Study on the transverse polarization of $\Lambda(\bar{\Lambda})$ at Belle

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On behalf of the Belle Collaboration

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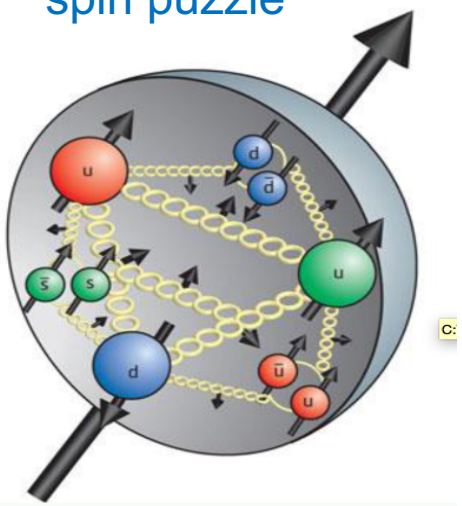
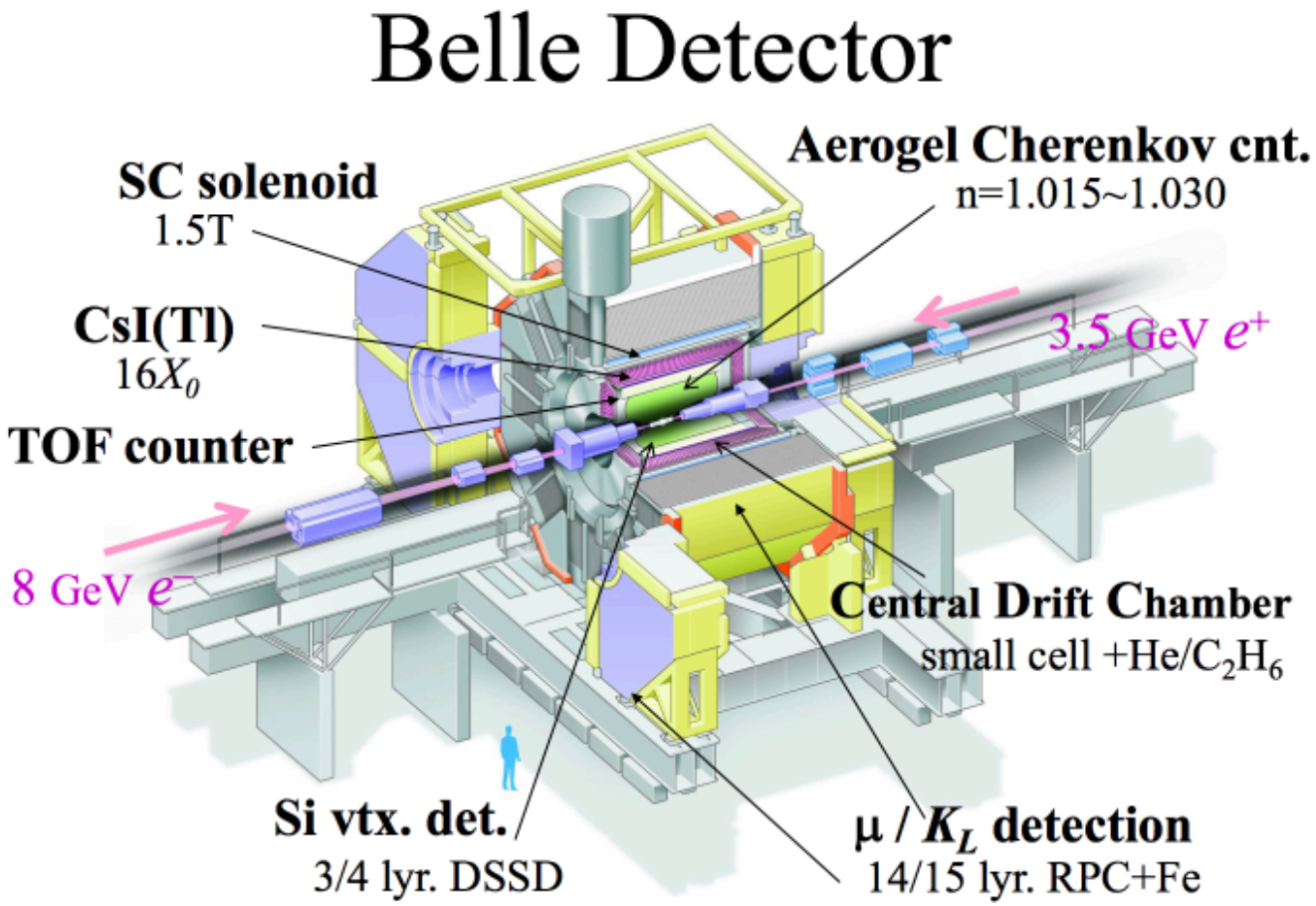
Introduction

- Large Λ transverse polarization was observed in unpolarized pp collision years ago. **PRL36, 1113 (1976); PRL41, 607 (1978)**
- The Polarizing Fragmentation Function(FF), $D_{1T}^{\perp}(z, p_{\perp}^{2})$, is assumed to play an important role in the "spontaneous" polarization. It describes an unpolarized quark fragmenting into a transversely polarized hadron.
- The counterpart of the Sivers parton distribution function.
- A non-vanishing $D_{1T}^{\perp}$ could help to shed light on the spin structure of the Λ, especially about the quark orbital angular momentum, a missing part of the spin puzzle of the nucleon. **PRL105,202001（2010）**
- Polarizing FF is chiral-even, has been proposed as a test of universality.
- OPAL experiment at LEP has been looking at transverse Λ polarization, no significant signal was observed. **Eur. Phys. J. C2, 49 (1998)**
- The Large data set at Belle would allow a precise measurement.

spin puzzle



KEKB and Belle Detector

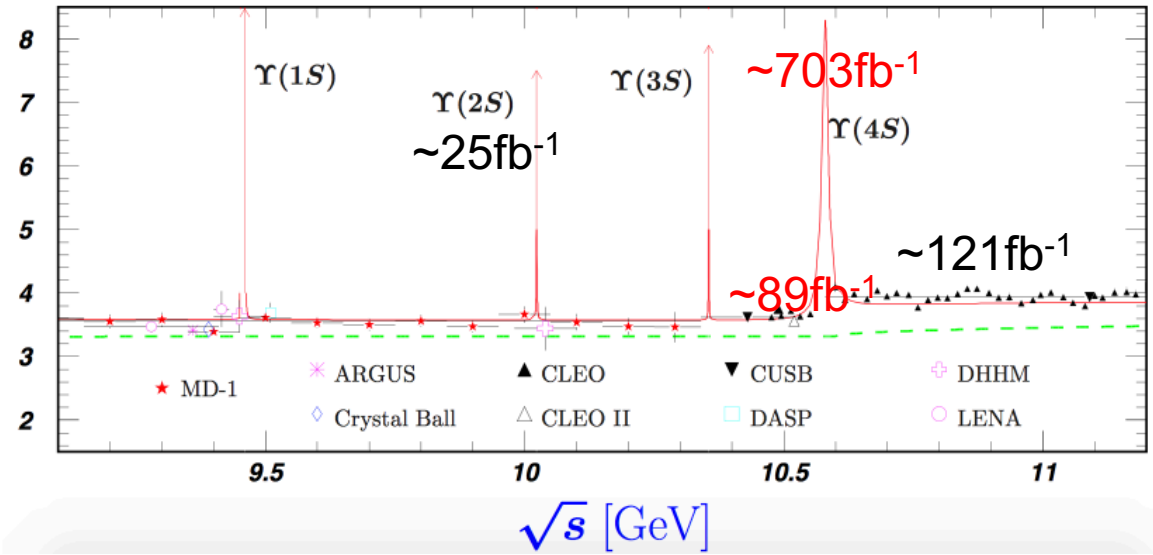


Nucl. Instrum. Meth. A479,117(2002)

KEKB@Tsukuba, Japan

Data set

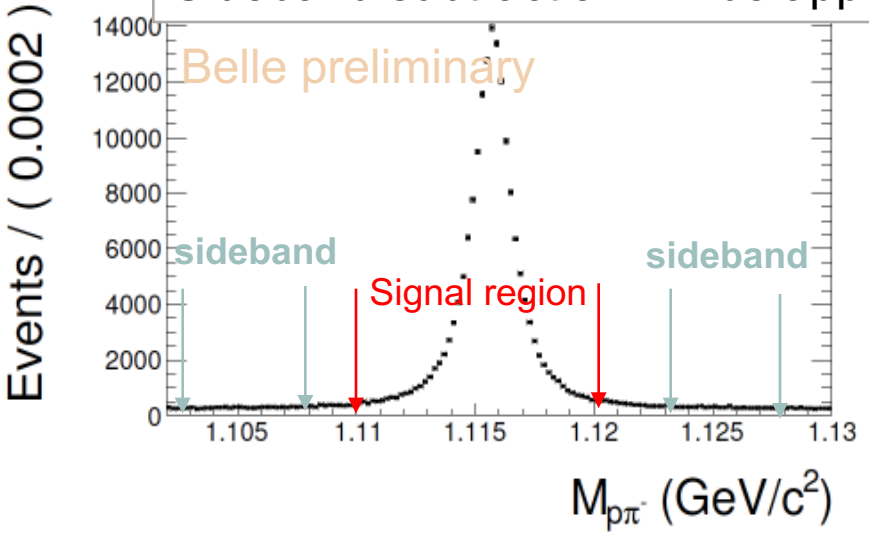
- Data sets: ~792 fb^{-1} at or near $\sqrt{s}$ ~10.58 GeV

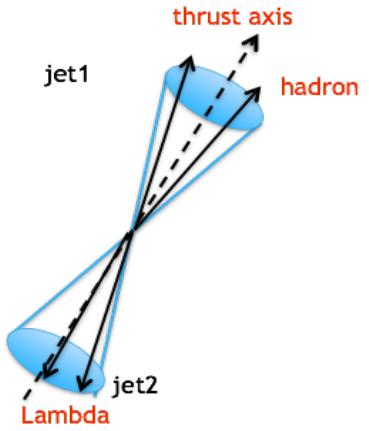


- Thrust>0.8 to select back-to-back event topology and suppress *B* decays to less than 1%.
- Signal process $\Lambda \to p\pi^-(\bar{\Lambda} \to \bar{p}\,\pi^+)$. Clear Λ peak.
- By considering light hadron ($K^{\pm}, \pi^{\pm}$) in the opposite hemisphere, we can emphasize or suppress one kind of flavor which contributes to $\Lambda(\bar{\Lambda})$.

PRL105,202001（2010）

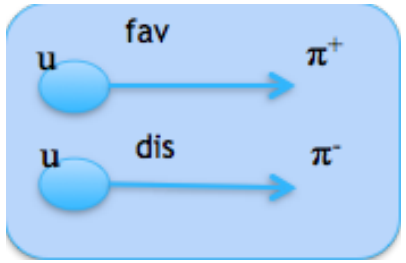
Sideband subtraction will be applied





flavor tag

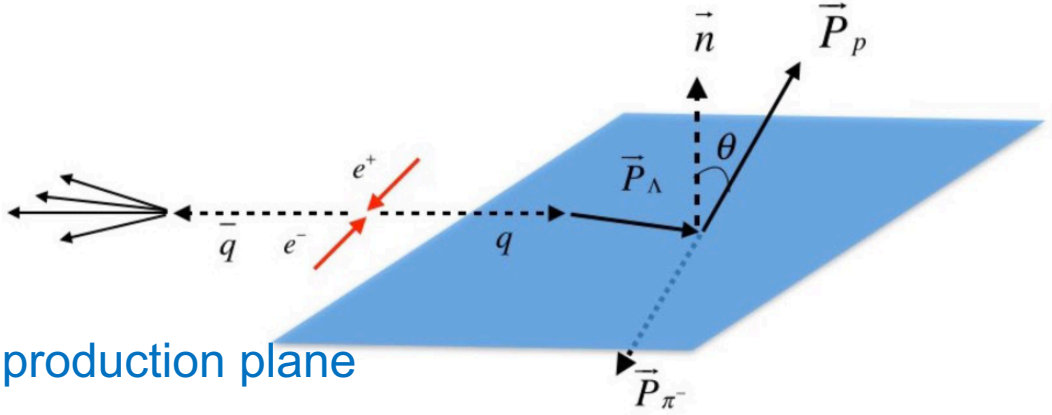
Λ(uds); π^+(u$\bar{d}$); K^+ (u$\bar{s}$)



$$T = \mathrm{Max}[\frac{\sum_h |\mathbf{P_h}^{\mathrm{CMS}} \cdot \hat{\mathbf{T}}|}{\sum_h |\mathrm{P_h^{CMS}}|}]$$

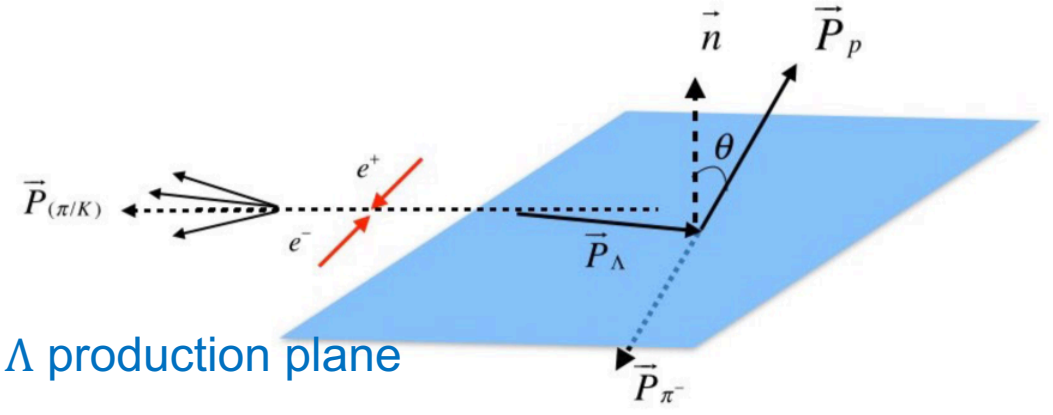
Reference frames

Thrust Frame



Λ production plane

Hadron Frame



Λ production plane

- The reference vector $\hat{n}$ is perpendicular to the Λ production plane.
- The p_t is defined as the transverse momentum of Λ relative to thrust axis in thrust frame and to hadron axis in hadron frame.
- Give a polarization of *P*, the yield of the events follow:

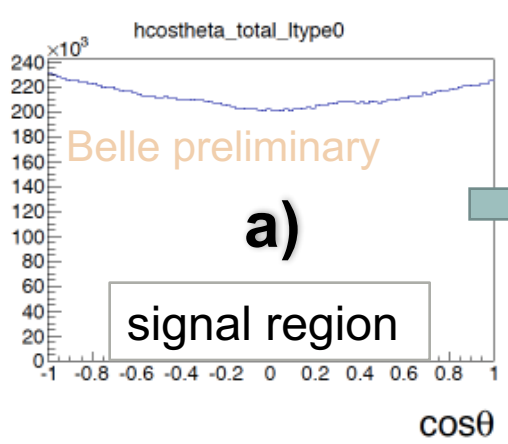
$$\frac{1}{N}\frac{dN}{d\cos\theta} = 1 + \alpha P \cos\theta$$

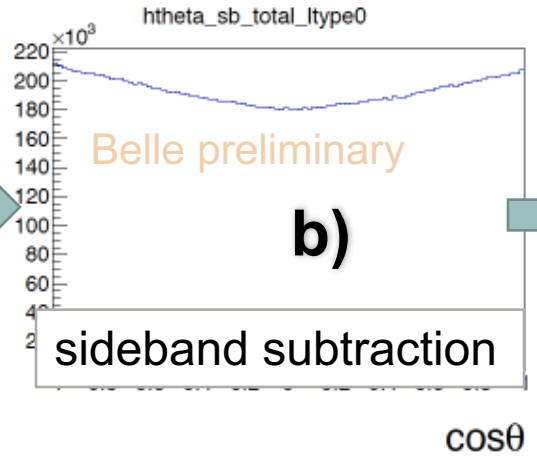
- where α is the decay parameter: α_+=0.642 ± 0.013 for Λ and α_-=-0.71 ± 0.08 for $\bar{\Lambda}$ (PDG).

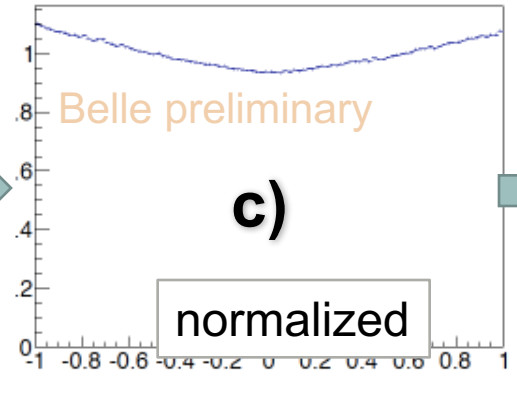
kinematic variables

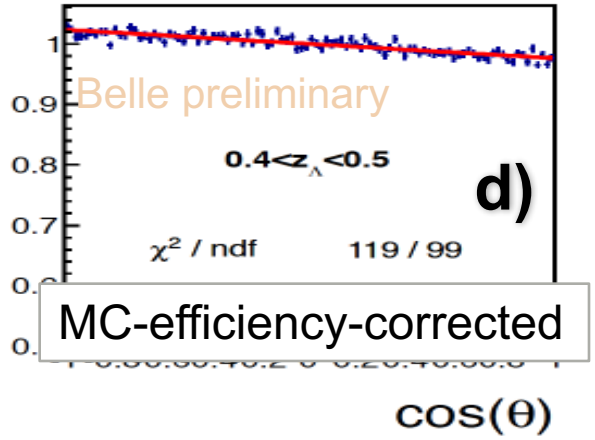
$\Lambda + X$	thrust frame	
variables	z_Λ , p_t	
$\Lambda + h + X$	thrust frame	hadron frame
variables	z_Λ, z_h, p_t	z_Λ, z_h, p_t

Analysis flow

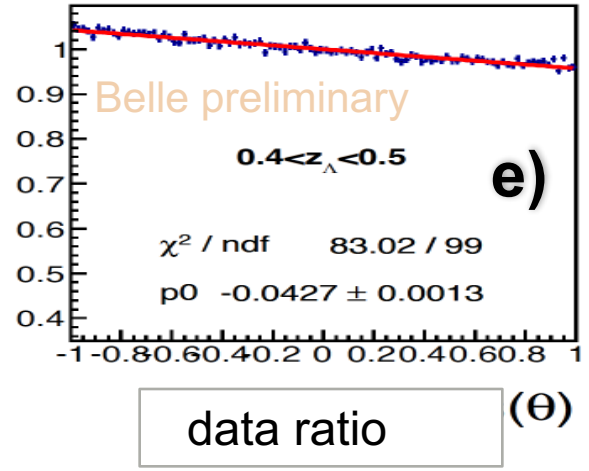






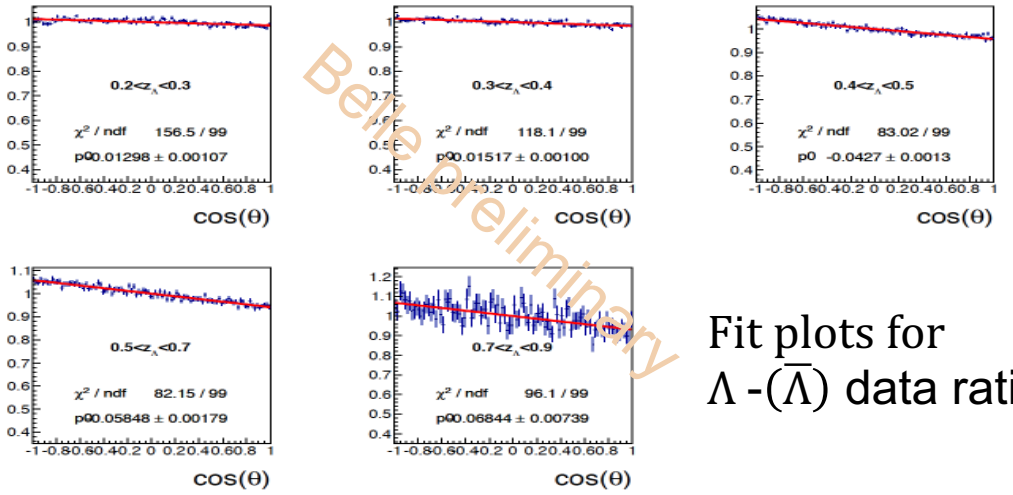


- Cosθ distribution in Λ signal region **a)** is corrected by sideband subtraction→ **b)**
- Normalized by itself, as shown in **c).**
- The shape **c)** is divided by the corresponding shape from MC, so that we obtain the efficiency-corrected curve **d)**.
- Or **c)** shape of Λ events is divided by that from anti-Λ events if we assume efficiency is independent on charge, that is **e),** this is called data ratios.
- We fit **d)** and **e)** to get the polarization of interest.

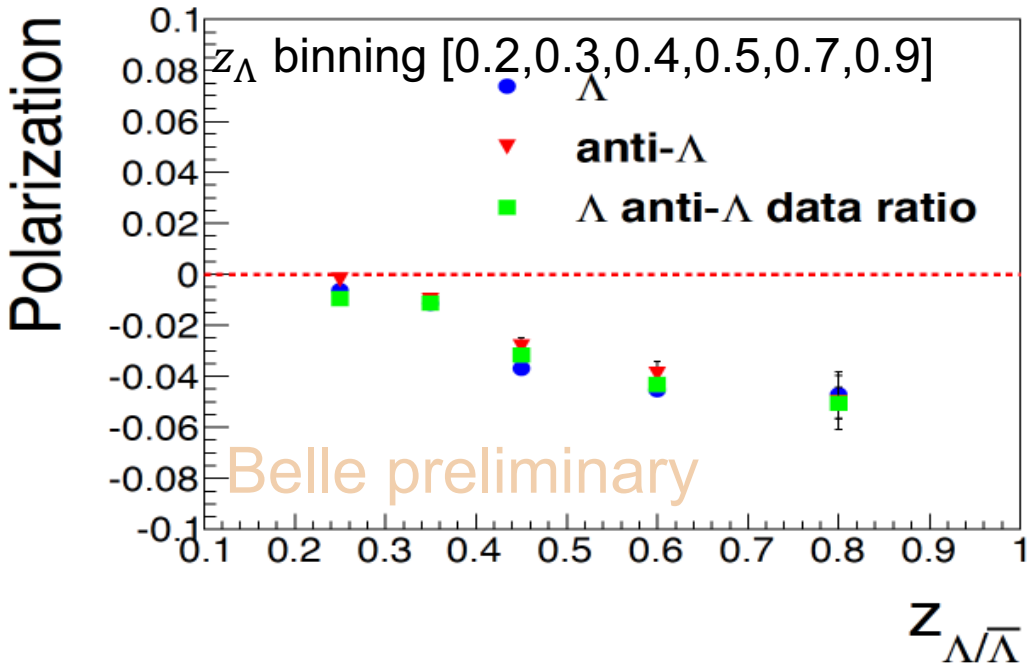


Fits and Extract polarization

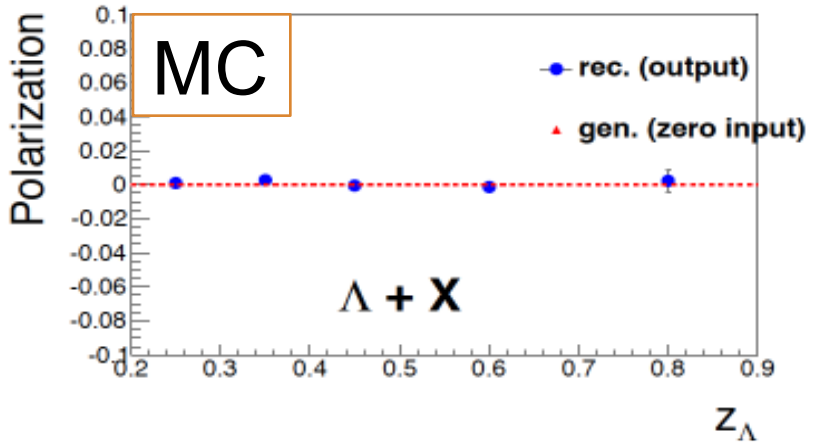
- Fit to the cosθ distributions with the simple function $1 + p_0 cos\theta$.
- The polarization of interest: p_0/α.
- In the data ratio, polarization is obtained via $p_0/(\alpha_+ - \alpha_-)$.
- In data ratios, the slope on the cosθ distributions are about two times larger than that in MC-corrected ratios, the $(\alpha_+ - \alpha_-)$ is also about times larger than $\alpha_+(\alpha_-)$.
- Results from MC-corrected ratio and data ratio are consistent with each other.
- Nonzero polarization was seen, the magnitude rises from zero to about ~5% with growing fraction energy $z_\Lambda = 2E_\Lambda/\sqrt{s}$.



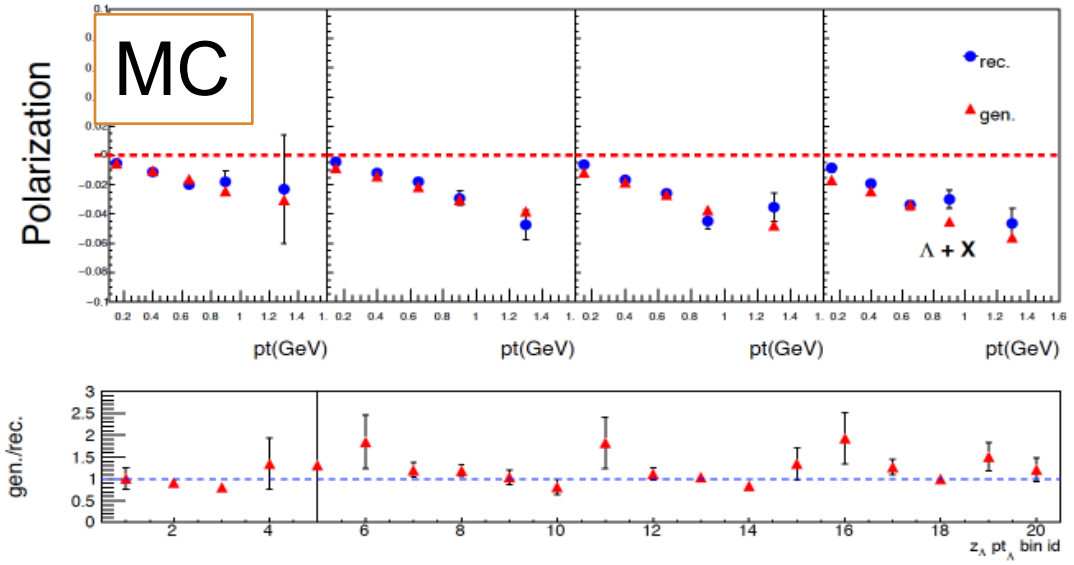
Fit plots for Λ -($\overline{\Lambda}$) data ratio.

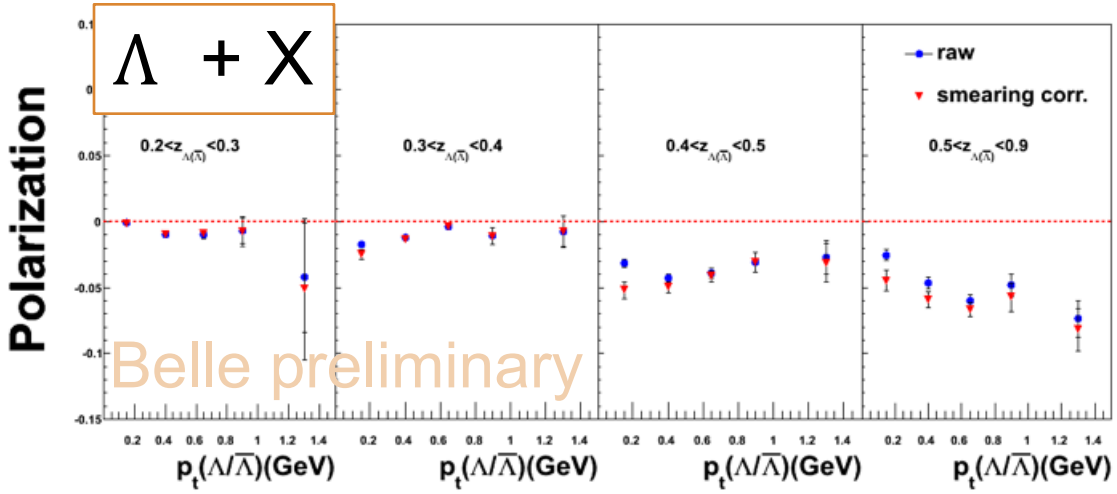


MC validation & Smearing correction



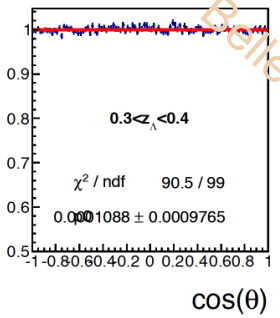
- Zero polarization is observed in MC, as expected.
- Smearing effects caused by the detector acceptance and resolution are estimated using the weighted-MC with nonzero polarization input.
- In thrust frame, the polarization is found underestimated in reconstruction, correction factors ranges 1.0-1.3 depends on the [z,p_t].
- In hadron frame, the polarization observed in reconstruction is consistent with input. No need for correction.

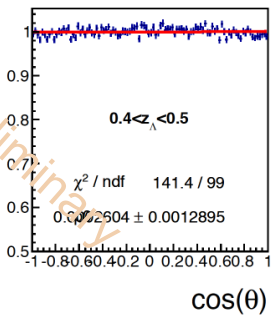


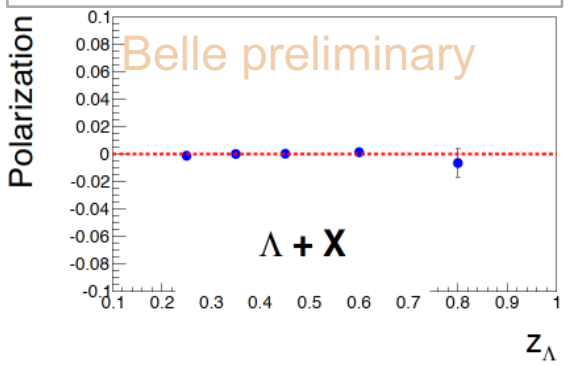


Systematics

Build fake angle θ

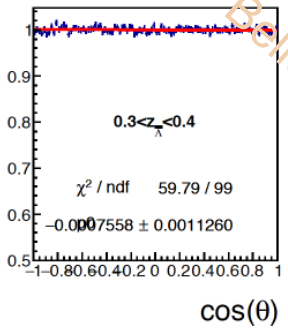


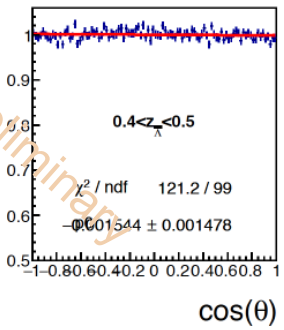


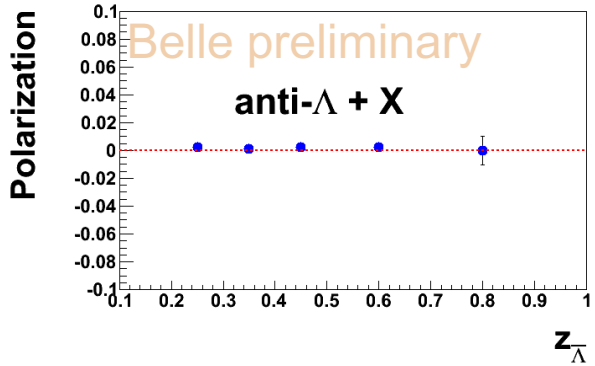


- Change the reference vector $\hat{n}$ to be in the Λ production plane. But still normal to $\vec{p}_{\Lambda}$.

Mixed events

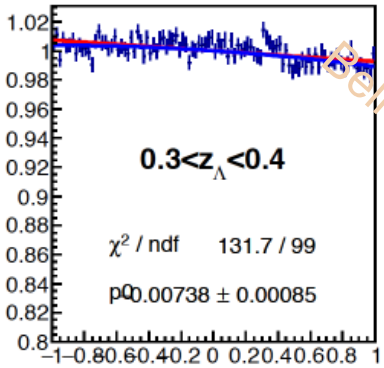


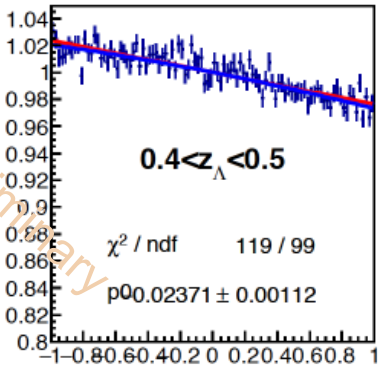




- Combine a proton in one event and pion in the other event to form a false Λ.

Vary the fit function

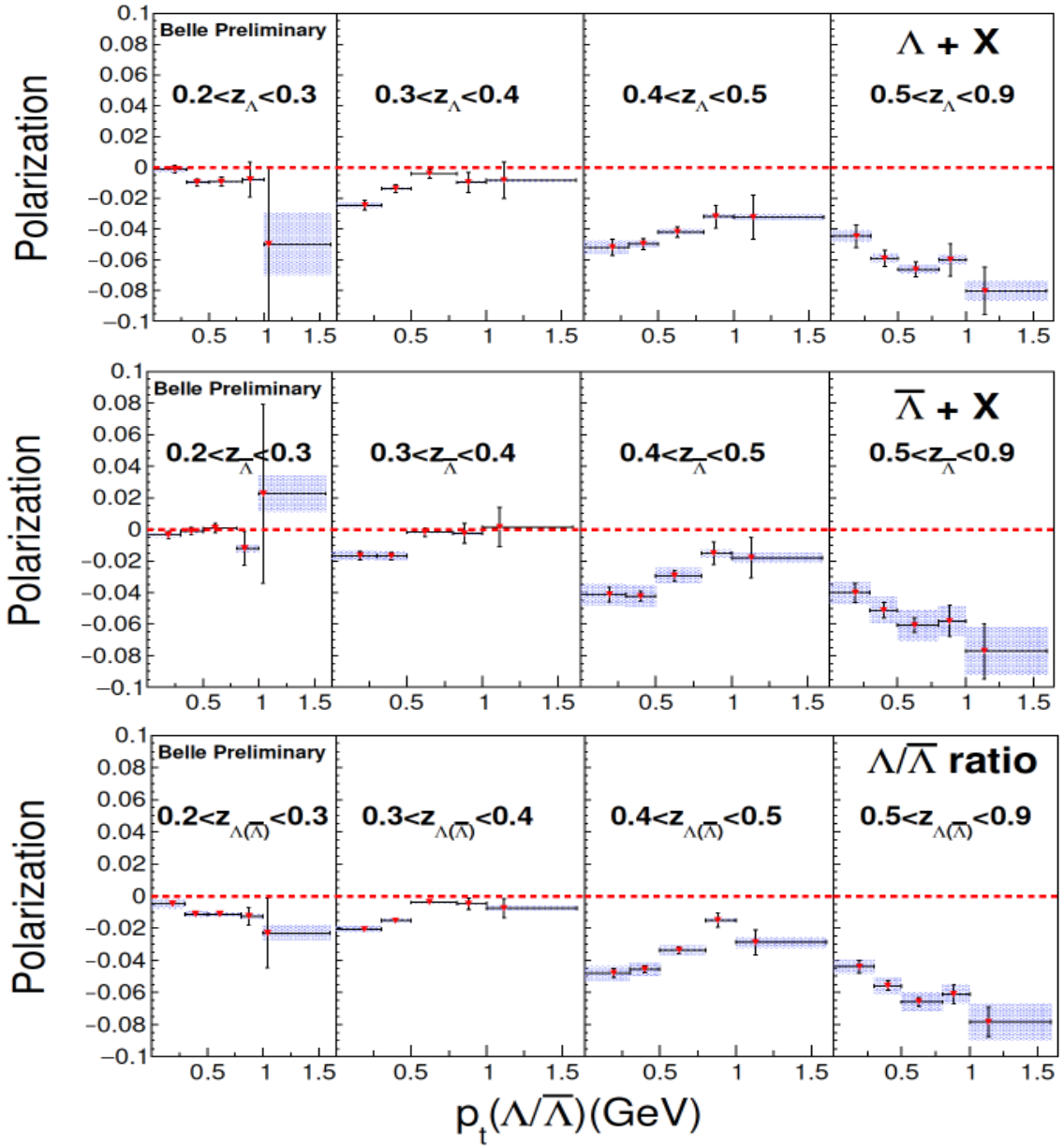




- The second order term was added in the fit function $1 + p_0 cos\theta + p_1 \, cos^2\theta$

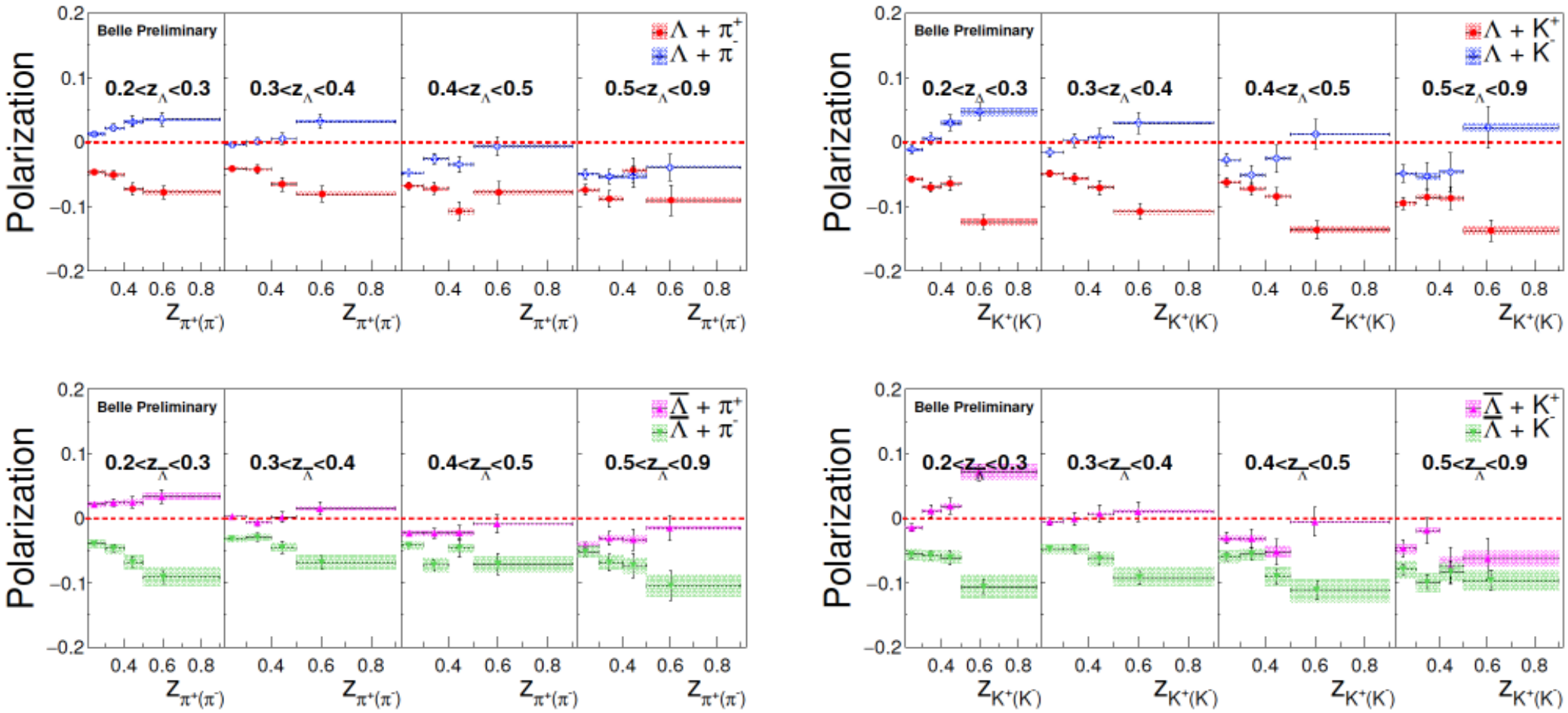
- Besides, uncertainties from smearing correction factors and sideband subtractions are included in systematics errors.
- Uncertainties of decay parameters are assigned as systematic errors.

Results in thrust frame vs. (z,p_t)



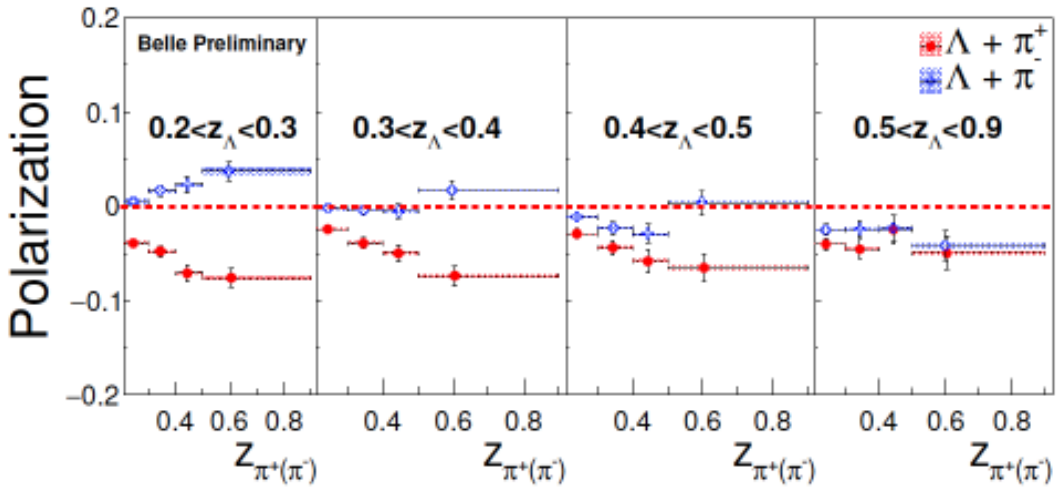
- Four z bins and five p_t bins are applied: z_Λ=[0.2,0.3,0.4,0.5,0.9]; p_t=[0.0,0.3,0.5,0.8,1.0,1.6] GeV
- Nonzero polarization was observed. Interesting shape as a function of (z_Λ, p_t).
- The polarization rise with higher p_t in the lowest z_Λ and highest z_Λ bin. But the dependence reverses around 1 GeV in the intermediate z_Λ bins.
- Results are consistent between Λ and ($\bar{\Lambda}$) and Λ -($\bar{\Lambda}$) data ratio.
- Error bars are statistical uncertainties and shaded areas show the systematic uncertainties.

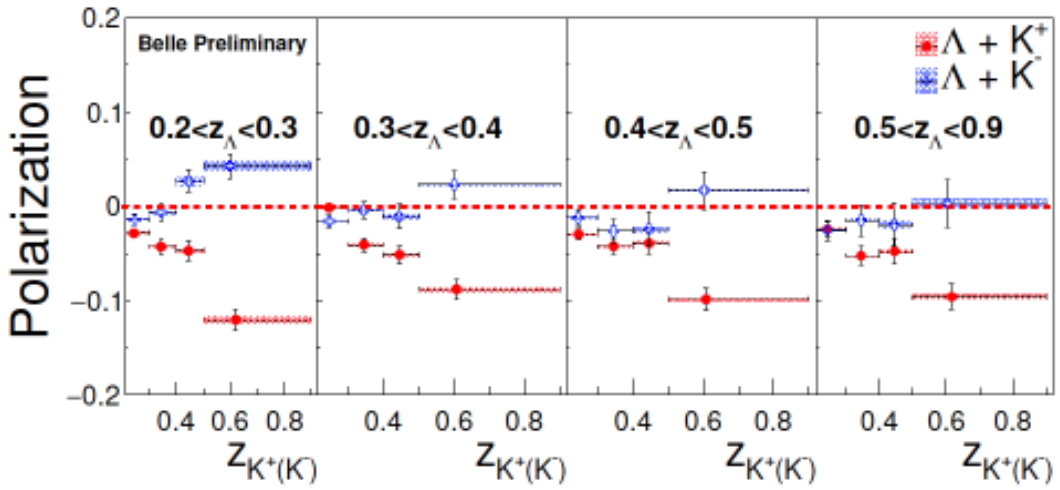
Results in thrust frame vs. (z_Λ, z_h)

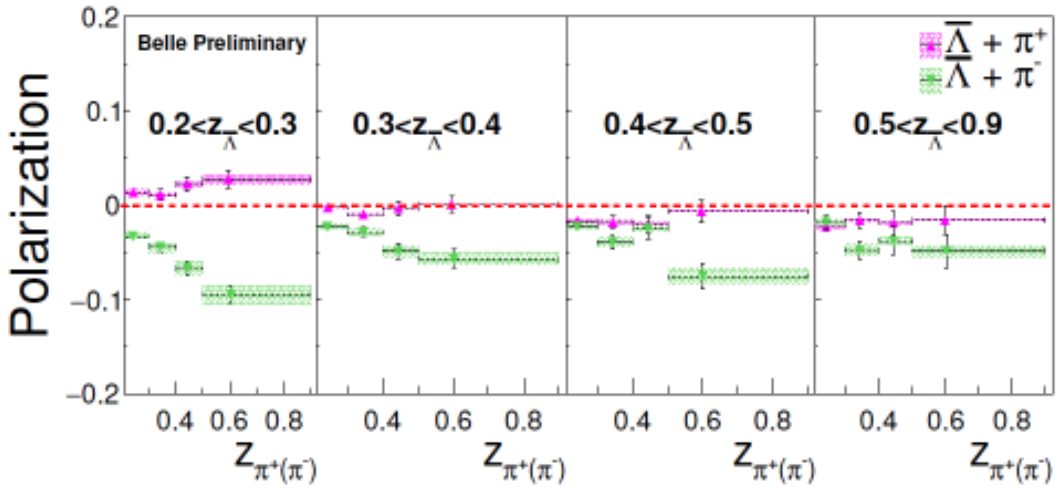


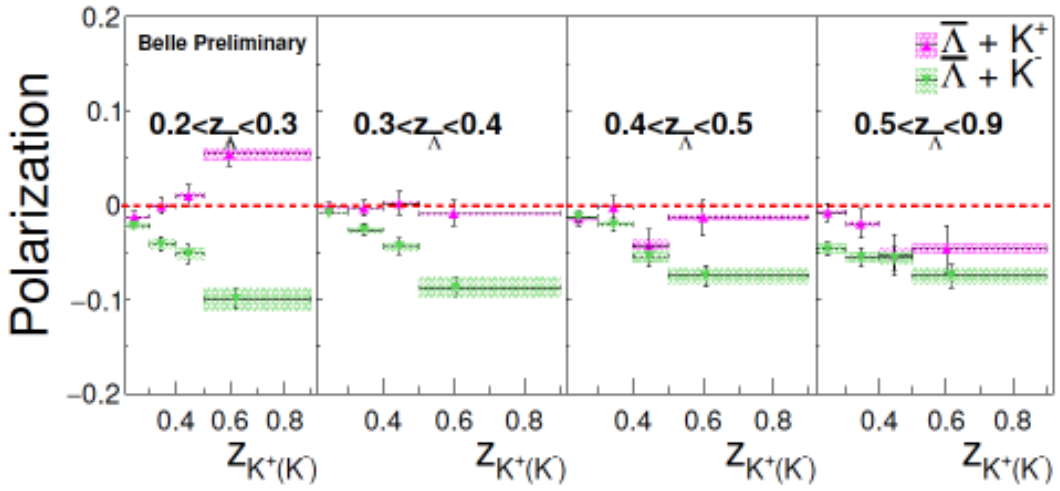
- At low z_Λ, polarization in $\Lambda + h^+$ and $\Lambda + h^-$ have opposite sign. The magnitude increases with higher z_h.
- At large z_Λ, the differences between $\Lambda + h^+$ and $\Lambda + h^-$ reduce. Small deviations can still be seen and depend on z_h.

Results in hadron frame vs. (z_Λ, z_h)



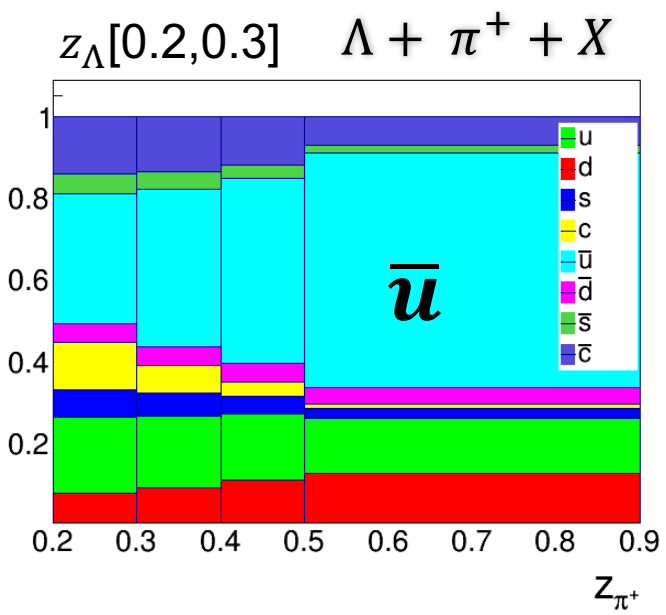


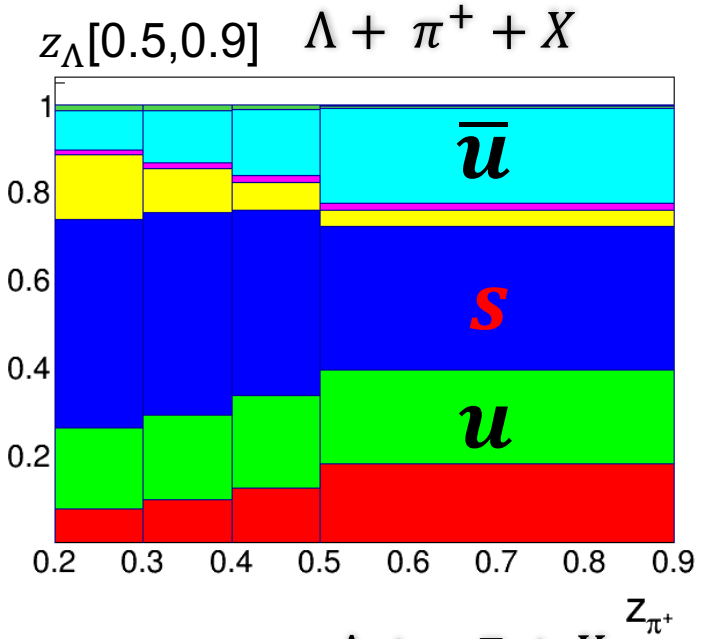


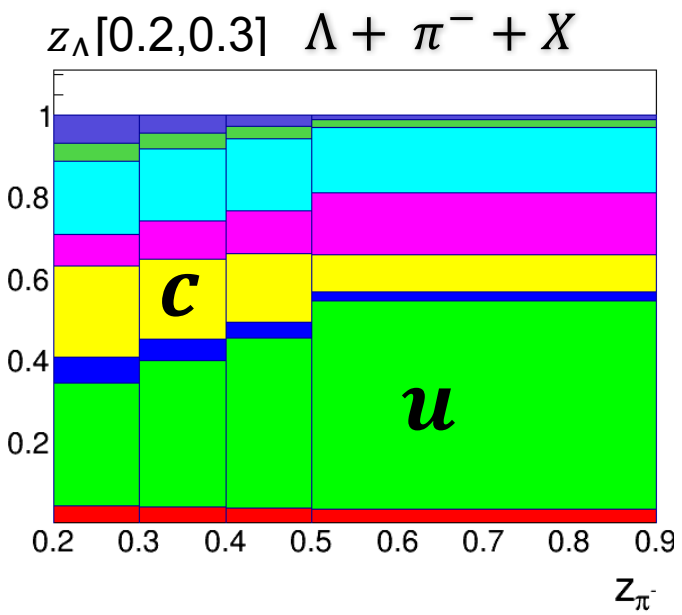


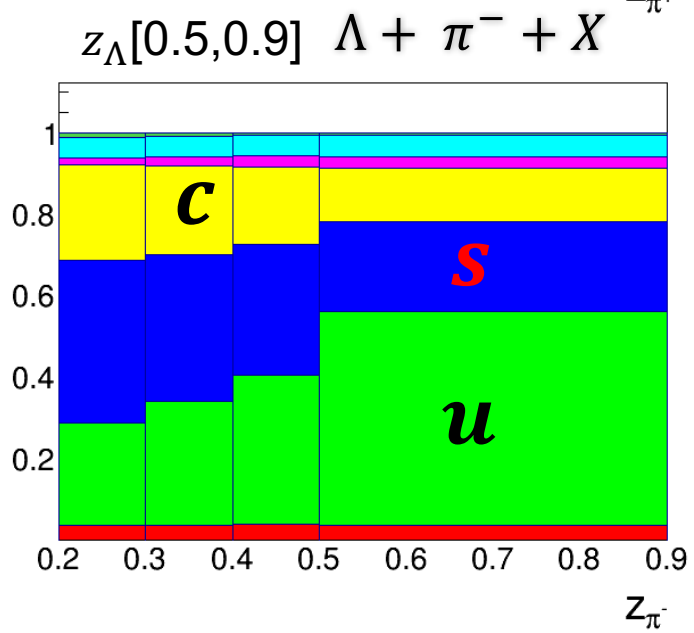
- Similar results with that in the thrust frame.
- Results from charge-conjugate modes are consistent with each other.

Quark flavor tag by the light hadron









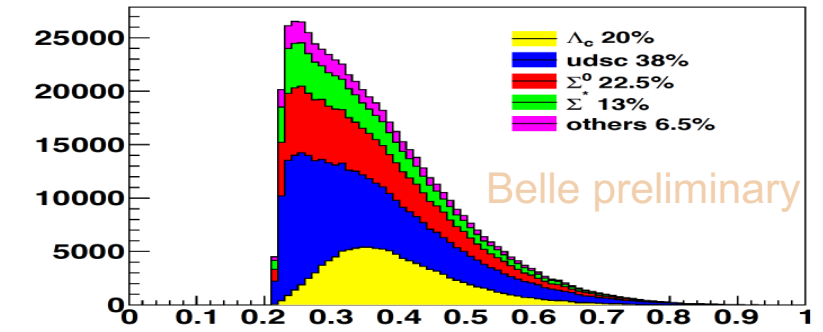
- An attempt to look at the flavor tag effect of the light hadron, based on MC. (Pythia6.2)
- The fractions of various quark flavors going to the Λ's hemisphere are shown in different $[z_\Lambda\ z_h]$ region.
- MC indicates that the tag of the quark flavors is more effective at low z_Λ and high z_h. It explains why at low z_Λ and high z_h, polarization in $\Lambda + h^+$ and $\Lambda + h^-$ have opposite sign.

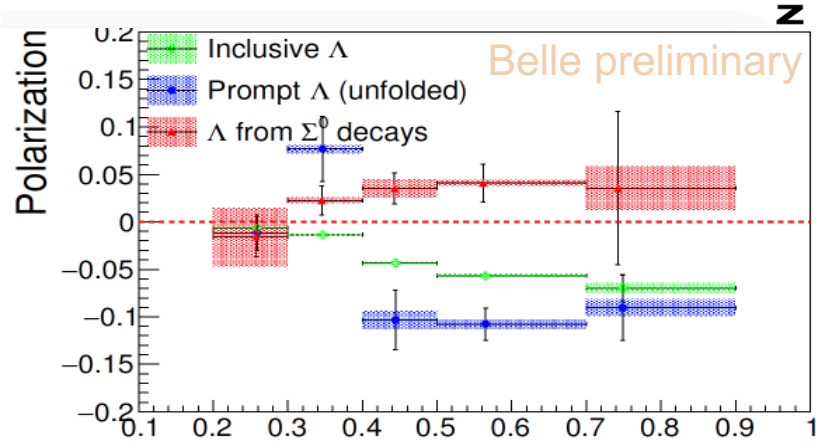
Background unfolding

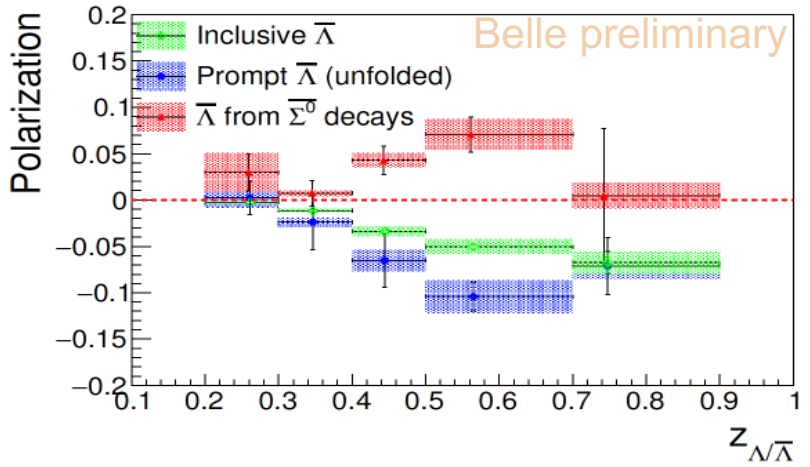
- Non-Λ backgrounds are excluded out in the sideband subtraction.
- Σ^* decays to Λ strongly, is included in the signal.
- Feed-down from Σ^0(22.5%), Λ_c(20%) decays need to be understood.
- The Σ^0-enhanced $(\Sigma^0 \to \Lambda + \gamma)$ (Br~100%). and Λ_c-enhanced($\Lambda_c \to \Lambda + \pi^+$)(Br~1.07%) data sets are selected and studied.
- The measured polarization can be expressed as:

$$P^{mea.} = (1 - \sum_i F_i) P^{true} + \sum_i F_i P_i,$$

- F_i is the fraction of feed-down component i, estimated from MC. P_i is polarization of component i.
- Polarization of Λ from Σ^0 decays is found has opposite sign with that of inclusive Λ.







R. Gatto, Phys. Rev. 109, 610 (1958); Phys.Lett.B303,350(1993)

Summary

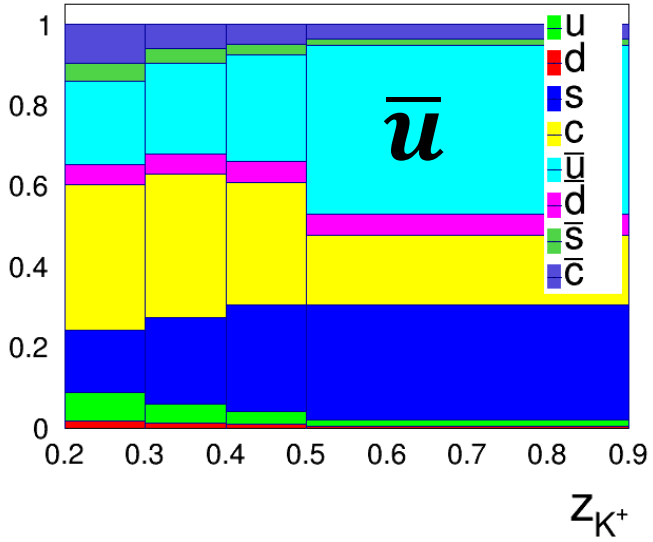
- The study on the transverse polarization of $\Lambda(\bar{\Lambda})$ in the inclusive process $e^+ e^- \to \Lambda(\bar{\Lambda}) + X$ and $e^+ e^- \to \Lambda(\bar{\Lambda}) + K^{\pm}(\pi^{\pm}) + X$ is performed at Belle.
- Nonzero transverse polarizations of $\Lambda(\bar{\Lambda})$ is observed for the first time at $e^+ e^-$ annihilation. Its magnitude as a function of z_Λ and p_{t} was presented.
- By selecting identified light hadrons ($K^{\pm}, \pi^{\pm}$) in the opposite hemisphere we also obtain sensitivity to the flavor dependence.

Thank you!

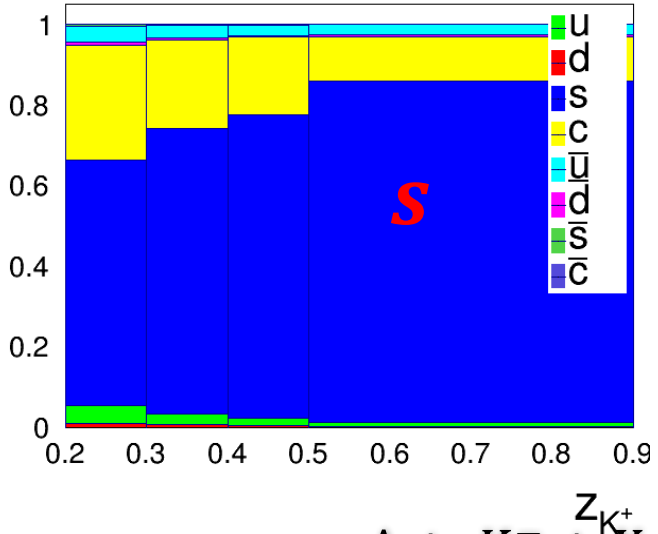
Backup slides

Quark flavor tag by the Kaon

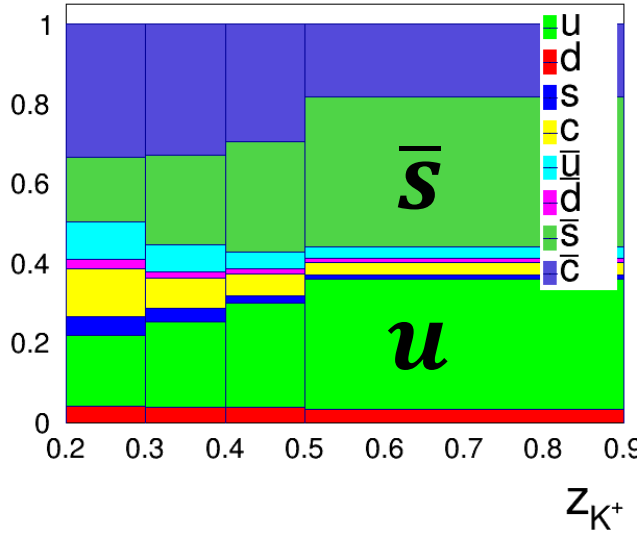
z_Λ[0.2,0.3] $\Lambda + K^+ + X$



z_Λ[0.5,0.9] $\Lambda + K^+ + X$



z_Λ[0.2,0.3] $\Lambda + K^- + X$



z_Λ[0.5,0.9] $\Lambda + K^- + X$