Recent results from BESIII

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IHEP, Beijing

for BESIII Collaboration

The 7th France China Particle Physics Laboratory Workshop

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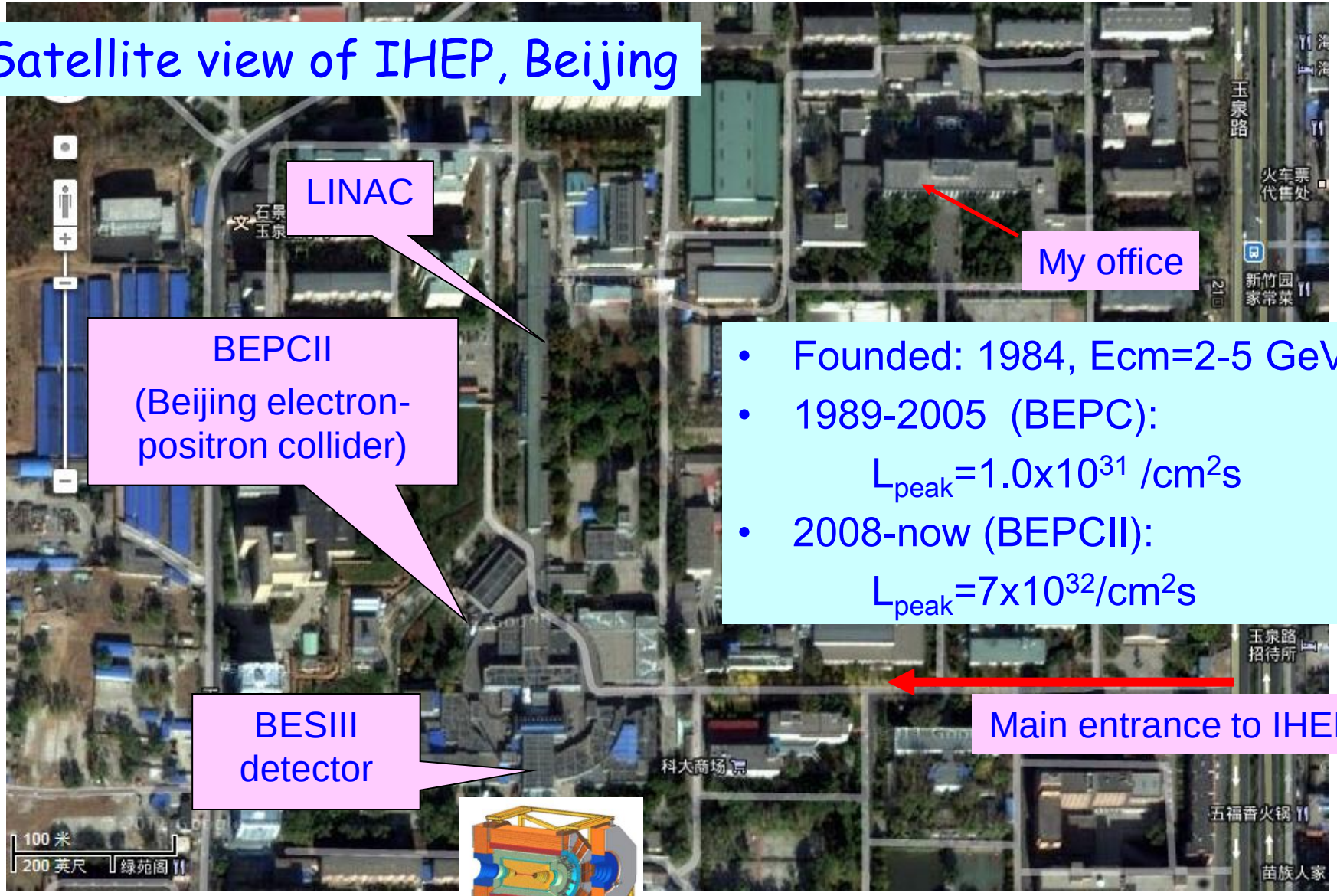
Outline

- Introduction
- Hadron spectroscopy
- XYZ Physics
- Charm physics
- Summary & Outlook

The Beijing Electron Positron Collider

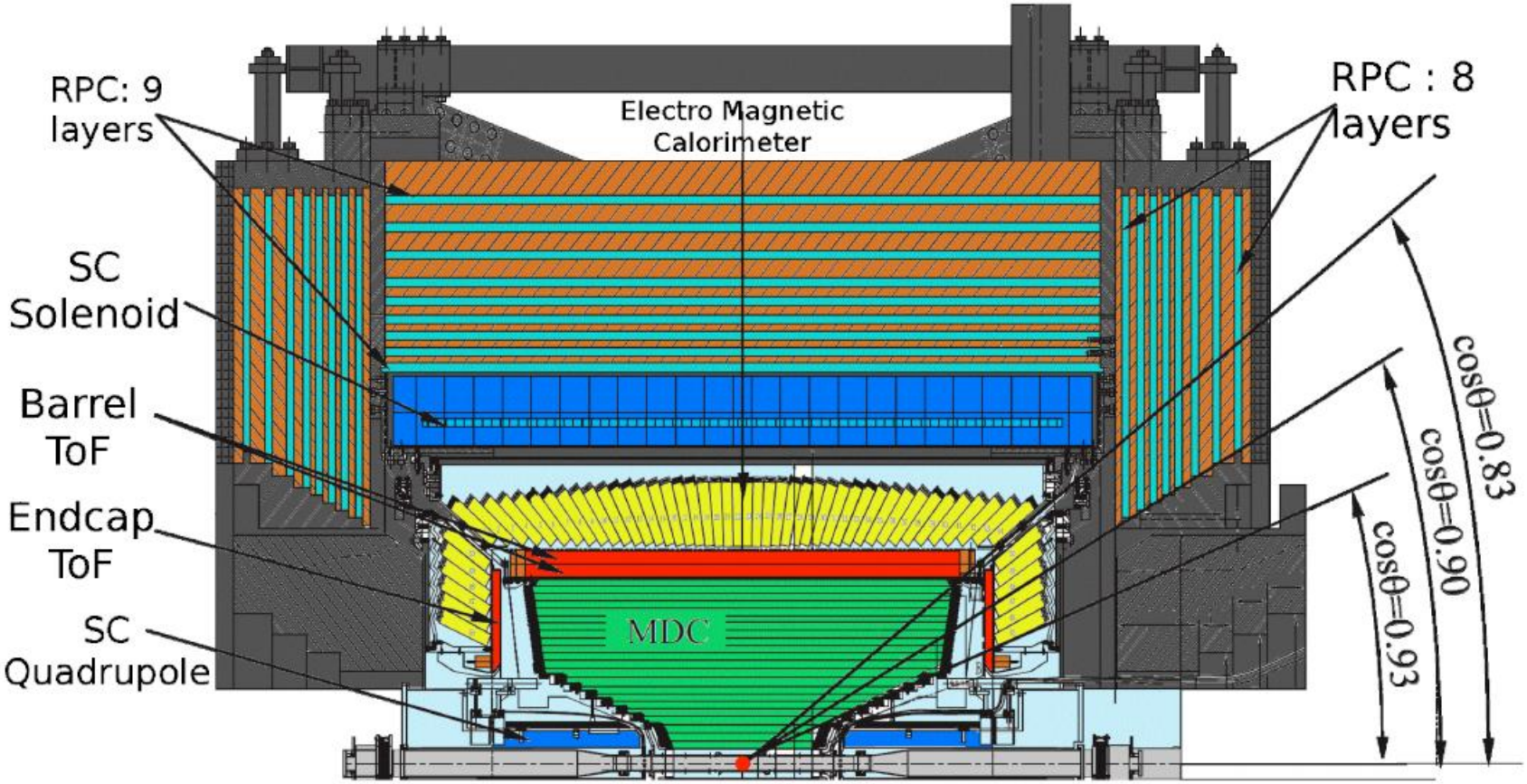
Satellite view of IHEP, Beijing



- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  $L_{peak}=1.0\times10^{31}$ /cm^{2}s
- 2008-now (BEPCII):
  $L_{peak}=7\times10^{32}$/cm^{2}s

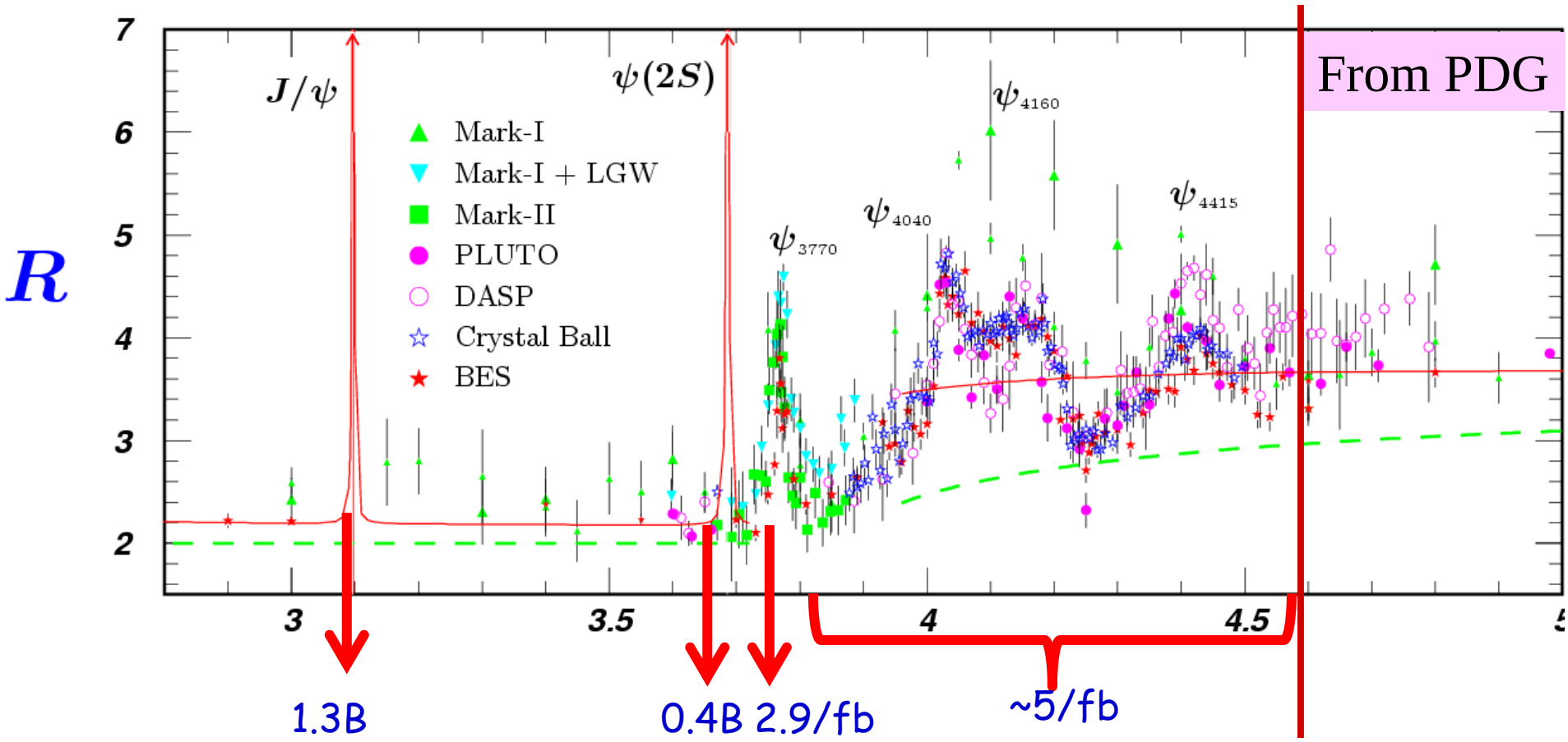
BESIII

53 institutions
22 outside China



Wire tracker (no Si); TOF + dE/dx for PID; CsI Ecal; RPC muon

BESIII: data and physics



Vector ψ/Y states can be produced directly

C-even states can be produced from radiative transitions

Light hadron spectroscopy

PWA of J/ψ→γηη

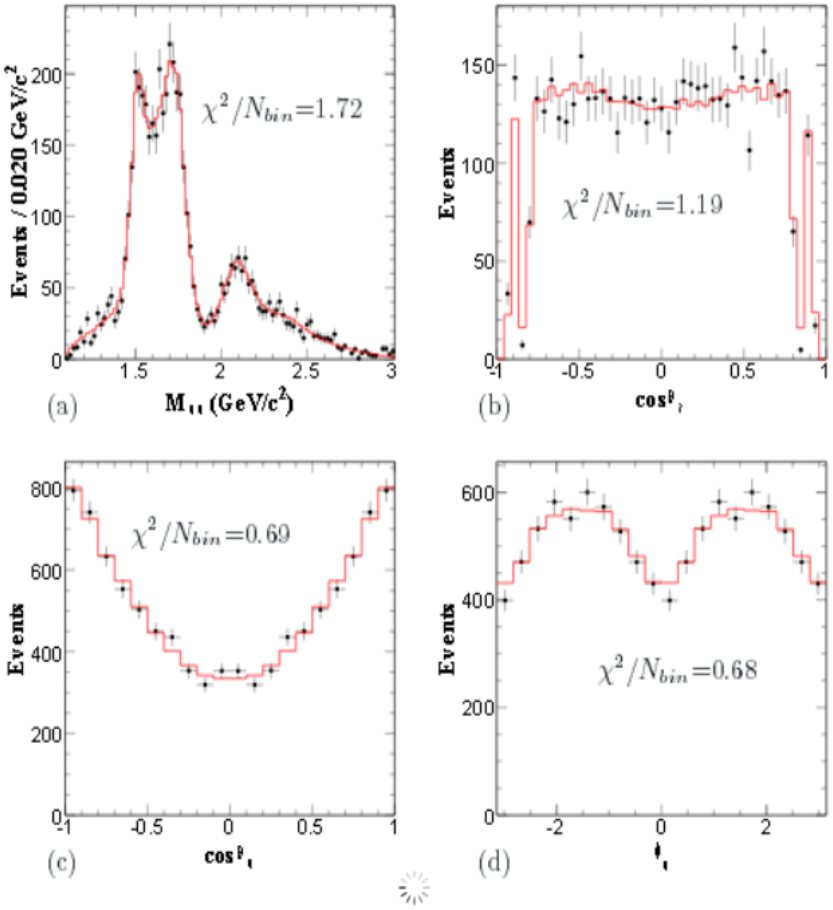
PRD 87, 092009

- **best solution:**

  $f_0(1500)$,$f_0(1710)$, $f_0(2100)$;
  $f_2'(1525)$, $f_2(1810)$, $f_2(2340)$;
  0++ phase space, ϕη

- **no significant evidence of:**
  - scalar: $f_0(1370)$, $f_0(1790)$, $f_0(2020)$, $f_0(2200)$, $f_0(2330)$
  - tensor: $f_2(2010)$, $f_2(2150)$, $f_J(2220)$ source of sys. unc.

- **ϕη background:**
  - interference of ϕ tail accounted for
  - source of systematic uncertainties



PWA of J/ψ→γηη

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

no significant evidence of:

- scalar: $f_0(1370)$, $f_0(1790)$, $f_0(2020)$, $f_0(2200)$, $f_0(2330)$
- tensor: $f_2(2010)$, $f_2(2150)$, $f_J(2220)$

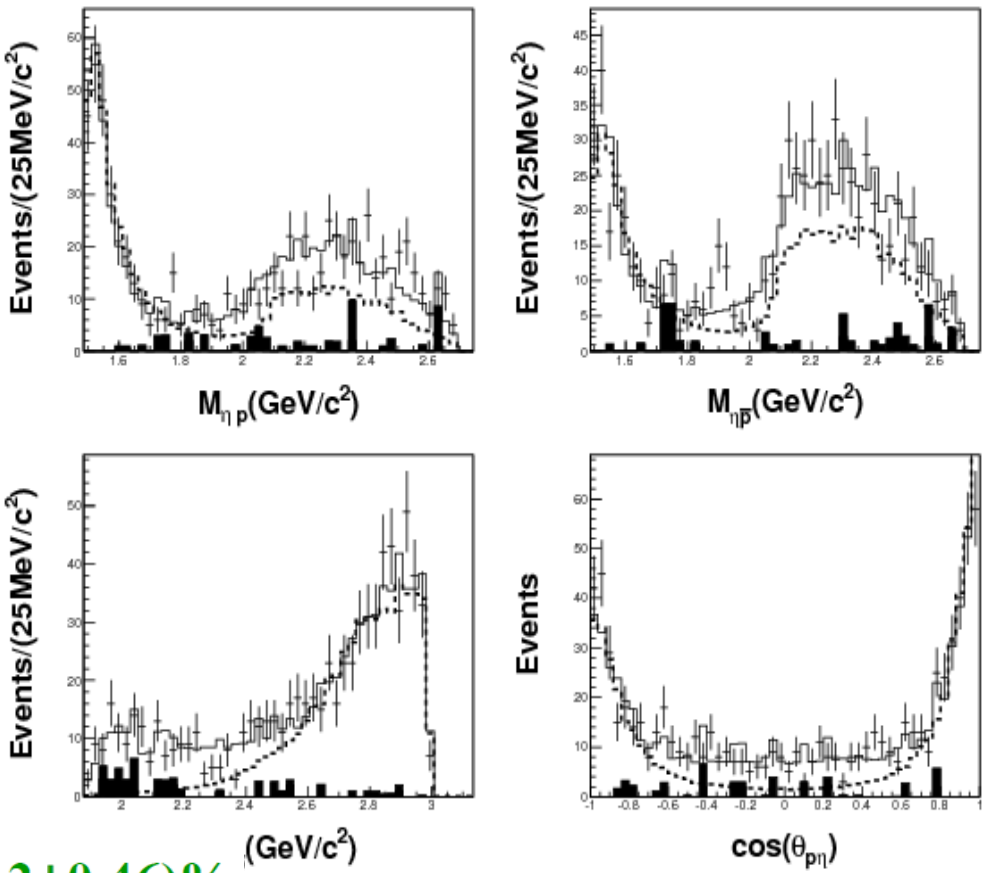
PRD 88, 032010

PWA of ψ'→ ppbar η

- **Low background:**
  - sidebands and continuum
- **Best solution:**
  - N(1535) combined with an interfering phase space
- **ppbar enhancement: <3σ**
- **N(1535):**

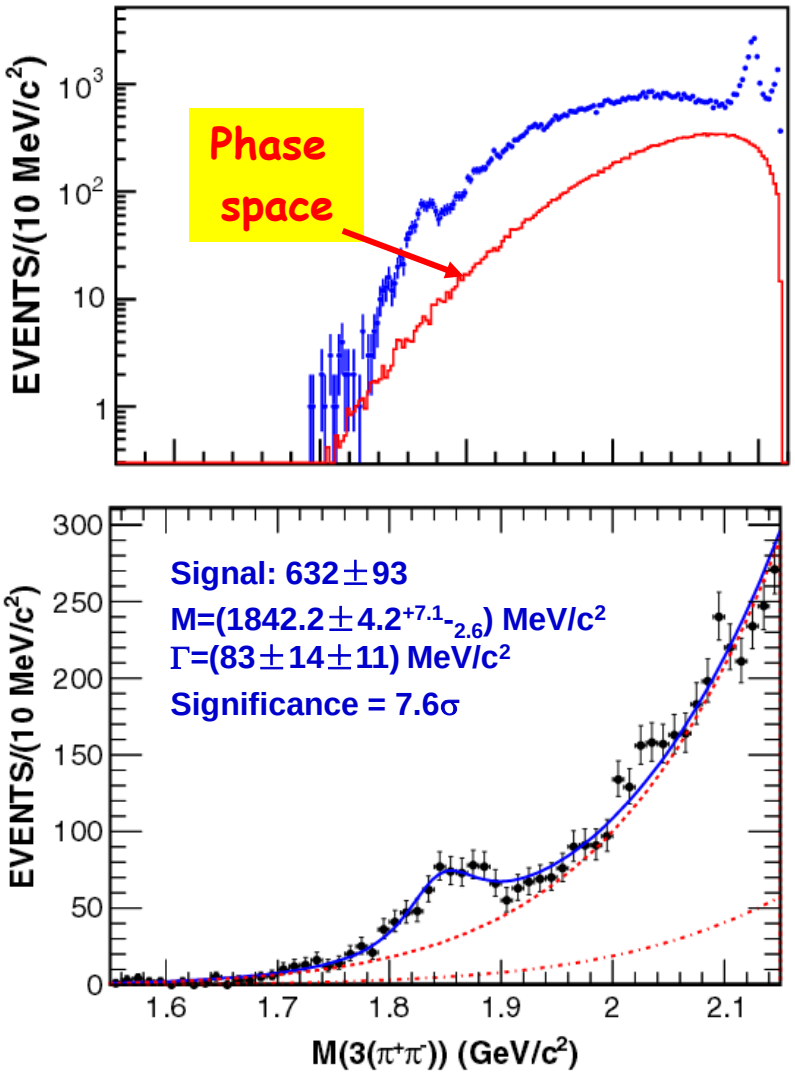
  M=(1524±5+10) MeV/c2

  Γ= (130+27+10) MeV/c2
- **Suppressed (<12%):**

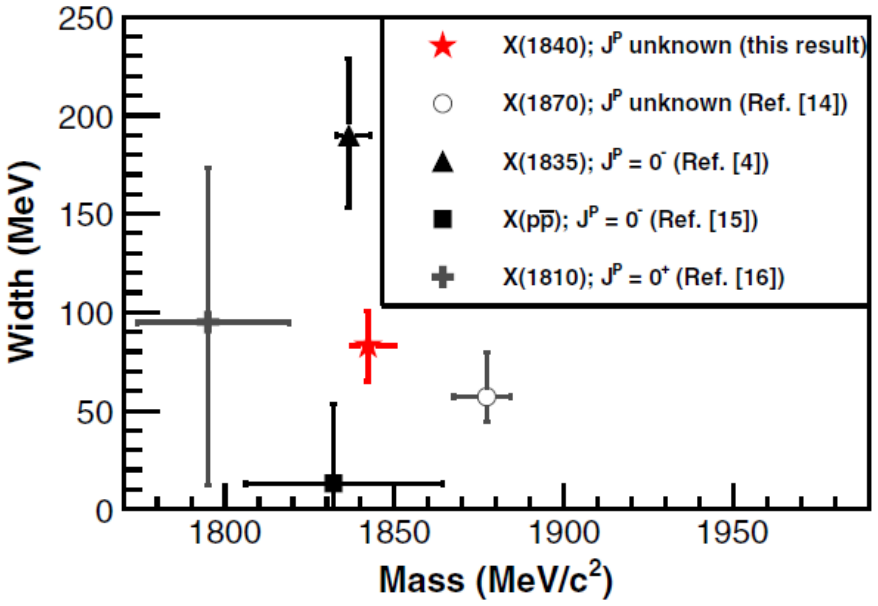


$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \to p\bar{p}\eta)}{\mathcal{B}(J/\psi \to p\bar{p}\eta)} = (3.2 \pm 0.46)\%$$

New structure around 1.84GeV in $J/\psi \rightarrow \gamma\, 3(\pi^+\pi^-)$

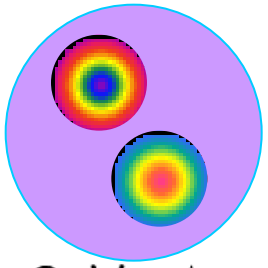


- **Comparison to the BESIII results of the masses and widths of the X(1835), X(ppbar), X(1870), and X(1810)**
- **Mass consistent with X(1835) and X(ppbar), but width different**



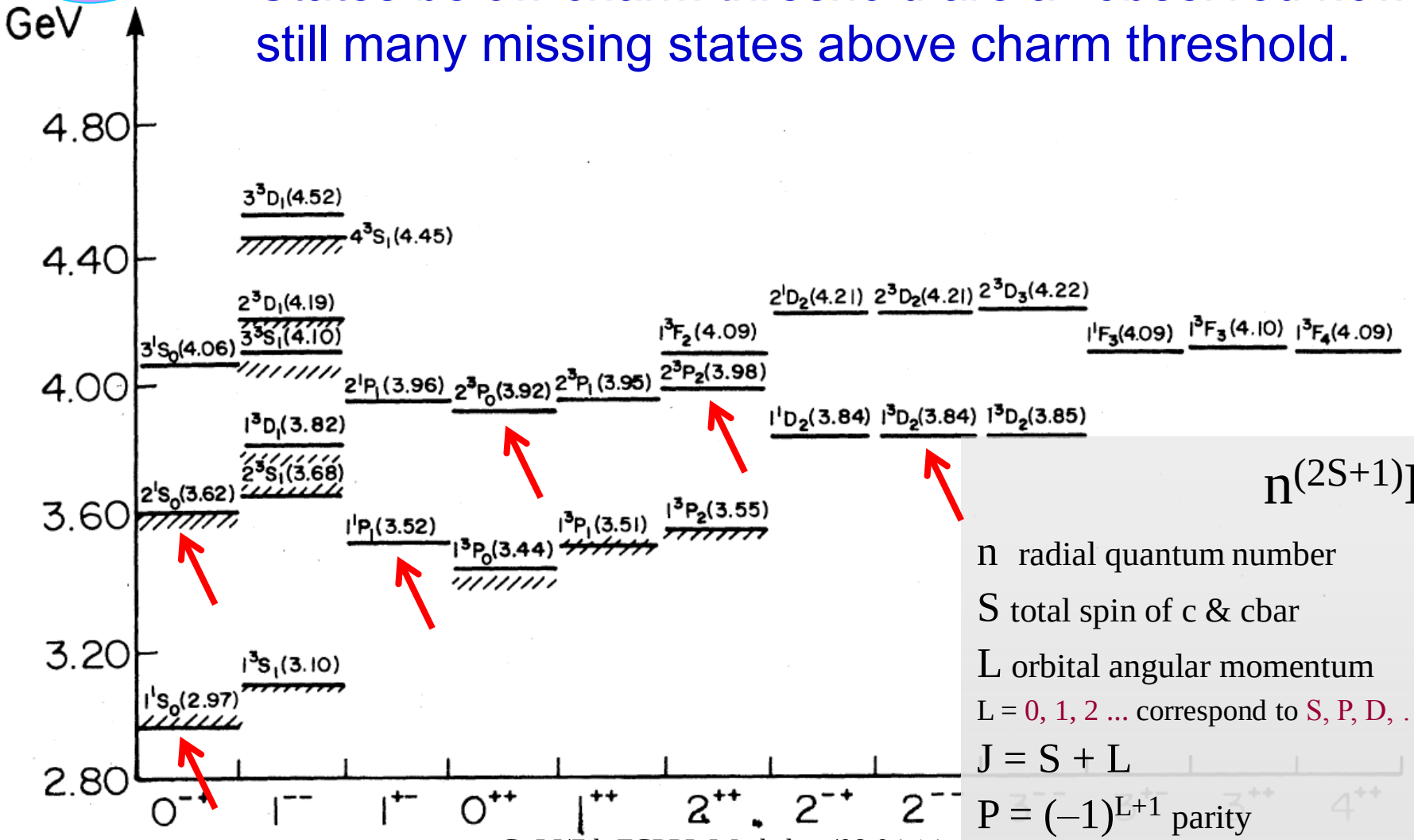
PRD88, 091502

XYZ Physics



Charmonium spectroscopy

States below charm threshold are all observed now, still many missing states above charm threshold.



$n^{(2S+1)}L_J$

n radial quantum number

S total spin of c & cbar

L orbital angular momentum

L = 0, 1, 2 ... correspond to S, P, D, …

$J = S + L$

$P = (-1)^{L+1}$ parity

$C = (-1)^{L+S}$ charge conj.

Godfrey & Isgur, PRD32, 189 (1985)

There are lots of XYZ states

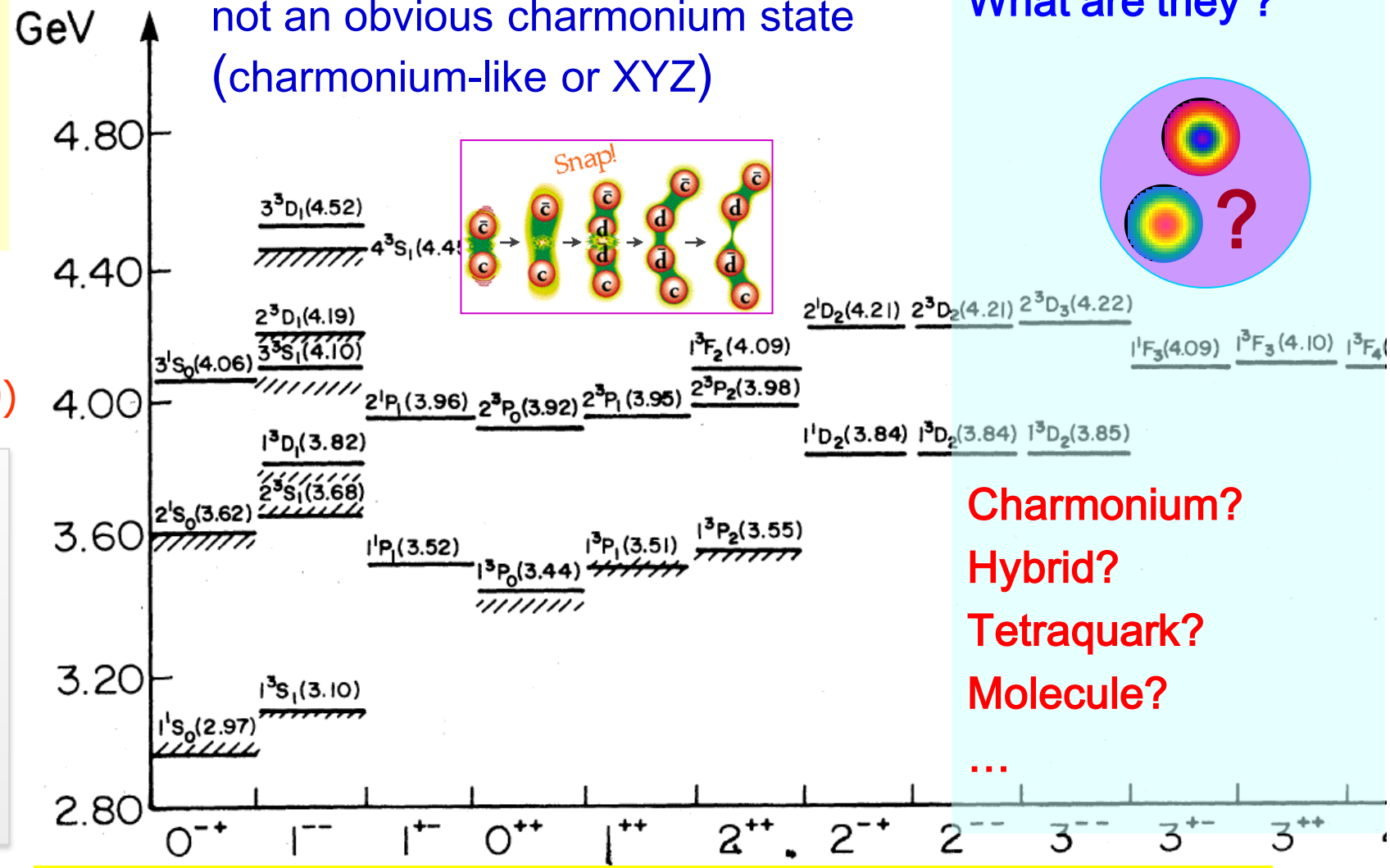
Z(4430)
Z(4250)
Z(4050)
Z(3900)
Z(4020)
Z(4025)

X(3872)

XYZ(3940)

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

Charmonium in the final state, but not an obvious charmonium state (charmonium-like or XYZ)

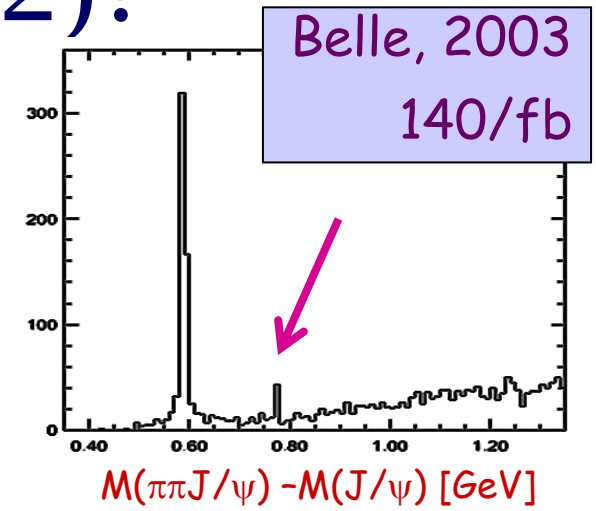


What are they ?

Charmonium?
Hybrid?
Tetraquark?
Molecule?
…

Not all of them are charmonia!

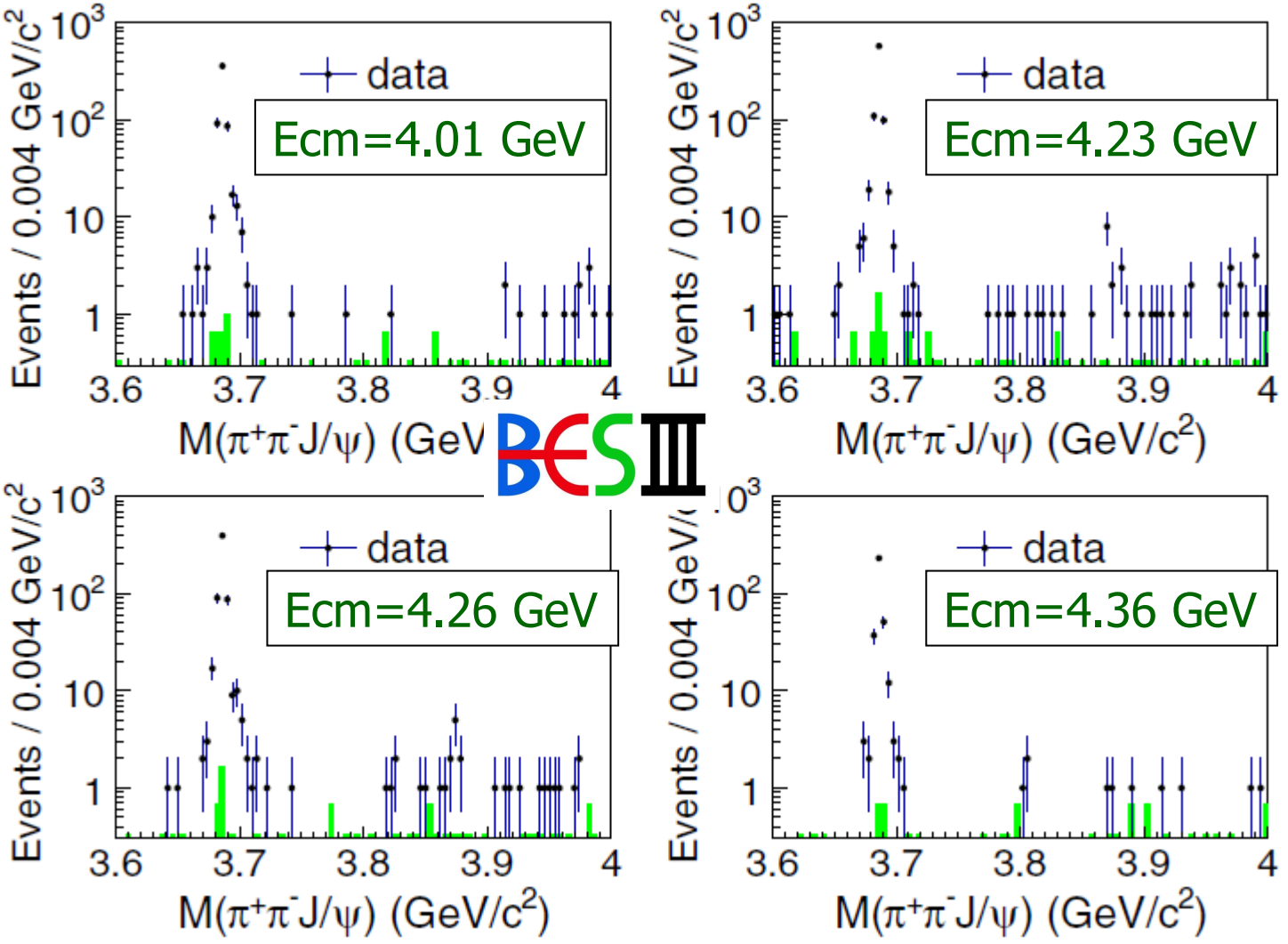
What is the X(3872)?



- Mass: Very close to D^0D^{*0} threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$ [LHCb]
- Production
  - in $\bar{p}p$/pp collison – rate similar to charmonia
  - In B decays – KX similar to $\bar{c}c$, K*X smaller than $\bar{c}c$
  - Y(4260)→γ+X(3872) [BESIII, see next slides]
- Decay BR: open charm ~ 50%, charmonium~O(%)
- Nature (very likely exotic)
  - Loosely $\bar{D}^0D^{*0}$ bound state (like deuteron?)?
  - Mixture of excited χ_{c1} and $\bar{D}^0D^{*0}$ bound state?
  - Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)

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

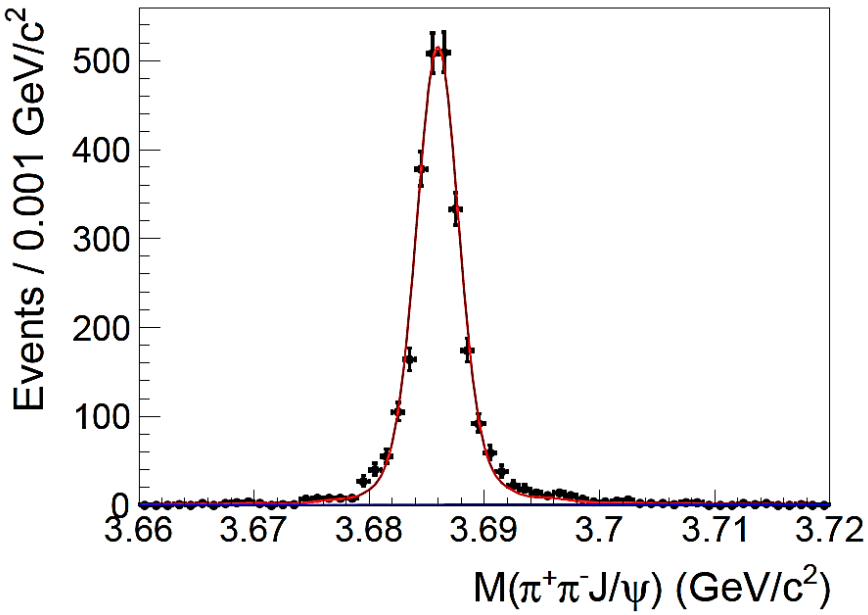
PRL 112,092001

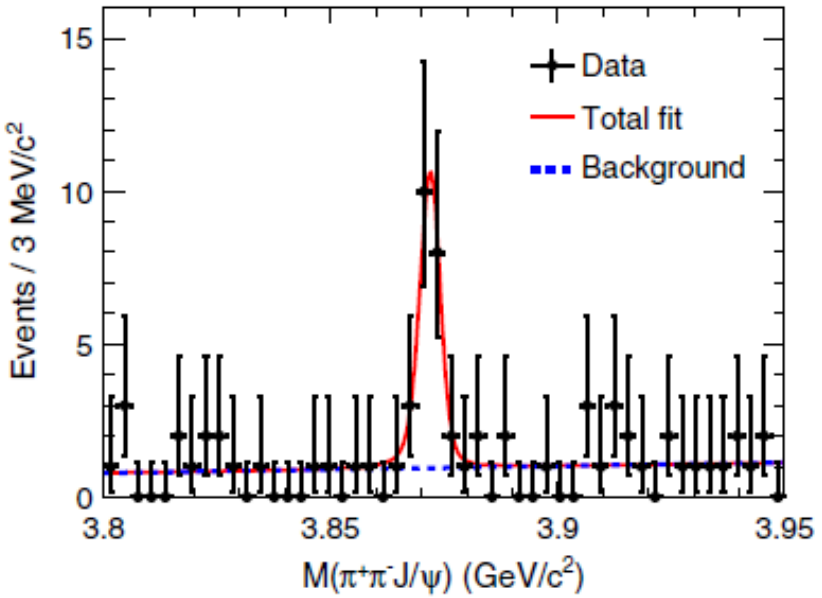


Clear ISR ψ' signal for data validation X(3872) signal at around 4.23-4.26 GeV

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

PRL 112,092001





ISR ψ' signal is used for rate, mass, and mass resolution calibration.

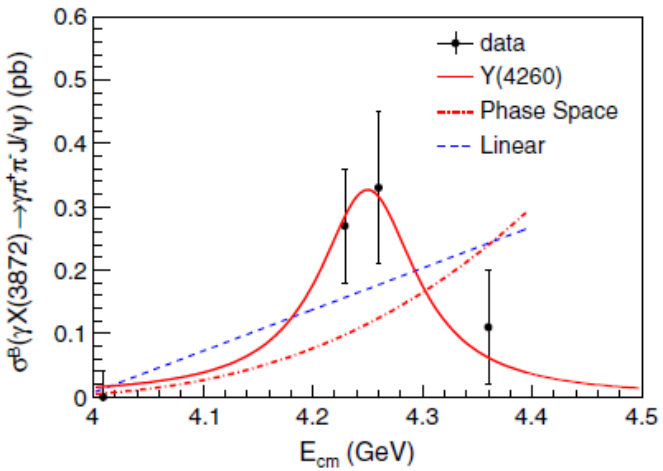
N(ψ')=1818 ; ΔM=-0.34±0.04 MeV; $\Delta \sigma_M$=1.14 ±0.07 MeV

N(X(3872))=20.1±4.5 **6.3σ**

M(X(3872)) = 3871.9±0.7±0.2 MeV [PDG: 3871.68 ±0.17 MeV]

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

$\sqrt{s}$ (GeV)	N^{obs}
4.009	0.0 ± 0.5
4.229	9.6 ± 3.1
4.260	8.7 ± 3.0
4.360	1.7 ± 1.4



$\sigma^B \cdot \mathcal{B}$ (pb)
$0.00 \pm 0.04 \pm 0.01$
$0.27 \pm 0.09 \pm 0.02$
$0.33 \pm 0.12 \pm 0.02$
$0.11 \pm 0.09 \pm 0.01$

These results suggest that X(3872) may comes from Y(4260) decays.

$\sigma^B[e^+e^- \to \gamma X(3872)]*B[X(3872) \to \pi^+\pi^- J/\psi]/\sigma^B[e^+e^- \to \pi^+\pi^- J/\psi] = (5.2 \pm 1.9) \times 10^{-3}$ at 4.26GeV.

If we take $B[X(3872) \to \pi^+\pi^- J/\psi] = 5\%$ (>2.6% in PDG), then

$$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 0.1$$

Indicates that Y(4260) has large E1 transition rate to X(3872)

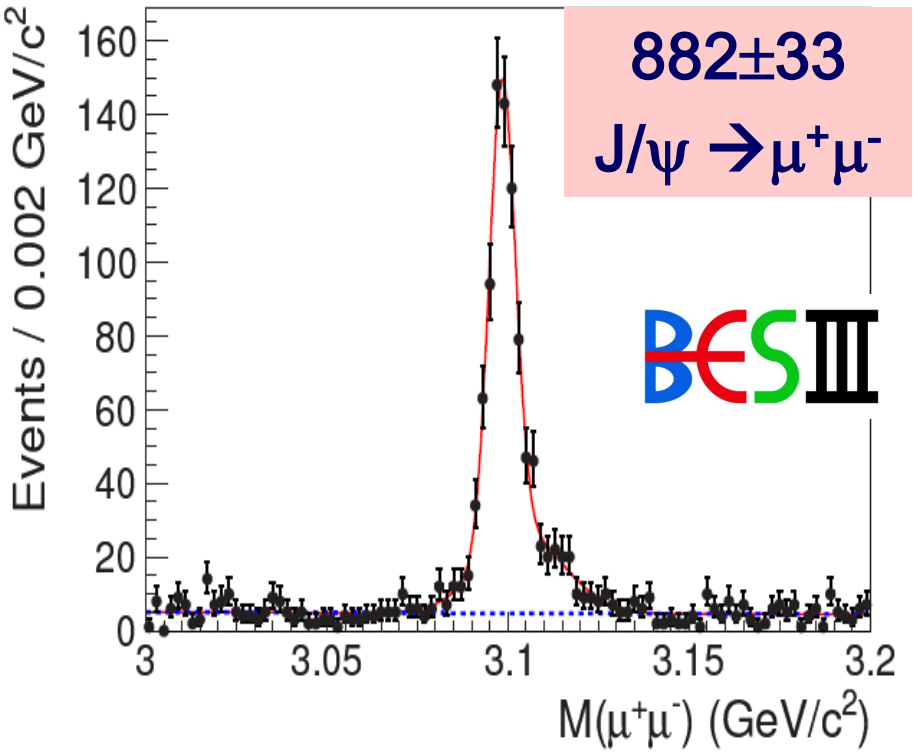
PRL 112,092001

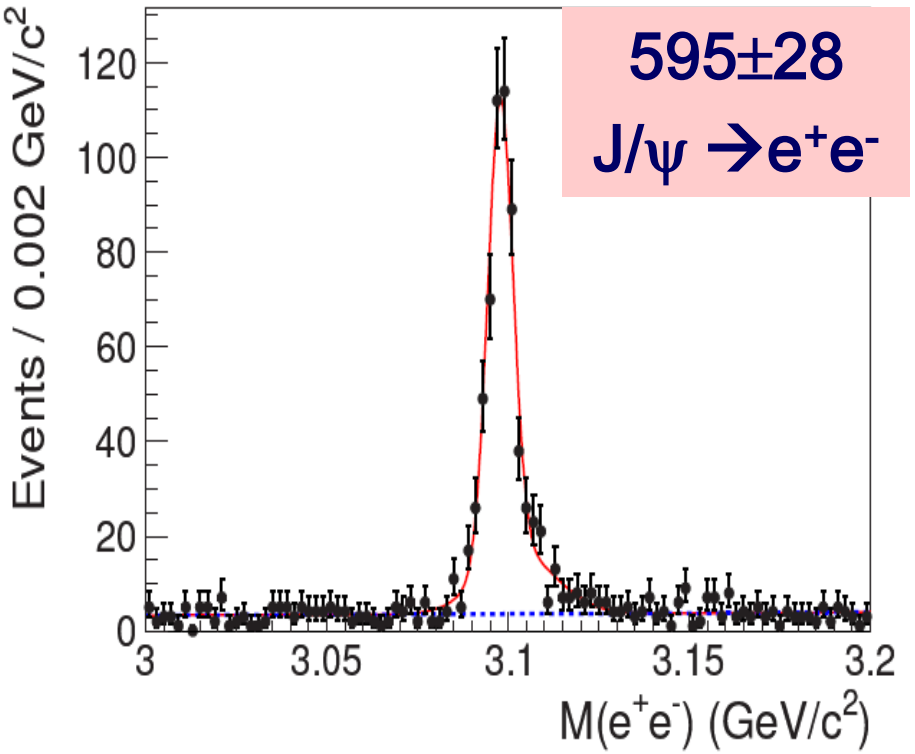
Y-family states

(vectors observed in Initial State Radiation)

+ $e^+e^- \rightarrow \pi^+\pi^- h_c$ from BESIII

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





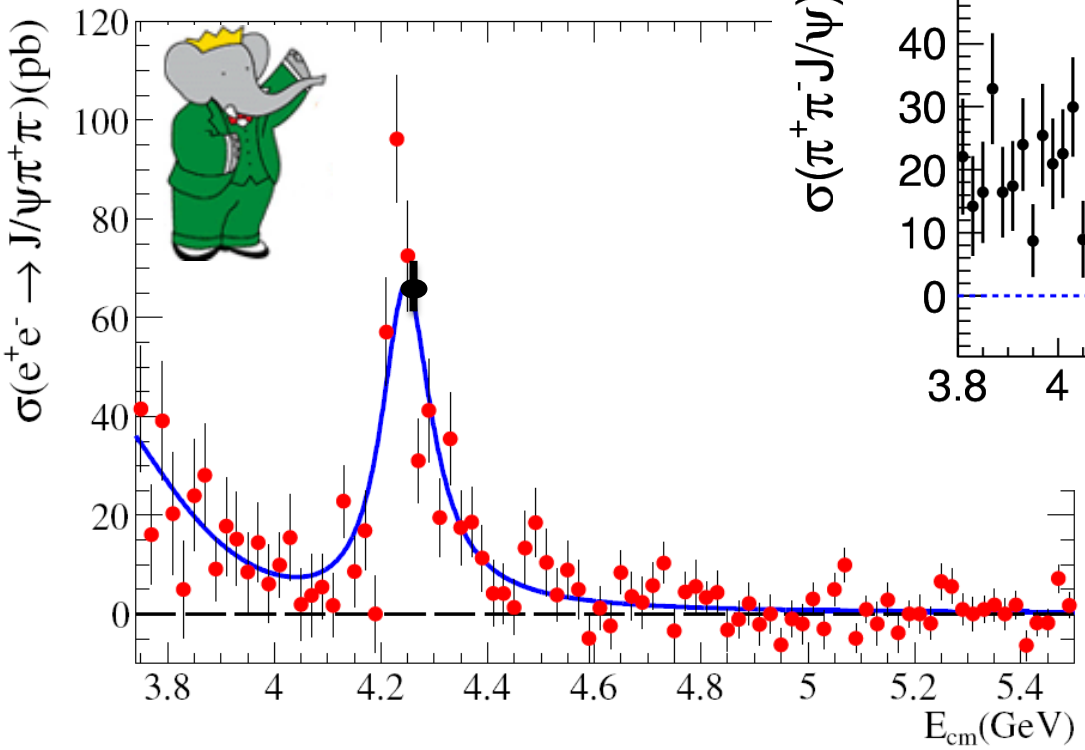
- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb

PRL110, 252001

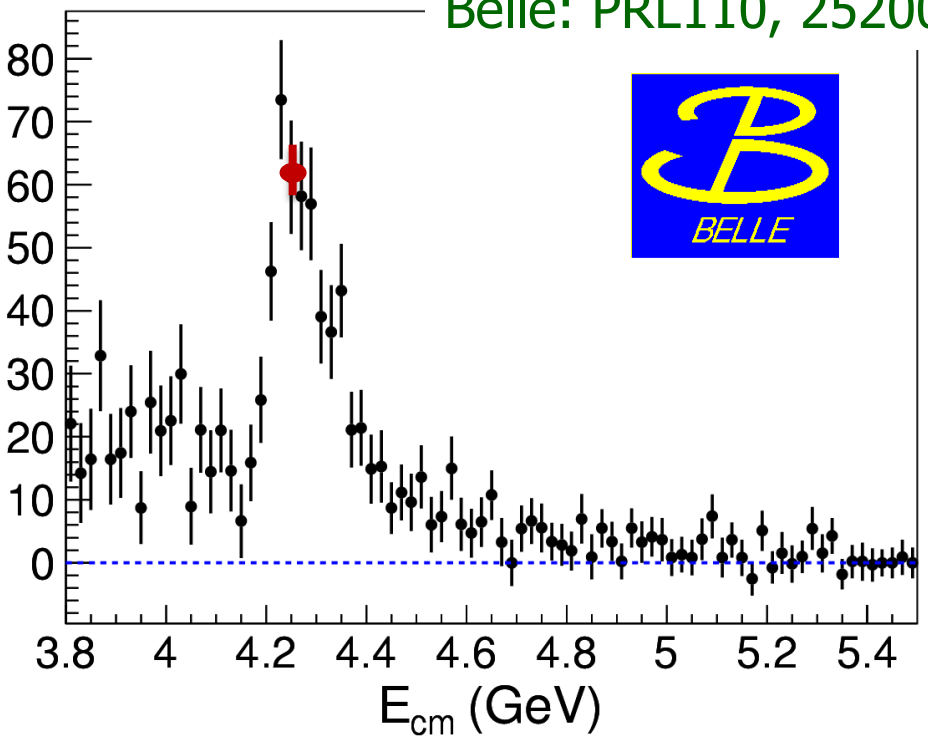
Cross section of $e^+e^- \to \pi^+\pi^- J/\psi$

BESIII

BaBar: PRD86, 051102 (2012)



Belle: PRL110, 252002



BESIII: PRL110, 252001

BESIII is measuring cross sections at more energy points, and more data being taken!

BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ = (62.9±1.9±3.7) pb

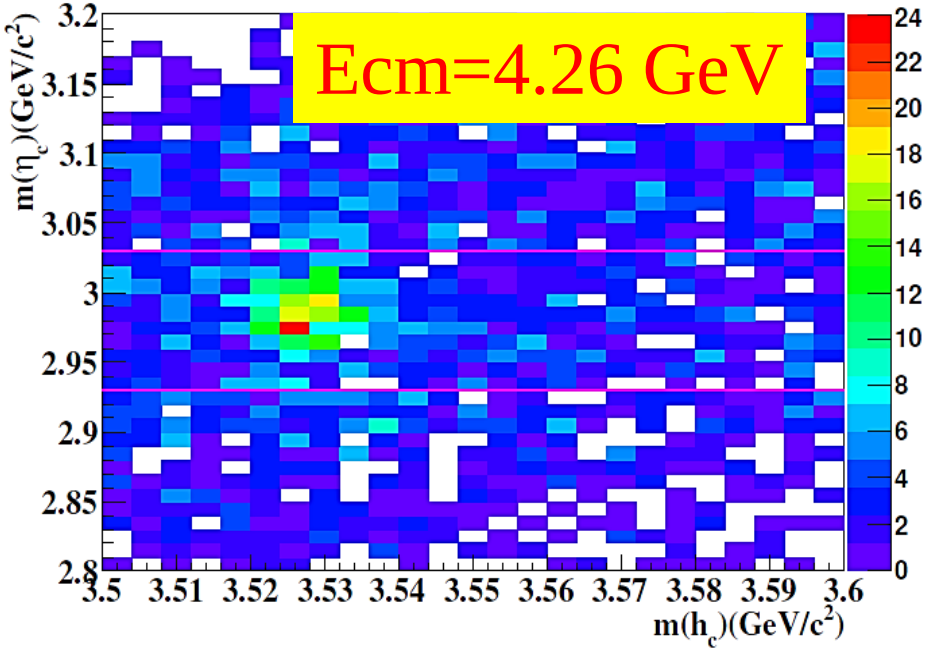
Agree with BaBar & Belle!

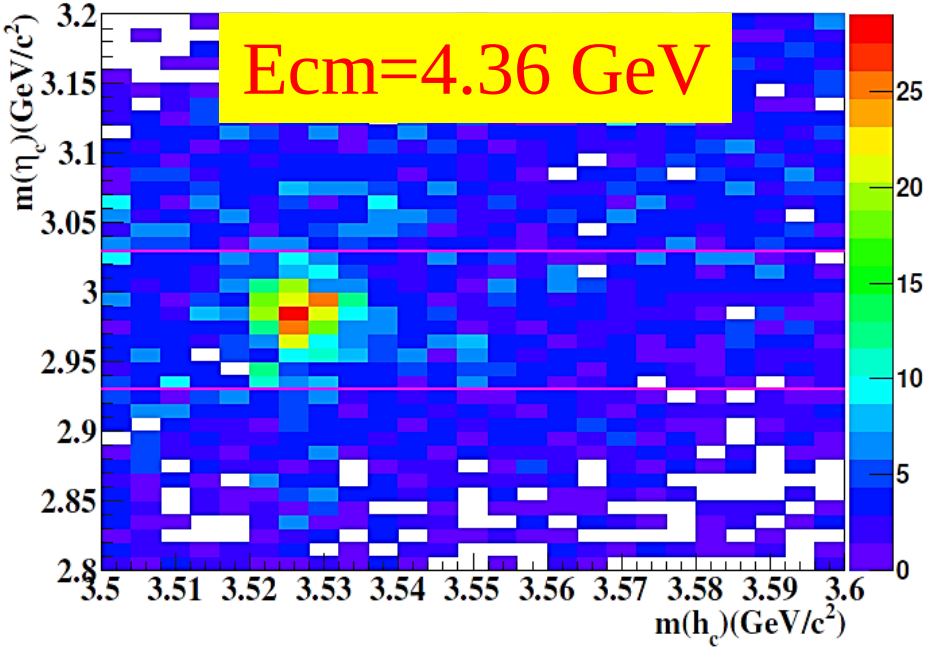
Best precision!

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

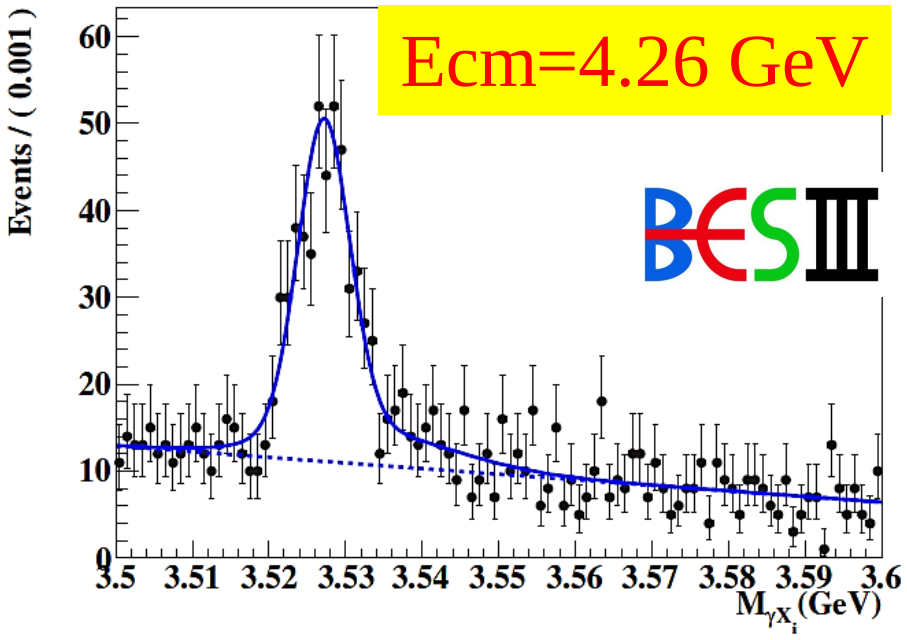
PRL 111,242001

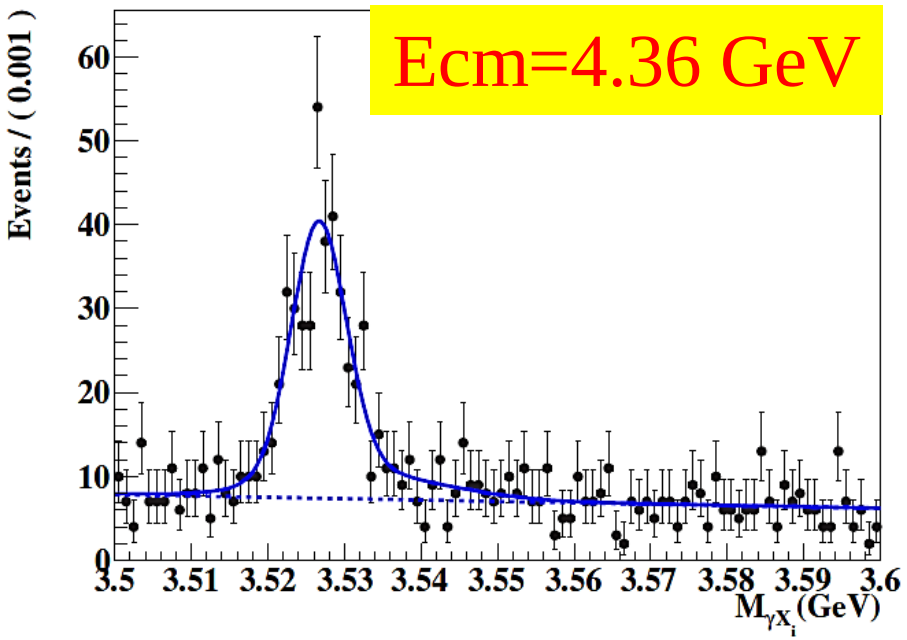
- $h_c \to \gamma\eta_c$, $\eta_c \to$hadrons [16 exclusive decay modes]
  - $p\bar{p}$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$,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





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





$N(h_c)=416\pm28$

Lum=827/pb

$\sigma^B= 41.0\pm2.8\pm7.4$ pb

$N(h_c)=357\pm25$

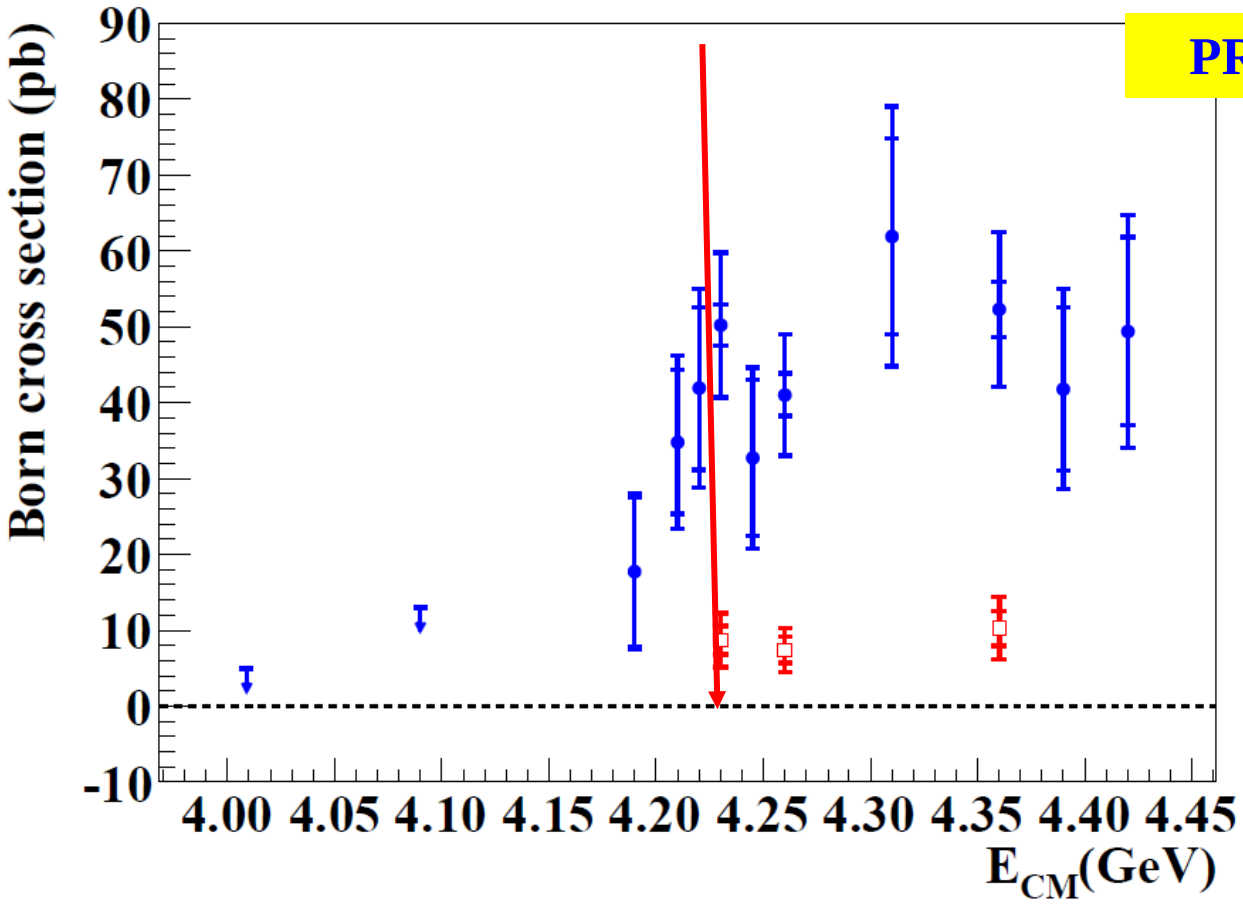
Lum=544/pb

$\sigma^B= 52.3\pm3.7\pm9.2$ pb

PRL 111,242001

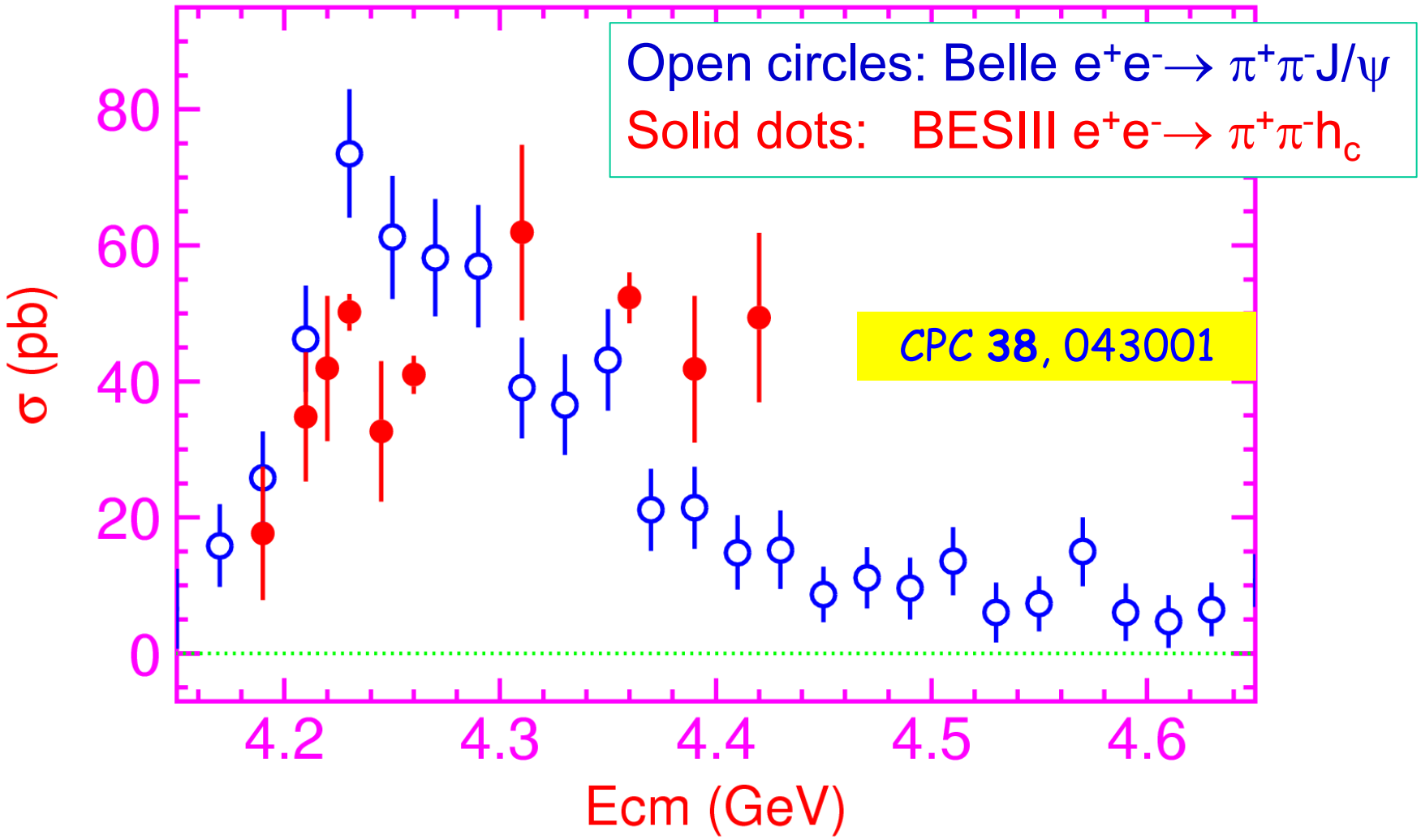
Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$

PRL 111,242001



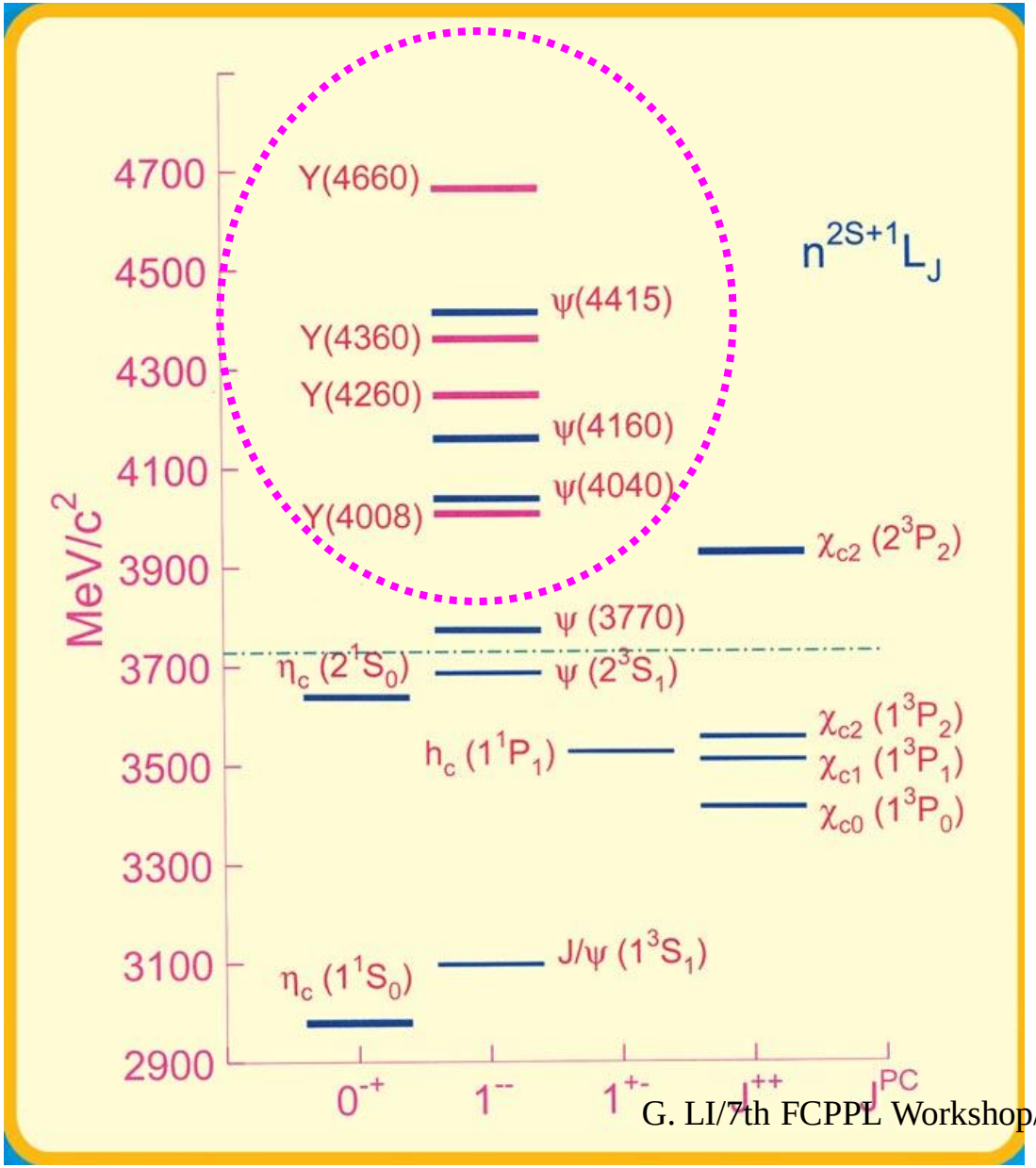
- $\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim \sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV
- Hint for a vector $\bar{c}cg$ hybrid? [PRD78, 056003 (Guo); 094504 (Dudek): $\bar{c}c$ in spin-singlet in hybrids!]

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.

What are the Y states?

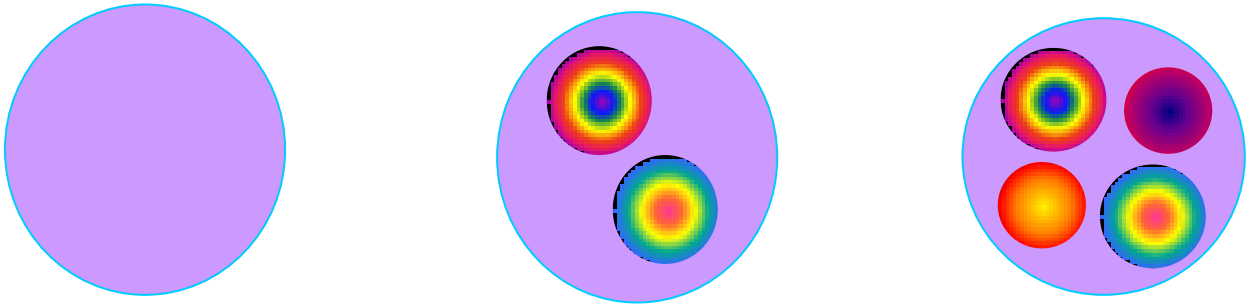


- Between 4 and 4.7 GeV, at most 5 states expected (3S, 2D, 4S, 3D, 5S), but 7 observed
- Hybrids are expected in this mass region
- Molecular states?
- Cannot rule out threshold effect/FSI/…
- Y(4260), Y(4360), Y(4660) are all narrow and similar

- $\pi^+\pi^- h_c$ add more complexity

Z_c: charged charmonium-like states

- Find a clear signature for exotic state!



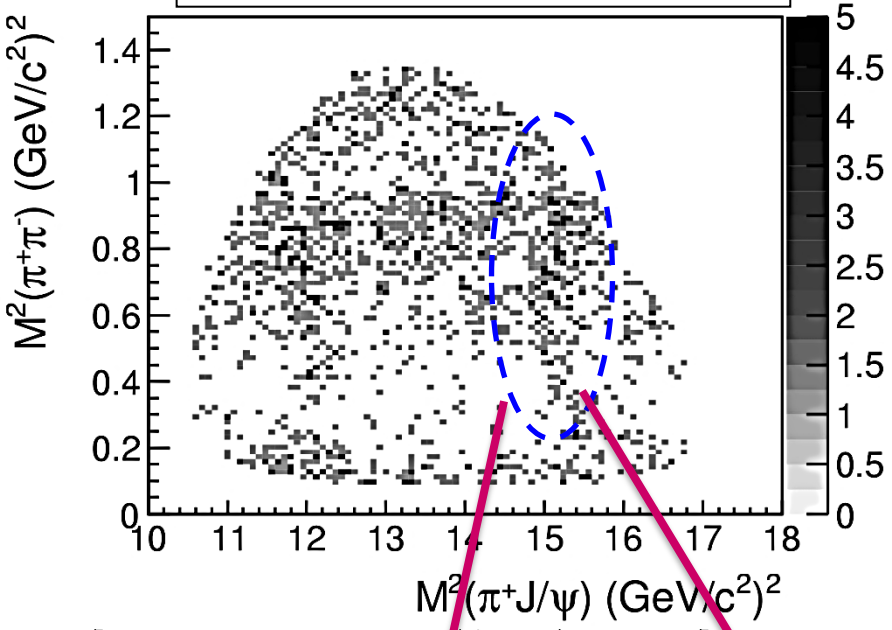
- Decays to charmonium thus has a $\bar{c}c$ pair!
- With electric charge thus has two more light quarks!

$$\Rightarrow N_{quark} \geq 4 \text{ !}$$

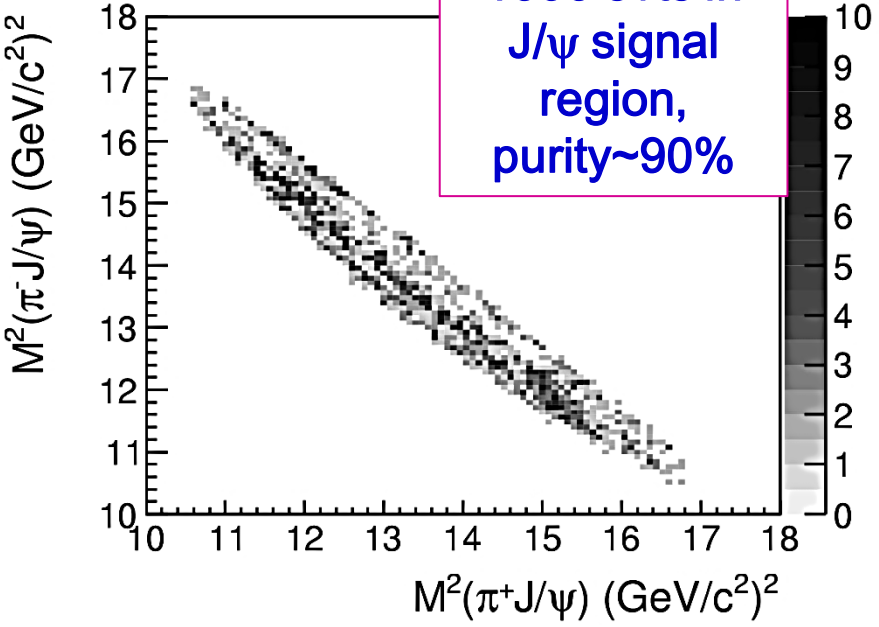
- Do searches in $\pi^{\pm}J/\psi$, $\pi^{\pm}h_c(1P)$, $\pi^{\pm}\psi(2S)$, $\pi^{\pm}\chi_{cJ}$, …
- BESIII: $e^+e^- \rightarrow \pi^{\pm}$+exotics, $\rho^{\pm}$+exotics, …

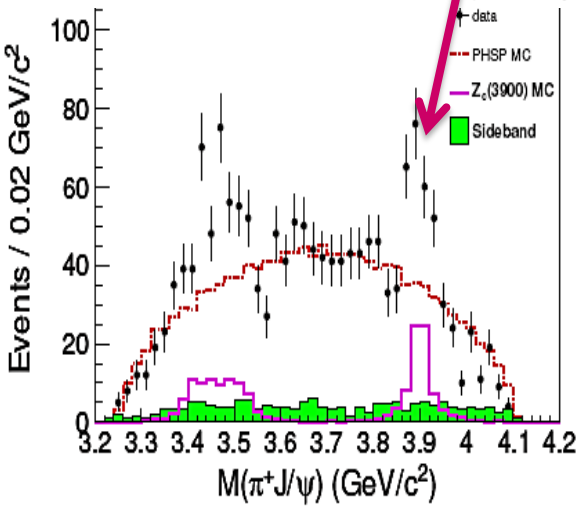
BESIII $e^+e^- \to \pi^+\pi^- J/\psi$ at Ecm=4.26 GeV

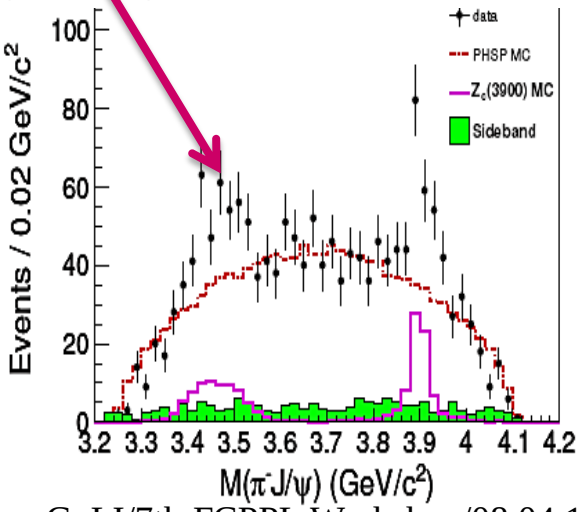
BESIII: PRL110, 252001

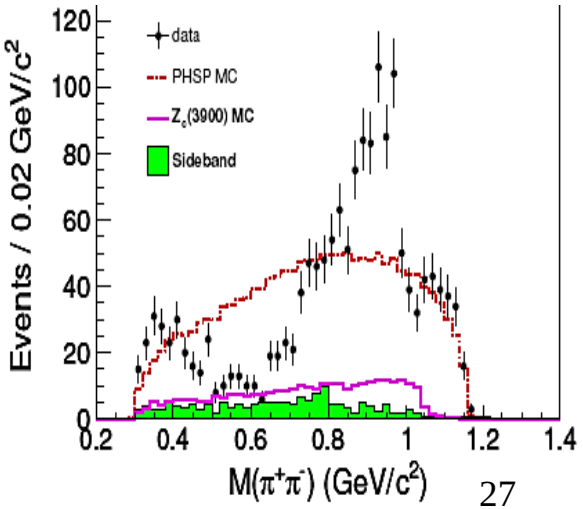


1595 evts in J/ψ signal region, purity~90%



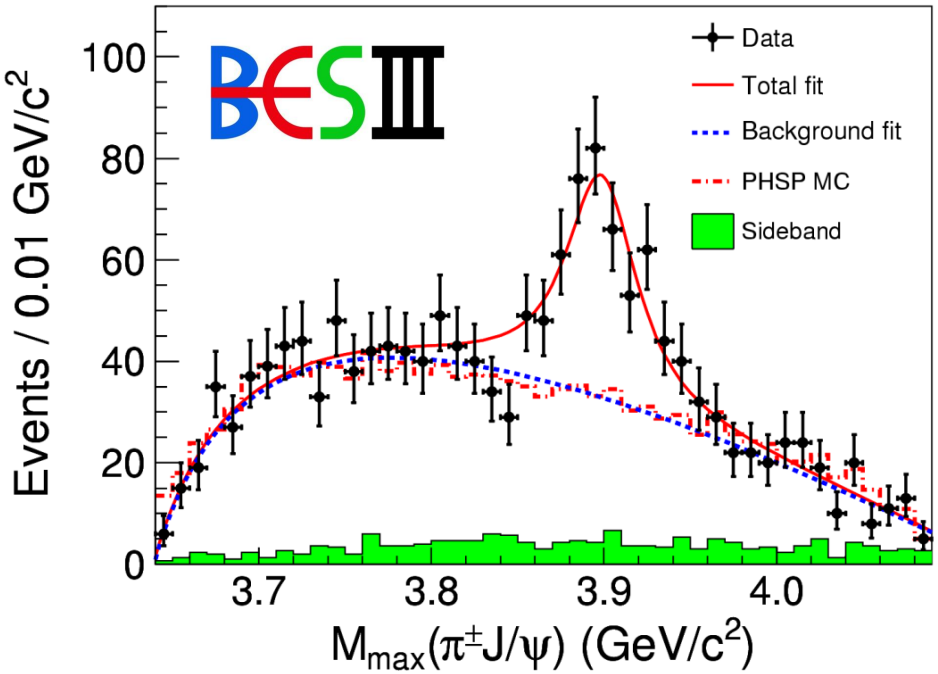






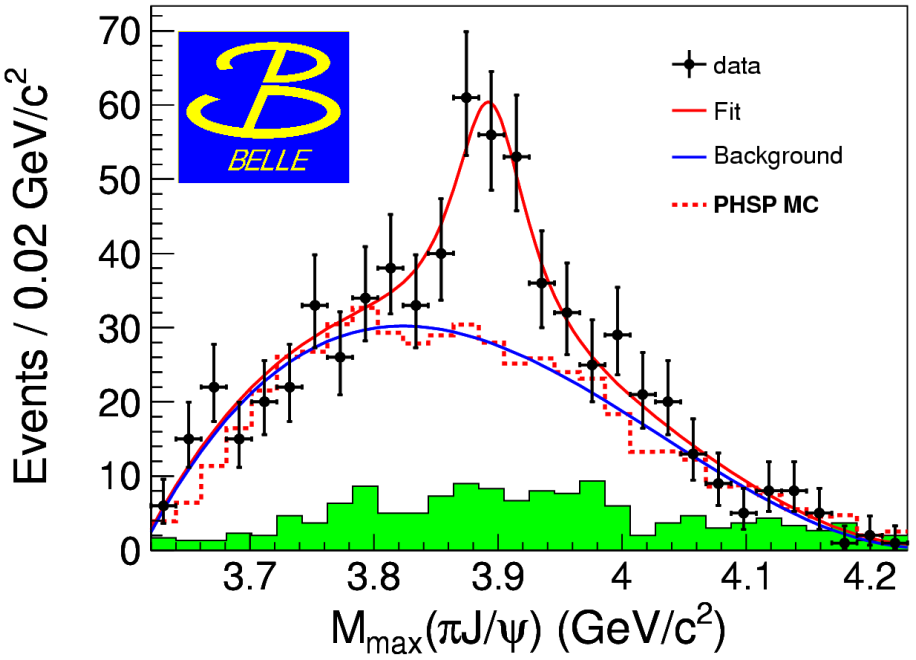
$Z_c(3900)$ observed in two experiments!

BES3 at 4.26 GeV: PRL110, 252001



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

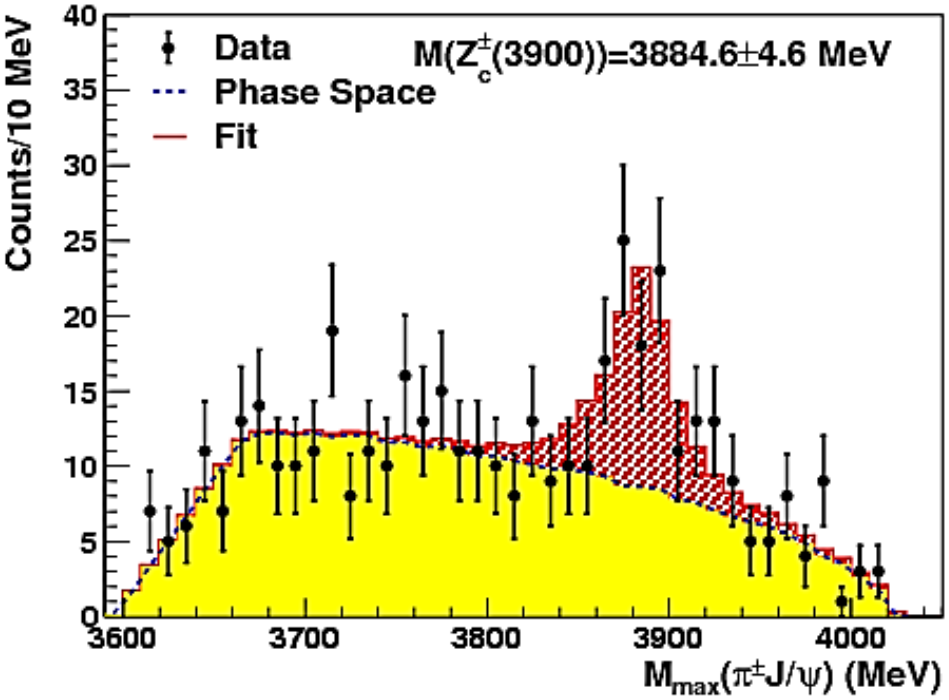
Belle with ISR: PRL110,252002



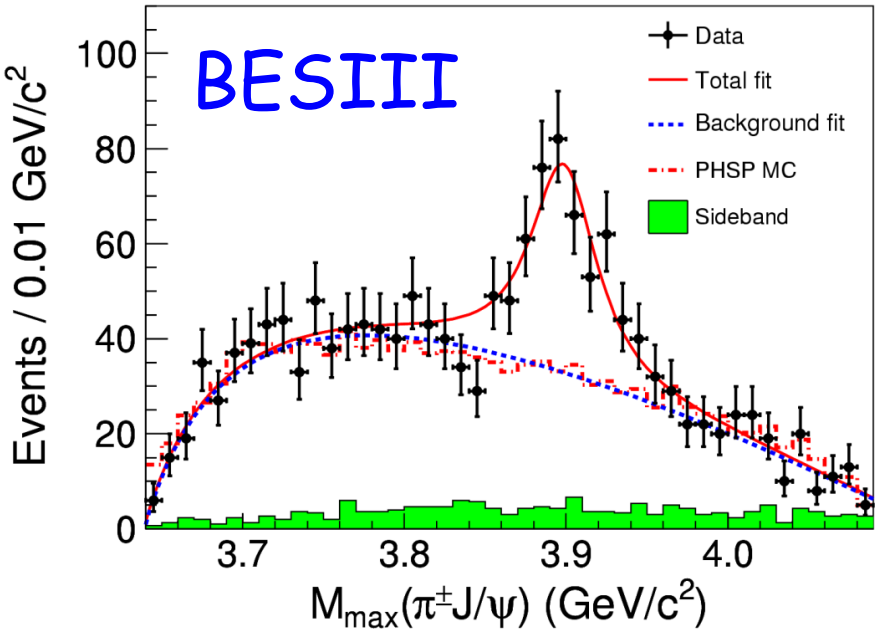
- M = 3894.5±6.6±4.5 MeV
- Γ = 63±24±26 MeV
- 159 ± 49 events
- >5.2σ

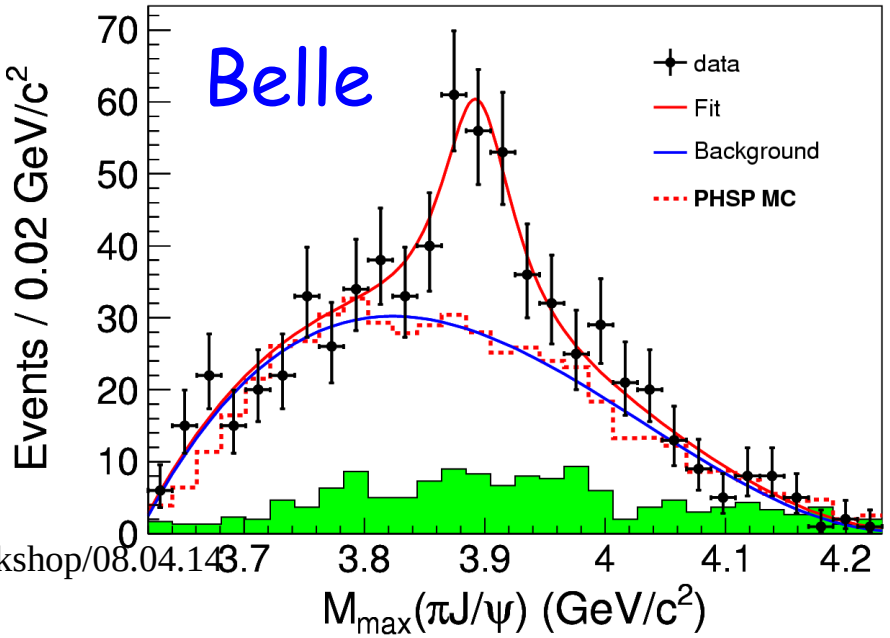
Confirmed with CLEOc data!

CLEOc data at 4.17 GeV:
PLB 727, 366

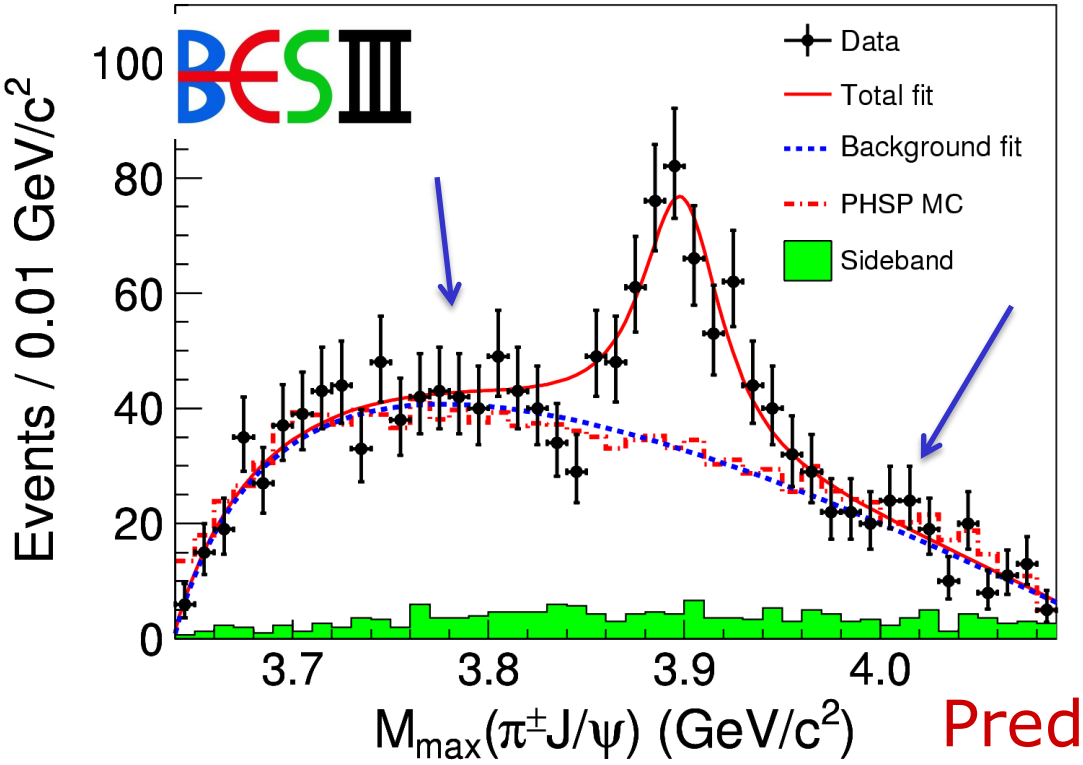


- M = 3885±5±1 MeV
- Γ = 34±12±4 MeV
- 81 ± 20 events
- 6.1σ

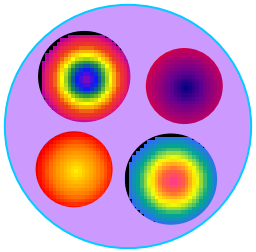




What is $Z_c(3900)$?



- Couples to $\bar{c}c$
- Has electric charge
- At least 4-quarks
- What is its nature?

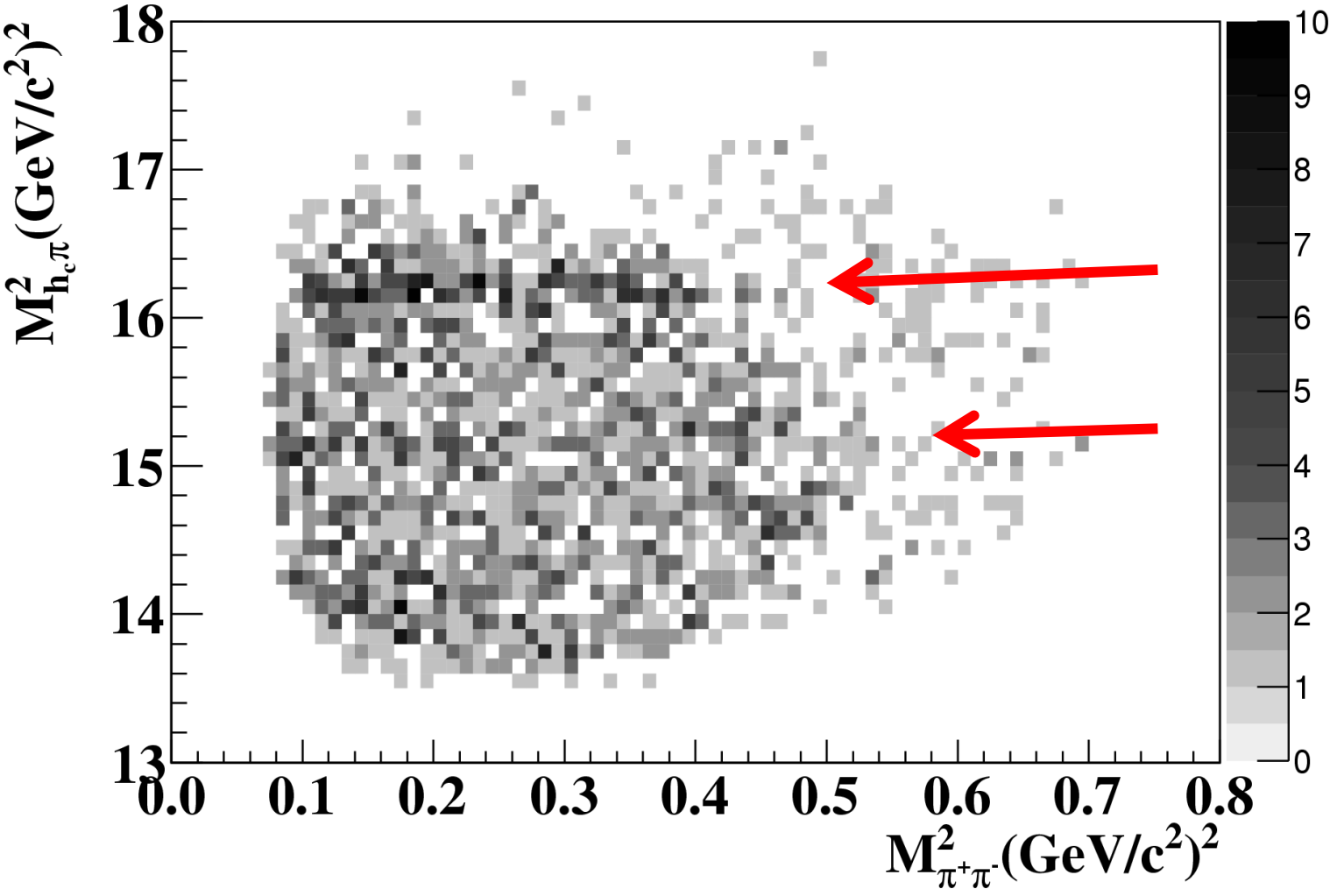


- $\bar{D}D^*$ molecule?
- Tetraquark state?
- Cusp?
- Threshold effect?
- …

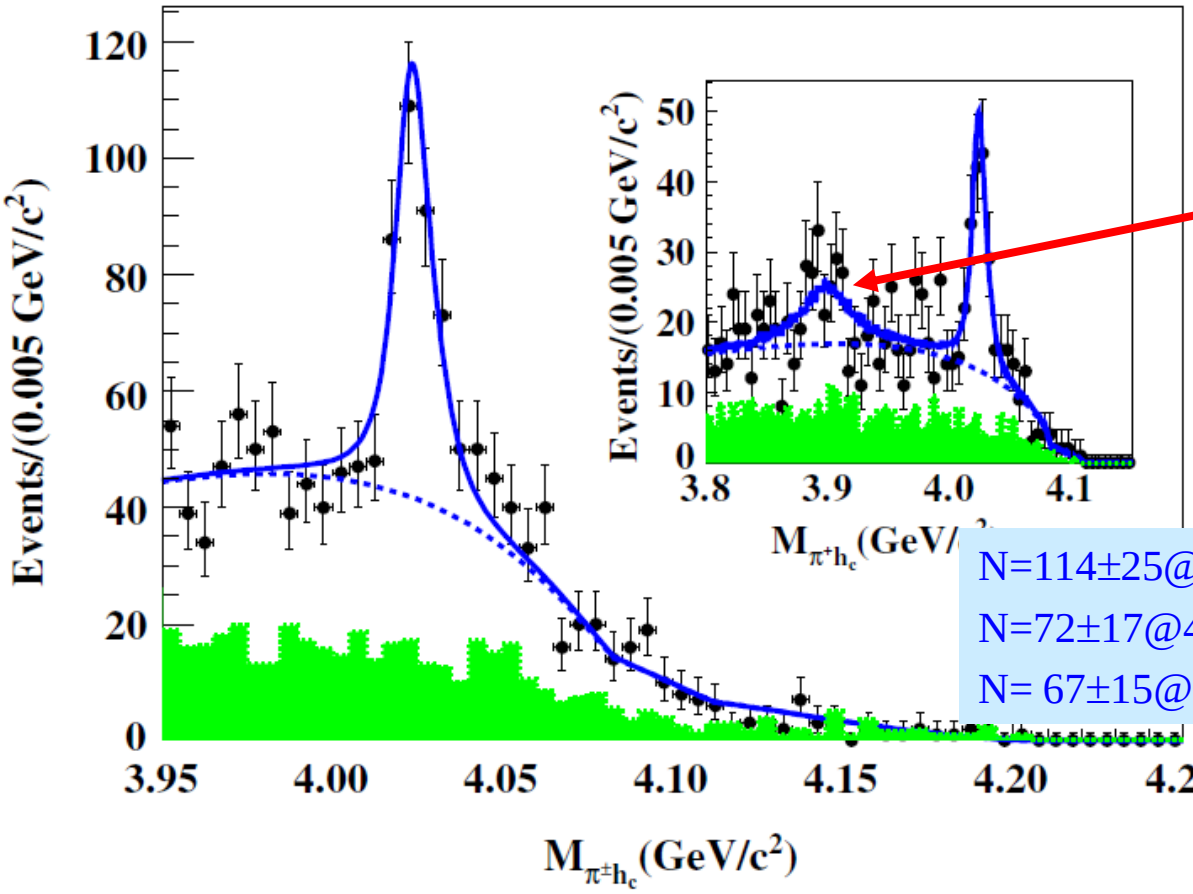
Predictions and more experimental information will be essential to understand its nature.

➔ A partner <u>below/above</u> Z_c?

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



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



PRL 111,242001

Reflection and possible $Z_c(3900)$ signal

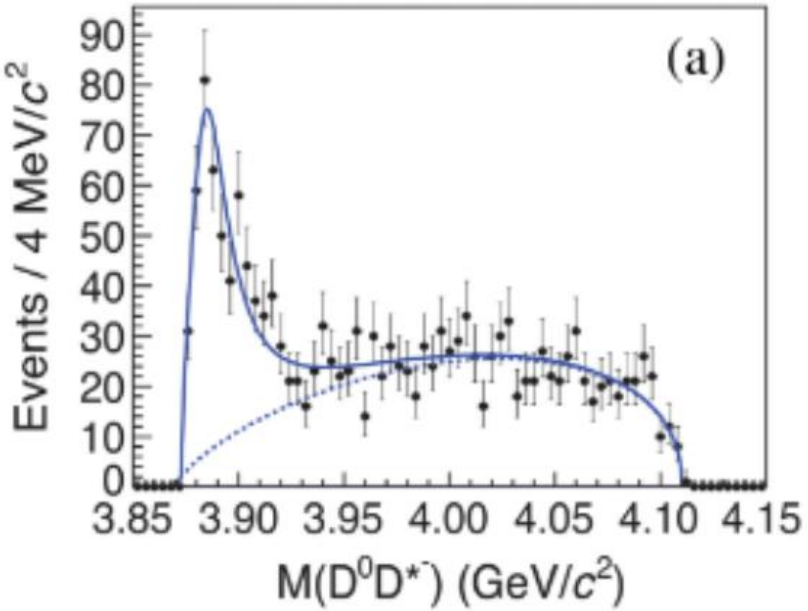
N=114±25@4.23GeV
N=72±17@4.26GeV
N= 67±15@4.36GeV

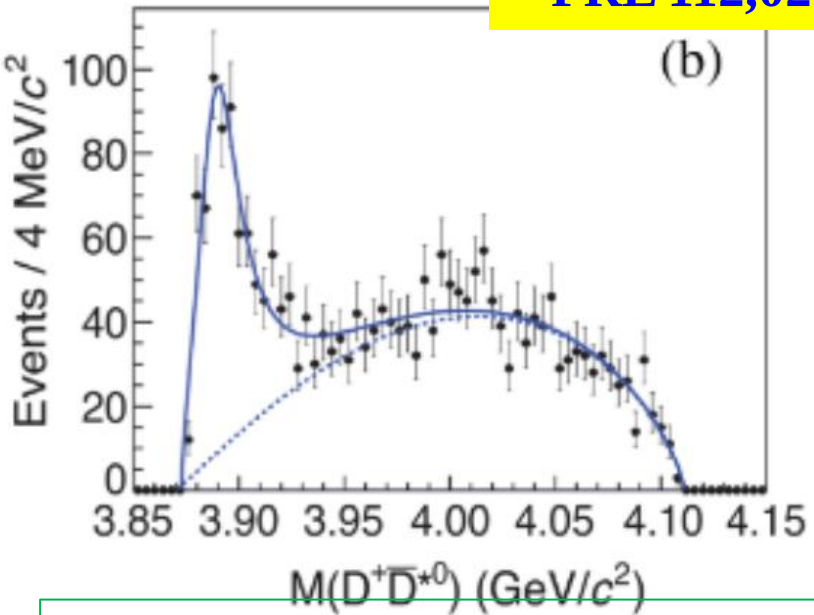
Simultaneous fit to 4.23/4.26/4.36 GeV data and 16 η_c decay modes: 8.9σ

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

e+e-→ πZc(3885) → π⁻ (DD*)⁺+c.c. @ 4.260 GeV

PRL 112,022001





M=3883.9±1.5±4.2 MeV;
Γ= 24.8±3.3±11.0 MeV

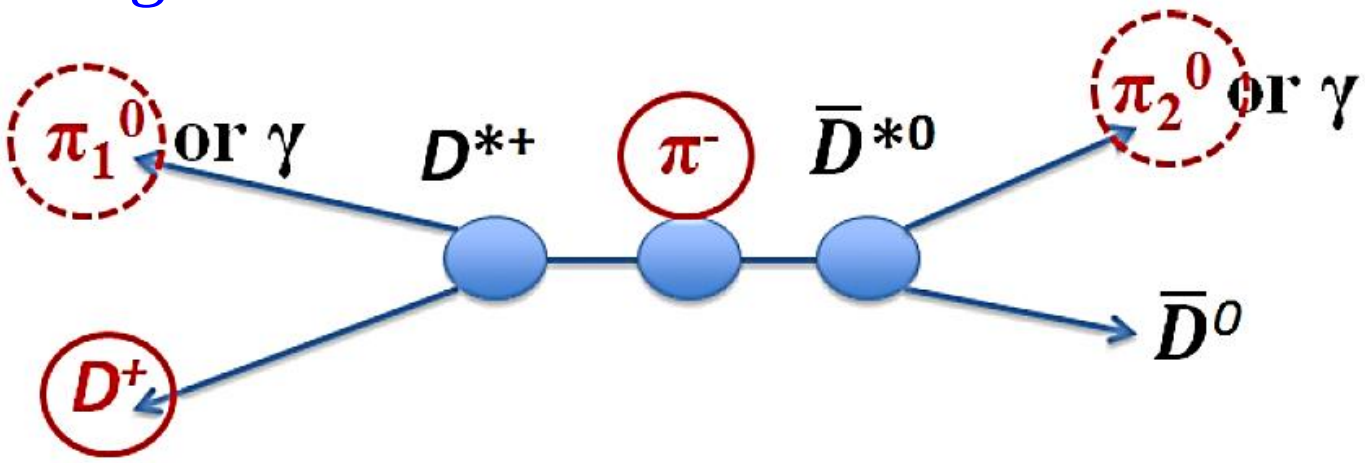
πZ_c ang. distr. favors 1+
disfavors 0- or 1-

$$\sigma(e^+e^- \to \pi^- Z_c(3885)^+ \times Z_c(3885)^+ \to (D\bar{D}^*)^+ + c.c.) = (83.5 \pm 6.6 \pm 22.0)\ pb$$

$$R = \frac{\Gamma(Z_c(3885) \to D^*\bar{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = (6.2 \pm 1.1 \pm 2.7)$$

$e^+e^- \to \pi^- (D^*\underline{D}^*)^+ + c.c.$ at 4.26GeV

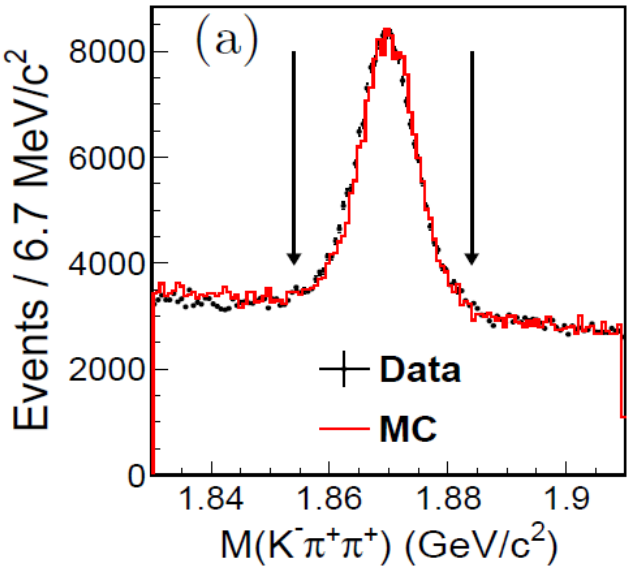
- 827 pb^{-1} data at Ecm=4.26 GeV
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.

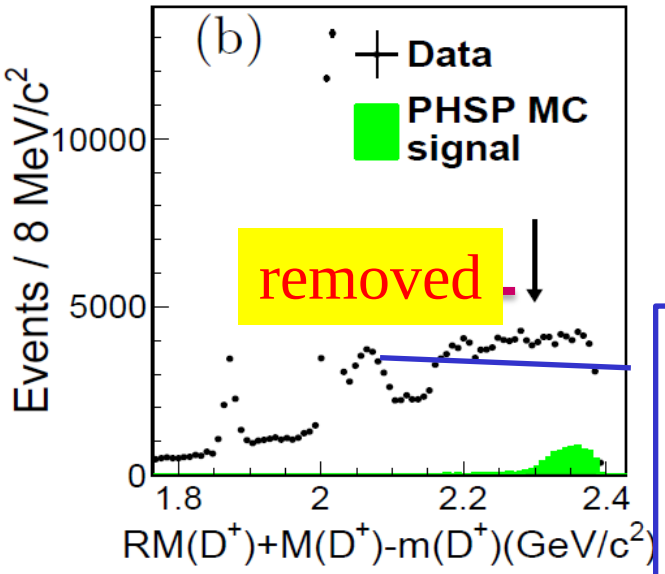


Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

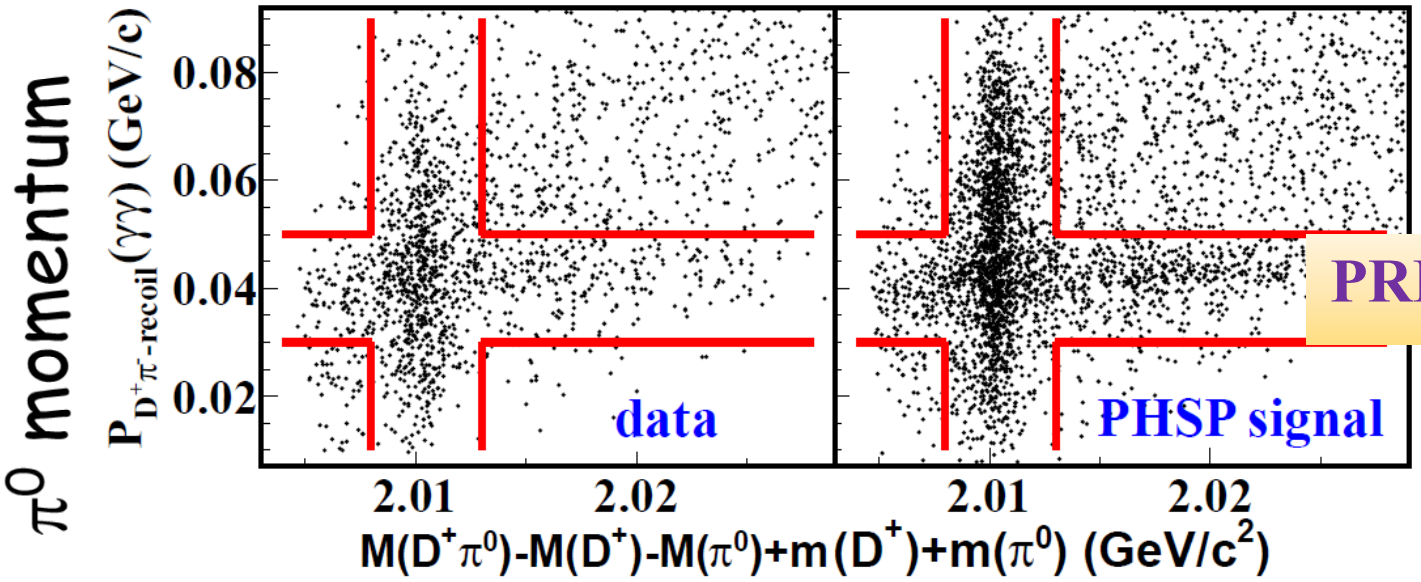
BESIII: 1308.2760, PRL 113,132001

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



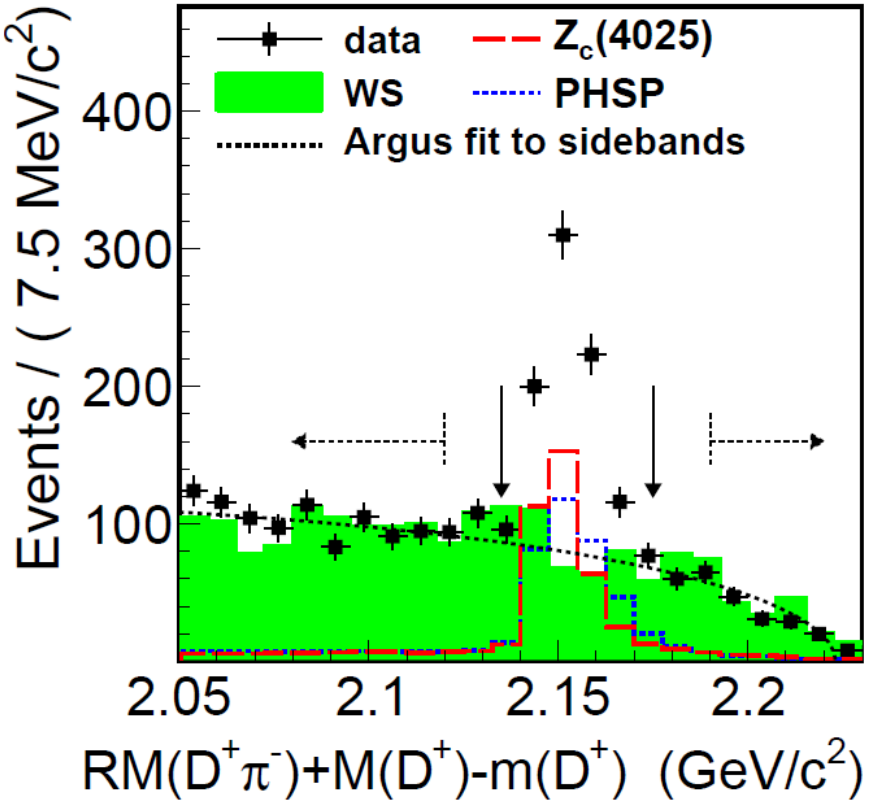


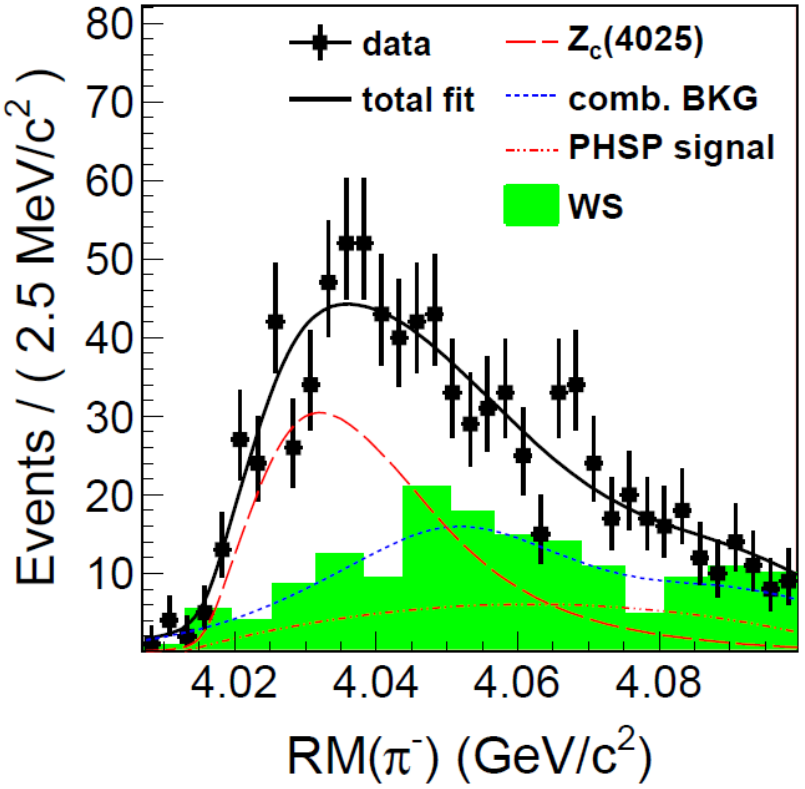
Remove DD, DD*, D*D*, DsDs, …



PRL 113,13200

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





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

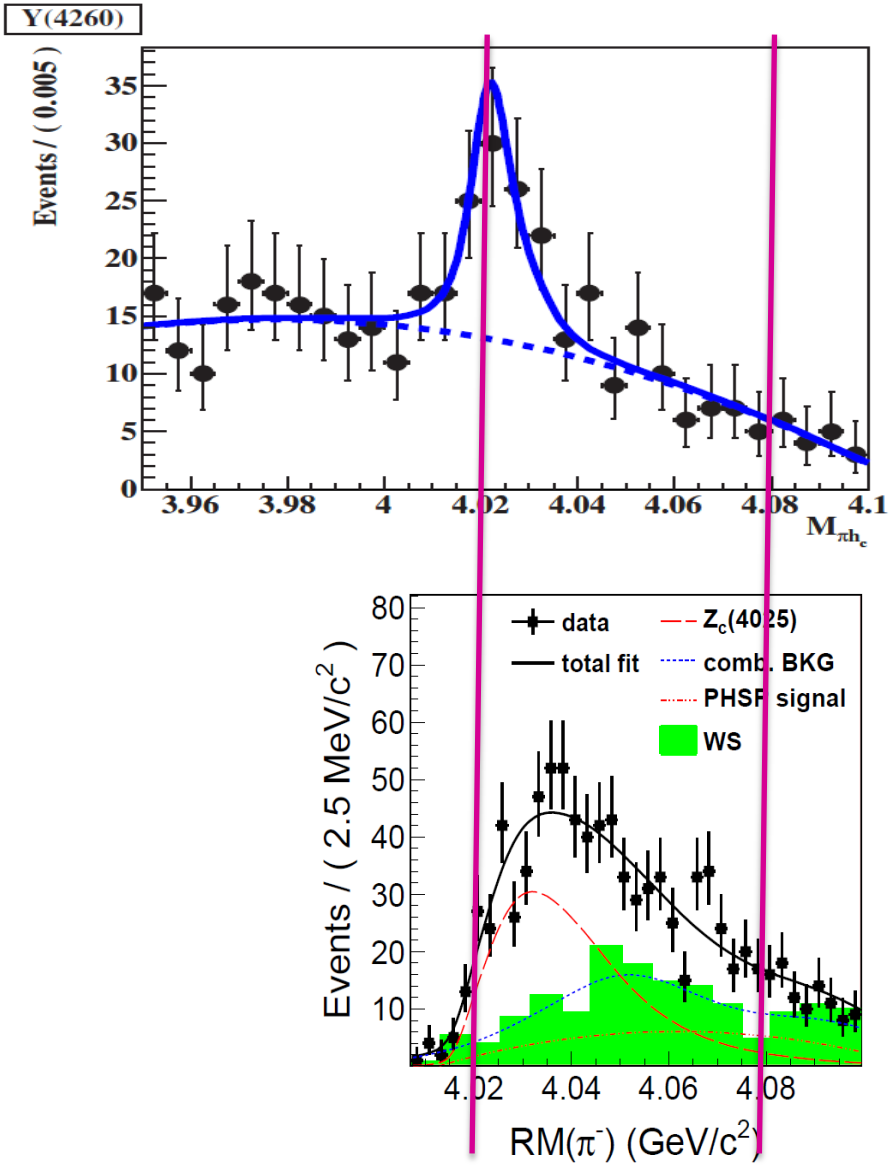
$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV; $\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7$ MeV

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

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

PRL 113,132001

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



- 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 consistent with each other but width ~1.5σ difference

Interference with other amplitudes may change the results

Coupling to $\bar{D}$*D* is much larger than to πh_c if they are the same state

Will fit with Flatte formula

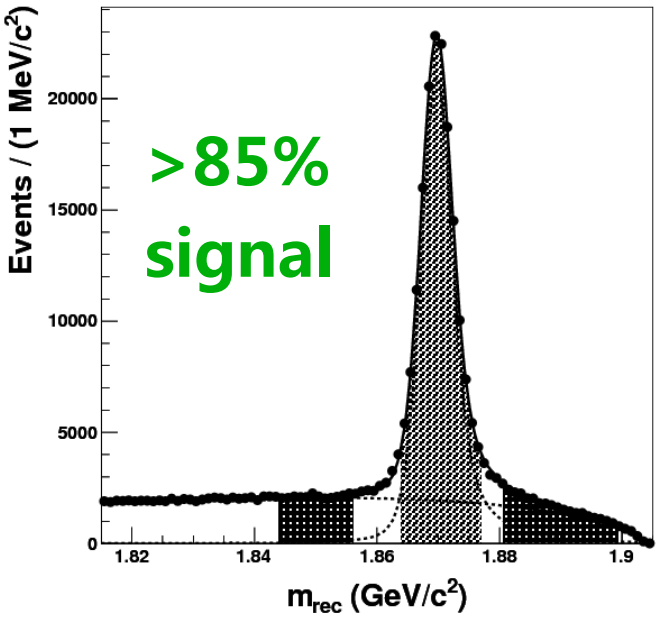
Charm Physics

$D^+ \to K_S \pi^+ \pi^0$ Dalitz

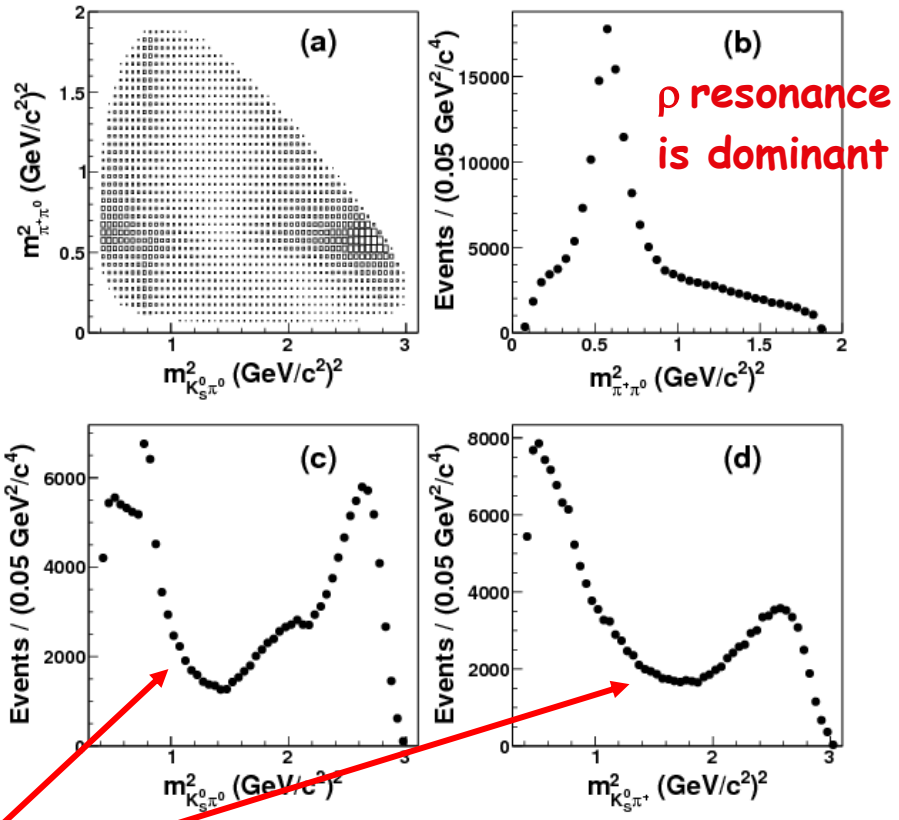
Good channel for $K_S\pi^0$ S-wave studies

Signal via Recoil Mass :

- Constrain $Ks\pi^+\pi^0$ to m_D
- 4 vector of e^+e^- and D give recoil mass



Resulting Dalitz Plot :



Other projections are dominated by "cos²-shadow" of ρ

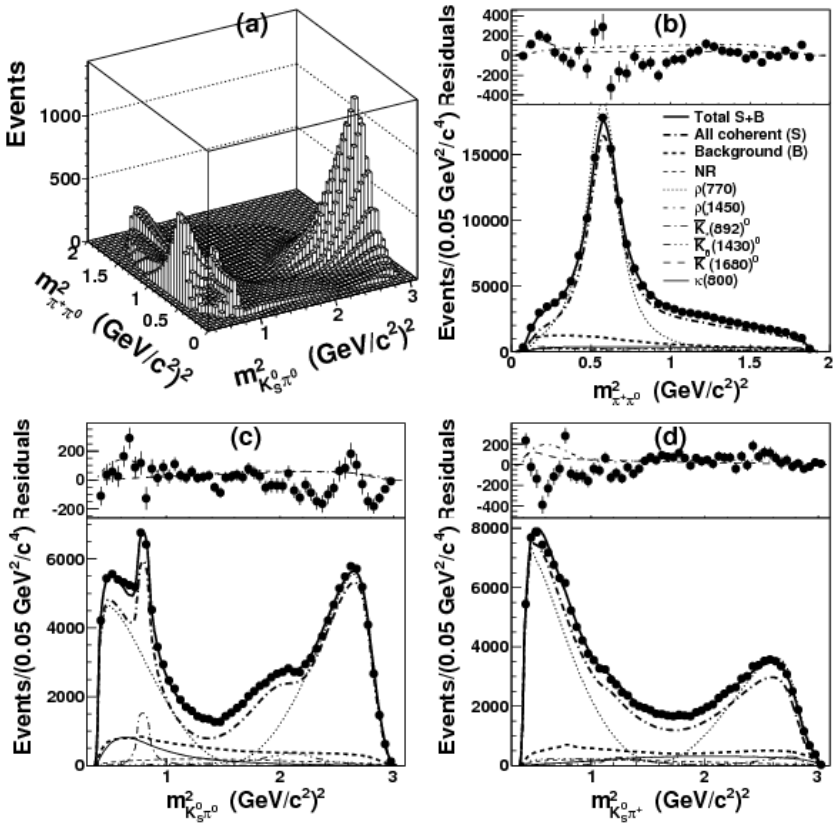
PRD 89,052001

$D^+ \to K_S \pi^+ \pi^0$ Dalitz

"Model D" Fit

- **Try many resonances**
- **Drop insignificant ones**
- **Contains $\kappa\pi$ and non-resoant**

PRD 89,052001

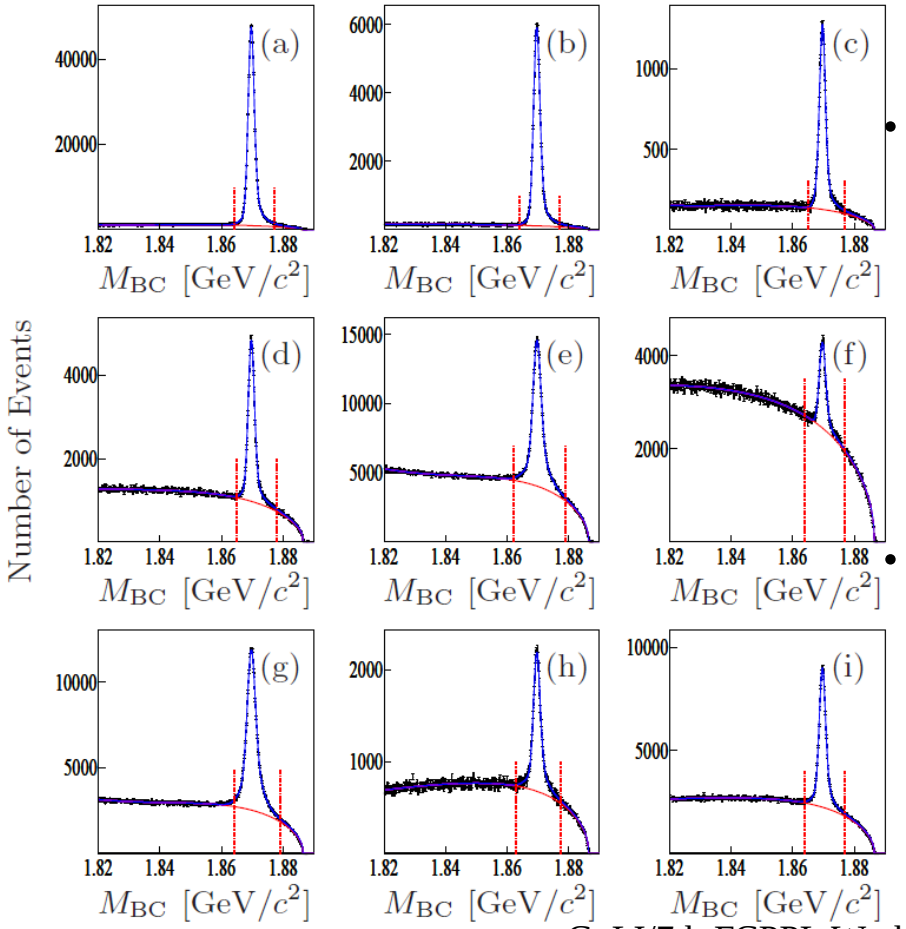


Parameters	Value	Statistical errors
NR FF (%)	4.6	0.7
NR phase (°)	279	6
$\rho(770)^+$ FF (%)	83.4 ←	2.2
$\rho(1450)^+$ FF (%)	2.1	0.3
$\rho(1450)^+$ phase (°)	187	3
$\bar{K}^*(892)^0$ FF (%)	3.58	0.17
$\bar{K}^*(892)^0$ phase (°)	293	2
$\bar{K}^*_0(1430)^0$ FF (%)	3.7	0.6
$\bar{K}^*_0(1430)^0$ phase (°)	334	5
$\bar{K}^*(1680)^0$ FF (%)	1.3	0.2
$\bar{K}^*(1680)^0$ phase (°)	252	2
$\bar{\kappa}^0$ FF (%)	7.7	1.2
$\bar{\kappa}^0$ phase (°)	93	7
$NR + \bar{\kappa}^0$ FF (%)	18.6 ←	1.7
$K^0_S\pi^0$ *S*-wave FF (%)	17.3	1.4

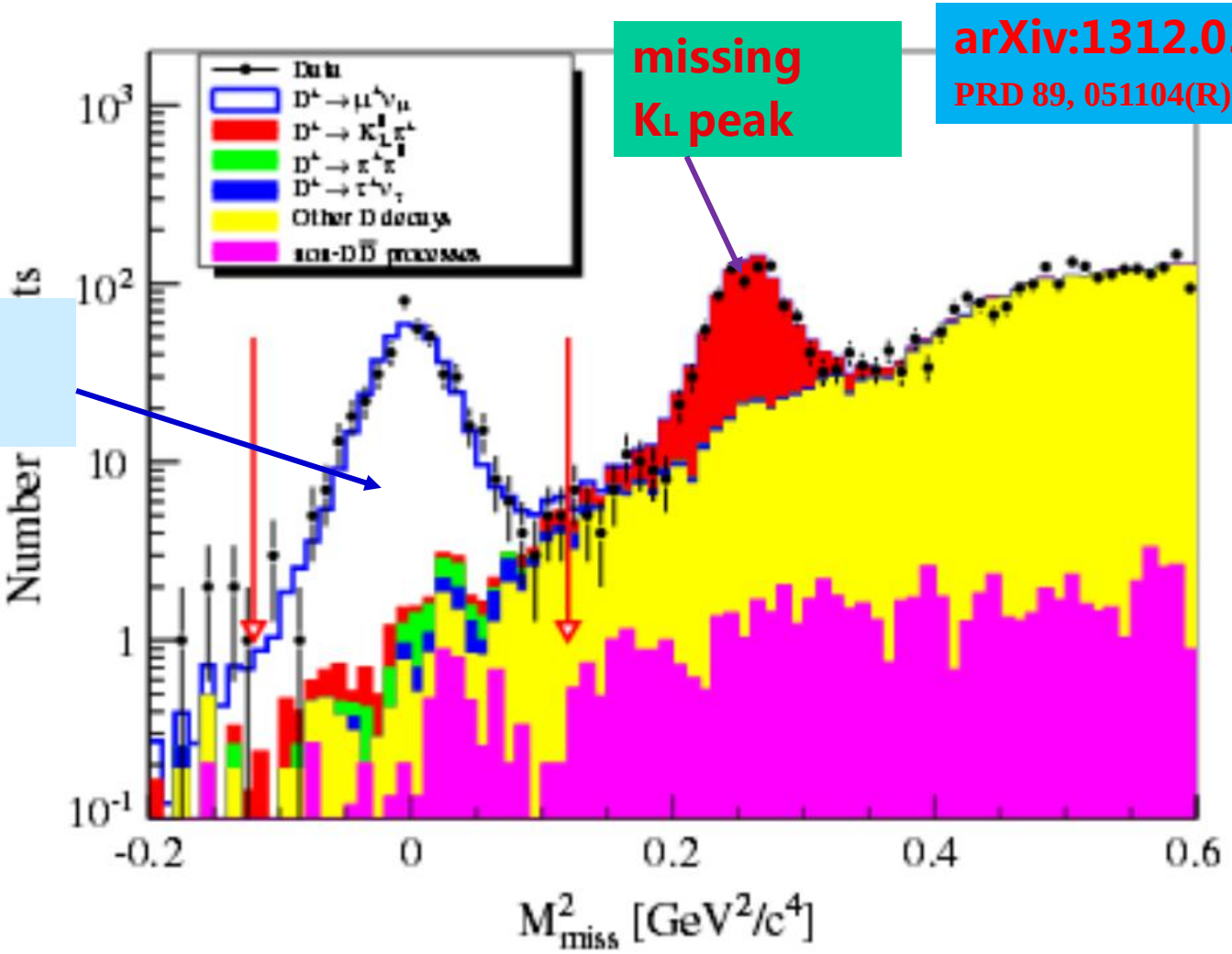
Precision measurements of f_{D+}

Uses 9 tag modes (for reference, CLEO-c used 6)

Even includes Cabibbo-suppressed modes !



- **Signal side: ONE track !**
  - Veto on extra tracks,
  - and un-matched showers
  - with E > 300 MeV
- **Reconstruct "MM2"= (missing-mass)^2,** presumably just a neutrino: signal peaks at 0



Combining with Vcd , GF , τD , mD :

fD = (203.2 ± 5.3 ± 1.8) MeV (± 2.6 ± 0.9)% *most precise !*

previous best: CLEO-c : (205.8 ± 8.5 ± 2.5) MeV

What next at BESIII?

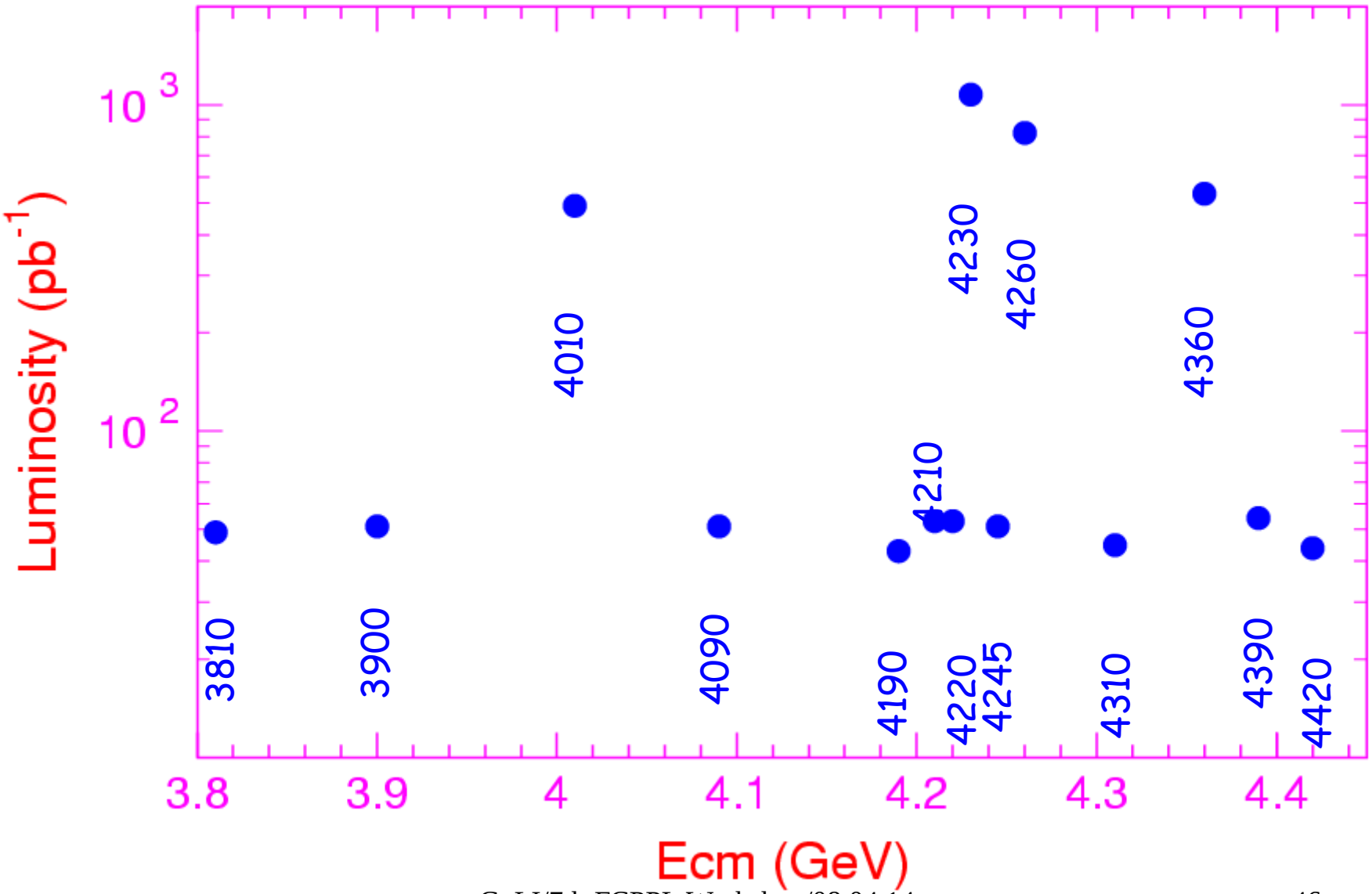
- Light hadron study
  - Light hadron Spectroscopy
  - Exotics searches
  - Rare decays
- XYZ physics
  - Spin-parity of Z_c and Z_c'
  - Neutral partners of Z_c and Z_c'
  - More decay modes [$\pi\psi'$, $\rho\eta_c$, open charm,…]
  - Excited Z_c, Z_c' states? $Z_{cs}\rightarrow KJ/\psi$ states?
- Charm physics: lots of analysis ongoing …
- More data at high energies coming …

Summary

- Lots of progress at BESIII based on the huge data samples
  - New light hadrons X(1840), N(1540) …
  - Observations and measurements of XYZ
  - Precision measurements on the charm decays
  - Sorry, many important results not covered by this talk
- More results will come soon, stay tuned!

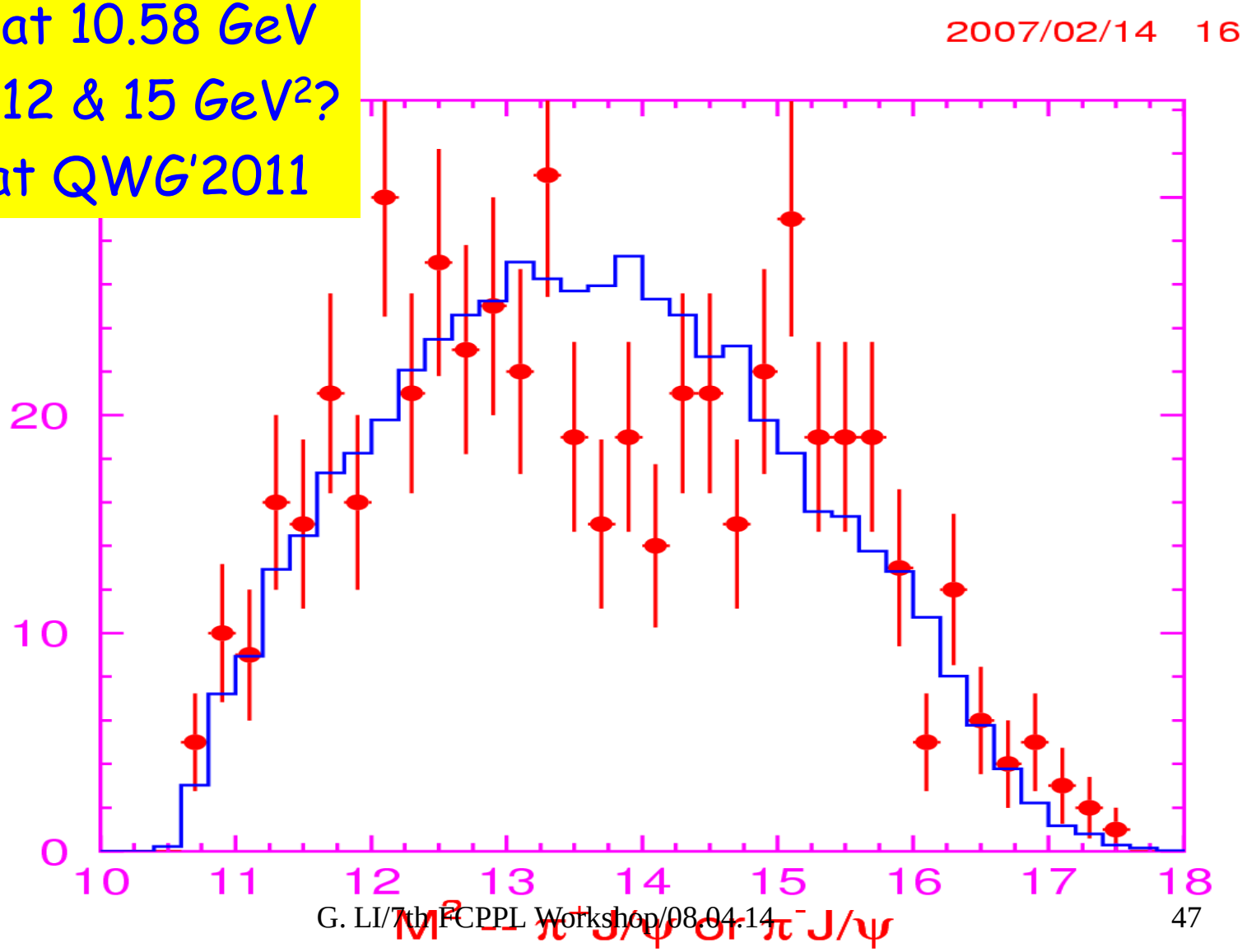
Thanks a lot!

BESIII collected 3.3/fb for XYZ study

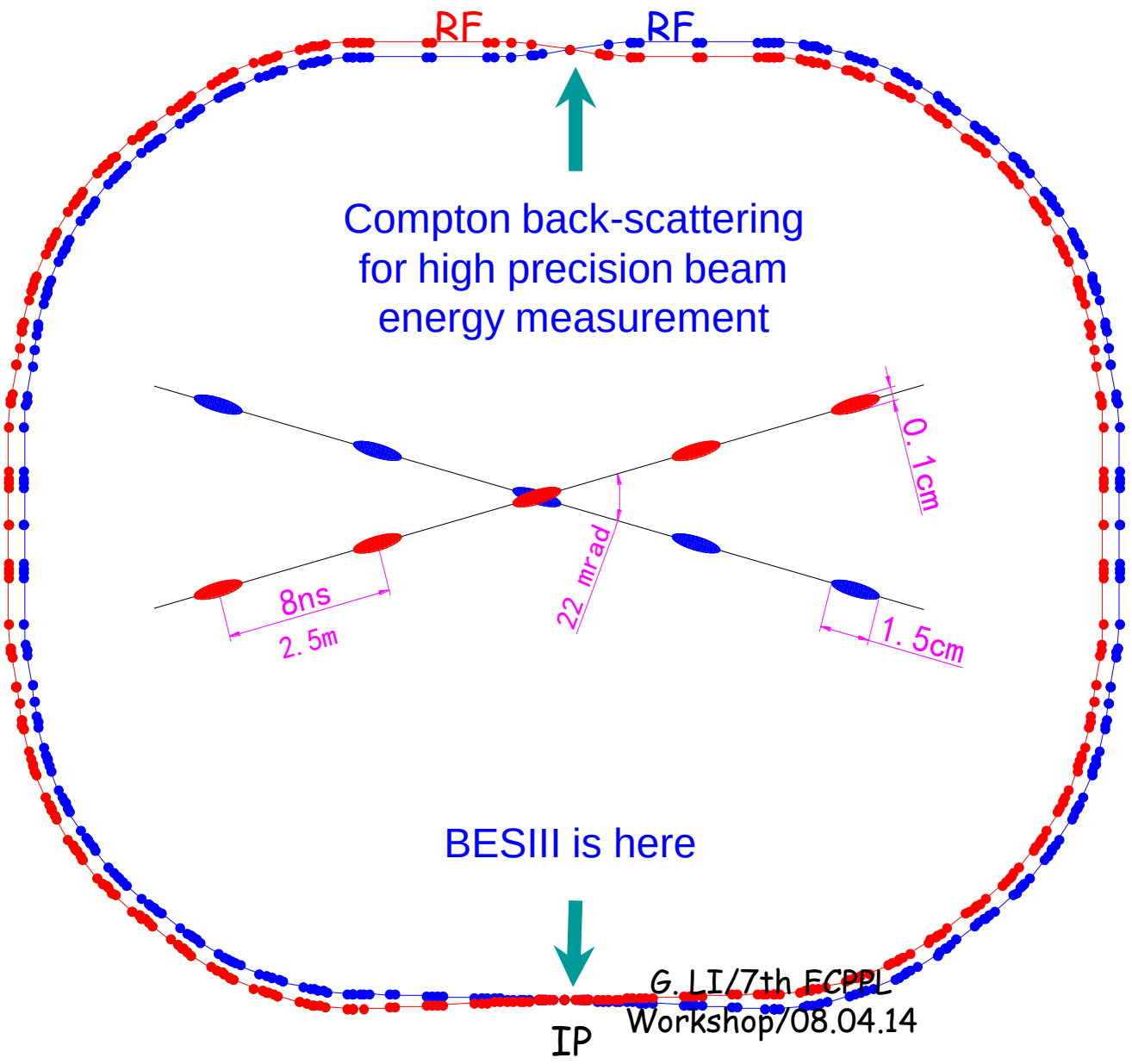


M(ππJ/ψ)∈[4.2, 4.4] GeV via ISR

548/fb at 10.58 GeV
Peaks at 12 & 15 GeV²?
Shown at QWG'2011



BEPC II: Large crossing angle, double-ring



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

BESIII Detector