# Measurements of the branching fraction for $\Xi^- \to \Lambda e^- \nu$
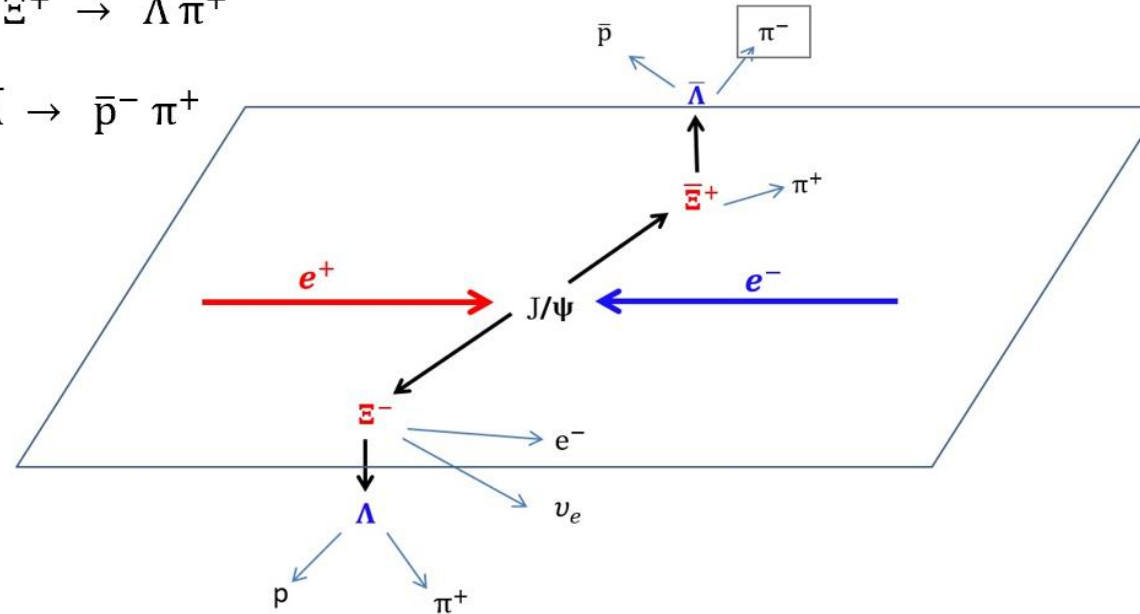
# Data set

$J/\psi \rightarrow \Xi^- \bar{\Xi}^+ ,$

$\Xi^- \rightarrow \Lambda\, e^-\, \nu\, , \quad \bar{\Xi}^+ \rightarrow \bar{\Lambda}\, \pi^+$

$\Lambda \rightarrow p^+\, \pi^-\, , \quad \bar{\Lambda} \rightarrow \bar{p}^-\, \pi^+$



Here I chose $\Xi^- \rightarrow \Lambda\, e^-\, \nu\, , \quad \bar{\Xi}^+ \rightarrow \bar{\Lambda}\, \pi^+$ as my data set.

# Event selection

➢ Charged Tracks
  ✓ No Vertex requirement; $|\cos\theta| < 0.93$; Ngood $\geq 6$;
➢ PID
  ✓ Proton: p>0.32 GeV/c;
  ✓ Pion: p<0.32 GeV/c;
  ✓ Electron: prob_e>prob_K && prob_e>prob_π; ie.size()==1;
➢ Vertex fit for $\overline{\Lambda}, \overline{\Xi}^+$
  ✓ For $\overline{\Lambda}, \overline{\Xi}^+$, primary and secondary vertex fit used for the $\bar{p}^-\pi^+$ for $\overline{\Lambda}, \overline{\Lambda}\pi^+$ for $\overline{\Xi}^+$.
    Loop all the pairs, select combination by minimizing $\chi^2 = \left(M(\bar{p}^-\pi^+) - M(\Lambda_{PDG})\right)^2 + \left(M\left(\overline{\Lambda}_{\bar{p}\pi^+}\pi^+\right) - M(\Xi_{PDG})\right)^2$

# Event selection

➢ Vertex fit for $\Lambda, \Xi^-$

    ✓ For $\Lambda$, primary and secondary vertex fit used for the $p^+\pi^-$ for $\Lambda$, $\Lambda$ for $\Xi^-$.

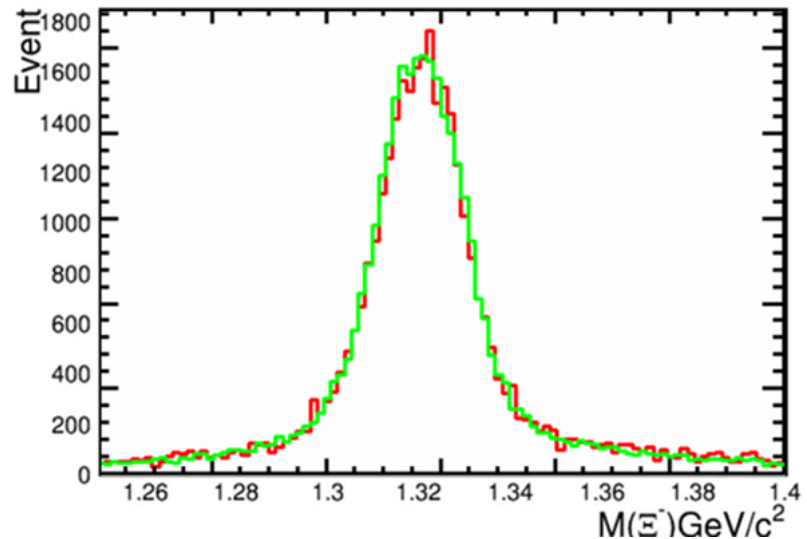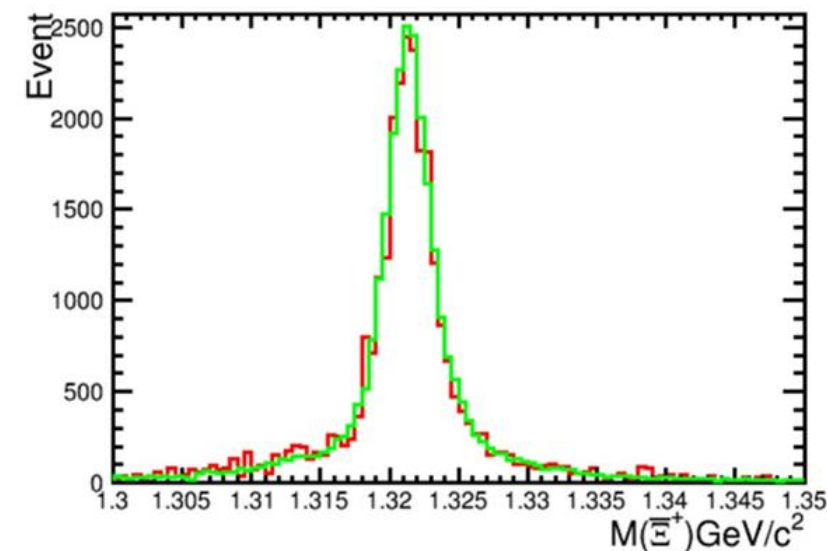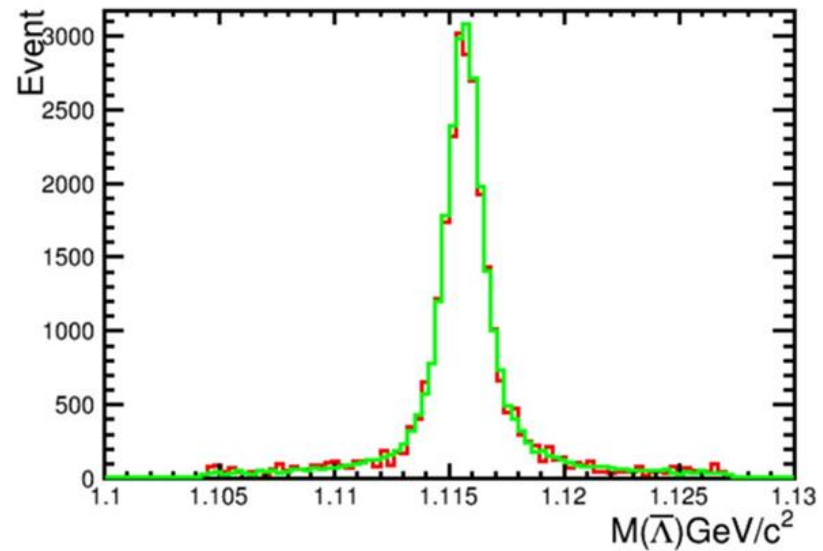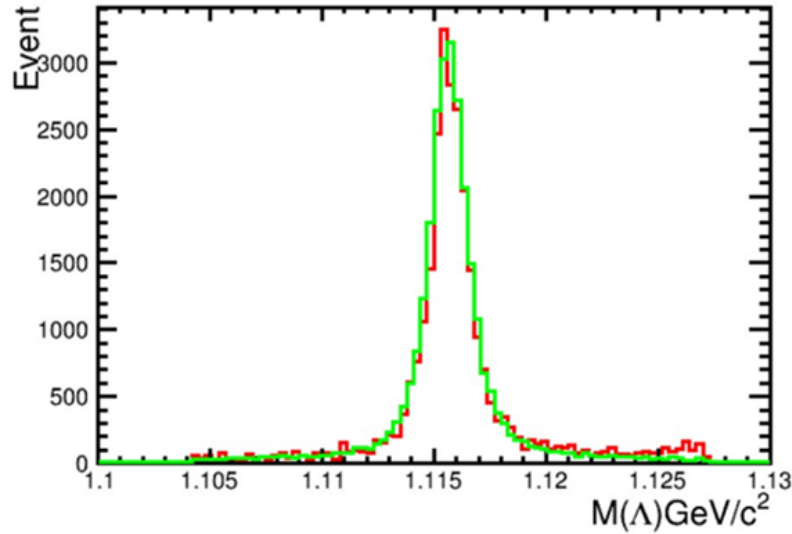    ✓ For $\Xi^-$, primary vertex fit used for the $\Lambda e^-$ for $\Xi^-$.

      Loop all the pairs, select combination by minimizing $\chi^2 = chisq_{p\pi^-} + chisq_{\Lambda} + chisq_{\Lambda e^-}$

# Background analysis

## $\Xi^-$ DECAY MODES

| | Mode | Fraction ($\Gamma_i/\Gamma$) | Confidence level |
|---|---|---|---|
| $\Gamma_1$ | $\Lambda\pi^-$ | $(99.887 \pm 0.035)\ \%$ | |
| $\Gamma_2$ | $\Sigma^-\gamma$ | $(\ 1.27\ \pm 0.23\ ) \times 10^{-4}$ | |
| $\Gamma_3$ | $\Lambda e^-\bar{\nu}_e$ | $(\ 5.63\ \pm 0.31\ ) \times 10^{-4}$ | |
| $\Gamma_4$ | $\Lambda\mu^-\bar{\nu}_\mu$ | $(\ 3.5\ {}^{+3.5}_{-2.2}\ ) \times 10^{-4}$ | |
| $\Gamma_5$ | $\Sigma^0 e^-\bar{\nu}_e$ | $(\ 8.7\ \pm 1.7\ ) \times 10^{-5}$ | |
| $\Gamma_6$ | $\Sigma^0\mu^-\bar{\nu}_\mu$ | $<\ 8 \times 10^{-4}$ | 90% |
| $\Gamma_7$ | $\Xi^0 e^-\bar{\nu}_e$ | $<\ 2.3 \times 10^{-3}$ | 90% |

The main background should be $\Xi^- \rightarrow \Lambda\pi^-$

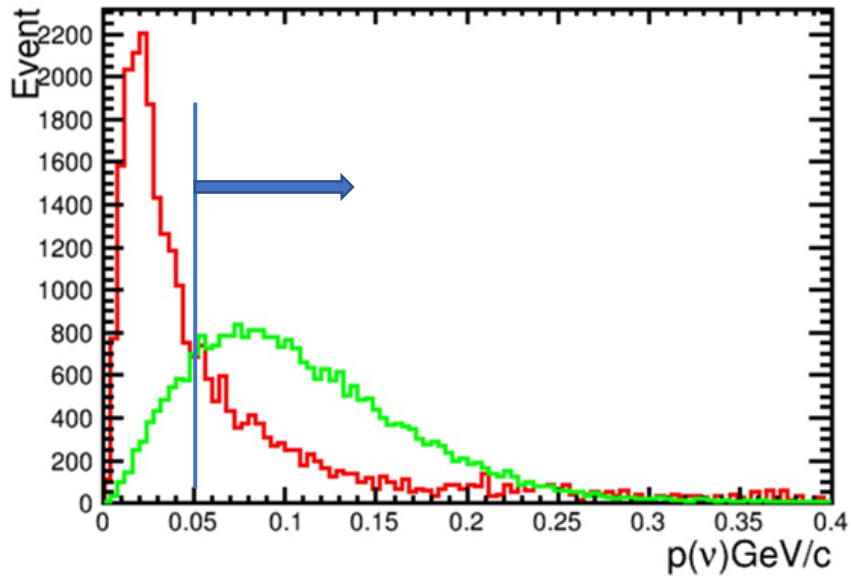# Background analysis



The green line is Signal which is $\Xi^- \to \Lambda\ e^-\ \nu$

The red line is background which is $\Xi^- \to \Lambda\ \pi^-$

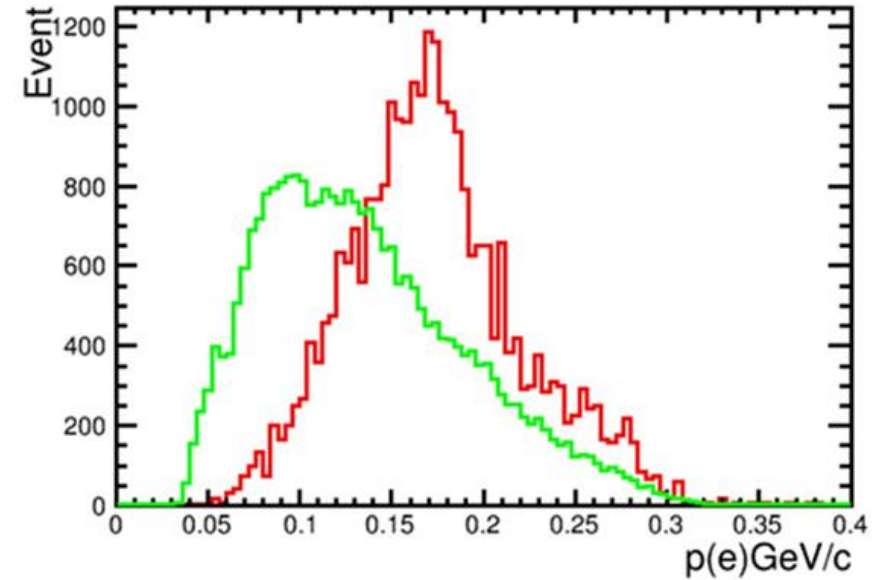Here are the mass spectrum of $\Lambda$ , $\Xi$.
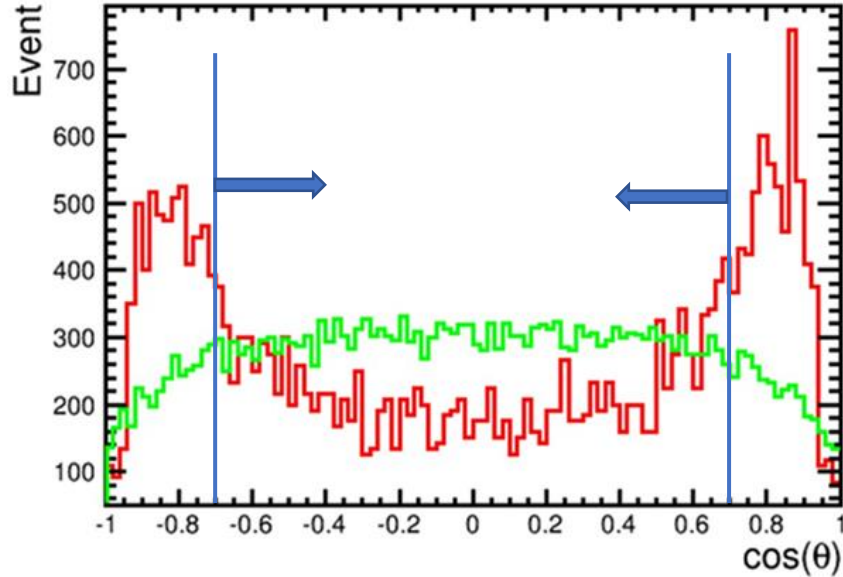
# Background analysis



$$\Xi^- \rightarrow \Lambda \ e^- \ \nu$$

$$\Xi^- \rightarrow \Lambda \ \pi^-$$

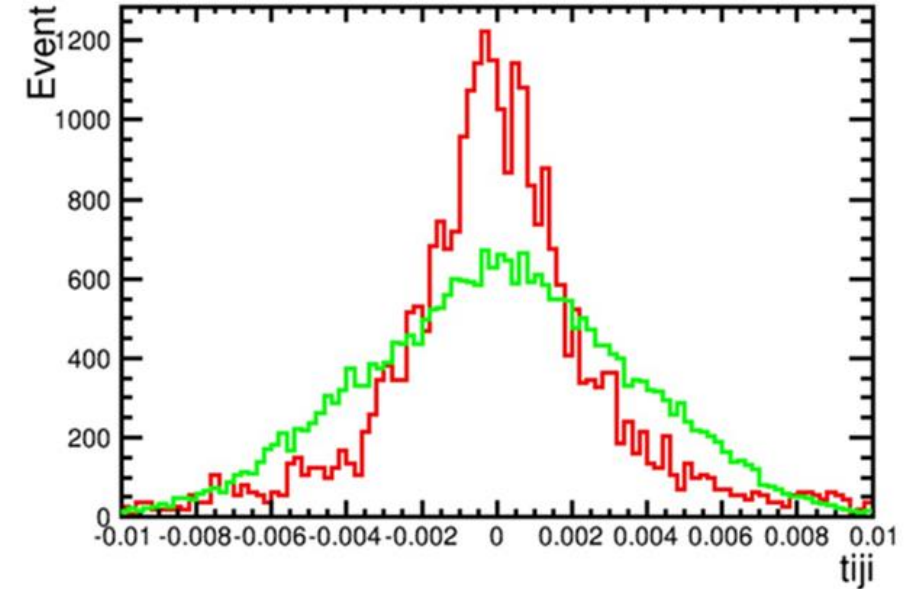The momentum cut of neutrino should be
higher than 0.05

# Background analysis



$$\Xi^- \rightarrow \Lambda \, e^- \, \nu$$

$$\Xi^- \rightarrow \Lambda \, \pi^-$$

$$\vec{P}_\pi = \vec{P}_{beam} - \vec{P}_\Lambda$$

$$(\vec{p}_\Xi \times \vec{p}_\Lambda) \cdot \vec{p}_e$$

Here is the costheta of recoiling pion. We prefer the modulus of costheta is smaller than 0.7
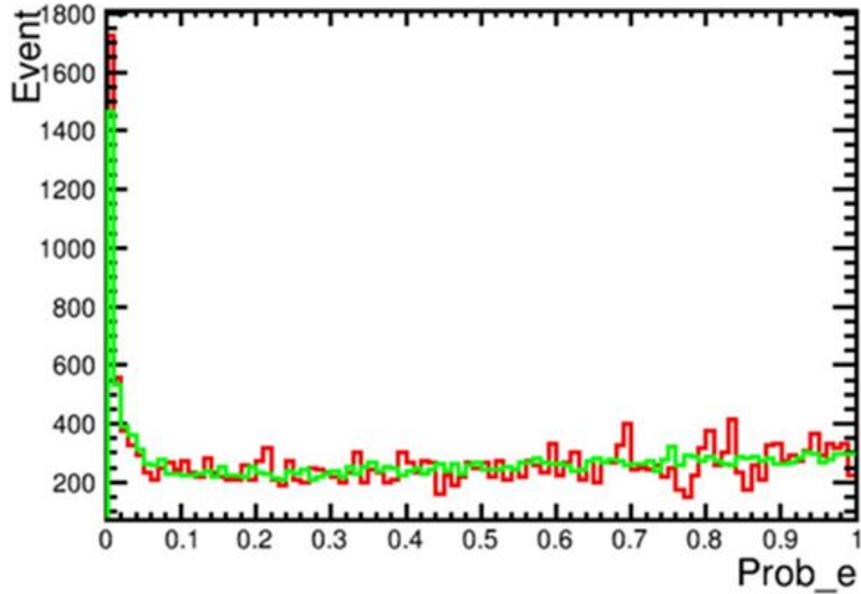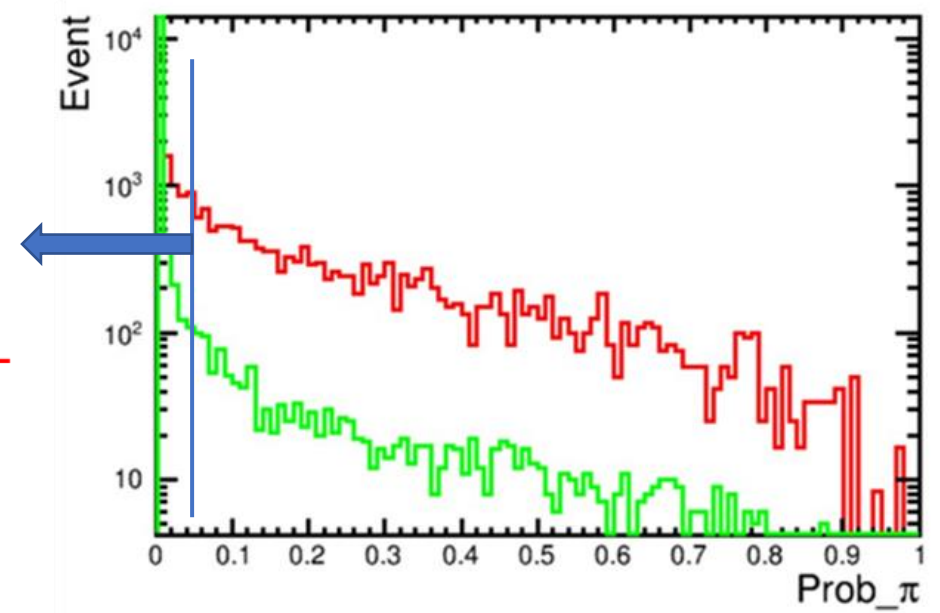
Because $\Xi \rightarrow \Lambda \, e \, \nu$ has 4 particles in this process and $\Xi \rightarrow \Lambda \, \pi$ only has 3. If we mistake $\pi$ for electron, this result should be zero as for the background.

# Background analysis



$$\Xi^- \rightarrow \Lambda\, e^-\, \nu$$

$$\Xi^- \rightarrow \Lambda\, \pi^-$$
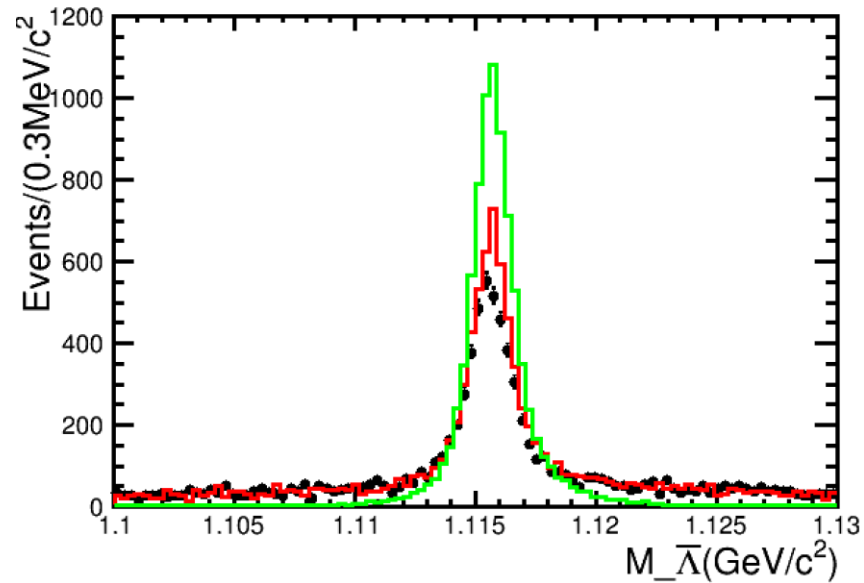
Probability of pion should be
smaller than 0.05

# Data sample

4.1 billion jpsi data ,
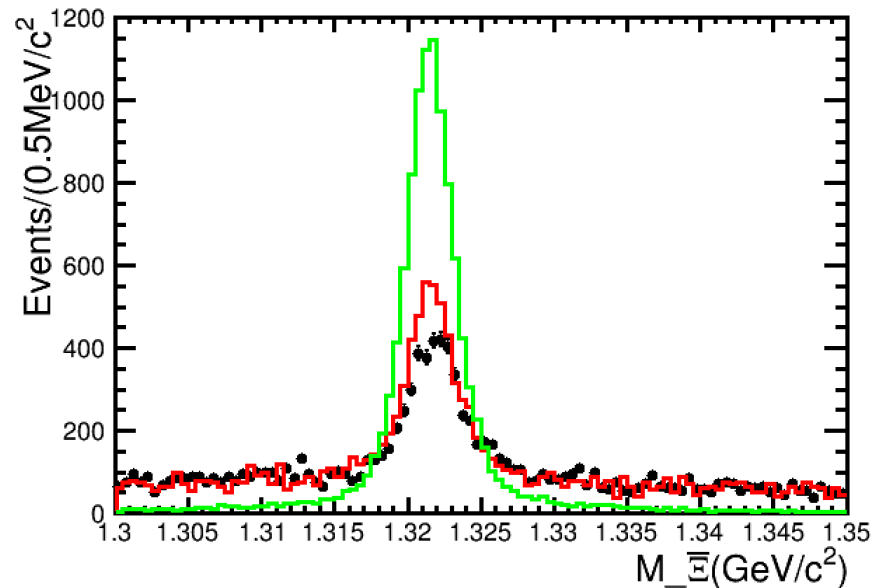4.1 billion jpsi inclusive mc data
2 million signal mc data.

# Apply selection to data

$$\Xi^- \rightarrow \Lambda\, e^- \nu$$

Inclusive MC

**Jpsi data**

# Apply selection to data



$$Umiss = E_\nu - |\vec{\mathrm{p}}_\nu|$$

$$E_\nu = E_{beam} - E_\Lambda - E_e$$

$$\vec{p}_\nu = \vec{p}_{all} - \vec{p}_{\overline{\Xi}} - \vec{p}_\Lambda - \vec{p}_e$$

$$\vec{p}_{\overline{\Xi}} = \hat{p}_{tag}\sqrt{E_{beam}^2 - m_{\overline{\Xi}}^2}$$

$$M_{miss}^2 = E_\nu^2 - |\vec{p}_\nu|^2$$

$$\frac{E_{electron}}{p_{electron}}$$

# Topology information of inclusive mc data

Table 1: Decay trees and their respective initial-final states.

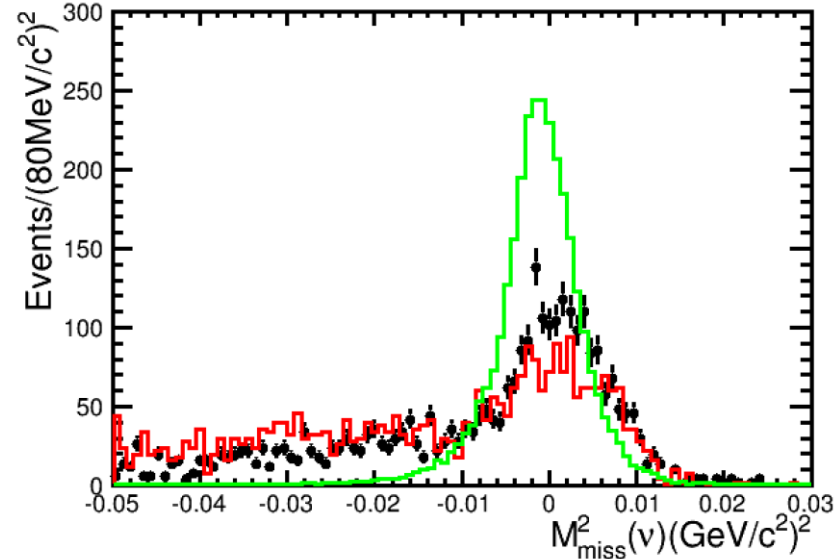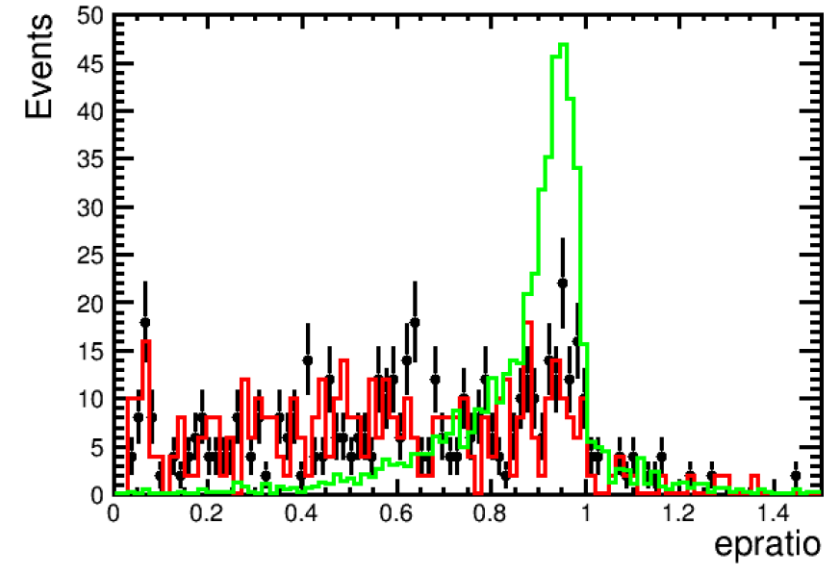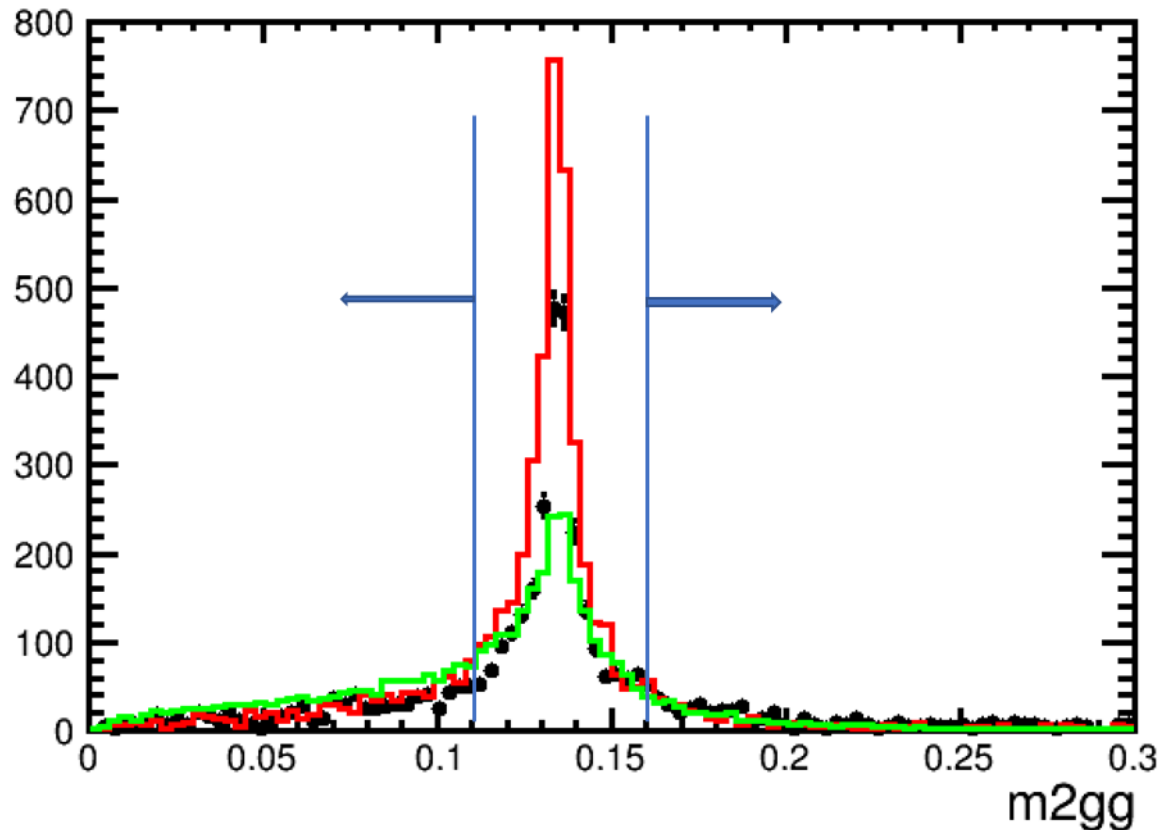We found that except
$\Xi^- \to \Lambda \pi^-$ there is
$\Xi^{*-} \to \pi^- \Xi^0$ and
$\Xi^{*-} \to \pi^0 \Xi^-$.

Then we decided to use
$\pi^0$ to eliminate these two
backgrounds.

| rowNo | decay tree (decay initial-final states) | iDcyTr | iDcyIFSts | nEtr | nCEtr |
|---|---|---|---|---|---|
| 1 | $J/\psi \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 7 | 0 | 2008 | 2008 |
| 2 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^-\Xi^0, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^0 \to \pi^0\Lambda, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 6 | 2 | 1240 | 3248 |
| 3 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^0\Xi^-, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^- \to \pi^-\Lambda, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 16 | 2 | 740 | 3988 |
| 4 | $J/\psi \to \Xi^0\bar{\Xi}^{*0}, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^{*0} \to \pi^-\bar{\Xi}^+, \Lambda \to \pi^-p, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 2 | 2 | 634 | 4622 |
| 5 | $J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 0 | 0 | 340 | 4962 |
| 6 | $J/\psi \to \eta_c\gamma, \eta_c \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma)$ | 1 | 1 | 334 | 5296 |
| 7 | $J/\psi \to \Xi^-\bar{\Xi}^{*+}, \Xi^- \to \pi^-\Lambda, \bar{\Xi}^{*+} \to \pi^0\bar{\Xi}^+, \Lambda \to \pi^-p, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 8 | 2 | 264 | 5560 |
| 8 | $J/\psi \to \Sigma^{*0}\bar{\Sigma}^{*0}, \Sigma^{*0} \to \pi^0\Lambda, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^-p\bar{p})$ | 4 | 4 | 208 | 5768 |
| 9 | $J/\psi \to \pi^0\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-)$ | 20 | 14 | 170 | 5938 |
| 10 | $J/\psi \to \Xi^-\bar{\Xi}^{*+}, \Xi^- \to \pi^-\Lambda, \bar{\Xi}^{*+} \to \pi^+\bar{\Xi}^0, \Lambda \to \pi^-p, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p})$ | 30 | 2 | 102 | 6040 |
| 11 | $J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^-p\bar{p})$ | 87 | 4 | 94 | 6134 |
| 12 | $J/\psi \to \Lambda\bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^+\pi^-p\bar{p}\gamma)$ | 40 | 25 | 92 | 6226 |
| 13 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^-\Xi^0, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^0 \to \pi^0\Lambda, \pi^0 \to e^+e^-\gamma^F,$ <br> $\Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow e^+e^-\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma^F)$ | 15 | 7 | 88 | 6314 |
| 14 | $J/\psi \to \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-)$ | 58 | 39 | 58 | 6372 |
| 15 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^0\Xi^-, \bar{\Lambda} \to \pi^+\bar{p}, \pi^0 \to e^+e^-\gamma^F, \Xi^- \to \pi^-\Lambda,$ <br> $\Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow e^+e^-\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma^F)$ | 10 | 7 | 56 | 6428 |

# Add new cut to data analysis



➢ Kmfit
  ✓ Momentums of 2 gamma, $\bar{\Xi}^+, \Lambda, \pi_{miss}^-$ and ecms
  ✓ Loop all the pairs, select combination by minimizing $\chi^2$ of kmfit

I eliminated the data which their $m_{\pi^0}$ are between 0.11 and 0.16.
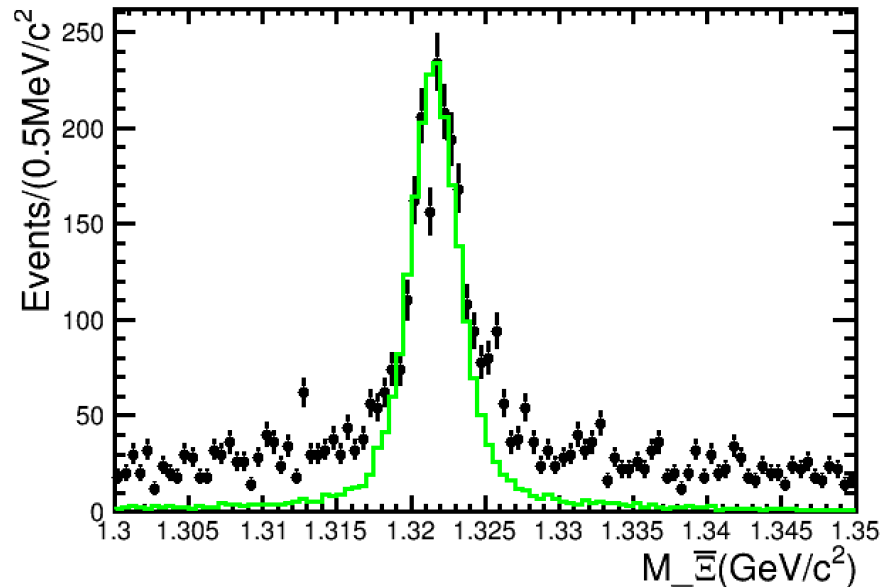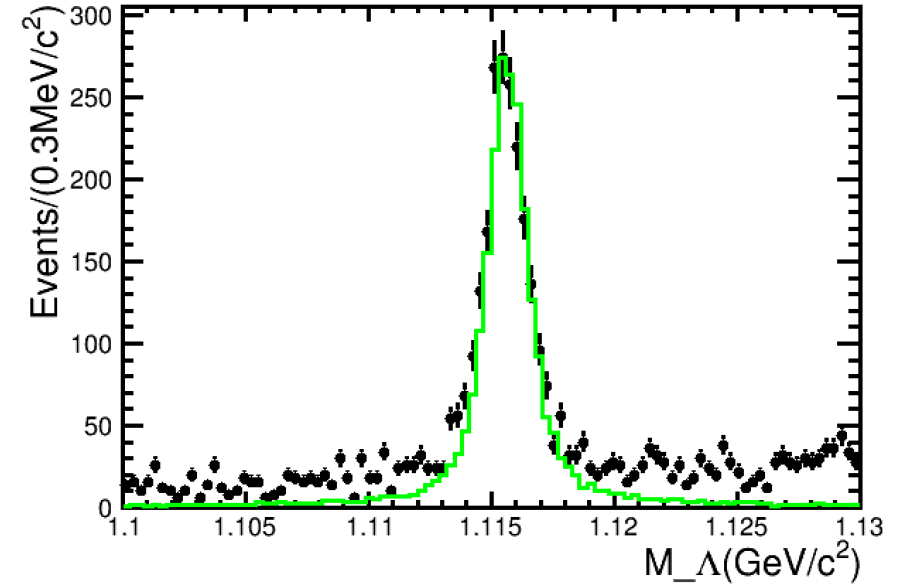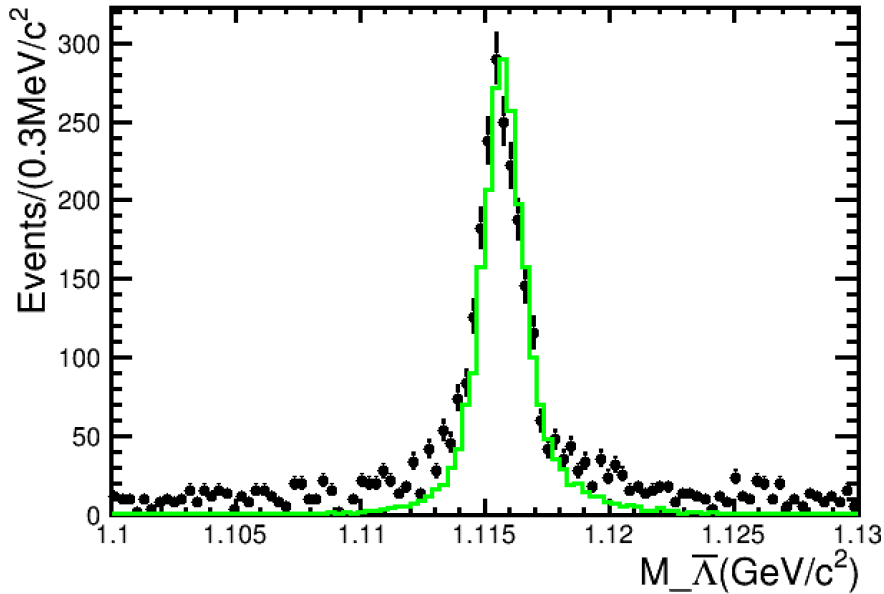
# Add new cut to data analysis

Table 1: Decay trees and their respective initial-final states.

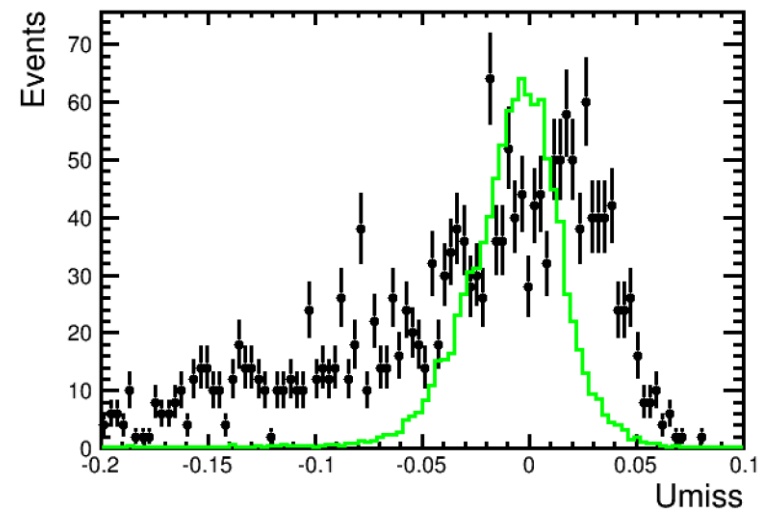| rowNo | decay tree (decay initial-final states) | iDcyTr | iDcyIFSts | nEtr | nCEtr |
|---|---|---|---|---|---|
| 1 | $J/\psi \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 0 | 0 | 1052 | 1052 |
| 2 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^-\Xi^0, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^0 \to \pi^0\Lambda, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 5 | 4 | 228 | 1280 |
| 3 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^0\Xi^-, \bar{\Lambda} \to \pi^+\bar{p}, \Xi^- \to \pi^-\Lambda, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 13 | 4 | 150 | 1430 |
| 4 | $J/\psi \to \eta_c\gamma, \eta_c \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^- p\bar{p}\gamma)$ | 7 | 6 | 120 | 1550 |
| 5 | $J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 21 | 0 | 80 | 1630 |
| 6 | $J/\psi \to \Xi^0\bar{\Xi}^{*0}, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^{*0} \to \pi^-\bar{\Xi}^+, \Lambda \to \pi^-p, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 4 | 4 | 72 | 1702 |
| 7 | $J/\psi \to \Lambda\bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}\gamma)$ | 11 | 9 | 34 | 1736 |
| 8 | $J/\psi \to \Xi^-\bar{\Xi}^{*+}, \Xi^- \to \pi^-\Lambda, \bar{\Xi}^{*+} \to \pi^0\bar{\Xi}^+, \Lambda \to \pi^-p, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 18 | 4 | 24 | 1760 |
| 9 | $J/\psi \to \bar{\Xi}^+\Xi^{*-}, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^{*-} \to \pi^0\Xi^-, \bar{\Lambda} \to \pi^+\bar{p}, \pi^0 \to e^+e^-\gamma^F, \Xi^- \to \pi^-\Lambda,$ <br> $\Lambda \to \pi^-p$ <br> $(J/\psi \dashrightarrow e^+e^-\pi^+\pi^+\pi^-\pi^- p\bar{p}\gamma^F)$ | 42 | 2 | 22 | 1782 |
| 10 | $J/\psi \to \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-)$ | 37 | 26 | 20 | 1802 |
| 11 | $J/\psi \to \Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}\gamma\gamma)$ | 34 | 23 | 20 | 1822 |
| 12 | $J/\psi \to \Sigma^{*0}\bar{\Sigma}^{*0}, \Sigma^{*0} \to \pi^0\Lambda, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p})$ | 10 | 8 | 18 | 1840 |
| 13 | $J/\psi \to \Xi^-\bar{\Xi}^{*+}, \Xi^- \to \pi^-\Lambda, \bar{\Xi}^{*+} \to \pi^+\bar{\Xi}^0, \Lambda \to \pi^-p, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$ <br> $(J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- p\bar{p})$ | 14 | 4 | 16 | 1856 |
| | $J/\psi \to \bar{\Xi}^+\Xi^-\gamma, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$ | | | | |

# Add new cut to data analysis

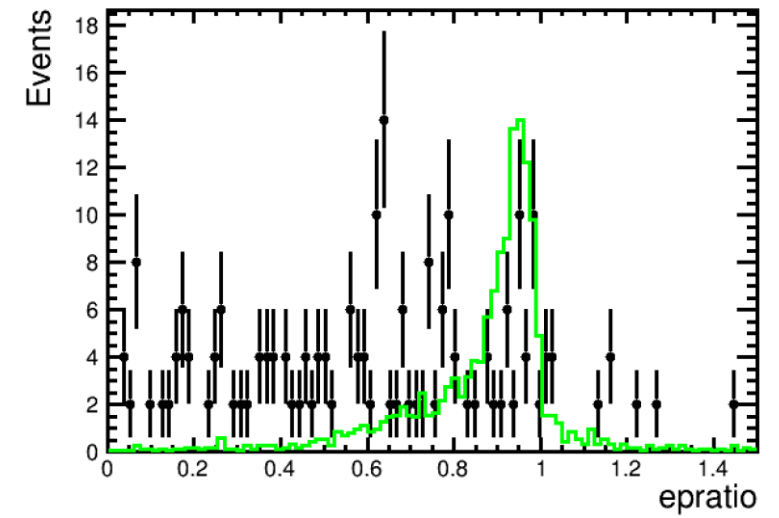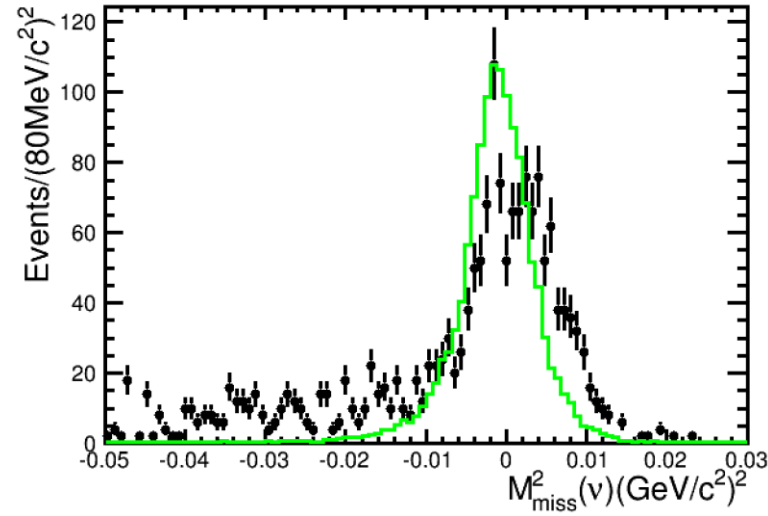$$\Xi^- \rightarrow \Lambda\, e^-\, \nu$$

**Jpsi data**

# Add new cut to data analysis



$$Umiss = E_v - p_v$$

$$\frac{E_{electron}}{p_{electron}}$$