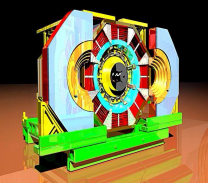


Charmonium(-like) spectroscopy and decays from BESIII

Liang Yan

On behalf of BESIII Collaboration

USTC, China

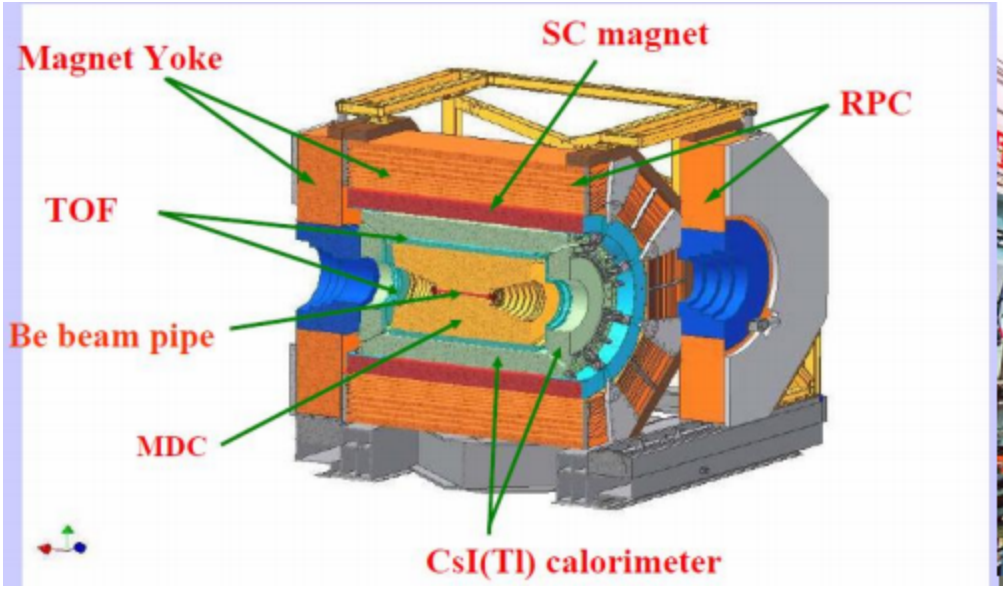
International Workshop on e+e- collisions from Phi to Psi (PHIPSI2013)

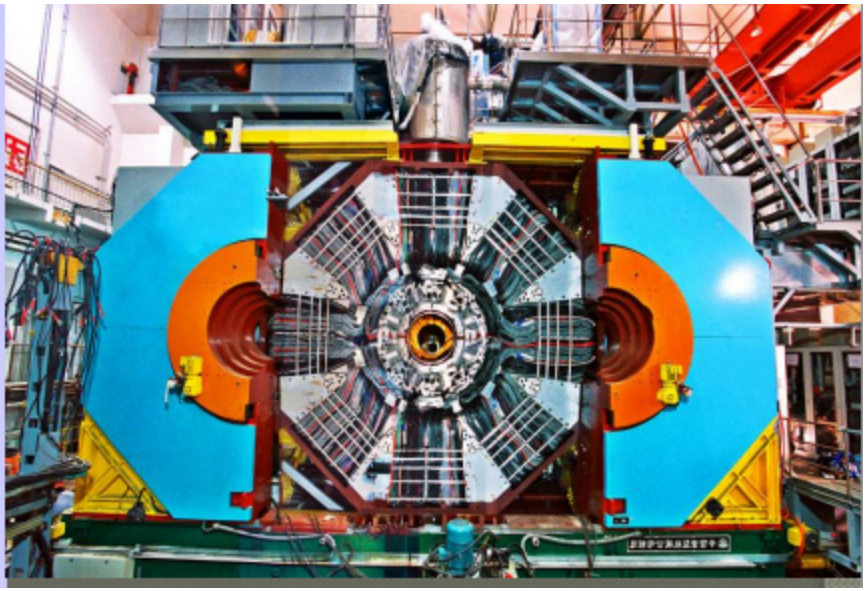
9 - 12 September 2013, Universita' di Roma La Sapienza, Italy

Outline

- Introduction to BESIII detectors
- Selected BESIII results
  - η_c
  - h_c
  - η_c'
  - XYZ study
- Summary

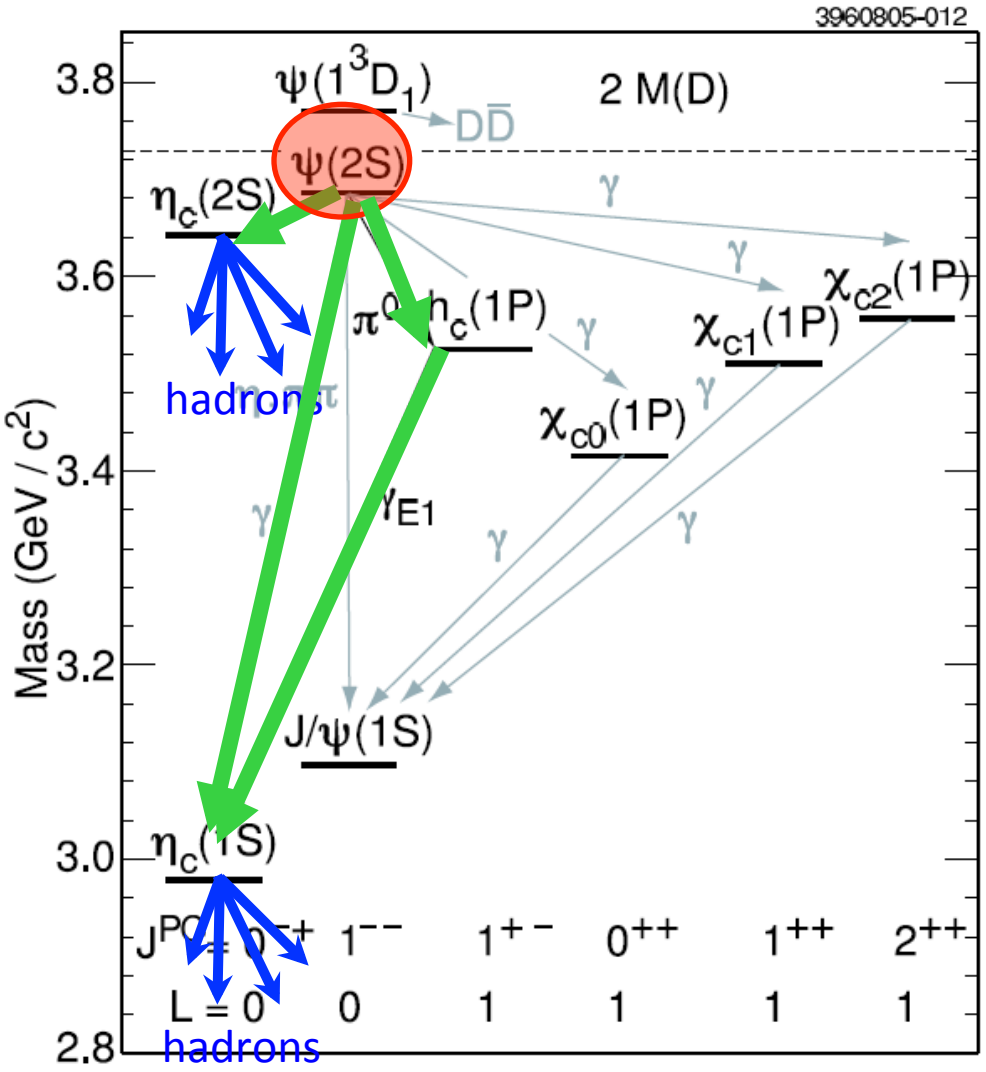
BESIII Detectors





Sub-detectors			Performance
MDC	Momentum resolution		0.5%@1GeV
	dE/dx resolution		6%
EMC	Energy resolution		2.5%@1GeV
	Spatial resolution		6 mm
TOF	Time resolution	Barrel	80 ps (Bhabha)
		Endcap	110 ps (Di-muon)
MUC	9 layers RPC, 8 layers for endcap		

$\psi(2S) \rightarrow \gamma\eta_c, \gamma\eta_c', \pi^0 h_c$

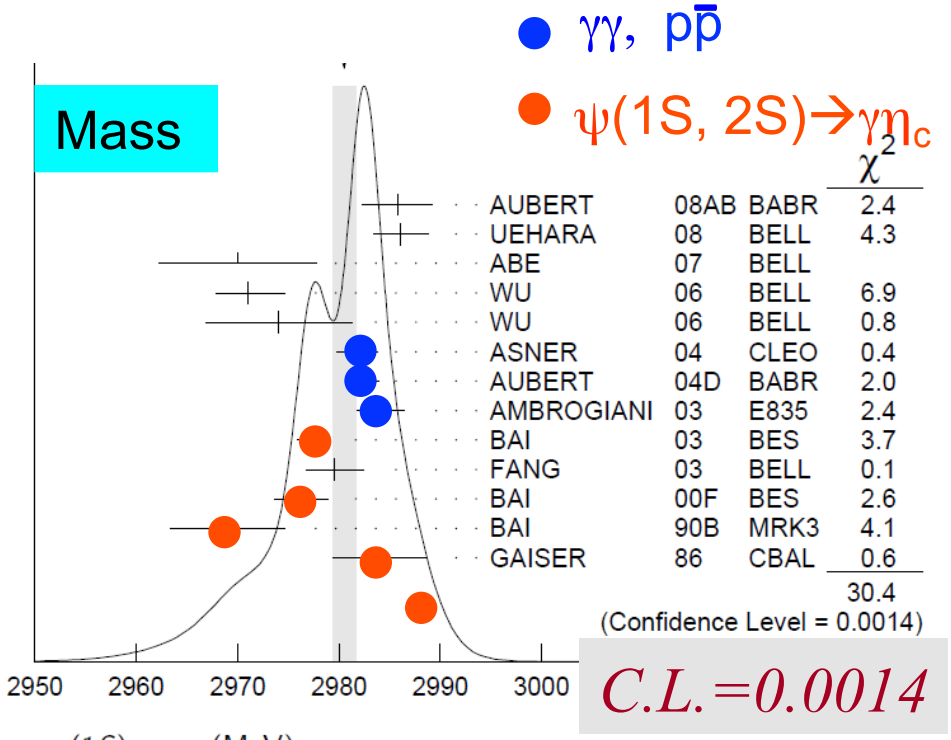


η_c

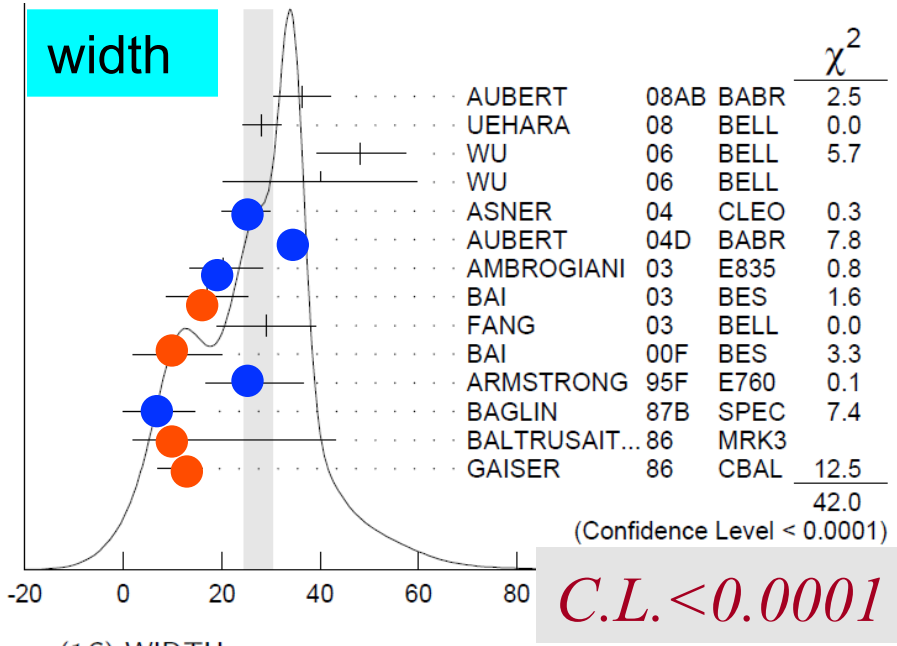
- The S-wave spin-singlet charmonium ground state, found in 1980
- The mass & width

  J/ψ radiative transition: M ~ 2978.0MeV/c^2, Γ ~ 10MeV

  γγ process: M = 2983.1±1.0 MeV/c^2, Γ = 31.3±1.9 MeV



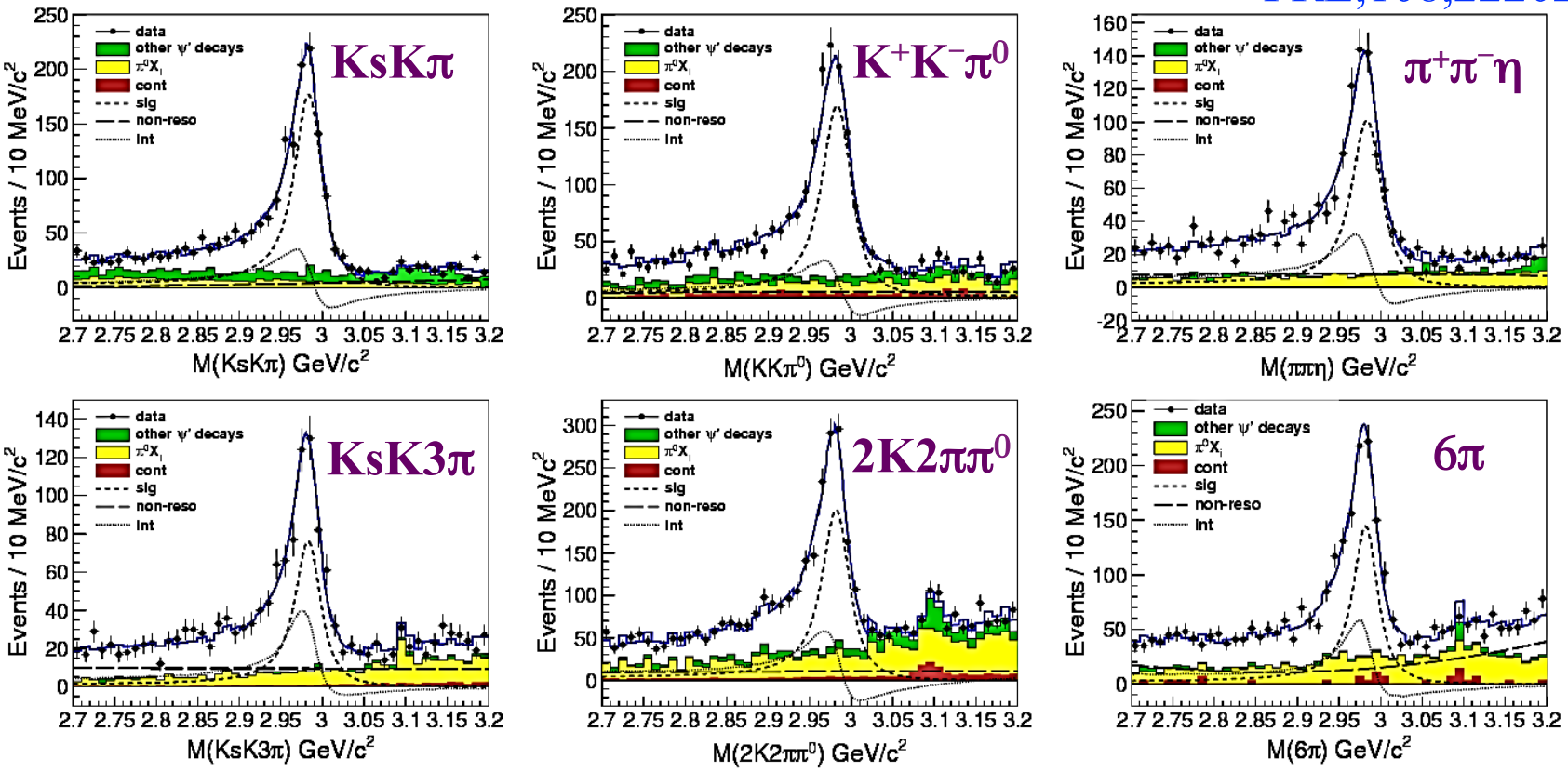
C.L.=0.0014



C.L.<0.0001

η_c resonance parameters from $\psi' \to \gamma\eta_c$

PRL,108,22202



The interference between η_c and non-resonant is significant.

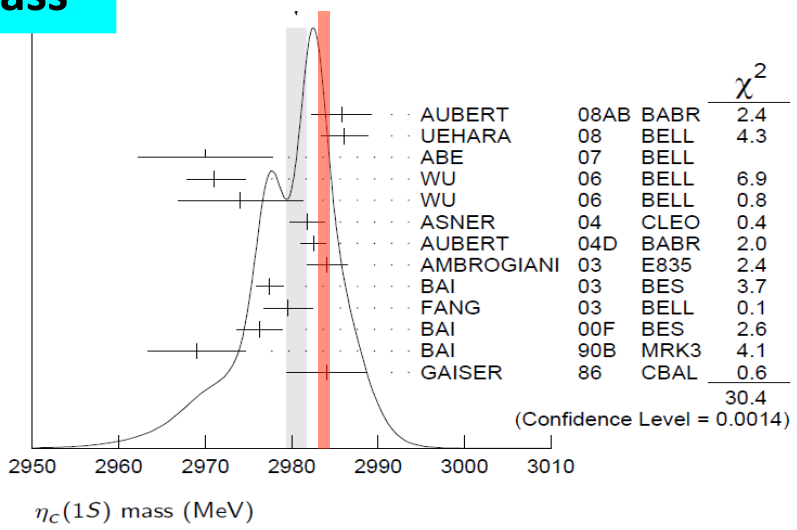
Simultaneous fit to 6 modes,

Mass = 2984.3±0.6±0.6 MeV/c²

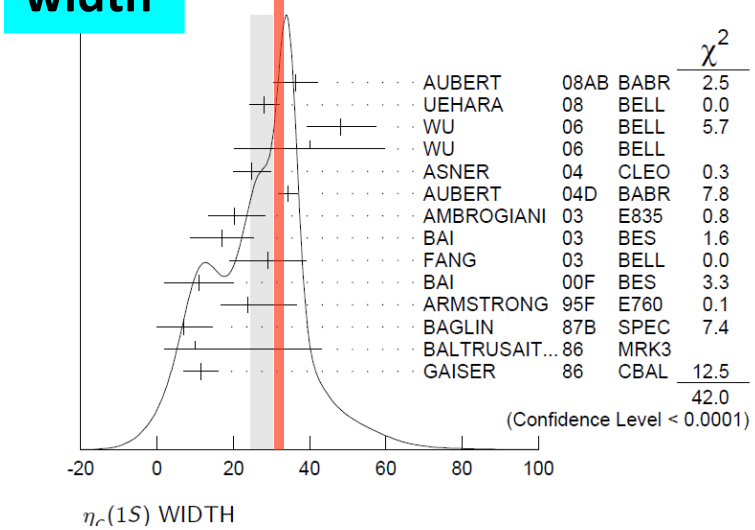
Width = 32.0±1.2±1.0 MeV

Comparison with previous η_c results

Mass



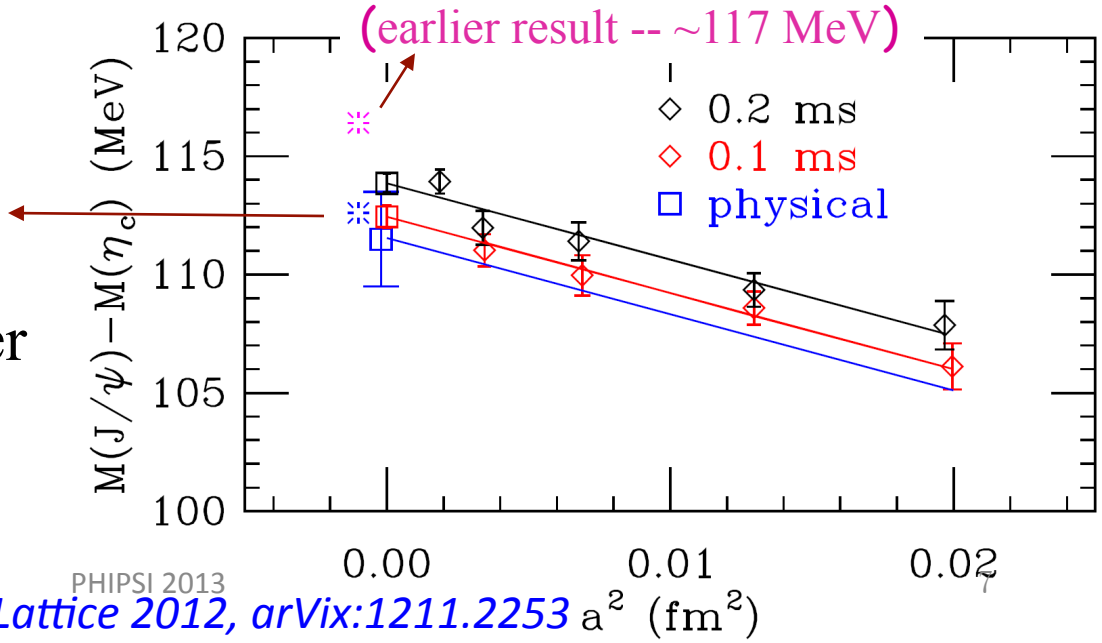
width



Hyperfine splitting (BESIII alone)

$\Delta M(1S) =$ **112.5±0.8** MeV

Closer to prediction than earlier result



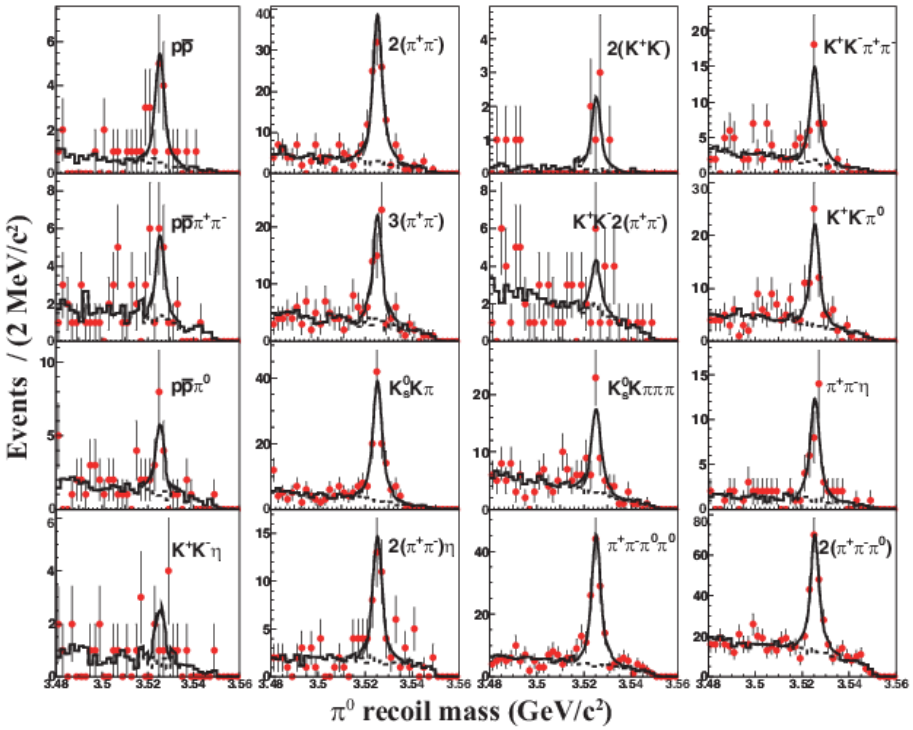
Lattice 2012, arVix:1211.2253

$h_c(^1P_1)$

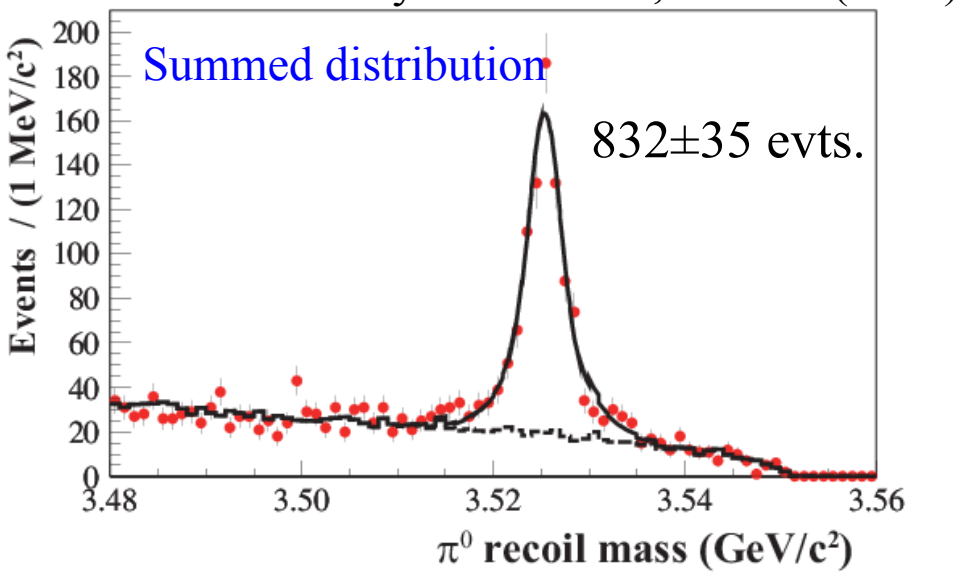
- Spin singlet P wave (S=0, L=1)
- Potential model: if non-vanishing P-wave spin-spin interaction,
  $\Delta M_{hf}(1P)=M(h_c)-\langle M(1\ ^3P_J)\rangle \neq 0$,
  where $\langle M(1\ ^3P_J)\rangle=[M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2})]/9$
- Theoretical predictions:
  - $B(\psi'\to\pi^0 h_c) = (0.4\text{-}1.3)\times10^{-3}$, $B(h_c\to\gamma\eta_c) = 41\%$ (NRQCD)
    $B(h_c\to\gamma\eta_c) = 88\%$ (PQCD)

    Y. P. Kuang, PR D65, 094024 (2002)
  - $B(h_c\to\gamma\eta_c) = 38\%$ *Godfrey and Rosner, PR D66, 014012 (2002)*

16 hadronic decays (~40% η_c decays)



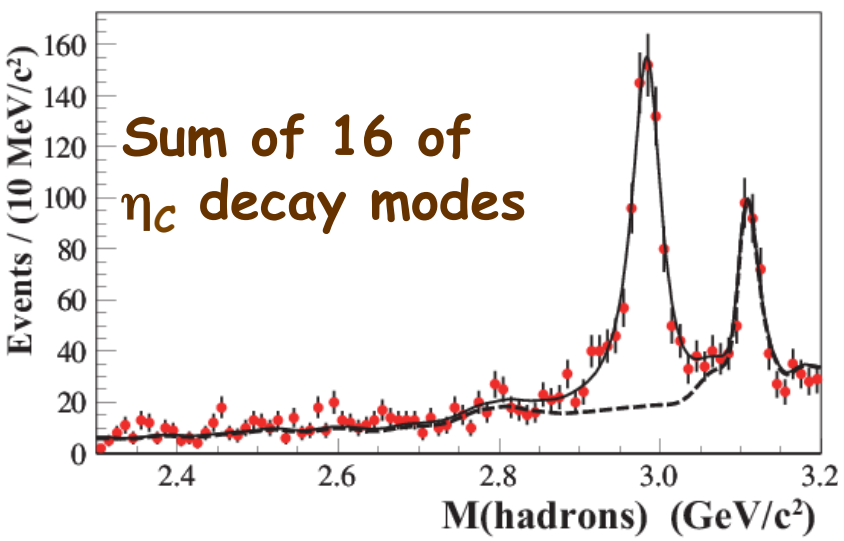
Phys. Rev. D 86, 092009 (2012)

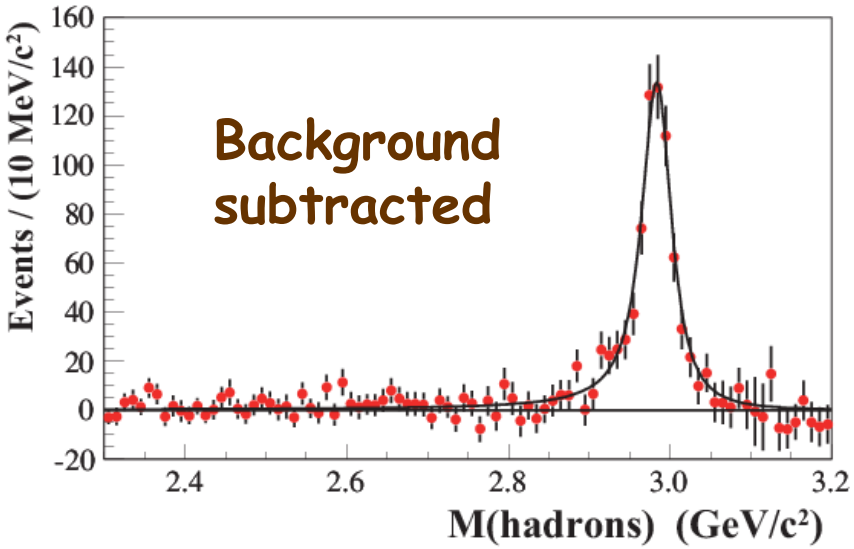


(MeV)	BESIII Exclusive	BESIII Inclusive	CLEO
mass	3525.31±0.11±0.14	3525.40±0.13±0.18	3525.21±0.27±0.14
width	0.70±0.28±0.22	0.73±0.45±0.28	--
$DM_{hf}(1P)$	-0.01±0.11± 0.15	0.10±0.13±0.18	0.08± 0.18± 0.12

BESIII: PRL 104 132002 (2010)
CLEOc: PRL 101 182003 (2008)

η_c lineshape from $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$





The η_c lineshape in $h_c \to \gamma\eta_c$ is not as distorted as in $\psi' \to \gamma\eta_c$ decays;
→the non-resonant interfering bkg is smaller than $\psi' \to \gamma\eta_c$.
→this channel will be best suited to determine η_c resonance parameters.

Mass = 2984.49±1.16±0.52 MeV/c²
Width = 36.4±3.2±1.7 MeV

Mass = 2984.3±0.6±0.6 MeV/c²
Width = 32.0±1.2±1.0 MeV

$\psi' \to \gamma\eta_c$

1. *Statistic errors are dominated, need more statistics.*
2. *Reults are consistent with those from $\psi' \to \gamma\eta_c$ decays within errors.*

η_c'

Crystal Ball's "first observation" of $\psi' \to \gamma X$ never been confirmed
PRL 48 70 (1982); until 2002, Belle found it in $B \to K\eta_c'$.

Observed in different production mechanisms,

1. $B \to K\eta_c'$
2. $\gamma\gamma \to \eta_c' \to KK\pi$
3. double charmonium production

Belle: PRL 89 102001 (2002)
CLEOc: PRL 92 142001 (2004)
Belle: NPPS.184 220 (2008); PRL 98 082001(2007)
BaBar: PRL 92 142002 (2004); PR D72 031101(2005)
BaBar: PR D84 012004 (2011)

M1 transition $\psi' \to \gamma\eta_c(2S)$

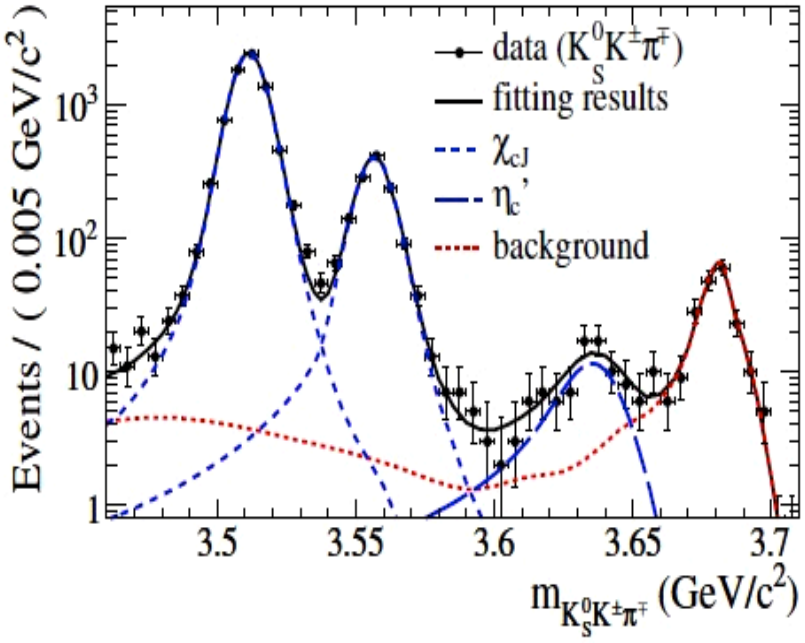
CLEO found no signals in 25M ψ'.

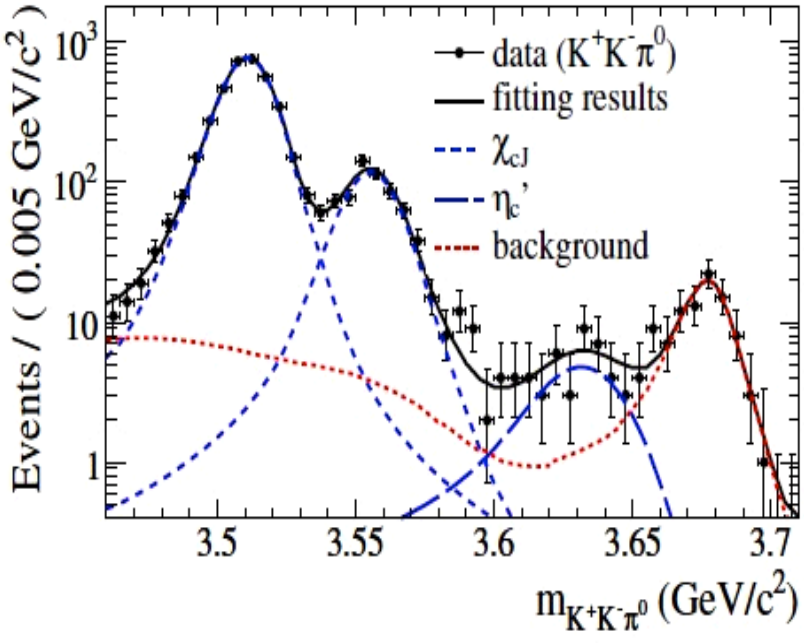
$BF(\psi' \to \gamma\eta_c(2S)) < 7.6\times10^{-4}$ *PRD 81 052002 (2010)*

BESIII made the first observation $\eta_c' \to KK\pi$;
find evidence in $\eta_c' \to KsK3\pi$

Observation of $\psi' \to \gamma\eta_c'$, $\eta_c' \to KK\pi$

PRL,109, 042003





M = *3637.6±2.9±1.6* MeV/c^2; Γ= *16.9±6.4±4.8* MeV

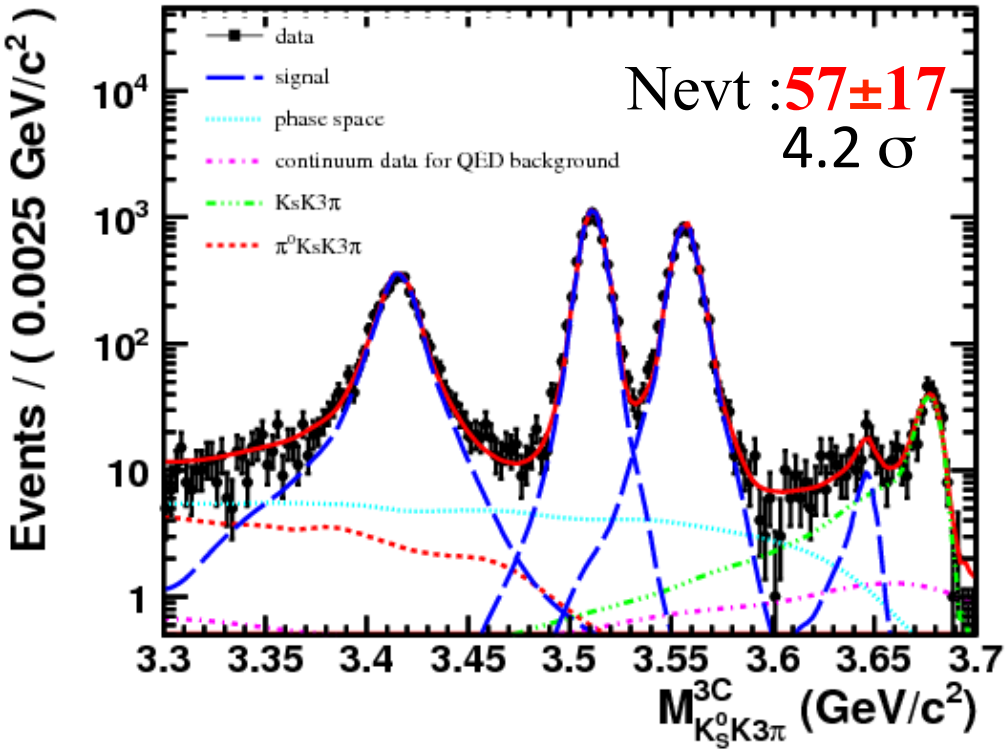
$B(\psi' \to \gamma\eta_c' \to \gamma KK\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$

$B(\psi' \to \gamma\eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

Potential model: $(0.1\text{-}6.2) \times 10^{-4}$
PRL89,162002(2002)

PRD 87 052005

$\psi' \to \gamma\eta_c', \eta_c' \to KsK3\pi$

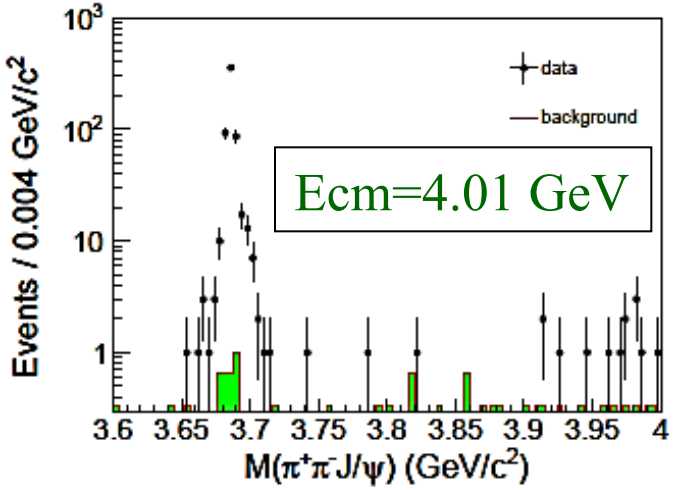


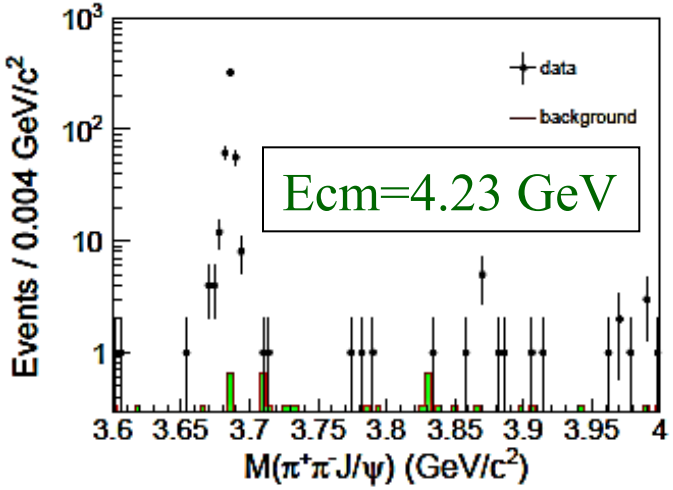
Mass = 3646.9±1.6±3.6 MeV/c^2;

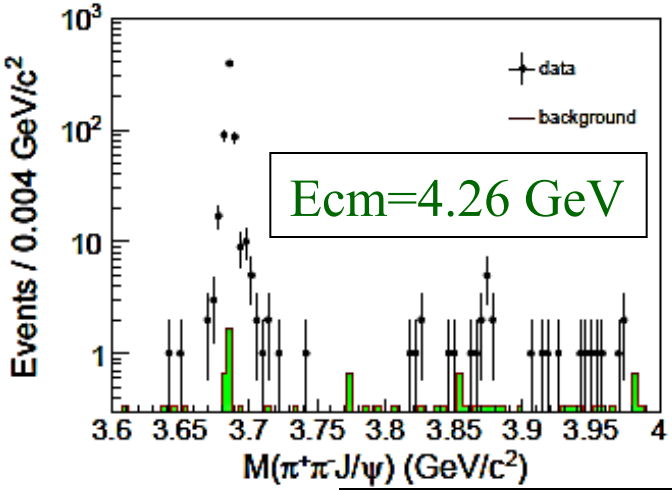
Γ = 9.2±4.8±2.9 MeV;

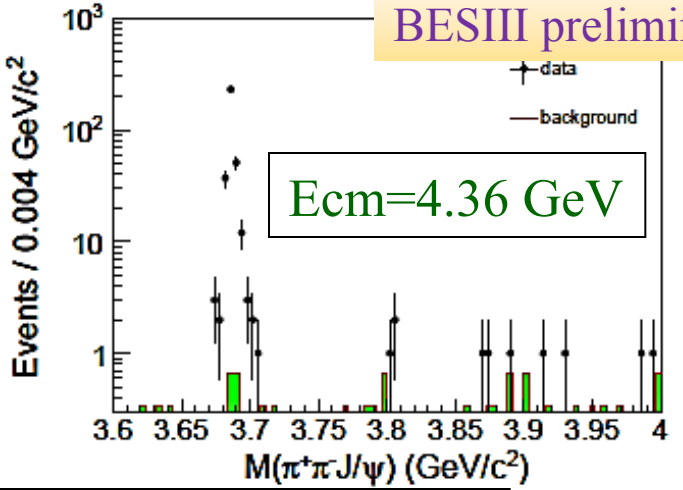
$B(\psi' \to \gamma\eta_c' \to \gamma KsK3\pi) = (7.03\pm2.10\pm0.70)\times10^{-6}$

Observation of $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$





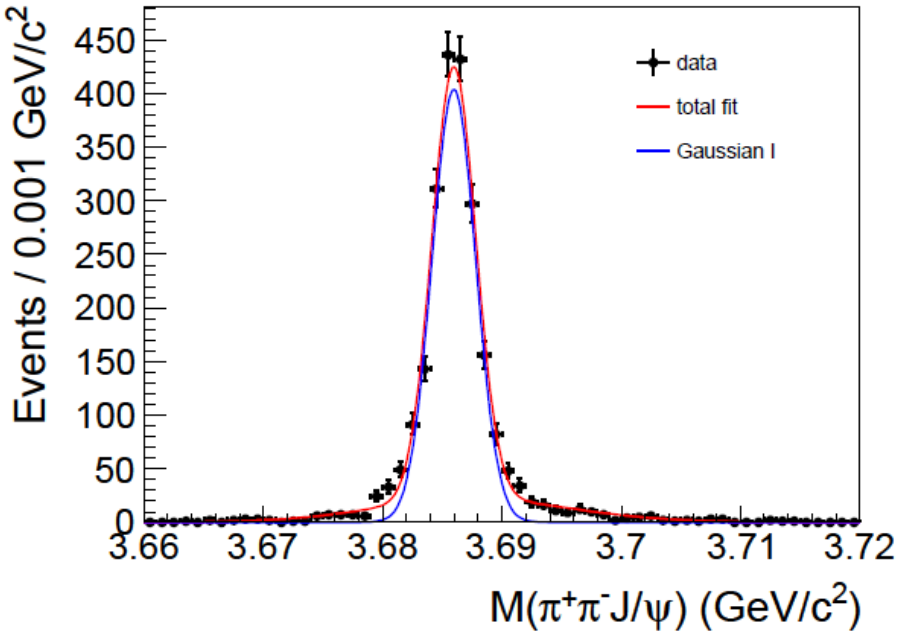


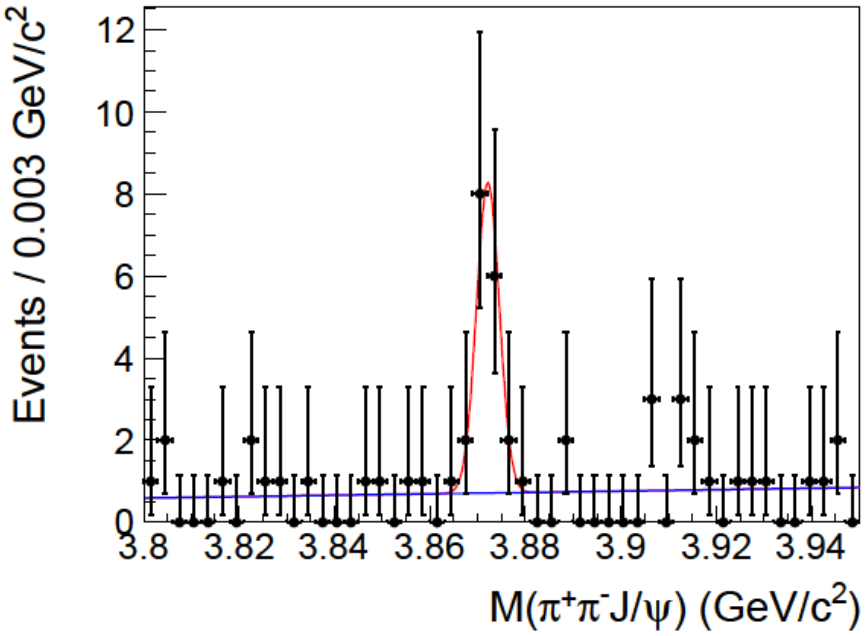


BESIII preliminary

Clear ISR ψ' signal for data validation
X(3872) signal at around 4.23-4.26 GeV

Observation of $e^+e^- \to \gamma X(3872)$





ISR ψ' signal is used for rate, mass, and mass resolution calibration.
N(ψ')=1242 ; Mass=3685.96±0.05 MeV; σ_M=1.84 ±0.06 MeV

BESIII preliminary

N(X(3872))=15.0±3.9 **5.3σ**
M(X(3872)) = 3872.1±0.8±0.3 MeV [PDG: 3871.68 ±0.17 MeV]

Observation of $e^+e^- \to \gamma X(3872)$

$\sqrt{s}$ (GeV)	$\sigma^B[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ (pb)
4.009	< 0.13 at 90% C.L.
4.230	$0.32 \pm 0.15 \pm 0.02$
4.260	$0.35 \pm 0.12 \pm 0.02$
4.360	< 0.39 at 90% C.L.

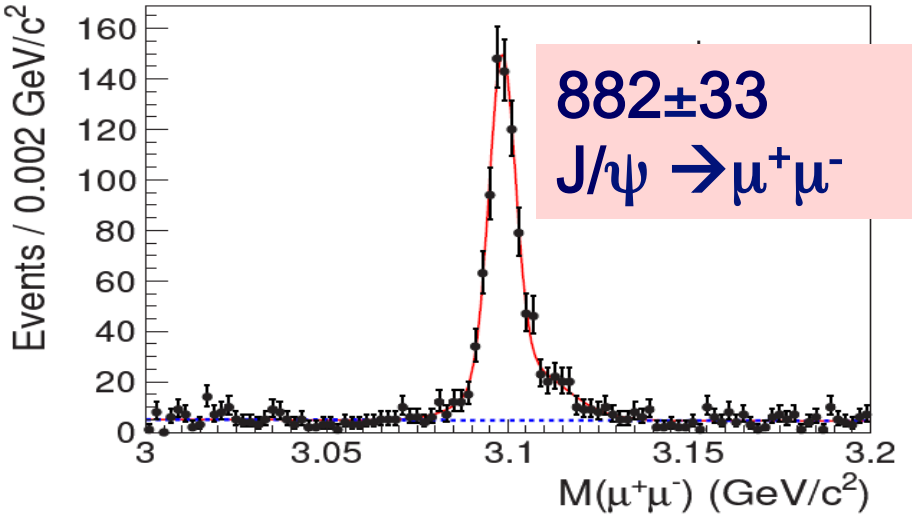
It seems X(3872) is from Y(4260) decays. At 4.26 GeV,
$\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb,

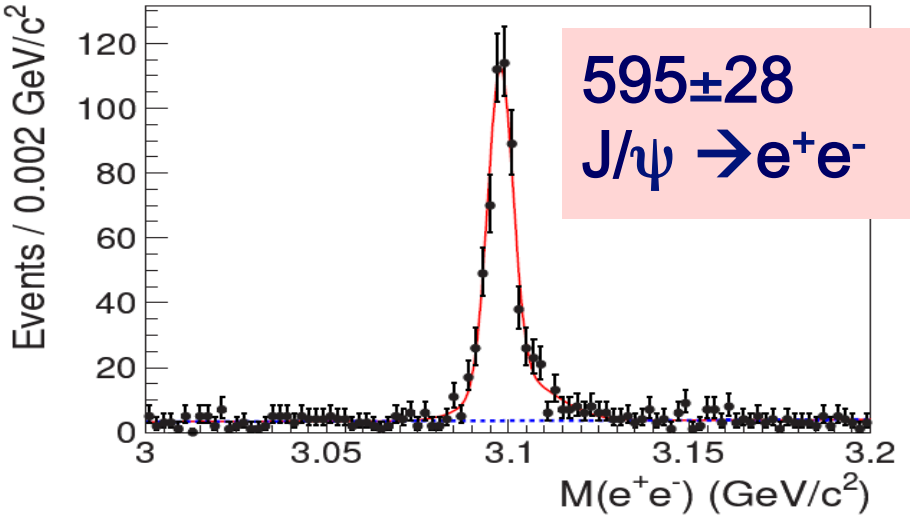
$$\frac{\sigma[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (5.6 \pm 2.0) \times 10^{-3}$$

If we take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) \sim 5\%$, (>2.6% in PDG)
$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 11.2\%$ Large transition ratio ! BESIII preliminary

$e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV @ BESIII

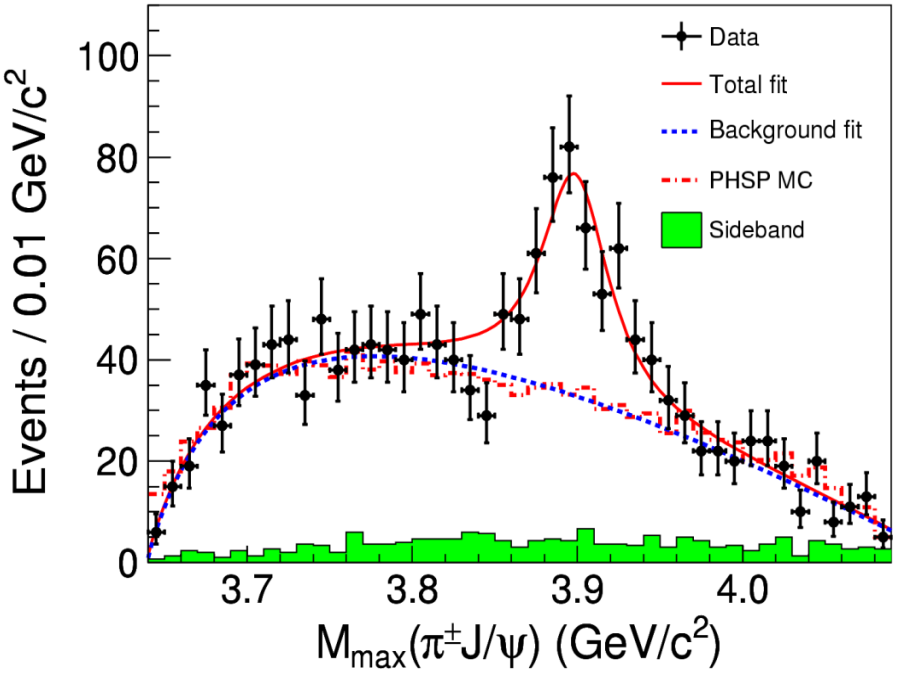
BESIII: PRL110, 252001





- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$= (62.9±1.9±3.7) pb, consistent with BaBar and BELLE's measurement.

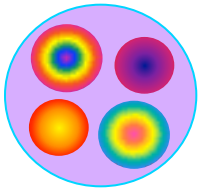
$e^+e^- \to \pi Zc(3900) \to \pi^+\pi^- J/\psi$ at 4.26 GeV



- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events
- >8σ

- Decays to charmonium thus has a c c-bar pair!
- With electric charge thus has two more light quarks!

  ➔ $N_{quark} \geq 4$!

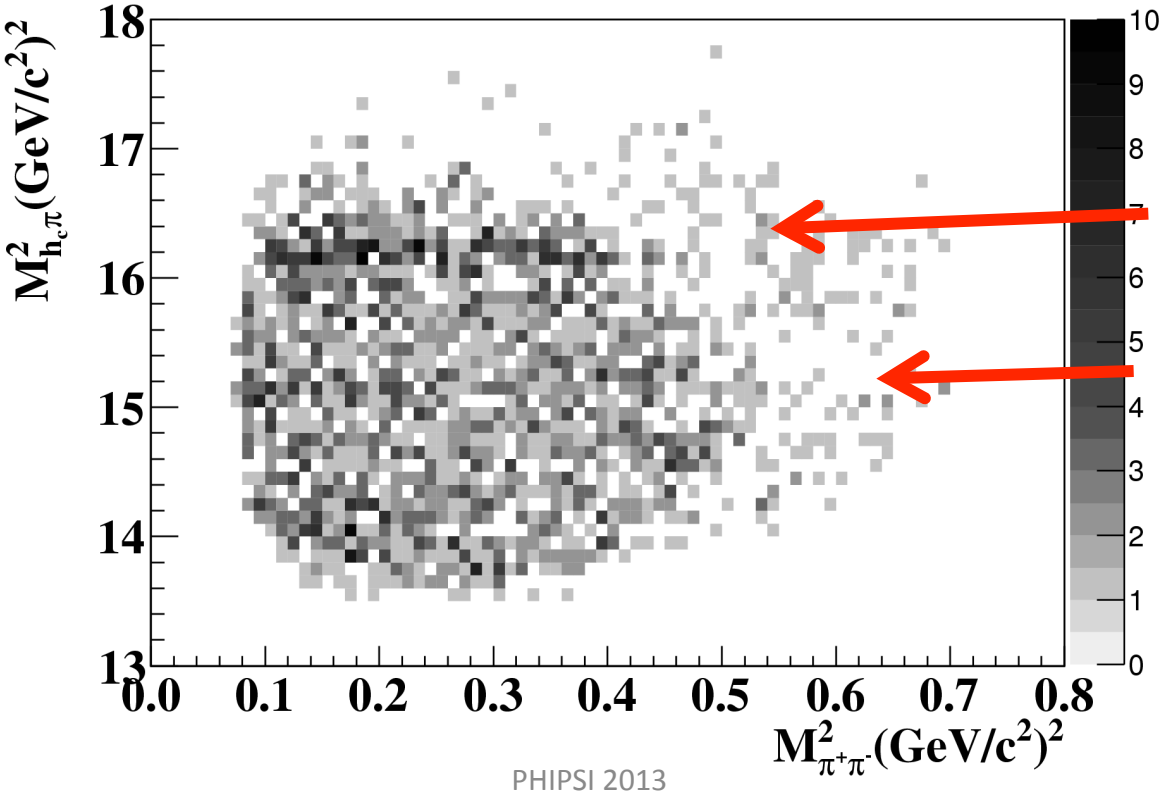


- Do searches in $\pi^\pm h_c(1P)$, $\pi^\pm\psi(2S)$, $\pi^\pm\chi_{cJ}$, …
- BESIII: e^+e^- → $\pi^\pm$+exotics, $\rho^\pm$ +exotics, …

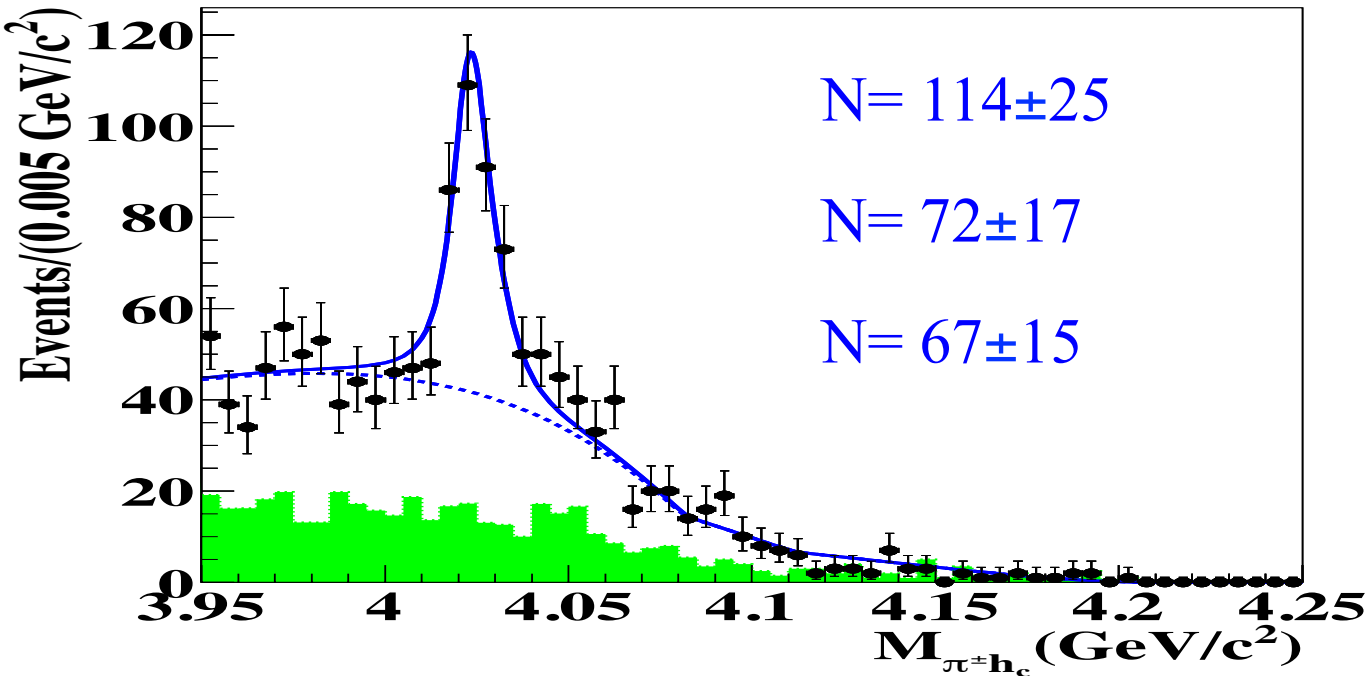
$e^+e^- \to \pi^+\pi^- h_c(1P)$

BESIII: 1309.1896, submitted to PRL

- $h_c \to \gamma\eta_c$, $\eta_c \to$hadrons [16 exclusive decay modes]
  - p p-bar, $\pi^+\pi^- K^+K^-$, $\pi^+\pi^-$p p-bar, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - p p-barπ^0, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$



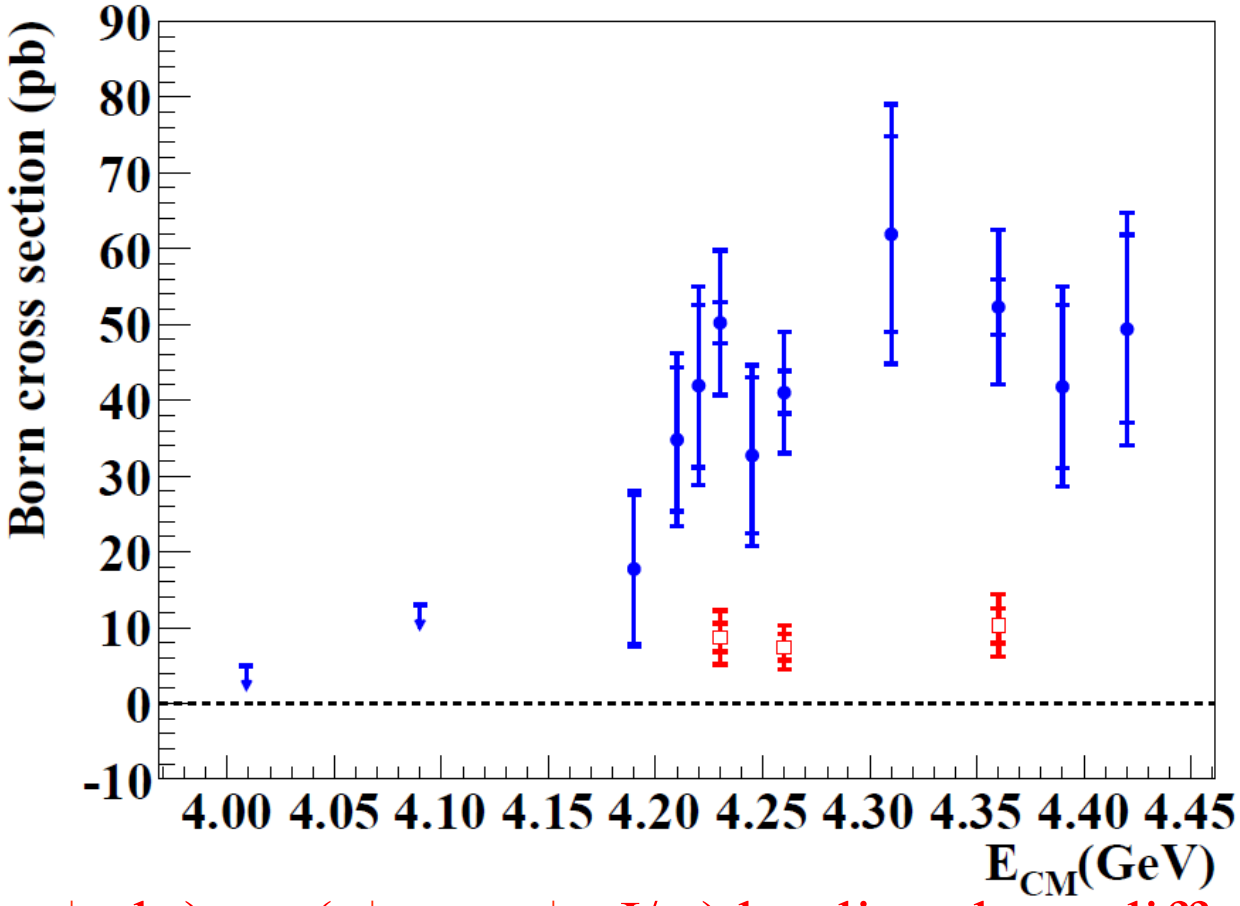
$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c(1P)$



Simultaneous fit to 4.23/4.26/4.36 GeV data and 16 η_c decay modes. 8.9σ

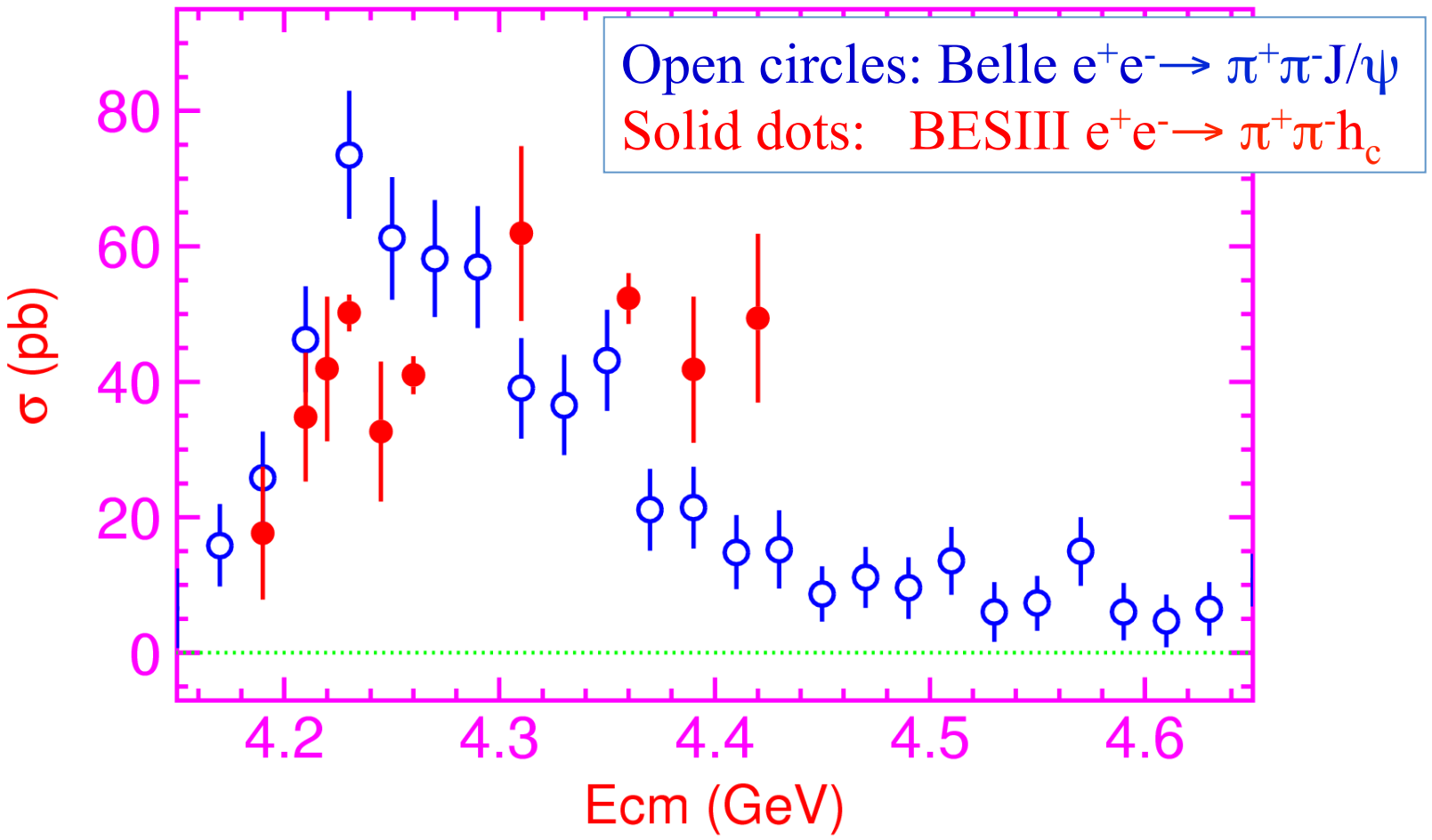
$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7$ MeV; $\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6$ MeV

Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$



- $\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim \sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV
- Hint for a vector $c\bar{c}g$ hybrid? [PRD78, 056003 (Guo); 094504 (Dudek): $c\bar{c}$ in spin-singlet in hybrids!]

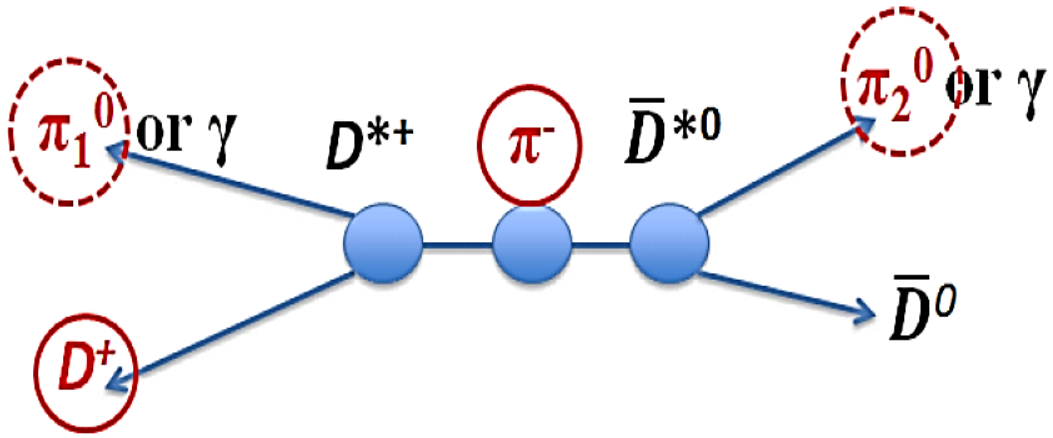
Comparison of $e^+e^- \to \pi^+\pi^- h_c$ and $\pi^+\pi^- J/\psi$



Broad structure at ~4.4 GeV? Need more data at high energies to complete the line shape measurement.

$e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ at BESIII

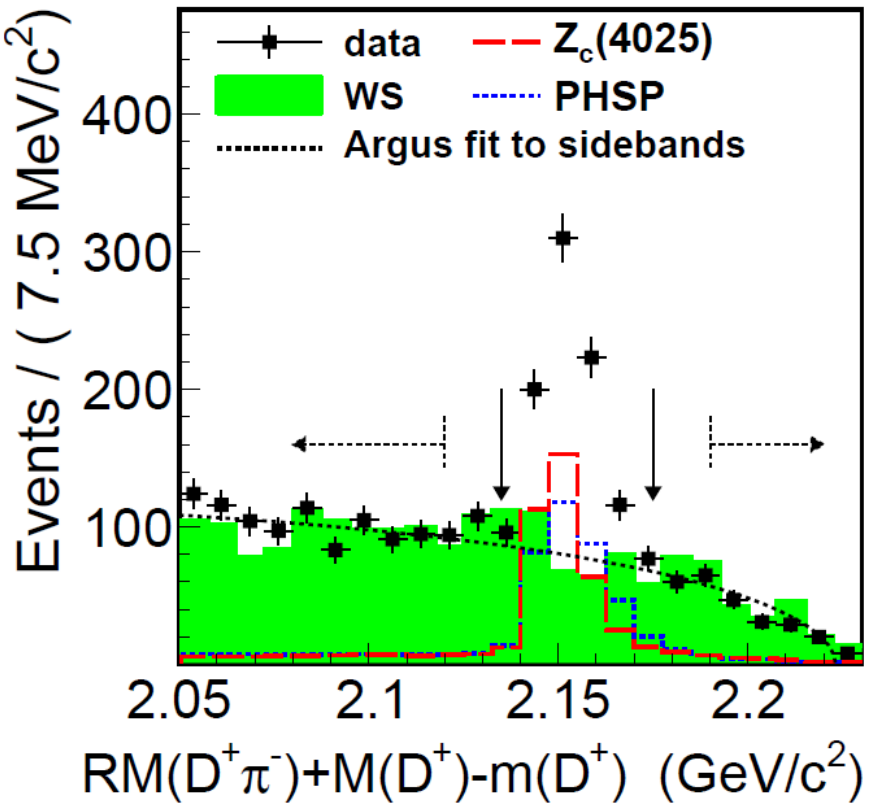
- 827 pb^{-1} data at Ecm=4.26 GeV
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.

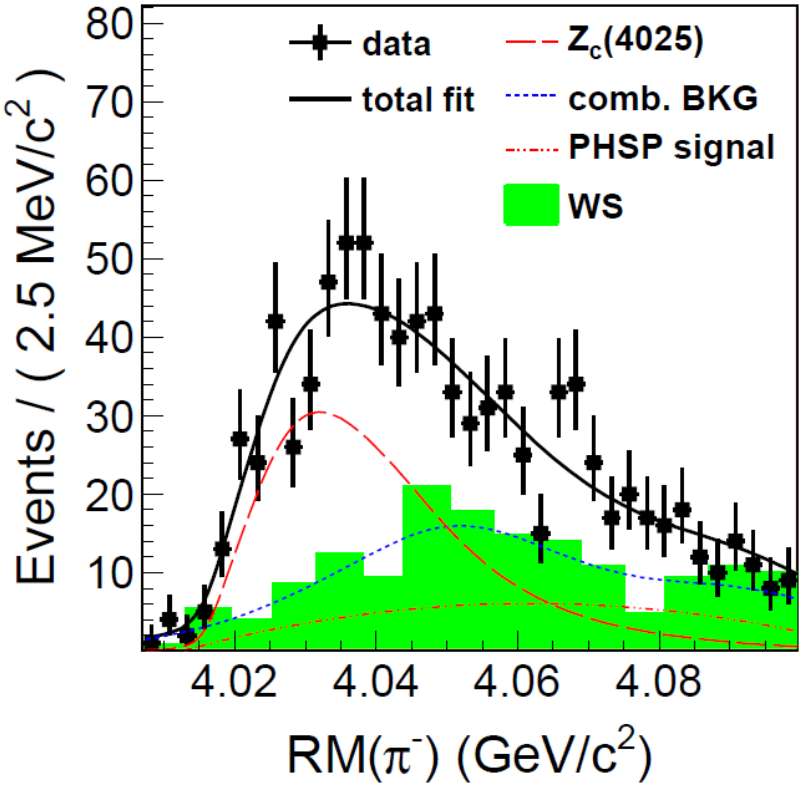


Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

BESIII: 1308.2760, submitted to PRL

$e^+e^- \to \pi Z_c(4025) \to \pi^- (D^*\bar{D}^*)^+ + c.c.$





Fit to $\pi^\pm$ recoil mass yields 401±47 $Z_c(4025)$ events. **>10σ**

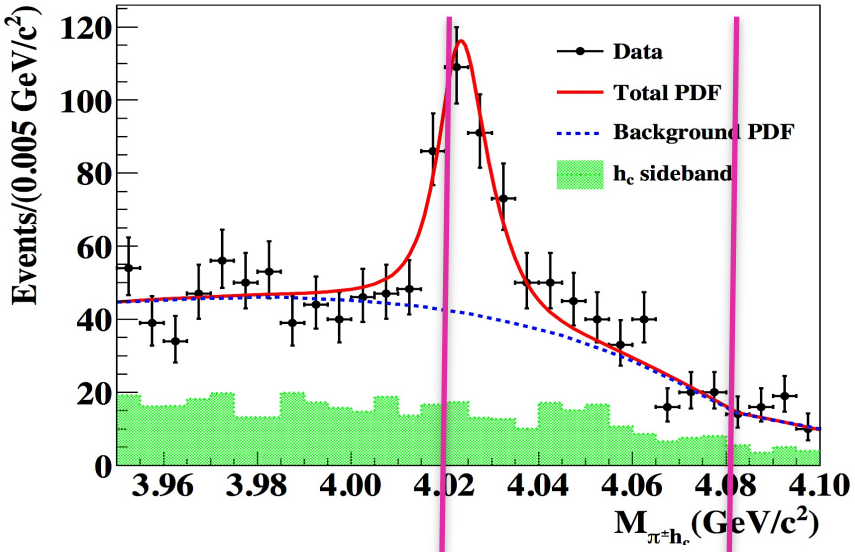
M($Z_c(4025)$) = 4026.3±2.6±3.7 MeV; Γ($Z_c(4025)$) = 24.8±5.6±7.7 MeV

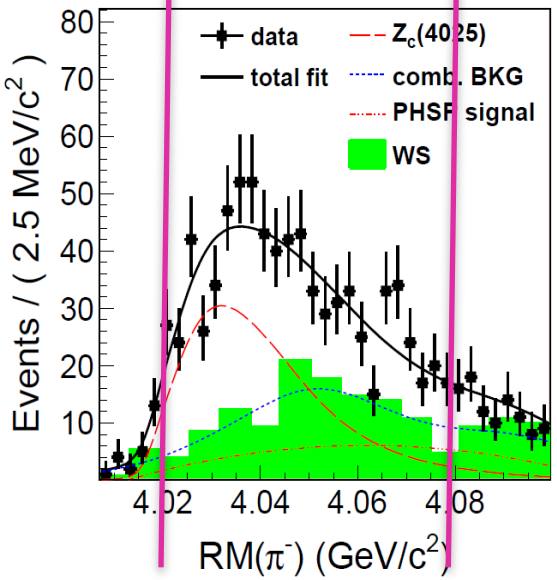
$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp(4025) \to \pi^\pm (D^*\bar{D}^*)^\mp)}{\sigma(e^+e^- \to \pi^\pm (D^*\bar{D}^*)^\mp)} = (65 \pm 9 \pm 6)\%$$

$$\sigma(e^+e^- \to \pi^\pm (D^*\bar{D}^*)^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

BESIII: 1308.2760

$Z_c(4020)=Z_c(4025)$?





BESIII preliminary
The Zc' is found!

- M(4020) = 4022.9±0.8±2.7 MeV
- M(4025) = 4026.3±2.6±3.7 MeV

- Γ(4020) = 7.9±2.7±2.6 MeV
- Γ(4025) = 24.8±5.6±7.7 MeV

Close to D*D* threshold=4017 MeV

Mass and width consistent within ~1.5σ

Interference with other amplitudes may change the results

Coupling to D*D* is much larger than to πh_c if they are the same state

Summary

- The mass and width of η_c is precisely measured.
- Absolute $B(\psi' \to \pi^0 h_c)$, $B(h_c \to \gamma \eta_c)$, and $\Gamma(h_c)$ are measured for the first time.
- η_c' is observed in the charmonium decay for the first time.
- Observation of $Y(4260) \to \gamma X(3872)$.
- First confirmed exotic state with at least four quarks, $Z_c(3900)^+$.
- Observation of the Z_c' at BESIII.

Thank you!

Y(4260) and Y(4360)

First observed by BaBar via ISR process, confirmed by CLEO and BELLE strong coupling to the hadronic transition processes