Longitudinal Spin Transfer to Λ^0 Hyperons in CLAS12

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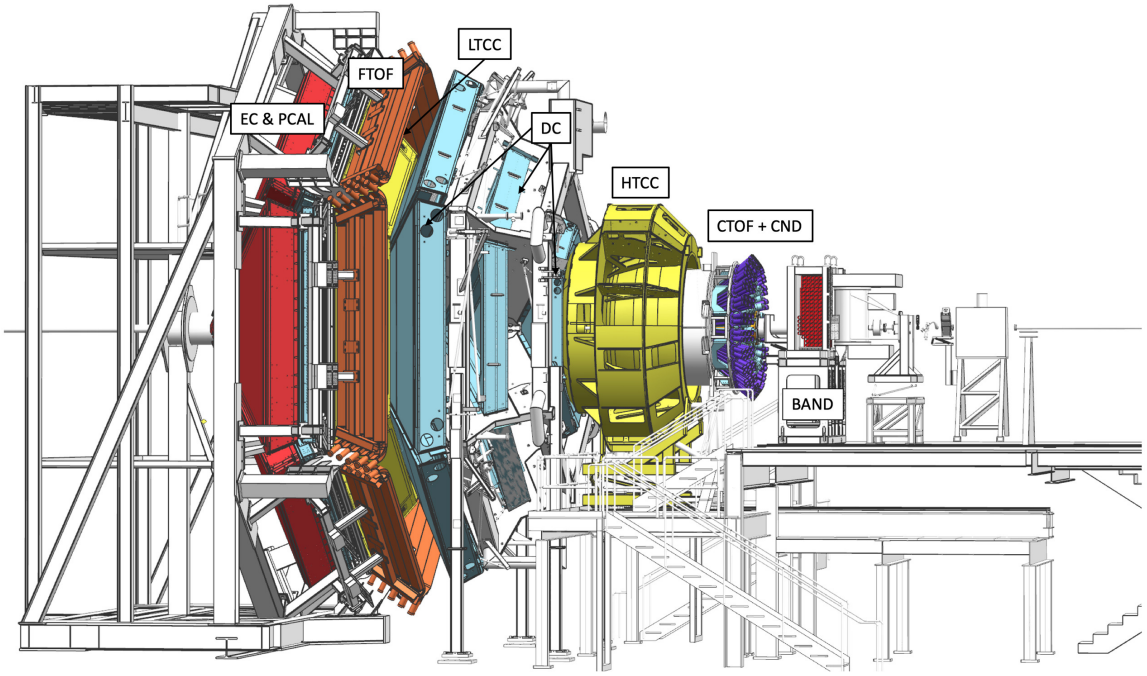
The CLAS12 Experiment



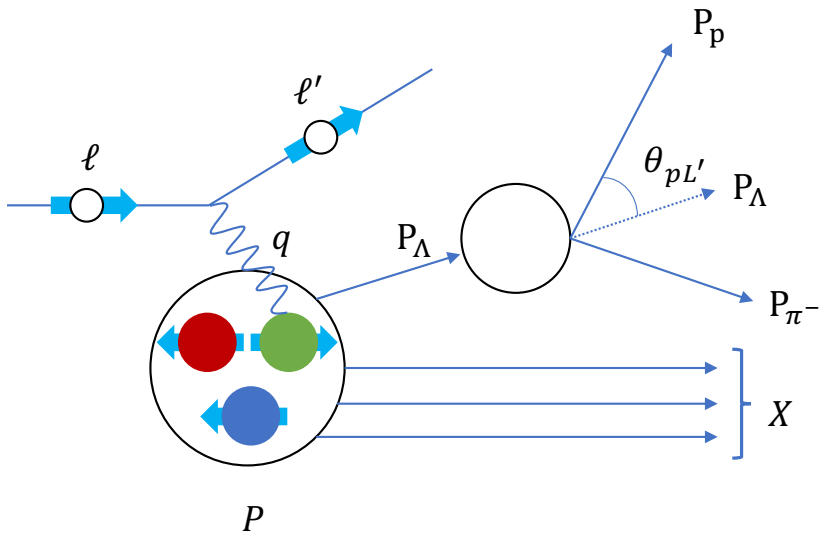
V. Burkert et al., The CLAS12 Spectrometer at Jefferson Laboratory, NIM A, January 2020

- Central Detector
  - Solenoid
  - Silicon Vertex Tracker
  - Central TOF Detector
  - Central Neutron Detector
- Forward Detector:
  - Torus Magnet
  - Drift Chambers
  - Forward TOF Detector
  - Calorimeters (ECAL and PCAL)
  - Cherenkov Counters
- Data Set:
  - Fall 2018 RGA Run Period
  - Unpolarized LH2 Target
  - 10.6 GeV beam with 86% polarization
  - Outbending torus

Spin Transfer

- Previous experiments (HERMES, NOMAD) observed small light quark spin transfer to Λ
- Λ spin transfer is easily accessible:

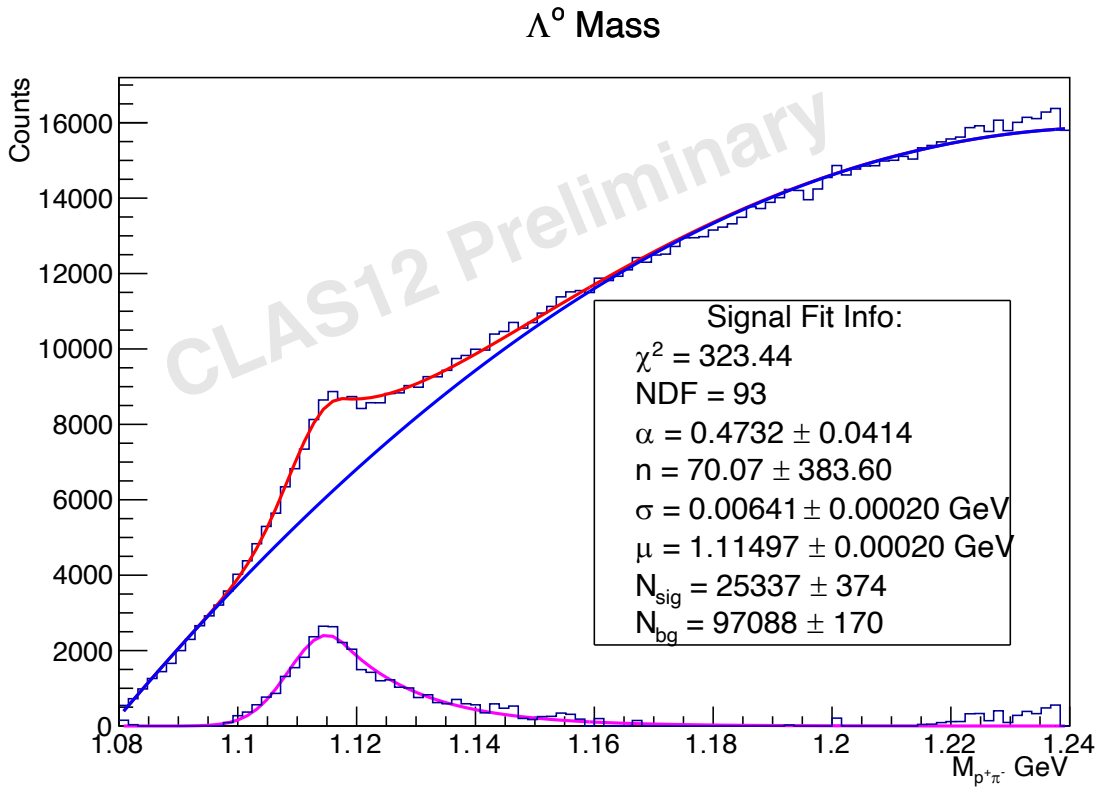
$$\frac{dN}{d\Omega_{\mathrm{p}}} \propto 1 + \alpha P_b D(y) D_{LL'}^{\Lambda} \cos\theta_{pL'}$$



- Strong u-quark dominance in e^- DIS so

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

Invariant Mass Signal

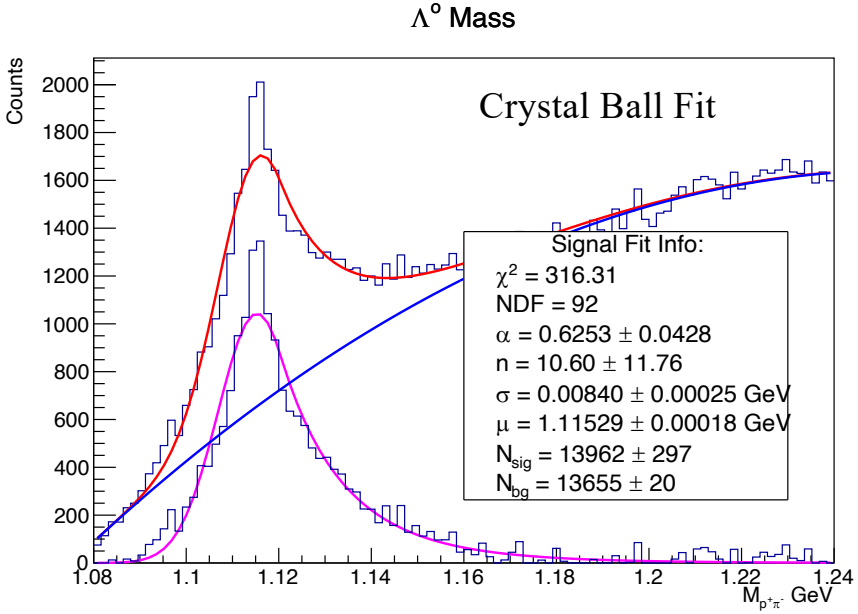


Standard SIDIS cuts:
$Q^2 > 1$ & $W > 2$ & $y < 0.8$ & $x_F > 0$ & $z < 1$
Also require identified $p^+\pi^-$ and scattered e^-

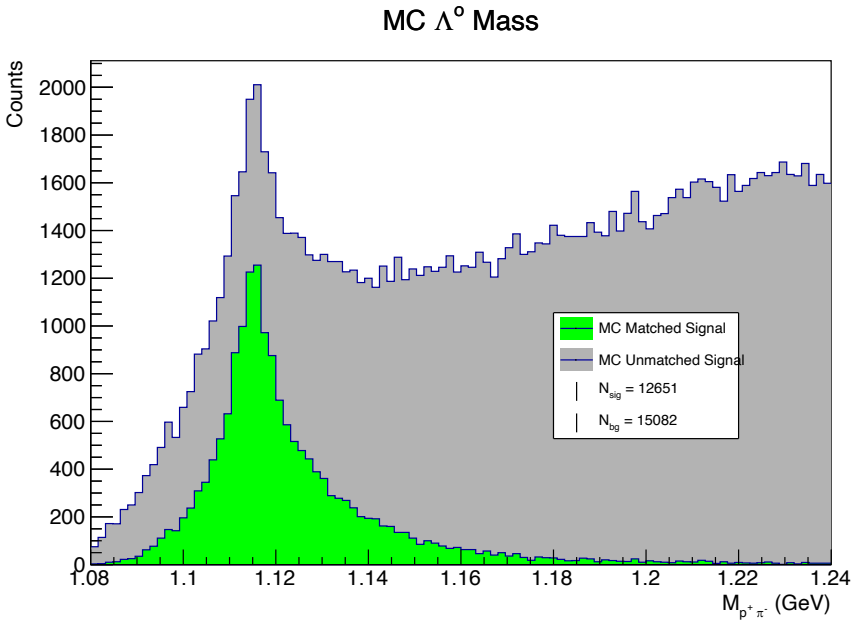
Crystal Ball Fit Function:

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

MC: Comparison with Truth-Matched Signal



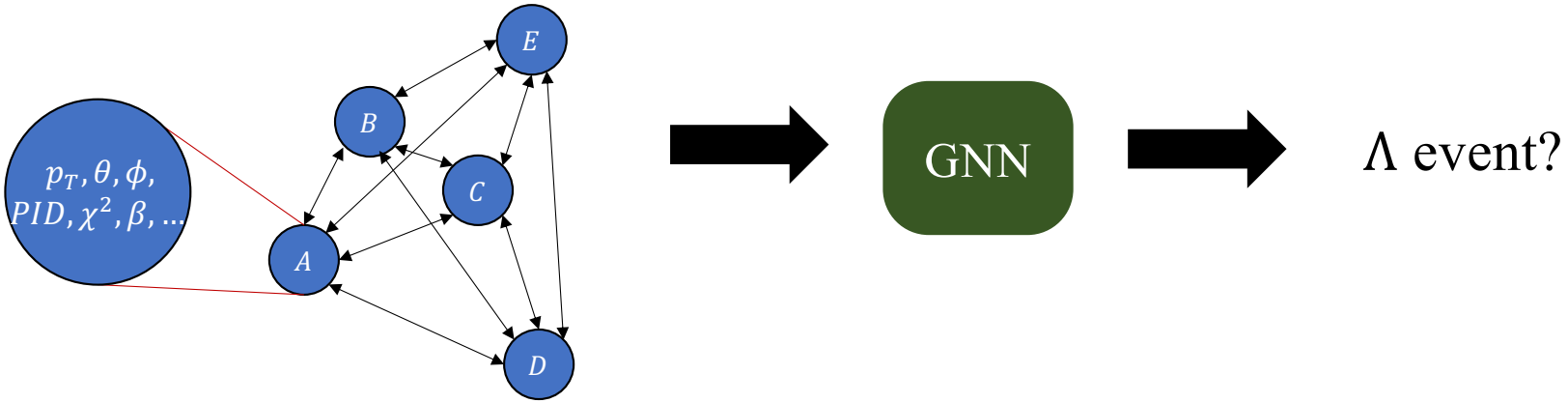
$Q^2 > 1$ & $W > 2$ & $y < 0.8$ & $x_F > 0$ & $z < 1$
and positive $p^+\pi^-$ PID and scattered e^-
(positive PID, $|\chi^2| < 3$, greatest momentum) required



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

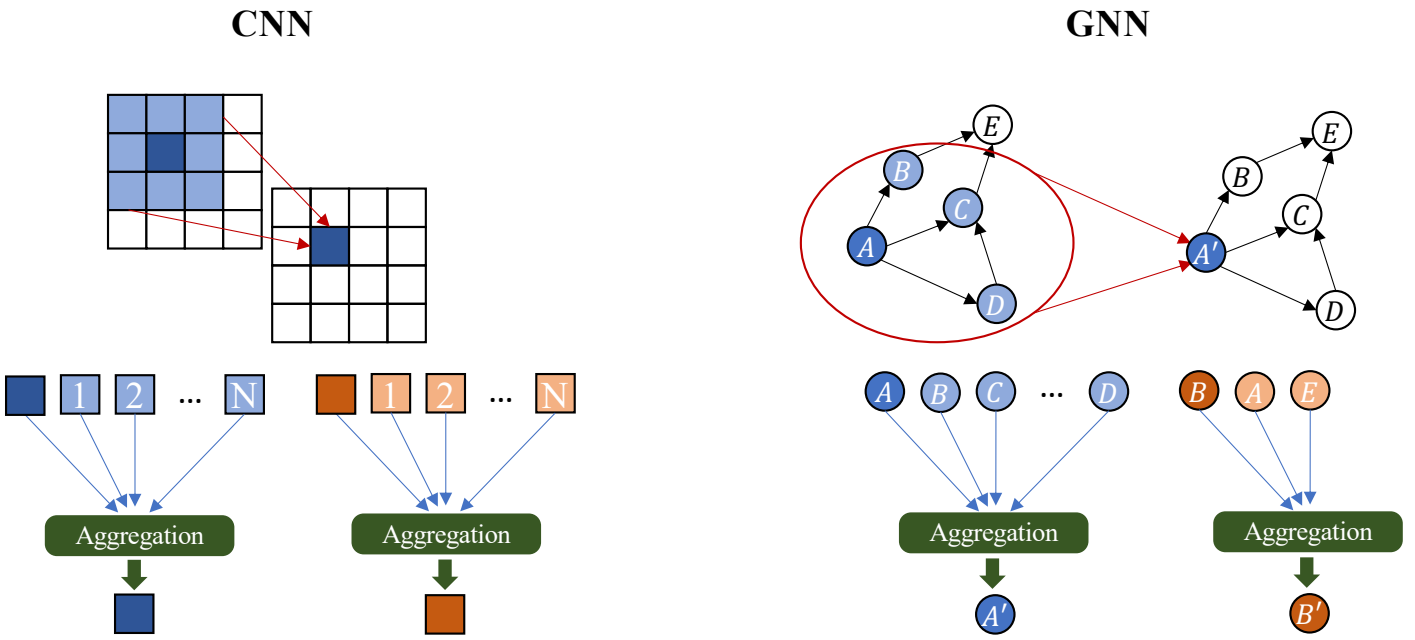
Graph Neural Networks (GNNs)

- **Idea**: use GNN to reduce background in invariant mass spectrum on event-by-event basis
- Pass each event as fully-connected, bidirectional graph
- Each particle is a node with its own data: p_T, θ, ϕ, etc.



Graph Neural Networks (GNNs)

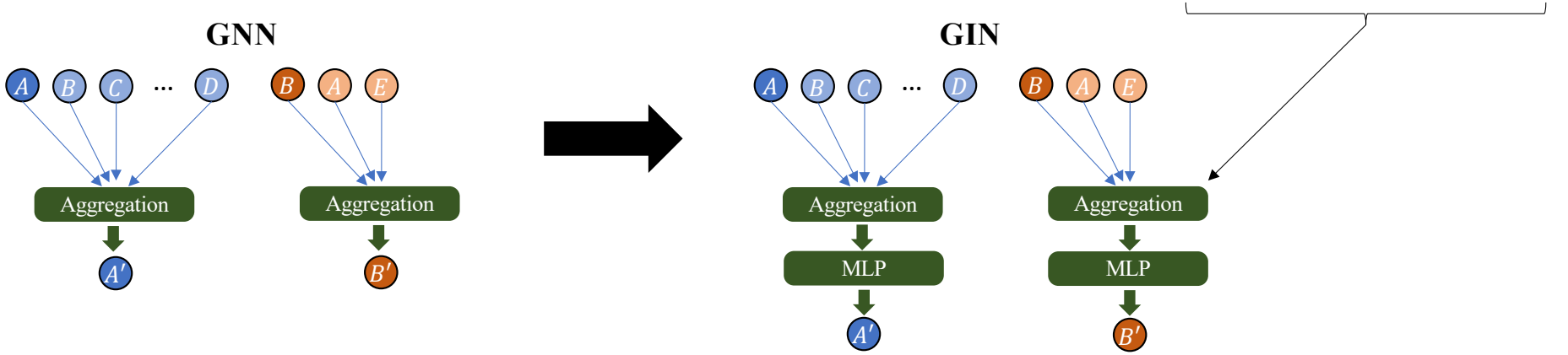
- At basic level, function as generalized form of CNNs



Graph Isomorphism Network (GIN)

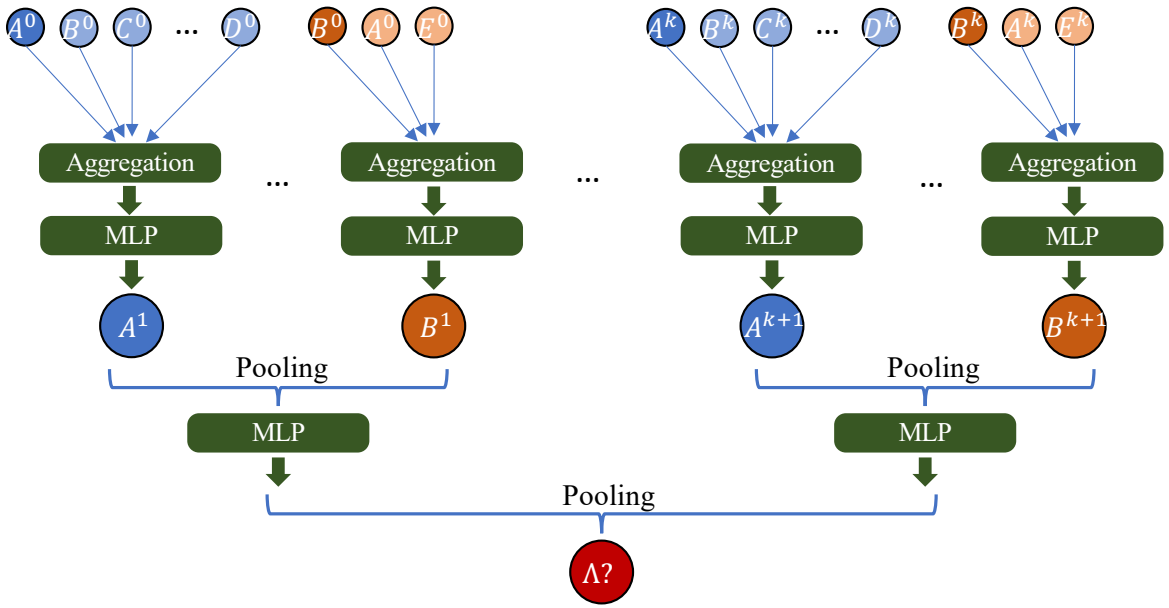
- Similar to Weisfeiler-Lehman (WL) Test, essentially ensures aggregation is injective
- Compare with basic GNN convolution:

$$h_v^{(k)} = \mathrm{MLP}^{(k)}\left(\left(1+\epsilon^{(k)}\right)\cdot h_v^{(k-1)} + \sum_{u\in\mathcal{N}(v)} h_u^{(k-1)}\right)$$



Graph Isomorphism Network (GIN)

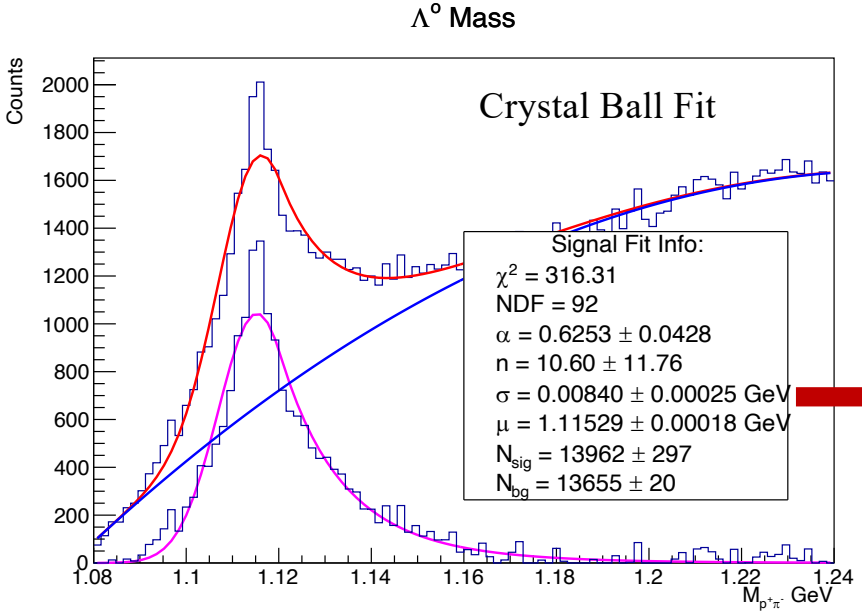
- Aggregation in final layer is across all previous layers/iterations



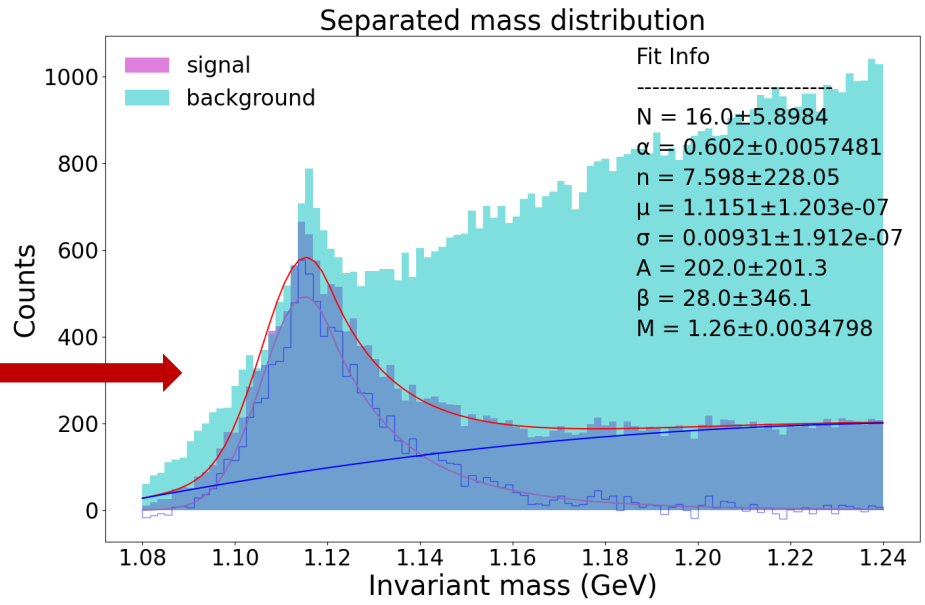
Implementation

- GIN: 5 layers, with 3-layer MLPs, Max pooling
- Dataset: Out-bending MC ~96k events with 50% Λ events, 75/25 training validation split, $p^+\pi^-$ mass $\in (1.10,1.13)$ GeV
- Particle features: $\Delta\widehat{p_T}$, $\Delta\hat{\phi}$, $\Delta\hat{\theta}$, β, χ^2 , PID, status/1000
- Edge features: $\Delta\widehat{p_T}_{ij}$, $\Delta\hat{\phi}_{ij}$, $\Delta\hat{\theta}_{ij}$ (Not used yet)
- Run for ~100 epochs on Duke Compute Cluster GPUs (CUDA 11.4)

MC Invariant Mass



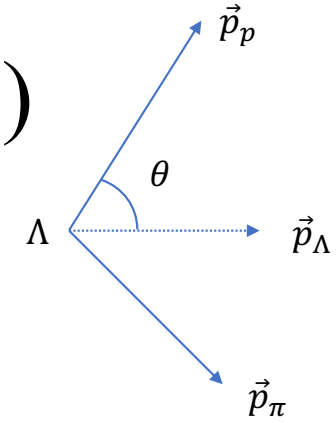
Before NN



After NN

85% test accuracy and background is significantly reduced!

Experimental Extraction (no GNNs)



- Choices for Λ spin quantization axis
  - Axis 1: along Λ momentum
  - Axis 2: along the virtual photon momentum in Λ rest frame
- Helicity balance method extracts on event-by-event basis:

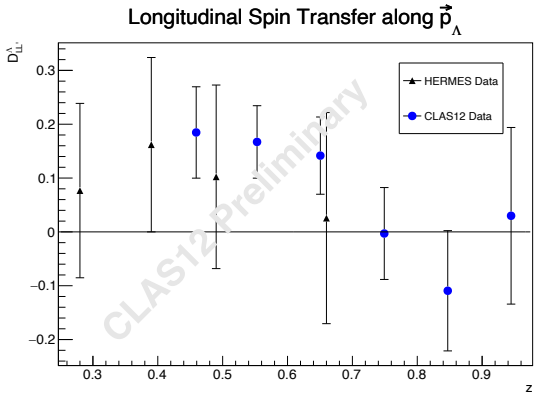
$$D^{\Lambda}_{LL'} = \frac{1}{\alpha \overline{P_b^2}} \cdot \frac{\Sigma_{i=1}^{N_\Lambda} P_{b,i} D(y_i) \cos\theta^i_{pL'}}{\Sigma_{i=1}^{N_\Lambda} D^2(y_i) \cos^2\theta^i_{pL'}}$$

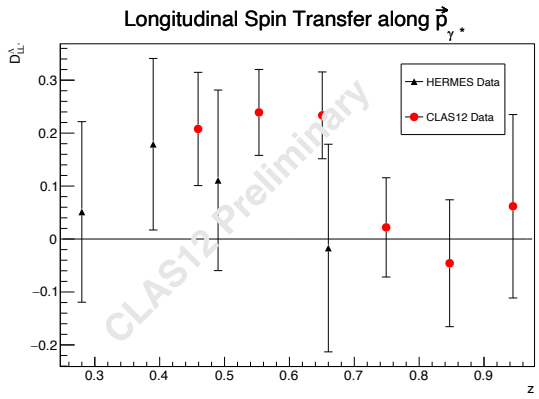
- Linear fit method looks at the cos θ distributions, however this requires acceptance correction.

Helicity Balance Results

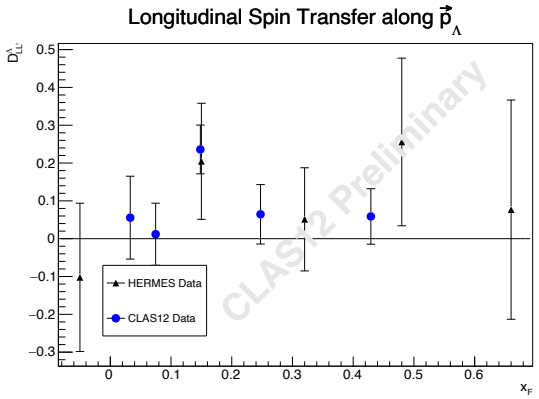
$$D_{LL}^{\Lambda} = \frac{D_{LL_{peak}} - \epsilon D_{LL_{bg}}}{1 - \epsilon}$$

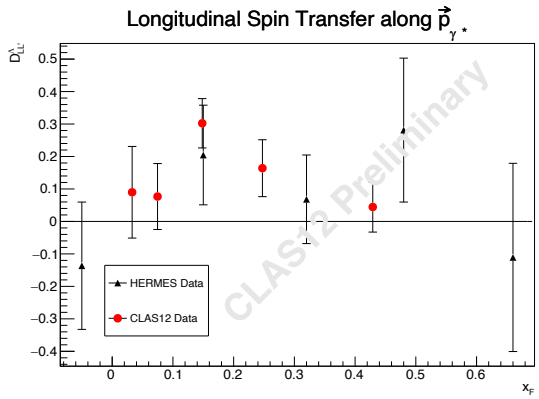
vs. z





vs. x_F





Note: errors are solely statistical

HERMES Results from:
A. Airapetian, et al. Physical Review D, 74(7), Oct 2006.

Summary

- Kinematically averaged $D_{LL'}$ results:

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

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

- **Next steps:**
  Improve GNN performance
  Transverse spin transfer measurement
  $\Lambda\, K$ spin correlations

Thank you!

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