中国科学院大学
University of Chinese Academy of Sciences

BESIII

26th International Symposium on Spin Physics
A Century of Spin

The Production and Decay Dynamics of the Lightest Charmed Baryon in e^+e^- Annihilations near threshold

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On behalf of the BESIII Collaboration

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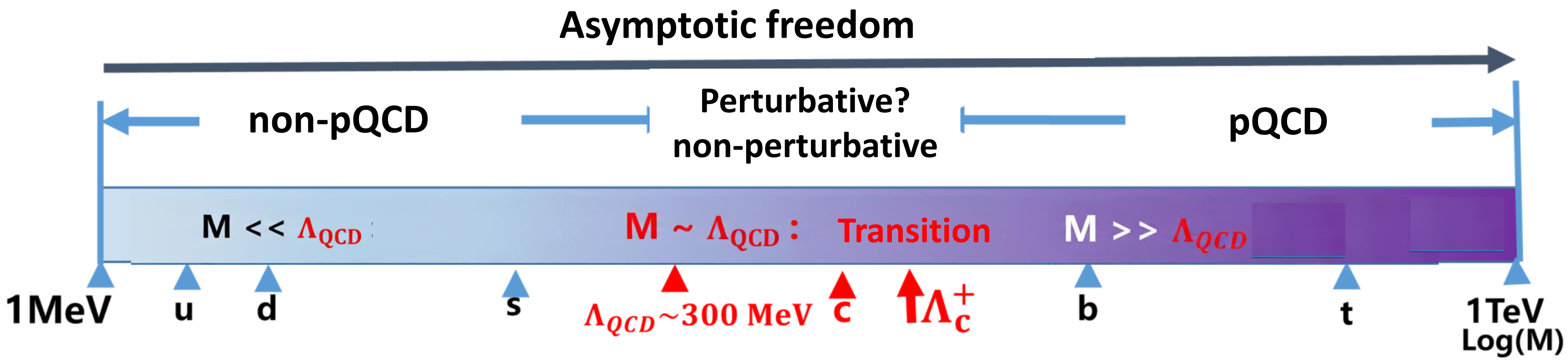
Outlines

- **Motivation**: Why study charm quarks and baryons?
- **Theoretical Background**: Transverse Polarization(EMFF phase difference) and Decay Asymmetry Parameters(as CPV tests)
- **Experiment**: BESIII, correlated baryon pairs from ee collision
- **Methods**: Decay Chain Angular distribution + Max. Likelihood Fit
- **Results and Discussion**: first observation of transverse polarization in charmed baryons; improved decay asymmetry precision
- **Conclusion**: Implications for future research and theoretical advancements.

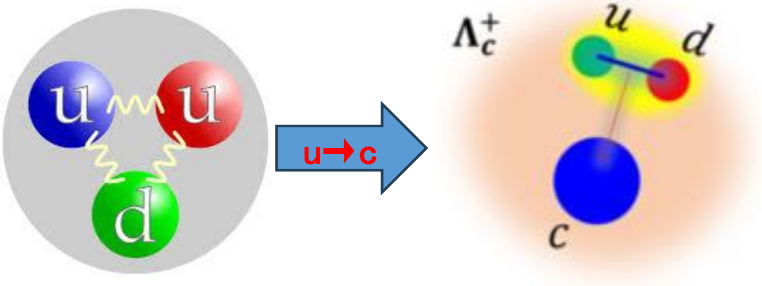
Motivation: QCD in intermediate region

- **Charm quark (~1.27 GeV/c^2):** a key role in understanding the transition in the intermediate region of perturbative and non-perturbative methods of QCD.



- **Charm baryon:** structure different from nucleus and hyperons by replacing light quarks; Test of SM in charm baryons.

$m(u){\sim}m(d) \ll m(p)$



$m(u){\sim}m(d) \ll m(\mathrm{c})$
Quark(c) – diquark(ud) structure?

on Λ_c^+

Decay Asymmetry: Penetrating CPV and QCD

- **Parity violation** in non-leptonic weak decay $\Lambda_c^+ \to B\left(\frac{1}{2}\right)P(0)$
- Described by Lee-Yang Parameters:

$$\alpha_{BP}^{\Lambda_c^+} = \frac{2\mathrm{Re}(S^*P)}{|S|^2 + |P|^2} = \frac{|B_{-1/2}|^2 - |B_{1/2}|^2}{|B_{1/2}|^2 + |B_{-1/2}|^2}$$

$$\beta = \sqrt{1-\alpha^2}\sin\Delta_{BP}^{\Lambda_c^+}, \gamma = \sqrt{1-\alpha^2}\cos\Delta_{BP}^{\Lambda_c^+}, \alpha^2 + \beta^2 + \gamma^2 = 1$$

with their antiparticle counterparts: $\alpha_{BP}^{\Lambda_c^+} = -\alpha_{BP}^{\bar{\Lambda}_c^-}, \Delta_{BP}^{\Lambda_c^+} = -\Delta_{BP}^{\bar{\Lambda}_c^-}$

- Observables for CP violation tests can be constructed:

$$A_{CP}^{\alpha} = (\alpha_{BP}^{\Lambda_c^+} + \alpha_{BP}^{\bar{\Lambda}_c^-})/(\alpha_{BP}^{\Lambda_c^+} - \alpha_{BP}^{\bar{\Lambda}_c^-}) \quad A_{CP}^{\beta} = (\beta_{BP}^{\Lambda_c^+} + \beta_{BP}^{\bar{\Lambda}_c^-})/(\beta_{BP}^{\Lambda_c^+} - \beta_{BP}^{\bar{\Lambda}_c^-})$$

- Unluckily, CPV is shrouded by **final state (strong) interaction** between the daughter baryon and meson; while in the semi-leptonic decay the strong contribution can be separated into a global form factor.

Decay Asymmetry: Separating Strong and Weak interaction

With full knowledge of the Lee-Yang parameters, CPV and FSI can be distinguished.

- When S-wave and P-wave amplitudes are dominant by one term:

$$S_1 = |S|e^{i(\delta_S+\xi_S)} \qquad P_1 = |P|e^{i(\delta_P+\xi_P)}$$

and their antiparticle counterparts are:

$$\overline{S}_1 = -|S|e^{i(\delta_S-\xi_S)} \qquad \overline{P}_1 = |P|e^{i(\delta_P-\xi_P)}$$

- $\xi_{S,P}$: **weak phases** from **CKM matrix** in SM, change sign with charge;
- $\delta_{S,P}$: **strong phases** from FSI, remain the same as charge changes
- Consequently, CPV is modified by strong phase:

$$A^{\alpha}_{CP} = -\tan(\delta_P - \delta_S)\tan(\xi_P - \xi_S)$$

- Since $\xi_{S,P}$ are relatively small values, the strong phase angle:

$$\delta_P - \delta_S = \arctan(\beta / \alpha) + n\pi$$

Science Bulletin 2025;70(8):1183-1185

- And the shrouded **CPV weak phases can be exposed.**

Decay Asymmetry: Improving QCD Prediction Ability

- Combined with **branch ratios**, decay asymmetry parameters provide a **full knowledge of the non-leptonic decay** of the **charmed baryons**.
- Theories lacks ability of prediction due to **complex inner structure** and **non-perturbative nature**.
- The amplitudes can be divided into:
- **Factorizable** components:

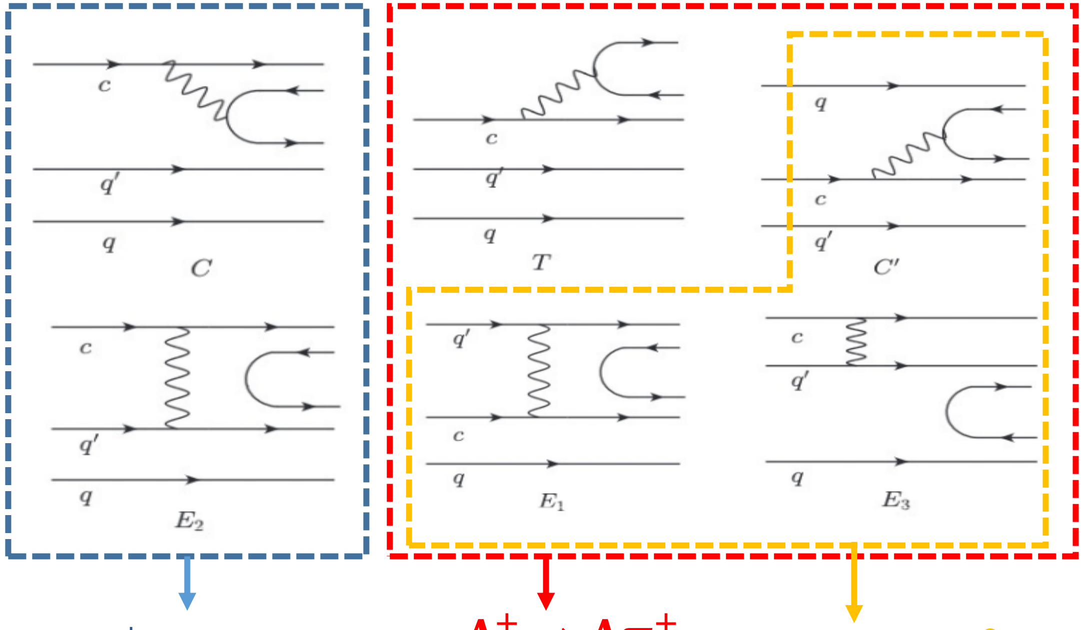
  Separable strong and weak interaction;

  Well factorized by effective field theory;
- **Non-Factorizable components**:

  Inseparable strong and weak interaction;

  Global fit based on **experimental input.**

Only C and T diagrams include factorizable components



$\Lambda_c^+ \to pK_S$

$\Lambda_c^+ \to \Lambda\pi^+$
$\Lambda_c^+ \to \Sigma^0\pi^+$

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

Accurate and comprehensive experimental measurements are crucial to improve theoretical prediction ability.

Decay Asymmetry: Polarization Transition

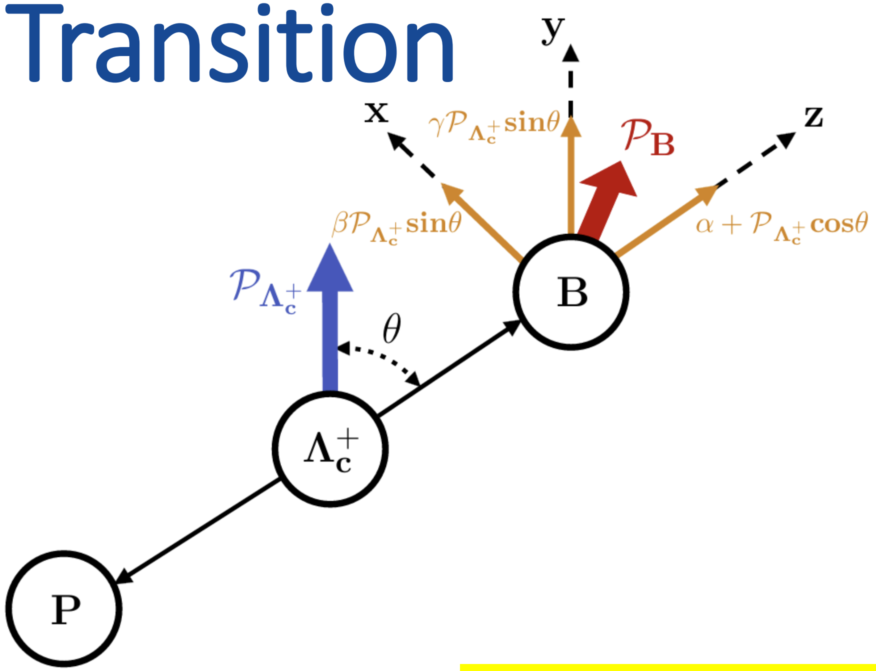
- In weak decays like $\Lambda_c^+ \to B\left(\frac{1}{2}\right)P(0)$, **decay asymmetry** can be extracted from **polarization transition** between mother and daughter baryons:

$$\boldsymbol{\mathcal{P}}_B = \frac{(\alpha + \boldsymbol{\mathcal{P}}_{\Lambda_c^+} \cdot \hat{\boldsymbol{n}})\hat{\boldsymbol{n}} + \beta(\boldsymbol{\mathcal{P}}_{\Lambda_c^+} \times \hat{\boldsymbol{n}}) + \gamma\hat{\boldsymbol{n}} \times (\boldsymbol{\mathcal{P}}_{\Lambda_c^+} \times \hat{\boldsymbol{n}})}{1 + \alpha\boldsymbol{\mathcal{P}}_B \cdot \hat{\boldsymbol{n}}}$$

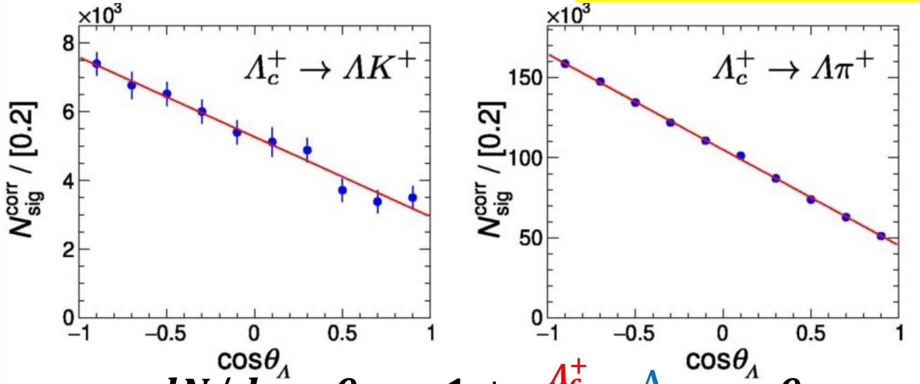
- $\mathcal{P}_{\boldsymbol{B}}$ can be inferred from **the helicity angular distribution** of B's daughters in decays like $B \to B_d(1/2)P(0)$ with known decay asymmetry.
  - If Λ_c^+ processes **polarization** $\mathcal{P}_{\Lambda_c^+}$, $\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}$ can be obtained by **polarization of the daughter** $\boldsymbol{\mathcal{P}}_{\boldsymbol{B}}$.
  - Even if **mother baryon is unpolarized**, the daughter baryon B has $\mathcal{P}_{\boldsymbol{B}} = \alpha\hat{\boldsymbol{n}}$, which lead to linear angular distribution in B's daughter baryon.

→ Only α can be measured with non-polarized Λ_c^+

❓ How to get polarized Λ_c^+ in current experiments without the help of polarized beam??



Sci. Bul. 68(6) 583-592(2023)



$$dN/d\cos\theta_p \propto 1 + \alpha_{\Lambda\pi^+}^{\Lambda_c^+}\alpha_{p\pi^-}^{\Lambda}\cos\theta_p$$

Linear distribution observed in $\Lambda_c^+ \to \Lambda h^+ (h = K, \pi)$ at Belle

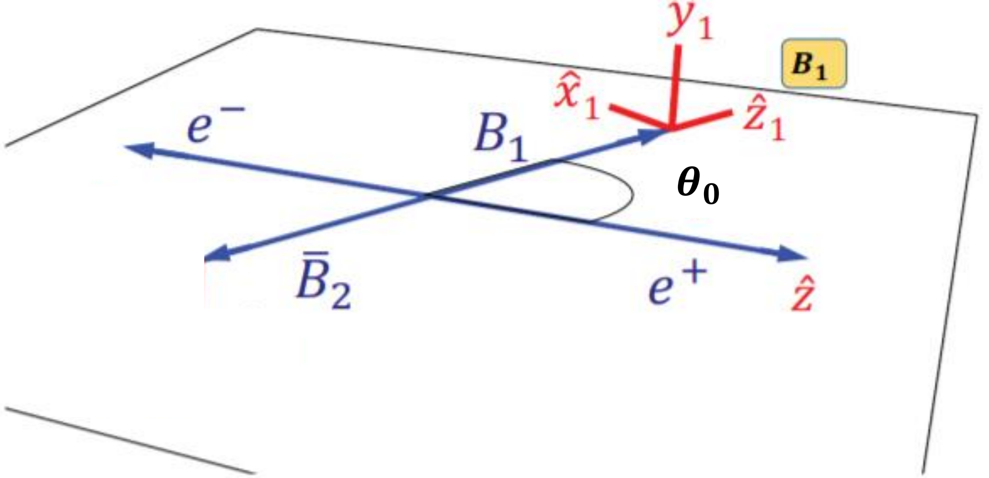
Transverse Polarization: a Spin-Correlation Effect

- ➢ In $e^+e^- \to \gamma^* \to \Lambda_c^+ \overline{\Lambda}_c^-$ with unpolarized beams, Λ_c^+ and $\overline{\Lambda}_c^-$ are polarized in the direction **perpendicular** to the reaction plane ($\hat{y}$).

$$P_y(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

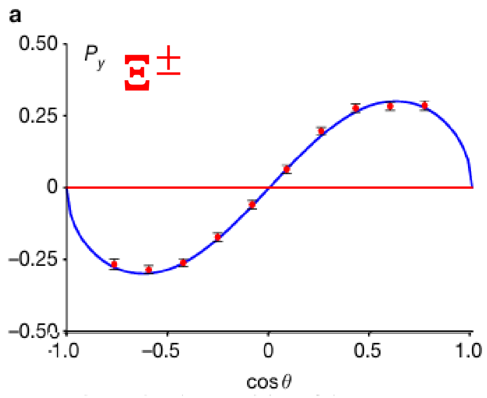
$$\alpha_0 = \{\mathrm{R}^2(1-v^2)-1\}/\{1+\mathrm{R}^2(1-v^2)\},\ \mathrm{R} = |\mathbf{G_E}/\mathbf{G_M}$$

$$\Delta\Phi = \arg(\mathbf{G_M}) - \arg(\mathbf{G_E})$$

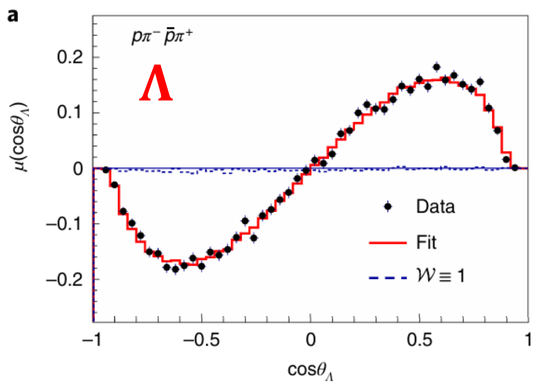


- Spin correlation between $\Lambda_c^+ \overline{\Lambda}_c^-$ from a single γ^*;
- Generated from non-zero phase **angle difference** (interference) between **EMFFs $\mathbf{G_M}$ and $\mathbf{G_E}$**, which we have even less knowledge about than **their modules**.
- Unique phenomena in pair production near threshold
- ➢ Λ_c^+ processes non-zero $\mathcal{P}_y$ depending on the **specific polar angle $\boldsymbol{\theta_0}$** but shows no $\mathcal{P}_y$ with θ_0 integrated.
- ➢ Access to **$\Delta\Phi$, Λ_c^+ decay asymmetry and corresponding CPV tests** at BESIII!

Nature 606, 64–69 (2022)



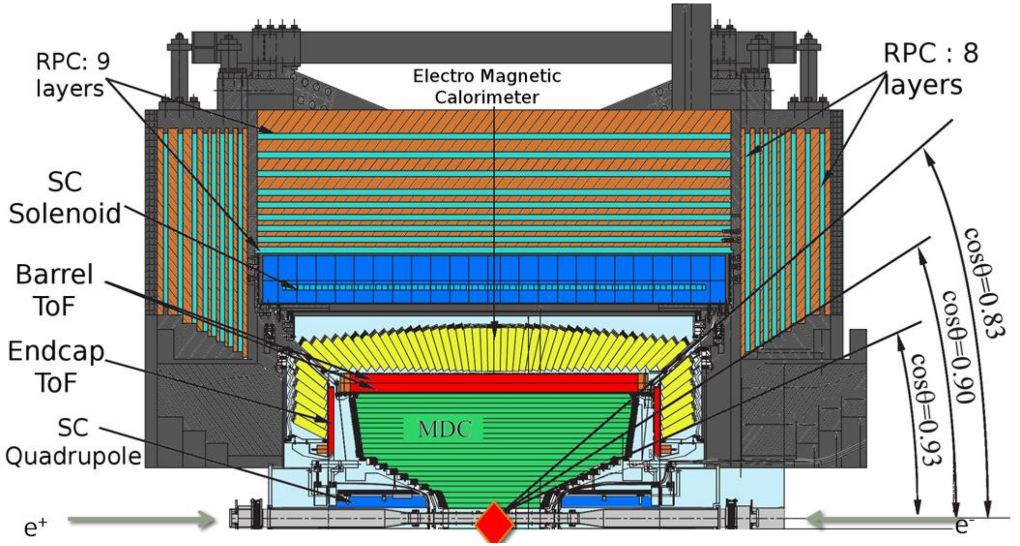
Nat. Phys15, 631–634 (2019)



Transverse polarization has been observed in hyperons!

BESIII: τ-Charm Factory on BEPCII

- ➢ Operating on **Beijing Electron-Positron Collider(BEPCII)；**
- ➢ Currently the only high-luminosity, dedicated experiment operating directly in the τ–charm region.
- ➢ Unique advantages as an ee collider experiment on charm physics thresholds:
- tunable beam energy
- clean backgrounds
- well-defined kinematic constraints
- ➢ **Upgraded recently for pair production near threshold of charmed baryons;**



Method: Conjoint Max.-Likelihood Analysis

- Conjoint Max.-Likelihood Fit with **5** decay chains and **13** energy points;

➢ Decay chains are reconstructed from Λ_c^+ to the final-level baryons, angular distribution functions of all decay chains are used to construct likelihood:

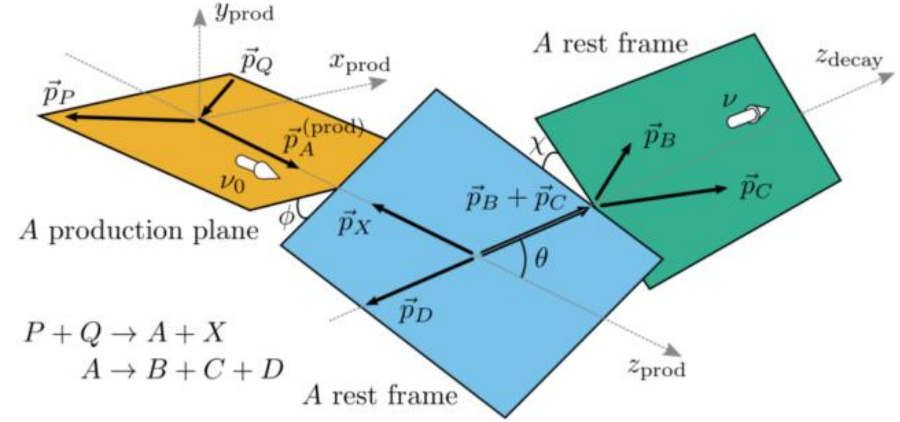
1. $\mathbf{\Lambda_c^+ \to pK_S}$: α_{pK_S} (no Δ_{pK_S} without secondary decay)
2. $\mathbf{\Lambda_c^+ \to \Lambda\pi^+,\ \ \Lambda \to p\pi^-}$: $\alpha_{\Lambda\pi^+}$、$\Delta_{\Lambda\pi^+}$;
3. $\mathbf{\Lambda_c^+ \to \Sigma^+\pi^0, \Sigma^+ \to p\pi^0}$: $\alpha_{\Sigma^+\pi^0}$、$\Delta_{\Sigma^+\pi^0}$;
4. $\mathbf{\Lambda_c^+ \to \Sigma^0\pi^+,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to p\pi^-}$: $\alpha_{\Sigma^0\pi^+}$、$\Delta_{\Sigma^0\pi^+}$,
5. $\mathbf{\Lambda_c^+ \to pK^-\pi^+}$: **3-body golden channel** for $\mathcal{P}_y$ determination.

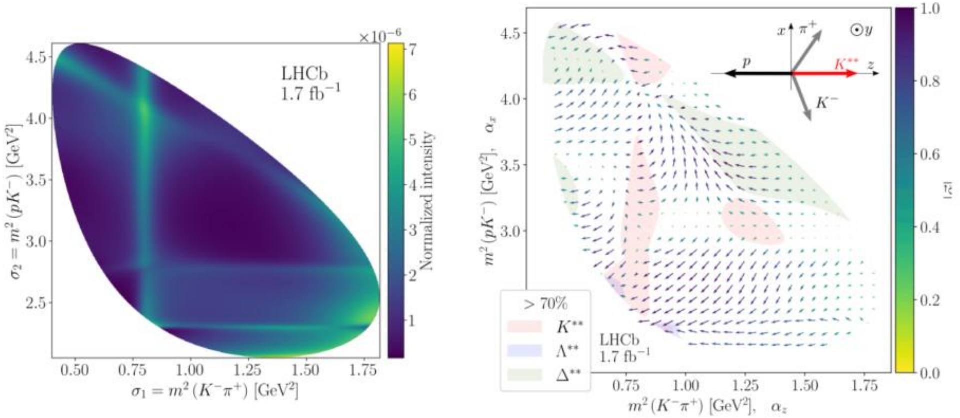
➢ 13 α_0s and 13 $\Delta\Phi$s, for 13 energy points;

➢ 13 + 13 + 7 = 33 parameters for CP conservation;

13+ 13 + 7*2 = 40 parameters for CP violation;

- 13 energy points from 4.60 to 4.95 GeV, with a data set of Lint = 6.4 fb^{-1}



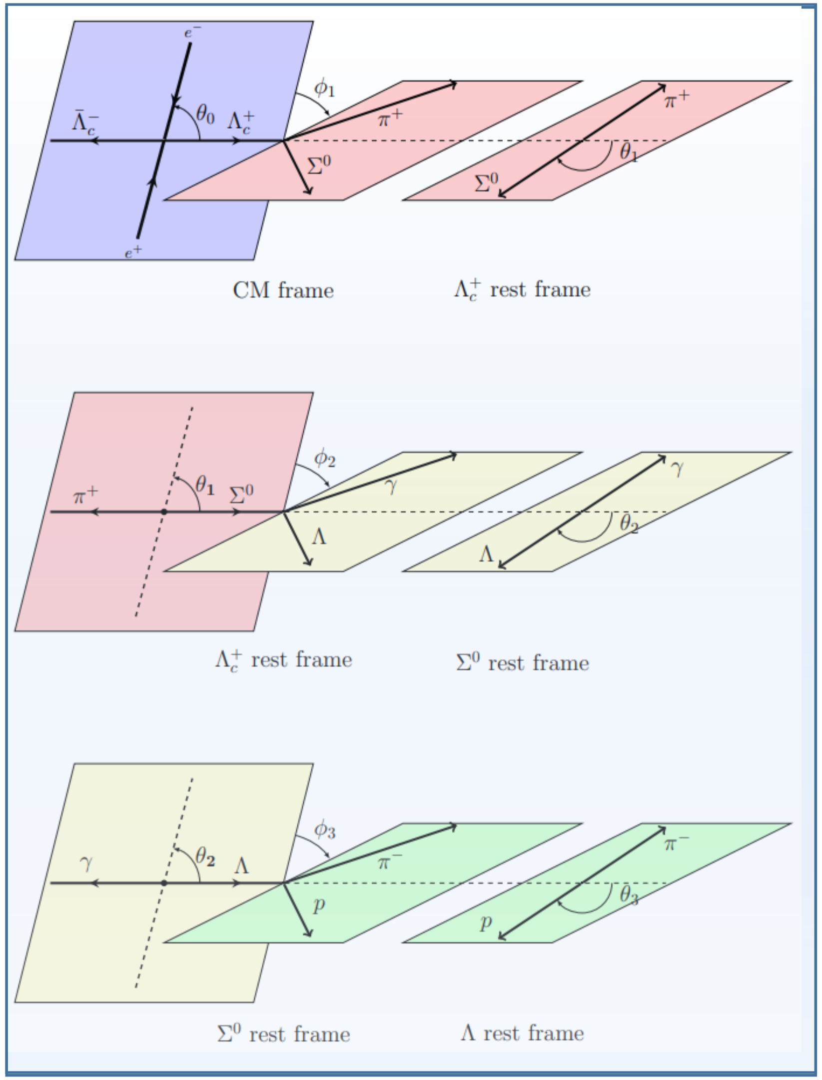


3-body $\Lambda_c^+ \to pK^-\pi^+$'s angular distribution is constructed according to partial wave analysis results from LHCb

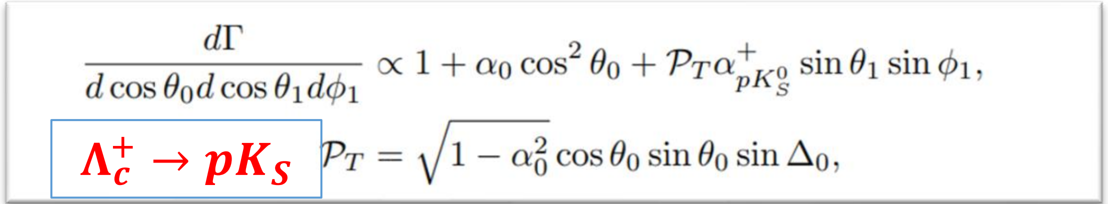
JHEP, 2023(7): 228(2023)

Method: Angular Distribution of Complete Chains

Machine deduction with the language of helicity amplitudes and helicity coordinate system.



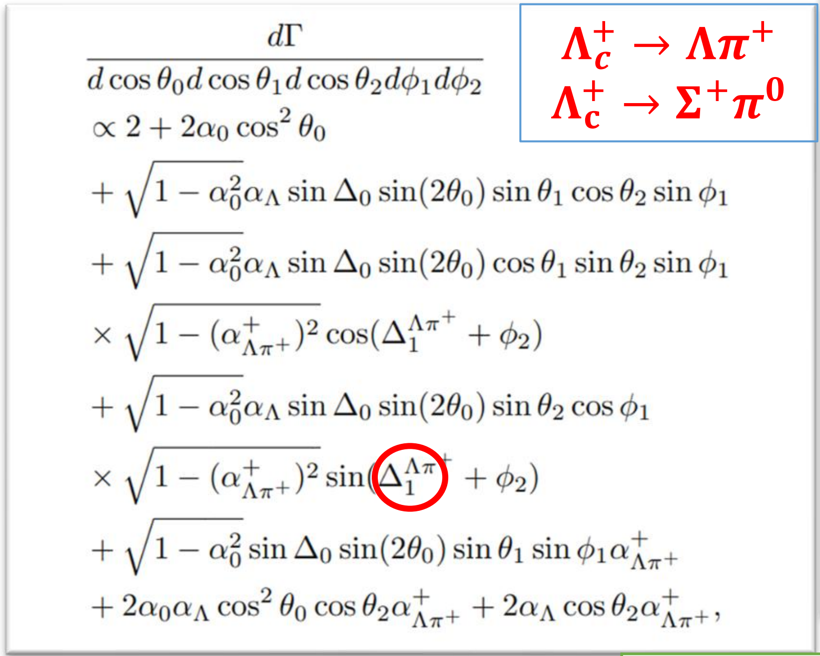
← **helicity angles**



$$\frac{d\Gamma}{d\cos\theta_0 d\cos\theta_1 d\phi_1} \propto 1 + \alpha_0 \cos^2\theta_0 + \mathcal{P}_T \alpha^+_{pK^0_S} \sin\theta_1 \sin\phi_1,$$

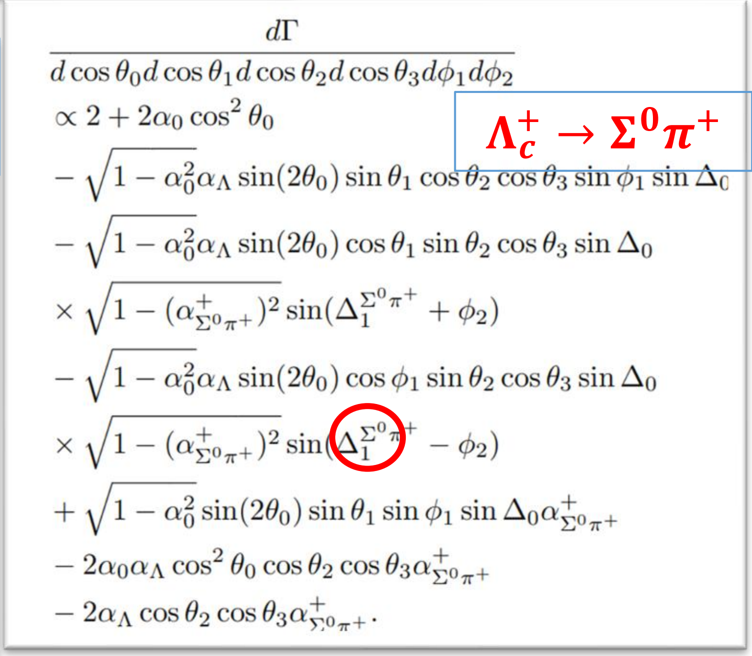
$$\mathcal{P}_T = \sqrt{1-\alpha_0^2}\cos\theta_0 \sin\theta_0 \sin\Delta_0,$$

$\Lambda_c^+ \to pK_S$



$$\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0 d\cos\theta_1 d\cos\theta_2 d\phi_1 d\phi_2} \\
&\propto 2 + 2\alpha_0\cos^2\theta_0 \\
&+ \sqrt{1-\alpha_0^2}\alpha_\Lambda \sin\Delta_0 \sin(2\theta_0)\sin\theta_1\cos\theta_2\sin\phi_1 \\
&+ \sqrt{1-\alpha_0^2}\alpha_\Lambda \sin\Delta_0 \sin(2\theta_0)\cos\theta_1\sin\theta_2\sin\phi_1 \\
&\times \sqrt{1-(\alpha^+_{\Lambda\pi^+})^2}\cos(\Delta_1^{\Lambda\pi^+} + \phi_2) \\
&+ \sqrt{1-\alpha_0^2}\alpha_\Lambda \sin\Delta_0 \sin(2\theta_0)\sin\theta_2\cos\phi_1 \\
&\times \sqrt{1-(\alpha^+_{\Lambda\pi^+})^2}\sin(\Delta_1^{\Lambda\pi^+} + \phi_2) \\
&+ \sqrt{1-\alpha_0^2}\sin\Delta_0\sin(2\theta_0)\sin\theta_1\sin\phi_1\alpha^+_{\Lambda\pi^+} \\
&+ 2\alpha_0\alpha_\Lambda\cos^2\theta_0\cos\theta_2\alpha^+_{\Lambda\pi^+} + 2\alpha_\Lambda\cos\theta_2\alpha^+_{\Lambda\pi^+},
\end{aligned}$$

$\Lambda_c^+ \to \Lambda\pi^+$
$\Lambda_c^+ \to \Sigma^+\pi^0$



$$\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0 d\cos\theta_1 d\cos\theta_2 d\cos\theta_3 d\phi_1 d\phi_2} \\
&\propto 2 + 2\alpha_0\cos^2\theta_0 \\
&- \sqrt{1-\alpha_0^2}\alpha_\Lambda\sin(2\theta_0)\sin\theta_1\cos\theta_2\cos\theta_3\sin\phi_1\sin\Delta_0 \\
&- \sqrt{1-\alpha_0^2}\alpha_\Lambda\sin(2\theta_0)\cos\theta_1\sin\theta_2\cos\theta_3\sin\Delta_0 \\
&\times \sqrt{1-(\alpha^+_{\Sigma^0\pi^+})^2}\sin(\Delta_1^{\Sigma^0\pi^+} + \phi_2) \\
&- \sqrt{1-\alpha_0^2}\alpha_\Lambda\sin(2\theta_0)\cos\phi_1\sin\theta_2\cos\theta_3\sin\Delta_0 \\
&\times \sqrt{1-(\alpha^+_{\Sigma^0\pi^+})^2}\sin(\Delta_1^{\Sigma^0\pi^+} - \phi_2) \\
&+ \sqrt{1-\alpha_0^2}\sin(2\theta_0)\sin\theta_1\sin\phi_1\sin\Delta_0\alpha^+_{\Sigma^0\pi^+} \\
&- 2\alpha_0\alpha_\Lambda\cos^2\theta_0\cos\theta_2\cos\theta_3\alpha^+_{\Sigma^0\pi^+} \\
&- 2\alpha_\Lambda\cos\theta_2\cos\theta_3\alpha^+_{\Sigma^0\pi^+}.
\end{aligned}$$

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

↑ **angular distribution**

Method: Background Subtraction

The massive likelihood fit requires backgrounds to be properly dealt with, especially the peak backgrounds and events wrongly reconstructed.

➢ **Peak Backgrounds:**

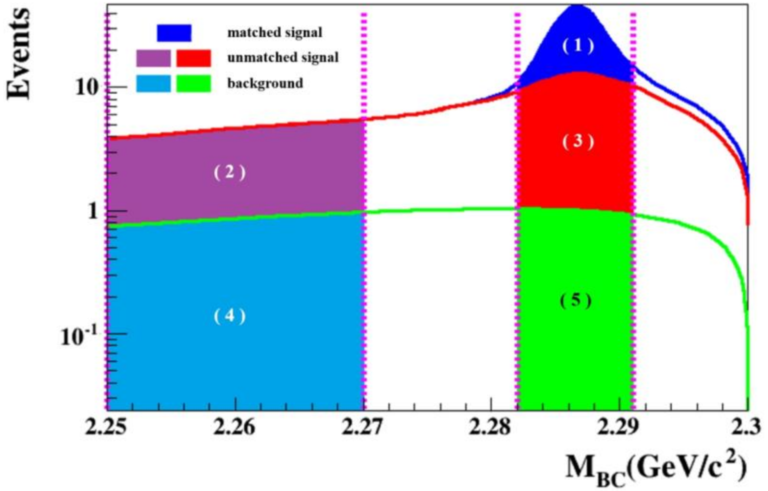
- Contributed by non-signal channels;
- Studied with cocktail MC;
- Sufficiently suppressed by optimized cuts such as PID, μ chamber/EMC information, $\Delta E = E - E_{beam}$ and invariant mass.

➢ **Wrongly Reconstructed Events:**

- Signal channel events with a random γ;
- Similar in spectrums but has different angular distribution: hard to suppress;
- Modeled by corresponding components from signal MC after truth-matching.

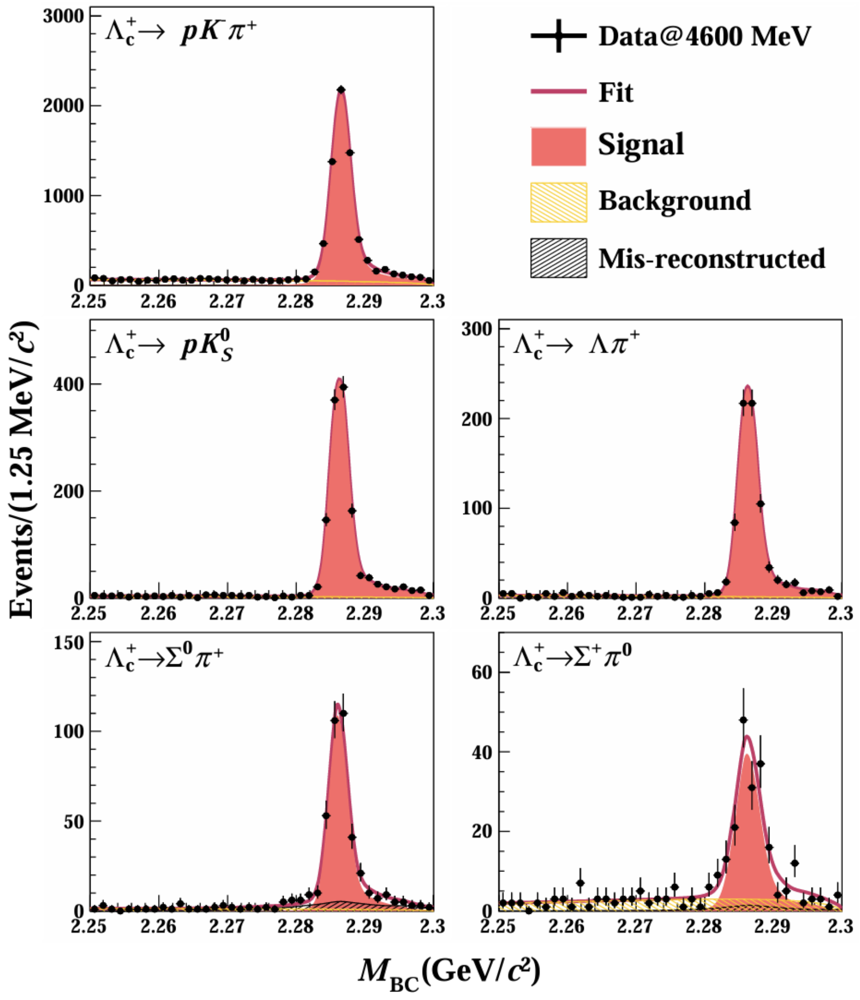
Backgrounds are subtracted from likelihood according to:

$$\overset{(1)}{-\ln \mathcal{L}_{(1)}} = K \times \left\{ \overset{(1)+(3)+(5)}{\left(-\ln \mathcal{L}^{\text{sig}}_{\text{data}}\right)} - \overset{(3)/(3_{MC})}{scale_1} \times \overset{(3_{MC})}{\left(-\ln \mathcal{L}^{\text{sig}}_{\text{WRMC}}\right)} \right.$$
$$\left. - \underset{(5)/(4)}{scale_2} \times \left[\underset{(2)+(4)}{\left(-\ln \mathcal{L}^{\text{sid}}_{\text{data}}\right)} - \underset{(2)/(2_{MC})}{scale_3} \times \underset{(2_{MC})}{\left(-\ln \mathcal{L}^{\text{sid}}_{\text{WRMC}}\right)} \right] \right\}$$

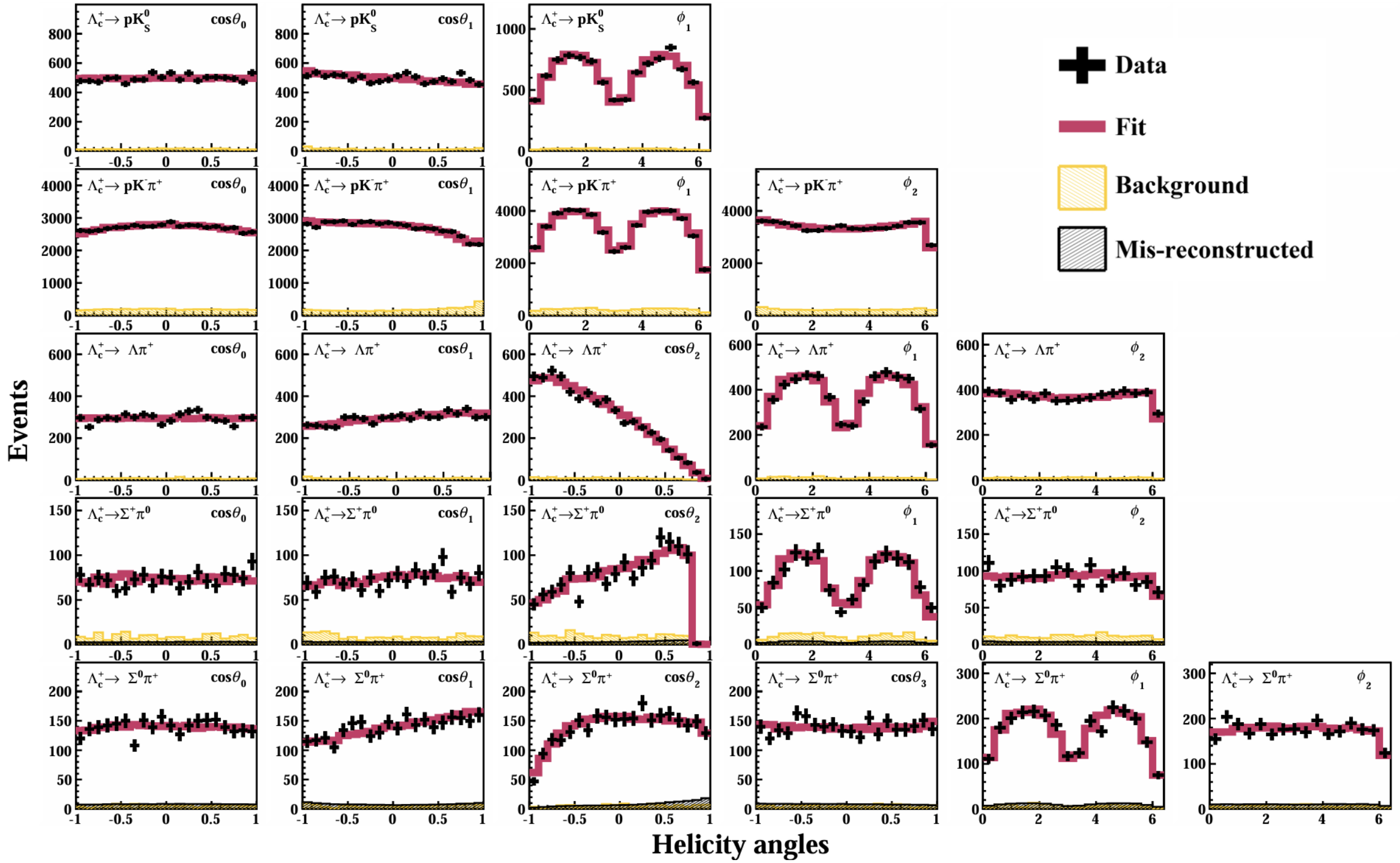


Method

- The numbers of the components are obtained by fitting the M_{BC} spectrums

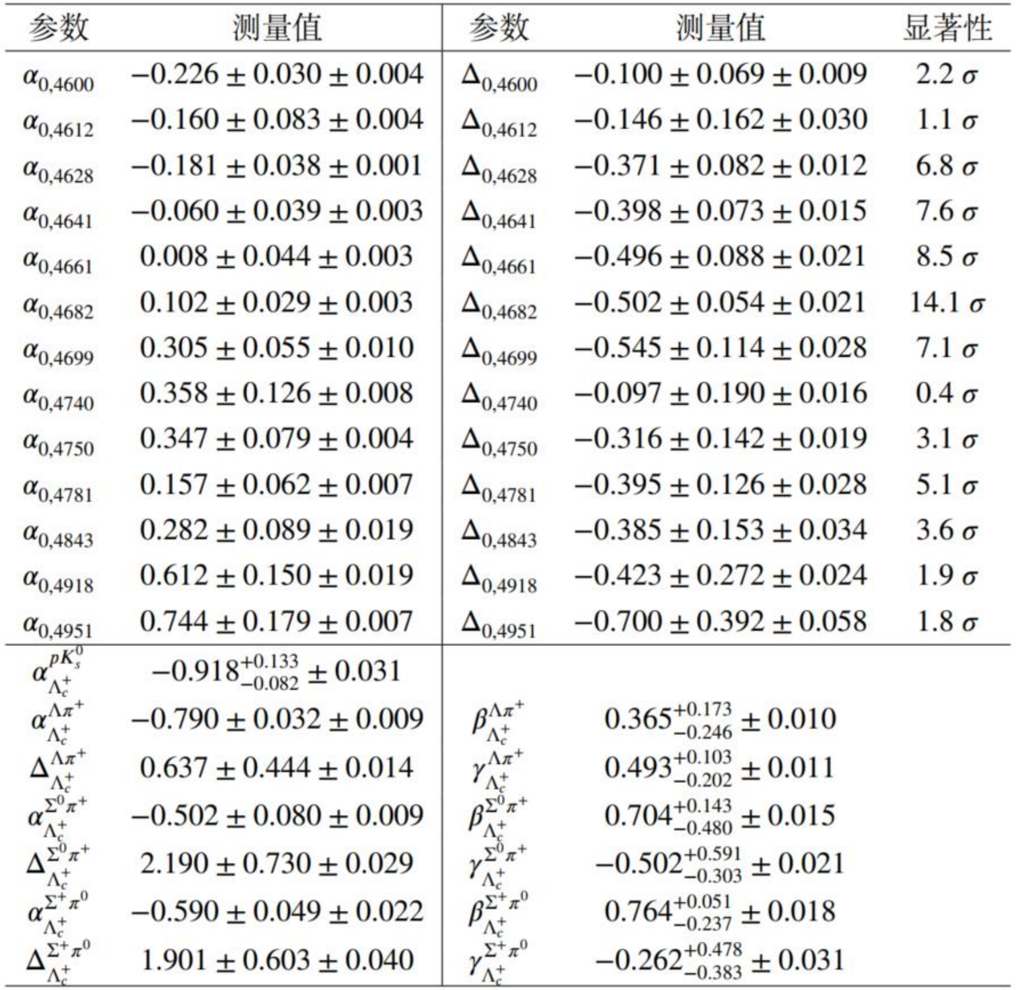


- Signal MC is obtained by reweighting PHSP MC according to the fit results:

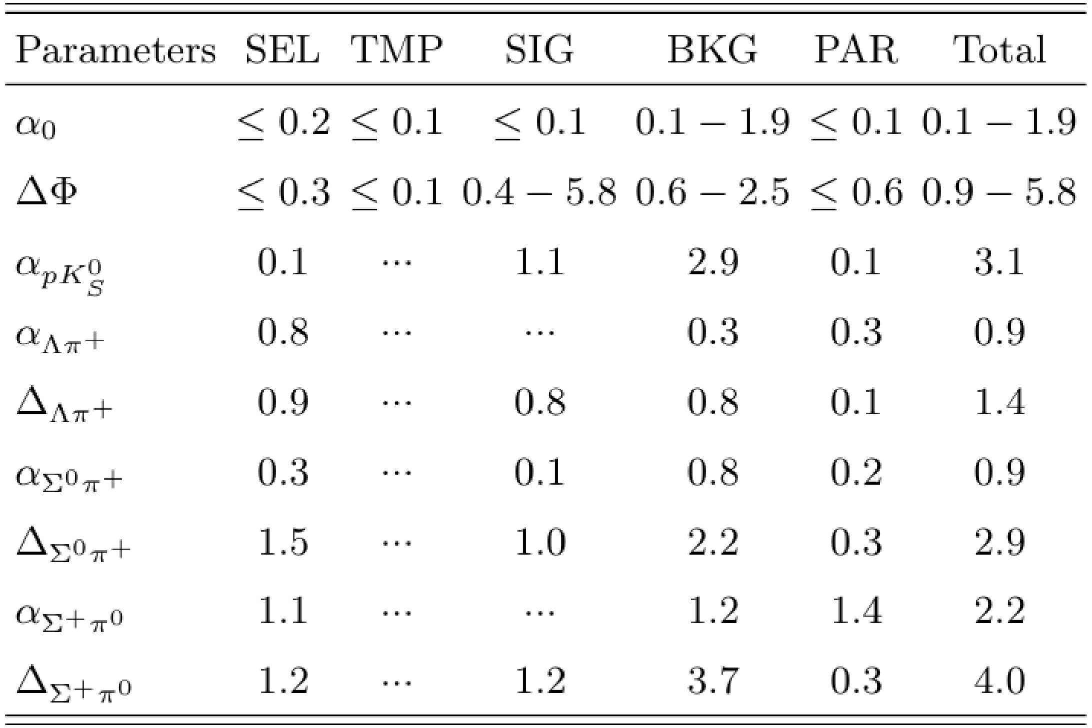


- **The fit results** are consistent with **data** in all the helicity angle distribution.

Systematic Uncertainty



参数	测量值	参数	测量值	显著性
$\alpha_{0,4600}$	$-0.226 \pm 0.030 \pm 0.004$	$\Delta_{0,4600}$	$-0.100 \pm 0.069 \pm 0.009$	$2.2\ \sigma$
$\alpha_{0,4612}$	$-0.160 \pm 0.083 \pm 0.004$	$\Delta_{0,4612}$	$-0.146 \pm 0.162 \pm 0.030$	$1.1\ \sigma$
$\alpha_{0,4628}$	$-0.181 \pm 0.038 \pm 0.001$	$\Delta_{0,4628}$	$-0.371 \pm 0.082 \pm 0.012$	$6.8\ \sigma$
$\alpha_{0,4641}$	$-0.060 \pm 0.039 \pm 0.003$	$\Delta_{0,4641}$	$-0.398 \pm 0.073 \pm 0.015$	$7.6\ \sigma$
$\alpha_{0,4661}$	$0.008 \pm 0.044 \pm 0.003$	$\Delta_{0,4661}$	$-0.496 \pm 0.088 \pm 0.021$	$8.5\ \sigma$
$\alpha_{0,4682}$	$0.102 \pm 0.029 \pm 0.003$	$\Delta_{0,4682}$	$-0.502 \pm 0.054 \pm 0.021$	$14.1\ \sigma$
$\alpha_{0,4699}$	$0.305 \pm 0.055 \pm 0.010$	$\Delta_{0,4699}$	$-0.545 \pm 0.114 \pm 0.028$	$7.1\ \sigma$
$\alpha_{0,4740}$	$0.358 \pm 0.126 \pm 0.008$	$\Delta_{0,4740}$	$-0.097 \pm 0.190 \pm 0.016$	$0.4\ \sigma$
$\alpha_{0,4750}$	$0.347 \pm 0.079 \pm 0.004$	$\Delta_{0,4750}$	$-0.316 \pm 0.142 \pm 0.019$	$3.1\ \sigma$
$\alpha_{0,4781}$	$0.157 \pm 0.062 \pm 0.007$	$\Delta_{0,4781}$	$-0.395 \pm 0.126 \pm 0.028$	$5.1\ \sigma$
$\alpha_{0,4843}$	$0.282 \pm 0.089 \pm 0.019$	$\Delta_{0,4843}$	$-0.385 \pm 0.153 \pm 0.034$	$3.6\ \sigma$
$\alpha_{0,4918}$	$0.612 \pm 0.150 \pm 0.019$	$\Delta_{0,4918}$	$-0.423 \pm 0.272 \pm 0.024$	$1.9\ \sigma$
$\alpha_{0,4951}$	$0.744 \pm 0.179 \pm 0.007$	$\Delta_{0,4951}$	$-0.700 \pm 0.392 \pm 0.058$	$1.8\ \sigma$
$\alpha_{\Lambda_c^+}^{pK_s^0}$	$-0.918^{+0.133}_{-0.082} \pm 0.031$			
$\alpha_{\Lambda_c^+}^{\Lambda\pi^+}$	$-0.790 \pm 0.032 \pm 0.009$	$\beta_{\Lambda_c^+}^{\Lambda\pi^+}$	$0.365^{+0.173}_{-0.246} \pm 0.010$	
$\Delta_{\Lambda_c^+}^{\Lambda\pi^+}$	$0.637 \pm 0.444 \pm 0.014$	$\gamma_{\Lambda_c^+}^{\Lambda\pi^+}$	$0.493^{+0.103}_{-0.202} \pm 0.011$	
$\alpha_{\Lambda_c^+}^{\Sigma^0\pi^+}$	$-0.502 \pm 0.080 \pm 0.009$	$\beta_{\Lambda_c^+}^{\Sigma^0\pi^+}$	$0.704^{+0.143}_{-0.480} \pm 0.015$	
$\Delta_{\Lambda_c^+}^{\Sigma^0\pi^+}$	$2.190 \pm 0.730 \pm 0.029$	$\gamma_{\Lambda_c^+}^{\Sigma^0\pi^+}$	$-0.502^{+0.591}_{-0.303} \pm 0.021$	
$\alpha_{\Lambda_c^+}^{\Sigma^+\pi^0}$	$-0.590 \pm 0.049 \pm 0.022$	$\beta_{\Lambda_c^+}^{\Sigma^+\pi^0}$	$0.764^{+0.051}_{-0.237} \pm 0.018$	
$\Delta_{\Lambda_c^+}^{\Sigma^+\pi^0}$	$1.901 \pm 0.603 \pm 0.040$	$\gamma_{\Lambda_c^+}^{\Sigma^+\pi^0}$	$-0.262^{+0.478}_{-0.383} \pm 0.031$	



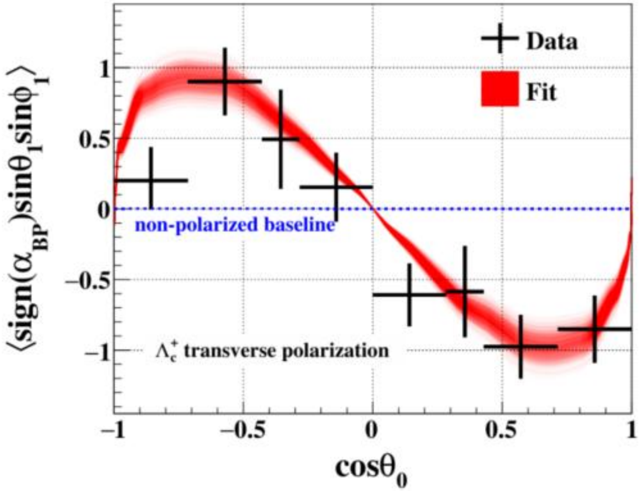
Parameters	SEL	TMP	SIG	BKG	PAR	Total
α_0	≤ 0.2	≤ 0.1	≤ 0.1	$0.1-1.9$	≤ 0.1	$0.1-1.9$
$\Delta\Phi$	≤ 0.3	≤ 0.1	$0.4-5.8$	$0.6-2.5$	≤ 0.6	$0.9-5.8$
$\alpha_{pK_S^0}$	0.1	$\cdots$	1.1	2.9	0.1	3.1
$\alpha_{\Lambda\pi^+}$	0.8	$\cdots$	$\cdots$	0.3	0.3	0.9
$\Delta_{\Lambda\pi^+}$	0.9	$\cdots$	0.8	0.8	0.1	1.4
$\alpha_{\Sigma^0\pi^+}$	0.3	$\cdots$	0.1	0.8	0.2	0.9
$\Delta_{\Sigma^0\pi^+}$	1.5	$\cdots$	1.0	2.2	0.3	2.9
$\alpha_{\Sigma^+\pi^0}$	1.1	$\cdots$	$\cdots$	1.2	1.4	2.2
$\Delta_{\Sigma^+\pi^0}$	1.2	$\cdots$	1.2	3.7	0.3	4.0

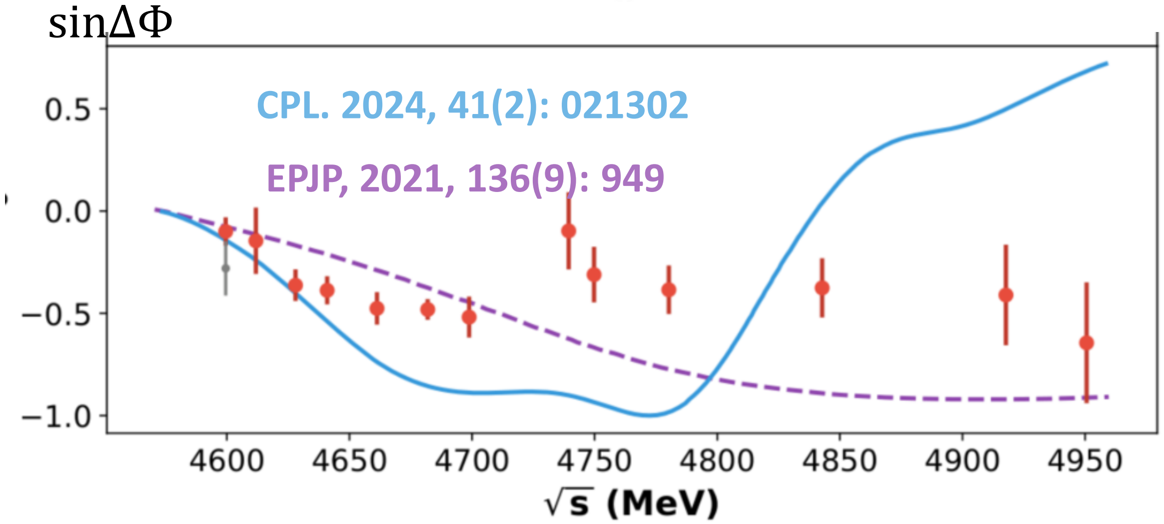
- Modeling of $\mathbf{\Lambda_c^+ \to pK^-\pi^+}$ is the dominant source of systematic uncertainty, but the golden channel lowers the statistic uncertainty significantly, especially for the **transverse polarization parameter $\boldsymbol{\Delta\Phi}$**;
- Statistic Uncertainty is **~10x** systematic uncertainty;

About 3x precision of BESIII previous work(2019)

Results: Transverse Polarization

- Transverse Polarization measured at 13 energy points from 4.60 to 4.95 GeV;
    - First measurement except 4.60 GeV!
- Significance of $\Delta\Phi$ exceeds 5σ at 11 energy points, with a maximum of $14.1\ \sigma$ (4.68 GeV)
    - First confirmation in charm baryon!
- Large $\mathcal{P}_y$ around 4.64 to 4.68 GeV
    - Optimized region for $\boldsymbol{\Lambda_c^+}$ decay asymmetry;
- Combined with $\boldsymbol{\Lambda_c^+}$ EMFF modules, a complete measurement of $\boldsymbol{\Lambda_c^+}$ EMFF is achieved:
    - **New and comprehensive** experimental constraint for theories about structure and behavior of charmed baryons.

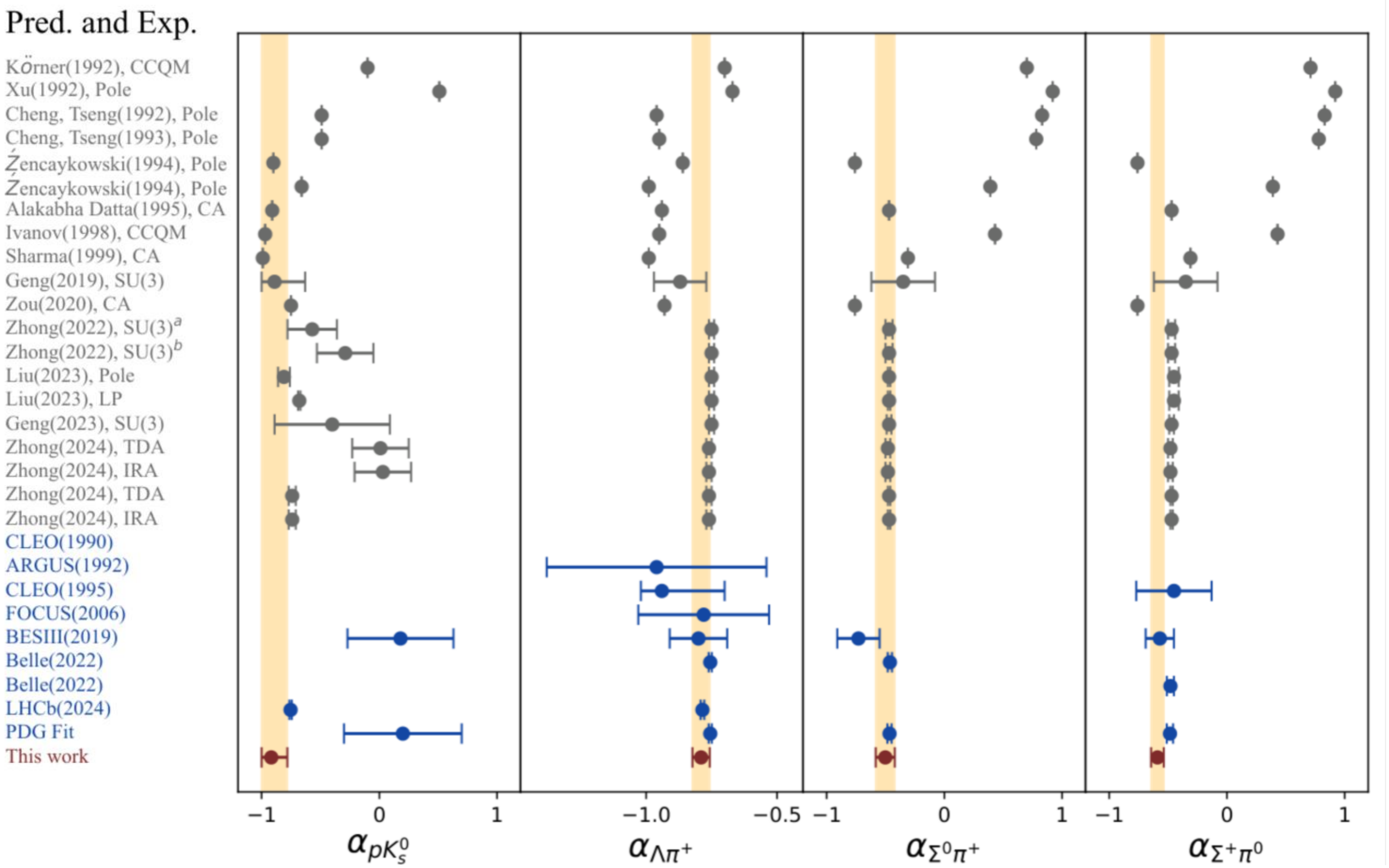




$\sin\Delta\Phi$ line shape shows complicated behavior, inconsistent with theory predictions based on results of **EMFF modules**.

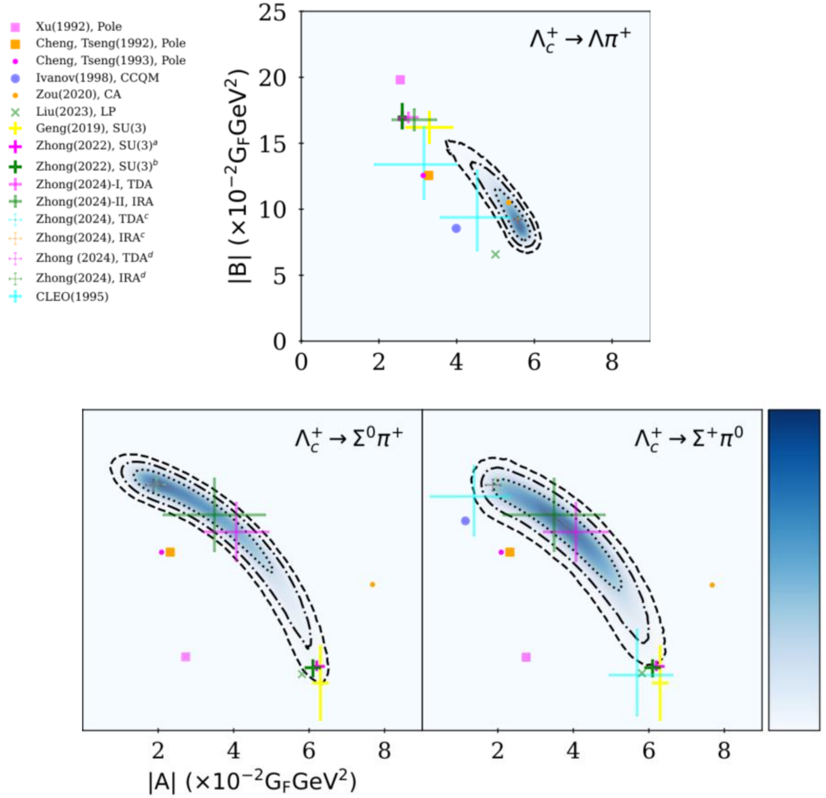
Results: Decay Asymmetry Parameters

- ➢ $\alpha_{pK_S^0} \sim -1$, consistent with LHCb results. Previous BESIII result with 4.60 GeV data(2019) gives positive $\alpha_{pK_S^0}$ with large uncertainty.
  - The discrepancy comes from small $\mathcal{P}_y$ at 4.60 GeV and BOSS software version.
- ➢ $\alpha_{\boldsymbol{\Sigma}^+\boldsymbol{\pi}^0}$ and $\alpha_{\boldsymbol{\Sigma}^0\boldsymbol{\pi}^+}$ are consistent within uncertainty as predicted by SU(3) flavor symmetry



Results: Decay Asymmetry Parameters and CPV Phases

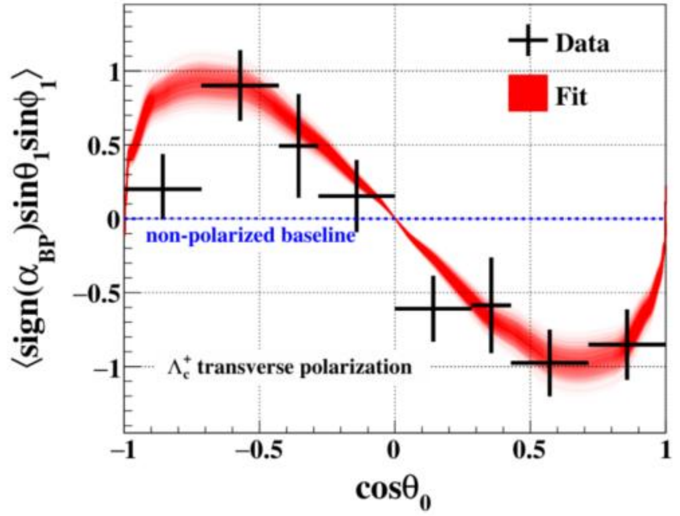
- Limited by statistics, the precision of the decay asymmetry measurement at BESIII is far inferior to the results of Belle and LHCb.
- But **clean background** and **well-defined kinematic constraints** at BESIII enable:
- Comprehensive measurement of decay asymmetry with more challenging decay chains;
- This work determine the parameters β and γ of $\boldsymbol{\Lambda_c^+ \to \Sigma^0\pi^+}$ and $\boldsymbol{\Sigma^+\pi^0}$ with unprecedented precision and provide results of $\boldsymbol{\Lambda_c^+} \to \Lambda\pi^+$ consistent with LHCb.
- A **comprehensive knowledge of** $\boldsymbol{\alpha, \beta}$ **and** $\boldsymbol{\gamma}$, i.e. s and p amplitudes, enables experimental test on theories and extract of **strong phases** and **CPV weak phases**.
- **First CPV test with** $\boldsymbol{\Lambda_c^+ \to \Sigma^0\pi^+}$**and** $\boldsymbol{\Sigma^+\pi^0}$**, no significant CPV is observed as SM predicted**
- But unlike hyperon, relatively **large strong phases** light hope in **CPV search with charmed baryons**.

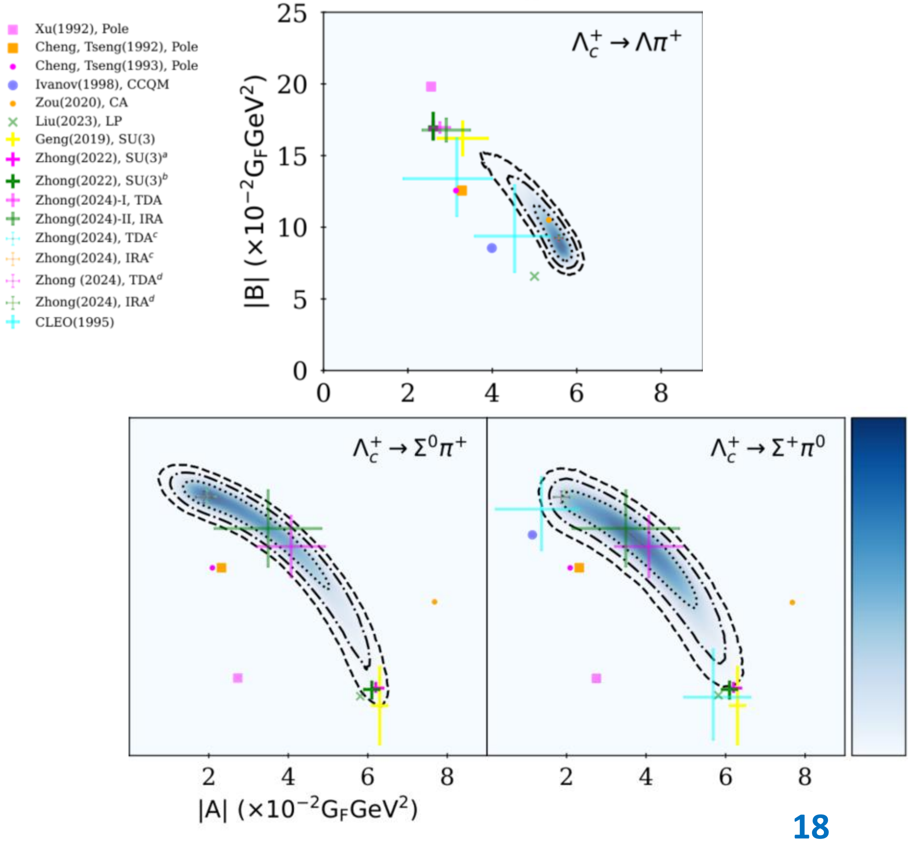


Parameter	$\Lambda_c^+ \to pK_S^0$	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\Lambda_c^+ \to \Sigma^+\pi^0$
$\langle\alpha_{BP}\rangle$	$-0.918^{+0.133}_{-0.082} \pm 0.031$	$-0.790 \pm 0.032 \pm 0.009$	$-0.502 \pm 0.080 \pm 0.009$	$-0.590 \pm 0.049 \pm 0.022$
$\langle\Delta_{BP}\rangle$	$\cdots$	$0.637 \pm 0.444 \pm 0.014$	$2.190 \pm 0.730 \pm 0.029$	$1.901 \pm 0.603 \pm 0.040$
$\langle\beta_{BP}\rangle$	$\cdots$	$0.365^{+0.173}_{-0.246} \pm 0.010$	$0.704^{+0.143}_{-0.480} \pm 0.015$	$0.764^{+0.051}_{-0.237} \pm 0.018$
$\langle\gamma_{BP}\rangle$	$\cdots$	$0.637^{+0.103}_{-0.202} \pm 0.011$	$-0.502^{+0.591}_{-0.303} \pm 0.021$	$-0.262^{+0.478}_{-0.383} \pm 0.031$
$\delta_p - \delta_s$	$\cdots$	$2.71^{+0.28}_{-0.17} \pm 0.02$	$2.19^{+0.49}_{-0.13} \pm 0.02$	$2.23^{+0.19}_{-0.06} \pm 0.03$
$A_{CP}^{\alpha_{BP}}$	$0.079^{+0.115}_{-0.101} \pm 0.019$	$0.002 \pm 0.047 \pm 0.017$	$0.206^{+0.188}_{-0.156} \pm 0.028$	$-0.086 \pm 0.081 \pm 0.085$
$\tan\phi_{CP}$	$\cdots$	$0.232 \pm 0.242 \pm 0.025$	$0.393 \pm 0.651 \pm 0.042$	$-0.007 \pm 0.474 \pm 0.034$
$\tan\Delta_s$	$\cdots$	$-0.475 \pm 0.242 \pm 0.029$	$-1.411 \pm 0.672 \pm 0.062$	$-1.297 \pm 0.478 \pm 0.068$

Summary:

- Simultaneous determination across 13 Ecms between 4.60 and 4.95 GeV of transverse polarization and the decay-asymmetry for four two-body weak decay modes.
- First observation of transverse polarization in charmed baryons.
- CPV tests in the lightest charmed baryons;
- Comprehensive information essential for understanding the production and weak decay of the lightest charmed baryon.
- The results enhances the understanding of CP violation and flavor physics in the charm sector.





Thanks!