Exotic and Charmonium(-like) states at BESIII

Yutie Liang
On behave of BESIII Collaboration

JLU Giessen, Germany
Yutie.liang@physik.uni-giessen.de

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Outline

- Introduction

  Exotic states, XYZ

- Selected recent results:

  X(3823), X(3872)

  Y(4260), Y(4360), …

  $Z_c(3900)^{\pm/0}$, $Z_c(3885)^{\pm}$

  $Z_c(4020)^{\pm/0}$, $Z_c(4025)^{\pm/0}$

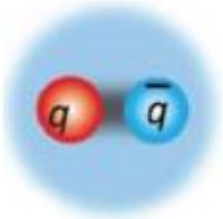
- Summary

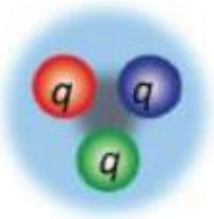
What's exotic state?

- Conventional hadrons consist of 2 or 3 quarks:

Naive Quark Model:

meson



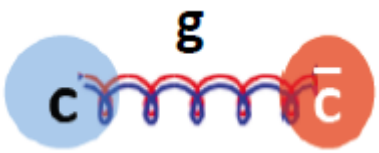


baryon

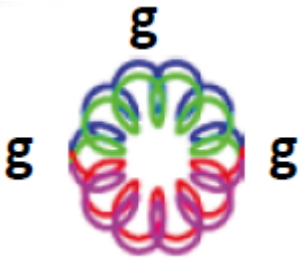
- QCD predicts the exotic state:

Multi-quark states: (N >= 4)

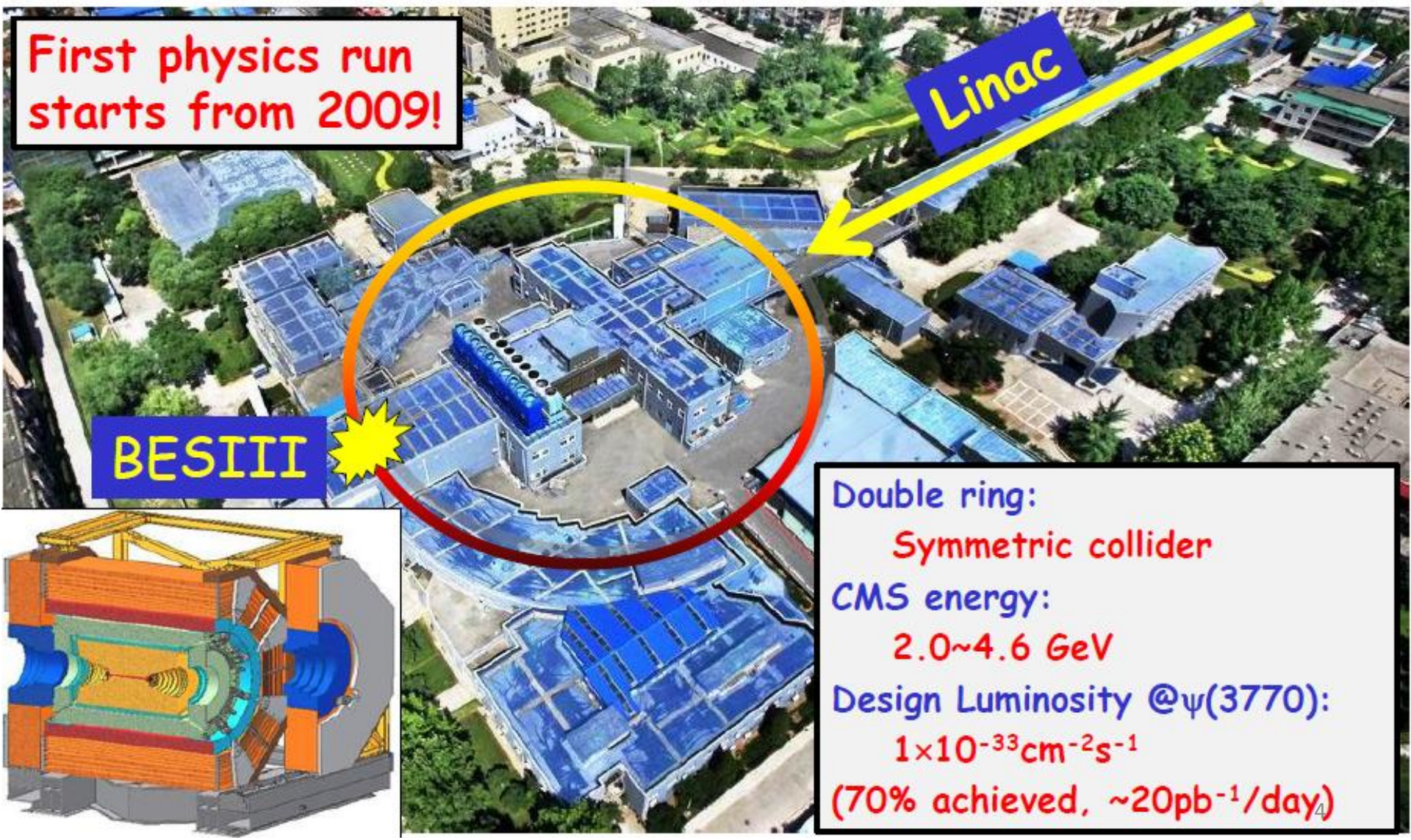
Hybrids: $q\bar{q}g$, qqqg…



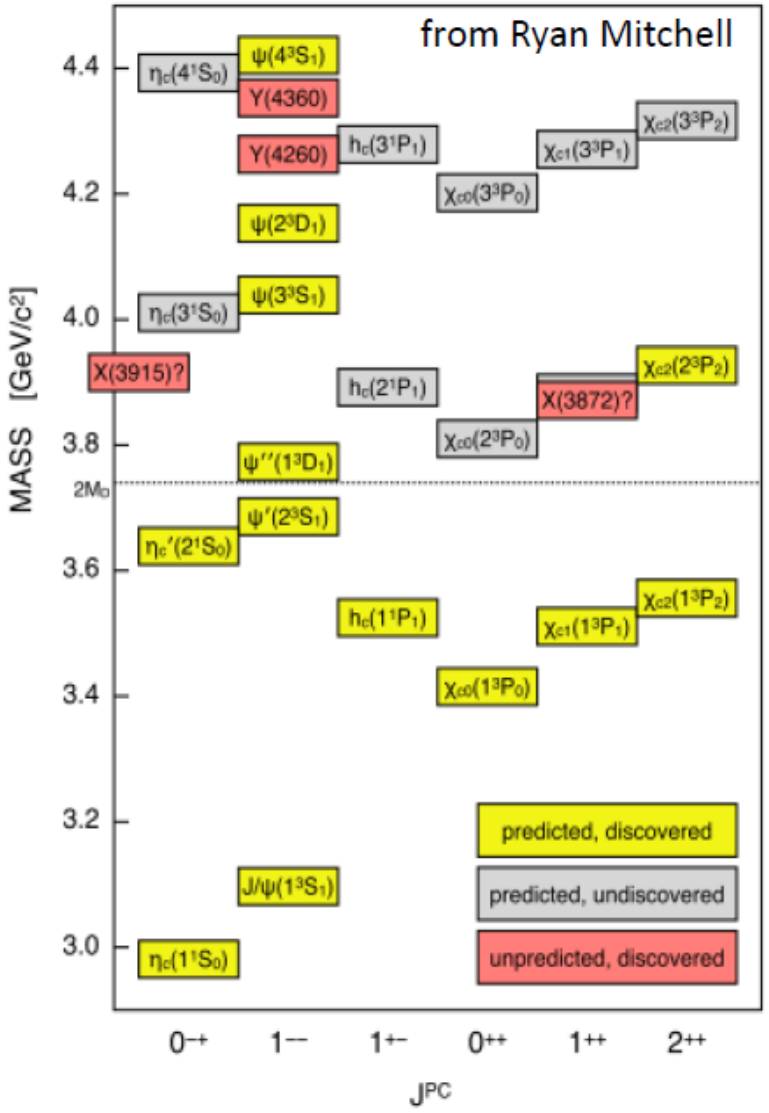
Glueballs: gg, ggg



BEPCII & BESIII



Charmonium Spectroscopy



- **Below open charm threshold:**

  Good agreement between discovery and theoretical prediction.

- **Above open charm threshold:**

- many expected states not observed
- many unexpected observed

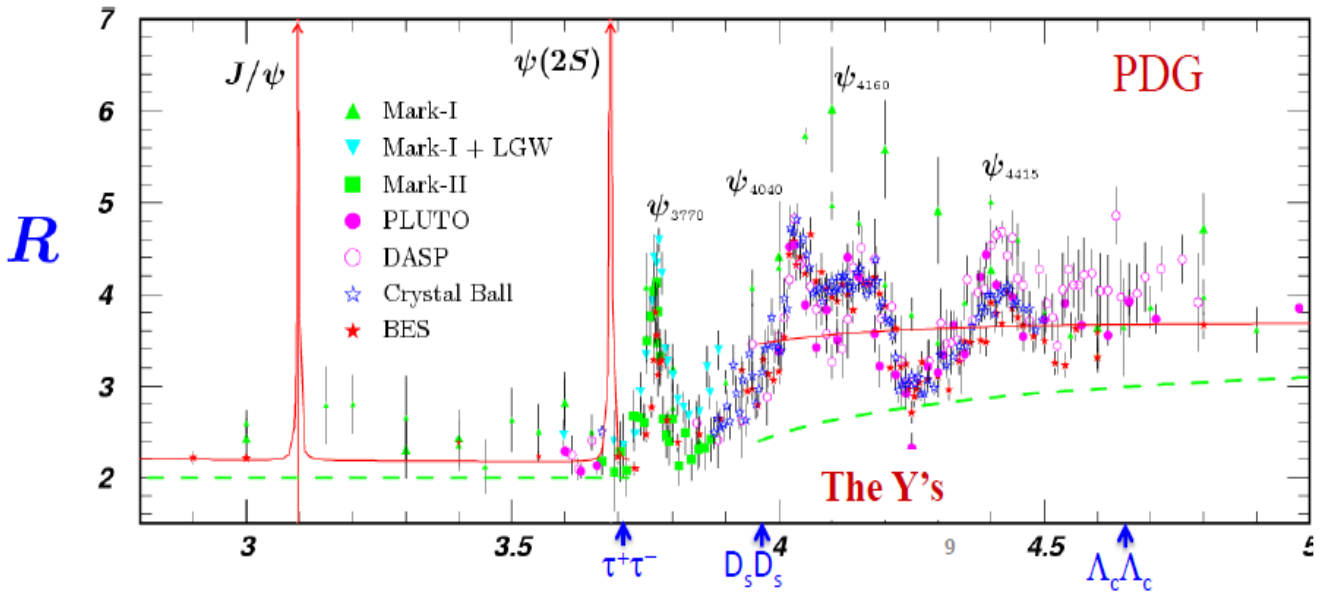
Z(4430)
Z(4250)
Z(4050)
Z(3900)

X(3872)

XYZ(3940)

X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)

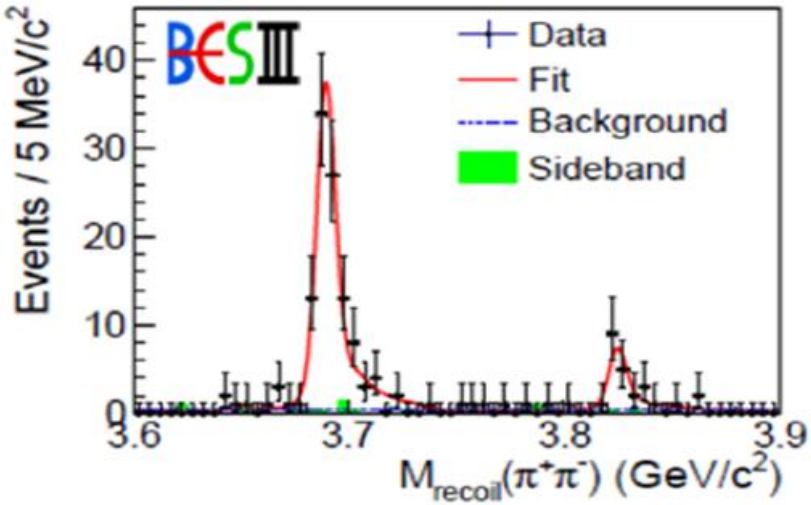
Data samples for XYZ physics at BESIII

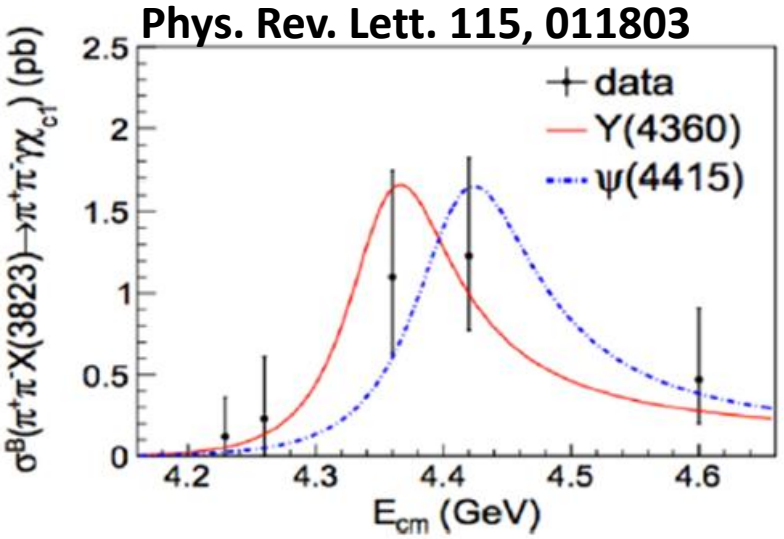


CM energy (GeV)	L (pb^{-1})
3.81	50.54±0.03
3.90	52.61±0.03
4.009	481.96±0.01
4.09	52.63±0.03
4.19	43.09±0.03
4.21	54.55±0.03
4.22	54.13±0.03
4.23[1]	44.40±0.03
4.23[2]	1047.34±0.14
4.245	55.59±0.04
4.26[1]	523.74±0.10
4.26[2]	301.93±0.08
4.31	44.90±0.03
4.36	539.84±0.10
4.39	55.18±0.04
4.42[1]	44.67±0.03
4.42[2]	1028.89±0.13
4.47	109.94±0.04
4.53	109.98±0.04
4.575	47.67±0.03
4.60	566.93±0.11

- **Luminosity ~ 5/fb.**
- **Huge data samples around ψ(4040), Y(4260), Y(4360), ψ(4415) and Y(4660).**

$e^+e^- \rightarrow \pi^+\pi^- X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$





- M = 3821±1.3±0.7 MeV, Γ < 16 MeV, Significance: 6.2σ!
- R = B[X(3823)→$\gamma\chi_{c2}$]/B[X(3823)→$\gamma\chi_{c1}$]<0.43 @ 90% C.L.
- Both Y(4360) and Ψ(4415) line shape give reasonable description.
  - Potential Model: D wave. M~(3.810-3.840) GeV, narrow.
  - R ~ 0.2

Agree with BELLE's 3.7σ evidence (PRL111, 032001)

X(3823) : good candidate of $\Psi(1^3D_2)$

$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^- J/\psi$

[BESIII PRL112, 092001]

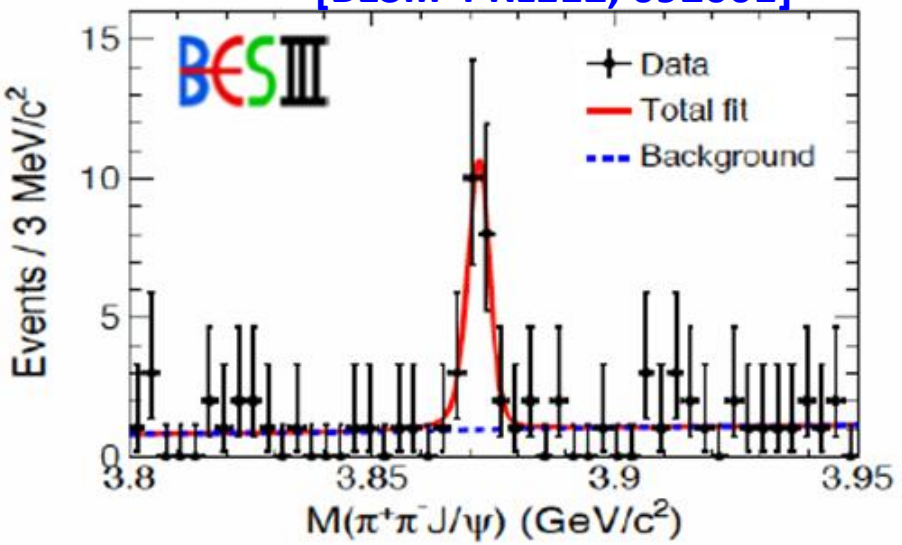
- Search for $\gamma X(3872)$ with $X(3872) \rightarrow \pi^+\pi^- J/\psi$ at Ecm = 4.23, 4.26, 4.36 GeV.

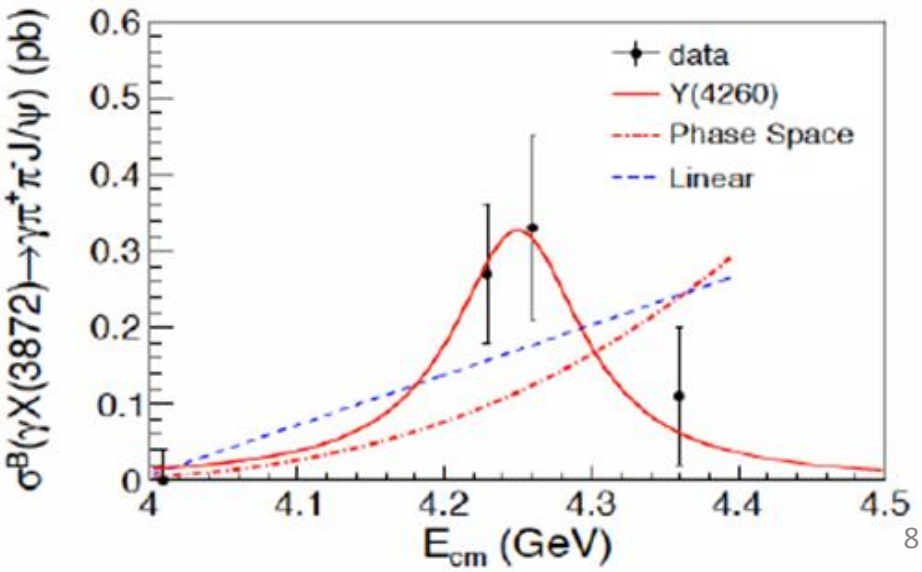
- X(3872) significance = 6.3σ, summed over all data.

- Production in Y(4260) decay suggestive, but not conclusive.

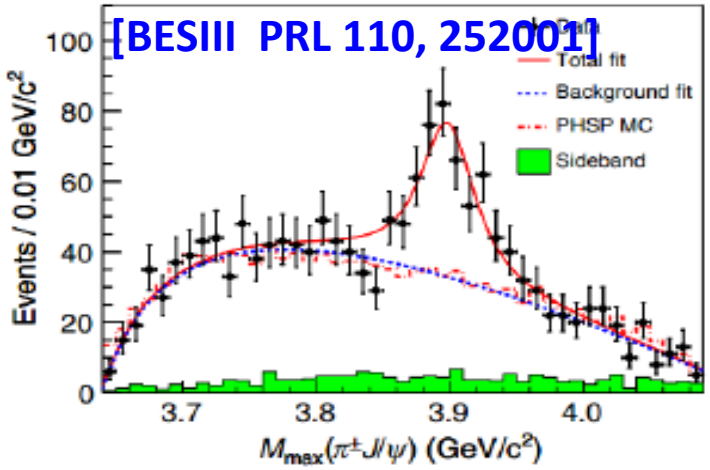
If from Y(4260):

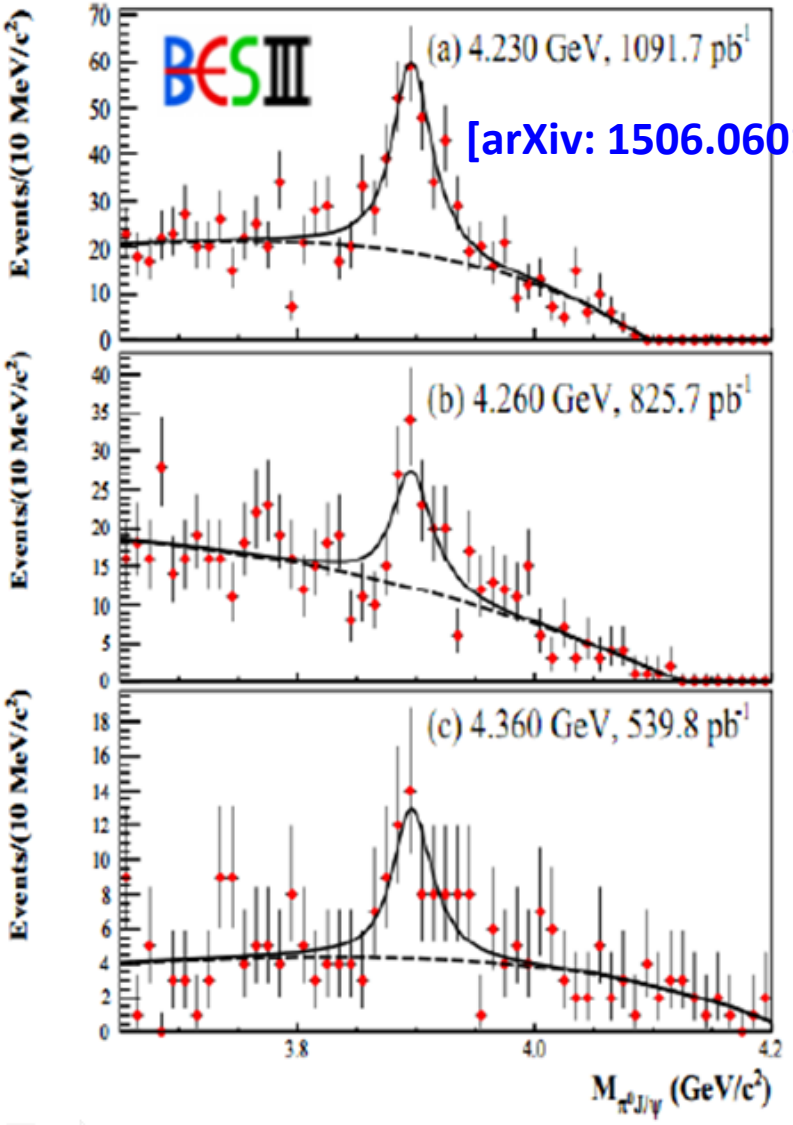
$$\frac{B(Y(4260) \rightarrow \gamma X(3872))}{B(Y(4260) \rightarrow \pi^+\pi^- J/\psi)} \sim 0.1$$





$Z_c(3900)^{\pm/0}$ in $e^+e^- \rightarrow \pi\pi J/\psi$





[arXiv: 1506.06018]

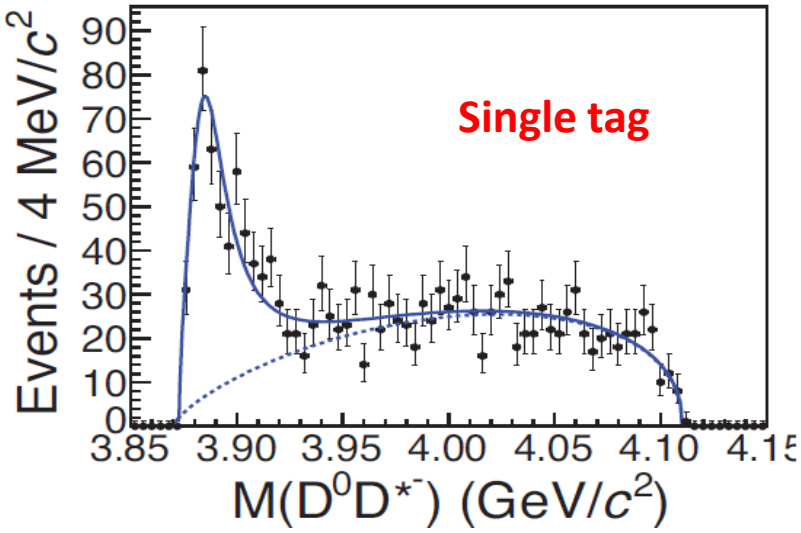
- $Z_c(3900)^{\pm}$, BESIII, Belle, CLEOc data, in 2013
- $Z_c(3900)^0$, evidence with 3.7σ by CLEOc, observed with >10σ by BESIII

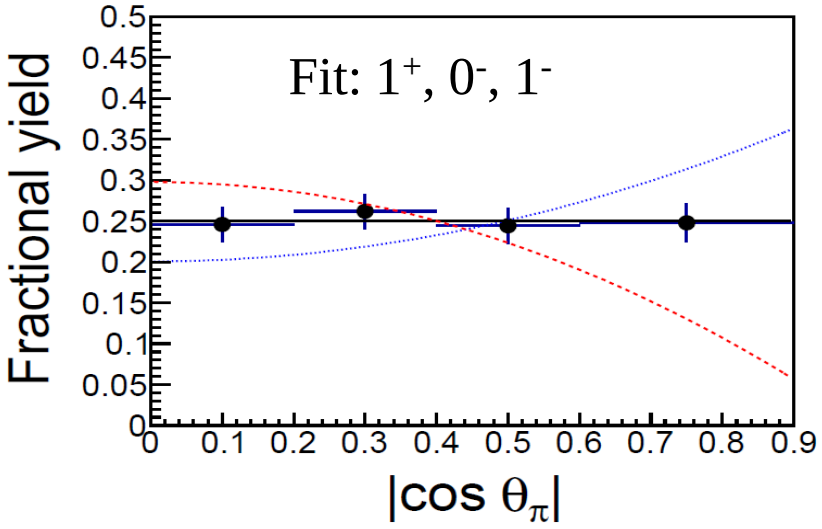
Zc(3900)	Mass(MeV)	Width(MeV)
$Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46±10±20
$Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2

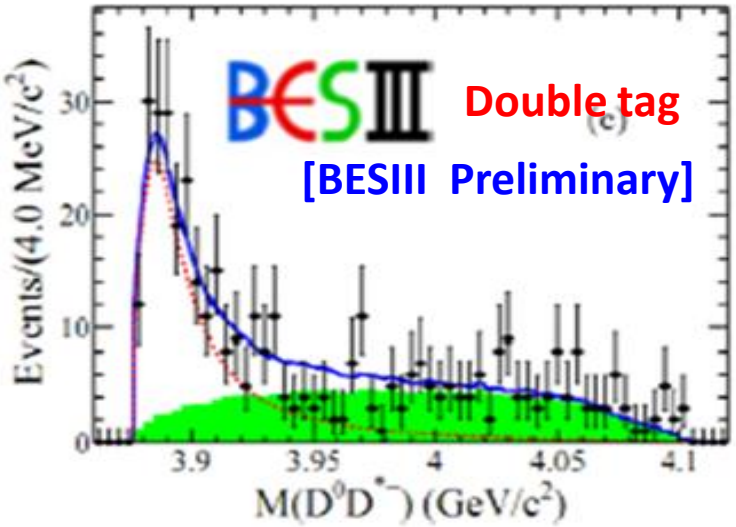
An iso-spin triplet established!

$Z_c(3885)^{\pm}$ in $e^+e^- \rightarrow \pi^{\pm}(D\bar{D}^*)^{-/+}$

[BESIII PRL 112, 022001(2014)]



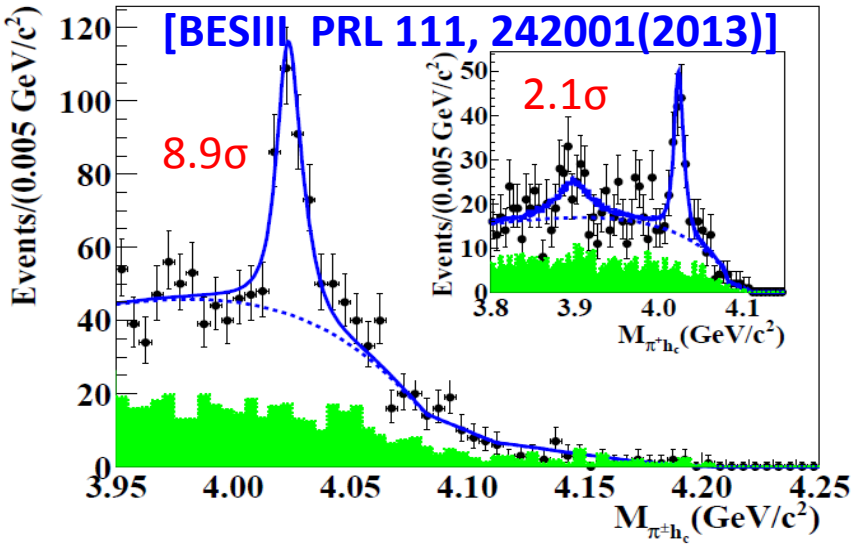


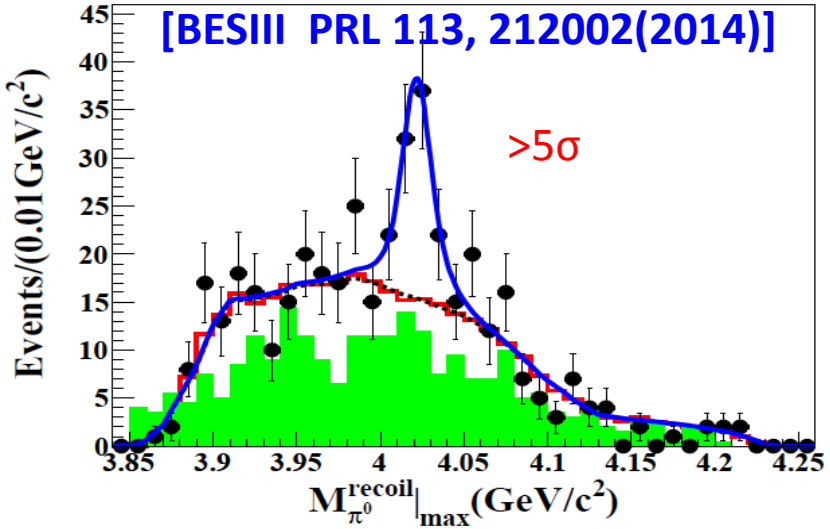


Mass = 3883.9±1.5±4.2 MeV
Width = 24.8±3.3±11.0 MeV
Fit to angular distribution favors 1^+

Mass and width close to $Z_c(3900)$

$Z_c(4020)^{\pm/0}$ in $e^+e^- \rightarrow \pi\pi h_c$





Zc(4020)	Mass(MeV)	Width(MeV)
$Z_c(4020)^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4020)^0$	4023.8±2.2±3.8	Fixed(=7.9)

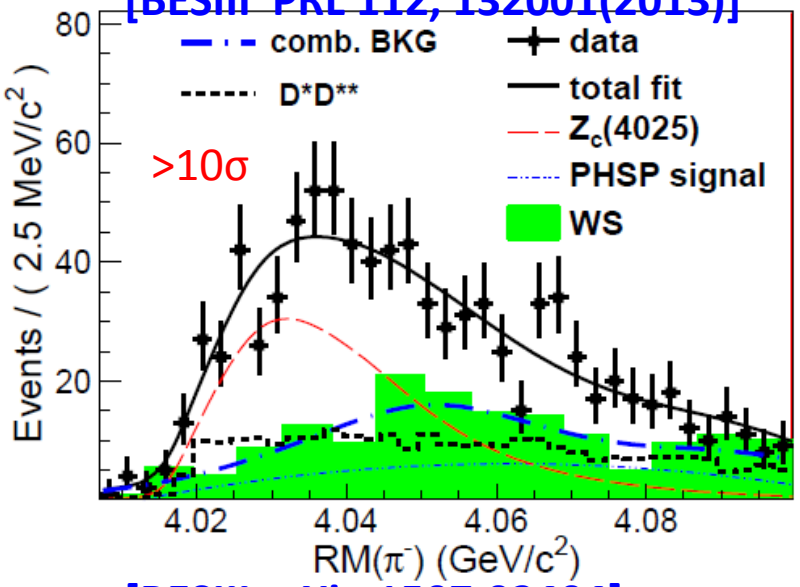
- $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ 16 hadronic channels
- $Z_c(4020)^{\pm}$, observed
- A weak evidence for $Z_c(3900) \rightarrow \pi^{\pm} h_c$

- $Z_c(4020)^0$, observed
- Another iso-spin triplet established!

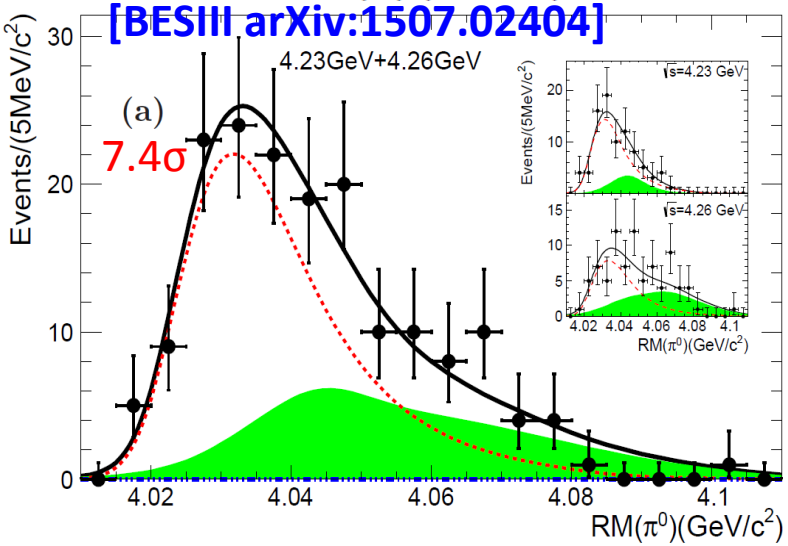
- $Z_c(4020)$, near the threshold of D*D*-bar.

$Z_c(4025)^{\pm/0}$ in $e^+e^- \rightarrow \pi^{\pm/0}(D^*\bar{D}^*)^{-/+/0}$

[BESIII PRL 112, 132001(2013)]



[BESIII arXiv:1507.02404]

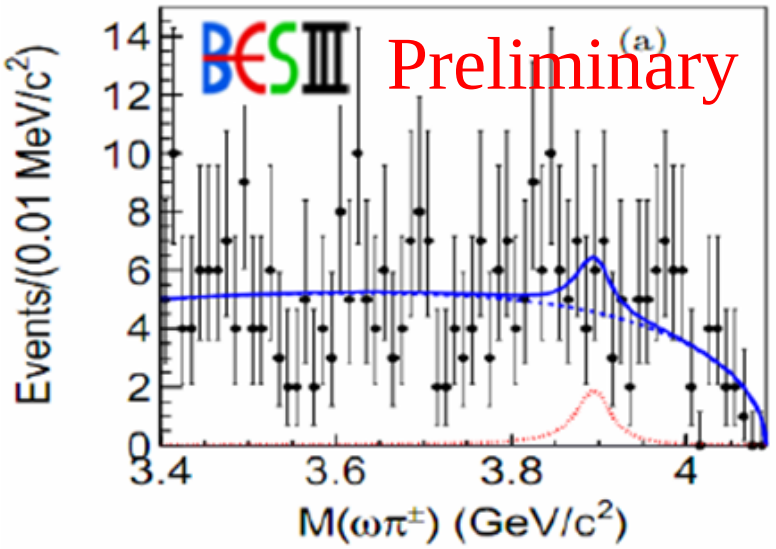


Zc(4025)	Mass(MeV)	Width(MeV)
$Z_c(4025)^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7}$±3.1	23.0±6.0±1.0

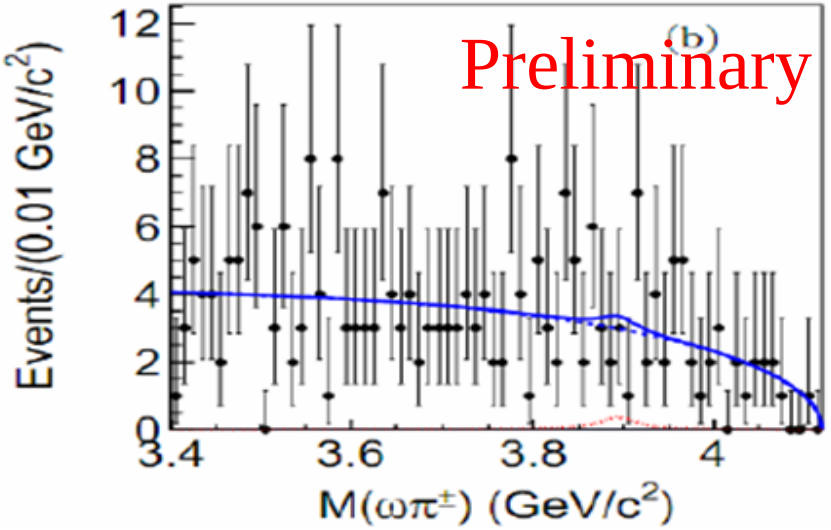
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background
- $Z_c(4025)^{\pm}$, observed
- Coupling to D*D*-bar is much larger than to πh_c if $Z_c(4025)$ and $Z_c(4020)$ are the same state.
- $Z_c(4025)^0$, observed

Search for $Z_c(3900)^{\pm}$ in $\omega\pi^{\pm}$

e^+e^- @4.23GeV



e^+e^- @4.26GeV

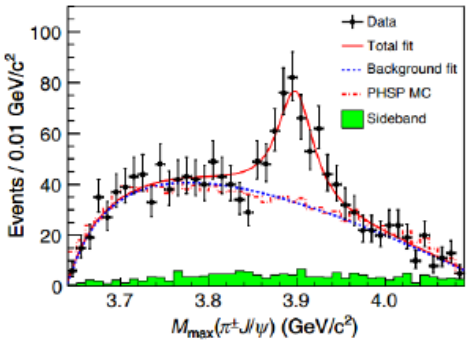


- Searching for new decay of $Z_c(3900)$ can provide useful information on its internal structure.
- No significant signals observed.

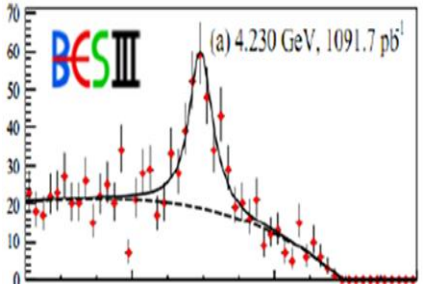
$\sigma(e^+e^- \to Z_c\pi, Z_c \to \omega\pi) < 0.27$ pb @ 4.23 GeV

$\sigma(e^+e^- \to Z_c\pi, Z_c \to \omega\pi) < 0.18$ pb @ 4.26 GeV

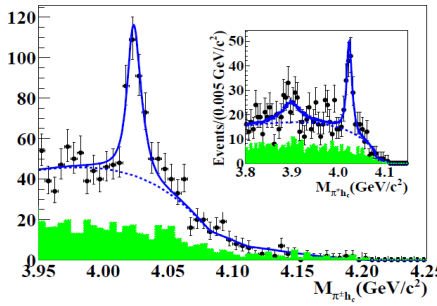
Summary on Z_c states



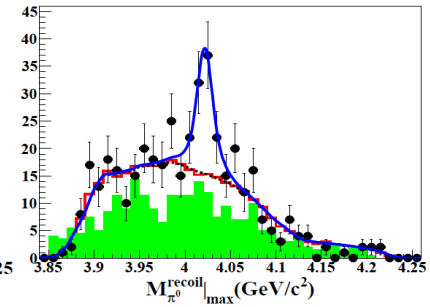
$e^+e^- \to \pi^-\pi^+ J/\psi$



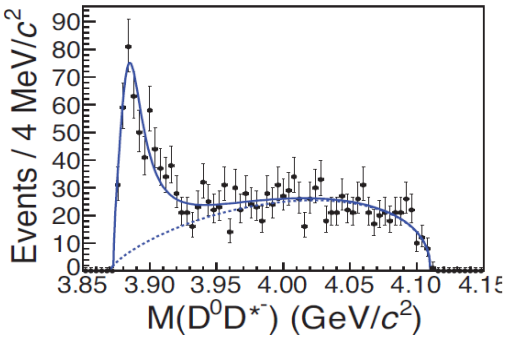
$e^+e^- \to \pi^0\pi^0 J/\psi$



$e^+e^- \to \pi^-\pi^+ h_c$



$e^+e^- \to \pi^0\pi^0 h_c$

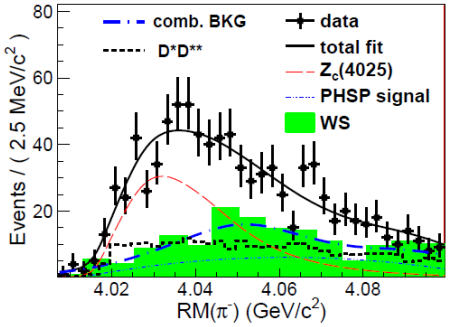


$e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{-/+}$

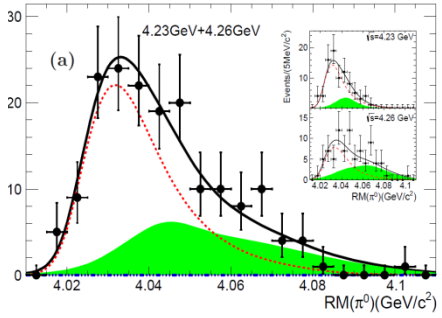
Preliminary

BESIII

soon…



$e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{-/+}$



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

$Z_c(3900)^{\pm}$?

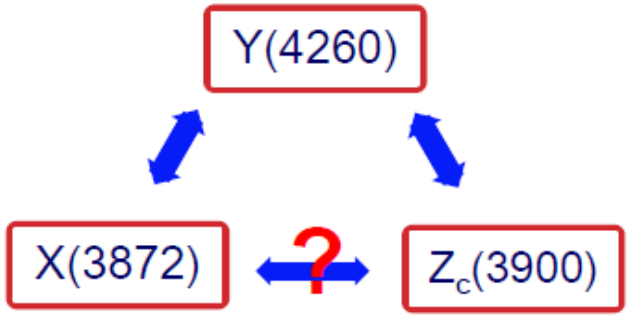
$Z_c(3900)^0$?

$Z_c(4020)^{\pm}$?

$Z_c(4020)^0$?

Summary

- Lots of progress in charmonium-like studies recently.
- Charged charmonium-like states (Z_c) has been observed.
- Neutral partners observed, make them isospin triplet states.
- No evidence of $Z_c(3900)$ in a light hadronic decay to $\omega\pi^{\pm}$.
- Observation of $e^+e^- \rightarrow \gamma X(3872)$ & $\pi^+\pi^- X(3823)$.
- X, Y, Z particles are correlated!



- More experimental effort is needed.

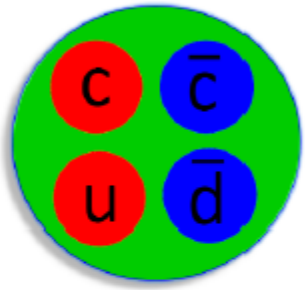
Thank You

Backup

NATURE of Z_c STATES

- At least 4 quarks, not a conventional meson

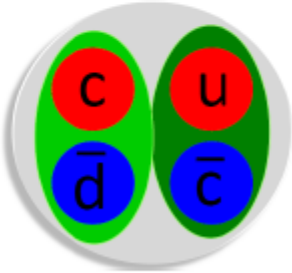
- Tetraquark state?



Phys. Rev. D87,125018(2013); Phys. Rev. D88, 074506(2013);

Phys. Rev. D89,054019(2014); Phys. Rev. D90,054009(2014); etc

- $D^{(*)}\ \bar{D}^{(*)}$ molecule state?



Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)

Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013); etc

- Final States Interactions?
- …