E12-06-121: Neutron g_2 and d_2

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Jefferson Lab

Outline

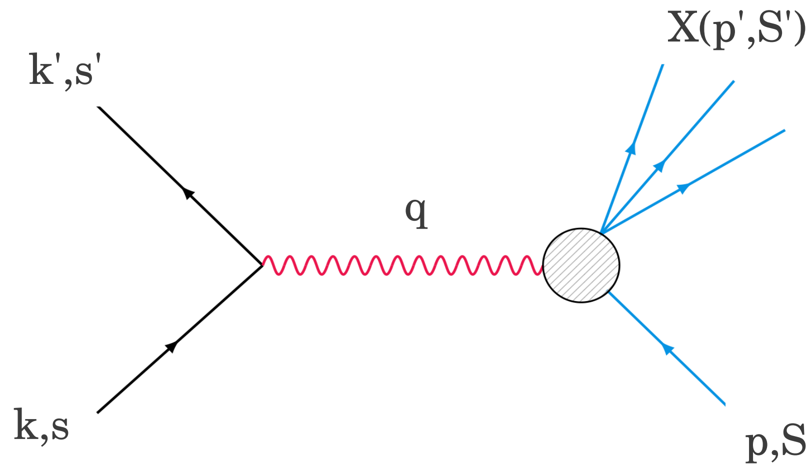
- Background
- The Experiment
  - Experimental Setup
  - Kinematic Coverage
- Experimental Data Analysis
  - Raw Cross-section
  - Raw Asymmetry
- Summary

Deep Inelastic Scattering

Unpolarized cross section:

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

- Unpolarized structure functions F_1 and F_2 contain information about the momentum structure of the target nucleon.



Polarized cross section:

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

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

- Polarized structure functions g_1 and g_2 encode information about the spin structure of the target nucleon.

Q^2 = 4-momentum transfer squared of the virtual photon

ν = E-E' = energy transfer

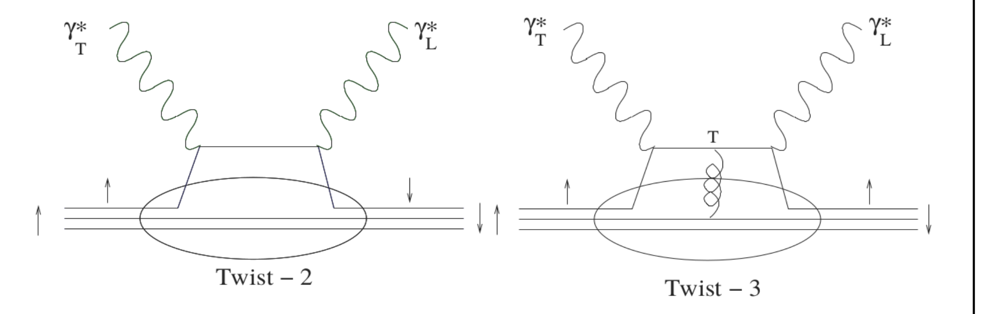
θ = scattering angle

x = Fraction of nucleon momentum carried by the struck quark

g_2 and Quark-Gluon Correlations

- g_2 has no interpretation in naive quark parton model, provides information on quark-gluon correlation.

- g_2 is among the cleanest higher twist observables – contributes to leading order (twist-2 is leading twist) at the transverse spin asymmetry.



$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

- Twist-2 term (*Wandzura & Wilczek*).

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y} dy$$

- Twist-3 term with a suppressed twist-2 piece (*Cortes, Pire & Ralston*).

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left(\frac{m_q}{M} h_T(y,Q^2) - \xi(y,Q^2)\right)\frac{dy}{y}$$

Transversity

Quark-gluon correlation

d_2: Clean Probe of Quark-Gluon Correlations

- d_2 is a clean probe of higher twist effects.

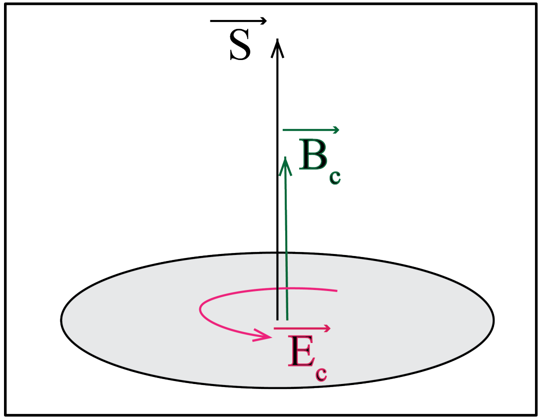
$$d_2(Q^2) = 3\int_0^1 x^2 [2g_1(x,Q^2) + 3g_2(x,Q^2)]dx = 3\int_0^1 x^2 \bar{g}_2(x,Q^2)dx$$

- Related to matrix element in OPE that represents average transverse color Lorentz force on the struck quark due to the remnant system.

- Connected to "color polarizabilities" of nucleon.

$$\chi_E = \frac{(4d_2 + 2f_2)}{3} \qquad \chi_B = \frac{(4d_2 - f_2)}{3}$$

- Computable using Lattice QCD



Response of the color $\vec{B}$ and $\vec{E}$ field to the nucleon polarization

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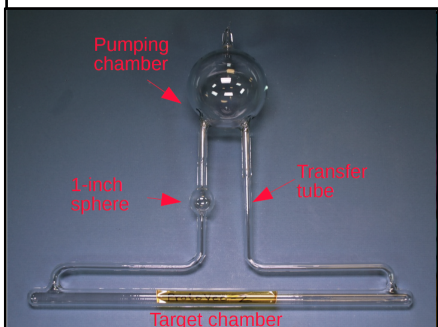
E12-06-121: Experimental Setup

The experiment E12-06-121 (neutron g_2 and d_2) was successfully completed on 21st September, 2020!

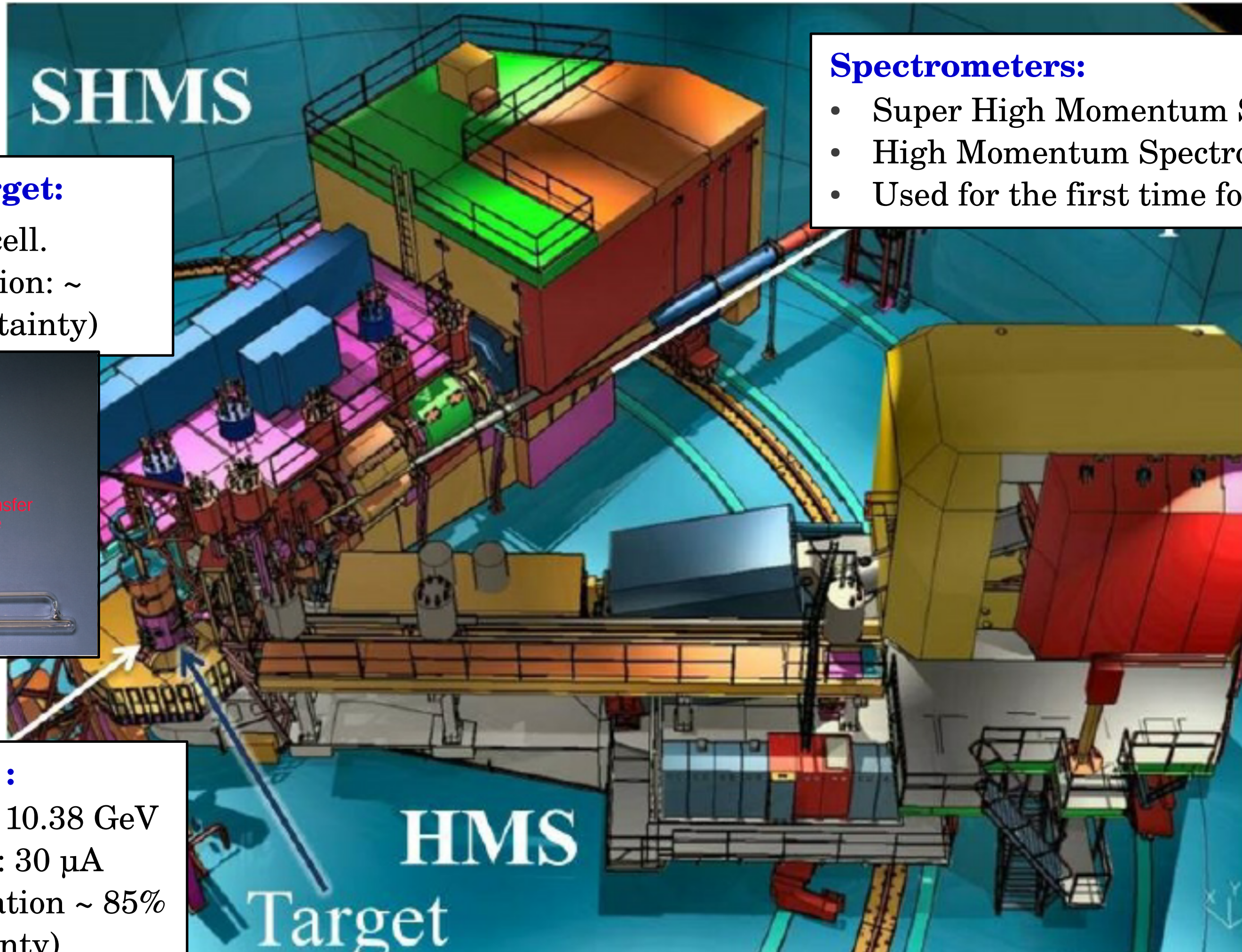
Polarized ^{3}He target:

- 40 cm long ^{3}He cell.
- Target polarization: ~ 45% (~3% uncertainty)



Spectrometers:

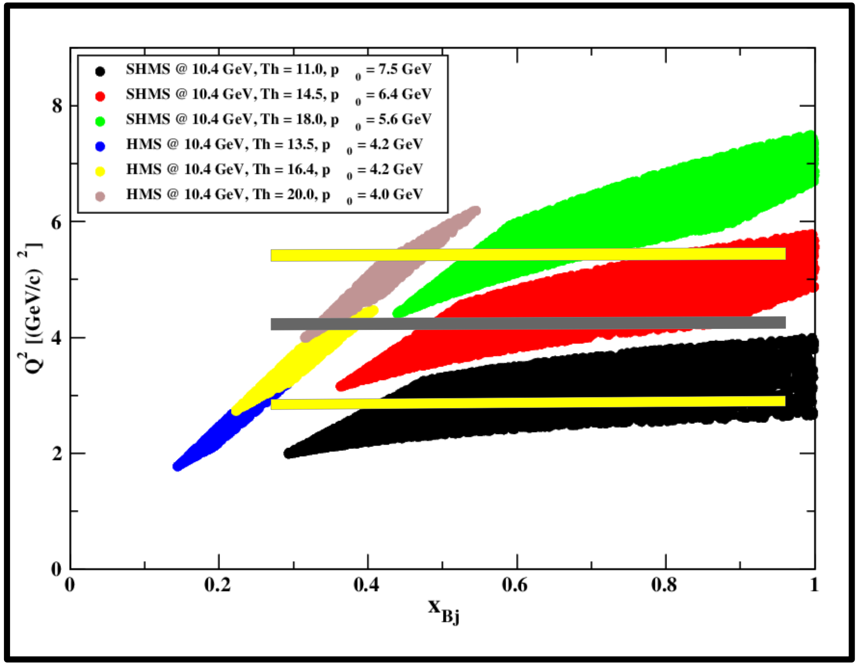
- Super High Momentum Spectrometer (SHMS)
- High Momentum Spectrometer (HMS)
- Used for the first time for extended target



Electron Beam :

- Beam energy: 10.38 GeV
- Beam current: 30 μA
- Beam polarization ~ 85% (~3% uncertainty)

E12-06-121: Kinematic Coverage



5-pass running

HMS Production

Setting	P_o (GeV/c)	Angle	x	Q^2 (GeV^2/c^2)	W (GeV)
A	4.2	13.5°	0.207	2.414	3.178
✕ B	4.2	16.4°	0.305	3.554	2.993
C	4.0	20.0°	0.418	5.018	2.806

SHMS Production

Setting	P_o (GeV/c)	Angle	x	Q^2 (GeV^2/c^2)	W (GeV)
X	7.5	11.0°	0.527	2.866	1.859
✕ Y	6.4	14.5°	0.565	4.240	2.036
Z	5.6	18.0°	0.633	5.701	2.046

- Above coverage reflects 25% reduction relative to Proposal to accommodate Accelerator schedule. Accelerator performance difficulties during run limited final data collected to:
  - Complete: Kin A, C, X, Z (Calib + Long + Transverse)
  - Partial: Kin B, Y (Calib + Long)
- Collected ~70% of required 1-pass data mostly ^{3}He longitudinal elastic.

1-pass running

Kinematic Setting	Spectrometer	P_o (GeV/c)	Angle
^{3}He elastic	SHMS	-2.12	8.5°
		-2.129	13°
	HMS	-2.082	17°
		-2.082	11.7°

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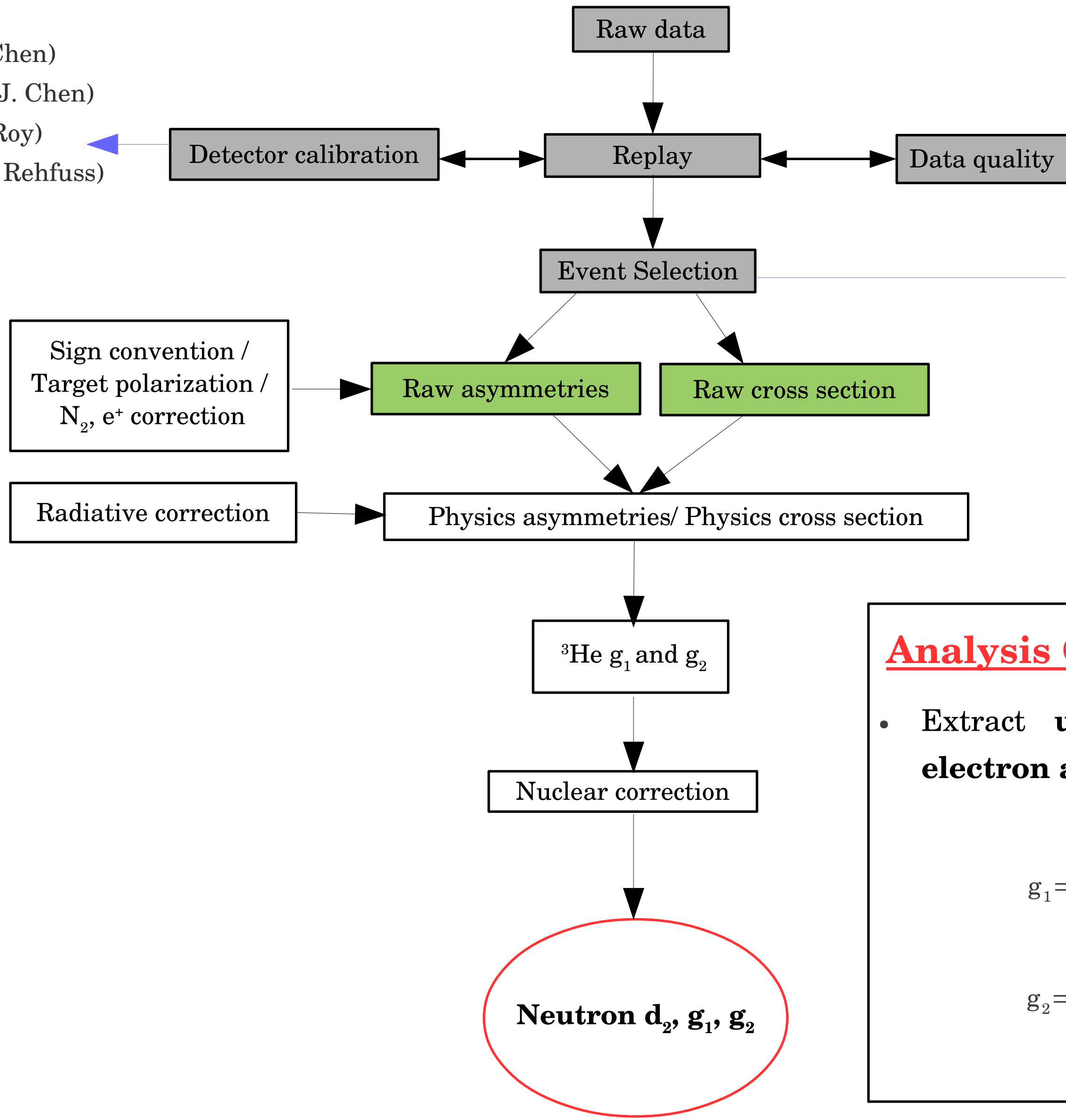
Analysis Status

1. Hodoscope (M. Chen)
2. Drift Chamber (J. Chen)
3. Cherenkov (M. Roy)
4. Calorimeter (M. Rehfuss)



1. Beam Trips and Beam Quality
2. Detector live time
3. Short runs

1. Target window cuts (M. Chen)
2. PID studies (M. Rehfuss)
3. Acceptance cuts for SHMS and HMS magnets (M. Roy)

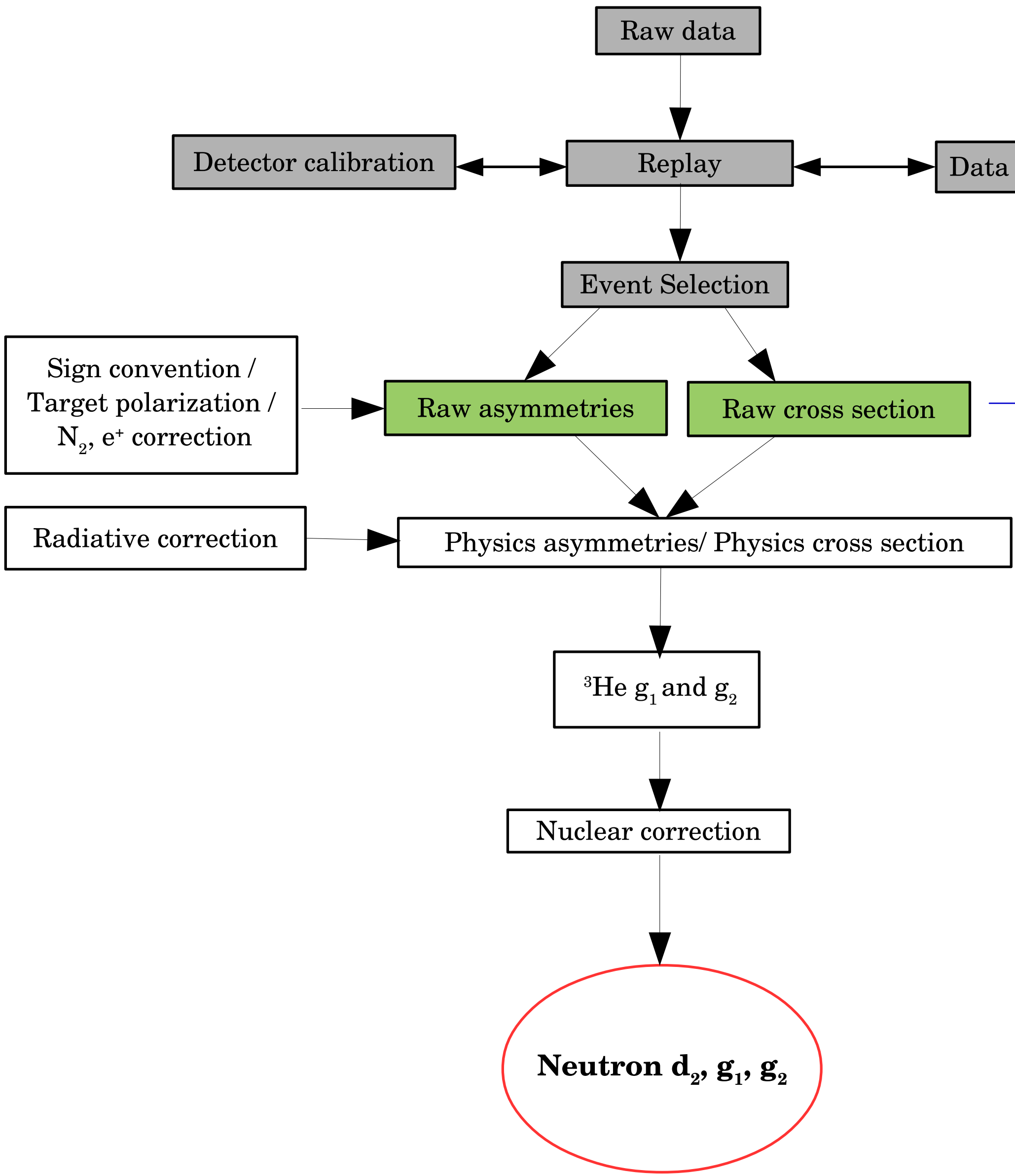
Analysis Goal:

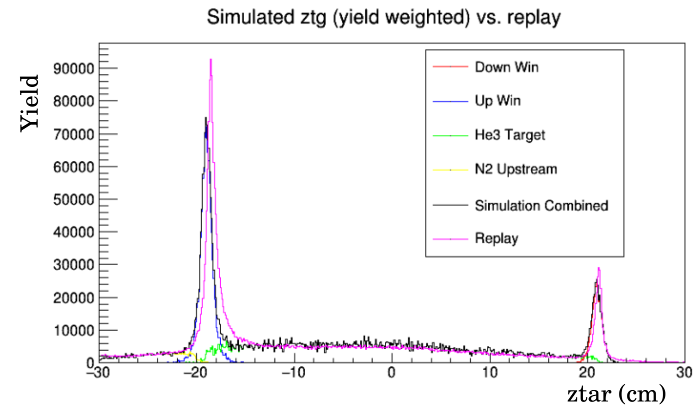
- Extract **unpolarized cross section (σ_0)** and **electron asymmetries ($A_\parallel$, $A_\perp$)**.

$$g_1 = \frac{MQ^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\sigma_0\left[A_\parallel + \tan\left(\frac{\theta}{2}\right)A_\perp\right]$$

$$g_2 = \frac{MQ^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\sigma_0\left[-A_\parallel + \frac{1+(1-y)\cos(\theta)}{(1-y)\sin(\theta)}A_\perp\right]$$

Analysis Status





Comparison of MC simulation and data
HMS-C (charge normalized yield)

Acceptance correction method

Cross Section Extraction

Acceptance correction method:

$$\frac{d\sigma}{d\Omega dE'} = \frac{Y(E',\theta)}{\left[(\Delta E\,\Delta\Omega).A(E',\theta).L\right]}$$

$Y(E',\theta)$: efficiency corrected electron yield

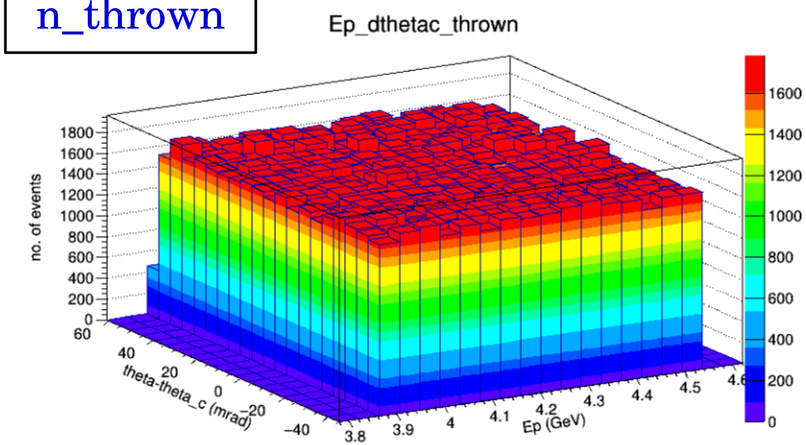
L : Integrated Luminosity

Cuts:

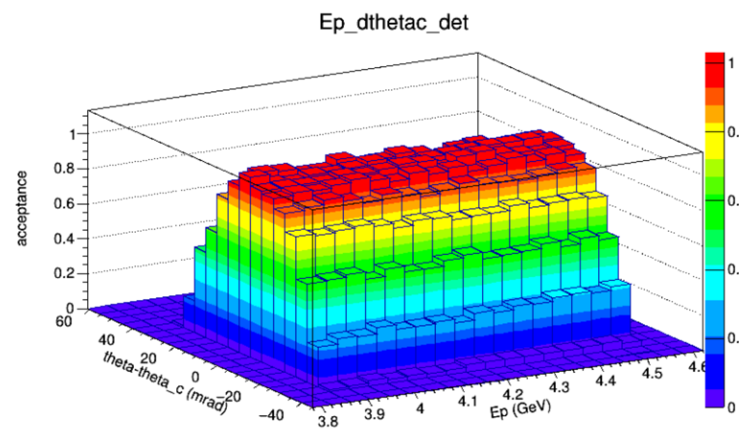
abs(z)<10 cm && abs(delta)<8

HMS @13.5°, -4.2 GeV/c

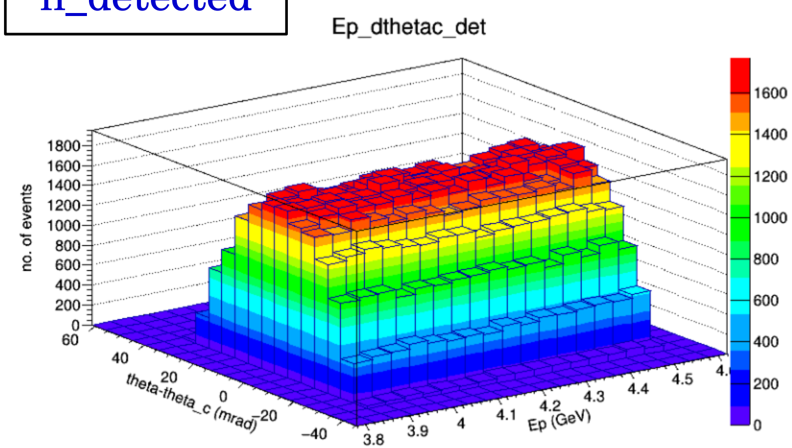
n_thrown



$A(E',\theta)$: n_detected / n_thrown



n_detected

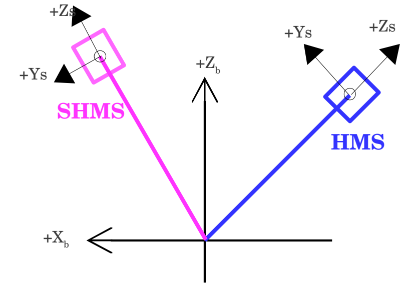


Probability that a particle will make it through the spectrometer.

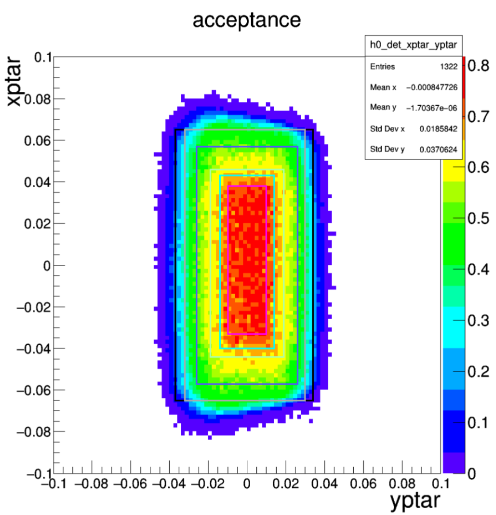
Determined from simulation!

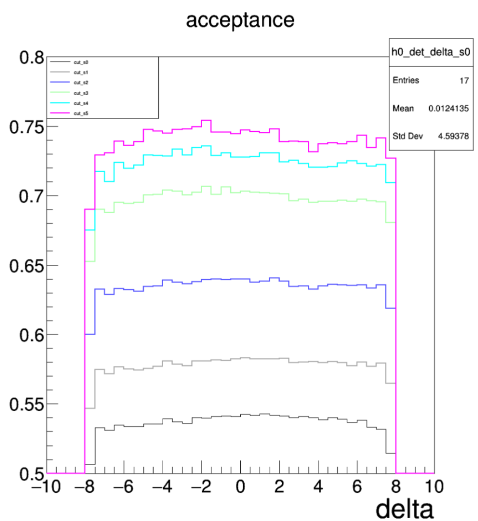
Spectrometer Acceptance Study

- Generate 1-D delta acceptance for different xp, yp rectangular cuts from the Monte Carlo Simulation.
- Determine xp, yp cuts to get uniform delta acceptance.

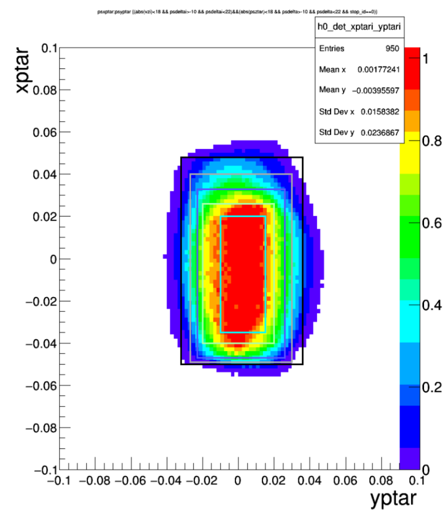


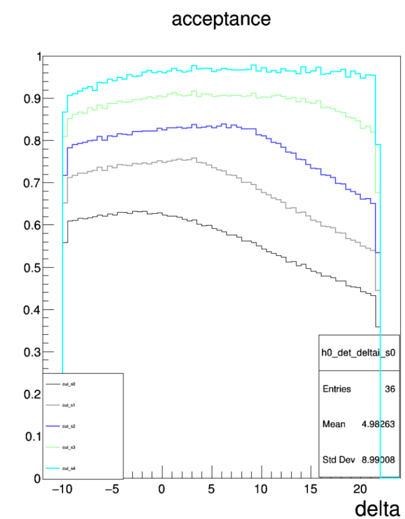
HMS Kin-C
20 deg, -4.0 GeV/c





SHMS Kin-C
18 deg, -5.6 GeV/c





<u>Cuts applied:</u>

Thrown variable: abs(vzi) < 18 && abs(hsdeltai)<8

Recon variable: abs(vzi) < 18 && abs(hsdeltai)<8 && abs(hsztar) < 18 && abs(hsdelta)<8 && stop_id==0

<u>Cuts applied:</u>

Thrown variable: abs(vzi) < 18 && psdeltai>-10 && psdeltai<22

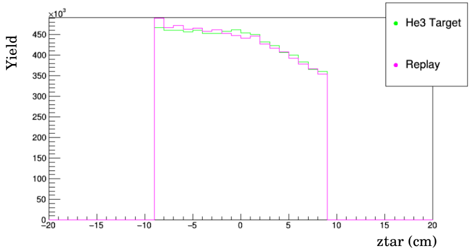
Recon variable: abs(vzi) < 18 && psdeltai>-10 && psdeltai<22 && abs(psztar) < 18 && psdelta>-10 && psdelta<22 && stop_id==0

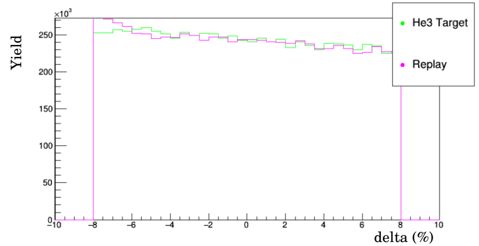
Acceptance Uncertainty

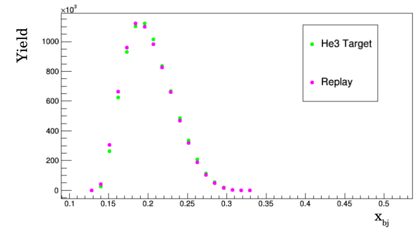
- Compare radiated simulated yield (weighted by F1F2IN21 xsection model) with data.
- Estimate scale factor to match simulated z yield to data yield for different acceptance cuts.

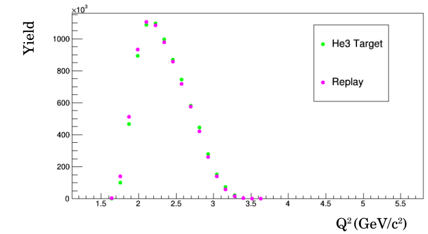
$$scale\ factor = \frac{data(ztg) \rightarrow Integral()}{simulation(ztg) \rightarrow Integral()}$$

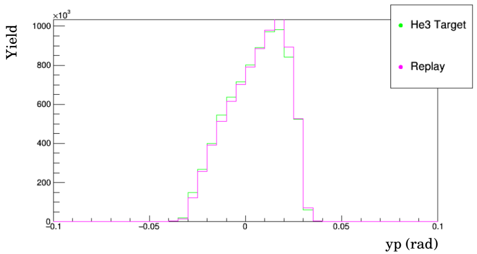
HMS @13.5°, -4.2 GeV/c

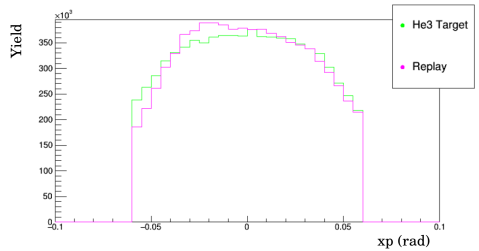


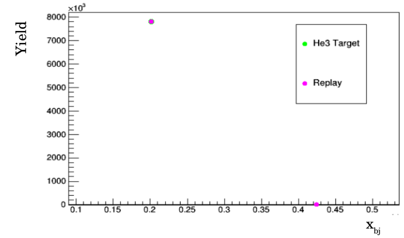


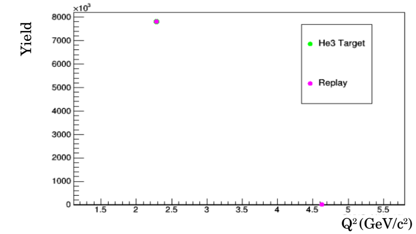












- Estimate percentage difference (P) between scaled simulated yield and data yield (x_{bj} binned) for different acceptance cuts.

$$P = \frac{(Yield_{replay} - Yield_{simulation}) * 100}{Yield_{simulation}}$$

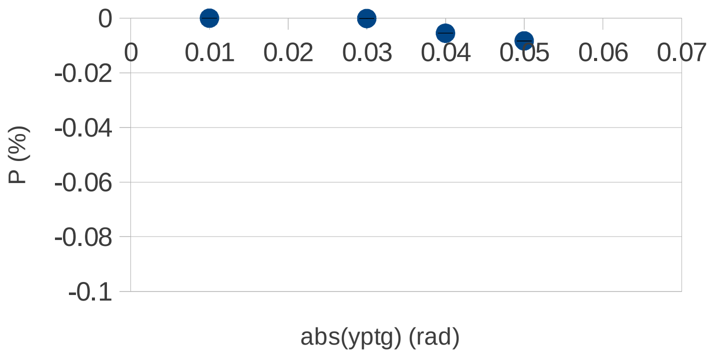
Acceptance Uncertainty

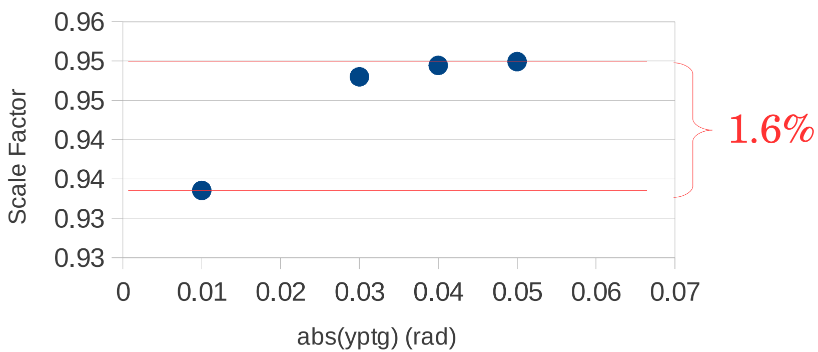
HMS @13.5°, -4.2 GeV/c

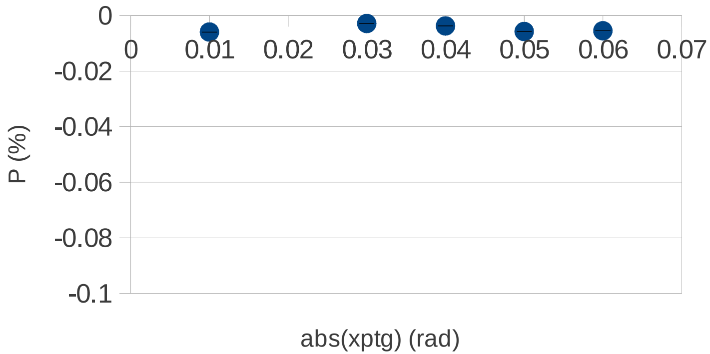
<u>Uncertainty:</u> The variation of scale factor and P(%) with different acceptance cuts

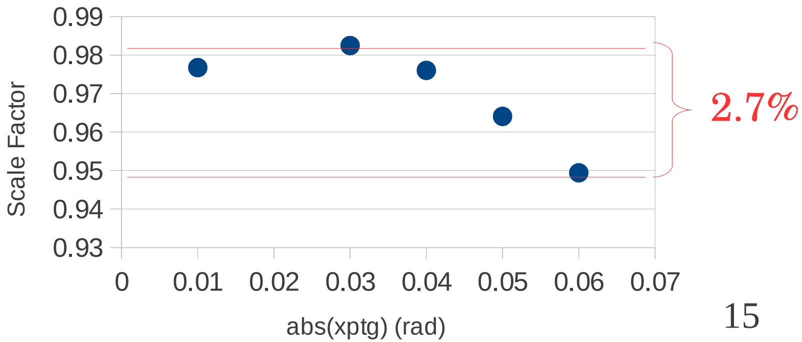
$$P = \frac{(Yield_{replay} - Yield_{simulation}) * 100}{Yield_{simulation}}$$

$$scale\ factor = \frac{data(ztg) \rightarrow Integral()}{simulation(ztg) \rightarrow Integral()}$$

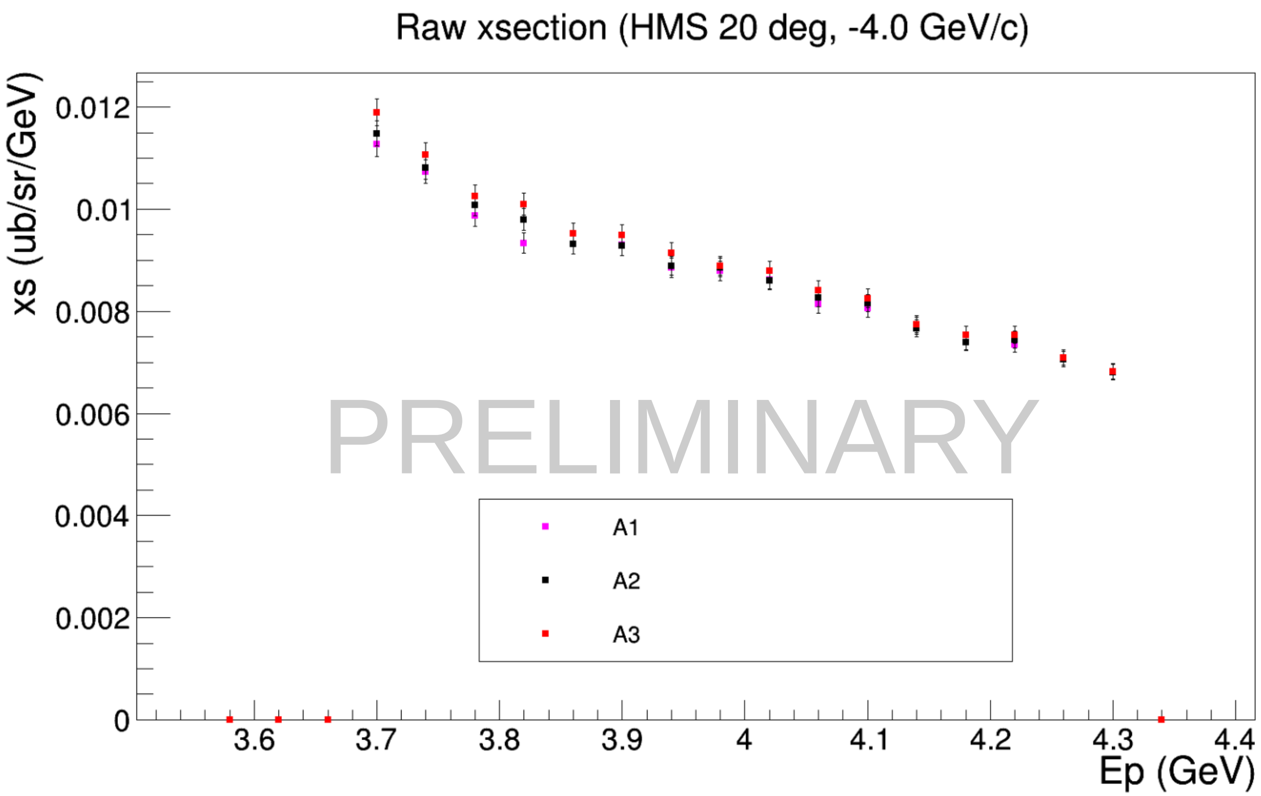








Raw Cross-section Extraction



*Ongoing work

- Finalizing systematic uncertainties
- Finalizing histogram binning

1. abs(H.gtr.dp)<8 && abs(H.react.z)<17
2. H.cal.etracknorm>0.8
3. H.cer.npesum>1

Theta (xp) – Phi (yp) cuts

Cut1: theta<38.0 && theta>-33.0 && phi<10.0 && phi>-10.0

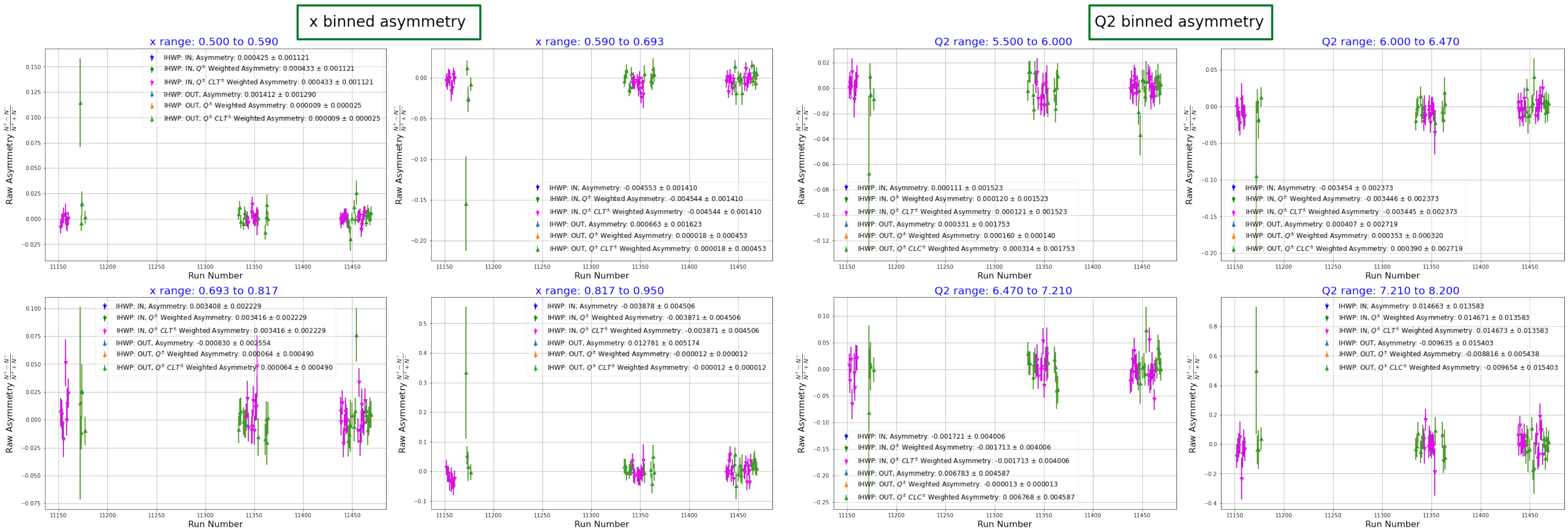
Cut2: theta<43.0 && theta>-40.0 && phi<14.0 && phi>-14.0

Cut3: theta<46.0 && theta>-44.0 && phi<19.0 && phi>-19.0

Raw Asymmetry

Slide Courtesy: J. Chen

Preliminary Results



Raw Asymmetry : $(N^+ - N^-) / (N^+ + N^-)$

Current Status:

- Working to get physics asymmetry.

Summary

- Completed: Detector Calibrations, Pressure Curve Study, PID Studies, Spectrometer Acceptance.

- Ongoing: Physics Asymmetry and Cross-section Extraction.

- Finally, d_2^n will be calculated for three constant Q^2 values and g_2^n will provide information on higher twist effects or quark gluon correlation.

Acknowledgments

Thanks to all the collaborators, shift takers, JLab alignment group and other JLab staff for making the experiment successful.

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

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Students


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Supporting Documentations

- Polarized Helium-3 Experiments wiki (2019/2020)
  https://hallcweb.jlab.org/wiki/index.php/Polarized_Helium-3_Experiments

- Proposals
  - https://hallcweb.jlab.org/wiki/images/c/cb/PR12-06-121.pdf
  - https://hallcweb.jlab.org/wiki/images/1/1a/D2n_HallC_PAC36-update_v2.pdf

- Polarized ^{3}He Target
  - https://hallcweb.jlab.org/wiki/index.php/Pol_He-3_Target_Information
  - https://www.jlab.org/indico/event/351/session/1/contribution/9/material/slides/0.pdf

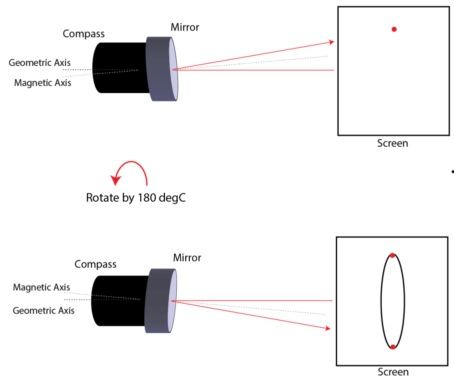
- E06-014 (2009 d_2^n experiment) wiki
  - https://hallaweb.jlab.org/wiki/index.php/Analysis_resources_for_d2n

Back-up Slides

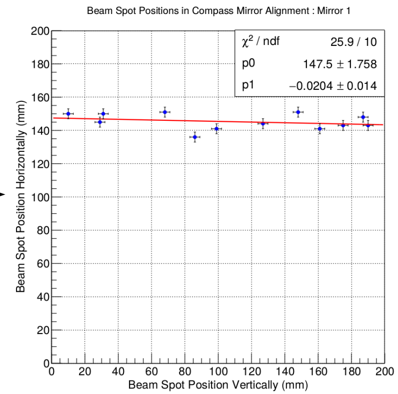
Target Polarization Direction Measurement

Goal: Measure the direction of the target magnetic field in the Hall C coordinate system precisely within ±0.1°

The air-floated compass

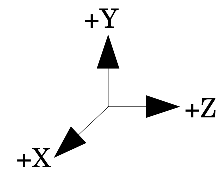


Compass mirror alignment



Horizontal error from mirror 1 alignment: ±0.06° (September 2020)

- The magnetic field direction was measured for all four polarization direction at three different locations along target length
- Measured twice : March, 2020 and September, 2020

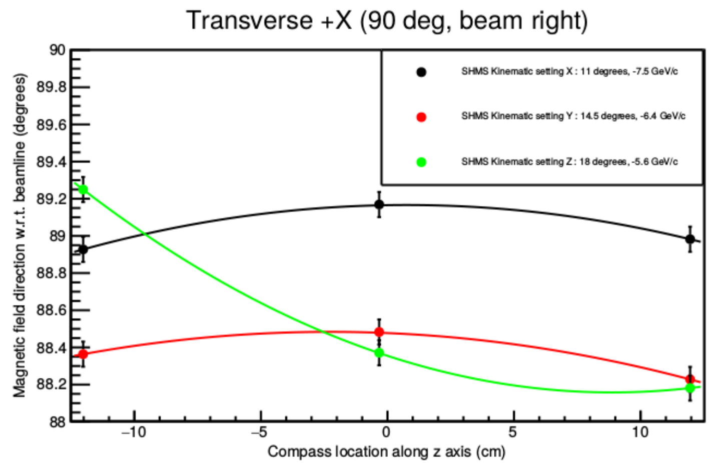


Systematic uncertainties:

1. Error in determining the angle (θ) the magnetic field makes with beam line: ~ ±(0.01°-0.03°)
2. Errors from the compass mirror alignment (θ_M): ~ ±(0.04°-0.08°)
3. Finite laser beam spot size: ~ ±0.006°
4. Position of incident laser beam on the compass mirror: ~ ±0.01°

Current Status:

- Data analysis has been completed for each set of measurements

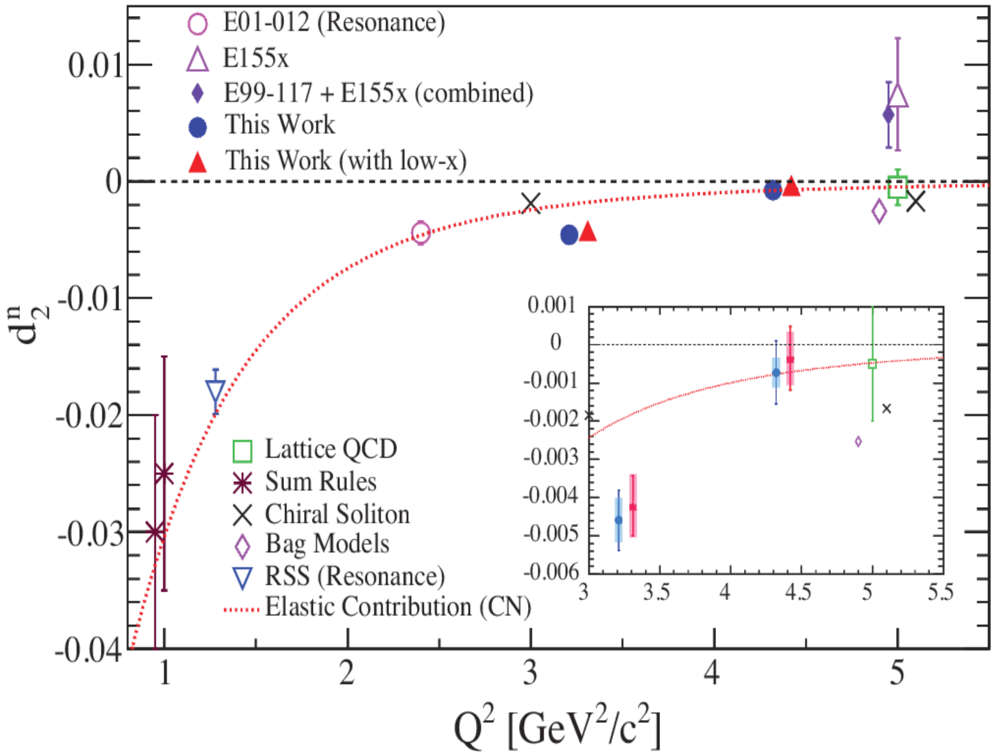


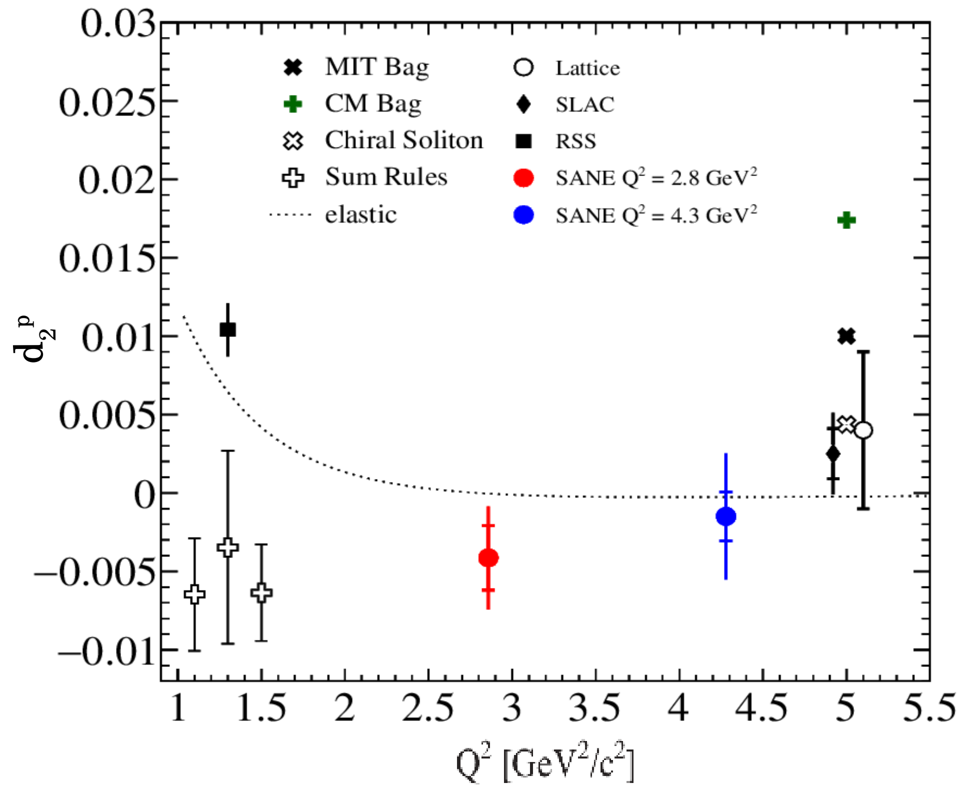
Example results from compass measurements (September 2020)

Existing results: d_2 for proton and neutron

Hint of a negative d_2^n, negative twist-3 at moderate $Q^2 \sim 3$ (GeV/c)^2 was noted in E06-014 at JLab.

Posik et al., 10.1103/PhysRevLett.113.022002 (d_2^n, color force extraction)
Flay et al., 10.1103/PhysRevD.94.05200 (Archival paper: g_1^n, g_2^n, d_2^n)
Parno, et al., 10.1016/j.physletb.2015.03.067 (A_1^n)





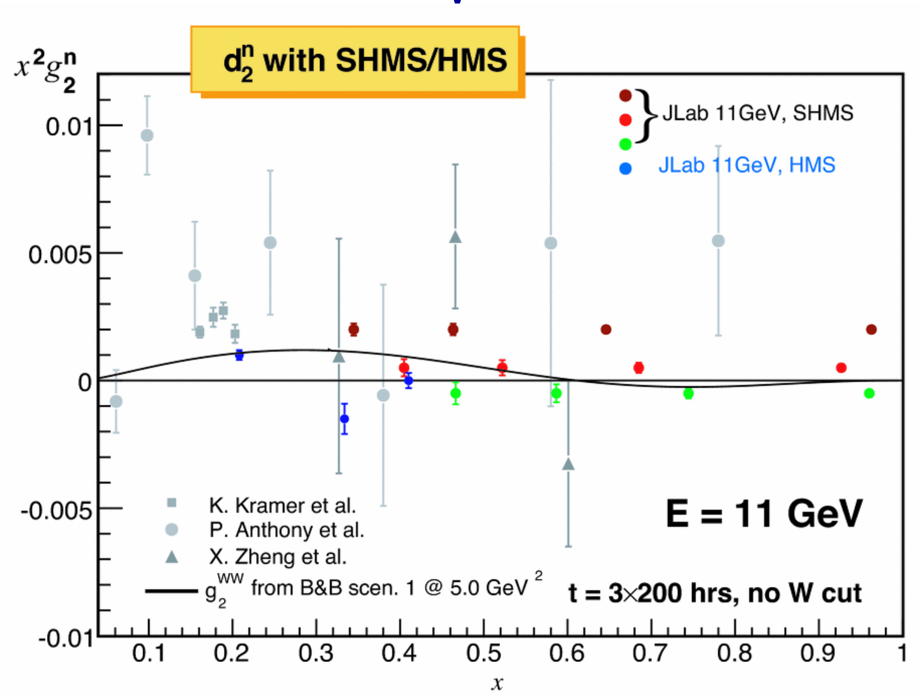
Similar hint of negative twist-3 (dips below CN elastic) in d_2^p data was noted in SANE experiment.

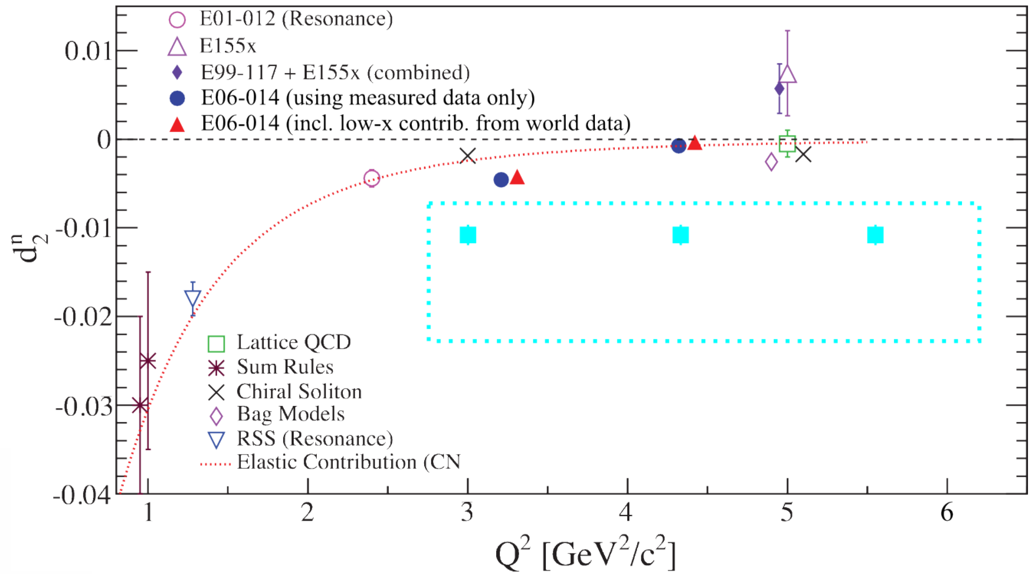
Armstrong et al., PRL 122, 022002 (2019)

E12-06-121: Projected Results

Projection of $x^2 g_2^n$ over broad range of x.

Points are vertically offset from zero along lines that reflect different (roughly) constant Q^2 values from 2.5Ð 6 GeV^2.





Projected results for d_2^n at truly constant Q^2 = 3, 4.3 and 5.6 GeV^2/c^2.

In this region,

- Models are thought to be accurate.
- Direct overlap with 6 GeV Hall A measurements.

Particle Identification (PID) Studies

We're measuring an asymmetry, so we need **clean electron** detection

The SHMS & HMS have two independent detectors for PID:

Combined Pion Rejection Factor = $PRF_{cherenkov} * PRF_{calorimeter}$

1. The **Gas Cherenkov**

$$Cherenkov\ Efficiency = \frac{electron\ sample\ that\ passed\ the\ Cherenkov\ cut}{electron\ sample\ selected\ with\ the\ Calorimeter}$$

$$Cherenkov\ PR\ Factor = \frac{pion\ sample\ selected\ with\ the\ Calorimeter}{pion\ sample\ that\ passed\ the\ Cherenkov\ cut}$$

→ e^-, π samples determined by the Calorimeter, Cherenkov used for PID

2. The Lead-Glass **Calorimeter**

$$Calorimeter\ Efficiency = \frac{electron\ sample\ that\ passed\ the\ Calorimeter\ (total\ \&\ preshower)\ cut}{electron\ sample\ selected\ with\ the\ Cherenkov}$$

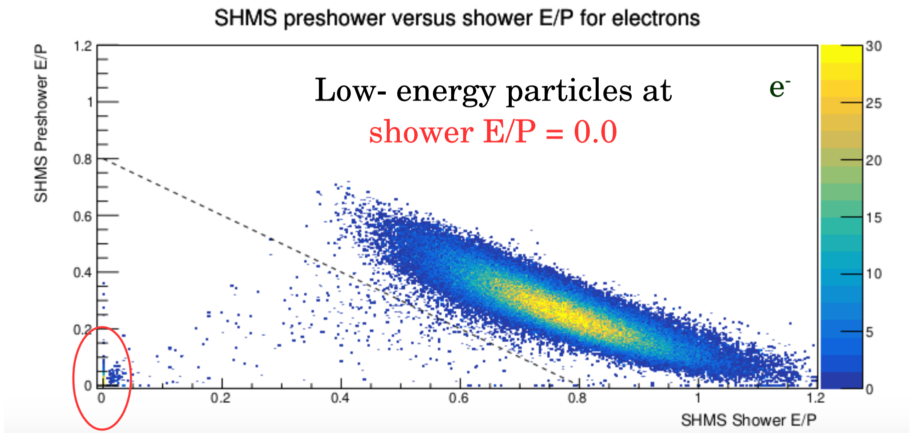
$$Calorimeter\ PR\ Factor = \frac{pion\ sample\ selected\ with\ the\ Cherenkov}{pion\ sample\ that\ passed\ the\ Calorimeter\ (total\ \&\ preshower)\ cut}$$

→ e^-, π samples determined by the Cherenkov, Calorimeter used for PID

PID: Calorimeter Efficiency & Pion Rejection

SHMS 11445
DIS, ^{3}He @ 90°
E_p= -5.6 GeV, 18°

Low-energy electrons are surviving the Cherenkov cut but not making the total calotimeter cut (dying in the pre-shower)



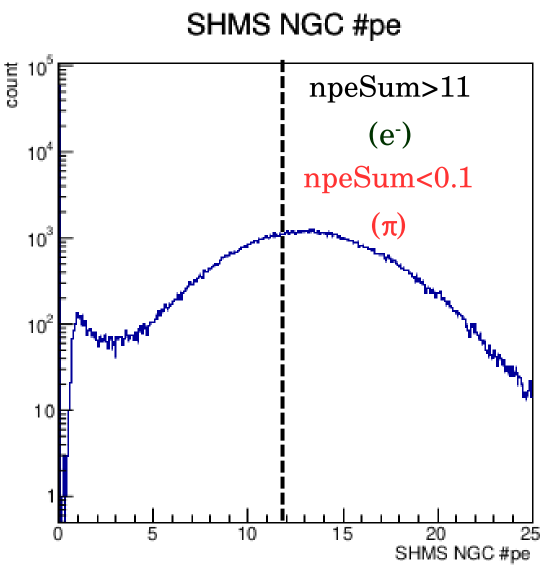
Calorimeter

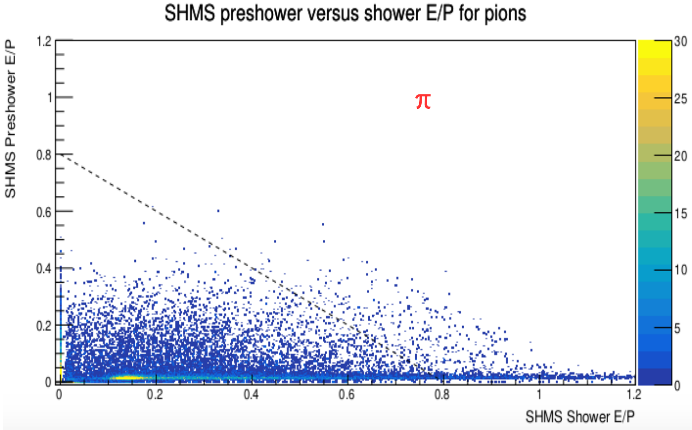
Step 1b

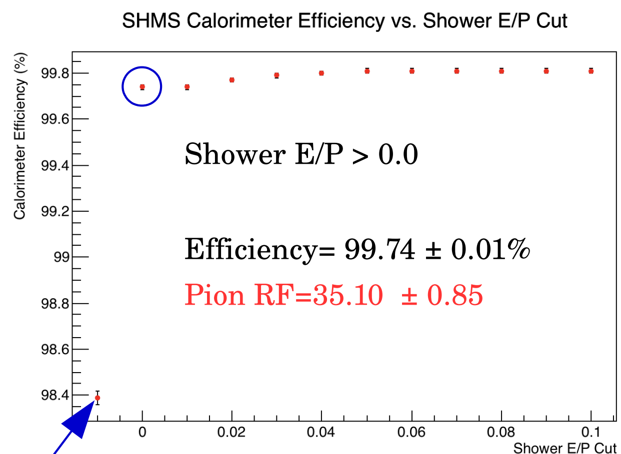
To ensure we are counting only good electrons, impose **a cut on the shower energy > 0.0**

Step 1a

Use the NGC npe sum cut to determine π and e⁻ samples.







No shower E/P cut

Slide Courtesy: M. Rehfuss

PID: Calorimeter Efficiency & Pion Rejection

SHMS 11445
DIS, ^{3}He @ 90°
E_p= -5.6 GeV, 18°

Calorimeter

Acceptance Cuts:
-10 < P.gtr.dp < 22
abs(P.gtr.ph) < 0.07
abs(P.gtr.th) < 0.05
abs(P.react.z) < 22

Sample Cuts:
NGC npeSum > 11
&& Shower E/P > 0 (e^-)
NGC npeSum < 0.1 (π)

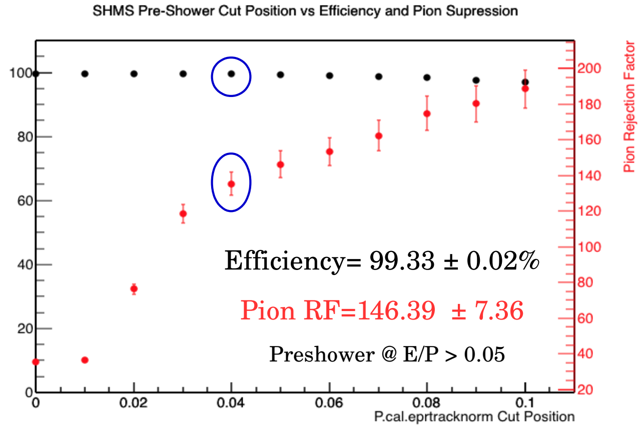
PID Cuts: Total E/P > 0.8

Step 2

Determine how many π and e^- pass the total E/P cut

Efficiency= 99.74 ± 0.01%
Pion RF=35.10 ± 0.85
@ Total E/P > 0.8

Add a preshower cut to the PID cut for a PRF boost

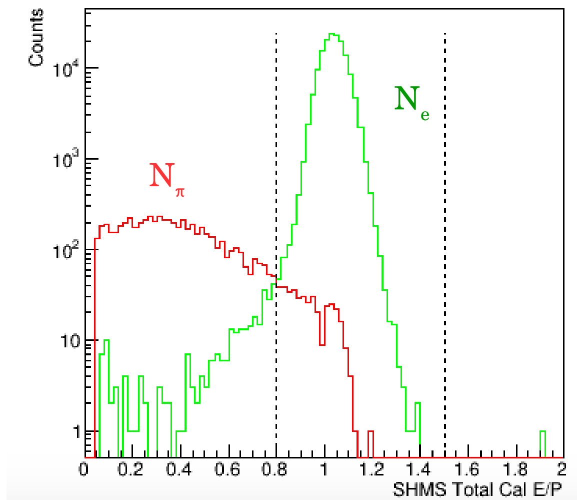


Pion Contamination with a Preshower Cut

Pion contamination= N_π / N_e

PID Cuts: Preshower E / P > 0.05

npeSum > 11 && shower E / P > 0
npeSum < 0.1



Spec	P_0 (GeV/c)	Cherenkov Cut	Cherenkv Efficiency	PRF	Calorimeter Cut	Calorimeter Efficiency	PRF	Combined Pion Cont.
SHMS	5.6	npe>2	99.82±0.01%	21.00±0.55	Total E/P > 0.8 Pre E/P > 0.05	99.33±0.03%	146.36±7.36	0.012%
SHMS	6.4	npe>2	99.80±0.01%	N/A	Total E/P > 0.8 Pre E/P > 0.05	99.33±0.02%	103.24±4.51	0.102%
SHMS	7.5	npe>2	99.73±0.01%	N/A	Total E/P > 0.8	99.29±0.01%	28.11±1.13	0.101%
HMS	4.0	npe>1	99.85±0.02%	36.27±0.20	Total E/P >0.8	99.11±0.02%	82.88±1.27	0.063%

PC from Calorimeter Only: 0.26%

Histogram is integrated over [0.80,1.50] to find percentage of pions in electron sample

(1/PRF) @ 2 npeSum cut from NGC study:
(1/21.00)

PC from Calorimeter + NGC: 0.01%

Slide Courtesy: M. Rehfuss

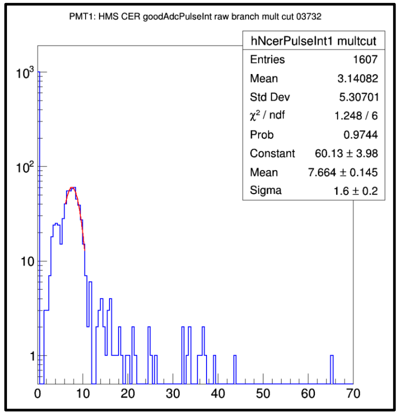
Detector Calibration: Cherenkov

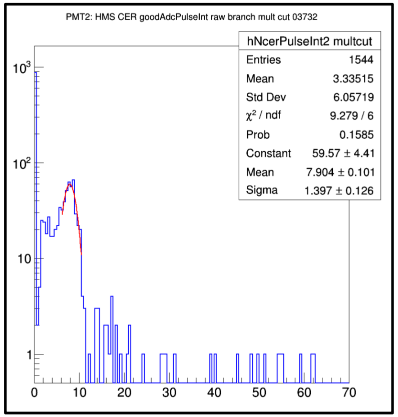
What is Cherenkov calibration?

How much charge (in pC) the PMT will output when one single photoelectron is extracted from the photocathode.

HMS Run 3732

Fit the clear single photo electron peak in goodAdcPulseInt (multiplicity==1) with Gaussian function





Calibration Constants:

- HMS: 1/μ

  1/7.664, 1/7.904

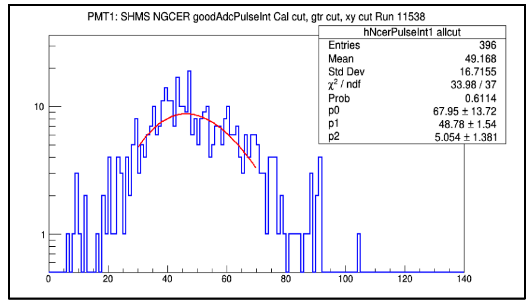
- SHMS: $1/p_2$

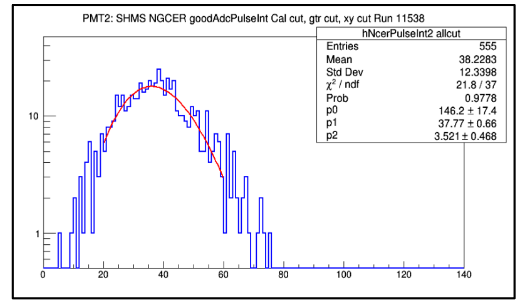
  1/5.054, 1/3.521, 1/4.419, 1/3.788

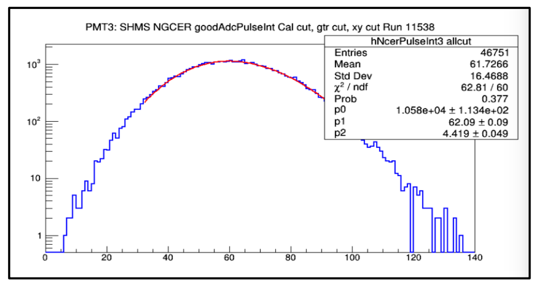
SHMS Run 11538

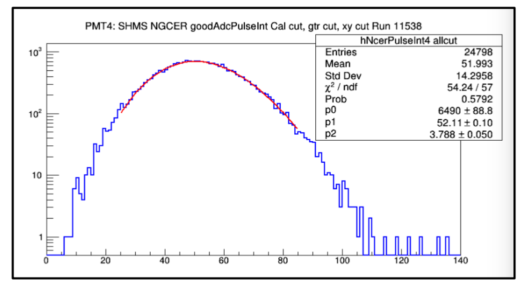
Fit goodAdcPulseInt (multiplicity==1) with: $p_0 \left(\frac{p_1}{p_2}\right)^{\frac{x}{p_2}} \frac{\exp\left(\frac{-p_1}{p_2}\right)}{Gamma\left(\frac{x}{p_2}+1\right)}$

$1/p_2$: Calibration constant









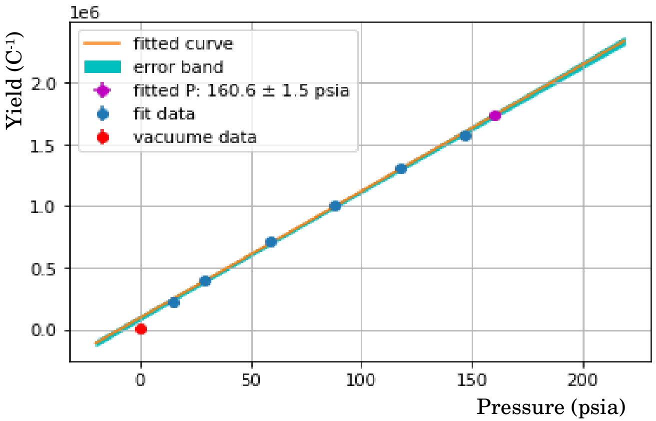
Cuts Used:

- -10< P.gtr.dp < 22 (Delta cut for SHMS)
- 0.8 < P.cal.etottracknorm < 1.4 to choose electrons
- X & Y cuts at the mirror planes.

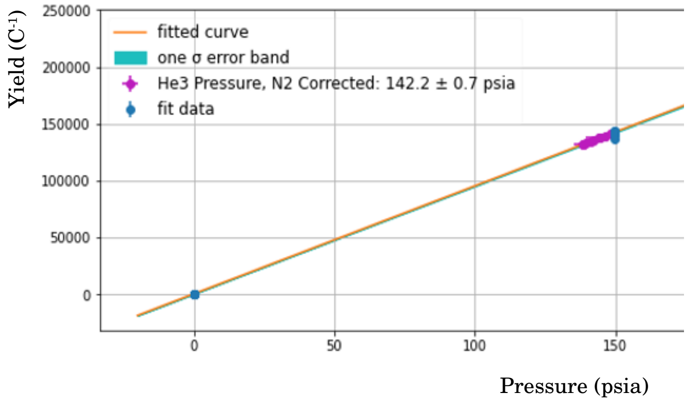
^{3}He Pressure Extraction

Slide Courtesy: J. Chen

Pressure Extraction using 1-Pass Runs



Pressure Extraction using DIS Runs



Method:

Using the yield-pressure curves of ^{3}He and N_2 reference cell runs to extract the ^{3}He pressure in polarized target cell.

Current Status:

- Got preliminary results for all production cells used in the A_1^n and d_2^n experiments.
- Still need to finalize systematic errors.

Pressure Extraction Results

Cell Name	Filling Density 3He/N2 (amagat)	PC/TC temperature in Production (°C)	PC/TC/TT Volume (cc)	TC He3/N2 Pressure in Production (psia)	1-Pass 12/2019 HMS: 11.7° -2.148 GeV/c (psia)	1-Pass 09/2020 SHMS: 8.5° -2.129 GeV/c (psia)	SHMS: 30° -2.6 GeV/c (psia)	SHMS: 30° -3.4 GeV/c (psia)	SHMS: 18° -5.6 GeV/c (psia)
Briana	6.938/0.1177	240/30	PC: 289.5 TC: 99.88 TT: 26.97	He3: 161.9 N2: 2.75	160.6 ± 1.5	NA	NA	NA	142.2 ± 0.7
Dutch	7.759/0.1102	240/30	PC: 297.15 TC:111.87 TT: 32.52	He3: 179.3 N2: 2.55	NA	NA	NA	191.1 ± 2.0	NA
Big Brother	7.093/0.1120	240/30	PC: 293.82 TC: 100.76 TT: 32.6	He3: 165.5 N2: 2.59	NA	NA	174.1 ± 1.0	178.5 ± 1.6	NA
Tommy	7.76/0.13	240/30	PC: 284 TC: 110 TT: 33	He3: 178.8 N2: 3.0	NA	170.0 ±1.0	NA	NA	157.0 ± 0.6

E12-06-121: Rate estimates

HMS Kin.	theta (deg)	E' (GeV)	Q^2 (GeV^2)	x	W (GeV)	e^- rate (Hz)	π^- rate (Hz)	$t_\parallel$ (Hz)	$t_\perp$ (Hz)	ΔA_{raw} (par) (10^{-4})	ΔA_{raw} (perp) (10^{-4})
A	13.5	4.2	2.474	0.216	3.14	3083	2973	8.06	116.9	2.71	0.7
B	16.4	4.2	3.643	0.318	2.948	179	100.3	9.6	115.4	4.48	1.297
C	20	4	5.018	0.418	2.806	39	13.9	11.2	113.8	8.91	2.8

SHMS Kin.	theta (deg)	E' (GeV)	Q^2 (GeV^2)	x	W (GeV)	e^- rate (Hz)	π^- rate (Hz)	$t_\parallel$ (Hz)	$t_\perp$ (Hz)	ΔA_{raw} (par) (10^{-4})	ΔA_{raw} (perp) (10^{-4})
X	11	7.5	2.866	0.527	1.859	3153	5.29	9.6	115.4	2.51	0.723
Y	14.5	6.4	4.24	0.565	2.036	528.2	5.62	11.38	113.6	5.63	1.78
Z	18	5.6	5.701	0.633	2.046	80.82	1.06	12.85	112.1	13.5	4.58

- The tables have a first estimate of the expected rates and error in raw asymmetries for the different kinematics (B. Sawatzky, W. Korsch).

Input parameters and assumptions →

E [GeV]	l_{tgt} [cm]	ρ_{tgt} (fill) [amg]	ρ_{tgt} (T-corr.) [amg]	P_{tgt}	P_{beam}	I [μA	Be [mil]	GE180 [μm]	A_{charge} [ppm]
10.4	40	8.26	10.56	0.50	0.80	30	10	280	200

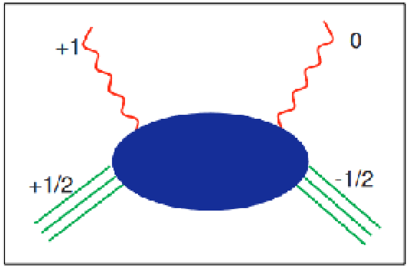
Assumptions:

- SHMS
  - SHMS acceptance: 50 cm, -15%, $+25\%$ (relative to p_0)
  - N_2 density of 1.4×10^{19} cm^{-3}
  - $\Delta P_{tgt} = 0$
  - $\Delta P_{beam} = 0$
  - $\Delta A_{charge} = 0$
- HMS
  - HMS acceptance: 10 cm, -10%, $+10\%$ (relative to p_0)
  - N_2 density of 1.4×10^{19} cm^{-3}
  - $\Delta P_{tgt} = 0$
  - $\Delta P_{beam} = 0$
  - $\Delta A_{charge} = 0$

Twist Expansion

- Quark electromagnetic current in forward Compton amplitude,

$$T_{\mu\nu} = i \int d^4z\, e^{iqz} < N \left| T\left(j_\mu(z) j_\mu(0)\right) \right| N >$$



- Operator product expansion (OPE) : $j_\mu(z) j_\mu(0) = \sum C_{\mu_1 \dots \mu_n} \mathcal{O}_{d,n}^{\mu_1 \dots \mu_n}$

$\mathcal{O}_{d,n}^{\mu_1 \dots \mu_n}$: Local quark gluon operators with mass dimension d and spin dimension n

- Dimension Analysis : $C_{\mu_1 \dots \mu_n} \mathcal{O}_{d,n}^{\mu_1 \dots \mu_n} \longrightarrow \frac{q_{\mu_1}}{Q} \dots \frac{q_{\mu_n}}{Q} Q^{2-d} M^{d-n-2} p^{\mu_1} \dots p^{\mu_n}$

$$\rightarrow \frac{P.q}{Q^n} Q^{2-d} M^{d-n-2}$$

$$\rightarrow \left(\frac{1}{x}\right)^n \left(\frac{Q}{M}\right)^{2+n-d}$$

$$\rightarrow \left(\frac{1}{x}\right)^n \left(\frac{Q}{M}\right)^{2-t}$$

	Quark	Gluon
d	3/2	2
n	1/2	1
t	1	1

Twist, t = d-n

Spectrometer Acceptance Study

***Ongoing work**

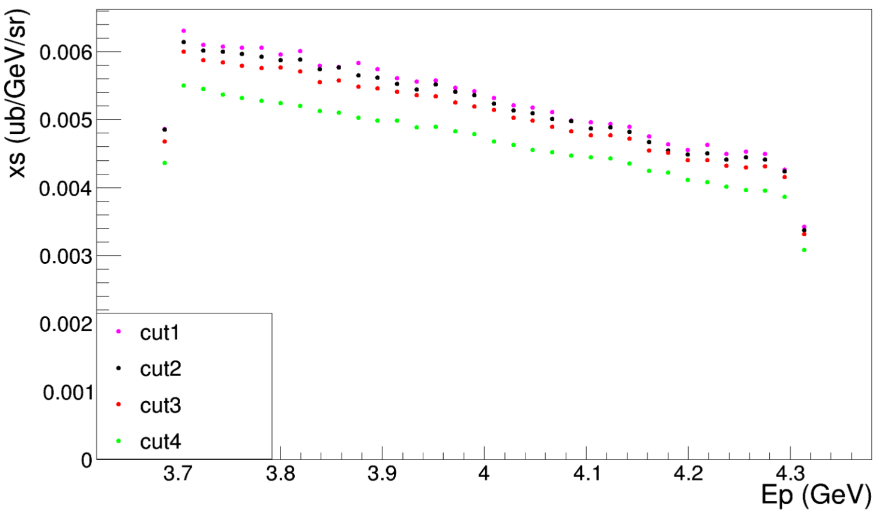
- Simulated yield is generated using cross section model F1F2IN09.
- **Cross section is extracted from the simulated yield** for the **different sets of acceptance cuts** to check the uncertainty in acceptance extraction.

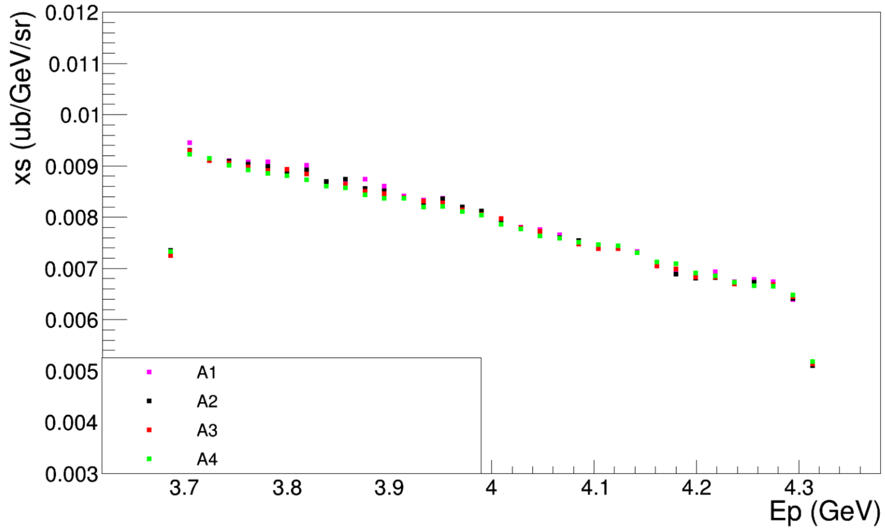
HMS Kin-C
20 deg, -4.0 GeV/c

Theta-Phi cuts	Acceptance
Cut1: theta<38.0 && theta>-33.0 && phi<10.0 && phi>-10.0	A1: 0.739502
Cut2: theta<43.0 && theta>-40.0 && phi<14.0 && phi>-14.0	A2: 0.723254
Cut3: theta<46.0 && theta>-44.0 && phi<19.0 && phi>-19.0	A3: 0.696565
Cut4: theta<57.0 && theta>-57.0 && phi<26.0 && phi>-26.0	A4: 0.634232

Uncorrected: $$\frac{d^2\sigma}{dE'd\Omega} = \frac{Yield*e}{\rho_{He3}*length_{target}*\Delta E'*\Delta\Omega}$$

Acceptance corrected: $$\frac{d^2\sigma}{dE'd\Omega} = \frac{Yield*e}{A*\rho_{He3}*length_{target}*\Delta E'*\Delta\Omega}$$





Systematic Error Table

Item description	Subitem description	Relative uncertainty
Target polarization		1.5 %
Beam polarization		3 %
Asymmetry (raw)		
	• Target spin direction (0.1°)	$< 5 \times 10^{-4}$
	• Beam charge asymmetry	$<$ 50 ppm
Cross section (raw)		
	• PID efficiency	$<$ 1 %
	• Background Rejection efficiency	$\approx$ 1 %
	• Beam charge	$<$ 1 %
	• Beam position	$<$ 1 %
	• Acceptance cut	2-3 %
	• Target density	$<$ 2%
	• Nitrogen dilution	$<$ 1%
	• Dead time	$<$ 1%
	• Finite Acceptance cut	$<$ 1%
Radiative corrections		$\leq$ 5 %
From ^{3}He to Neutron correction		5 %
Total systematic uncertainty (for both $g_2^n(x,Q^2)$ and $d_2(Q^2)$)		$\leq$ 10 %
Estimate of contributions to d_2 from unmeasured region	$\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$	4.8×10^{-4}
Projected absolute statistical uncertainty on d_2		$\Delta d_2 \approx 5 \times 10^{-4}$
Projected absolute systematic uncertainty on d_2 (*assuming* $d_2 = 5 \times 10^{-3}$)		$\Delta d_2 \approx 5 \times 10^{-4}$

Neutron Asymmetries from ³He

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

- $A_2^n = \frac{1}{P_n} \frac{F_2^{3He}}{F_2^n \left(1+\frac{0.056}{P_n}\right)} \left(A_2^{3He} - 2P_p \left(1 - \frac{0.014}{2P_p}\right) \frac{F_2^p}{F_2^{3He}} A_2^p \right)$

- $\frac{g_1^n}{F_1^n} = \frac{1}{P_n} \frac{F_2^{3He}}{F_2^n \left(1+\frac{0.056}{P_n}\right)} \left(\frac{g_1^{3He}}{F_1^{3He}} - 2P_p \left(1 - \frac{0.014}{2P_p}\right) \frac{F_2^p}{F_2^{3He}} \frac{g_1^p}{F_1^p} \right)$

- $\frac{g_2^n}{F_1^n} = \frac{1}{P_n} \frac{F_2^{3He}}{F_2^n \left(1+\frac{0.056}{P_n}\right)} \left(\frac{g_2^{3He}}{F_1^{3He}} - 2P_p \left(1 - \frac{0.014}{2P_p}\right) \frac{F_2^p}{F_2^{3He}} \frac{g_2^p}{F_1^p} \right)$

P_p, P_n : Effective proton and neutron polarizations in ^{3}He