Study of the $\Xi^- \uparrow \bar{\Xi}^+ \uparrow$ decay parameters in $J/\psi \rightarrow \Xi^- \uparrow \bar{\Xi}^+ \uparrow$

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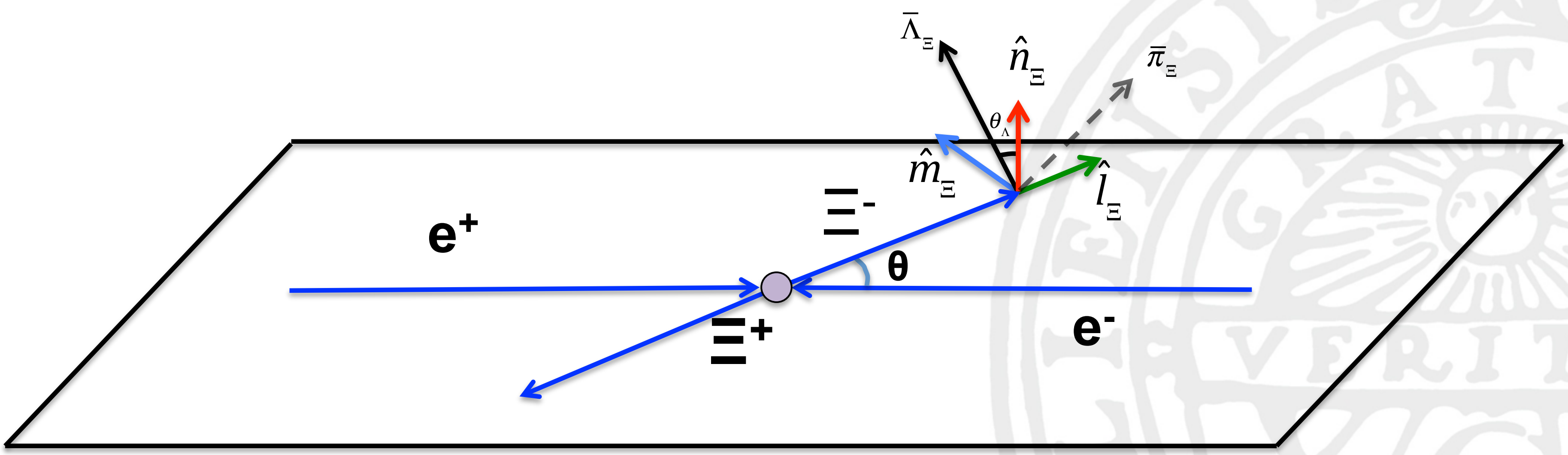
Charmonium Group Meeting, May 8, 2018

Motivation

- Measure decay parameters
- To study hyperon-hyperon bar spin correlations
- Test CP violation in hyperon non-leptonic decays



General two spin ½ particle state

$$\rho_{1/2,\overline{1/2}} = \frac{1}{4}\sum_{\mu\nu} C_{\mu\bar{\nu}}\sigma_\mu \otimes \sigma_{\bar{\nu}}$$

16 parameters for each θ:
I(θ), polarizations (6)
Spin correlations (9)

$$\mathcal{W}(\boldsymbol{\xi}) = \mathcal{I}(\theta)\Big\{1 + \alpha_\Lambda \sum_k P_k(\theta)\mathbf{n}_k + \alpha_{\bar{\Lambda}} \sum_{\bar{k}} P_{\bar{k}}(\theta)\mathbf{n}_{\bar{k}} + \alpha_\Lambda \alpha_{\bar{\Lambda}} \sum_{\bar{k}k} C_{\bar{k}k}(\theta)\mathbf{n}_{\bar{k}}\mathbf{n}_k\Big\}$$

polarizations (6)

Spin correlations (9)

$$P_y(\theta) = \sqrt{1-\alpha_\psi^2}\frac{\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}\sin(\Delta\Phi)$$

$$P_{\bar{y}}(\theta) = P_y(\theta).$$

$$\mathcal{I}(\theta) = 1 + \alpha_\psi\cos^2\theta.$$

$$C_{\bar{z}z}(\theta)\mathcal{I}(\theta) = -\alpha_\psi + \cos^2\theta$$

$$C_{\bar{x}x}(\theta)\mathcal{I}(\theta) = -\sin^2\theta$$

$$C_{\bar{y}y}(\theta)\mathcal{I}(\theta) = -\alpha_\psi\sin^2\theta$$

$$C_{\bar{x}z}(\theta)\mathcal{I}(\theta) = -\sqrt{1-\alpha_\psi^2}\cos\theta\sin\theta\cos(\Delta\Phi)$$

$$C_{\bar{z}x}(\theta) = C_{\bar{x}z}(\theta)$$

moments: $$M(\theta) = \sum_i^{N(\theta)} \mathbf{n}_\mu^i \mathbf{n}_\nu^i$$ (uncorrected for acceptance)

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BAM116: $\Lambda\Lambda$

Master formula for $\Lambda\boldsymbol{\Lambda}$:

$$W(\xi)=1+\alpha_{\psi}\cos^{2}\theta_{\Lambda}+\alpha_{-}\alpha_{+}(\sin^{2}\theta_{\Lambda}\sin\theta_{1}\sin\theta_{2}\cos\phi_{1}\cos\phi_{2}+\cos^{2}\theta_{\Lambda}\cos\theta_{1}\cos\theta_{2})$$
$$+\alpha_{-}\alpha_{+}\sqrt{1-\alpha_{\psi}^{2}}\cos(\Delta\Phi)\left[\sin\theta_{\Lambda}\cos\theta_{\Lambda}(\sin\theta_{1}\cos\theta_{2}\cos\phi_{1}+\cos\theta_{1}\sin\theta_{2}\cos\phi_{2})\right]$$
$$+\alpha_{-}\alpha_{+}\alpha_{\psi}(\cos\theta_{1}\cos\theta_{2}-\sin^{2}\theta_{\Lambda}\sin\theta_{1}\sin\theta_{2}\sin\phi_{1}\sin\phi_{2})$$
$$+\sqrt{1-\alpha_{\psi}^{2}}\sin(\Delta\Phi)\sin\theta_{\Lambda}\cos\theta_{\Lambda}(\alpha_{-}\sin\theta_{1}\sin\phi_{1}+\alpha_{+}\sin\theta_{2}\sin\phi_{2})$$

$$\alpha_{-}=\alpha(\Lambda\rightarrow p\pi^{-})$$
$$\alpha_{+}=\alpha(\bar{\Lambda}\rightarrow \bar{p}\pi^{+})$$

$$\xi=(\theta_{\Lambda},\theta_{1},\varphi_{1},\theta_{2},\varphi_{2})$$

$$G_{E}^{\psi}=\frac{\sqrt{s}}{2M_{\Lambda}}\sqrt{\frac{1-\alpha_{\psi}}{1+\alpha_{\psi}}}\,e^{i\Delta\Phi}\,G_{M}^{\psi}$$

Current work ΛΛ̄

Master formula for ΛΛ̄:

$$W(\xi)=1+\alpha_\psi\cos^2\theta_\Lambda+\alpha_-\alpha_+(\sin^2\theta_\Lambda\sin\theta_1\sin\theta_2\cos\phi_1\cos\phi_2+\cos^2\theta_\Lambda\cos\theta_1\cos\theta_2)$$
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\left[\sin\theta_\Lambda\cos\theta_\Lambda(\sin\theta_1\cos\theta_2\cos\phi_1+\cos\theta_1\sin\theta_2\cos\phi_2)\right]$$
$$+\alpha_-\alpha_+\alpha_\psi(\cos\theta_1\cos\theta_2-\sin^2\theta_\Lambda\sin\theta_1\sin\theta_2\sin\phi_1\sin\phi_2)$$
$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda(\alpha_-\sin\theta_1\sin\phi_1+\alpha_+\sin\theta_2\sin\phi_2)$$

α_ψ : $=0.461(6)_{stat}(7)_{syst}$

$\Delta\Phi=\arg(G_E^\psi/G_M^\psi)=0.740(10)_{stat}(8)_{syst}$

$\alpha_-=\alpha(\Lambda\to p\pi^-)=0.750(9)_{stat}(4)_{syst}$

$\alpha_+=\alpha(\bar\Lambda\to\bar p\pi^+)=-0.758(10)_{stat}(7)_{syst}$

BAM-116

J. Liu, J. Jiao, R. Ping, H.-B. Li, A. Kupsc

Current work ΛΛ̄

Master formula for ΛΛ̄:

$$W(\xi)=1+\alpha_\psi \cos^2\theta_\Lambda+\alpha_-\alpha_+(\sin^2\theta_\Lambda \sin\theta_1 \sin\theta_2 \cos\phi_1 \cos\phi_2+\cos^2\theta_\Lambda \cos\theta_1 \cos\theta_2)$$
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\left[\sin\theta_\Lambda \cos\theta_\Lambda(\sin\theta_1 \cos\theta_2 \cos\phi_1+\cos\theta_1 \sin\theta_2 \cos\phi_2)\right]$$
$$+\alpha_-\alpha_+\alpha_\psi(\cos\theta_1 \cos\theta_2-\sin^2\theta_\Lambda \sin\theta_1 \sin\theta_2 \sin\phi_1 \sin\phi_2)$$
$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\sin\theta_\Lambda \cos\theta_\Lambda(\alpha_- \sin\theta_1 \sin\phi_1+\alpha_+ \sin\theta_2 \sin\phi_2)$$

$$\alpha_\psi = 0.461(6)_{stat}(7)_{syst} \qquad \alpha_- = \alpha(\Lambda \to p\pi^-) = 0.750(9)_{stat}(4)_{syst}$$

$$\Delta\Phi = \arg(G_E^\psi / G_M^\psi) = 0.740(10)_{stat}(8)_{syst} \qquad \alpha_+ = \alpha(\bar{\Lambda} \to \bar{p}\pi^+) = -0.758(10)_{stat}(7)_{syst}$$

- **Non-zero phase**
- **Decay parameter α_- differs from current PDG by more than 15%**

$\Xi^-\bar{\Xi}^+$

- What about $e^+e^- \rightarrow J/\Psi \rightarrow \Xi\bar{\Xi}$? Is phase non-zero phase?

- If yes it becomes possible to measure α_{Ξ^-} and $\alpha_{\bar{\Xi}^+}$ simultaneously and test CP. Also possible to measure simulataneously φ_{Ξ^-} (measured), $\varphi_{\bar{\Xi}^+}$ (not measured), ... and cross check α_- value

- Exclusive analysis on decay chain $\Xi^-\bar{\Xi}^+ \rightarrow \Lambda\pi^- \bar{\Lambda}\pi^+ \rightarrow p\pi^-\pi^- \bar{p}\pi^+\pi^+$

  (use Uppsala approach: G.Fäldt, AK, S. Leupold, E. Perotti)

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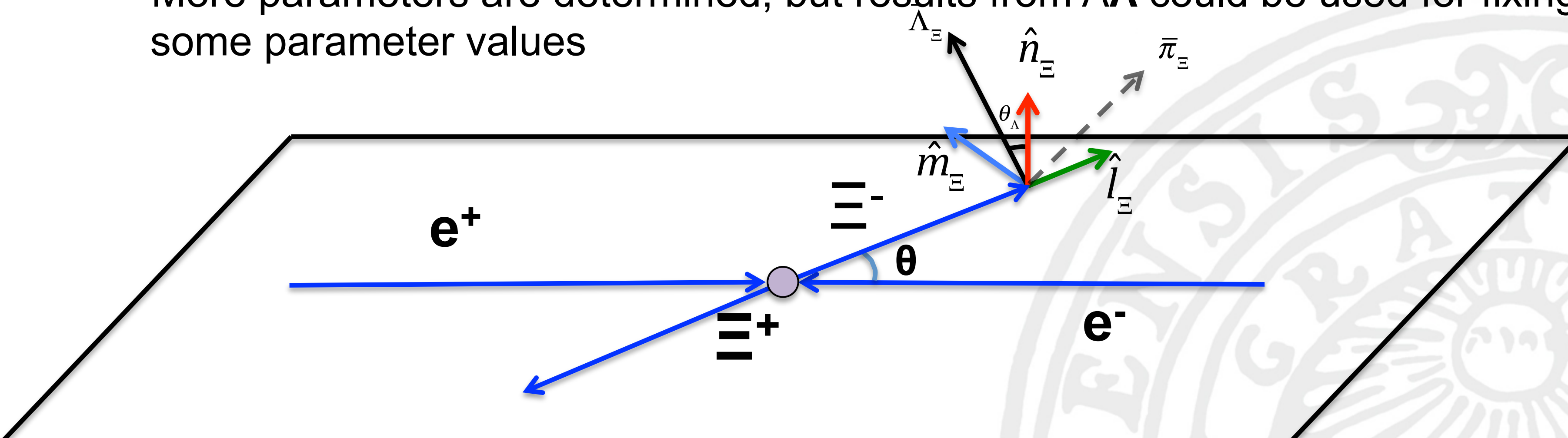
General Motivation

- 9-dimensional phase space (compared to 5D for ΛΛ)
- Angles are given in the helicity frame $\xi = (\theta_{\Xi}, \theta_{\Lambda}, \varphi_{\Lambda}, \theta_{\bar{\Lambda}}, \varphi_{\bar{\Lambda}}, \theta_{p}, \varphi_{p}, \theta_{\bar{p}}, \varphi_{\bar{p}})$
- More parameters are determined, but results from ΛΛ could be used for fixing some parameter values



$$\alpha_{\Xi^-} = \alpha(\Xi^- \to \Lambda\pi^-) \qquad \alpha_- = \alpha(\Lambda \to p\pi^-) \qquad \varphi_{\Xi^-} = \varphi(\Xi^- \to \Lambda\pi^-)$$

$$\alpha_{\Xi^+} = \alpha(\bar{\Xi}^+ \to \bar{\Lambda}\pi^+) \qquad \alpha_+ = \alpha(\bar{\Lambda} \to \bar{p}\pi^+) \qquad \varphi_{\Xi^+} = \varphi_{\Xi^-} + \pi$$

Previous work $\Xi^-\Xi^+$

Xiaongfei Wang inclusive analysis based on 225 mill J/ψ and 106.4 mill ψ(3686)

[(BESIII) PRD 93, 072003 (2016)]

J/ψ

ψ(3686)

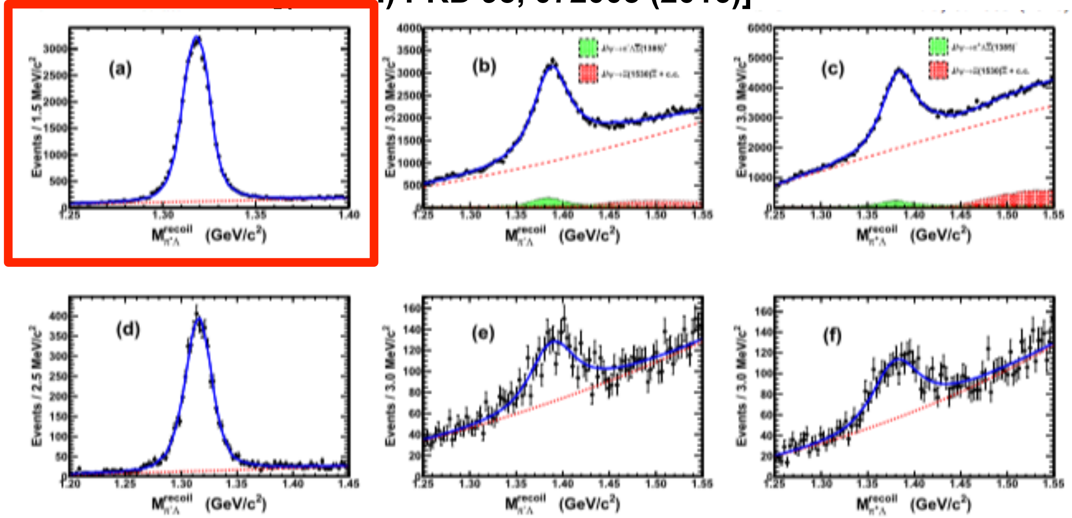


TABLE I. The number of the observed events $N_{\rm obs}$, efficiencies ϵ, α values, and branching fractions $\mathcal{B}$ for $\psi \to \Xi^-\bar{\Xi}^+$, $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$. Only statistical uncertainties are indicated.

Channel	$N_{\rm obs}$	$\epsilon(\%)$	α	$\mathcal{B}(\times 10^{-4})$
$J/\psi \to \Xi^-\bar{\Xi}^+$	42810.7 ± 231.0	18.40 ± 0.04	0.58 ± 0.04	10.40 ± 0.06
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$	42594.8 ± 466.8	17.38 ± 0.04	-0.58 ± 0.05	10.96 ± 0.12
$J/\psi \to \Sigma(1385)^+\bar{\Sigma}(1385)^-$	52522.5 ± 595.9	18.67 ± 0.04	-0.49 ± 0.06	12.58 ± 0.14
$\psi(3686) \to \Xi^-\bar{\Xi}^+$	5336.7 ± 82.6	18.04 ± 0.04	0.91 ± 0.13	2.78 ± 0.05
$\psi(3686) \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$	1374.5 ± 97.8	15.12 ± 0.04	0.64 ± 0.40	0.85 ± 0.06
$\psi(3686) \to \Sigma(1385)^+\bar{\Sigma}(1385)^-$	1469.9 ± 94.6	16.45 ± 0.04	0.35 ± 0.37	0.84 ± 0.05

Decay parameters $\Xi^-\Xi^+$

- Best results from HyperCP experiment measuring 117×10^6 Ξ^- and 42×10^6 Ξ^+
  CP asymmetry: $A_{\Xi\Lambda} = [\,0.0 \pm 5.1(\text{stat.}) \pm 4.4(\text{syst.})\,] \times 10^{-4}$
  [PRL 93 (2004) 262001]

- Spin decay parameter $\varphi_\Xi = (-2.39 \pm 0.64 \pm 0.64)^\circ$ for $\Xi^- \rightarrow \Lambda\pi^-$
  [PRL 93 (2004) 011802]

- $\alpha_\Xi = -0.458(12)$ from PDG, BUT α_Ξ and β_Ξ are calculated from $\alpha_\Xi\ \alpha_\Lambda / \alpha_{\Lambda,PDG} (= 0.642)$

- Cross check prel. BESIII result for $\alpha_\Lambda = 0.750$

Decay parameters at BESIII

Best results from HyperCP experiment measuring 117 x 10^6 Ξ^- and 42 x 10^6 $\bar{\Xi}^+$
$A_{\Xi\Lambda}$ = [0.0 ± 5.1(stat.) ± 4.4(syst.)] x 10^{-4}
[PRL 93 (2004) 262001]

BESIII lower statistics but:

- symmetric particle/anti particle conditions with very clean background situation—>controlled systematic uncertainties
- $\Xi^-\bar{\Xi}^+$ measured in the same event
- use spin-spin correlations and polarization
- part of larger program, e.g. also $\Xi^0\bar{\Xi}^0$
- Direct measurement of α(Ξ→ Λπ) and verification of α(Λ →p π)

General analysis strategy

Builds off of Xiaongfei Wang's (XW) original code, but modified. BOSS v6.6.4.

1) Charged track selection, using standard $|\cos(\theta)_{\pm}| < 0.93$ selection. At least 3 positively and 3 negatively charged tracks required.

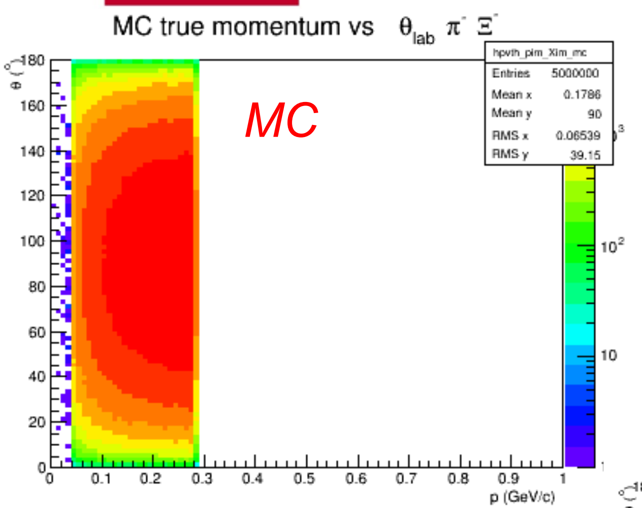
2) Select best $\Lambda/\mathbf{\Lambda}$ candidates from protons and pions. Then perform primary and secondary vertex fit keeping events passing fit. Pair closest to $m(\Lambda)$ selected as candidate.
No PID used, but momentum cuts for separating protons from pions.

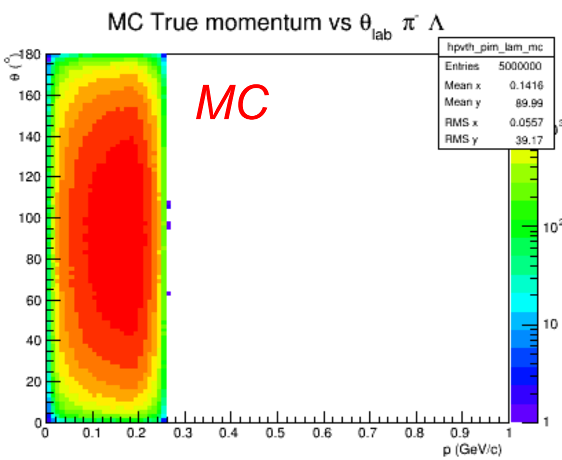
3) In the same loops pair the best Λ and $\mathbf{\Lambda}$ with remaining pions. Here a primary and secondary vertex fit is used for the $\Lambda\pi$ pairs Select combination closest to $\Xi^-/\mathbf{\Xi}^+$ mass.

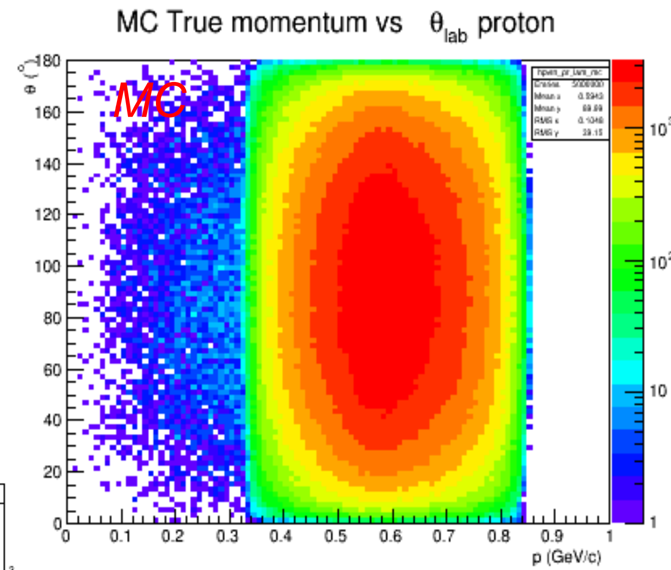
4) Run Kalman Kinematic Fit 4C on hyp. e+e- --> $\Xi^-\mathbf{\Xi}^+$

5) Final event selection: CL kinfit as veto + 4σ cuts on $\Lambda/\mathbf{\Lambda}$ and $\Xi^-/\mathbf{\Xi}^+$ mass distributions

True distributions



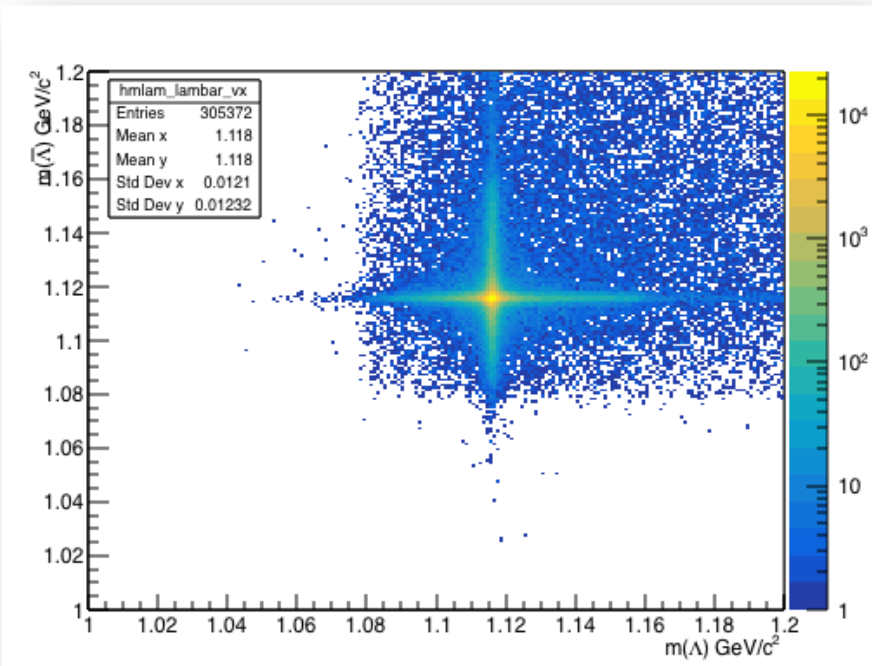


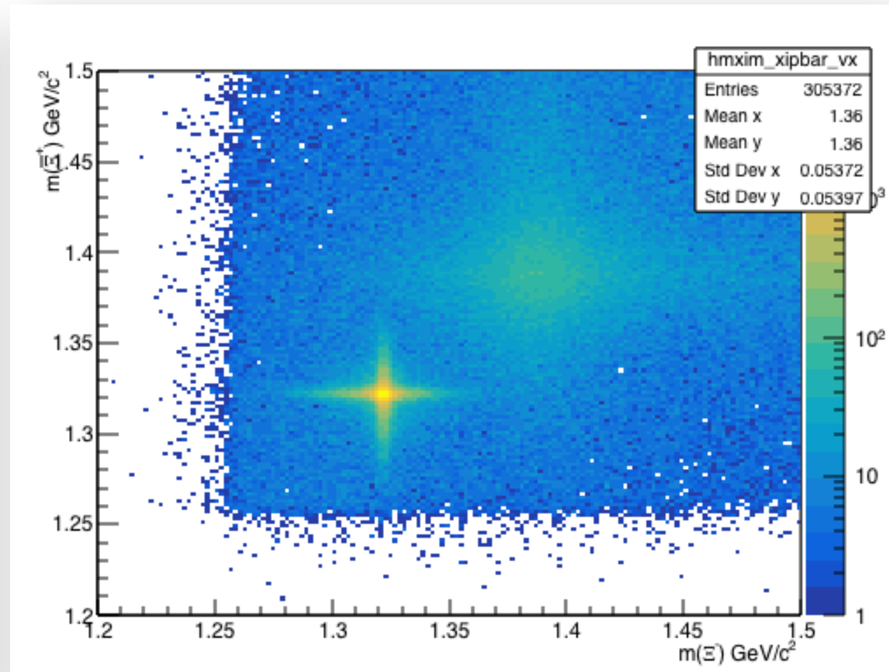


[Pr, π(Λ), π(Ξ)] = [> 0.32 , < 0.30 , < 0.30] GeV/c

Momentum vs theta angle. Momentum cuts for particle selection

Pre-selected data sample



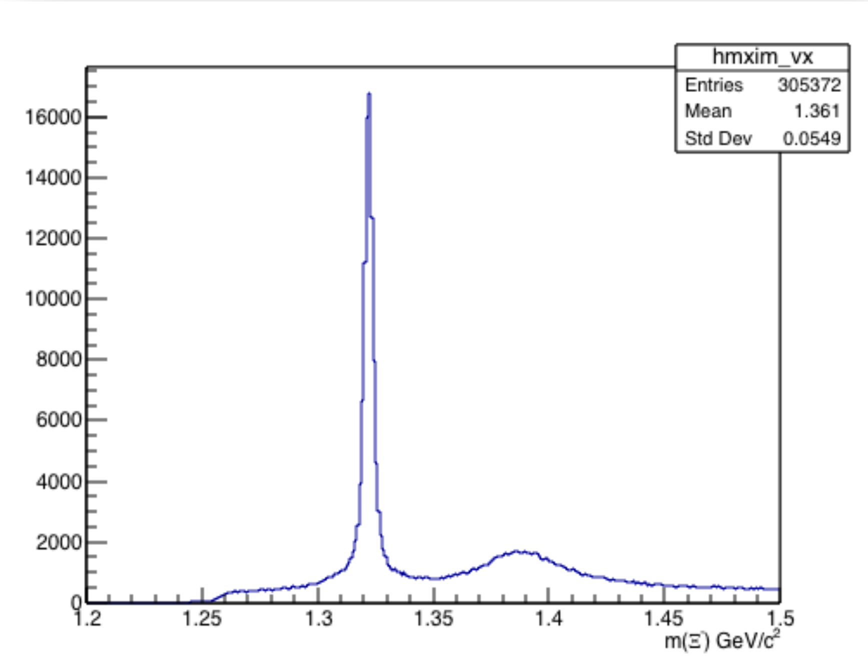


M(Λ) vs M(**Λ**)

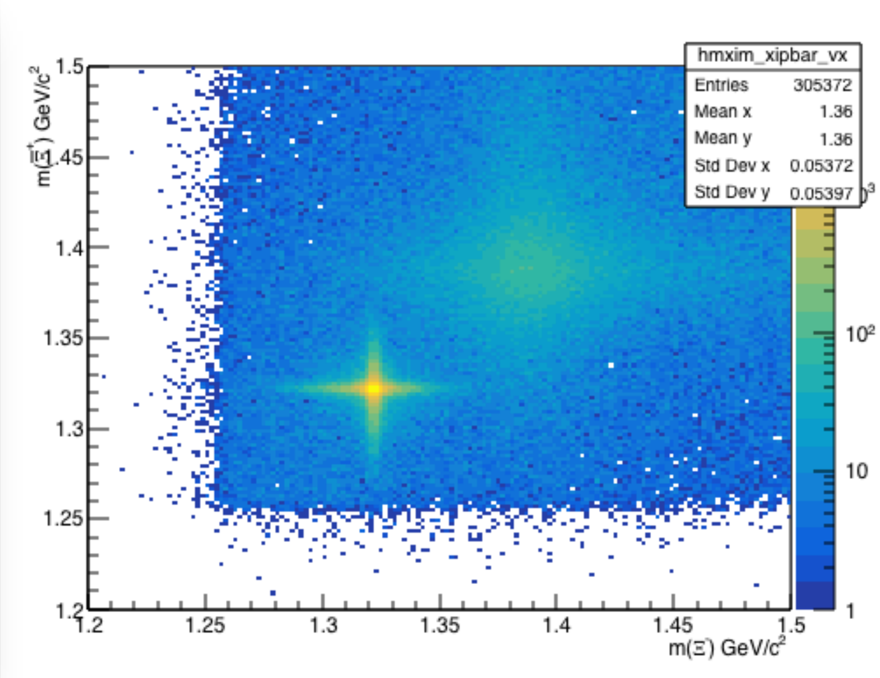
M(Ξ) vs M(**Ξ**)

After pre-selection of data, requiring that KinFit converged ($X^2(4C) < 200$)

Pre-selected data sample



M(Ξ⁻)



M(Ξ⁻) vs M(Ξ⁺)

After pre-selection of data, requiring that KinFit converged ($X^2(4C) < 200$)

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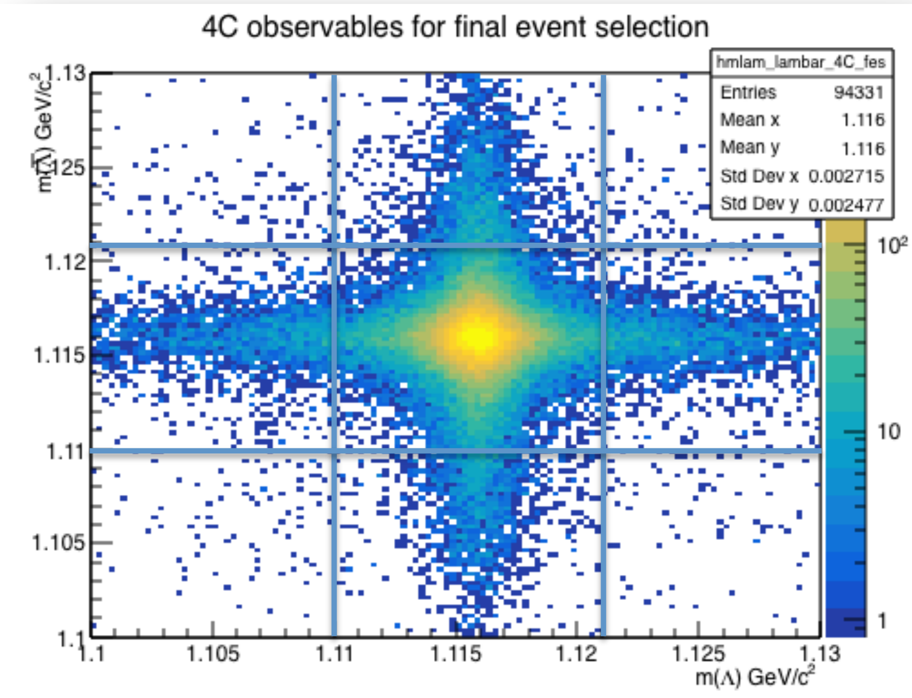
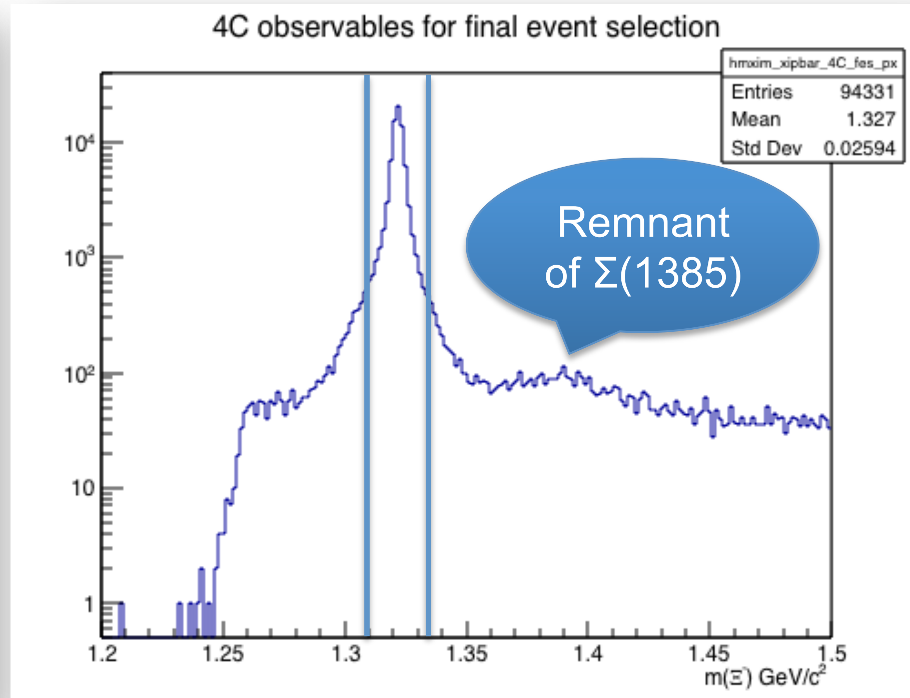
Event sample after cut on KinFit-4C $\chi^2 < 100$





M(Λ) vs M(**Λ**)

M(Ξ^-) vs M(**Ξ^+**)

~4σ cuts on Λ/**Λ (6 MeV)** and Ξ^-/**Ξ^+ (12 MeV)**

In final event sample, 67200 events ~ 1-2% background contamination

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Remarks

- Only exploratory analysis with respect to final event selection
- For all analysis steps more careful systematic studies have to be performed and e.g. background considered.

Max log-likelihood method

$$P\left(\xi_1, \xi_2, \xi, \dots, _{60000}, \xi_{N=67164}; \alpha_{J/\psi}, \Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda}\right)$$

$$= \prod_{k=1}^{N} P\left(\xi_k; \alpha_{J/\psi}, \Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda}\right)$$

$$= \prod_{k=1}^{N} \frac{W\left(\xi_k; \alpha_{J/\psi}, \Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda}\right) * \varepsilon(\xi_k)}{N(\Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda})}$$

$$L = -\ln L = -\sum_{k=1}^{N} \ln \frac{W\left(\xi_k; \alpha_{J/\psi}, \Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda}\right)}{N(\Delta\Phi, \alpha_{\Xi-}, \alpha_{\Xi+}, \phi_{\Xi}, \alpha_{\Lambda})}$$

MLL fit values exp data

$$\alpha_{J/\Psi} = 0.43(2) \quad \Delta\Phi = 0.76(4) \quad \alpha_{\Xi} = -0.45(1) \quad \alpha_{\bar{\Xi}} = -0.47(1)$$

$$\alpha_{\Lambda} = 0.50(1), \quad \alpha_{\bar{\Lambda}} = -0.50(1) \quad \varphi_{\Xi} = 0.19(5)$$

“best fit” -ln L = -2193

$$\alpha_{J/\Psi} = 0.34(1) \quad \Delta\Phi = 0.54(2) \quad \alpha_{\Xi} = -0.363(8) \quad \alpha_{\bar{\Xi}} = -0.380(8)$$

$$\alpha_{\Lambda} = 0.75(fix), \quad \alpha_{\bar{\Lambda}} = -0.75(fix), \quad \varphi_{\Xi} = +0.18(3)$$

“fixed fit” -ln L = -1714

Results shows definitely polarization of ΞΞ

Big discrpancy for asymmetry parameters of Λ --> pπ

General two spin ½ particle state

$$\rho_{1/2,\overline{1/2}} = \frac{1}{4}\sum_{\mu\nu} C_{\mu\bar{\nu}}\sigma_\mu \otimes \sigma_{\bar{\nu}}$$

16 parameters for each θ:
I(θ), polarizations (6)
Spin correlations (9)

$$\mathcal{W}(\boldsymbol{\xi}) = \mathcal{I}(\theta)\Big\{1 + \alpha_\Lambda \sum_k P_k(\theta)\mathbf{n}_k + \alpha_{\bar{\Lambda}} \sum_{\bar{k}} P_{\bar{k}}(\theta)\mathbf{n}_{\bar{k}} + \alpha_\Lambda\alpha_{\bar{\Lambda}} \sum_{\bar{k}k} C_{\bar{k}k}(\theta)\mathbf{n}_{\bar{k}}\mathbf{n}_k\Big\}$$

polarizations (6)

Spin correlations (9)

$$P_y(\theta) = \sqrt{1-\alpha_\psi^2}\frac{\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}\sin(\Delta\Phi)$$

$$P_{\bar{y}}(\theta) = P_y(\theta).$$

$$\mathcal{I}(\theta) = 1 + \alpha_\psi\cos^2\theta.$$

$$C_{\bar{z}z}(\theta)\mathcal{I}(\theta) = -\alpha_\psi + \cos^2\theta$$

$$C_{\bar{x}x}(\theta)\mathcal{I}(\theta) = -\sin^2\theta$$

$$C_{\bar{y}y}(\theta)\mathcal{I}(\theta) = -\alpha_\psi\sin^2\theta$$

$$C_{\bar{x}z}(\theta)\mathcal{I}(\theta) = -\sqrt{1-\alpha_\psi^2}\cos\theta\sin\theta\cos(\Delta\Phi)$$

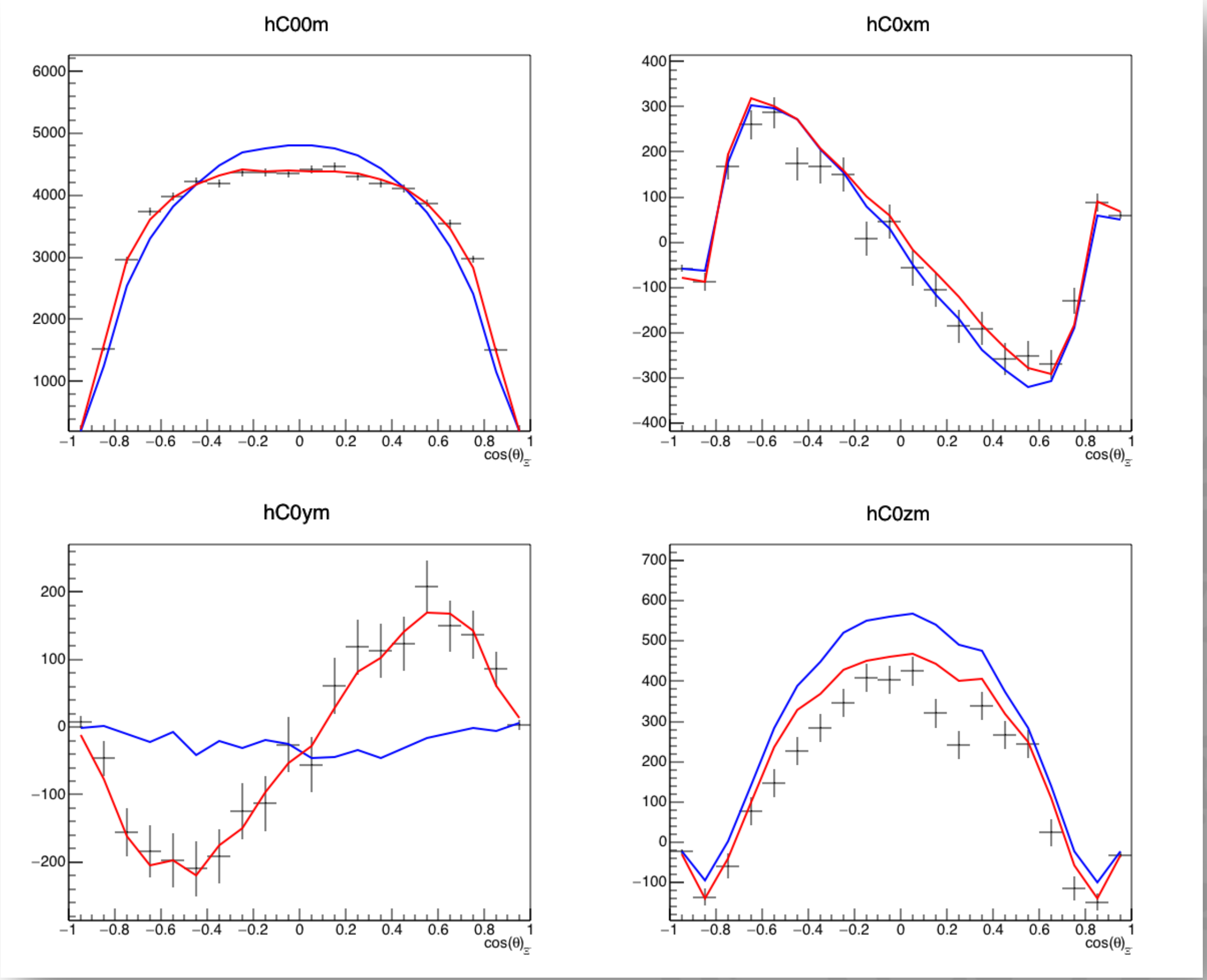
$$C_{\bar{z}x}(\theta) = C_{\bar{x}z}(\theta)$$

moments: $$M(\theta) = \sum_i^{N(\theta)} \mathbf{n}_\mu^i\mathbf{n}_\nu^i$$ (uncorrected for acceptance)

Moments best fit

Phase Space

Fit values



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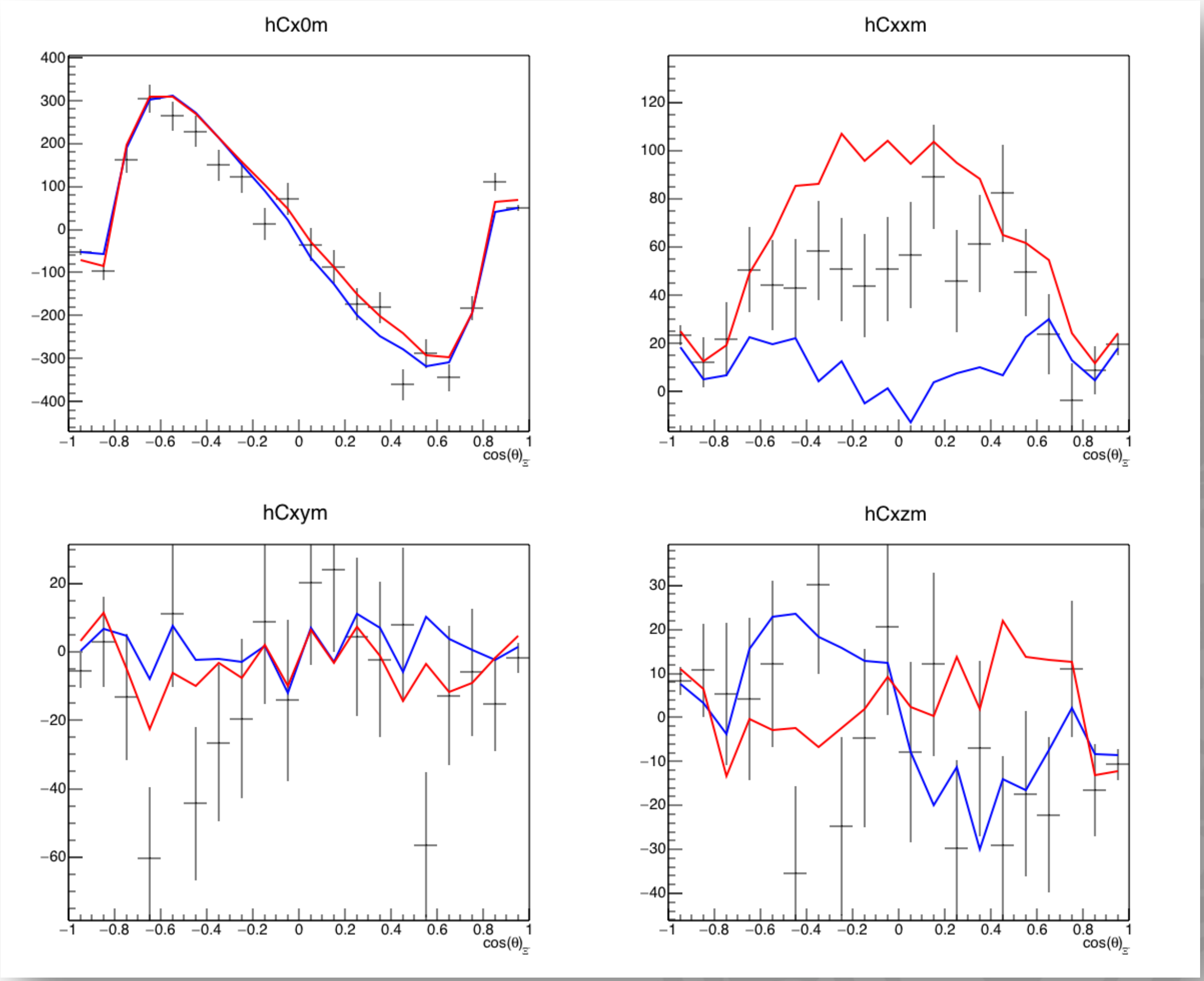
Moments best fit

Phase Space

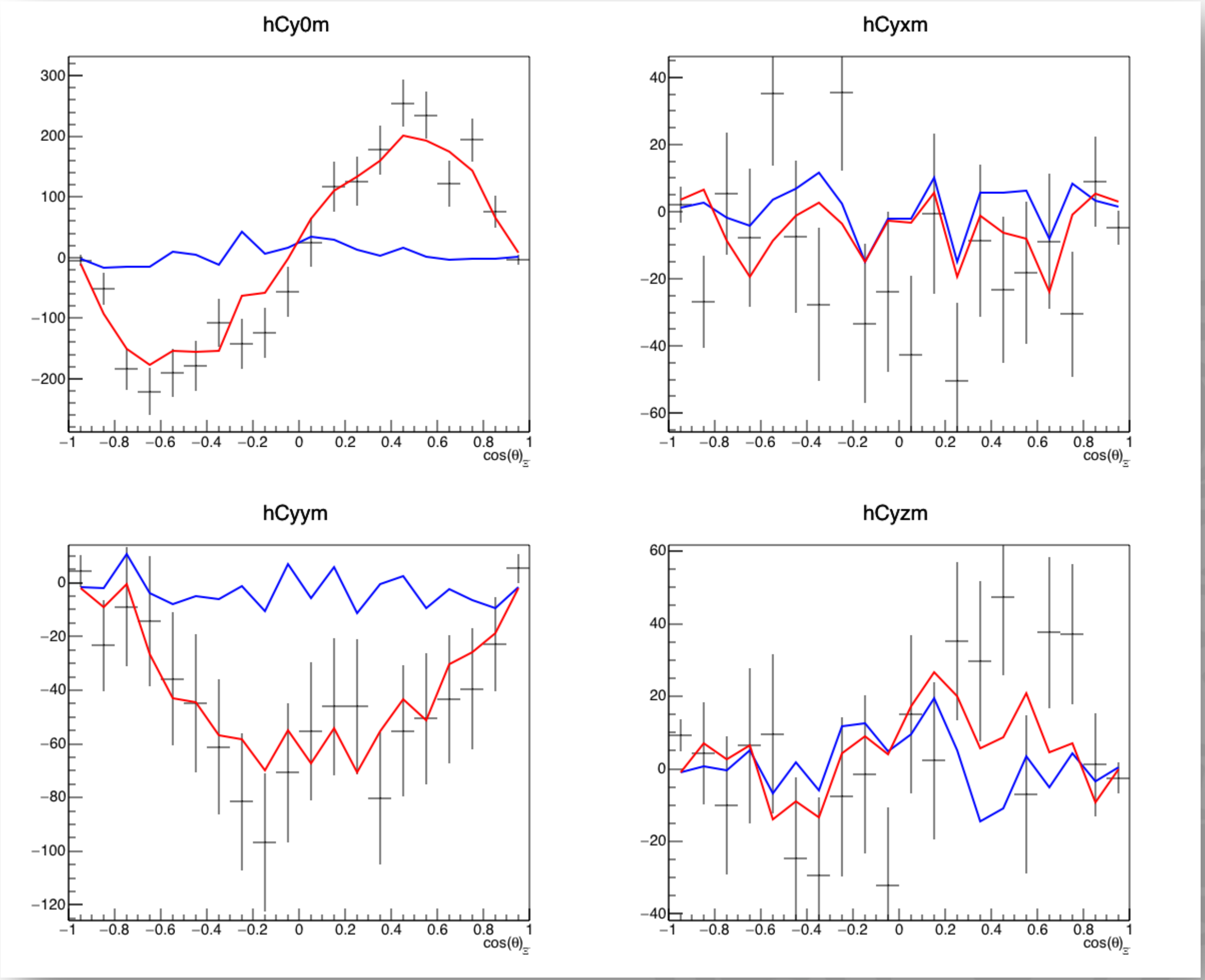
Fit values



Moments best fit

Phase Space

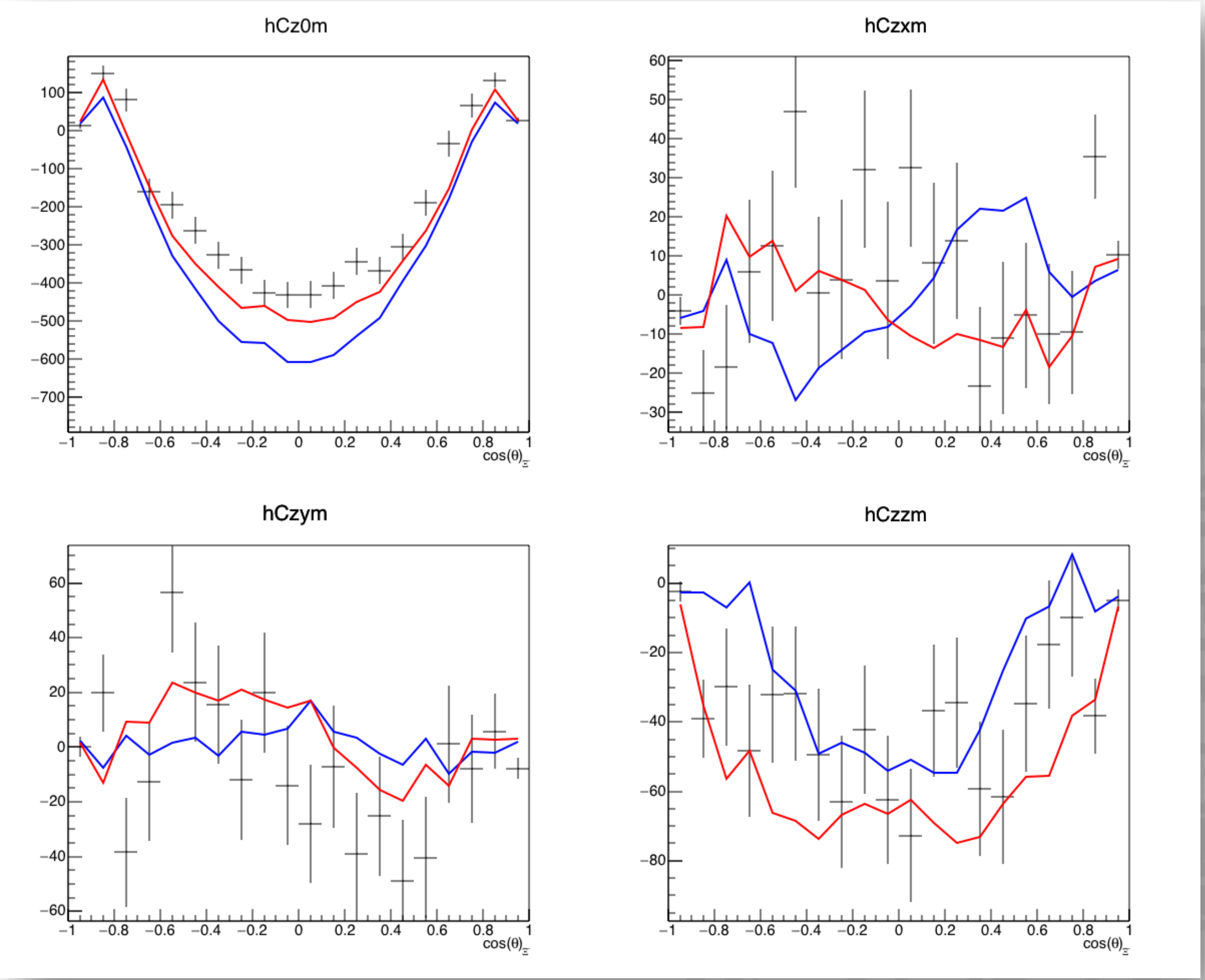
Fit values



Moments best fit

Phase Space

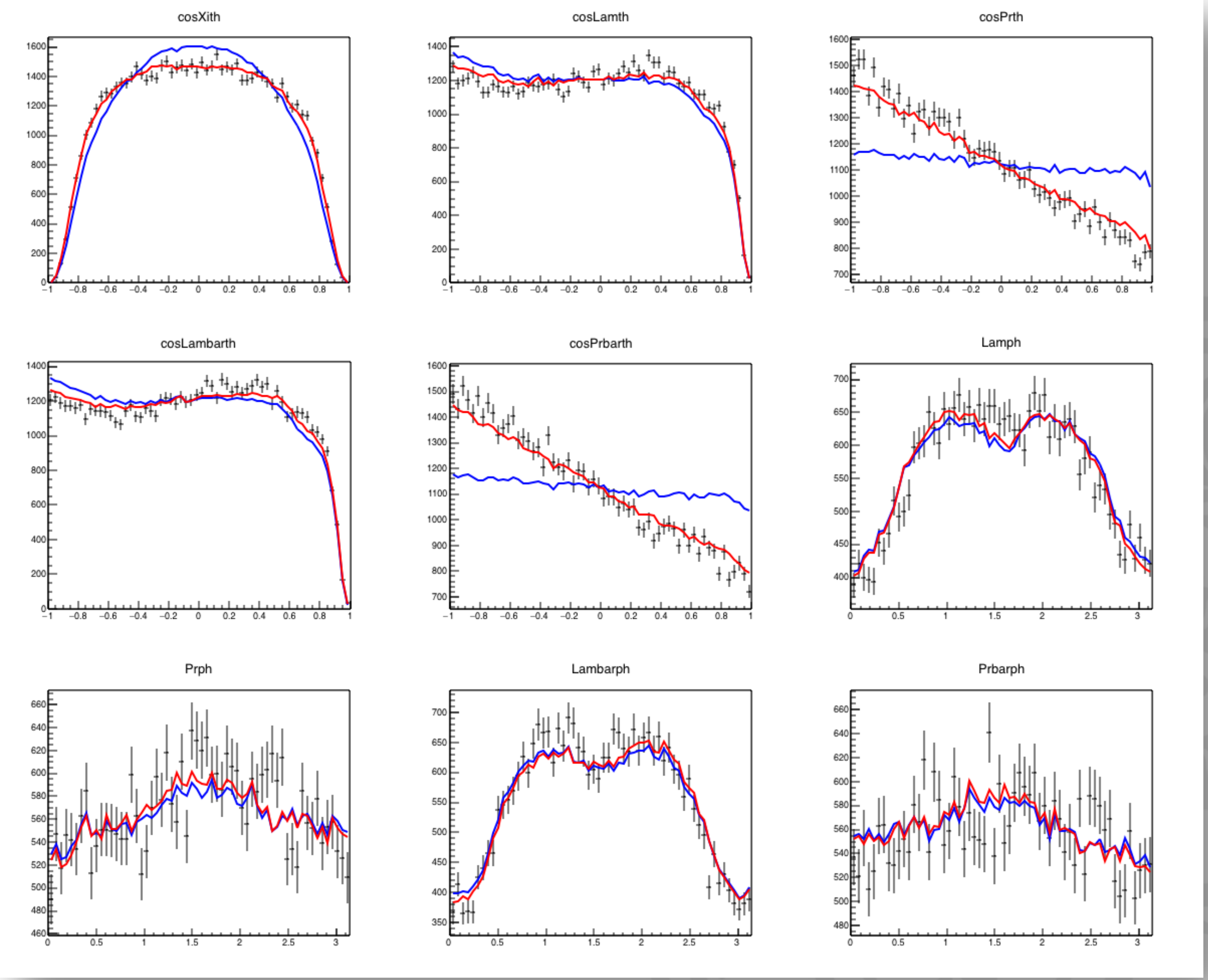
Fit values



Helicity angles best fit

Phase Space

Fit values



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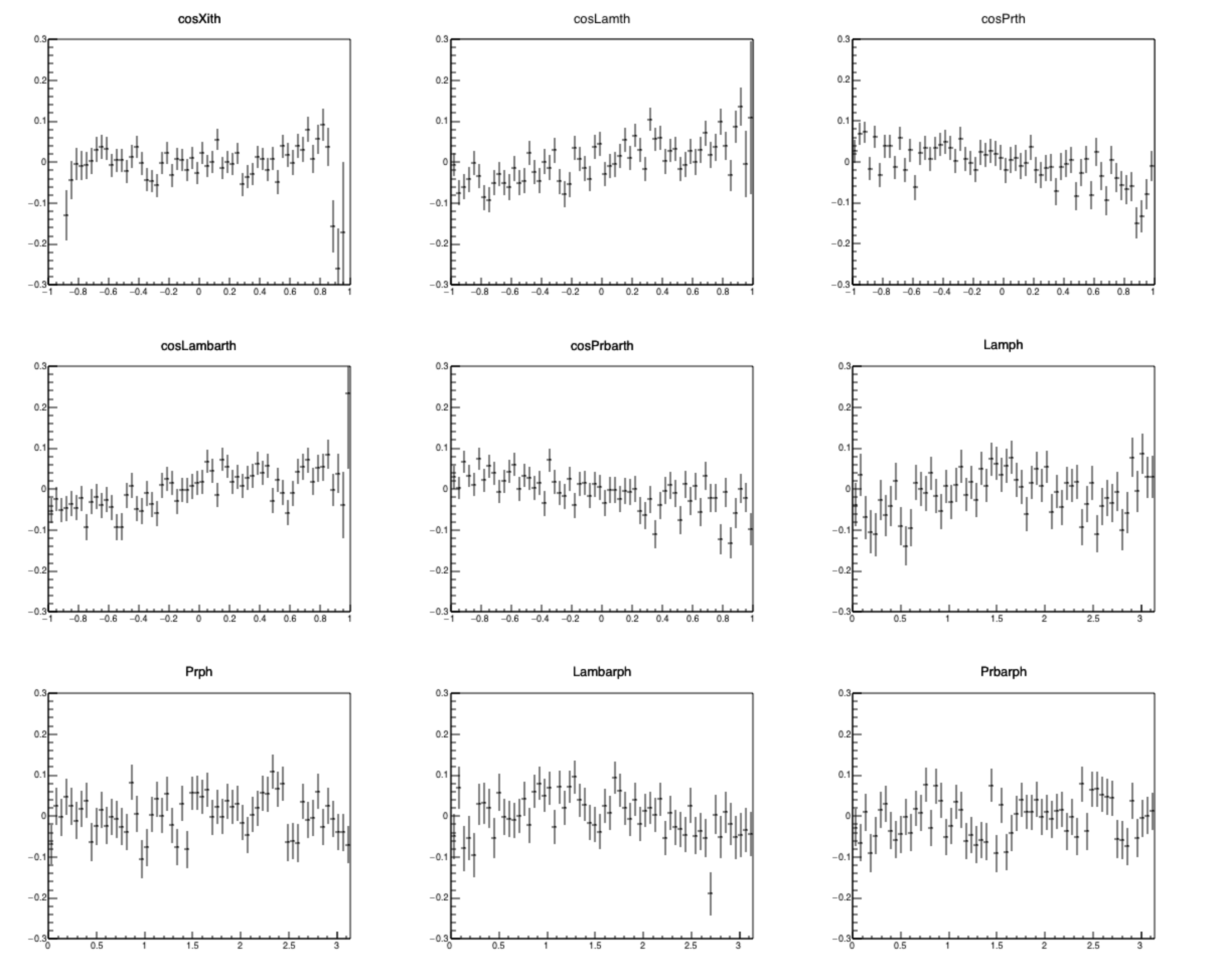
Helicity angles best fit

Data / best fit

deviatons from 0 seen



Data MC comparison

- MC sample obtained with hit-and-miss method to reproduce the experimental distribution *exactly*, i.e. with the production and decay process fully described (within error bars of best fit)

$$\alpha_{J/\Psi} = 0.45 \quad \Delta\Phi = 0.79 \quad \alpha_{\Xi} = -0.45 \quad \alpha_{\bar{\Xi}} = 0.45$$

$$\alpha_{\Lambda} = 0.50, \quad \alpha_{\bar{\Lambda}} = -0.50, \quad \varphi_{\Xi} = +0.20$$

MLL fit values exp data

$$\alpha_{J/\Psi} = 0.45 \quad \Delta\Phi = 0.79 \quad \alpha_{\Xi} = -0.45 \quad \alpha_{\bar{\Xi}} = 0.45$$

$$\alpha_{\Lambda} = 0.50, \quad \alpha_{\bar{\Lambda}} = -0.50, \quad \varphi_{\Xi} = +0.20$$

True parameters

$$\alpha_{J/\Psi} = 0.45(2) \quad \Delta\Phi = 0.84(4) \quad \alpha_{\Xi} = -0.46(1) \quad \alpha_{\bar{\Xi}} = 0.45(1)$$

$$\alpha_{\Lambda} = 0.52(1), \quad \alpha_{\bar{\Lambda}} = -0.50(1), \quad \varphi_{\Xi} = +0.17(3)$$

“pseudo data” -ln L = -2577

In relatively good agreement with true input

MLL fit values exp data

$$\alpha_{J/\Psi} = 0.43(2) \quad \Delta\Phi = 0.76(4) \quad \alpha_{\Xi} = -0.45(1) \quad \alpha_{\bar{\Xi}} = -0.47(1)$$

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“best fit” -ln L = -2193

$$\alpha_{J/\Psi} = 0.45(2) \quad \Delta\Phi = 0.84(4) \quad \alpha_{\Xi} = -0.46(1) \quad \alpha_{\bar{\Xi}} = 0.45(1)$$

$$\alpha_{\Lambda} = 0.52(1), \quad \alpha_{\bar{\Lambda}} = -0.50(1), \quad \varphi_{\Xi} = +0.17(3)$$

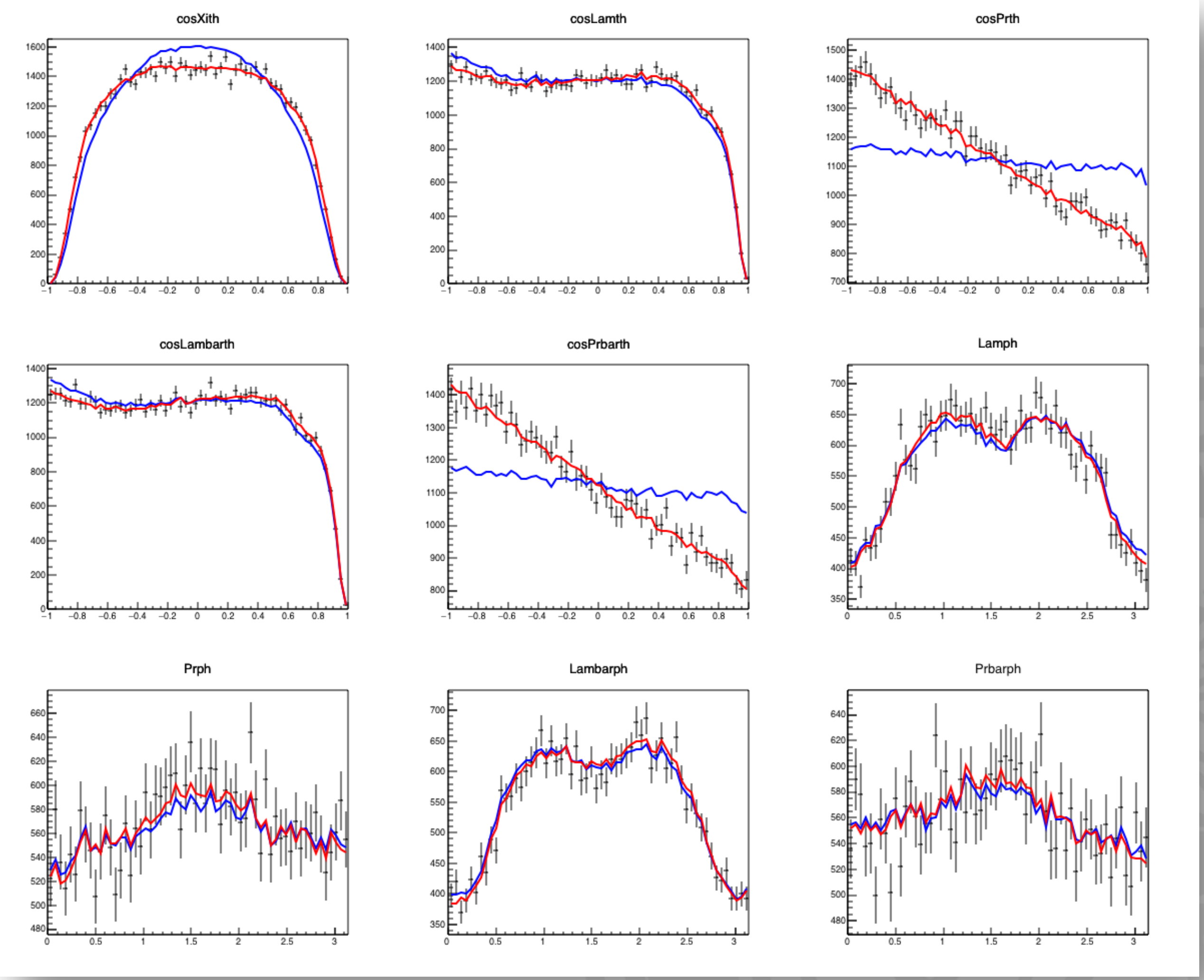
“pseudo data” -ln L = -2577

Disagreement between exp data and pseudo data log likelihood value

Helicity angles pseudo data

Phase Space

Fit values



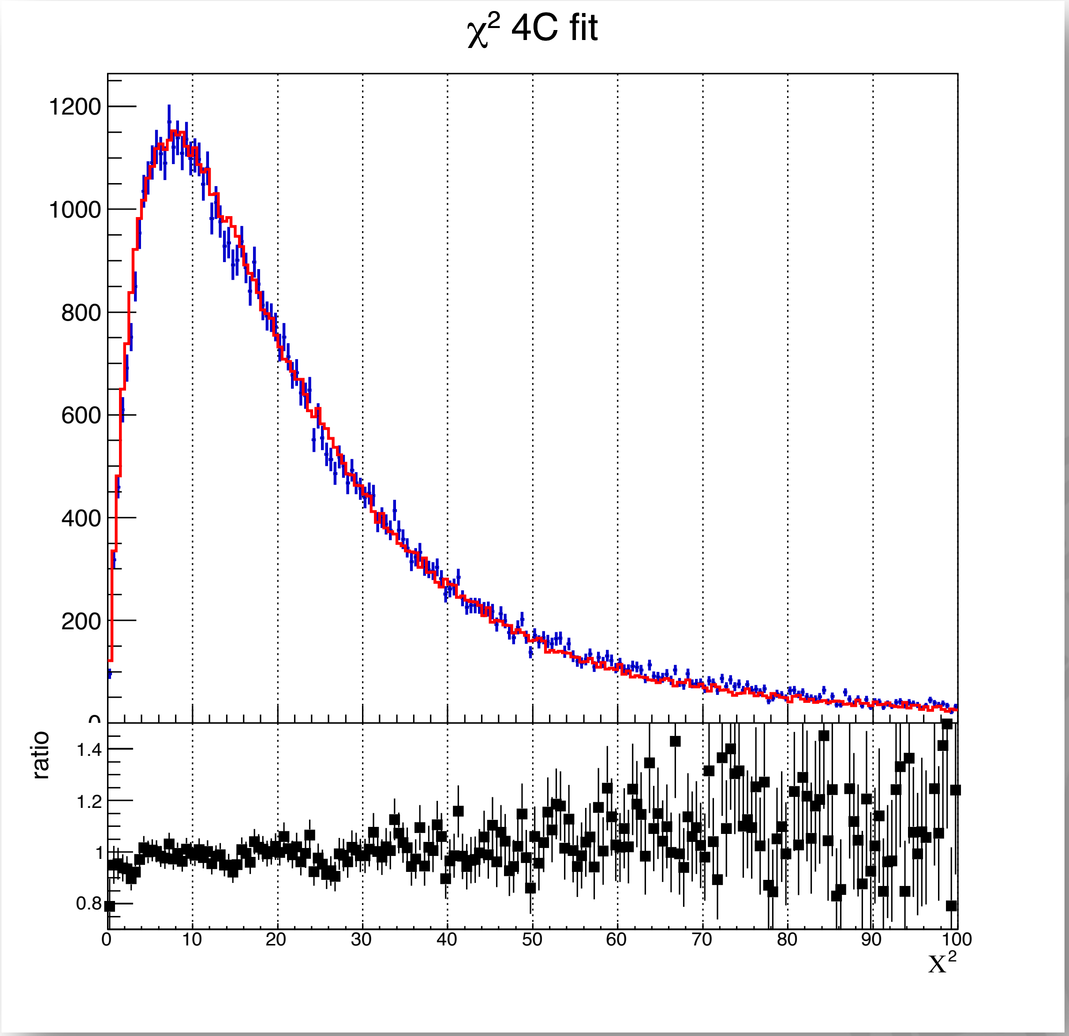
Red follows pseudo data points better compared to real data!

Indication of systematic effect in experimental data

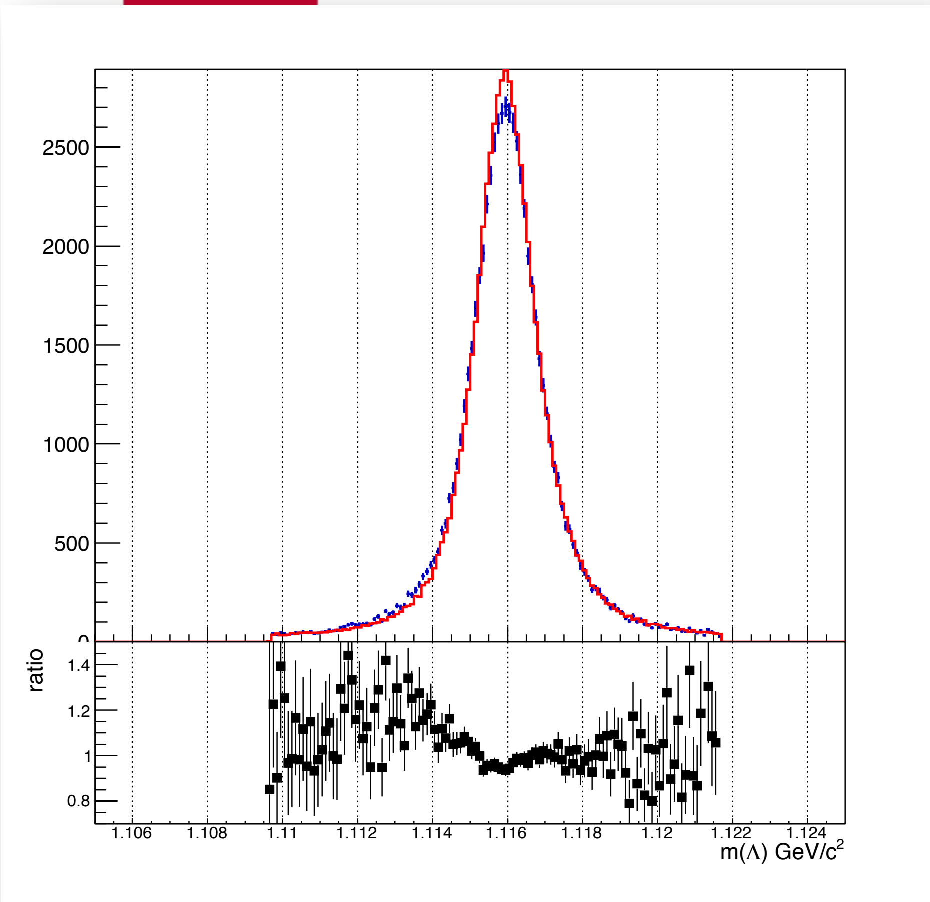
Data MC comparison

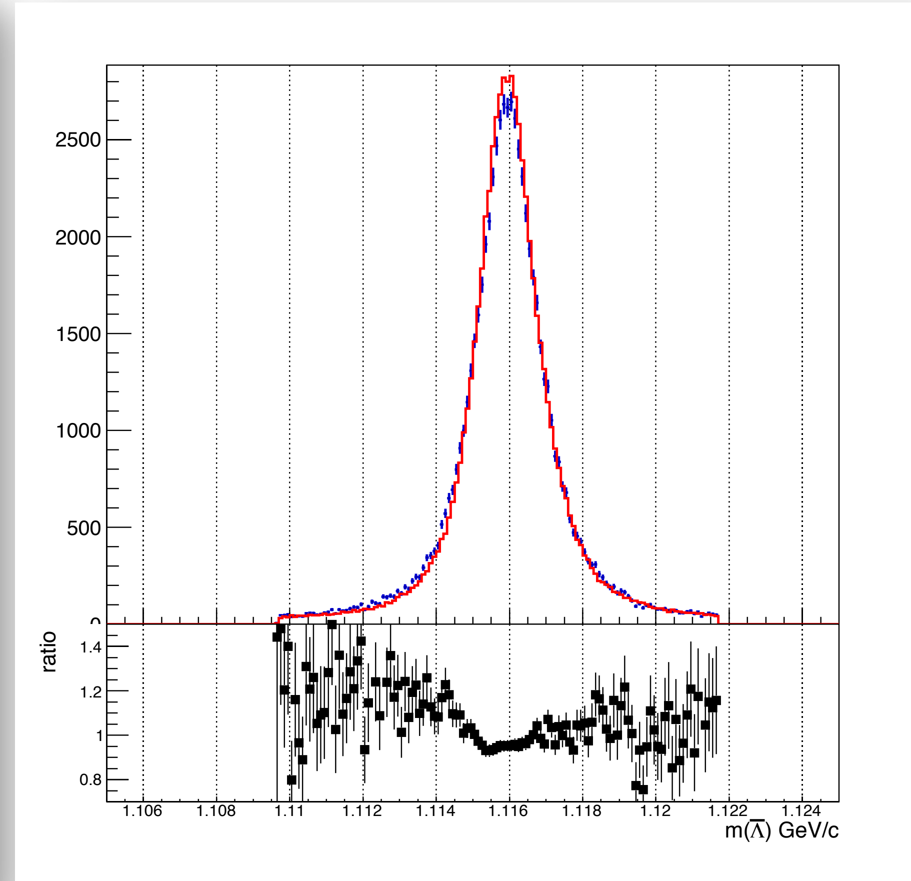
- In the following, each figure is shown is the final event sample comparing data (blue points) with MC (red histogram), normalized to the experimental data
- Again, MC is the sample generated with the hit-and-miss method and supposed to be exact representation of experimental data
- In sub-plots the ratio (data/mc) is shown
- In experimental data the 1-2% background events are not taken into account (i.e. pure ΞΞ sample is assumed)

Data MC comparison χ2

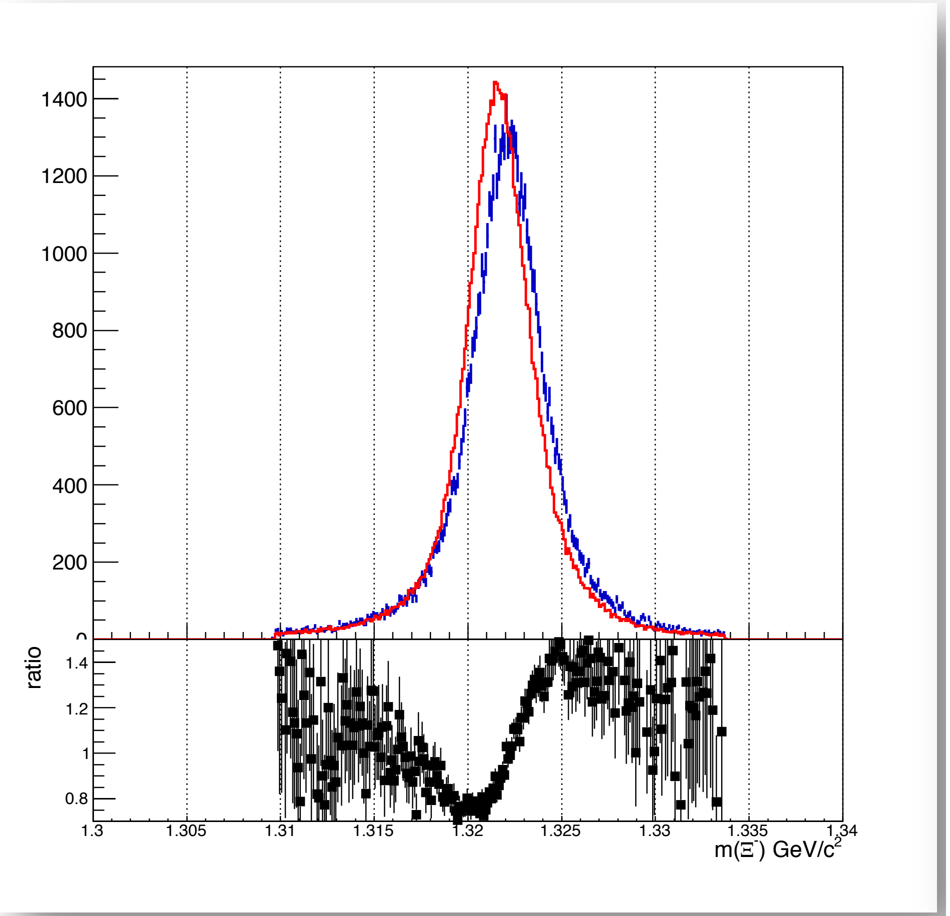


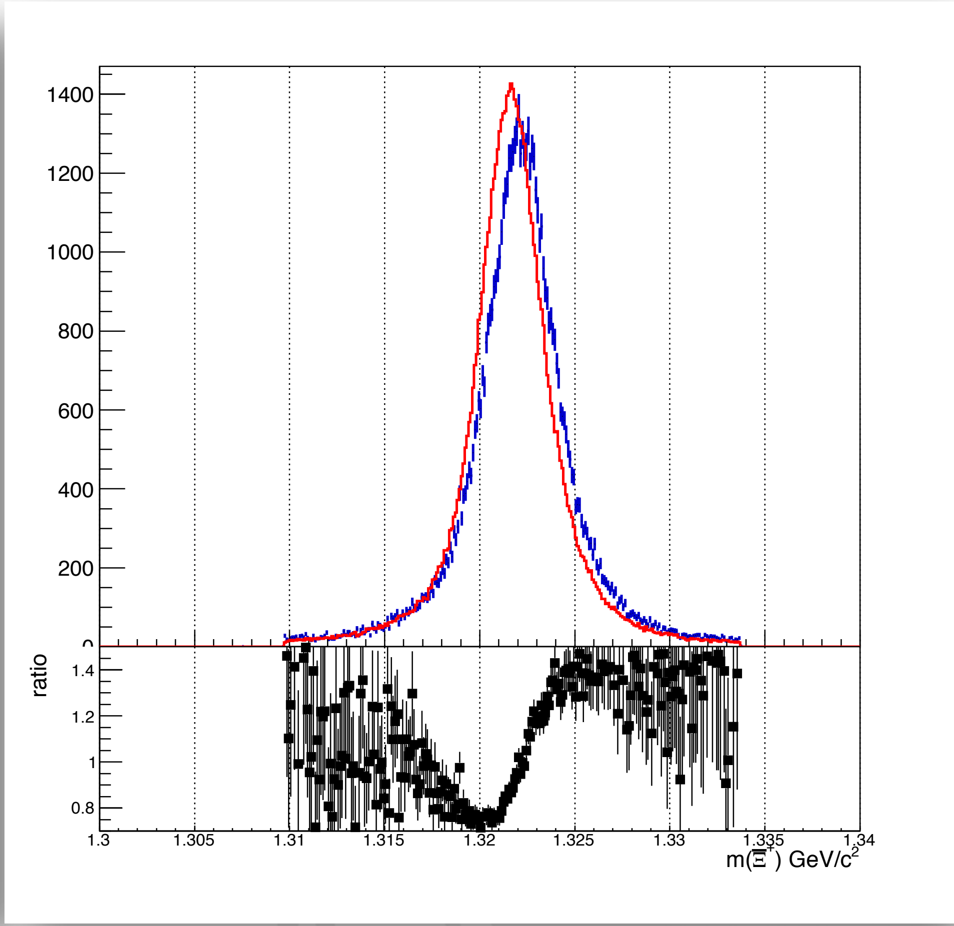
Data MC comparison m(Λ) + bar vertex fit





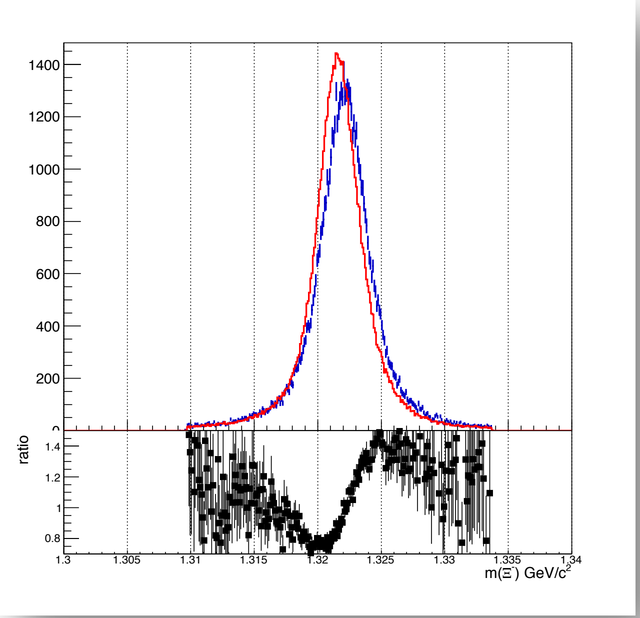
Data MC comparison m(Ξ) + bar vertex fit

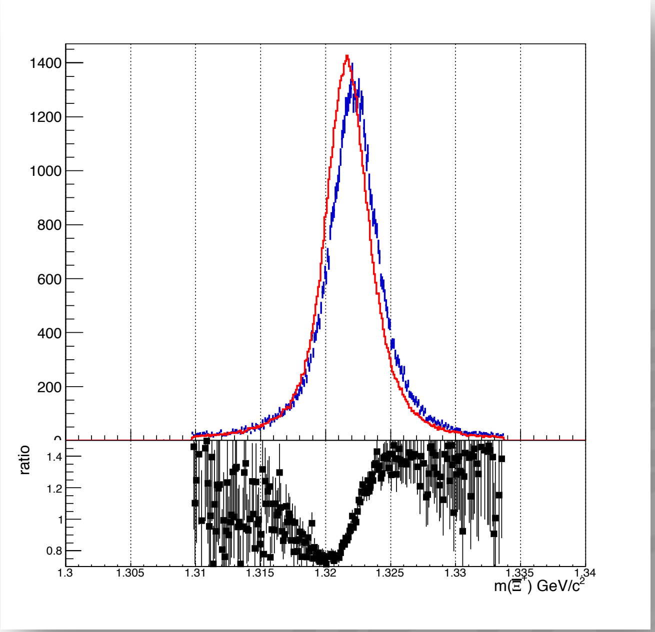




Is PDG mass off? Is MC generated mass off? Is nominal magnetic field value off?

Data MC comparison m(Ξ) + bar vertex fit



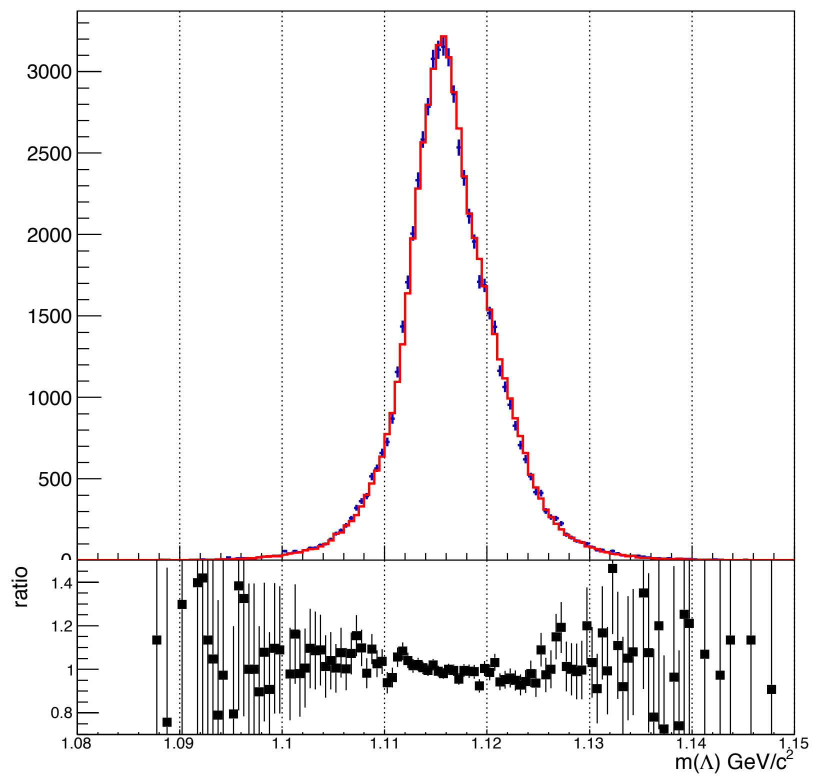


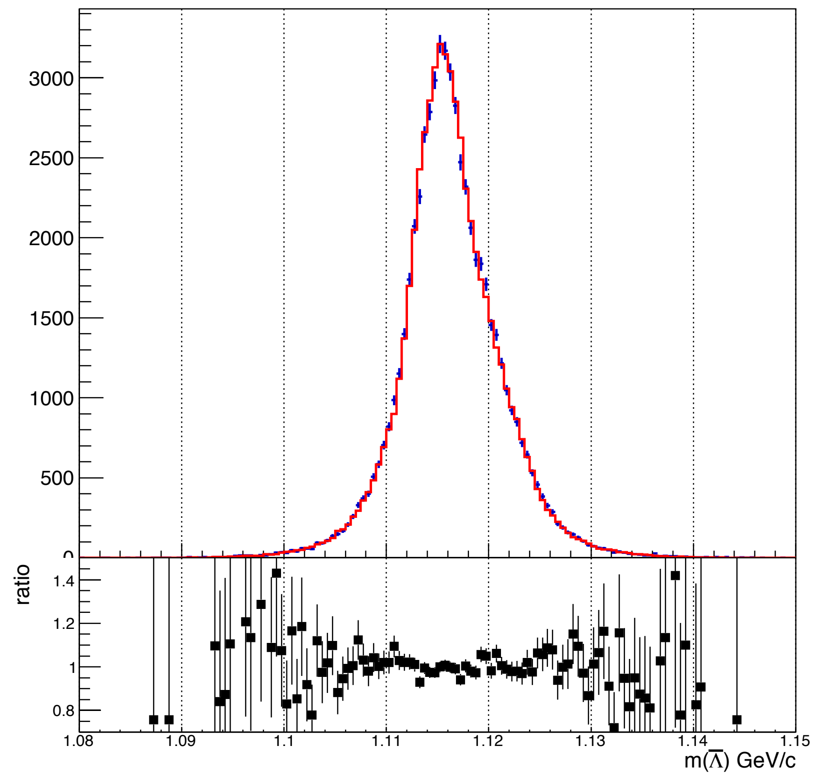
Is PDG mass off? Is MC generated mass off? Is nominal magnetic field value off?

PDG = 1321.71(7) MeV   MC = 1321.32 MeV

Previous analysis

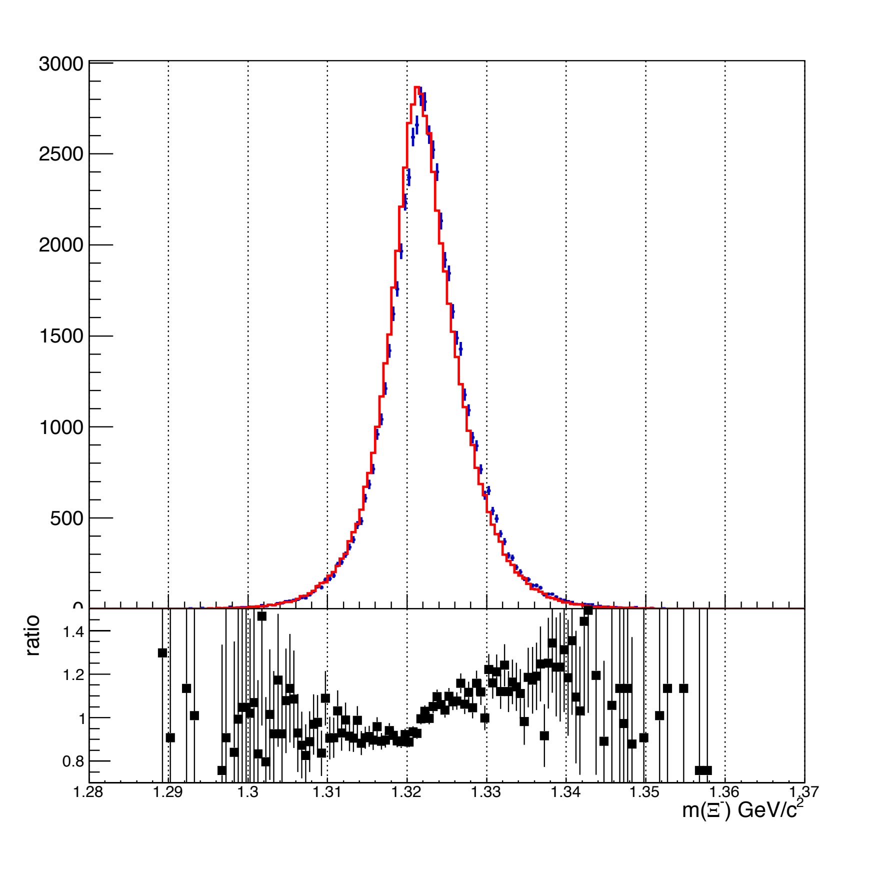
In previous iteration of this analysis I used reconstructed, instead of fitted observables, also here some slight deviation seen

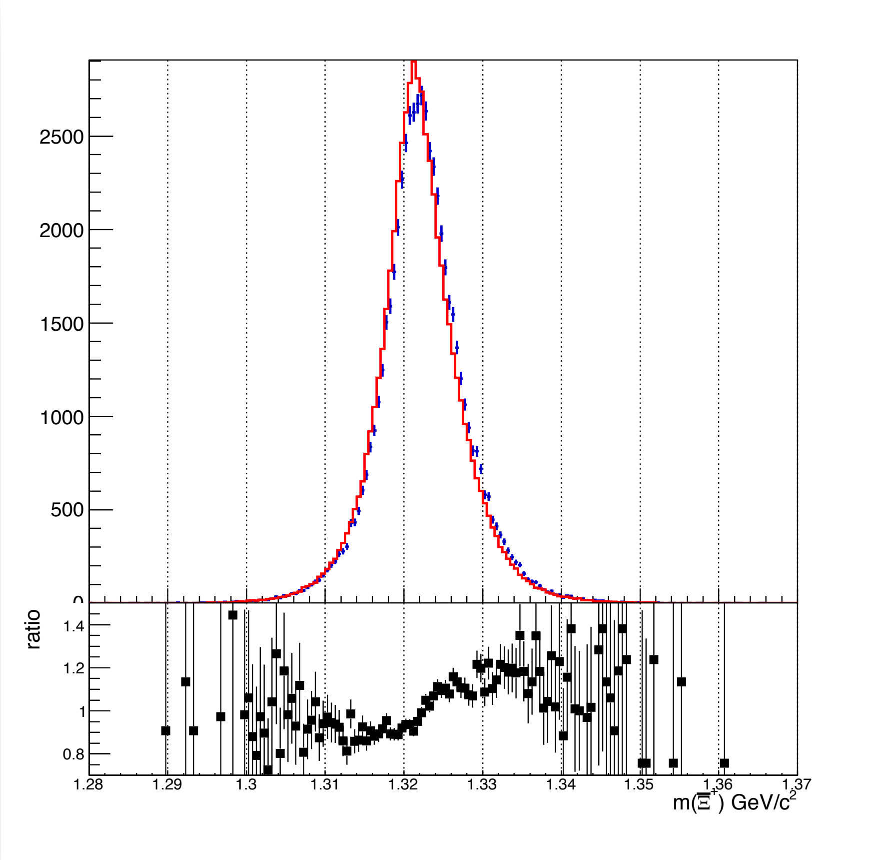




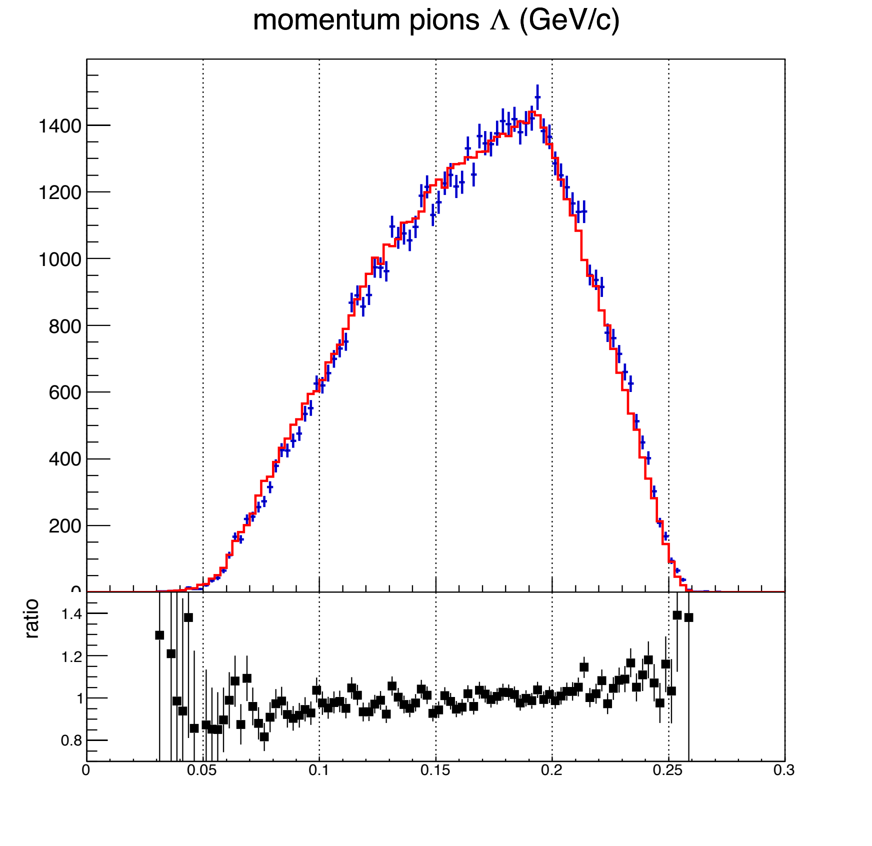
Previous analysis

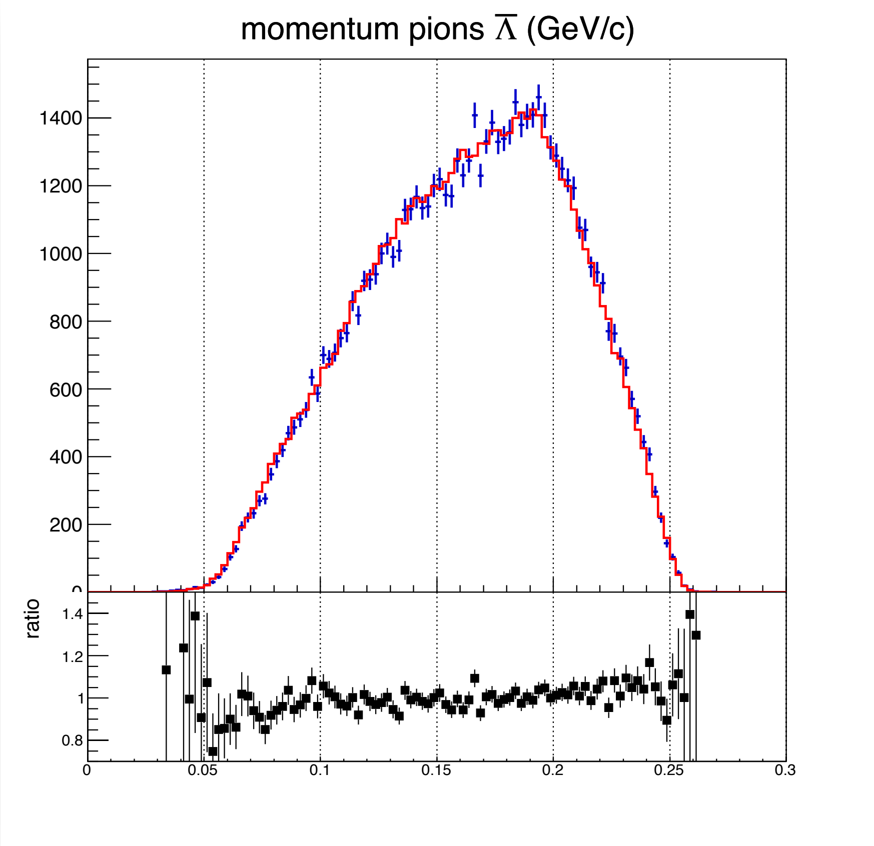
…again more so for ΞΞ



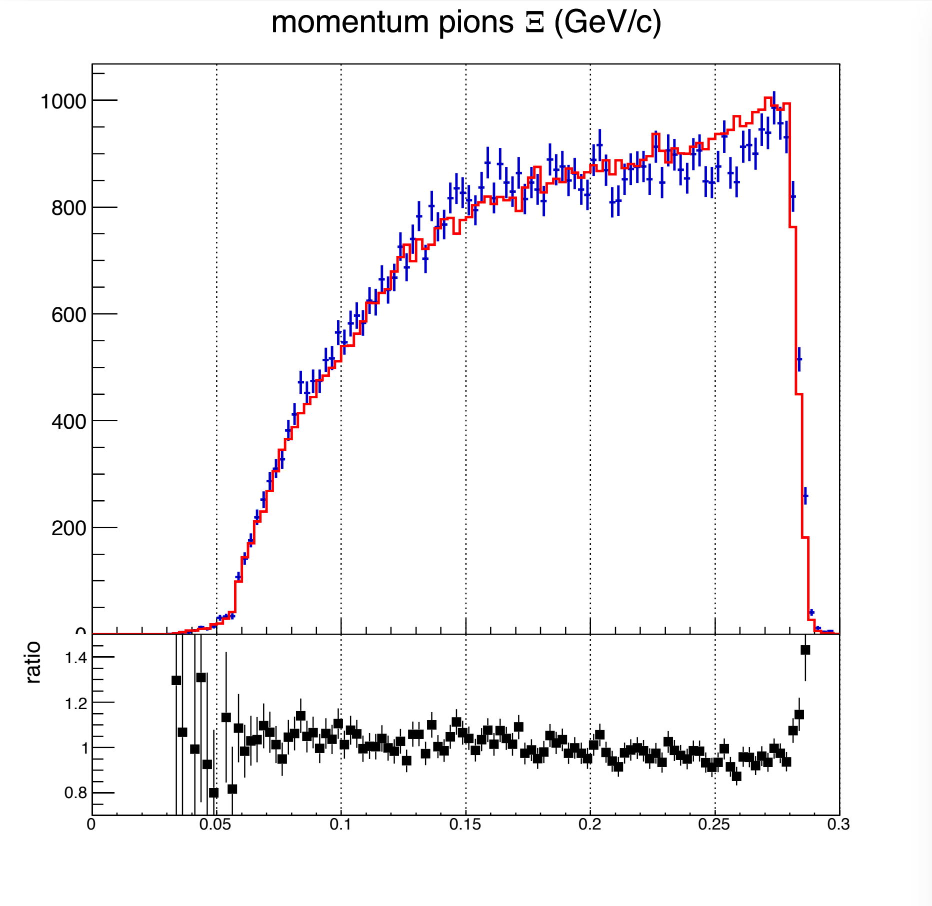


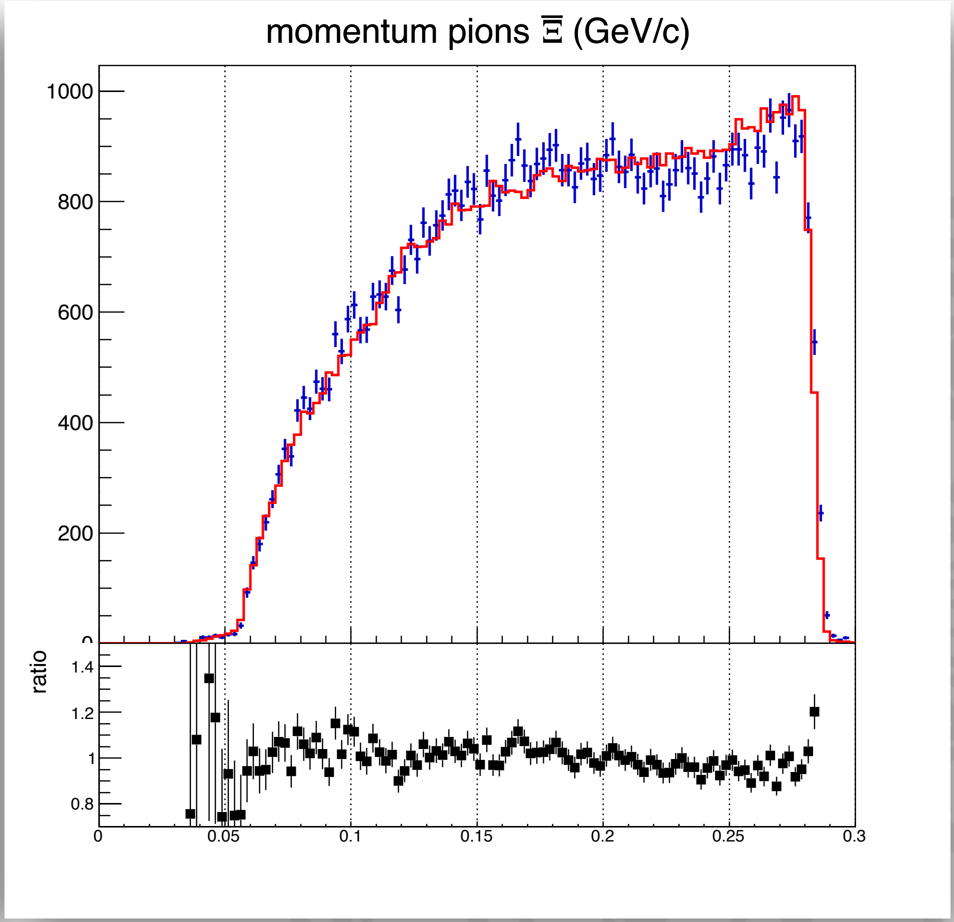
Data MC comparison momentum



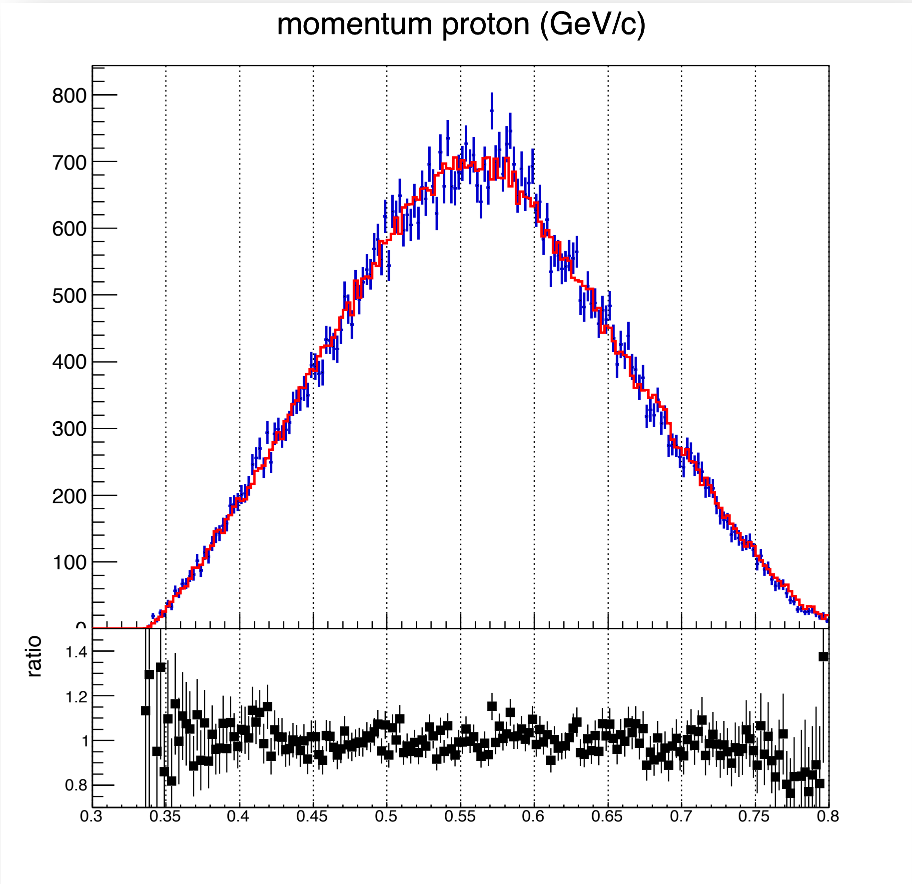


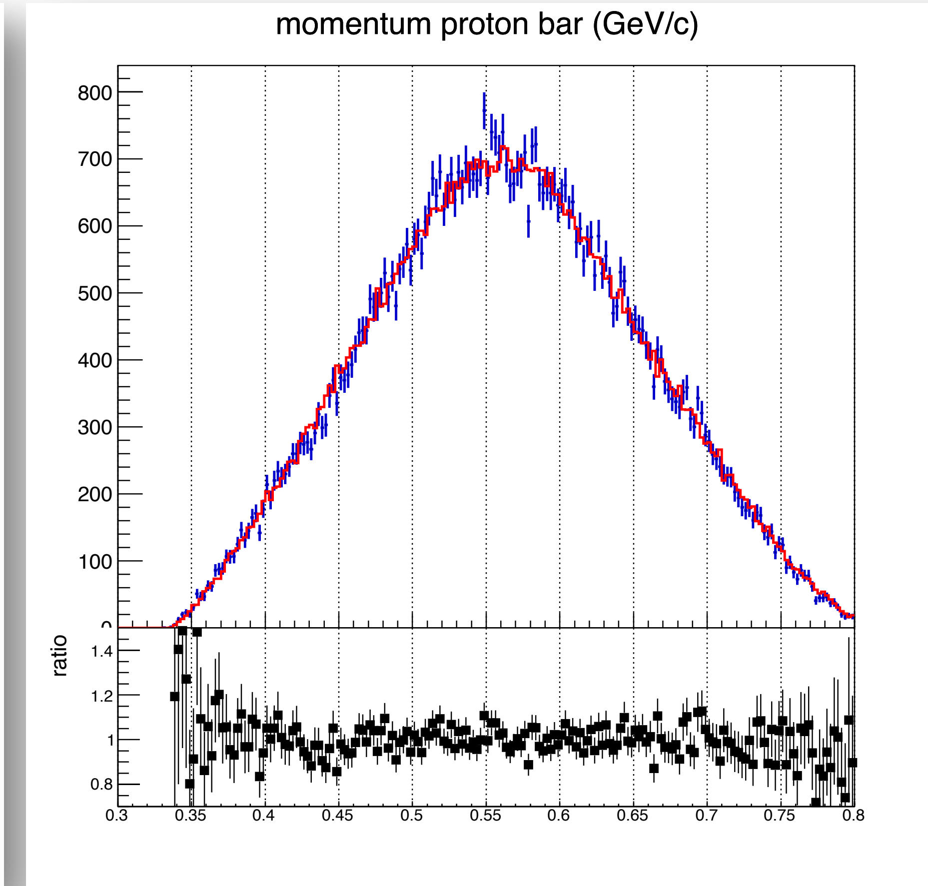
Data MC comparison momentum





Data MC comparison momentum proton





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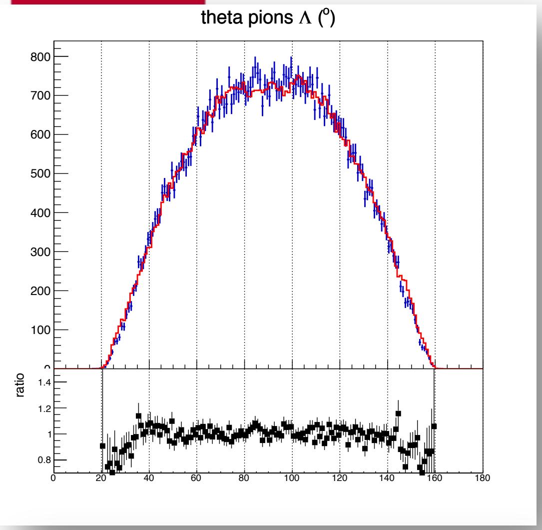
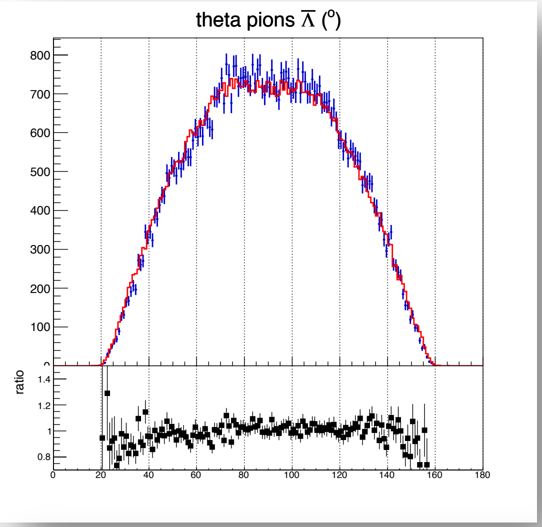
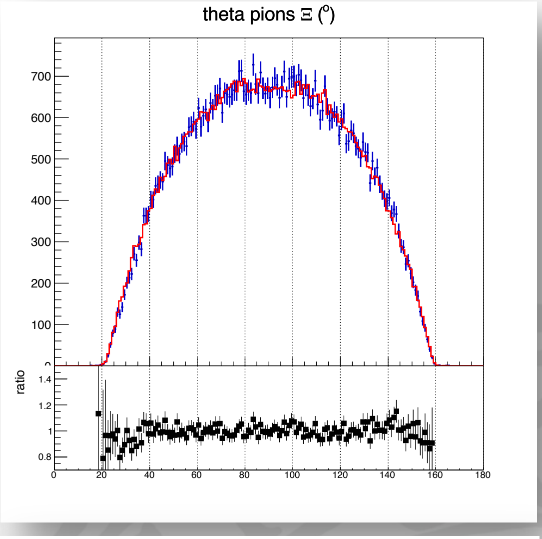
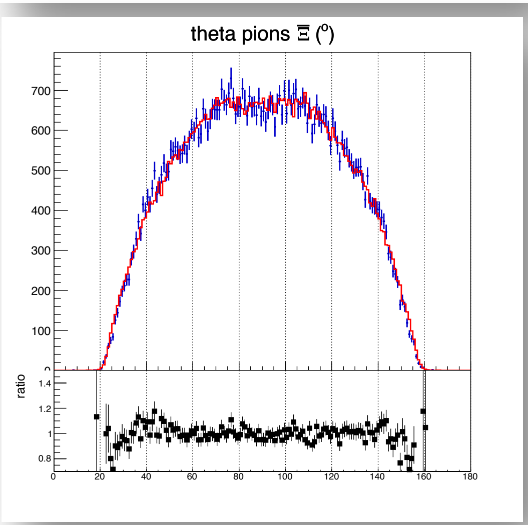
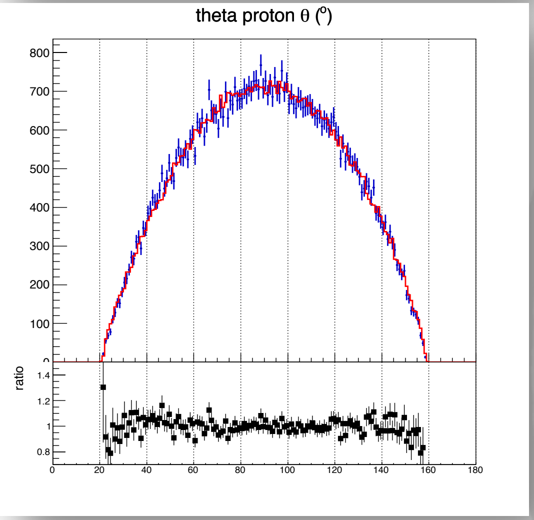
Data MC comparison angles

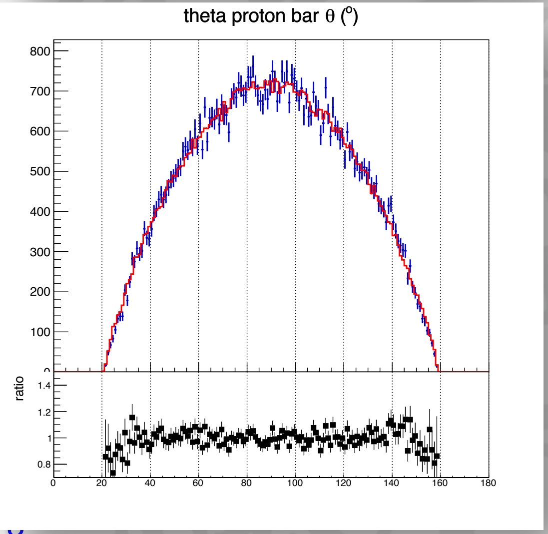




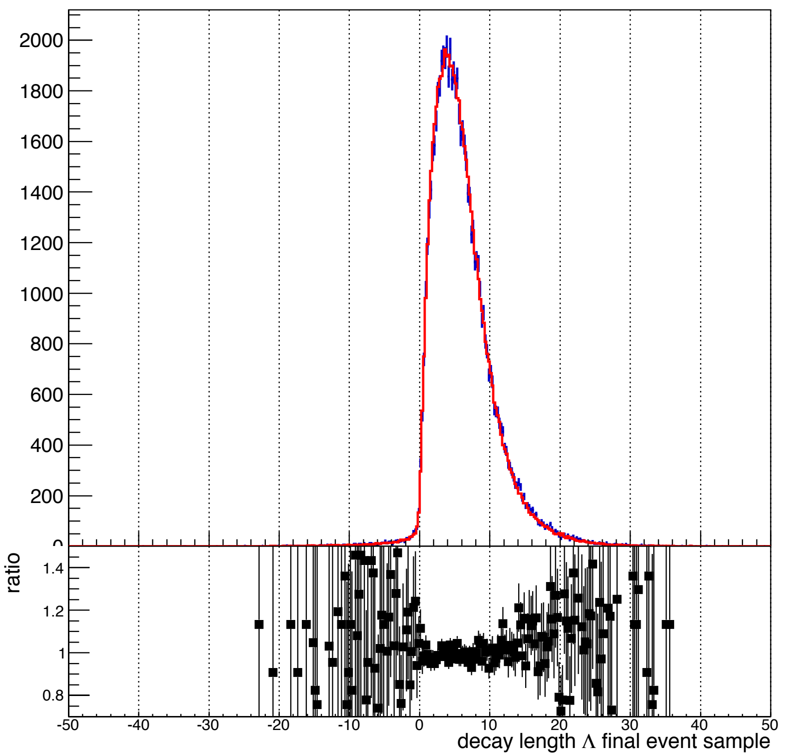


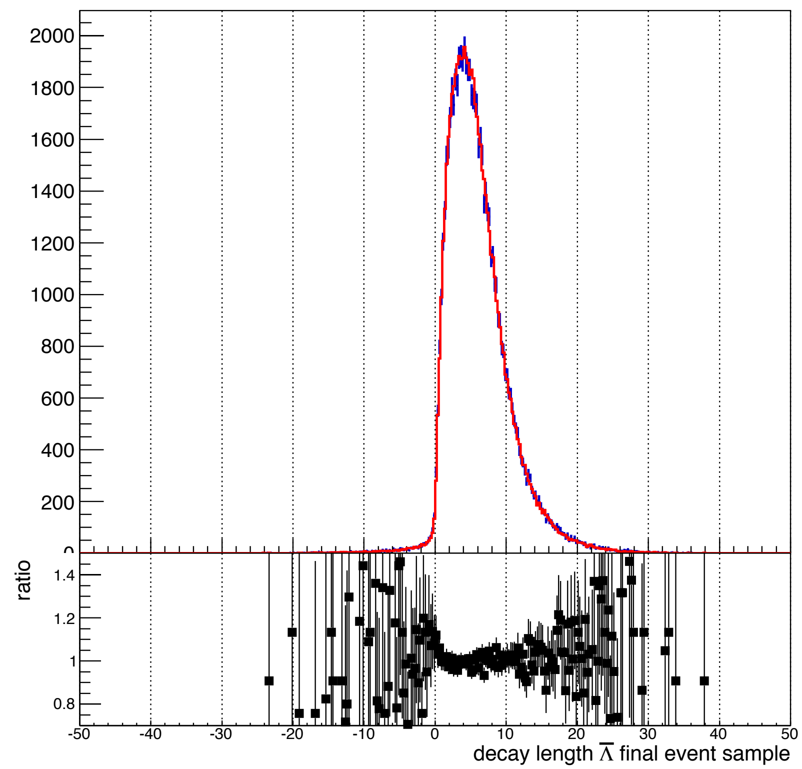




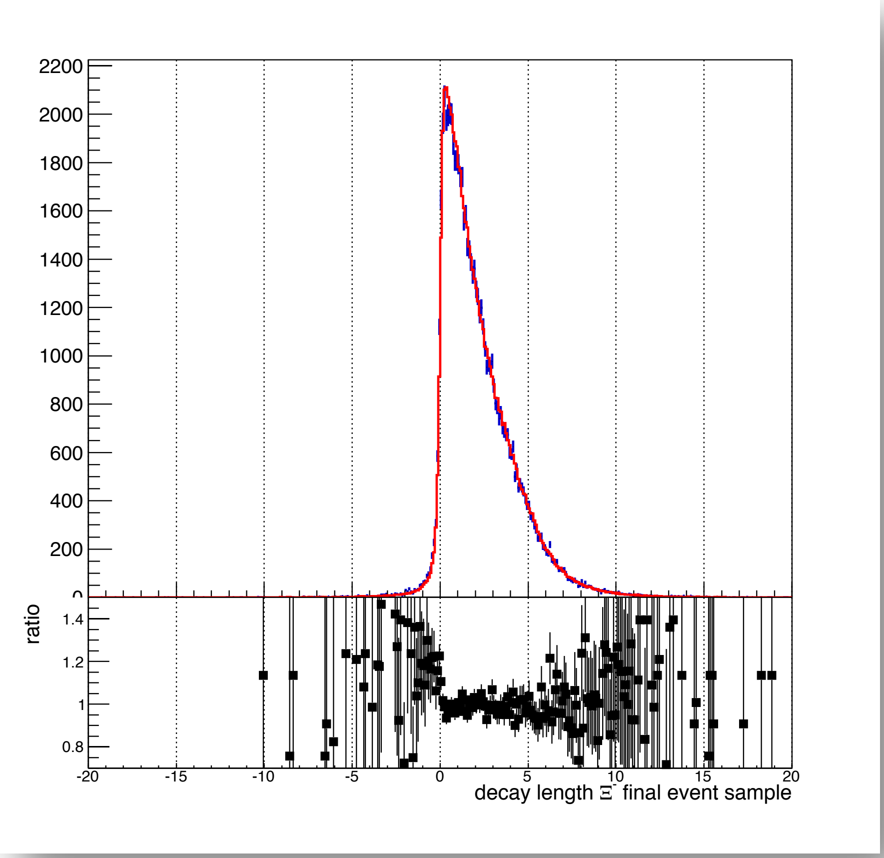


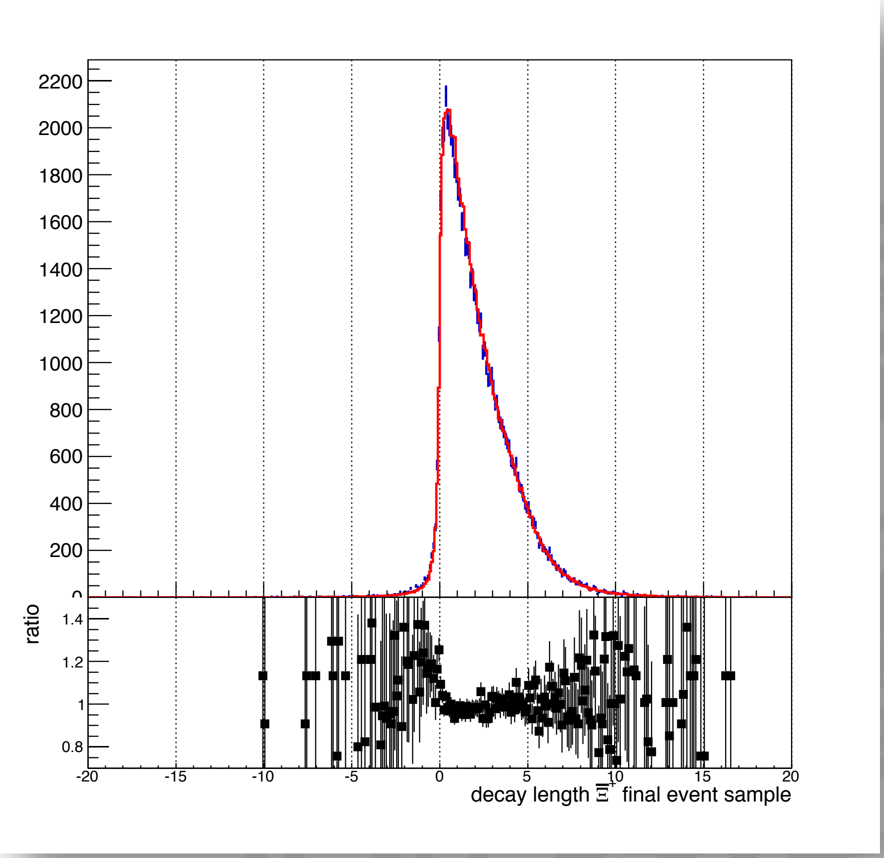
Data MC comparison decay lengths Λ





Data MC comparison decay lengths Ξ





Next steps

- Change masses in MC to better agree with what is seen experimentally? (how to do this technically?)
- Continue with the $\Xi^0\bar{\Xi}^0$ analysis
- Perhaps also study of $\Sigma^0\bar{\Sigma}^0$ as a cross check of depending on the outcome of the neutral cascades.

Thank you