Amplitude analysis of $\Xi_c^0 \to \Lambda^0 K^- \pi^+$

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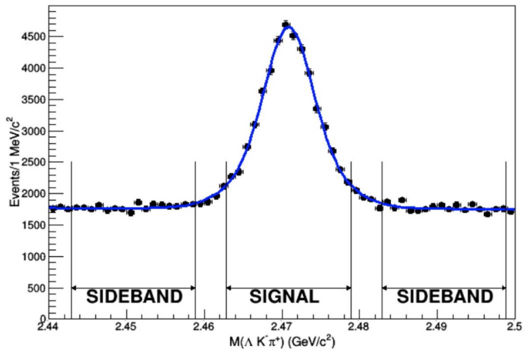
Outline

- Motivation and early works
- Theoretical background
- Signal separation from background
- Dalitz plots
- AmpTools and fitting results
- Summary of the works

Motivation

- Many charmed baryon decays display a rich substructure of hyperon resonances which are otherwise hard to study
- Belle has observed many decays of Λ, $\Xi_c^{\,0}$, $\Xi_c^{\,+}$ and Ω_c but none have been subjected to a full Dalitz-plot analysis
  - $\Xi_c^{\,0}$, $\Xi_c^{\,+}$ are particularly worth studying because the excited Ξ spectrum is not understood
  - M. Sumihama-san et al recently published the $\Xi_c^{\,+} \rightarrow (\Xi^- \pi^+)\pi^+$ substructure, confirming the existence of the $\Xi(1620)^0$ and is also looking $\Xi(1690)^0$ in $\Lambda_c^{\,+}$ decays
  - Joseph McNeil and John Yelton performed the amplitude analysis of this type in the similar type of decay $\Xi_c^{\,+} \rightarrow \Xi^0\ (K^- K^+)$
- Potential resonant substructure in the decay $\Xi_c^{\,0} \rightarrow \Lambda^0\ K^-\ \pi^+$
  - John Yelton (Florida) has investigated this decay channel in Belle data, but not the resonant substructure.

$$\Xi(1690)^- \rightarrow \Lambda^0 K^-$$
$$\Xi(1820)^- \rightarrow \Lambda^0 K^-$$
$$\Sigma(1385)^+ \rightarrow \Lambda^0 \pi^+$$
$$K^*(892)^0 \rightarrow K^- \pi^+$$



Theoretical background

- Let U^{M,λ_Λ} represent the amplitude for Ξ_c^0 decays to Λ, K^- and π^+ ($\Xi_c^0 \to \Lambda^0 K^- \pi^+$)

$$U^{M,\lambda_\Lambda}(\vec{x}) =< \Lambda K^- \pi^+ | H | \Xi_c^0 >$$

- The amplitude can be parameterized as:

$$U^{M,\lambda_\Lambda}(\vec{x}) = \sum_{j_X,\lambda_X} V_{j_X,\lambda_X} \; A^{M,\lambda_\Lambda}_{j_X,\lambda_X}(\vec{x})$$

where $V_{j_X,\lambda_X} = k_{j_X,\lambda_X} BW_{j_X,\lambda_X}$ describes the propagator of the intermediate state and its coupling to Ξ_c^0 and $A^{M,\lambda_\Lambda}_{j_X,\lambda_X}$ describes the angular distribution of final-state particles.

- The density of events at $\vec{x}$ is given by the intensity:

$$I(\vec{x}) = \sum_{M,\lambda_\Lambda} |U^{M,\lambda_\Lambda}(\vec{x})|^2$$

- To extract the couplings, k_{j_X,λ_X} , an unbinned maximum likelihood fit is performed on $\Lambda^0 K^- \pi^+$ invariant mass.

Theoretical background contd….

- The probability to make N independent observations of a quantity *X* (X_1,..., X_N) is given by a joint probability density function (pdf)

$$P(X|\vec{\zeta}) = P(X_1, \ldots, X_N|\vec{\zeta}) = \prod_{i=1}^{N} f(X_i|\vec{\zeta})$$

where, $f(X_i|\vec{\zeta})$ is the pdf to observe a quantity *X* with a set of parameters $\vec{\zeta}$. When the variable *X* is replaced by experiment observations $\vec{x}$, this quantity is called a likelihood:

$$L(\vec{x}, \vec{\zeta}) = \prod_{i=1}^{N} f(x_i|\vec{\zeta})$$

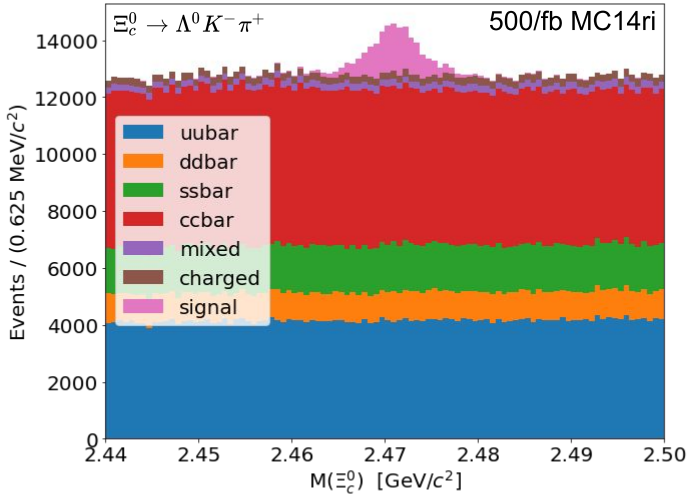
- The probability to find an event in the detector at some location in phase space, $\vec{x}$, is given by

$$f(x_i|\vec{\zeta}) = \frac{\eta(\vec{x})\, I(\vec{x}|\vec{\zeta})}{\int \eta(\vec{x})\, I(\vec{x}|\vec{\zeta})\, dx}$$, $\eta(\vec{x})$ is the efficiency of the detector to find an event at $\vec{x}$

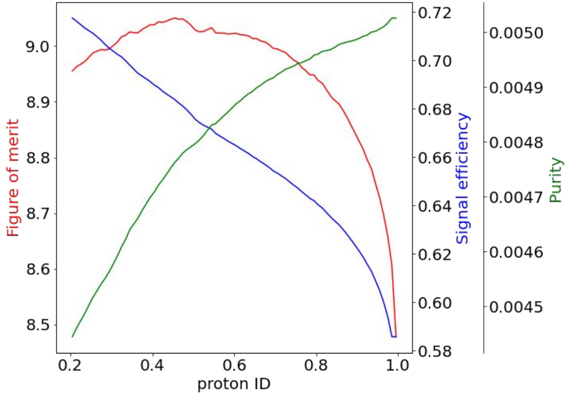
- The propagator is described by a Breit-Wigner function and the coupling is set as a free parameter in an unbinned, maximum likelihood fit to the data. The number and type of intermediate states is varied until an optimal solution is found. Any remaining backgrounds are accounted using background samples added to the data set with negative weights.

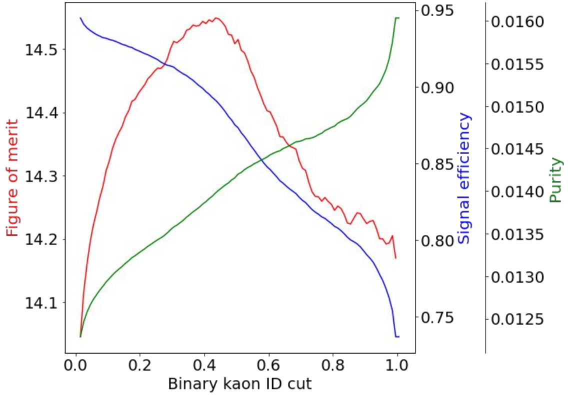
$$L(\vec{\zeta}) = \prod_{i=1}^{N_{data}} f(\vec{x_i}|\vec{\zeta}) \prod_{j=1}^{N_{MC}^{bkg}} f(\vec{x_i}|\vec{\zeta})^{-w_j}$$

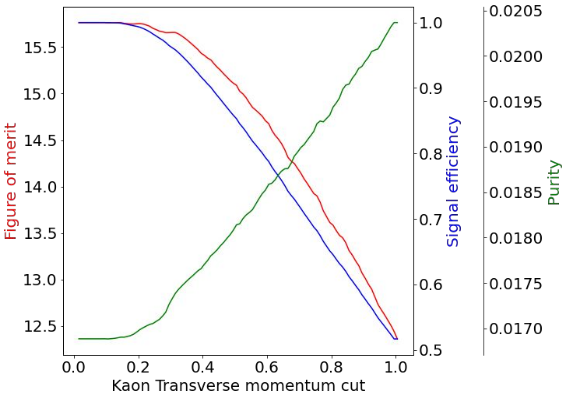
FOM optimization ($S/\sqrt{S+B}$)

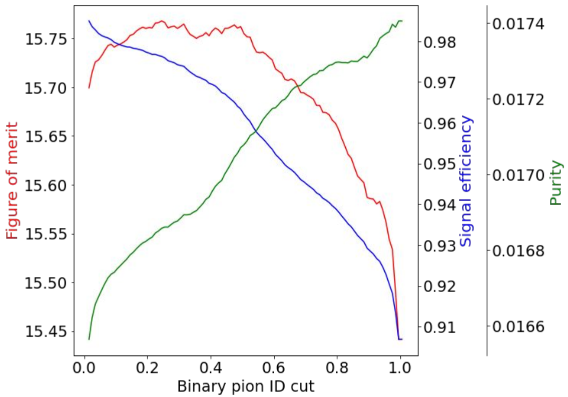


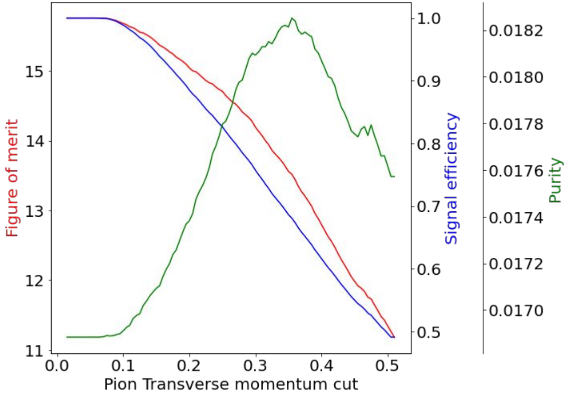
# of signal = 24397
# of background = 6216643











Signal extraction

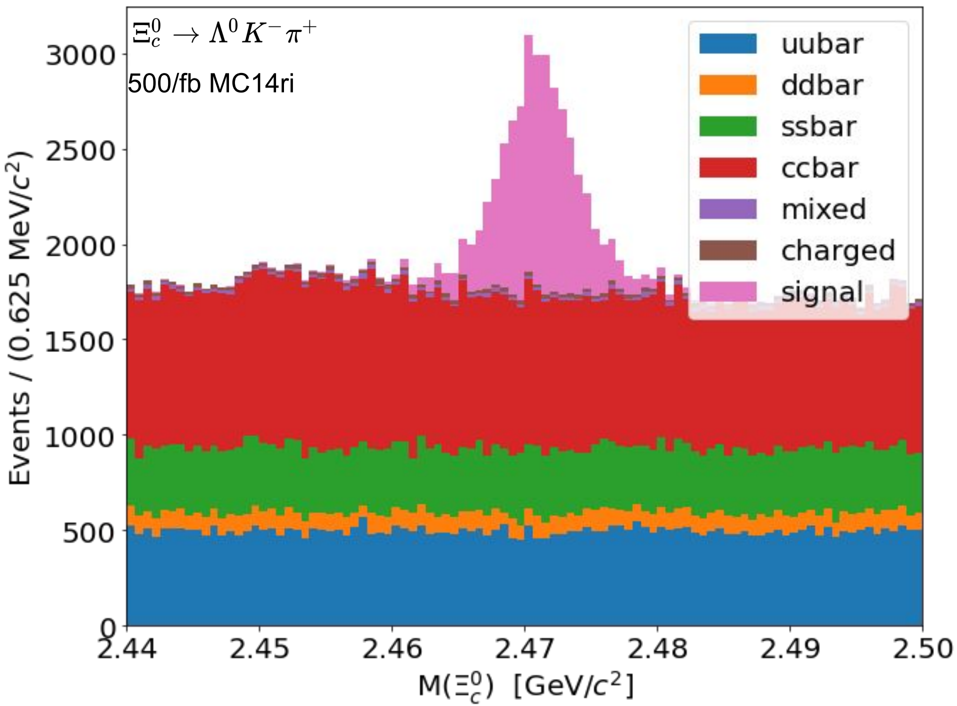
Selection criteria

- For tracks:
  - thetaInCDCAcceptance
  - nCDCHits > 20
  - dr < 1 and abs(dz) < 4 (prompt only)

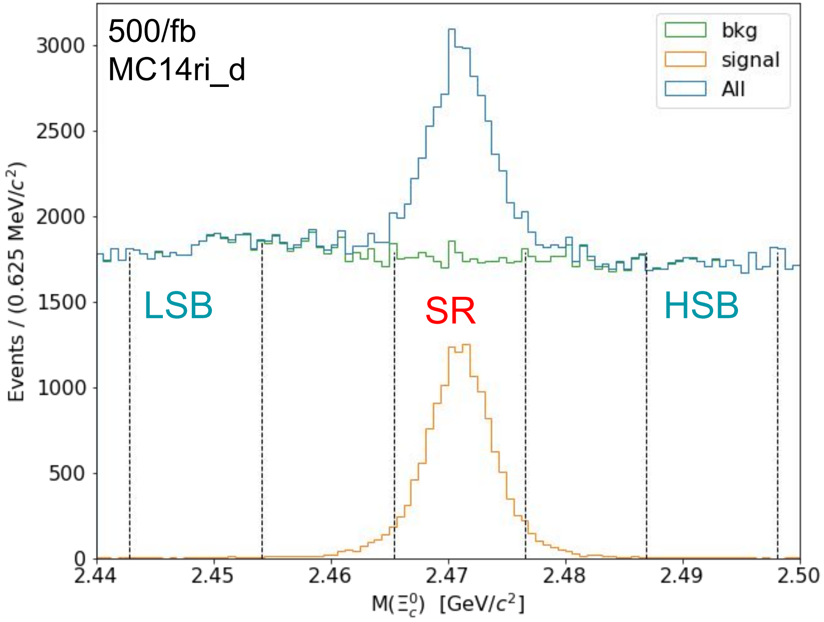
- For proton decaying from Lambda:
  - protonID > 0.5

- Xic CMS momentum > 2.4
- Treefit chiProb > 0.001
- Binary K/pi ID > 0.44 (kaons)
- Binary pi/K ID > 0.3 (pions)
- Kaon pt > 0.1
- Pion pt > 0.1

signal after cut = 14362
background after cut = 170178



To prepare a realistic sample

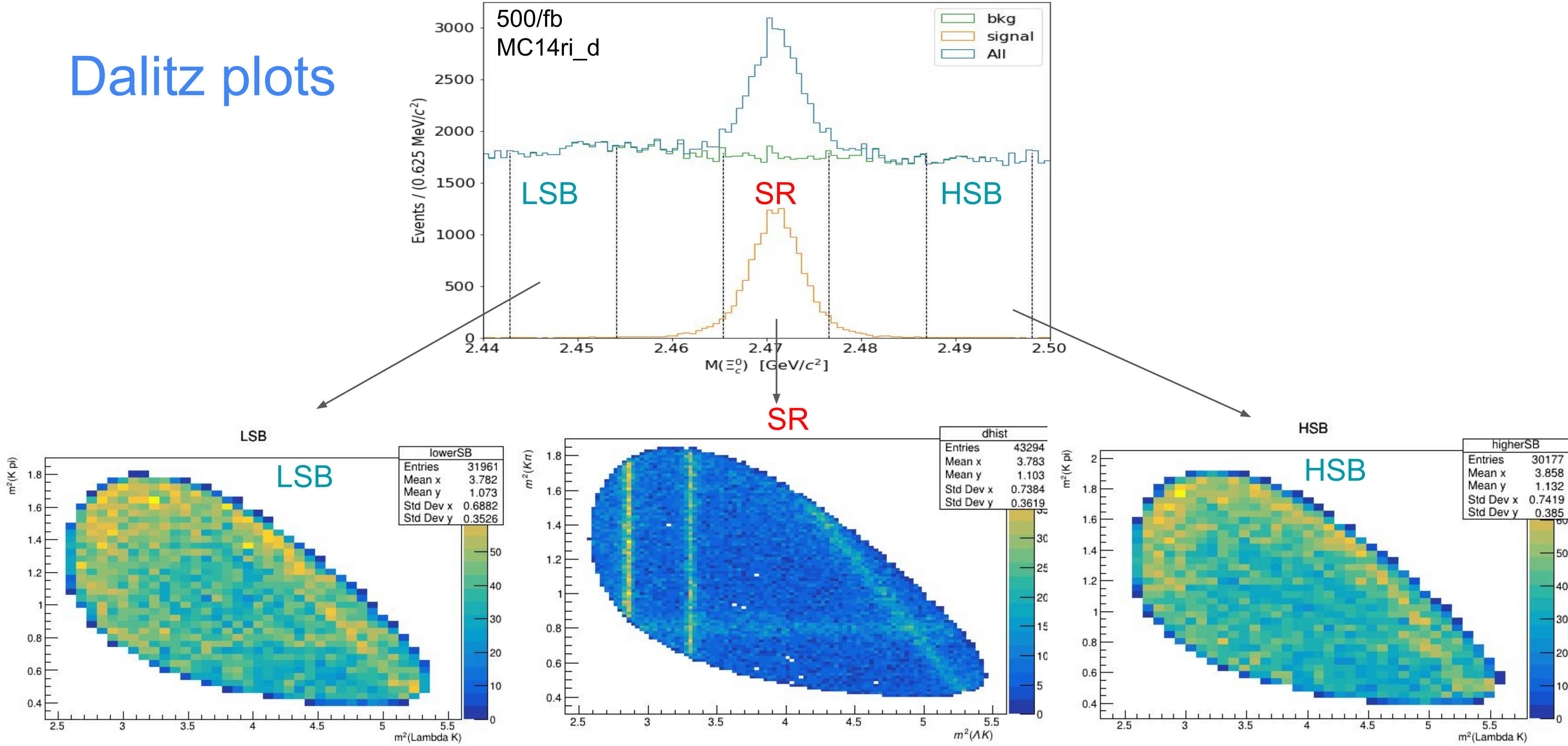


# of signal = 14364
# of signal in SR = 12742

Signal region (SR): 2.4654 - 2.4766 GeV/c^2
Lower sideband (LSB): 2.4429 - 2.4541 GeV/c^2
Higher sideband (HSB): 2.4869 - 2.4981 GeV/c^2

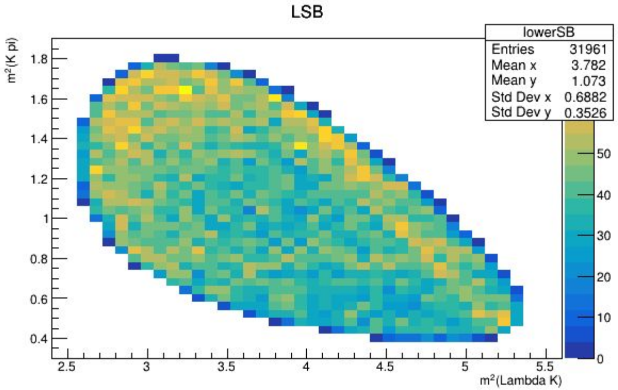
- Along with the generic sample, 400K signal MC consisting only 4 resonances were generated.
- True signal (isSignal) events from Generic MC was removed, and replaced by scaled (12742 events) signal MC that has 4 resonances.
- Assuming that the bkg in SR behaves the same way as the bkg in SB, events from both side-band region are merged and given the weight of -0.5.
- Bkg subtraction: Finally, SB sample is merged with SR sample for the bkg subtraction of SR.

Dalitz plots

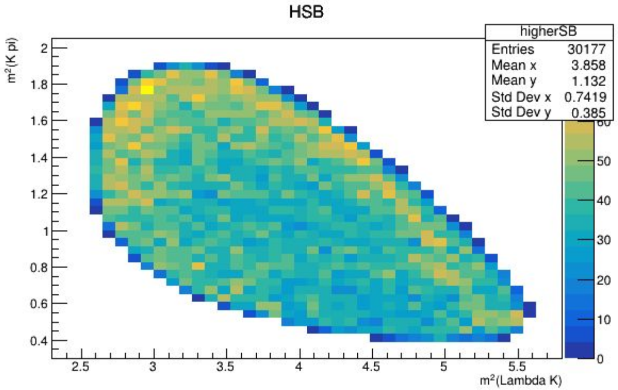


Difference of Side band dalitz plots

Lower SB (LSB)

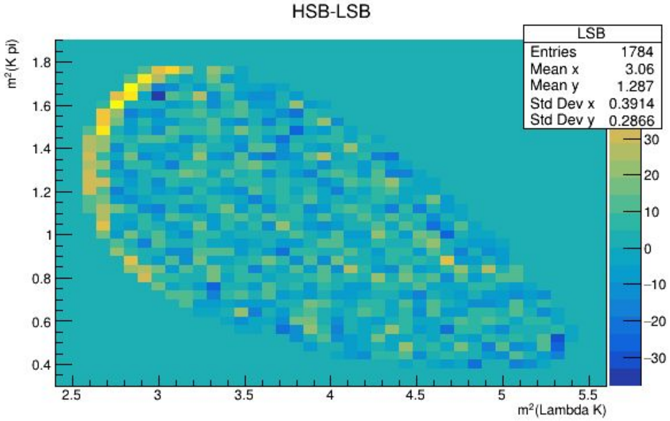


Higher SB (HSB)



- Bkg: 500/fb MC14ri reconstructed without constraining the Xi_c0 mass and applied all the selection criteria.

Difference: HSB-LSB



Fit to realistic sample (Signal MC and Generic background)

Test to see which parameter would give best result in terms of fitting fraction:

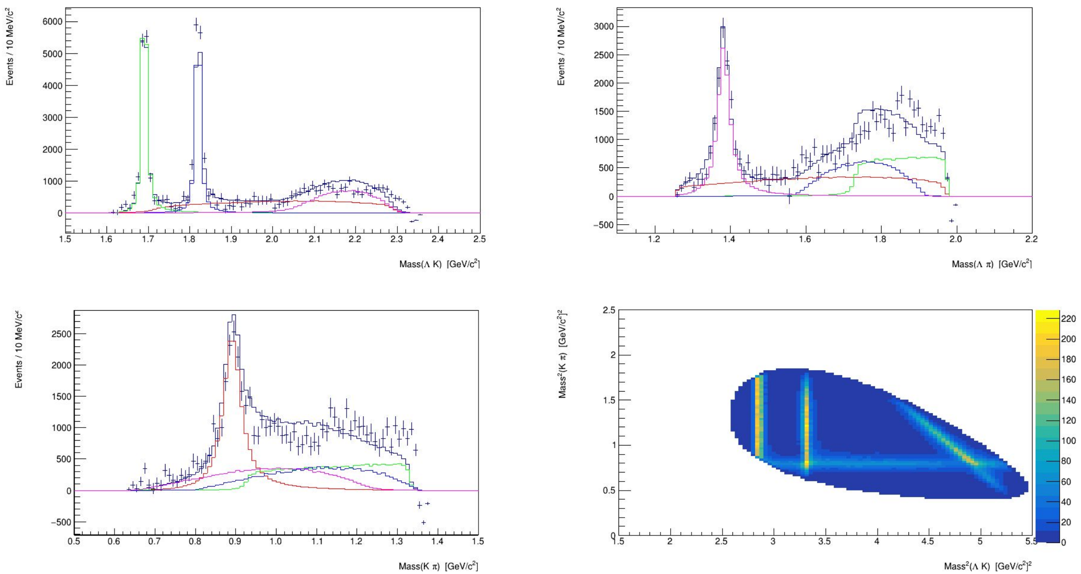
Case 1: Spin of Xi 1820 = 3/2, fixed mass and width of resonances

- 12742 reconstructed signal MC (four resonances) + generic background (500/fb) in the SR - SB
- 1M phasespace sample: generated and reconstructed for fitting

- **Fitted with 'correct' parameters:**
  Spin Σ* =3/2, K* =1, Xi 1690 = 1/2,
  Xi 1820 = 3/2
- Fitting fractions:
  - Generated: 25% each
  - Measured:

    K* = 0.315 ± 0.006
    Xi 1690 = 0.260 ± 0.005
    Xi 1820 = 0.225 ± 0.004
    Σ* = 0.227 ± 0.005

Likelihood: -256892.010



Fit to realistic sample (Signal MC and Generic background)

Test to see which parameter would give best result in terms of fitting fraction:

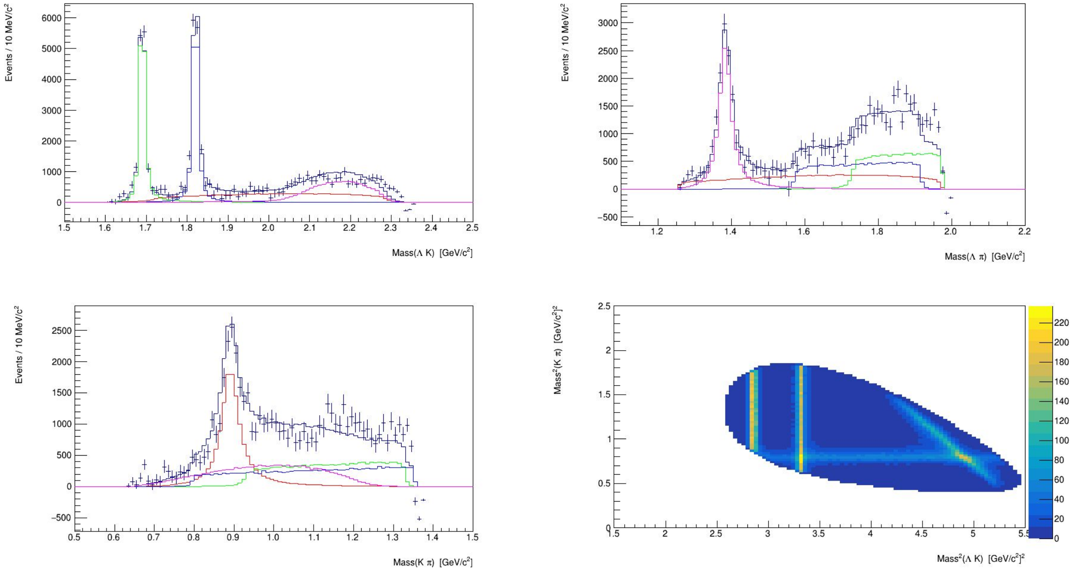
Case 2: Spin of Xi 1820 = 1/2, fixed mass and width of resonances

- 12742 reconstructed signal MC (four resonances) + generic background (500/fb) in the SR - SB
- 1M phasespace sample: generated and reconstructed for fitting

- **Change in the spin of Xi 1820:**
  Spin Σ* =3/2, K* =1, Xi 1690 = 1/2,
  Xi 1820 = 1/2
- Fitting fractions:
  - Generated: 25% each
  - Measured:

    K* = 0.236 ± 0.005
    Xi* 1690 = 0.241 ± 0.004
    Xi* 1820 = 0.243 ± 0.005
    Σ* = 0.219 ± 0.005

  Likelihood: -261331.952



Fit to realistic sample (Signal MC and Generic background)

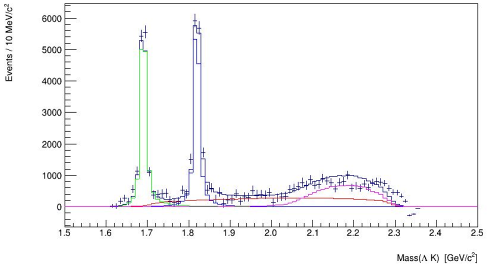
Test to see which parameter would give best result in terms of fitting fraction:

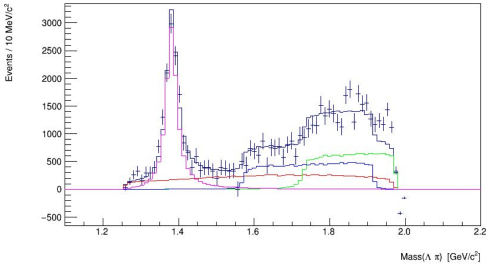
Case 3: Spin of Xi 1820 = 1/2, floating mass and width of resonances except K*

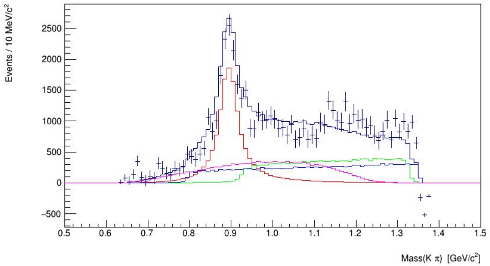
- 12742 reconstructed signal MC (four resonances) + generic background (500/fb) in the SR - SB
- 1M phasespace sample: generated and reconstructed for fitting
- Spin Σ* =3/2, K* =1, Xi 1690 = 1/2, Xi 1820 = 1/2
- Fitted mass and width of resonances:
  - Mass (xi1690) = 1.6901 (1.690)
  - Width (xi1690) = 0.0103 (0.01)
  - Mass (xi1820) = 1.8194 (1.820)
  - Width (xi1820) = 0.0104 (0.01)
  - Mass Σ* = 1.3810 (1.3828)
  - Width Σ* = 0.0311 (0.036)
- Fitting fractions measured:

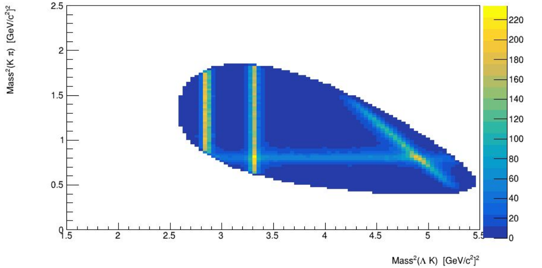
K* = 0.240 ± 0.005
Xi* 1690 = 0.242 ± 0.004
Xi* 1820 = 0.241 ± 0.005
Σ* = 0.219 ± 0.005

Likelihood: -261412.285







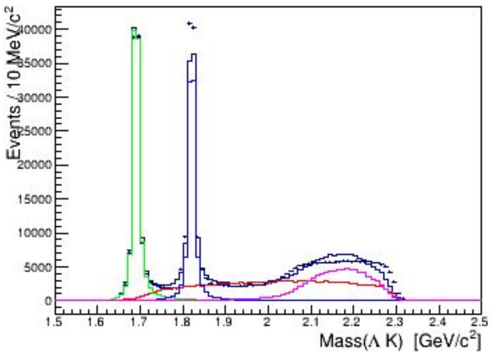


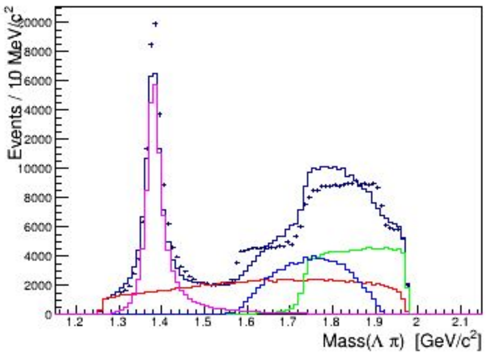
Fit to generated sample with "correct" parameters

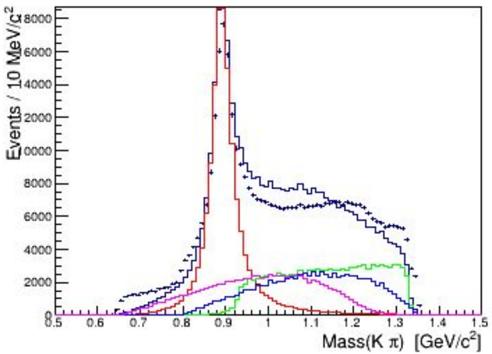
K* = 0.3450 +- 0.0011
Xi*(1690) = 0.2659 +- 0.0009
Xi*(1820) = 0.2197 +- 0.0008
Sigma* = 0.2183 +- 0.0009

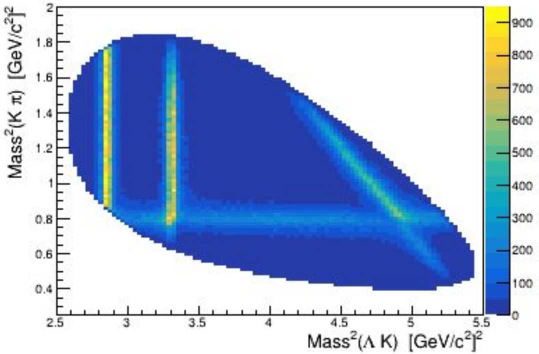
Likelihood: -10268241.235

Spin of resonances:
Σ* =3/2
K* =1
Xi 1690 = 1/2
Xi 1820 = 3/2







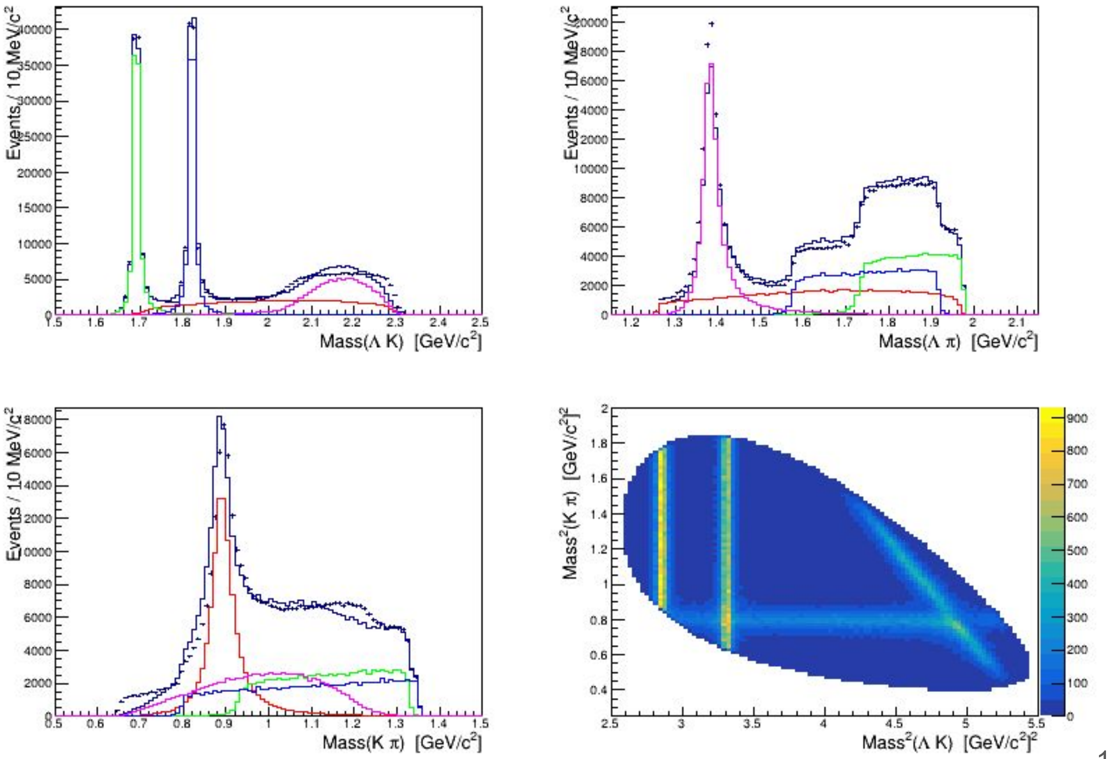


Fit to generated sample with spin ½ Xi*(1820)

K* = 0.2451 +- 0.0010
Xi*(1690) = 0.2425 +- 0.0008
Xi*(1820) = 0.2426 +- 0.0008
Sigma* = 0.2375 +- 0.0010

Likelihood: -10395182.763

Spin of resonances:
Σ* =3/2
K* =1
Xi 1690 = 1/2
Xi 1820 = 1/2

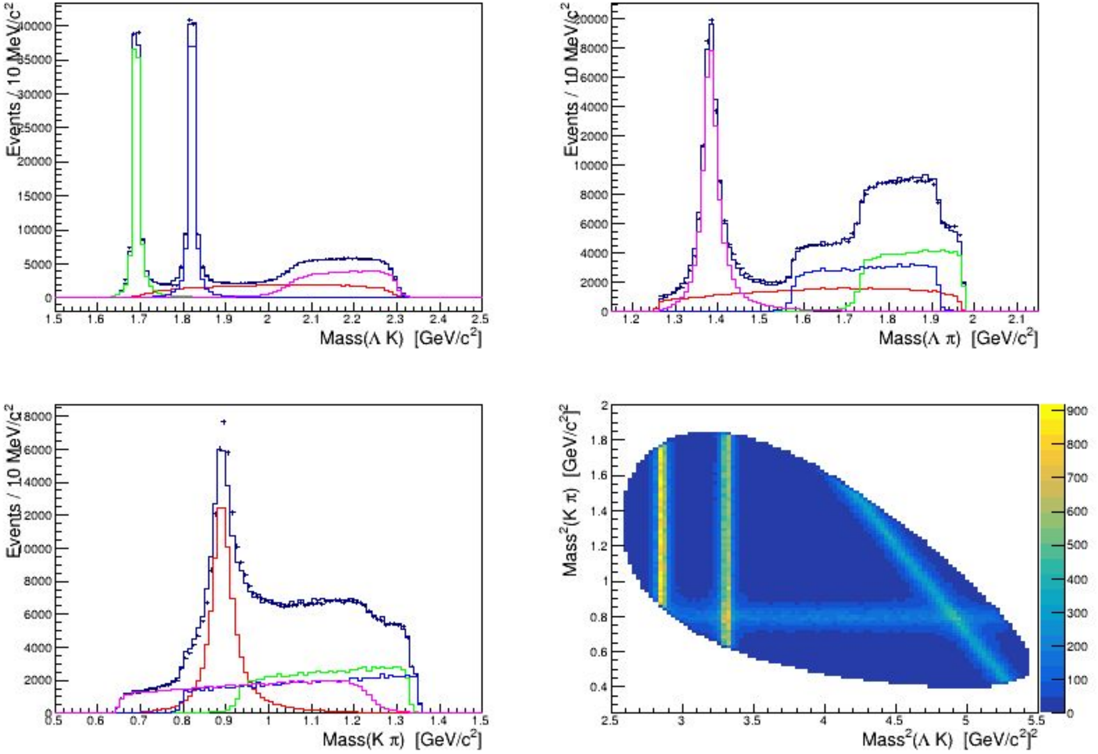


Fit to generated sample with spin ½ Sigma*

K* = 0.2317 +- 0.0009
Xi*(1690) = 0.2435 +- 0.0008
Xi*(1820) = 0.2514 +- 0.0008
Sigma* = 0.2428 +- 0.0009

Likelihood: -10517900.458

Spin of resonances:
Σ* =1/2
K* =1
Xi 1690 = 1/2
Xi 1820 = 1/2



Summary

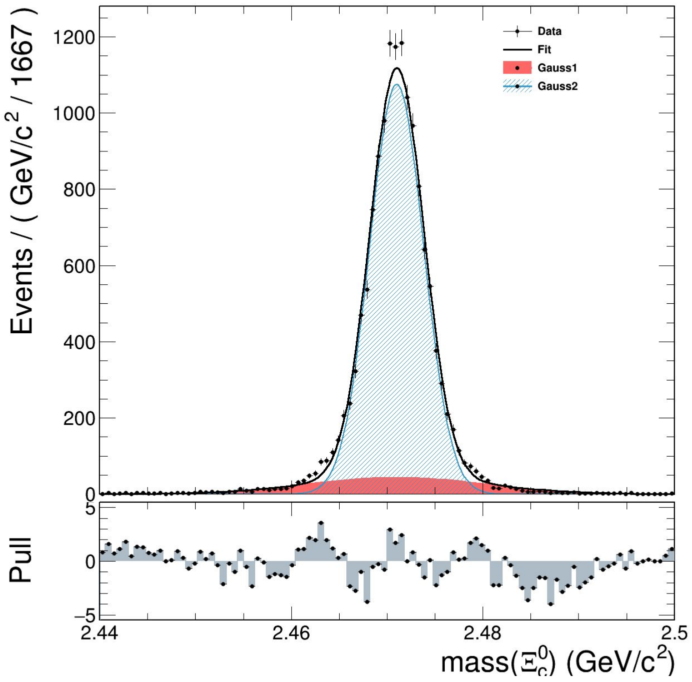
- Signal is separated from the background using several selection criteria.
- Signal region and sideband are separated using the sigma value gotten from the fitting (Double gaussian) of signal events of 500/fb of MC14ri sample.
- Fitting is done in the generated sample to see if we can extract the input parameters.
- Fitting is also done to the “realistic sample” of the SR taking into account the bkg subtraction.

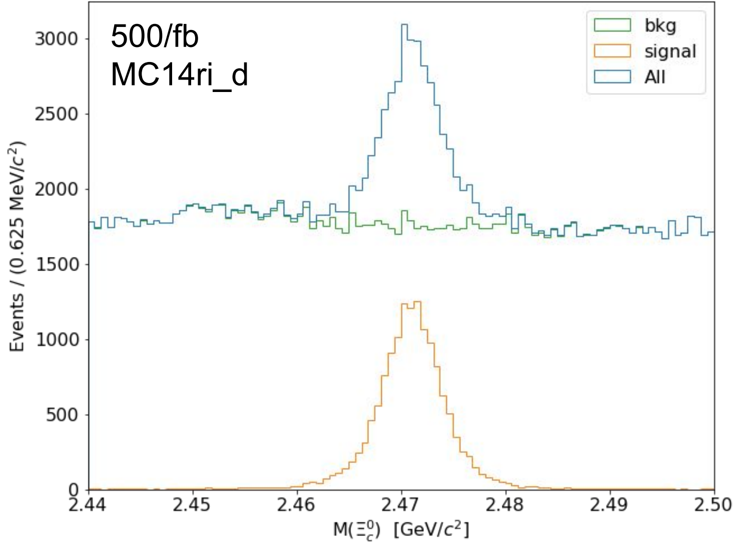
THANK YOU !

Backup slides

Double gaussian fit to signal

- Double gaussian fitting to signal only
- 500/fb MC14ri_d





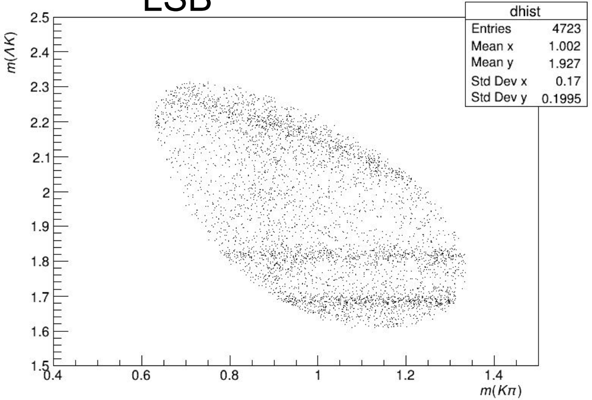
Number of signal = 14364
Number of background = 170178

- The fitting is done to separate the signal region and sideband region using sigma value of the fit.
- σ = 0.0028
- Since the entire mass window is from 2.44 - 2.50, the 5σ forces the SB to lie out of the mass window. So 4σ is used here.

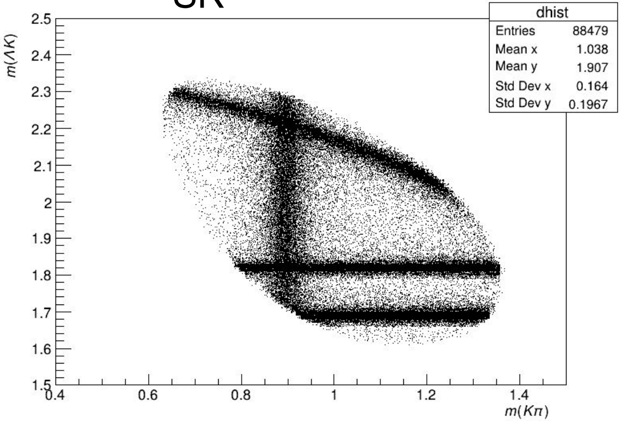
Dalitz plots of Generated sample

Xi_c0 mass NOT constrained

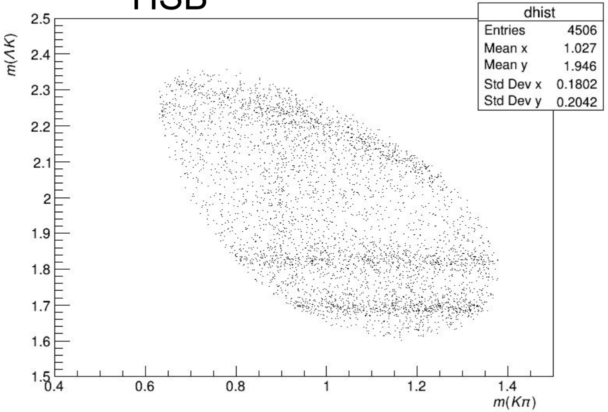
LSB



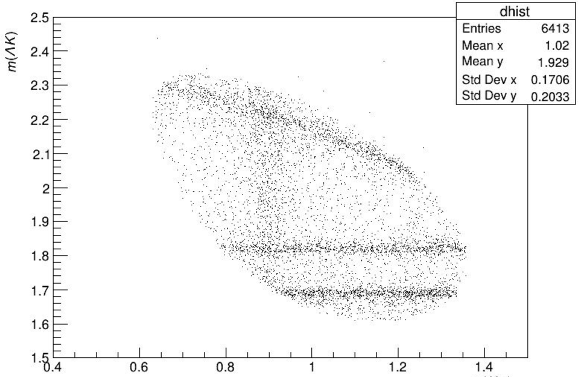
SR

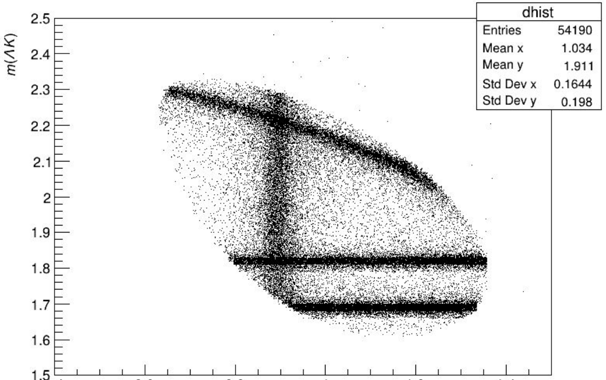


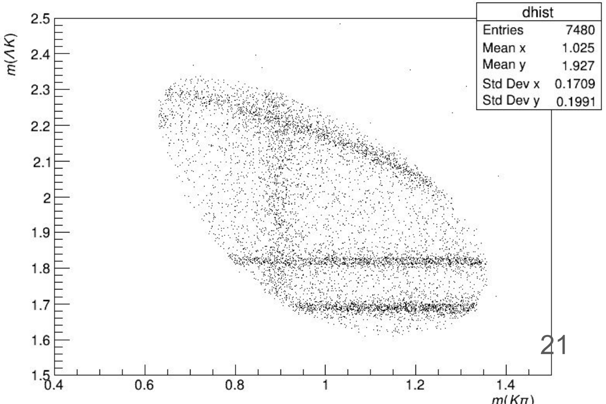
HSB



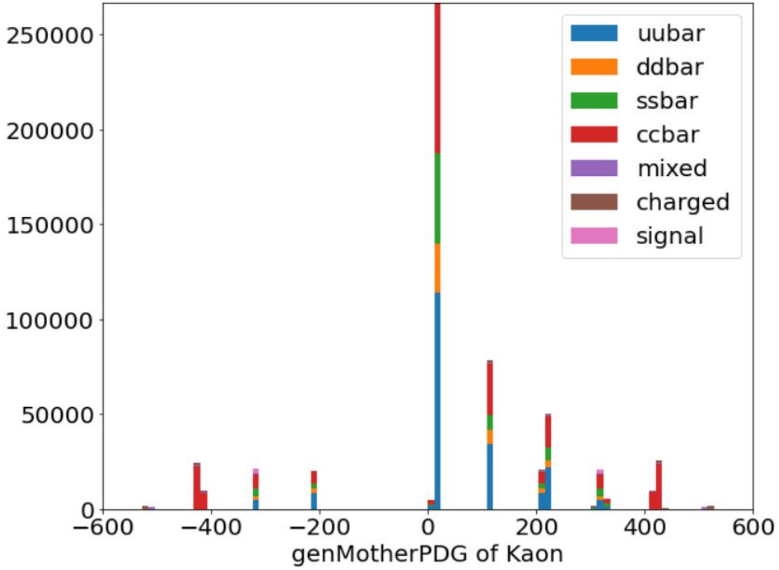
Xi_c0 mass constrained

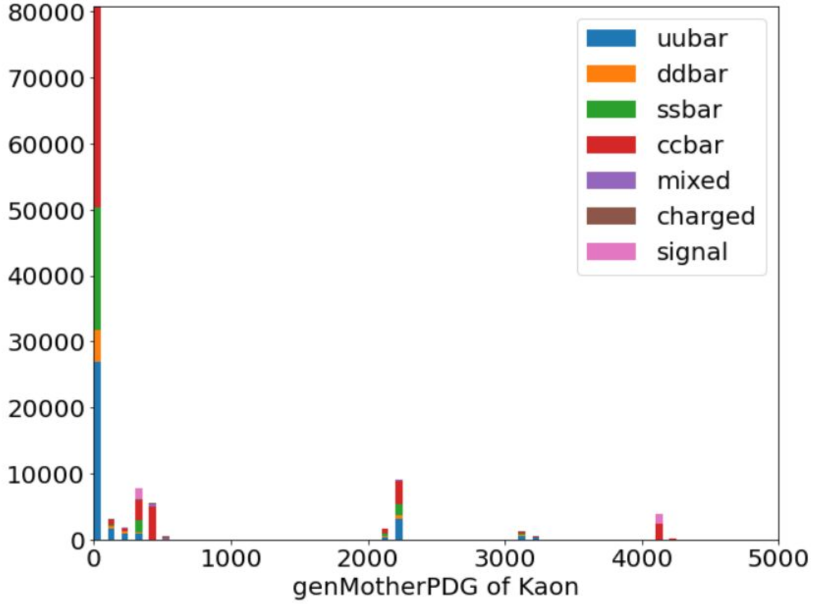






Background (100/fb)






```
mother PDG of kaon = [-411.  421. -511. ... -421. -421. -313.]
Number of background from Z0 = 864211
Number of background from ρ(770)0 = 295173
Number of background from ρ(770)+ = 76138
Number of background from ρ(770)- = 87220
Number of background from K*(892)0bar = 67248
Number of background from K*(892)0 = 63887
Number of background from B0bar = 18624
Number of signal from Xic0 = 4267
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```
After applying all the cuts:
Number of background from Z0 = 80314
Number of background from ρ(770)0 = 2962
Number of background from ρ(770)+ = 634
Number of background from ρ(770)- = 665
Number of background from K*(892)0bar = 5556
Number of background from K*(892)0 = 5483
Number of background from B0bar = 161
Number of signal from Xic0 = 1682
```