Longitudinal Spin Transfer to Λ^0 Hyperons in CLAS12

2/Jun./21, Matthew McEneaney, Duke University

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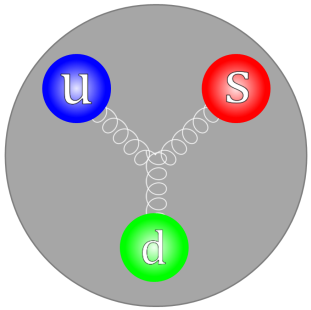
Why Lambdas?



- Similar spin structure to proton
- Constituent Quark Model predicts spin carried by s quark alone: $\Delta q_s^{\Lambda} = 1$ (Denote contribution of quarks of flavor f to Λ spin: $\Delta q_f^{\Lambda} = q_f^{\Lambda+} - q_f^{\Lambda-}$)
- Previous experiments have observed small spin transfer coefficients but are unable to discriminate between models:

HERMES: $\Delta q_u^{\Lambda} = 0.11 \pm 0.10(stat) \pm 0.03(syst)$

NOMAD result: $-P_{\Lambda}^{\nu} = 0.09 \pm 0.06\,(stat) \pm 0.03\,(syst)$

A. Airapetian, et al. Physical Review D, 74(7), Oct 2006.
NOMAD Collaboration, P. Astier et al., Nucl. Phys. B 588, 3 (2000).

Spin Transfer

- Spin transfer to Lambda described by:

$$\frac{dN}{d\Omega_{\mathrm{p}}} \propto 1 + \alpha P_b D(y) D^{\Lambda}_{LL'} \cos\theta_{pL'}$$

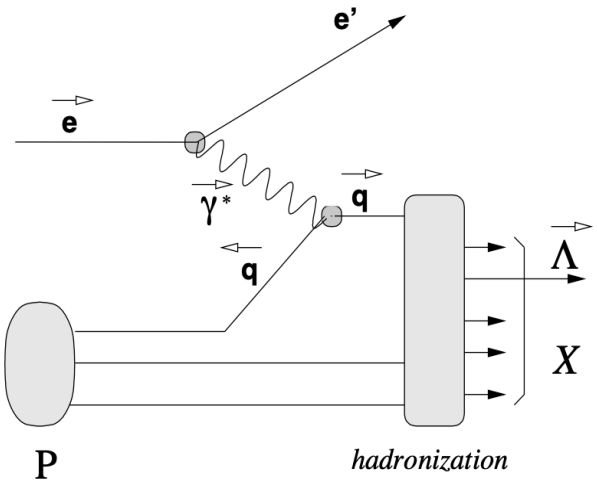
where $D(y) \simeq \frac{1-(1-y)^2}{1+(1-y)^2}$ is the depolarization factor

- Partial spin transfer from struck quark to Λ:

$$D^{\Lambda}_{LL',f}(z) = \frac{G^{\Lambda}_{1,f}(z)}{D^{\Lambda}_{1,f}(z)} = \frac{D^{\Lambda+}_{1,f+}(z) - D^{\Lambda-}_{1,f+}(z)}{D^{\Lambda+}_{1,f+}(z) + D^{\Lambda-}_{1,f+}(z)} \simeq \frac{\Delta q^{\Lambda}_f}{q^{\Lambda}_f}$$

- Since there is a strong u-quark dominance in e^- DIS

$$D^{\Lambda}_{LL'}(z) \approx D^{\Lambda}_{LL',u}(z)$$



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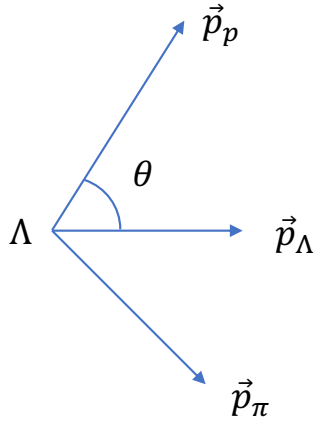
Experimental Extraction



- Going back to the angular distribution:

$$\frac{dN}{d\Omega_{\mathrm{p}}} \propto 1 + \alpha P_b D(y) D^{\Lambda}_{LL'} \cos\theta_{pL'}$$

Where $\cos\theta_{pL'}$ is the angle between p^+momentum and Λ spin quantization axis.

- Axis 1: along Λ momentum
- Axis 2: along the virtual photon momentum in Λ rest frame

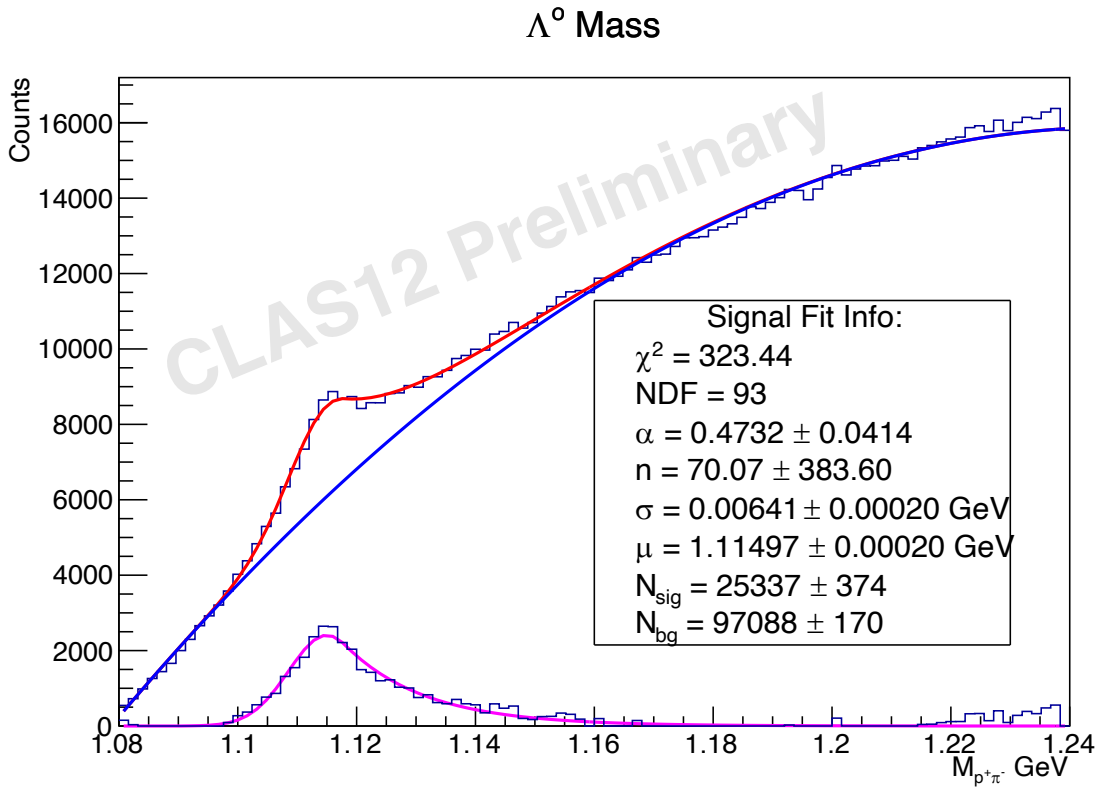
Experimental Extraction

- Maximum likelihood (helicity balance) method allows us to extract on event-by-event basis:

$$D_{LL'}^{\Lambda} = \frac{1}{\alpha \overline{P_b^2}} \cdot \frac{\Sigma_{i=1}^{N_\Lambda} P_{b,i} D(y_i) \cos\theta_{pL'}^{i}}{\Sigma_{i=1}^{N_\Lambda} D^2(y_i) \cos^2\theta_{pL'}^{i}}$$

- No acceptance corrections needed since $\overline{P_b} = 0$ (beam polarization reverses at 30Hz).
- Linear fit method for the $\cos\theta$ distributions requires acceptance correction.

Invariant Mass Signal



Standard SIDIS cuts:
$Q^2 > 1$ & $W > 2$ & $y < 0.8$ & $x_F > 0$ & $z < 1$
Also require identified $p^+\pi^-$ and scattered e^-

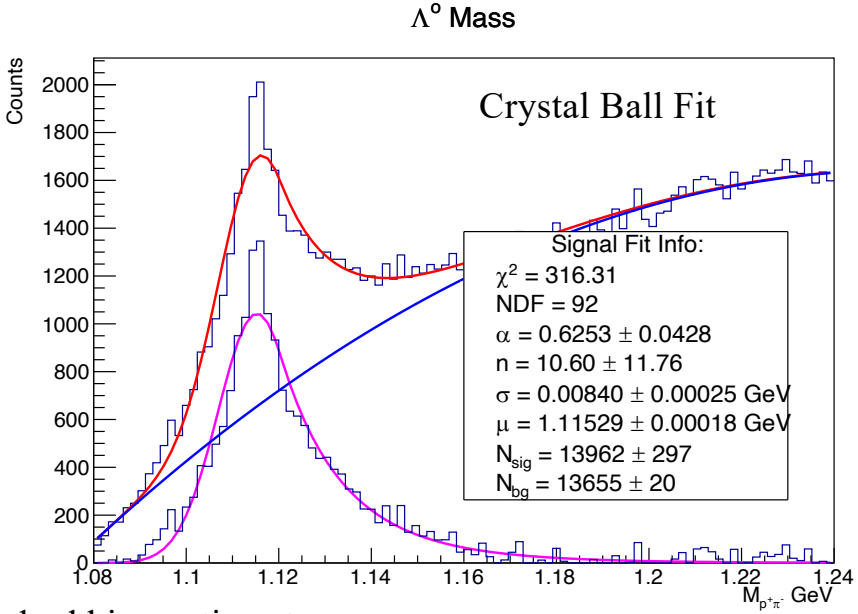
Crystal Ball Fit Function:

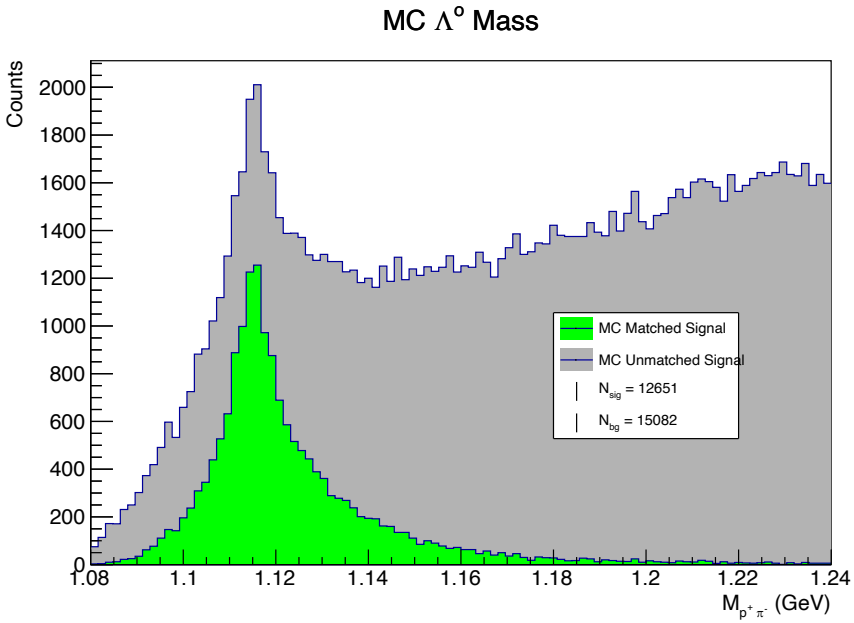
$$CB(M;\alpha,n,\mu,\sigma) = N \cdot \exp\left(-\frac{(m-\mu)^2}{2\sigma^2}\right), \frac{m-\mu}{\sigma} > -\alpha$$

$$= N \cdot \mathrm{A}\left(B - \frac{m-\mu}{\sigma}\right)^{-n}, \frac{m-\mu}{\sigma} < -\alpha$$

/volatile/clas12/rg-a/production/recon/fall2018/torus+1/pass1/v0/dst/train/skim4/

MC: Comparison with Truth-Matched Signal





Standard kinematic cuts:
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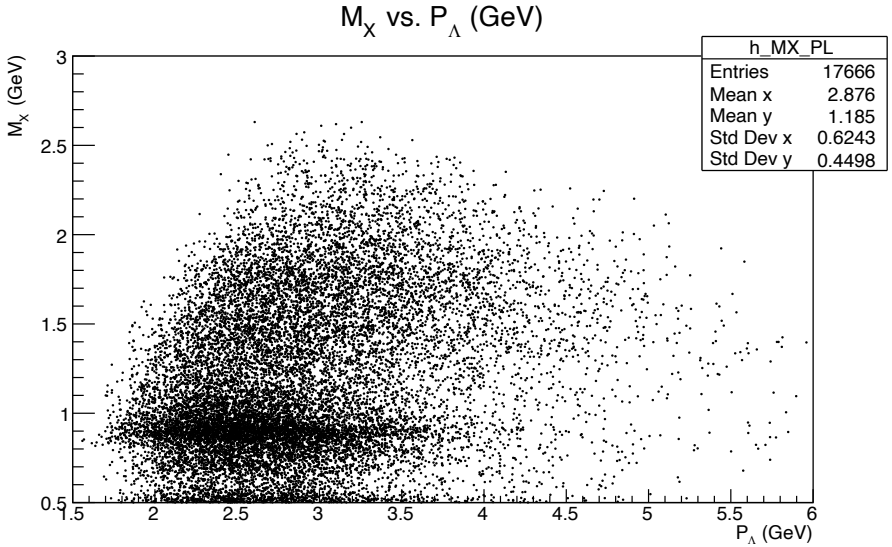
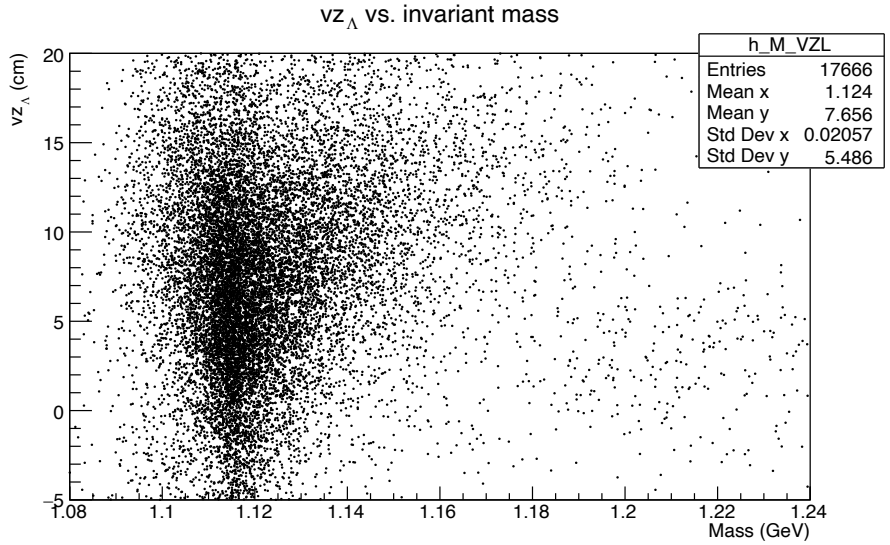
and positive $p^+\pi^-$ PID and scattered e^-
(positive PID, $|\chi^2| < 3$, greatest momentum) required.

Truth Matching:
Require a MC truth Λ in event with
$|P^{\Lambda}_{Rec} - P^{\Lambda}_{MC}| < 0.1GeV$

/work/clas12/rg-a/montecarlo/fall2018/torus+1/clasdis/nobg/

MC: Λ Kinematics Correlations





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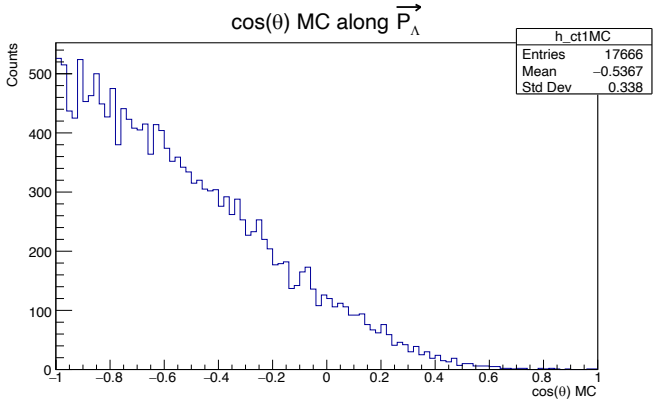
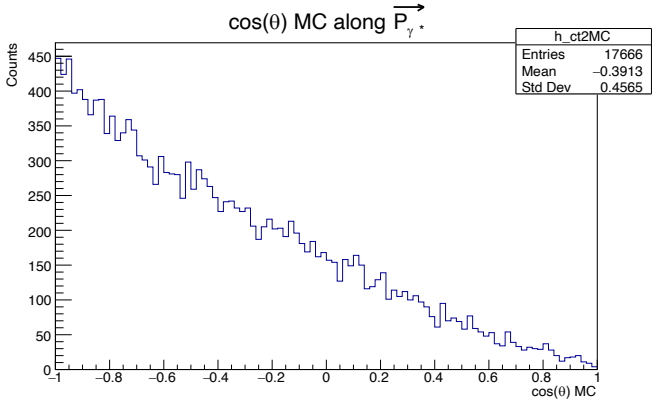
/work/clas12/rg-a/montecarlo/fall2018/torus+1/clasdis/nobg/

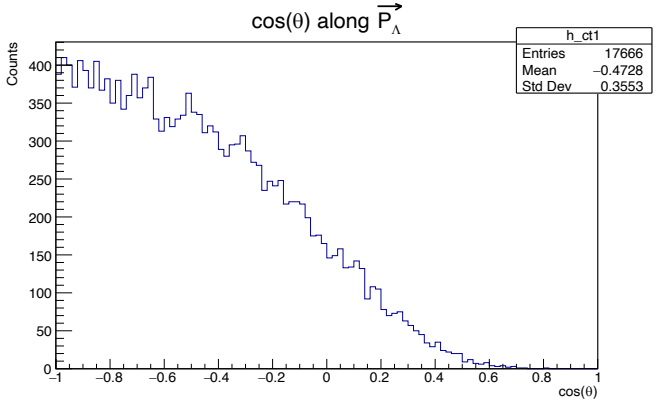
MC: cos θ Distributions

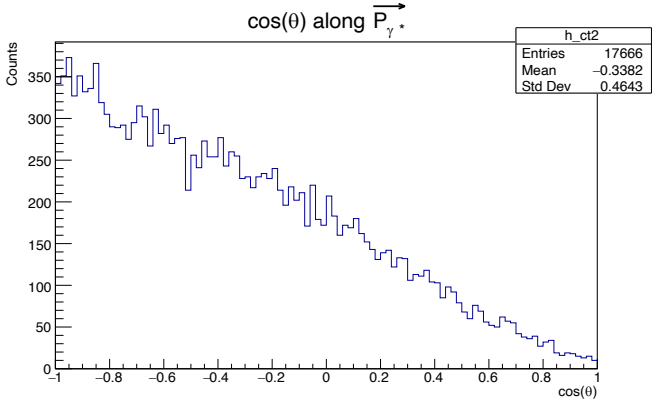
MC Truth





REC Matched





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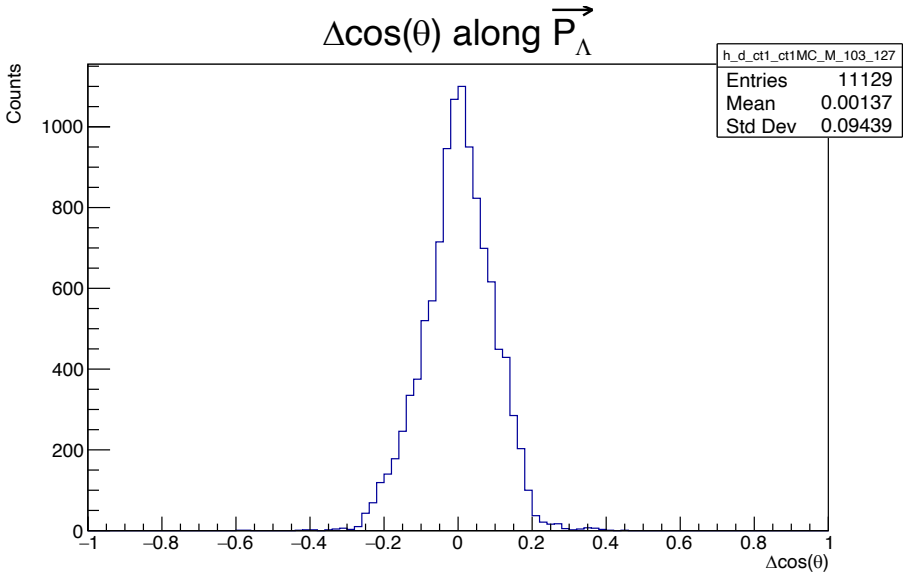
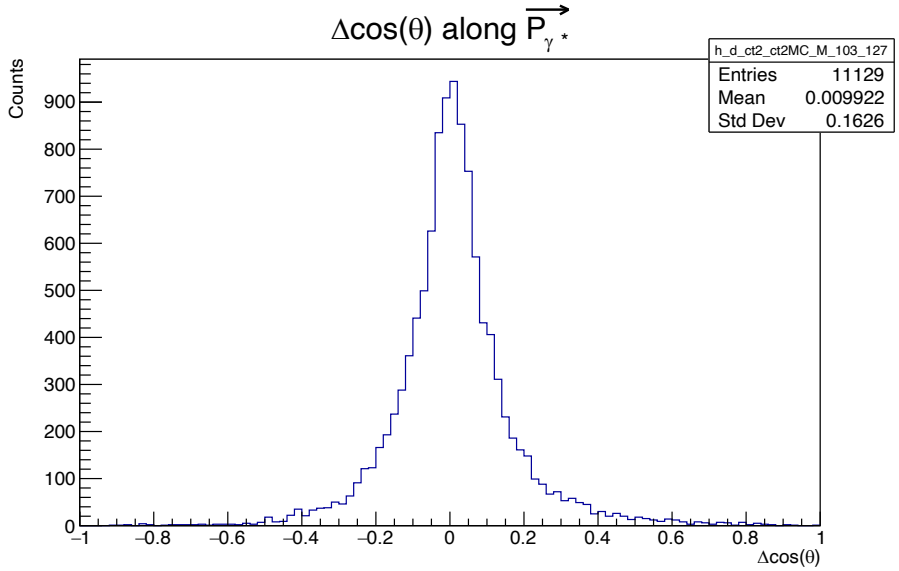
MC: $\cos\theta$ Resolution in Signal Region





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REC $cos\theta$ Distributions

Standard kinematic cuts:
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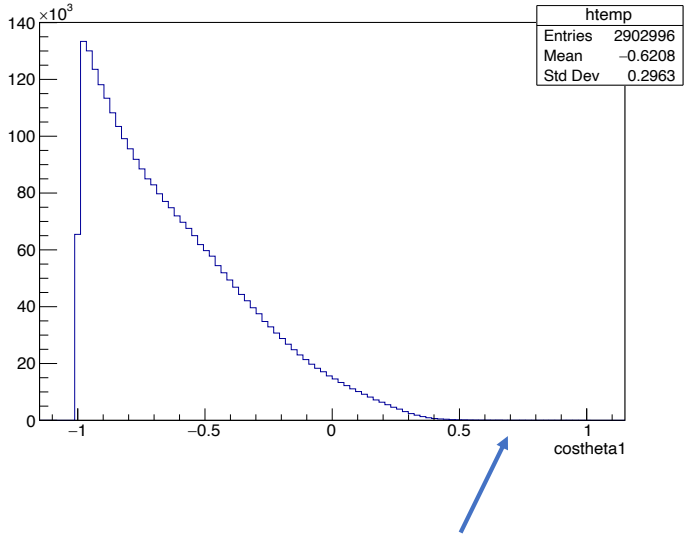
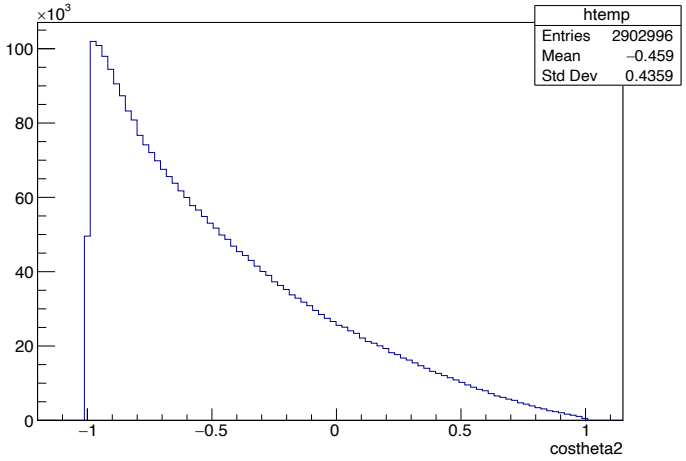
$\cos\theta_1$



$\cos\theta_2$

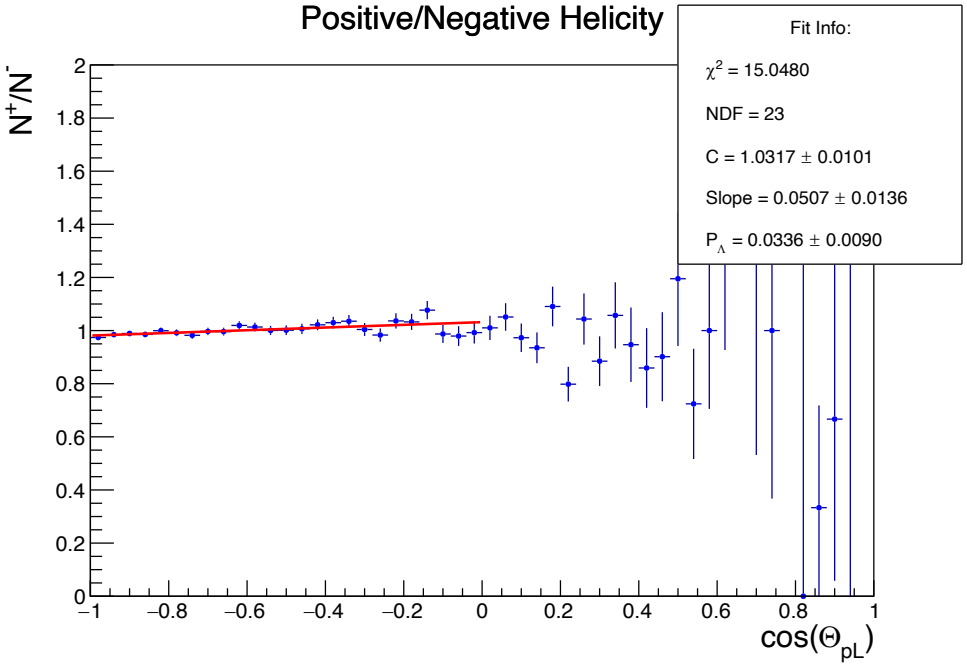


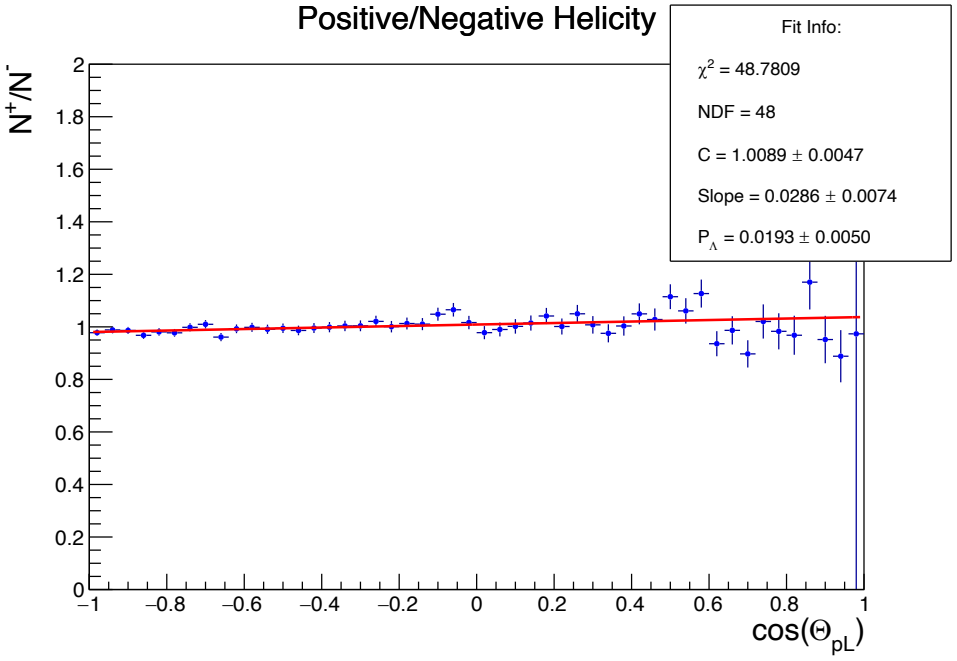
On the order of 20 counts per bin past $\cos(\theta) = 0.5$

/volatile/clas12/rg-a/production/recon/fall2018/torus+1/pass1/v0/dst/train/skim4/

Fit $cos\theta_1$ (acceptance corrected)

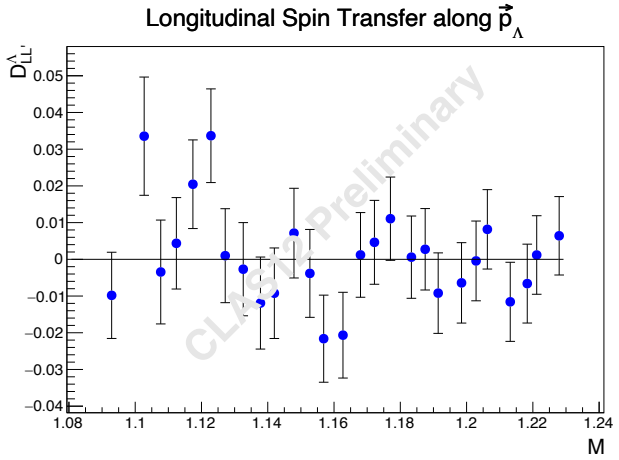
$$P_\Lambda = \frac{1}{\alpha}\frac{Slope}{C}$$

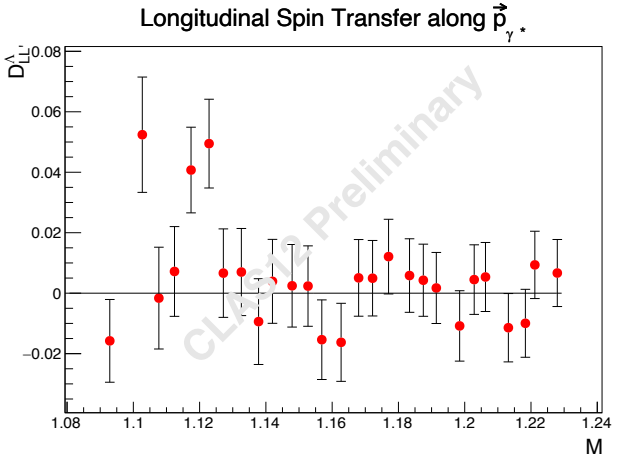




Helicity Balance vs. Invariant Mass

vs. Invariant Mass





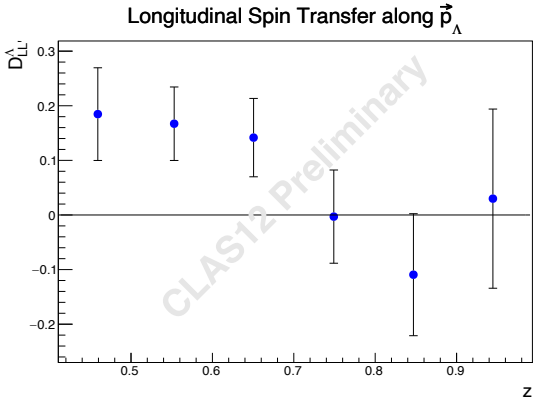
Note: errors are solely statistical

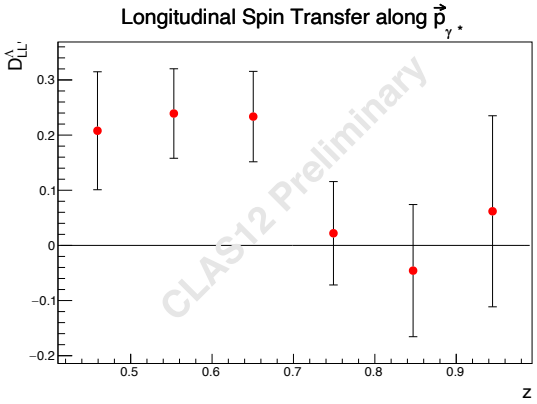
No BG Correction

Helicity Balance (BG corrected)

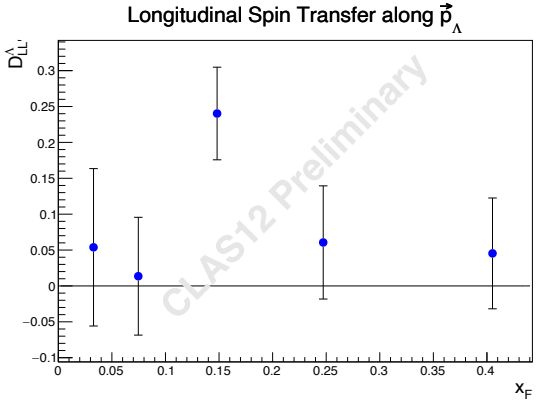
$$D_{LL}^{\Lambda} = \frac{D_{LL_{peak}} - \epsilon D_{LL_{bg}}}{1 - \epsilon}$$

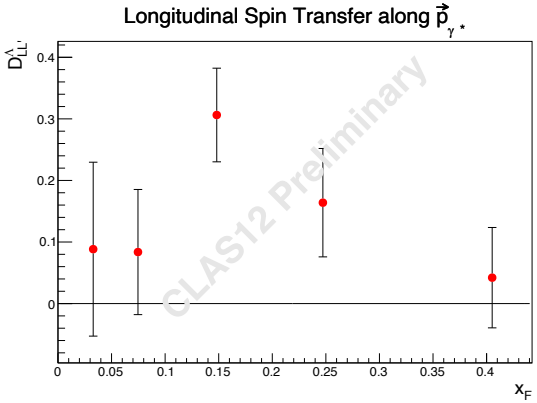
vs. z





vs. x_F



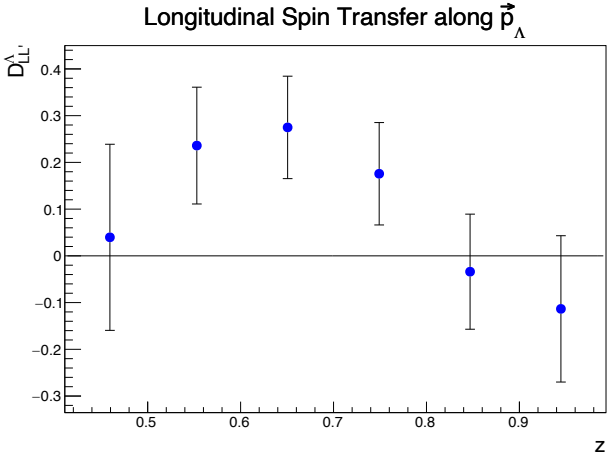


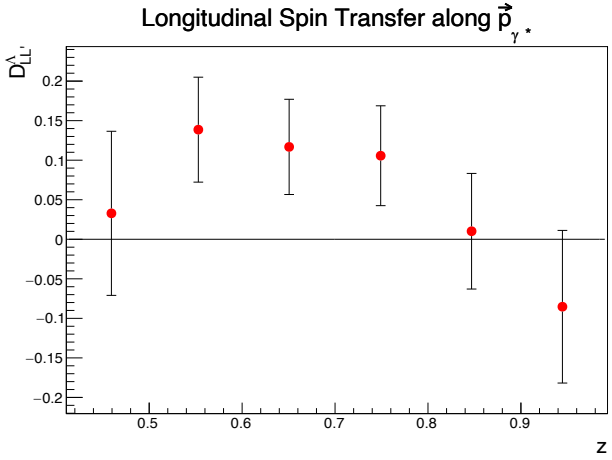
Note: errors are solely statistical

Linear Fit (BG corrected)

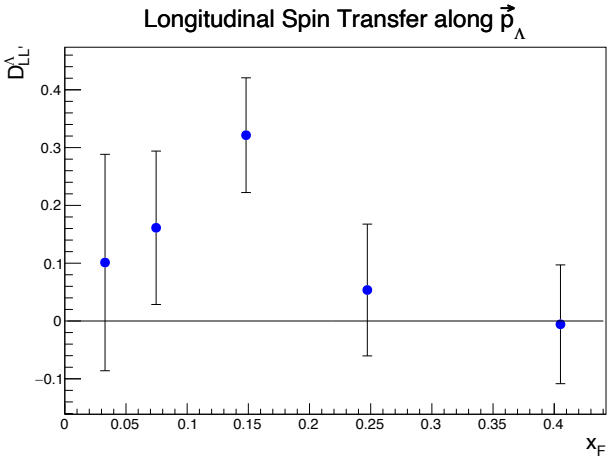
$$D_{LL}^{\Lambda} = \frac{D_{LL_{peak}} - \epsilon D_{LL_{bg}}}{1 - \epsilon}$$

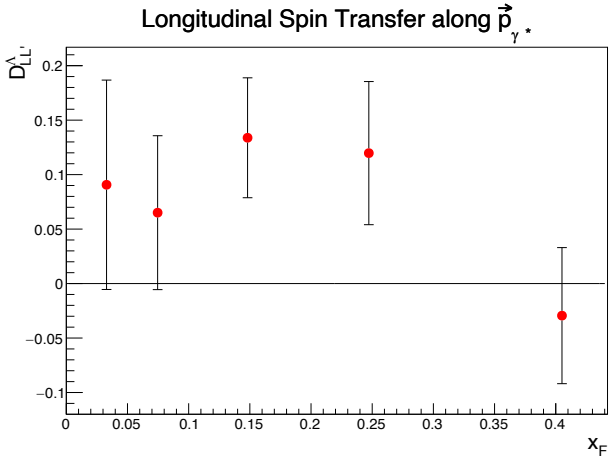
vs. z





vs. x_F





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Systematic Uncertainties

- Uncertainties from fit errors and incorrect particle PID were minimal (<0.001).
- Spin transfer in sidebands is also fairly small:

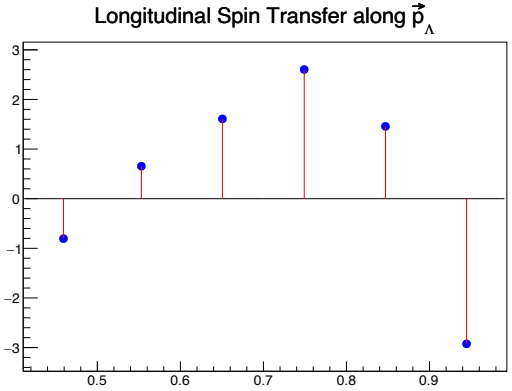
Preliminary Helicity Balance

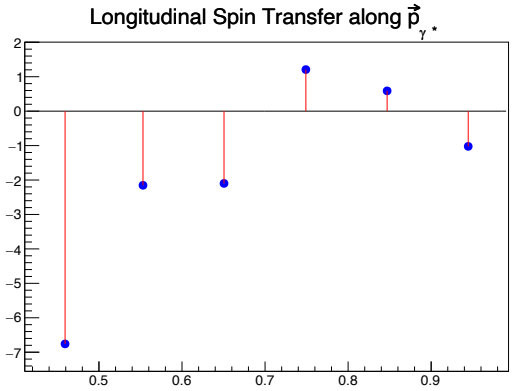
$\cos\theta_{pL'}$ along $\vec{p_\Lambda}$	$\cos\theta_{pL'}$ along $\vec{p_\gamma}$
-0.00141 ± 0.01293	0.00113 ± 0.01387
-0.00185 ± 0.03183	-0.00810 ± 0.03535

- Results from linear fit method are consistent within uncertainties, but require better statistics.

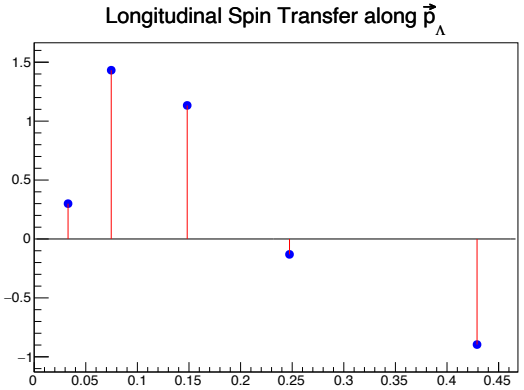
Systematic Uncertainties: Method Pulls

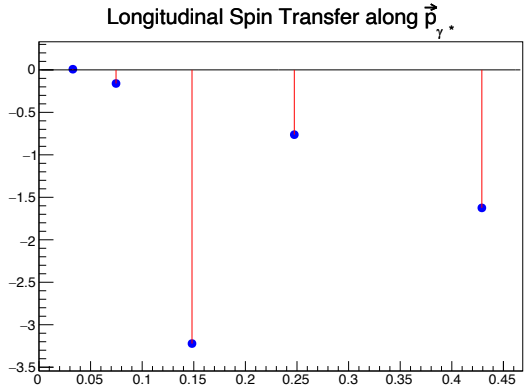
vs. z





vs. x_F



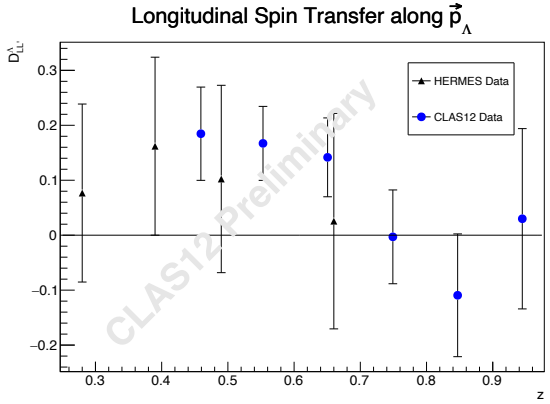


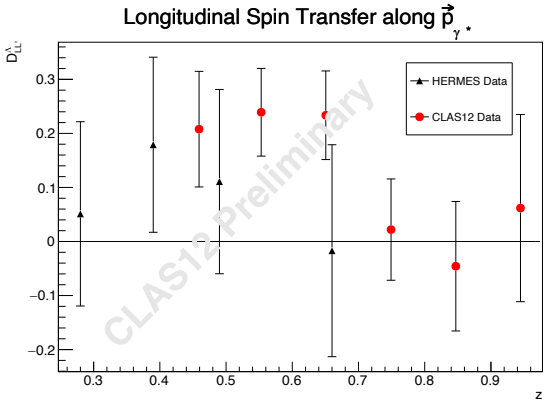
Pulls between methods calculated assuming the results from each are completely correlated:

pull = $\Delta D_{LL'}/\sqrt{|\sigma_A^2 - \sigma_B^2|}$

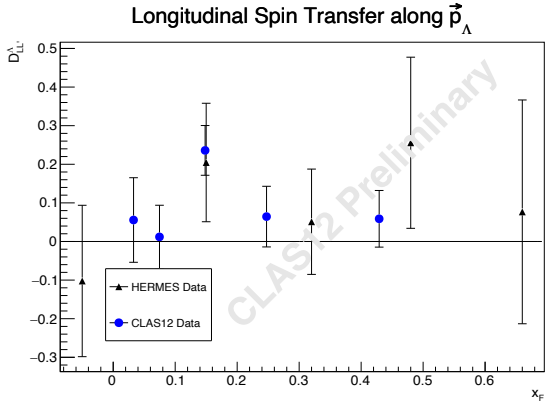
Helicity Balance: Comparison with HERMES

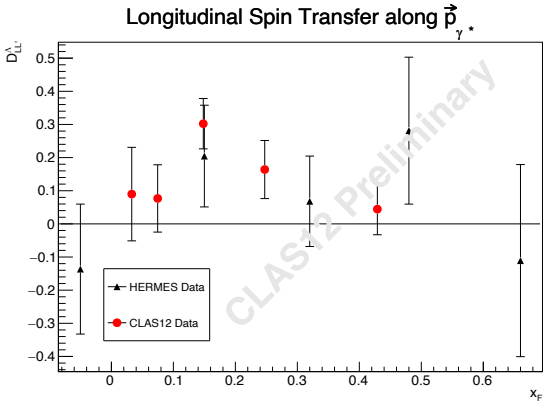
vs. z





vs. x_F





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Summary

- Preliminary averaged $D_{LL'}$ measurements:

Preliminary Helicity Balance	
$\cos\theta_{pL'}$ along $\vec{p_\Lambda}$	$\cos\theta_{pL'}$ along $\vec{p_\gamma}$
0.0618 ± 0.0963	0.118 ± 0.107

- In general, consistent with HERMES ($D_{LL'} = 0.11 \pm 0.10(stat) \pm 0.03(syst)$ and NOMAD ($-P_\Lambda^\nu = 0.09 \pm 0.06\ (stat) \pm 0.03\ (syst)$)

- Current/future work: Deep Sets Networks and Graph Neural Networks for Λ event identification, such as in arXiv:1810.05165v2 and arXiv:1902.08570v3

Thank you!

Research supported by:

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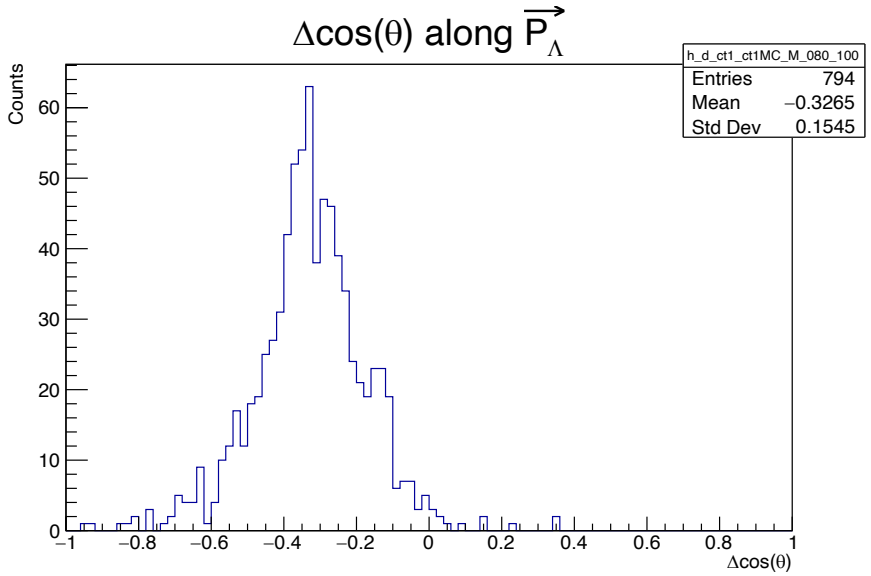
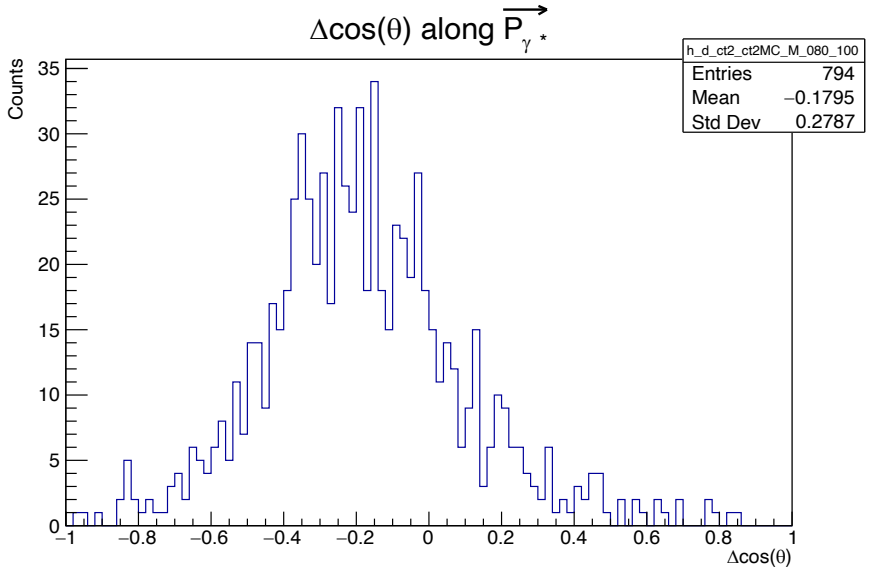
MC: $\cos\theta$ Resolution in Lower Sideband





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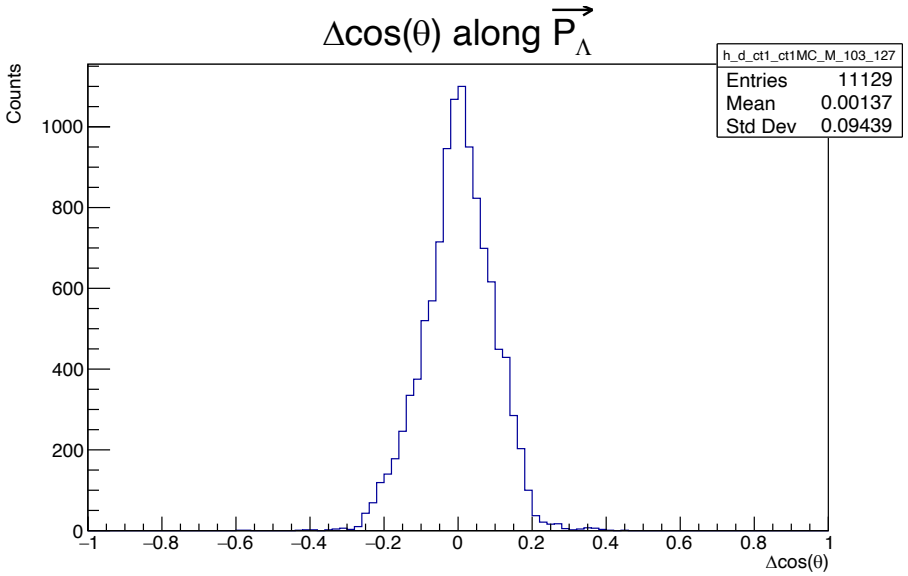
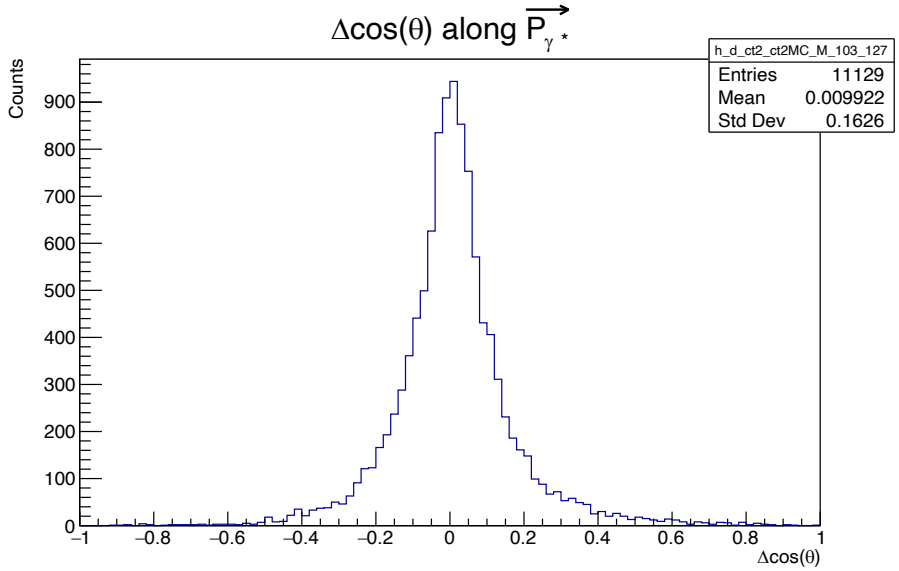
/work/clas12/rg-a/montecarlo/fall2018/torus+1/clasdis/nobg/

MC: $\cos\theta$ Resolution in Signal Region





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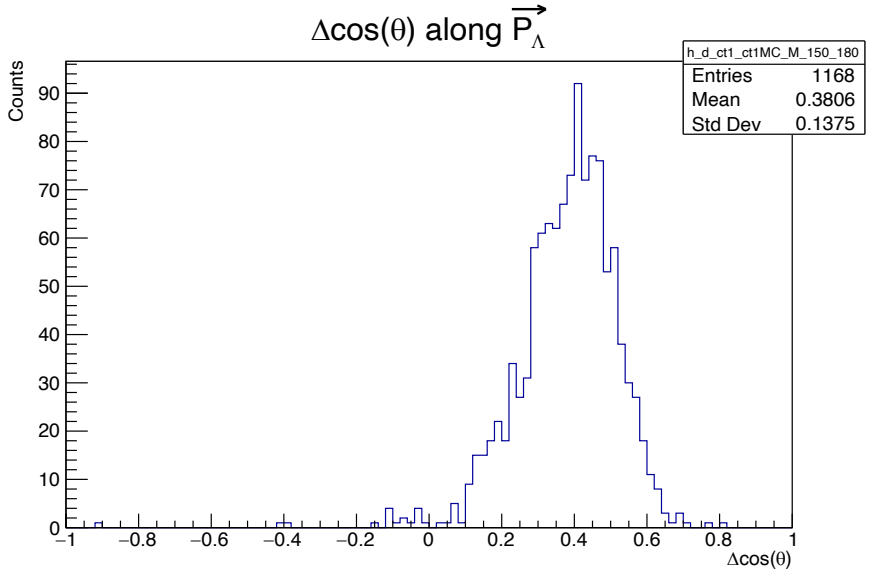
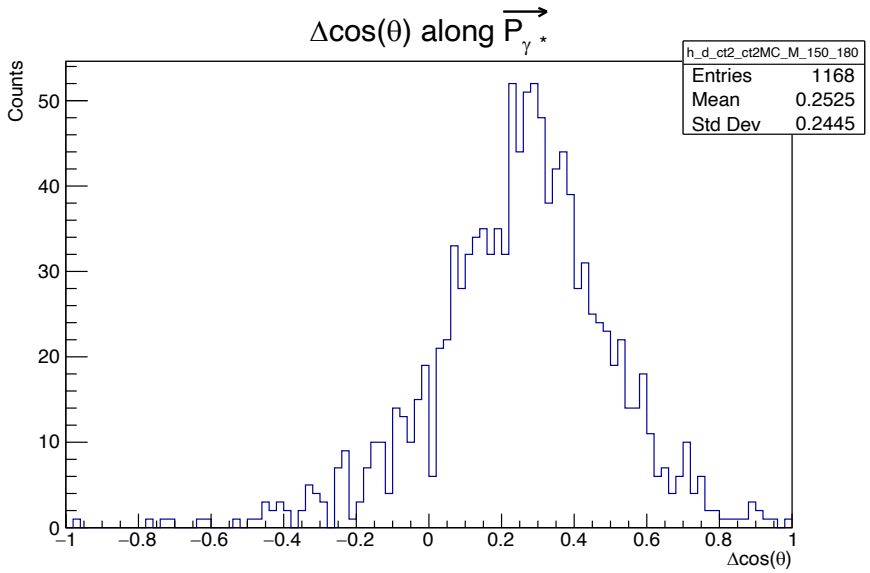
MC: $\cos\theta$ Resolution in Upper Sideband



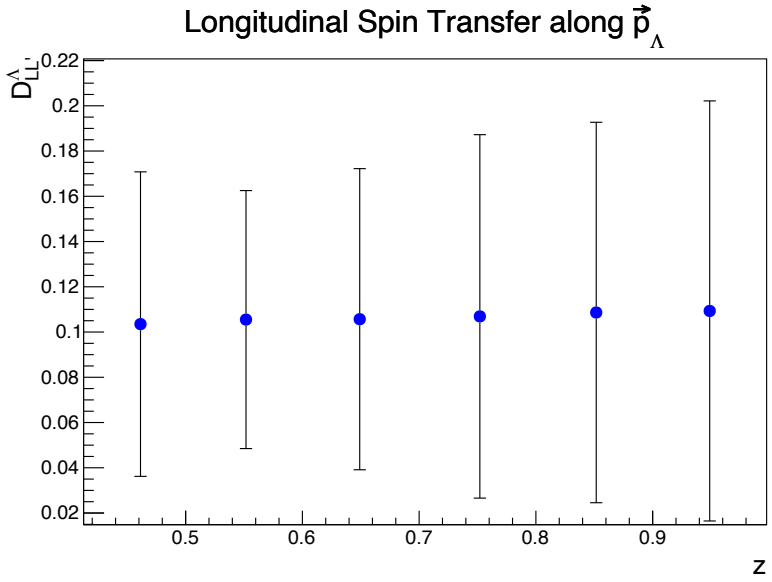


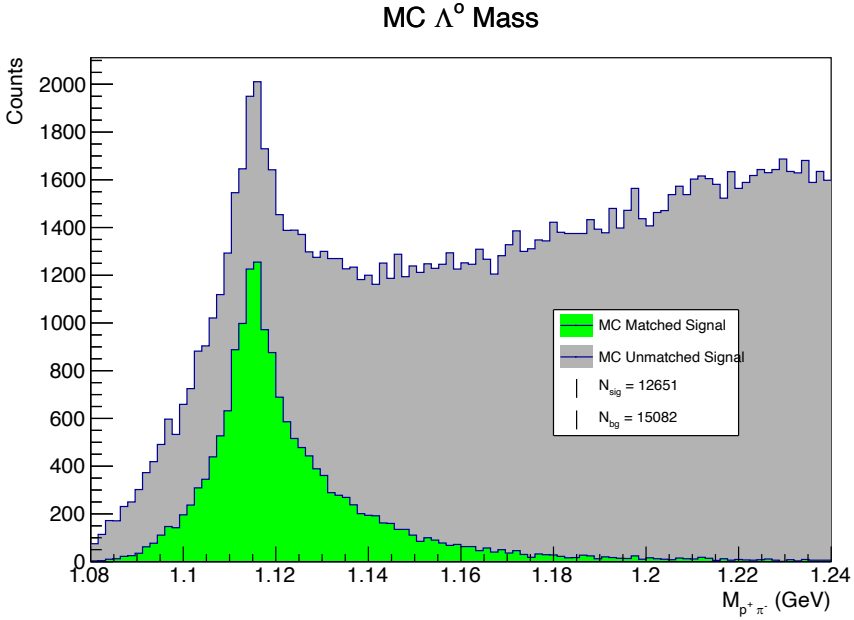
Standard kinematic cuts:
$Q^2 > 1$ & $W > 2$ & $y < 0.8$ & $x_F > 0$ & $z < 1$
and positive $p^+\pi^-$ PID and scattered e^-
(positive PID, $|\chi^2| < 3$, greatest momentum) required.

Truth Matching:
Require a MC truth Λ in event with
$|P^{\Lambda}_{Rec} - P^{\Lambda}_{MC}| < 0.1GeV$

/work/clas12/rg-a/montecarlo/fall2018/torus+1/clasdis/nobg/

MC: Asymmetry Injection Helicity Balance





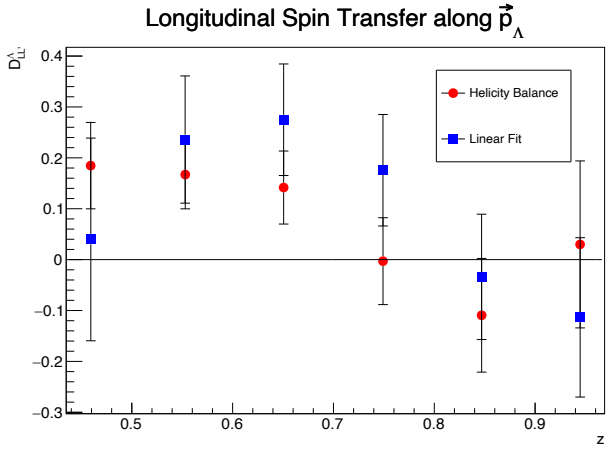
Weight $cos\theta_{REC}$ by $1 + \alpha D(y) P_b D_{ll,injected} cos\theta_{MC}$
with $D_{ll,injected} = 0.1$, averaged result is $D_{ll} = 0.107 \pm 0.078$

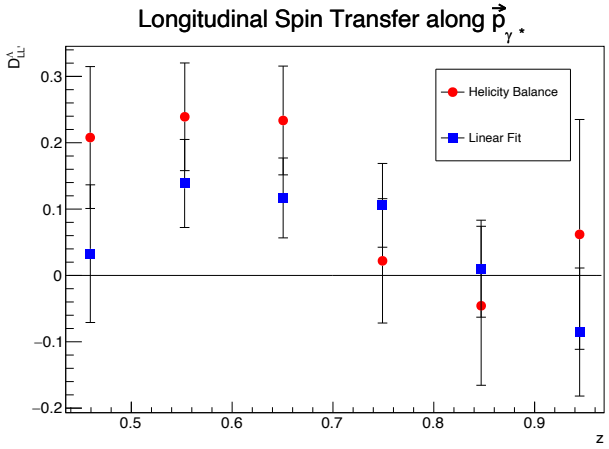
Truth Matching:
Require a MC truth Λ in event with
$|P^{\Lambda}_{Rec} - P^{\Lambda}_{MC}| < 0.1 GeV$

/work/clas12/rg-a/montecarlo/fall2018/torus+1/clasdis/nobg/

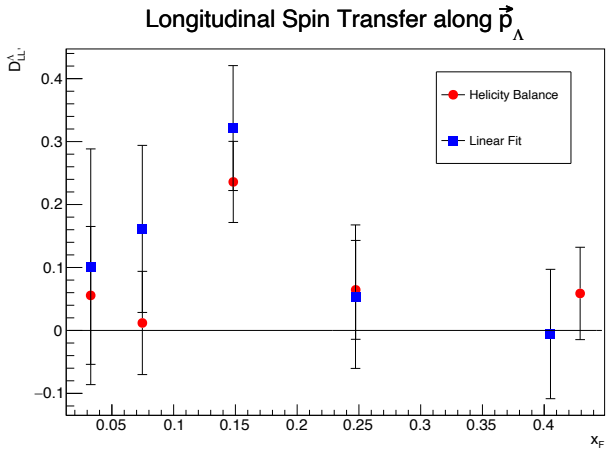
Method Comparison

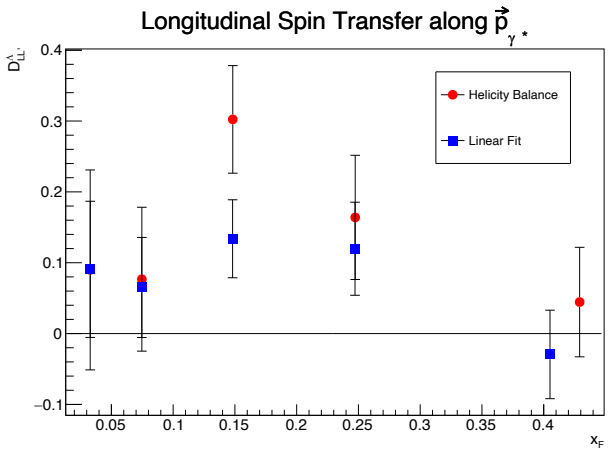
vs. z





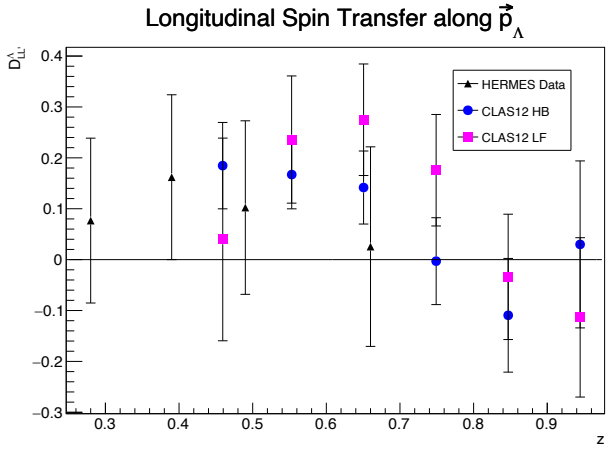
vs. x_F

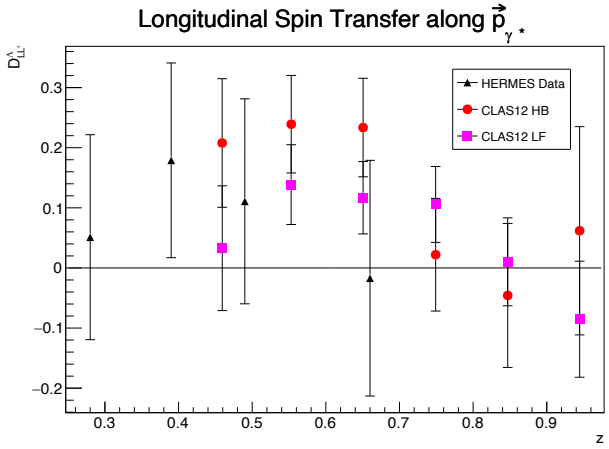




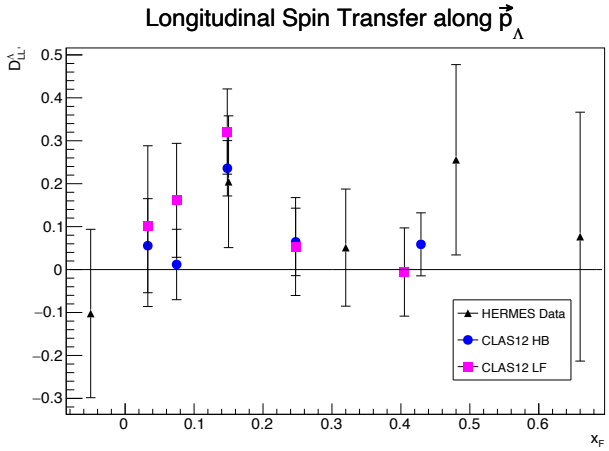
Method Comparison with HERMES

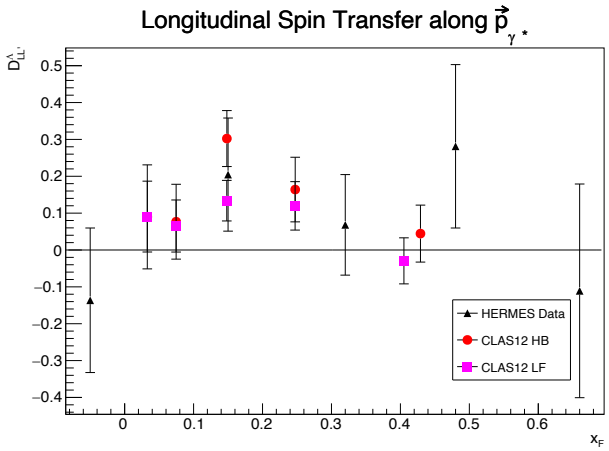
vs. z





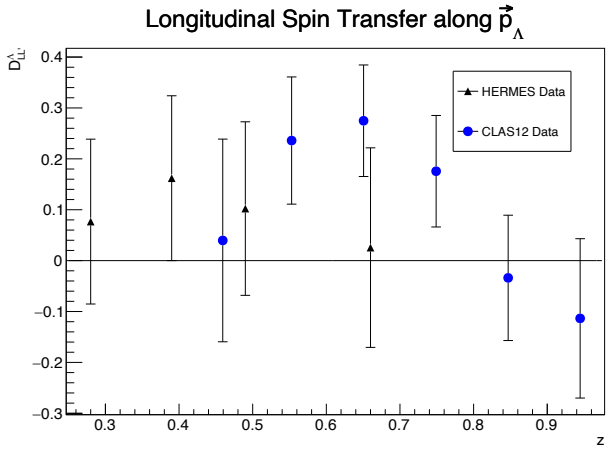
vs. x_F

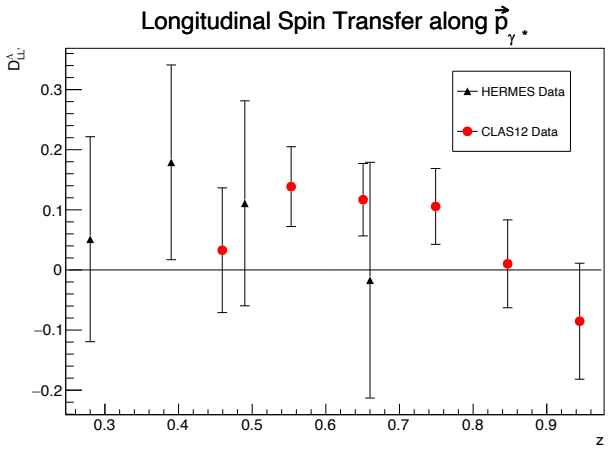




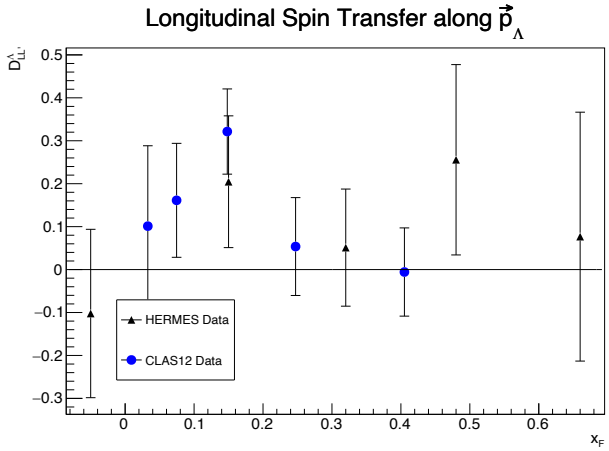
Linear Fit: Comparison with HERMES

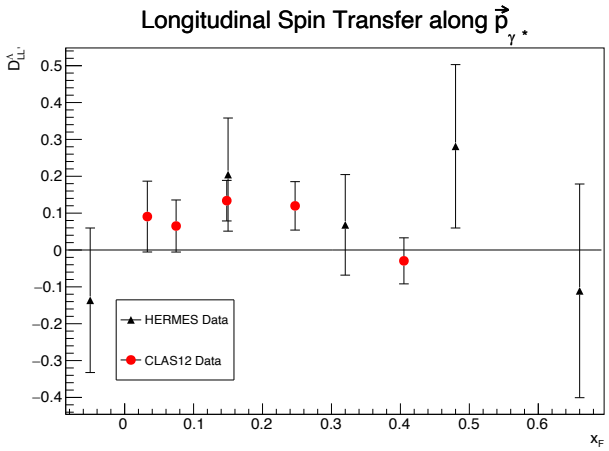
vs. z





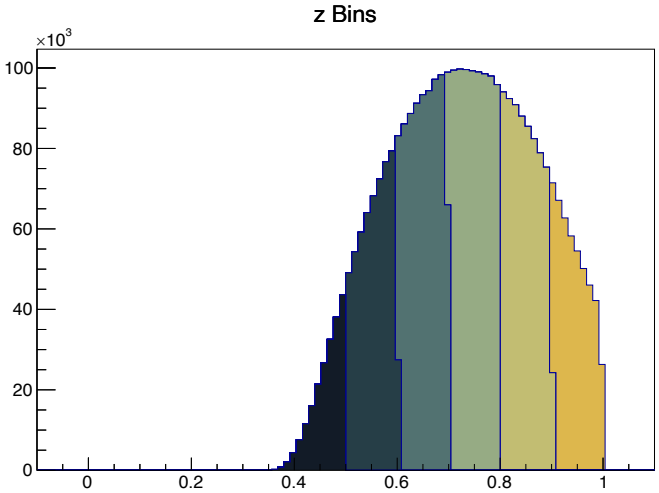
vs. x_F

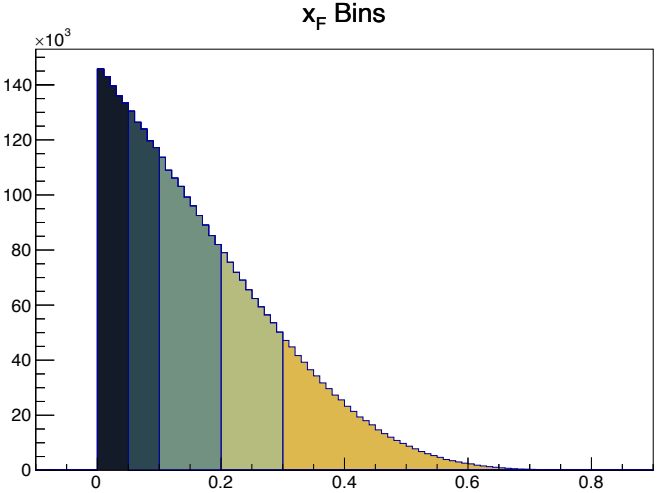




Note: errors are solely statistical

Binning

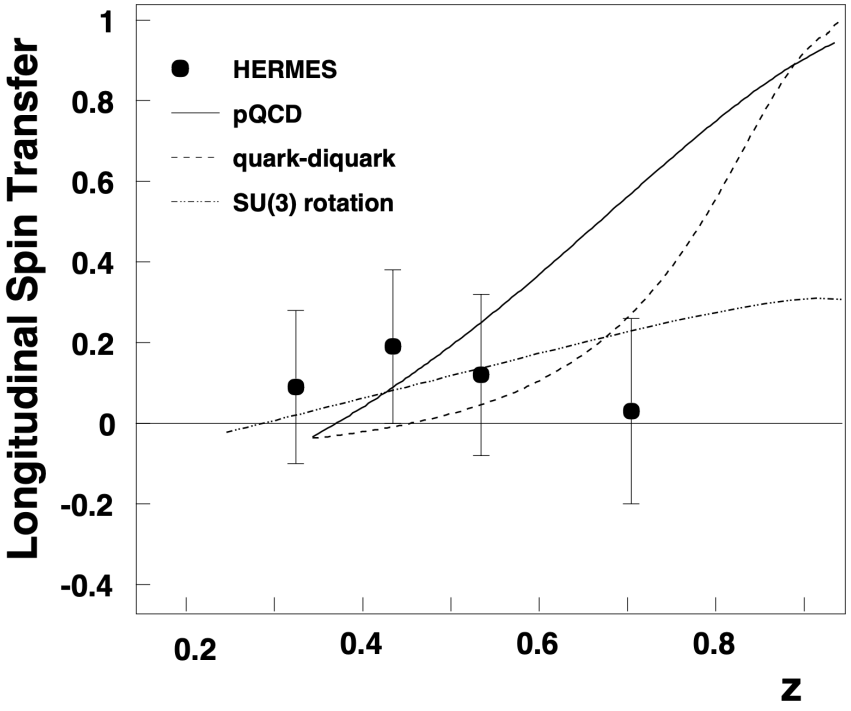


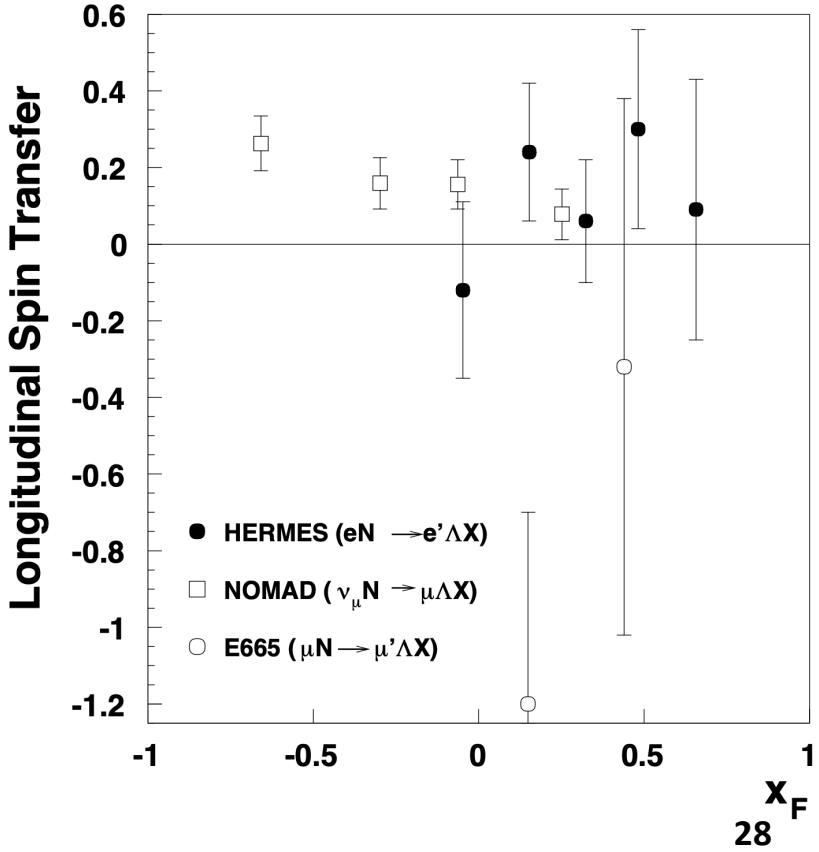


Standard kinematic cuts:

$Q^2 > 1$ & $W > 2$ & $y < 0.8$ & $x_F > 0$ & $z < 1$

HERMES Results





arXiv:hep-ex/0607004.