Exotic Hadrons @BESIII

Francesca De Mori
Università di Torino e INFN Torino
On behalf of BESIII collaboration

Mirò J.

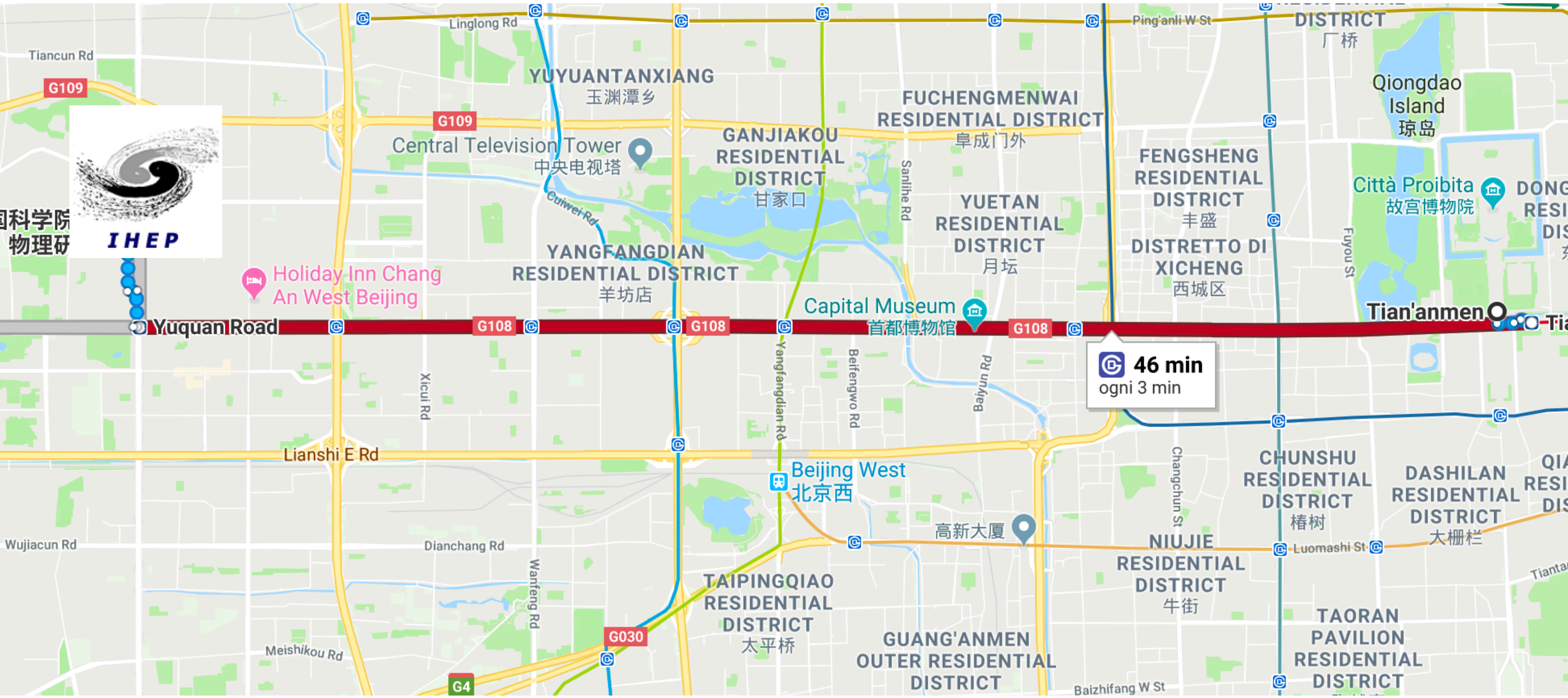
Outline

- Introduction to BEPCII & BESIII
- XYZ studies :
  selected results
- Summary

INFN TORINO
Istituto Nazionale di Fisica Nucleare
Sezione di Torino

BESIII

About 8200 km
11016
Beijing
中国科学院高能
物理研究所
Ocean Atlantico settentrionale
Mare di Norvegia
Mare di Barents
Mare di Kara
Mare di Okhotsk
Irlanda
Regno Unito
Svezia
Finlandia
Danimarca
Russia
Francia
Portogallo
Bielorussia
Italia
Ucraina
Giappone
Sahara
Mongolia
Tunisia
Algeria
Grecia
Kazakistan
Mar Mediterraneo
Mar Cinese Orientale
Turchia
Mali
Uzbekistan
Kirghizistan
Cina
Libia
Siria
Turkmenistan
Mare delle Filippine
Niger
Egitto
Iraq
Iran
Afghanistan
Nigeria
Ciad
Pakistan
Nepal
Filippine
Arabia Saudita
Myanmar (Birmania)
Sudan
India
Oman
Thailandia
Vietnam
Gabon
Sudan del Sud
Yemen
Golfo di Aden
Golfo del Bengala
Golfo del Siam
Mar di Banda
Repubblica Democratica
Etiopia
Mar Arabico
Malesia
Indonesia

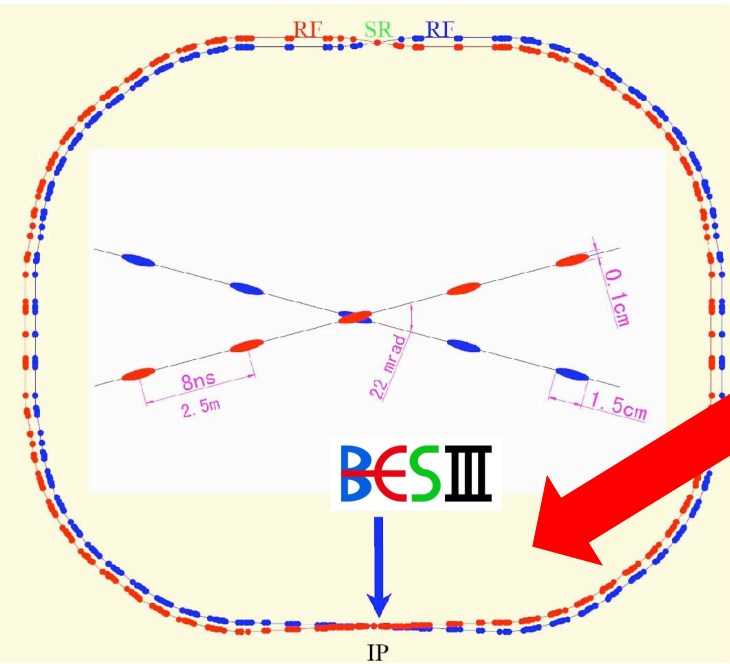


IHEP
Yuquan Road
Tian'anmen
46 min
ogni 3 min
Holiday Inn Chang An West Beijing
Central Television Tower
中央电视塔
Capital Museum
首都博物馆
Beijing West
北京西
Città Proibita
故宫博物院
Qiongdao Island
琼岛
高新大厦
YUYUANTANXIANG
玉渊潭乡
FUCHENGMENWAI RESIDENTIAL DISTRICT
阜成门外
GANJIAKOU RESIDENTIAL DISTRICT
甘家口
FENGSHENG RESIDENTIAL DISTRICT
丰盛
YUETAN RESIDENTIAL DISTRICT
月坛
DISTRETTO DI XICHENG
西城区
YANGFANGDIAN RESIDENTIAL DISTRICT
羊坊店
CHUNSHU RESIDENTIAL DISTRICT
椿树
DASHILAN RESIDENTIAL DISTRICT
大栅栏
NIUJIE RESIDENTIAL DISTRICT
牛街
TAIPINGQIAO RESIDENTIAL DISTRICT
太平桥
GUANG'ANMEN OUTER RESIDENTIAL DISTRICT
TAORAN PAVILION RESIDENTIAL DISTRICT
Lianshi E Rd
Linglong Rd
Tiancun Rd
Wujiacun Rd
Dianchang Rd
Meishikou Rd
Xicui Rd
Wanfeng Rd
Yangfangdian Rd
Beifengwo Rd
Baiyun Rd
Sanlihe Rd
Changchun St
Fuyou St
Luomashi St
Baizhifang W St
Ping'anli W St
Cuiwei Rd
G109
G108
G030
G4

BEPCII and BESIII

IHEP

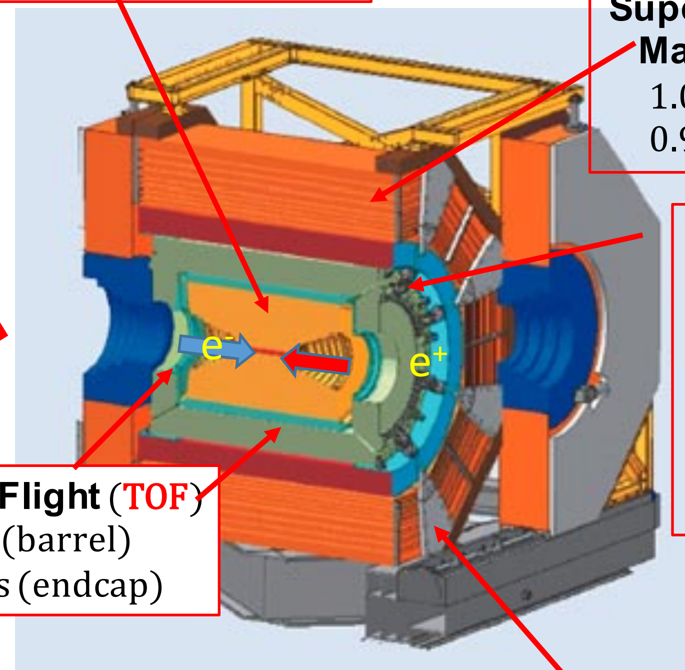
Upgrade of BEPC (started 2004, first collisions in July 2008)



Beam energy 1 . . . 2.3 GeV
Optimum energy 1.89 GeV
Single beam current 0.91 A
Crossing angle: ±11 mrad
Design luminosity: 10^{33} cm^{-2} s^{-1}, achieved in in April 5th, 2016
Beam energy measurement by Laser compton backscattering
$\Delta E/E \approx 5 * 10^{-5}$ (50 keV at τ threshold)

Main Drift Chamber(MDC)
$\sigma_P/P = 0.5\%$ (1 GeV)
$\sigma_{dE/dx} = 6\%$

Super-Conducting Magnet
1.0 T (2009)
0.9 T(2012)



Electromagnetic Calorimeter
CsI (Tl)
$\sigma_E/\sqrt{E} =$ 2.5% (1 GeV)
$\sigma_{z,\varphi} =$ 0.5 - 0.7 cm/$\sqrt{E}$

Time of Flight (TOF)
σ_T: 90 ps (barrel)
110 ps (endcap)

μ Counter (MUC)
8 - 9 layers RPC
$\delta_{R\Phi} = 1.4$ cm ~ 1.7 cm

NIM A614, 345 (2010)

93% of 4π acceptance

BESIII: the collaboration

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (16)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz, Univ. of Munster
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. di Torino, Univ. di Ferrara, LNF Frascati
INFN-Torino,INFN-Fe
Netherland ：KVI/Univ. of Groningen
Sweden: Uppsala Univ.
UK: University of Manchaster and Oxford
Turkey: Turkey Accelerator Center

Mongolia (1)

Institute of Physics and Technology

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

India (1)

Indian Institute of Technology, Madras

Pakistan (3)

Univ. of Punjab
COMSAT CIIT
University of Lahore

China(39)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

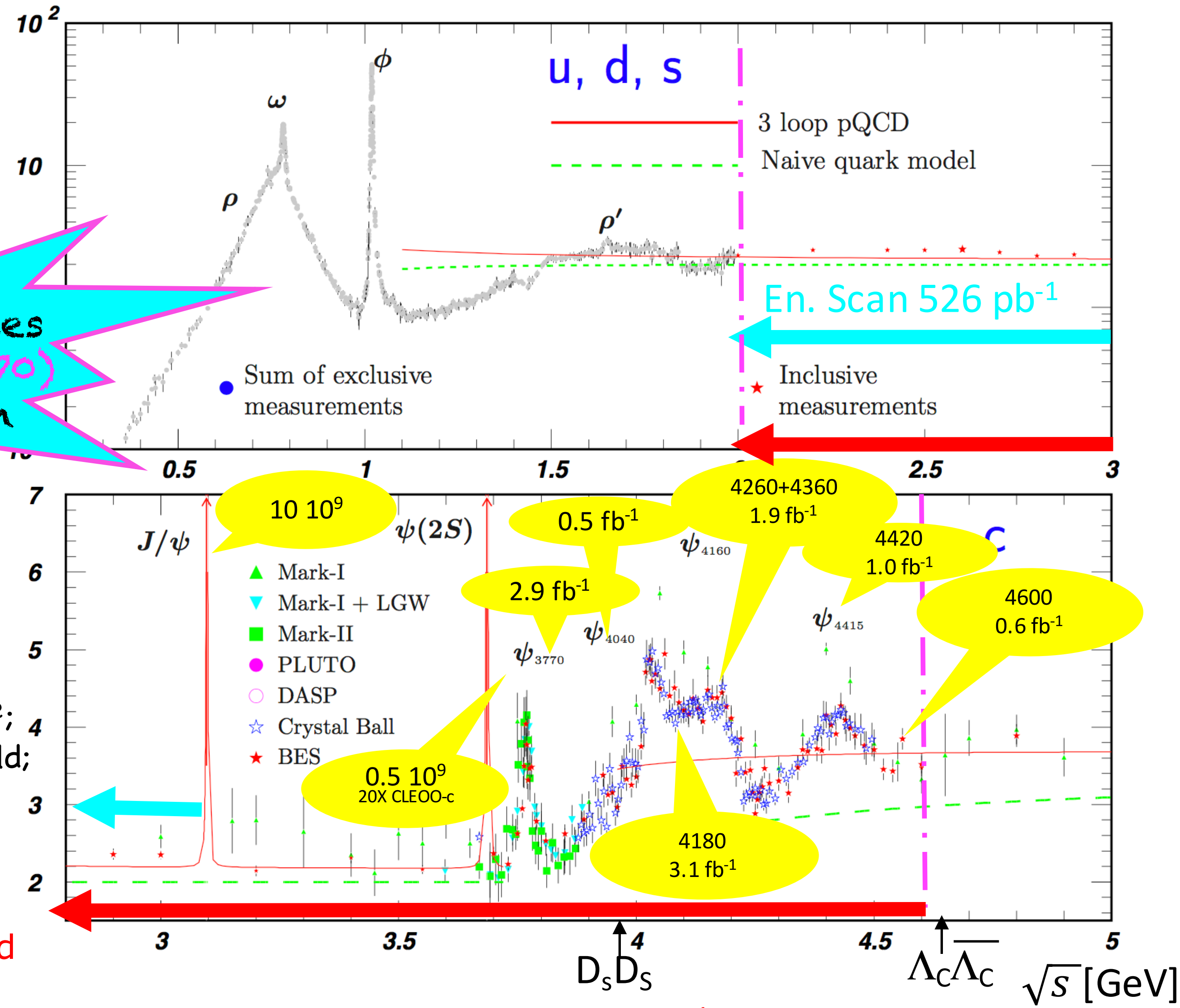
400 members
67 institutions
14 nations

BESIII: Data Samples

$$R_{had} = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

World largest samples of J/ψ , ψ(2S), ψ(3770) directly produced in e^+e^- collisions

PDG2017

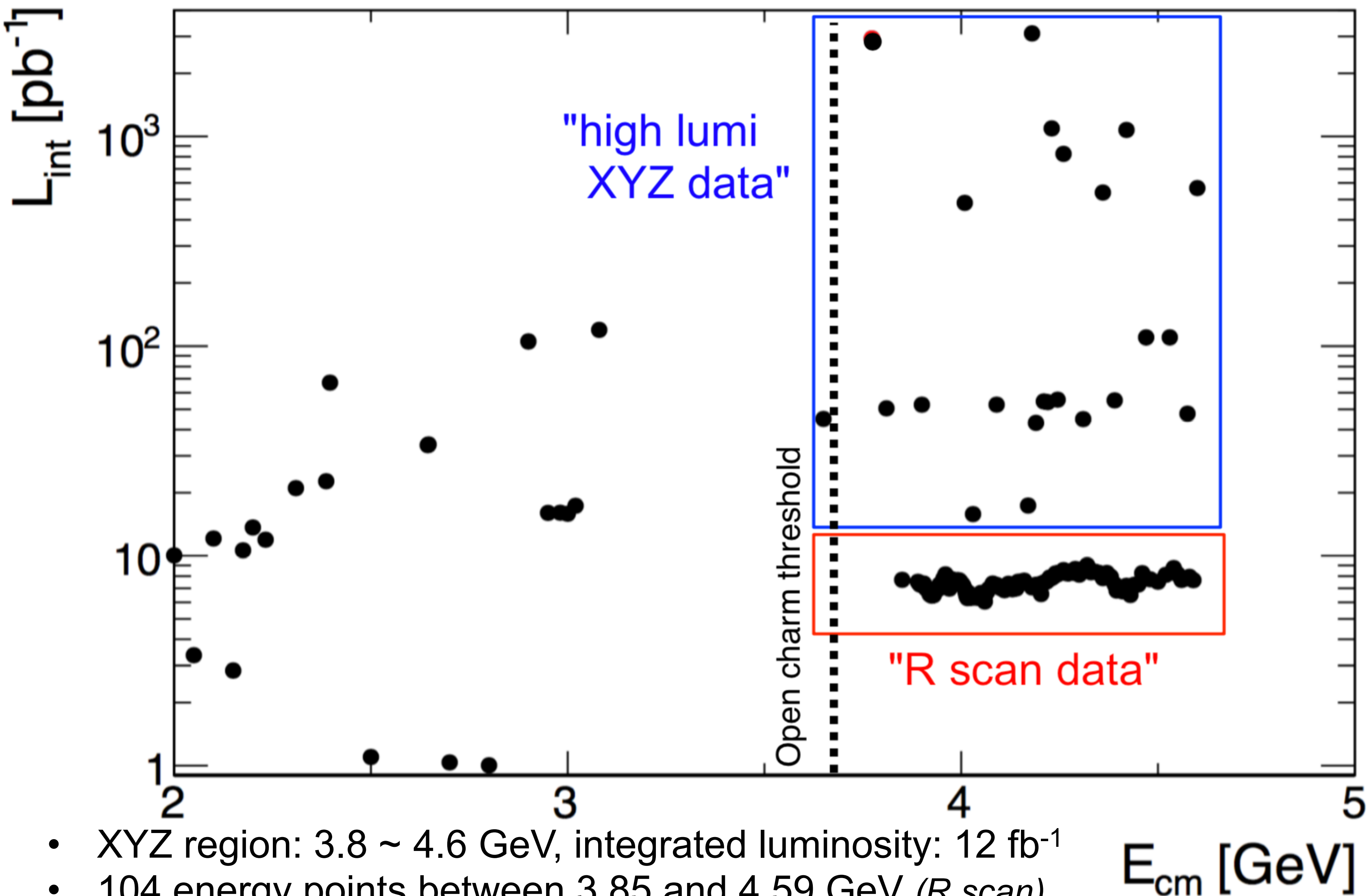


MORE:
Coarse scan 4100-4400 MeV/c²;
0.04 fb⁻¹ around $\Lambda_c \bar{\Lambda}_c$ threshold;
Data taking on-going

10 billion J/ψ sample reached on Feb. 11, together with a continuum data sample

R scan 1.5 fb⁻¹ 130 points 2-4.6 GeV

BESIII: Data Samples for XYZ studies

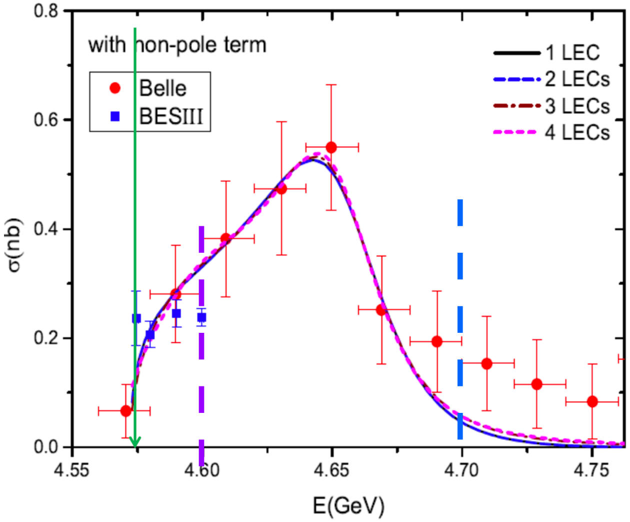


- XYZ region: 3.8 ~ 4.6 GeV, integrated luminosity: 12 fb^{-1}
- 104 energy points between 3.85 and 4.59 GeV *(R scan)*
- ~20 energy points between 2.0 and 3.1 GeV

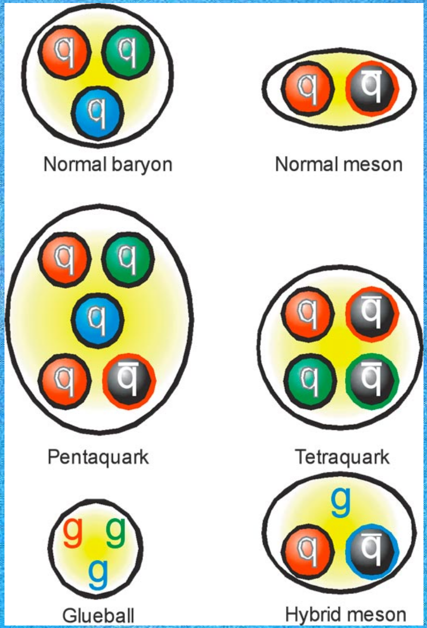
BEPCII upgrade

- Increase beam energy: 4.60 GeV → 4.70 GeV
  Explore a new energy region
  - To start in 2018/2019 after the summer shutdown
  - Increse to 4.90 GeV under study(upgrade two ISPB magnets)

- Top Up injection:
  - Data taking increase by 20-30%
  - Testing commissioning in Nov. 2018
  - To start after the summer shutdown



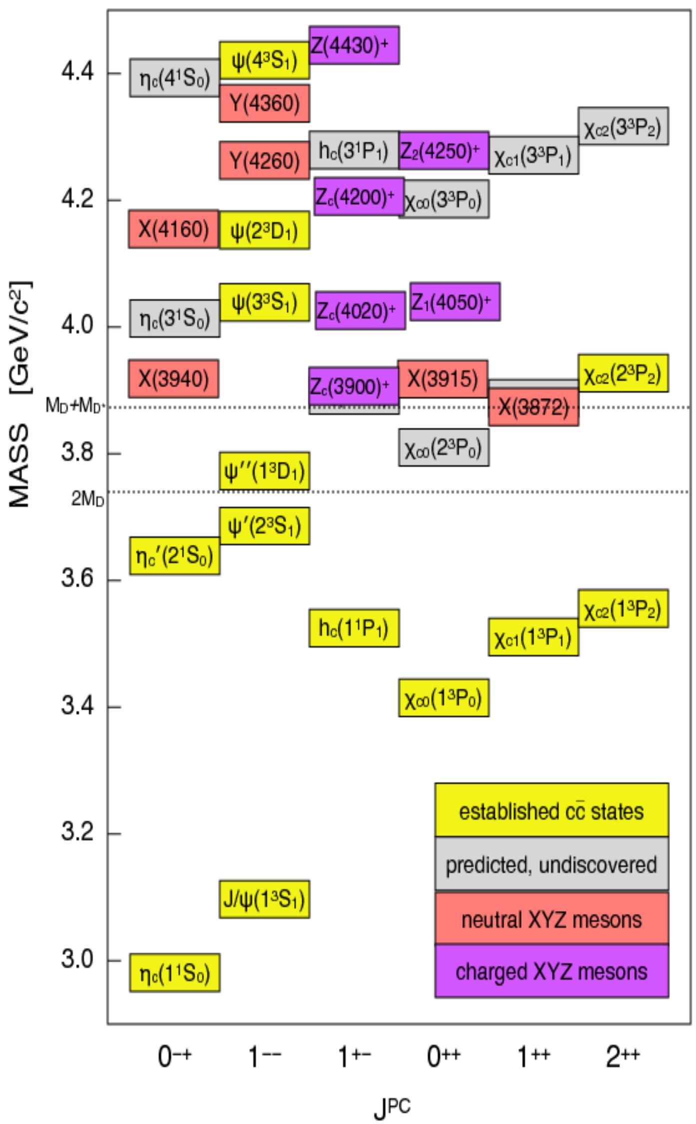
Present limit   Upgrade at 4.7 GeV



Exotics @BESIII

Miro

Exotics spectroscopy



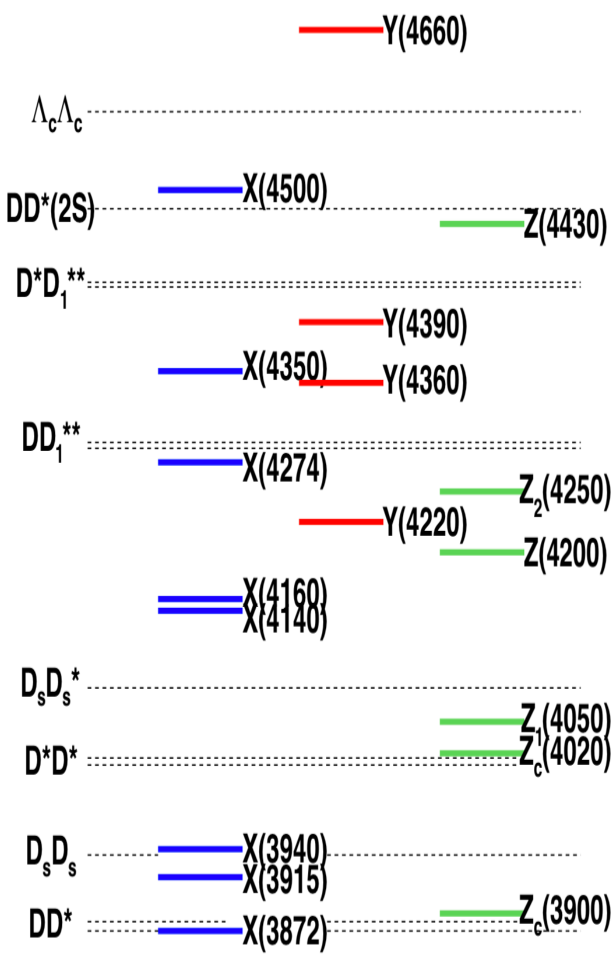
Many unexpected states reported above the $D\overline{D}$ threshold (the so-called XYZ).

J^PC

For predict. Barnes *et al.*, PRD 72, 054026 (2005)
(not all XYZ candidates shown!)

Exotics spectroscopy

BESIII



S.L.Olsen,arXiv:1812.10947

X : charmonium-like states with $J^{PC} \neq 1^{--}$
Observed in B decays, collisions

radiative or hadronic transition from Y

Y : charmonium-like states with $J^{PC} = 1^{--}$
Can be produced in direct e+e- annihilation (or in ISR)

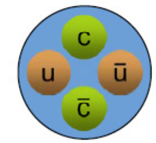
Hadronic transition from Y

Z : charmonium-like states which can carry electric charge. Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair

BEPCII& BESIII can be used as a Y(4260) (Y(4360)) factory. We can study the connections between X , Y and Z and the cross-section as CME function.

Nature of XYZ states

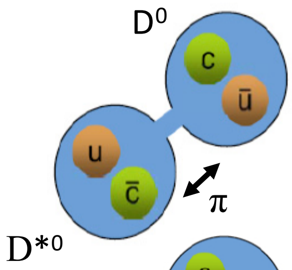
- **Tetraquarks**



  - Bound states of **(coloured diquark anti-diquark), Large number** of states (charged and neutral) foreseen (a nonet for each spin-parity) ,

  Small widths above threshold

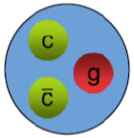
- **Hadronic Molecules**



  - Loosely bound states of **pair of mesons**, **Small number** of states,

  Small widths above threshold

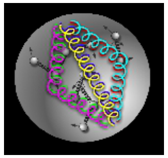
- **Hybrids**



  - Bound States with a pair of quarks and **excited gluonic** degrees of freedom
  - Lattice and model predictions for the **lowest-mass** hybrid ~ **4.2 GeV/c^2**

- **Glueball**

  Bound states of gluons



Unprecedented possibility to test the our knowledge of the QCD

- **HadroCharmonium**

Compact charmonium enbadded in light quark mesonic excitation interacting by analog of Van der Waals force

- **Others: Threshold**, **cusp**, or **coupled-channel** effect produce a **cross section enhancement**

EXPERIMENTAL CONTRIBUTION

1)Establish the spectrum: search for more XYZ states, determine their properties and investigate new decays for known ones

2) Build connections: look for transitions between different states

- $X(3872) \rightarrow \omega J/\psi$
- $X(3872) \rightarrow \pi^0 \chi_{c1}(1P)$

X(3872)

The X(3872) was discovered by Belle in 2003 in $\boldsymbol{B^{+} \rightarrow K^{+} J/\psi\pi^{+}\pi^{-}}$

$M = 3871.69 \pm 0.17$ MeV/c^{2}

Very close to the $D^0\bar{D}^{*0}$thr,Very narrow(< 1.2 MeV/c^2)

Confirmed by BABAR, CDF, D0, LHCb.

-$J^{PC} = 1^{++}$,

-no isospin partners currently known –

-decays into $D^0\bar{D}^0\pi^0$ (dominant), $D^{*0}\bar{D}^0$, $J/\psi\,\pi^+\pi^-$, $J/\psi\,\pi^+\pi^-\pi^0$, $\gamma J/\psi$, $\gamma\psi(2S)$.

Also isospin-violating → $\rho J/\psi$ and $\omega J/\psi$.

X(3872)

The X(3872) was discovered by Belle in 2003 in $\boldsymbol{B^+ \rightarrow K^+ J/\psi\pi^+\pi^-}$

$M = 3871.69 \pm 0.17$ MeV/c^2

Very close to the $D^0\overline{D}^{*0}$ threshold, Very narrow(< 1.2 MeV/c^2)

Confirmed by BABAR, CDF, D0, LHCb.

-$J^{PC} = 1^{++}$,

-no isospin partners currently known –

-decays into $J/\psi\ \pi^+\pi^-$, $D^{*0}\overline{D}^0$, $J/\psi\ \pi^+\pi^-\pi^0$, $D^0D^0\pi^0$, $\gamma J/\psi$, $\gamma\psi(2S)$. Also isospin-violating → $\rho J/\psi$ and $\omega J/\psi$.

Unconventional meson candidate :

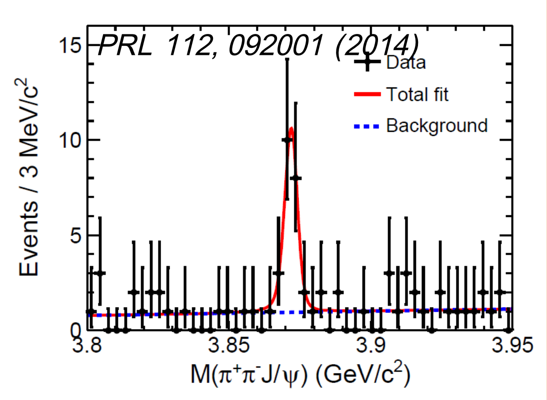
molecular states, tetraquark states, mixture of excited χ_{c1} and D^0D^{*0} bound state. …

Much is now known about the X(3872), except exactly what it is

X(3872)

BESIII previously observed $e^+e^- \to \gamma X(3872) \to \gamma J/\psi\pi^+\pi^-$

@4 center-of-mass energies (ECM).:*4.01 (0.5 fb^{-1}), 4.23 (1.1 fb^{-1}), 4.26 (0.8 fb^{-1}), and 4.36 GeV (0.5 fb^{-1})*



FIRST CONNECTION BETWEEN charmonium like states

Since then, BESIII has collected a total of

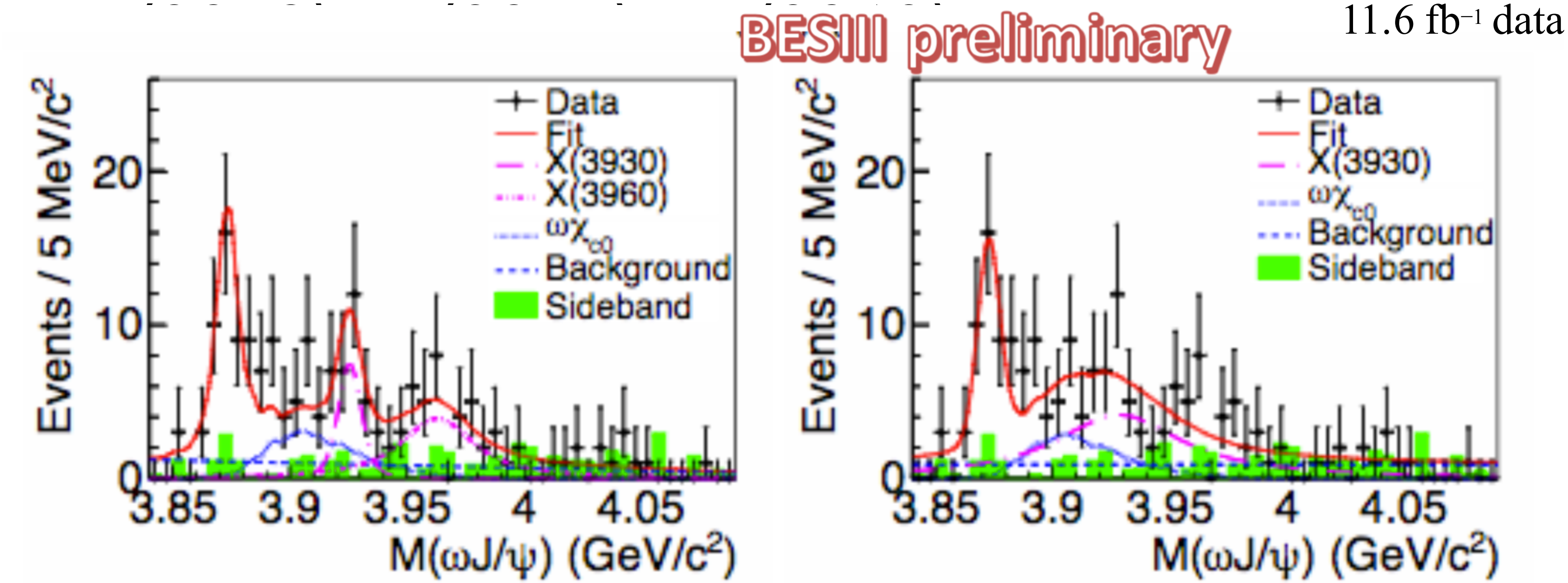
9.0 fb^{-1} for $4.15 < E_{CM} < 4.30$ GeV,
0.7 fb^{-1} for $4.00 < E_{CM} < 4.15$ GeV,
2.8 fb^{-1} for $4.30 < E_{CM} < 4.60$ GeV,

opportunity to search for new decay modes of the X(3872)!!!!

$e^+e^- \to \gamma X(3872) \to \gamma\omega J/\psi$

The hadronic molecule model predicts that the decay of $X(3872) \to \omega J/\psi$ is sensitive to its internal structure

Previously, Belle and *BABAR* reported weak evidence for this decay

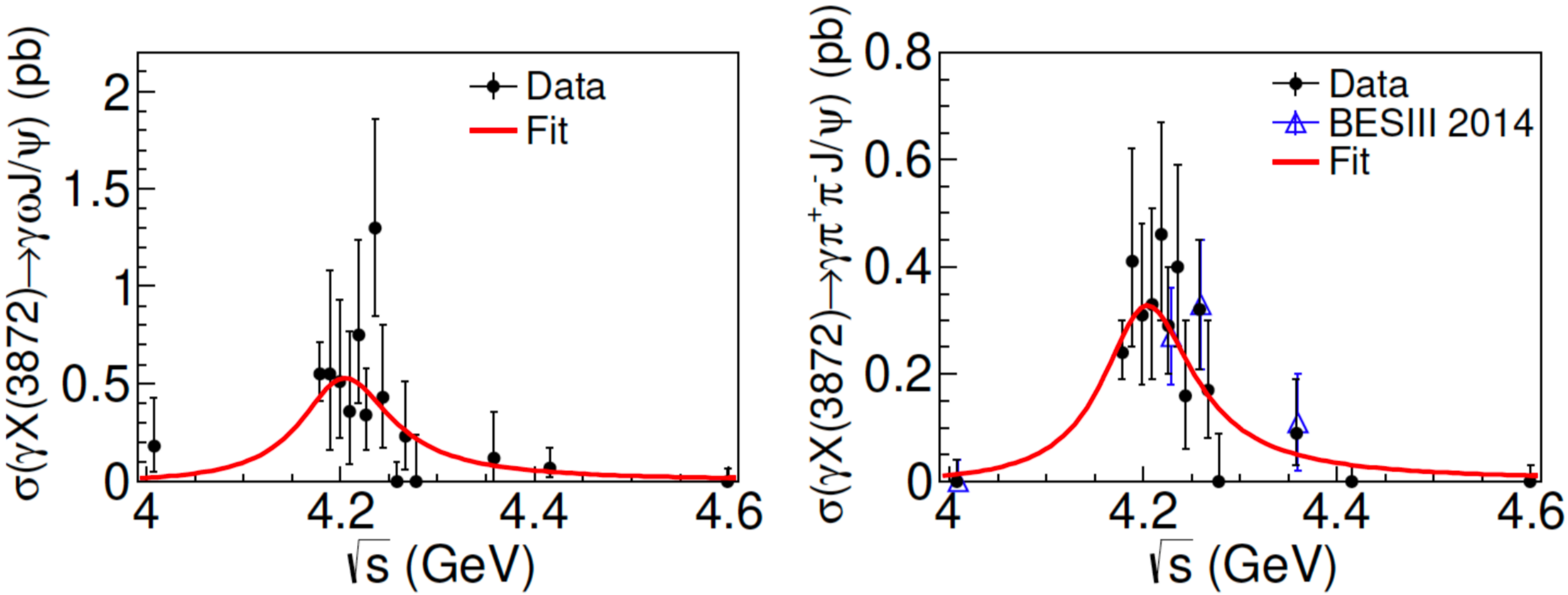


X(3872)+ X(3915) + X(3960)   X(3872)+ X(3915)

at least one additional Breit-Wigner

X(3872) (M=3873 ± 1.1 ± 1.0) signal significance >5.1σ, including systematic errors

$Y \rightarrow \gamma X(3872) \longrightarrow \gamma\omega J/\psi$



Simultaneous($\omega J/\psi$ and $\pi\pi J/\psi$)fit to the cross section with a single Breit-Wigner resonance

$$M[Y(4200)] = 4200.6^{+7.9}_{-13.3} \pm 3.0 \text{ MeV}/c^2$$

agree with the ψ(4160) or Y (4260)

$$\Gamma[Y(4200)] = 115^{+38}_{-26} \pm 12 \text{ MeV}$$

not compatible with hadronic molecule

relative decay ratio

free parameter

$$\mathcal{R} = \frac{\mathcal{B}[X(3872)\rightarrow\omega J/\psi]}{\mathcal{B}[X(3872)\rightarrow\pi^+\pi^- J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2$$

Predicted about 60% by Swanson, Phys. Lett. B 588, 189 (2004);

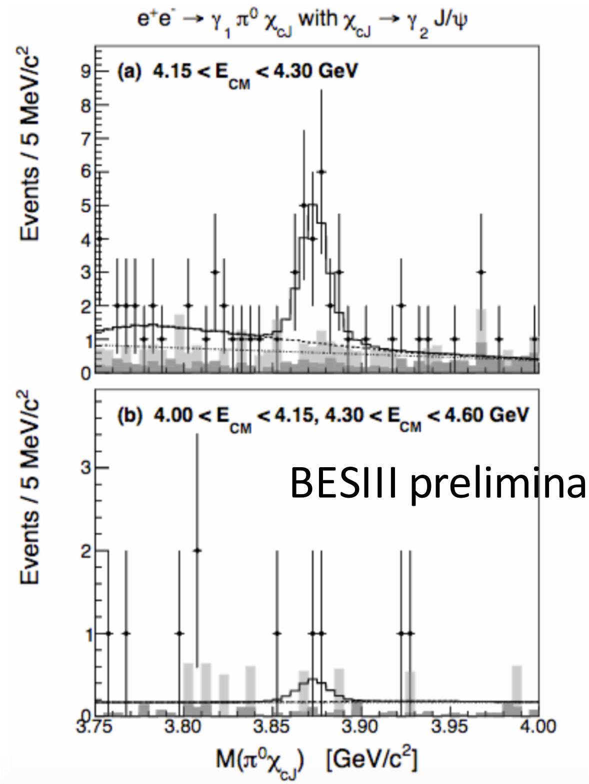
Study of $X(3872) \to \pi^0 \chi_{cj}(1P)$

The **X(3872)** → **$\pi^0\chi_{cJ}$** decays are sensitive to the internal structure of the X(3872).

$\Gamma(X(3872) \to \pi^0\chi_{c1}(1P)) \sim 0.06$ keV *(i.e. very small) if* χ (2P) pure charmonium state
$\Gamma(X(3872) \to \pi^0\chi_{c1}(1P))$ greatly enhanced for tetraquark state.
[Dubynskiy, Voloshin, PRD 77, 014013 (2008)]

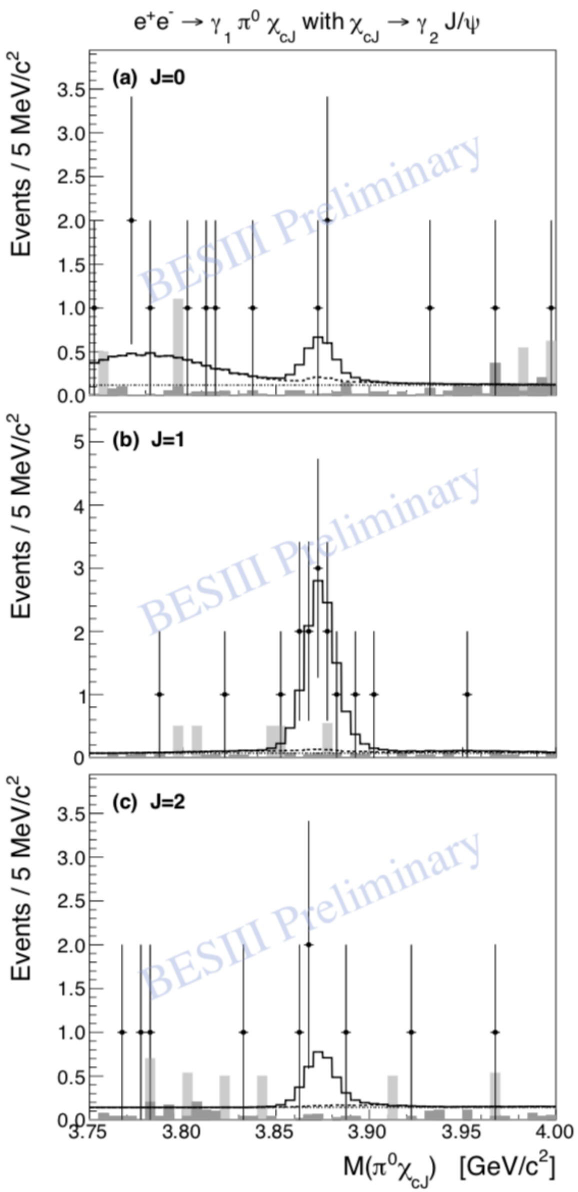
9.0 fb^{-1} for $4.15 < E_{CM} < 4.30$ GeV,
0.7 fb^{-1} for $4.00 < E_{CM} < 4.15$ GeV,
2.8 fb^{-1} for $4.30 < E_{CM} < 4.60$ GeV,

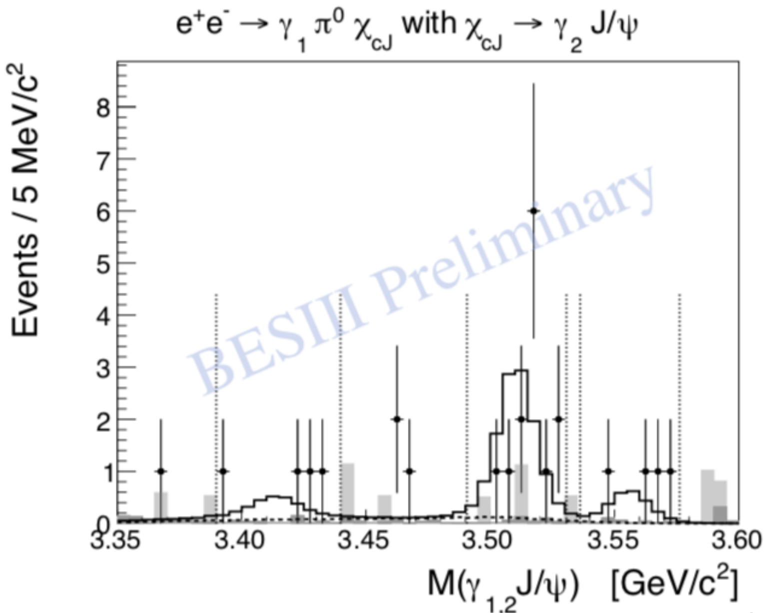
In the range of 4.15<Ecm<4.30 GeV
A clear X(3872) signal is seen choosing the range of the three χ_{cj}
None in the other ranges.



arXiv:1901.03992.
Submitted to PRL

Observation of X(3872)→ $\pi^0\chi_{c1}(1P)$





First observation(5.2σ) of X(3872)→ $\pi^0\chi_{c1}$(1P)
No signal for J=0,2.
Measured BR:

$R_J = B(X \to \pi^0\chi_{cJ}) / B(X \to \pi^+\pi^- J/\psi)$:

$R_0 < 19$ (90% U.L.)

$R_1 = 0.88^{+0.31}_{-0.26} \pm 0.14$

$R_2 < 1.0$ (90% U.L.)

Observation of X(3872)→ $\pi^0\chi_{c1}(1P)$

Using BR(X(3872) → $\pi^+\pi^- J/\psi$) > 3.2% [PDG] and BR(X(3872) → $\pi^+\pi^- J/\psi$) < 6.4%,
(obtained by assuming all measured X(3872) decays add to less than 100%)
we find:
BR(X(3872) → $\pi^0\chi_{c1}$) ~ 3−6%.

If the X(3872) IS the χ_{c1}(2P) state of charmonium, then Γ(X(3872) → $\pi^0\chi_{c1}$) ~ 0.06 keV,
[Dubynskiy, Voloshin, PRD 77, 014013 (2008)]

-> unrealistically small **Γ_{TOT}(X(3872)) ~ 0.5 – 1.0 keV.**
(…several orders of magnitude smaller than Γ_{TOT}(J/ψ) ~ 100 keV)

Large R_1 disfavours the χ (2P) interpretation of the X(3872).

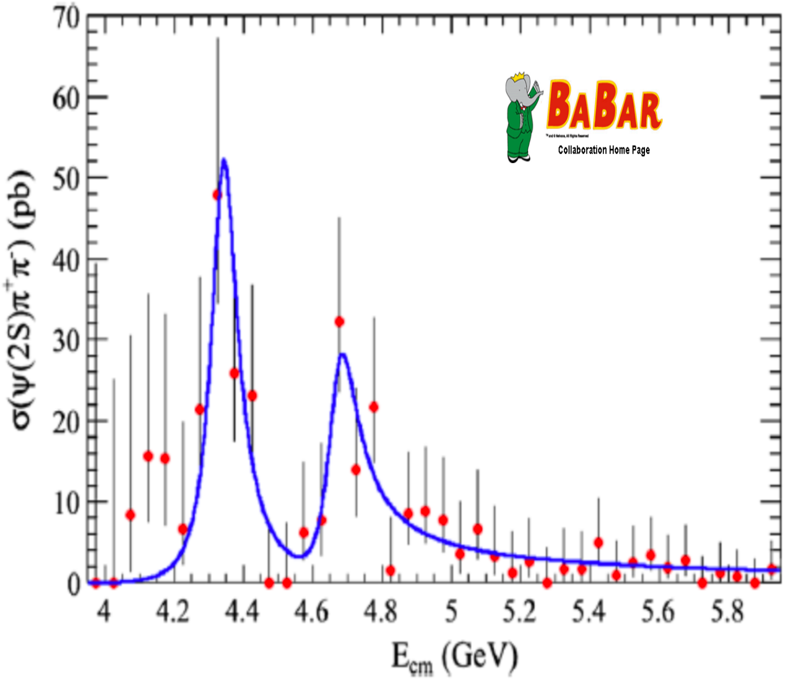
the hadrocharmonium interpretation is somehow in trouble as well


Y(4660)

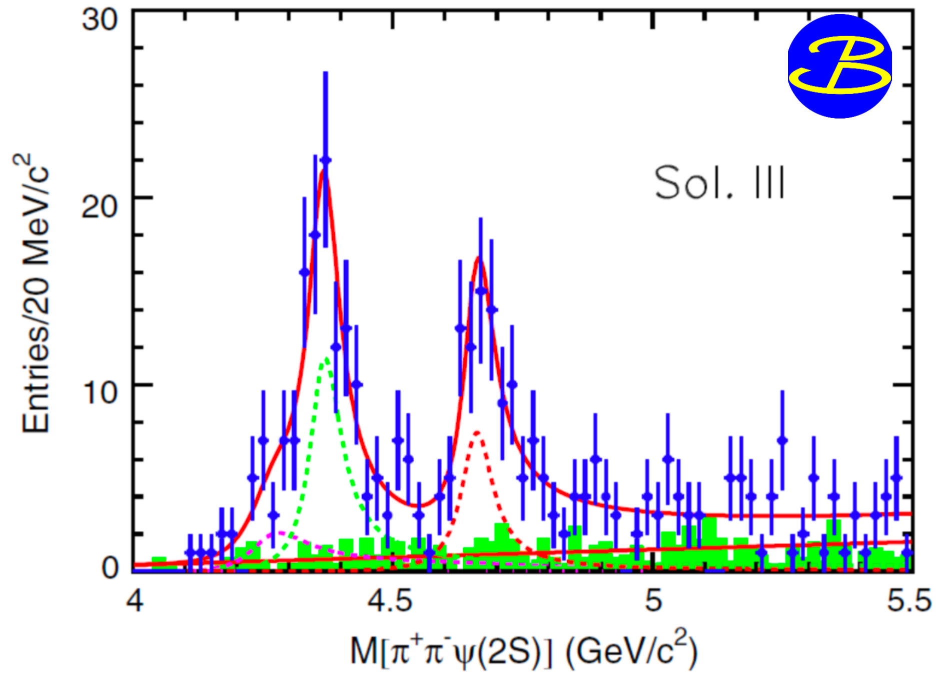
$e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-\psi(3686)$

Evidences of the Y(4660), ISR technique

PHYSICAL REVIEW D **89**, 111103(R) (2014)

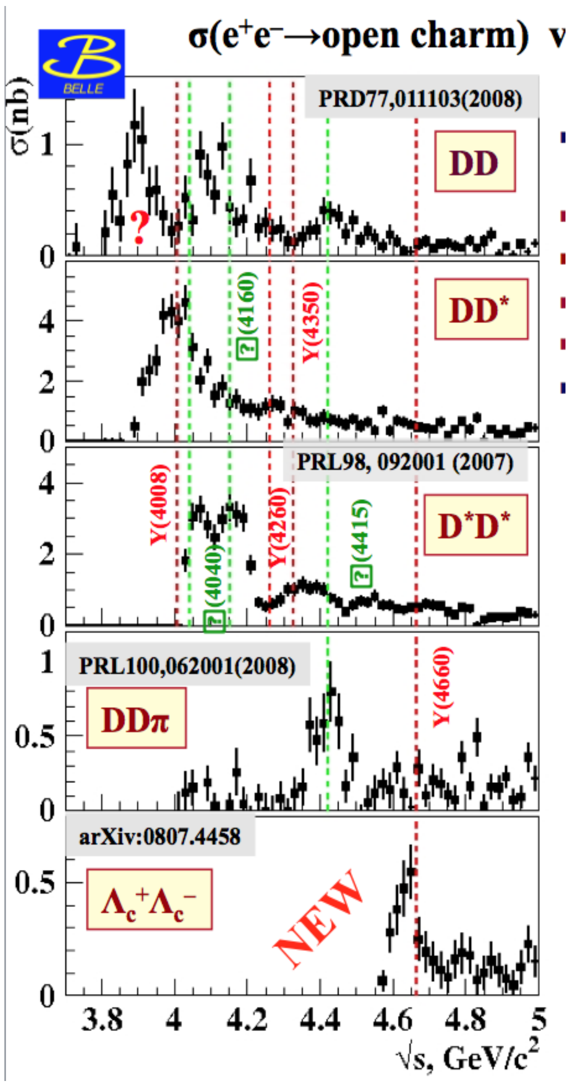


PHYSICAL REVIEW D **91**, 112007 (2015)



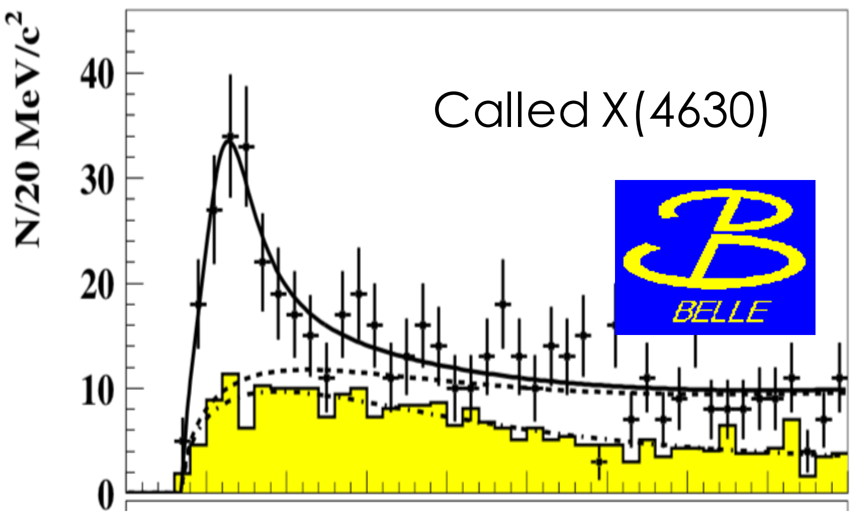
PDG:
M=(4643 ± 9) MeV
Γ=(72 ±11) MeV

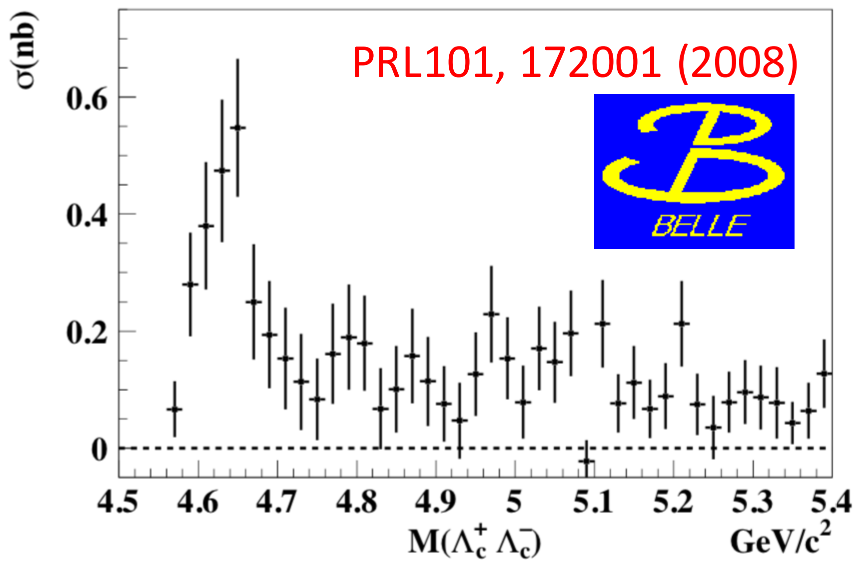
..but not observed in $\pi^+\pi^- J/\psi$



Y(4660) not observed in $e^+ e^- \to DD, DD^*, D^*D^*$ (courtesy Steve Olsen)

Y(4660) in $e^+e^- \to \gamma_{ISR}\Lambda_C\overline{\Lambda_C}$





Ling-Yun Dai, Johann Haidenbauer, Ulf-G. Meißner fit to Belle

Resonance Y(4660) [called X(4660)]

+ FSI @thr:

PRD 96, 116001 (2017)

M= (4652.5 ± 3.4) MeV

Γ = (62.6 ± 5.6) MeV

σ_{peak} ~ 0.55 nb [comparable to $\sigma(e^+e^- \to pp_{bar})$ ~ 0.8 nb @ threshold]

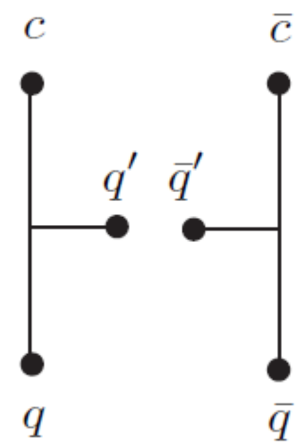
- in $e^+e^- \to \psi(3686)\,\pi\pi$, $\sigma_{peak} \sim$ **0.04** $\pm$ 0.025 nb

  to be compared to $\sigma_{peak}\,(e^+e^- \to \Lambda_c\overline{\Lambda_c}) \sim$ **0.55** nb

- Y(4660) baryonic coupling $\geq$ 10 mesonic coupling → Unexpected !

Is Y(4660) a Hidden charm Baryonium ?

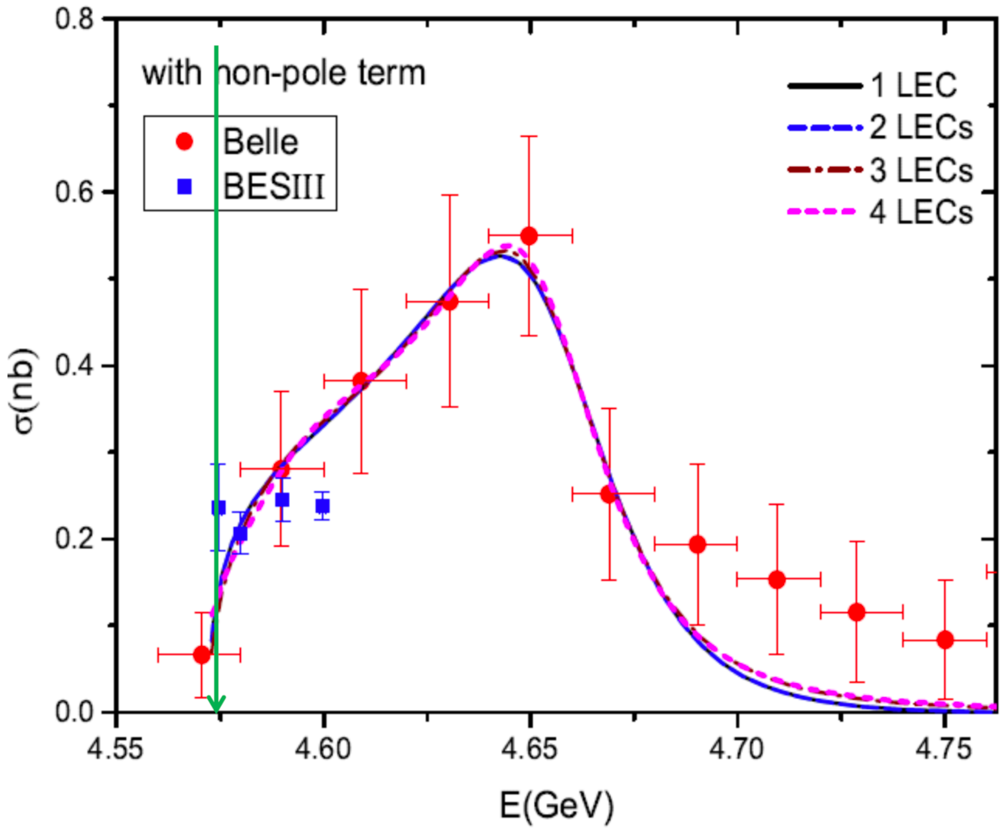
- R. Faccini et al., PRL 104, 132005 (2010)
- [also L. Maiani et al., PRD 72, 031502 (2005)]



- Y(4660) mass, close to the threshold, favours its interpretation as a charmed baryonium.
- Y(4660)-> $\Lambda_c\overline{\Lambda_c}$ width, actually (expected large, according to the Rossi Veneziano model Nucl.Phys. B123,507(1977)) constrained by the threshold close by.

$Y(4660)$ in $e^+e^- \to \Lambda_c\overline{\Lambda_c}$

Using 10 decay process to reconstruct $\mathbf{\Lambda_c}$, $\boldsymbol{\sigma}(e^+e^- \to \Lambda_c\overline{\Lambda_c})$ is measured @ 4 energy points, good detection efficiency @thr (weak decay)



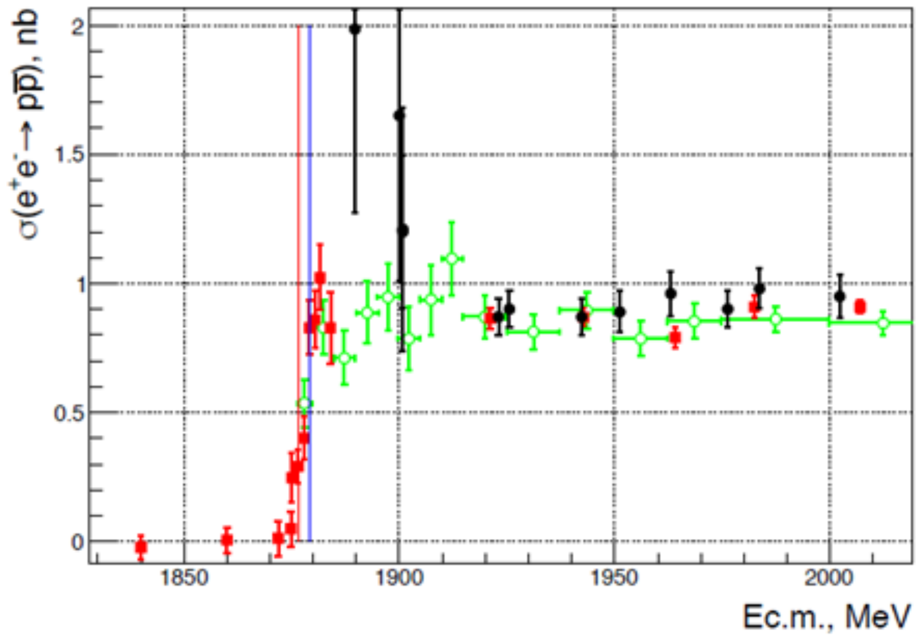
PRL101, 172001 (2008)

PRL120, 132001 (2018)

Fit from PRD 96, 116001 (2017) (E<4.68 GeV)

At thr $\sigma(\mathbf{e}^+\boldsymbol{e}^- \to \boldsymbol{\Lambda_c}\overline{\boldsymbol{\Lambda_c}})$ shows a step, it is close to the pointlike value, once the Coulomb enhancement factor is taken into account: $\sigma(\mathbf{e}^+\boldsymbol{e}^- \to \boldsymbol{\Lambda_c}\overline{\boldsymbol{\Lambda_c}})_{\text{pointl}} \approx \pi^2\alpha^3/(2M_B^2) \approx 145$ pb

e+e- -> ppbar Born cross section



Our new 2017 data in comparison with BaBar and CMD-3 2011-2012 scans
(R.R. Akhmetshin et al., (CMD-3 Collaboration), Phys. Lett. B759, 634 (2016).)

from E. Solodov

Same behaviour @threshold !!

Y(4660) in $e^+e^- \to \Lambda_c\overline{\Lambda_c}$

BESIII and BELLE do not agree so well

○Concerning BESIII measurements in PRD 96, 116001 (2017) :

" While they agree with the Belle data, as for as cross sections magnitude, they indicate a different trend in energy. It is impossible to fit both data.

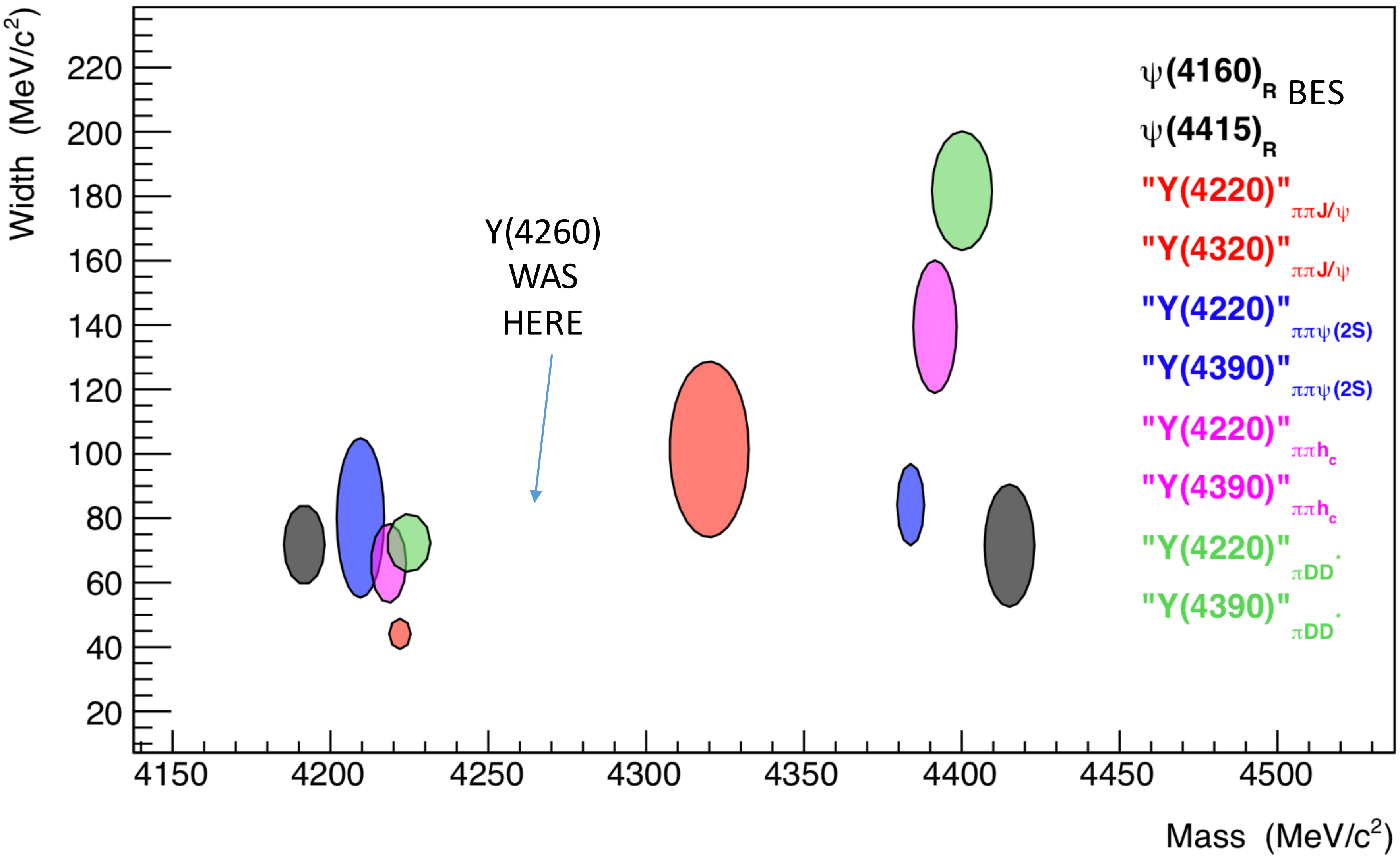
Hopefully BESIII will extend their measurements at higher energies and thereby clarify the situation"

Waiting for more data of BESIII @threshold and above 4.6 GeV (after upgrade)!!

It will be important if Y(4660) can be confirmed, for the baryonium hypothesis!

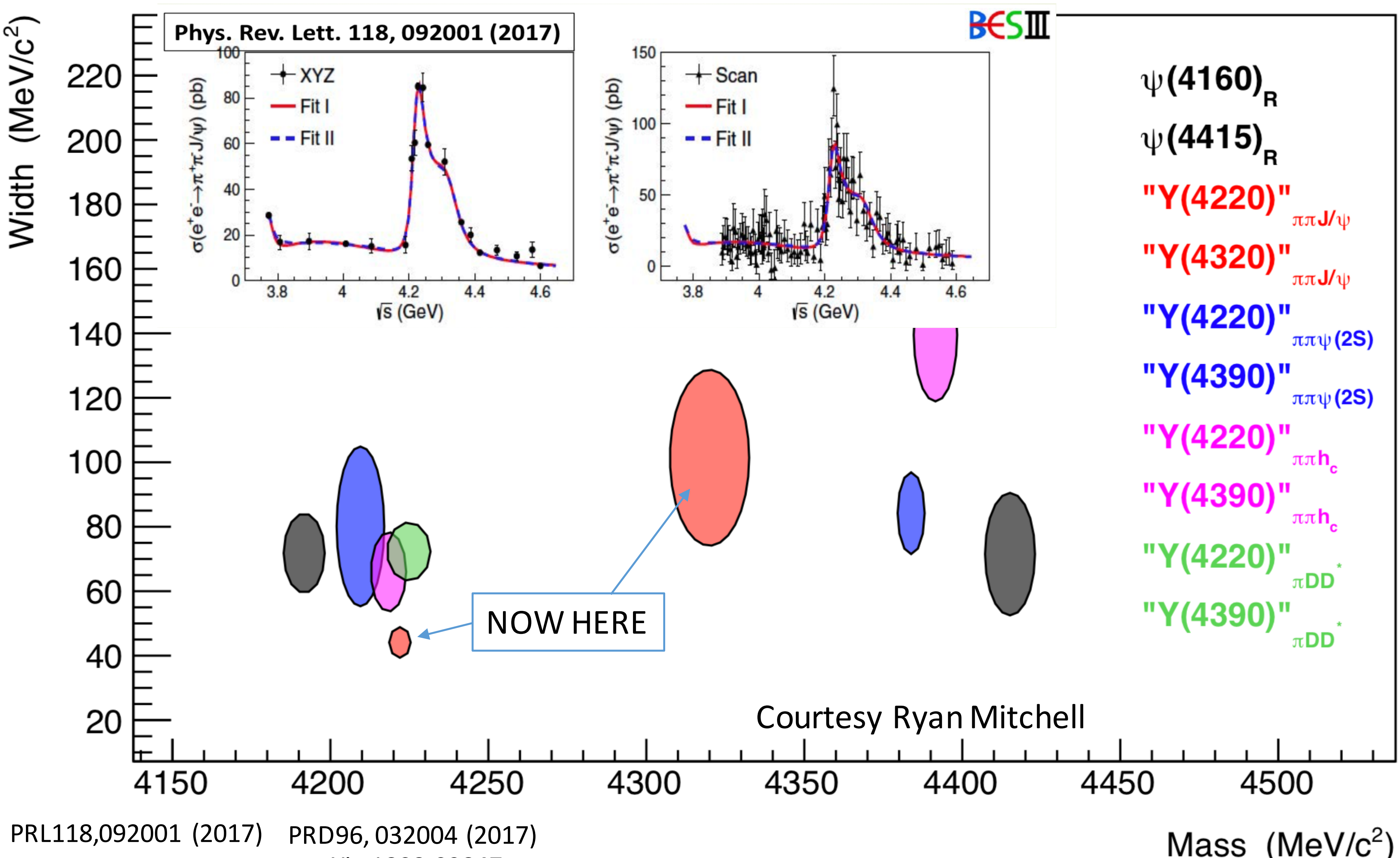
Y(4220), previously Y(4260)

The so-called "Y problem"



Courtesy Ryan Mitchell

Summarizing



PRL118,092001 (2017)
PRL 118, 092002 (2017)
PRD96, 032004 (2017)
arXiv:1808.02847

$e^+e^- \to \omega\chi_{cj}$

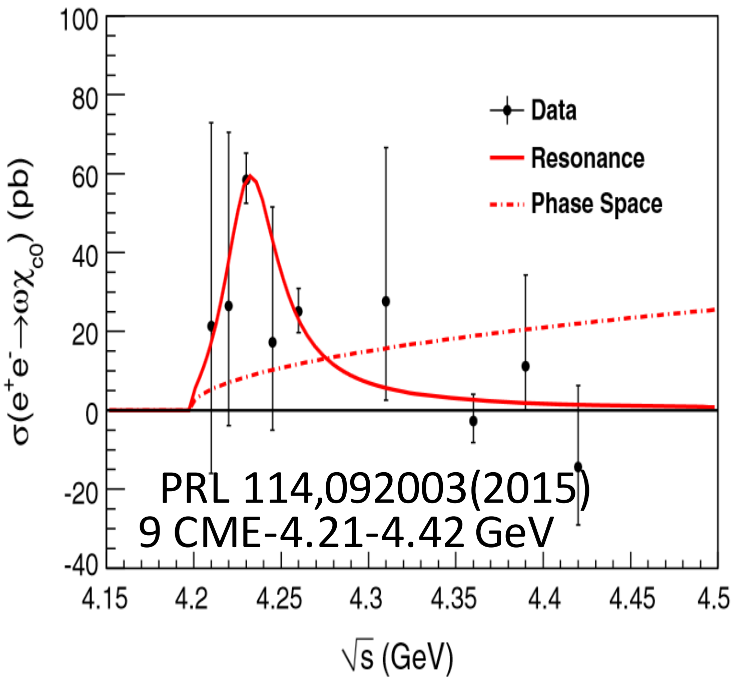
Breit-Wigner+PHSP term

arxiv:1903.02359

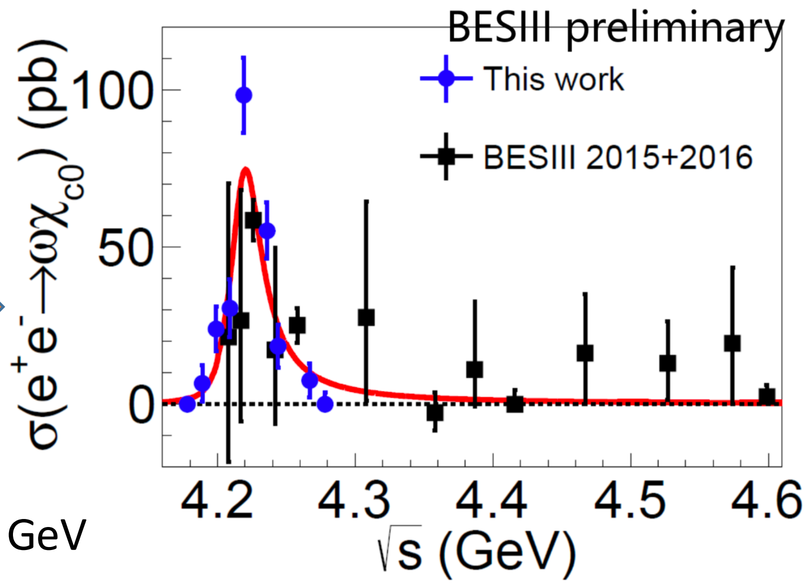
clear enhancement Y(4220)

$$BW(\sqrt{s}) = \frac{\Gamma_{ee}\mathcal{B}(\omega\chi_{c0})\Gamma_t}{(s-M^2)^2+(M\Gamma_t)^2} \times \frac{\Phi(\sqrt{s})}{\Phi(M)}$$

signal only for $e^+e^- \to \omega\chi_{c0}$



9 CME
4.178-4278 GeV
7fb^{-1}



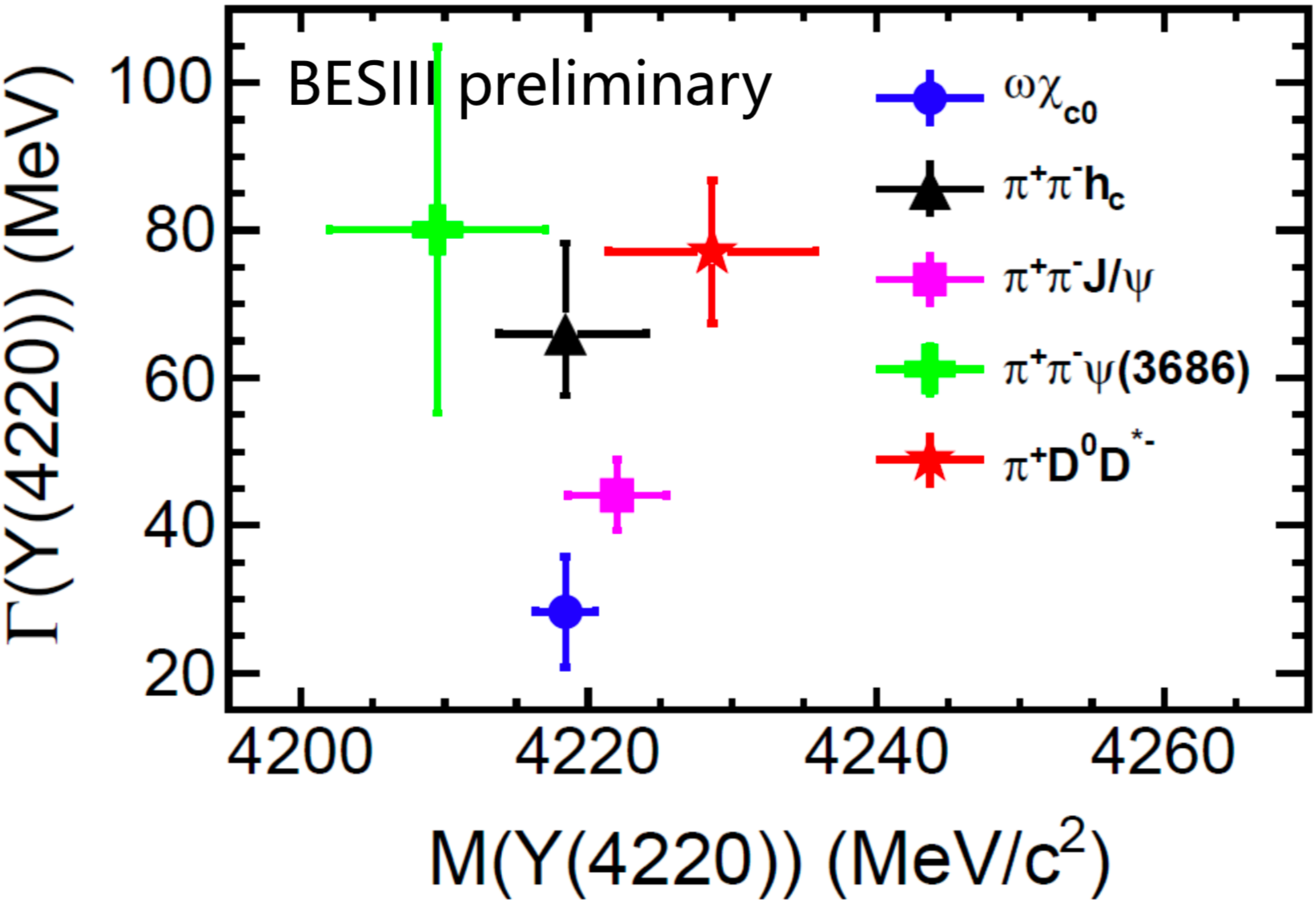
$$\Gamma_{ee}\mathcal{B}(\omega\chi_{c0}) = (2.5 \pm 0.2 \pm 0.4)\ \text{eV}$$

$$M(Y) = (4218.5 \pm 1.6 \pm 1.3)\ \text{MeV}/c^2$$

$$\Gamma_t = (28.2 \pm 3.9 \pm 6.4)\ \text{MeV}$$

with significance $> 9\sigma$

Y agrees with in $e^+e^- \to \pi^+\pi^- h_c$ e $e^+e^- \to \pi^+\pi^- J/\psi$


BESIII preliminary
ωχc0
π+π-hc
π+π-J/ψ
π+π-ψ(3686)
π+D0D*-
Γ(Y(4220)) (MeV)
M(Y(4220)) (MeV/c2)
100
80
60
40
20
4200
4220
4240
4260

Z_c states

-J^p for Zc(3990)

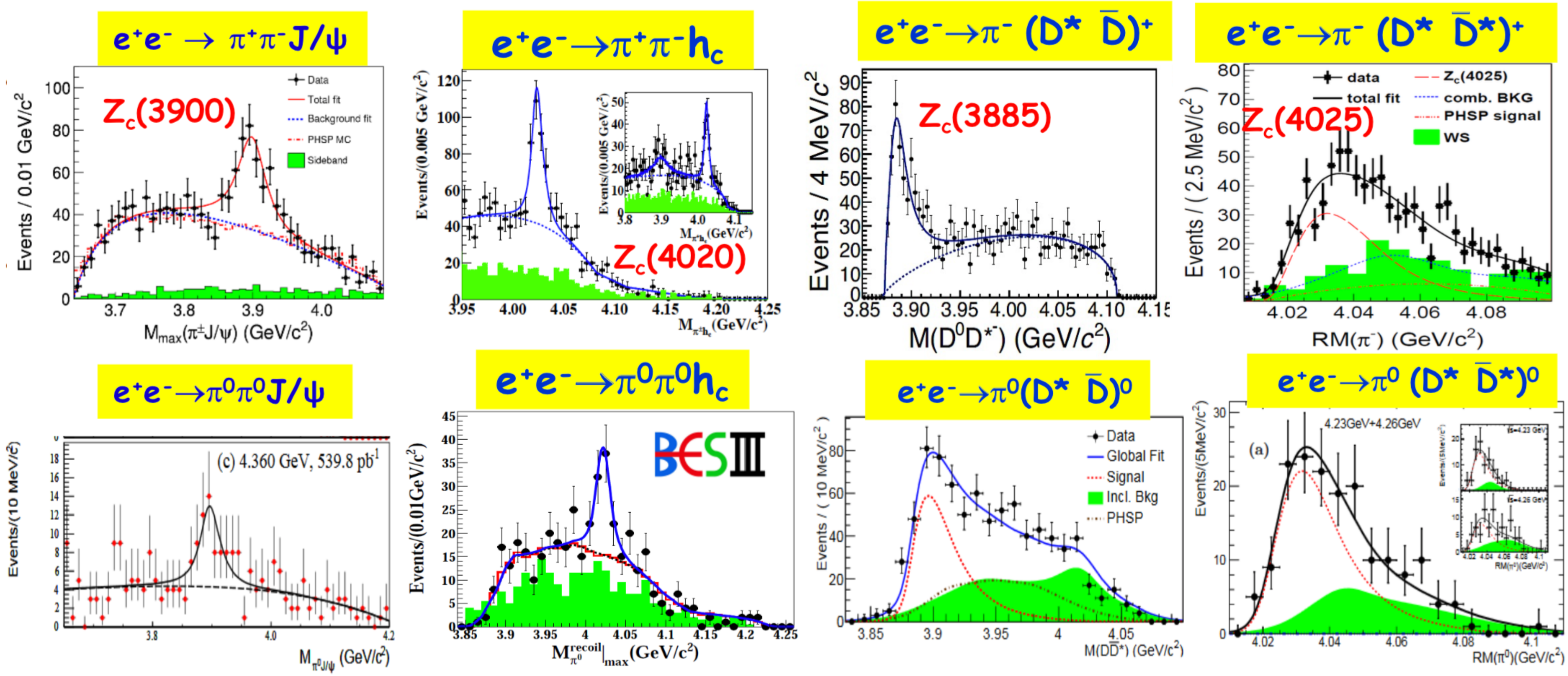
-$Z_C \to \rho\eta_C$

$Z_c(3900)/Z_c(4020)$

Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair:exotic!

PRL110, 252001 (2013)

PRD 92, 092006



PRL112, 022001 (2014) PRL115, 222002 (2015) PRL112, 132001 (2014)

PRL111, 242001 (2013)

PRL113, 212002 (2014)

PRL115 , 182002(2015)

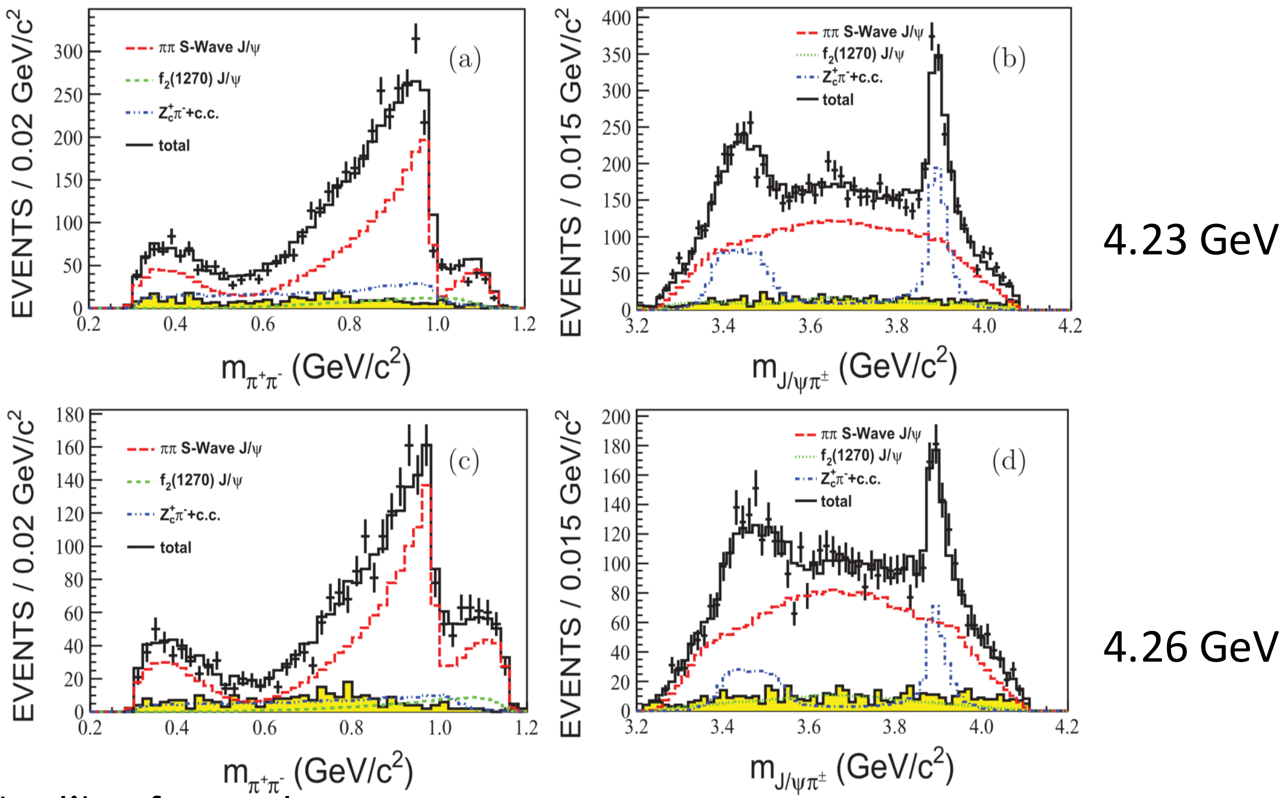
- Observed in various channels
- strong coupling with $D\overline{D^*}$. $D^*\overline{D^*}$
- 2 Isospin triplets estabilished by BESIII

Jp determination for Zc(3900)

Phys. Rev. Lett. **119**, 072001

PWA with Z_c using helicity formalism

Simultaneous fit @ 4.23 e 4.26 GeV



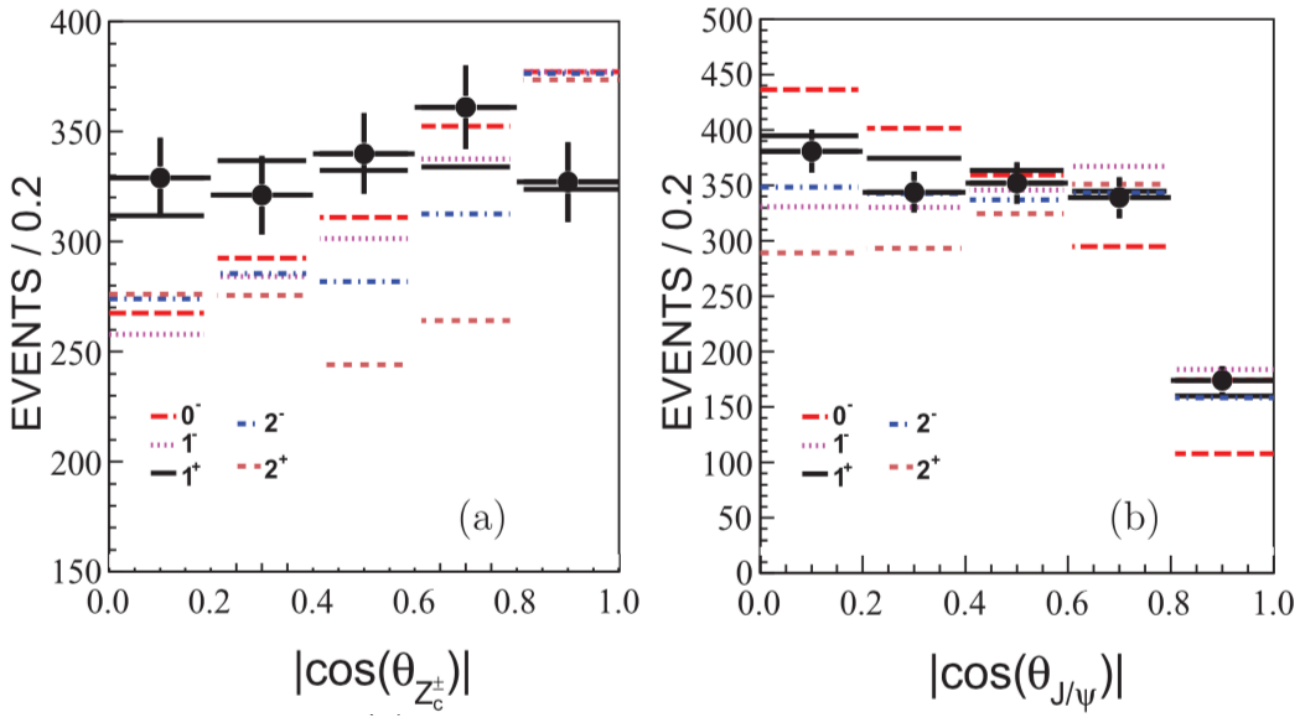
- Z_C line shape with Flatte-like formula
- and with σ, $f_0(980)$, $f_2(1270)$, $f_0(1370)$, Z_C

Z_c pole mass and with:

$$M_{pole} = 3887.0 \pm 0.8 \pm 10.0 \text{ MeV}, \; \Gamma_{pole} = 45.2 \pm 4.8 \pm 16.8 \text{ MeV}$$

Jp determination for Zc(3900)

$m_{J/\psi\pi^{\pm}} \in (3.86, 3.92)\ \mathrm{GeV}/c^2$



$e^+e^- \to Z_c^+\pi^- + \mathrm{c.c.}$

Helicity angle for J/Psi

$Z_c^{\pm} \to \pi^{\pm} J/\psi$

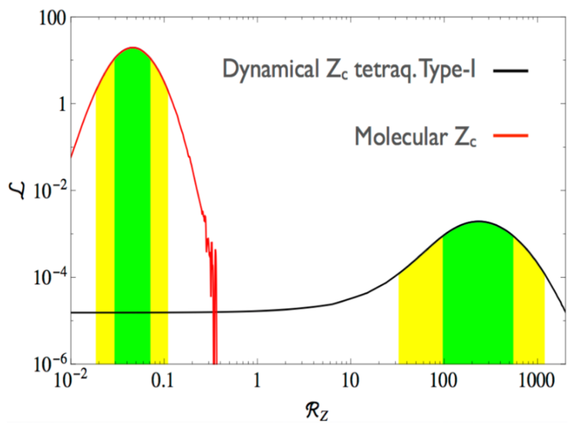
Hypothesis	$\Delta(-2\ln L)$	$\Delta(\mathrm{ndf})$	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

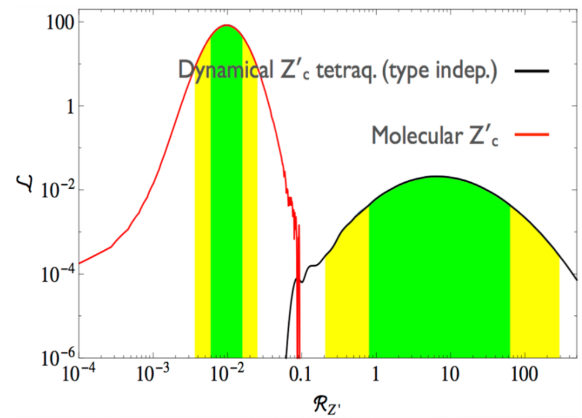
Z_C is 1^+ with signif.>7.6 σ

Evidence of $Z_C \rightarrow \rho\eta_C$

Theoretical expectations exist for the ratio of BF of $Z_C^{(\prime)} \rightarrow \rho\eta_C$ e $Z_C^{(\prime)} \rightarrow \pi J/\psi(\pi h_c)$
They can help in understanding their nature, in particular btw tetra-quark(Type-1) e molecole

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



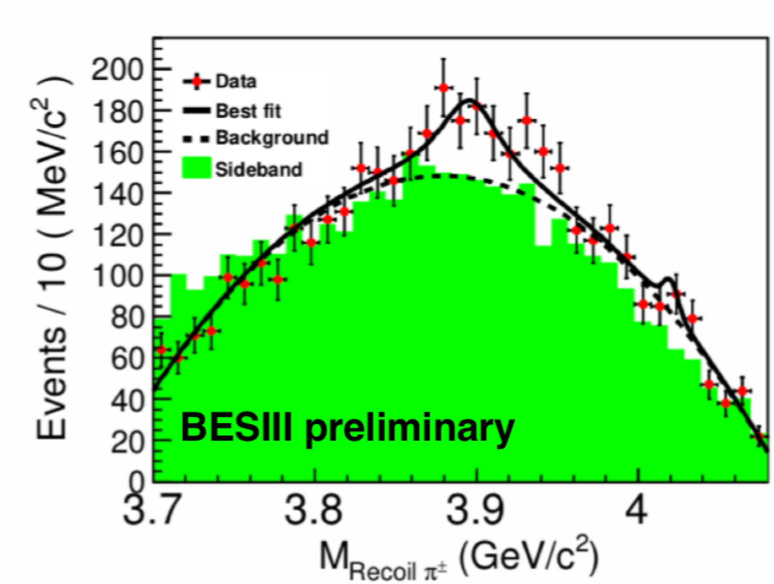


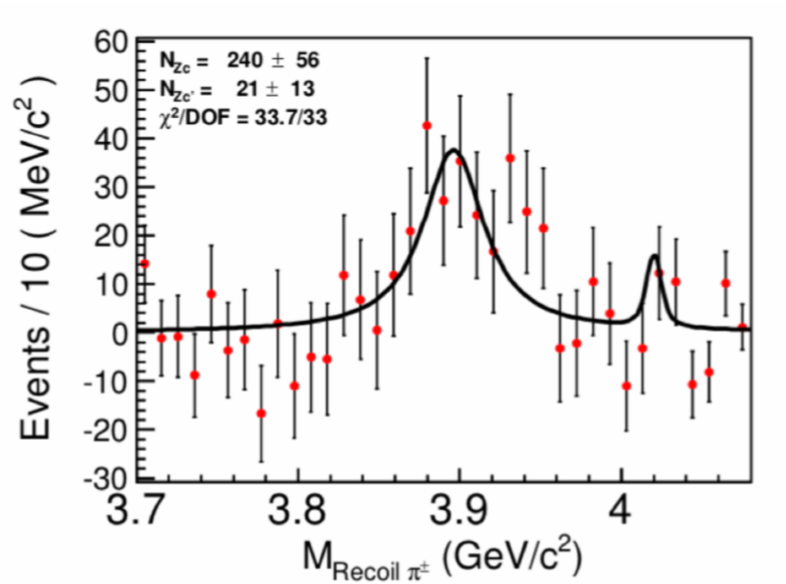
A. Esposito
Phys. Lett. B 746, 194 (2015)

Evidence of $Z_c \to \rho\eta_c$

Nine decay channels to reconstruct η_c.

Zc parameter are fixed to latest measurement.





No significant $Z'_c \to \rho\eta_c$ observed.

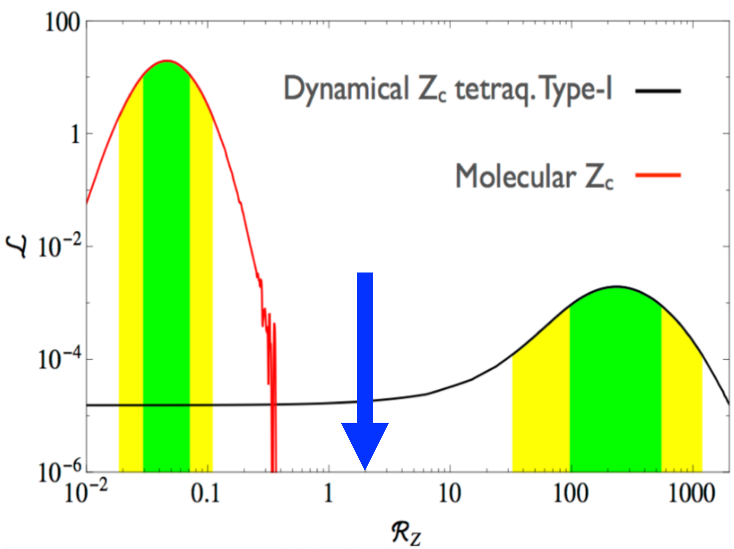
- Strong evidence of $e^+e^- \to \pi Z_c$ e $Z_c \to \rho\eta_c$ @4.23 GeV, stat. signif. 4.3σ.

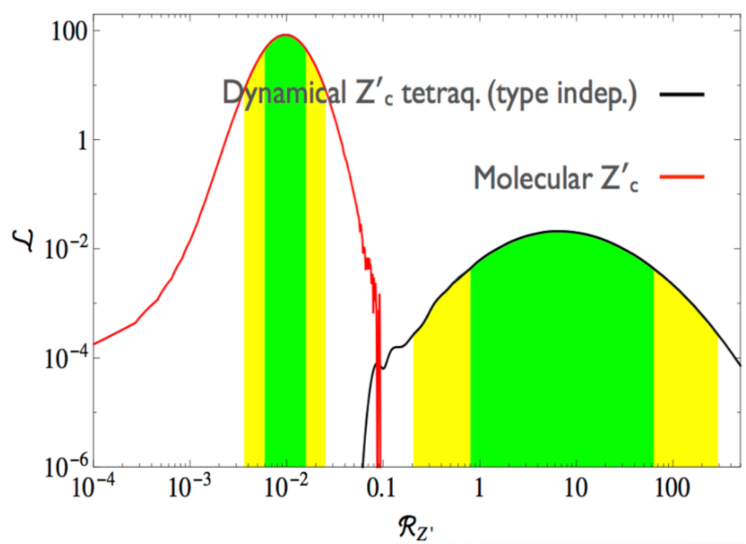
	$\sqrt{s} = 4.23\,\mathrm{GeV}$	$\sqrt{s} = 4.26\,\mathrm{GeV}$	$\sqrt{s} = 4.36\,\mathrm{GeV}$	Tetra-quarks-I	Tetra-quarks-II	Molecule
$R_{Z_c(3900)}$	2.1 ± 0.8	< 6.4	...	230^{+330}_{-140}	$0.27^{+0.40}_{-0.17}$	$0.046^{+0.025}_{-0.017}$
$R_{Z_c(4020)}$	< 1.9	< 1.2	< 1.0		$6.6^{+56.8}_{-5.8}$	$0.010^{+0.006}_{-0.004}$

Evidence of $Z_C \to \rho\eta_C$

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

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





A. Esposito
Phys. Lett. B 746, 194 (2015)

Our measurement doesn't agree with both molecular Zc and tetraquark Zc Type-1 assumptions

Summary

- BESIII is taking data since 2009 and already has world's largest data samples of various Y and charmonia
- It will take data until 2022, at least
- Important upgrades of BEPCII and BESIII detector forseen in the next future
- Many interesting results in the XYZ studies
- Many others are on the way by BESIII
- Still remain unanswered questions:
- strong interplay between theory and experiment needed.

- Expected more data in the future. (XYZ data taking on-going,

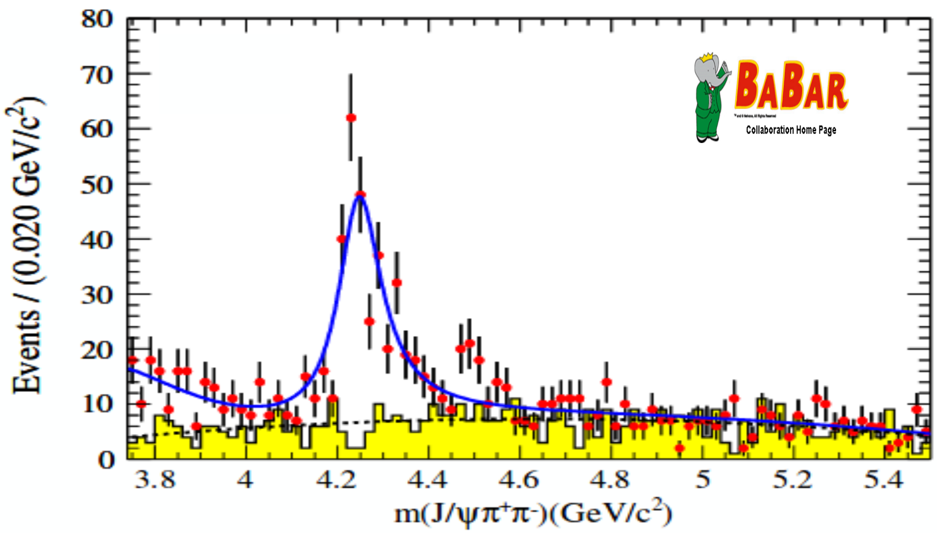
(~3.9fb-1 XYZ data in 128 days)

謝謝

-Y(4260) and Y(4360)
-Y(4660)

Y(4260)

PRL **95**, 142001 (2005)



Y(4260) observed first by BaBar (2005) In $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^- J/\psi$.
CONFIRMED BY Belle e CLEO.
no sign of Y(4260) → $D^{(*)}\,\overline{D}^{(*)}$

WEIGHTED MEAN:
M = 4259±9 MeV, Γ=120±12 MeV

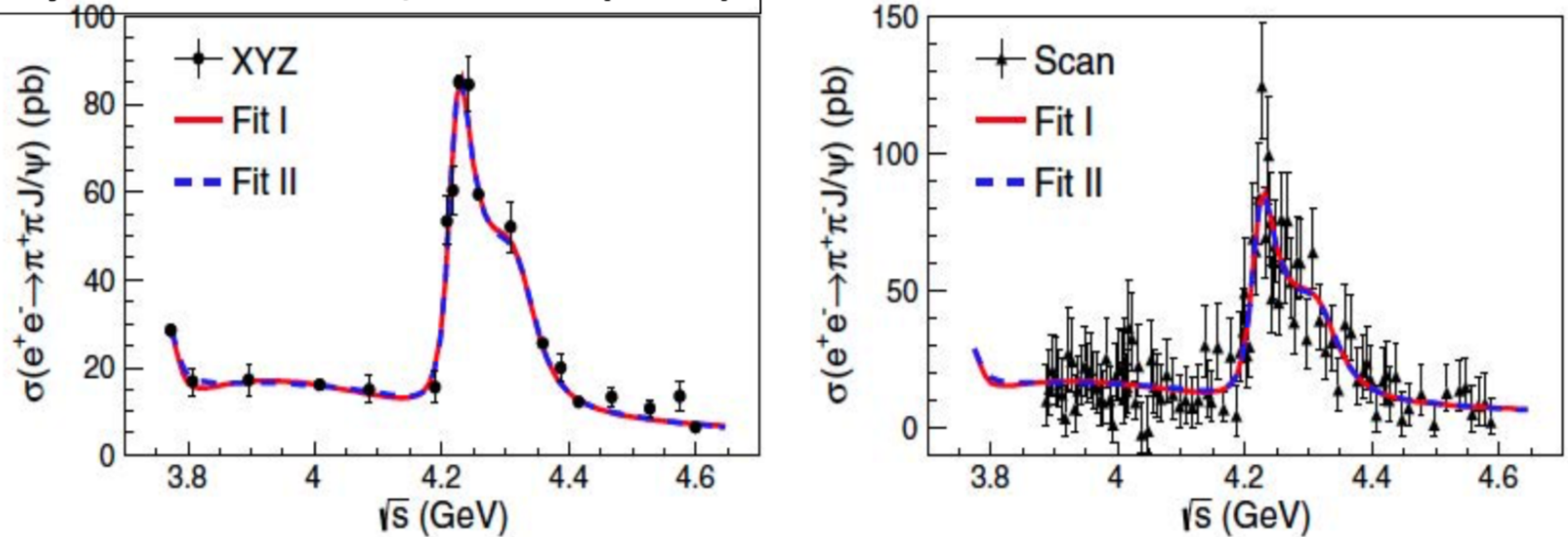
$e^+e^- \to \pi^+\pi^- J/\psi$

Cme from 3.77 to 4.60 GeV 9.05 fb^{-1}

simultaneous FIT on scan e XYZ data

BESIII

Phys. Rev. Lett. 118, 092001 (2017)



Coherent sum of three BW + not coherent ψ(3770)

Coherent sum of two BW + exp. In low mass region

M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV

(Compared with Y(4260) PDG lower mass and narrower)

Y(4260)

Y(4220) + Y(4330)

M =(4320.0±10.4±7.0) MeV, Γ = (101.4±25±10) MeV

(a bit lower mass than Y(4360) PDG, previously observed by *BABAR* and Belle)

Significance of the second BW →7.9σ

First resonance agrees with the Y(4260).

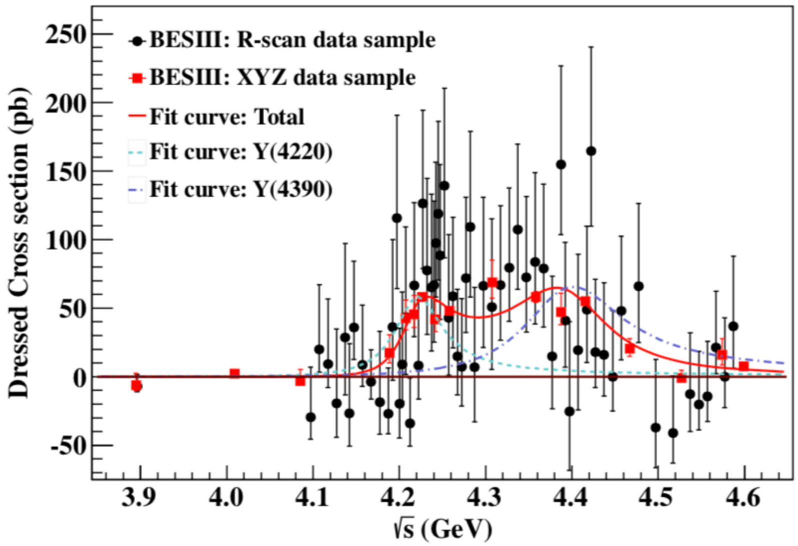
First observation of Y(4360) in this channel

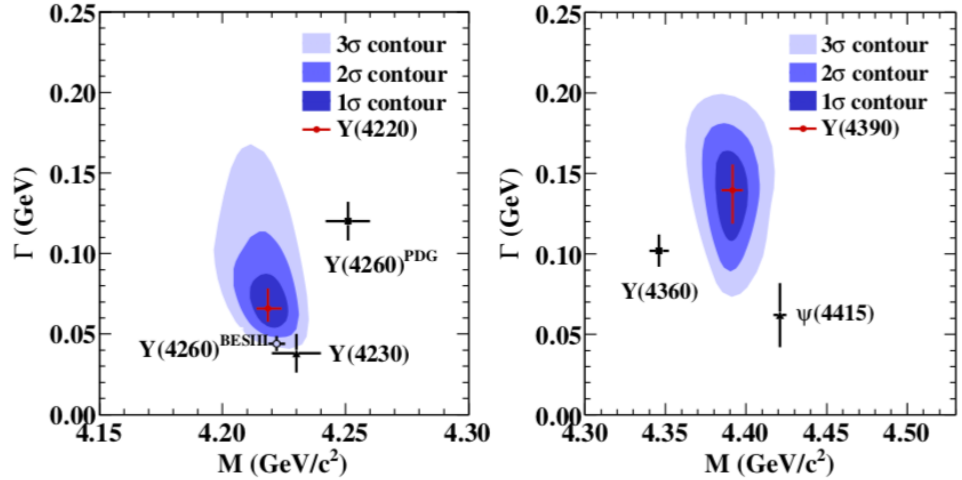
Y(4008) not necessary to explain the data.

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

PRL 118, 092002 (2017)

79 c.m. energy points from 3.896 to 4.600 GeV





Fit with coherent sum of two resonances

$M_1 = 4218 \pm 4$ MeV $\Gamma_1 = 66 \pm 9$ MeV **Y(4220)**

$M_2 = 4392 \pm 6$ MeV $\Gamma_2 = 140 \pm 16$ MeV **Y(4390)**

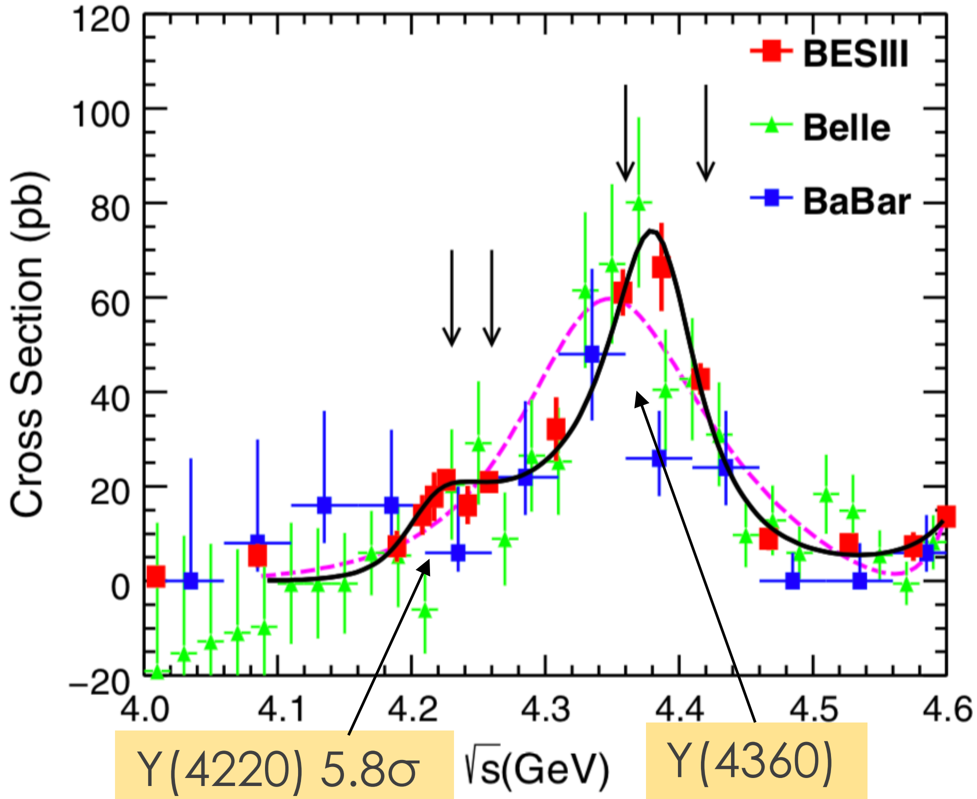
Y(4220) consistent with the one in $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

$e^+e^- \to \pi^+\pi^-\psi(2S)$

BESIII

16 energies btw 4.008 e 4600 GeV

PRD96, 032004 (2017)



Fit with coherent sum of 3 Breit-Wigner of BESIII data.
Fit w/o Y(4220) .

Tail of Y(4660)
Fixed paremeters (Belle)

M_1=4209.5 ±7.4 ± 1.4 MeV /c^2;Γ_1=80.1 ±24.6 ±2.9 MeV
M_2=4383.8 ±4.2 ± 0.8 MeV/c^2 ;Γ_2=84.2 ±12.5 ±2.1 MeV

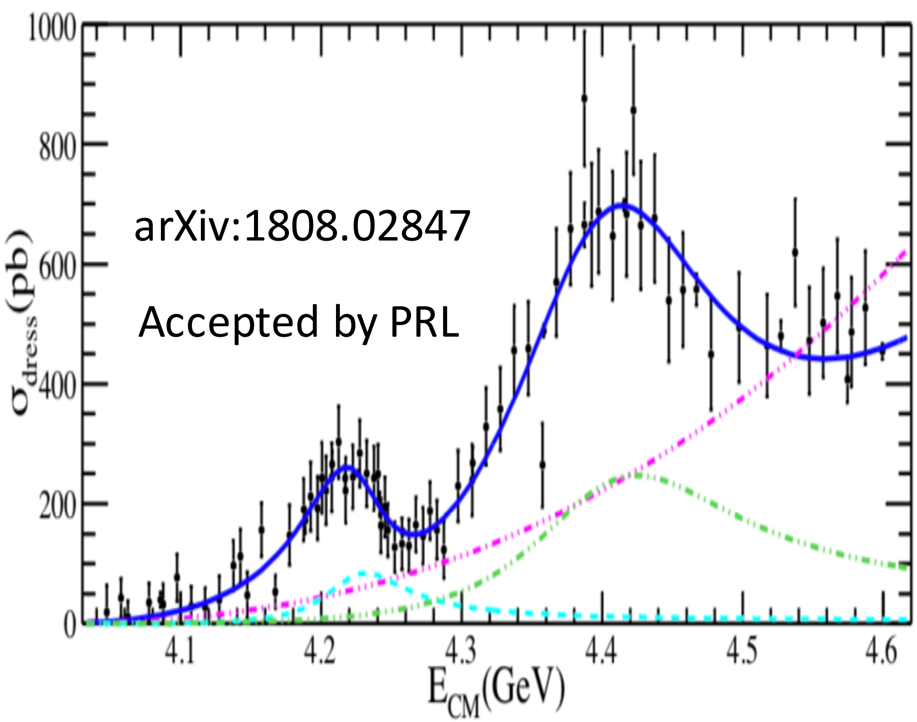
Y(4360) compatible with BaBar e Belle with better precision.

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

Fit with a three body phase space term and two relativistic BW functions

$$\sigma_{\rm dress}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1} B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi_2} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}}|^2$$

$M(Y(4220)) = (4228.6 \pm 4.1 \pm 5.9)$ MeV/c^2,
$\Gamma(Y(4220)) = (77.1 \pm 6.8 \pm 6.9)$ MeV.
With stat signif. more than 5.0σ.



Models including one additional known resonance, either Y (4260), Y (4320), Y (4360), or ψ(4415) (mass &widths @world average values)

Summarizing

Process	M_1 (MeV/c^2)	Γ_1 (MeV)	M_2 (MeV/c^2)	Γ_2 (MeV)
$e^+e^- \to \omega\chi_{c0}$	$4230 \pm 8 \pm 6$	$38 \pm 12 \pm 2$ [37]		
$e^+e^- \to \pi^+\pi^- J/\psi$	$4220.0 \pm 3.1 \pm 1.4$	$44.1 \pm 4.3 \pm 2.0$	$4320.0 \pm 10.4 \pm 7.0$	$101.4^{+25.3}_{-19.7} \pm 10.2$[9]
$e^+e^- \to \pi^+\pi^- h_c$	$4218.4^{+5.5}_{-4.5} \pm 0.9$	$66.0^{+12.3}_{-8.3} \pm 0.4$	$4391.5^{+6.3}_{-6.8} \pm 1.0$	$139.5^{+16.2}_{-20.6} \pm 0.6$ [10]
$e^+e^- \to \pi^+ D^0 D^{*-} + c.c$	$4224.8 \pm 5.6 \pm 4.0$	$72.3 \pm 9.1 \pm 0.9$	$4400.1 \pm 9.3 \pm 2.1$	$181.7 \pm 16.9 \pm 7.4$ [38]
$e^+e^- \to \pi^+\pi^- \psi(3686)$	$4209.5 \pm 7.4 \pm 1.4$	$80.1 \pm 24.6 \pm 2.9$	$4383.8 \pm 4.2 \pm 0.8$	$84.2 \pm 12.5 \pm 2.1$