Overview and Highlights of the Spin Asymmetries of the Nucleon Experiment - SANE

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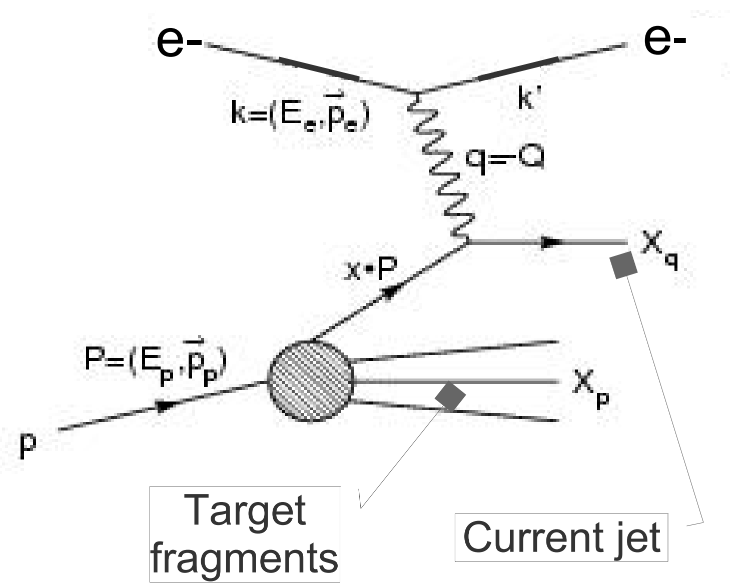
Probing the Nucleon with Transverse Polarized Electromagnetic Scattering

Inelastic *e* - *nucleon* Scattering

- Inclusive EM scattering is described by hadronic and leptonic tensors
- Symmetries reduce hadronic tensor to four structure functions:
  - Symmetric part: unpolarized $\boldsymbol{W_1}$, $\boldsymbol{W_2}$
  - Anti-symmetric part: double-polarized $\boldsymbol{G_1}$, $\boldsymbol{G_2}$



(http://www.desy.de/~gbrandt/feyn/)

$$W^A_{\mu\nu} = 2\epsilon_{\mu\nu\lambda\sigma} q^\lambda \left\{ M^2 S^\sigma \boldsymbol{G_1}(\nu, Q^2) + \left[M \nu S^\sigma - p^\sigma S \cdot q \right] \boldsymbol{G_2}(\nu, Q^2) \right\}$$

Inclusive scattering: undetected final state

- Talk focus is on inclusive double-polarization measurement with Transverse and Longitudinal target polarization

Structure Functions in Inclusive DIS

- The four SF's G_1, G_2, W_1 and W_2, contain all the information on nucleon structure that can be extracted from inclusive data
- In the high energy regime of DIS, g_1 and g_2 are expected to scale like F_1 and F_2 (up to log violations)

$$\lim_{Q^2,\nu\to\infty} M^2\nu G_1(\nu,Q^2)=g_1(x)$$
$$\lim_{Q^2,\nu\to\infty} M\nu^2 G_2(\nu,Q^2)=g_2(x)$$
$$Bjorken\ x=Q^2/(2M\nu)$$

$$\lim_{Q^2,\nu\to\infty} M W_1(\nu,Q^2)=F_1(x)$$
$$\lim_{Q^2,\nu\to\infty} \nu W_2(\nu,Q^2)=F_2(x)$$
$$\frac{F_2(x)}{F_1(x)}=2x \quad (Callan-Gross)$$

- In the quark parton model g_1 and F_1 are also related to PDF's:

$$F_1(x)=\frac{1}{2}\sum e_f^2(q_f^{\uparrow}(x)+q_f^{\downarrow}(x))$$
$$g_1(x)=\frac{1}{2}\sum e_f^2(q_f^{\uparrow}(x)-q_f^{\downarrow}(x))$$

Virtual Compton Asymmetries

- The spin SF's are also related to virtual photon cross-sections and spin asymmetries (SA)
  - Along the γ^* axis, the helicity of the photon-nucleon system is 3/2 or ½ for transverse photons, ½ for longitudinal ones

- The SA $\boldsymbol{A_1}$ is defined in terms of the difference for 3/2 and ½ helicity cross sections

$$\boldsymbol{A_1} = \frac{\sigma_T^{(3/2)} - \sigma_T^{(1/2)}}{\sigma_T^{(3/2)} + \sigma_T^{(1/2)}}$$

$$\boldsymbol{A_1} = \frac{1}{F_1}\left(g_1 - \gamma^2 g_2\right); \quad \gamma = \frac{2xM}{\sqrt{Q^2}}$$

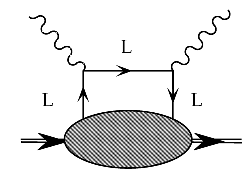
- The SA $\boldsymbol{A_2}$ is defined in terms of the interference between initial transverse and final longitudinal amplitudes

$$\boldsymbol{A_2} = \frac{\sigma_{TL}^{(1/2)}}{\sigma_T^{(3/2)} + \sigma_T^{(1/2)}} \leq \boldsymbol{R} = \frac{\sigma_L}{\sigma_T}$$

$$\boldsymbol{A_2} = \frac{\gamma}{F_1}\left(g_1 + g_2\right) = \frac{\gamma}{F_1}\boldsymbol{g_T}$$

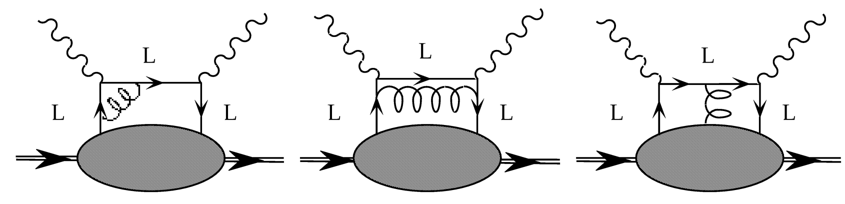
Transverse Polarized Scattering: Unlocking Twist-3

- Twist-2 and twist-3 operators contribute at same order in transverse polarized scattering
  - twist-2: handbag diagram
  - twist-3: *qgq* correlations
- direct access to twist-3 via $\boldsymbol{g_2}$:
  - "*Unique feature of spin-dependent scattering*" (R. Jaffe)
- difference of transverse cross sections



(b)

twist-2



(c) (d) (e)

log Q^2 α_{QCD} twist-3

(Comments NPP 19, 239 (1990))

$$\frac{d^2\sigma^{(\uparrow\rightarrow)}}{d\Omega\, dE'} - \frac{d^2\sigma^{(\downarrow\rightarrow)}}{d\Omega\, dE'} = \frac{4\alpha^2 E'}{Q^2 E} E' \sin\theta \cos\phi \left[M\, \boldsymbol{G_1}(\nu, Q^2) + 2E\, \boldsymbol{G_2}(\nu, Q^2) \right]$$

Why is g_2 interesting?

- tests <u>twist-3</u> effects = *quark-gluon* correlations
- higher twist corrections to g_1 with 3rd moment d_2 matrix element
- test of lattice QCD, QCD sum rules, quark models from moments
- polarizabilities of color fields (with twist-4 matrix element f_2)
    - magnetic $\chi_B = (4d_2 + f_2)/3$ and electric $\chi_E = (4d_2 - 2f_2)/3$.
- 3rd moment related to color Lorentz force on transverse polarized quark (M. Burkardt, AIP Conf.Proc. 1155 (2009) 26)
    - sign of d_2 related to sign of transverse deformation (anomalous κ^q)
- contains chiral odd twist-2 = quark transverse spin (mass term)
    - test quark masses (covariant parton models)

g_2 and g_T Spin Structure Functions

Experimentally measured quantities

$$g_T(x) = g_1(x) + g_2(x) = \frac{1}{2}\sum e_q^2 g_T^q(x)$$

Decomposition of g_T^q and TMD distributions [1]

$$g_T(x) = \int d^2\vec{k}_t \frac{\vec{k}_t^2}{2M^2}\frac{\boldsymbol{g_{1T}^q}(x,\vec{k}_t^2)}{x} + \frac{m}{M}\frac{h_1(x)}{x} + \tilde{g}_T(x)$$

twist-3 TMD quark mass term qgq interaction

Applying twist-2 Wandzura-Wilczek approximation of g_2

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

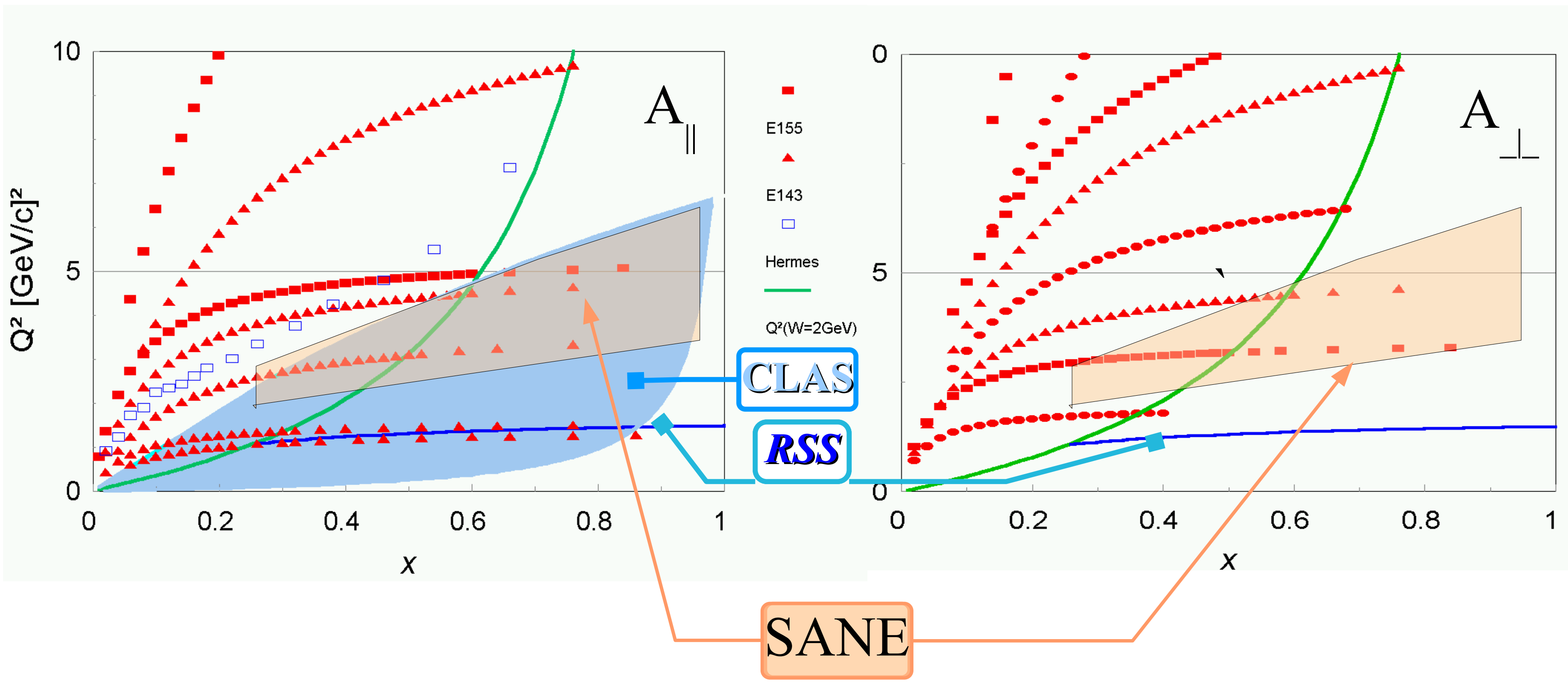
$$g_T(x) = \int_x^1 dy \frac{g_1(y)}{y} + \frac{m}{M}\left[\frac{h_1(x)}{x} - \int_x^1 \frac{dy}{y}\frac{h_1(y)}{y}\right] + \tilde{g}_T(x) - \int_x^1 \frac{dy}{y}\left(\tilde{g}_T(y) - \hat{g}_T(y)\right)$$

Twist-3 for the nucleon (neglecting quark mass)

$\bar{g}_2 = \frac{1}{2}\sum e_q^2\left[\tilde{g}_T^q - \int_x^1 \frac{dy}{y}\left(\tilde{g}_T^q(y) - \hat{g}_T^q(y)\right)\right]$; $\tilde{g}_T = qg$ term, $\hat{g}_T$ = Lorentz invariance [2]

[1] hep-ph/9408305v1
[2] JHEP 0911 (2009) 093

Proton world $A_{\parallel}$, $A_{\perp}$ data before SANE



- Two beam energies: 5.9 GeV, 4.7 GeV
- Very good high ***x*** coverage with detector at 40°

Experiment

Spin Asymmetries of the Nucleon Experiment
(TJNAF E07-003)

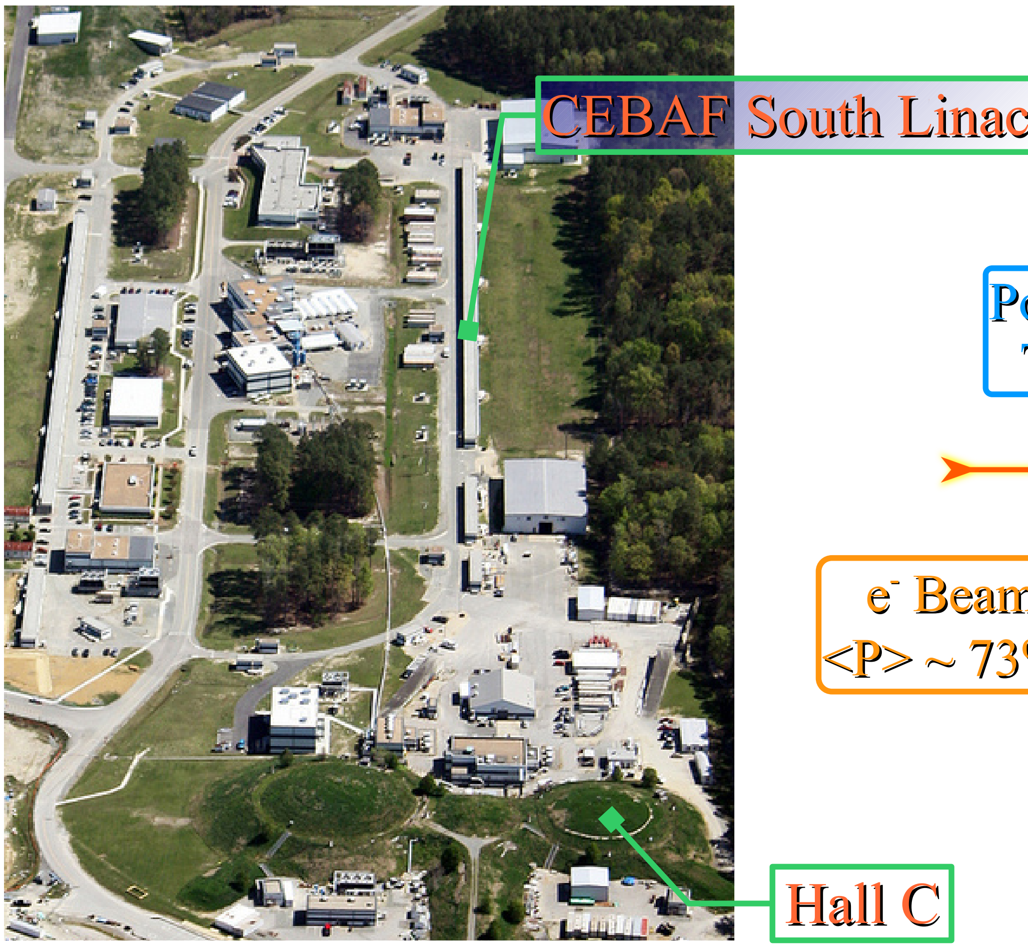
SANE Collaboration
Argonne National Lab., Christopher Newport U., Florida International U.,
Hampton U., Jefferson Lab., U. of New Hampshire, Norfolk S. U.,
North Carolina A&T S. U., Mississippi S. U., Ohio U., IHEP - Protvino, U. of Regina,
Rensselaer Polytechnic I., Rutgers U., Seoul National U., Southern U. New Orleans,
Temple U., Tohoku U., U. of Virginia , Yerevan Physics I., Xavier U.

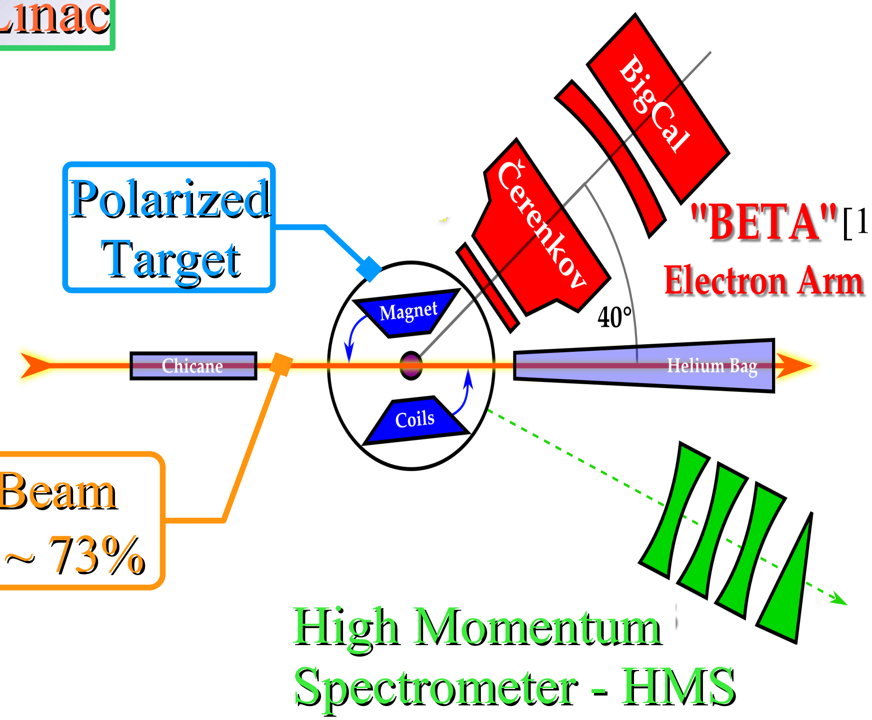
Spokespersons:
S. Choi (Seoul), M. Jones (JLab), Z-E. Meziani (Temple), O. A. Rondon (U. of Virginia)

Goal: Measure the proton spin structure function $\boldsymbol{g_2(x, Q^2)}$ and spin asymmetry $\mathbf{A_1}\,\boldsymbol{(x, Q^2)}$ for $2.5 \leq \boldsymbol{Q^2} \leq 6.5$ GeV² and $0.3 \leq \boldsymbol{x} \leq 0.8$

Method: Measure inclusive spin asymmetries for two orientations of target spin relative to beam helicity (anti-parallel and near-perpendicular), detect electrons with novel large solid angle electron telescope **BETA**

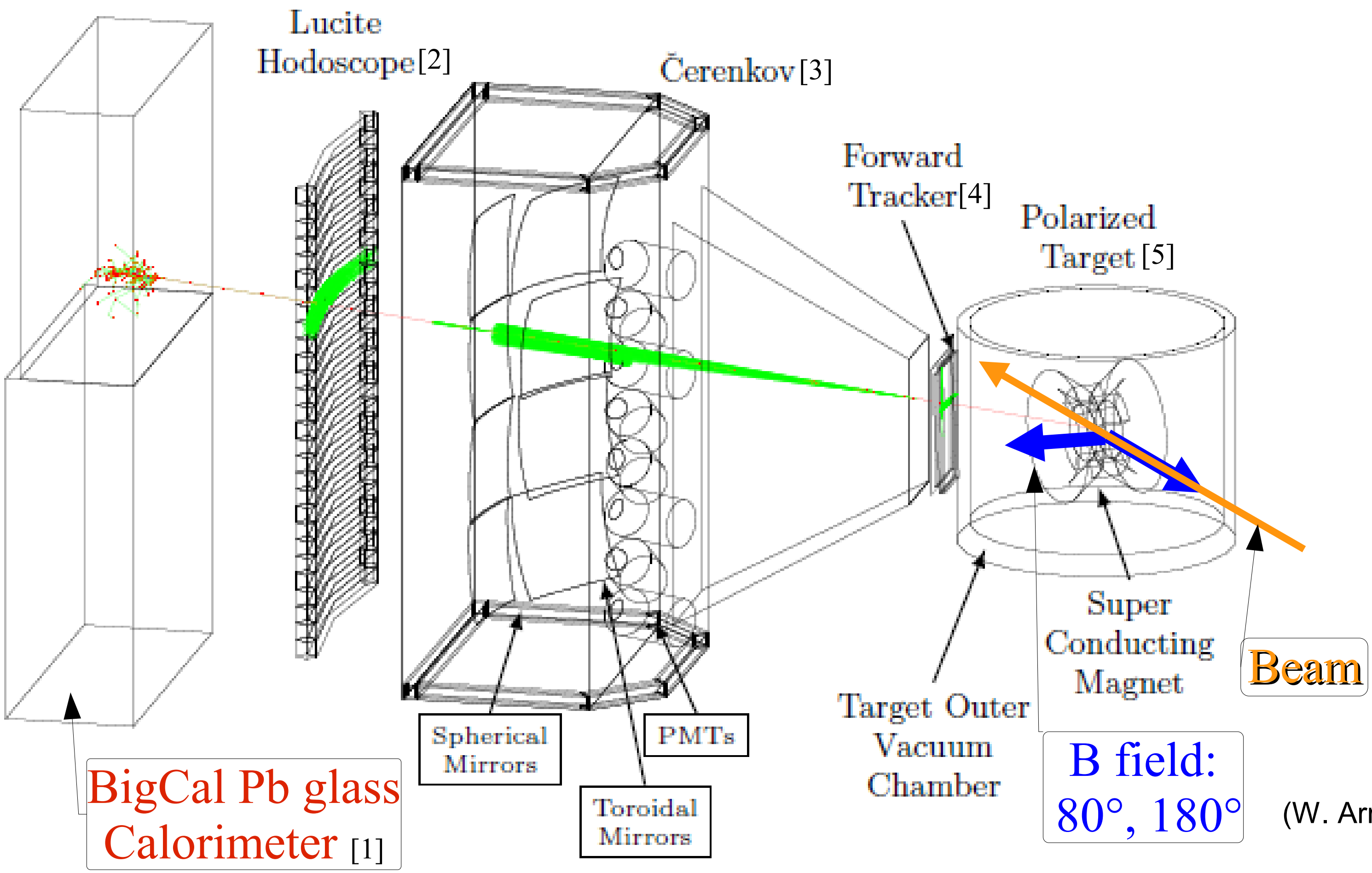
SANE Layout in JLab's Hall C





[1] Big Electron Telescope Array
$\Delta\Omega \sim 190$ msr; $\Delta\theta = \pm 10°$

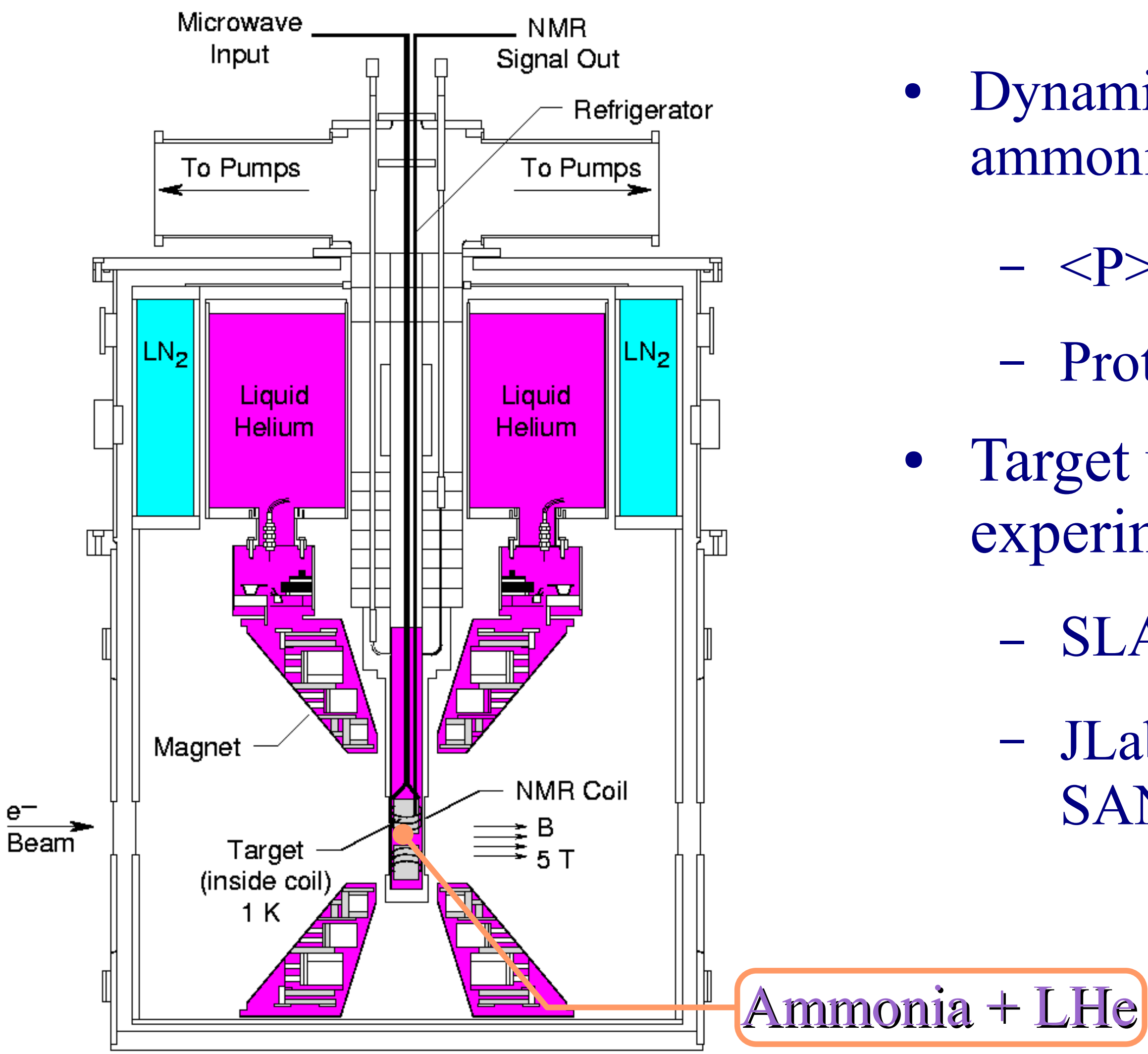
BETA with DIS electron simulation



(W. Armstrong)

[1] BigCal Collaboration
[2] North Carolina A&T U.
[3] Temple U
[4] Norfolk State U. and U. of Regina
[5] UVA- JLab

Polarized Target



- Dynamic Nuclear Polarized ammonia $^{14}NH_3$ at 5T and 1K
  - <P> ~ 70% in beam
  - Proton luminosity ~10^{35} Hz cm^{-2}
- Target used in multiple experiments:
  - SLAC: E143, E155, E155x (g_2)
  - JLab: GEn98, GEn01, *RSS*, SANE

Data

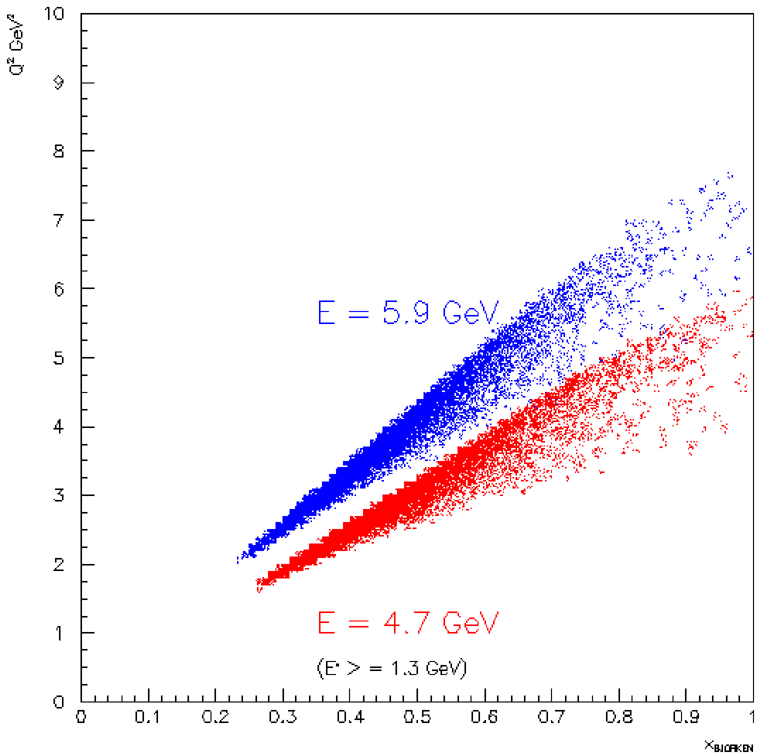
DATA

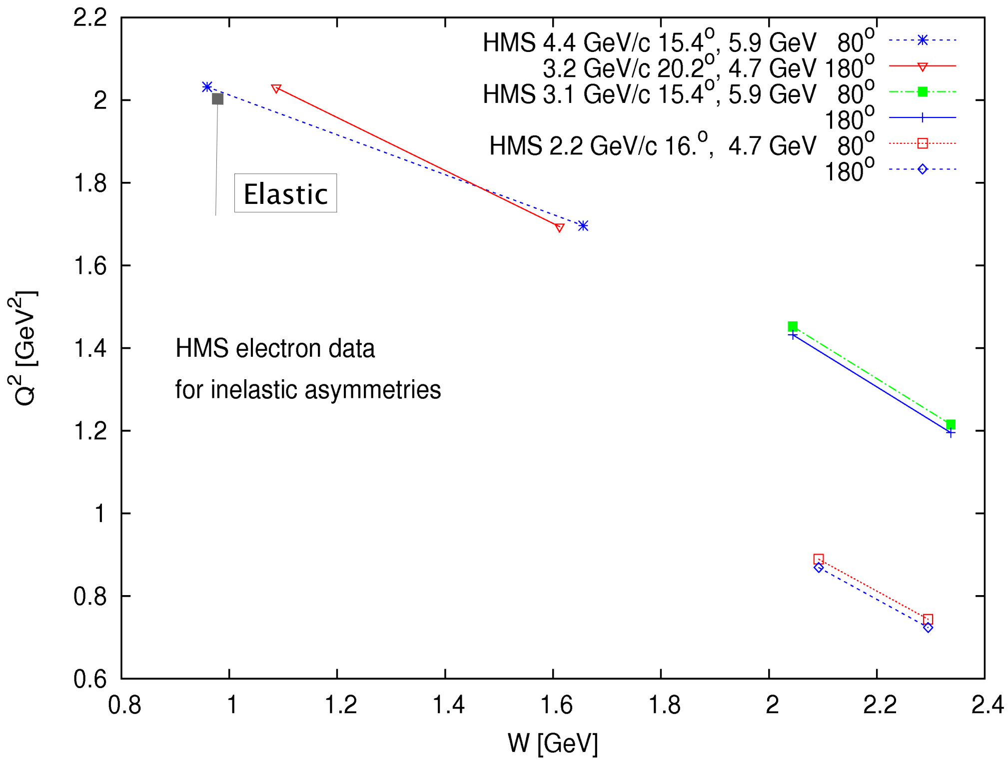
Detector	Detected particle	Scattering Type	Beam Energy [GeV]	Field Direction	Target
BETA	*e*, π^0	Inclusive inelastic	5.9, 4.7	180°, 80°	NH3
HMS	*e*	Inclusive inelastic	5.9, 4.7	180°, 80°	NH3 C, LHe [1]
		Inclusive elastic	5.9	80°	NH3
BETA - HMS	*e* - *p*	Coincidence elastic	5.9	80°	NH3

[1] Unpolarized, for dilution factor

- Data taken in January - March 2009

BETA and HMS data





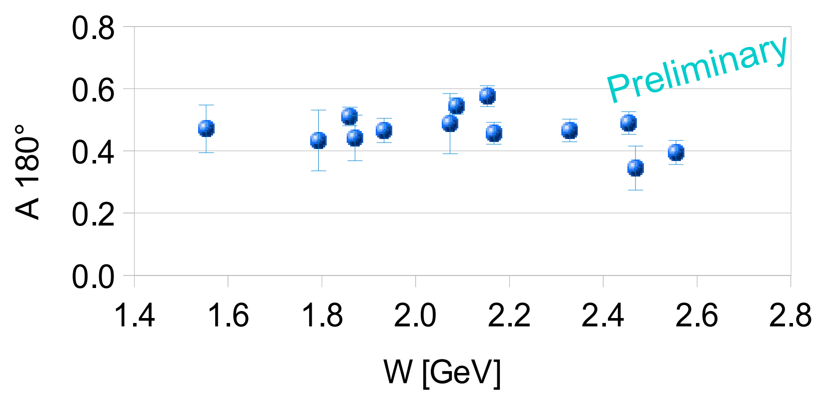
- $Q^2 - x$ phase space of BETA's 80° data
  - cut on E' ≥ 1.3 GeV
- Central kinematics of HMS inclusive asymmetry data

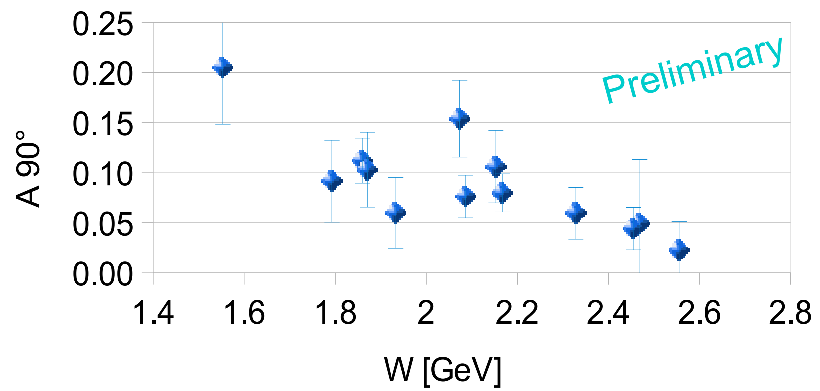
Measured Asymmetries A(80°), A(180°)

$$A_m = \frac{\epsilon}{f\,P_b P_t C_N}; \quad \epsilon = \frac{N^- - N^+}{N^- + N^+}$$

$$A_{phys} = \frac{1}{f_{rc}}\left(\frac{A_m - f_b A_b}{1 - f_b}\right) + A_{rc}$$

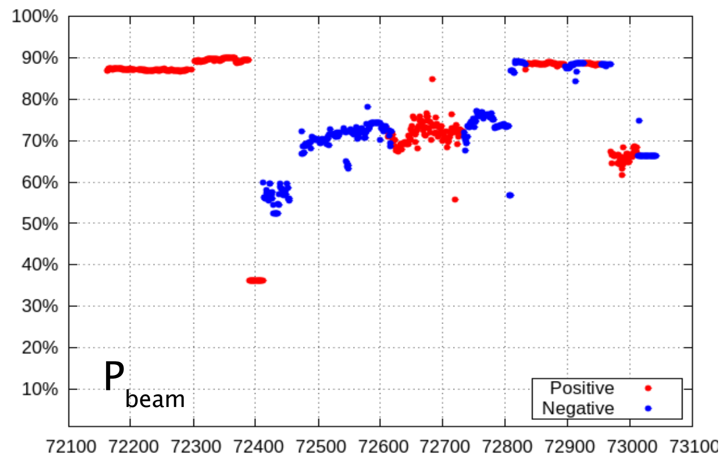
- $N^{+,-}$ = charge normalized, dead time corrected yields
- P_b, P_t = beam, target polarizations
- f = polarized dilution factor
- C_N = ^{14}N polarization correction
- A_b, f_b = background corrections
- A_{rc}, f_{rc} = radiative corrections

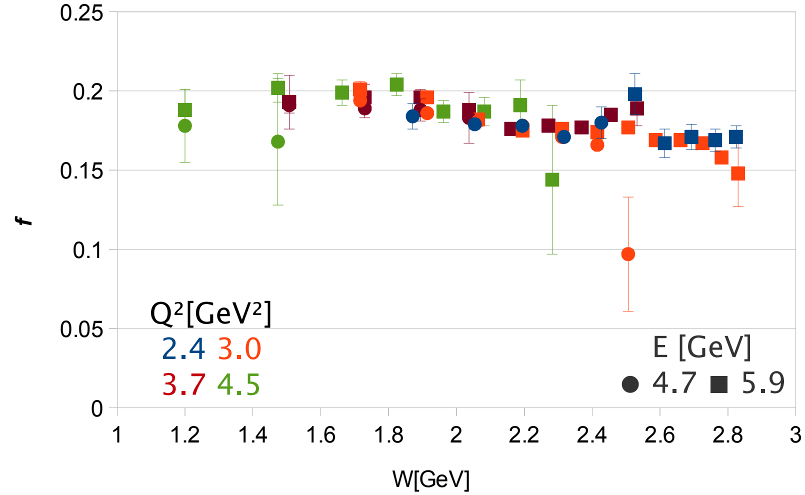


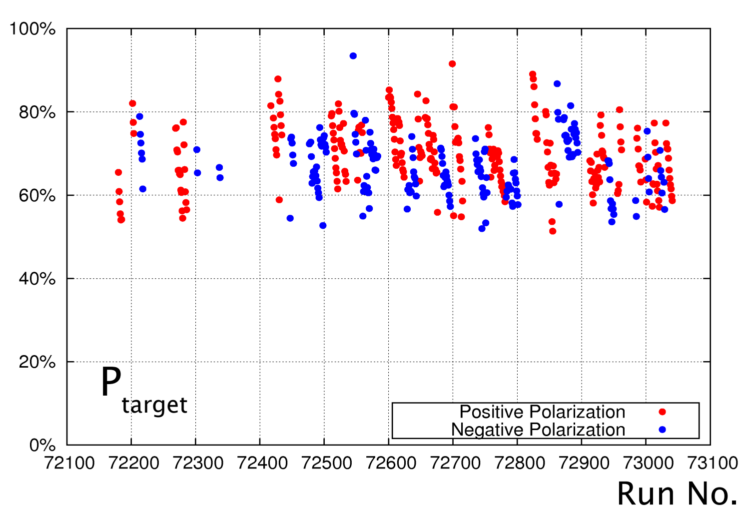


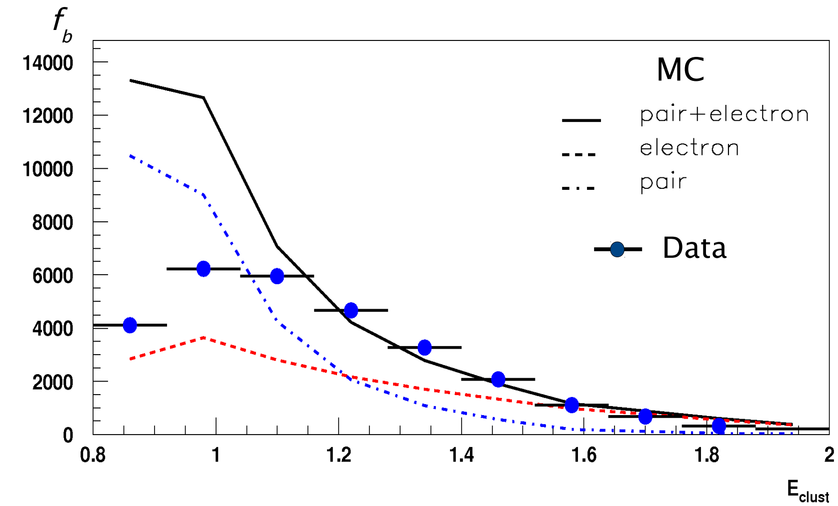
$$A_\perp = (A_{180}\cos 80 + A_{80})/\sin 80$$

Sample of Normalizations and corrections









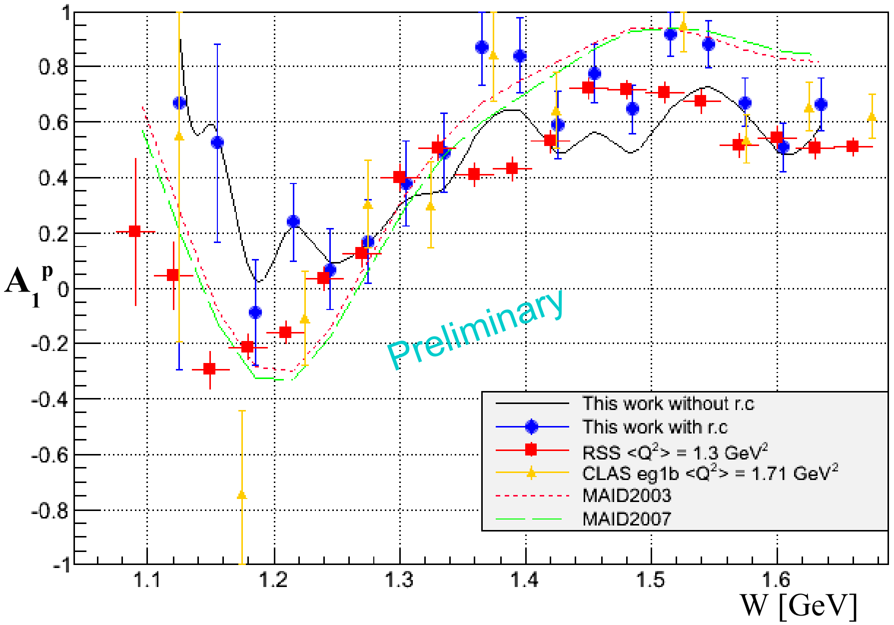
Preliminary Results

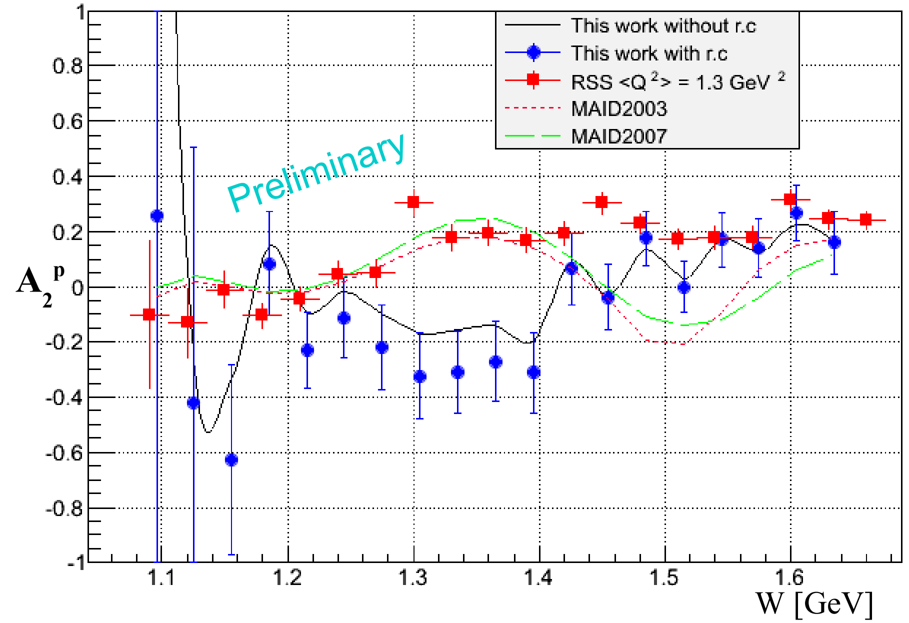
Spin Asymmetries A_1 and A_2

- HMS single arm data in the resonances, <Q²>=1.8 GeV²
  - Model independent separation from measured asymmetries

$$A_1 = \frac{1}{D'}\left(\frac{E - E'\cos\theta}{E+E'} A_{180} + \frac{E'\sin\theta}{(E+E')\cos\phi} \frac{A_{180}\cos 80° + A_{80}}{\sin 80°} \right)$$

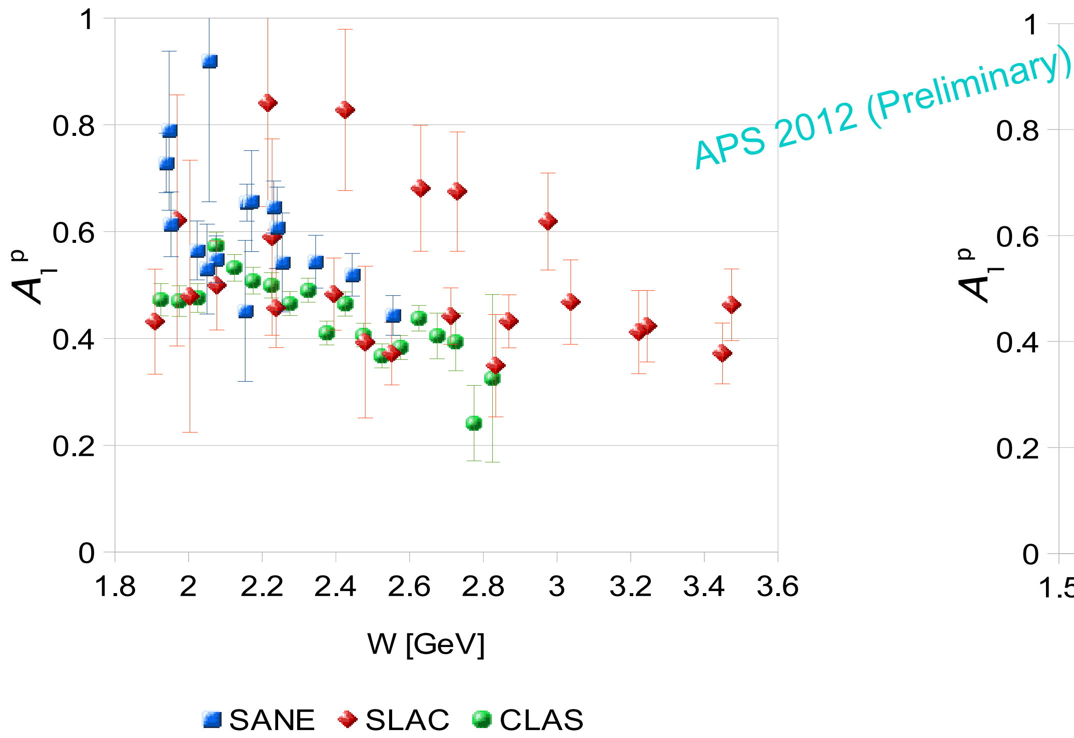
$$A_2 = \frac{1}{D'}\frac{1}{2E}\left(\sqrt{Q^2} A_{180} - \sqrt{Q^2} \frac{E - E'\cos\theta}{E'\sin\theta\cos\phi} \frac{A_{180}\cos 80° + A_{80}}{\sin 80°} \right)$$

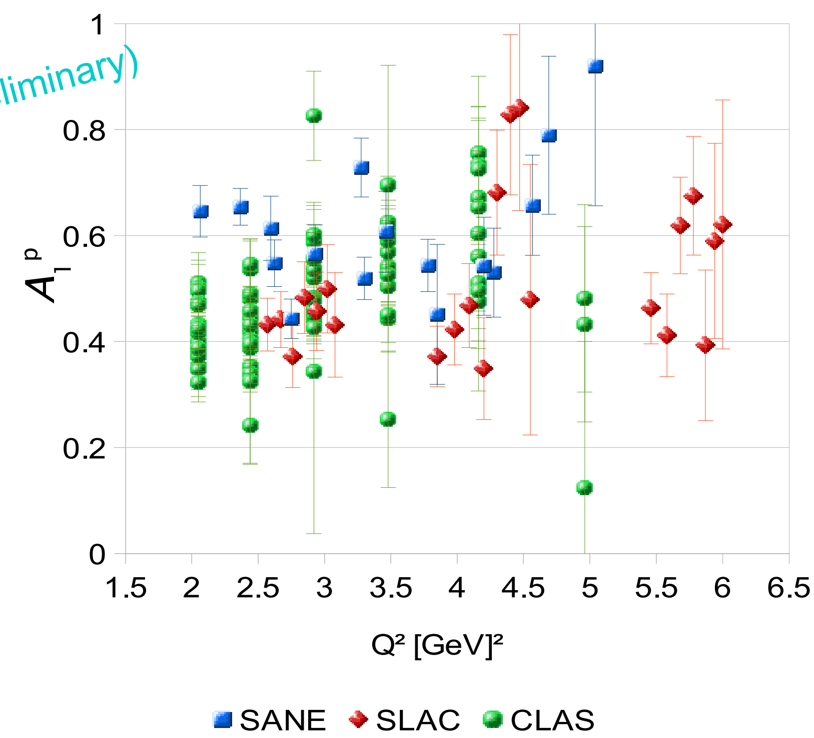




(H-y. Kang)

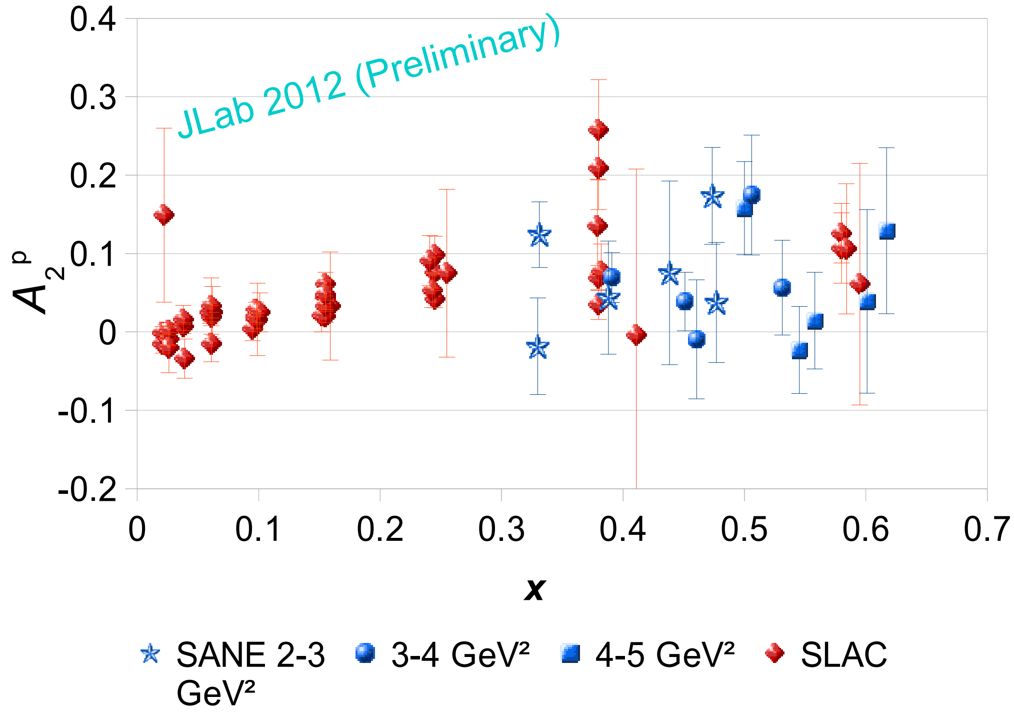
DIS Spin Asymmetry A_1





- Statistical errors only
- CLAS data of same W but different Q^2 are merged in $A_1^p(W)$

DIS Spin Asymmetry A_2

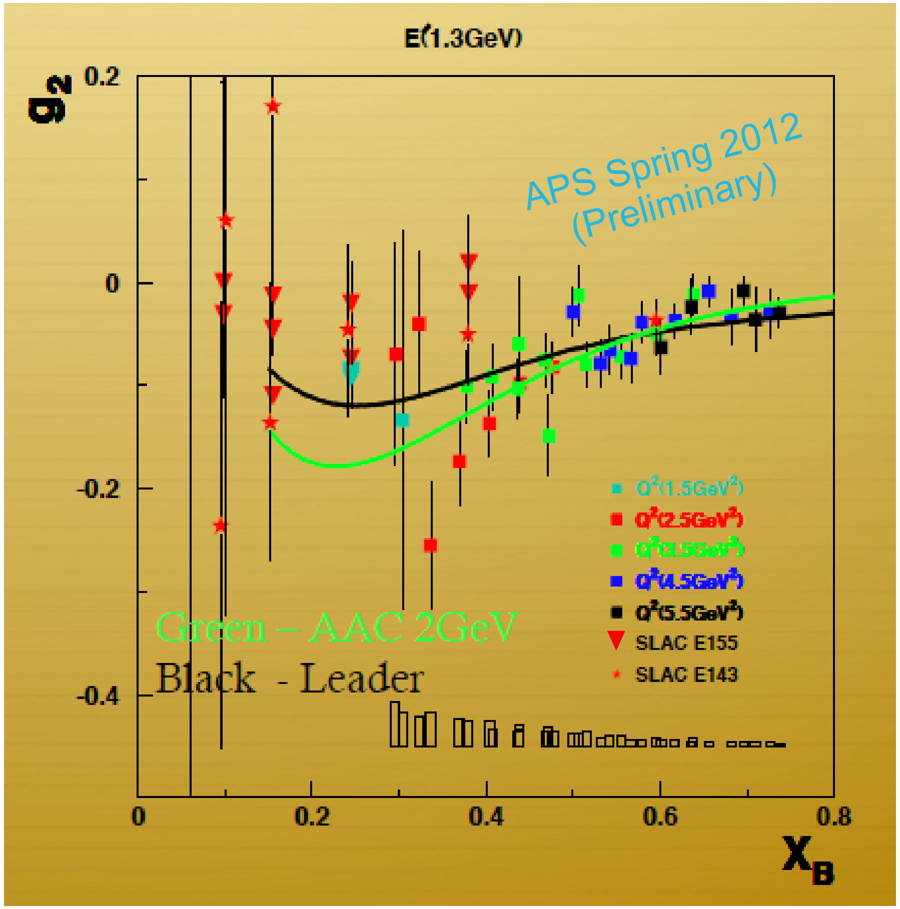


- DIS A_2^p not zero is signal of parton transverse momentum
  - connection to transverse twist-3 TMD $g_{1T}^{\perp}$ $\quad g_2(x) = \frac{d}{dx} g_{1T}^{(1)}(x) + \hat{g}_T(x)$

g_2 in DIS and Resonances

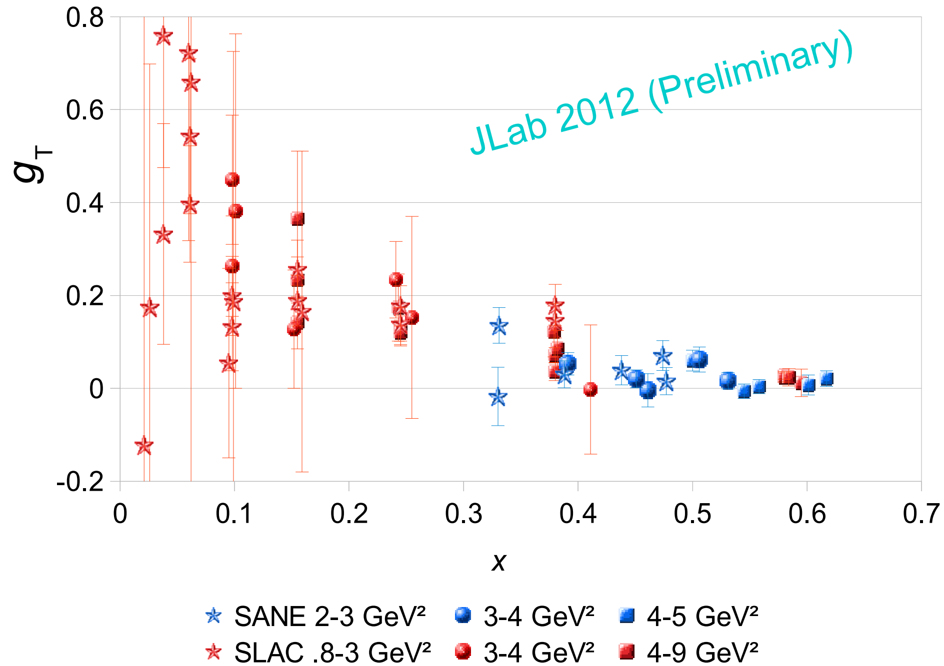
- BETA proton data
  - DIS and resonances

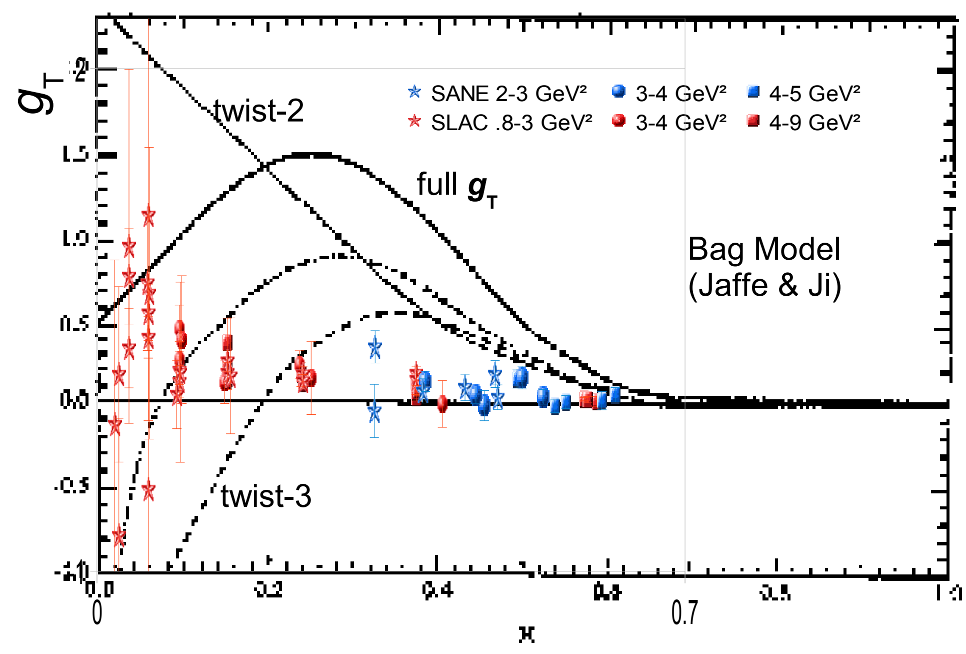
    $0.3 < x < 0.8$, $2.5 < Q^2 < 6.$, $E' \geq 1.3$ GeV (more data available down to 0.9 GeV)
  - Twist-2 $g_2^{WW}(2\ \text{GeV}^2)$ from PDF's (AAC03, LSS06)
- SLAC E143 and E155 DIS data



(H. Baghdasaryan)

DIS Transverse Spin SF g_T^p



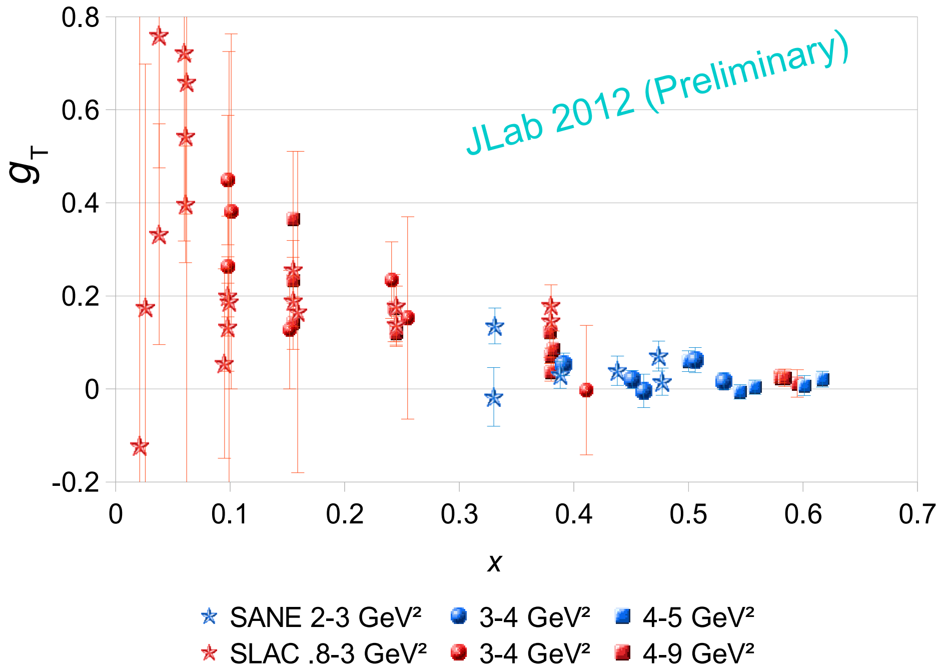


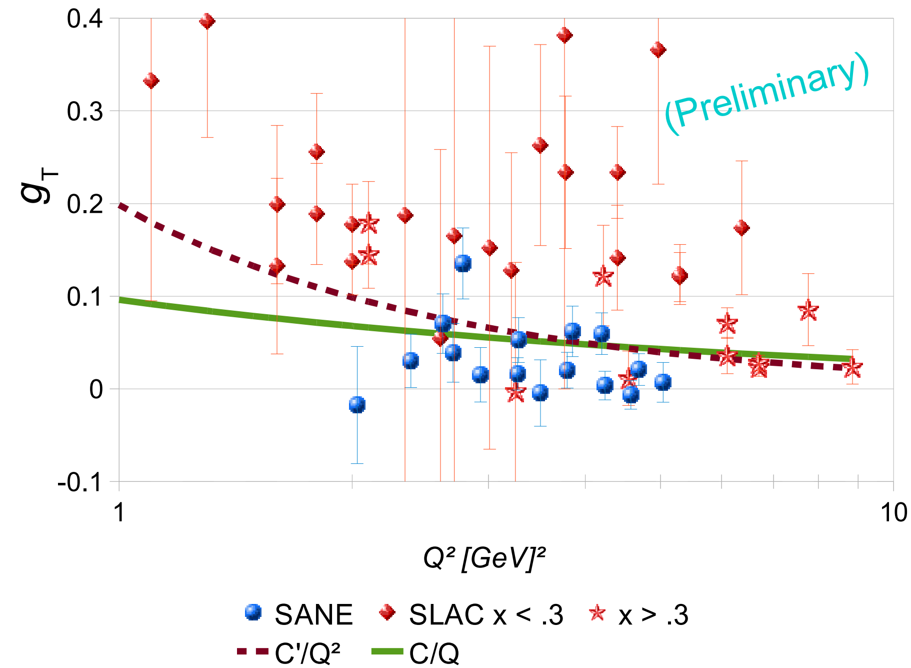
Tangerman & Mulders hep-ph/9408305v1

- $g_T^p = F_1 A_2/\gamma$ measures spin distribution normal to γ^*
- SANE $\langle g_T^p(x>.3)\rangle = 0.023 \pm 0.006$

- Bag Model (1990's)
  - Data scaled × 2.5
  - Model updates needed

DIS Transverse Spin SF g_T^p





- $g_T^p = F_1\, A_2 / \gamma$ measures spin distribution normal to γ^*
- SANE $\langle g_T^p(x > .3)\rangle = 0.023 \pm 0.006$
- g_T evolution non-trivial: no NLO simplification (NPB 608 (2001) 235)
- d_2's pQCD evolution is known (Shuryak-Vainshtein)

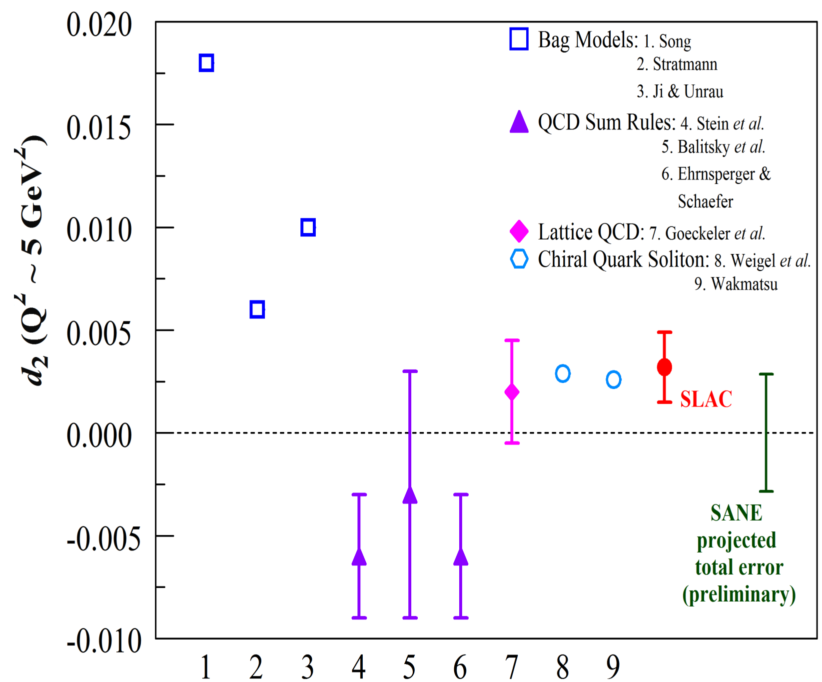
Operator Product Expansion for Spin SF's

- OPE connects SF's Cornwall-Norton moments to twist-2, twist-3 matrix elements $\boldsymbol{a}_N$, $\boldsymbol{d}_N$

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

$$\int_0^1 x^N g_2(x,Q^2)\,dx = \frac{N(\boldsymbol{d}_N - \boldsymbol{a}_N)}{2(N+1)} + tmc,\ N = 2,4,..$$

(tmc: target mass corrections)



SANE's measured C-N $\boldsymbol{d}_2$
(all data $E' > 1.3\,\mathrm{GeV}$, $W > 2\,\mathrm{GeV}$.
Only projected error shown.)

- At moderate Q^2 Nachtmann moments are needed to get dynamic twist-3 free of *tmc*

$$\boldsymbol{d}_2(Q^2) = \int_0^1 dx\,\xi^2\left(2\frac{\xi}{x}g_1 + 3\left(1 - \frac{\xi^2 M^2}{2Q^2}\right)g_2\right) \Rightarrow_{Q^2\to\infty} \int_0^1 dx\,x^2(2g_1 + 3g_2)$$

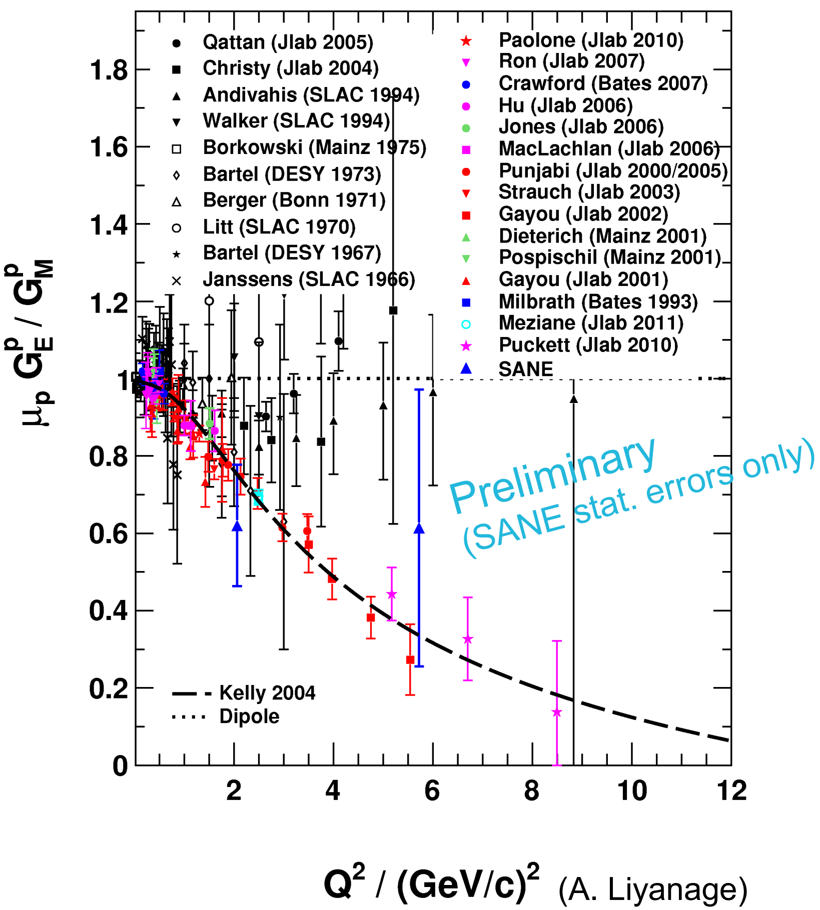
G_E^p/G_M^p from inclusive and coincidence data

Ratio from:

- Inclusive HMS *e* data at $Q^2 = 2.06$ GeV²
  - $A_{el}^p = -0.20 \pm 0.02$
  - $G_E^p/G_M^p = 0.60 \pm 0.18 \pm 0.06$

    (statistical + systematic error)
- BETA–HMS *e*–*p* coincidences at $Q^2 = 5.66$ GeV²
  - $G_E^p/G_M^p = 0.67 \pm 0.36$

    (statistical error only)



SANE Status and Plans

- DIS $\boldsymbol{g_T}^p = \boldsymbol{g_1} + \boldsymbol{g_2}$ – working on improved low x systematics
- Moments of $\boldsymbol{g_1}$, $\boldsymbol{g_2}$, twist-3 matrix element $\boldsymbol{d_2}$
  - working on extending x range, optimized binning to try $\boldsymbol{d_2}(Q^2)$
- Spin Asymmetries $\boldsymbol{A_1}$, $\boldsymbol{A_2}$
  - BETA – parameterizing W and Q^2 dependence for world data fits
  - HMS inelastic asymmetries – finalizing radiative corrections
- Ratio of elastic form factors – publication in preparation
- Three PhD degrees awarded (UVA: J. Maxwell, J. Mulholland; Hampton: A. Liyanage), three more coming (Temple: W. Armstrong; Seoul National: H. Kang; Mississipi State: L. Ndukum)
  - Long paper draft in progress

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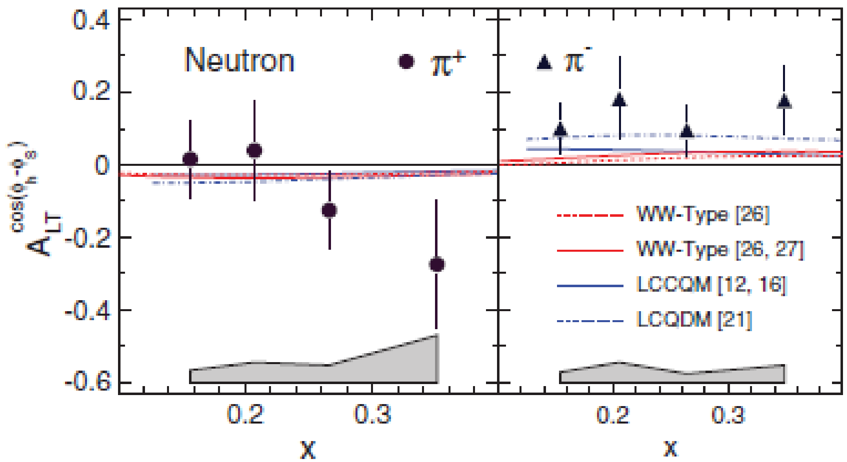
Extras

Double Spin SIDIS A_{LT}

- $g_{1T}^{\perp}(x, \boldsymbol{k_t})$ is chiral-even TMD for quarks with longitudinal helicity in a transverse polarized target
- Weighted by $\boldsymbol{k_t}^2/2M^2$ and integrated over k_t, generates a $\cos(\phi-\phi_s)$ azimuthal A_{LT}, measurable in SIDIS



Hall A E06-010,
PRL 108 (2012) 05200

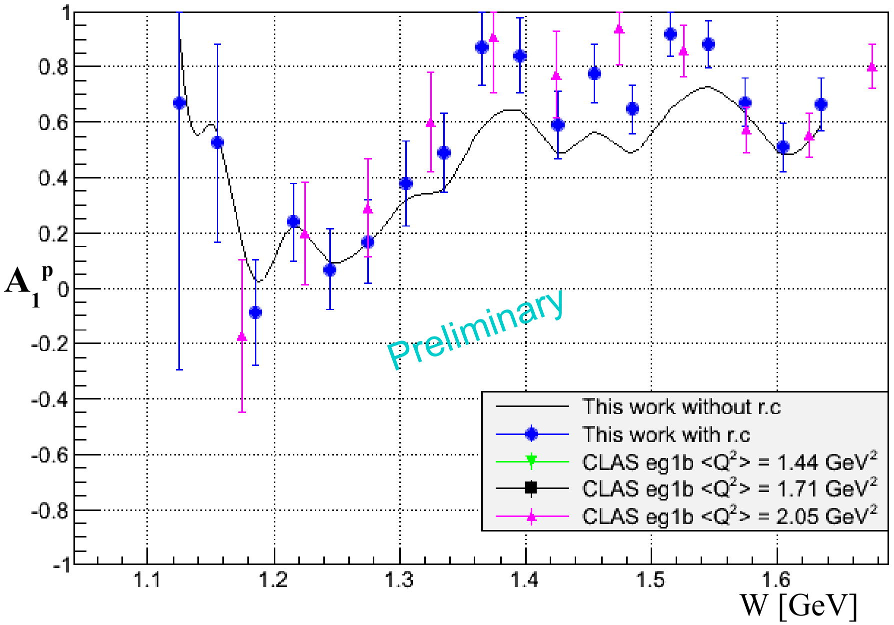
$$\frac{A_{LT}(x,y,z)}{(|\vec{P}_T|/M)\cos(\phi-\phi_s)} = \frac{C(x,y)\sum e^2 \boldsymbol{g_{1T}^{(1)(x)}} D^h(z)}{C'(x,y)\sum e^2 f_1(x) D^h(z)}$$

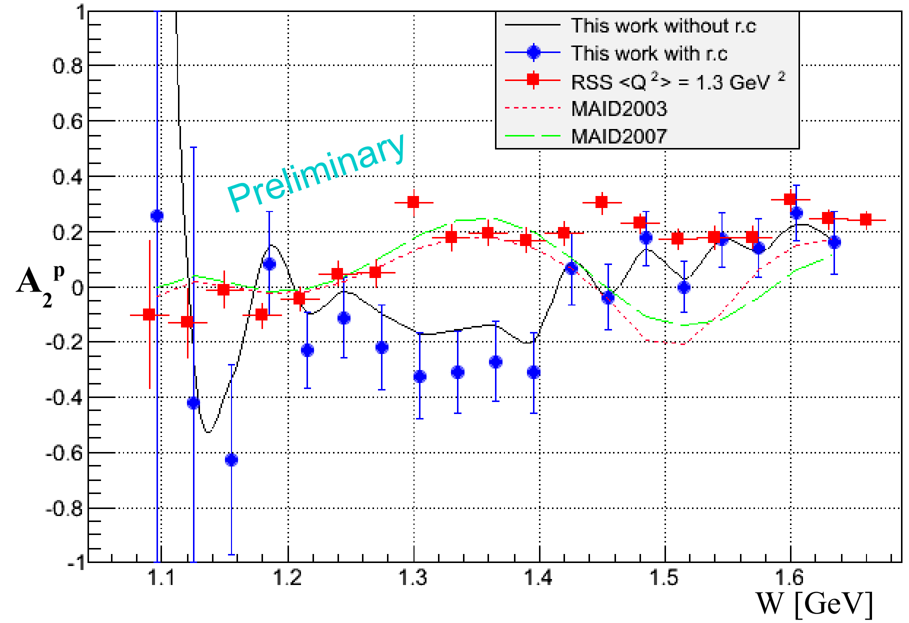
Spin Asymmetries A_1 and A_2

- HMS single arm data in the resonances, <Q²>=1.8 GeV²
  - Model independent separation from measured asymmetries

$$A_1 = \frac{1}{D'}\left(\frac{E-E'\cos\theta}{E+E'}A_{180} + \frac{E'\sin\theta}{(E+E')\cos\phi}\frac{A_{180}\cos 80° + A_{80}}{\sin 80°}\right)$$

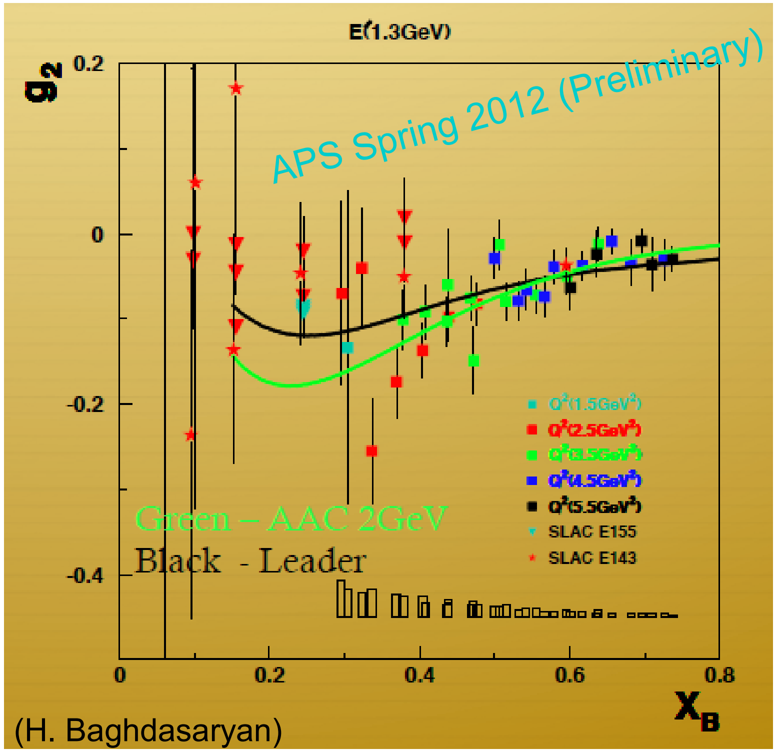
$$A_2 = \frac{1}{D'}\frac{1}{2E}\left(\sqrt{Q^2}A_{180} - \sqrt{Q^2}\frac{E-E'\cos\theta}{E'\sin\theta\cos\phi}\frac{A_{180}\cos 80° + A_{80}}{\sin 80°}\right)$$

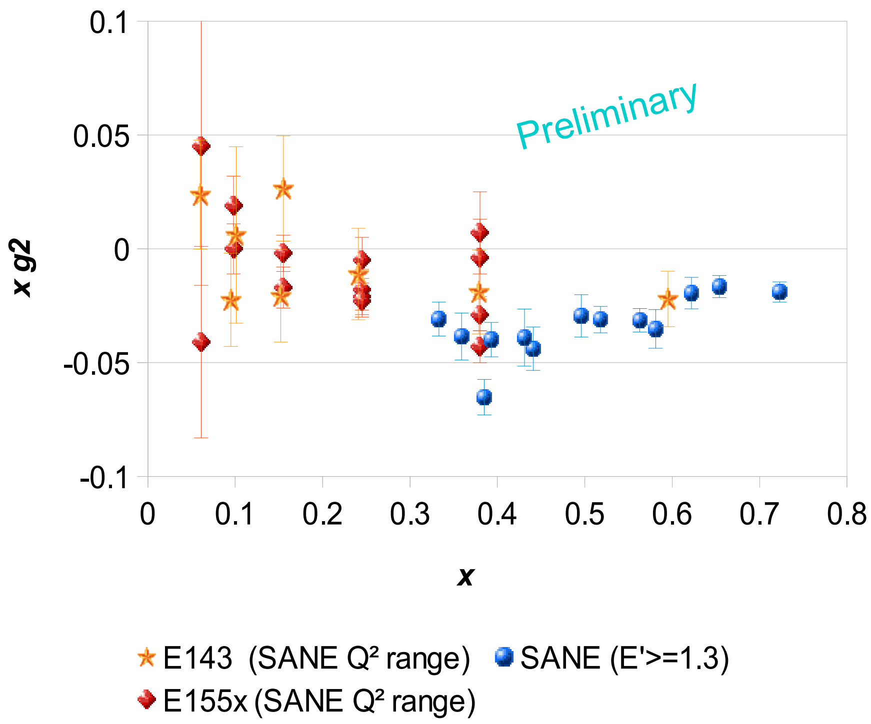




(H-y. Kang)

g_2 in DIS and Resonances

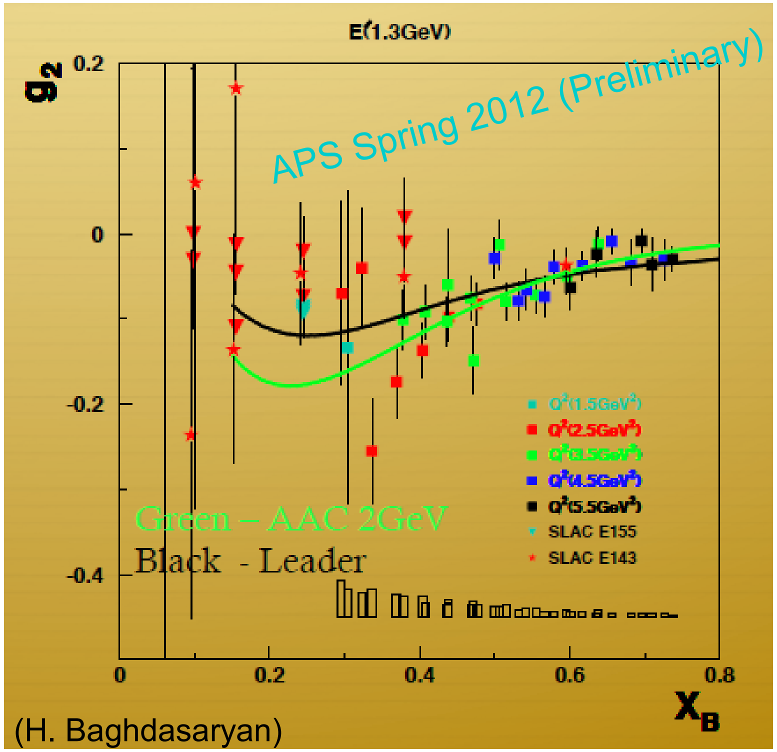


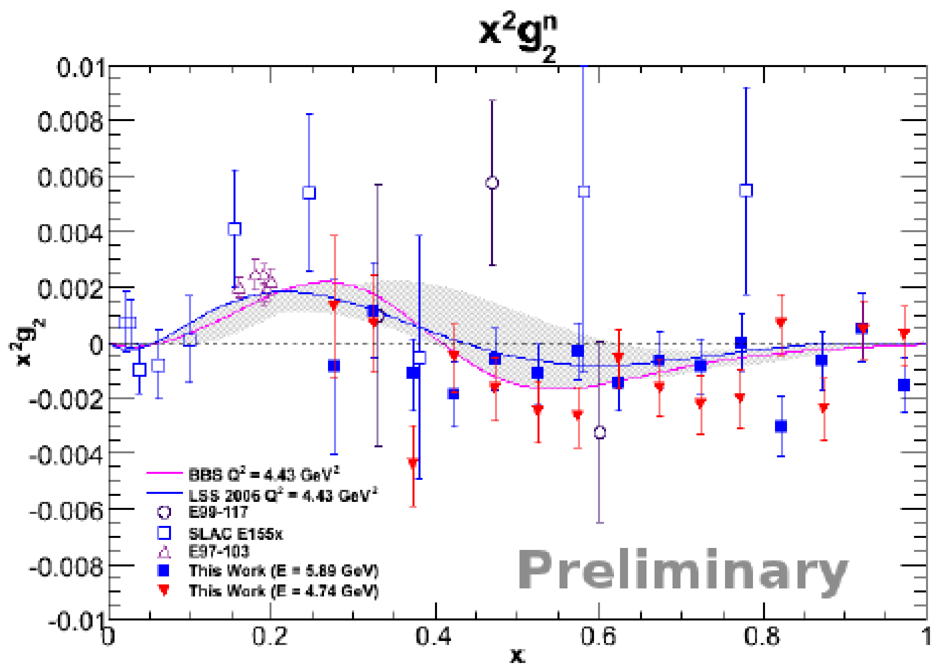


- Proton (NH_3)
  - Hall C SANE (E07-003)
  - $0.3 < x < 0.8 \quad 2.5 < Q^2 < 6.5$

- SLAC $x\, g_2$($2 < Q^2 < 6$ GeV²)
- Total errors SANE & E143, statistical only E155x

g_2 in DIS and Resonances





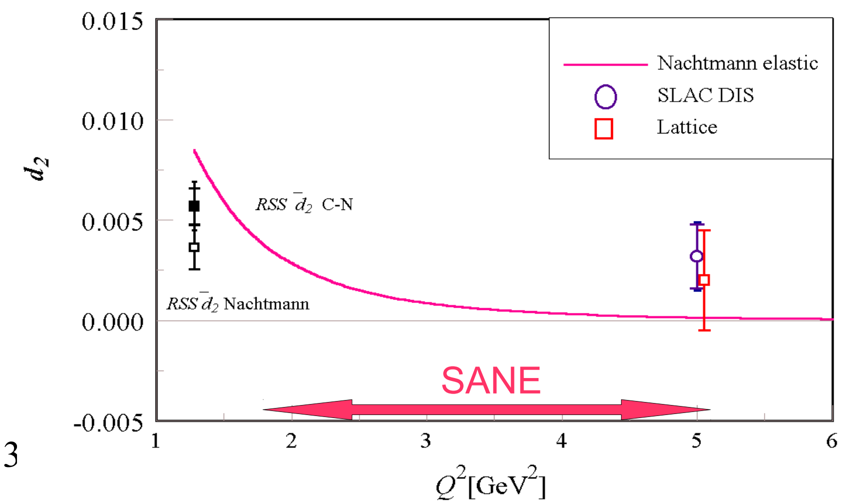
(M. Posik) (No external radiative corrections)

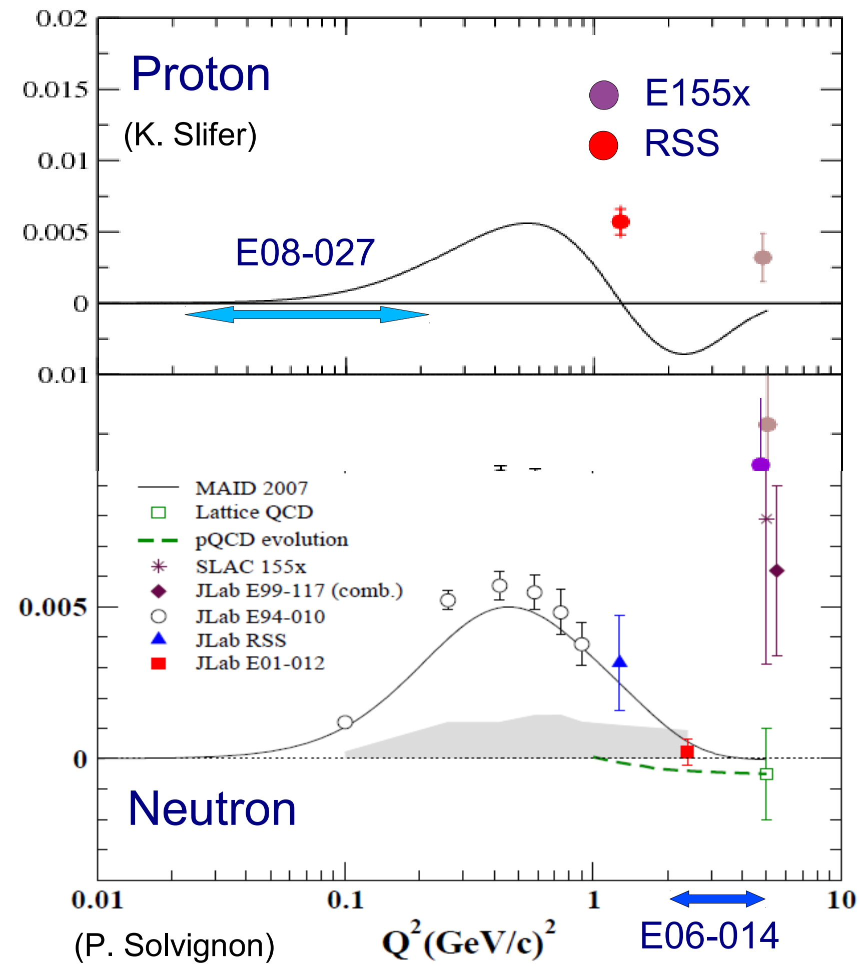
- Proton (NH_3)
  - Hall C SANE (E07-003)
  - $0.3 < x < 0.8 \quad 2.5 < Q^2 < 6.5$
- Neutron (on ^{3}He)
  - Hall A d2n (E06-014)
  - 4.7 and 5.9 GeV beam

Resonances d_2

- Plots show contribution of resonances to d_2 CN integral
  - Data with $Q^2 < \sim 4$ GeV^2 need Nachtmann integrals
  - Add Nachtmann elastic: dominant at $Q^2 < 2$ GeV^2

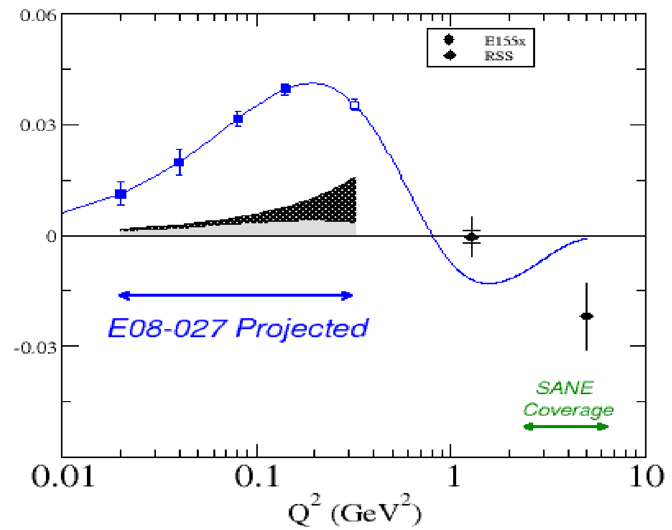
(E155x, E99-117 DIS too)

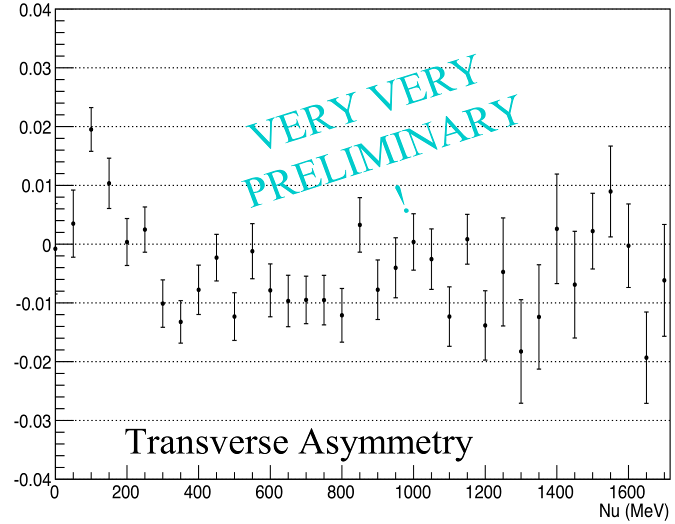




g_2^n at Low Q^2 – E08-027

- Goals:
  - BC Sum Rule: violation suggested for proton at large Q^2, but found satisfied for the neutron and ^{3}He.
  - Spin Polarizability: Major failure (>8σ) of χPT for neutron δ_{LT}. Need g_2 isospin separation to solve.
  - Hydrogen Hyper Fine Splitting and Proton Charge Radius: Lack of knowledge of g_2 at low Q^2, is one of the leading uncertainties (E08-007)
- Took data in 2012. Analysis in progress

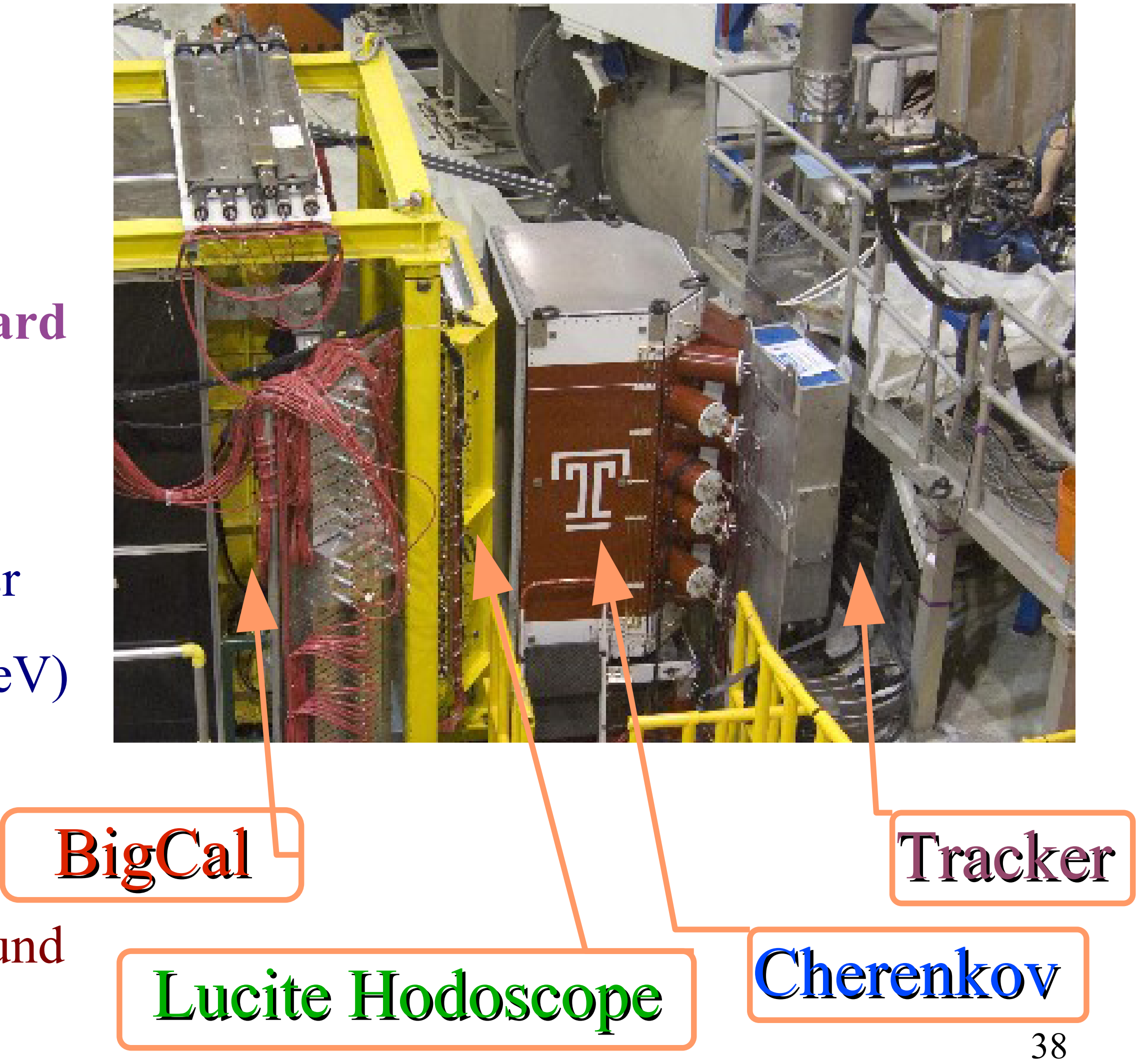




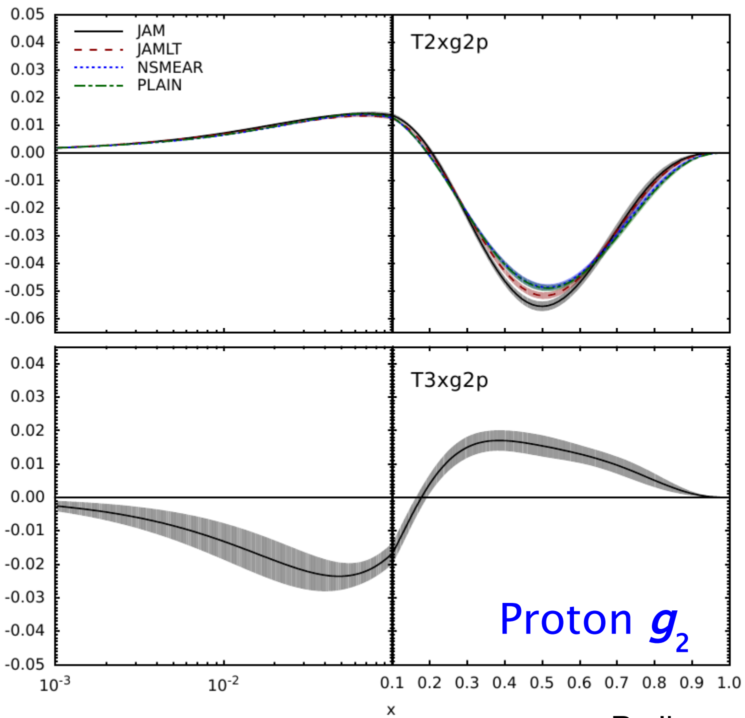
(K. Slifer)

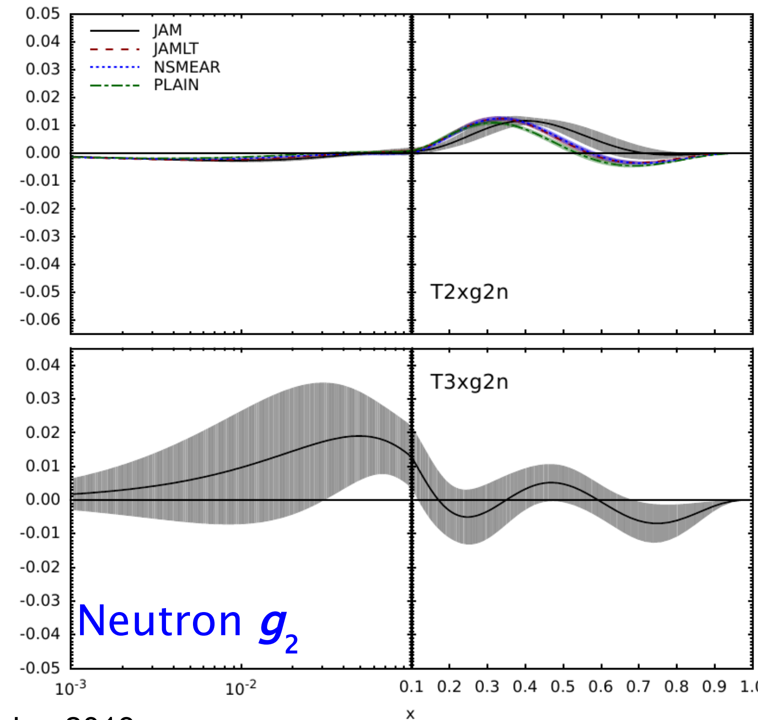
Big Electron Telescope Array – BETA

- BigCal lead glass calorimeter: main detector used in *GEp-III.*
- Tracking **Lucite hodoscope**
- **Gas Cherenkov:** pion rejection
- Tracking fiber-on-scintillator **forward hodoscope**
- BETA specs
  - Effective solid angle = 0.194 sr
  - Energy resolution 10%/$\sqrt{E}$(GeV)
  - 1000:1 pion rejection
  - angular resolution ~ 1 mr
- Target field sweeps low *E* background
  - 180 MeV/c cutoff



Jefferson Angular Momentum – JAM Collaboration





P. Jimenez- Delgado APS Spring 2013

- Joint theorists and experimentalists effort to "*study the quark and gluon spin structure of the nucleon by performing global fits of PDFs*".
- JAM's spin PDFs are tailored for studies at large Bjorken *x*, as well as the resonance-DIS transition region at low and intermediate ***W*** and ***Q***²^{2}.
  http://wwwold.jlab.org/theory/jam/

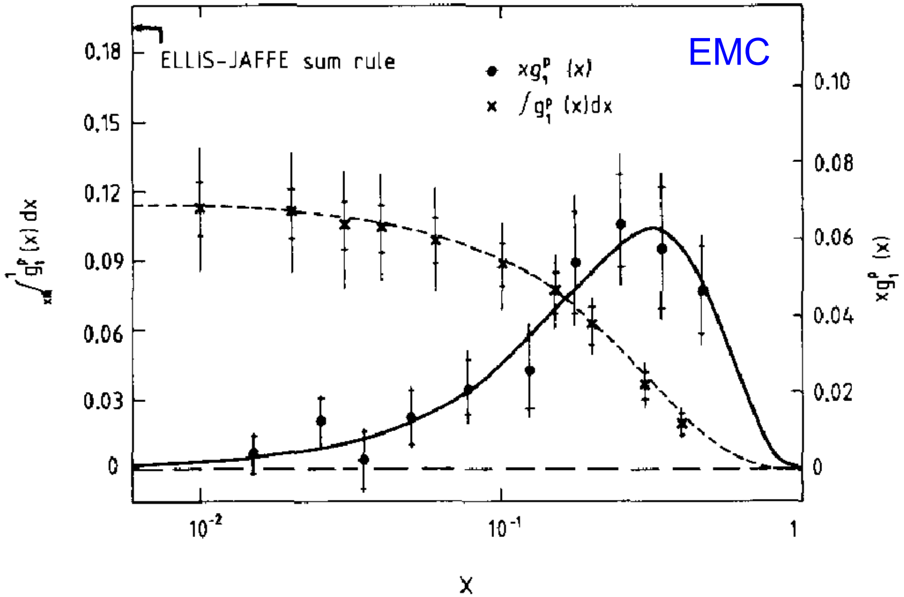
Nucleon Spin "Crisis"

- Nucleon spin is calculated from the first moment of $\boldsymbol{g_1}$

$$\int_0^1 dx\, g_1^p(x) = \frac{1}{36}\left[4E_0 \boldsymbol{a_0} + 3E_3 a_3 + E_8 a_8\right]$$

$$\boldsymbol{a_0} = \sum q = \Delta u + \Delta d + \Delta s$$

- Singlet axial-vector matrix element $\boldsymbol{a_0}$ is sum of quark spins: $\boldsymbol{a_0 = 0.33 \pm .03 \pm .05}$ (COMPASS 2007)



(PL B206, 364 (1988))

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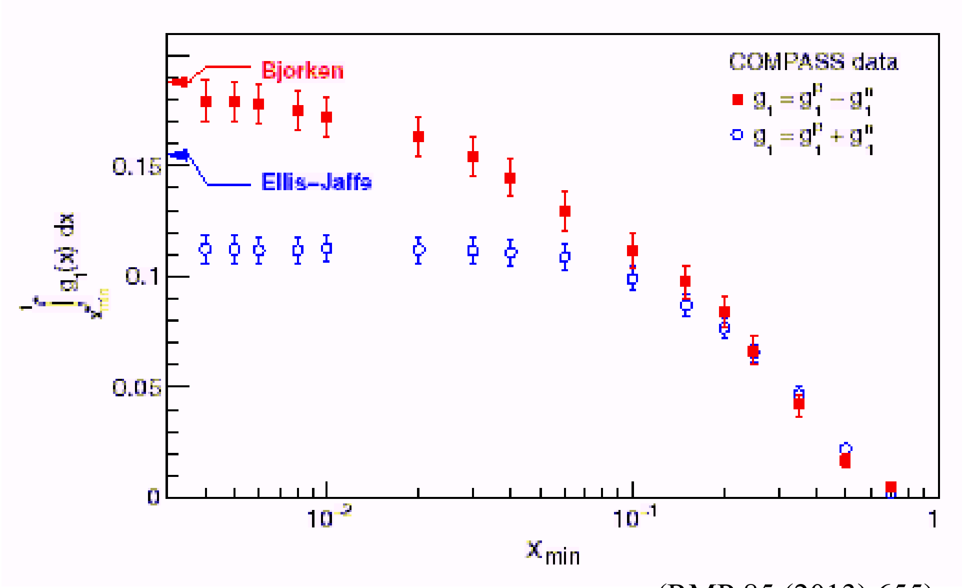
- Δg ~ 0: need L to get ½ h/2π



(RMP 85 (2013) 655)

$$\frac{1}{2} = \frac{1}{2}\sum \Delta q + \Delta g + L$$

$$= (.12 \pm .03) + (.11 \pm .12) + L$$

$\overline{MS}$ scheme at 4 GeV^2

(Nocera et al. (NFRR) arXiv:1206.0201)

Nucleon Spin beyond G_1 and G_2

- Need to go beyond a_0 to understand nucleon spin
  - Orbital angular momentum (OAM) ***L*** is needed.
- Partons have transverse momentum, implies OAM
  - Mulders *et al.*, Transverse Momentum dependent Distributions – TMDs
  - functions of x and k_t
  - Semi-inclusive scattering (detect final e, one hadron)

Transverse Momentum Distributions by Polarization			
Target ↓ \ quark →	***U***	***L***	***T***
U	$\boldsymbol{f_1}(x, k_t)$		$h_1^{\perp}$
L		$\boldsymbol{g_1}$	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	$\boldsymbol{g_{1T}^{\perp}}$	$\boldsymbol{h_1}$ $h_{1T}^{\perp}$

Longitudinal SSF (leading twist)

$$g_1(x)=\sum g_1^q(x)=\sum\int d^2\vec{k}_t\, g_{1L}(x,\vec{k}_t^2)$$

Transverse SSF (twist-3)

$$g_{1T}^{(1)}(x)=\sum g_{1T}^{q(1)}(x)=\sum\int d^2\vec{k}_t\,\frac{\vec{k}_t^2}{2M^2}\,\boldsymbol{g_{1T}^q}(x,\vec{k}_t^2)$$

$$g_T(x)=g_1(x)+\frac{d}{dx}g_{1T}^{(1)}=g_1(x)+g_2(x)$$

d_2 from *RSS* Third Moments

Moments at $\langle Q^2 \rangle = 1.3$ GeV^2, in three regions:

- measured $.32 < x < .8$; elastic (quasi-el. for deuteron);
- unmeasured $x < 0.32$, suppressed by x^2.

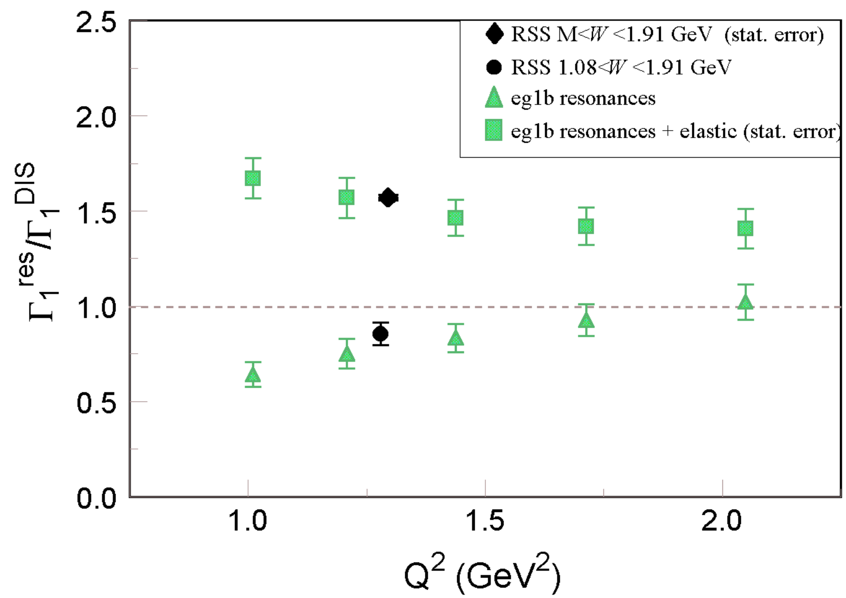
x ranges	Proton	Deuteron	Neutron
Measured			
CN	0.006±0.001	0.008±0.002	0.003±0.002
Nachtmann	0.004±0.001	0.005±0.002	0.002±0.001
0 < *x* < 1			
CN	0.036±0.003	0.017±0.004	-0.018±0.003
Nachtmann	**0.010± 0.001**	**0.003± 0.002**	**-0.008± 0.002**

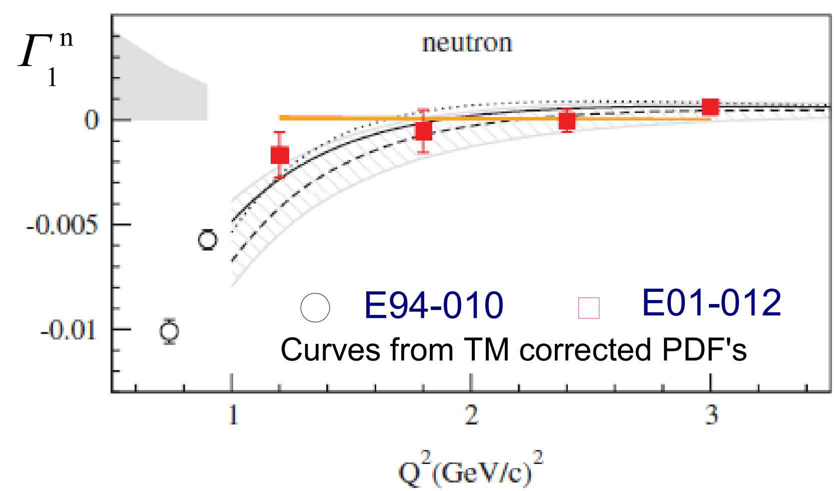
- Non-zero d_2 for both nucleons (total errors shown)
  - OPE valid to $N=2 < Q^2/M_0^2 \sim 1.3/0.5^2$ (DIS – resonances duality)

    (Ji & Unrau, PR D52 (1995) 72)
  - Neutron approximated as D-state corrected d - p (good to $O(1\%)$)
- Ratios Nachtmann/CN < 1: large contribution of kinematic HT

Duality in g_1

- Bloom – Gilman duality for spin SF's
  - Local Duality only above Δ(1232)
  - Global duality (for $W > \pi$ threshold, or from elastic) obtains above $Q^2 > 1.8\ \mathrm{GeV}^2$
  - seen in p, d, and ^{3}He
  - DIS SSF's from PDF's extrapolated with target mass corrections





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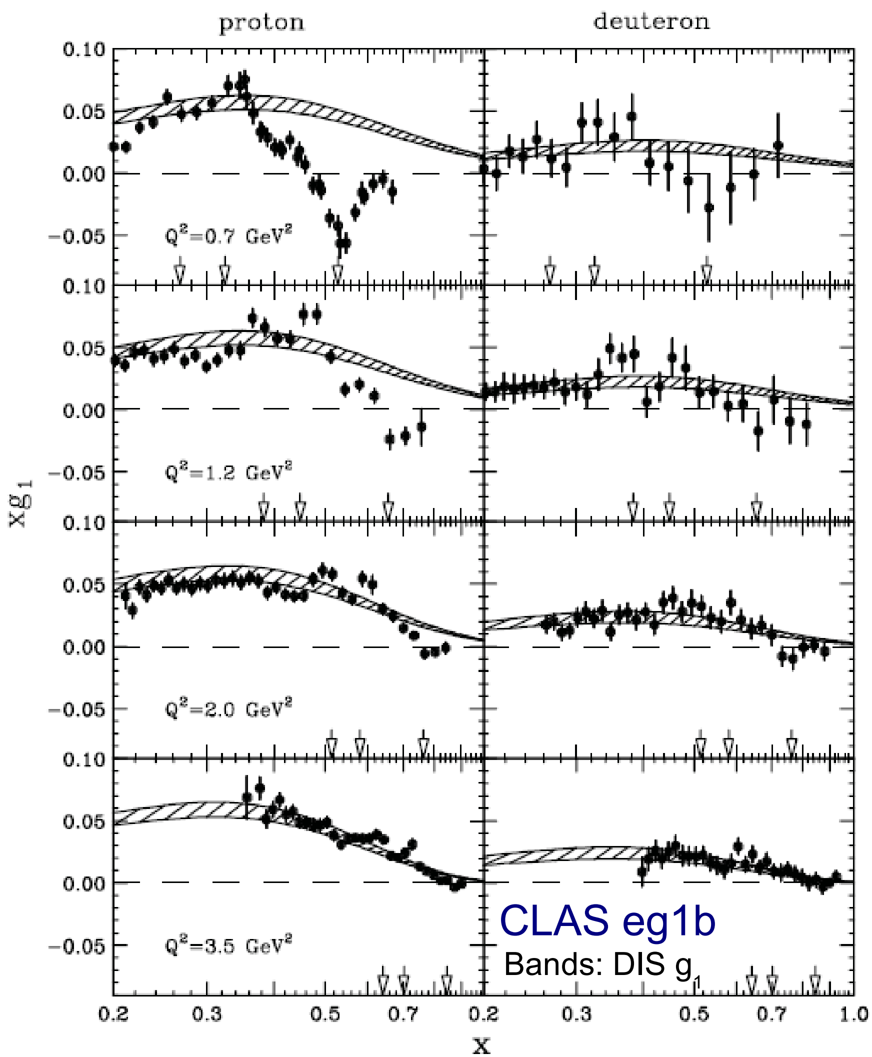
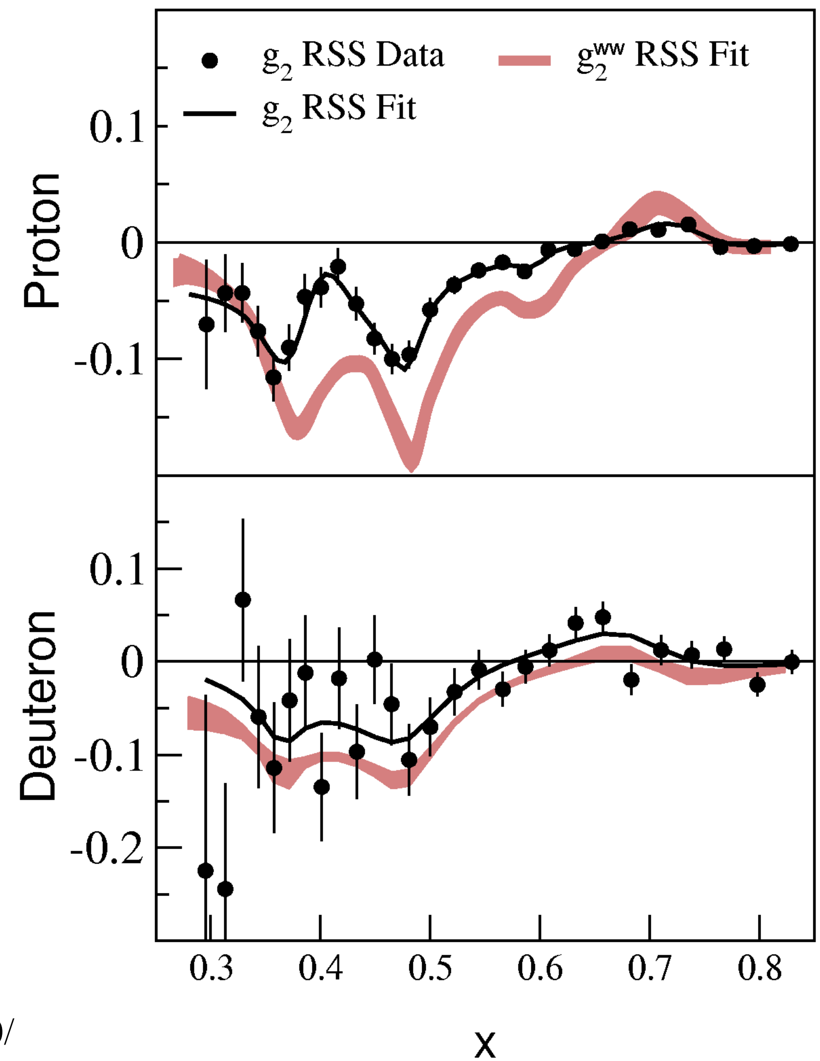


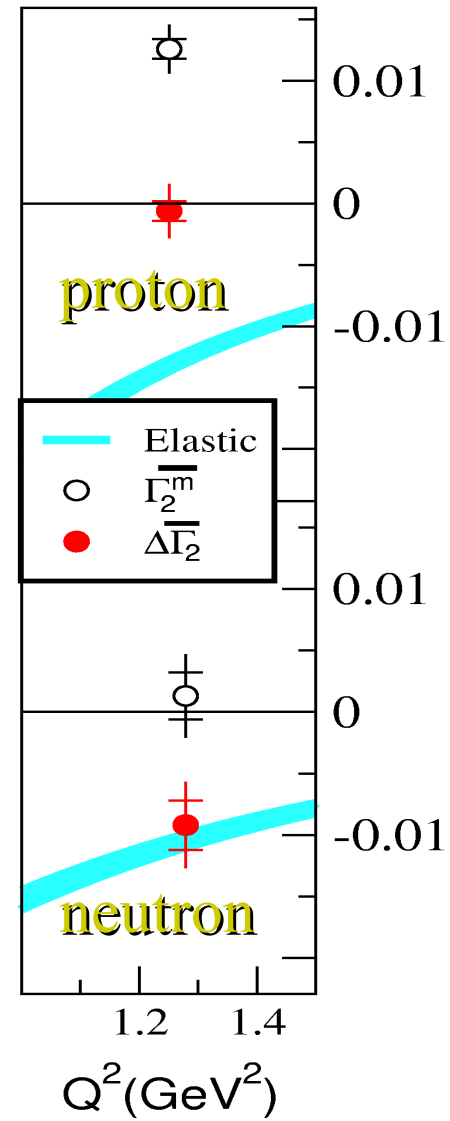
g_2 Spin Structure Functions



- First world data for $\boldsymbol{g_2}^{\mathbf{p,d}}$ in the resonances
- $\boldsymbol{g_2}^{\mathbf{ww}}$ computed using *RSS* fit to $\boldsymbol{g_1}$ point by point
- HT $\overline{g_2}$(low x) $\cong 0$ within errors
  - $\overline{g_2}(x < x_{min} = 0.317) = 0 \pm \delta\overline{g_2}$
  - systematic error $\delta\overline{g_2}$ estimated by extrapolating fit errors $\delta\overline{g_2}(x_{min})$ to $x = 0$

Twist-3 and the Burkhardt-Cottingham Sum Rule

- BC sum rule $\Gamma_2 = 0 = \Gamma_2^{ww} + \overline{\Gamma}_2 + \Gamma_2(\mathrm{el})$
  - dispersion relation not from OPE, free from gluon radiation, TMC's
  - twist-2 part $\Gamma_2^{ww} \equiv 0$
- BC is higher-twist + elastic
  - $\Gamma_2 = \overline{\Gamma}_2(\mathrm{unm.}) + \overline{\Gamma}_2(\mathrm{measur.}) + \Gamma_2(\mathrm{el})$
  - $\Delta\overline{\Gamma}_2 = \Gamma_2 - \overline{\Gamma}_2(\mathrm{u}) = \overline{\Gamma}_2(\mathrm{m}) + \Gamma_2(\mathrm{el})$
- $\Delta\overline{\Gamma}_2 \neq 0$: assuming BC, implies significant HT at $x < x_{min}$, **<u>or</u>**, if twist-3 ~ 0 at low x,
  - BC fails: isospin dependence? nuclear effects?



Kinematics Space at JLab