Measuring the Neutron Spin Asymmetry A_1^n in the Valence Quark Region in Hall C at Jefferson Lab

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On Behalf of the E12-06-110 Collaboration

Hall C Collaboration Meeting
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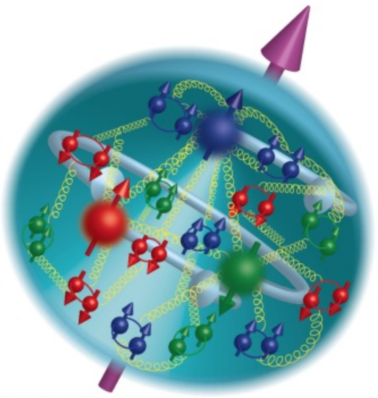
Nucleon spin structure: current status

Nucleon spin sum rule:
(Jaffe & Manohar)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

- $\Delta\Sigma$ → quark intrinsic spin
- ΔG → gluon intrinsic spin
- L_q → quark OAM
- L_g → gluon OAM



Designed by Z.-E. Meziani

→ Today: **large uncertainties! in** $\boldsymbol{\Delta G}$

$$\Delta\Sigma = \int \left(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}\right)dx \sim 30\%$$

$$\Delta G = \int dx\, \Delta g \sim 20\%,\ L_q \sim ??,\ L_g \sim ??$$

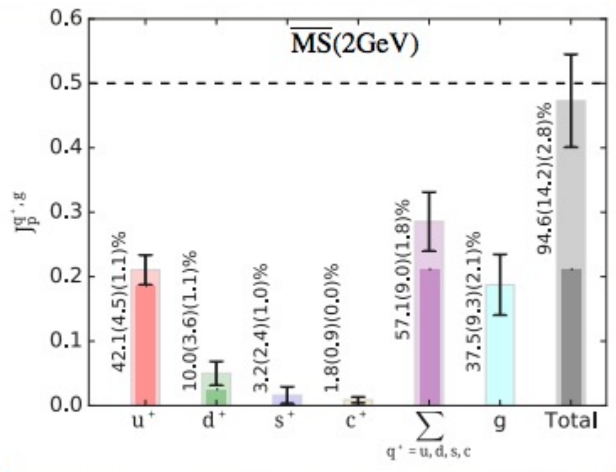
Little known about **quark OAM** ($\boldsymbol{L_q}$)

Quark spin seems to play a smaller role in the nucleon spin decomposition than predicted by the CQM, which expected $\Delta\Sigma \sim 75\%$, $L_q \sim 25\%$

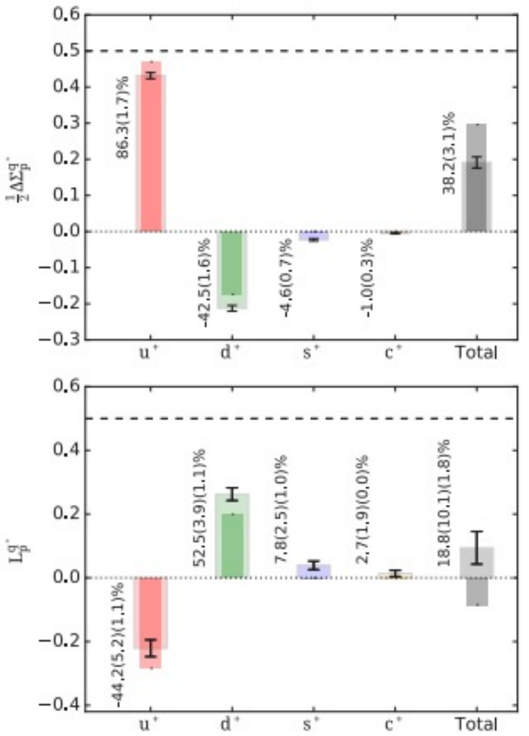
LQCD & high-$\boldsymbol{x}$ physics can help!

Due to the non-perturbative nature of QCD, making absolute predictions of nucleon spin structure is generally difficult, but …

→ **LQCD** can compute $L_q = J_q - \Delta\Sigma_q$, J_g (@ physical π mass!)



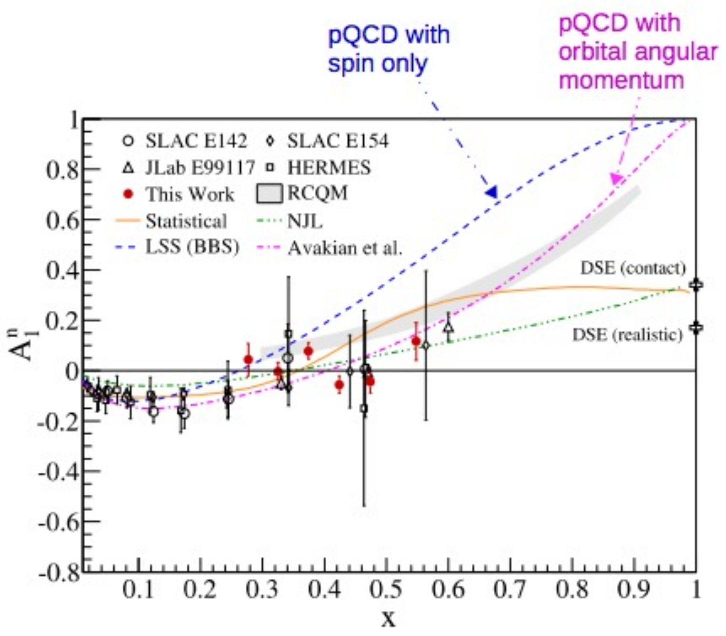
See *C. Alexandrou et al., Phys. Rev. D 101, 094513 (2020), arXiv:2003.08486*

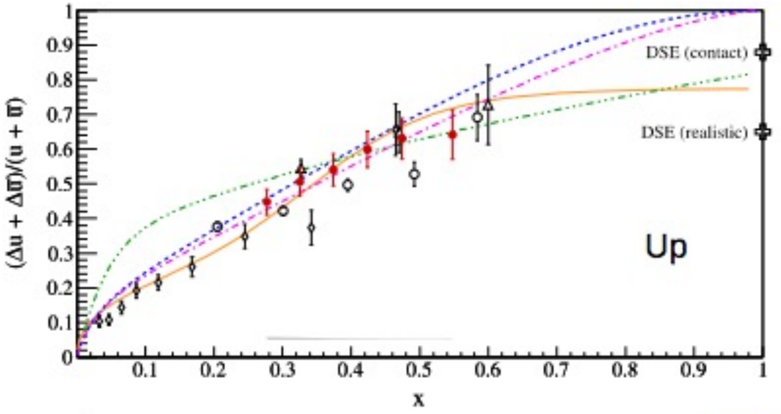


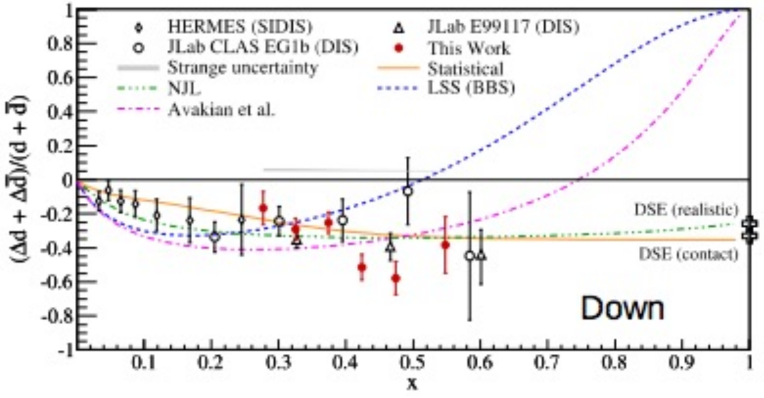
→ direct calculations using **LQCD (quasi-PDFs)** promising

→ The valence domain ($\boldsymbol{x > 0.5}$) enables us to discriminate between models that include/exclude L_q

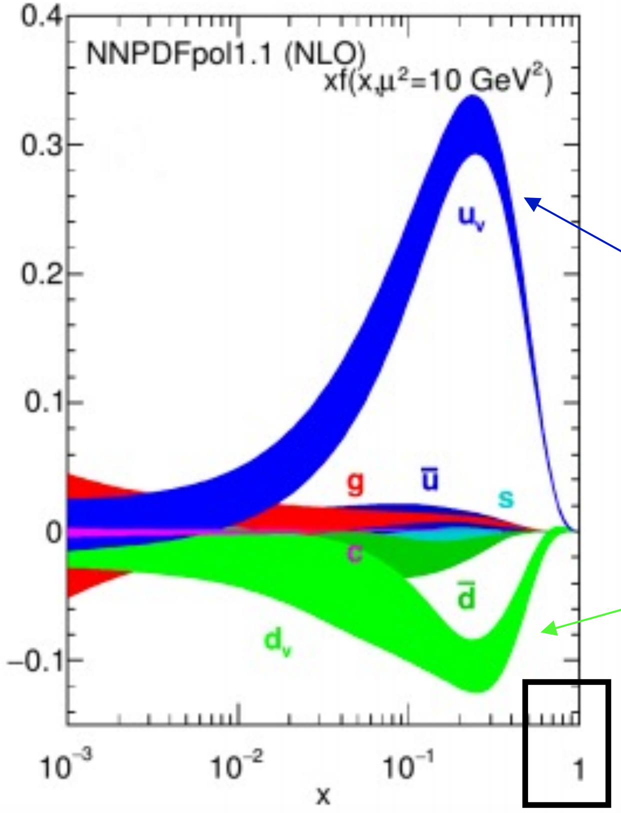
A_1^n @ high- x: a key observable for spin structure







This experiment will provide the first precision data on A_1^n for $x > 0.61$ (went up to $x = 0.75$!)



$x > 0.5$ region dominated by valence quarks

Polarized and sea quark PDFs for $Q^2 = 10$ GeV^2 from the NNPDFpol1.1 parameterization

See *Nocera ER, et al. Nucl. Phys. B887:276 (2014).*

The **valence domain** ($x > 0.5$):

- Free of sea effects ($q\bar{q}$ pairs and hard gluons)
- Spin is assumed to be carried by the valence quarks

→ A poorly-explored region due to low rates at high x (need high luminosity, Hall C's 12 GeV-era polarized ^{3}He target reached 2x10^{36} cm^{-2}s^{-1}!)

- **Which models will our data agree with**? How much of a role does L_q play in forming the nucleon spin?

For large Q^2,

$$A_1 \approx g_1(x)/F_1(x)$$

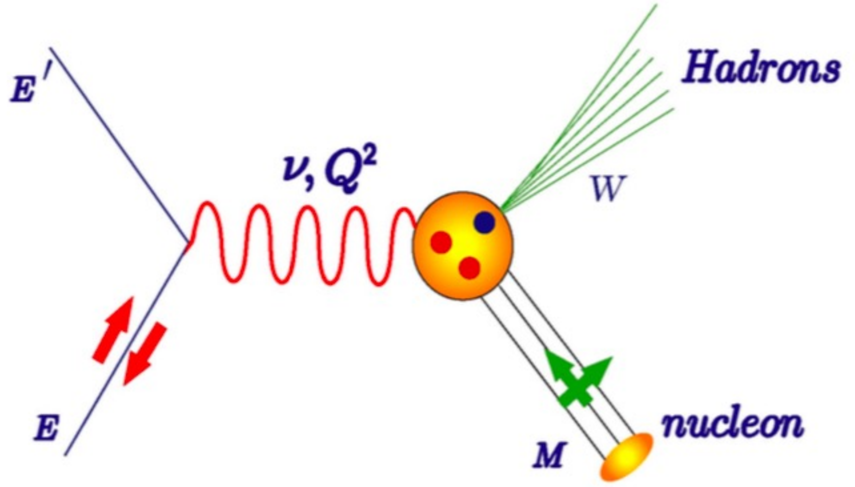
Accessing spin structure: polarized DIS cross sections

U: $$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2\sin^4\left(\frac{\theta}{2}\right)}\left(\frac{2}{M}F_1(x,Q^2)\sin^2\left(\frac{\theta}{2}\right) + \frac{1}{\nu}F_2(x,Q^2)\cos^2\frac{\theta}{2}\right)$$

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

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

$Q^2 = 4EE'\sin^2(\theta/2)$	4-momentum transfer
$\nu = E - E'$	Energy transfer
$W = M^2 + 2M\nu - Q^2$	Final state hadronic mass
θ	Scattering angle
$x = Q^2/2M\nu$	Quark fractional momentum



Quark Parton Model:

- $F_1(x) = \frac{1}{2}\Sigma e_i^2[q_i^{\uparrow}(x) + q_i^{\downarrow}(x)]$

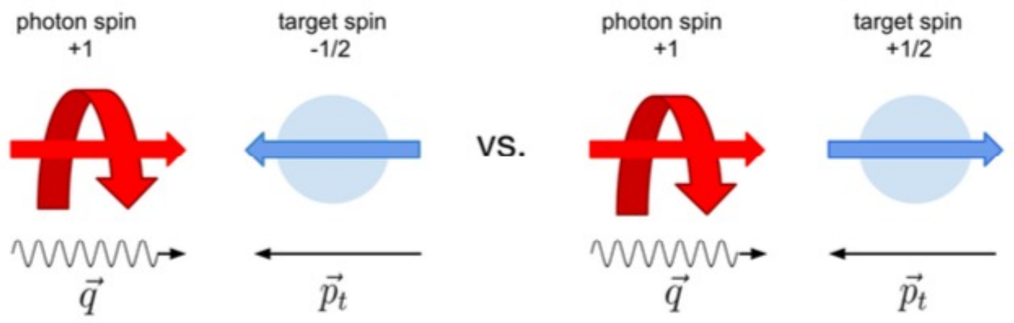
where $q_i(x) = q_i^{\uparrow}(x) + q_i^{\downarrow}(x)$ is the probability of finding a quark q of flavor i with momentum fraction x

- $g_1(x) = \frac{1}{2}\Sigma e_i^2[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)]$

where $\Delta q_i(x) = q_i^{\uparrow}(x) - q_i^{\downarrow}(x)$ is the sum over the helicity distribution for a quark q of flavor i with momentum fraction x

- $g_2(x)$ describes the **transverse** spin structure of the nucleon, which vanishes in the QPM (quark-gluon correlations)

What is A_1? the virtual photon-nucleon asymmetry



Anti-parallel spins $h = 1 - \frac{1}{2} = \frac{1}{2}$

Parallel spins $h = 1 + \frac{1}{2} = \frac{3}{2}$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)}$$

where $\gamma^2 = (2Mx)^2/Q^2$ and M = nucleon mass

For large Q^2, $A_1 \approx g_1(x)/F_1(x)$

- Our wide Q^2 range (over 10 GeV^2) will allow for further study of A_1's $\boldsymbol{Q^2}$ **−dependence @ a given x value in the valence region**

- We need a transverse and longitudinal component to reconstruct the asymmetry along the virtual photon direction:

$$A_\parallel = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} \quad \text{and} \quad A_\perp = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$

$$\rightarrow \quad A_1 = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{\eta A_\perp}{d(1+\eta\xi)}$$

- $\sigma^{\downarrow\Uparrow}(\sigma^{\uparrow\Uparrow})$ is the cross section for a **longitudinally polarized target** with the electron spin aligned antiparallel (parallel) to the target spin

- $\sigma^{\downarrow\Rightarrow}(\sigma^{\uparrow\Rightarrow})$ is the cross section for a **transversely polarized target** with the electron spin aligned antiparallel (parallel) to the beam direction

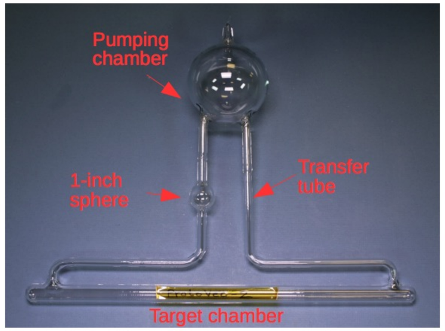
- η, ξ, and d are kinematic factors, and D depends on the ratio of the longitudinal and transverse virtual-photon absorption cross sections $R = \sigma_L/\sigma_T$

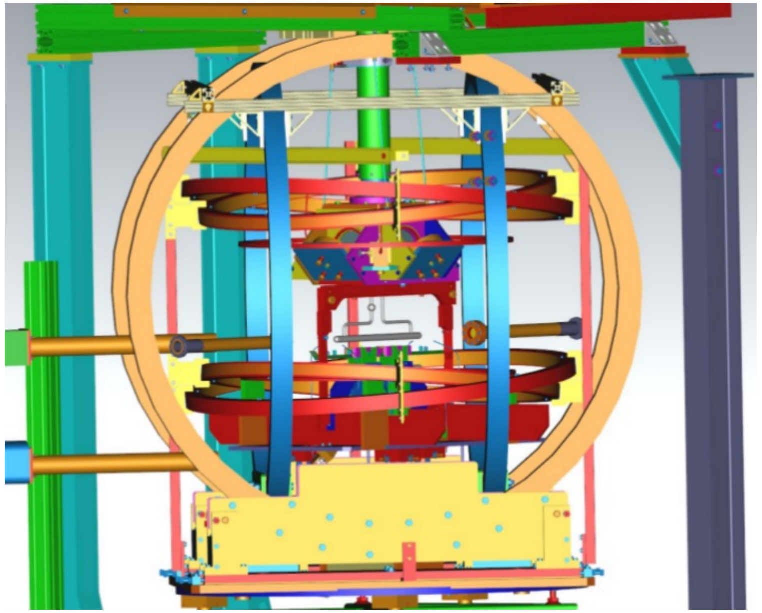
Experimental Setup

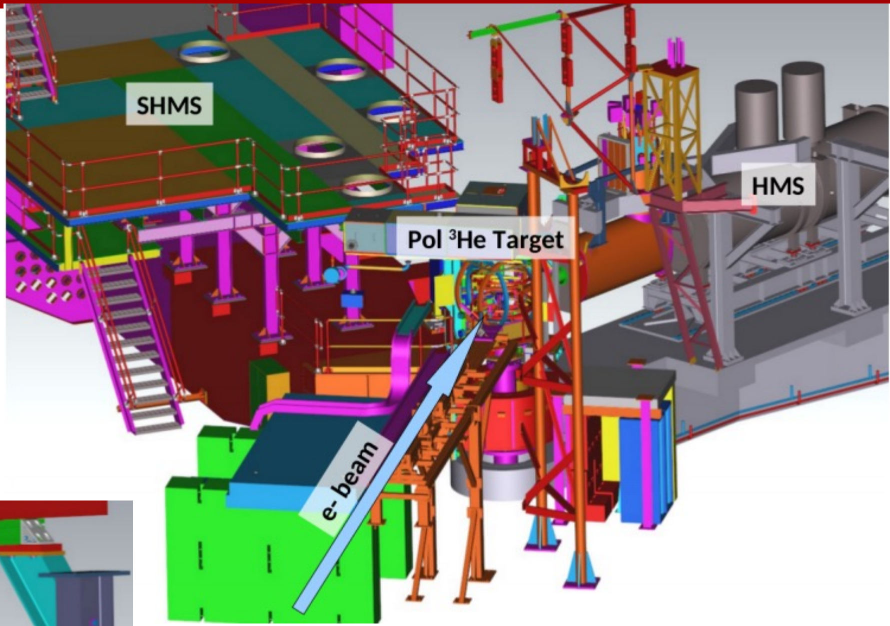
Spectrometers:
- High Momentum Spectrometer (HMS)
- Super High Momentum Spectrometer (SHMS)

Electron Beam:
- 1-pass @ 2.2 GeV (elastic, Δ(1232))
- 5-pass @ 10.5 GeV (DIS)
- Beam polarization: 85%
  (< 3% uncertainty according to Moller)
- Circular beam raster with ~ 2.0 mm radius
- < 50 ppm avg. charge asymmetry

Polarized ^{3}He Target
- ^{3}He production cell (40 cm)
- ~ 50% in-beam polarization
- 30 uA beam current
- 3% uncertainty in polarimetry

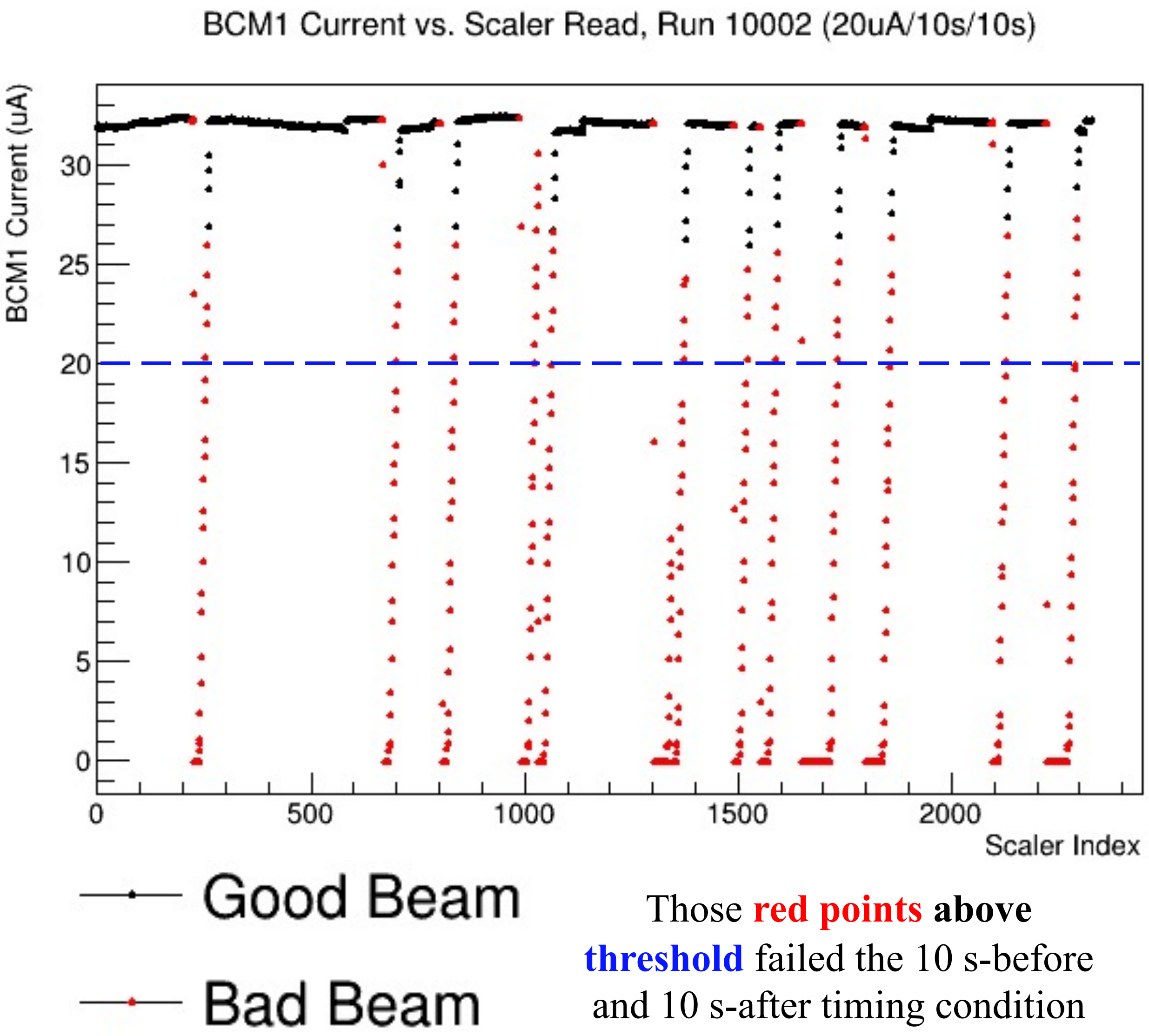




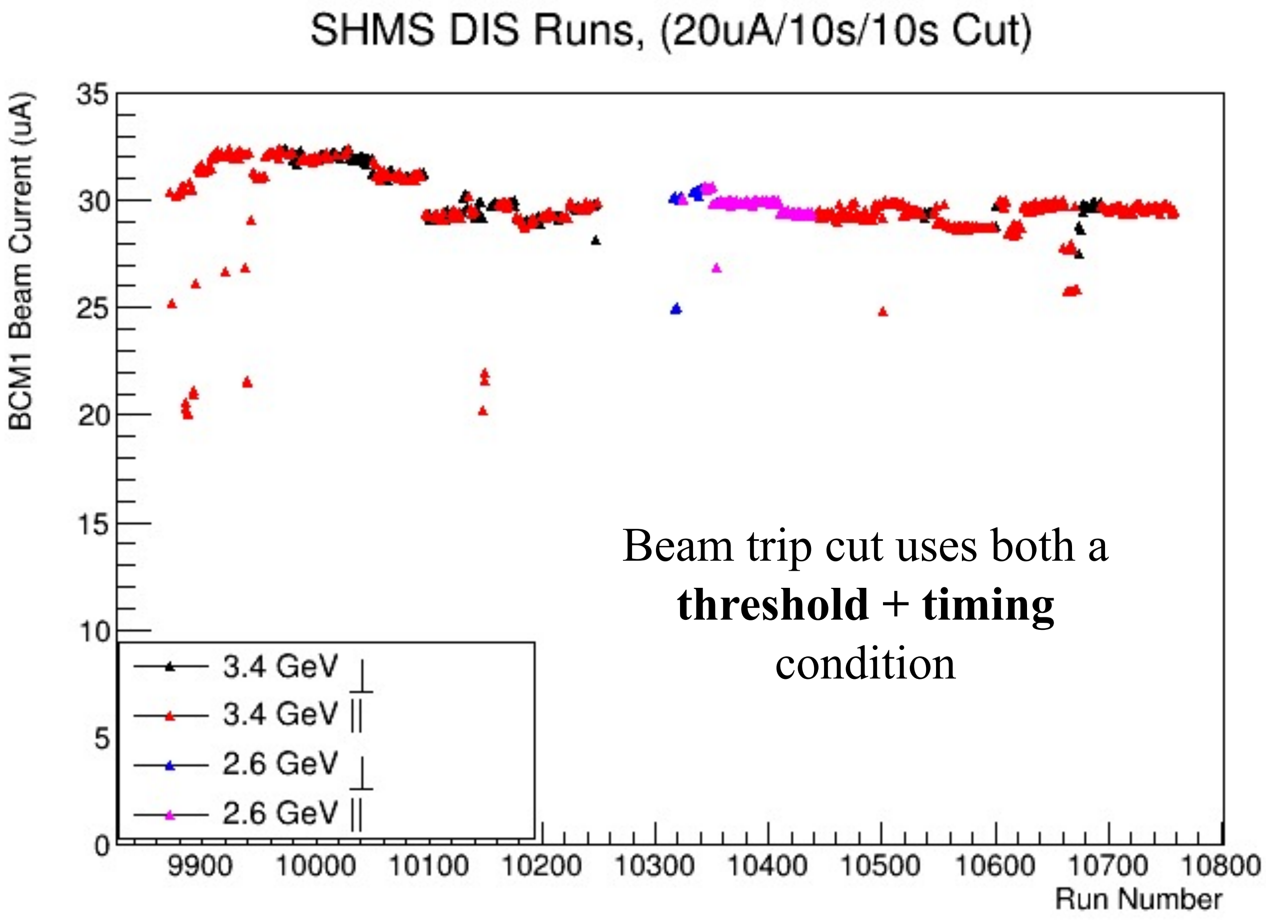


A_1^n production began on Jan. 12th, 2020 and ended on March 13th, 2020

Data Quality: Helicity-sorted charge, live-time, and **beam trip cuts**



Those **red points above threshold** failed the 10 s-before and 10 s-after timing condition



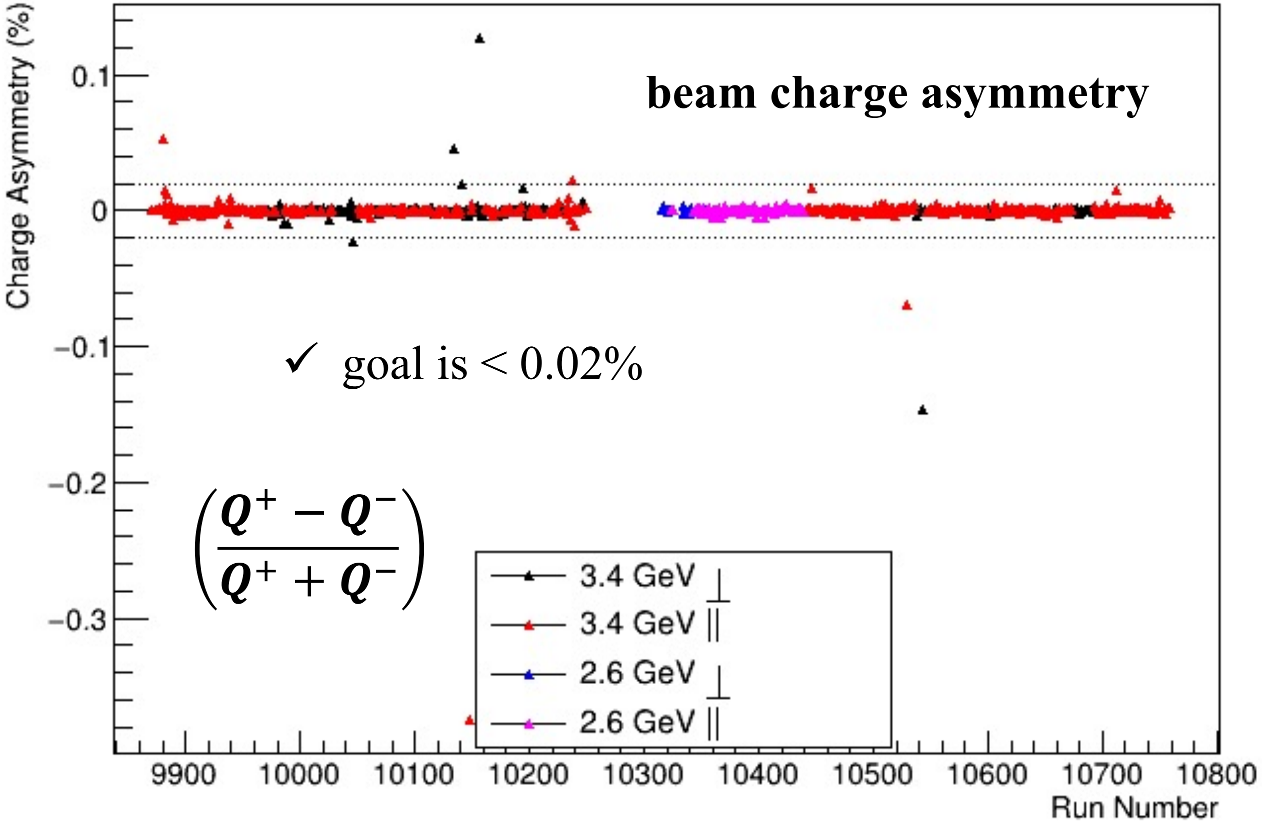
Beam trip cut uses both a **threshold + timing** condition

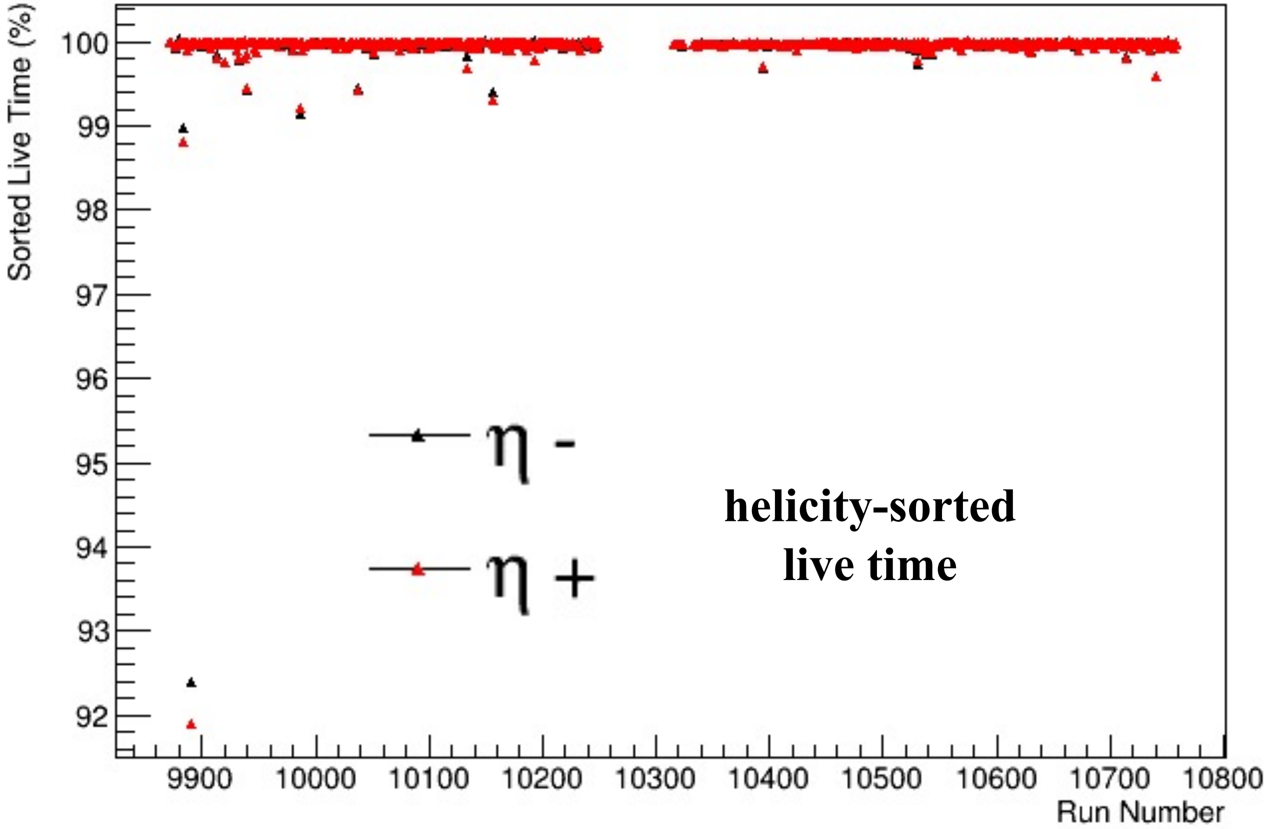
Beam condition: current must be at least **20 uA for 10 seconds before and after** a trip occurs → this is to minimize any negative impacts ramping the beam back up might have on its polarization

Data Quality: **Helicity-sorted charge, live-time**, and beam trip cuts

SHMS DIS RUNS

(20 uA/10 s/10 s current cut applied)





The counts (N^+, N^-) that form the asymmetries are normalized by the total incident charge and DAQ live-time (Q^+, Q^- and η^+, η^- respectively) to correct for any biasing

Sign Convention for $A_{\parallel}$: ^{3}He Elastic Asymmetries

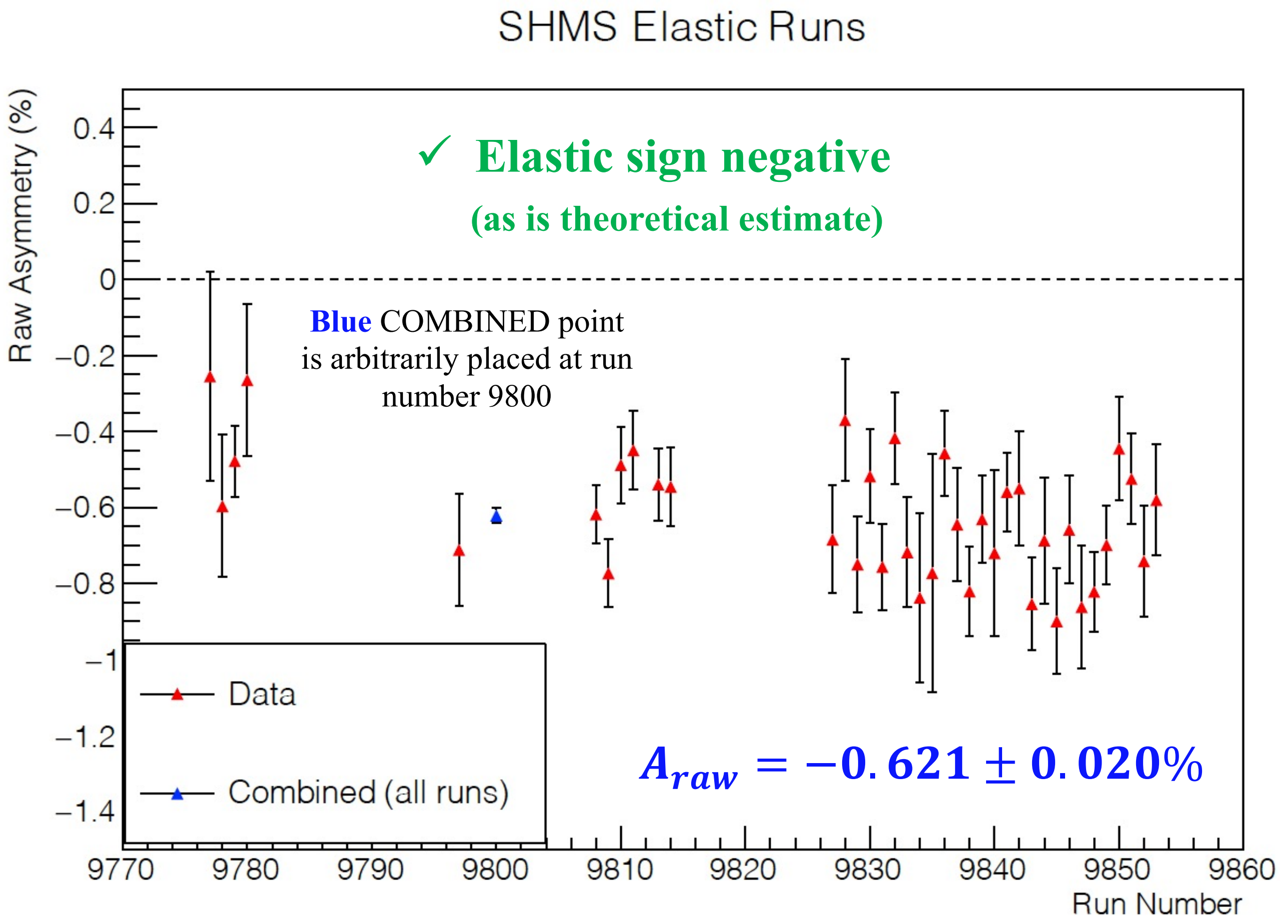
What exactly does N^+, N^- mean?

SHMS Elastic Runs:
^{3}He @ 180°
E_p= -2.1286 GeV, 8.5°

$$A_{raw} = \frac{N^+ - N^-}{N^+ + N^-}$$

By definition: N^+ should describe the # of incident e^- whose spin is **anti-∥** to the ^{3}He target spin

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}}$$



e^- beam spin direction:

Period	IHWP = IN	IHWP = OUT	^{3}He spin direction
1-pass (Dec. 2019) (elastic + delta)	UPSTREAM ($\vec{e}^-$ anti-∥ $^3\vec{He}$) ($\vec{e}^-$ anti-∥ beam direction)	DOWNSTREAM ($\vec{e}^-$ ∥ $^3\vec{He}$) ($\vec{e}^-$ ∥ beam direction)	180°: DOWNSTREAM 90°: BEAM LEFT
	pass change		
5-pass (DIS) (thru SHMS 10354, HMS 3162)	DOWNSTREAM ($\vec{e}^-$ ∥ $^3\vec{He}$) ($\vec{e}^-$ ∥ beam direction)	UPSTREAM ($\vec{e}^-$ anti-∥ $^3\vec{He}$) ($\vec{e}^-$ anti-∥ beam direction)	180°:DOWNSTREAM 90°: BEAM LEFT
	Wien-flip		
5-pass (DIS) (SHMS 10355+, HMS 3163+)	UPSTREAM ($\vec{e}^-$ anti-∥ $^3\vec{He}$) ($\vec{e}^-$ anti-∥ beam direction)	DOWNSTREAM ($\vec{e}^-$ ∥ $^3\vec{He}$) ($\vec{e}^-$ ∥ beam direction)	180°: DOWNSTREAM 90°: BEAM LEFT

- **^{3}He target spin direction fixed**
- Incident e^- spin direction (relative to its momentum) changes with IHWP state, Wien-flip, and pass change → imperative to keep N^+, N^- consistent!

Sign Convention for $A_\perp$: ^{3}He Δ(1232) Asymmetries

What exactly does N^+, N^- mean?

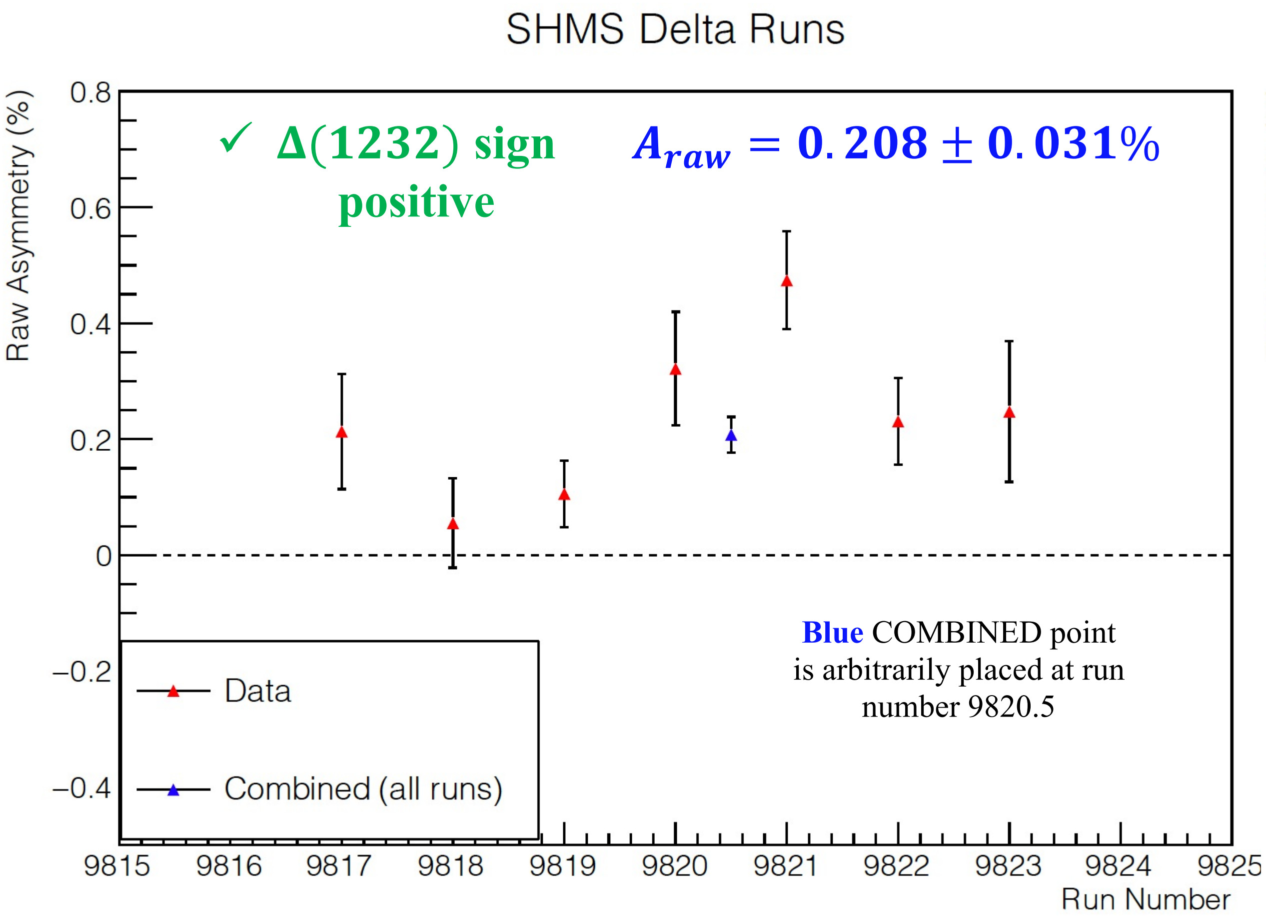
SHMS Δ(1232) Runs:
^{3}He @ 90°
E_p= -1.7583 GeV, 8.5°

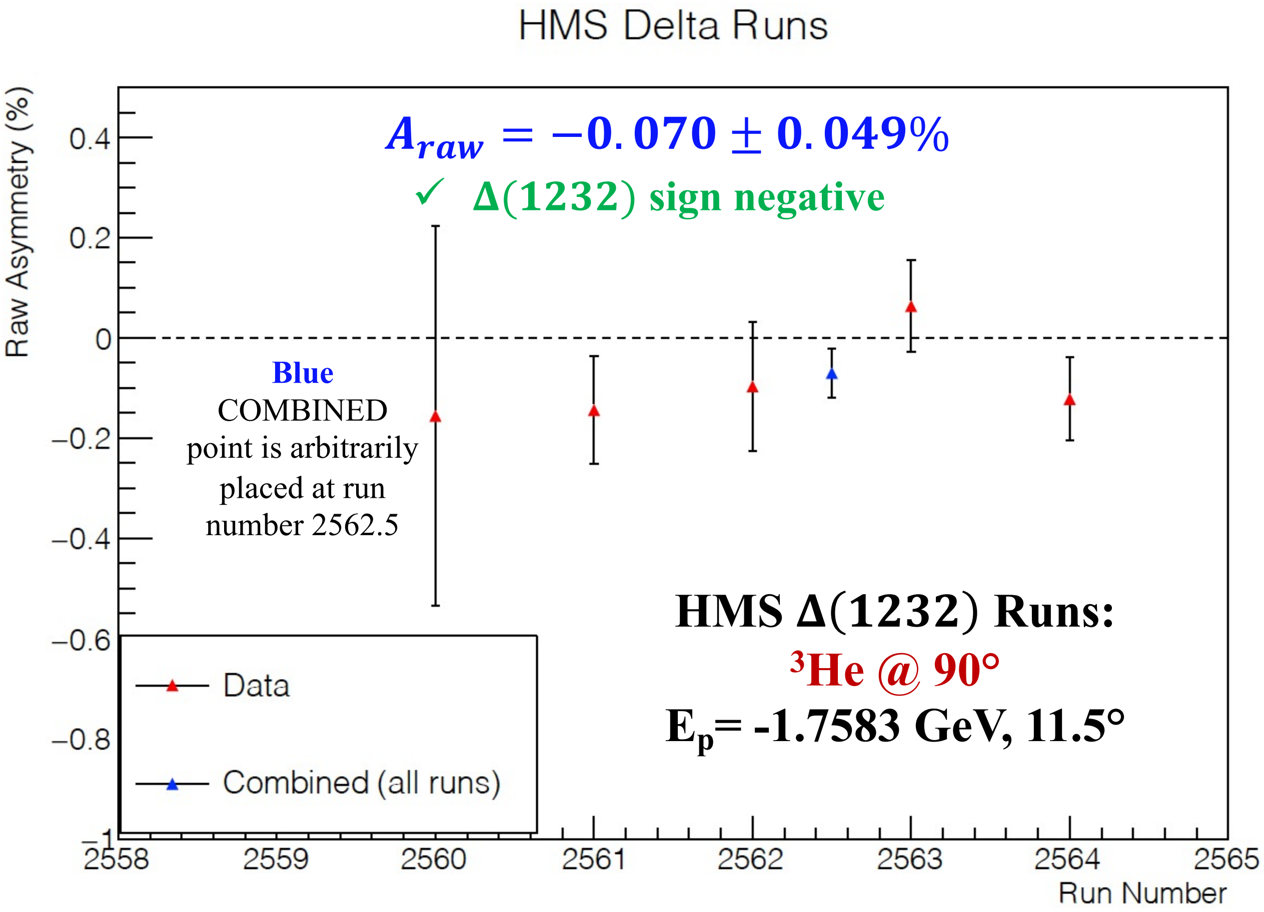
$$A_{raw} = \frac{N^+ - N^-}{N^+ + N^-}$$

By definition: N^+ should describe the # of incident e^- whose spin is **anti-∥** to the **beam direction**, and the scattered e^- being detected on the **same side of the beam** as that to which the **^{3}He spins are pointing**:

$$A_\perp = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$

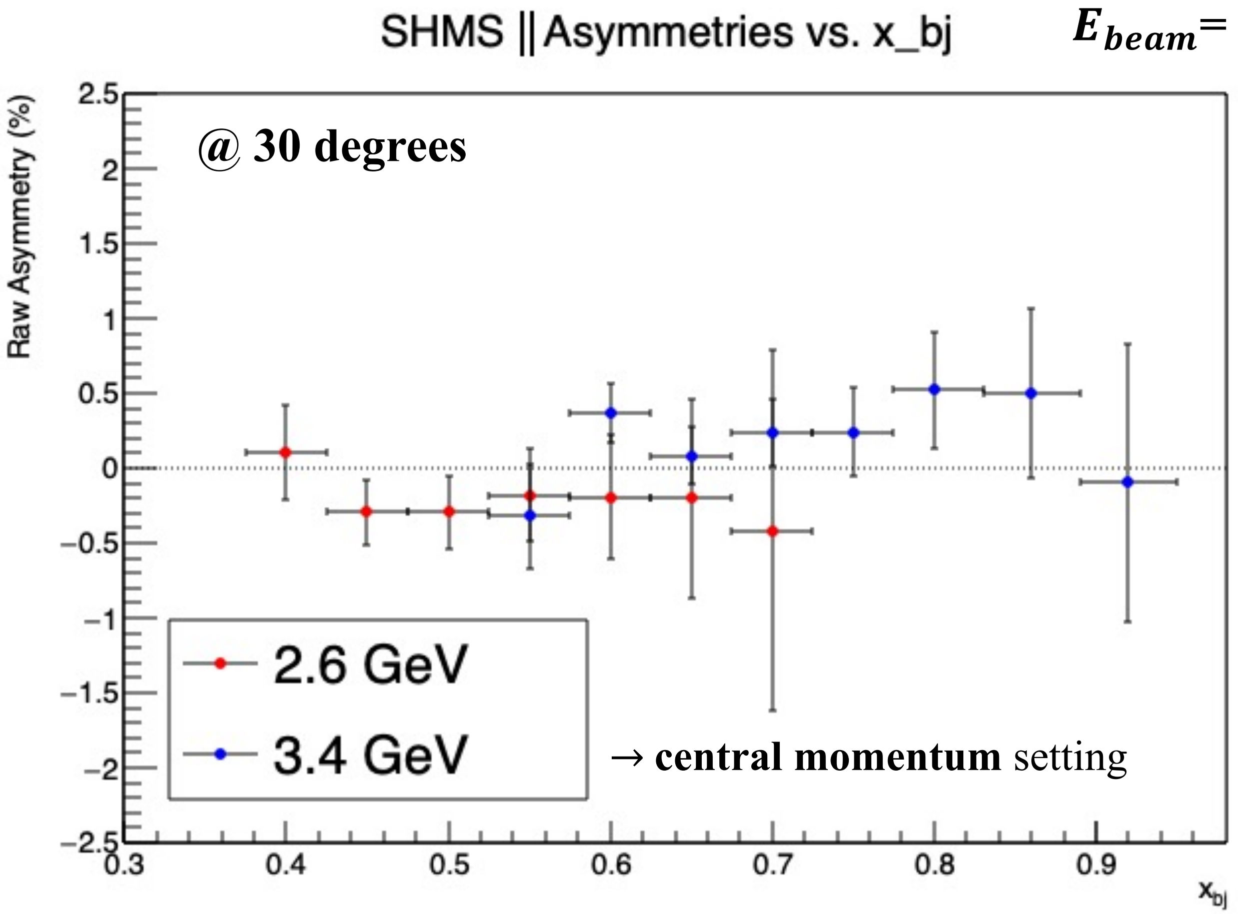
(beam left → SHMS!)

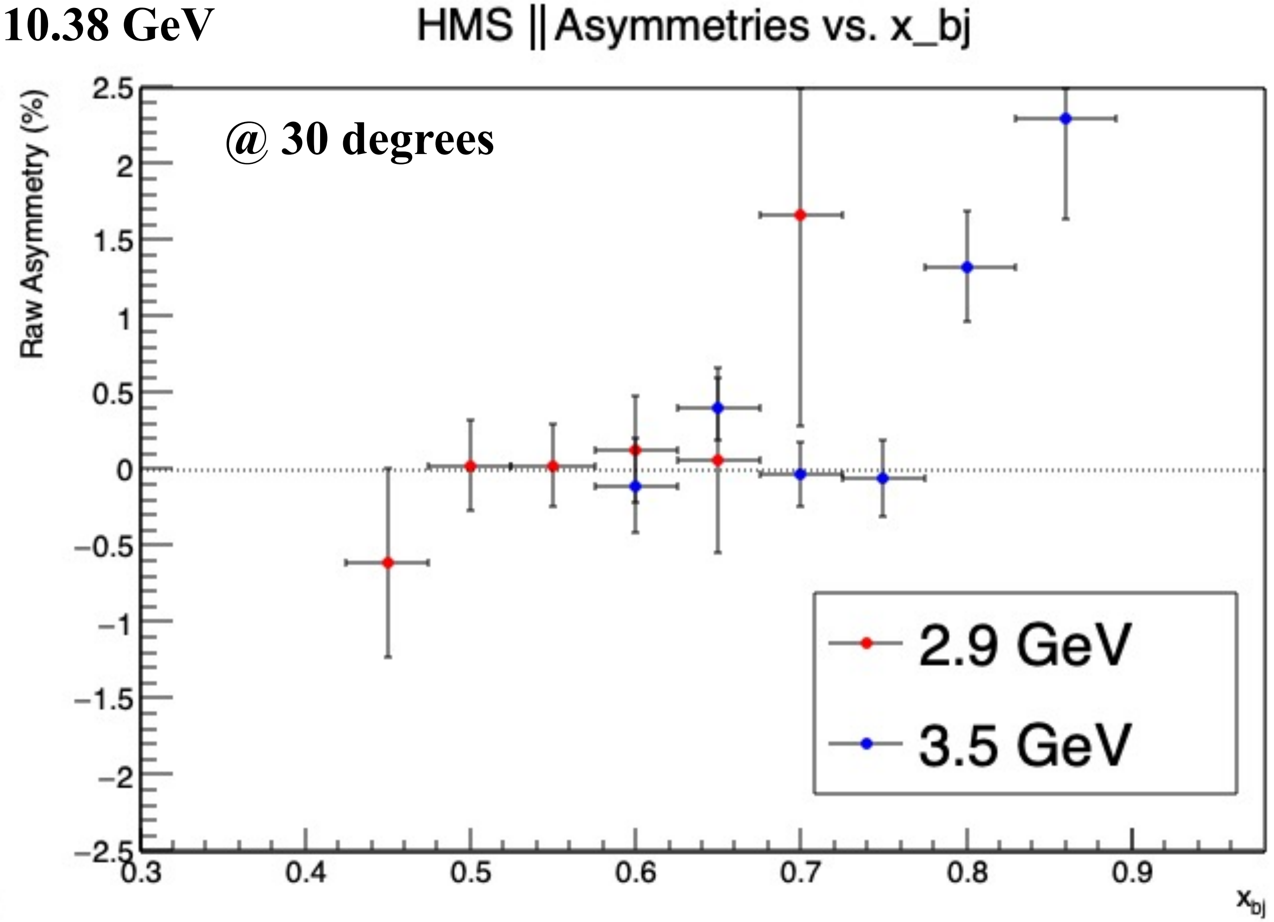




SHMS & HMS **Parallel RAW** Asymmetries

E_{beam}= 10.38 GeV





$N^{\pm}$ ~ helicity-sorted counts
$Q^{\pm}$ ~ integrated beam charge
$\eta^{\pm}$ ~ DAQ live-time

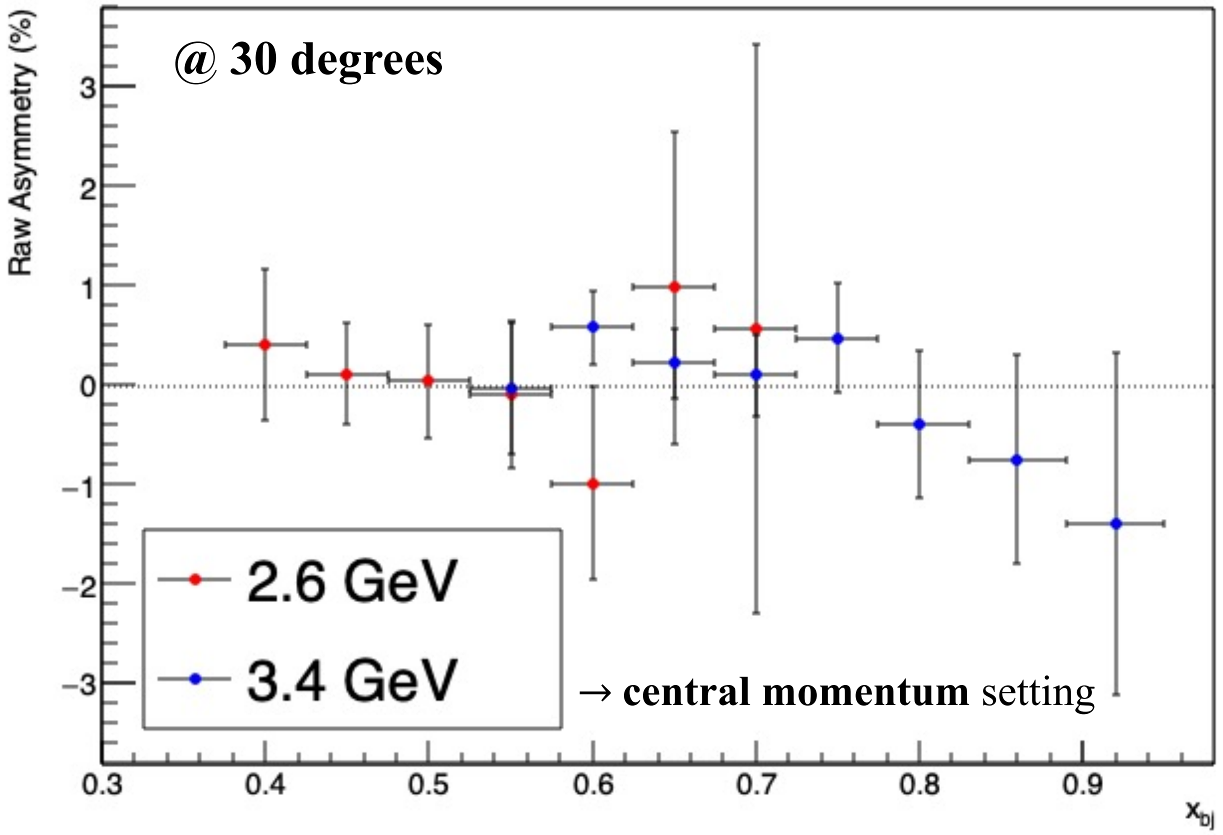
$$A_{raw} = \frac{\frac{N^+}{Q^+\eta^+} - \frac{N^-}{Q^-\eta^-}}{\frac{N^+}{Q^+\eta^+} + \frac{N^-}{Q^-\eta^-}}, \quad A_{phys} = \frac{A_{raw}}{P_b P_t f_{N_2}}$$

P_b ~ Beam polarization ~ 85%
P_t ~ ^{3}He target polarization ~ 50%
f_{N_2} ~ Nitrogen dilution factor ~ 0.92

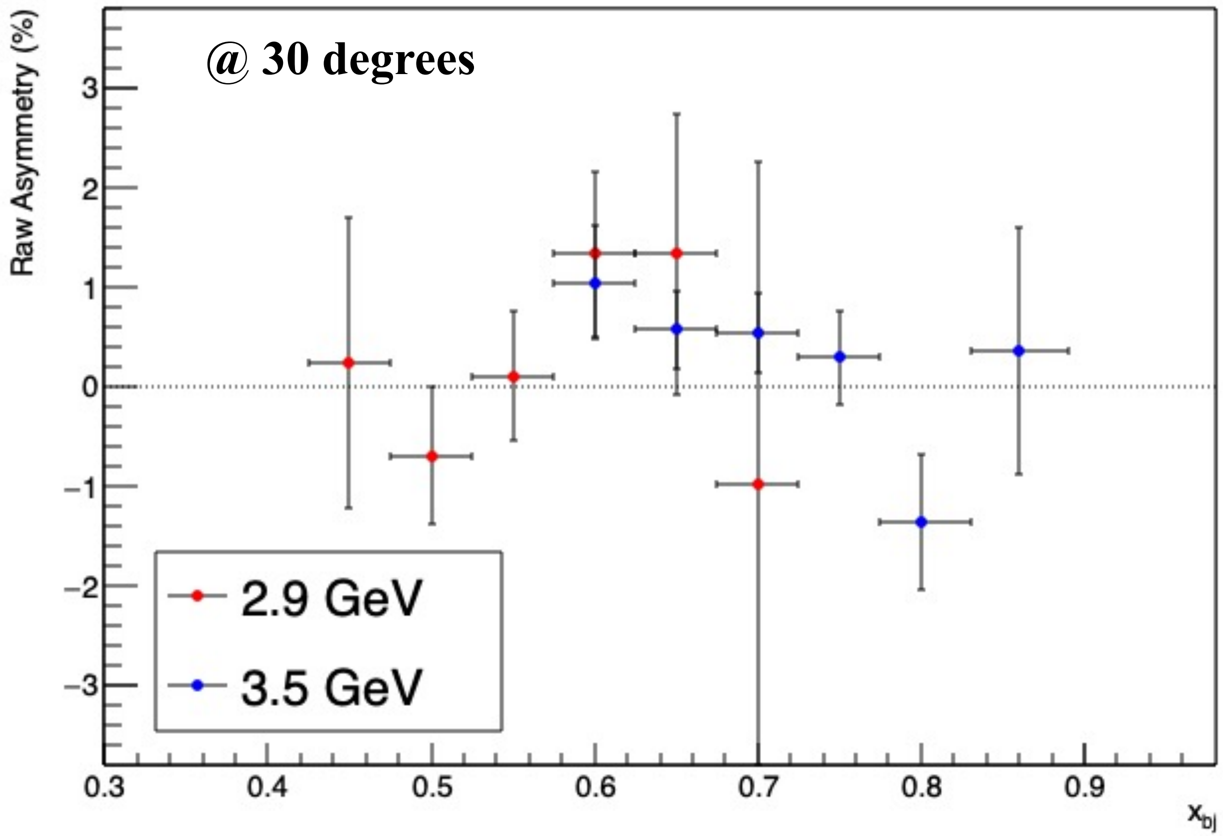
SHMS & HMS **Perpendicular RAW** Asymmetries

SHMS ⊥ Asymmetries vs. x_bj

E_{beam} = 10.38 GeV



HMS ⊥ Asymmetries vs. x_bj



$N^{\pm}$ ~ helicity-sorted counts
$Q^{\pm}$ ~ integrated beam charge
$\eta^{\pm}$ ~ DAQ live-time

$$A_{raw} = \frac{\frac{N^+}{Q^+\eta^+} - \frac{N^-}{Q^-\eta^-}}{\frac{N^+}{Q^+\eta^+} + \frac{N^-}{Q^-\eta^-}}, \quad A_{phys} = \frac{A_{raw}}{P_b P_t f_{N_2}}$$

P_b ~ Beam polarization ~ 85%
P_t ~ ^{3}He target polarization ~ 50%
f_{N_2} ~ Nitrogen dilution factor ~ 0.92

Summary

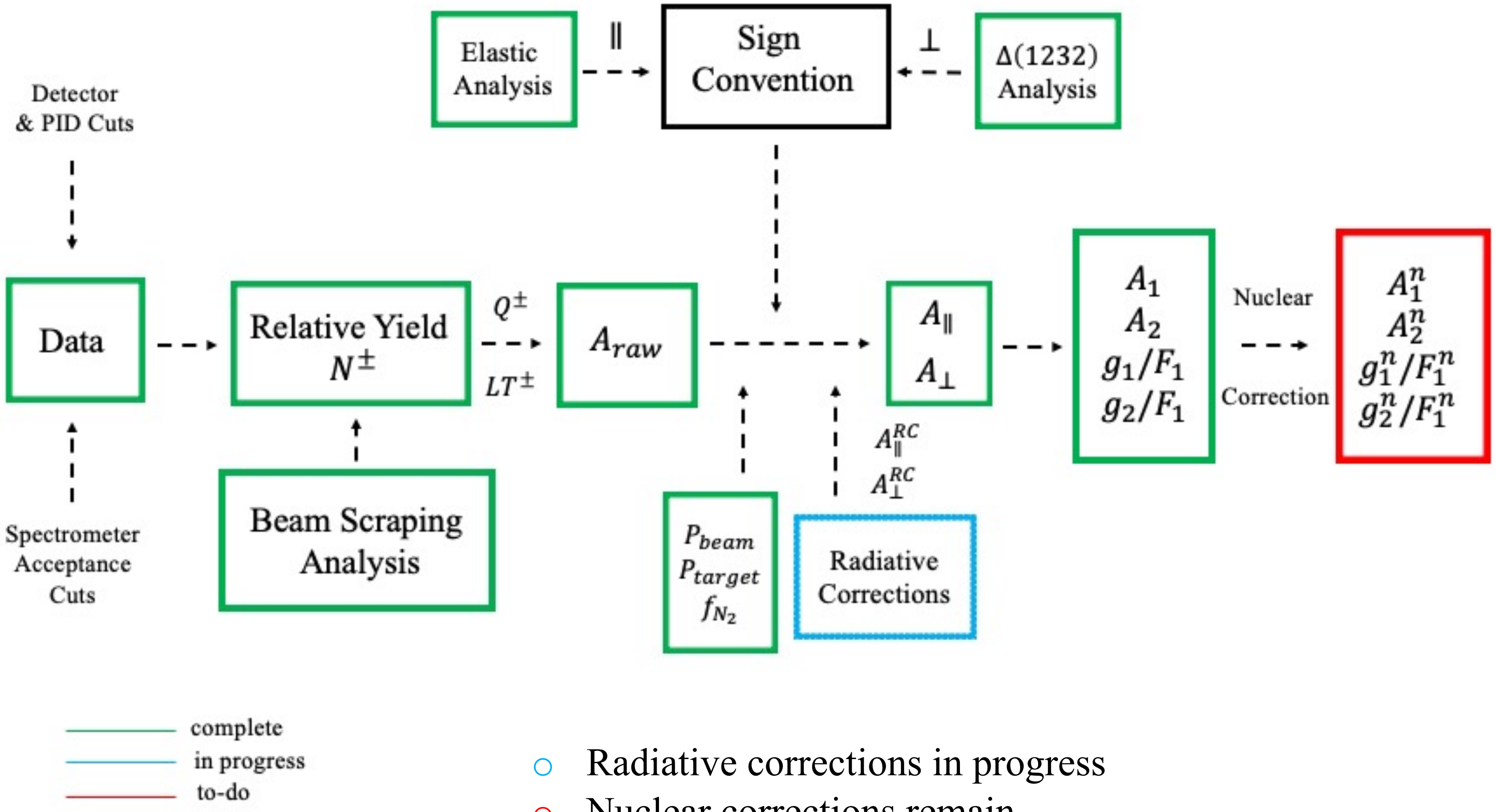
E12-06-110 is a high-impact experiment on nucleon spin-structure

- The measurements of $\boldsymbol{A_1^n}$ **at high** $\boldsymbol{x}$ allow us to test fundamental predictions of the nucleon spin structure
- Combined with precision proton data, the high-precision neutron data will allow us to extract polarized-to-unpolarized quark PDF ratios distributions (Δq) and **spin-flavor distributions** ($\Delta u/u$) and ($\Delta d/d$)

The results will help answer questions like,
How much of a role does L_q play?
(to what degree are the quarks' spin aligned parallel to the nucleon spin?)

Thanks for listening!

Analysis Flowchart

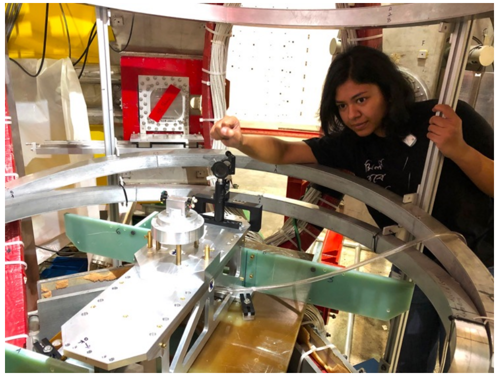


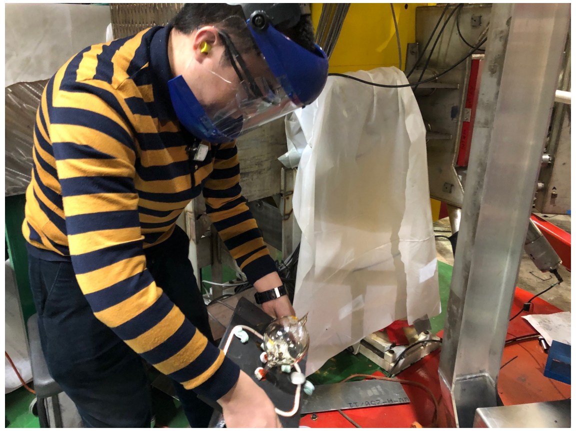
- ○ Radiative corrections in progress
- ○ Nuclear corrections remain

Acknowledgements:
The Polarized ^{3}He Run Group Collaboration (A_1^n/d_2^n)

D. Androic, W. Armstrong, T. Averett, X. Bai, J. Bane, S. Barcus, J. Benesch, H. Bhatt, D. Bhetuwal, D. Biswas, A. Camsonne, G. Cates, J-P. Chen, J. Chen, M. Chen, C. Cotton, M-M. Dalton, A. Deur, B. Dhital, B. Duran, S.C. Dusa, I. Fernando, E. Fuchey, B. Gamage, H. Gao, D. Gaskell, T.N. Gautam, N. Gauthier, C.A. Gayoso, O. Hansen, F. Hauenstein, W. Henry, G. Huber, C. Jantzi, S. Jia, K. Jin, M. Jones, S. Joosten, A. Karki, B. Karki, S. Katugampola, S. Kay, C. Keppel, E. King, P. King, W. Korsch, V. Kumar, R. Li, S. Li, W. Li, D. Mack, S. Malace, P. Markowitz, J. Matter, M. McCaughan, Z-E. Meziani, R. Michaels, A. Mkrtchyan, H. Mkrtchyan, C. Morean, V. Nelyubin, G. Niculescu, M. Niculescu, M. Nycz, C. Peng, S. Premathilake, A. Puckett, A. Rathnayake, M. Cardona, P. Reimer, G. Riley, Y. Roblin, J. Roche, M. Roy, M. Satnik, B. Sawatzky, S. Seeds, S. Sirca, G. Smith, N. Sparveris, H. Szumila-Vance, A. Tadepalli, V. Tadevosyan, Y. Tian, A. Usman, H. Voskanyan, S. Wood, B. Yale, C. Yero, A. Yoon, J. Zhang, Z. Zhao, X. Zheng, J. Zhou

PhD Candidates Spokespeople





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Backup Slides

SHMS & HMS Asymmetries

- $\boldsymbol{LT^{\pm}}$, $\boldsymbol{Q^{\pm}}$, **IHWP-corrected, Wien-Flip corrected (2/18/20, beginning w/ SHMS 10355 & HMS 3163)**

- $\boldsymbol{x_{BJ}}$ **bins** = 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75
all $\pm$ **0.025**

- $\boldsymbol{x_{BJ}}$ **bins** = 0.80 (0.775, 0.83), 0.86 (0.83, 0.89), 0.92 (0.89, 0.95), 0.98 (0.95, 1.0)

$$A = \frac{\sum_i \left(\frac{A_i}{(\Delta A_i)^2}\right)}{\sum_i \left(\frac{1}{(\Delta A_i)^2}\right)} \qquad \Delta A = \sqrt{\frac{1}{\sum_i \left(\frac{1}{(\Delta A_i)^2}\right)}} \qquad i \sim \text{run \#}$$

$$\Delta A_i = \sqrt{\frac{1 - A_i^2}{N}} \qquad \Delta A_{phys,i} = \frac{\Delta A_i}{P_b P_t f_{N_2}}$$

f_{N_2} = 0.92
(for now)

Extracting $g_{1,2}/F_1$ & A_1, A_2

$$\frac{g_1^{^3He}}{F_1^{^3He}} = \left(\frac{1}{d'}\right)\left(A_\parallel + \tan\left(\frac{\theta}{2}\right) A_\perp\right)$$

$$\frac{g_2^{^3He}}{F_1^{^3He}} = \left(\frac{y}{2d'}\right)\left(-A_\parallel + \left(\frac{E - E'\cos(\theta)}{E'\sin(\theta)}\right) A_\perp\right)$$

$$A_1 = \frac{1}{D(1+\eta\xi)} A_\parallel - \frac{\eta}{d(1+\eta\xi)} A_\perp$$

$$A_2 = \frac{\xi}{D(1+\eta\xi)} A_\parallel + \frac{1}{d(1+\eta\xi)} A_\perp$$

$A_\parallel$ & $A_\perp$ are the electron **physics** double-spin asymmetries

Electron Beam Energy E = 10.38 GeV (fixed)

$$D = \frac{E - \epsilon E'}{E(1+\epsilon R)}$$

$$\epsilon = \frac{1}{1 + 2\left(1 + \frac{\nu^2}{Q^2}\right) tan^2(\frac{\theta}{2})}$$

$$\eta = \frac{\epsilon\sqrt{Q^2}}{E - E'\epsilon} \qquad \xi = \eta(1+\epsilon)/2\epsilon$$

$$\nu = E - E' \qquad y = \nu/E$$

$$d = D\sqrt{\frac{2\epsilon}{1+\epsilon}} \qquad R(x, Q^2) = \frac{\sigma_L}{\sigma_T} (1998)$$

$$d' = \frac{(1-\epsilon)(2-y)}{y(1+\epsilon R)}$$

Nuclear Corrections & Quark Flavor Decomposition

- A_1^n is ultimately extracted from $A_1^{^3He}$ as

$$A_1^n = \frac{F_2^{^3He}\left[A_1^{^3He} - 2\left(\frac{F_2^p}{F_2^{^3He}}\right)P_p A_1^p\left(1 - \frac{0.014}{2P_p}\right)\right]}{P_n F_2^n(1 + \frac{0.056}{P_n})}$$

where $P_n = 0.86^{+0.036}_{-0.02}$ and $P_p = -0.028^{+0.009}_{-0.004}$ are the effective nucleon polarizations of the neutron and proton inside ^{3}He

- Combining neutron g_1/F_1 data with measurements on the proton allows a flavor decomposition to separate the polarized-to-unpolarized-PDF ratios for up and down quarks:

$$\frac{\Delta u + \Delta\bar{u}}{u + \bar{u}} = \frac{4}{15}\frac{g_1^p}{F_1^p}\left(4 + R^{du}\right) - \frac{1}{15}\frac{g_1^n}{F_1^n}\left(1 + 4R^{du}\right)$$

$$\frac{\Delta d + \Delta\bar{d}}{d + \bar{d}} = \frac{-1}{15}\frac{g_1^p}{F_1^p}\left(1 + \frac{4}{R^{du}}\right) + \frac{4}{15}\frac{g_1^n}{F_1^n}\left(4 + \frac{1}{R^{du}}\right)$$

$$R^{du} = \frac{\mathrm{d} + \bar{\mathrm{d}}}{u + \bar{u}}$$ (parameterization)

$$\frac{g_1^p}{F_1^p}$$ (modeled with world data)

A_1^p: 3-parameter, Q^2 − independent fit

$$A_1^p = (0.041 \pm 0.008) + (1.442 \pm 0.081)x + (-0.599 \pm 0.163)x^2$$

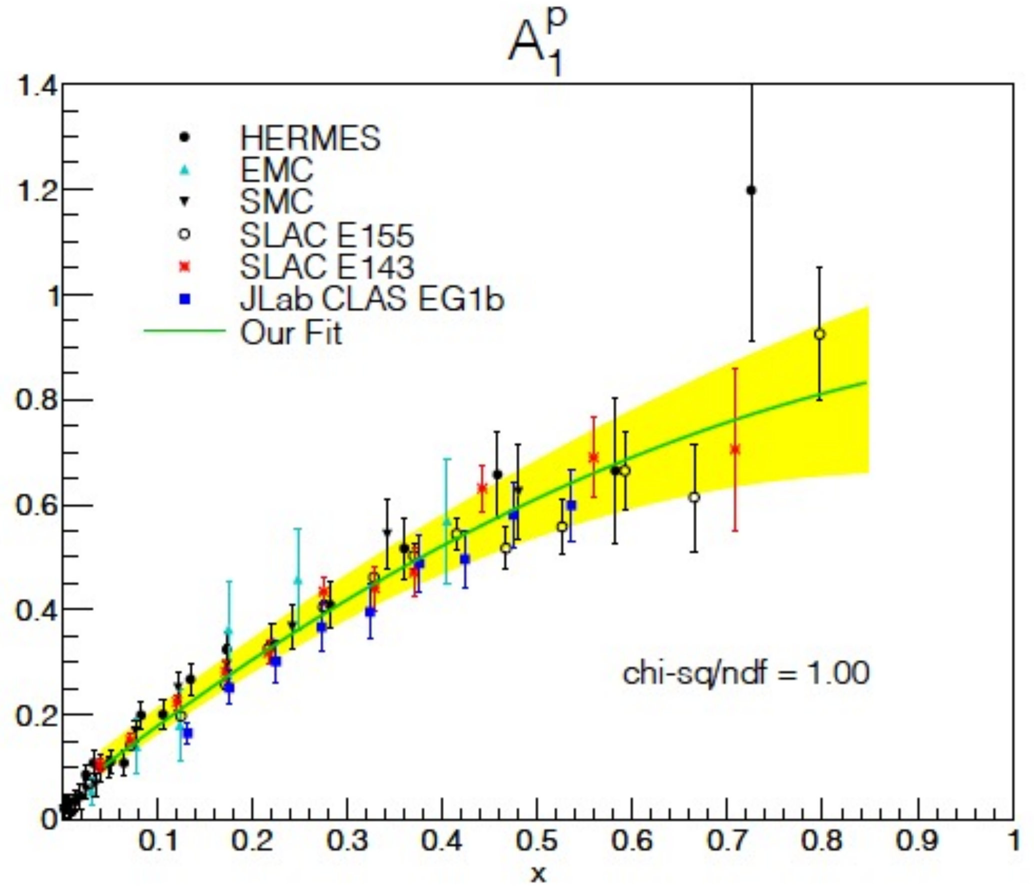


Figure D.1: Our fit to world A_1^p data. The error bars on the data are the in-quadrature sum of their statistical and systematic errors. The yellow band indicates the error on the fit.

David Flay Thesis, Appendix D.2

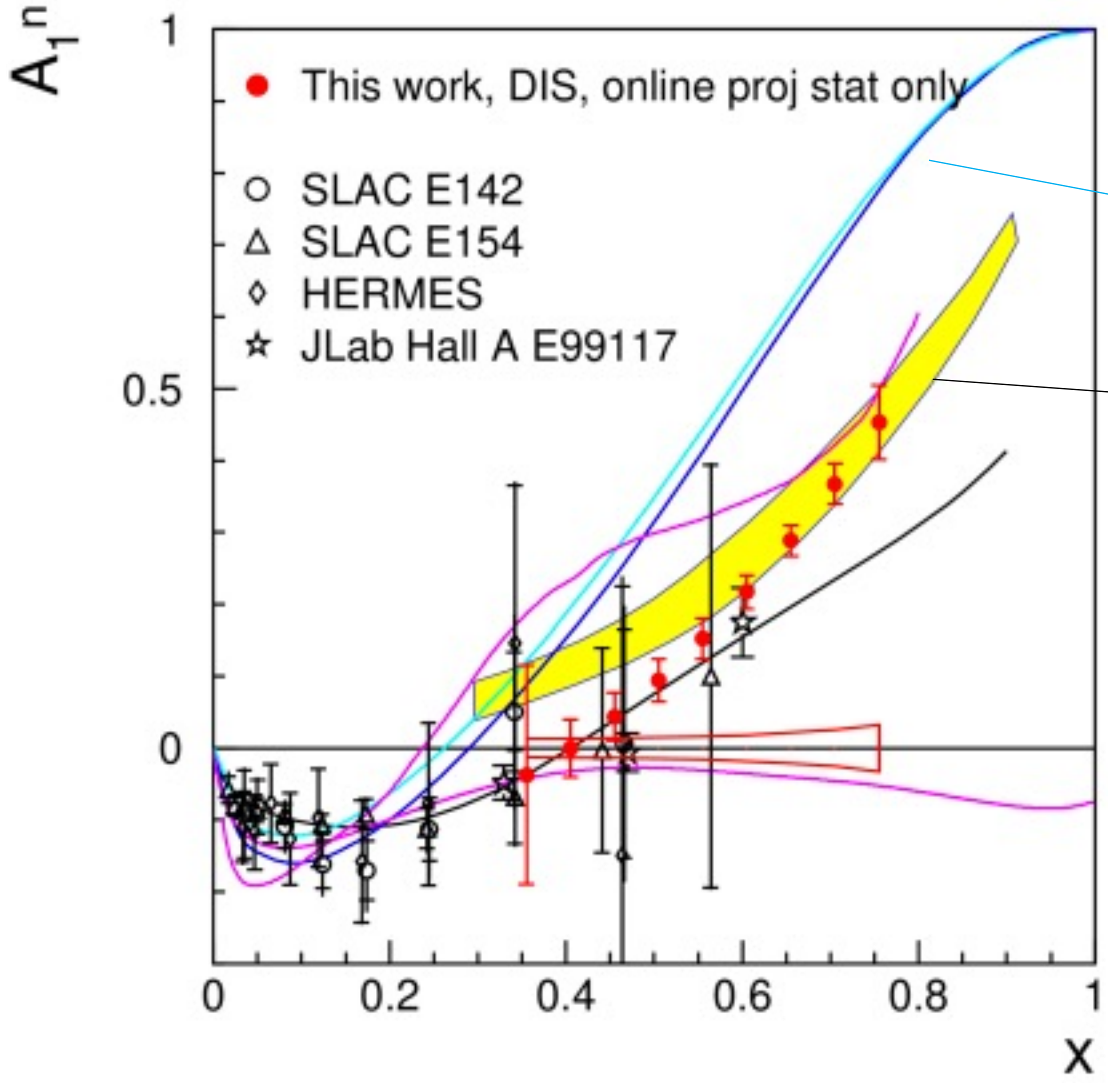
Kinematics and Beam Time

Kine	Spec	E_b GeV	E_p GeV	θ ($\circ$)	beam time (hours)
$\Delta(1232)$	SHMS	2.183	-1.79736	8.5	4.0
Elastic	SHMS	2.183	-2.12860	8.5	8.0

Kine	Spec	E_b GeV	E_p GeV	θ ($\circ$)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
DIS							
3	HMS	10.5	2.90	30.0	88.0	0.0	88.0
4	HMS	10.5	3.50	30.0	511.0	0.0	511.0
B	SHMS	10.5	3.40	30.0	511.0	4.0	515.0
C	SHMS	10.5	2.60	30.0	88.0	4.0	92.0

- Longitudinal asymmetry of elastic scattering and transverse asymmetry of $\Delta(1232)$ are used to check $P_b P_t$ (sign convention)
- SHMS (B) and HMS (4) used to determine physics asymmetry of ^{3}He at high x, high Q^2
- SHMS (C) and HMS (3) used to cover medium x with high Q^2 to improve upon 6 GeV results

Projected Results



spin-only pQCD disfavored!

pQCD with **spin only**

RQCM with **spin + OAM**

30 μA beam, 40 cm target length, 85% beam polarization, 50% target polarization

A_1^n and Δq/q predictions as $x \to 1$

SU(6) spin-flavor symmetric neutron wavefunction polarized in $+\hat{z}$ direction, with diquark states $(qq)_{S,S_z}$:

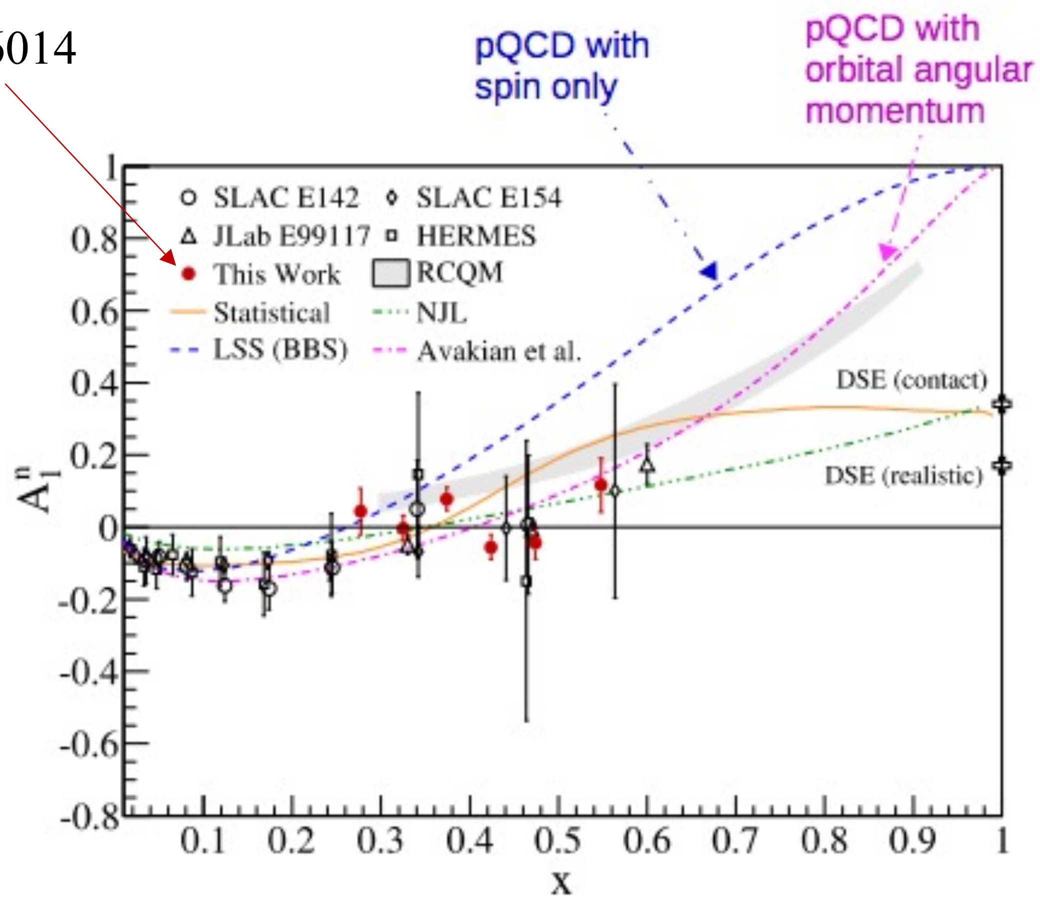
$$|n^\uparrow\rangle = \frac{1}{\sqrt{2}}|d^\uparrow(ud)_{00}\rangle + \frac{1}{\sqrt{18}}|d^\uparrow(ud)_{10}\rangle - \frac{1}{3}|d^\downarrow(ud)_{11}\rangle - \frac{1}{3}|u^\uparrow(dd)_{10}\rangle - \frac{\sqrt{2}}{3}|u^\downarrow(dd)_{11}\rangle$$

	$\frac{F_2^n}{F_2^p}$	$\frac{d}{u}$	$\frac{\Delta d}{\Delta u}$	$\frac{\Delta u}{u}$	$\frac{\Delta d}{d}$	A_1^n	A_1^p
DSE-1	0.49	0.28	−0.11	0.65	−0.26	0.17	0.59
DSE-2	0.41	0.18	−0.07	0.88	−0.33	0.34	0.88
$0^+_{[ud]}$	$\frac{1}{4}$	0	0	1	0	1	1
NJL	0.43	0.20	−0.06	0.80	−0.25	0.35	0.77
SU(6)	$\frac{2}{3}$	$\frac{1}{2}$	$-\frac{1}{4}$	$\frac{2}{3}$	$-\frac{1}{3}$	0	$\frac{5}{9}$
CQM	$\frac{1}{4}$	0	0	1	$-\frac{1}{3}$	1	1
pQCD	$\frac{3}{7}$	$\frac{1}{5}$	$\frac{1}{5}$	1	1	1	1

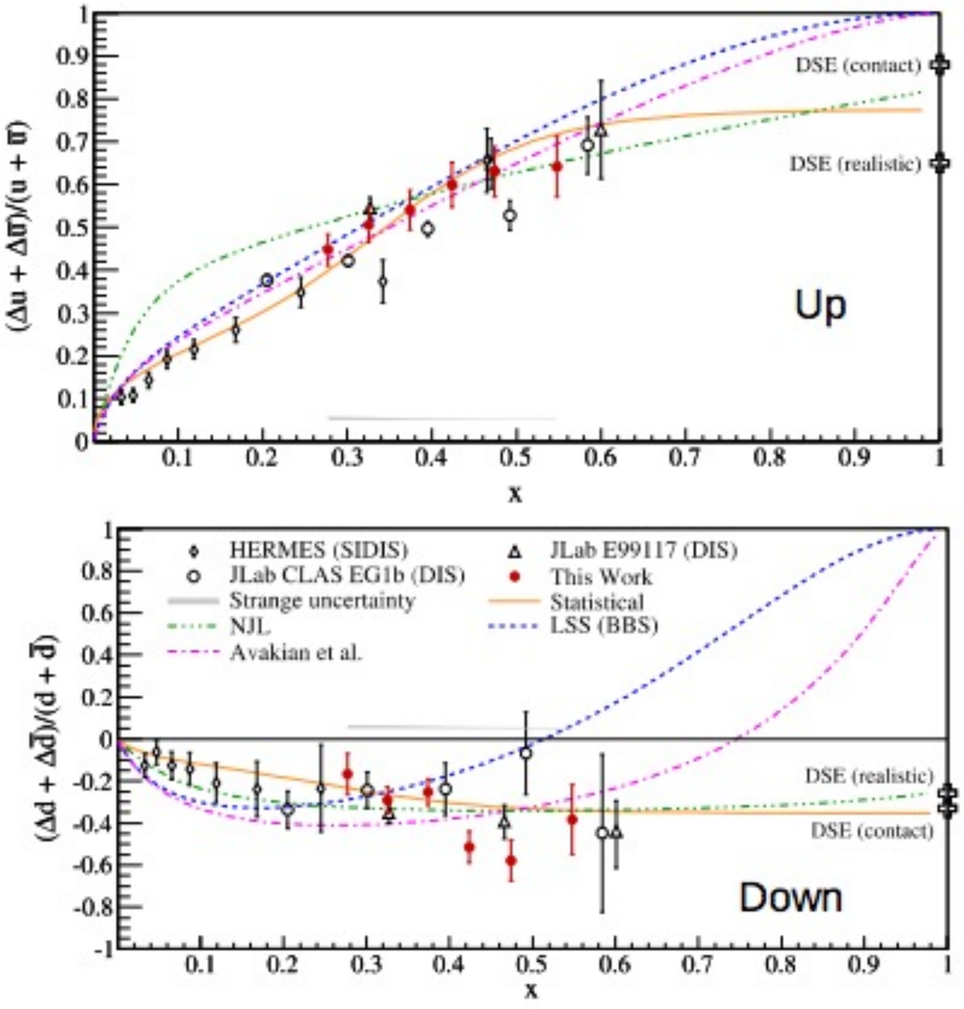
Craig D. Roberts, et al: *10.1016/j.physletb.2013.09.038*

Previous Results

JLab E06014

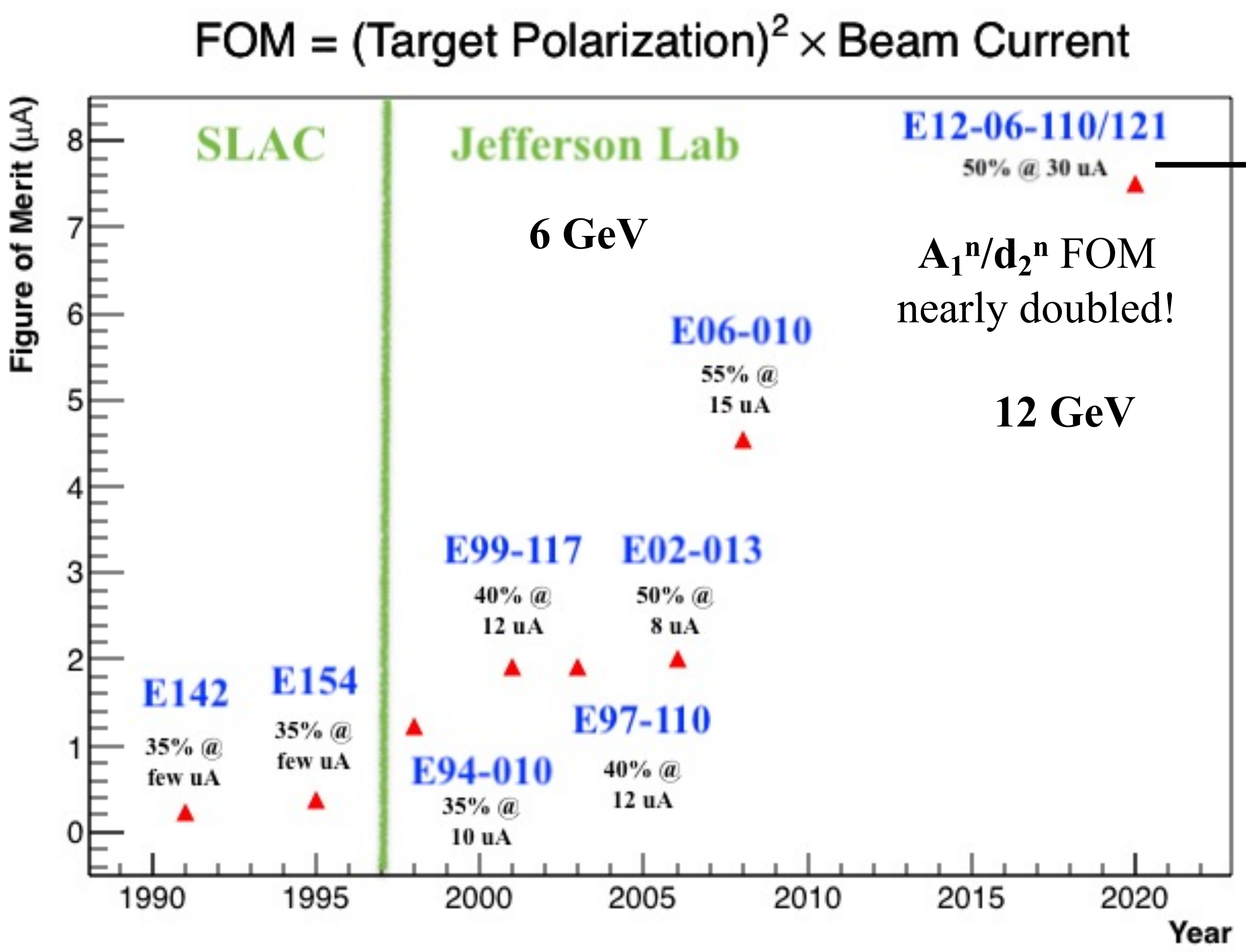


Parno et al., Phy Let B DOI: 10.1016/j.physletb.2015.03.067
X. Zheng et al., PRL 92, 012004 (2004); PRC 70, 065207 (2004)

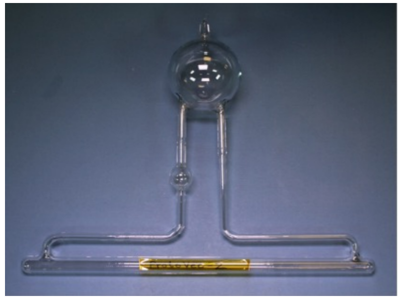


^{3}He Performance Evolution

12 GeV era achieved **double the luminosity** of 2×10^{36} cm^{-2}s^{-1} @ 30 μA



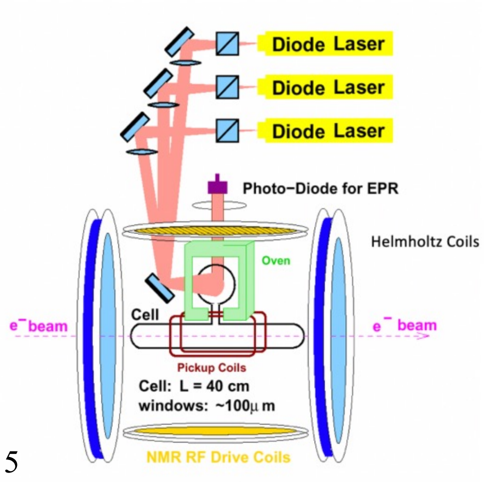
A_1^n/d_2^n FOM nearly doubled!



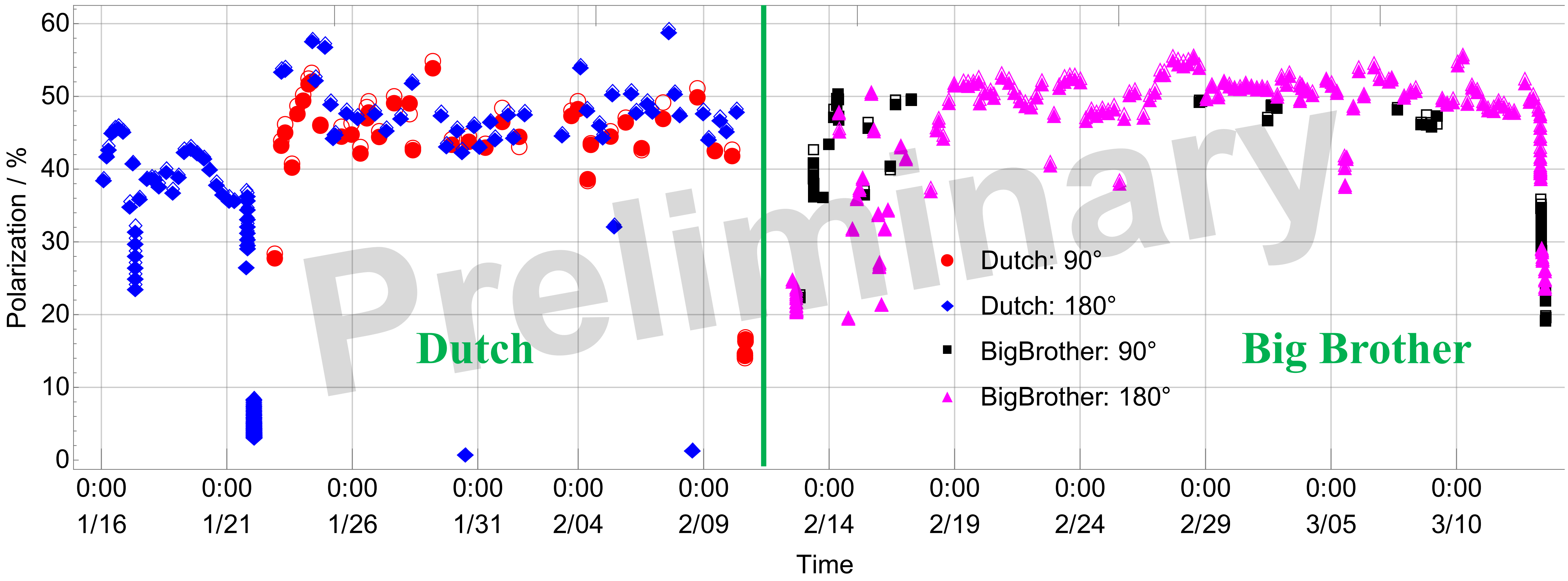
Convection-style cells (instead of diffusion cells used in the 6 GeV era) used for A1n/d2n

→ allows for more uniform polarization between target and pumping chamber

Each laser at 795 nm @ 30 W



^{3}He Target Polarization throughout A_1^n Production Running



90° → ⊥ to e^- beam
180° → ∥ to e^- beam

Plot courtesy of Junhao Chen, College of William & Mary

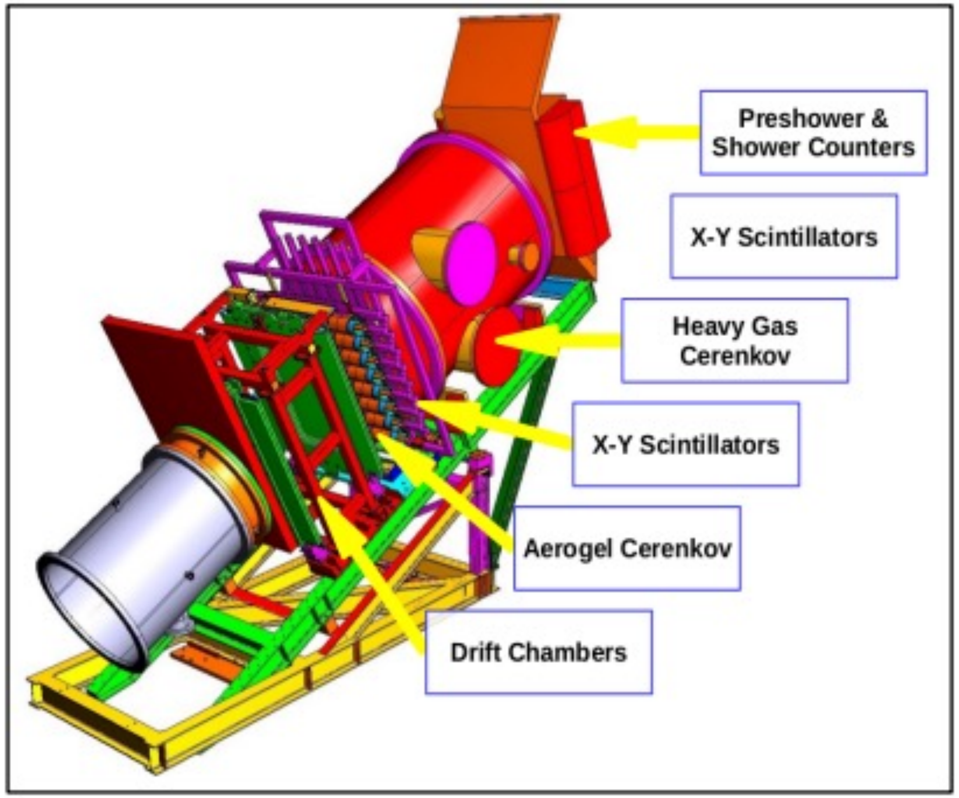
Target Field/Spin Direction

Target Holding Field Direction	^{3}He Spin Direction
+X Beam RIGHT (90°)	Beam LEFT
-X Beam LEFT (270°)	Beam RIGHT
+Z DOWNSTREAM (0°)	UPSTREAM
-Z UPSTREAM (180°)	DOWNSTREAM

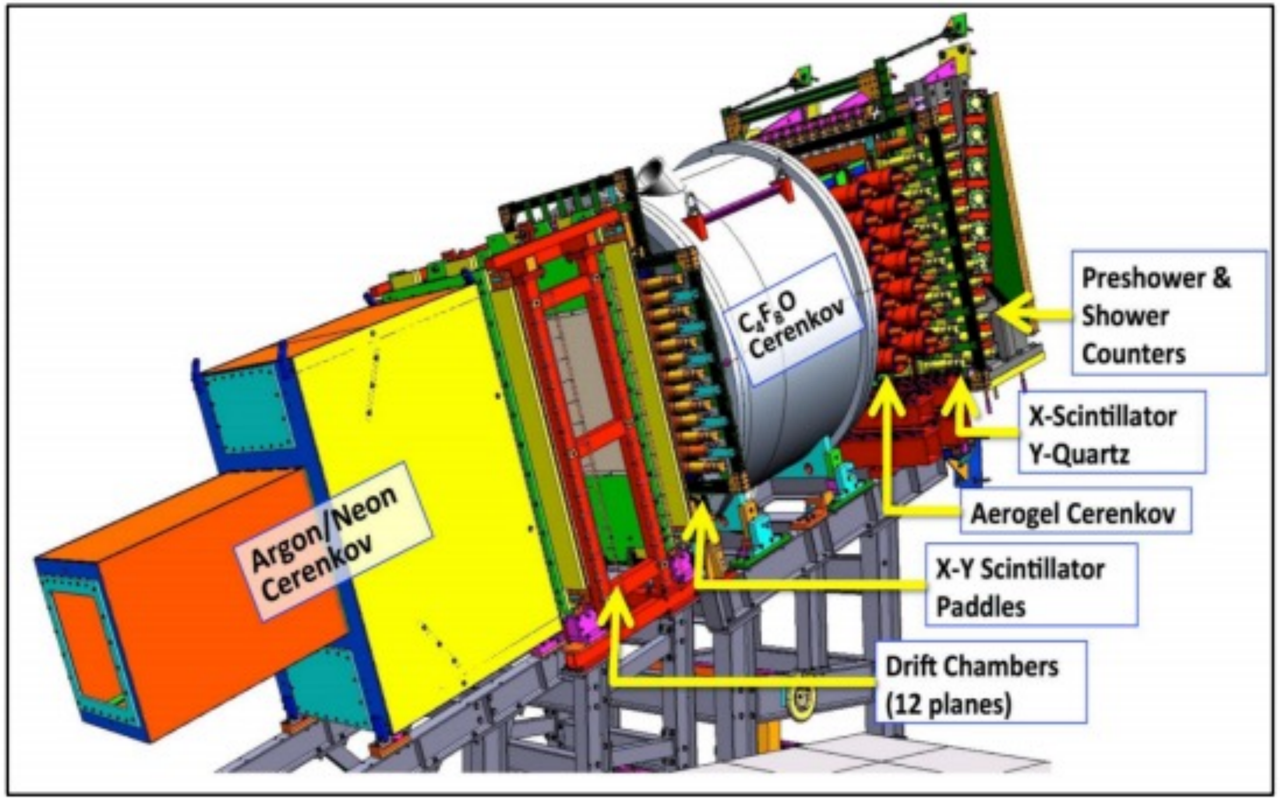
The target was always pumped in the low-energy state
(^{3}He spin is **opposite of the holding field**) during data-taking

Hall C Spectrometers & Detectors

HMS detectors



SHMS detectors



Spectrometer	Central Momentum (GeV/c)	Momentum Acceptance	Momentum Resolution	Scattering Angle	Solid Angle Acceptance (msr)	Horizontal Acceptance (mrad)	Vertical Acceptance (mrad)
HMS	0.5 – 7.5	(-9%, 9%)	0.02%	12.5° - 90°	8.1	±32	±85
SHMS	2.0 - 11.0	(-10%, 22%)	0.03% - 0.08%	5.5° - 40°	> 4.0	±24	±40