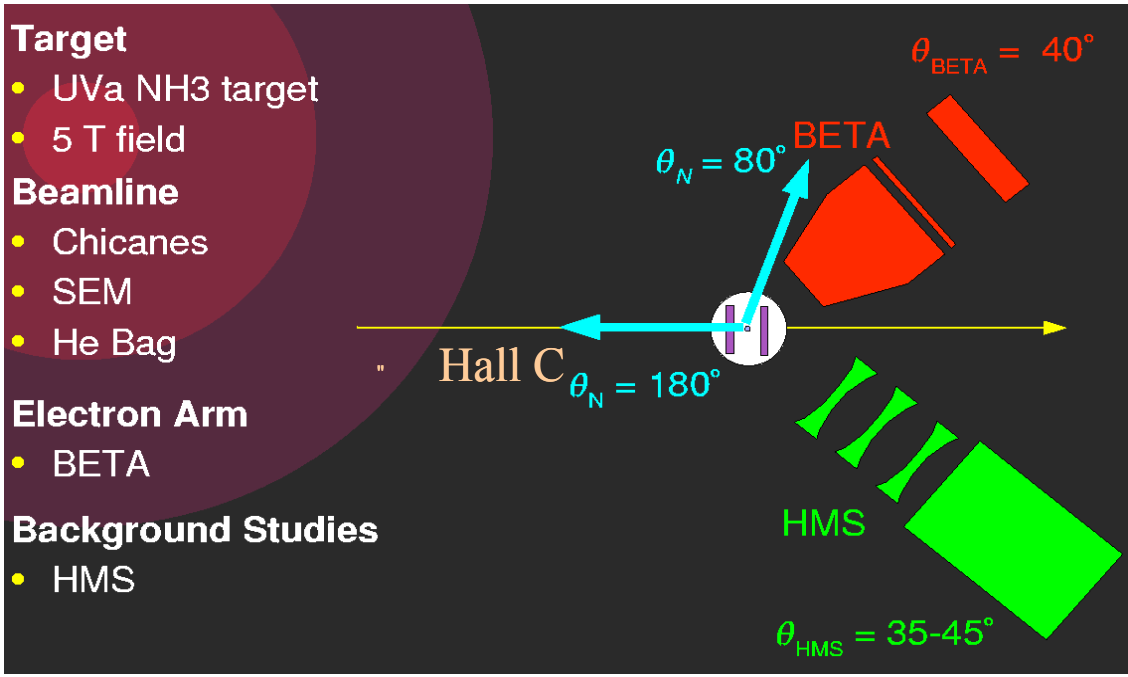


- At large Q^2, d_2 coincides with the reduced twist-3 matrix element of gluon and quark operators
- At low Q^2, d_2 is related to the spin polarizabilities



SANE experiment in Hall C





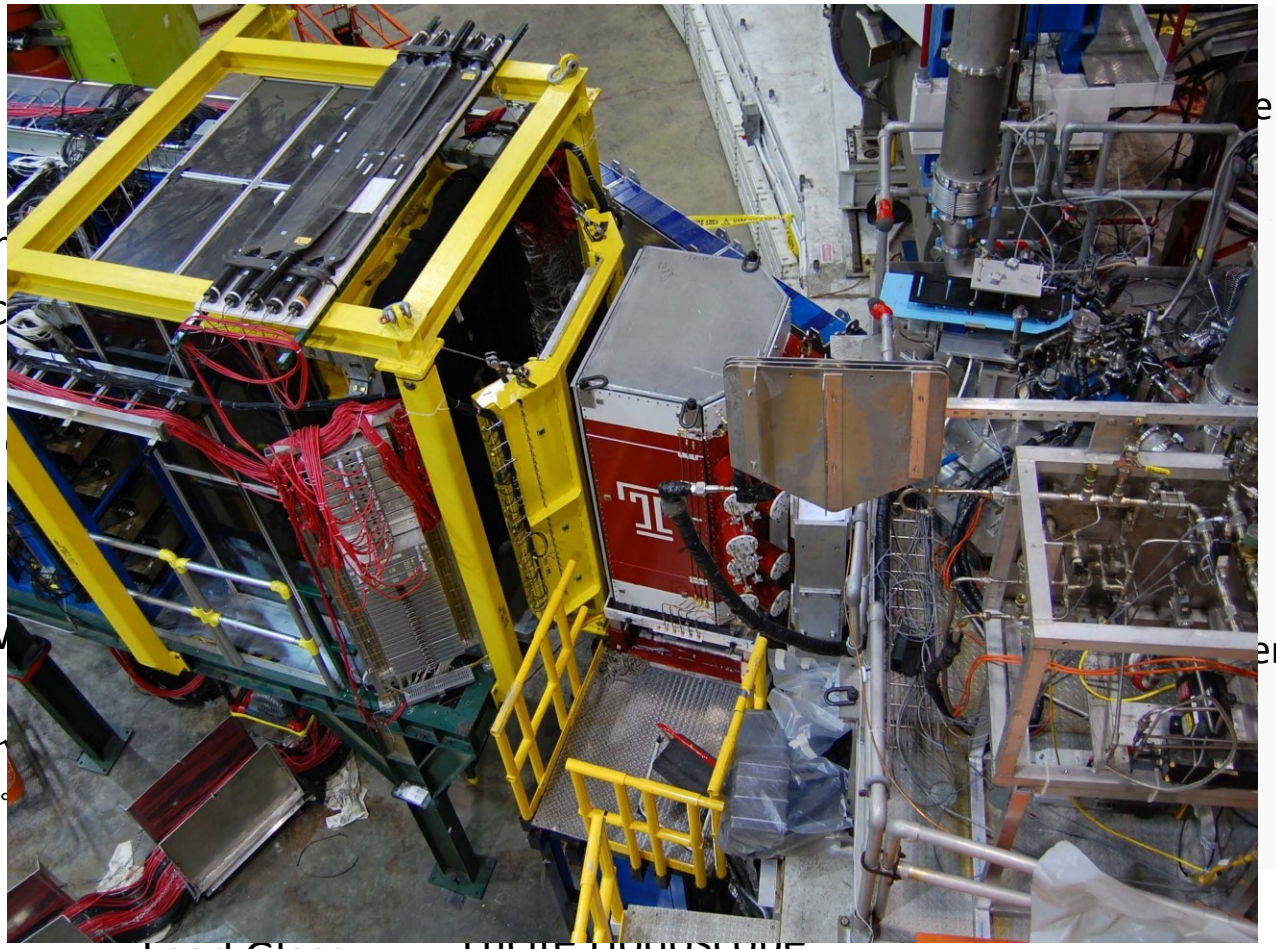
- Two beam energies:
  - **6.0 GeV (black)**
  - **4.8 GeV (green)**

- CEBAF polarized beam
  - 85 nA
  - 75% beam polarization

Experiment Ran January-March 09

BETA detector

- Three subsystems:
  - Lead glass calorimeter Energy Measurement
  - Gas Cherenkov: e- ider
  - Lucite hodoscope: trac
  - Front tracker: tracking
- Target field sweeps l background
- Characteristics
  - Effective solid angle (w 0.194 sr
  - Energy resolution 5%/
  - *angular resolution = 2°*
  - *1000:1 pion rejection*

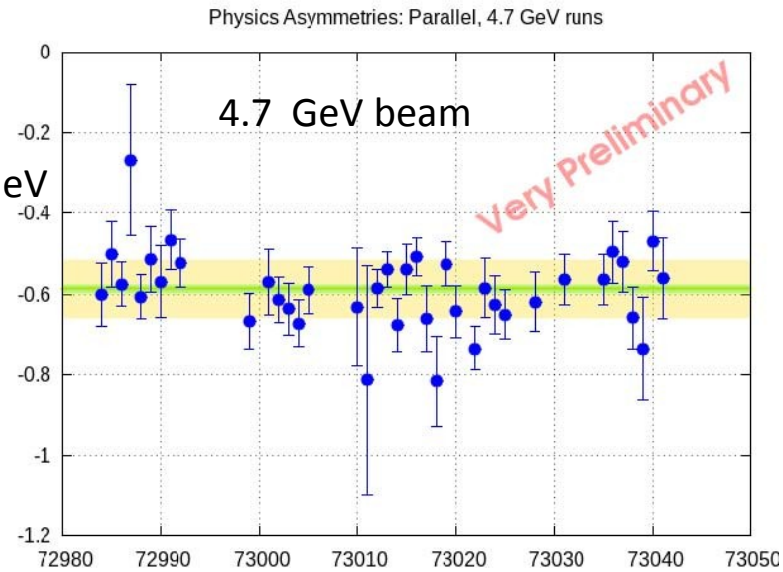


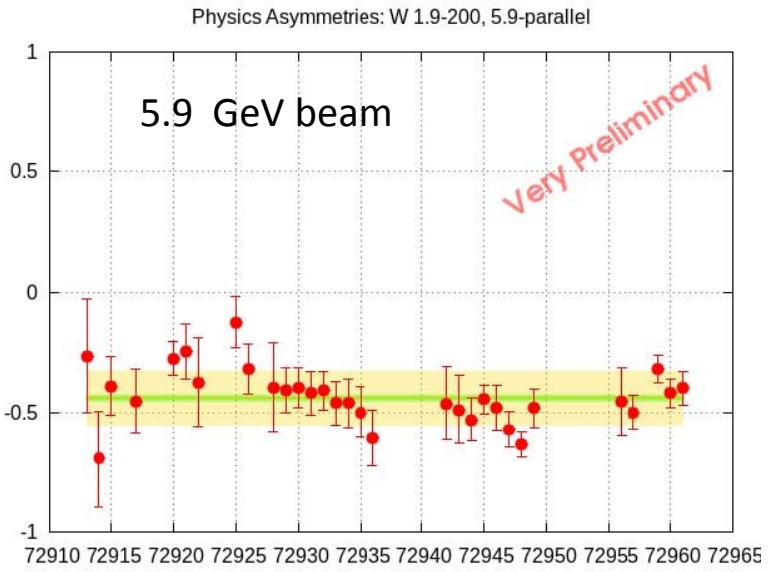
Lead Glass Calorimeter

Lucite Hodoscope

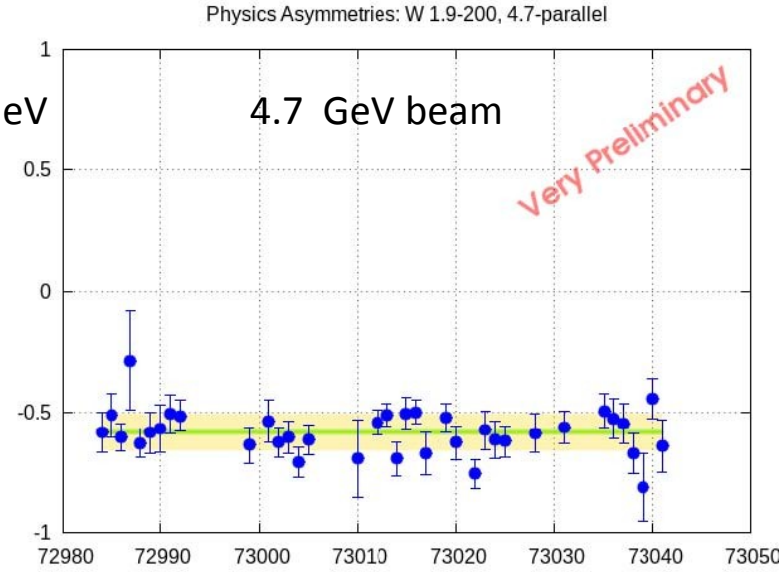
Preliminary Results: Parallel w /Kinematic Cuts

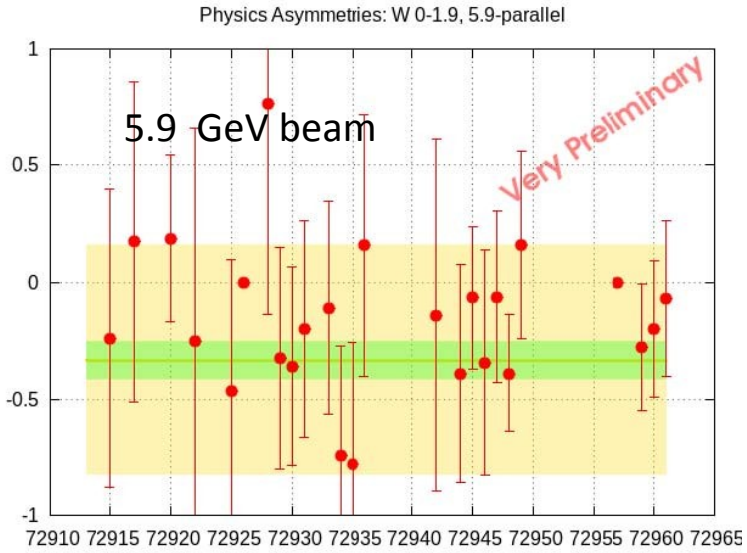
W>1.9 GeV



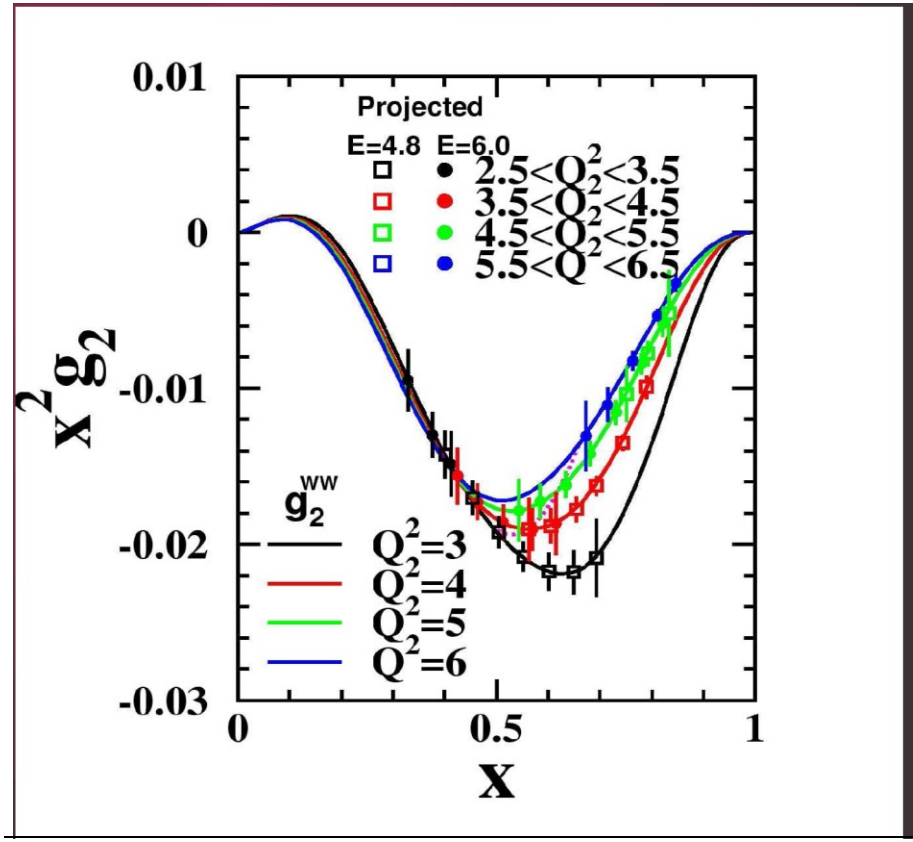


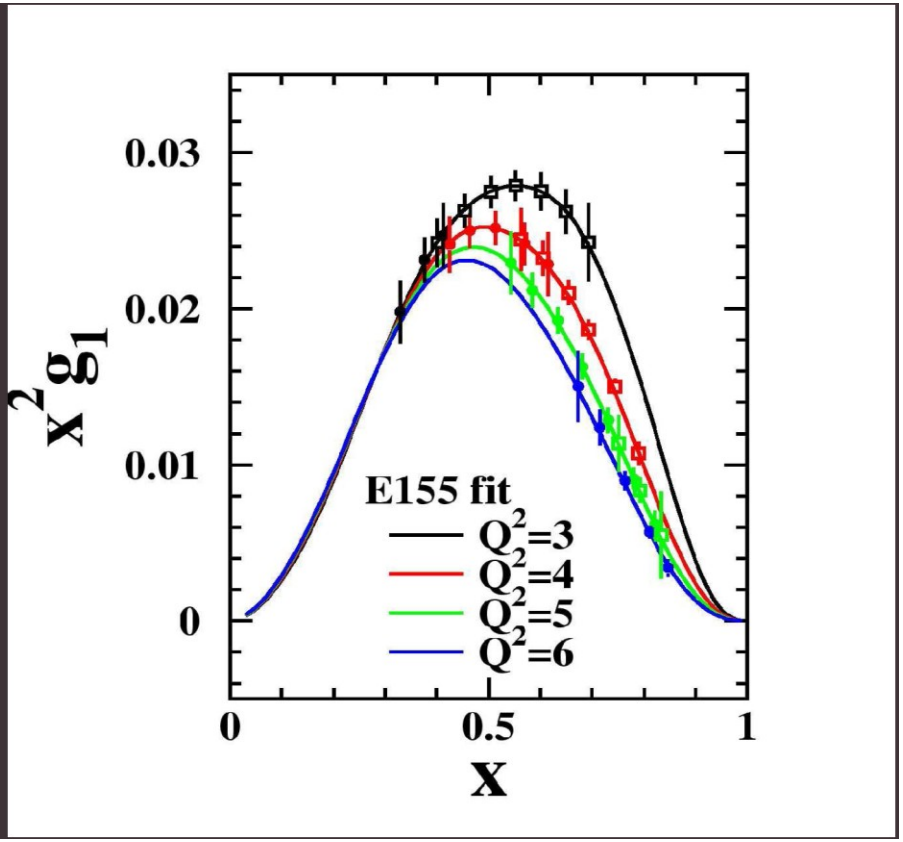
W<1.9 GeV





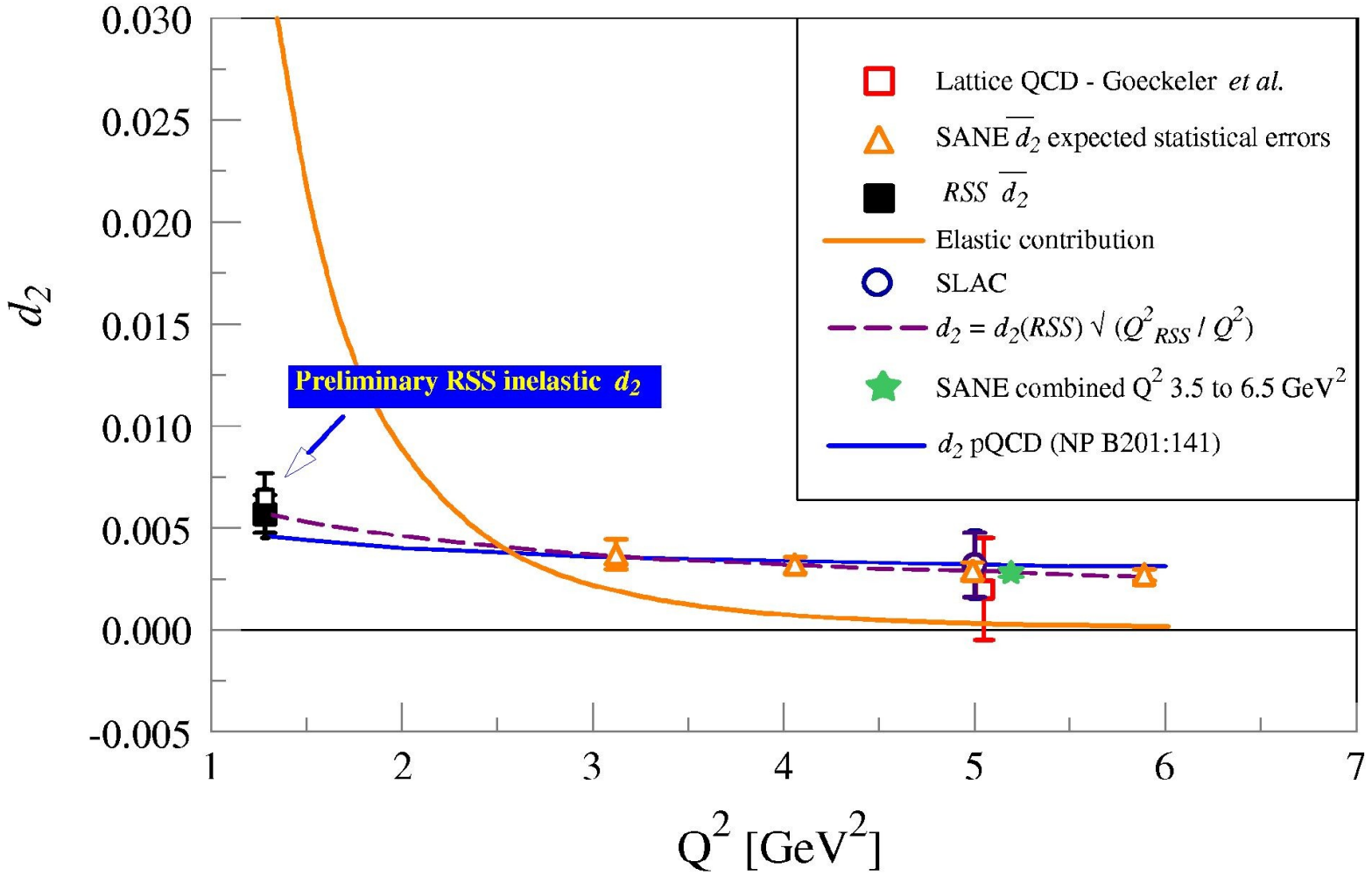
SANE experiment g_2, g_1 projected errors





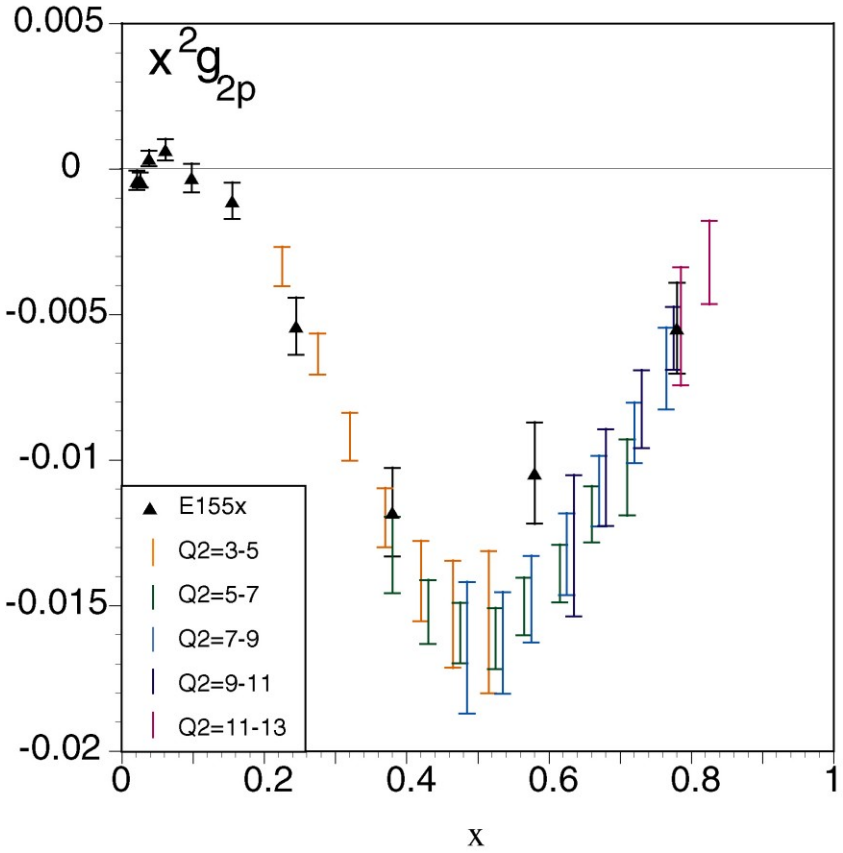
d_2^p RSS and SANE d_2^p projection in Hall C

RSS spokesperons: M. Jones, O. Rondon
SANE spokespersons: S. Choi, M. Jones, O. Rondon, Z.-E. M

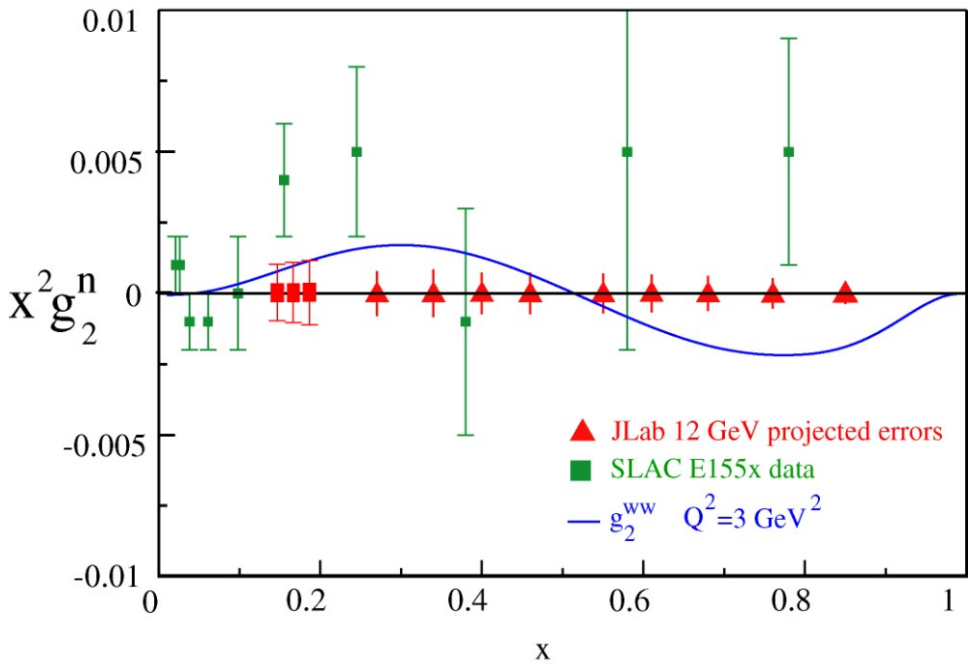


g_2 at JLab with 11 GeV

CLAS 12



Hall C HMS/SHMS



Summary

- SIDIS experiment in Hall A using a transversely polarized ^{3}He target is a window on transversity in the neutron but more precision is needed as well as the extension of the kinematic range.
- Issue with δ_{LT} at low Q^2. Results confirmed and chiral perturbation calculation disagree.
- g_2 for the proton to be measured at low Q^2 to improve on the polarizabilities calculations of the hydrogen hyperfine splitting
- In the next year we will have final results SANE in Hall C (proton) and E06-14 in Hall A (neutron). Preliminary results are encouraging.
  - Extracted average color Lorentz force will be improved
- SIDIS and DIS will continue with the 12 GeV upgrade for more precision and extension of the kinematic range in the relevant variables.