J/Ψ->invisible

Suyu XIAO from IHEP
2017/09/20

Motivation

The only allowed invisible decay of quarkonium states in the SM is the decay to ννbar via annihilation into a virtual Z^0 boson.

If the invisible decay rate is observed to have a larger branching fraction than the SM prediction, it implies physics beyond the SM.

The decay $J/\psi \rightarrow \nu\bar{\nu}$ provides an additional window for new-physics searches.

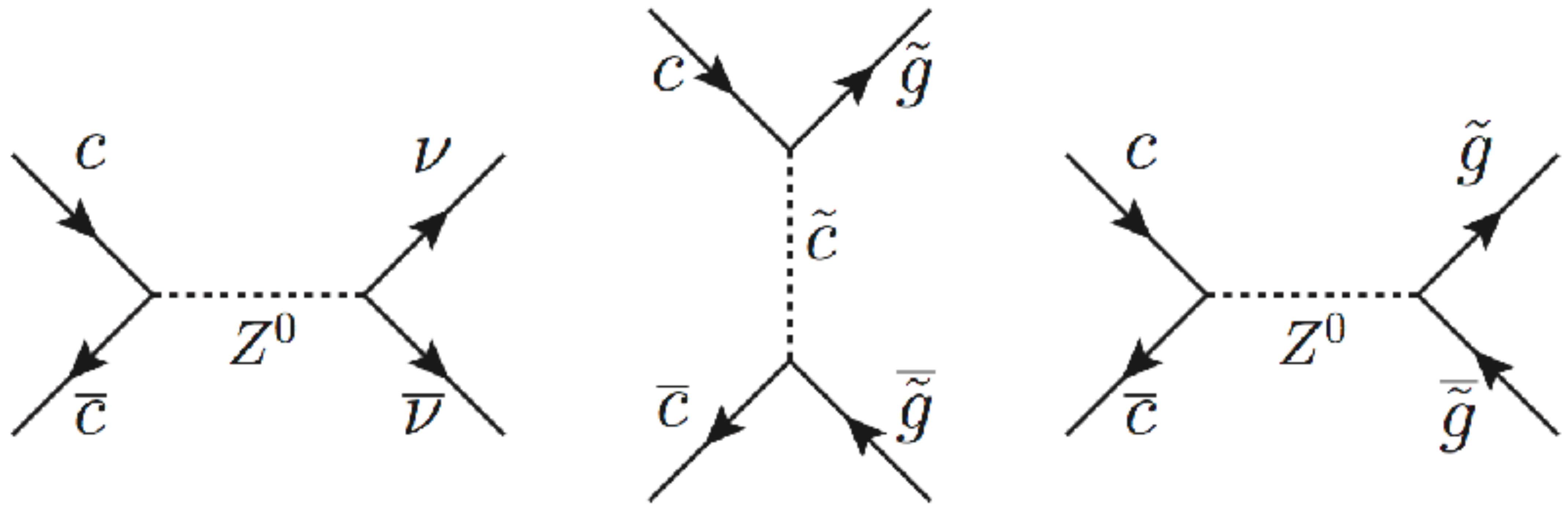


Figure 1: Lowest-order Feynman diagrams of(from left to right) the SM decay $c\bar{c} \rightarrow \nu\bar{\nu}$, the SUSY decay $c\bar{c}$ into a pair of goldstinos ($\tilde{g}$) via a c-squark in the t-channel, and the SUSY decay $c\bar{c} \rightarrow \tilde{g}\bar{\tilde{g}}$ via a virtual Z^0 in the s-channel.

Motivation

Astronomical observations of a bright 511 keV γ-ray line from the galactic bulge have been reported by the SPI spectrometer on the INTEGRAL satellite. The corresponding galactic positron flux, as well as the smooth symmetric morphology of the 511 keV emission, may be interpreted as originating from the annihilation of LDM particles into e^+e^- pairs. It is in any case very interesting to search for such light invisible particles in collider experiments.

Motivation

Neglecting polarization effects and taking into account e+e− production through a photon only, one get:

$$\frac{\Gamma(J/\psi \to \nu\bar{\nu})}{\Gamma(J/\psi \to e^+e^-)} = \frac{27G^2M^4_{J/\psi}}{256\pi^2\alpha^2}\left(1 - \frac{8}{3}\sin^2(\theta_W)\right)^2 = 4.54 \times 10^{-7},$$

with G and α being the Fermi and the fine structure constants respectively.

However, based on a model-independent calculation, using only the result from the Wilkinson Microwave Anisotropy Probe Probe on the relic density of the Universe, the author has predicted the decay branching fraction of the J/ψ to a pair of dark matter particles to be $\mathcal{B}(J/\psi \to \chi\chi) \approx 0.023\%$

Motivation

Kinematic factors arising from the mass of the dark matter particles or the mediator can either enhance or suppress this branching fraction. Invisible J/ψ decays can produce a pair of dark matter particles with mass less than $M_{J/\psi}/2$ assuming the decay is mediated by a vector boson. The predicted branching fraction $B(J/\psi \to \chi\chi)$ gives a significantly larger value than prediction, which could indeed increase the invisible decay rate. This motivates the search for invisible decays of the J/ψ.

Using 14.0×10^6 $\psi(2S)$ events, the BESII experiment obtained a first upper limit, $B(J/\psi \to \text{invisible})/B(J/\psi \to \mu^+\mu^-) < 1.2\times10^{-2}$, corresponding to $B(J/\psi \to \text{invisible}) < 7\times10^{-4}$ via the $\psi(2S) \to \pi^+\pi^- J/\psi$ transition. We present here updated results of search for the invisible decay of the J/ψ. The data sample used consists of $(106.41 \pm 0.86) \times 10^6$ $\psi(2S)$ events collected with the BESIII detector at the BEPCII collider.

Analysis Strategy

We first select an exclusive sample, which is designed to contain signal events of $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to$ invisible, by requiring only the two soft pions are detected.

Events with a J/ψ can be identified by the recoil mass against the dipion (equivalent to the missing mass if only the two pions are considered in the event), which produces a peak at the J/ψ mass above a smooth combinatoric background. The signal yield (signal plus peaking background) can be extracted using a fit to the $\pi\pi$ recoil mass spectrum.

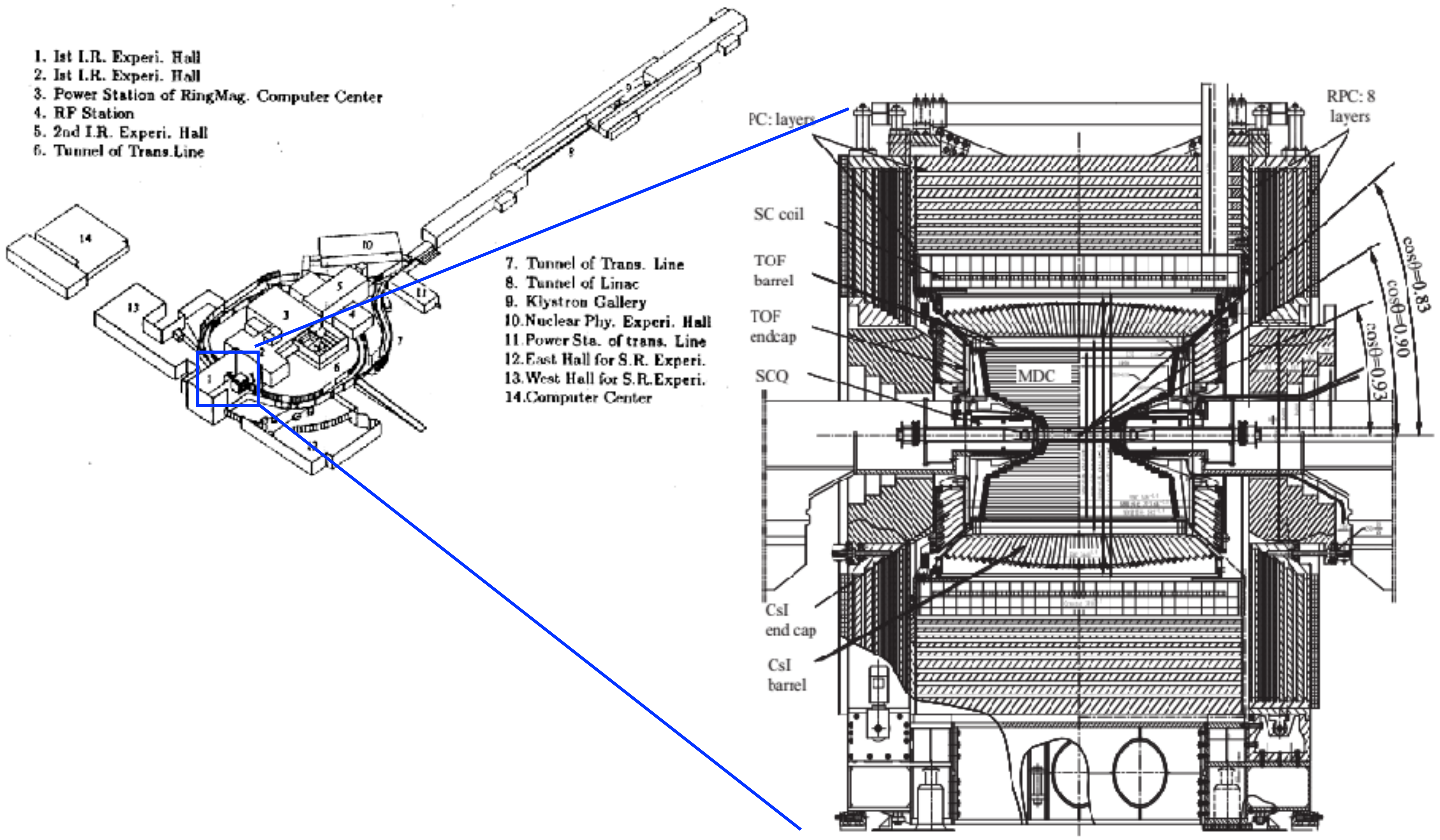
Then we subtract the peaking background, which is mostly from two-body decays of the J/ψ.

In order to better estimate the peaking background, avoiding systematic uncertainties related to the number of $\psi(2S)$ decays and the soft pion tracking, we select an inclusive sample of $\psi(2S) \to \pi^+\pi^- J/\psi$ events by finding the pion candidates, and a similar exercise is performed upon it to extract the yield. Then, a sample of $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to l^+l^-$ ($l = e,\mu$) events is selected, which is used to calculate the ratio of invisible J/ψ decays to $J/\psi \to \mu^+\mu^-$ to cancel some common uncertainties.

The relative branching fraction $B(J/\psi \to \text{invisible})/B(J/\psi \to \mu^+\mu^-)$ is calculated with the equation:

$$\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = \frac{N_{\text{invi}}/(\epsilon_{\text{invi}} \times N_{\text{tot}})}{N_{\mu\mu}/(\epsilon_{\mu\mu} \times N_{\text{tot}})} = \frac{N_{\text{invi}}/\epsilon_{\text{invi}}}{N_{\mu\mu}/\epsilon_{\mu\mu}}$$

BEPCII and BESIII detector



BESIII总体结构沿束流线的剖面图

BEPCII design parameters compared with those of BEPC.

Parameters	BEPCII	BEPC
Center of mass energy (GeV)	2–4.6	2–5
Circumference (m)	237.5	240.4
Number of rings	2	1
RF frequency f_{rf} (MHz)	499.8	199.5
Peak luminosity at 2 × 1.89 GeV ($cm^{-2}s^{-1}$)	$\sim 10^{33}$	$\sim 10^{31}$
Number of bunches	2 × 93	2 × 1
Beam current (A)	2 × 0.91	2 × 0.035
Bunch spacing (m/ns)	2.4/8	–
Bunch length (σ_z; cm)	1.5	~5
Bunch width (σ_x; μm)	~380	~840
Bunch height (σ_y; μm)	~5.7	~37
Relative energy spread	5×10^{-4}	5×10^{-4}
Crossing angle (mrad)	±11	0

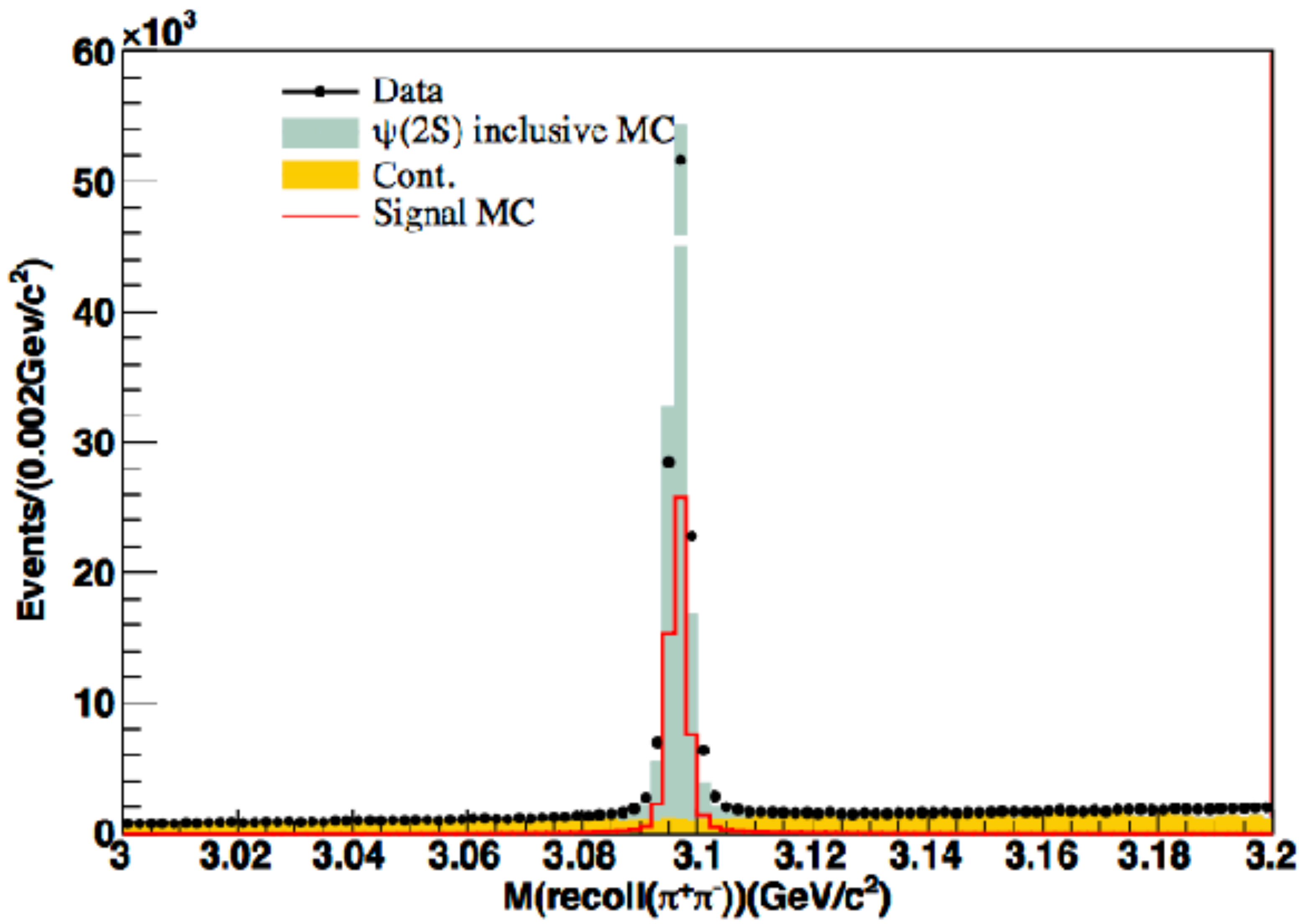
Detector parameters and performance comparison between BESIII and BESII.

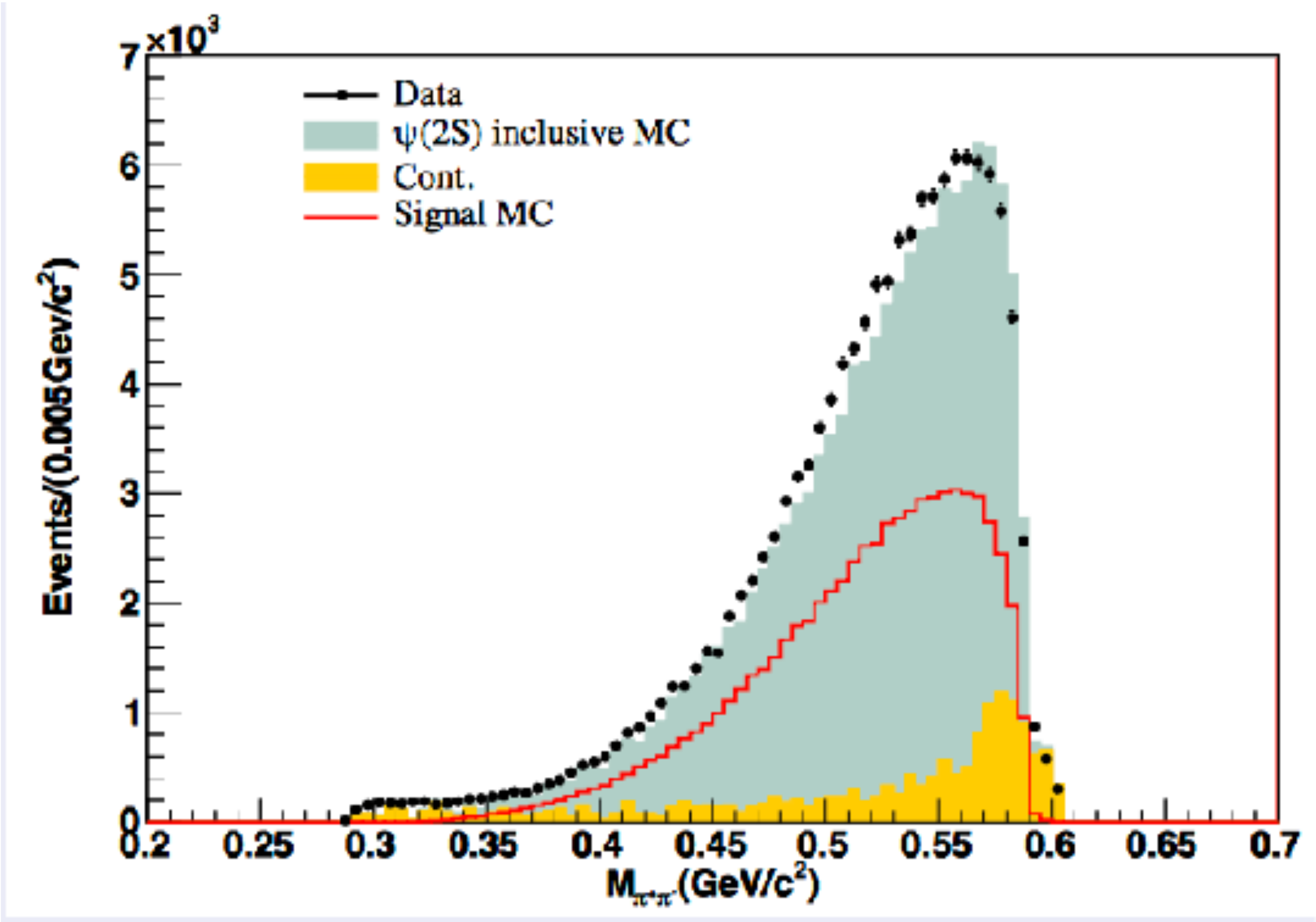
Subsystem	BESIII	BESII
MDC		
Single wire $\sigma_{r\phi}$ (μm)	130	250
σ_p/p (1 GeV/c) (%)	0.5	2.4
σ (dE/dx) (%)	6	8.5
EMC		
σ_E/E (1 GeV) (%)	2.5	22
Position resolution (1 GeV) (cm)	0.6	3
TOF		
σ_T (ps)		
Barrel	100	180
End cap	110	350
Muon		
No. of layers (barrel/end cap)	9/8	3
Cut-off momentum (MeV/c)	0.4	0.5
Solenoid magnet field (T)	1.0	0.4
$\Delta\Omega/4\pi$	93%	80% (used)

Selection Criteria

for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$ invisible:

2 good charged tracks, no good photon

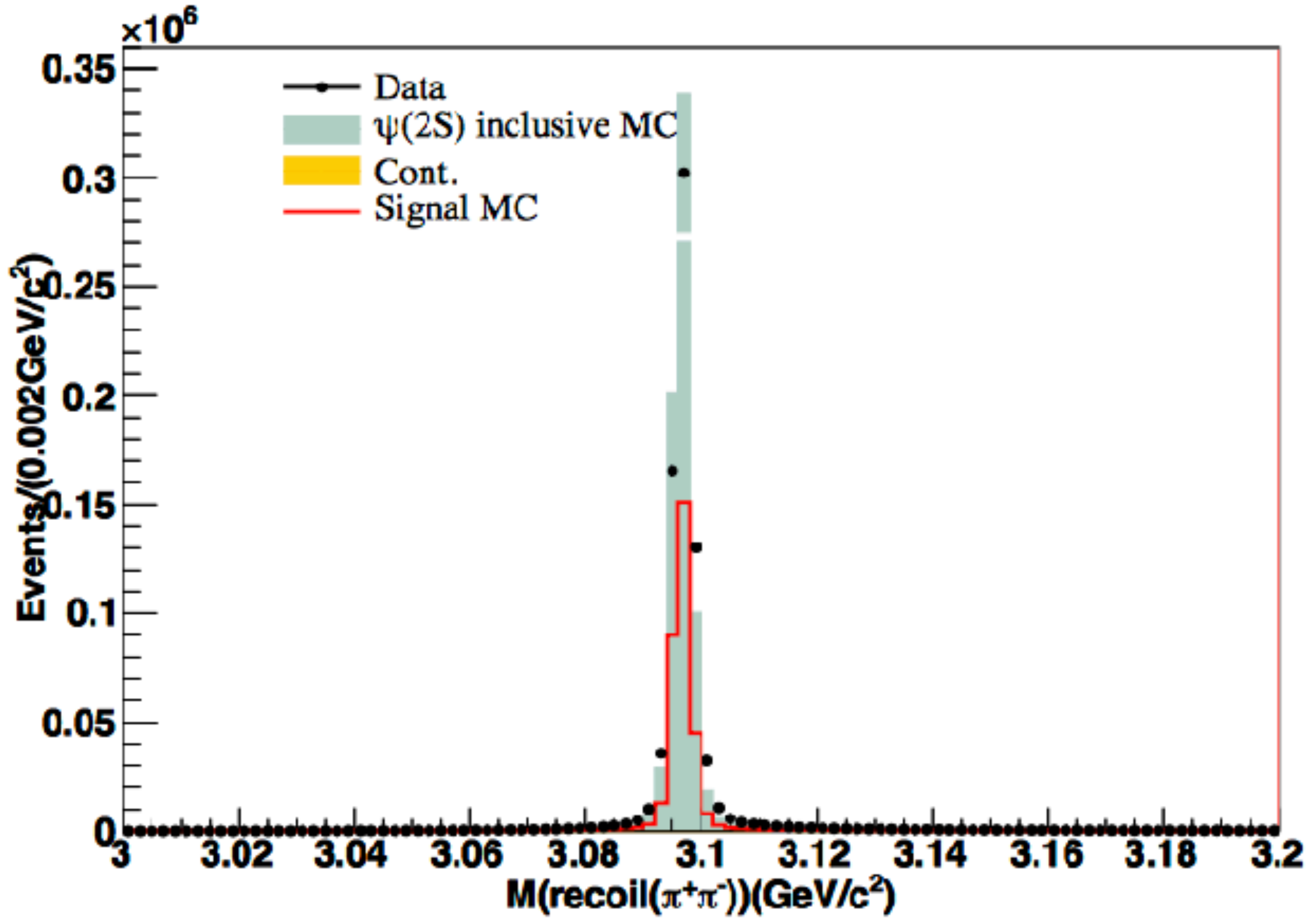


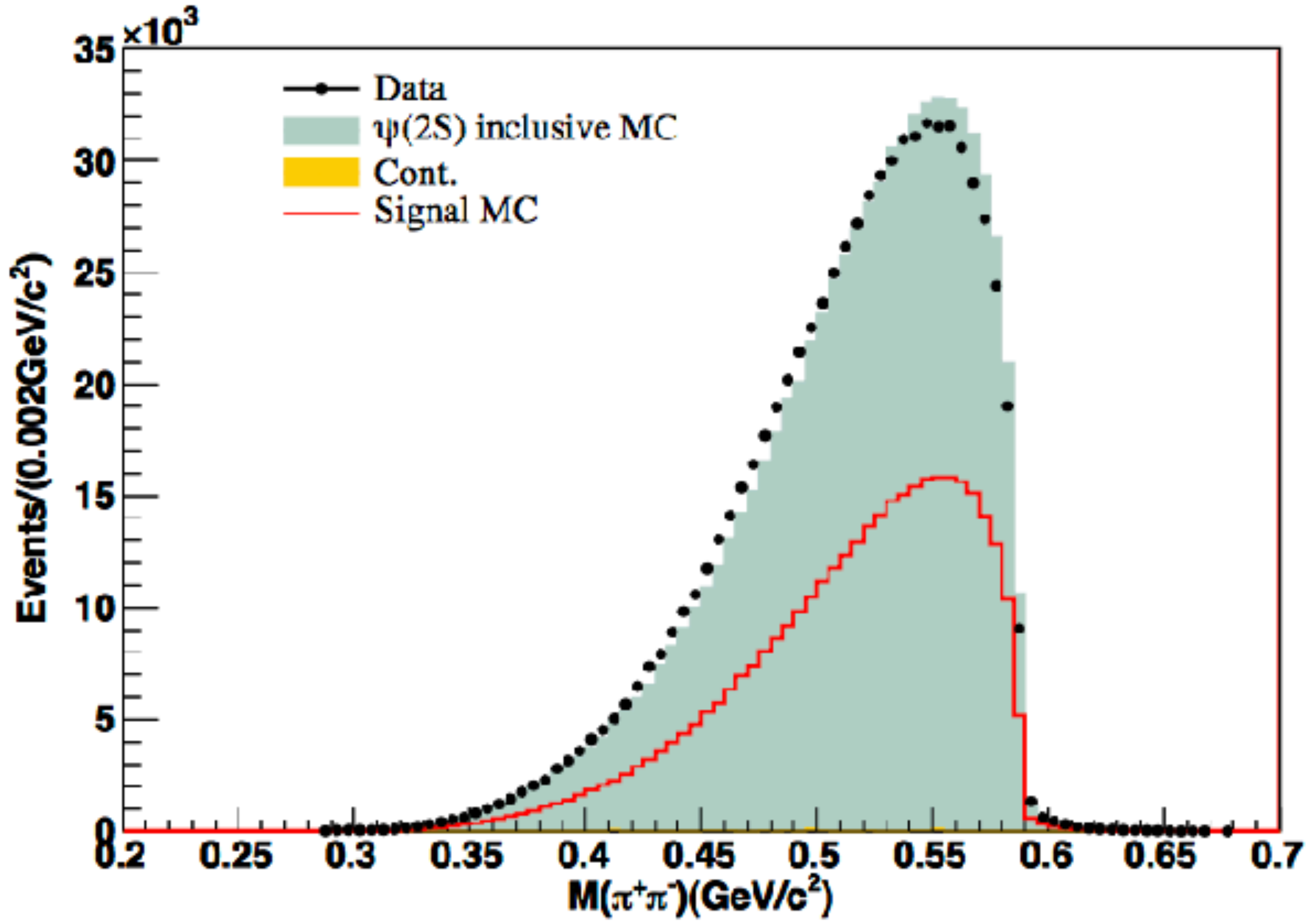


Selection Criteria

for $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \mu^+\mu^-$:

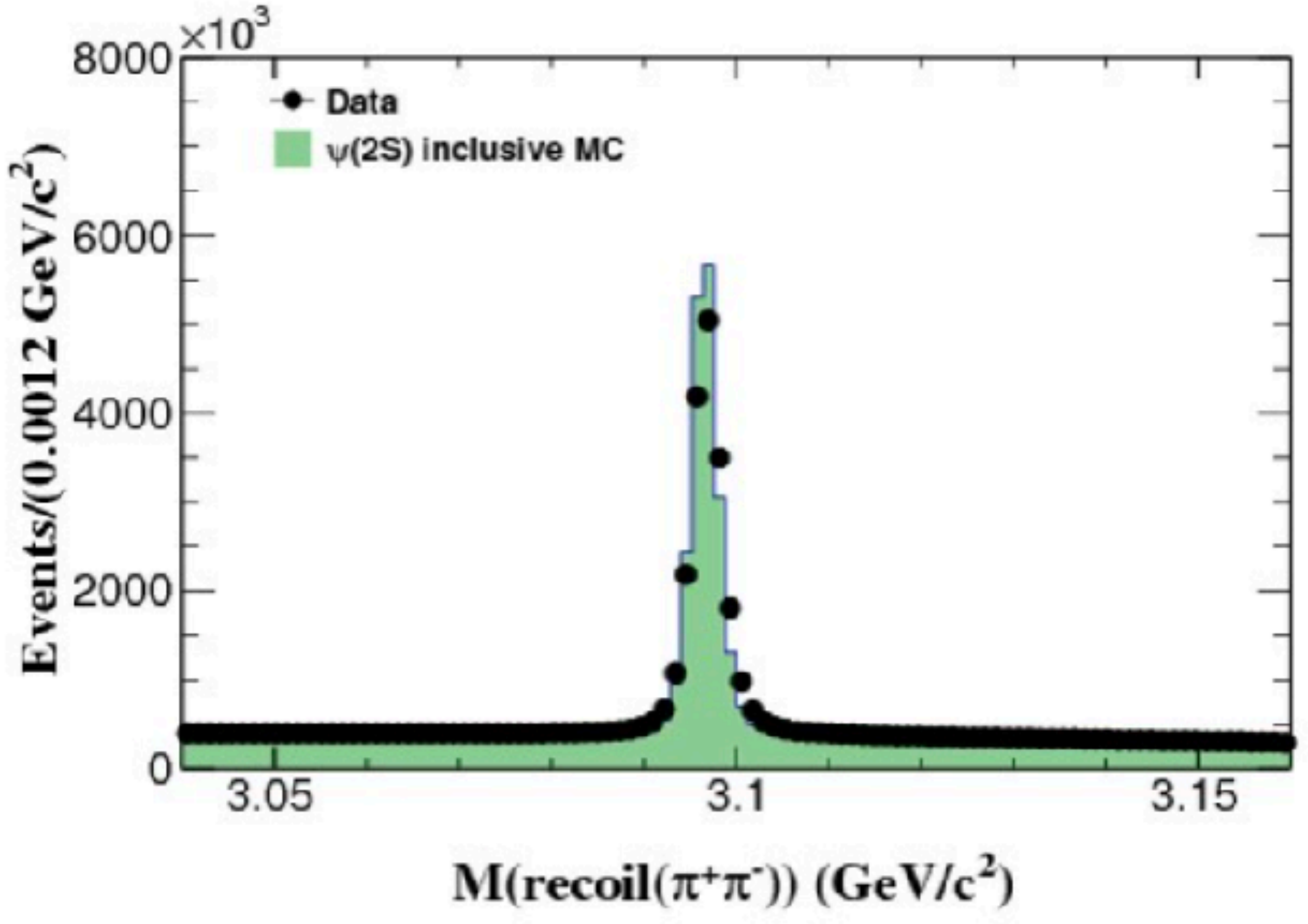
4 good charged tracks, no good photon

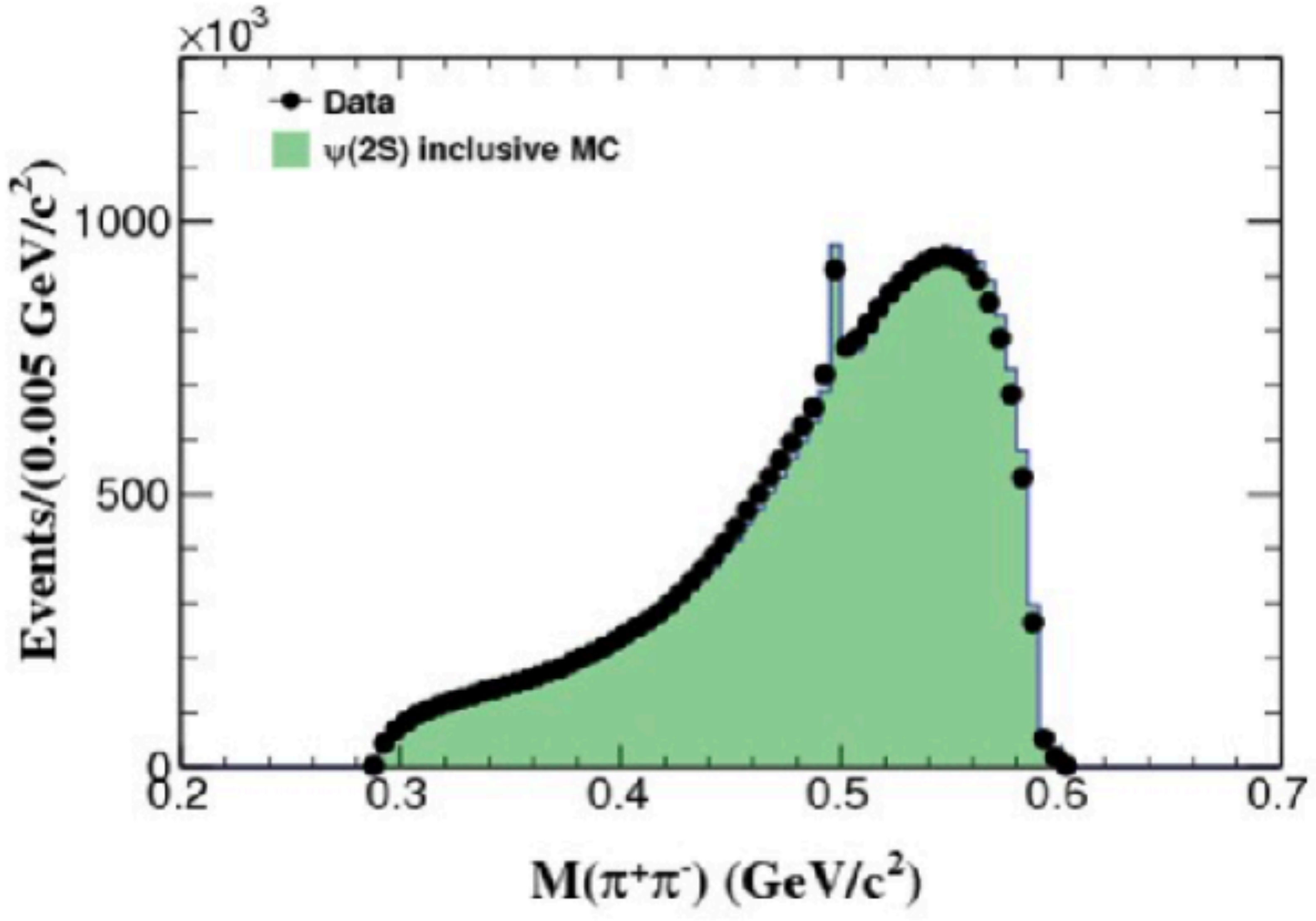




Selection Criteria

for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$ anything :





Background Study

for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$ invi :

Peaking bkg :

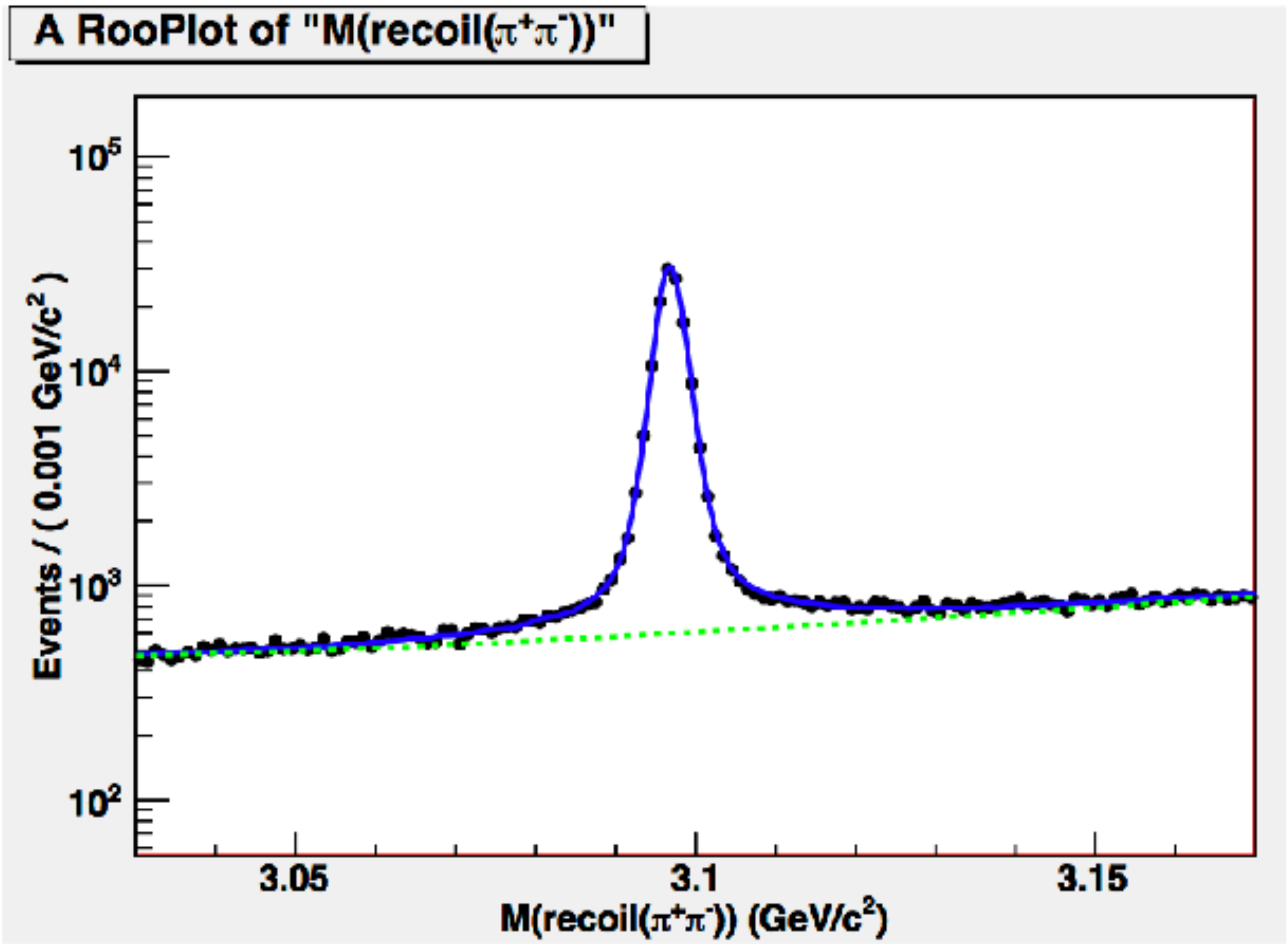
No.	Decay chain	N_{events}
0	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to \mu^+\mu^-$	63480
1	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to e^+e^-$	60363
2	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to n\bar{n}$	1977
3	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to p\bar{p}$	979
4	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to \Lambda\bar{\Lambda},\ \Lambda \to p\pi^-,\ \bar{\Lambda} \to \bar{p}\pi^+$	137
5	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to \bar{p}n\pi^+$	99
6	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to K^{*-}K^+,\ K^{*-} \to \bar{K}^0\pi^-$	96
7	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to \rho^0\pi^0, \rho^0 \to \pi^+\pi^-$	90
8	$\psi(2S) \to \pi^+\pi^- J/\psi,\ J/\psi \to K^{*+}K^-,\ K^{*+} \to K^0\pi^+$	82

126799/127303=99.6%

Four main contributions: two-body decays($J\psi \to \mu^+\mu^-$, e^+e^-, ppbar, nnbar).

Signal Extraction

for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$ invi :



Signal:shape from selected $J/\psi \to e^+e^-$

Signal Extraction

The yield obtained for invisible J/ψ decays is 122887±383 events, and (18459.1±5.0)*10^3 events for inclusive J/ψ decays, where the errors are statistical only.

Table 5: Expected number of peaking background events.

Channel	$\mathcal{B}_{2B}(\%)$	$\epsilon_{2B}(\%)$	$\epsilon_{\mathrm{trig}}(\%)$	Event number
$J/\psi \to \mu^+\mu^-$	5.961 ± 0.033	5.74 ± 0.02	99.4 ± 0.1	62781 ± 1332
$J/\psi \to e^+e^-$	5.971 ± 0.032	5.45 ± 0.02	99.4 ± 0.1	59709 ± 1282
$J/\psi \to n\bar{n}$	0.209 ± 0.016	4.68 ± 0.02	99.4 ± 0.1	1795 ± 471
$J/\psi \to p\bar{p}$	0.2120 ± 0.0029	2.35 ± 0.01	99.4 ± 0.1	914 ± 26
Total				125199 ± 2604

After subtracting the expected background due to J/ψ → 2B decays from the invisible signal extracted from the fit to the invisible data sample, we obtain an invisible signal yield of

$$N(J/\psi \to \text{invisible}) = -2312 \pm 383 \pm 2605$$

Where the first error is statistical and the second one is systematic.

Systematic Uncertainties

Table 10: Summary of the relative systematic uncertainties (%) in the peaking background estimation.

Sources	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$	$J/\psi \to n\bar{n}$	$J/\psi \to p\bar{p}$
$\mathrm{N}(\pi^+\pi^- J/\psi)$ statistics		0.03		
Fit in $\mathrm{N}(\pi^+\pi^- J/\psi)$		0.47		
$N_\gamma = 0$		1.90		
Trigger		0.12		
$\mathcal{B}(J/\psi \to 2B)$	0.55	0.54	7.66	1.37
MC statistics	0.32	0.33	0.44	0.63
$N_{\mathrm{extra\ trk(shower)}} = 0$	0.5	0.6	25.0	1.3

Results and Discussion

We obtain an invisible signal yield of

$$N(J/\psi \to \text{invisible}) = -2312 \pm 383(\text{stat.}) \pm 2605(\text{syst.})$$

The relative branching fraction is determined as

$$\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = \frac{N_{\text{invi}}/(\epsilon_{\text{invi}} \times N_{\text{tot}})}{N_{\mu\mu}/(\epsilon_{\mu\mu} \times N_{\text{tot}})} = (-2.66 \pm 0.44(\text{stat.}) \pm 3.00(\text{syst.})) \times 10^{-3}$$

Results and Discussion

Lacking evidence for this decay, we use a Bayesian technique to set an upper limit on the relative branching fraction. We convolute the statistical likelihood, a function of $B(J/\psi \to \text{invisible})/B(J/\psi \to \mu^+\mu^-)$, with Gaussian functions representing the total systematic error. The normalized likelihood distribution, which is smeared by systematic error, is shown in Fig. 55. We assume a prior probability that is flat in branching fraction and integrate the likelihood from 0 to a value such that 90% of the total integral above 0 is enclosed. The resulting limit is $B(J/\psi \to \text{invisible})/B(J/\psi \to \mu^+\mu^-) < 3.6 \times 10^{-3}$ at the 90% C.L..

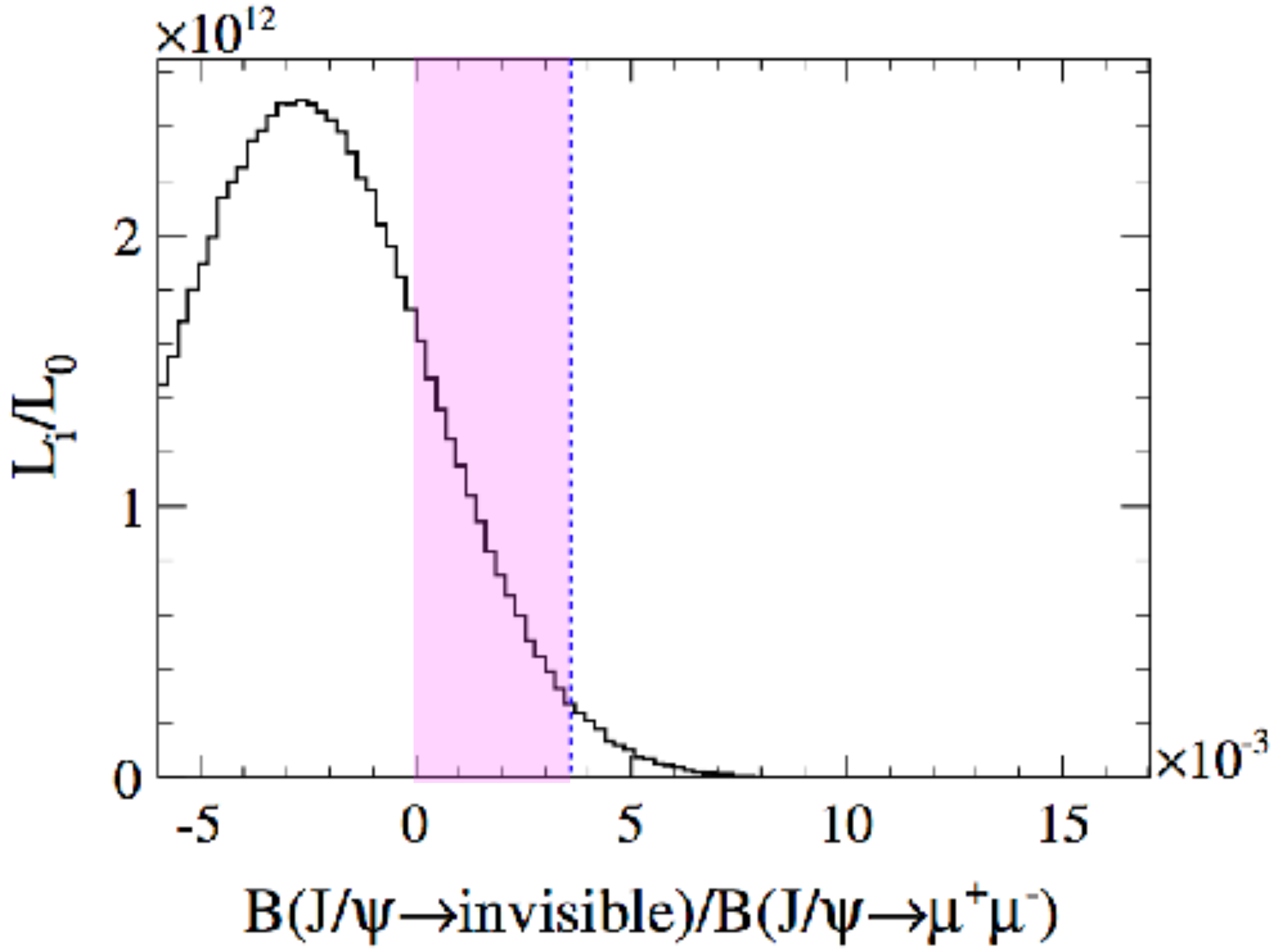


Figure 55: The normalized likelihood distribution versus $\frac{B(J/\psi \to \text{invisible})}{B(J/\psi \to \mu^+\mu^-)}$, which is smeared by systematic error.

Results and Discussion

In conclusion, we search for invisible decays of the J/ψ meson. We do so by looking for evidence of the decay of the J/ψ into undetectable final states recoiling against the di-pion system in $\psi(2S) \to \pi^+\pi^- J/\psi$, using a sample of $(106.41 \pm 0.86) \times 10^6$ $\psi(2S)$ mesons. We find no evidence for $J/\psi \to$ invisible and set an upper limit on the ratio $\mathcal{B}(J/\psi \to \text{invisible})/\mathcal{B}(J/\psi \to \mu^+\mu^-)$ at 3.6×10^{-3} at the 90% C.L.. This limit is almost an order of magnitude closer to the SM prediction than the best previous limit. The comparisons of this result with the previous results from other experiments are summarized in Table 11.

Table 11: Comparisons of the upper limit.

References	$\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)}$	$\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to e^+e^-)}$	$\mathcal{B}(J/\psi \to \text{invisible})$
BESII	$< 1.2 \times 10^{-2}$	...	...
BABAR	...	$< 6.6 \times 10^{-2}$	...
PDG	...	...	$< 7 \times 10^{-4}$
This work	$< 3.6 \times 10^{-3}$	...	...

Thanks!