BESIII: New results and upgrades

Xiaoyan SHEN

Institute of High Energy Physics, China

INFN-IHEP Meeting, May 16, 2014, IHEP, Beijing

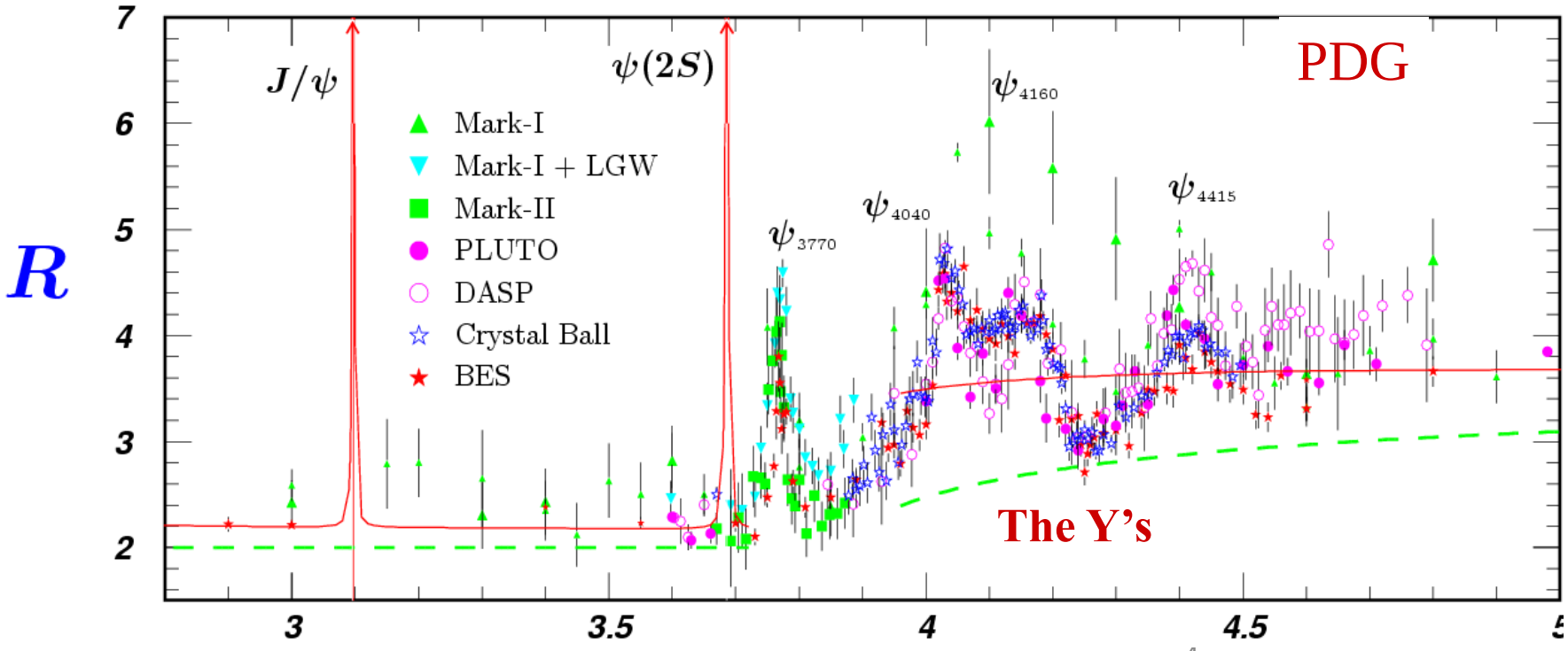
Outline

- Introduction
- Status of BESIII
- BESIII collaboration with INFN (By Marco)
- Outlook

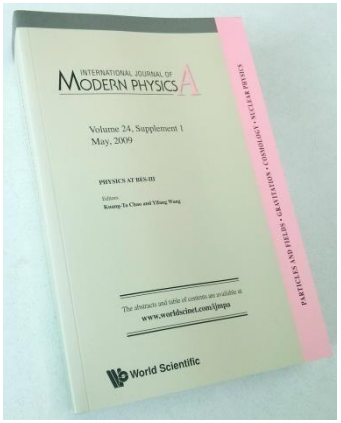
Beijing Electron Positron Collider (BEPC)

Features of the BEPC Energy Region

- Rich of resonances: charmonia and charmed mesons
- Threshold characteristics (pairs of τ, D, D_s, …)
- Transition between smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the new hadrons: glueballs, hybrids, multi-quark states



Physics Topics at BESIII



Int. J. Mod. Phys. A, Vol. 24 (2009)

- Hadron spectroscopy
  - search for the new forms of hadrons
  - meson spectroscopy
  - baryon spectroscopy
- Study of the production and decay mechanisms of charmonium states: J/ψ, $\psi(2S)$, $\eta_C(1S)$, $\chi_{C\{0,1,2\}}$, $\eta_C(2S)$, $h_C(^1P_1)$, $\psi(3770)$, etc.

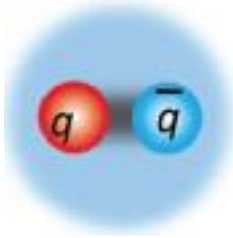
  Calibrate QCD
- Precise measurement of R values, τ mass, ...
- Precise measurement of CKM matrix
- Search for DD mixing, CP violation, etc.

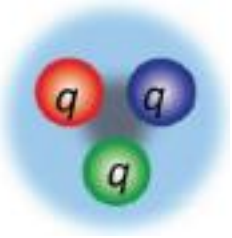
New forms of hadrons

- **Conventional hadrons consist of 2 or 3 quarks:**

Naive Quark Model:

meson

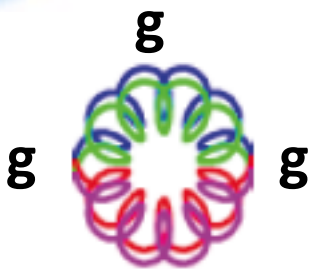


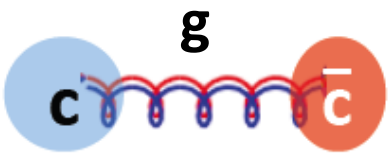


baryon

- **QCD predicts the new forms of hadrons:**
  - **Multi-quark states： Number of quarks >＝ 4**

  - **Hybrids： $q\bar{q}g$， qqqg …**
  - **Glueballs： gg， ggg …**

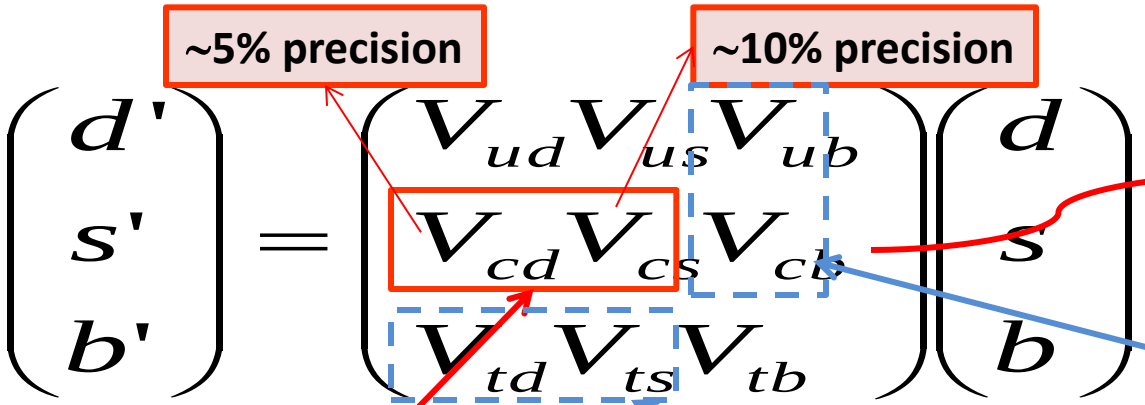




None of the new forms of hadrons is settled !

Precision measurement of CKM elements -- Test EW theory

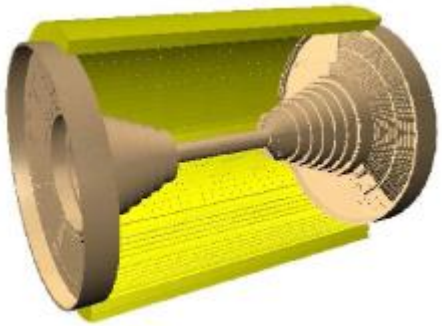
CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.



Precision measurement of CKM matrix elements
-- a precise test of SM model
New physics beyond SM?

BESIII Detector

MDC

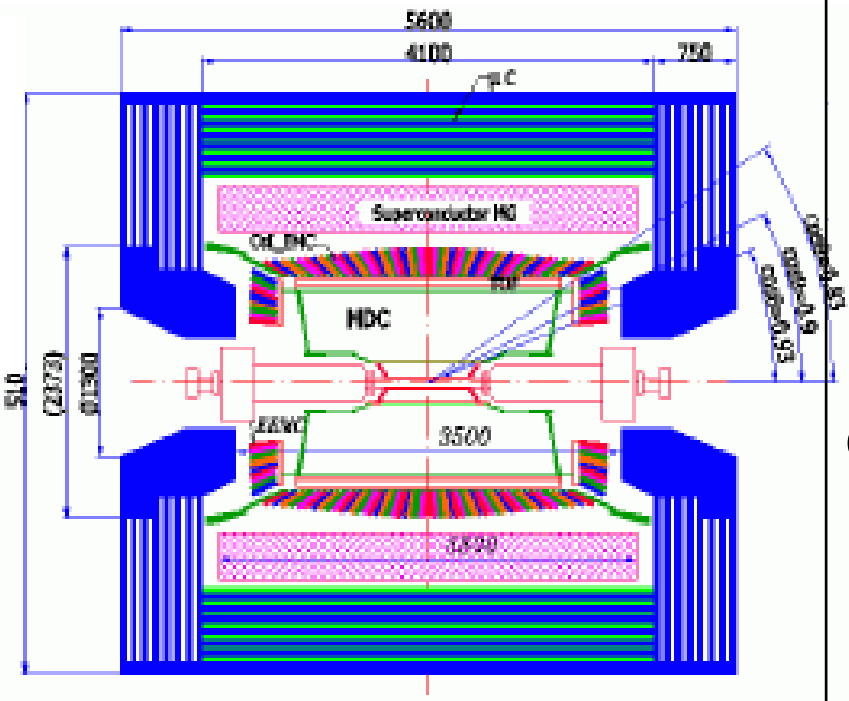


R inner: 63mm ;

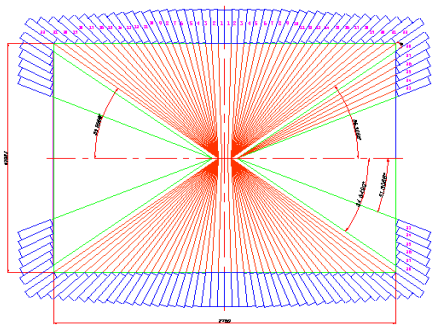
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



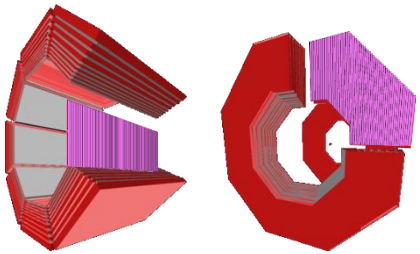
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

TOF

BTOF: two layers

ETOF: 48 crys. for each

BESIII Detector Performance

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEOc	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII (2013)	115 μm	<5% (Bhabha)	2.4%

Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII (2013)	68 ps (BTOF) 98 ps (ETOF)

MUC: Efficiency ~ 96%

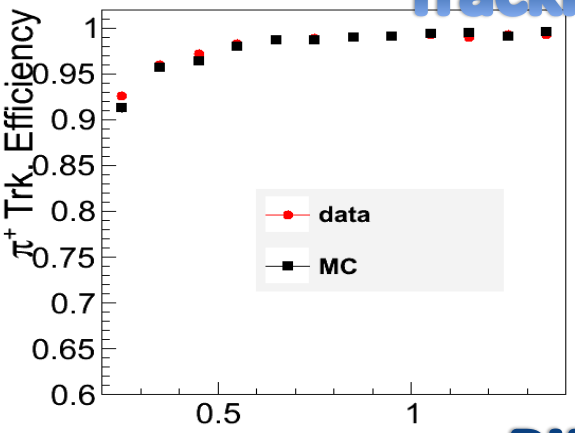
BG level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

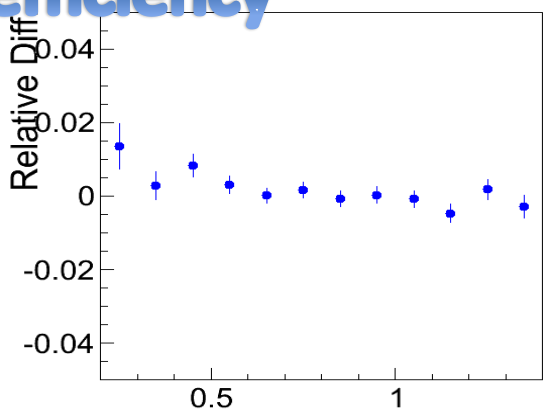
MDC: Malter effect in inner chamber, add water vapor to the chamber to cure the aging problem.

Data/Monte-Carlo Consistency

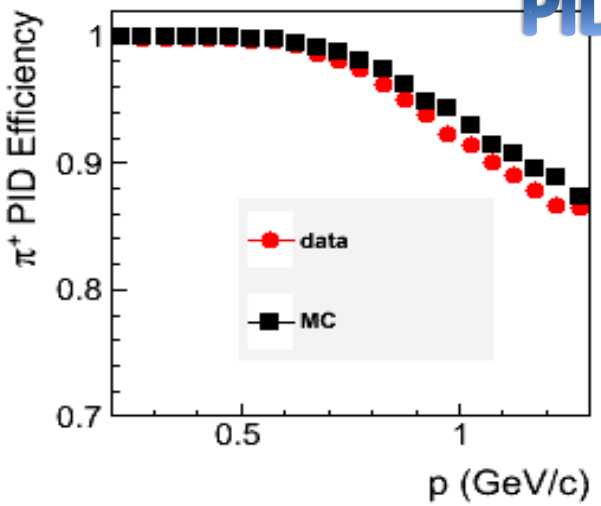
- For tracking efficiency, data/MC difference < 1%
- For particle identification efficiency, data/MC difference < 2%

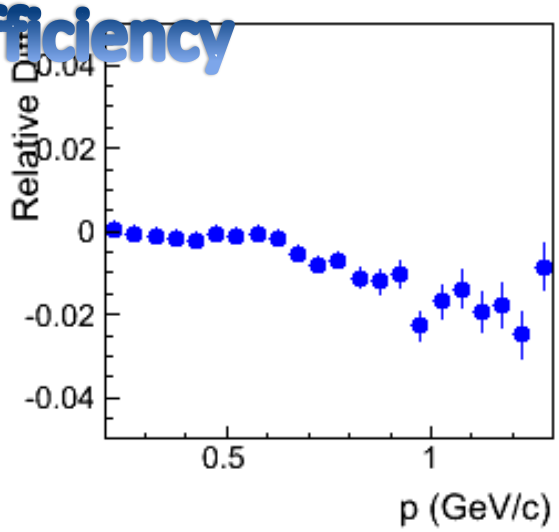
Tracking efficiency





PID efficiency





The BESIII Collaboration

US (5)

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

Europe (13)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab, Ferrara Univ.
Netherland： KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

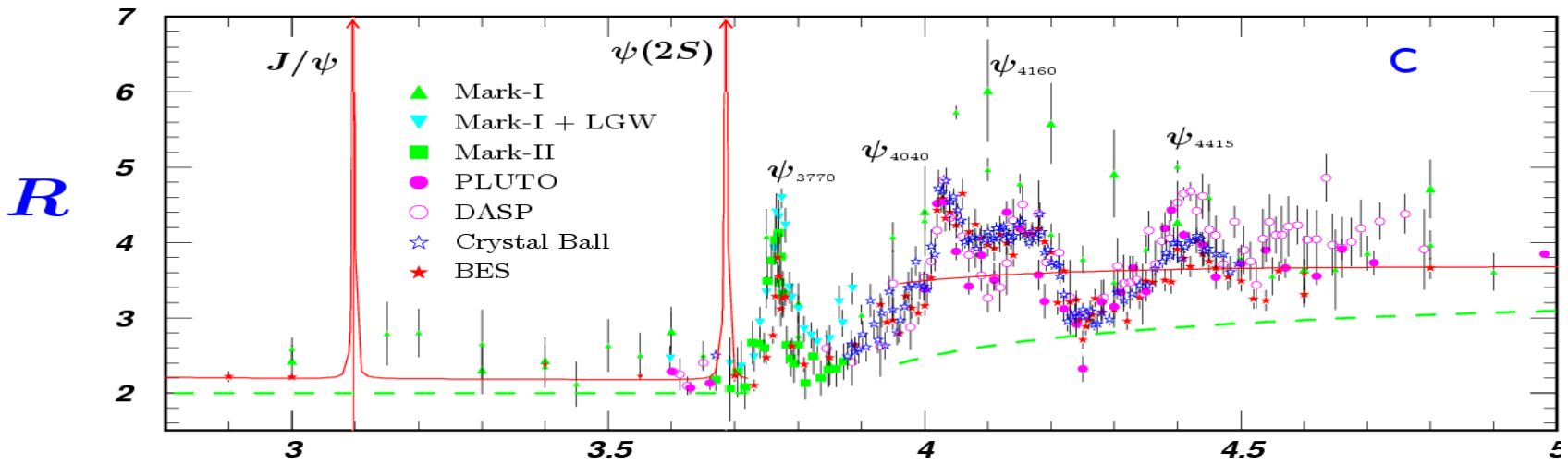
China(29)

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., Beihang 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.

~400 members
52 institutions from 11 countries

BESIII data taking status & plan

	Previous data	BESIII present & future	Goal
J/ψ	BESII 58M	1.2 B 20* BESII	10 B
ψ’	CLEO： 28 M	0.5 B 20* CLEOc	3B
ψ”	CLEO： 0.8/fb	2.9/fb 3.5*CLEOc	20 /fb
Above open charm threshold	CLEO： 0.6/fb @ ψ(4160)	0.5/fb @ ψ(4040) 2.3/fb@~4260, 0.5/fb@4360 0.5/fb@4600， 1/fb@4420	5-10 /fb
R scan & Tau	BESII	3.8-4.6 GeV at 105 energy points	



BESIII Physics Results (since 2009)

- **Papers published:**
  - 65 papers published (PRL 16, PRD 44, PLB 1, CPC 4)

    2010: 4 (PRL 2, PRD 1, CPC 1)

    2011: 11 (PRL 3, PRD 8)

    2012: 17 (PRL 5, PRD 10, PLB 1, CPC 1)

    2013: 25 (PRL 3, PRD 20, CPC 2)

    2014: 8 (PRL 3, PRD 5)

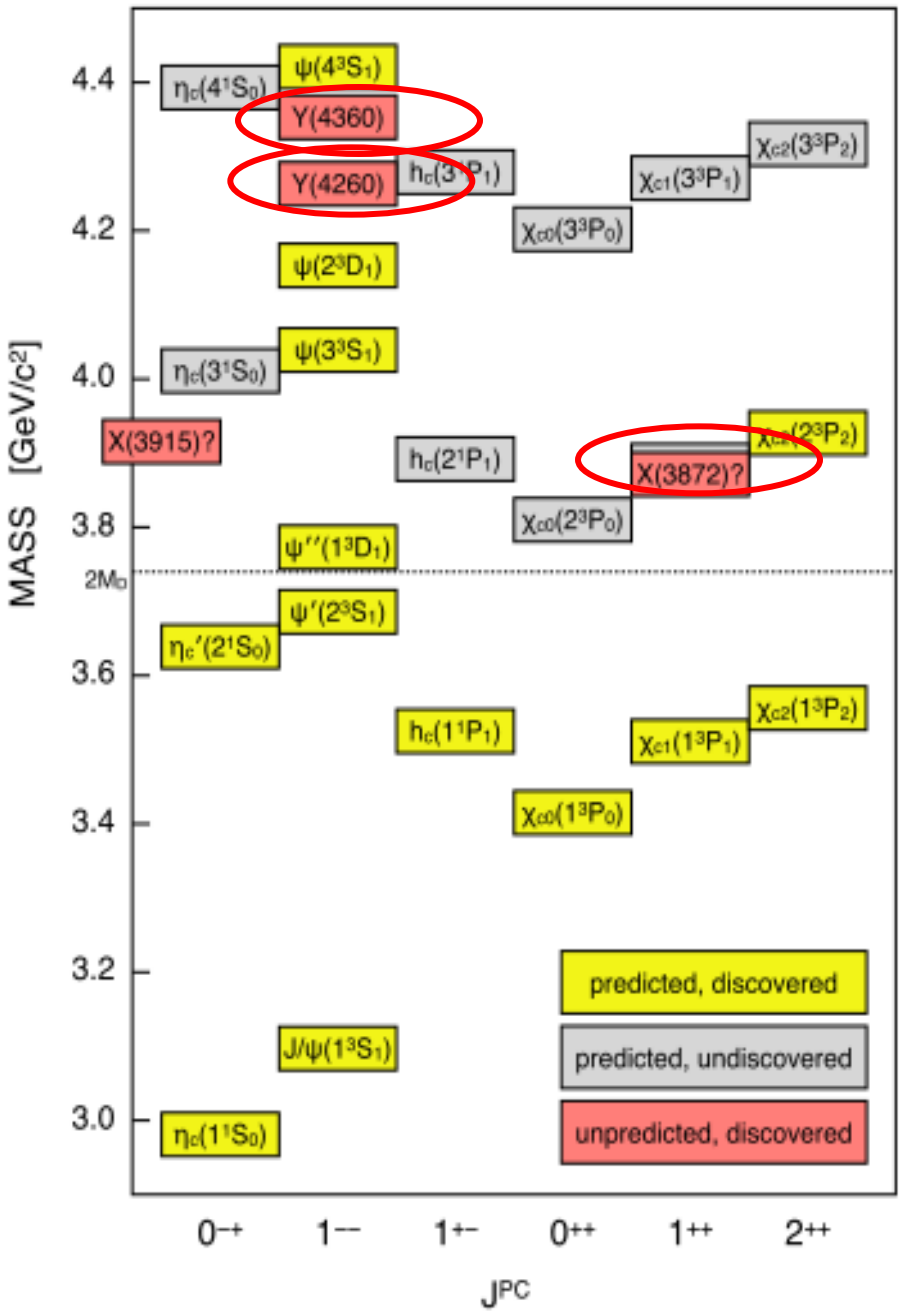
    submitted 6 (PRL 1, PLB 2, PRD 3)

- **International conference talks**

  About 50 talks at the international conferences every year.

  Among them, about half are the invited talks.

Charmonium spectroscopy



- **Below open charm threshold**

  All charmonium states observed. No surprising found.

- **Above open charm threshold:**

  ✓ **many expected states not observed**

  ✓ **many unexpected discovered**

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

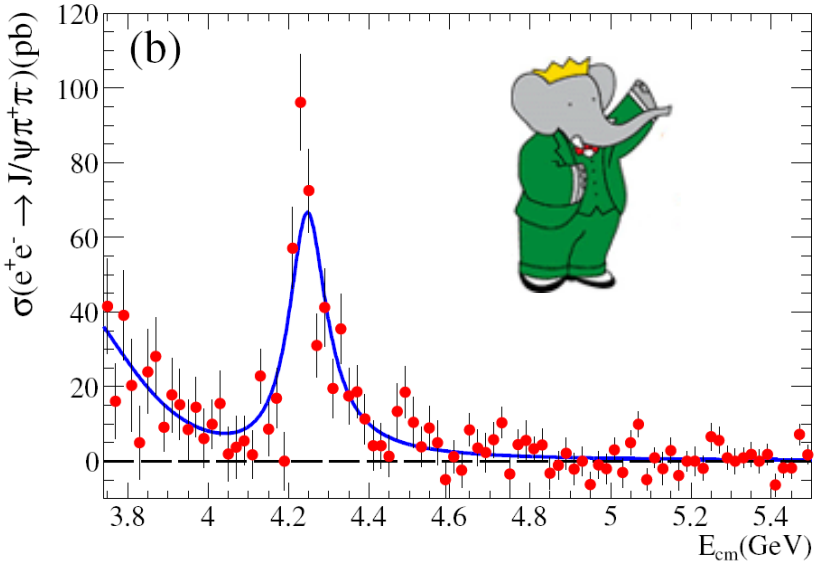
X(3872)

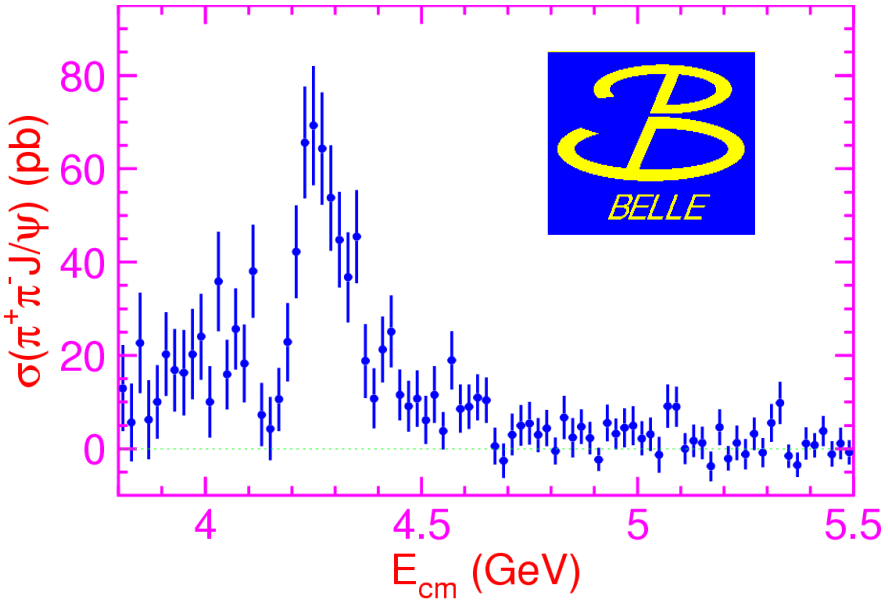
XYZ(3940)

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

About Y(4260)

- Y(4260) was first observed by BaBar in 2005.
- Confirmed by Belle at KEK.





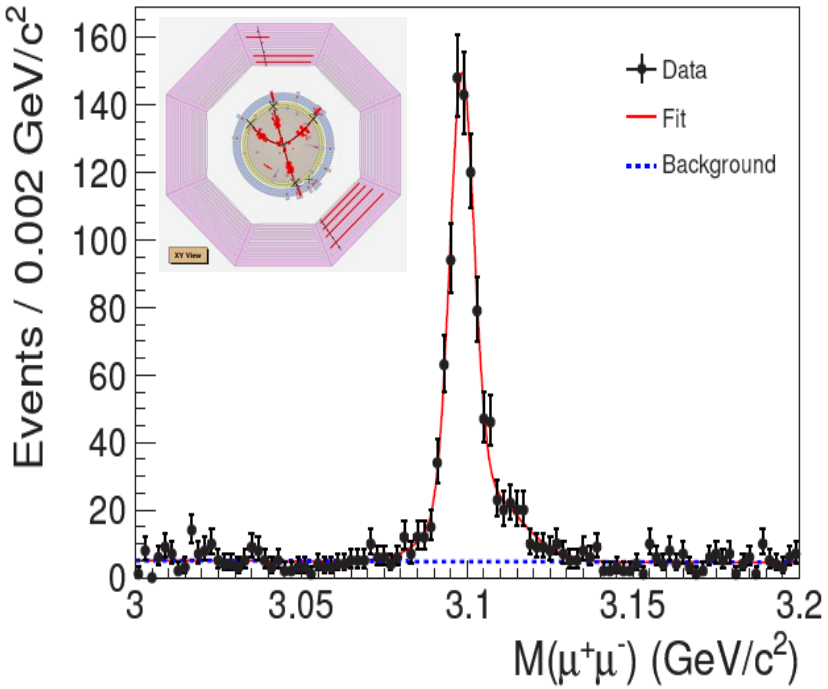
- Nature of Y(4260) not clear yet.

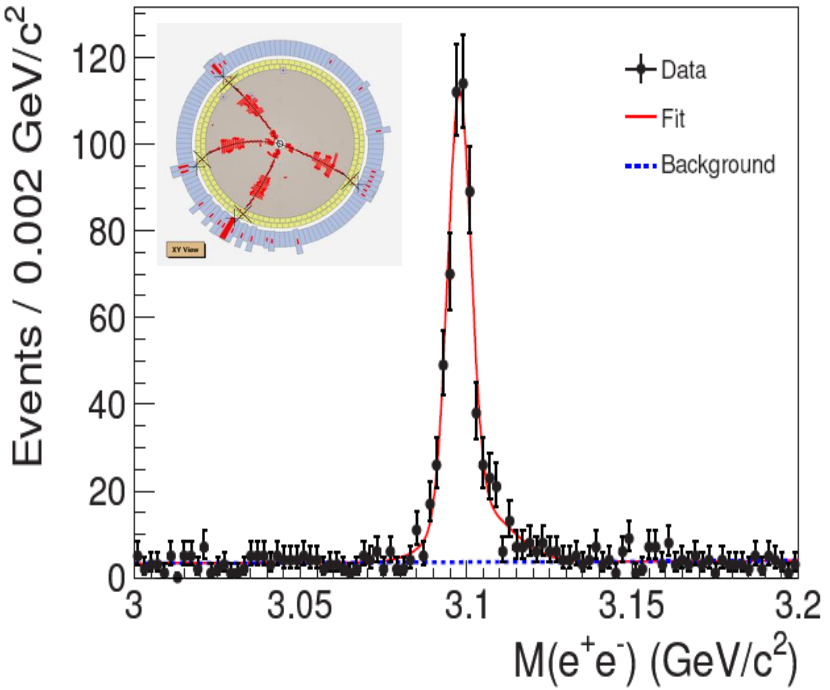
BESIII: Observation of the $Z_c(3900)$ — a charged charmonium-like structure

BESIII: PRL110, 252001 (2013)

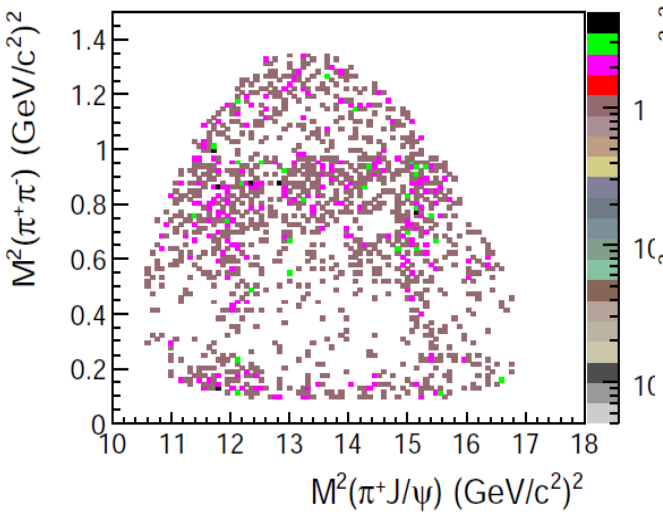
- Select $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ @ 4.26 GeV

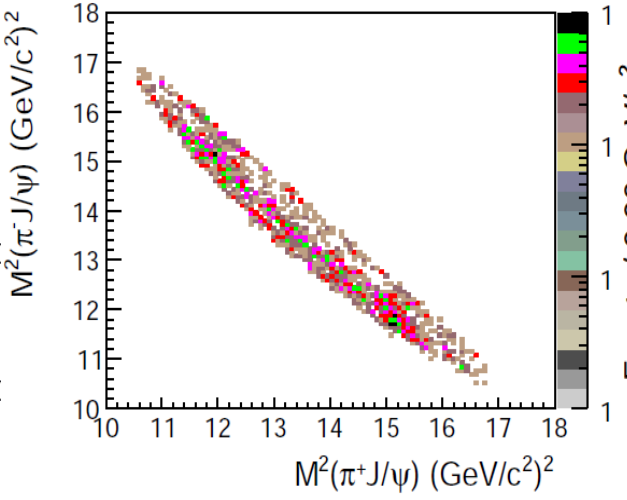
525/pb @4.26 GeV

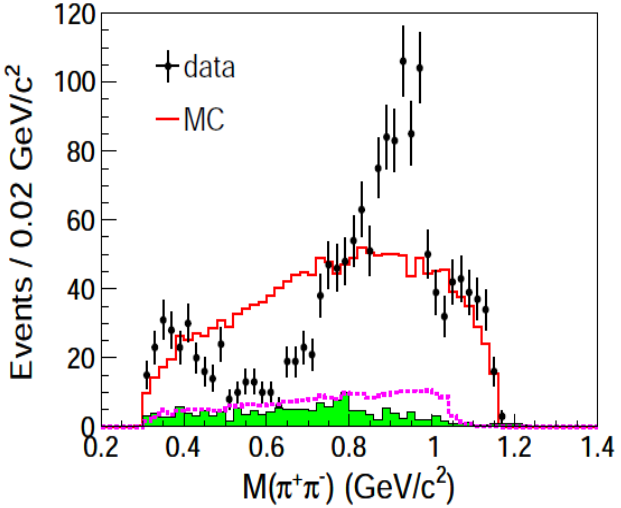


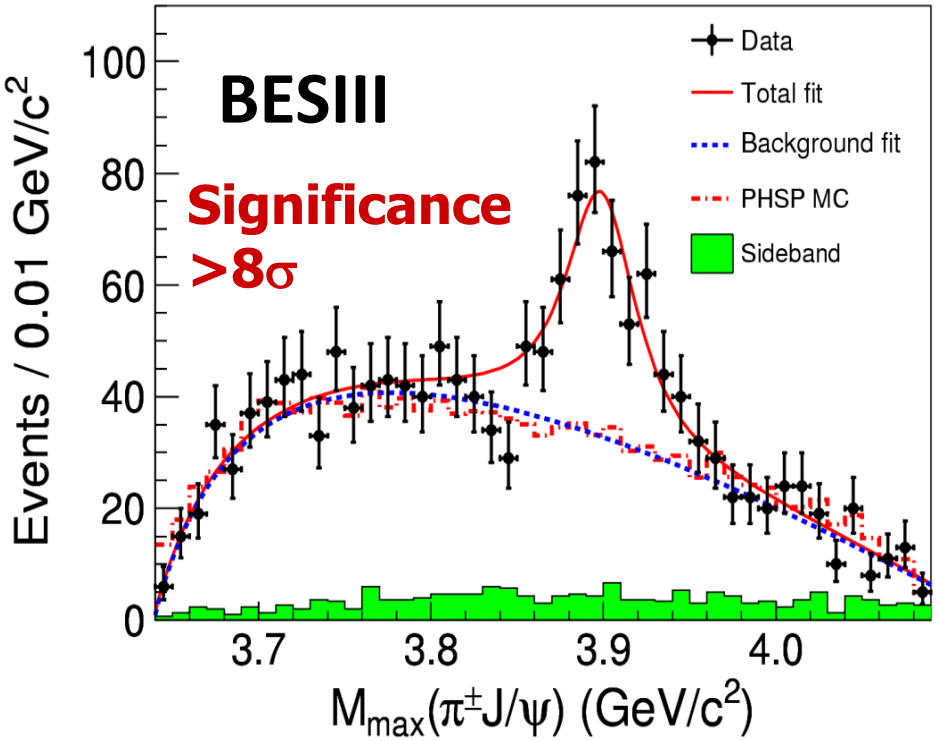


BESIII: PRL110, 252001 (2013)









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

American Physics Society (APS): 11 highlights of 2013
"Discovery of four-quark matter" on the top of 11

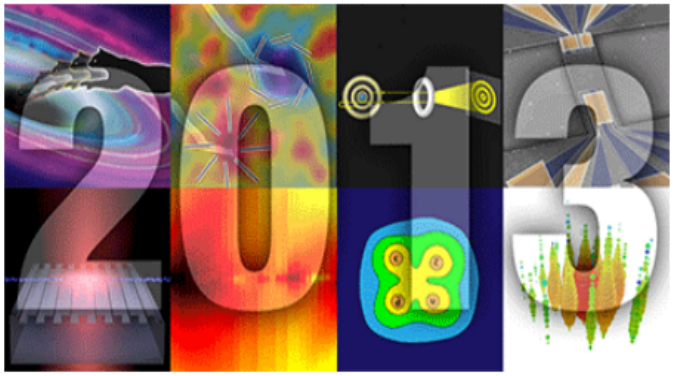
Notes from the Editors: Highlights of the Year

Published December 30, 2013 | Physics **6**, 139 (2013) | DOI: 10.1103/Physics.6.139

***Physics* looks back at the standout stories of 2013.**

As 2013 draws to a close, we look back on the research covered in *Physics* that really made waves in and beyond the physics community. In thinking about which stories to highlight, we considered a combination of factors: popularity on the website, a clear element of surprise or discovery, or signs that the work could lead to better technology. On behalf of the *Physics* staff, we wish everyone an excellent New Year.

– Matteo Rini and Jessica Thomas



Images from popular *Physics* stories in 2013.

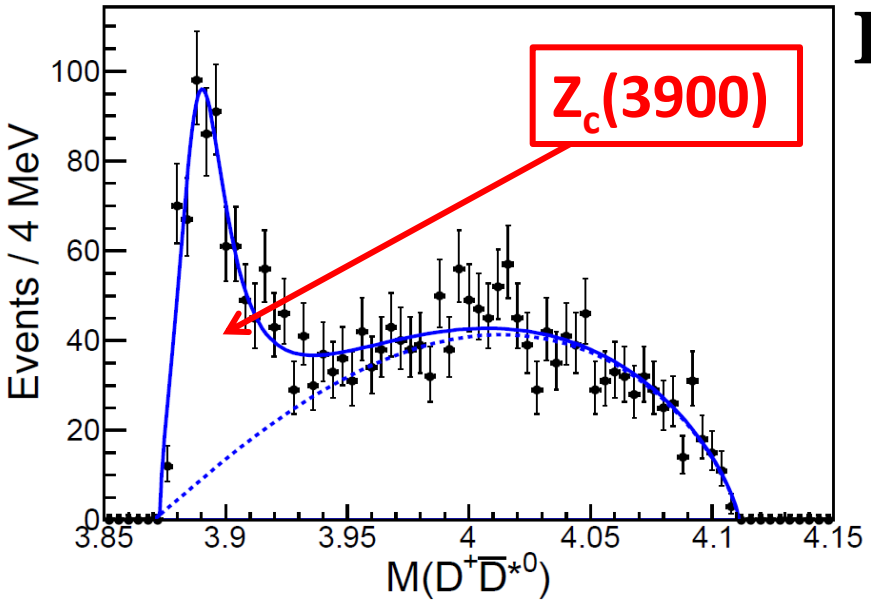
Four-Quark Matter

Quarks come in twos and threes—or so nearly every experiment has told us. This summer, the BESIII Collaboration in China and the Belle Collaboration in Japan reported they had sorted through the debris of high-energy electron-positron collisions and seen a mysterious particle that appeared to contain four quarks. Though other explanations for the nature of the particle, dubbed $Z_c(3900)$, are possible, the "tetraquark" interpretation may be gaining traction: BESIII has since seen a series of other particles that appear to contain four quarks.

Strangers from Beyond our Solar System

Detector experiments hunting for rare events can go years and never see anything out of the ordinary. So it was cause for excitement when IceCube, a giant neutrino telescope at the South Pole, reported the detection of two neutrinos with energies of around 1000

Observation of $Z_c(3885)$ in $D^{\pm}\bar{D}^{*0}$



$M(Z_c) = 3883.9 \pm 1.5 \pm 4.2$ MeV

$\Gamma(Z_c) = 24.8 \pm 3.3 \pm 11.0$ MeV

$$\frac{\Gamma(Z_c(3900) \to D^{\pm}\bar{D}^{*0})}{\Gamma(Z_c(3900) \to \pi^{\pm}J/\psi)} \sim 6$$

J^P favors 1^+

Very important in understanding $Z_c(3900)$!

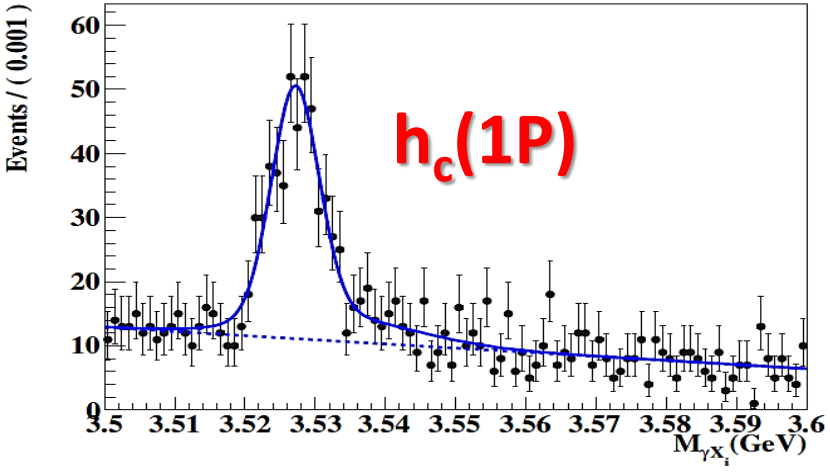
BESIII： PRL 112, 022001 (2014)

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

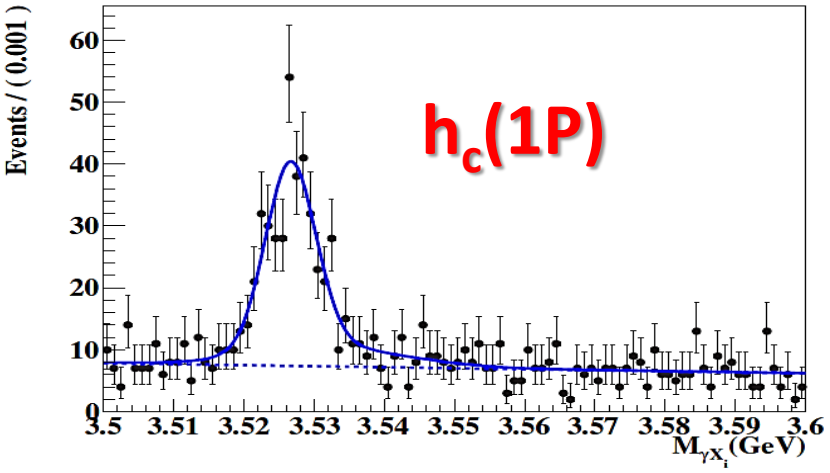
- 827 pb^{-1} at Ecm=4.26 GeV; 544 pb^{-1} at Ecm=4.36 GeV; …

- $h_c \to \gamma\eta_c$, $\eta_c \to$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., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$

Ecm=4.26 GeV



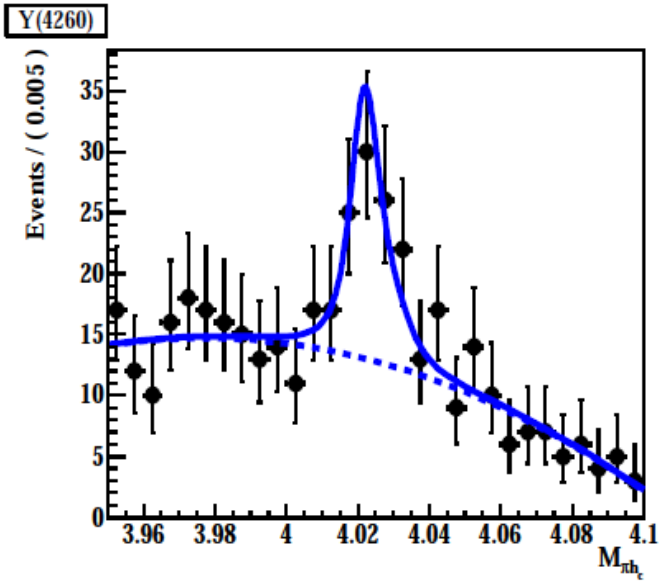
Ecm=4.36 GeV



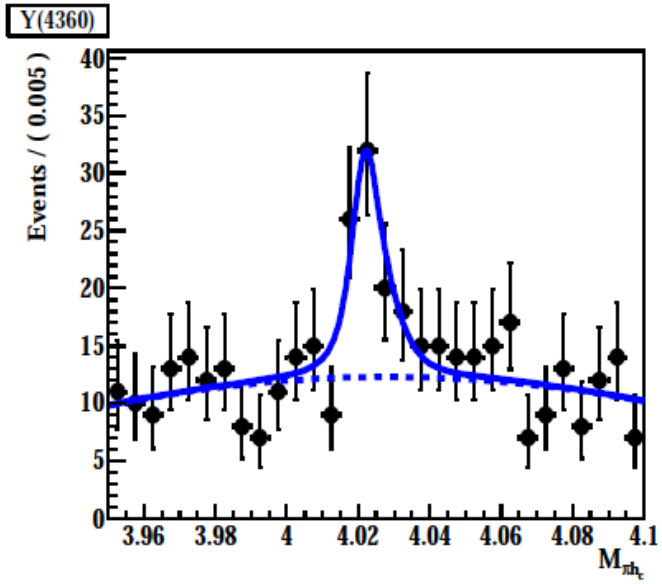
BESIII： PRL 111, 242001 (2013)

Observation of $Z_c^{\pm}(4020)$ in $e^+e^- \rightarrow \rightarrow \pi^+\pi^- h_c(1P)$

Ecm=4.26 GeV



Ecm=4.36 GeV



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

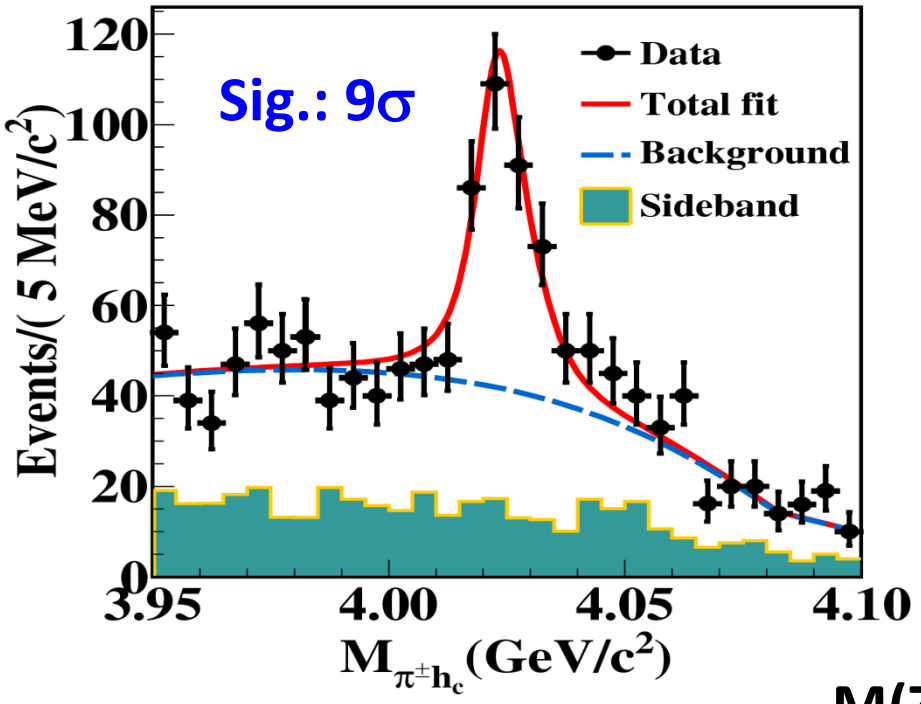
$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7$ MeV
$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6$ MeV

BESIII: PRL 111, 242001 (2013)

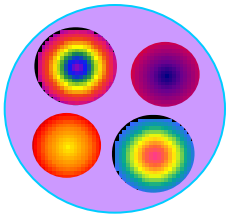
$$R = \frac{\sigma(e^+e^- \rightarrow \pi^\pm Z_c^\mp \rightarrow \pi^+\pi^- h_c(1P))}{\sigma(e^+e^- \rightarrow \pi^+\pi^- h_c(1P))} = (16.2 \pm 4.1 \pm 0.7)\% \qquad (16.6 \pm 5.2 \pm 0.8)\%$$

Observation of $Z_c^{\pm}(4020)$ in $\pi^{\pm}hc$

No significant $Z_c^{\pm}(3900)$ in $\pi^{\pm}hc$



What is $Z_c(4020)$?



- Couples to $c\bar{c}$
- Has electric charge
- At least 4-quarks

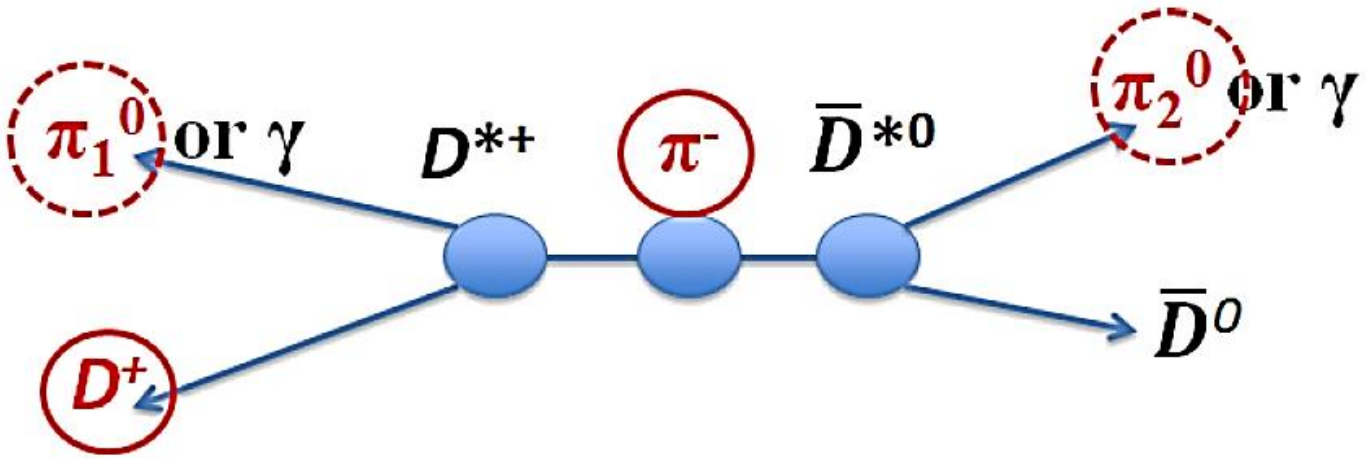
$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7$ MeV

$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6$ MeV

BESIII： PRL 111, 242001 (2013)

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

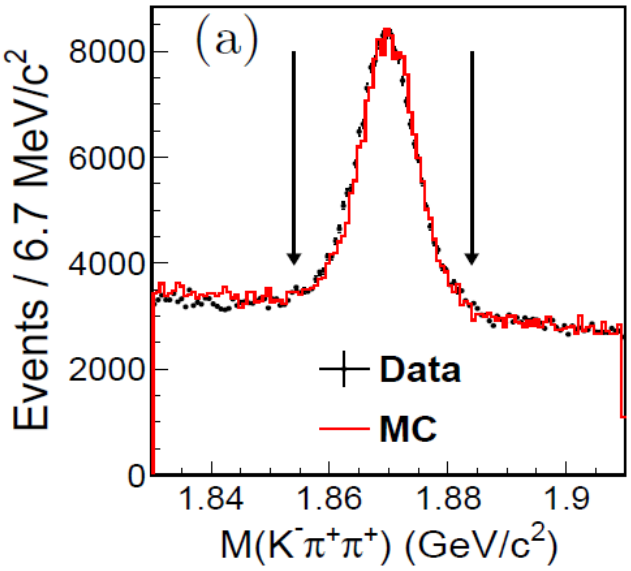
- **827 pb^{-1} data at Ecm=4.26 GeV**
- **Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.**

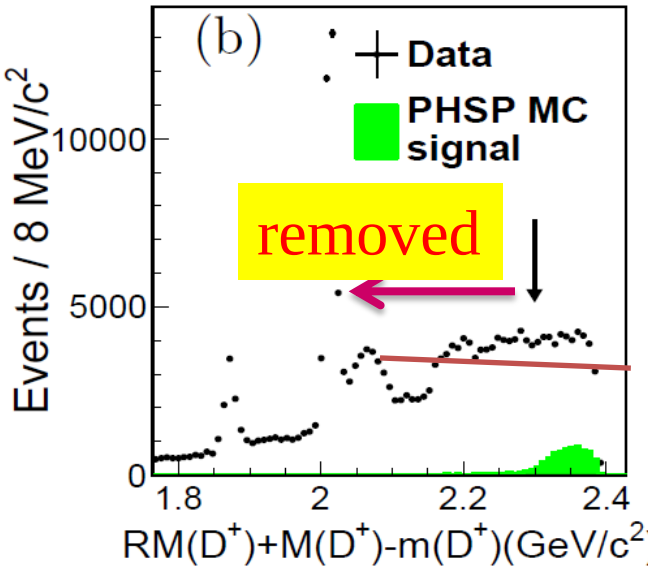


Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

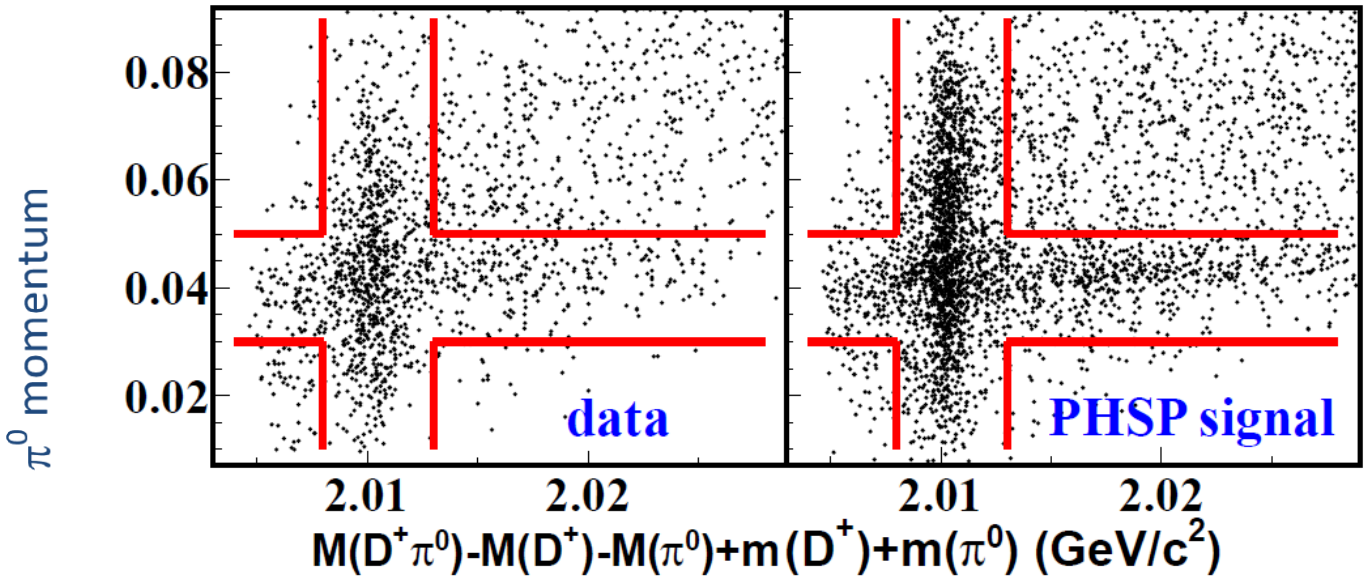
BESIII: PRL 112, 132001 (2014)

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

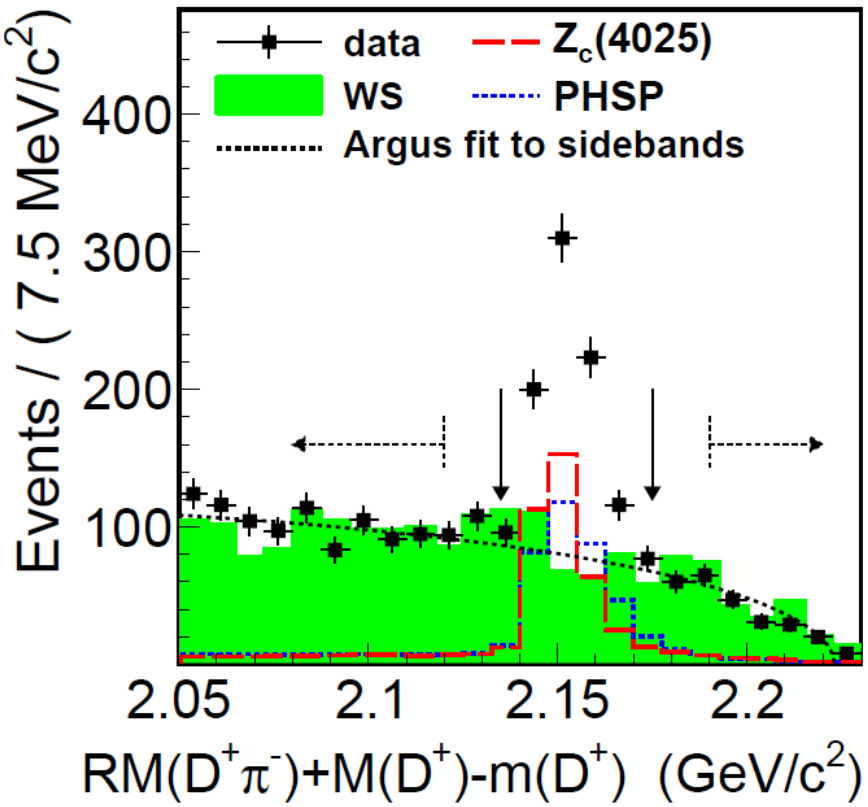


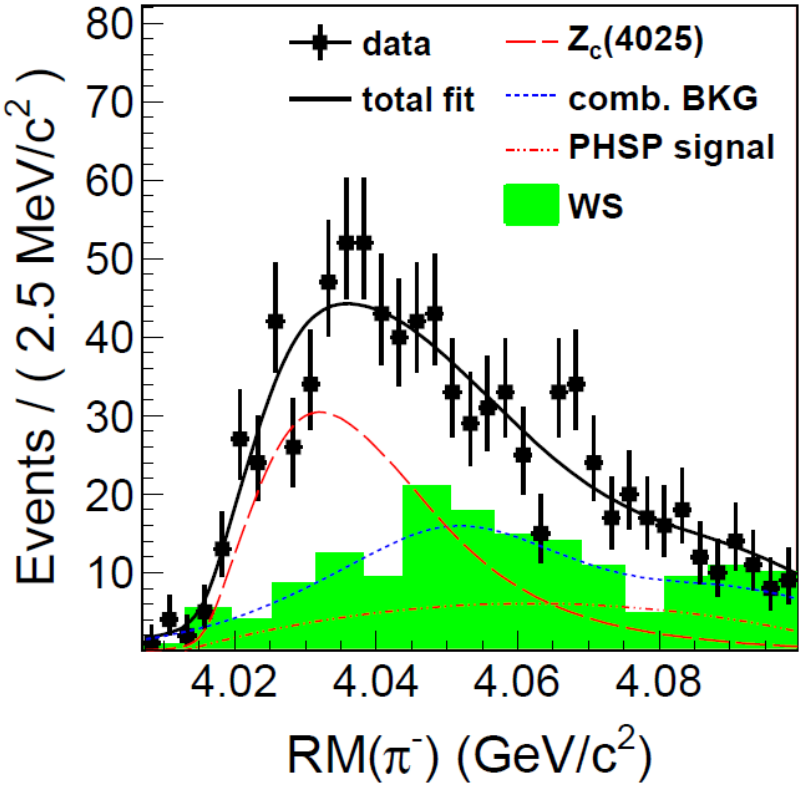


Remove DD, DD*, D*D*, DsDs, …



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





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

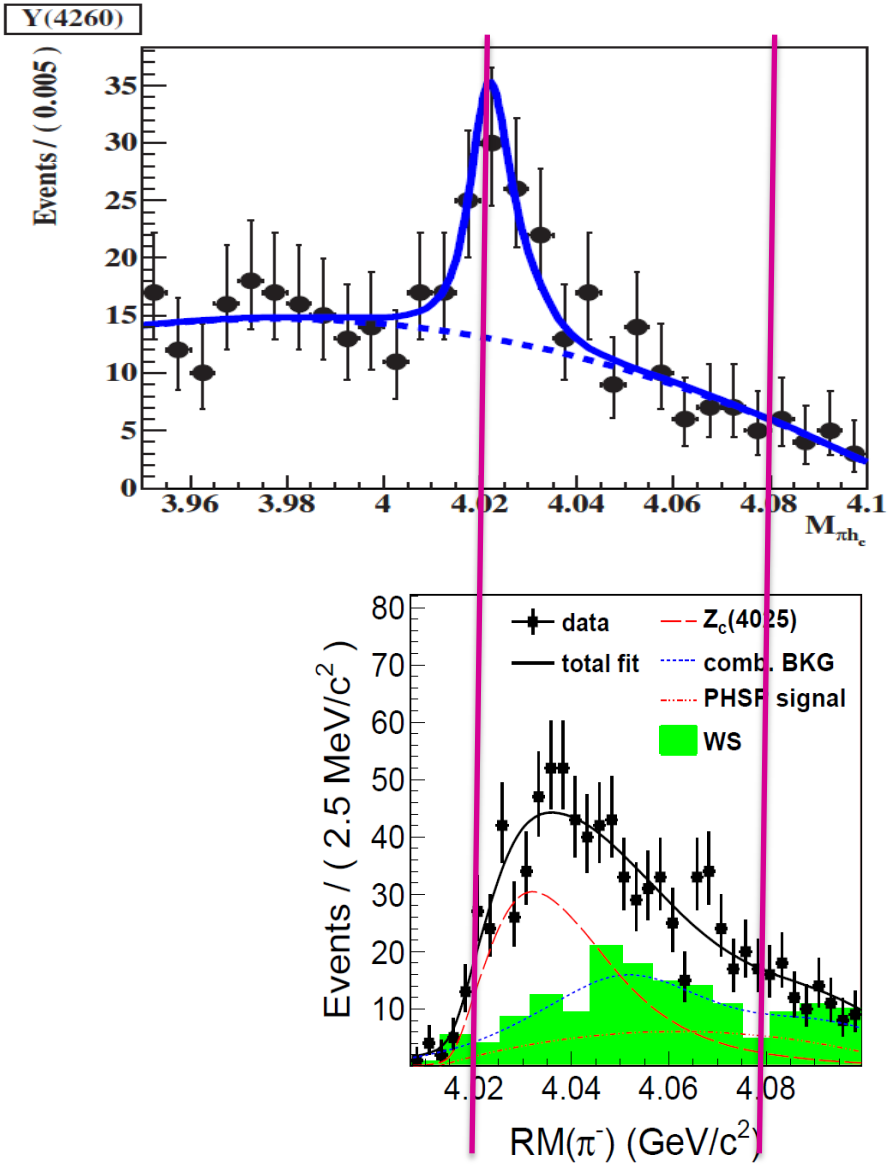
M($Z_c(4025)$) = 4026.3±2.6±3.7 MeV; Γ($Z_c(4025)$) = 24.8±5.6±7.7 MeV

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

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

BESIII: 1308.2760

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



- M(4020) = 4021.8±1.0±2.5 MeV
- M(4025) = 4026.3±2.6±3.7 MeV
- Γ(4020) = 5.7±3.4±1.1 MeV
- Γ(4025) = 24.8±5.6±7.7 MeV

Close to D*$\underline{D}$* threshold=4017 MeV

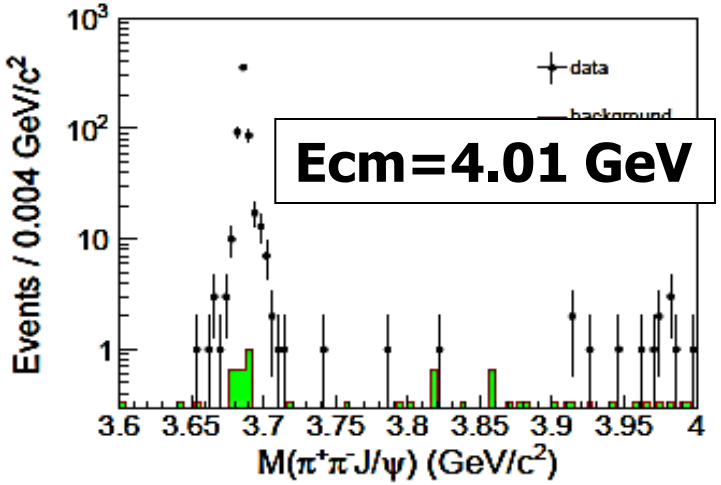
Mass consistent with each other but width ~2σ difference

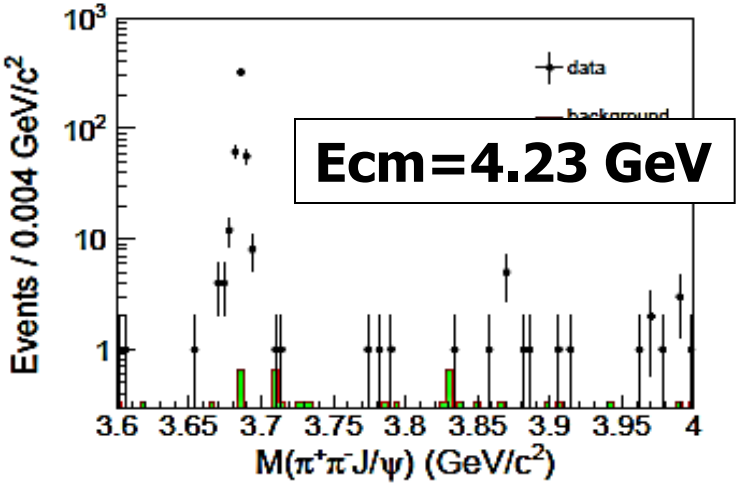
Interference with other amplitudes may change the results

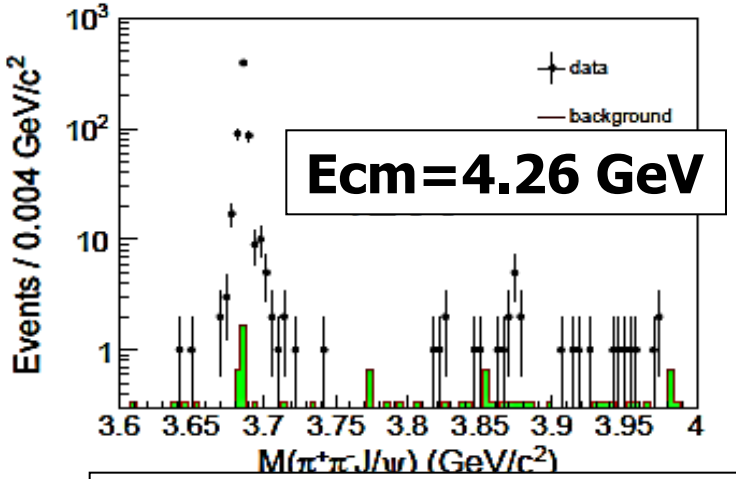
Coupling to D*$\underline{D}$* is much larger than to πh_c if they are the same state

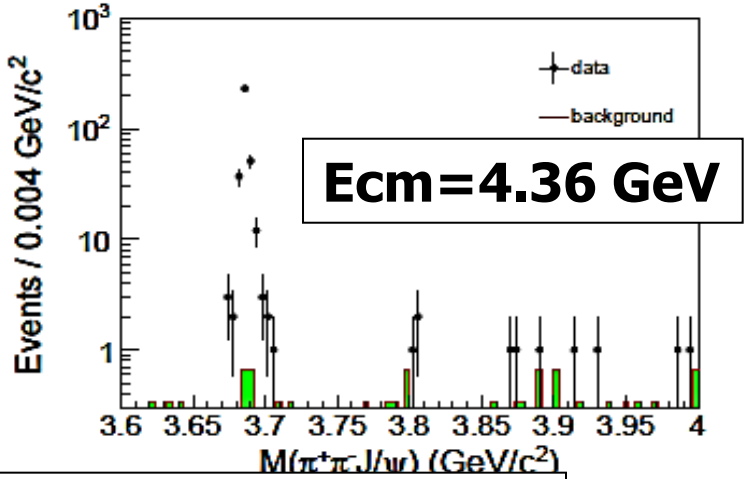
Will fit with Flatte formula

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







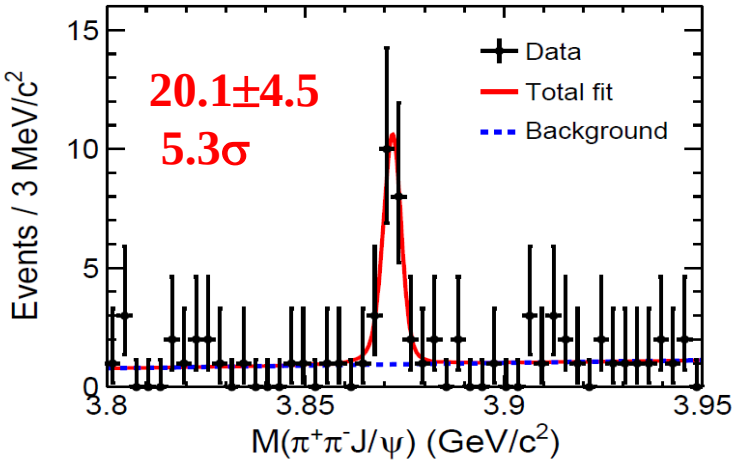


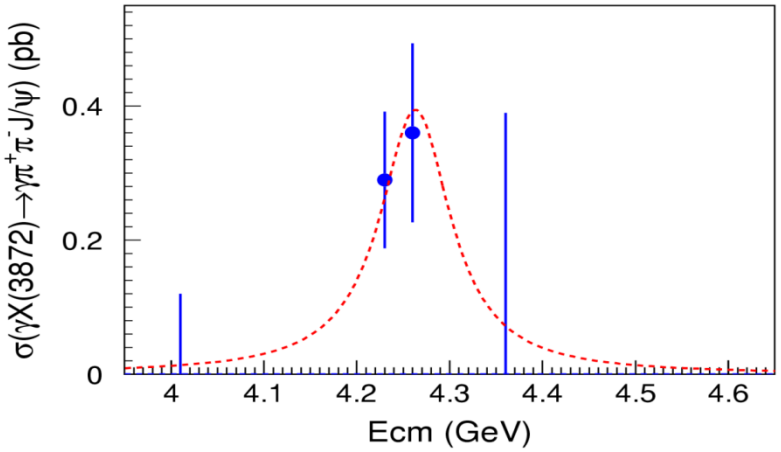
Clear ISR ψ' signal for data validation
X(3872) signal at around 4.23-4.26 GeV

PRL 112, 092001 (2014)

observation of e+e-→ γX(3872)→γπ⁺π⁻J/ψ

PRL 112, 092001 (2014)





ISR ψ' is used for the calibration of the mass, resolution and eff.

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

$$\frac{\sigma(e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (5.7 \pm 2.2) \times 10^{-3}$$

Assuming all from Y(4260), and take $B[X(3872) \to \pi^+\pi^- J/\psi] = 5\%$

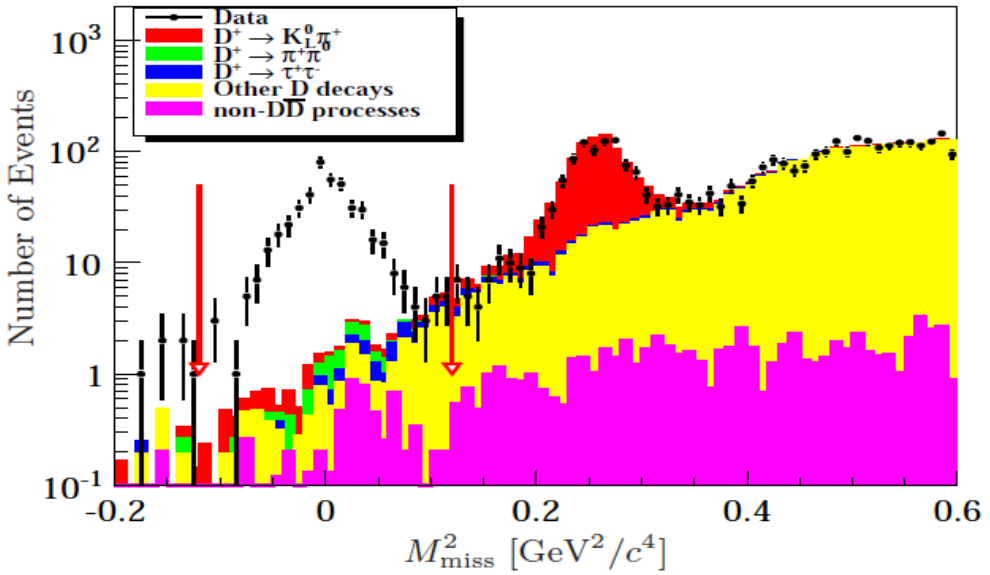
$$\frac{B[Y(4260) \to \gamma X(3872)]}{B[Y(4260) \to \pi^+\pi^- J/\psi]} = 11\%$$

Measurement of $D^+ \to \mu\nu$ at BESIII

$$\Gamma(D^+ \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+}^2}{8\pi} \mid V_{cd} \mid^2 m_\ell^2 m_{D^+} \left(1 - \frac{m_\ell^2}{m_{D^+}^2}\right)^2$$

- **9 singly D^- tag modes**

PRD 89, 051104(R) (2014)

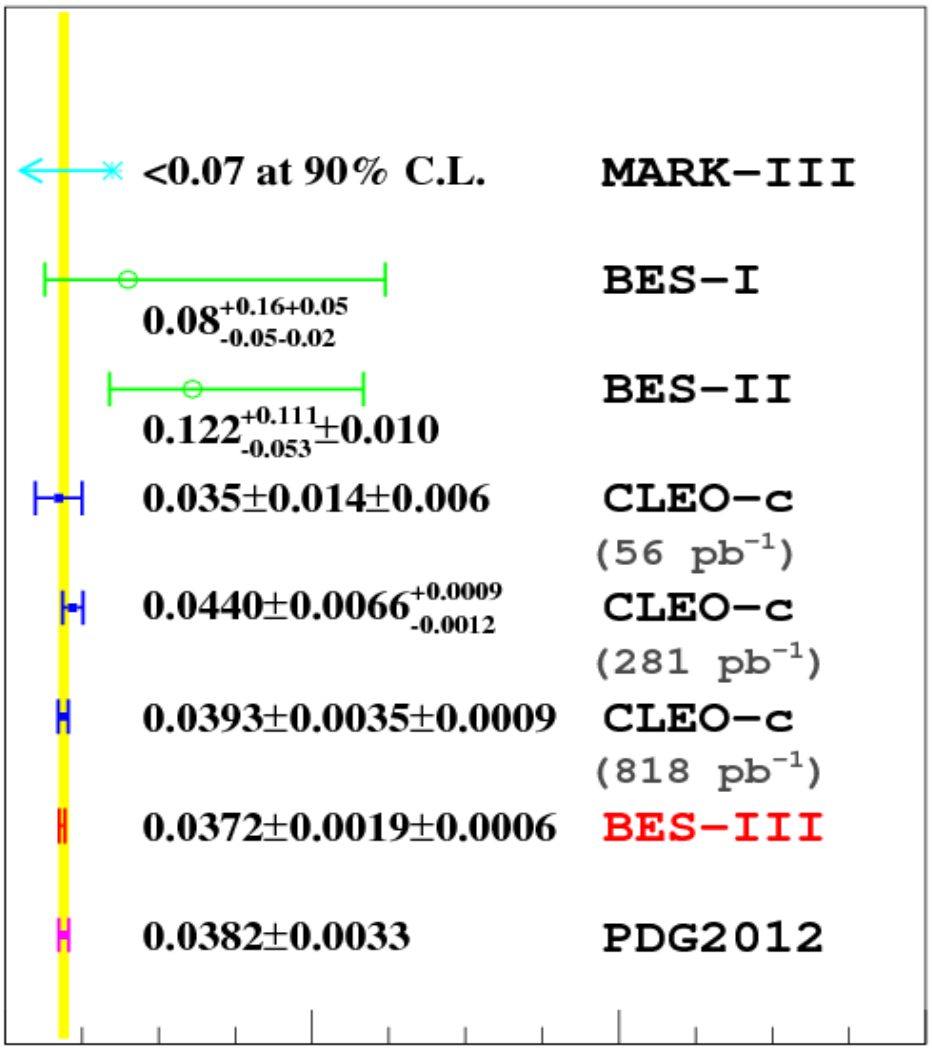


$$B(D^+ \to \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$$

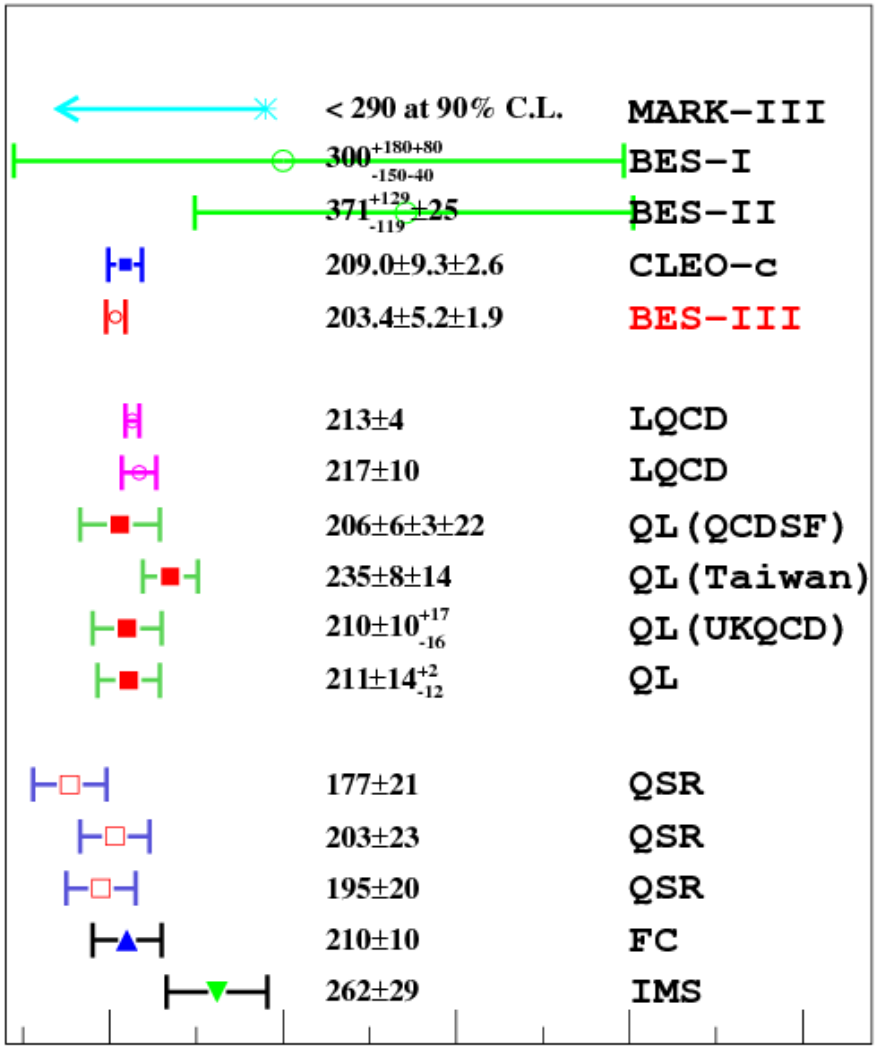
$$f_{D^+} = (203.2 \pm 5.3 \pm 1.8) \quad \text{MeV}$$

$$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$$

$B(D^+ \to \mu^+\nu)$


<0.07 at 90% C.L.
MARK-III
$0.08^{+0.16+0.05}_{-0.05-0.02}$
BES-I
$0.122^{+0.111}_{-0.053}\pm0.010$
BES-II
0.035±0.014±0.006
CLEO-c
(56 pb^{-1})
$0.0440\pm0.0066^{+0.0009}_{-0.0012}$
CLEO-c
(281 pb^{-1})
0.0393±0.0035±0.0009
CLEO-c
(818 pb^{-1})
0.0372±0.0019±0.0006
BES-III
0.0382±0.0033
PDG2012
0
0.2
0.4

f_{D+}


< 290 at 90% C.L.
MARK-III
$300^{+180+80}_{-150-40}$
BES-I
$371^{+129}_{-119}\pm25$
BES-II
209.0±9.3±2.6
CLEO-c
203.4±5.2±1.9
BES-III
213±4
LQCD
217±10
LQCD
206±6±3±22
QL(QCDSF)
235±8±14
QL(Taiwan)
$210\pm10^{+17}_{-16}$
QL(UKQCD)
$211\pm14^{+2}_{-12}$
QL
177±21
QSR
203±23
QSR
195±20
QSR
210±10
FC
262±29
IMS
200
300
400
500
600

Prospects of BESIII

- In 2013-2014 physics run, R scan from 3.8 – 4.6 GeV. The goal: reach the precision of ~2% for R values.
- New data @4600, 4420 MeV. More results on XYZ will come ➔ understand the nature of XYZ
- Search for glueballs, hybrids, … with huge J/ψ data.
- Precision measurement of CKM elements
- τ mass : expected to have an error of 0.1MeV.
- BESIII will run another 8 years or so.
- Endcap TOF upgrade on going
- Inner drift chamber upgrade

Further collaboration with Italian group expected.

Thank you!

Fundamental questions need to be answered

- **How does QCD work at low energy?**

  ➔ Do the new forms of hadrons predicted by QCD exist ?

  ➔ How to calibrate QCD at low energy ?

  Search for the new hadrons and systematic study of the spectroscopy – a way of understanding the internal structure of hadrons.

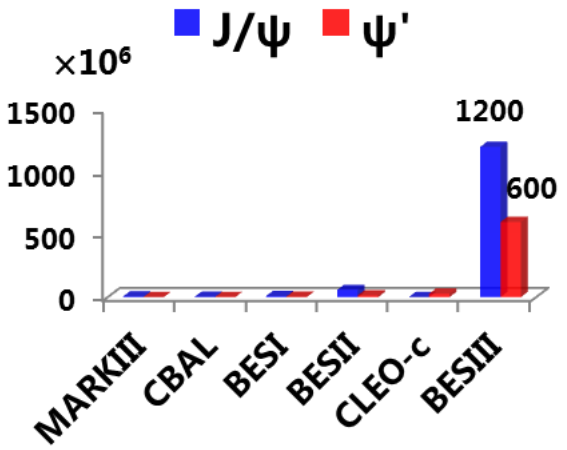
- **Does the physics beyond Standard Model exist?**

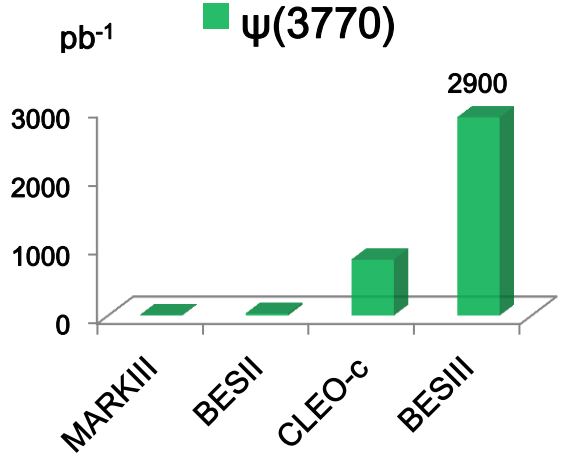
  ➔ How to test EW theory precisely in τ-charm region?

  ➔ Where is the new physics in τ-charm sector ?

BESIII results

- **Charmonium physics**
  - Charmonium spectroscopy
  - Transitions and decays
- **Light hadron spectroscopy**
  - Meson & baryon spectroscopy
  - Search for unconventional hadrons – glueballs, hybrids, multi-quark states
- **Charm physics**
  - Decay constant f_D
  - CKM matrix elements: *Vcd, Vcs*
- **τ mass measurement, R scan**





65 papers published or accepted

Many talks at the international conferences