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

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Outline

- Motivation
- $\Lambda(\bar{\Lambda})$ Reconstruction
- Measurement Method
- D_{TT} measurement results
- Summary

Motivation

- The transverse spin transfer of $\Lambda(\bar{\Lambda})$ can provide insights into transversely polarized fragmentation function and transversity distribution.

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

$$d\Delta_T\sigma^{(p_\perp p \to H_\perp X)} \propto \sum_{abcd} \int dx_a\, dx_b dz \delta f_a(x_a) f_b(x_b) d\Delta_T\sigma^{(a_\perp b \to c_\perp d)} \Delta_T D_c^H(z)$$

Xu, Qing-hua *et al.*
Phys.Rev. D73 (2006) 077503

transversity distribution

pQCD calculation

transversely polarized fragmentation function

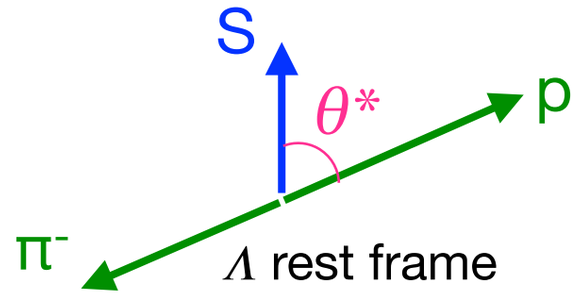
- Transversity is one of the important pdfs to describe the transverse spin structure of nucleon.

$$\delta q(x, Q^2) = q^\uparrow(x, Q^2) - q^\downarrow(x, Q^2)$$

- $\Lambda(\bar{\Lambda})$ 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 $\Lambda(\bar{\Lambda})$

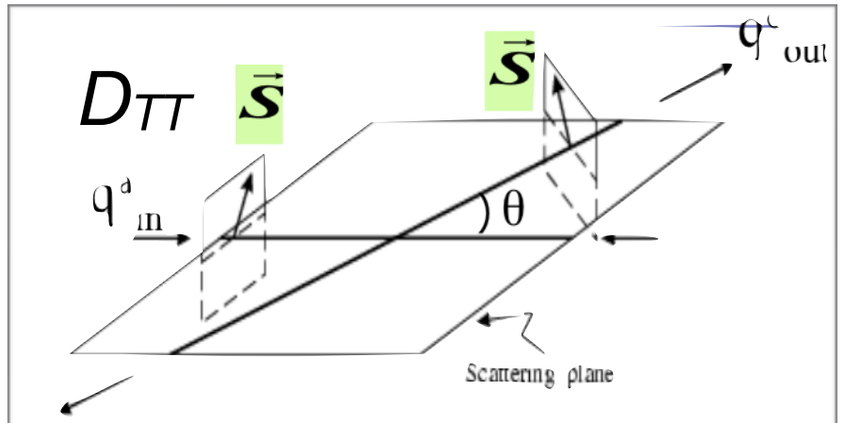


θ* : the angle between decay particle (proton) momentum in Λ's rest frame and the direction of Λ polarization

Definition of Transverse Spin Transfer

- 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

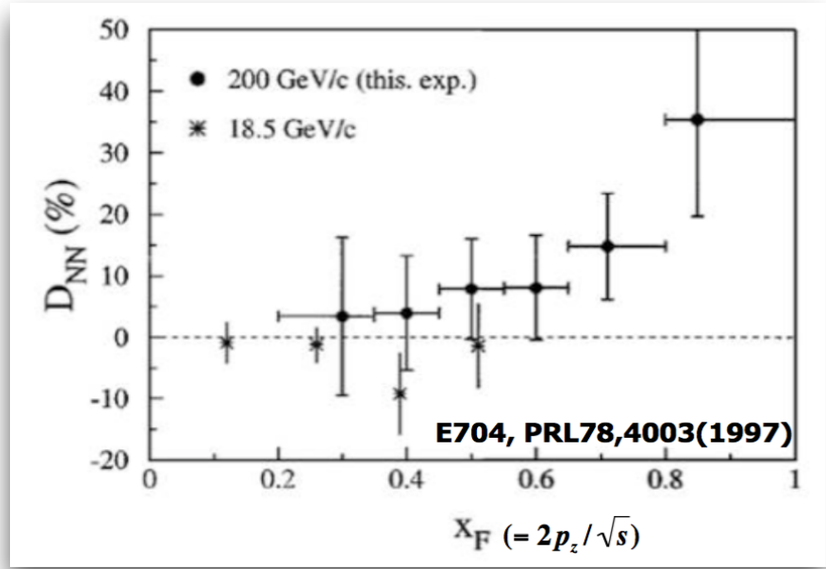


J.Collins et al, NPB420 (1994)565

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

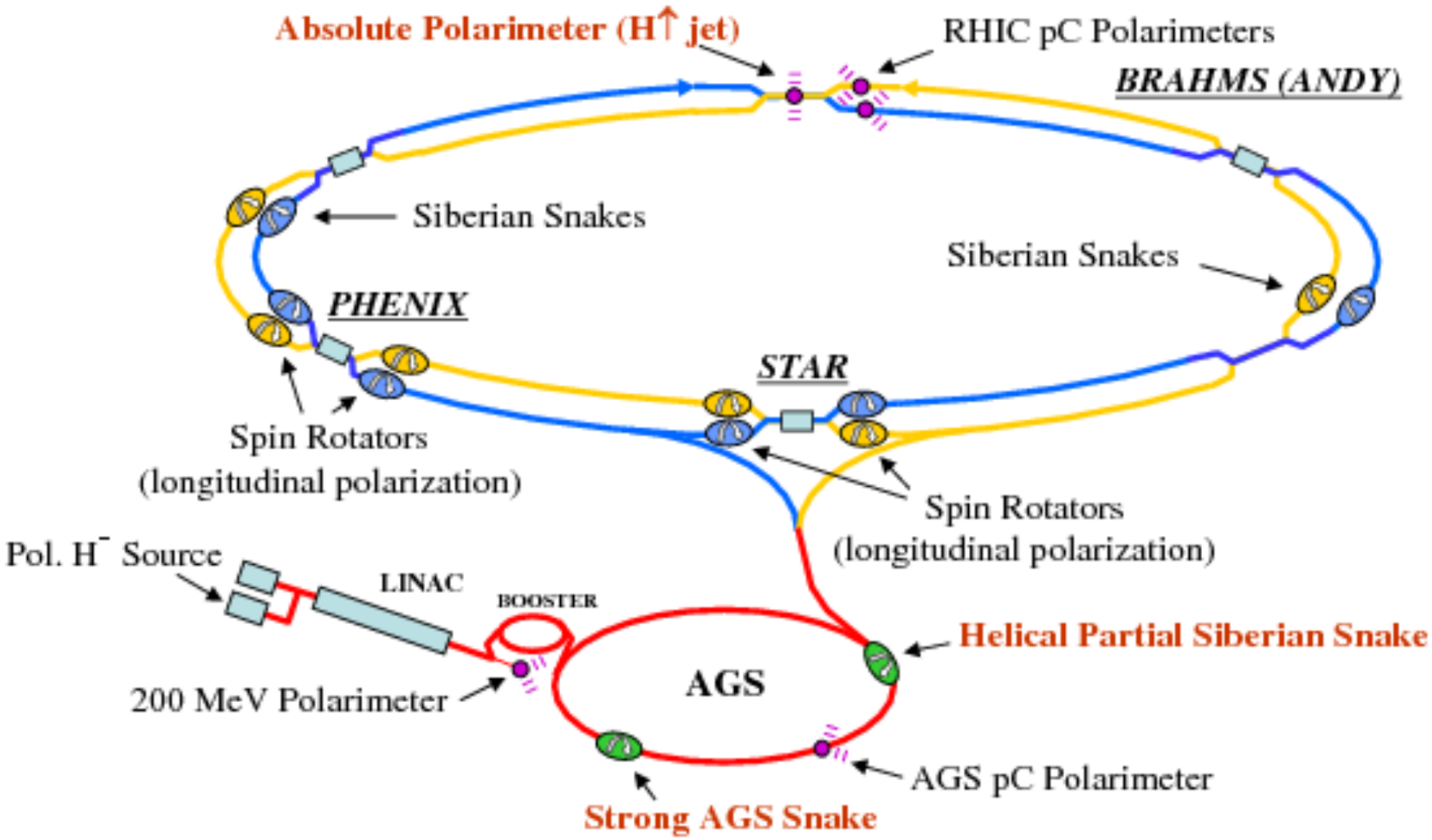
  D_{NN} : spin transfer along normal direction of Λ production plane.

  Significant spin transfer was found at large x_F.



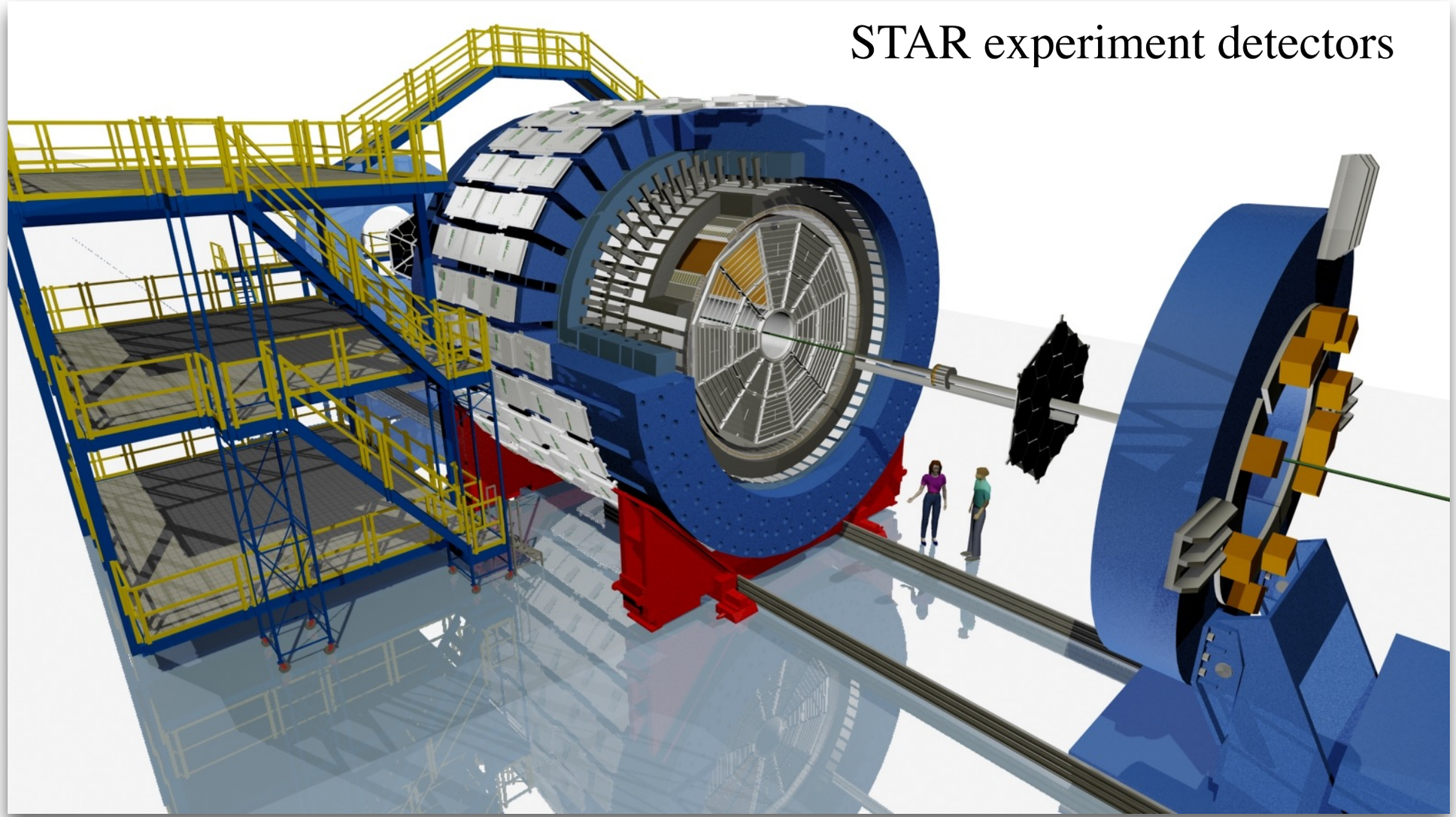
$$\vec{N} = \frac{\vec{p}_b \times \vec{p}_\Lambda}{|\vec{p}_b \times \vec{p}_\Lambda|}$$

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 collision at 200GeV at STAR taken in 2012.
- RHIC Beam polarization: blue beam: 64%, yellow beam: 58% (2012_PP200GeV)

STAR Detectors



- TPC : Time Projection Chamber $\eta \sim (-1.2, 1.2)$

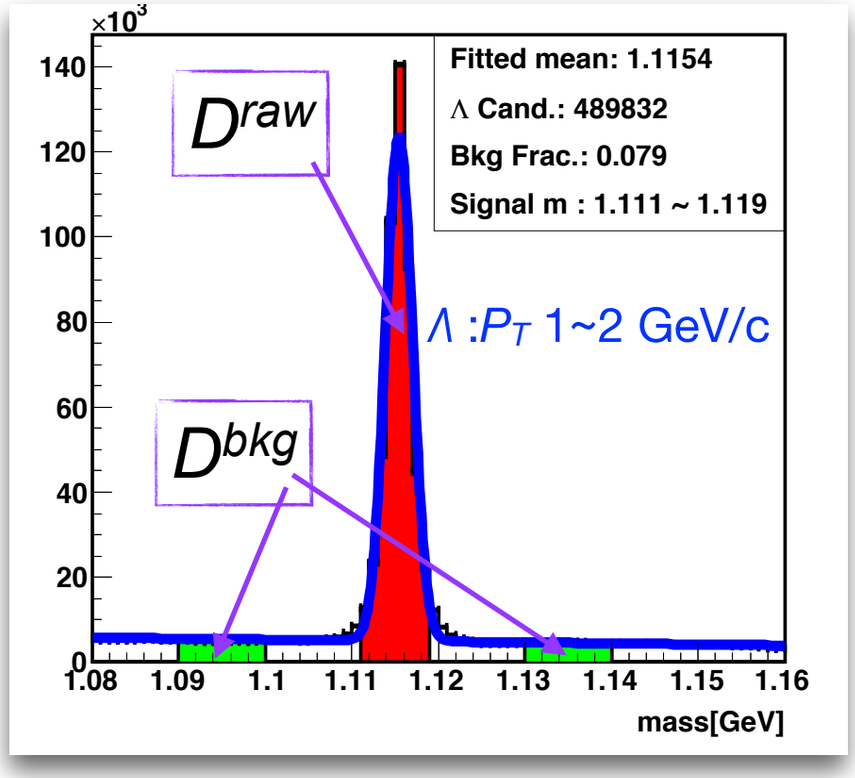
  Track reconstruction of charged particles and charged particle identification.

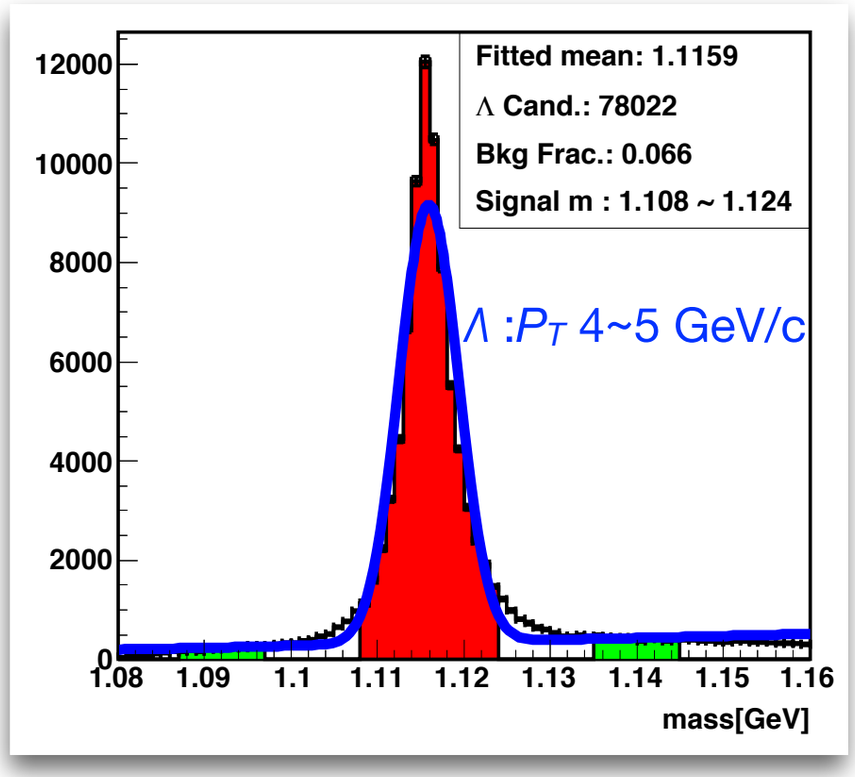
- BEMC: Barrel Electromagnetic Calorimeter $\eta \sim (-1.0, 1.0)$

  For triggering.

Λ and $\bar{\Lambda}$ Reconstruction

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





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

PT [GeV/c]	Λ	$\bar{\Lambda}$
1~2	489832	544212
2~3	322603	381872
3~4	182517	201413
4~5	78022	74312
5~6	32480	26279
6~8	20272	13773
Total	1125726	1241861

Background fraction is estimated by side bands.

The obtained D^{raw} and their statistical uncertainties were corrected for the residual background:

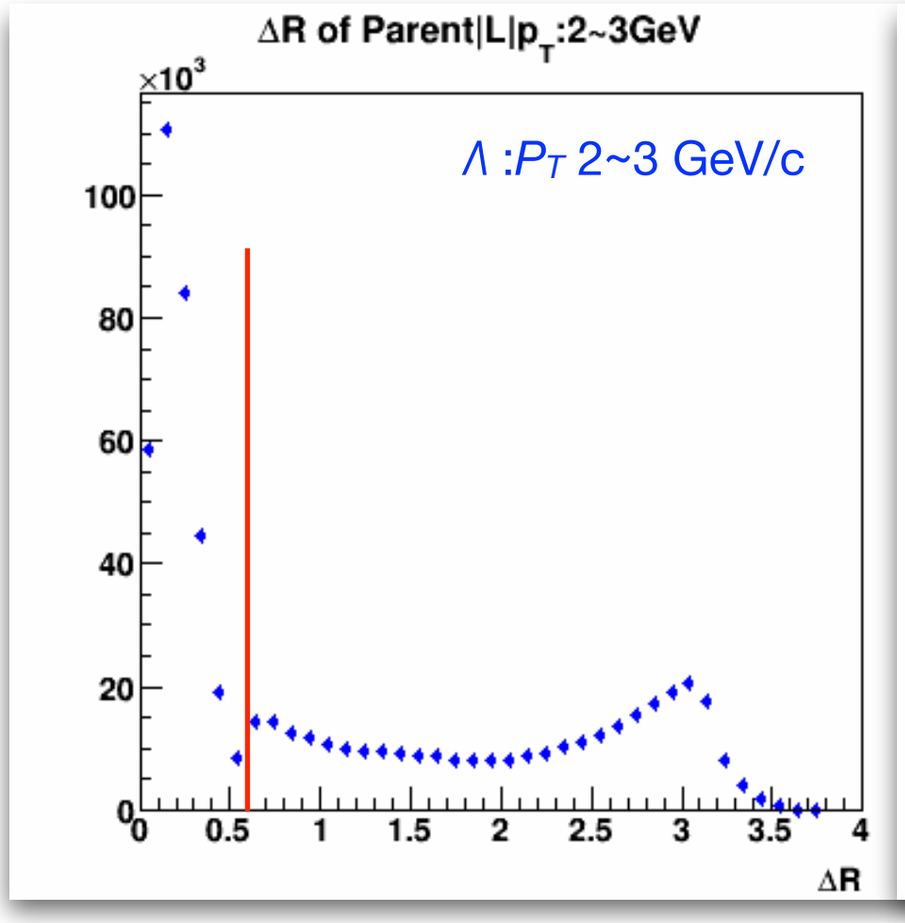
$$D_{TT} = \frac{D_{TT}^{raw} - rD_{TT}^{bkg}}{1-r}$$

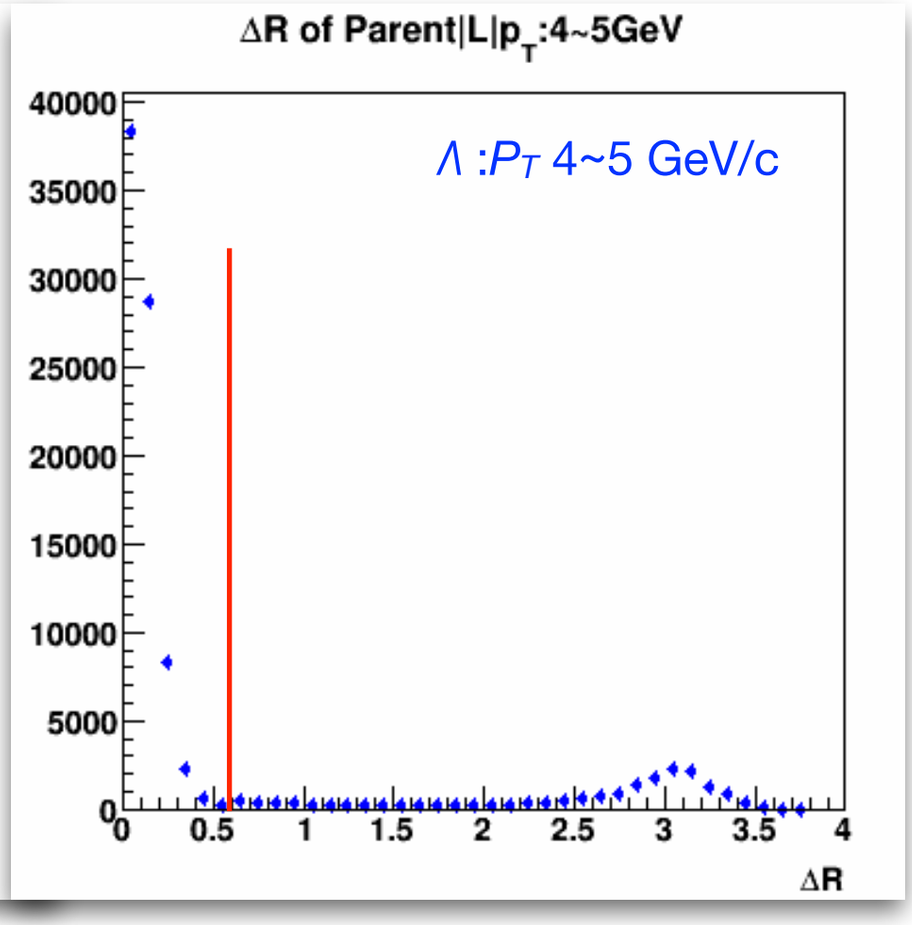
$$\delta D_{TT} = \frac{\sqrt{(\delta D_{TT}^{raw})^2 + \left(r\delta D_{TT}^{bkg}\right)^2}}{1-r}$$

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:

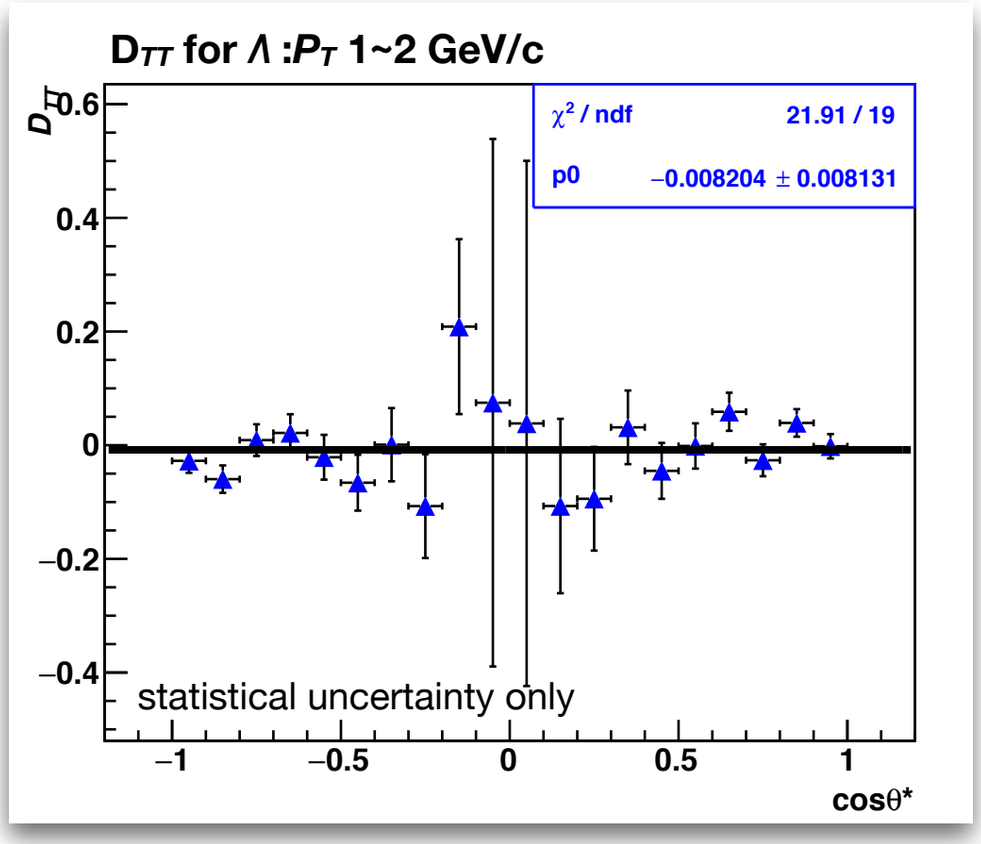
$$D_{TT} = \frac{1}{\alpha P_{beam} < \cos\theta^* >} \frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}$$

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.

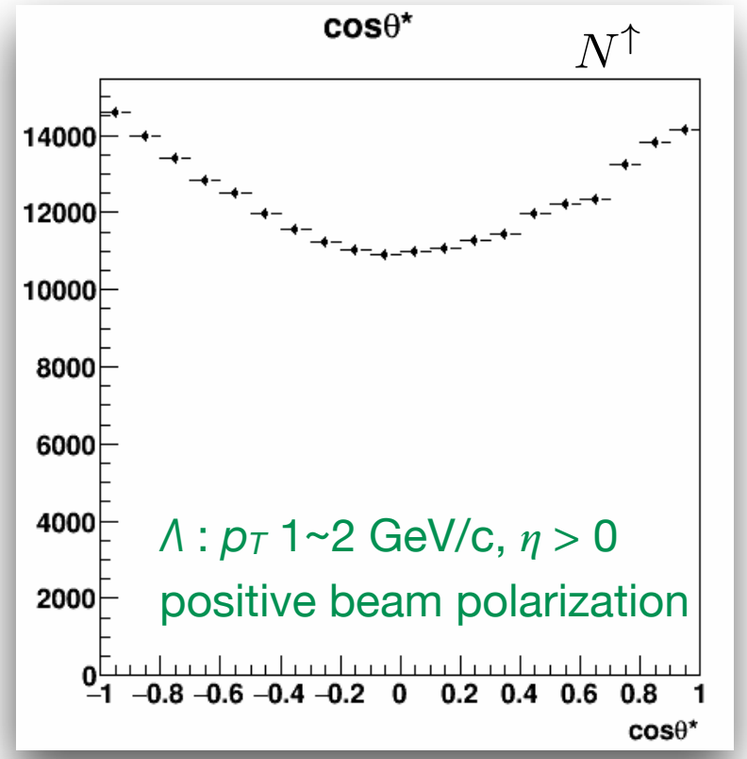
Extraction of Spin Transfer D_{TT}

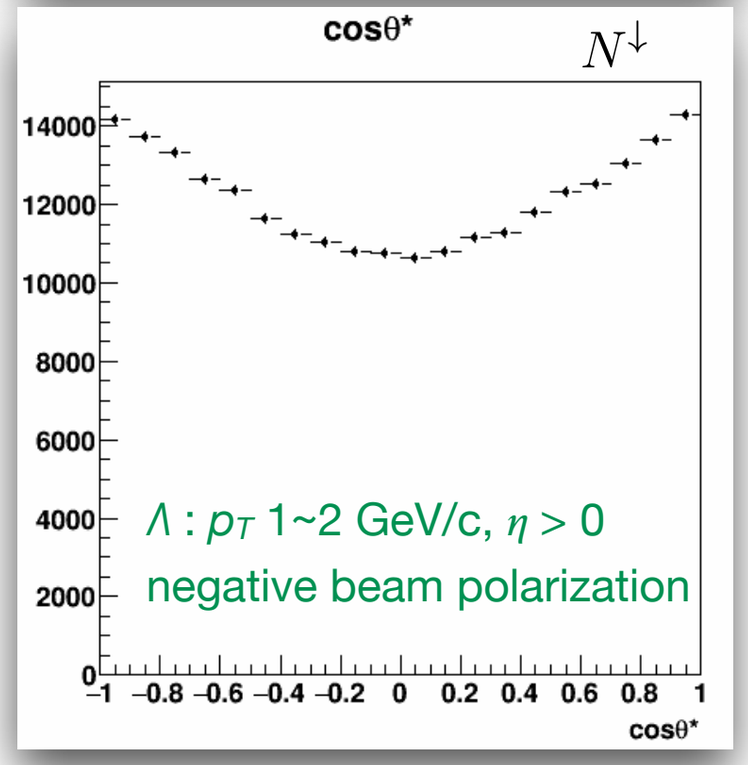
- D_{TT} extraction in each cosθ*



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

- Separate the whole range of cosθ* into 20 bins.
- Obtain a D_{TT} in each bin.
- 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^0_S





Systematic Uncertainty

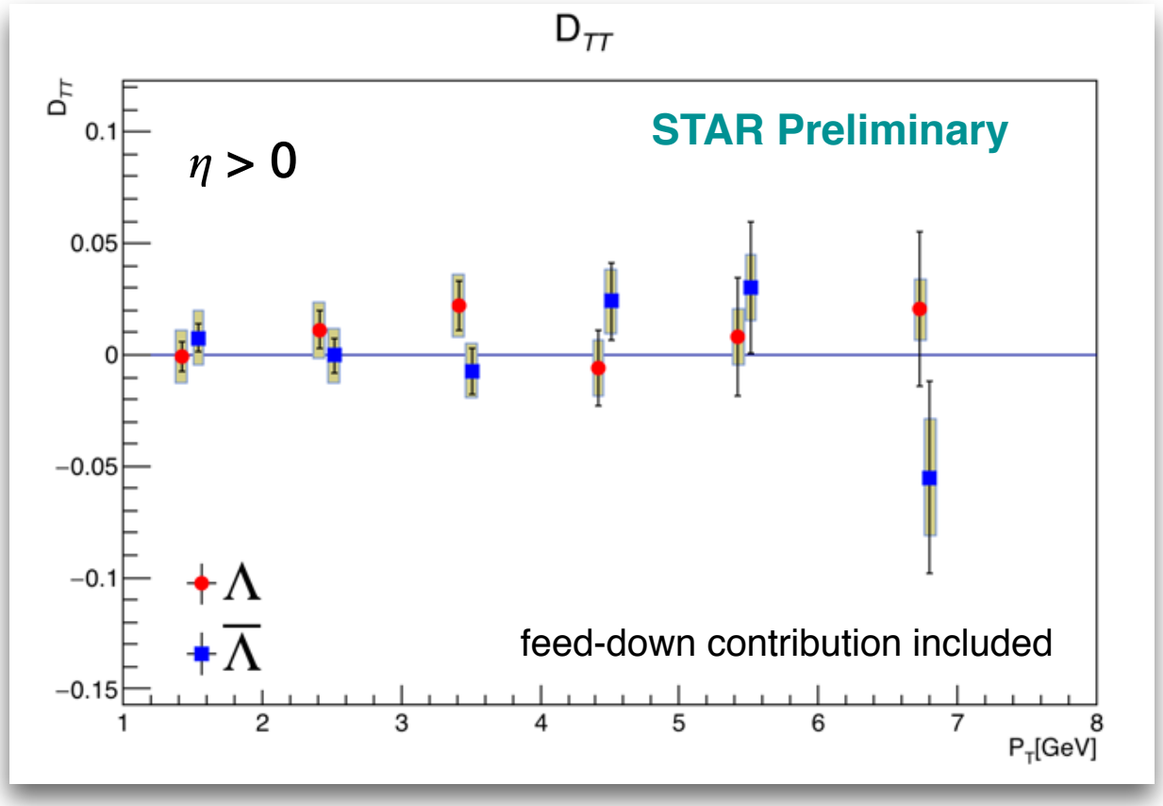
- 1.2% scale uncertainty from RHIC beam polarization measurement.
- 2% from decay parameter (0.642 ± 0.013).
- 0.012 from relative luminosity measurement.
- Trigger bias estimated from MC simulation.
- Residual background fraction estimation.
- Pileup effect.

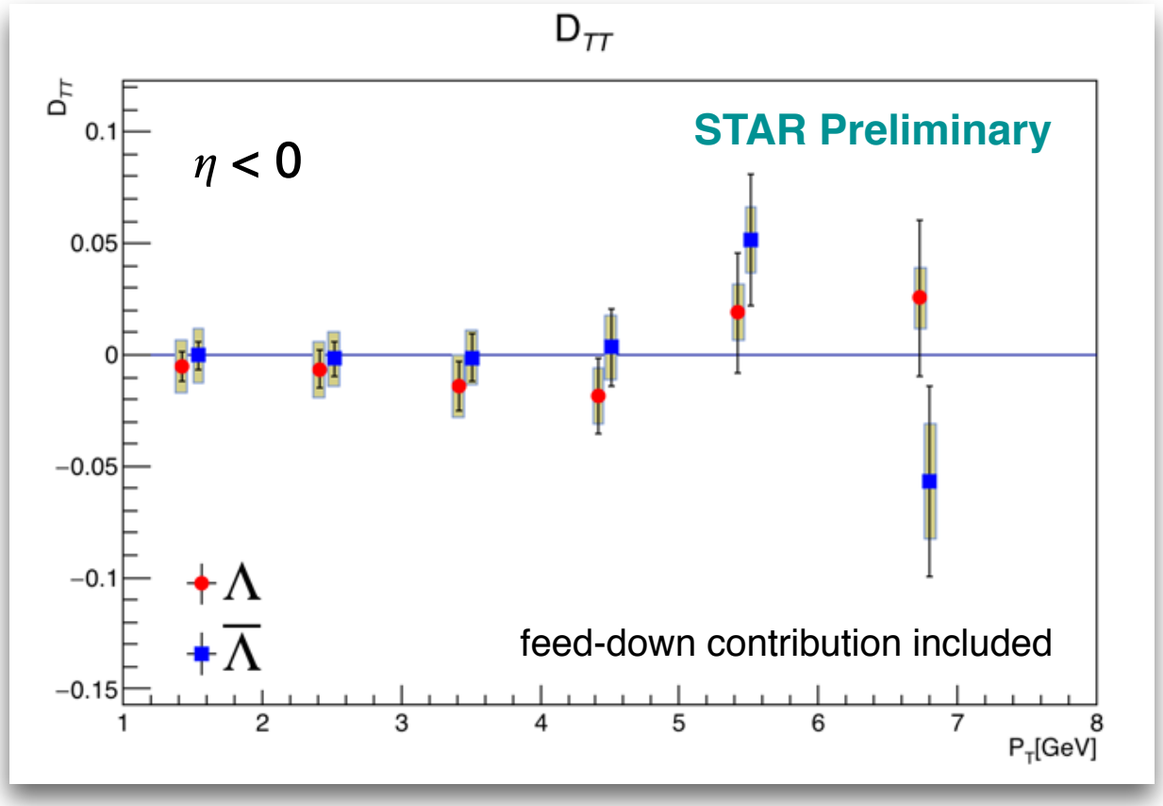
Systematic Uncertainty Summary

$\eta > 0$	Trigger Bias		Residual Background fraction		Pileup effect		Total Systematic Uncertainty	
pT[GeV/c]	Λ	$\bar{\Lambda}$	Λ	$\bar{\Lambda}$	Λ	$\bar{\Lambda}$	Λ	$\bar{\Lambda}$
1-2	1.98E-04	2.07E-03	1.05E-05	8.44E-06	8.22E-04	9.57E-04	1.20E-02	1.22E-02
2-3	3.47E-03	1.11E-04	9.45E-06	0.00E+00	1.13E-03	7.07E-04	1.25E-02	1.20E-02
3-4	6.62E-03	1.95E-03	1.49E-05	2.41E-05	1.08E-03	3.09E-04	1.38E-02	1.22E-02
4-5	1.87E-03	7.58E-03	1.12E-05	1.42E-04	2.99E-03	5.78E-04	1.25E-02	1.42E-02
5-6	2.07E-03	8.01E-03	9.61E-04	1.25E-04	3.11E-03	1.05E-03	1.26E-02	1.45E-02
6-8	4.39E-03	2.28E-02	3.08E-03	1.91E-03	3.42E-03	1.89E-03	1.36E-02	2.59E-02

D_{TT} Results from STAR measurement

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





- 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.
- D_{TT} of Λ and $\bar{\Lambda}$ are consistent with each other and consistent with zero within uncertainty.

Summary

- First measurement on transverse spin transfer of $\Lambda(\bar{\Lambda})$ in P+P collision, which can provide insights into transversely polarized fragmentation function and nucleon transversity distribution.

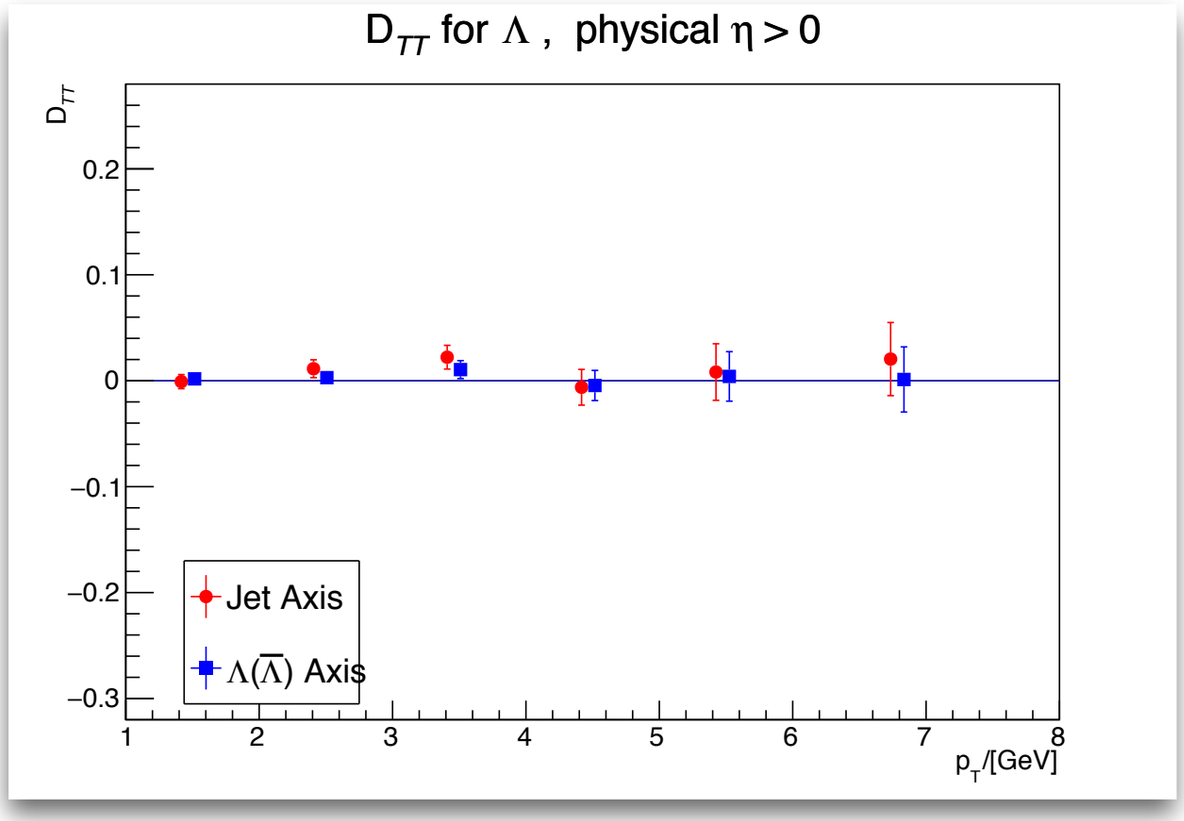
- The Λ ($\bar{\Lambda}$) sample is the largest so far in P+P collision at RHIC and the precision of D_{TT} is ~0.04 at Λ ($\bar{\Lambda}$), which reach p_T ~8 GeV/c.

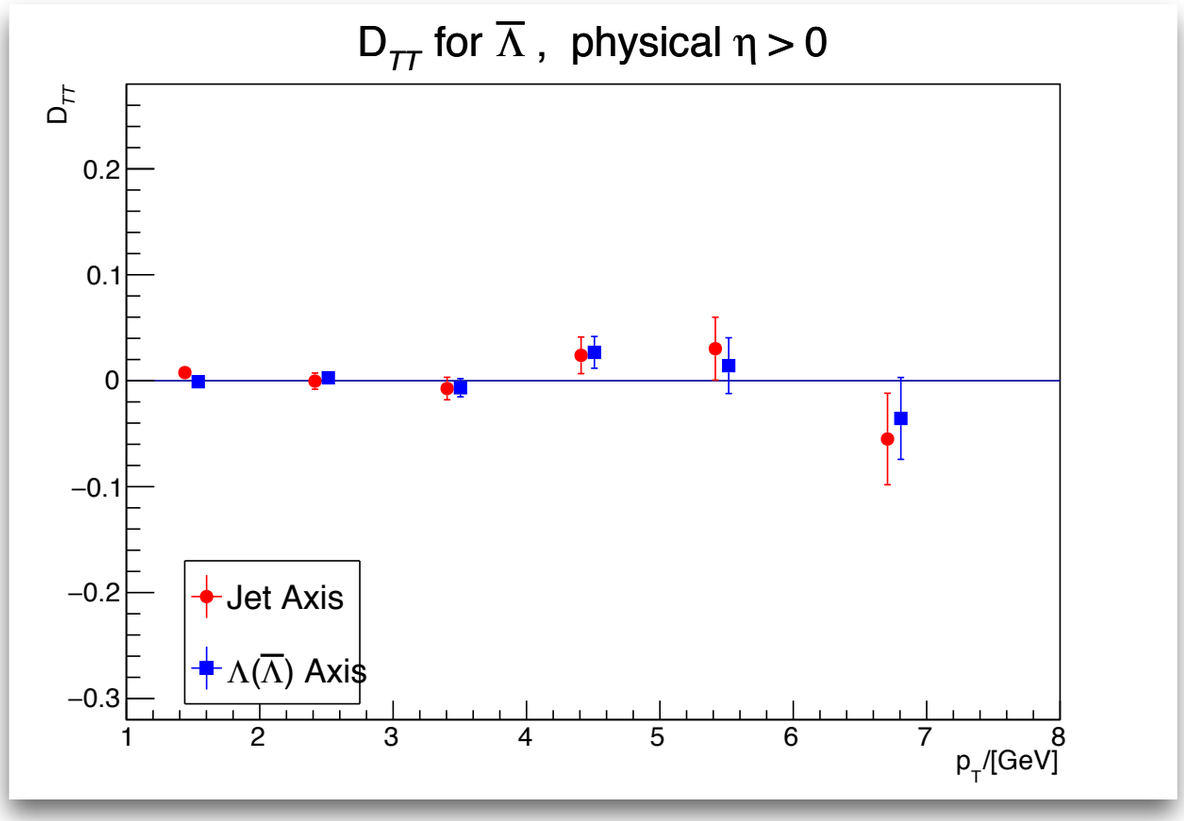
- D_{TT} of Λ and $\bar{\Lambda}$ are consistent with each other and consistent with zero within uncertainty.

Thanks for Your Attention!

Backup

D_{TT} comparison two axises





Theory Predict

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

Positive η is taken along the polarized beam direction.