Measurement of transverse polarization of $\Lambda(\bar{\Lambda})$ in unpolarized p+p collisions at 200 GeV

Taoya Gao(高涛亚)

Shandong University
For the STAR Collaboration

Sep 26, 2023

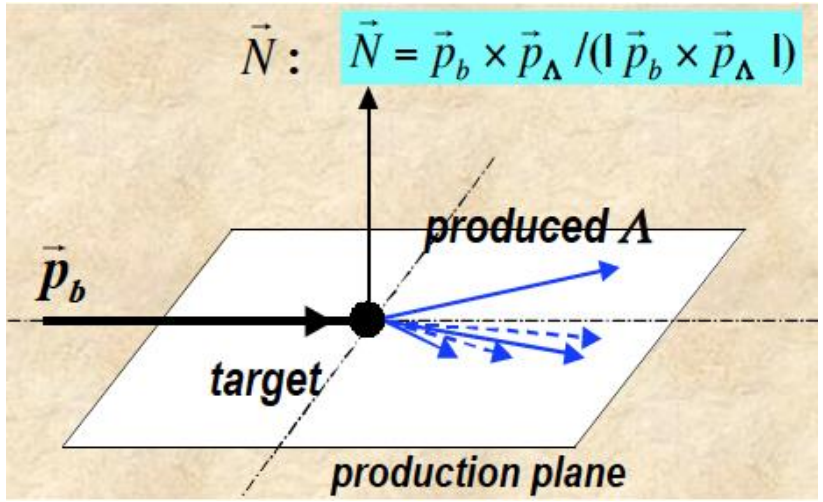
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

NSFC
National Natural Science Foundation of China

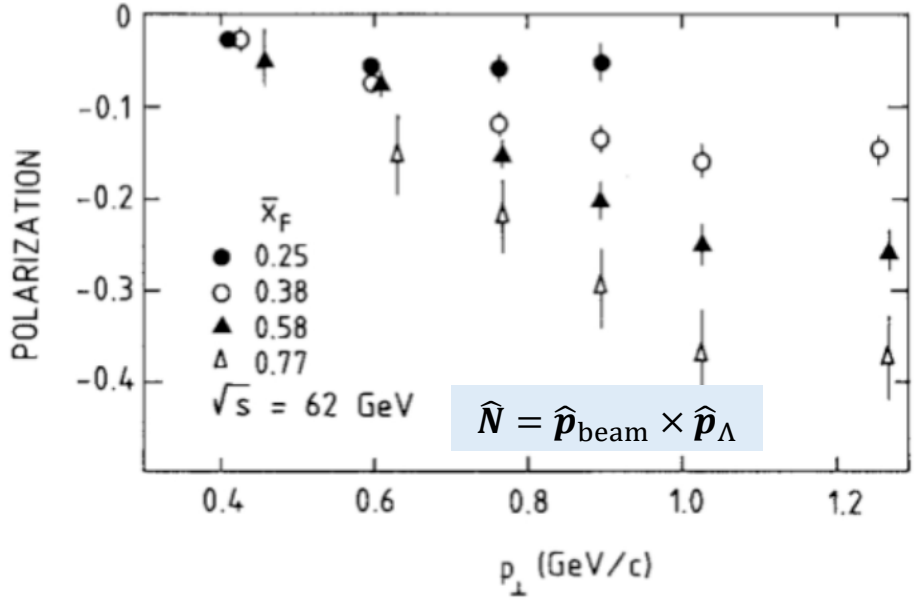
Λ spontaneous polarization puzzle

- First observation of large transverse polarization of hyperon in unpolarized hadron scatterings in 1976 *G.Bunce et al. PRL 36, 1113 (1976)*
- Numerous follow-up measurements in e+e-, SIDIS, hadron-hadron scatterings
- pQCD calculation predicted ~0 polarization from hard-scattering

Kane, Pumplin & Repko, PRL 41, 1689 (1978)



A.D. Panagiotou, Int.J.Mod.Phys.A 5, 1197 (1990)

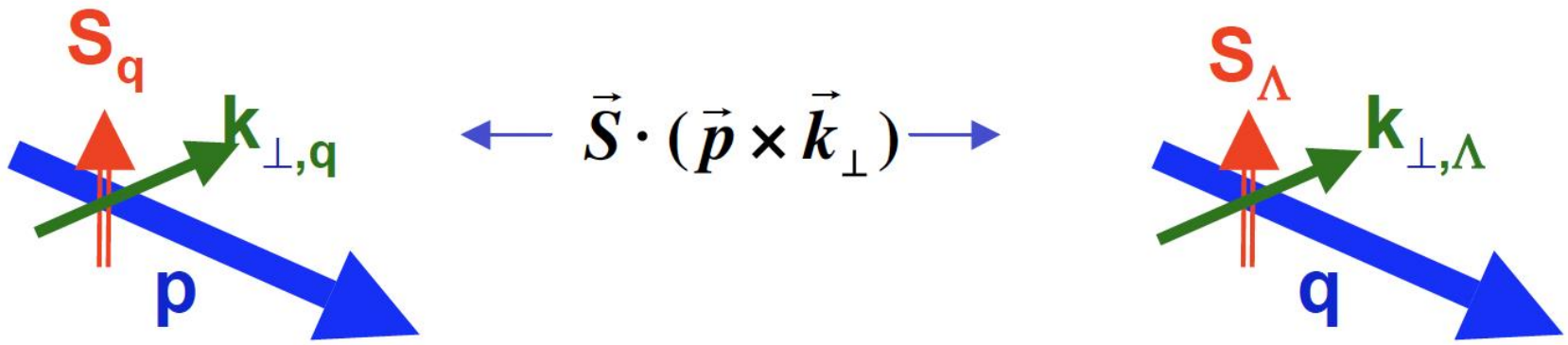


Theoretical understanding of Λ polarization

The polarization was attributed to either of initial-state or final-state

Polarizing distribution

Polarizing Fragmentation Functions(pFFs)



- Boer-Mulders function
- High twist correlation function

Zhou, Yuan, Liang, PRD 79,114022 (2009)
Kanazawa, Koike, PRD 64, 034019 (2001)

- Fit of data *M. Anselmino et al, PRD 65, 114014 (2002)*
- Experimental test: pol. within a jet
- Predictions of pol. within a jet for LHC / RHIC:

Boer et al, PLB 671, 91-98 (2008)
Kang, Lee, Zhao, PLB 809, 135756 (2020)

Measurement of pFFs in e^+e^-

- At LEP ($\sqrt{s} = 90$ GeV)
  - ALEPH $P_T^{\Lambda,\bar{\Lambda}} = 0.016 \pm 0.007$

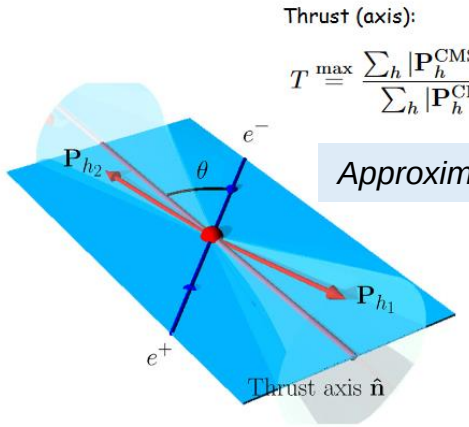
  ALEPH, PLB 374, 319 (1996)
  - OPAL $P_T^{\Lambda} = 0.019 \pm 0.014$ ($p_T > 0.3$ GeV/c)

  OPAL, EPJC 2, 49 (1998)
- At Belle ($\sqrt{s} = 10.6$ GeV)
  - Significant polarization with z dependence
  - Using π, K mesons tag quark flavor
- Extraction of polarizing Fragmentation Function(pFFs)

  Callos, Kang, Terry, PRD 102, 096007 (2020)

  D'Alesio, Murgia, Zaccheddu, PRD 102, 054001 (2020)

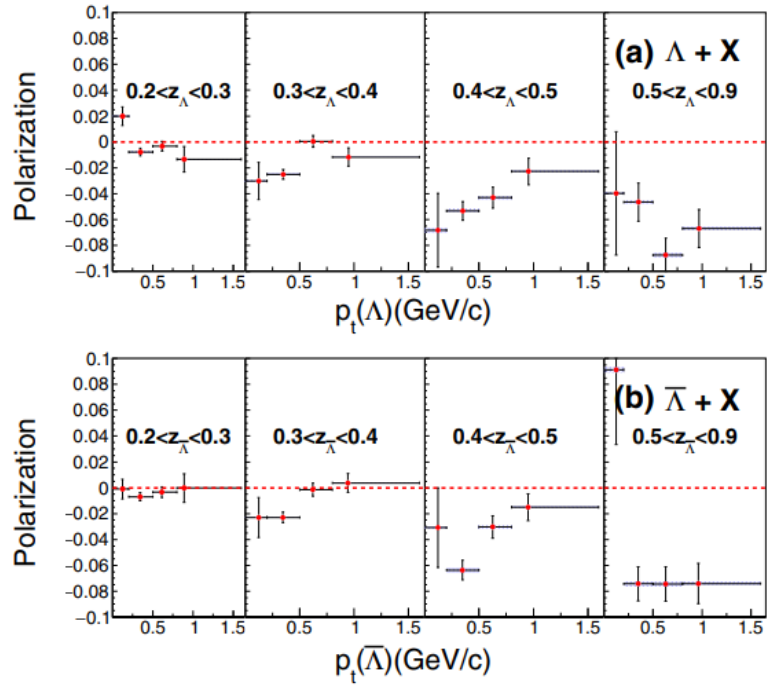
  Chen, Liang, Pan, Song, Wei, PLB 816, 136217 (2021)



Approximate jet axis

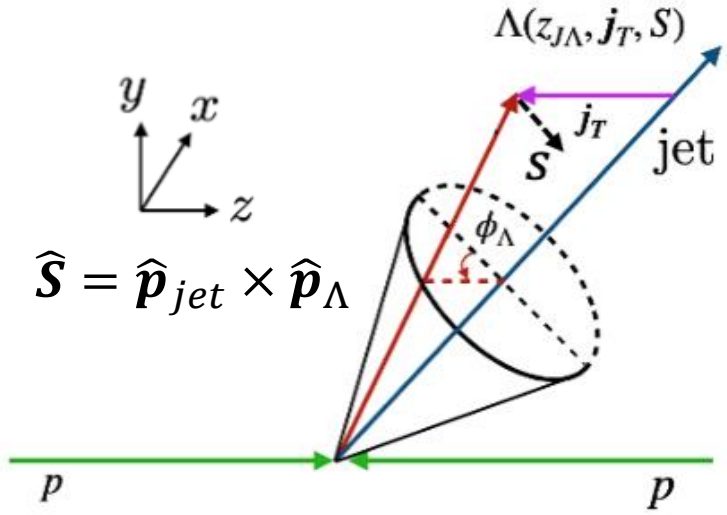
$$\hat{\boldsymbol{S}} = \hat{\boldsymbol{n}}_{\mathrm{thrust}} \times \hat{\boldsymbol{p}}_{\Lambda}$$

Belle, PRL 122, 042001 (2019)



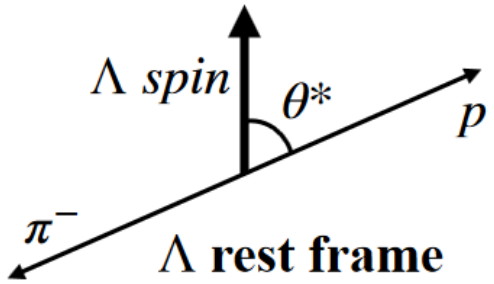
What can we do at RHIC?

- Polarizing Fragmentation Functions(pFFs) can be accessed by transverse polarization of Λ-in-jet in pp collision
- Cover a wide range of jet p_T: 5~50 GeV/c for measurement of energy scale dependence
- Test universality of pFFs
- Λ polarization extraction

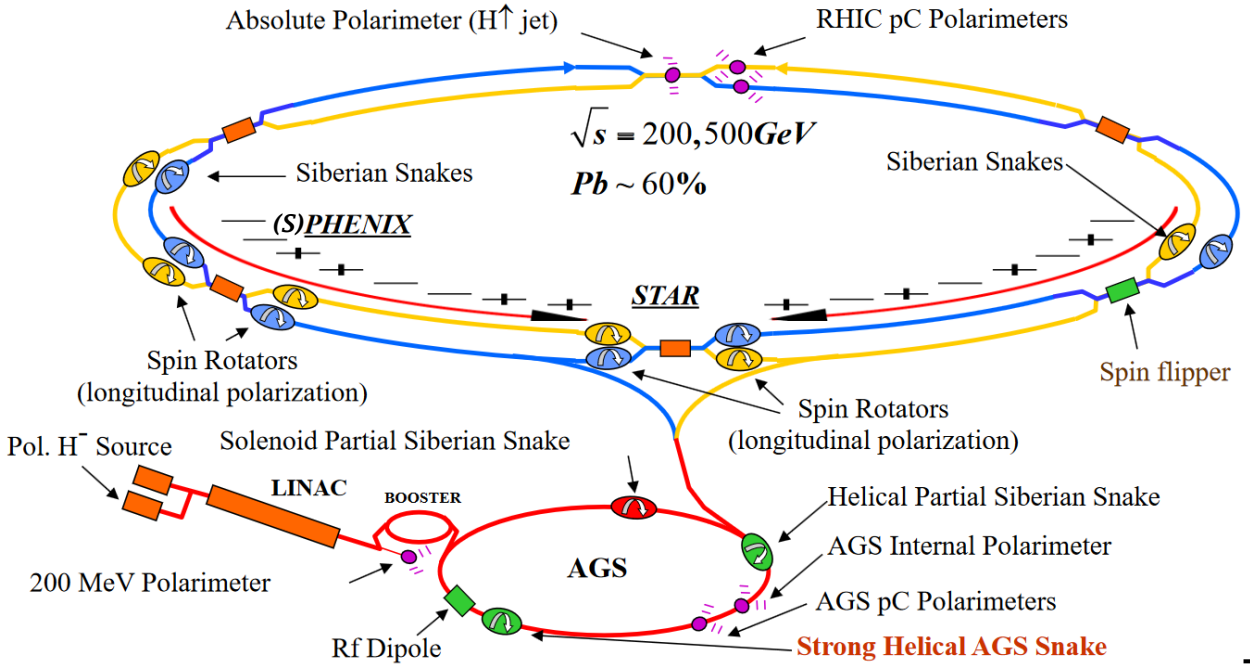


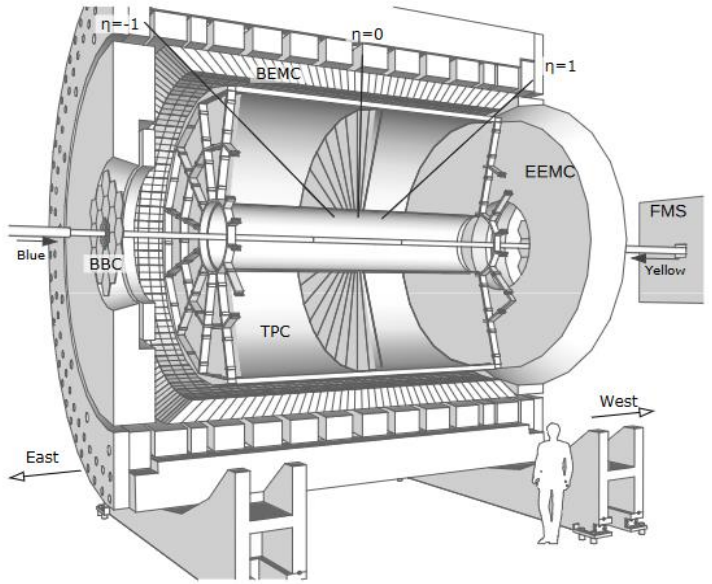
$$\frac{dN}{d\cos\theta^*} \propto (1 + \alpha P \cos\theta^*)$$

$\alpha = 0.732 \pm 0.014$
P: Λ polarization
θ^*: angle between p and spin direction



RHIC and STAR





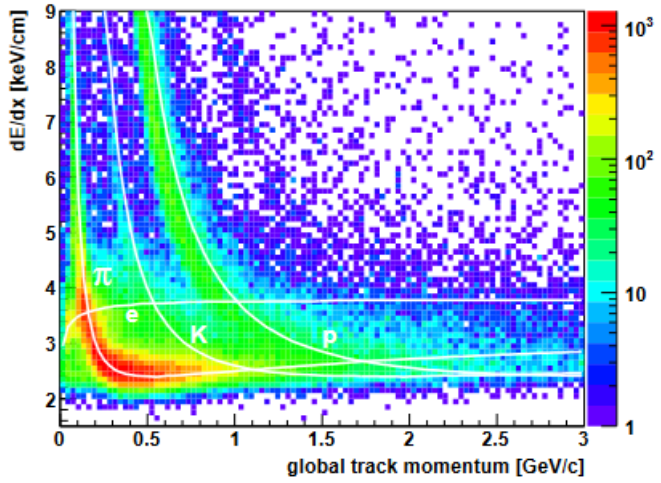
- Datasets:
  - pp collision at $\sqrt{s} = 200$ GeV
  - Integrated luminosity: 104 pb^{-1}
- Hard scattering event was selected by the jet triggers

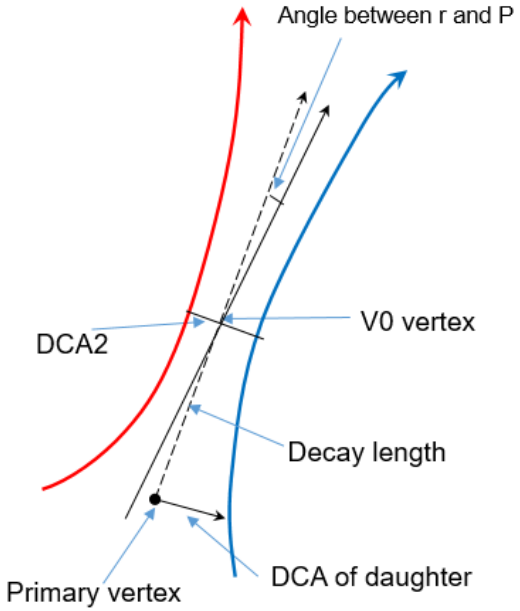
- TPC (Time Projection Chamber):
  - Tracking and particle identification
  - $-1.3 < \eta < 1.3, \phi \in [0,2\pi]$
- Calorimeter system:
  - BEMC (Barrel Electromagnetic Calorimete
    $-1 < \eta < 1, \phi \in [0,2\pi]$
  - EEMC (Endcap Electromagnetic Calorimeter)
    $1.086 < \eta < 2, \phi \in [0,2\pi]$

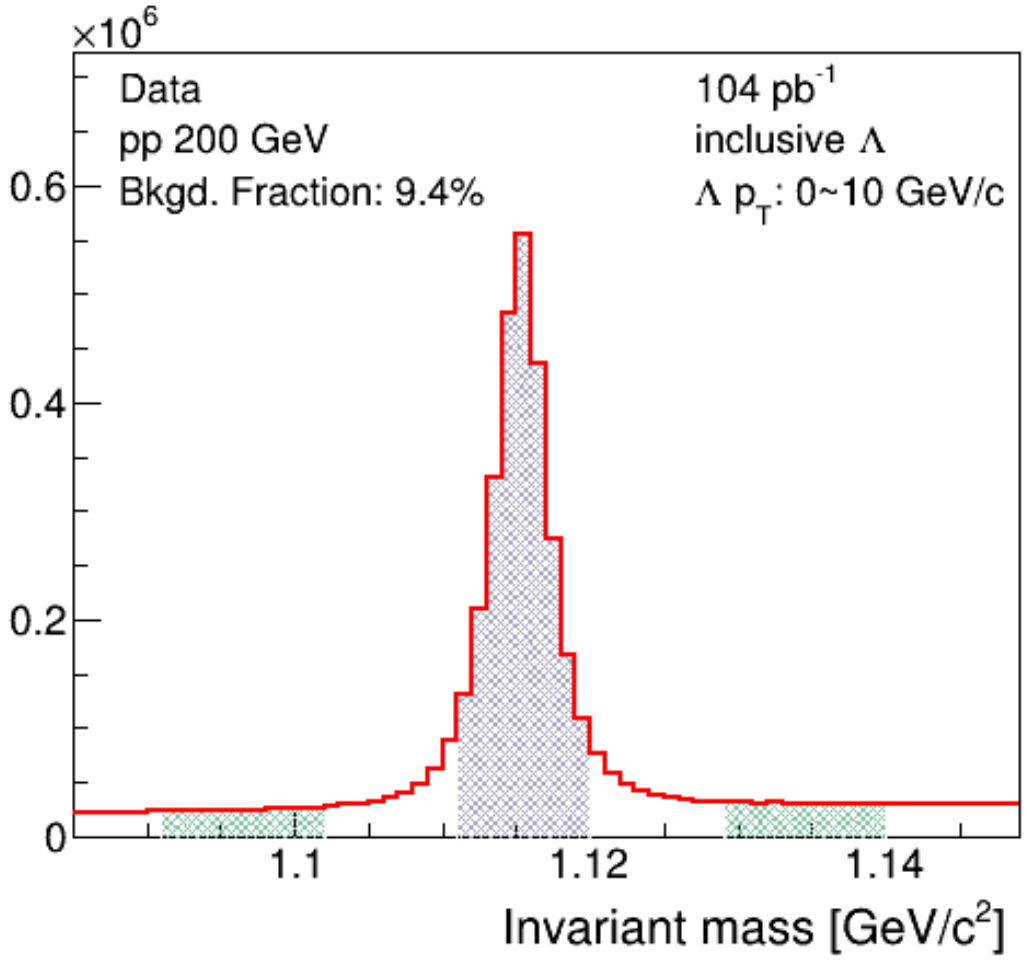
$\Lambda(\bar{\Lambda})$ reconstruction

- Reconstruction using TPC tracks:
  - $\Lambda \to p + \pi^-$; $\quad \bar{\Lambda} \to \bar{p} + \pi^+$
  - Particle identification by ionizing energy loss
  - Topological cuts

Ming Shao et al. PRC 75, 064901 (2007)

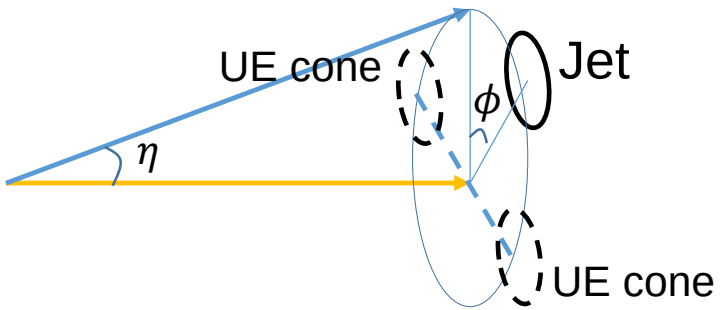


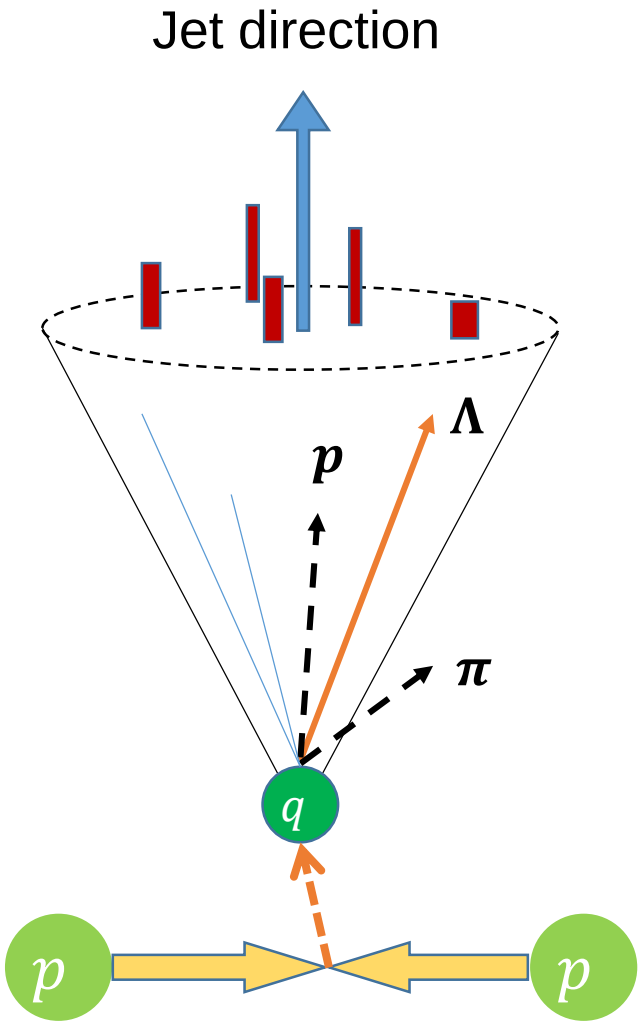




V0-jet reconstruction

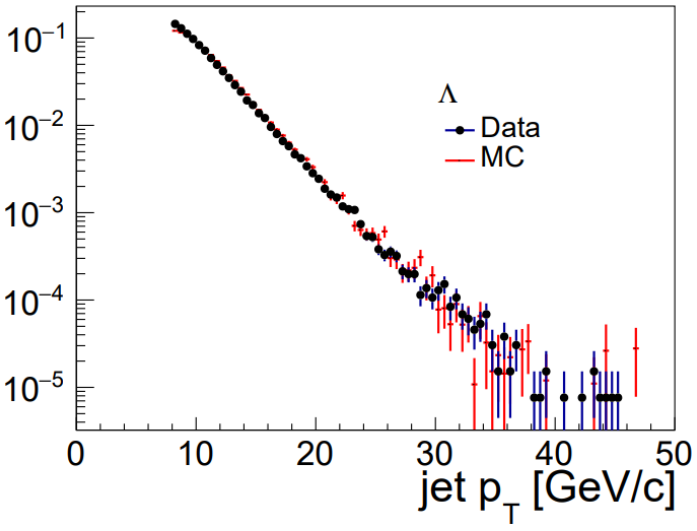
- Jet reconstruction
  - Anti-k_T with $\mathrm{R} = 0.6$
  - Particle list: TPC tracks and EMC energy deposit
  - $\Lambda, \overline{\Lambda}$ as input particles
  - Removing daughter particles to avoid double counting
- Underlying event correction by off-axis method

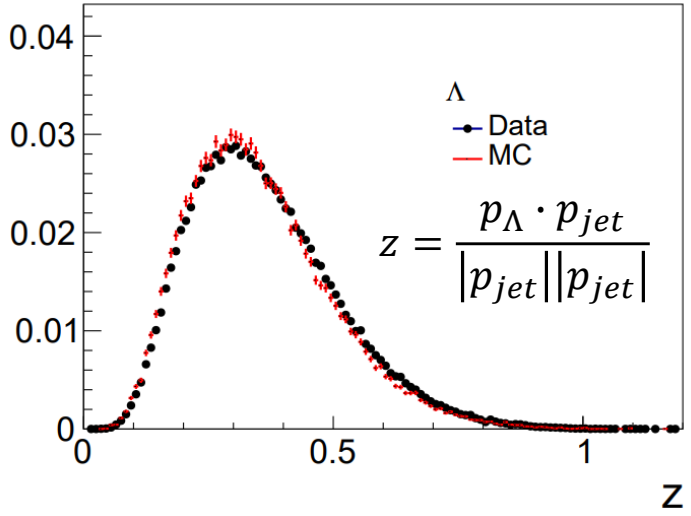




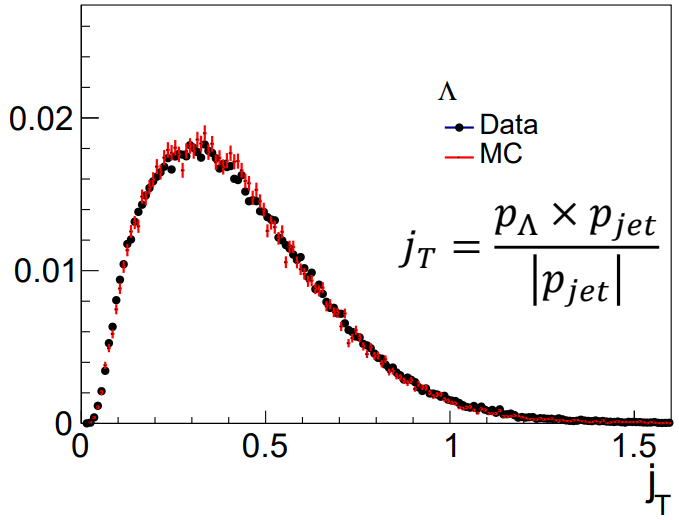
MC simulation

- Generator: PYTHIA 6.4.28
- Full GEANT3 simulation of detector response
- Λ filter and trigger filter
- Same analysis algorithm applied for MC sample as for data





Jet momentum fraction carried by $\Lambda(\bar{\Lambda})$

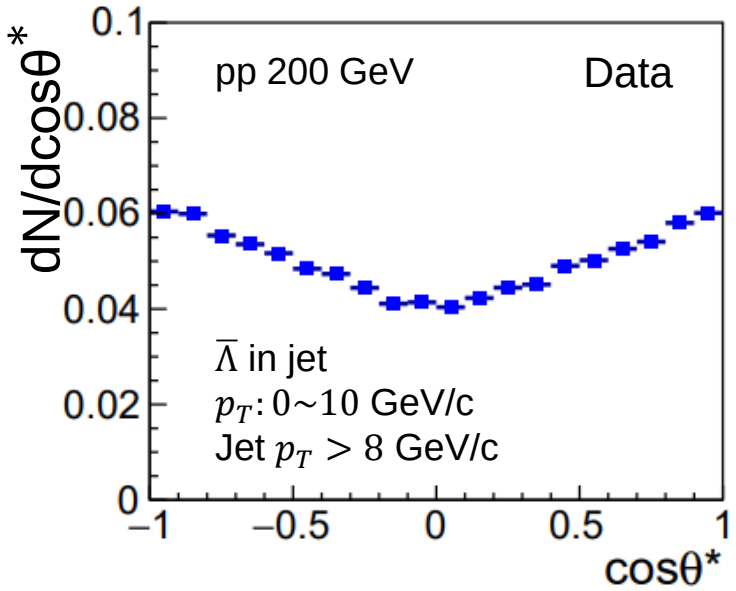


Transverse momentum of $\Lambda(\bar{\Lambda})$ w.r.t. jet axis

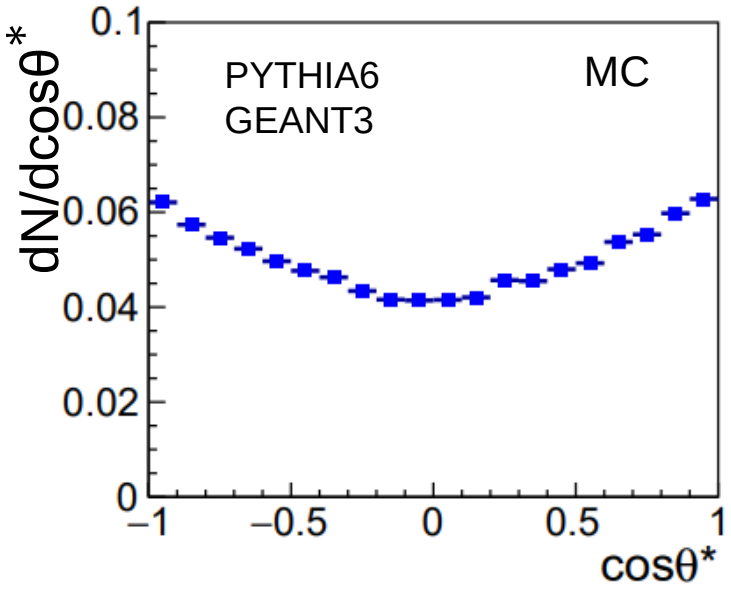
Acceptance correction and polarization extraction

Extracting polarization through fitting: $\frac{dN}{d\cos\theta^*} \propto A(\cos\theta^*)(1+\alpha P\cos\theta^*)$

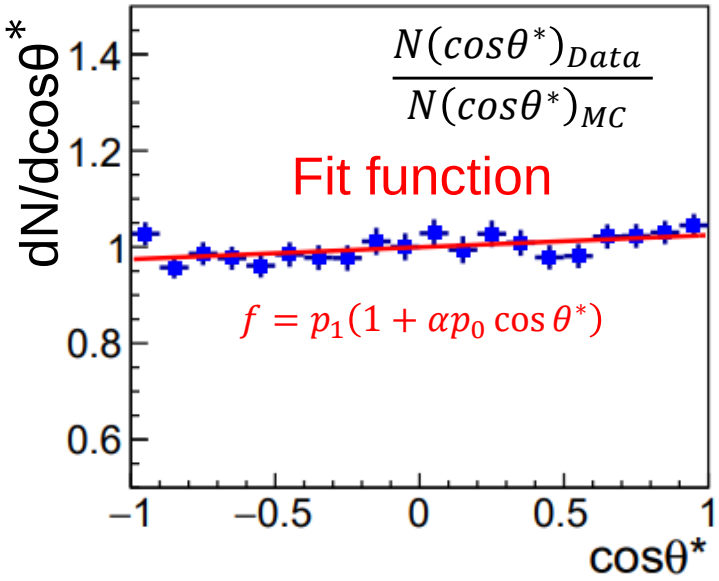
Note: normalized to 1



The shape of $cos\theta^*$ caused by detector acceptance



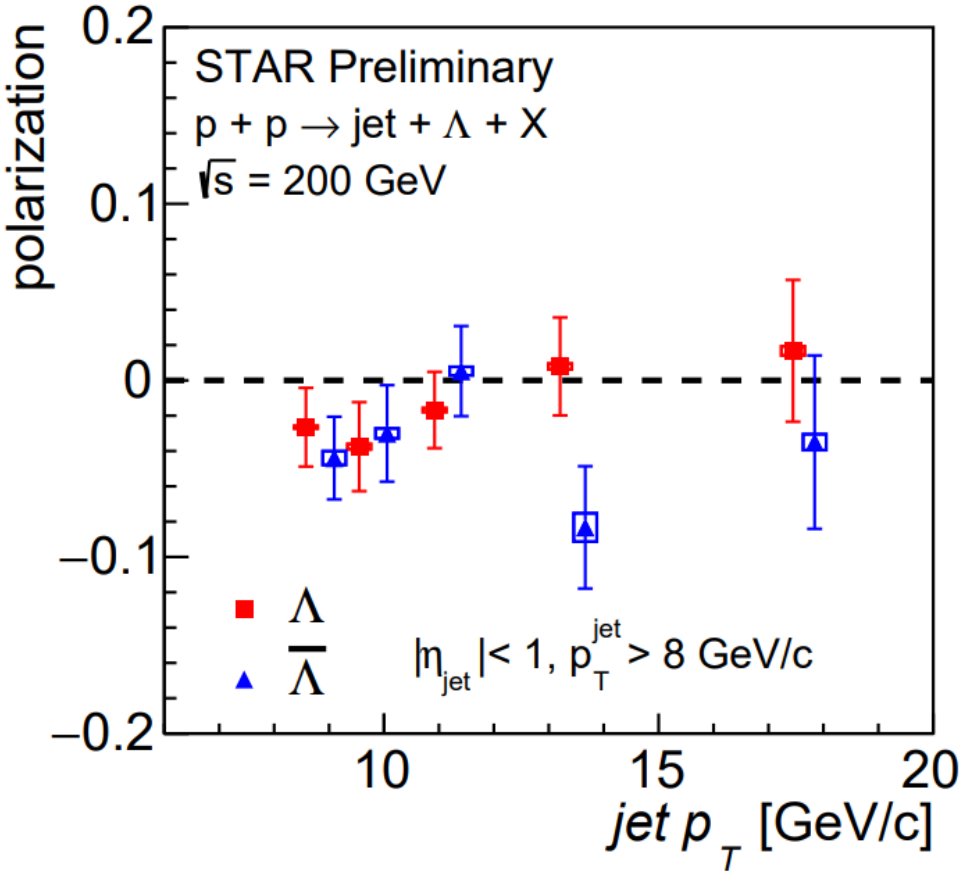
$A(\cos\theta^*)$: Acceptance correction function obtained from MC simulation

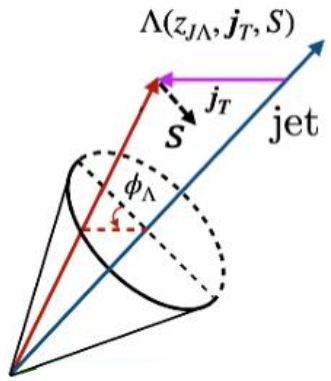


Polarization extraction by corrected $cos\theta^*$ distribution

Preliminary results from 200 GeV pp collision

Polarization as a function of jet p_T





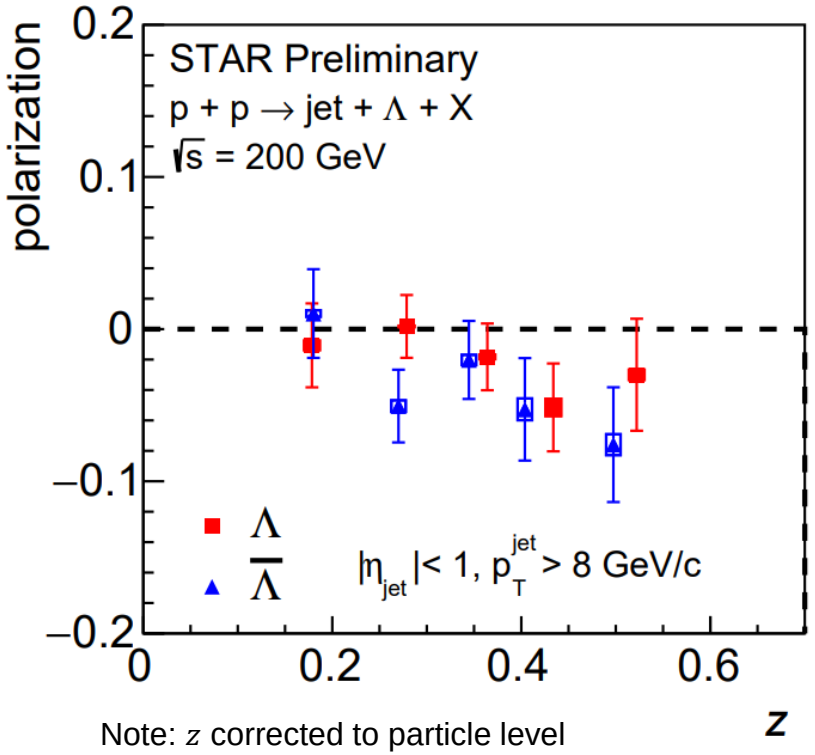
$$\hat{\boldsymbol{S}} = \hat{\boldsymbol{p}}_{jet} \times \hat{\boldsymbol{p}}_{\Lambda}$$

- Cover jet p_T range: 8~25 GeV/c
- No significant jet p_T dependence
- Indication of non-zero $\overline{\Lambda}$ polarization ($\sim 2\sigma$) from average value

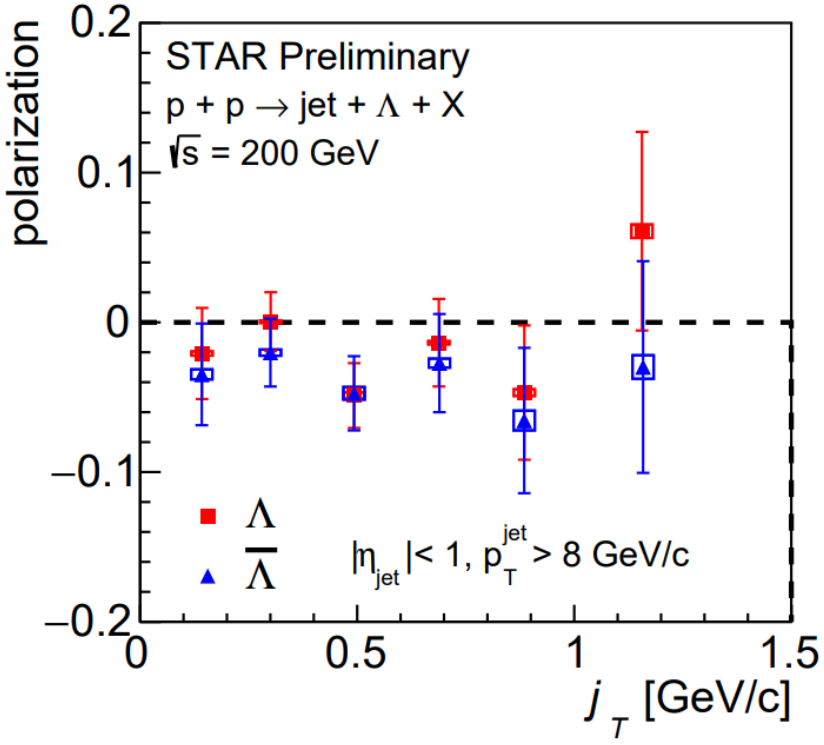
Note: $\Lambda(\overline{\Lambda})$ jet p_T corrected to particle level

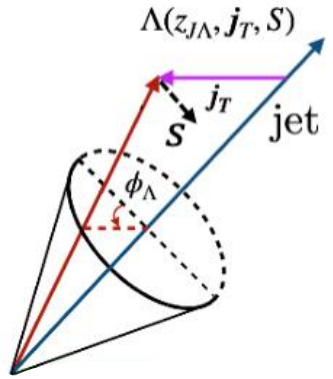
Preliminary results from 200 GeV pp collision

Polarization as a function of z and j_T



Note: z corrected to particle level

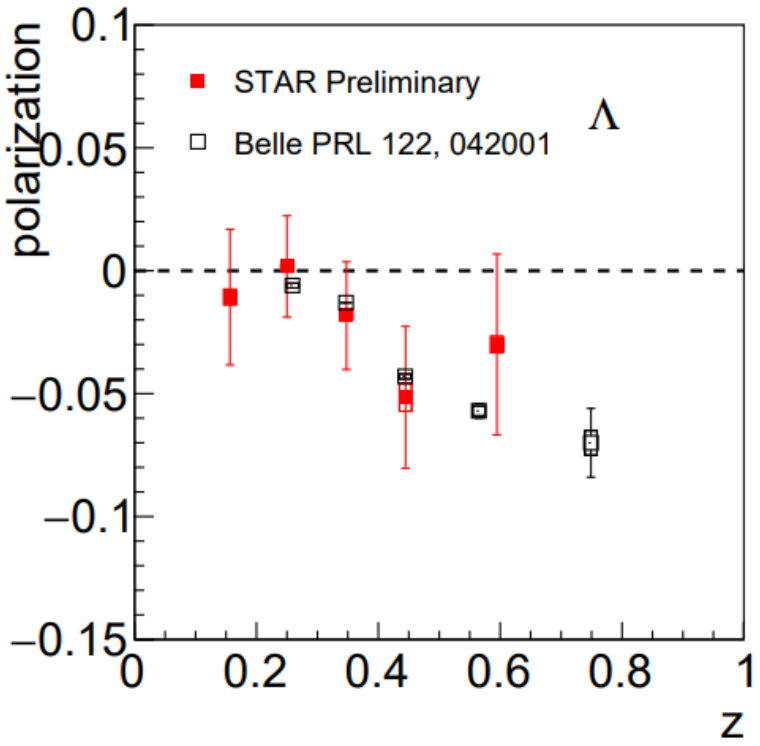


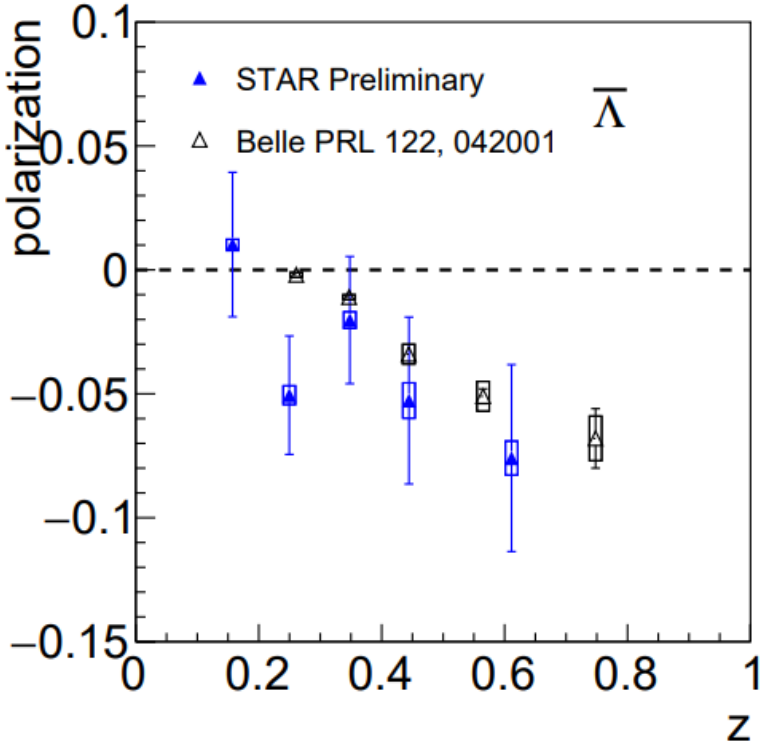


$$\hat{\boldsymbol{S}} = \hat{\boldsymbol{p}}_{jet} \times \hat{\boldsymbol{p}}_{\Lambda}$$

- Weak z dependence of polarization
- No significant j_T dependence
- Providing new data for pFFs

Comparison with Belle results





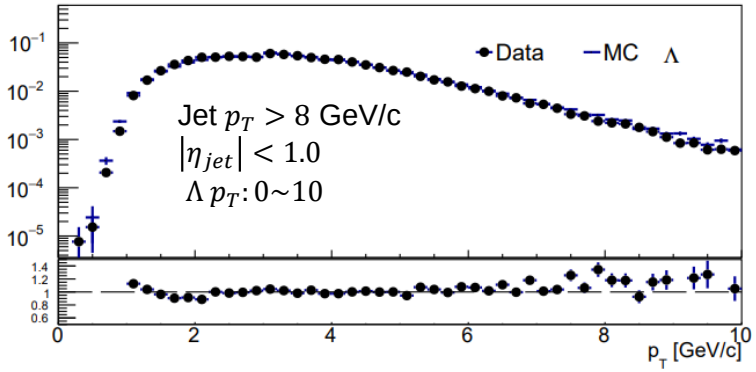
- STAR energy scale: jet $\langle p_T \rangle$~11 GeV/c
- Λ production at pp is different from Belle
- Similar polarization trend as Belle

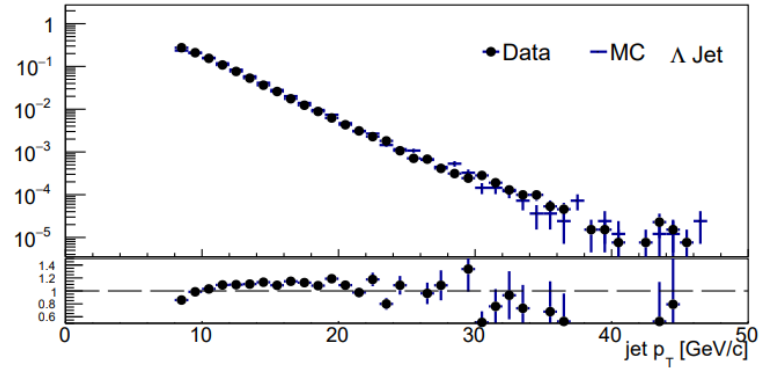
Summary

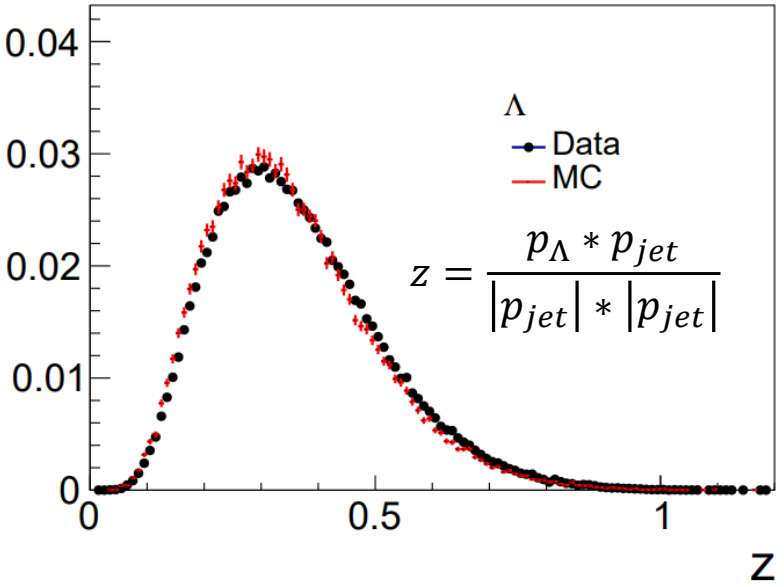
- Transverse polarization of Λ-in-jet in pp collision can probe polarizing fragmentation function which might contribute to Λ spontaneous polarization
- First measurement of transverse polarization of Λ-in-jet using RHIC 200 GeV pp data.
  - Λ average polarization was consistent with 0
  - Indication of non-zero $\overline{\Lambda}$ polarization ($\sim 2\sigma$)
- Providing new constraint for pFFs:
  - energy scale dependence
  - universality test
- 510 GeV data will extend jet p_T coverage, bridging Belle and LEP
  - Large dataset on disk ~10 times in integrated luminosity

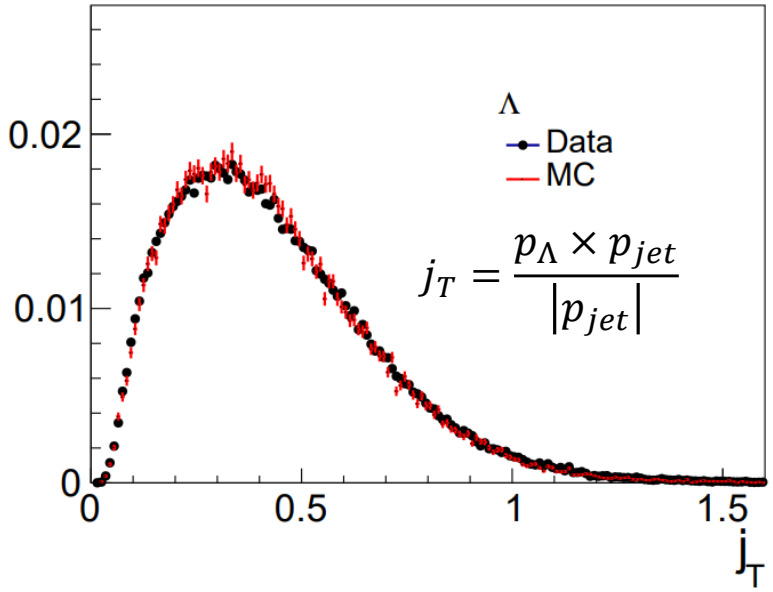
Backup

Comparison of data and MC





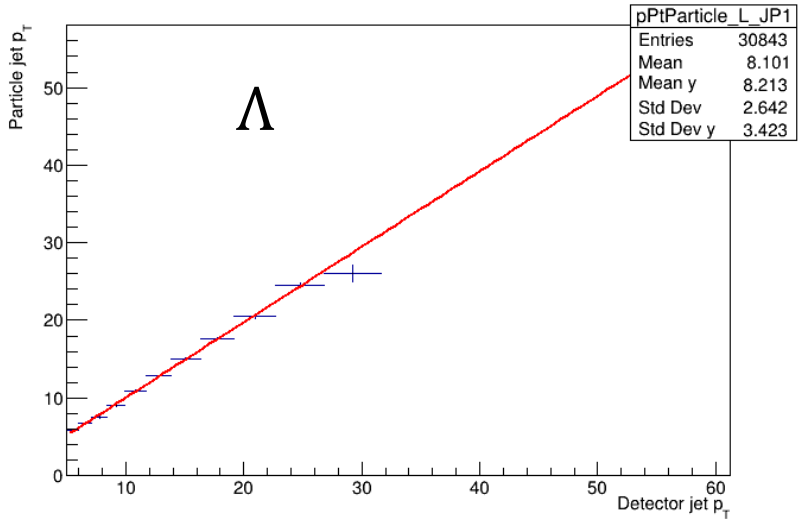


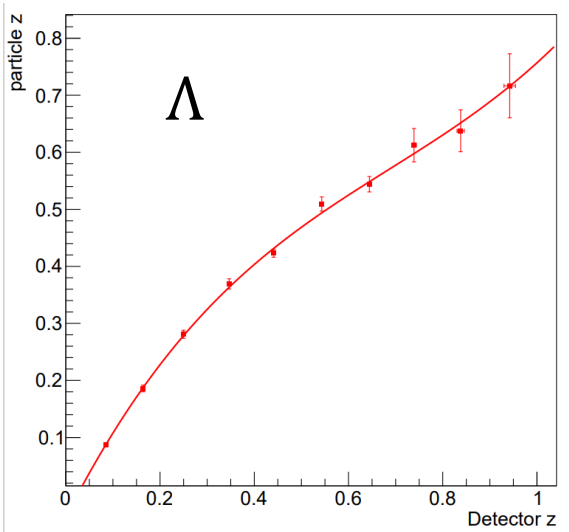


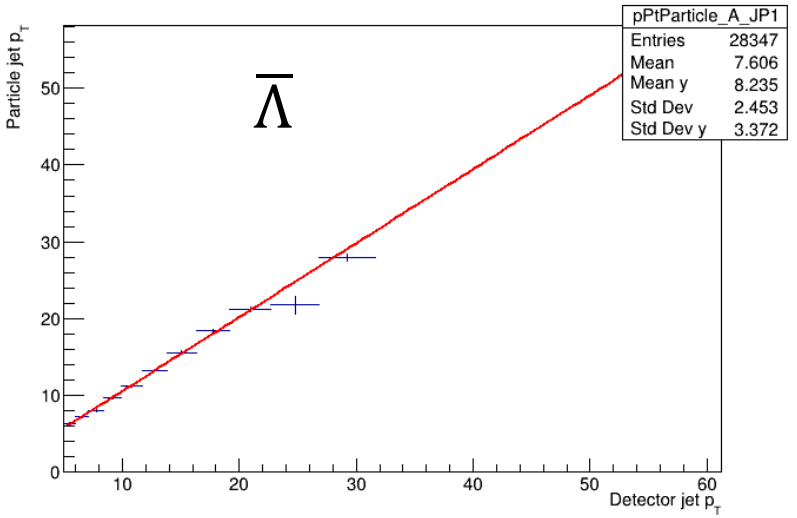
Λ z and jet p_T correction

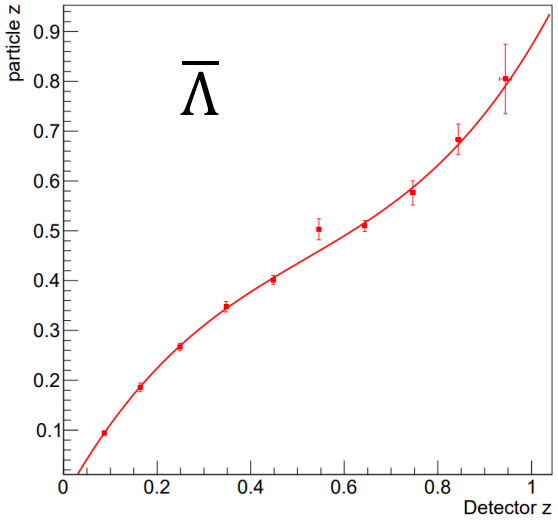
The correlations between detector level and particle level are from embedding

$\Lambda(\overline{\Lambda})$ z and jet p_T have been corrected to particle level by fitting function









Systematic uncertainties

- Trigger bias

$\mathrm{E}_{bias} = (1 - f_{bias}) * \max(\text{signal, statistic error})$

- Systematic Uncertainty of Background Estimation

$$E_{bkg} = \frac{\sum_i^n |P_\Lambda - P_i^{bkg}|}{n}$$

- The relative systematic uncertainty of decay parameter

$$\alpha = 0.732 \pm 0.014;\ E_\alpha = \frac{0.014}{0.732} \times P_\Lambda$$

$$E_s = \sqrt{E_\alpha^2 + E_{bkg}^2 + E_{bias}^2}$$

- Average polarization
  - $\Lambda(\%)$: $-1.72 \pm 1.13(\text{stat.}) \pm 0.08(\text{syst.})$
  - $\overline{\Lambda}(\%)$: $-3.42 \pm 1.30(\text{stat.}) \pm 0.32(\text{syst.})$