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STAR

Transverse Spin Transfer of Λ and $\bar{\Lambda}$ Hyperons in Polarized p+p Collisions at $\sqrt{s} = 200\ \mathrm{GeV}$ at RHIC-STAR

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- **RHIC & STAR Detector**
- **Λ and $\bar{\Lambda}$ Hyperon Selections**
- **Transverse Spin Transfer Results**
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  - ✓ D_{TT} **vs.** z **in jet**
- **Summary**

Motivation

- **Transverse spin transfer D_{TT} for $\Lambda(\bar{\Lambda})$ in p+p collisions:**

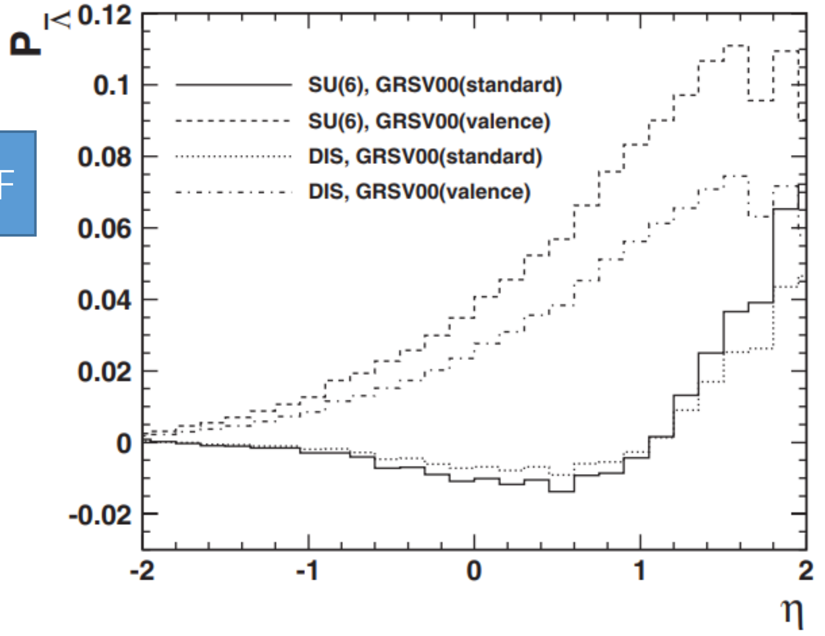
$$D_{TT}^{\Lambda} \equiv \frac{\sigma^{(p^{\uparrow}p\to\Lambda^{\uparrow}X)}-\sigma^{(p^{\uparrow}p\to\Lambda^{\downarrow}X)}}{\sigma^{(p^{\uparrow}p\to\Lambda^{\uparrow}X)}+\sigma^{(p^{\uparrow}p\to\Lambda^{\downarrow}X)}} = \frac{d\delta\sigma^{\Lambda}}{d\sigma^{\Lambda}}$$

$$d\delta\sigma^{\Lambda} \propto \sum_{abcd}\int dx_a\, dx_b dz \boxed{\delta f_a(x_a)} f_b(x_b) \boxed{\delta\sigma^{(a^{\uparrow}b\to c^{\uparrow}d)}} \boxed{\delta D_c^{\Lambda}(z)}$$

Polarized FF

pQCD

transversity distributions



Q. Xu, Z. T. Liang, E. Sichtermann, PRD73, 077503 (2006).

- D_{TT} provides connections to the transversity distributions and transversely **polarized fragmentation functions (FF).**

- Experimentally, D_{TT} can be measured through Λ polarization, which can be determined from the angular distribution of its weak decay product ($\Lambda \to p\pi^{-}$):

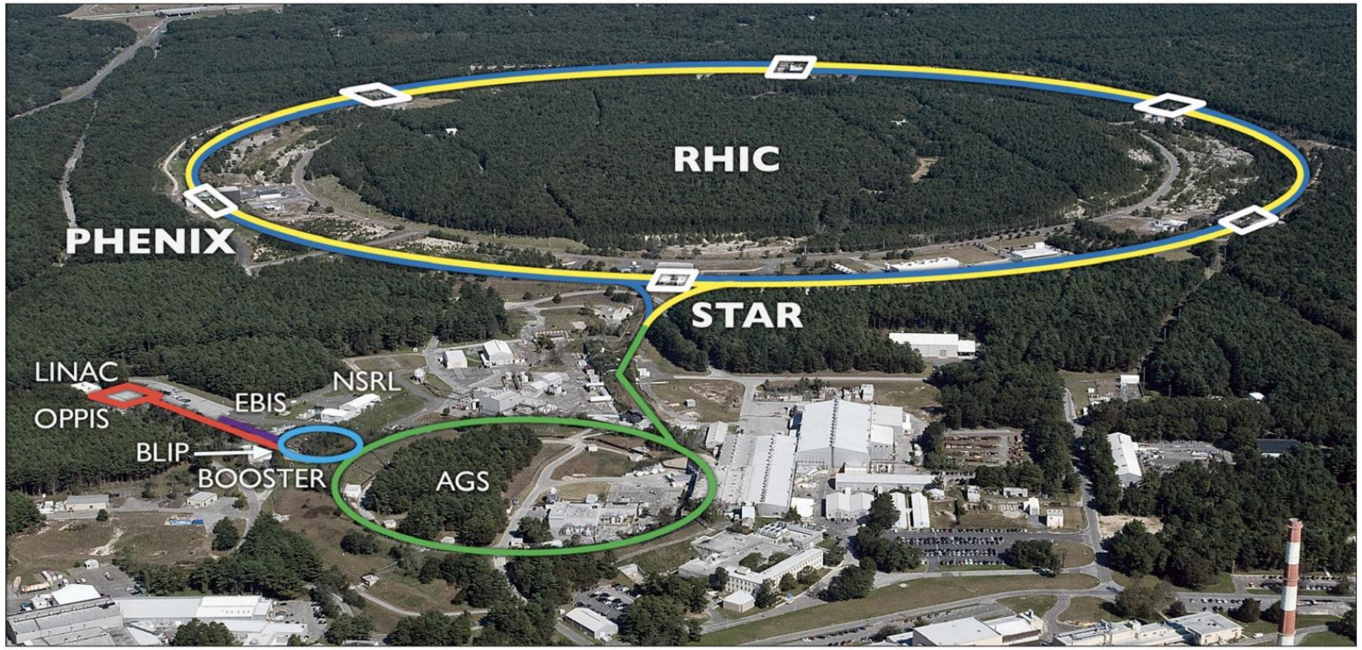
$$\mathrm{d}N \propto \left(1+\alpha P_{\Lambda(\bar{\Lambda})} cos\theta^{*}\right)\mathrm{d}cos\theta^{*}$$

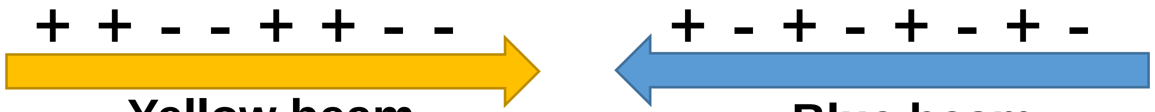
Relativistic Heavy Ion Collider

- **RHIC is the world's first (and only) polarized hadron collider.**

  RHIC consists of two 3.8 km rings, one ("Blue") clockwise and the other ("Yellow") for counter-clockwise beams.

- **RHIC can provide all 4 collision pattens: ++, --, +-, -+.**





\+ + - - + + - -

Yellow beam

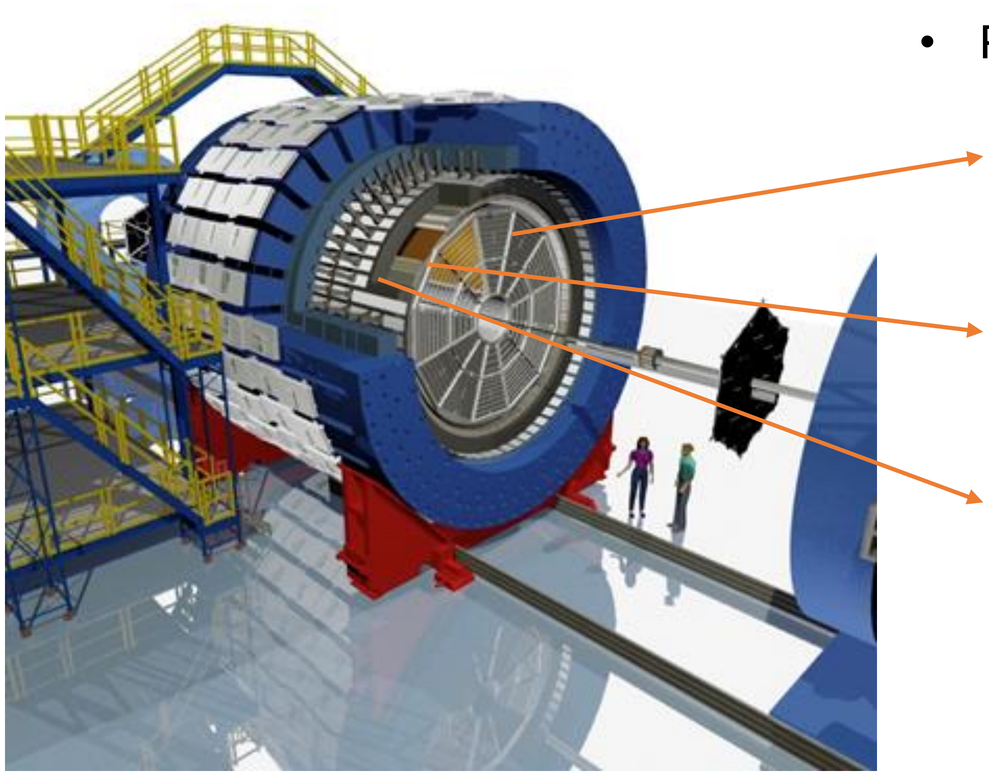
\+ - + - + - + -

Blue beam

- For p+p, RHIC can run at $\sqrt{s} = \mathbf{200\ GeV}$ and $\sqrt{s} = \mathbf{510\ GeV}$ with beams longitudinally or transversely polarized.
- The data set used are from transversely polarized collisions at **200 GeV** with an integrated luminosity of **18 $\mathbf{pb^{-1}}$ in 2012 and 52 $\mathbf{pb^{-1}}$ in 2015.**
- 2012 beam transverse polarization:
  - Blue beam: ~64%
  - Yellow beam: ~58%
- 2015 beam transverse polarization:
  - Blue beam: ~57%
  - Yellow beam: ~57%

Solenoidal Tracker At RHIC

- For D_{TT} analysis, the following sub-detectors are used:



✓ **TPC** is the main detector for tracking and PID.
   - ➢ covering $|\eta| < 1.3$ and $\phi \in [0,2\pi]$.

✓ **TOF** is used to improve PID of the tracks.
   - ➢ covering $|\eta| < 1.0$ and $\phi \in [0,2\pi]$.

✓ **EMC** include:
   - ➢ BEMC (Barrel EMC) : covering $|\eta| < 1.0$ and $\phi \in [0,2\pi]$.
   - ➢ EEMC(Endcap EMC): covering $1.086 < \eta < 2.00$ and $\phi \in [0,2\pi]$.

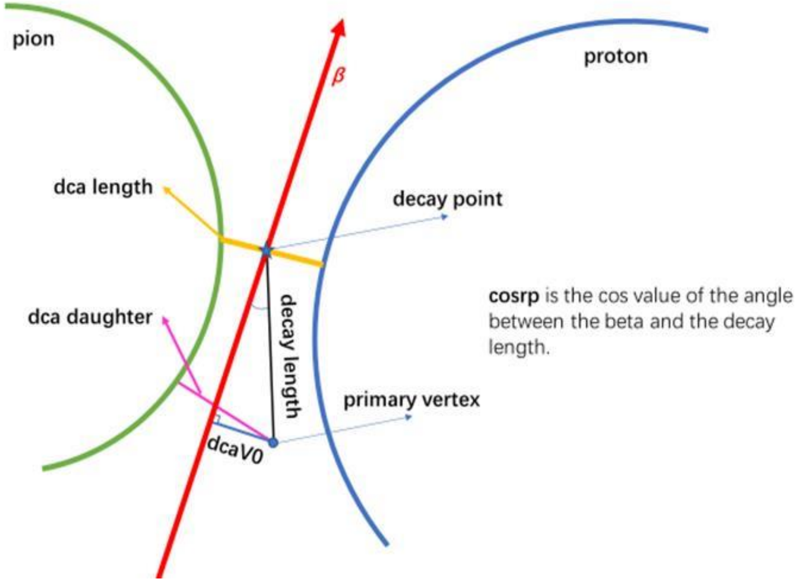
- We select the **hard scattering events** by the Jet triggers which are based on energy depositions in the **EMC**.

Λ and $\bar{\Lambda}$ reconstruction

- Proton and pion tracks are paired to reconstruct the Λ and $\bar{\Lambda}$ candidates.
- A series of topological cuts are tuned to further reduce the background.
- **Side-band method** is used to estimate the residual background fraction, which is ~ 10%.
- The spin transfer signal is obtained by subtracting the contribution from residual background with:

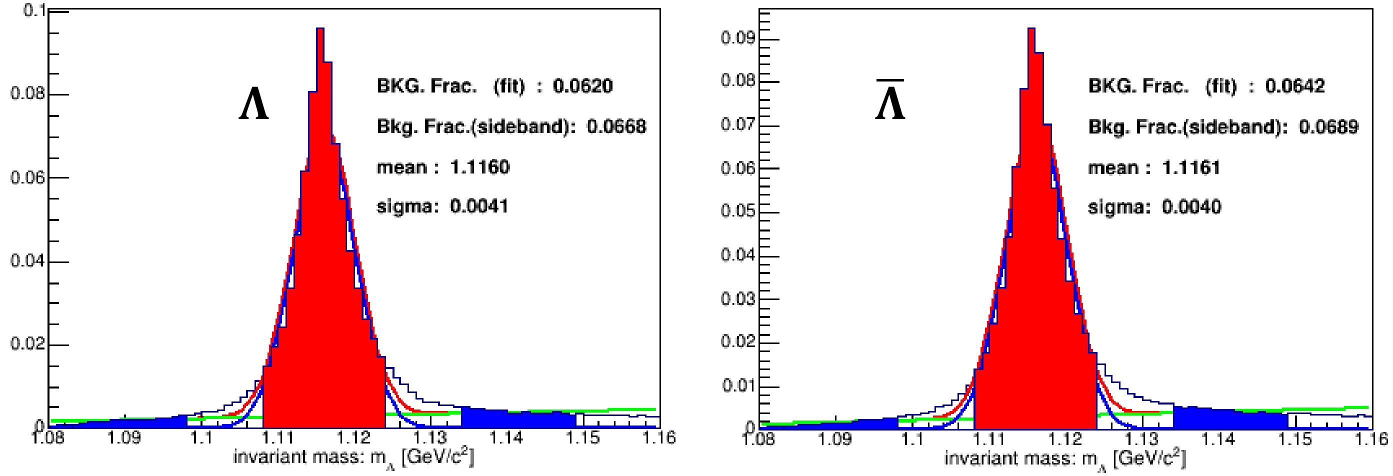
$$D_{TT} = \frac{D_{TT}^{raw} - rD_{TT}^{bkg}}{1-r} \quad (r \text{ is the background fraction})$$

Topological cut

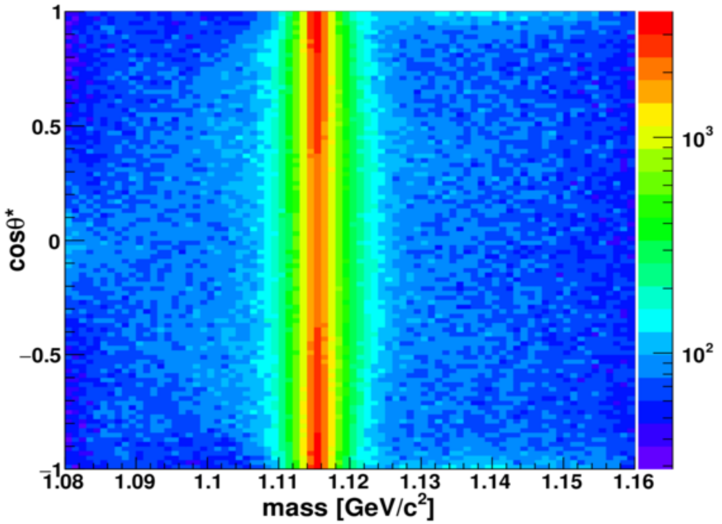


cosrp is the cos value of the angle between the beta and the decay length.

Examples of invariant mass distribution for D_{TT} of Λ and $\bar{\Lambda}$ in p_T 3~4 GeV



STAR, PRD 98, 091103R (2018)



D_{TT} determination at STAR

- In **hard partonic scattering,** the direction of transverse polarization is **rotated along the normal direction** of the scattering plane.

- D_{TT} measures the spin transfer to the final state Λ polarization along the polarization direction of outgoing quark.

- **Jet axis** is used as the surrogate of fragmenting parton to obtain the polarization direction after rotation.

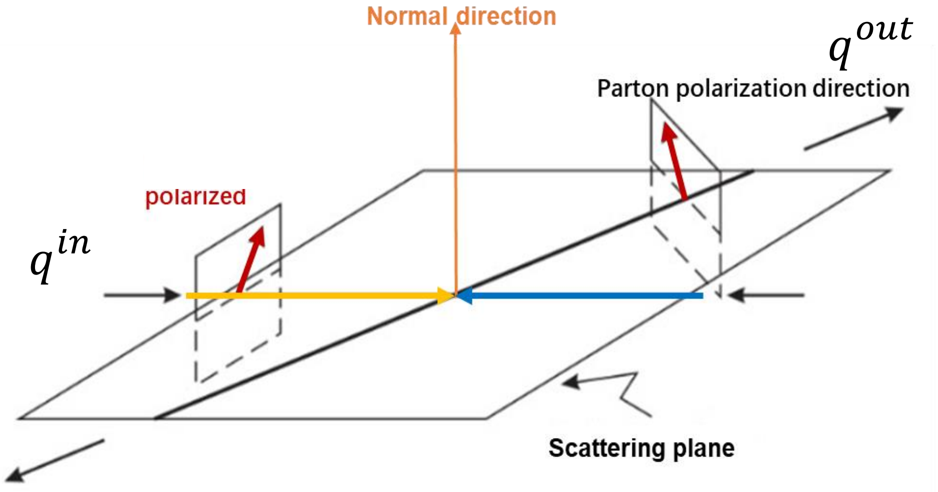
  ✓ The anti-k_{T} algorithm with $R = 0.6$ to reconstruct jets.

  ✓ Require η_{jet} ~ (-0.7, 0.9), p_T > 5.0 GeV/c

  ✓ ΔR cone < 0.6 is used to correlate $\Lambda(\bar{\Lambda})$ candidate with a jet in D_{TT} vs. p_T measurement.

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2};\ \Delta\phi = \phi_\Lambda - \phi_{jet};\ \Delta\eta = \eta_\Lambda - \eta_{jet}$$

The Λ polarization direction for D_{TT}



J.Collins, S.Heppelmann, G.Ladinsky, NPB420 (1994)565

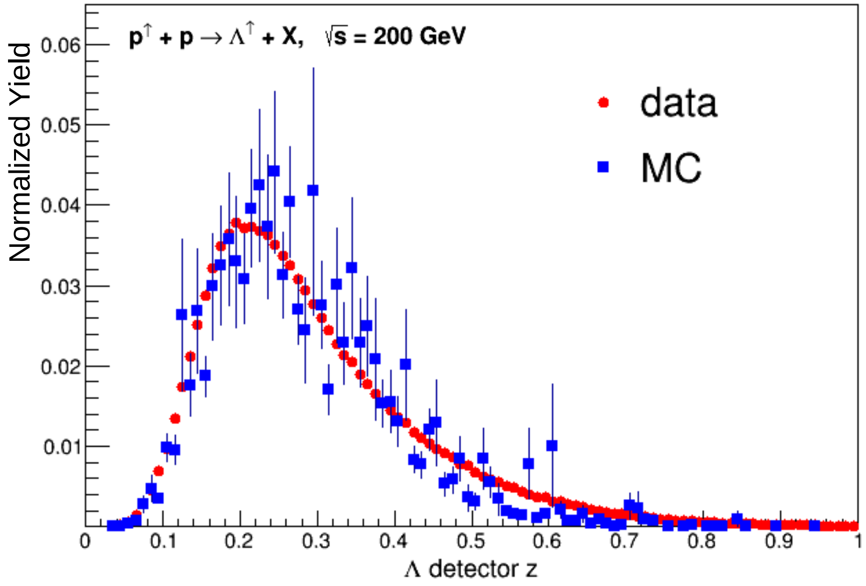
Λ in jet and z determination

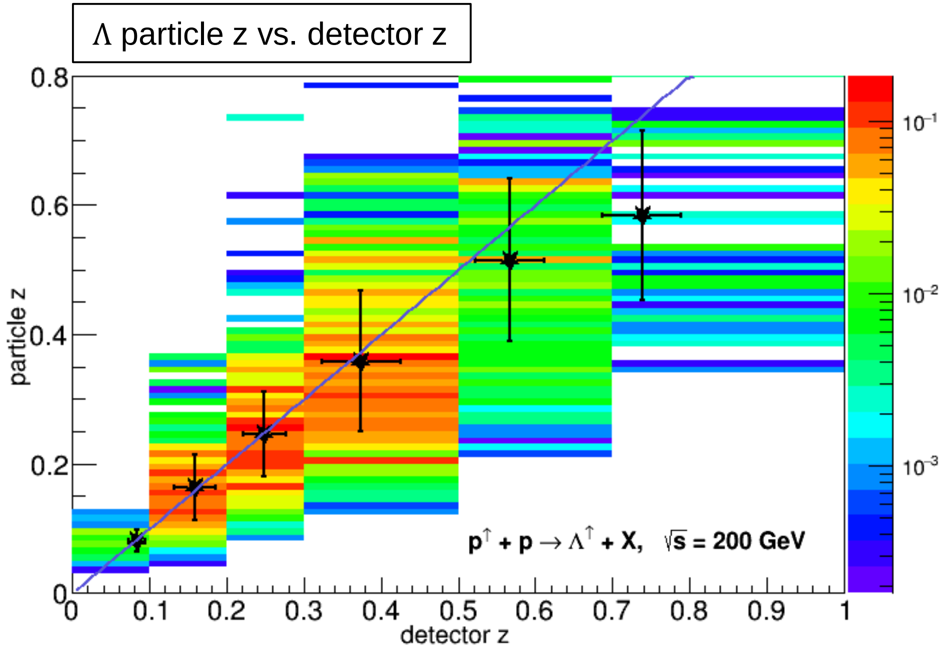
- D_{TT} vs. z provides the direct information of transversely polarized fragmentation function.
- z is defined as :

$$\mathrm{z} = \frac{\boldsymbol{p_{\Lambda}} \cdot \boldsymbol{p_{jet}}}{|\boldsymbol{p_{jet}}|^2}$$

  - ✓ Jets are reconstructed using TPC tracks and EMC energy deposits. → **detector z**
  - ✓ In theoretical calculations, all the particles are used for the jet. → **particle z**

- **Measuring D_{TT} vs. particle z**
  - ✓ Obtain the detector z and calculate the D_{TT} in each detector z bin.
  - ✓ Correct the average detector z to particle z, using correction factors obtained from MC simulation based on Pythia6 + Geant.





Cross-ratio method for D_{TT}

- D_{TT} is extracted from a **cross-ratio asymmetry** using Λ counts with opposite beam polarization configurations within a small interval of $cos\theta^*$

$$\boldsymbol{D_{TT} = \frac{1}{\alpha P_{beam}\langle cos\theta^*\rangle}\frac{\sqrt{N^{\uparrow}(cos\theta^*)N^{\downarrow}(-cos\theta^*)}-\sqrt{N^{\uparrow}(-cos\theta^*)N^{\downarrow}(cos\theta^*)}}{\sqrt{N^{\uparrow}(cos\theta^*)N^{\downarrow}(-cos\theta^*)}+\sqrt{N^{\uparrow}(-cos\theta^*)N^{\downarrow}(cos\theta^*)}}}$$

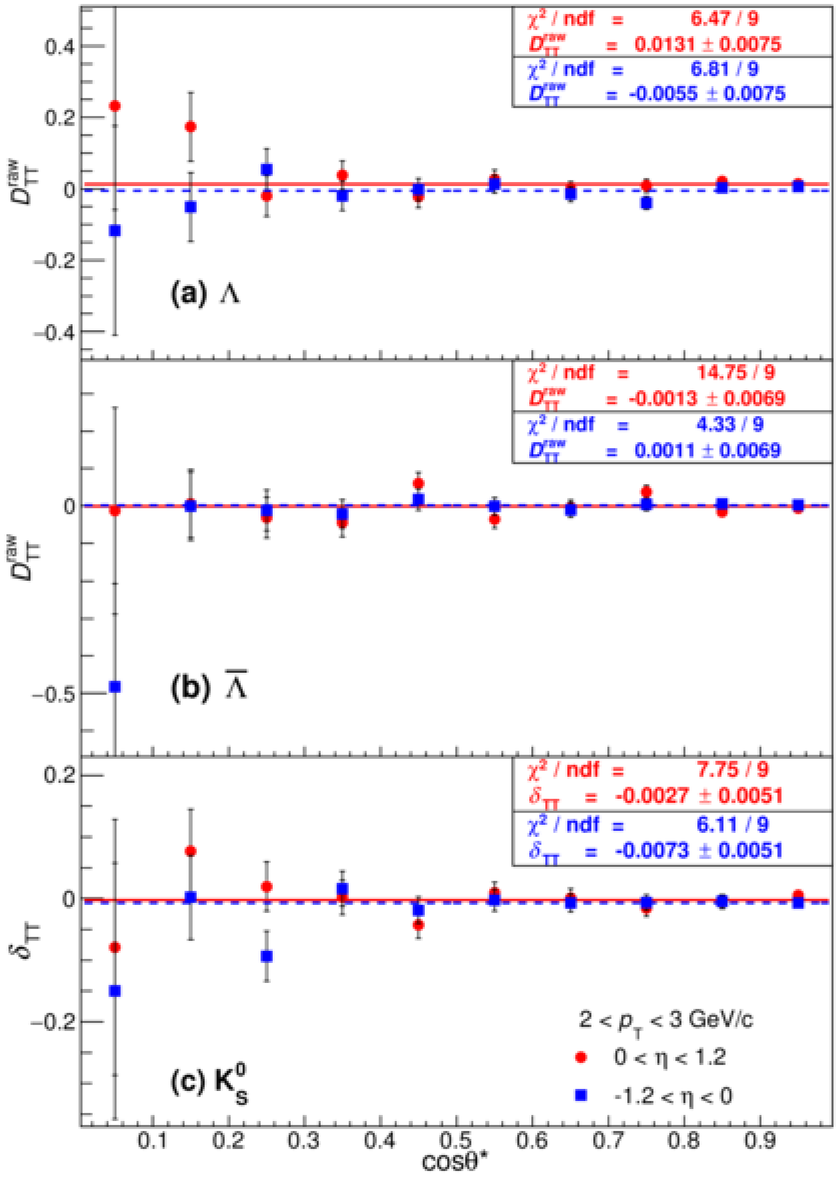
STAR, PRD 98, 091103R (2018)

  - ✓ $N^{\uparrow/\downarrow}$: the number of Λ hyperon when the beam polarization is ↑/↓
  - ✓ α: decay parameter
  - ✓ P_{beam} : beam polarization

- **The relative luminosity and the detector acceptance are both canceled.**

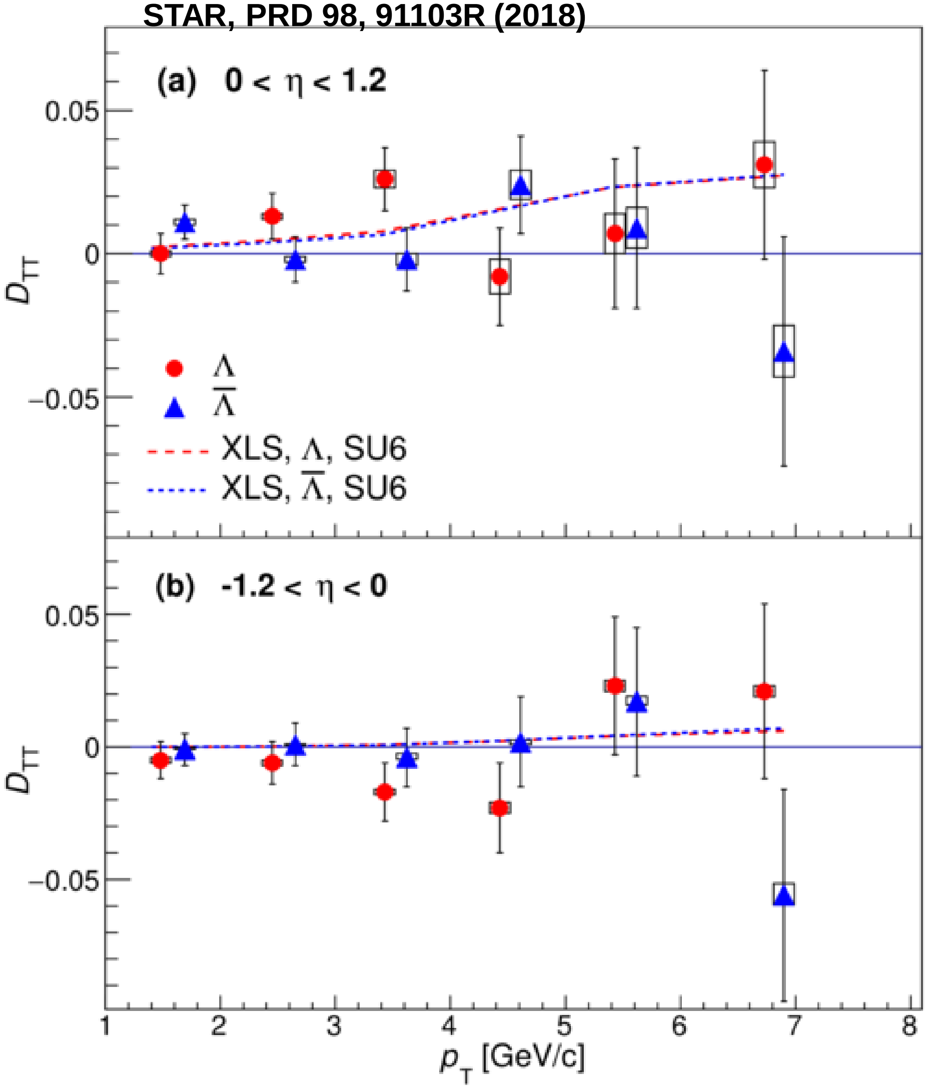
- K_S^0 was used to do a null check. α of K_S^0 is assumed equal to 1.

STAR, PRD 98, 091103R (2018)



D_{TT} vs. p_T results from STAR 2012 data

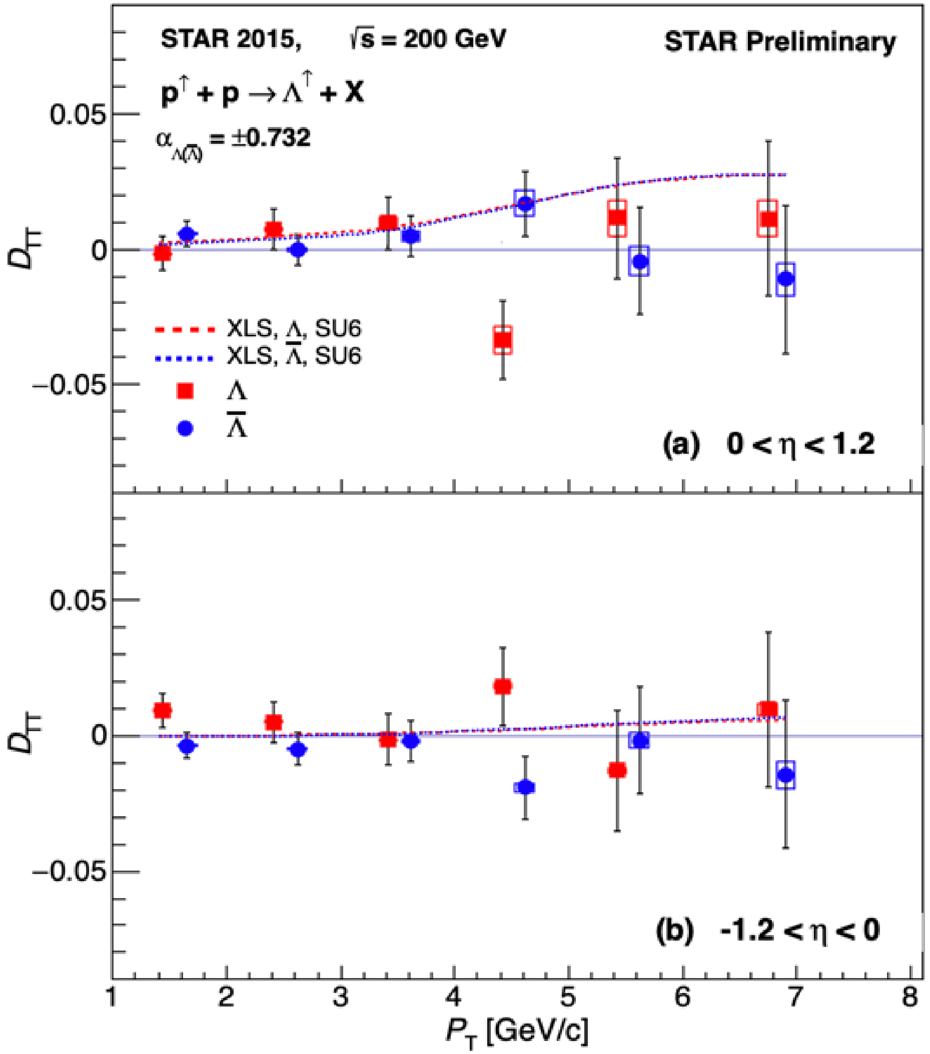
STAR, PRD 98, 91103R (2018)



Note: The Λ results have been offset to slightly smaller p_T values for clarity.

- **First measurement** of D_{TT} for $\Lambda(\overline{\Lambda})$ in transversely polarized p+p collisions at 200 GeV using STAR 2012 data.
- D_{TT} results are consistent with the model predictions, and also consistent with zero.
  - ✓ The measurement precision needs to be improved.

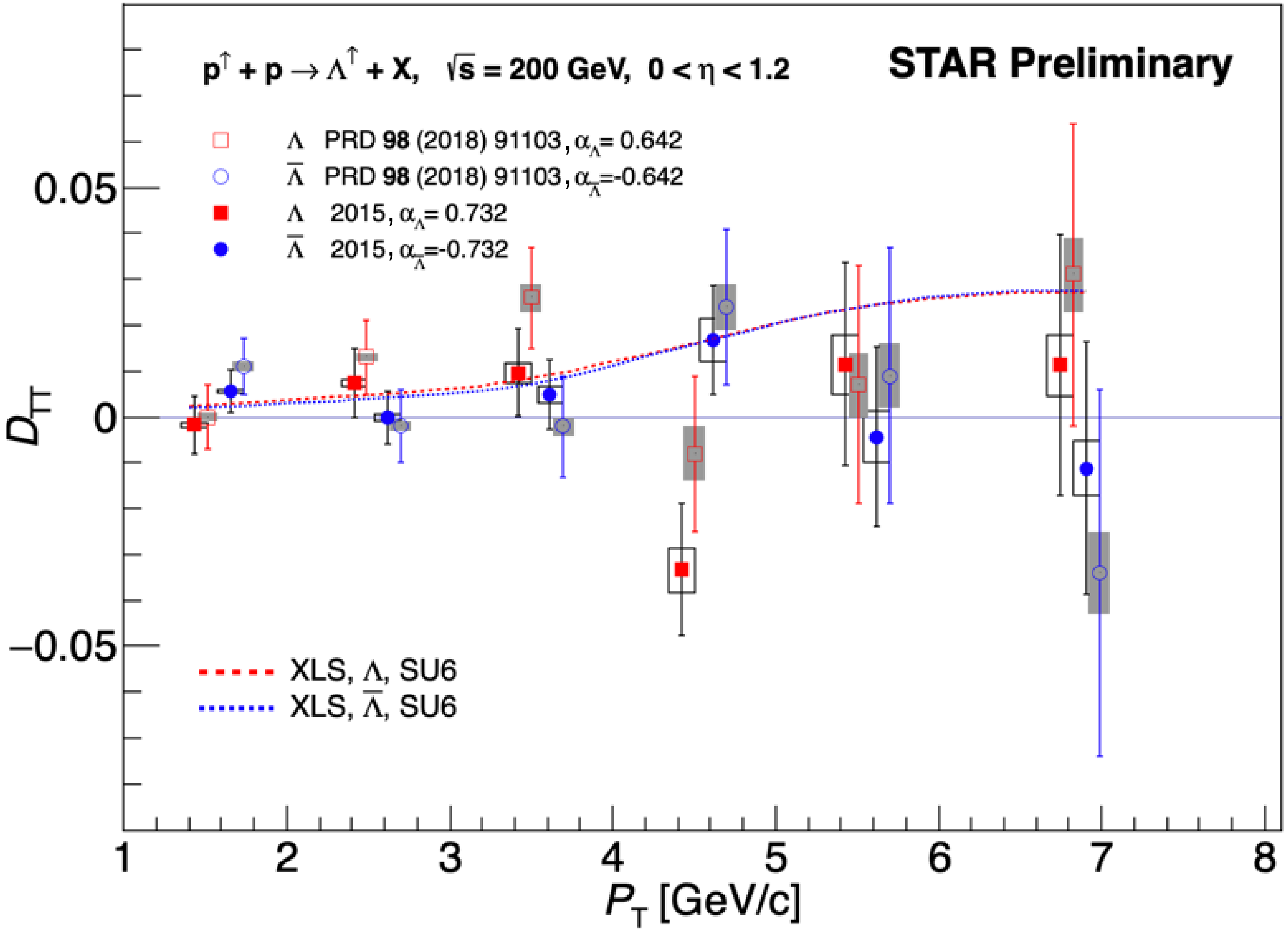
D_{TT} vs. p_T results from STAR 2015 data



- In 2015, STAR collected the largest transversely polarized p+p collision data sample at $\sqrt{s} = 200$ GeV.
- 2015 data set is twice as large as the 2012 data set.
- D_{TT} of Λ is consistent with $\bar{\Lambda}$, and also consistent with zero.
- D_{TT} from STAR 2015 data is also consistent with the model prediction.

Note: The Λ results have been offset to slightly smaller p_T values for clarity.

Results: 2012 vs. 2015 data

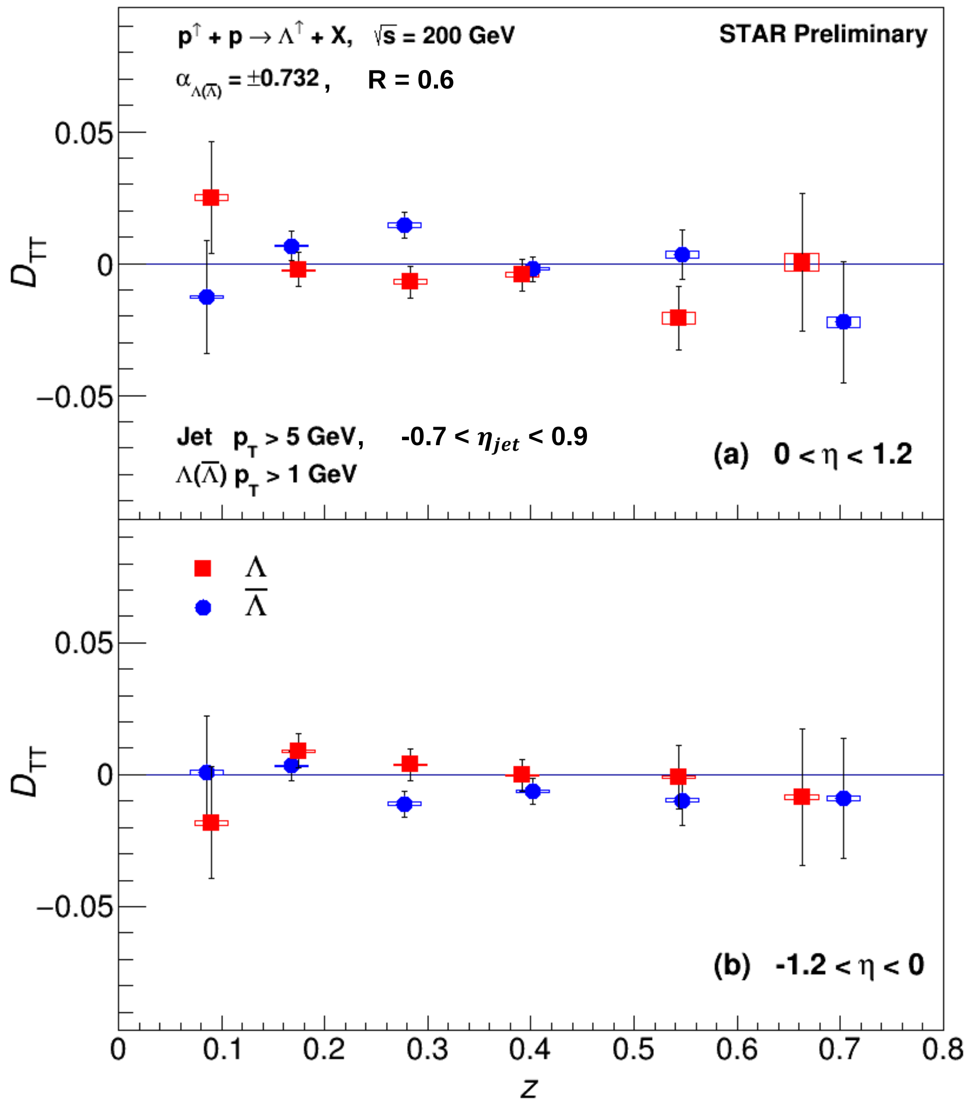


Note: The previously published results have been offset to slightly larger p_T values.

- The D_{TT} results from 2 data sets are consistent.

- The new measurements have a factor of $\sim\sqrt{2}$ improvement in statistical precision.

D_{TT} vs. z results from STAR 2015 data



$$z = \frac{\boldsymbol{p}_{\Lambda} \cdot \boldsymbol{p}_{jet}}{|\boldsymbol{p}_{jet}|^2}$$

- **First measurement of D_{TT} vs. z** for $\Lambda(\bar{\Lambda})$ in p+p collisions.
- Results are consistent with zero within uncertainties.
- D_{TT} vs. z directly probes the transversely polarized FF of the $\Lambda(\bar{\Lambda})$.

Summary

- The transverse spin transfer D_{TT} for the $\Lambda(\bar{\Lambda})$ in p+p collisions can provide access to transversely polarized fragmentation function and transversity distributions in the proton.
- New preliminary results of D_{TT} in p+p collisions at $\sqrt{s} = 200$ GeV with STAR 2015 data, which is about two times larger in statistics than 2012 data.
- The first measurement of D_{TT} versus z, which provides direct information on the transversely polarized fragmentation functions.
- STAR forward detector upgrade enables Λ measurements in the forward rapidity region. More transversely polarized p+p data will be collected at STAR in 2022 and 2024.

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Thanks!