# Search for $Z_c(3900)$ decays to $\omega\ \pi$
# and
# Search for the isospin violating decay $Y(4260) \to J/\psi \eta \pi^0$


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# Search for $Z_c(3900)$ decays to $\omega\ \pi$

# Introduction

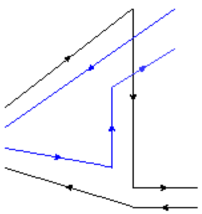
Zc(3900):

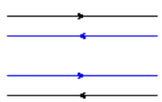
- What we know we know: I=1,JP=1+; slightly above D*D threshold; decays to J/psi pi and D*D;
- What we know we don’t know -- its nature
  - molecule?
  - tetraquark?
  - hadro-charmonium?
  - cusp?
  - triangle singularity?

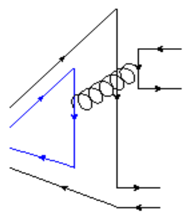
# Introduction (cont.)

**Exploring new decay modes is crucial to ID the near threshold structures: genuine QCD states, dynamical generated, threshold effects, …**

**Strong decays of charmonium-like states: 3 important modes**





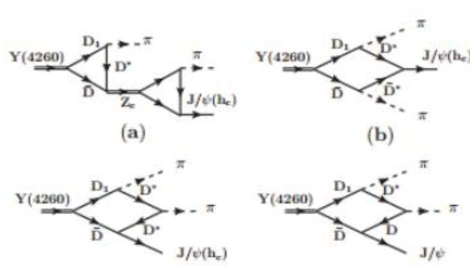


Hidden charm Open charm **ccbar Annihilation**

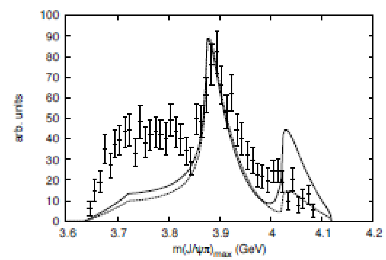
**-- a unique signature**

**Involving with threshold effects**, e.g.

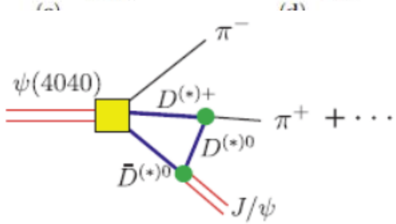
**Meson loop models: [PRL 111 132003, PLB 725 106] and references therein**




**Cusp: [PRD 91 034009, Europhys. Lett. 96, 11002]**




**ISPE model: [PRD88 036008] and references therein**




**LQCD studies provide theoretical support for the *X*(3872)** [PRL 111 192991] **but no evidence for *Zc*(3900) is found**

[PLB 727 172, PRD 89 094506, PRD 91 914594, arxiv:1410.8828, arxiv:1411.1389].

* Those studies were carried out on small volumes with unphysically heavy up and down quarks.

# annihilation to light hadrons plays an important role in charmonium decays

**LHCb, Eur.Phys.J. C73 (2013) 2462**

$$\frac{\mathcal{B}(X(3872)\to p\bar{p})}{\mathcal{B}(X(3872)\to J/\psi\pi^+\pi^-)} < 2.0\times 10^{-3}.$$

This limit challenges some of the predictions for the molecular interpretations of the $X(3872)$ state and is approaching the range of predictions for a conventional $\chi_{c1}(2P)$ state [16, 17].

a slide borrowed from Prof. Jin's talk at 1st XYZ workshop

## Zc → light hadrons (LH)

- **Γ (eta_c→LH exclusive) ~ 400keV**
- **Γ (Zc→LH exclusive) > 400keV ?**
- **C.f.: Γ (Zc→piJ/psi) ~ 5MeV (~20% BR of 30MeV total width)**

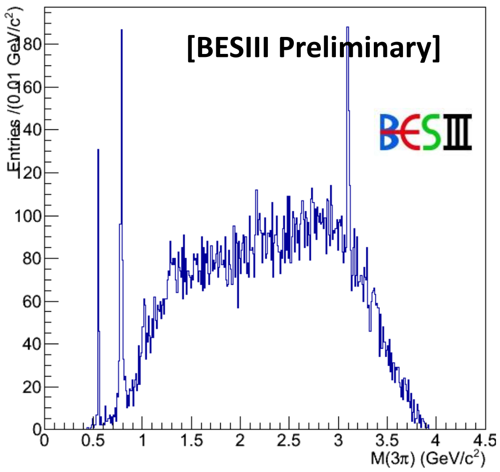
**→**

**Γ (Zc→ LH exclusive) / Γ (Zc→pi/Jpsi) ~10%???**

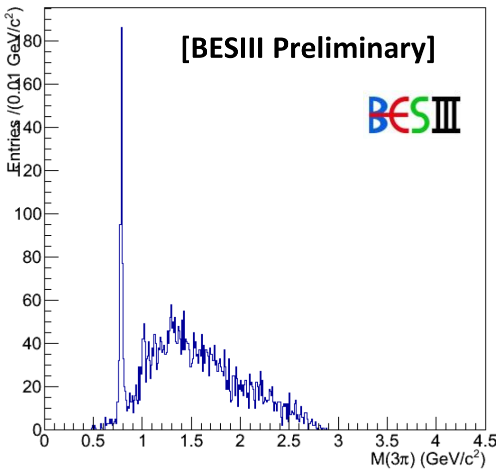
**Estimates of annihilation widths to light hadrons will be order of magnitude guesses at best due to uncertainties in wave function effects and QCD corrections.*

# $e^+e^- \rightarrow \omega\, \pi^+ \pi^- \rightarrow 2(\pi^+ \pi^-)\, \pi^0$

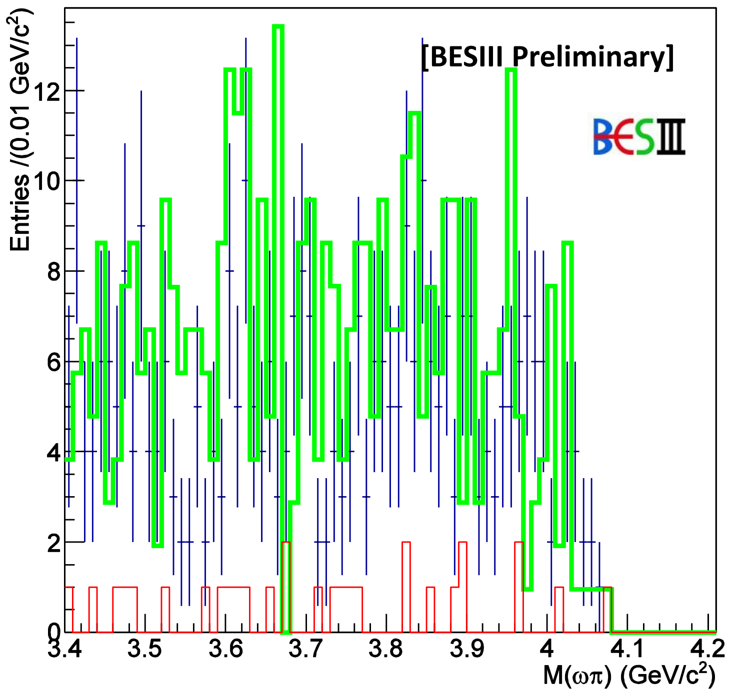
M(3π)




All 4 combinations/ event



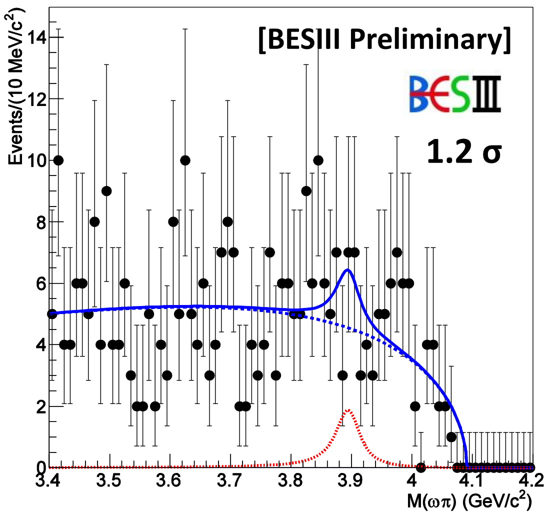

Closest to ω



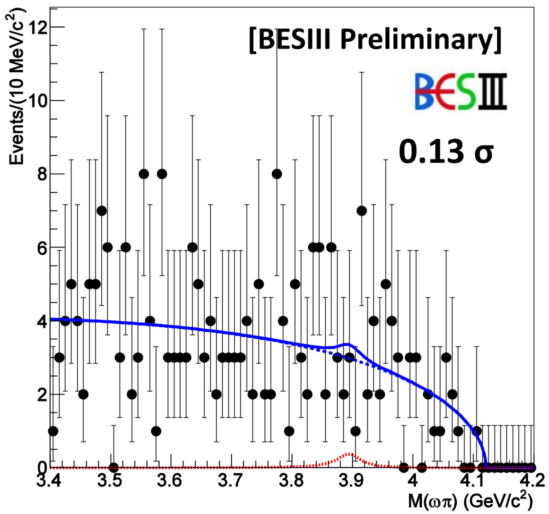

M(ω π)

The dots with error bars show the invariant mass distribution of $M(\omega\pi^{\pm})$ for $e^+e^- \rightarrow \omega\, \pi^+ \pi^-$ candidates @ 4230. The red histogram is for the ω sidebands. The green histogram shows the backgrounds from inclusive MC sample, which is dominantly from continuum.

# No significant $Z_c \rightarrow \omega\pi$




1094 $pb^{-1}$ @4230




827 $pb^{-1}$ @4260

- Fitting with acceptance weighted S-wave BW folded with Gaussian + ARGUS BG
  - No interference is considered

# Summary

- **No significant $Z_c \rightarrow \omega\,\pi$ is observed in 4230 data sets nor 4260 data sets**

**@4230 : [BESIII Preliminary] $\sigma(e^+e^- \rightarrow Z_c^{\pm}\pi^{\mp}, Z_c \rightarrow \omega\,\pi) <$ 0.27 pb**

**@4260: [BESIII Preliminary] $\sigma(e^+e^- \rightarrow Z_c^{\pm}\pi^{\mp}, Z_c \rightarrow \omega\,\pi) <$ 0.18 pb**

- **Comparing to the sum of $\sigma(e^+e^- \rightarrow Z_c^{\pm}\pi^{\mp}, Z_c \rightarrow J/\psi\pi)$ and $\sigma(e^+e^- \rightarrow Z_c^{\pm}\pi^{\mp}, Z_c \rightarrow D^*D)$ , the decay width , $Z_c \rightarrow \omega\,\pi$ is smaller than 0.2 % of Zc's total width.**

*<tens of keV*

- **The non-observation of $Z_c \rightarrow \omega\,\pi$ (a typical decay mode of a $1^+$ resonance) may indicate that the annihilation of ccbar in Zc is suppressed.**

- **No resonant structure in J/ψπ was seen in $\bar{B}^0 \rightarrow J/\psi\pi^+\pi^-$ by BELLE and $\bar{B}^0 \rightarrow J/\psi\pi^+K^-$ by LHCb or in $\gamma p \rightarrow J/\psi\pi^+ n$ by COMPASS.**
- **Complementary to the searches for Zc(3900) production, exploring new Zc(3900) decay mode provides a significant input to clarify its dynamical origin.**

# Search for the isospin violating decay $Y(4260) \to J/\psi \eta \pi^0$

# Introduction

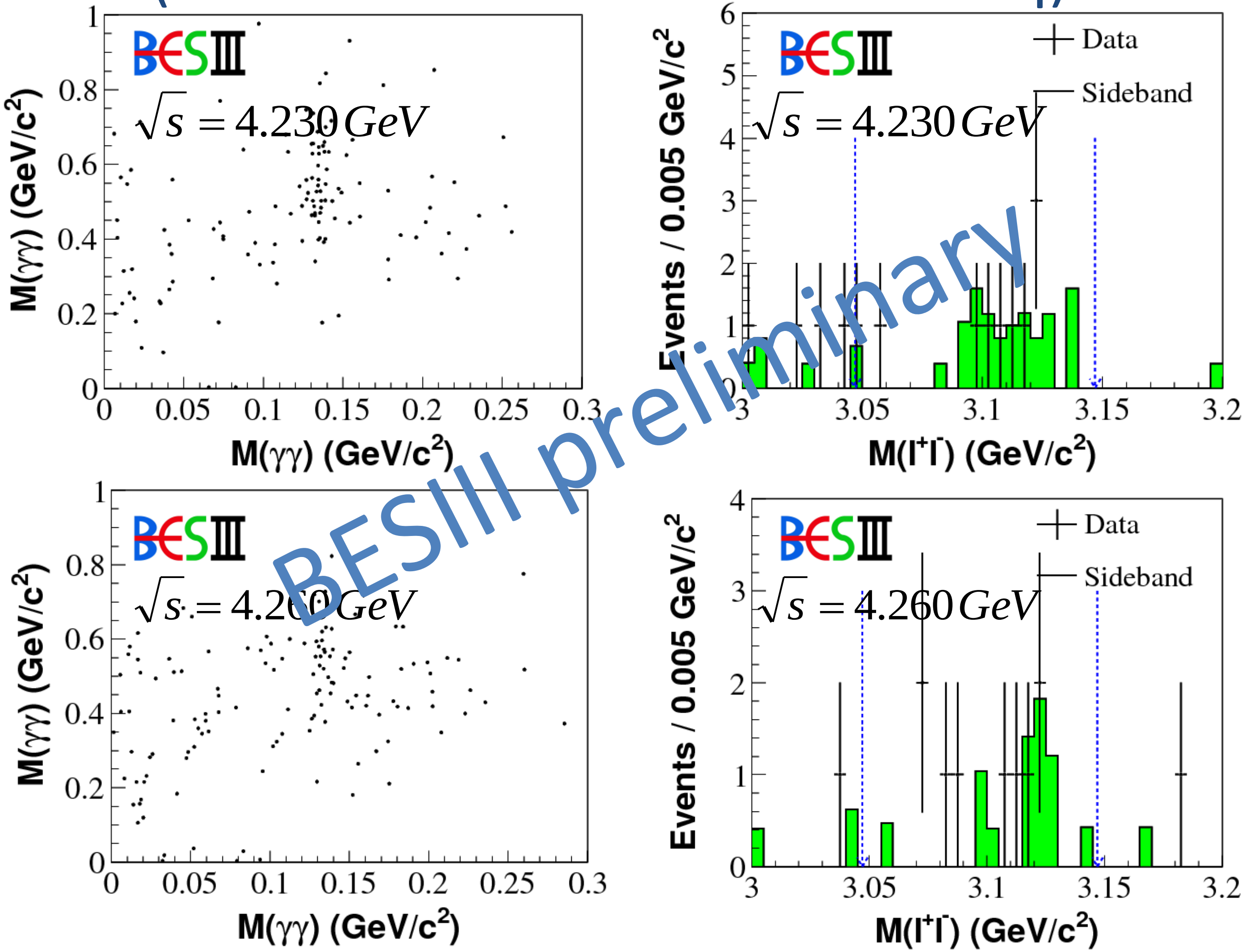
- Y(4260) does not fit into $1^{--}$ quarkonium spectrum. $D_1D$ molecule? hybrid charmonim? …?
- Recent observations at BESIII:
  - Coupling to $Z_c(3900)$ at 4.260 GeV is observed
  - Transition of $e^+e^- \to \gamma X(3872)$ near Y(4260) is observed
- Search for the isospin violating decay of Y(4260) may shed a light on its nature.
  - e.g. $X(3872) \to J/\psi\rho$ , $J/\psi\omega$ indicates large coupling to DD*

Theoretical works:

- Hadronium of $Z_b$ and $Z_c$:
  - Prediction of $\Upsilon(5S) \to \eta\pi^0$+ bottomonium, M.Voloshin, PRD 86 034013
- Tetraquark interpretation of $Z_b$ and $Z_c$:
  - Prediction of $\Upsilon(5S) \to \Upsilon(1S)\eta\pi^0$, A. Ali et al., PRL 104 162001, PRL 106 092002
  - Proposed search of $Z^+_c(1^{++})$ in $Y(4260) \to J/\psi\eta\pi^0$, L. Maiani et al., PRD 87 111102
- $D_1\overline{D}$ molecule:
  - Prediction of $Y(4260) \to J/\psi\eta\pi^0$, X. Wu et al., PRD 89, 054038

# Scatter Plot of M($\gamma\gamma$) and M($l^+l^-$)

## (combination closest to $\pi^0$ and η)



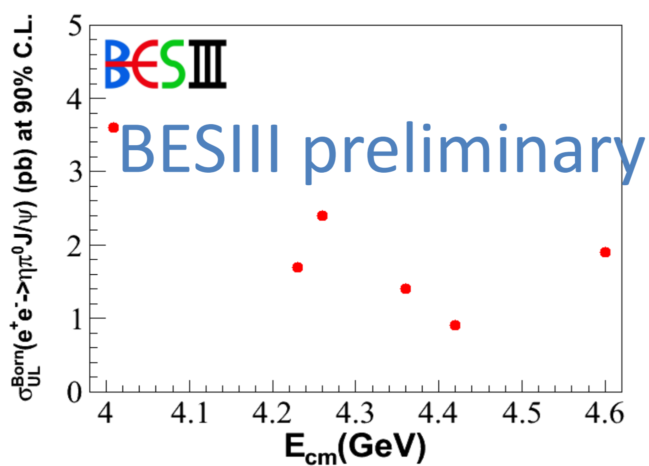

- No signal of J/ψη$\pi^0$ exceeding background is observed.
- Background is estimated from normalized 2D η$\pi^0$ sidebands.

# Upper Limit of Cross Section of $e^+e^- \to J/\psi\eta\pi^0$

- No signal of $J/\psi\eta\pi^0$ is observed.
- Preliminary upper limit at the 90% C.L. for $\sigma^B$ ($e^+e^- \to J/\psi\eta\pi^0$) is set using profile likelihood method [ NIM A551:493-503,2005 ].
- The systematic uncertainty of cross section measurement and background estimation are included.

| $\sqrt{s}$ (GeV) | $\mathcal{L}$ (pb$^{-1}$) | $(1+\delta^r)$ | $(1+\delta^v)$ | $(\epsilon^{ee}Br^{ee} + \epsilon^{\mu\mu}Br^{\mu\mu})$ (%) | $N^{obs}$ | $N^{bkg}$ | $N^{up}$ | $\sigma^{Born}_{UL}$ (pb) |
|---|---|---|---|---|---|---|---|---|
| 4.009 | 482 | 0.838 | 1.044 | $2.1 \pm 0.1(sys.)$ | 5 | 1 | 598.1 | 3.6 |
| 4.230 | 1007 | 0.844 | 1.056 | $2.2 \pm 0.1(sys.)$ | 12 | 11 | 592.9 | 1.7 |
| 4.260 | 804 | 0.847 | 1.054 | $2.2 \pm 0.1(sys.)$ | 12 | 8 | 654.1 | 2.4 |
| 4.360 | 523 | 0.942 | 1.051 | $2.2 \pm 0.1(sys.)$ | 5 | 4 | 283.2 | 1.4 |
| 4.420 | 1023 | 0.951 | 1.053 | $2.3 \pm 0.1(sys.)$ | 5 | 6 | 342.7 | 0.9 |
| 4.600 | 567 | 0.965 | 1.055 | $2.4 \pm 0.1(sys.)$ | 6 | 3 | 418.4 | 1.9 |

- Preliminary upper limit is well above the prediction of $D_1\bar{D}$ molecule model (0.05 pb at 4.260 GeV) [PRD 89, 054038]



# Search for $Z_c^0$-> $J/\psi\eta$

It is also possible to set upper limits on $e^+e^- \to Z_c^0\pi^0 \to J/\psi\eta\pi^0$. The number of observed events and number of estimated background events in the $Z_c^0$ signal region ( 3.850 <M($J/\psi\eta$) < 3.940 GeV/$c^2$) is 7 and 4 $\pm 2$, respectively, at $\sqrt{s} = 4.230$ GeV, and 8 and $3 \pm 2$, respectively, at $\sqrt{s} = 4.260$ GeV. The upper limit on $\sigma(e^+e^- \to Z_c^0\pi^0 \to J/\psi\eta\pi^0)$ is determined to be 1.3 pb at $\sqrt{s} = 4.23$ GeV and 2.0 pb at $\sqrt{s} = 4.26$ GeV, where only the statistical uncertainty is given.

$$\frac{\sigma(e^+e^- \to Z_c^0\pi^0 \to J/\psi\,\eta\,\pi^0)}{\sigma(e^+e^- \to Z_c^0\pi^0 \to J/\psi\,\pi^0\pi^0)} < 10\%, \text{ unlike } X(3872)$$

$$\frac{\Gamma\left(X(3872) \to J/\psi\,\omega\right)}{\Gamma\left(X(3872) \to J/\psi\,\pi^+\pi^-\right)} = 0.8 \pm 0.3.$$

# Summary and outlook

- **Null results** of $Z_c^{\pm}(3900) \to \omega\pi^{\pm}$ ,$Y(4260) \to J/\psi\eta\pi^0$ , $Z_c^0(3900) \to J/\psi\eta$ **provide useful inputs to understand the nature of Y and Z.**
- Using more data samples in the future, we may further pin down the puzzles by
  - **Precision pole properties** → *more Y(4260) + sophisticated analysis*
  - **New decay modes/partners**→ *more Y(4260)*
  - **Patterns of production / Variations of lineshape** → *more data + smart choice of energy points*

*Thank you*