d_2^n:PROBING QUARK-GLUON CORRELATIONS IN THE NEUTRON

On Behalf of d_2^n Collaboration
Junhao Chen
The College of William & Mary

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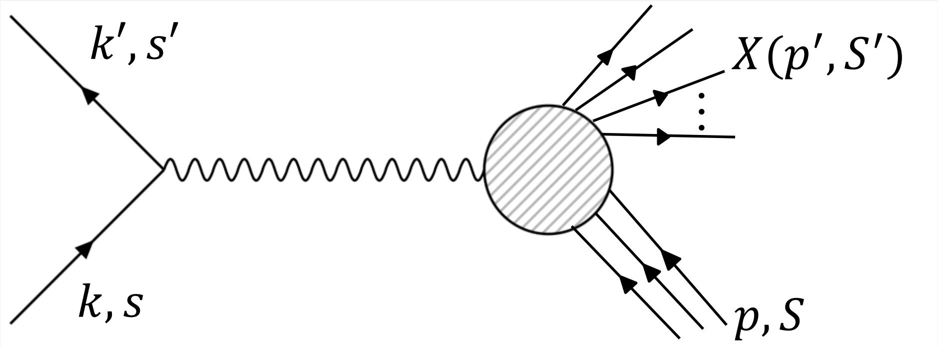
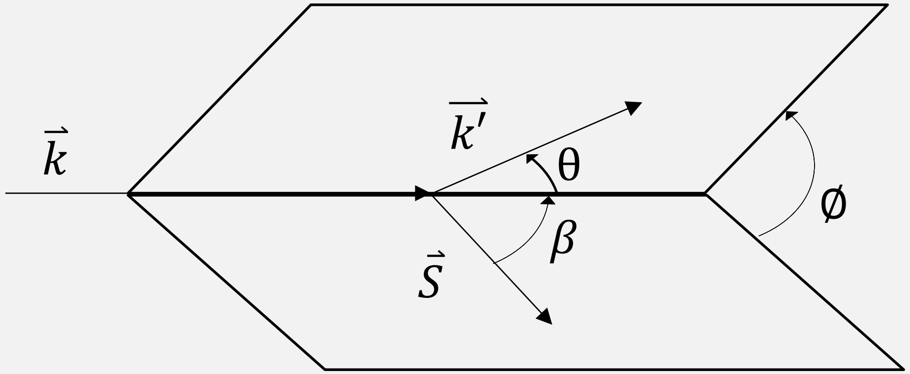
POLARIZED STRUCTURE FUNCTION





Target Spin Longitudinal to Electron Spin

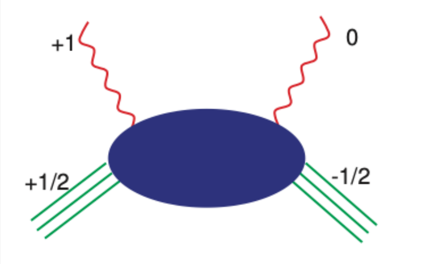
$$\frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} = \frac{4\,\alpha^2 E'}{Q^2 E}\left[\frac{(E + E'\cos\theta)}{M\nu} g_1(x,Q^2) - \frac{Q^2}{M\nu^2} g_2(x,Q^2)\right]$$

Target Spin Transverse to Electron Spin

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

g_2 AND QUARK-GLUON CORRELATION

- g_2 could not be understood through simple quark gluon model, but rather be interpreted as a higher twist structure function
- g_2 is the imaginary part of the spin-dependent Compton amplitude for the process



$$\gamma^*(+1)+N(+1/2)\rightarrow\gamma^*(0)+N(-1/2)$$

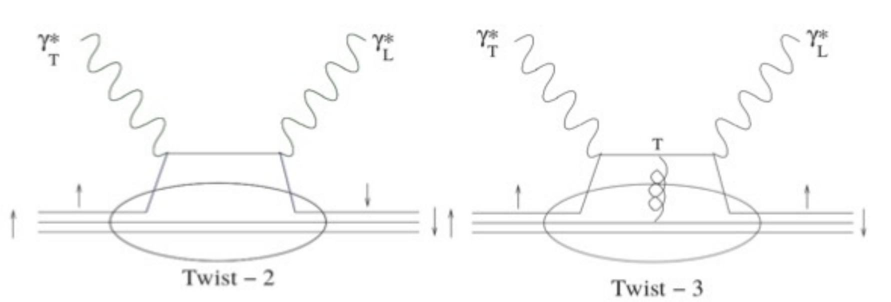
$$\overline{g_2}(x,Q^2) = -\int_x^1 \frac{dy}{y}\frac{d}{dy}\left[\frac{m}{M}h_T(y,Q^2)+\xi(y,Q^2)\right]$$

(Cortes, Pire & Ralston)

$h_T(x,Q^2)$: transverse polarization density function (Transversity)

ξ: twist-3 term from quark-gluon correlations

Helicity exchange occur in two ways



$\gamma^*(+1)+N(1/2)\rightarrow\gamma^*(0)+N(-1/2)$

Plot reproduced by Murchhana Roy

$$g_2 = g_2^{WW}(x,Q^2)+\overline{g_2}$$

- A direct probe of the quark-gluon correlation

Twist 2 Wandzura - Wilczek term

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

WHAT IS d_2

d_2: second moment in x of a linear combination of g_1 and g_2

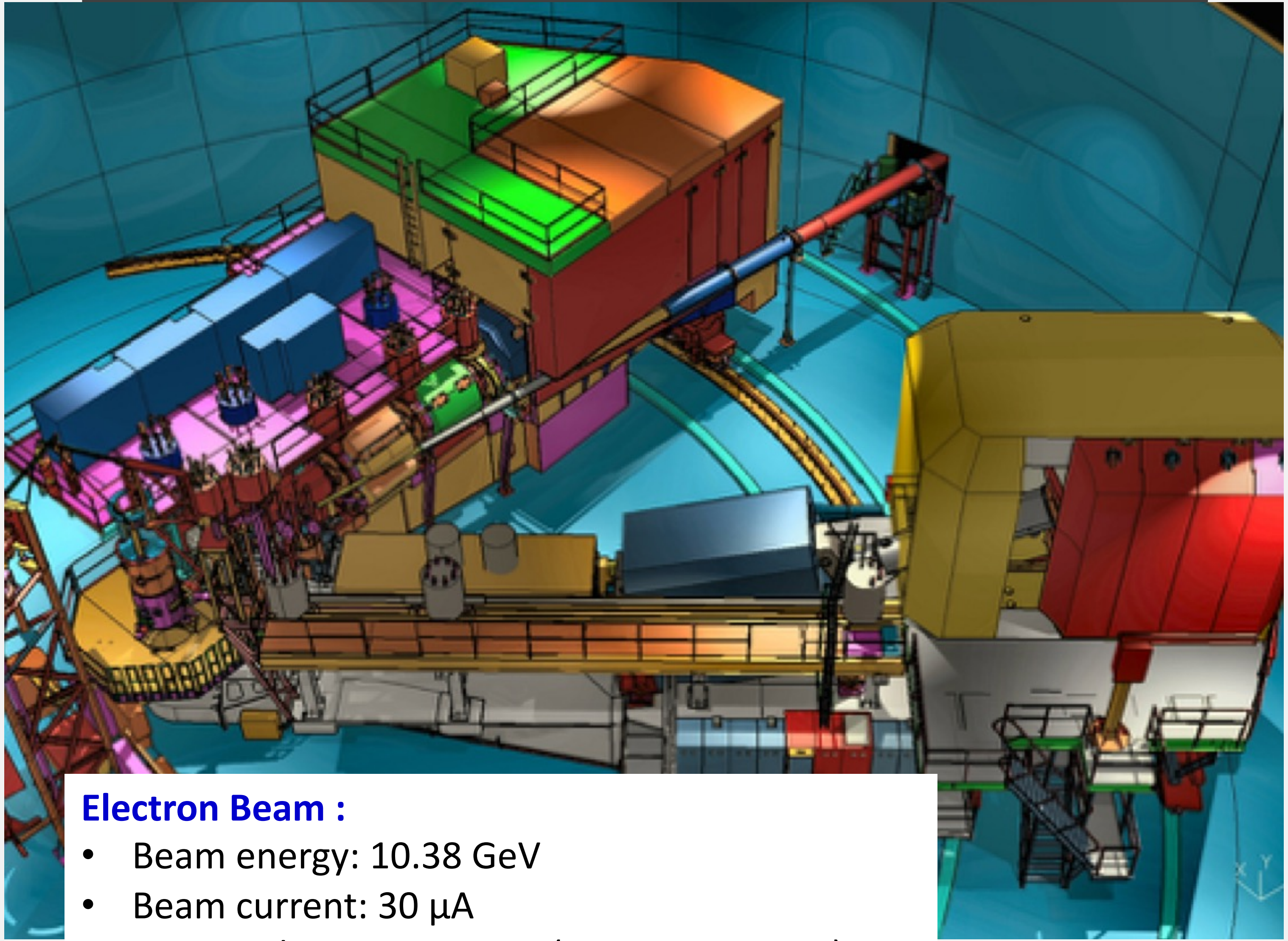
$$d_2(Q^2) = \int_0^1 x^2\,[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$
$$= 3\int_0^1 x^2\,[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$
$$= 3\int_0^1 x^2\,\overline{g_2}(x,Q^2)\,dx$$

- Clean probe to higher twist effects
- Been thoroughly studied in Lattice QCD
- Reflects the response of color electric and magnetic fields to the polarization of the nucleon

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

f_2: twist-4 reduced matrix element which contains non-trivial quark-gluon interactions

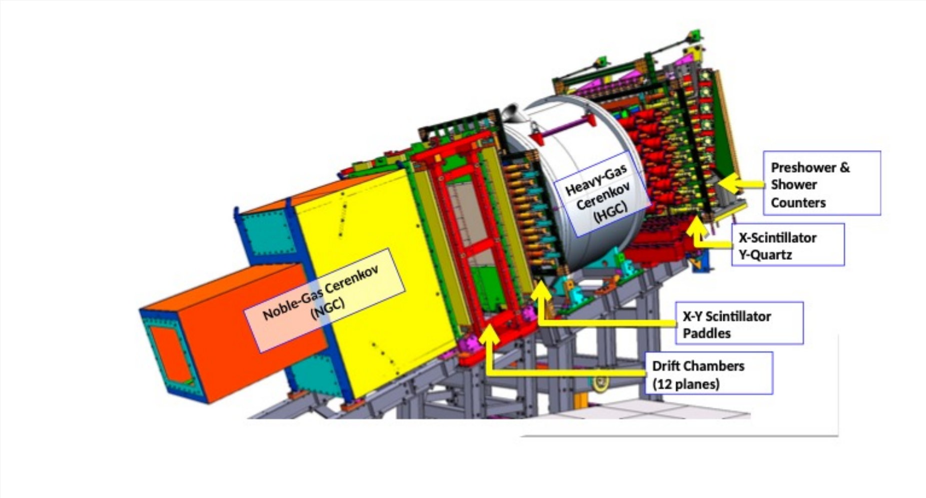
HALL C SETUP



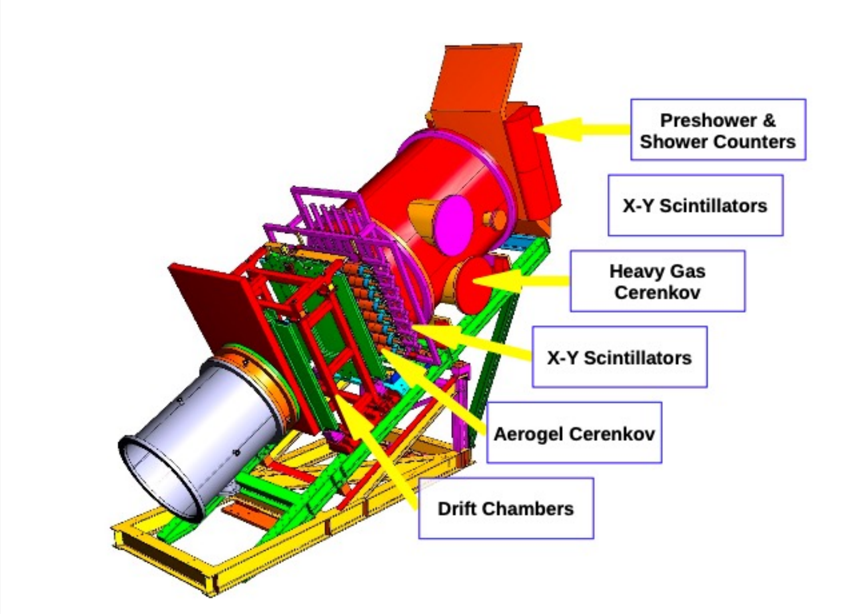
Electron Beam :

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

SHMS Detectors

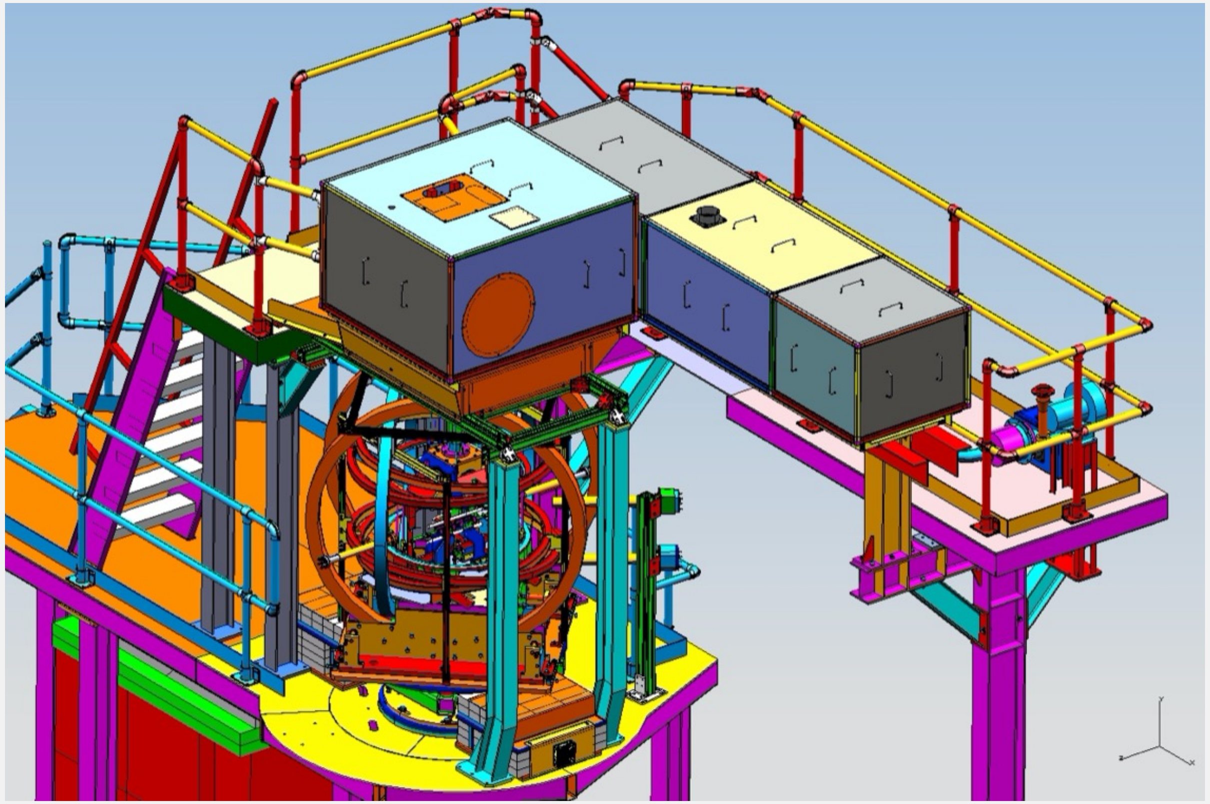


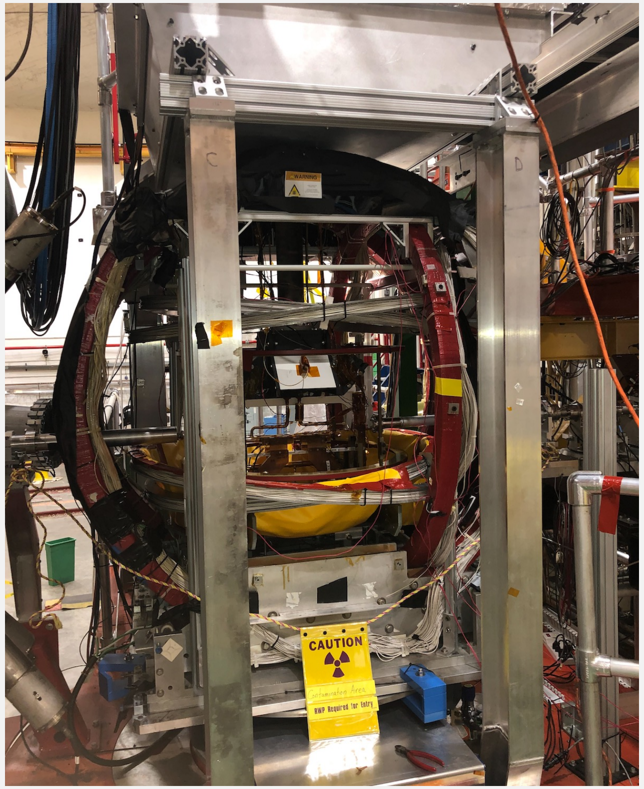
HMS Detectors

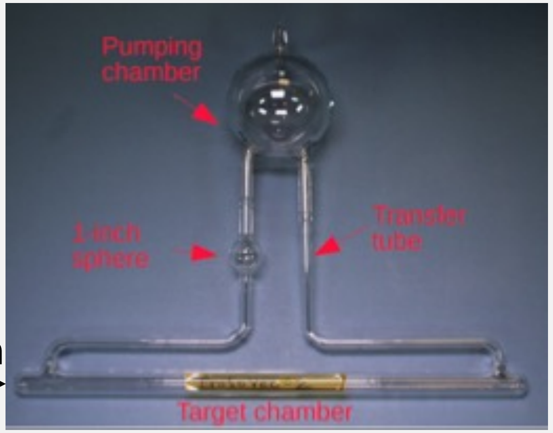


Used for the first time for extended target (40cm)

TARGET







e beam

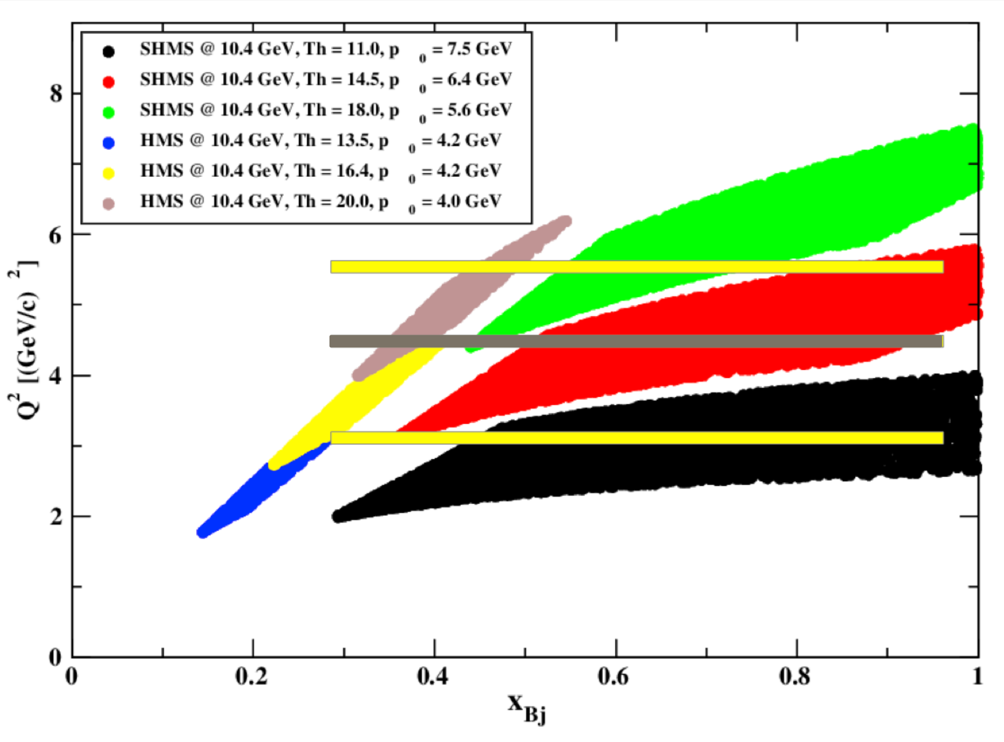
40 cm

- Polarized ^{3}He target:

  Target polarization: 45% to 50% (~5% uncertainty).

  About 10 atm ^{3}He in beam.
- reference target : N_2, H_2, un-porlarized ^{3}He.

EXPERIMENT COVERAGE



SHMS Production					
Setting	P_0 (GeV)	Angle (°)	x	Q^2 (GeV^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

HMS Production					
Setting	P_0 (GeV)	Angle (°)	x	Q^2 (GeV^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

- 25% reduction in coverage relative to Proposal to accommodate Accelerator schedule. Accelerator performance difficulties during run limited final data collected to:
    - Completed: Kin A, C, X, Z
    - Partial: Kin Y, B
-

EXTRACTING g_1, g_2, d_2

Extract g_1, g_2, d_2 through measured unpolarized cross section(σ_0) and asymmetries($A_\parallel, A_\perp$)

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

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

$$d_2 = \int_0^1 \frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0\left[\left(3\frac{1+(1-y)\cos\theta}{(1-y)\sin\theta} + \frac{4}{y}\tan\frac{\theta}{2}\right)A_\perp + A_\parallel\left(\frac{4}{y}-3\right)\right]dx$$

$$A_{\parallel\perp} = \frac{1}{P_t P_b D_{N_2}}\frac{1}{(\cos\emptyset)}\frac{N^{\downarrow\Uparrow(\Rightarrow)} - N^{\uparrow\Uparrow(\Rightarrow)}}{N^{\downarrow\Uparrow(\Rightarrow)} + N^{\uparrow\Uparrow(\Rightarrow)}}$$

P_t: target polarization

P_b: beam polarization

D_{N_2}: N_2 Dilution

$N^{\downarrow\Uparrow(\Rightarrow)}$: count when target polarization is longitudinal(transverse to election polarization)

$$\sigma_{raw}(E',\theta) = \frac{\text{Yield}_{cor}(E',\theta)}{L * A * \Delta\Omega * \Delta E'}$$

L = η_{tar} * l_{tar} * Q_{tot} / |e| (integrated luminosity)

ΔΩ= solid angle generated per (E',θ) bin

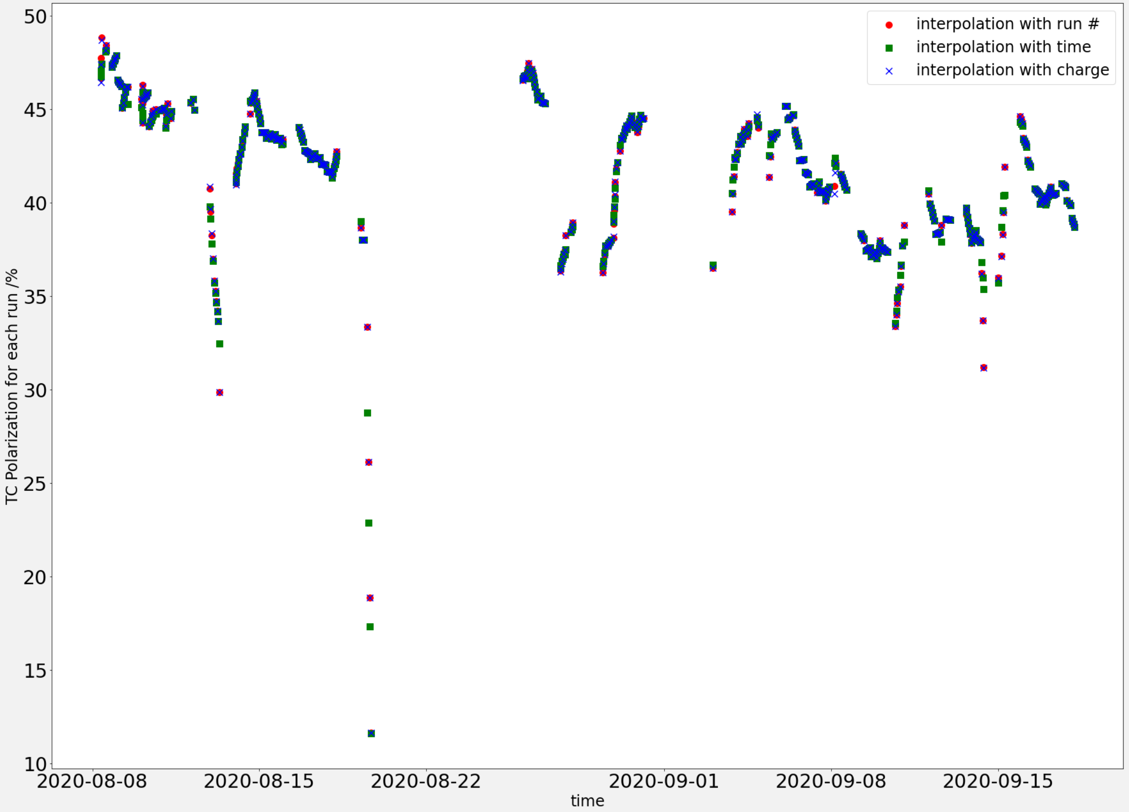
ΔE'= momentum acceptance per (E',θ) bin

A(E',θ) = $N_{detected}$(E',θ)/N_{thrown}(E',θ) (**section 7.4.7)**

Credit to Murchhana Roy

TARGET POLARIZATION

Target polarization for each run



Polarimetry Uncertainties

Uncertainty contributors	Uncertainty
Density Model	0.9%
$\kappa_{^{39}K}$ Parameterization	0.9%
$\sigma(\kappa(T_{pc})n_{pc}(T_{tc},T_{pc}))$ due to Pumping Chamber Temperature	0.3%/5℃
Target Chamber Temperature	0.7%/5℃
V_{pc}, V_{tc}, V_{tt} (uncorrelated)	$\frac{0.13\%}{\%}, \frac{0.10\%}{\%}, \frac{0.02\%}{\%}$
n^{3He}	Undetermined expecting to be 5%

Less than 3% (combined)

BEAM POLARIZATION

DIRECTION OF BEAM POLARIZATION FOR H+ state

Period	Double WIEN	IHWP IN	IHWP OUT	| Beam Polarization | (+/- ~2.5 %)
1 pass Dec 2019	FLIP RIGHT	UPSTREAM	DOWNSTREAM	84.5%
5 pass before Feb 17th, 2020	FLIP RIGHT	DOWNSTREAM	UPSTREAM	85.4%
5 pass Feb17th to MEDCON6	FLIP LEFT	UPSTREAM	DOWNSTREAM	85.4%
5 pass D2n	FLIP RIGHT	DOWNSTREAM	UPSTREAM	85.6%
1 pass (end of run)	FLIP RIGHT	UPSTREAM	DOWNSTREAM	81.7%

Credit to William Henry

NITROGEN DILUTION

$$D_{N_2} = 1 - \frac{\Sigma_{N_2}(N_2)}{\Sigma_{total}(^3He)} \frac{t_{ps}(N_2)}{t_{ps}(^3He)} \frac{Q(^3He)}{Q(N_2)} \frac{t_{LT}(^3He)}{t_{LT}(N_2)} \frac{n_{N_2}(^3He)}{n_{N_2}(N_2)},$$

$$= \frac{Yield_{N_2}(N_2)}{Yield_{Total}(^3He)} \times \frac{n_{N_2}(^3He)}{n_{N_2}(N_2)}$$

- $Yield_{N_2} = \frac{\Sigma\, t_{ps}}{Q\, t_{LT}}$
- (N2 or 3He): N2 target or Pol-3He target
- $_{\text{N2 or 3He}}$: gas in target
- Σ: good events from root file
- t_{ps}: pre-scaler factor
- t_{LT}: live time
- n: density

~9% for d_2^n targets

PHYSICS ASYMMETRY

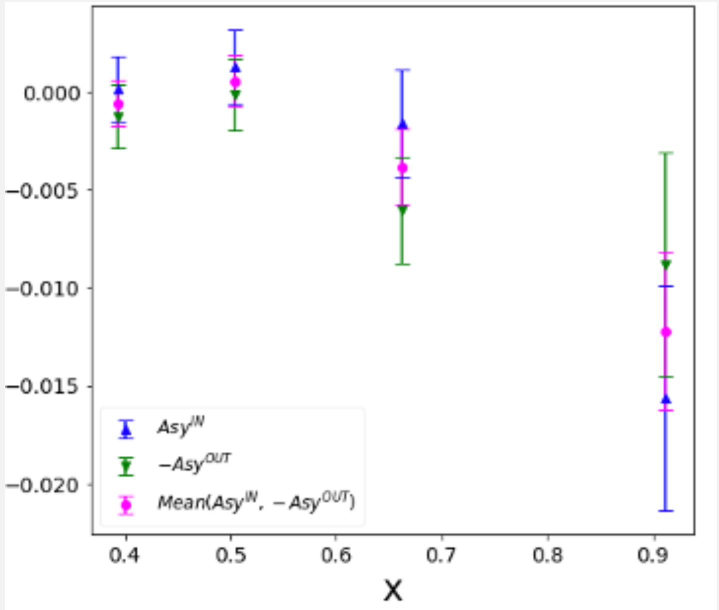
$$A_{phys} = \frac{\frac{N^+}{Q^+CLT^+} - \frac{N^-}{Q^-CLT^-}}{\frac{N^+}{Q^+CLT^+} + \frac{N^-}{Q^-CLT^-}} / (D_{N_2} P_t P_b)$$

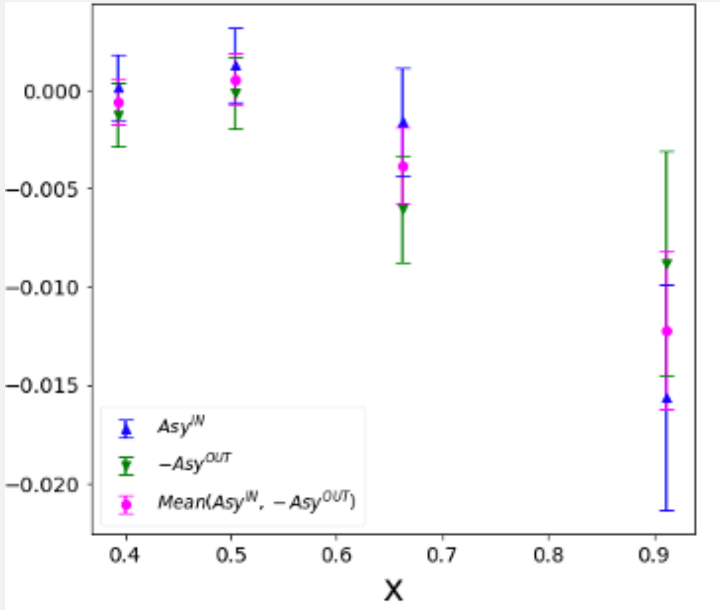
D_{N_2}: Nitrogen dilution factor

P_b: Beam polarization

P_t: Target polarization

$\bar{A}_{phys}$: Averaged physics asymmetry with same run condition





Raw Cross-section Extraction: (Section 7.5)

$$\sigma_{raw}(E',\theta) = \frac{\text{Yield}_{cor}(E',\theta)}{\text{L} * \text{A} * \Delta\Omega * \Delta\text{E}'}$$

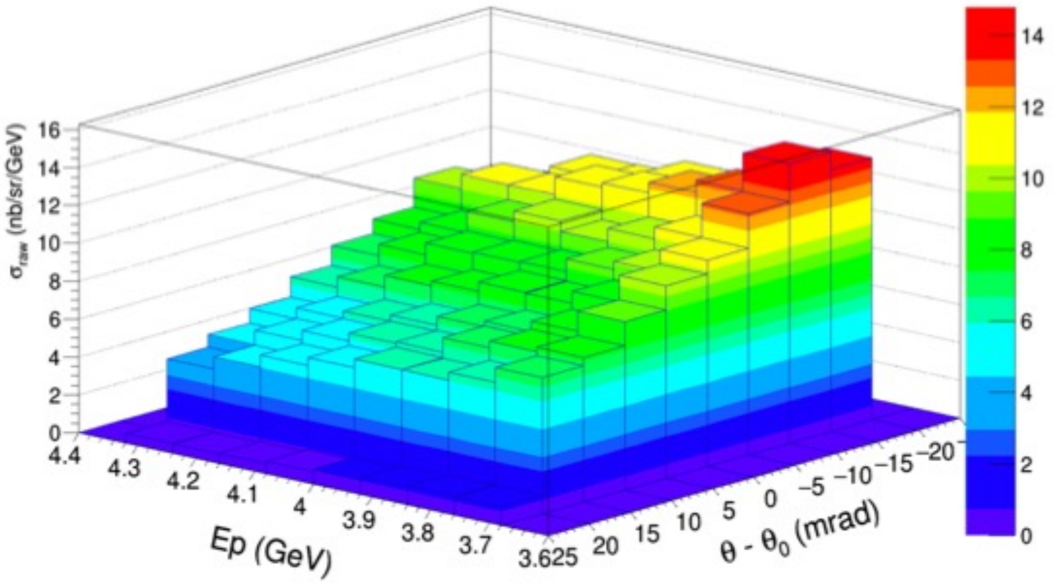
$$\text{Yield}_{cor}(E',\theta) = \frac{\text{Yield}(E',\theta)}{\varepsilon_{cal} * \varepsilon_{cheren} * \varepsilon_{tr} * \varepsilon_{trig} * livetime}$$

$L = \eta_{tar} * l_{tar} * Q_{tot} / |e|$ (integrated luminosity)

ΔΩ= solid angle generated per (E',θ) bin

ΔE'= momentum acceptance per (E',θ) bin

$A(E',\theta) = N_{detected}(E',\theta)/N_{thrown}(E',\theta)$ (section 7.4.7)



HMS Kin-C (20°, -4.0 GeV/c)

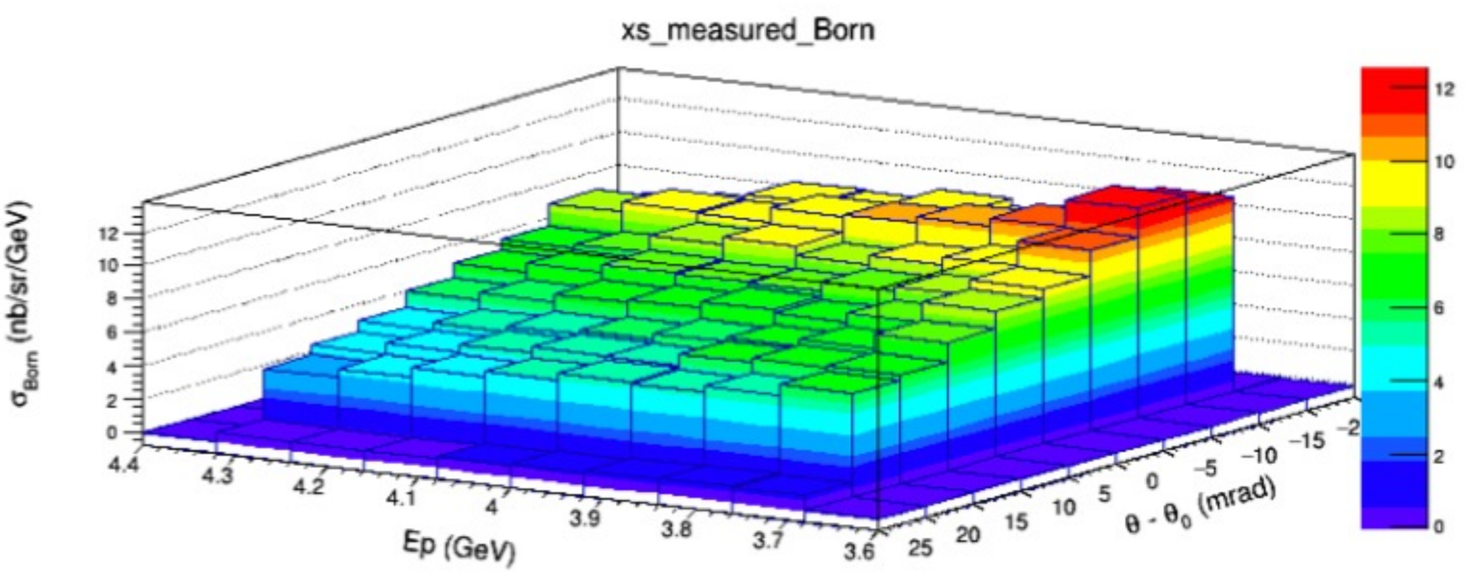
Cuts used:

- -9<z<9 (cm)
- -8<δ<8 (%)
- -0.04<xp<0.04 (rad)
- -0.02<yp<0.02 (rad)
- PID Cuts: 0.2<E/P<2 (calorimeter), npe>1 (Cherenkov)

Slide by Murchhana Roy
mroy@jlab.org

Cross-section Extraction: Radiative Correction

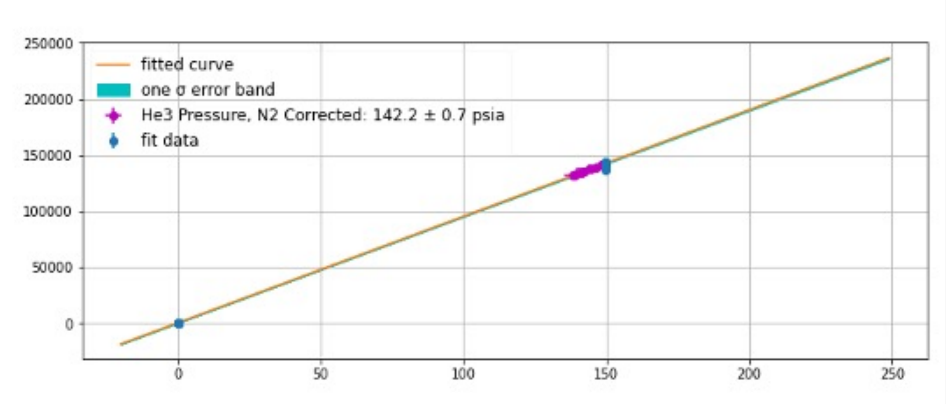
$$\sigma_{\text{Born}} = \left(\sigma_{rad} - \sigma_{rad}^{elastic,\,model} - \sigma_{rad}^{quasielastic,\,model}\right) * \frac{\sigma_{\text{Born}}^{model}}{\sigma_{rad}^{inelastic,\,model}}$$

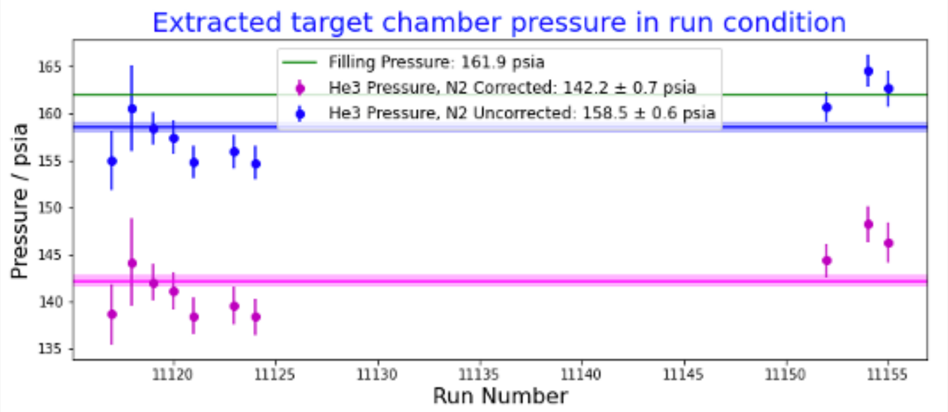


Slide by Murchhana Roy
mroy@jlab.org

^3He DENSITY EXTRACTION: PRESSURE CURVE

	Filling Density 3He/N2(amagat)	PC/TC temperature in Production (℃)	PC/TC/TT Volume (cc)	TC He3/N2 Pressure in Production (psia)	One Pass 12/2019 HMS: 11.7° -2.148 GeV/c (pisa)	One Pass 09/2020 SHMS: 8.5° -2.129 GeV/c (pisa)	SHMS: 30° -2.6 GeV/c (pisa)	SHMS: 30° -3.4 GeV/c (pisa)	SHMS: 18° -5.6 GeV/c (pisa)	SHMS: 11° -7.5 GeV/c (pisa)
Briana	6.938/0.1177	240/30	PC: 289.5 TC: 99.88 TT: 26.97	He3: 161.9 N2: 2.75	160.6 ± 1.5 164.5 ± 1.5	NA	NA	NA	142.2 ± 0.7 158.5 ± 0.6	
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 ± 2.0 209.4 ± 2.1	NA	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 ± 1.0 192.0 ± 1.0	178.5 ± 1.6 196.7 ± 1.7	NA	NA
Austin	7.498/0.1145	240/30	PC: 305.9 TC: 106.5 TT: 37.92	He3: 174.6 N2: 2.70	NA	NA	NA	NA	NA	
Tommy	7.76/0.13	240/30	PC: 284 TC: 110 TT: 33	He3: 178.8 N2: 3.0	NA	170.0 ± 184.1 ±	NA	NA	157.0 ± 0.6 173.3 ± 0.5	



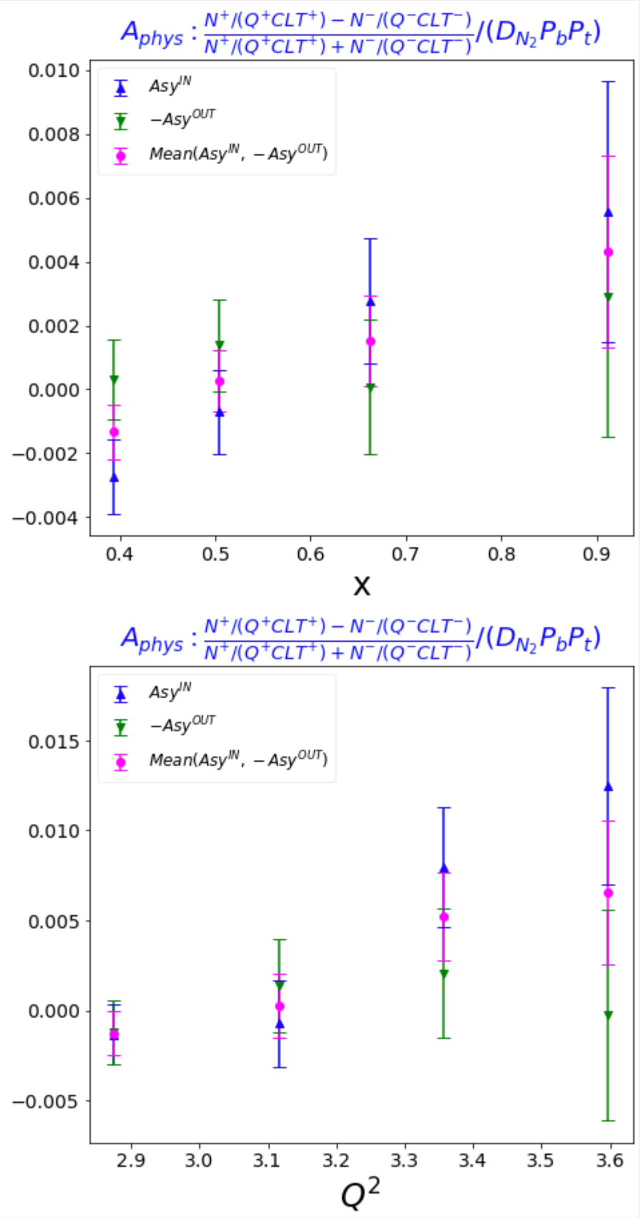


SUMMARY

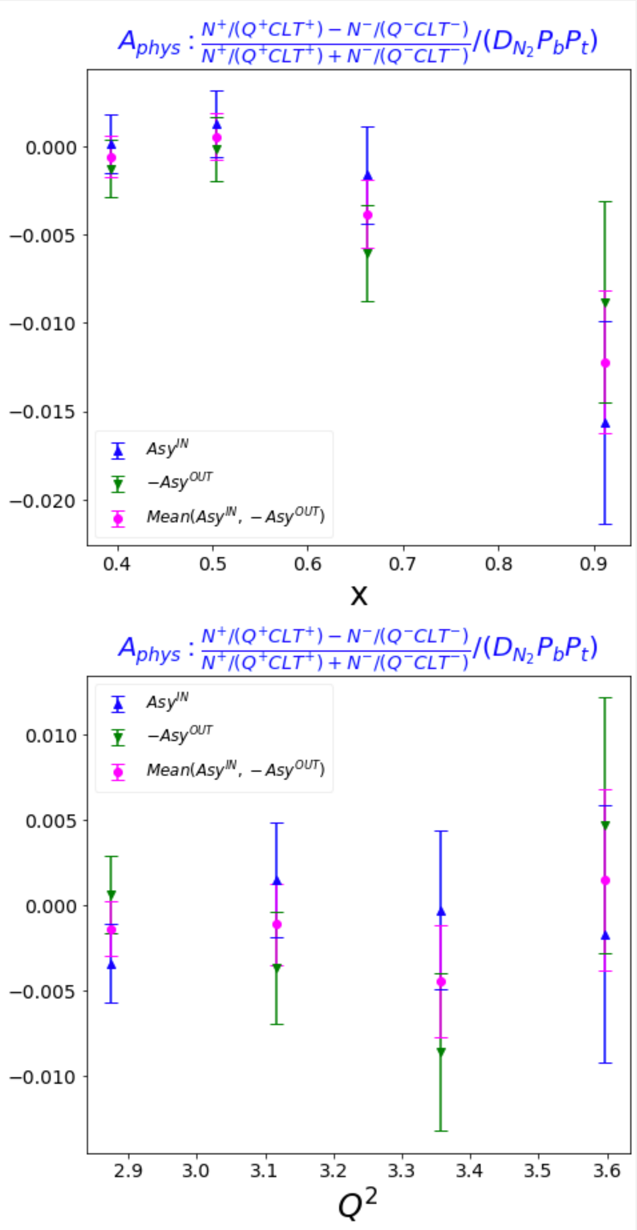
- E12-06-121 experiment was successfully completed in September 2020
- Physical value extractions are still going on
  - Asymmetry: doing radiative correction
  - Cross section: several uncertainties still need to be finalized

BACKUP SLIDES

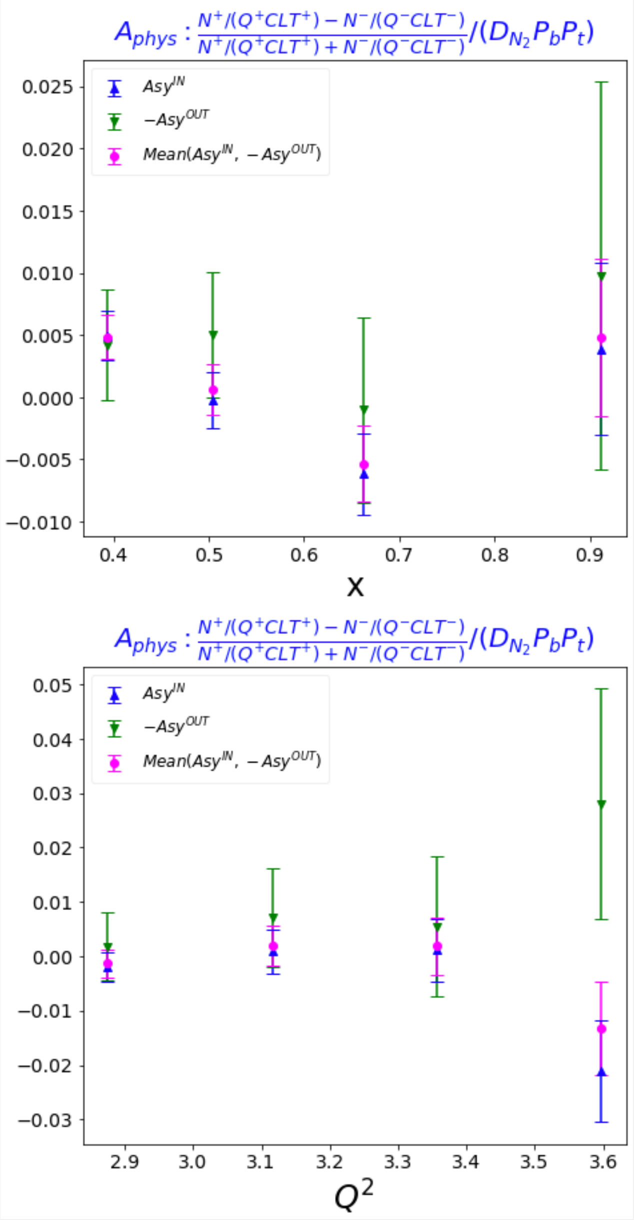
Kin-X 90°



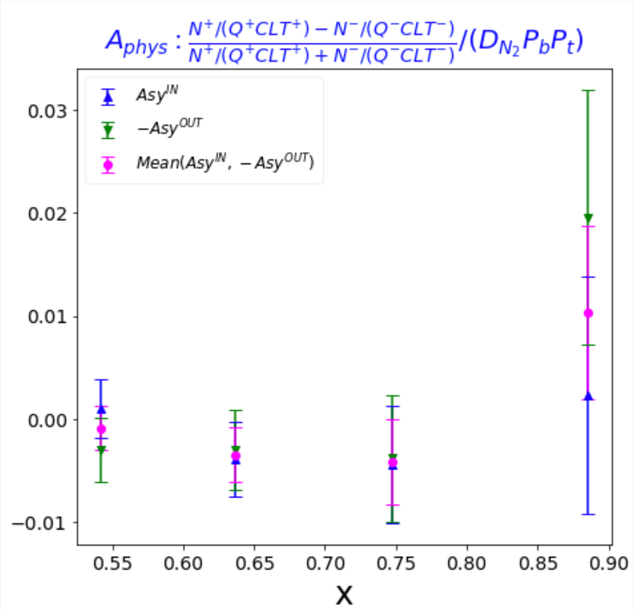
Kin-X 270°

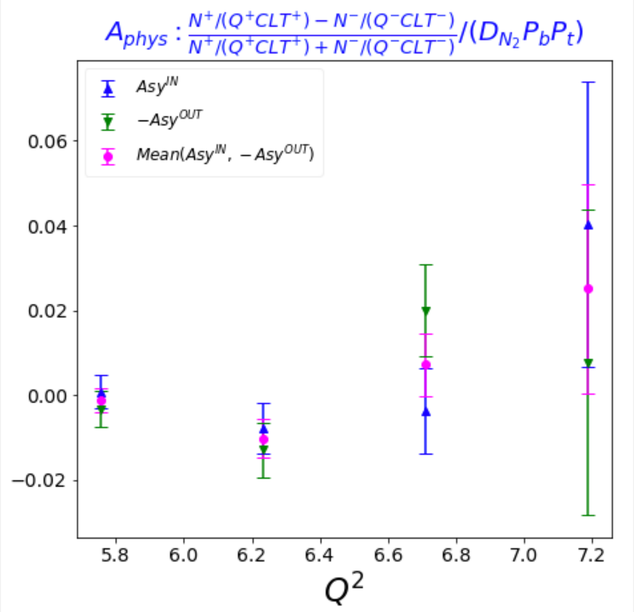


Kin-X 180°

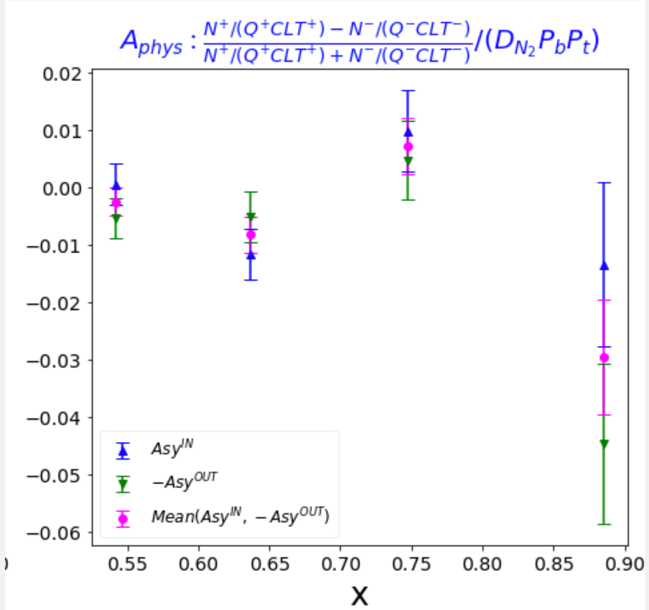


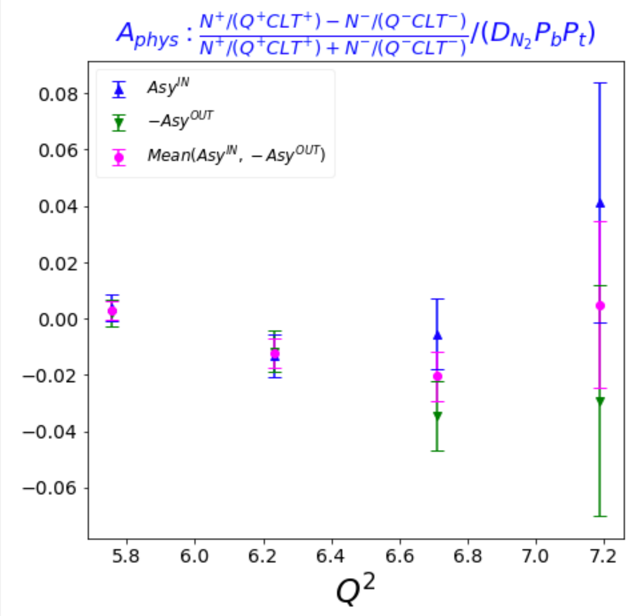
Kin-Z 90°



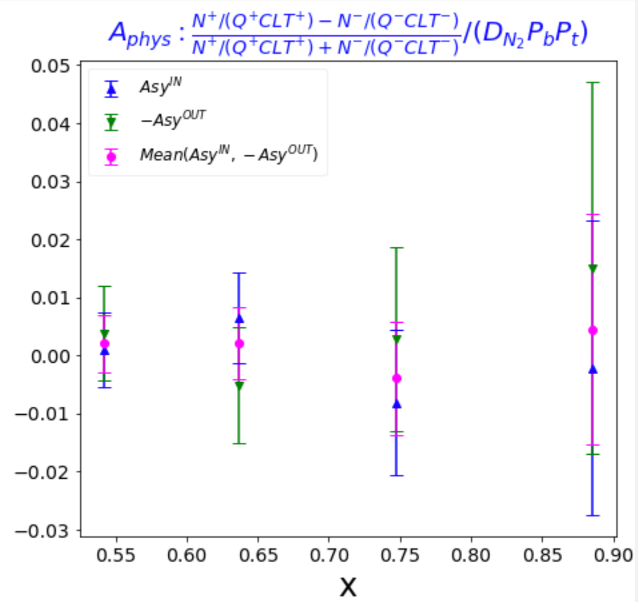


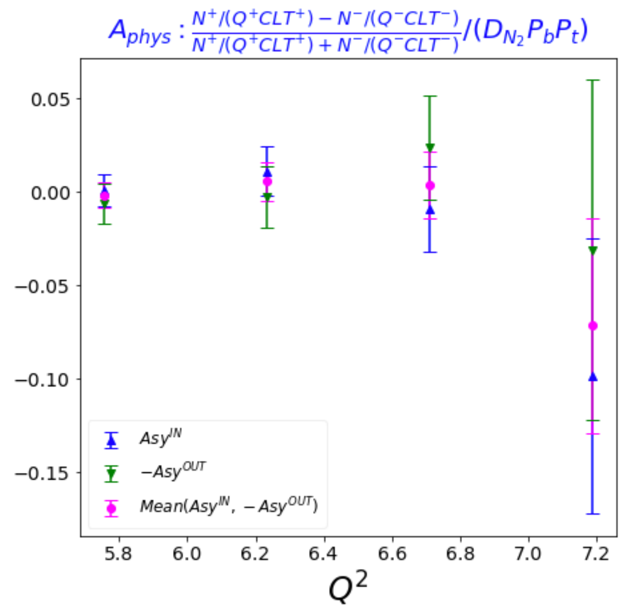
Kin-Z 270°



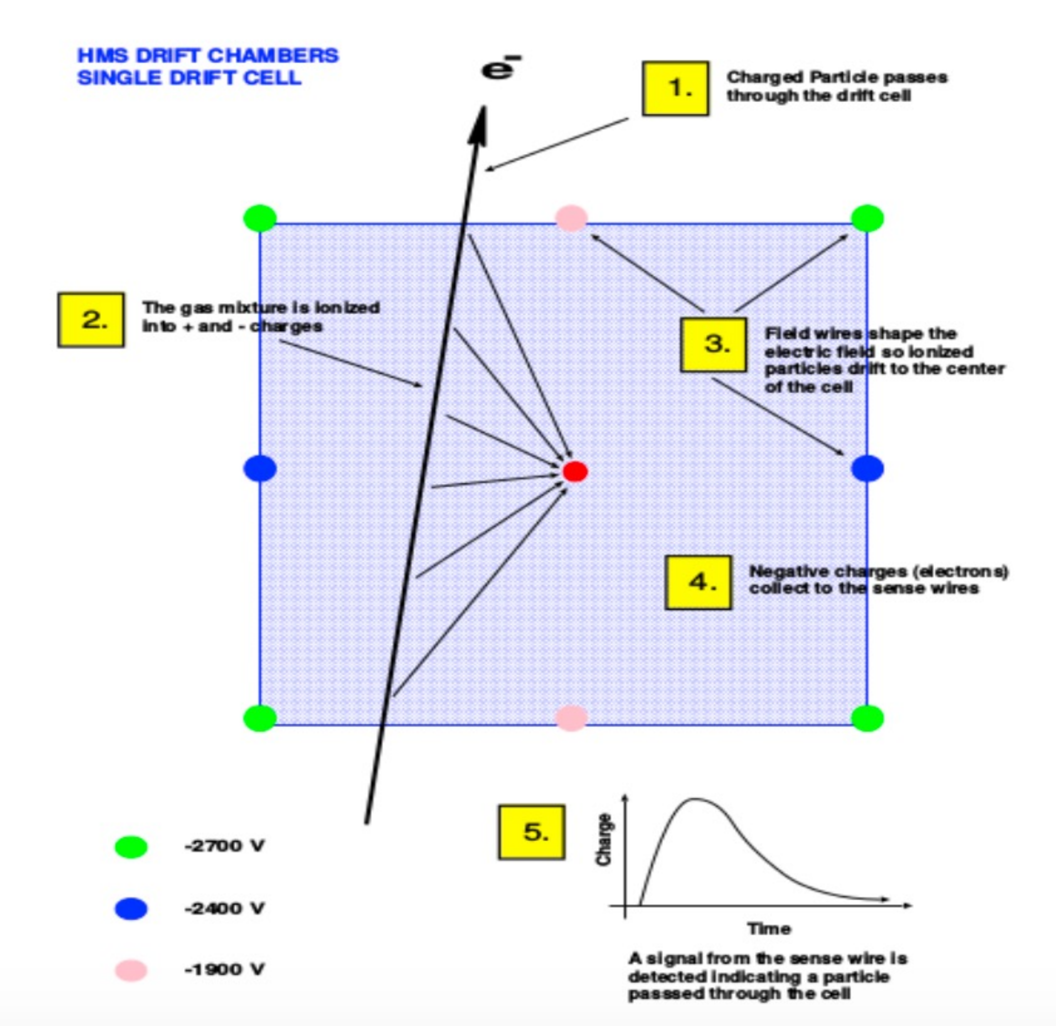


Kin-Z 180°





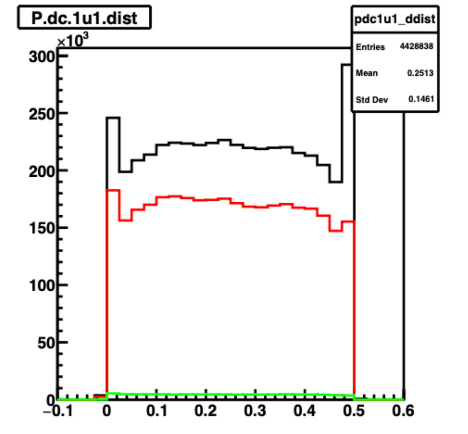
DRIFT CHAMBER CALIBRATION

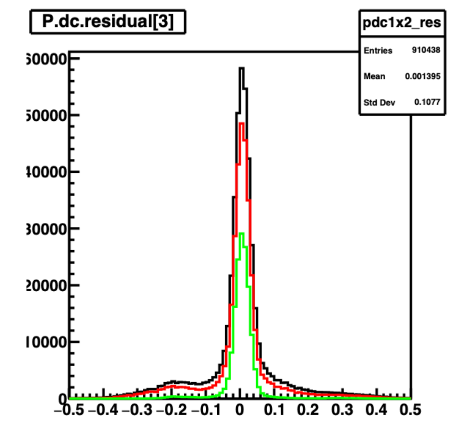


Pictures credit to Carlos Yero

What to calibrate:

The drift distance for each wire calibrated from drift time



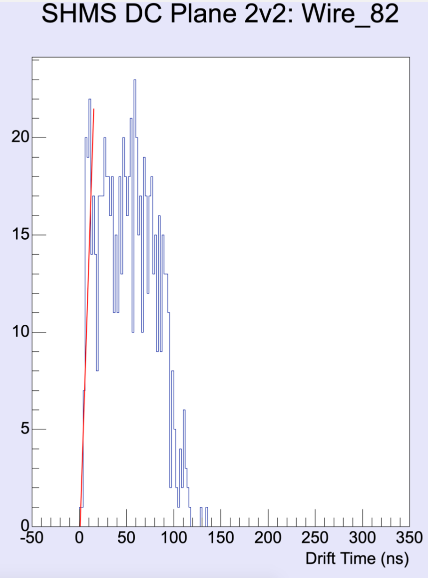


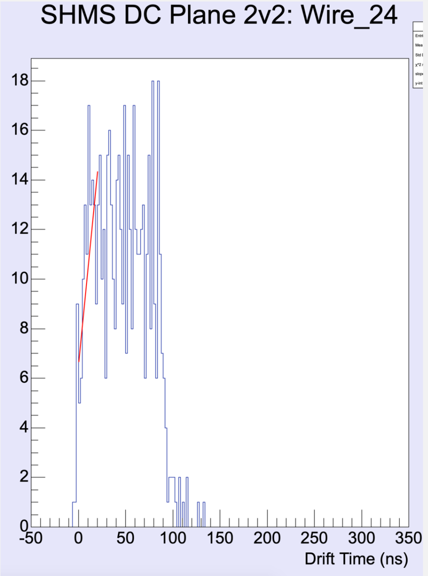
Assumptions for calibration:

- The minimum drift time is 0
- Charged particles pass through single drift cell uniformly

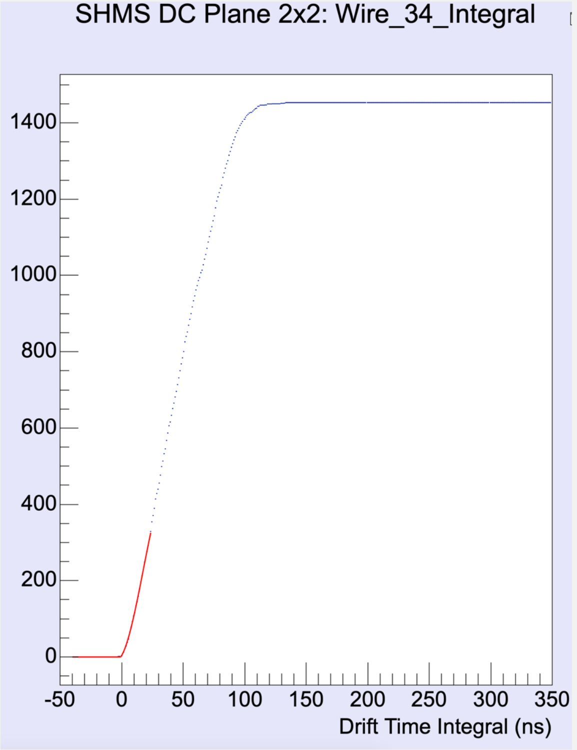
DRIFT CHAMBER CALIBRATION

- Add a new time offset per wire fitting method
  - Fit the integrated drift time with step function to increase the fitting stability

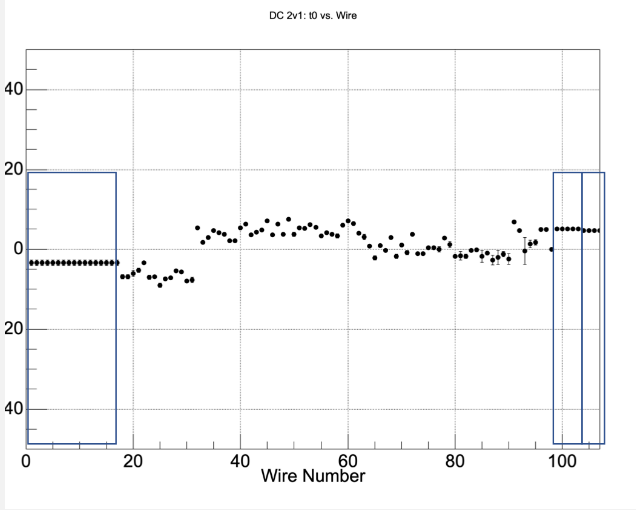




Fit time offset directly



Fit time offset with integrated drift time

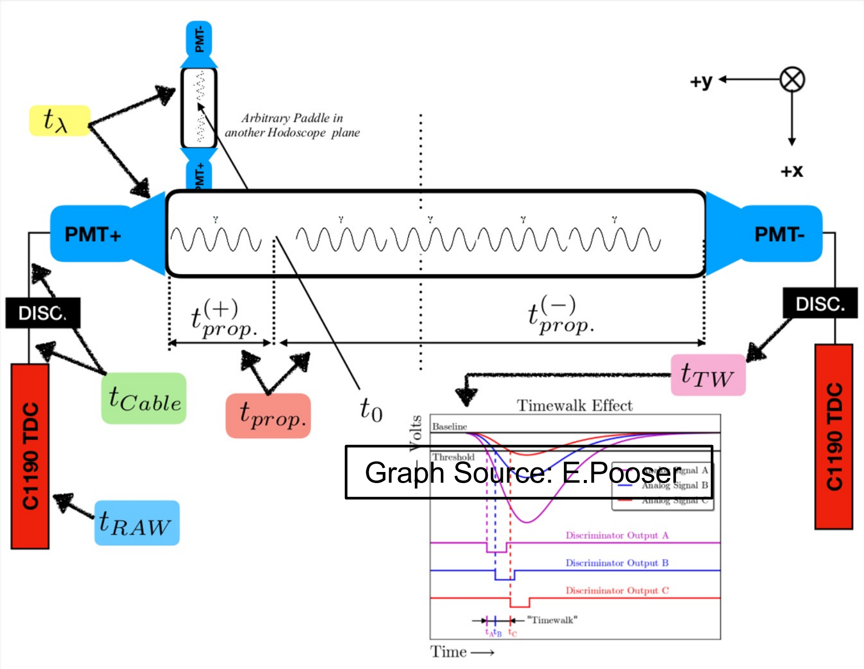


More robust time offset per wire fit

- Have finished first round calibration
- Hodoscope params was updated this week, is doing a 2nd round calibration
- Expecting finish 2nd round this week

HODOSCOPE CALIBRATION

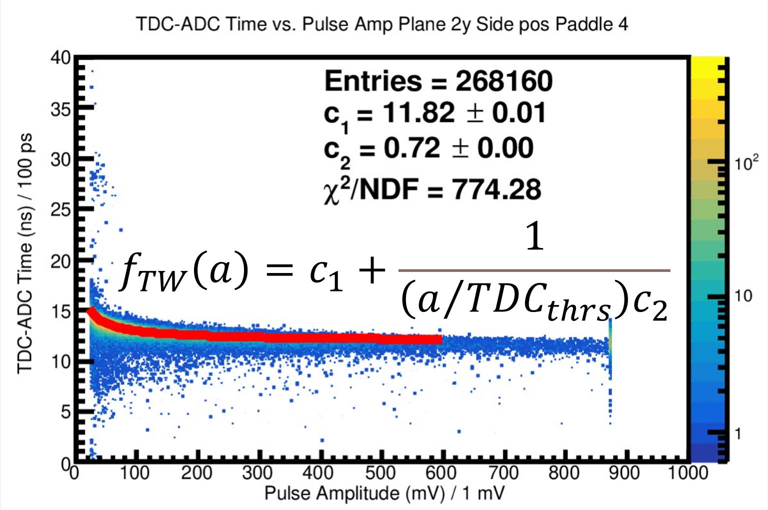
- HMS 3994: ^{3}He DIS, d_2^n experiment
- Longitudinal 180 deg
- Kin-B: E_p=6.4 GeV, 14.5°
- Trigger: 3/4 (hTRIG1)



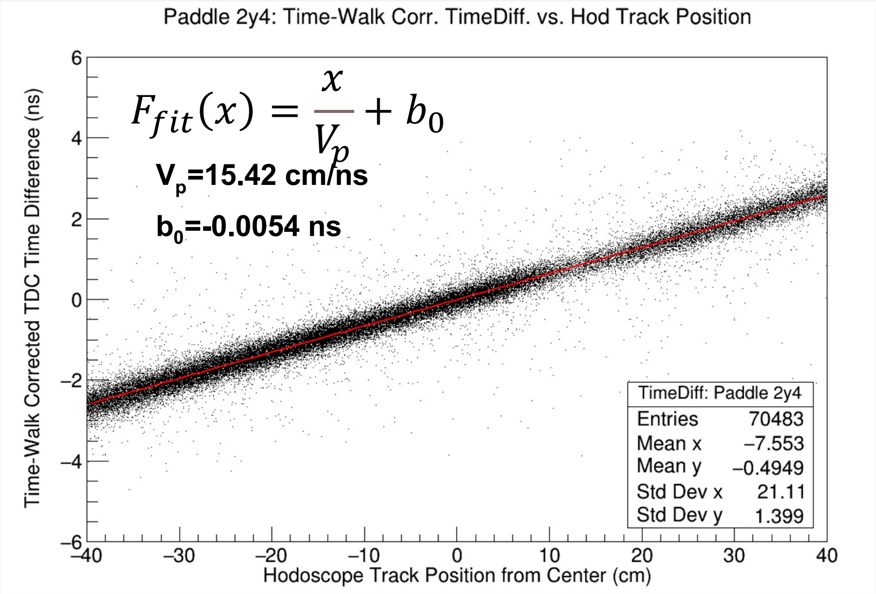
Graph Source: E.Pooser

$$t_{Corr} = t_{RAW} - t_{TW} - t_{Cable} - t_{propagation} - t_\lambda$$

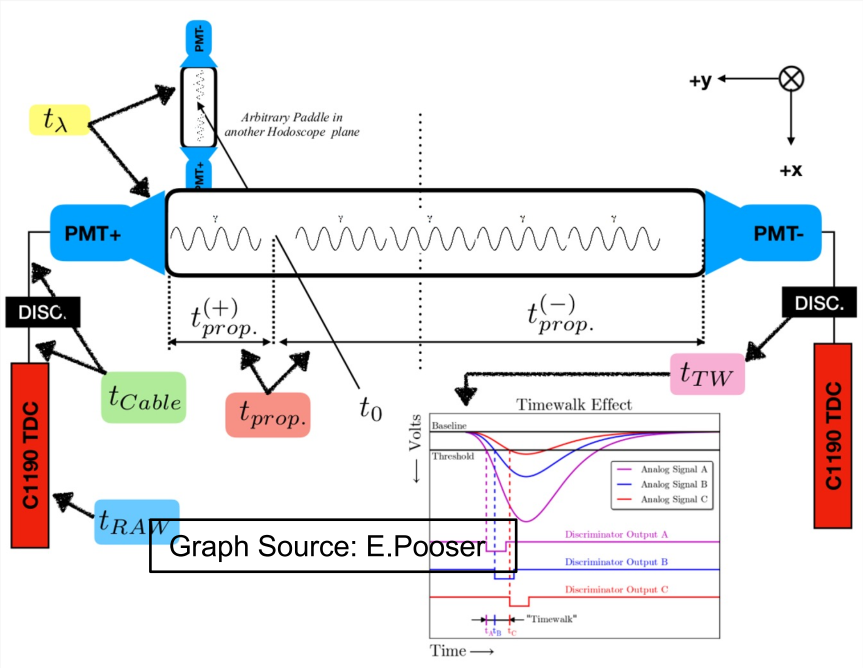
- TW : Time-walk Corrections
- tcable: Cable Time Corrections
- tprop: Propagation Time Corrections
- tλ: Hodoscope Planes Time Difference Corrections



- a is ADC amplitude; TDC_{thrs}=120 mV



HODOSCOPE CALIBRATION



$$t_{Corr} = t_{RAW} - t_{TW} - t_{Cable} - t_{propagation} - t_{\lambda}$$

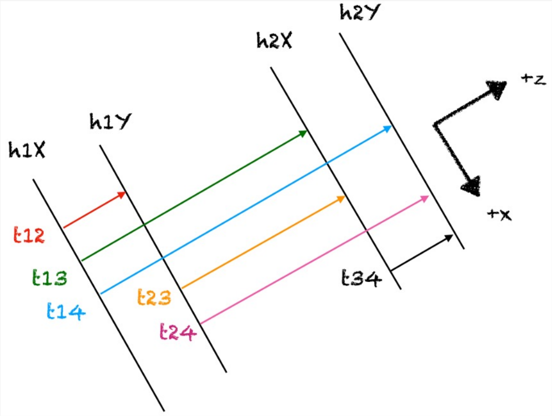
$$t^{(+)}_{Corr.} = t^{(+)}_{Corr.} - (L_+ - \text{hit})\frac{1}{v_p}, \quad \text{where } t^{(+)}_{prop.} \equiv (L_+ - \text{hit})\frac{1}{v_p}$$

$$t^{(-)}_{Corr.} = t^{(-)}_{Corr.} - (\text{hit} - L_-)\frac{1}{v_p}, \quad \text{where } t^{(-)}_{prop.} \equiv (\text{hit} - L_-)\frac{1}{v_p}$$

$$t_{avgCorr.} = \frac{1}{2}(t^{(+)}_{Corr.} + t^{(-)}_{Corr.}) = \frac{1}{2}(t^{(+)}_{TW_{Corr.}} + t^{(-)}_{TW_{Corr.}})$$

- This correction is done in hcana.

- HMS 3994: ^{3}He DIS, d_2^n experiment
- Longitudinal 180 deg
- Kin-B: E_p=6.4 GeV, 14.5°
- Trigger: 3/4 (hTRIG1)



- All possible time difference combinations considered; solve the system of six linear equations.