Search for *CP* violation in $\Lambda_c^+ \to \Lambda K^+$, $\Sigma^0 K^+$, and $\Sigma^+ K_S^0$ decays

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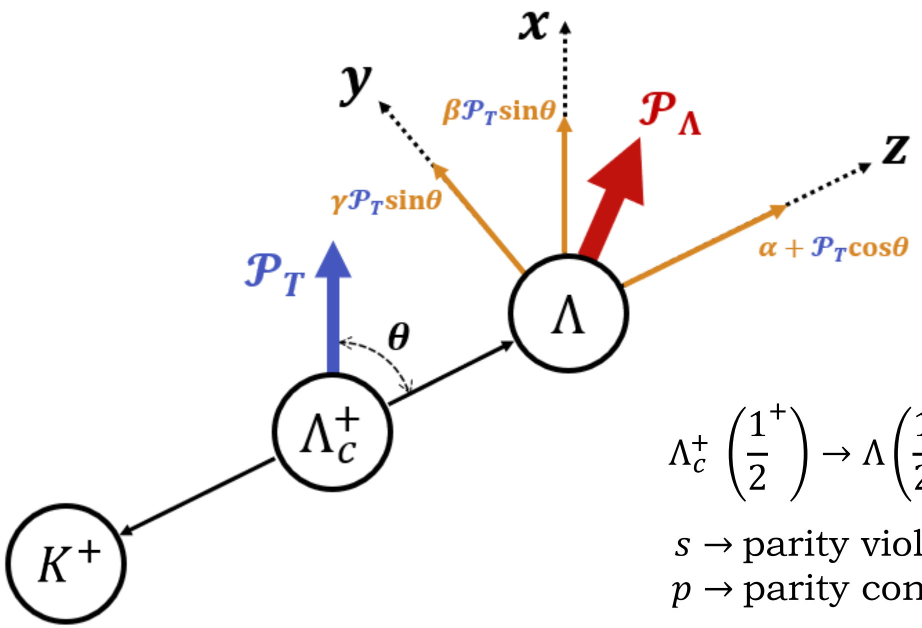
P violation in charmed baryon



$\Lambda_c^+\left(\frac{1}{2}^+\right)\to\Lambda\left(\frac{1}{2}^+\right)K^+(0^-)$

$s\to$ parity violation

$p\to$ parity conservation

$$\mathcal{P}_\Lambda=\frac{(-\alpha-\mathcal{P}_T\cdot\hat{n}_z)\hat{n}_z+\beta(\mathcal{P}_T\times\hat{n}_z)+\gamma\hat{n}_z\times(\mathcal{P}_T\times\hat{n}_z)}{1+\alpha\mathcal{P}_T\cdot\hat{n}_z}$$

$$\alpha=\frac{2\mathrm{Re}(s^*p)}{|s|^2+|p|^2}\quad\beta=\frac{2\mathrm{Im}(s^*p)}{|s|^2+|p|^2}\quad\gamma=\frac{|s|^2-|p|^2}{|s|^2+|p|^2}$$

$$\alpha^2+\beta^2+\gamma^2=1$$

If parity violation exists: $\alpha,\ \beta\neq 0,\ \gamma\neq -1$

- **Another definition:**

$$\alpha=\frac{\left|H_{\frac{1}{2}}\right|^2-\left|H_{-\frac{1}{2}}\right|^2}{\left|H_{\frac{1}{2}}\right|^2+\left|H_{-\frac{1}{2}}\right|^2}\qquad\beta=\sqrt{1-\alpha^2}\sin\Delta\quad\gamma=\sqrt{1-\alpha^2}\cos\Delta\qquad\Delta=\delta_{-\frac{1}{2}}-\delta_{\frac{1}{2}}$$

$$\alpha^2+\beta^2+\gamma^2=1$$

- **Transform using a simple linear relation**

$$H^{0\to1+2}_{\lambda_1,\lambda_2}=\sum_{ls}g_{ls}\sqrt{\frac{2l+1}{2J_0+1}}\langle ls,0\ \delta|J_0,\delta\rangle\langle J_1J_2,\lambda_1-\lambda_2|s,\delta\rangle$$

CP violation in charmed baryon

$\Lambda_c^+\left(\frac{1}{2}^+\right) \to \Lambda\left(\frac{1}{2}^+\right) K^+(0^-)$ as an example:

$$s = |s|e^{i\xi_s}e^{i\phi_s} \qquad p = |p|e^{i\xi_p}e^{i\phi_p}$$

under CP transformation →

$$\bar{s} = -|s|e^{i\xi_s}e^{-i\phi_s} \qquad \bar{p} = |p|e^{i\xi_p}e^{-i\phi_p}$$

ϕ weak phase
ξ strong phase

$$\left[\ \alpha = \frac{2\mathrm{Re}(s^* p)}{|s|^2 + |p|^2} \quad \beta = \frac{2\mathrm{Im}(s^* p)}{|s|^2 + |p|^2} \quad \gamma = \frac{|s|^2 - |p|^2}{|s|^2 + |p|^2}\ \right]$$

- If CP conserved:

$$s \xrightarrow{\text{CP}} -s \qquad p \xrightarrow{\text{CP}} p$$

⇒

$$\alpha \xrightarrow{\text{CP}} \bar{\alpha} = -\alpha \qquad \beta \xrightarrow{\text{CP}} \bar{\beta} = -\beta \qquad \gamma \xrightarrow{\text{CP}} \bar{\gamma} = +\gamma$$

$$A_{CP}^{\alpha} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = \tan\phi_{CP}\tan\Delta_S$$

$$\tan\phi_{CP} = \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}} = \frac{\sqrt{1-\alpha^2}\sin\Delta + \sqrt{1-\bar{\alpha}^2}\sin\bar{\Delta}}{\alpha - \bar{\alpha}}$$

$$\tan\Delta_S = \frac{\beta - \bar{\beta}}{\alpha - \bar{\alpha}} = \frac{\sqrt{1-\alpha^2}\sin\Delta - \sqrt{1-\bar{\alpha}^2}\sin\bar{\Delta}}{\alpha - \bar{\alpha}}$$

All polarization induced CPV observables can be derived using $\alpha/\bar{\alpha}$ and $\Delta/\bar{\Delta}$.

Data samples

- MC sample is simulated under OSCAR version: 2.6.2

- Signal processes:

ΛK^+ channel: $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$, $\Lambda_c^+ \to \Lambda K^+$, and $\Lambda \to p\pi^-$,
$\Sigma^0 K^+$ channel: $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$, $\Lambda_c^+ \to \Sigma^0 K^+$, $\Sigma^0 \to \gamma\Lambda$ and $\Lambda \to p\pi^-$,
$\Sigma^+ K_S^0$ channel: $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$, $\Lambda_c^+ \to \Sigma^+ K_S^0$, $\Sigma^+ \to p\pi^0$, $\pi^0 \to \gamma\gamma$, and $K_S^0 \to \pi^+\pi^-$.

- Only signal process based on PHSP model is generated, and the size is about 4 million.

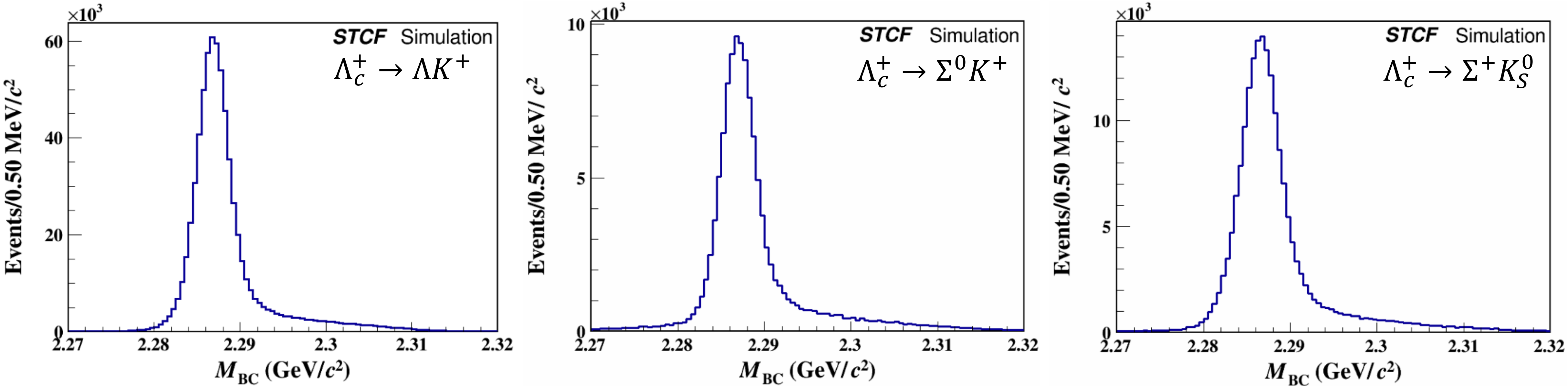
Event selection

- Proton:
  - $|V_z| < 20$ cm, $|\cos\theta| < 0.93$
  - PID: $\text{prob}(p) > 0\&\&\text{prob}(p) > \text{prob}(K)\&\&\text{prob}(p) > \text{prob}(\pi)$
- Pion:
  - $V_z < 20$ cm, $|\cos\theta| < 0.93$
- Kaon:
  - $|V_r| < 1$ cm, $|V_z| < 20$ cm, $|\cos\theta| < 0.93$
  - PID: $\text{prob}(\pi) > 0\&\&\text{prob}(\pi) > \text{prob}(K)$
- Good shower:
  - $E > 0.025$ GeV (barrel: $|\cos\theta| < 0.8325|$)
  - $E > 0.050$ GeV (endcap: $0.8325 < |\cos\theta| < 0.9445|$)
  - Angle with charged tracks should be larger than $10°$

- π^0:
  - 1C chis<200
  - Invariant mass lies in (0.115,0.150) GeV/c^2
- K_S^0:
  - Primary vertex fit:$\chi^2 < 100$
  - Second vertex fit: $L/\sigma_L > 2$
  - Invariant mass lies in (0.487,0.511) GeV/c^2
- Λ:
  - Primary vertex fit:$\chi^2 < 100$
  - Second vertex fit: $L/\sigma_L > 2$
  - Invariant mass lies in (1.111,1.121) GeV/c^2
- Σ^0: Invariant mass lies in (1.179,1.203) GeV/c^2
- Σ^+: Invariant mass lies in (1.176,1.200) GeV/c^2

- If there is more than one candidate in one events, the candidate with the minimum $|E_{\Lambda_c^+} - E_{\text{beam}}|$ is selected.
- Beam-constrained mass: $M_{\text{BC}} = \sqrt{E_{beam}^2/c^4 - \left|\hat{p}_{\Lambda_c^+}\right|^2/c^2}$

Mass spectrum

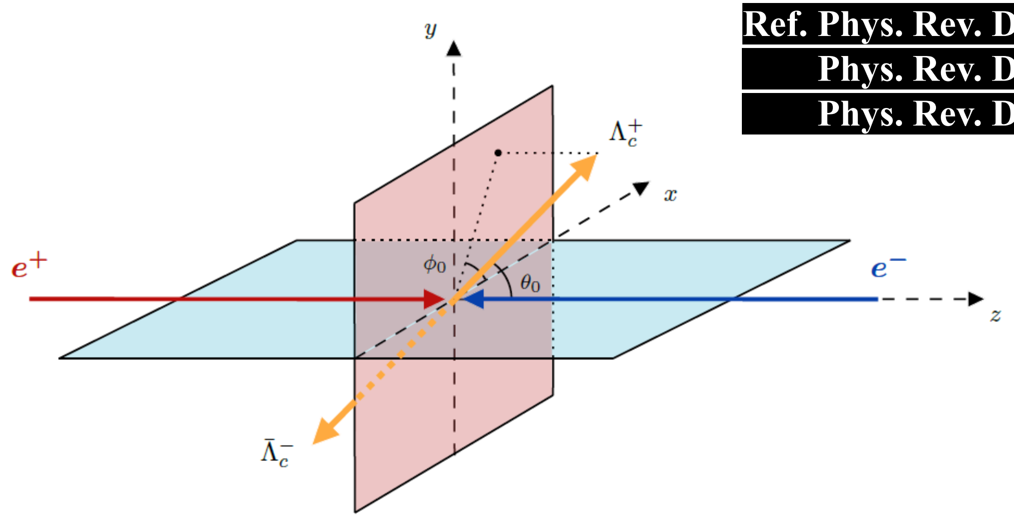


Modes	ΔE	M_{BC}	Efficiency
$\Lambda_c^+ \to \Lambda K^+$			~29.1%
$\Lambda_c^+ \to \Sigma^0 K^+$	$[-25,20]$ MeV	$[2.282,2.291]$ GeV/c^2	~4.8%
$\Lambda_c^+ \to \Sigma^+ K_S^0$			~7.7%

Polarized beam on STCF

Ref. Phys. Rev. D 110.014035
Phys. Rev. D 105.116022
Phys. Rev. D 99.056008

- P_T: beam transverse polarization
- P_Z: beam longitudinal polarization



Spin density matrix:

$$
\begin{aligned}
\rho^{\gamma^*}(\phi_0,\theta_0) = \frac{1}{4}&\begin{pmatrix} \frac{1+\cos^2\theta_0}{2} & -\frac{\sin\theta_0\cos\theta_0}{\sqrt{2}} & \frac{\sin^2\theta_0}{2} \\ -\frac{\sin\theta_0\cos\theta_0}{\sqrt{2}} & \sin^2\theta_0 & \frac{\sin\theta_0\cos\theta_0}{\sqrt{2}} \\ \frac{\sin^2\theta_0}{2} & \frac{\sin\theta_0\cos\theta_0}{\sqrt{2}} & \frac{1+\cos^2\theta_0}{2} \end{pmatrix} \\
+\frac{P_T\bar{P}_T}{4}&\begin{pmatrix} \frac{\sin^2\theta_0\cos 2\phi_0}{2} & \frac{\sin\theta_0\cos\theta_0\cos 2\phi_0 - i\sin\theta_0\sin 2\phi_0}{\sqrt{2}} & \frac{(1+\cos^2\theta_0)\cos 2\phi_0 - 2i\cos\theta_0\sin 2\phi_0}{2} \\ \frac{\sin\theta_0\cos\theta_0\cos 2\phi_0 + i\sin\theta_0\sin 2\phi_0}{\sqrt{2}} & -\sin^2\theta_0\cos 2\phi_0 & \frac{-\sin\theta_0\cos\theta_0\cos 2\phi_0 + i\sin\theta_0\sin 2\phi_0}{\sqrt{2}} \\ \frac{(1+\cos^2\theta_0)\cos 2\phi_0 + 2i\cos\theta_0\sin 2\phi_0}{2} & \frac{-\sin\theta_0\cos\theta_0\cos 2\phi_0 - i\sin\theta_0\sin 2\phi_0}{\sqrt{2}} & \frac{\sin^2\theta_0\cos 2\phi_0}{2} \end{pmatrix} \\
+\frac{1}{4}&\begin{pmatrix} \frac{-2(P_Z+\bar{P}_Z)\cos\theta_0 + P_Z\bar{P}_Z(1+\cos^2\theta_0)}{2} & \frac{(P_Z+\bar{P}_Z)\sin\theta_0 - P_Z\bar{P}_Z\sin\theta_0\cos\theta_0}{\sqrt{2}} & \frac{P_Z\bar{P}_Z\sin^2\theta_0}{2} \\ \frac{(P_Z+\bar{P}_Z)\sin\theta_0 - P_Z\bar{P}_Z\sin\theta_0\cos\theta_0}{\sqrt{2}} & P_Z\bar{P}_Z\sin^2\theta_0 & \frac{(P_Z+\bar{P}_Z)\sin\theta_0 + P_Z\bar{P}_Z\sin\theta_0\cos\theta_0}{\sqrt{2}} \\ \frac{P_Z\bar{P}_Z\sin^2\theta_0}{2} & \frac{(P_Z+\bar{P}_Z)\sin\theta_0 + P_Z\bar{P}_Z\sin\theta_0\cos\theta_0}{\sqrt{2}} & \frac{2(P_Z+\bar{P}_Z)\cos\theta_0 + P_Z\bar{P}_Z(1+\cos^2\theta_0)}{2} \end{pmatrix}.
\end{aligned}
$$

For simplicity: $\bar{P}_Z = 0$ and $\bar{P}_T = P_T$

Generation of baryon & anti-baryon on STCF

Ref. Phys. Rev. D 110.014035
Phys. Rev. D 105.116022
Phys. Rev. D 99.056008

Based on the spin density matrix,
joint density matrix of baryon & anti-baryon pair:

$$(C_{\mu\nu}) = \frac{3}{2(3+\alpha_0)} \begin{pmatrix} 1+\alpha_0\cos^2\theta_0 & 0 & \beta_0\sin\theta_0\cos\theta_0 & 0 \\ 0 & \sin^2\theta_0 & 0 & \gamma_0\sin\theta_0\cos\theta_0 \\ -\beta_0\sin\theta_0\cos\theta_0 & 0 & \alpha_0\sin^2\theta_0 & 0 \\ 0 & -\gamma_0\sin\theta_0\cos\theta_0 & 0 & -\alpha_0-\cos^2\theta_0 \end{pmatrix}$$

$$+\frac{3\hat{P}_T^2}{2(3+\alpha_0)} \begin{pmatrix} \alpha_0\sin^2\theta_0\cos 2\phi_0 & -\beta_0\sin\theta_0\sin 2\phi_0 & -\beta_0\sin\theta_0\cos\theta_0\cos 2\phi_0 & 0 \\ -\beta_0\sin\theta_0\sin 2\phi_0 & (\alpha_0+\cos^2\theta_0)\cos 2\phi_0 & -(1+\alpha_0)\cos\theta_0\sin 2\phi_0 & -\gamma_0\sin\theta_0\cos\theta_0\cos 2\phi_0 \\ \beta_0\sin\theta_0\cos\theta_0\cos 2\phi_0 & (1+\alpha_0)\cos\theta_0\sin 2\phi_0 & (1+\alpha_0\cos^2\theta_0)\cos 2\phi_0 & -\gamma_0\sin\theta_0\sin 2\phi_0 \\ 0 & \gamma_0\sin\theta_0\cos\theta_0\cos 2\phi_0 & -\gamma_0\sin\theta_0\sin 2\phi_0 & -\sin^2\theta_0\cos 2\phi_0 \end{pmatrix}$$

$$+\frac{3\hat{P}_Z}{2(3+\alpha_0)} \begin{pmatrix} 0 & \gamma_0\sin\theta_0 & 0 & (1+\alpha_0)\cos\theta_0 \\ \gamma_0\sin\theta_0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_0\sin\theta_0 \\ -(1+\alpha_0)\cos\theta_0 & 0 & \beta_0\sin\theta_0 & 0 \end{pmatrix},$$

$$\alpha_0 := (\mathcal{H}_{\frac{1}{2},\frac{1}{2}} - 2\mathcal{H}_{\frac{1}{2},-\frac{1}{2}})/(\mathcal{H}_{\frac{1}{2},\frac{1}{2}} + 2\mathcal{H}_{\frac{1}{2},-\frac{1}{2}})$$

$$\Delta_0 := \mathrm{Arg}(\mathcal{H}_{\frac{1}{2},-\frac{1}{2}}/\mathcal{H}_{\frac{1}{2},\frac{1}{2}})$$

$$\beta_0 = \sqrt{1-\alpha_0^2}\sin\Delta_0,\ \gamma_0 = \sqrt{1-\alpha_0^2}\cos\Delta_0$$

You can clearly see the contributions from:

1) non-polarization;
2) transverse polarization;
3) longitudinal polarization.

Baryon decay

Ref. Phys. Rev. D 110.014035
Phys. Rev. D 105.116022
Phys. Rev. D 99.056008

α-matrix: $\Lambda_c^+/\Sigma^+/\Lambda$ decay:

$$\begin{pmatrix} 1 & 0 & 0 & \alpha_{BP} \\ \alpha_{BP}\sin\theta_1\cos\phi_1 & \gamma_{BP}\cos\theta_1\cos\phi_1 - \beta_{BP}\sin\phi_1 & -\beta_{BP}\cos\theta_1\cos\phi_1 - \gamma_{BP}\sin\phi_1 & \sin\theta_1\cos\phi_1 \\ \alpha_{BP}\sin\theta_1\sin\phi_1 & \beta_{BP}\cos\phi_1 + \gamma_{BP}\cos\theta_1\sin\phi_1 & \gamma_{BP}\cos\phi_1 - \beta_{BP}\cos\theta_1\sin\phi_1 & \sin\theta_1\sin\phi_1 \\ \alpha_{BP}\cos\theta_1 & -\gamma_{BP}\sin\theta_1 & \beta_{BP}\sin\theta_1 & \cos\theta_1 \end{pmatrix}$$

- This matrix is only for $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$

Note:

$\Sigma^0 \to \gamma\Lambda$ ⟶ P conserved

$$a^{\Sigma^0}_{0,0} = 1$$

$$a^{\Sigma^0}_{1,3} = -\sin\theta_2\cos\phi_2$$

$$a^{\Sigma^0}_{2,3} = -\sin\theta_2\sin\phi_2$$

$$a^{\Sigma^0}_{3,3} = -\cos\theta_2$$

For $\Lambda_c^+ \to \Lambda K^+$: $$\mathcal{F}^{\Lambda_c^+}(\xi;\omega) = \frac{1}{(4\pi)^3}\sum_{\mu=0}^{3} C_{\mu 0}\cdot\sum_{\mu'=0,\mu''=0}^{3} a^{\Lambda_c^+}_{\mu\mu'} a^{\Lambda}_{\mu' 0}$$

For $\Lambda_c^+ \to \Sigma^0 K^+$: $$\mathcal{F}^{\Lambda_c^+}(\xi;\omega) = \frac{1}{(4\pi)^3}\sum_{\mu=0}^{3} C_{\mu 0}\cdot\sum_{\mu'=0,\mu''=0}^{3} a^{\Lambda_c^+}_{\mu\mu'} a^{\Sigma^0}_{\mu'\mu''} a^{\Lambda}_{\mu'' 0}$$

For $\Lambda_c^+ \to \Sigma^+ K_S^0$: $$\mathcal{F}^{\Lambda_c^+}(\xi;\omega) = \frac{1}{(4\pi)^3}\sum_{\mu=0}^{3} C_{\mu 0}\cdot\sum_{\mu'=0,\mu''=0}^{3} a^{\Lambda_c^+}_{\mu\mu'} a^{\Sigma^+}_{\mu'\mu''} a^{\Lambda}_{\mu'' 0}$$

All angular distribution formulas can be derived.

Statistical uncertainty of other experiments

- Simple scaling using yield (luminosity) based on current statistical uncertainty.

$$\sigma \propto \frac{1}{\sqrt{\mathcal{L}}}$$

Parameters	LHCb			Belle (II)	
	Nowadays	2030	2041	Nowadays	2043
Luminosity	9 fb^{-1}	50 fb^{-1}	300 fb^{-1}	980 fb^{-1}	50 ab^{-1}
$\alpha_{\Lambda K^+}$	0.05	0.021	0.009	0.049	0.007
$\Delta_{\Lambda K^+}$	0.103	0.044	0.018	$\cdots$	$\cdots$
$\alpha_{\Sigma^0 K^+}$	$\cdots$	$\cdots$	$\cdots$	0.18	0.025
$A_{CP}^{\alpha_{\Lambda K^+}}$	0.08	0.034	0.014	0.086	0.012
$A_{CP}^{\alpha_{\Sigma^0 K^+}}$	$\cdots$	$\cdots$	$\cdots$	0.35	0.049

Estimated method

Simulation →

Sampling:

1. Using the Angular Distribution Model
2. Input parameters

Processes	Parameters	Values	Sources
$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$	α_0 ($\bar{\alpha}_0$)	0.10	Estimated
	Δ_0 ($\bar{\Delta}_0$)	-0.50	Estimated
$\Lambda_c^+ \to \Lambda K^+$	$\alpha_{\Lambda K^+}$	-0.52	Ref. [a]
	$\Delta_{\Lambda K^+}$	2.74	Ref. [a]
$\bar{\Lambda}_c^- \to \bar{\Lambda} K^-$	$\alpha_{\bar{\Lambda} K^-}$	$-\alpha_{\Lambda K^+}$	CP conservation
	$\Delta_{\bar{\Lambda} K^-}$	$-\Delta_{\Lambda K^+}$	CP conservation
$\Lambda_c^+ \to \Sigma^0 K^+$	$\alpha_{\Sigma^0 K^+}$	-0.52	Ref. [b]
	$\Delta_{\Sigma^0 K^+}$	-0.59	Ref. [b]
$\bar{\Lambda}_c^- \to \bar{\Sigma}^0 K^-$	$\alpha_{\bar{\Sigma}^0 K^-}$	$-\alpha_{\Sigma^0 K^+}$	CP conservation
	$\Delta_{\bar{\Sigma}^0 K^-}$	$-\Delta_{\Sigma^0 K^+}$	CP conservation
$\Lambda_c^+ \to \Sigma^+ K_S^0$	$\alpha_{\Sigma^+ K_S^0}$	-0.52	Ref. [b]
	$\Delta_{\Sigma^+ K_S^0}$	-0.59	Ref. [b]
$\bar{\Lambda}_c^- \to \bar{\Sigma}^+ K_S^0$	$\alpha_{\bar{\Sigma}^- K_S^0}$	$-\alpha_{\Sigma^+ K_S^0}$	CP conservation
	$\Delta_{\bar{\Sigma}^- K_S^0}$	$-\Delta_{\Sigma^+ K_S^0}$	CP conservation
$\Lambda \to p\pi^-$	$\alpha_{p\pi^-}$	0.747	PDG(2024) [c]
$\bar{\Lambda} \to \bar{p}\pi^+$	$\alpha_{\bar{p}\pi^+}$	-0.757	PDG(2024) [c]
$\Sigma^+ \to p\pi^0$	$\alpha_{p\pi^0}$	-0.982	PDG(2024) [c]
$\bar{\Sigma}^- \to \bar{p}\pi^0$	$\alpha_{\bar{p}\pi^0}$	0.990	PDG(2024) [c]

→

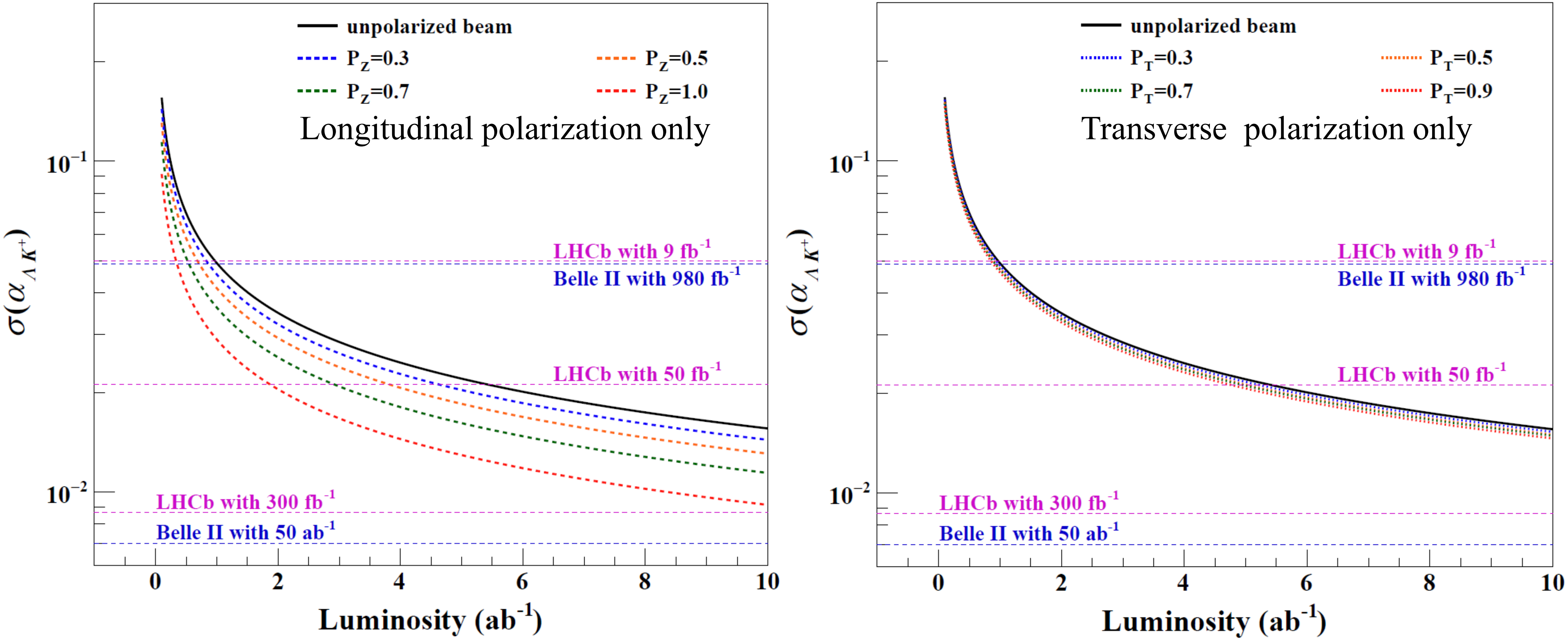
Fit:

1. Likelihood fit
2. Fix different beam polarization
3. Give the absolute statistical uncertainty

[a] Phys.Rev.Lett.133.261804; [b] Phys.Rev.D.109.L071302;

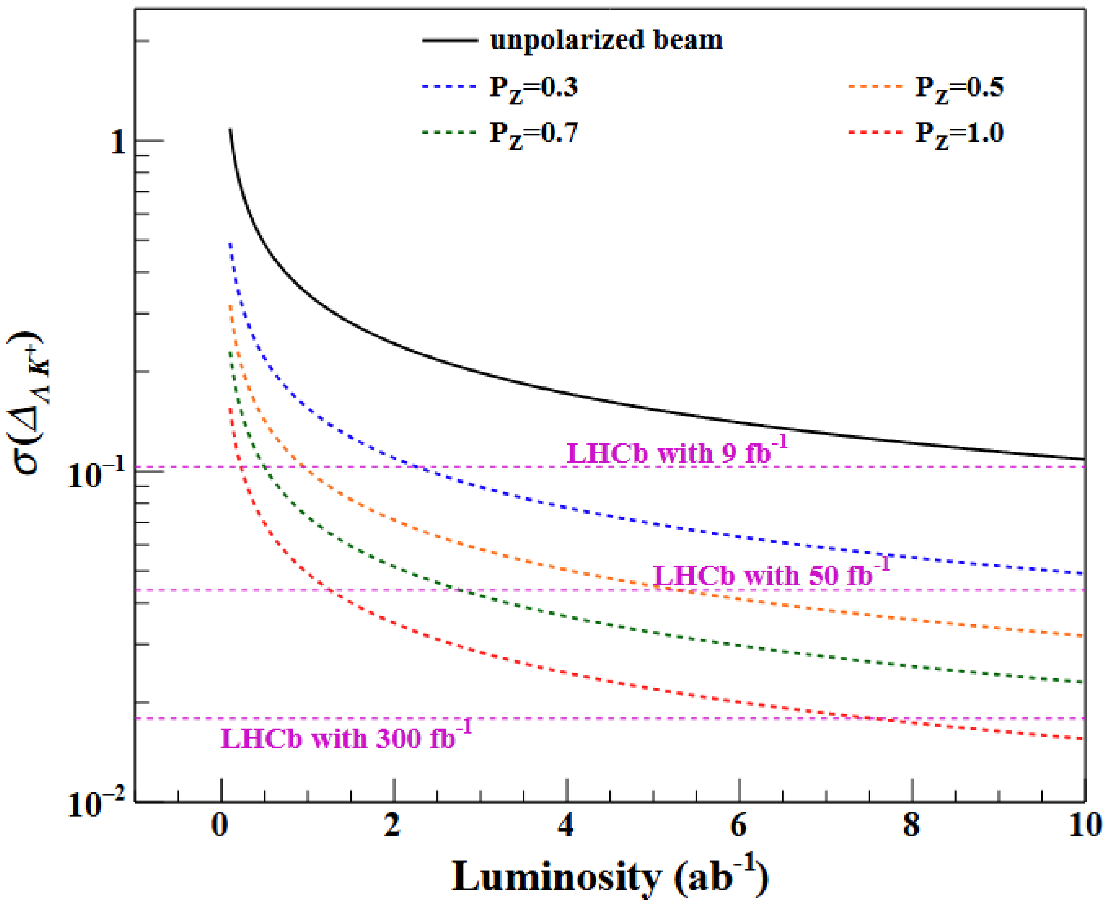
[c] Phys.Rev.D.110.030001.

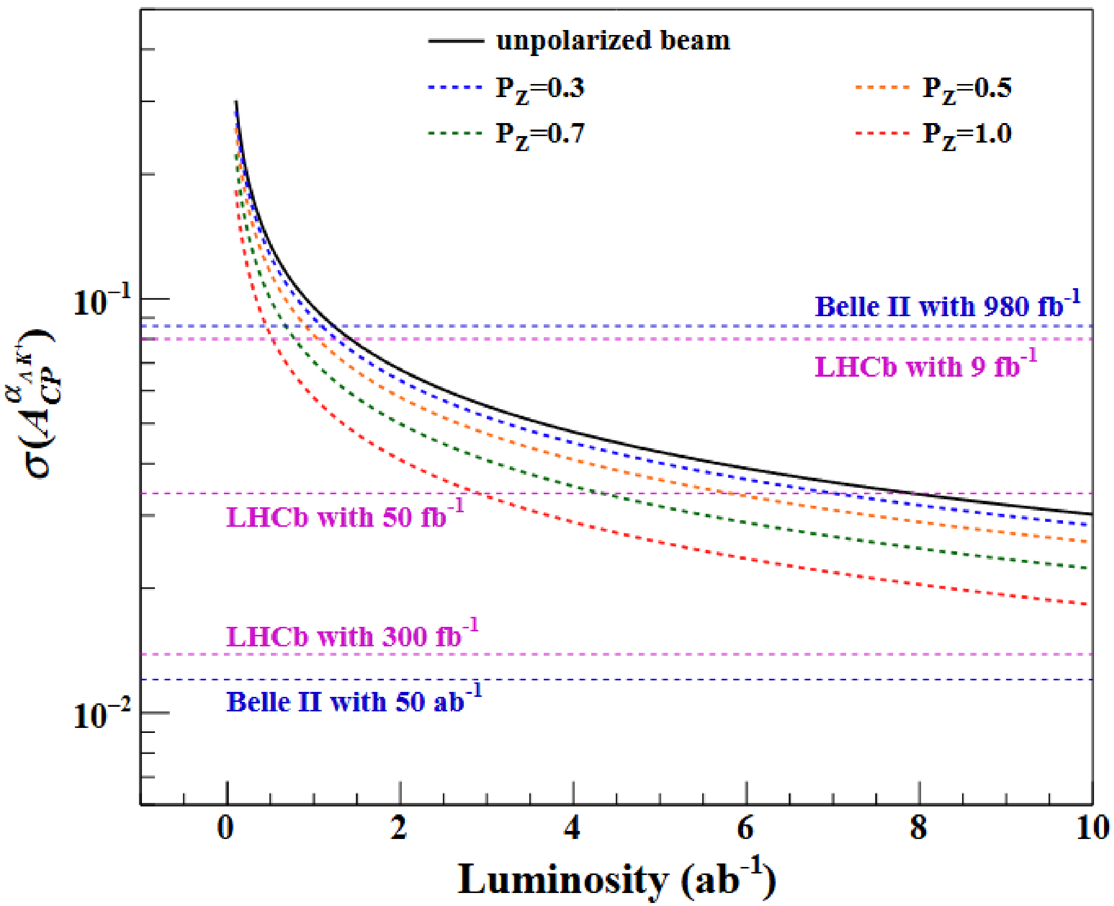
Statistical uncertainty estimation for $\alpha_{\Lambda K^+}$



- Longitudinal beam polarization has greater advantages in measuring polarization parameters.
- When the longitudinal polarization is 50%, it needs four years to achieve the accuracy of LHCb experiment based on 50 fb^{-1}.

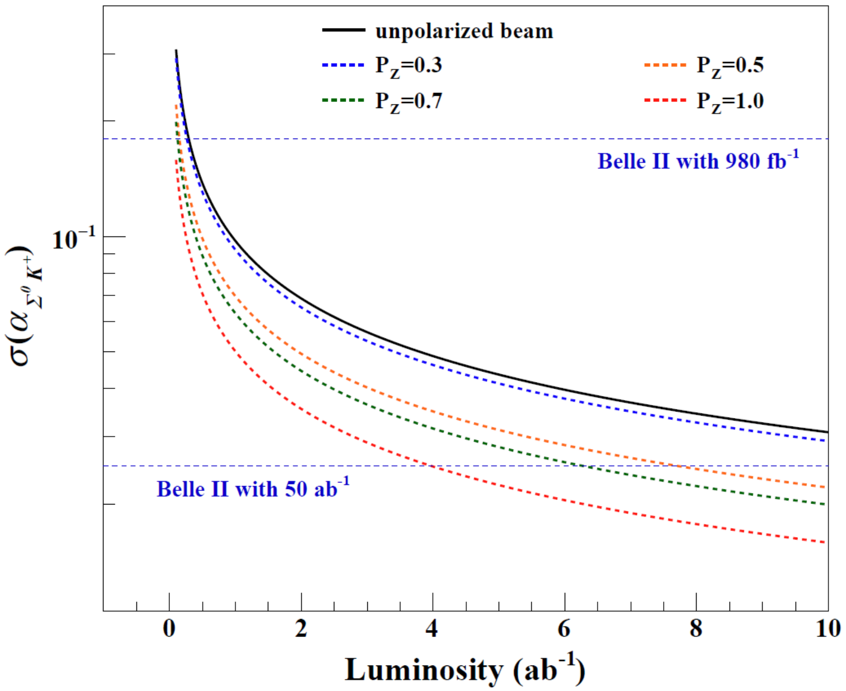
Statistical uncertainty estimation for $\Delta_{\Lambda K^+}$ and $A_{CP}^{\alpha_{\Lambda K^+}}$

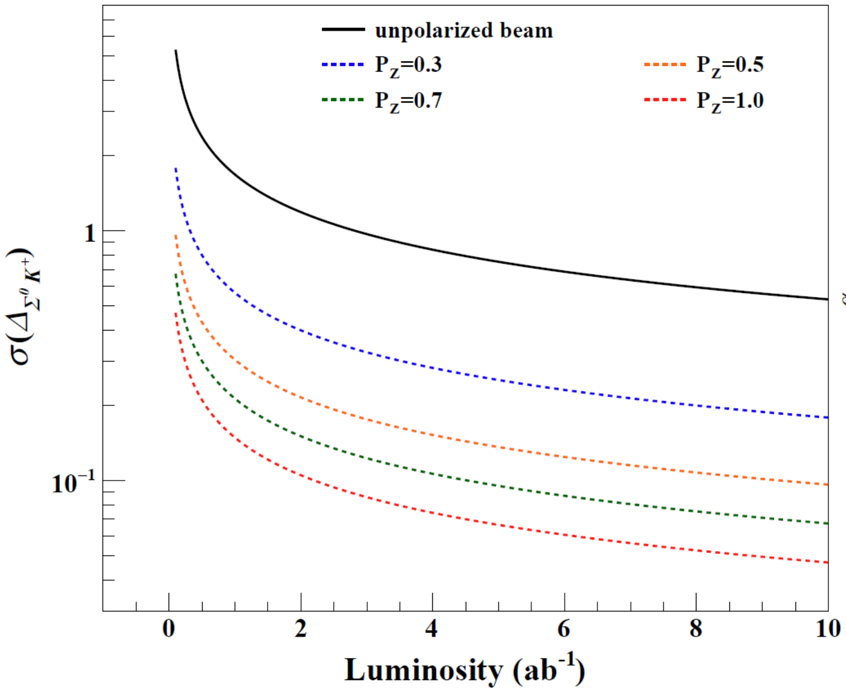


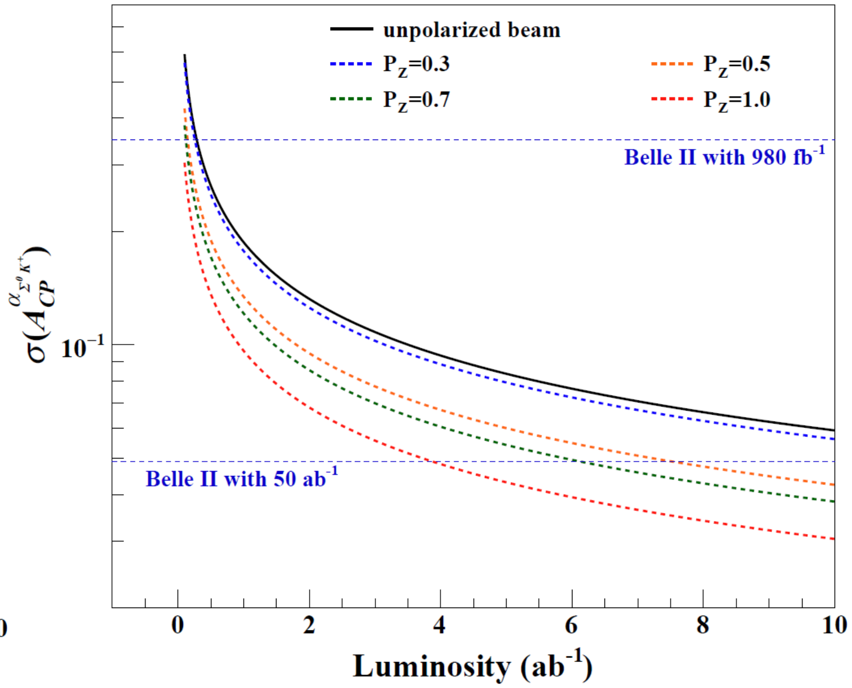


- Using high longitudinal polarization beam, the advantages of STCF is particularly evident.
- Especially in $\Delta_{\Lambda K^+}$, measuring β-induced CPV could be possible in the future.
- But α-induced CPV seems worse than LHCb and Belle II.

Statistical uncertainty estimation for $\alpha_{\Sigma^0 K^+}$, $\Delta_{\Sigma^0 K^+}$, and $A_{CP}^{\Sigma^0 K^+}$

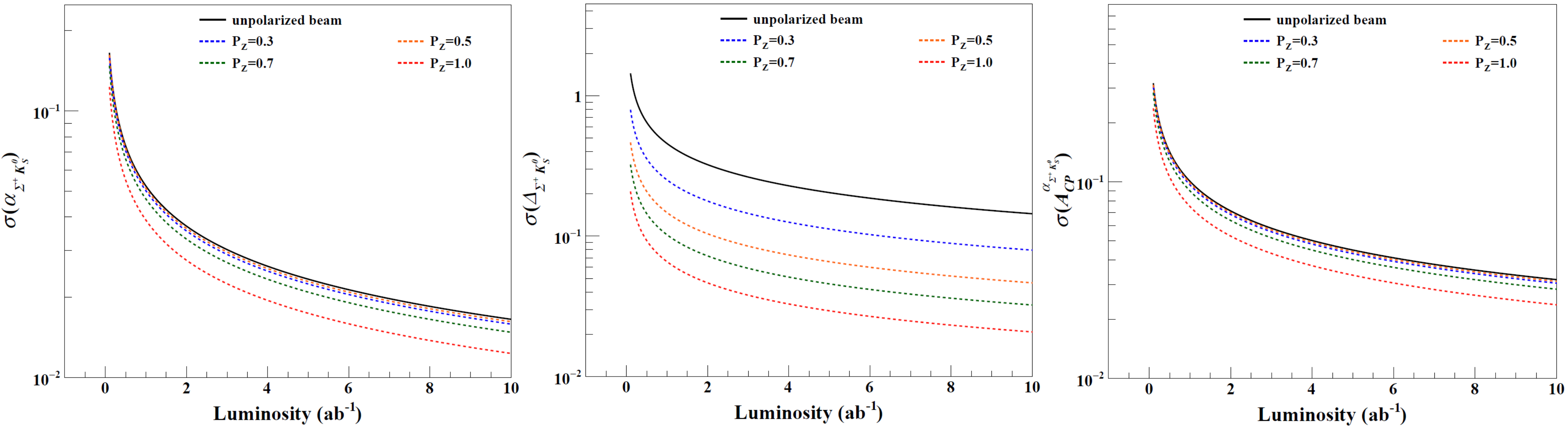






All the parameters studied can achieve overall better accuracy than Belle II on STCF using 4 ab^{-1} data with a large longitudinal polarized beam.

Statistical uncertainty estimation for $\alpha_{\Sigma^+ K_S^0}$, $\Delta_{\Sigma^+ K_S^0}$, and $A_{CP}^{\Sigma^+ K_S^0}$



- There is no Belle II or LHCb measurement yet.
- Hard to reach precision of SM prediction (10^{-4}~10^{-5}).

Conclusion

1. Longitudinal polarization has a greater improvement in precision compared to transverse polarization.

2. Large longitudinal polarization is necessary for P and CP violation parameters measurement.

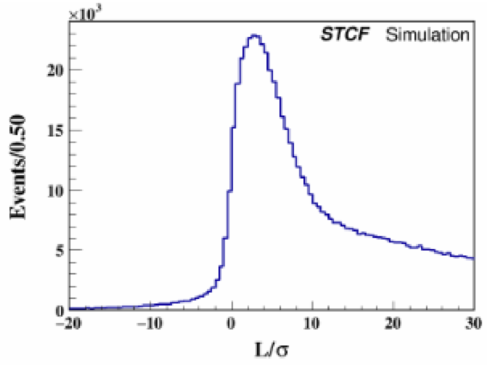
3. Polarization parameters Δ have significant precision advantages on STCF!

4. Precision of Δ will allow us to explore β-induced CPV.

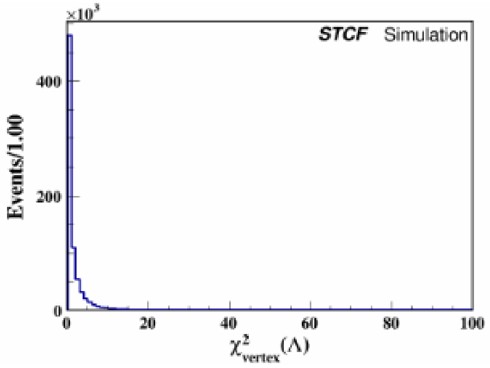
5. There is still a lack of data to test the CPV phenomenon in SM in the exploration of polarization-induced CPV.

Thank you!

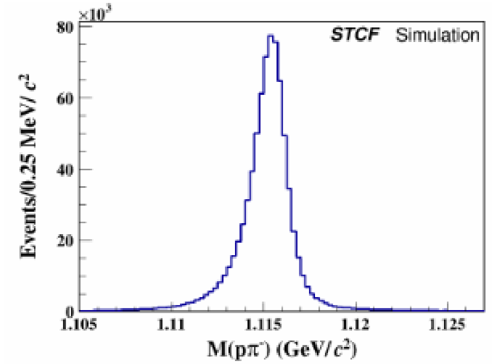
backup



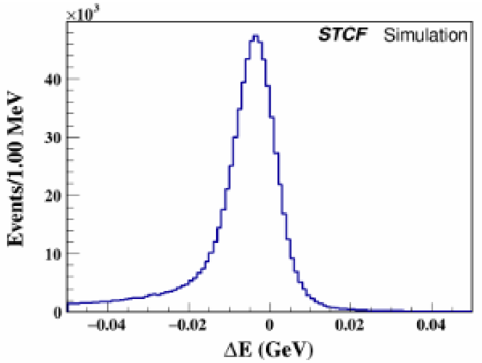
(a) Decay length / its error of Λ.



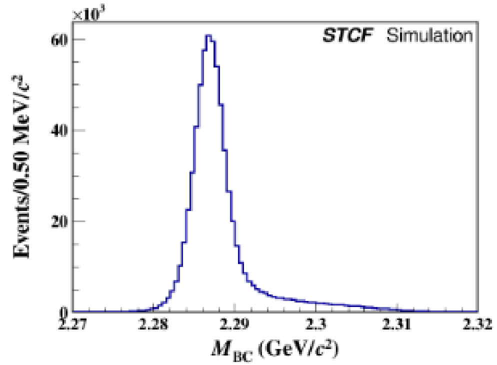
(b) $\chi^2_{\text{vertex fit}}$ of Λ.



(c) Λ invariant mass, which has been updated by vertex fit.

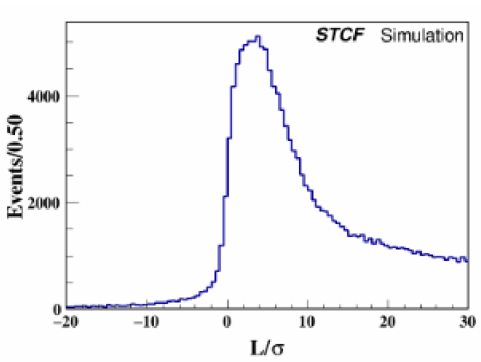


(d) ΔE.



(e) Beam constrain mass of Λ_c^+ in data.

Fig. 1: Some spectrums of $\Lambda_c^+ \to \Lambda K^+$ channel.



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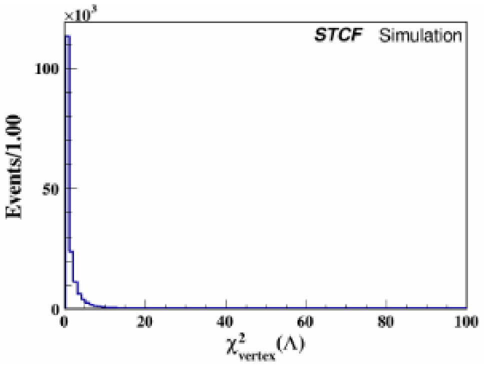

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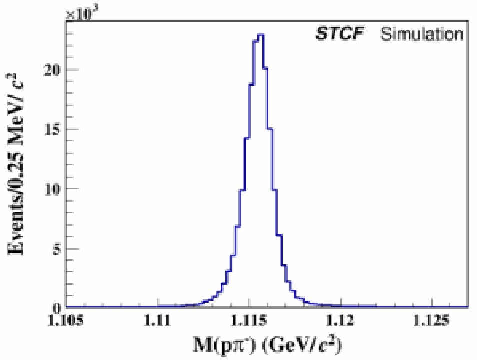
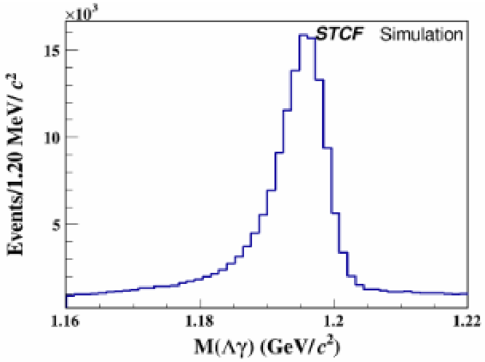
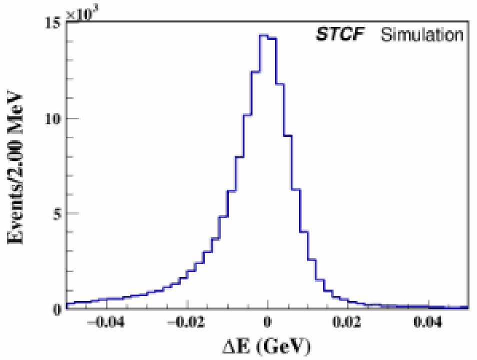


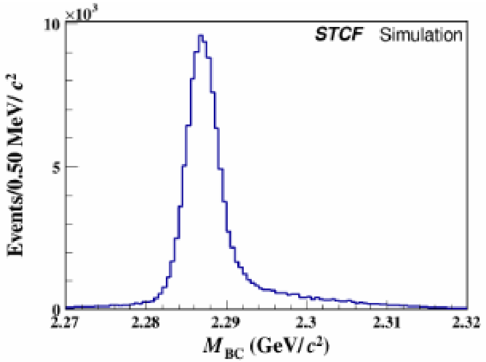
(c) Λ invariant mass, which has been updated by vertex fit.



(d) Σ^0 invariant mass.

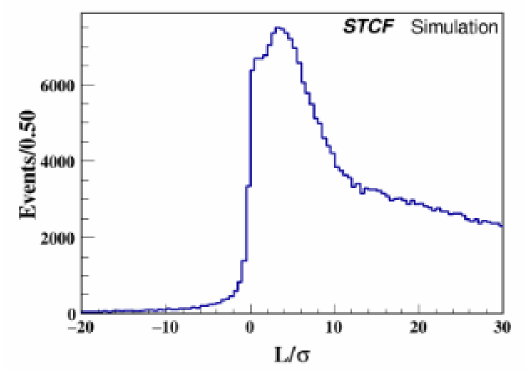


(e) ΔE.

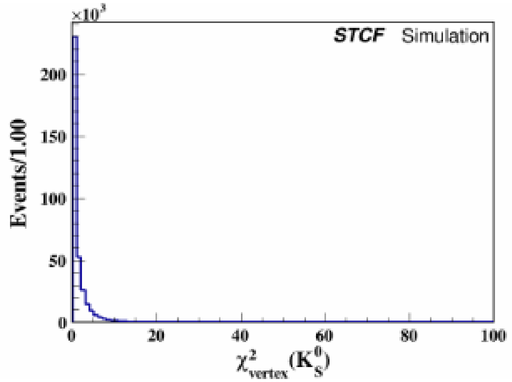


(f) Beam constrain mass of Λ_c^+ in data.

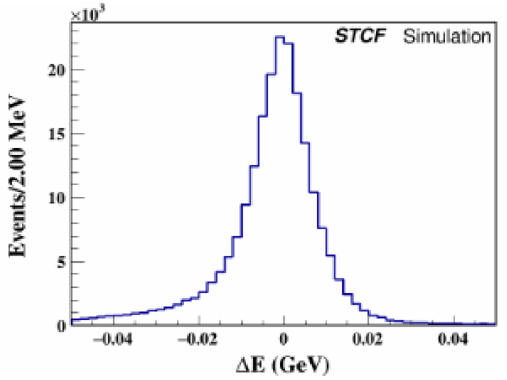
Fig. 2: Some spectrums of $\Lambda_c^+ \to \Sigma^0 K^+$ channel.



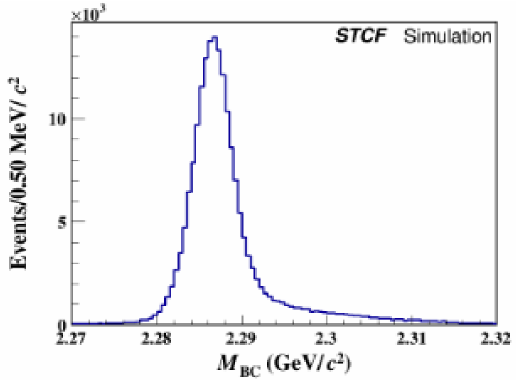
(a) Decay length / its error of K_S^0.



(b) $\chi^2_{\text{vertex fit}}$ of K_S^0.

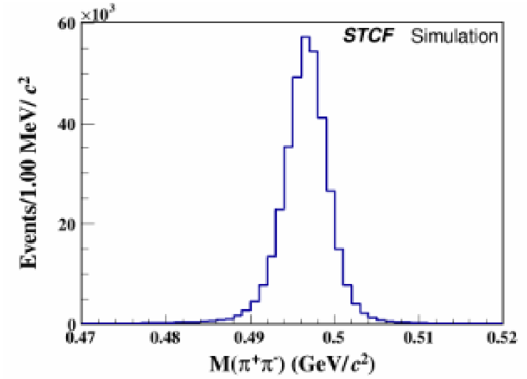


(g) ΔE.

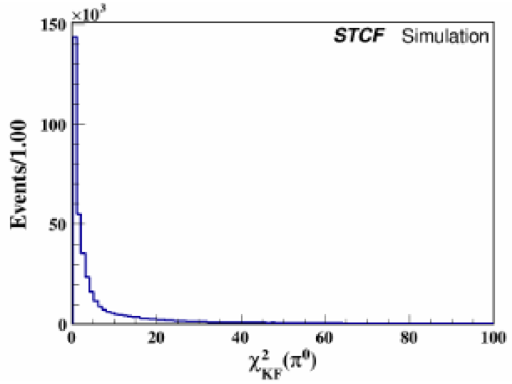


(h) Beam constrain mass of Λ_c^+ in data.

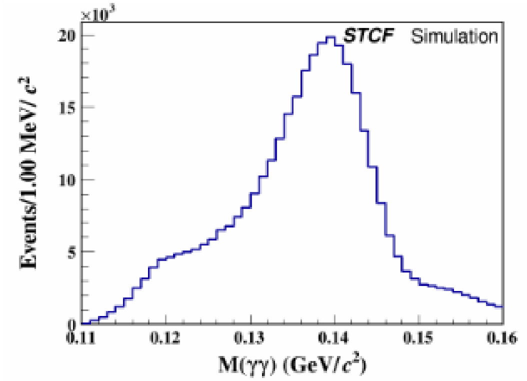
Fig. 3: Some spectrums of $\Lambda_c^+ \to \Sigma^+ K_S^0$ channel.



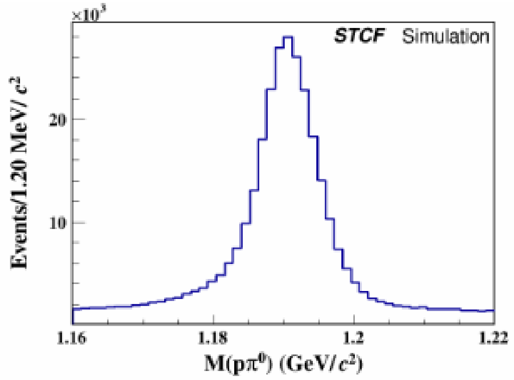
(c) K_S^0 invariant mass, which has been updated by vertex fit.



(d) $\chi^2_{\text{kinematic fit}}$ of π^0.

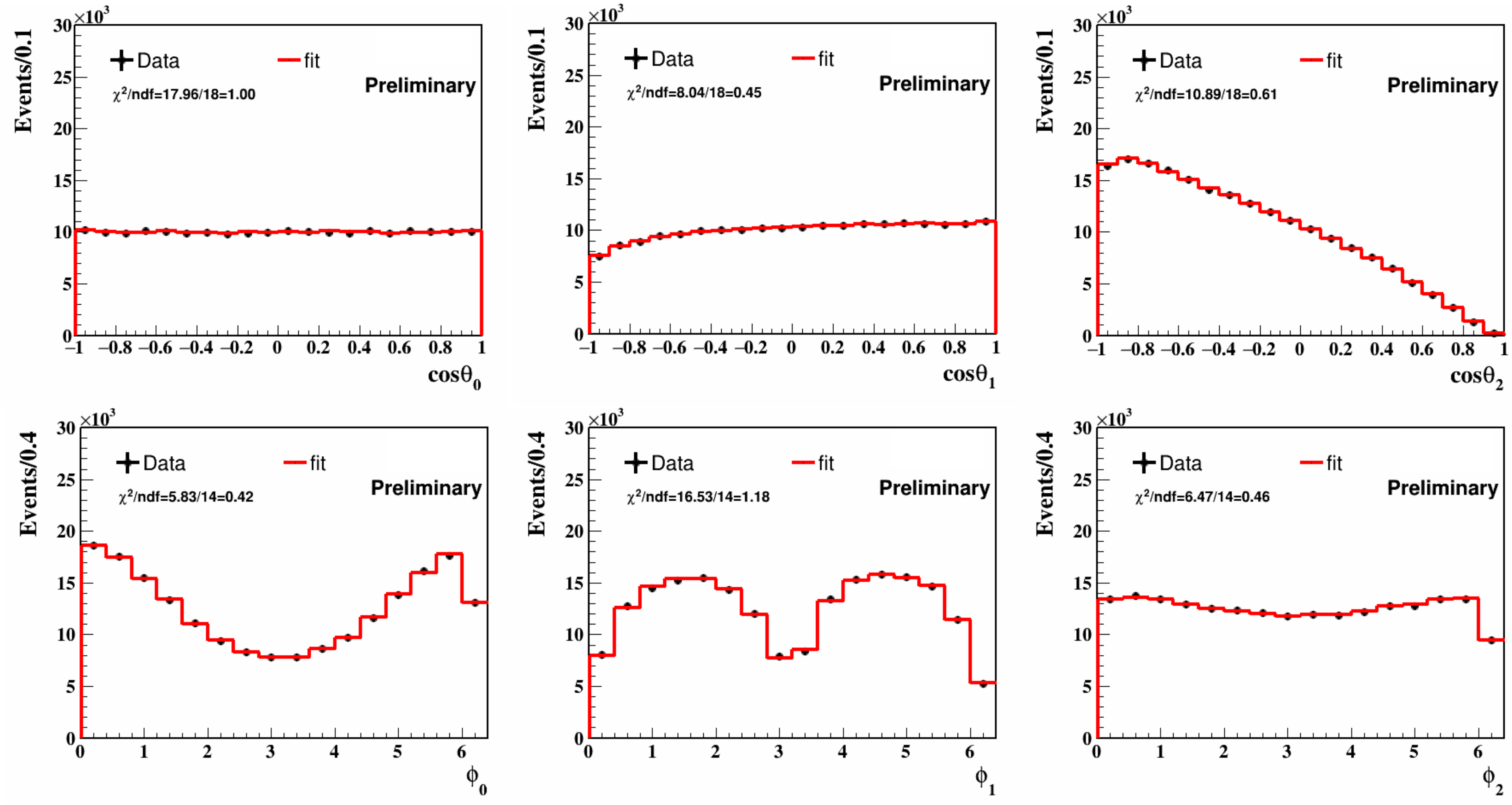


(e) π^0 invariant mass.

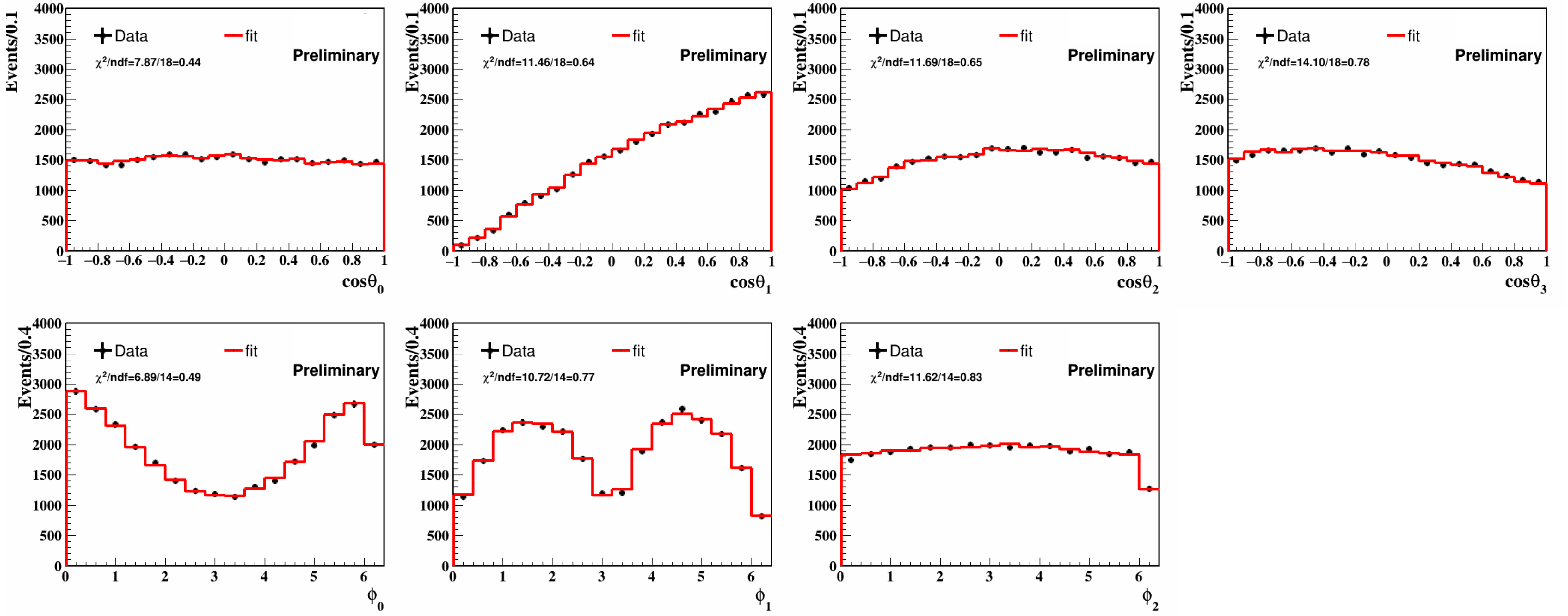


(f) Σ^+ invariant mass.

$\Lambda_c^+ \to \Lambda K^+$



$\Lambda_c^+ \to \Sigma^0 K^+$



$\Lambda_c^+ \to \Sigma^+ K_S^0$