Update on the A_1^n experiment

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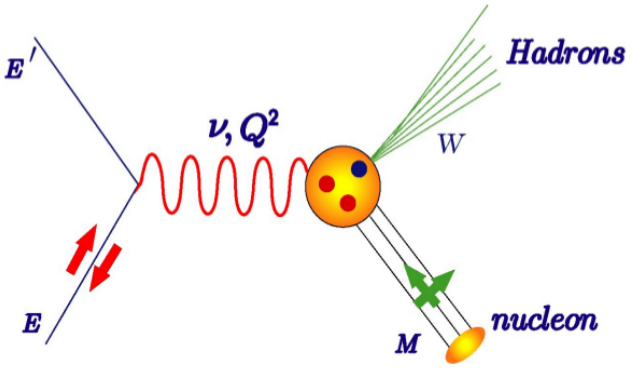
Outline:

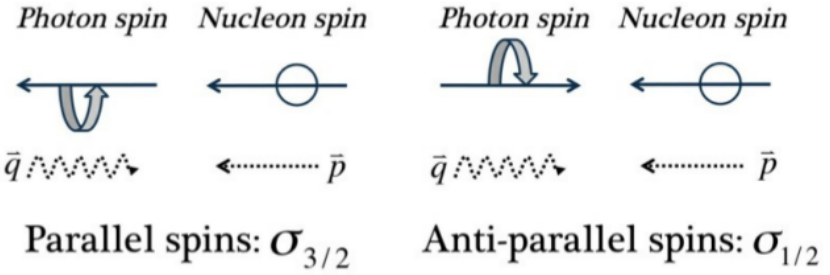
1. A_1^n at High x_{Bj} Region
2. Experimental Setup and Status
3. Polarized ^{3}He Target Performance
4. Online Asymmetry Results
5. Summary

Longitudinal Virtual Photon Asymmetry A_1

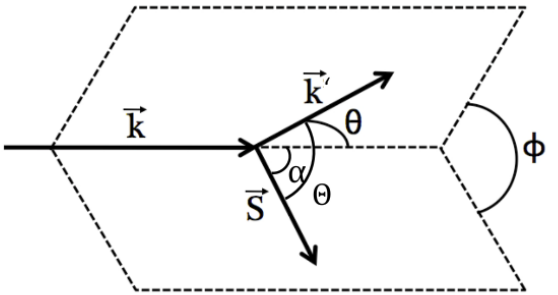
- Q^2 = 4-momentum of virtual photon squared
- ν = Energy transfer
- θ = Scattering angle
- $x = \frac{Q^2}{2M\nu}$ = Fraction of nucleon momentum carried by the struck quark



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



$$A_1 = \frac{1}{(E+E')D'}\left[(E - E'\cos\theta)A_{\parallel} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right]$$



$$A_{\parallel} = \frac{\sigma_{\downarrow\uparrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\downarrow\uparrow} + \sigma_{\uparrow\uparrow}}$$

$$A_{\perp} = \frac{\sigma_{\downarrow\rightarrow} - \sigma_{\uparrow\rightarrow}}{\sigma_{\downarrow\rightarrow} + \sigma_{\uparrow\rightarrow}}$$

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

- Angular kinematics for polarized electron scattering

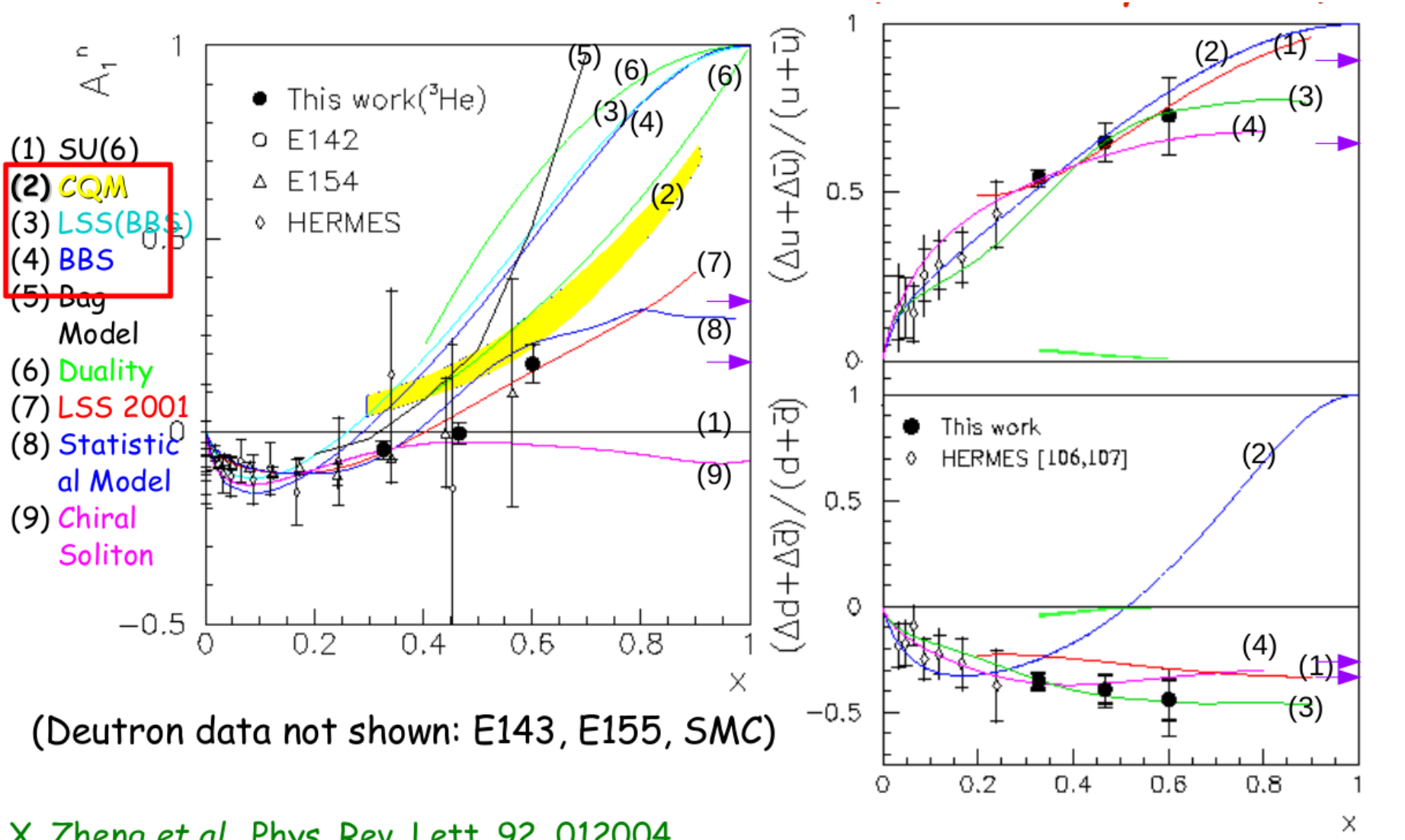
Goals for A_1^n Experiment

- Precisely measure the neutron spin asymmetry A_1^n in the far valence domain ($0.61<x<0.77$) for the first time.
- Explore the Q^2 dependence of A_1^n with large x value.
- After combining with proton data (CLAS12), extract polarized to unpolarized parton distribution function (PDF) ratios $\Delta u/u$ ($\Delta d/d$) for large x region.
- Give more insights on understanding the spin structure of neutron.

Model	F_2^n/F_2^p	d/u	Δ u/u	Δ d/d	A_1^n	A_1^p
SU(6) = SU3 flavor + SU2 spin	2/3	1/2	2/3	-1/3	0	5/9
Valence Quark + Hyperfine	1/4	0	1	-1/3	1	1
pQCD + HHC	3/7	1/5	1	1	1	1
DSE-1	0.49	0.28	0.65	-0.26	0.17	0.59
DSE-2	0.41	0.18	0.88	-0.33	0.34	0.88

- Predictions for x=1 value for various models.
  From Craig D. Robert et al.

Previous Results for A_1^n and PDF



(Deutron data not shown: E143, E155, SMC)

X. Zheng *et al.*, Phys. Rev. Lett. 92, 012004 (2004); Phys. Rev. C 70, 065207 (2004)

(1)CQM (2)LSS(BBS):pQCD+HHC
(3)Statistical Model (4)LSS 2001

Experimental Setup

PhD students:
A1n: Mingyu Chen (UVa), Melanie Rehfuss
(Temple U) Target: Chris Jantzi (UVa)

Detectors:

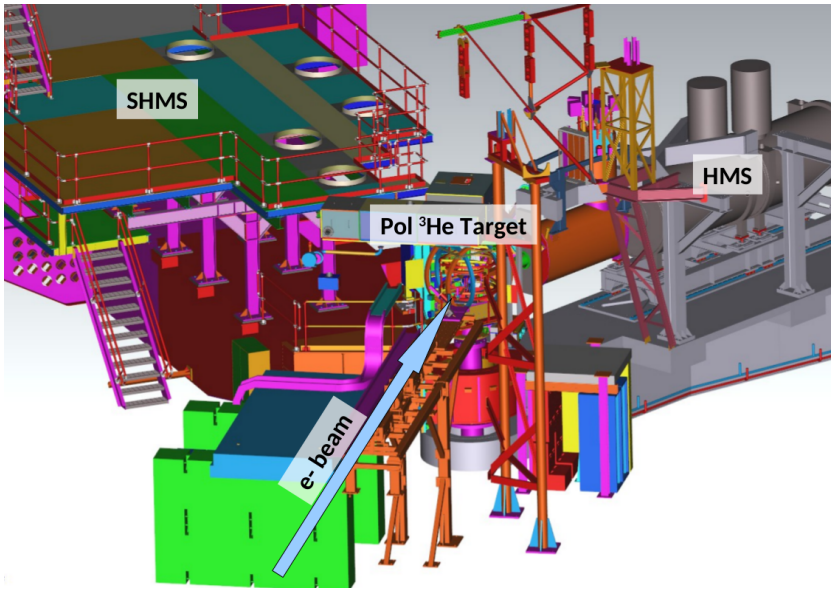
- High Momentum Spectrometer (HMS)
- Super HMS (SHMS)

(Spokespeople: X. Zheng, G. Cates, JP Chen, Z-E Meziani)

Electron Beam:

- E_{beam}=2.17 GeV (elastic, Δ(1232))
- E_{beam}=10.38 GeV (DIS, resonance)
- Beam polarization: 85%

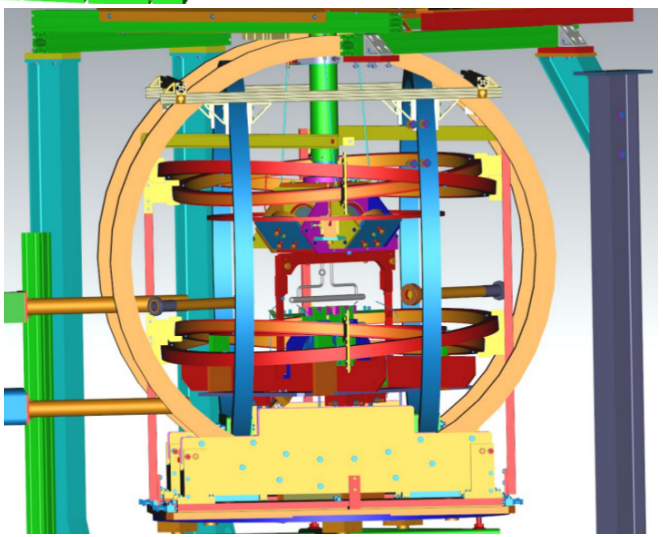
  (3% uncertainty by Moller Polarimeter)
- Circular beam raster with 2.0-2.5mm radius
- < 50 ppm charge asymmetry (average over ~ 1–2 hr run)



Polarized ^{3}He target:

- ^{3}He production cell (40cm)
- 55–60% polarization without beam
- 30 uA beam current

  (doubles performance compare to 6 GeV era)
- 3% uncertainty for polarimetry



Experimental Status

Completed 1-pass commissioning

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

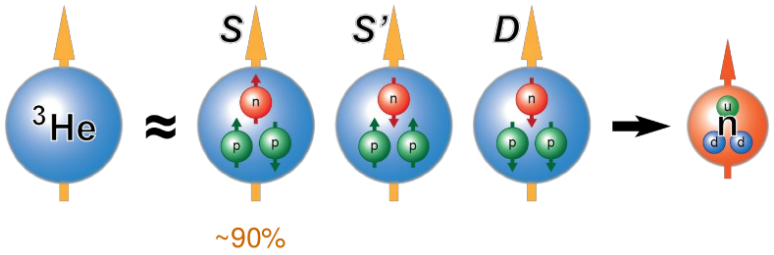
Completed 5-pass DIS production runs for kine 3, kine 4, kine B, Kine C.

Completed most of the kinematics!

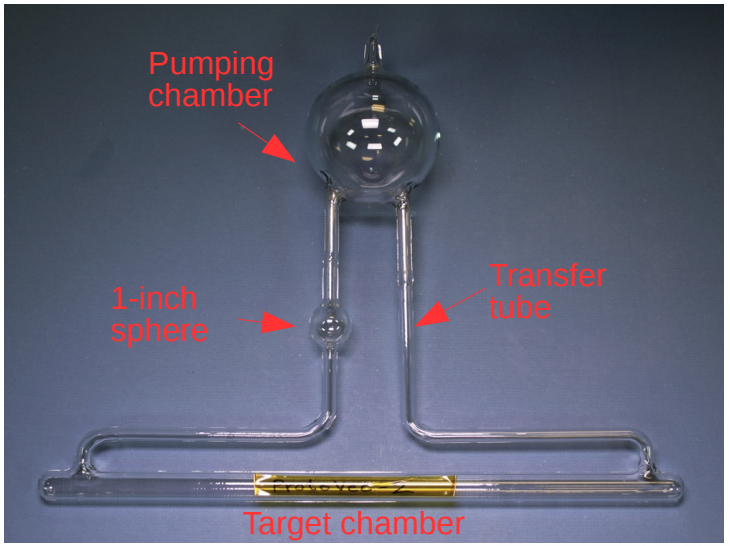
Kine	Spec	E_b GeV	E_p GeV	θ (∘)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
DIS							
1	HMS	10.5	6.00	11.7	84.0	0.0	84.0
3	HMS	10.5	2.90	30.0	88.0	0.0	88.0
4	HMS	10.5	3.50	30.0	511.0	0.0	511.0
B	SHMS	10.5	3.40	30.0	511.0	4.0	515.0
C	SHMS	10.5	2.60	30.0	88.0	4.0	92.0
Resonances							
D	SHMS	10.5	6.90	11.0	84.0	0.0	84.0

- Longitudinal asymmetry of elastic scattering and transverse asymmetry of Δ(1232) are used to check $P_b P_t$ and other systematics.
- The SHMS setting B and HMS setting 4 are used to determine physics asymmetry of ^{3}He at high x, high Q^2.
- The SHMS setting C and HMS setting 3 are used to cover the medium x with high Q^2 region in order to improve previous 6 GeV results.
- Due to the limitation of beam time, did not perform HMS kine 1 which measures the physics asymmetry of ^{3}He at low Q^2 and SHMS kine D resonance measurements which will provide data needed for radiative corrections.

Polarized ^{3}He Target



- Free Neutron mean life: 880.2 s
- Neutron carries the majority of the ^{3}He nucleus polarization

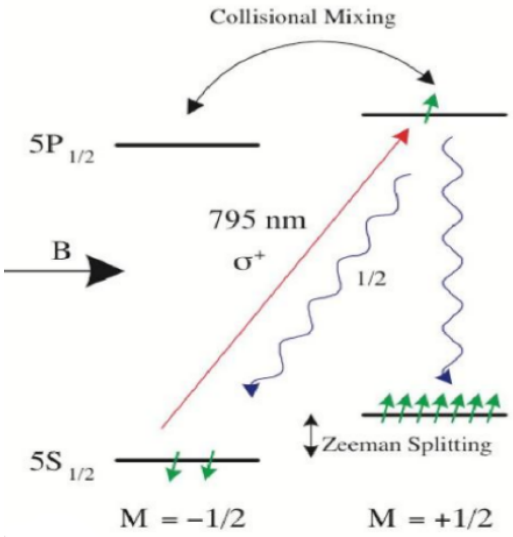


12 GeV era target cell performance:

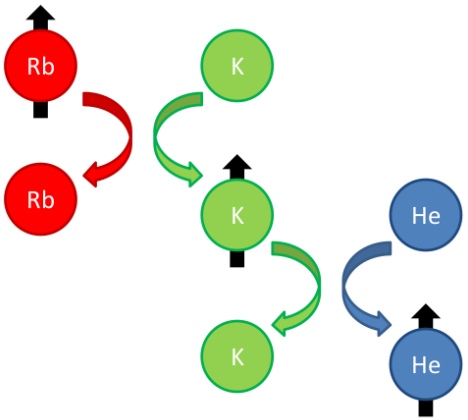
Beam Current: 30uA

Expected in beam polarization: 50%

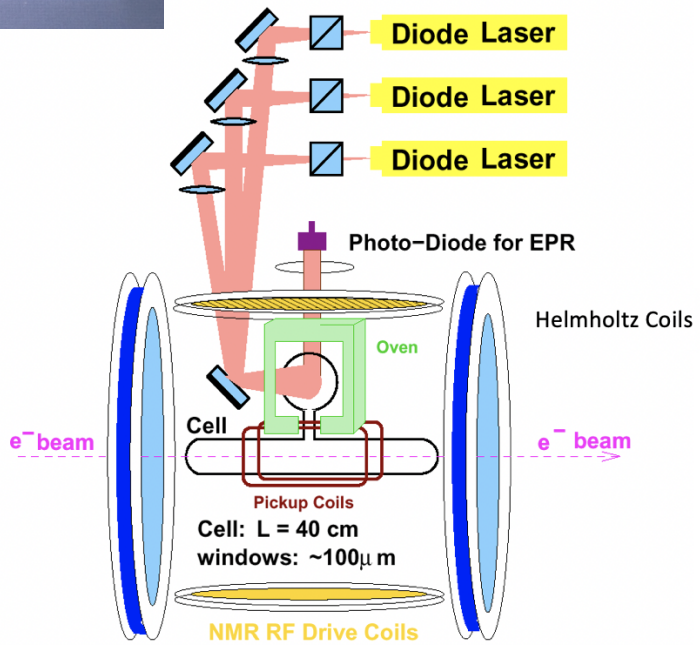
Luminosity: ~ 2.2×10^{36} cm^{-2}s^{-1} Convection Cell



1. Optical Pumping

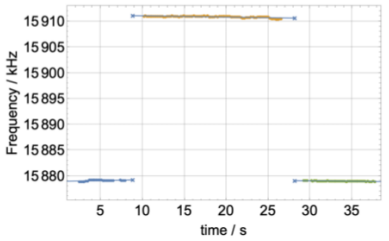


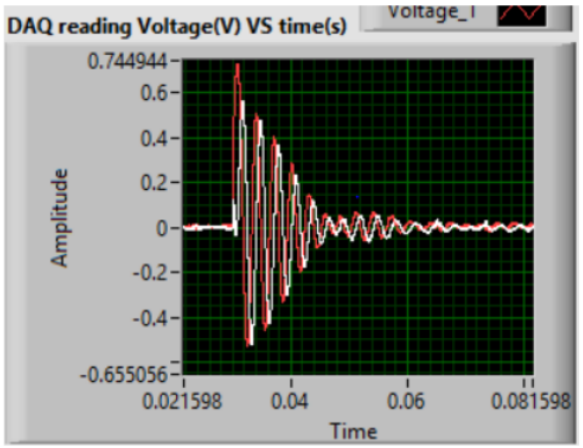
2. Spin Exchange

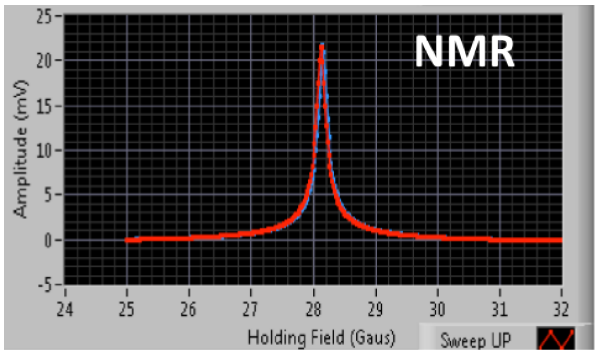


Polarimetry for ^{3}He in Target Cell

EPR







1. Adiabatic Fast Passage Nuclear Magnetic Resonance (AFP-NMR)

Junhao Chen (W&M)

- Magnetic Resonance of ^{3}He Nucleus
- Sweep the holding field under AFP condition to flip the Nucleon spin direction back and forth.
- Relative measurement, calibrate with water NMR or EPR.

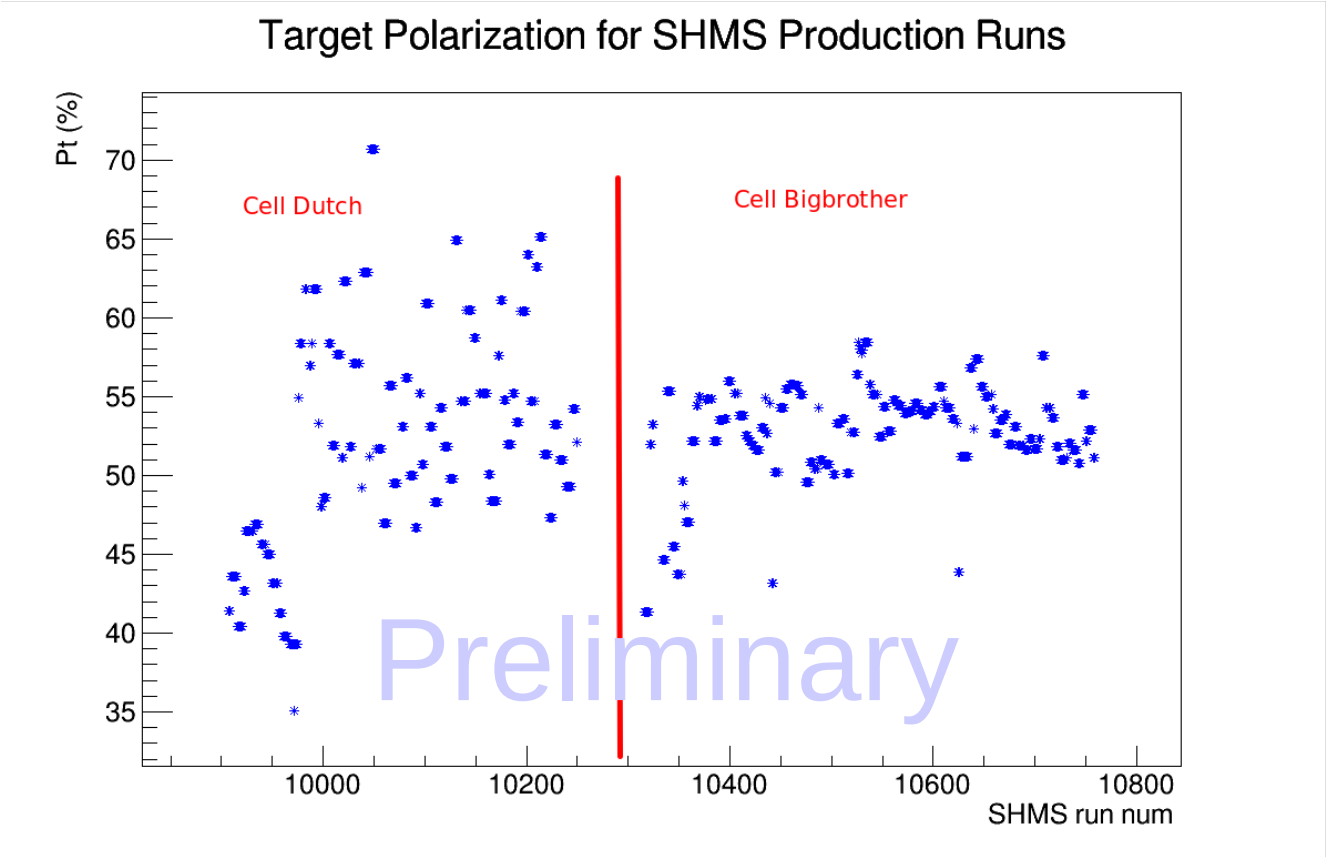
2. Pulse NMR Mingyu Chen (UVa)

- Use resonance RF pulse to tilts the Nucleon spin to a certain angle.
- Relative measurement, calibrate with AFP-NMR.

3. Electron Paramagnetic Resonance (EPR) Melanie Rehfuss (Temple)

- Magnetic resonance of the alkali atoms
- Resonance shifted due to polarized ^{3}He, get the resonance frequency difference by flipping the ^{3}He polarization direction.
- Get ^{3}He polarization from resonance frequency difference. Absolute measurement.

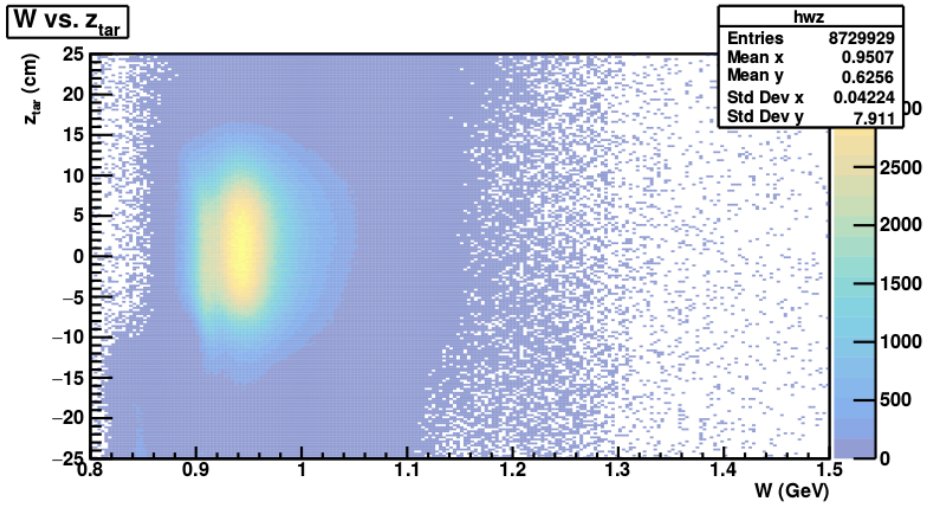
Target Performance

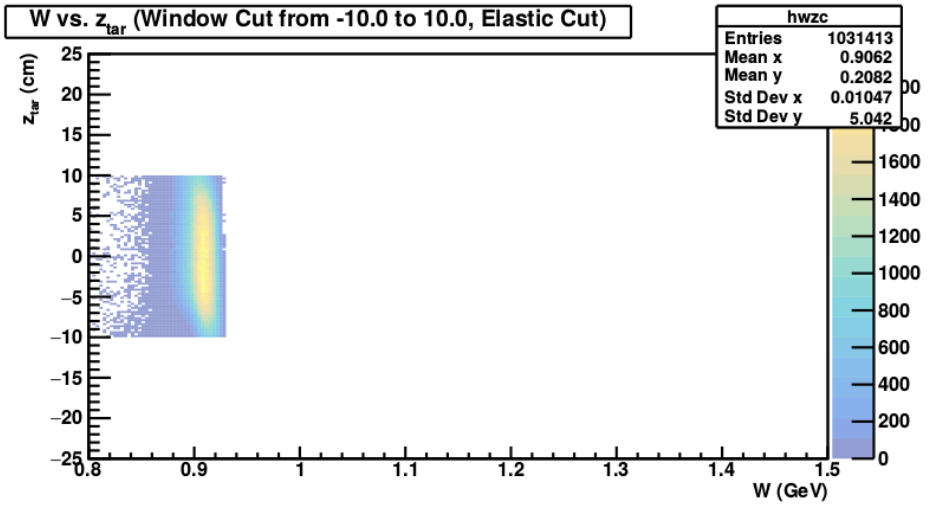


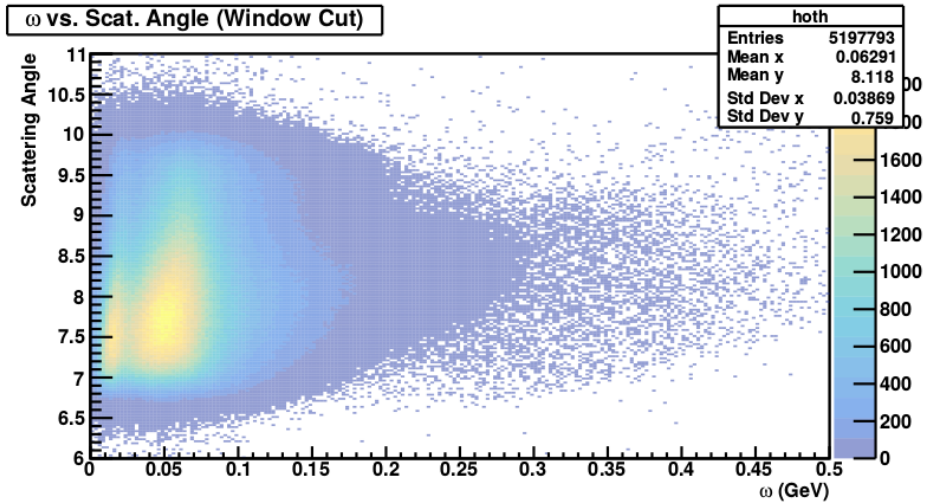
- Target cell polarimetry is performed by AFP-NMR in pumping chamber and calibrated with EPR measurements.
- The polarization for Cell Dutch in this plot is ~ 10% higher, need reanalysis the EPR vs. NMR calibration.
- Still need to do detailed analysis to get target polarization in target chamber with systemic uncertainties.

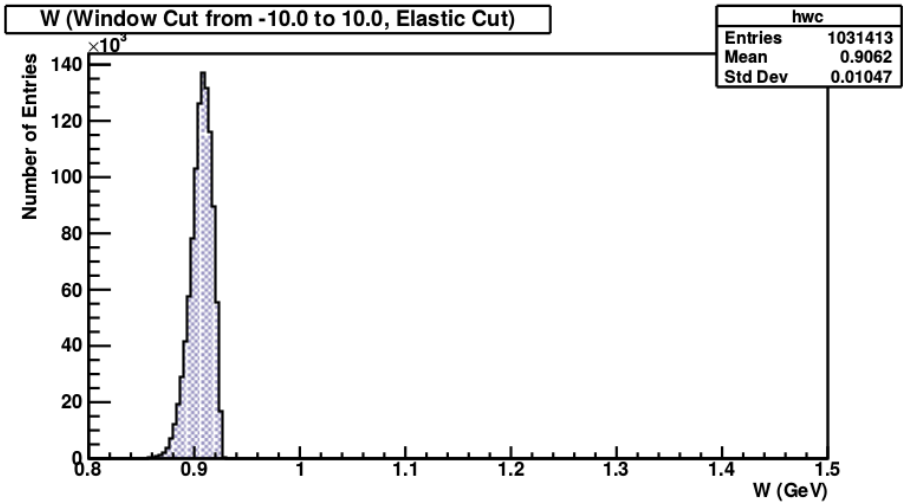
Typical Elastic Run Online Results

(count number of elastic events from SHMS)

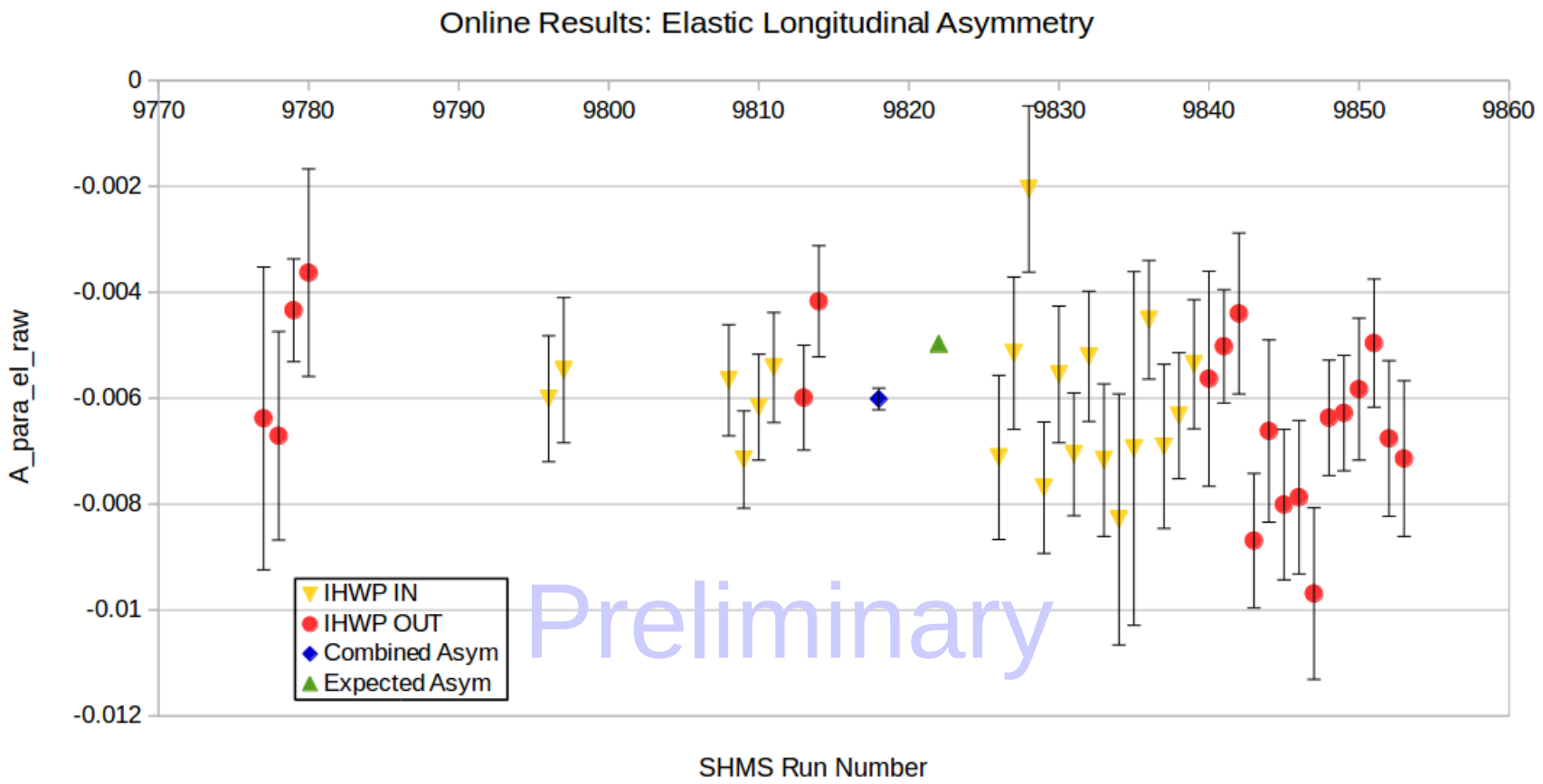








A_{el} Online Results



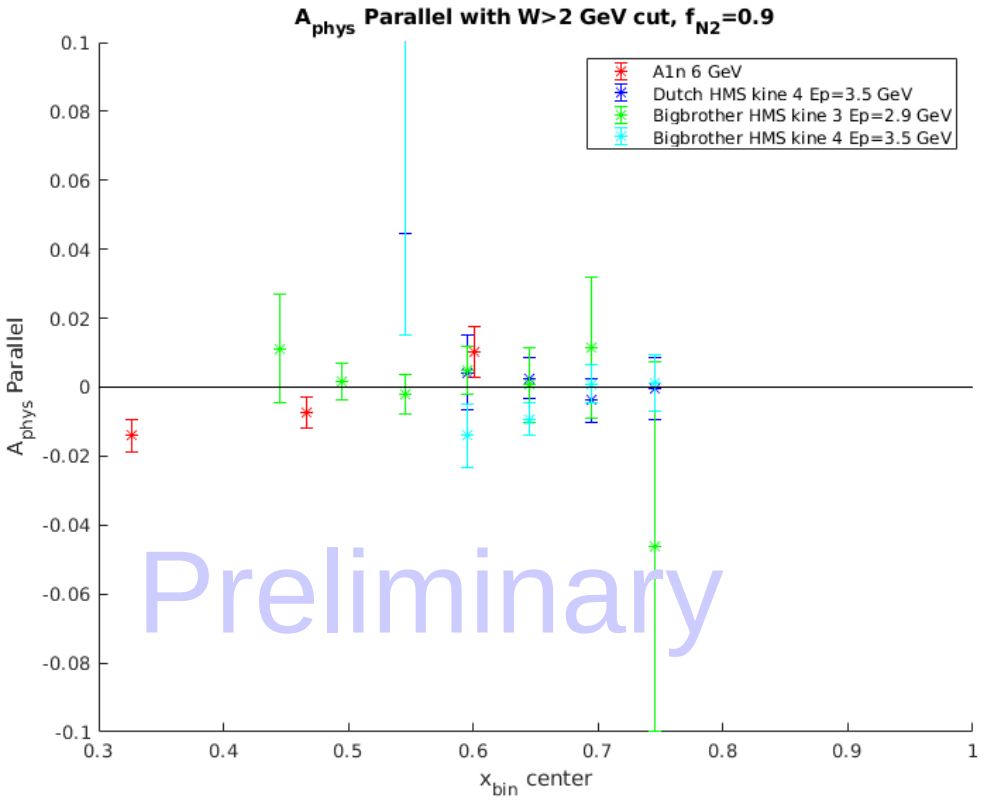
- For “IHWP OUT”, multiply all asymmetries with sign=-1 to account IHWP flip.
- The combined asymmetry for SHMS runs is 0.60%, with uncertainty 0.020%. Then ΔA/A=3.4%.
- The expected physics asymmetry is 2.6%, if we use 85% P_b, 50% P_t, 0.9 f_{N2} and 0.457 f_{QE} to calculate the expected raw asymmetry be about 0.45%.

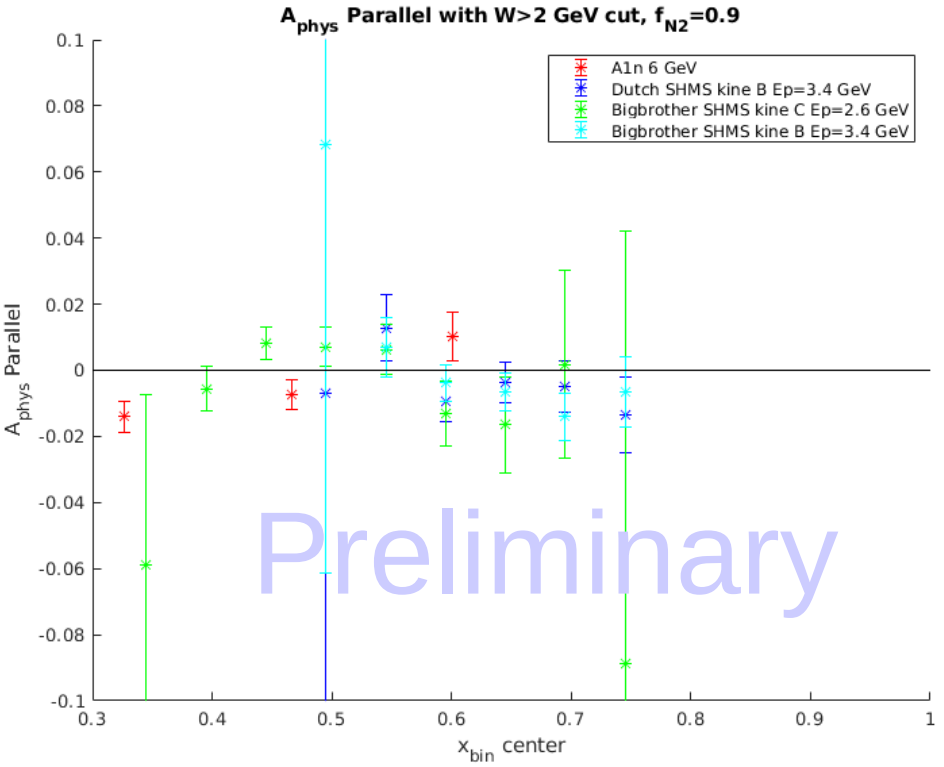
  (need further correction for QE asymmetry f_{QE})

$$A_{physics} = \frac{A_{raw}}{P_b P_t f_{N2} f_{QE}}$$

A_{para} Online Results

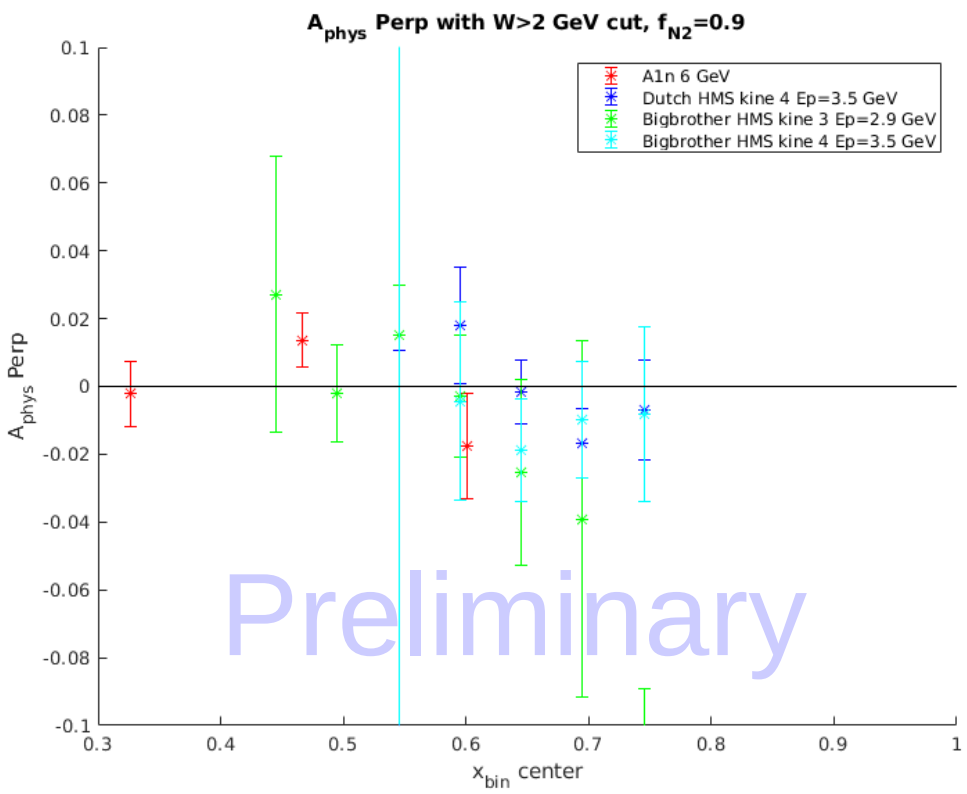
(for each cell, with W> 2 GeV cut, f_N2=0.90)

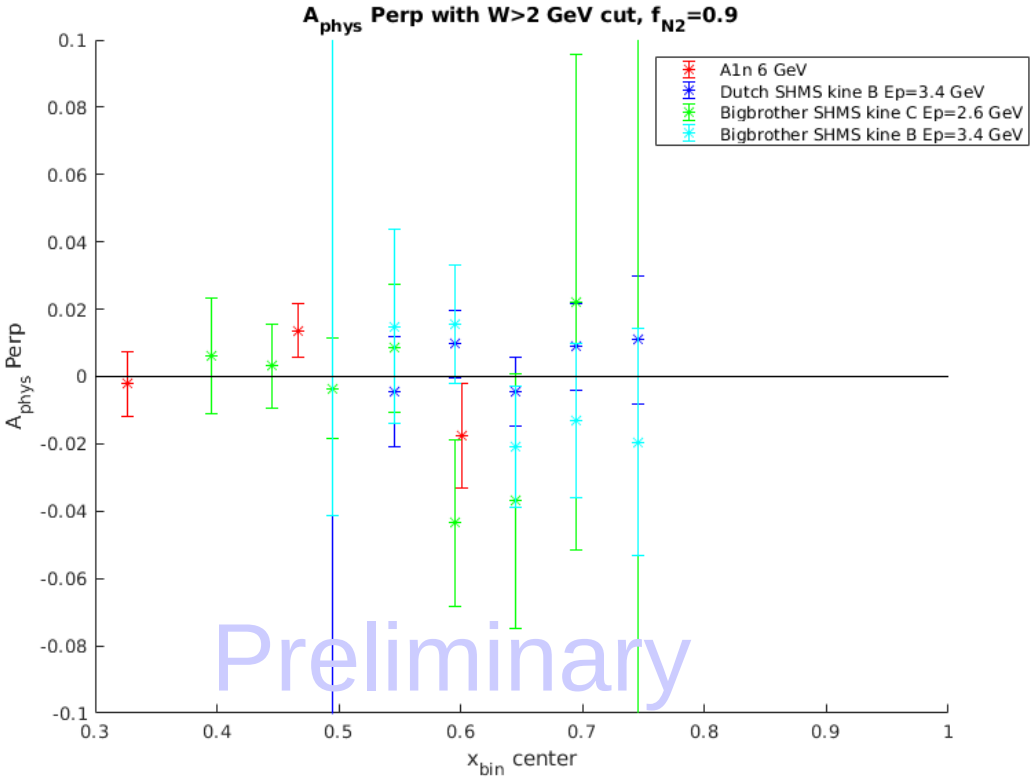




A_{perp} Online Results

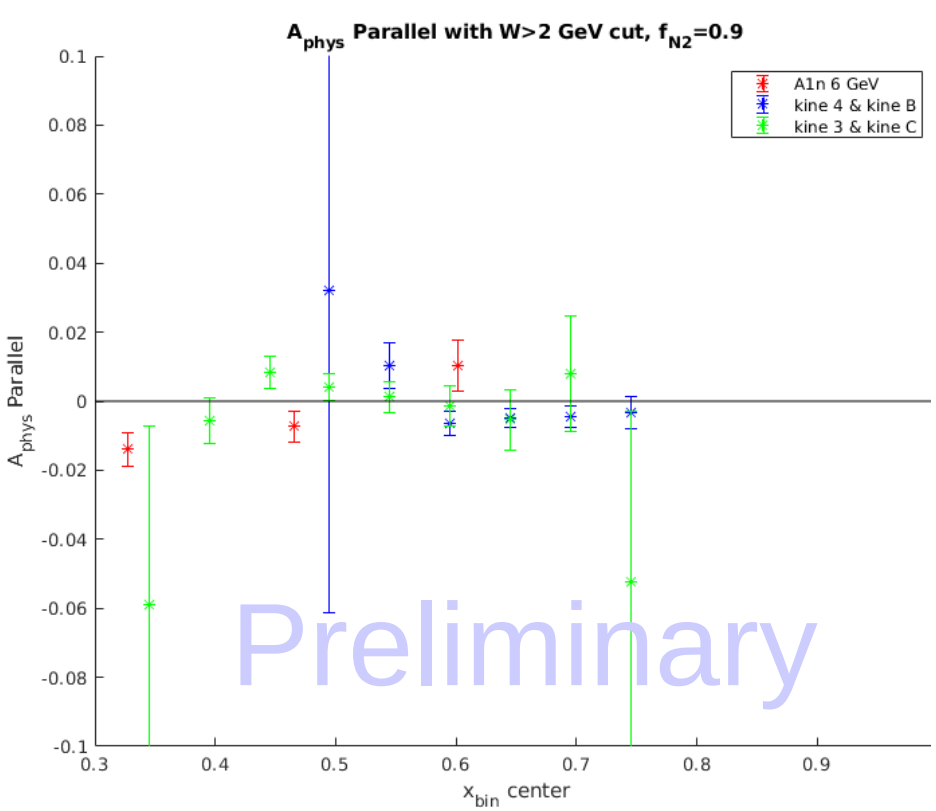
(for each cell, with W> 2 GeV cut ,f_N2=0.90)

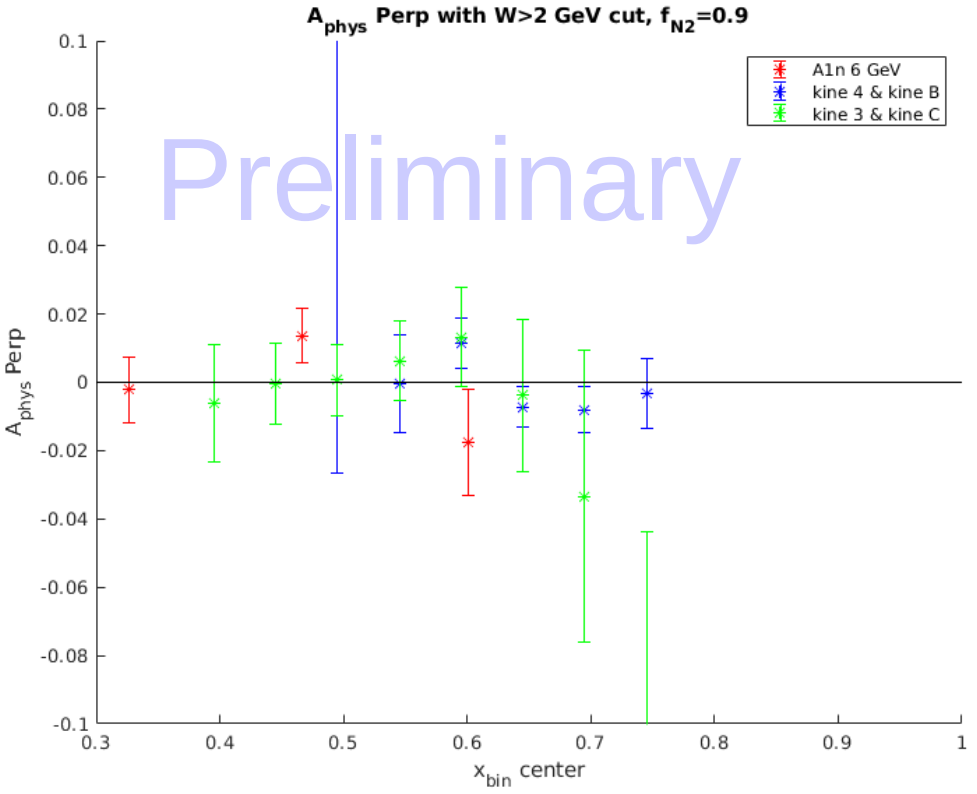




A_{phys} Online Results

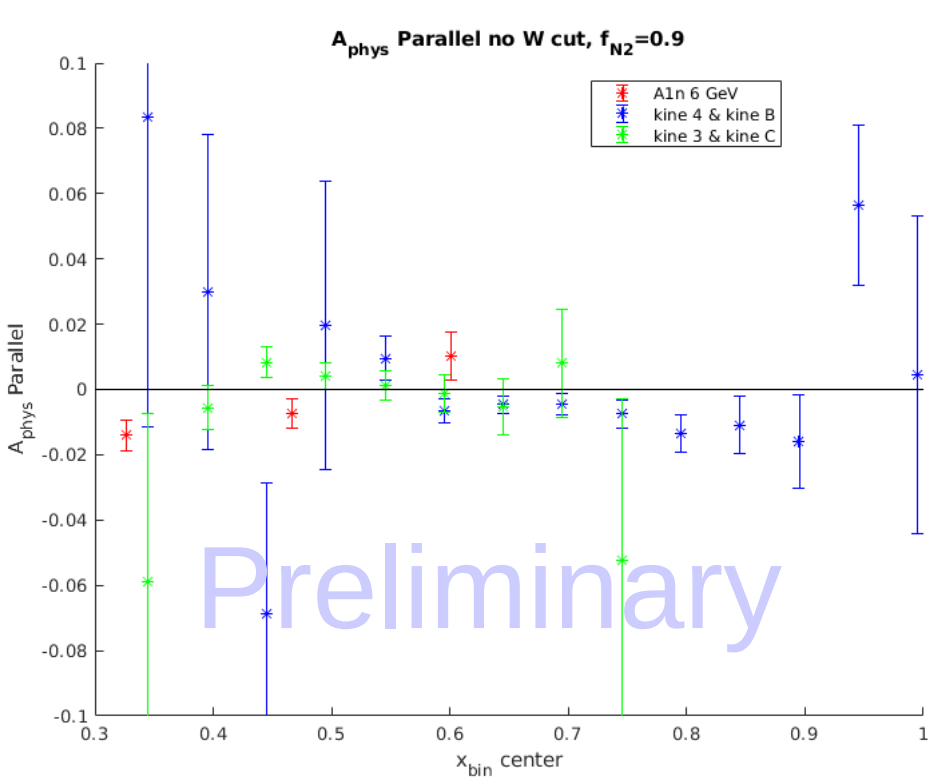
(Combine two Spec, with W> 2 GeV cut, f_N2=0.90)

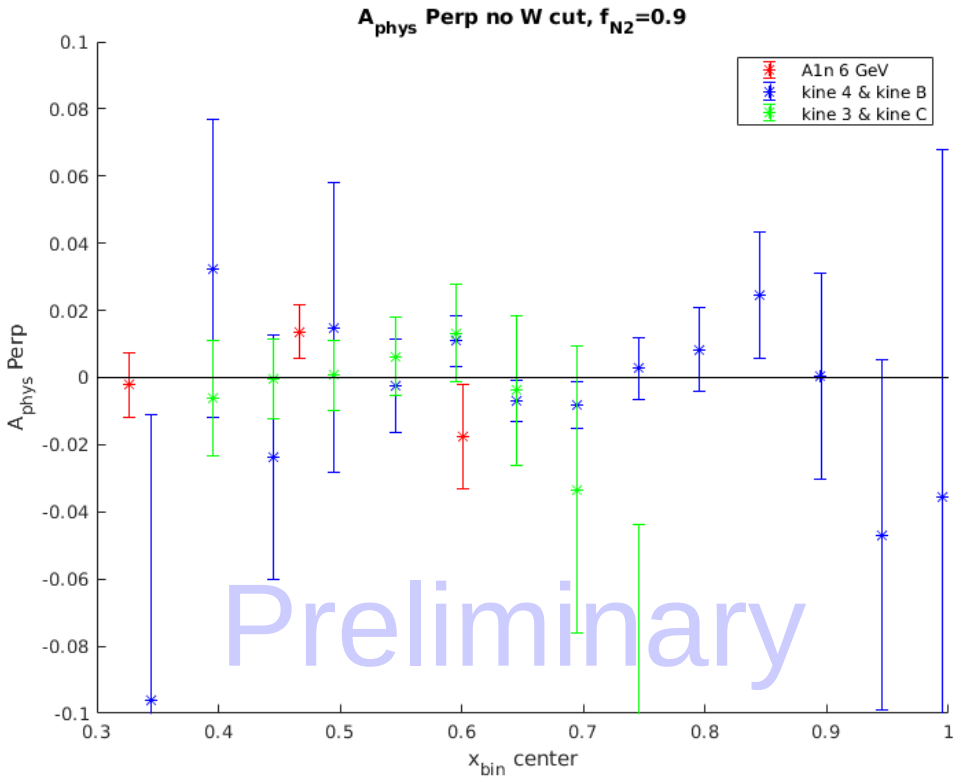




A_{phys} Online Results

(Combine two Spec, without W cut, f_N2=0.90)



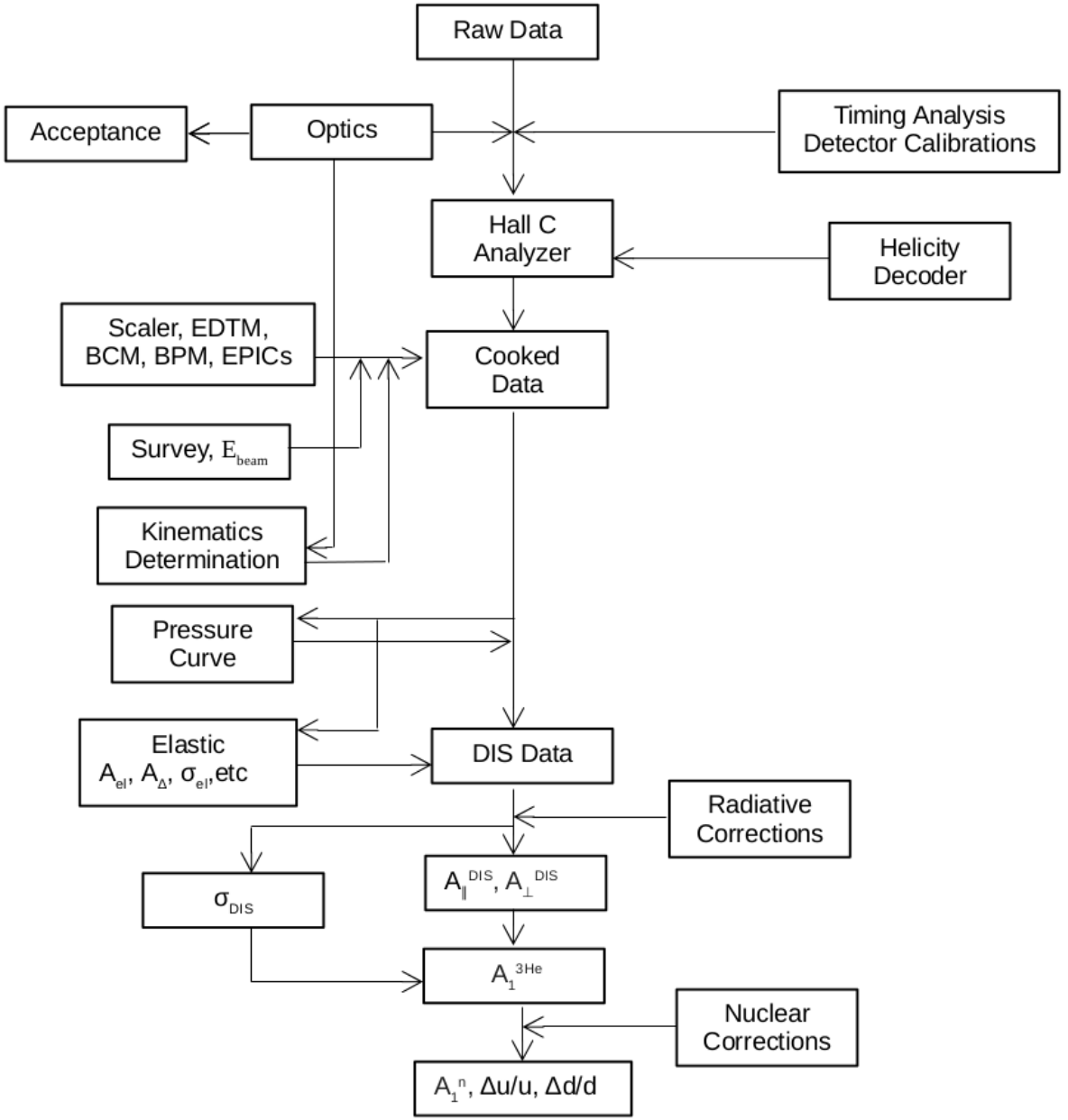


Summary

- The A_1^n experiment (E12-06-110) is a flag-ship, high impact experiment which will give more insights on understanding the spin structure of neutron.
- Overcame a lot of challenges during target installation. The polarized ^3He target performed well through out the experiment.
- The data collection for A_1^n was finished on March 13th , 2020. Completed 1-pass commission and 5-pass DIS production for high x and medium x region.
- Offline detailed analysis is in progress, and it is a exciting time.

Backup Slides

Analysis Outlook



Expected Values of ΔA_1^n for 5-pass Runs

x_{bj}	ΔA_1^n (stat.) Low Q^2	ΔA_1^n(stat.) High Q^2	ΔA_1^n(stat.) two Q^2 combined	ΔA_1^n(syst.)	ΔA_1^n(total.)
0.25	0.0027	0.0000	0.0027	0.0133	0.0136
0.30	0.0029	0.0000	0.0029	0.0130	0.0133
0.35	0.0038	0.0544	0.0038	0.0131	0.0137
0.40	0.0056	0.0243	0.0055	0.0135	0.0146
0.45	0.0094	0.0200	0.0085	0.0141	0.0165
0.50	0.0181	0.0191	0.0131	0.0149	0.0199
0.55	0.0606	0.0162	0.0156	0.0162	0.0225
0.60	0.0000	0.0145	0.0145	0.0179	0.0231
0.65	0.0000	0.0157	0.0157	0.0206	0.0260
0.71	0.0000	0.0186	0.0186	0.0257	0.0317
0.77	0.0000	0.0414	0.0414	0.0485	0.0638

Table 1: Statistical and systematic uncertainties for DIS data at different x and Q^2

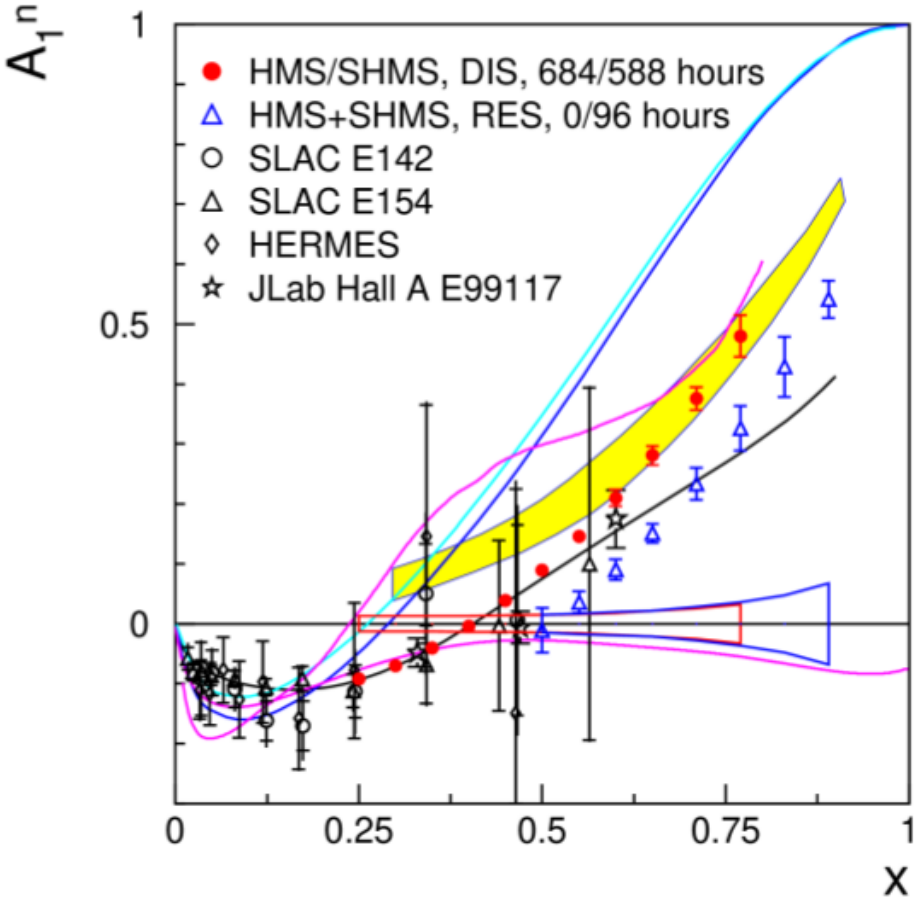
x_{bj}	ΔA_1^n (stat.)	ΔA_1^n(syst.)	ΔA_1^n(total.)
0.40	0.0335	0.0134	0.0361
0.45	0.0144	0.0138	0.0199
0.50	0.0121	0.0148	0.0191
0.55	0.0130	0.0156	0.0203
0.60	0.0134	0.0175	0.0220
0.65	0.0214	0.0222	0.0308
0.71	0.0271	0.0291	0.0398
0.77	0.0364	0.0376	0.0523
0.83	0.0212	0.0512	0.0555
0.89	0.0958	0.1083	0.1446

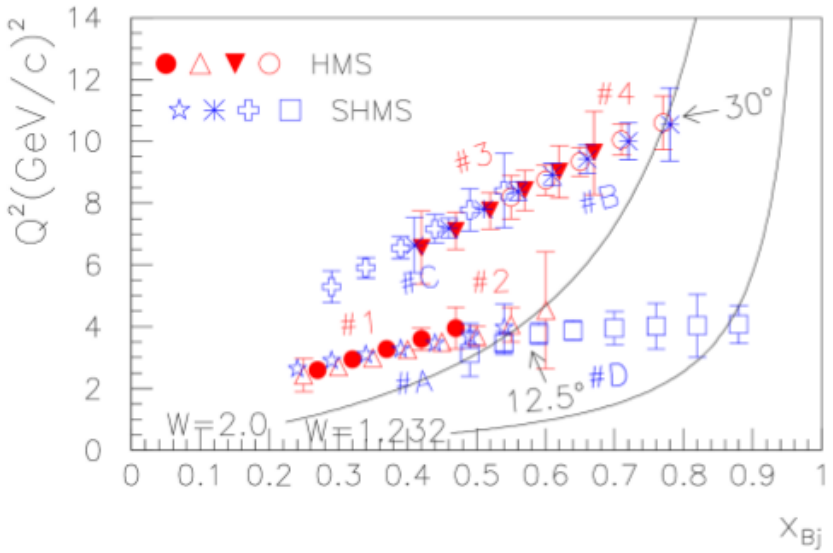
Table 2: Statistical and systematic uncertainties for Resonance data at different x and Q^2

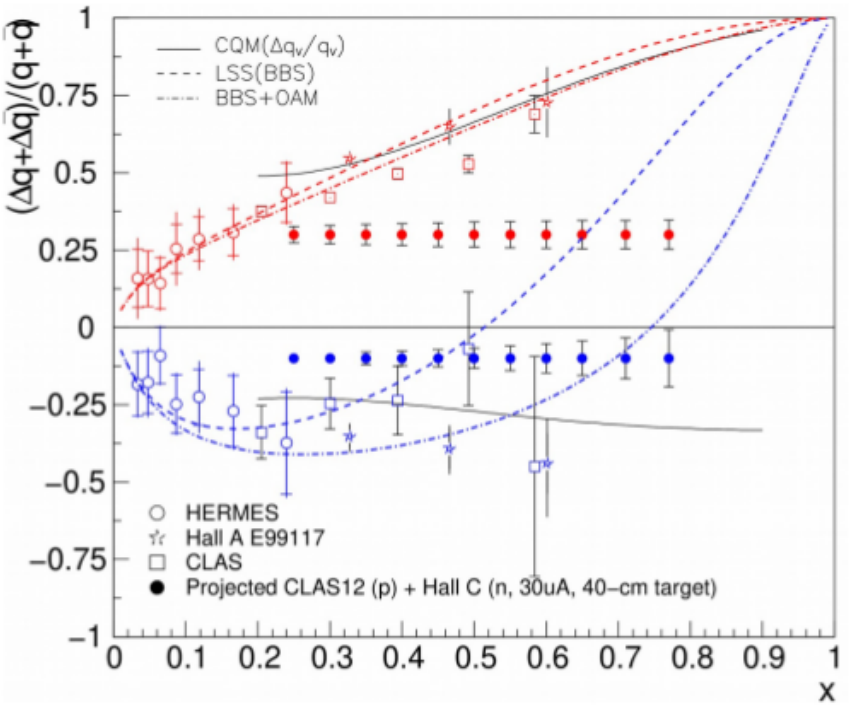
Expected Results

A_1^n Kinematics and Expected Results (approved 36 days)

30uA, 85% beam, 40cm, 60% target







- Slide from X. Zheng ‘s March 2018 readiness review.