DETERMINING THE POLARISATION OF Λ_c FROM THE DALITZ ANALYSIS OF THE $\Lambda_c \to p K \pi$ DECAY

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my side from 2018 FU meeting...
(see also talk by A. Fomin)

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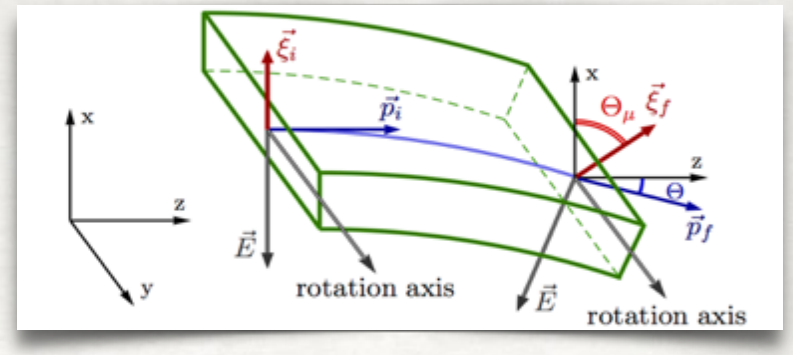


Towards $\mu_{\Lambda c}$ measurement

- The magnetic moment can be determined by measuring the Λ_c polarisation passing through the bent crystal.
- Thus, Λ_c polarisation has to be measured.
- The angular distribution of the Λ_c decay carries information of polarisation however, it can not be separated so-called asymmetry parameter **α**.
- We need to measure this parameter at LHCb in advance.

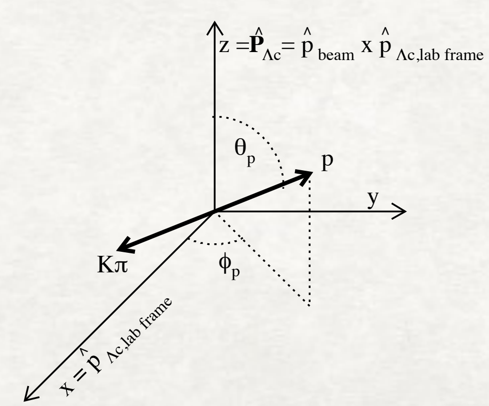
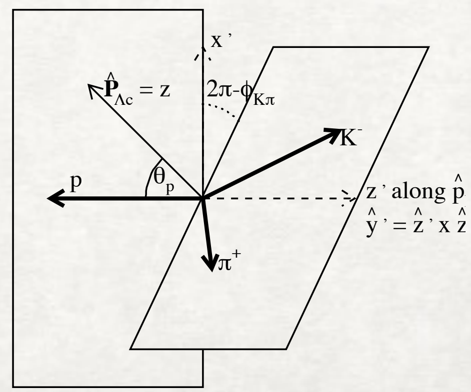
PHD PROJECT OF E. NIEL (IJCLAB)

$$\frac{1}{N}\frac{dN}{d\cos\vartheta_k} = \frac{1}{2}\left(1 + \alpha\,\xi_k \cos\vartheta_k\right)\Big|_{k=x,y,z}$$

weak parameter polarisation

INTERNSHIP PROJECT OF MAKSYM LIUL

- Theoretical computation of the Λc→Kpπ decays

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What we understood in 2018...

- We studied the three body decays.
- $\Lambda c \to \Lambda\pi \to p\pi\pi$ decay

$$\begin{aligned}\frac{dN}{d\cos\theta} &= 4m_\Lambda^2 N_1 N_2 (1+\alpha_1\alpha_2\cos\theta - \xi(\alpha_1-\alpha_2\cos\theta)) \\ &= 4m_\Lambda^2 N_1 N_2 (1-\xi\alpha_1+\alpha_2(\alpha_1+\xi)\cos\theta)\end{aligned}$$

$$\begin{aligned}N_1 &= (E_{\Lambda_c}+m_{\Lambda_c})|A|^2+(E_{\Lambda_c}-m_{\Lambda_c})|B|^2 \\ N_2 &= (E_p+m_p)|a|^2+(E_p-m_p)|b|^2 \\ \alpha_1 &= \frac{2\mathrm{Re}(AB^*)|\vec{p}_{\Lambda_c}|}{N_1} \\ \alpha_2 &= \frac{2\mathrm{Re}(ab^*)|\vec{p}_p|}{N_2}\end{aligned}$$

A,B: form factor for $\Lambda c \to \Lambda\pi$decay
a,b: form factor for $\Lambda \to p\pi$decay

parity violating

- In this case where the first and the second decays are weak decays (both include parity violation), the angular dependence together with the information of α_2=0.642±0.013 allows to determine ξ and α_1 separately.
- Problem: the decay rate is very small.

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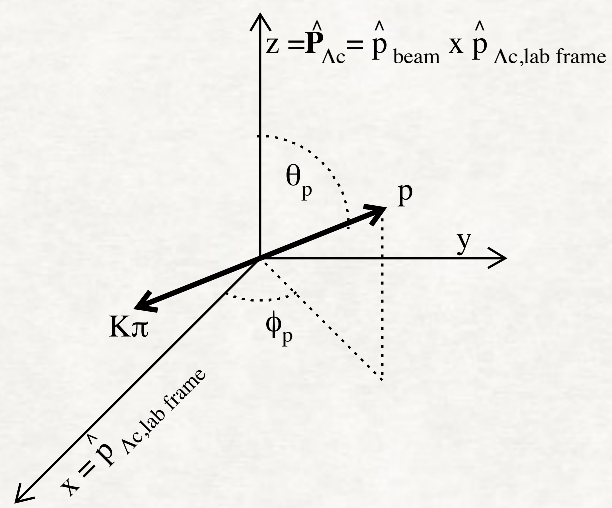
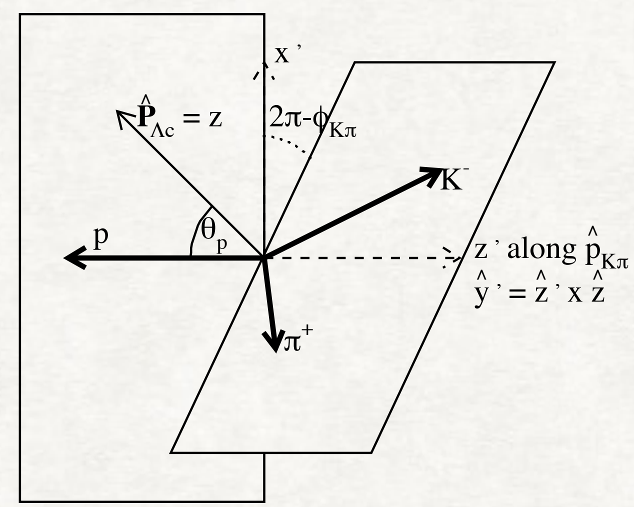
What we understood in 2018…

- $\Lambda c \to (K^{*}p, \Delta^{++}K, \Lambda\pi) \to pK\pi$ decay
- This decay was studied by the Fermilab E791 experiment.
- We first followed their formalism (helicity amplitude method).





What we understood in 2018…

- $\Lambda c \to (K^{*}p, \Delta^{++}K, \Lambda\pi) \to pK\pi$ decay

The $\Lambda_c \to K^*(\to K\pi)p$ decays

$$\frac{d\Gamma}{d\cos\theta d\cos\theta' d\phi} = a0 + a1\cos 2\theta' + P_{\Lambda_c}\cos\theta(b0 + b1\cos 2\theta') + P_{\Lambda_c}\sin\theta\sin 2\theta'(c1\cos(\phi-\phi') + c2\sin(\phi-\phi'))$$

$$\begin{aligned}
a0 &= \frac{1}{8}(E_1^2 + 2E_2^2 + 2E_3^2 + E_4^2) \\
a1 &= -\frac{1}{8}(E_1^2 - 2E_2^2 - 2E_3^2 + E_4^2) \\
b0 &= \frac{1}{8}(E_1^2 - 2E_2^2 + 2E_3^2 - E_4^2) \\
b1 &= -\frac{1}{8}(E_1^2 + 2E_2^2 - 2E_3^2 - E_4^2) \\
c1 &= \frac{1}{2\sqrt{2}}(E_1E_2\cos(\phi_1 - \phi_2) - E_3E_4\cos(\phi_3 - \phi_4)) \\
c2 &= \frac{1}{2\sqrt{2}}(E_1E_2\sin(\phi_1 - \phi_2) - E_3E_4\sin(\phi_3 - \phi_4))
\end{aligned}$$

E1,E4: form factor for S wave decay
E2,E3: form factor for P wave decay
parity violating

$P_{\Lambda c}$: polarisation (= ξ)

- We can not separately measure all the form factors and the polarisation in this case.

$$\{a0, a1, b0, b1, c1, c2\} \longrightarrow \{|E_1|, |E_2|, |E_3|, |E_4|, (\phi_1 - \phi_2), (\phi_3 - \phi_4), P_{\Lambda_c}\}$$

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What we understood in 2018...

- $\Lambda c \to (K^* p, \Delta^{++} K, \Lambda \pi) \to pK\pi$ decay

The $\Lambda_c \to \Delta^{++}(1232)(\to p\pi)K$ decays

$$\frac{d\Gamma}{d\cos\theta d\cos\theta' d\phi} = a0 + a1\cos 2\theta' + P_{\Lambda_c}\cos\theta(b0 + b1\cos 2\theta')$$

$$\begin{aligned} a0 &= \frac{5}{16}(F_1^2 + F_2^2) \\ a1 &= \frac{3}{16}(F_1^2 + F_2^2) \\ b0 &= \frac{5}{16}(F_1^2 - F_2^2) \\ b1 &= \frac{3}{16}(F_1^2 - F_2^2) \end{aligned}$$

The $\Lambda_c \to \Lambda(1520)(\to pK)\pi$ decays

$$\frac{d\Gamma}{d\cos\theta d\cos\theta' d\phi} = a0 + a1\cos 2\theta' + P_{\Lambda_c}\cos\theta(b0 + b1\cos 2\theta')$$

$$\begin{aligned} a0 &= \frac{5}{16}(H_1^2 + H_2^2) \\ a1 &= \frac{3}{16}(H_1^2 + H_2^2) \\ b0 &= \frac{5}{16}(H_1^2 - H_2^2) \\ b1 &= \frac{3}{16}(H_1^2 - H_2^2) \end{aligned}$$

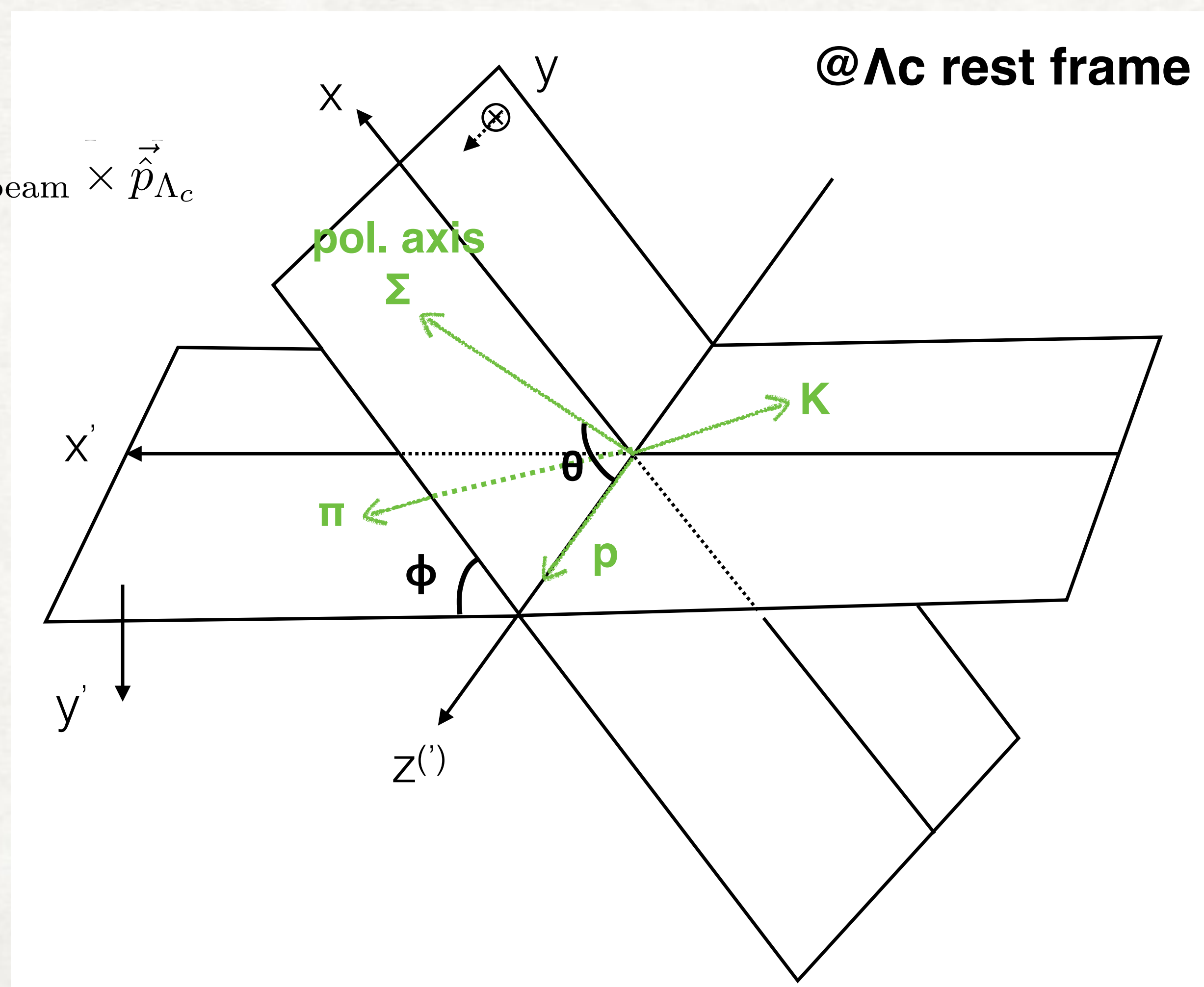
- The same conclusions: we can not separately measure all the form factors and the polarisation.
- The interference of these intermediate states allow the separation ???

Computing the interference terms

E.K. A. Korchin, V. Kovalchuk in progress

- It seems complicated to compute the interference term in the helicity amplitude method where we use various rest frames (→this problem is discussed and a solution is proposed in arXiv:1910.04566).
- We decided to use a single frame defined as

$\vec{\Sigma} = \vec{p}_{\mathrm{beam}} \times \vec{p}_{\Lambda_c}$



We use Λc rest frame with

- x′-y′-z′: the pKπ decay plane
- x-z: p-Σ plane
- z(′): proton direction

Computing the interference terms

E.K. A. Korchin, V. Kovalchuk in progress

- We don’t rely on the helicity amplitude method and compute it according to Feynman rules.

$$d\Gamma(\xi) = \frac{1}{(2\pi)^4}\frac{1}{32 s^{3/2}}|\mathcal{M}|^2 dm_{12}^2 dm_{23}^2 d\theta$$

$$\mathcal{M} = \mathcal{M}_{\Lambda'}\mathcal{BW}_{\Lambda'}(s_{12}) + \mathcal{M}_{\Delta^{++}}\mathcal{BW}_{\Delta^{++}}(s_{13}) + \mathcal{M}_{K^*}\mathcal{BW}_{K^*}(s_{23})$$

$$\begin{aligned}
\mathcal{M}_{\Lambda'} &= \overline{u}(p)_{\lambda_p}\mathcal{A}_{\Lambda'}u_{\Lambda_c}(Q)\\
\mathcal{M}_{\Delta^{++}} &= \overline{u}(p)_{\lambda_p}\mathcal{A}_{\Delta^{++}}u_{\Lambda_c}(Q)\\
\mathcal{M}_{K^*} &= \overline{u}(p)_{\lambda_p}\mathcal{A}_{K^*}u_{\Lambda_c}(Q)
\end{aligned}$$

$$\mathcal{BW}_R(s_R) = \frac{1}{s_R - m_R^2 + i m_R \Gamma_R}$$

$$\begin{aligned}
\mathcal{A}_{\Lambda'} &= G_{\Lambda'}\mathcal{BW}_{\Lambda'}(s_{12})\Big\{p_\mu\gamma_5(\not{q}_1 + m_{\Lambda'})R^{\mu\nu}(q_1)C_\nu^{\Lambda'}\Big\}\\
\mathcal{A}_{\Delta^{++}} &= G_{\Delta^{++}}\mathcal{BW}_{\Delta^{++}}(s_{13})\Big\{p_\mu(\not{q}_2 + m_{\Delta^{++}})R^{\mu\nu}(q_2)C_\nu^{\Delta^{++}}\Big\}\\
\mathcal{A}_{K^*} &= G_{K^*}\mathcal{BW}_{K^*}(s_{23})\Big\{R^\mu(q_3)C_\mu^{K^*}\Big\}
\end{aligned}$$

$$\begin{aligned}
C_\nu^{\Lambda'} &= Q_\nu(C\gamma_5 + D)\\
C_\nu^{\Delta^{++}} &= Q_\nu(A\gamma_5 + B)\\
C_\mu^{K^*} &= E_1\gamma_\mu + E_2 Q_\mu + \gamma_5(F_1\gamma_\mu + F_2 Q_\mu)
\end{aligned}$$

parity violating

(interim) Results...

E.K. A. Korchin, V. Kovalchuk in progress

- Let us first see the individual resonance contributions. It turned out that the angular distribution fit in single expression:

$$d\Gamma(\xi) \propto [a_0 - b_0 \xi \cos\theta - b_1 \xi \sin\theta \cos\phi]$$

a_0, b_0, b_1 are VERY complicated functions of the Dalitz variables

example of $\Lambda c \rightarrow \Delta^{++} K \rightarrow pK\pi$

a_0, b_0, b_1 are proportional to

$$\begin{aligned} a_0 &: |A|^2, |B|^2 \\ b_0 &: \xi Re(AB^*) \\ b_1 &: \xi Re(AB^*) \end{aligned}$$

Dalitz analysis gives information of

$$\begin{aligned} a_0 &\longrightarrow |A|, |B| \\ b_0 &\longrightarrow \xi |A||B| \cos\delta_{AB} \end{aligned}$$

$$\delta_{AB} = \delta_A - \delta_B$$

a_0, $b_{0,1}$ give information of |A|, |B| and ξ cosδ_{AB}

and can not provide ξ (unless δ_{AB}=0)

(interim) Results...

E.K. A. Korchin, V. Kovalchuk in progress

- Next we see the interference terms

example of $\Lambda c \to \Delta^{++} K \to pK\pi$ $\Lambda c \to \Lambda\pi \to pK\pi$ intermediate term

$$d\Gamma(\xi) \propto [a_0 - b_0 \xi \cos\theta - b_1 \xi \sin\theta \cos\phi]$$

$$\begin{aligned}
a_0 &: |A|^2, |B|^2, |C|^2, |D|^2, Re(AD^*), Re(BC^*), Im(AD^*), Im(BC^*) \\
b_0 &: \xi Re(AB^*), \xi Im(AB^*), \xi Re(CD^*), \xi Im(CD^*), \xi Re(AC^*), \xi Im(AC^*), \xi Re(BD^*), \xi Im(BD^*) \\
b_1 &: \xi Re(AB^*), \xi Im(AB^*), \xi Re(CD^*), \xi Im(CD^*), \xi Re(AC^*), \xi Im(AC^*), \xi Re(BD^*), \xi Im(BD^*)
\end{aligned}$$

imaginary part is now accessible!!!

$$\begin{aligned}
a_0 &\longrightarrow |A|, |B|, |C|, |D|, \; |A||D|\cos\delta_{AD}, |A||D|\sin\delta_{AD}, \; |B||C|\cos\delta_{BC}, |B||C|\sin\delta_{BC} \\
b_0 &\longrightarrow \xi|A||B|\cos\delta_{AB}, \xi|A||B|\sin\delta_{AB}, \; \xi|C||D|\cos\delta_{CD}, \xi|C||D|\sin\delta_{CD}, \\
&\quad\;\; \xi|A||C|\cos\delta_{AC}, \xi|A||C|\sin\delta_{AC}, \; \xi|B||D|\cos\delta_{BD}, \xi|B||D|\sin\delta_{BD}
\end{aligned}$$

then, using the following relation, we can separate ξ !!!

$$\frac{(\xi|A||B|\cos\delta_{AB})^2 + (\xi|A||B|\sin\delta_{AB})^2}{|A|^2|B|^2} = \xi^2$$

(interim) Results...

E.K. A. Korchin, V. Kovalchuk in progress

- Why are we accessible to the imaginary part???
- The A, B, C… function are actually multiplied by the Breit-Wigner of each resonance:

$$A \longrightarrow A\ \mathcal{BW}_{\Delta^{++}}(s_{13}), \quad B \longrightarrow B\ \mathcal{BW}_{\Delta^{++}}(s_{13})$$
$$C \longrightarrow C\ \mathcal{BW}_{\Lambda'}(s_{12}), \quad D \longrightarrow D\ \mathcal{BW}_{\Lambda'}(s_{12})$$

- When we compute a single resonance, it simply factors out, e.g.

$$Re(AB^*) \longrightarrow Re(AB^*)|\mathcal{BW}_{\Delta^{++}}(s_{13})|^2$$

- When we have two resonances, these interfere and make it possible separate the real and imaginary parts

$$Re(AD^*) \longrightarrow Re(AD^*)Re(\mathcal{BW}_{\Delta^{++}}(s_{13})\mathcal{BW}^*_{\Lambda'}(s_{12})) - Im(AD^*)Im(\mathcal{BW}_{\Delta^{++}}(s_{13})\mathcal{BW}^*_{\Lambda'}(s_{12}))$$

What's next ?

E.K. A. Korchin, V. Kovalchuk in progress

- We need to perform the sensitivity study "how precisely we can measure the polarisation ξ at LHCb/SMOG" (for now, with three resonances).
- By doing such study, one can clarify, e.g.
    - ☑ Is the Dalitz distributions different enough for the different resonances to distinguish A, B, C… parameters?
    - ☑ Is ϕ distribution important in ξ determination?
- These are simultaneous fit of 8x2 form factors and 1 polarisation parameter.
- We developed a fit program called "Gampola" during internship of B. Knysh (now Belle II-IJCLab group), which can do such a fit very fast.
- It will be great if a very motivated internship student could join to work on this exciting project!

Conclusions

- The charm magnetic moment determination with bent-crystal requires a measurement of the Λ_c polarisation.
- It has been puzzling for us how to separately measure the asymmetry parameter and the polarisation.
- We introduced a new frame to compute the interference of the different intermediate states and have shown that indeed, the intermediate terms give extra information to determine full form factors and polarisation.
- We are now ready do perform the sensitivity study.
- The French-Ukraine collaboration have been very fruitful!
- Stay tuned!