Measurement of CP asymmetries in singly Cabbibo suppressed Ξ_c^+ and Λ_c^+ decays

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Charm & CPV probes: two pathways

- Null Hypothesis:
  - Directly test the Standard Model
  - Via direct CP asymmetry measurements
  - e.g. Belle [arXiv:1712.00619]

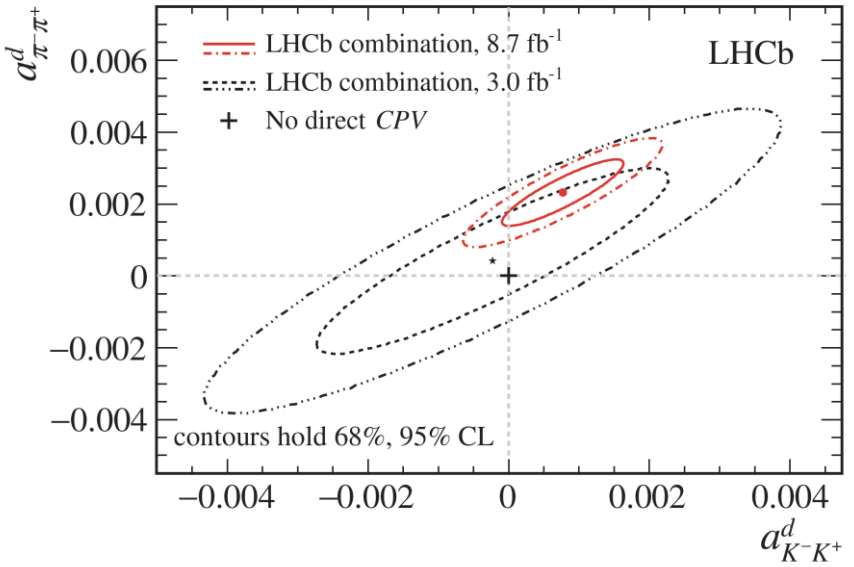
$a_{CP}^{dir}(D^+ \to \pi^+\pi^0) = 0$
(isospin limit & experimental sensitivity)

$a_{CP}^{dir}(D^+ \to \pi^+\pi^0) = (2.31 \pm 1.24 \pm 0.23)\%$
[arXiv:1712.00619]

- Over-constrain the Standard Model:
  - Sum rules relating CP asymmetries in different channels
  - e.g. U spin sum rule (invariance under the interchange of d and s quarks)
  - LHCb measured sum rules [arXiv:2209.03179] at level of 2.7σ

$a_d(D^0 \to K^-K^+) + a_d(D^0 \to \pi^-\pi^+) \neq 0$

- Needs to explore other modes to get the complete picture.



arXiv:2209.03179

CP asymmetries in charm baryons: $\Xi_c^+ \to \Sigma^+ h^+ h^-$ and $\Lambda_c^+ \to p^+ h^+ h^-$

- LHCb studied the CP asymmetry difference in singly Cabibbo suppressed Λ_c^+ decay channels:

$$\Delta A_{CP}^{W} = A_{CP}(pK^-K^+) - A_{CP}^{W}(p\pi^-\pi^+) = (0.30 \pm 0.91 \pm 0.61)\%$$ [JHEP 03, 182 (2018)]

- Direct CP asymmetries are more of a theoretical significance than asymmetry differences.
  - Belle II has unique opportunities for such measurements

- Charm meson discovery modes ($D^0 \to K^-K^+, \pi^-\pi^+$) are related by U spin sum rules.
  - suggest looking at Λ_c^+ and Ξ_c^+ decays.

$$A_{CP}^{dir}(\Lambda_c^+ \to pK^+K^-) + A_{CP}^{dir}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) = 0$$

$$A_{CP}^{dir}(\Lambda_c^+ \to p\pi^+\pi^-) + A_{CP}^{dir}(\Xi_c^+ \to \Sigma^+K^+K^-) = 0$$

Methodology

- Raw asymmetry from number counting,

$$A_{raw}^{\Xi_c} = \frac{N(\Xi_c^+ \to \Sigma^+ h^+ h^-) - N(\bar{\Xi}_c^- \to \bar{\Sigma}^- h^- h^+)}{N(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) + N(\bar{\Xi}_c^- \to \bar{\Sigma}^- h^- h^+)}$$

- Raw asymmetry includes CPV, production (forward-backward), and detection asymmetries.

$$A_{raw}^{\Xi_c} = A_{CP}^{\Xi_c} + A_{FB}^{\Xi_c} + A_p$$

- The forward-backward asymmetry is expected to be antisymmetric as a function of $cos(\theta^*)$
  - cancel by averaging over bins in $|cos(\theta^*)|$
- Take difference with CF control channel $\Lambda_c^+ \to \Sigma^+ h^+ h^-$ to cancel the detection asymmetry

$$A_{raw}^{\Lambda_c} = A_{FB}^{\Lambda_c} + A_p \text{ (no CPV)}$$

- Isolate CP asymmetry for signal mode

$$A_{CP}^{\Xi_c} = \frac{A_{raw}^{\Xi_c}(cos\theta_{\Xi_c}^*) + A_{raw}^{\Xi_c}(-cos\theta_{\Xi_c}^*)}{2} - \frac{A_{raw}^{\Lambda_c}(cos\theta_{\Lambda_c}^*) + A_{raw}^{\Lambda_c}(-cos\theta_{\Lambda_c}^*)}{2}$$

Methodology ($\Lambda_c^+ \to p^+h^+h^-$)

- Raw asymmetry includes CPV, production (forward-backward), and detection asymmetries.

$$A_{raw}^{\Lambda_c\,-p\,h\,h} = A_{CP}^{\Lambda_c\,-p\,h\,h} + A_{FB}^{\Lambda_c\,-p\,h\,h} + A_p$$

- The forward-backward asymmetry is expected to be antisymmetric as a function of $cos(\theta^*)$
  - cancel by averaging over bins in $|cos(\theta^*)|$

- Take difference with CF control channel $\Lambda_c^+ \to p^+K^-\pi^-$ to cancel the detection asymmetry

$$A_{raw}^{\Lambda_c\,-p\,K\,\pi} = A_{FB}^{\Lambda_c\,-p\,K\,\pi} + A_p + A_{K/\pi} \text{ (no CPV)}$$

- Take difference with CF control channel $D^0 \to K^-\pi^+\pi^+\pi^-$ to cancel the K/π detection asymmetry

$$A_{raw}^{D^0\to K\,\pi\pi\pi} = A_{FB}^{D^0\to K\,\pi\pi\pi} + A_{K/\pi} \text{ (no CPV)}$$

- Isolate CP asymmetry for signal mode

$$A_{CP}^{\Lambda_c\,-p\,h\,h} = \frac{A_{raw}^{\Lambda_c\,-p\,h\,h}(cos(\theta^*_{\Lambda_c}))+A_{raw}^{\Lambda_c\,-p\,h\,h}(-cos(\theta^*_{\Lambda_c}))}{2} - \frac{A_{raw}^{\Lambda_c\,-p\,K\,\pi}(cos(\theta^*_{\Lambda_c}))+A_{raw}^{\Lambda_c\,-p\,K\,\pi}(-cos(\theta^*_{\Lambda_c}))}{2} + \frac{A_{raw}^{D^0\to K\,\pi\pi\pi}(cos(\theta^*_{D^0}))+A_{raw}^{D^0\to K\,\pi\pi\pi}(-cos(\theta^*_{D^0}))}{2}$$

Reconstruction Criteria

Description	Selection
charged tracks (K, π, p)	in CDC acceptance minimum number (> 0) of hits in CDC
proton (p)	$\text{proton trinaryID} > 0.2$
Mass	$2.35 < M(\Xi_c) < 2.60\ [GeV/c^2]$ $2.15 < M(\Lambda_c) < 2.40\ [GeV/c^2]$ $1.75 < M(D^0) < 1.95\ [GeV/c^2]$
CM momentum (Ξ_c, Λ_c, D^0)	$CM\ momentum > 2.0[GeV/c]$
treeFit (Ξ_c, Λ_c, D^0)	$chiProb > 0.001$
$\Xi_c^+ \to \Sigma^+ h^+ h^-$	
photon (γ)	$E_{forward} > 0.080$ GeV, Ebarrel > 0.030 GeV, Ebackward > 0.060 GeV, clusterNHits > 1.5, 0.2967 < clusterTheta < 2.6180
π^0	$0.125 < M(\pi^0) < 0.145\ [GeV/c^2]$
Σ	$1.159 < M(\Sigma) < 1.219\ [GeV/c^2]$
$D^0 \to K^- \pi^+ \pi^+ \pi^-$	
charged tracks (K, π)	dr < 1 [cm] and abs(dz) < 3 [cm]
K	$\text{kaon binaryID} > 0.2$

Selection Criteria ($\Xi_c^+ \to \Sigma^+ h^+ h^-$)

Description	Selection
Mass	2. 40< M(Ξ_c) < 2.54 $[GeV/c^2]$ 2.24 < M(Λ_c) < 2.34 $[GeV/c^2]$
kaon (K)	kaon binaryID > 0.2
proton (p)	proton trinaryID > 0.8

MVA – Multi Variate Analysis

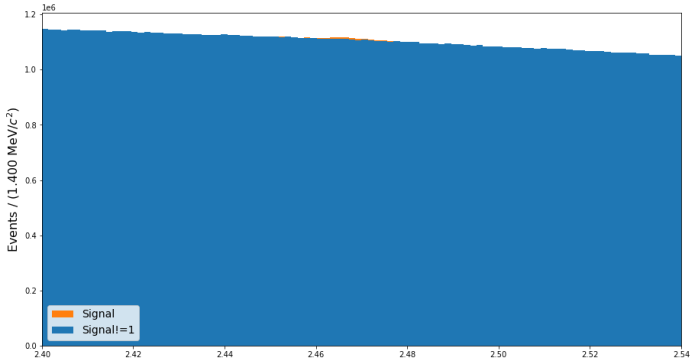
	$\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-$	$\Xi_c^+ \to \Sigma^+ K^+ K^-$
fake photon suppression (fps)	fps > 0.7	fps > 0.3
beam background suppression (bbs)	bbs > 0.8	bbs > 0.8
MVA	MVA > 0.1	MVA > 0.7

- proton trinaryID
  - $\frac{\text{proton ID}}{(\text{proton ID} + \text{kaon ID} + \text{pion ID})}$
- kaon binaryID
  - $\frac{\text{kaon ID}}{(\text{kaon ID} + \text{pion ID})}$

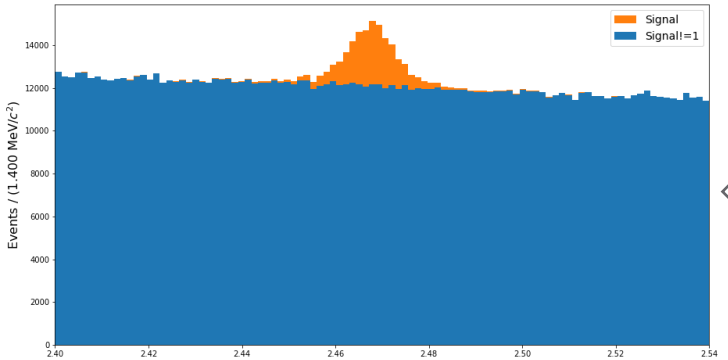
- Multi Variate Analysis (MVA)
  - Σ flight distance
  - χ^2 of vertex fit
  - K dr or pi dr
  - π^0(Σ) CM momentum

Mass Distributions ($\Xi_c^+ \to \Sigma^+ h^+ h^-$)

- Mass distributions of $\Xi_c^+ \to \Sigma^+\pi^+\pi^-$ and $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ after reconstruction and after applying selections.

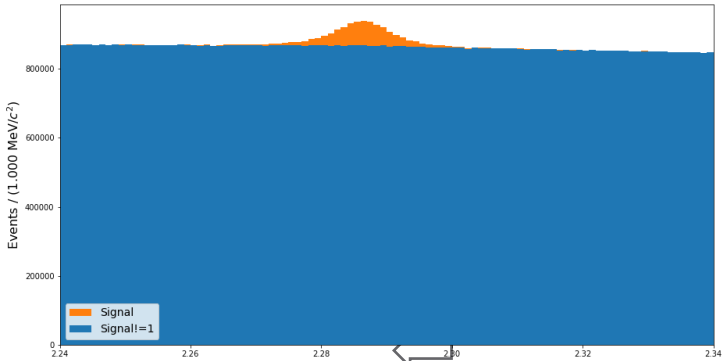


Ξ_c^+ Mass ($\Xi_c^+ \to \Sigma^+\pi^+\pi^-$)

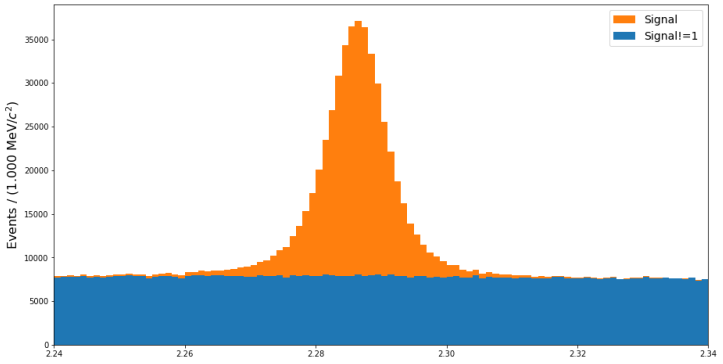


Ξ_c^+ Mass ($\Xi_c^+ \to \Sigma^+\pi^+\pi^-$)

⇦ signal efficiency – 49%



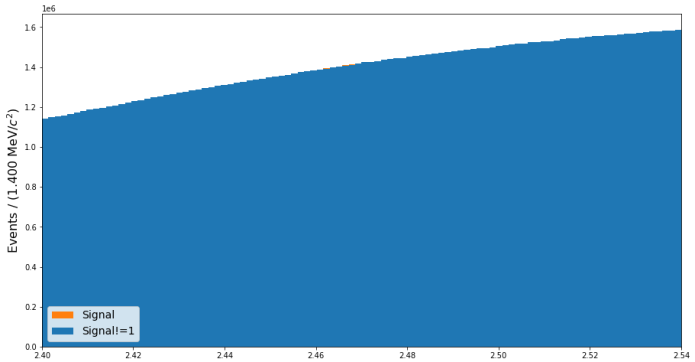
Λ_c^+ Mass ($\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$)



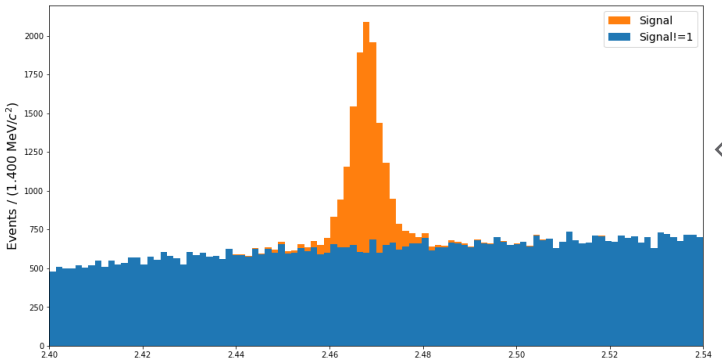
Λ_c^+ Mass ($\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$)

Mass Distributions ($\Xi_c^+ \to \Sigma^+ h^+ h^-$)

- Mass distributions of $\Xi_c^+ \to \Sigma^+ K^+ K^-$ and $\Lambda_c^+ \to \Sigma^+ K^+ K^-$, after reconstruction and after applying selections.

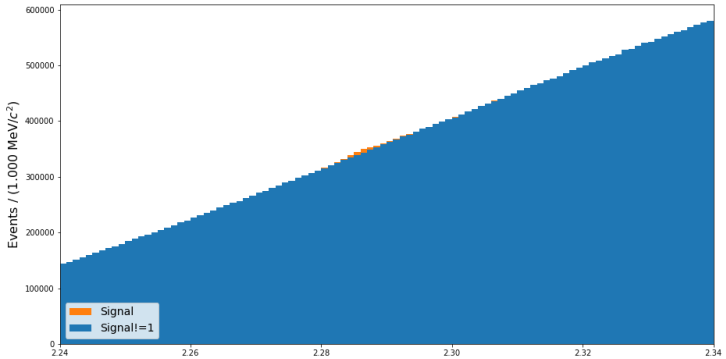


Ξ_c^+ Mass ($\Xi_c^+ \to \Sigma^+ K^+ K^-$)

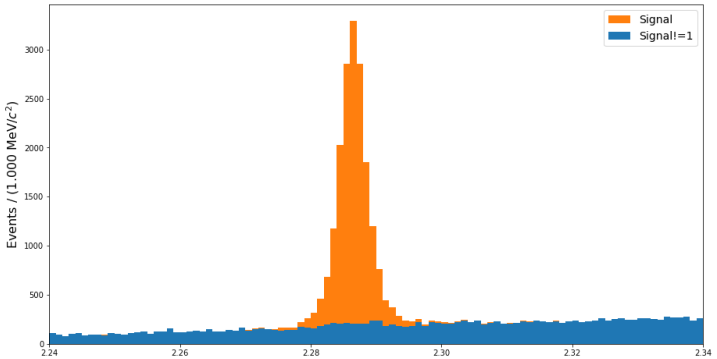


Ξ_c^+ Mass ($\Xi_c^+ \to \Sigma^+ K^+ K^-$)

⇦ signal efficiency – 51%



Λ_c^+ Mass ($\Lambda_c^+ \to \Sigma^+ K^+ K^-$)



Λ_c^+ Mass ($\Lambda_c^+ \to \Sigma^+ K^+ K^-$)

Selection Criteria ($\Lambda_c^+ \to p^+ h^+ h^-$)

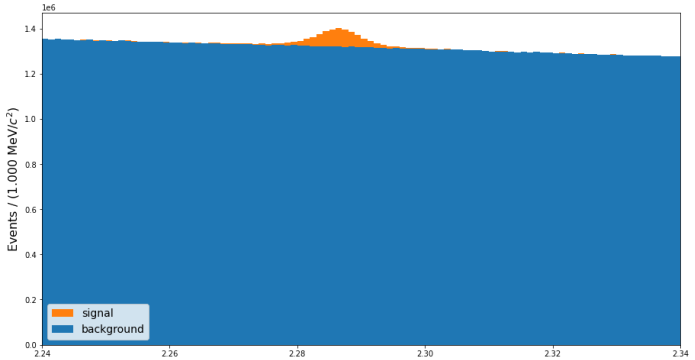
Description	Selection
Mass	$2.24 < M(\Lambda_c) < 2.34\ [GeV/c^2]$ $1.80 < M(D^0) < 1.92\ [GeV/c^2]$
charged tracks (K, π, p)	dr < 1 [cm] and abs(dz) < 3 [cm]
Λ_c	Λ_c flight distance $> 0\ [cm]$
	Λ_c CM momentum $> 2.5[GeV/c]$
kaon (K)	kaon binaryID > 0.7
proton (p)	proton trinaryID > 0.9
	$\Lambda_c^+ \to p^+\pi^+\pi^-$
Λ_c	Λ_c significance of distance $> 0.25\ [cm]$
pion (π)	pion momentum $> 0.30\ [GeV/c]$
proton (p)	proton momentum $> 0.85[GeV/c]$

- proton trinaryID
  - $\frac{\text{proton ID}}{(\text{proton ID} + \text{kaon ID} + \text{pion ID})}$
- kaon binaryID
  - $\frac{\text{kaon ID}}{(\text{kaon ID} + \text{pion ID})}$

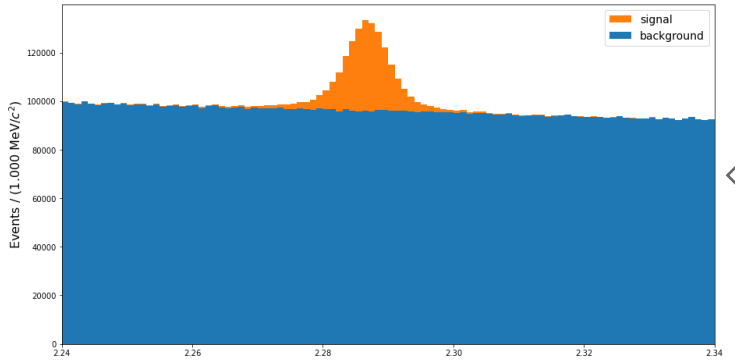
Mass Distributions ($\Lambda_c^+ \to p^+h^+h^-$)

- Mass distributions of Λ_c^+ channels used in A_{cp} calculations of $\Lambda_c^+ \to p^+\pi^+\pi^-$, after reconstruction and after applying square cut selections.

signal efficiency – 100%
purity – 3.14%

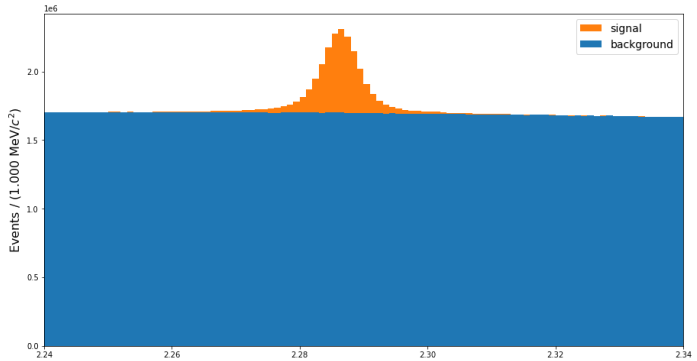


Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+\pi^-$)

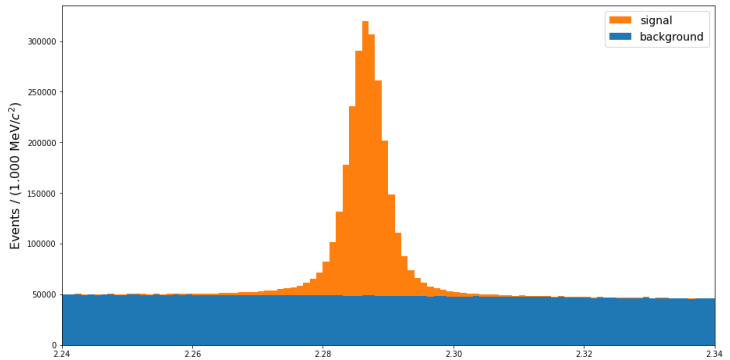


Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+\pi^-$)

signal efficiency – 44%
purity – 16.7%



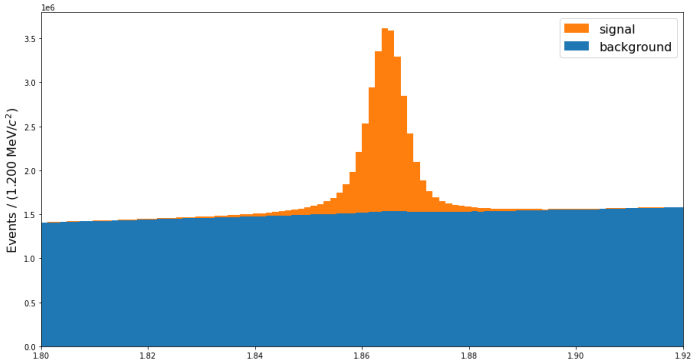
Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+K^-$)



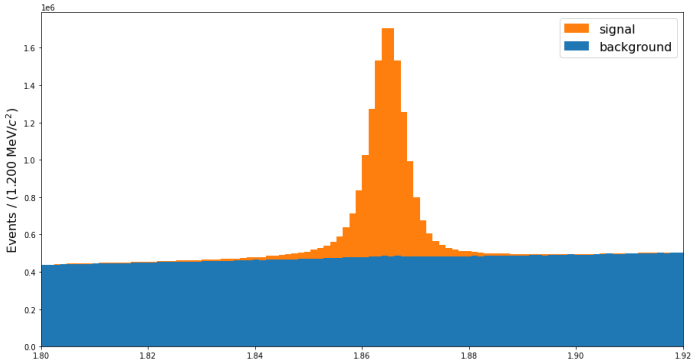
Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+K^-$)

Mass Distributions ($\Lambda_c^+ \to p^+h^+h^-$)

- Mass distributions of $D^0 \to K^-\pi^+\pi^+\pi^-$ channel used in A_{cp} calculations of $\Lambda_c^+ \to p^+\pi^+\pi^-$ after reconstruction and after applying square cut selections.



D^0 Mass ($D^0 \to K^-\pi^+\pi^+\pi^-$)

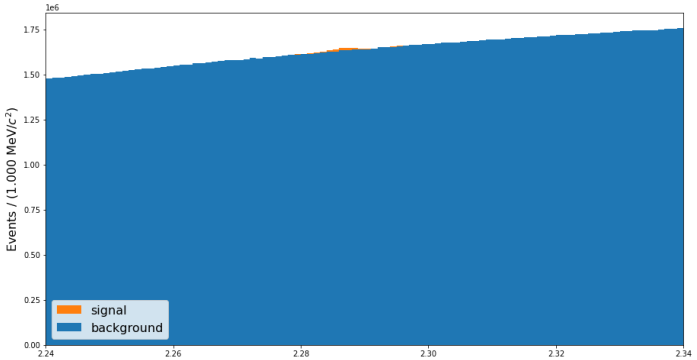


D^0 Mass ($D^0 \to K^-\pi^+\pi^+\pi^-$)

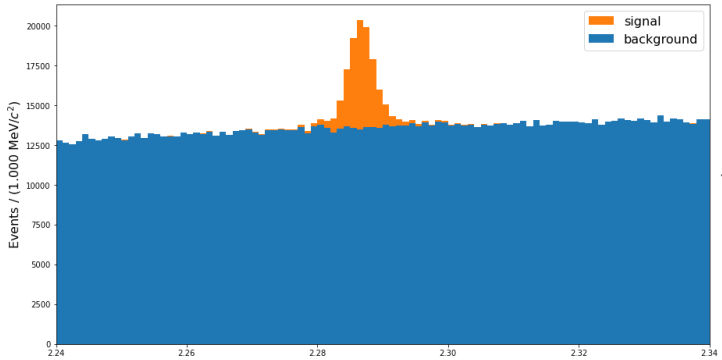
Mass Distributions ($\Lambda_c^+ \to p^+h^+h^-$)

- Mass distributions of Λ_c^+ channels used in A_{cp} calculations of $\Lambda_c^+ \to p^+K^+K^-$, after reconstruction and after applying square cut selections.

signal efficiency – 100%
purity – 0.27%

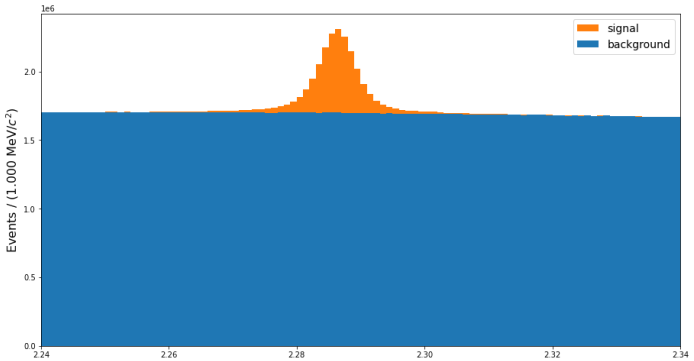


Λ_c^+ Mass ($\Lambda_c^+ \to p^+K^+K^-$)

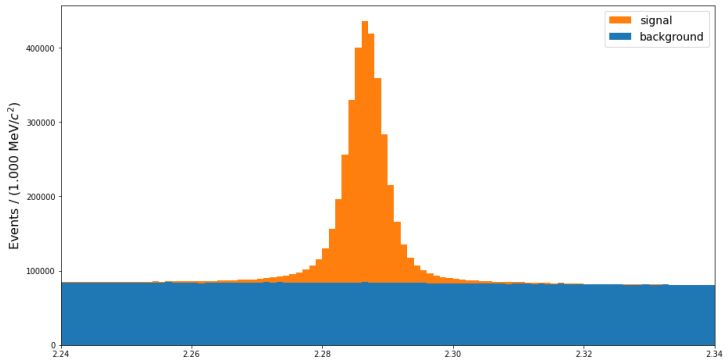


Λ_c^+ Mass ($\Lambda_c^+ \to p^+K^+K^-$)

signal efficiency – 49%
purity – 13.9%



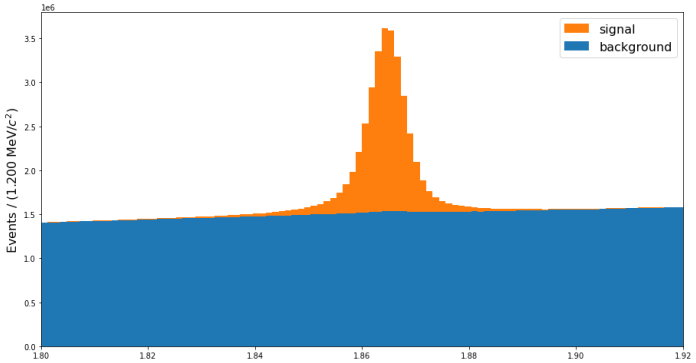
Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+K^-$)



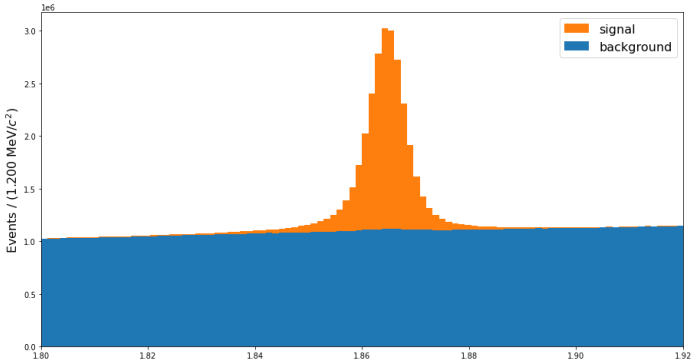
Λ_c^+ Mass ($\Lambda_c^+ \to p^+\pi^+K^-$)

Mass Distributions ($\Lambda_c^+ \to p^+h^+h^-$)

- Mass distributions of $D^0 \to K^-\pi^+\pi^+\pi^-$ channel used in A_{cp} calculations of $\Lambda_c^+ \to p^+K^+K^-$ after reconstruction and after applying square cut selections.



D^0 Mass ($D^0 \to K^-\pi^+\pi^+\pi^-$)



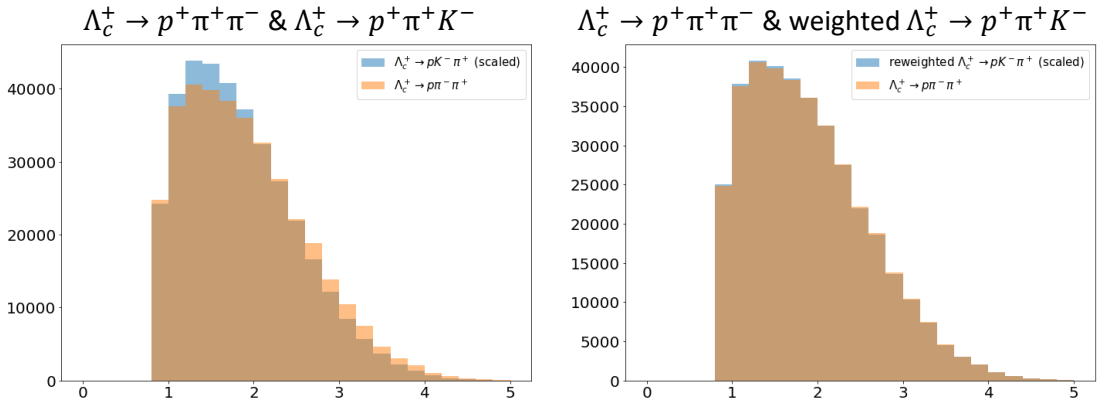
D^0 Mass ($D^0 \to K^-\pi^+\pi^+\pi^-$)

proton detection asymmetry

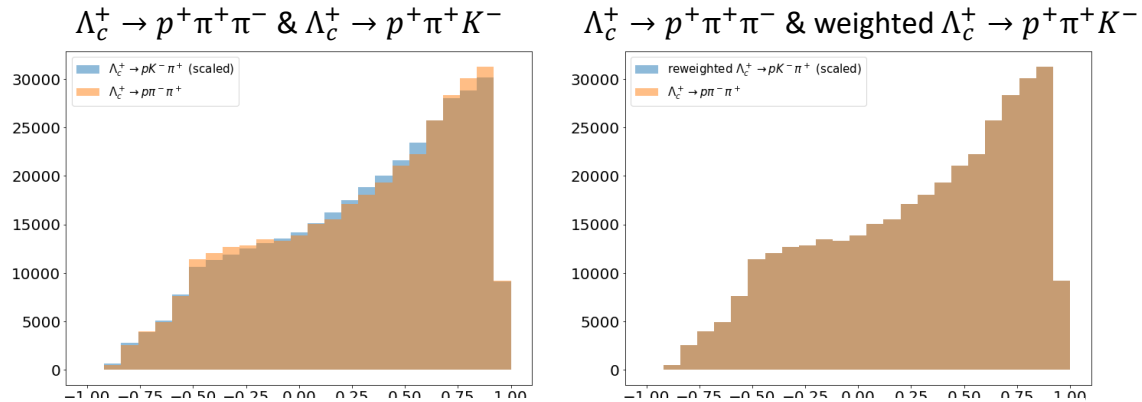
- Recall, raw asymmetries include effects from CPV, production (forward-backward), and detection asymmetries.
- For the modes, that the final states have a proton(Sigma),

$$A_{raw} = A_{CP} + A_{FB} + A_p$$

- Proton in the final state of signal channel and control channel might cover different regions of phase space.
  - Control channel proton was weighted to match the signal channel proton in phase space.
  - Weights were taken as a combination of proton momentum and proton cosθ.



proton momentum



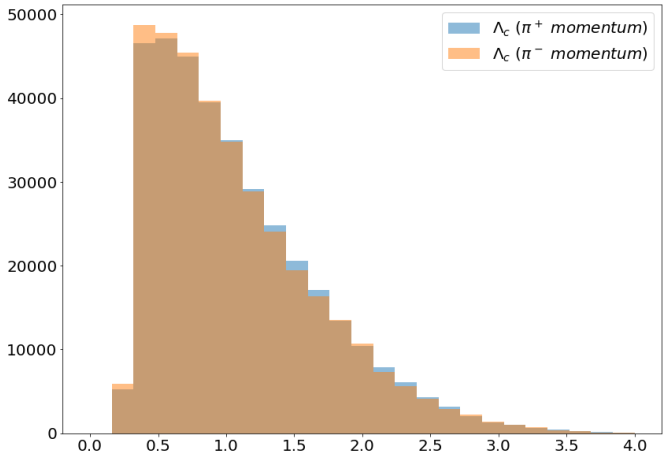
proton cosTheta

	A_{raw} % (Truth-matched)	A_{raw} % (Fitted)
$\Lambda_c^+ \to p^+\pi^+K^-$	2.89 ± 0.07	2.92 ± 0.13
weighted $\Lambda_c^+ \to p^+\pi^+K^-$	2.80 ± 0.07	2.82 ± 0.11

hh detection asymmetry

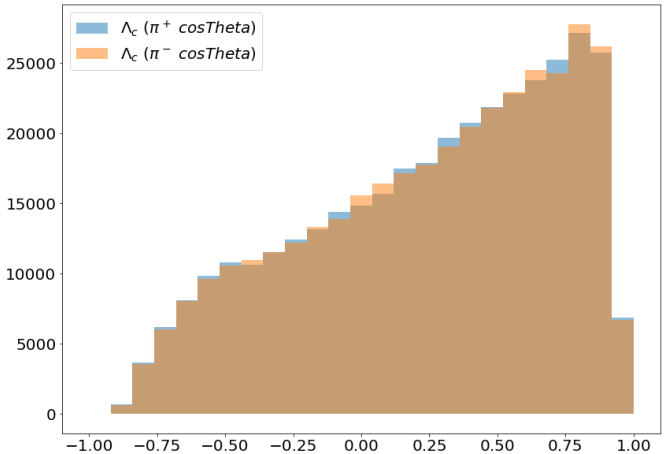
- Recall, raw asymmetries should include h^+h^- detection asymmetry for channels with final state h^+h^- .
- We assume detection asymmetry of h^+h^- cancels out, as the final state contains both sign pions/kaons.
- h^+ and h^- might cover different regions of phase space.
- Initial checks suggest no significant effect of this.

$\Lambda_c^+ \to p^+\pi^+\pi^-$



pion momentum

$\Lambda_c^+ \to p^+\pi^+\pi^-$



pion cosTheta

K and π detection asymmetry ($\Lambda_c^+ \to p^+h^+h^-$)

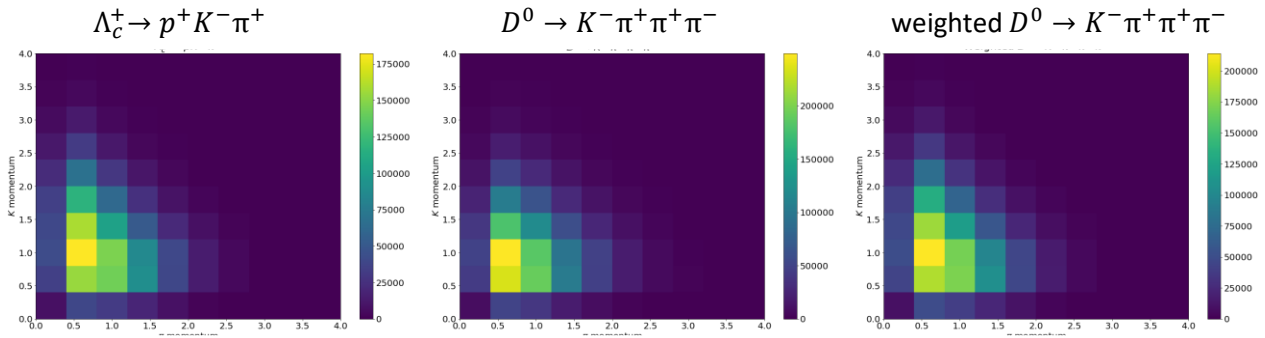
- Recall, raw asymmetries of $\Lambda_c^+ \to p^+K^-\pi^-$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ includes effects from, production (forward-backward), and detection asymmetries

$$A_{raw}^{\Lambda_c \to p\,K\,\pi} = A_{FB}^{\Lambda_c \to p\,K\,\pi} + A_p + A_{K/\pi}$$

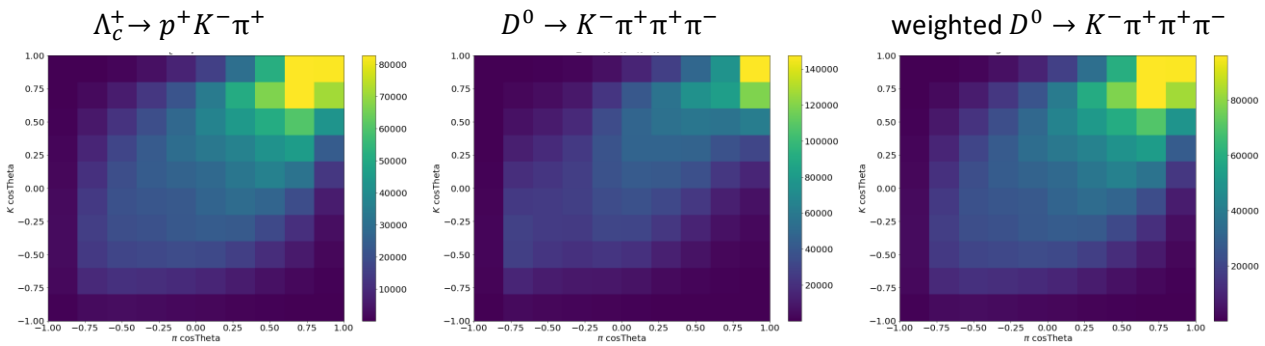
$$A_{raw}^{D^0 \to K\,\pi\pi\pi} = A_{FB}^{D^0 \to K\,\pi\pi\pi} + A_{K/\pi}$$

- K and π in the final state of these channels might cover different regions of phase space.
  - D^0 channel K and π was weighted to match the weighted $\Lambda_c^+ \to p^+K^-\pi^-$ channel K and π in phase space.
  - Weights were taken as a 2D combination of K and π momentum and K and π cosθ.

x axis – π momentum
y axis – K momentum



x axis – π cosTheta
y axis – K cosTheta



	A_{raw} % (Truth-matched)	A_{raw} % (Fitted)
$D^0 \to K^-\pi^+\pi^+\pi^-$	-0.83 ± 0.06	-0.94 ± 0.16
weighted $D^0 \to K^-\pi^+\pi^+\pi^-$	-0.86 ± 0.07	-0.95 ± 0.19

Fitting Strategy

- Invariant mass fits were modeled.
  - Double Gaussian function for the signal
  - 2nd order polynomial function for the background

$$f_g(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)}{2\sigma^2}}$$

$$f_{sig}(x|\mu,\sigma_1,\sigma_2,f_g) = f_g.f(x|\mu,\sigma_1) + (1-f_g).f(x|\mu,\sigma_2)$$

$$f_{bkg}(x|a,b) = ax + bx^2$$

- Invariant mass distribution fit for the truth matched events in the signal channel
  - extract signal channel parameters
- Invariant mass distribution fit for all events in the control channel
  - extract control channel parameters
- Fits of invariant mass distribution are performed in bins of $cos(\theta^*)$
  - Simultaneously for the both signal and control channels
  - $\mu + \delta\mu$, $\sigma_1 \times \delta\sigma_1$, and $\sigma_2 \times \delta\sigma_2$ are fixed from extracted parameters

signal parameters
$(\Lambda_c^+ \to p^+\pi^+\pi^-)$

Parameters

name	value	(rounded)
sig_yield		356198
fg1		0.170363
mu		2.28667
s1		0.0171379
s2		0.00349743

control parameters
$(\Lambda_c^+ \to p^+\pi^+K^-)$

Parameters

name	value	(rounded)
sig_yield		1.95701e+06
bkg_yield		4.90514e+06
fg1		0.715278
mu		2.28671
s1		0.00243441
s2		0.00585479
a1		-0.0509389
a2		-0.0306419

$cos(\theta^*)$ bin1 parameters
$(\Lambda_c^+ \to p^+\pi^+\pi^-)$

Parameters

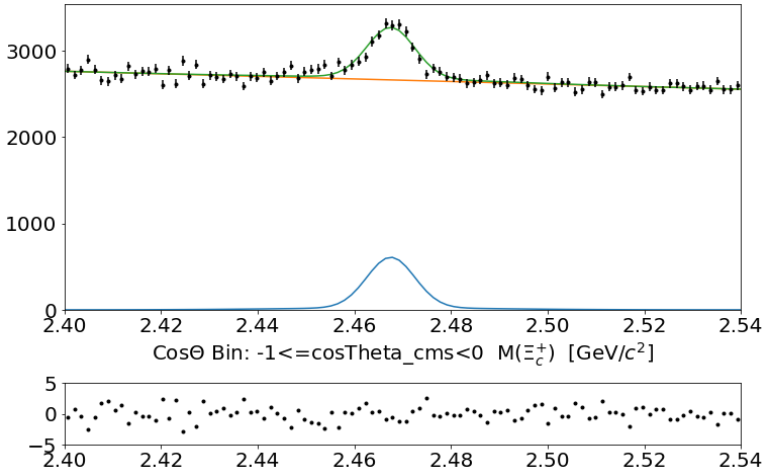
name	value	(rounded)
sig_sig_yield		84557.7
sig_bkg_yield		1.87335e+06
smu		-8.48046e-05
ss1		1.35579
ss2		1.34374
sig_a1		-0.0244853
sig_a2		-0.00201133
asig_sig_yield		78054.5
asig_bkg_yield		1.7667e+06
asig_a1		-0.0238782
asig_a2		-0.00159945
ctr_sig_yield		462804
ctr_bkg_yield		931717
ctr_fg1		0.728149
ctr_a1		-0.0488542
ctr_a2		-0.0406715
actr_sig_yield		428104
actr_bkg_yield		887373
actr_fg1		0.719981
actr_a1		-0.0472417
actr_a2		-0.0355868

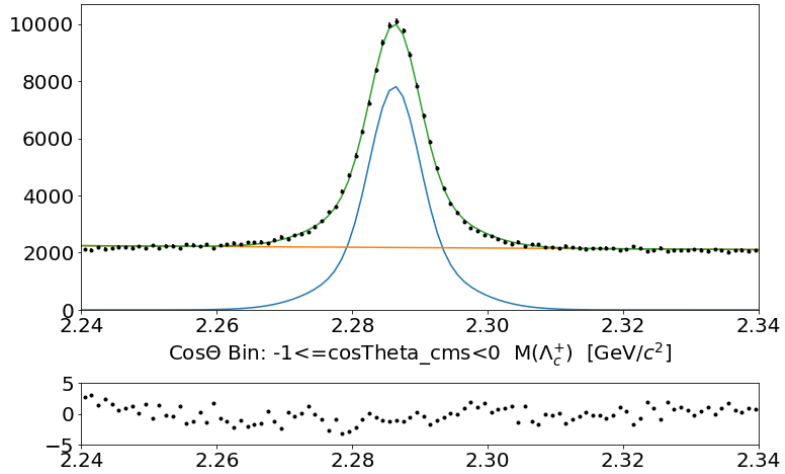
Results for $\Xi_c^+ \to \Sigma^+\pi^+\pi^-$ using MC15rd default MC

- Truth-matching was used to extract the raw asymmetries and compare them with results from the invariant mass fits.

MC (~1680 /fb)	A_{raw} % ($\Xi_c^+ \to \Sigma^+\pi^+\pi^-$)	A_{raw} % ($\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$)	A_{cp} % ($\Xi_c^+ \to \Sigma^+\pi^+\pi^-$)
Truth-matched	6.27 ± 0.59	6.33 ± 0.15	-0.05 ± 0.61
Fitted	6.22 ± 2.08	6.60 ± 0.44	-0.38 ± 2.13

- Results are consistent with the A_{cp}= 0





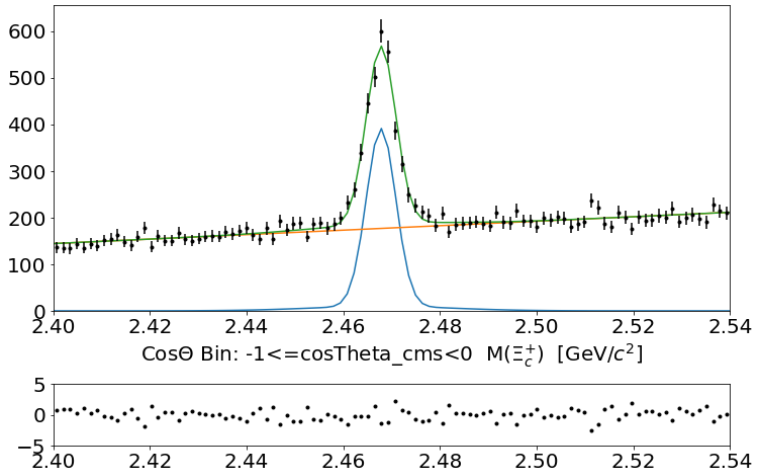
- $cos(\theta^*)$ bin 1 matter distributions of $\Xi_c^+ \to \Sigma^+\pi^+\pi^-$, and weighted $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$

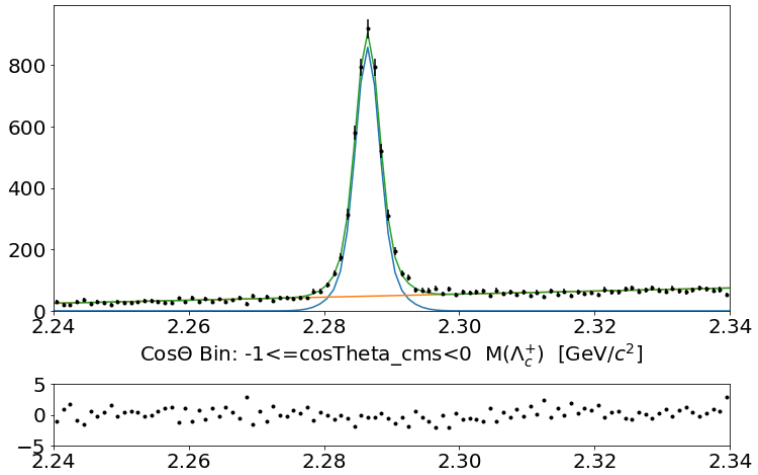
Results for $\Xi_c^+ \to \Sigma^+ K^+ K^-$ using MC15rd default MC

- Truth-matching was used to extract the raw asymmetries and compare them with results from the invariant mass fits.

MC (~1680 /fb)	A_{raw} % ($\Xi_c^+ \to \Sigma^+ K^+ K^-$)	A_{raw} % ($\Lambda_c^+ \to \Sigma^+ K^+ K^-$)	A_{cp} % ($\Xi_c^+ \to \Sigma^+ K^+ K^-$)
Truth-matched	5.46 ± 1.08	6.07 ± 0.79	-0.61 ± 1.34
Fitted	5.91 ± 1.68	6.46 ± 0.73	-0.55 ± 1.83

- Results are consistent with the A_{cp}= 0





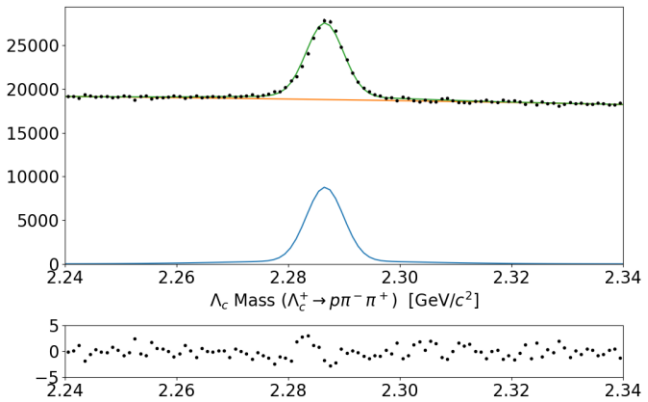
- $cos(\theta^*)$ bin 1 matter distributions of $\Xi_c^+ \to \Sigma^+ K^+ K^-$, and weighted $\Lambda_c^+ \to \Sigma^+ K^+ K^-$

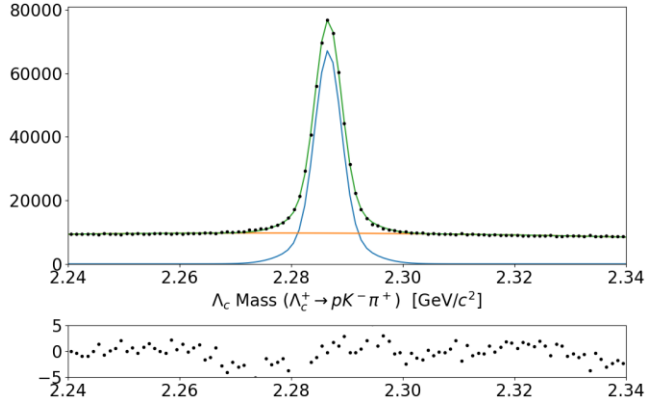
Results for $\Lambda_c^+ \to p^+\pi^+\pi^-$ using MC15rd default MC

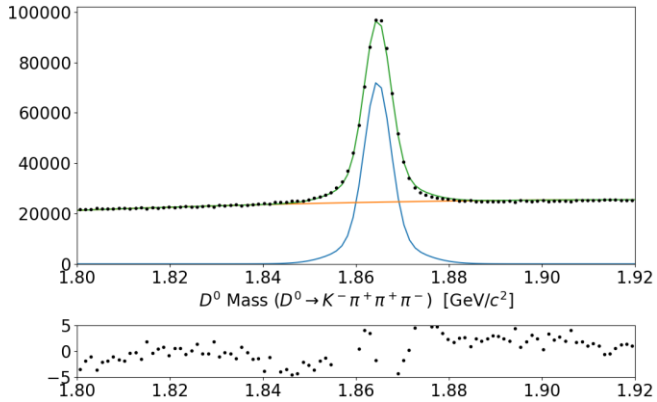
- Truth-matching was used to extract the raw asymmetries and compare them with results from the invariant mass fits.
- *Subset of the full MC sample corresponding to 105 /fb was used for $D^0 \to K^-\pi^+\pi^+\pi^-$ mode.

MC (~1680 /fb)	A_{raw} % ($\Lambda_c^+ \to p^+\pi^+\pi^-$)	A_{raw} % ($\Lambda_c^+ \to p^+\pi^+K^-$)	A_{raw}% ($D^0 \to K^-\pi^+\pi^+\pi^-$)*	A_{cp} % ($\Lambda_c^+ \to p^+\pi^+\pi^-$)
Truth-matched	3.23 ± 0.17	2.80 ± 0.07	-0.86 ± 0.07	-0.39 ± 0.20
Fitted	3.79 ± 0.53	2.82 ± 0.11	-0.95 ± 0.19	0.02 ± 0.57

- Results are consistent with the A_{cp}= 0







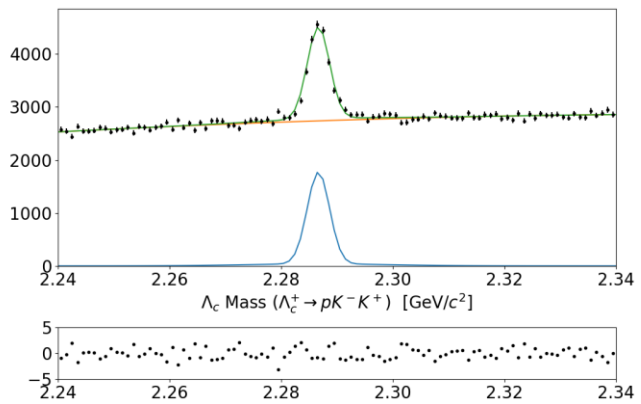
- $cos(\theta^*)$ bin 1 matter distributions of $\Lambda_c^+ \to p^+\pi^+\pi^-$, weighted $\Lambda_c^+ \to p^+\pi^+K^-$, and weighted $D^0 \to K^-\pi^+\pi^+\pi^-$

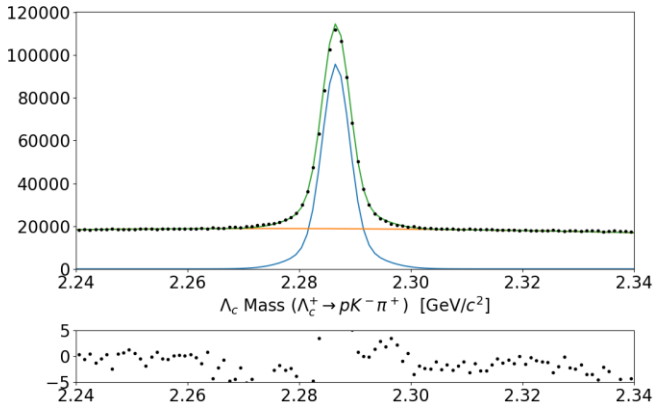
Results for $\Lambda_c^+ \to p^+K^+K^-$ using MC15rd default MC

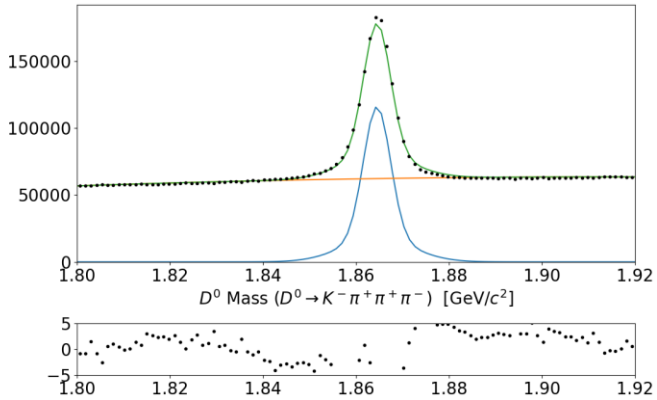
- Truth-matching was used to extract the raw asymmetries and compare them with results from the invariant mass fits.
- *Subset of the full MC sample corresponding to 105 /fb was used for $D^0 \to K^-\pi^+\pi^+\pi^-$ mode.

MC (~1680 /fb)	A_{raw} % ($\Lambda_c^+ \to p^+K^+K^-$)	A_{raw} % ($\Lambda_c^+ \to p^+\pi^+K^-$)	A_{raw}% ($D^0 \to K^-\pi^+\pi^+\pi^-$)*	A_{cp} % ($\Lambda_c^+ \to p^+K^+K^-$)
Truth-matched	3.69 ± 0.52	3.22 ± 0.06	-0.63 ± 0.05	-0.16 ± 0.53
Fitted	3.33 ± 1.20	3.19 ± 0.13	-0.74 ± 0.19	0.60 ± 1.22

- Results are consistent with the A_{cp}= 0







- $cos(\theta^*)$ bin 1 matter distributions of $\Lambda_c^+ \to p^+K^+K^-$, weighted $\Lambda_c^+ \to p^+\pi^+K^-$, and weighted $D^0 \to K^-\pi^+\pi^+\pi^-$

Remarks

- We are looking into detection asymmetry of *hh* more closely.
- We are bootstrapping on a subset of the full Monte Carlo sample, corresponding to the integrated luminosity of the available data sample (426.6 /fb).
- ~~We are investigating the potential reasons for the difference between the truth-matched and fitted A_{CP} values of $\Lambda_c^+ \to p^+\pi^+\pi^-$ mode.~~
- We are in the final phase of completing the first version of Belle2Note.
- We hope to ask for a working group review soon.

initial

ctr_sig_yield	466665	+/- 1.2e+03	-1.2e+03	+1.2e+03	-1.2e+03	+1.2e+03	False
ctr_bkg_yield	940361	+/- 1.4e+03	-1.4e+03	+1.4e+03	-1.4e+03	+1.4e+03	False
ctr_fg1	0.26006	+/- 0.005	- 0.0049	+ 0.0051	- 0.0049	+ 0.0051	False
ctr_a1	-0.0490723	+/- 0.0018	- 0.0018	+ 0.0018	- 0.0018	+ 0.0018	False
ctr_a2	-0.0378251	+/- 0.0024	- 0.0024	+ 0.0024	- 0.0024	+ 0.0024	False
actr_sig_yield	431170	+/- 1.1e+03	-1.1e+03	+1.1e+03	-1.1e+03	+1.1e+03	False
actr_bkg_yield	896059	+/- 1.3e+03	-1.3e+03	+1.3e+03	-1.3e+03	+1.3e+03	False
actr_fg1	0.268196	+/- 0.0051	- 0.005	+ 0.0052	- 0.005	+ 0.0052	False
actr_a1	-0.0474012	+/- 0.0018	- 0.0018	+ 0.0018	- 0.0018	+ 0.0018	False
actr_a2	-0.032489	+/- 0.0025	- 0.0024	+ 0.0024	- 0.0024	+ 0.0024	False

weighted

ctr_sig_yield	462804	+/- 9.6e+02	- 1e+03	+ 1e+03	- 1e+03	+ 1e+03	False
ctr_bkg_yield	931717	+/- 9.6e+02	-1.2e+03	+1.2e+03	-1.2e+03	+1.2e+03	False
ctr_fg1	0.728149	+/- 0.0042	- 0.0041	+ 0.0041	- 0.0041	+ 0.0041	False
ctr_a1	-0.0488542	+/- 0.0018	- 0.0018	+ 0.0018	- 0.0018	+ 0.0018	False
ctr_a2	-0.0406715	+/- 0.0022	- 0.0022	+ 0.0022	- 0.0022	+ 0.0022	False
actr_sig_yield	428104	+/- 9.2e+02	-9.8e+02	+9.9e+02	-9.8e+02	+9.9e+02	False
actr_bkg_yield	887373	+/- 9.2e+02	-1.2e+03	+1.2e+03	-1.2e+03	+1.2e+03	False
actr_fg1	0.719981	+/- 0.0044	- 0.0042	+ 0.0042	- 0.0042	+ 0.0042	False
actr_a1	-0.0472417	+/- 0.0018	- 0.0019	+ 0.0019	- 0.0019	+ 0.0019	False
actr_a2	-0.0355868	+/- 0.0023	- 0.0023	+ 0.0023	- 0.0023	+ 0.0023	False

	A_{raw} % (Truth-matched)	A_{raw} % (Fitted)
$\Lambda_c^+ \to p^+\pi^+K^-$	2.8868 ± 0.0694	2.9217 ± 0.1296
weighted $\Lambda_c^+ \to p^+\pi^+K^-$	2.7978 ± 0.0698	2.8219 ± 0.1098

initial

ctr_sig_yield	534753	+/- 1.4e+03	-1.4e+03	+1.4e+03	-1.4e+03	+1.4e+03	False
ctr_bkg_yield	1.56553e+06	+/- 1.7e+03	-1.7e+03	+1.7e+03	-1.7e+03	+1.7e+03	False
ctr_fg1	0.307921	+/- 0.0068	- 0.0067	+ 0.0069	- 0.0067	+ 0.0069	False
ctr_a1	-0.0546453	+/- 0.0014	- 0.0014	+ 0.0014	- 0.0014	+ 0.0014	False
ctr_a2	-0.0281748	+/- 0.0018	- 0.0018	+ 0.0018	- 0.0018	+ 0.0018	False
actr_sig_yield	514914	+/- 1.4e+03	-1.4e+03	+1.4e+03	-1.4e+03	+1.4e+03	False
actr_bkg_yield	1.53976e+06	+/- 1.7e+03	-1.7e+03	+1.7e+03	-1.7e+03	+1.7e+03	False
actr_fg1	0.316439	+/- 0.0069	- 0.0068	+ 0.007	- 0.0068	+ 0.007	False
actr_a1	-0.0527385	+/- 0.0014	- 0.0014	+ 0.0014	- 0.0014	+ 0.0014	False
actr_a2	-0.0294822	+/- 0.0018	- 0.0018	+ 0.0018	- 0.0018	+ 0.0018	False

weighted

ctr_sig_yield	539310	+/- 1.2e+03	-1.2e+03	+1.3e+03	-1.2e+03	+1.3e+03	False
ctr_bkg_yield	1.55789e+06	+/- 1.2e+03	-1.6e+03	+1.6e+03	-1.6e+03	+1.6e+03	False
ctr_fg1	0.69584	+/- 0.0052	- 0.0049	+ 0.0048	- 0.0049	+ 0.0048	False
ctr_a1	-0.0539323	+/- 0.0014	- 0.0014	+ 0.0014	- 0.0014	+ 0.0014	False
ctr_a2	-0.0286019	+/- 0.0018	- 0.0017	+ 0.0017	- 0.0017	+ 0.0017	False
actr_sig_yield	520772	+/- 1.2e+03	-1.2e+03	+1.2e+03	-1.2e+03	+1.2e+03	False
actr_bkg_yield	1.53421e+06	+/- 1.2e+03	-1.6e+03	+1.6e+03	-1.6e+03	+1.6e+03	False
actr_fg1	0.686616	+/- 0.0053	- 0.0049	+ 0.0049	- 0.0049	+ 0.0049	False
actr_a1	-0.0522247	+/- 0.0014	- 0.0014	+ 0.0014	- 0.0014	+ 0.0014	False
actr_a2	-0.0295979	+/- 0.0018	- 0.0017	+ 0.0018	- 0.0017	+ 0.0018	False

	A_{raw} % (Truth-matched)	A_{raw} % (Fitted)
$\Lambda_c^+ \to p^+\pi^+K^-$	2.8868 ± 0.0694	2.9217 ± 0.1296
weighted $\Lambda_c^+ \to p^+\pi^+K^-$	2.7978 ± 0.0698	2.8219 ± 0.1098