DETERMINING Λ_C POLARISATION FROM USING $\Lambda_C \to P K \Pi$ DECAY

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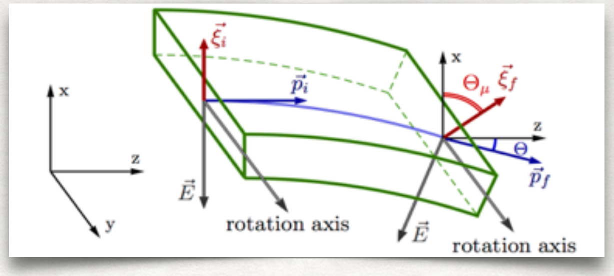
in collaboration with A. Korchin and V. Kovalchuk
AND
A. Lukianchuk and F. Callet (internships)

French-Ukrainian workshop, 28 October 2021 at IJCLab

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

A. Fomin et al
Eur.Phys.J.C 80 (2020)



Towards $\mu_{\Lambda c}$ measurement

- The magnetic moment can be determined by measuring the Λ_c polarisation passing through the bent crystal.
- 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)

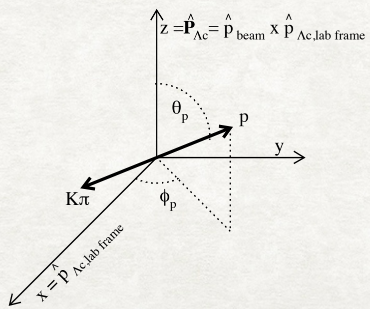
$$\frac{1}{N}\frac{dN}{d\cos\vartheta_k} = \frac{1}{2}\left(1 + \alpha\,\xi_k \cos\vartheta_k\right)\Big|_{k=x,y,z}$$

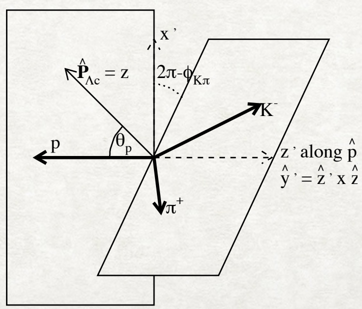
weak parameter
(parity violating)

polarisation

INTERNSHIP PROJECT
OF MAKSYM LIUL

- Theoretical computation of the Λc→Kpπ decays

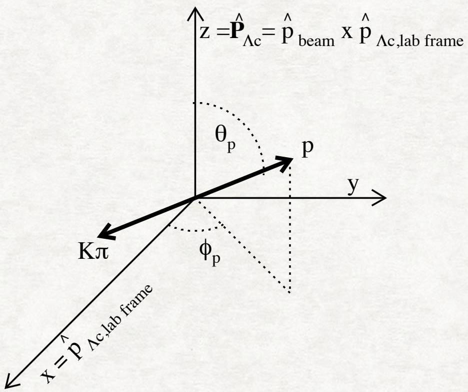


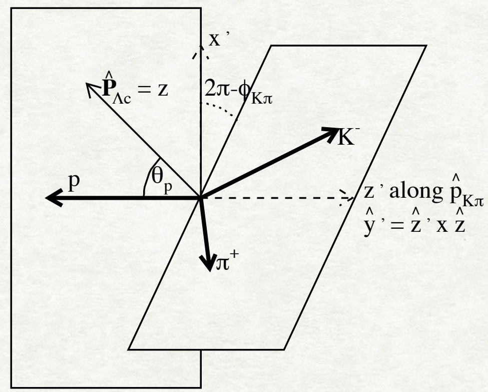


Polarisation measurement in the past...

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

- It was first studied by the Fermilab E791 experiment.
- E791: amplitude analysis including 3 resonances, using the helicity amplitude method.



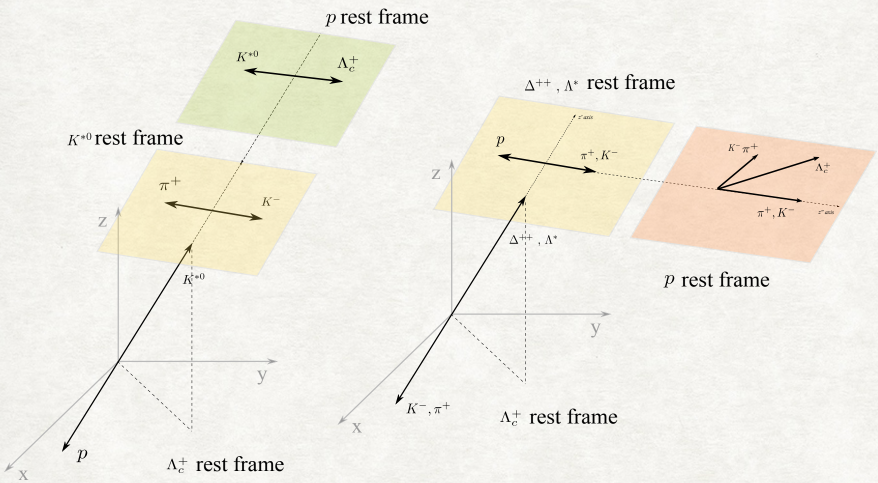


Polarisation measurement at LHCb @ IJCLab

PHD @ LHCB GROUP
E. NIEL (IJCLAB)

$\Lambda_c \rightarrow (K^*p, \Delta^{++}K, \Lambda\pi^+ \ldots\ldots) \rightarrow pK\pi$ decay

- The first polarisation measurement in pp collision (LHC)
- Amplitude analysis including dozens of resonances
- The (modified) helicity amplitude method



Res	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
pK channel													
$\Lambda^*(1405)$	✗	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Lambda^*(1520)$	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Lambda^*(1600)$	✗	✗	✔	✔	✔	✔	✔	✔	✗	✗	✔	✔	✔
$\Lambda^*(1670)$	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Lambda^*(1690)$	✗	✗	✗	✗	✗	✗	✗	✔	✔	✗	✗	✔	✔
$\Lambda^*(1800)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(1810)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(1820)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(1830)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(1890)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(2000)$	✗	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Lambda^*(2100)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\Lambda^*(2110)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$p\pi$ channel													
$\Delta^{++}(1232)$	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Delta^{++}(1600)$	✗	✗	✗	✗	✔	✔	✔	✔	✔	✔	✔	✔	✔
$\Delta^{++}(1620)$	✗	✗	✗	✗	✗	✗	✔	✔	✔	✔	✔	✔	✗
$\Delta^{++}(1700)$	✗	✗	✗	✗	✗	✔	✔	✔	✔	✔	✔	✔	✔
$K\pi$ channel													
$K^*(700)$	✗	✗	✗	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$K^*(892)$	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
$K^*(1410)$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✔	✔	✗
$K_0^*(1430)$	✗	✗	✗	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

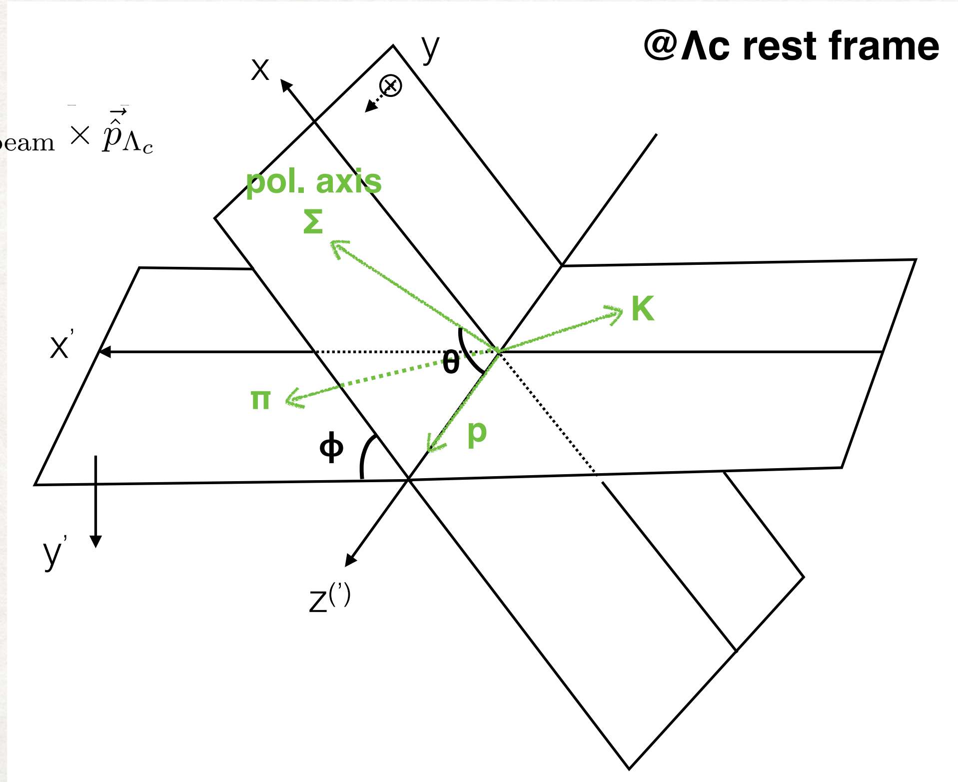
Theory for Polarisation measurement @ IJCLab-Kharkov

E.K. A. Korchin, V. Kovalchuk

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

- Amplitude computation by Feynman diagram
- Only intermediate 3 resonances (3/2+, 3/2-, 1-), to start…
- Choice of frame : common for 3 resonances

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



We use Λc rest frame with

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

INTERNSHIP PROJECT OF ALEKSEY LUKIANCHUK

Theory for Polarisation measurement @ IJCLab-Kharkov

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- The decay rate is written by form factors and Breite-Wigner for each resonance, on top of the polarisation parameter ξ.

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

In this work, we include only 3 intermediate resonances: Λ′ (3/2-)Δ++(3/2+),K(1-)*

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

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

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

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

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

parity violating

INTERNSHIP PROJECT OF ALEKSEY LUKIANCHUK

Theory for Polarisation measurement @ IJCLab-Kharkov

E.K. A. Korchin, V. Kovalchuk

- Our final result can be written in a simple form:

$$\frac{d\Gamma}{ds_{12}d_{13}d\cos\theta d\phi}$$
$$= a(s_{12}, s_{13}) + \xi\Big(\underbrace{b_0(s_{12}, s_{13})\cos\theta + b_1(s_{12}, s_{13})\sin\theta\cos\phi + b_2(s_{12}, s_{13})\sin\theta\sin\phi}_{\equiv b(s_{12}, s_{13}, \cos\theta, \phi)}\Big)$$

a, b_0, b_1, b_2 are written by the form factors, A, B, C, D, E_i, F_i and the Breit-Wigner of each resonance (see previous page).

A ($\cancel{\mathscr{P}}$), B($\mathscr{P}$)
C ($\mathscr{P}$), D($\cancel{\mathscr{P}}$)
$E_{1,2}$ ($\mathscr{P}$), $F_{1,2}$($\cancel{\mathscr{P}}$)

a : Dalitz distribution (parity even)
b_0 : Equivalent to α (parity odd)
b_2 : triple product (CP or T odd ?)

- a contains $|A|^2$, $|B|^2$, … $|F_i|^2$ and interferences, BC, AD, $BE_{1,2}$, $AF_{1,2}$….
- b_0 contains interferences, AB, CD, $E_{1,2}F_{1,2}$, AC, BD, $AE_{1,2}$, $BF_{1,2}$….
- b_2 contains imaginary part

INTERNSHIP PROJECT
OF ALEKSEY LUKIANCHUK

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We perform the simultaneous fit of form factor (A, B…F_i) and polarisation ξ using 4 dimensional kinematics (s_{12}, s_{13}, θ ϕ).

A ($\not{\mathscr{P}}$), B($\mathscr{P}$)
C ($\mathscr{P}$), D($\not{\mathscr{P}}$)
$E_{1,2}$ ($\mathscr{P}$), $F_{1,2}$($\not{\mathscr{P}}$)

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INTERNSHIP PROJECT OF ALEKSEY LUKIANCHUK

The sensitivity study: proof of concept

E.K. A. Korchin, V. Kovalchuk

Step 1) Obtain a example MC data from LHCb (with only 3 resonances)
Step 2) Construct our model (i.e. fitting our form factors using the MC Dalitz plot)
Step 3) Perform the simultaneous fit using events generated using our model

We use the “omega” method (c.f. Gampola, tau polarisation measurement, ILC top spin measurement…).

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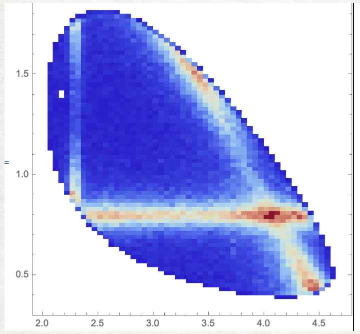
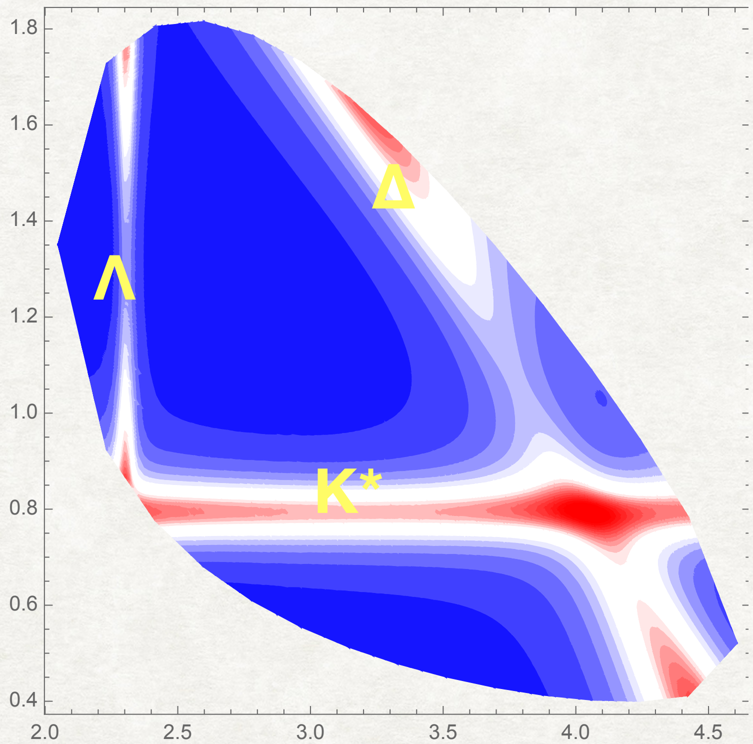
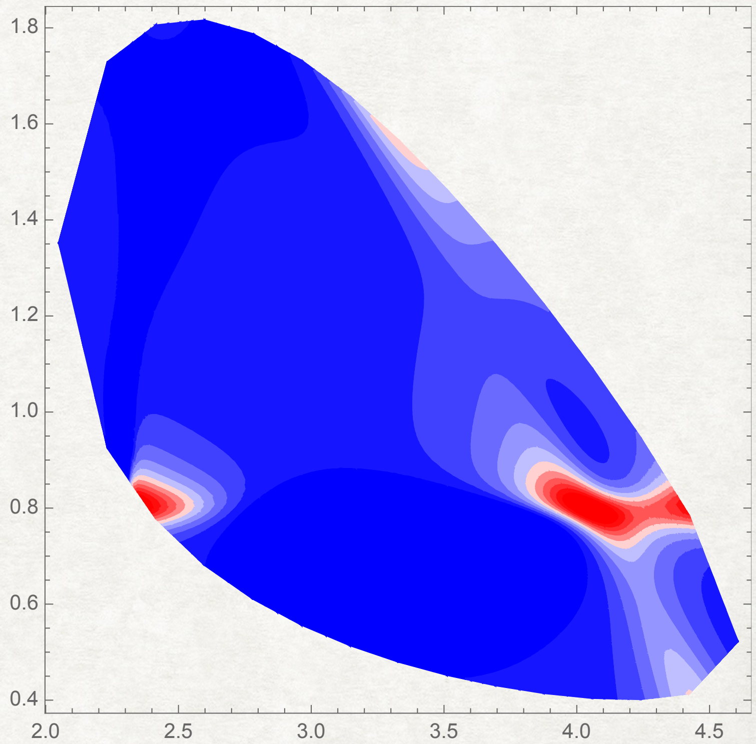


P1: p
P2: K
P3: pi

a coefficient on m12-m23 Dalitz plane



b_0 coefficient on m12-m23 Dalitz plane



INTERNSHIP PROJECT OF FLAVIEN CALLET

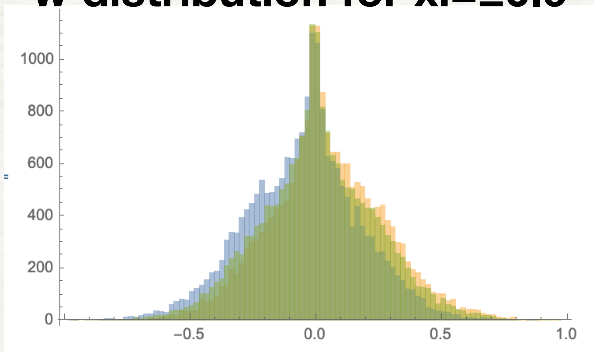
The sensitivity study: proof of concept

E.K. A. Korchin, V. Kovalchuk

Preliminary result of fit

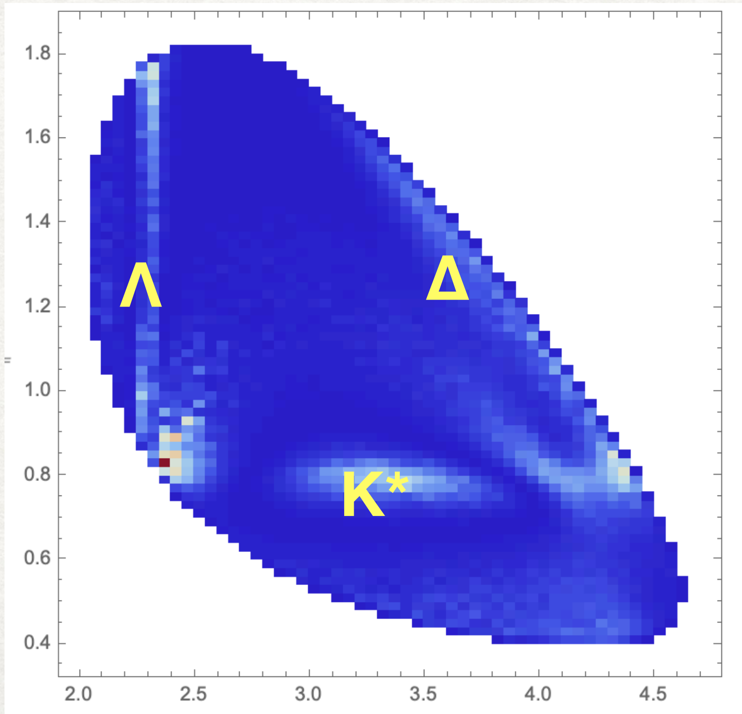
```
Param :
A,B,C,D,A1,A2,B1,B2
-0.762658,1.14336,4.65073,1.25921,-0.278177,0.0303613,0.257899,-0.480634
```

w distribution for xi=±0.9



	A	B	C	D	A1	A2	B	B2
A	1	0.221319	0.423237	-0.518167	0.435468	-0.435138	0.259507	-0.0576802
B	0.221319	1	0.437175	-0.25942	-0.25835	0.150533	0.213008	-0.0084081
C	0.423237	0.437175	1	-0.642163	-0.013463	0.0186317	0.0825147	0.1264
D	-0.518167	-0.25942	-0.642163	1	-0.150709	0.0912629	-0.11742	-0.212142
A1	0.435468	-0.25835	-0.013463	-0.150709	1	-0.957669	0.227852	-0.0970739
A2	-0.435138	0.150533	0.0186317	0.0912629	-0.957669	1	-0.27546	0.309624
B1	0.259507	0.213008	0.0825147	-0.11742	0.227852	-0.27546	1	-0.302171
B2	-0.0576802	-0.0084081	0.1264	-0.212142	-0.0970739	0.309624	-0.302171	1

w^2 weighted Dalitz plot on m12-m23 with xi=0.9



<u>Fit result for ξ (for ξ=0.9)</u>

ξ=0.890±0.009 (for 200k event)

ξ=0.882±0.028 (for 20k event)

The w^2 distribution is approximately 1/sigma_xi^2 distribution (sigma_xi =error on xi), i.e. the plot shows the region of high sensitivity

INTERNSHIP PROJECT OF FLAVIEN CALLET

Conclusions and outlook

- The charm magnetic moment determination with bent-crystal requires a measurement of the Λ_c polarisation.
- Last few years, there have been impressive progresses on the Λ_c polarisation measurement at LHCb.
- Our theoretical computation has been finished and it is ready to be used for sensitivity studies. Our result can be extended to include more resonances.
- The French-Ukrainian collaboration have been very fruitful! We hope we can continue this collaboration !

Backup

Polarisation measurement in the past...

- $\Lambda_c \to \Lambda\pi \to p\pi\pi$ decay

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

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

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.

The sensitivity study: proof of concept

E.K. A. Korchin, V. Kovalchuk

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INTERNSHIP PROJECT OF FLAVIEN CALLET