Observation of a charged charmoniumlike structure in $e^+e^-\to\pi^+\pi^- J/\Psi$ at $\sqrt{s}$ = 4.26 GeV

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Movement

- The famous Y (4260) state was first observed by BaBar Collaboration in Initial-State-Radiation(ISR) e^+e^- → γISR$\pi^+\pi^-J/\psi$ process, with 233 fb^{-1} data collected around $\sqrt{s}$ = 10.58 GeV. It was rapidly confirmed by CLEO experiment with a much smaller data sample and by Belle experiment with much more luminosity using the same technique.
- Since Y(4260) state is produced through ISR in e+e− annihilation, its quantum number must be $J^{PC} = 1^{--}$. However, this new resonance seems to be rather different from the known charmonium states with $J^{PC} = 1^{--}$ in the same mass scale, such as ψ(4040), ψ(4160), and ψ(4415).
  - Being well above the DDbar threshold, instead of decaying predominantly into DDbar final states, the Y (4260) shows strong coupling to the π+π−J/ψ final state
  - Clear signals of ψ(4040) and ψ(4160) to ηJ/ψ hadronic transition were observed. The entirely different patterns in π+π−J/ψ transition and ηJ/ψ transition of charmonium states are difficult to understand. This indicates the Y (4260) state might be a non-conventional charmonium state
- Try to use 525 pb^{-1} data taken by BESIII directly at $\sqrt{s}$ = 4.26 GeV. Study the properties of the Y (4260), and study the intermediate states of Y (4260) decay to $\pi^+\pi^-J/\psi$.

Data analysis –– MC simulation

- Data sample: 525 pb^{-1} data taken by BESIII directly at $\sqrt{s}$ = 4.26 GeV
- MC simulation: GEANT4-based simulation software BOOST
- MC sample 1: $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$ ($e^+e^- \to \pi^+\pi^- J/\psi$[3.8-4.26GeV], KKMC)
- MC sample 2: Y(4260)→π +π-J/ ψ→e+e-/μ+μ-(PHOTOS)
- MC sample event: 100,000/signal mode
- MC background: ψ(4260) resonance, Initial State Radiation of the vector charmonium states, and QED events are generated with KKMC

Data analysis –– Event selection criteria

π +π-J/ ψ

1. Originate from the interaction point, with Vxy =$\sqrt{(V_x^2 + V_y^2)}$< 1 cm, |Vz| < 10 cm
2. Good photon candidate: .Edep > 25MeV(barrel,|cos θ|<0.8); Edep > 50MeV(endcap, 0.86< |cos θ|<0.92, 0<t<14[in unit of 50 ns])
3. The number of good charged tracks is required to be four with zero net charge. P>1.0 GeV/c(leptons), P<1.0 GeV/c(pions)
4. cosθ<0.98

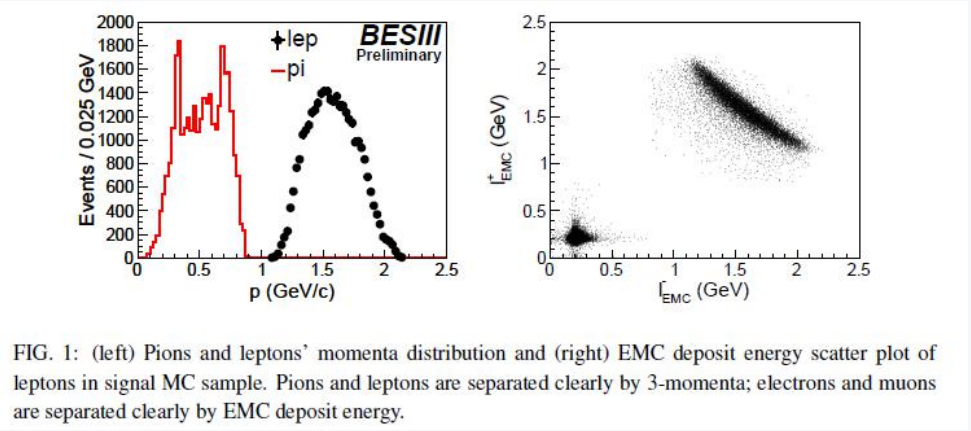

FIG. 1: (left) Pions and leptons' momenta distribution and (right) EMC deposit energy scatter plot of leptons in signal MC sample. Pions and leptons are separated clearly by 3-momenta; electrons and muons are separated clearly by EMC deposit energy.

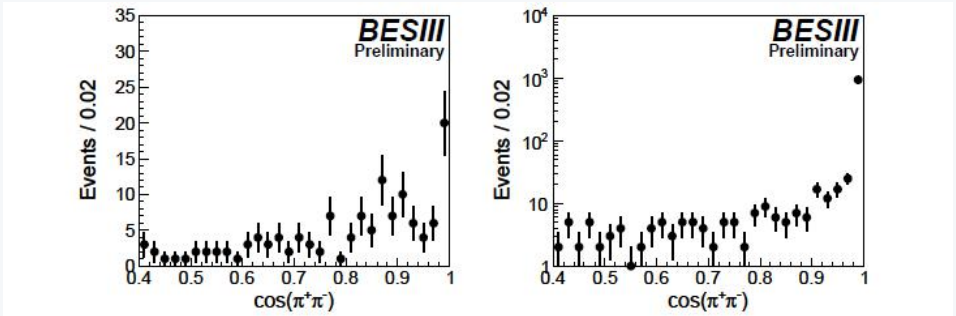

FIG. 2: The opening angle of $\pi^+\pi^-$ for $\mu^+\mu^-$ mode (left) and e^+e^- mode (right) in data, respectively. The bumping bin around 1 corresponds to gamma-conversion events.

Data analysis –– Event selection criteria

5. Four-constraint (4C) kinematic fits are performed with the four charged tracks ($\pi^+\pi^-e^+e^-$ or $\pi^+\pi^-\mu^+\mu^-$) to improve resolution and help suppress background. $\chi^2 < 60$

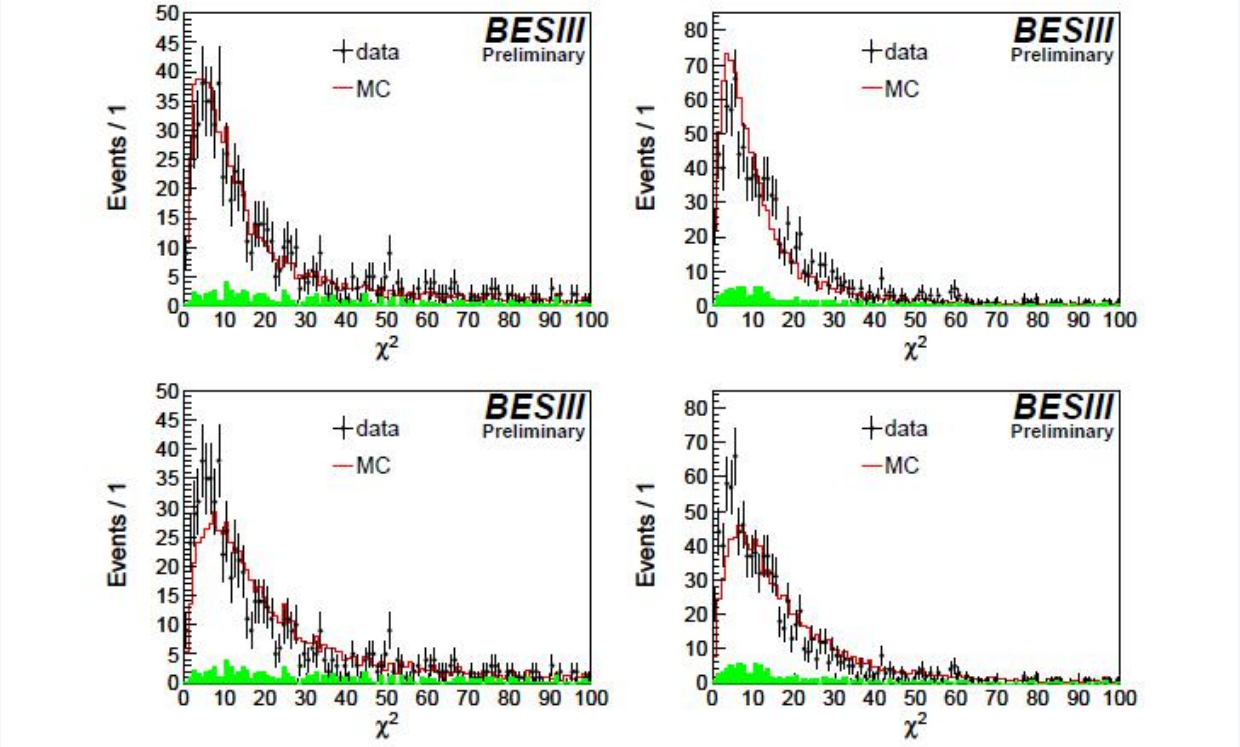

FIG. 4: 4C Kinematic fit χ^2 distribution for e^+e^- mode (left) and $\mu^+\mu^-$ mode (right) before track PULL distribution correction (upper row) and after track PULL distribution correction (bottom row). Dots with error bars are data, red histograms are signal MC simulation (with background added) and green shaded histograms are background events.

Data analysis –– Data and background analysis

invariant mass distribution of l+l− :

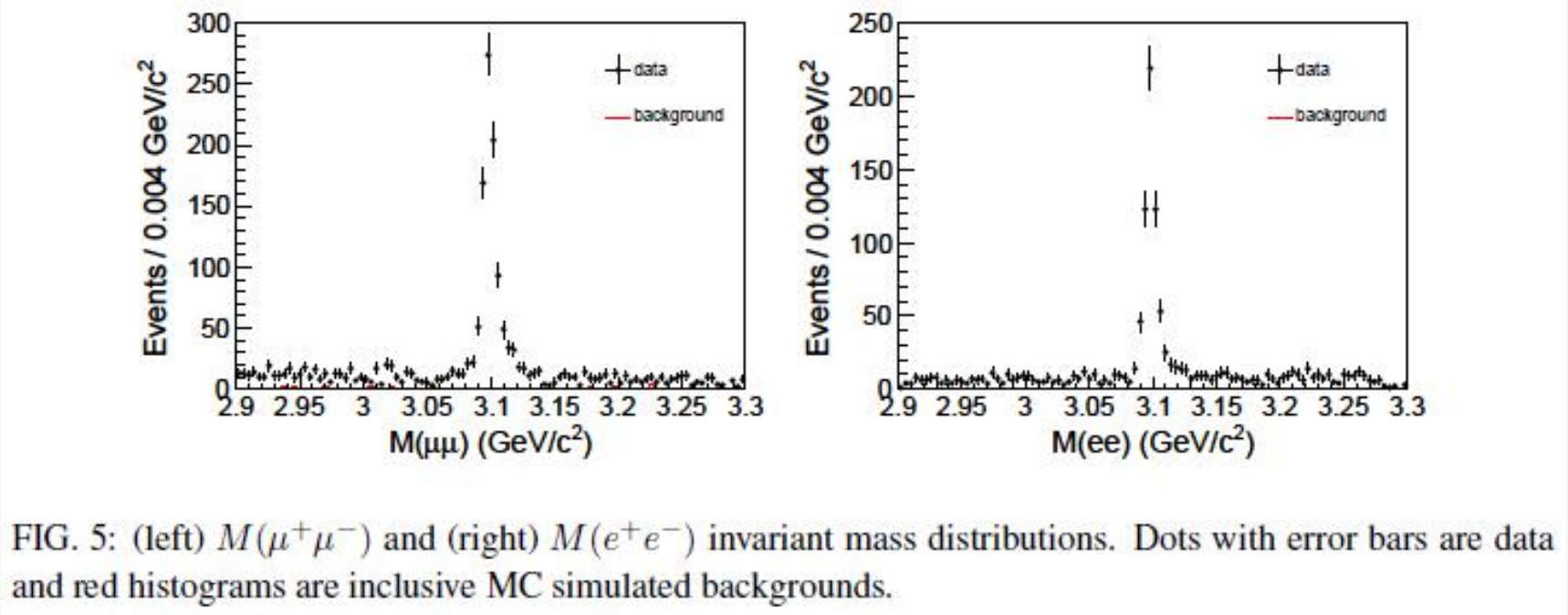

FIG. 5: (left) $M(\mu^+\mu^-)$ and (right) $M(e^+e^-)$ invariant mass distributions. Dots with error bars are data and red histograms are inclusive MC simulated backgrounds.

From the plot, we can see inclusive MC simulated background events are underestimated.

Data analysis –– Data and background analysis

- Dominant background events : e+e− → π+π−π+π−
- Simulate e+e-→qqbar by PYTHIA
- Use J/ψ mass sideband events to estimate the possible background contribution
- Fit lepton pair invariant mass distributions by double Gaussian function with a liner background term

	J/ψ mass	σ	signal events
e+e-	3097.9 ± 0.3 MeV	4.0 MeV	595 ± 28
μ+μ-	3098.4 ± 0.3 MeV	3.7 MeV	882 ± 33

- Selecte J/ψ mass window as 3.08 <M(ℓ+ℓ−) < 3.12 GeV/c2, sideband as 3.0 < M(ℓ+ℓ−) < 3.06 or 3.14 < M(ℓ+ℓ−) <3.20 GeV/c2, which is 3 times of signal region.

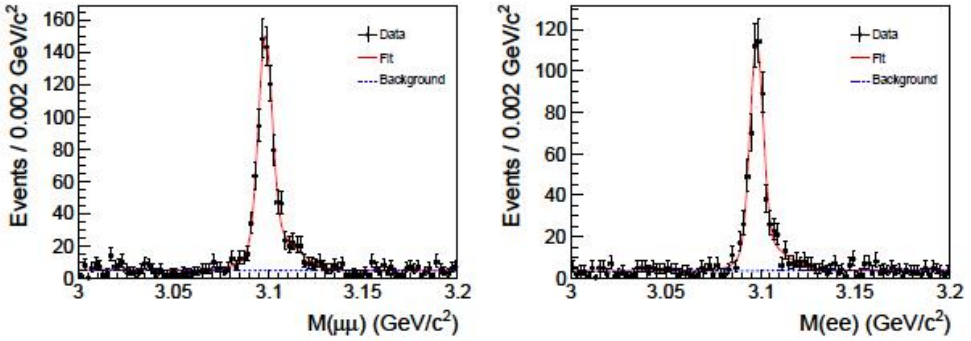

FIG. 6: Fit the invariant mass distribution of (left) $M(\mu^+\mu^-)$ and (right) $M(e^+e^-)$ with double Gaussian function and a linear background. Dots with error bars are data, red curves are the fit results and blue dashed curves shows the background term.

Data analysis –– Intermediate state

In Y (4260) → π+π−J/ψ decays, possible intermediate states includes π+π− resonances, such as σ, f0(980), f2(1270) and so on.

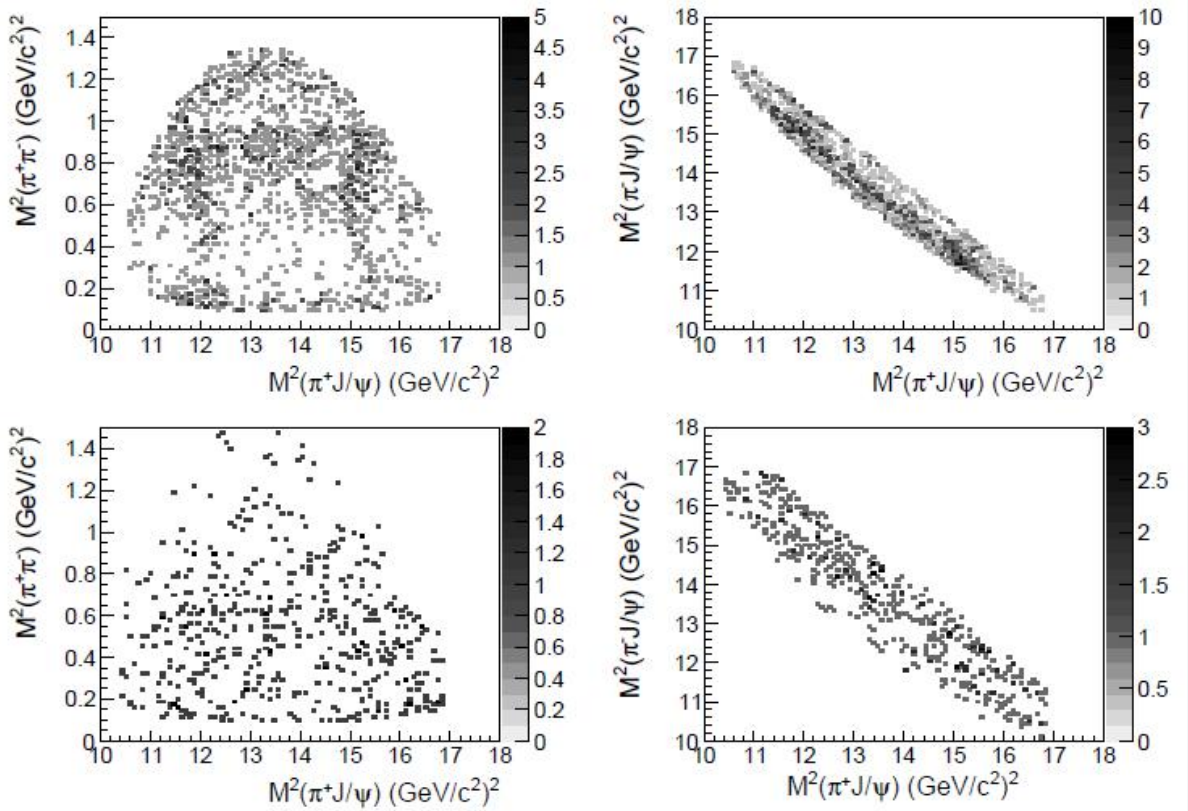

FIG. 8: Dalitz distribution of $M^2(\pi^+\pi^-)$ vs. $M^2(\pi^+J/\psi)$ (left) and $M^2(\pi^-J/\psi)$ vs. $M^2(\pi^+J/\psi)$ (right) in $Y(4260) \to \pi^+\pi^-J/\psi$ decays for data (upper row) and J/ψ sideband background events (bottom).

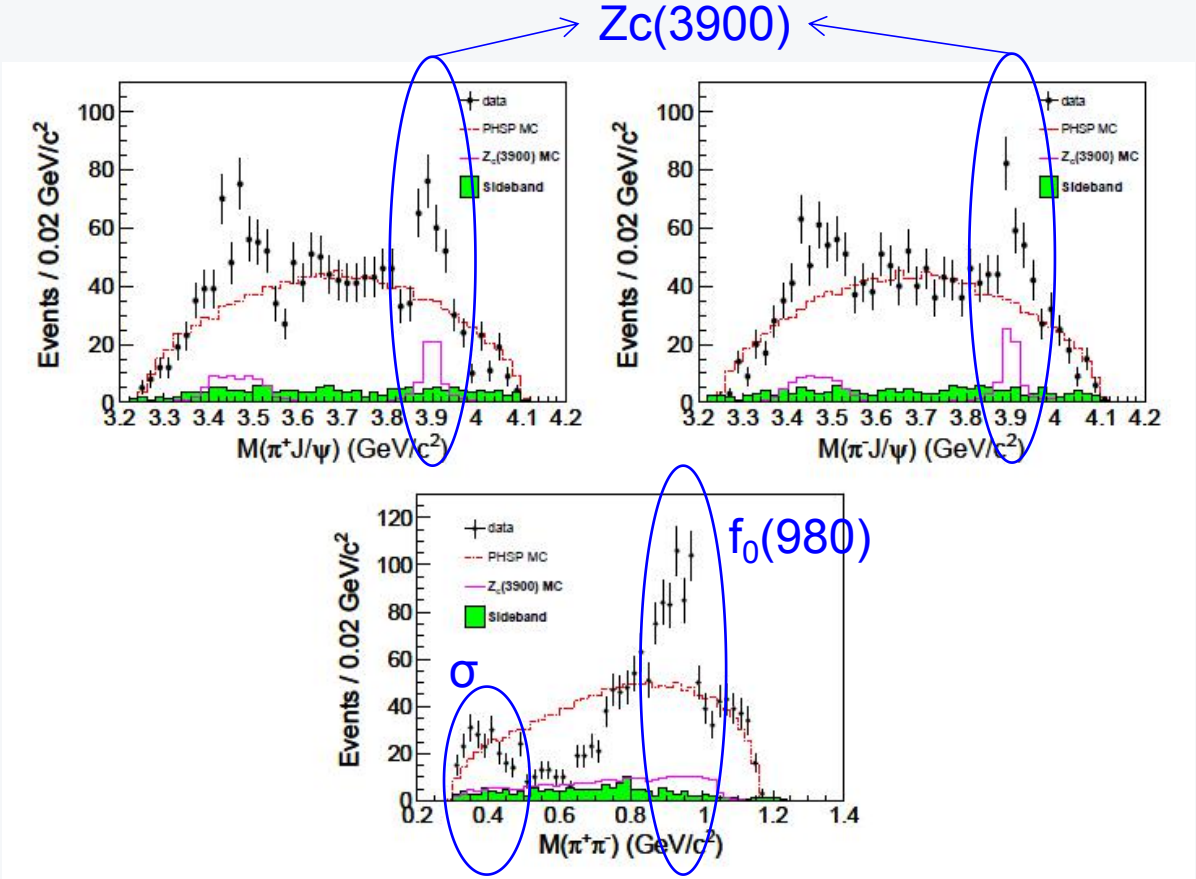

FIG. 9: 1D projection of $M(\pi^+J/\psi)$, $M(\pi^-J/\psi)$, $M(\pi^+\pi^-)$ invariant mass distributions. Dots with error bars are data, red dashed histograms are phase space MC simulation, red solid histograms are $Z_c(3900)$ signal MC simulation and green shaded histograms are sideband background events.

Data analysis –– Intermediate state

1. Signal function: Breit-Wigner function convolving Gaussian resolution
   Background shape: $a/(x-3.6)^b + c + dx$
2. M(Zc(3900)) = 3899.0±3.6 MeV/c2, Γ(Zc(3900)) = 45.8 ±9.7 MeV/c2
3. N(Zc(3900)) = 307±48
4. Fraction of Zc(3900) events

$$R = \frac{Y(4260)\to\pi^{\pm}Z_c(3900)^{\mp}}{Y(4260)\to\pi^{+}\pi^{-}J/\psi} = (21.5 \pm 3.3)\%$$

5. Considering the number of degree of freedom changing is 3, the significance is calculated to be 20.5σ. That means the Zc(3900) resonance is significantly observed. By testing all kinds of background shapes and fit ranges, we find the statistical significance is always larger than 8σ.

Data analysis –– Cross section measurement

Born-order cross section:

$$\sigma^B = \frac{N^{obs}}{\mathcal{L}_{int}(1+\delta)\epsilon\mathcal{B}}$$

- N^{obs}: number of observed events
- $\mathcal{B}$: branching ratio of J/ψ → ℓ+ℓ−
- ϵ: selection efficiency
- $\mathcal{L}_{int}$: integrate luminosity

(1+δ) is the radiative correction factor, which is defined as:

$$(1+\delta) = \frac{\sigma^{obs}}{\sigma^B} = \frac{\int \mathrm{BW}(s(1-x))F(x,s)dx}{\mathrm{BW}(s)}$$

- $F(x,s)$: radiator function
- $\mathrm{BW}(s)$: Born cross section shape of the Y (4260) resonance

	$\mu^+\mu^-$	e^+e^-
1+δ(KKMC)	0.818	0.818
ε	53.8%	38.4%
σ^B	(63.8 ± 2.5)pb	(60.3 ± 2.9)pb
σ^B	(62.3 ± 1.9)pb	

Error analysis

TABLE I: Summary of the systematic errors for $Z_c(3900)$ resonant parameters.

Source	Mass (MeV/c^2)	Width (MeV/c^2)	Branching ratio (%)
Absolute mass scale	1.8	-	-
Fit model	2.1	3.7	2.6
Background shape	2.5	11.3	7
Resolution	-	1.0	0.2
Total	3.7	12.0	7.5

TABLE II: Summary of the systematic errors (%) in $\mu^+\mu^-$ mode and e^+e^- mode.

Source	$\mu^+\mu^-$	e^+e^-
Luminosity	1.0	1.0
Tracking	4.0	4.0
Background shape	0.5	3.4
$Y(4260)$ line-shape	0.6	0.6
Kinematic fit	2.2	2.3
Branching ratios	1.0	1.0
Decay model	3.1	3.1
Others	1.0	1.0
Total	5.9	6.8

Summary

1. We observed a charged charmoniumlike state Zc(3900) in $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s} = 4.26$ GeV for the first time.
2. The statistical significance is estimated to be larger than 8σ.
3. A fit to the Mmax($\pi J/\psi$) mass spectrum yields $M(Zc(3900)) = 3899.0 \pm 3.6 \pm 3.7$ MeV/c2 and $\Gamma(Zc(3900)) = 45.8 \pm 9.7 \pm 12.0$ MeV/c2, where the first errors are statistical and second ones systematic.
4. The branching ratio of Zc(3900) is measured to be $R = (21.5 \pm 3.3 \pm 7.5)\%$.
5. The Born cross section for $e^+e^- \to Y(4260)$ is measured to be $62.3 \pm 1.9 \pm 3.7$ pb, which is in good agreement with previous measurements. Here the first error is statistical, and second systematic.


THANK YOU