Updates on...

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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BESIII

Weekly Charmonium Meeting
14th June 2023

Preamble

Previous Slides: HERE
PhD Thesis: HERE

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]

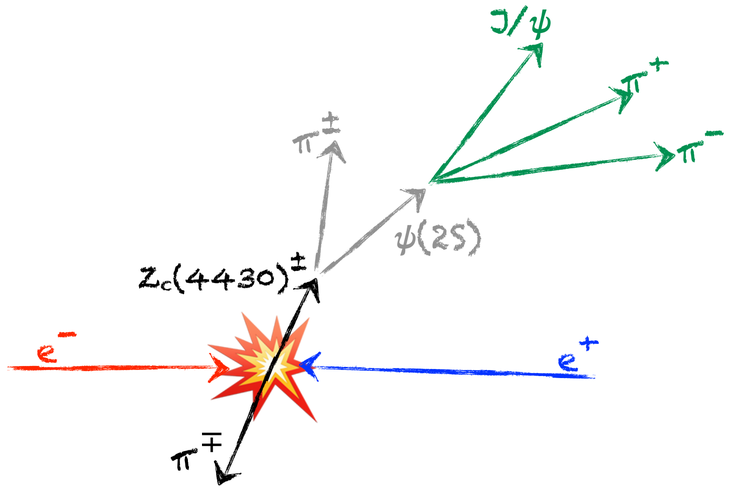
Study of the exotic $Z_c(4430)$ state through the $e^+e^- \to \pi^\pm Z_c(4430) \to \pi^+\pi^-\psi(2S)$

$Z^+_c(4430)$ 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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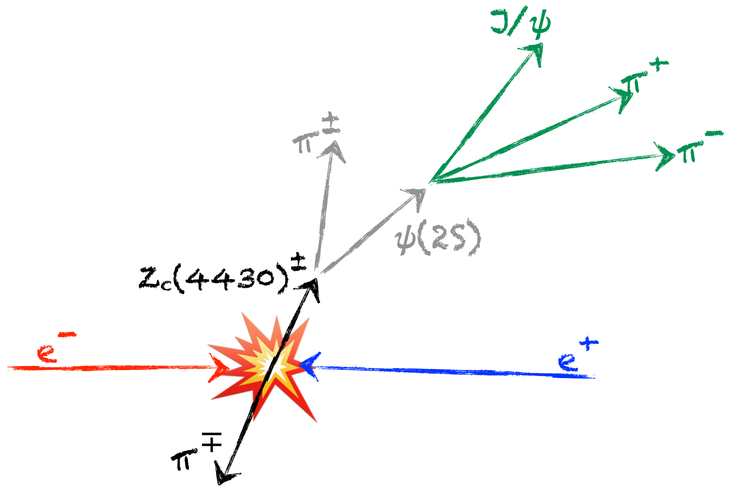
How

The study will make use of the 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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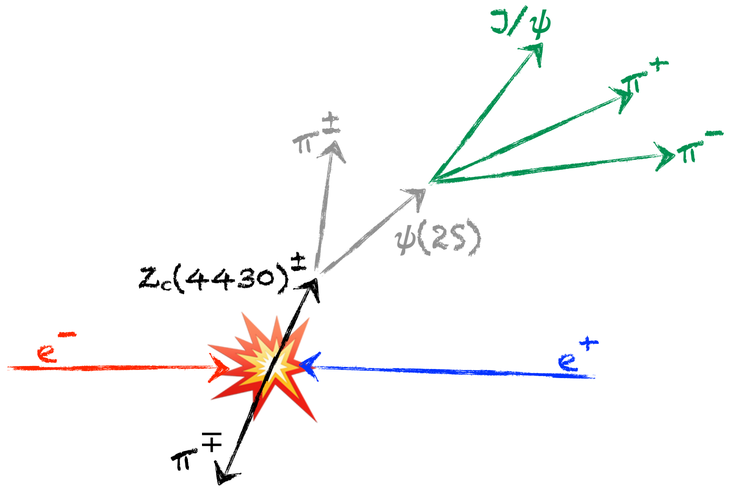
What's New?

(i) Systematic uncertainties were added

(ii) Now expanded @$\sqrt{s}$ > 4.7 GeV

(iii) Analytical shape for the $f_0(500)$ and an interference term were tested

(iv) KKMC is being implemented to study ISR and VP correction factors



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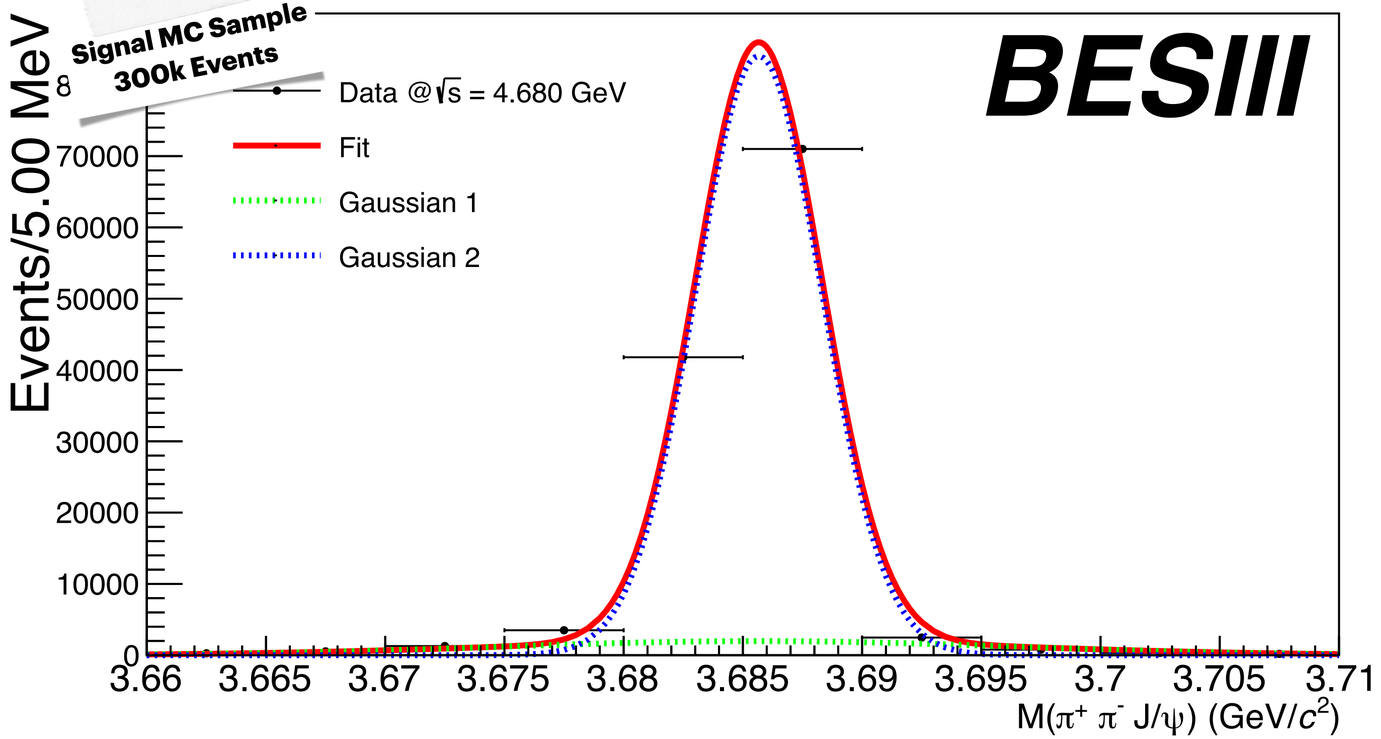
Extraction of the $\sigma(e^+e^- \longrightarrow \pi^+\pi^-\psi(2S))$

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

OLD

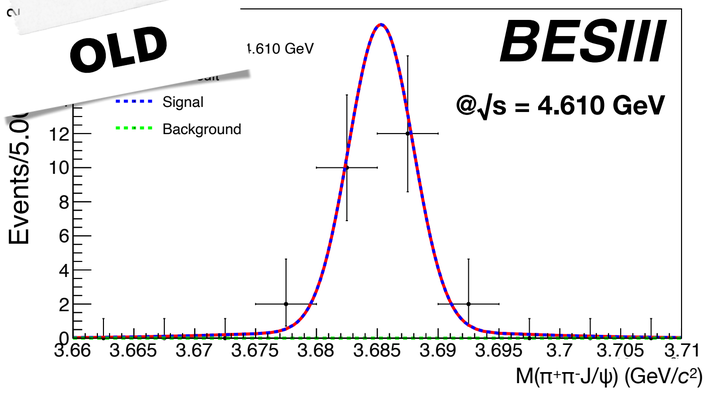
Signal Shape & Efficiency

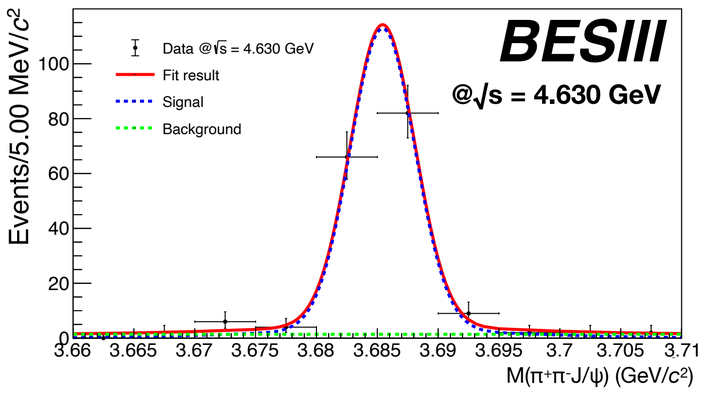


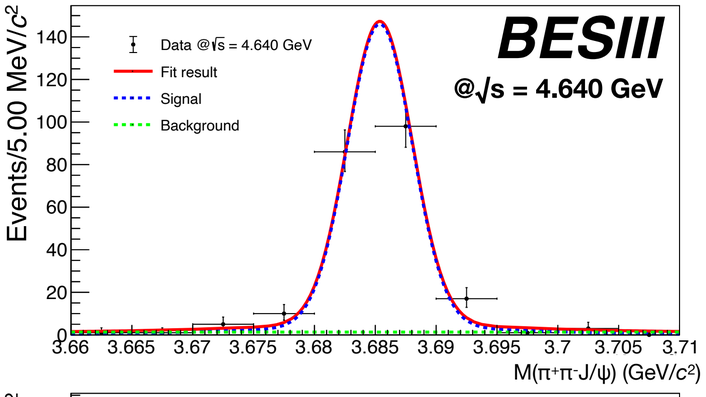
For **each √s**, the **signal** is modelled via a signal MC sample with a **sum of Gaussian and Crystal Ball** functions

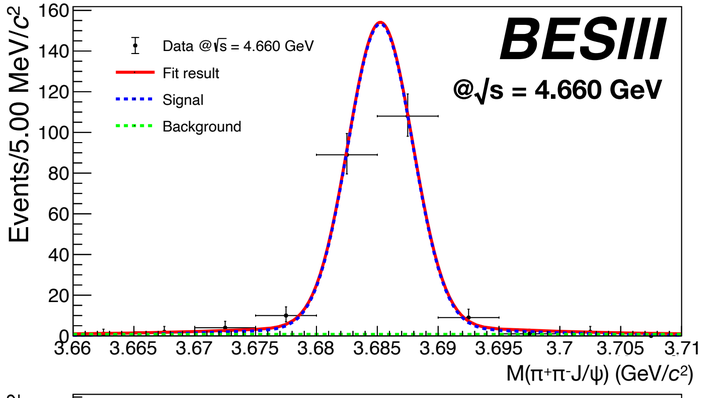
√s [GeV]	Efficiency [%]
4.612	38.90
4.626	40.45
4.640	41.59
4.660	41.54
4.680	40.72
4.700	39.16

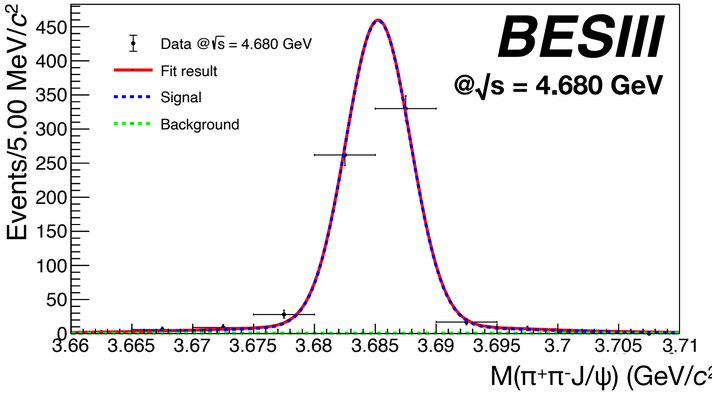
Extraction of the $\sigma(e^+e^- \longrightarrow \pi^+\pi^-\psi(2S))$

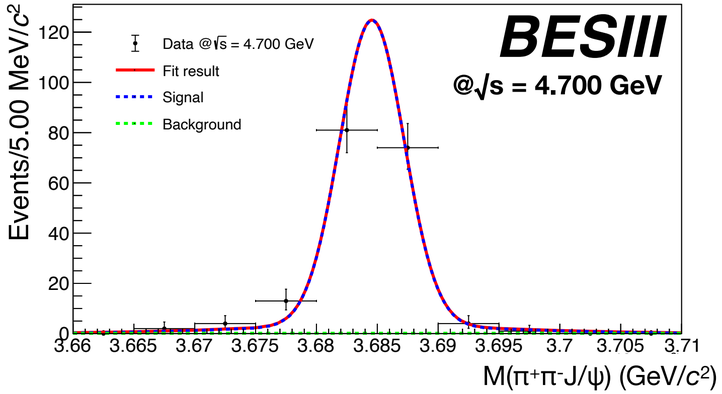












Data Fits

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

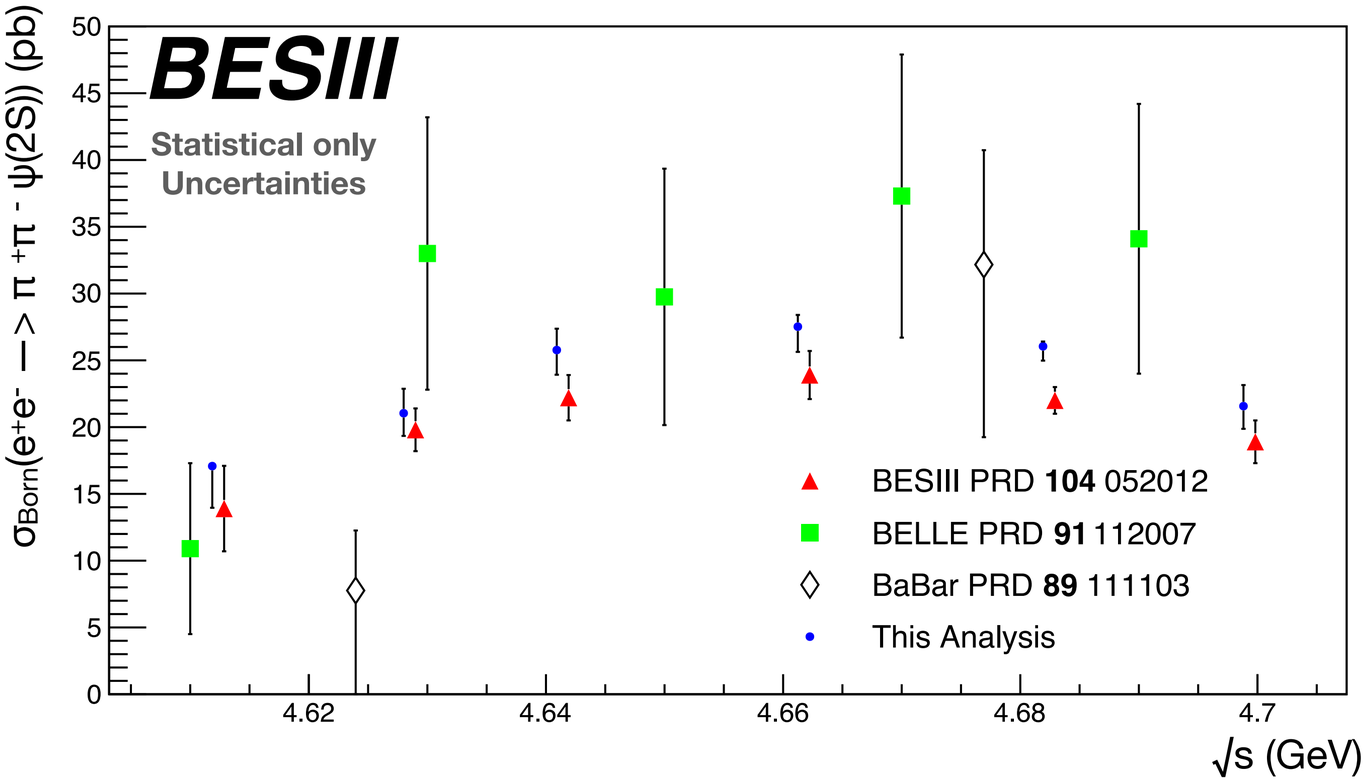
The **signal** is modelled with a **sum of Gaussian and Crystal Ball**

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

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

Semi-OLD

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



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

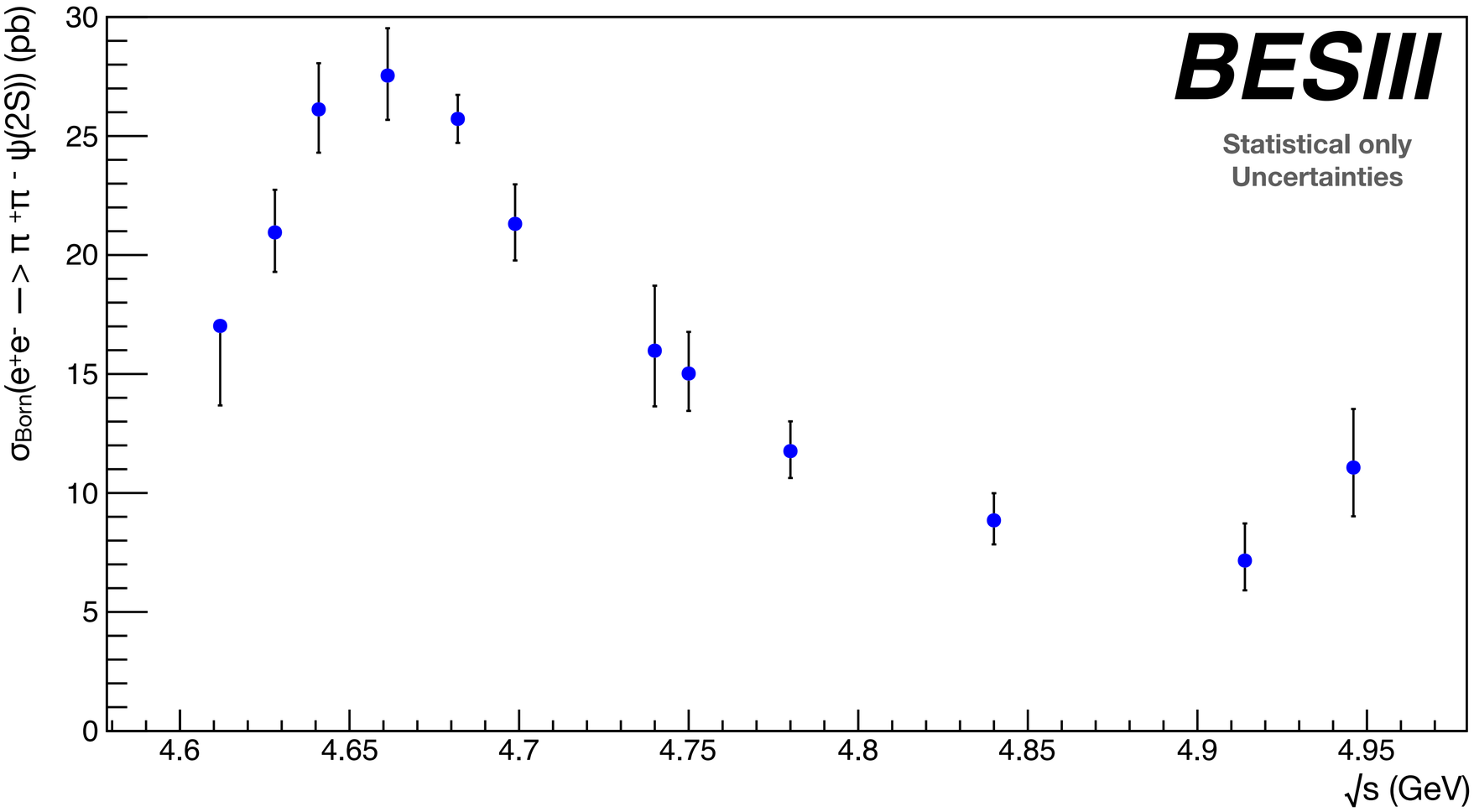
Results from BELLE and BaBar are reported too, further **confirming the compatibility** of this thesis' results with the published literature

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

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

NEW

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



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

NEW

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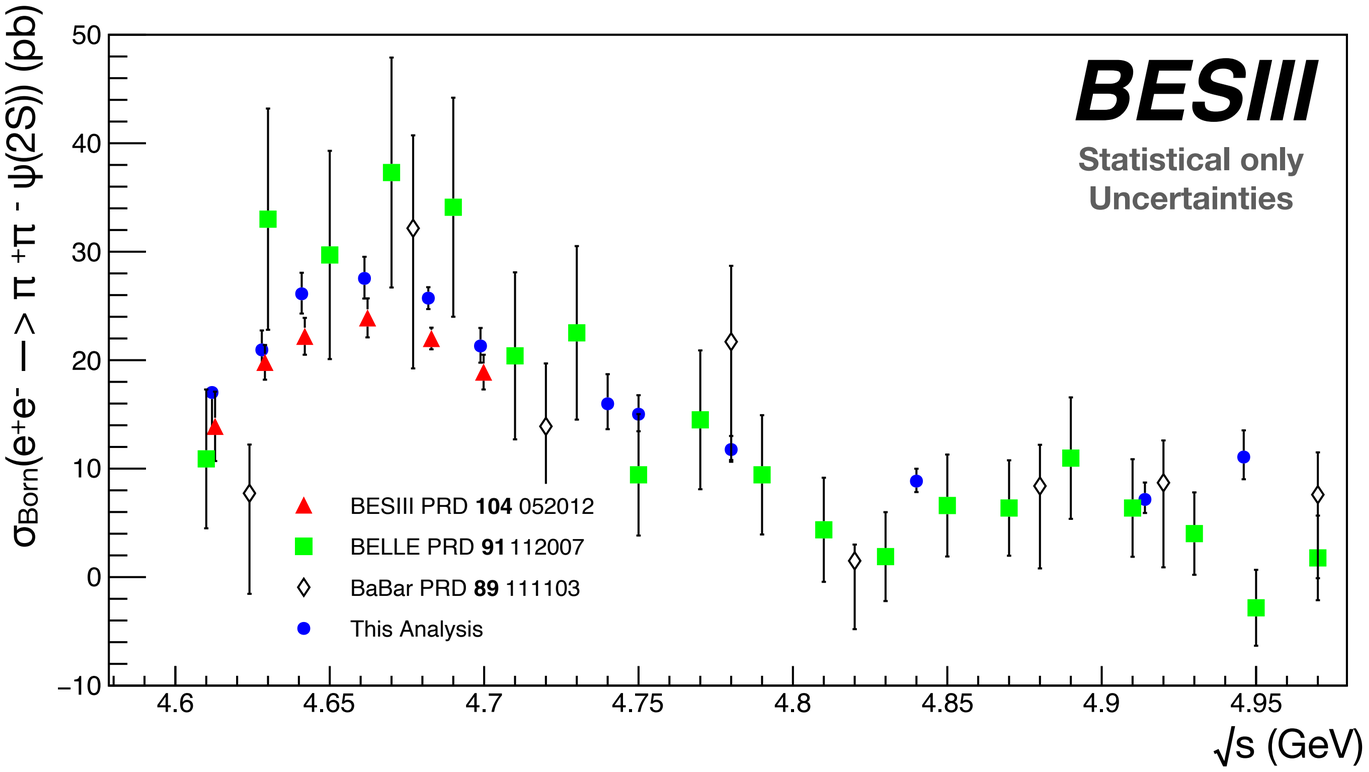

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Study of the Intermediate States

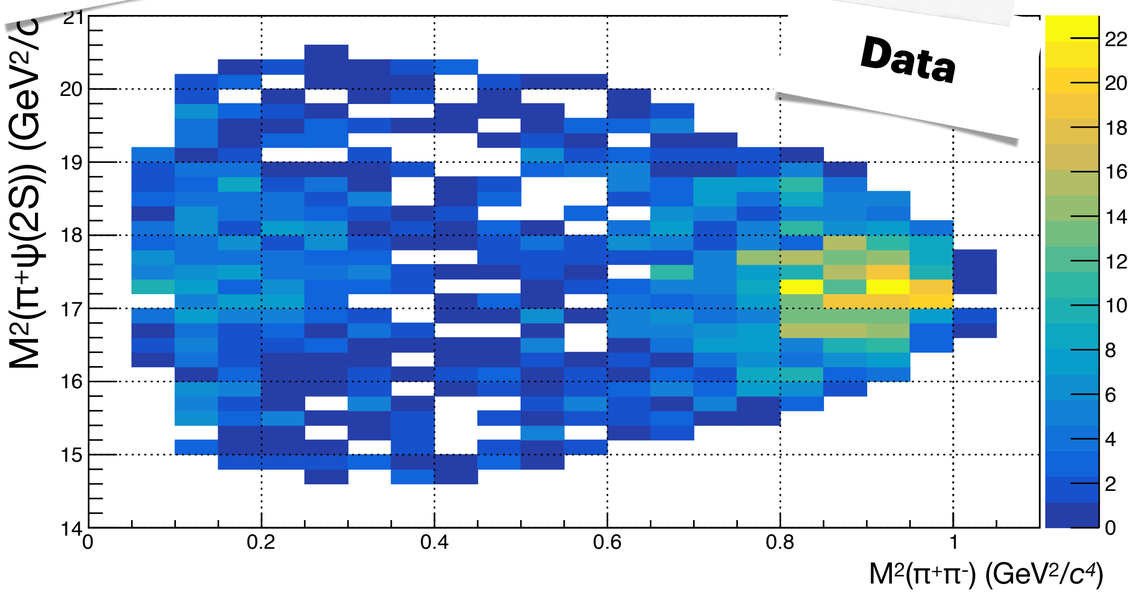
Study of $e^+e^- \to \pi^+\pi^-\psi(2S)$ at $\sqrt{s} > 4.6$ GeV and search for the $Z_c(4430)^\pm$ - Marco Scodeggio

Study of the Intermediate States

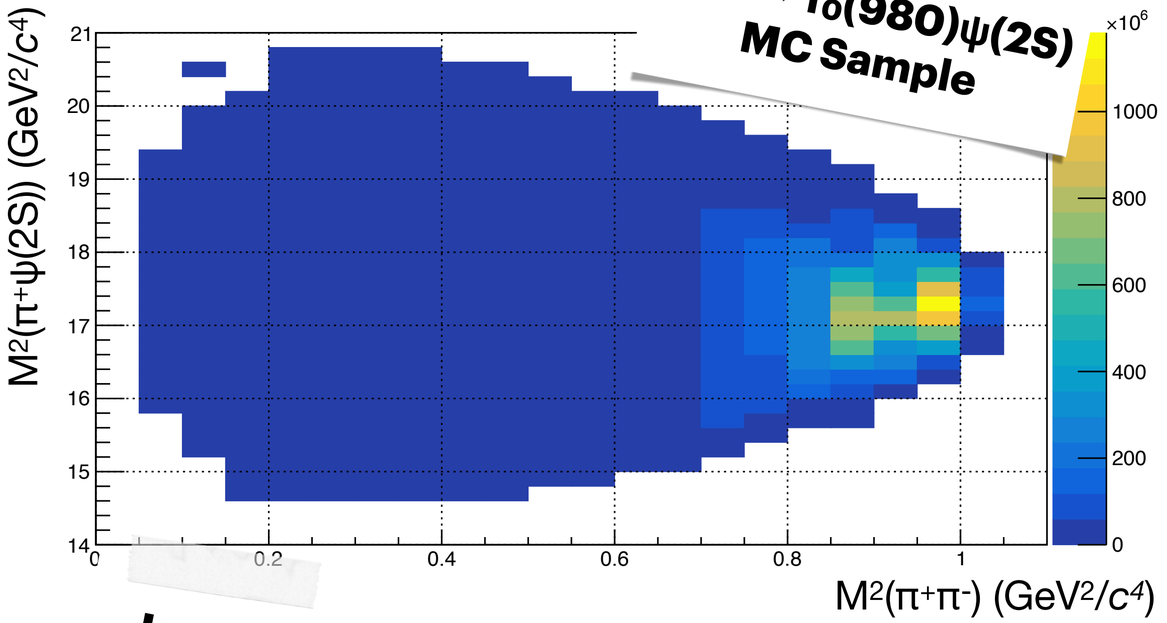
Dalitz Plots

OLD

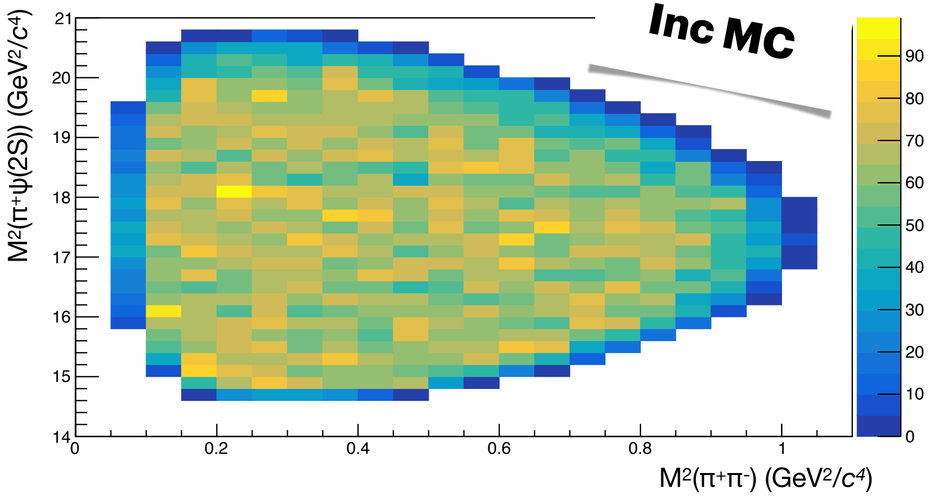
Data



$e^+e^- \to f_0(980)\psi(2S)$ MC Sample



Inc MC



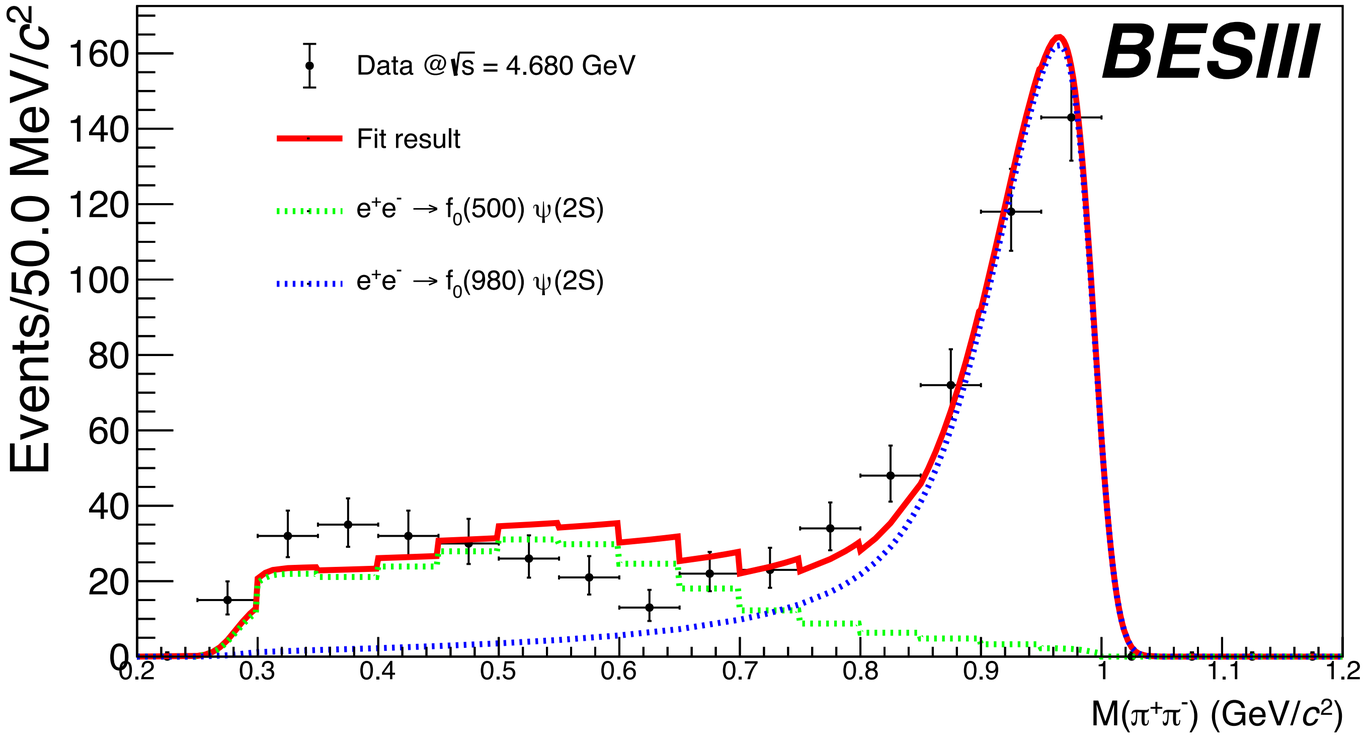
In **Ref.[11]**, a **simplified PWA** performed on the data sets highlighted **$f_0(500)$** and **$f_0(980)$** contributions

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

Extraction of the σ(f_0(980) ψ(2S))

OLD

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** function

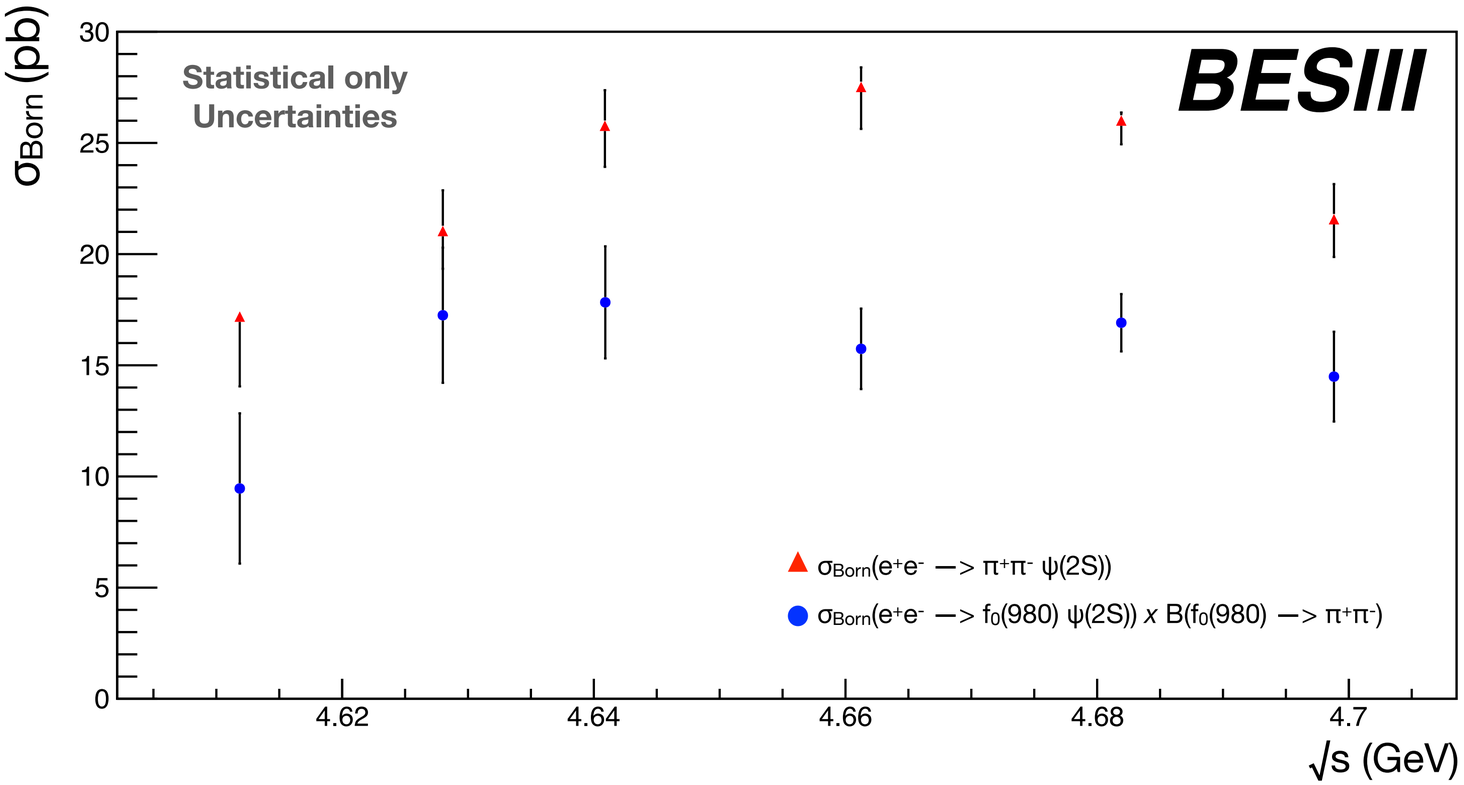
$$BW(s) = \frac{1}{s - M^2 + i\left(g_1\rho_{\pi\pi}(s) + g_2\rho_{KK}(s)\right)}$$

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

Extraction of the σ(f_0(980) ψ(2S))

f_0(980) contribution

OLD



No particular structures
can be recognised

Within the statistical uncertainty,
σ_{Born} ***x*** **B** is **flat** wrt σ_{Born}(ππψ(2S))

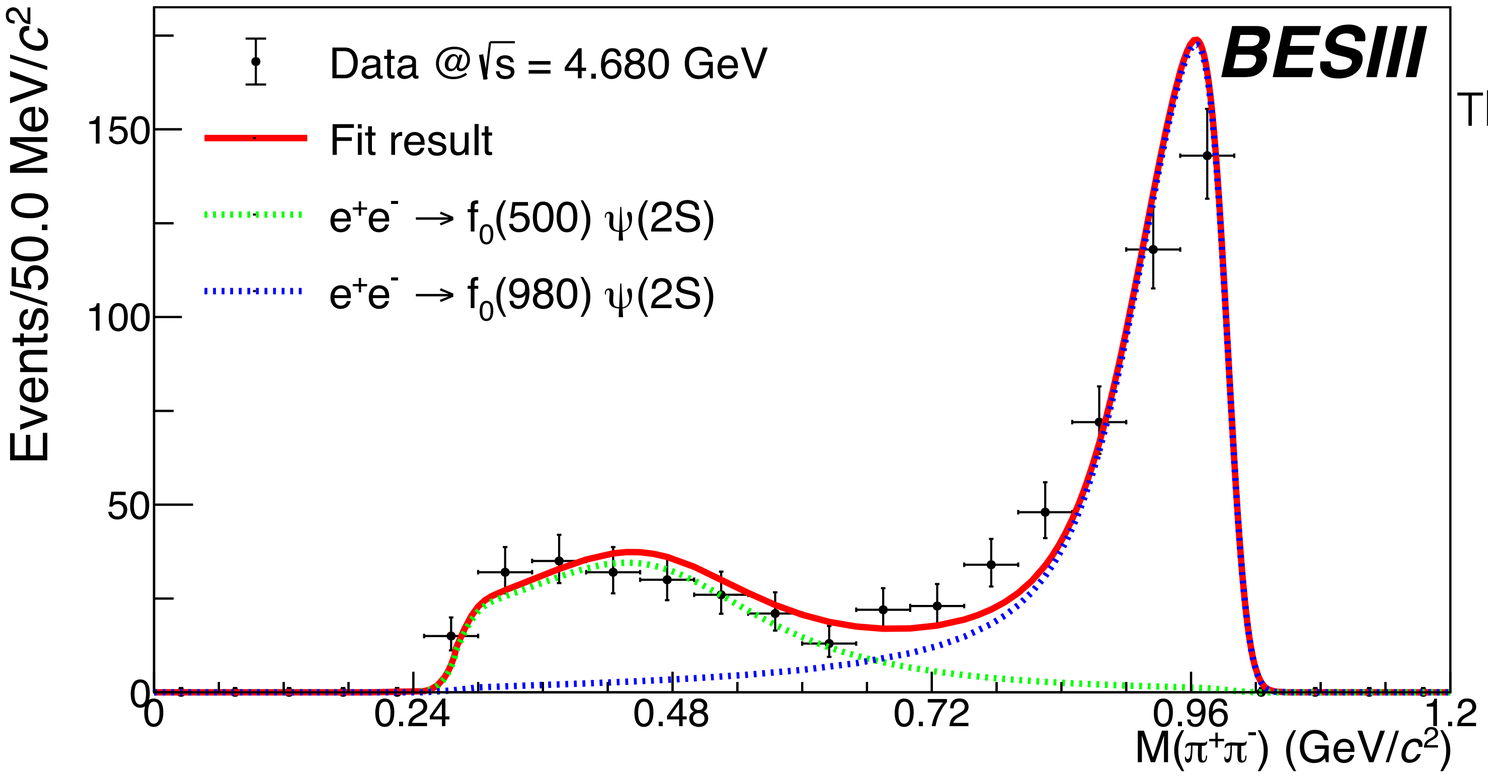
The hypothesis of the **Y(4660)** being
an ***f_0(980) - ψ(2S)*** **molecule**[12]
cannot be confirmed

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

Extraction of the σ($f_0(980)$ ψ(2S))

NEW

$f_0(980)$ contribution



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

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

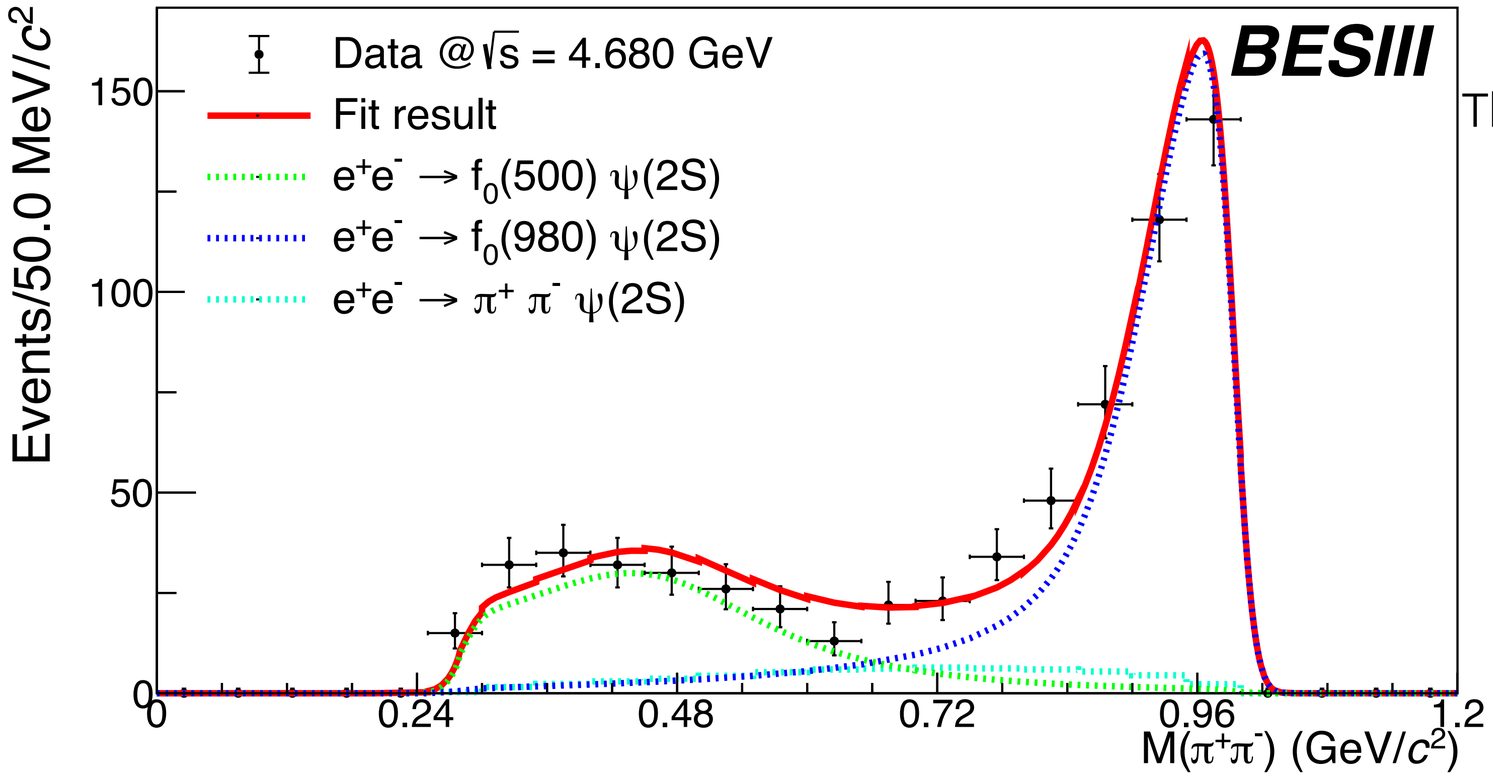
with an energy-dependent width à la E791…

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

Extraction of the σ($f_0(980)$ ψ(2S))

NEW

$f_0(980)$ contribution



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Systematic Uncertainties on the Cross-sections

NEW

- *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

Systematic Uncertainties on the Cross-sections

NEW

The systematic uncertainties come from the integrated **luminosity**, the **vacuum polarisation**, the ISR **radiative corrections**, the **tracking efficiency**, and **residual sources**

Source	4.610 (pb)	4.630 (pb)	4.640 (pb)	4.660 (pb)	4.680 (pb)	4.700 (pb)
Luminosity	0.17	0.21	0.26	0.28	0.26	0.22
Vacuum polarisation	0.09	0.11	0.13	0.14	0.13	0.11
ISR corrections	0.07	0.07	0.00	0.03	0.03	0.02
Tracking efficiency	0.60	0.74	0.90	0.96	0.91	0.75
Intermediate states branching fractions	0.16	0.20	0.25	0.26	0.25	0.21
Other sources	0.17	0.21	0.26	0.28	0.26	0.22
Total systematic uncertainty	0.68	0.83	1.01	1.08	1.02	0.85

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

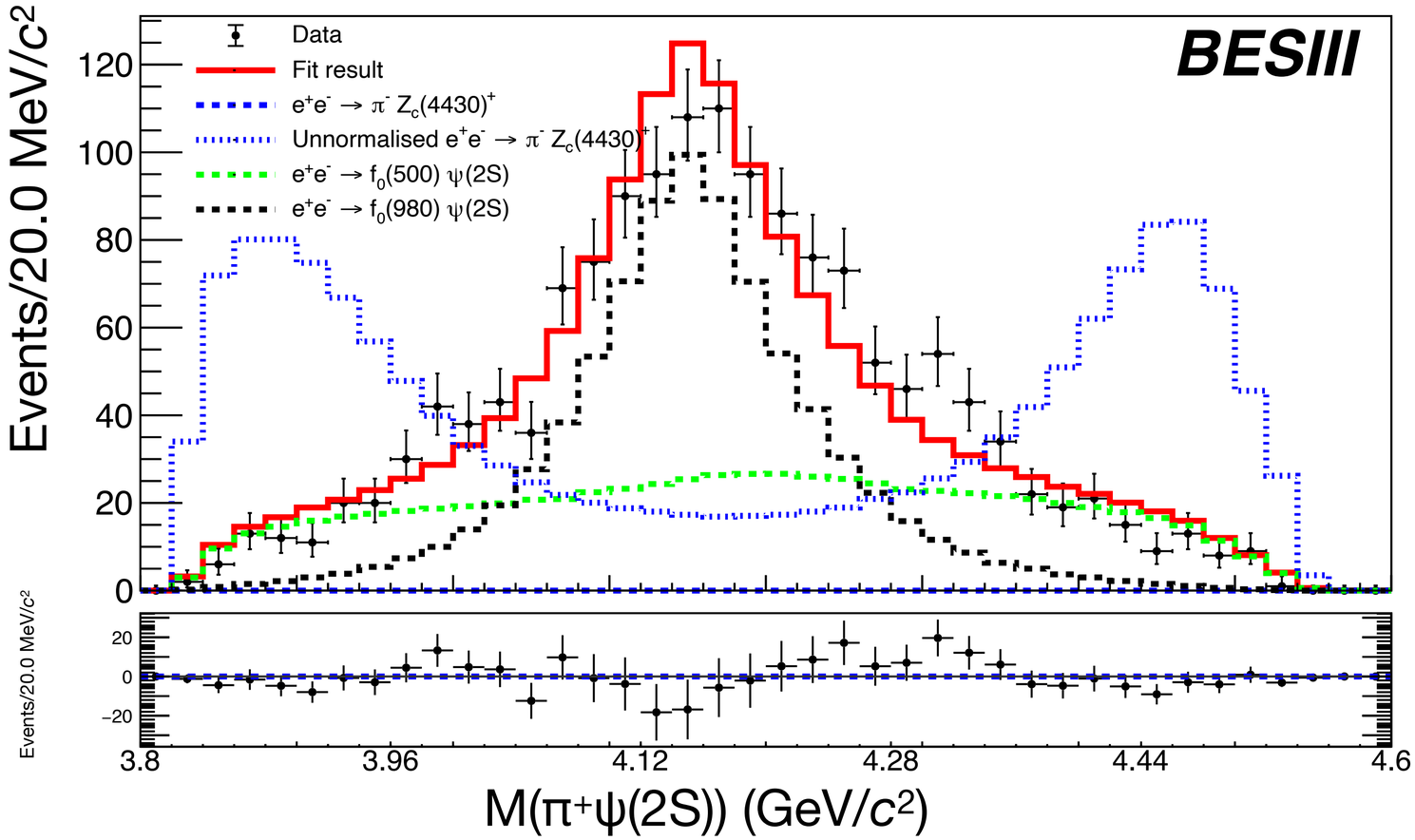
Analysis of the $\pi^{\pm}\psi(2S)$ Invariant Mass and Search for the $Z_c(4430)^{\pm}$

Semi-OLD

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 $Z_c(4430)^{\pm}$

Semi-OLD

Production Ratio Estimation

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

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

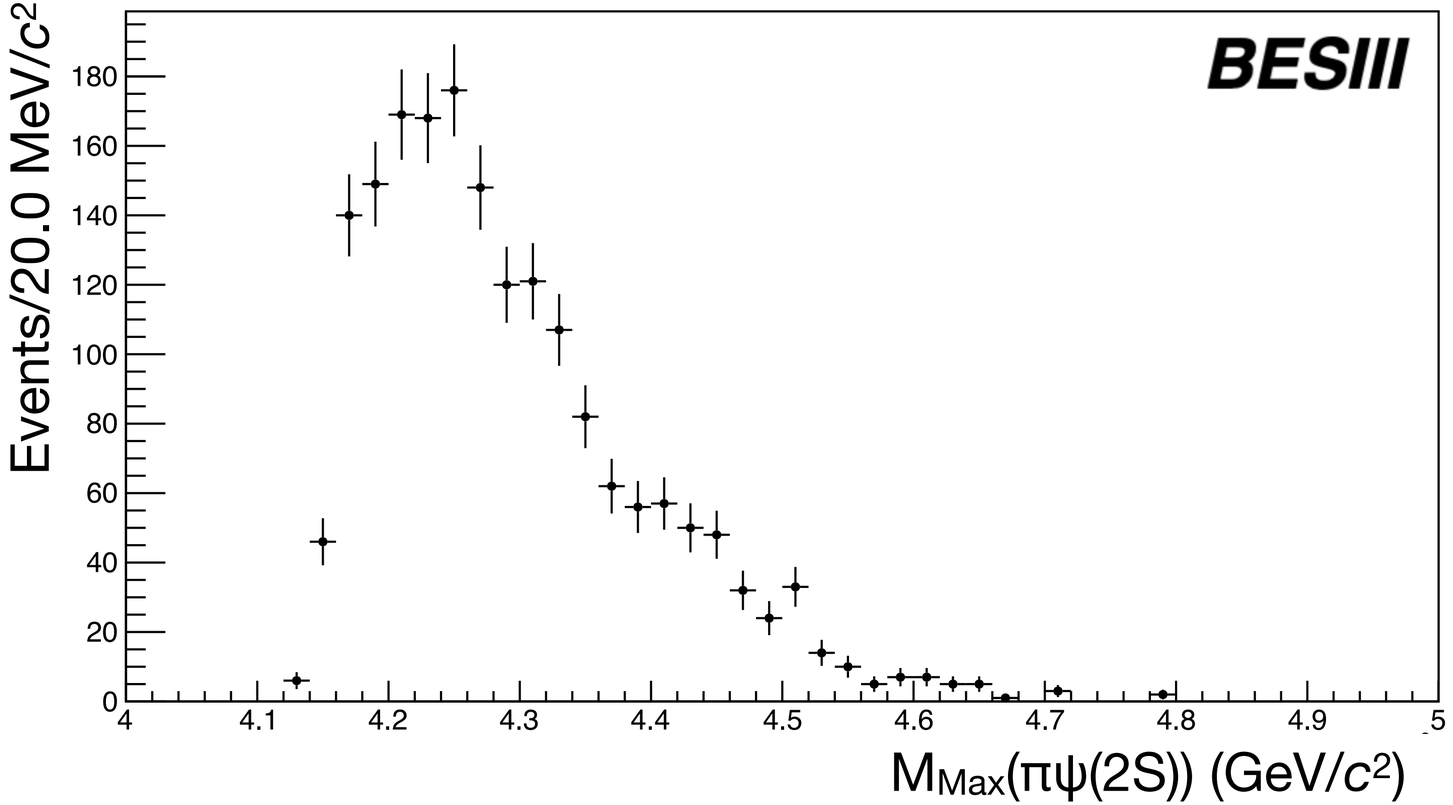
When **compared with the paper**[10] used as motivation for this analysis, the **$Z_c(4430)^{\pm}$** state **production** in the $e^+e^- \to \pi^+\pi^-\psi(2S)$ channel is **suppressed by** at least **20 times with respect to** that of the **$Z_c(3900)^{\pm}$** hadron in $e^+e^- \to \pi^+\pi^- J/\psi$

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

NEW

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

Fit and U.L. are under study



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

The extension of the analysis @$\sqrt{s} > 4.7$ GeV is under completion

1. the **$e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$** reaction is studied up to its systematic uncertainties (with the caveat of KKMC recalculation of ISR and VP corrections)
2. the **$e^+e^- \rightarrow f_0(980)\psi(2S)$** sub-process is under optimization with an analytical function and a potential interference term
3. the **$Z_c(4430)$** is searched in another mass distribution to potentially increase its significance

Thanks for your attention!

Back-up Slides

Final Born Cross-sections Results

Sample	$\sigma_{\mathrm{Born}}(\pi^+\pi^-\psi(2S))$ (pb)	$\sigma_{\mathrm{Born}}(f_0(980)\psi(2S))\times \mathcal{B}(f_0(980)\to\pi^+\pi^-)$ (pb)
4.610	$17.19^{+0.15}_{-3.14}\pm 0.68$	$6.88^{+2.46}_{-2.46}\pm 0.37$
4.630	$21.04^{+1.83}_{-1.70}\pm 0.83$	$12.48^{+2.20}_{-2.20}\pm 0.68$
4.640	$25.77^{+1.60}_{-1.85}\pm 1.01$	$14.24^{+2.01}_{-2.01}\pm 0.70$
4.660	$27.52^{+0.88}_{-1.89}\pm 1.08$	$13.66^{+1.56}_{-1.56}\pm 0.62$
4.680	$26.00^{+0.36}_{-1.07}\pm 1.02$	$14.48^{+1.09}_{-1.09}\pm 0.67$
4.700	$21.57^{+1.58}_{-1.70}\pm 0.85$	$12.18^{+1.69}_{-1.69}\pm 0.57$