Measurement of Transverse Spin Transfer of Λ and $\bar{\Lambda}$ in Transversely Polarized Proton+Proton Collisions at RHIC-STAR

Jincheng Mei
(for STAR Collaboration)
Shandong University

Outline

- Motivation
- Experiment Setup
- $\Lambda\,(\bar{\Lambda})$ Reconstruction
- Measurement Method
- D_{TT} Measurement Results
- Summary

Motivation

- Transversely polarized cross section of hyperons could be parameterized into three parts:

$$d\Delta_T\sigma^{(p_\perp p\to H_\perp X)} \propto \sum_{abcd}\int \underbrace{dx_a\, dx_b dz \delta f_a(x_a)}_{\text{transversity distribution}} f_b(x_b) \underbrace{d\Delta_T\sigma^{(a_\perp b\to c_\perp d)}}_{\text{pQCD calculation}} \underbrace{\Delta_T D_c^H(z)}_{\text{transversely polarized fragmentation function}}$$

Xu, Liang, Sichtermann. Phys.Rev. D73 (2006) 077503

Crucial elements for the study of nucleon spin structure: transversity distribution and transversely polarized fragmentation

- The transverse spin transfer is defined as:

$$D^H = P^H = \frac{d\sigma^{(p^\uparrow p\to H^\uparrow X)} - d\sigma^{(p^\uparrow p\to H^\downarrow X)}}{d\sigma^{(p^\uparrow p\to H^\uparrow X)} + d\sigma^{(p^\uparrow p\to H^\downarrow X)}} = \frac{d\Delta_T\sigma}{d\sigma}$$

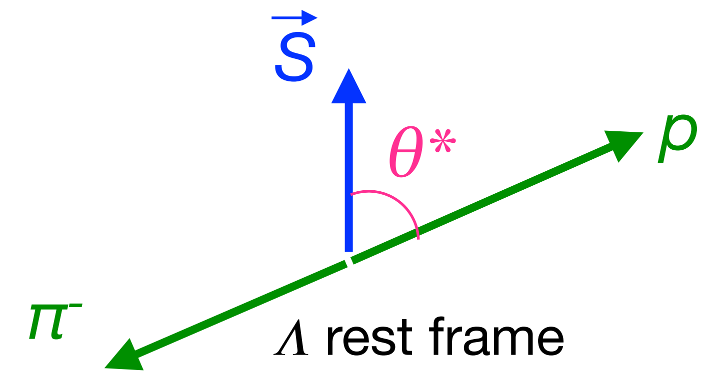
- The transverse spin transfer provides insights into transversely polarized fragmentation function and transversity distribution function.

Frames and Azimuthal Distributions

- $\Lambda\,(\bar{\Lambda})$ polarization can be extracted from the angular distribution of its decay product in its rest frame.

$$\frac{d\sigma}{dcos\theta^*} \propto (1 + \alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} cos\theta^*)$$

α: decay parameter
0.642 for Λ and -0.642 for $\bar{\Lambda}$
P_Λ: polarization of $\Lambda(\bar{\Lambda})$

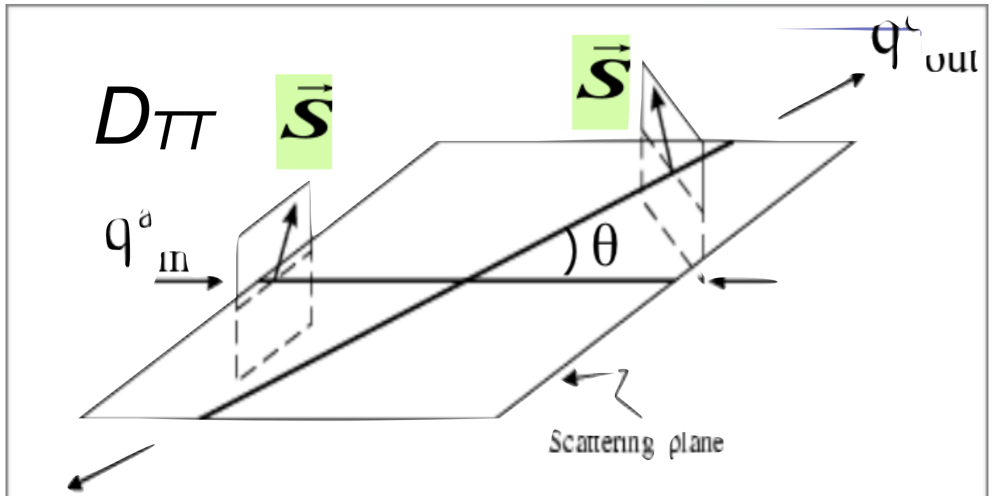


θ^* : the angle between decay particle (proton) momentum in Λ's rest frame and the direction of Λ polarization

In transverse case, azimuthal angle of polarization needs to be determined which is not needed in longitudinal case.

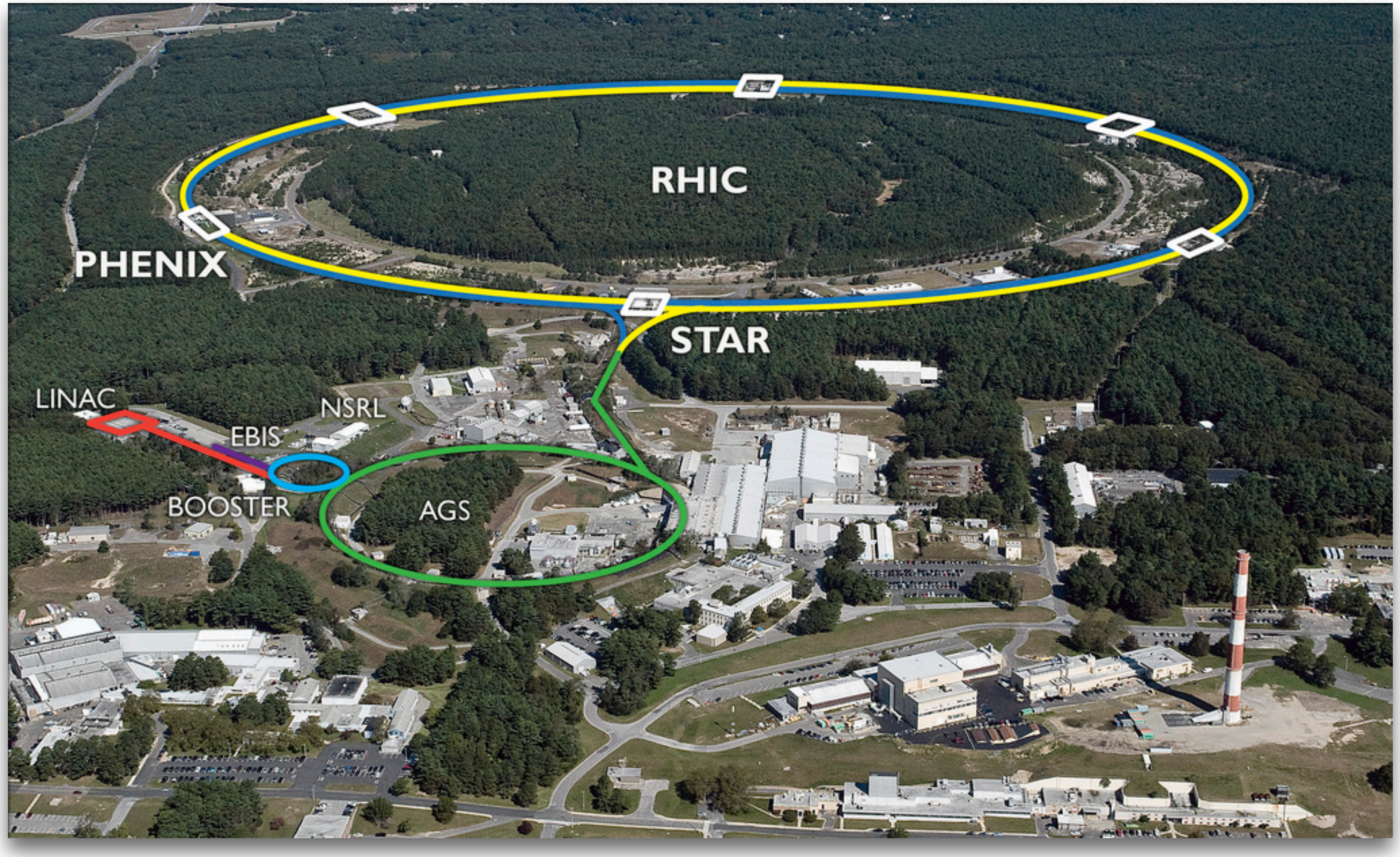
- D_{TT} : the spin transfer along the polarization of outgoing quark considering the rotation in scattering plane.

In this analysis, reconstructed jet axis is used as substitute of the outgoing quark momentum direction



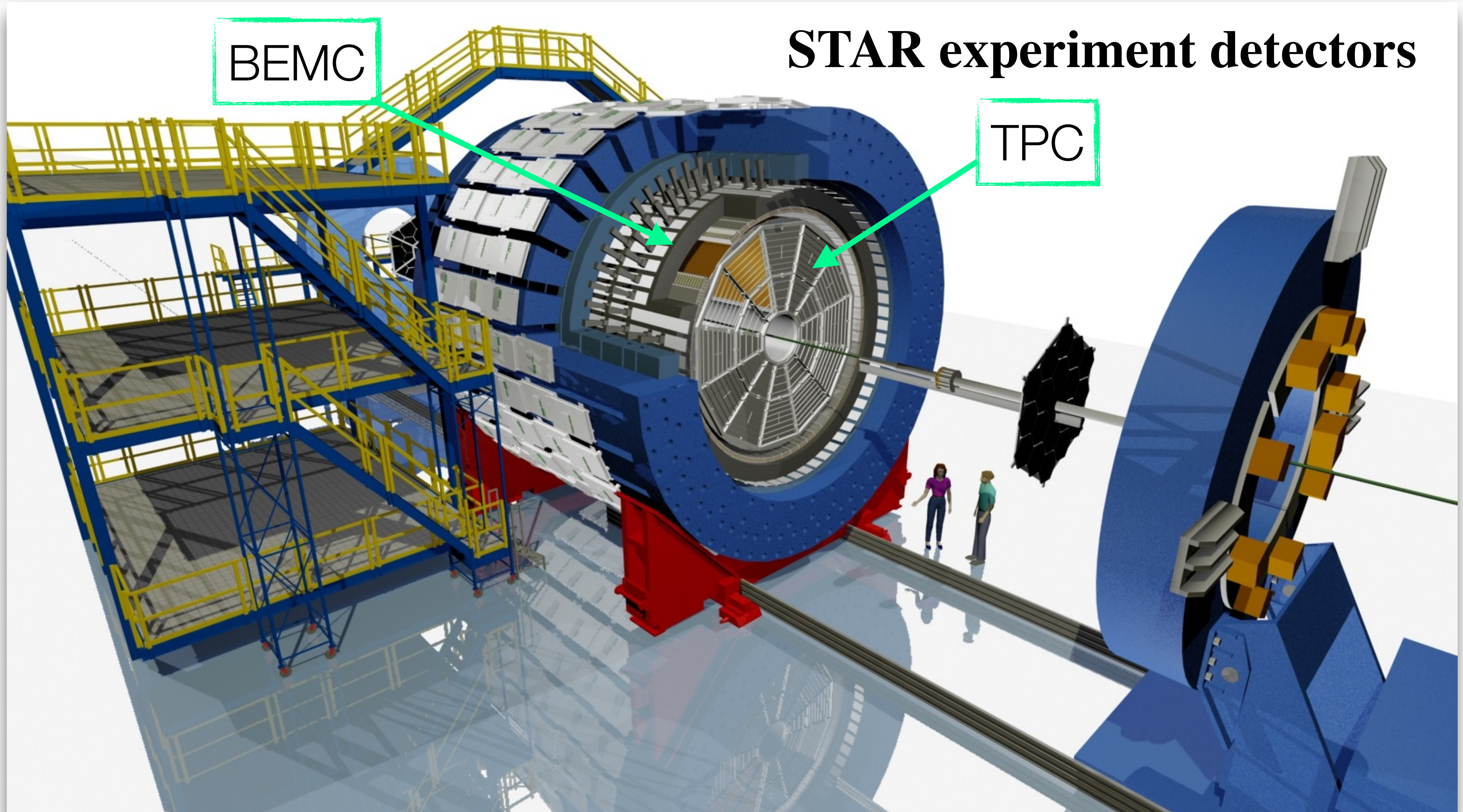
J.Collins et al, NPB420 (1994)565

RHIC - Relativistic Heavy Ion Collider



- The Relativistic Heavy Ion Collider (RHIC) is the first and only polarized proton collider in the world.
- Data sample: transversely polarized p+p collisions at 200GeV taken with STAR detector in 2012.
- RHIC Beam polarization: blue beam: 64%, yellow beam: 58%.

STAR Detectors

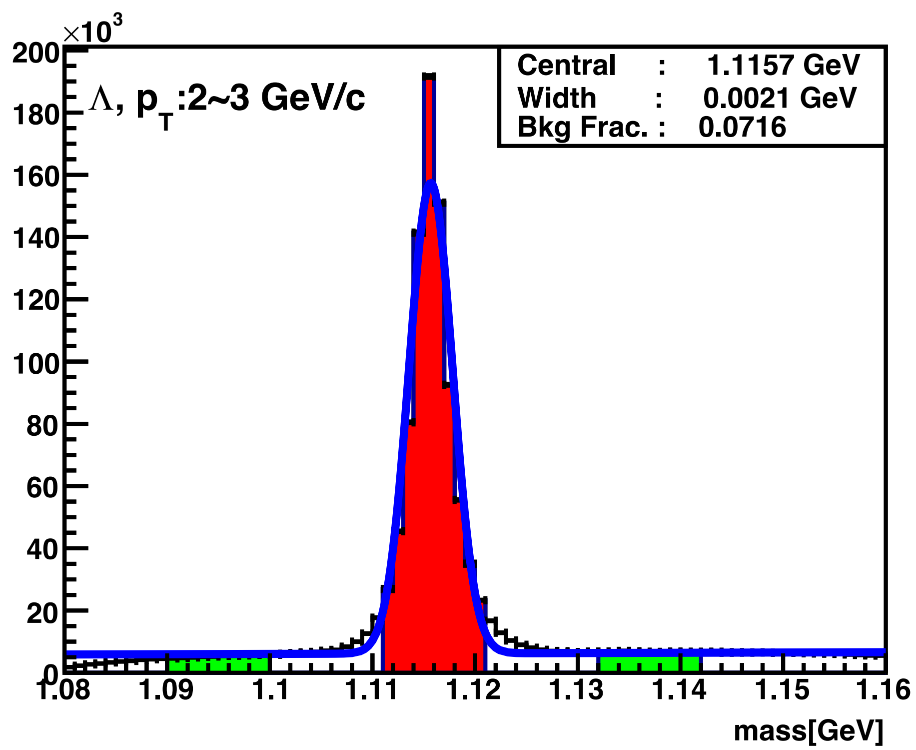


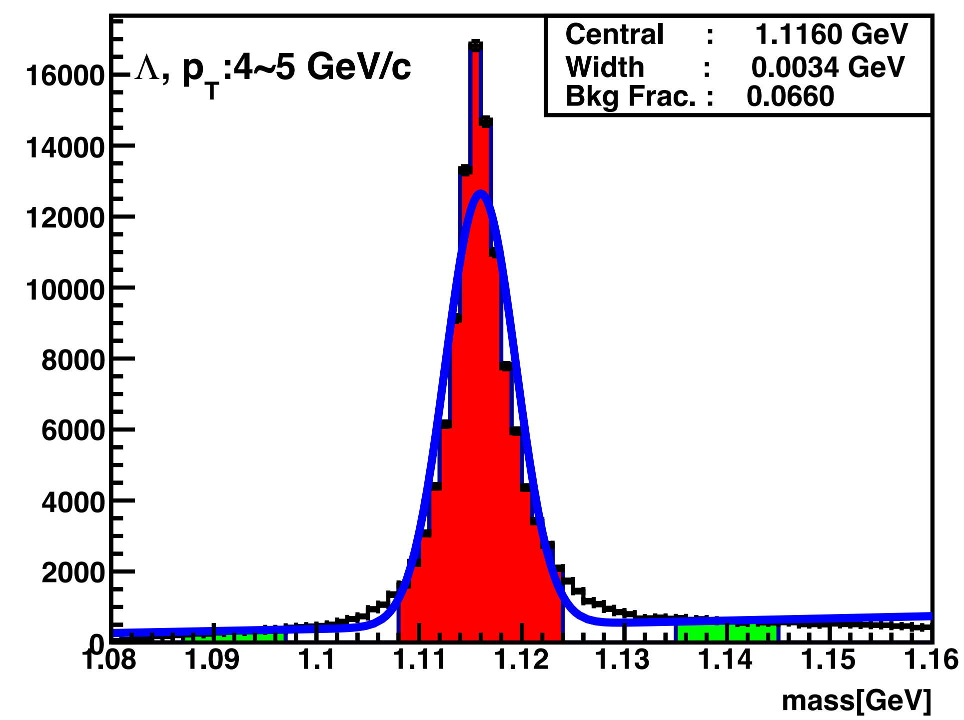
Sub detectors involved in this analysis:

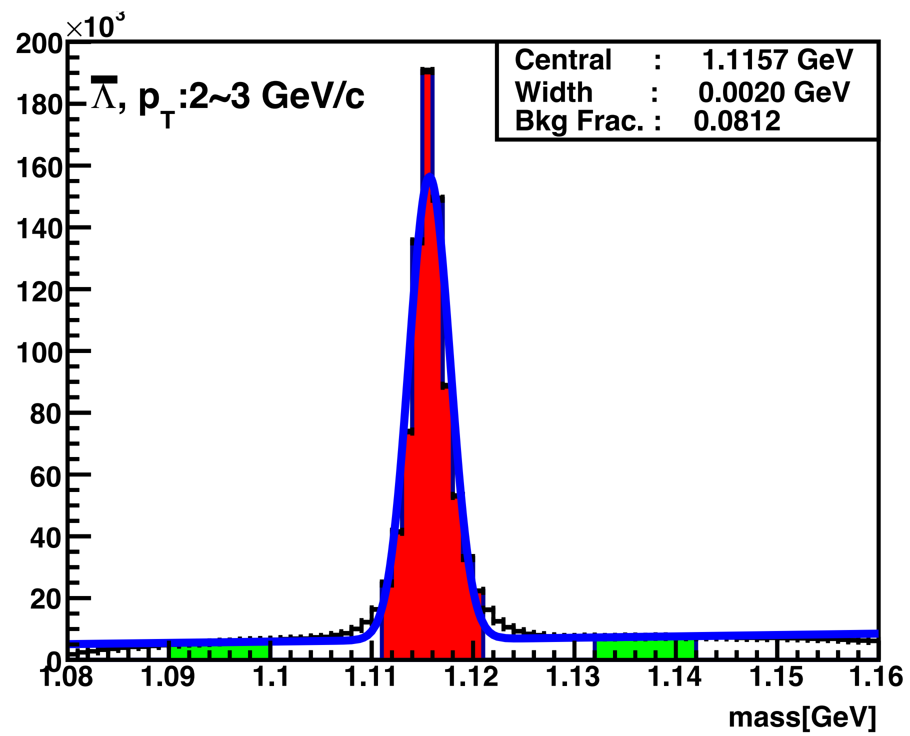
- TPC : Time Projection Chamber $\eta \sim (-1.2, 1.2)$
  Track reconstruction of charged particles and charged particle identification.
- BEMC: Barrel Electromagnetic Calorimeter $\eta \sim (-1.0, 1.0)$
  For triggering.

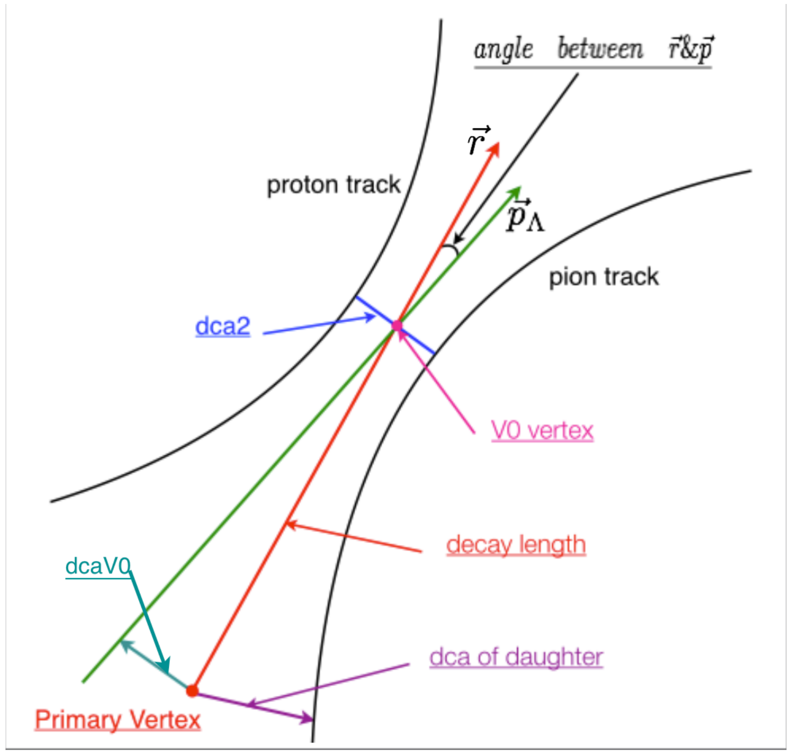
Λ and $\bar{\Lambda}$ Reconstruction

- Applied topological cuts to reconstruct Λ and $\bar{\Lambda}$ via their decay channels: $\Lambda \rightarrow p\pi^{-}$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^{+}$









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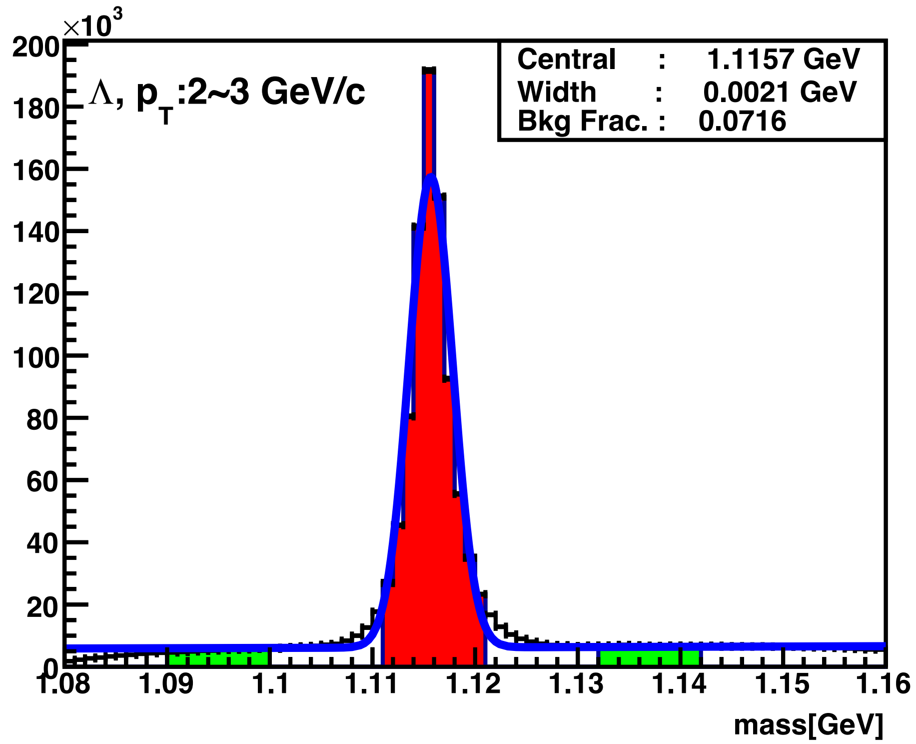
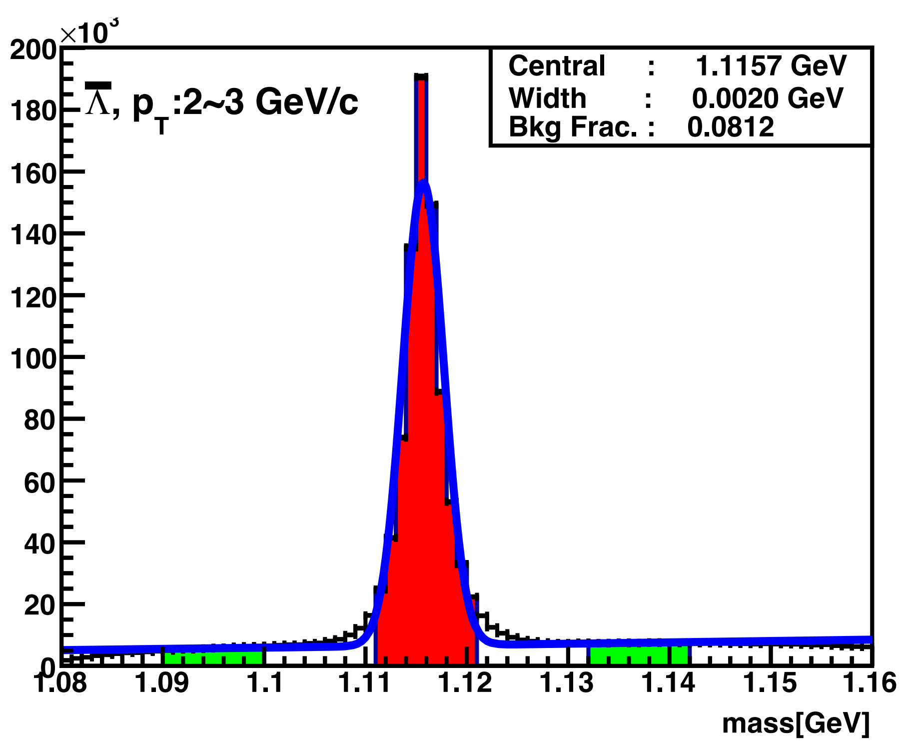
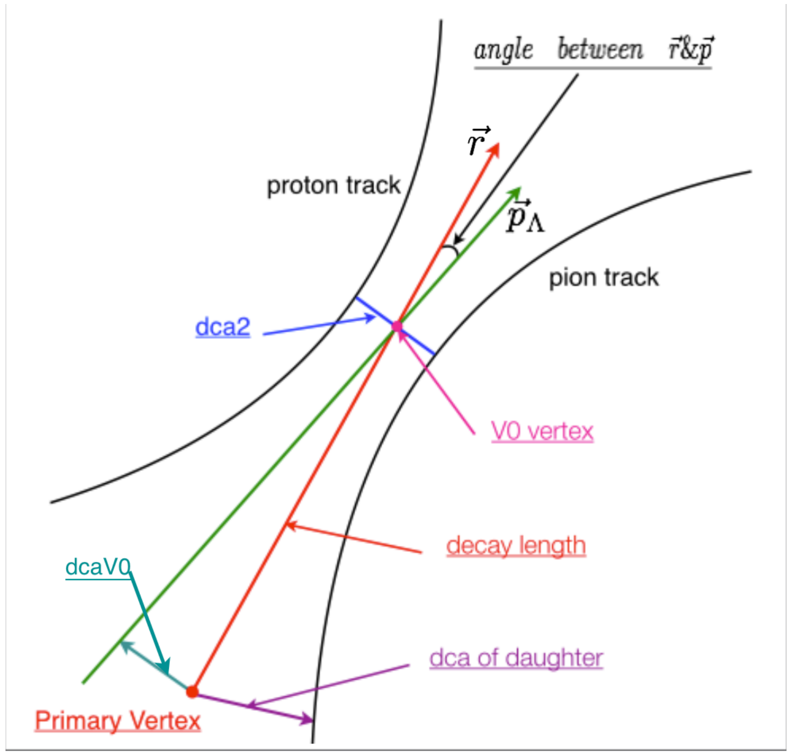
- Applied topological cuts to reconstruct Λ and $\bar{\Lambda}$ via their decay channels: $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$



Raw yields of Λ and $\bar{\Lambda}$ after selection

P_T [GeV/c]	Λ	$\bar{\Lambda}$
1~2	490 k	544 k
2~3	323 k	382 k
3~4	183 k	201 k
4~5	78 k	74 k
5~6	32 k	26 k
6~8	20 k	14 k
Total	1126 k	1242 k





Λ and $\bar{\Lambda}$ Reconstruction

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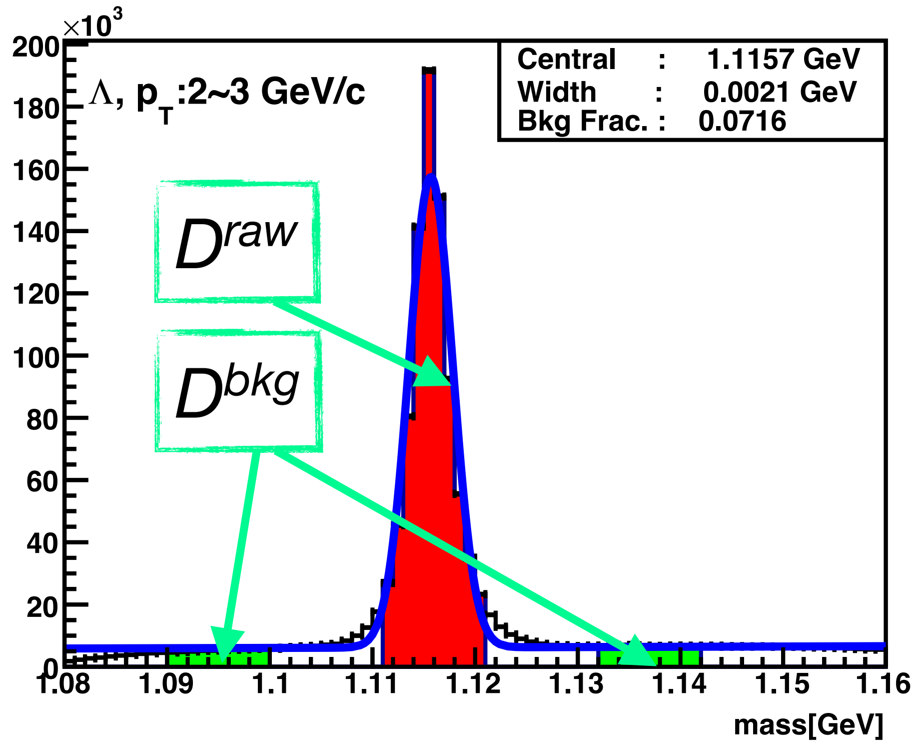

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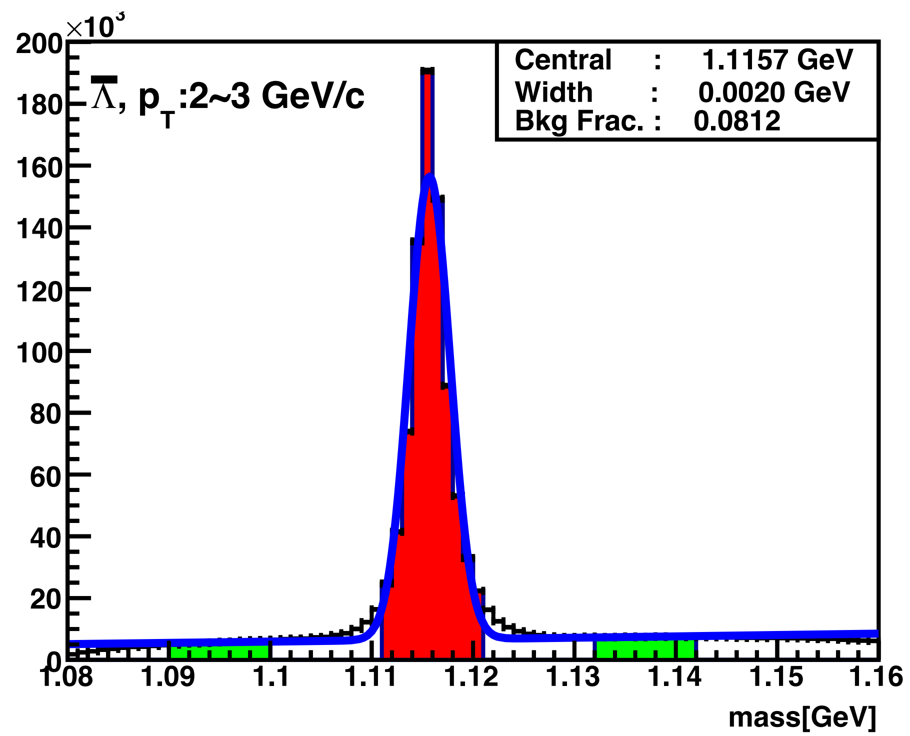


Background fraction is estimated by side bands.
The obtained D^{raw} and their statistical uncertainties were corrected for the residual background:

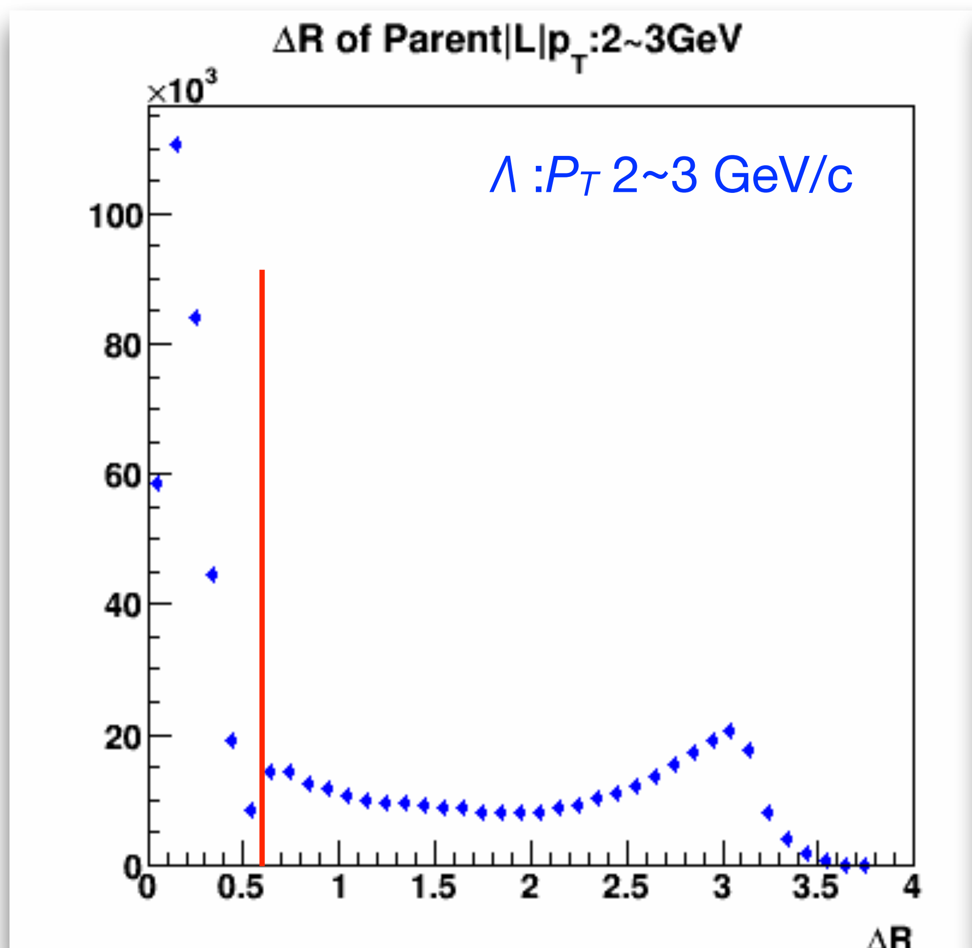
$$D_{TT} = \frac{D_{TT}^{raw} - rD_{TT}^{bkg}}{1-r}$$

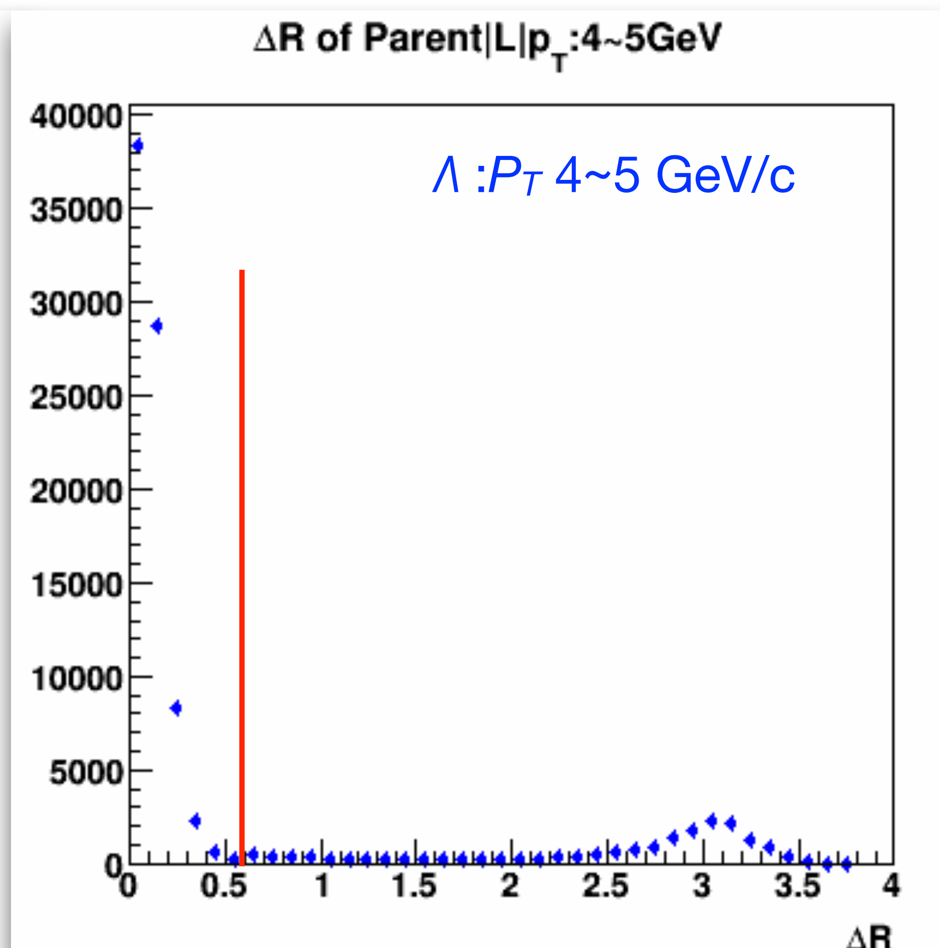
$$\delta D_{TT} = \frac{\sqrt{(\delta D_{TT}^{raw})^2 + \left(r\delta D_{TT}^{bkg}\right)^2}}{1-r}$$

r : residual background fraction

Jet Correlation

- Use anti-Kt algorithm to reconstruct jet then make correlation to a $\Lambda\,(\bar{\Lambda})$by calculating ΔR.
- Request $\eta_{jet} \sim (-0.7, 0.9)$, $P_T > 5.0$ GeV/c, neutral fraction of Jet < 0.95.
  If $\Delta R < 0.6$ (near side), we use the jet momentum direction as outgoing quark direction to obtain quark's polarization direction.





$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

$$\Delta\phi = \phi_{\Lambda} - \phi_{jet}$$

$$\Delta\eta = \eta_{\Lambda} - \eta_{jet}$$

Measurement Method

- Based on the relationship between polarization of $\Lambda(\bar{\Lambda})$ and the angular distribution of its decay product in its rest frame.

$$\frac{d\sigma}{dcos\theta^*} \propto (1 + \alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} cos\theta^*)$$

- In this analysis, D_{TT} is extracted from the asymmetry of Λ counts with opposite beam polarization in a small cosθ* bin:

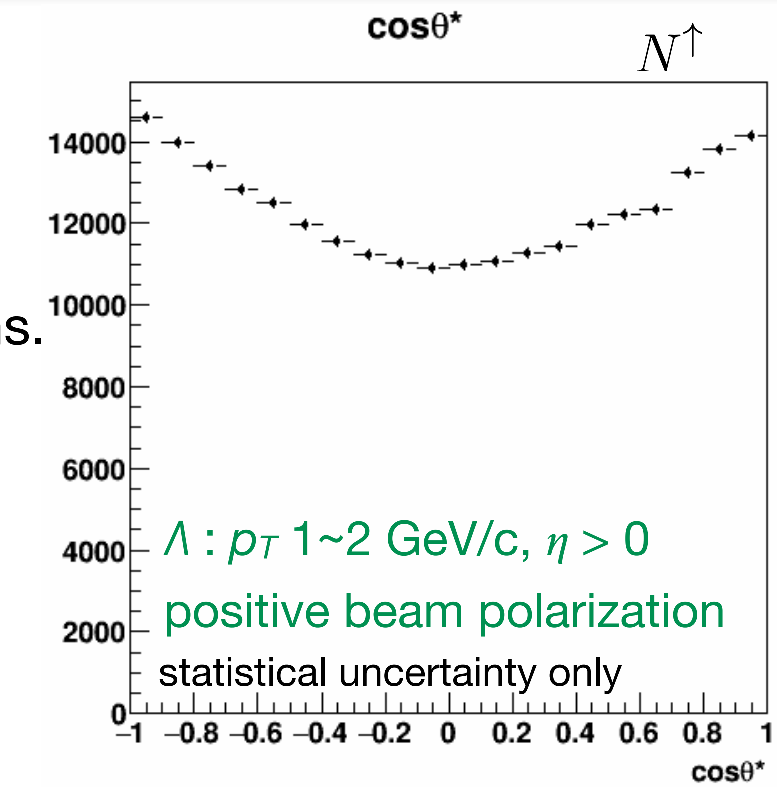
$$D_{TT} = \frac{1}{\alpha P_{beam} < \cos\theta^* >} \frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}$$

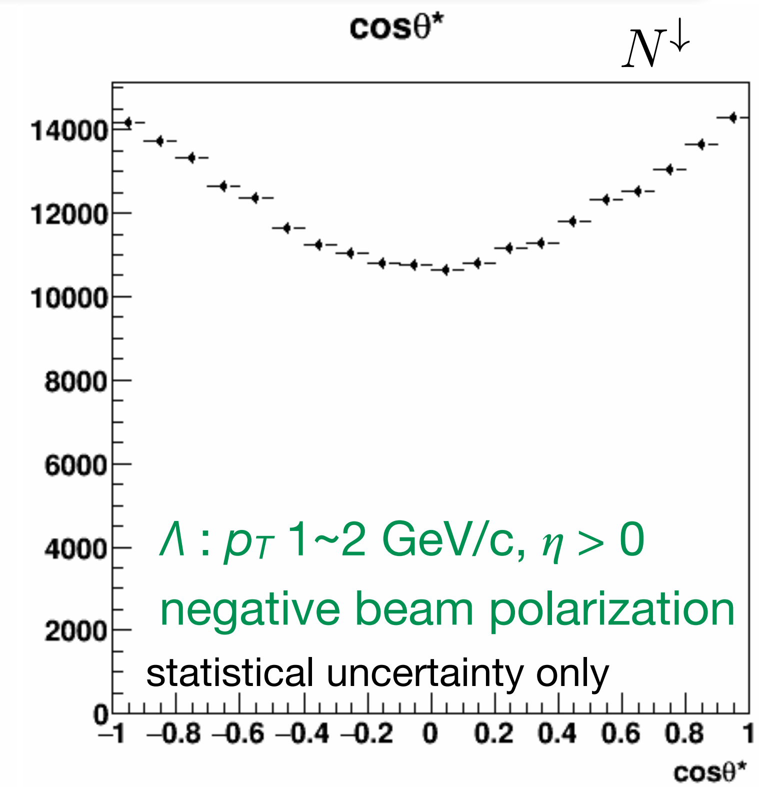
P_{beam} : polarization of beam
<cosθ*> : mean in each cosθ* bin
$N^{\uparrow}$: $\Lambda(\bar{\Lambda})$ counts with positive beam polarization
$N^{\downarrow}$: $\Lambda(\bar{\Lambda})$ counts with negative beam polarization
R: relative luminosity

- Acceptance of reverse beam polarization is expected to be the same in each cosθ* bin, and thus cancelled.

Extraction of Spin Transfer D_{TT}

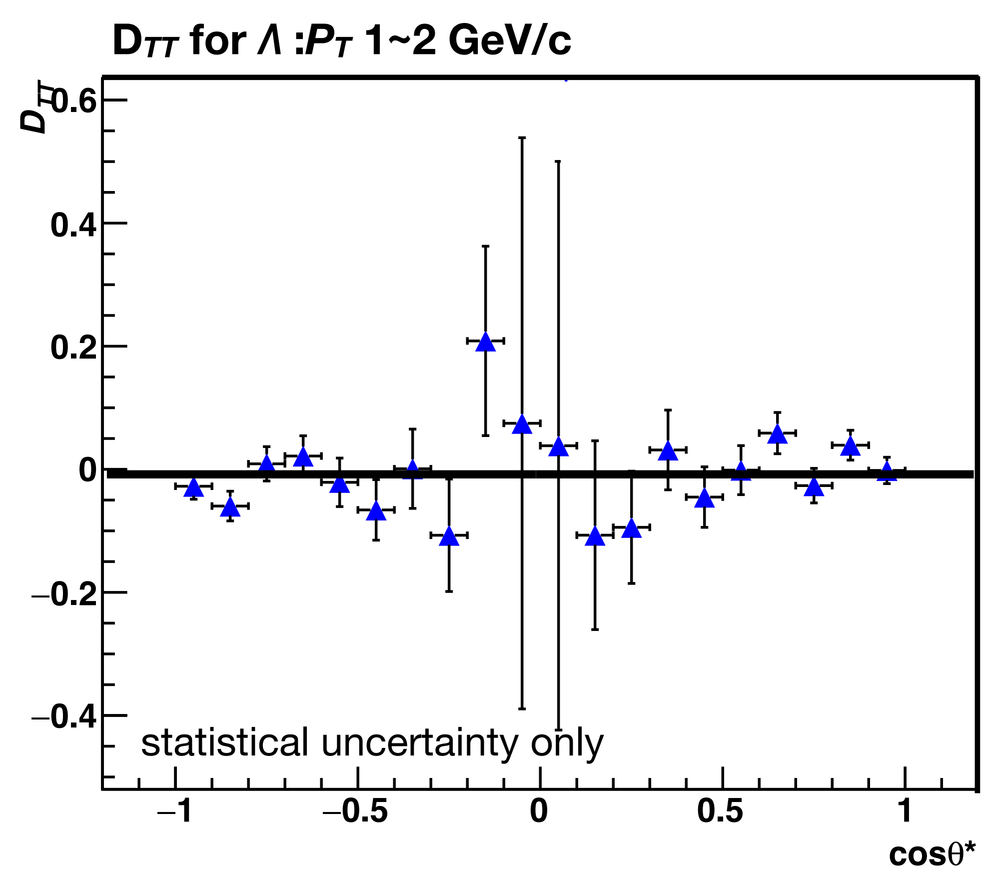
Λ counts versus *cosθ**
with opposite beam polarization.
Separate the whole range of *cosθ** into 20 bins.





D_{TT} extraction in each *cosθ**

$$D_{TT} = \frac{1}{\alpha P_{beam} < \cos\theta^* >} \frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}$$



Fit the 20 D_{TT} with a constant.
Fitted result as the D_{TT} in the p_T bin.

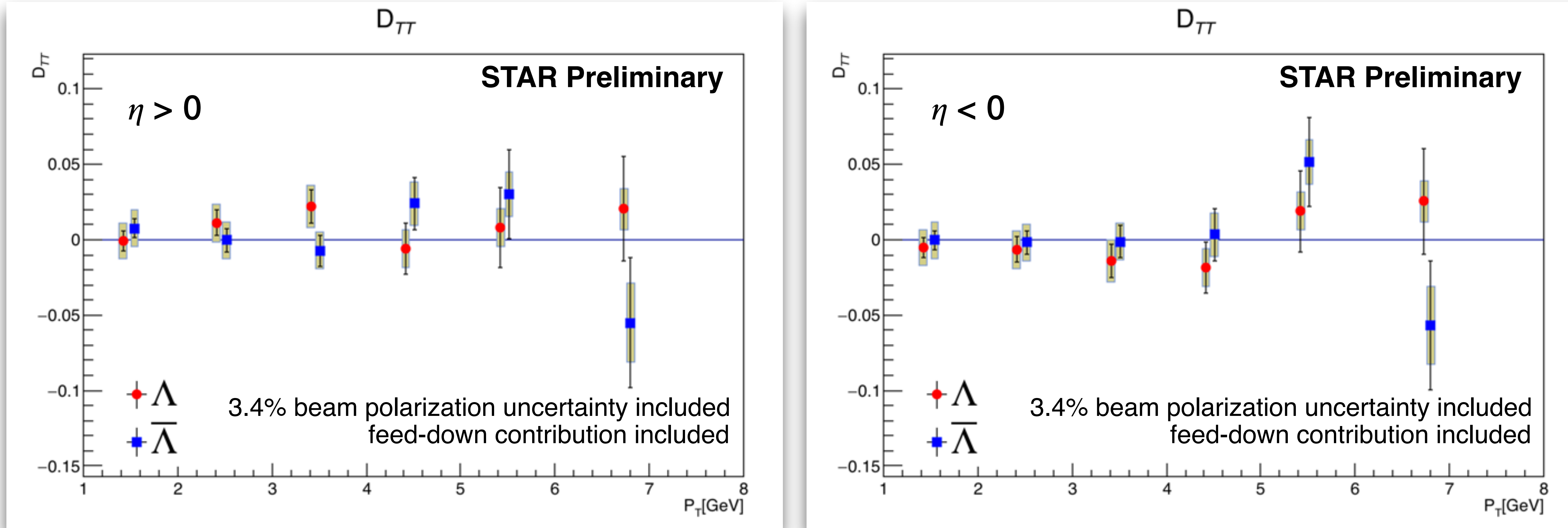
The method passed the null check with K_S^0

Systematic Uncertainty

- 3.4% scale uncertainty from RHIC beam polarization measurement.
  —obtained from the polarimetry group of RHIC
- 2% from decay parameter (0.642 ± 0.013).
  —PDG
- 0.012 from relative luminosity measurement.
- Residual background fraction estimation.
  —Compare two methods of residual background fraction (fit and side-band)
- Trigger bias estimated from MC simulation.
- Pileup effect.
- The sum of systematic uncertainty is range of 0.012 ~ 0.026

Results of D_{TT}

- Results of transverse spin transfer D_{TT} of Λ and $\bar{\Lambda}$ in p+p collision at 200 GeV.



- Most precise measurement on $\Lambda\,(\bar{\Lambda})$ polarization in p+p collision at RHIC, which reach p_T ~8 GeV/c with statistical uncertainty of 0.04 .
- The dominant source of systematic uncertainty is from relative luminosity in low p_T.
- D_{TT} of Λ and $\bar{\Lambda}$ are consistent with each other and consistent with zero at the current precision.

Summary

- First measurement on transverse spin transfer of $\Lambda(\bar{\Lambda})$ in p+p collisions, which can provide insights into transversely polarized fragmentation function and nucleon transversity distribution.
- The Λ ($\bar{\Lambda}$) sample is the largest so far in p+p collision at RHIC and the precision of D_{TT} is ~0.04 at p_T ~8 GeV/c for Λ ($\bar{\Lambda}$)
- D_{TT} of Λ and $\bar{\Lambda}$ are consistent with each other and consistent with zero at the presently available precision.

Thanks for Your Attention!

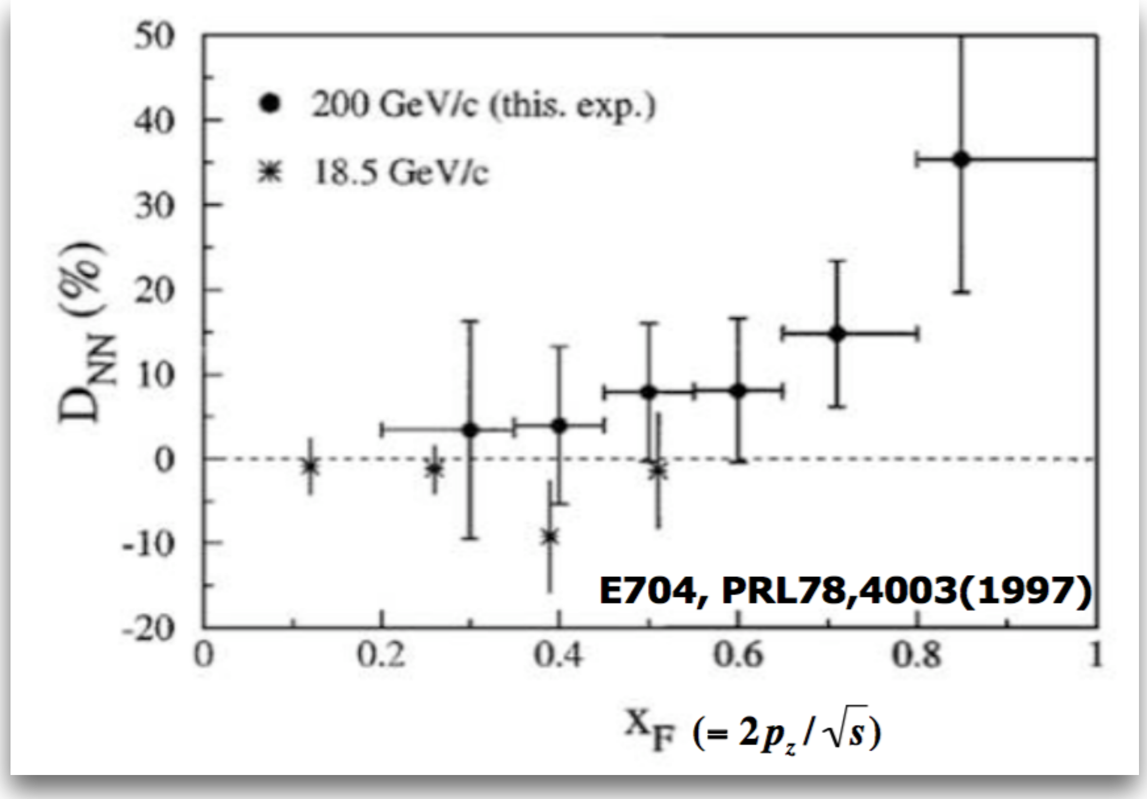
Backup

Previous Results

- Previous measurement of transverse spin transfer.
  -Only D_{NN} spin transfer w.r.t. production plane (Fermilab E704 Collaboration,1997).

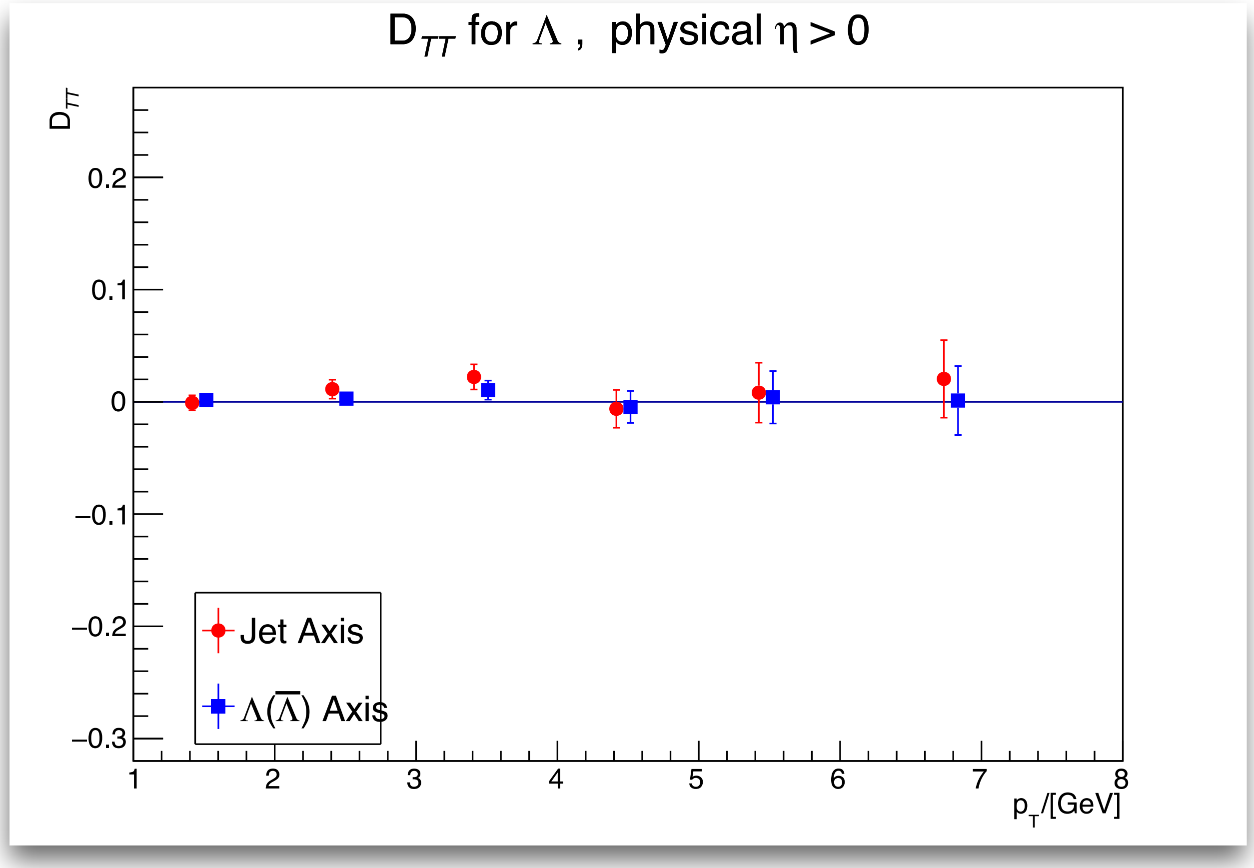
D_{NN} : spin transfer along normal direction of Λ production plane.

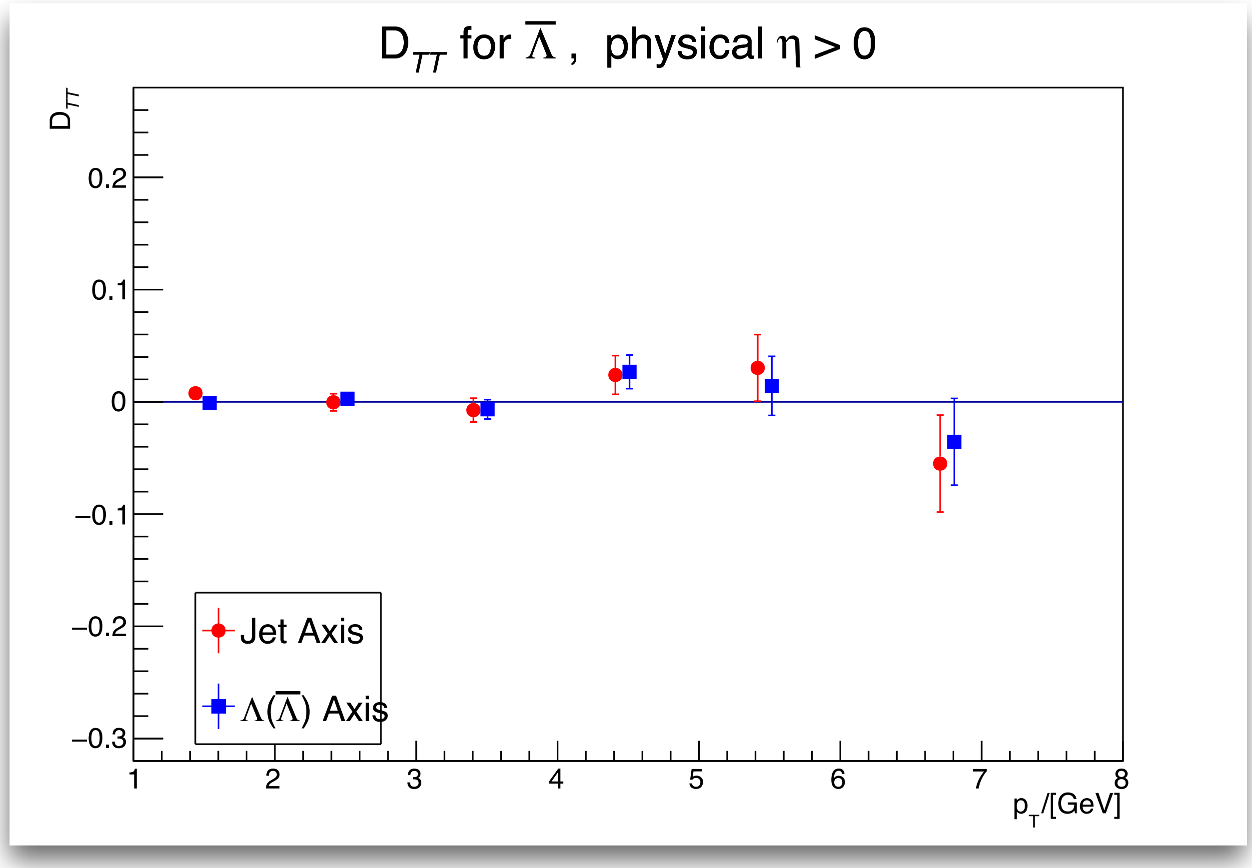
Significant spin transfer was found at large x_F.



$$\vec{N} = \frac{\vec{p}_b \times \vec{p}_\Lambda}{|\vec{p}_b \times \vec{p}_\Lambda|}$$

D_{TT} comparison two axises



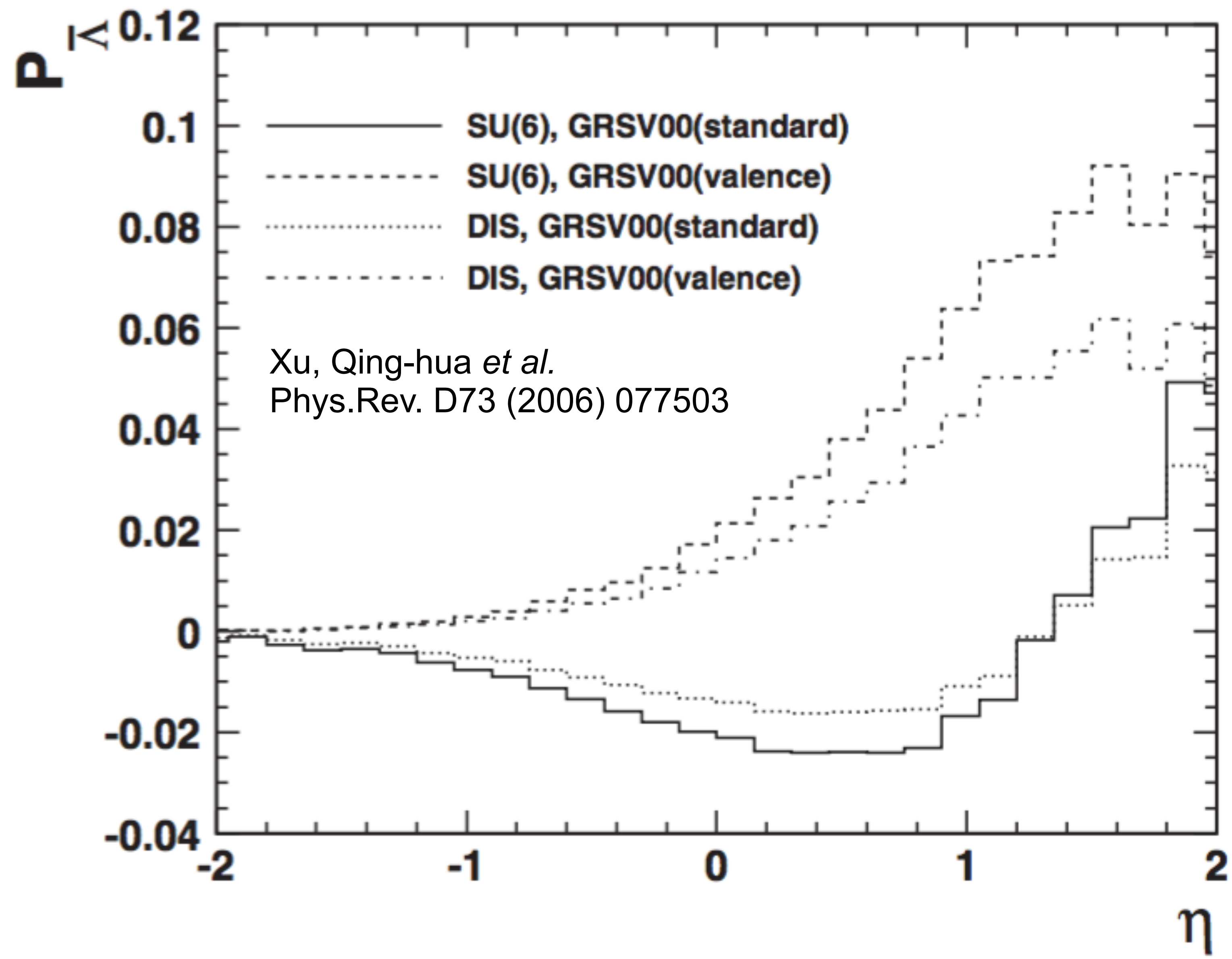


Comparison for different substitutes of outgoing quark momentum direction:
1, jet direction
2, hyperon direction

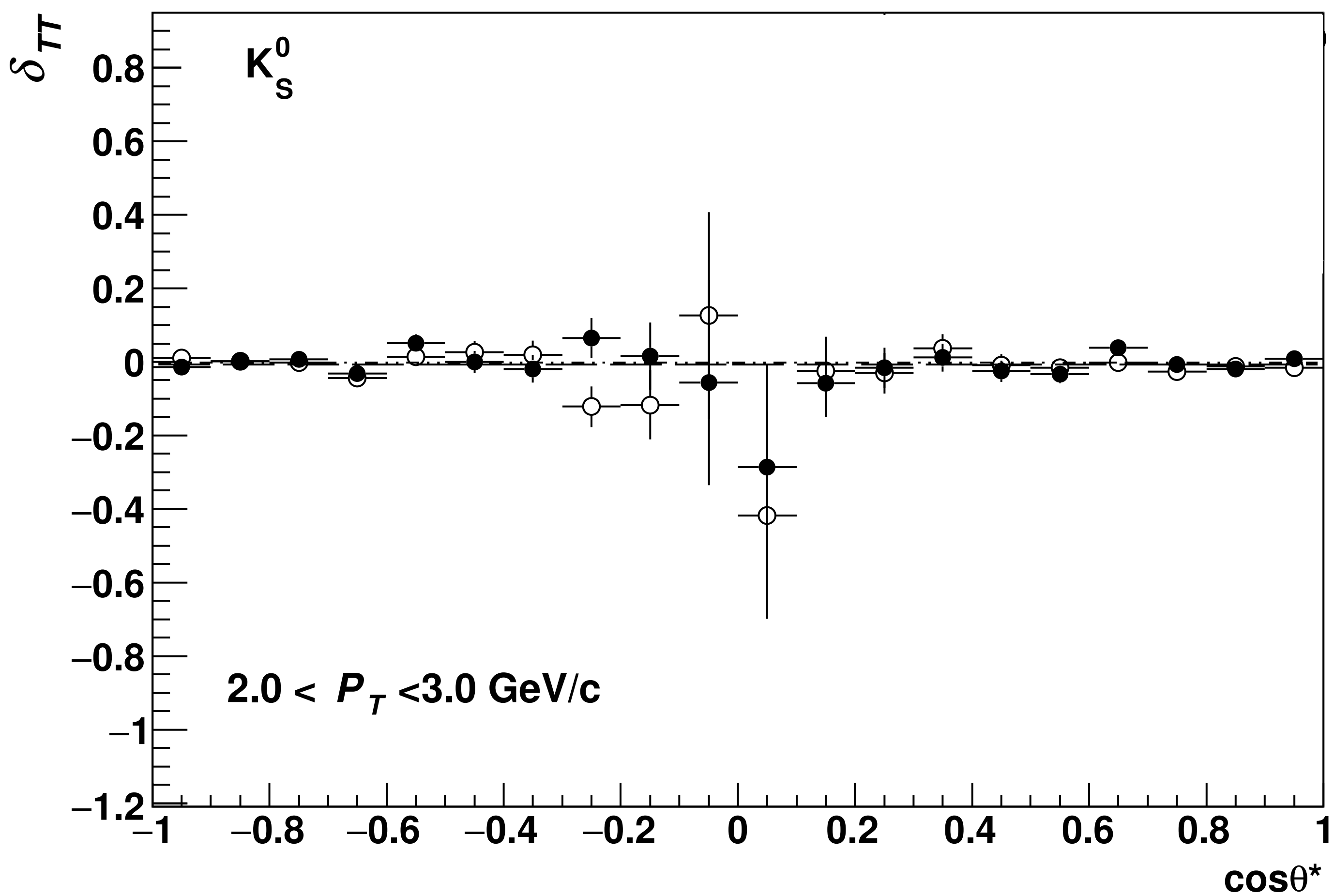
Theory Prediction

Transverse $\bar{\Lambda}$ polarization for transverse momentum pT ≧ 8 GeV/c in PP collisions at 200 GeV with one transversely polarized beam versus pseudorapidity $\boldsymbol{\eta}$ of the $\bar{\Lambda}$

Positive $\boldsymbol{\eta}$ is taken along the polarized beam direction.



K_S^0 Check



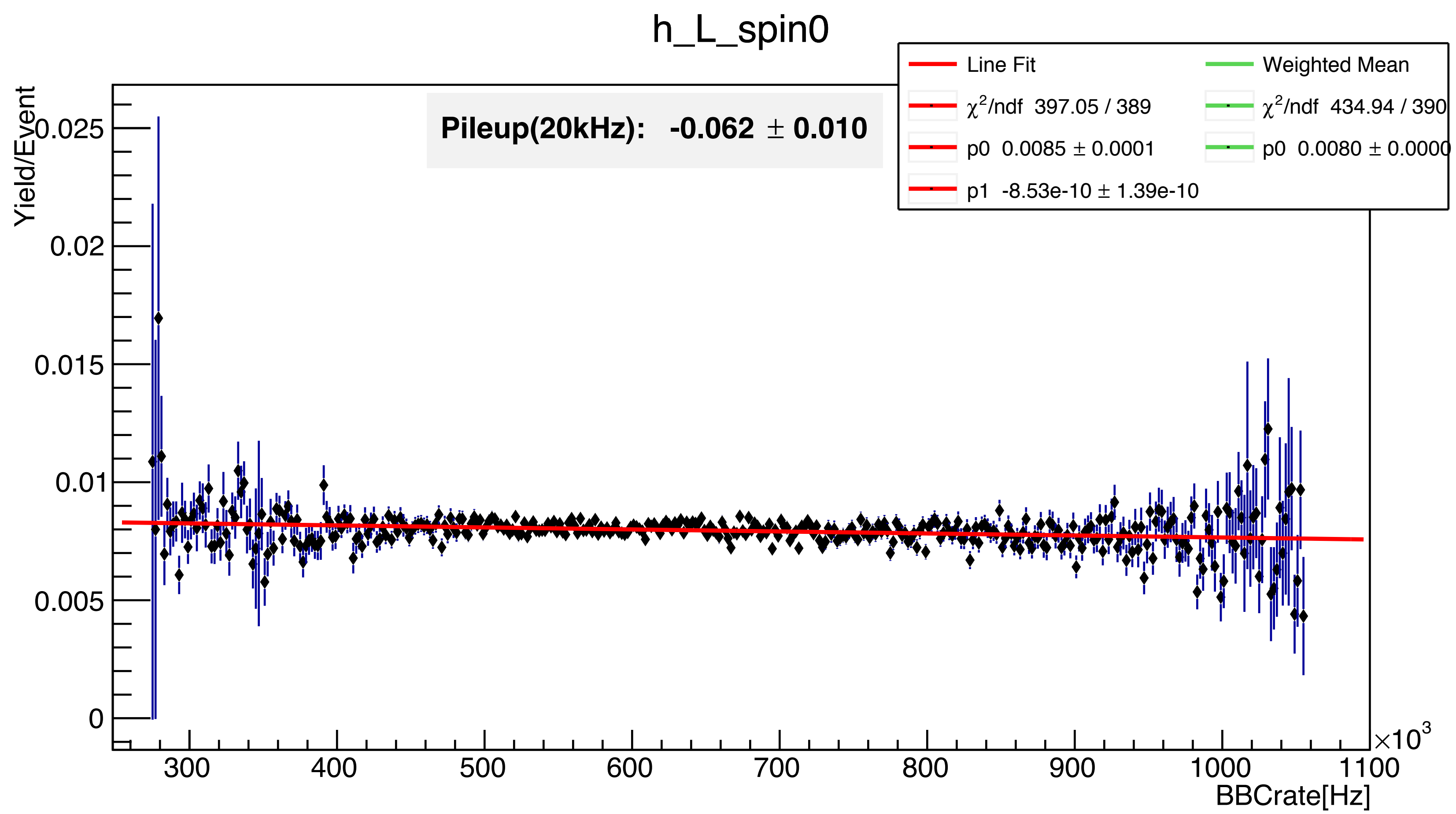
The spin asymmetry for K_S^0 was also extracted, which is used as a null check (K_S^0 is spin zero), and the results are consistent with zero as expected.
It is also a good check for acceptance assumption.

Pileup Effect Estimation

Plot of Lambda yield vs. collision rate.

Four beam polarization sets in RHIC p+p collision: ++, +-, -+, --.

The factor (u for each set is the difference between linear fit and constant fit at collision rate = 20kHz



The uncertainty of D_{TT} from pileup effect is estimated by :

$$\left(\delta D_{TT}{}^{sys.pileup}\right)^2 = \sum_{\substack{k=++,-+,\\ +-,--}} \left[D_{TT}(n^k) - D_{TT}\left((1-u^k)n^k\right)\right]^2$$