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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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]

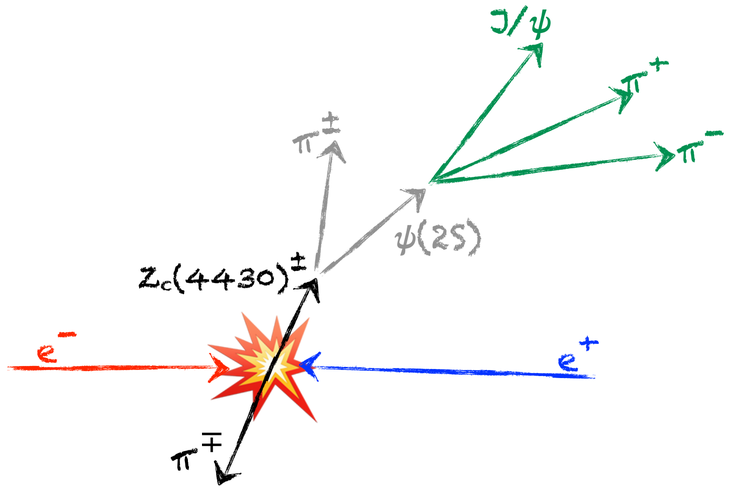
Study of the exotic $Z_c(4430)$ state through the $e^+e^- \to \pi^\pm Z_c(4430) \to \pi^+\pi^-\psi(2S)$

$Z^+_c(4430)$ 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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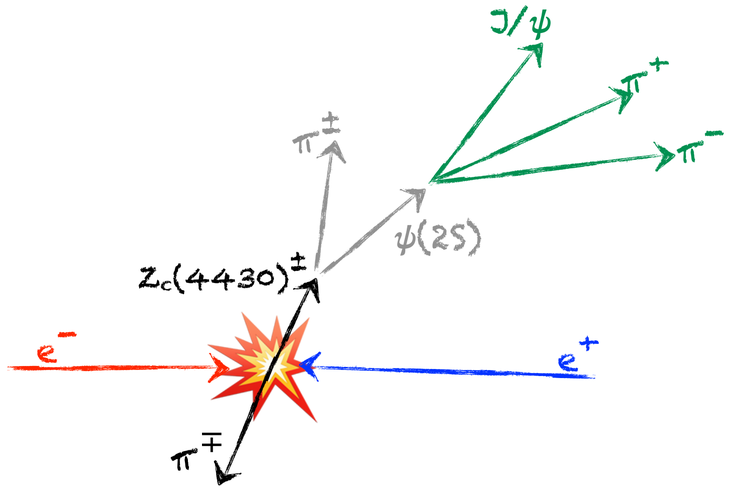
How

The study will make use of the 12 datasets @$\sqrt{s}$ > 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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Preamble

Datasets

Dataset	E_{CoM} (MeV)	$\mathcal{L}$ (pb^{-1})	Boss Version
4610	4611.86±0.12±0.30	103.65±0.05±0.55	
4620	4628.00±0.06±0.32	521.53±0.11±2.76	
4640	4640.91±0.06±0.38	551.65±0.12±2.92	7.0.6
4660	4661.24±0.06±0.29	529.43±0.12±2.81	
4680	4681.92±0.08±0.29	1667.39±0.21±8.84	
4700	4698.82±0.10±0.36	535.54±0.12±2.84	
4740	4739.70±0.20±0.30	163.87±0.07±0.87	
4750	4750.05±0.12±0.29	366.55±0.10±1.94	
4780	4780.54±0.12±0.30	511.47±0.12±2.71	7.0.7
4840	4843.07±0.20±0.31	525.16±0.12±2.78	
4914	4918.02±0.34±0.34	207.82±0.08±1.10	
4946	4950.93±0.36±0.38	159.28±0.07±0.84	

How

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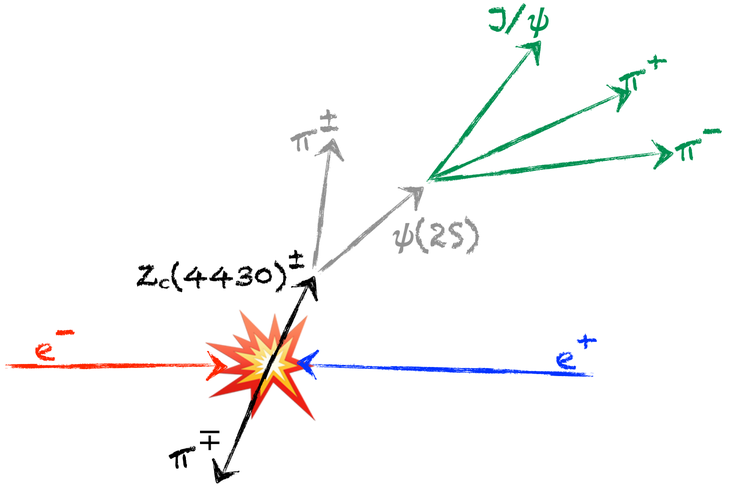

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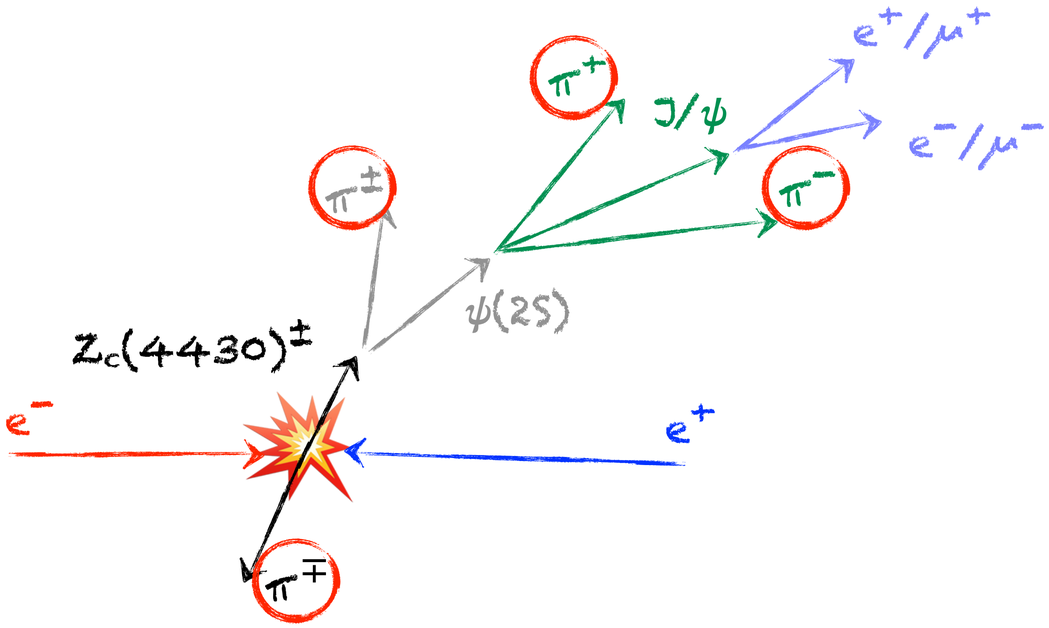
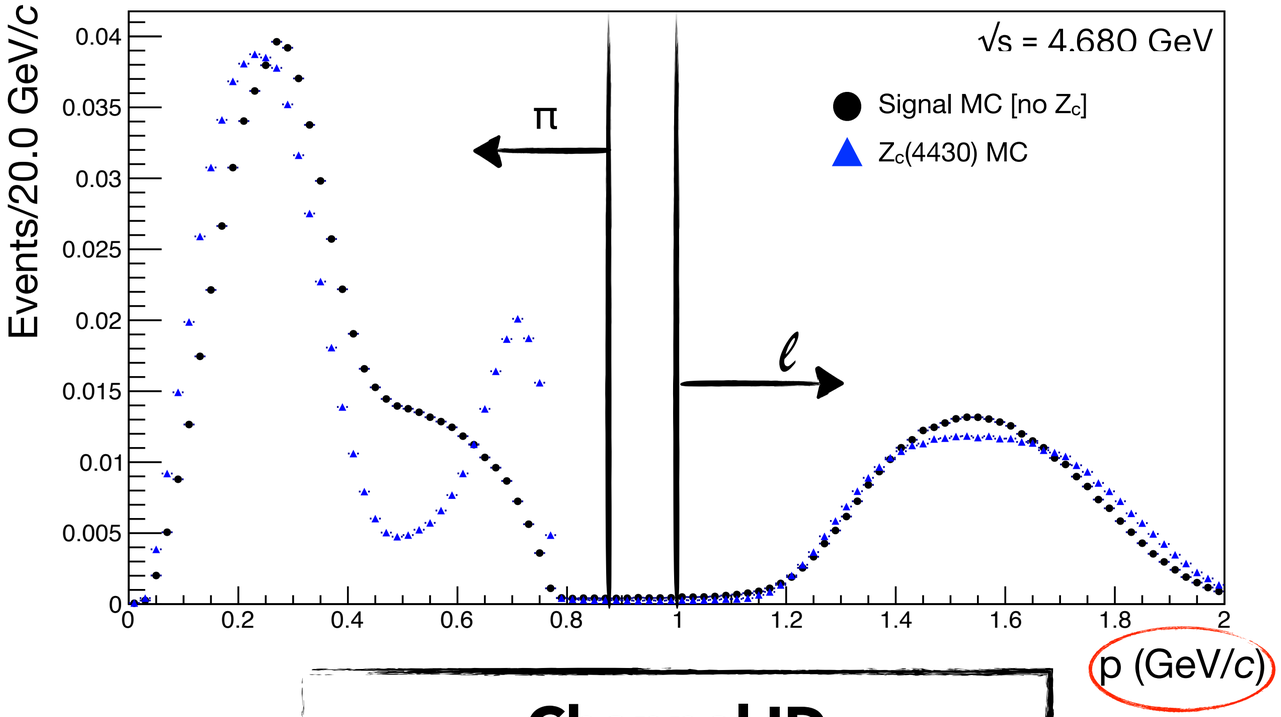
Event Selection

Signal MC sample
300k events





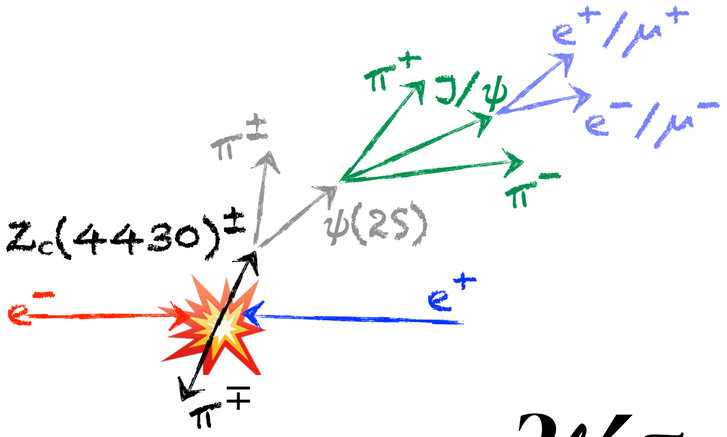
2 good charged topologies

$2\ell 4\pi$

$2\ell 3\pi$

Channel ID

Pions	Leptons
p < 0.85 GeV	p > 1.00 GeV
	E/p (e) > 0.7
	E/p (μ) < 0.6



Event Selection

Topology-dependent Kinematic Fits

$2\ell 4\pi$

6-constraint (6C) kinematic fit

1C on the $M_{J/\psi}$
1C on the $M_{\psi(2S)}$
4C on the $p_{Tot} = (\sqrt{s}*\sin(0.011), 0, 0, M_{\sqrt{s}})$

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

$2\ell 3\pi$

2-constraint (2C) kinematic fit

1C on the $M_{J/\psi}$
1C on the $M_{\psi(2S)}$
$[p_{Tot} = (\sqrt{s}*\sin(0.011), 0, 0, M_{\sqrt{s}})]$

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

*π_{Miss} either from prompt production or from $\psi(2S)$ decay, but not from $Z_c(4430)$

Background Rejection

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

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	...	...	...

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

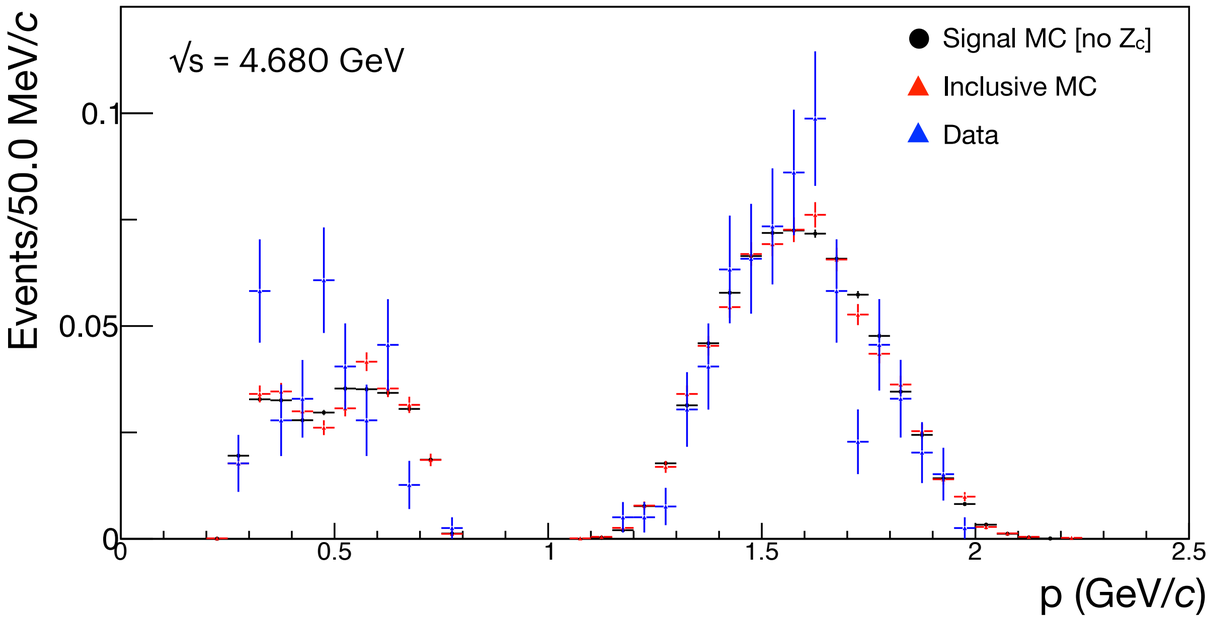
Virtually **only the hadron component** is surviving after the selection criteria

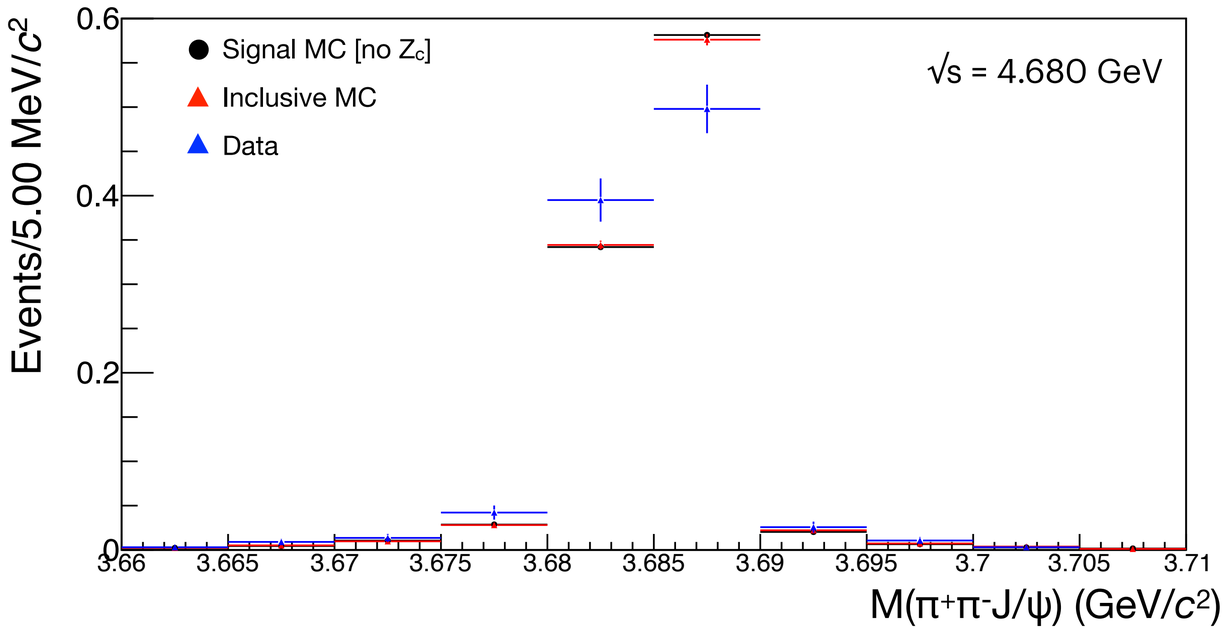
Out of 28136 total **IncMC events**, the events are from

- > 90% Non-resonant **ππψ(2S)** signal
- < 10% Multi-π states

After Selection Comparison

Inclusive MC / Signal MC [no Z_c]/ Data

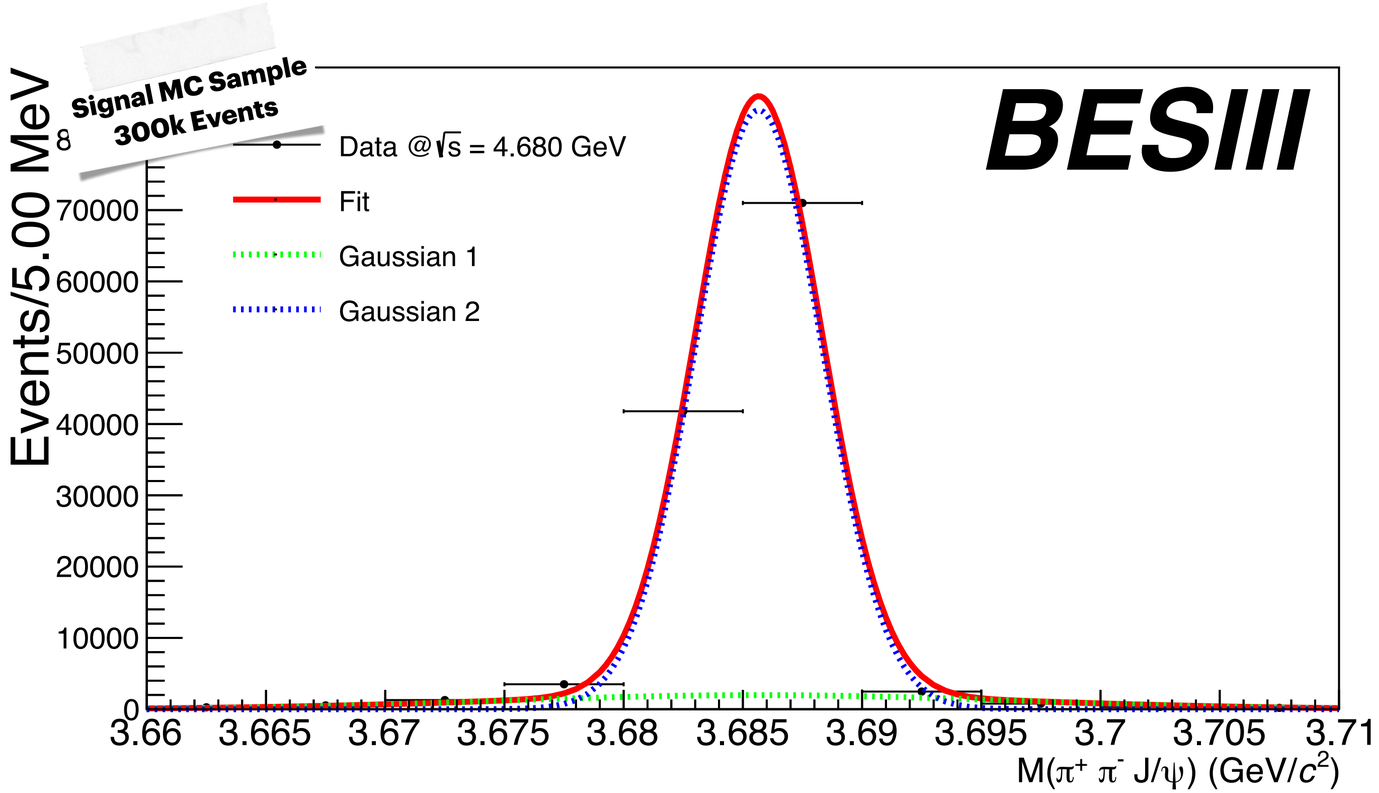




Extraction of the $\sigma(e^+e^- \longrightarrow \pi^+\pi^-\psi(2S))$

Extraction of the $\sigma(e^+e^- \rightarrow \pi^+\pi^-\psi(2S))$

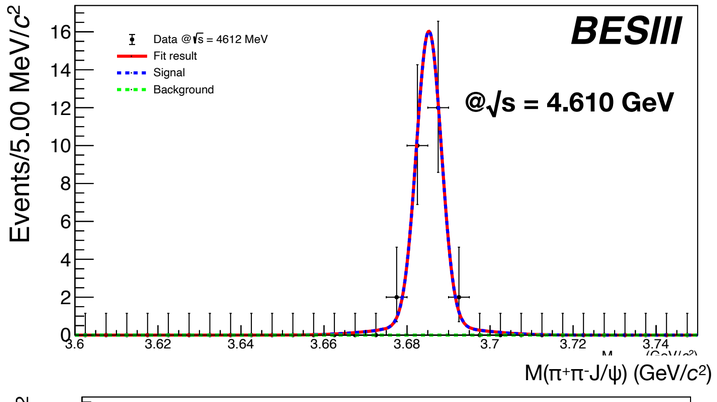
Signal Shape & Efficiency

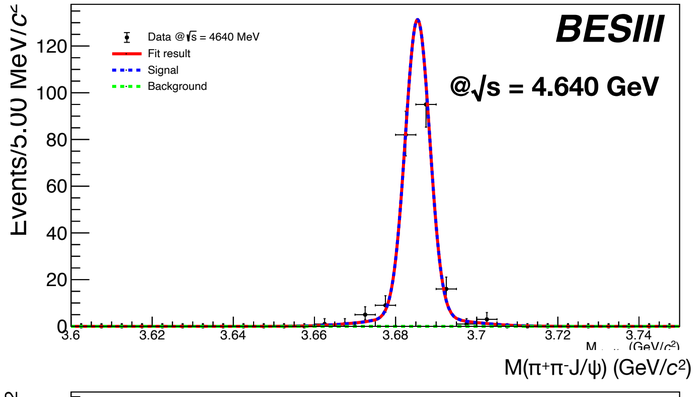


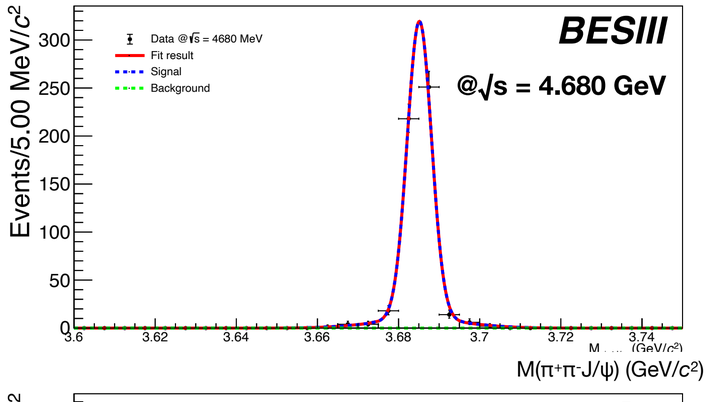
For **each √s**, the **signal** is modelled via a signal MC sample with a **sum of Gaussian and Crystal Ball** functions

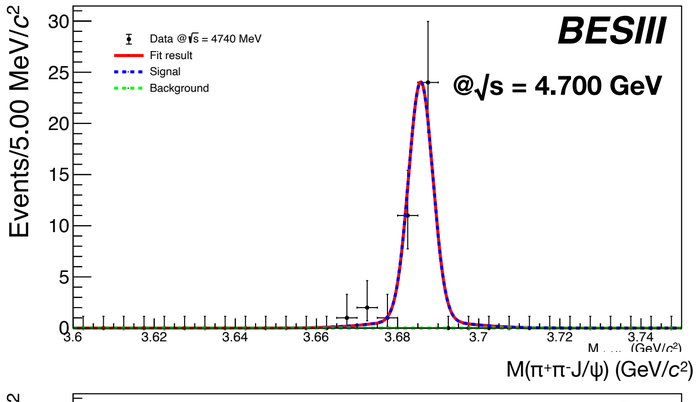
<Efficiency> ~36%$_{Conexc}$ (34%$_{KKMC}$)

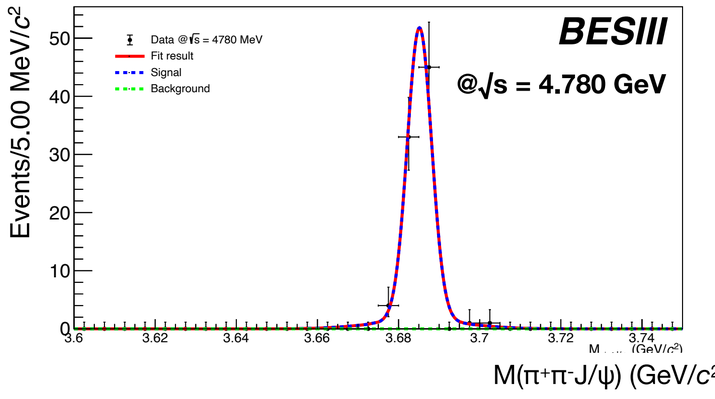
Extraction of the $\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$

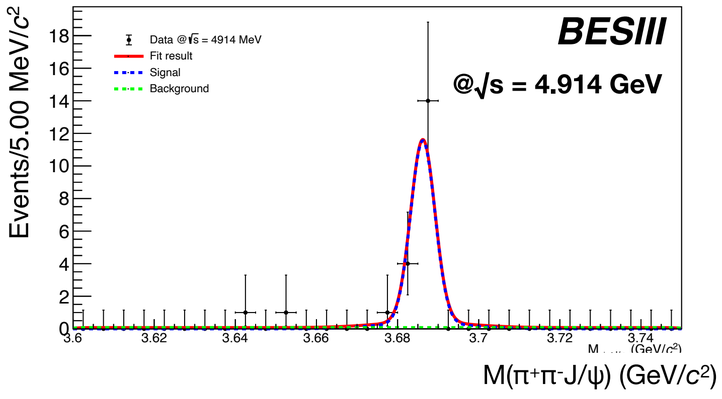












Data Fits

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**

A **polynomial** function is used to describe the **background**

Extraction of the $\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$

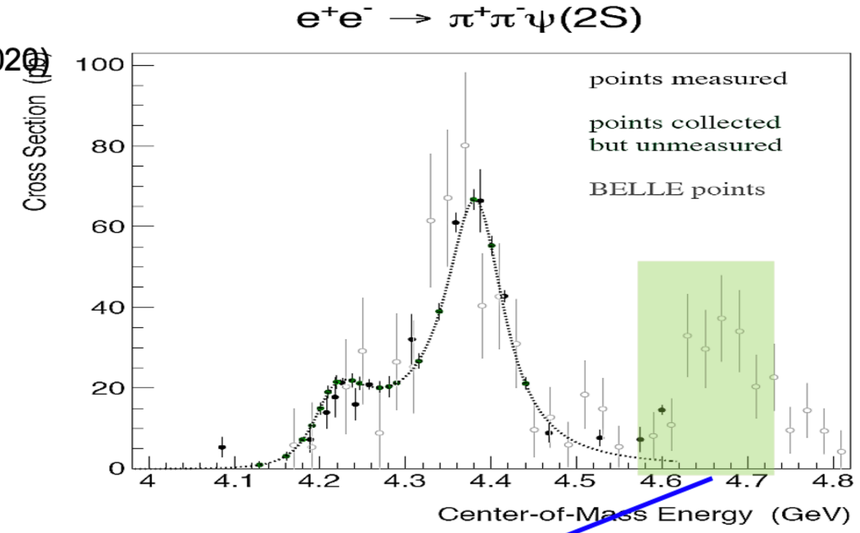
The Energy and Luminosity Update on BEPCII

Urgency from HEP

Future Physics Program of BESIII, Chin. Phys. C 44, 040001 (2020)

Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

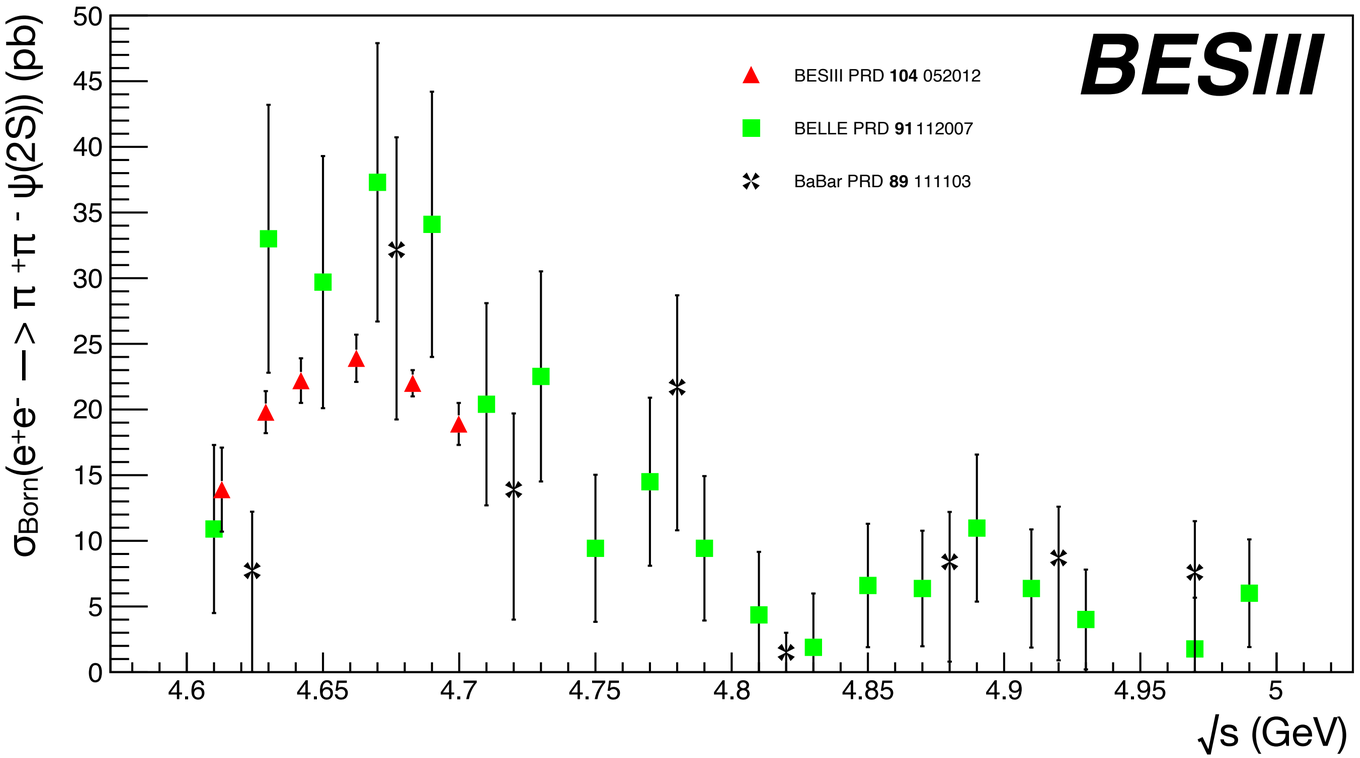
Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\Lambda_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days



The Progress on the BEPCII Upgrade, LIU Y. D.

Extraction of the $\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$

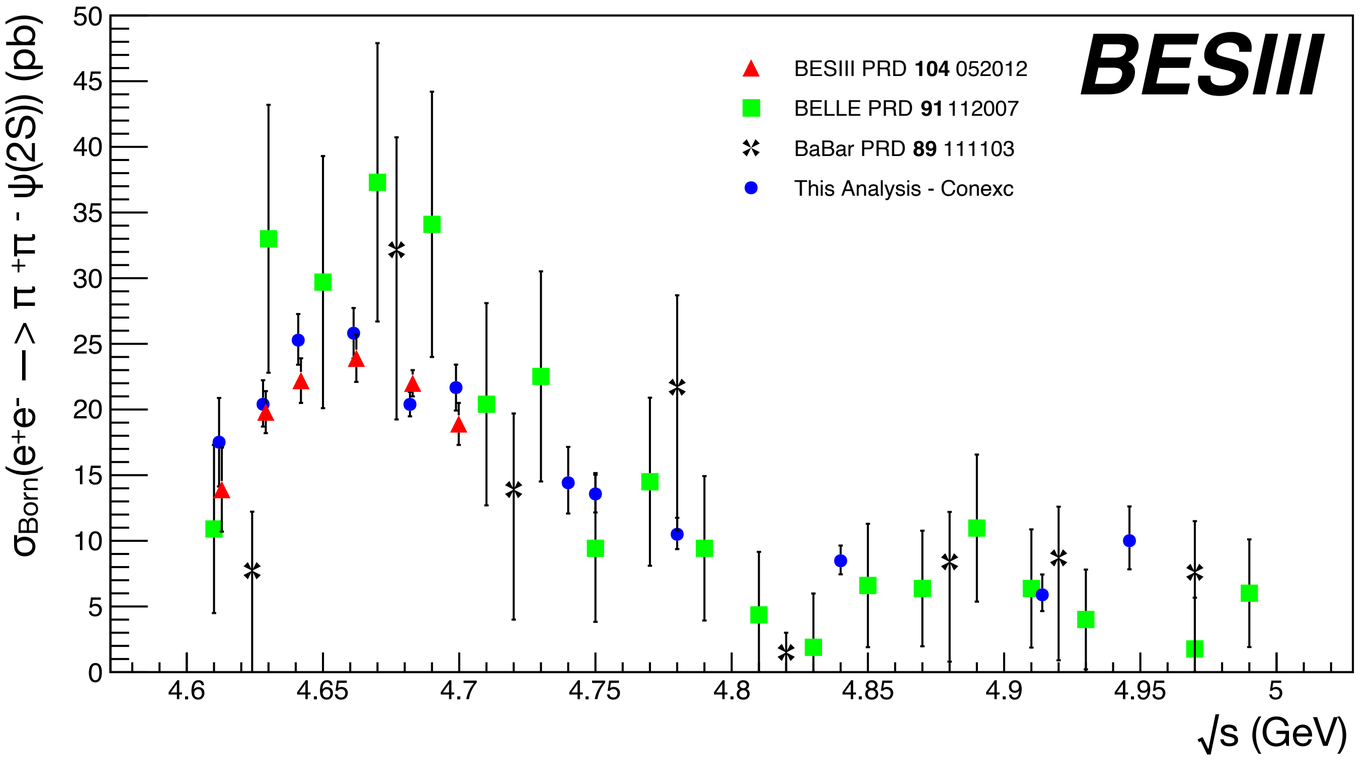
$\pi\pi\psi(2S)$ cross-section



[11] Phys. Rev. D **104**, 052012

Extraction of the $\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$

$\pi\pi\psi(2S)$ cross-section



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

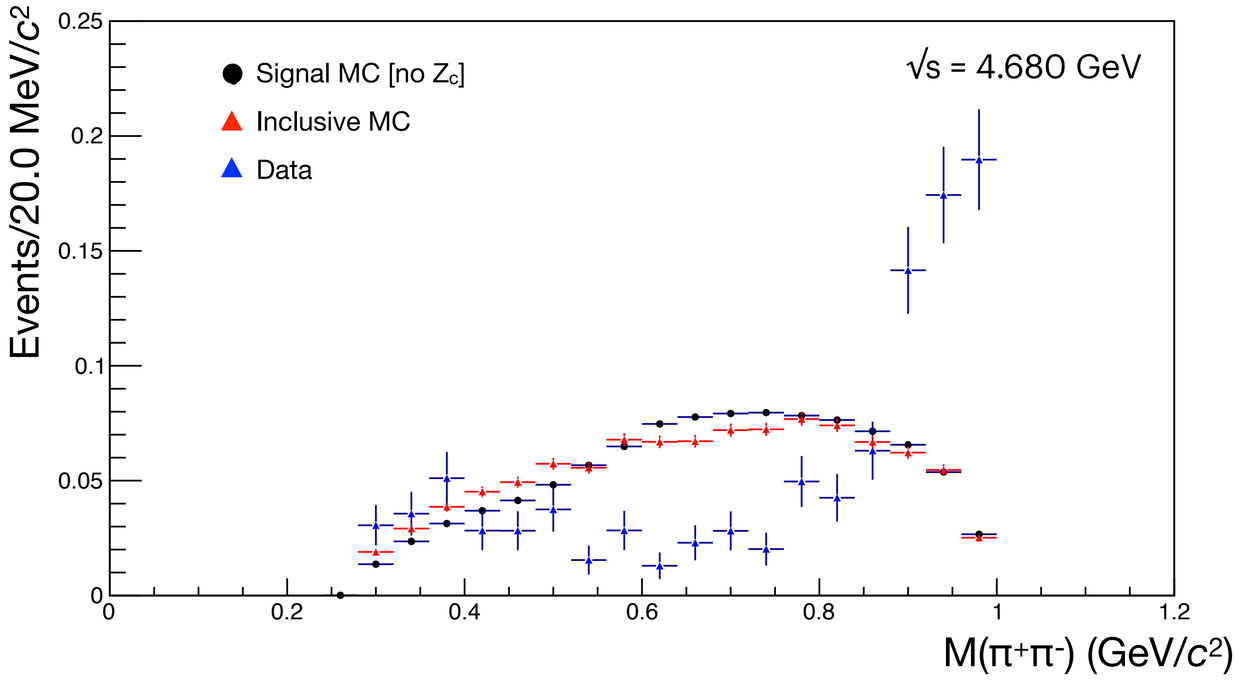
The observed **cross-section** is **compatible with** the previous result of **Ref. [11]**

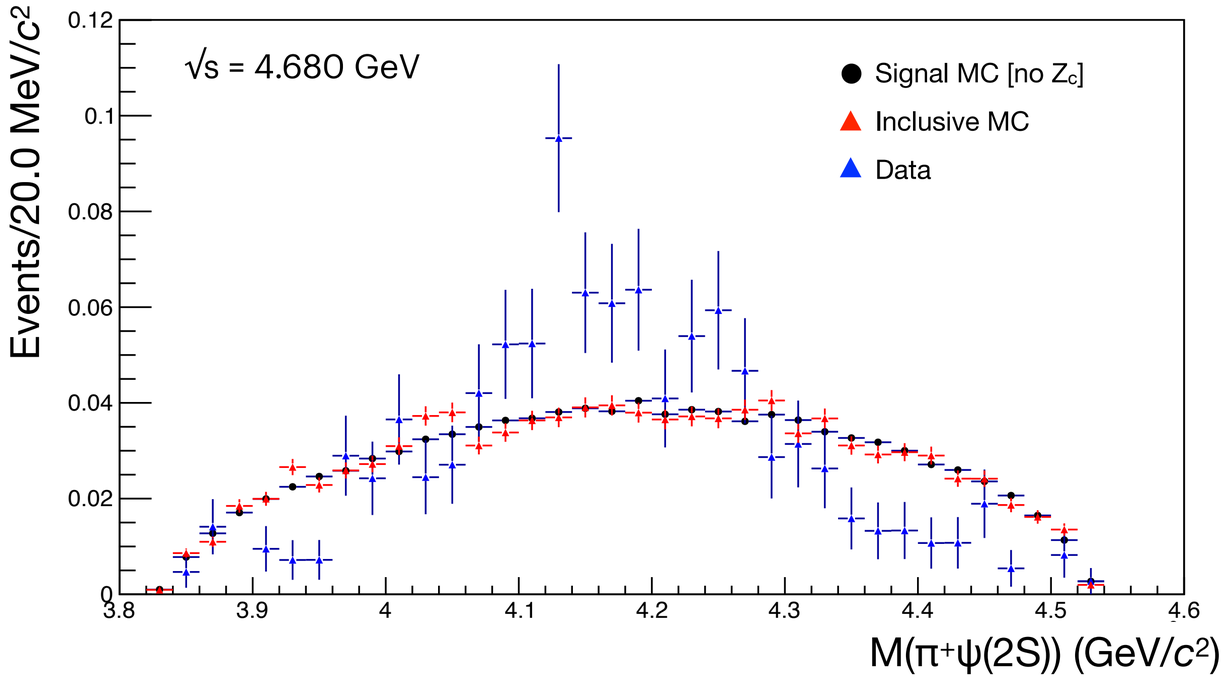
Results from BELLE and BaBar are reported too, further **confirming the compatibility** of this thesis' results with the published literature

[11] Phys. Rev. D **104**, 052012

Study of the invariant masses profiles

Inclusive MC / Non-resonant MC/ Data



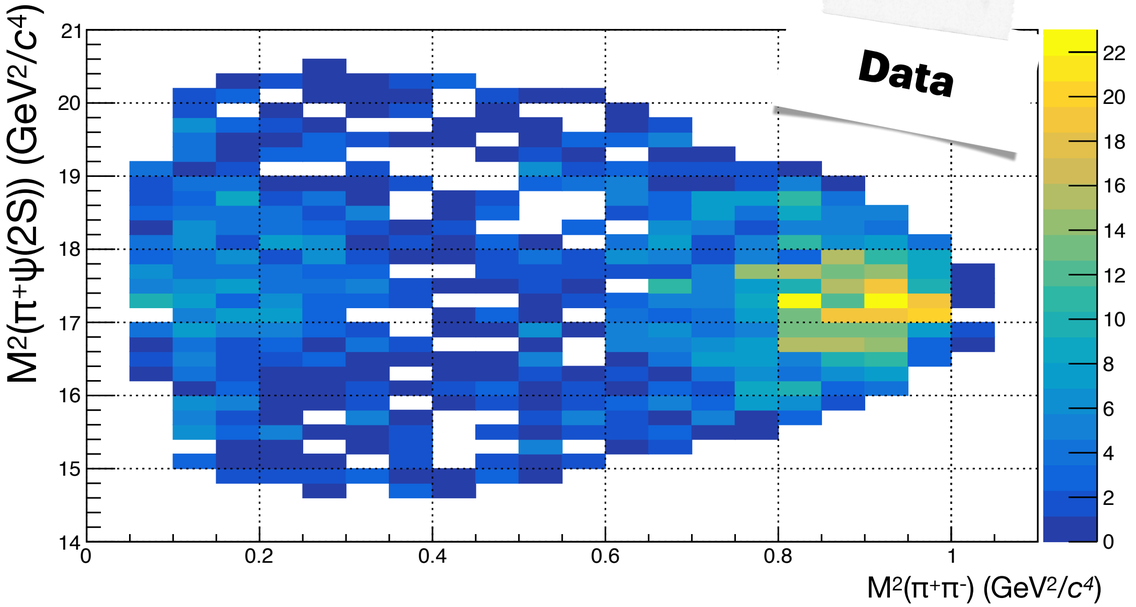


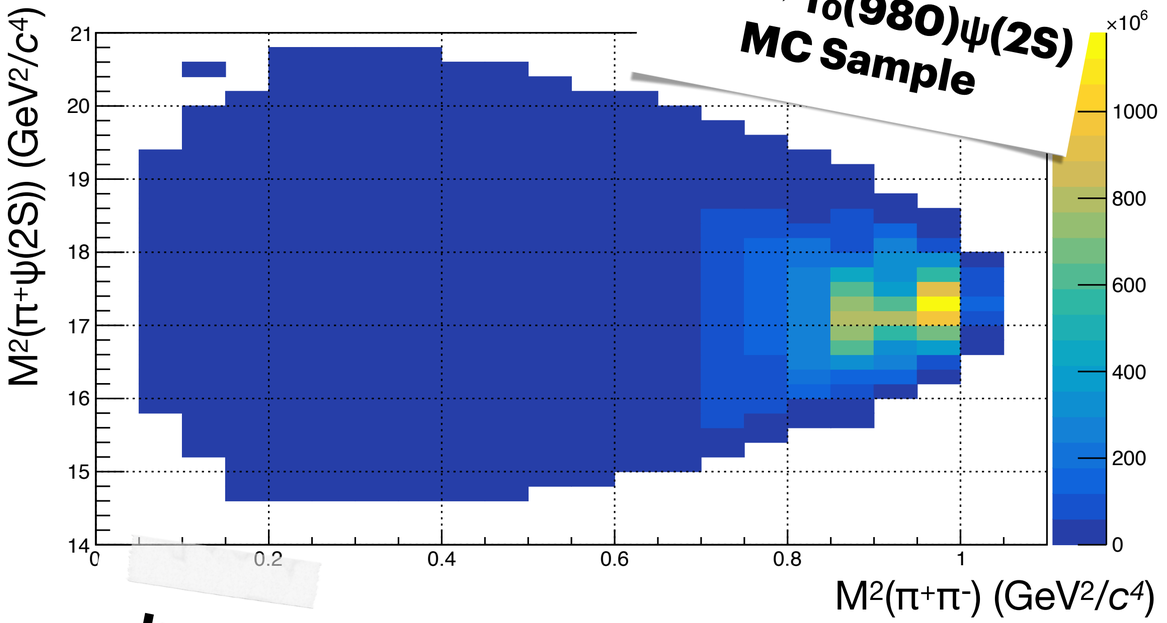
Study of the Intermediate States

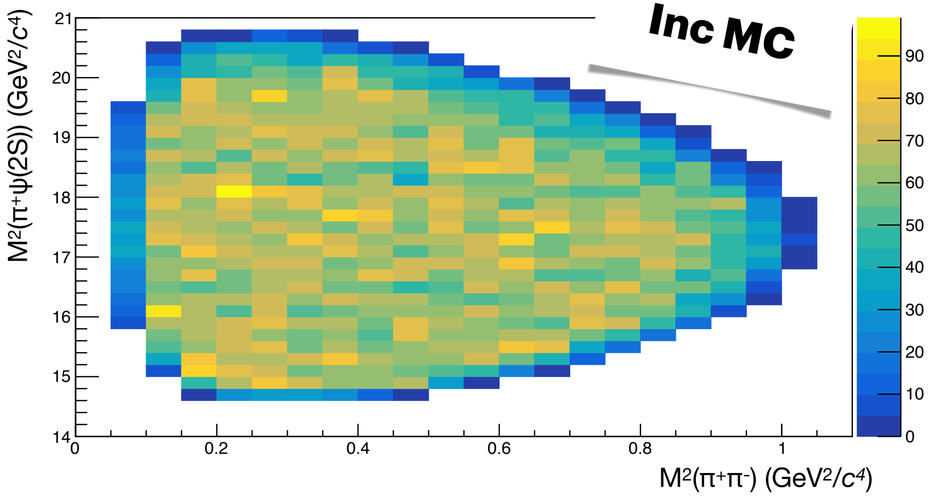
Study of $e^+e^- \to \pi^+\pi^-\psi(2S)$ at $\sqrt{s} > 4.6$ GeV and search for the $Z_c(4430)^\pm$ - Marco Scodeggio

Study of the Intermediate States

Dalitz Plots





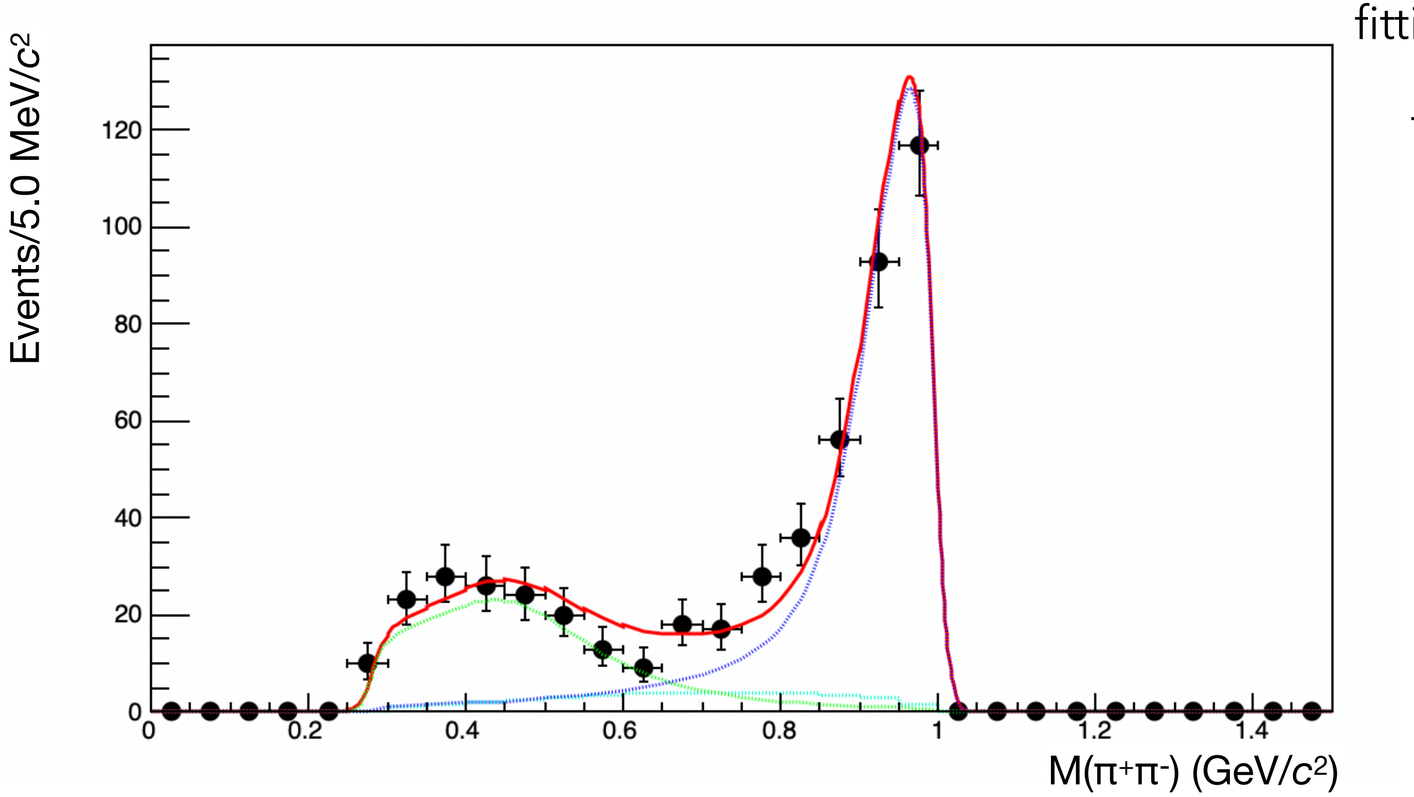


In **Ref.[11]**, a **simplified PWA** performed on the data sets highlighted **$f_0(500)$** and **$f_0(980)$** contributions

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

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

$f_0(980)$ contribution



For **each √s**, the **$f_0(980)$** contribution is extracted by fitting the M(ππ) and M(πψ(2S)) invariant distributions

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

$$BW(s) = \frac{1}{s - M^2 + i\left(g_1\rho_{\pi\pi}(s) + g_2\rho_{KK}(s)\right)}$$

The **$f_0(500)$** contribution is modelled with

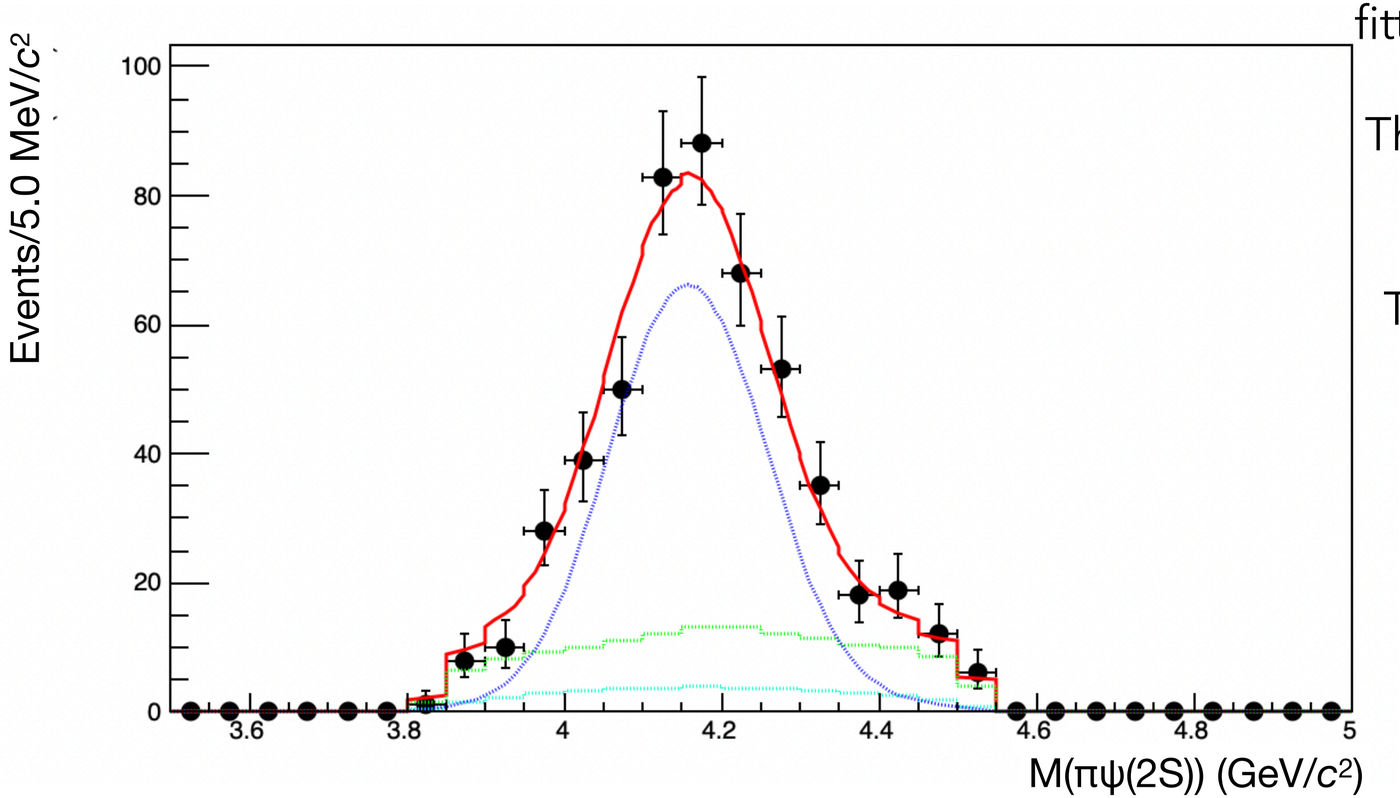
$$BW(s) = \frac{1}{s - M_0^2 + i\sqrt{s}\Gamma}$$

with an energy-dependent width à la E791…

$$\Gamma(s) = \sqrt{1 - \frac{4m_{\pi^\pm}^2}{s}}\Gamma$$

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

$f_0(980)$ contribution



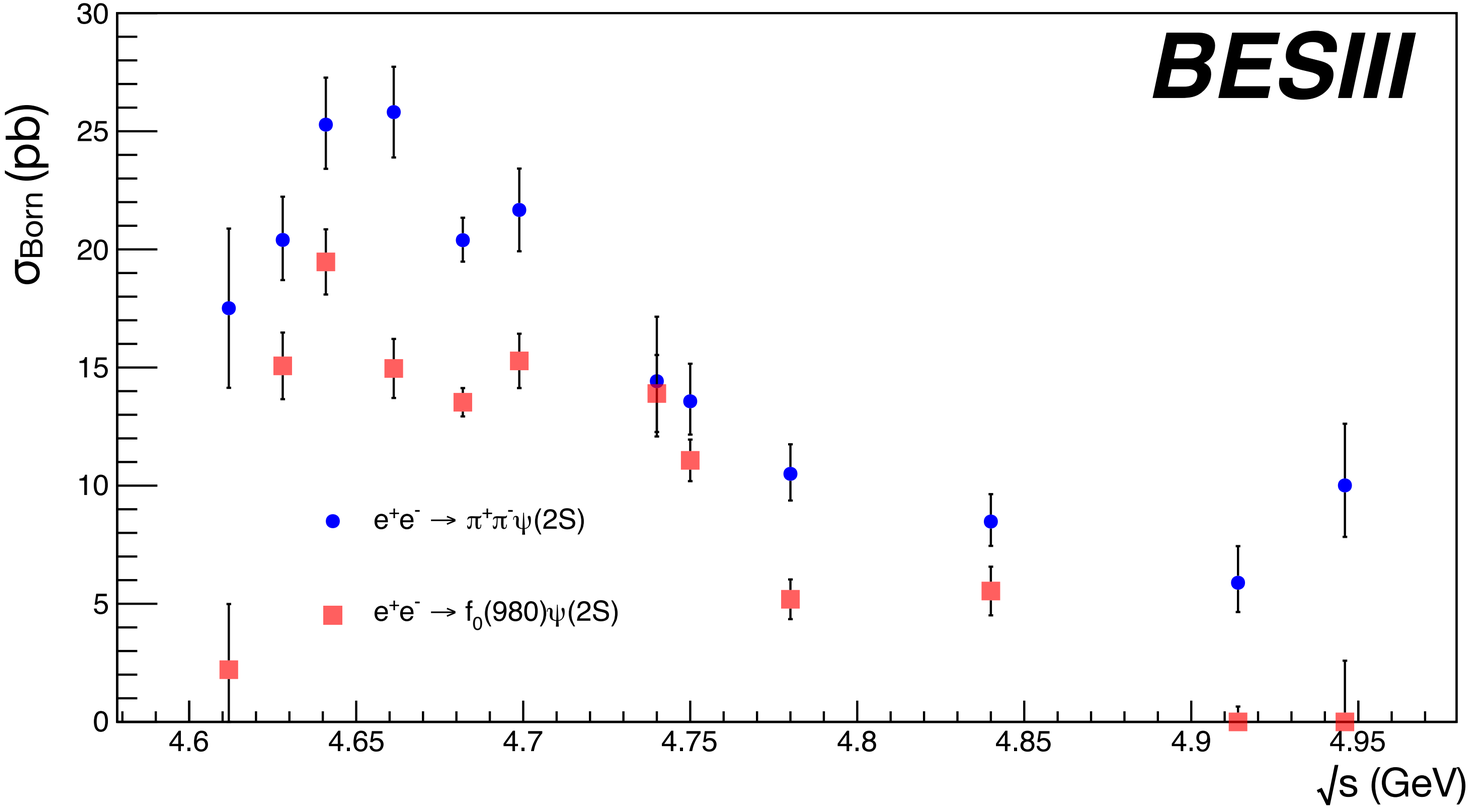
For **each √s**, the **$f_0(980)$** contribution is extracted by fitting the M(ππ) and M(πψ(2S)) invariant distributions

The signal is a **MS shape smeared by a Gauss(0, σ)**

The **$f_0(500)$** and **PHSP** contributions are modelled too by a **MS shape**

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

$f_0(980)$ contribution



No particular structures
can be recognised

Within the statistical uncertainty,
σ_{Born} ***x*** **B** is **flat** wrt $\sigma_{Born}(\pi\pi\psi(2S))$

The hypothesis of the **Y(4660)** being
an ***$f_0(980)$ - $\psi(2S)$*** **molecule**[12]
cannot be confirmed

[12] Phys. Lett. B 665, 26-29 (2008)

Systematic Uncertainties on the Cross-sections

- *Luminosity*: 1% as from Ref. [13]
- *Vacuum polarisation*: 0.5% from Ref. [14]
- *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]

[10] Phys. Rev. Lett **110**, 252001
[11] Phys. Rev. D **104**, 052012
[13] Chin. Phys. C **46**, 11, 113003
[14] Sov. J. Nucl. Phys **41**, 466-472

Final Born Cross-sections Results

E_{CoM} (MeV)	$\sigma^{e^+e^-\to\pi^+\pi^-\psi(2S)}_{\text{Born}}$	$\sigma^{e^+e^-\to f_0(980)\psi(2S)}_{\text{Born}} \times \mathcal{B}(f_0(980)\to\pi^+\pi^-)$
4.612	$17.51 \pm 3.37 \pm 0.68$	$2.21 \pm 2.78 \pm 0.09$
4.626	$20.40^{+1.83}_{-1.70} \pm 0.80$	$15.07 \pm 1.41 \pm 0.58$
4.640	$25.28^{+1.99}_{-1.87} \pm 0.99$	$19.47 \pm 1.38 \pm 0.75$
4.660	$25.81 \pm 1.92 \pm 1.01$	$14.96 \pm 1.25 \pm 0.58$
4.680	$20.39^{+0.95}_{-0.91} \pm 0.80$	$13.53 \pm 0.60 \pm 0.53$
4.700	$21.67^{+1.75}_{-1.75} \pm 0.85$	$15.28 \pm 1.15 \pm 0.59$
4.740	$14.42^{+2.73}_{-2.34} \pm 0.57$	$13.90 \pm 1.63 \pm 0.54$
4.750	$13.57^{+1.59}_{-1.41} \pm 0.54$	$11.07 \pm 0.88 \pm 0.43$
4.780	$10.50^{+1.25}_{-1.13} \pm 0.42$	$5.19 \pm 0.84 \pm 0.21$
4.840	$8.48^{+1.16}_{-1.03} \pm 0.34$	$5.54 \pm 1.03 \pm 0.22$
4.914	$5.89^{+1.55}_{-1.24} \pm 0.24$	$0.00 \pm 0.65 \pm 0.00$
4.946	$10.01^{+2.61}_{-2.18} \pm 0.39$	$0.00 \pm 2.59 \pm 0.00$

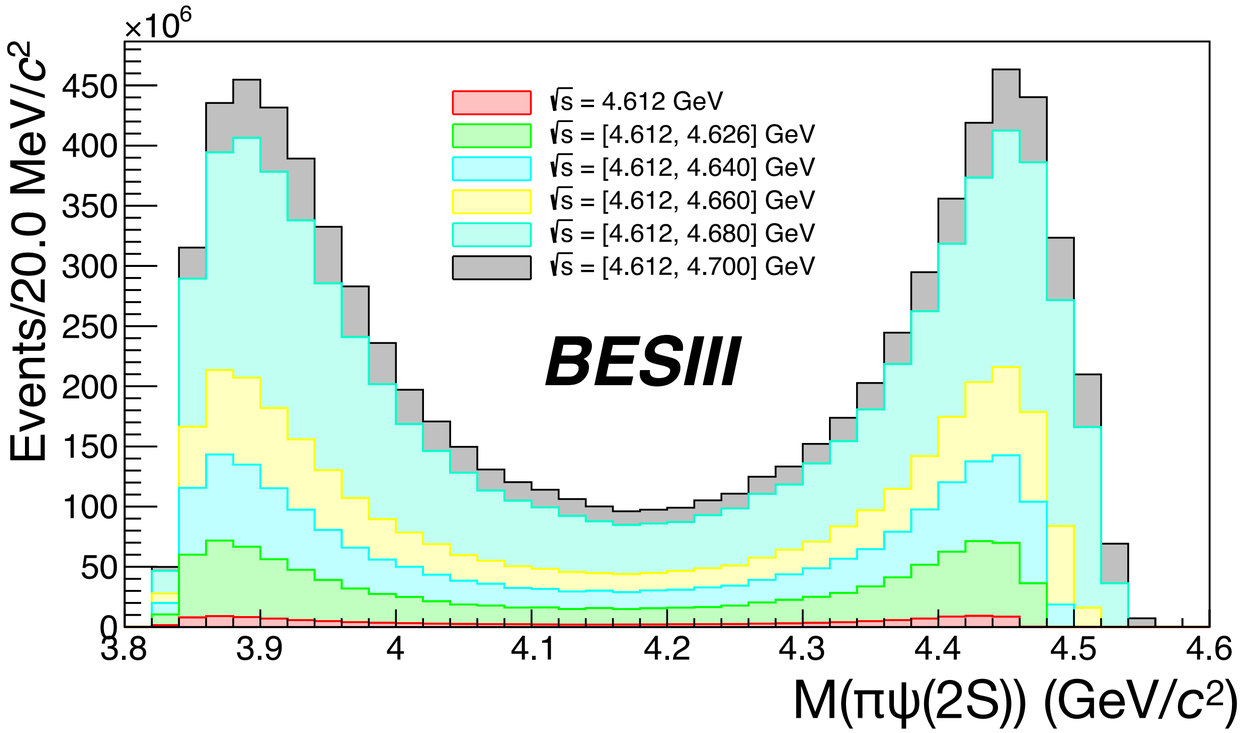
Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Signal MC Shape Extraction

Z_c Signal MC sample
300k events

√s [GeV]	$w_{\text{Normalised}} = (\sigma \times \mathcal{L})/(\sigma \times \mathcal{L})\vert_{4.680}$
4.612	0.05
4.626	0.31
4.640	0.41
4.660	0.40
4.680	1.00
4.700	0.34
4.740	0.07
4.750	0.15
4.780	0.16
4.840	0.13
4.914	0.04
4.946	0.05



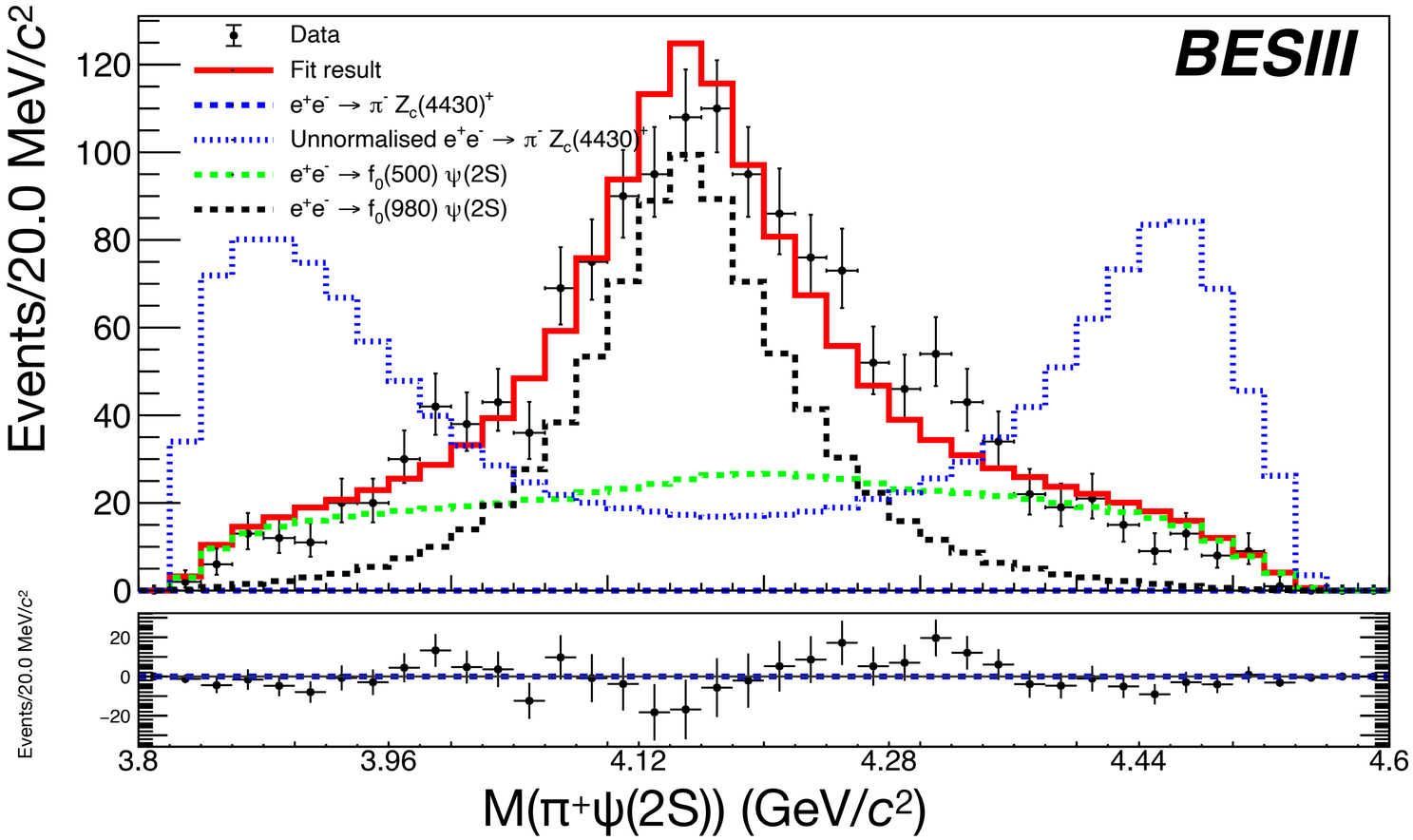
Signal function
MC Signal Shape

Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

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

Yield is 0 ± 4, hence no evident $Z_c(4430)$ contribution is present

Bayesian U.L. @90% C.L. is set



Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Production Ratio Estimation

Bayesian U.L. @90%
N(Z_c(4430)) < 17

$$R = \frac{\sigma_{\mathrm{Born}}(e^+e^- \to \pi^{\pm} Z_c(4430)^{\mp} \to \pi^+\pi^-\psi(2S))}{\sigma_{\mathrm{Born}}(e^+e^- \to \pi^+\pi^-\psi(2S))} < 1.1\ \%$$

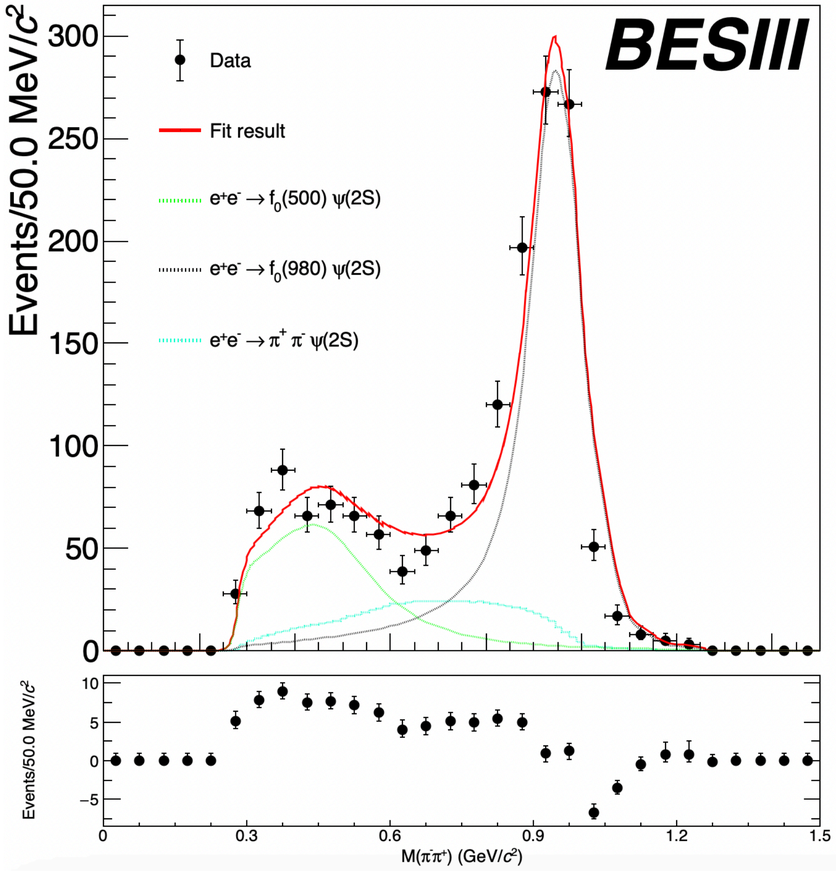
When **compared with the paper**[10] used as motivation for this analysis, the **$Z_c(4430)^{\pm}$** state **production** in the $e^+e^- \to \pi^+\pi^-\psi(2S)$ channel is **suppressed by** at least **20 times with respect to** that of the **$Z_c(3900)^{\pm}$** hadron in $e^+e^- \to \pi^+\pi^- J/\psi$

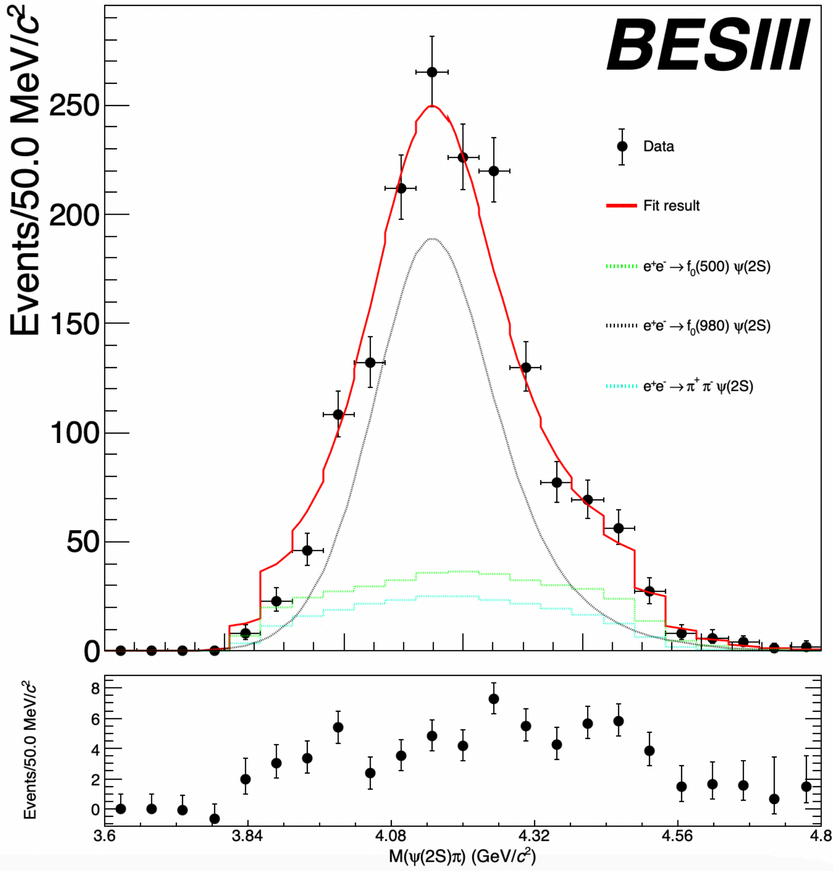
Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Drawing from the $f_0(980)$ study, the the **M(ππ)** and **M(πψ(2S))** invariant distributions are **fitted without $Z_c(4430)$** contribution

The two f_0 states are described by analytical shapes, with the $f_0(980)$ being a weighted sum of 12 Flattés

All the other shapes are taken from MC simulation



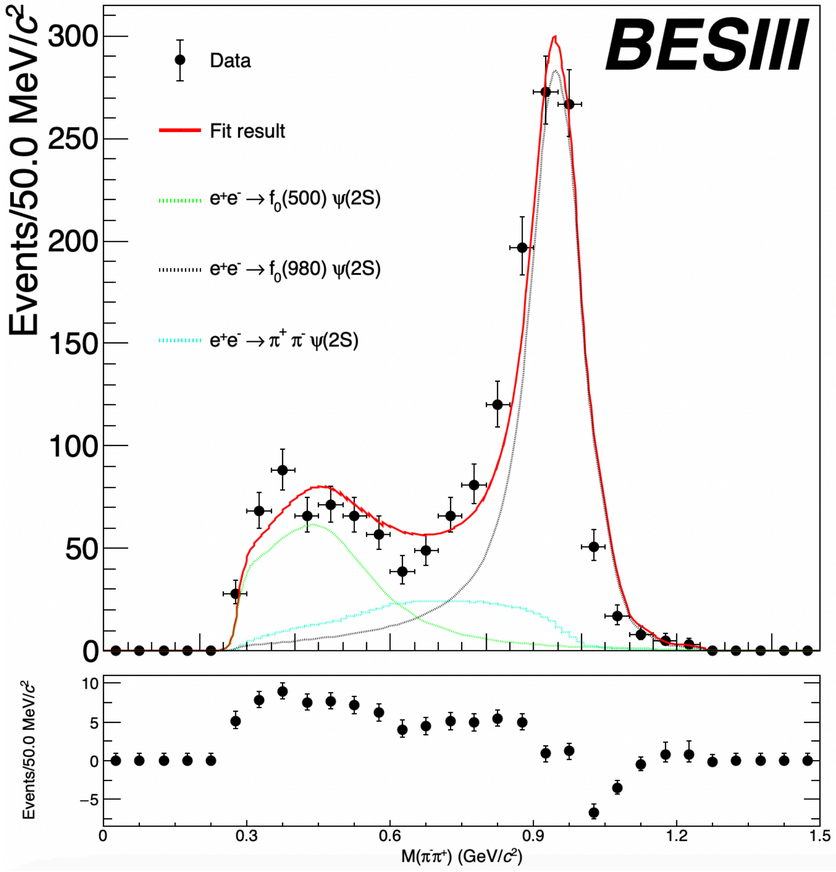


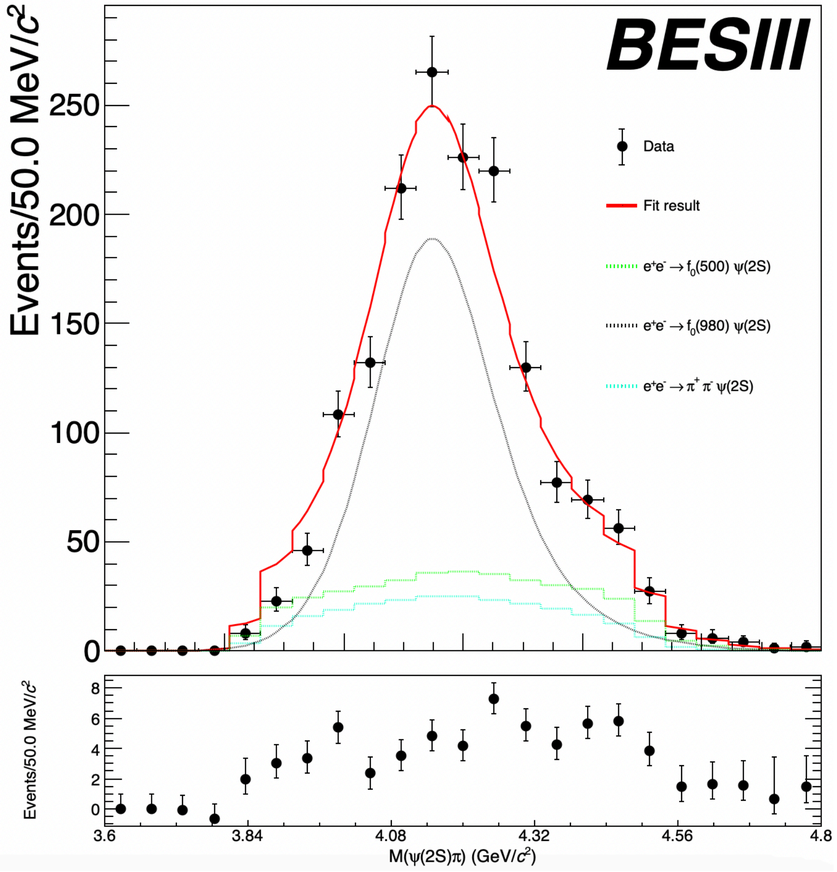
Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Drawing from the $f_0(980)$ study, the the **M(ππ)** and **M(πψ(2S))** invariant distributions are **fitted without $Z_c(4430)$** contribution

Adding $Z_c(4430)$ contribution does not improve the fit significantly

	Value
N(f_0(980))	988 ± 29
N(f_0(500))	384 ± 29
N(PHSP)	248 ± 41





NB
Constrained to total number of events

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 @$\sqrt{s} < 4.7$ GeV is performed via the **$e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$** reaction, but **no evident $Z_c(4430)$** is found

The **$e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$** reaction is studied @$\sqrt{s} > 4.7$ GeV and two different generators (ISR and VP corrections) are tested and found to be comparable

The **$Z_c(4430)$** 2D-fit with all the datasets does not show any exotic contribution

MEMO is almost ready, with the caveat of the $Z_c(4430)$ fit to be finalised (i.e., Upper Limit)

Thanks for your attention!

Back-up Slides

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.x

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

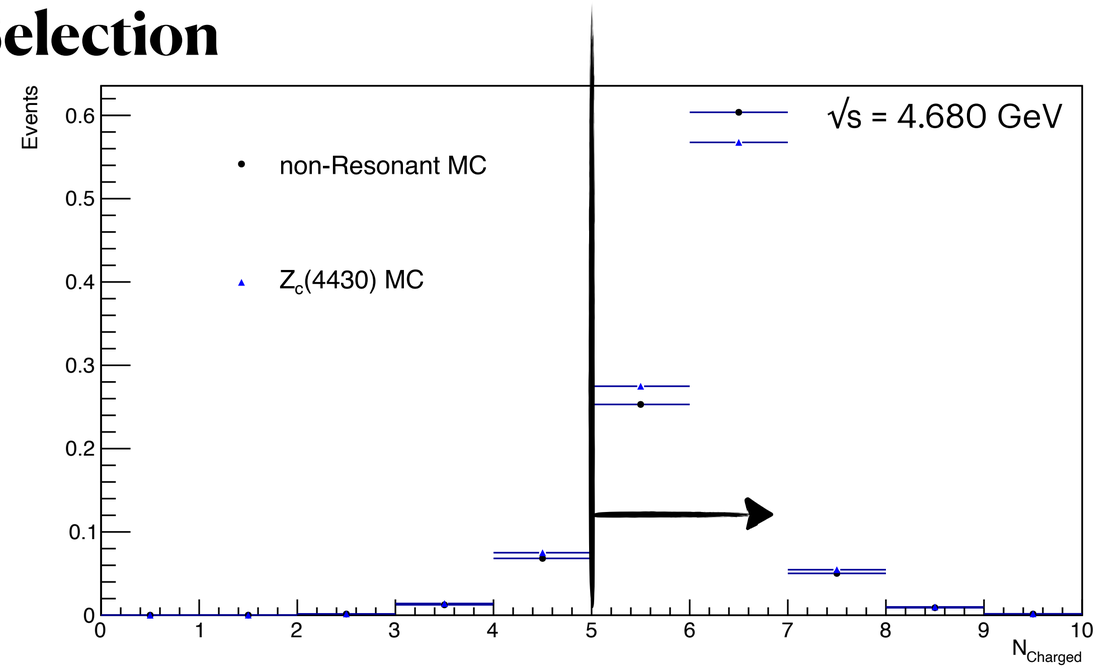
Goodness Cuts

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

Polar angle: |cos θ| < 0.93

Channel ID

charged tracks > 4



Signal MC Studies

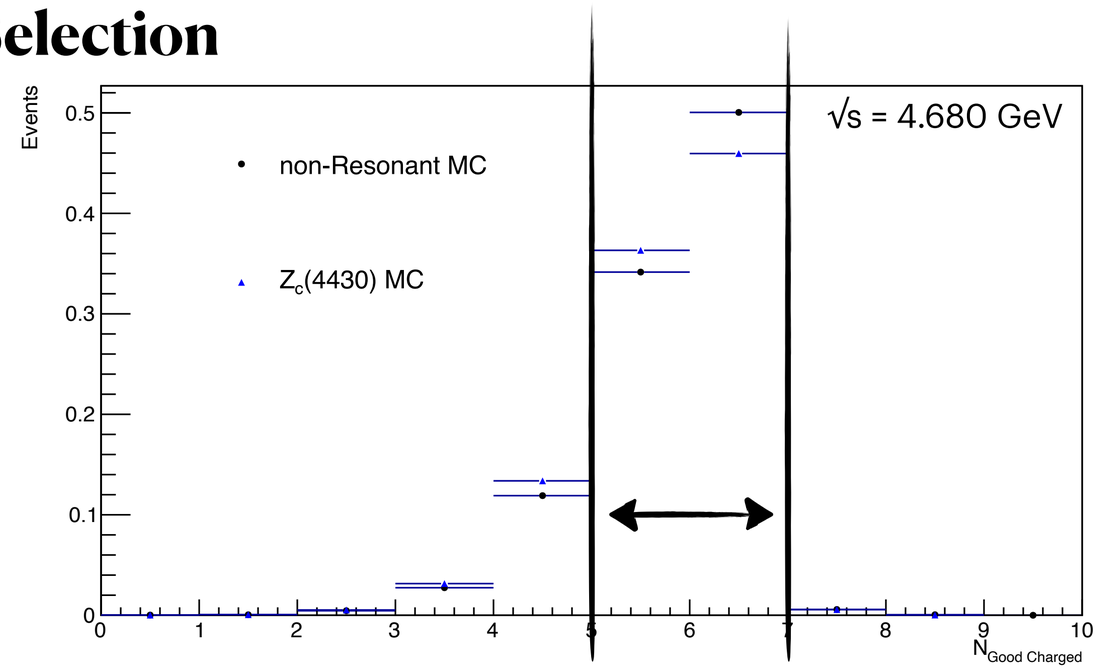
Signal MC sample
300k events

Event Selection

Goodness Cuts

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

Polar angle: |cos θ| < 0.93



Channel ID

charged tracks > 4

2 good charged topologies

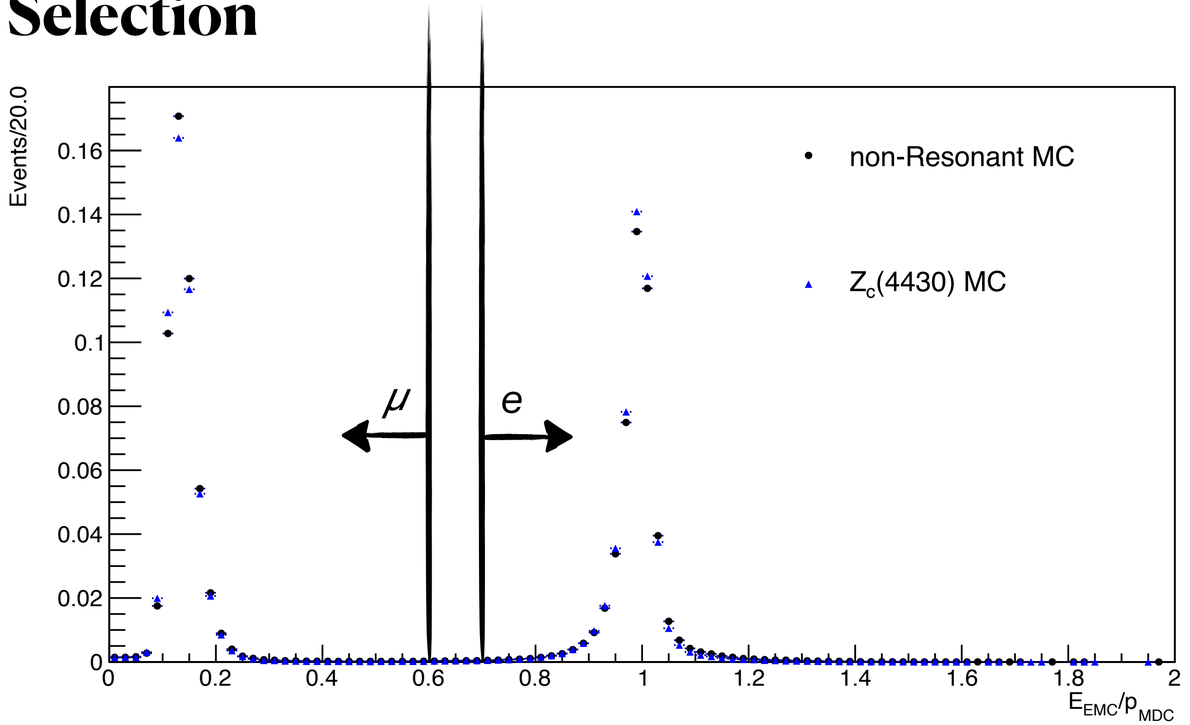
$2\ell\,3\pi$

$2\ell\,4\pi$

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 E/p (e) > 0.7 E/p (μ) < 0.6	p_T < 0.85 GeV

2 good charged topologies

$2\ell\,3\pi$

$2\ell\,4\pi$

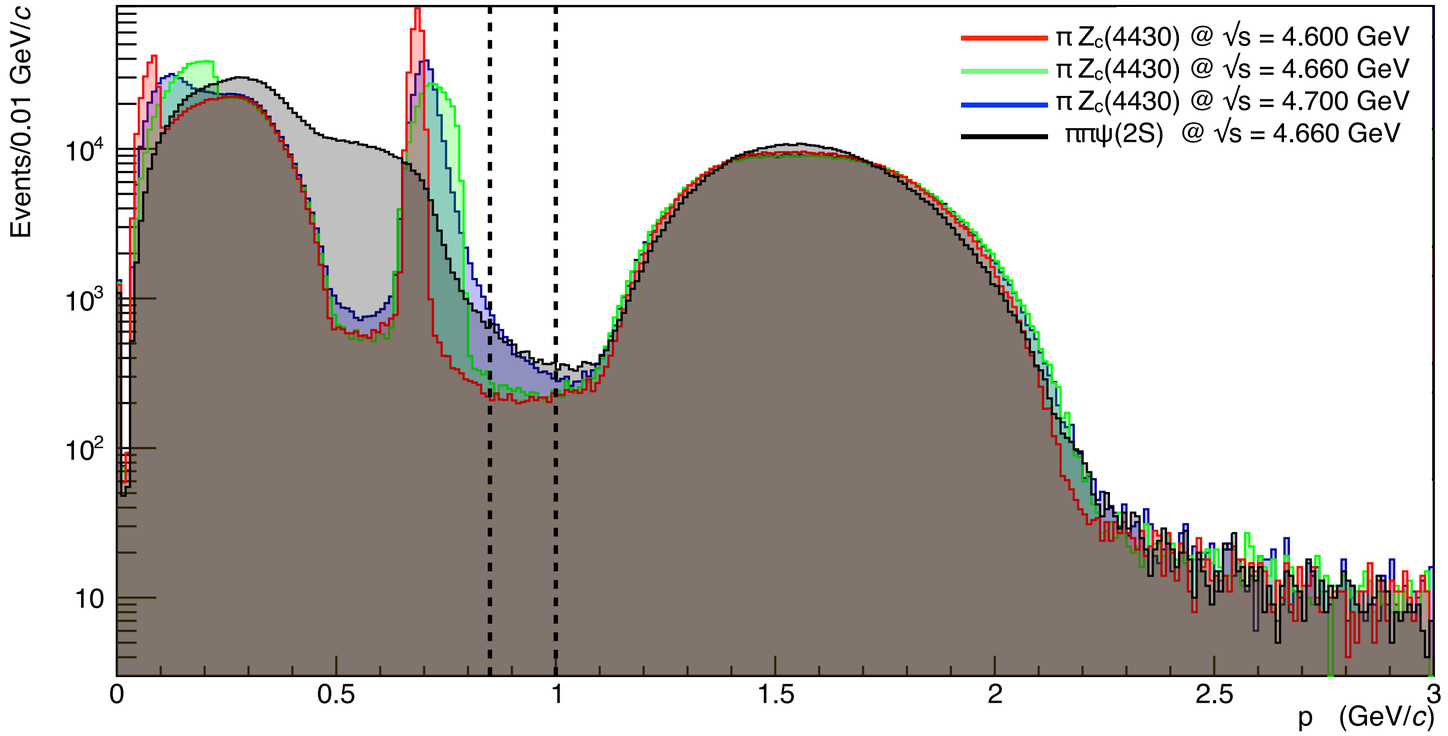
Signal MC Studies

Charged Particles Momentum Comparison

Signal MC sample
300k events

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

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

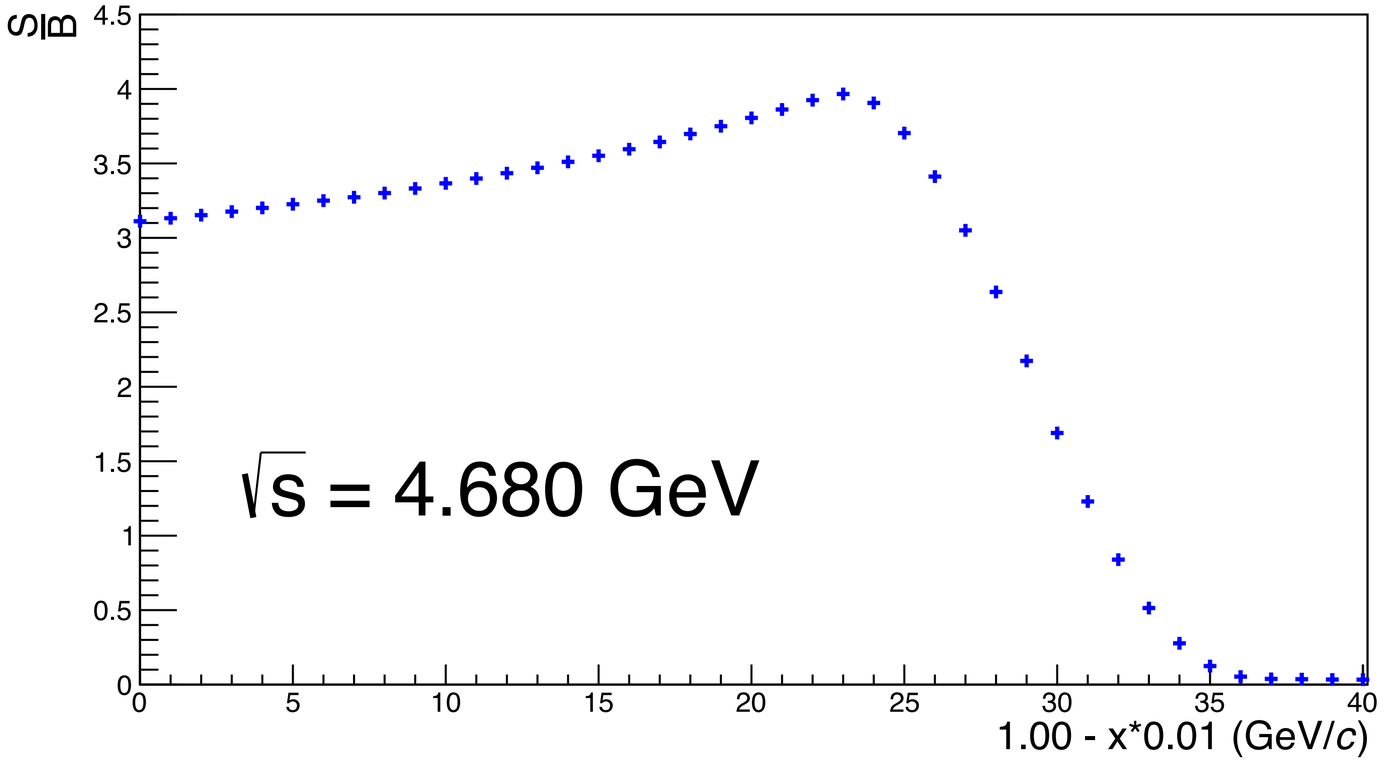


Event Selection

Charged Particles Momentum Optimisation

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

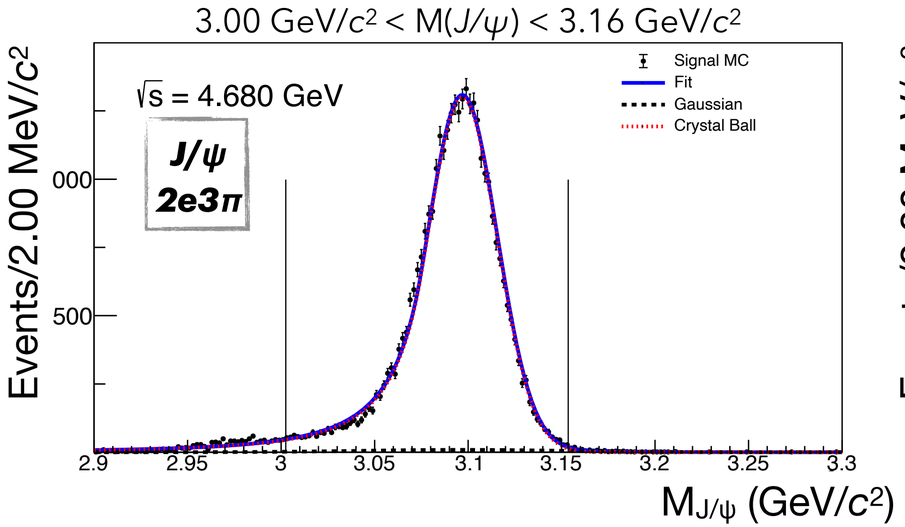
√s	p_{ch} [GeV/*c*]	√s	p_{ch} [GeV/*c*]
4.612	0.71	4.740	0.71
4.626	0.73	4.750	0.82
4.640	0.74	4.780	0.85
4.660	0.75	4.840	0.86
4.680	0.77	4.914	0.96
4.700	0.79	4.946	0.97

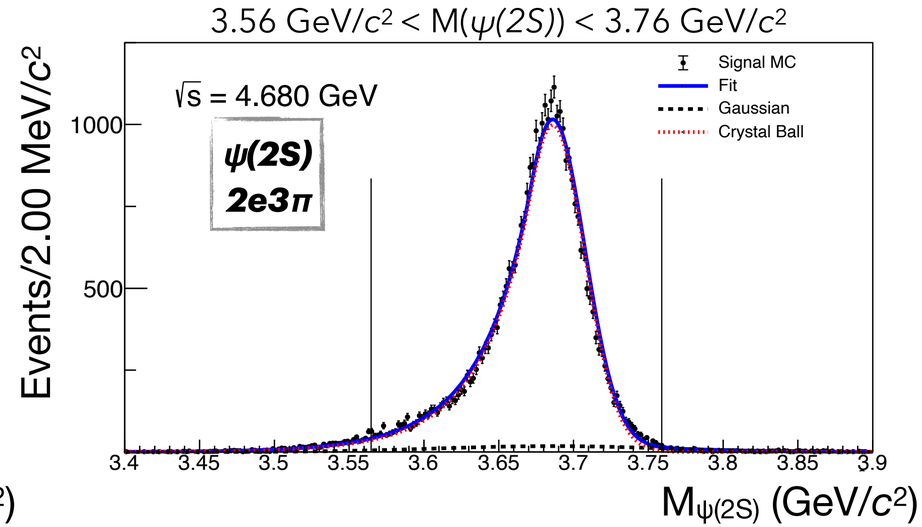


Event Selection

Signal Windows Definition

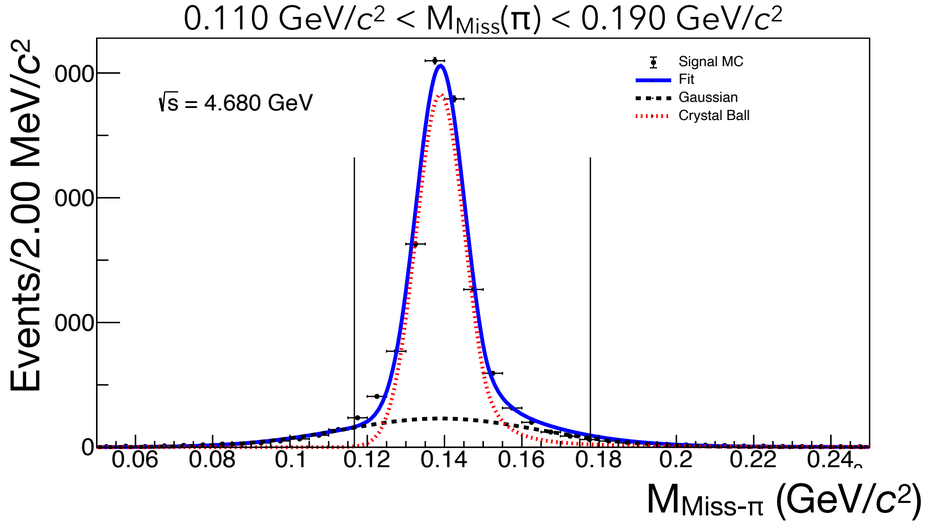
Signal MC sample
300k Events





Selection performed on both the topologies on M(J/ψ) and M(ψ(2S))

An additional selection is applied on $M_{Miss}(\pi)$ for the $2\ell 3\pi$ topology

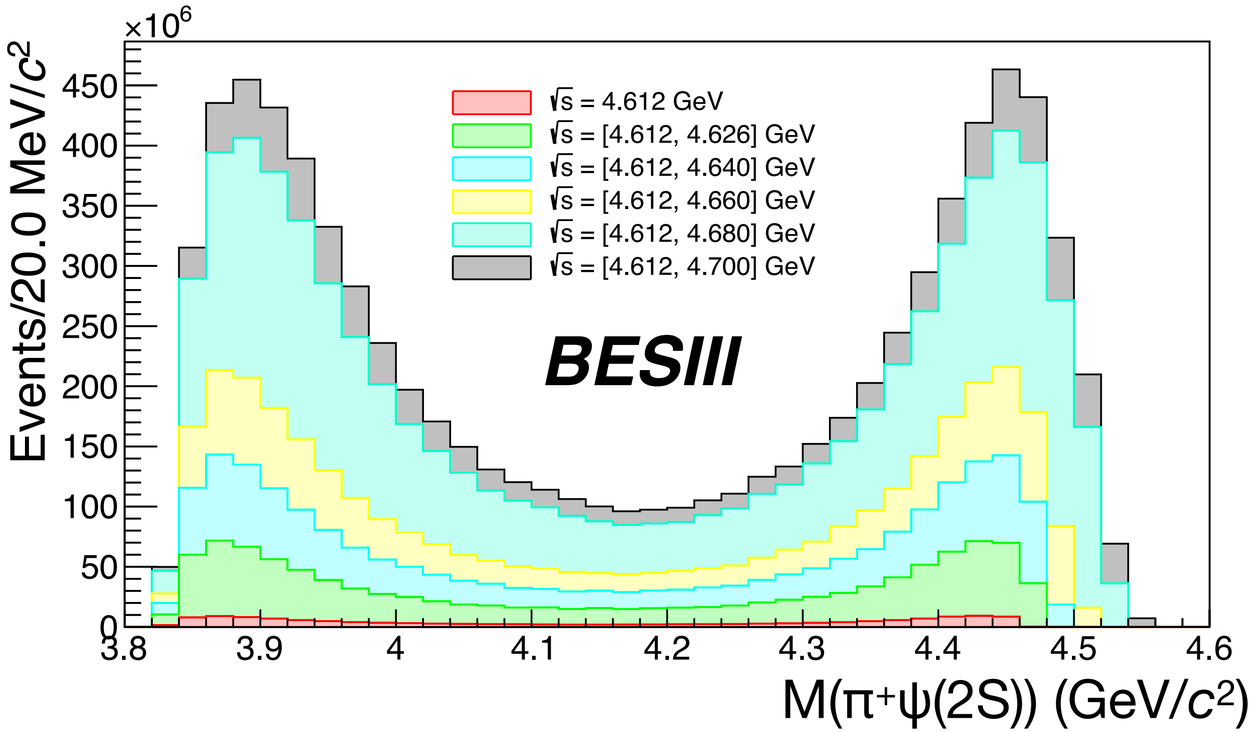


Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Signal MC Shape Extraction

Z_c Signal MC sample 300k events

√s [GeV]	$w_{\text{Normalised}} = (\sigma \times \mathcal{L})/(\sigma \times \mathcal{L})\vert_{4.680}$	Resolution [MeV/c^2]
4.612	0.04	— —
4.626	0.28	2.33
4.640	0.32	0.77
4.660	0.35	0.69
4.680	1.00	0.67
4.700	0.27	0.74

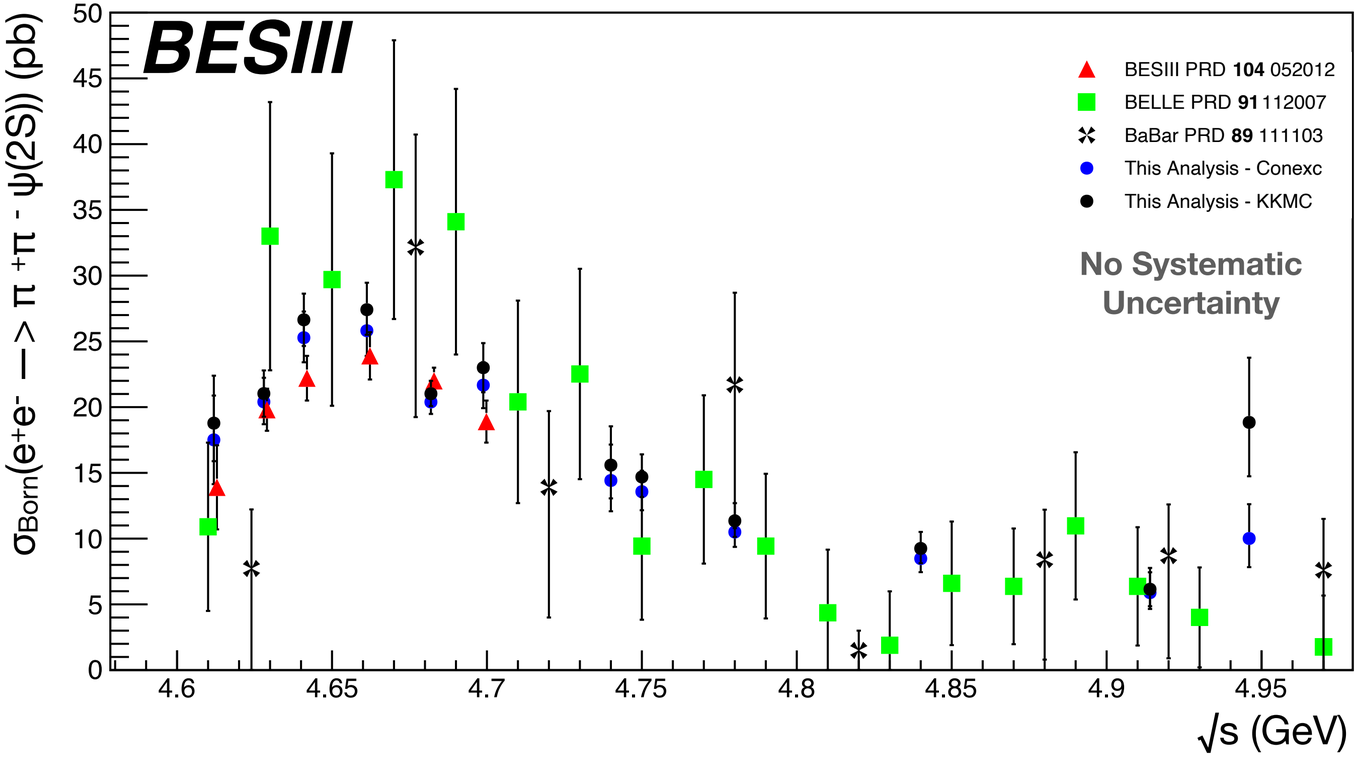


Signal function

MC Signal Shape

Extraction of the $\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$

$\pi\pi\psi(2S)$ cross-section



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

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

Results from BELLE and BaBar are reported too, further **confirming the compatibility** of this thesis' results with the published literature

[11] Phys. Rev. D **104**, 052012

$\sigma(e^+e^- \longrightarrow \pi^+\pi^-\psi(2S))$ vs $\sigma(f_0(980)\psi(2S))$

Number of Events

E_{CoM} (MeV)	$N_{e^+e^-\to\pi^+\pi^-\psi(2S)}$	$N_{e^+e^-\to f_0(980)\psi(2S)}$
4.612	26 ± 5	16 ± 4
4.626	156^{+14}_{-13}	107 ± 10
4.640	203^{+16}_{-15}	155 ± 11
4.660	202 ± 15	120 ± 10
4.680	518^{+24}_{-23}	337 ± 15
4.700	173 ± 14	120 ± 9
4.740	37^{+7}_{-6}	34 ± 4
4.750	77^{+9}_{-8}	63 ± 5
4.780	84^{+10}_{-9}	43 ± 7
4.840	66^{+9}_{-8}	43 ± 8
4.914	19^{+5}_{-4}	0 ± 2
4.946	23^{+6}_{-5}	0 ± 6

Systematic Uncertainties on the Cross-sections

$\pi\pi\psi(2S)$ cross-section

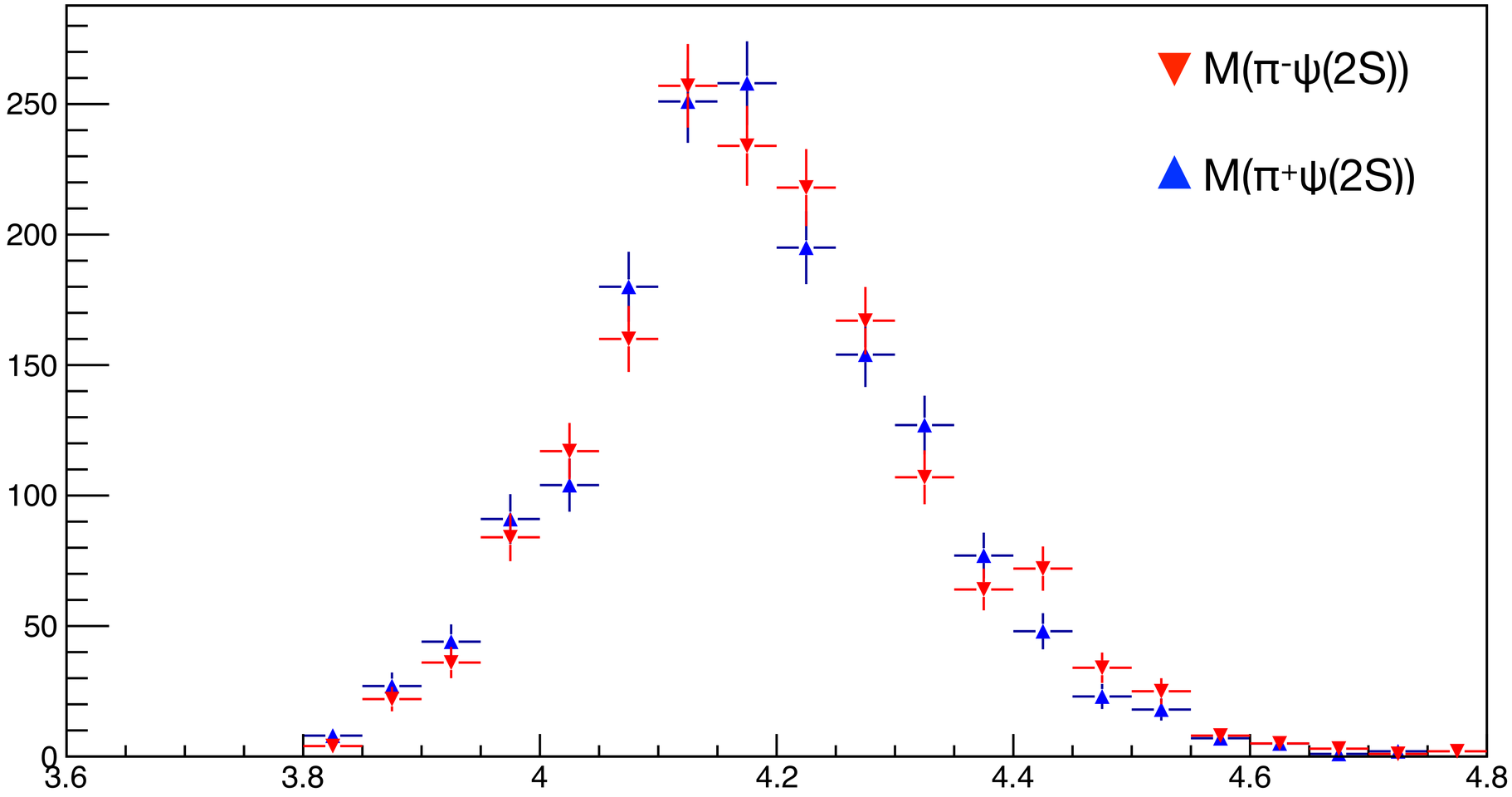
$\sqrt{s}$ [GeV]	Lumi.	Vacuum Polarization	ISR Corrections	Tracking Efficiency	Other Sources	Final States $\mathcal{B}$	Total
4.612	0.18	0.09	0.00	0.61	0.18	0.16	0.68
4.626	0.20	0.10	0.00	0.71	0.20	0.18	0.80
4.640	0.25	0.13	0.00	0.88	0.25	0.22	0.99
4.660	0.26	0.13	0.00	0.90	0.26	0.23	1.01
4.680	0.20	0.10	0.02	0.71	0.20	0.19	0.80
4.700	0.22	0.11	0.07	0.76	0.22	0.20	0.85
4.740	0.14	0.07	0.03	0.50	0.14	0.15	0.57
4.750	0.14	0.07	0.01	0.47	0.14	0.14	0.54
4.780	0.10	0.05	0.01	0.37	0.10	0.12	0.42
4.840	0.08	0.04	0.01	0.30	0.08	0.10	0.34
4.914	0.06	0.03	0.01	0.21	0.06	0.07	0.24
4.946	0.10	0.05	0.00	0.35	0.10	0.10	0.39

Systematic Uncertainties on the Cross-sections

$f_0(980)\,\psi(2S)$ cross-section

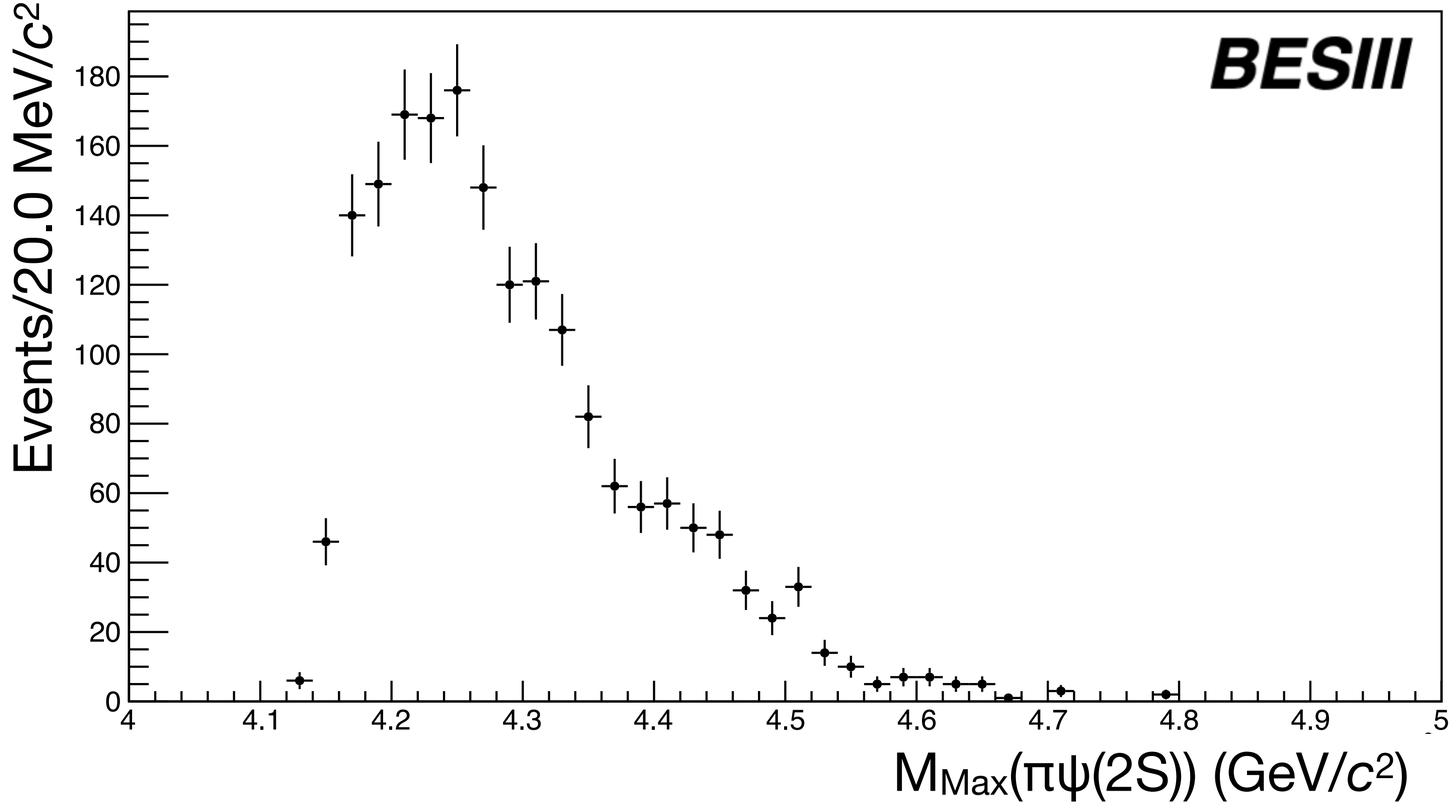
$\sqrt{s}$ [GeV]	Lumi.	Vacuum Polarization	ISR Corrections	Tracking Efficiency	Other Sources	Final States $\mathcal{B}$	Total
4.612	0.02	0.01	0.00	0.08	0.02	0.02	0.09
4.626	0.15	0.08	0.00	0.53	0.15	0.10	0.58
4.640	0.19	0.10	0.00	0.68	0.19	0.14	0.75
4.660	0.15	0.07	0.01	0.52	0.15	0.12	0.58
4.680	0.14	0.07	0.01	0.47	0.14	0.11	0.53
4.700	0.15	0.08	0.00	0.53	0.15	0.12	0.59
4.740	0.14	0.07	0.00	0.49	0.14	0.12	0.54
4.750	0.11	0.06	0.02	0.39	0.11	0.10	0.43
4.780	0.05	0.03	0.00	0.18	0.05	0.06	0.21
4.840	0.06	0.03	0.00	0.19	0.06	0.05	0.22

M(π±ψ(2S)) Comparison



Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Instead of looking at the whole $\pi\psi(2S)$ mass spectrum, could be worthwhile to check the $M_{Max}(\pi\psi(2S))$ as it was done for the $Z_c(3900)$



Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Drawing from the **$f_0(980)$** study, the the M(ππ) and M(πψ(2S)) invariant distributions are fitted

Fit is again inconclusive… parameters have ~100% uncertainties