

# Study of Excited $\Xi$ Baryons in $\bar{p}p$ -Collisions with $\overline{\text{PANDA}}$

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# Abstract

Understanding the excitation pattern of baryons is indispensable for a deep insight into the mechanism of non-perturbative QCD. Up to now only the nucleon excitation spectrum has been subject to systematic experimental studies while very little is known on excited states of double or triple strange baryons.

In studies of antiproton-proton collisions the  $\overline{\text{PANDA}}$  experiment is well-suited for a comprehensive baryon spectroscopy program in the multi-strange and charm sector. A large fraction of the inelastic  $\bar{p}p$  cross section is associated to final states with a baryon-antibaryon pair together with additional mesons, giving access to excited states both in the baryon and the antibaryon sector.

In the present study we focus on excited  $\Xi$  states. For final states containing a  $\Xi \bar{\Xi}$  pair cross sections up to the order of  $\mu\text{b}$  are expected, corresponding to production rates of  $\sim 10^6/\text{d}$  at a Luminosity  $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$  (5% of the full value). A strategy to study the excitation spectrum of  $\Xi$  baryons in antiproton-proton collisions will be discussed. The reconstruction of reactions of the type  $\bar{p}p \rightarrow \Xi^* \bar{\Xi}$  (and their charge conjugated) with the  $\overline{\text{PANDA}}$  detector will be presented based on a specific exemplary reaction and decay channel.

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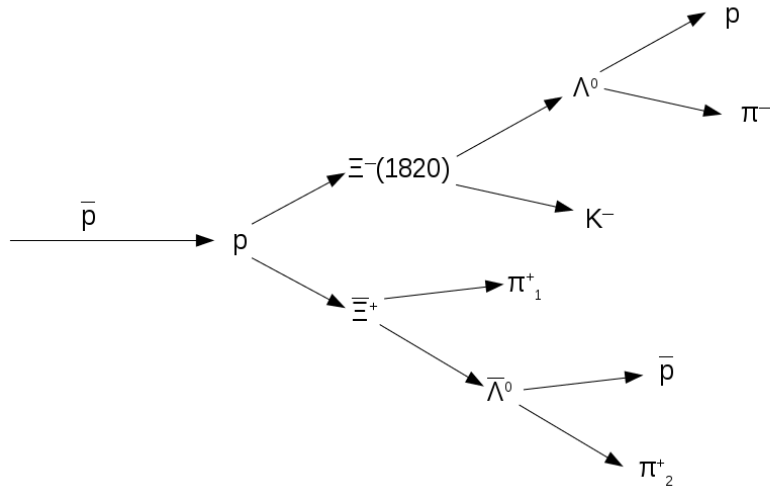
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# 1 Event generation

To study excited  $\Xi$  baryons the simulation of signal events is needed. For this study 1.5 million signal events have been generated. The decay channel for the simulation is shown in figure 1.1.



**Figure 1.1:** Simulated decay channel

For the charge conjugated channel were also 1.5 million signal events generated. The parameter which are used for the event generation are shown in table 1.1.

The chosen beam momentum value is 100 MeV over the production threshold of  $\Xi(1820)$  and  $\bar{\Xi}$ . The production cross section is expected to be of the same order ( $\sim \mu\text{b}$ ) as for  $\Xi$  [1].

**Table 1.1:** Parameter for event generation

Parameter	Value
Beam momentum	4.6 GeV/c <sup>2</sup>
Production	PHSP
Tracking	Ideal
Particle ID	Ideal

The used software versions for Pandaroot and the external software is listed in table 1.2

**Table 1.2:** Used software versions

Software	Version
FairSoft	mar15
FairRoot	v-15.03a
PandaRoot	trunk revision 28555
Geant	3
Genfit	1

The  $\Xi(1820)$  was not defined in the evt.pdl file. The Lines in the code snippet 1.1 shown how the particle was added to the file. As the properties of  $\Xi(1820)$  I am using the values which are shown in table 1.3. These values are taken from [2].

**Listing 1.1:** snippet from evt.pdl

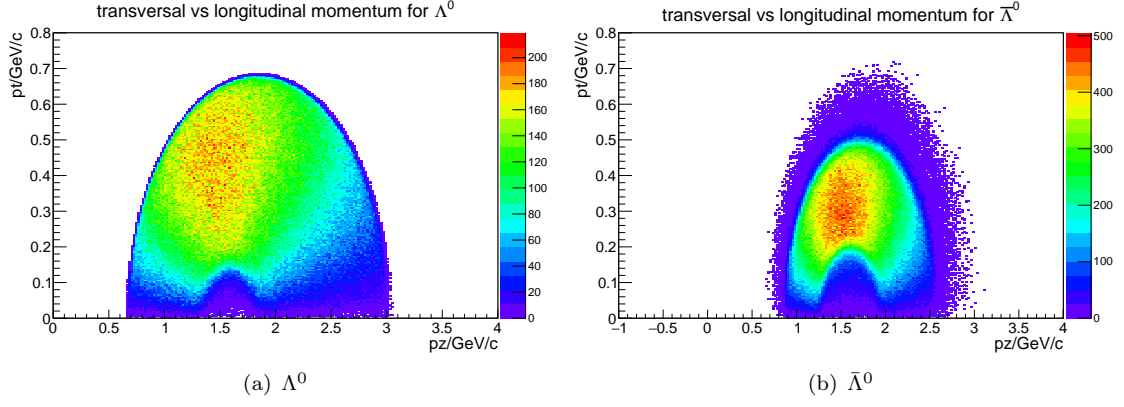
```
add p Particle Xi(1820)- 23314 1.8230000e+00 2.4000000e-02
    2.0000000e-01 -3 3 0.0000000e+00 23314
add p Particle anti-Xi(1820)+ -23314 1.8230000e+00 2.4000000e-02
    2.0000000e-01 3 3 0.0000000e+00 -23314
```

The generated transverse momentum against the longitudinal momentum for  $\Lambda^0$ ,  $\bar{\Lambda}^0$ ,  $\Xi$  and  $\Xi(1820)$  is presented in figure 1.2

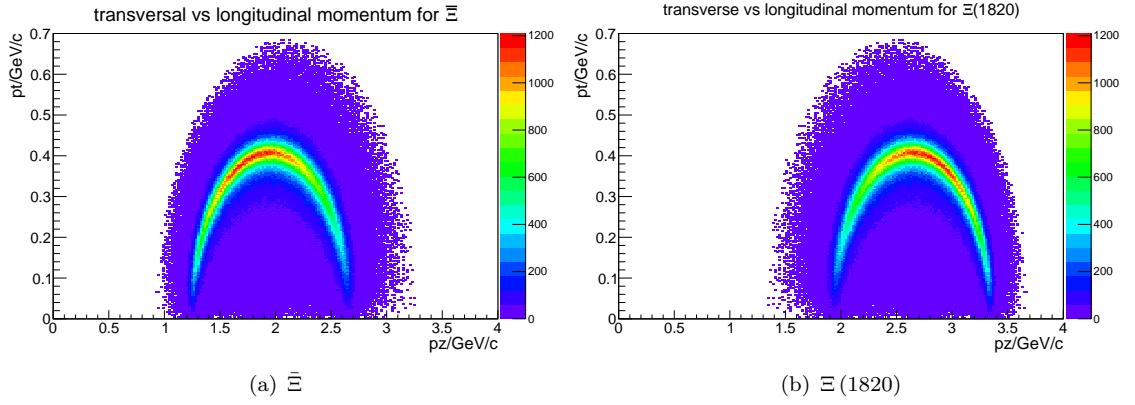
Figure 1.4 shows the Dalitz plot for the  $\Lambda^0$ ,  $K^-$  and  $\Xi$  final states for the channel  $\bar{p}p \rightarrow \Xi(1820) \Xi$ .

**Table 1.3:** Values for  $\Xi(1820)$  and  $\bar{\Xi}(1820)$  from [2]

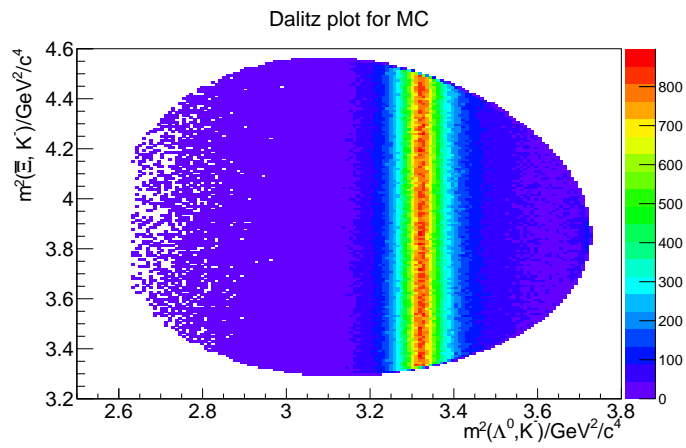
Particle	J	I	P	Charge	Mass	Width
$\Xi(1820)$	$\frac{3}{2}$	$\frac{1}{2}$	(-1)	(-1)	$(1.823 \pm 5)\text{GeV}/c^2$	$(0.024 \pm 6) \text{ GeV}$
$\bar{\Xi}(1820)$	$\frac{3}{2}$	$\frac{1}{2}$	(-1)	1	$(1.823 \pm 5)\text{GeV}/c^2$	$(0.024 \pm 6) \text{ GeV}$



**Figure 1.2:** Figure a) shows transversal against the longitudinal momentum distribution for  $\Lambda^0$ . Figure b) transversal versus longitudinal momentum distribution for  $\bar{\Lambda}^0$ .



**Figure 1.3:** Figure a) shows transversal against the longitudinal momentum distribution for  $\Xi$ . Figure b) transversal versus longitudinal momentum distribution for  $\Xi(1820)$ .



**Figure 1.4:** Dalitz plot for simulation. On x axis is the mass square of  $\Lambda^0$  and  $K^-$  and on the y axis there is the mass square of  $\Xi$  and  $K^-$

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## 2 Analysis

To reconstruct all the simulated particles we start with the final state particles and go backwards through the reaction chain.

### 2.1 Final state particle

The selected final state particles are protons, antiproton,  $\pi^-$ ,  $\pi^+$ ,  $K^-$  and  $K^+$  mesons. For the reconstruction of these final state particles I used an ideal tracking. To make the selection a bit more realistic only particles with more than 3 hits in any inner tracking detector (MVD, STT and GEM) are selected. The selection criterion is chosen because three hits are defining a circle. A fourth hit point is then a validation of the track hypothesis.

The particle identification (PID) is also ideal. The selection criterion is set to 'best'.

The reconstruction efficiency for the final state particles is shown in table 2.1 and figure

2.1.

Table 2.2 shows the reconstruction efficiency for the c.c. channel.

### 2.2 Reconstruction of $\Lambda^0$ and $\bar{\Lambda}^0$

#### Combination

For the reconstruction of

- $\Lambda^0$  a proton and a  $\pi^-$  meson are combined and

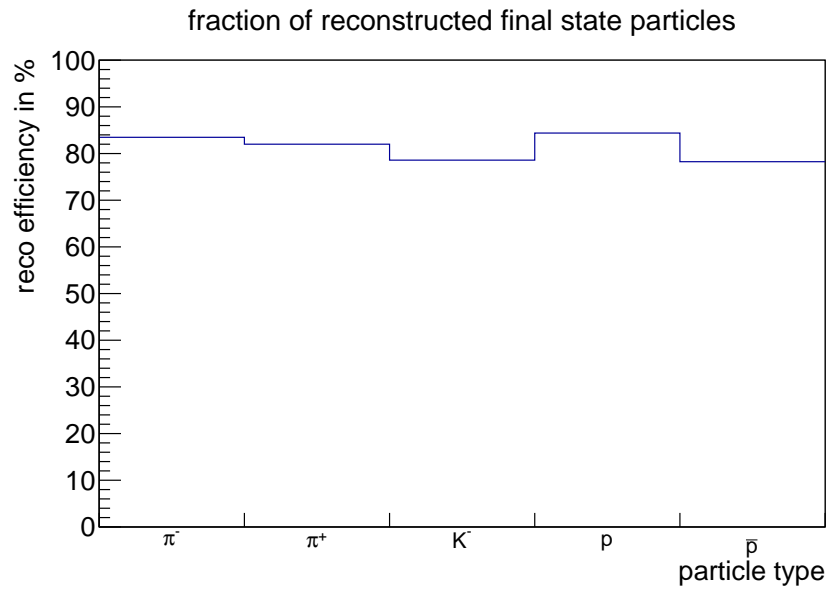
**Table 2.1:** reco efficiency and momentum resolution for  $\bar{p}p \rightarrow \Xi(1820) \bar{\Xi}$

final state	N/%	$\frac{\sigma p}{p}/\%$
$\pi^-$	83.48	1.53
$\pi_1^+ (\bar{\Xi})$	80.93	1.38
$\pi_2^+ (\bar{\Lambda}^0)$	83.07	1.49
$K^-$	78.59	1.58
p	84.39	1.61
$\bar{p}$	78.25	1.61

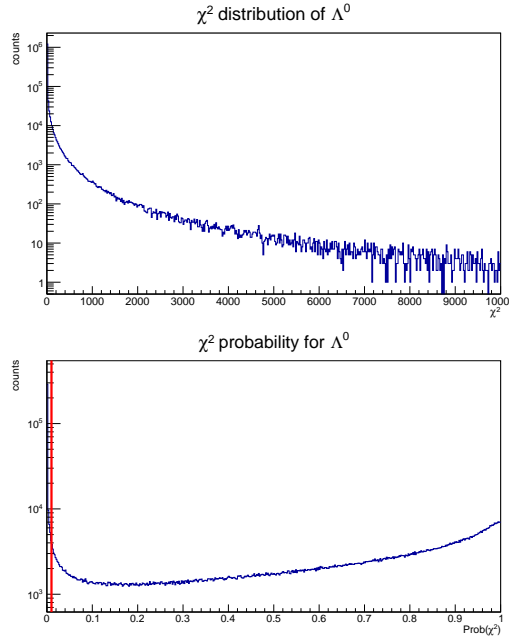


**Table 2.2:** reco efficiency and momentum resolution for  $\bar{p}p \rightarrow \bar{\Xi}(1820) \Xi$

final state	N/%	$\frac{\sigma p}{p}/\%$
$\pi^+$		
$\pi_1^- (\Xi)$		
$\pi_2^- (\Lambda^0)$		
$K^+$		
p		
$\bar{p}$		



**Figure 2.1:** Reconstruction efficiency for final state particles. The x axis shows the particle type. On the y axis is shown the fraction of reconstructed particles, like it is shown in table 2.1



**Figure 2.2:** upper:  $\chi^2$  distribution; lower:  $\chi^2$  probability distribution

- for the reconstruction of  $\bar{\Lambda}^0$  a  $\bar{p}$  and a  $\pi^+$  are combined.

After the combination of the daughter particles a mass window cut is performed. Only those particles are chosen which have a mass within  $0.3\text{GeV}/c^2$ .

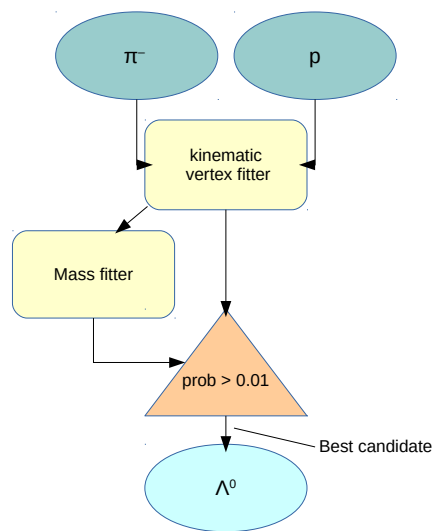
## Fitting

A vertex constraint fit with the PndKinVertexFitter is performed on the selected particle. This means that the tracks of the daughter particles are fitted to a common vertex point. The  $\chi^2$  and  $\chi^2$ -Probability distribution of the vertex fit for  $\Lambda^0$  is shown in figure 2.2.

In the  $\chi^2$ -probability distribution one can see a increasing number of events for probabilities going to one. This feature is not coming from vertex fitting. There is still a problem with covariance matrices which causes the effect.

The fit information coming from the vertex fit are used to perform a mass constraint fit with the kinematic fitter PndKinFitter. After using both fitters the selection criterion is set. One selects only those particles which have a probability greater than 1% in both fitters. A scheme which shows how the events are selected can be found in figure 2.3.

If there is more than one candidate left after the cuts the best fitted candidate is chosen.



**Figure 2.3:** Scheme for  $\Lambda^0$  reconstruction

### Results

This subsection presents the results for the  $\Lambda^0$  and  $\bar{\Lambda}^0$  selection with the selection criteria introduced above. The mass distributions for different cuts are shown in figure 2.4 and figure 2.5.

The reconstructed mass can be derived by performing a double gaussian fit on the cutted mass. The mass distribution and the double gaussian fit are exemplarily shown for  $\Lambda^0$  in figure 2.6

The mean value of the inner gaussian fit is the reconstructed mass. The result for  $\Lambda^0$  is  $m_{\Lambda^0} = (1.116 \pm 3.5 \cdot 10^{-5}) \text{ GeV}/c^2$  and for  $\bar{\Lambda}^0$ :  $m_{\bar{\Lambda}^0} = (1.116 \pm 1 \cdot 10^{-5}) \text{ GeV}/c^2$ . The small fit errors could be a result from the wrong covariance matrices. But this has to be checked.

- transverse vs longitudinal momentum shown in figure 2.7
- the reconstruction efficiency for  $\Lambda^0$  is 50.33% and for  $\bar{\Lambda}^0$  41.46%
- reason:  $\Lambda^0$  is emitted by  $\Xi(1820)$  which has a very little decay length; lambda decay length is  $c\tau = 7.98 \text{ cm}$  [2];  $\Lambda^0$  decays in MVD detector; high precision for reconstructed final state particles;  $\bar{\Lambda}^0$  is produced by  $\bar{\Xi}$  which has a decay length of  $c\tau = 4.91 \text{ cm}$ ;  $\bar{\Lambda}^0$  is produced deep in MVD, so that final state particles coming from  $\bar{\Lambda}^0$  are produced at the edge of the MVD detector. See figure 2.8

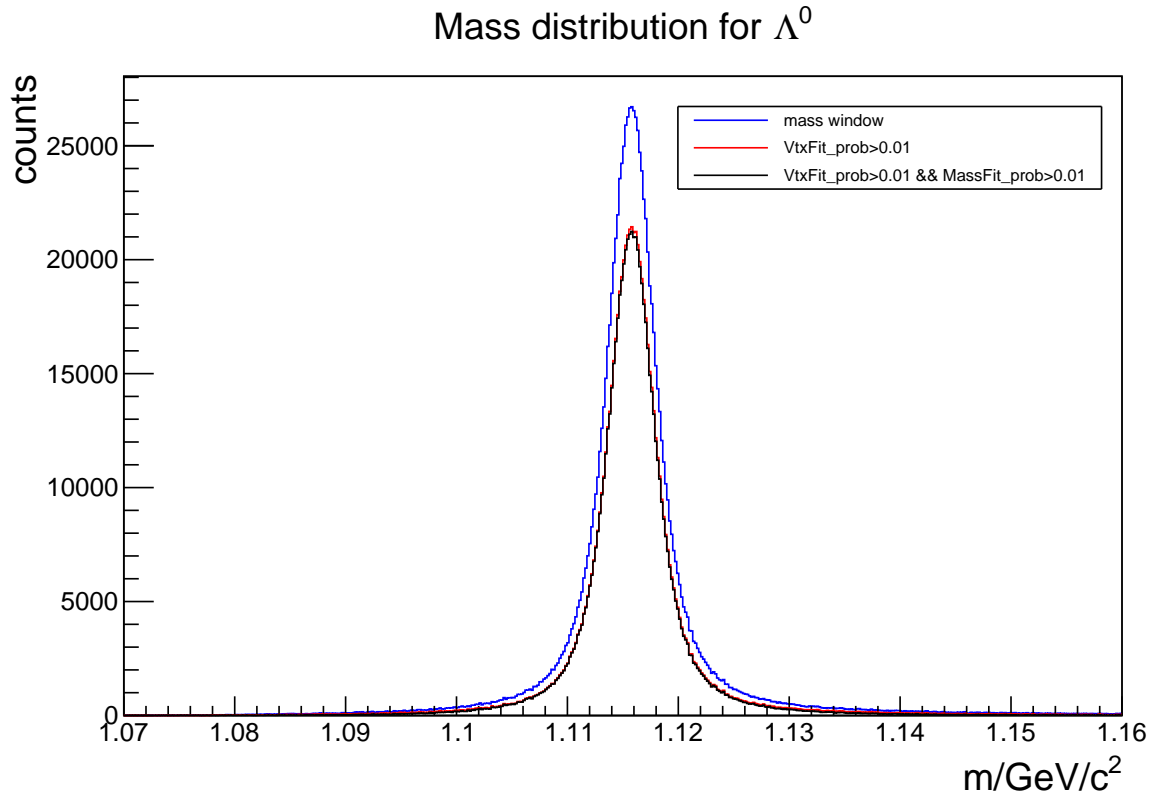
## 2.3 Reconstruction of $\Xi$ and $\bar{\Xi}$

### Combination

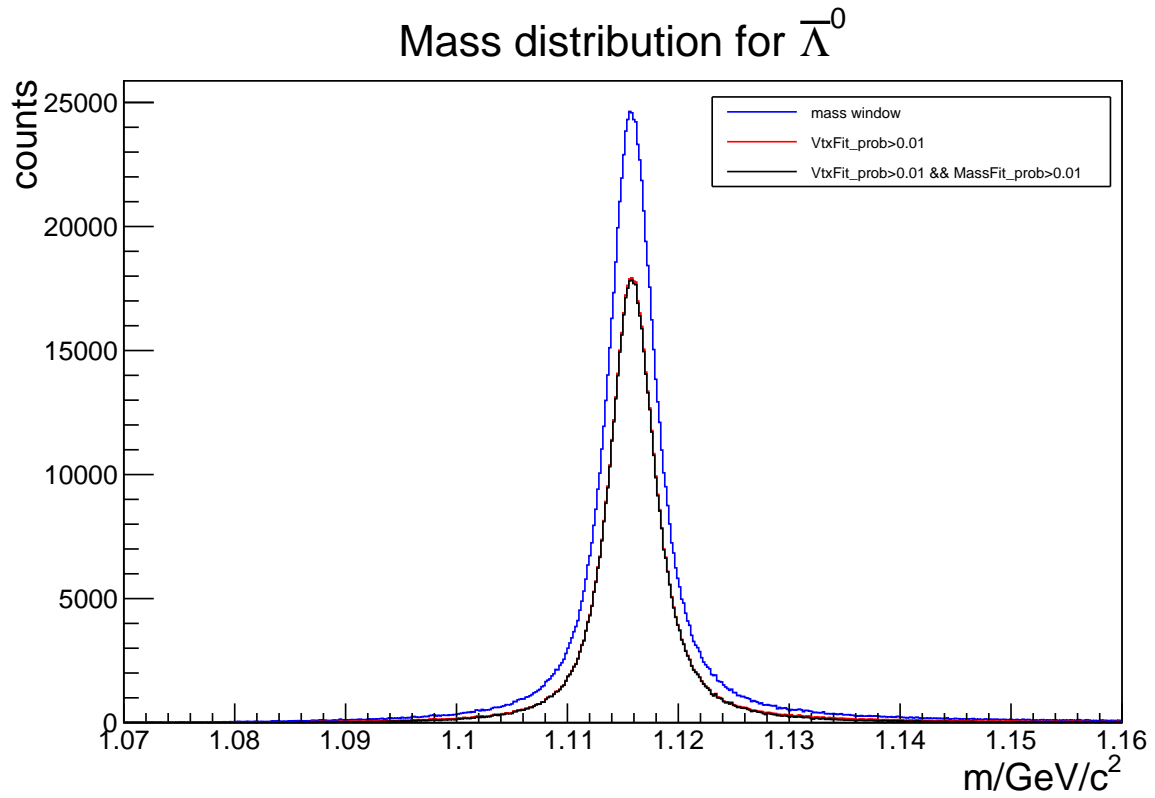
- similar scheme for  $\Lambda^0$  and  $\bar{\Lambda}^0$
- daughter particles for  $\bar{\Xi}$ :  $\bar{\Lambda}^0$  and  $\pi^+$  here  $\pi_1^+$
- daughter particles for  $\Xi$ :  $\Lambda^0$  and  $\pi^-$  meson here  $\pi_1^-$
- using best candidate from  $\Lambda^0$  and  $\bar{\Lambda}^0$
- performing a mass window cut with width of  $0.3 \text{ GeV}/c^2$  means  $m_{\Xi} \pm 0.15 \text{ GeV}/c^2$  with  $m_{\Xi} = 1.32171 \text{ GeV}/c^2$  [2]

### Fitting

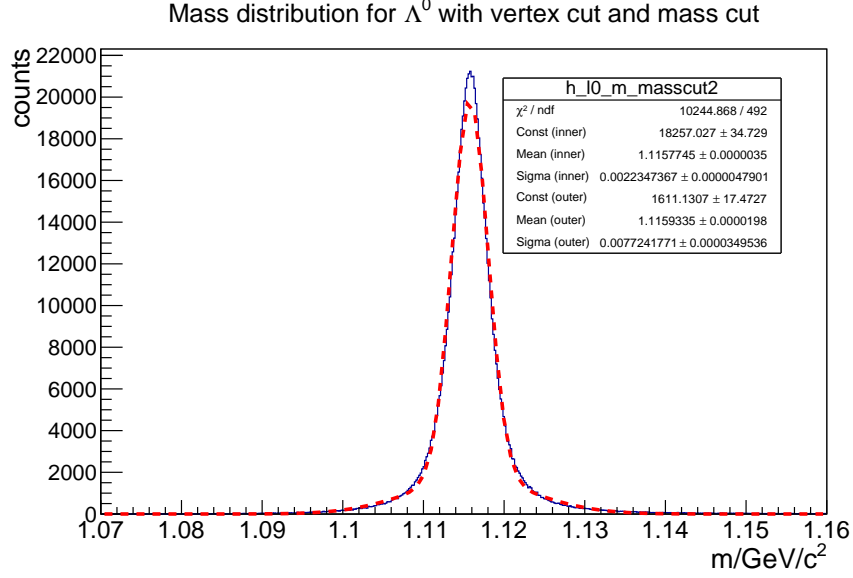
- fitting particles to common vertex with PndKinVtxFitter
- fit information are given to PndKinFitter with mass constraint
- scheme in figure 2.9
- only select particles with prob bigger than 0.01 for both fitters (figure 2.10)
- if there is more than one particle, choose best candidate
- vertex resolution shown in table 2.3



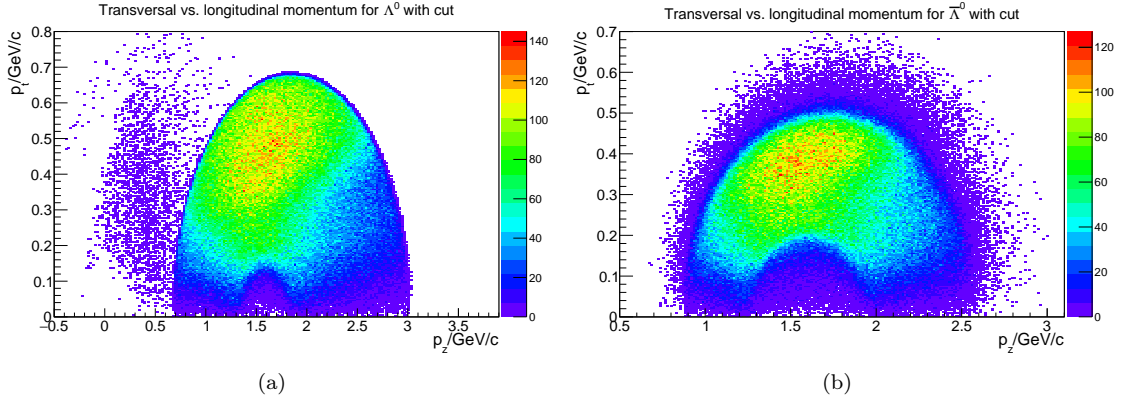
**Figure 2.4:** Mass distribution of  $\Lambda^0$  for different cuts



**Figure 2.5:** Mass distribution of  $\bar{\Lambda}^0$  for different cuts



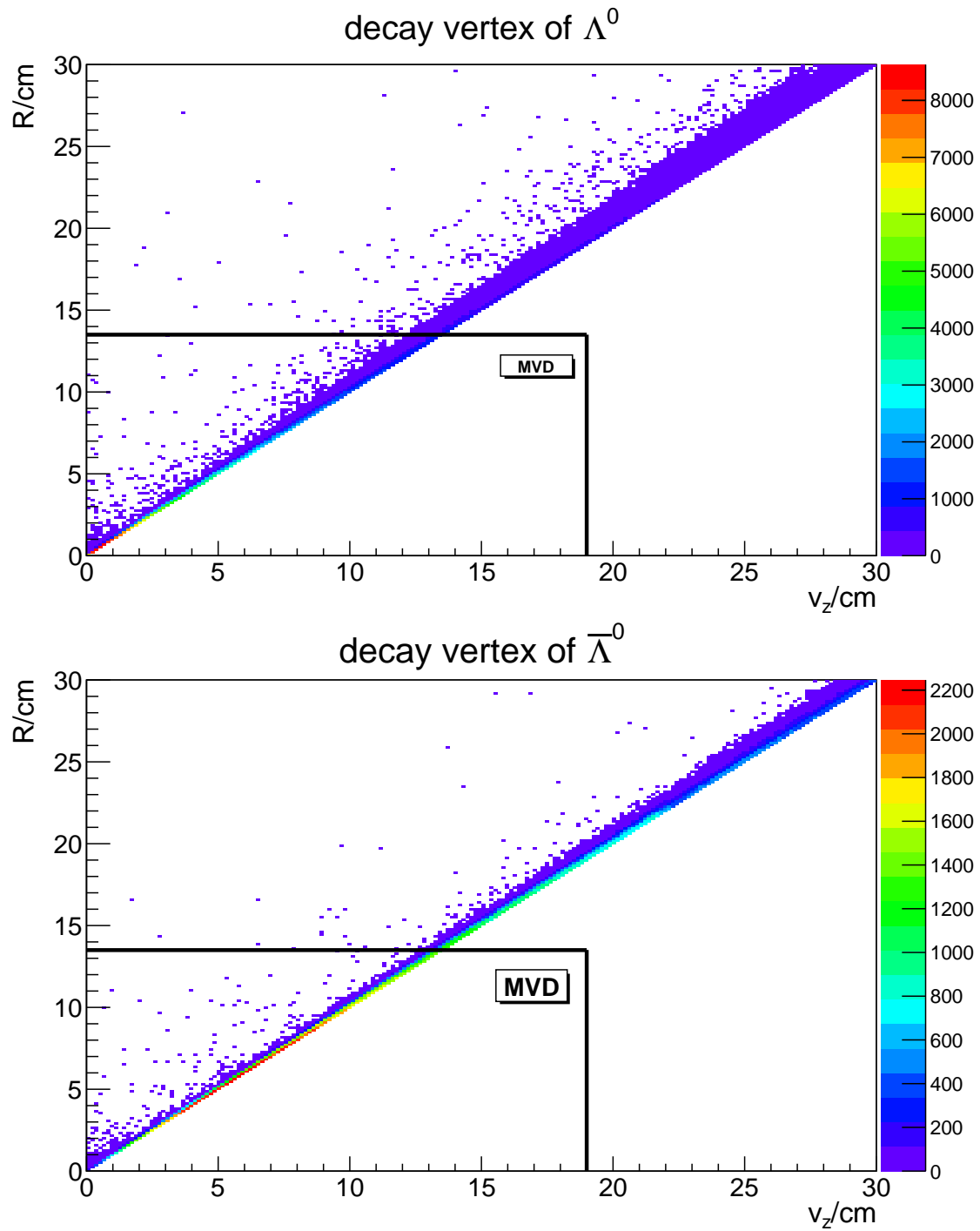
**Figure 2.6:** Mass distribution – blue line – for  $\Lambda^0$  fitted with a double gaussian fit shown as red dashed line.



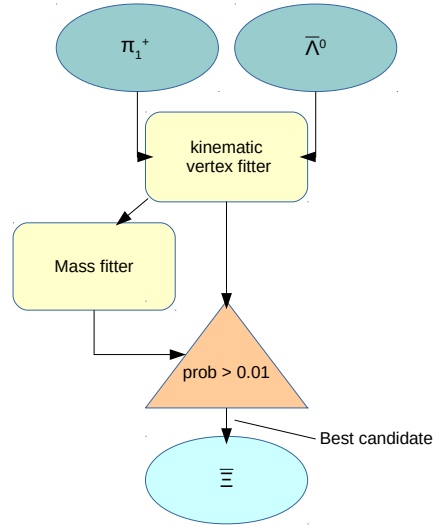
**Figure 2.7:** The plots shows the transverse against the longitudinal momentum for  $\Lambda^0$

**Table 2.3:** Vertex resolution for  $\Xi$  and  $\Xi$  (c.c. channel)

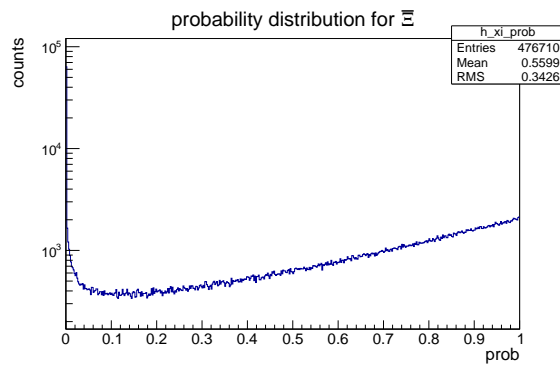
position	$\Xi$	cascade(from c.c.)
x	$0.03282 \pm 0.00017$	
y	$0.03326 \pm 0.00017$	
z	$0.12054 \pm 0.00058$	



**Figure 2.8:** Upper plot shows the decay vertex of  $\Lambda^0$ ; lower plot shows decay vertex of  $\bar{\Lambda}^0$

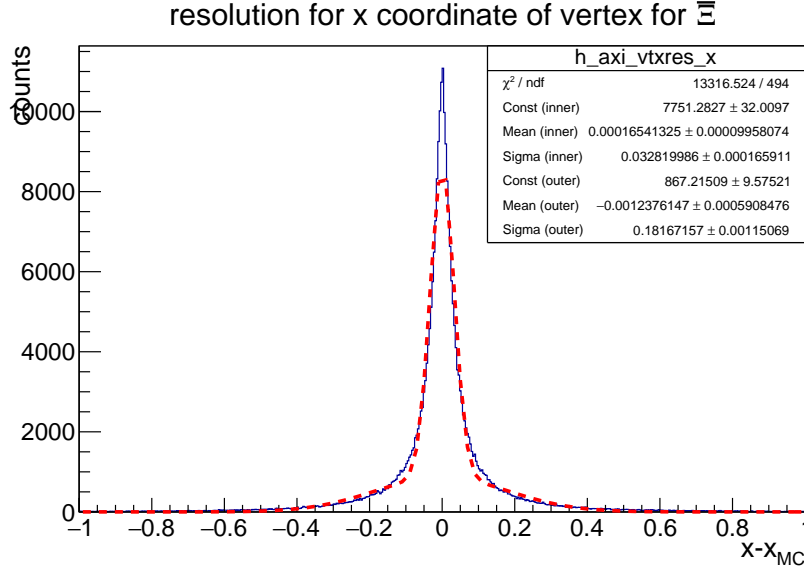


**Figure 2.9:** Scheme for  $\Xi$  reconstruction



**Figure 2.10:**  $\chi^2$  probability for  $\Xi$  reconstruction





**Figure 2.11:** Vertex resolution of x position for  $\Xi$

-vertex resolution is determined by using a double Gaussian fit; "inner"  $\sigma$  is vertex resolution, see figure 2.11 and figure 2.12

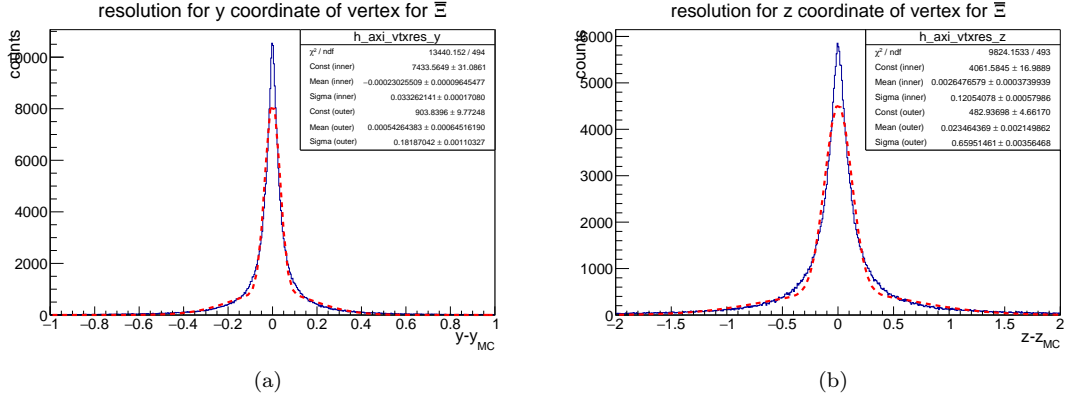
## Results

- mass distribution for different cuts see figure 2.13 and figure 2.14
- performing a double gaussian fit on cutted mass for  $\Xi$  and  $\Xi$  (example see figure 2.15)
- result of massfit  $m = (1.3721716 \pm 9.2 \cdot 10^{-5}) \text{ GeV}/c^2$
- small error seems to come from wrong covariance matrices.
- transverse vs longitudinal momentum for  $\Xi$  and  $\Xi$  is shown in figure 2.16
- the reconstruction efficiency for  $\Xi$  is 18.39% and for  $\Xi$  18.64%

## 2.4 Reconstruction of $\Xi(1820)$ and $\Xi(1820)$

### Combination

- daughter particles for  $\Xi(1820)$ :  $\Lambda^0$  and  $K^-$  meson
- daughter particles for  $\Xi(1820)$ :  $\bar{\Lambda}^0$  and  $K^+$
- using best candidate from  $\Lambda^0$  and  $\bar{\Lambda}^0$
- $K^+$  and  $K^-$  with more than 3 Hits in one subdetector
- performing a mass window cut with width of  $0.3 \text{ GeV}/c^2$



**Figure 2.12:** left plot: Vertex resolution of y position for  $\Xi$ ; right plot: Vertex resolution of z position for  $\Xi$ .

### Fitting

- fitting particles to common vertex with PndKinVtxFitter
- only select particles with prob bigger than 0.01
- scheme in figure 2.17
- if there is more than one particle, choose best candidate
- $\chi^2$  probability distribution for vertex fit shown in figure 2.18

### Results

- mass for different cuts see figure 2.19
- mass fit figure 2.20

## 2.5 Reconstruction of hole chain

### combination

- using best candidate from  $\Xi$  (1820) and  $\Xi$
- for c.c :  $\Xi$  (1820) and  $\Xi$
- mass window of  $0.3\text{GeV}/c^2$

### Fitting

- use PndKinFitter with four momentum constrained
- initial four momentum vector is

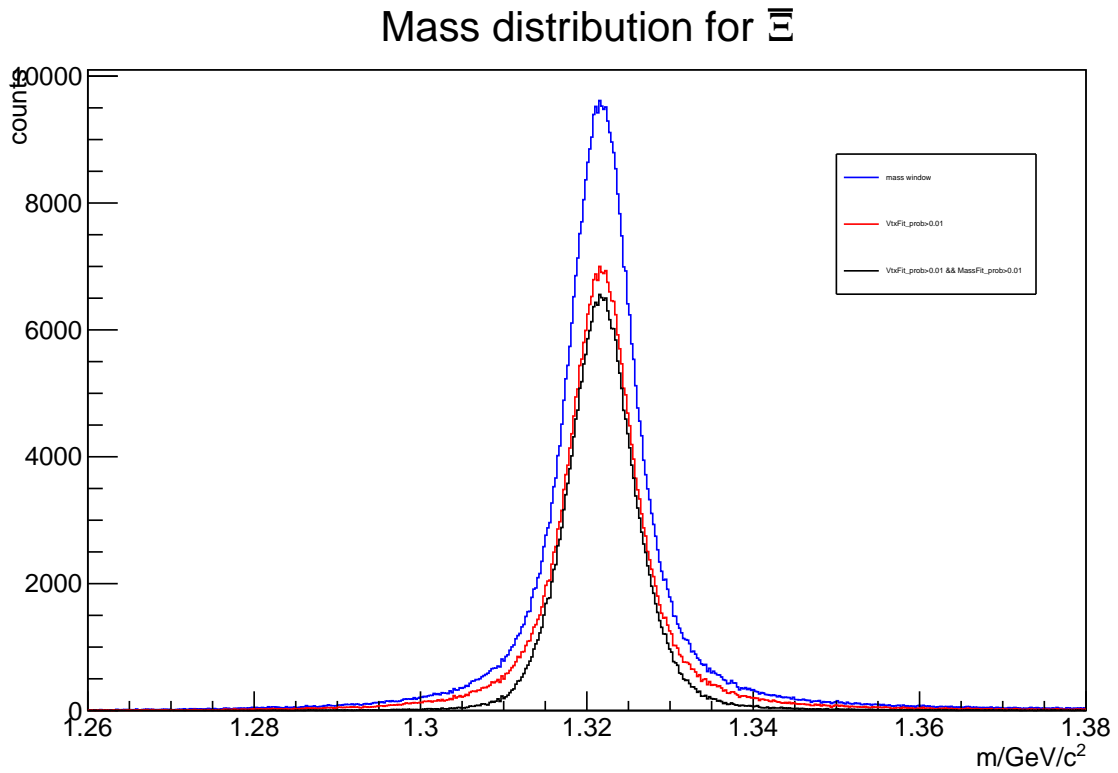


Figure 2.13: Mass distribution of  $\Xi^-$  for different cuts

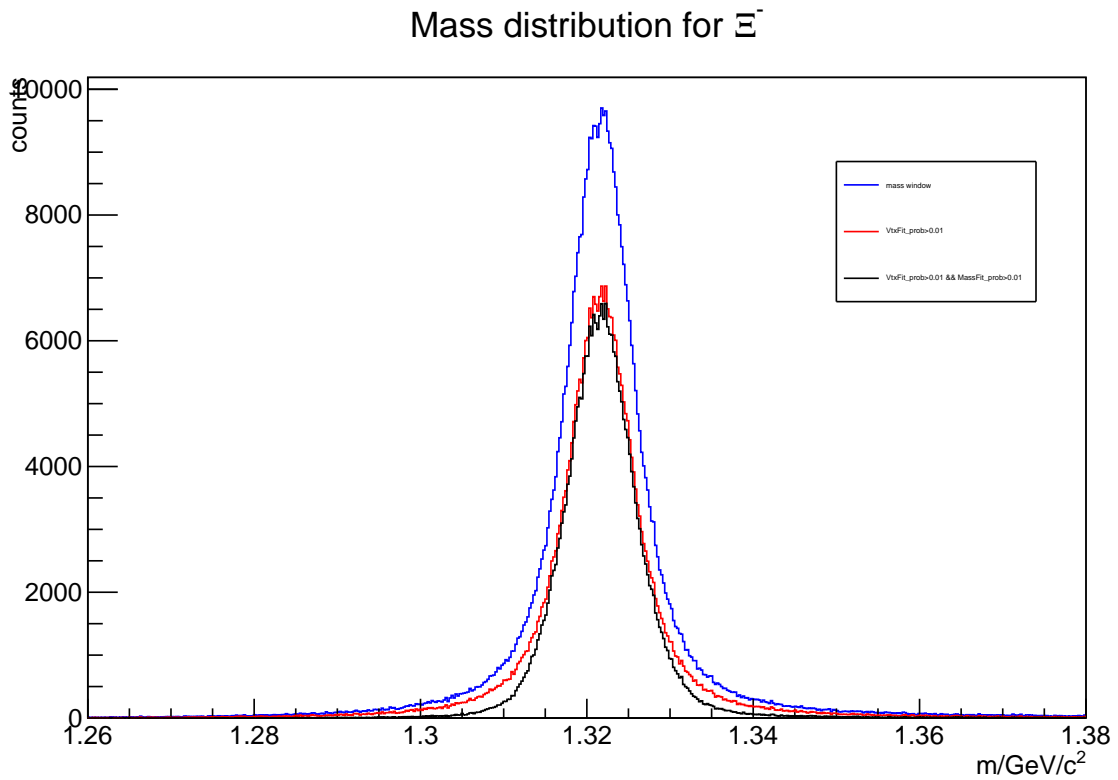


Figure 2.14: Mass distribution of  $\Xi^-$  for different cuts

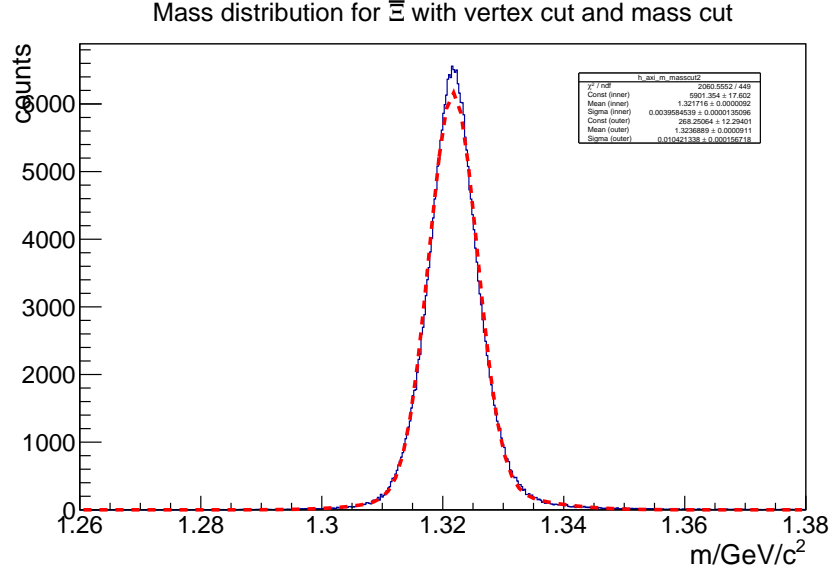


Figure 2.15: Mass fit with a double gaussian fit

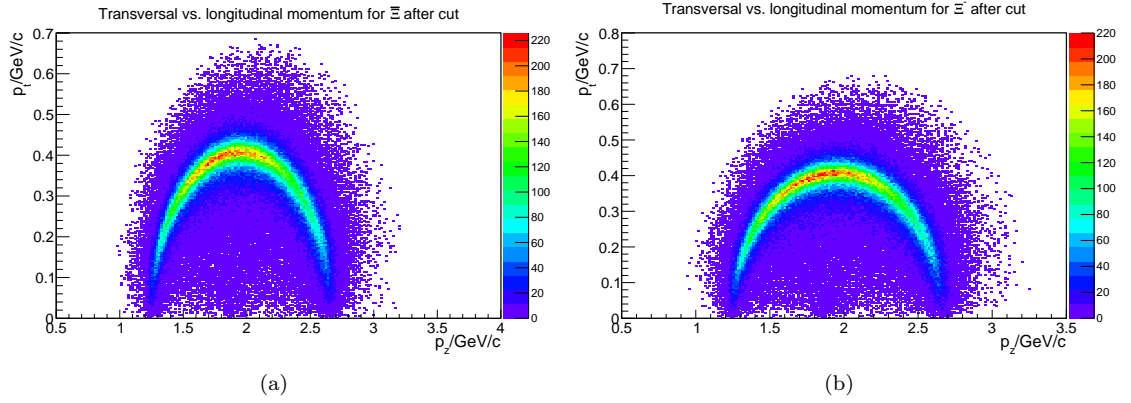
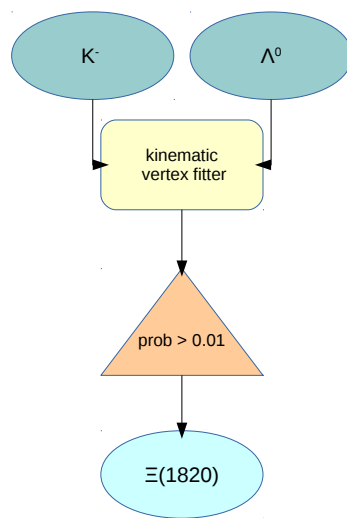
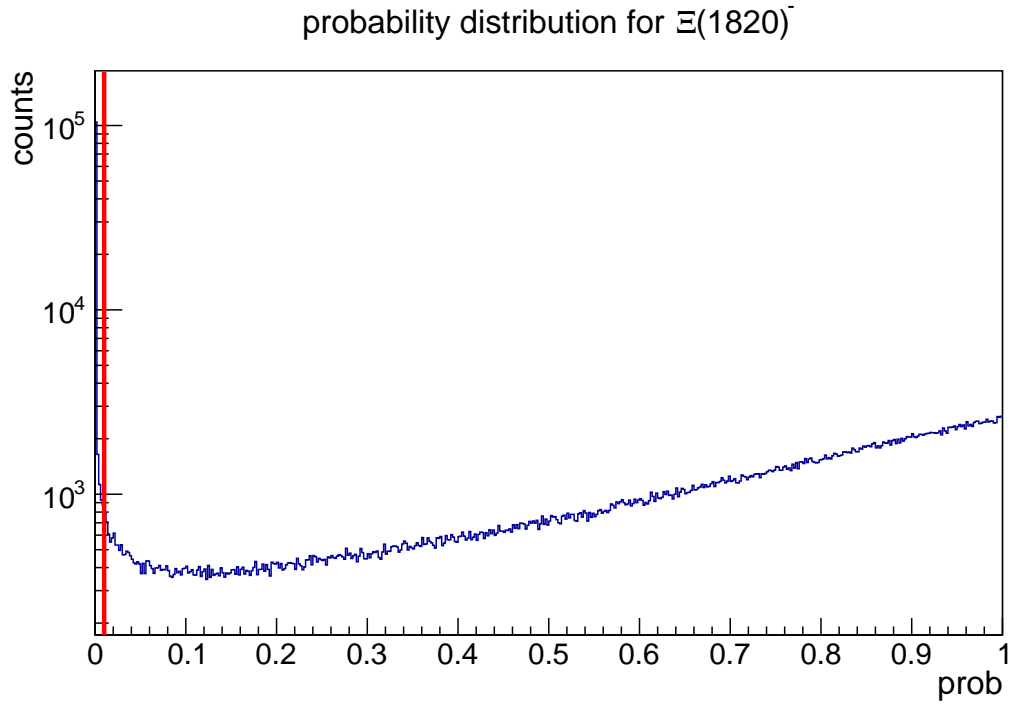


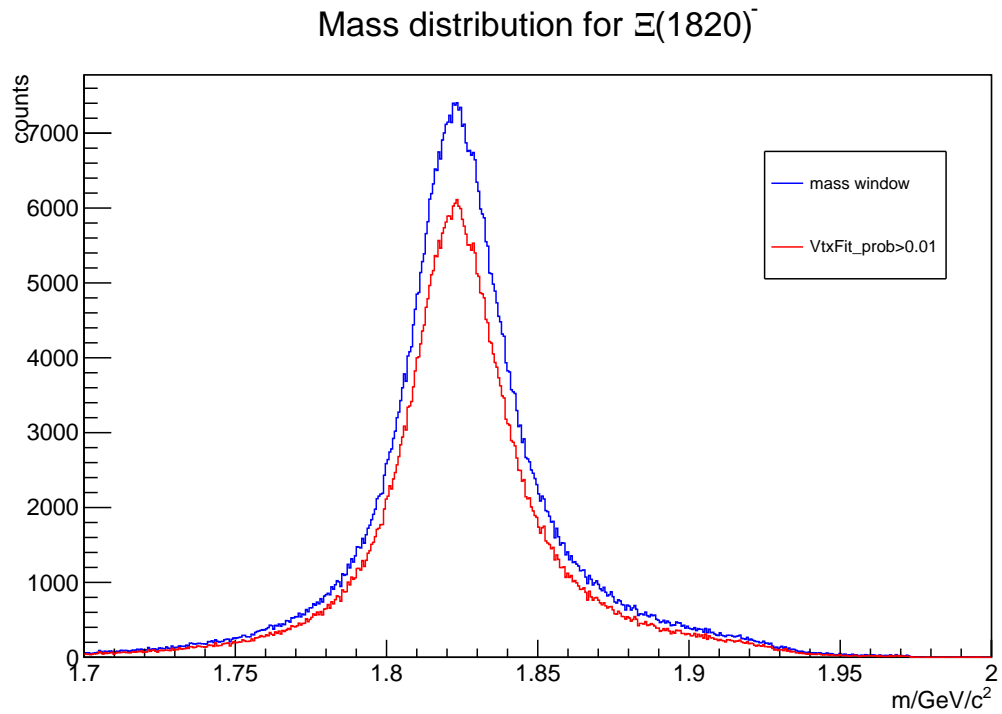
Figure 2.16: The plots shows the transverse against the longitudinal momentum for  $\Xi$  and  $\Xi$



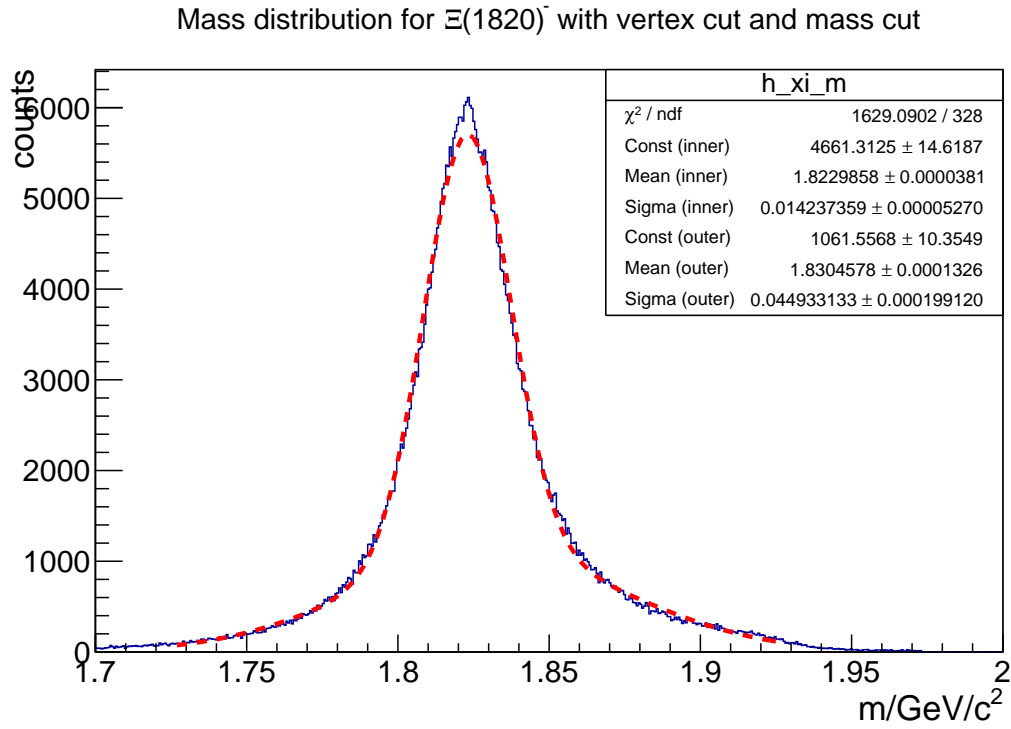
**Figure 2.17:** Scheme for  $\Xi(1820)$  reconstruction



**Figure 2.18:**  $\chi^2$  probability distribution of kinematic vertex fit for  $\Xi(1820)^-$ .



**Figure 2.19:** Mass distribution for  $\Xi(1820)^-$  for the different cuts



**Figure 2.20:** Mass distribution after all cuts for  $\Xi(1820)$ .

**Figure 2.21:** 4-constraint fit probability

$$(p_x, p_y, p_z, E) = (0, 0, 4.6, 5.63)$$

- if probability is better than 1% keep candidate
- scheme shown in figure 2.22
- table 2.4 shows summary of reconstruction efficiency for non-final state particles
- dalitz plot is shown in figure 2.23

**Table 2.4:** reconstruction efficiency for non-final state particles for  $\bar{p}p \rightarrow \Xi(1820) \bar{\Xi}$

particle	reco efficiency in %	dp/p in %
$\Lambda^0$		
$\bar{\Lambda}^0$		
$\bar{\Xi}$		
$\Xi(1820)$		
$\Xi \bar{\Xi}$ system		

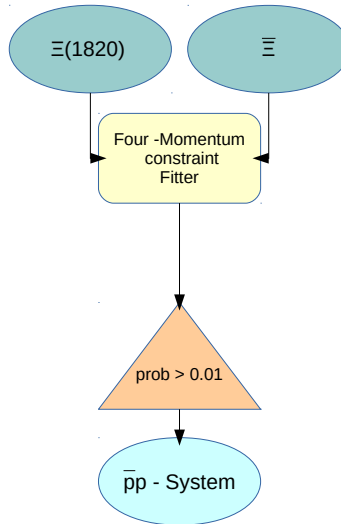


Figure 2.22: Scheme for 4-Constraint Fit

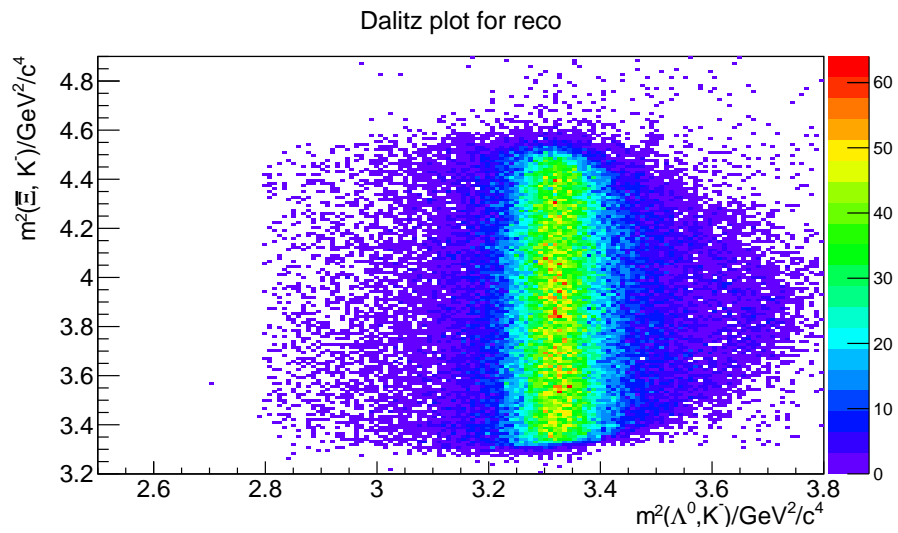


Figure 2.23: Dalitz plot for reconstructed particles



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## 3 Background

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## Bibliography

- [1] W. Erni, I. Keshelashvili, B. Krusche, M. Steinacher, Y. Heng, Z. Liu, H. Liu, X. Shen, O. Wang, H. Xu, *et al.*, “Physics performance report for panda: Strong interaction studies with antiprotons,” *arXiv preprint arXiv:0903.3905*, 2009.
- [2] J. B. et al., *Particle Data Group*. Phys. Rev. D86, 010001, 2012.