A1n Update

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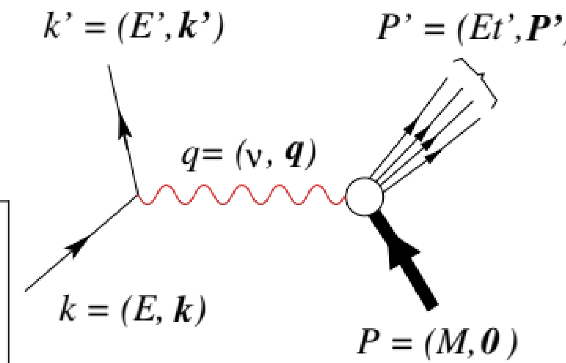
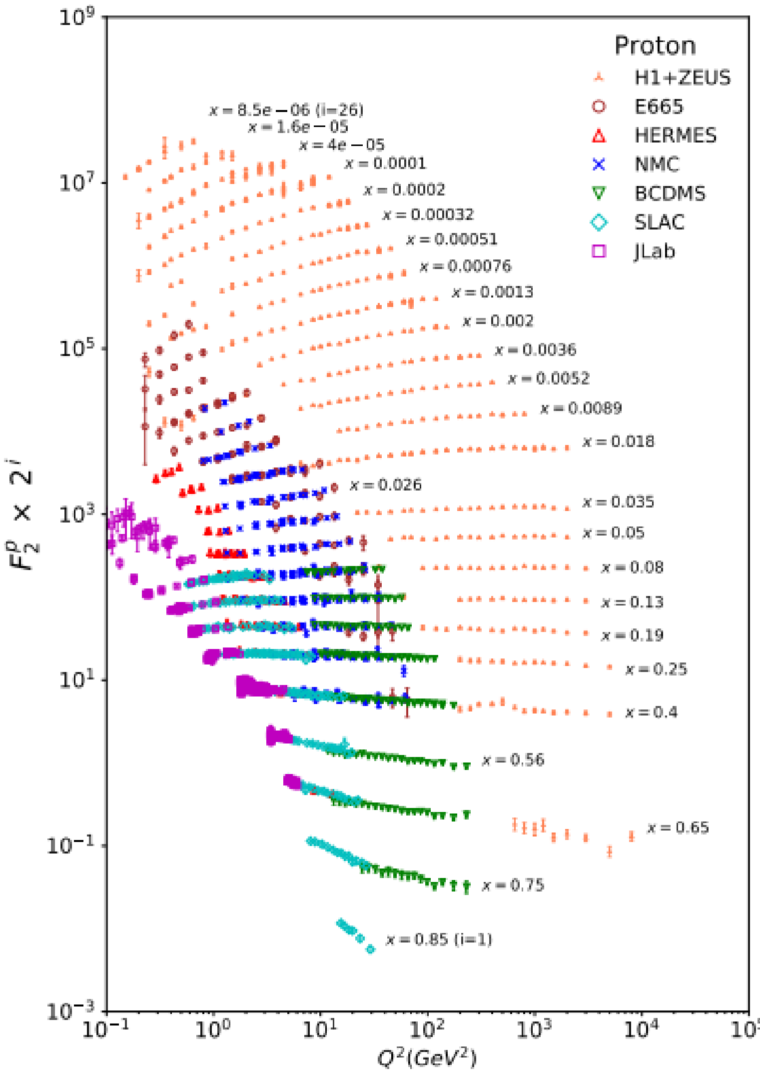
University of Virginia
January 27, 2026

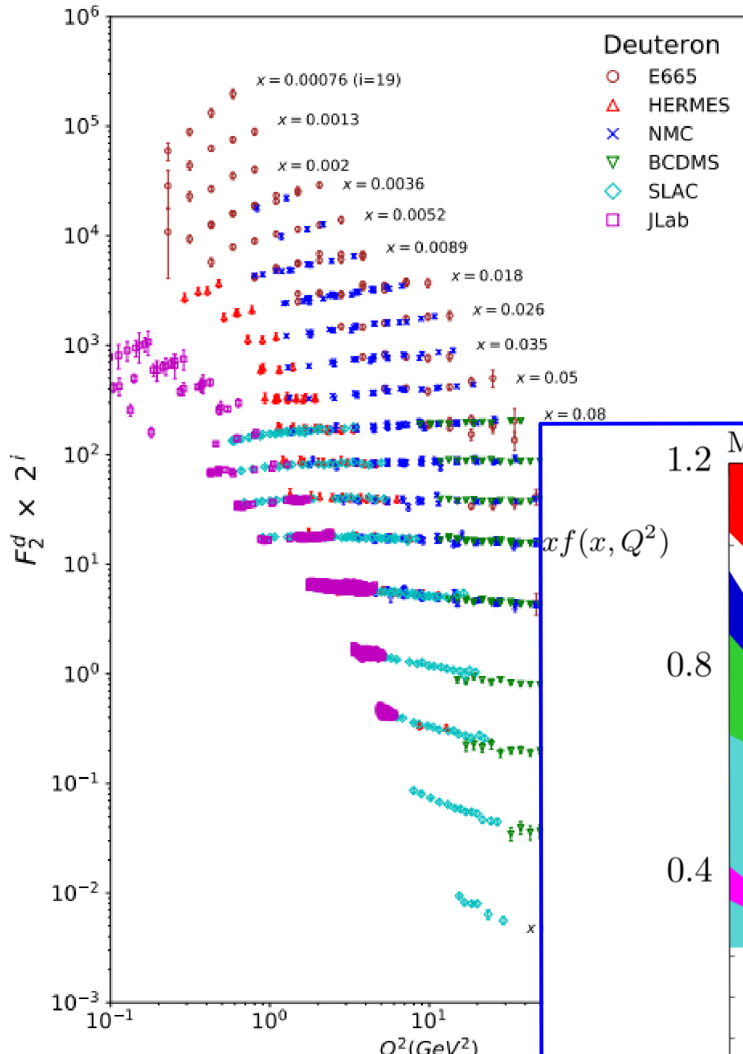
For the JLab E12-06-110 Collaboration

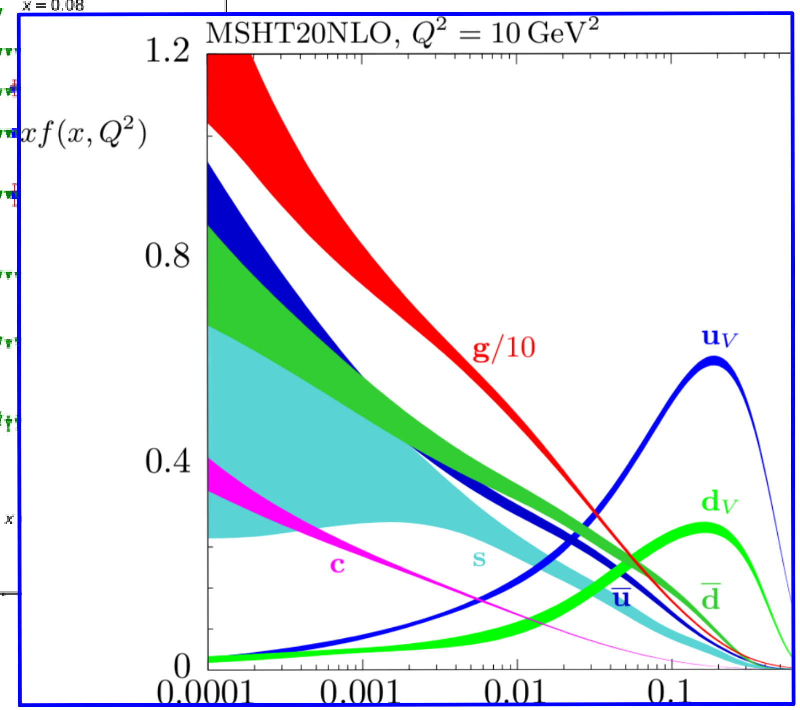
Inclusive Lepton Scattering Formalism (Unpolarized)

$$\frac{d^2\sigma_0}{d\Omega\, dE'} \propto \sigma_{Mott}\left[\alpha F_2\left(x, Q^2\right) + \beta F_1\left(x, Q^2\right) \tan^2\frac{\theta}{2}\right]$$









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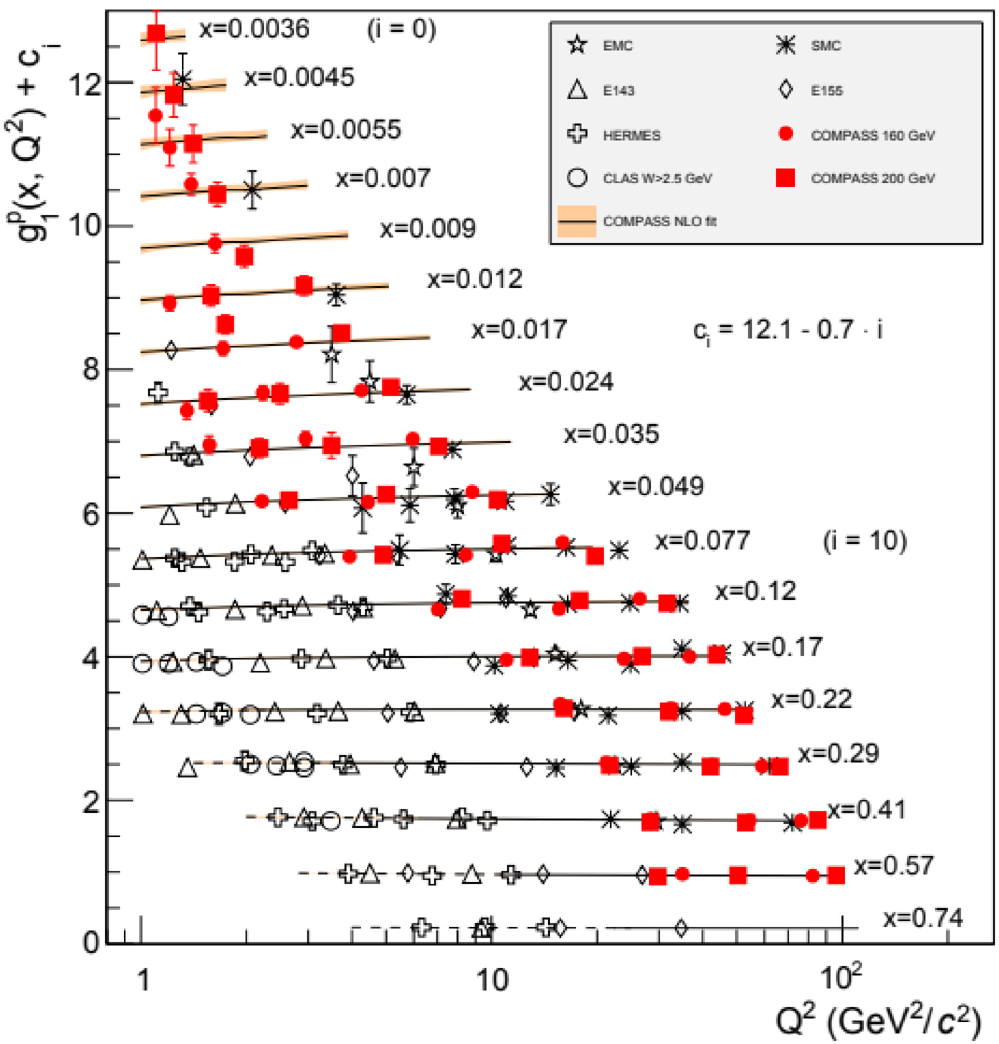
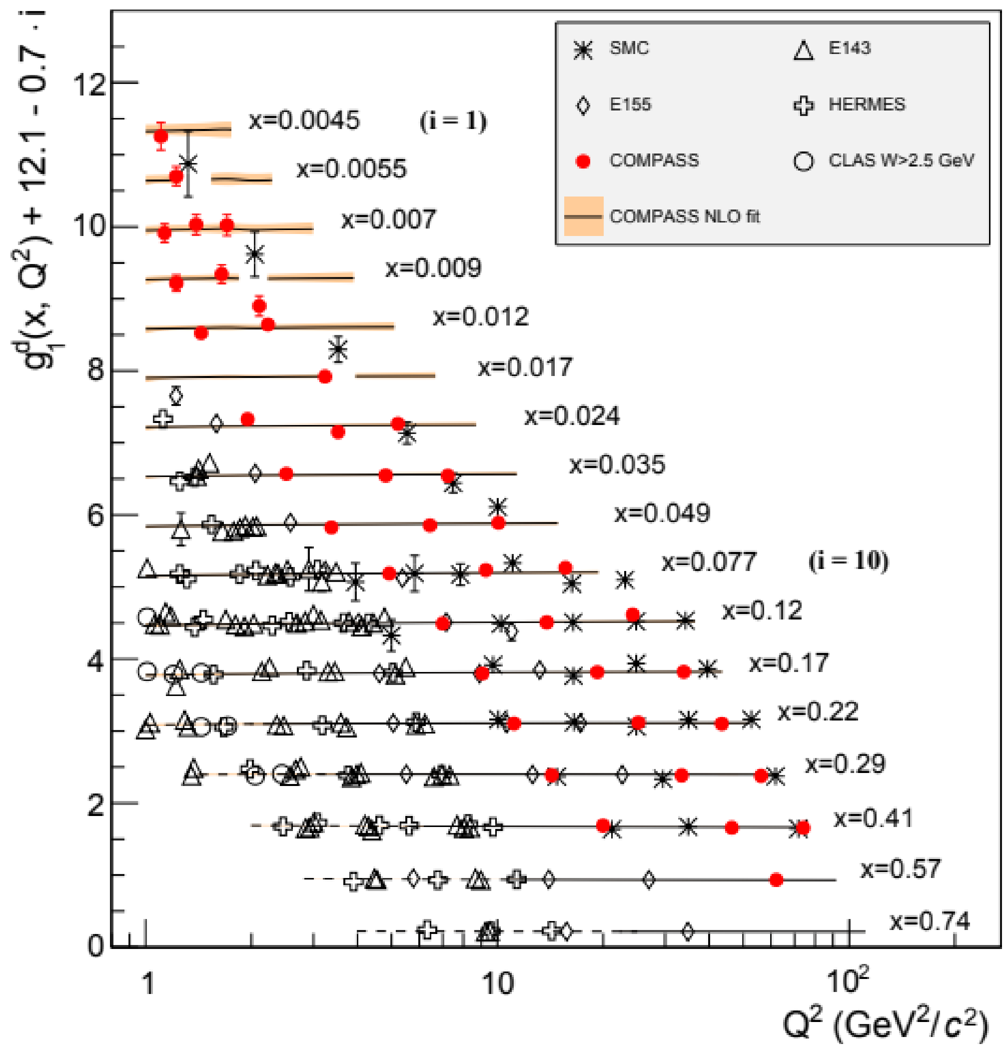
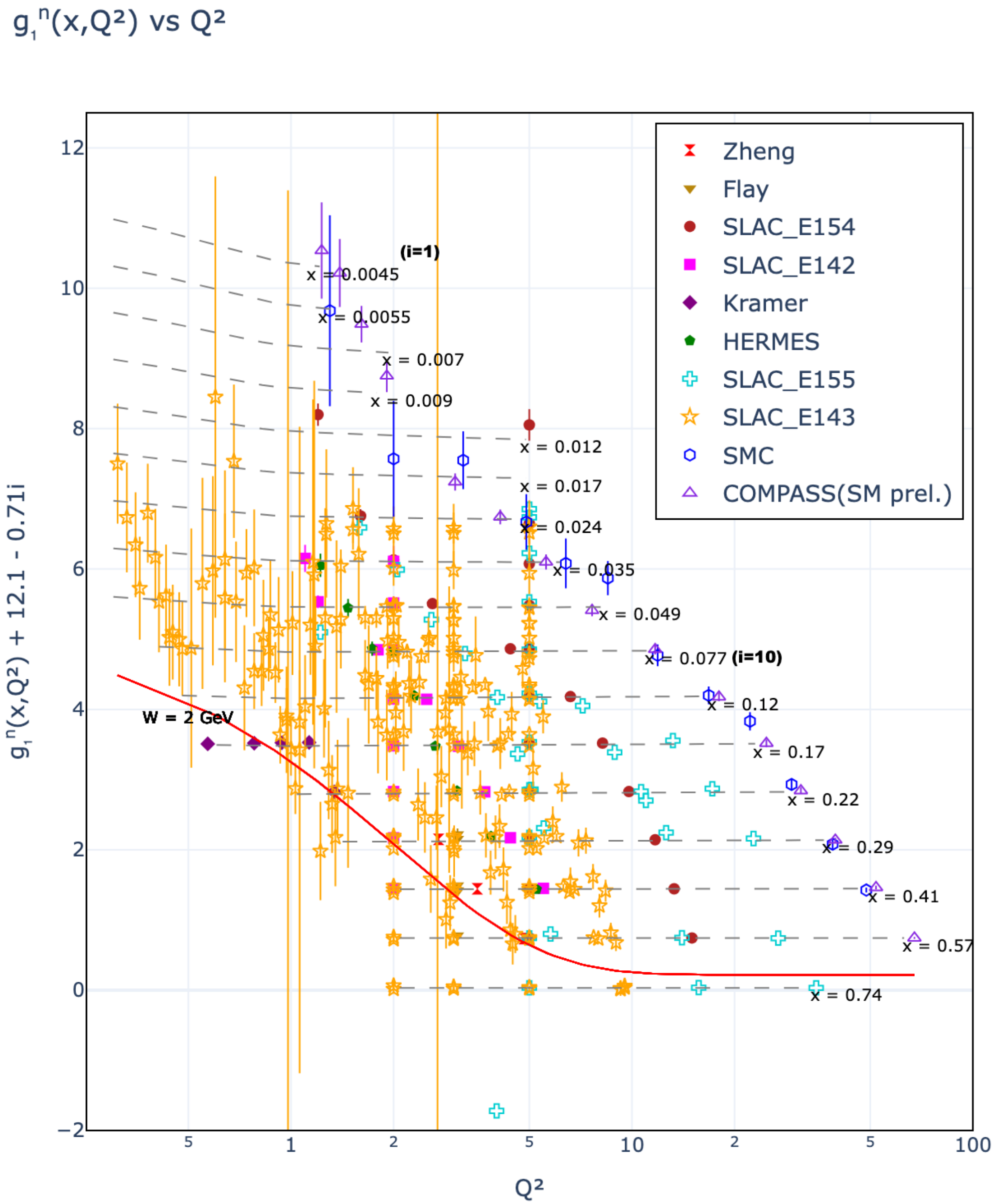
Inclusive Lepton Scattering Formalism (Polarized)

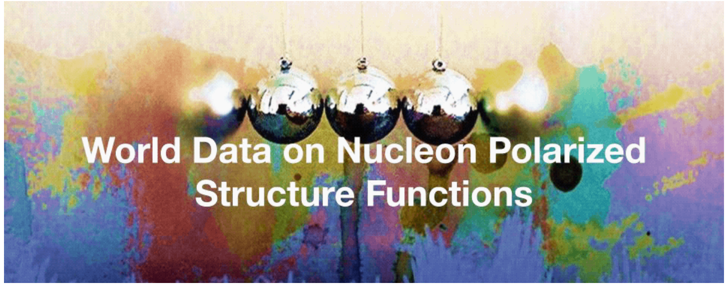
$$\frac{d^2\sigma^{\uparrow\downarrow}}{d\Omega\, dE'} - \frac{d^2\sigma^{\uparrow\uparrow}}{d\Omega\, dE'} \propto \sigma_{\text{point-like}}\left[\alpha' g_1\left(x, Q^2\right) + \beta' g_2\left(x, Q^2\right)\right]$$





Inclusive Lepton Scattering Formalism (Polarized)





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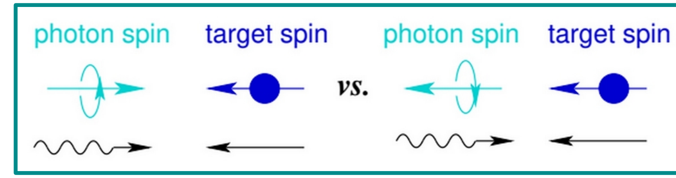
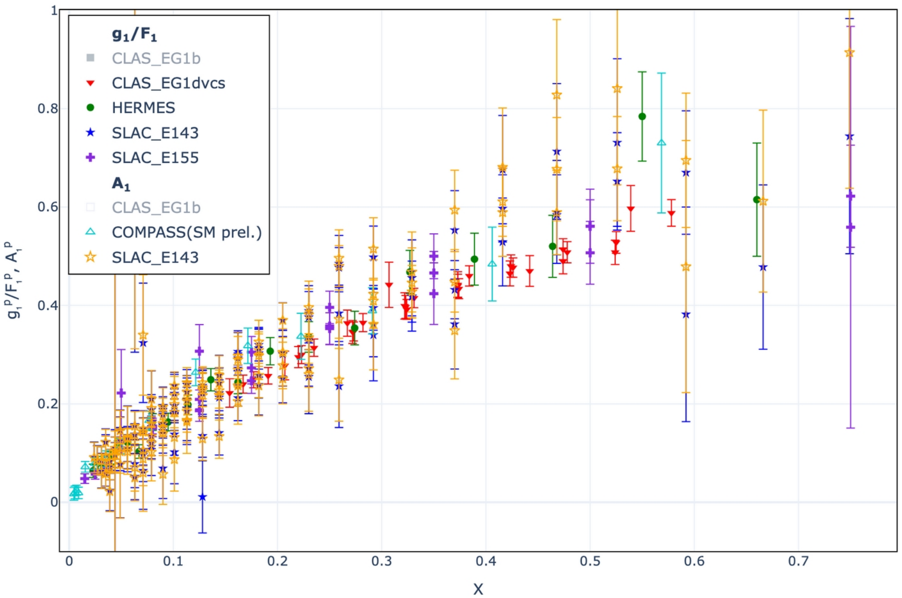
website built by Scarlett Morse (UVA):
https://qnz3gx.github.io/sim.github.io/

World Data on Spin Asymmetries

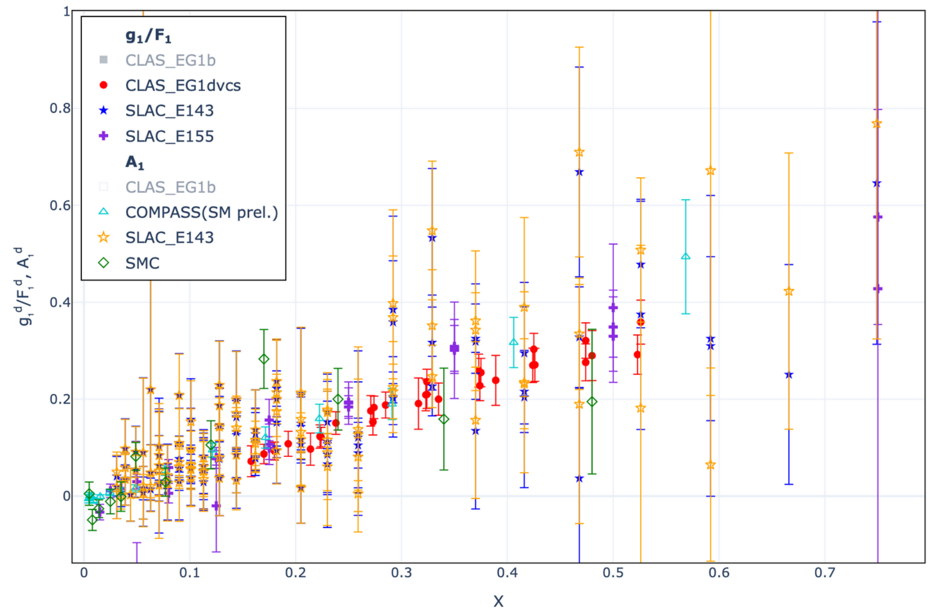
$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1}$$

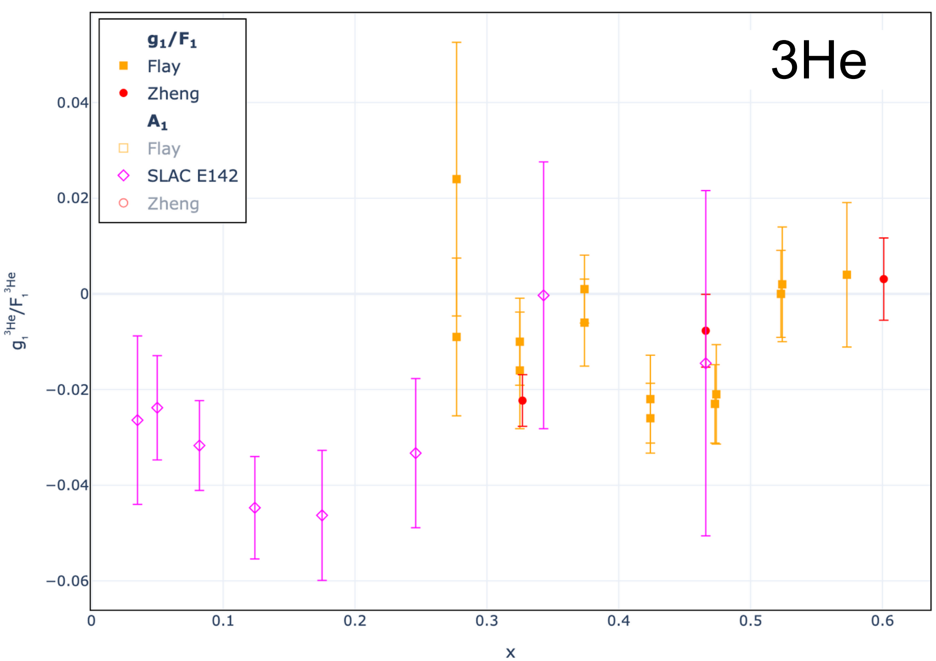


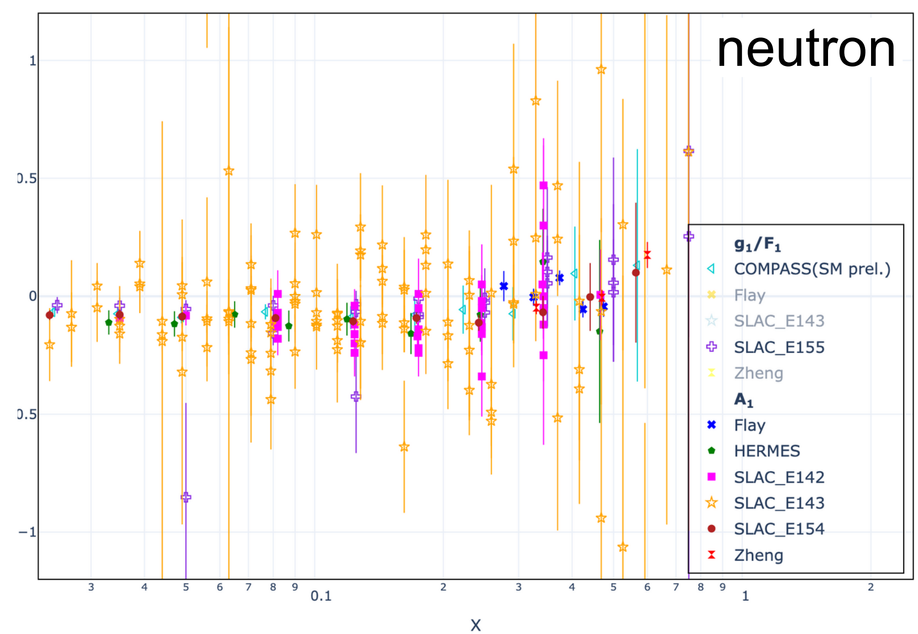
proton



deuteron





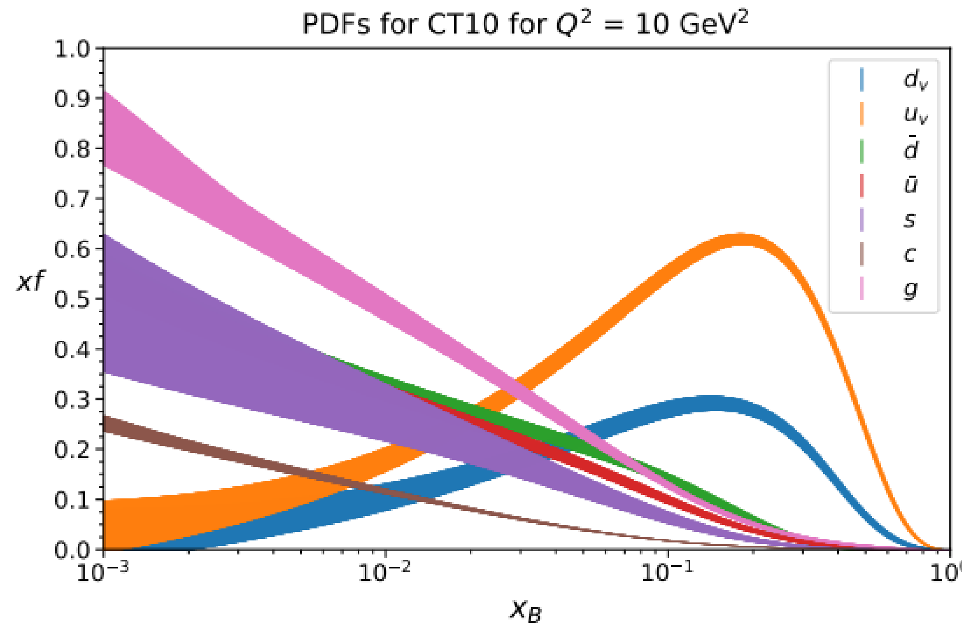


website built by Scarlett Morse (UVA): https://qnz3gx.github.io/sim.github.io/

Spin at high x as part of the Nucleon Structure and QCD Study

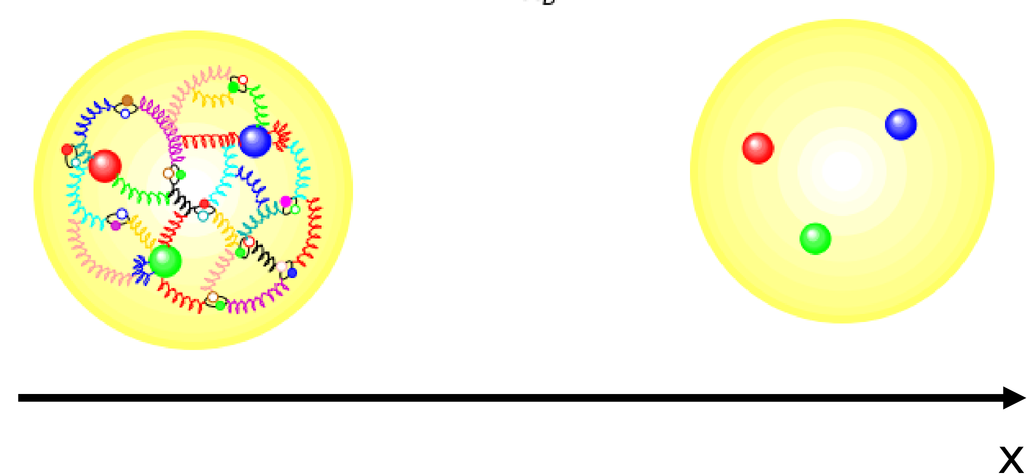
$$|p^{\uparrow}\rangle = \frac{1}{\sqrt{2}}|u^{\uparrow}(ud)_{00}\rangle + \frac{1}{\sqrt{18}}|u^{\uparrow}(ud)_{10}\rangle - \frac{1}{3}|u^{\downarrow}(ud)_{11}\rangle - \frac{1}{3}|d^{\uparrow}(uu)_{10}\rangle - \frac{\sqrt{2}}{3}|d^{\downarrow}(uu)_{11}\rangle$$

Model	$\frac{F_2^n}{F_2^p}$	$\frac{d}{u}$	$\frac{\Delta d}{\Delta u}$	$\frac{\Delta u}{u}$	$\frac{\Delta d}{d}$	A_1^n	A_1^p
CSM	0.45(5)	0.23(6)	-0.14(3)	0.63(8)	-0.38(7)	0.15(5)	0.58(8)
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	0.2	-0.06	0.8	-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
HLFQCD	0.28	0.035	0.035	1	1	1	1



Nucleon structure functions at high x:

1. "simplest" picture of the nucleon internal structure, valence quark dominate
2. predictions exist from theories, models, and/or phenomenology



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Spin at high x as part of the Nucleon Structure and QCD Study

Model	$\frac{F_2^n}{F_2^p}$	$\frac{d}{u}$	$\frac{\Delta d}{\Delta u}$	$\frac{\Delta u}{u}$	$\frac{\Delta d}{d}$	A_1^n	A_1^p
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CQM	$\frac{1}{4}$	0	0	1	$-\frac{1}{3}$	1	1
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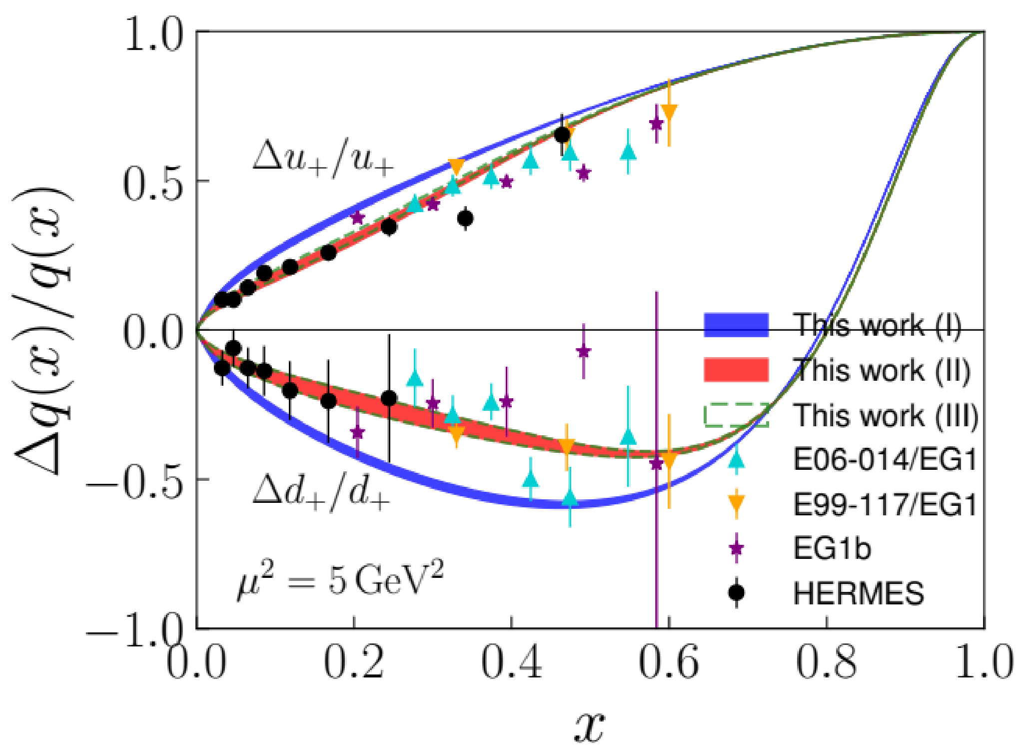
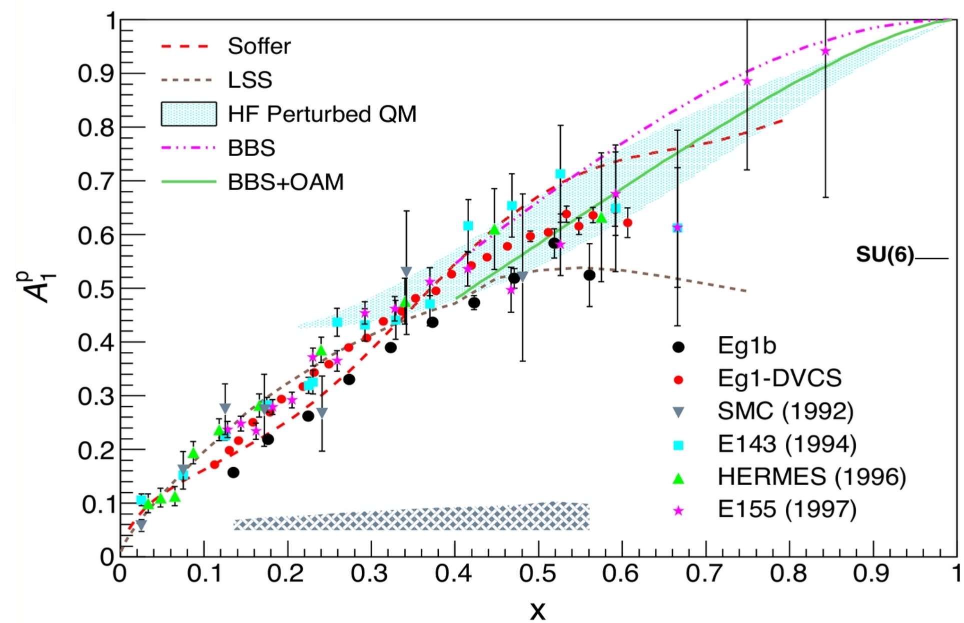
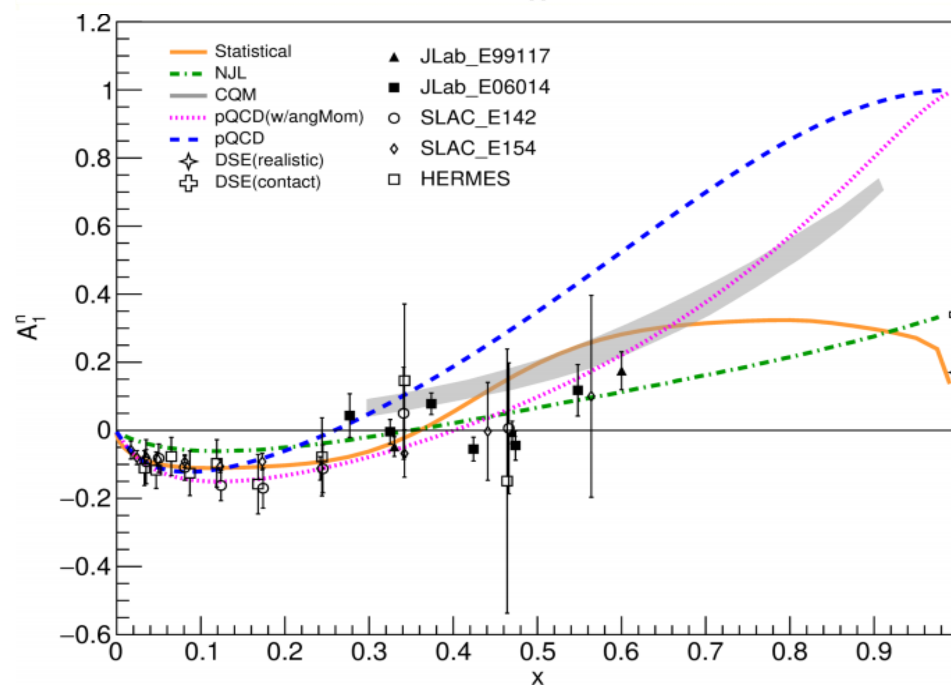


T. Liu et al., [Phys. Rev. Lett. 124, 082003 (2020)arXiv:1909.13818]





D. Parno et al. Phys.Rev.Lett. 113 (2014) 2, 022002, 1404.4003

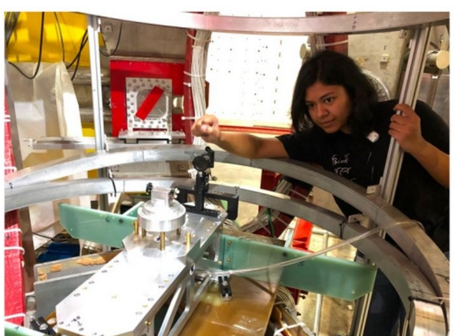
Hall C 12 GeV A1n/d2n Collaboration

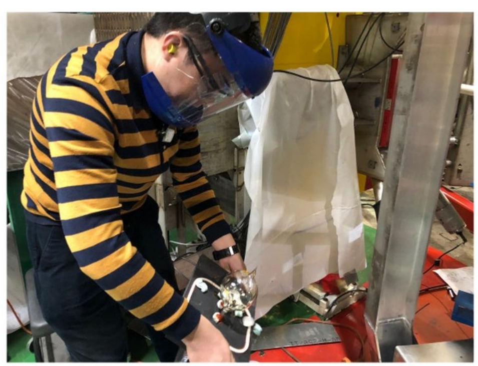
PhD (all graduated)

People

Spokespeople

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, I. Li, 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. Rehfuss, 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, R. Trottar, A. Usman, H. Voskanyan, S. Wood, B. Yale, C. Yero, A. Yoon, J. Zhang, Z. Zhao, X. Zheng, J. Zhou





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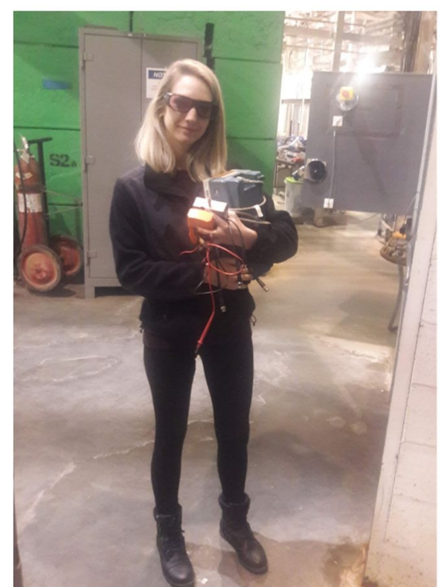
Institutions

A.I. Alikhanian National Science Laboratory; Argonne National Laboratory; Artem Alikhanian National Laboratory (AANL).; Christopher Newport University; Duke University; Florida International University; Hampton University ; James Madison University ; Jefferson Lab; Kent State University; Mississippi State University; Ohio University; Old Dominion University; Rutgers University; Syracuse University; Temple University; The College of William and Mary; Univ. of Ljubljana; University of Connecticut; University of Kentucky; University of Kentucky; University of New Hampshire; University of Regina; University of Tennessee; University of Virginia; University of Virginia; University of Zagreb



JLab 12 GeV A_1^n E12-06-110 (Hall C)

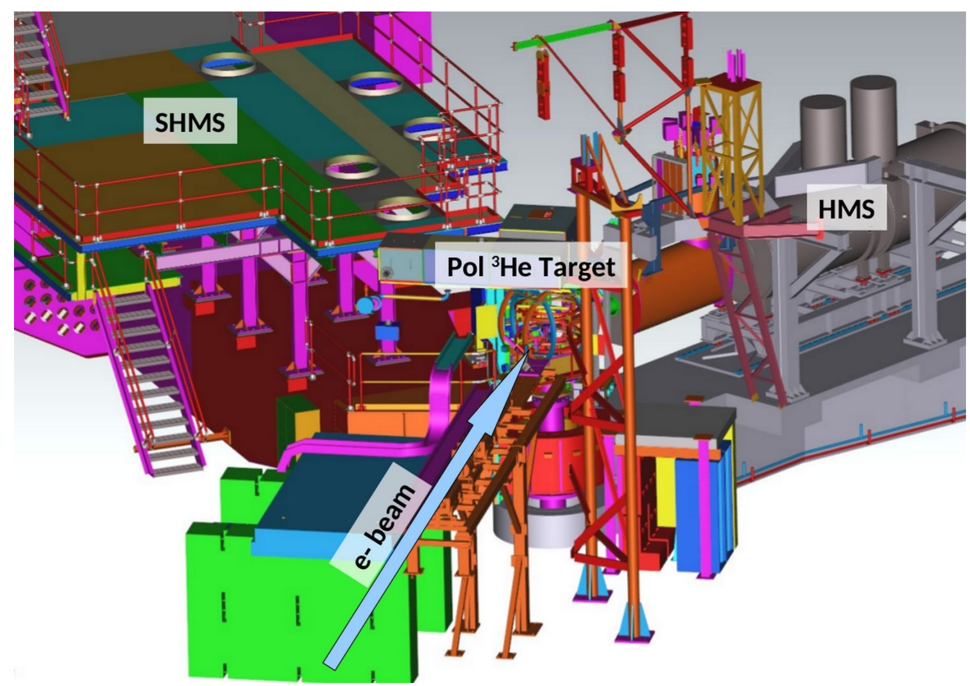
- 10.4 GeV beam, 85% longitudinal polarization, 30 uA
  - First in Hall C's 12 GeV era to utilize polarized beam
- HMS and SHMS detecting electrons in the inclusive mode
- Polarized 3He target (40cm)
  - first time use in Hall C
  - 50-55% in-beam polarization → factor 2 increase in 3He target FOM vs. 6 GeV era

Kine	Spec	E_b GeV	E_p GeV	θ ($\circ$)	beam time (hours)
$\Delta(1232)$	SHMS	2.17	-1.79736	8.5	4.0
Elastic	SHMS	2.17	-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	10.38	2.90	30.0	88.0	0.0	88.0
4	HMS	10.38	3.50	30.0	511.0	0.0	511.0
B	SHMS	10.38	3.40	30.0	511.0	4.0	515.0
C	SHMS	10.38	2.60	30.0	88.0	4.0	92.0

- Beam charge asymmetry controlled by parity DAQ (PREX-II/CREX) – below 50ppm per one-hour run

Ran from Dec. 2019 to March 2020



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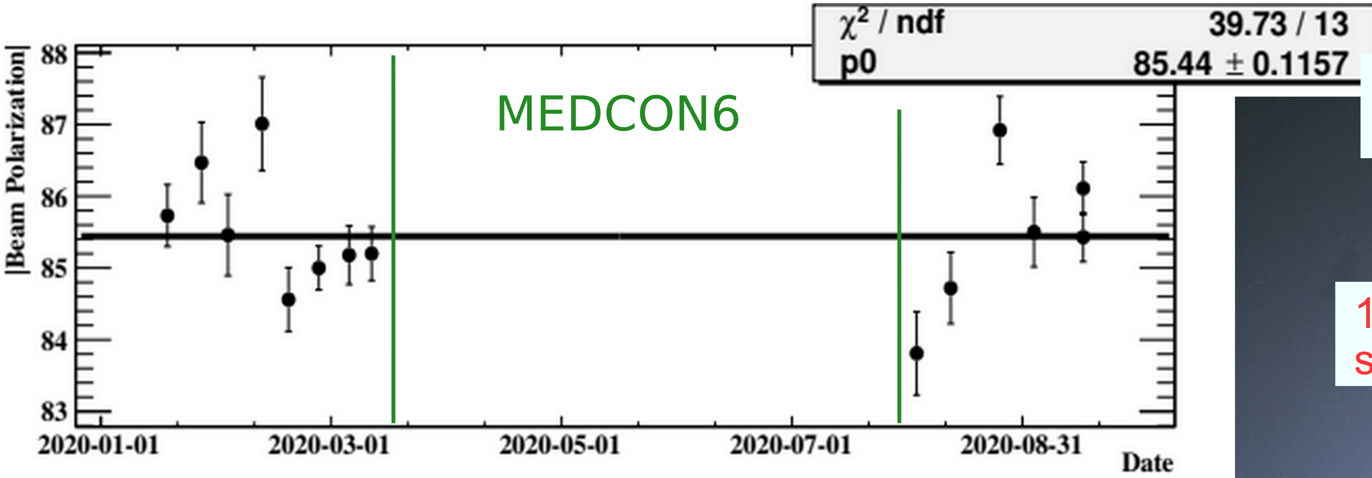
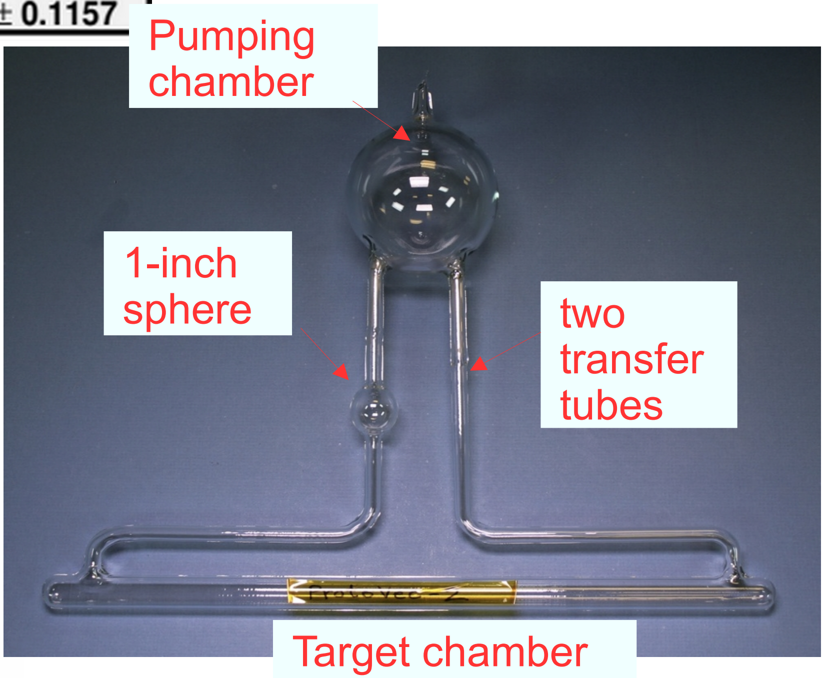
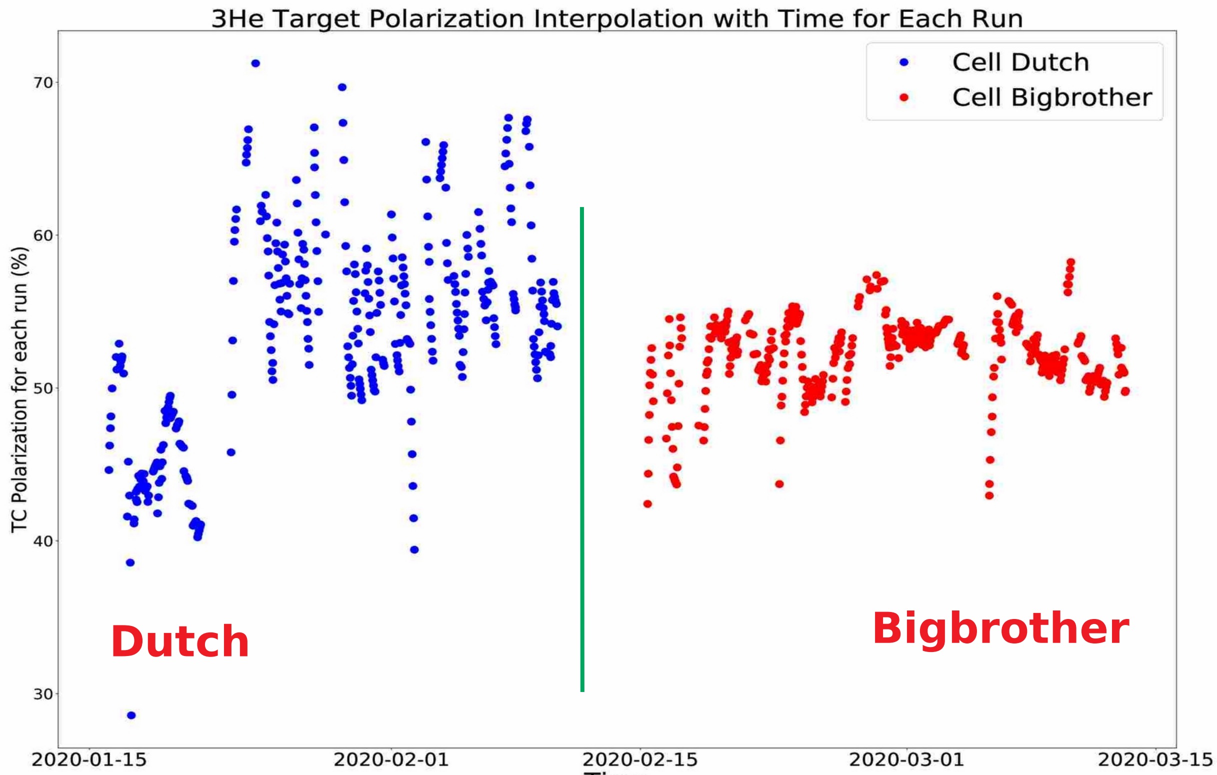
Polarizations During A1n







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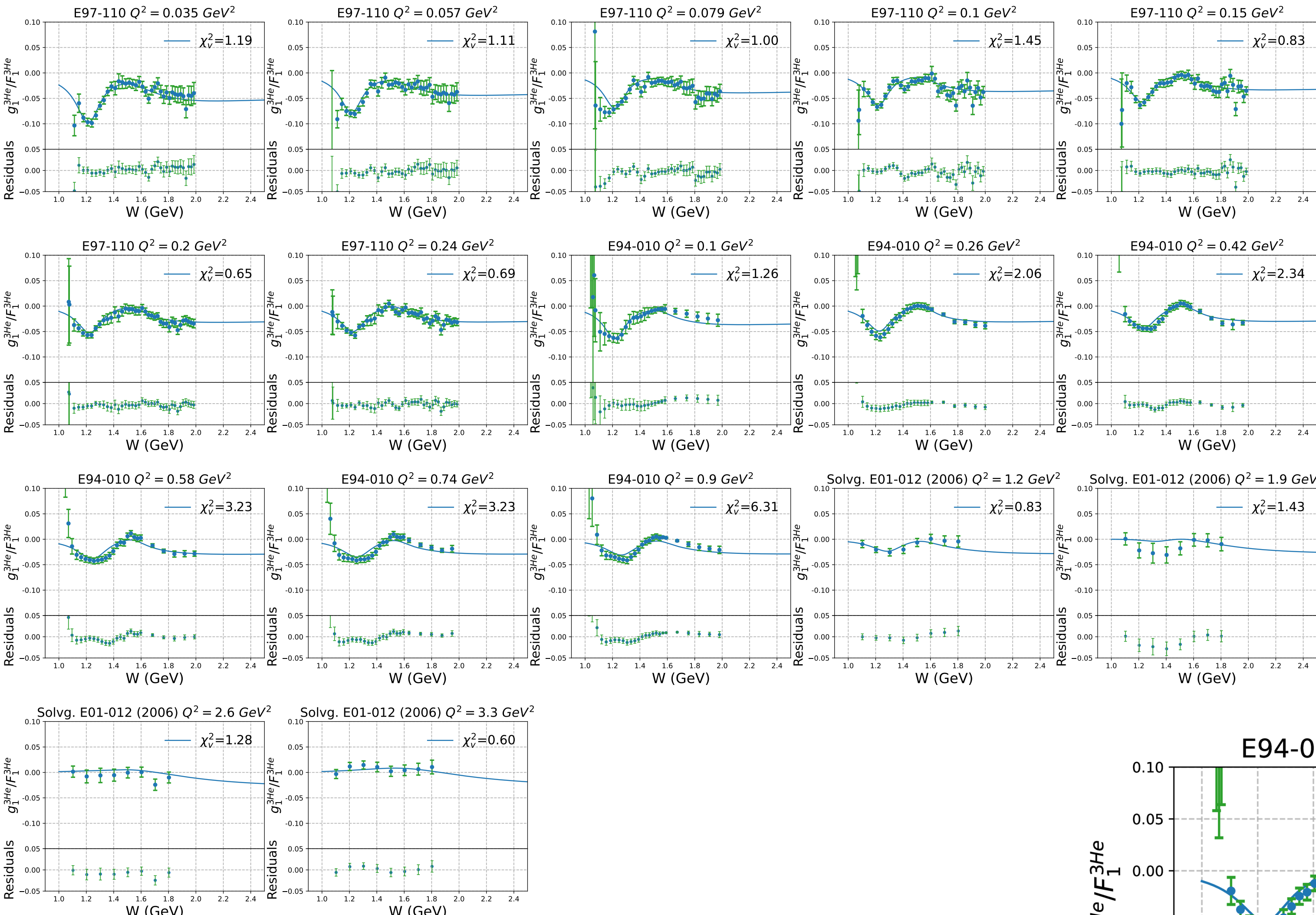
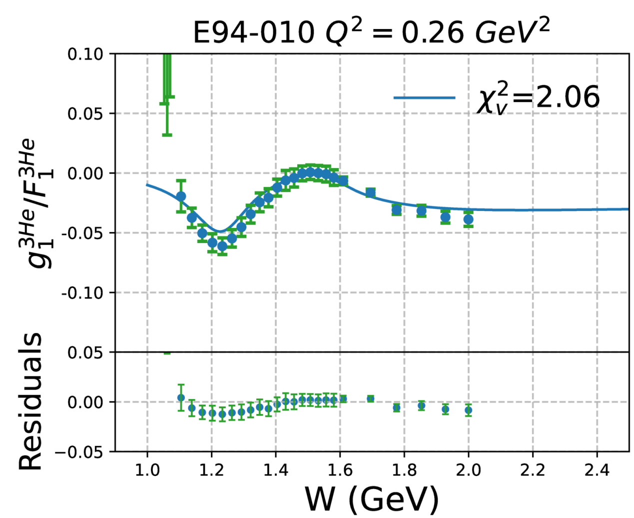
Analysis Status

Timeline:

- Ran from Dec. 2019 to March 2020 (d2n ran later in 2020);
- Two PhD's: Melanie Cardona and Mingyu Chen both graduated in 2023, with preliminary 3He asymmetries;
- Radiative correction and double-checking: 2024-2025 ("second analysis team");
- Preliminary results presented at SPIN'25 (Sept 2025);
- 3He QE asymmetry paper reviewed by PLB (Jan 2026);
- Draft short paper on A1n in progress;
- Inclusive pion analysis started.

Fit of g1/F1 (3He) for Radiative Corrections





Fit done by: R. Trotta → will be expanded to p and n
RC done by: I. Li, XZ

W (GeV)

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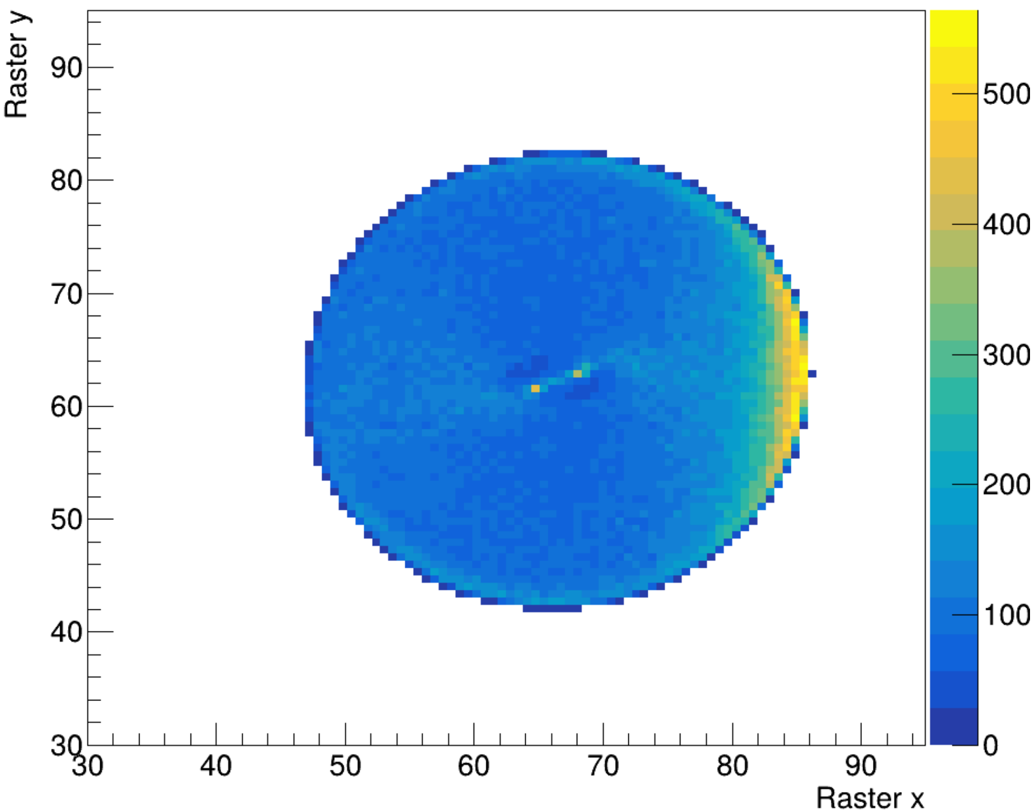
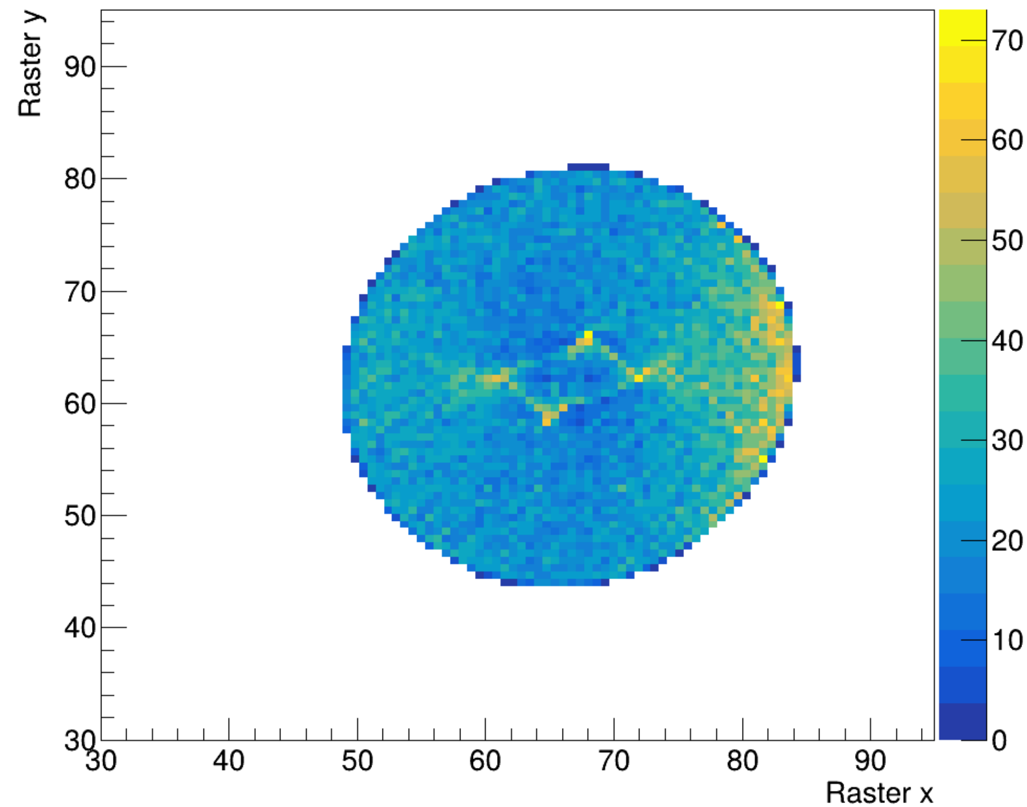
Beam Scraping of 3He Glass Cell checked with Hydra



A scraping run identified by Melanie



A scraping run picked up by Hydra

Work done by: M. Nycz

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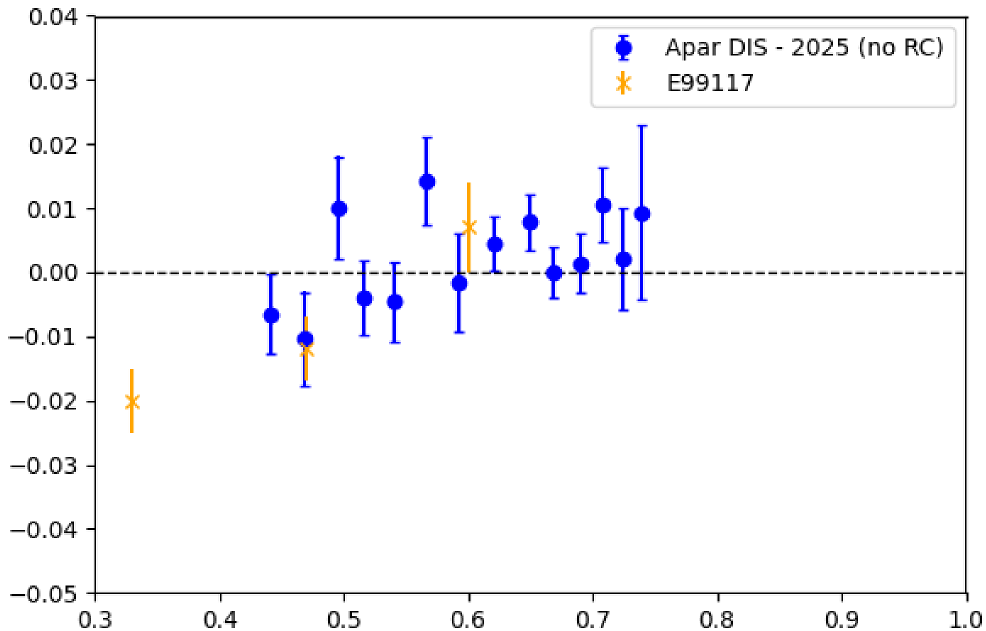
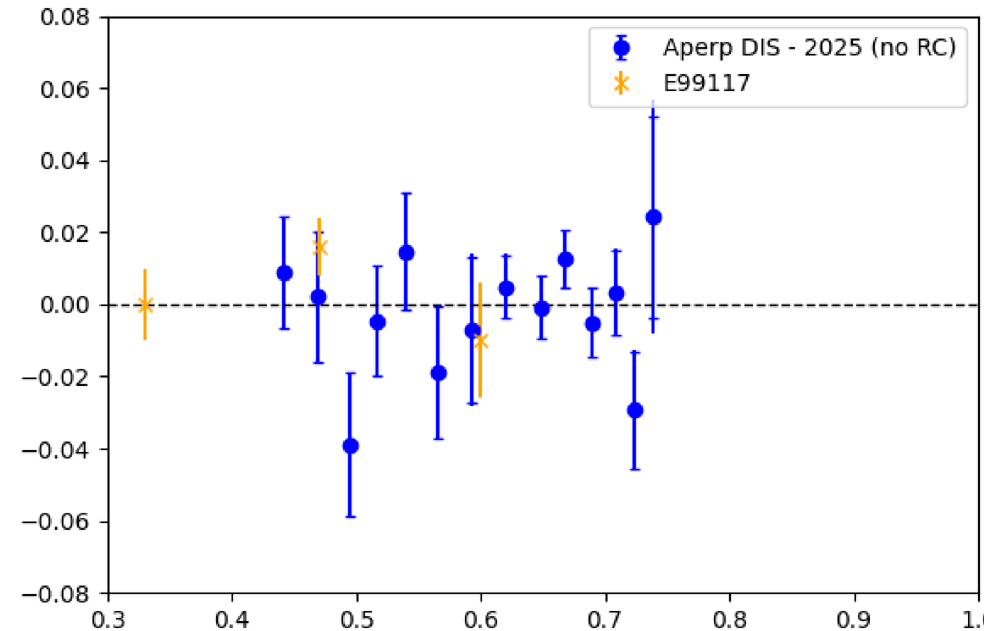
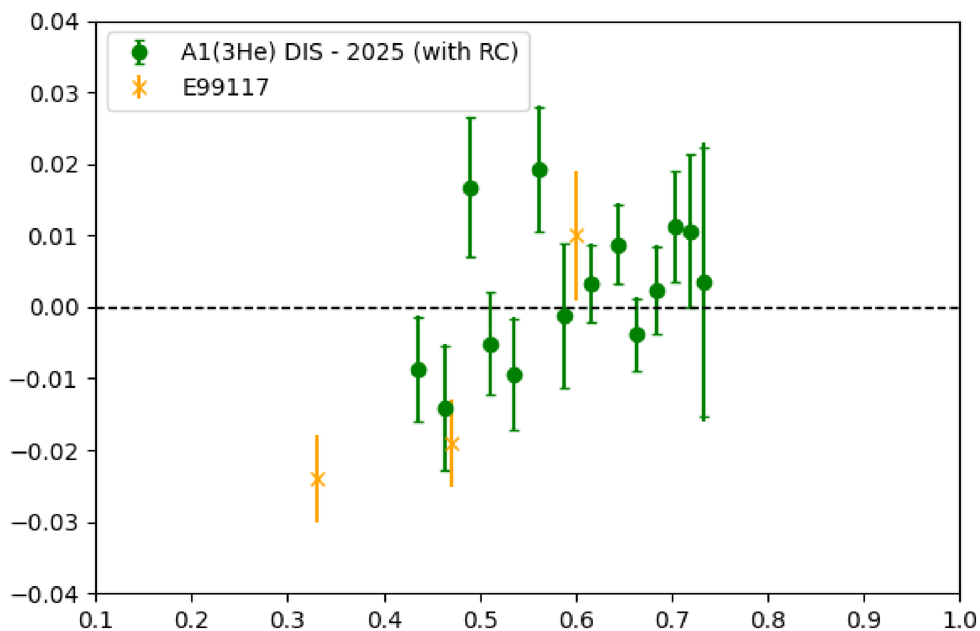
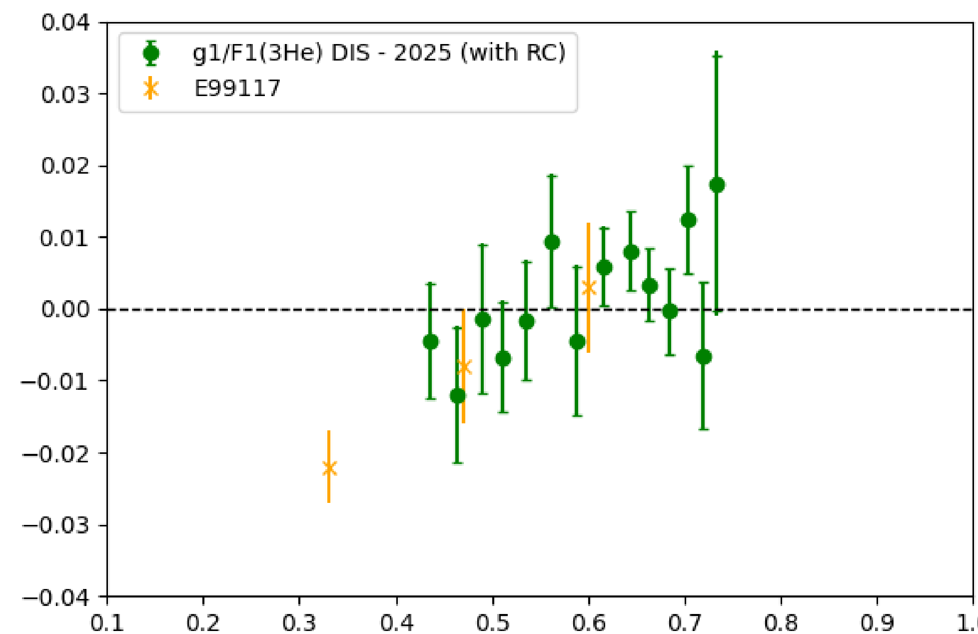
Preliminary Results

Preliminary Results on 3He Asymmetries (DIS)



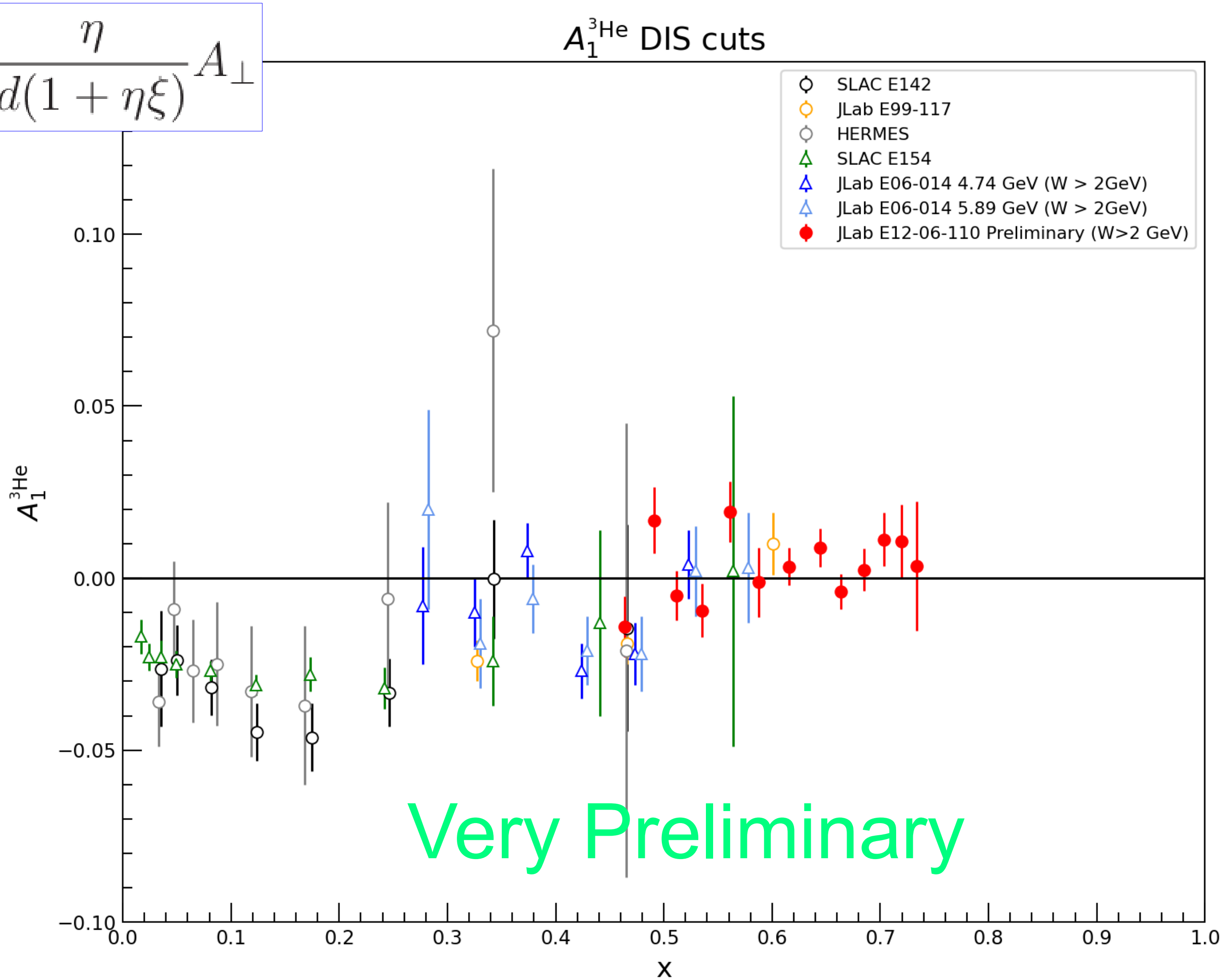






Very Preliminary Results on A1(3He) (DIS)

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



Work done by: M. Chen, M. Cardona, M. Nycz, R. Trotta, XZ (and the E12-06-110 collaboration)

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Nuclear (un)smearing in Progress

1. Comparison between effective polarization and full nuclear smearing ongoing – M. Nycz, I. Li
2. Full nuclear unsmearing will allow us to extract resonance A1n

$$A_1^n = \frac{1}{P_n}\frac{F_2^{^3\mathrm{He}}}{F_2^n}\left(A_1^{^3\mathrm{He}} - 2P_p\frac{F_2^p}{F_2^{^3\mathrm{He}}}A_1^p\right)$$

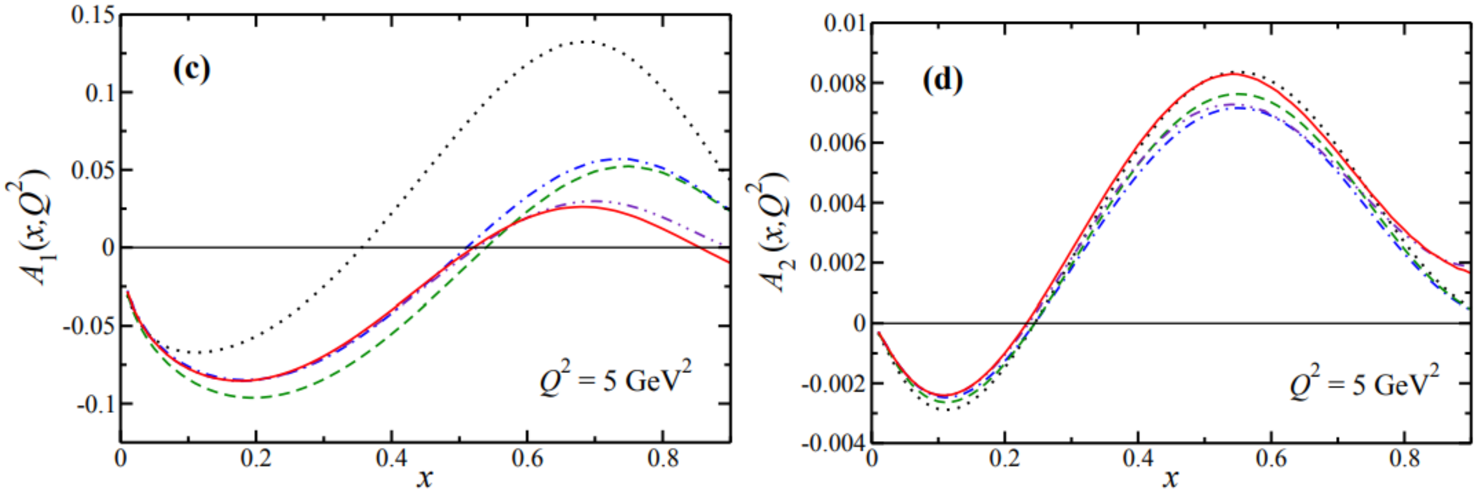

FIG. 6: As in Fig. 2, but for the polarization asymmetries A_1 and A_2 of the neutron and ^{3}He at $Q^2 = 1$ GeV^2 [**(a)** and **(b)**] and $Q^2 = 5$ GeV^2 [**(c)** and **(d)**], constructed from ratios of the spin-dependent structure functions in Fig. 2 and the unpolarized F_1 structure function from the Bosted-Christy parametrization [55]. Note that the ^{3}He asymmetries are scaled by a factor $(1 + 2F_1^p/F_1^n)$.

From https://arxiv.org/pdf/1308.3723, the difference between effective polarization and full nuclear smearing is significant above x=0.6

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Proton g1/F1 DIS Fit in Progress

6 GeV fit:
$$\frac{g_1^p}{F_1^p} = x^{\alpha}(a+bx)\left(1+\frac{\beta}{Q^2}\right)$$

New fit:
$$\frac{g_1^p}{F_1^p} = \xi^{\alpha}(a+b\,\xi)\left(1+\frac{\beta}{Q^2}\right)$$

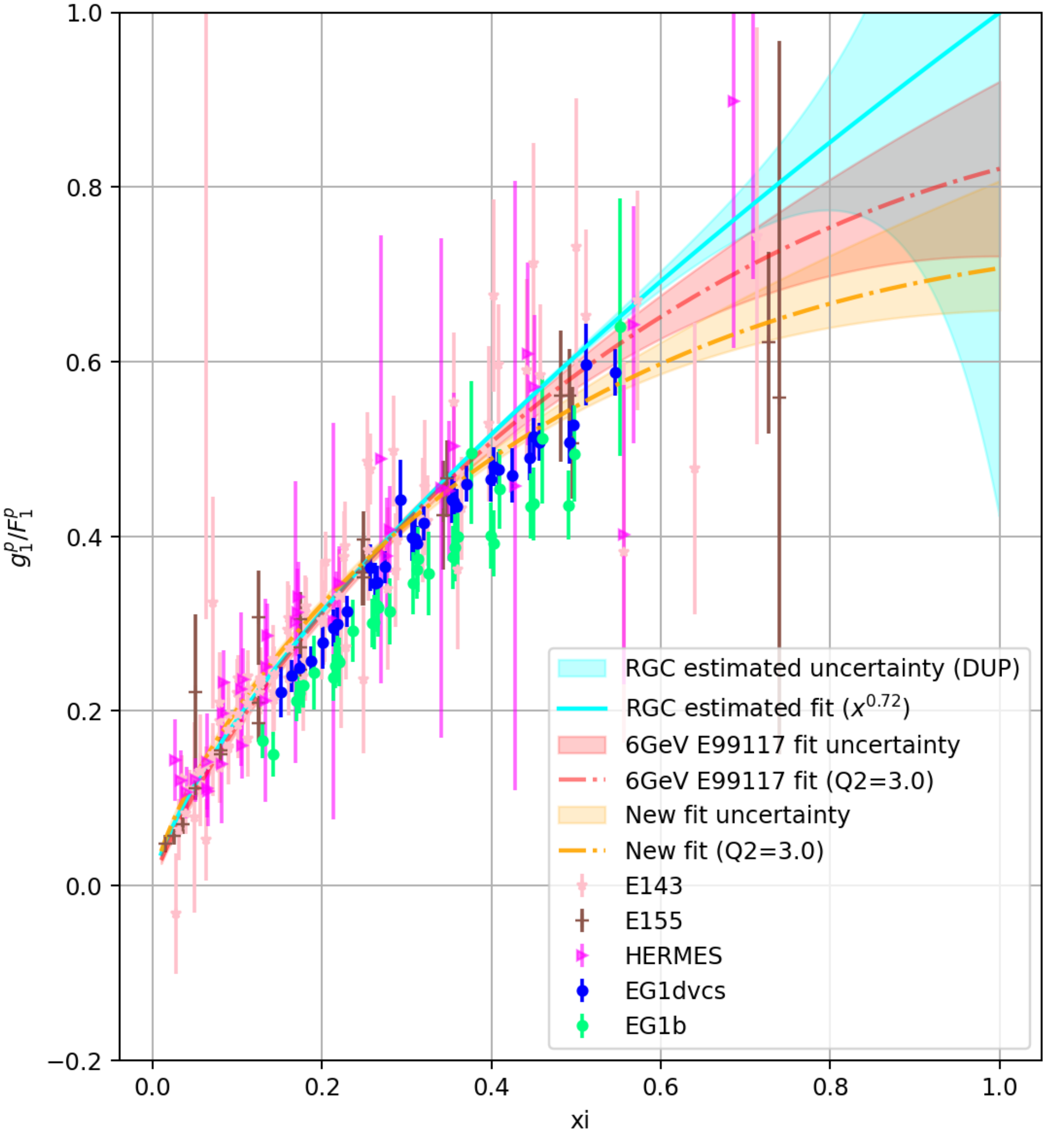
New fit:
Fit parameters:
[0.7103 1.1221 -0.3457 -0.2703]

χ^2/dof: 0.7735509561589263

Parameter errors:
[0.0216 0.0687 0.1191 0.0248]

Correlation matrix:
[[1.   0.9405 -0.9038 -0.1618]
 [0.9405 1.   -0.977 -0.3975]
 [-0.9038 -0.977   1.   0.3215]
 [-0.1618 -0.3975 0.3215 1.   ]]

err = sqrt(stat2. + syst**2.)**



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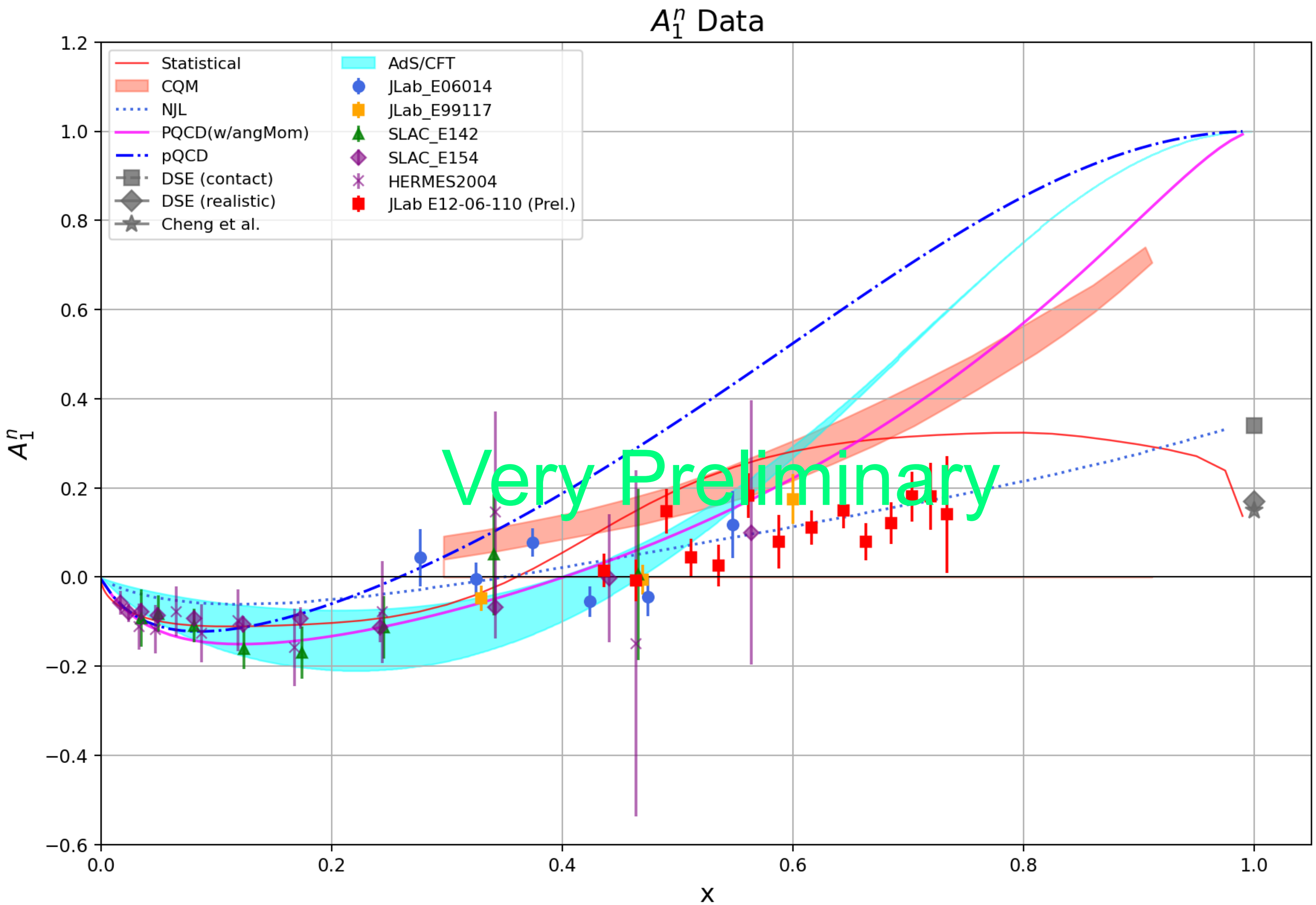
Very Preliminary Results on A1n (DIS)

A1n extracted using effective polarizations, the 6 GeV fit for the proton A1p, F1F221 (p, n, plus our own 3He fit)

$$A_1^n = \frac{1}{P_n}\frac{F_2^{^3\mathrm{He}}}{F_2^n}\left(A_1^{^3\mathrm{He}} - 2P_p\frac{F_2^p}{F_2^{^3\mathrm{He}}}A_1^p\right)$$

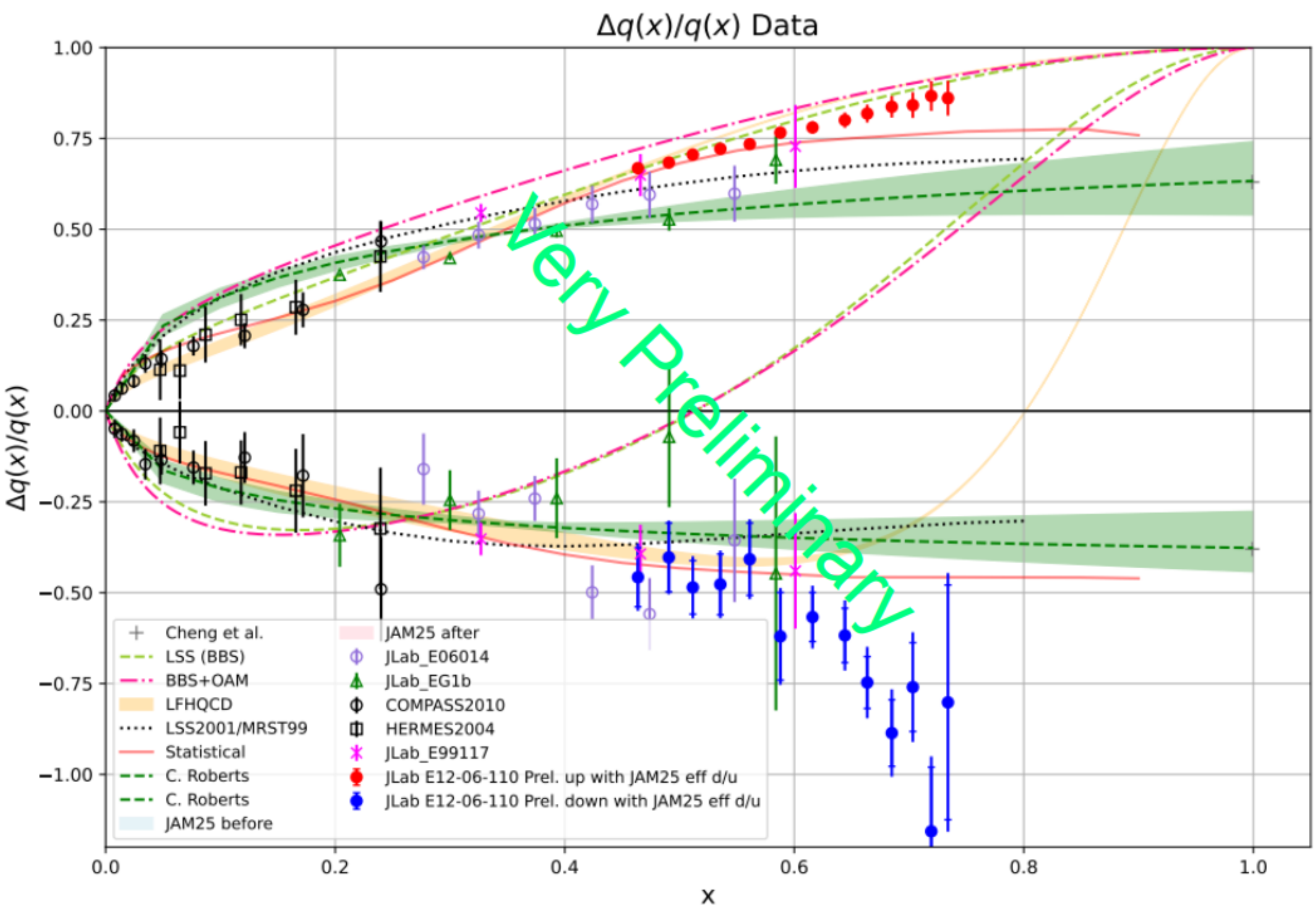


Preliminary Results on Quark Polarizations

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

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

$$R^{du}=\frac{d+\bar{d}}{u+\bar{u}}$$



At high x, we need to consider significant TMC. Two approaches:

1. calculate d/u at Natchmann x, not Bjorken x;

2. use full SF fits to extract “effective” d/u.

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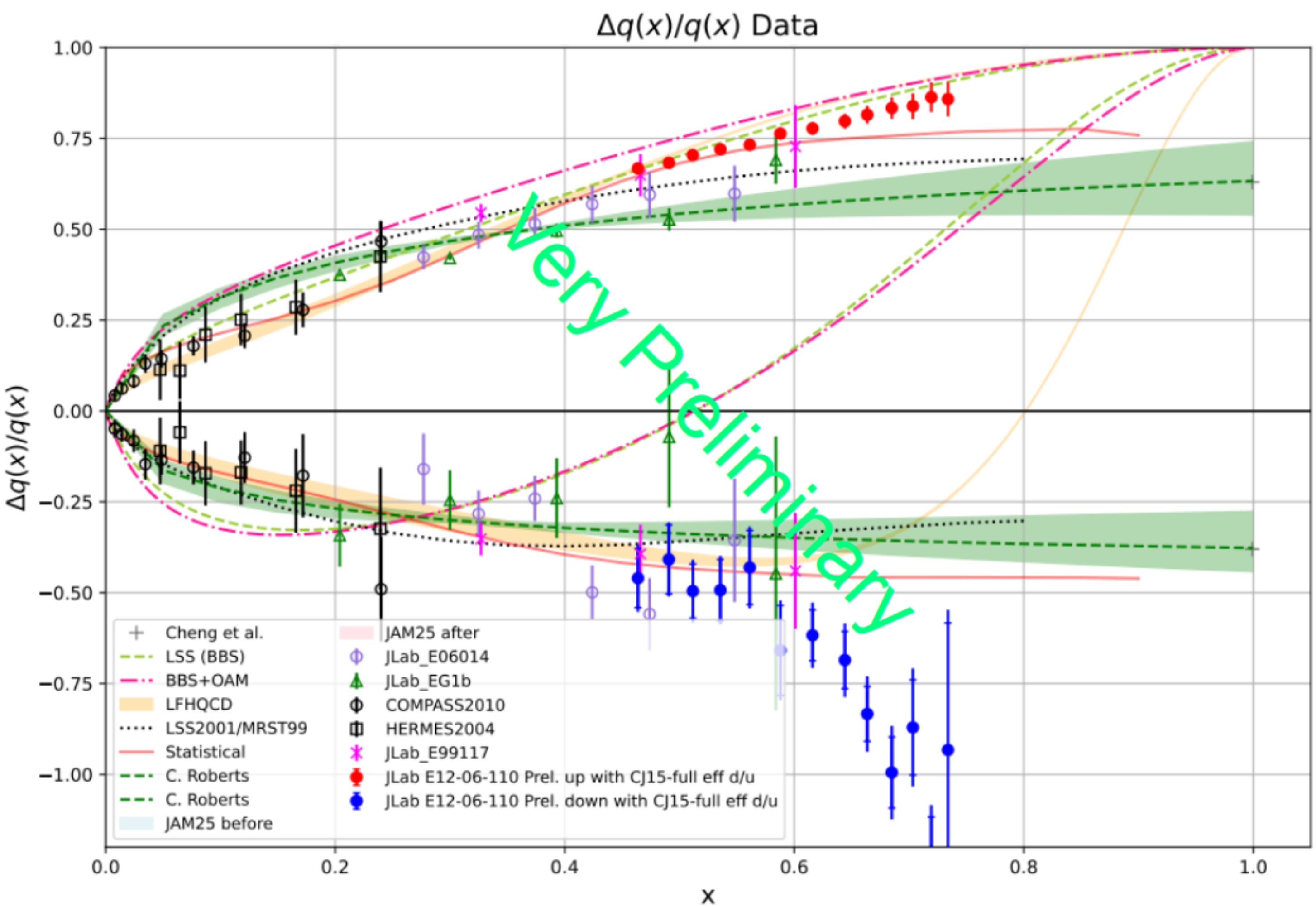
Treatment of d/u matters

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

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

$$R^{du}=\frac{d+\bar{d}}{u+\bar{u}}$$



At high x, we need to consider significant TMC. Two approaches:

1. calculate d/u at Natchmann x, not Bjorken x;

2. use full SF fits to extract “effective” d/u.

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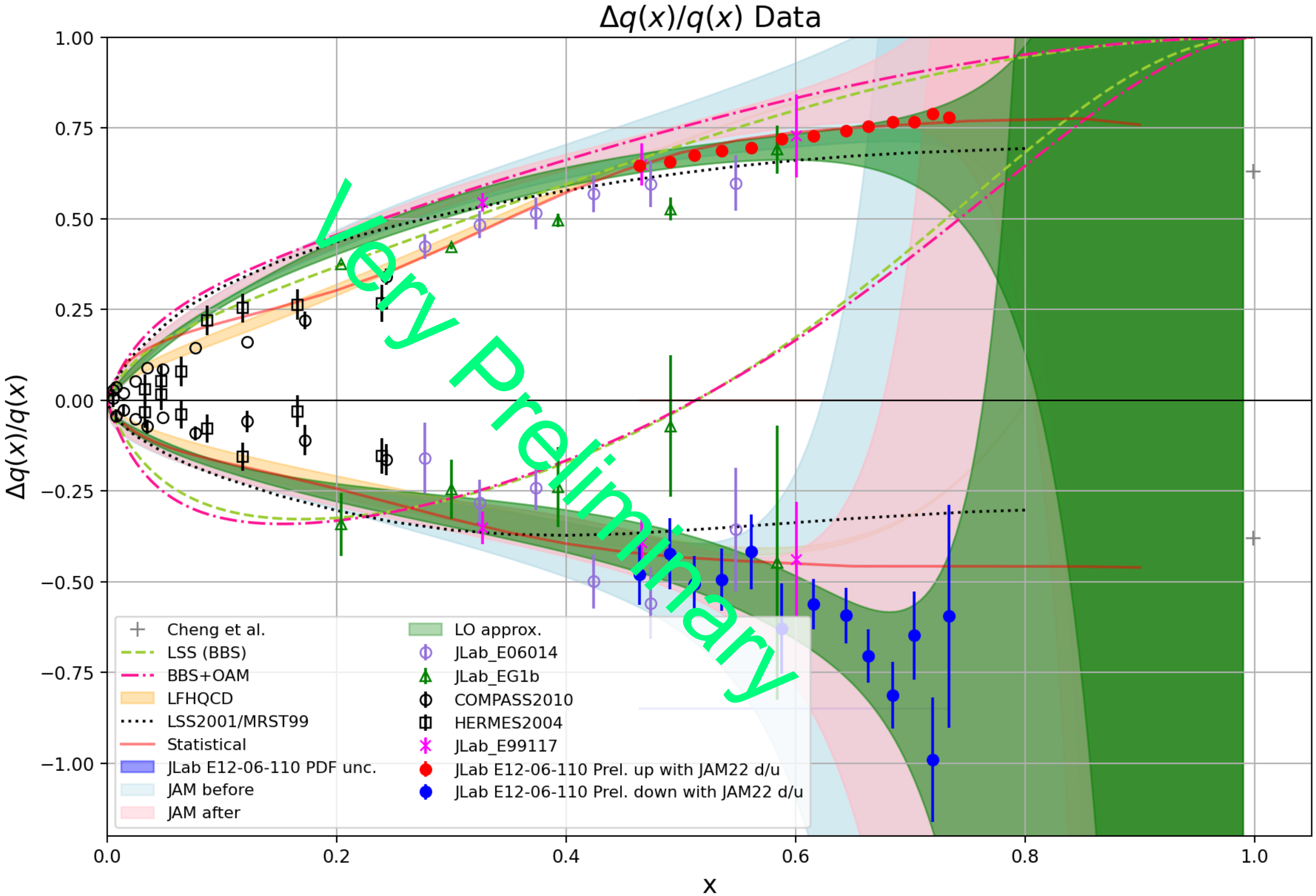
JAM Fits

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

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



$$R^{du}=\frac{d+\bar{d}}{u+\bar{u}}$$

(JAM22 here)

Light blue: Full global analysis, with positivity constraint

Pink: with Hall C Apar, Aperp added

Green: LO approx. (naive parton model)

Figure credit:

C. Cocuzza, N. Sato

(JAM collaboration)

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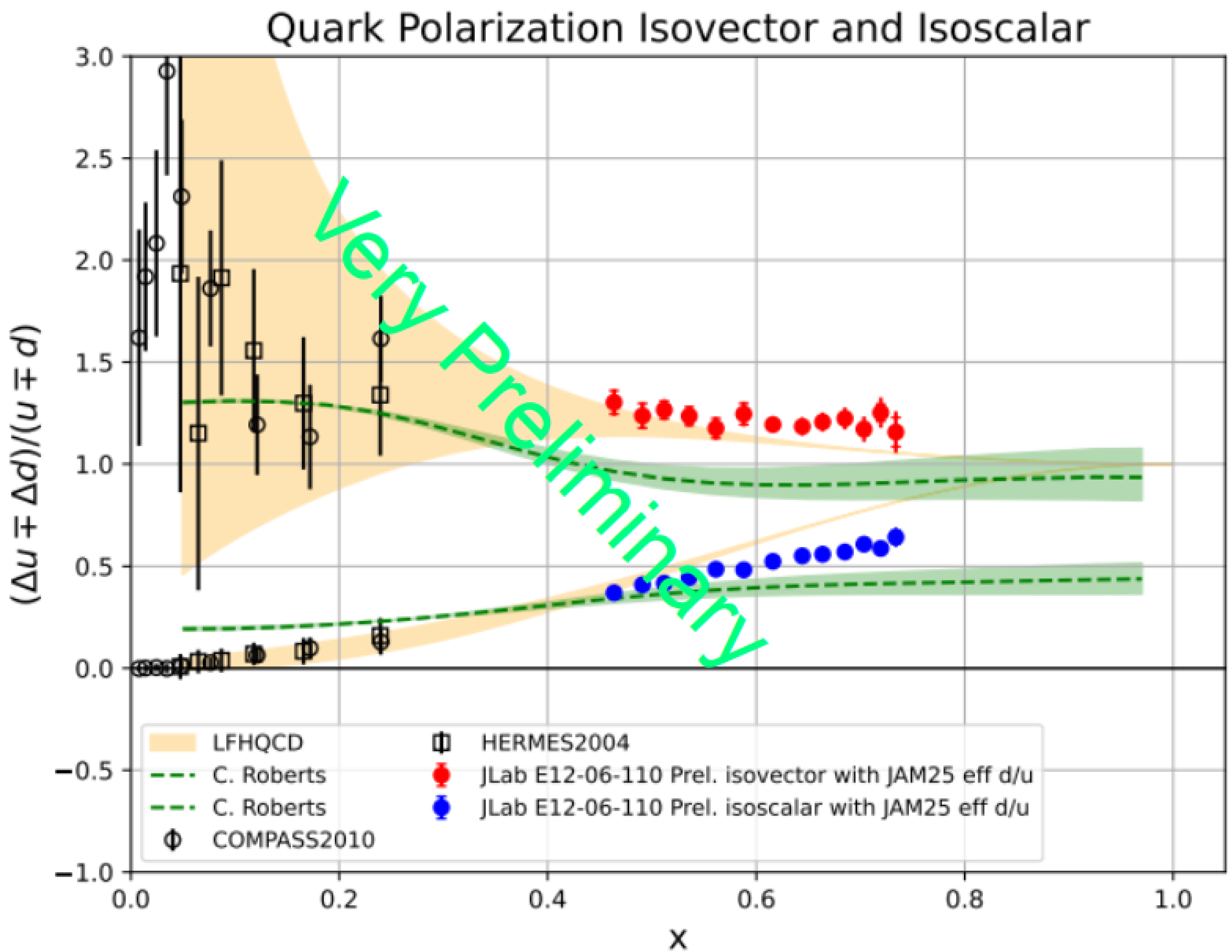
Isoflavor Combinations

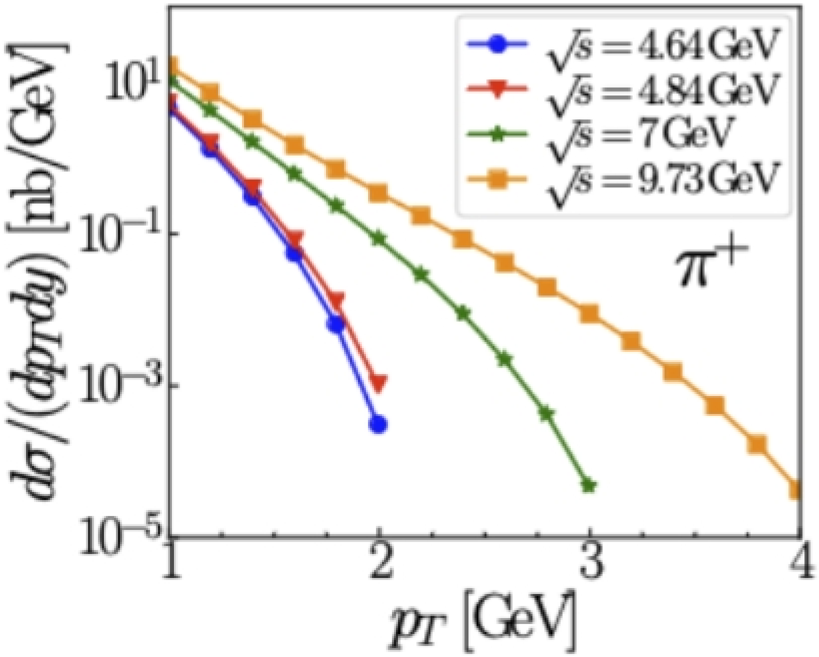


More Ideas – Inclusive Pion Production

- Traditionally considered a major background in DIS, single pion production in ep collision can **carry significant physics implication** on its own.
- By comparing inclusive pion cross section with calculations based on lepton distributions and fragmentation functions (see Fig), we can study how many of the pions in DIS are actually from fragmentation of the parton, and **that would be a pre-requisite of interpretation of SIDIS data**, particularly at JLab energies.
- If indeed the pions produced are mostly from non-prompt effects such as **vector meson** (e.g. ρ) decay, we need to at least understand them before interpreting SIDIS data using fragmentation alone.

See Jianwei Qiu's talk, Inclusive Pion Production in Lepton-Hadron Collision – Prerequisite for understanding SIDIS data with current factorization formalism

SoLID Collaboration Meeting, July 7-8, 2025



https://indico.jlab.org/event/948/contributions/17185/attachments/12994/20883/SoLID2025July_Qiu.pdf

Summary and Outlook

- Experiment measurement of the neutron A_1 completed at JLab in 2020
  - 10.4 GeV 85% beam; 40cm long 50-55% polarized ^{3}He target, 30 uA beam
  - DIS up to x=0.75
- Analysis (all preliminary):
  - 3He asymmetries done
  - Neutron asymmetries – effective pol method done, full smearing in progress
  - Quark polarizations – LO method done, global fit in progress
  - Iso vector combination
  - Inclusive pion cross section and asymmetry extraction started.
- Publications:
  - short A1n paper drafted
  - long paper will start later this year
  - inclusive pion – possibly two more publications

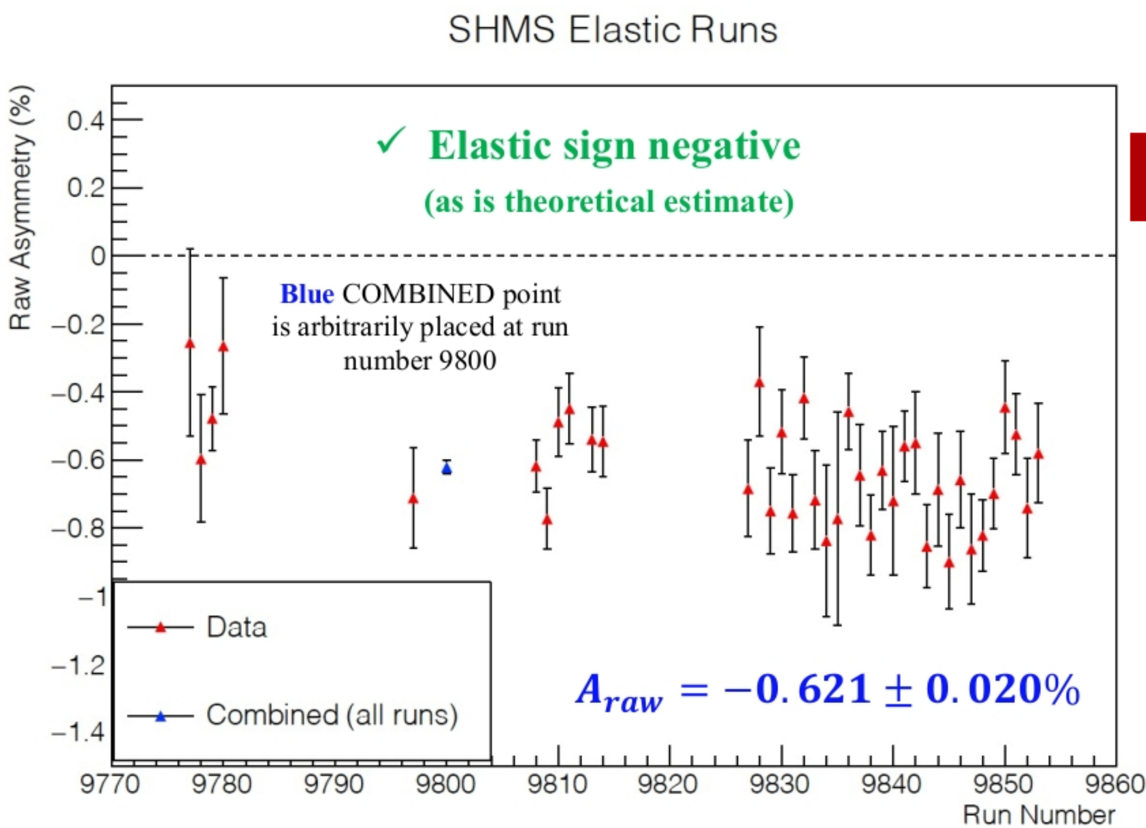
This work is supported by DOE, Office of Science, Nuclear Physics, Medium Energy Physics

Backup Slides

A_{para}: ^{3}He Elastic Asymmetries

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-∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ anti-∥ beam direction)	DOWNSTREAM ($\vec{e}^-$ ∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ ∥ beam direction)	180°: DOWNSTREAM 90°: BEAM LEFT
	pass change		
5-pass (DIS) (thru SHMS 10354, HMS 3162)	DOWNSTREAM ($\vec{e}^-$ ∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ ∥ beam direction)	UPSTREAM ($\vec{e}^-$ anti-∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ anti-∥ beam direction)	180°:DOWNSTREAM 90°: BEAM LEFT
	Wien-flip		
5-pass (DIS) (SHMS 10355+, HMS 3163+)	UPSTREAM ($\vec{e}^-$ anti-∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ anti-∥ beam direction)	DOWNSTREAM ($\vec{e}^-$ ∥ $\overrightarrow{^3He}$) ($\vec{e}^-$ ∥ beam direction)	180°: DOWNSTREAM 90°: BEAM LEFT

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

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

- **^{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!

- Credit to Melanie Cardona (Temple U.)

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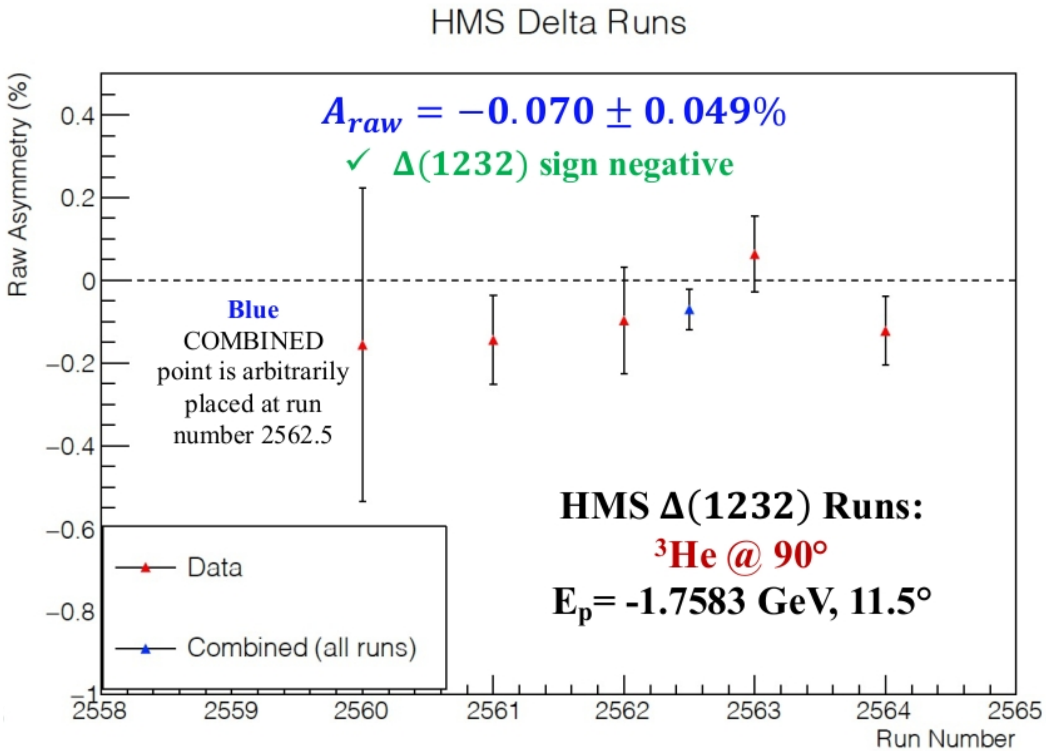
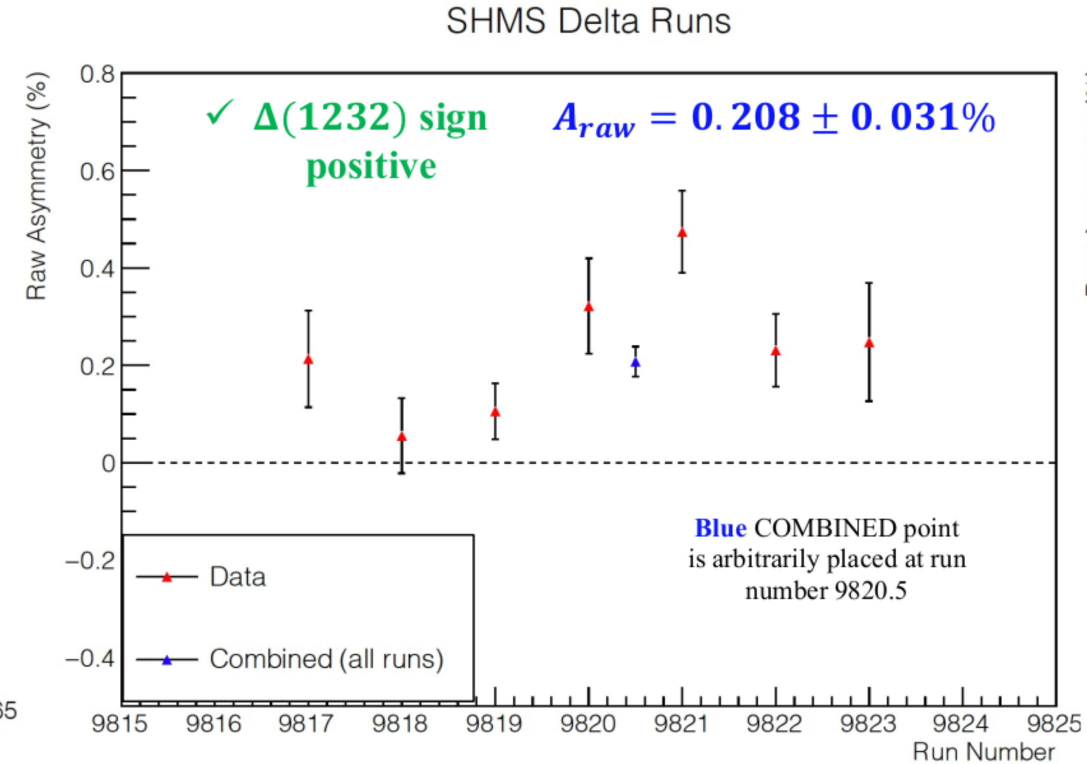
A_{perp}: ^{3}He Δ(1232) Asymmetries

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!)





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

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

- Credit to Melanie Cardona (Temple U.)

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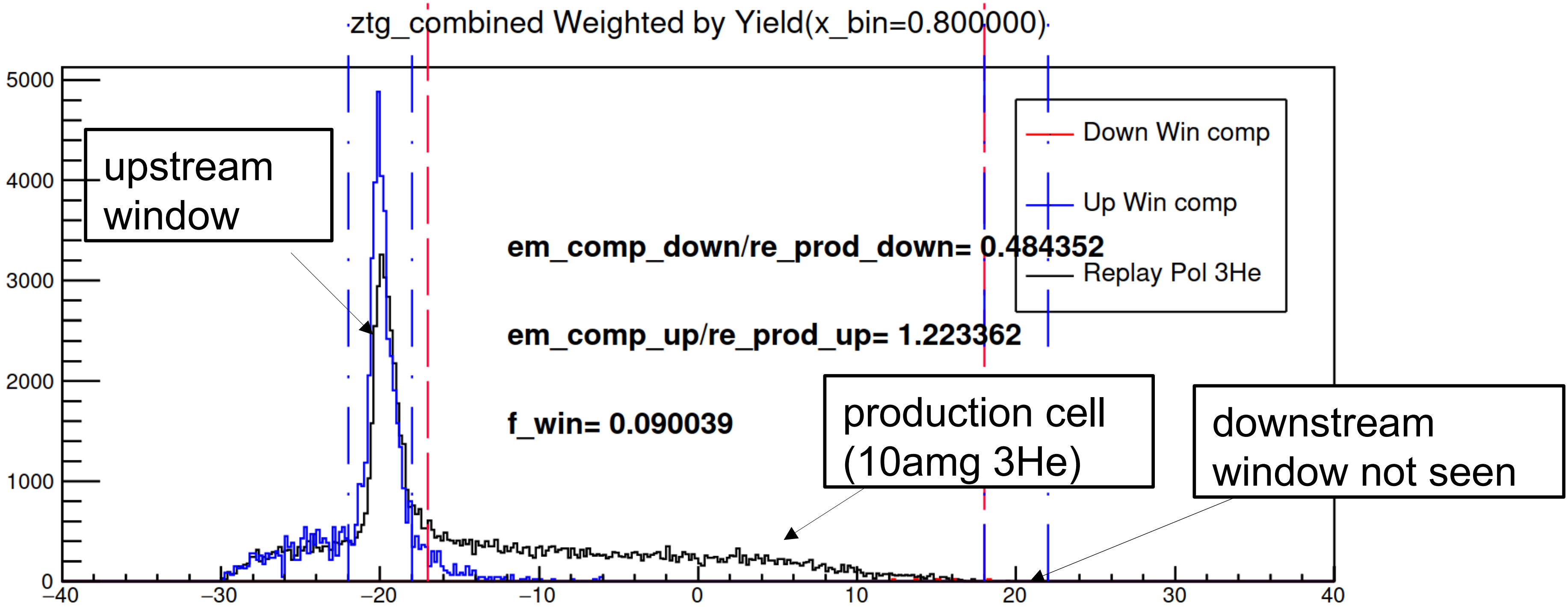
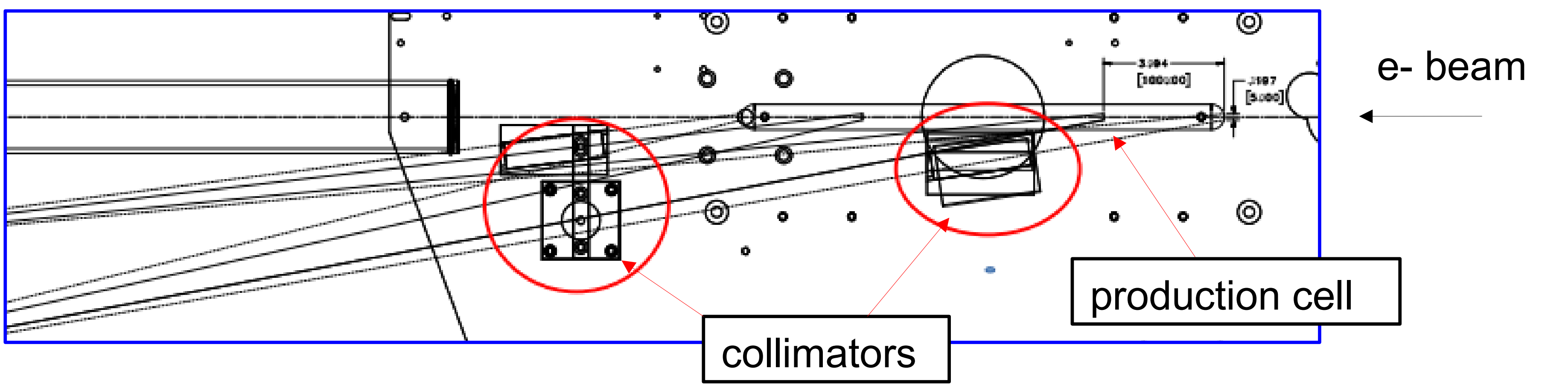
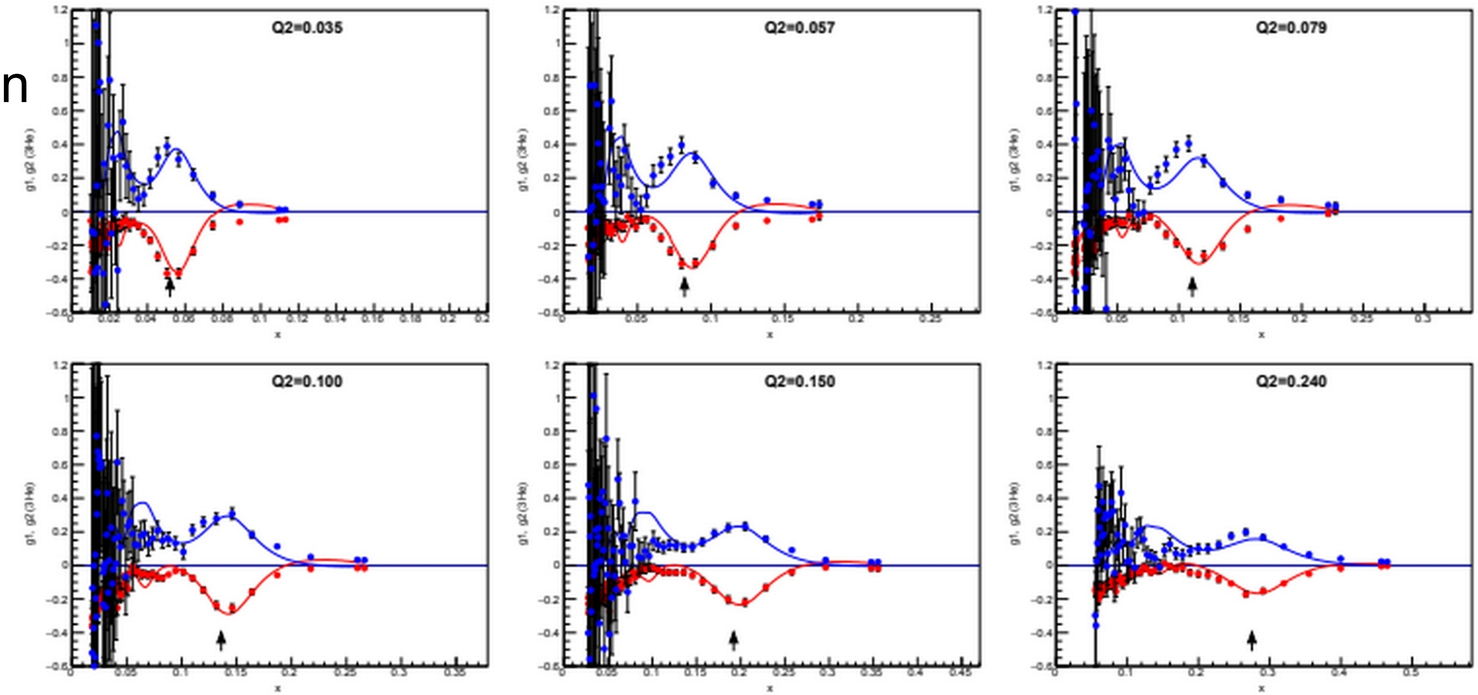
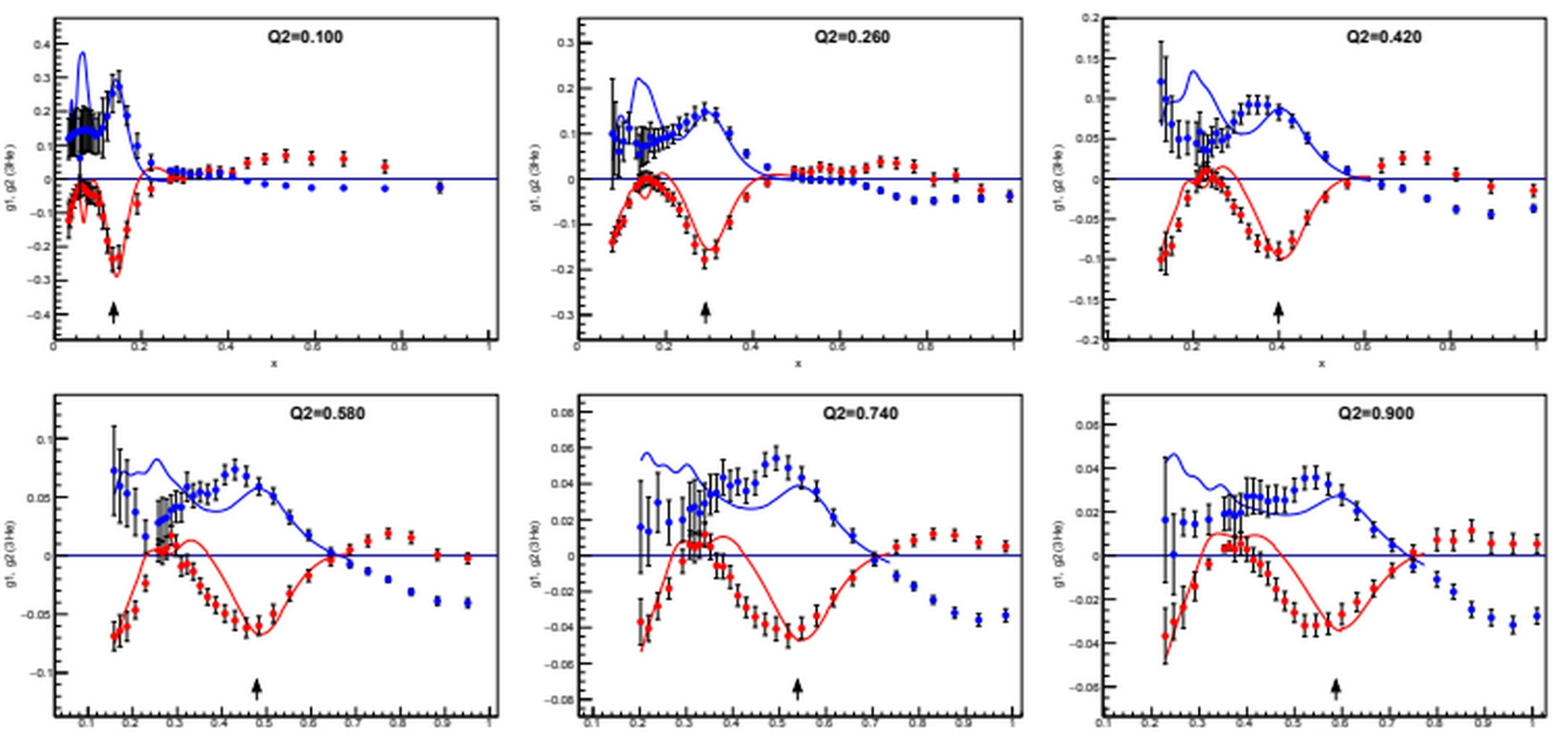
Background from Unpolarized Glass Windows

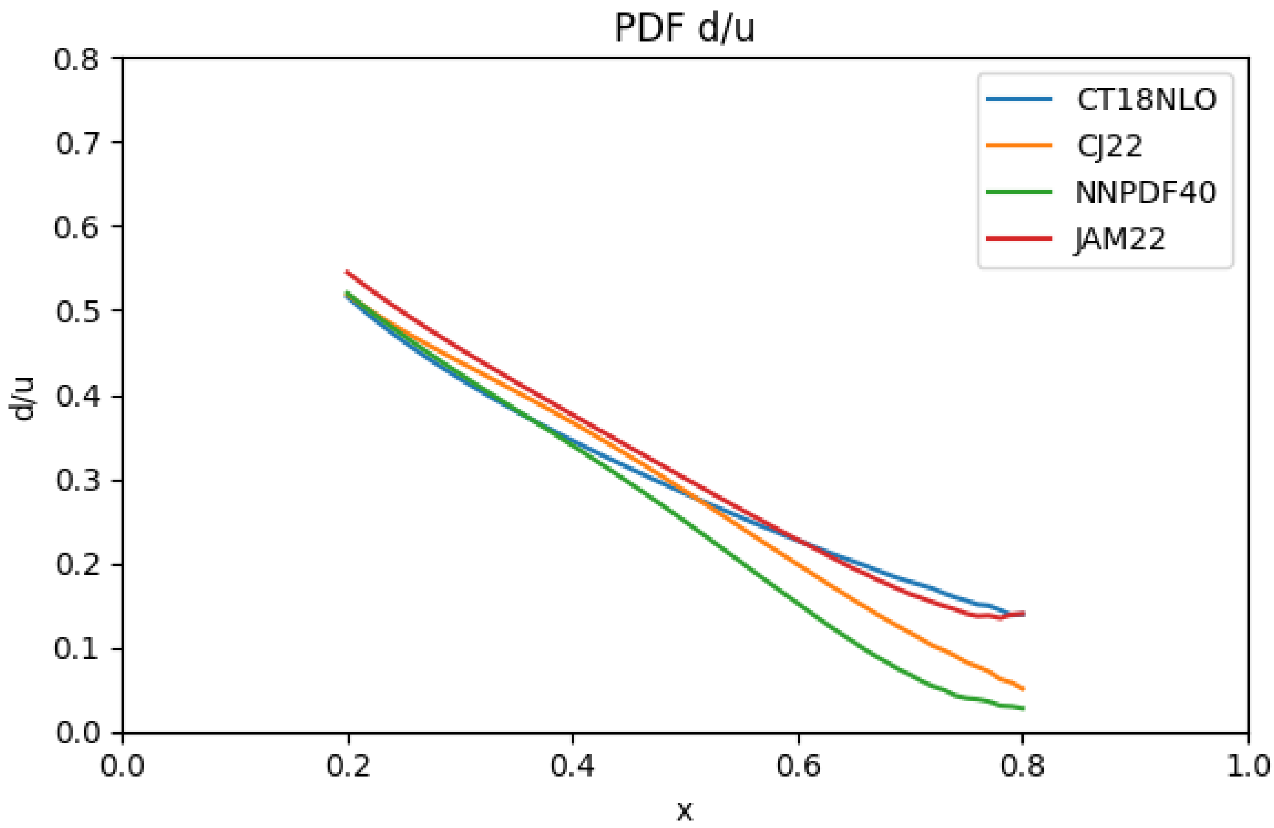




CLAS Parameterization of g1, g2 in the resonance region



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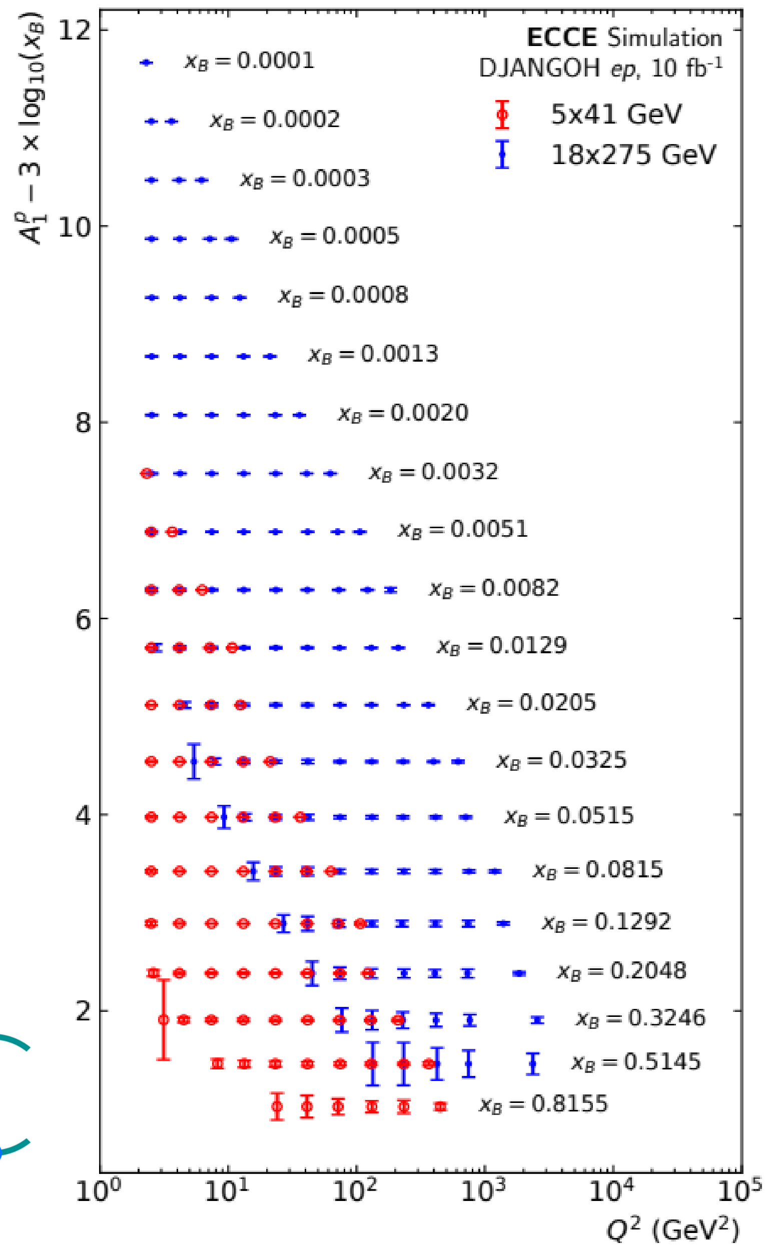
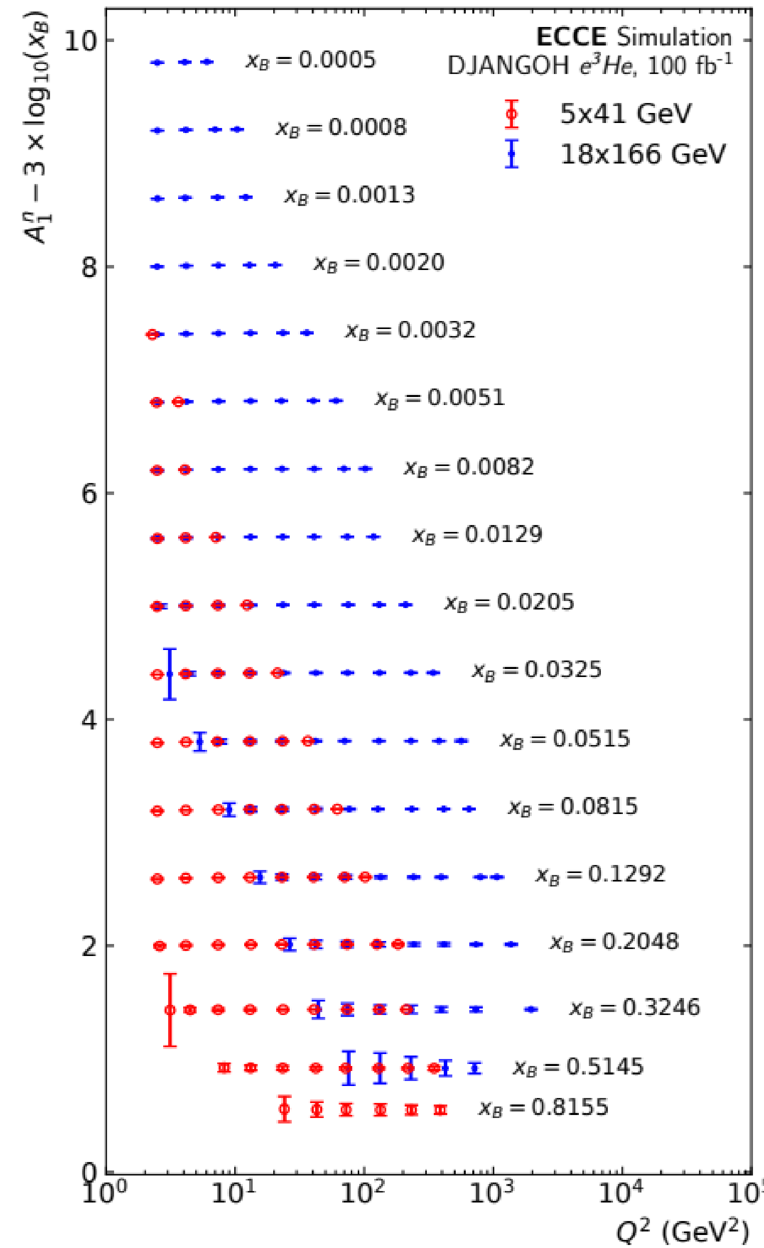
JAM22

High X Spin Structure Function at the Electron Ion Collider

Figure credit:
Tyler Kutz,
Dien Nguyen,
Jackson Pybus

and ECCE





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