

Search for the $Z_c(4430)$ (in $Y(4660)$ decay)

Marco Scodeggio

BESIII



Dipartimento
di Fisica
e Scienze della Terra

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Preamble

What and Why

Study of two exotic states through the chain

$$e^+e^- \rightarrow (Y(4660) \rightarrow) Z_c(4430) \pi \rightarrow \psi(2S) \pi \pi \rightarrow J/\psi \pi \pi \pi \pi \rightarrow 2\ell 4\pi$$

$Z_c^+(4430)$ was **observed** and studied in the B meson decays in the $\pi\psi(2S)$ invariant mass **by BELLE** [PRD **88**, 074026] (and by LHCb [PRL **112**, 222002])

$Y(4660)$, already **observed by BaBar** [PRD **89**, 111103(R)] and **BELLE** [PRD **91**, 112007], was **hypothesised** to be a **baryonium**

How

The study will make use of the **$\sim 5 \text{ fb}^{-1}$** data @ $\sqrt{s} > 4.6 \text{ GeV}$

No $Z_c^+(4430)$ signal was observed in the mono-energetic datasets,
so the main idea is to merge all the data @ $\sqrt{s} > 4.6 \text{ GeV}$ to use the whole statistics

Signal MC Studies

Y and Z_c Resonant

```
noPhotos
```

```
Decay dummy00_1
```

```
0.5000 dummy10_1 pi- PHSP;
```

```
0.5000 anti-dummy10_1 pi+ PHSP;
```

```
Enddecay
```

```
Decay dummy10_1
```

```
1.0000 pi+ psi(2S) PHSP;
```

```
Enddecay
```

```
Decay anti-dummy10_1
```

```
1.0000 pi- psi(2S) PHSP;
```

```
Enddecay
```

```
Decay psi(2S)
```

```
1.0000 pi+ pi- J/psi PHSP;
```

```
Enddecay
```

```
Decay J/psi
```

```
0.5000 e+ e- PHSP;
```

```
0.5000 mu+ mu- PHSP;
```

```
Enddecay
```

```
End
```

Y(4660)

$$M_Y = 4633 \pm 7 \text{ MeV}$$

$$\sigma_Y = 64 \pm 9 \text{ MeV}$$

Z_c(4430)

$$M_Y = 4478^{+15}_{-18} \text{ MeV}$$

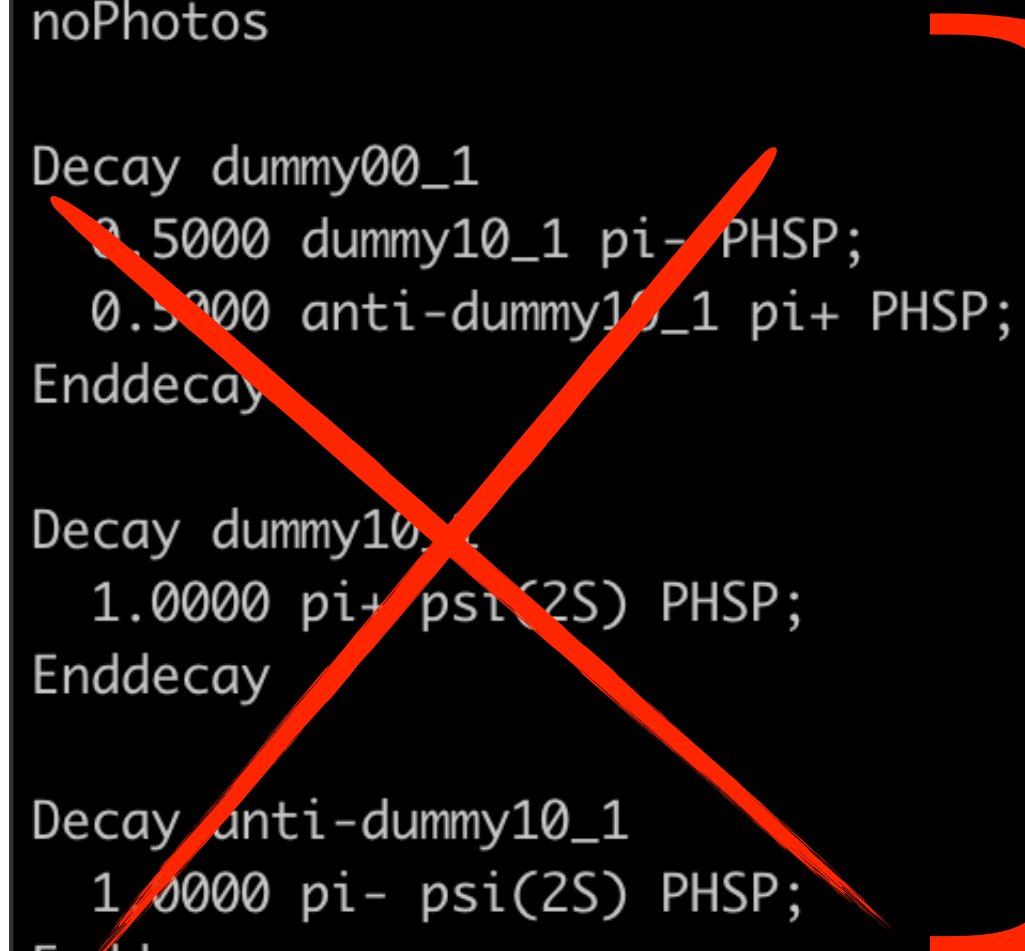
$$\sigma_Y = 181 \pm 31 \text{ MeV}$$

Signal MC sample
300k events

(Signal) MC Studies

Non-resonant Continuum

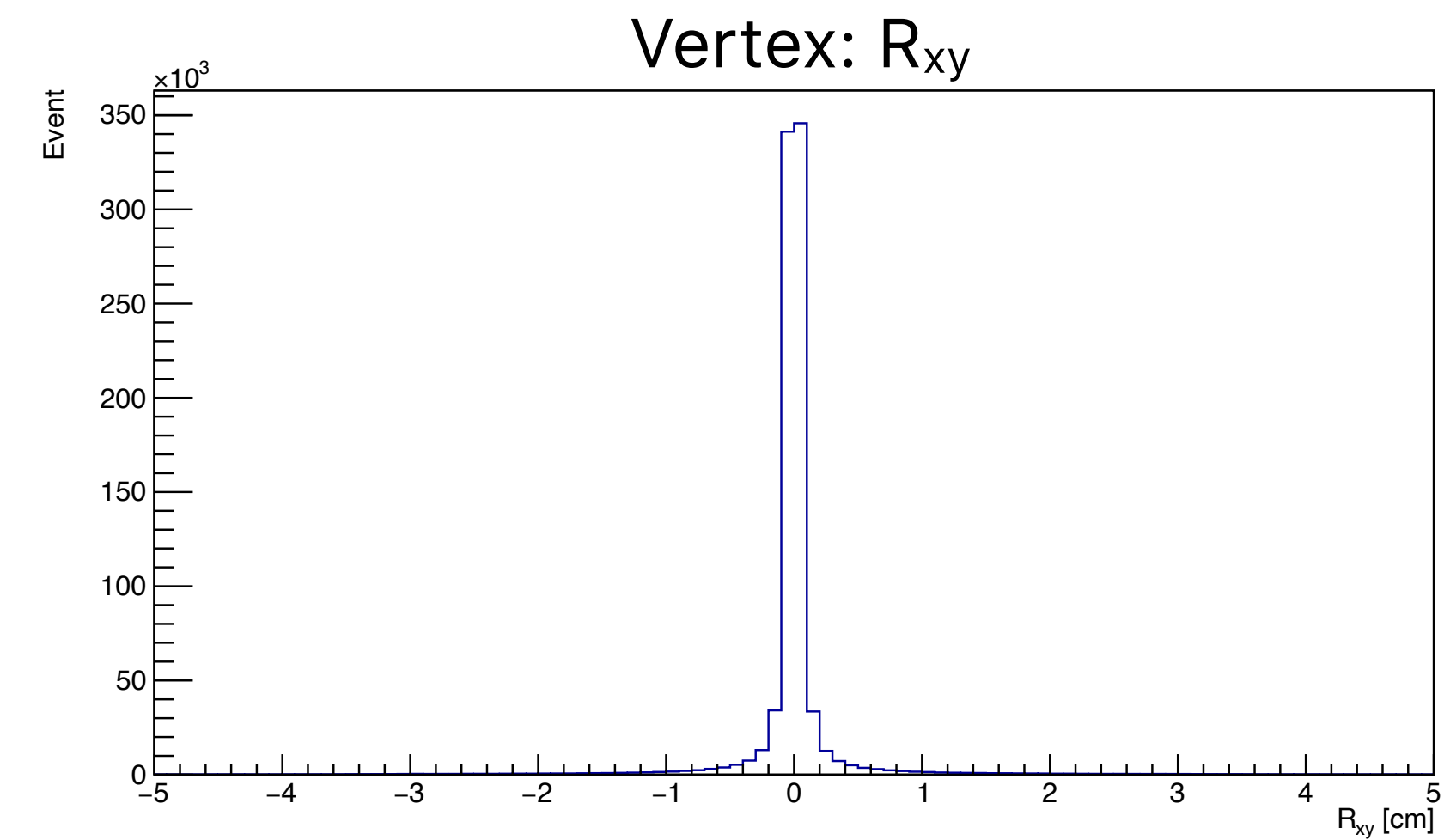
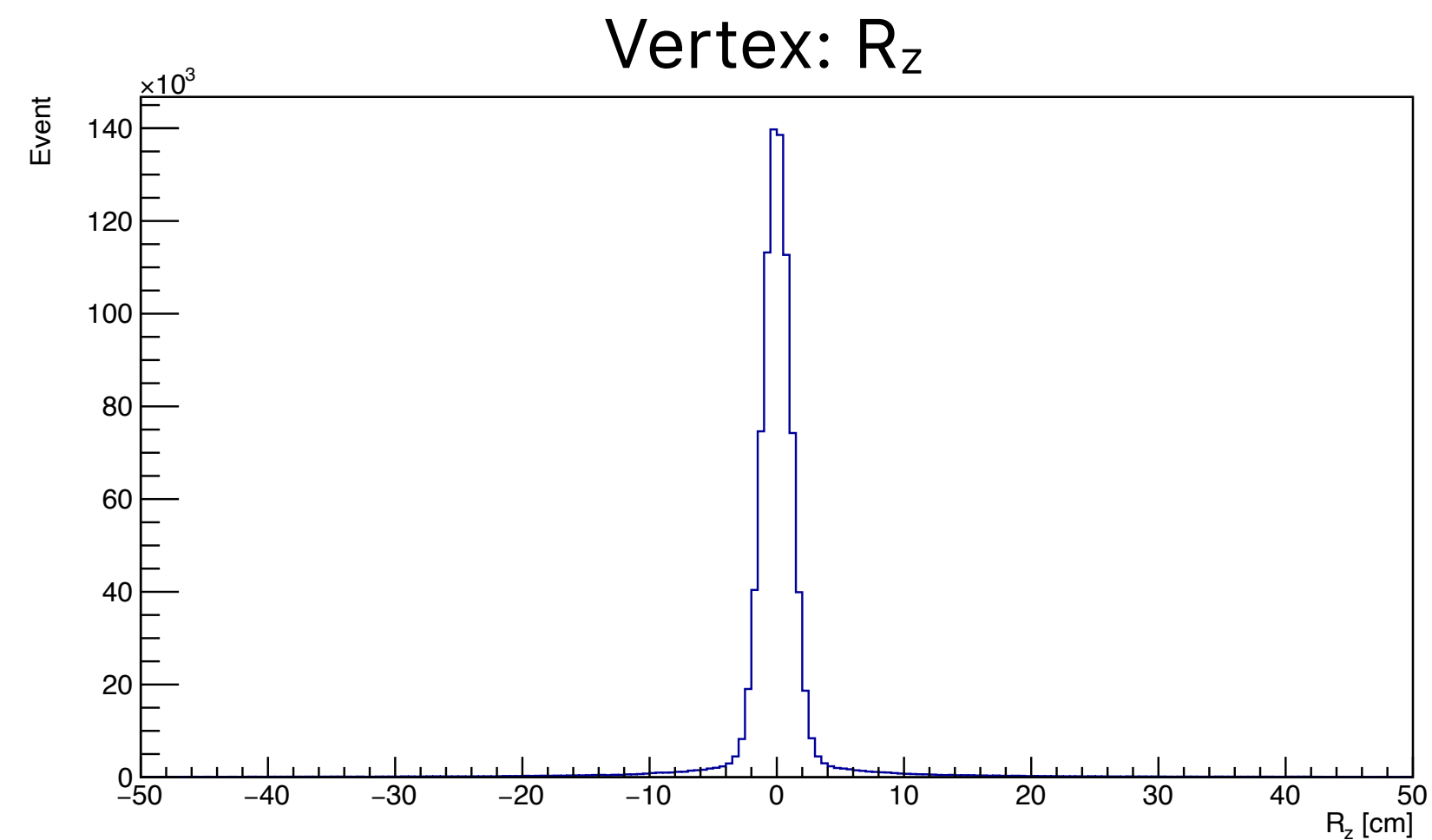
```
noPhotos  
Decay dummy00_1  
  0.5000 dummy10_1 pi- PHSP;  
  0.5000 anti-dummy10_1 pi+ PHSP;  
Enddecay  
  
Decay dummy10_1  
  1.0000 pi+ psi(2S) PHSP;  
Enddecay  
  
Decay anti-dummy10_1  
  1.0000 pi- psi(2S) PHSP;  
Enddecay  
  
Decay psi(2S)  
  1.0000 pi+ pi- J/psi PHSP;  
Enddecay  
  
Decay J/psi  
  0.5000 e+ e- PHSP;  
  0.5000 mu+ mu- PHSP;  
Enddecay  
  
End
```



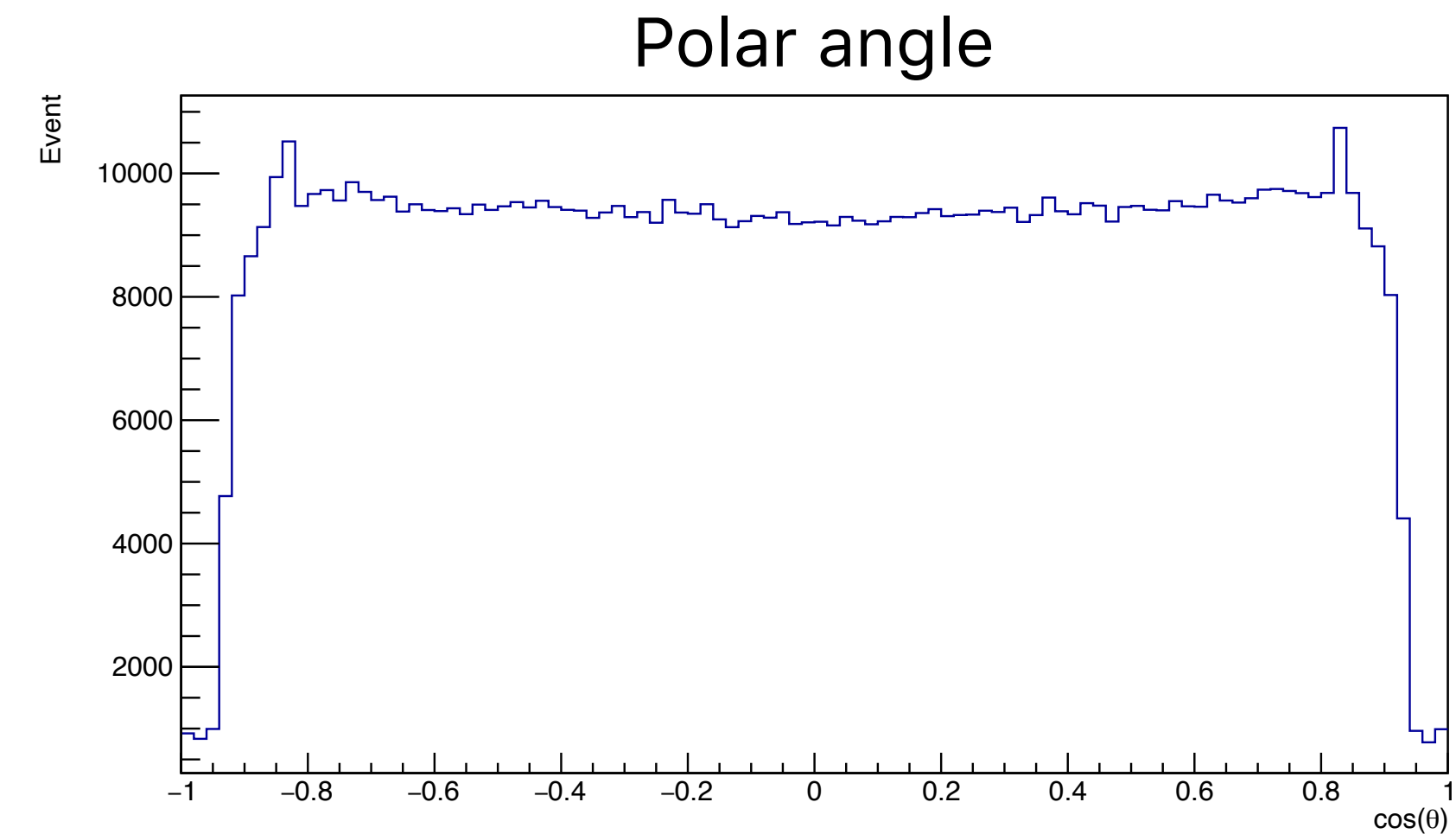
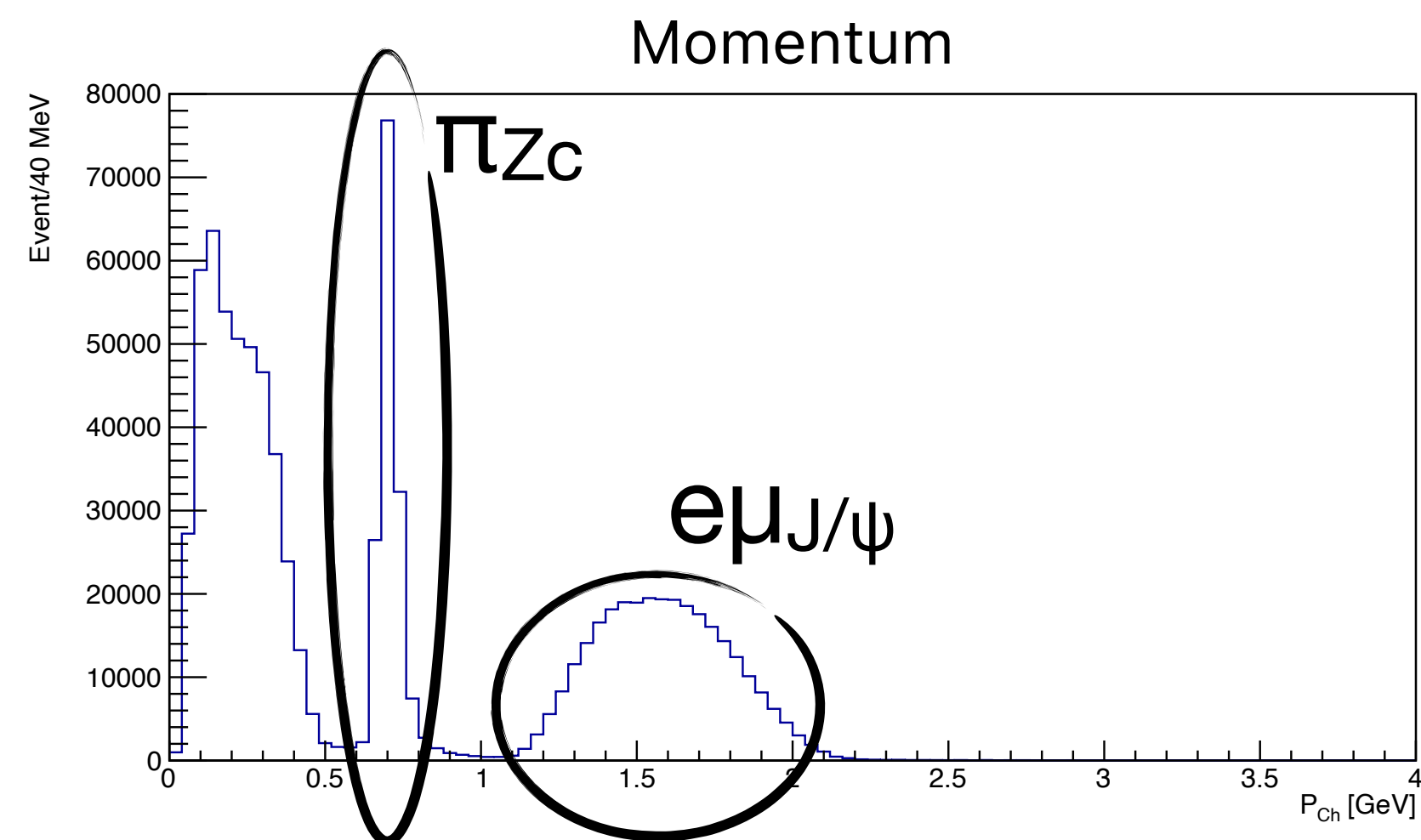
```
noPhotos  
Particle vpho 4.633 0  
  
Decay vpho  
  1.0000 pi+ pi- psi(2S) PHSP;  
Enddecay  
  
Decay psi(2S)  
  1.0000 pi+ pi- J/psi PHSP;  
Enddecay  
  
Decay J/psi  
  0.5000 e+ e- PHSP;  
  0.5000 mu+ mu- PHSP;  
Enddecay  
  
End
```

**MC samples
300k events**

Signal MC Studies

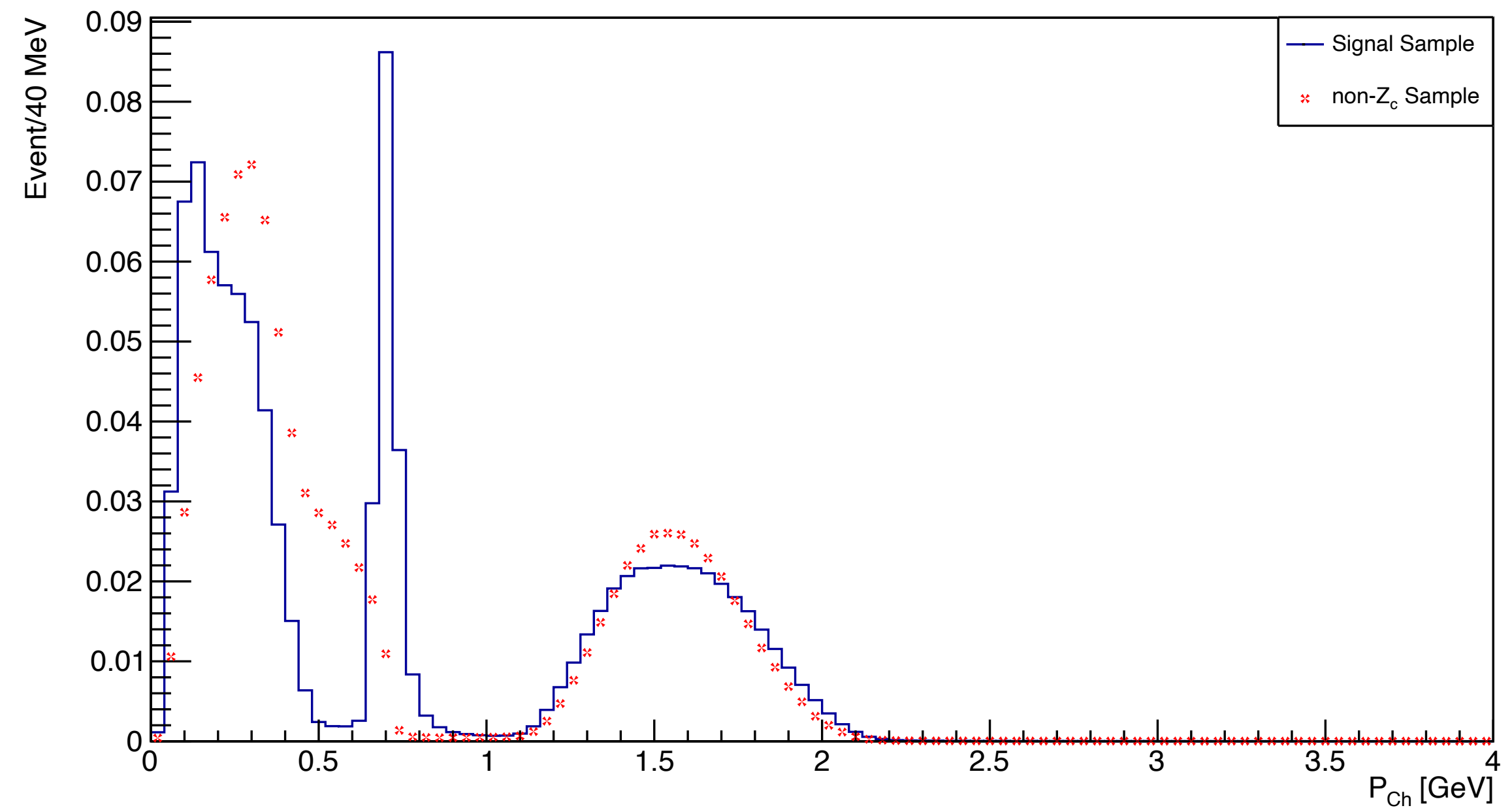
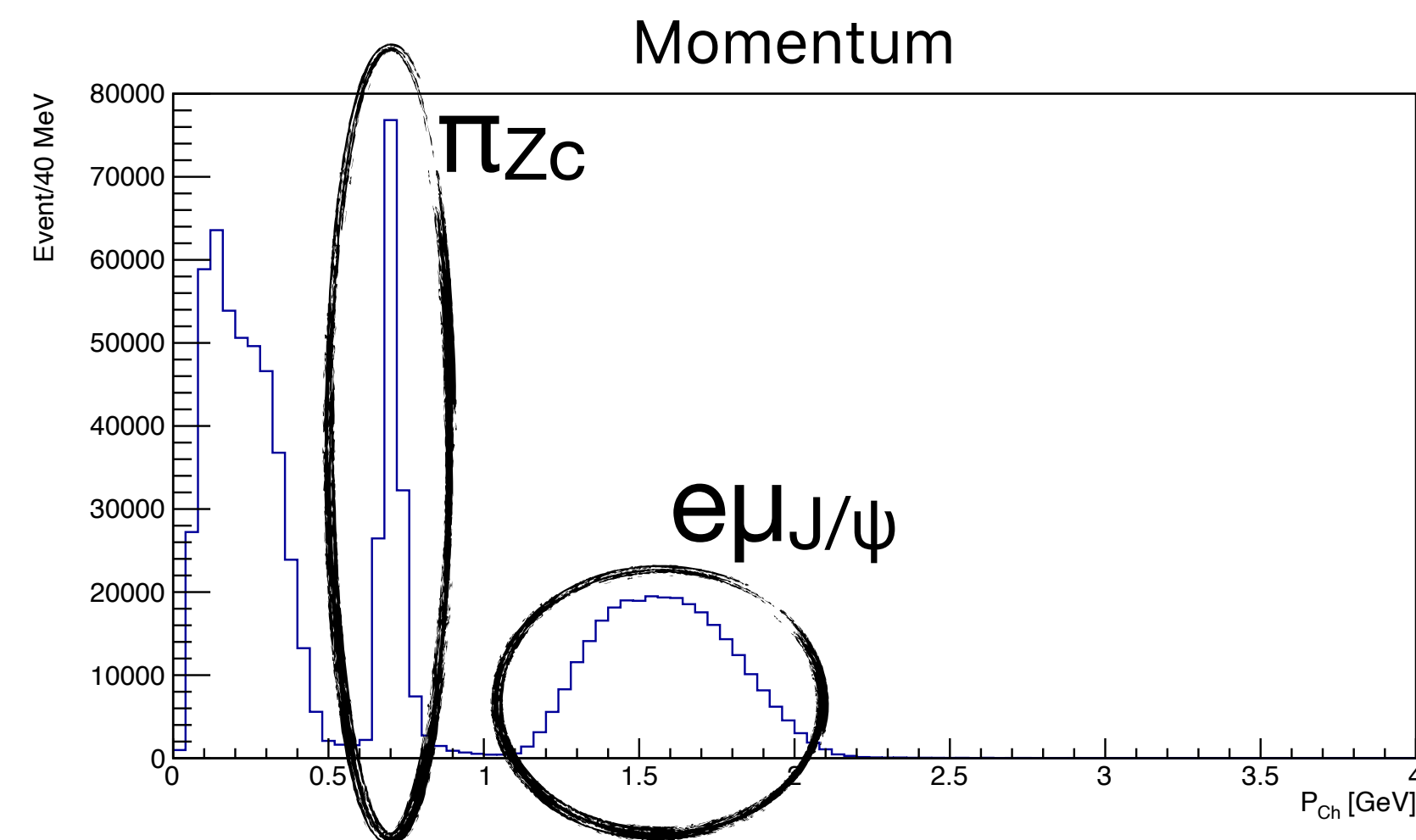


**Charged
Tracks**



Signal MC Studies

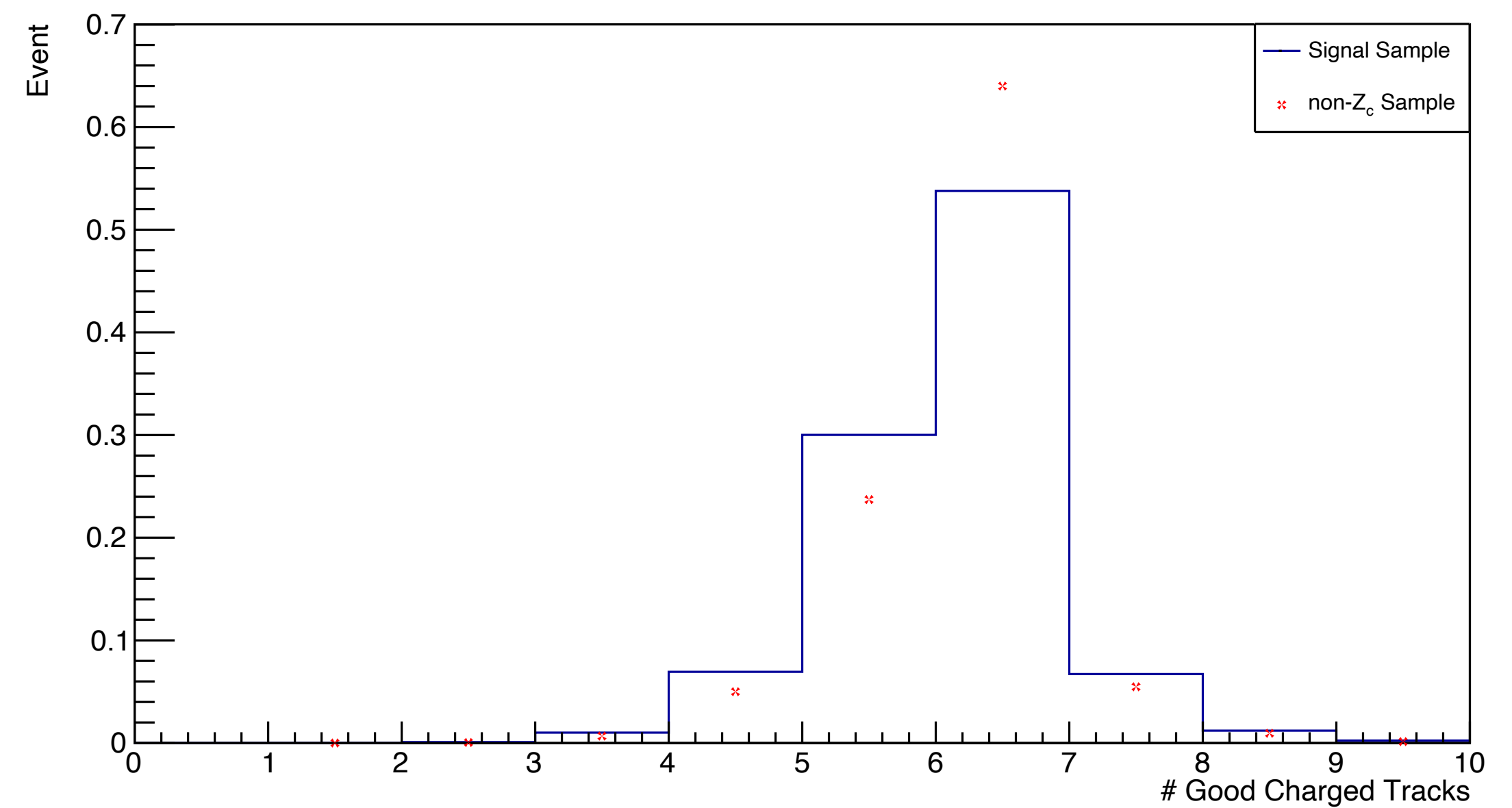
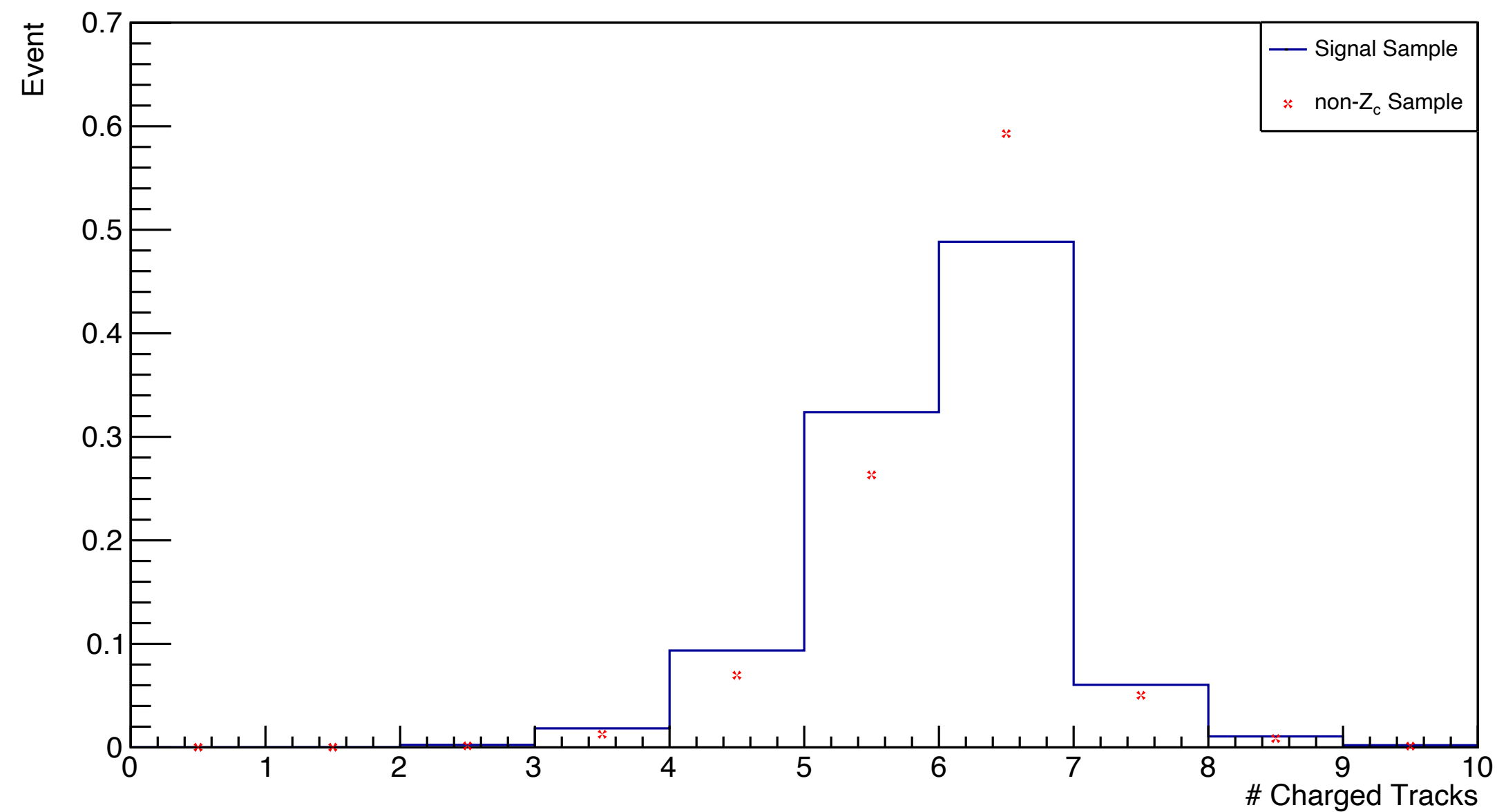
**Charged
Tracks**



**Continuum vs Resonant
Comparison**

Signal MC Studies

Continuum vs Resonant Comparison



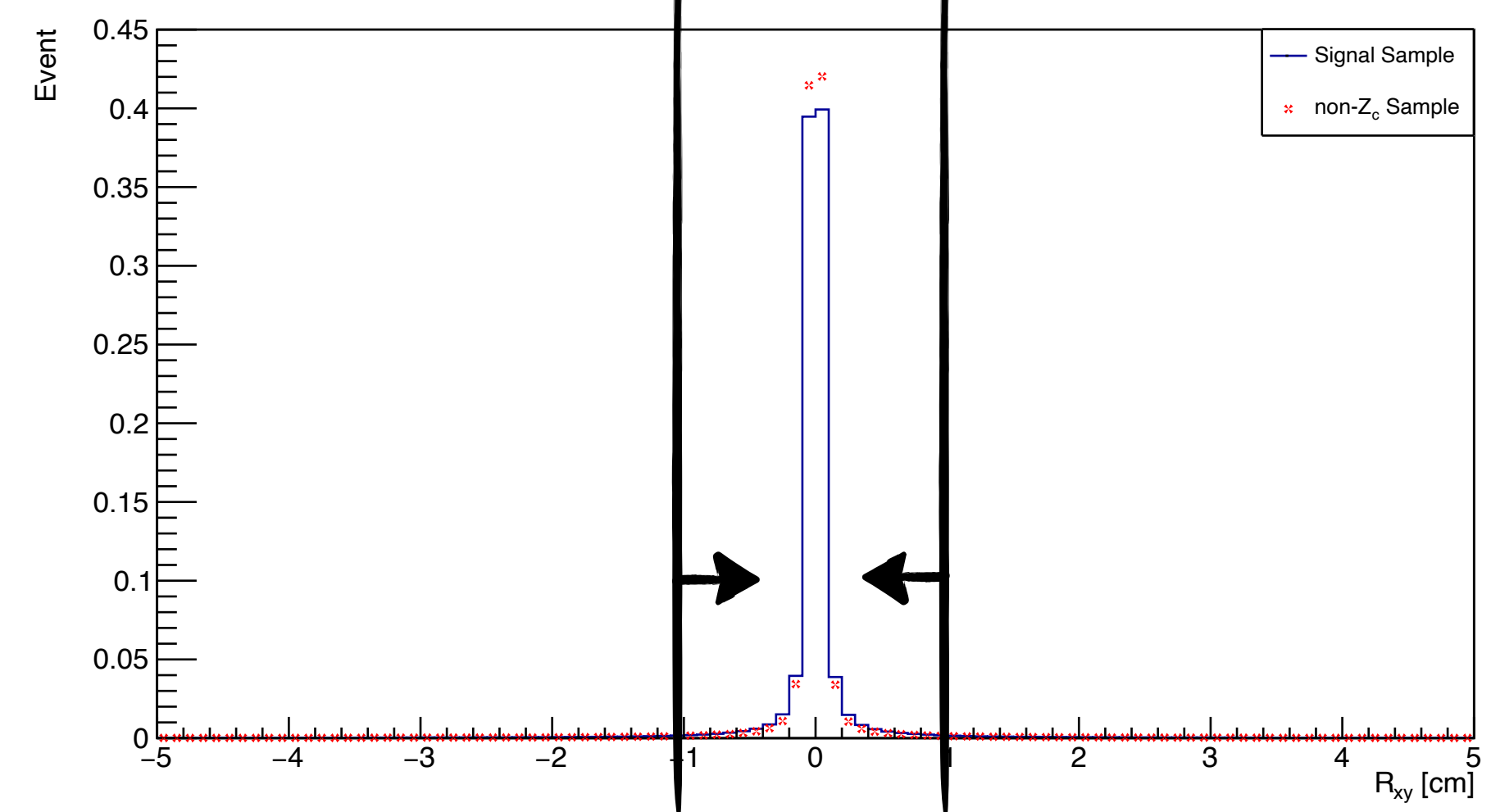
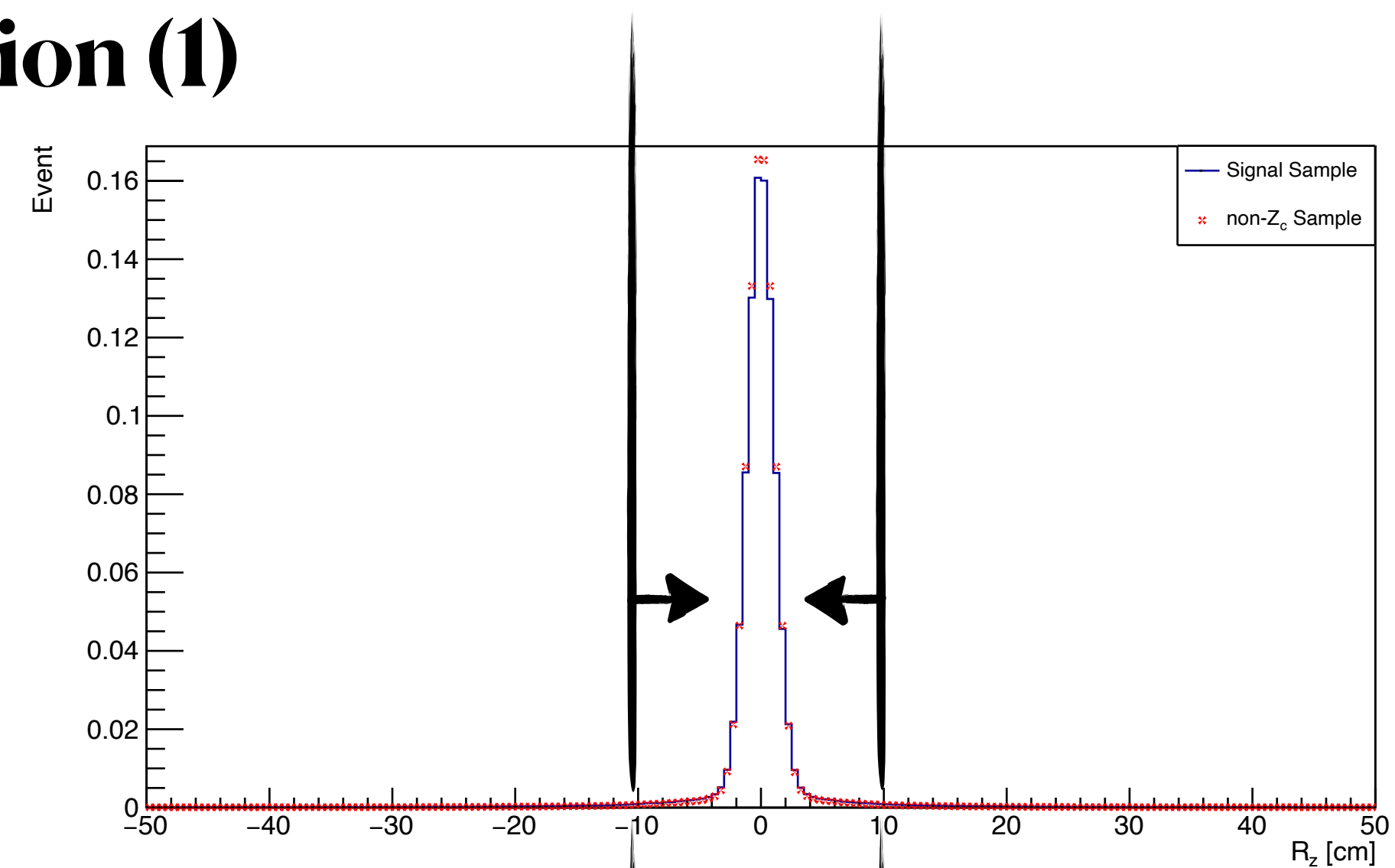
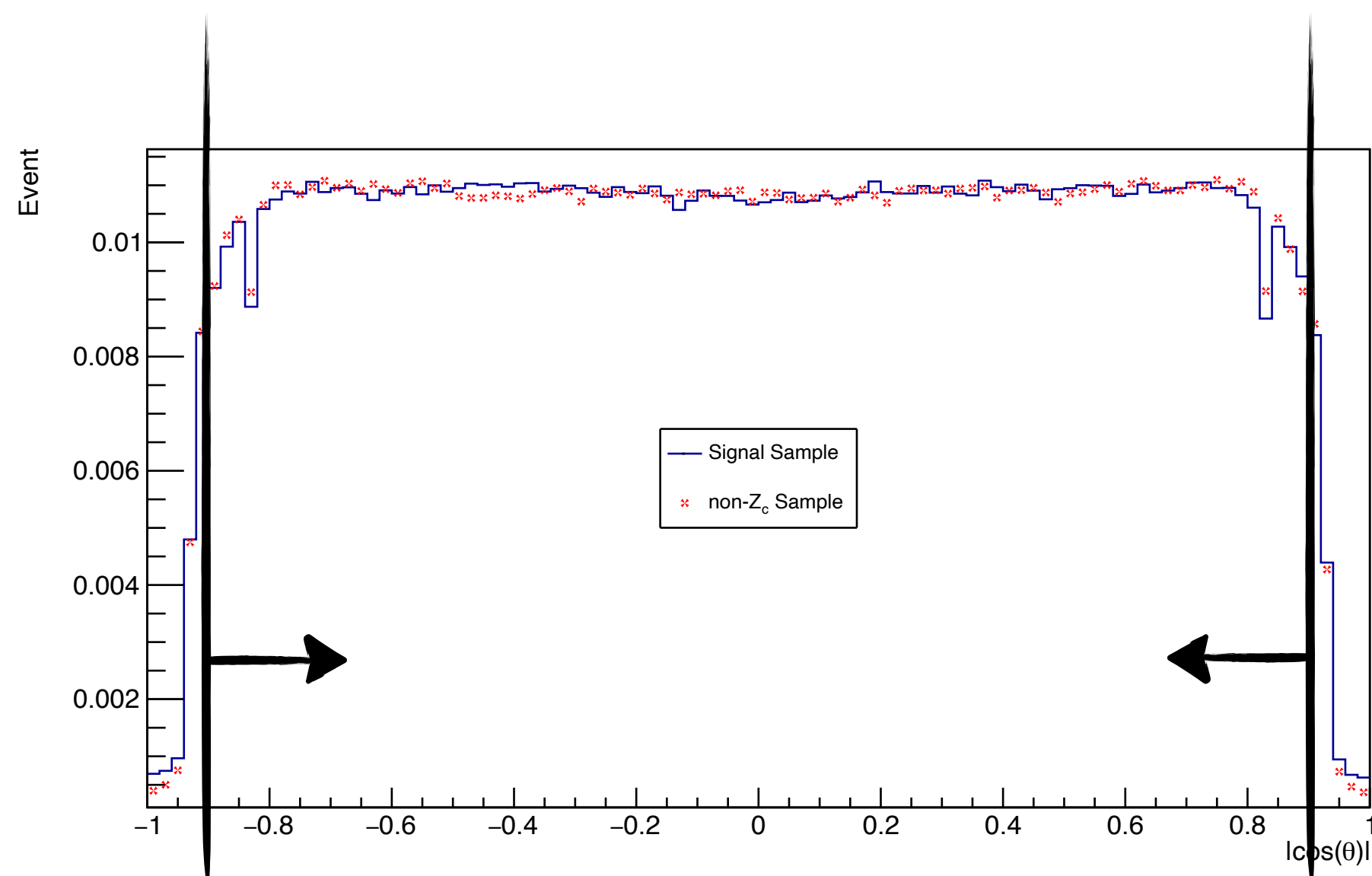
Signal MC Studies

Event Selection (1)

Goodness Cuts

Vertex: $R_{xy} < 1\text{cm}$ & $R_z < 10\text{ cm}$

Polar angle: $|\cos \theta| < 0.93$



Signal MC Studies

Event Selection (1)

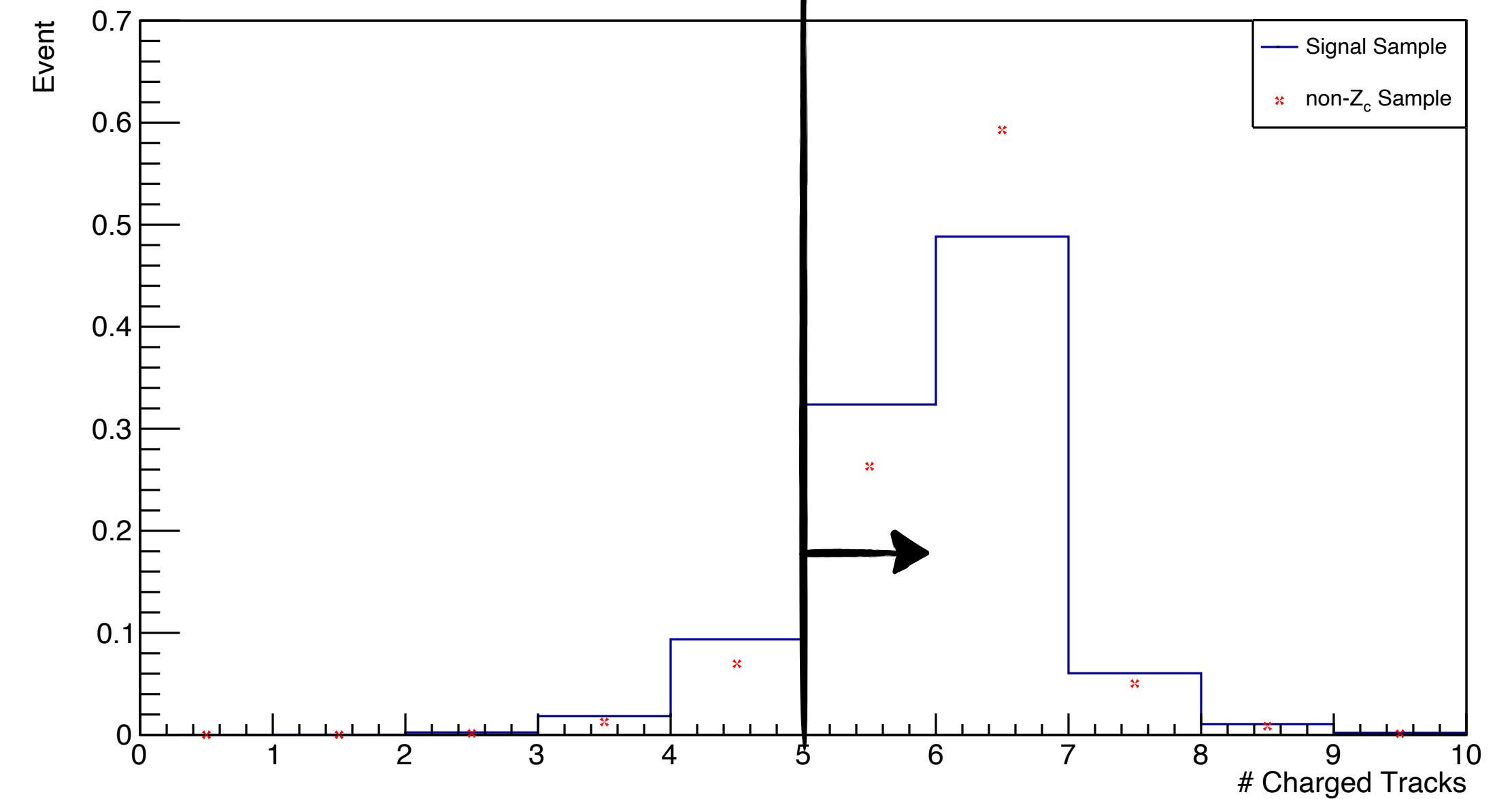
Goodness Cuts

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Polar angle: $|\cos \theta| < 0.93$

Channel ID

charged tracks > 4



Signal MC Studies

Event Selection (1)

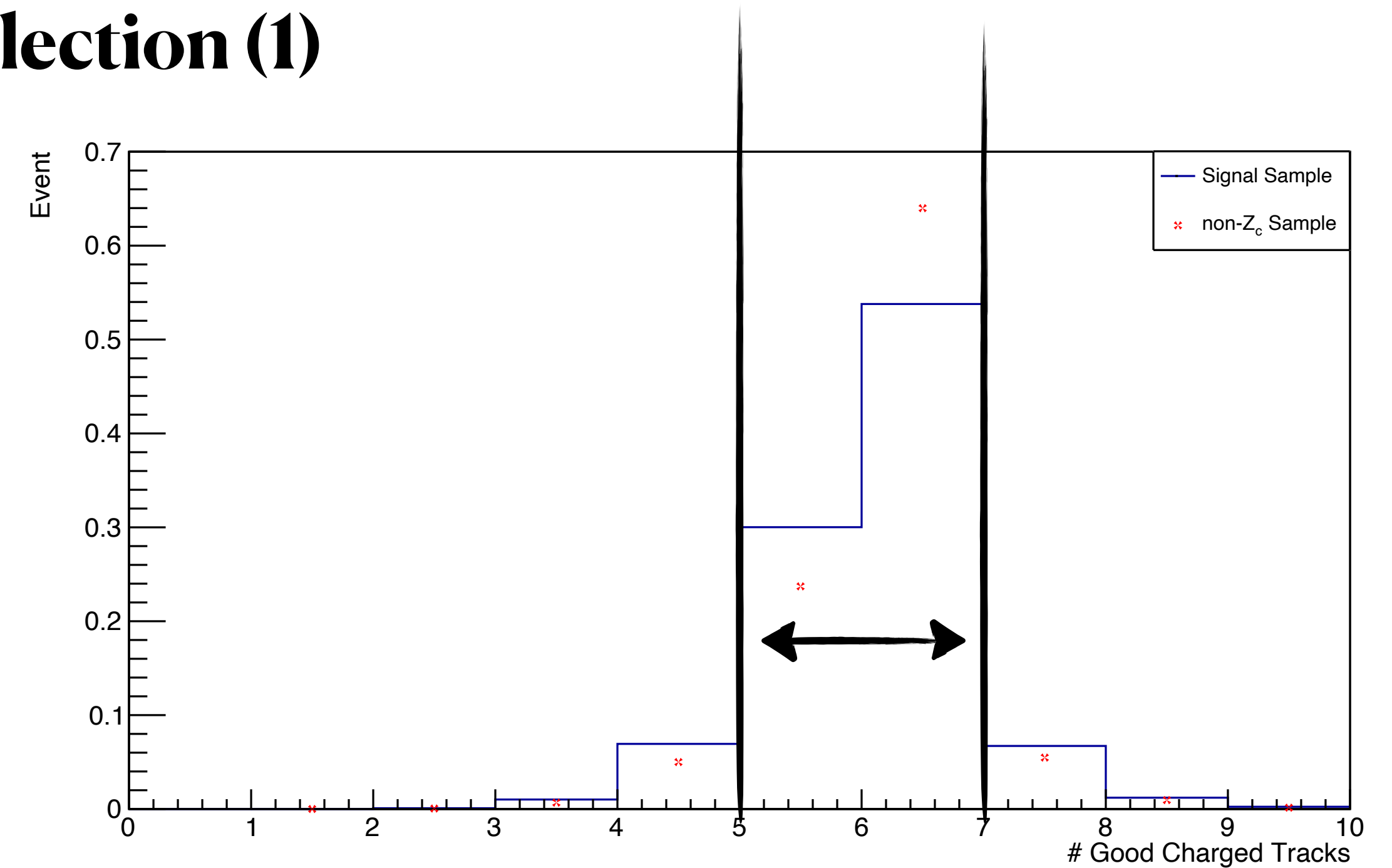
Goodness Cuts

Vertex: $R_{xy} < 1\text{cm}$ & $R_z < 10\text{ cm}$

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charged tracks > 4



2 good charged topologies

$2\ell 3\pi$

$2\ell 4\pi$

Signal MC Studies

Event Selection (1)

Goodness Cuts

Vertex: $R_{xy} < 1\text{cm}$ & $R_z < 10\text{ cm}$

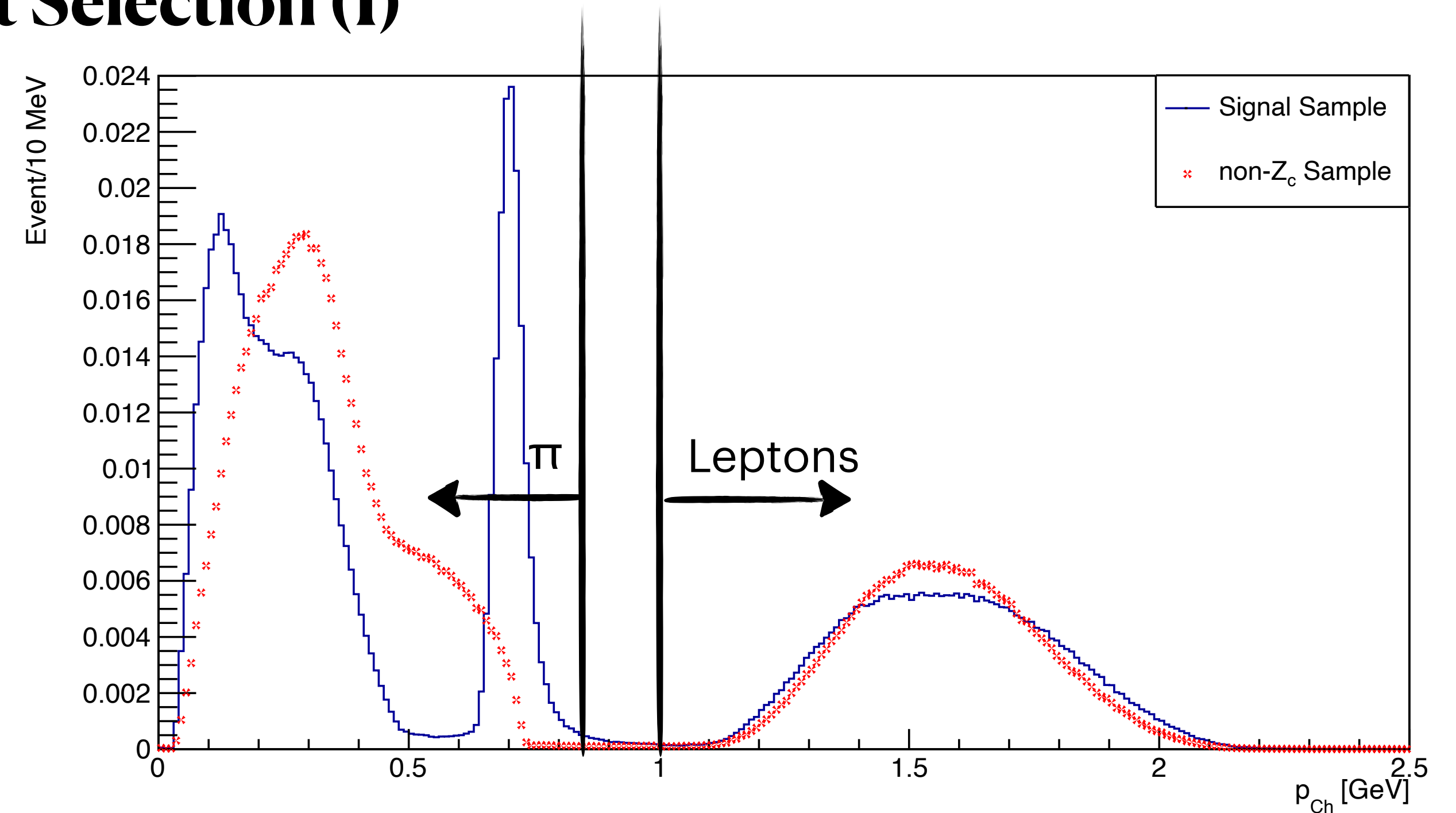
Polar angle: $|\cos \theta| < 0.93$

Channel ID

charged tracks > 4

Leptons
 $p_T > 1\text{ GeV}$

Pions
 $p_T < 0.85\text{ GeV}$



2 topologies

$2\ell\ 3\pi$

$2\ell\ 4\pi$

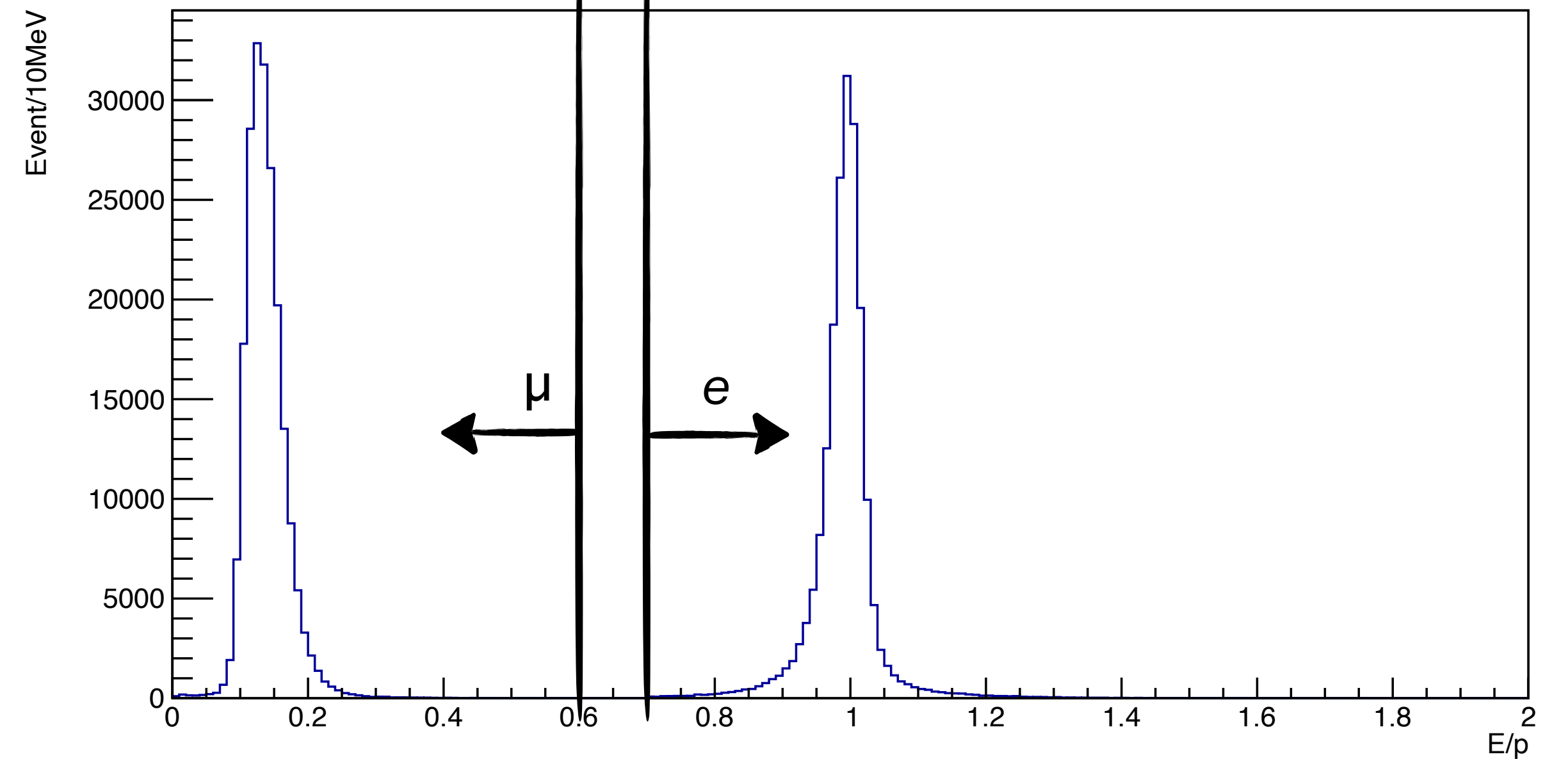
Signal MC Studies

Event Selection (1)

Goodness Cuts

Vertex: $R_{xy} < 1\text{cm}$ & $R_z < 10\text{ cm}$

Polar angle: $|\cos \theta| < 0.93$



Channel ID

charged tracks > 4

Leptons
 $p_T > 1\text{ GeV}$
 $E/p (e) > 0.7$
 $E/p (\mu) < 0.6$

Pions
 $p_T < 0.85\text{ GeV}$

2 topologies

$2\ell 3\pi$

$2\ell 4\pi$

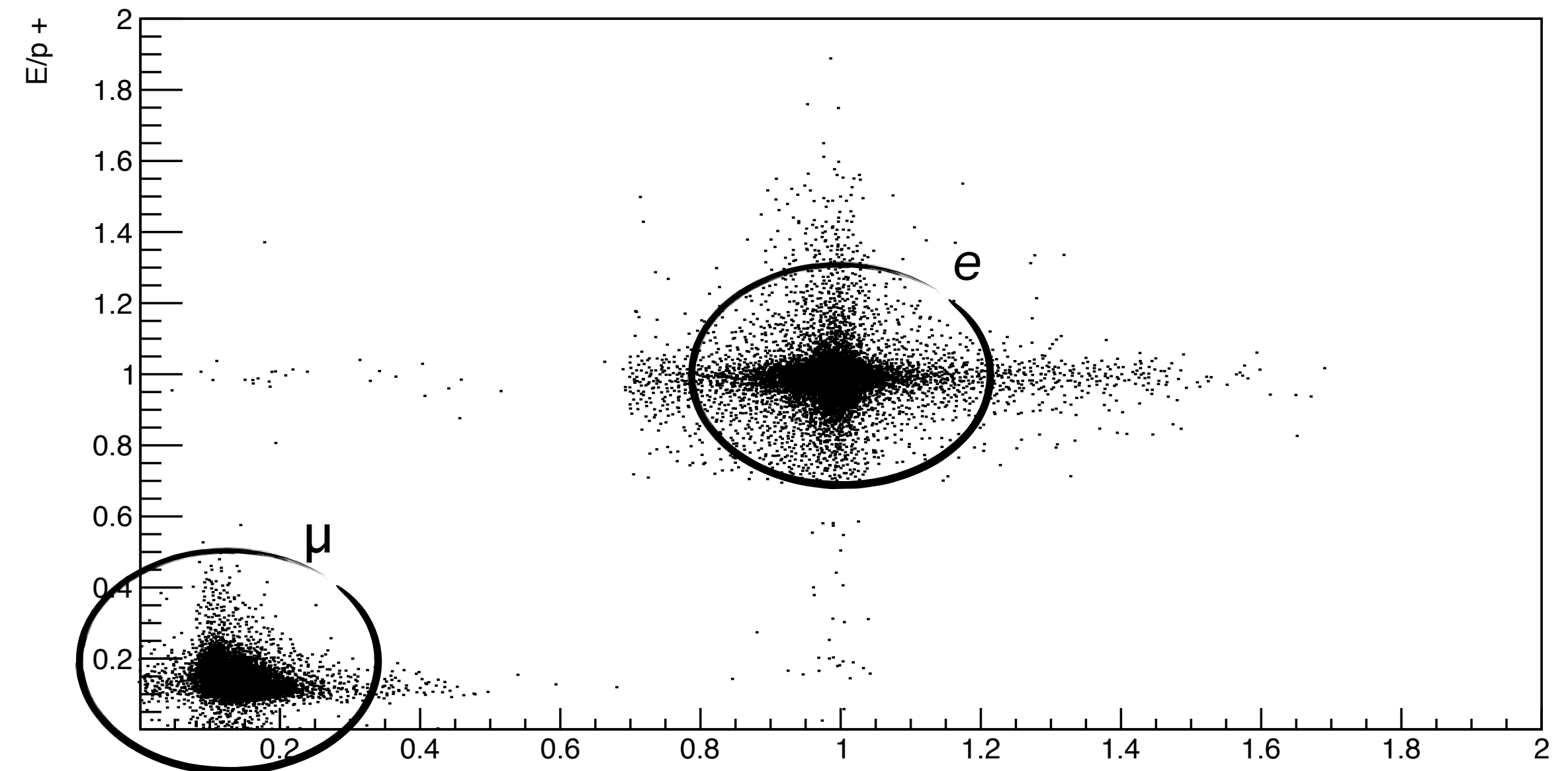
Signal MC Studies

Event Selection (1)

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charged tracks > 4

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 $E/p(e) > 0.7$
 $E/p(\mu) < 0.6$

Pions
 $p_T < 0.85\text{ GeV}$

2 topologies

$2\ell 3\pi$

$2\ell 4\pi$

Signal MC Studies

Event Selection (2)

Topology dependent KALMAN Fits

$2\ell 4\pi$

5C Kalman fit

4C on the $p_{\text{Tot}} = (0.051, 0, 0, M_{Y(4660)})$
1C on the $M_{\psi(2S)}$

The $\pi\pi$ couples are selected via the best χ^2

$2\ell 3\pi$

2C Kalman fit

1C on the $M_{J/\psi}$
1C on the $|\mathbf{p}_{\text{Tot}}|$

π_{Miss} can come either from the $Z_c\text{-}\psi(2S)$ system
(i.e. $Y(4660)$ decay) or from the $\psi(2S)$ decay

The $\pi\pi$ and $\pi\pi_{\text{Miss}}$ couples are selected by
minimising the $M^{\text{Reco}}_{\psi(2S)} - M^{\text{PDG}}_{\psi(2S)}$ difference

Signal MC Studies

Event Selection (2)

Topology dependent KALMAN Fits

$2\ell 4\pi$

5C Kalman fit

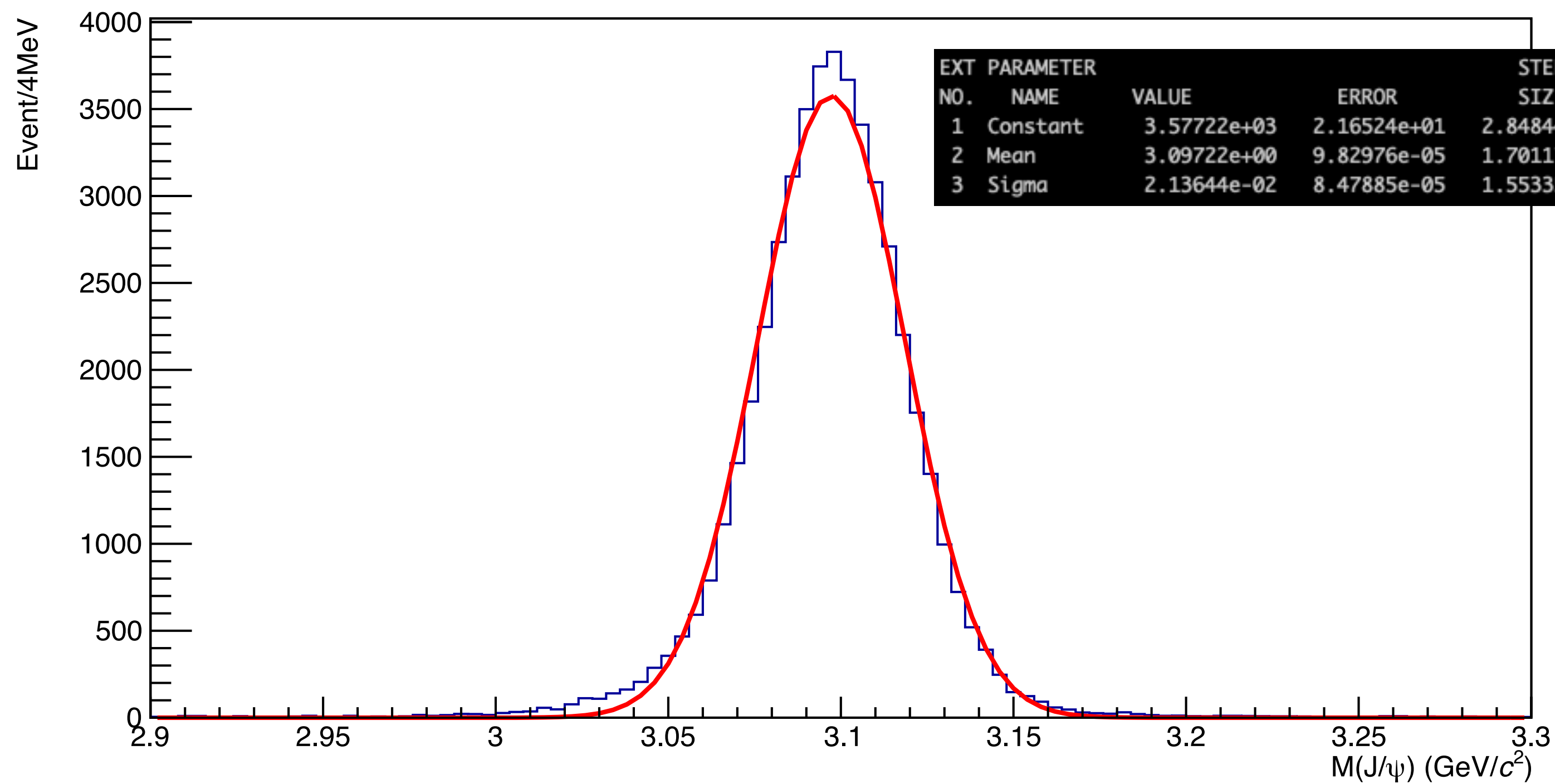
4C on the $p_{\text{Tot}} = (0.051, 0, 0, M_{Y(4660)})$

1C on the $M_{\psi(2S)}$

The $\pi\pi$ couples are selected via the best χ^2

Signal MC Studies

$$2\ell 4\pi$$

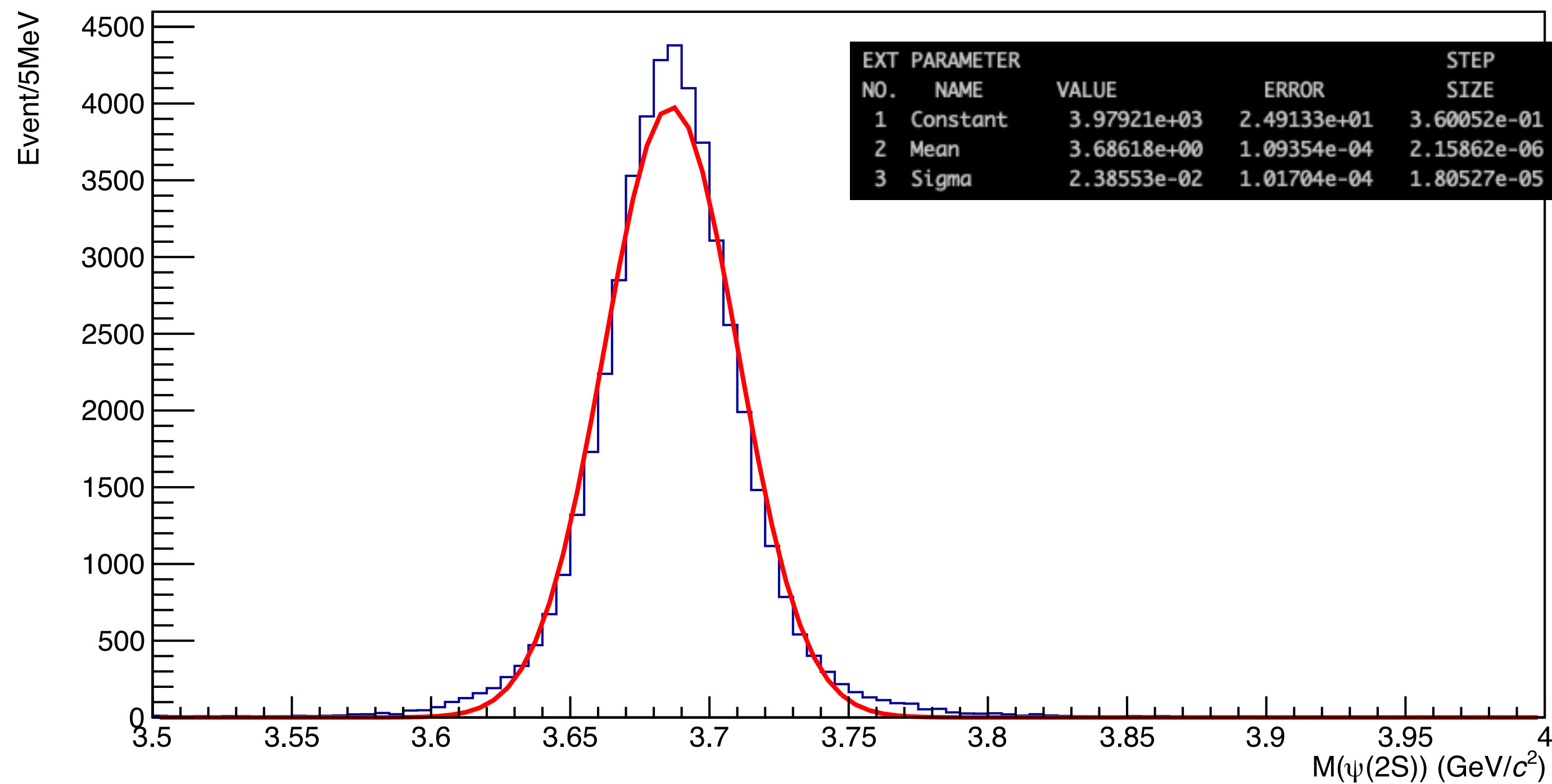


Reconstructed $M_{J/\psi}$

The distribution follows a gaussian shape

Signal MC Studies

$2\ell 4\pi$

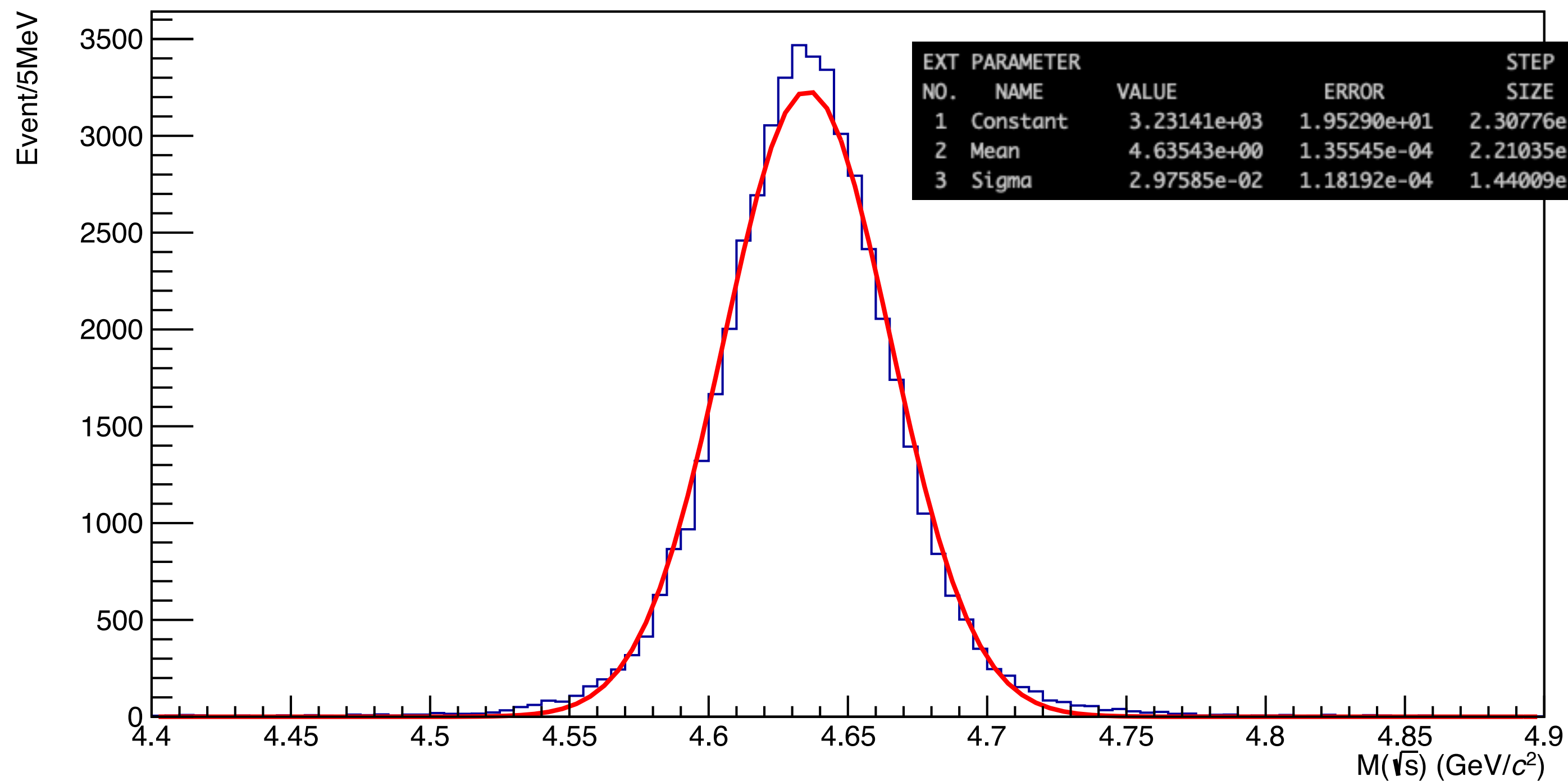


Reconstructed $M_{\psi(2S)}$

The distribution follows a gaussian shape

Signal MC Studies

$2\ell 4\pi$



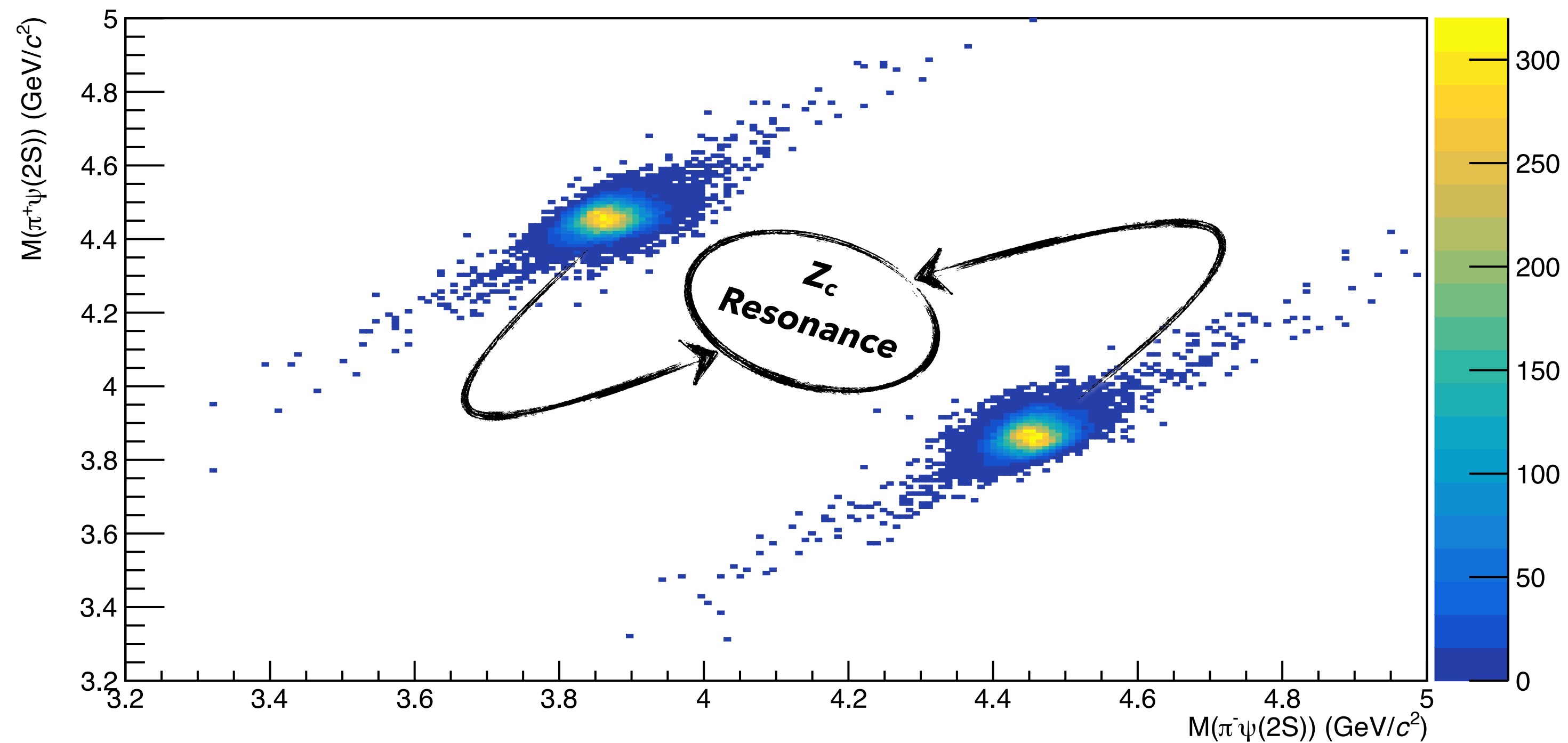
Reconstructed total invariant mass

The distribution follows a gaussian shape

Signal MC Studies

$2\ell 4\pi$

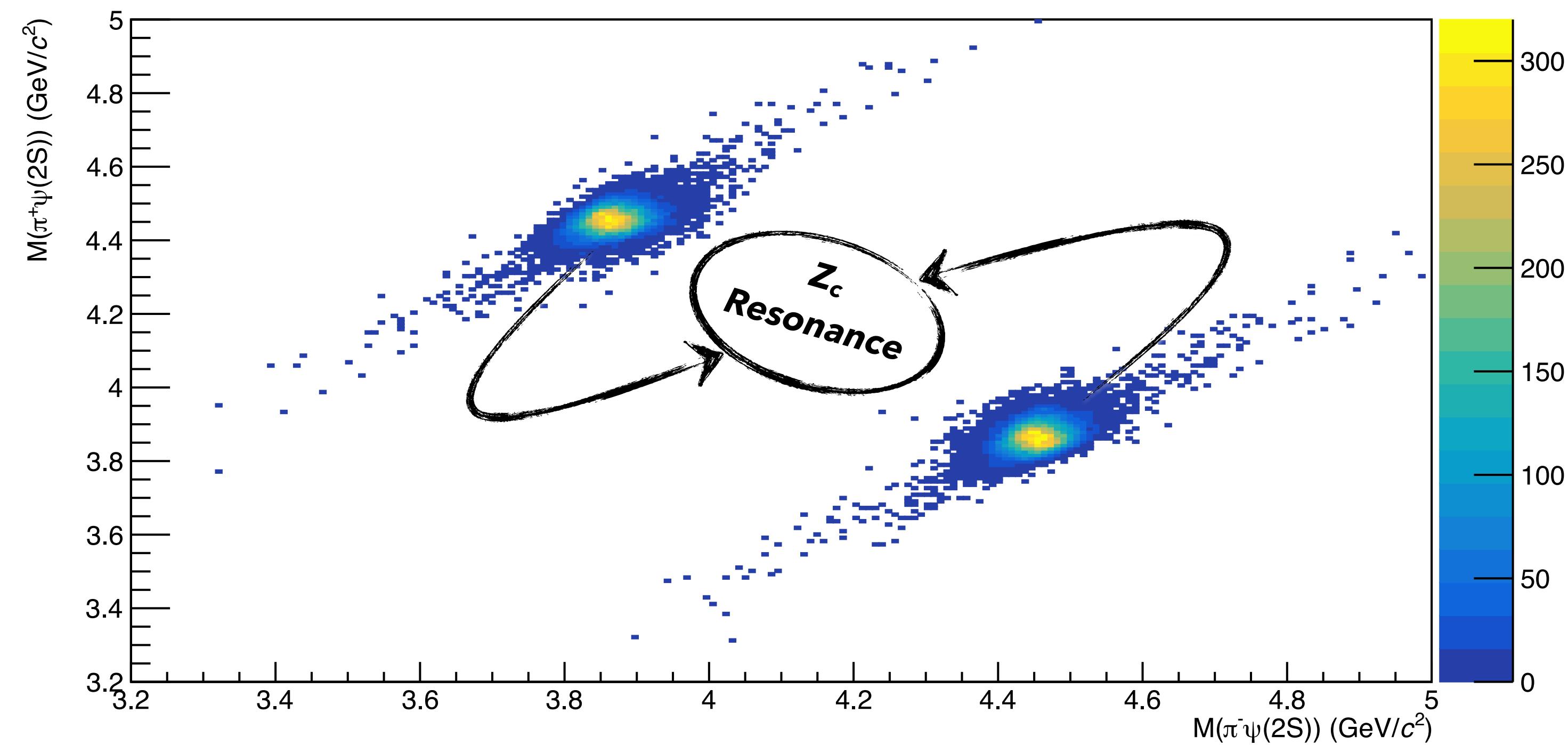
Reconstructed Z_c resonance invariant mass



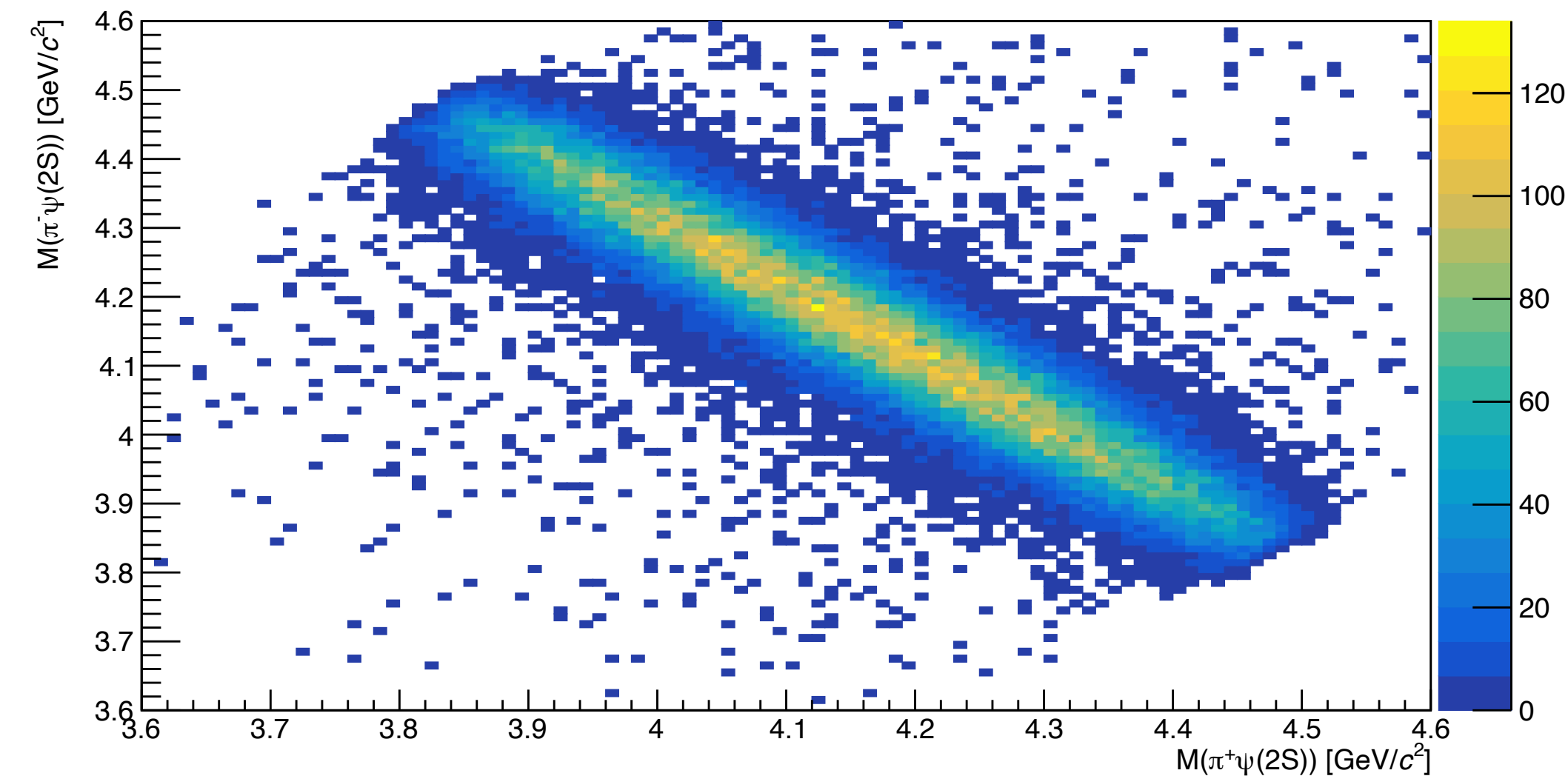
Signal MC Studies

$2\ell 4\pi$

Reconstructed Z_c resonance invariant mass



Continuum vs Resonant
Comparison



Signal MC Studies

Event Selection (2)

Topology dependent KALMAN Fits

$2\ell 3\pi$

2C Kalman fit

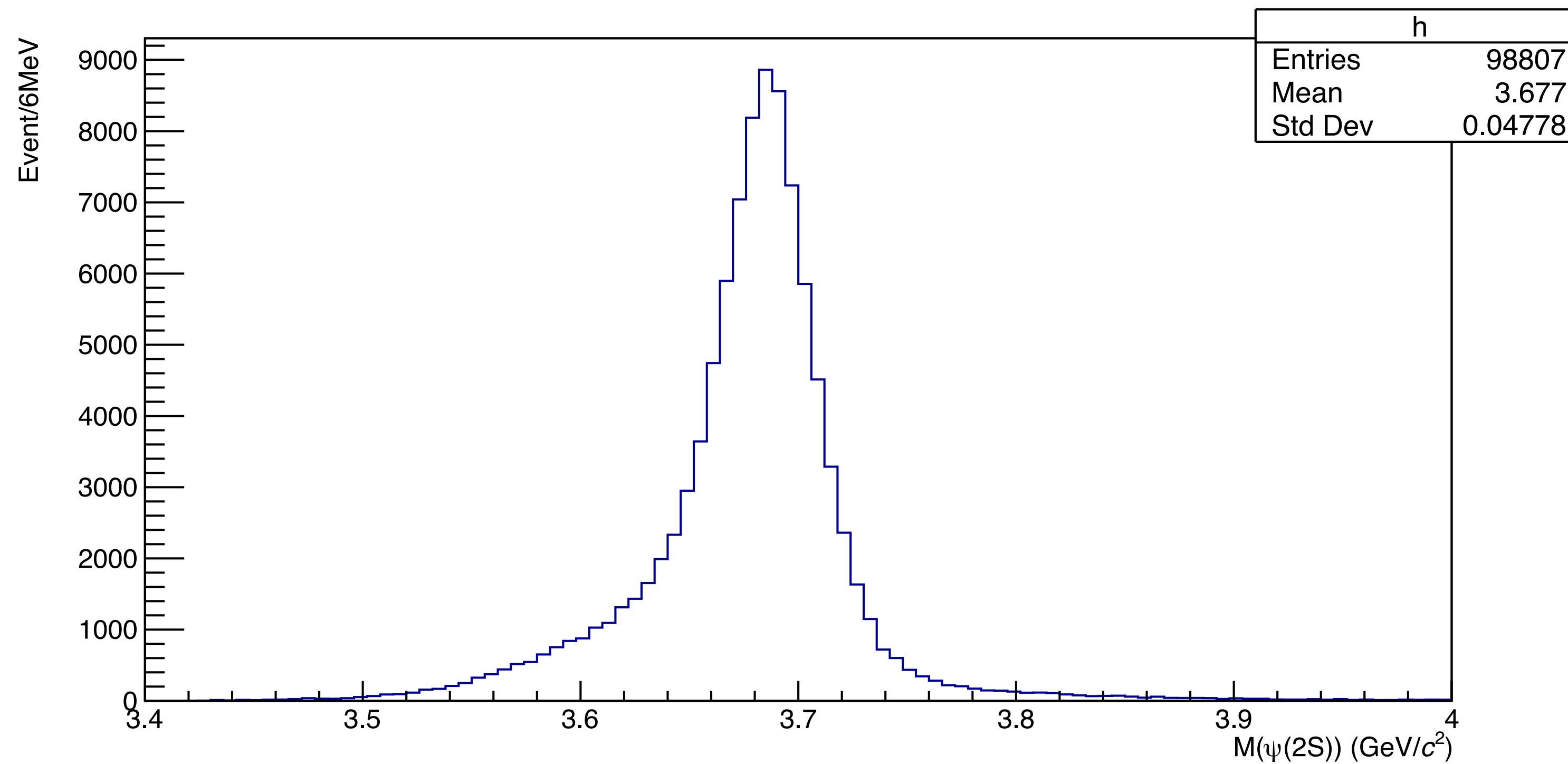
1C on the $M_{J/\psi}$
1C on the $|\mathbf{p}_{\text{Tot}}|$

$\pi\pi_{\text{Miss}}$ can come either from the $Z_c\text{-}\psi(2S)$ system
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The $\pi\pi$ and $\pi\pi_{\text{Miss}}$ couples are selected by
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Signal MC Studies

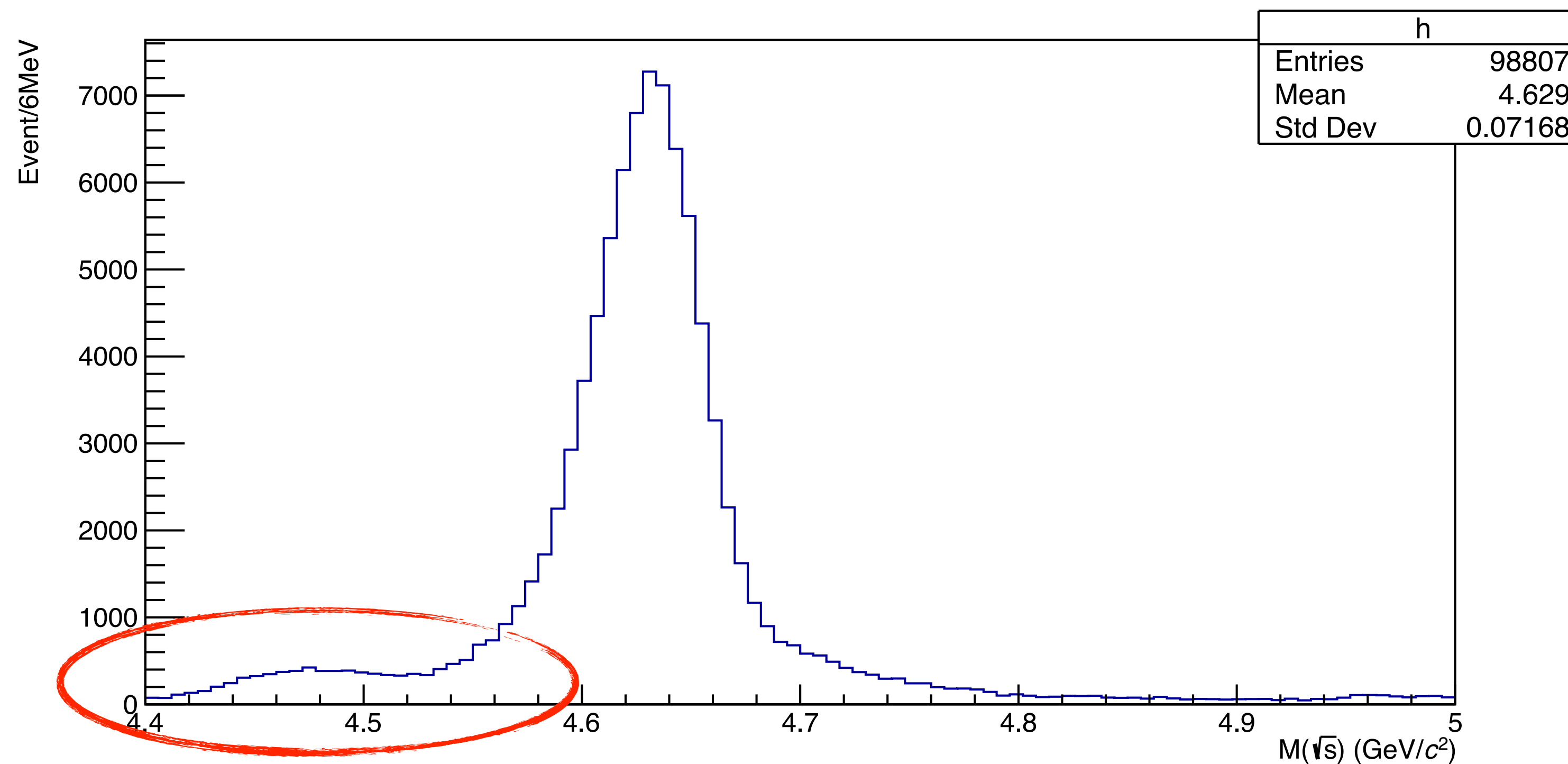
$2\ell 3\pi$



Reconstructed $M_{\psi(2S)}$, which seems to follow a crystal-ball distribution

Signal MC Studies

$2\ell 3\pi$

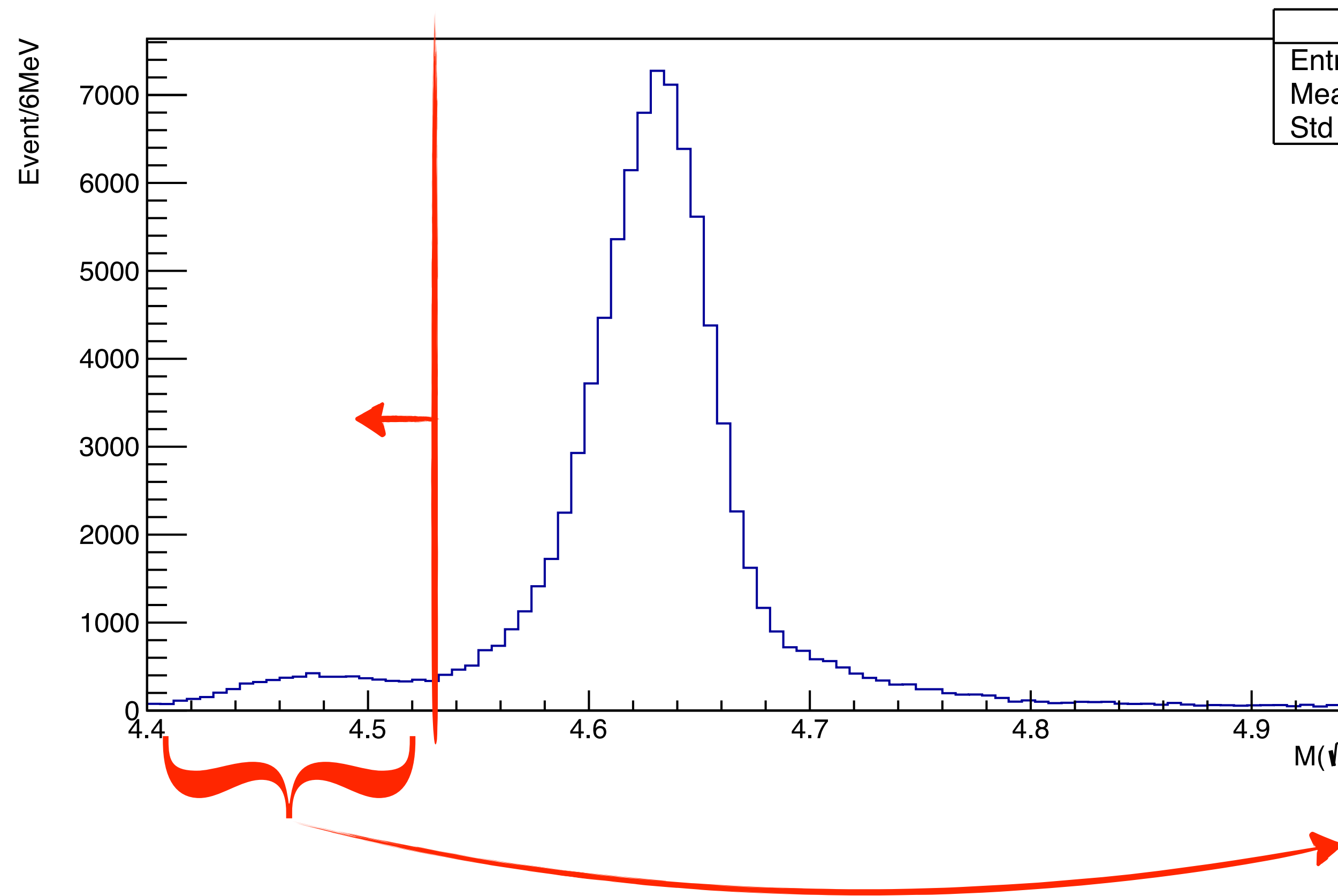


Reconstructed total invariant mass

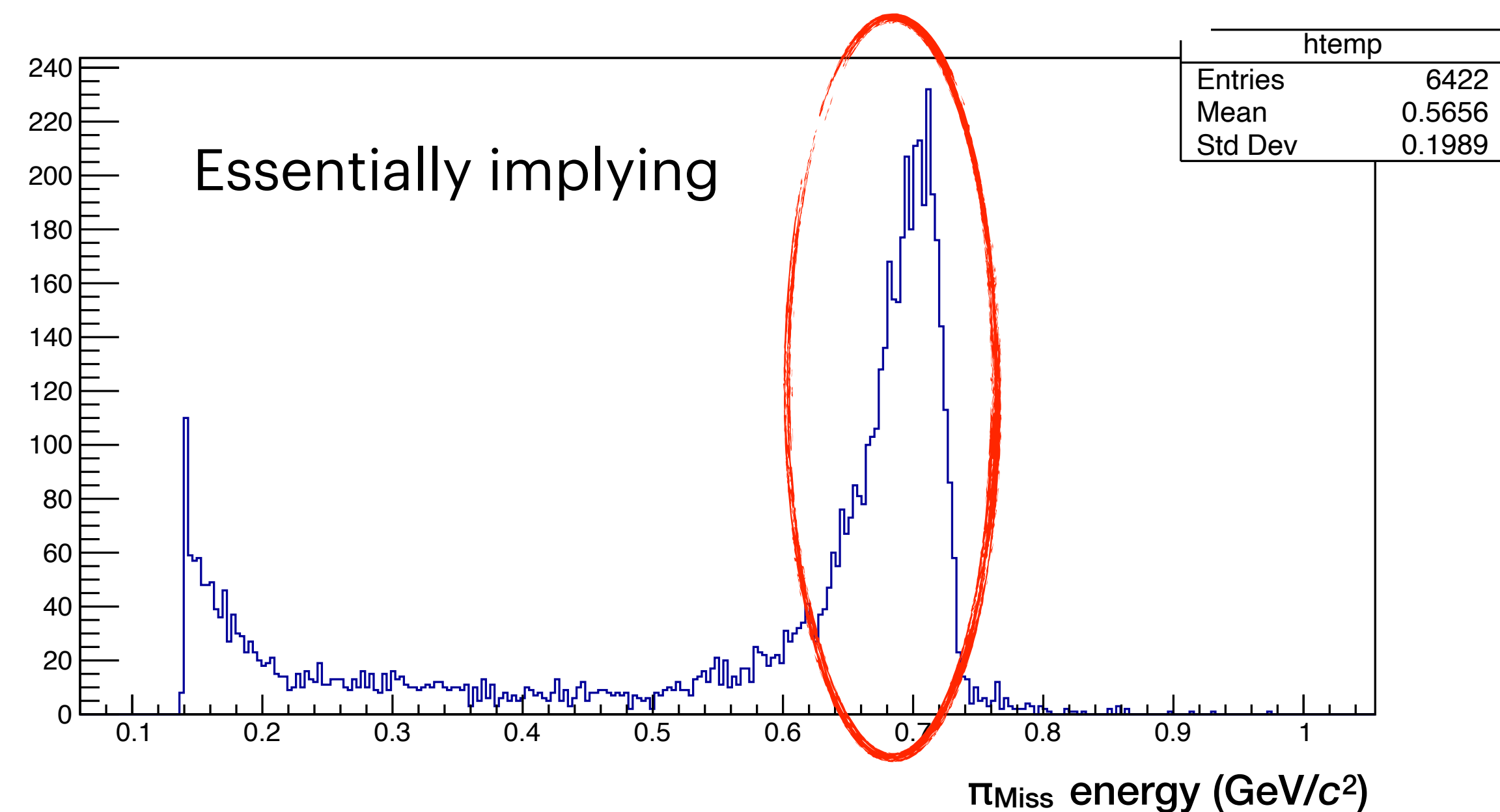
A peculiar feature at low energies and a long tail at high momenta were found

Signal MC Studies

$2\ell 3\pi$

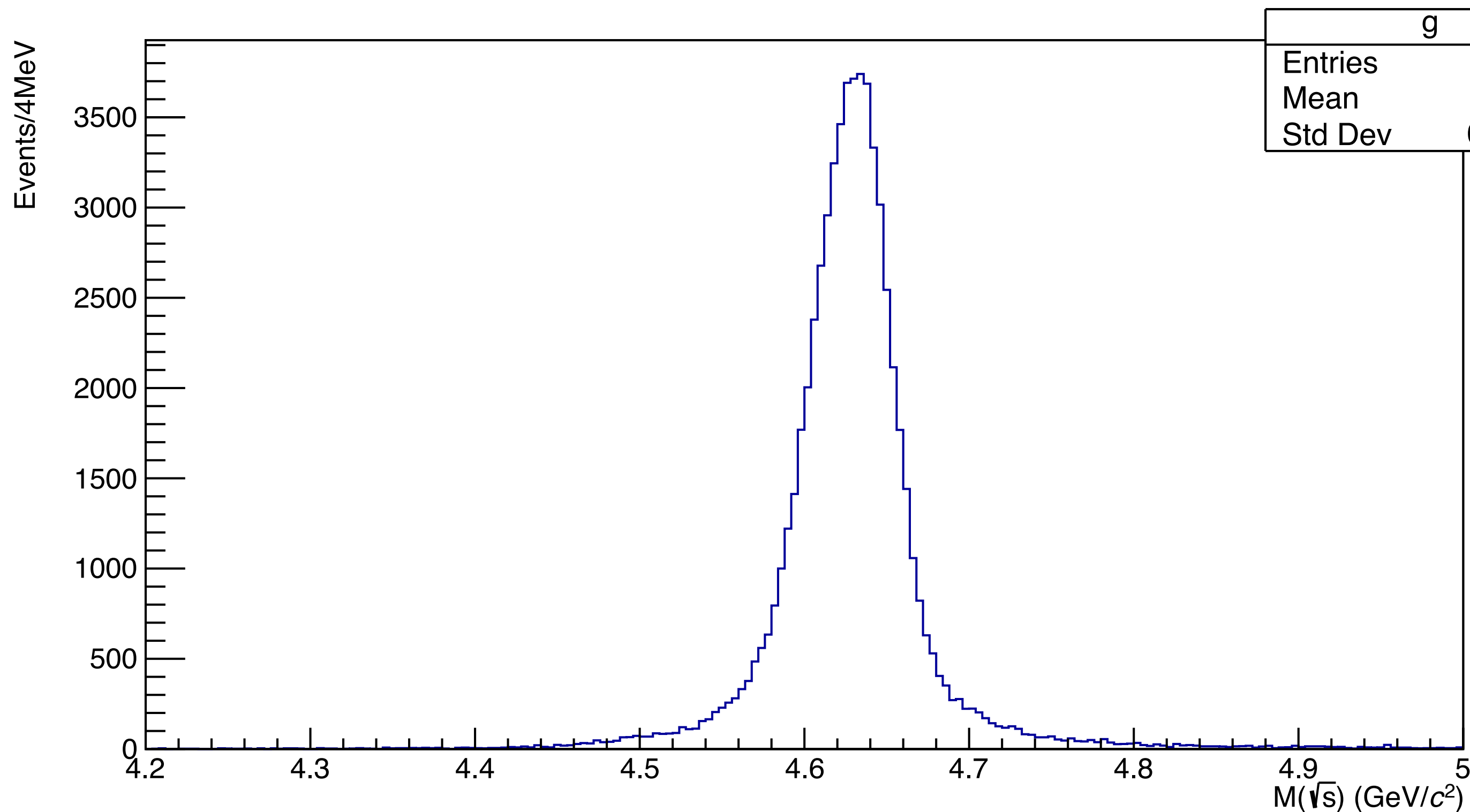


The shape was found to be originated from the π_{Miss} coming from the $Z_c(4430) \rightarrow \psi(2S)$ decay



Signal MC Studies

$2\ell 3\pi$



Removing all the events with
 $E(\pi_{\text{Miss}}) > 0.5 \text{ GeV}/c^2$ and with $p(\pi_{\text{Miss}}) > E(\pi_{\text{Miss}})$

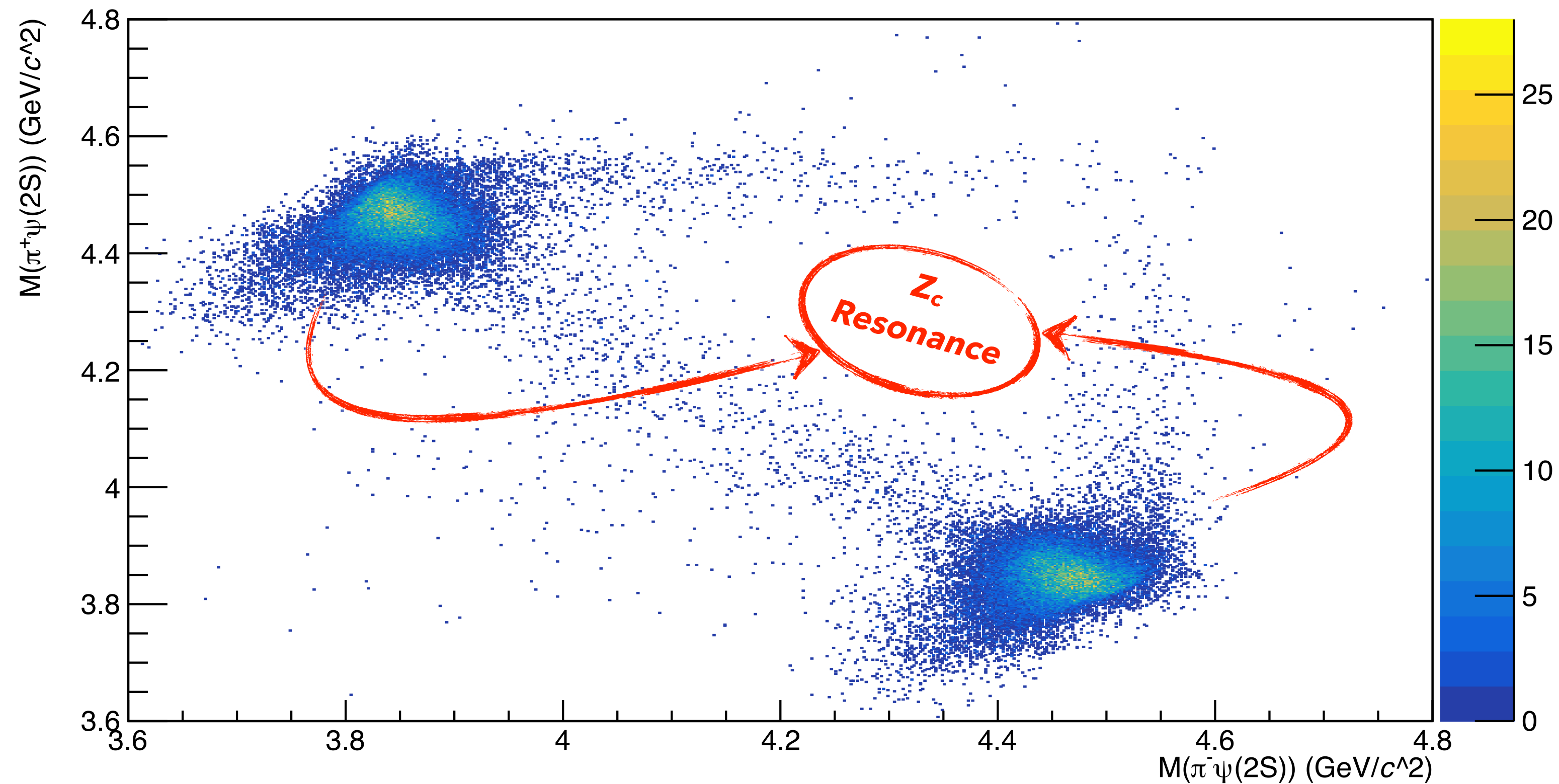
Hard to kinematically
constrain the event,
if the π_{Miss} comes from the
 $Z_c(4430)$ decay

Unphysical
events

Signal MC Studies

$2\ell 3\pi$

Reconstructed Z_c resonance invariant mass



Summary

A search for the **$Z_c(4430)$** state via the $Y(4660)$ decay was started

Aim of the analysis is to **confirm BELLE's** findings **and** to investigate a possible **connection between the $Z_c(4430)$ and $Y(4660)$ states**

The analysis will use the **$\sim 5 \text{ fb}^{-1}$** data @ **$\sqrt{s} > 4.6 \text{ GeV}$**

The **event** and topology **selection** can be considered **finalised**

Off-peak datasets (e.g. $\sqrt{s} = 4.6/4.7 \text{ GeV}$) are **under study**

Now one can move towards the **background studies**

**Thanks
for your
attention!**

