Polarization measurements of Λ baryons in LHCb

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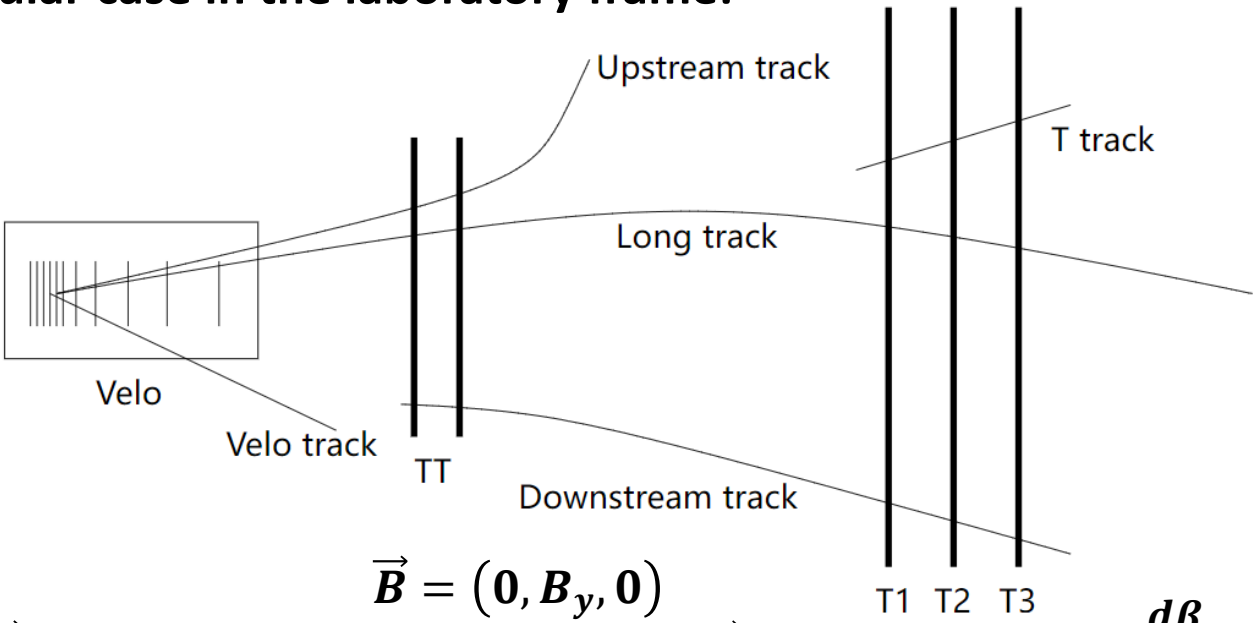
(On behalf of Working Groups)

2nd workshop on EMDMs of unstable particles

Motivation

- Λ baryon EMD/MDM measurement through spin polarization vector precession in the magnetic field
- Require first polarization measurement of Λ before precession
- A particular case in the laboratory frame:

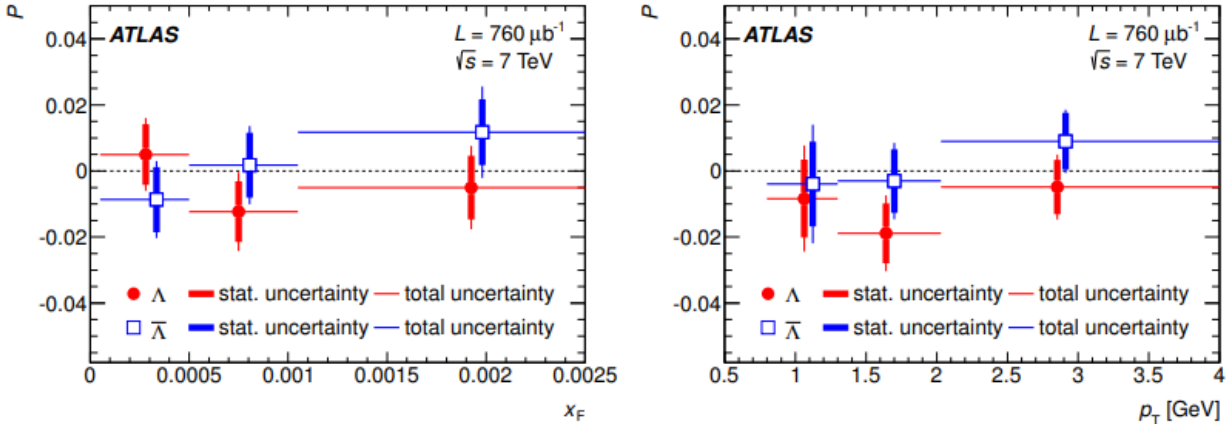


$$\vec{P}_0 = (0, 0, P_0) \xrightarrow{\vec{B} = (0, B_y, 0)} \vec{P}_f = \left(-P_0 \sin\phi,\ -P_0 \frac{d\beta}{g} sin\,\phi,\ P_0 \cos\phi\right)$$

- Higher $\vec{P}_0 \rightarrow$ higher sensibility on dipole moments

Initial Λ polarization in LHCb

- Λ directly produced from pp collisions via strong interactions:
  - ✓ Initial polarization is perpendicular to production plane, $\vec{p}_{\mathrm{beam}} \times \vec{p}_{\Lambda}$
  - ✓ Polarization increase with $P_T(\Lambda)$
  - ✓ Not easy to reconstruct
  - ✓ Prompt Λ is not polarized at LHC [*]



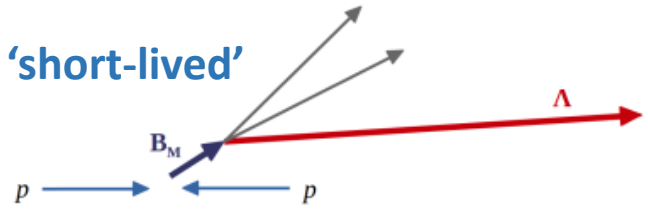
- Λ produced from heavy baryon weak decays:
  - ✓ Large longitudinal polarization: $\sim -90\%$ in $\Lambda_c^+ \to \Lambda\pi^+$
  - ✓ Polarization measured via analysis angular distribution of $\Lambda \to p\pi^-$ decay

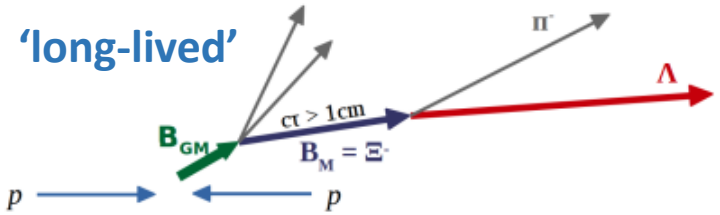
[*]G. Aad *et al.* [ATLAS], Phys. Rev. D 91, 032004 (2015)

Source and production of Λ (c-baryon decays)

Table 1: Dominant Λ production mechanisms from heavy baryon decays and estimated yields produced per fb^{-1} at $\sqrt{s} = 13\,\text{TeV}$, shown separately for SL and LL topologies. The Λ baryons from Ξ^- decays, produced promptly in the pp collisions, are given in terms of the unmeasured production cross section. [*]

SL events	$N_\Lambda/\,\text{fb}^{-1}$ $(\times 10^{10})$	LL events, $\Xi^- \to \Lambda\pi^-$	$N_\Lambda/\,\text{fb}^{-1}$ $(\times 10^{10})$
$\Xi_c^0 \to \Lambda K^-\pi^+$	7.7	$\Xi_c^0 \to \Xi^-\pi^+\pi^+\pi^-$	23.6
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	3.3	$\Xi_c^0 \to \Xi^-\pi^+$	7.1
$\Xi_c^+ \to \Lambda K^-\pi^+\pi^+$	2.0	$\Xi_c^+ \to \Xi^-\pi^+\pi^+$	6.1
$\Lambda_c^+ \to \Lambda\pi^+$	1.3	$\Lambda_c^+ \to \Xi^-K^+\pi^+$	0.6
$\Xi_c^0 \to \Lambda K^+K^-$ (no ϕ)	0.2	$\Xi_c^0 \to \Xi^-K^+$	0.2
$\Xi_c^0 \to \Lambda\phi(K^+K^-)$	0.1	Prompt Ξ^-	$0.13 \times \sigma_{pp\to\Xi^-}$ $[\mu\text{b}]$



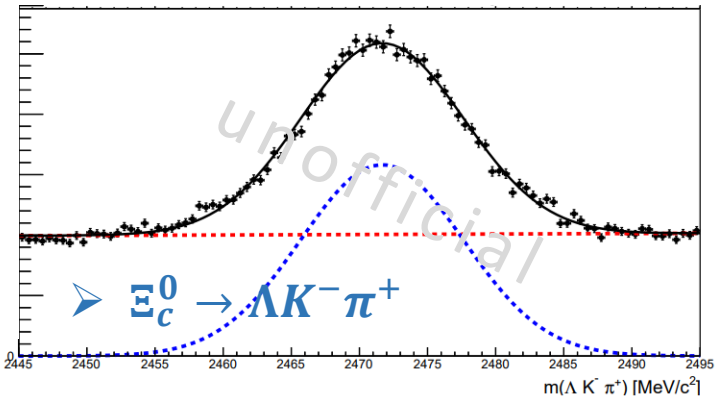


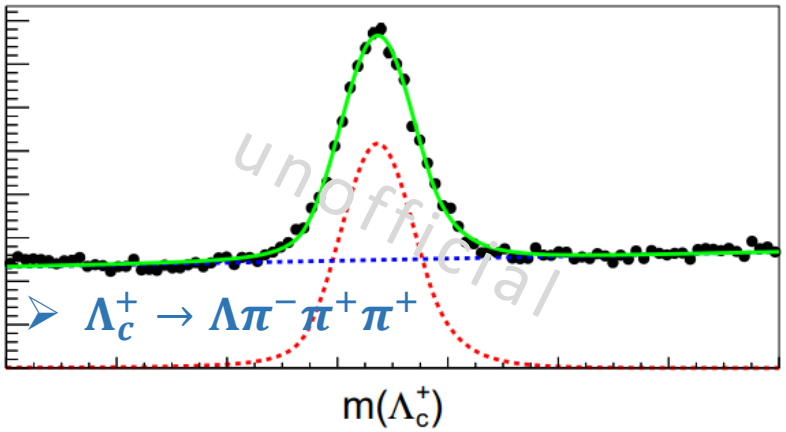
Decays are working in progress:

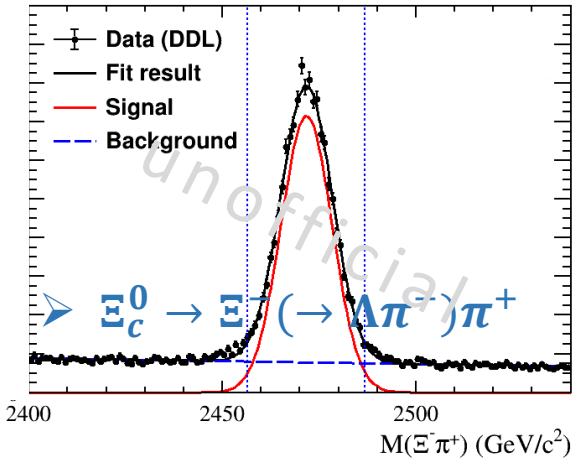
- ✓ $\Xi_c^0 \to \Lambda K^-\pi^+$
- ✓ $\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$
- ✓ $\Xi_c^0 \to \Xi^-(\to \Lambda\pi^-)\pi^+$
- ✓ $\Xi_c^0 \to \Xi^-\pi^-\pi^+\pi^+$

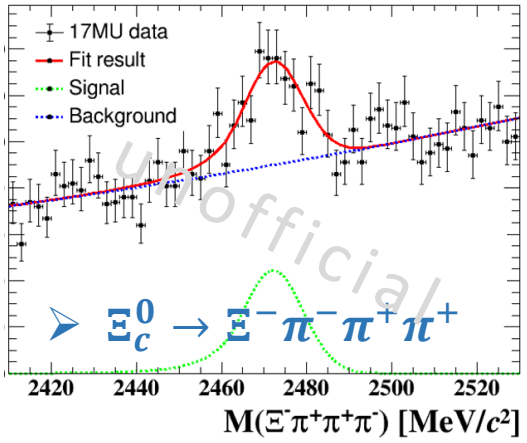
[*] F. J. Botella, L. M. Garcia Martin, D. Marangotto, F. M. Vidal, A. Merli, N. Neri, A. Oyanguren and J. R. Vidal, Eur. Phys. J. C77, 181 (2017)

Available candidates after selection



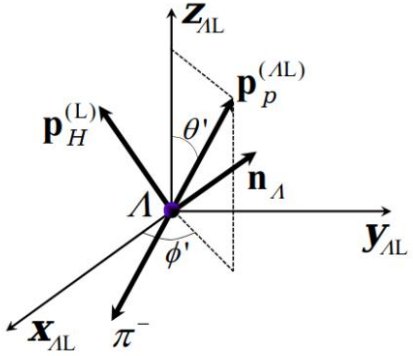






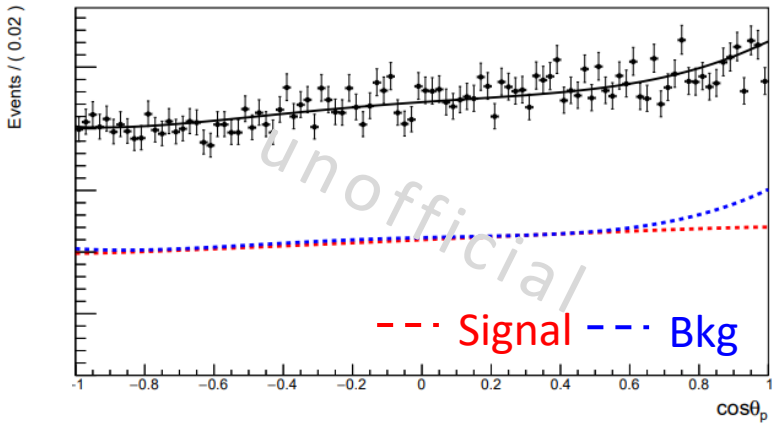
Decays	Data sets	Yields	Purity
$\Xi_c^0 \to \Lambda K^- \pi^+$	2015/16/17	~60k	~50%
$\Lambda_c^+ \to \Lambda \pi^- \pi^+ \pi^+$	2016	~24k	~54%
$\Xi_c^0 \to \Xi^- \pi^+$	2017	~23k	~80%
$\Xi_c^0 \to \Xi^- \pi^- \pi^+ \pi^+$	2017MagUp	~0.4k	~15%

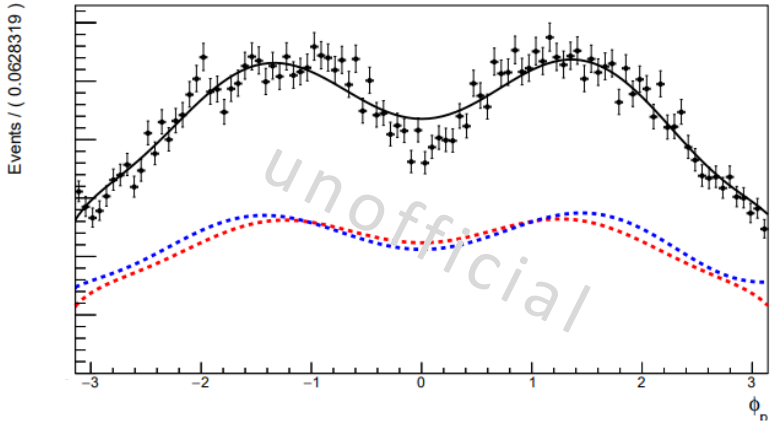
Λ baryon polarization in $\Xi_c^0 \to \Lambda K^- \pi^+$ decay



$$\frac{d\Gamma}{d\Omega}(\cos\theta_p, \phi_p, \vec{P}) \propto 1 + \alpha_\Lambda P_x \sin\theta_p \cos\phi_p + \alpha_\Lambda P_y \sin\theta_p \sin\phi_p + \alpha_\Lambda P_z \cos\theta_p$$

- α_Λ is fixed as PDG value



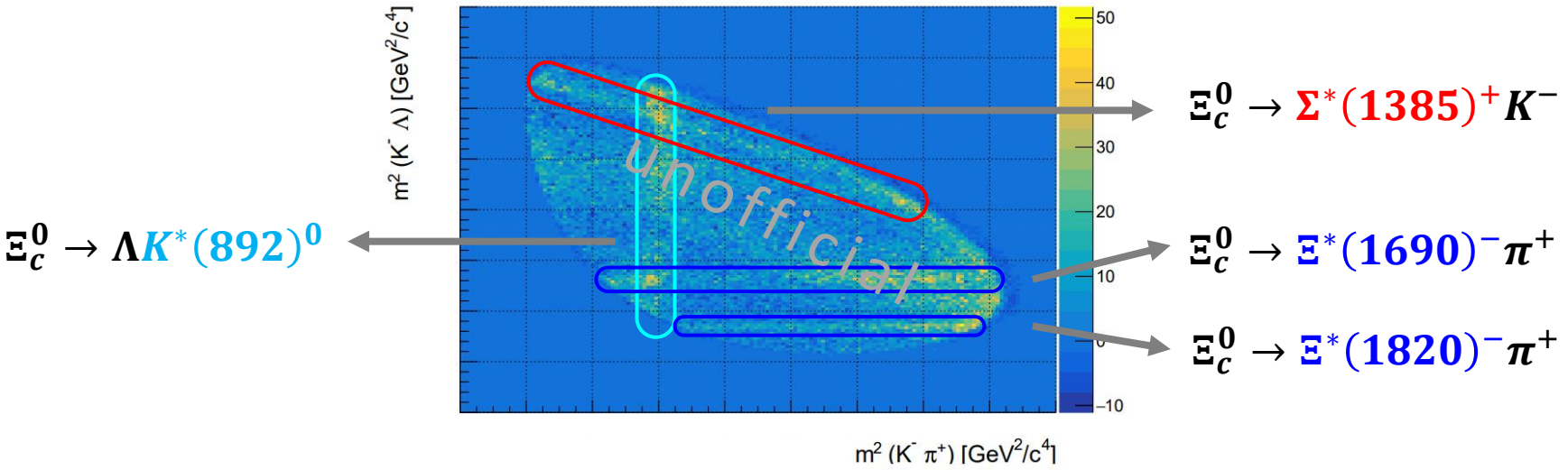


Sensitivity	P_x	P_y	P_z	$\lvert\vec{P}\rvert$
$\Xi_c^0 \to \Lambda K^- \pi^+$	$\pm 0.01 \pm 0.01$	$\pm 0.013 \pm 0.005$	$\pm 0.014 \pm 0.004$	$\pm 0.02 \pm 0.01$

- Good sensitivity on polarization but it may not be as large as other week decays.

Λ baryon polarization dilution

- **Interference of polarization of different decay chains**



- **Polarization suppressed in strong decays [*].**

$$P_\Lambda = C \cdot P_M, C < 1$$

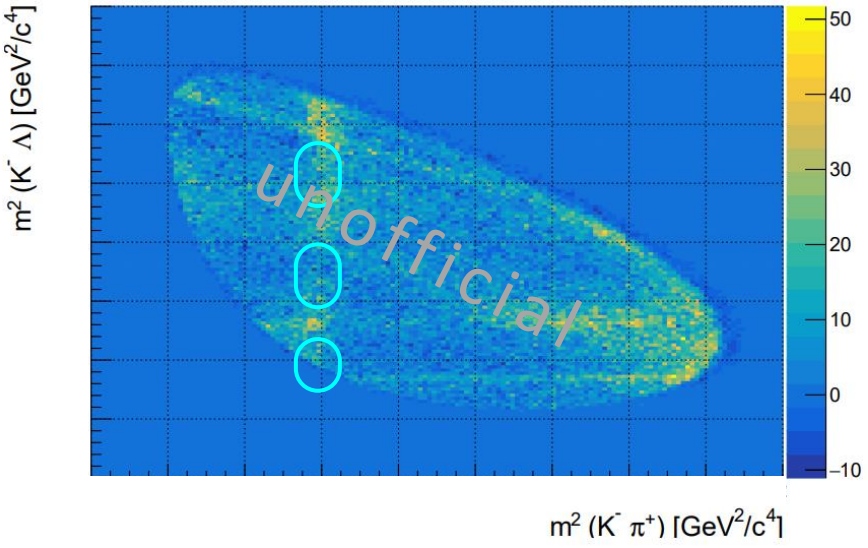
P_M: **polarization of the mother particle**

Decay	C
parity-conserving: $^1/_2^+ \to {}^1/_2^+ \; 0^-$	$-1/3$
parity-conserving: $^1/_2^- \to {}^1/_2^+ \; 0^-$	1
parity-conserving: $^3/_2^+ \to {}^1/_2^+ \; 0^-$	$1/3$
parity-conserving: $^3/_2^- \to {}^1/_2^+ \; 0^-$	$-1/5$

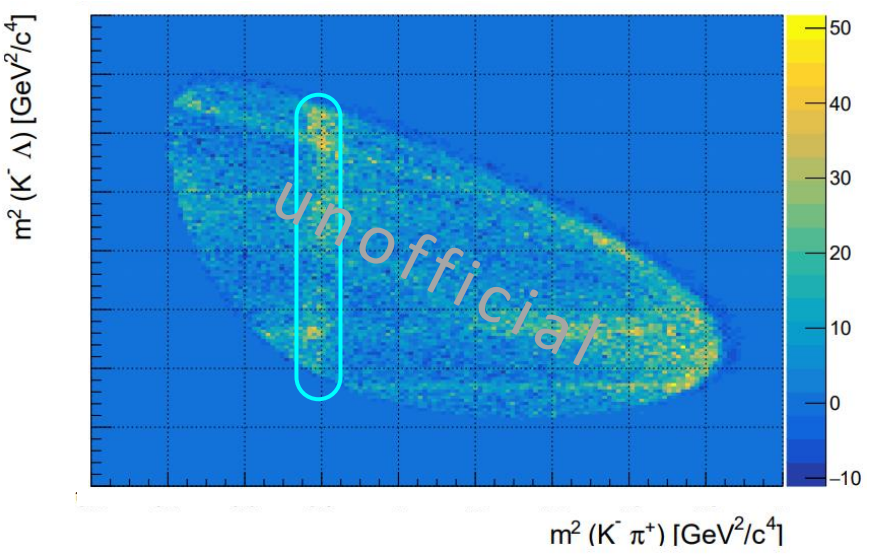
[*] F. Becattini, I. Karpenko, M. Lisa, I. Upsal and S. Voloshin, Phys. Rev. C 95, 054902 (2017)

Λ baryon polarization dilution

➢ **Interference of polarization of different decay chains**



✓ **Only 2-body week decay**

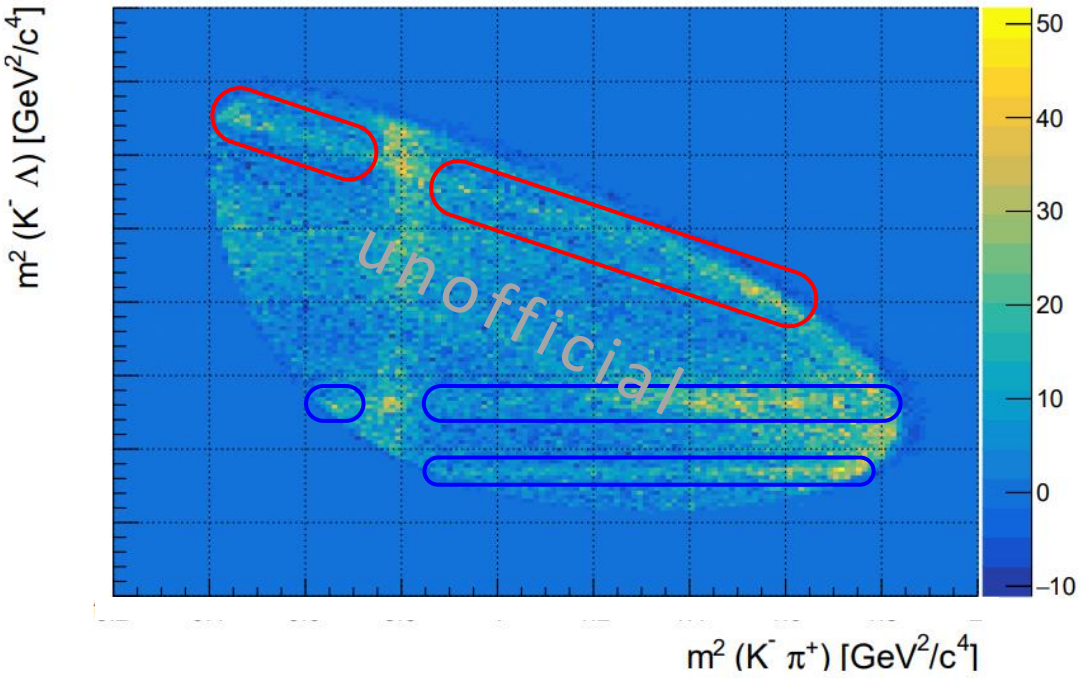


✓ **Interference of different resonances**

Decay		$\lvert\vec{P}\rvert$
$\Xi_c^0 \to \Lambda K^*(892)^0$	Only 2-body week decay	$\sim 0.4x$
	Interference of different resonances	$\sim 0.2x$

Λ baryon polarization dilution

- **Polarization suppressed in strong decays**



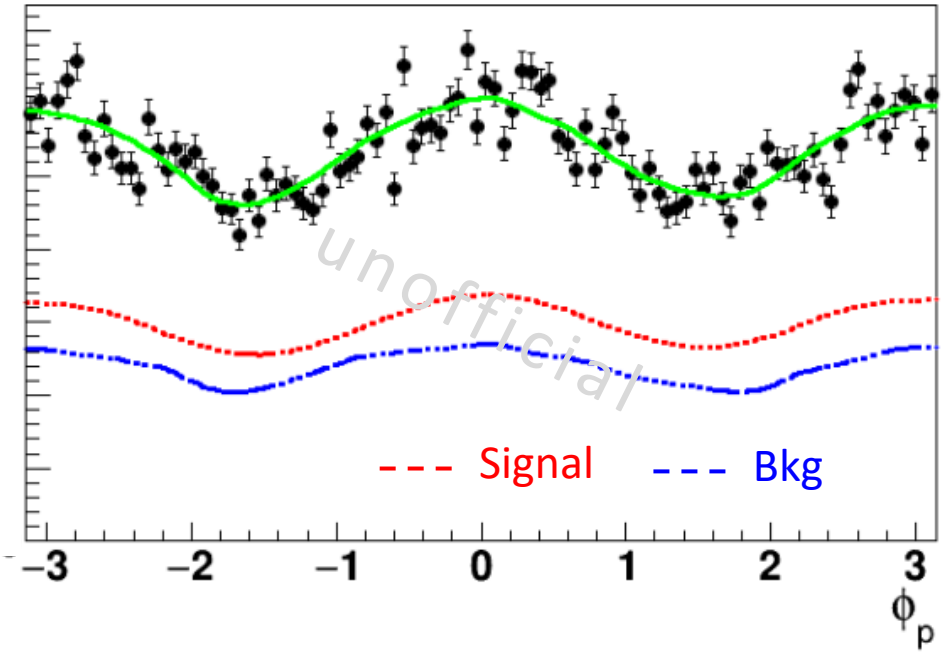
Decay		$\lvert\vec{P}\rvert$
$\Xi_c^0 \to \Sigma^*(1385)^+ K^-$	$\Sigma^*(1385)^+ \to \Lambda\pi^+ \ (3/2^- \to 1/2^+ 0^+)$	$\sim 0.1x$
$\Xi_c^0 \to \Xi^*\pi^+$	$\Xi^*(1690)^- \to \Lambda K^- \ (1/2^- \to 1/2^+ 0^+)$	$\sim 0.2x$
	$\Xi^*(1820)^- \to \Lambda K^- \ (3/2^+ \to 1/2^+ 0^+)$	$\sim 0.0x$

Λ baryon polarization in $\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$ decay

➢ **Angular distribution of $\Lambda \to p\pi^-$**

$$H(\cos\theta_p, \phi_p) \propto 1 + \alpha_\Lambda[(s_x \cos\phi_p + s_y \sin\phi_p) \sin\theta_p + s_z \cos\theta_p]$$

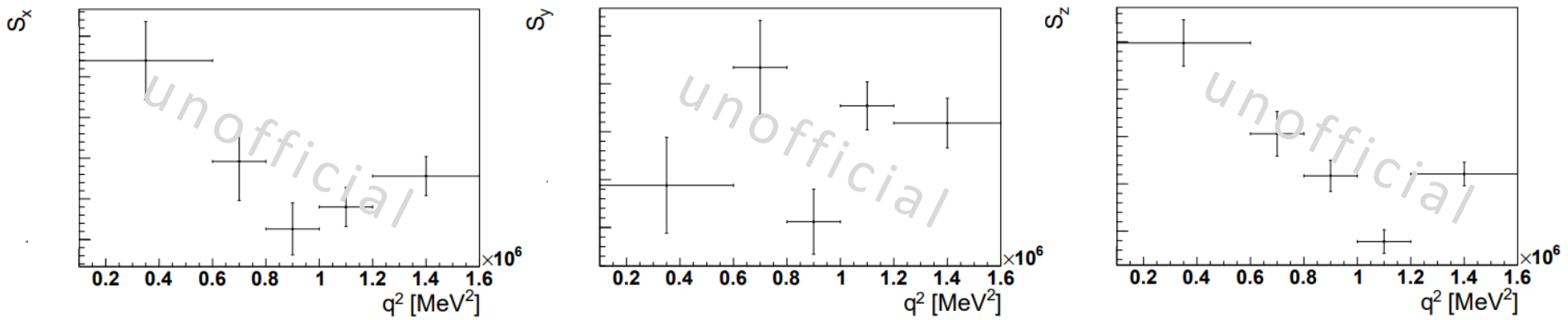
- α_Λ is fixed as PDG value



Sensitivity	P_x	P_y	P_z
$\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$	$\pm 0.02 \pm 0.01$	$\pm 0.02 \pm 0.02$	$\pm 0.02 \pm 0.01$

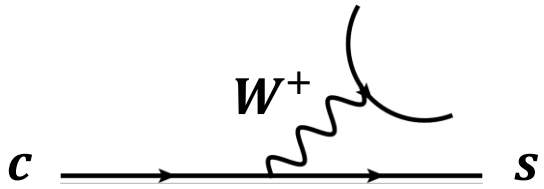
- Based on 2016 data set and only Λ_{DD} sample

Λ baryon polarization in $\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$ decay



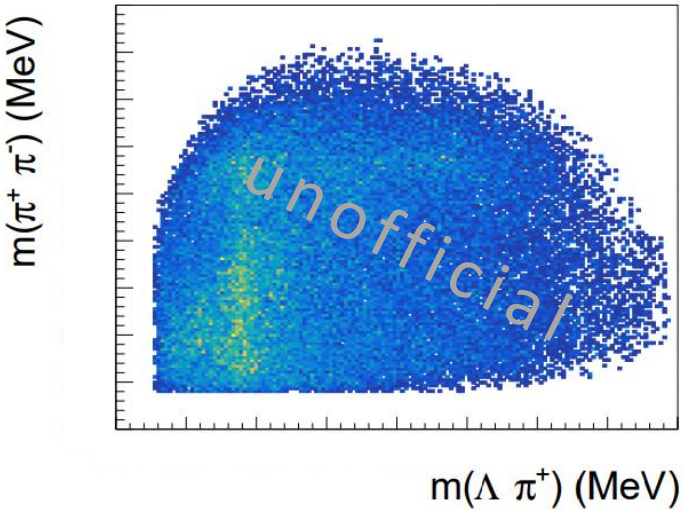
$$q^2 = \left(p_{\Lambda_c^+} - p_\Lambda\right)^2$$

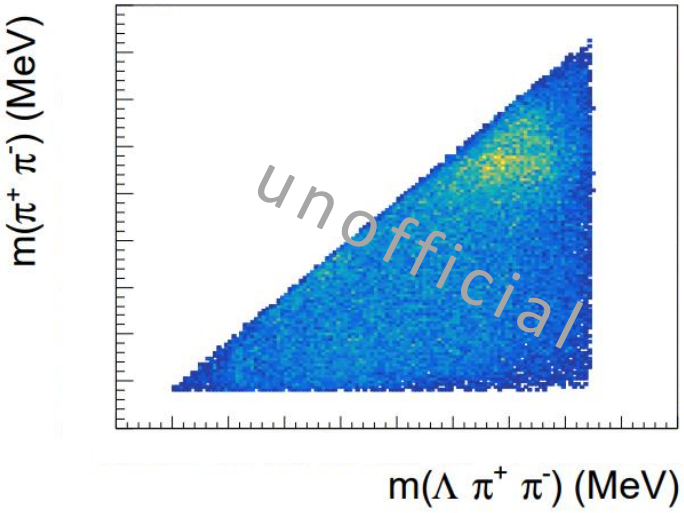
- Strong dependence on q^2 as suggested by leading order diagram

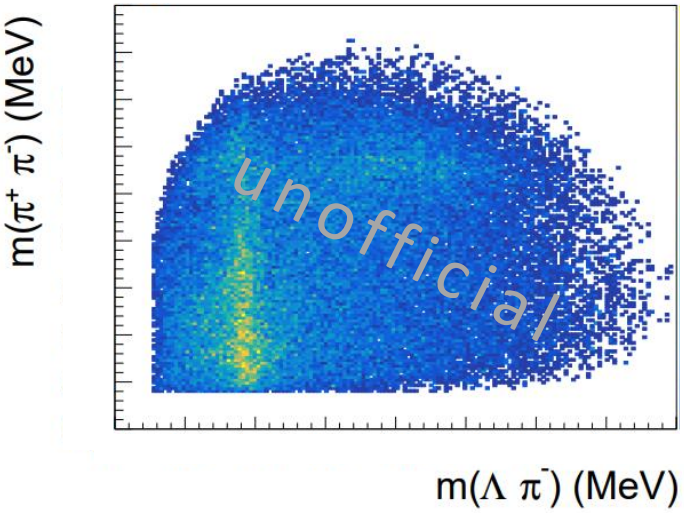


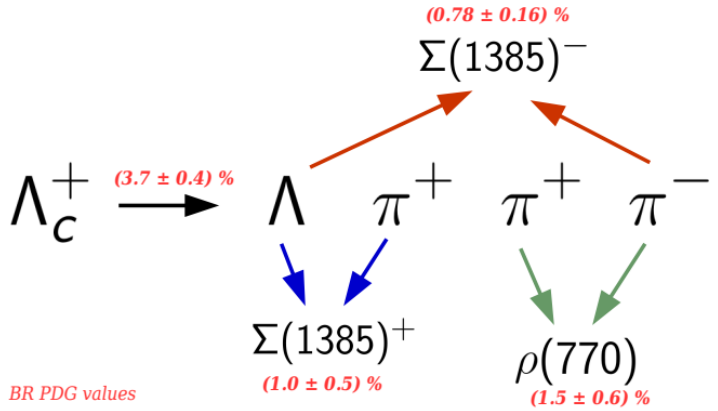
- Further studies to investigate the link between polarization and q^2

Resonant structures in $\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$





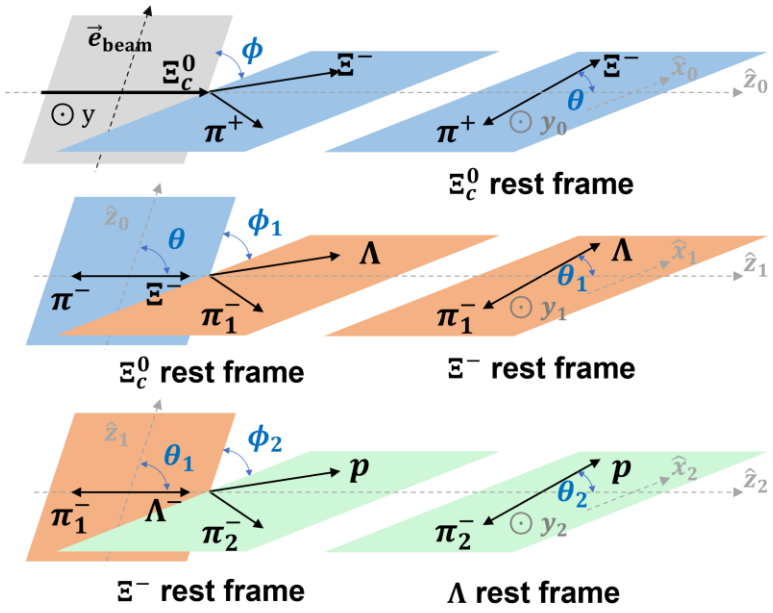




- **A partial-wave-analysis work is ongoing**

Λ baryon polarization in $\Xi_c^0 \to \Xi^-(\to \Lambda\pi^-)\,\pi^+$ decays

- **Definition with helicity amplitudes and helicity coordinate system.**



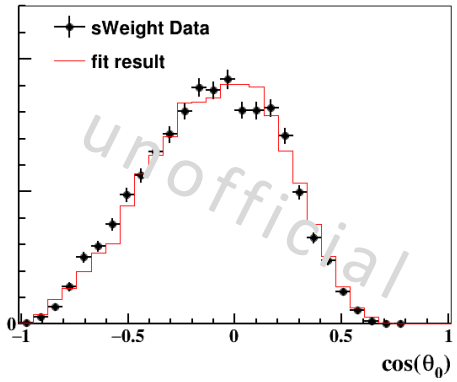
Helicity angle	Helicity amplitudes	Lee-Yang Parameters
(θ, ϕ)	$\mathcal{H}_m, \mathcal{H}_{m'}$	α, β, γ
(θ_1, ϕ_1)	$h_{\lambda_1}, h_{\lambda_1'}$	$\alpha_1, \beta_1, \gamma_1$
(θ_2, ϕ_2)	$f_{\lambda_2}, f_{\lambda_2'}$	$\alpha_2, \beta_2, \gamma_2$

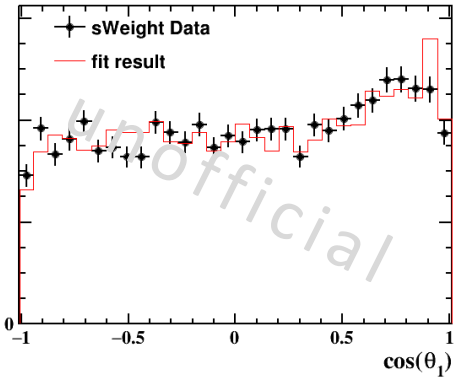
- **The parameters can be extracted from angular formula:**
  - (P_x, P_y, P_z): the polarization of Ξ_c^0
  - (α, β, γ): asymmetry parameters of Ξ_c^0
  - $(\alpha_1, \beta_1, \gamma_1)$: asymmetry parameters of $\Xi^-(\Omega^-)$

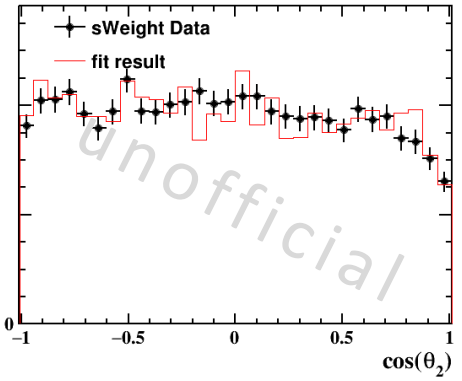
< As the first step >

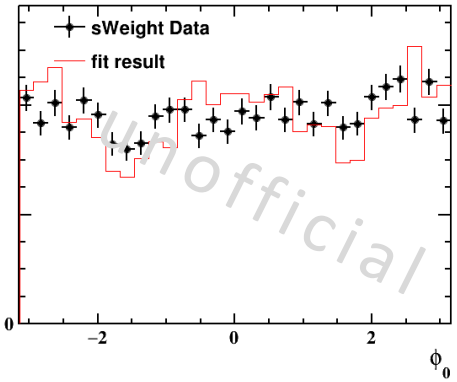
- **With the full angular formula → Λ polarization**

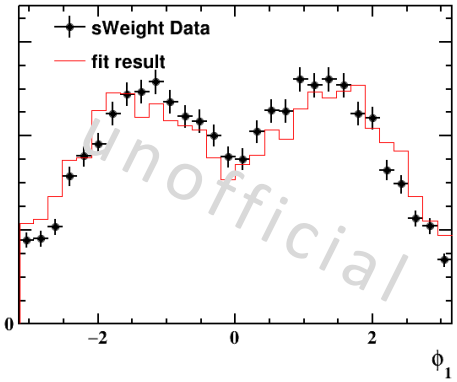
Angular distribution of $\Xi_c^0 \to \Xi^-(\to \Lambda\pi^-)\,\pi^+$

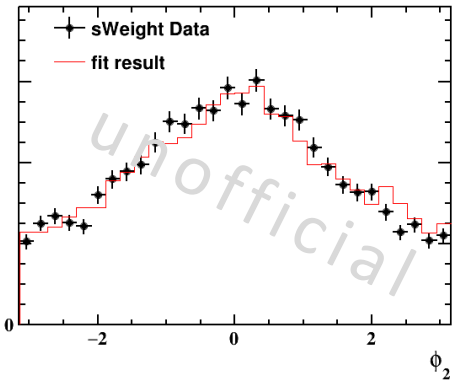












Sensitivity	α	$\phi(°)$	α_1	$\phi_1(°)$
Decay Pars	± 0.02	± 21.5	± 0.02	± 2.5

Sensitivity	P_x	P_y	P_z
polarization of Ξ_c^0	± 0.02	± 0.02	± 0.02

- Based on 2017 data set and only $\Lambda_{\mathrm{DD}}\pi_{\mathrm{L}}$ sample

Summary

- **A precise measurement of Λ baryon polarization in charm baryon decay is promising.**
- **Λ from charm baryons can get a large polarization.**
- **Many measurements on the way for $H_c \to \Lambda X$:**

✓ $\Xi_c^0 \to \Lambda K^- \pi^+$

✓ $\Lambda_c^+ \to \Lambda \pi^- \pi^+ \pi^+$

- **'short-lived'**
- **Many possible intermediate states**

✓ $\Xi_c^0 \to \Xi^- (\to \Lambda \pi^-) \pi^+$ →

- **'long-lived'**
- **Higher purity**

$\Longrightarrow$ CP Violation through Λ polarization,

decay parameters,

…

Backup