
بسم الله الرحمن الرحيم
إبراهيم ١٤٢١

Search for $(J/\psi\ ,\ \psi(2S))$ Decays into $P\overline{P}K_S^0$

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Charmonium Group Meeting, April 17, 2019

Outline

- Overview
- Motivation
- Data Analysis
- Results
- Conclusions

Motivation

- In this study we searched isospin and strangeness violating decay, which is highly suppressed but kinematically it is possible.

- To find any hint beyond the Standard Model of Particle Physics.

- This work is based upon the analysis of $J/\psi \to P\bar{P}K_S^0$ and try to measure its branching fraction using the large statistics at BESIII.

Initial Events Selection

- **Charged tracks**
  - **4 good tracks and |cosθ|<0.93.**
  - **$\Sigma Q_i=0$**
- **PID**

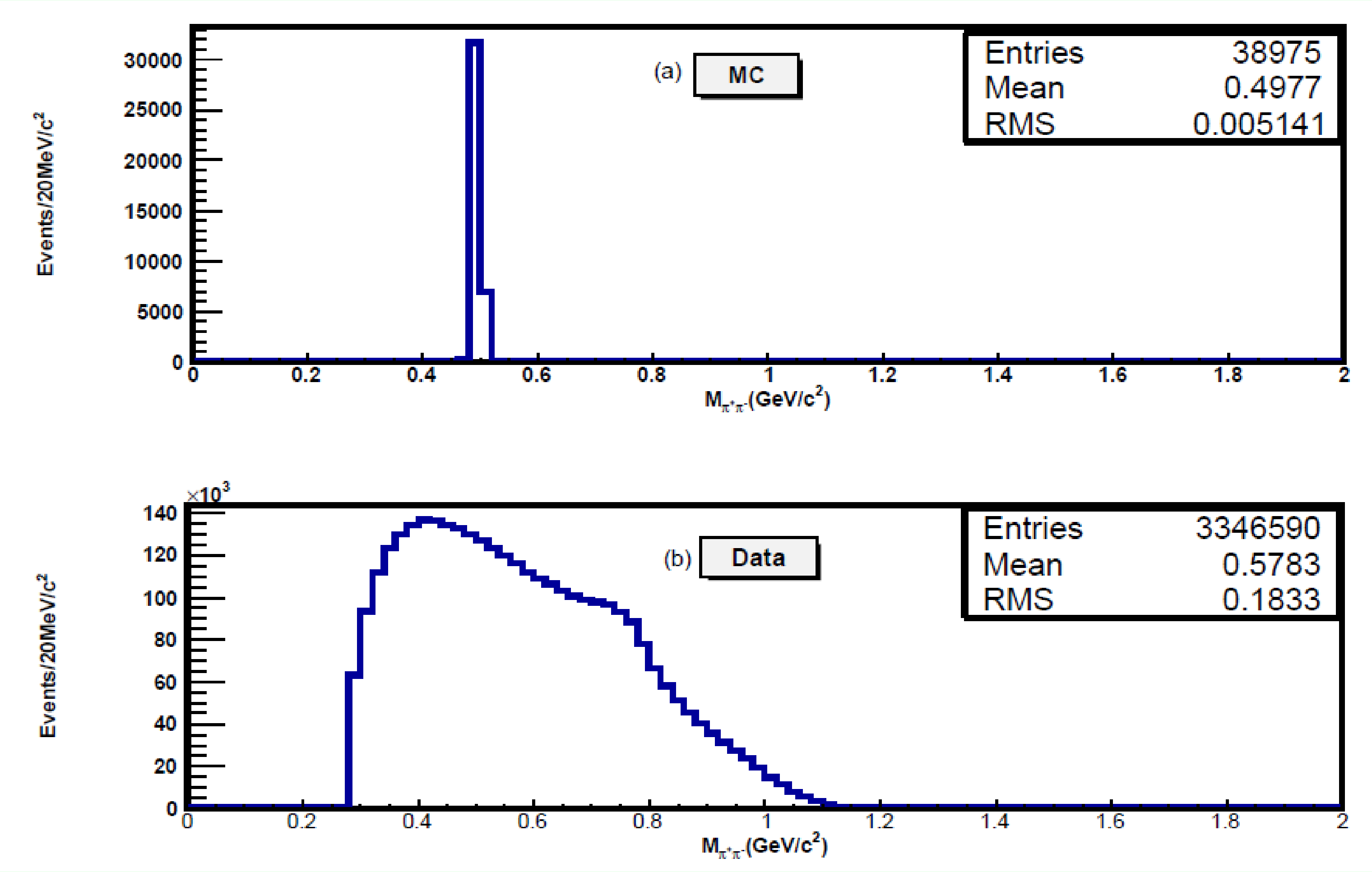
  dE/dx and TOF information are combined to identify particles.

  - For pion identification, it is required that $prob(\pi) > prob(K)$ and $prob(\pi) > prob(P)$.
  - For proton identification, it is required that $prob(P) > prob(\pi)$ and $prob(P) > prob(K)$.

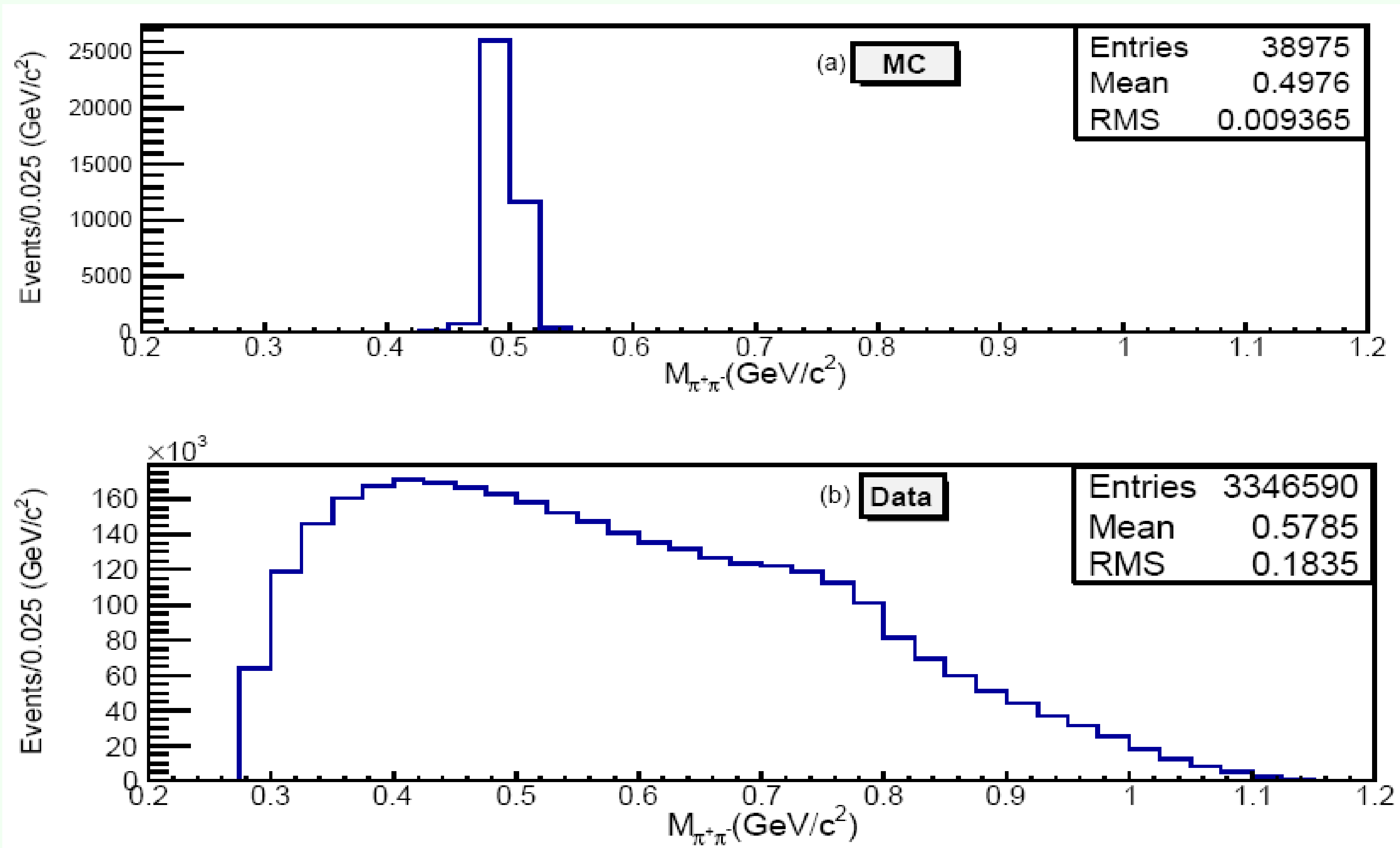
- **Pt > 0.5**

$V_{r0} = 1.0cm$ $\qquad$ $V_{z0} = 10.0cm$

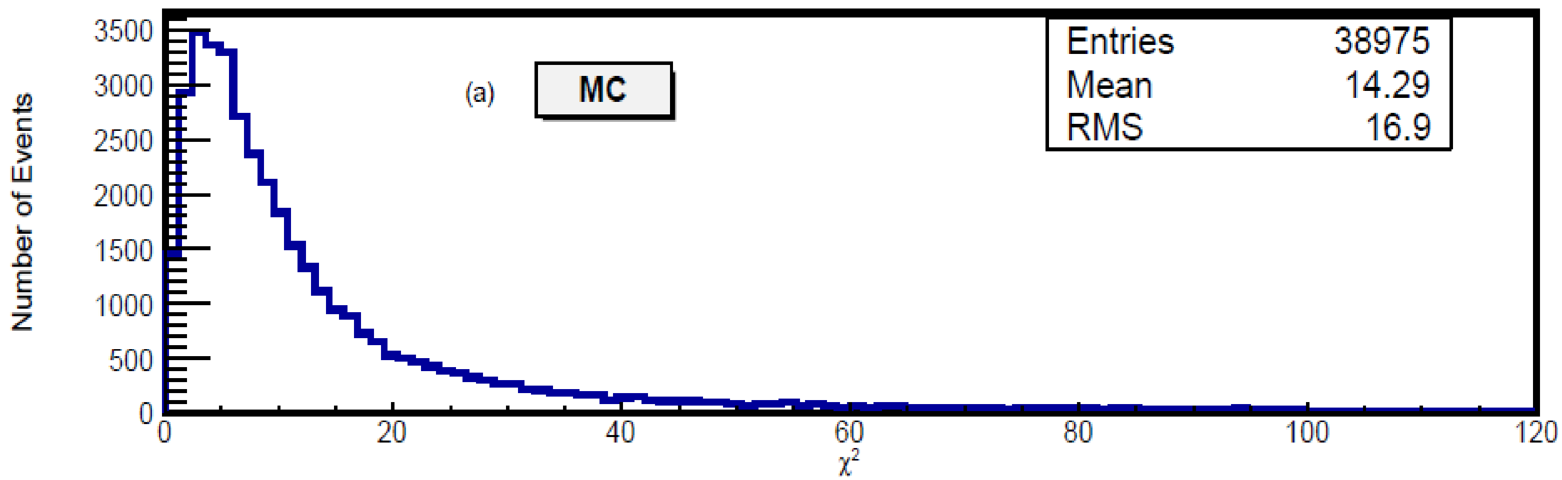
Selection of K_S^0 after Vertex Fitting

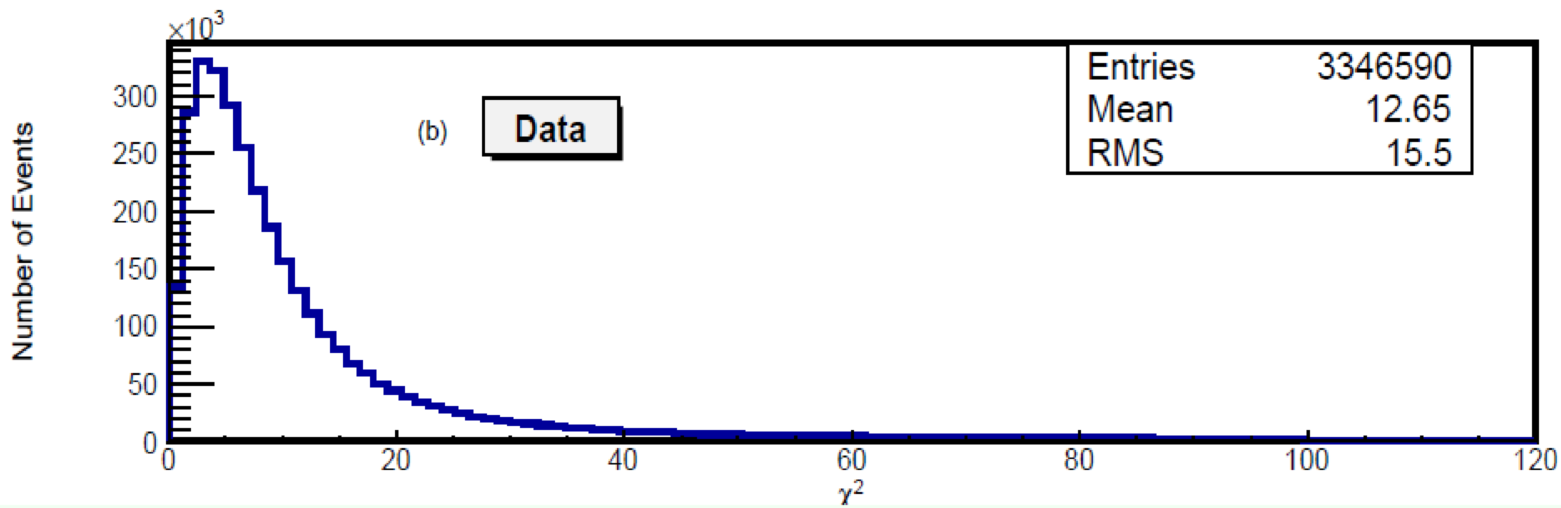


Selection of K_S^0 after Kinematic Fitting

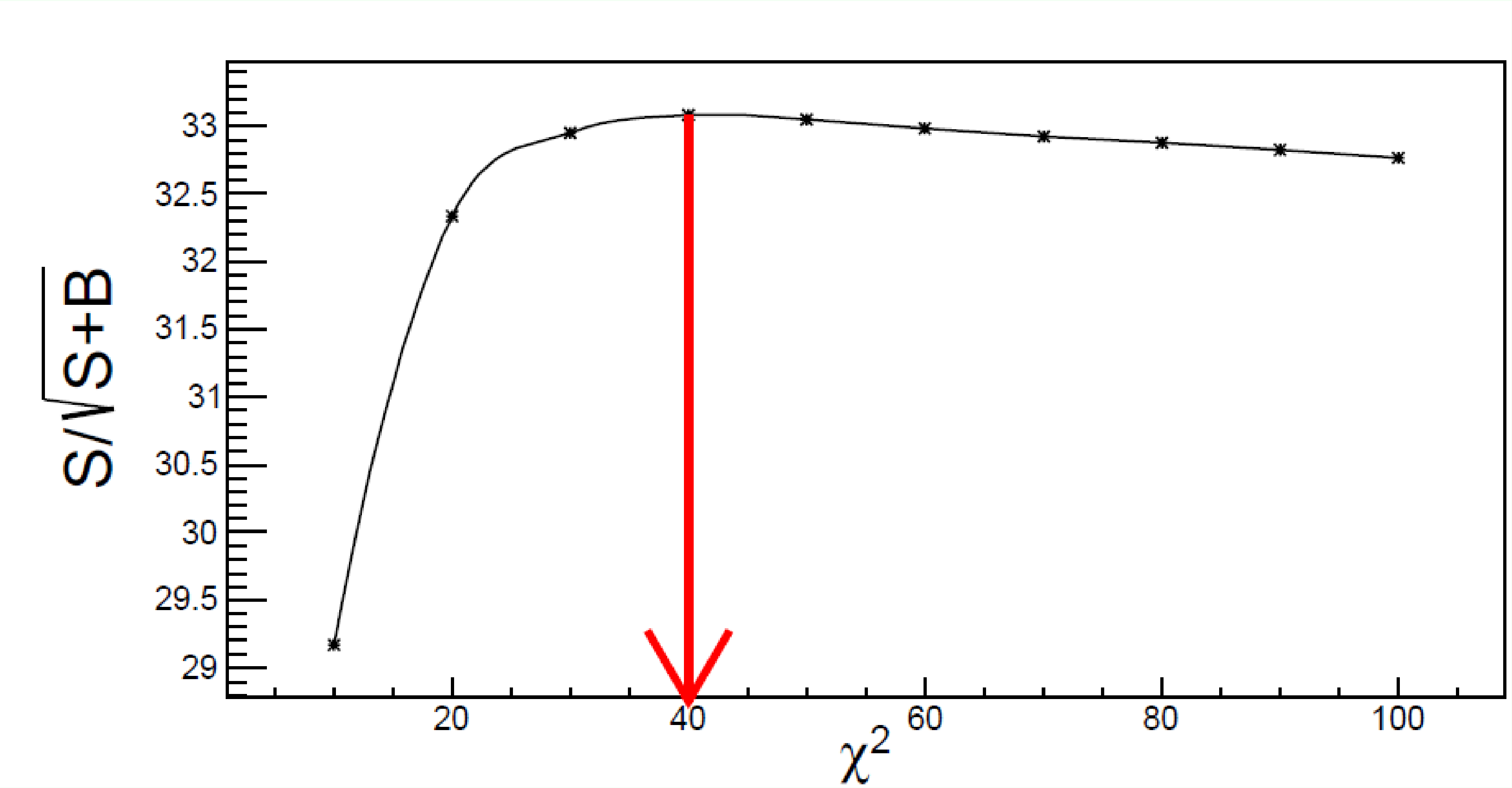


Optimized χ^2





Optimized χ^2



Final Event Selection

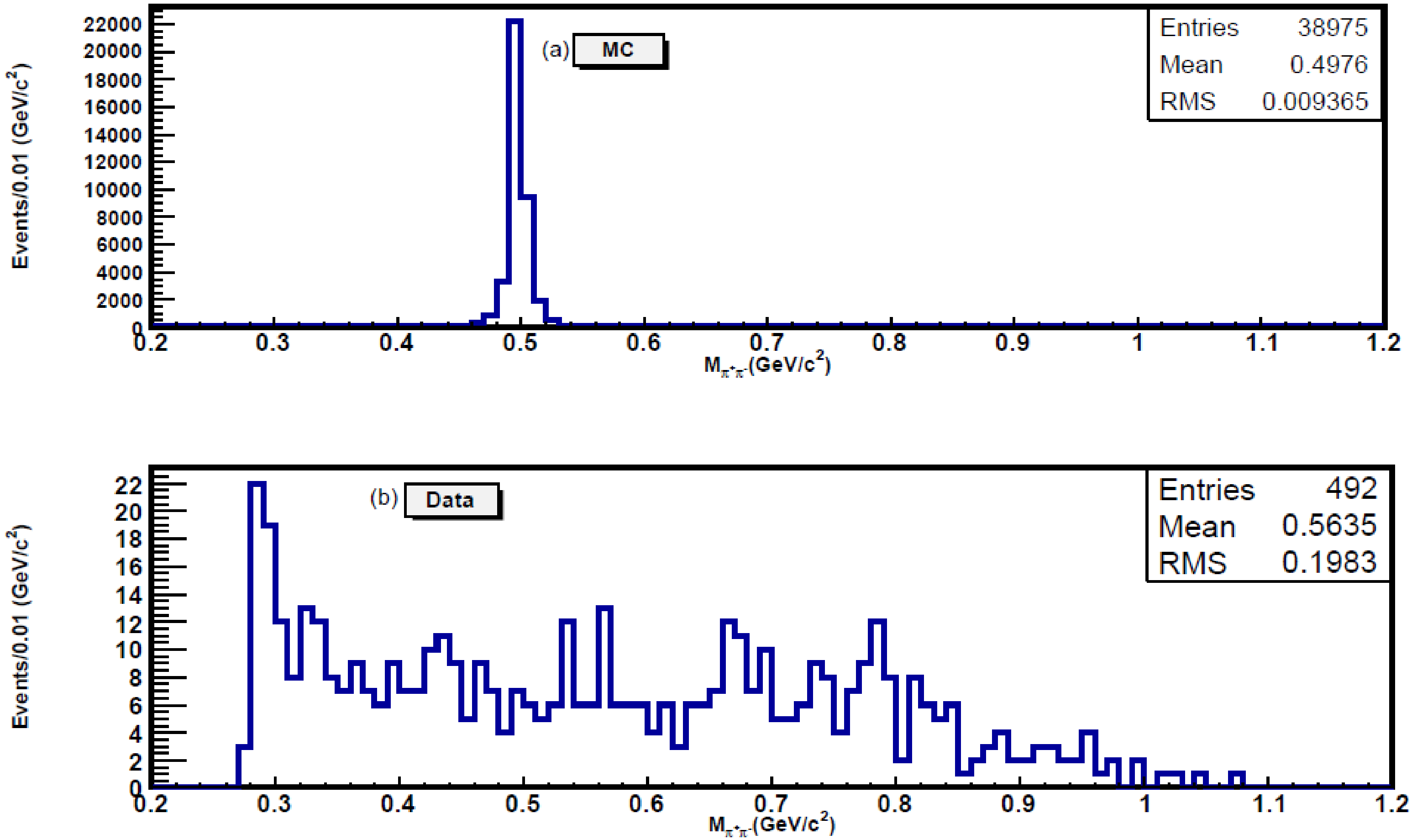
- $\chi^2_{4C} < 40$
- $|M_{P\pi^-} - 1.1156| > 0.015\ GeV/c^2$
- $|M_{\bar{P}\pi^+} - 1.1156| > 0.015\ GeV/c^2$
- $|M_{P\pi^+} - 1.232| > 0.25 GeV/c^2$
- $|M_{\bar{P}\pi^-} - 1.232| > 0.25 GeV/c^2$
- $|V_{zP}| < 10$ cm
- $|V_{rP}| < 1$ cm
- $|V_{z\bar{P}}| < 10$ cm
- $|V_{r\bar{P}}| < 1$ cm
- $|V_{r\pi^+}| < 1$ cm
- $|V_{z\pi^+}| < 10$ cm

Final selection criteria

$$Decay\ Length\ Ratio = \left|\frac{Decay\ Length\ of\ K_S^0}{Decay\ Length\ Error\ of\ K_S^0}\right| > 3$$

$$|M_{K_S^0} - 0.497| < 0.021$$

Invariant mass of $\pi^+\pi^-$ MC & Data after selection criteria



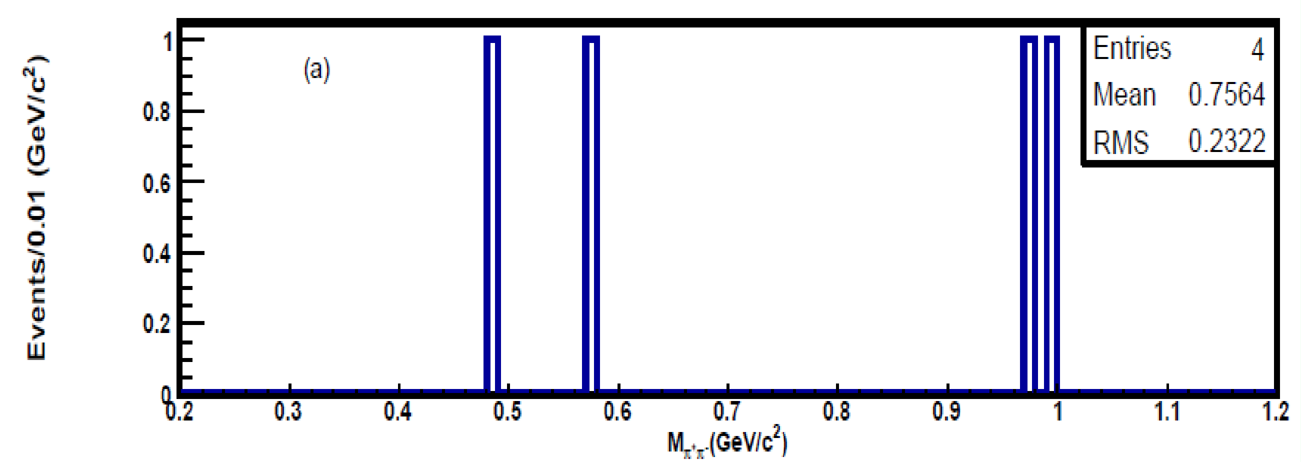
Inclusive Backgrounds

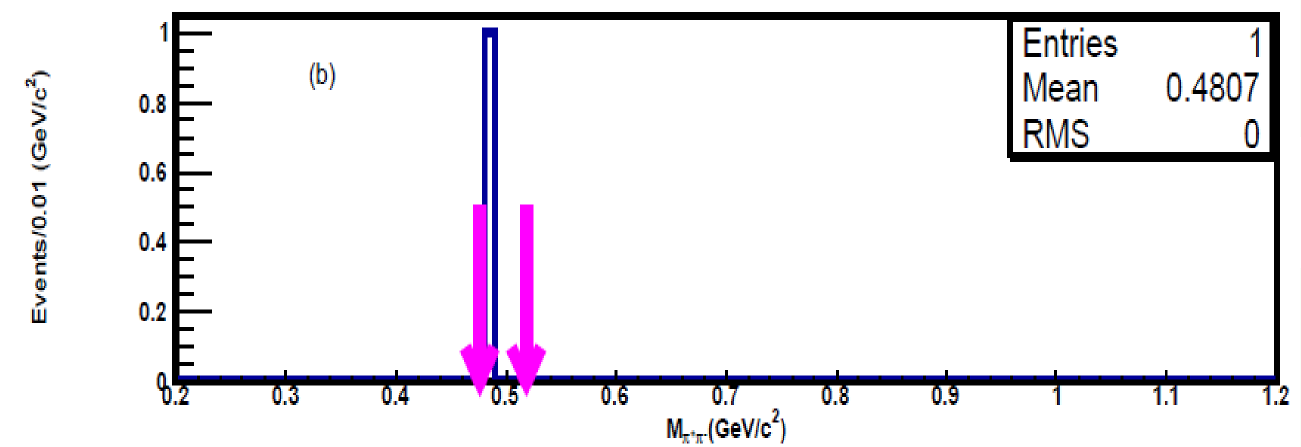
The Inclusive Backgrounds Obtained for $J/\psi \to P\bar{P}K_S^0$ Channel with $K_S^0 \to \pi^+\pi^-$

Channels	N_{gen}	Branching Fractions	N_{obs}
$J/\psi \to \Delta^{++}\pi^-\bar{P}$	100000	$(1.6 \pm 0.5) \times 10^{-3}$	0
$J/\psi \to \bar{\Delta}^{--}\pi^+P$	100000	-	1
$J/\psi \to \bar{\Delta}^0\pi^-P$	100000	-	1
$J/\psi \to \bar{P}P\pi^+\pi^-$	100000	$(6.0 \pm 0.5) \times 10^{-3}$	2
$J/\psi \to \Delta^0\bar{\Delta}^0$	100000	-	0
$J/\psi \to \Delta^{++}\bar{\Delta}^{--}$	100000	$(1.10 \pm 0.29) \times 10^{-3}$	0
$J/\psi \to \Lambda\bar{\Lambda}$	100000	$(1.61 \pm 0.15) \times 10^{-3}$	0
$J/\psi \to \pi^+\bar{P}\Delta^0$	100000	-	0
$J/\psi \to P\bar{P}f_0'$	100000	-	0
$J/\psi \to P\bar{P}f_2$	100000	-	0
$J/\psi \to P\bar{P}\omega$	100000	$(9.8 \pm 1.0) \times 10^{-4}$	0
$J/\psi \to P\bar{P}\rho$	100000	$< 3.1 \times 10^{-4}$ at $C.L = 90\%$	0

Inclusive Background

$$J/\psi \rightarrow \bar{\Delta}^{--}\pi^{+}P$$

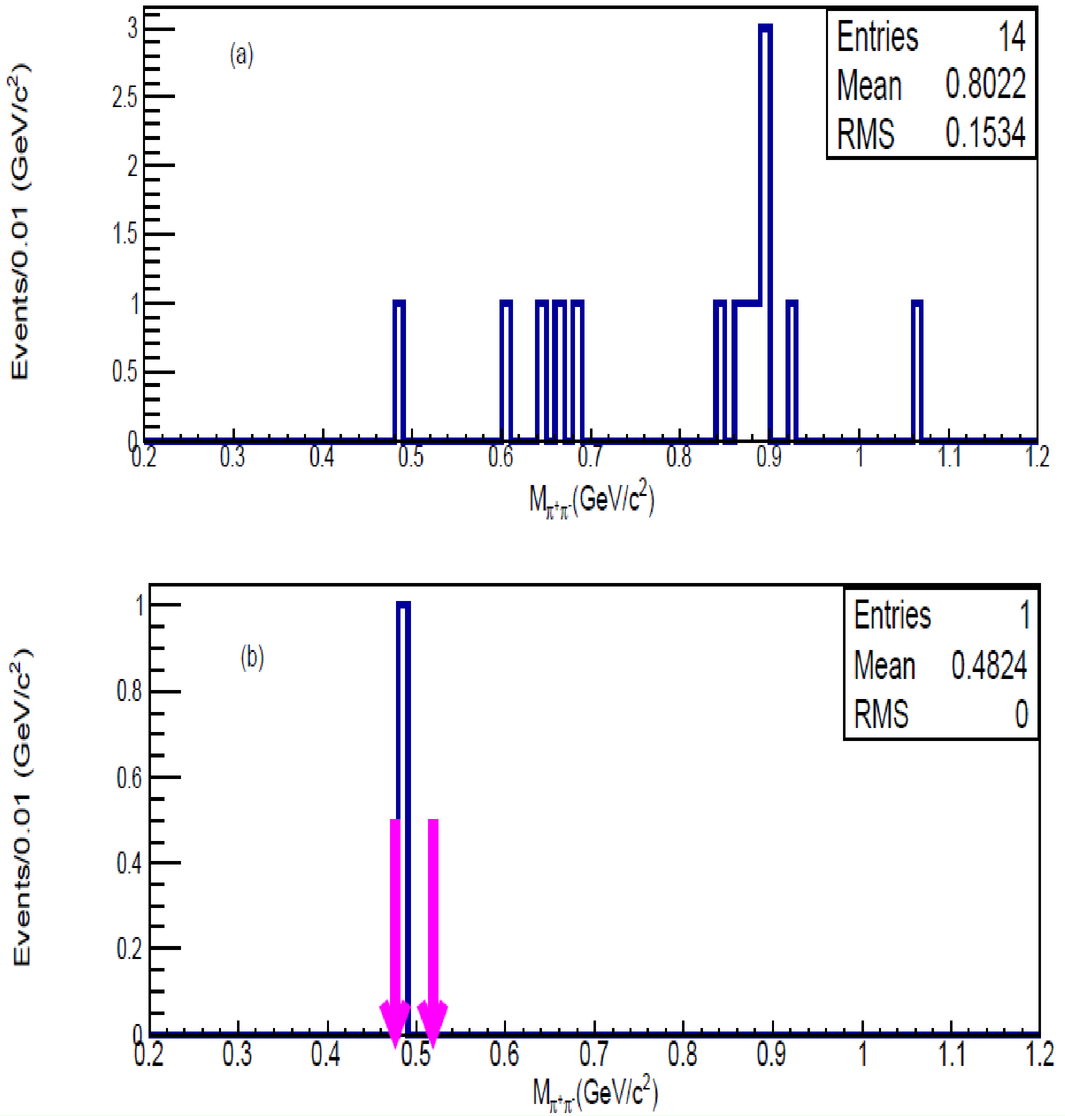




$$|M_{K_S^0} - 0.497| < 0.021$$

Cont…

Inclusive Background



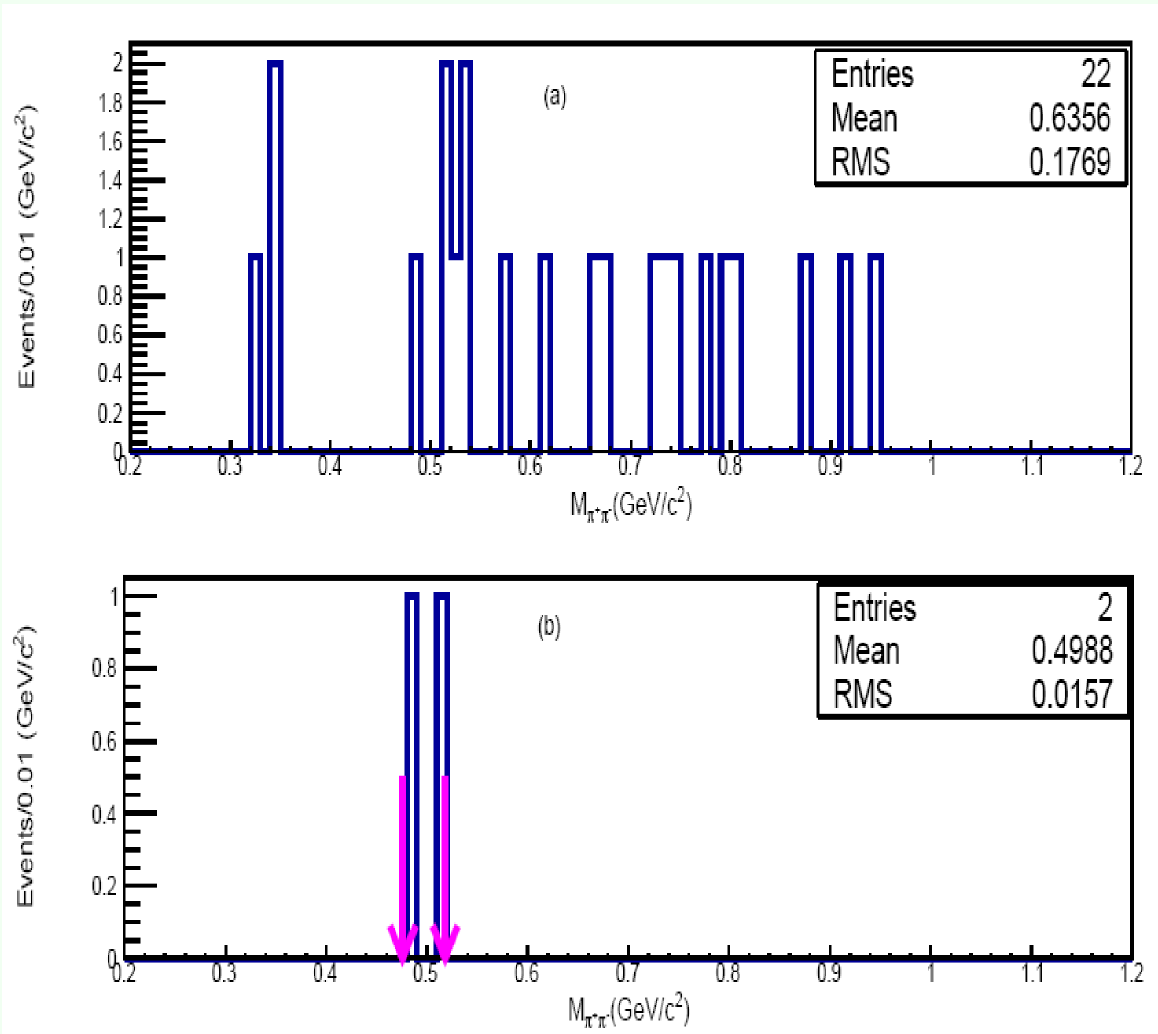
To suppress the channel

$$J/\psi \to \bar{\Delta}^0 \pi^- P$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



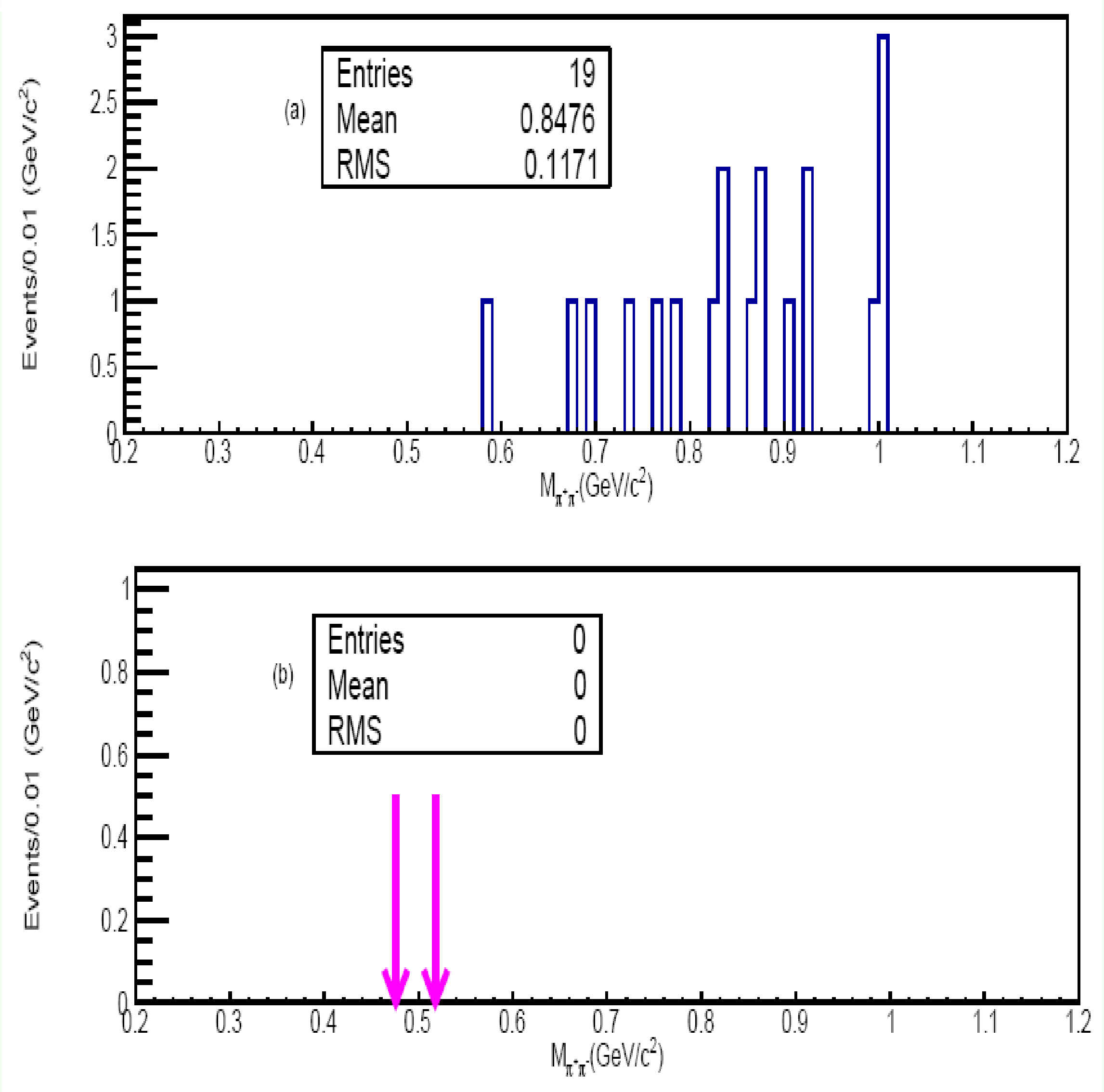
To suppress the channel

$$J/\psi \to \bar{P}P\pi^+\pi^-$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



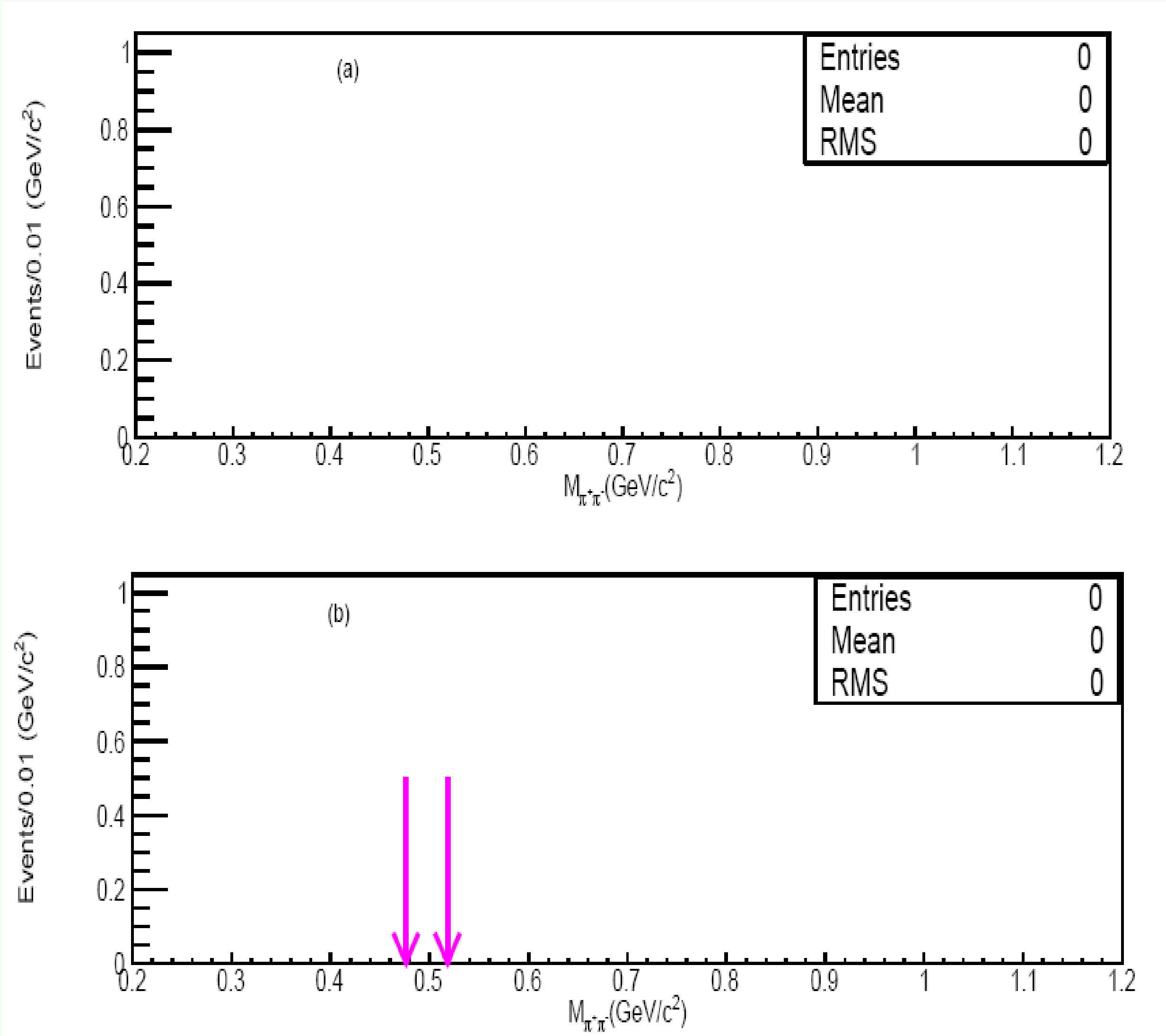
To suppress the channel

$$J/\psi \to \Delta^0\bar{\Delta}^0$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



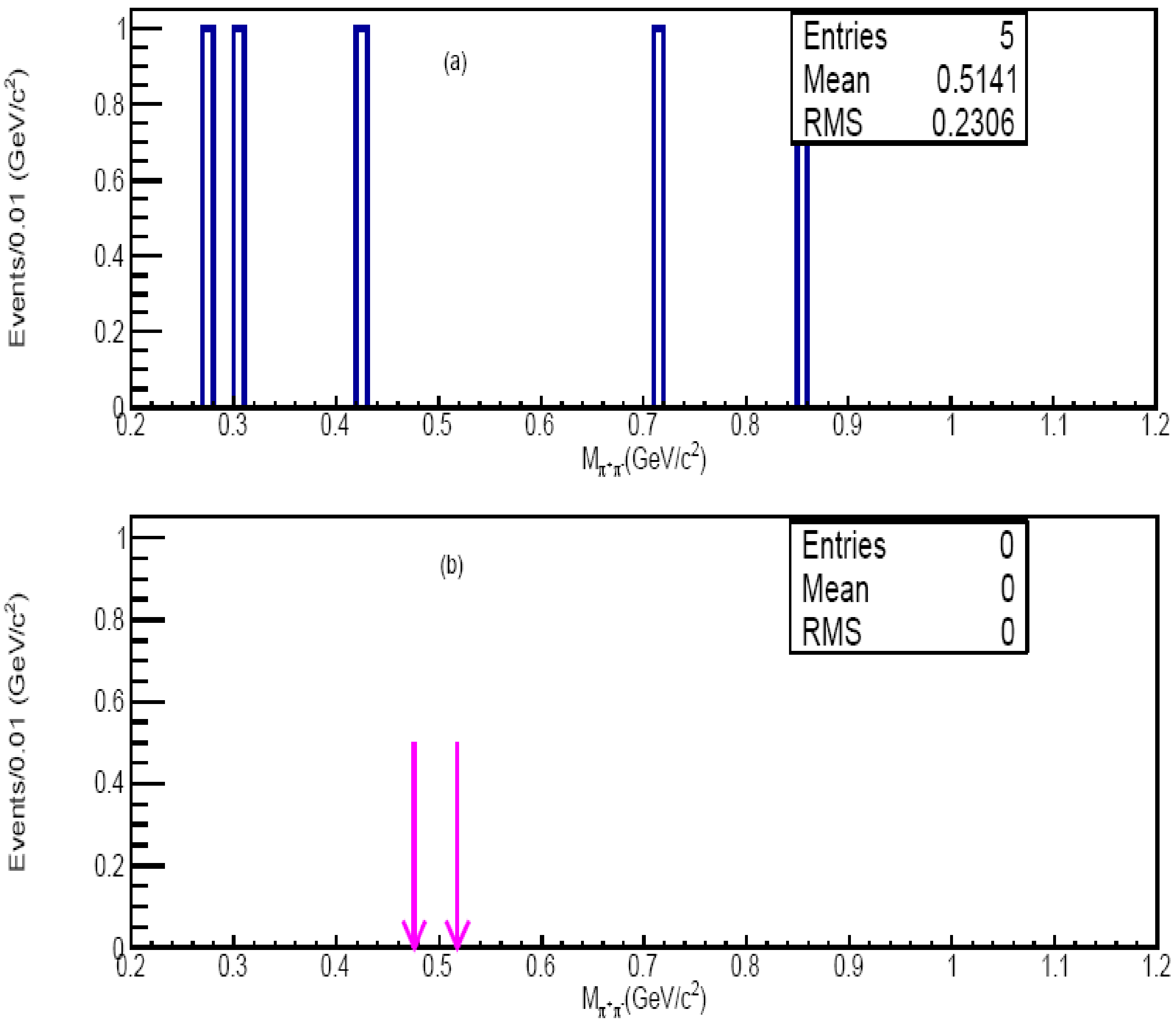
To suppress the channel

$$J/\psi \to \Delta^{++}\bar{\Delta}^{--}$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



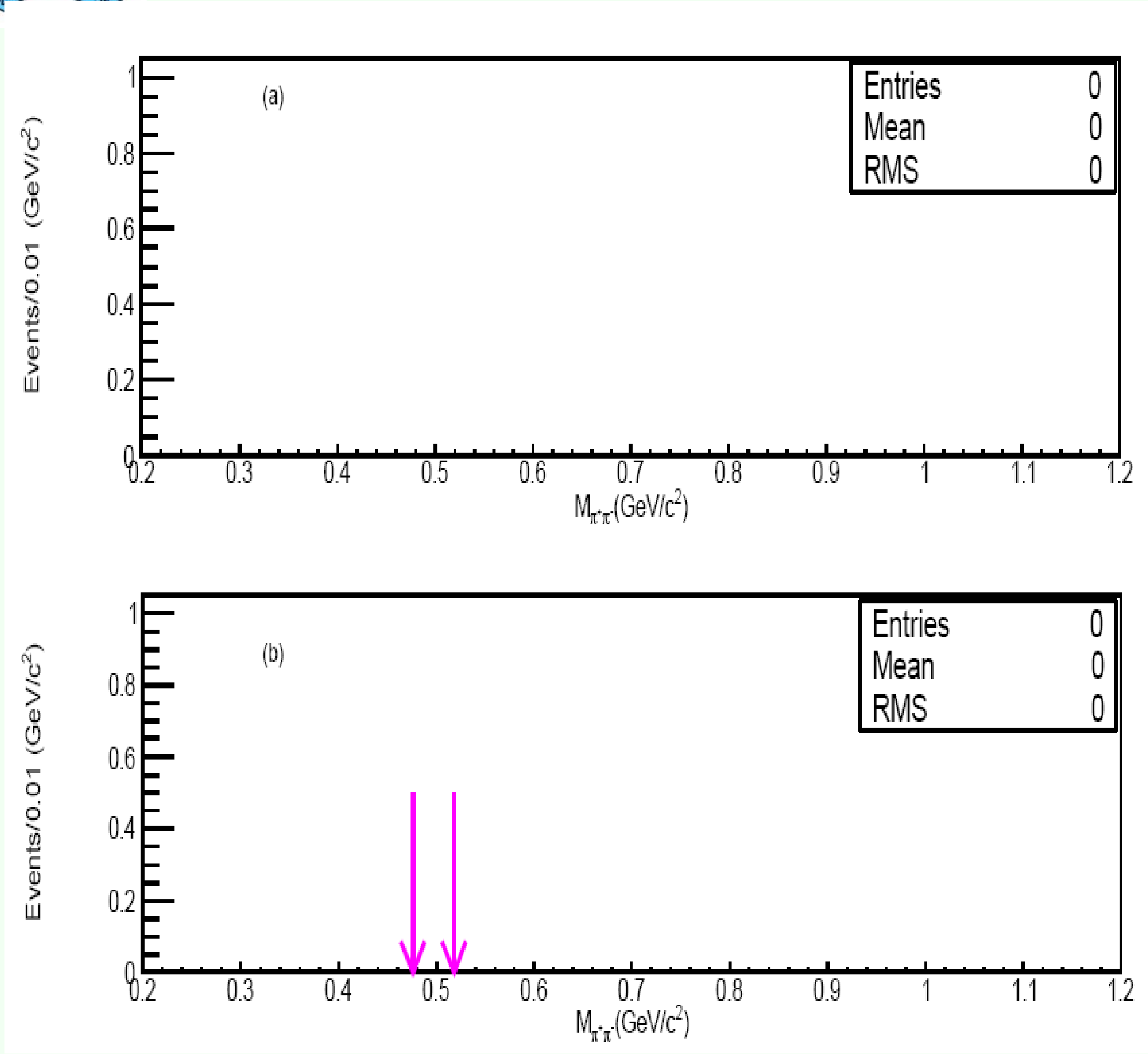
To suppress the channel

$$J/\psi \rightarrow \Delta^{++}\bar{P}\pi^-$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



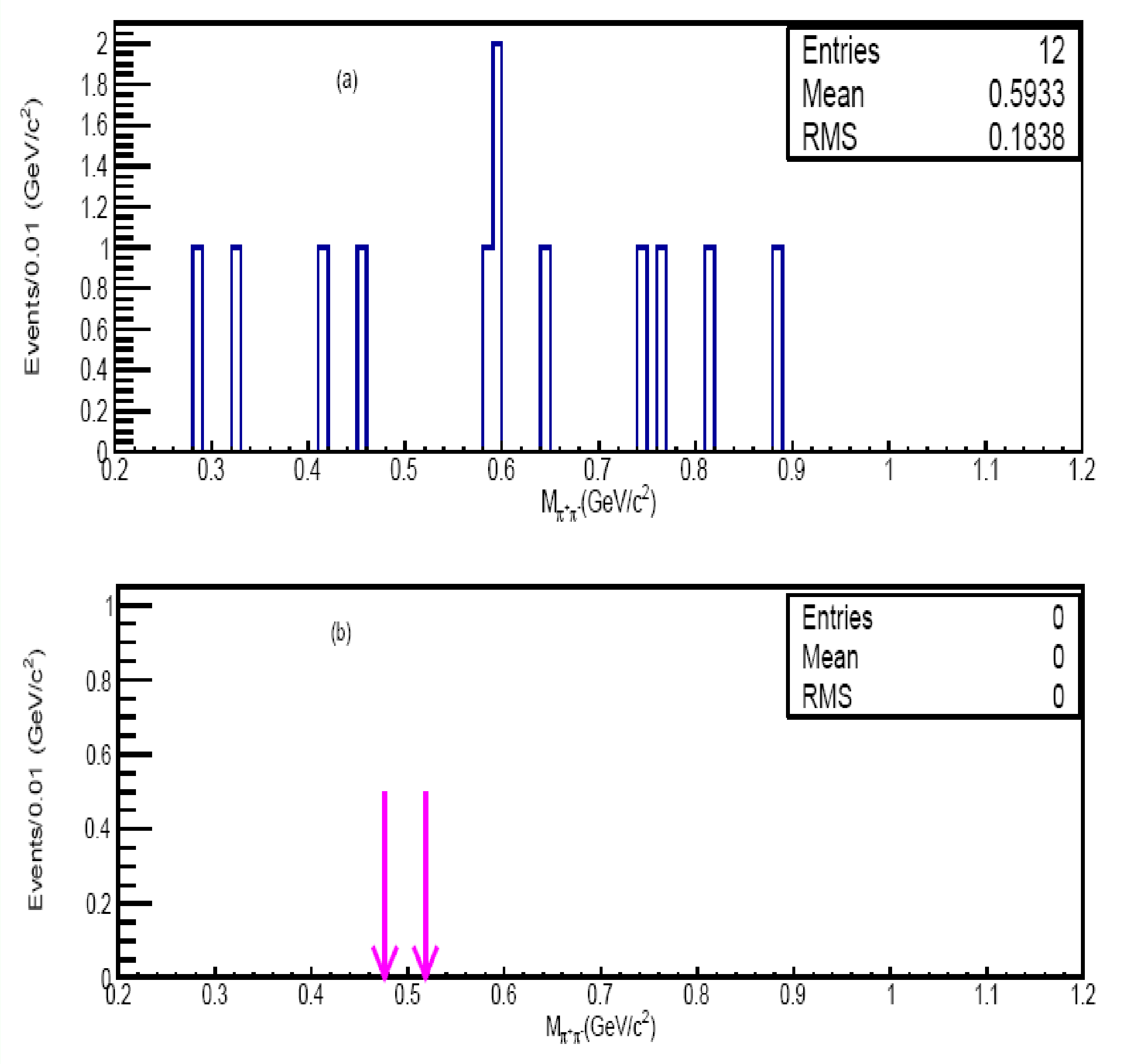
To suppress the channel

$$J/\psi \to \Lambda\bar{\Lambda}$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



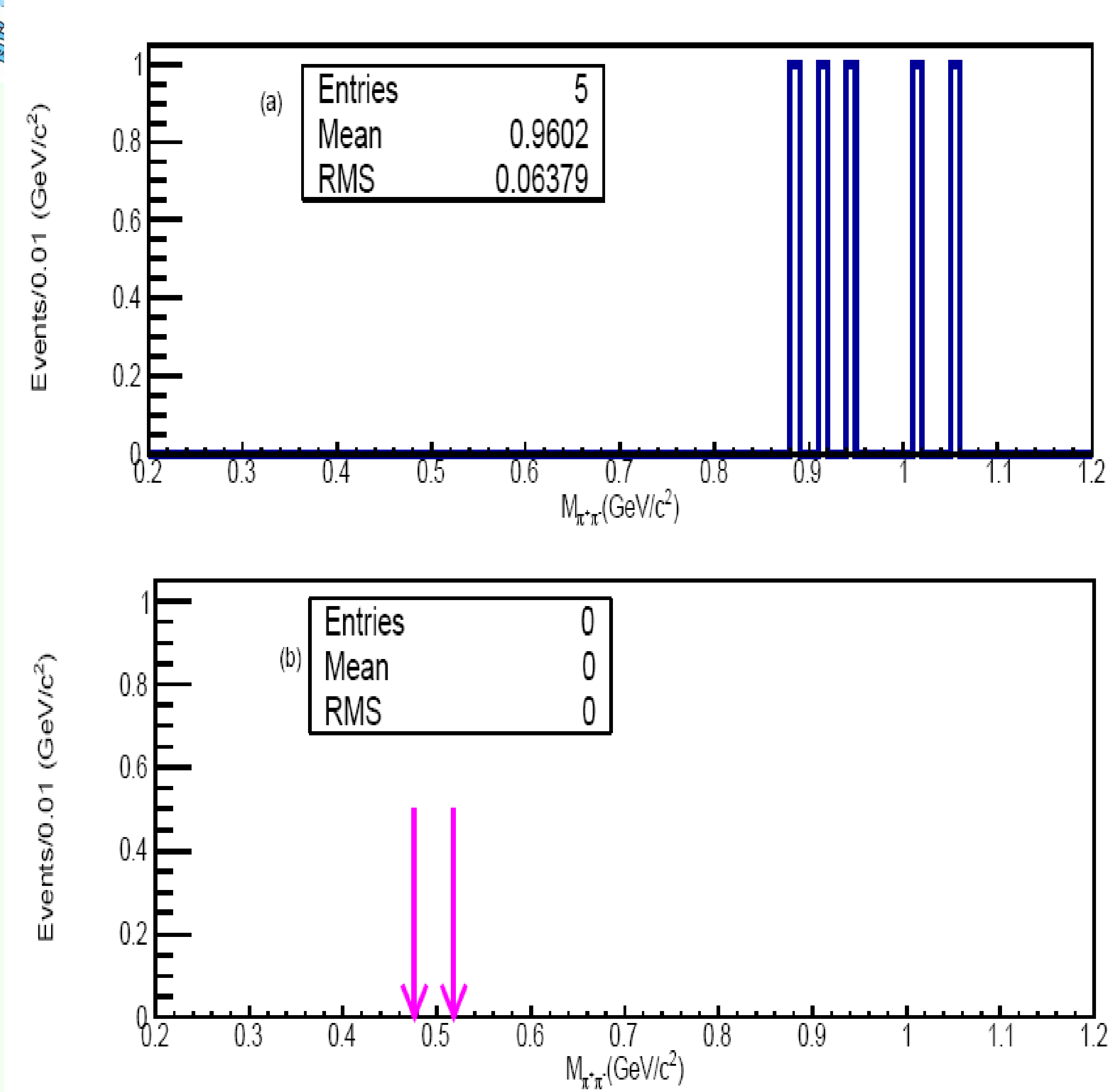
To suppress the channel

$$J/\psi \to \pi^+ \bar{P} \Delta^0$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



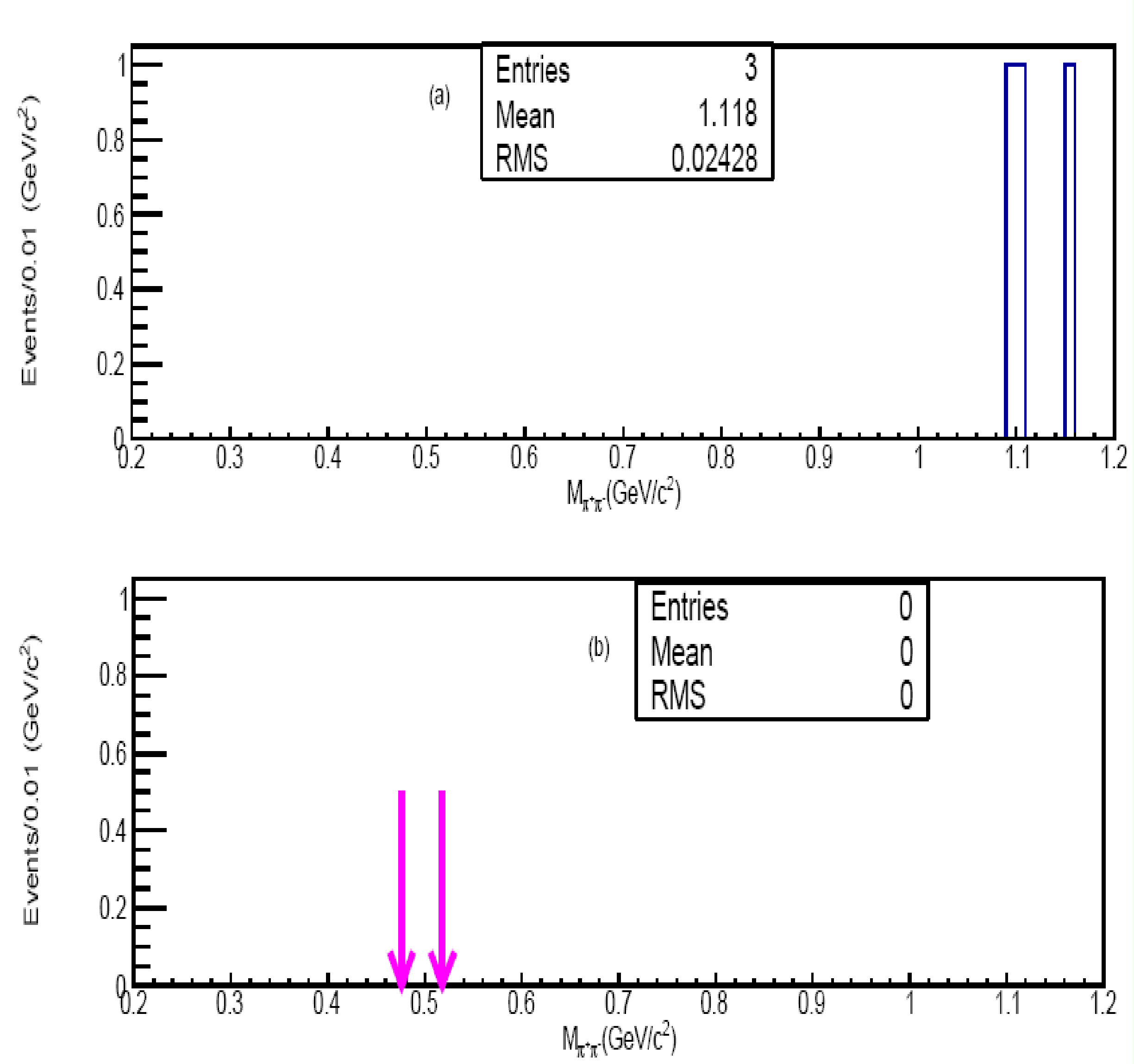
To suppress the channel

$$J/\psi \to P\bar{P}f_0'$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



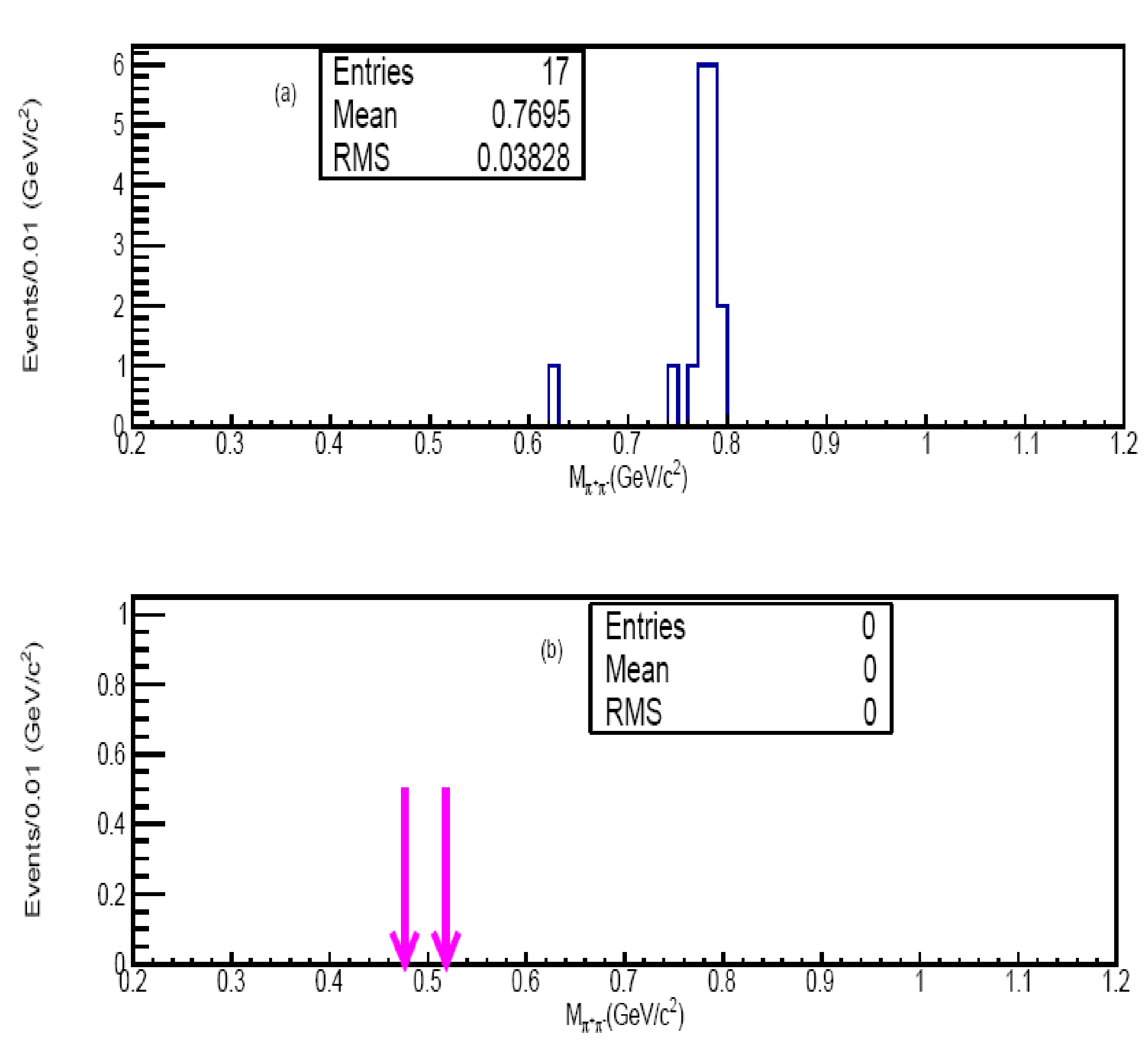
To suppress the channel

$$J/\psi \to P\bar{P}f_2$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



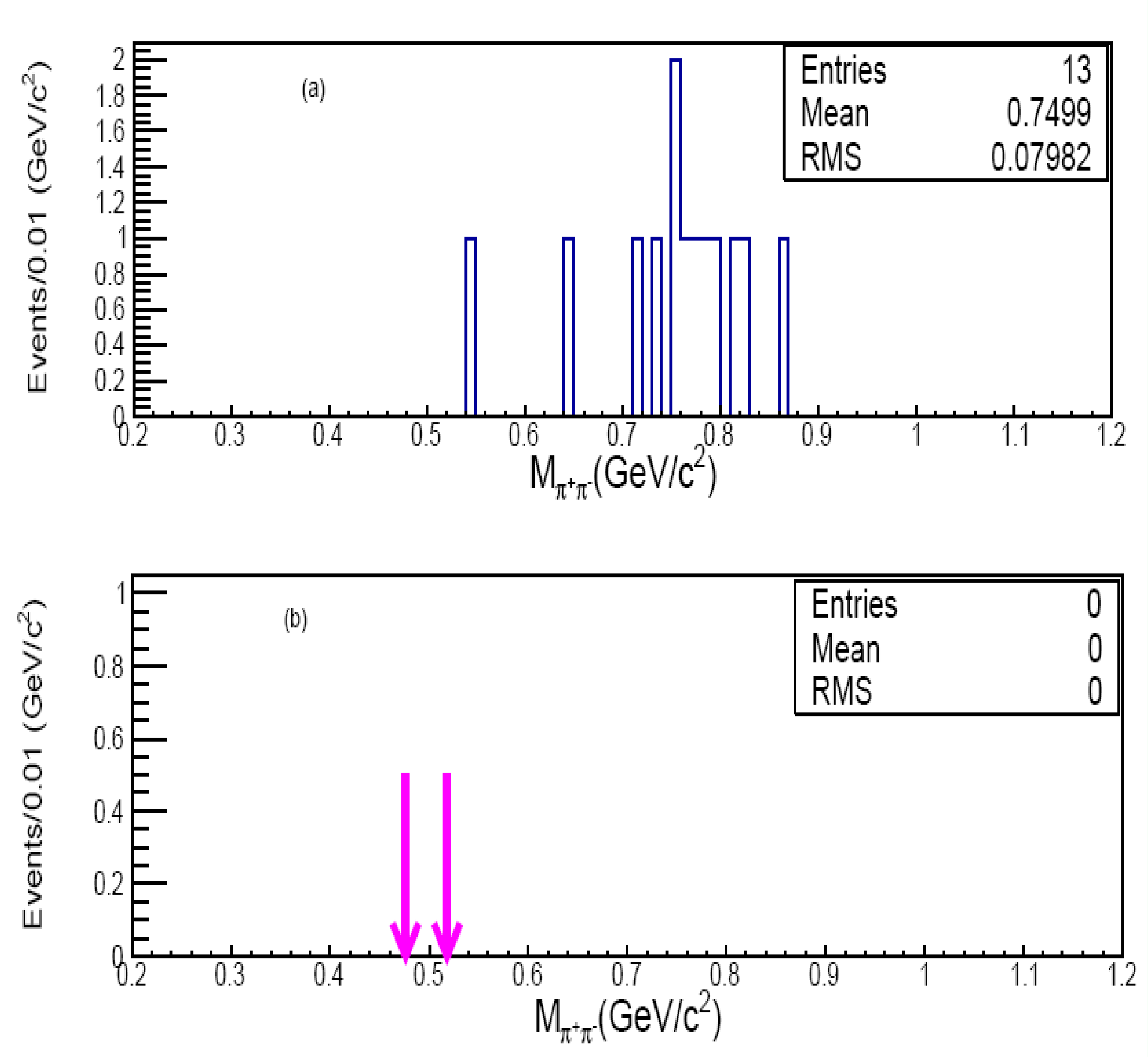
To suppress the channel

$$J/\psi \rightarrow P\bar{P}\omega$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Inclusive Background



To suppress the channel

$$J/\psi \to P\bar{P}\rho$$

use

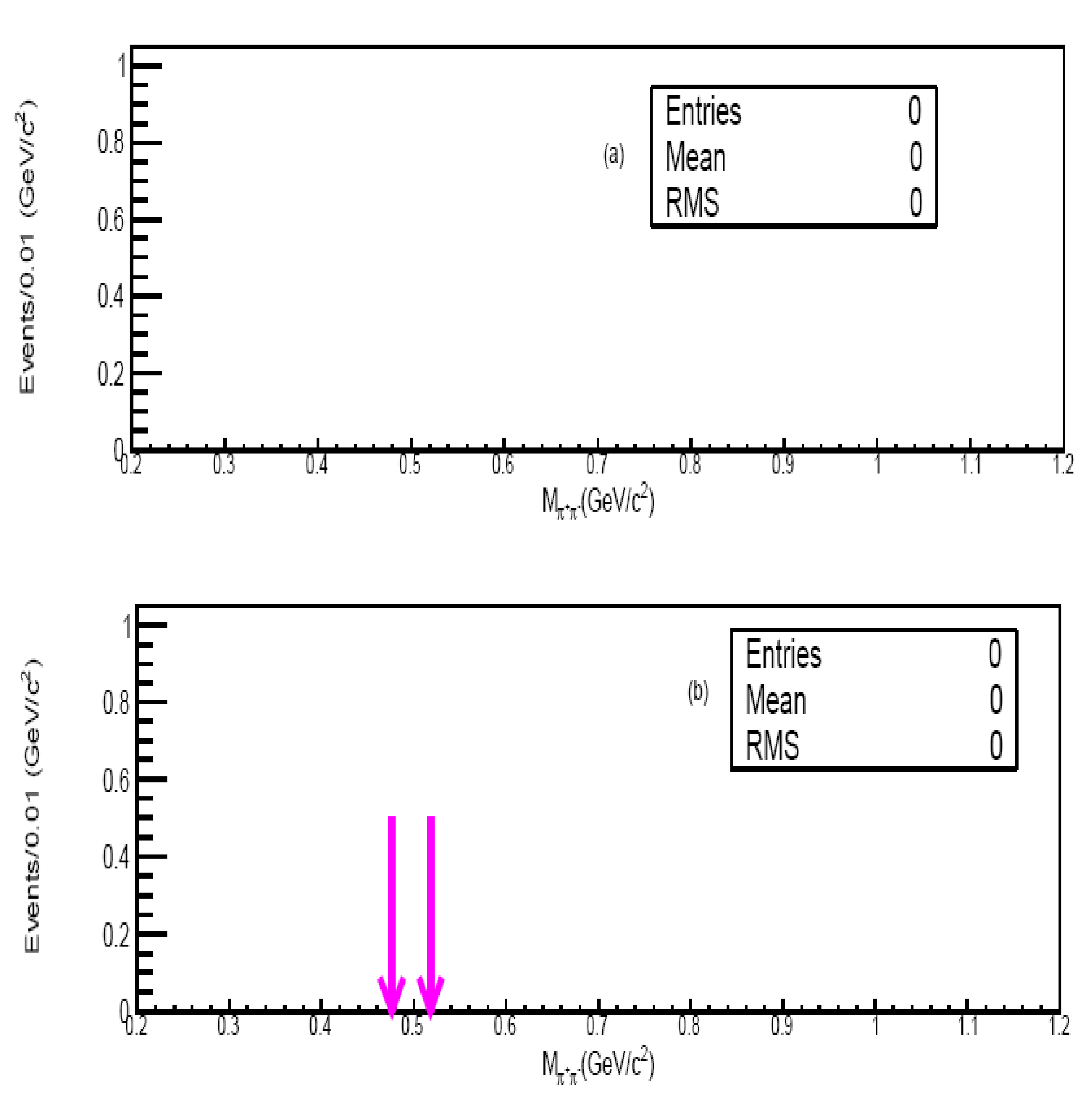
$$|M_{K_S^0} - 0.497| < 0.021$$

Estimated Exclusive Backgrounds for $J/\psi \to P\bar{P}K_S^0$

The Exclusive Backgrounds Obtained for $J/\psi \to P\bar{P}K_S^0$ Channel with $K_S^0 \to \pi^+\pi^-$

Channels	N_{gen}	Branching Fractions	N_{obs}
$J/\psi \to \Lambda\bar{\Lambda}$	100000	-	0
$J/\psi \to PK^-\bar{\Lambda}$	100000	$(8.9 \pm 1.6) \times 10^{-4}$	0
$J/\psi \to P\bar{P}\eta$	100000	$(2.00 \pm 0.12) \times 10^{-3}$	0
$J/\psi \to P\bar{P}\acute{\eta}(958)$	100000	$(2.1 \pm 0.4) \times 10^{-4}$	0
$J/\psi \to P\bar{P}\phi$	100000	$(4.5 \pm 1.5) \times 10^{-5}$	0

Exclusive Background



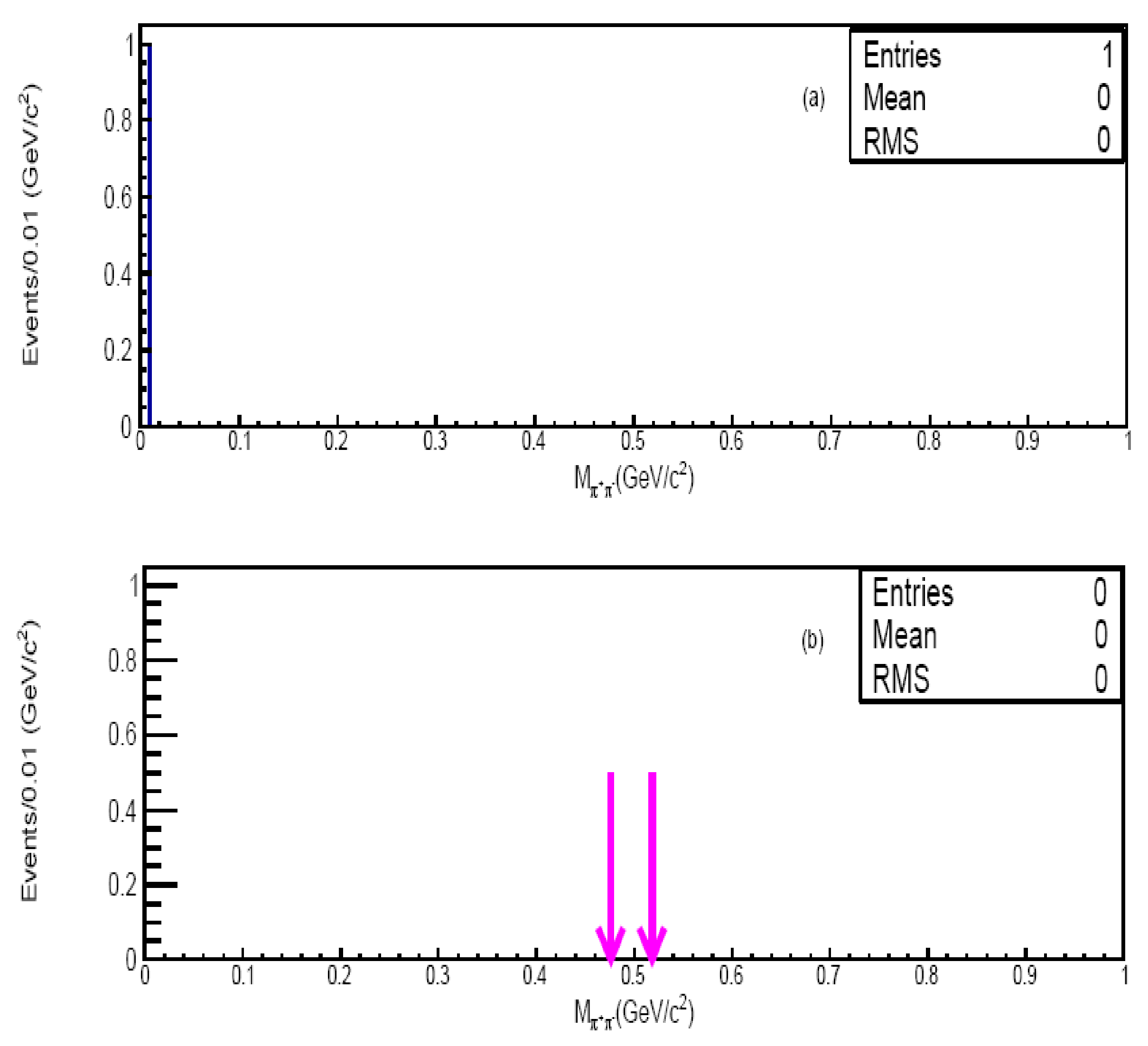
To suppress the channel

$$J/\psi \to \Lambda\bar{\Delta}$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Exclusive Background



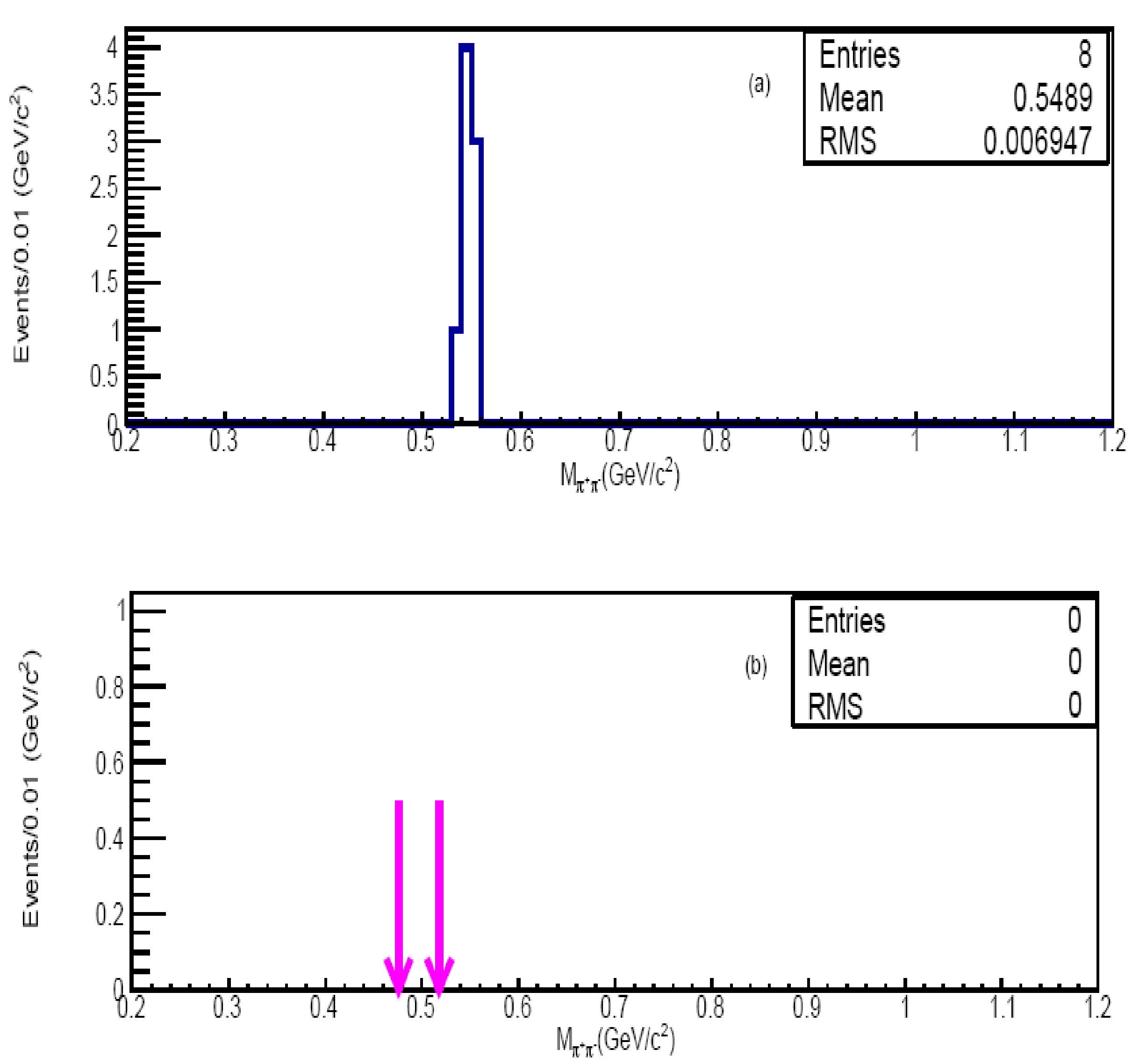
To suppress the channel

$$J/\psi \to PK^{-}\bar{\Lambda}$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Exclusive Background



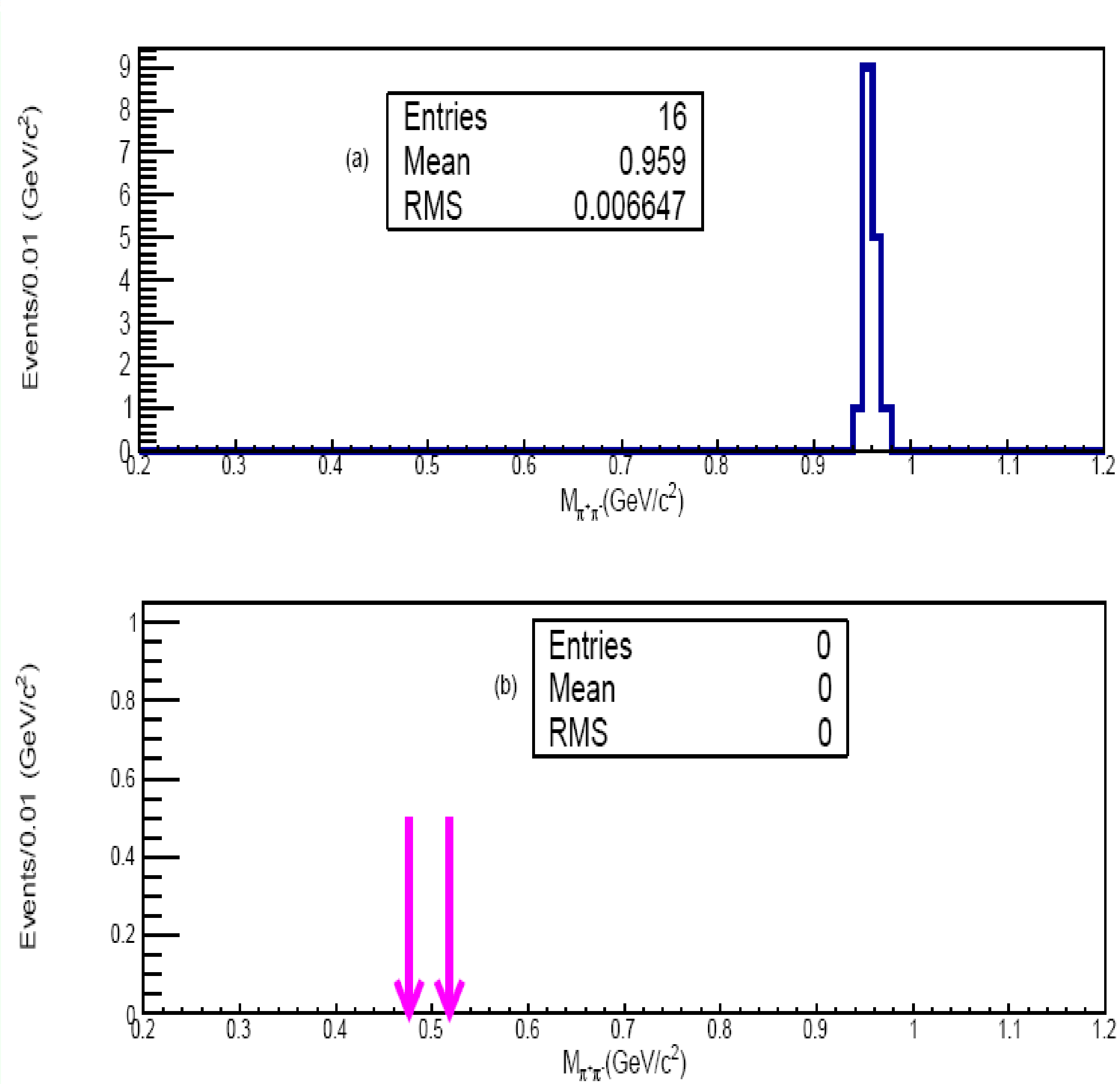
To suppress the channel

$$J/\psi \rightarrow P\bar{P}\eta$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Exclusive Background



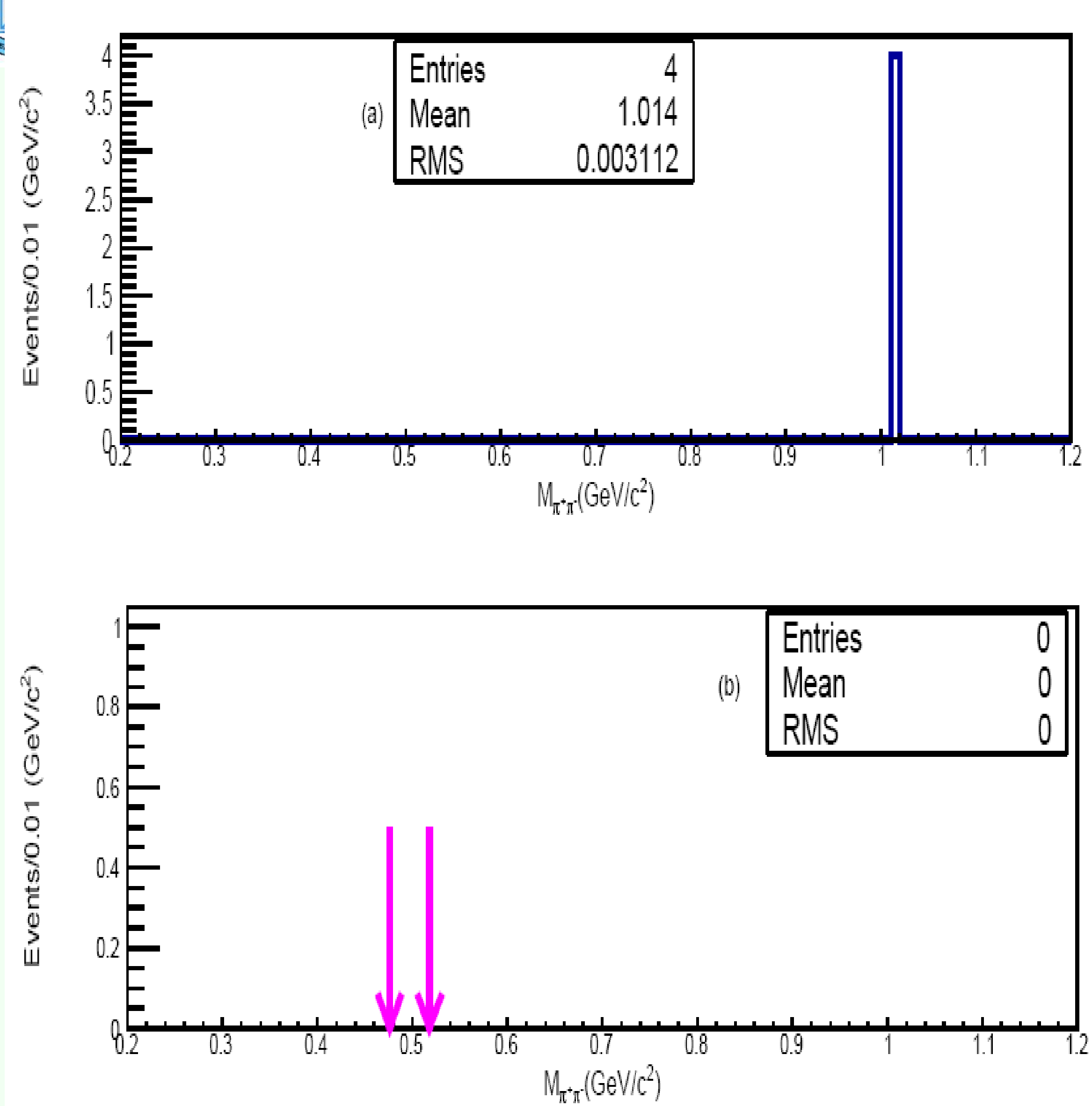
To suppress the channel

$$J/\psi \to P\bar{P}\acute{\eta}(958)$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Exclusive Background



To suppress the channel

$$J/\psi \to P\bar{P}\phi$$

use

$$|M_{K_S^0} - 0.497| < 0.021$$

Systematic Error Analysis for $J/\psi \to P\bar{P}K_S^0$

Sources	Relative Error (%)
Monte Carlo Model	14.66%
PID	4%
MDC Tracking	8%
4C Kinematic Fit	10.59%
K_S^0 Vertex Fitting	0.62%
MC Statistics	0.22%
$\psi(2S)$ Total Number of Events	0.7%
Branching Fraction of intermediate states	0.05%
Total Error	20.63%

Cont…

Upper Limit of $J/\psi \to P\bar{P}K_S^0$ with $K_S^0 \to \pi^+\pi^-$

For upper limit approximation, the upper limit of number of signal events N_{obs}^{UL} is calculated by using poisson distribution. The formula for the upper limit on the number of events through poisson distribution is given below;

$$\gamma = P(n \le n_{obs}; s, b) = \sum_{n=0}^{n_{obs}} \frac{(s+b)^n}{n!} e^{-(s+b)}$$

Suppose we have negligible amount of signal events i.e. $n_{obs} = 0$ and $\gamma = 0.05$. Solving it to evaluate upper number of events, we get

$$\beta = \sum_{n=0}^{n_{obs}} \frac{b^n}{n!} = e^{-b}$$

$$b = -\ln \beta$$

Upper Limit of $J/\psi \to P\bar{P}K_S^0$ with $K_S^0 \to \pi^+\pi^-$

Let $\beta = 0.05$, calculating an upper limit at confidence level $(1-\beta) = 95\%$

$$b = -\ln(0.05) = 2.996 \approx 3 (the\ upper\ limit\ on\ number\ of\ events)$$

The evidence for the presence of signal event is not statistically significant. We have to set upper limit on parameter 's'.

MC detection efficiency is 38.975%.

Upper Limit of $J/\psi \to P\bar{P}K_S^0$ with $K_S^0 \to \pi^+\pi^-$

$$B(J/\psi \to P\bar{P}K_S^0) < \frac{N_{obs}^{UL}}{N_{J/\psi}.B(K_S^0 \to \pi^+\pi^-).\varepsilon.(1-\sigma_{sys})}$$

$$Br(J/\psi \to P\bar{P}K_S^0) < 1.069 \times 10^{-8}$$

No PDG value for this upper limit exists for this decay channel $J/\psi \to P\bar{P}K_S^0$.

Analysis of $\psi(2S) \to P\bar{P}K_S^0$

The analysis for this decay mode is carried out by using BESIII Offline Software System (BOSS) with version 6.6.4.P01. The $\psi(2S)$ data sample of 447.9×10^6 events have been used (Ablikim et al., 2017). For Monte Carlo studies, sample of 0.1 Million events, each for signal and background channels, is generated and reconstructed by using the BOSS664.p01.

Initial Events Selection

The signal channel needs four good charge tracks. Each good charge track must satisfy the following criteria:

- 4 good tracks and $|\cos\theta|<0.93$.
- $\Sigma Qi=0$

- **PID**

  dE/dx and TOF information are combined to identify particles.

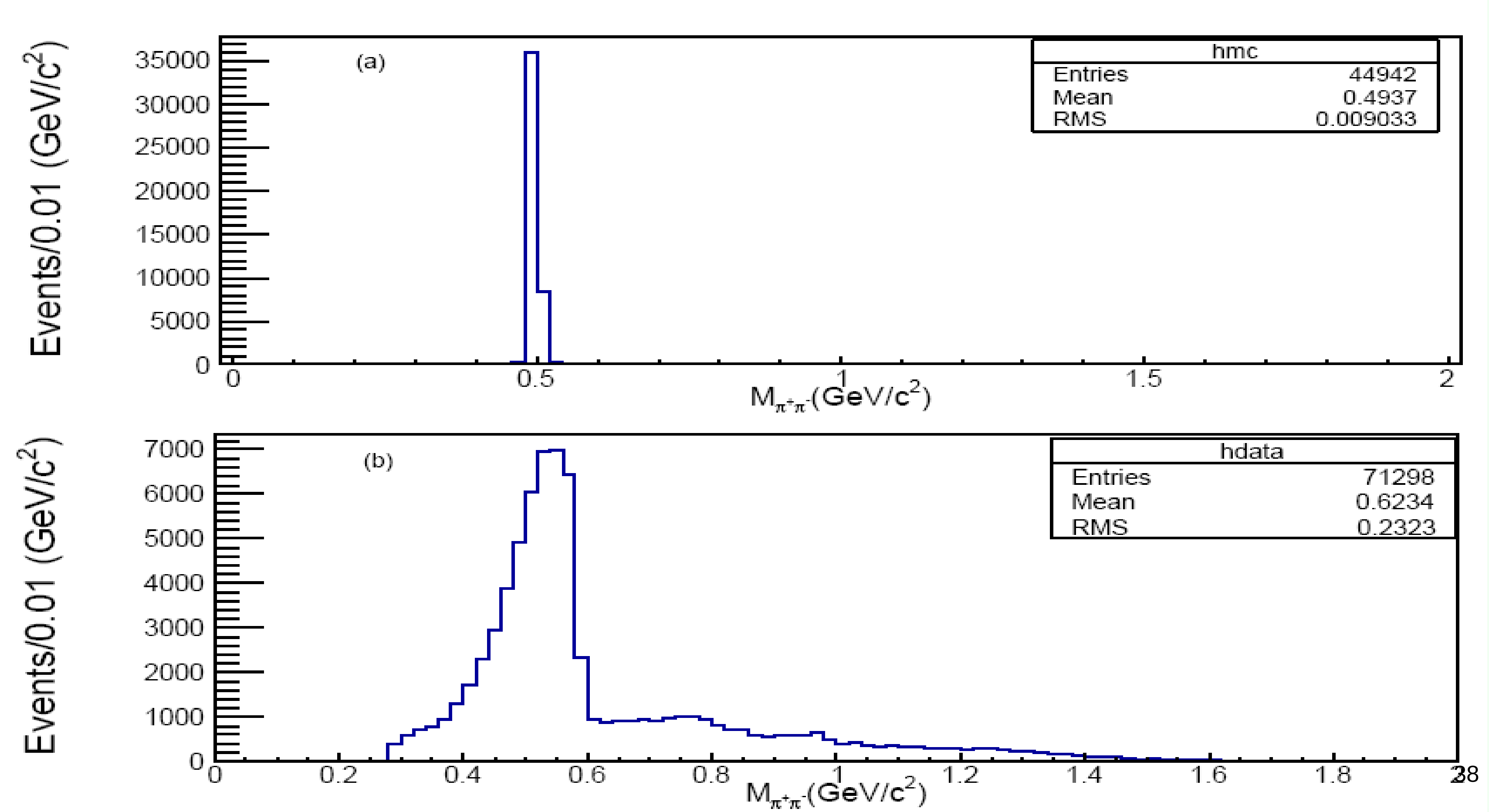
  - For pion identification, it is required that $prob(\pi) > prob(K)$ and $prob(\pi) > prob(P)$.
  - For proton identification, it is required that $prob(P) > prob(\pi)$ and $prob(P) > prob(K)$.

- **Pt > 0.5**

$V_{r0} = 1.0cm$ $V_{z0} = 10.0cm$

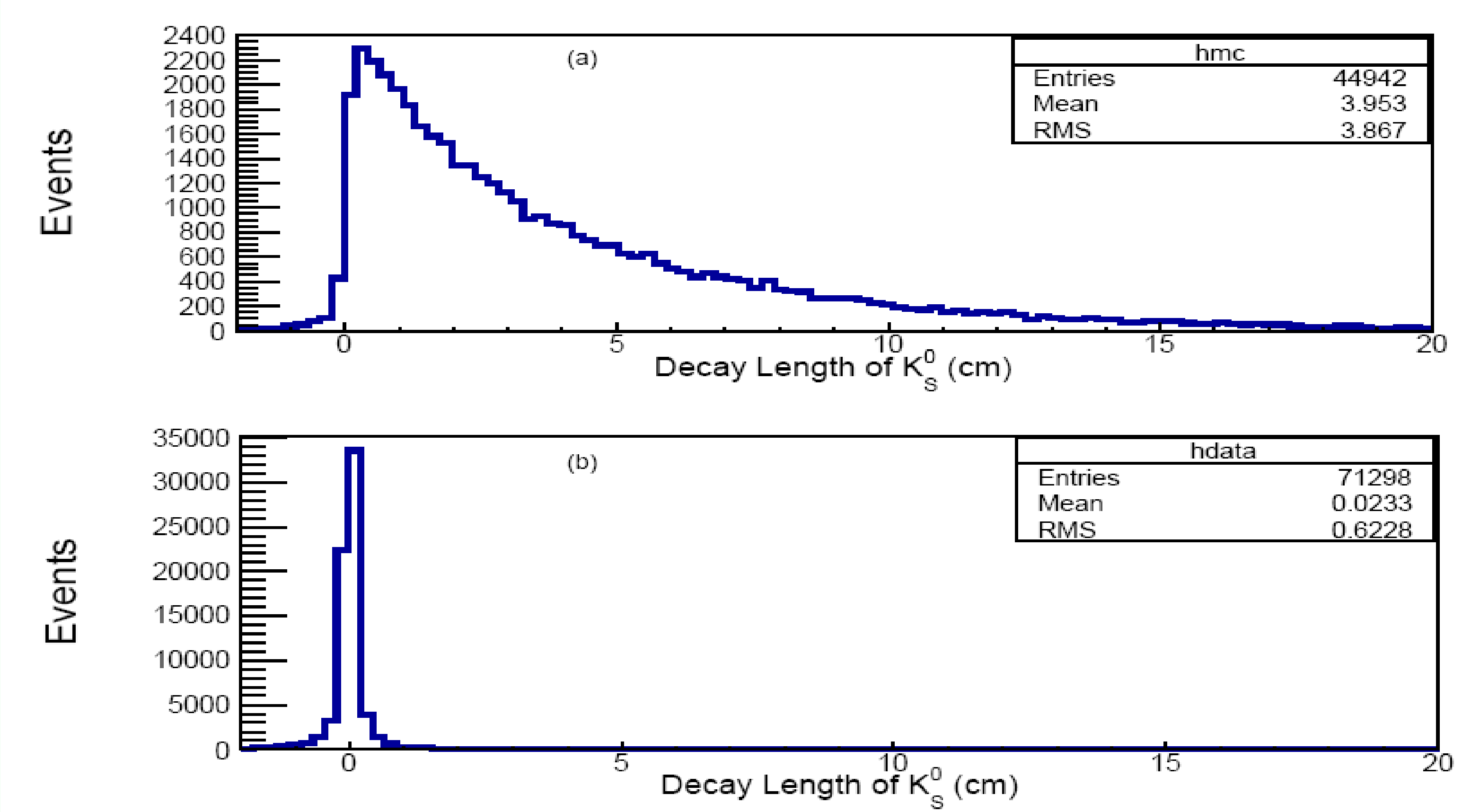
Selection of K_S^0 after Vertex Fitting

The $\pi^+\pi^-$ invariant mass distribution obtained from primary vertex fit



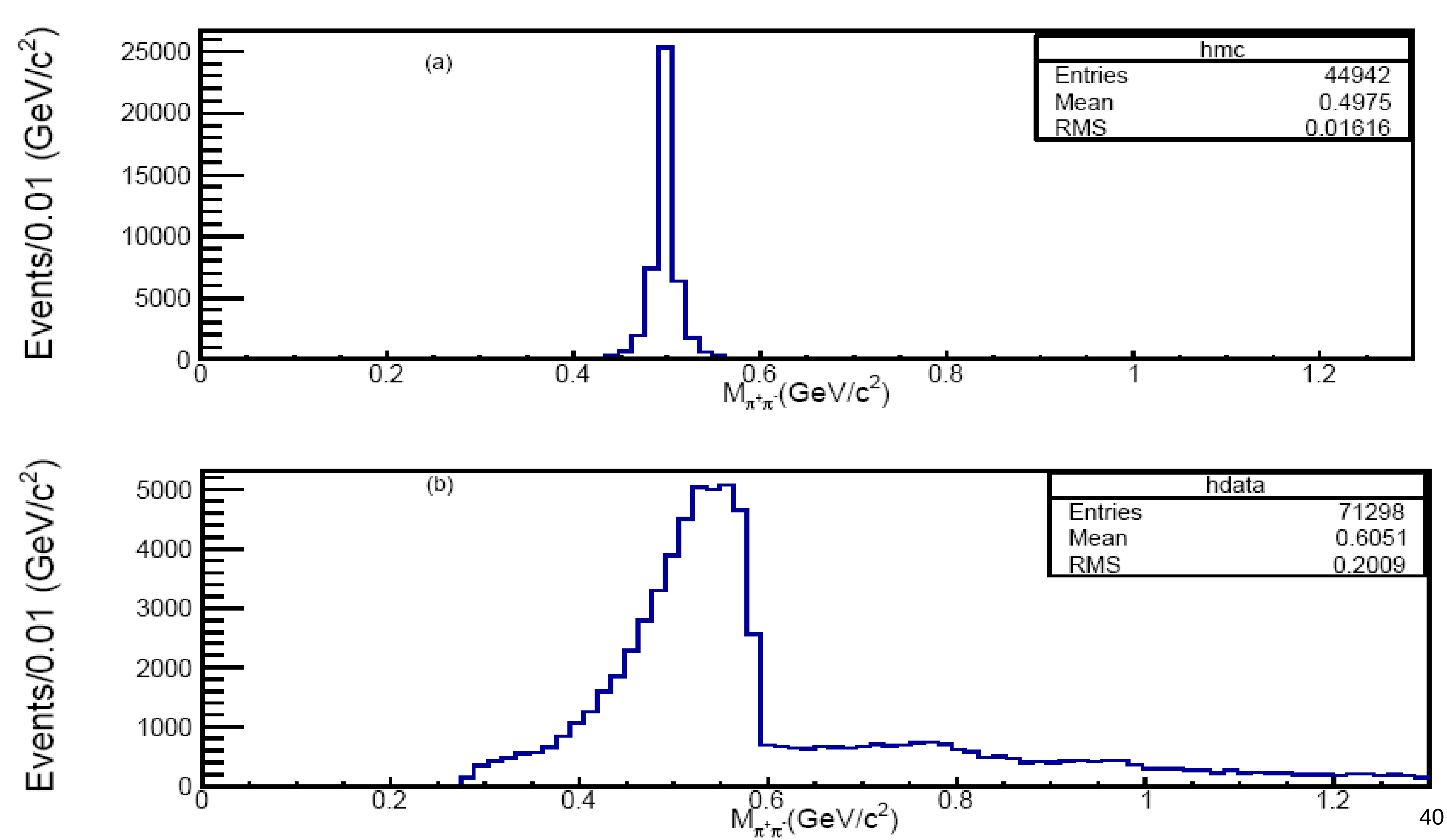
Selection of K_S^0 after Vertex Fitting

The secondary vertex fit results of decay length for K_S^0 candidates are shown



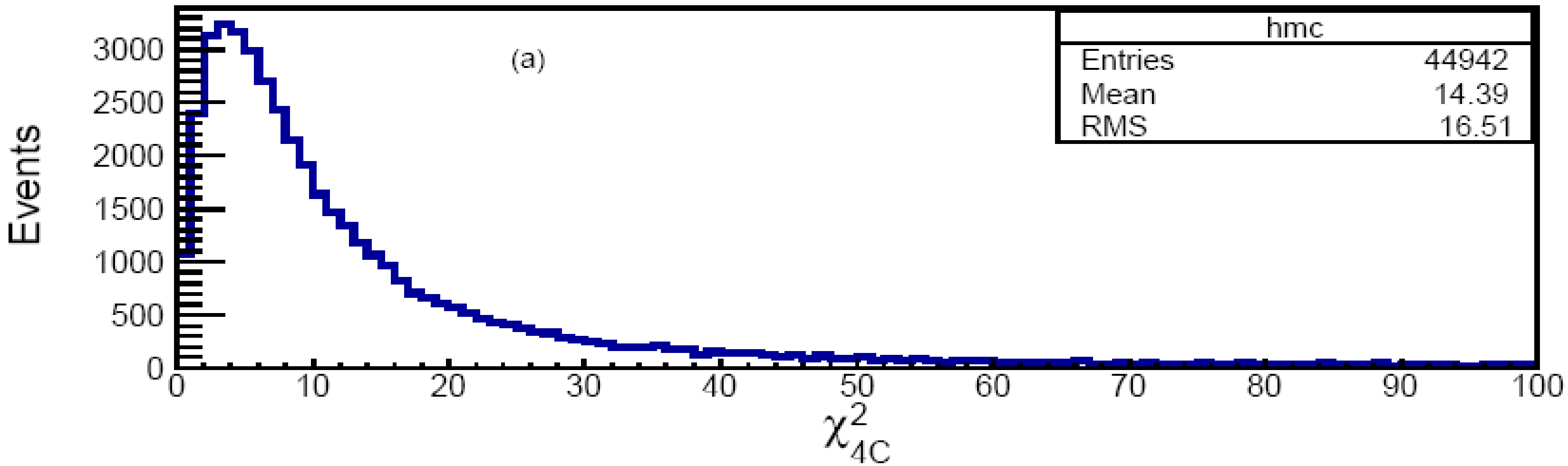
Selection of K_S^0 after Kinematic Fitting

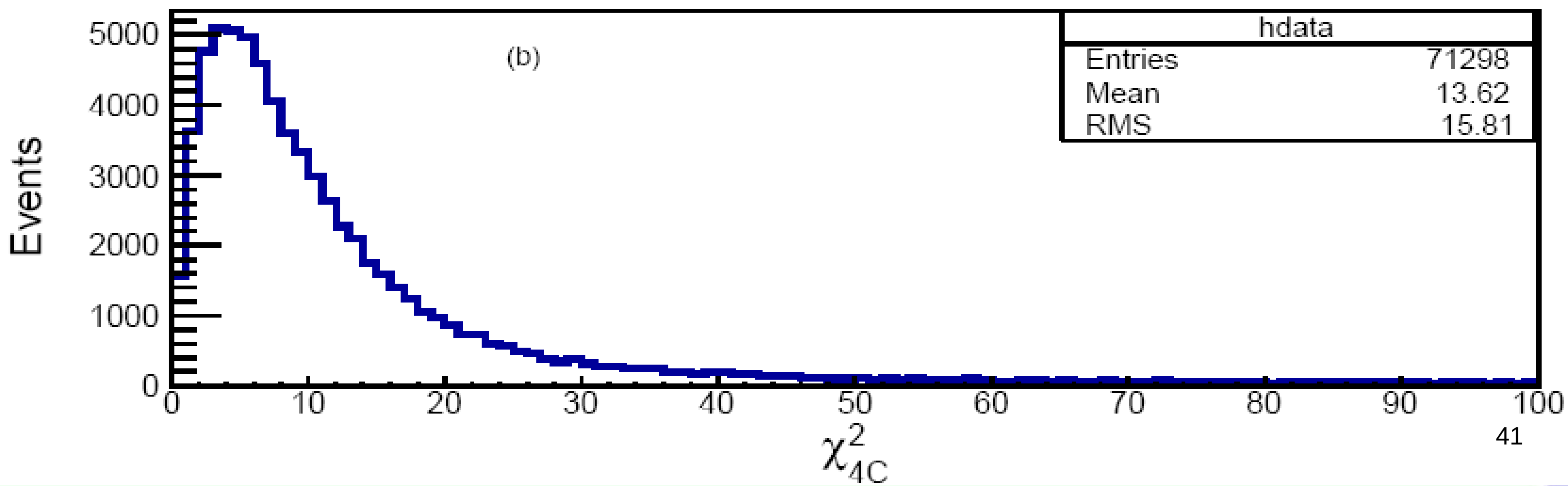
After successful primary and secondary vertex fits, 4*C* kinematic fit is employed



Optimized χ^2

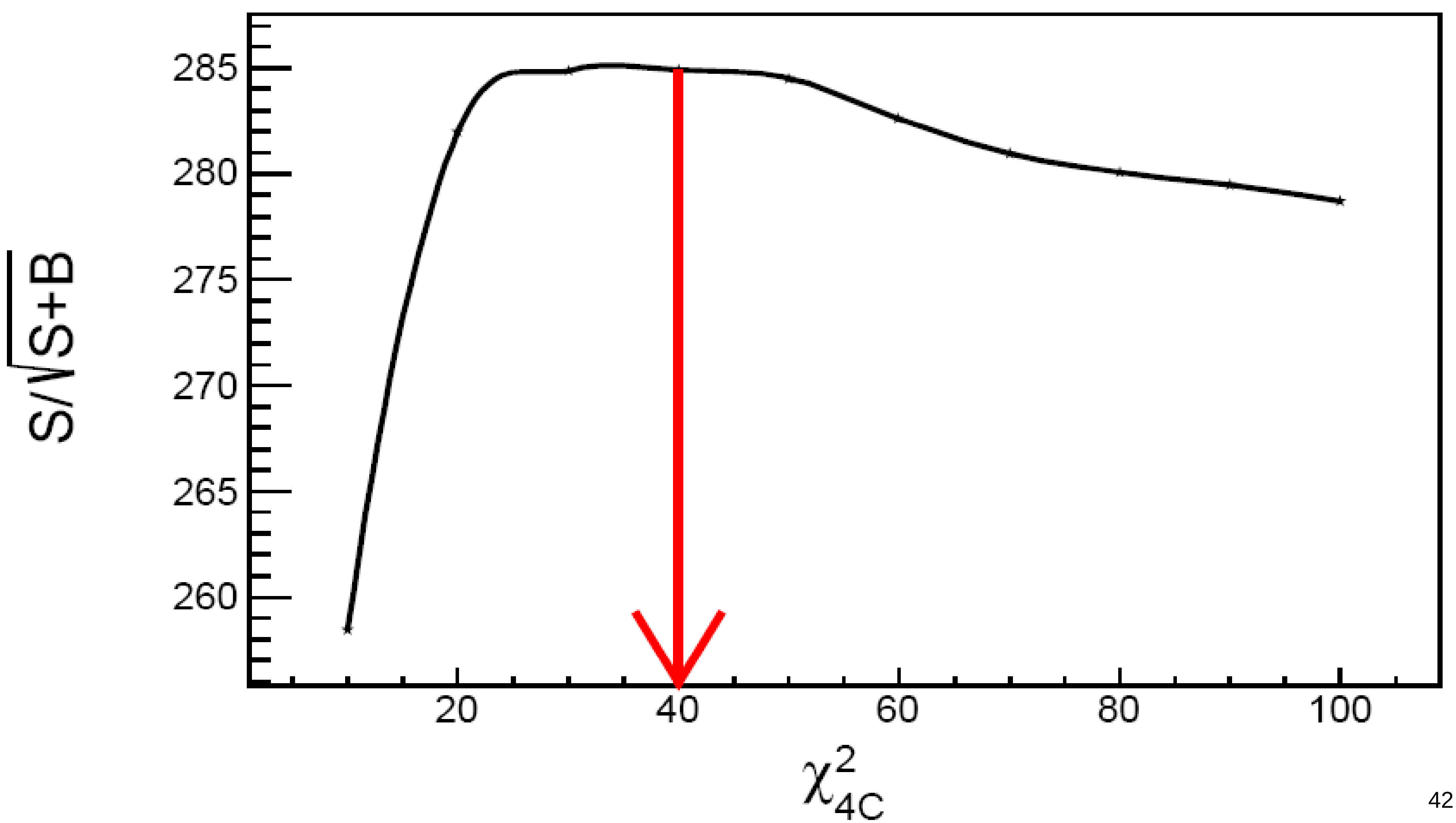
$\chi^2_{4C} < 100$ is applied in order to select successfully passing events.





Optimized χ^2

A cut of $\chi^2_{4C} < 40$ is determined by optimizing $S/\sqrt{S+B}$



Final Event Selection for $\psi(2S) \rightarrow P\bar{P}K_S^0$

The events passing kinematic fit successfully are used for final event selection. In the final event selection, the following cuts (inclusive and exclusive) have been applied in order to get invariant mass distribution of $\pi^+\pi^-$ to search for K_S^0 signatures.

- $\chi^2_{4C} < 40$
- $|M_{P\pi^-} - 1.1156| > 0.015\ GeV/c^2$
- $|M_{\bar{P}\pi^+} - 1.1156| > 0.015\ GeV/c^2$
- $|M_{P\pi^+} - 1.232| > 0.25\ GeV/c^2$
- $|M_{\bar{P}\pi^-} - 1.232| > 0.25\ GeV/c^2$
- $|V_{zP}| < 10$ cm
- $|V_{rP}| < 1$ cm
- $|V_{z\bar{P}}| < 10$ cm
- $|V_{r\bar{P}}| < 1$ cm

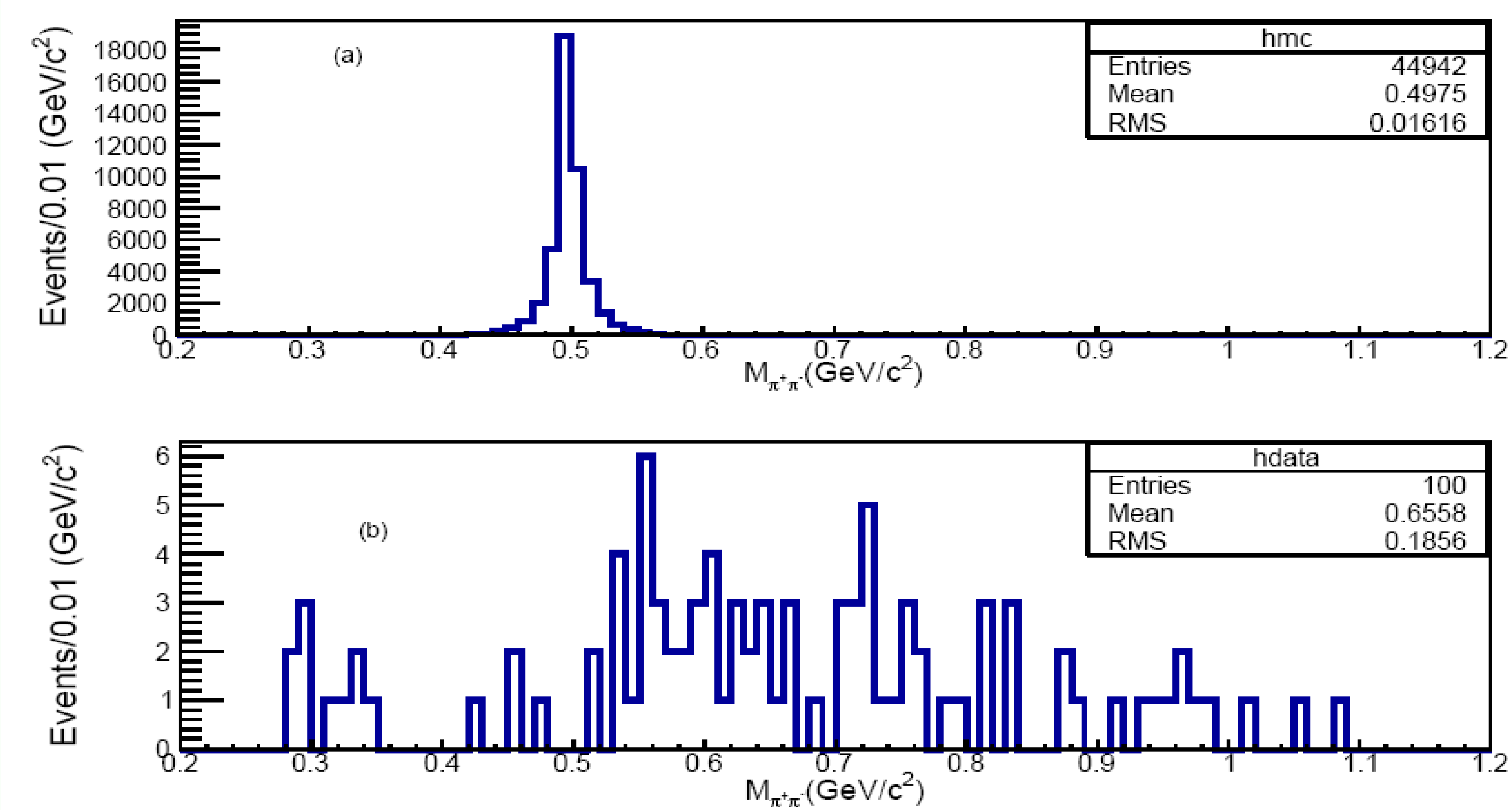
Final Event Selection for $\psi(2S) \to P\bar{P}K_S^0$

- $|V_{r\pi^+}| < 1$ cm
- $|V_{z\pi^+}| < 10$ cm
- An exclusive cut has been applied on the Decay Length ratio of K_S^0 i.e.

$$Decay\ Length\ Ratio = \left|\frac{Decay\ Length\ of\ K_S^0}{Decay\ Length\ Error\ of\ K_S^0}\right| > 3$$

Invariant mass of $\pi^+\pi^-$ MC & Data after selection criteria

The $\pi^+\pi^-$ invariant mass distribution after applying all above cuts



Background Analysis for $\psi(2S) \rightarrow P\bar{P}K_S^0$

About 400 M inclusive $\psi(2S)$ events have been used to investigate the background

Channels	N_{gen}	Branching Fractions	N_{obs}
$\psi(2S) \rightarrow \Delta^{++}\pi^-\bar{P}$	100000	-	1
$\psi(2S) \rightarrow \bar{\Delta}^{--}\pi^+P$	100000	-	3
$\psi(2S) \rightarrow \bar{\Delta}^0\pi^-P$	100000	-	5
$\psi(2S) \rightarrow \bar{P}P\pi^+\pi^-$	100000	$(6.0 \pm 4.0) \times 10^{-4}$	8
$\psi(2S) \rightarrow \Delta^0\bar{\Delta}^0$	100000	-	6
$\psi(2S) \rightarrow \Delta^{++}\bar{\Delta}^{--}$	100000	$(1.28 \pm 0.35) \times 10^{-4}$	0
$\psi(2S) \rightarrow \Lambda\bar{\Lambda}$	100000	$(3.57 \pm 0.18) \times 10^{-4}$	4
$\psi(2S) \rightarrow \pi^+\bar{P}\Delta^0$	100000	-	1
$\psi(2S) \rightarrow P\bar{P}f_0'$	100000	-	0
$\psi(2S) \rightarrow P\bar{P}f_2$	100000	-	0
$\psi(2S) \rightarrow P\bar{P}\omega$	100000	$(6.9 \pm 2.1) \times 10^{-5}$	0
$\psi(2S) \rightarrow P\bar{P}\rho$	100000	$(5.0 \pm 2.2) \times 10^{-5}$	5

Estimated Exclusive Backgrounds for $\psi(2S) \to P\bar{P}K_S^0$

The $\psi(2S)$ exclusive background analysis was carried out by using MC samples of 100,000

Channels	N_{gen}	Branching Fractions	N_{obs}
$\psi(2S) \to \Lambda\bar{\Delta}$	100000	-	0
$\psi(2S) \to PK^-\bar{\Lambda}$	100000	-	0
$\psi(2S) \to P\bar{P}\eta$	100000	$(6.00 \pm 0.4) \times 10^{-5}$	2
$\psi(2S) \to P\bar{P}\acute{\eta}(958)$	100000	-	0
$\psi(2S) \to P\bar{P}\phi$	100000	$< 2.4 \times 10^{-5}$ at C.L 90%	0

Systematic Error Analysis for $\psi(2S)$ decays into $P\bar{P}K_S^0$

Sources	Relative Error (%)
Monte Carlo Model	14%
PID	4%
MDC Tracking	8%
4C Kinematic Fit	10.59%
K_S^0 Vertex Fitting	0.62%
MC Statistics	0.202%
$\psi(2S)$ Total Number of Events	0.7%
Branching Fraction of intermediate states	0.05%
Total Error	20.19%

Cont…

Upper Limit of $\psi(2S) \to P\bar{P}K_S^0$ with $K_S^0 \to \pi^+\pi^-$

After background analysis, it is found that 1 event is selected inside the K_S^0 mass window.

Therefore an upper limit on the branching fraction for the decay channel $\psi(2S) \to P\bar{P}K_S^0$ is estimated. For upper limit approximation, the upper limit of number of signal events N_{obs}^{UL} is calculated by using poisson distribution. The formula for the upper limit on the number of events through poisson distribution is given below;

$$\gamma = P(n \leq n_{obs}; s, b) = \sum_{n=0}^{n_{obs}} \frac{(s+b)^n}{n!} e^{-(s+b)}$$

Upper Limit of $\psi(2S) \rightarrow P\bar{P}K_S^0$ with $K_S^0 \rightarrow \pi^+\pi^-$

Suppose we have negligible amount of signal events i.e. $n_{obs} = 0$ and $\gamma = 0.05$. Solving it to evaluate upper number of events, we get

$$\beta = \sum_{n=0}^{n_{obs}} \frac{b^n}{n!} = e^{-b}$$

$$b = -\ln\beta$$

Let $\beta = 0.05$, calculating an upper limit at confidence level $(1-\beta) = 95\%$

$$b = -\ln(0.05) = 2.996 \approx 3(the\ upper\ limit\ on\ number\ of\ events)$$

Upper Limit of $\psi(2S) \to P\bar{P}K_S^0$ with $K_S^0 \to \pi^+\pi^-$

The evidence for the presence of signal event is not statistically significant. We have to set upper limit on parameter 's'. In this analysis, the $\psi(2S) \to P\bar{P}K_S^0$ has been investigated using 447.9×10^6 $\psi(2S)$ collected from BESIII detector at BEPCII. MC detection efficiency is 44.94%. And the upper limit on the branching fraction is calculated by using the following formula;

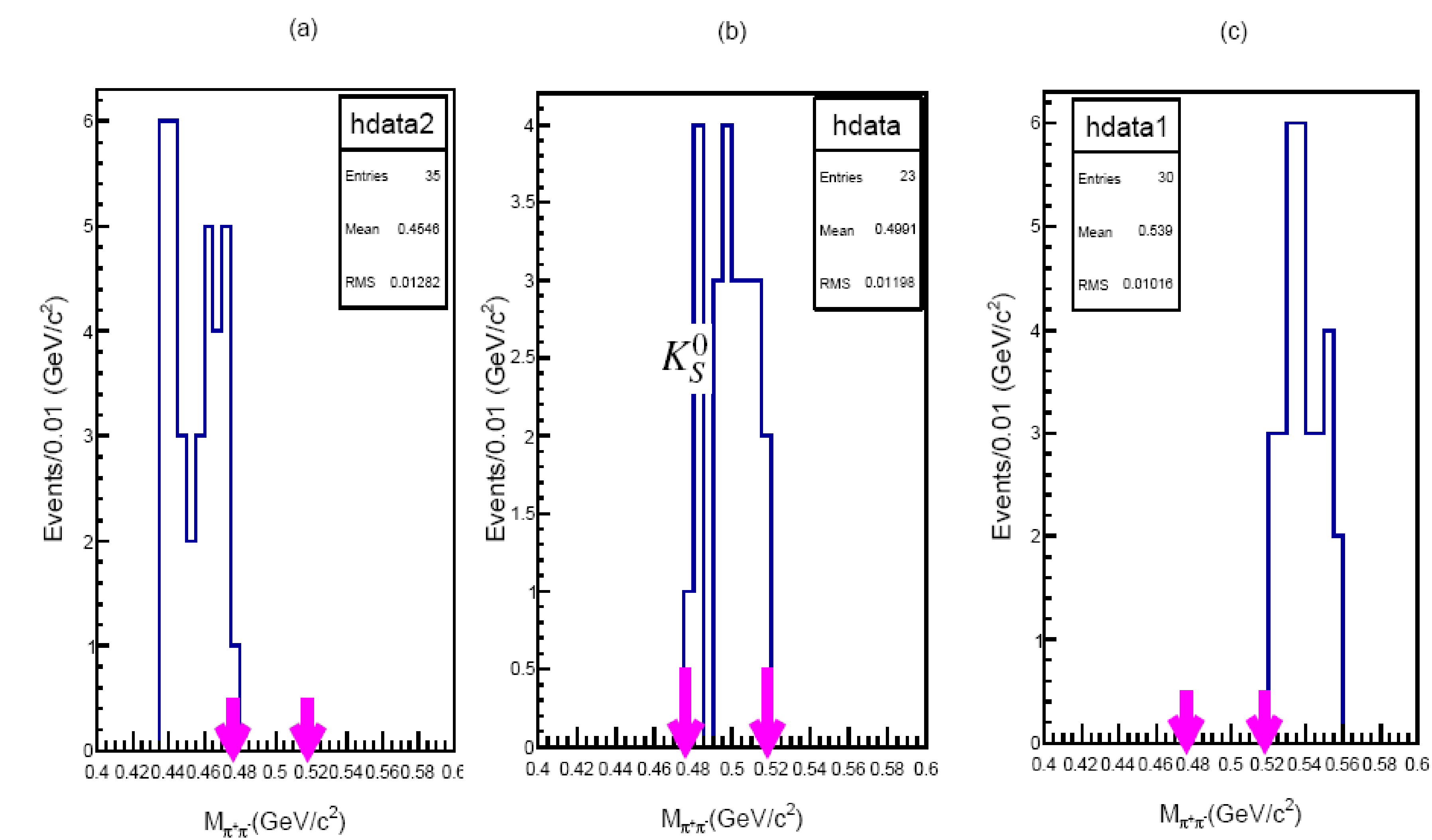
$$B(\psi(2S) \to P\bar{P}K_S^0) < \frac{N_{obs}^{UL}}{N_{\psi(2S)}.B(K_S^0 \to \pi^+\pi^-).\varepsilon.(1-\sigma_{sys})}$$

$$Br(\psi(2S) \to P\bar{P}K_S^0) < 2.698 \times 10^{-8}$$

No PDG value for this upper limit exists for this decay channel $\psi(2S) \to P\bar{P}K_S^0$.

Thanks

Distribution of K_S^0 Signal



Distribution of K_S^0 Signal for $\psi(2S)$