# Study of the $e^+e^- \to \pi^+\pi^-\psi(2S)$ reaction at $\sqrt{s} > 4.6$ GeV and search for the charged $Z_c(4430)$ exotic state


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Istituto Nazionale di Fisica Nucleare

# Preamble

## What and Why

The **$e^+e^- \to \pi^+\pi^-\psi(2S)$** reaction offers the possibility to probe the ***XYZ* sector**,
via the investigation of 2 exotic states

The **Y(4660)** via the $e^+e^- \to [\pi^+\pi^-/f_0(980)]\psi(2S)$

Y(4660), **observed by BaBar**[1], **BELLE**[2], and **BESIII**[3]
hypothesised to be a **baryonium**[4], a **molecule**[5],
or a **tetraquark**[6]

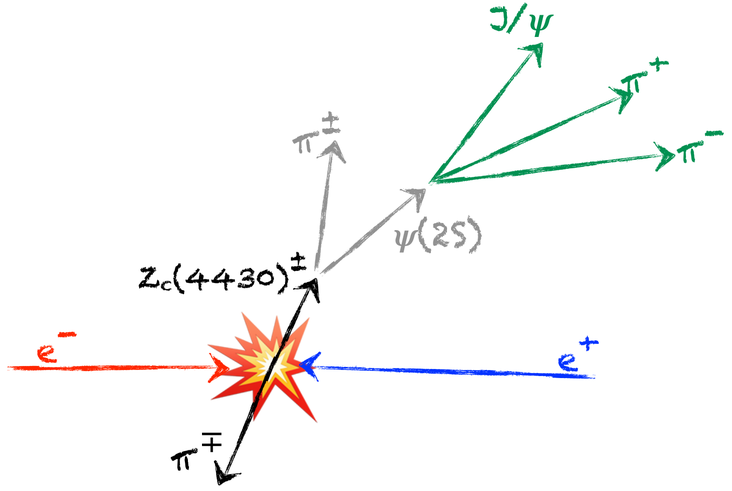
Study of the exotic $Z_c(4430)$ state through the
$e^+e^- \to \pi^\pm Z_c(4430) \to \pi^+\pi^-\psi(2S)$

**$Z^+_c(4430)$** was **observed** and studied in the *B*-decays in the $\pi\psi(2S)$ invariant mass **by BELLE**[7] (and **by LHCb**[8])

## Motivation

In Refs. [9, 10], the $Z_c(3900)^\pm$ state is seen both in $\pi\psi(2S)$ and $\pi J/\psi$, and in relation with the Y(4260) resonance

Ref. [10] finds $R = \sigma(\pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi)/\sigma(\pi^+\pi^- J/\psi) \sim 22\%$,
neglecting the the J/ψ to ψ(2S) PHSP change,
~100 events are expected around Y (4660)





[1] Phys. Rev. D **89**, 111103
[2] Phys. Rev. D **91**, 112007
[3] Phys. Rev. D **104**, 052012
[4] J. Phys. G **35**, 075008 (2008)
[5] Phys. Lett. B **665**, 26-29
[6] Phys. Rev. D **89**, 114010
[7] Phys. Rev. D **88**, 074026
[8] Phys. Rev. Lett. **112**, 222002
[9] Phys. Rev. D **96**, 032004
[10] Phys. Rev. Lett **110**, 252001

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Study of the exotic $Z_c(4430)$ state through the $e^+e^- \to \pi^\pm Z_c(4430) \to \pi^+\pi^-\psi(2S)$

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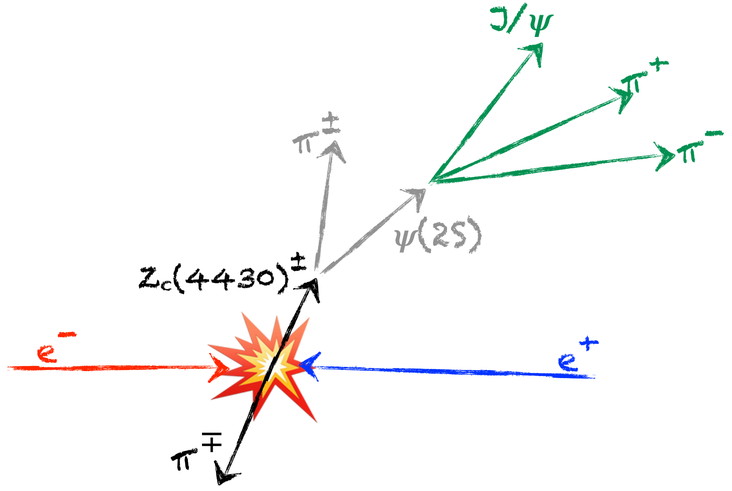
## How

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

**No** $Z_c(4430)$ **signal** was observed in the **mono-energetic datasets**[11], so the main idea is to merge all the data @$\sqrt{s}$ > 4.6 GeV to use the whole statistics





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# DEC Cards

## $Z_c$ Resonant

```
noPhotos
Particle vpho 4.680 0

Decay vpho
  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 J/psi pi+ pi- JPIPI;
Enddecay

Decay J/psi
  0.5000 e+ e- PHOTOS VLL;
  0.5000 mu+ mu- PHOTOS VLL;
Enddecay

End
```

$Z_c(4430)$

$M_{Zc} = 4478^{+15}_{-18}$ MeV

$\sigma_{Zc} = 181 \pm 31$ MeV

**Signal MC samples**
**300k events**

**BOSS Release**
**7.0.6**

## non-Resonant

```
Particle vpho 4.6812 0.0
Decay vpho
  1.0000 ConExc -2 100443 211 -211;
Enddecay

Decay vhdr
  1.0000 psi(2S) pi+ pi- VVPIPI;
Enddecay

Decay psi(2S)
1.000 J/psi pi+ pi- JPIPI;
Enddecay

Decay J/psi
  0.5000 e+ e- PHOTOS VLL;
  0.5000 mu+ mu- PHOTOS VLL;
Enddecay

End
```

# Signal MC Studies

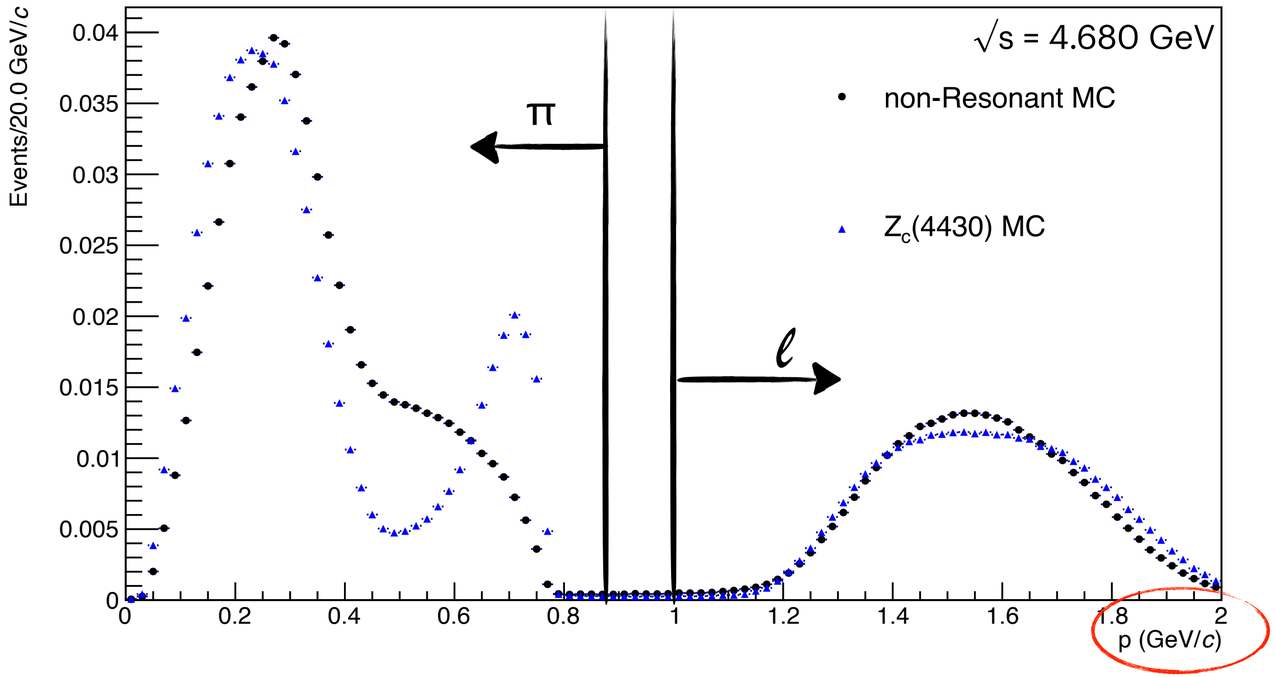
Signal MC sample
300k events

## Event Selection

### Goodness Cuts

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

Polar angle: |cos θ| < 0.93




### Channel ID

| Leptons | Pions |
|---|---|
| p > 1 GeV<br>E/p (e) > 0.7<br>E/p (μ) < 0.6 | p < 0.85 GeV |

2 good charged topologies

$2\ell\,3\pi$

$2\ell\,4\pi$

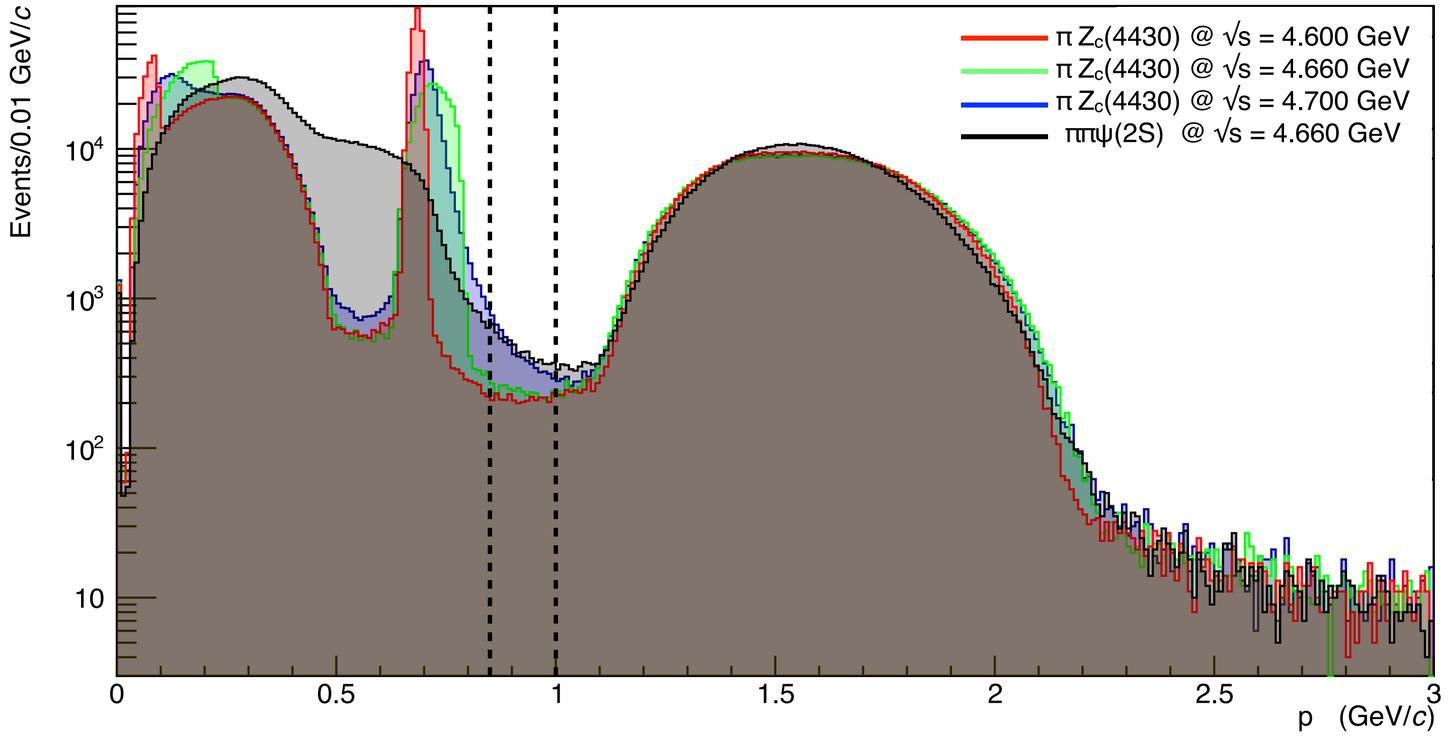
# Signal MC Studies

## Charged Particles Momentum Comparison

Signal MC sample
300k events

Let’s check it in more detail… the upper bound for $p_\pi$ (< 0.85 GeV) can be improved?

S($Sig_{MC}$ $Z_c$)/B($Inc_{MC}$) optimisation

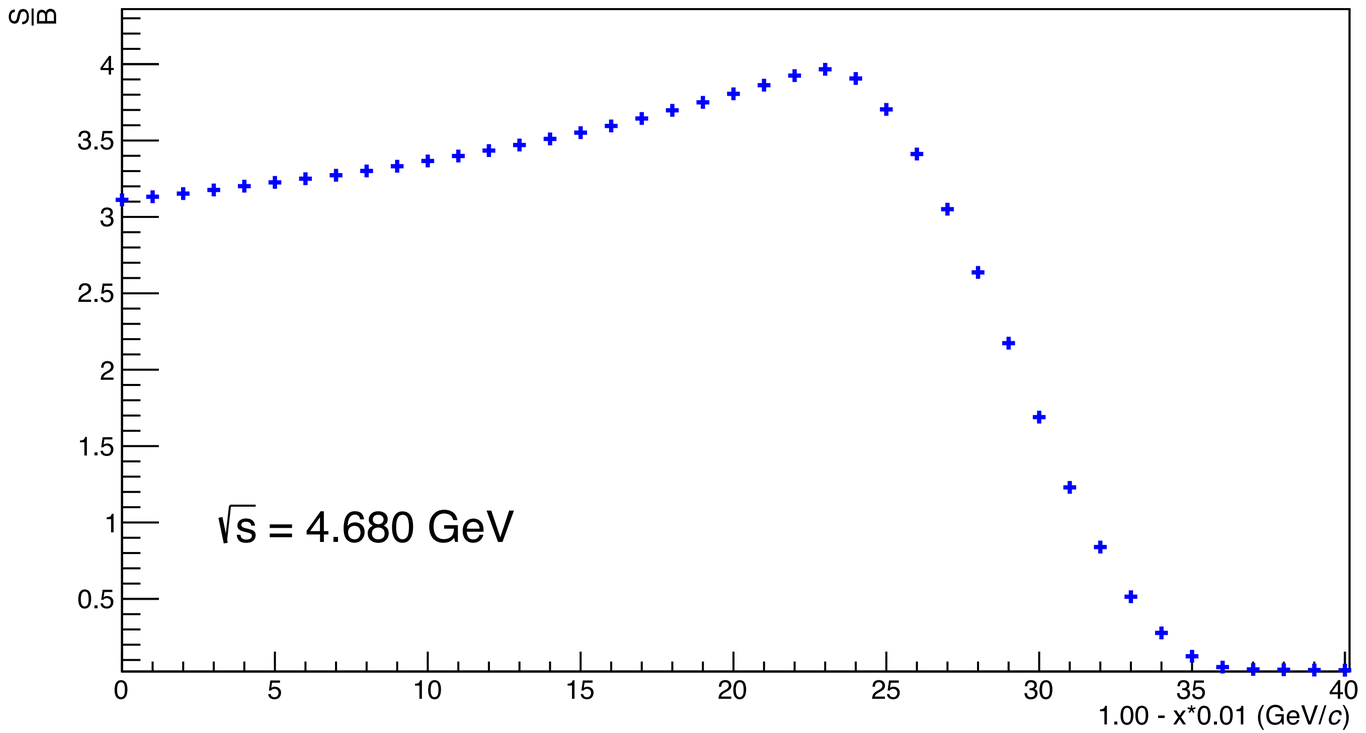


# MC Studies

## Charged Particles Momentum Optimisation

S($Sig_{MC}$ $Z_c$)/B($Inc_{MC}$) optimisation
∀ $\sqrt{s}$ and using only MC datasets

| $\sqrt{s}$ | $p_{ch}$ [GeV/$c$] |
|---|---|
| 4.612 | 0.72 |
| 4.626 | 0.73 |
| 4.640 | 0.74 |
| 4.660 | 0.75 |
| 4.680 | 0.77 |
| 4.700 | 0.78 |



# Signal MC Studies

## Event Selection

## Topology dependent KALMAN Fits

### $2\ell 4\pi$

6C Kalman fit

1C on the $M_{J/\psi}$
1C on the $M_{\psi(2S)}$
4C on the $p_{Tot}$ = (0.051, 0, 0, $M_{\sqrt{s}}$)

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

### $2\ell 3\pi$

6C Kalman fit

1C on the $M_{J/\psi}$
1C on the $M_{\psi(2S)}$
4C on the $p_{Tot}$ = (0.051, 0, 0, $M_{\sqrt{s}}$)

$\pi_{Miss}$ either from prompt production or from $\psi(2S)$ decay

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

# Signal MC Studies

## Event Selection

## Topology dependent KALMAN Fits

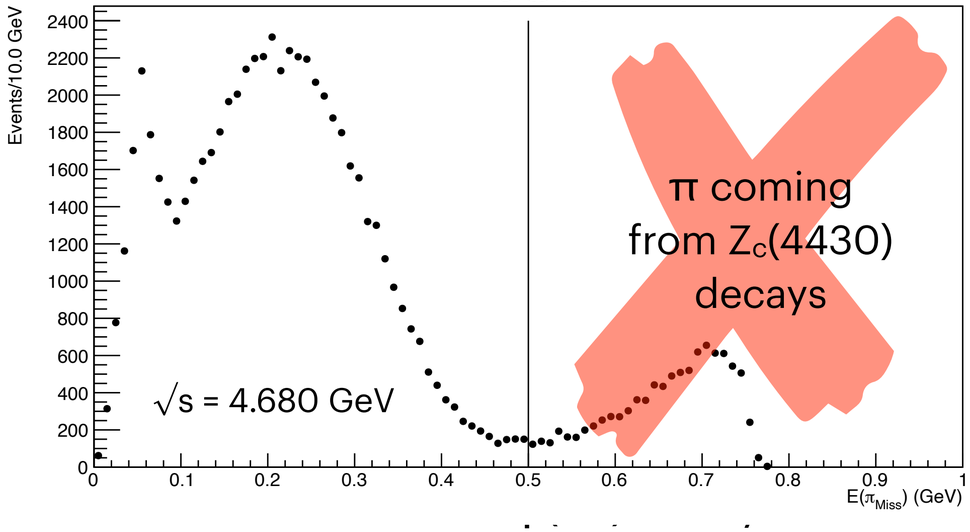
### $2\ell 4\pi$

6C Kalman fit

1C on the $M_{J/\psi}$
1C on the $M_{\psi(2S)}$
4C on the $p_{Tot}$ = (0.051, 0, 0, $M_{\sqrt{s}}$)

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

### $2\ell 3\pi$

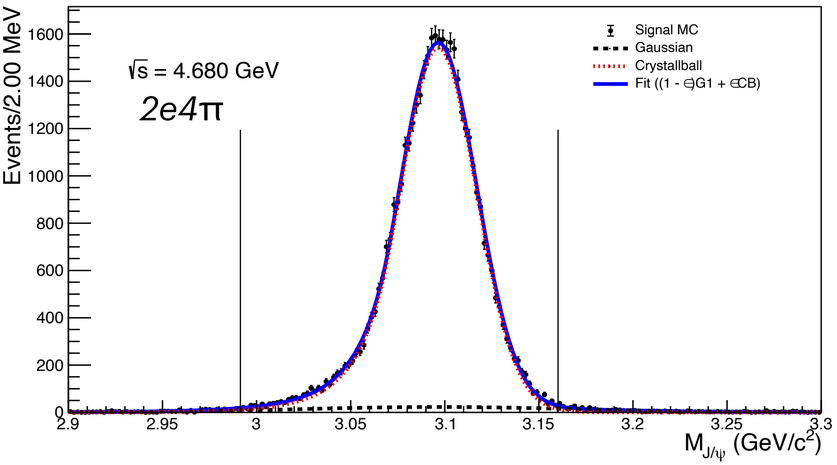


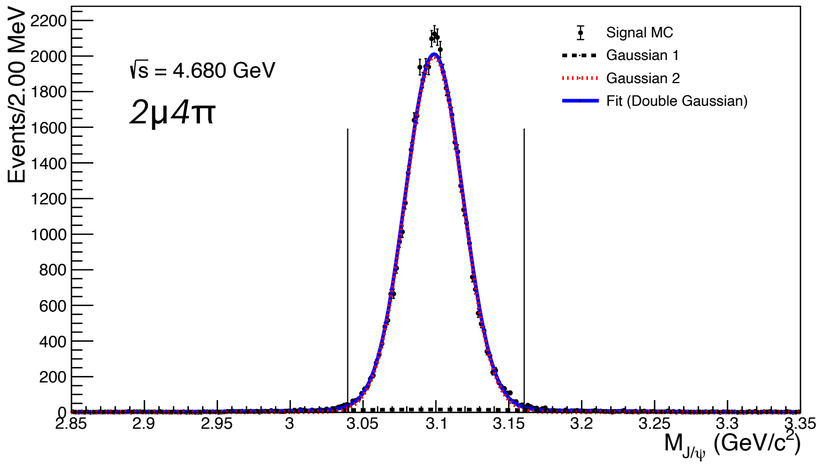

$\pi\pi$ and $\pi\pi_{Miss}$ couples are selected by minimising $M^{Reco}_{\psi(2S)}$-$M^{PDG}_{\psi(2S)}$

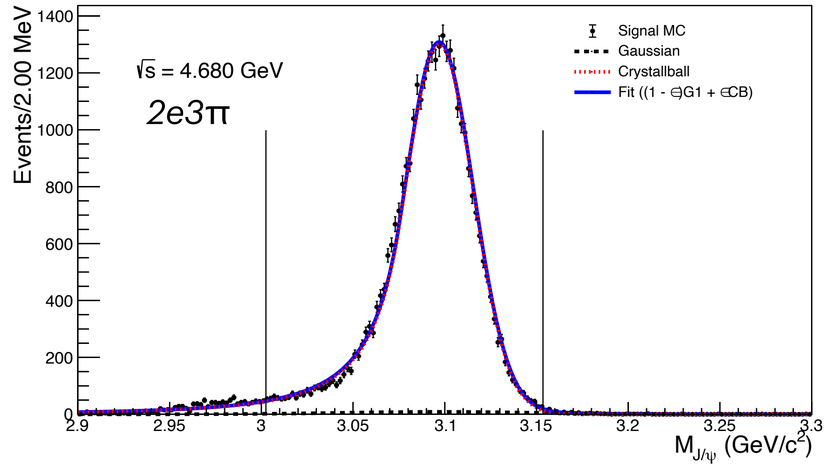
# MC Studies

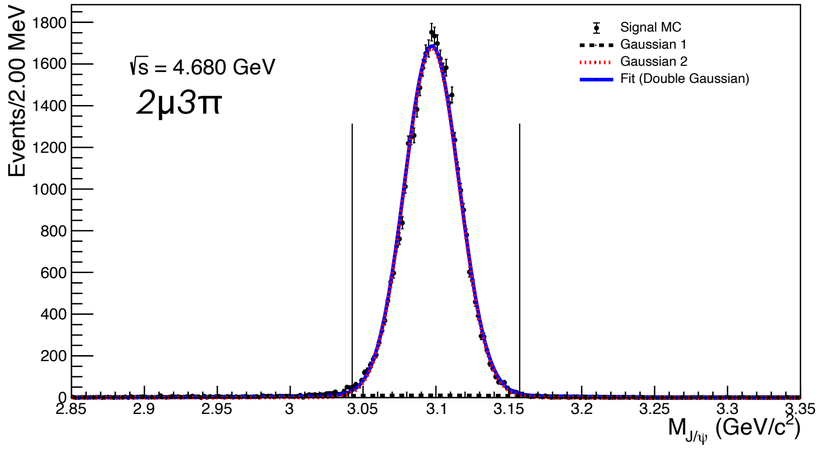
Signal MC sample
300k events

## Just a bit more... $M_{J/\psi}$ Signal Windows




Selection on

**M(ψ(n))** both for **2ℓ4π** and **2ℓ3π**

$M_{Miss}(\pi)$ for $2\ell\,3\pi$

Given the width (σ) of the distribution:

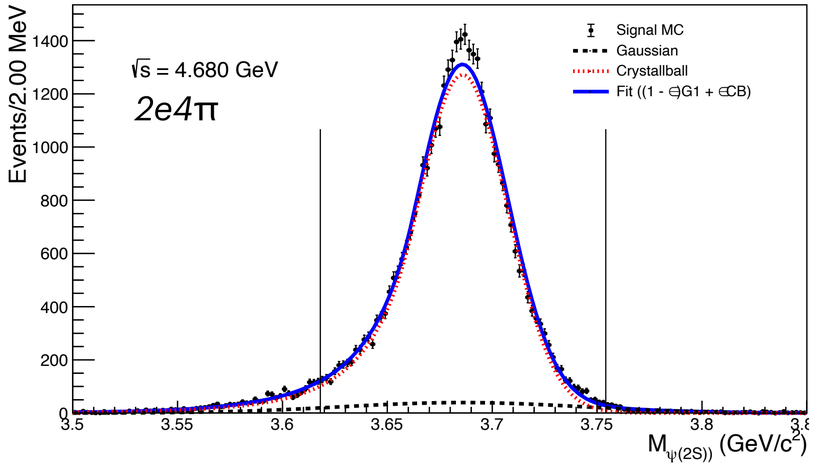
ee channel: $-5\sigma < M < +3\sigma$

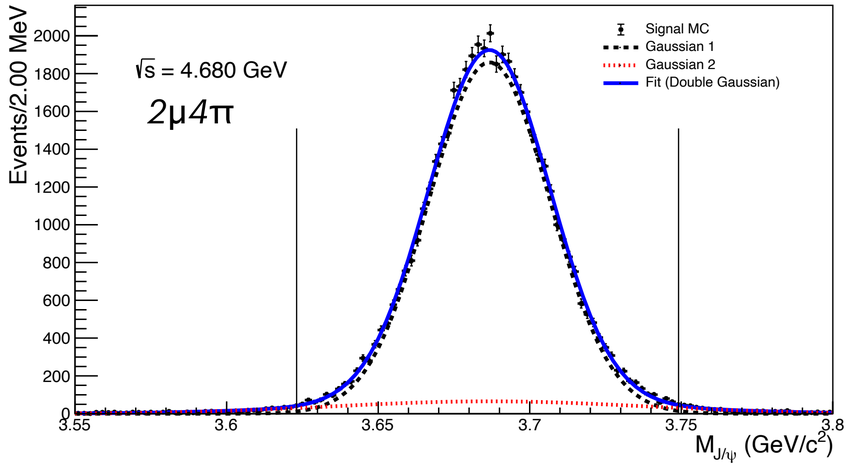
μμ channel: $-3(5)\sigma < M < +3\sigma$

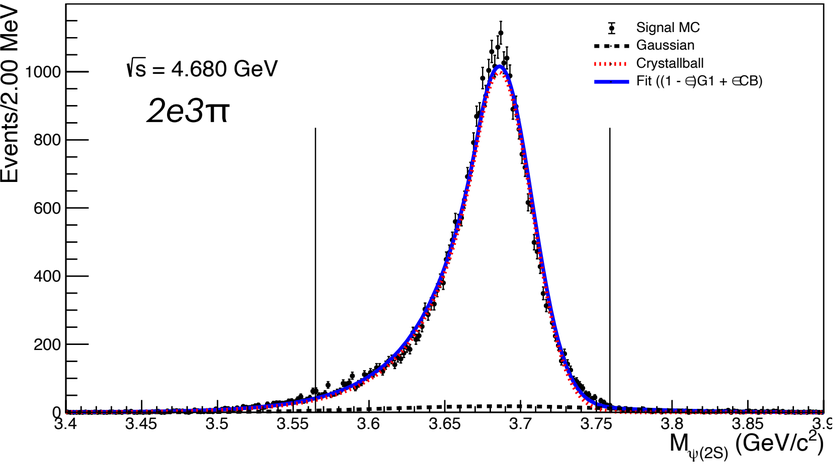
# MC Studies

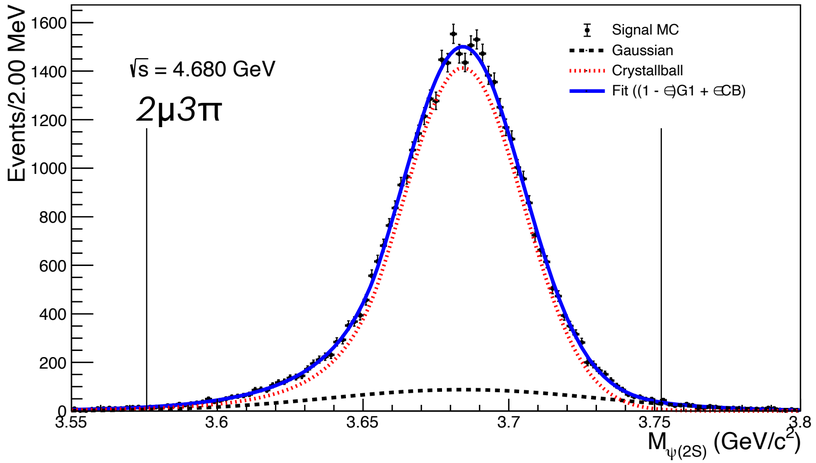
Signal MC sample
300k events

## Just a bit more... $M_{\psi(2S)}$ Signal Windows

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$M_{Miss}(\pi)$ for $2\ell\,3\pi$

Given the width (σ) of the distribution:

ee channel: $-5\sigma < M < +3\sigma$

μμ channel: $-3(5)\sigma < M < +3\sigma$

# MC Studies

Signal MC sample
300k events

## Just a bit more... $M_{Miss}(\pi)$ for $2\ell 3\pi$ Signal Window

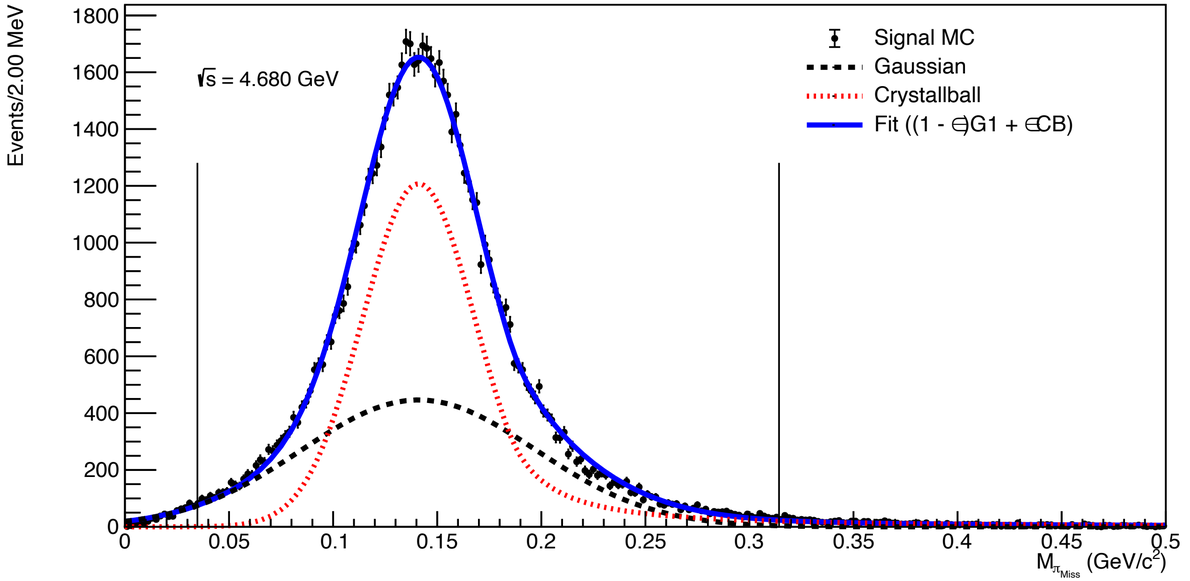
Given the width (σ) of the distribution, ∀ √s:

$$-3\sigma < M < +5\sigma$$

| √s | σ(Miss-π) [MeV/$c^2$] |
|---|---|
| **4.612** | 29 |
| **4.626** | 30 |
| **4.640** | 32 |
| **4.660** | 34 |
| **4.680** | 35 |
| **4.700** | 37 |

$M_{Miss}(\pi) = \pi\pi^+\pi^-\ell^+\ell^-$ recoil mass

Fit function: sum of Gaussian and Crystal Ball



# MC Studies

## Background Rejection

Inclusive MC sample
10x $\mathcal{L}$ data

**From 1.3 billion** inclusive MC events, **28136 survive**, with a survival rate of ~ O(10ppm)

Virtually **only hadron component** is surviving after the selection criteria

| √s 4.680 GeV | $\Lambda_c\Lambda_c$ | ττ | Hads | μμ | ee | γγ | Tot | Eff. [%] |
|---|---|---|---|---|---|---|---|---|
| NTot | 35047250 | 56093530 | 287911230 | 69508120 | 55673000 | 10815600 | 515048730 | 100,0000 |
| NCutCh | 152301 | 751 | 97416298 | 930 | 1513908 | 3877322 | 102961510 | 19,9906 |
| NCutGoodCh | 243 | 238 | 1034648 | 315 | 19755 | 442 | 1055641 | 0,2050 |
| NCut_5trks | 0 | 1 | 5585 | 1 | 0 | 0 | 5587 | 0,0011 |
| NCut_6trks | 0 | 0 | 8786 | 0 | 0 | 0 | 8786 | 0,0017 |
| NCut_Alltrks | 0 | 1 | 14371 | 1 | 0 | 0 | 14373 | 0,0028 |

# MC Studies

Inclusive MC sample
10x $\mathcal{L}$ data

## Background Rejection

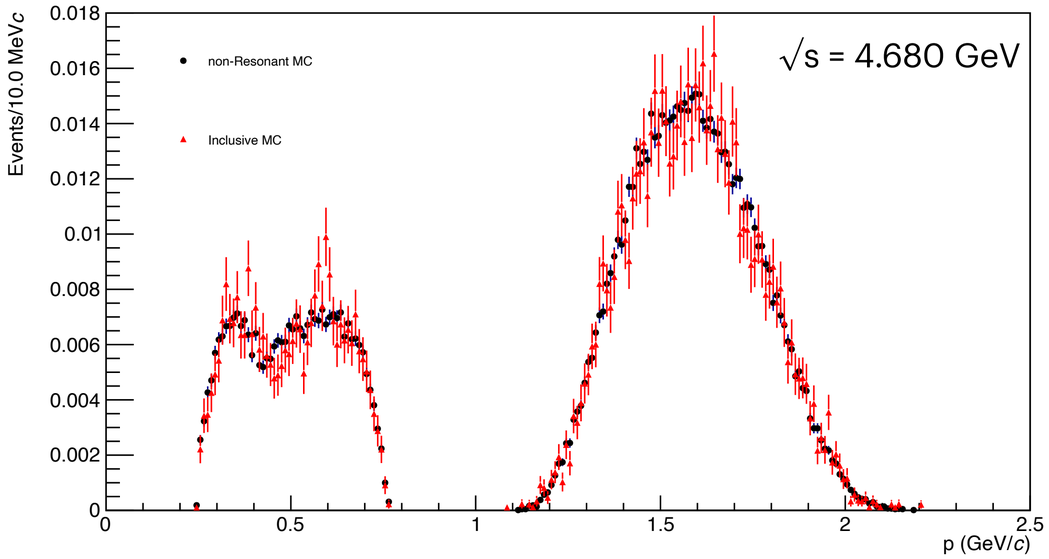
| Index $(i)$ | Decay tree | $N_{Evts}$ | $\sum_i^{\text{Tot}} N_{Evts}$ |
|---|---|---|---|
| 1 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 3389 | 3389 |
| 2 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 2983 | 6372 |
| 3 | $e^+e^- \to \pi^+\pi^-\psi'\gamma^I, \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 2875 | 9247 |
| 4 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 2528 | 11775 |
| 5 | $e^+e^- \to \pi^+\pi^-\psi'\gamma^I, \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 2499 | 14274 |
| 6 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 2313 | 16587 |
| 7 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 1346 | 17933 |
| 8 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 1249 | 19182 |
| 9 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 1037 | 20219 |
| 10 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 907 | 21126 |
| 11 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 307 | 21433 |
| 12 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 289 | 21722 |
| 13 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 276 | 21998 |
| 14 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 245 | 22243 |
| 15 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 240 | 22483 |
| 16 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 197 | 22680 |
| 17 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 188 | 22868 |
| 18 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 161 | 23029 |
| 19 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 156 | 23185 |
| 20 | $e^+e^- \to \pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$ | 144 | 23329 |
| 21 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 132 | 23461 |
| 22 | $e^+e^- \to \pi^+\pi^-\psi', , \psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-$ | 109 | 23570 |
| 23 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 104 | 23674 |
| 24 | $e^+e^- \to \pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\gamma^I$ | 103 | 23777 |
| 25 | $e^+e^- \to \pi^+\pi^-\psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$ | 96 | 23873 |
| 26 | ... | ... | ... |

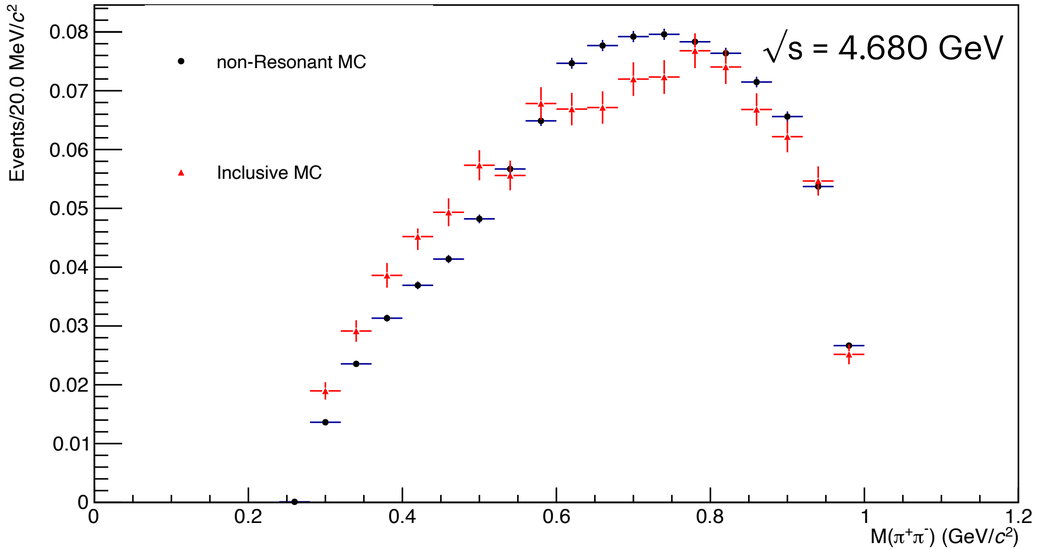
Out of 28136 total **IncMC events**, more of the **90%** of events are from

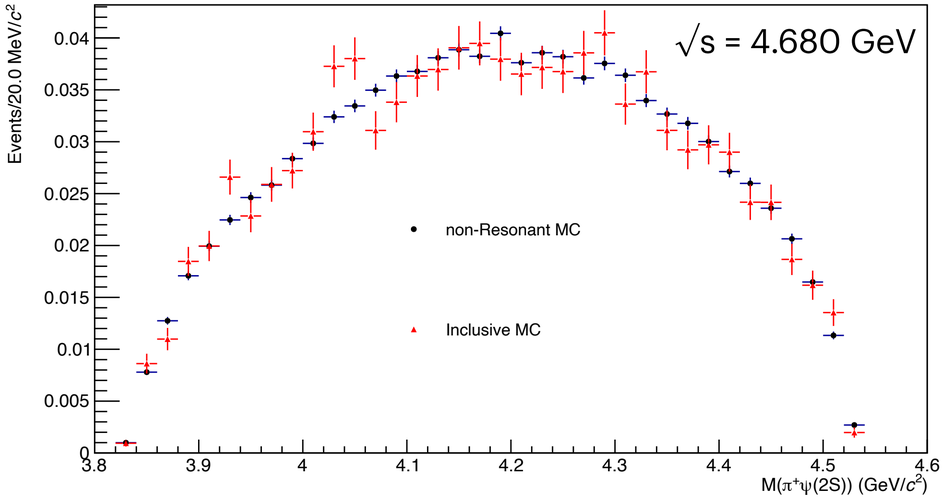
- Non-resonant **ππ ψ(2S)** signal
- Multi-π states

# MC Studies

## Inclusive / Non-resonant MC Comparison

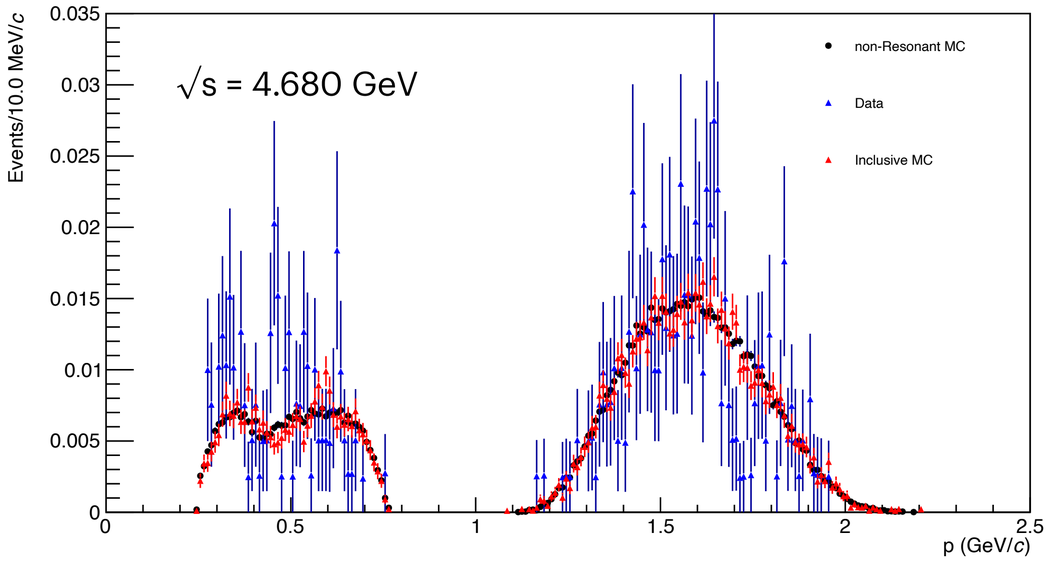


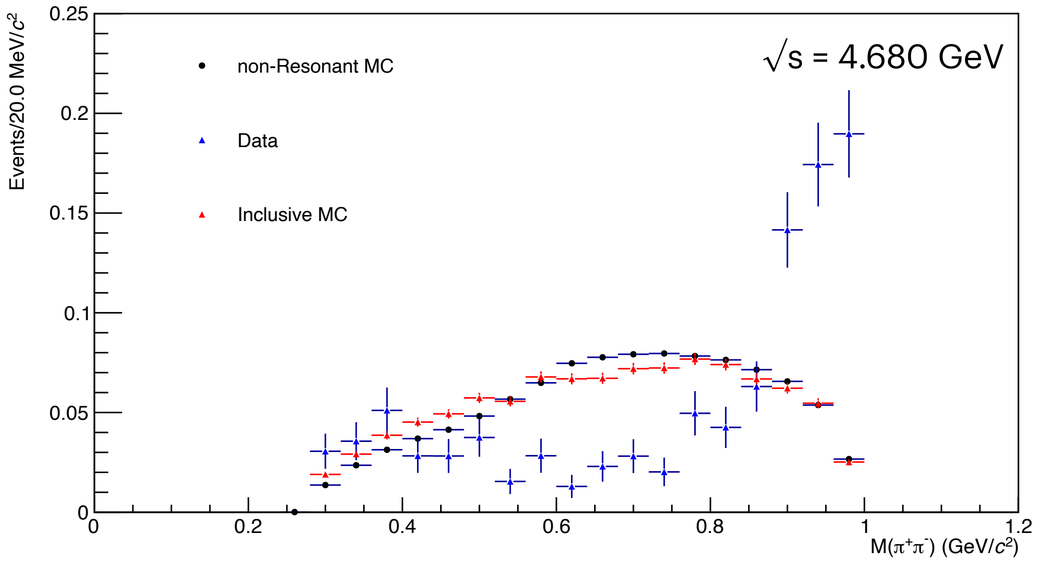



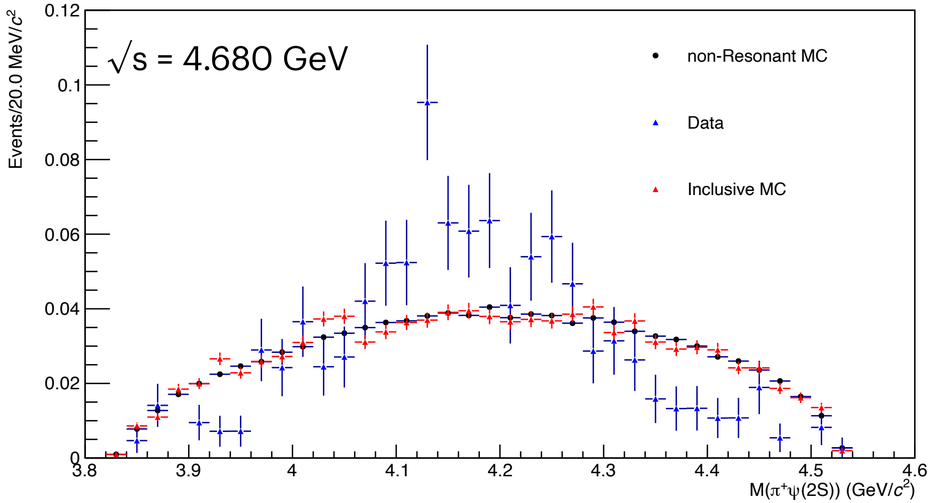



# MC Studies

## Inclusive MC / Non-resonant MC/ Data Comparison



# Extraction of the σ(ππψ(2S))

## Efficiency and Cut-flow

Non-resonant
Signal MC sample
300k events

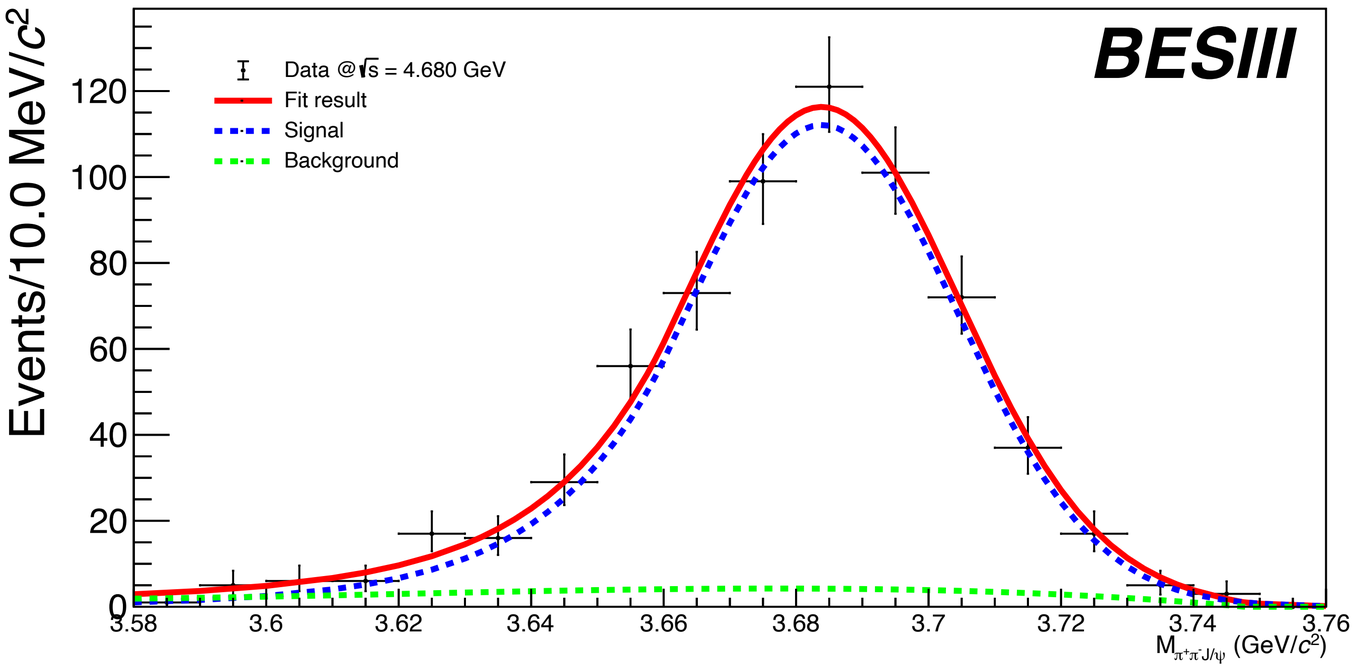
**CONEXC**

5 iterations

| Sample | Efficiency [%] | ISR*VP Corr. Factor. | *d*(ISR*VP) Corr. Factor. | VP Corr. Factor |
|---|---|---|---|---|
| 4,612 | 49,42 | 0,7230 | 0,0001 | 1,05453 |
| 4,626 | 48,39 | 0,7677 | 0,0002 | 1,05444 |
| 4,640 | 47,97 | 0,7760 | 0,0003 | 1,05442 |
| 4,660 | 46,91 | 0,8142 | 0,0004 | 1,05441 |
| 4,680 | 45,38 | 0,8588 | 0,0005 | 1,05448 |
| 4,700 | 43,84 | 0,8950 | 0,0005 | 1,05453 |

# Extraction of the σ(ππψ(2S))

## ππψ(2S) cross-section



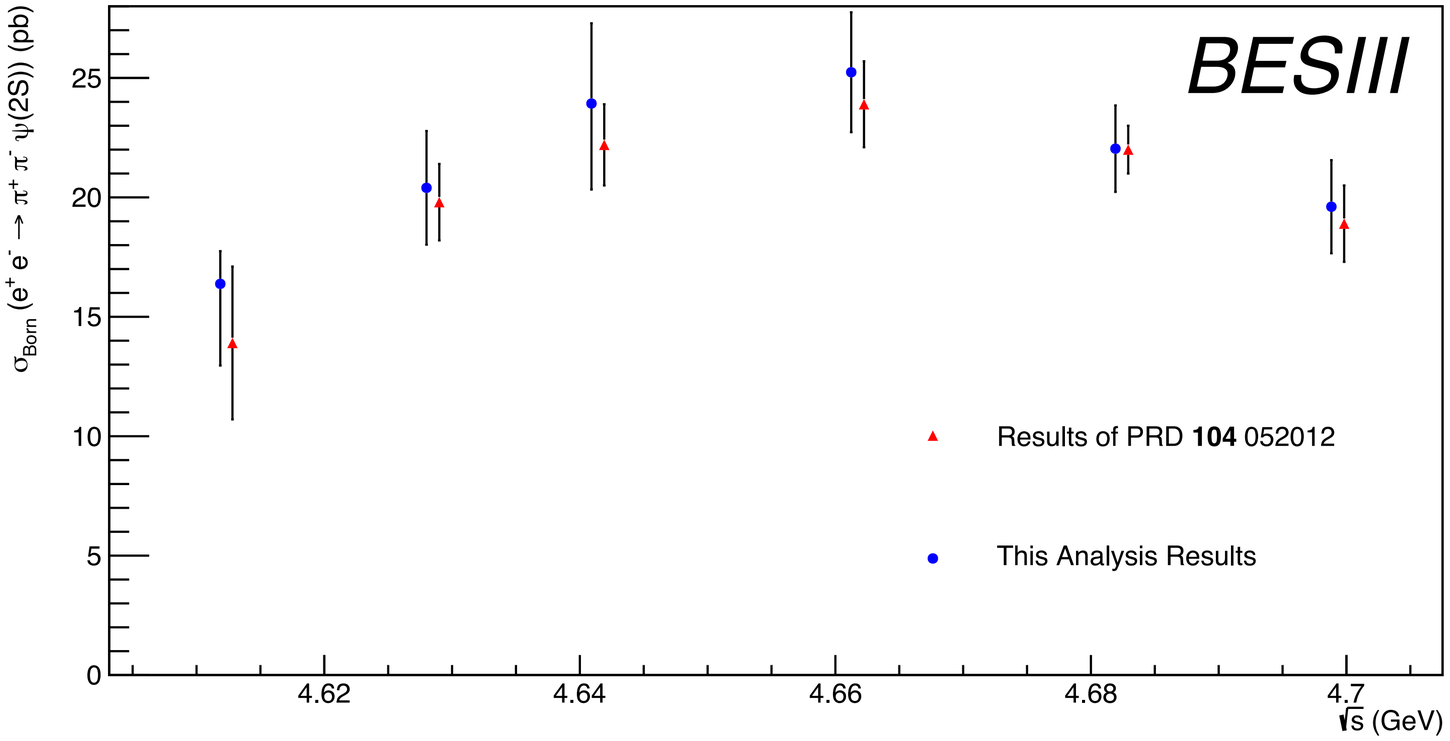

For each √s, the ππψ(2S) contribution is extracted by fitting the M(ππJ/ψ) invariant spectrum

The signal is modelled with a sum of Gaussian and Crystal Ball functions

A polynomial function is used to describe the background

# Extraction of the σ(ππψ(2S))

## ππψ(2S) cross-section

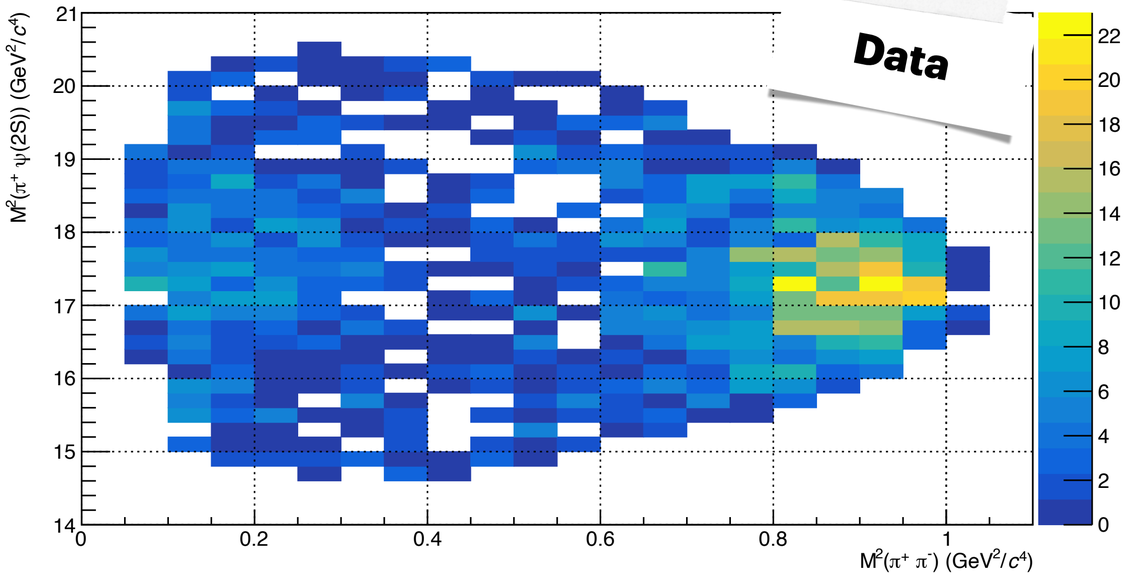


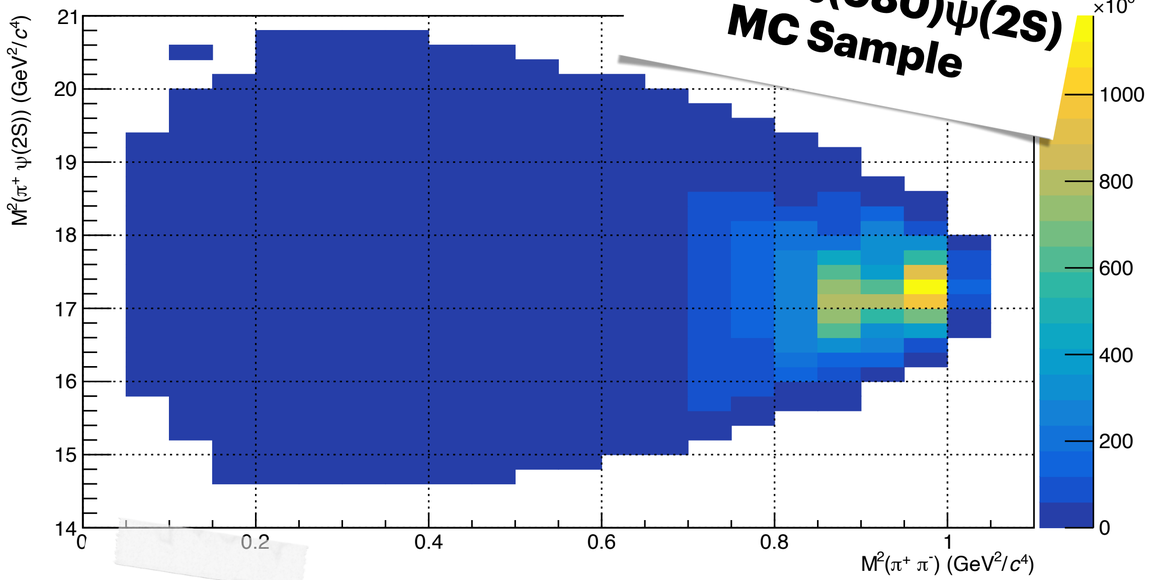

$$\sigma_{\mathrm{Born}} = \frac{N_{\mathrm{Obs}}}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\epsilon\mathcal{B}}$$

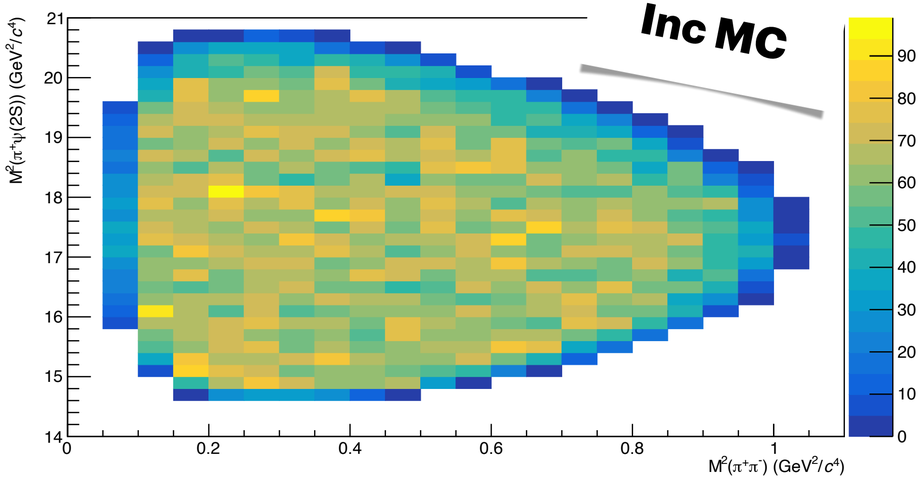
The observed **cross-section** is **compatible with** the previous result of **Ref. [11]**

# Study of the Intermediate States

## Dalitz Plots



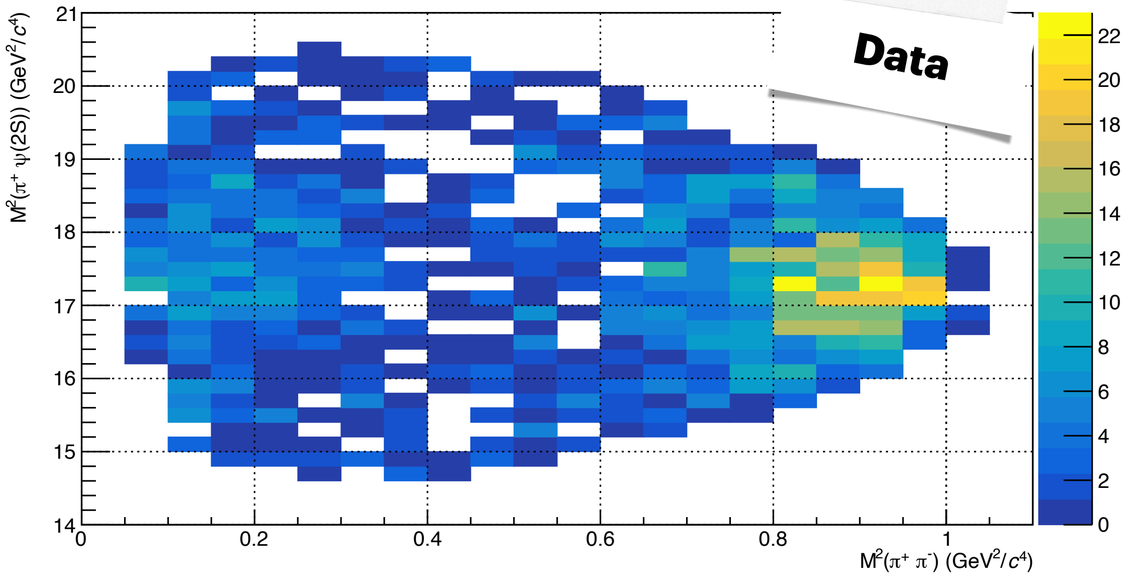



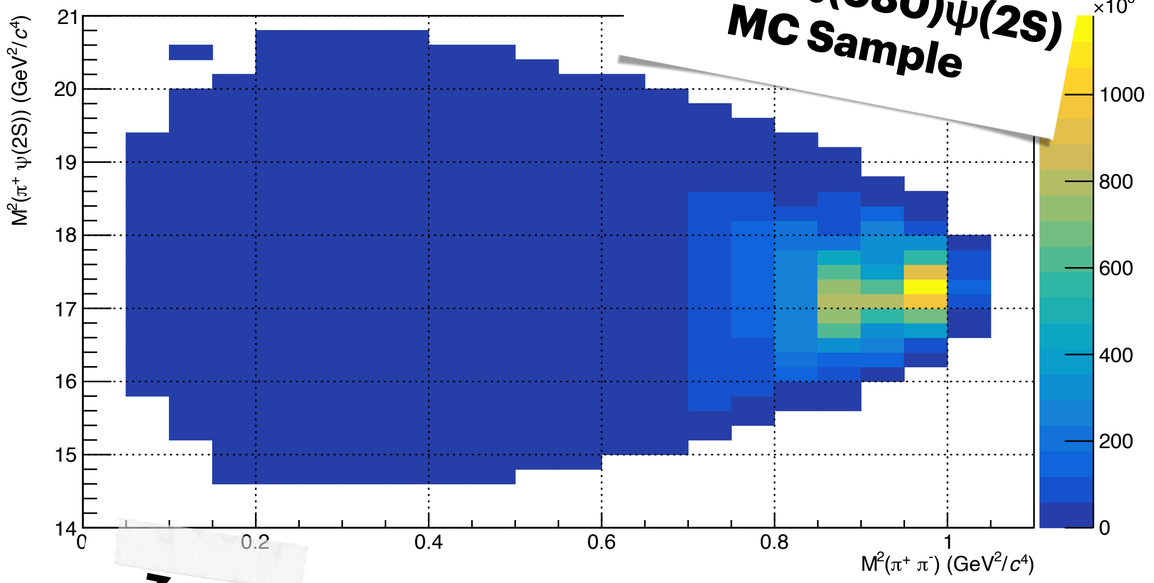

In **Ref.[11]**, a **simplified PWA** performed on the data sets highlighted **$f_0(500)$** and **$f_0(980)$** contributions

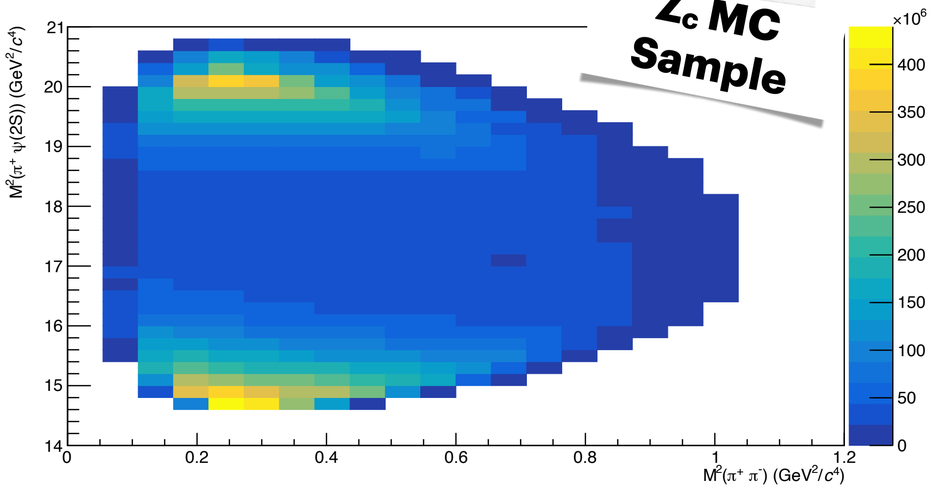
The six **data samples** are **merged together** to have more statistical significance

# Study of the Intermediate States

## Dalitz Plots

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# Study of the Intermediate States

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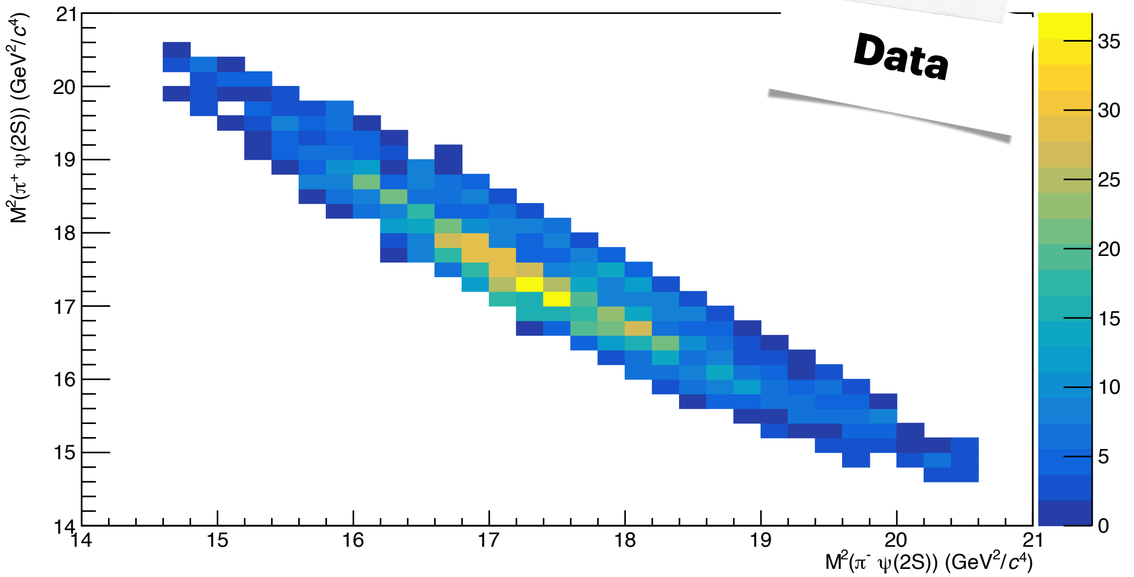


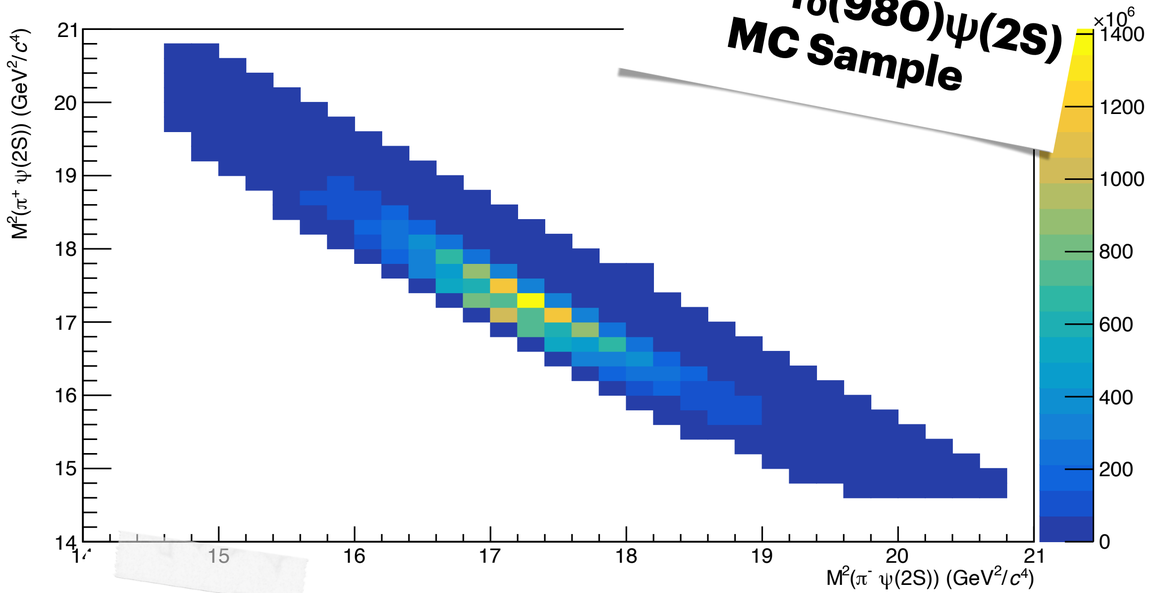


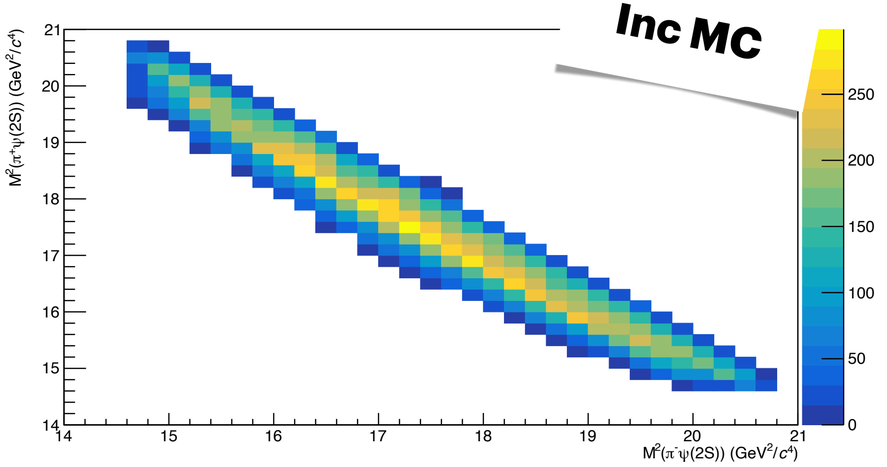


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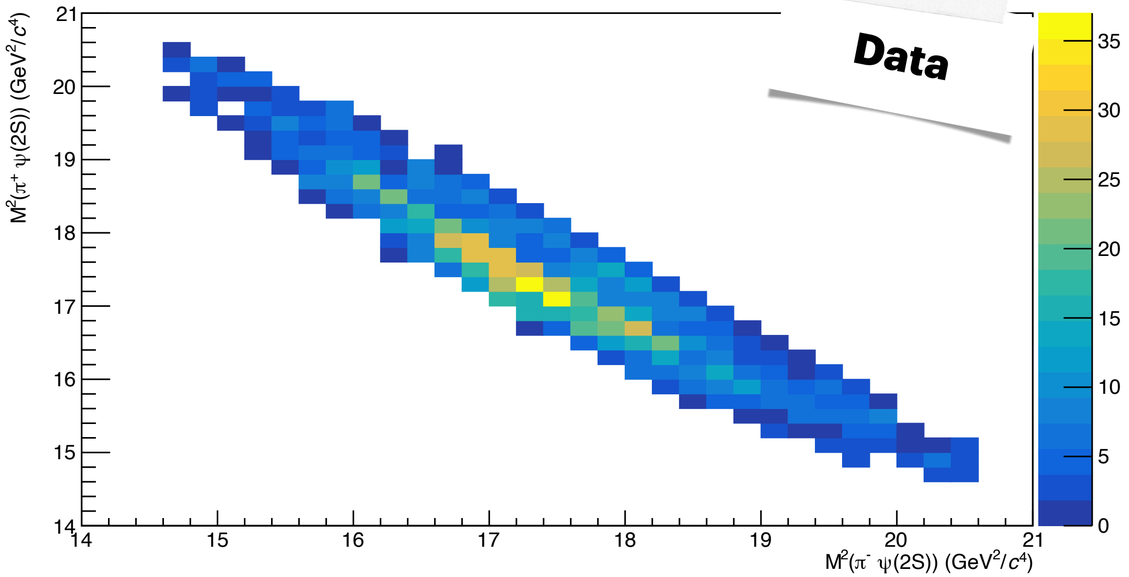
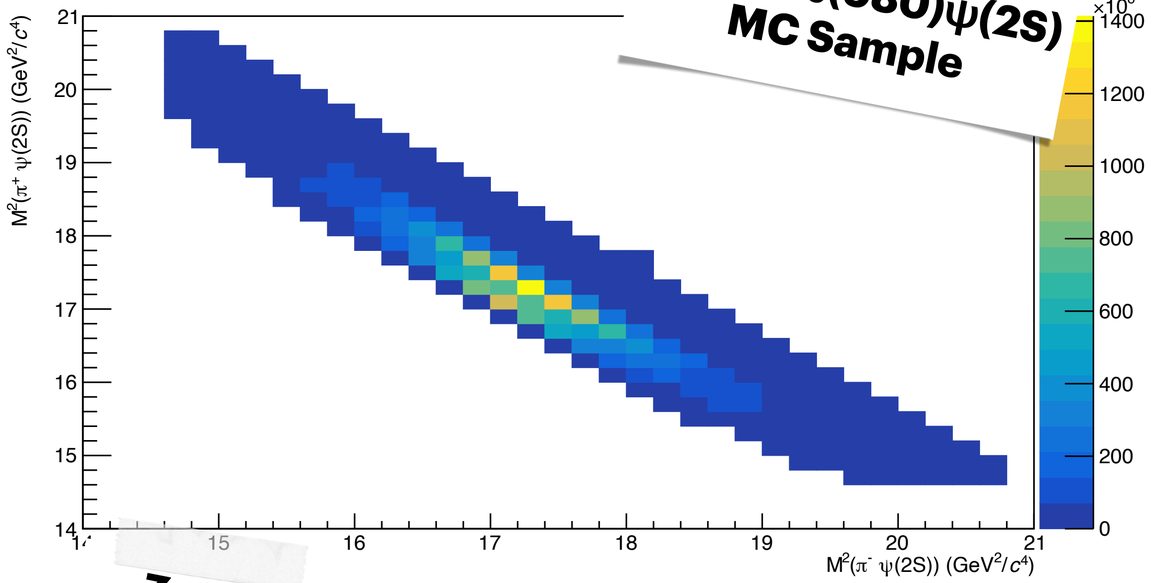
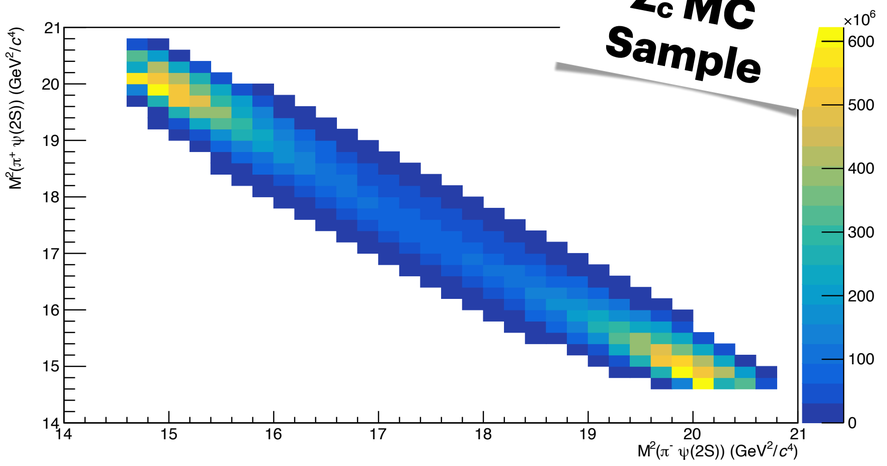
# Study of the Intermediate States

## Dalitz Plots



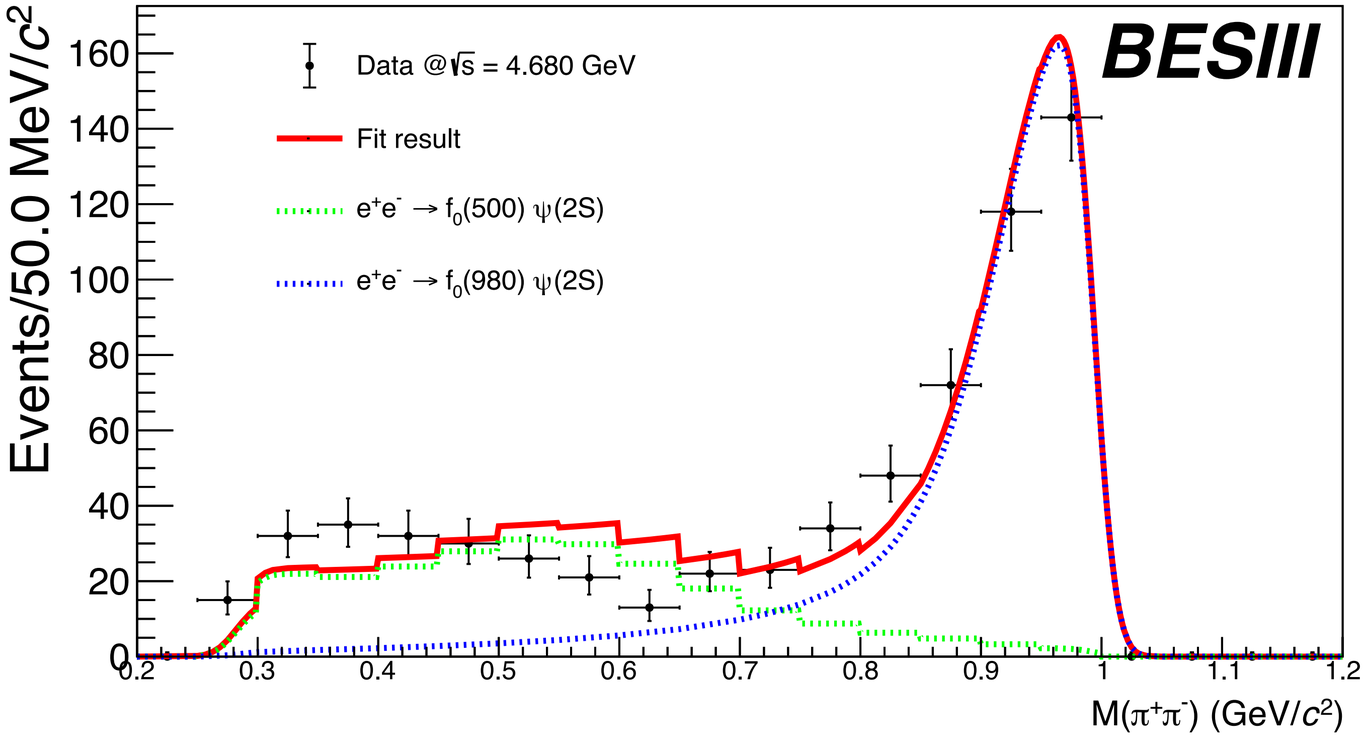




In **Ref.[11]**, a **simplified PWA** performed on the data sets highlighted **$f_0(500)$** and **$f_0(980)$** contributions

The six **data samples** are **merged together** to have more statistical significance

# Extraction of the σ($f_0$(980) ψ(2S))

## $f_0$(980) contribution



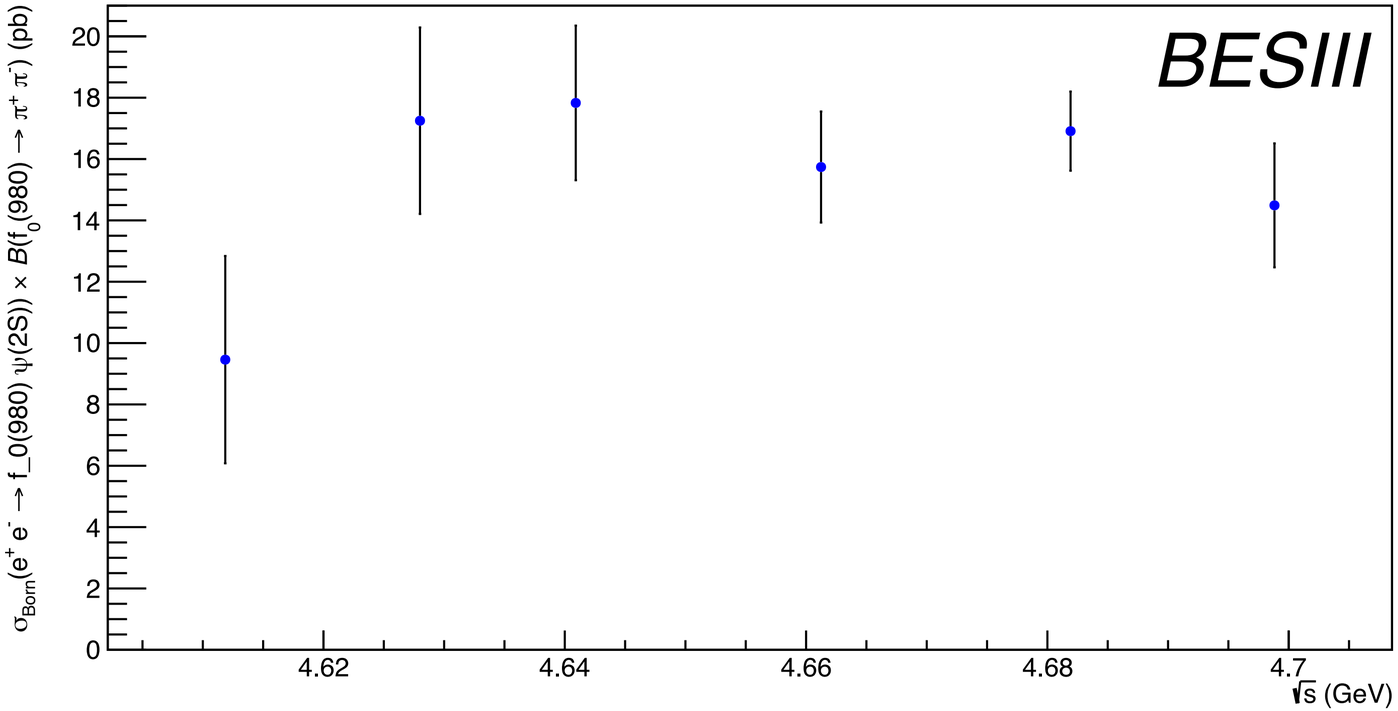

For each √s, the $f_0$(980) contribution is extracted by fitting the m(ππ) invariant distribution

The signal is a Flatté smeared by a Gauss(0, σ) multiplied by a threshold

The $f_0$(500) contribution is modelled using a MC shape

# Extraction of the σ(f₀(980) ψ(2S))

## f₀(980) contribution

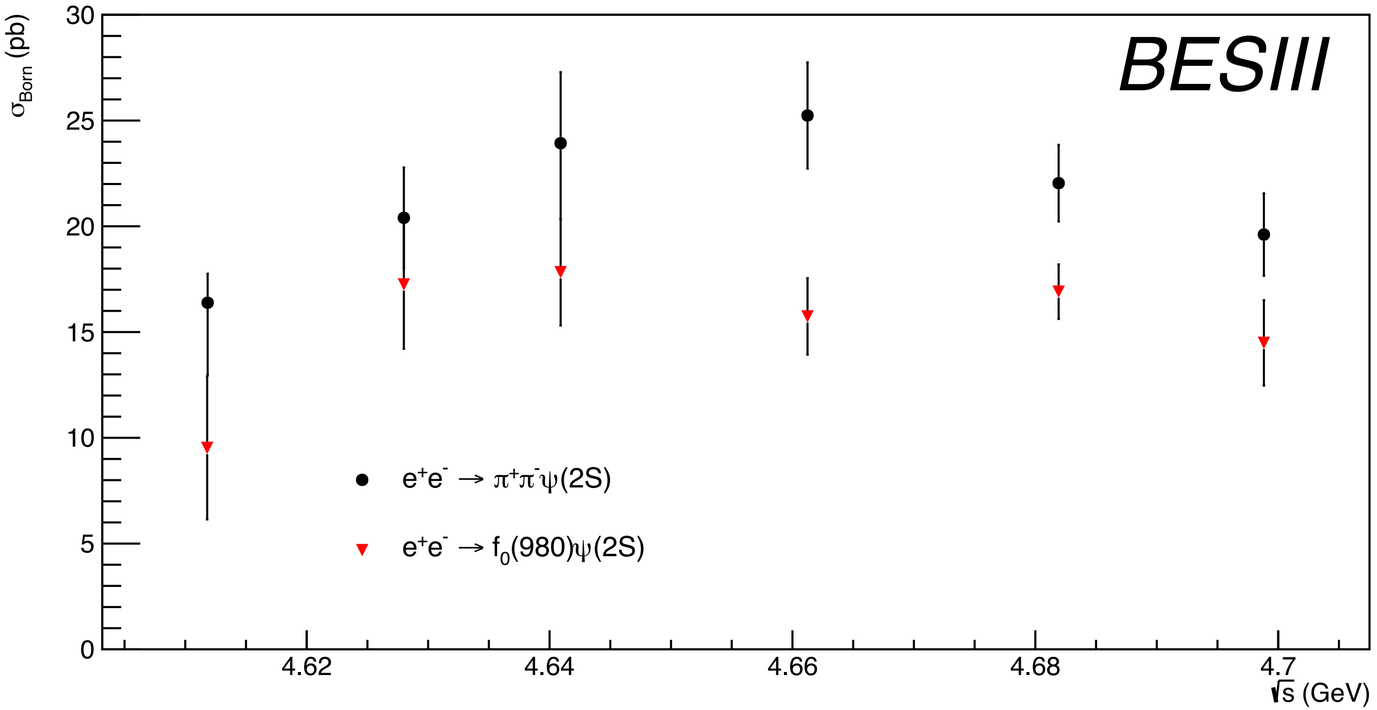



**Product** of the **$f_0(980) \to \pi^+\pi^-$ branching fraction and** the **Born cross-section** of the $e^+e^- \to f_0(980)\psi(2S)$ process

$$\mathcal{B}(f_0(980) \to \pi^+\pi^-) \times \left( \frac{N_{\text{Obs}}^{f_0(980)}}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\epsilon^{f_0(980)}\mathcal{B}} \right)$$

# Extraction of the σ($f_0$(980) ψ(2S))

## $f_0$(980) contribution




**Product** of the **$f_0$(980) → π⁺π⁻ branching fraction and** the **Born cross-section** of the $e^+e^- \to f_0(980)\psi(2S)$ process

No particular structures can be recognised as the statistical uncertainty prevents any conclusion to be possible

# Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass

## Efficiency and Cut-flow

**$Z_c$ Signal MC sample**
**300k events**

| √s = 4.680 GeV | Events | Efficiency [%] |
|---|---|---|
| NTot | 300000 | 100 |
| NCutCh | 248899 | 82,97 |
| NCutGoodCh | 215894 | 71,96 |
| NCut_5trks | 62850 | 20,95 |
| NCut_6trks | 100828 | 33,61 |
| NCut_Alltrks | 163678 | 54,56 |

Explicative sample (@$\sqrt{s}$ = 4.680 GeV)

But overall efficiency ~ 50% $\forall$ $\sqrt{s}$

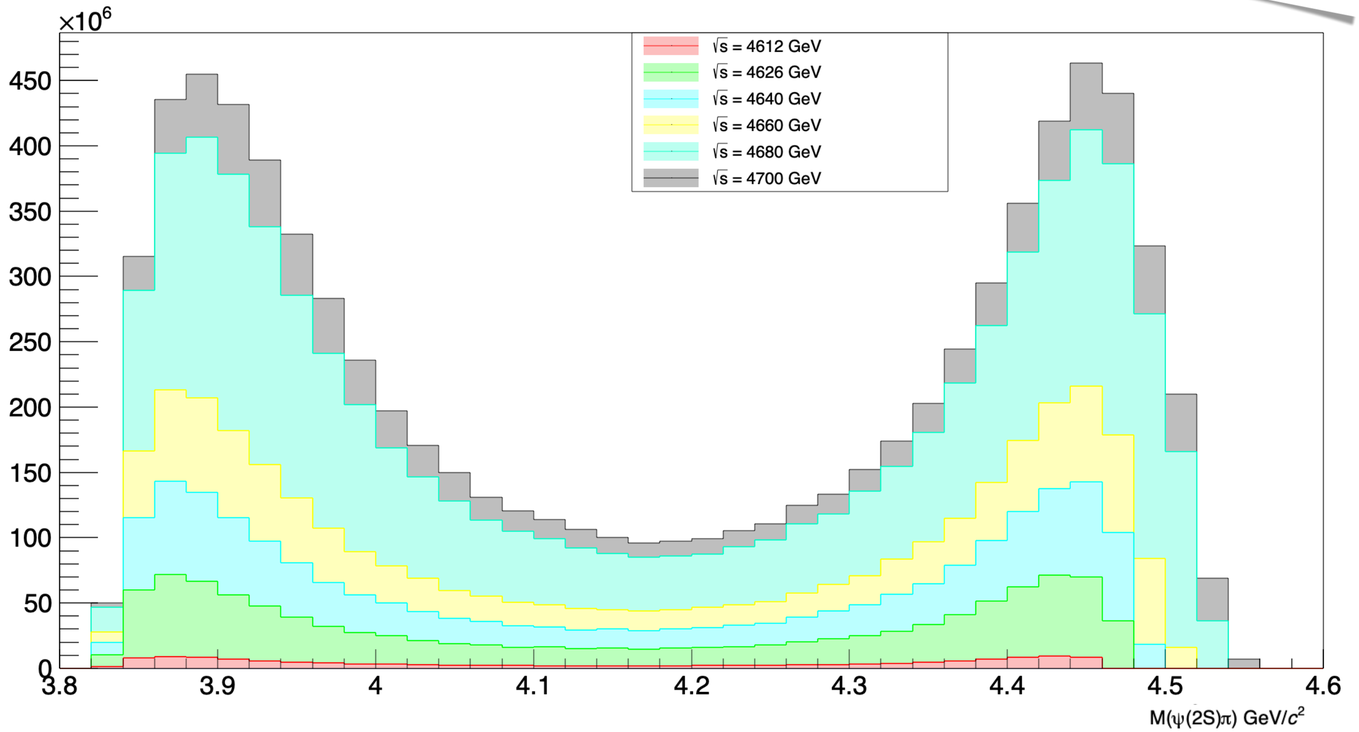
No assumption is made on the production cross-section

# Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass

## Signal MC Shape Extraction

**$Z_c$ Signal MC sample**
**300k events**

| √s [GeV] | σ [pb] | $\mathcal{L}$ [pb$^{-1}$] | w |
|---|---|---|---|
| 4.600 | 12,9 | 586,9 | 7571,01 |
| 4.612 | 14,4 | 102,5 | 1476,00 |
| 4.626 | 20 | 511,06 | 10221,20 |
| 4.640 | 21,7 | 541,37 | 11747,73 |
| 4.660 | 24 | 523,63 | 12567,12 |
| 4.680 | 22,1 | 1637,43 | 36187,20 |
| 4.700 | 18,9 | 526,2 | 9945,18 |



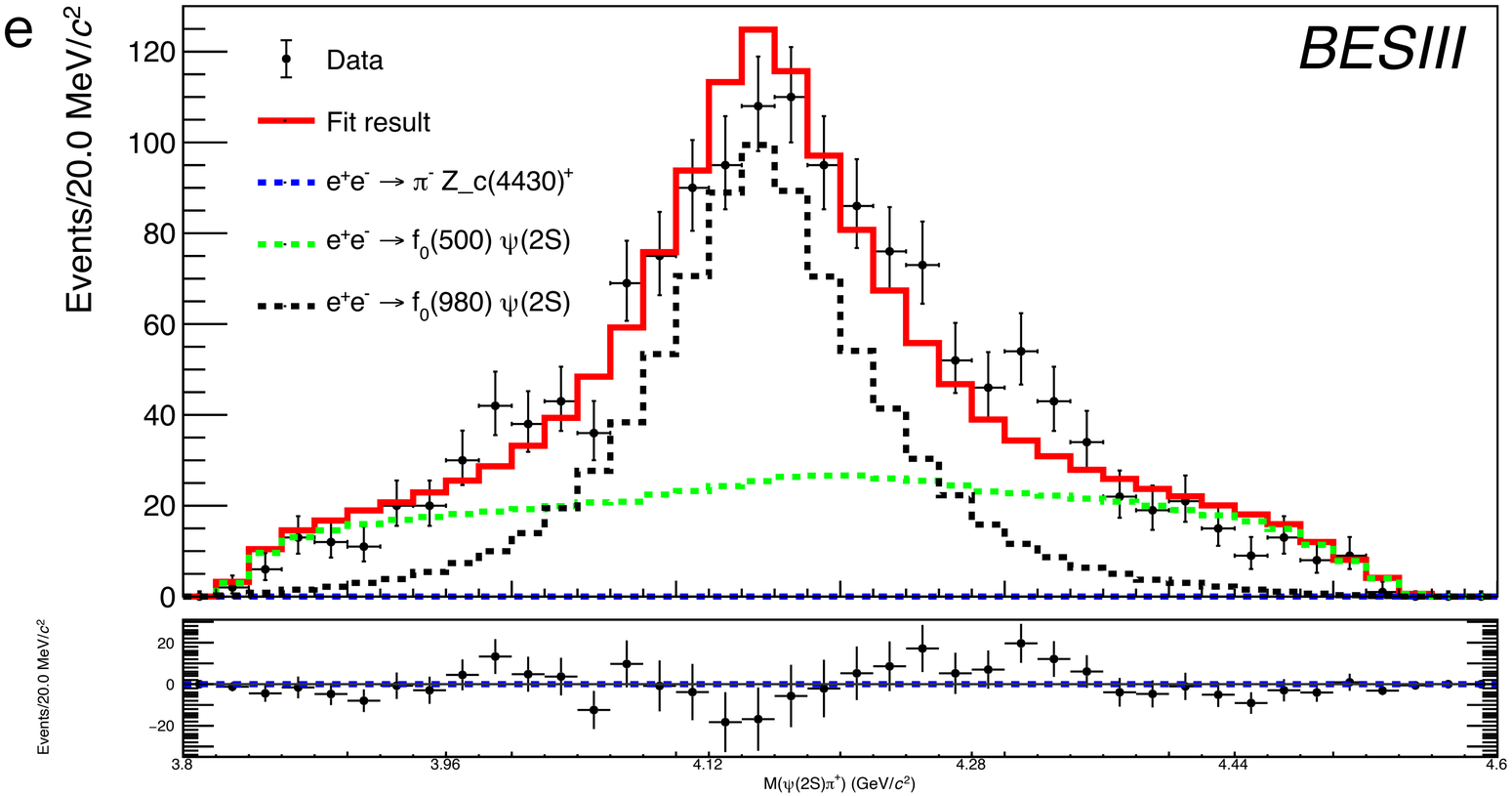

Signal function
MC Signal Shape

# Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass

In accordance with Ref.[11] and the Dalitz plots only $f_0$ contributions are considered

No evident $Z_c(4430)$ contribution is present (0 ± 4)

A Bayesian U.L. @90% will be given



# Systematic Uncertainties

On the **cross-sections**, the systematic uncertainties come from the **selection efficiencies**, the integrated **luminosity**, the **vacuum polarisation**, the ISR **radiative corrections**, the **tracking efficiency**, and residual sources

- *Luminosity*: 1% as from Ref. [12]
- *Vacuum polarisation*: 0.5% from Ref. [13]
- *ISR radiative corrections*: Difference in the (1 + δ) between the last two iterations
- *Tracking efficiency*: 1.0% per track[10], 2.0% (leptons) and 3.5% (average of 2 pion-topologies)
- *Intermediate states* branching fractions: from PDG
- *Lepton separation*, *trigger efficiency*, and *FSR*: 1.0% from Ref. [11]

[12] Chin. Phys. C **46**, 11, 113003
[13] Sov. J. Nucl. Phys **41**, 466-472

# Systematic Uncertainties

The systematic sources **on the $Z_c(4430)$ U.L.** come from the fitting procedure and choices, such as the **binning**, the **signal range**, and the **parametrisation of the signal and background**

These uncertainties are **estimated with a toy MC** simulation and then **incorporated as a Gaussian prior** in the Bayesian U.L.

An **additional** systematic uncertainty comes from the **number and** selection **efficiency** of **$e^+e^- \to \pi^+\pi^-\psi(2S)$** events for the production ratio estimation

$$R = \sigma(e^+e^- \to \pi^\pm Z_C(4430)^\mp \to \pi^+\pi^-\psi(2S))/\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$$

# Conclusions and Outlook

The **results found** in this analysis **confirm Ref.[11]** and clearly **highlight** the **$f_0$ contributions** to the $\pi^+\pi^-\psi(2S)$ cross-section

A **search for the $Z_c(4430)$** exotic state is performed via the **$e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$** reaction, but **no evident $Z_c(4430)$** is found

For the $Z_c(4430)$ studies, a **fitting model** can be chosen **following a PWA-motivated** generated signal **MC sample**

An **analytical $f_0(500)$** shape can be implemented

Possible **interference between the two $f_0$ states** needs to be accounted for

# Thanks for your attention!

# Back-up Slides

# Signal MC Studies

Signal MC sample
300k events

## Event Selection

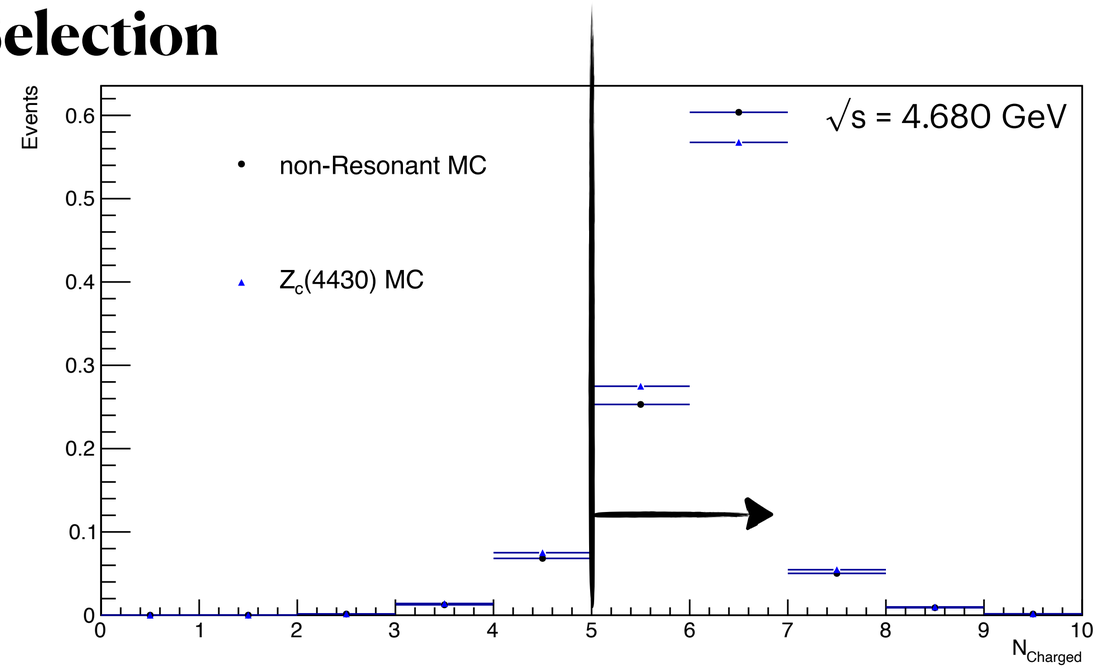
### Goodness Cuts

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

Polar angle: |cos θ| < 0.93

### Channel ID

# charged tracks > 4



# Signal MC Studies

Signal MC sample
300k events

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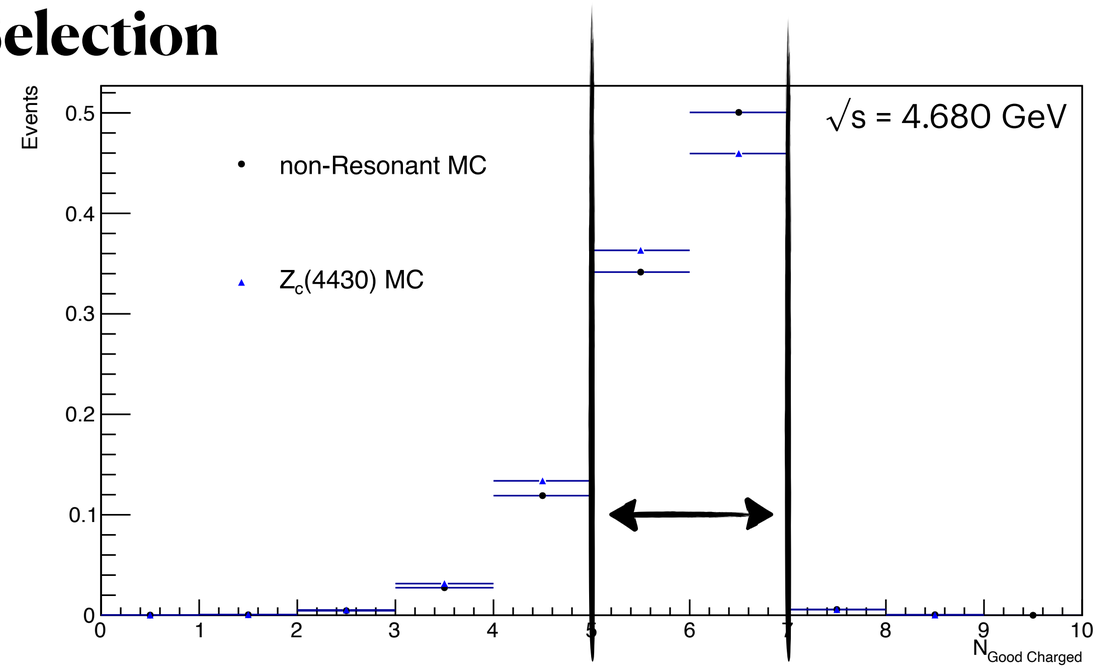



### Channel ID

# charged tracks > 4

2 good charged topologies

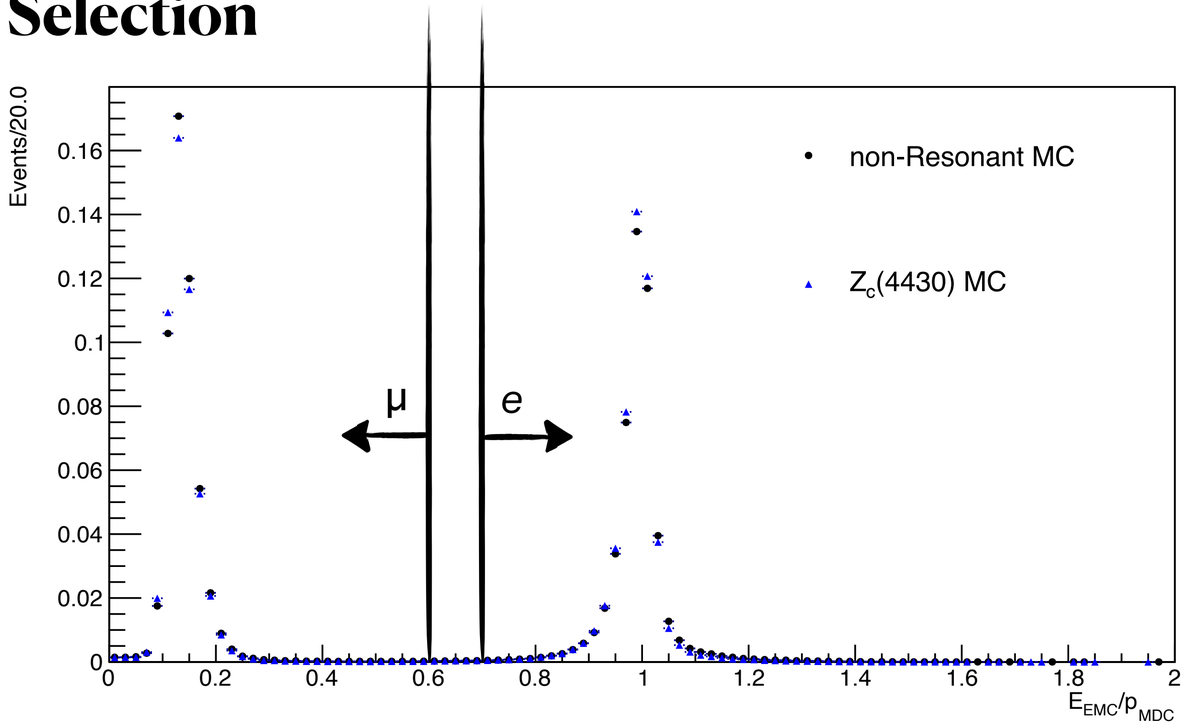
$2\ell\,3\pi$

$2\ell\,4\pi$

# Signal MC Studies

Signal MC sample
300k events

## E/p Selection




### Goodness Cuts

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

Polar angle: |cos θ| < 0.93

### Channel ID

# charged tracks > 4

| Leptons | Pions |
|---|---|
| $p_T$ > 1 GeV<br>E/p (e) > 0.7<br>E/p (μ) < 0.6 | $p_T$ < 0.85 GeV |

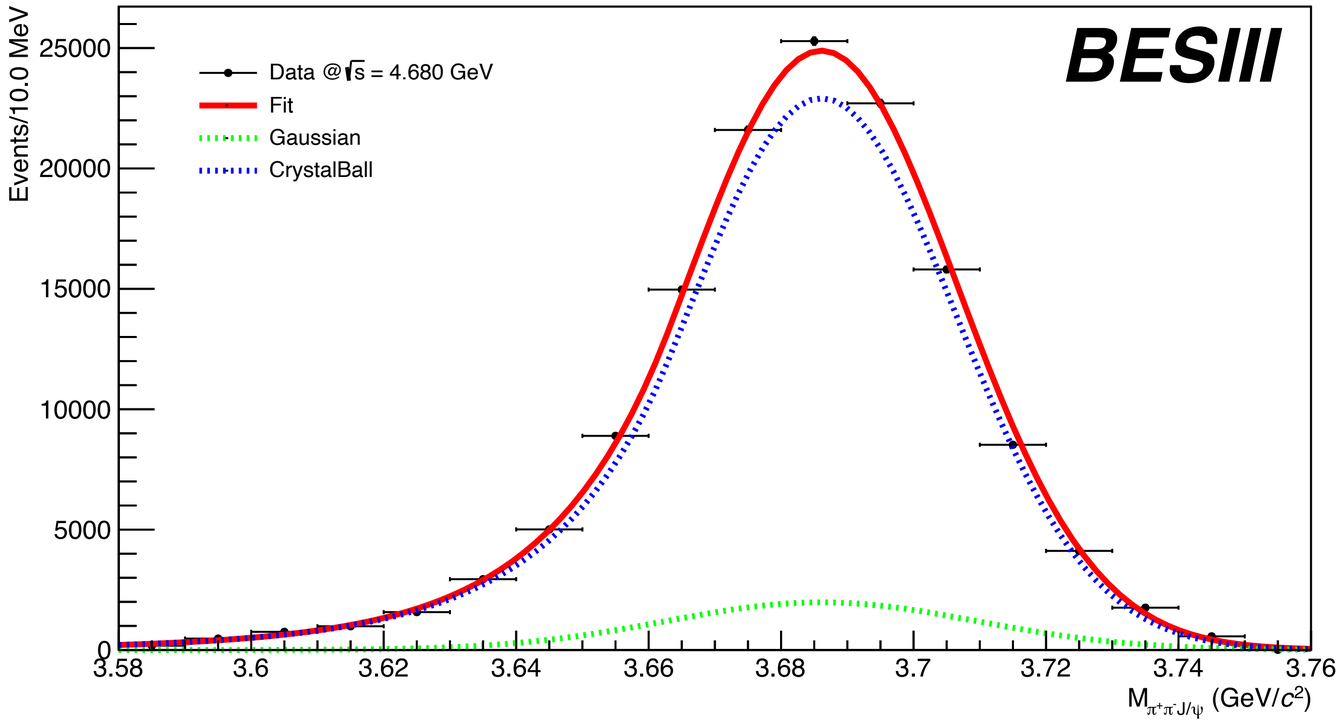
2 good charged topologies

$2\ell\, 3\pi$

$2\ell\, 4\pi$

# Extraction of the σ(ππψ(2S))

## ππψ(2S) cross-section

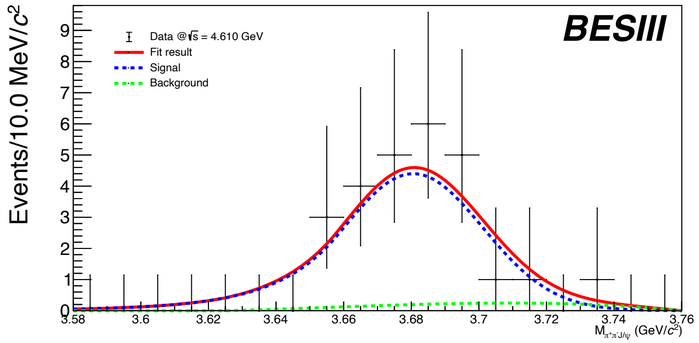


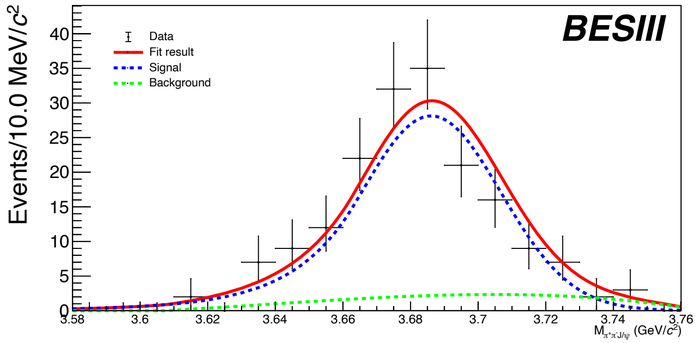

For each √s, the ππψ(2S) contribution is extracted by fitting the M(ππJ/ψ) invariant spectrum

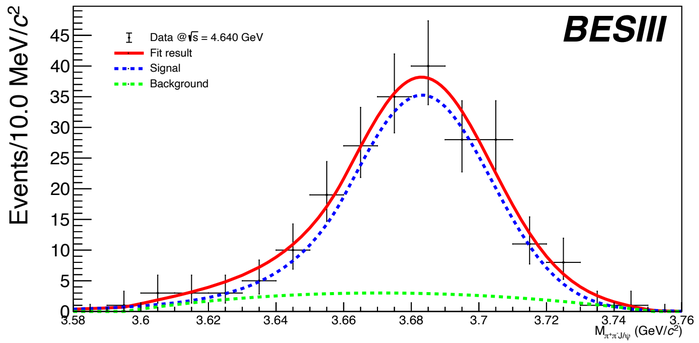
The signal is modelled with a sum of Gaussian and Crystal Ball functions

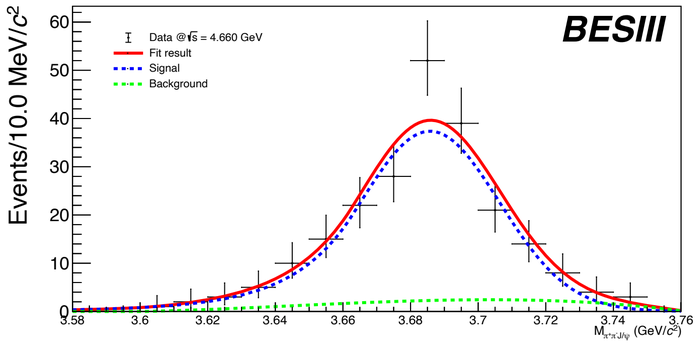
# Extraction of the σ(ππψ(2S))

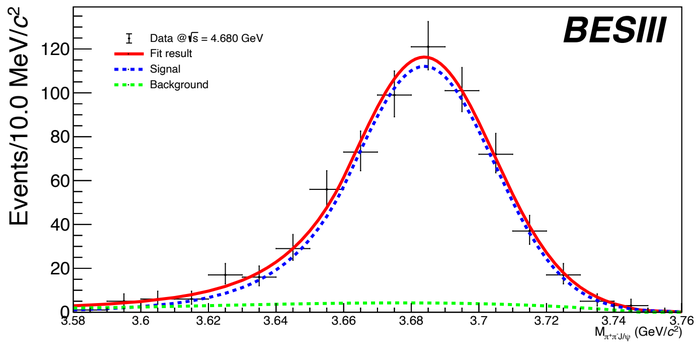
## ππψ(2S) cross-section

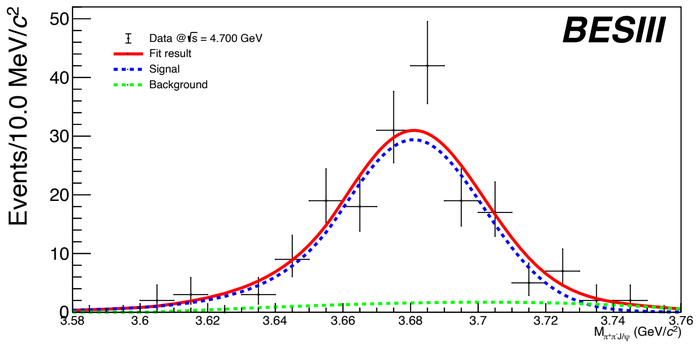


# Extraction of the σ(ππψ(2S))

## ππψ(2S) cross-section

| $E_{CoM}$ (MeV) | $\mathcal{L}$ (pb$^{-1}$) | $N_{\text{Obs}}$ | $\epsilon$ (%) | $(1+\delta)$ | $\frac{1}{\lvert 1-\Pi\rvert^2}$ | $\sigma_{\text{Born}}$ |
|---|---|---|---|---|---|---|
| 4611.86 | 103.83 | $24^{+2}_{-5}$ | $49.42 \pm 0.13$ | 0.723 | 1.05453 | $16.38^{+1.37}_{-3.42}$ |
| 4628.00 | 521.52 | $155^{+18}_{-18}$ | $48.39 \pm 0.13$ | 0.768 | 1.05444 | $20.40^{+2.38}_{-2.38}$ |
| 4640.91 | 552.41 | $193^{+27}_{-29}$ | $47.97 \pm 0.13$ | 0.776 | 1.05442 | $23.93^{+3.36}_{-3.60}$ |
| 4661.24 | 529.63 | $202^{+20}_{-20}$ | $46.91 \pm 0.13$ | 0.814 | 1.05441 | $25.24^{+2.51}_{-2.51}$ |
| 4681.92 | 1669.31 | $563^{+46}_{-46}$ | $45.38 \pm 0.12$ | 0.859 | 1.05448 | $22.04^{+1.81}_{-1.81}$ |
| 4698.82 | 536.45 | $162^{+16}_{-16}$ | $43.84 \pm 0.12$ | 0.895 | 1.05453 | $19.61^{+1.95}_{-1.95}$ |

# MC Studies

## Efficiency

$f_0(980)$
Signal MC sample
300k events

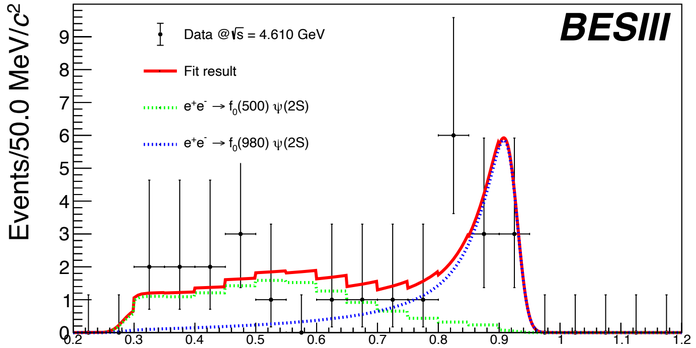
**CONEXC**

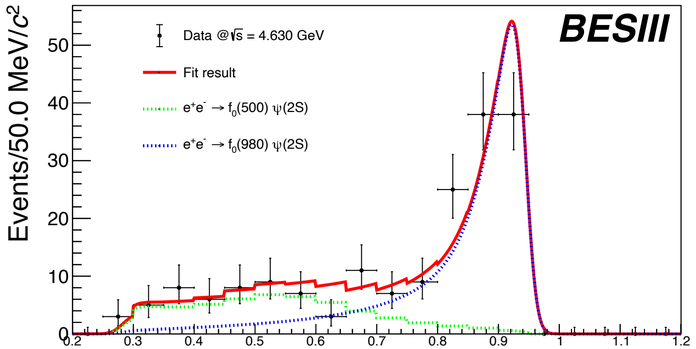
5 iterations

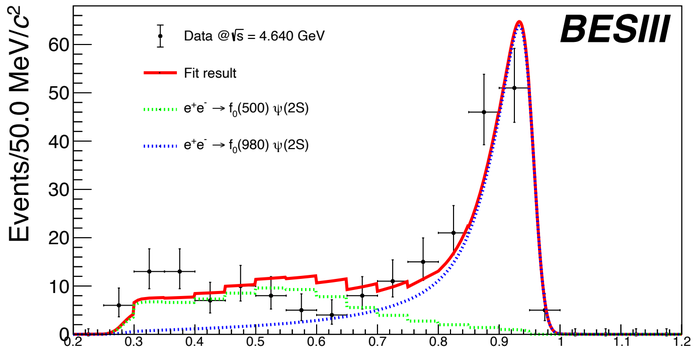
| Sample | Efficiency [%] | ISR*VP Corr. Factor. | *d*(ISR*VP) Corr. Factor. | VP Corr. Factor |
|---|---|---|---|---|
| 4,612 | 49,57 | 0,7281 | 0,0001 | 1,05453 |
| 4,626 | 48,99 | 0,7234 | 0,0002 | 1,05444 |
| 4,640 | 48,30 | 0,7984 | 0,0003 | 1,05442 |
| 4,660 | 45,76 | 0,8676 | 0,0004 | 1,05441 |
| 4,680 | 44,86 | 0,8531 | 0,0004 | 1,05448 |
| 4,700 | 44,83 | 0,8404 | 0,0005 | 1,05453 |

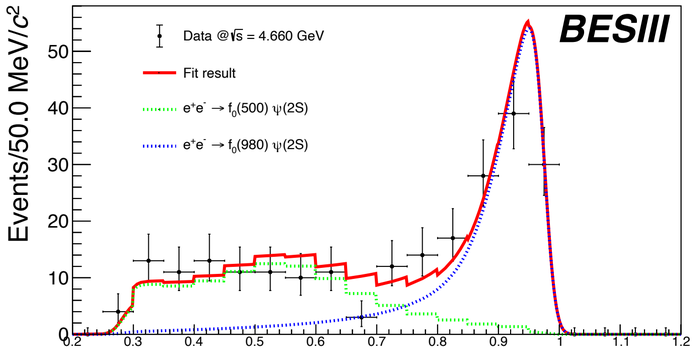
# Extraction of the σ($f_0$(980) ψ(2S))

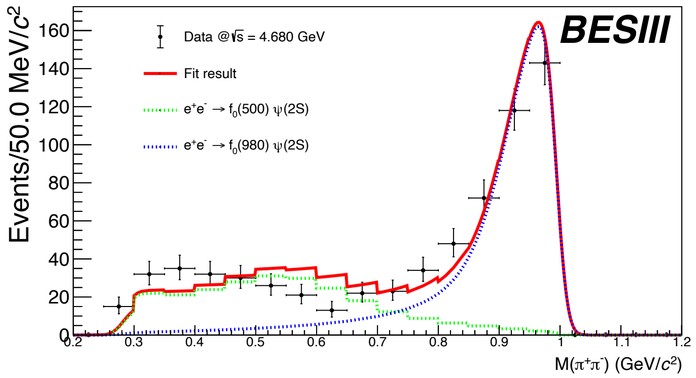
## $f_0$(980) contribution

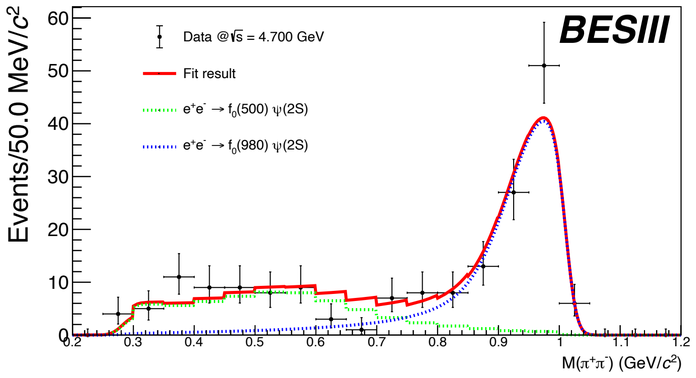


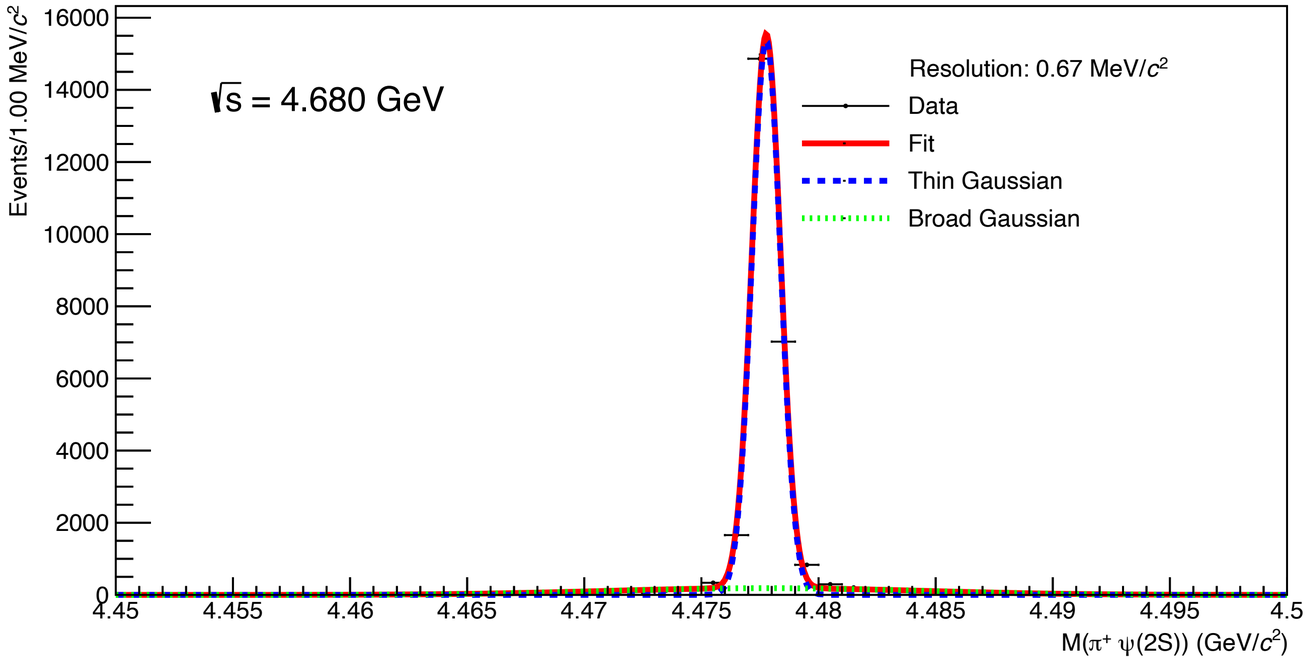
# Extraction of the $\sigma(f_0(980)\,\psi(2S))$

## $f_0(980)$ contribution

| $E_{CoM}$ (MeV) | $N_{\mathrm{Obs}}^{f_0(980)}$ | $\epsilon^{f_0(980)}$ (%) | $(1+\delta)$ | $\frac{1}{\lvert 1-\Pi\rvert^2}$ | $\sigma \times \mathcal{B}$ |
|---|---|---|---|---|---|
| 4611.86 | $14 \pm 5$ | $49.57 \pm 0.13$ | 0.728 | 1.05453 | $9.46 \pm 3.38$ |
| 4628.00 | $125 \pm 22$ | $48.99 \pm 0.13$ | 0.723 | 1.05444 | $17.25 \pm 3.04$ |
| 4640.91 | $149 \pm 21$ | $48.30 \pm 0.13$ | 0.798 | 1.05442 | $17.83 \pm 2.52$ |
| 4661.24 | $131 \pm 15$ | $45.76 \pm 0.12$ | 0.868 | 1.05441 | $15.74 \pm 1.81$ |
| 4681.92 | $424 \pm 32$ | $44.86 \pm 0.12$ | 0.853 | 1.05448 | $16.91 \pm 1.29$ |
| 4698.82 | $115 \pm 16$ | $44.83 \pm 0.12$ | 0.840 | 1.05453 | $14.49 \pm 2.02$ |

# Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass

## Resolution Studies




| | | Resolution [MeV/$c^2$] |
|---|---|---|
| √s = 4.612 GeV | 4,612 | -- |
| √s = 4.626 GeV | 4,626 | 2.33 |
| √s = 4.640 GeV | 4,640 | 0.77 |
| √s = 4.660 GeV | 4,660 | 0.69 |
| √s = 4.680 GeV | 4,680 | 0.67 |
| √s = 4.700 GeV | 4,700 | 0.74 |