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Study of $(J/\Psi, \Psi(2S)) \rightarrow \Lambda X$

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Charmonium Group Meeting
April 17, 2019

Outline

- Overview
- Motivations
- Experiment Overview
- Data Analysis
- Results
- Conclusion

Motivations

- The isospin conserving modes containing baryon pair with meson has been reported in PDG, also some searches have been performed to explore isospin violation process.
- In this study we searched the violation process in two ways isospin and strangeness which is highly suppress but kinematic ally it is possible.
- To find any hint beyond the Standard Model of Particle Physics.
- This work is devoted to the analysis of $J/\psi, \psi(2S) \to \Lambda\bar{\Delta}, \Lambda\bar{\Sigma}, \Lambda\bar{\Xi}$nd try to measure its branching fraction using the large statistics at BESIII

What is "X"

- Here X can be any anti baryon e.g $\overline{\Delta}$, $\overline{\Sigma}$, $\overline{\Xi}$. Here we will discuss these channels

$$J/\psi \to \Lambda\overline{\Delta} \qquad \psi(2S) \to \Lambda\overline{\Delta}$$

$$J/\psi \to \Lambda\overline{\Sigma} \qquad \psi(2S) \to \Lambda\overline{\Sigma}$$

$$J/\psi \to \Lambda\overline{\Xi} \qquad \psi(2S) \to \Lambda\overline{\Xi}$$

Observation of $J/\psi \to \Lambda X$

This study is based upon two steps

- Monte Carlo (MC) simulations.
- Real data results
- Where real data contain 1.3×10^9 J/ψ events and
- 4.4×10^8 $\psi(2S)$ events

MC simulation

- A MC sample of 100000 events is generated using different generators for each channel.

Event Selection for $J/\psi \to \Lambda\overline{\Sigma}$

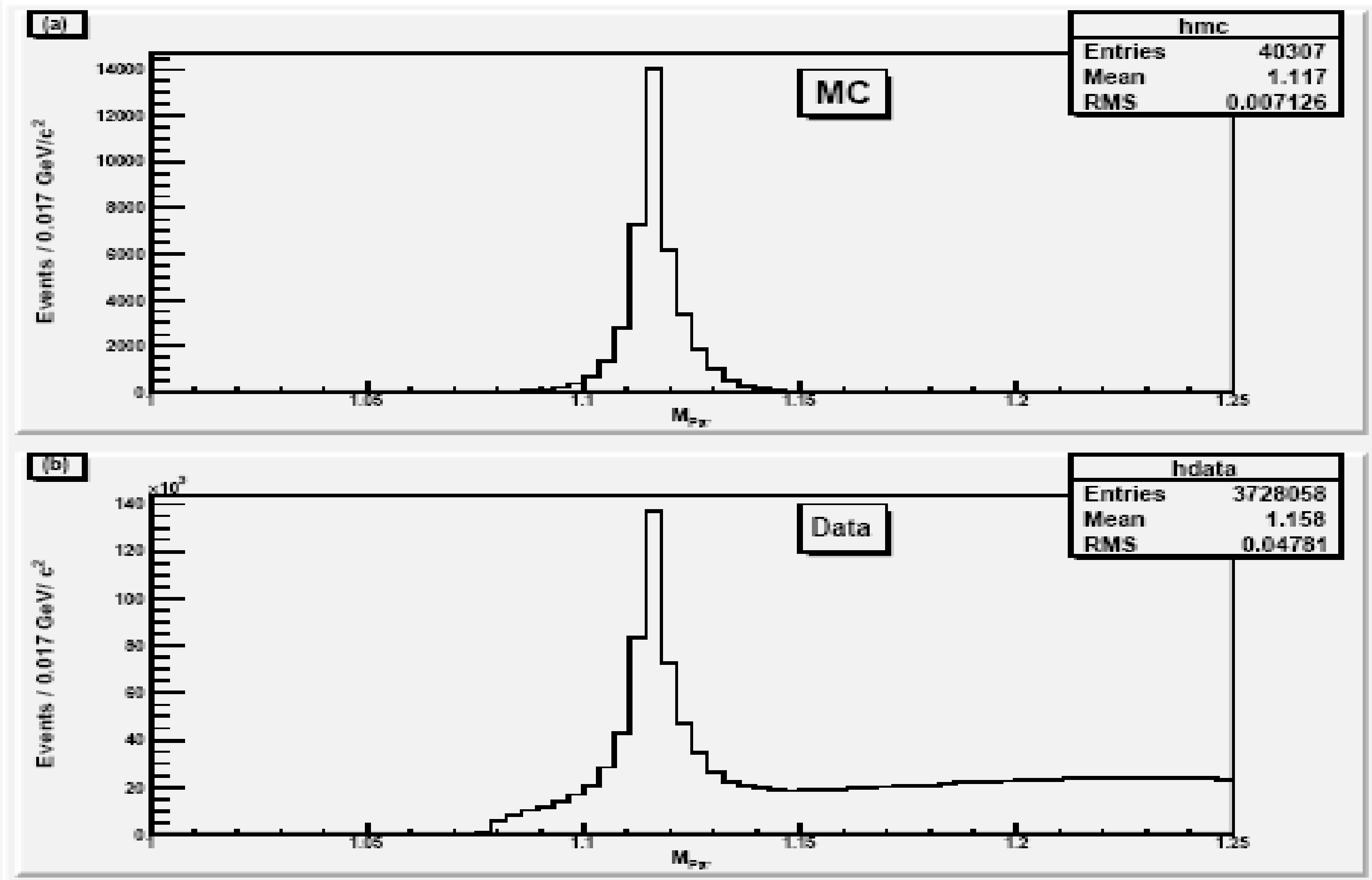
There are 4 charge tracks in $J/\psi \to \Lambda\overline{\Sigma}$ as $\Lambda \to P\pi^-$ and $\overline{\Sigma} \to \overline{p}\pi^+\gamma$

Only those events are selected having

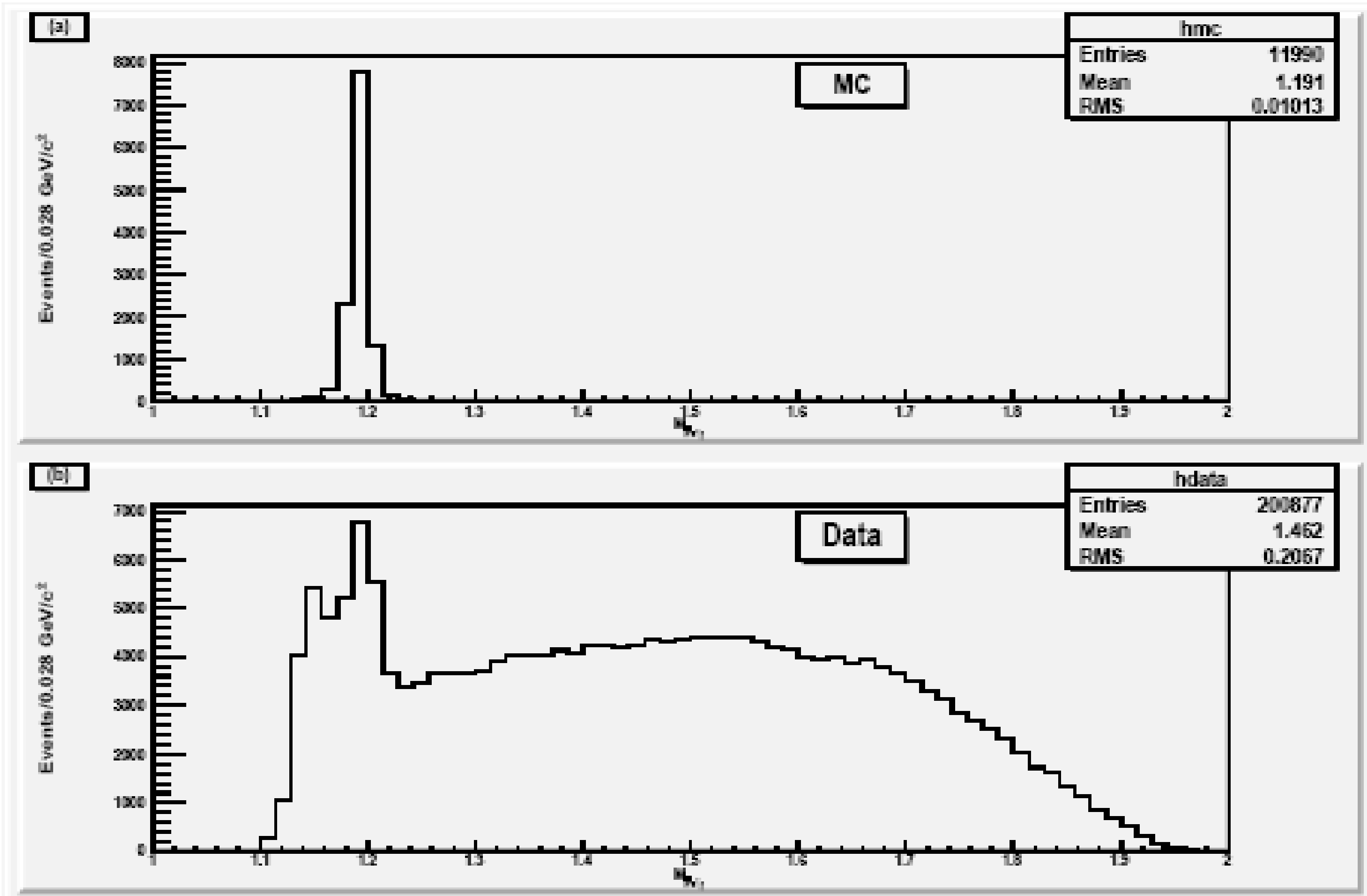
- nGood == 4
- number of γ == 1
- nCharge == 0

PID is applied to select events having 1 proton 1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to P\pi^-$ using kinematic fit for $J/\psi \to \Lambda\overline{\Sigma}$



MC and Data invariant mass of $\overline{\Sigma} \to \overline{p}\pi^{+}\gamma$ using kinematic fit for

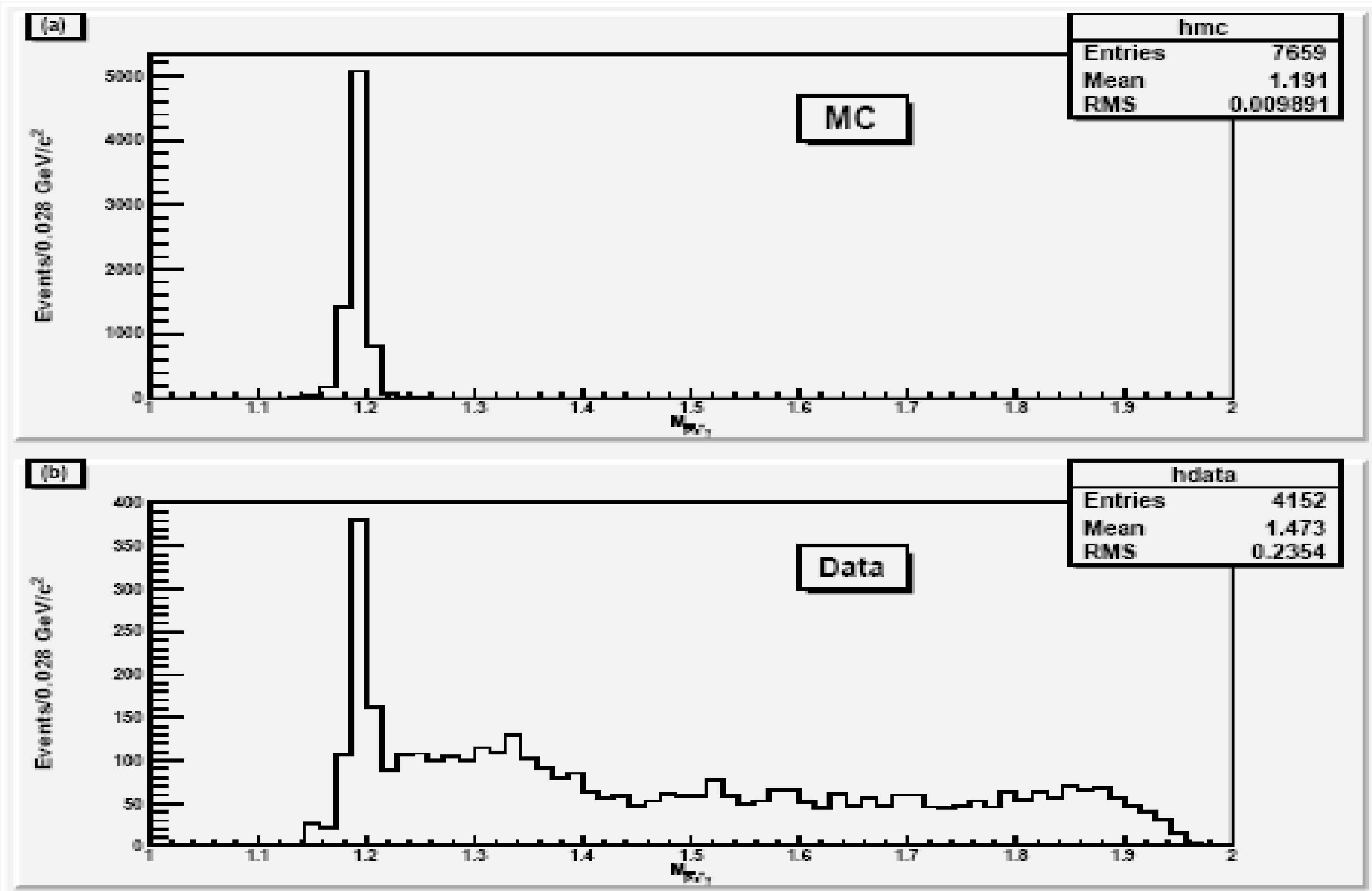


Background Analysis for $J/\psi \to \Lambda\overline{\Sigma}$

For final event selection we applied the following constraints to mass resolution of $\overline{\Sigma} \to \overline{p}\pi^{+}\gamma$.

- $\chi^2 < 40$
- $|M_{p\pi^-} - M_{\Lambda}| < 0.005$
- $|M_{p\pi^-\gamma\gamma} - M_{\Xi}| > 0.03532$
- $|M_{p\pi^-\gamma} - M_{\Sigma}| > 0.03117$
- $|M_{p\pi^-} - M_{\Delta}| > 0.24$
- number of $\gamma = 1$
- Decay Length of $\Lambda > 2$
- Rxy < 4

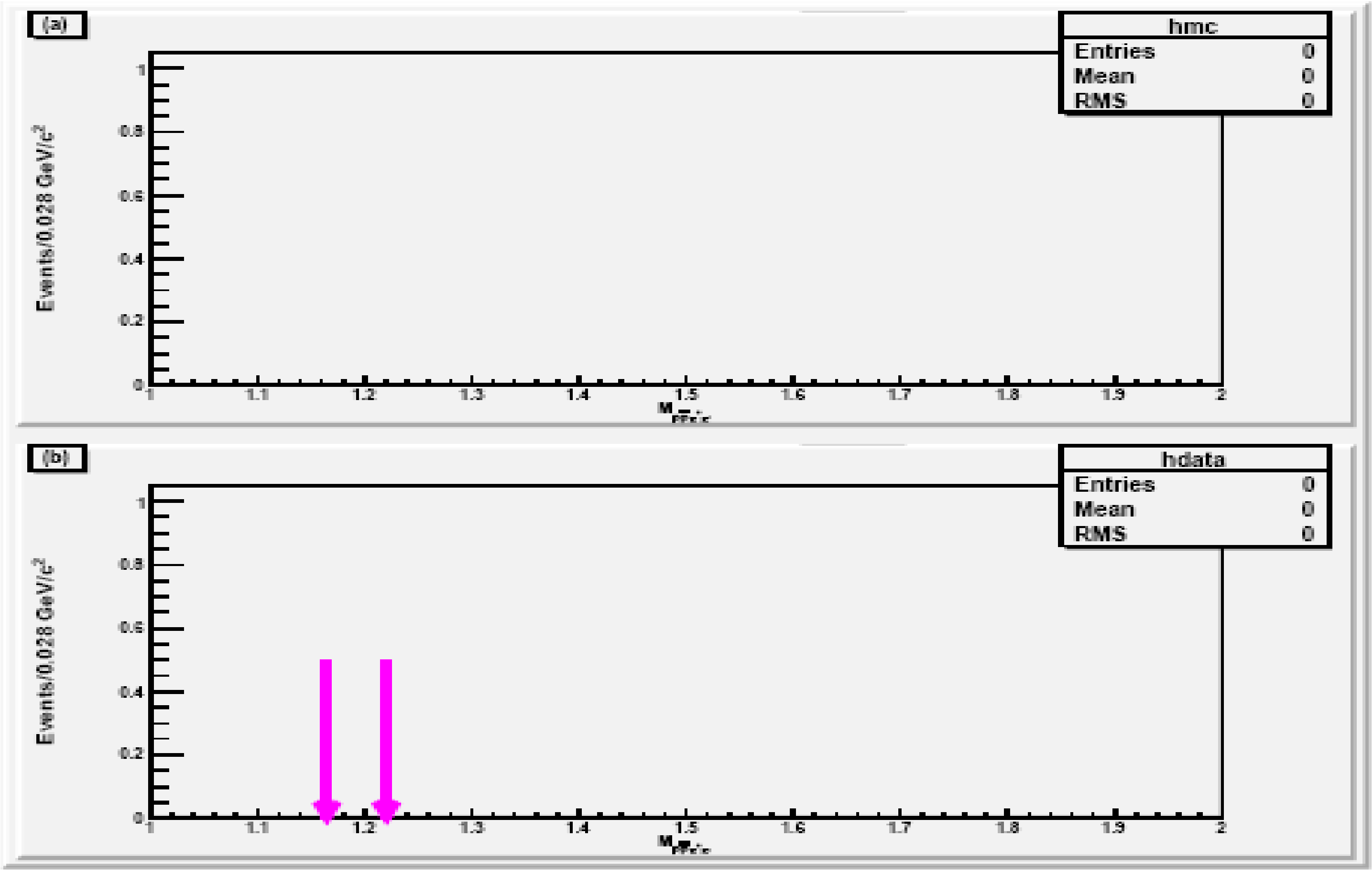
MC and Data invariant mass of $\overline{\Sigma} \to \overline{p}\pi^+\gamma$ after applying cuts



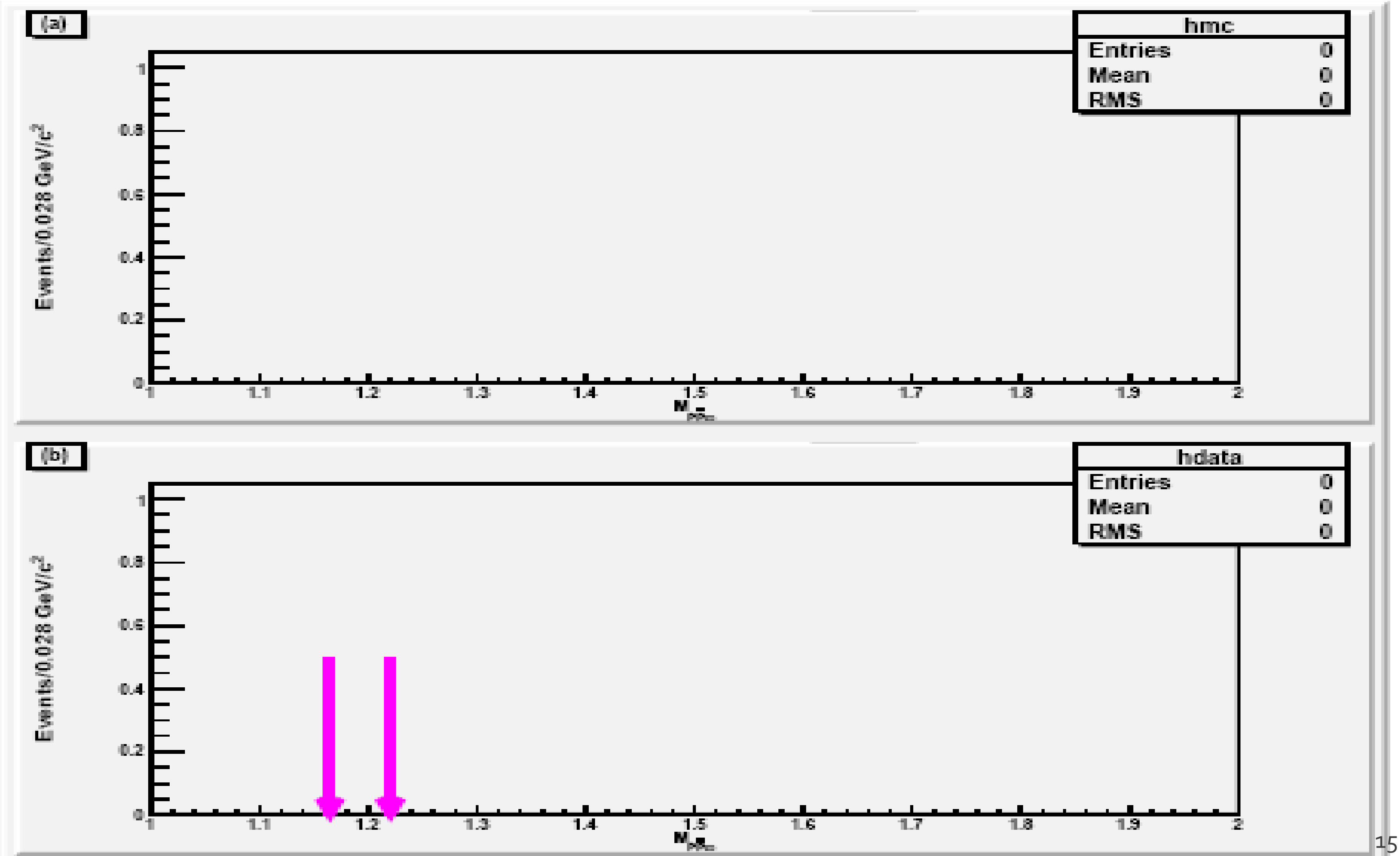
Observed background channels for $J/\psi \to \Lambda\overline{\Sigma}$ using 10^5 MC events

Background channel	Number of events	Normalized events	Branching fraction
$P\overline{P}\pi^+\pi^-$	0	0	$(6.0 \pm 0.5) \times 10^{-3}$
$P\overline{P}\omega$	0	0	$(9.8 \pm 1.0) \times 10^{-4}$
$\Delta^{++}\overline{P}\pi^-$	0	0	$(1.6 \pm 0.5) \times 10^{-3}$
$\Delta^{++}\overline{\Delta}^{--}$	1	0	$(1.10 \pm 0.29) \times 10^{-3}$
$\Lambda\overline{\Lambda}$	4	2	$(1.61 \pm 0.15) \times 10^{-3}$
$P\overline{P}\rho$	1	0	$< 3.1 \times 10^{-4}$ CL = 90
$\Sigma^0\overline{\Sigma}^0$	23	9	116.4×10^{-3}

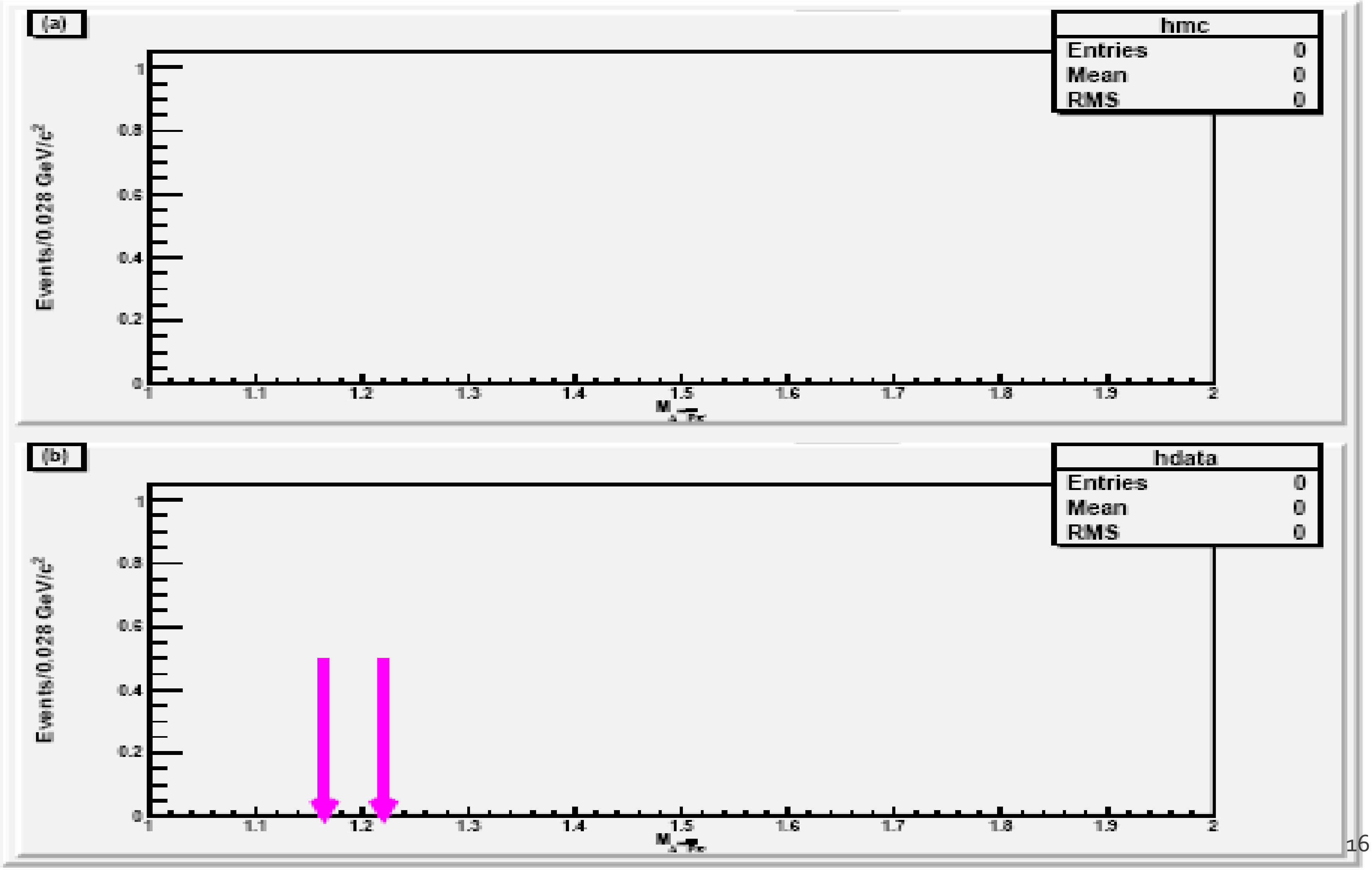
(a) Invariant mass distribution of $M_{P\overline{P}\pi^+\pi^-}$ for $J/\psi \rightarrow \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of $M_{P\overline{P}\pi^+\pi^-}$ for $J/\psi \rightarrow \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^+\gamma} - M_{\overline{\Sigma}}| < 0.0277$.



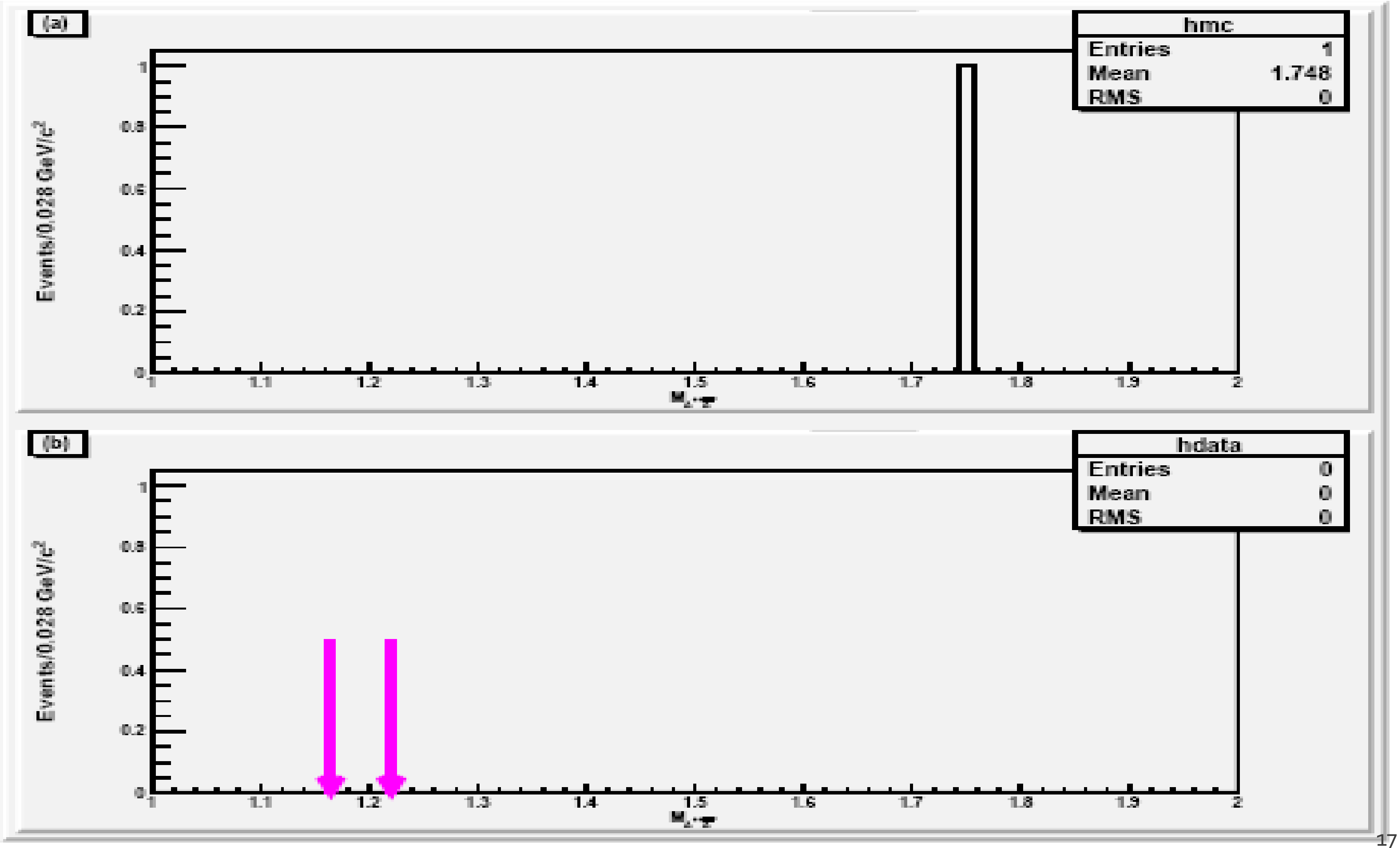
(a) Invariant mass distribution of $M_{p\overline{p}\omega}$ for $J/\psi \to \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of $M_{p\overline{p}\omega}$ for $J/\psi \to \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0277$



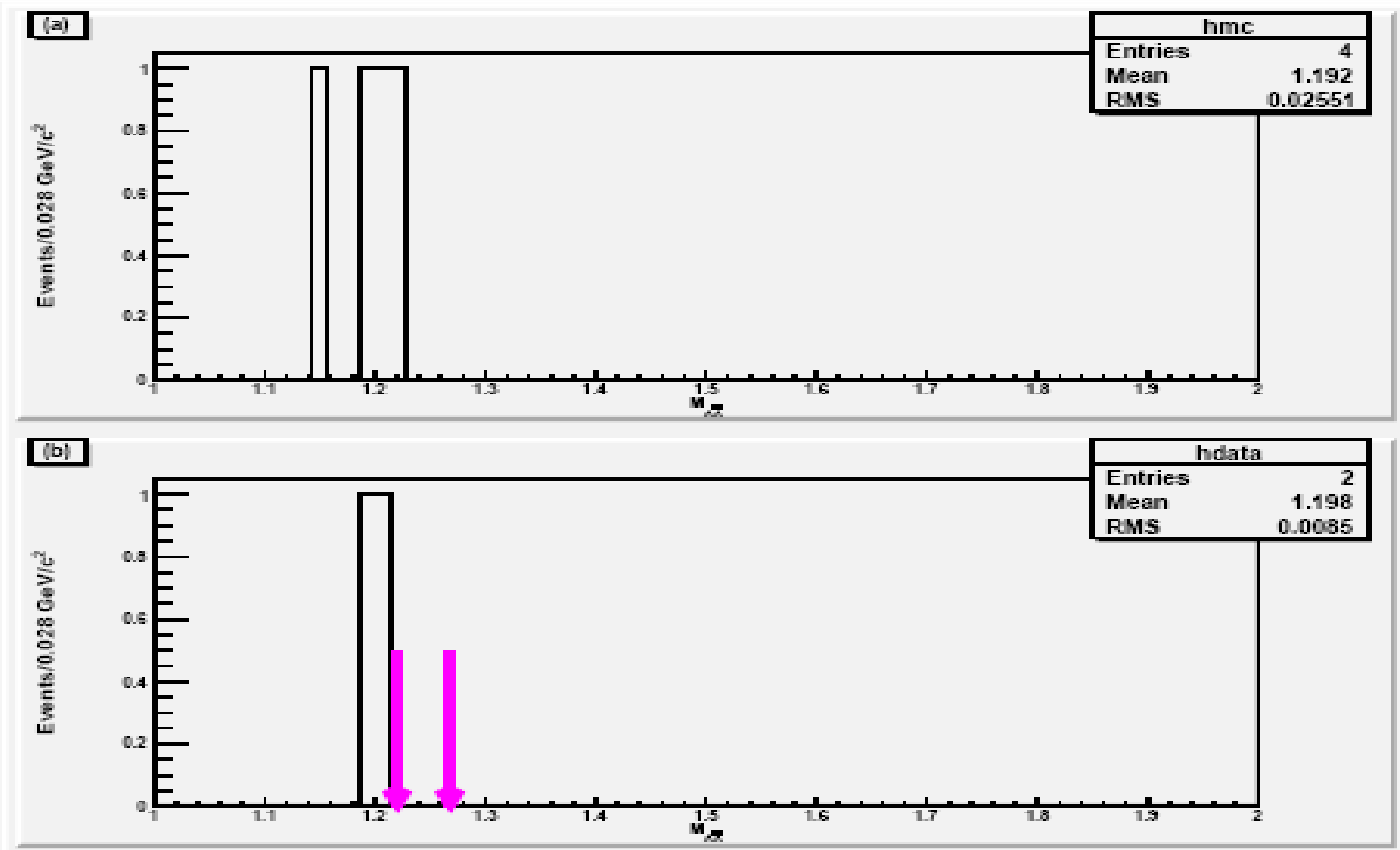
(a) Invariant mass of $M_{\Delta^{++}\overline{p}\pi^{-}}$ for $J/\psi \rightarrow \Lambda\overline{\Sigma}$. (b) Invariant mass of $M_{\Delta^{++}\overline{p}\pi^{-}}$ for $J/\psi \rightarrow \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0277$.



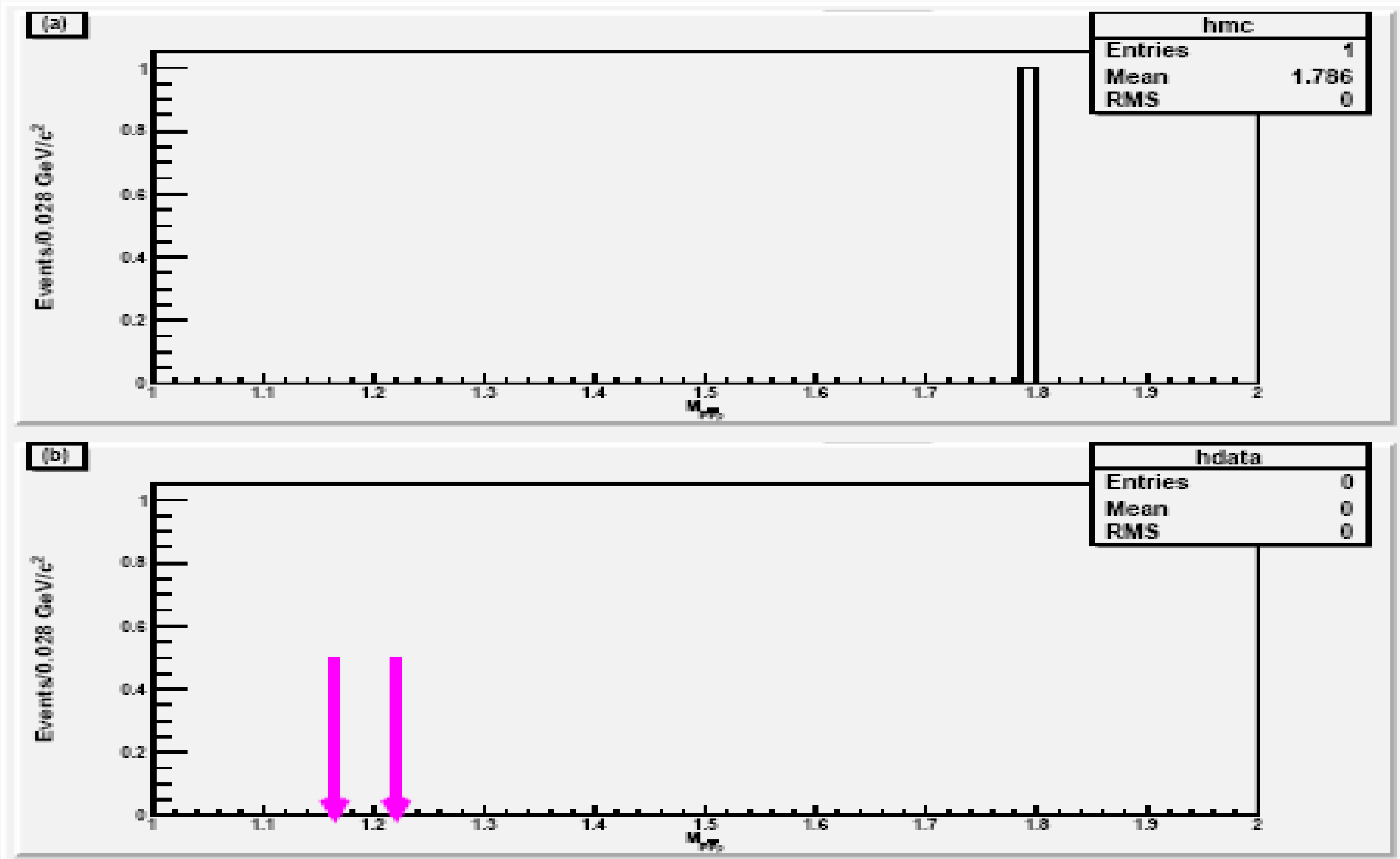
(a) Invariant mass of $M_{\Delta^{++}\overline{\Delta}^{--}}$ for $J/\psi \to \Lambda\overline{\Sigma}$. (b) Invariant mass of $M_{\Delta^{++}\overline{\Delta}^{--}}$ for $J/\psi \to \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0277$.



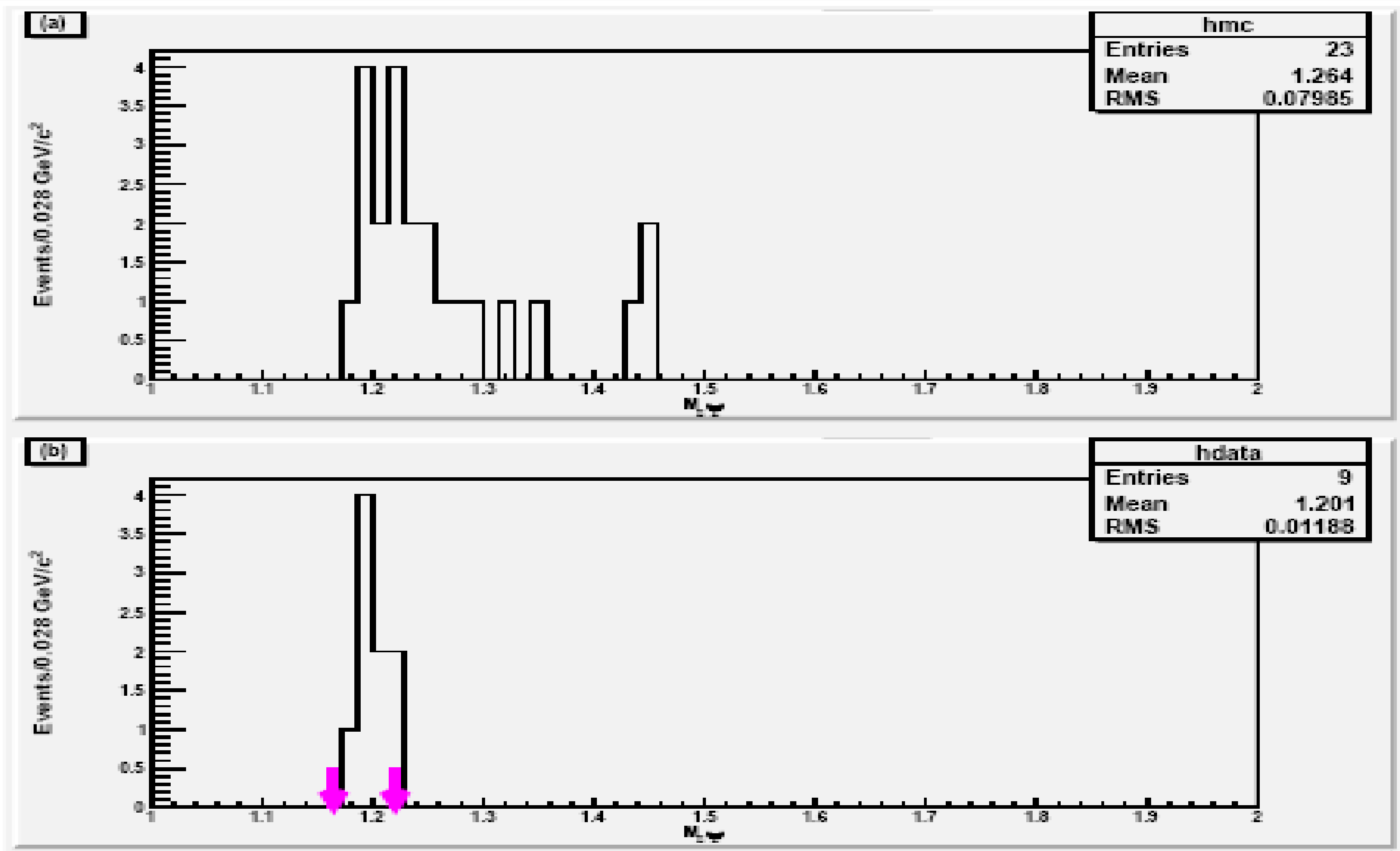
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ for $J/\psi \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ for $J/\psi \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^{+}\gamma} - M_{\bar{\Sigma}}| < 0.0277$.



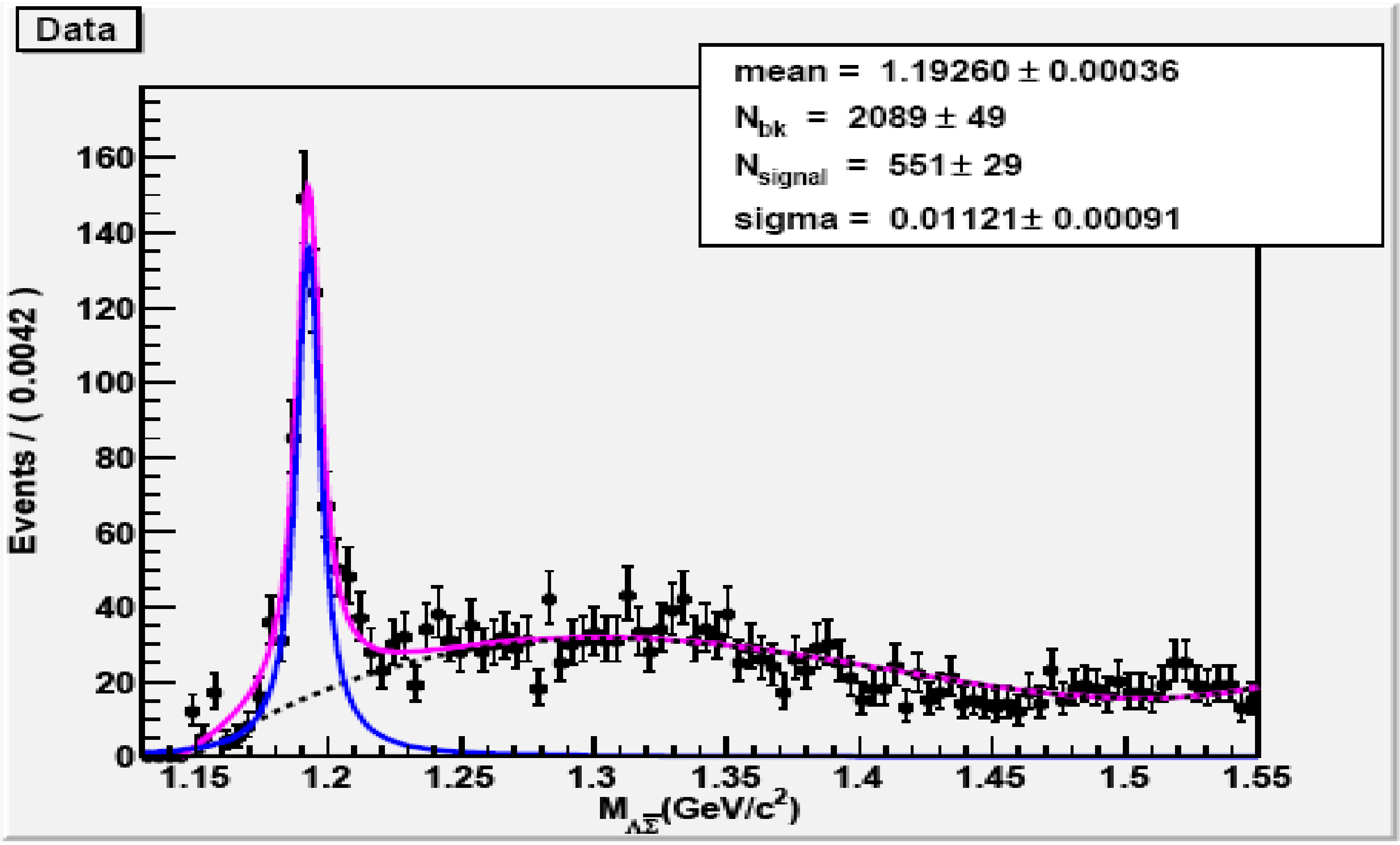
(a) Invariant mass distribution of $M_{p\overline{p}\rho}$ for $J/\psi \to \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of $M_{p\overline{p}\rho}$ for $J/\psi \to \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^+\gamma} - M_{\overline{\Sigma}}| < 0.0277$.



(a) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ for $J/\psi \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{\gamma^0\bar{\gamma}^0}$ for $J/\psi \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0277$.



Fit result of $M(\overline{\Sigma} \to \overline{P}\pi^{+}\gamma)$



Calculated Branching Fraction for $J/\psi \to \Lambda\overline{\Sigma}$

Formula for the calculation of Branching fraction is given bellow

$$B(J/\psi,\psi(2S) \to B\overline{B}) = \frac{N_{obs}}{N_{J/\psi,\psi(2S)} \times \varepsilon \times B_i}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(J/\psi \to \Lambda\overline{\Sigma}) = (1.8 \pm 0.19) \times 10^{-6}$$

Initial Event Selection for $J/\psi \rightarrow \Lambda\overline{\Delta}$

There are 4 charge tracks in $J/\psi \rightarrow \Lambda\overline{\Delta}$ as $\Lambda \rightarrow P\pi^-$ and

$\overline{\Delta} \rightarrow \overline{p}\pi^+$

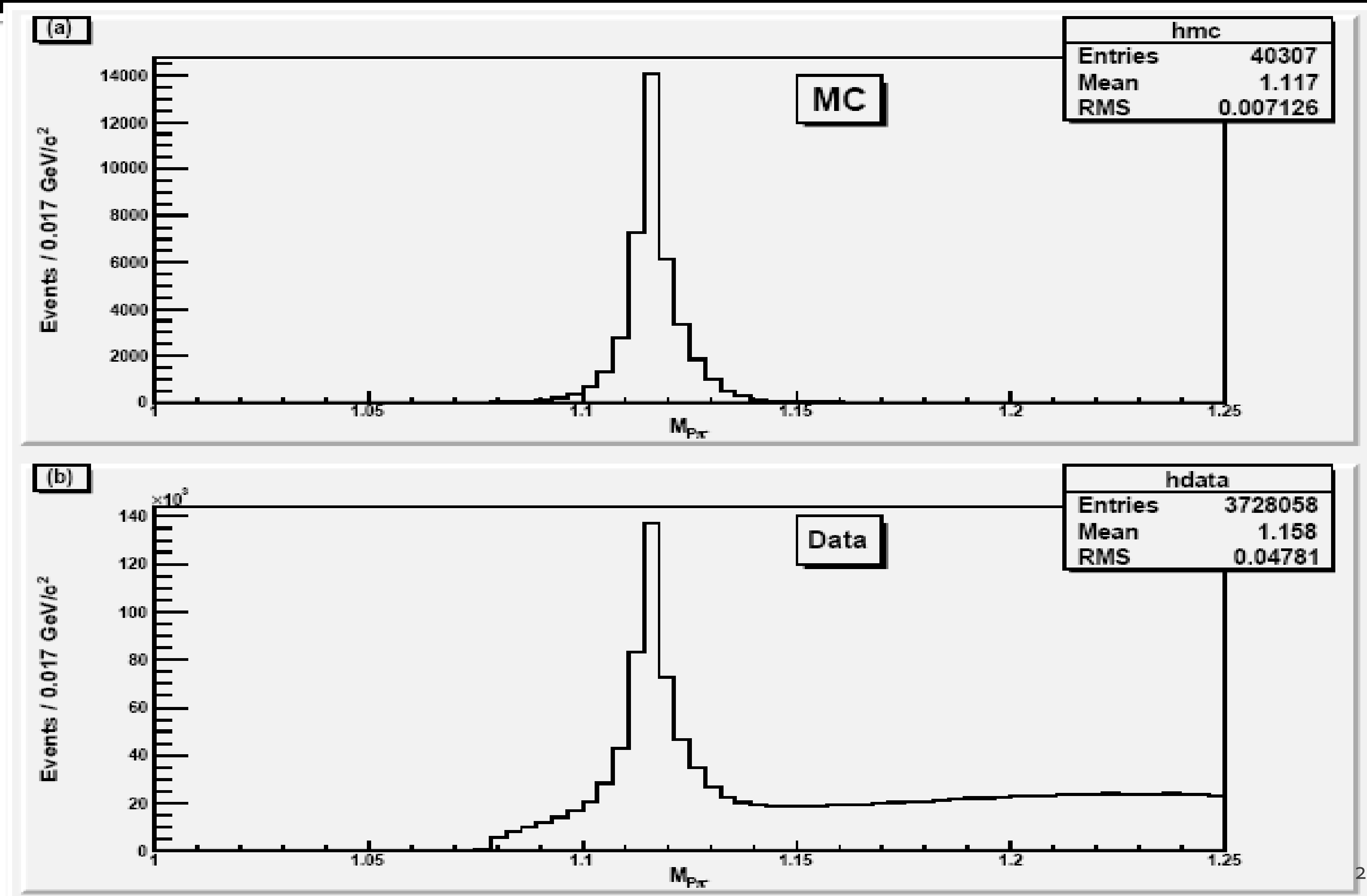
Only those events are selected having

•nGood == 4

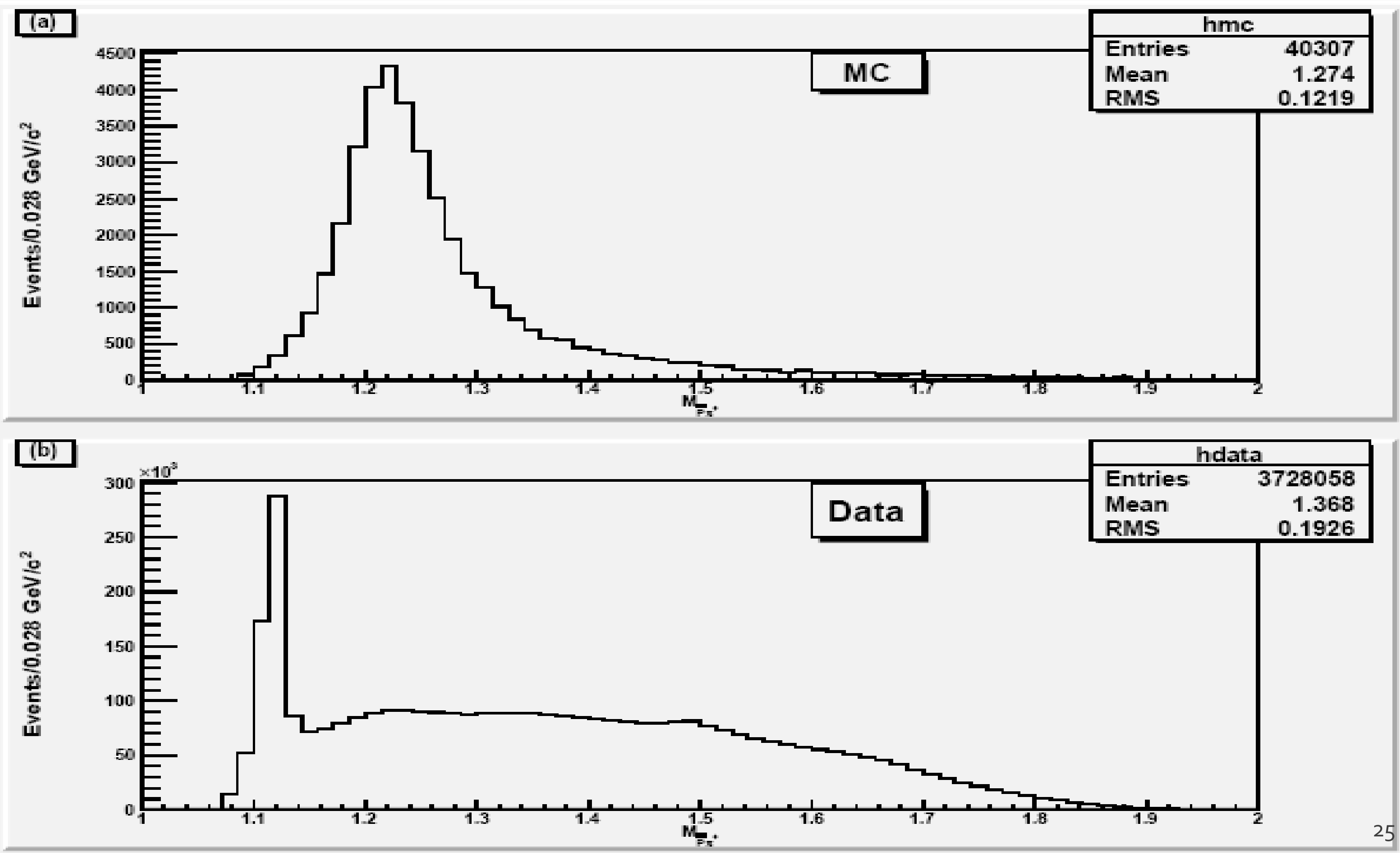
•nCharge == 0

PID is applied to select events having 1 proton 1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to P\pi^-$ using kinematic fit



MC and Data invariant mass of $\overline{\Delta} \to \overline{p}\pi^+$ using Kinematic fit

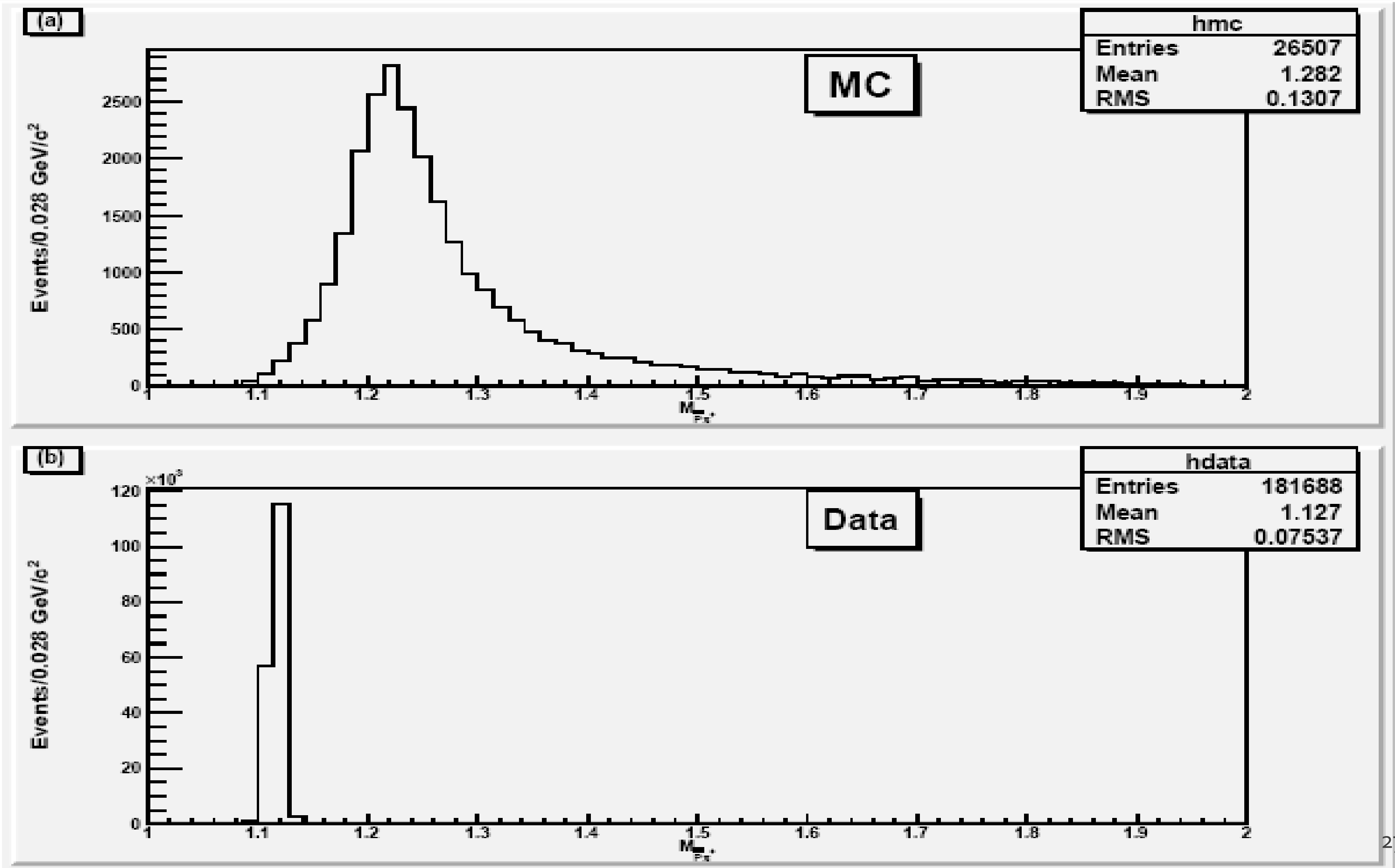


Final Event Selection for $\overline{\Delta} \to \overline{p}\pi^{+}$

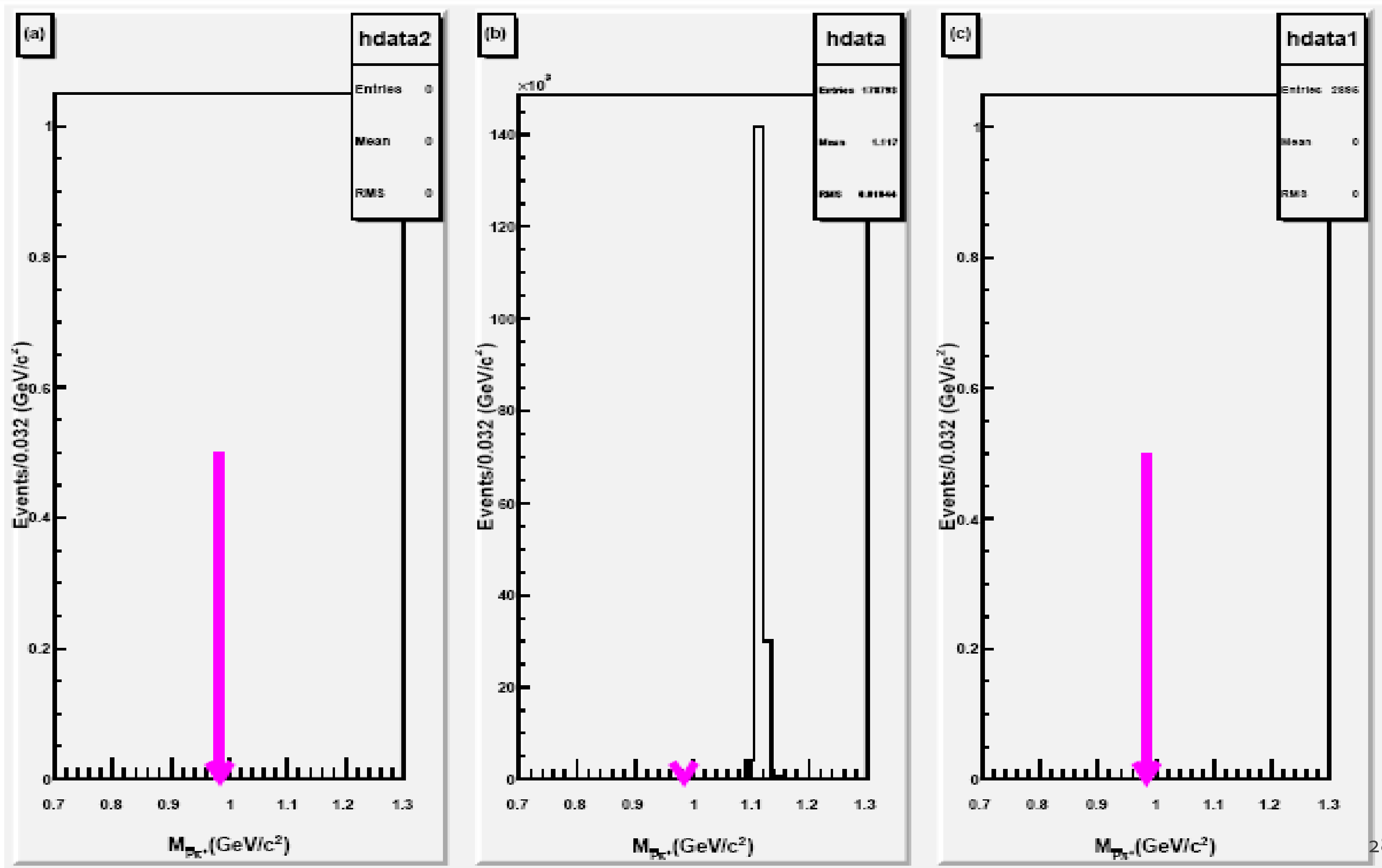
Constraints applied on $J/\psi \to \Lambda\overline{\Delta}$ are

- $\chi^2 < 40$
- $|M_{p\pi^-} - M_{\Lambda}| < 0.005$
- $|M_{p\pi^-\gamma\gamma} - M_{\Xi}| > 0.03532$
- $|M_{p\pi^-\gamma} - M_{\Sigma}| > 0.03117$
- number of $\gamma = 0$
- Decay Length of $\Lambda > 2$
- Rxy < 4

MC and Data invariant mass of $\overline{\Delta} \rightarrow \overline{p}\pi^+$ after applying cuts



Sideband Analysis for $\overline{\Delta} \rightarrow \overline{p}\pi^{+}$



Upper Limit using Poisson Distribution

0 1 2 3 4

$\hat{\theta}$

An important case: $n_{obs} = 0$

$$\beta = \sum_{n=0}^{0} \frac{b^n e^{-b}}{n!} = e^{-b} \quad \rightarrow \quad b = -\log \beta$$

Calculate an upper limit at confidence level (1-β) = 95%

$$b = -\log(0.05) = 2.996 \approx 3$$

Useful table:

n_{obs}	lower limit a			upper limit b		
	$\alpha = 0.1$	$\alpha = 0.05$	$\alpha = 0.01$	$\beta = 0.1$	$\beta = 0.05$	$\beta = 0.01$
0	–	–	–	2.30	3.00	4.61
1	0.105	0.051	0.010	3.89	4.74	6.64
2	0.532	0.355	0.149	5.32	6.30	8.41
3	1.10	0.818	0.436	6.68	7.75	10.04
4	1.74	1.37	0.823	7.99	9.15	11.60
5	2.43	1.97	1.28	9.27	10.51	13.11

Calculated Upper Limit at 95% Confidence Level for $\overline{\Delta} \to \overline{p}\pi^+$

Formula for the calculation of upper limit is given bellow

$$B(J/\psi, \psi(2S) \to B\overline{B}) < \frac{N_{obs}}{N_{J/\psi,\psi(2S)} \times \varepsilon \times B_i(1-\sigma_{sys})}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(J/\psi \to \Lambda\overline{\Delta}) < 1.1 \times 10^{-8}$$

Initial Event Selection for $J/\psi \to \Lambda\overline{\Xi}$

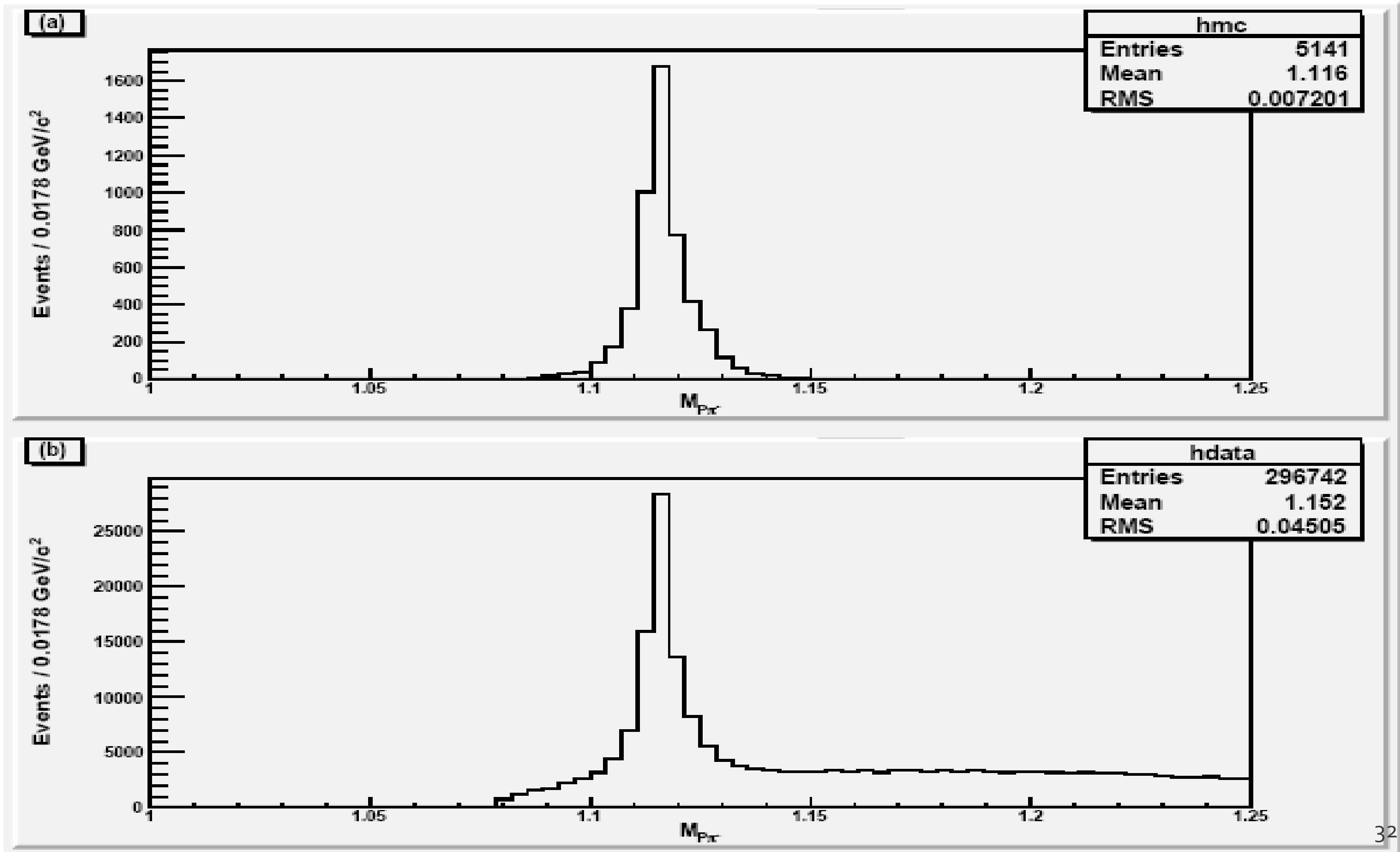
There are 4 charge tracks in $J/\psi \to \Lambda\overline{\Xi}$ as $\Lambda \to P\pi^-$ and $\overline{\Xi} \to \overline{p}\pi^+\gamma\gamma$

Only those events are selected having

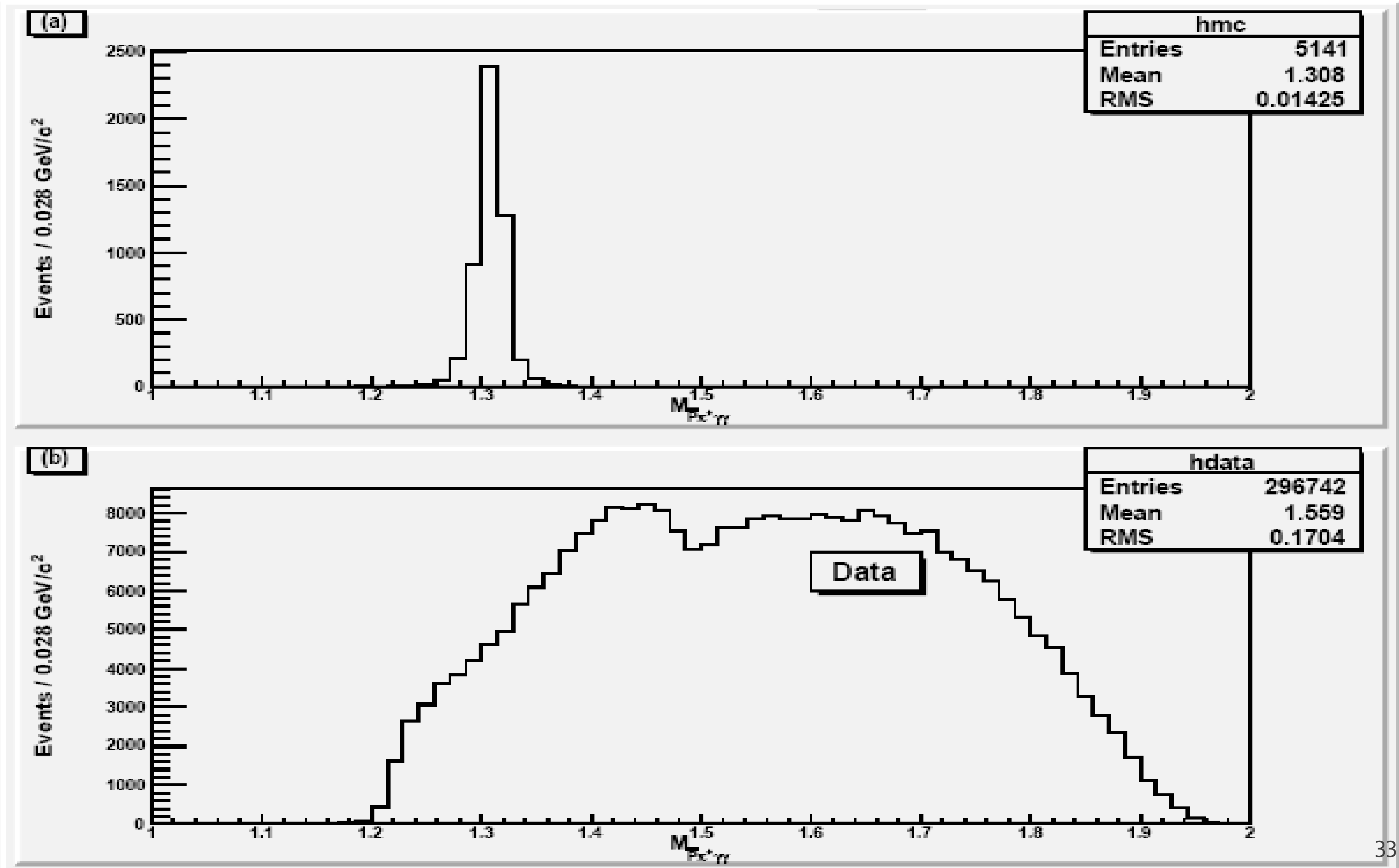
- nGood == 4
- number of ɣ == 2
- nCharge == 0

PID is applied to select events having 1 proton 1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to p\pi^-$ using kinematic fit for $J/\psi \to \Lambda\overline{\Xi}$



MC and Data invariant mass of $\overline{\Xi} \rightarrow \overline{p}\pi^{+}\gamma\gamma$ using kinematic fit for $J/\psi \rightarrow \Lambda\overline{\Xi}$

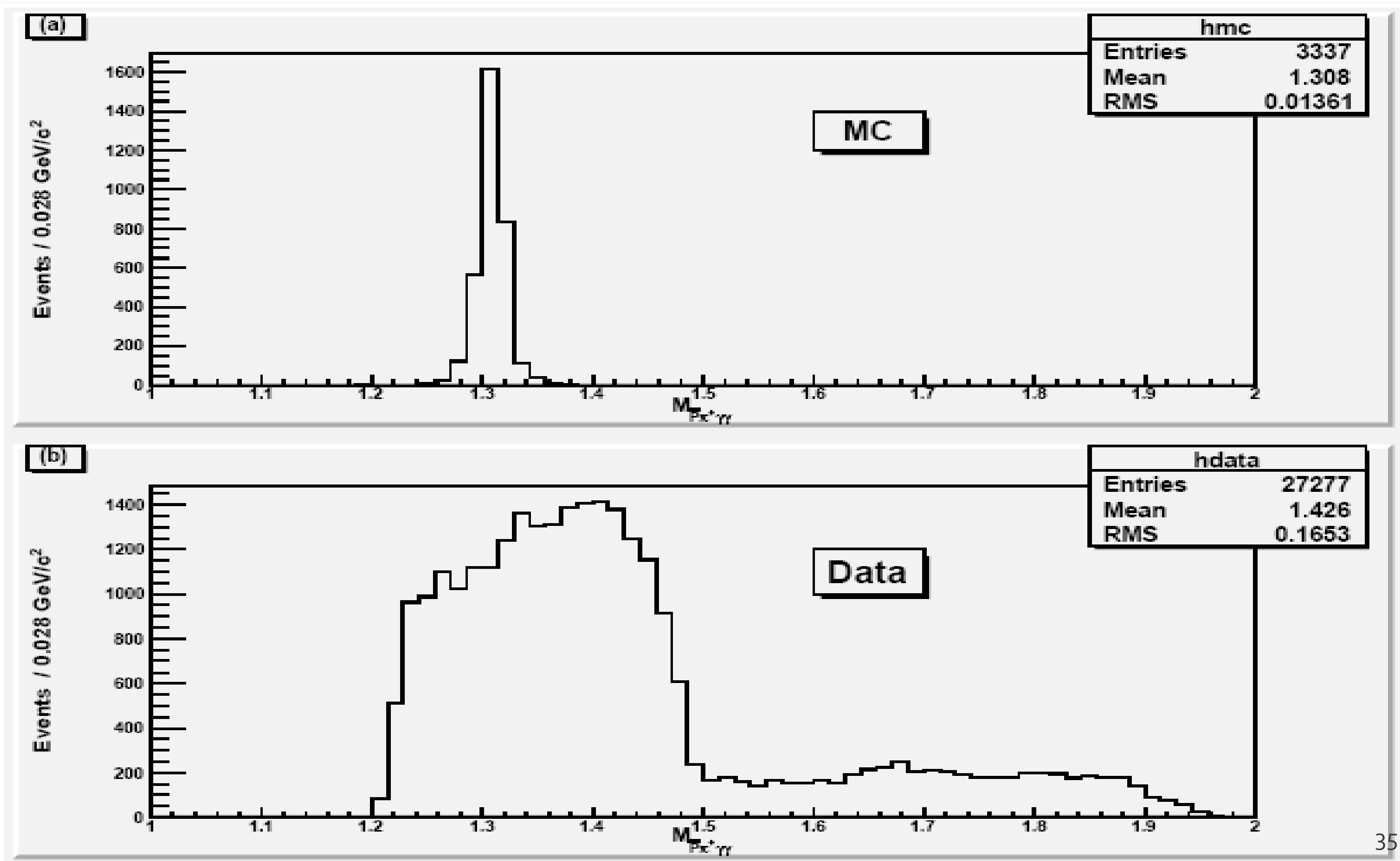


Background Analysis for $J/\psi \to \Lambda\overline{\Xi}$

Constraints applied on $J/\psi \to \Lambda\overline{\Xi}$ are

- $\chi^2 < 40$
- $|M_{p\pi^-} - M_\Lambda| < 0.005$
- $|M_{p\pi^-\gamma\gamma} - M_\Lambda| > 0.005$
- $|M_{p\pi^-\gamma} - M_\Sigma| > 0.006$
- $|M_{p\pi^-} - M_\Delta| > 0.008$
- number of $\gamma = 2$
- Decay Length of $\Lambda > 4$
- Rxy < 4

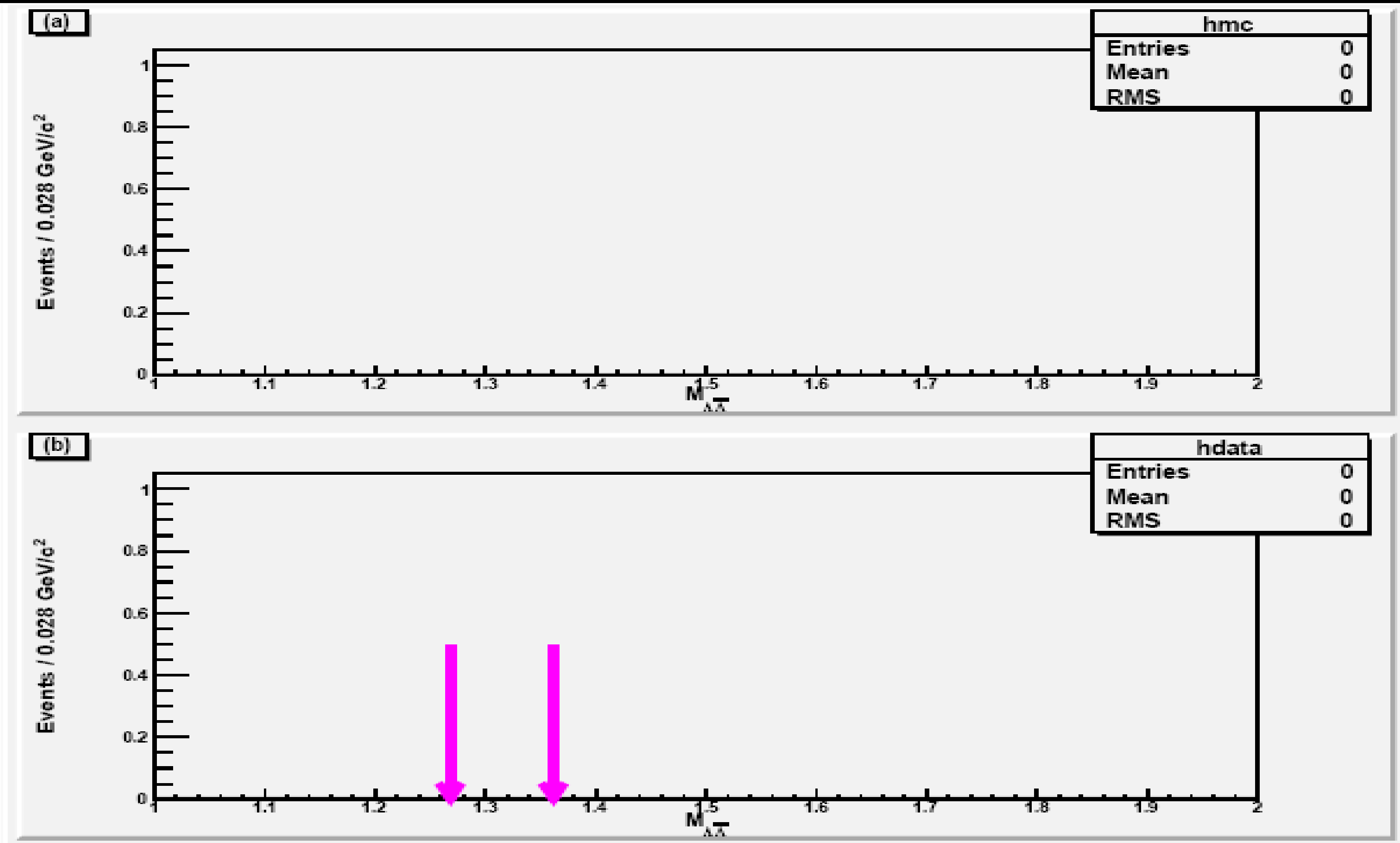
MC and Data invariant mass of $\overline{\Xi} \rightarrow \overline{p}\pi^{+}\gamma\gamma$ after applying cuts



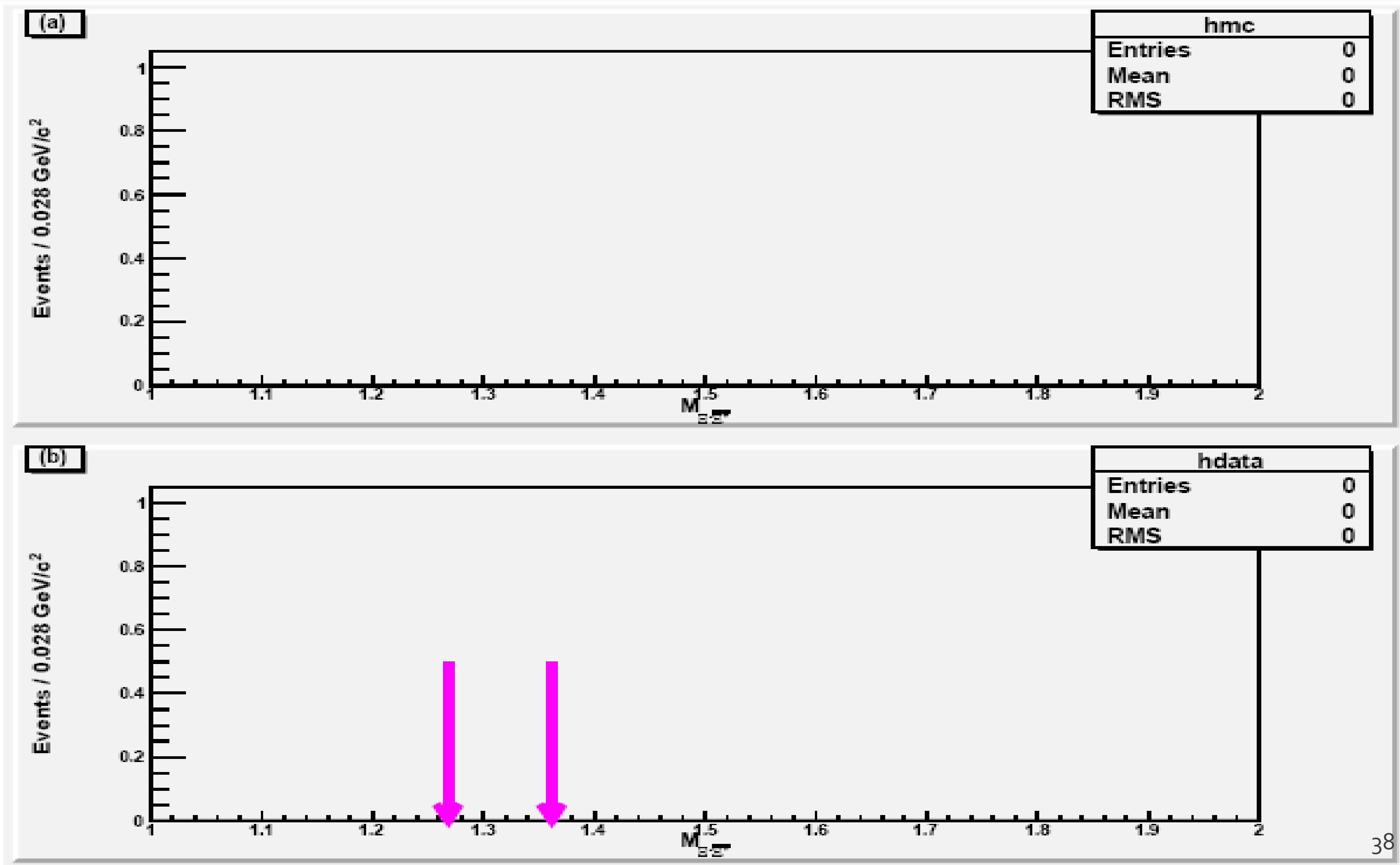
Observed background channels for $J/\psi \to \Lambda\Xi$ using 10^5 MC events

Background Channal	Number of events	Normalized events	Branching fraction
$\Lambda\overline{\Lambda}$	0	0	$(1.61 \pm 0.15) \times 10^{-3}$
$\Xi^-\overline{\Xi}^+$	0	0	$(8.6 \pm 1.1) \times 10^{-4}$
$\Lambda\overline{\Lambda}\eta$	1	0	$(1.62 \pm 0.17) \times 10^{-4}$
$\Lambda\overline{\Lambda}\pi^0$	1603	170	$(3.8 \pm 0.4) \times 10^{-5}$
$P\overline{P}\eta$	1	0	$(2.00 \pm 0.12) \times 10^{-3}$
$P\overline{P}\acute{\eta}$	0	0	$(2.1 \pm 0.4) \times 10^{-4}$
$P\overline{P}\omega$	0	0	$(9.8 \pm 1.0) \times 10^{-4}$
$P\overline{P}\phi$	1	0	$(4.5 \pm 1.5) \times 10^{-5}$
$P\overline{P}\pi^+\pi^-$	0	0	$(6.0 \pm 0.5) \times 10^{-3}$
$P\overline{P}\pi^+\pi^-\pi^0$	10	0	$(2.3 \pm 0.9) \times 10^{-3}$
$P\overline{P}\rho$	0	0	$< 3.1 \times 10^{-4}$ CL 90
$\Sigma^0\overline{\Sigma}^0$	3252	1213	$(1.29 \pm 0.09) \times 10^{-3}$
$\Sigma^+\overline{\Sigma}^-$	0	0	$(1.50 \pm 0.24) \times 10^{-3}$

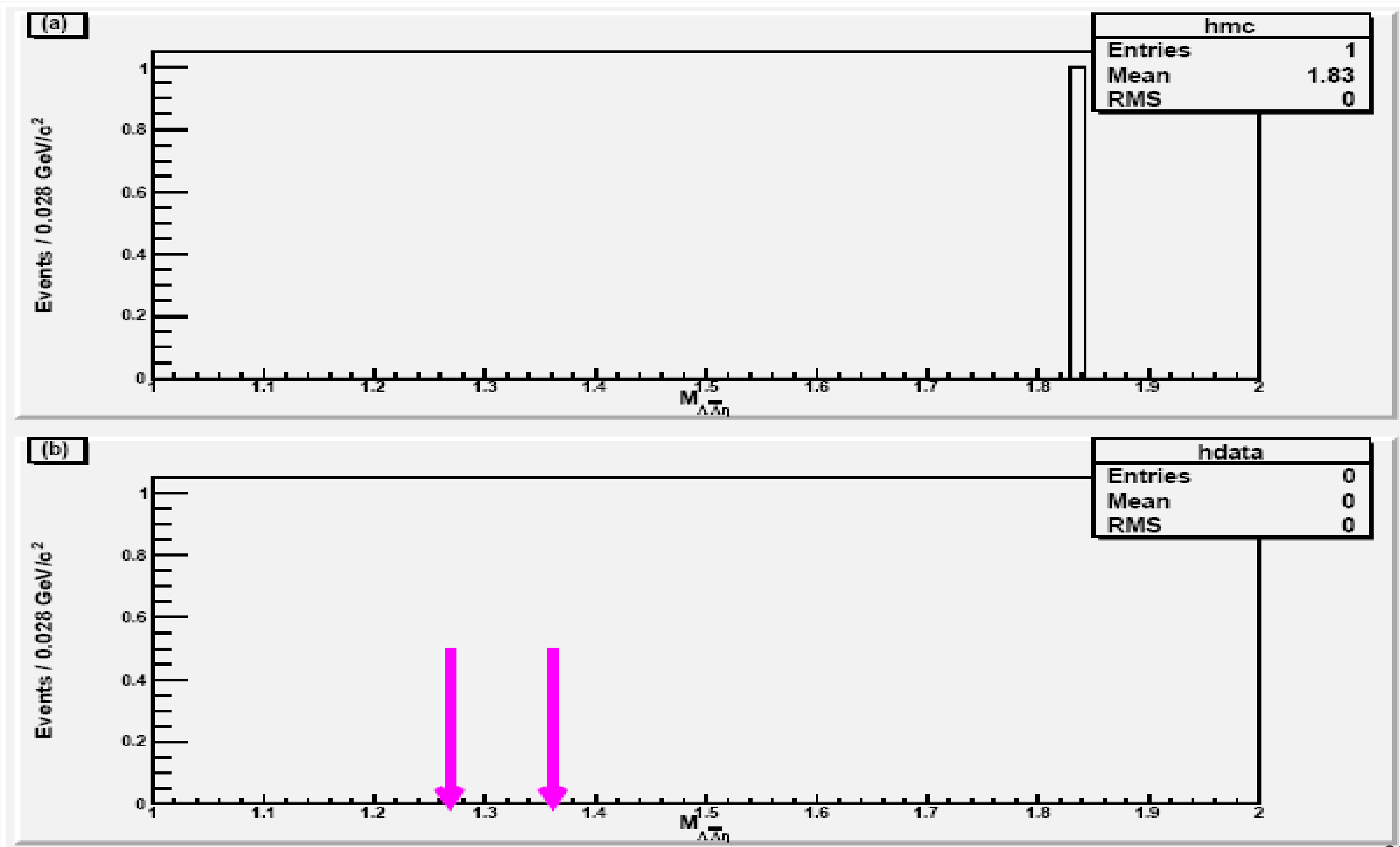
(a) Invariant mass distribution of $M_{\Lambda\overline{\Lambda}}$ for $J/\psi \rightarrow \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\overline{\Lambda}}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $\overline{J}/\psi \rightarrow \Lambda\Xi$



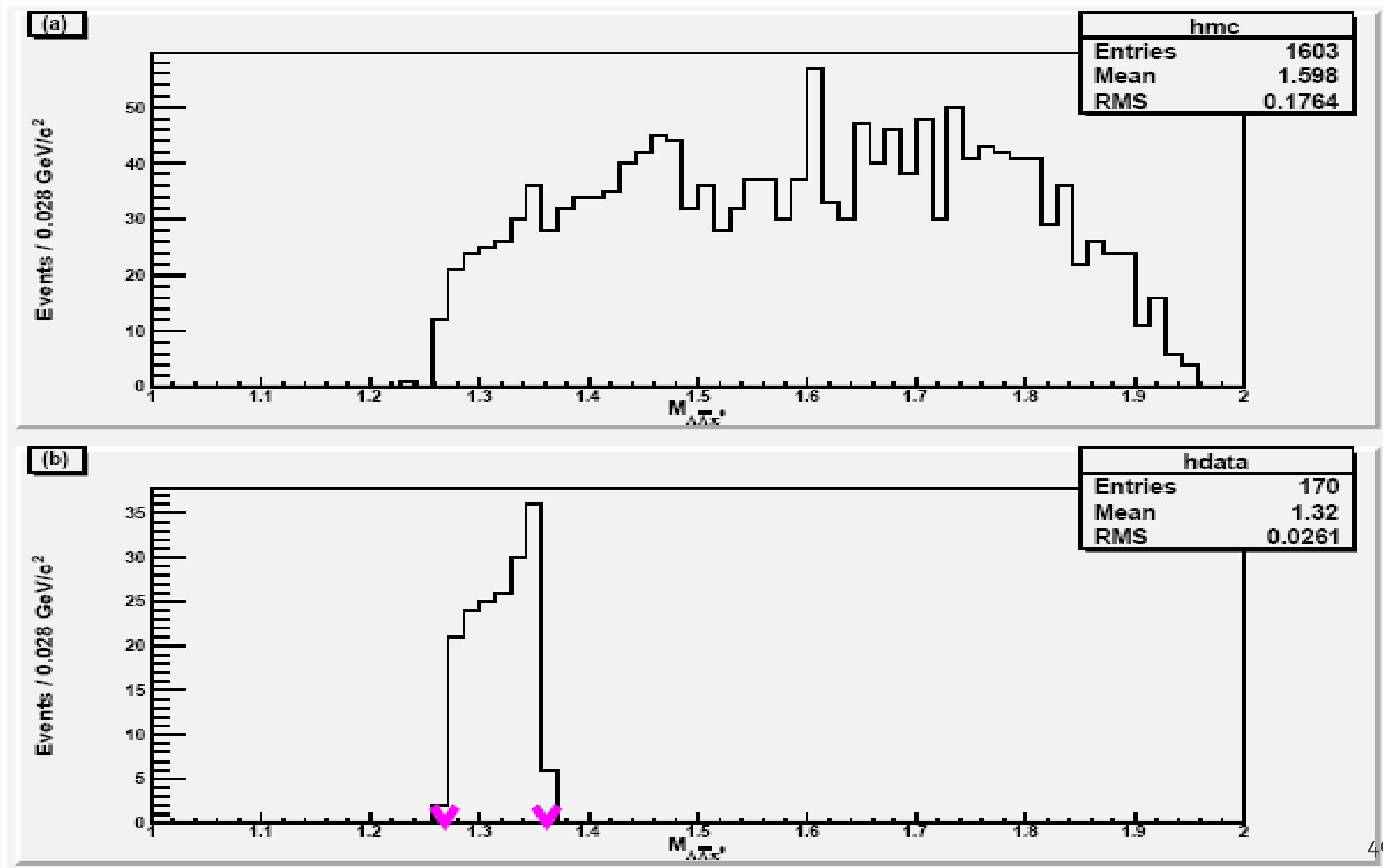
(a) Invariant mass distribution of $M_{\Xi^-\overline{\Xi}^+}$ for $J/\psi \rightarrow \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{\Xi^-\overline{\Xi}^+}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \rightarrow \Lambda\overline{\Xi}$



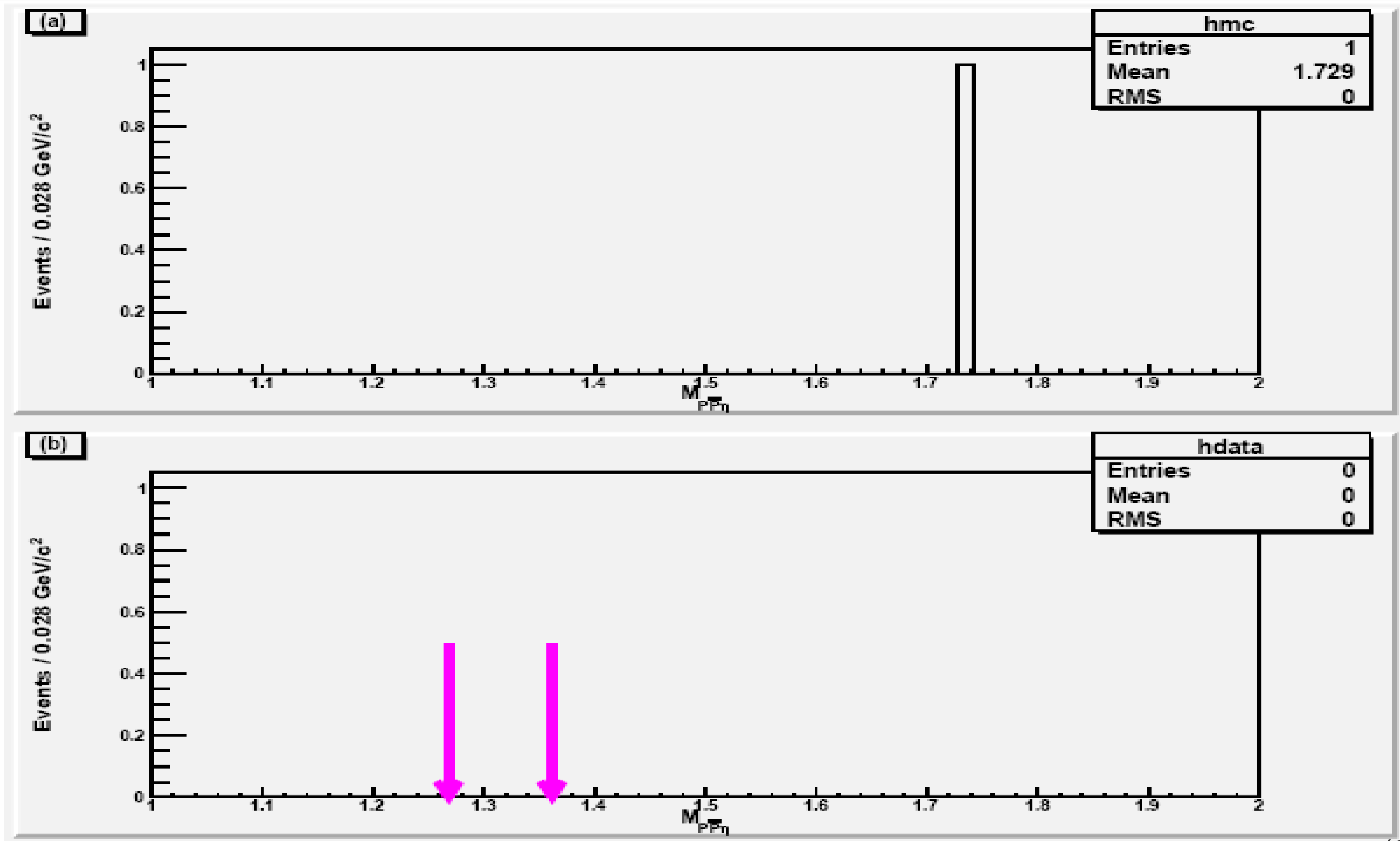
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\bar{\Xi}$



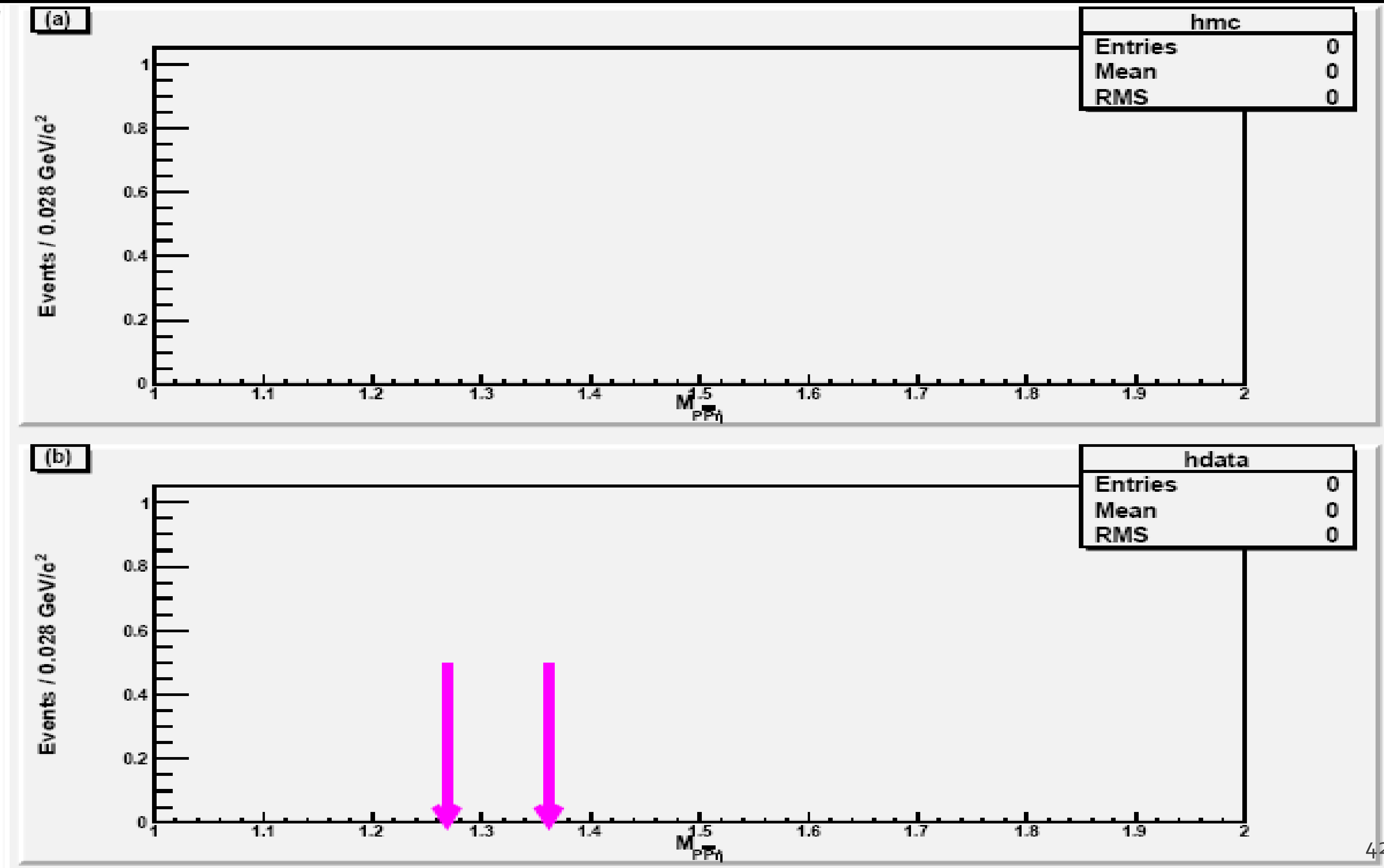
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\pi^0}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\pi^0}$ with mass window cut $|M_{p\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



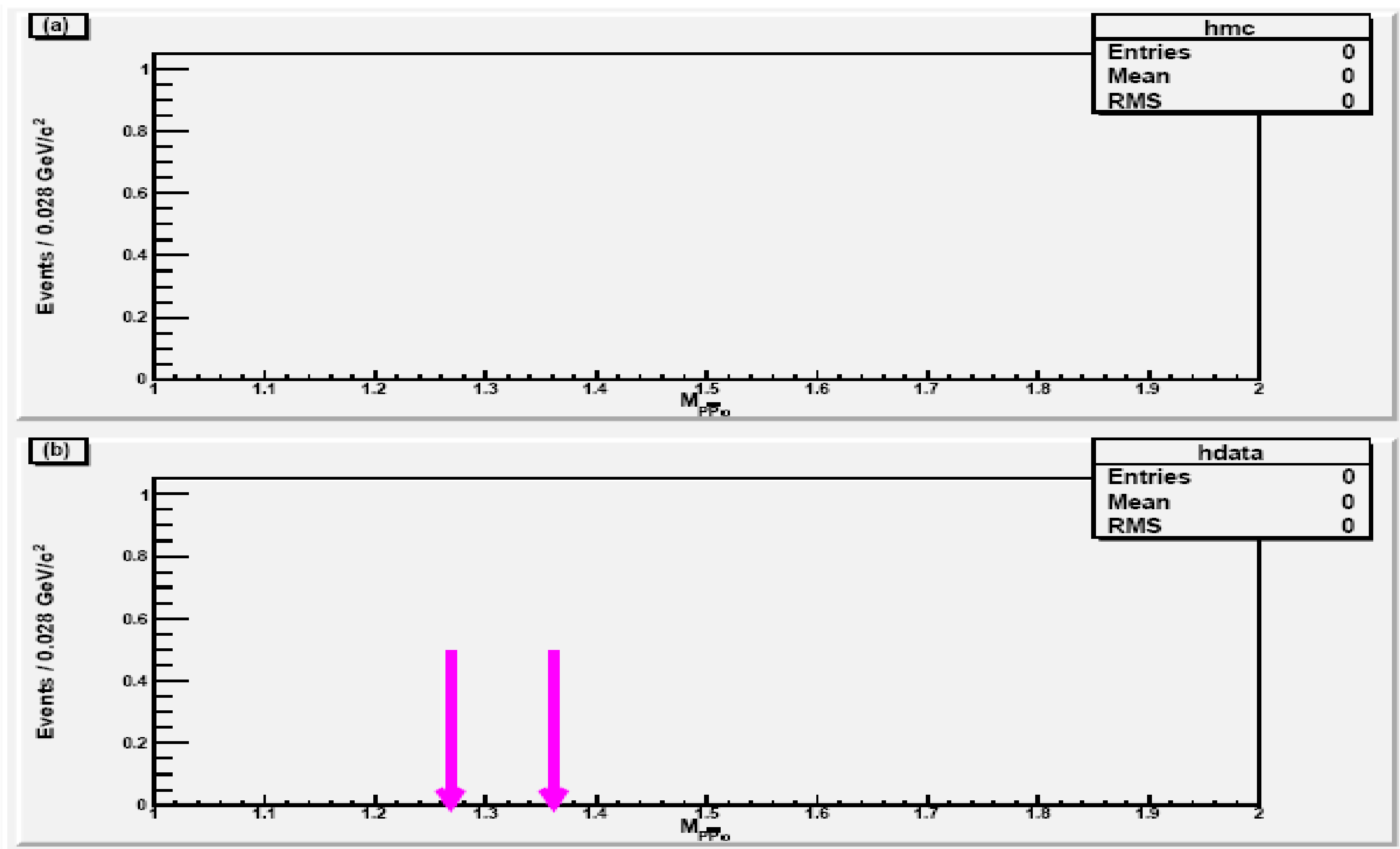
(a) Invariant mass distribution of $M_{p\bar{p}\eta}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\eta}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



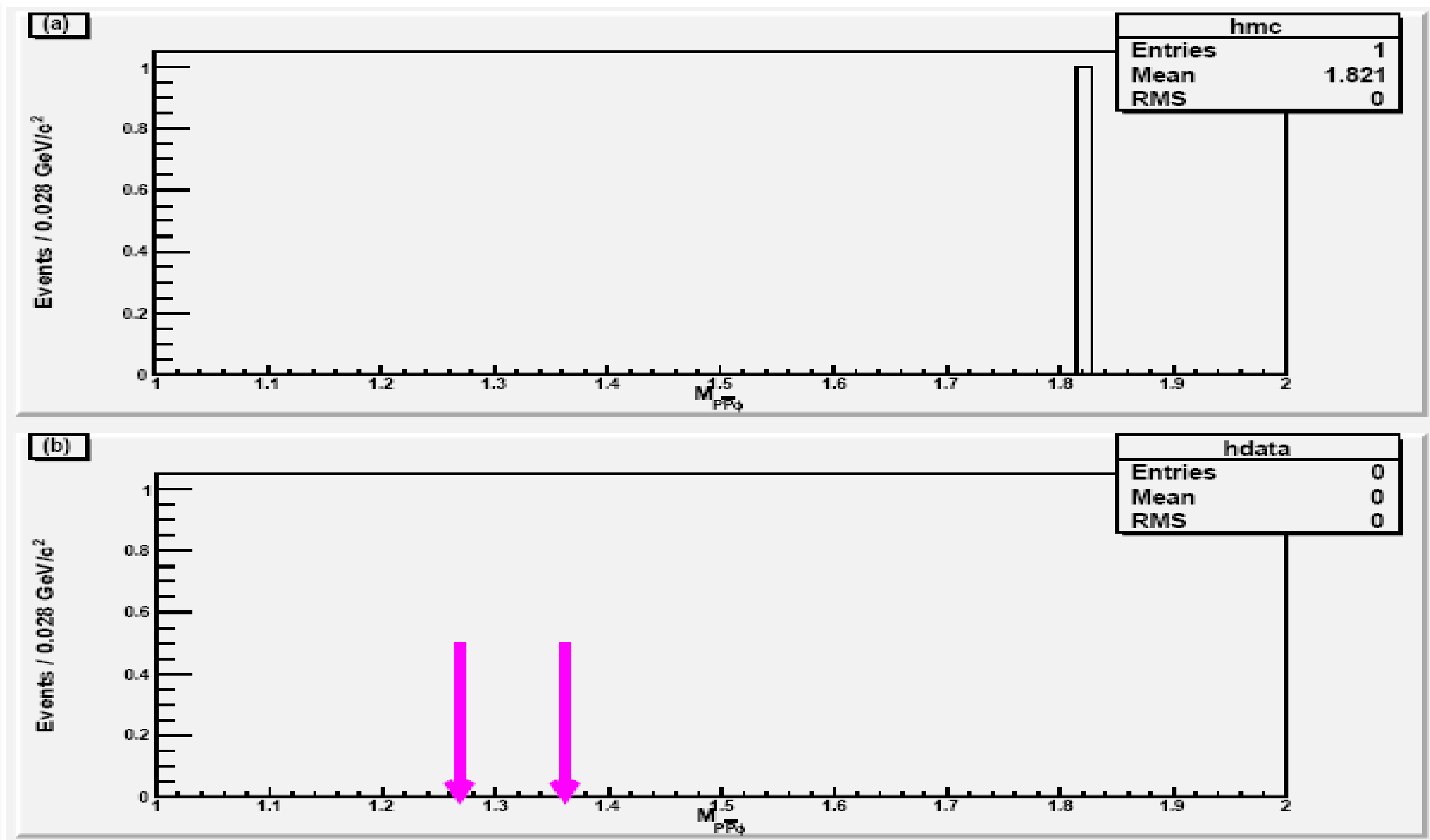
(a) Invariant mass distribution of $M_{p\overline{p}\acute{\eta}}$ for $J/\psi \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{p\overline{p}\acute{\eta}}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\overline{\Xi}$



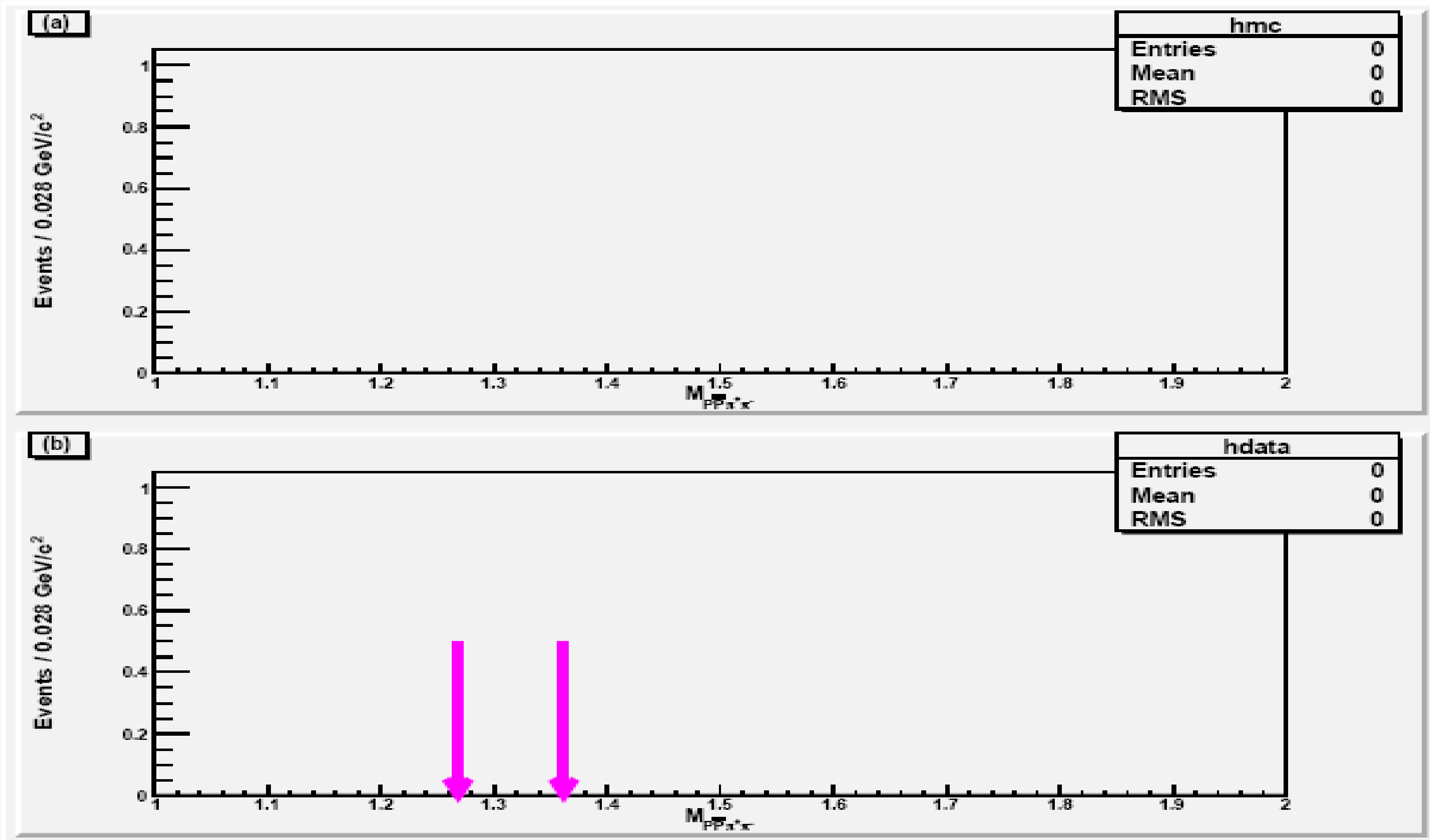
(a) Invariant mass distribution of $M_{p\bar{p}\omega}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\omega}$ with mass window cut $|M_{\bar{p}\pi^{+}\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



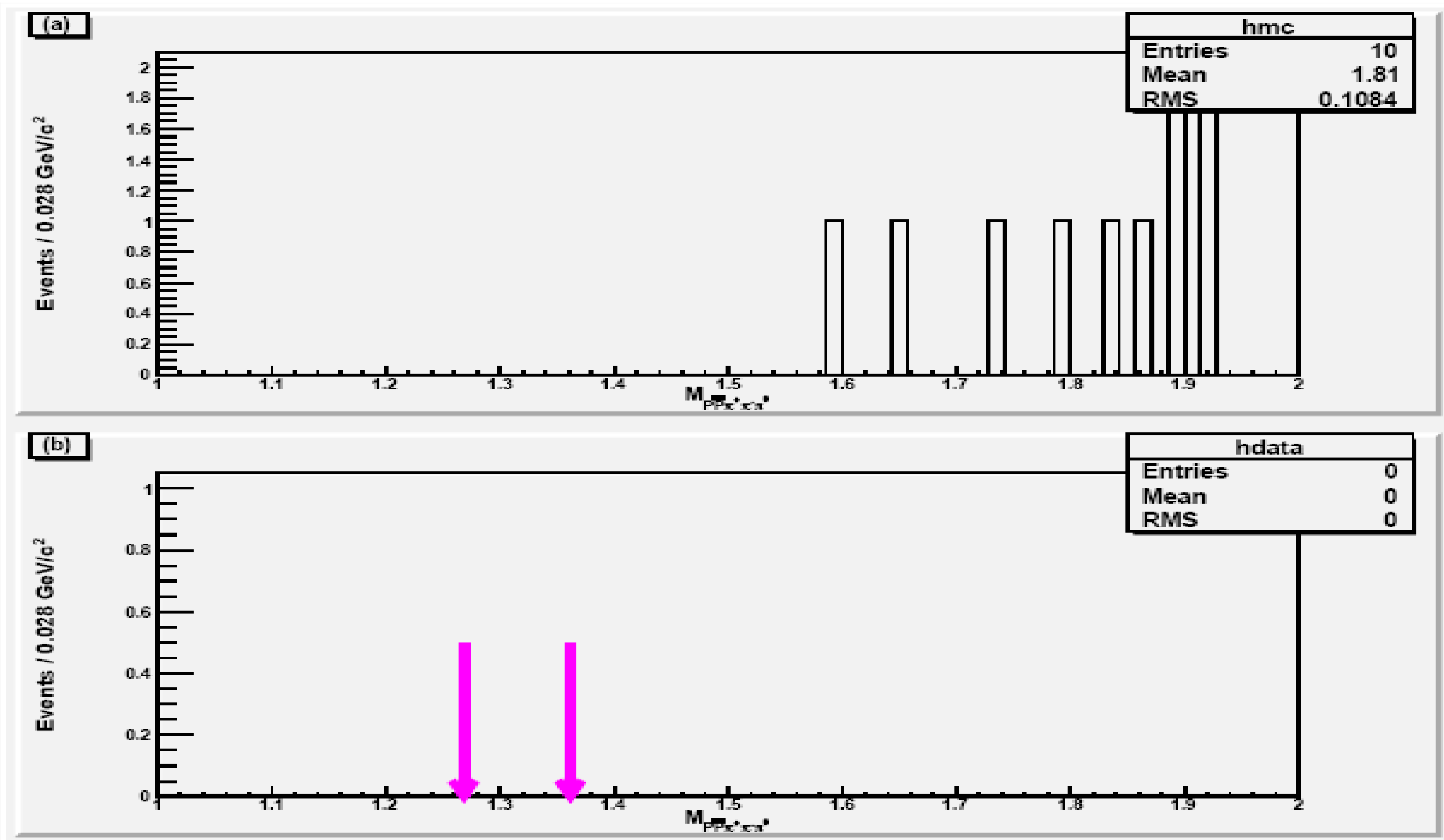
Invariant mass distribution of $M_{p\overline{p}_\phi}$ for $J/\psi \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{p\overline{p}_\phi}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\overline{\Xi}$



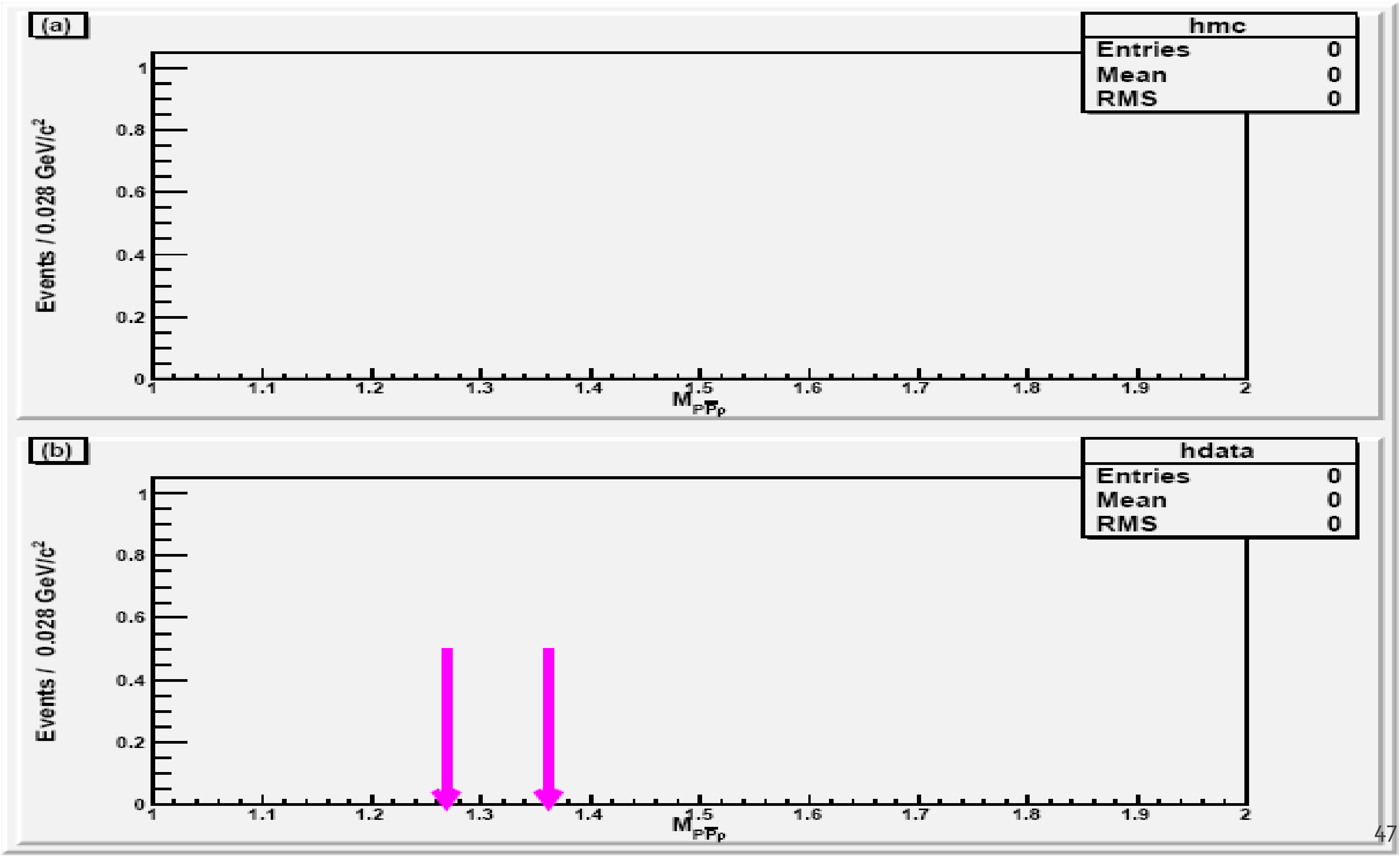
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



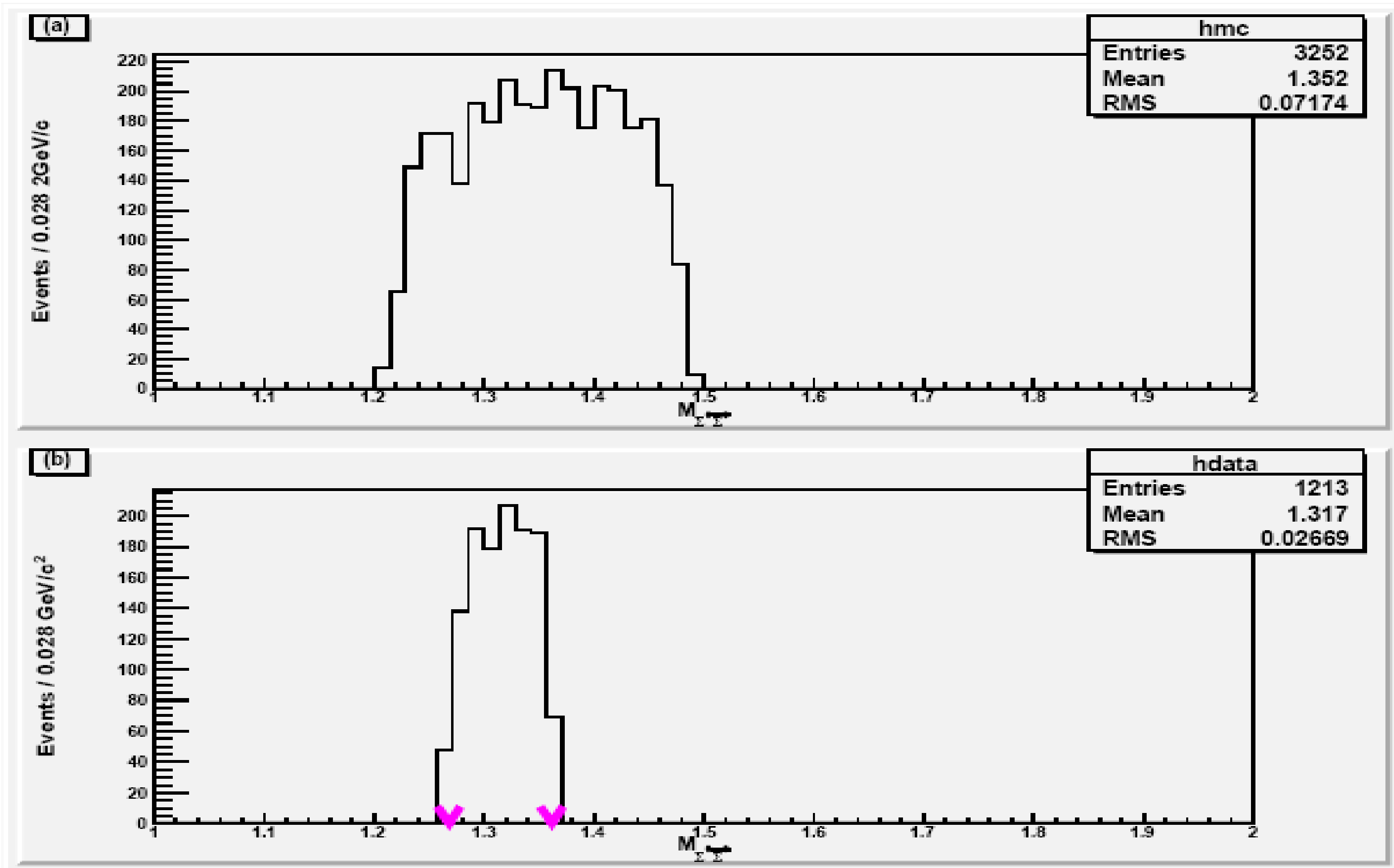
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



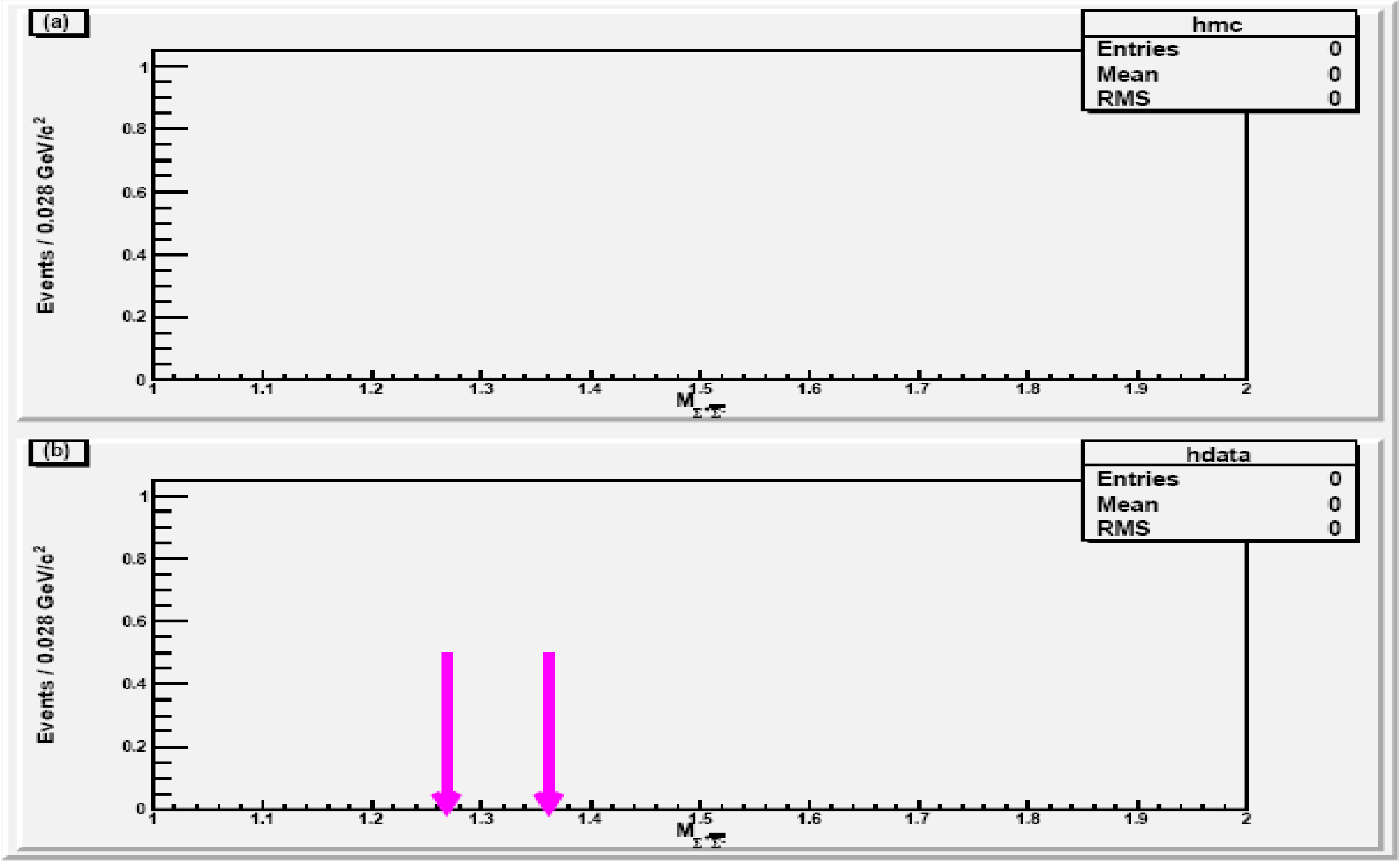
(a) Invariant mass distribution of $M_{p\bar{p}_\rho}$ for $J/\psi \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}_\rho}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\overline{\Xi}$



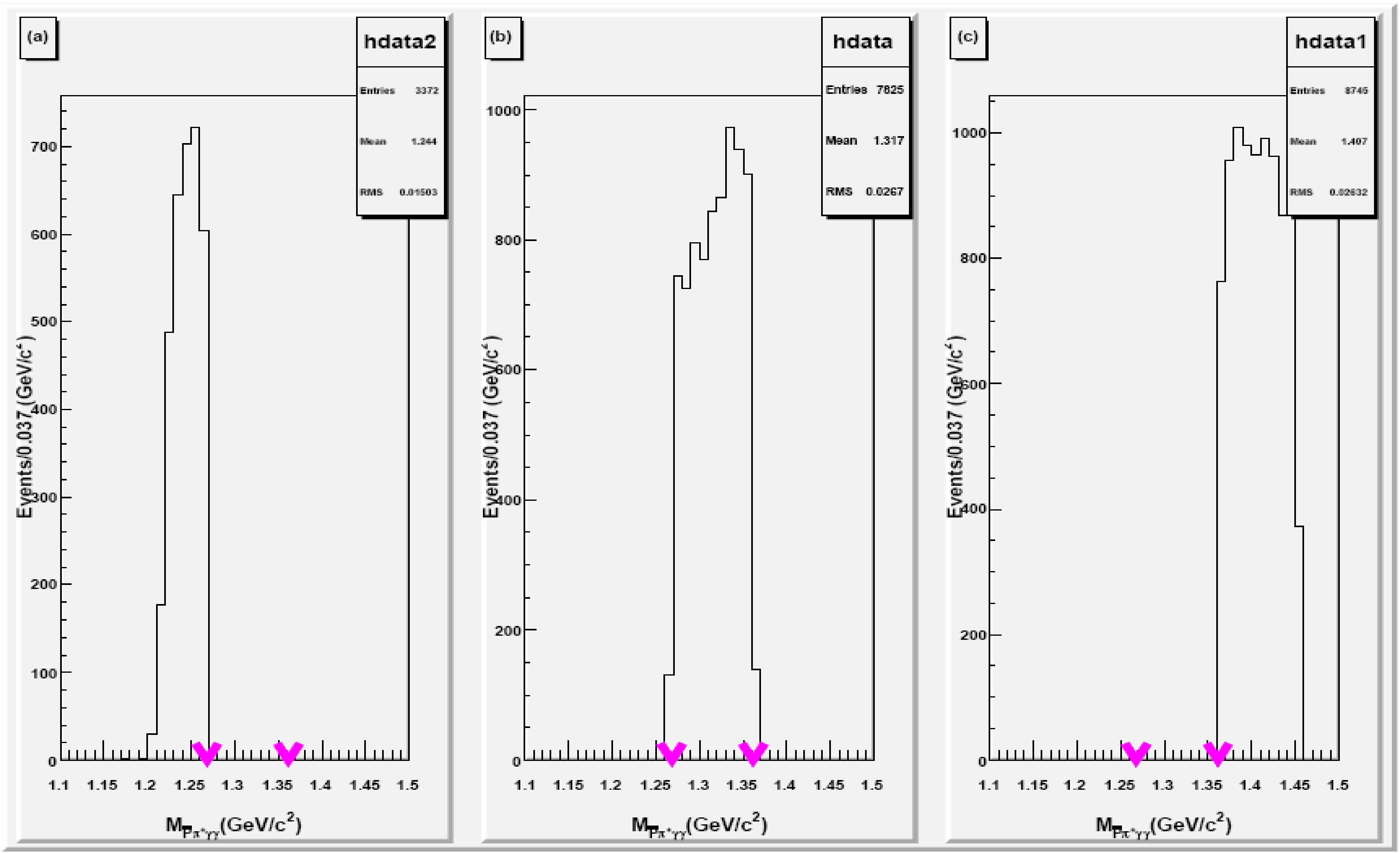
(a) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ for $J/\psi \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\bar{J}/\psi \to \Lambda\Xi$



(a) Invariant mass distribution of $M_{\Sigma^+\overline{\Sigma}^-}$ for $J/\psi \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{\Sigma^+\overline{\Sigma}^-}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\overline{\Xi}$



Sideband Analysis for $J/\psi \to \Lambda\overline{\Xi}$



Calculated Upper Limit at 95% Confidence Level for $J/\psi \to \Lambda\overline{\Xi}$

Formula for the calculation of upper limit is given bellow

$$B(J/\psi, \psi(2S) \to B\overline{B}) < \frac{N_{obs}}{N_{J/\psi,\psi(2S)} \times \varepsilon \times B_i(1-\sigma_{sys})}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(J/\psi \to \Lambda\overline{\Xi}) < 8.9 \times 10^{-8}$$

The systematic errors for $J/\psi \to \Lambda\overline{\Delta}, \Lambda\overline{\Sigma}, \Lambda\overline{\Xi}$

Sources	% error for $\Lambda\overline{\Delta}$	% error for $\Lambda\overline{\Sigma}$	% error for $\Lambda\overline{\Xi}$
MDC Tracking	8	8	8
PID (Ablikim et al., 2017)	4	5	6
MC Model (Ablikim et al., 2017)	-	0.83	5.9
Statistical Error	0.16	1.78	0.27
$B(\Lambda \to P\pi^-)$ (Patrignani et al., 2016)	0.5	0.5	0.5
J/ψ number (Ablikim et al., 2017)	7.0	7.0	7.0
Kinematic fit for $\Lambda\overline{\Lambda}$	15	15	15
$\Lambda \to P\pi^-$	0.5	0.5	0.5
$\overline{\Sigma^0} \to \overline{p}\pi^+\gamma$	–	0	–
$\overline{\Xi} \to \overline{\Lambda}\pi^0$	–	–	0.012
Total error	18.83	19.166	20.23

Initial Event Selection for $\psi(2S) \rightarrow \Lambda\overline{\Delta}$

There are 4 charge tracks in $\psi(2S) \rightarrow \Lambda\overline{\Delta}$ as $\Lambda \rightarrow P\pi^-$ and

$\overline{\Delta} \rightarrow \overline{p}\pi^+$

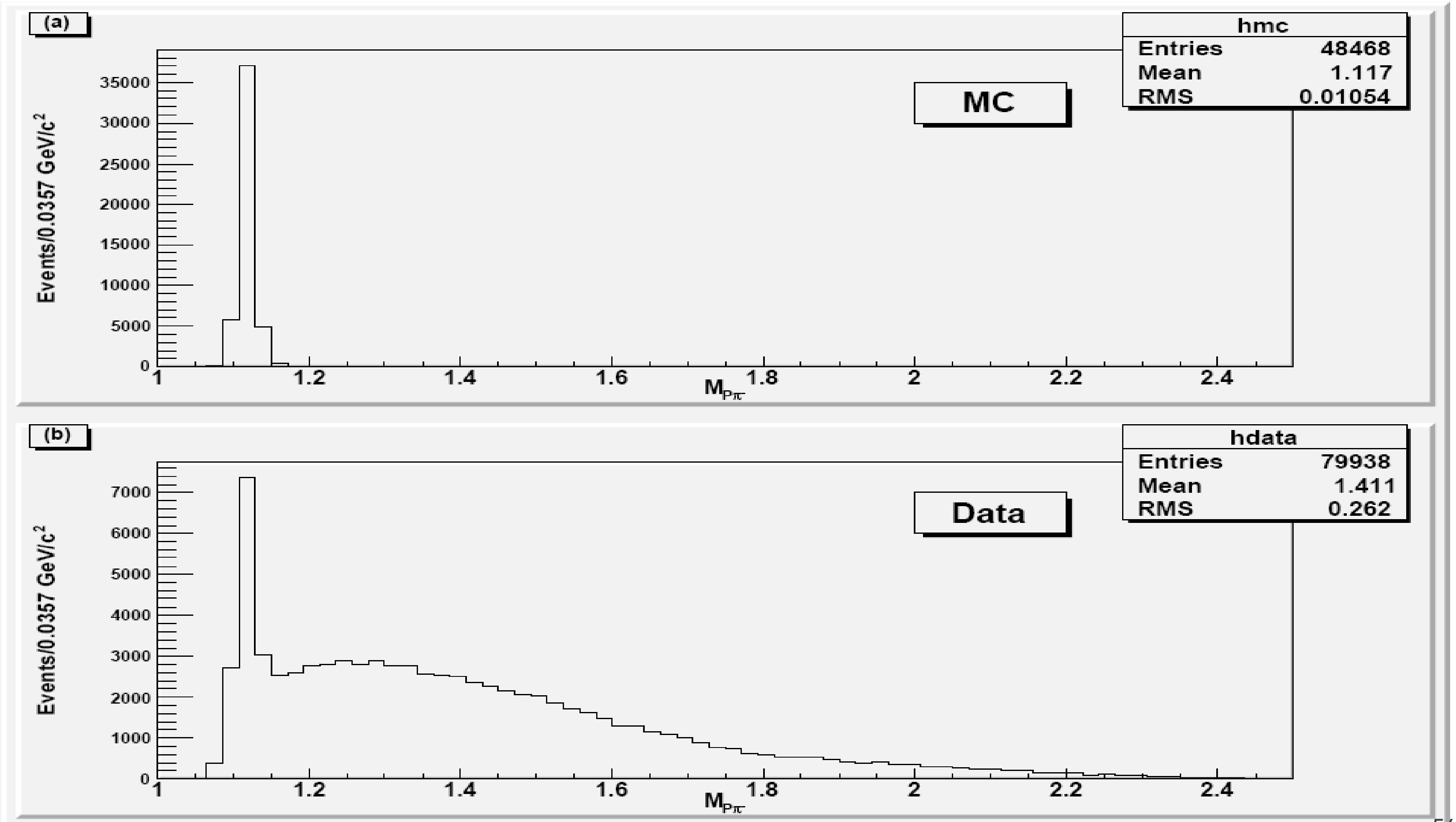
Only those events are selected having

•nGood == 4

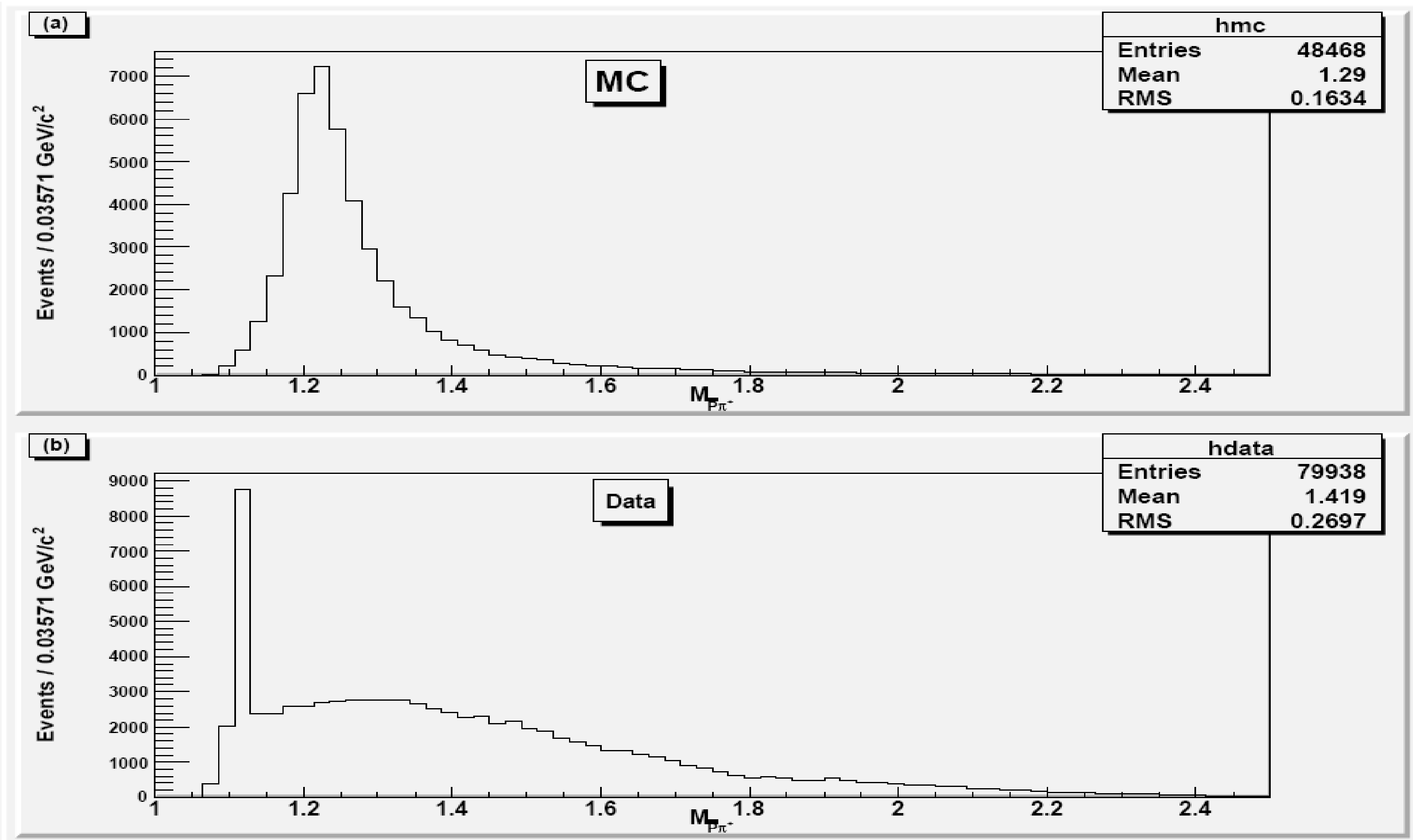
•nCharge == 0

PID is applied to select events having 1 proton
1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to P\pi^-$ using kinematic fit for $\psi(2S) \to \Lambda\bar{\Delta}$



MC and Data invariant mass of $\overline{\Delta} \to \overline{p}\pi^+$ using kinematic fit $\psi(2S) \to \Lambda\overline{\Delta}$

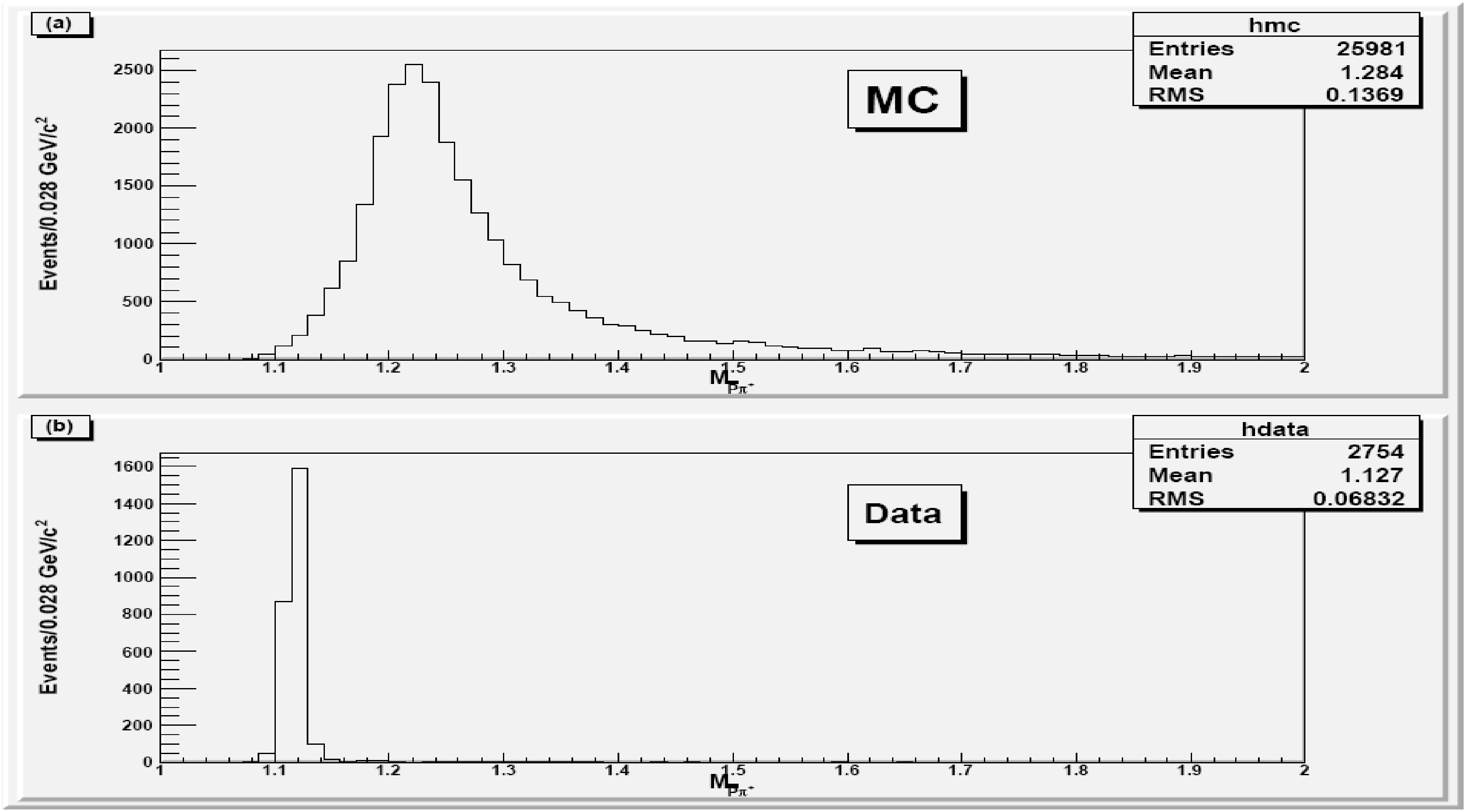


Background Analysis for $\psi(2S) \to \Lambda\bar{\Delta}$

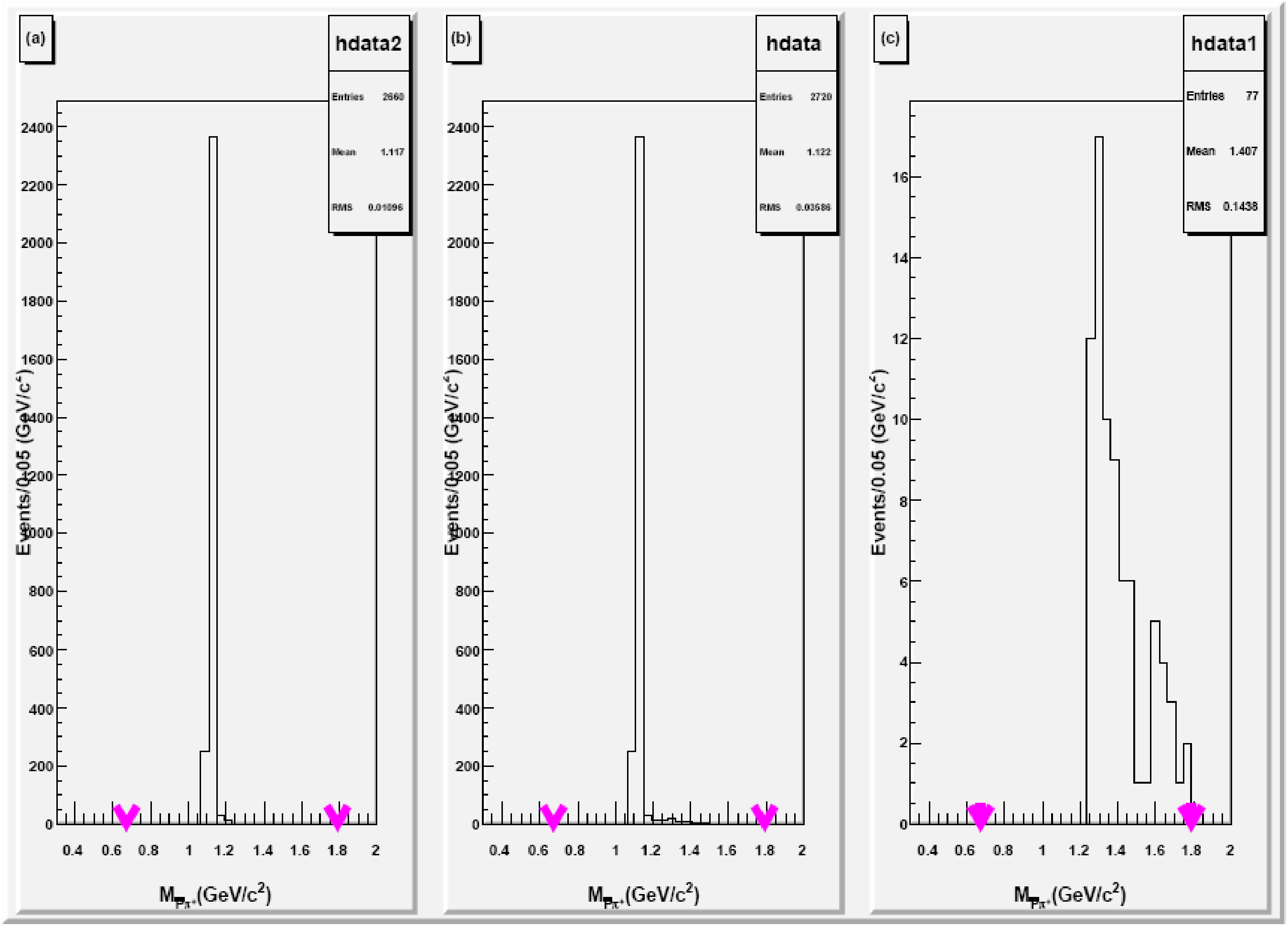
Constraints applied on $\psi(2S) \to \Lambda\bar{\Delta}$ are

- $\chi^2 < 40$
- $|M_{p\pi^-} - M_\Lambda| < 0.005$
- $|M_{p\pi^-\gamma\gamma} - M_\Xi| > 0.03532$
- $|M_{p\pi^-\gamma} - M_\Sigma| > 0.03117$
- number of $\gamma = 0$
- Decay Length of $\Lambda > 2$
- Rxy < 4

MC and Data invariant mass of $\overline{\Delta} \to \overline{p}\pi^+$ after applying cuts



Sideband Analysis for $\psi(2S) \to \Lambda\bar{\Delta}$



Calculated Upper Limit at 95% Confidence Level for $\psi(2S) \to \Lambda\overline{\Delta}$

Formula for the calculation of upper limit is given bellow

$$B(J/\psi,\psi(2S) \to B\overline{B}) < \frac{N_{obs}}{N_{J/\psi,\psi(2S)} \times \varepsilon \times B_i(1-\sigma_{sys})}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(\psi(2S) \to \Lambda\overline{\Delta}) < 0.21 \times 10^{-7}$$

Event Selection for $\psi(2S) \to \Lambda\overline{\Sigma}$

There are 4 charge tracks in $\psi(2S) \to \Lambda\overline{\Sigma}$ as $\Lambda \to P\pi^-$ and

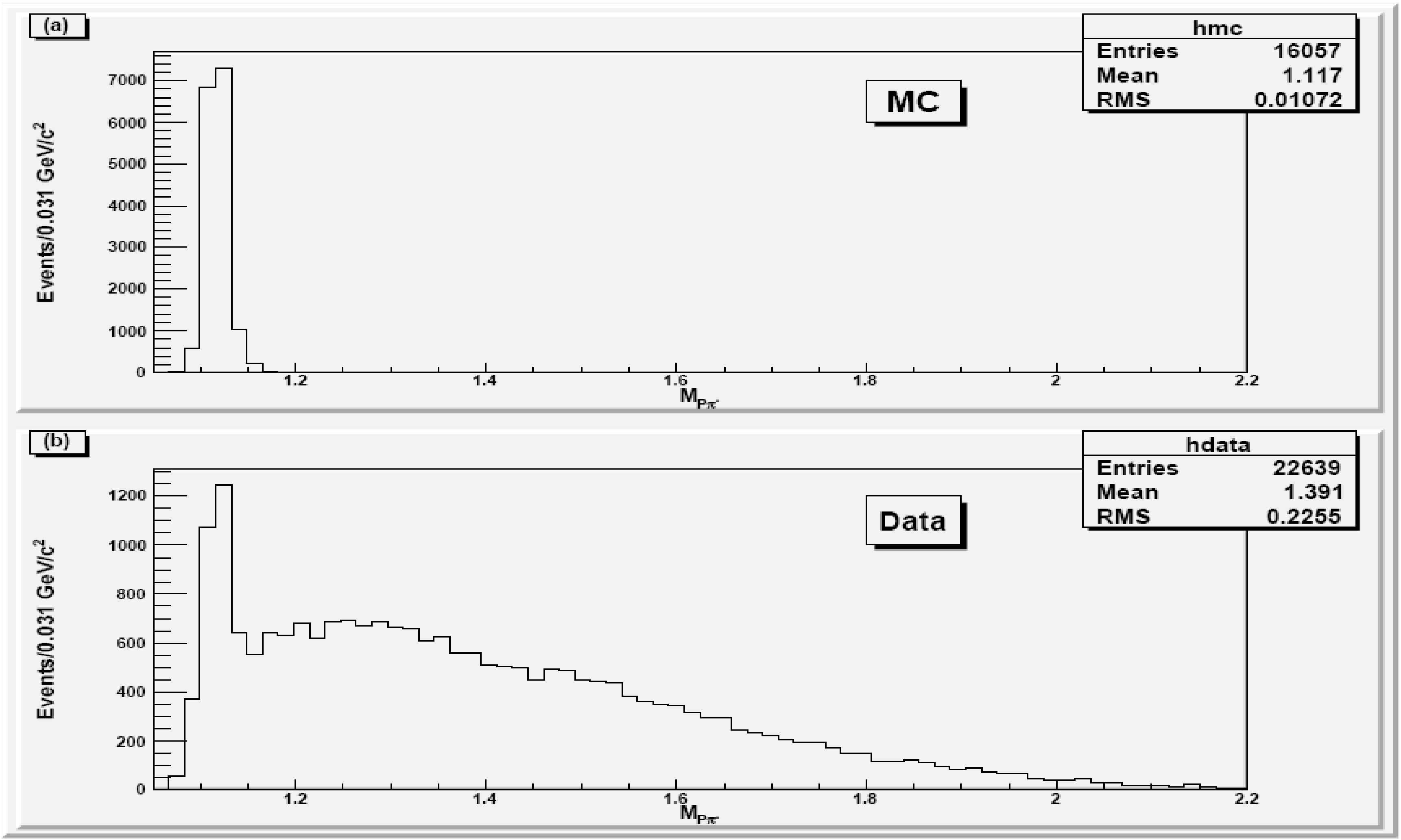
$\overline{\Sigma} \to \overline{p}\pi^+\gamma$

Only those events are selected having

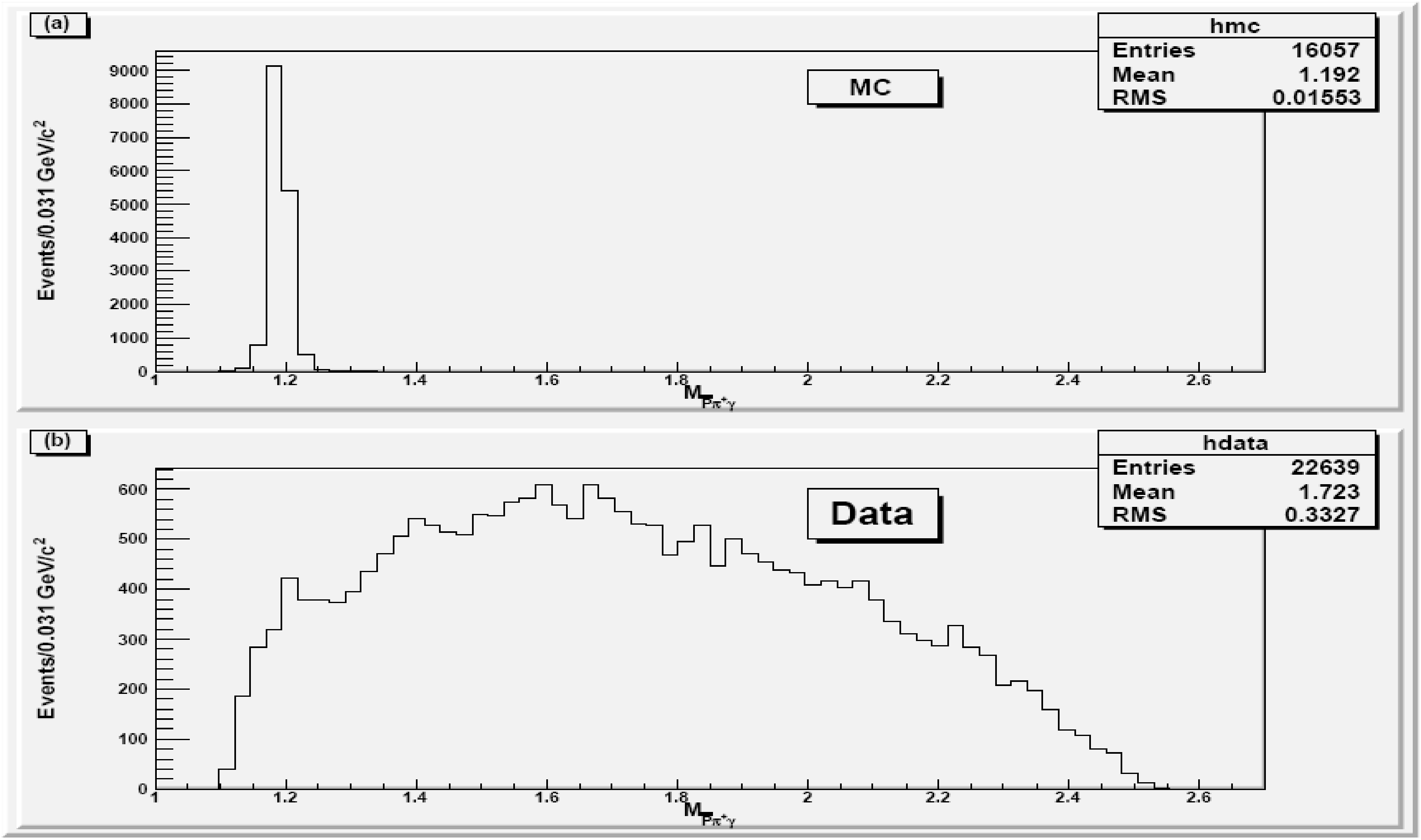
- nGood == 4
- number of ɣ == 1
- nCharge == 0

PID is applied to select events having 1 proton
1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to p\pi^-$ using kinematic fit for $\psi(2S) \to \Lambda\bar{\Sigma}$



MC and Data invariant mass of $\overline{\Sigma} \to \overline{p}\pi^+\gamma$ using kinematic fit for $\psi(2S) \to \Lambda\overline{\Sigma}$



Background Analysis for $\psi(2S) \to \Lambda\overline{\Sigma}$

Some cuts are applied to remove the background on both Monte carlo and data signals.

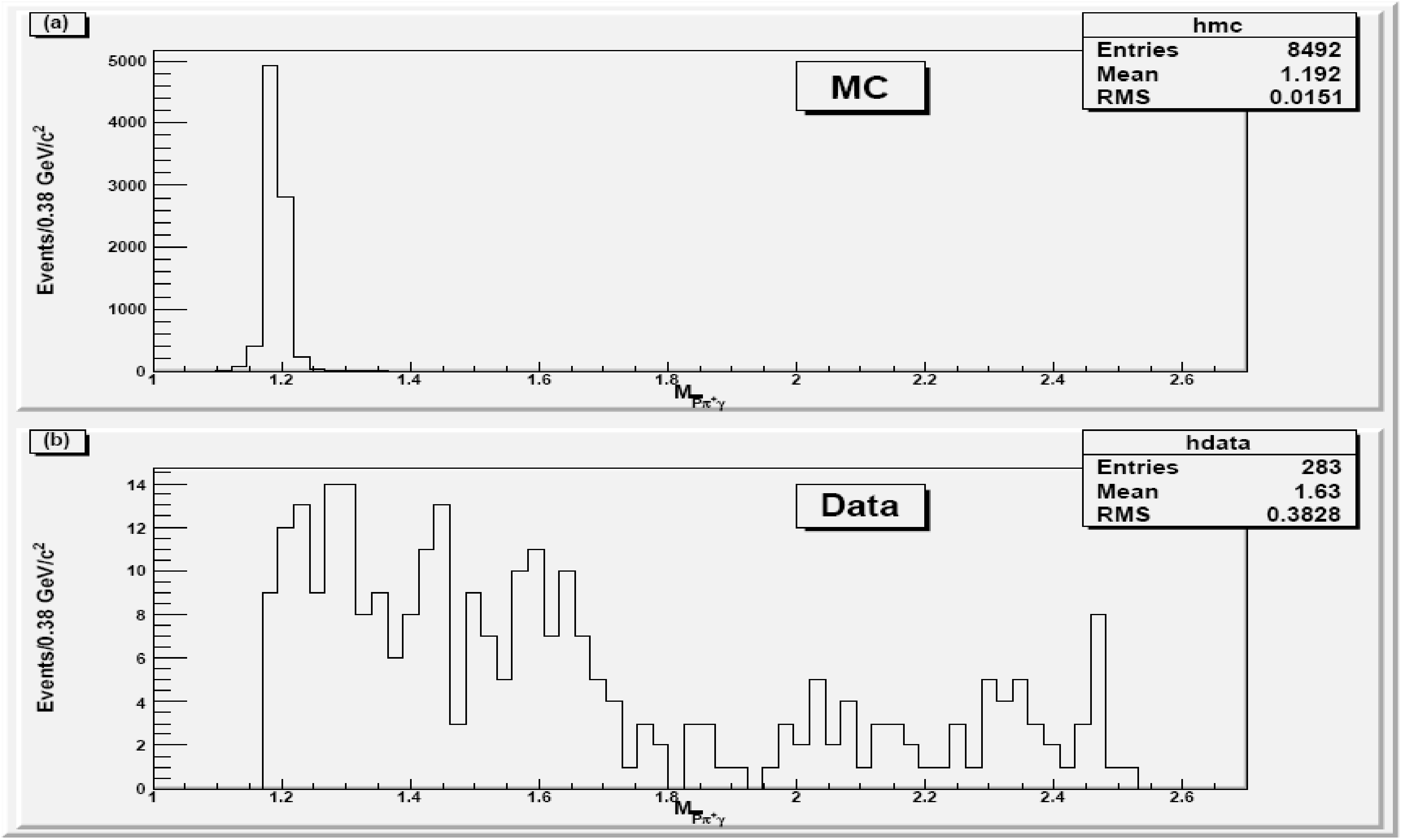
Cut applied on MC is

- including cut of Λ

Cut applied on real data signals are

- $\chi^2 < 40$
- $|M_\Lambda - 1.1156| < 0.005$
- $|M_\Xi - 1.31486| > 0.03532$
- $|M_\Sigma - 1.11583| > 0.03117$
- $|M_\Delta - 1.232| > 0.24$
- no. of gamma == 1
- decay length ratio $\Lambda > 2$
- Rxy < 4

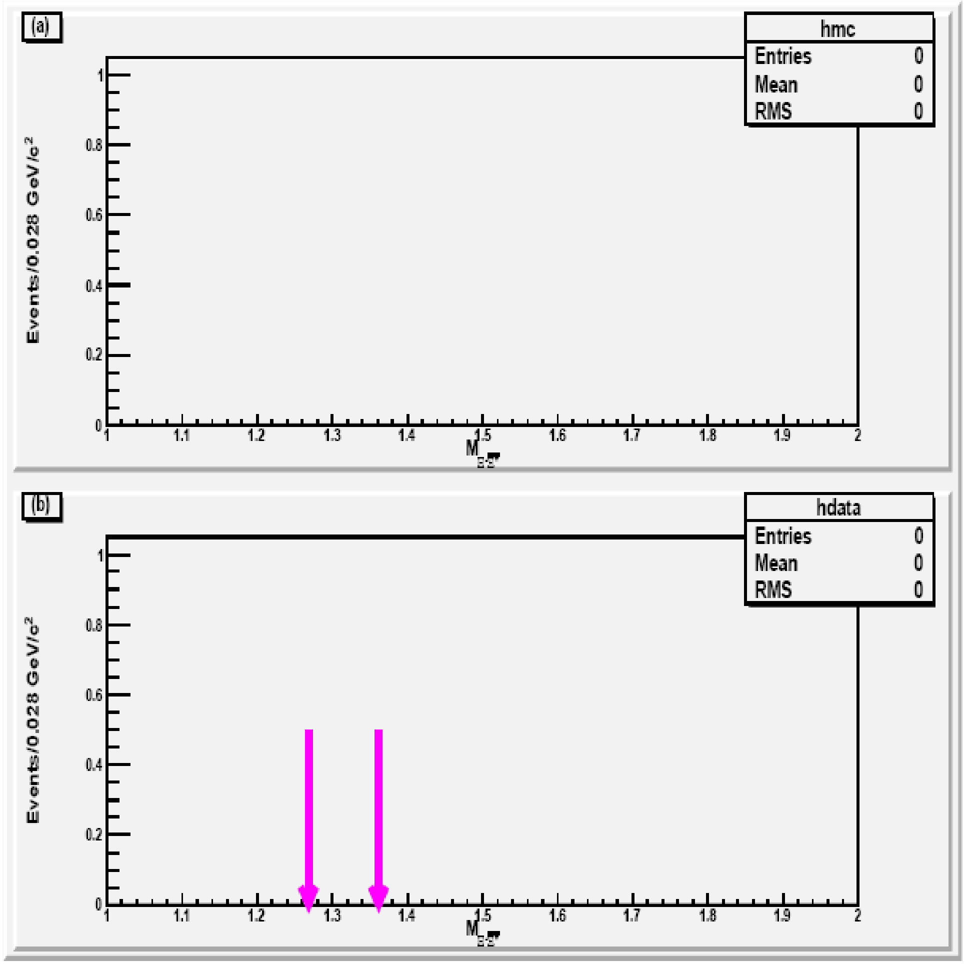
MC and Data invariant mass of $\overline{\Sigma} \to \overline{p}\pi^+\gamma$ after applying cuts for $\psi(2S) \to \Lambda\overline{\Sigma}$



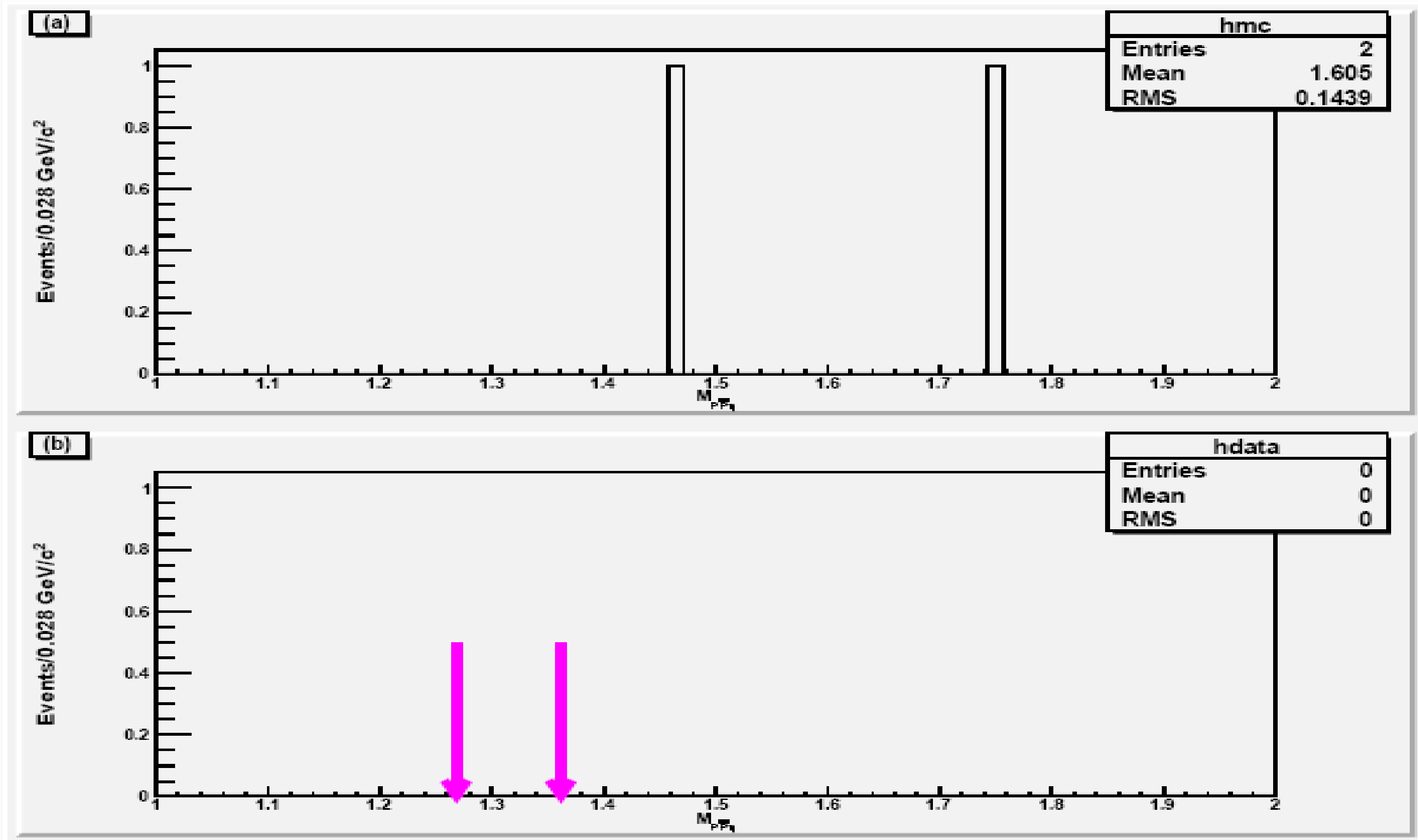
Observed background channels for $\psi(2S) \to \Lambda\overline{\Sigma}$ after applying cuts

background channel	number of events	Normalized events	Branching fraction
$\Xi^-\overline{\Xi^+}$	0	0	$(2.64 \pm 0.18) \times 10^{-4}$
$P\overline{P}\eta$	2	0	$(6.0 \pm 0.4) \times 10^{-5}$
$\Lambda\overline{\Lambda}\pi^0$	3	0	$< 2.9 \times 10^{-6}$
$P\overline{P}\acute{\eta}$	0	0	—
$P\overline{P}\omega$	2	0	$(6.9 \pm 2.1) \times 10^{-5}$
$P\overline{P}\pi^+\pi^-$	0	0	$(6.0 \pm 0.4) \times 10^{-4}$
$P\overline{P}\pi^+\pi^-\pi^0$	0	0	$(7.3 \pm 0.7) \times 10^{-4}$
$P\overline{P}\rho$	2	0	$(5.0 \pm 2.2) \times 10^{-5}$
$\Lambda\overline{\Lambda}\eta$	2	0	$(2.5 \pm 0.4) \times 10^{-5}$
$\Lambda\overline{\Lambda}$	5	0	$(3.57 \pm 0.18) \times 10^{-4}$
$\Sigma^0\overline{\Sigma^0}$	5	0	$(2.32 \pm 0.16) \times 10^{-4}$

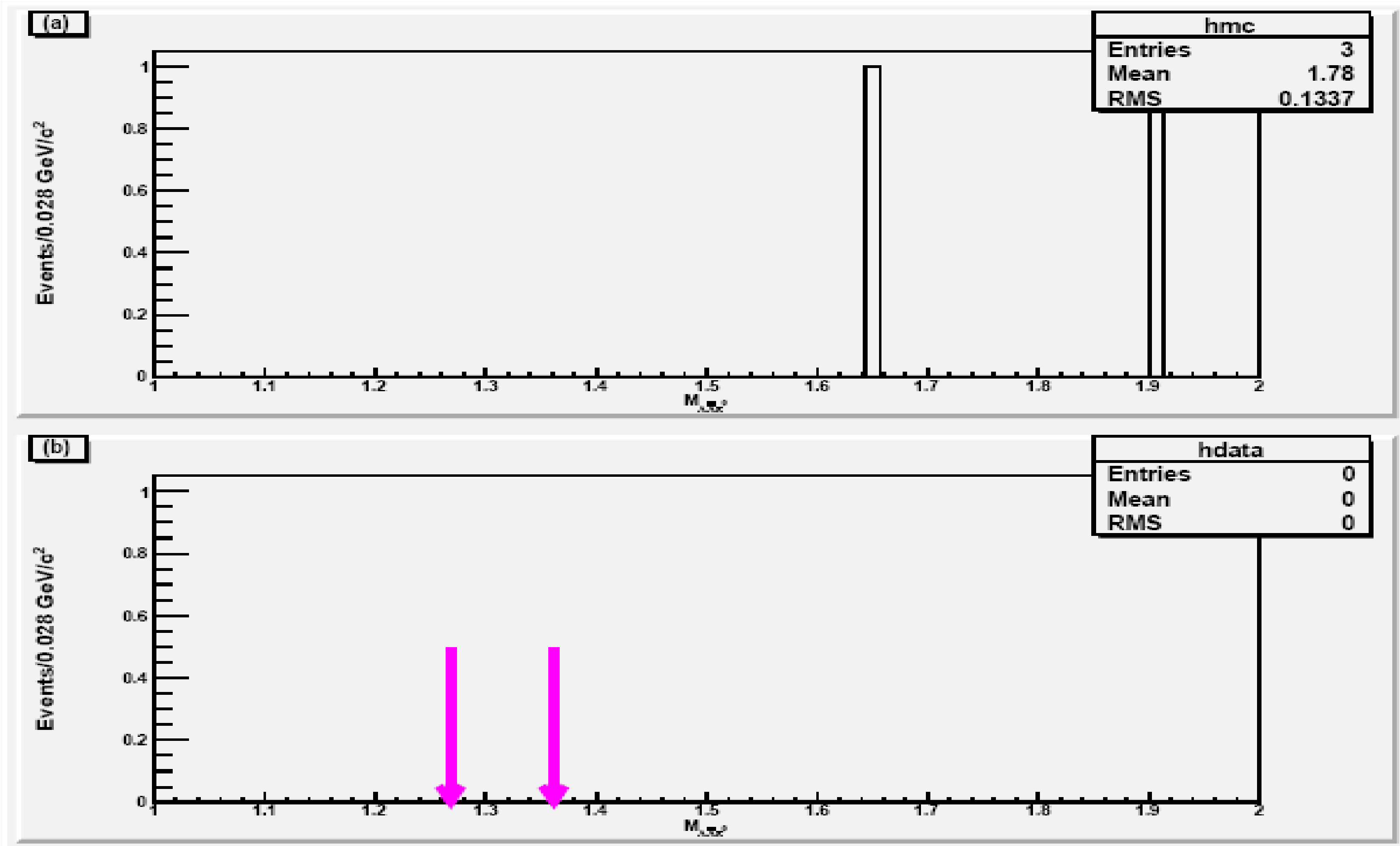
(a) Invariant mass distribution of $M_{\Xi^-\overline{\Xi}^+}$ for $\psi(2S) \to \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of background $M_{\Xi^-\overline{\Xi}^+}$ for $\psi(2S) \to \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^+\gamma} - M_{\overline{\Sigma}}| < 0.0467$



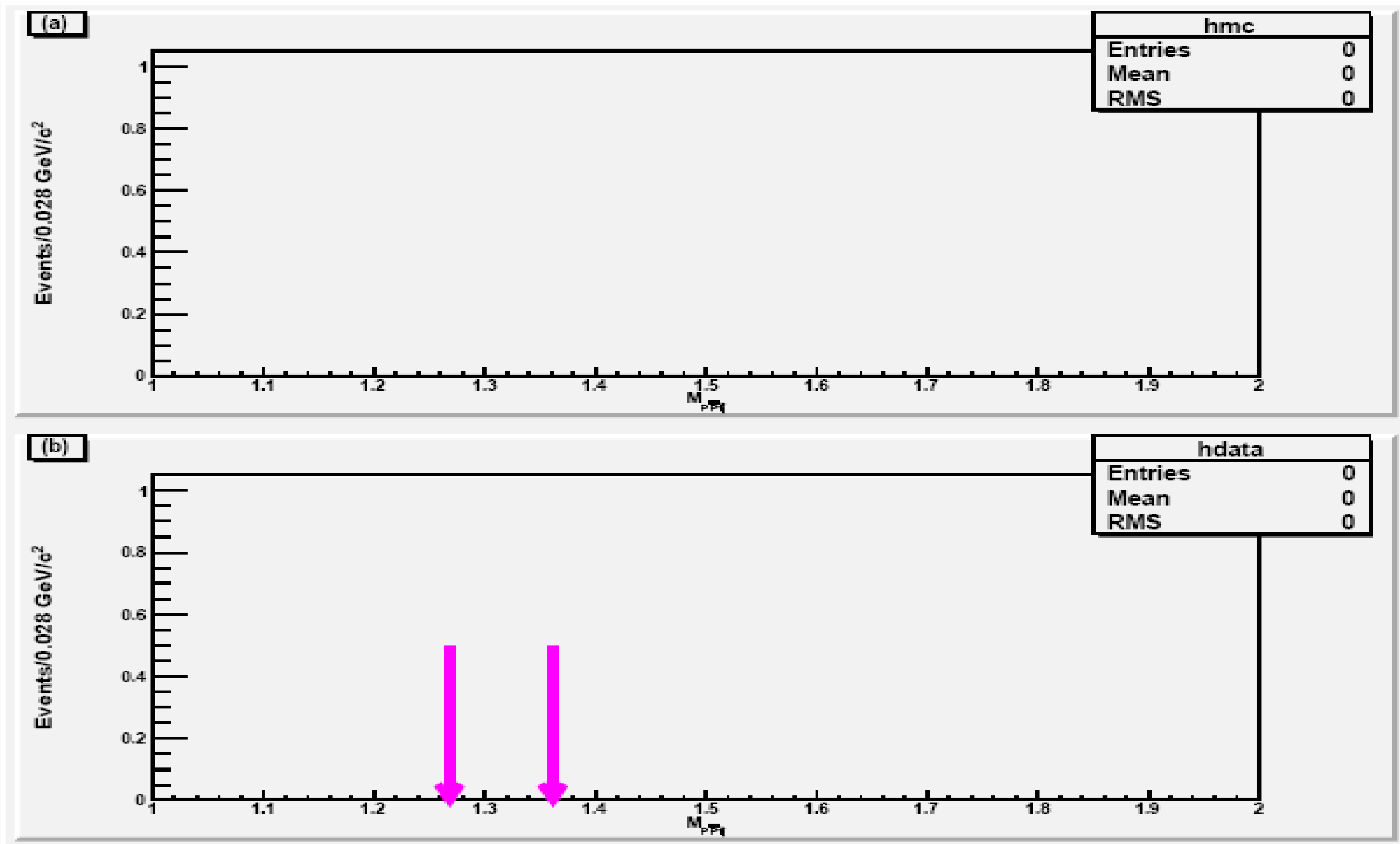
(a) Invariant mass distribution of $M_{p\bar{p}\eta}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{p\bar{p}\eta}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$



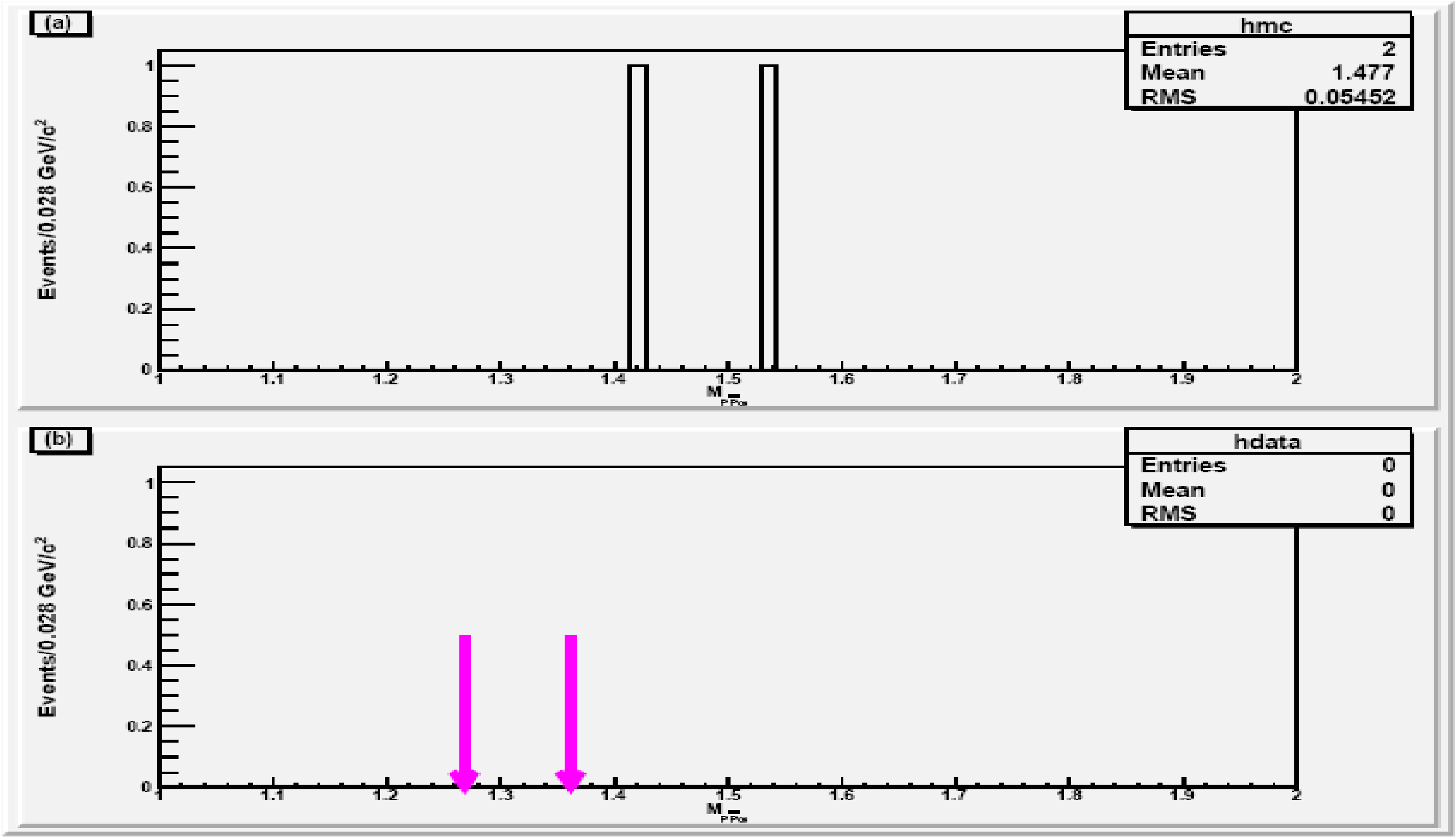
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\bar{\pi}^0}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\bar{\pi}^0}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$



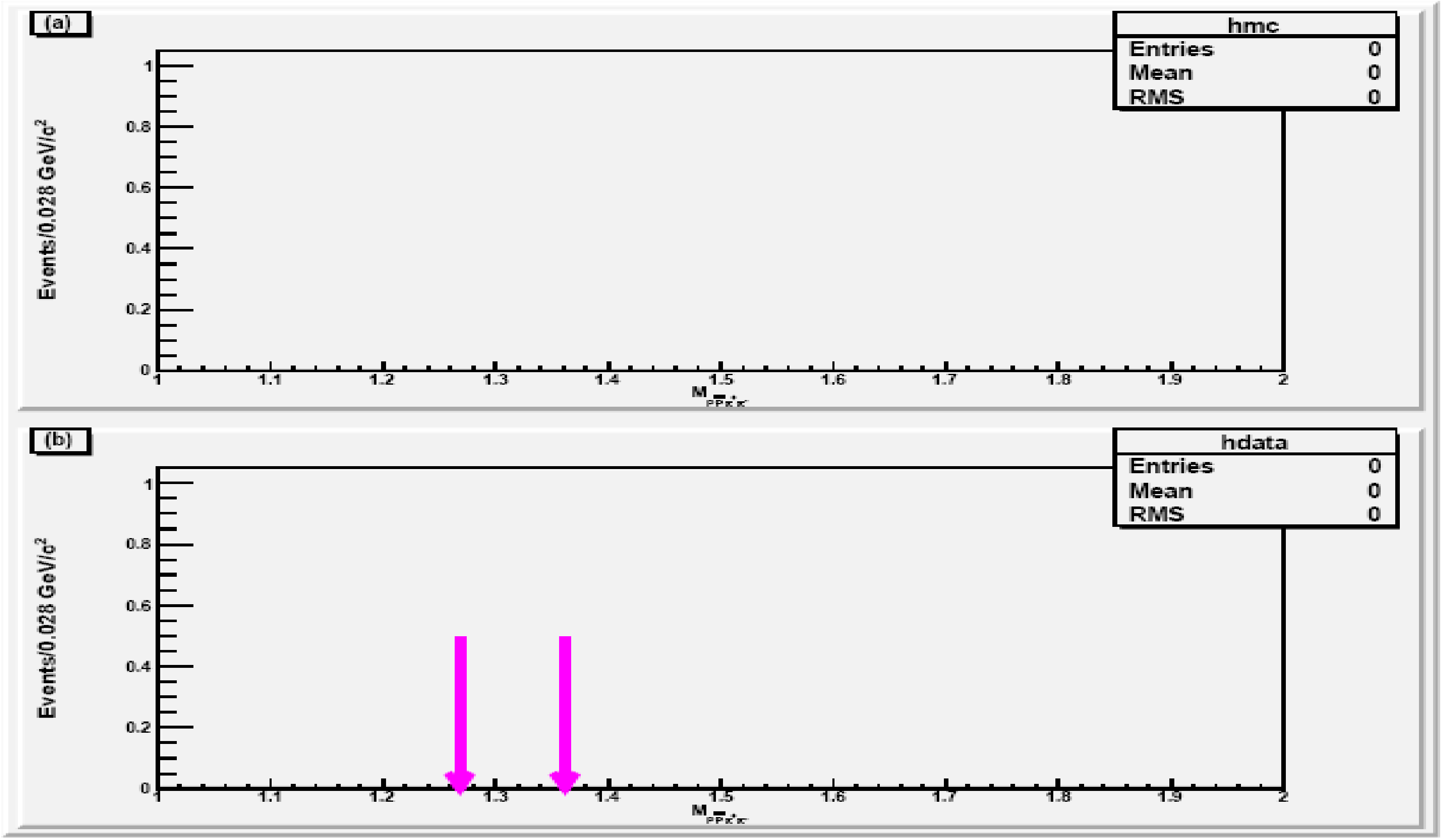
(a) Invariant mass distribution of $M_{p\overline{p}\acute{\eta}}$ for $\psi(2S) \rightarrow \Lambda\overline{\Sigma}$ (b) Invariant mass distribution of $M_{p\overline{p}\acute{\eta}}$ for $\psi(2S) \rightarrow \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0467$



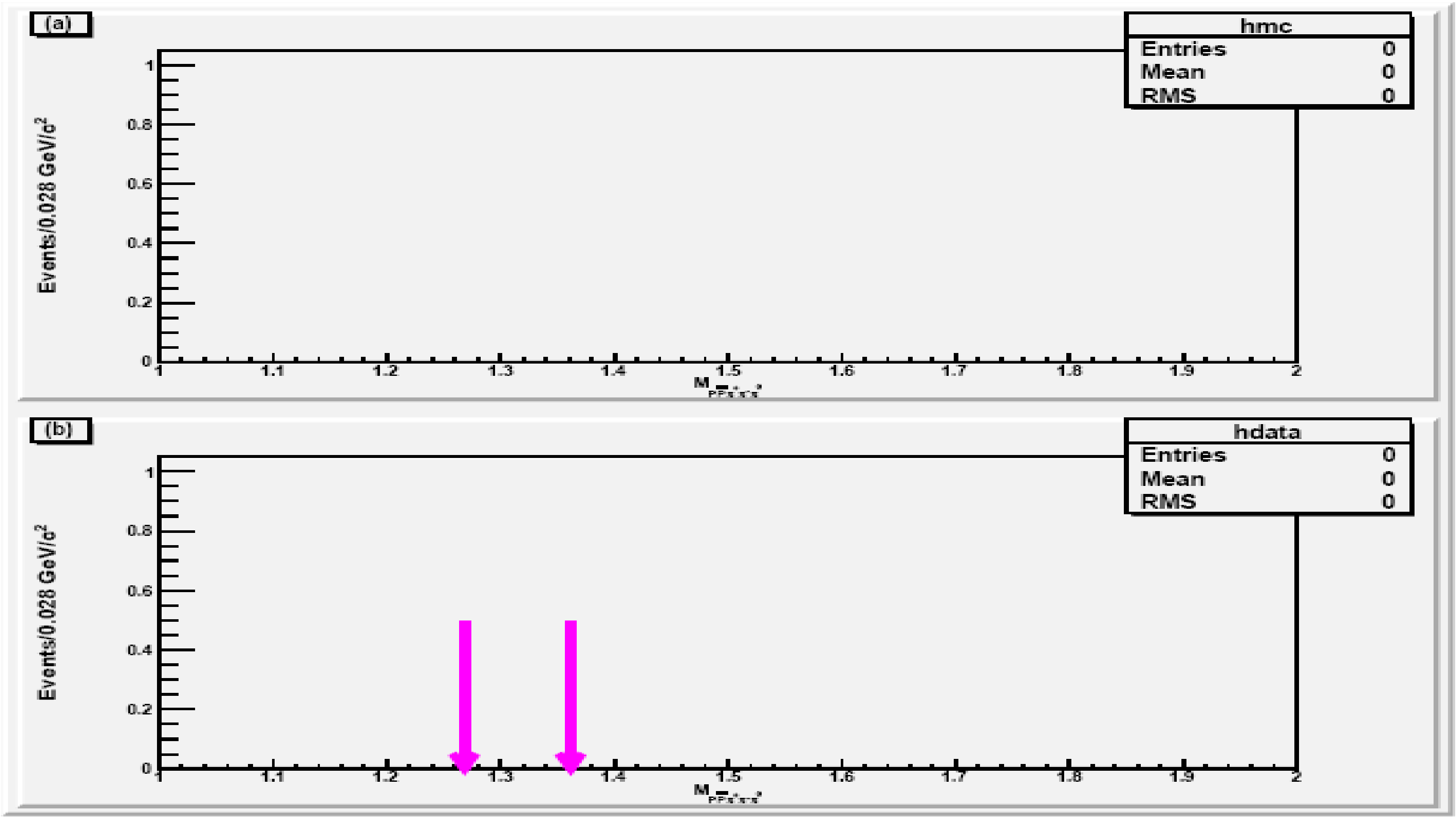
(a) Invariant mass distribution of $M_{p\overline{p}\omega}$ for $\psi(2S) \to \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of $M_{p\overline{p}\omega}$ for $\psi(2S) \to \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0467$



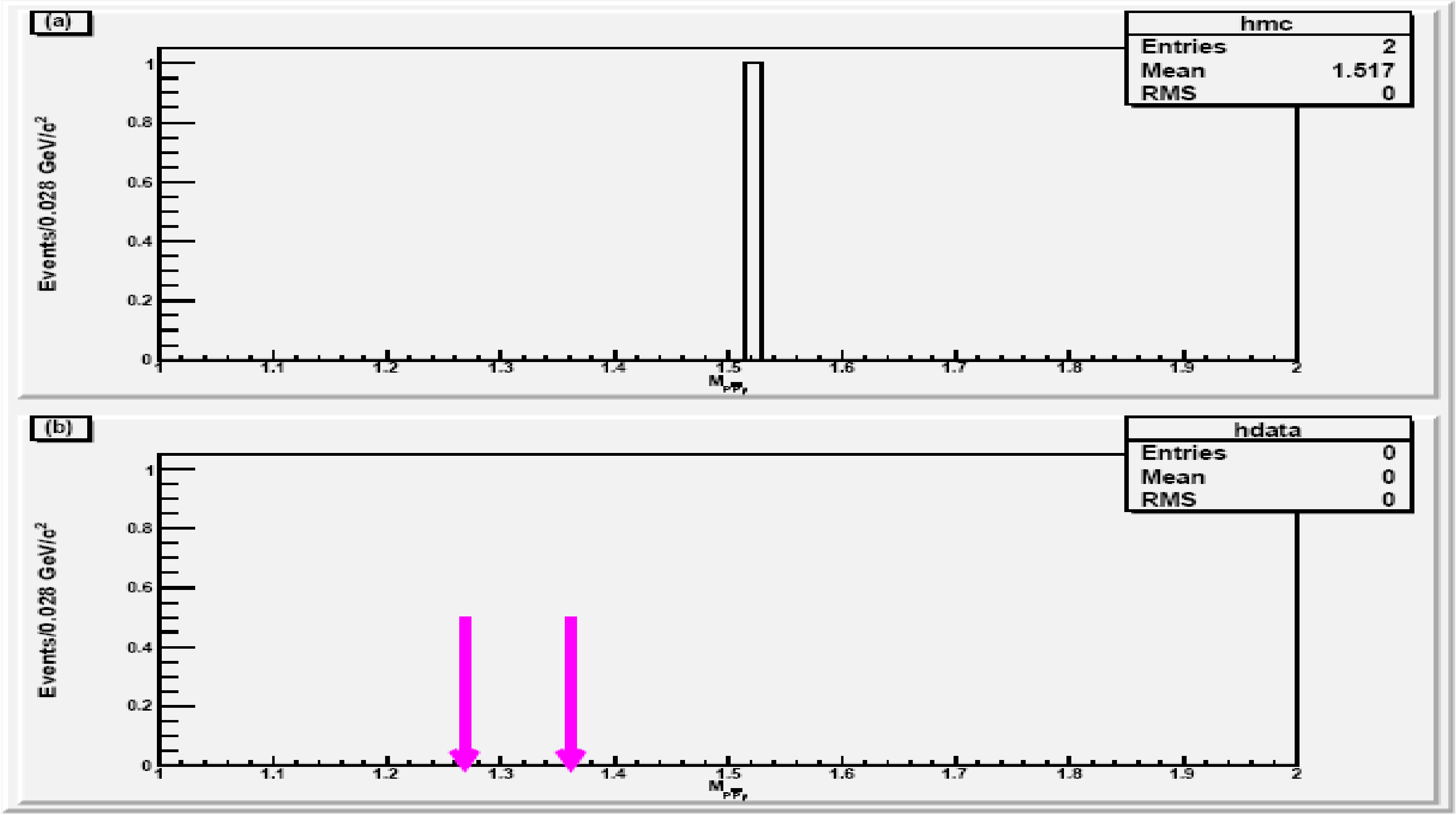
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$



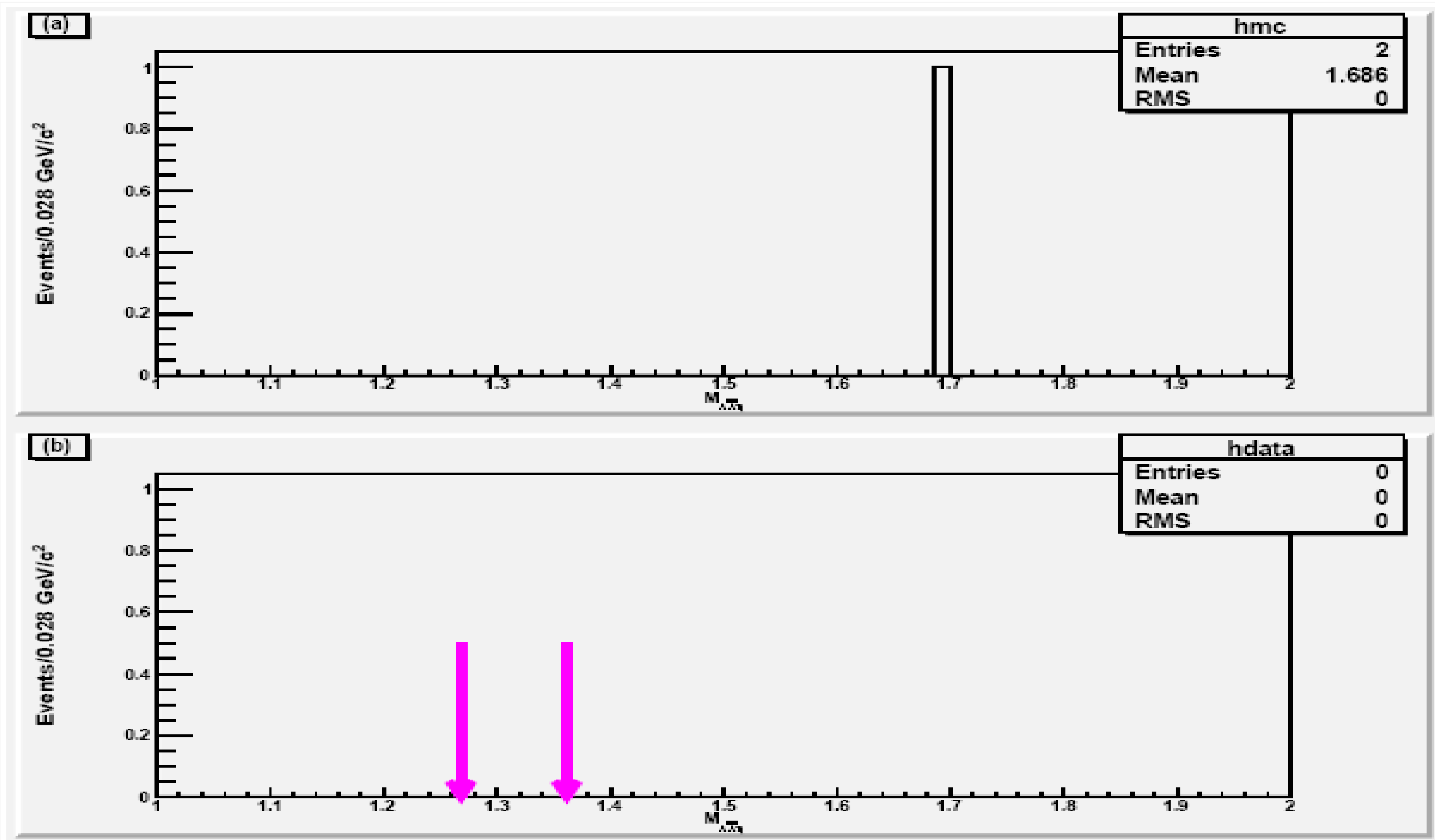
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ for $\psi(2S)\to\Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ for $\psi(2S)\to\Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma}-M_{\bar{\Sigma}}|<0.0467$



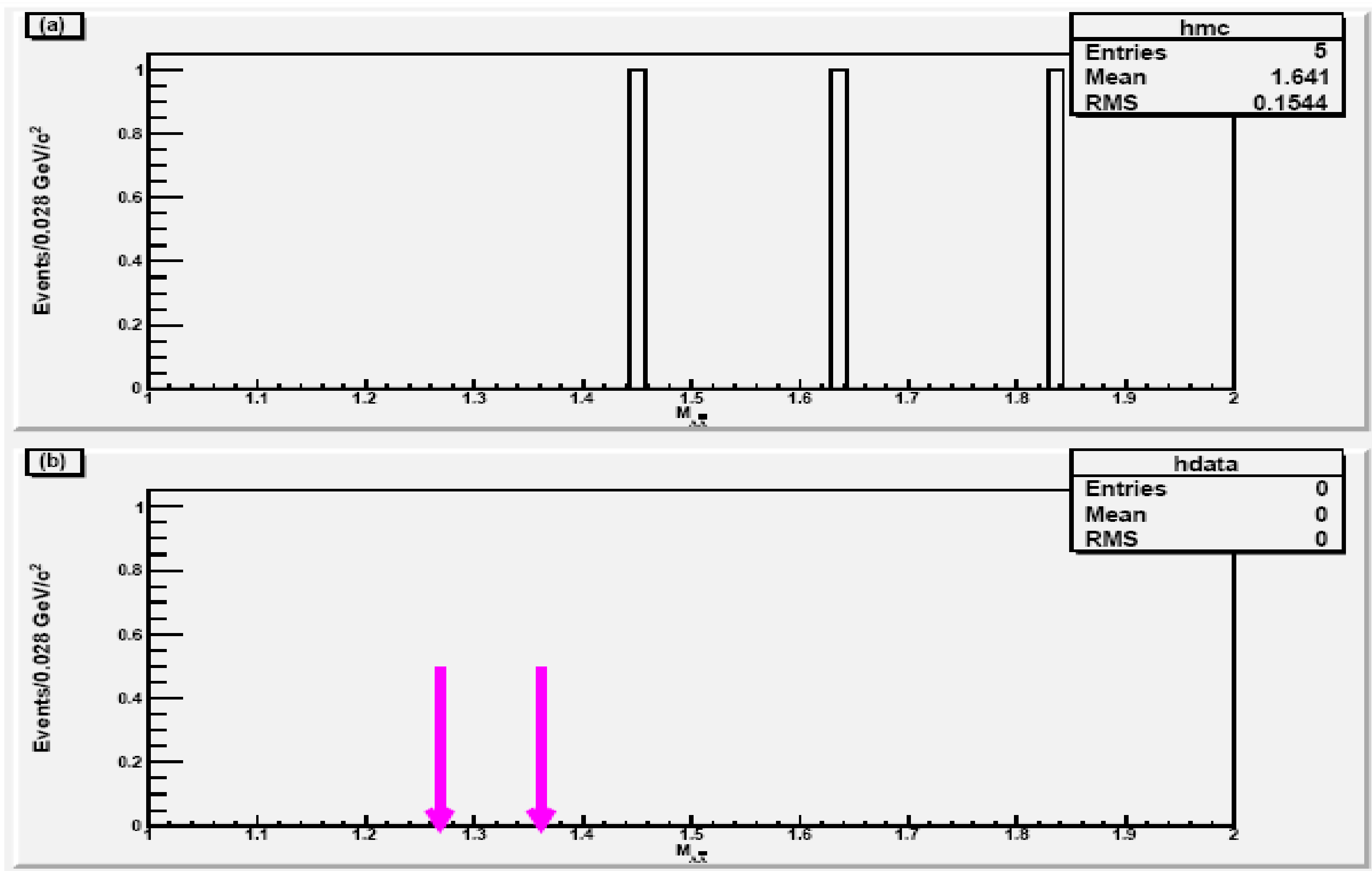
(a) Invariant mass distribution of $M_{p\bar{p}\rho}$ for $\psi(2S) \rightarrow \Lambda\overline{\Sigma}$. (b) Invariant mass distribution of $M_{p\bar{p}\rho}$ for $\psi(2S) \rightarrow \Lambda\overline{\Sigma}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma} - M_{\overline{\Sigma}}| < 0.0467$.



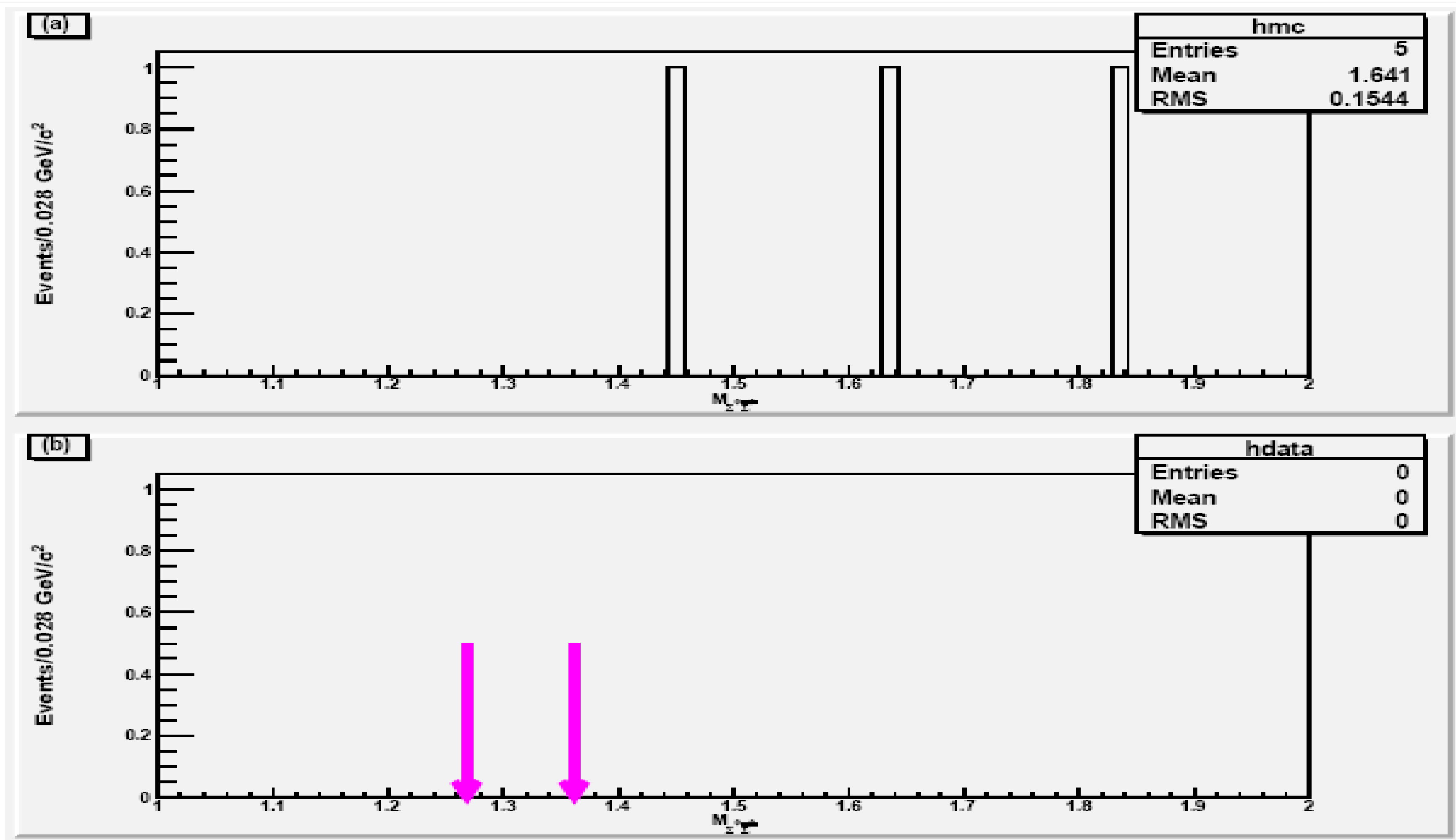
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$.



(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ for $\psi(2S) \to \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$.

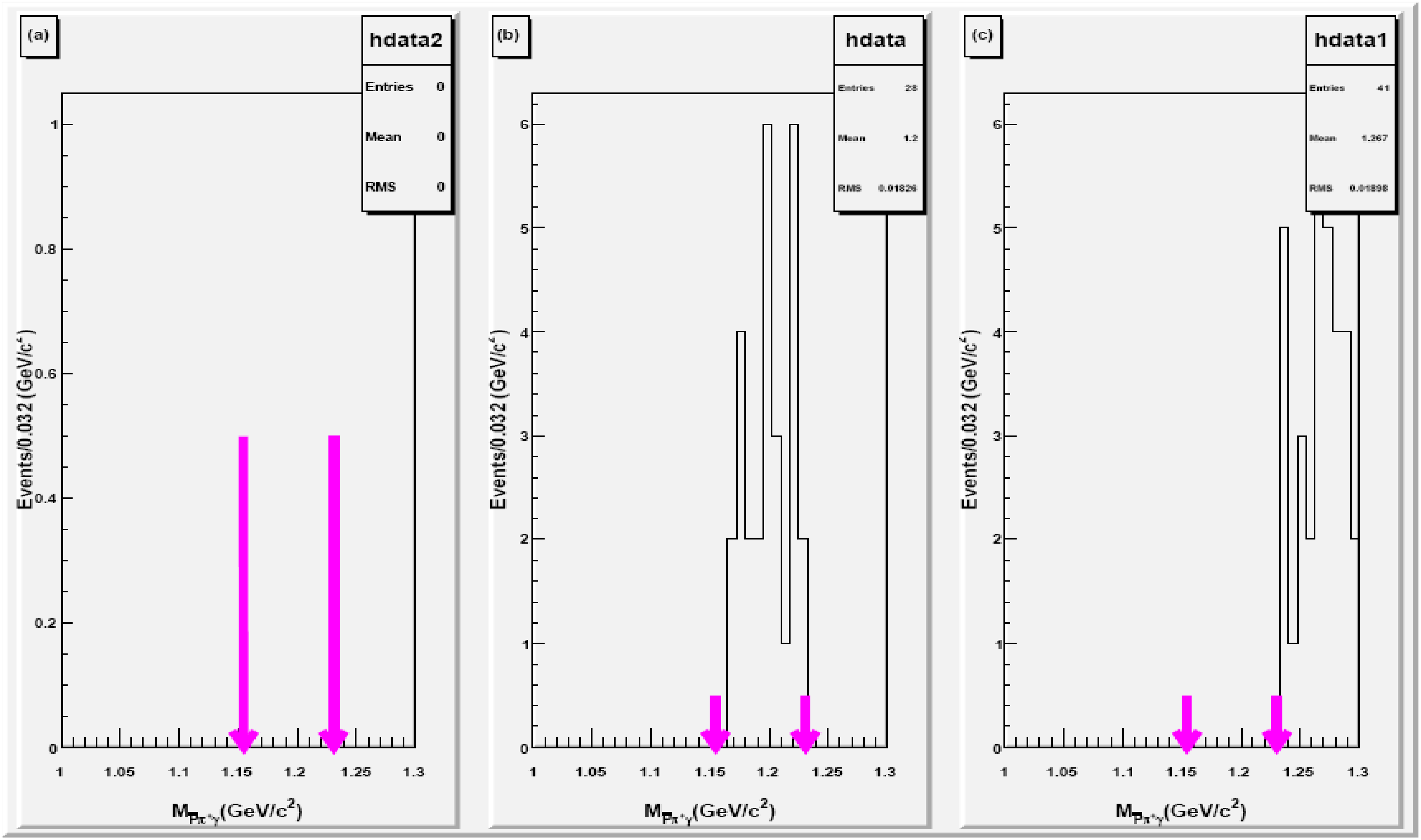


(a) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ for $\psi(2S) \rightarrow \Lambda\bar{\Sigma}$. (b) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ for $\psi(2S) \rightarrow \Lambda\bar{\Sigma}$ with mass window cut $|M_{\bar{p}\pi^+\gamma} - M_{\bar{\Sigma}}| < 0.0467$.



Sideband Analysis for

$$\psi(2S) \to \Lambda\bar{\Sigma}$$



Calculated Upper Limit at 95% Confidence Level for $\psi(2S) \to \Lambda\overline{\Sigma}$

Formula for the calculation of upper limit is given bellow

$$B(J/\psi \to B\overline{B}) \leq \frac{N_{obs}}{N_{J/\psi} \times \varepsilon \times B_i}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(\psi(2S) \to \Lambda\overline{\Sigma}) < 0.66 \times 10^{-7}$$

Event Selection for $\psi(2S) \to \Lambda\overline{\Xi}$

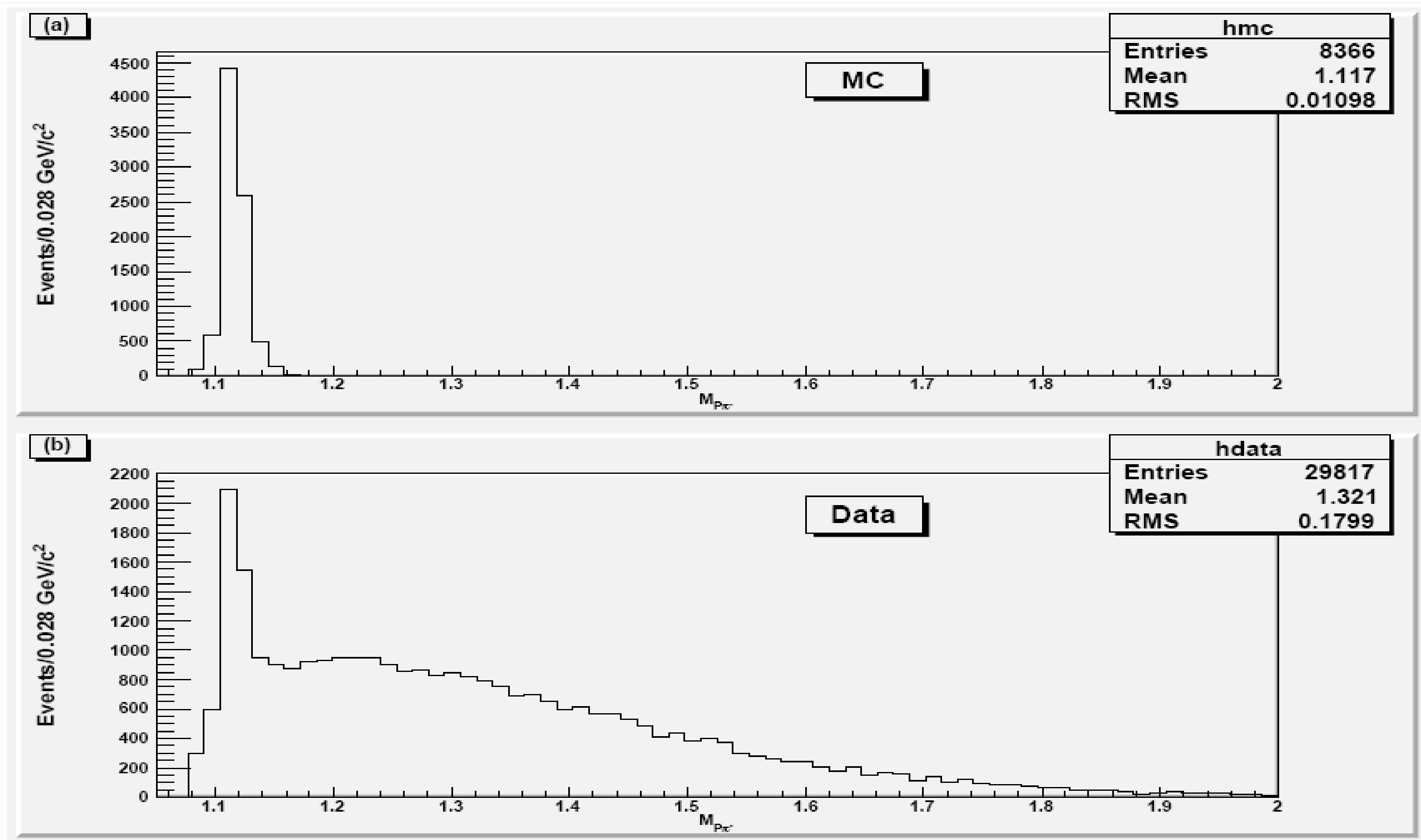
There are 4 charge tracks in $\psi(2S) \to \Lambda\overline{\Xi}$ as $\Lambda \to P\pi^-$ and $\overline{\Xi} \to \overline{p}\pi^+\gamma\gamma$

Only those events are selected having

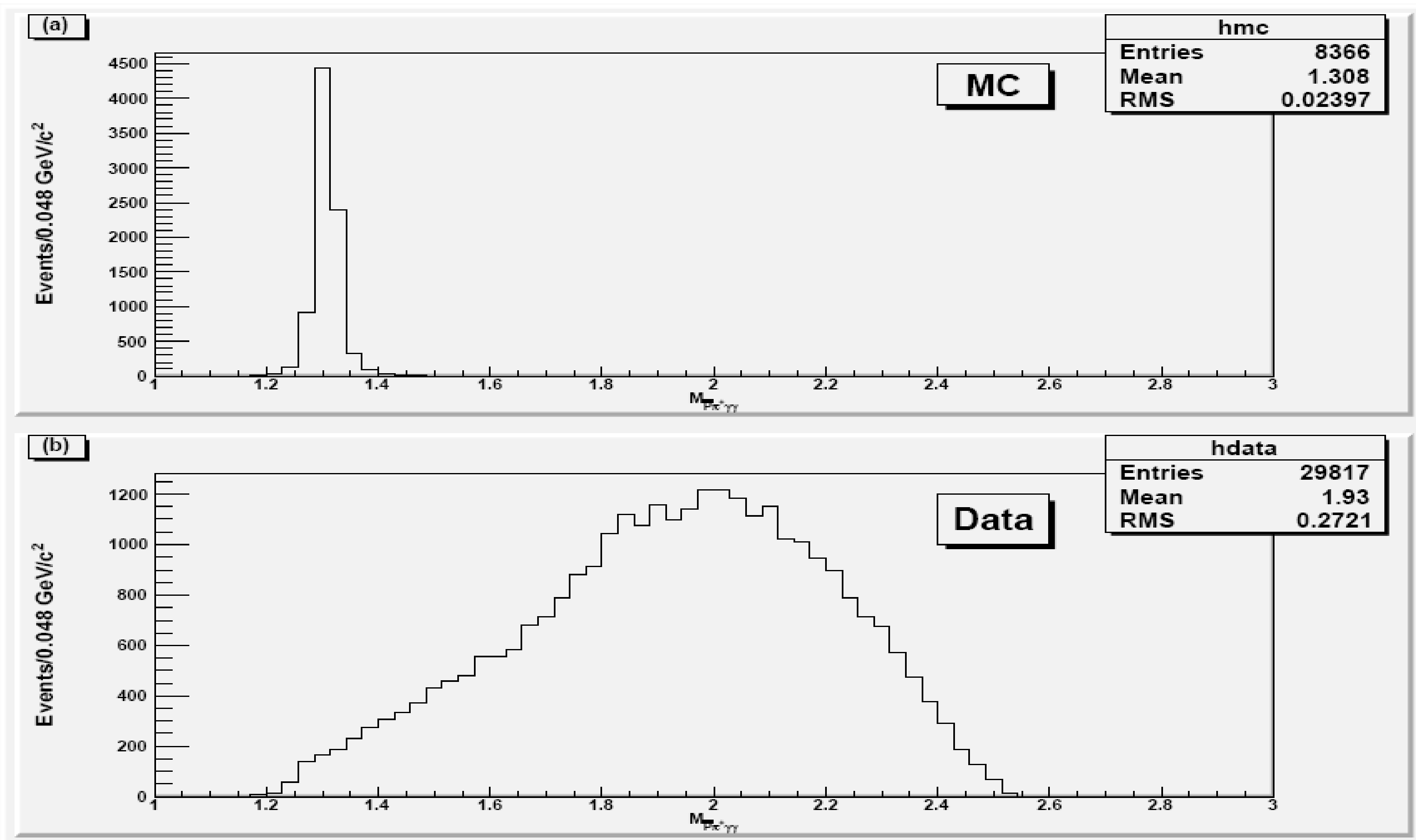
- nGood == 4
- number of ɣ == 2
- nCharge == 0

PID is applied to select events having 1 proton 1 anti proton 1 pion and 1 anti pion

MC and Data invariant mass of $\Lambda \to p\pi^-$ using kinematic fit for $\psi(2S) \to \Lambda\overline{\Xi}$



MC and Data invariant mass of $\overline{\Xi} \to \overline{p}\pi^{+}\gamma\gamma$ using kinematic fit for $\psi(2S) \to \Lambda\overline{\Xi}$



Background Analysis for $\psi(2S) \to \Lambda\overline{\Xi}$

Some cuts are applied to remove the background on both Monte carlo and data signals.

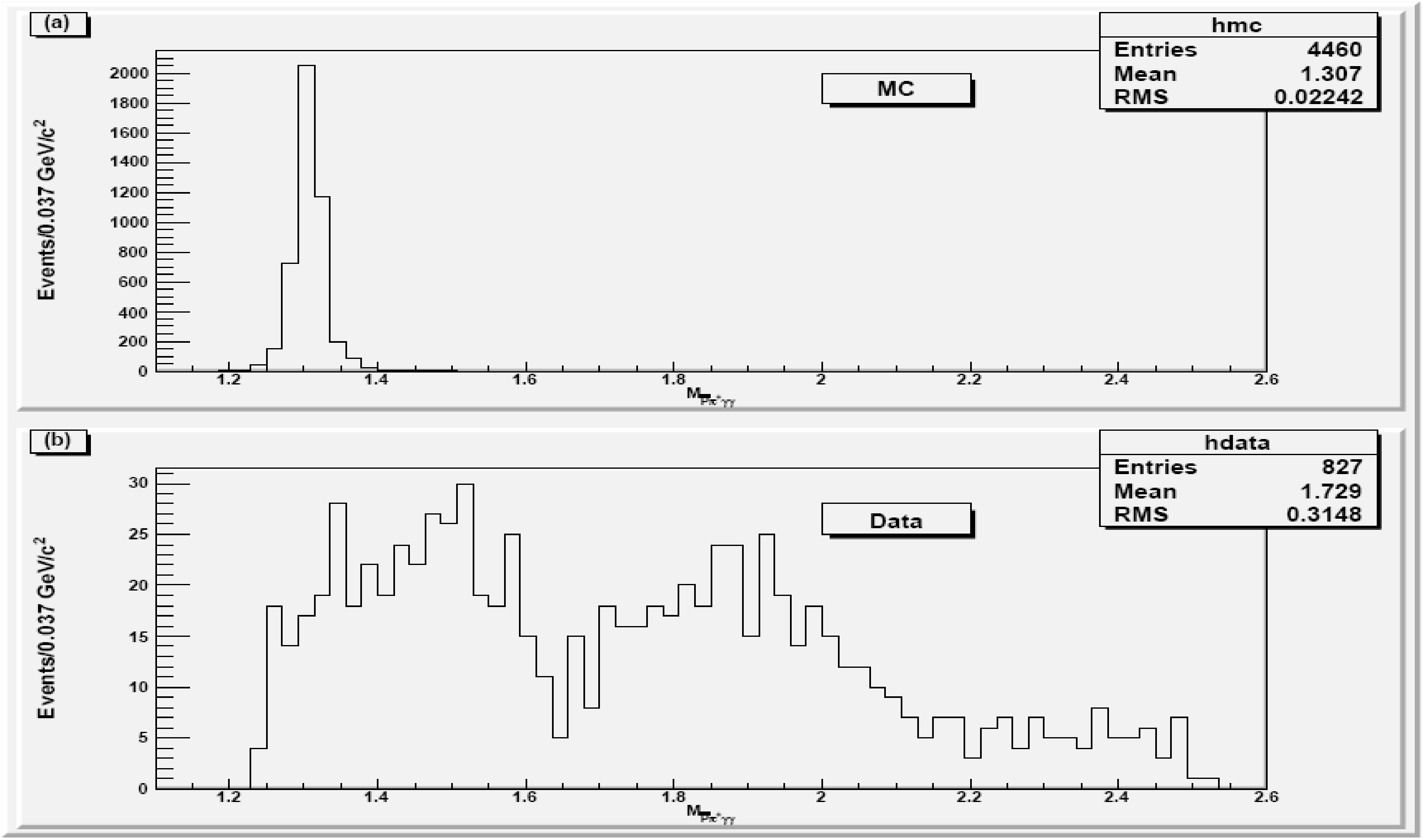
Cut applied on MC is

- including cut of Λ

Cut applied on real data signals are

- $\chi^2 < 40$
- $|M_\Lambda - 1.1156| < 0.005$
- $|M_\Xi - 1.1156| > 0.005$
- $|M_\Sigma - 1.19142| > 0.006$
- $|M_\Delta - 1.232| > 0.008$
- no. of gamma == 2
- decay length ratio $\Lambda > 2$
- Rxy < 4

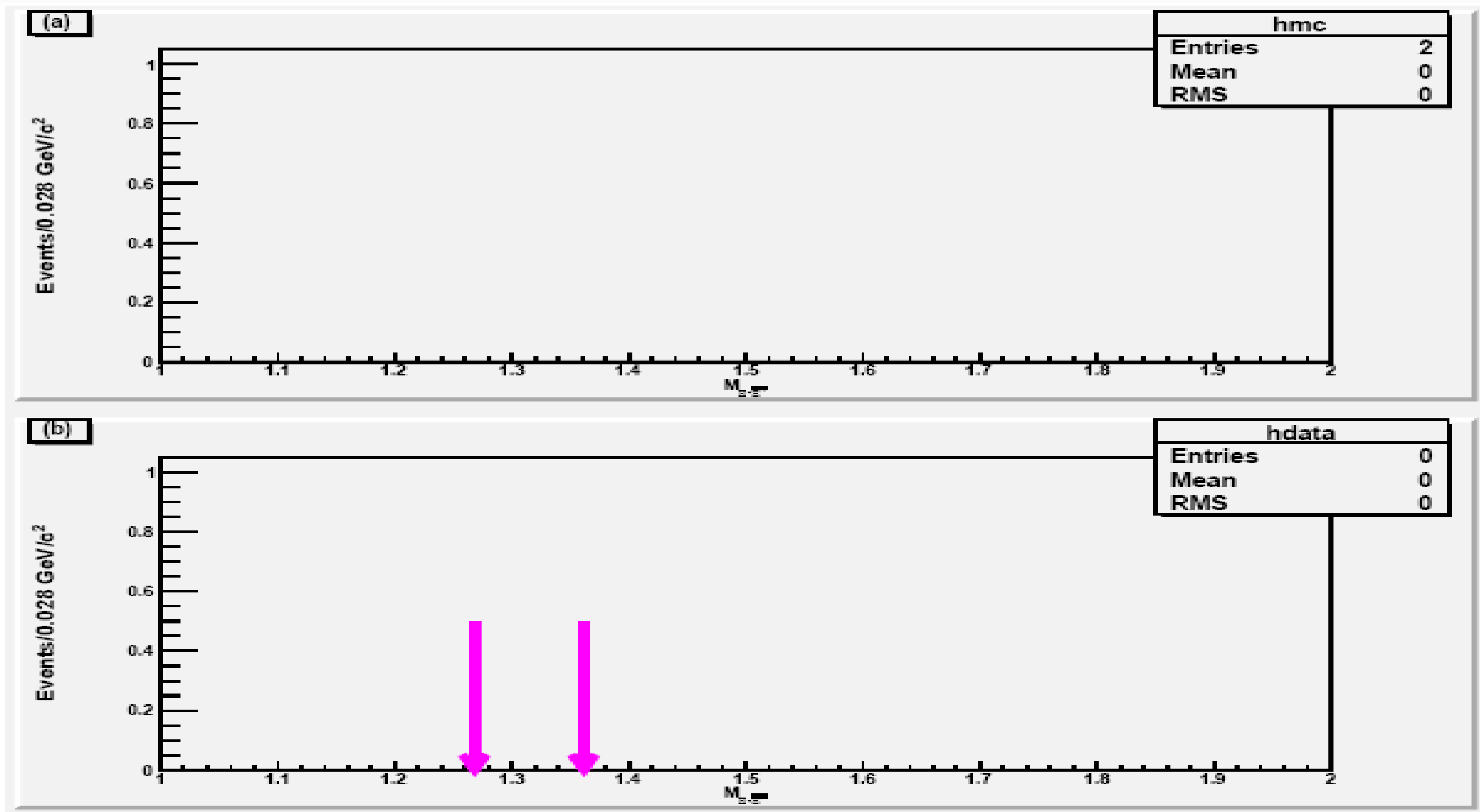
MC and Data invariant mass of $\Xi \to \overline{p}\pi^{+}\gamma\gamma$ after applying cuts for $\psi(2S) \to \Lambda\overline{\Xi}$



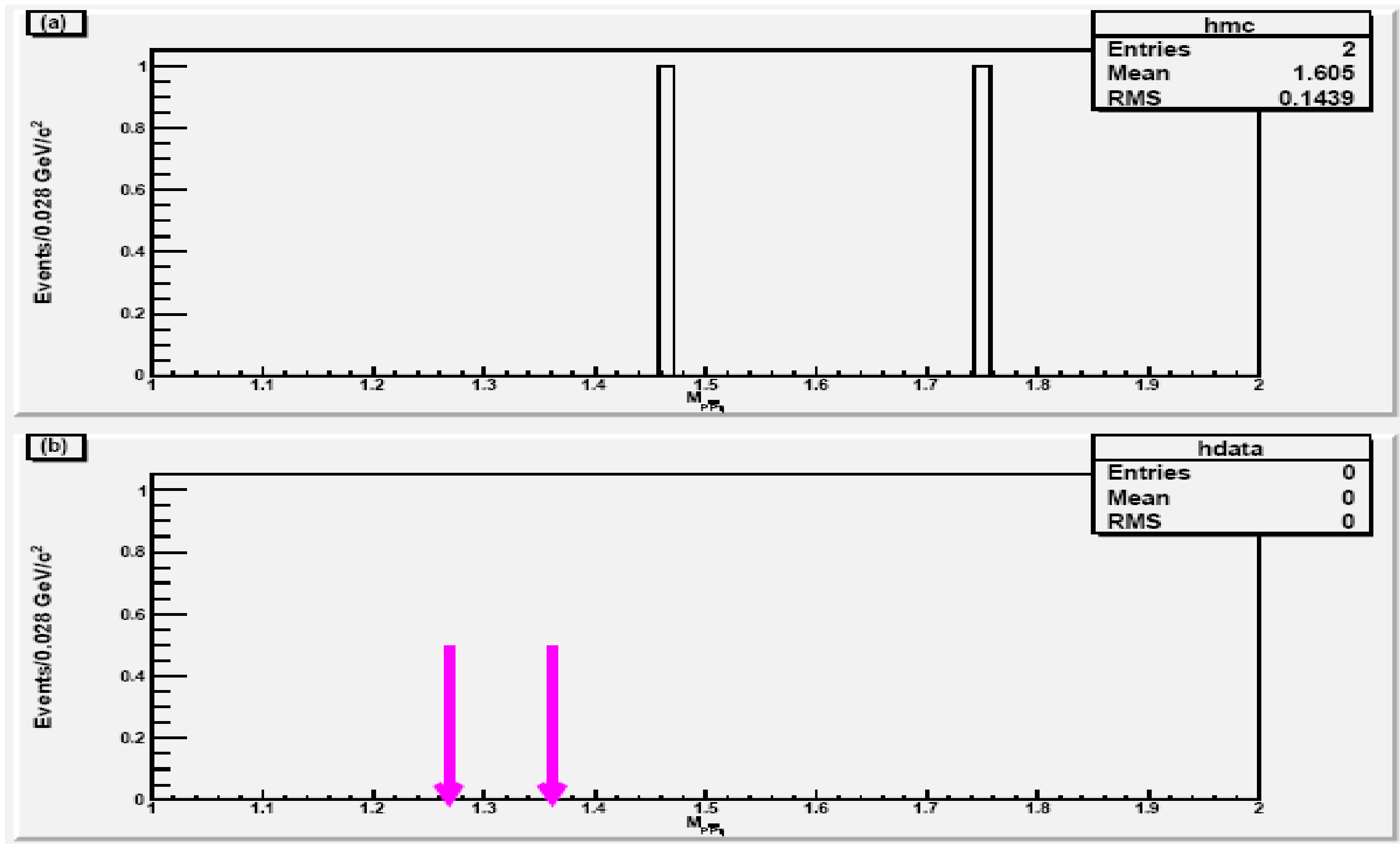
Observed background channels for $\psi(2S) \to \Lambda\overline{\Xi}$ using 10^5 MC events

background channel	number of events	Normalized events	Branching fraction
$\Xi^-\overline{\Xi}^+$	2	0	$(2.64 \pm 0.18) \times 10^{-4}$
$P\overline{P}\eta$	2	0	$(6.0 \pm 0.4) \times 10^{-5}$
$\Lambda\overline{\Lambda}\pi^0$	1	0	$< 2.9 \times 10^{-6}$
$P\overline{P}\acute{\eta}$	2	0	—
$P\overline{P}\omega$	0	0	$(6.9 \pm 2.1) \times 10^{-5}$
$P\overline{P}\pi^+\pi^-$	0	0	$(6.0 \pm 0.4) \times 10^{-4}$
$P\overline{P}\pi^+\pi^-\pi^0$	1	0	$(7.3 \pm 0.7) \times 10^{-4}$
$P\overline{P}\rho$	2	0	$(5.0 \pm 2.2) \times 10^{-5}$
$\Lambda\overline{\Lambda}\eta$	1	0	$(2.5 \pm 0.4) \times 10^{-5}$
$\Lambda\overline{\Lambda}$	0	0	$(3.57 \pm 0.18) \times 10^{-4}$
$\Sigma^0\overline{\Sigma^0}$	0	0	$(2.32 \pm 0.16) \times 10^{-4}$

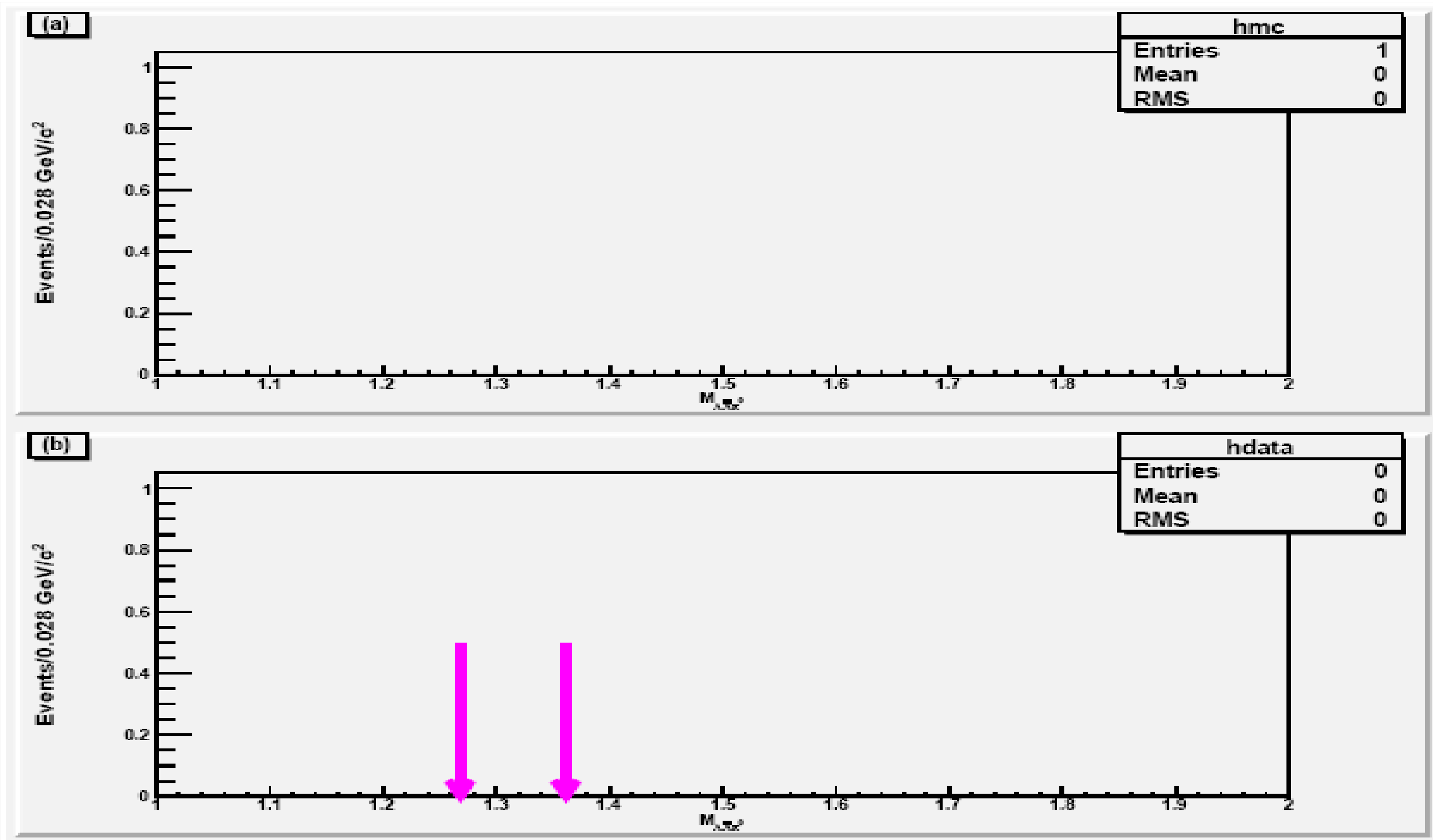
(a) Invariant mass distribution of $M_{\Xi^-\overline{\Xi}^+}$ for $J/\psi \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{\Xi^-\overline{\Xi}^+}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $J/\psi \to \Lambda\overline{\Xi}$



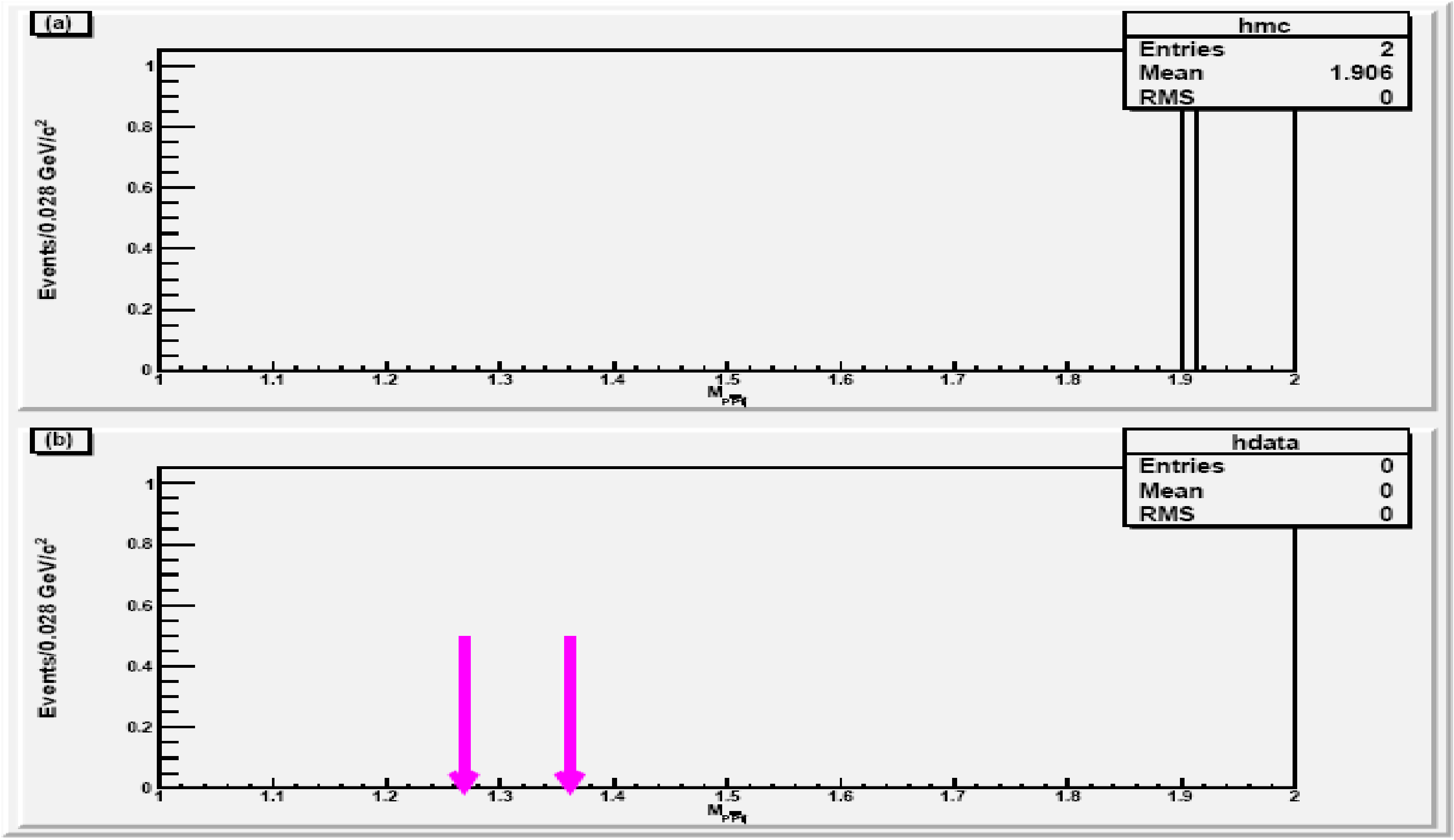
(a) Invariant mass distribution of $M_{p\bar{p}_\eta}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}_\eta}$ with mass window cut $|M_{\bar{p}\pi+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\overline{\psi(2S)} \to \Lambda\Xi$



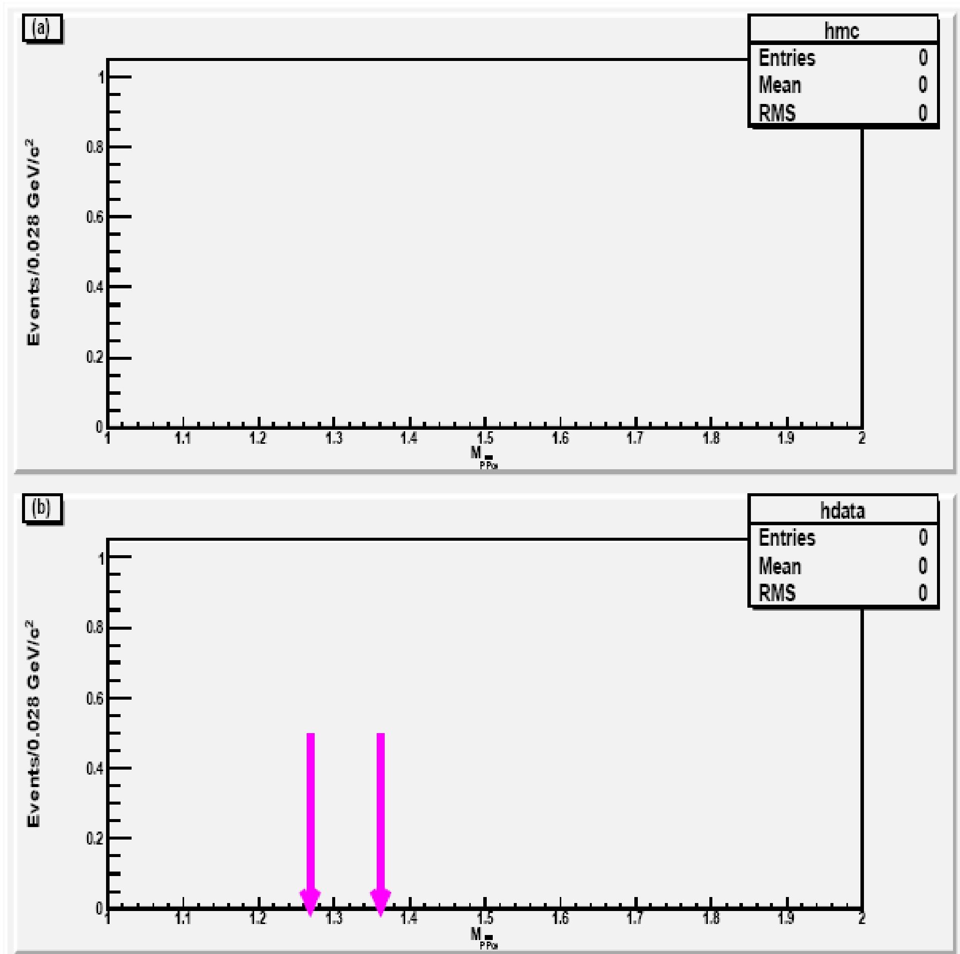
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\pi^0}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\pi^0}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\overline{\psi(2S)} \to \Lambda\Xi$



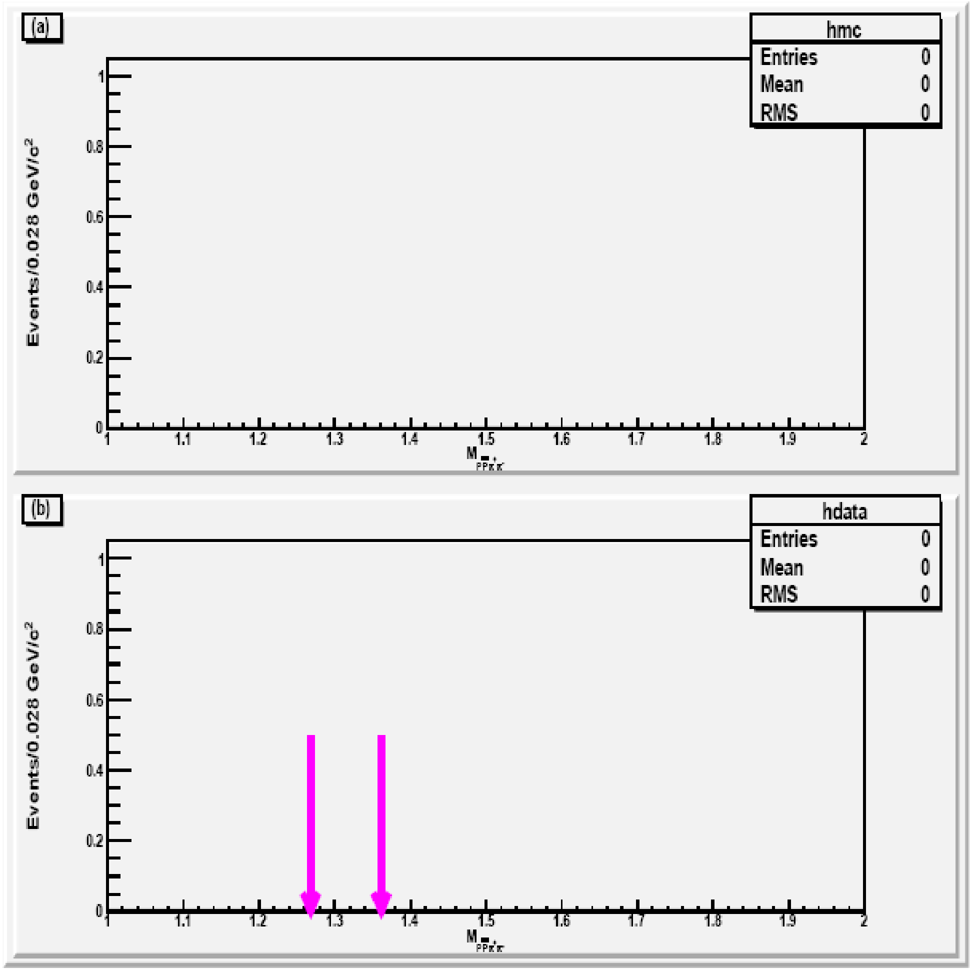
(a) Invariant mass distribution of $M_{p\bar{p}\acute{\eta}}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\acute{\eta}}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



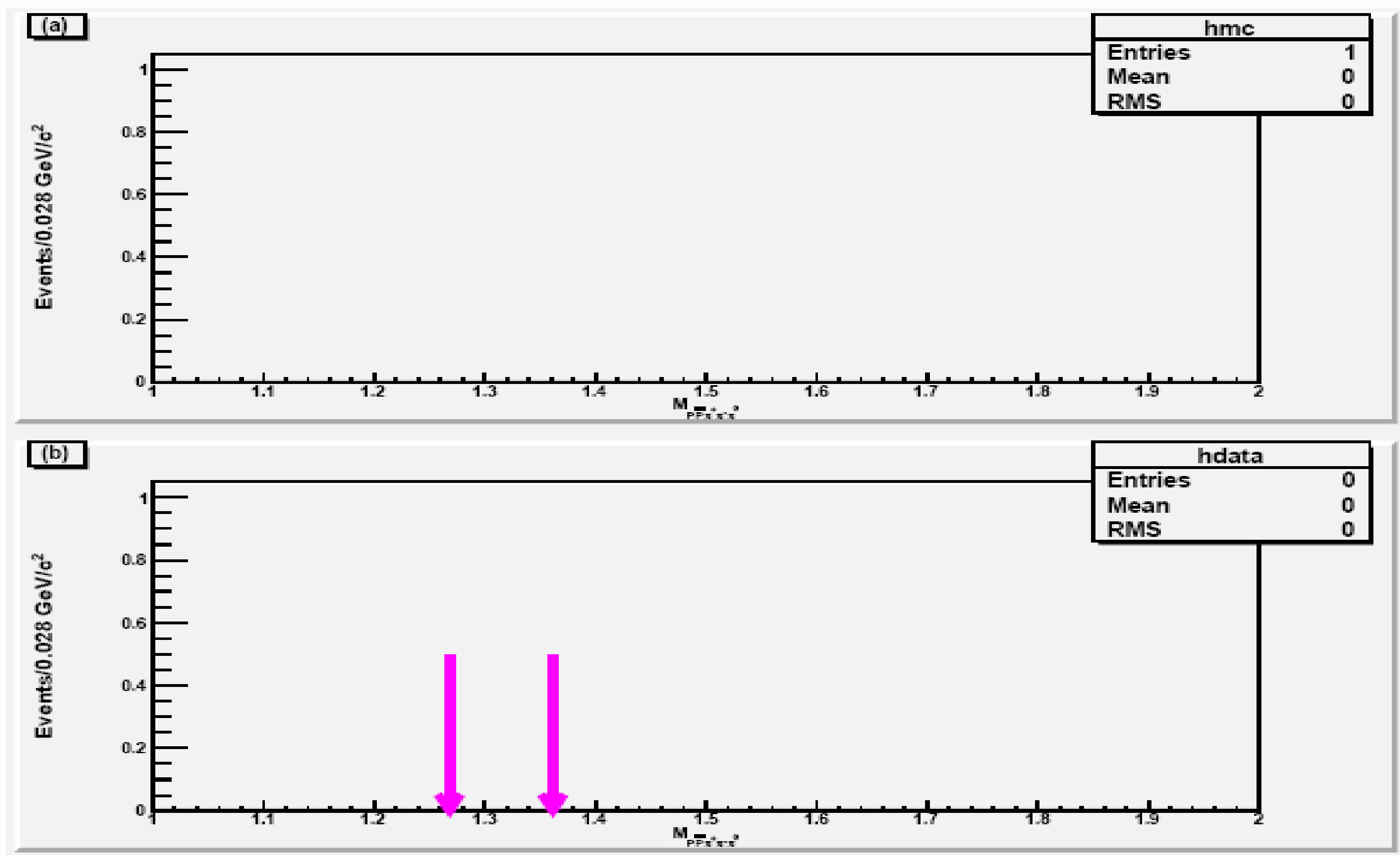
(a) Invariant mass distribution of $M_{p\overline{p}\omega}$ for $\psi(2S) \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{p\overline{p}\omega}$ with mass window cut $|M_{\overline{p}\pi^{+}\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $\overline{\psi}(2S) \to \Lambda\Xi$



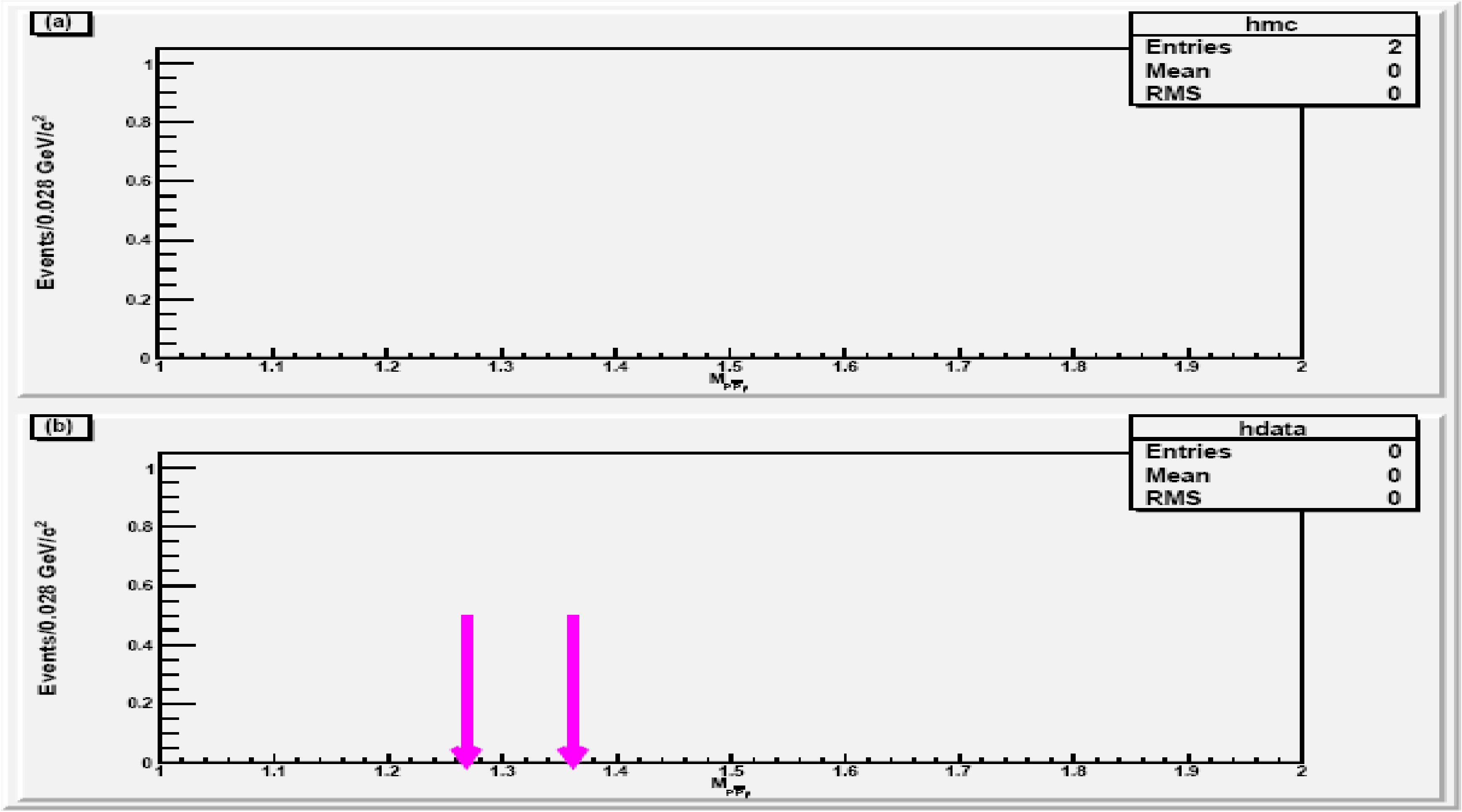
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



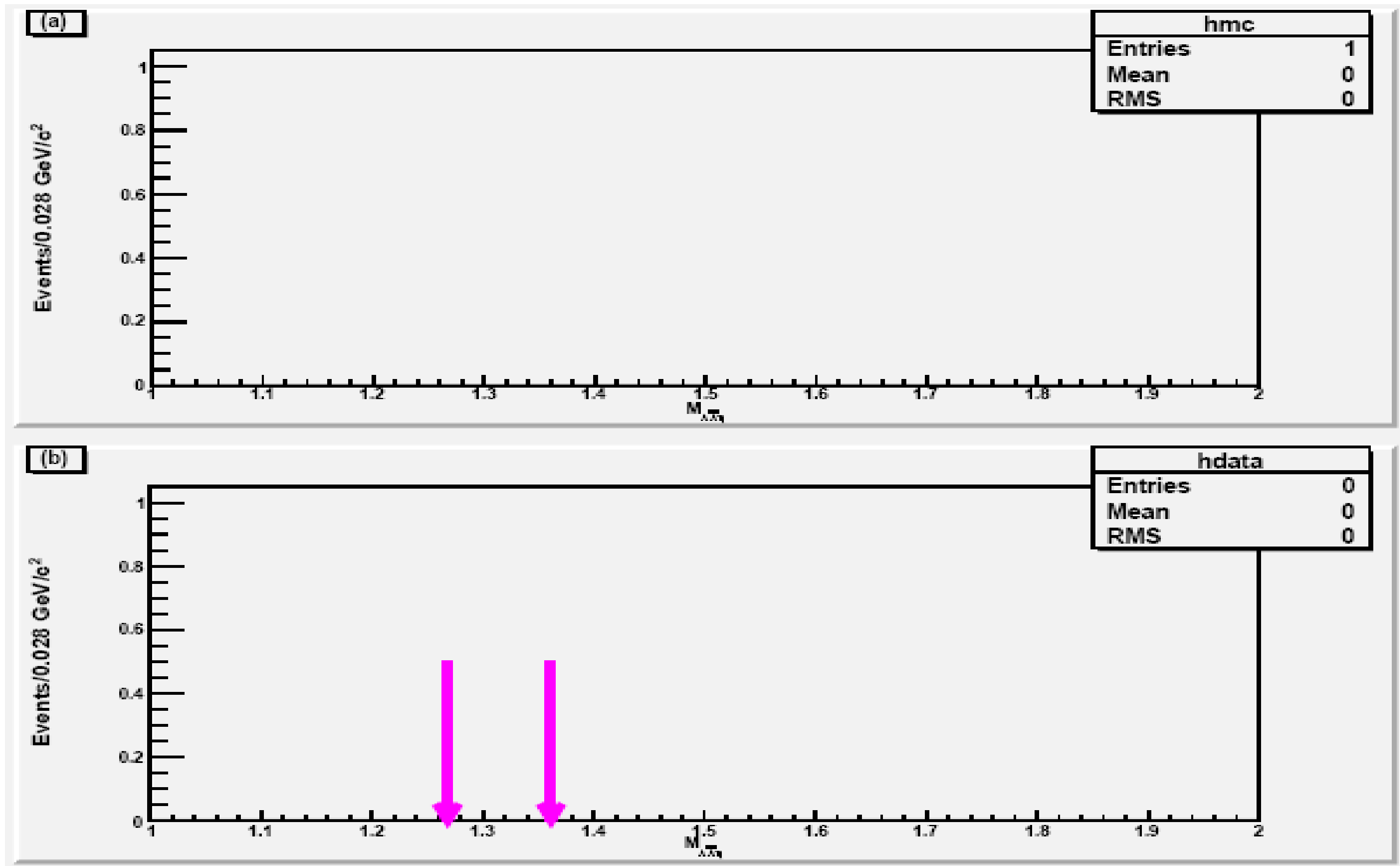
(a) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{p\bar{p}\pi^+\pi^-\pi^0}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



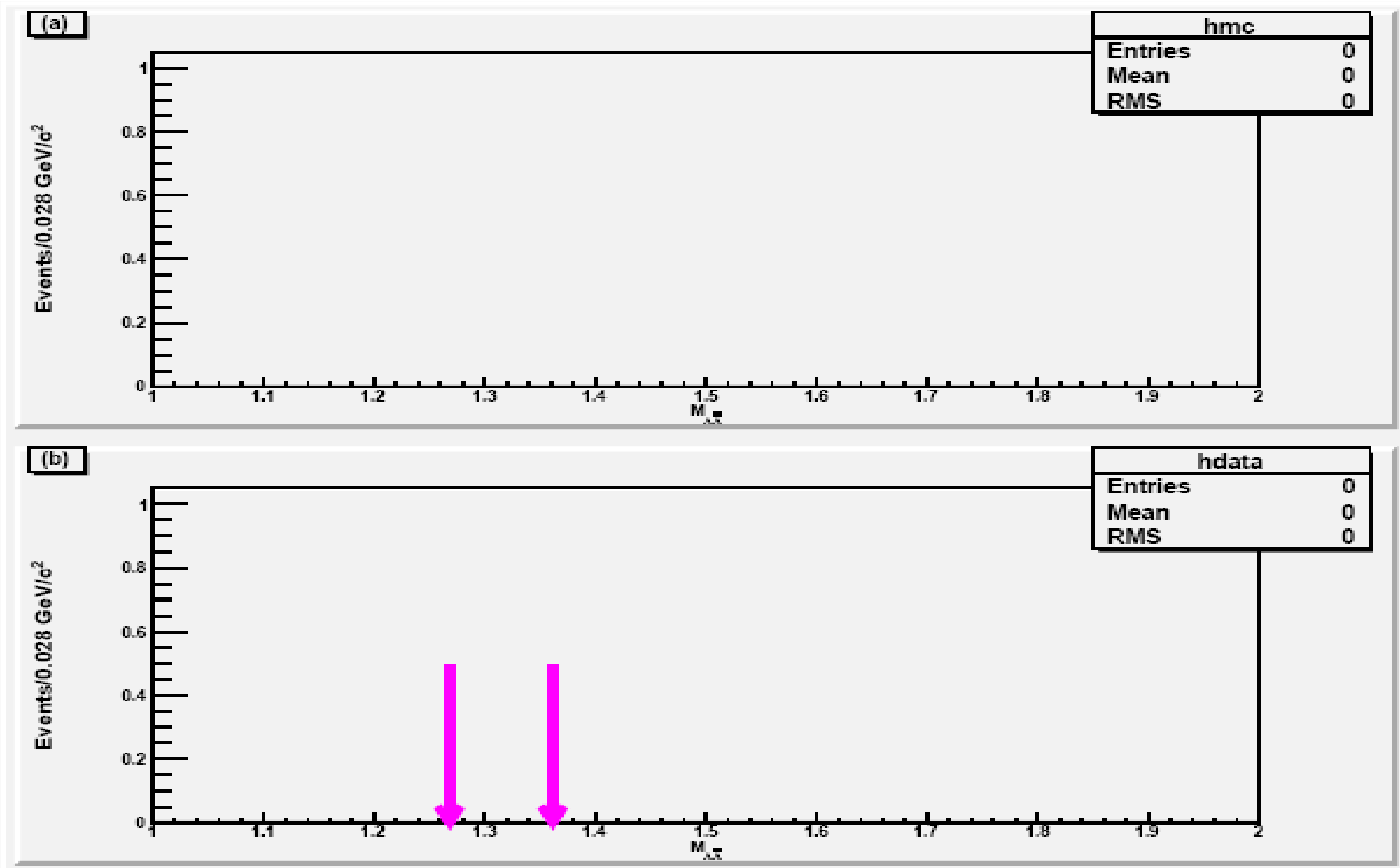
(a) Invariant mass distribution of $M_{p\overline{p}\rho}$ for $\psi(2S) \to \Lambda\overline{\Xi}$. (b) Invariant mass distribution of $M_{p\overline{p}\rho}$ with mass window cut $|M_{\overline{p}\pi^+\gamma\gamma} - M_{\overline{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\overline{\Xi}$



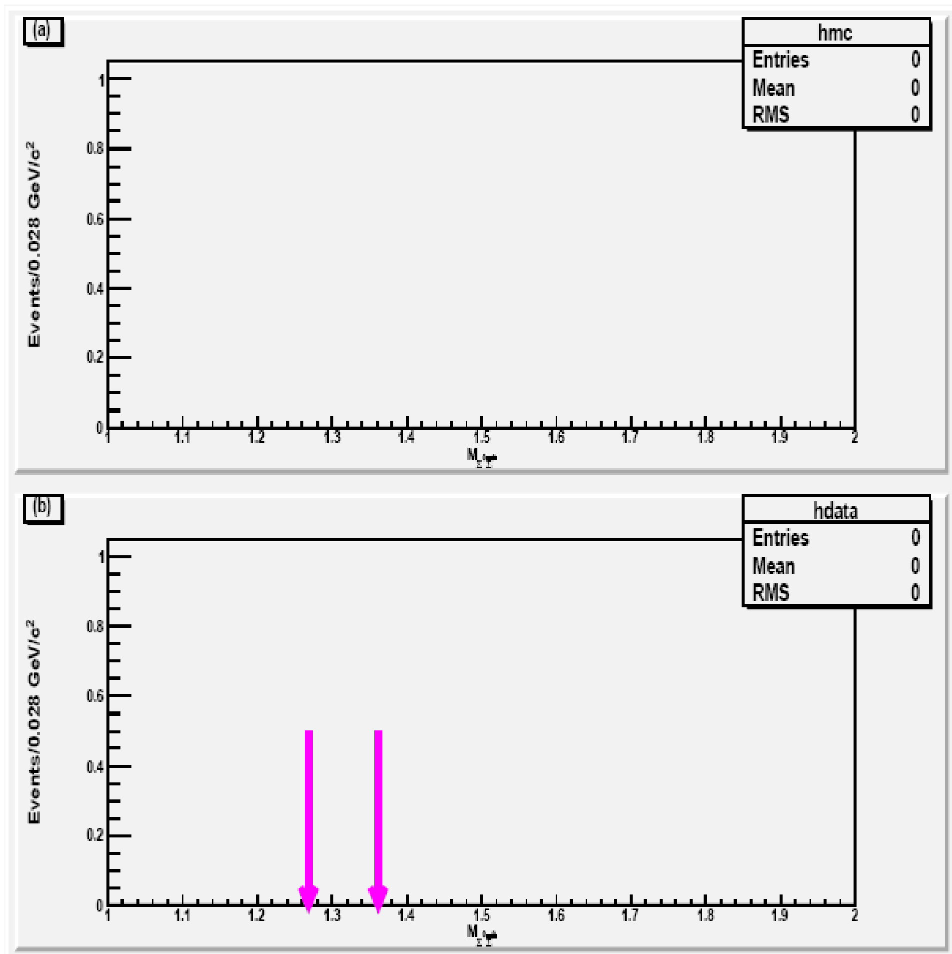
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}\eta}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



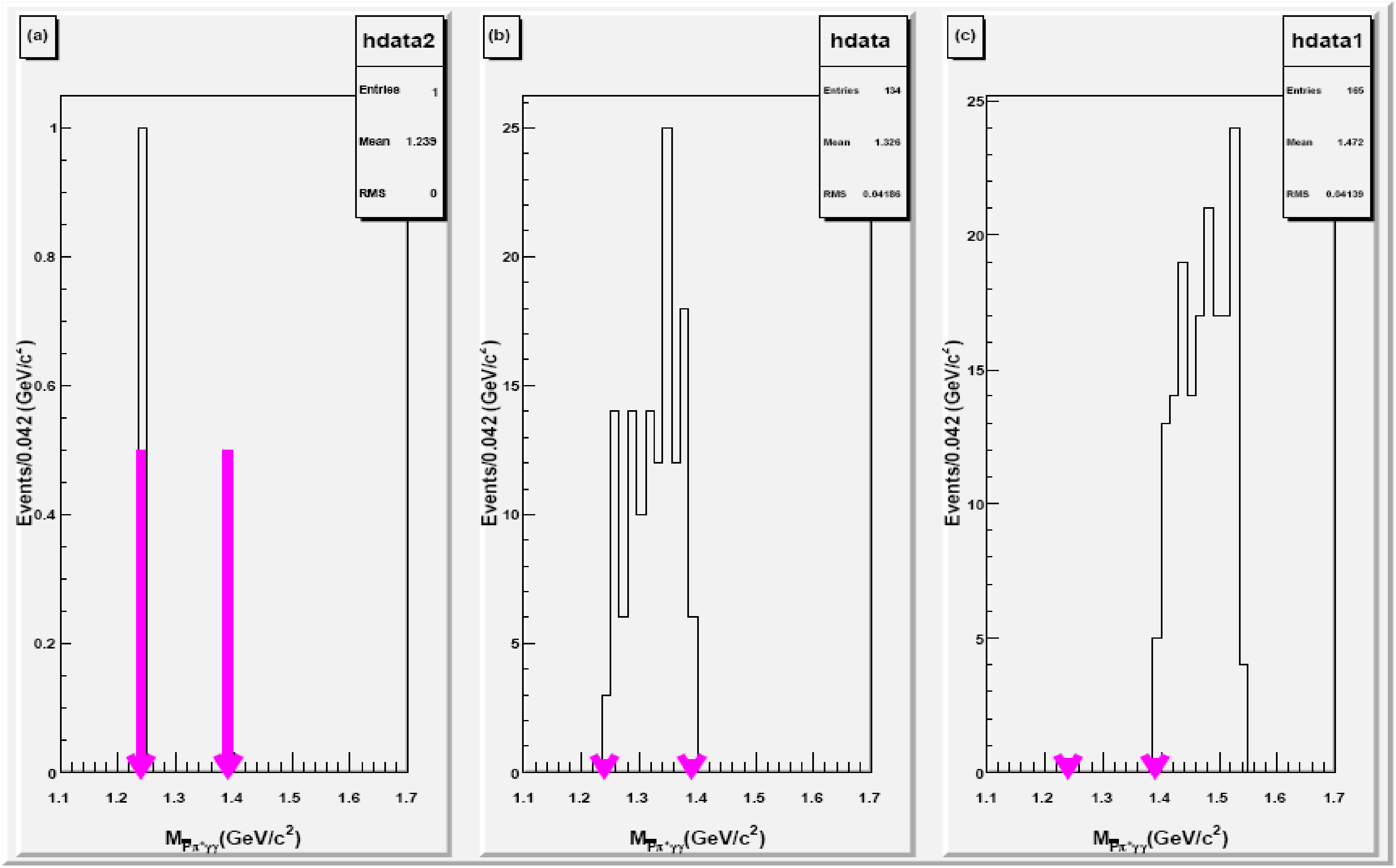
(a) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Lambda\bar{\Lambda}}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



(a) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ for $\psi(2S) \to \Lambda\bar{\Xi}$. (b) Invariant mass distribution of $M_{\Sigma^0\bar{\Sigma}^0}$ with mass window cut $|M_{\bar{p}\pi^+\gamma\gamma} - M_{\bar{\Xi}}| < 0.0467$ for $\psi(2S) \to \Lambda\bar{\Xi}$



Sideband Analysis for $\psi(2S) \to \Lambda\overline{\Xi}$



Calculated Upper Limit at 95% Confidence Level for $\psi(2S) \rightarrow \Lambda\overline{\Xi}$

Formula for the calculation of upper limit is given bellow

$$B(J/\psi \rightarrow B\overline{B}) \leq \frac{N_{obs}}{N_{J/\psi} \times \varepsilon \times B_i}$$

Here N_{obs}, ε and B_i epresents number of observed signal events, detection efficiency and intermediate branching fraction . The calculated branching fraction is

$$B(\psi(2S) \rightarrow \Lambda\overline{\Xi}) < 0.12 \times 10^{-6}$$

The systematic errors for $\psi(2S) \to \Lambda\overline{\Delta}, \Lambda\overline{\Sigma}, \Lambda\overline{\Xi}$

Sources	% error for $\Lambda\overline{\Delta}$	% error for $\Lambda\overline{\Sigma}$	% error for $\Lambda\overline{\Xi}$
MDC Tracking (Ablikim et al., 2017)	8	8	8
PID (Ablikim et al., 2017)	4	5	6
$\psi(2S)$ number (Ablikim et al., 2017)	2.9	2.9	2.9
$\Lambda \to P\pi^-$ (Patrignani et al., 2016)	0.5	0.5	0.5
$\overline{\Sigma^0} \to \overline{p}\pi^+\gamma$ (Patrignani et al., 2016)	–	0	–
$\overline{\Xi} \to \overline{\Lambda}\pi^0$ (Patrignani et al., 2016)	–	–	0.012
Total error	9.41	9.88	10.42

Results

- Calculated Branching fraction and upper limits are

$B(J/\psi \rightarrow \Lambda\overline{\Sigma}) = (1.8 \pm 0.19) \times 10^{-6}$ $B(\psi(2S) \rightarrow \Lambda\overline{\Sigma}) < (6.6 \pm 0.098) \times 10^{-8}$

$B(J/\psi \rightarrow \Lambda\overline{\Delta}) < (8.0 \pm 0.18) \times 10^{-9}$ $B(\psi(2S) \rightarrow \Lambda\overline{\Delta}) < (2.1 \pm 0.094) \times 10^{-8}$

$B(J/\psi \rightarrow \Lambda\overline{\Xi}) < (7.14 \pm 0.2) \times 10^{-8}$ $B(\psi(2S) \rightarrow \Lambda\overline{\Xi}) < (1.2 \pm 0.01) \times 10^{-7}$

Thanks