26th International Symposium on Spin Physics

A Century of Spin

Measurement of transverse polarization of $\Lambda/\bar{\Lambda}$ within jets in unpolarized pp collisions at $\sqrt{s}$ = 510 GeV

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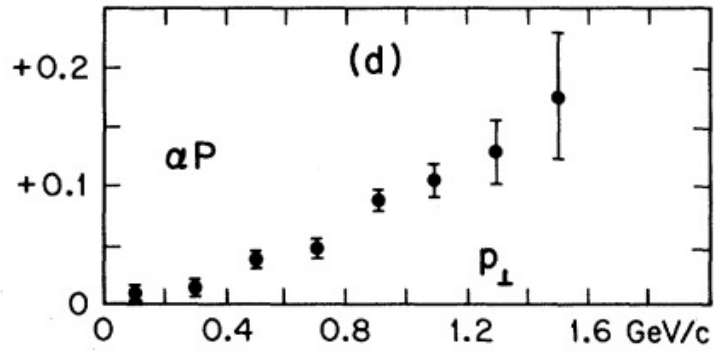
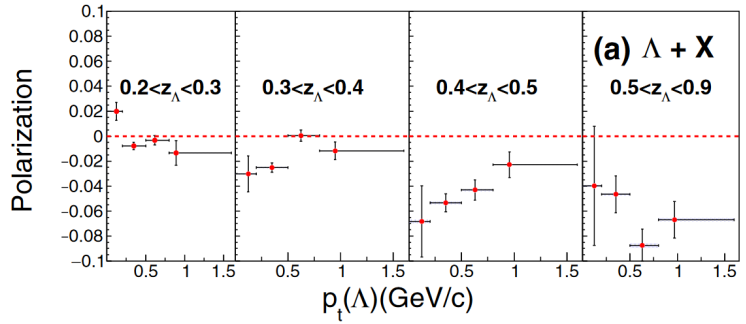
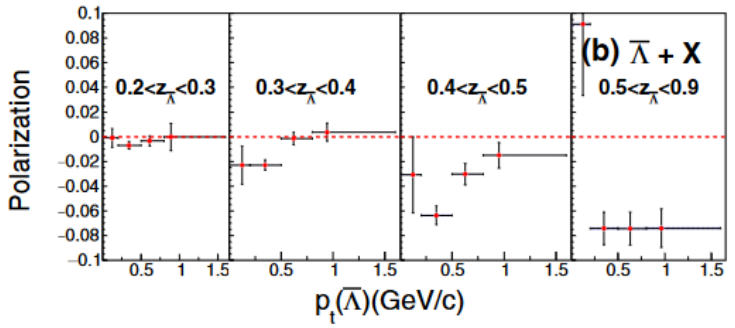
Motivation

- Λ spontaneous polarization first observed in unpolarized $p + Be$ scattering in 1976
- Based on pQCD calculation, contribution from hard-scattering ~0 *Kane, Pumplin & Repko, PRL 41, 1689 (1978)*
- **Polarizing fragmentation function (PFF)** describes the process in which an unpolarized parton produces a polarized hadron during fragmentation
- **Belle**: observed significant transverse polarization at ~10.6 GeV in e^+e^-annihilation

G.Bunce et al. PRL 36, 1113 (1976)







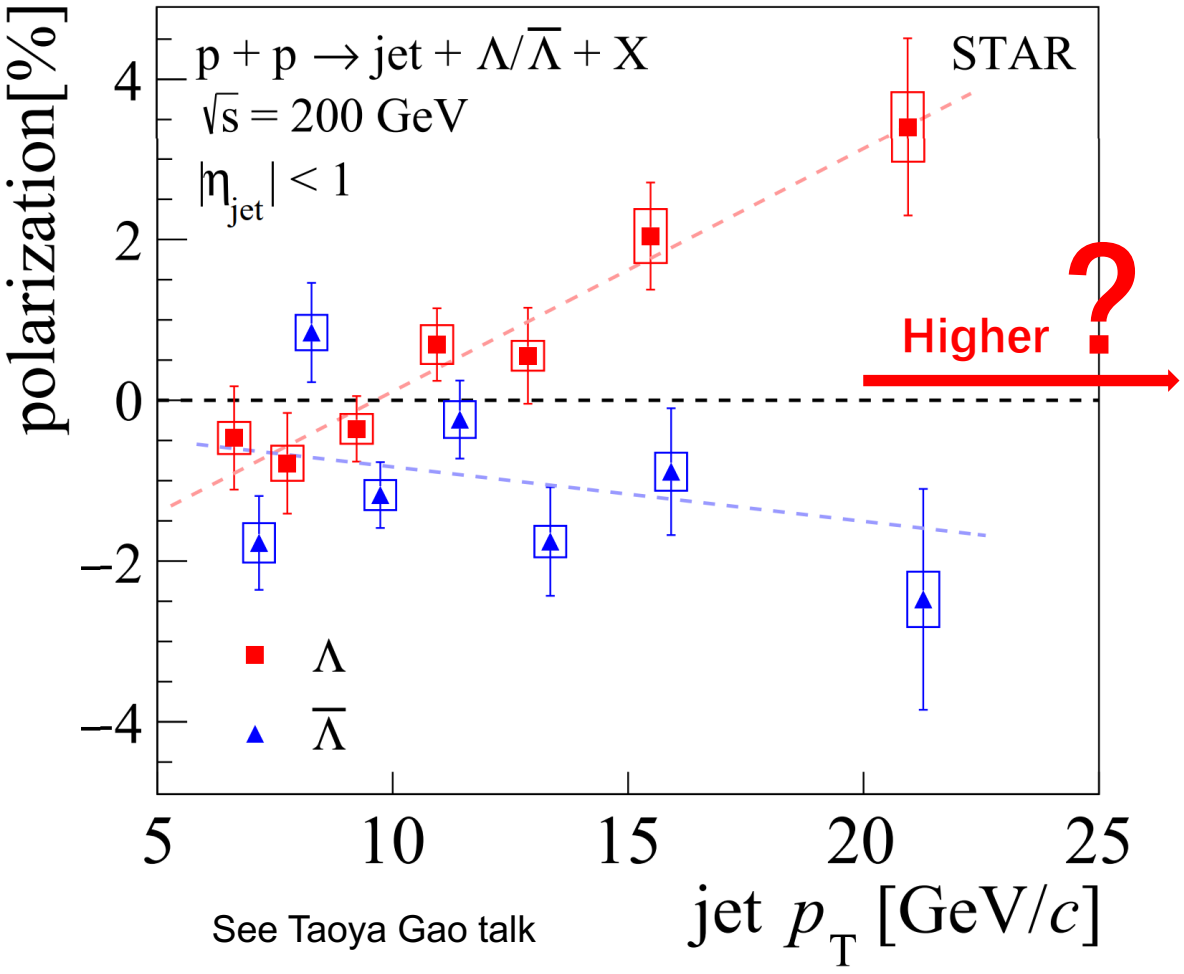
Belle. Phys. Rev. Lett. 122, 042001 (2019).

Motivation

At RHIC:

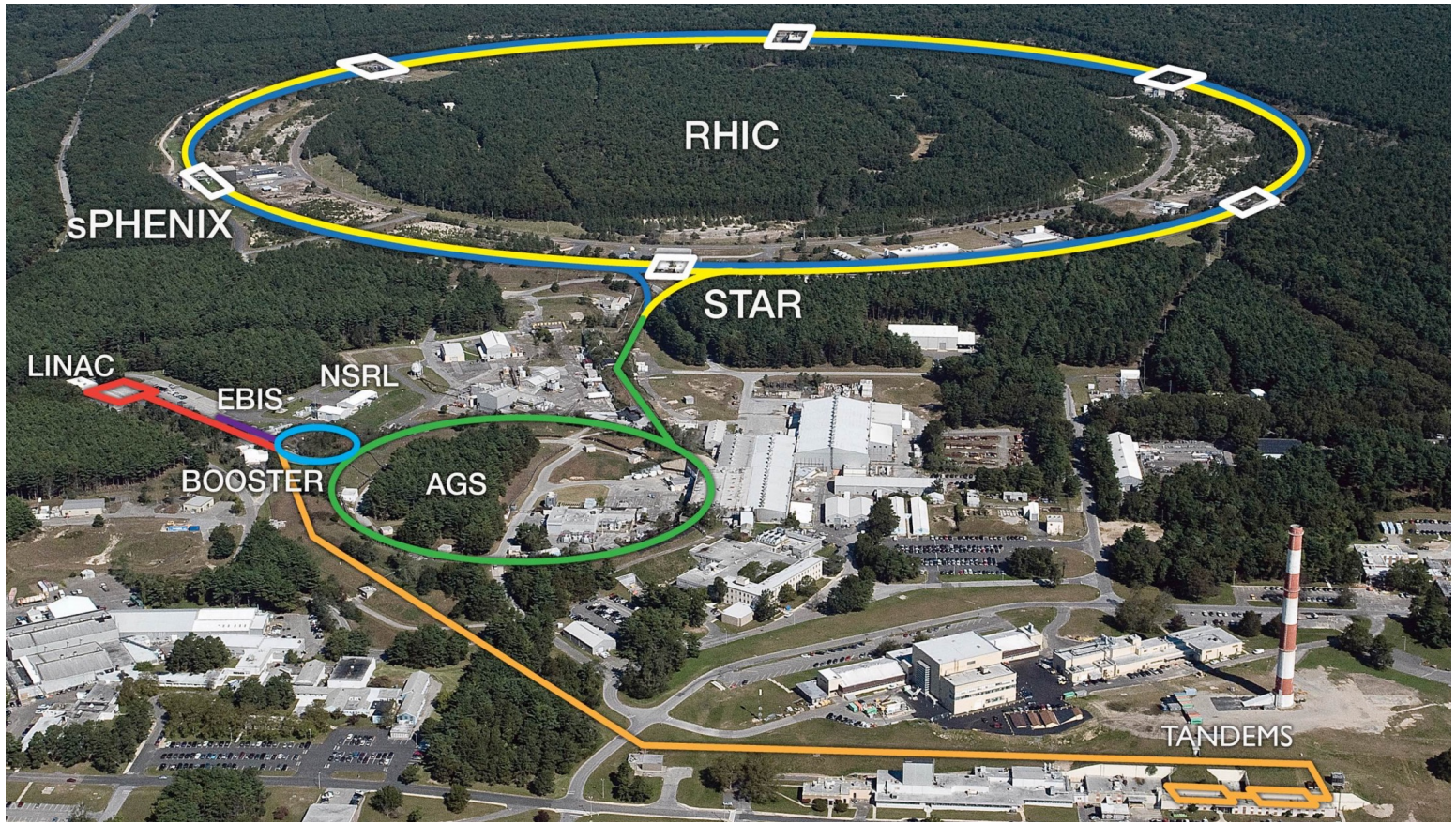
- Significant polarizations of Λ are observed with clear dependence on jet p_T at $\sqrt{s}$ = 200 GeV
- **How about in the higher jet p_T region?**
  - Measure the Λ polarization in pp collisions at higher energies (510 GeV)
  - Together with Belle 10.6 GeV and STAR 200 GeV, the 510 GeV data are crucial to study the **TMD evolution** and test the **universality of PFFs** between $e^+e^-$and pp collisions.

STAR,arXiv:2509.17487



See Taoya Gao talk

The Relativistic Heavy Ion Collider



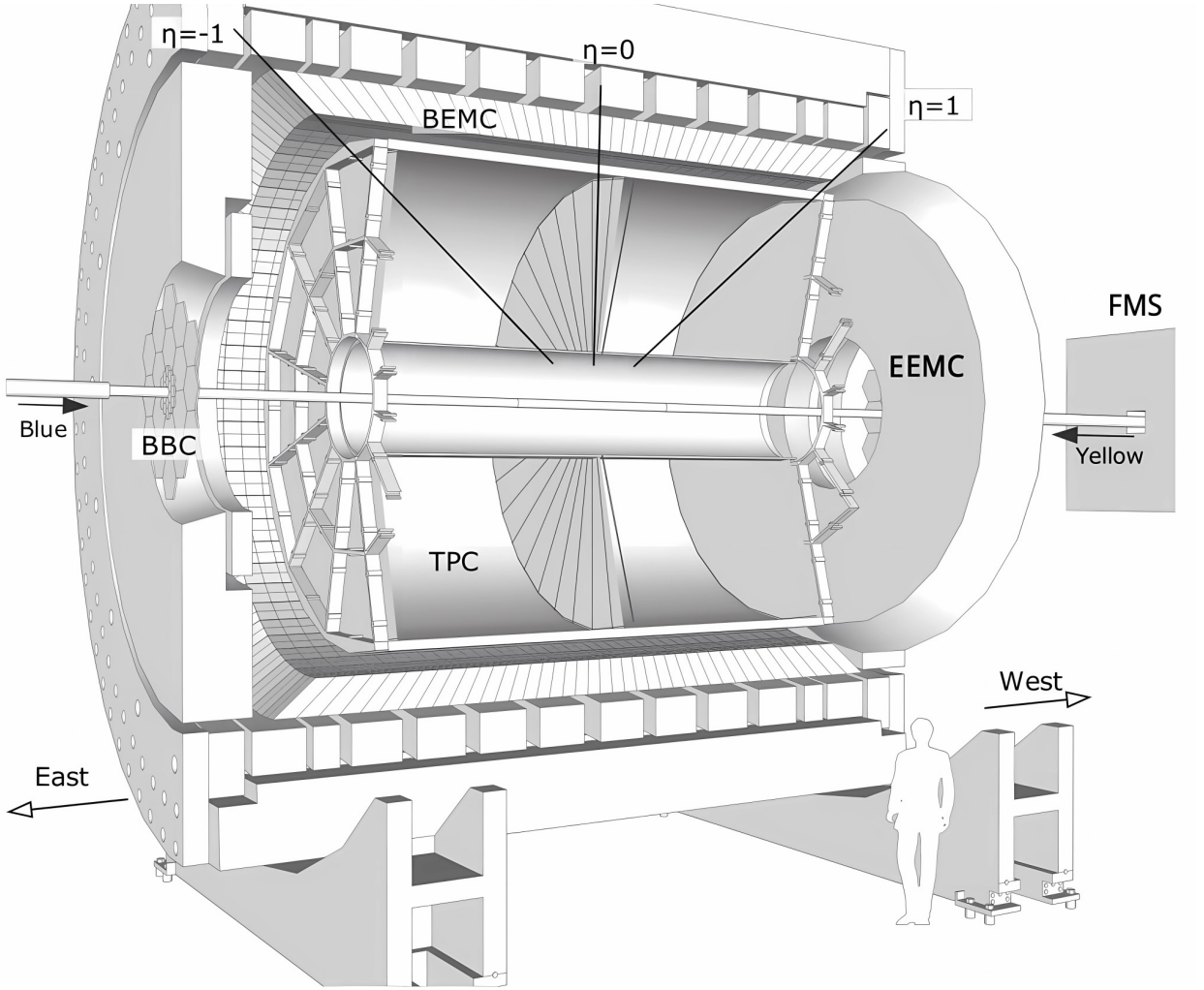
The first and only polarized pp collider in the world

	Year	$\sqrt{s}$ (GeV)	$\int L\,(pb^{-1})$	P_{beam}(%)
Long	2006	62.4/200	--/6.8	48/57
	2009	200/500	25/10	38/55
	2011	500	12	48
	2012	510	82	56
	2013	510	256	56
	2015	200	52	53
Trans	2006	62.4/200	0.2/8.5	48/57
	2008	200	7.8	45
	2011	500	25	55
	2012	200	22	60
	2015	200	52	53
	2017	510	350	55
	2022	508	400	52
	2024	200	170	55

Polarized pp collision samples taken at STAR

Used in this analysis

The Solenoidal Tracker at RHIC

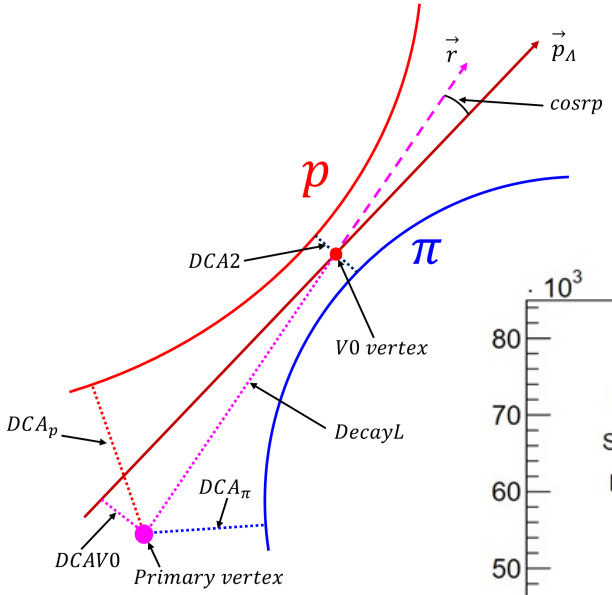


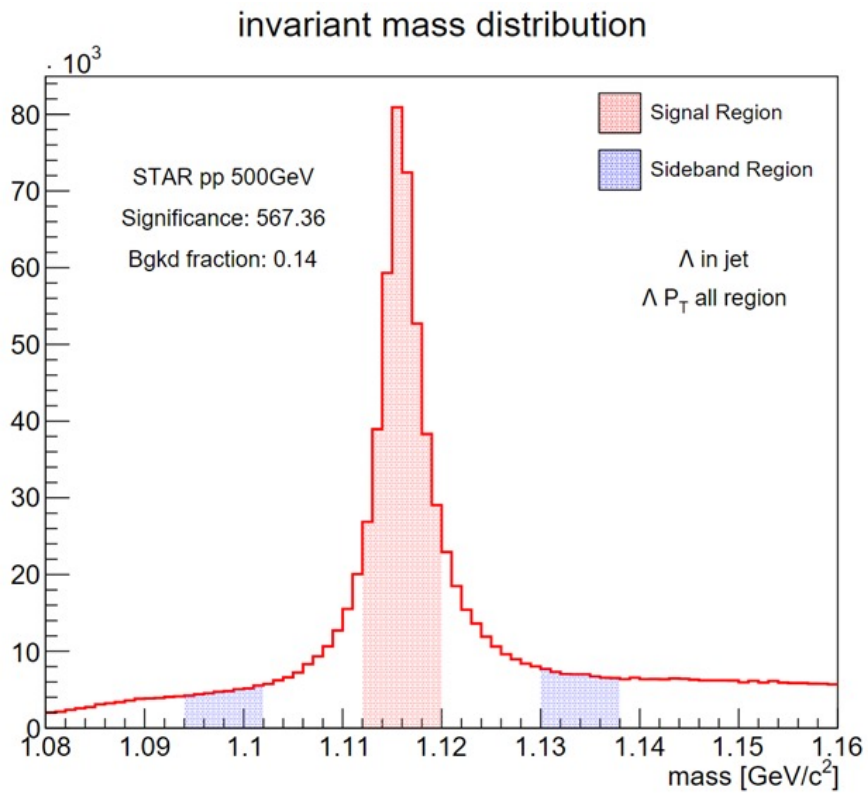
- **Time Projection Chamber (TPC)**
  - **$|\eta| < 1.3$ and $0 \leq \phi \leq 2\pi$**
  - **Tracking and particle identification(PID)**
- **Electromagnetic Calorimeter (EMC)**
  - **Barrel EMC(BEMC): $|\eta| < 1.0$ and $0 \leq \phi \leq 2\pi$**
  - **Endcap EMC(EEMC): $1.086 < \eta < 2.0$ and $0 \leq \phi \leq 2\pi$**
  - **Used for detecting EM energies and triggering**
- Time of Flight (TOF) detector
- Vertex Position Detector (VPD)
- …

☐ Jet trigger samples are used to select hard QCD scattering events

Λ reconstruction

- **Λ reconstruction:**
  - Topological criteria
  - $\Lambda \to p + \pi^-$, $\bar{\Lambda} \to \bar{p} + \pi^+$
  - Tracking and particle identification by TPC



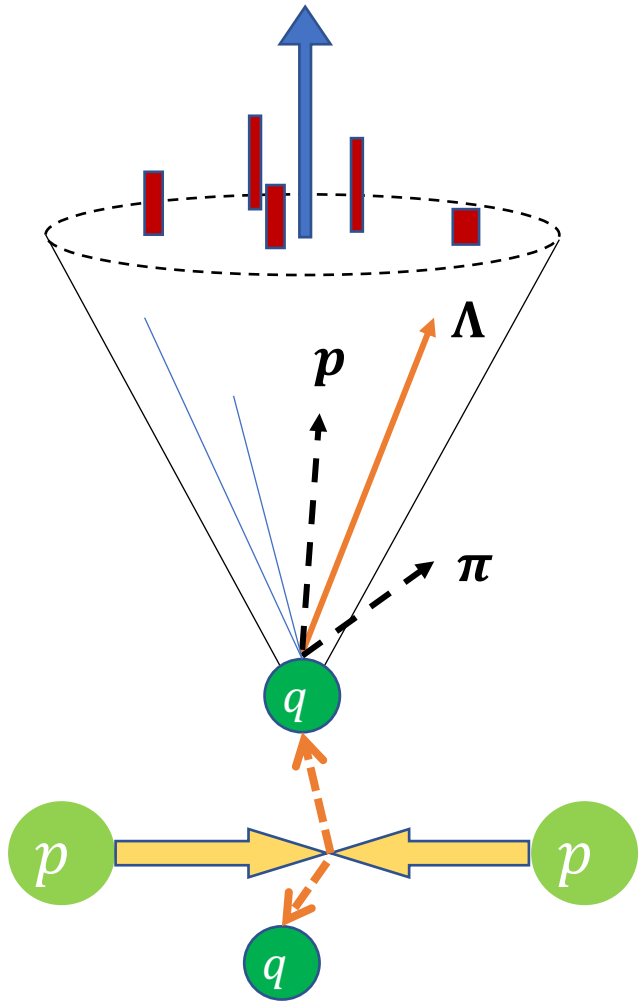


$\Lambda/\bar{\Lambda}$ Topological cuts

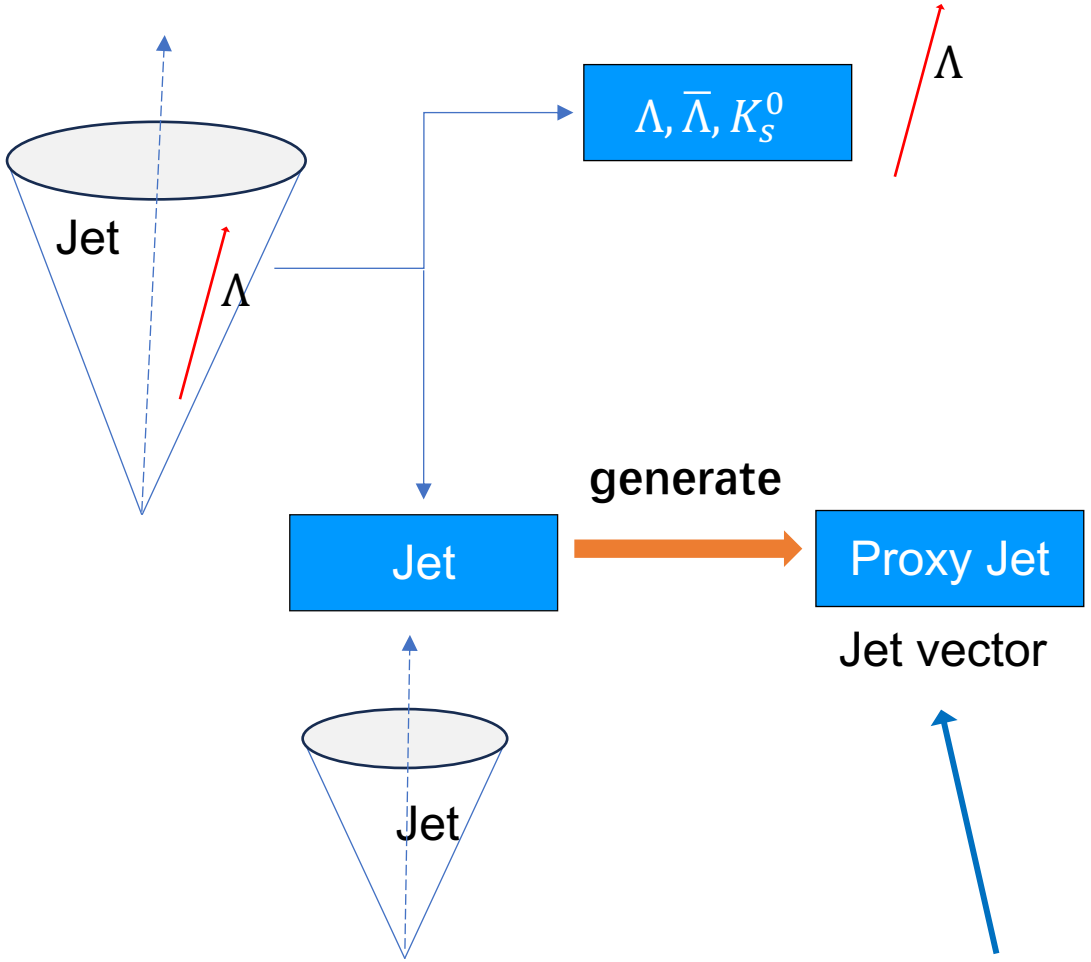
p_T(GeV)	0-1	1-2	2-3	3-4	4-5	5-6	6-8
$DCA2(cm) <$	0.65	0.65	0.60	0.55	0.50	0.45	0.40
$DCA_{p(cm)} >$	0.45	0.35	0.15	0.15	0.005	0.005	0.005
$DCA_{\pi(cm)} >$	0.65	0.65	0.55	0.55	0.50	0.50	0.50
$DCAV0(cm) >$	0.55	0.65	1.0	1.0	1.0	1.0	1.0
$DecayL(cm) >$	3.0	3.0	3.5	3.5	4.0	4.5	5.5
$cosrp >$	0.995	0.995	0.995	0.995	0.995	0.995	0.995

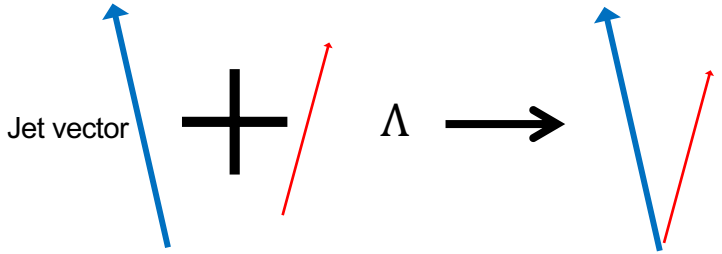
Jet reconstruction

- Anti-k_T with $\mathrm{R} = 0.5$
- Reconstructed $\Lambda, \overline{\Lambda}$ as inputs
- Including tracks and tower energies
- Jet candidates cuts
  - Jet p_T > 9.6 GeV/c
  - Jet η: $-1 < \eta < 1$
  - Jet detector η: $-0.7 < \eta_{det} < 0.9$
  - Neutral energy fraction < 0.95



Mixed event method





- **Mixed event method to study the detector acceptance effect**
- Instead of using fully reconstructed jets, we use a **"proxy jet"** — represented only by its direction (jet vector) — to mix with Λ candidates
- Large size mixed event sample

Generate proxy jets (jet kinematics: p_T, η, ϕ) based on real data, then mix real Λ with them

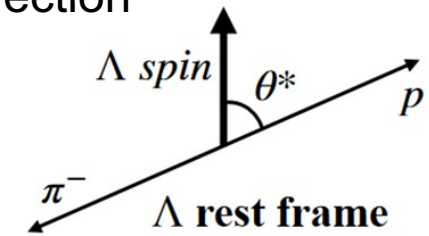
Polarization Extraction

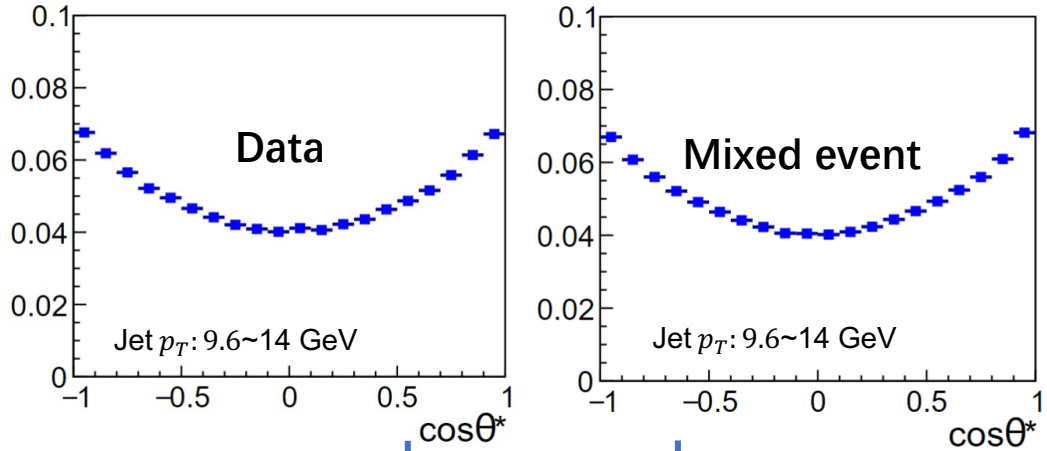
- Angular distribution of the Λ daughter particle in the Λ rest frame

$$\frac{dN}{dcos\theta^*} \propto A(cos\theta^*)(1 + \alpha_\Lambda P_\Lambda cos\theta^*)$$

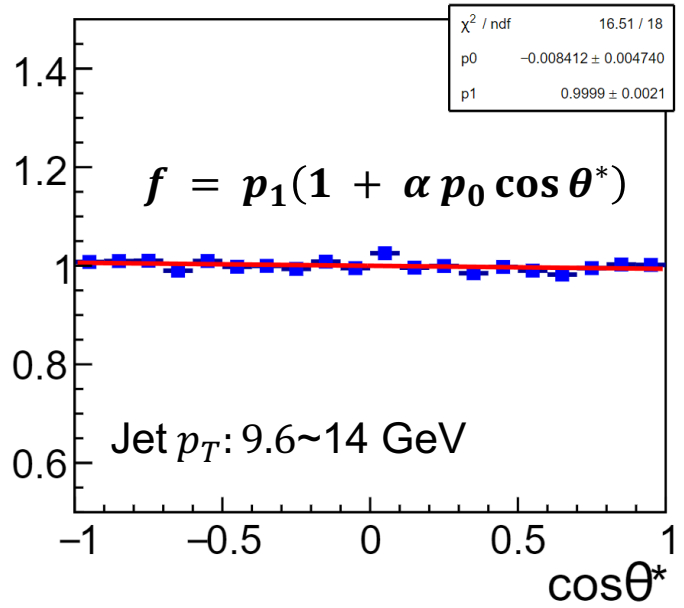
  - $A(cos\theta^*)$ is the acceptance function
  - θ^* is the angle between Λ polarization direction and its daughter p in the Λ rest frame
  - $P_{\Lambda/\bar{\Lambda}}$ is the polarization value.
  - $\alpha_{\Lambda/\bar{\Lambda}}$ = 0.747/-0.757 is the decay parameter

PDG. Phys. Rev. D 110, 030001 (2024)

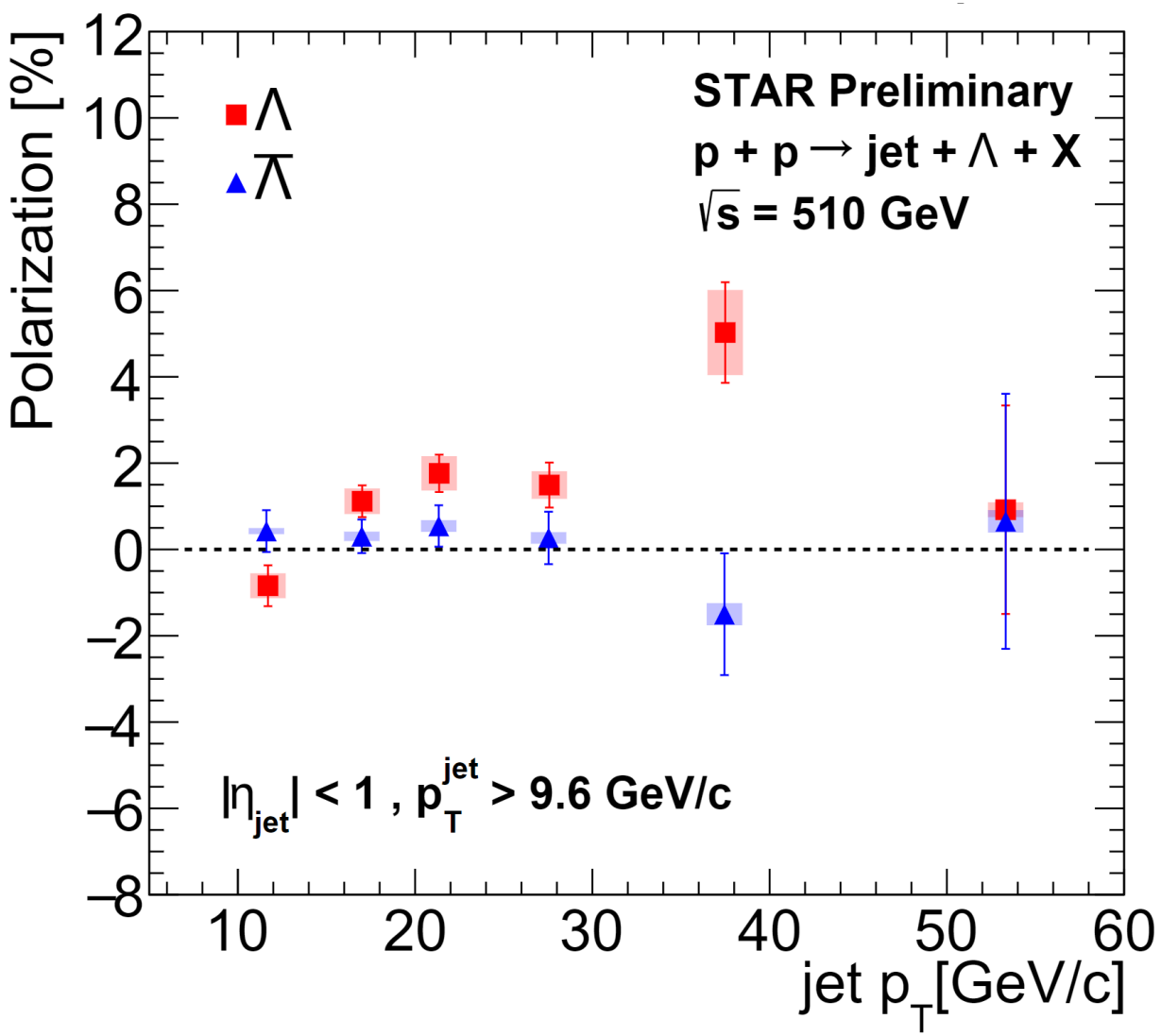




Acceptance correction $\frac{N_{data}}{N_{mixed}}(cos\theta^*)$

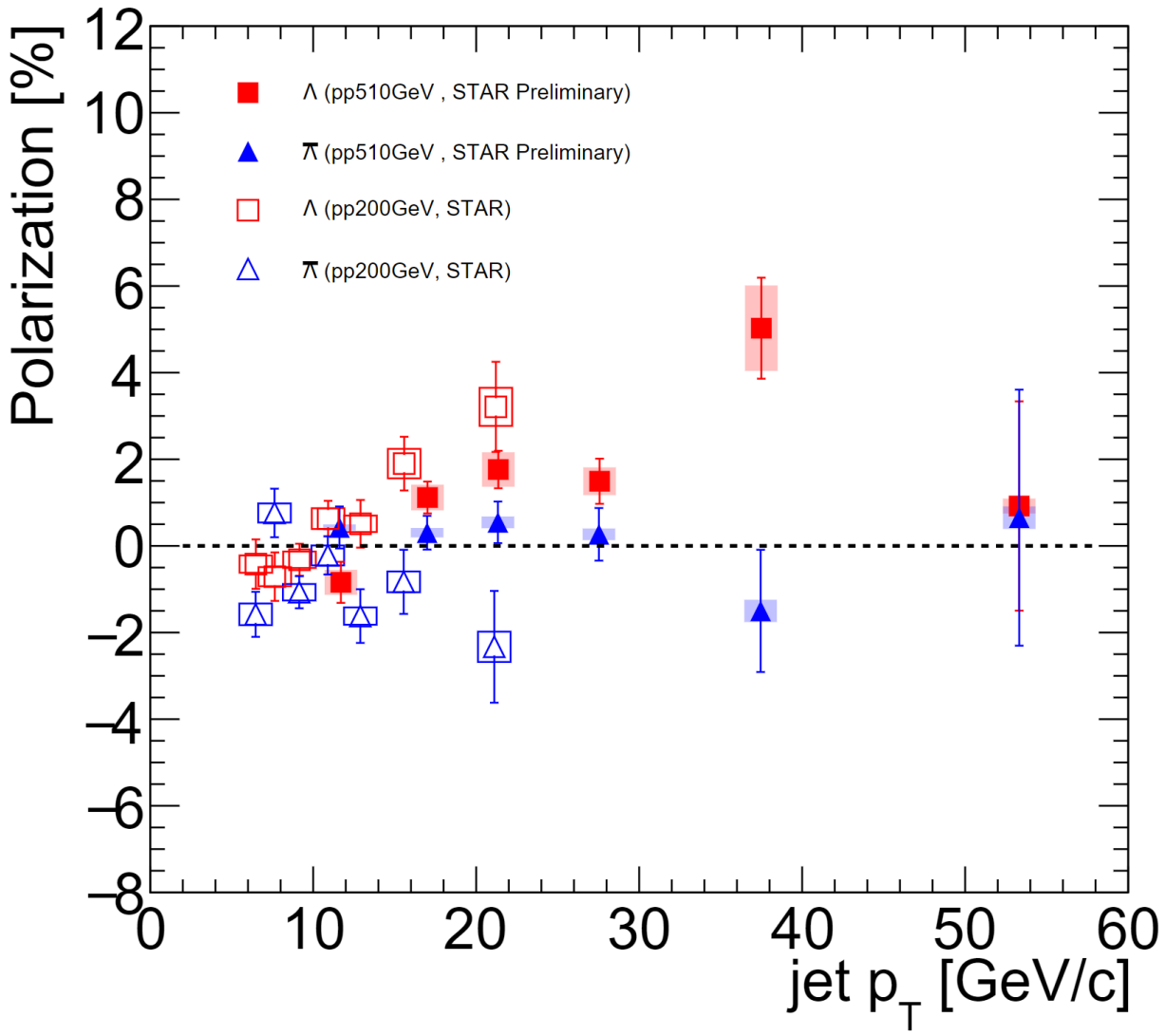


Polarization as function of jet p_T at $\sqrt{s}$ = 510 GeV



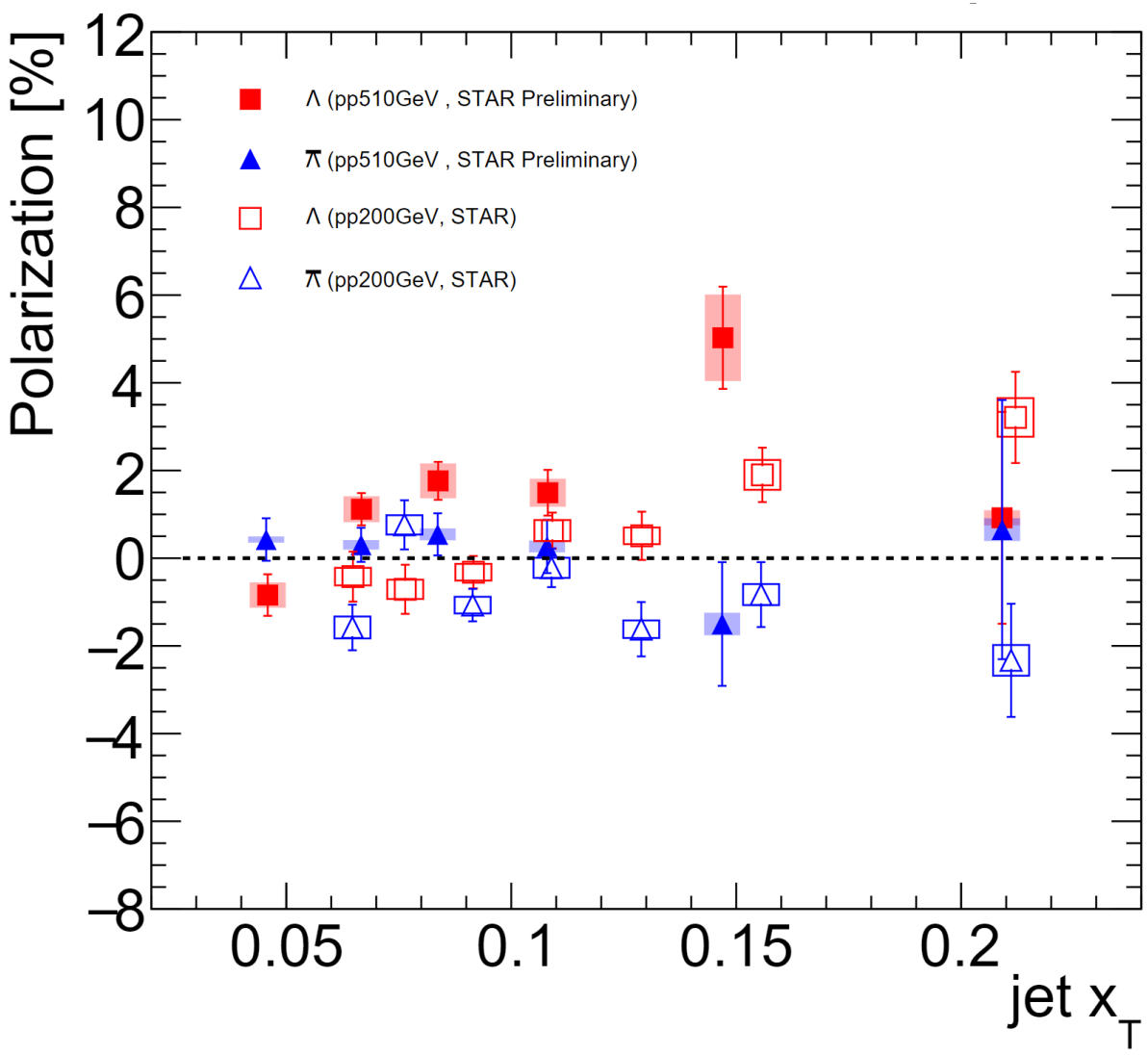
- The preliminary results at $\sqrt{s}$=510 GeV cover jet p_T up to 50 GeV

Polarization as function of jet p_T at $\sqrt{s}$ = 510 GeV



- The preliminary results at $\sqrt{s}$=510 GeV cover jet p_T up to 50 GeV
- Λ polarization as a function of jet p_T consistent with the trend at $\sqrt{s}$ = 200 GeV
- The relative contribution from different partons is different from $\sqrt{s}$= 200 GeV and $\sqrt{s}$=510 GeV even at same jet p_T

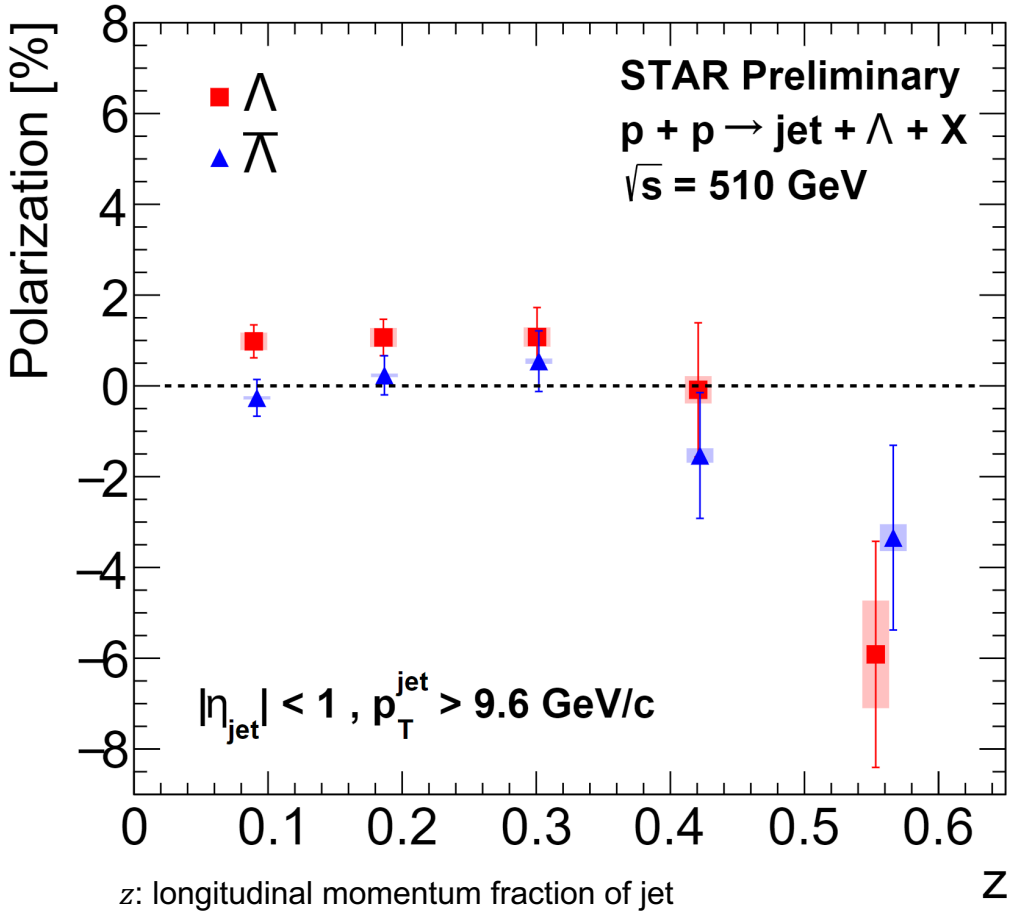
Polarization as function of jet x_T at $\sqrt{s}$ = 510 GeV



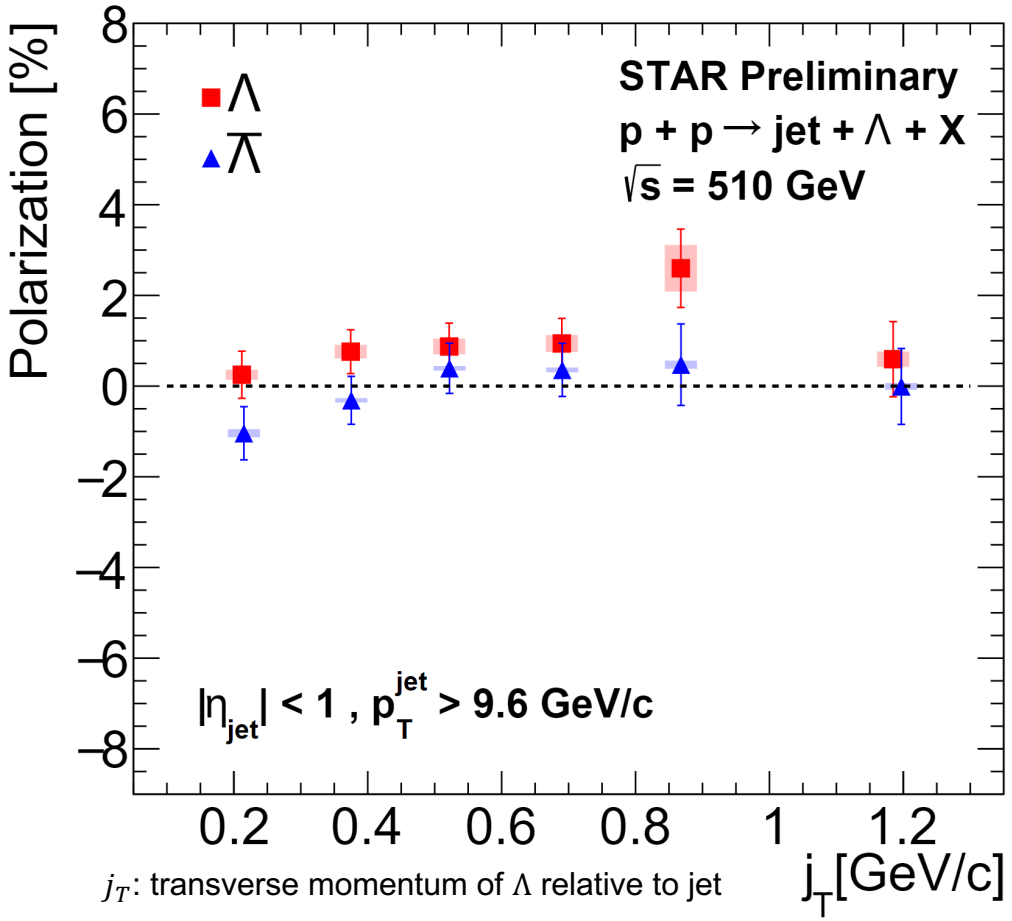
$$x_T = \frac{2p_T}{\sqrt{s}}$$

- x_T approximate to the momentum fractions of scattering partons at $\sqrt{s}$ = 200 and 510 GeV
- The comparison between $\sqrt{s}$ = 200 GeV and 510GeV at same x_T, then reflects the scale dependence; with a factor of 2.55 difference

Polarization as function of z and j_T at $\sqrt{s}$ = 510 GeV



z: longitudinal momentum fraction of jet



j_T: transverse momentum of Λ relative to jet

$$j_T = \frac{p_\Lambda \times p_{jet}}{|p_{jet}|}$$

- No clear z and j_T dependence of Λ or $\bar{\Lambda}$ polarization
- Providing more constraints on PFFs, especially gluon PFFs

Summary

- **First measurement of transverse polarization of Λ in jets in pp collisions at 510 GeV at STAR**
- **The preliminary results at $\sqrt{s}$ = 510 GeV cover jet p_T up to 50 GeV**
  - New data at $\sqrt{s}$ = 510 GeV consistent with the trend at $\sqrt{s}$ = 200 GeV as a function of jet p_T
  - Providing more constraints on gluon PFFs, and testing the universality of PFFs
  - The comparison versus x_T between 200 GeV and 510 GeV providing inputs to TMD evolution effect of PFFs
- **Outlook**
  - More 500 GeV pp data have been collected in 2013 and 2022
  - 200 GeV pAu data being analyzed to study the nuclear medium effect

Thank you for your attention

Back up

Systematic uncertainty

- Trigger bias
- Systematic Uncertainty of Background Estimation
- The relative systematic uncertainty of decay parameter

$$\sigma_{trig} = \left| \frac{f_{nobias} - f_{trigger}}{f_{nobias}} \right| \times max(|P_\Lambda|, \sigma_{stat})$$

$$\sigma_{bkg} = max|\Delta P_\Lambda| = max|P_\Lambda - P_{bkg}|$$

$$\sigma_\alpha = 0.009/0.747 \times |P_\Lambda|$$

$$\sigma_{sys} = \sqrt{\sigma_{trig}^2 + \sigma_{bkg}^2 + \sigma_\alpha^2}$$