Exotics at BESIII

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On behalf of the BESIII Collaboration

Lake Louise Winter Institute
02/25/2017 – Lake Louise

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Università degli Studi di Ferrara - Ex Labore Fructus -

Outline

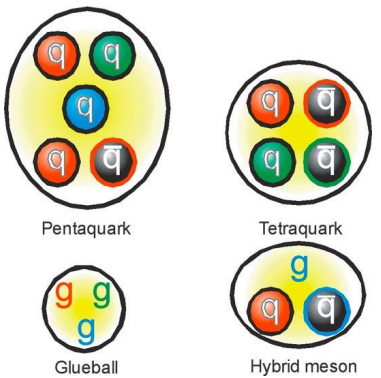
- Introduction
- BESIII and BEPCII
- Selected results in the charmonium spectrum
- X(1835) case: exotic in light hadron spectroscopy

Exotics...

Exotics...

Exotics...

Exotics...


q q q q q
Pentaquark
q q q q
Tetraquark
g g g
Glueball
g q q
Hybrid meson

Exotics in Naive Quark Model

- States predicted but difficult to observe (if they exist)
  - Glueballs
  - Tetraquarks
  - Pentaquarks
  - Hybrids

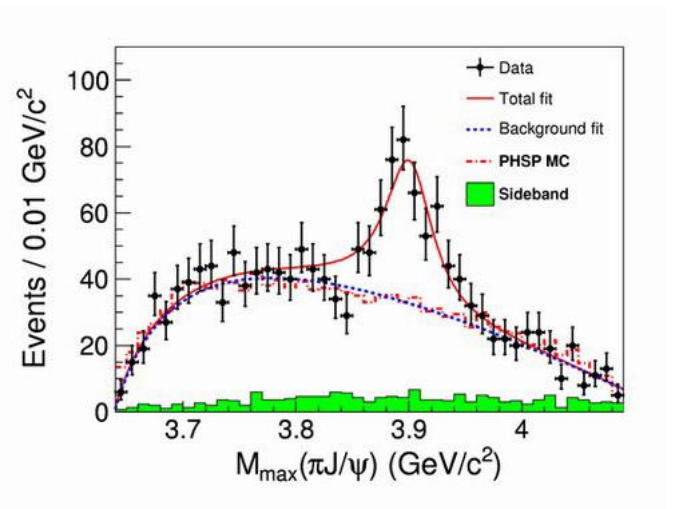
Glueball

Tetraquark

Hybrid meson

Pentaquark

- States unpredicted but observed (XYZ)



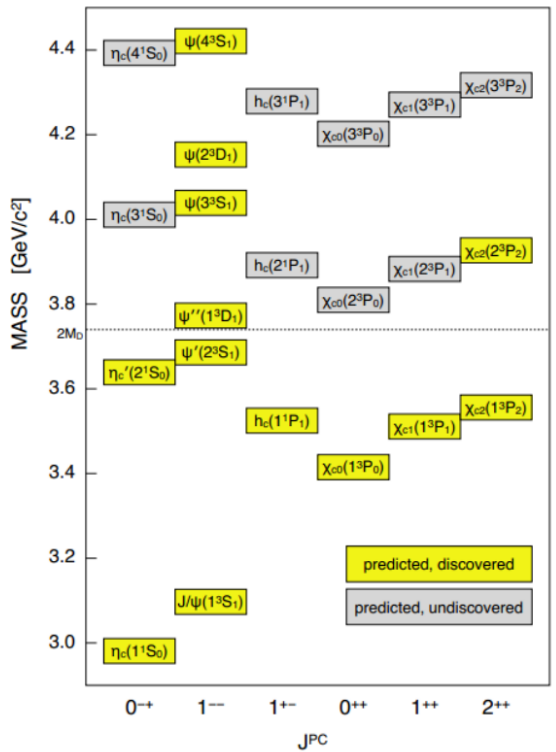
PRL 110, 252001 (2013)

Exotics...(XYZ)

November Revolution in 1974

J/ψ discovery → Charmonium family

2003 situation



PRD 72, 054026 (2005)

Exotics...(XYZ)

November Revolution in 1974

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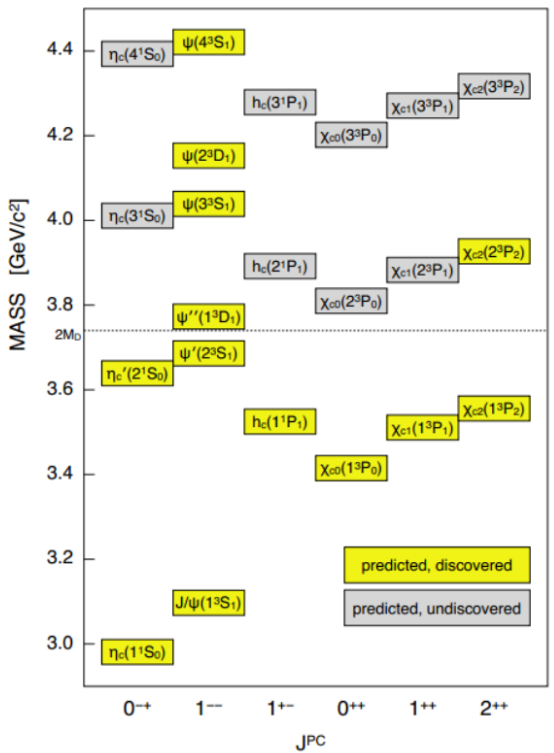
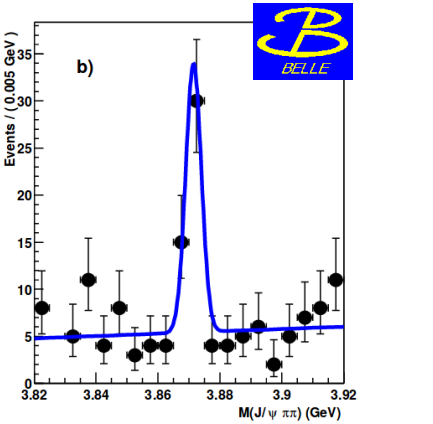


PRD 72, 054026 (2005)



PRL 91, 262001 (2003)

Structure in $B^+ \to K\pi\pi J/\psi$

Exotics...(XYZ)

November Revolution in 1974

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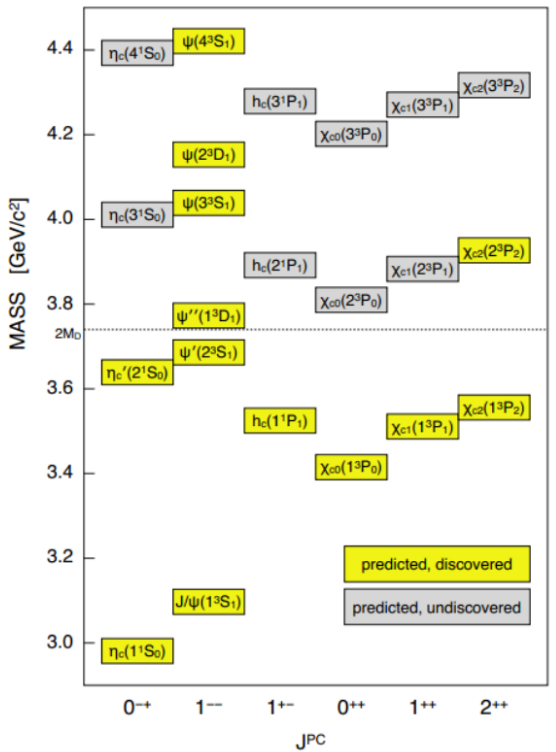
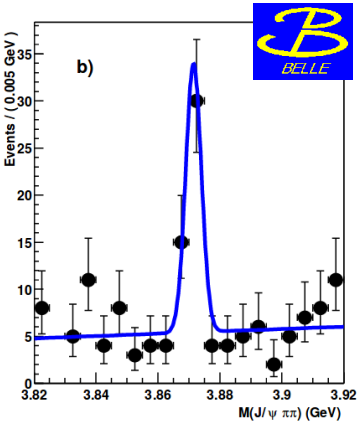


PRD 72, 054026 (2005)



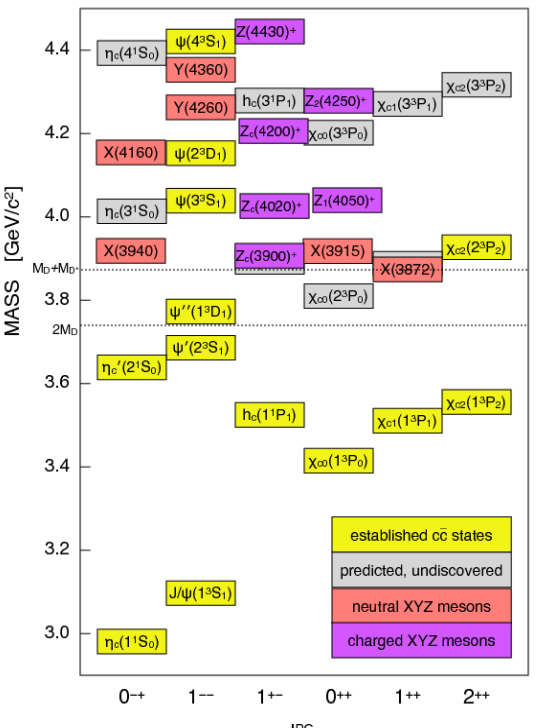
PRL 91, 262001 (2003)

Structure in $B^+ \to K\pi\pi J/\psi$

A new revolution above

open charm threshold

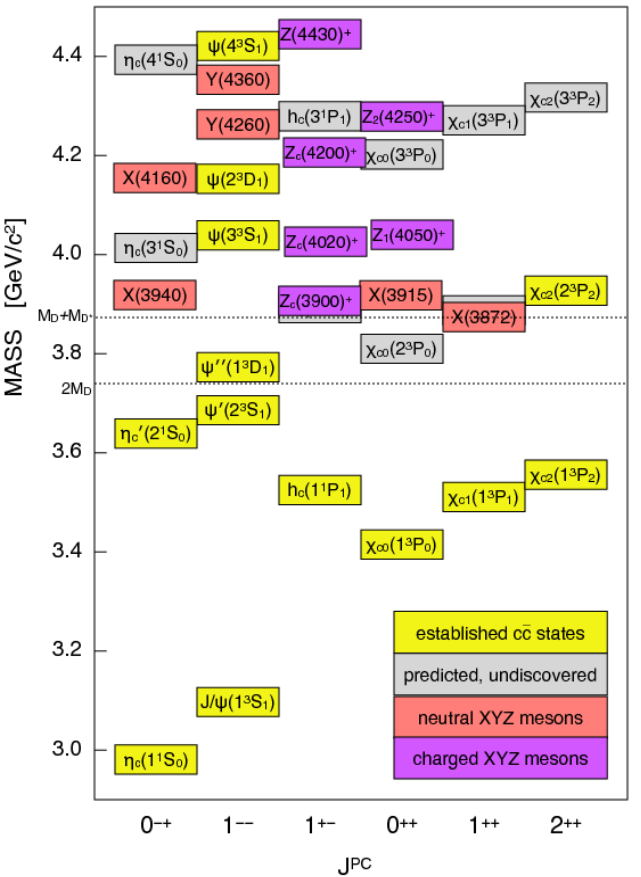
Status in 2016



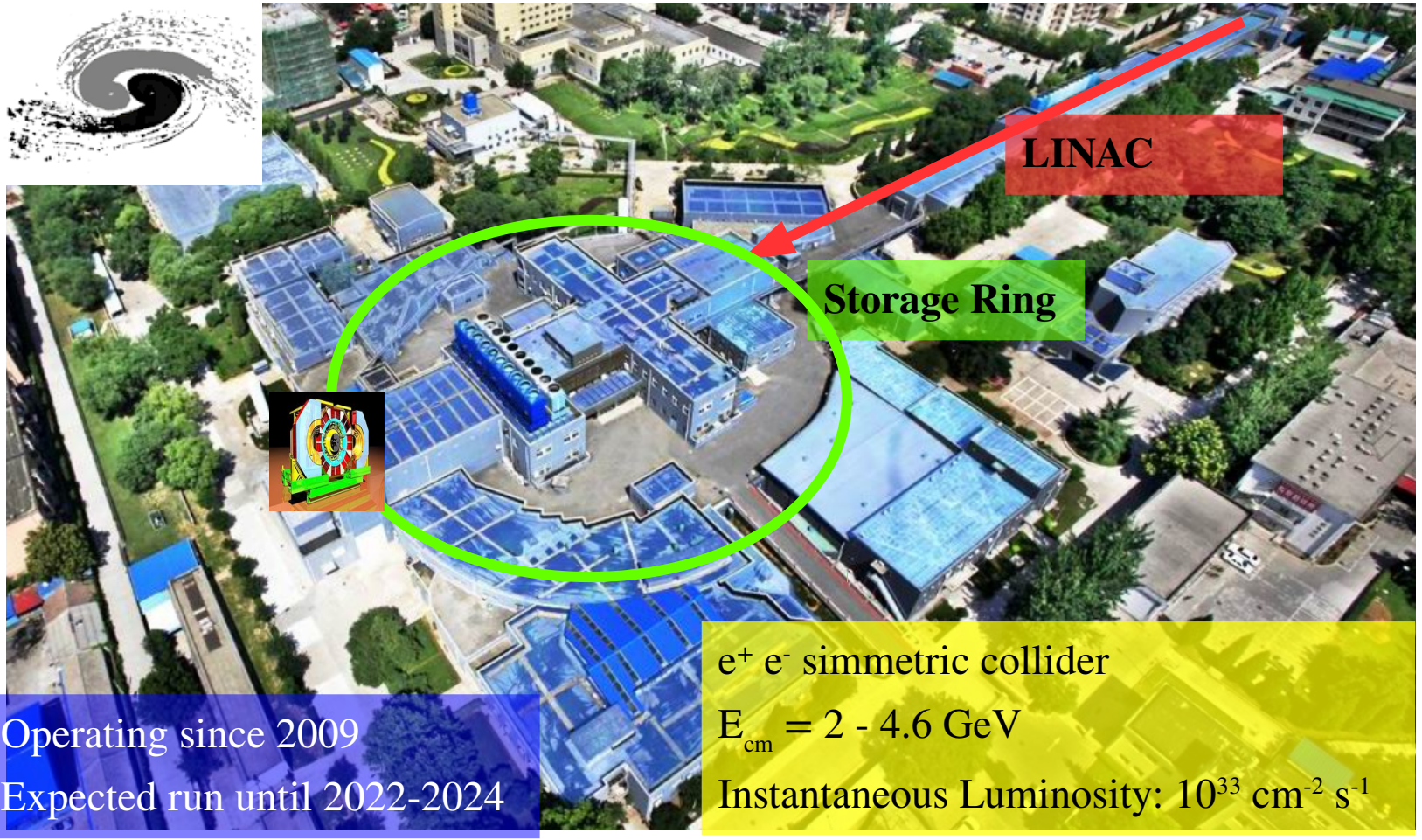
S. Olsen: PoS Bormio 050 (2015)

XYZ states

- X states:
  - Neutral, $J^{PC} \neq 1^{--}$
  - X(3872) (PRL 91, 262001 2003),X(3940) (PRL 98, 082001, 2007)
- Y states:
  - Neutral $J^{PC} = 1^{--}$
  - Y(4260) (PRD 86, 051102, 2012) , Y(4360) (PRD 91,112007, 2015)
- Z states:
  - Charged, isospin triplet
  - Z(3900) (PRL 110, 252001, 2013), Z(4020) (PRL 111, 242001 (2013)), Z(4430) (PRL 100, 142001, 2008)



BESIII and BEPCII



Operating since 2009

Expected run until 2022-2024

e^+ e^- simmetric collider

E_{cm} = 2 - 4.6 GeV

Instantaneous Luminosity: 10^{33} cm^{-2} s^{-1}

BESIII and BEPCII

TOF:

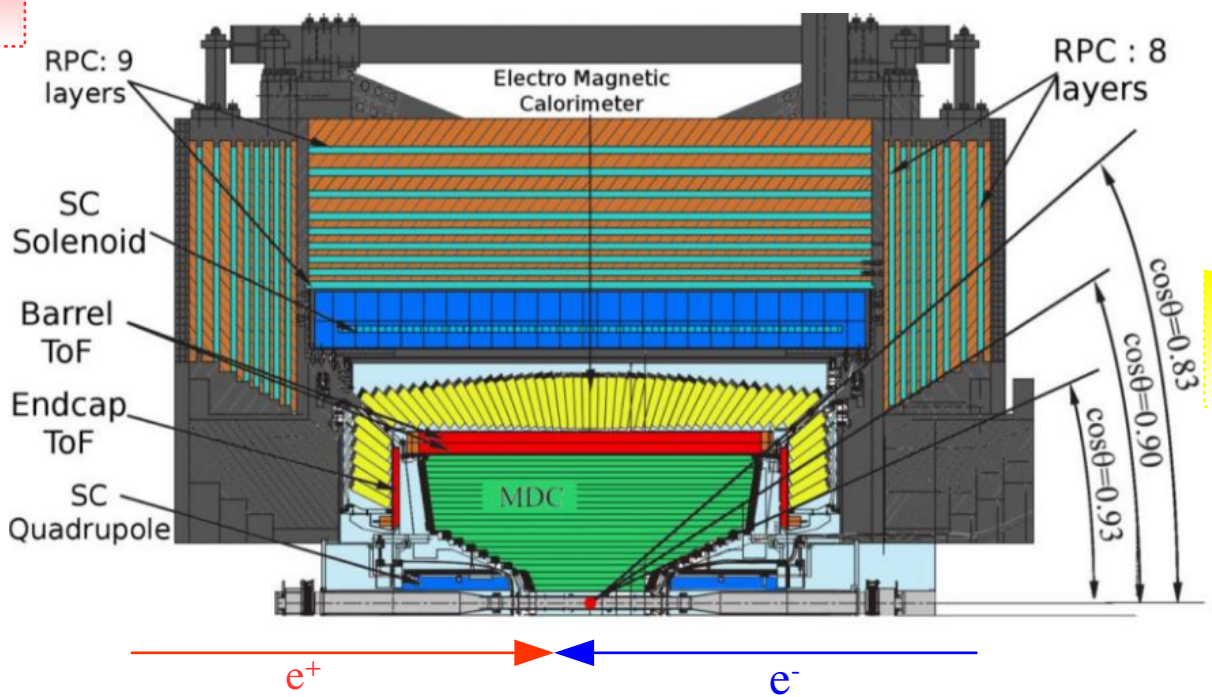
σ_t (barrel) = 90 ps

σ_t (endcap) = 110 ps

1 Tesla Magnetic field

RPCs:

$\delta_{r\phi}$ = 1.4 cm – 1.7 cm



ECAL:

dE/$\sqrt{E}$ (1 GeV) = 2.5 %

MDC:

σ_x (1 GeV/c) ~ 130 um

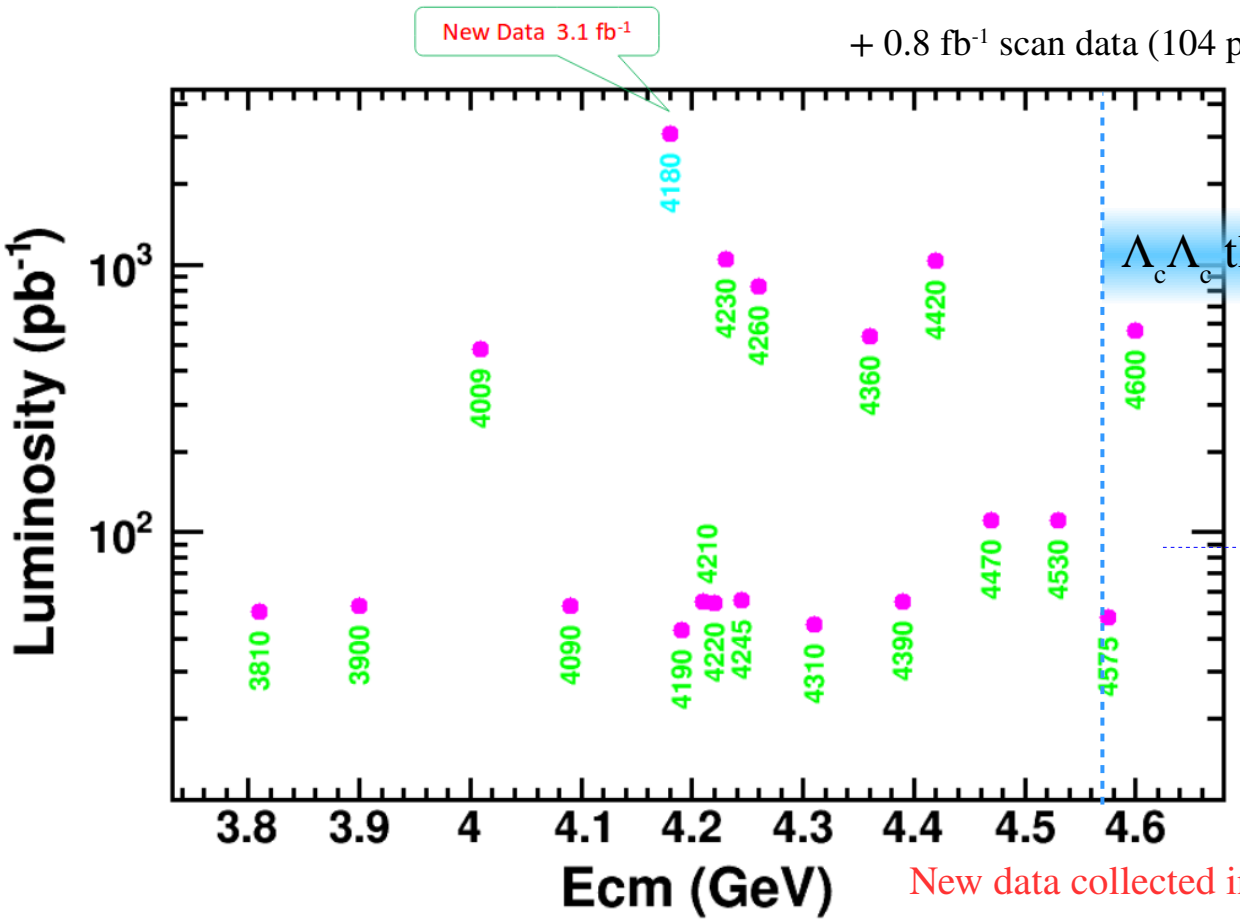
dp/p (1 GeV/c) = 0.5 %

Selected results in the charmonium region

BESIII dataset in charmonium region

BESIII can access XYZ via:

- Direct production of 1^{--} states
- Decay chain



4600 MeV represent also machine limit

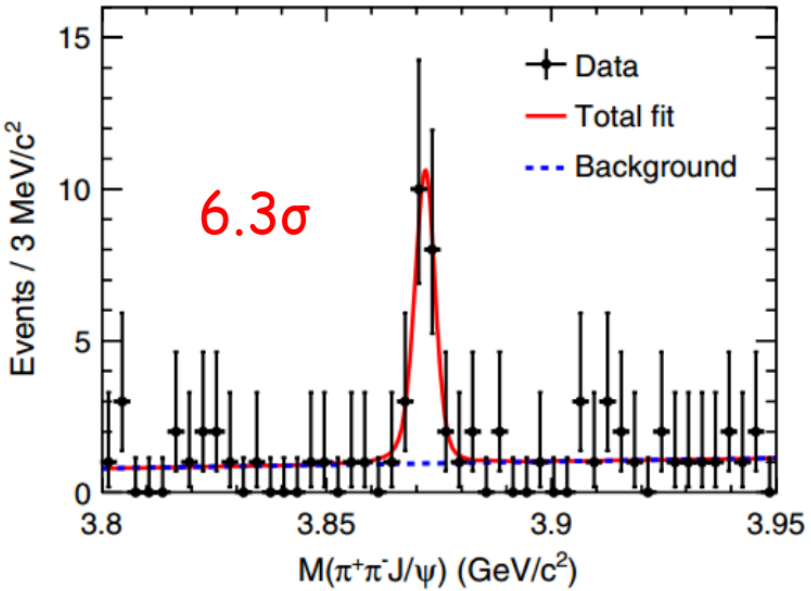
Plan to upgrade to reach Y(4660)

New data collected in 2017 data taking

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

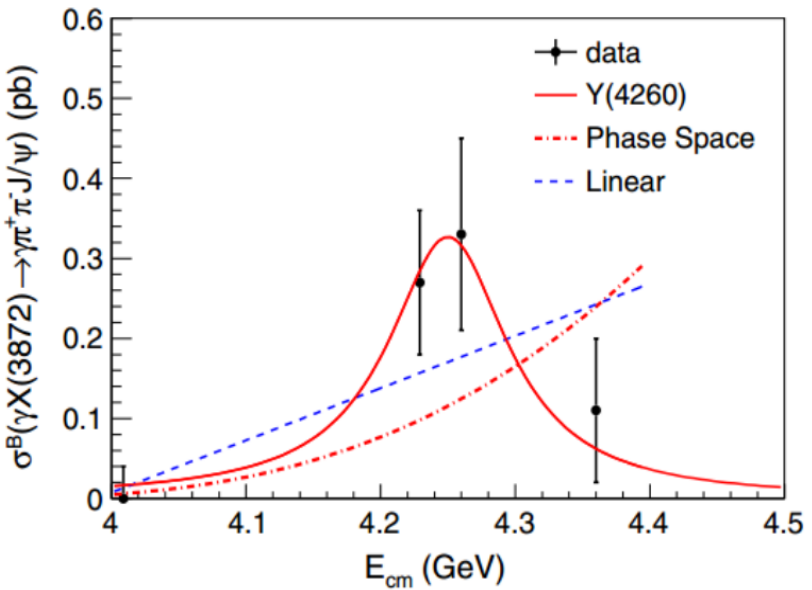
Observed by BESIII: PRL 112 092001 (2014)

Narrow 1^{++} state close to D^0D^{0*} threshold



Mass: (3871 ± 0.7 ± 0.2) MeV/c²

Compatible with BELLE data

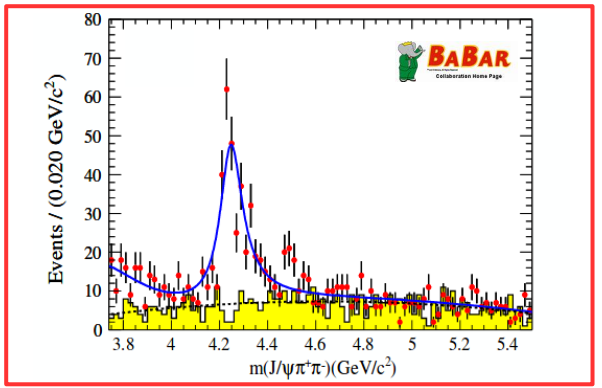


Cross section studies shows a suggestion of

Y(4260) → γX(3872)

Y(4260) lineshape measurement

PRD 86, 051102 (2012)

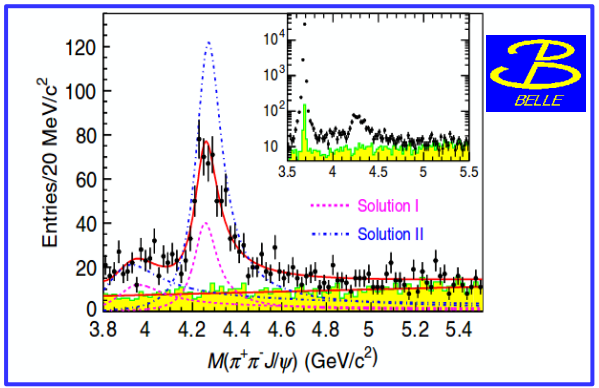


Results with ISR

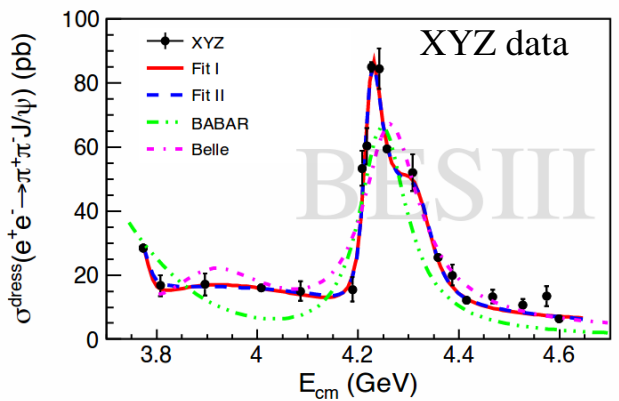
BaBar

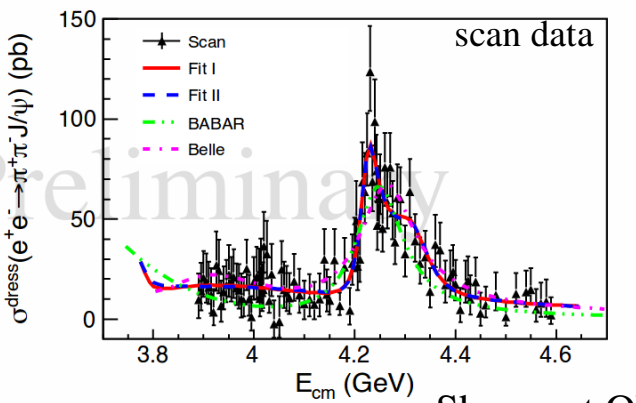
Belle

PRL 110, 252002 (2013)



BESIII direct measurements





The cross section is inconsistent with a single peak for the Y(4260)

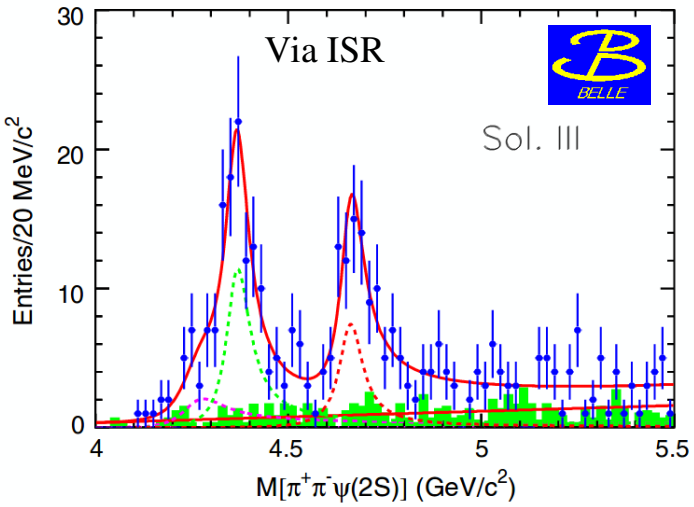
Shown at QWG2016

Submitted to PRL

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

Search for charmonium-like structures following the classical charmonium picture

PRD 91, 112007 (2015)

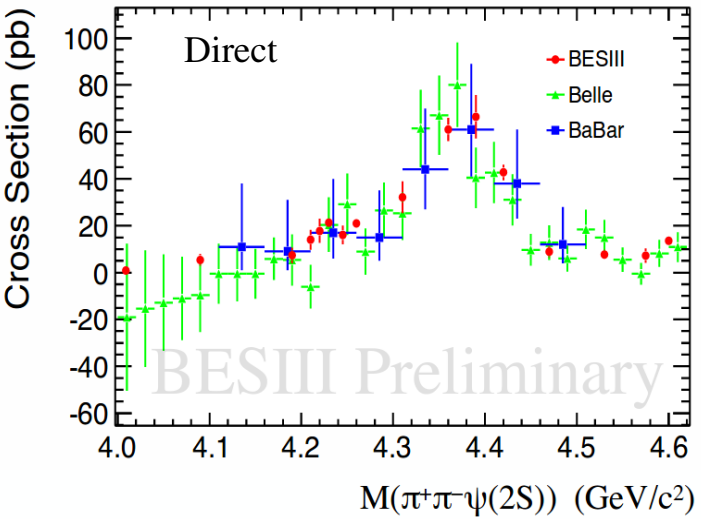


No evidence of Y(4260)

Clear structure

Y(4360) - Y(4660)

Shown at QWG2016



BESIII confirms the Y(4360) lineshape

$Z_c(3900)$

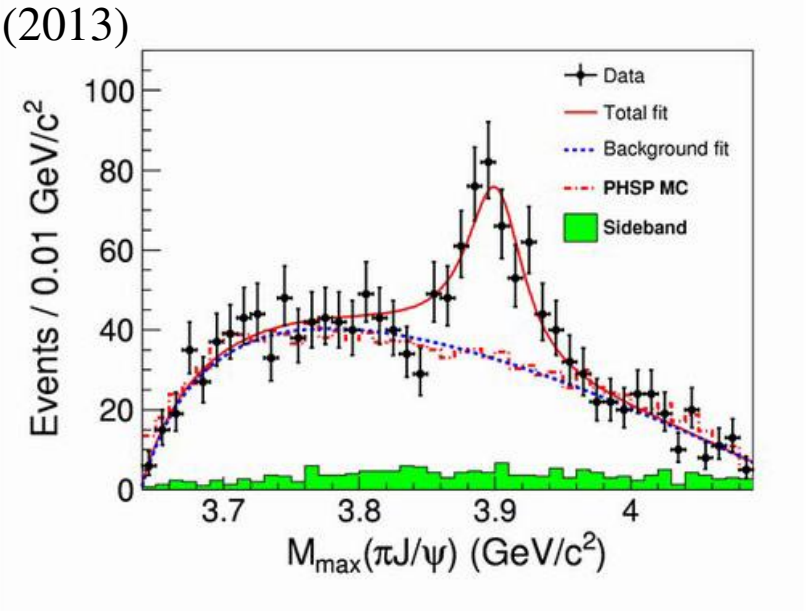
Discovered by BESIII in

$\pi J/\psi$ invariant mass in $e^+e^- \to \pi\pi J/\psi$ studies

PRL 110, 252001 (2013)

Charged charmonium-like structure

- Decays in $J/\psi \to$ must have a $c\bar{c}$ component
- Eletrically charged $\to$ contains a ud



$\sigma[e^+e^- \to \pi^+\pi^- J/\psi\,] = (62.9 \pm 1.9 \pm 3.7)$ pb @4.26 GeV

$$\frac{\sigma[e^+e^- \to \pi^\pm Zc(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi\,]} = (21.5 \pm 3.3 \pm 7.5)\%$$

$m = (3899.0 \pm 3.6 \pm 4.9)$ MeV/c²

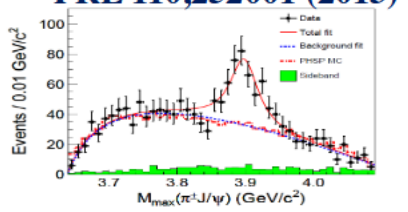
$\Gamma = (46 \pm 10 \pm 20)$ MeV

Later confirmed by Belle and CLEO-c

BESIII Z_c status

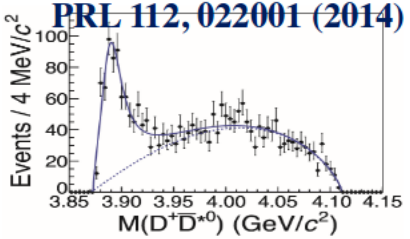
Summary of the Z observed at BESIII

PRL 110,252001 (2013)



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

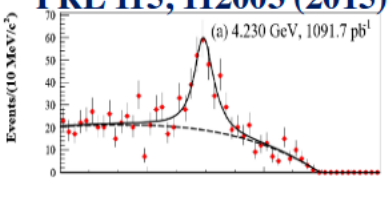
PRL 112, 022001 (2014)



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

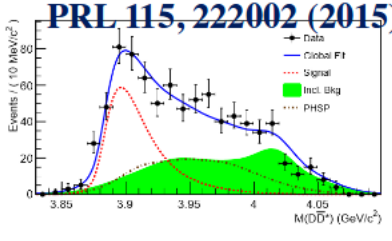
$Z_c(3900)^{\pm}$?

PRL 115, 112003 (2015)



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

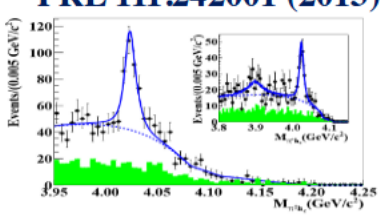
PRL 115, 222002 (2015)



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

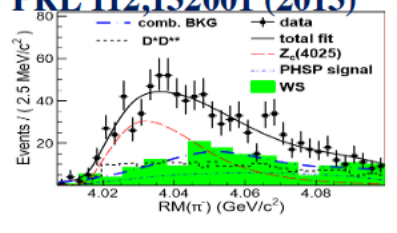
$Z_c(3900)^0$?

PRL 111.242001 (2013)



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

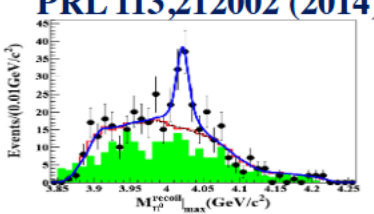
PRL 112,132001 (2013)



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

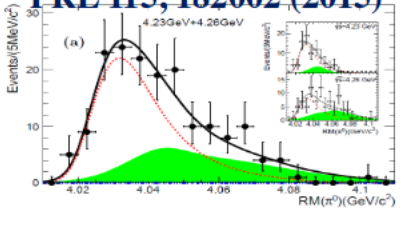
$Z_c(4020)^{\pm}$?

PRL 113,212002 (2014)



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

PRL 115, 182002 (2015)



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

$Z_c(4020)^0$?

Each of them seems to have a $D^{(*)}D^*$ counterpart → indication of nature of Z states?

X(1835): exotic in light hadron spectrum

X(1835)/X($p\bar{p}$)

X(1835)

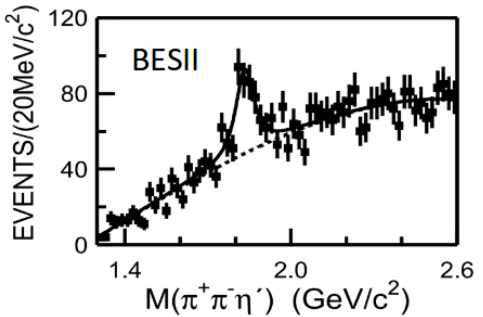
Discovered by BESII

in $J/\psi \to \gamma\eta'\pi^+\pi^-$

$M = 1836.5 \pm 3.0^{+5.6}_{-2.1}$ MeV/c^2

$\Gamma = 190 \pm 9^{+38}_{-36}$ MeV/c^2

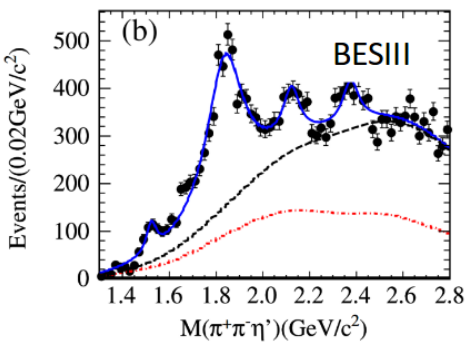
PRL 95, 262001 (2005)



Confirmed by BESIII in

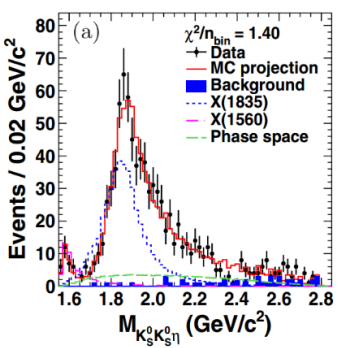
$J/\psi \to \gamma\eta'\pi^+\pi^-$

PRL 106, 072002 (2011)



$J/\psi \to \gamma\eta K_s K_s$

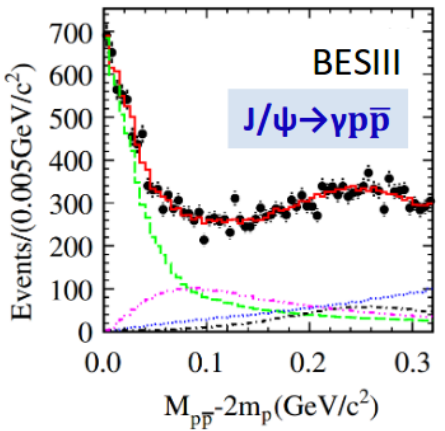
PRL 115, 091803 (2015)



J^{pc} compatible with 0^{-+}

X($p\bar{p}$)

PRL 91, 022001 (2003)



$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/c^2

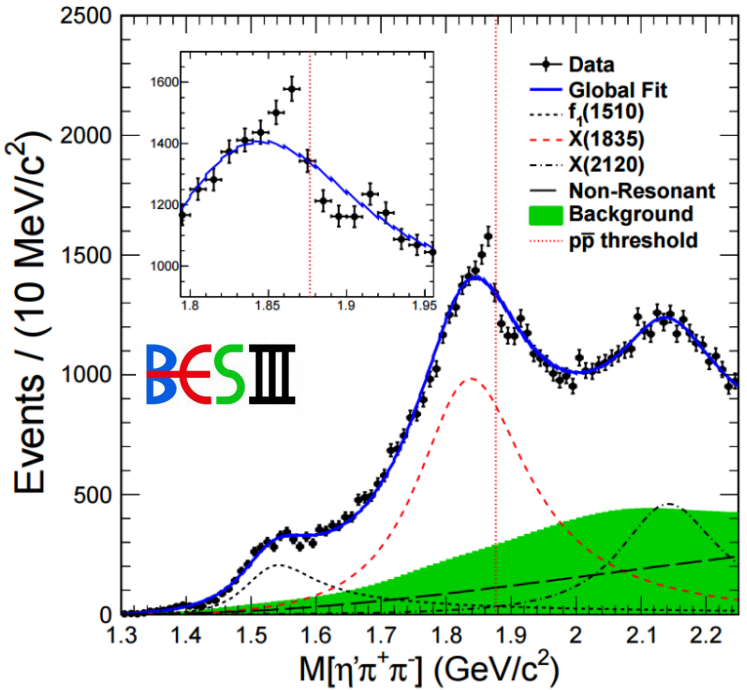
$\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c^2 @ 90% C.L.)

- Discovered by BESII in $J/\psi \to \gamma p\bar{p}$
- Confirmed by BESIII $\to \gamma p\bar{p}$
  - Determined $J^{pc} = 0^{-+}$

X(1835)/X($p\bar{p}$) lineshape

Recently performed a study of the lineshape of $\eta'\pi\pi$ near the $p\bar{p}$ mass threshold

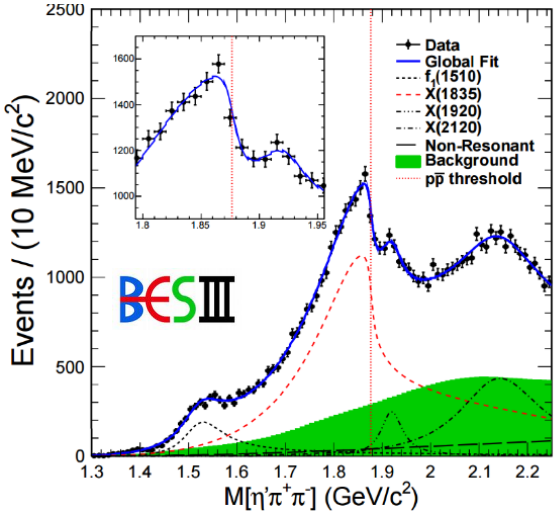
PRL 117, 042002 (2016)



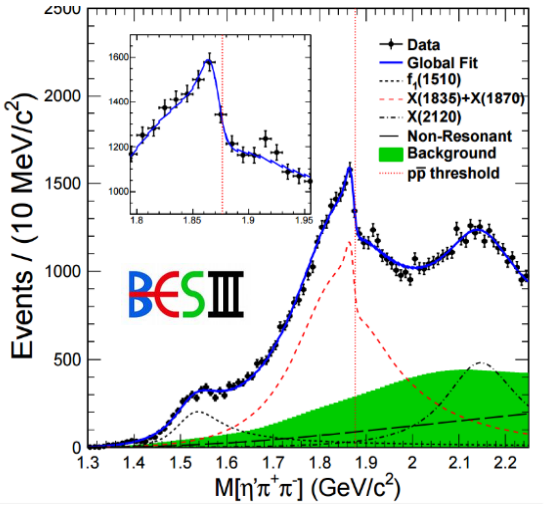
- Simultaneous fit of two η' decay modes
- Simple Breit-Wigner description fails to fit the lineshape

X(1835)/X($p\bar{p}$) lineshape

Two equally good solutions can solve anomaly



PRL 117, 042002 (2016)



Flatté formula

$$T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}$$

- $\sum_k g_k^2 \rho_k \simeq g_0^2(\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2}\rho_{p\bar{p}})$
- $g_{p\bar{p}}^2/g_0^2$ is the ratio between the coupling strength to the p$\bar{p}$ channel and the summation of all other channels

Significance of $g_{p\bar{p}}^2/g_0^2$ being non-zero is larger than 7σ

Coherent sum of 2 BW

$$T = \frac{\sqrt{\rho_{out}}}{M_1^2 - s - iM_1\Gamma_1} + \frac{\beta \cdot e^{i\theta} \cdot \sqrt{\rho_{out}}}{M_2^2 - s - iM_2\Gamma_2}$$

X(1835) X(1870)

Significance of narrow X(1870) is larger than 7σ

Outlook

- BESIII operates successfully from 2009
  - Many interesting results from a very broad physics program in τ-charm region
  - In 2016 BEPCII reached the world record luminosity for machine in this energy regime

- XYZ program in charmonium started in 2012
  - Unique opportunity to produce and study XYZ states
  - A new dedicated data taking is taking place in this year.

- X(1835)/X($p\bar{p}$) represent exotic in light hadron spectra
  - Interesting nature of those states would require a larger data samples

- Don't miss Zhen Gao's talk on results of $e^+e^- \to K^+K^-$ measurements!

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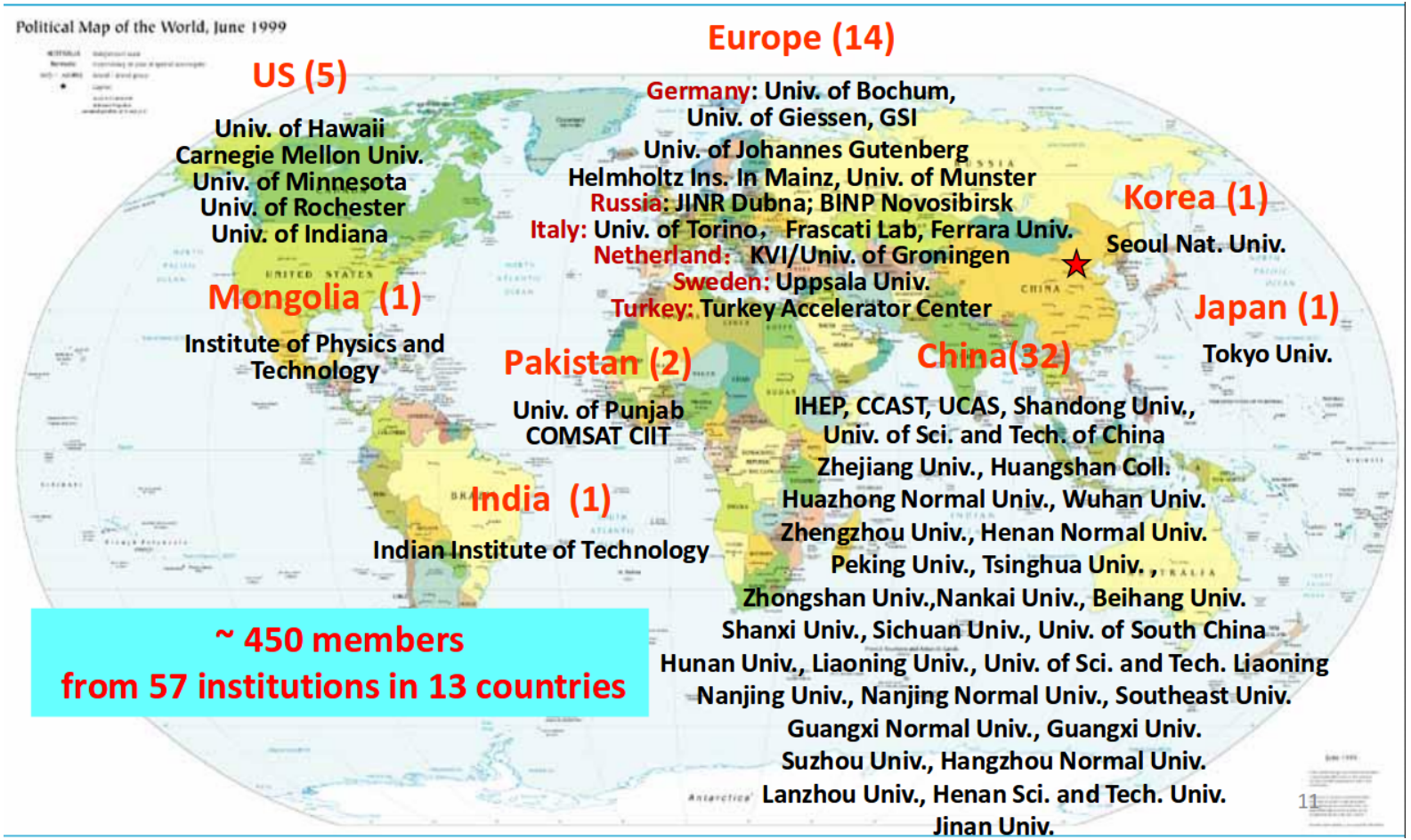
Additional Material

BESIII Collaboration



BESIII Collaboration

On exotic nature of XYZ states

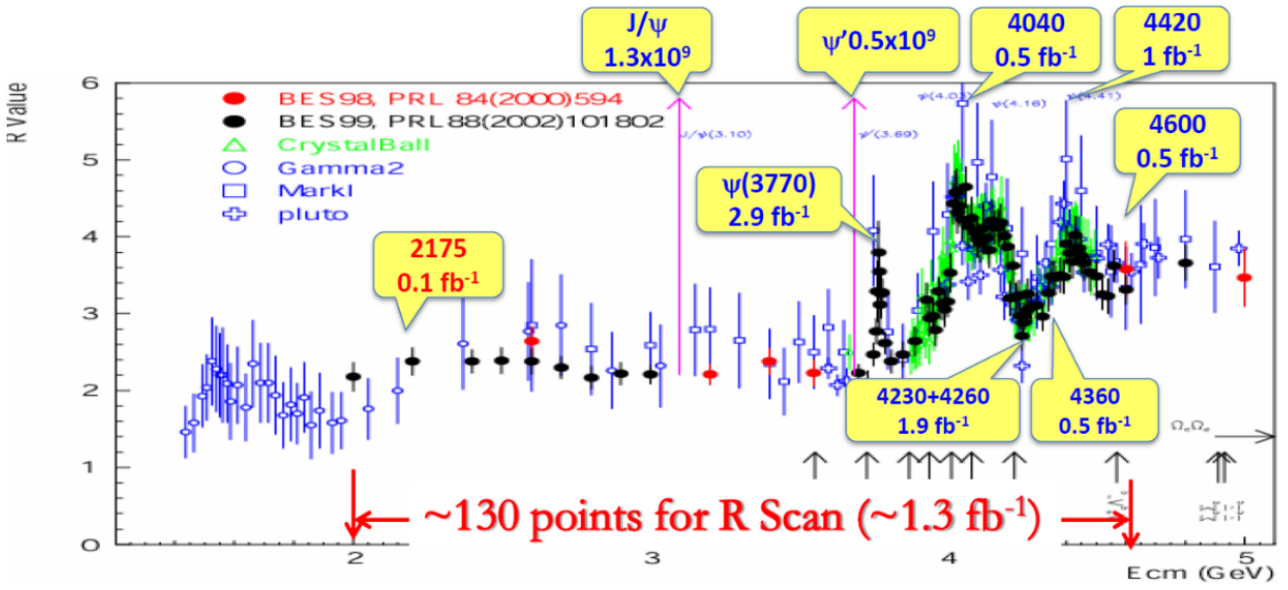
Underlying naive logic on defining those states:

- X: extremely narrow resonances that decay in charmonia above DD thresholds
- Y: produced only via ISR or directly, no other observation in decay chains
- Z: Charged charmonia

Some exceptions:

- X observed at in J/yf have larger witdh (few tenths MeV)
- Y(3940) in B decay at BELLE (arxiv:0711.2047[hep-ex])
- Z(3930) observed in gamma gamma is now identified as chi_c2(2P)

BESIII Complete Dataset



2009: 106M ψ(2S)
225M J/ψ
2010: 975 pb^{-1} at ψ(3770)
2011: 2.9 fb^{-1} at **ψ(3770)** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **ψ(2S)** *(total)*
1.3B **J/ψ** *(total)*
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at **4.26 GeV**
540 pb^{-1} at **4.36 GeV**
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.21, 4.22, 4.245, 4.31, 4.39, 4.42 GeV**
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)
2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for **D_s**) *JUST COMPLETED*
*2017: ~10 × 500 pb^{-1} between **4.19** and **4.30 GeV***
2017 SUBJECT TO CHANGE, OF COURSE!

X(1835)/X($p\bar{p}$) lineshape

The state around 1.85 GeV/c^2	
$\mathcal{M}$ (MeV/c^2)	$1638.0\ ^{+121.9\ +127.8}_{-121.9\ -254.3}$
g_0^2 ((GeV/c^2)^2)	$93.7\ ^{+35.4\ +47.6}_{-35.4\ -43.9}$
$\mathbf{g^2_{p\bar{p}}/g^2_0}$	$\mathbf{2.31\ ^{+0.37\ +0.83}_{-0.37\ -0.60}}$
$\mathbf{M_{pole}}$ **(MeV/c^2) ***	$\mathbf{1909.5\ ^{+15.9\ +9.4}_{-15.9\ -27.5}}$
$\mathbf{\Gamma_{pole}}$ **(MeV/c^2) ***	$\mathbf{273.5\ ^{+21.4\ +6.1}_{-21.4\ -64.0}}$
Branching Ratio	$(3.93\ ^{+0.38\ +0.31}_{-0.38\ -0.84}) \times 10^{-4}$

* The pole nearest to the $p\bar{p}$ mass threshold

X(1835)	
M (MeV/c^2)	$1825.3\ ^{+2.4\ +17.3}_{-2.4\ -2.4}$
Γ (MeV/c^2)	$245.2\ ^{+14.2\ +4.6}_{-12.6\ -9.6}$
B.R. (constructive interference)	$(3.01\ ^{+0.17\ +0.26}_{-0.17\ -0.28}) \times 10^{-4}$
B.R. (destructive interference)	$(3.72\ ^{+0.21\ +0.18}_{-0.21\ -0.35}) \times 10^{-4}$
X(1870)	
M (MeV/c^2)	$\mathbf{1870.2\ ^{+2.2\ +2.3}_{-2.3\ -0.7}}$
Γ (MeV/c^2)	$\mathbf{13.0\ ^{+7.1\ +2.1}_{-5.5\ -3.8}}$
B.R. (constructive interference)	$(2.03\ ^{+0.12\ +0.43}_{-0.12\ -0.70}) \times 10^{-7}$
B.R. (destructive interference)	$(1.57\ ^{+0.09\ +0.49}_{-0.09\ -0.86}) \times 10^{-5}$