The Status of *P* and *CP* violation Parameters for Charmed Baryon on BESIII and the Prospects on STCF

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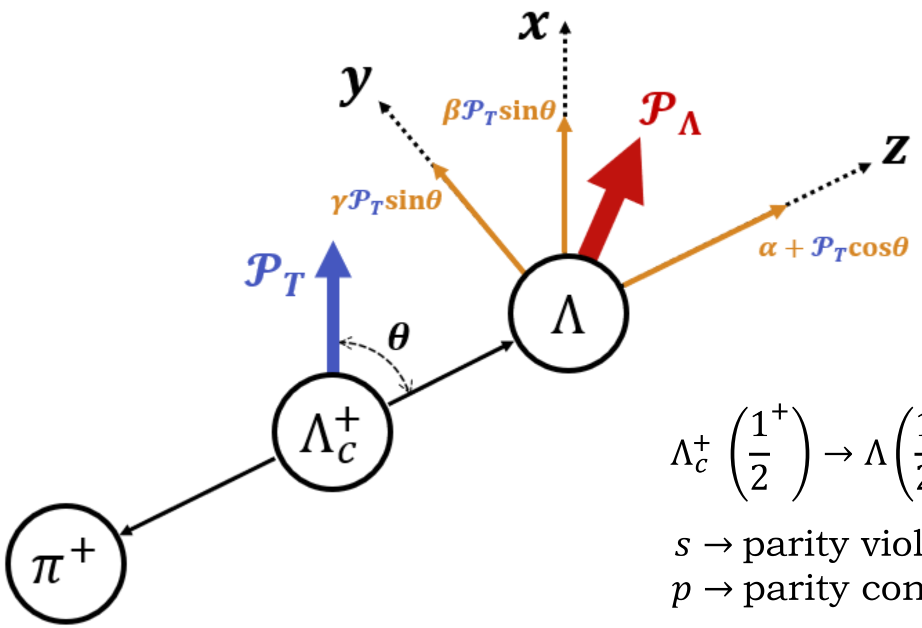
P violation in charmed baryon



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

$s\to$ 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: $\boldsymbol{\alpha,\ \beta\neq 0,\ \gamma\neq -1}$

- **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**

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

CP violation in charmed baryon

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

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

$p \xrightarrow{\text{CP}} p$

⟹

$\alpha \xrightarrow{\text{CP}} \bar{\alpha} = -\alpha$

$\beta \xrightarrow{\text{CP}} \bar{\beta} = -\beta$

$\gamma \xrightarrow{\text{CP}} \bar{\gamma} = +\gamma$

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

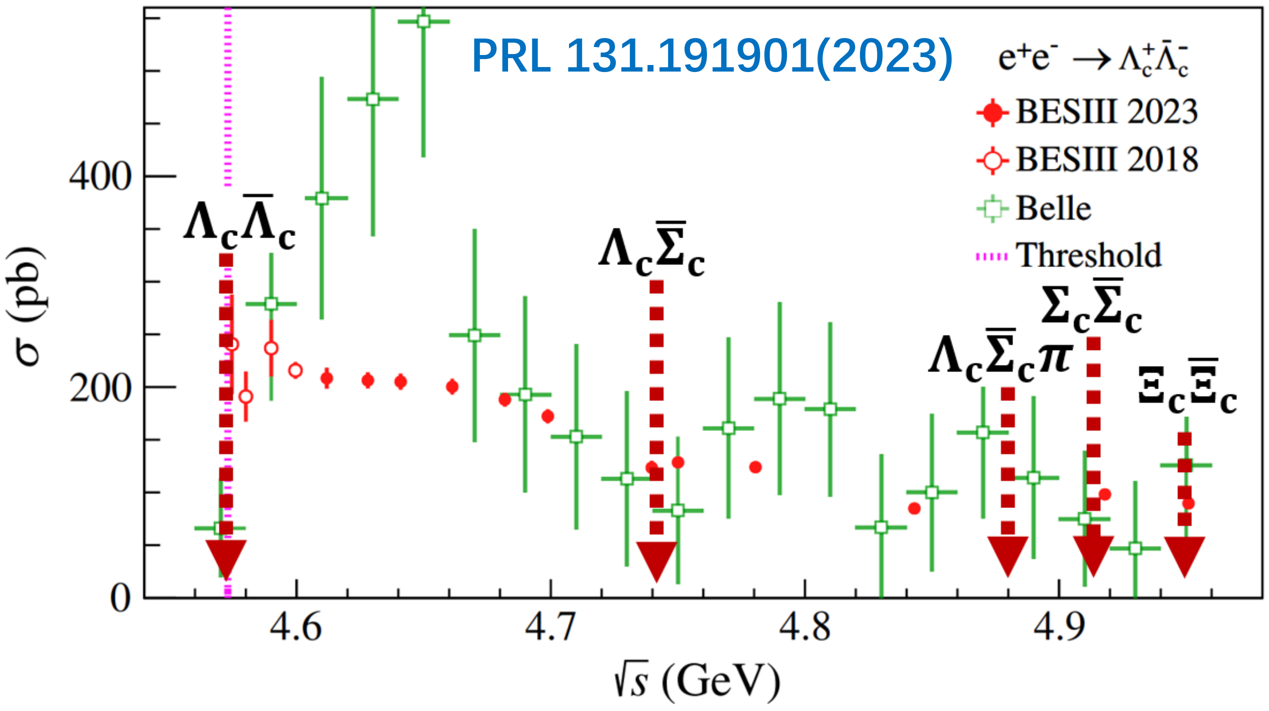
$$\tan\phi_{CP} = \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}} = \frac{\sqrt{1-\alpha^2}\sin\Delta + \sqrt{1-\bar{\alpha}^2}\sin\bar{\Delta}}{\alpha - \bar{\alpha}}$$

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

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

Datasets on BESIII experiment

➢ *Close to the production threshold, a relatively clean background environment.*



Sample	E_{cms}/MeV	$\mathscr{L}_{Bhabha}$/pb^{-1}
4610	4611.86±0.12±0.30	103.65±0.05±0.55
4620	4628.00±0.06±0.32	521.53±0.11±2.76
4640	4640.91±0.06±0.38	551.65±0.12±2.92
4660	4661.24±0.06±0.29	529.43±0.12±2.81
4680	4681.92±0.08±0.29	1667.39±0.21±8.84
4700	4698.82±0.10±0.36	535.54±0.12±2.84
4740	4739.70±0.20±0.30	163.87±0.07±0.87
4750	4750.05±0.12±0.29	366.55±0.10±1.94
4780	4780.54±0.12±0.30	511.47±0.12±2.71
4840	4843.07±0.20±0.31	525.16±0.12±2.78
4920	4918.02±0.34±0.34	207.82±0.08±1.10
4950	4950.93±0.36±0.38	159.28±0.07±0.84

CPC 46.113003(2022)

Available data for charmed baryons

✓ 0.587 fb^{-1} at 4.6 GeV (35 days in 2014)

✓ 3.9 fb^{-1} scan at 4.61, 4.63, 4.64, 4.66, 4.68, 4.70 GeV (186 days in 2020)

✓ 1.93 fb^{-1} scan at 4.74, 4.75, 4.78, 4.84, 4.92, 4.95 GeV (99 days in 2021)

Total:
6.4 fb^{-1}

Current results on BESIII

➢ There were no α-induced CPV measurement results for charmed baryon in the BESIII experiment.

I. Angular analysis
Two-body decay

II. Partial wave analysis
Multi-body decay

$\Lambda_c^+ \to pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+, \Sigma^+\pi^0$ — **PRD 100.072004 (2019)**

$\Lambda_c^+ \to \Lambda\pi^+\pi^0$ — **JHEP 12.033 (2022)**

$\Lambda_c^+ \to \Xi^0 K^+$ — **PRL 132.031801 (2024)**

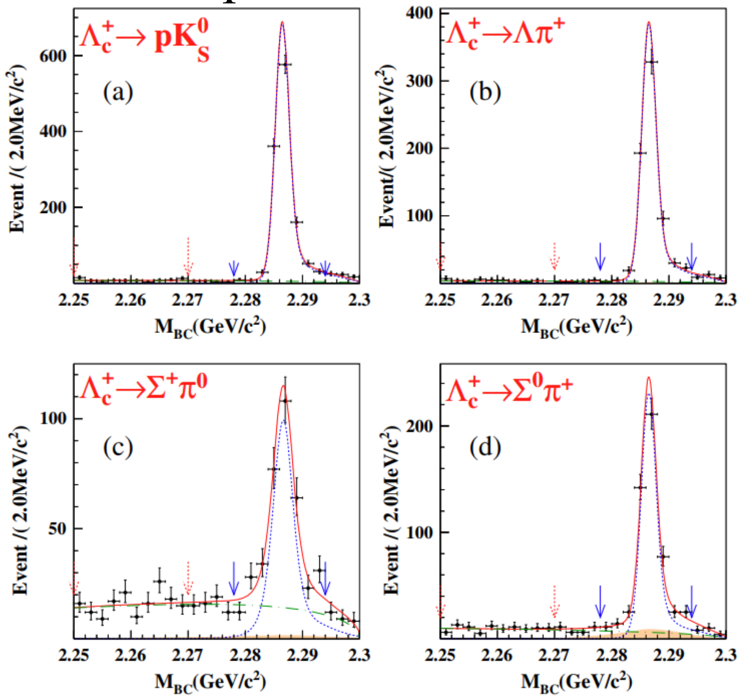
$\Lambda_c^+ \to \Lambda\pi^+\eta$ — **arXiv: 2407.12270**

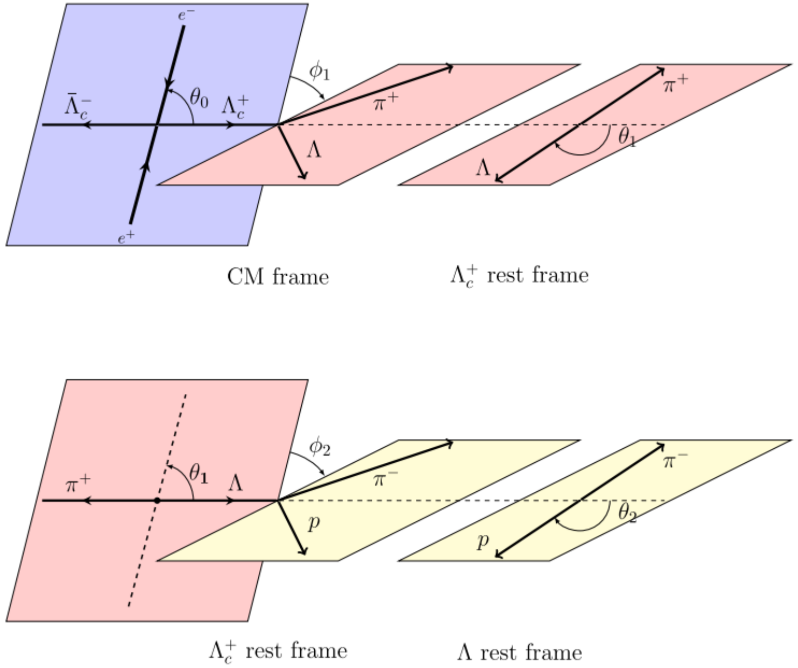
Timeline

Current results on BESIII: Angular analysis

PRD 100.072004 (2019)

- The first polarization measurement about Λ_c^+ in the BESIII experiment.





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

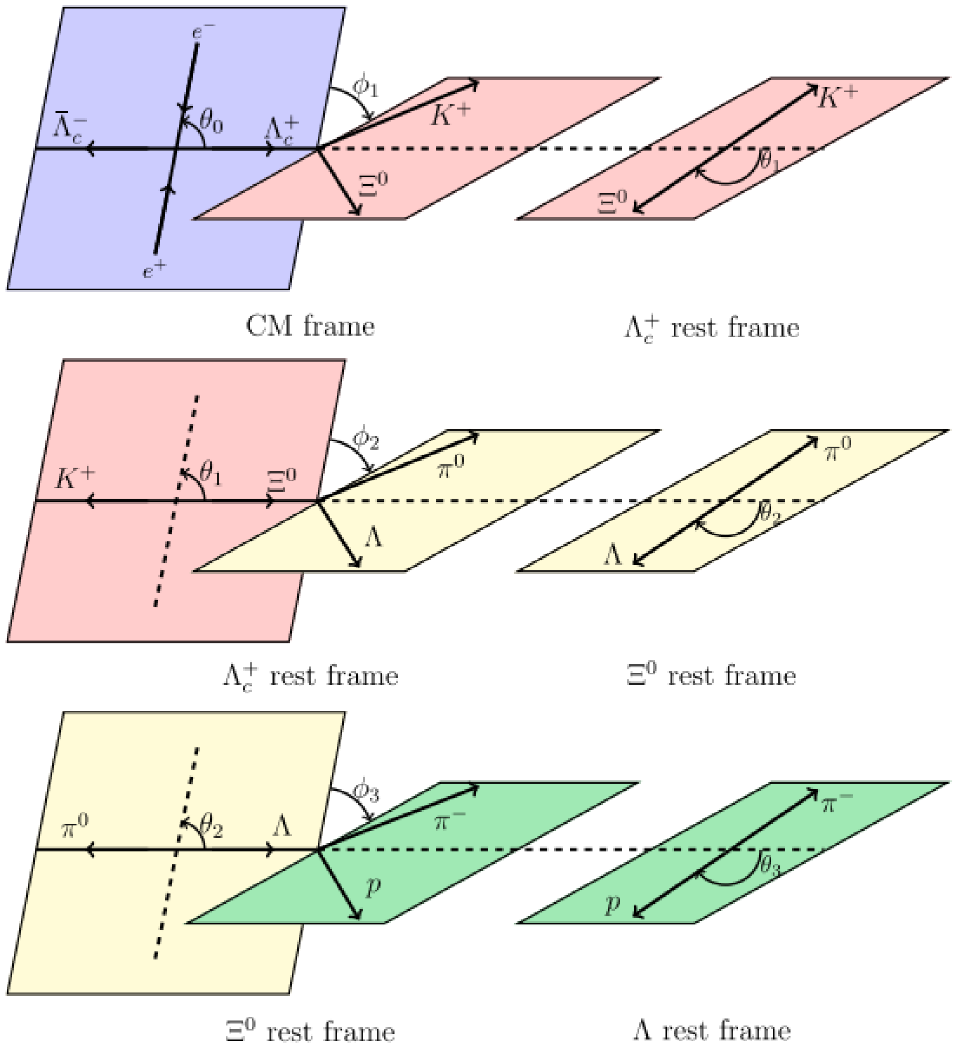
Parameters	$\Lambda_c^+ \to pK_S^0$	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
α_{BP}^+	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$
α_{BP}^+ (PDG)	···	-0.91 ± 0.15	-0.45 ± 0.32	···
β_{BP}	···	$0.06^{+0.58+0.05}_{-0.47-0.06}$	$-0.66^{+0.46+0.22}_{-0.25-0.02}$	$0.48^{+0.35+0.07}_{-0.57-0.13}$
γ_{BP}	···	$-0.60^{+0.96+0.17}_{-0.05-0.03}$	$-0.48^{+0.45+0.21}_{-0.42-0.04}$	$0.49^{+0.35+0.07}_{-0.56-0.12}$
Δ_1^{BP}(rad)	···	$3.0 \pm 2.4 \pm 1.0$	$4.1 \pm 1.1 \pm 0.6$	$0.8 \pm 1.2 \pm 0.2$

- To be updated using total Λ_c^+ data with 6.4 fb^{-1} on the BESIII experiment.

Current results on BESIII: Angular analysis

PRL 132.031801 (2024)

- Focus on the polarization in the pure W-exchange diagram $\Lambda_c^+ \to \Xi^0 K^+$.

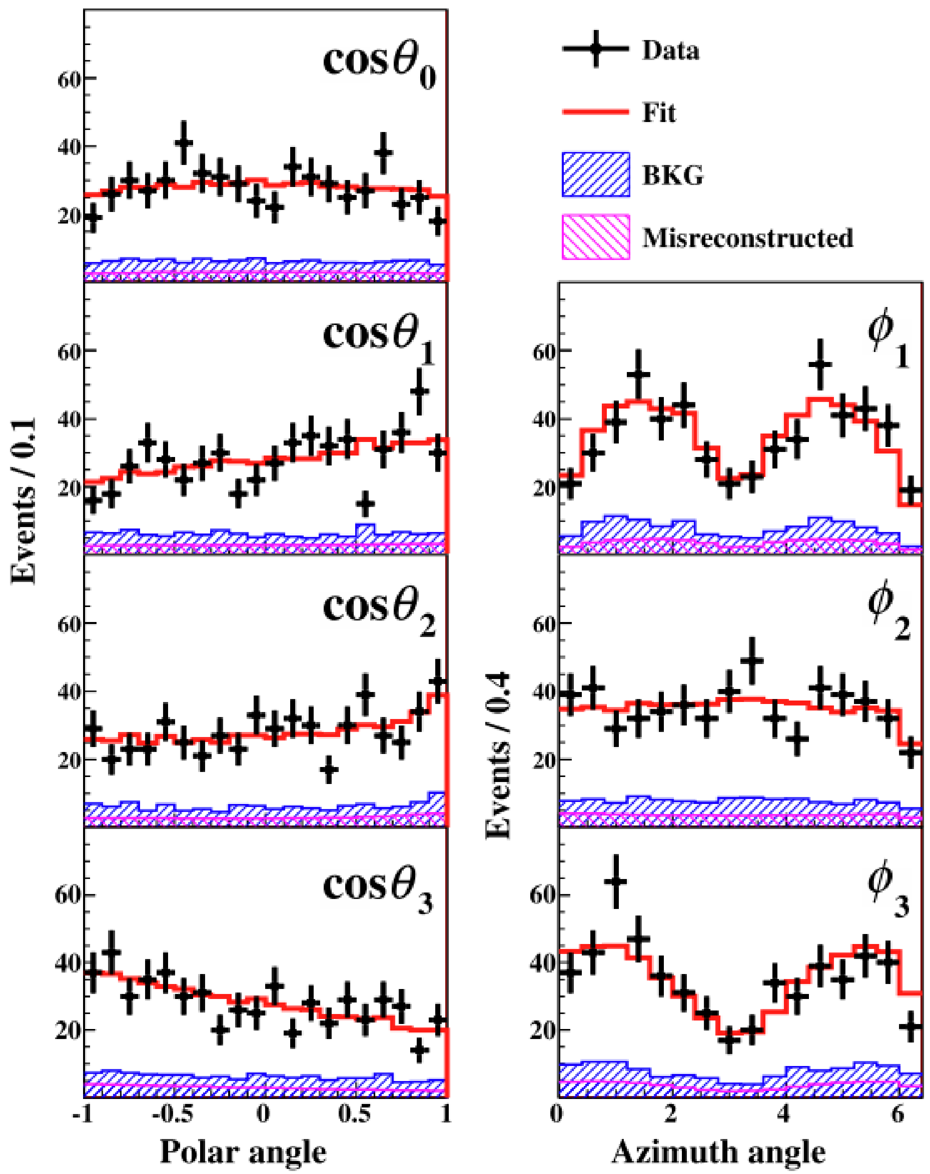


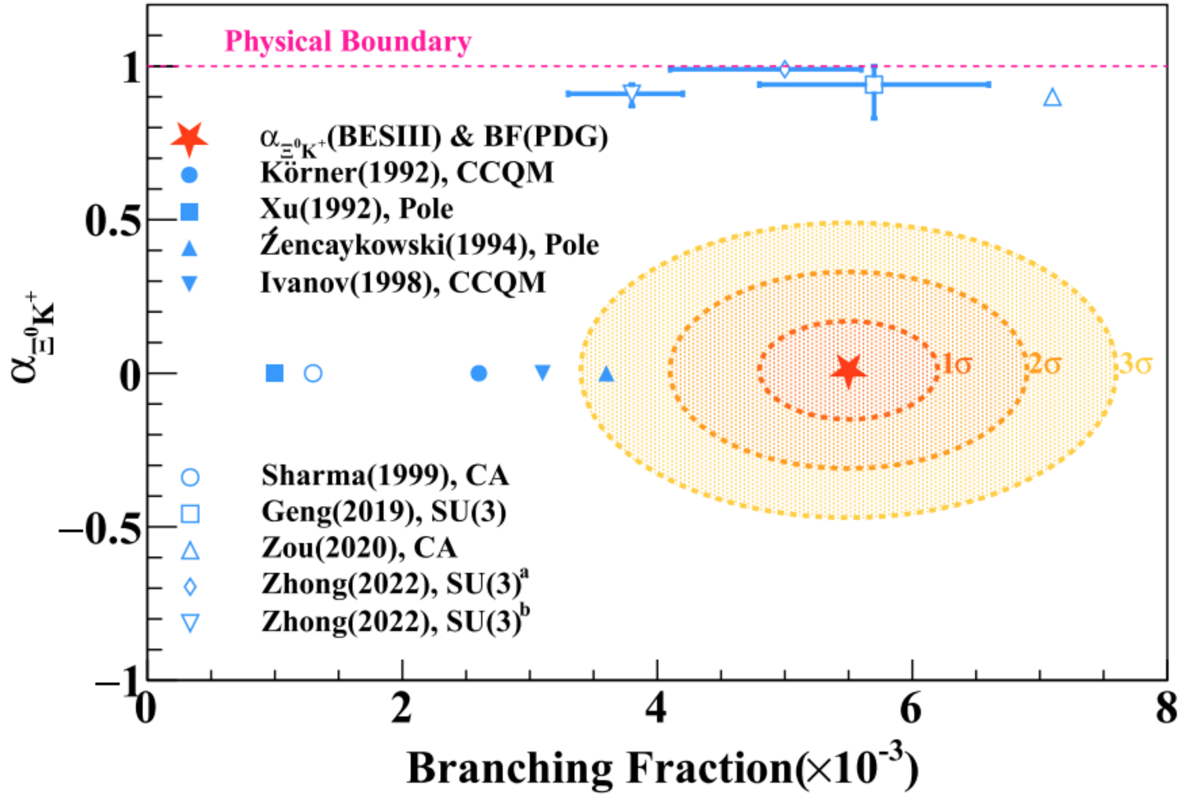
$$
\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0\ d\cos\theta_1\ d\cos\theta_2\ d\cos\theta_3\ d\phi_1\ d\phi_2\ d\phi_3} \\
&\propto 1+\alpha_0\cos^2\theta_0 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\cos\theta_2 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{p\pi^-}\cos\theta_2\cos\theta_3 \\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\cos\theta_3 \\
&-(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\sin\theta_1\sin\phi_1 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Lambda\pi^0}\sin\theta_1\sin\phi_1\cos\theta_2 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_3 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_2\cos\theta_3 \\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\sin\theta_1\sin\phi_1\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{\Lambda\pi^0}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{\Lambda\pi^0}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3 \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \alpha_{p\pi^-}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3 \\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\ \sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\cos\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\phi_1\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3) \\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha^2_{\Xi^0K^+}}\sqrt{1-\alpha^2_{\Lambda\pi^0}}\ \alpha_{p\pi^-}\cos\phi_1\cos\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)
\end{aligned}
$$

A seven-dimensional angular analysis.

Current results on BESIII: Angular analysis

PRL 132.031801 (2024)





$$\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16 \pm 0.03$$

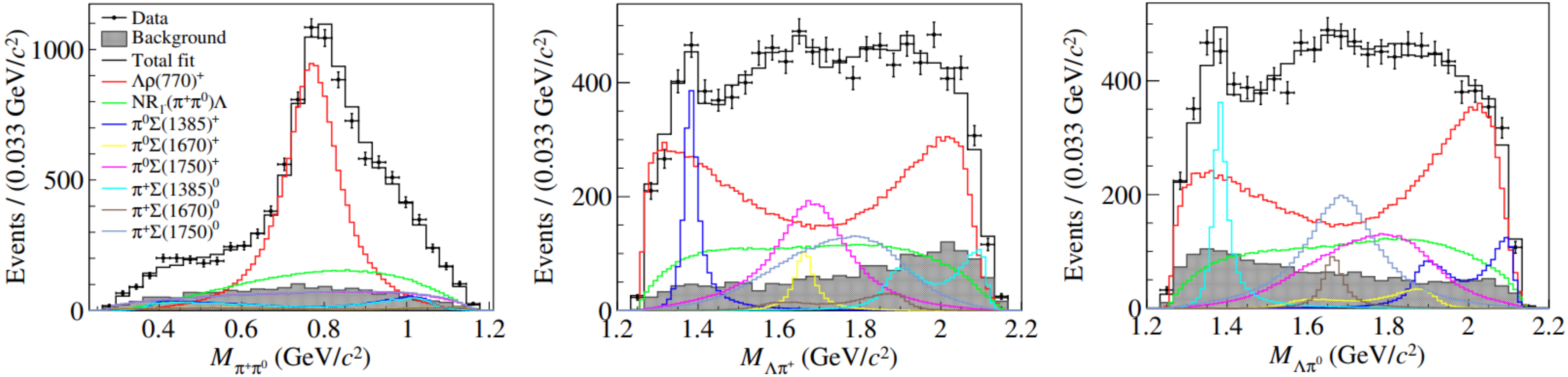
$$\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90 \pm 0.17 \text{ rad}$$

Strong phase shift: $-1.55(1.59) \pm 0.25 \pm 0.05$ rad

Current results on BESIII: Partial wave analysis

JHEP 12.033 (2022)

Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$



$$H^{\rho}_{-\frac{1}{2},-1} = -\frac{g^{\rho}_{0,\frac{1}{2}}}{\sqrt{3}} + \frac{g^{\rho}_{1,\frac{1}{2}}}{\sqrt{3}} - \frac{g^{\rho}_{1,\frac{3}{2}}}{\sqrt{6}} + \frac{g^{\rho}_{2,\frac{3}{2}}}{\sqrt{6}}, \qquad H^{\rho}_{\frac{1}{2},0} = \frac{g^{\rho}_{0,\frac{1}{2}}}{\sqrt{6}} - \frac{g^{\rho}_{1,\frac{1}{2}}}{\sqrt{6}} - \frac{g^{\rho}_{1,\frac{3}{2}}}{\sqrt{3}} + \frac{g^{\rho}_{2,\frac{3}{2}}}{\sqrt{3}},$$

$$H^{\rho}_{-\frac{1}{2},0} = -\frac{g^{\rho}_{0,\frac{1}{2}}}{\sqrt{6}} - \frac{g^{\rho}_{1,\frac{1}{2}}}{\sqrt{6}} - \frac{g^{\rho}_{1,\frac{3}{2}}}{\sqrt{3}} - \frac{g^{\rho}_{2,\frac{3}{2}}}{\sqrt{3}}, \qquad H^{\rho}_{\frac{1}{2},1} = \frac{g^{\rho}_{0,\frac{1}{2}}}{\sqrt{3}} + \frac{g^{\rho}_{1,\frac{1}{2}}}{\sqrt{3}} - \frac{g^{\rho}_{1,\frac{3}{2}}}{\sqrt{6}} - \frac{g^{\rho}_{2,\frac{3}{2}}}{\sqrt{6}}.$$

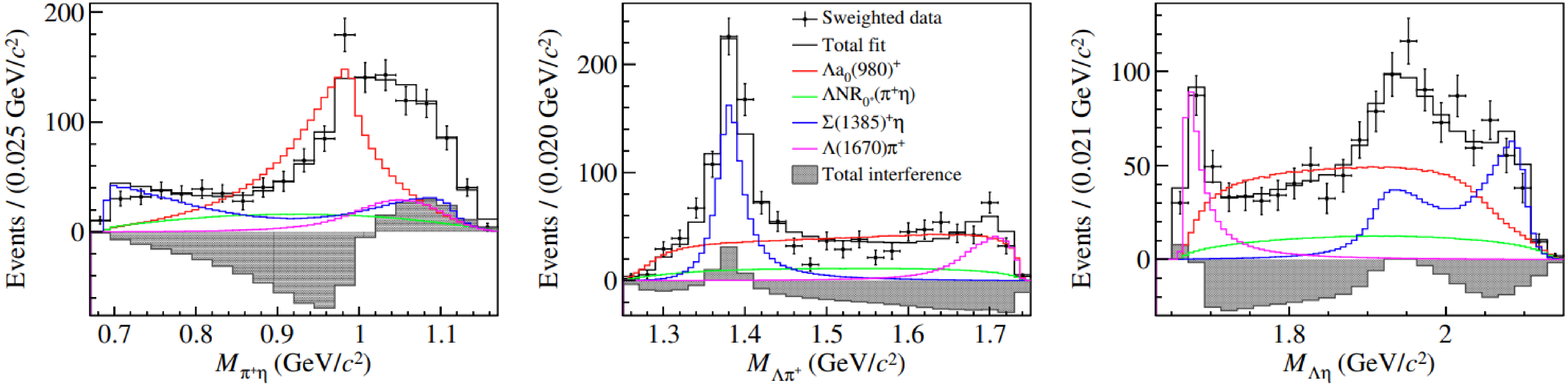
$$\alpha_{\Lambda\rho(770)^+} = \frac{|H^{\rho}_{\frac{1}{2},1}|^2 - |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 - |H^{\rho}_{-\frac{1}{2},0}|^2}{|H^{\rho}_{\frac{1}{2},1}|^2 + |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 + |H^{\rho}_{-\frac{1}{2},0}|^2}$$
$$= \frac{\sqrt{\frac{1}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{1}{2}} - g^{\rho}_{1,\frac{3}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right) - \sqrt{\frac{8}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{3}{2}} + g^{\rho}_{1,\frac{1}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right)}{|g^{\rho}_{0,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{3}{2}}|^2 + |g^{\rho}_{2,\frac{3}{2}}|^2}$$

	Result
$\frac{\mathcal{B}(\Lambda_c^+\to\Lambda\rho(770)^+)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(57.2 \pm 4.2 \pm 4.9)\%$
$\frac{\mathcal{B}(\Lambda_c^+\to\Sigma(1385)^+\pi^0)\cdot\mathcal{B}(\Sigma(1385)^+\to\Lambda\pi^+)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(7.18 \pm 0.60 \pm 0.64)\%$
$\frac{\mathcal{B}(\Lambda_c^+\to\Sigma(1385)^0\pi^+)\cdot\mathcal{B}(\Sigma(1385)^0\to\Lambda\pi^0)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}$	$(7.92 \pm 0.72 \pm 0.80)\%$
$\mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	$(4.06 \pm 0.30 \pm 0.35 \pm 0.23) \times 10^{-2}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	$(5.86 \pm 0.49 \pm 0.52 \pm 0.35) \times 10^{-3}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	$(6.47 \pm 0.59 \pm 0.66 \pm 0.38) \times 10^{-3}$
$\alpha_{\Lambda\rho(770)^+}$	$-0.763 \pm 0.053 \pm 0.045$
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.917 \pm 0.069 \pm 0.056$
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.789 \pm 0.098 \pm 0.056$

Current results on BESIII: Partial wave analysis

arXiv: 2407.12270

Observation of $\Lambda_c^+ \to \Lambda a_0(980)^+$ and evidence for $\Sigma(1380)^+$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$



$$\alpha_{\Lambda a_0(980)^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{0,\frac{1}{2}}\; g^{\Lambda_c^+\to\Lambda a_0(980)^+ *}_{1,\frac{1}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{0,\frac{1}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{1,\frac{1}{2}}\right|^2},$$

$$\alpha_{\Sigma(1385)^+\eta} = \frac{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{1,\frac{3}{2}}\; g^{\Lambda_c^+\to\Lambda a_0(980)^+ *}_{2,\frac{3}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{1,\frac{3}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda a_0(980)^+}_{2,\frac{3}{2}}\right|^2},$$

$$\alpha_{\Lambda(1670)\pi^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2} = \frac{2\,\mathrm{Re}\left(g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{0,\frac{1}{2}}\; g^{\Lambda_c^+\to\Lambda(1670)\pi^+ *}_{1,\frac{1}{2}}\right)}{\left|g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{0,\frac{1}{2}}\right|^2 + \left|g^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{1,\frac{1}{2}}\right|^2}.$$

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$0.91^{+0.09}_{-0.18} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0^+}	15.4 ± 5.3	6.7σ	...

Future plan for BESIII

Energy	Physics motivations	Current data	Expected final data
4.6 - 4.9 GeV	Charmed baryon/*XYZ* cross-sections	6.4 fb^{-1}	15 fb^{-1} at different $\sqrt{s}$
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section		1.0 fb^{-1}
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section		1.0 fb^{-1}
4.95 GeV	Ξ_c decays		1.0 fb^{-1}

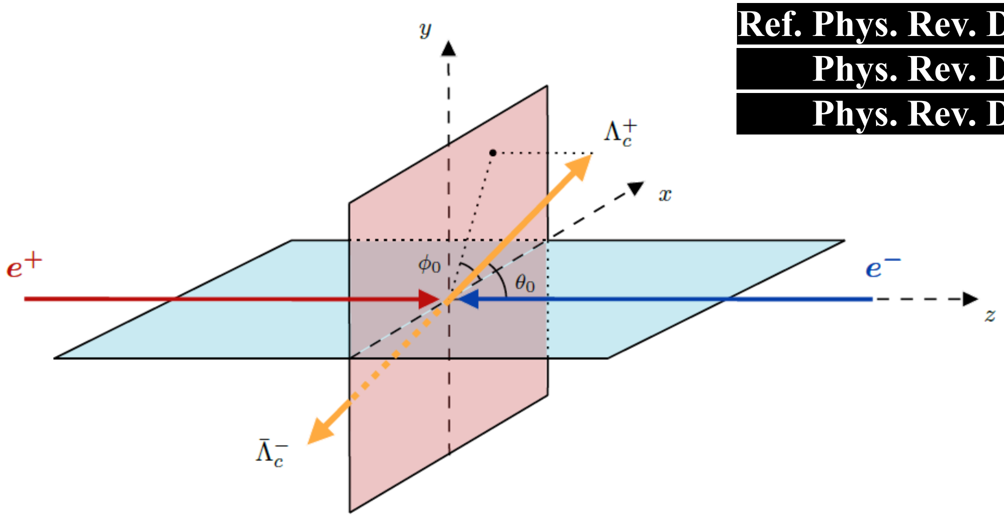
$\Lambda_c^+ \to$ modes	α	Luminosity	Future precision (statistical uncertainty only)
pK_s^0	$0.18 \pm 0.43 \pm 0.14$	0.6 fb^{-1}	~ 0.18
$\Lambda\pi^+$	$-0.80 \pm 0.11 \pm 0.02$		~ 0.02
$\Sigma^0\pi^+$	$-0.73 \pm 0.17 \pm 0.07$		~ 0.03
$\Sigma^+\pi^0$	$-0.57 \pm 0.10 \pm 0.07$		~ 0.02
$\Lambda\rho(770)^+$	$-0.763 \pm 0.053 \pm 0.045$	4.4 fb^{-1}	~ 0.029
$\Sigma(1385)^+\pi^0$	$-0.917 \pm 0.069 \pm 0.056$		~ 0.037
$\Sigma(1385)^0\pi^+$	$-0.789 \pm 0.098 \pm 0.056$		~ 0.053
Ξ^0K^+	$0.01 \pm 0.16 \pm 0.03$		~ 0.09
$\Lambda a(980)^+$	$0.91^{+0.09}_{-0.18} \pm 0.08$	6.1 fb^{-1}	~ 0.11
$\Sigma(1385)^+\eta$	$-0.61 \pm 0.15 \pm 0.04$		~ 0.10
$\Lambda(1670)\pi^+$	$0.21 \pm 0.27 \pm 0.33$		~ 0.17

- If beam is polarized, how is the precision about Λ_c^+ polarization parameters?

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:

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

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

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

$$\alpha_0 := (\mathcal{H}_{\frac12,\frac12} - 2\mathcal{H}_{\frac12,-\frac12})/(\mathcal{H}_{\frac12,\frac12} + 2\mathcal{H}_{\frac12,-\frac12})$$

$$\Delta_0 := \mathrm{Arg}(\mathcal{H}_{\frac12,-\frac12}/\mathcal{H}_{\frac12,\frac12})$$

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

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

$\boldsymbol{a}$-matrix: Λ_c^+ and daughter particle decay:

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

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

Note:

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

$$a_{0,0}^{\Sigma^0} = 1$$

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

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

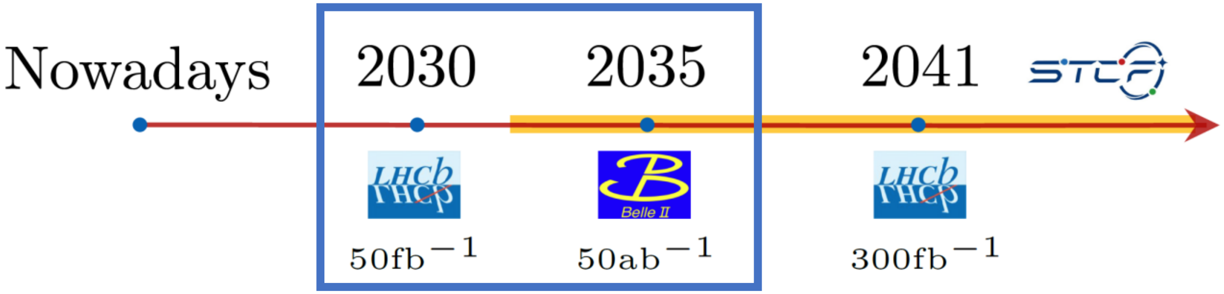
$$a_{3,3}^{\Sigma^0} = -\cos\theta_2$$

For $\boldsymbol{\Lambda_c^+ \to pK_s^0}$: $\mathcal{F}^{\Lambda_c^+}(\boldsymbol{\xi};\boldsymbol{\omega}) = \frac{1}{(4\pi)^2}\sum_{\mu=0}^{3} C_{\mu 0}\cdot a_{\mu 0}^{\Lambda_c^+}$

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

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 experiment			Belle(II) experiment	
	Nowadays	2030	2041	Nowadays	2035
Luminosity	8.7 fb^{-1}	50 fb^{-1}	300 fb^{-1}	980 fb^{-1}	50 ab^{-1}
$\alpha_{pK_s^0}$	0.008	0.0033	0.0014	$\cdots$	$\cdots$
$\alpha_{\Lambda\pi^+}$	0.006	0.0025	0.0010	0.005	0.0007
$\alpha_{\Sigma^0\pi^+}$	$\cdots$	$\cdots$	$\cdots$	0.016	0.0023
$\Delta_{\Lambda\pi^+}$	0.025	0.0104	0.0043	$\cdots$	$\cdots$
$A_{CP}^{\alpha_{pK_s^0}}$	0.011	0.0046	0.0019	$\cdots$	$\cdots$
$A_{CP}^{\alpha_{\Lambda\pi^+}}$	0.008	0.0033	0.0014	0.007	0.0010
$A_{CP}^{\alpha_{\Sigma^0\pi^+}}$	$\cdots$	$\cdots$	$\cdots$	0.034	0.0047

Estimated method

Simulation:

1. Using PHSP model
2. BESIII efficiency response
3. Same event selection requirements as BESIII

Sampling:

1. Using the Angular Distribution Model
2. Input parameters

Processes	Parameters	Values	
$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$	α_0 $(\bar{\alpha}_0)$	0.10	
	Δ_0 $(\bar{\Delta}_0)$	-0.50	
$\Lambda_c^+ \to pK_s^0$	$\alpha_{pK_s^0}$	-0.754	[a]
$\bar{\Lambda}_c^- \to \bar{p}K_s^0$	$\alpha_{\bar{p}K_s^0}$	$-\alpha_{pK_s^0}$	
$\Lambda_c^+ \to \Lambda\pi^+$	$\alpha_{\Lambda\pi^+}$	-0.785	[a]
	$\Delta_{\Lambda\pi^+}$	0.656	[a]
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-$	$\alpha_{\bar{\Lambda}\pi^-}$	$-\alpha_{\Lambda\pi^+}$	
	$\Delta_{\bar{\Lambda}\pi^-}$	$-\Delta_{\Lambda\pi^+}$	
$\Lambda_c^+ \to \Sigma^0\pi^+$	$\alpha_{\Sigma^0\pi^+}$	-0.452	[b]
	$\Delta_{\Sigma^0\pi^+}$	2.0	
$\bar{\Lambda}_c^- \to \bar{\Sigma}^0\pi^-$	$\alpha_{\bar{\Sigma}^0\pi^-}$	$-\alpha_{\Sigma^0\pi^+}$	
	$\Delta_{\bar{\Sigma}^0\pi^-}$	$-\Delta_{\Sigma^0\pi^+}$	
$\Lambda \to p\pi^-$	$\alpha_{p\pi^-}$	0.7519	[c]
$\bar{\Lambda} \to \bar{p}\pi^+$	$\alpha_{\bar{p}\pi^+}$	-0.7559	[c]

[a] arXiv: 2409.02759;

[b] Sci. Bull. 68, 583-592 (2023);

[c] Phys. Rev. Lett.129.131801;

Others are estimated values.

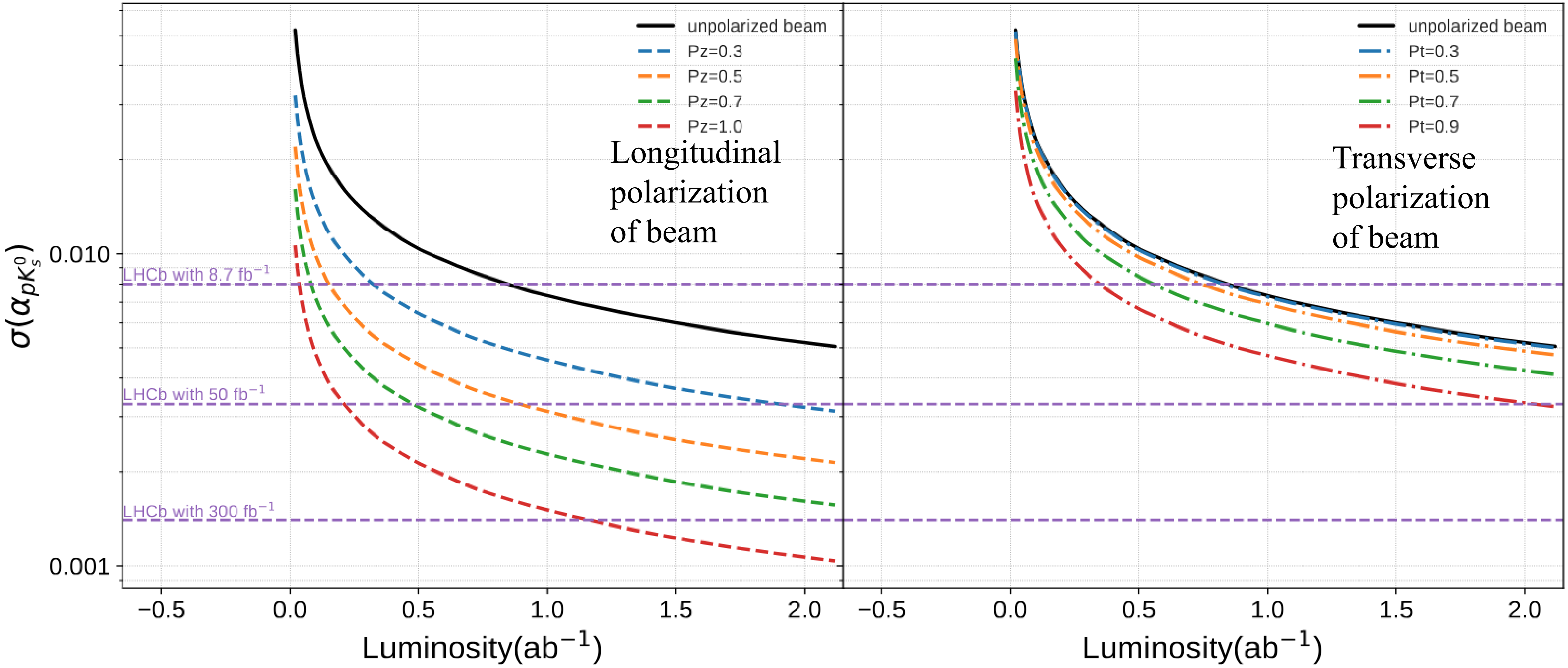
3. Mix background from BESIII with the same signal-background ratio

Fit:

1. Likelihood fit
2. Fix different beam polarization
   Can be determined by other efficiency method
3. Give the absolute statistical uncertainty

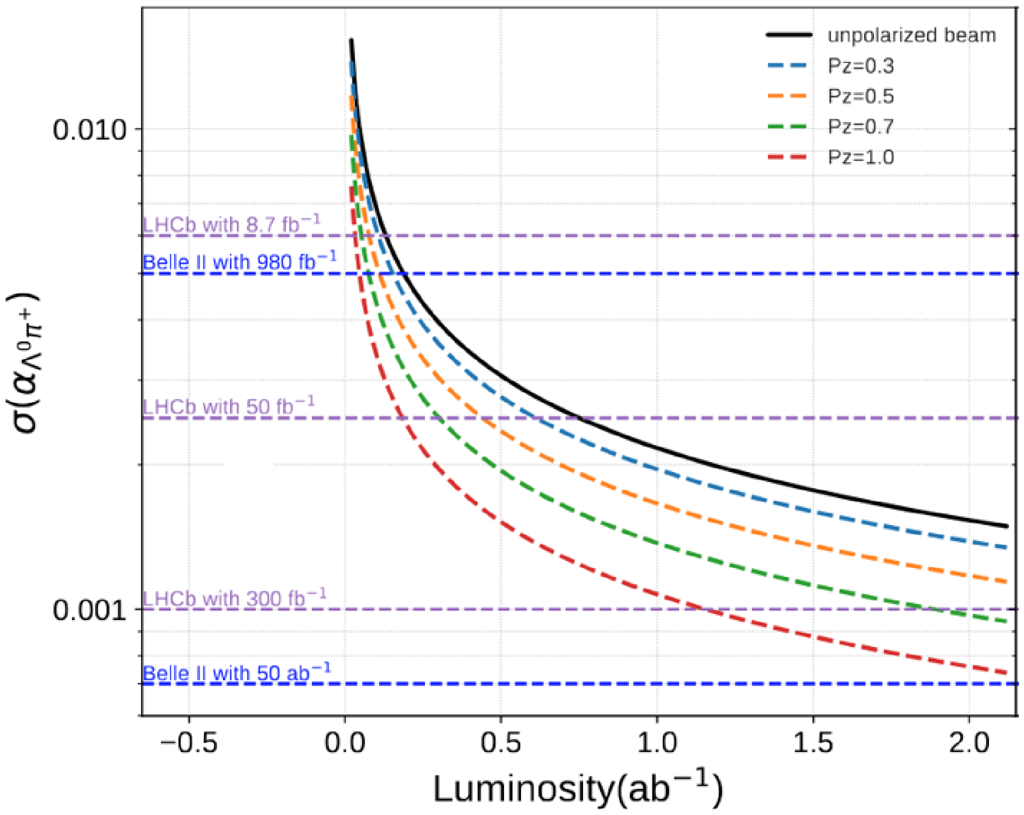
P.S. : Based on the study of *FastSim package* designed for STCF, efficiency curve has little impact.

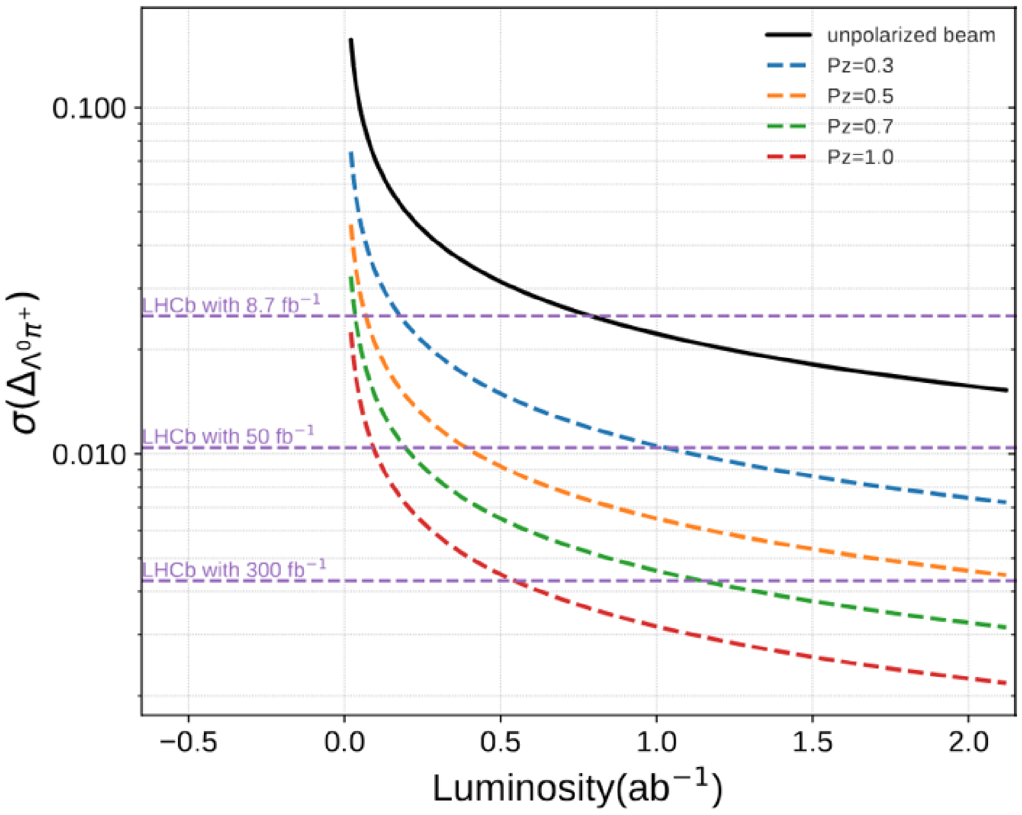
Statistical uncertainty estimation for $\alpha_{pK_s^0}$



1. Longitudinal beam polarization has greater advantages in measuring P violation parameters.
2. When the longitudinal polarization is 50%, it only takes one year to achieve the accuracy of LHCb experiment based on 50 fb^{-1}.

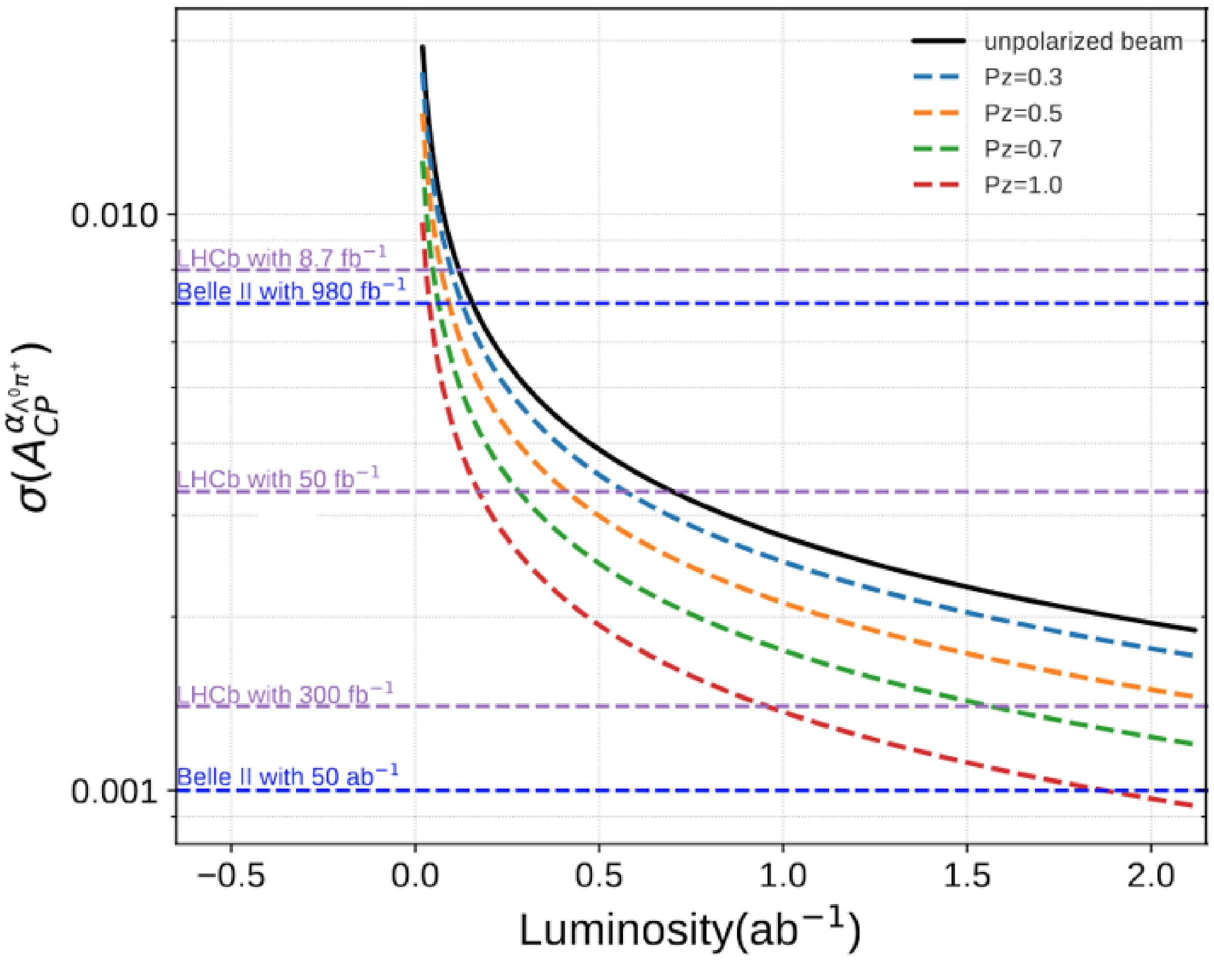
Statistical uncertainty estimation for $\alpha_{\Lambda\pi^+}$ and $\Delta_{\Lambda\pi^+}$





- ✓ Using high longitudinal polarization beam, Belle II’s and LHCb’s measurement precision can also be achieved on STCF.
- ✓ Even we can test β-induced CPV.

Statistical uncertainty estimation for $A_{CP}^{\Lambda\pi^+}$



✓ The improvement of beam polarization often corresponds to a decrease in the demand for integrated luminosity.

All the parameters studied can close or achieve accuracy of Belle II and LHCb on STCF using 2 ab^{-1} data with a large longitudinal polarized beam.

A short summary

- Estimated based on the $\boldsymbol{\alpha_{\Lambda\pi^+}} = \mathbf{-0.785}$, and $\mathbf{A_{CP}^{\Lambda\pi^+} = 0}$.

$\Lambda_c^+ \to \Lambda\pi^+$	P_Z	$\alpha_{\Lambda\pi^+}$ precision with 1 ab^{-1} (statistical uncertainty only)		A_{CP}^{α} precision with 1 ab^{-1} (statistical uncertainty only)
Non-polarized	0.0	2.17×10^{-3}	⬅ 0.02 for BESIII now	2.76×10^{-3}
Longitudinal polarization	0.3	1.96×10^{-3}		2.49×10^{-3}
	0.5	1.66×10^{-3}		2.12×10^{-3}
	1.0	1.07×10^{-3}		1.37×10^{-3}

- The absolute value of CPV is not very important in prediction, since the value is so small ($10^{-3\sim4}$) in charmed baryon.

- How to estimate the A_{CP} precision for SCS decay $\Lambda_c^+ \to \Lambda K^+$?
  1) At the same luminosity (1.0 ab^{-1}), it is necessary to consider the impact of branching fraction on yield $\frac{\mathcal{B}(\Lambda_c^+\to\Lambda K^+)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+)} = \frac{0.0642\%}{1.29\%}$ ⟶ $\frac{\sigma(\alpha)}{|\alpha|}$
  2) Considering the difference in $\frac{\alpha_{\Lambda K^+}}{\alpha_{\Lambda\pi^+}} = \frac{-0.58}{-0.755}$ ⟶
  3) The detection efficiency of $K^\pm$ and $\pi^\pm$ is similar.

$$\sigma(A_{CP}) \sim (1 - A_{CP})^2 \times \frac{\sigma(\alpha)}{|\alpha|}$$

$(1 - A_{CP})^2 \sim 1$

When $P_Z = 1.0$ ⟶ $\sigma(A_{CP}^{\Lambda K^+}) \sim \sigma(A_{CP}^{\Lambda\pi^+}) \times \sqrt{\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)}{\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)}} / \frac{\alpha_{\Lambda K^+}}{\alpha_{\Lambda\pi^+}} = 8 \times 10^{-3}$

Still difficult to test CPV in SM

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. All $\boldsymbol{\Lambda_c^+}$ polarization parameters have significant precision advantages on STCF!

4. Precision of $\boldsymbol{\Delta}$ will allow us to explore β-induced CPV.

5. Although the current research focuses on the CF processes, their formula form are exactly the same as SCS processes.

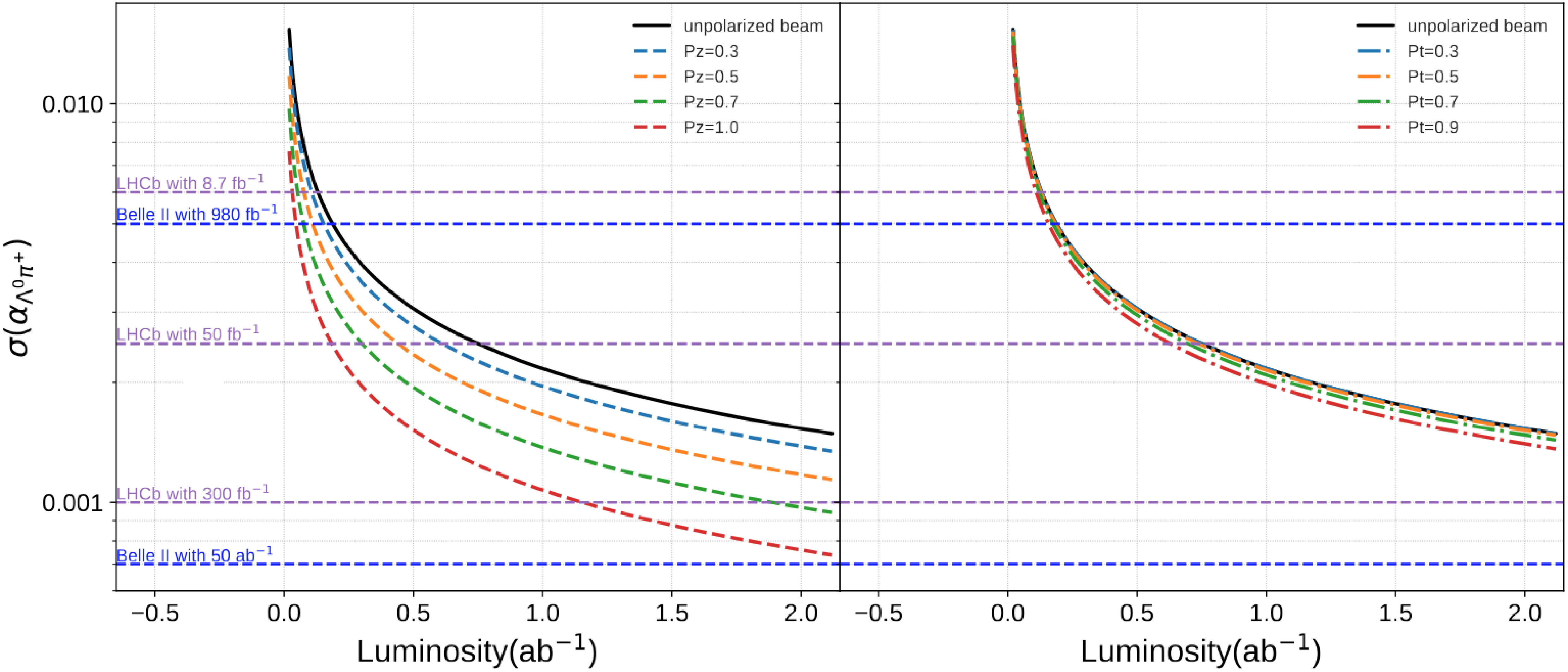
CF		SCS
$\Lambda_c^+ \to \mathrm{p}K_S^0$		$\Lambda_c^+ \to p\eta$
$\Lambda_c^+ \to \Lambda\pi^+$	→	$\Lambda_c^+ \to \Lambda K^+$
$\Lambda_c^+ \to \Sigma^0\pi^+$		$\Lambda_c^+ \to \Sigma^0 K^+$

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

Many thanks!

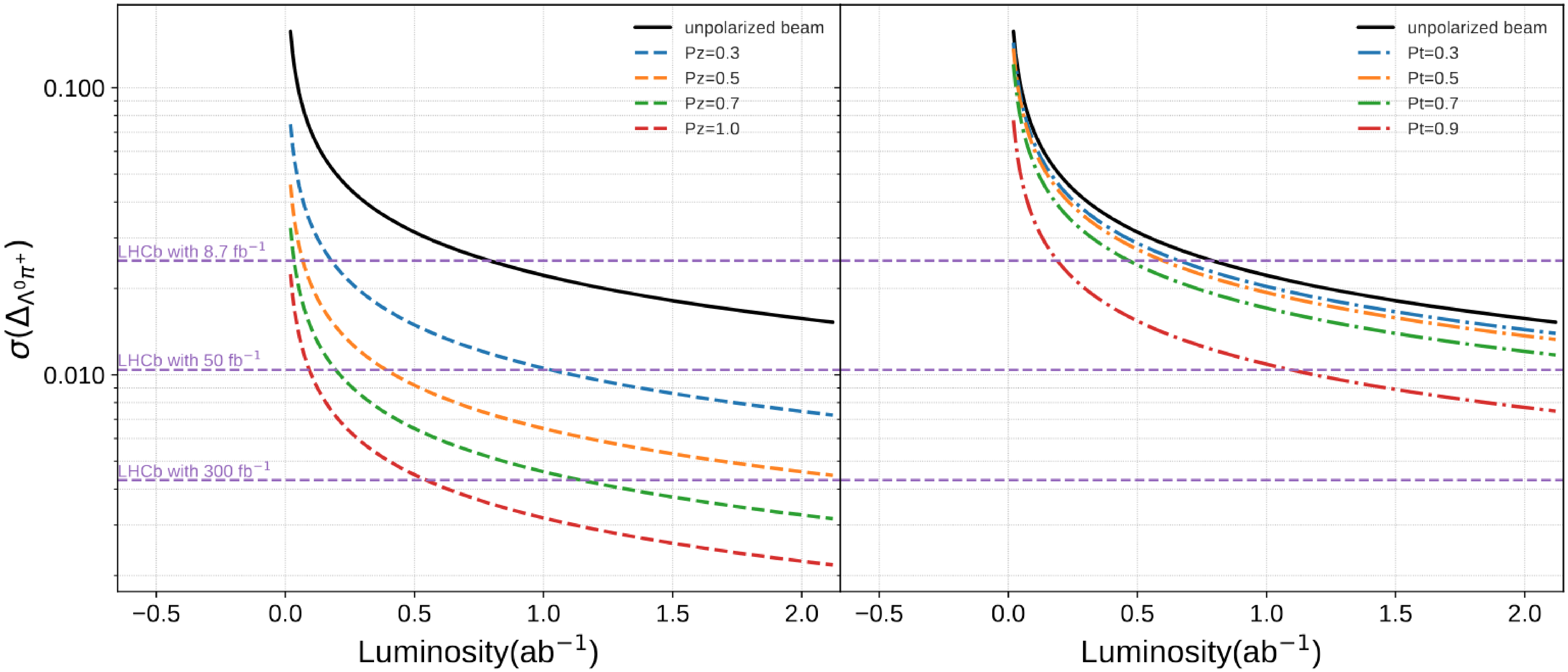
backup

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



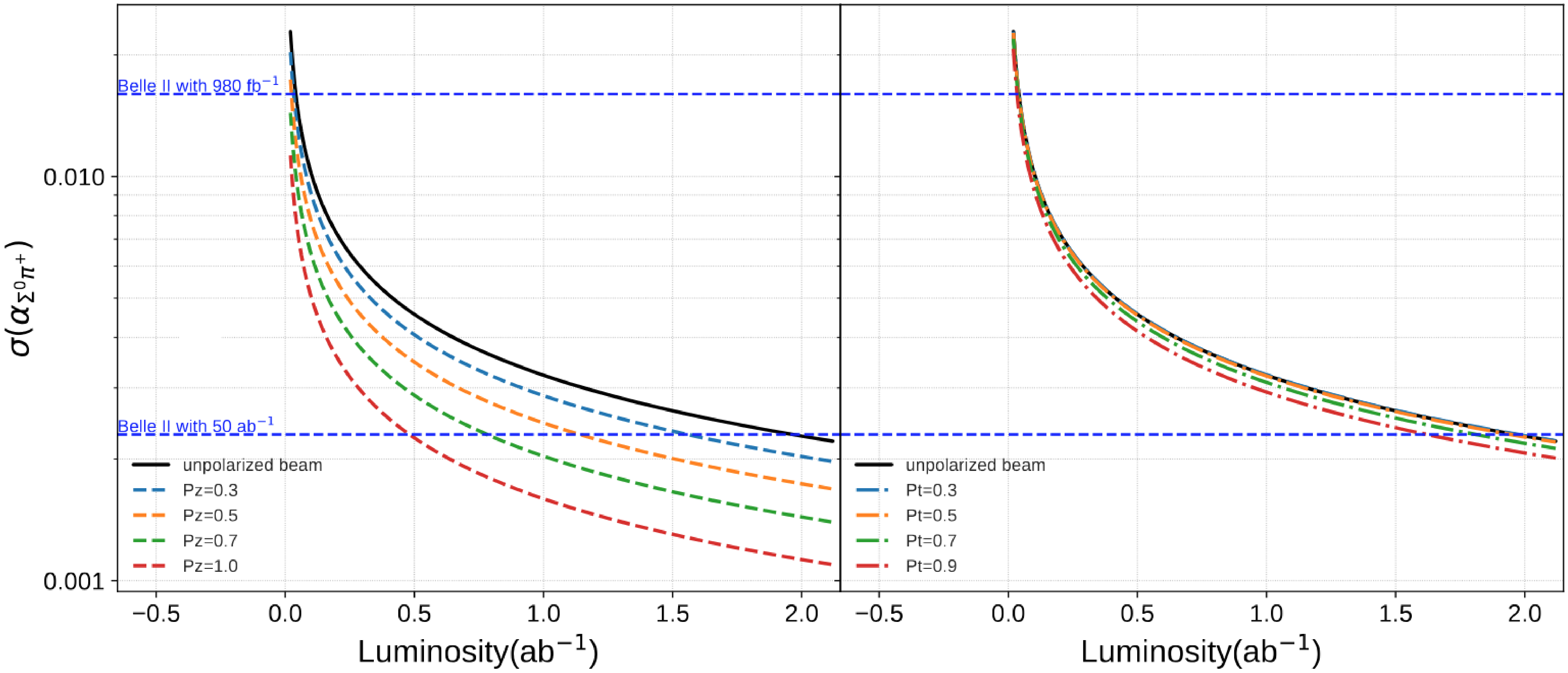
(b) Uncertainty prediction of P violating parameters $\alpha_{\Lambda\pi^+}$.

Statistical uncertainty estimation for $\Delta_{\Lambda\pi^+}$



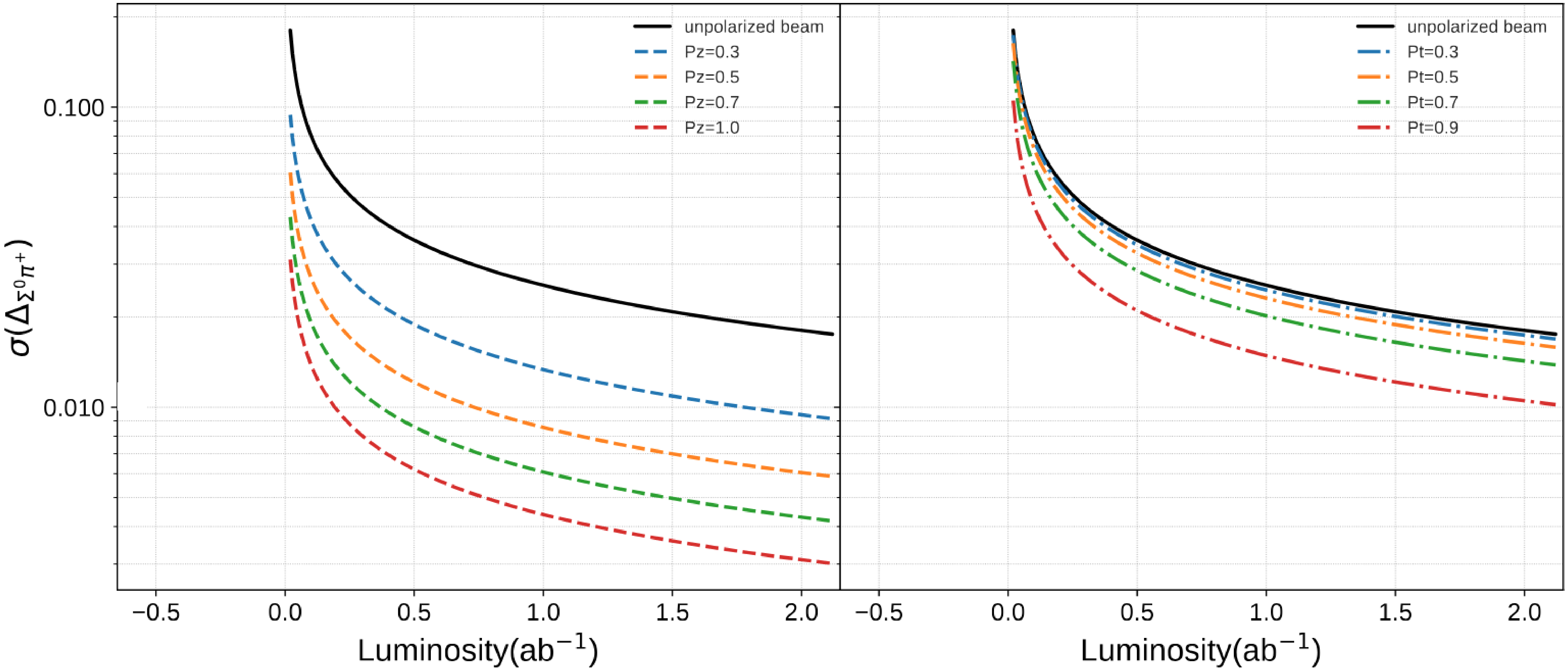
(c) Uncertainty prediction of P violating parameters $\Delta_{\Lambda\pi^+}$.

Statistical uncertainty estimation for $\alpha_{\Sigma^0\pi^+}$



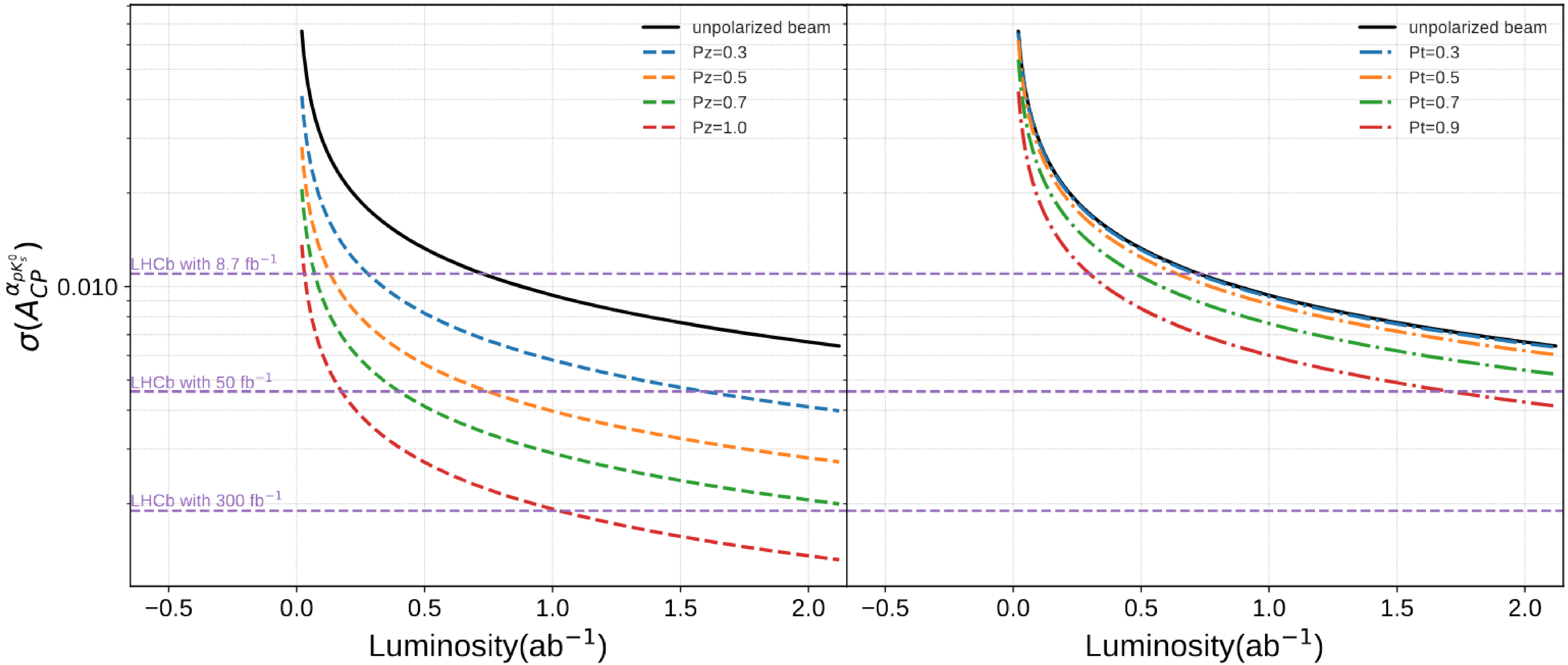
(a) Uncertainty prediction of P violating parameters $\alpha_{\Sigma^0\pi^+}$.

Statistical uncertainty estimation for $\Delta_{\Sigma^0\pi^+}$



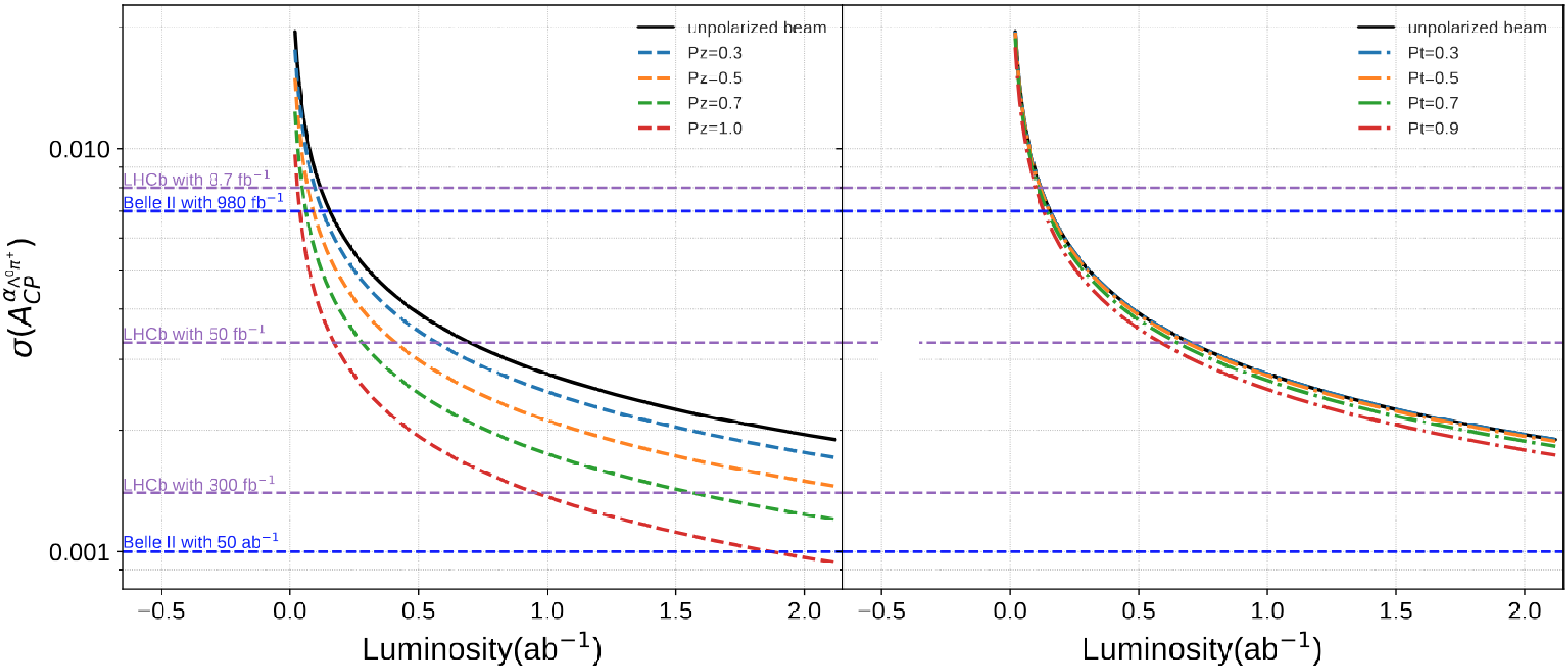
(b) Uncertainty prediction of P violating parameters $\Delta_{\Sigma^0\pi^+}$.

Statistical uncertainty estimation for $A_{CP}^{pK_s^0}$



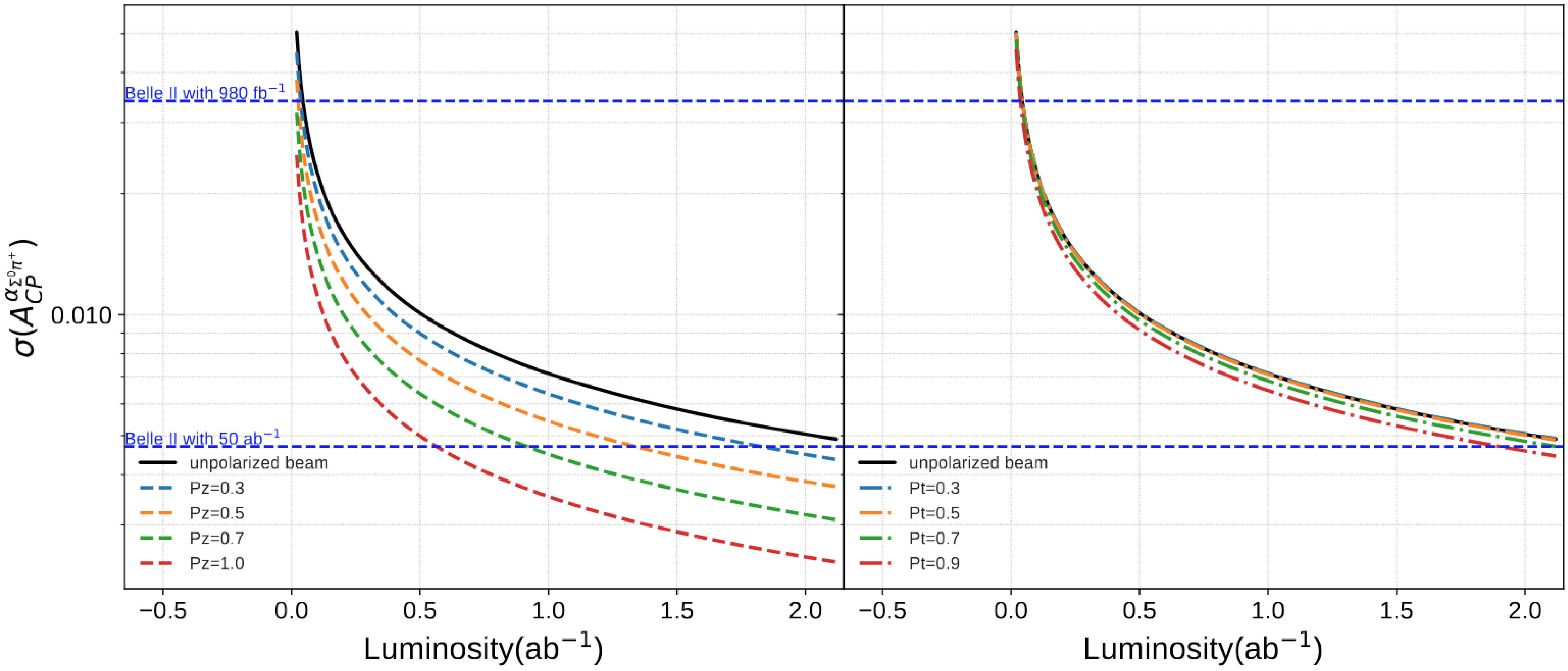
(a) Uncertainty prediction of CP violating parameters $A_{CP}^{\alpha_{pK_s^0}}$ for channel $\Lambda_c^+ \to pK_s^0$.

Statistical uncertainty estimation for $A_{CP}^{\Lambda\pi^+}$



(b) Uncertainty prediction of CP violating parameters $A_{CP}^{\alpha_{\Lambda\pi^+}}$ for channel $\Lambda_c^+ \to \Lambda\pi^+$.

Statistical uncertainty estimation for $A_{CP}^{\Sigma^0\pi^+}$



(c) Uncertainty prediction of CP violating parameters $A_{CP}^{\alpha_{\Sigma^0\pi^+}}$ for channel $\Lambda_c^+ \to \Sigma^0\pi^+$.

Partial wave analysis

- The amplitude for each decay level: $R_{ab} \to a + b$

$$A^{R_{ab}\to a+b}_{\lambda_{R_{ab}},\lambda_{R_a},\lambda_{R_b}} = H^{R_{ab}\to a+b}_{\lambda_{R_a},\lambda_{R_b}} D^{J^*_{R_{ab}}}_{\lambda_{R_{ab}},\lambda_{R_a}-\lambda_{R_b}}(\phi,\theta_0,0)$$

- The helicity coupled amplitude can be expanded by LS coupling formula:

$$H^{R_{ab}\to a+b}_{\lambda_{R_a},\lambda_{R_b}} = \sum_{ls} g_{ls}\sqrt{\frac{2l+1}{2J_0+1}}\langle ls,0\,\delta|J_0,\delta\rangle\langle J_1 J_2,\lambda_1-\lambda_2|s,\delta\rangle q^l B_l'(q,q_0,d)$$

- Take the decay $\rho(770)^+ \to \pi^+ + \pi^0$ as an example:

$$A^{\rho(770)^+}_{\lambda_{\Lambda_c^+},\lambda_\Lambda} = \sum_{\lambda_{\rho(770)^+},\lambda_\Lambda} A^{\Lambda_c^+\to\Lambda\rho(770)^+}_{\lambda_{\Lambda_c^+},\lambda_{\rho(770)^+},\lambda_\Lambda} R_{\rho(770)^+}(M_{\pi^+\pi^0}) A^{\rho(770)^+\to\pi^+ + \pi^0}_{\lambda_{\rho(770)^+},0,0}$$

- For the resonance $\rho(770)^+$, Gounaris Sakurai model is used.

- For the other resonance model, like relativistic Breit-Wigner (RBW) formular, the DV-Bugg model, and Flatte-like model can be used.

- Finally, we can use the g_{ls} results to construct many polarization parameters.

Phase shift

The amplitude for the two-body weak decay $B_i \to B_f + P$ can be parameterized as

$$M\left(B_i \to B_f + P\right) = i\bar{u}_f(A - B\gamma_5)u_i$$

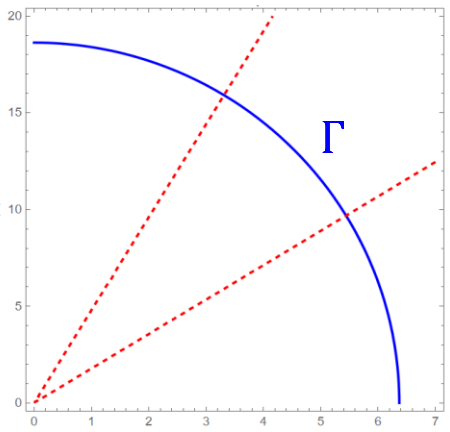
$$A \to s, B \to p/\kappa$$

$$\kappa = |\vec{p}_c|/(E_\Lambda + m_\Lambda)$$

$$\Gamma = \frac{\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)}{\tau_{\Lambda_c^+}} = \frac{|\vec{p}_c|}{8\pi}\left[\frac{\left(m_{\Lambda_c^+} + m_\Lambda\right)^2 - m_{\pi^+}^2}{m_{\Lambda_c^+}^2}|A|^2 + \frac{\left(m_{\Lambda_c^+} - m_\Lambda\right)^2 - m_{\pi^+}^2}{m_{\Lambda_c^+}^2}|B|^2\right]$$

$$\alpha = \frac{2\kappa|A||B|\cos(\delta_p - \delta_s)}{|A|^2 + \kappa^2|B|^2} \qquad \Delta = \arctan\frac{2\kappa|A||B|\sin(\delta_p - \delta_s)}{|A|^2 - \kappa^2|B|^2}$$

Three unknowns and three independent equations.



$|B|$

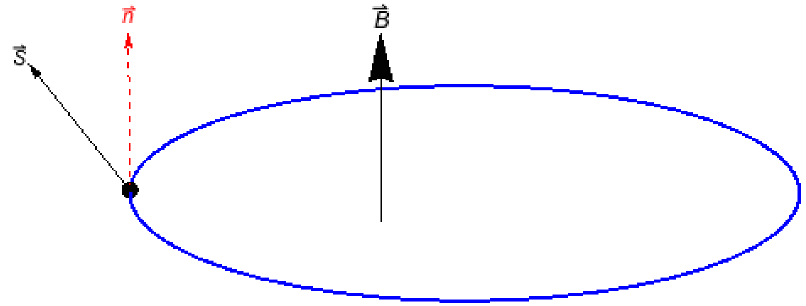
$|A|$

$$\gamma = \frac{|A|^2 - \kappa^2|B|^2}{|A|^2 + \kappa^2|B|^2}$$

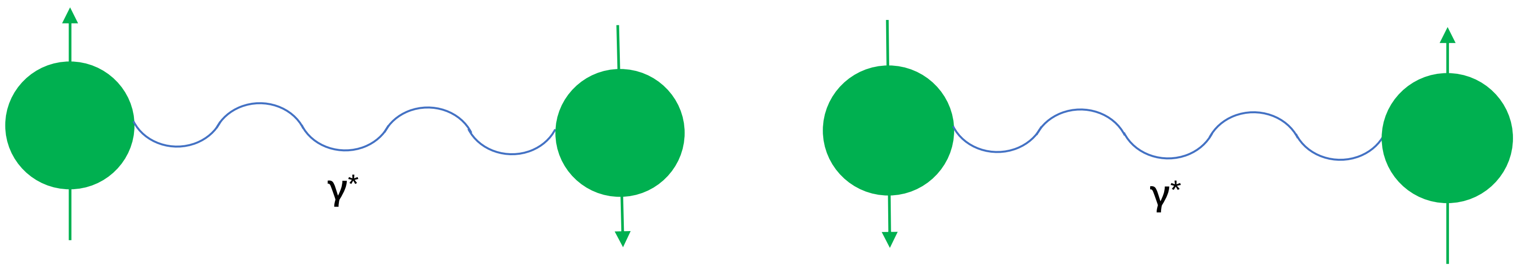
✓ Once $\gamma > 0$ or $\gamma < 0$, one solution will be determined.

The emission of synchrotron radiation could lead to transverse polarization of the beam in electron positron storage rings.

(Sokolov Ternov effect, 1964)



Emission of synchrotron radiation causes spontaneous spin flip, with different probability between the two scenarios.



Cited from Yutie's talk