Z_c@BESIII

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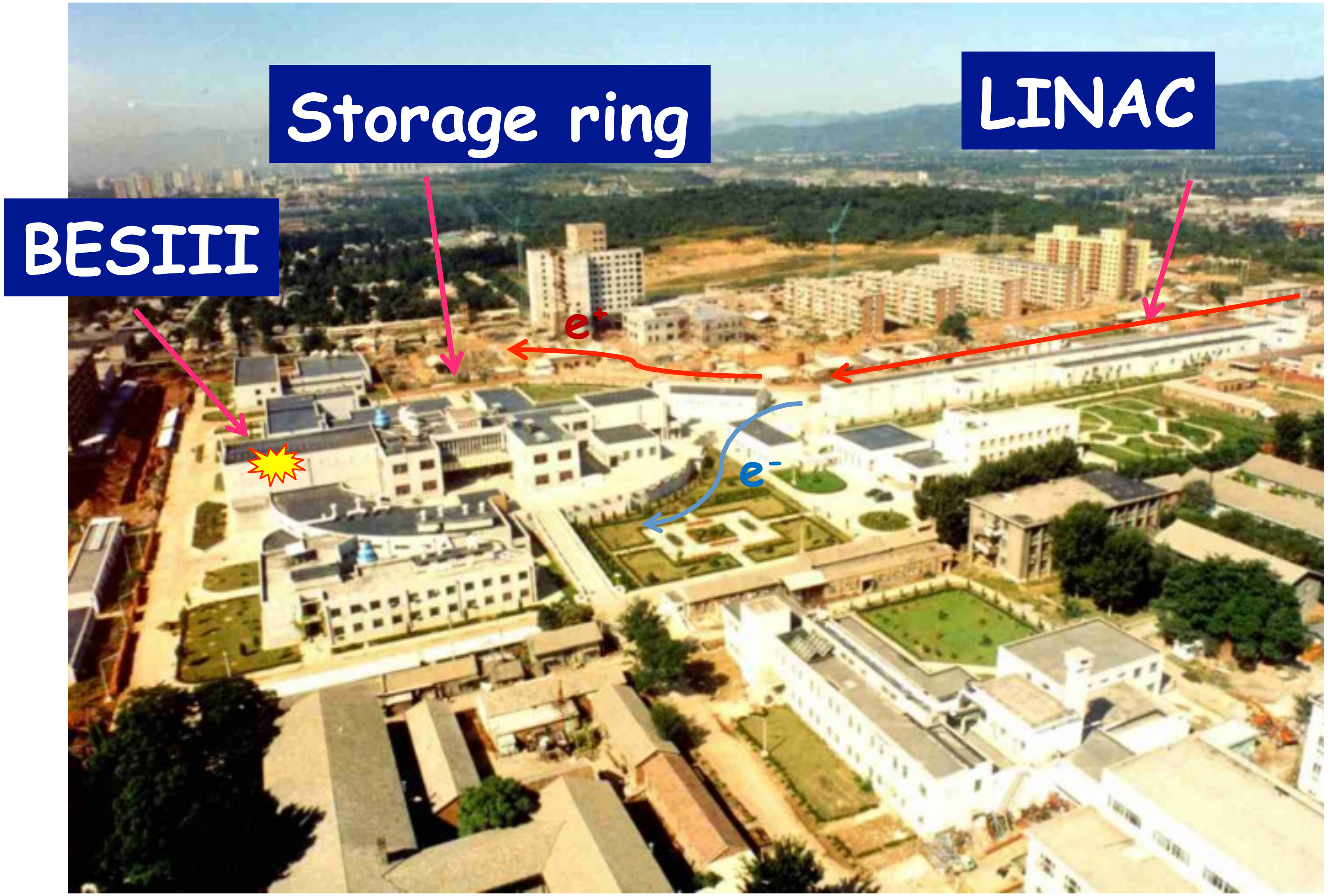
Outline

- ❑ Introduction
  - ➢ BEPCII and BESIII
  - ➢ BESIII data samples
- ❑ Z_c results from BESIII
  - ➢ Zc(3900), Zc(4020) discovery
  - ➢ Determination of J^p of Zc(3900)
  - ➢ Structures in $e^+e^- \rightarrow \pi^+\pi^- \psi'$
  - ➢ No evidence of Zc(3900)$\rightarrow \pi\omega$
  - ➢ Evidence of Zc(3900)$\rightarrow \rho\eta_c$
- ❑ Something about Argand plot
- ❑ Summary

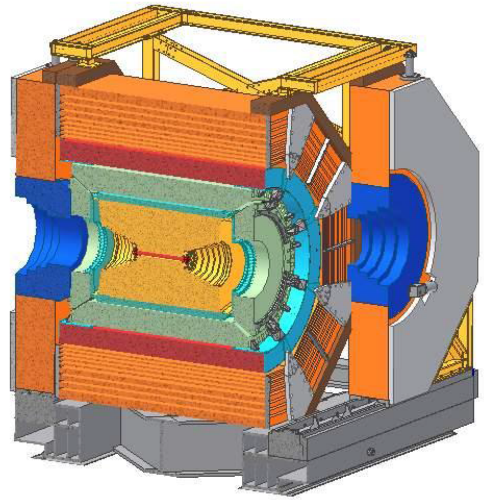
Beijing Electron and Positron Collider(BEPCII)

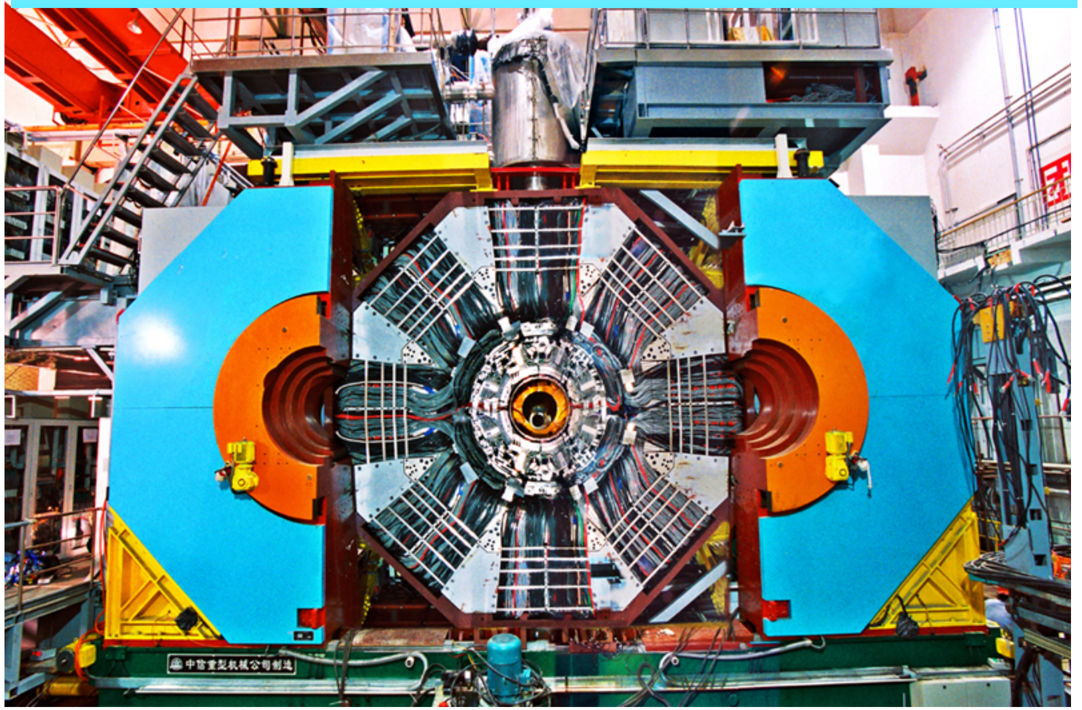


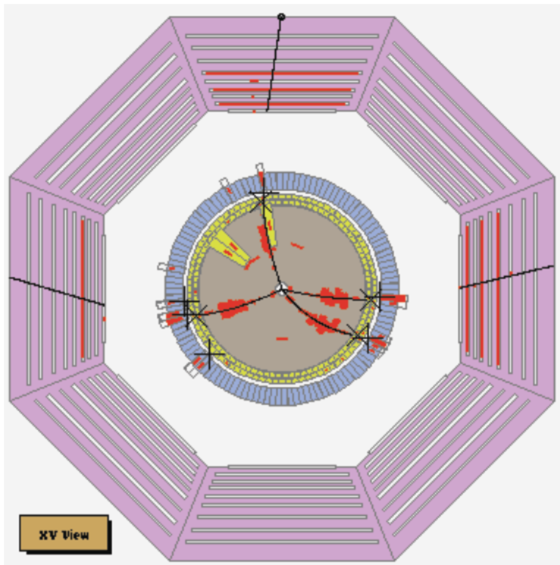
Beam energy: 1~2.3GeV

Beijing Spectrometer (BESIII)

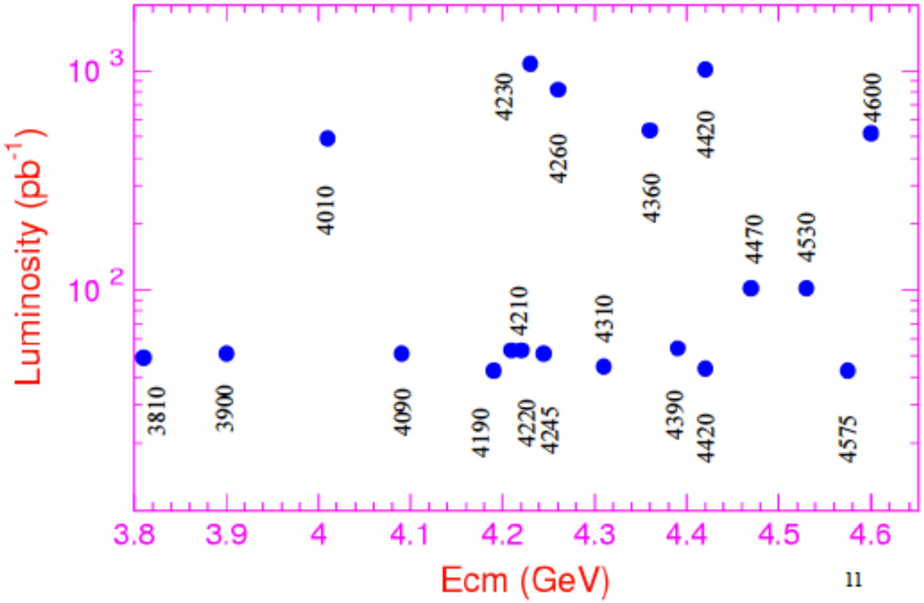
- Inner to Outside：
- ✓ Main Drift chamber(MDC),
- ✓ Time of flight System(TOF),
- ✓ Electromagnetic Calorimeter(EMC),
- ✓ Solenoid super-conducting magnet(SSM),
- ✓ Muon chamber(MUC)
- Acceptance: 93% of 4π





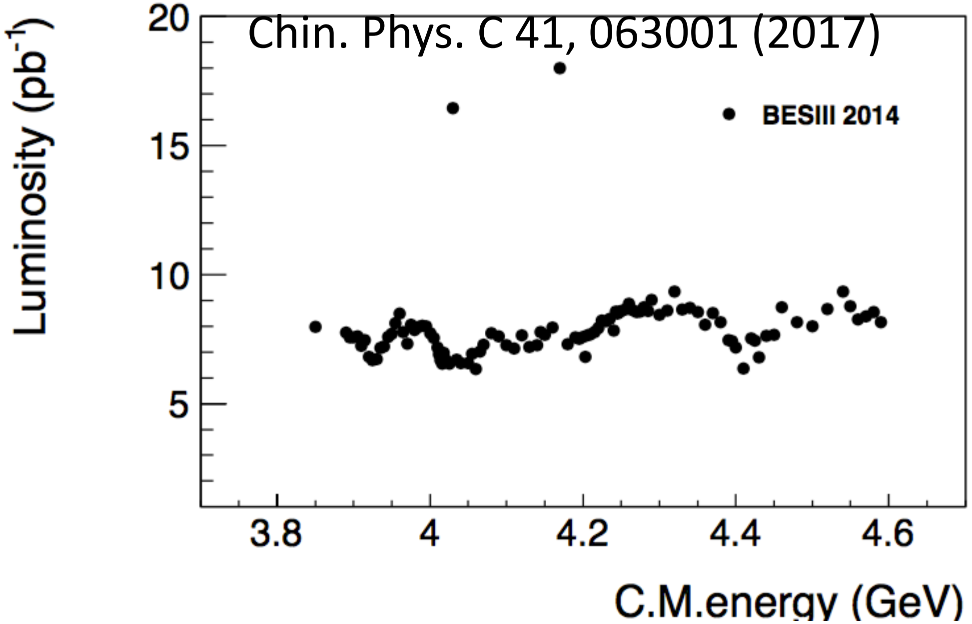


BESIII data sets for XYZ study



XYZ data

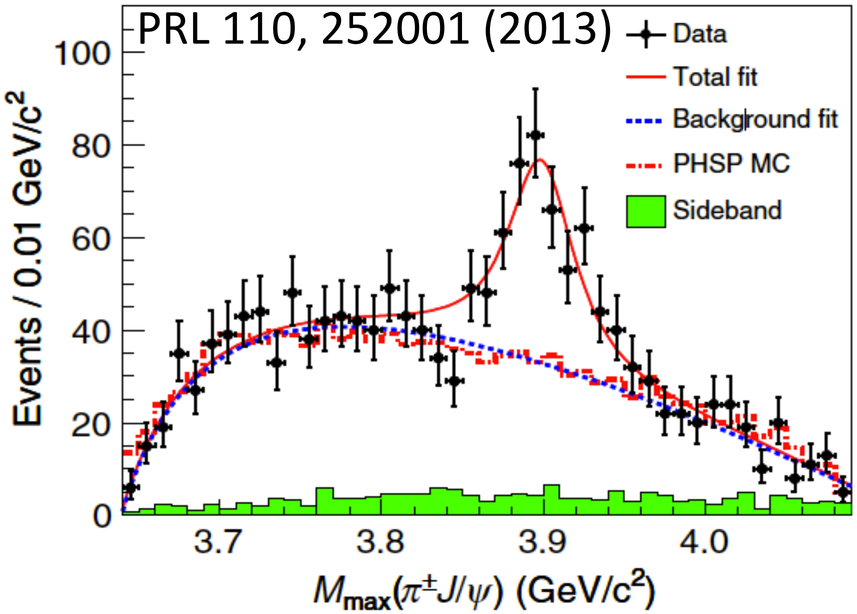
- 5 fb^{-1} e^+e^- collision data event in open charm region from 3.8-4.6GeV.
- Massive events on several special energy points: Such as
  4.26GeV, 828pb^{-1}
  4.36GeV, 544pb^{-1}
  4.23GeV, 1100pb^{-1}

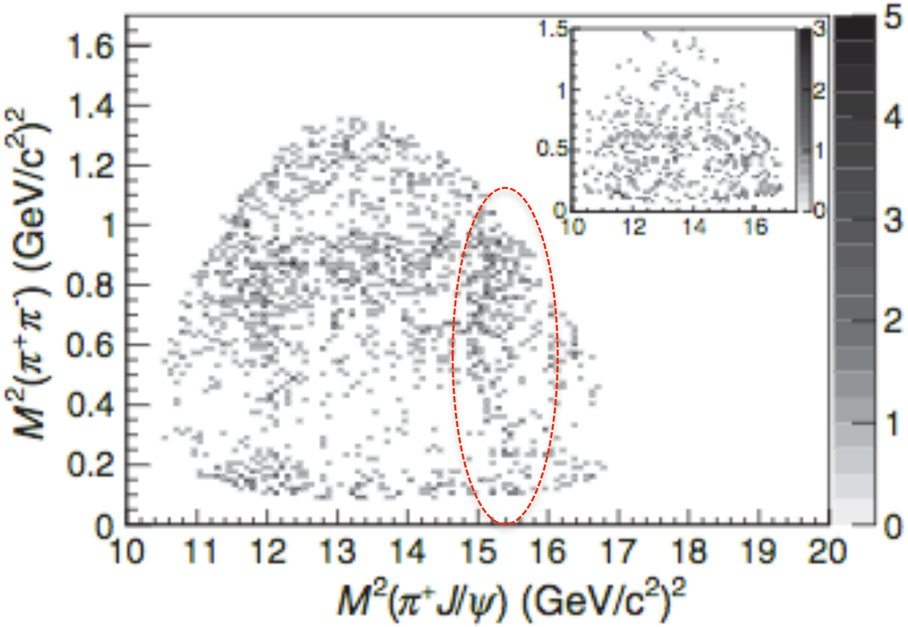


R-scan data

- Dozens of energy points with luminosity < 20 pb^{-1}
- Initially taken for R study, can also help the XYZ study

Zc(3900)$^{\pm}$ observed in $e^+e^- \rightarrow \pi^+\pi^- J/\psi$





- $e^+e^- \rightarrow \pi^+\pi^- J/\psi$
- Measured with 525pb^{-1} data at E_{cms}=4.26GeV
- The peak is not a kinematic reflection of $\pi^+\pi^-$ system
- Zc(3900) parameters, S-wave BW

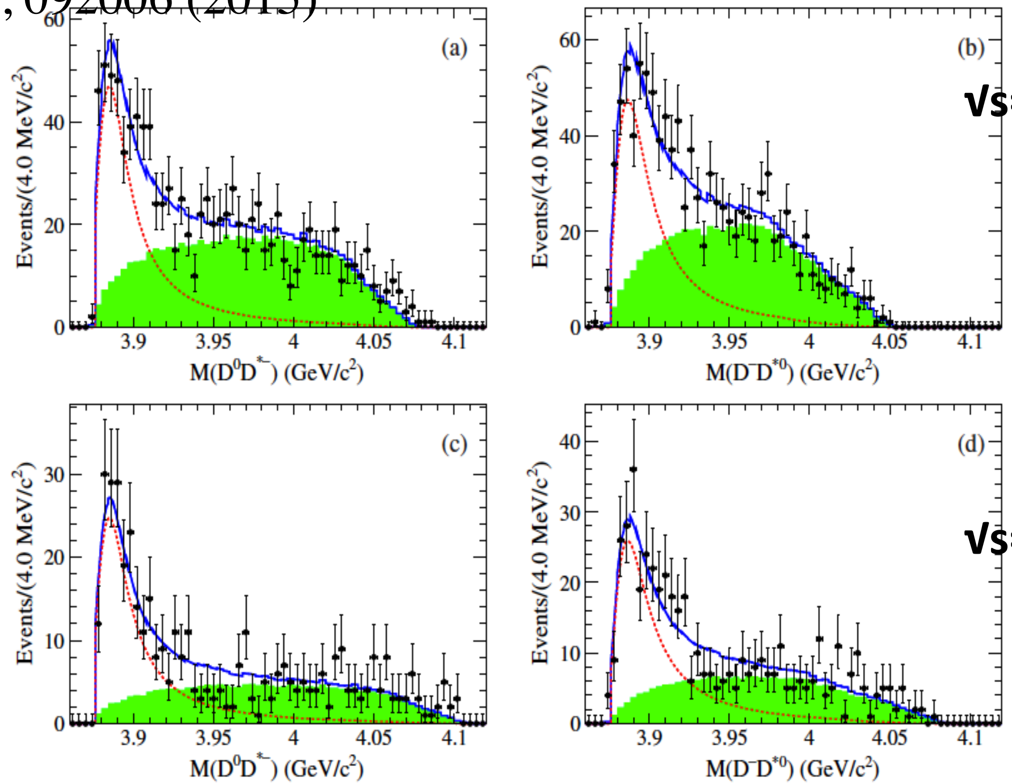
M=(3899.0±3.6±4.9) MeV, Γ=(46±10±20)MeV

$$R = \frac{\sigma(e^+e^- \rightarrow \pi^{\pm}Z_c(3900)^{\mp} \rightarrow \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi)} = (21.5 \pm 3.3 \pm 7.5)\%$$

$\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)\,pb$, $\quad \sigma(e^+e^- \rightarrow \pi^{\pm}Z_c(3900)^{\mp} \rightarrow \pi^+\pi^- J/\psi) \approx (13.5 \pm 5.2)\,pb$

Zc(3885)$^{\pm}$ observed in $e^+e^- \to \pi^{\pm} Z_c(3885)^{\pm} \to \pi^{\pm}(D\overline{D^*})^{\mp}$

PRL 112, 022001 (2014)
PRD 92, 092006 (2015)



√s=4.23GeV

√s=4.26GeV

$e^+e^- \to \pi^+(D^0 D^{*-})$ $e^+e^- \to \pi^+(D^- D^{*0})$

- ❑Using two data samples: 1092pb^{-1}@4.23GeV, 826pb^{-1}@4.26GeV
- ❑And using double tag method in two isospin process to select signal.
- ❑A simultaneous fit is performed to the events from two samples and two processes.

Zc(3885)$^{\pm}$

- Zc(3885)$^{\pm}$ is fitted with s-dependent Breit-Wigner

$$S_{\mathrm{I}}(m_{D\bar{D}^*}) \propto dN/dm_{D\bar{D}^*}$$
$$\propto (\kappa^*)^{2L+1} f_L^2(\kappa^*) |BW_{\mathrm{I}}(m_{D\bar{D}^*})|^2$$

$$BW_{\mathrm{I}}(m_{D\bar{D}^*}) \propto \frac{\sqrt{m_{D\bar{D}^*}\Gamma_{\mathrm{I}}}}{m_{Z_c}^2 - m_{D\bar{D}^*}^2 - i\frac{1}{2}m_{Z_c}(\Gamma_a + \Gamma_b)},$$

- The fitted m_{Zc}=(3890.3±0.8) MeV, Γ_{Zc}=31.5±3.3 MeV.
- The pole mass and width of Zc(3900) is

M=3881.7±1.6±1.6 MeV, Γ=26.6±2.0±2.1 MeV

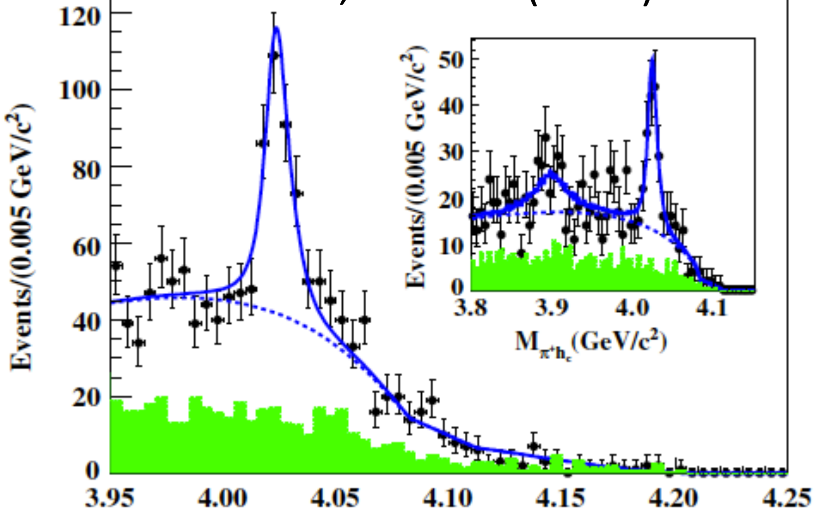
- The cross section@4.26GeV

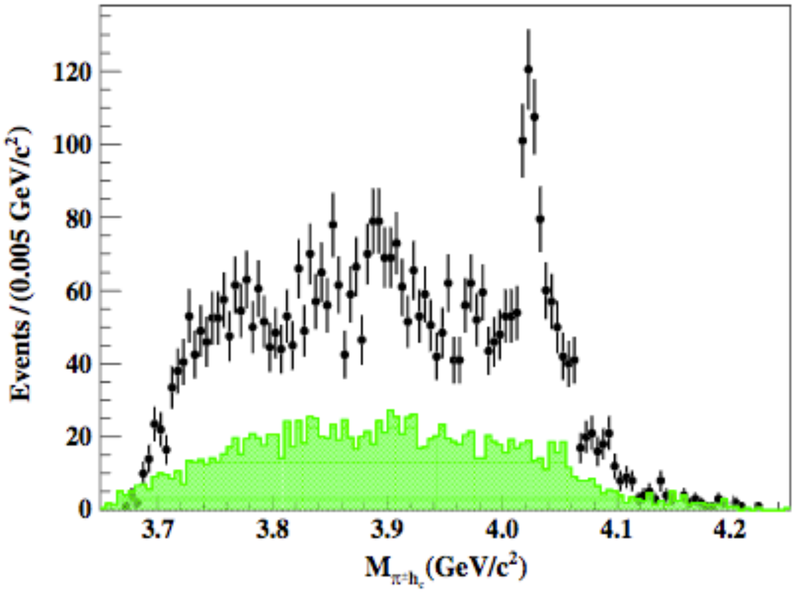
$$\sigma(e^+e^- \to \pi^\pm Z_c(3885)^\mp) \times Br(Z_c(3885)^\mp \to (DD^*)^\mp)$$
$$= (108.4 \pm 6.9 \pm 8.8)\,pb.$$

$$\frac{\Gamma(Z_c(3885) \to D\overline{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = 8.0 \pm 3.2 \qquad \frac{\Gamma(\psi(4040) \to D^{(*)}\overline{D}^{(*)})}{\Gamma(\psi(4040) \to \eta J/\psi)} = 192 \pm 27$$

$Z_c(4020)^{\pm}$ in $e^+e^- \rightarrow \pi^+\pi^- h_c$

PRL 111, 242001 (2013)





•The process used is $e^+e^- \rightarrow \pi^+\pi^- h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$16 exclusive modes.

•A simultaneous fit to the data at 4.23GeV, 4.26GeV and 4.36GeV gives

✓M(Zc(4020) $^{\pm}$)=4022.9±0.8±2.7 MeV, Γ(Zc(4020) $^{\pm}$)=7.9±2.7±2.6 MeV

✓significance of Zc(4020) >8.9σ, significance of Zc(3900) =2.1σ

❑J^{PC} of h_c is 1^{+-}, J^{PC} of J/psi is 1^{--} .

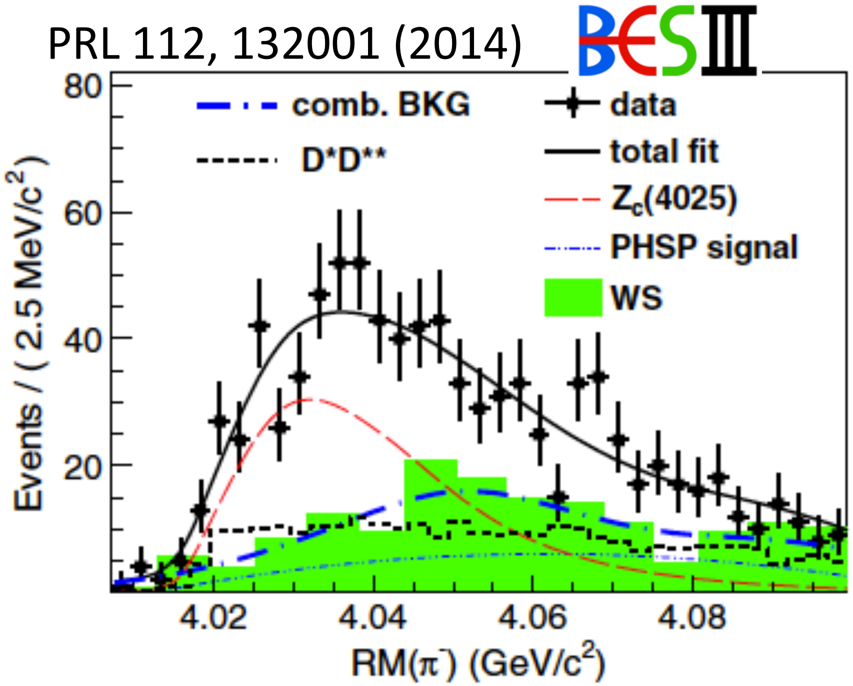
❑If Z_c is 1^+, $Z_c \rightarrow \pi J/\psi$ is dominated by S-Wave, $Z_c \rightarrow \pi h_c$ is P wave. Zc(3900)$\rightarrow \pi h_c$ might be suppressed by angular momentum barrier.

•Cross section@4.26GeV

$\sigma\,(e^+e^- \rightarrow \pi Zc(4020) \rightarrow \pi^+\pi^- hc)$=(7.4±1.7±2.1±1.2)pb

Zc(4025)$^{\pm}$ observed at the threshold of (D*D*) with $e^+e^- \to \pi^\pm (D^* \overline{D}^*)^\mp$

PRL 112, 132001 (2014)



- Measured with 827pb^{-1} data at E_{cms}=4.26GeV
- Zc(4025)$^{\pm}$ parameters, S-wave BW
  M=(4026.3±2.6±3.7) MeV,
  Γ=(24.8±5.6±7.7)MeV
- Significance > 10σ

$$\sigma(e^+e^- \to \pi^\pm (D^* \overline{D^*})^\mp) = 137 \pm 9 \pm 15\, pb \quad @4.26GeV$$

$$\frac{\sigma(e^+e^- \to \pi^\pm (Z_c)^\mp \to \pi^\pm (D^* \overline{D^*})^\mp)}{\sigma(e^+e^- \to \pi^\pm (D^* \overline{D^*})^\mp)} = 0.65 \pm 0.09 \pm 0.06\, pb \quad @4.26GeV$$

$$\frac{\Gamma(Z_c(4025) \to D^* \overline{D}^*)}{\Gamma(Z_c(4020) \to \pi h_c)} = 12.1 \pm 5.4$$

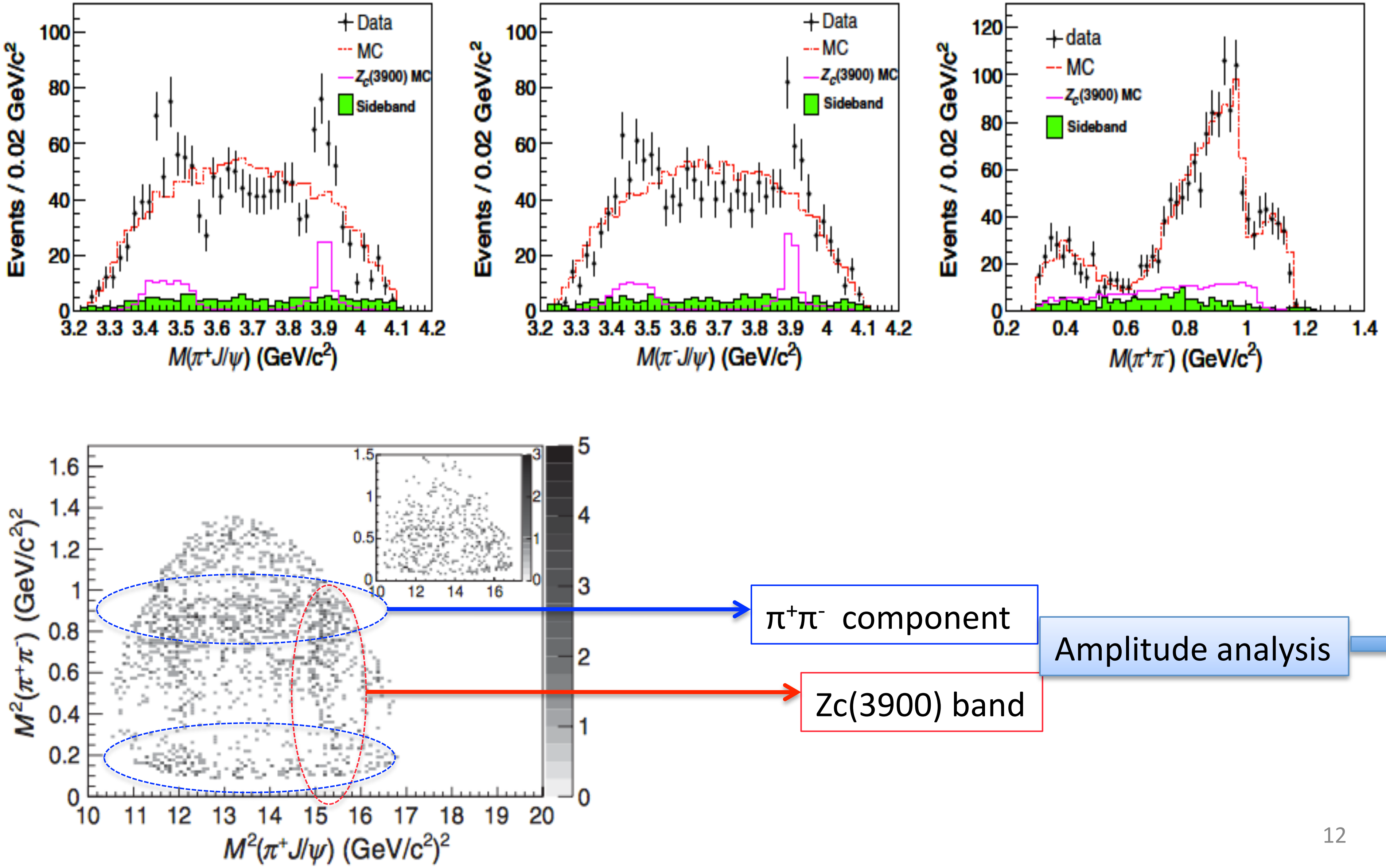
The BESIII result for Zc family

For reference: the mass threshold of m(DD*)~3875MeV, M(D*D*)~4014MeV

- **Is Zc(3900) and Zc(3885) same sates? Zc(4020) and Zc(4025)?**

	C/N	channel	Mass (MeV)	Width (MeV)	σ(ee→πZc, Zc→...) @4.26GeV pb
Zc(3900)	charged	$\pi^{\pm} J/\psi$	3899.0±3.6±4.9	46±10±20	13.5±5.2
	Neutral	$\pi^{0} J/\psi$	3894.8±2.3±2.7	29.6±8.2±8.2	4.0±0.9
Zc(3885)	charged	$(DD^*)^{\pm}$	3881.7±1.6±1.6	26.6±2.0±2.1	108.4±6.9±8.8
	Neutral	$(DD^*)^{0}$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	47±9±10
Zc(4020)	Charged	$\pi^{\pm} h_c$	4022.9±0.8±2.7	7.9±2.7±2.6	7.4±1.7±2.1±1.2
	Neutral	$\pi^{0} h_c$	4023.9±2.2±3.8	Fixed	8.5±2.9±1.1±1.3
Zc(4025)	charged	$(D^*D^*)^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7	89.0±18.7
	Neutral	$(D^*D^*)^{0}$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	23.0±6.0±1.0	43.4±8.0±5.4

Amplitude analysis for $e^+e^- \rightarrow \pi^+\pi^- J/\psi$



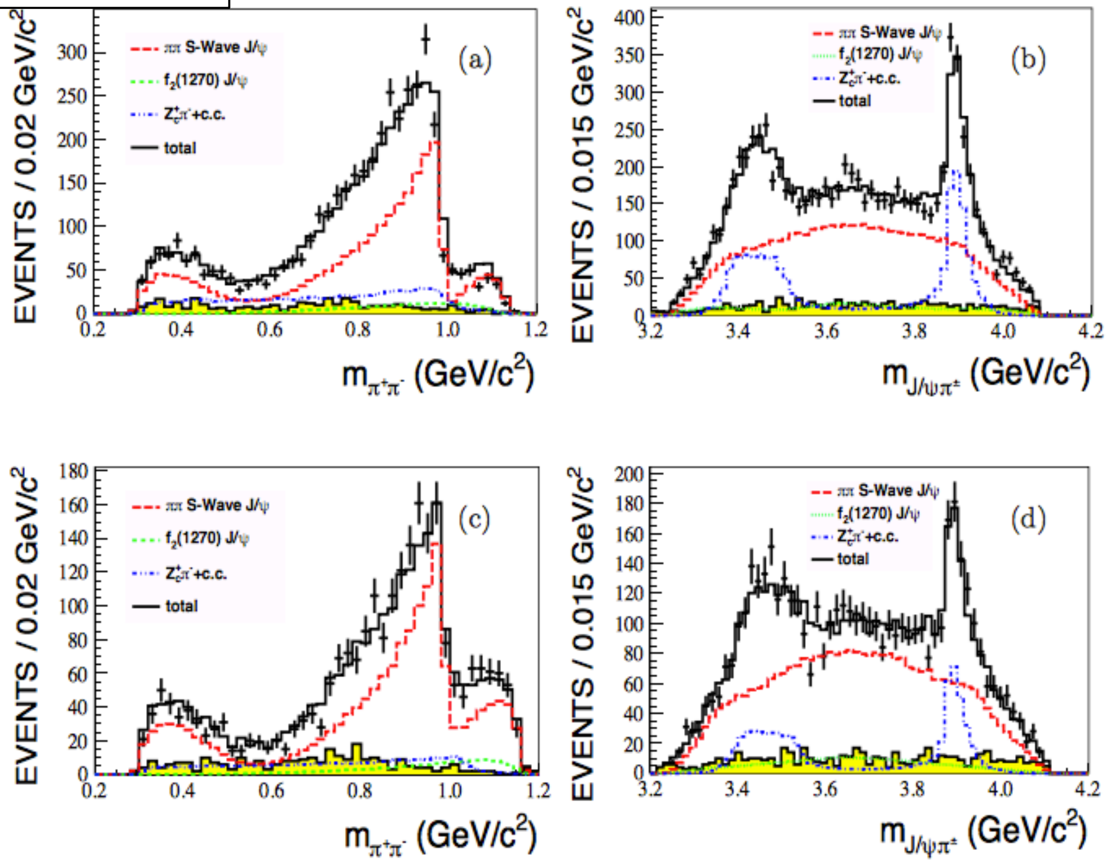
$\pi^+\pi^-$ component

Zc(3900) band

Amplitude analysis

Determination of J^P of Zc(3900)

PRL 119, 072001 (2017)



√s=4.23GeV

√s=4.26GeV

- ❑Amplitude analysis with helicity formalism formalism taking $\pi^+\pi^- J/\psi$ as final states
- ❑Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- ❑$\pi^+\pi^-$ spectrum is parameterized with σ, $f_0(980)$, $f_0(1370)$ and $f_2(1270)$

Determination of J^p of Zc(3900)

- **Zc is parameterized with Flatte formula**

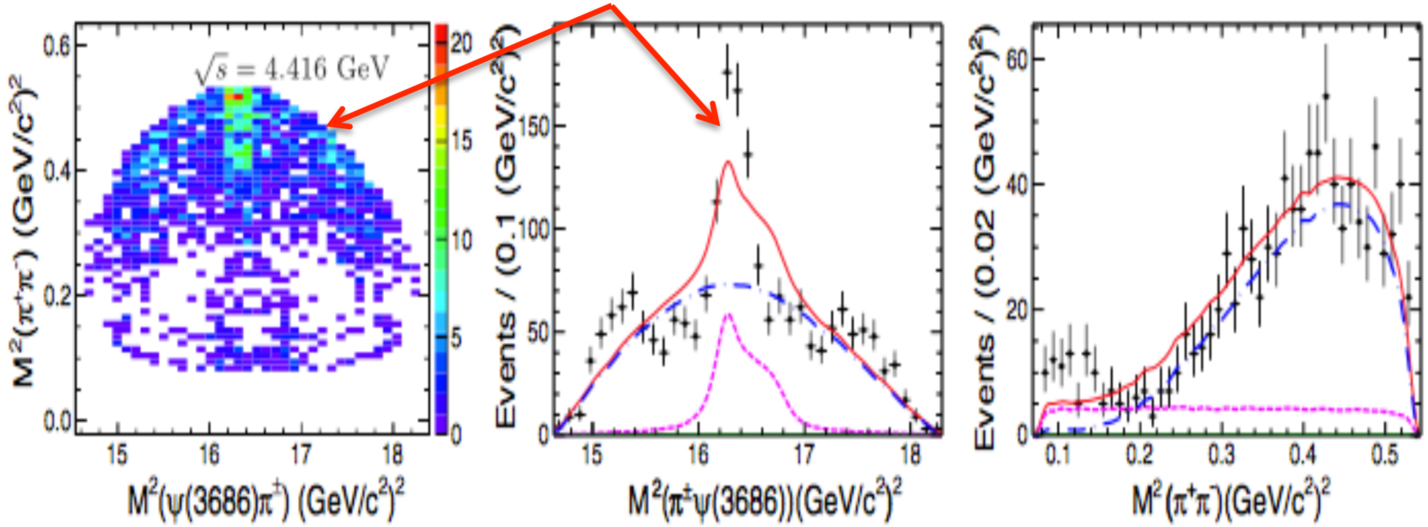
$$BW(s, M, g'_1, g'_2) = \frac{1}{s - M^2 + i[g'_1\rho_1(s) + g'_2\rho_2(s)]}$$

- **M=（3901.5±2.7±38.0）MeV, g_1'=(0.075±0.006±0.025)GeV^2, g_2'/g_1'=27.1±2.0±1.9**

  Which corresponding to pole Mass=（3881.2±4.2±52.7）MeV, pole width=（51.8±4.6±36.0)MeV
- **J^p of Zc favor to be 1^+ with statistical significance larger than7σ over other quantum numbers**
- **The significance of Zc(4020) process is found to be 3σ**

Structure in $\pi^+\pi^-\psi'$

PRD 96, 032004 (2017) **Zc(4020)?**



√s=4.416GeV

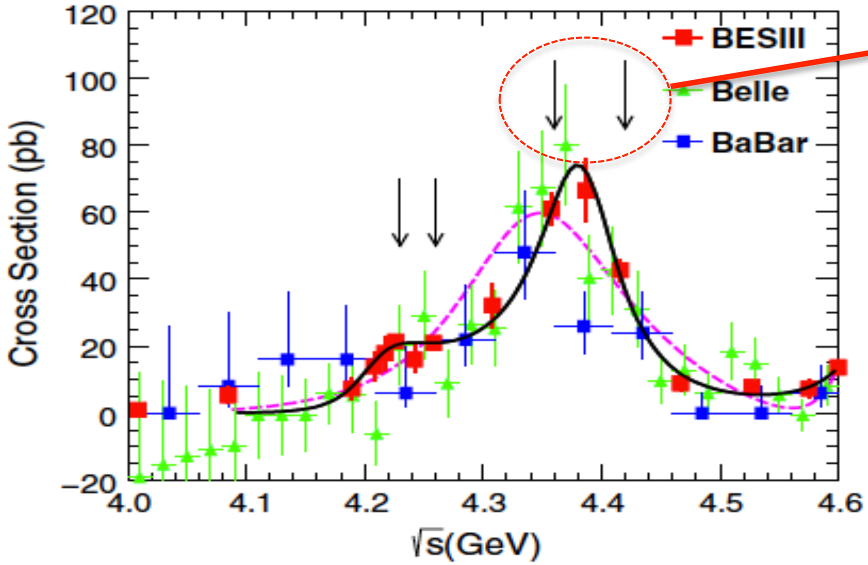
- **A narrow peak around 4.03GeV is observed on M($\pi^\pm\psi'$),**
- **a 2D fit is performed on dalitz plot. Where x, y represent $M^2(\pi^+\psi')$, $M^2(\pi^-\psi')$**

$$\frac{p\cdot q/c^2}{(M_R^2-x)^2+M_R^2\cdot\Gamma^2/c^4}+\frac{p\cdot q/c^2}{(M_R^2-y)^2+M_R^2\cdot\Gamma^2/c^4}$$

- **M=4032.1±2.4 MeV, Γ =26.1±5.3 MeV**

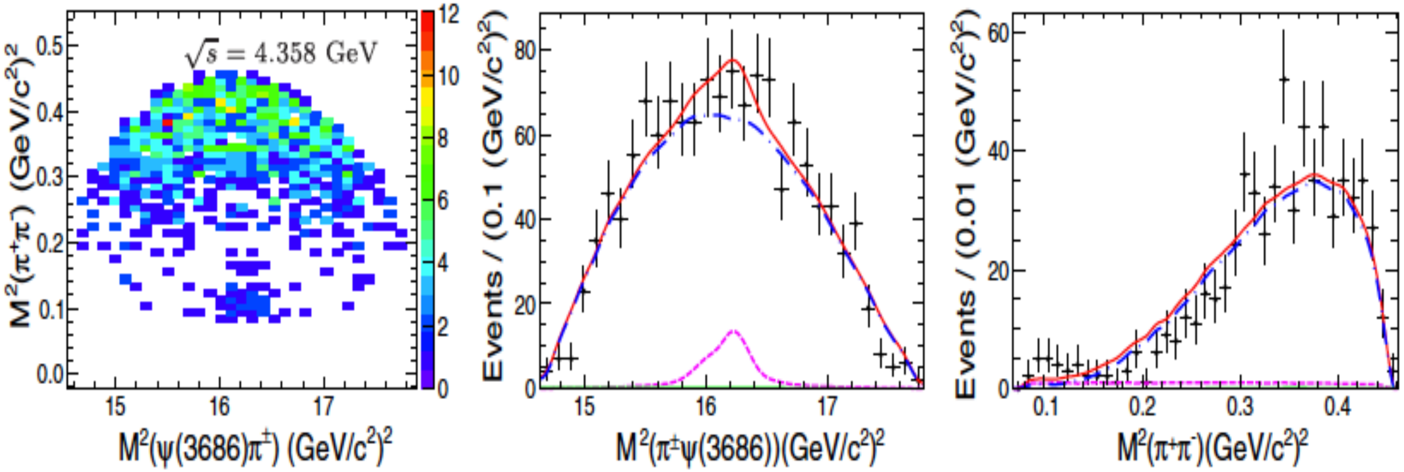
The fit quality is bad.

Structure in $\pi^+\pi^-\psi'$



√s=4.416GeV and √s=4.358GeV are both at the Y(4360) peak?

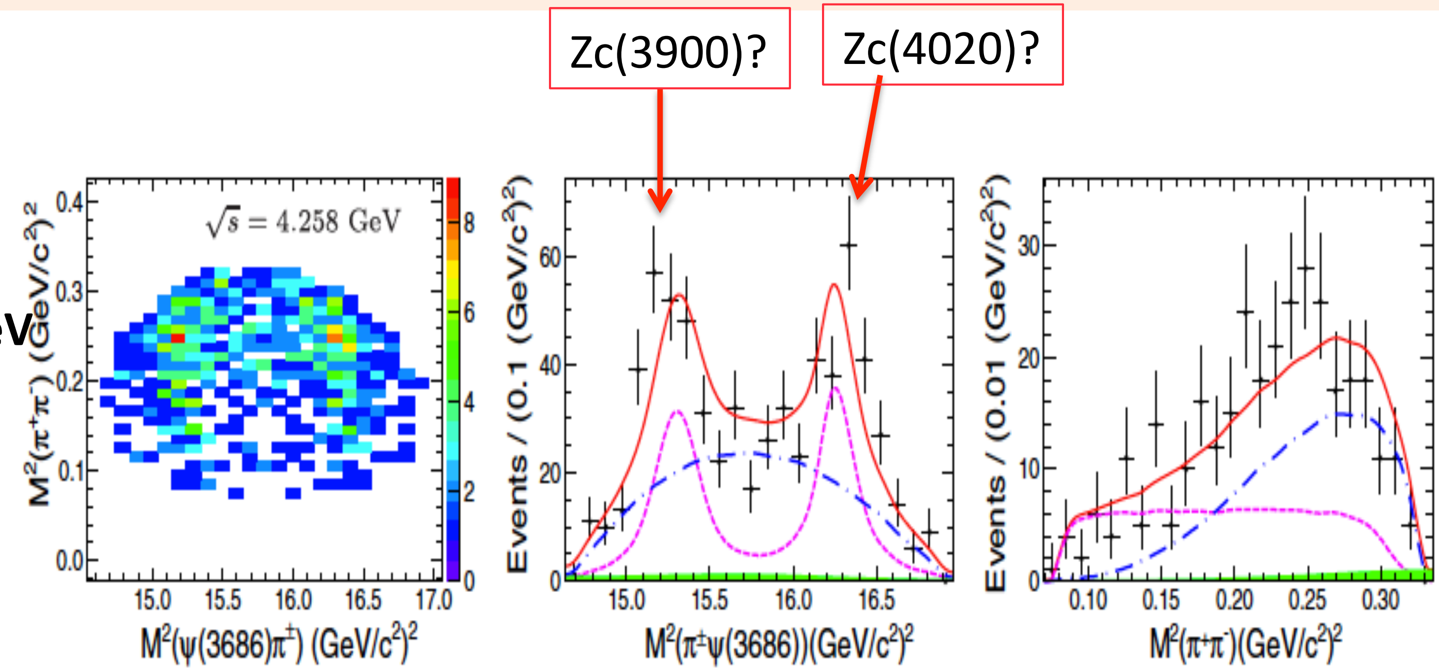
√s=4.358GeV



Where is the Zc(4020) peak if 4.416GeV and 4.358GeV are both dominant from Y(4360)?

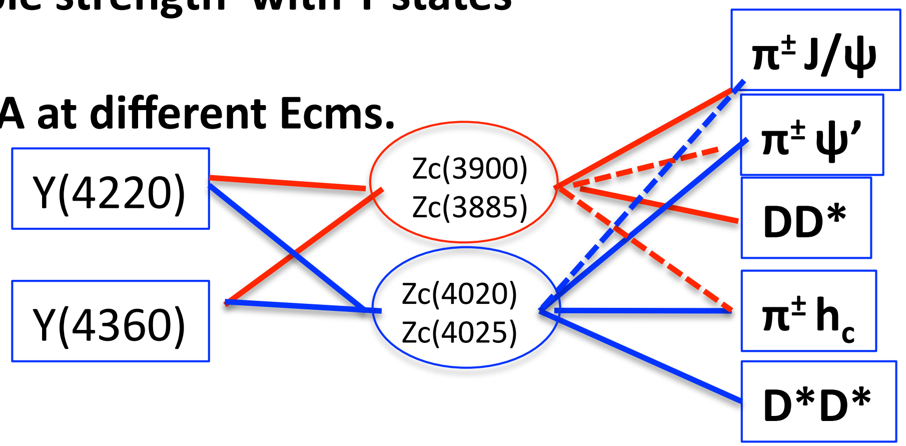
Structure in $\pi^+\pi^-\psi'$

√s=4.258GeV



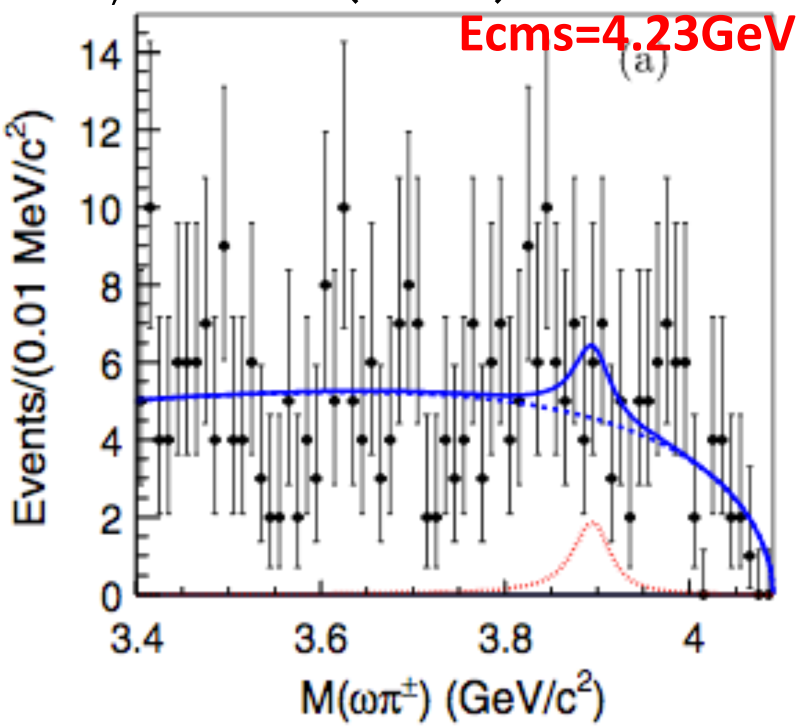
- ❑At a certain Ecms, it might has overlap between different Y states.
- ❑Different Zc states have different couple strength with Y states
- ❑One Zc decay to different channels
- ❑ To clarify their relation, we need PWA at different Ecms.

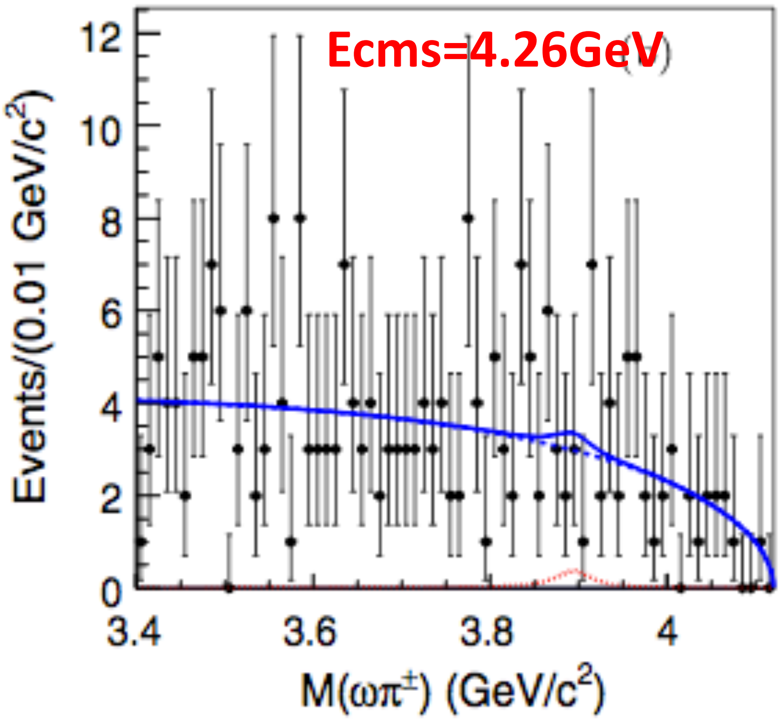
Coupled channels analysis?



Search for Zc(3900)→$\pi^{\pm}$ ω with e^+e^-→$\pi^+\pi^-$ ω

PRDD 92,032009 (2015)





- This channel doesn’t contain charmonium final sates.
- The significance at Ecms=4.23GeV is 1.2σ,

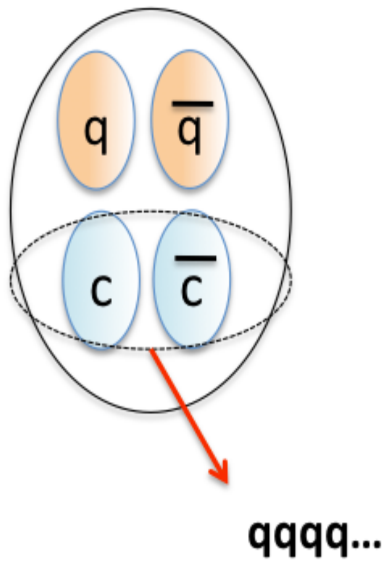
$$\sigma(e^+e^- \to \pi^{\pm} Z_c(3900)^{\mp}, Z_c(3900)^{\mp} \to \omega\pi^{\mp}) < 0.26\, pb$$

- The significance at Ecms=4.26GeV is 0.1σ

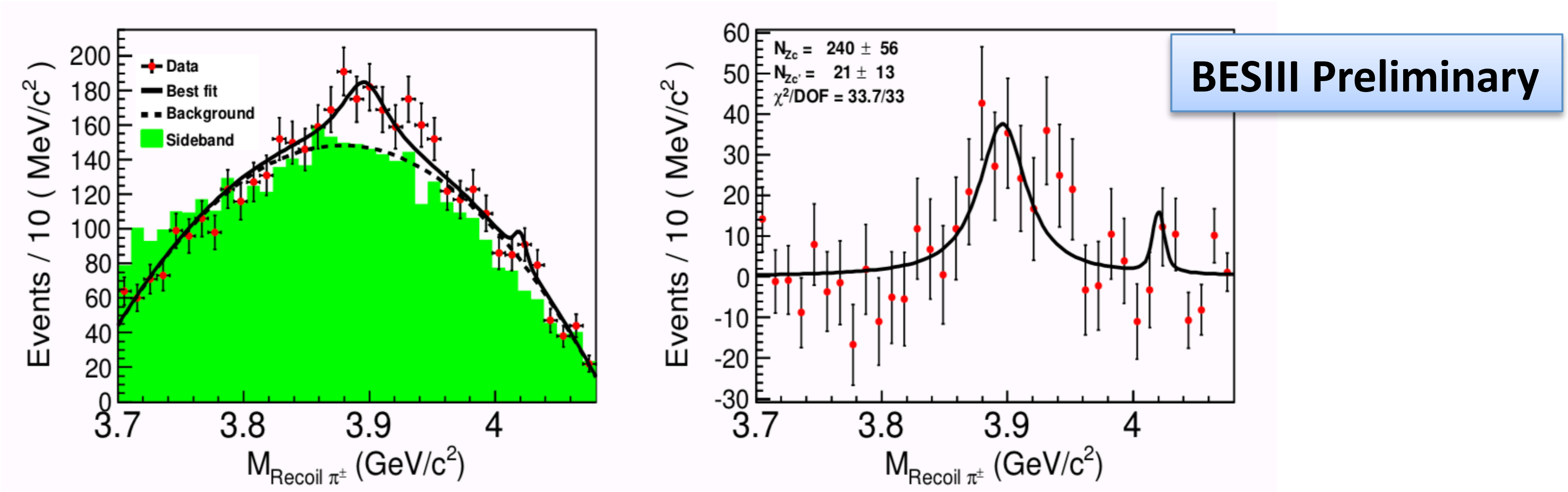
$$\sigma(e^+e^- \to \pi^{\pm} Z_c(3900)^{\mp}, Z_c(3900)^{\mp} \to \omega\pi^{\mp}) < 0.18\, pb$$

Search for Zc(3900)→$\pi^\pm \omega$ with $e^+e^- \to \pi^+\pi^- \omega$

- σ (Zc(3900)→$\pi^\pm \omega$) is very small means the ccbar annihilation rate in Zc(3900) is very small



Search for $e^+e^- \rightarrow \pi Z_c^{(\prime)}, Z_c^{(\prime)} \rightarrow \rho\, \eta_c$

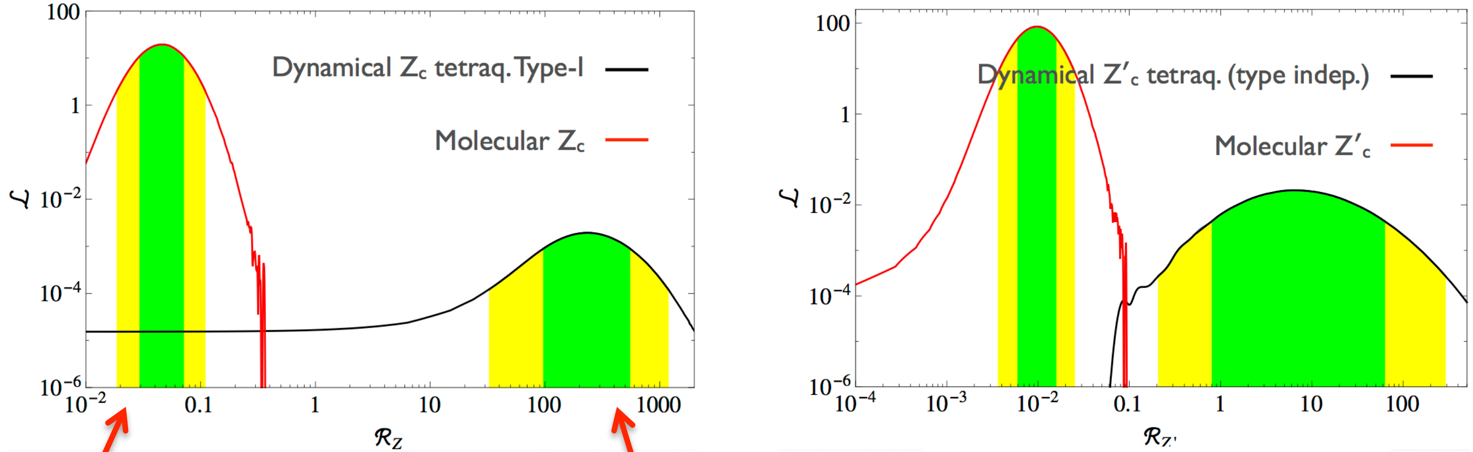


$e^+e^- \rightarrow \pi Z_c, Z_c \rightarrow \rho\, \eta_c$ @ 4.23 GeV

- ❑Nine η_c channels are used to reconstruct η_c.
- ❑After the η_c and ρ mass window, a hint of Z_c(3900) peak can be seen on the recoiled mass of the bachelor π.
- ❑The green histogram is η_c sideband. Z_c parameter are fixed to latest measurement.

- ❑Strong evidence of Zc(3900) → $\rho\eta_c$ is observed at $\sqrt{s}$=4.23GeV, with statistical significance 4.3σ(3.9σ including systematic uncertainty)
- ❑No significant Zc'(4020)→ $\rho\eta_c$ observed.

Theoretical prediction for this channel



$$R_z = \frac{Br(Z_c \to \rho\eta_c)}{Br(Z_c \to \pi J/\psi)} \qquad R_{z'} = \frac{Br(Z_c' \to \rho\eta_c)}{Br(Z_c' \to \pi h_c)}$$

A.Esposito et.al., PLB 746(2015), 194-201

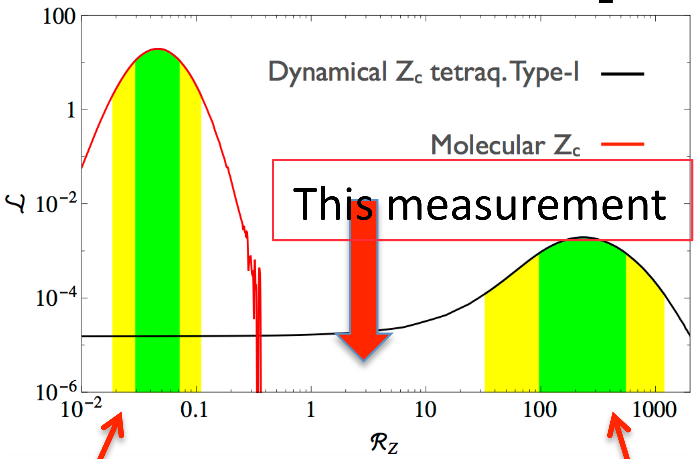
Molecular Zc

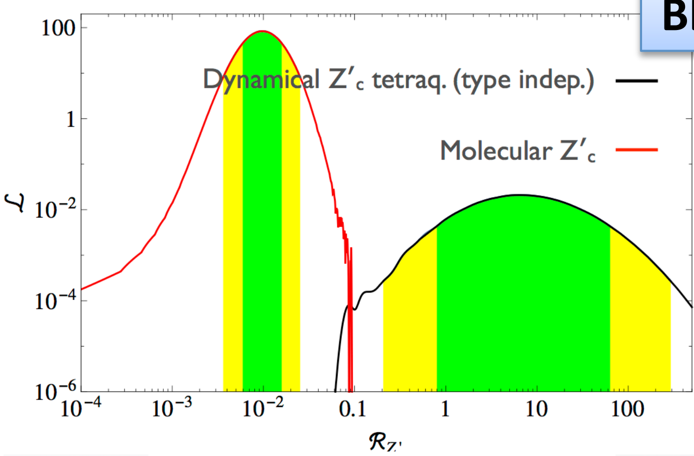
Tetraquak Type-1

- ❑**This channel is important for the discrimination between different multi-quark schemes.**
- ❑**The green band and yellow band show the 1σ and 2σ confidence range of the corresponding theoretical model.**

Comparison between measurement and prediction

BESIII Preliminary





$$R_z = \frac{Br(Z_c \to \rho\eta_c)}{Br(Z_c \to \pi J/\psi)}$$

$$R_{z'} = \frac{Br(Z_c' \to \rho\eta_c)}{Br(Z_c' \to \pi h_c)}$$

A.Esposito et.al., PLB 746(2015), 194-201

Molecular Zc

Tetraquak Type-1

- **The cross section measured at √s= 4.23GeV**

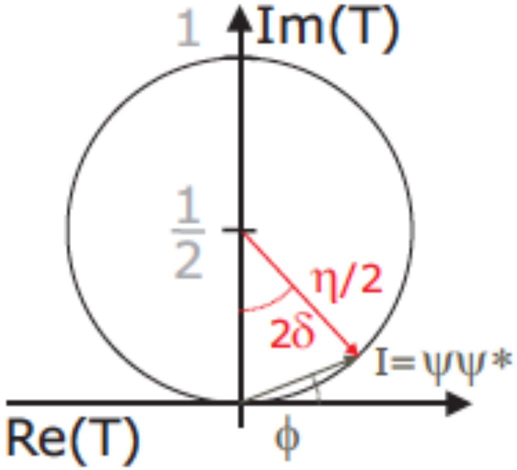
$$\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c) = (46 \pm 12 \pm 10)\text{pb}$$
$$\sigma^B(e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c) = (47 \pm 11 \pm 11)\text{pb}$$

$$R_z = 2.1 \pm 0.8$$

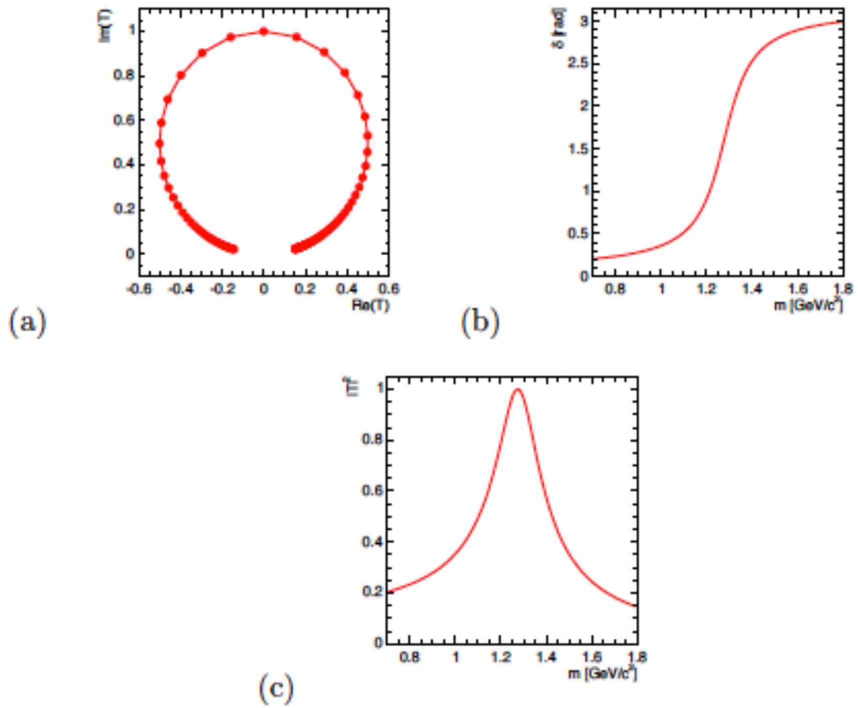
- **Our measurement doesn't agree with neither molecular Zc Assumption nor tetraquark Zc Type-1**

Something about Argand Plot

Definition of Argand Plot



arXiv:hep-ph/0412069 v1

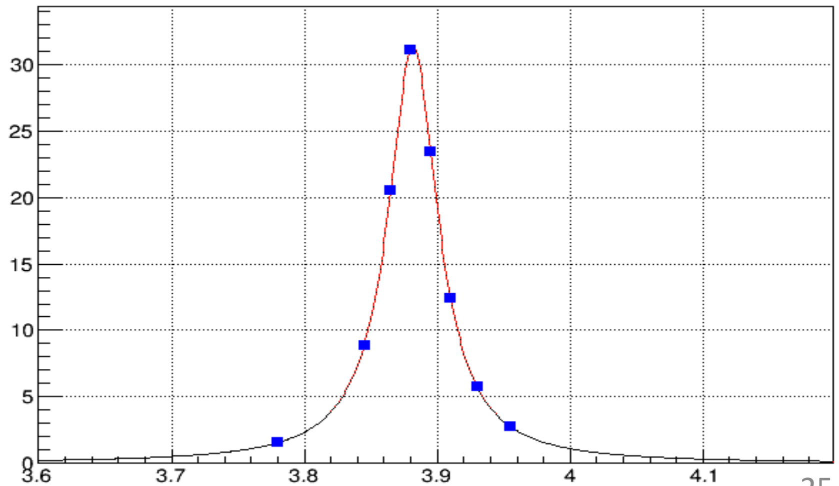


. 2. – Simple relativistic Breit-Wigner. (a) Argand, (b) phase δ and (c) intensity plot.

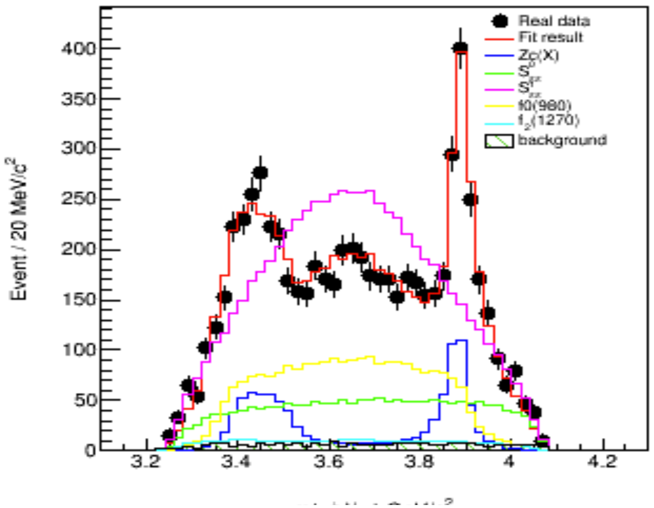
Argand Plot: The 2D plot of imaginary part vs. Real part of T matrix (propagator)

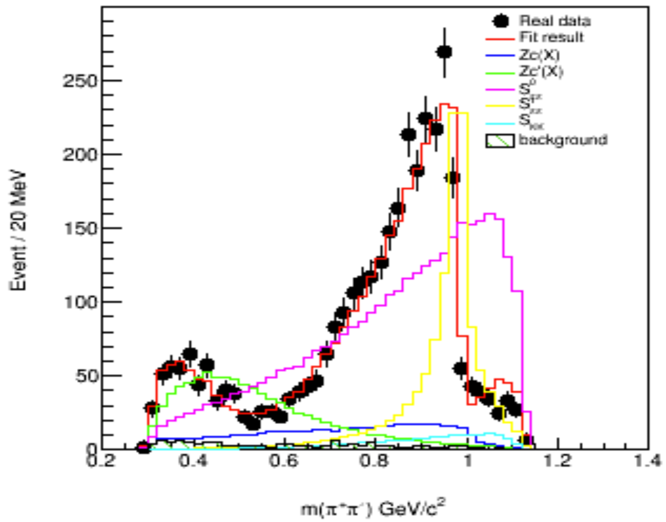
Method to get the Argand plot

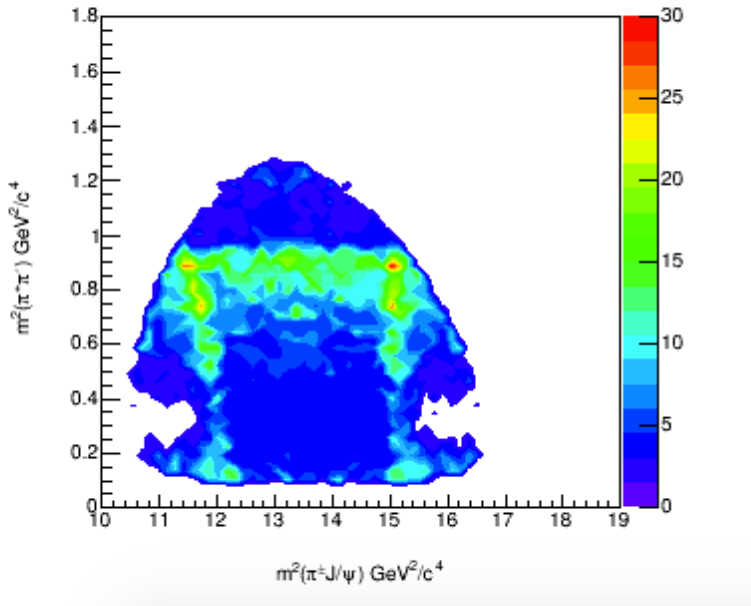
- Select 8 Knot points: 3.78, 3.845, 3.865, 3.88, 3.895, 3.91, 3.93, 3.955 around Zc(3900)
- And the amplitude value at these knots points are represented by complex number.
- The amplitude at other energy between the knots are gotten with interpolate method. The complex number will be determined by fit.



Problem I of Argand plot study







1. It require a clear understanding of other Components in the process

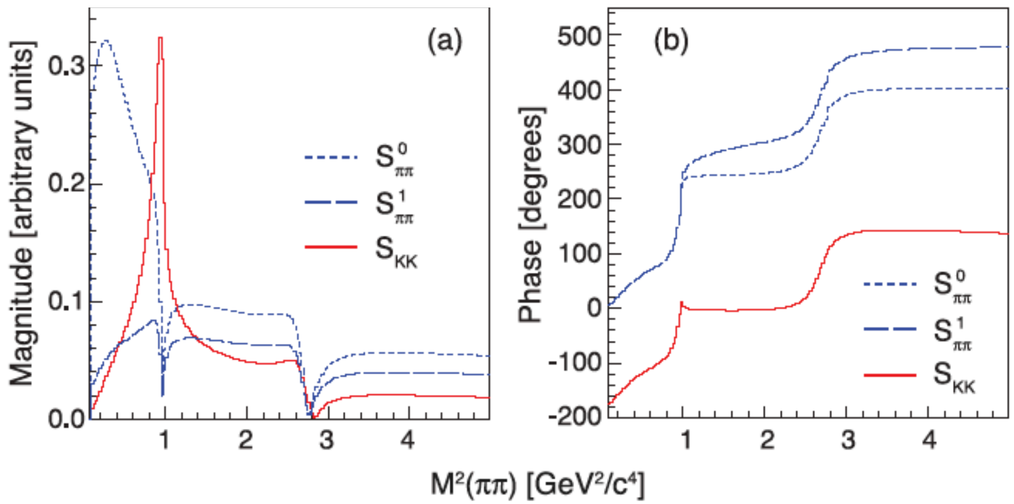
As we can see from the dalitz plot, the vertical Band of Zc can interference with the horizental Band of (ππ) component.

Different (ππ) parameterization method will influence the Argand plot of Zc

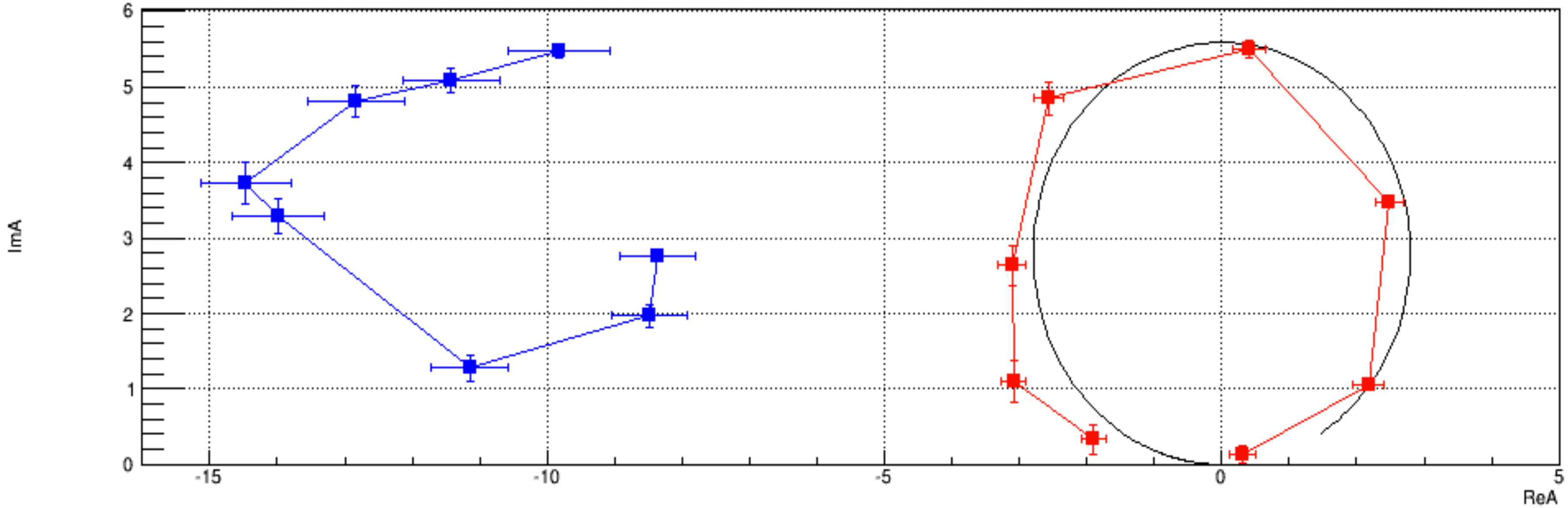
- Parameterization 1: σ (600)+ $f_0(980)+f_0(1370)+f_2(1270)$
- Parameterization 2: The ππ→ππ and KK→ππ scattering amplitude is written in N/D form,

$$S_{\pi\pi}(s) = \frac{1 + z(s) + z(s)^2 + \ldots}{D(s)} = S^0_{\pi\pi} + c_1 S^1_{\pi\pi}(s) + c_2 S^2_{\pi\pi}(s) + \ldots$$

$$z(s) = \frac{\sqrt{s+s_0} - \sqrt{4m_k^2 - s}}{\sqrt{s+s_0} + \sqrt{4m_k^2 - s}}$$



Different (ππ) parameterization method will influence the Argand plot of Zc



•Toy MC is generated with (ππ) parameterization method 1, and Zc is represented with Breit-Wigner

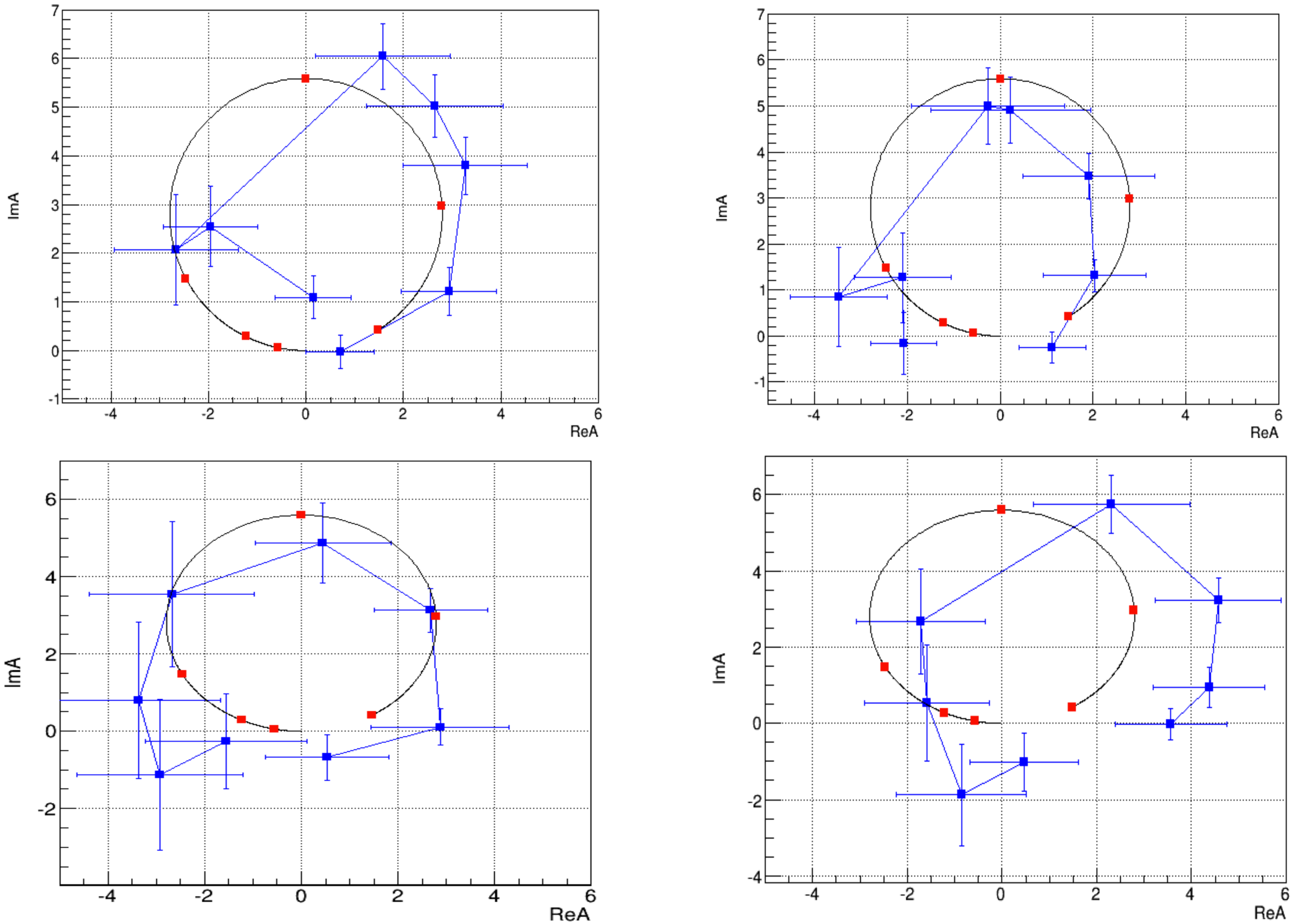
•When getting Argand plot, the red points are from the fit when (ππ) is also parameterized with Method 1.

•The blue points are from the fit when (ππ) is parameterized with method 2, we can see they are quite different.

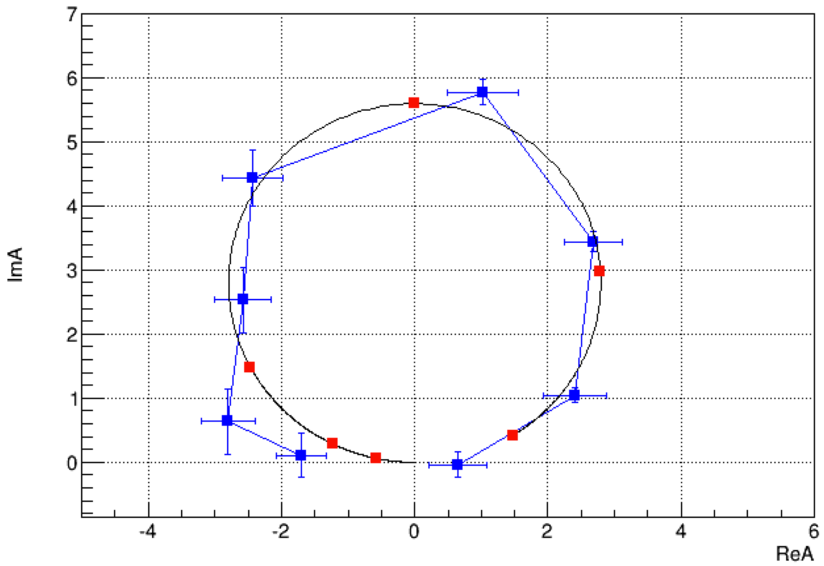
Problem II: need enough statistics

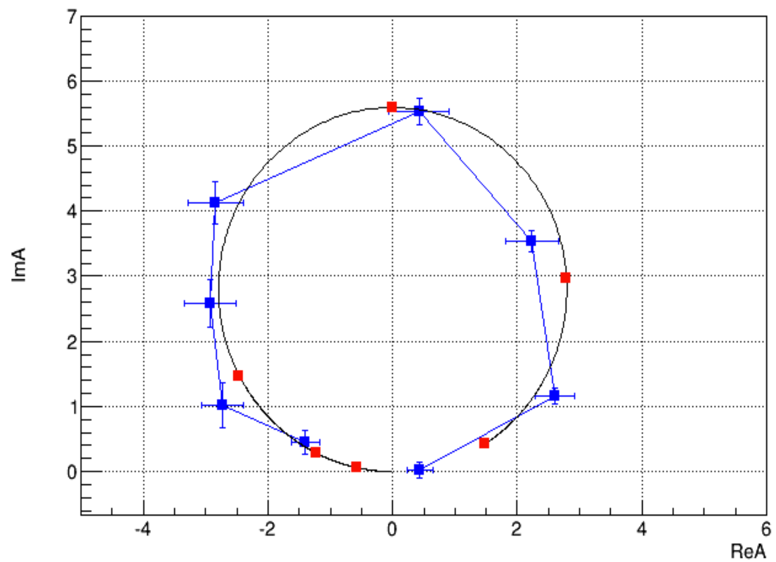
- DIY MC check:
- To make the Input-Output check and to check how many events can give a reliable argand plot, DIY MC is generated according to the realdata fit result with Zc as a Breit-Wigner function. So we exactly know the (ππ) parameterization in this MC.
- We then randomly pick 4 samples which have same signal number as realdata (N(Zc)≈15%×N(ππJ/ψ)≈480), the Argand plots is shown in next slide. Large fluctuation can be seen.

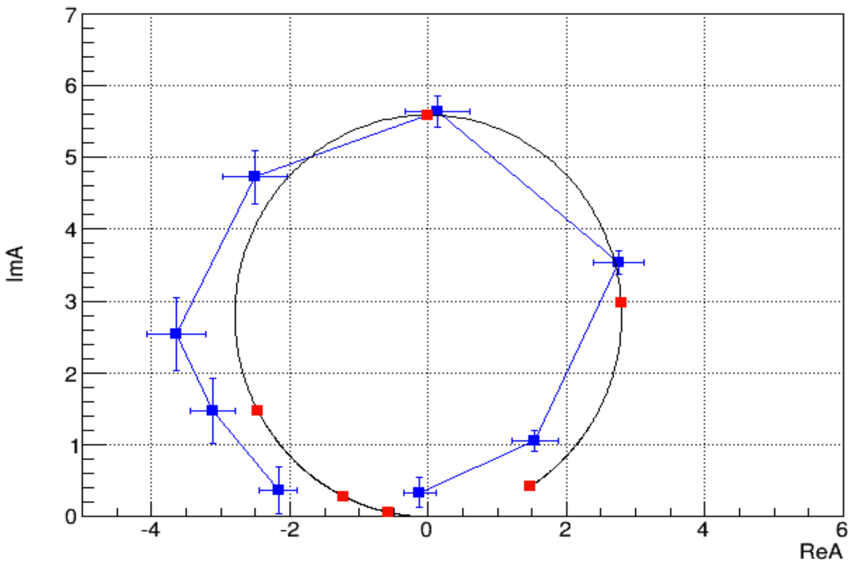
The argand plot from 4 DIYmc samples which has 1X realdata event number

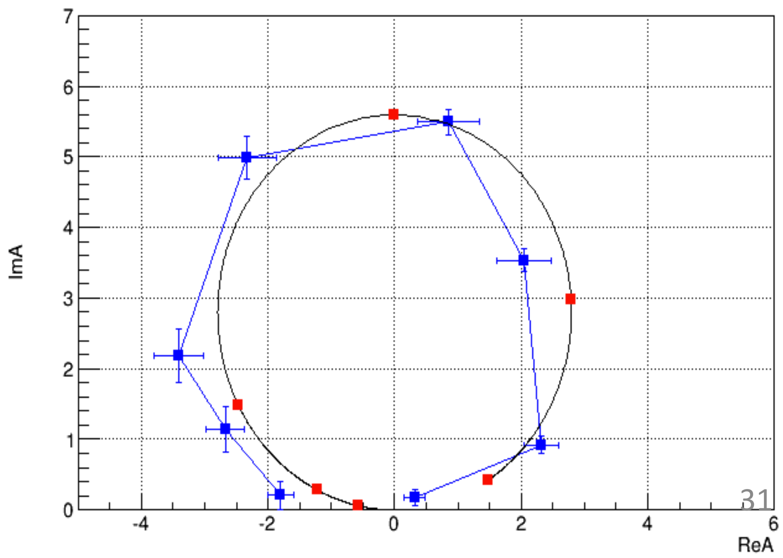


The argand plot from 4 DIYmc samples which has 10X realdata event number



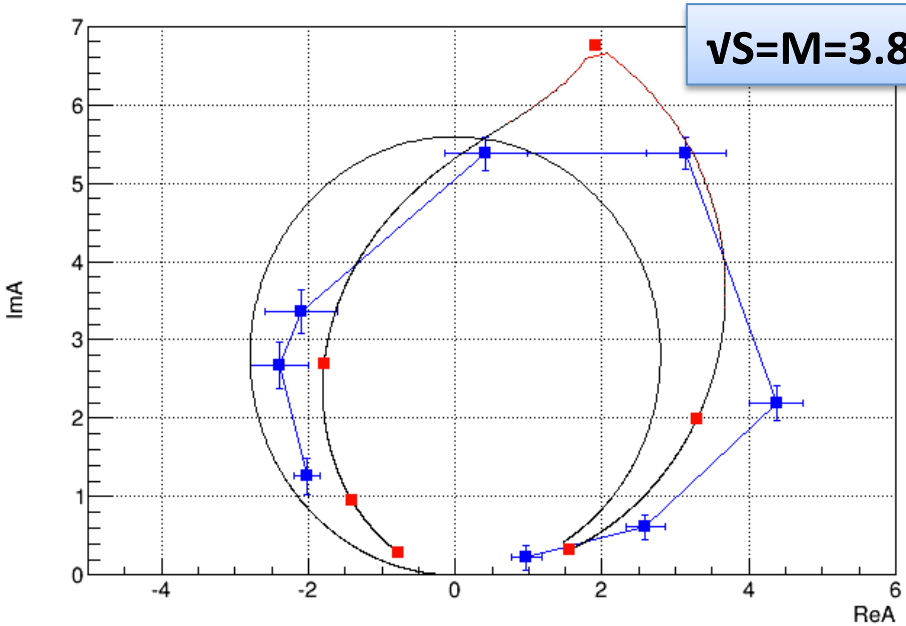






DIY MC check

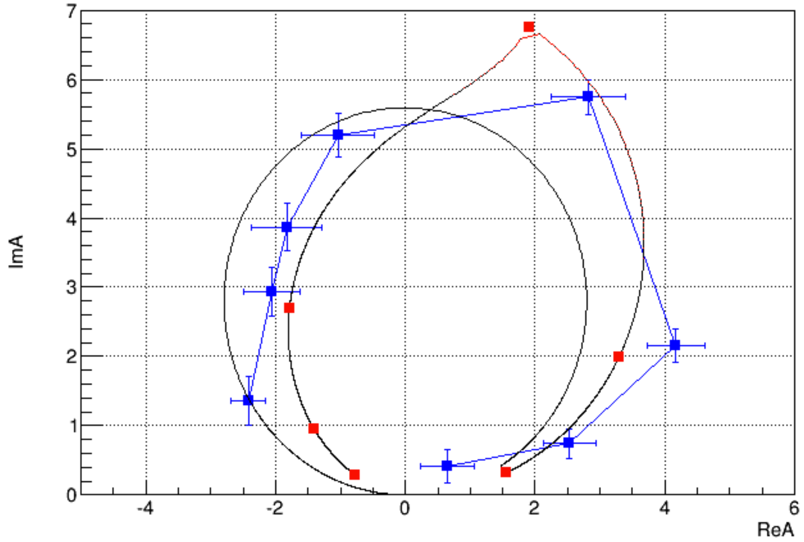
- We also generate DIY MC according to the realdata fit result with Zc as a Flatte function.
- We then randomly pick 4 samples which have 10 times of signal number as realdata, the argand plots is shown

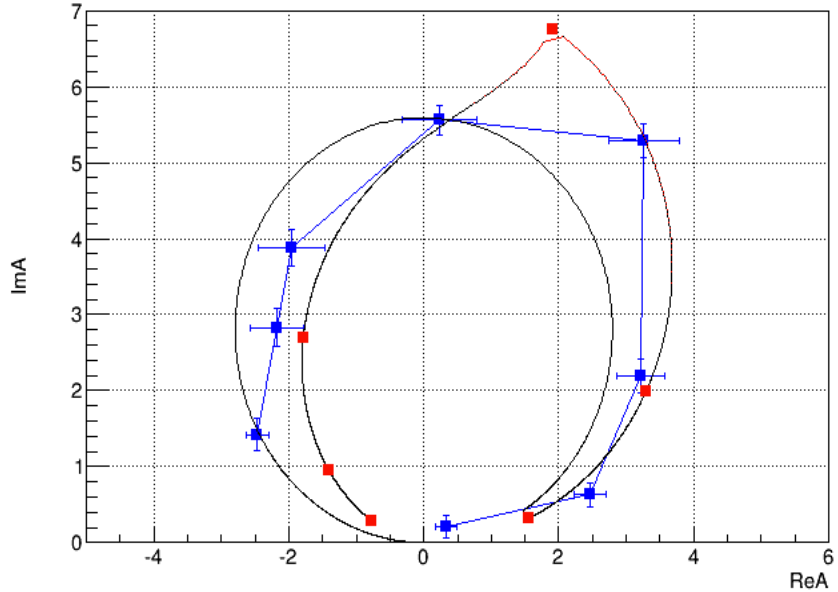


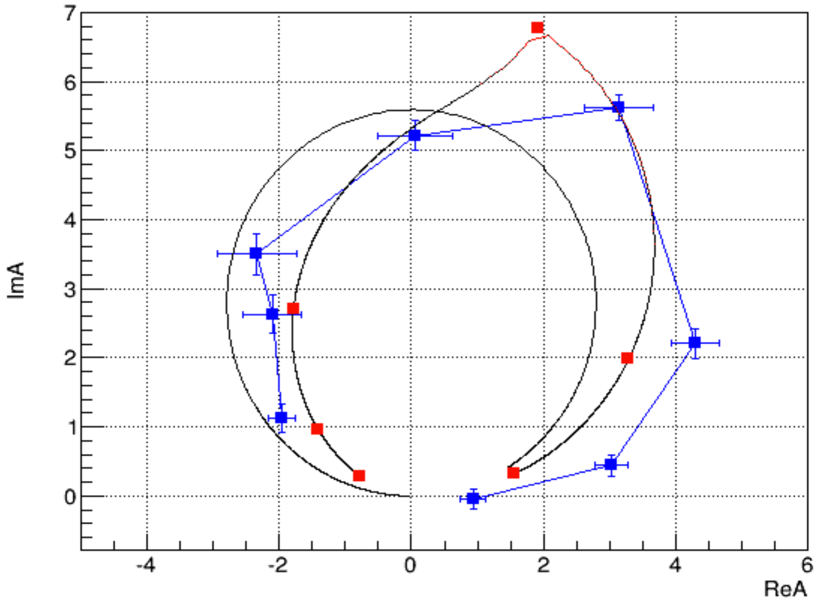
√S=M=3.87984=m(D)+m(D*)

The blue points are amplitude at 8 knot points:
3.78, 3.845, 3.865, 3.88, 3.895, 3.91, 3.93, 3.955
The red points are
3.8, 3.86, 3.87984, 3.92, 3.98, 4.1
The black circle is a Breit-Wigner with Mass = 3.8817, width =0.0461 which is the fitted parameter to real data

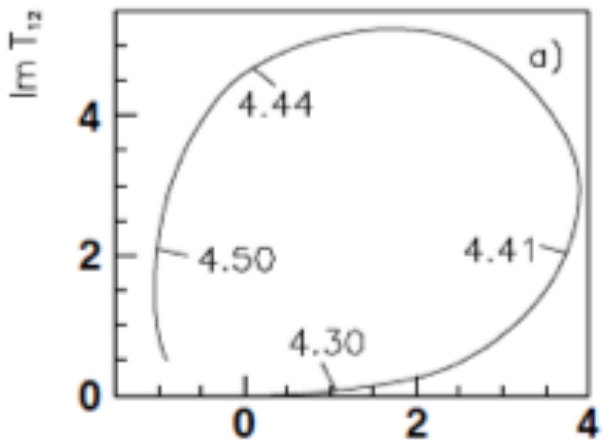
Argand plots from other 3 samples







Problem III: How distinctive of the Argand plot from different models



arXiv:0802.0934v2

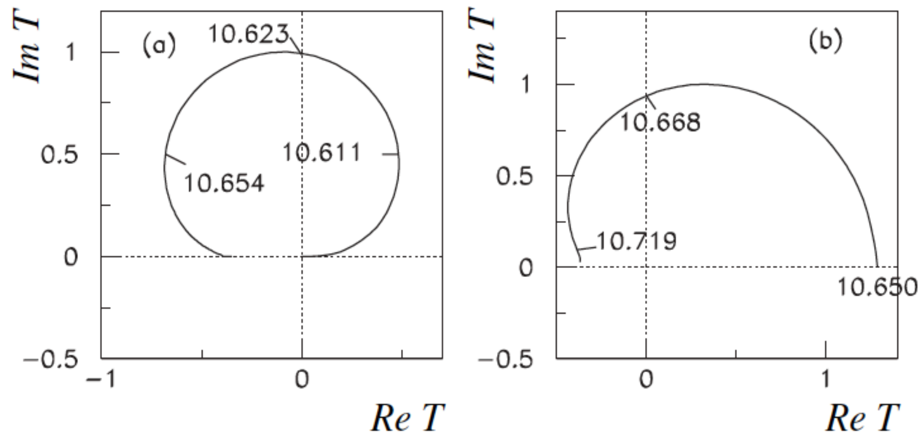


Fig. 4: Argand diagrams for (a) $B^*\bar{B} \to B^*\bar{B}$, (b) $B^*\bar{B}^* \to B^*\bar{B}^*$; numbers are masses in GeV.

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Some conclusion from reference papers.

CUSP alone cant't produce a resonance.

But with the additional strong enough attraction from meson exchange, a resonance can Be generated, otherwise , a virtual state is generated.

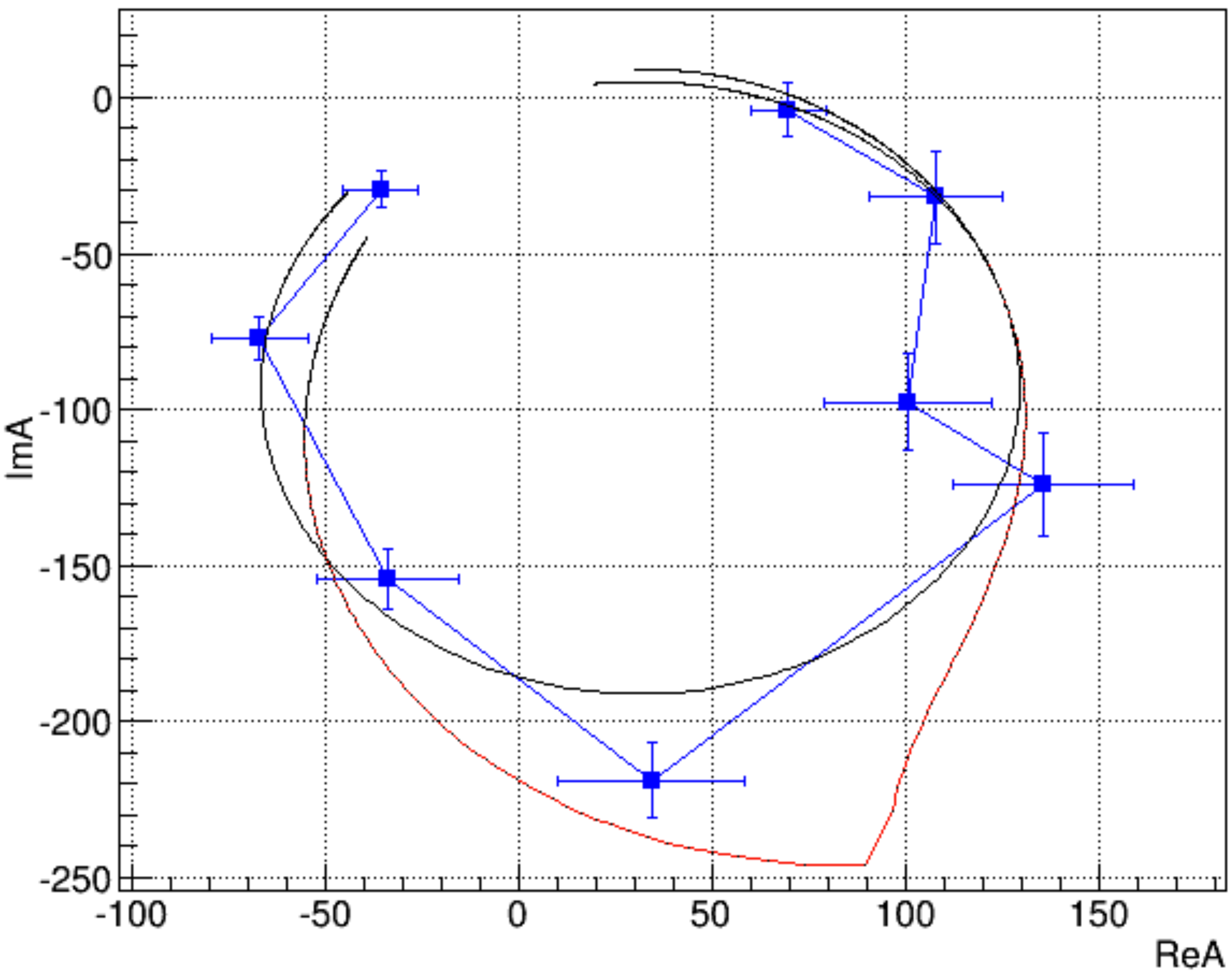
The argand plot from cusp effect can be very similar to a ordinary resonance. While it can also be very weird and distinctive.

Two Zc partner's width should be almost same, eg. (Zc(3900) from DD* loop, should have Similar width with Zc(4020) from D*D* loop)

Y(4260) should dominant decay to DD*/D*D* to produce strong enough attraction.

Summary

- After the discovery of Zc states, we have tried some new ideas to understand these states' relation and properties
  - ✓ PWA to get the J^p of Zc(3900)
  - ✓ Searching new decay channels under the theorist's guidance
- More PWA work is needed for further understanding of these states. The entanglement between XYZ states require PWA which is challenging, simultaneous analysis of coupled channels and multi-energy points.
- A reliable argand plot need more data


0
-50
-100
-150
-200
-250
ImA
-100
-50
0
50
100
150
ReA