Spin Asymmetries of the Nucleon -SANE

(Proton Spin Structure)

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for SANE collaboration
SPIN 2012-Dubna

Outline

Physics (Structure of the protons)

- Inclusive scattering
- Structure of the nucleons
- What do we know?

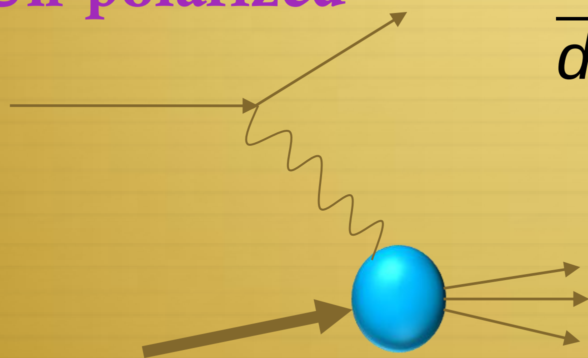
Experiment (Spin Structure Functions of Proton)

- Recent Experiment SANE
- Results

Summary

Inclusive Scattering

Un-polarized



$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}$$

From inelastic inclusive scattering

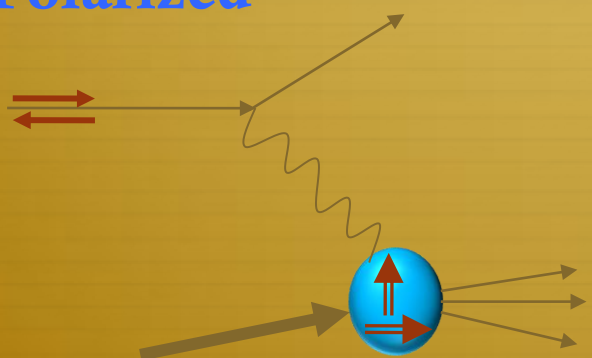
- Nucleon is not point like particle
- Structure functions F_1, F_2

$$\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M_p}F_1(x,Q^2)\tan^2\left(\frac{\theta}{2}\right)\right]$$

$$+\gamma g_1(x,Q^2) + \delta g_2(x,Q^2)$$

Adding spin degrees of freedom

Polarized



$$Q^2 = 4EE'\sin^2\frac{\theta}{2}$$ Four momentum transfer

$$x = \frac{Q^2}{2M(E-E')}$$ Bjorken X

$E' - Energy\,of\,scattered\,electron$

$\theta - scattering\,angle$

Structure Functions

- F_1 and g_1 can be described in terms of quark-parton distributions
  - In Quark-Parton Model

$$F_1(x) = \frac{1}{2}\sum_i e_i^2(q_i^+ + q_i^-) \qquad g_1(x) = \frac{1}{2}\sum_i e_i^2(q_i^+ - q_i^-)$$

  - F_1 is the charge weighted momentum distribution of the quarks for each flavor
  - g_1 is the charge weighted net helicity distribution for each flavor

F_2 related to F_1 by Callan-Gross relation

$g_2 = g_2^{WW} + \bar{g}_2$ consists of

  - twist-2 part g_2^{WW} (Wandzura-Wilczek) which is function of g_1 only
  - $\bar{g}_2$ which has part of twist-2 chiral odd transversity and twist-3 effect (responsible for quark-gluon correlations)

Transverse Spin Structure Function

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

$$= -g_1(x,Q^2) + \int_x^1 g_1(x',Q^2)\frac{dx'}{x'} - \int_x^1 \frac{\partial}{\partial x'}\left[\frac{m}{M}h_T(x',Q^2) + \xi(x',Q^2)\right]\frac{dx'}{x'}$$

- – Wandzura-Wilczek g_2^{WW} depends on g_1; h_T is twist-2 chiral odd transversity
- – ξ represents quark-gluon correlations (twist-3).

- Transverse spin structure function g_T measures spin distribution normal to virtual γ

$$g_T = g_1 + g_2 = \int_x^1 \left[g_1 - \frac{\partial}{\partial x'}\left(\frac{m}{M}h_t + \xi\right)\right]\frac{dx'}{x'} = \frac{\nu}{\sqrt{Q^2}}F_1(x,Q^2)A_2(x,Q^2)$$

Proton Un-polarized SF

- Structure Functions F_1, F_2

(Investigated extensively)

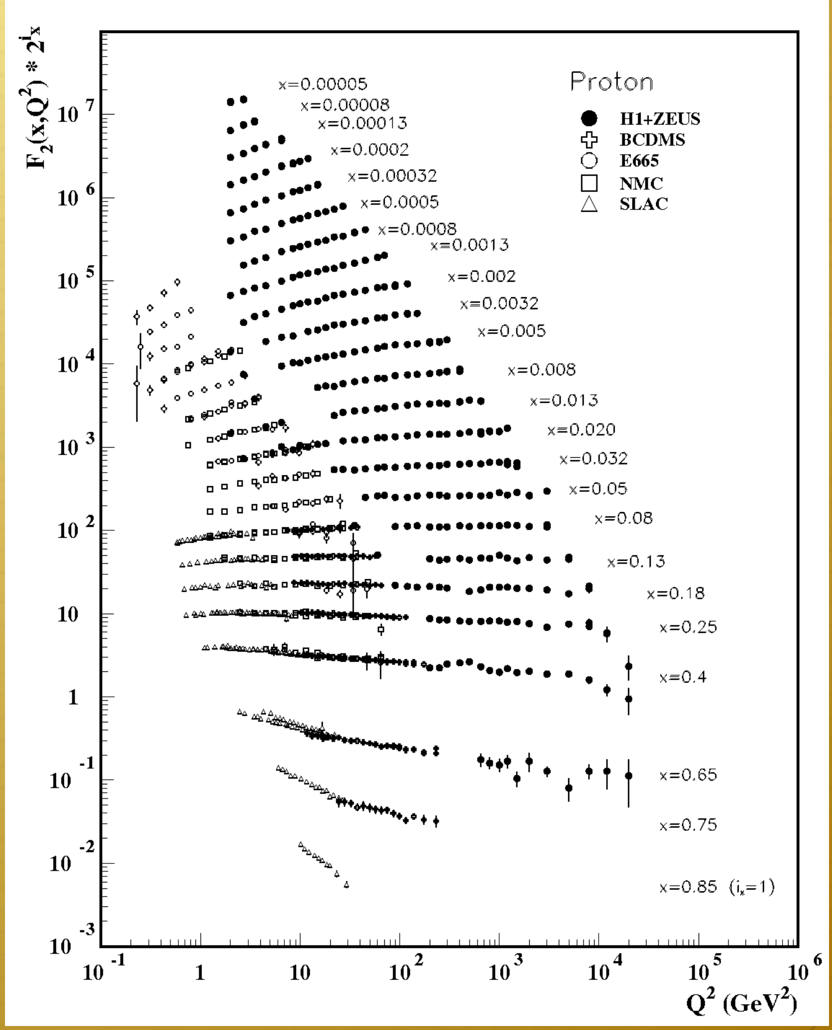
At large Q² $F_2(x, Q^2) \rightarrow F_2(x)$

Callan –Gross relation

$$F_2(x, Q^2) = 2xF_1(x, Q^2)$$

at JLab energies Callan-Gross relation

$$F_2 = \frac{2x(1+R)F_1}{(1+(2Mx)^2/Q^2)} \quad R = \frac{\sigma_L}{\sigma_T}$$



Proton Polarized SF g_1^p

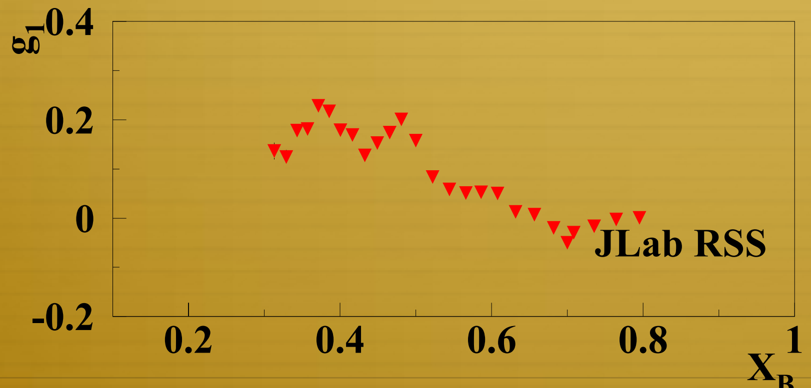
- Structure Function g_1

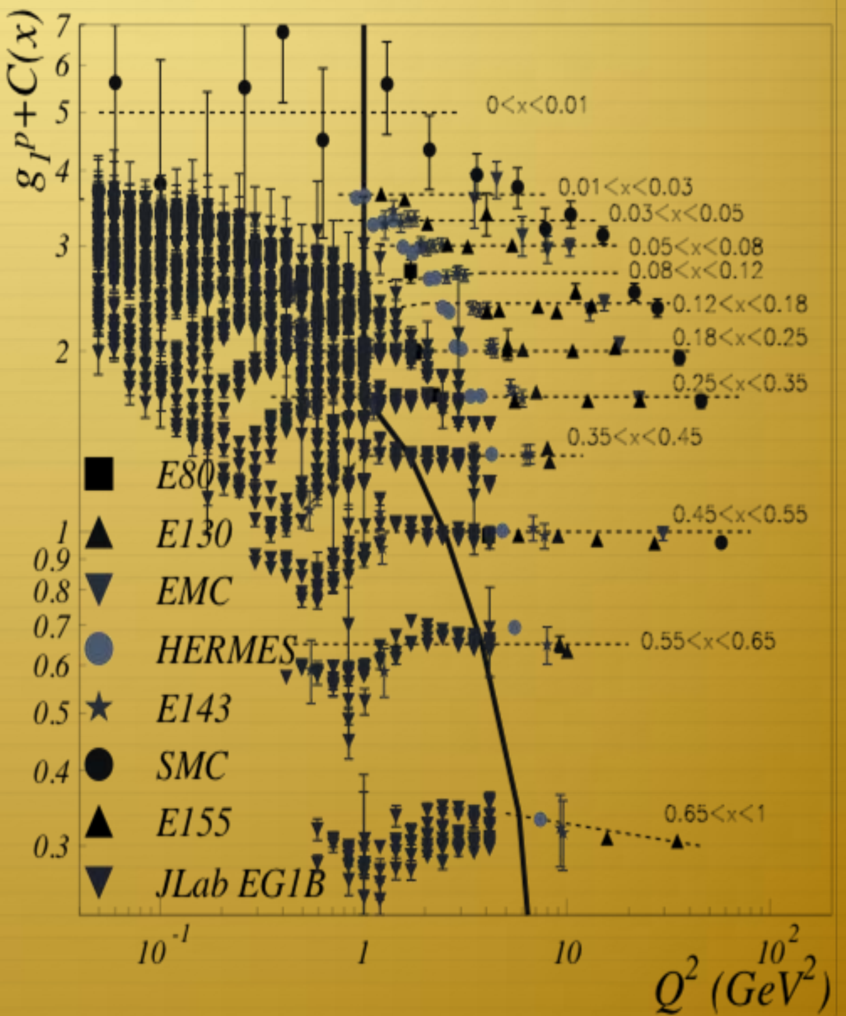
(Investigated extensively)

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 (q_i^+ - q_i^-)$$

Most of the data are model dependent
- g_2 is negligible
- model for g_2

g_1 scales at large Q^2





Proton Polarized SF g_2

- Structure Function g_2^p

$$g_2 = g_2^{WW} + \bar{g}_2$$

$$g_2^{WW} = -g_1 + \int_x^1 \frac{dy}{y} g_1$$

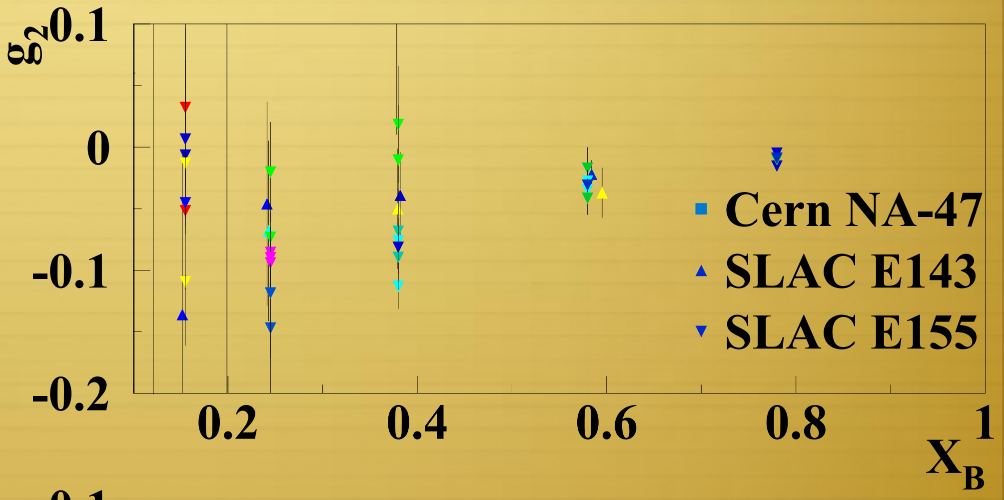
Only 5 experiments
SLAC (E143, E155, E155x),
JLab (RSS), CERN (NA-47)

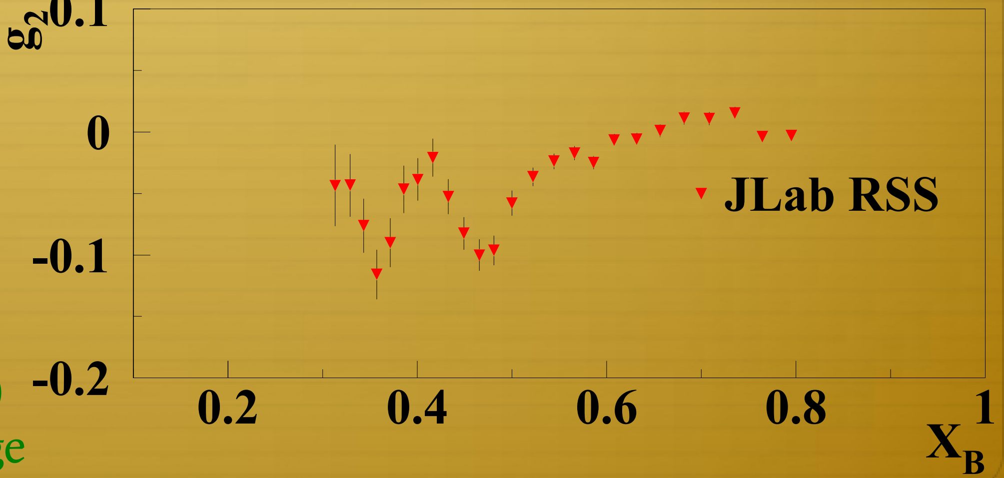
Resonance region

- RSS data at $Q^2 \sim 1.3 GeV^2$

DIS region (E143, E155, E155x, NA-47)

- DIS data Scattered over large Q^2 range





Transverse Spin Structure Sum Rules

The OPE is a connection between quark matrix elements of the nucleon and the moments of the spin structure functions.

- Cornwall-Norton moments of $\boldsymbol{g_1}$ related to twist-2 ($\boldsymbol{a_N}$).
- moments of $\boldsymbol{g_2}$ related to twist-2 ($\boldsymbol{a_N}$) and twist-3 ($\boldsymbol{d_N}$) matrix elements.

$$\int_0^1 x^N g_1(x,Q^2)\,dx = \frac{1}{2}\boldsymbol{a}_N + O(M^2/Q^2), \qquad N = 0, 2, 4, \ldots$$

$$\int_0^1 x^N g_2(x,Q^2)\,dx = \frac{N}{2(N+1)}(\boldsymbol{d}_N - \boldsymbol{a}_N) + O(M^2/Q^2), \quad N = 2, 4, \ldots$$

Nachtmann moments remove higher order target mass corrections

- $\boldsymbol{d_N}$ measure twist-3 contributions

$$d_N(Q^2) = \frac{2(N+1)}{N}\int_0^1 x^N \overline{g_2}(x,Q^2)\,dx$$

World Data of d_2^p

World Data (or lack of it for proton)

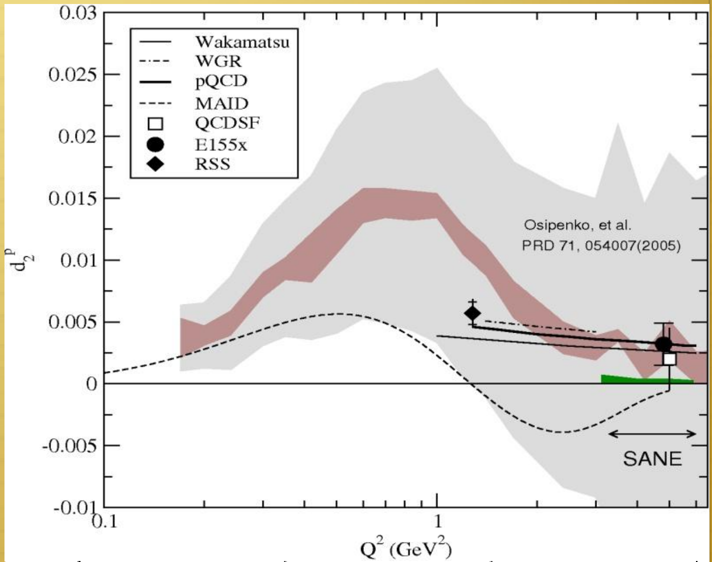
- Only two points in regards to $d_2 = \int_0^1 x^2(2g_1 + 3g_2)\,\mathrm{d}x$

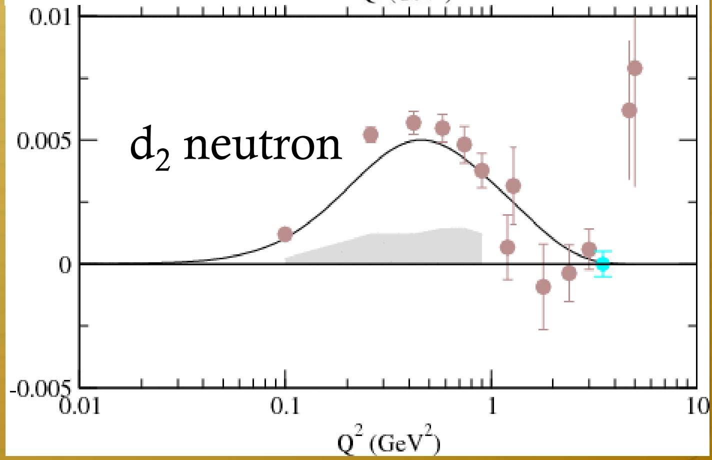
d_2 Interpretation (M. Burkardt)

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

$$< F^y(0) >= -M^2 d_2$$

d_2 and f_2 (responses of the color fields B and E to the nucleon polarization) give direct direct access to color polarizabilities χ_E and χ_B (X. Ji)





Goal and methods of the SANE experiment

Goal

- Extract A_1^p and A_2^p
- Extract g_1^p and g_2^p (Spin Structure Functions)
- Calculate Twist-3 matrix element $d_2 = \int_0^1 x^2 (2g_1 + 3g_2)\,\mathrm{d}x$
- Probe the Approach of A_1 to x=1 at constant Q^2 to test quark models and pQCD predictions

Method

- Measure A_{80} and $A_{||}$ on polarized protons in frozen ammonia with polarized electron beam

Spokes people: S. Choi, M. Jones, Z.-E. Meziani, O. Rondon

SANE Experiment

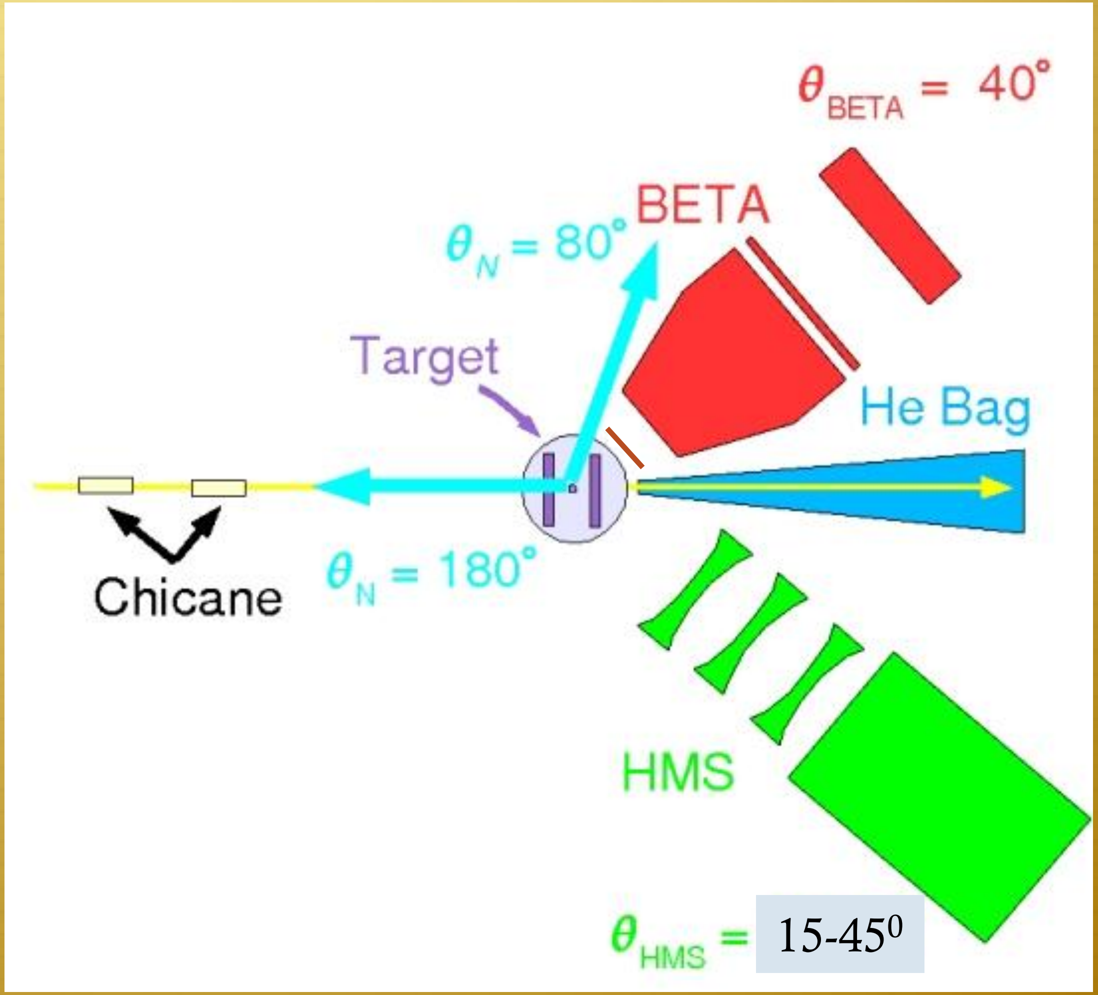
Hall-C –TJNAF

UVA NH_3 Polarized target
80 and 180 degree

Electron arm BETA detector
Tracker (NSU, Regina)
Cerenkov (Temple)
Lucite (N.Carolina A&T)
BigCal

HMS arm
15-45^o

BEAM
80-100nA current
Chicane
He bag (Miss. S. U.)



Extraction

$$A_\alpha \sim [(\cos(\theta_0)\cos(\alpha) + \sin(\alpha)\sin(\theta_0)\cos(\phi))E' + \cos(\alpha)E]M_p G_1 + 2[\cos(\theta_0)\cos(\alpha) - \cos(\alpha) + \sin(\alpha)\sin(\theta_0)\cos(\phi)]E'EG_2$$

$$A_{180} \sim ((\cos(\theta_0)E' + E)M_p G_1 - Q^2 G_2)$$

Solve for $\frac{M_p \cdot G_1}{W_1}, \frac{G_2}{W_1}$ which can be used to extract A_1 and A_2

$$A_1 = v \cdot \frac{M_p \cdot G_1}{W_1} - Q^2 \cdot \frac{G_2}{W_1} \qquad g_1 = \nu M_p^2 G_1$$

$$A_2 = \sqrt{Q^2}\left(\frac{M_p \cdot G_1}{W_1} + v \cdot \frac{G_2}{W_1}\right) \qquad g_2 = \nu^2 M_p G_2$$

A_1 and A_2 are obtained in model independent way using experimental asymmetries only

Models

For g_1 and g_2 we used Parton Distribution Functions (PDF)

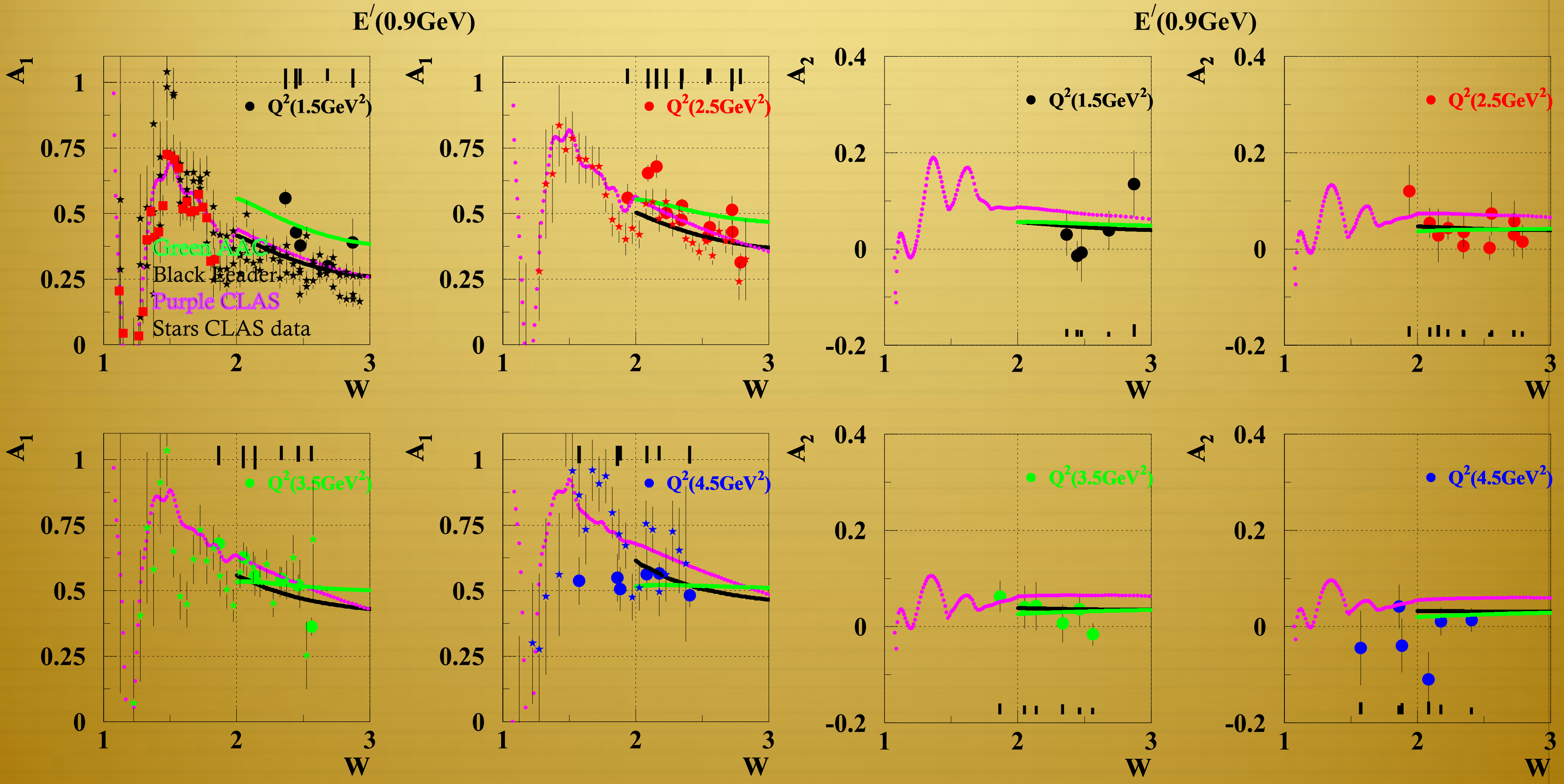
- Leader, Sidorov, Stamenov LSS 2006 (Phys. Rev, D75 2007 074027) (target mass corrected)
- AAC 2003 (Phys. Rev, D69 2004 054021) (target mass corrected)
- CLAS fit to world data (S. Kuhn & N. Guler)

To obtain A_1 and A_2 from PDF's we use

$$A_1 = \frac{g_1 - (4M^2x^2/Q^2)g_2^{WW}}{F_1} \qquad A_2 = \frac{2Mx}{\sqrt{Q^2}}\frac{g_1 + g_2^{WW}}{F_1}$$

Where F_1 is obtained from P. Bosted and E. Christy fit to Hall-C & world data

Physics Asymmetries



Black bars shows systematic error

Physics Asymmetries

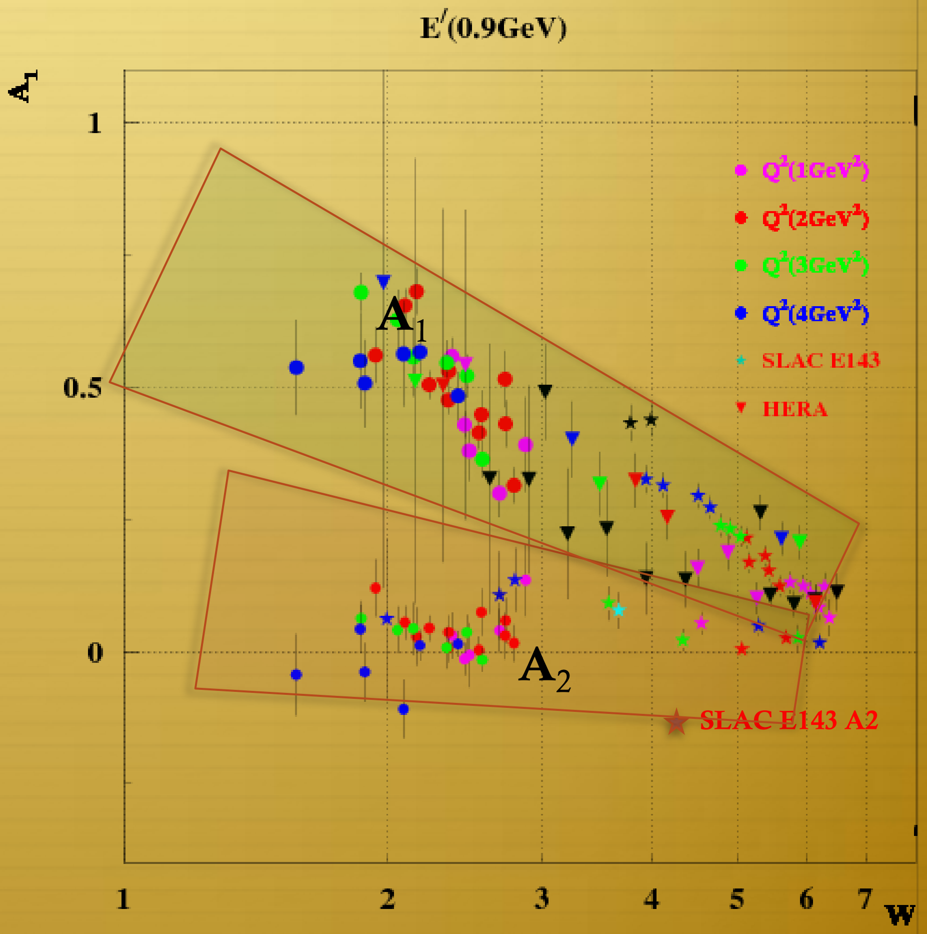
SANE shows good agreement with world data at large W

A_1 has linear trend versus log(W), and slope seems to have almost no Q^2 dependence

A_2 is non-zero at low W and high x_B

A_2 is consistent with E143 although the E143 data at W(1-3 GeV) have different Q^2

This agreement can indicate low Q^2 dependence of A_2 besides W dependence on Q^2



Physics Asymmetries

We observe A_1 dependence on Q^2

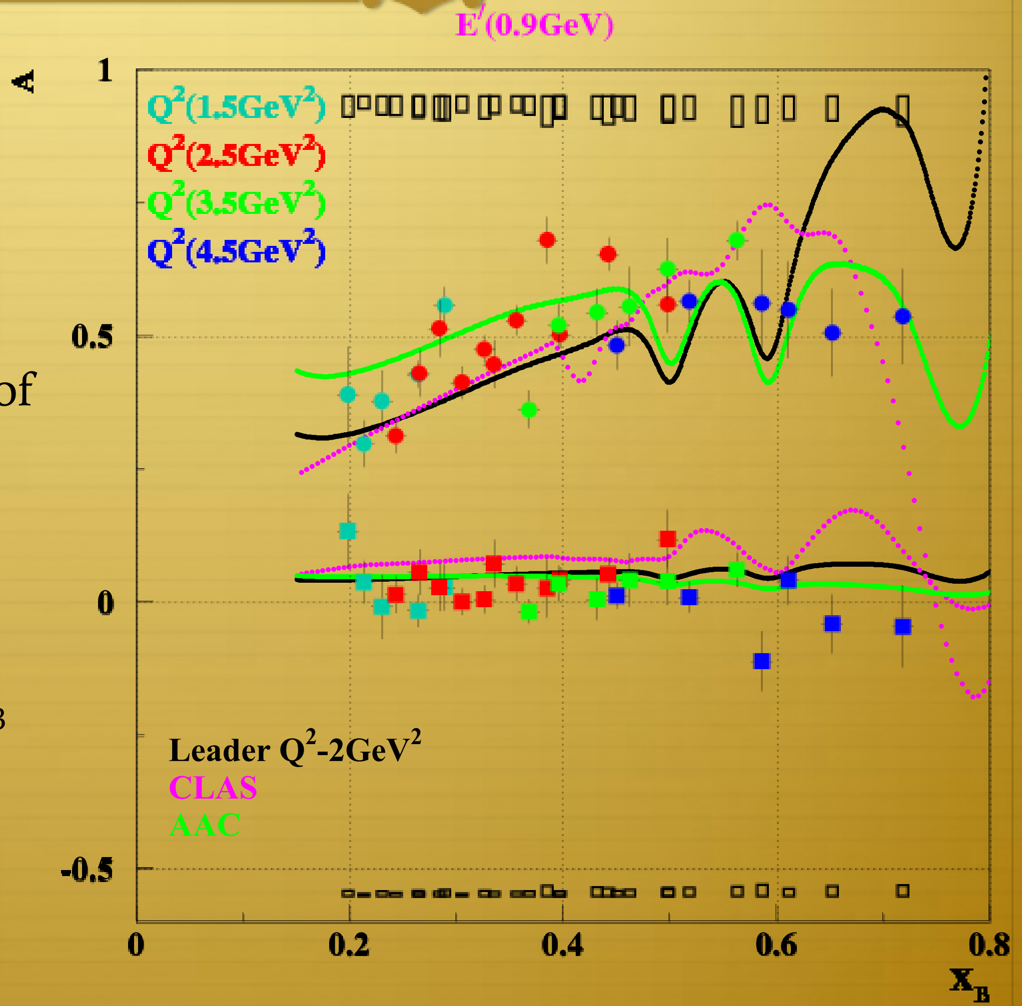
A_1 decreases with Q^2

Apparent dependence on Q^2 mostly comes from kinematical dependence of W on four momentum transfer

$$W = \sqrt{M^2 + Q^2/x - Q^2}$$

A_2 is non-zero both at low and high x_B

Models for A_2 within the errors although data shows some structure



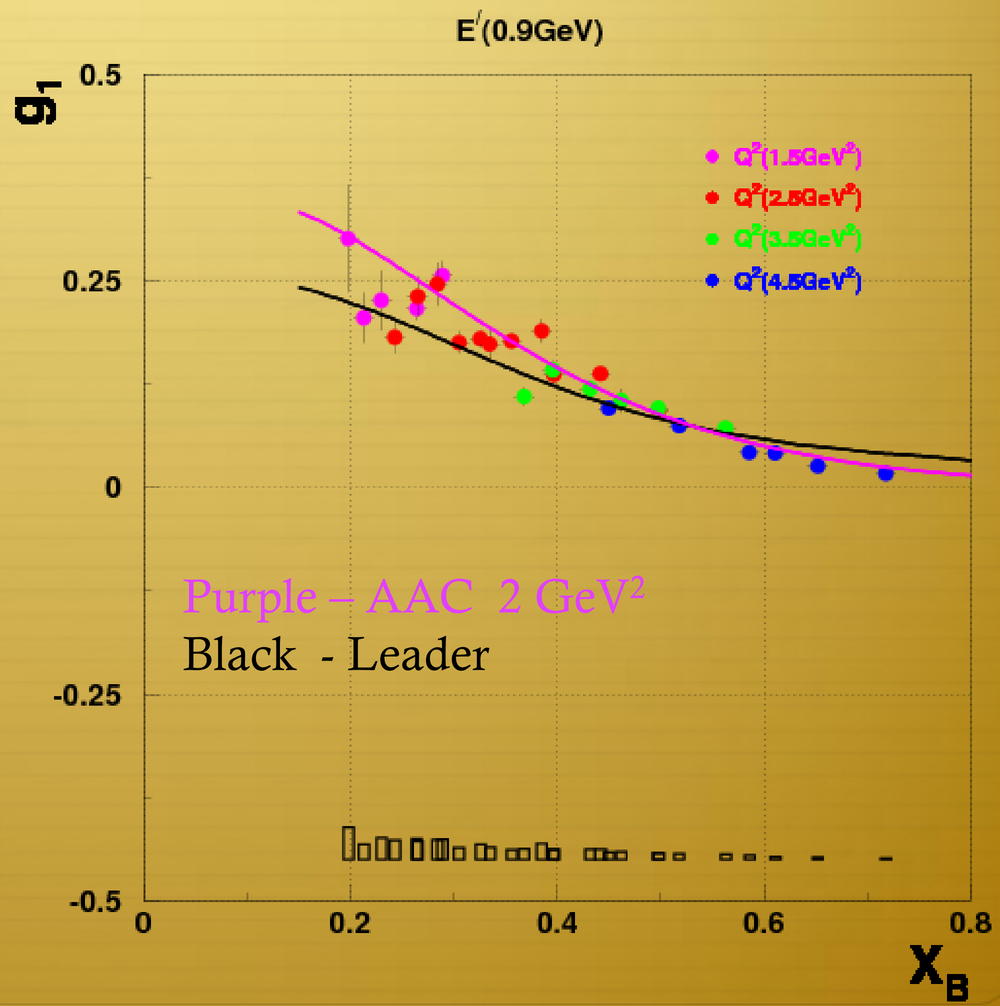
Spin Structure Function g_1

Leader parameterization calculated at $Q^2 = 2\ GeV^2$

AAC $Q^2 \sim 2GeV^2$

AAC parameterization gives better agreement with data

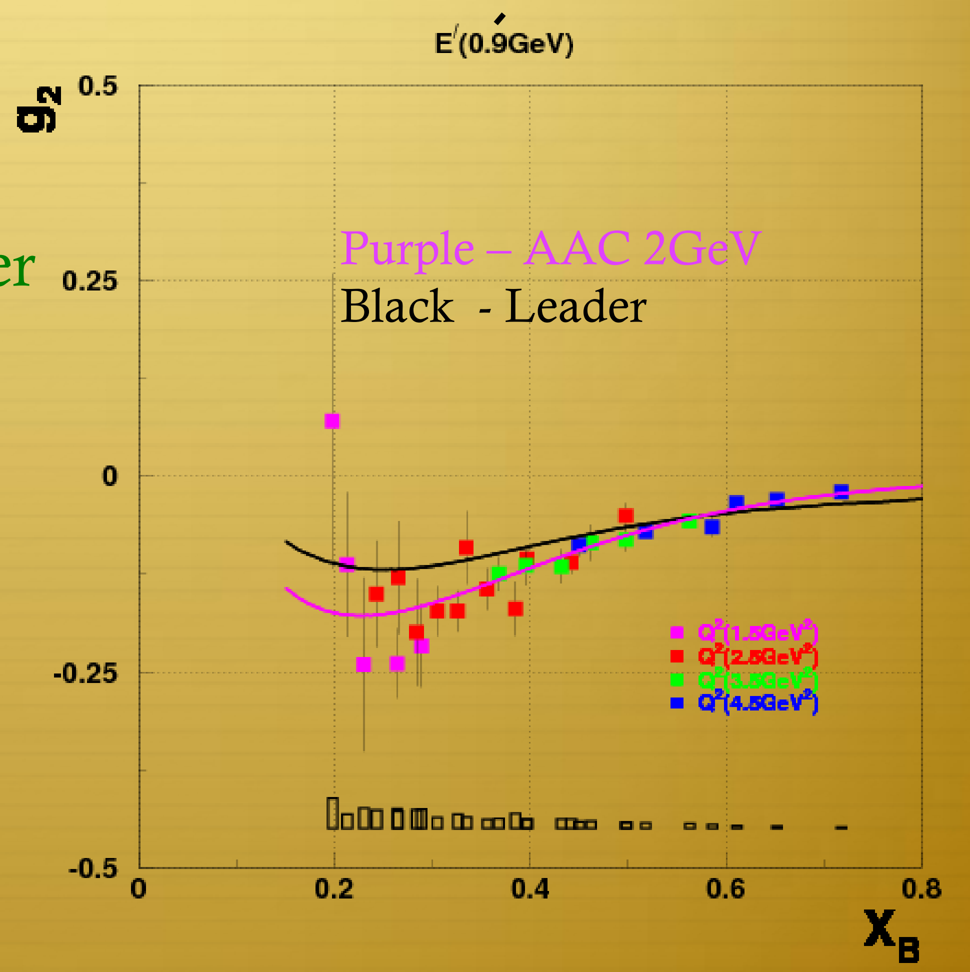
Largest contribution to systematic error comes from positron



Spin Structure Functions g_2

Our data is in agreement with World data for g_2

g_2^{WW} for AAC model gives better agreement with SANE



Spin Structure Functions $\overline{g}_2$

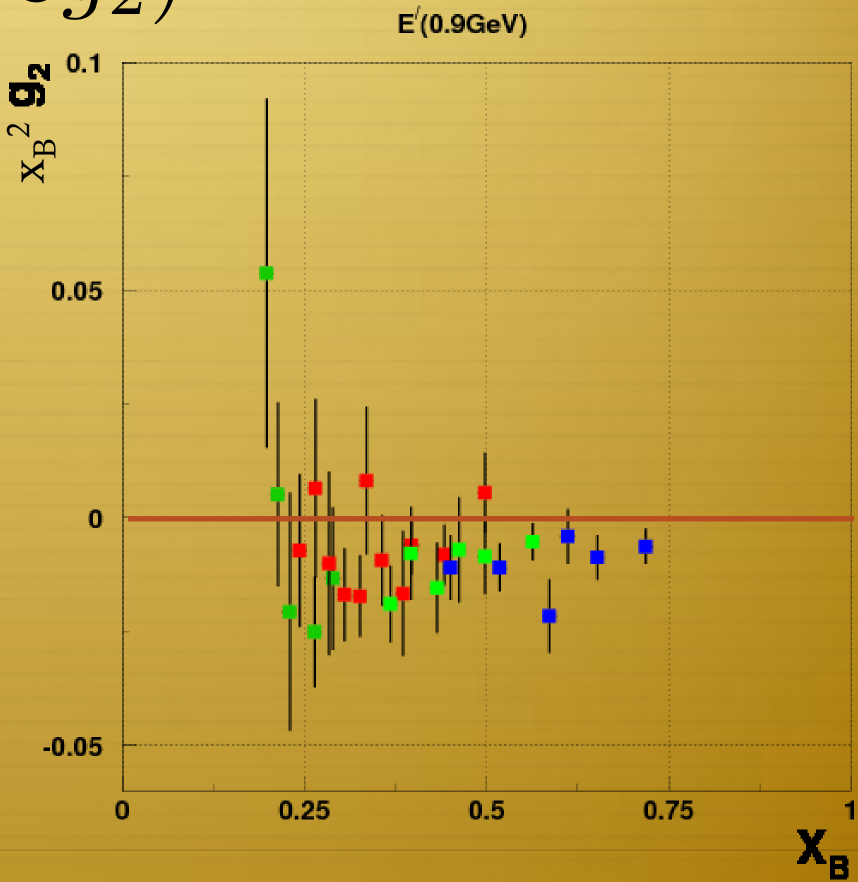
$$x_B^2 \cdot \bar{g}_2 = x_B^2 \cdot (2g_1 + 3g_2)$$

Is essential for calculation of d_2 moment

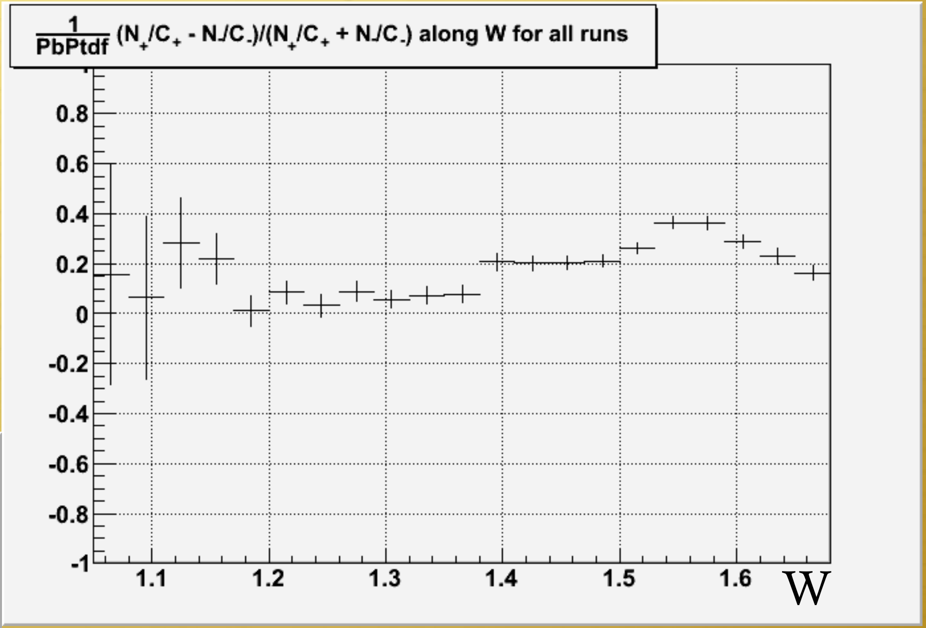
g_1 and g_2 are the data

$\overline{g}_2$ is negative hence

d_2 twist-3 matrix element is negative?

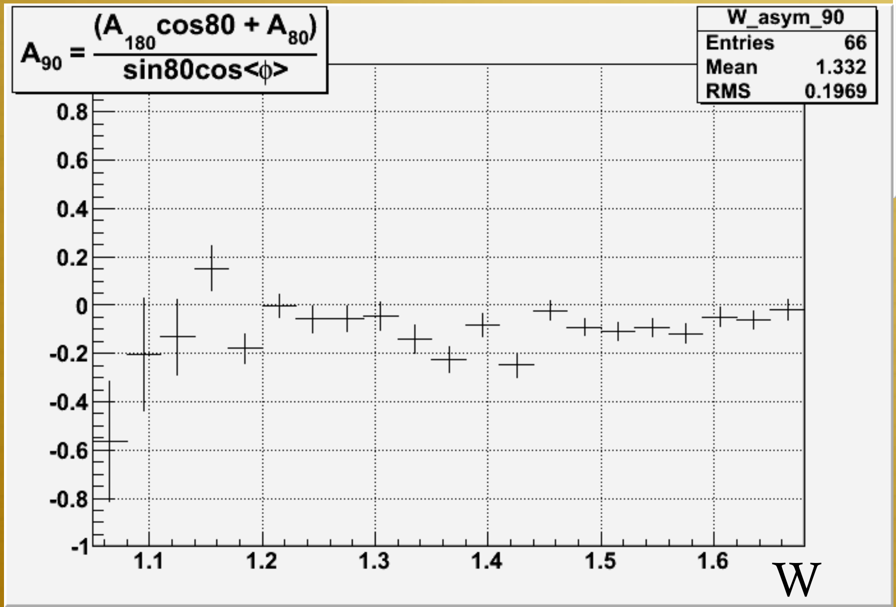


Longitudinal and transverse asymmetries from HMS



Longitudinal Asymmetry A_{180}

$Q^2 \sim 1.8$ GeV^2



Transverse Asymmetry A_{90}
Houyong Kang

Also we have some results for elastic

Summary

- A_1 shows linear trend vs log(W) (little or no Q^2 dependence)
- A_1 at low Q^2 higher than CLAS data
- A_2 (W) consistent with SLAC E143, even considering the difference in Q^2 at constant W between SANE and E143. May indicate small Q^2 dependence
- g_1 and g_2 agrees better with AAC PDF
- Data indicate the negative twist-3
- More data will be available from HMS data set in resonance region

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Run Info

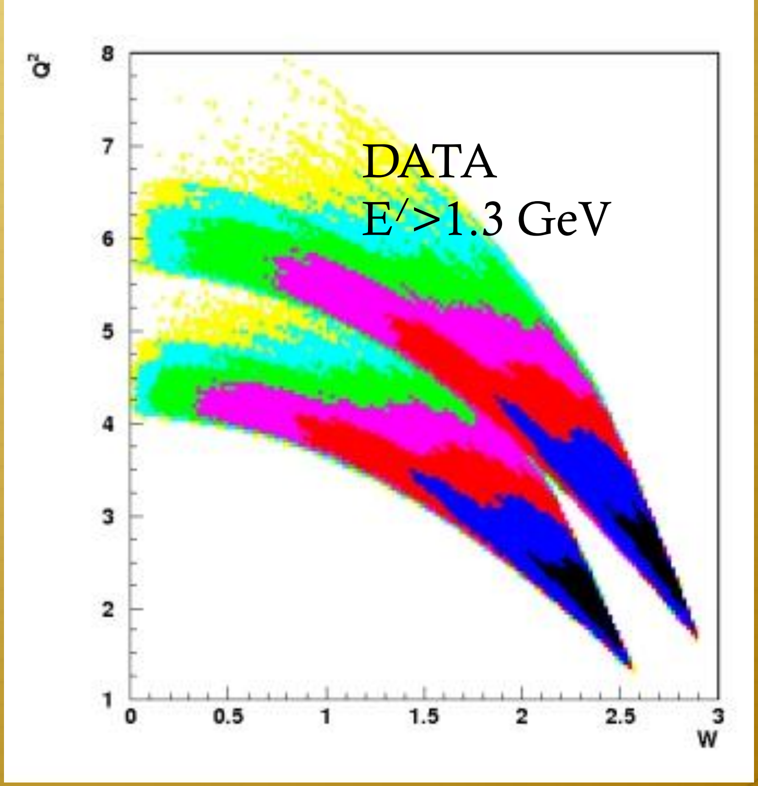
- **Experiment ran Feb – Mar 2009**
- **Energy/field — Beam Pol* — Proposed /FOM****

Energy/field	Beam Pol*	Proposed /FOM**
4.7 GeV Parallel	66%	39%
5.9 GeV Parallel	88%	35%
4.7 GeV Perp	85%	58%
5.9 GeV Perp	71%	62%

Target Pol 69%

(*) Measured by Moller polarimeter

(**) FOM=$(P_{targ}*P_{Beam})^2*I_{Beam}$

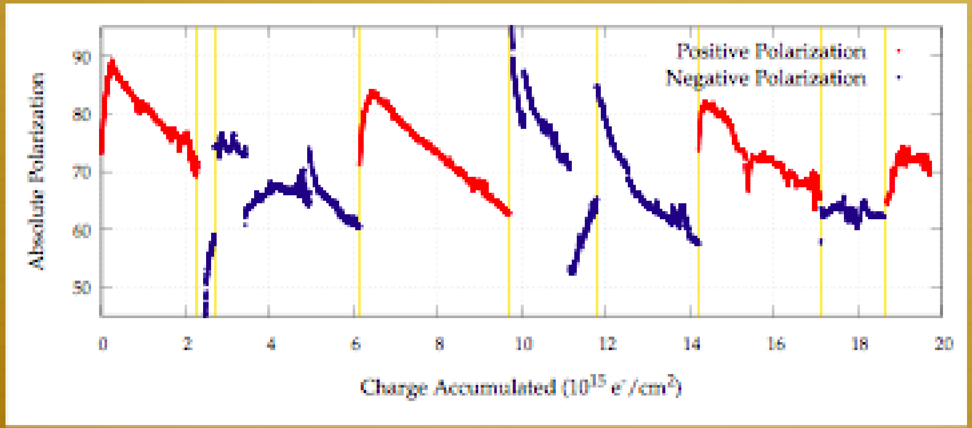


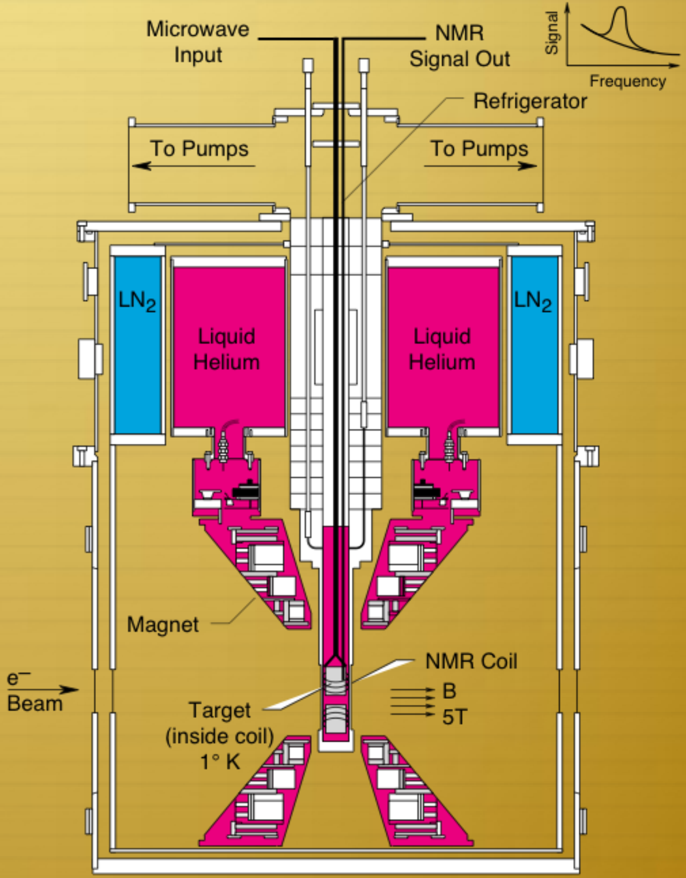
Polarized Target

UVA polarized target

- SANE, RSS, E143, E155, G_E^n experiments
- 5T Superconducting magnet
- Insert with NH_3 material
- Microwaves ~140 GHz
- NMR -213 MHz

Method Dynamic Nuclear Polarization (DNP)

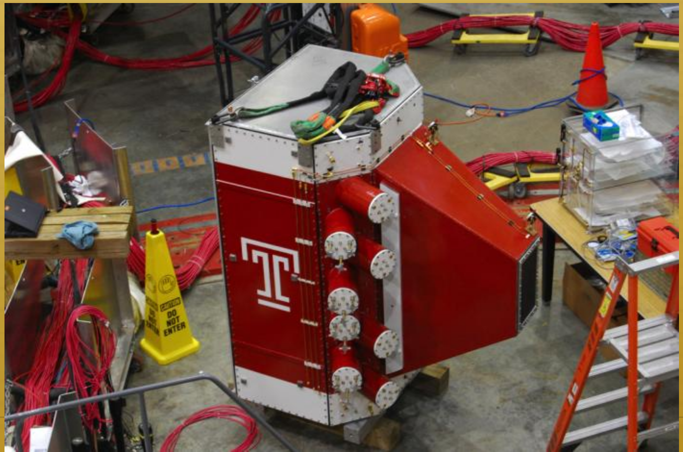




Detectors

- Tracker
  - 3 planes of 3mm bars X(64),Y1, Y2(128 bars each)
- Cerenkov
  - 8 Mirrors (4 spherical, 4 thoroidal)
- Lucite
  - 28 Lucite bars
- BigCal
  - Protvino 32x32(3.82cm)
  - RCS 24x30(4cm)

  Total 1744 lead glass bars



80^0 Field Orientation

- Q^2 1.7 GeV^2
- Q^2 2.5 GeV^2
- Q^2 3.5 GeV^2

- Starting from A_{180} and A_{80}
- Only constant dilution factor applied
- Large energy range (>0.8 GeV)

What else should be done for Asymmetry extraction

- Kinematics dependent dilution factors
- Radiative (elastic and internal)corrections
- Correct for Pair symmetric background contribution
- Final data are completely corrected.