Overview of BESIII Experiment

Xiaoyan SHEN

(On behalf of BESIII Collaboration)

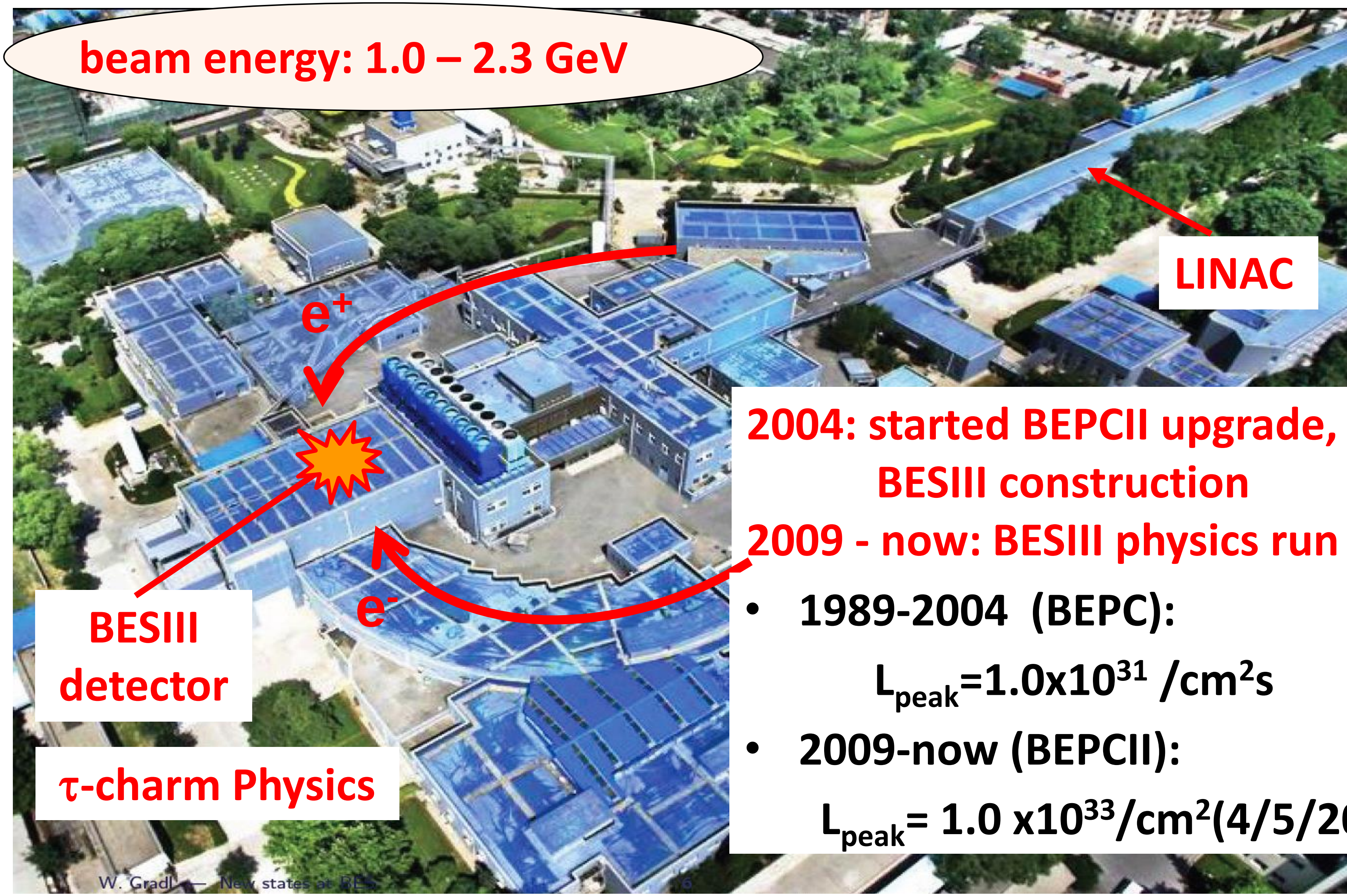
Institute of High Energy Physics, China

The 56th International Winter Meeting on Nuclear Physics
Jan. 22-26, 2018, Bormio, Italy

Outline

- Introduction
- Status of BESIII
- Recent highlights of BESIII
- Upgrade plan
- Summary

Beijing Electron Positron Collider (BEPC)



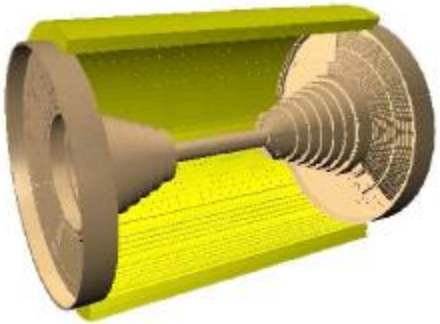
2004: started BEPCII upgrade, BESIII construction

2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^2s
- 2009-now (BEPCII):
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

BESIII Detector

MDC

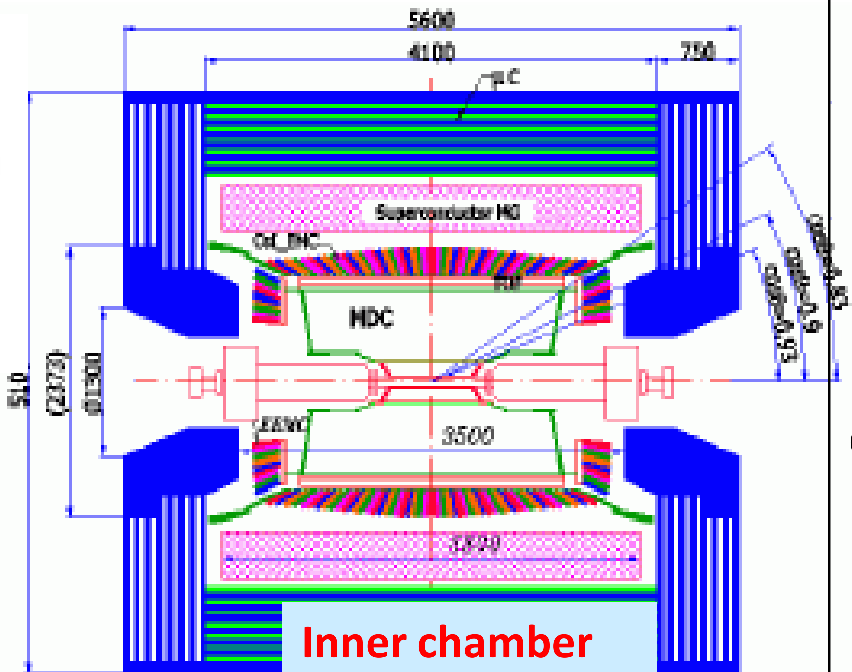


R inner: 63mm ;

R outer: 810mm

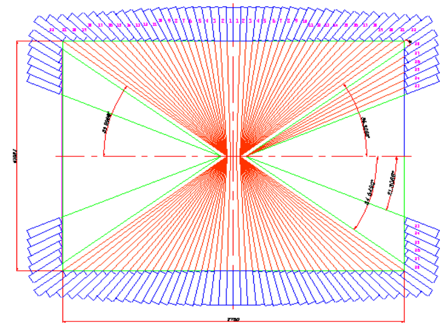
Length: 2582 mm

Layers: 43



Inner chamber replaced by CGEM is ongoing

CsI(Tl) EMC



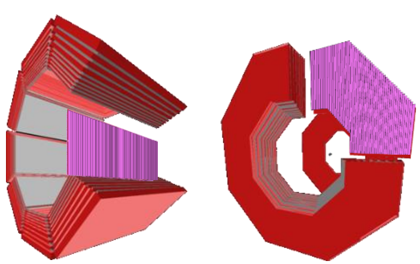
Crystals: 28 cm(15 X_0)

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: → MRPC

Installation completed in Oct., 2015

60ps (120ps)

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	115 μm	<5% (Bhabha)	2.4%

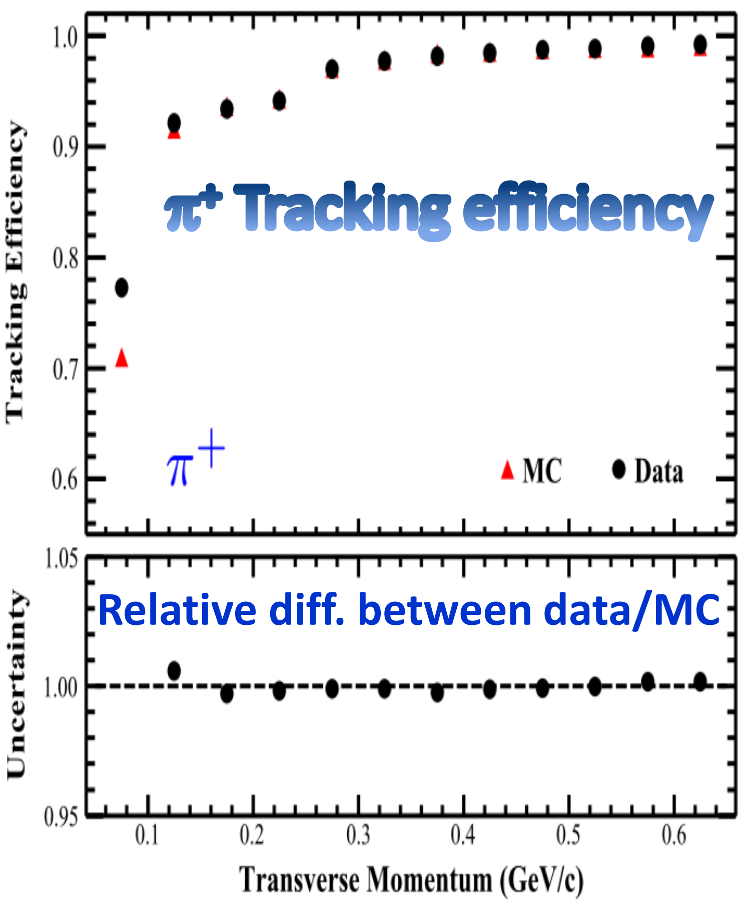
Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

MUC: Efficiency ~ 96%

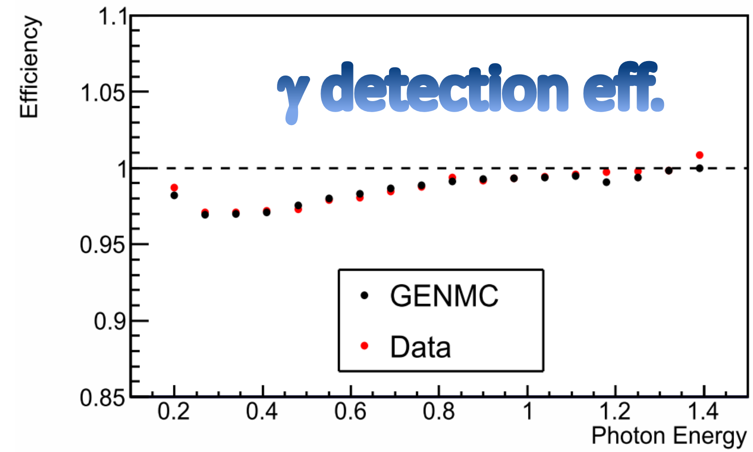
BG level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

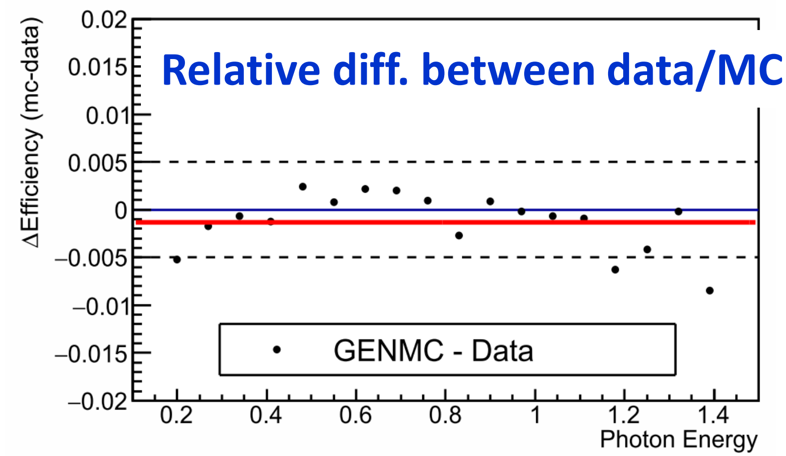
Data/Monte-Carlo Consistency

- For tracking efficiency data/MC difference < 1%



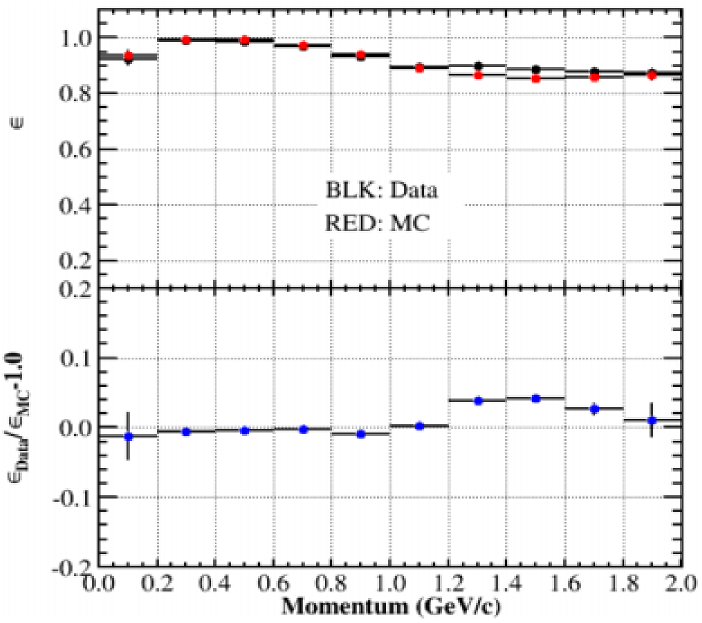
- For photon detection efficiency data/MC difference < 1%



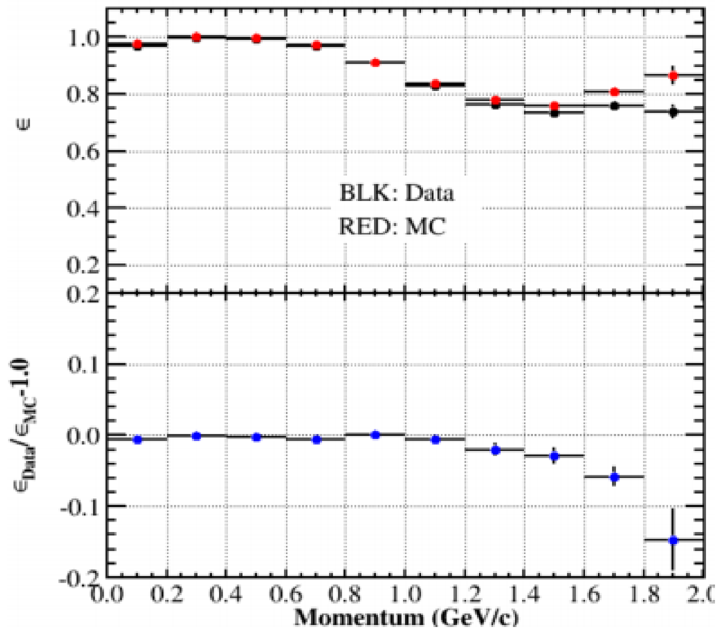


- **For particle identification efficiency, data/MC difference ~1% (TOF+ dE/dx) when p<1.2 GeV**

K/π PID efficiency of data/MC (dE/dx+TOF)

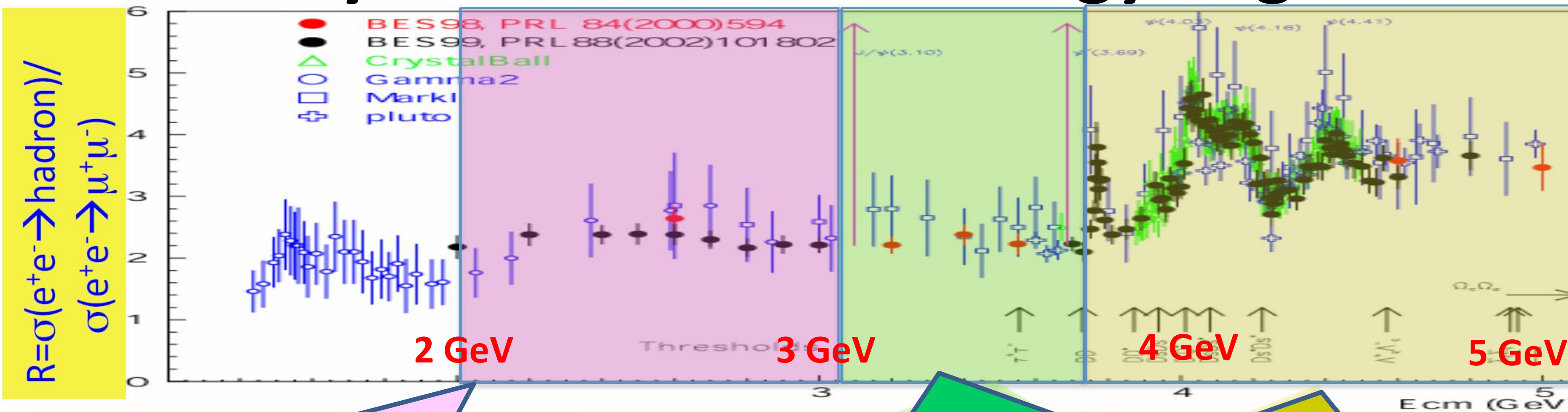


Kaon



Pion

Physics at τ - charm Energy Region



- Hadron form factors
- Y(2175)
- Zs states ?
- QCD test

- Light hadron spectroscopy
- Glueballs, hybrids, multi-quark states
- Rare decays
- Tau physics

- XYZ
- D and Ds physics (f_D and f_{Ds}, mixing, ~~CP~~)
- Charmed baryons

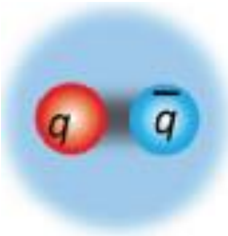
- Rich of **resonances:** charmonia, charmed mesons, charmed baryons
- **Threshold** characteristics (pairs of τ, D, D_s, …) -- **low BG at threshold, high X-section -- indirect probe of NP**
- **Transition between** pQCD and non-pQCD
- Energy location of the **new forms of hadrons**

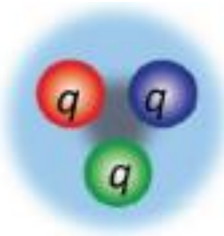
New forms of hadrons

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

Naive Quark Model：

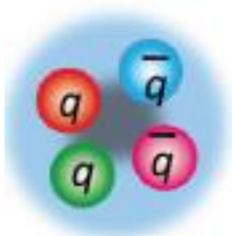
meson

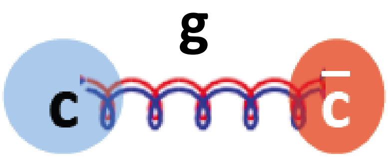




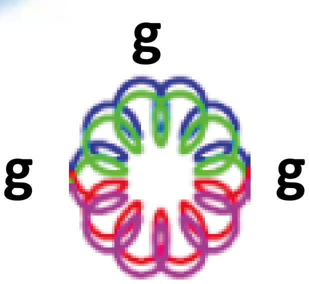
baryon

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

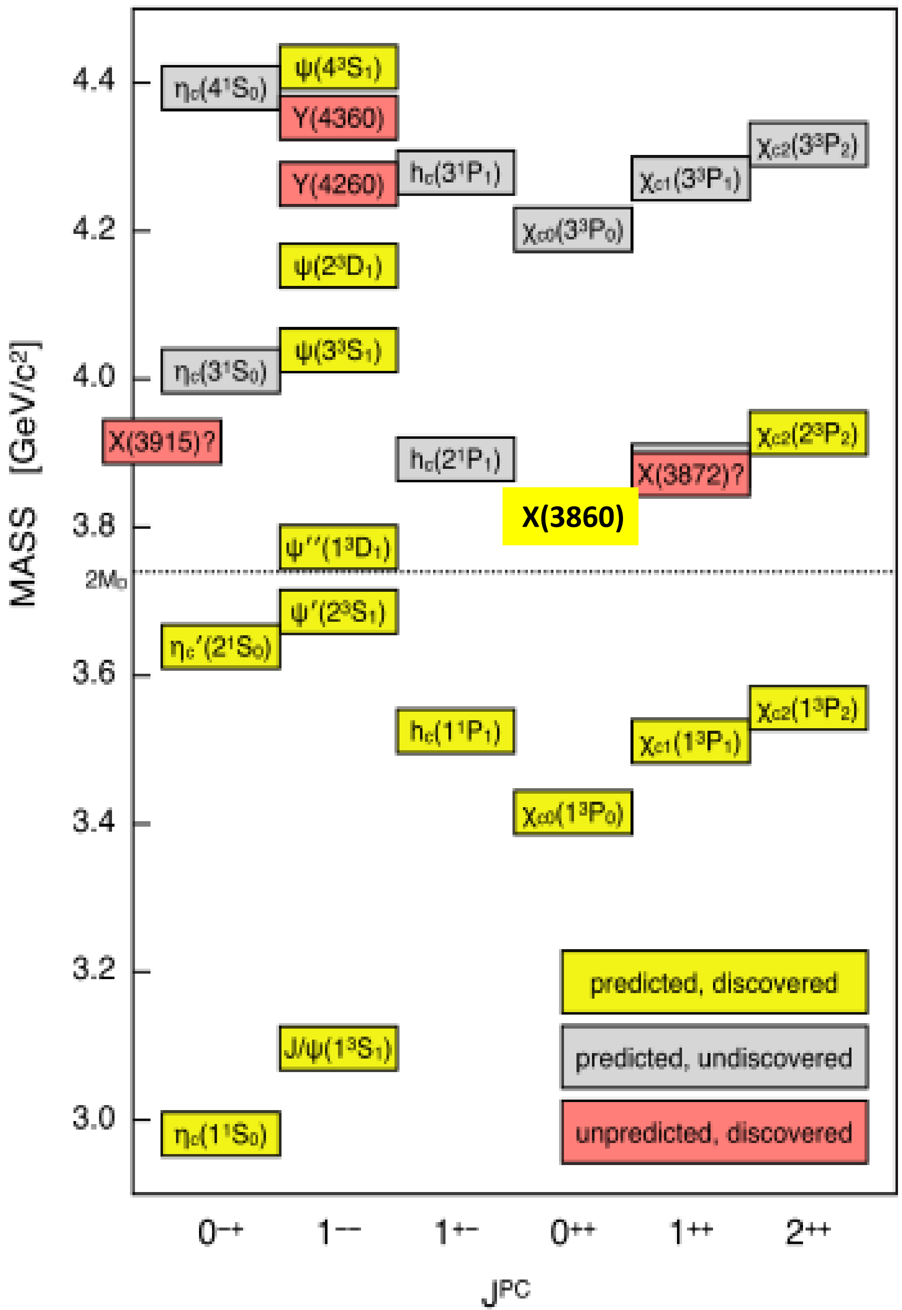




  - **Hybrids： $q\bar{q}g$， qqqg …**
  - **Glueballs： gg， ggg …**



None of the new forms of hadrons is settled！



Charmonium spectroscopy

- Charmonium states below open charm threshold are all observed

Above open charm threshold:

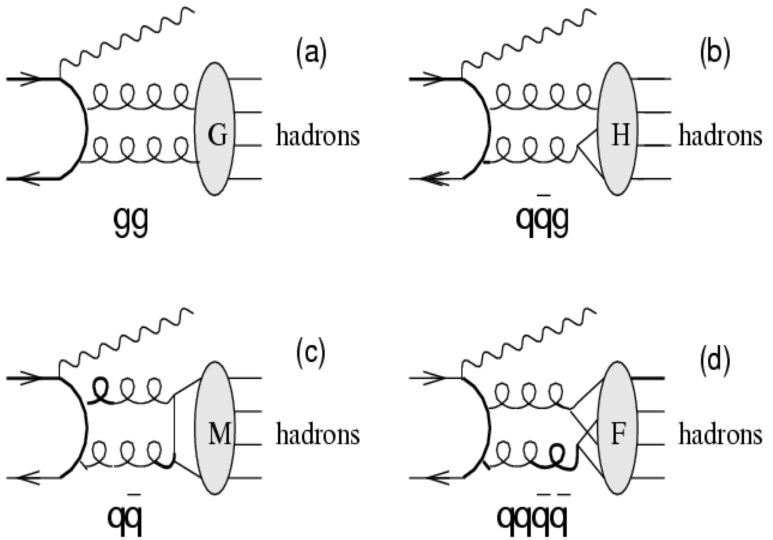
- many expected states not observed
- many unexpected observed

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)

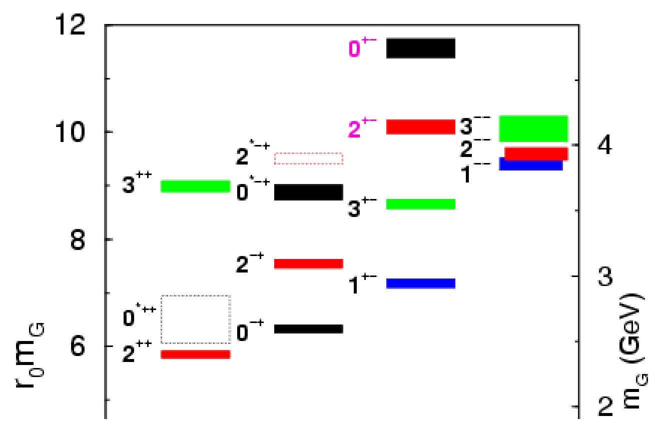
Charmonium decays provide ideal hunting ground for light glueballs and hybrids



$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$$

$$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$$

- "Gluon-rich" process
- Clean high statistics data samples from e^+e^- annihilation
- $I(J^{PC})$ filter in strong decays of charmonium



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.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LHCb + LQCD

Three generations of quark?

Unitary matrix?

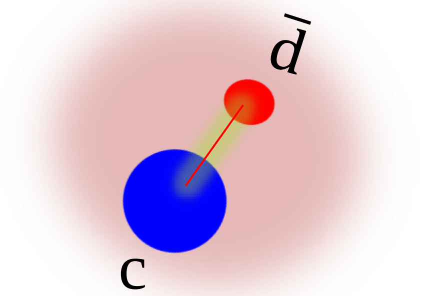
Expected precision < 2% at BESIII

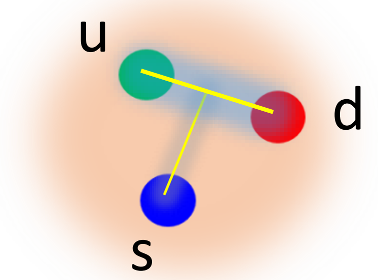
BESIII + B factories + LHCb + LQCD

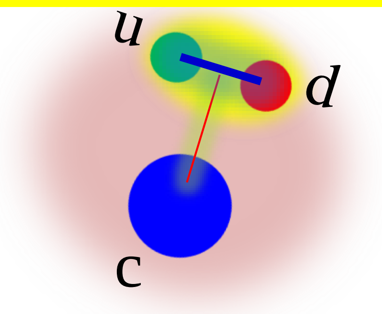
Precision measurement of CKM matrix elements
-- a precise test of SM model
New physics beyond SM?

Λ_c measurement at BESIII

Λ_c^+: a heavy quark (c) with a unexcited spin-zero diquark (u-d)







Charmed meson ($D^+[c\bar{d}]$)

$m_d << m_c$ → **quark + heavy quark**
(q) (Q)

Strange baryons (Λ[uds])

m_u, $m_d \approx m_s$ → **(qqq)** uniform

Charmed baryon (Λ_c[udc])

m_u, $m_d << m_c$ → **diquark + quark**
(qq) (Q)

Λ_c^+ may provide complementary powerful test on internal dynamics to charmed meson.

- The lightest charmed baryon
- Most of the charmed baryons will eventually decay to Λ_c^+
- $B(\Lambda_c^+ \to pK^-\pi^+)$: dominant error for V_{ub} via b-baryon decay

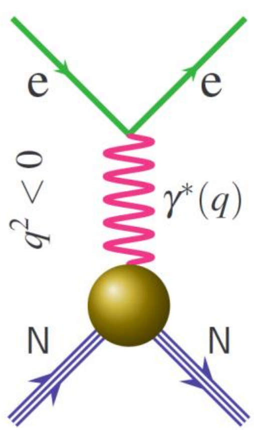
Nucleon Form Factor

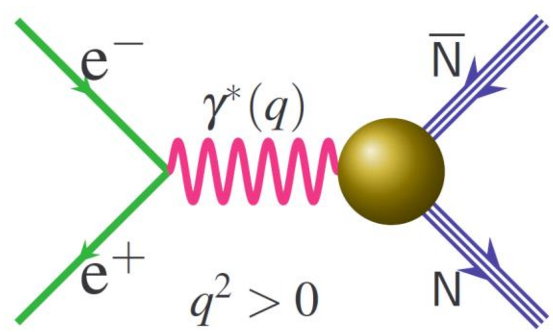
- Fundamental properties of the nucleon
  - Connected to charge, magnetization distribution
  - Crucial testing ground for models of the nucleon internal structure
  - Necessary input for experiments probing nuclear structure, or trying to understand modification of nucleon structure in nuclear medium
- **Can be measured from space-like processes (eN) (precision 1%) or time-like process (e^+e^- annihilation) (precision 10%-30%)**

eN → eN

$e^+e^- \leftrightarrow N\overline{N}\ ,\Lambda\overline{\Lambda}$

Space-like:
FF real





Time-like:
FF complex

Status of BESIII

BESIII Collaboration

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. of Torino，Frascati Lab, Ferrara Univ.
Netherland: KVI-CART/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center
UK: Oxford Univ., Univ. of Manchester

US (4)

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

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Mongolia (1)

Institute of Physics and Technology

India (1)

Indian Institute of Technology

Pakistan (2)

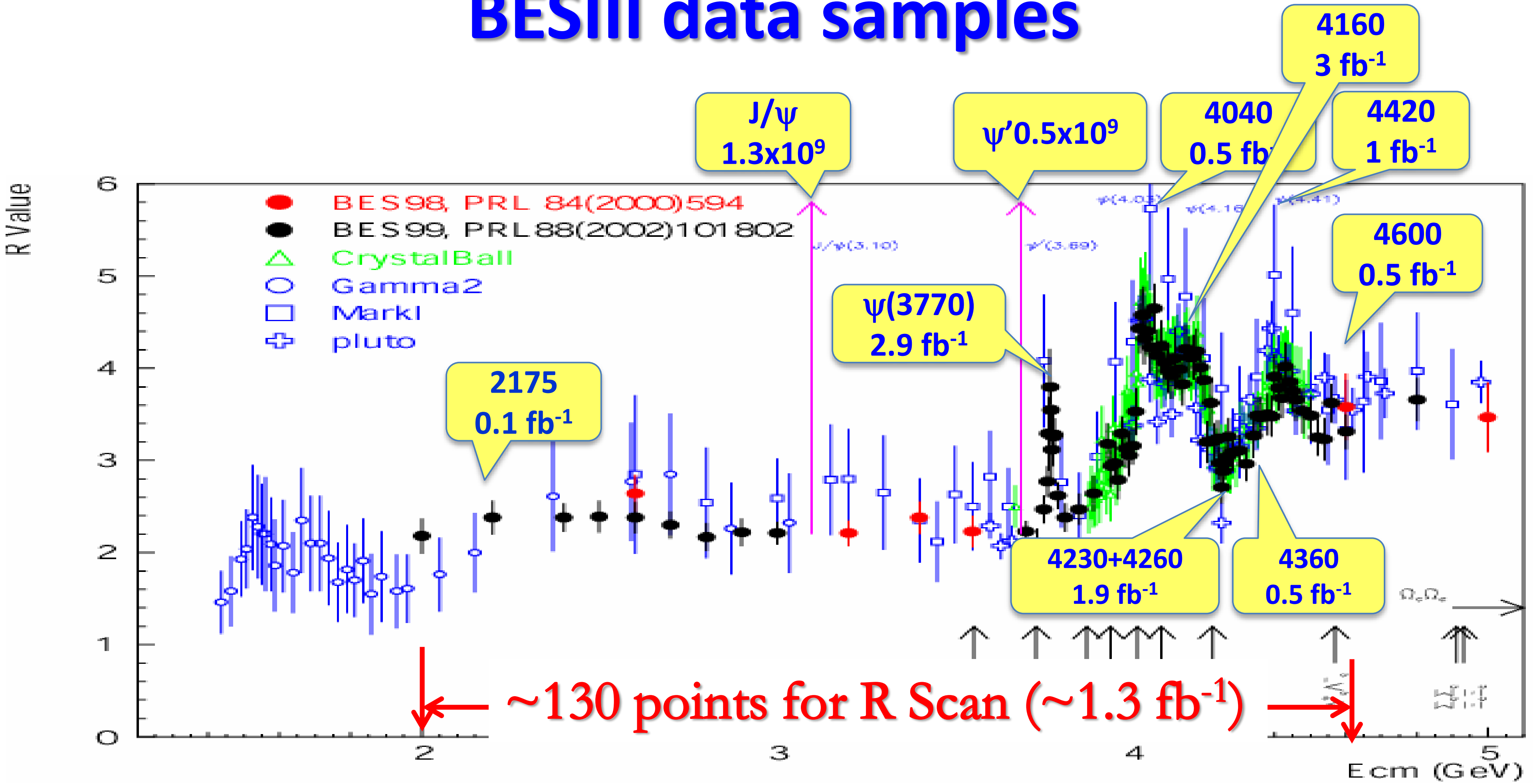
Univ. of Punjab
COMSAT CIIT

China(37)

IHEP, CCAST, UCAS, Shandong Univ., Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll., Shanghai Jiaotong Univ.
Huazhong Normal Univ., Wuhan Univ., Xingyang Normal Univ.
Zhengzhou Univ., Henan Normal Univ., Hunan Normal Univ.
Peking Univ., Tsinghua Univ. , *Beijing Inst. of Petro-chemical Tech.*
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ., Univ. of Sci. and Tech. Liaoning
Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Jinan Univ., Fudan Univ.

~ 450 members
from 64 institutions in 14 countries

BESIII data samples



World largest J/ψ, ψ(2S), ψ(3770), ψ(4160), Y(4260), … produced directly from e^+e^- collision

3.5/fb in 4.2-4.3 GeV, 500/pb at each energy

J/ψ data taking in this run

Recent selected BESIII highlights

- Hadron spectroscopy
  - XYZ
  - Light hadron spectroscopy
- Λ_c absolute branching fractions
- Ds decay constant

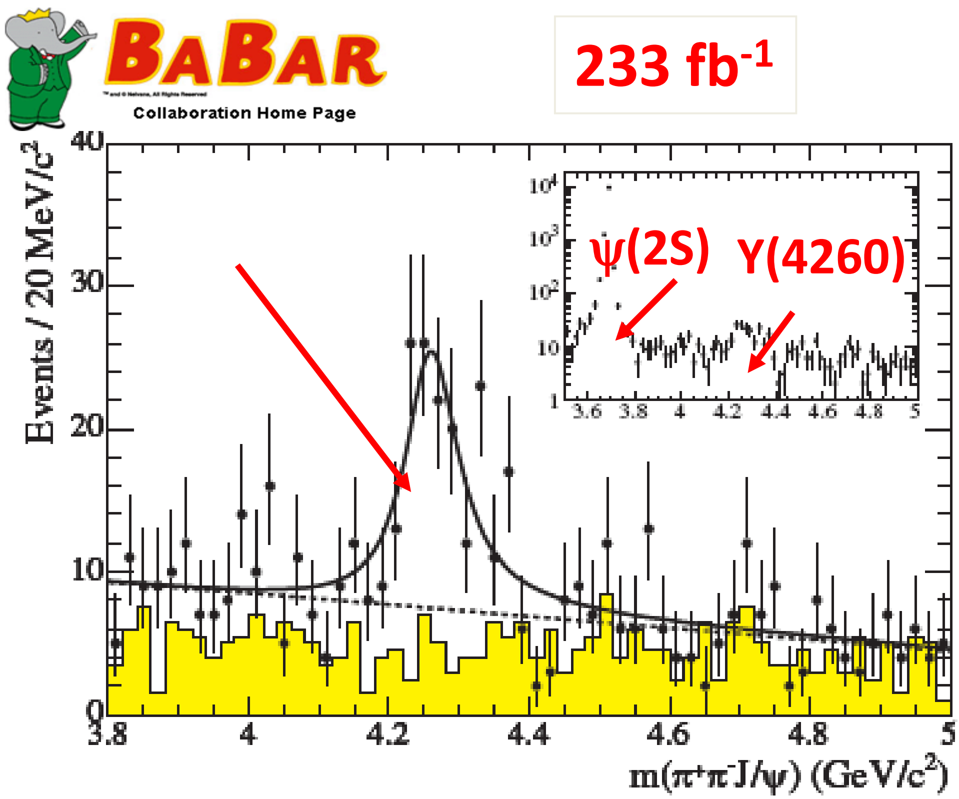
Y(4260)

Y(4260) was first observed by BaBar

$$e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^- J/\psi\ (J/\psi \to e^+e^- \text{ or } \mu^+\mu^-)$$

233 fb^{-1}

PRL 95 (2005) 142001



$\sigma(e^+e^-\to\pi^+\pi^- J/\psi)\sim 50$ pb

$$M = 4259 \pm 8^{+2}_{-6}\ \ \mathrm{MeV/c^2}$$

$$\Gamma = 88 \pm 23^{+6}_{-4}\ \ \mathrm{MeV/c^2}$$

$$\Gamma(Y\to e^+e^-)\times B(Y\to\pi^+\pi^- J/\psi) = 5.5\pm1.0^{+0.8}_{-0.7}\ \ \mathrm{eV}$$

$> 8\,\sigma$

Overpopulation of 1^{--} state.

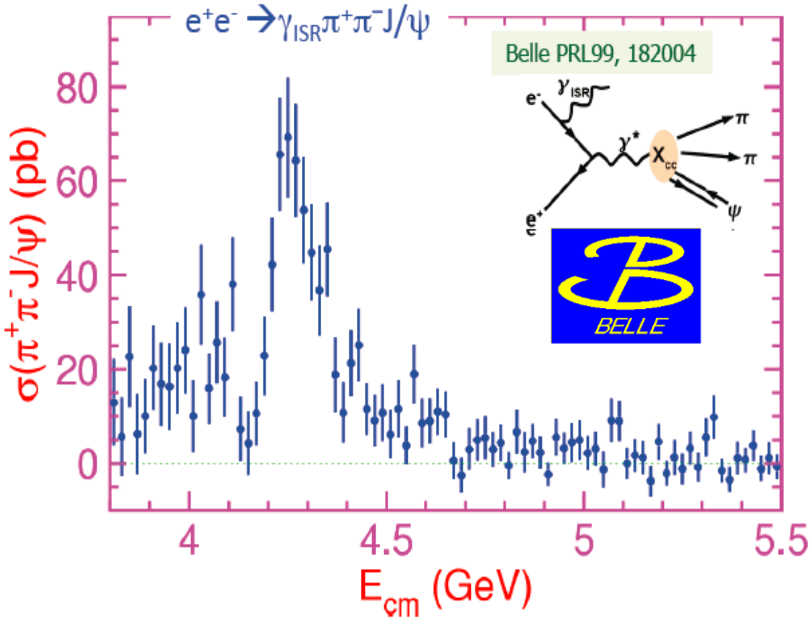
S-wave states: J/ψ, ψ’, ψ(4040), ψ(4415)

P-wave states: ψ(3770), ψ(4160).

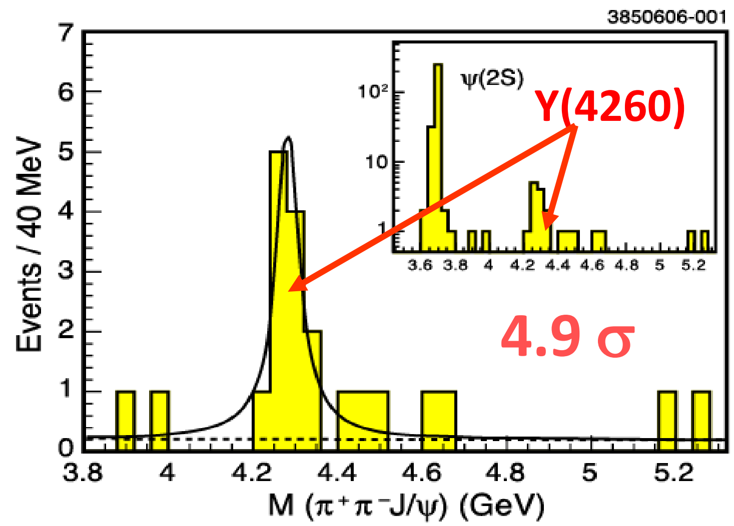
No place for Y(4260) in QM spectrum

Y(4260) is confirmed by Belle, CLEOIII and BESIII

$$e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi\ (J/\psi \to e^+e^-\ \text{or}\ \mu^+\mu^-)$$



13.3 fb^{-1} CLEOIII data @ $\sqrt{s}$=10 GeV

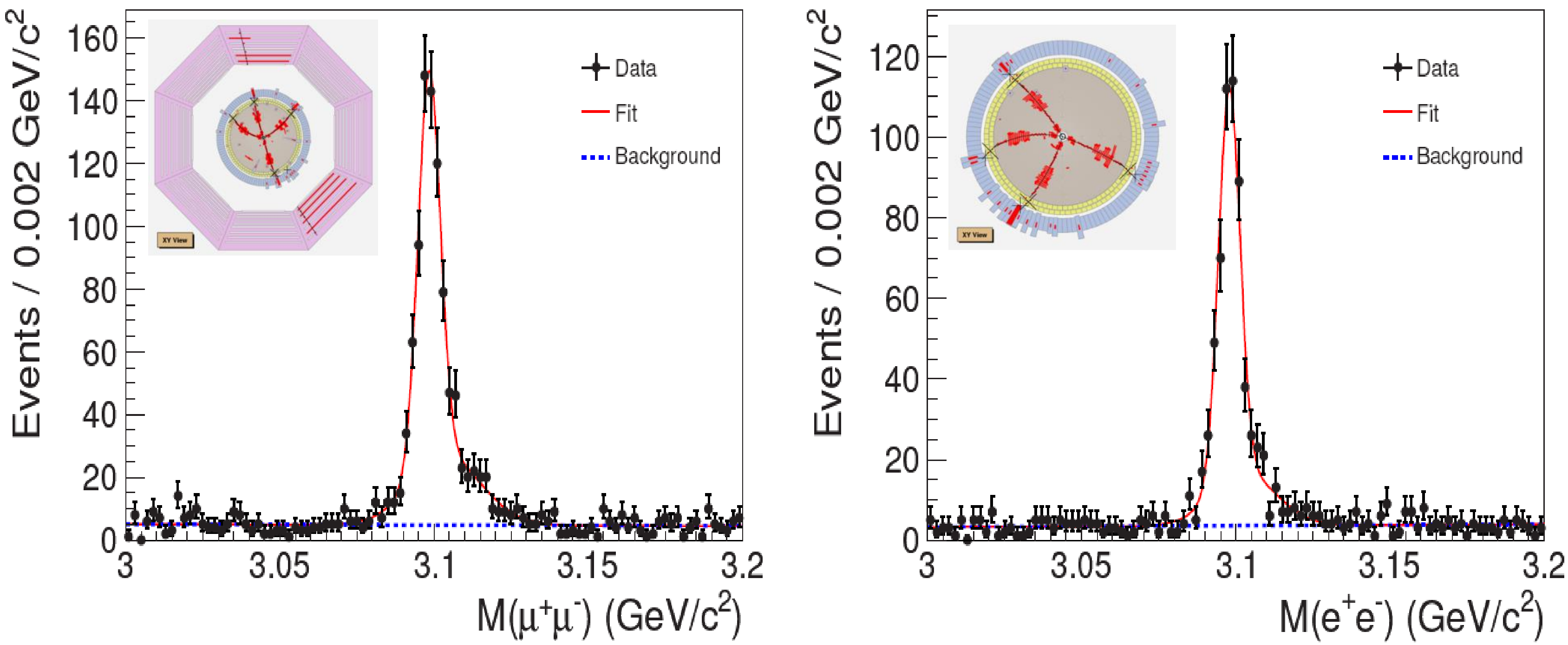


$$M = 4295 \pm 10^{+10}_{-3}\ \text{MeV/c}^2$$
$$\Gamma = 133 \pm 26^{+13}_{-6}\ \text{MeV/c}^2$$

$$M(Y(4260)) = 4284^{+17}_{-16} \pm 4\ \text{MeV/c}^2$$
$$\Gamma(Y(4260)) = 73^{+39}_{-25} \pm 5\ \text{MeV/c}^2$$

Y(4260): $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

525/pb @4.26 GeV PRL110, 252001 (2013)



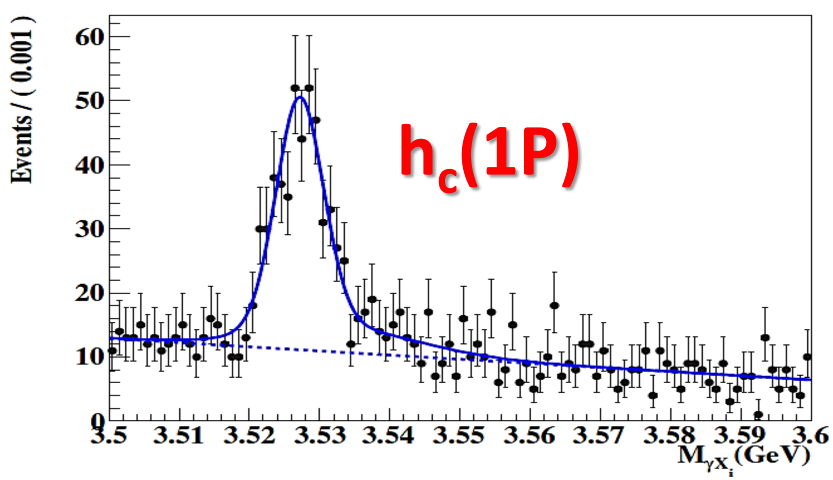
- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb

BESIII $Y(4260)$: $e^+e^- \to \pi^+\pi^- h_c(1P)$

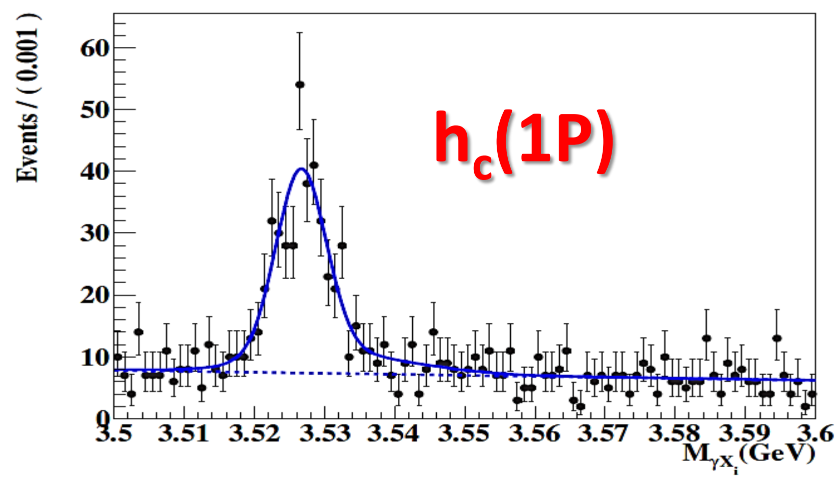
- **827 pb^{-1} at Ecm=4.26 GeV; 544 pb^{-1} at Ecm=4.36 GeV; …**

- $h_c \to \gamma\eta_c$, $\eta_c \to$ 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

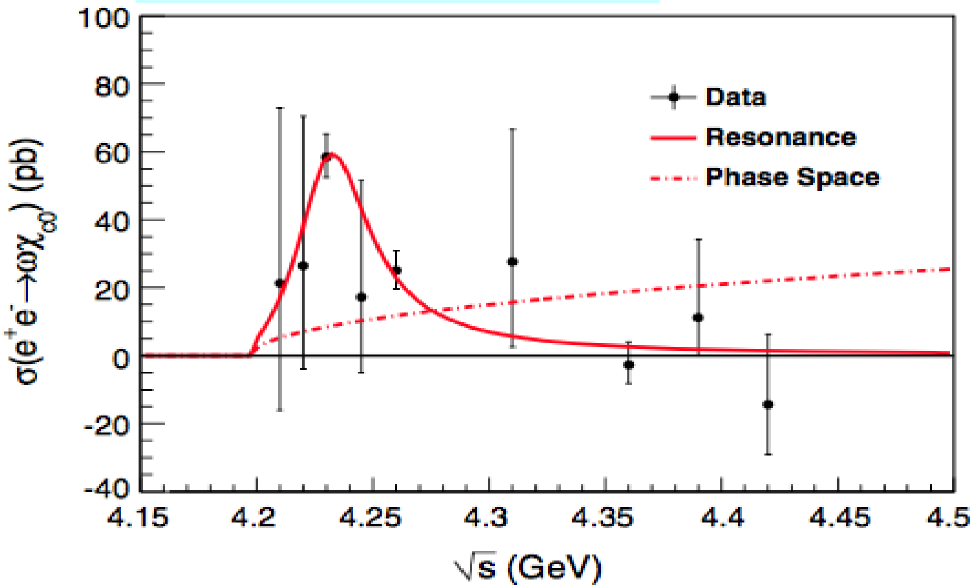


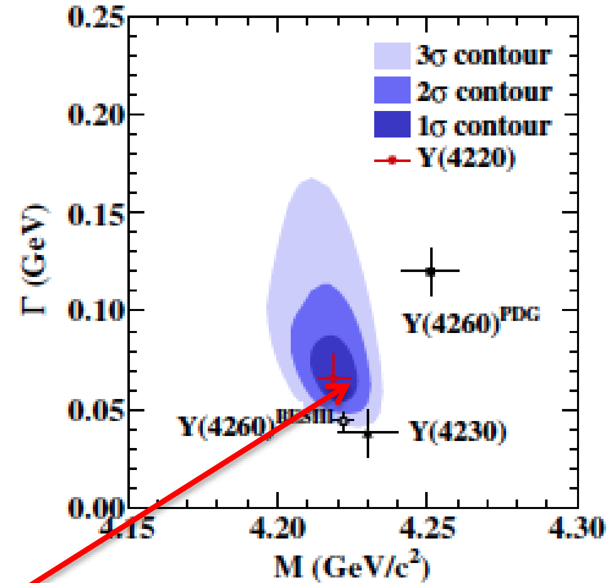
BESIII: PRL 111, 242001 (2013)

Cross section measurement in different processes at BESIII

Cross section measurement of $e^+e^- \rightarrow \omega\chi_{cJ}$

PRL 114, 092003 (2015)





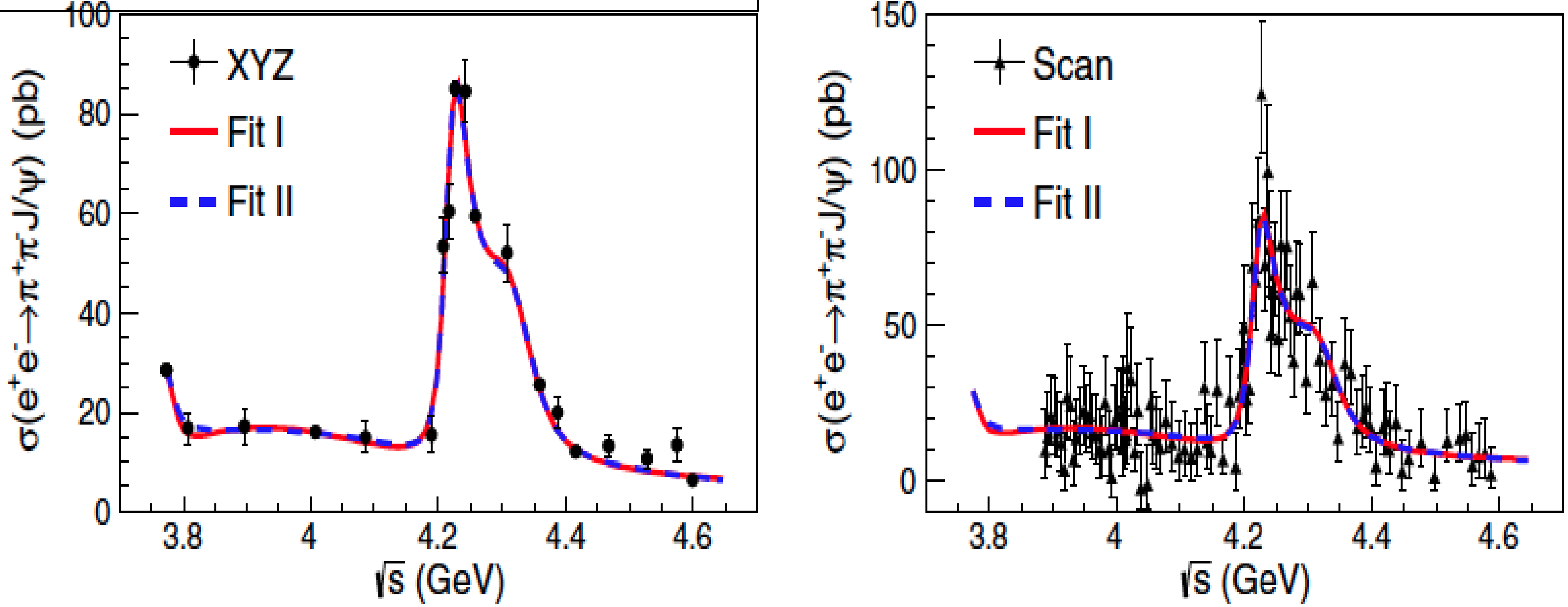
- Only $\omega\chi_{c0}$ has significant signal
- The cross section is fitted with coherent sum of a BW and a phase space term

  $M = 4230 \pm 8 \pm 6$ MeV , $\Gamma = 38 \pm 12 \pm 2$ MeV
- The mass and width are compatible with the Y observed in $\pi^+\pi^- J/\psi$ and $e^+e^- \rightarrow \pi^+\pi^- h_c$

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

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

BESIII



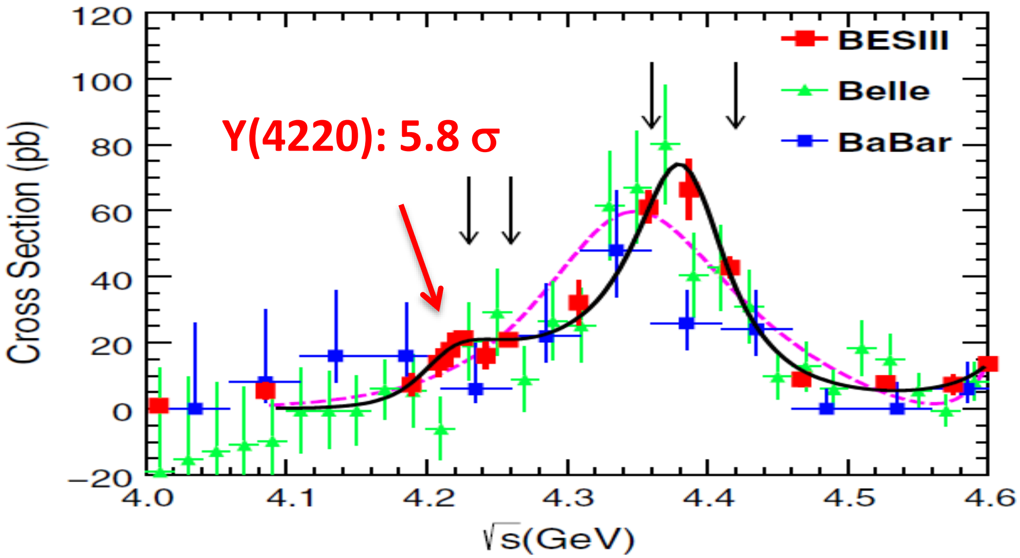
- ❑Coherent sum of two BW-like structures + one incoherent ψ(3770)
  - ➢M = (4222.0±3.1±1.4) MeV,   Γ = (44.1±4.3±2.0) MeV

    Lower and narrower than previous Y(4260) PDG values
  - ➢M = (4320.0±10.4±7) MeV,   Γ = (101.4±25±10) MeV

    a little bit lower than Y(4360) PDG value
- ❑Compared with one BW fit, the sig. of the second BW is 7.6σ
- ❑Y(4260) + Y(4360) ? The first observation of $Y(4360)\rightarrow\pi^+\pi^- J/\psi$?

Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^-\psi'$

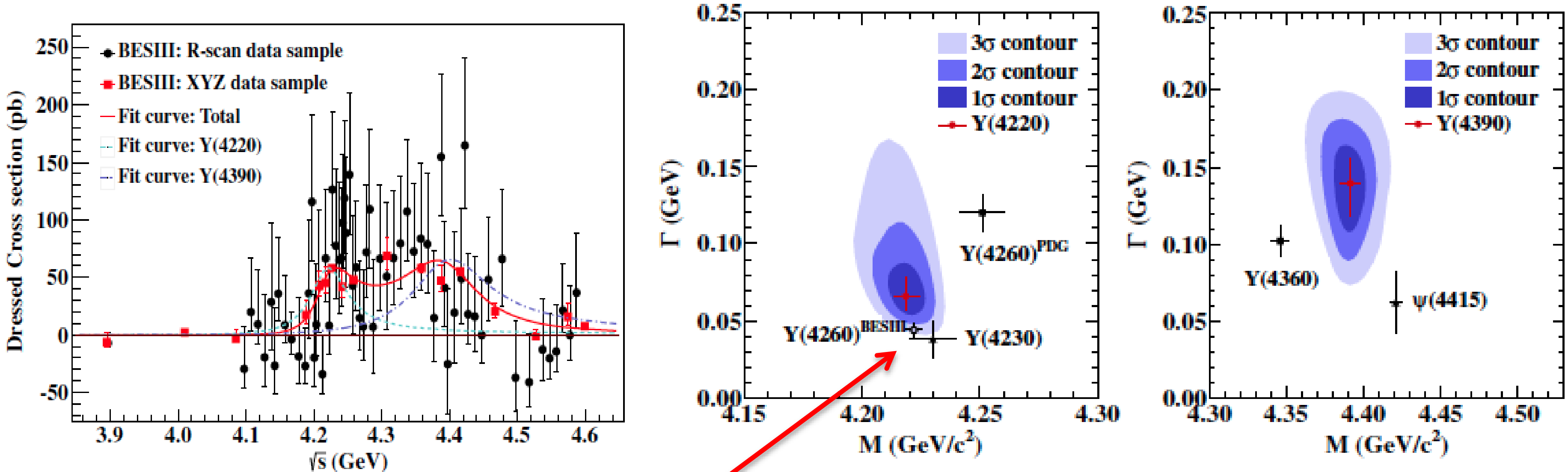
Phys. Rev. D 96, 032004 (2017)



- Cross section of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ has been measured at 16 energy points from 4.008 to 4.600 GeV.
- Solid curve: binned χ^2 fit with 3 coherent BWs -- Y(4220), Y(4360) and Y(4660)); dashed curve: 2 coherent BWs.
- A clear bump around Y(4360), consistent with the results from Belle and BaBar, but with much improved precision

Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^-h_c$

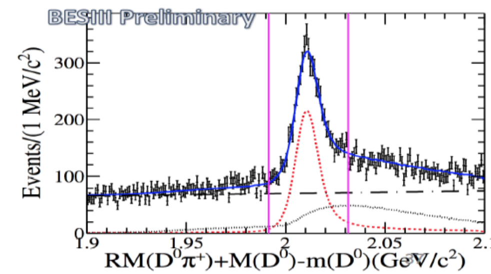
Phys. Rev. Lett., 118, 092002 (2017)



- **Fitted with coherent sum of two BW-like structures**
  - M_1=4218.4$^{+5.5}_{-4.5}$±0.9 MeV/c^2, Γ_1= 66.0$^{+12.3}_{-8.3}$±0.4 MeV → Y(4220)
  - M_2=4391.5$^{+6.3}_{-6.8}$±1.0 MeV/c^2, Γ_2=139.5$^{+16.2}_{-20.6}$±0.6 MeV → Y(4390)
- **The Y(4220) here is consistent with the state observed in $\pi^+\pi^-J/\psi$ around 4222MeV**

Cross section of $e^+e^- \to \pi^+ D^0 D^{*-}$+c.c.

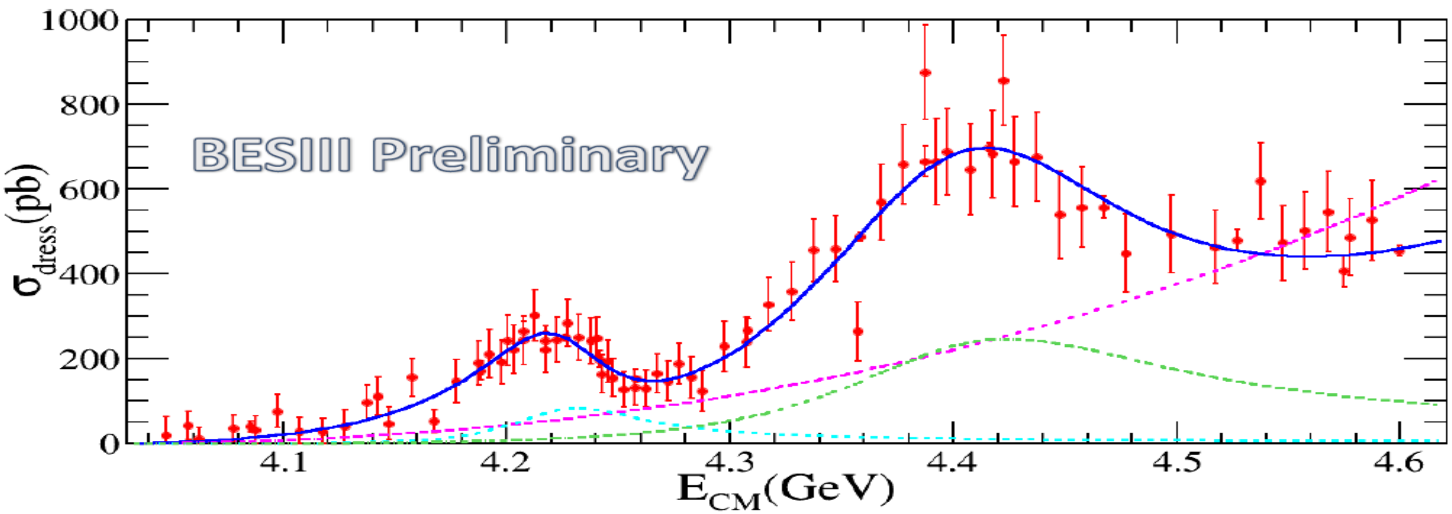
- Reconstruct $D^0 \to K^-\pi^+$
- Find another π^+
- 1.9 < $(RM(D^0\pi^+) + M(D^0) - m(D^0))$ < 2.1 GeV



Fit to the dressed cross section of $e^+e^- \to \pi^+ D^0 D^{*-}$+c.c.

$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)B(D^0 \to K^-\pi^+)\varepsilon}$$

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



Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

Resonant parameters

Parameters	SolutionI	SolutionII	SolutionIII	SolutionIV
$c\ (10^{-4})$	5.5±0.6			
$M_1\ (\mathrm{MeV}/c^2)$	4224.8±5.6			
$\Gamma_1\ (\mathrm{MeV})$	72.3±9.1			
$M_2\ (\mathrm{MeV}/c^2)$	4400.1±9.3			
$\Gamma_2\ (\mathrm{MeV})$	181.7±16.9			
$\Gamma_1^{\mathrm{el}}\ (\mathrm{eV})$	62.9±11.5	7.2±1.8	81.6±15.9	9.3±2.7
$\Gamma_2^{\mathrm{el}}\ (\mathrm{eV})$	88.5±15.8	55.3±8.7	551.9±85.3	344.9±70.6
ϕ_1	-2.1±0.1	2.8±0.3	-0.9±0.1	-2.3±0.2
ϕ_2	1.9±0.3	2.3±0.2	2.3±0.1	-1.9±0.1

The error are statistical only.

BESIII Preliminary

- Statistical significance is greater than 10σ.
- Consistent with those of Y(4220) and Y(4390) in $e^+e^- \to \pi^+\pi^- h_c$.

Masses and widths of vector charmonium states observed in different processes at BESIII

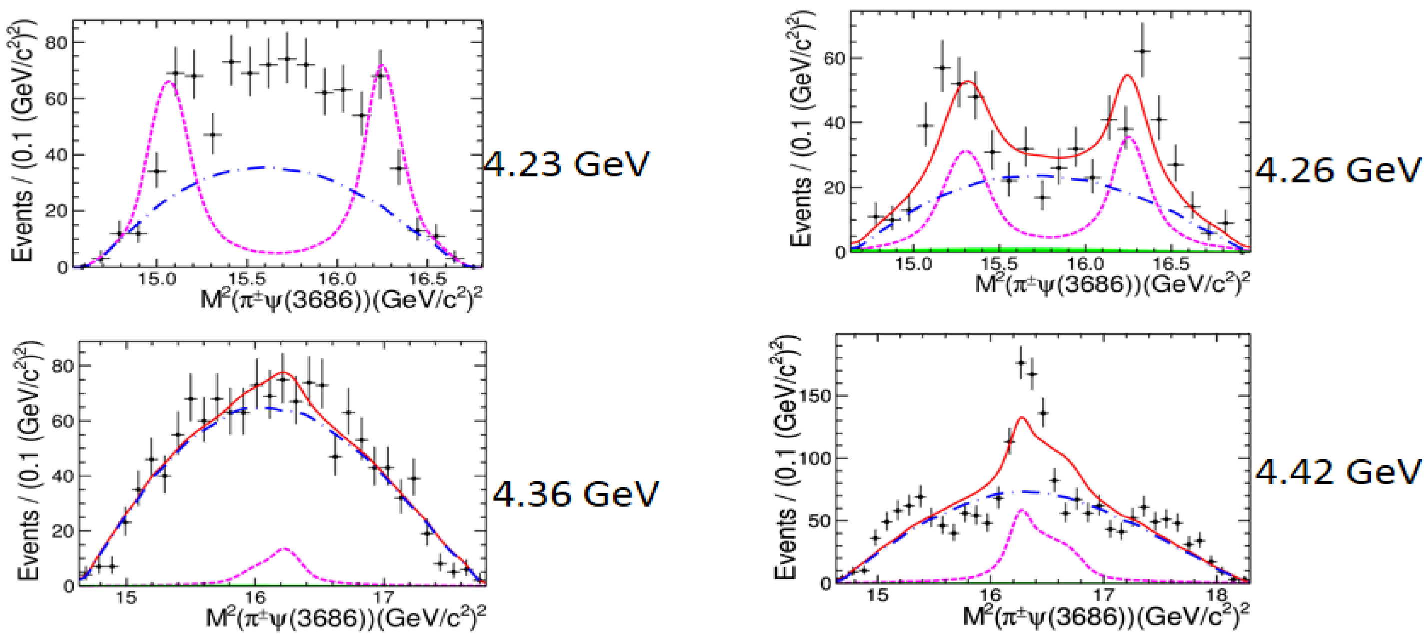
Process	M_1 (MeV/c^2)	Γ_1 (MeV)	M_2 (MeV/c^2)	Γ_2 (MeV)
$e^+e^- \to \omega\chi_{c0}$	$4230 \pm 8 \pm 6$	$38 \pm 12 \pm 2$ [37]		
$e^+e^- \to \pi^+\pi^- J/\psi$	$4220.0 \pm 3.1 \pm 1.4$	$44.1 \pm 4.3 \pm 2.0$	$4320.0 \pm 10.4 \pm 7.0$	$101.4^{+25.3}_{-19.7} \pm 10.2$ [9]
$e^+e^- \to \pi^+\pi^- h_c$	$4218.4^{+5.5}_{-4.5}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

BESIII $e^+e^- \to \pi^\pm\pi^\mp\psi(3686)$

Charged structures in $e^+e^- \to \pi^+\pi^-\psi'$

Unresolved discrepancies between the fit model (theory input) and data (stat.)

Phys. Rev. D 96, 032004 (2017)

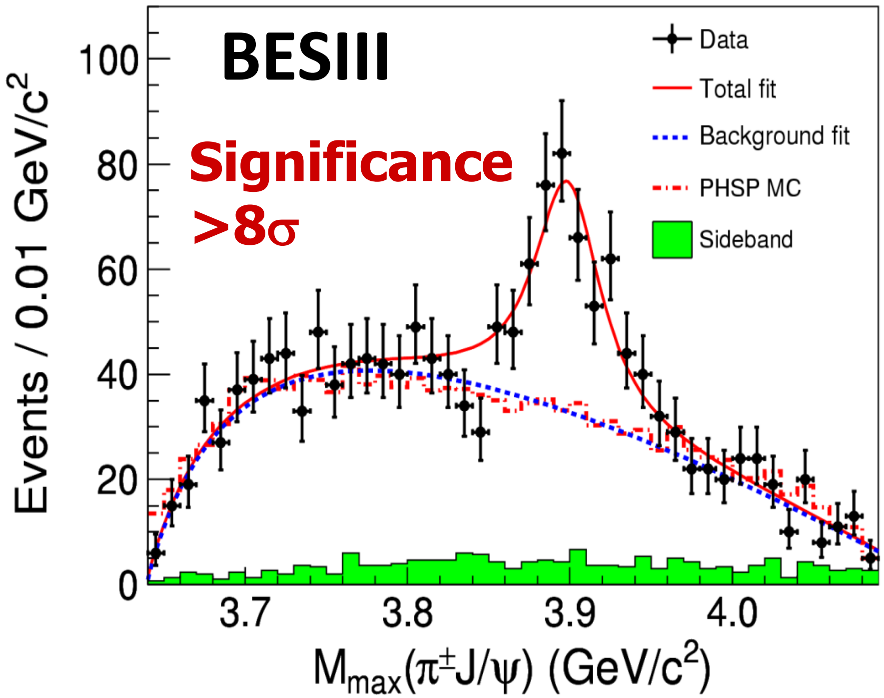


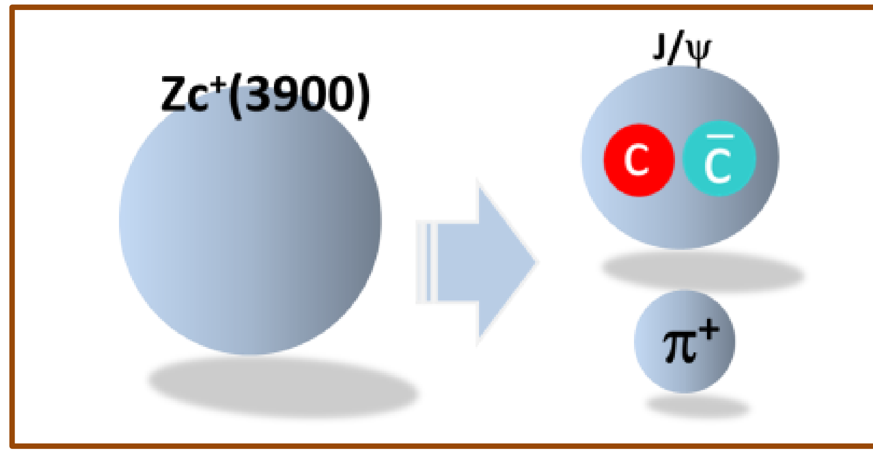
$\pi\psi(3686)$ spectra very different at different c.m. energies.

Z states

$Z_c^+(3900)$ in $e^+e^- \rightarrow Y(4260) \rightarrow \pi^+\pi^- J/\psi$

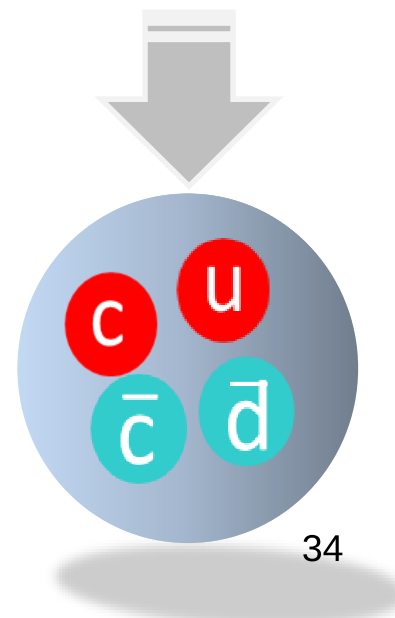
BESIII: PRL110, 252001 (2013)



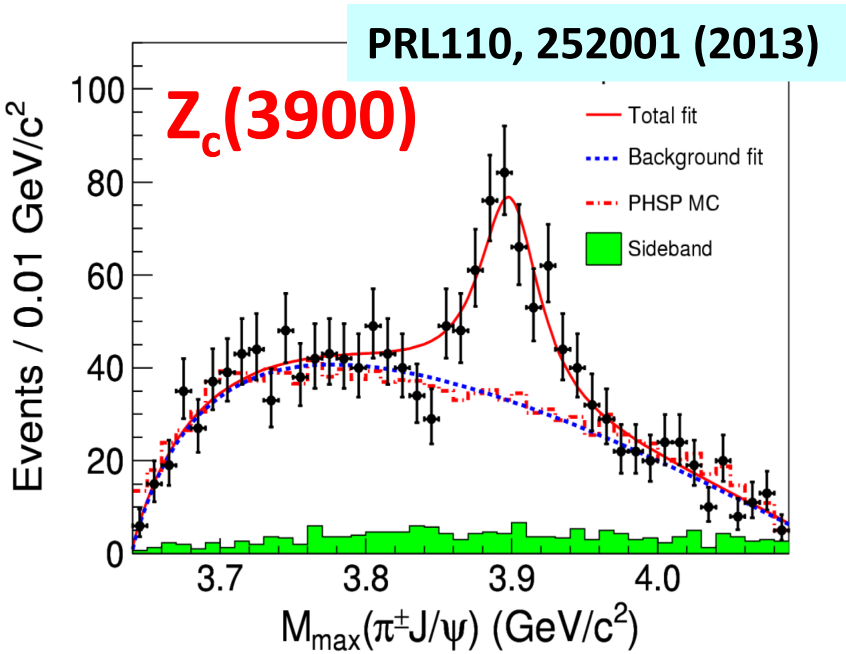


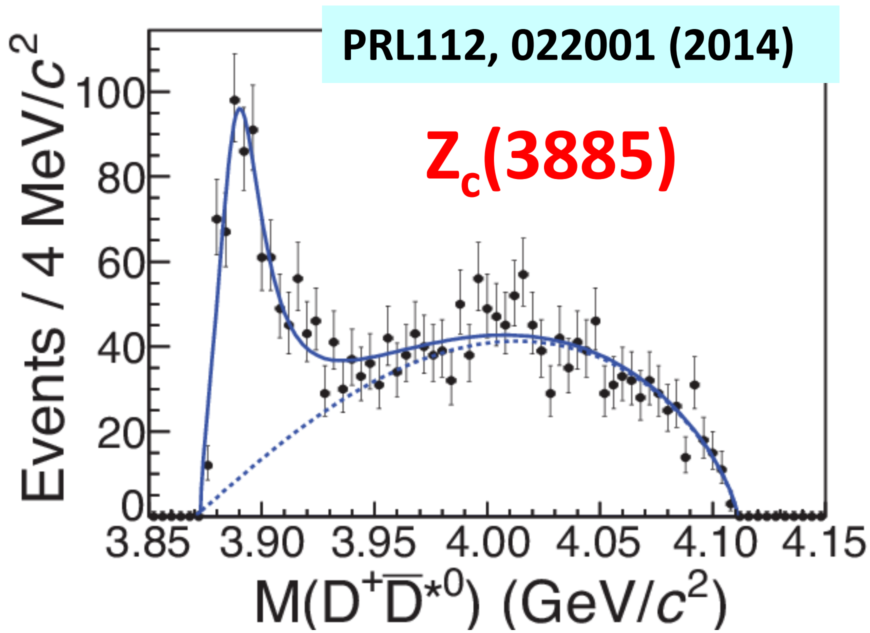
- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV
- $\Gamma = 46 \pm 10 \pm 20$ MeV
- 307 ± 48 events

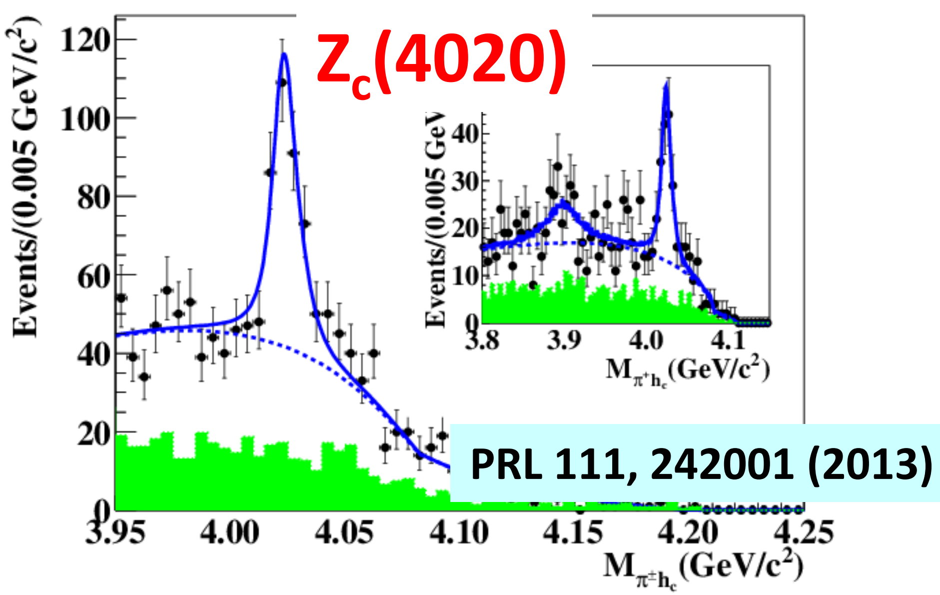
- Decays to $c\bar{c}$, has $c\bar{c}$
- Charged
- At least has 4 quarks

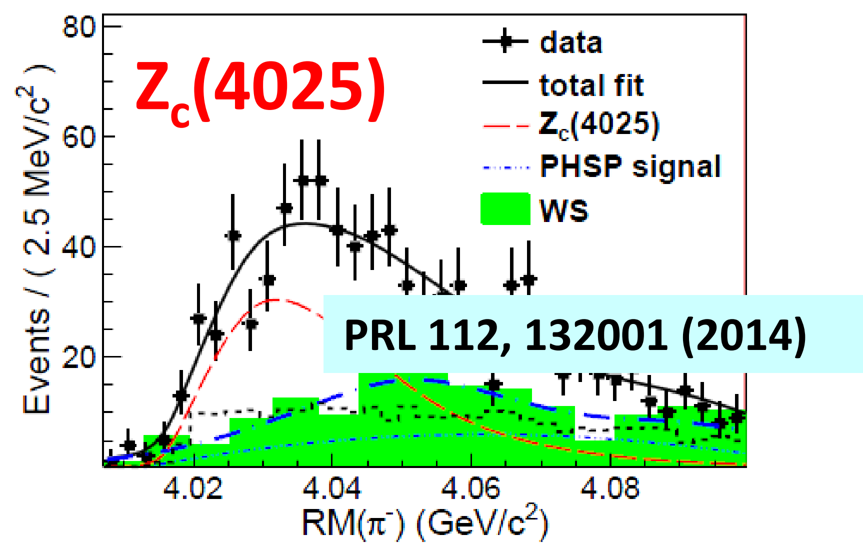


- 4 charged Zc's at BESIII





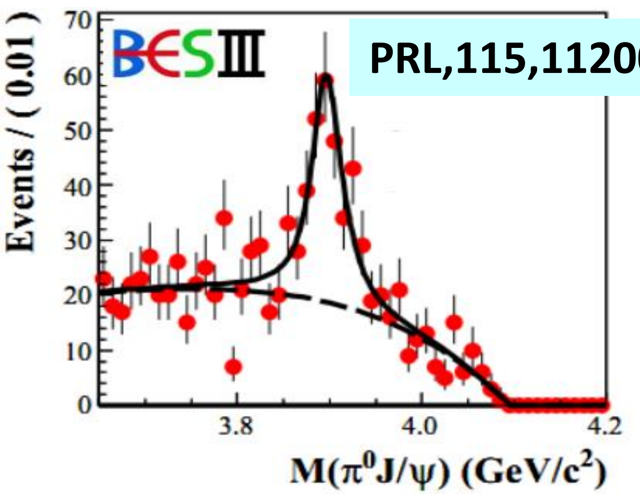




Neutral $Z_c(3900)$, $Z_c(3885)$, $Z_c(4020)$

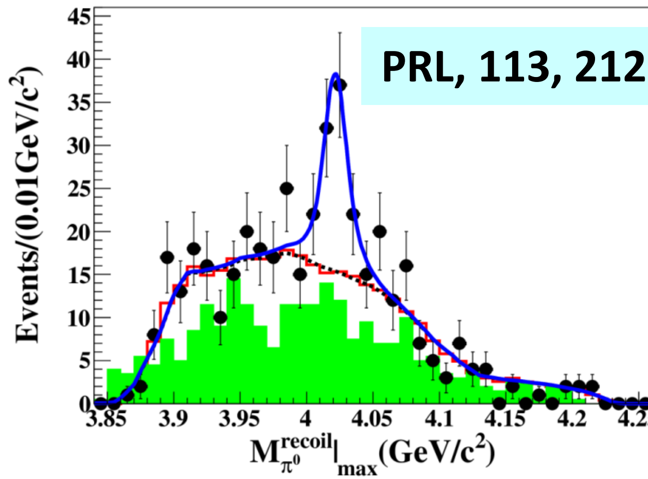
$Z_c^0(3900)$ in $e^+e^- \to \pi^0\pi^0 J/\psi$

PRL,115,112003(2015)



$Z_c^0(4020) \to \pi^0 h_c$ in $e^+e^- \to \pi^0\pi^0 h_c$

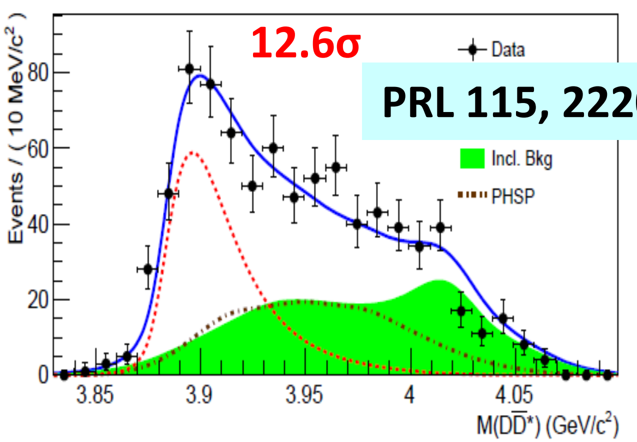
PRL, 113, 212002 (2014)



$e^+e^- \to Z_c(3885)^0\pi^0 \to (D\bar{D}^*)^0\,\pi^0$

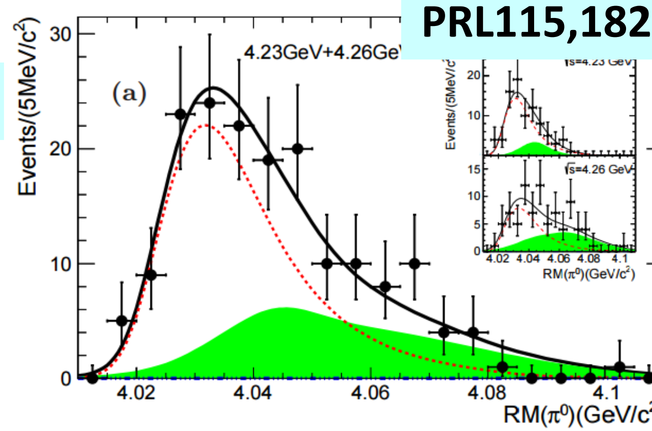
12.6σ

PRL 115, 222002(2015)

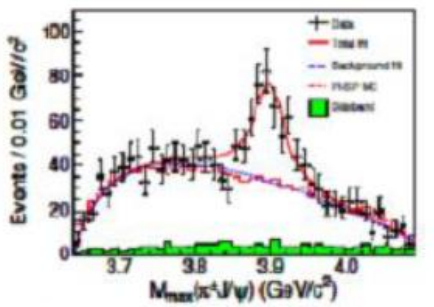


$Z_c(4025)^0$ in $e^+e^- \to (D^*\bar{D}^*)^0\pi^0$

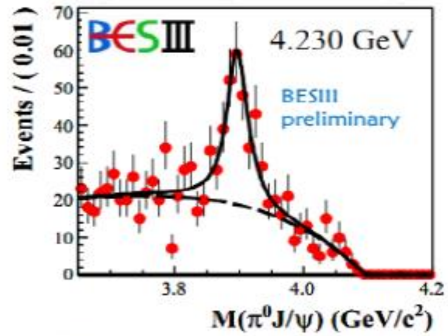
PRL115,182002(2015)



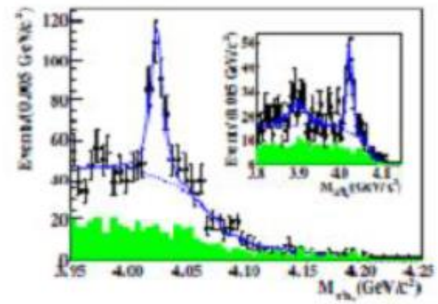
Summary of Z_c's at BESIII



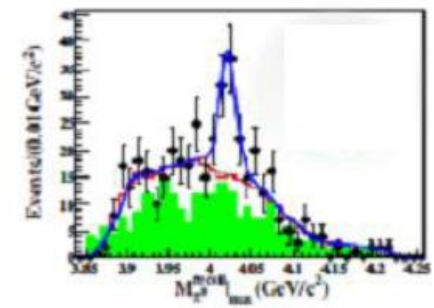
$e^+e^- \to \pi^-\pi^+ J/\psi$



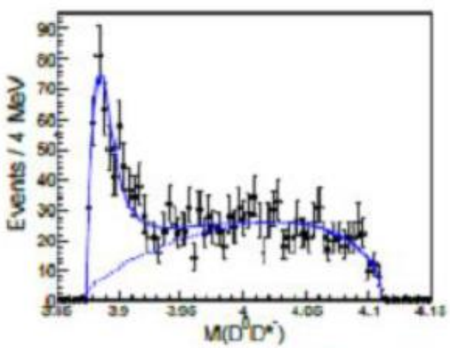
$e^+e^- \to \pi^0\pi^0 J/\psi$



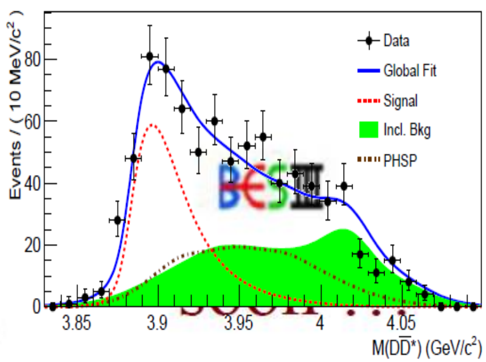
$e^+e^- \to \pi^-\pi^+ h_c$



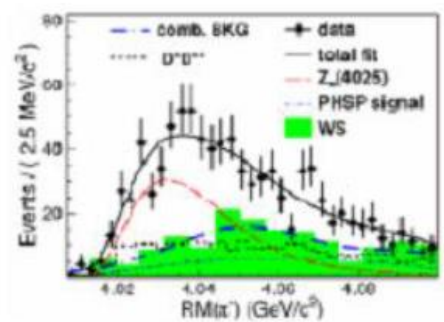
$e^+e^- \to \pi^0\pi^0 h_c$



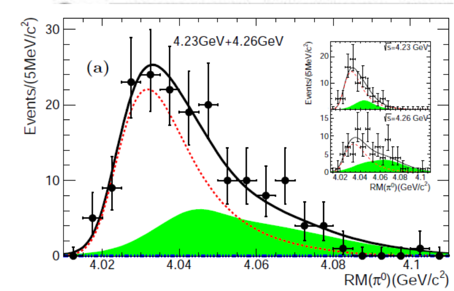
$e^+e^- \to \pi^-(D\bar{D}^*)^+$



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



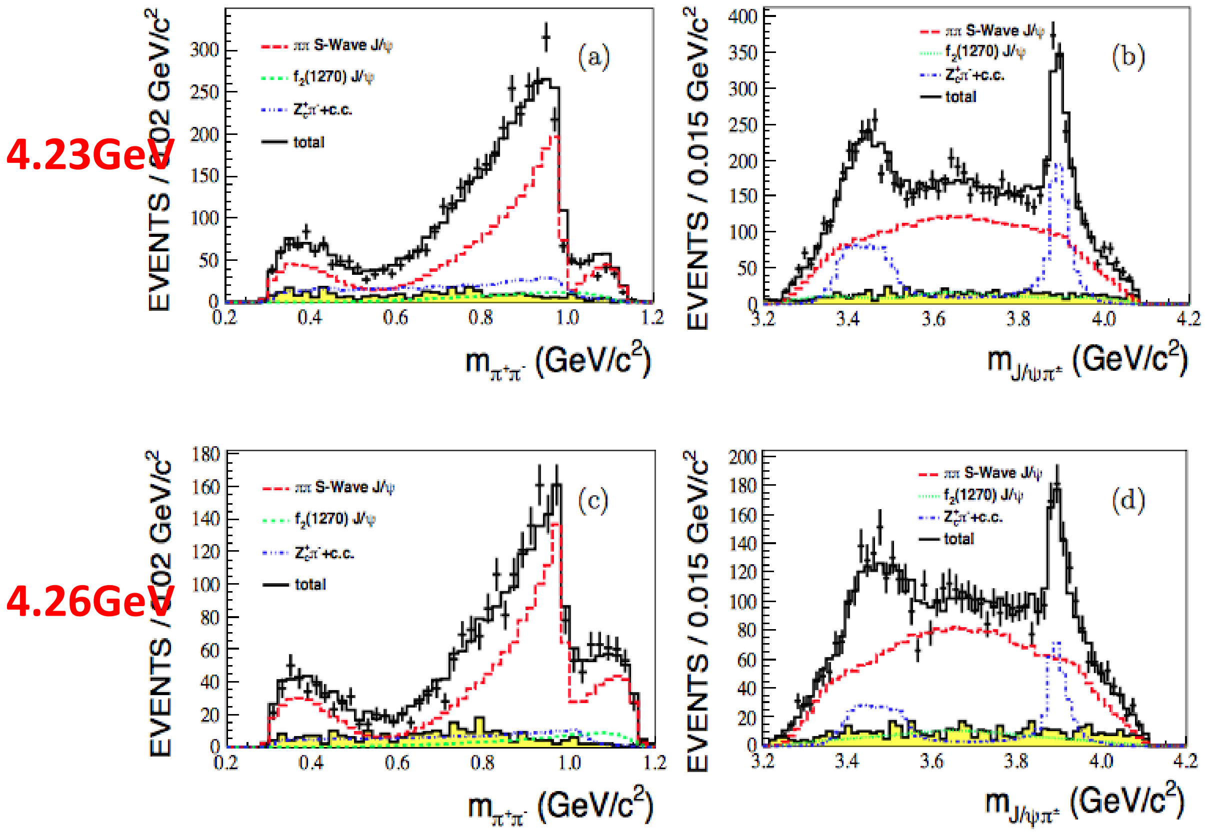
$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$



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

$Z_c(3900)^+$? **$Z_c(3900)^0$?** **$Z_c(4020)^+$?** **$Z_c(4020)^0$?**

Determination of J^P of $Z_c(3900)$ from $e^+e^- \to \pi^+\pi^- J/\psi$



J^P of Zc favor 1^+ with statistical significance larger than 7.3σ over other quantum numbers.

PRL 119, 072001 (2017)

- ❑Amplitude analysis with helicity formalism
- ❑Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- ❑$\pi^+\pi^-$ spectrum is parameterized by σ, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$

Determination of J^p of $Z_c(3900)$ from $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

PRL 119, 072001 (2017)

$Z_c : J^P$	M (MeV)	$g'_1(\mathrm{GeV}^2)$	g'_2/g'_1	$-\ln L$
0^-	3906.3 ± 2.3	0.079 ± 0.007	25.8 ± 2.9	-1528.8
1^-	3903.1 ± 1.9	0.063 ± 0.005	26.5 ± 2.6	-1457.7
1^+	3900.2 ± 1.5	0.075 ± 0.006	21.8 ± 1.7	-1569.8
2^-	3905.2 ± 2.1	0.060 ± 0.004	28.7 ± 2.7	-1516.5
2^+	3894.3 ± 1.9	0.051 ± 0.005	23.4 ± 3.3	-1316.2

- J^p of Z_c favor 1^+ with statistical significance larger than 7.3σ over other quantum number assumptions

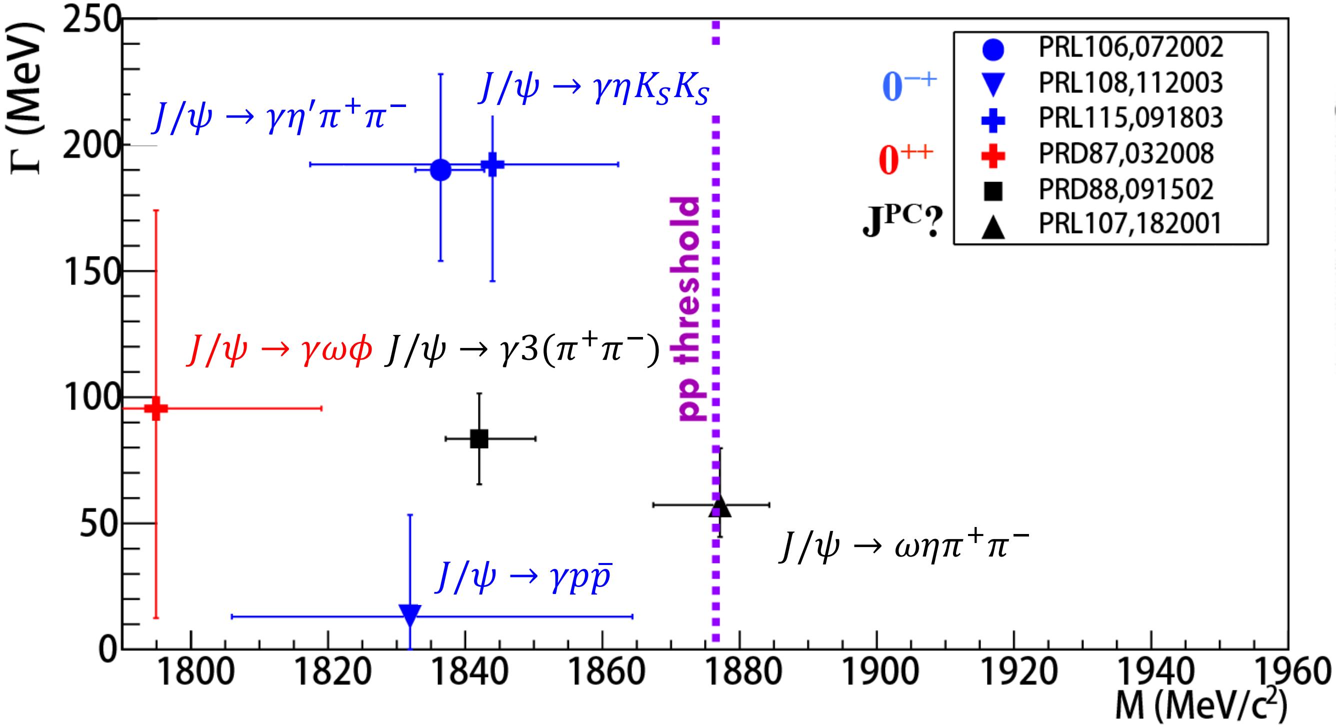
- Significance for $e^+e^- \rightarrow Z_c^+(4020)\ \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi$ is $\sim 3\sigma$.

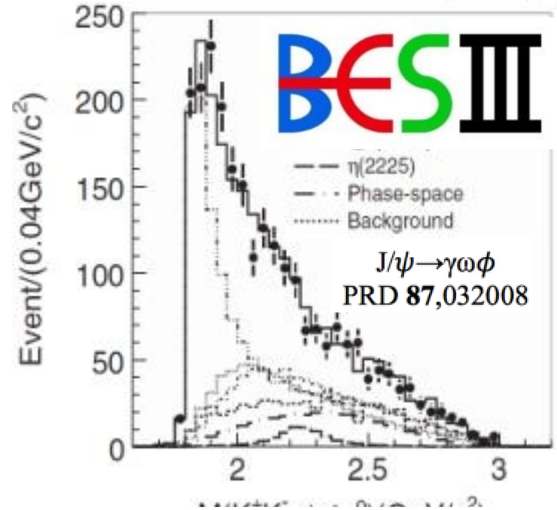
Upper limits at 90% C.L.:

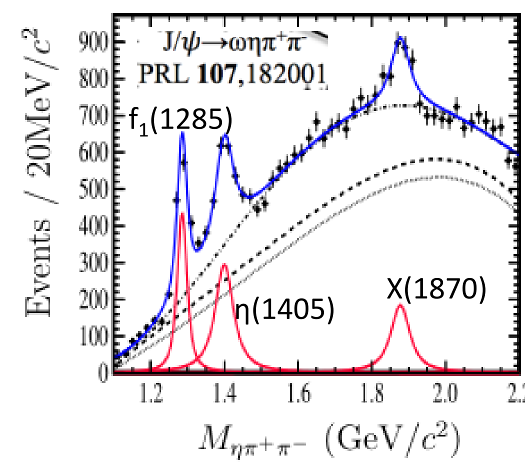
$$\frac{\sigma(e^+e^- \rightarrow Z_c^+(4020)\ \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \rightarrow Z_c^+(3900)\ \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi)} < 3.3\% \text{ at } 4.23 \text{ GeV}$$

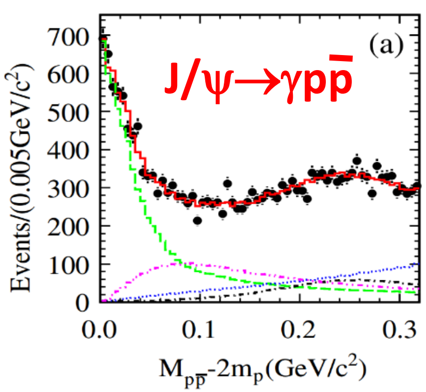
$<25.1\%$ at 4.26 GeV

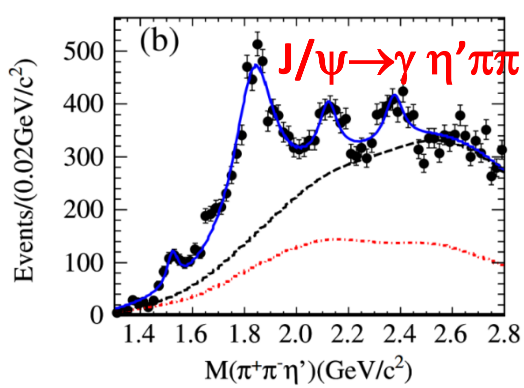
Light hadron spectroscopy from charmonium decays

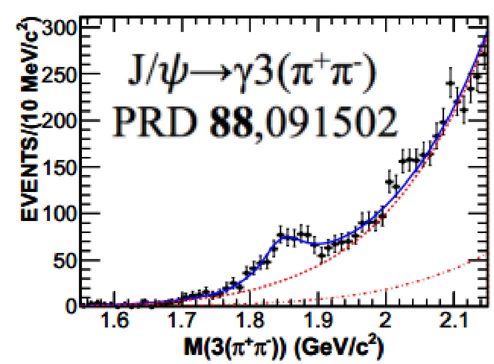










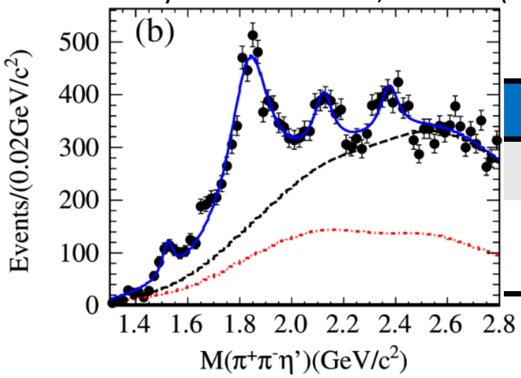


- **Any relations?**
- **What is the role of the ppbar threshold (and other thresholds)?**
- **Patterns in the production and decay modes**

Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold: connection between X(1835) and X($p\bar{p}$)

X(1835) observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$

Phys. Rev. Lett. 106, 072002 (2011)



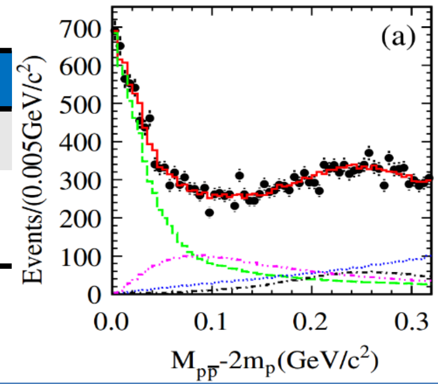
X(1835) $J^{PC}=0^{-+}$
$M = 1844 \pm 9^{+16}_{-25}$ MeV/c^2
$\Gamma = 192^{+20+62}_{-17-43}$ MeV/c^2

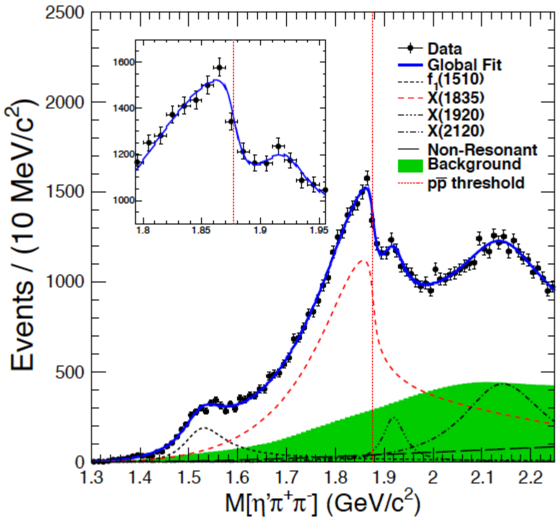
X($p\bar{p}$) observed in $J/\psi \to \gamma p\bar{p}$

PRL 108, 112003 (2012)

PRL 115, 091803 (2015)

X($p\bar{p}$) $J^{PC}=0^{-+}$
$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/c^2
$\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c^2 @ 90% C.L.)



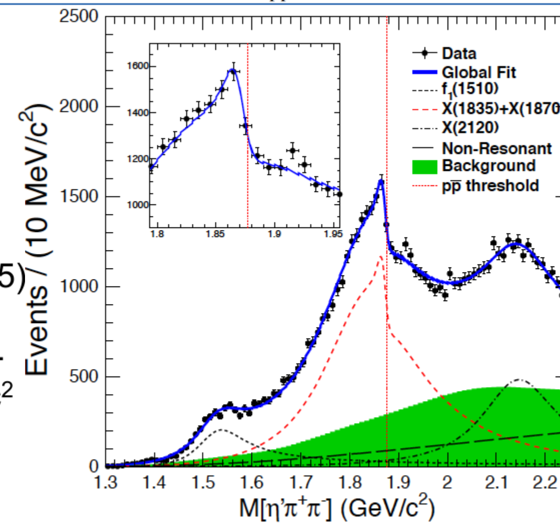


Connection is emerging

PRL 117, 042002 (2016)

Model 1:
Flatte lineshape with strong coupling to $p\bar{p}$ and one additional, narrow Breit-Wigner at ~1920 MeV/c^2

Model 2:
Coherent sum of X(1835) Breit-Wigner and one additional, narrow Breit-Wigner at ~1870 MeV/c^2



- **Suggest the existence of a state, either a broad one with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass thresh.**
- **Support the existence of a $p\bar{p}$ molecule-like state or bound state**

Λ_c^+ experimental status

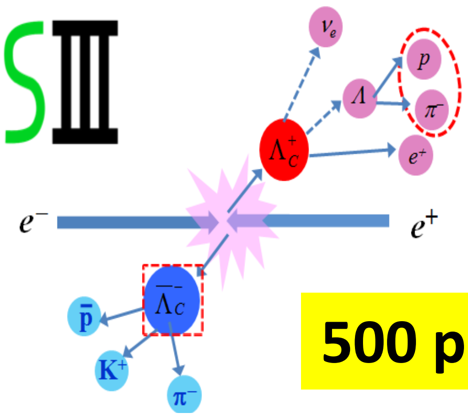
Λ_c Measurements [PDG2015]

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	$\Delta B/B$
Hadronic modes with a p: $S=-1$ final states				
$p\overline{K}^0$		(3.21 ± 0.30) %		9.3%
$pK^-\pi^+$		$(6.84^{+0.32}_{-0.40})$ %		5.8%
$p\overline{K}^*(892)^0$	[q]	(2.13 ± 0.30) %		14.1%
$\Delta(1232)^{++}K^-$		(1.18 ± 0.27) %		22.9%
$\Lambda(1520)\pi^+$	[q]	(2.4 ± 0.6) %		25.0%
$pK^-\pi^+$ nonresonant		(3.8 ± 0.4) %		10.5%
$p\overline{K}^0\pi^0$		(4.5 ± 0.6) %		13.3%
$p\overline{K}^0\eta$		(1.7 ± 0.4) %		23.5%
$p\overline{K}^0\pi^+\pi^-$		(3.5 ± 0.4) %		11.4%
$pK^-\pi^+\pi^0$		(4.6 ± 0.8) %		13.0%
$pK^*(892)^-\pi^+$	[q]	(1.5 ± 0.5) %		33.3%
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(5.0 ± 0.9) %		18.0%
$\Delta(1232)\overline{K}^*(892)$		seen		
$pK^-\pi^+\pi^+\pi^-$		$(1.5\pm1.0)\times10^{-3}$		66.7%
$pK^-\pi^+\pi^0\pi^0$		(1.1 ± 0.5) %		45.4%
Hadronic modes with a p: $S=0$ final states				
$p\pi^+\pi^-$		$(4.7\pm2.5)\times10^{-3}$		45.4%
$pf_0(980)$	[q]	$(3.8\pm2.5)\times10^{-3}$		53.2%
$p\pi^+\pi^+\pi^-\pi^-$		$(2.5\pm1.6)\times10^{-3}$		64.0%
pK^+K^-		$(1.1\pm0.4)\times10^{-3}$		36.4%
$p\phi$	[q]	$(1.12\pm0.23)\times10^{-3}$		
pK^+K^- non-ϕ		$(4.8\pm1.9)\times10^{-4}$		
Hadronic modes with a hyperon: $S=-1$ final states				
$\Lambda\pi^+$		(1.46 ± 0.13) %		8.9%
$\Lambda\pi^+\pi^0$		(5.0 ± 1.3) %		26.0%
$\Lambda\rho^+$		<6 %	CL=95%	
$\Lambda\pi^+\pi^+\pi^-$		(3.59 ± 0.28) %		7.8%
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		(1.0 ± 0.5) %		20.0%
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		$(7.5\pm1.4)\times10^{-3}$		18.7%

Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	$\Delta B/B$
$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %		42.8%
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		$(5\pm4)\times10^{-3}$		80.0%
$\Lambda\pi^+\pi^+\pi^-$ nonresonant		<1.1 %	CL=90%	
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(2.5 ± 0.9) %		36.0%
$\Lambda\pi^+\eta$	[q]	(2.4 ± 0.5) %		20.8%
$\Sigma(1385)^+\eta$	[q]	(1.16 ± 0.35) %		30.2%
$\Lambda\pi^+\omega$	[q]	(1.6 ± 0.6) %		37.5%
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		$<9\times10^{-3}$	CL=90%	
$\Lambda K^+\overline{K}^0$		$(6.4\pm1.3)\times10^{-3}$	S=1.6	20.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		$(1.8\pm0.6)\times10^{-3}$		33.3%
$\Sigma^0\pi^+$		(1.43 ± 0.14) %		10.0%
$\Sigma^+\pi^0$		(1.37 ± 0.30) %		21.9%
$\Sigma^+\eta$		$(7.5\pm2.5)\times10^{-3}$		33.3%
$\Sigma^+\pi^+\pi^-$		(4.9 ± 0.5) %		10.2%
$\Sigma^+\rho^0$		<1.8 %	CL=95%	
$\Sigma^-\pi^+\pi^+$		(2.3 ± 0.4) %		17.4%
$\Sigma^0\pi^+\pi^0$		(2.5 ± 0.9) %		36.0%
$\Sigma^0\pi^+\pi^+\pi^-$		(1.13 ± 0.31) %		27.4%
$\Sigma^+\pi^+\pi^-\pi^0$		—		
$\Sigma^+\omega$	[q]	(3.7 ± 1.0) %		27.1%
$\Sigma^+K^+K^-$		$(3.8\pm0.6)\times10^{-3}$		15.8%
$\Sigma^+\phi$	[q]	$(4.3\pm0.7)\times10^{-3}$		16.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Sigma^+K^-$		$(1.11\pm0.29)\times10^{-3}$		26.2%
$\Sigma^+K^+K^-$ nonresonant		$<9\times10^{-4}$	CL=90%	
Ξ^0K^+		$(5.3\pm1.3)\times10^{-3}$		24.5%
$\Xi^-K^+\pi^+$		$(7.0\pm0.8)\times10^{-3}$	S=1.1	11.4%
$\Xi(1530)^0K^+$	[q]	$(3.5\pm1.0)\times10^{-3}$		28.6%
Hadronic modes with a hyperon: $S=0$ final states				
ΛK^+		$(6.9\pm1.4)\times10^{-4}$		20.3%
$\Lambda K^+\pi^+\pi^-$		$<6\times10^{-4}$	CL=90%	
Σ^0K^+		$(5.7\pm1.0)\times10^{-4}$		17.5%
$\Sigma^0K^+\pi^+\pi^-$		$<2.9\times10^{-4}$	CL=90%	
$\Sigma^+K^+\pi^-$		$(2.3\pm0.7)\times10^{-3}$		30.4%
$\Sigma^+K^*(892)^0$	[q]	$(3.8\pm1.2)\times10^{-3}$		31.6%
$\Sigma^-K^+\pi^+$		$<1.3\times10^{-3}$	CL=90%	
…suppressed modes				
		$<3.1\times10^{-4}$	CL=90%	
…nic modes				
		(2.8 ± 0.4) %		
		(2.9 ± 0.5) %		17.2%
		(2.7 ± 0.6) %		22.2%

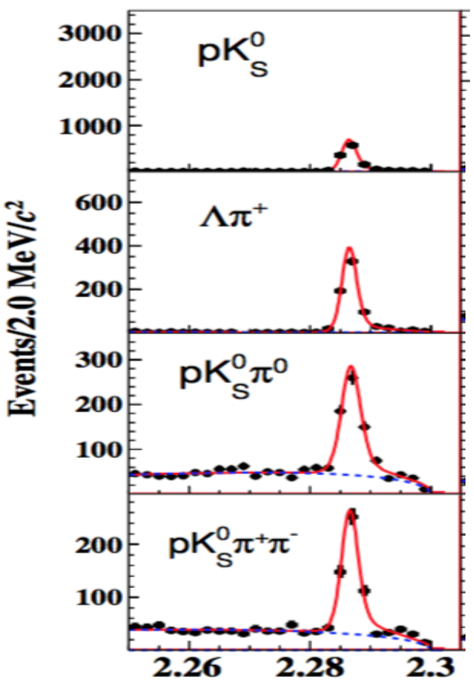
- **Total BFs < 65%**
- **Large uncertainties, most larger than 20%**
- **Most BFs are measured relative to $\Lambda c \to pK\pi$**

Absolute BFs of Λ_c^+ Cabibbo-Favored hadronic decays



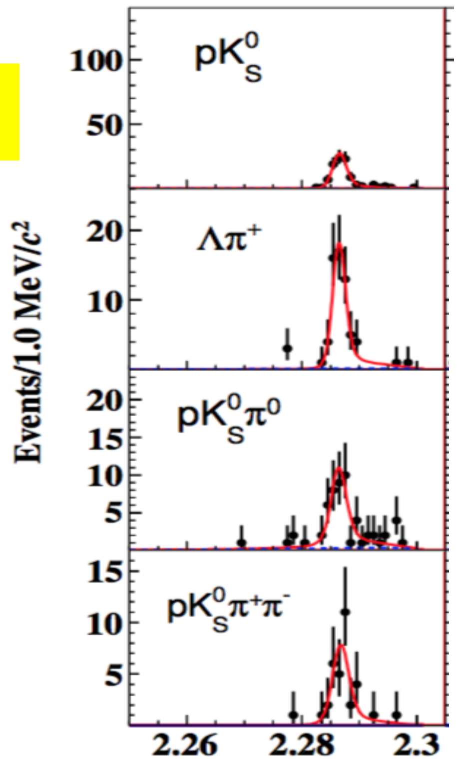
Signal Tag Variable : $M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$

500 pb^{-1} @ 4.6 GeV



ST yields

modes	N_i^{ST}
pK_S	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK_S\pi^0$	558 ± 33
$pK_S\pi^+\pi^-$	454 ± 28
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	586 ± 32
$\Sigma^+\pi^0$	271 ± 25
$\Sigma^+\pi^+\pi^-$	836 ± 43
$\Sigma^+\omega$	157 ± 22



DT yields

Decay modes	N_{-j}^{DT}
pK_S	89 ± 10
$pK^-\pi^+$	390 ± 21
$pK_S\pi^0$	40 ± 7
$pK_S\pi^+\pi^-$	29 ± 6
$pK^-\pi^+\pi^0$	148 ± 14
$\Lambda\pi^+$	59 ± 8
$\Lambda\pi^+\pi^0$	89 ± 11
$\Lambda\pi^+\pi^-\pi^+$	53 ± 7
$\Sigma^0\pi^+$	39 ± 6
$\Sigma^+\pi^0$	20 ± 5
$\Sigma^+\pi^+\pi^-$	56 ± 8
$\Sigma^+\omega$	13 ± 3

Almost background free

PRL 116, 052001 (2016)

Results of 12 CF hadronic BFs

- ☐ Straightforward and model independent *PRL 116, 052001 (2016)*
- ☐ A least square global simultaneous fit : *[CPC 37, 106201 (2013)]*

Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

- ☐ $B(\Lambda_c^+ \to pK^-\pi^+)$: BESIII precision comparable with Belle's
- ☐ BESIII $B(\Lambda_c^+ \to pK^-\pi^+)$ is compatible with BELLE's within 2σ
- ☐ Improved precisions of the other 11 modes significantly

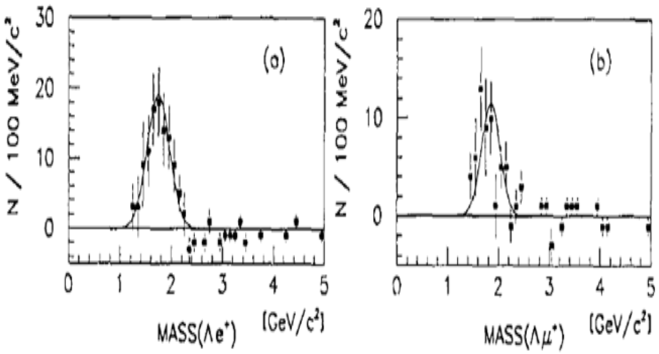
Semi-Leptonic decay $\Lambda_c^+ \to \Lambda l^+ \nu_l$

- ARGUS first measurement :

  Phys. Lett. B 269, 234 (1991).

$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71\ \mathrm{pb}$$

$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda \mu^+ X) = 3.91 \pm 2.02 \pm 0.90\ \mathrm{pb}$$

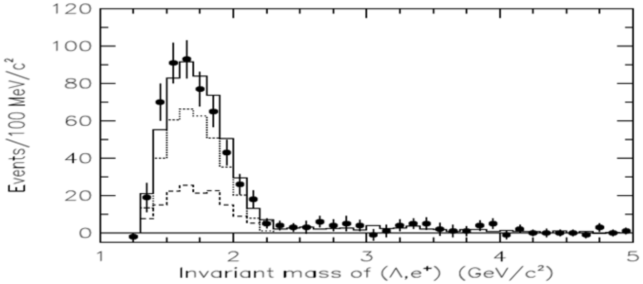


- CLEO improved measurement :

  Phys. Lett. B 323, 219 (1994).

$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda e^+ X) = 4.87 \pm 0.28 \pm 0.69\ \mathrm{pb}$$

$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda \mu^+ X) = 4.43 \pm 0.51 \pm 0.64\ \mathrm{pb}$$



- Combined with the $\tau(\Lambda_c^+)$ and the assumption of form factors

$\Lambda \ell^+ \nu_\ell$	***PDG 2015***	[r]	(2.8 ± 0.4) %
$\Lambda e^+ \nu_e$			(2.9 ± 0.5) %
$\Lambda \mu^+ \nu_\mu$			(2.7 ± 0.6) %

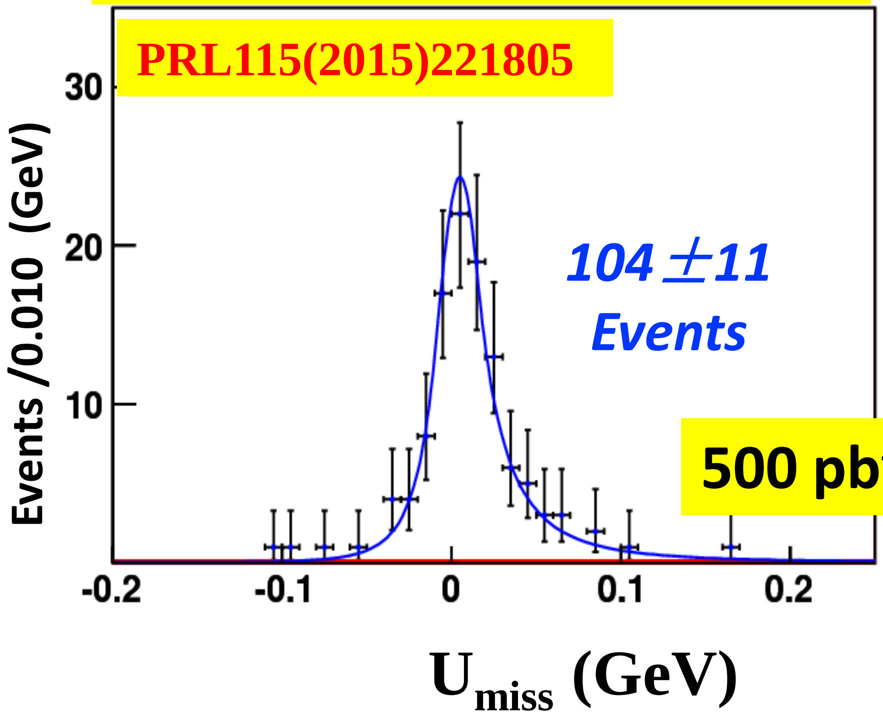
Not a direct measurement!

Theoretical calculations on the BF ranges from 1.4% to 9.2%

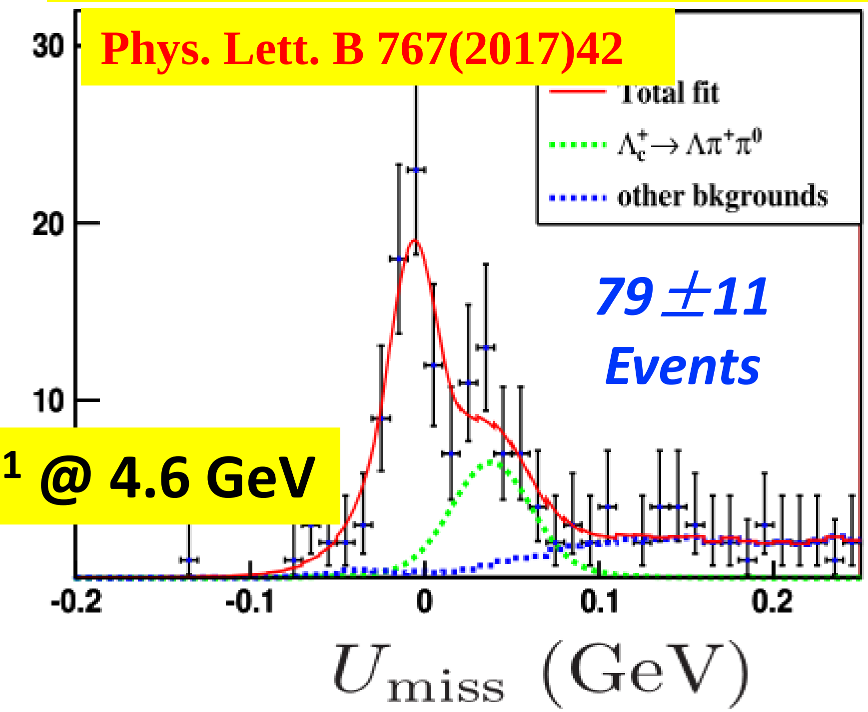
BFs of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ decays

First direct measurement, optimized variables : $U_{\rm miss} = E_{\rm miss} - c|\vec{p}_{\rm miss}|$

$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$



$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$



500 pb^{-1} @ 4.6 GeV

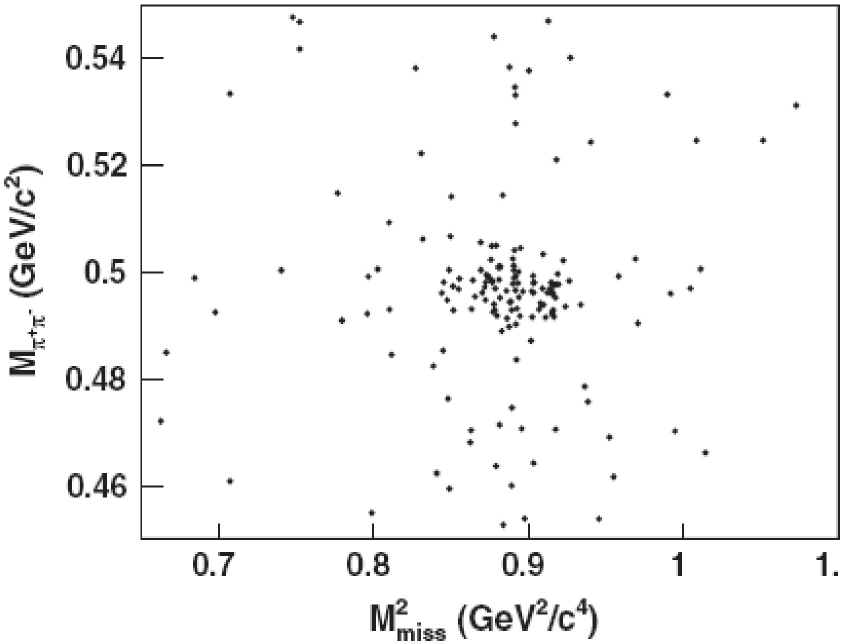
$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

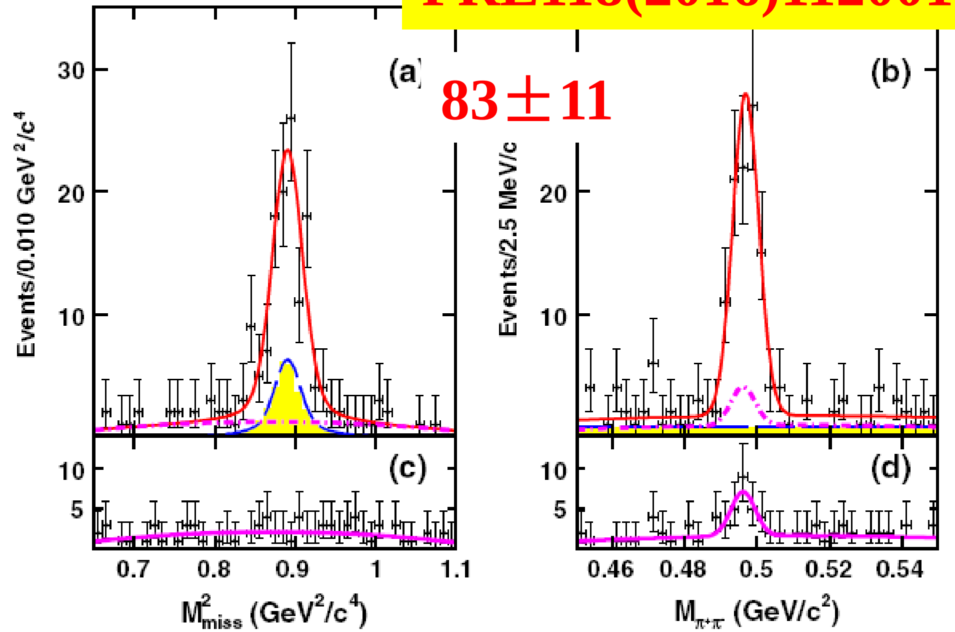
Important to test and calibrate LQCD and lepton universality.

Observation of $\Lambda_c^+ \to nK_S^0\pi^+$

First observation of Λ_c^+ decays involving the neutron in final states.

PRL118(2016)112001





$B[\Lambda_c^+ \to nK_S^0\pi^+] = (1.82\pm0.23\pm0.11)\%$

$B[\Lambda_c^+ \to nK^0\pi^+]/B[\Lambda_c^+ \to pK^-\pi^+] = 0.62\pm0.09$

$B[\Lambda_c^+ \to nK^0\pi^+]/B[\Lambda_c^+ \to pK^0\pi^0] = 0.97\pm0.16$

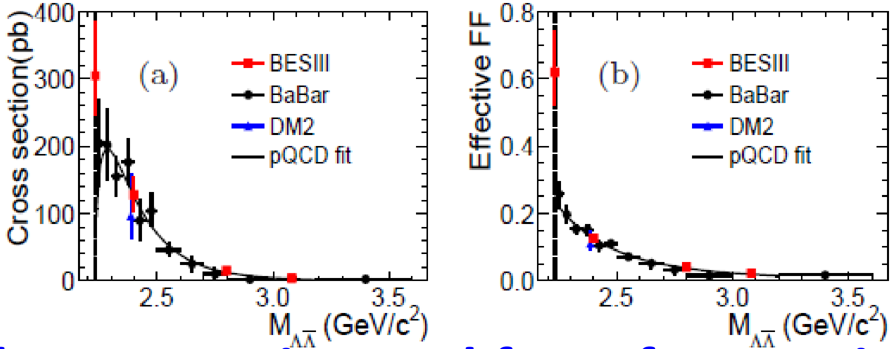
The phase difference between $I^{(0)}$ and $I^{(1)}$:

$\cos\delta = -0.24 \pm 0.08$

and relative strength: $|I^{(1)}|/|I^{(0)}| = 1.14 \pm 0.11$

The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry and extract the strong phases of different final states.

Cross section measurement of $e^+e^- \to \Lambda\bar{\Lambda}$



arXiv:1709.10236 , Submitted to PRL

– Measured cross section and form factor with improved precision

– Threshold effect in form factor contradicts with theoretical expectation

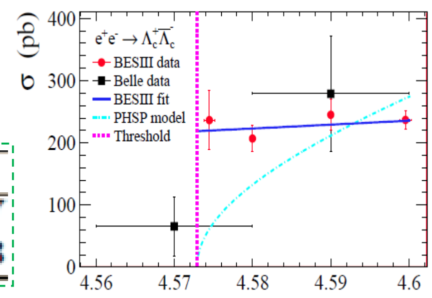
Cross section measurement of $e^+e^- \to \Lambda_c\bar{\Lambda}_c$

arXiv:1710.00150 , Submitted to PRL

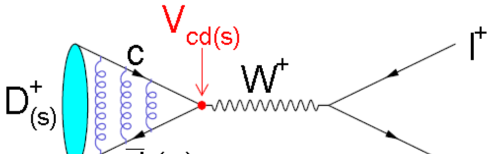
– Confirmed threshold effect

– First measurement of $|G_E/G_M|$

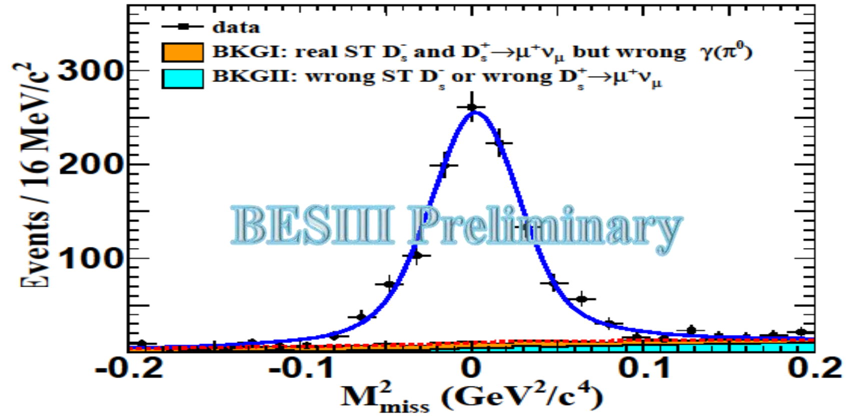
$\sqrt{s}$ (MeV)	$\lvert G_E/G_M \rvert$
4574.5	$1.14 \pm 0.14 \pm 0.07$
4599.5	$1.23 \pm 0.05 \pm 0.03$



$D_s^+ \to \mu^+ \nu$ @ 4.18 GeV (3 fb^{-1})



$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

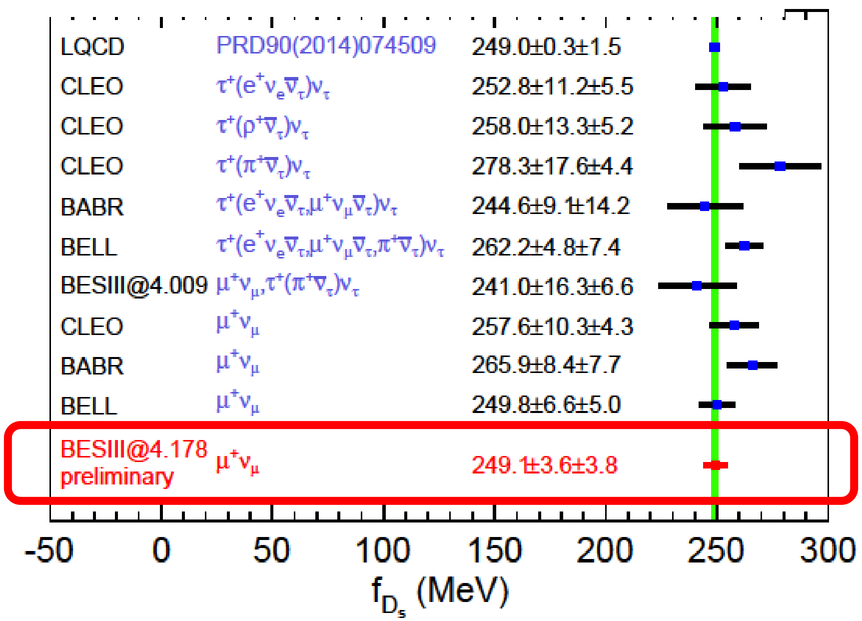


Bridge to precisely measure

- ✓ Decay constant f_{D_s+} with input $|V_{cs}|^{CKMfitter}$
- ✓ CKM matrix element $|V_{cs}|$ with input f^{LQCD}_{Ds+}

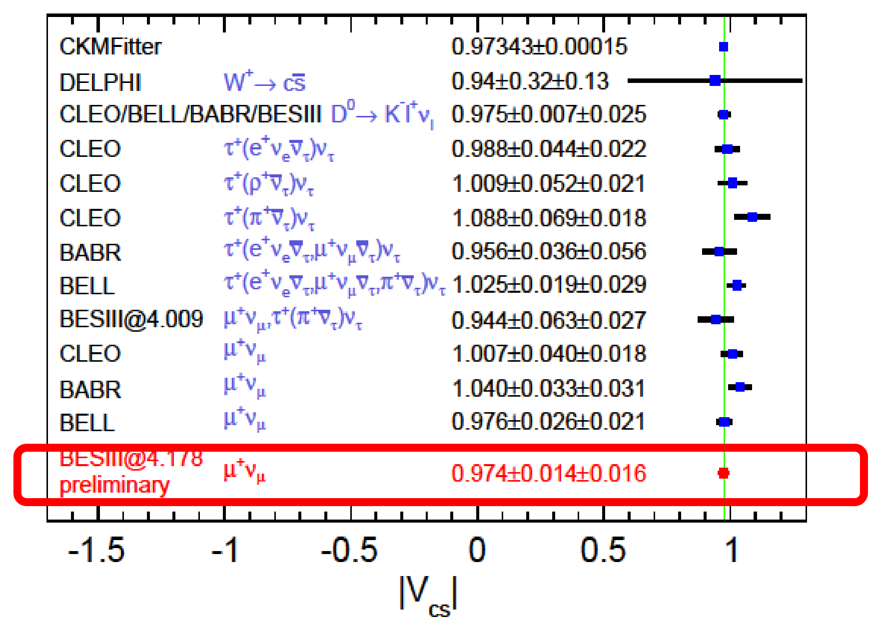
Take $|V_{cs}|^{CKMfitter}$ as input：

$$f_{D_s^+} = 249.1 \pm 3.6_{stat.} \pm 3.8_{syst.} \text{ MeV}$$



Take f_{Ds}^{LQCD} as input：

$$|V_{cs}| = 0.974 \pm 0.014_{stat.} \pm 0.016_{syst.}$$



Upgrade plan and physics prospects

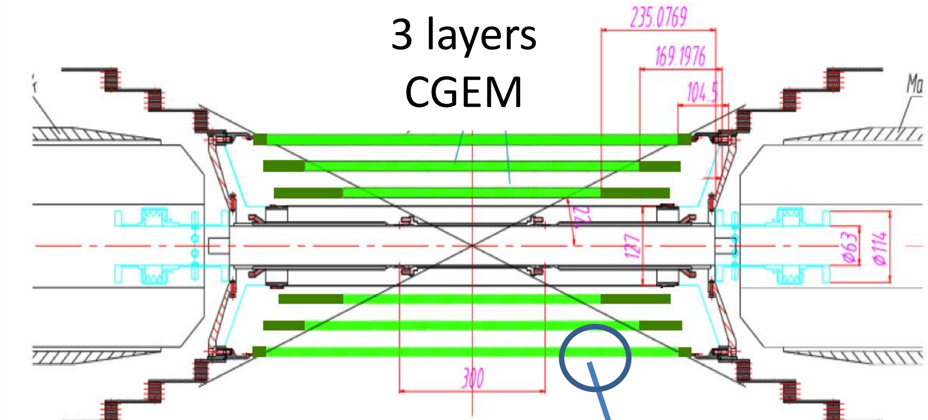
BESIII upgrade

- ☐ ETOF → MRPC: 120ps → 60 ps, finished in Oct. 2015
- ☐ MDC: Malter effect found in inner chamber in 2012, add water vapor to the chamber to cure the aging problem.
  - New inner chamber, built by IHEP, is ready now.
  - CGEM as the inner chamber ongoing : Italy group in collaboration with other groups.

- ☐ Crystal Zero Degree detector
- ☐ New valve box for superconducting magnet
- ☐ Other possible upgrade plan is under discussion

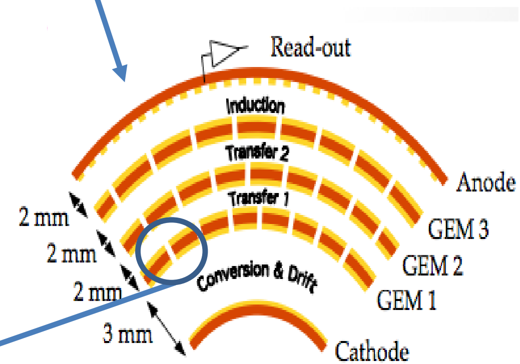
Cylindrical GEM Inner Tracker

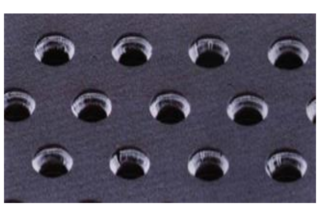
BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.



- Low Material budget ≤ 1.5% of X_0 for all layers
- High Rate capability: ~10^4 Hz/cm^2
- Coverage: 93%
- Spatial resolution $\sigma_{r\phi}$ ~130 μm in 1 T magnetic filed
- Operation duration at least 5 years

Each layer composed by a triple cylindrical GEM





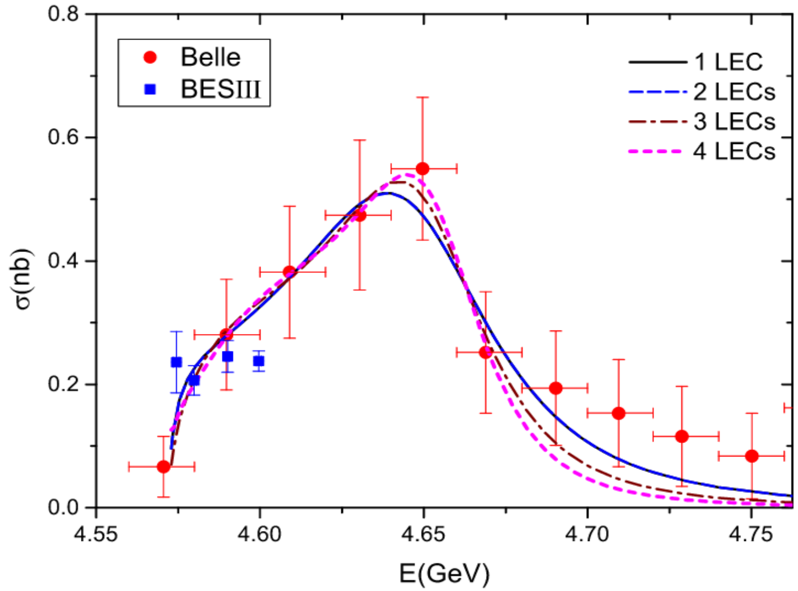
The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

Formation of a consortium: INFN (Ferrara, Frascati, Perugia and Torino), Mainz, Uppsala, IHEP

- **Will challenge accelerator beam energy limit**

from 2.30 →2.35→ 2.45 GeV(4.6→ 4.7→4.9 GeV)

- ➢ **Λc study**



With larger Λ_c data sample

- **PWA ⇒ intermediate structures in 3-body decays**
- **More semileptonic decays: $nl\nu$, $\Lambda^* l\nu$, $\Sigma X l\nu$ …**
- **Decay asymmetry parameters α ⇐ $\Lambda_c^+ \rightarrow BP/BV$**
- **Λ_c^+ Rare decays search**
  - **Weak radiative decay $\Lambda_c^+ \rightarrow \gamma\Sigma^+$**
  - **FCNC $\Lambda_c^+ \rightarrow p l^+ l^-$**
  - **LNV $\Lambda_c^+ \rightarrow p e \mu$**

- ➢ **XYZ study: Y(4660), ….**

- **Accelerator top-up project**

data taking efficiency: increased by 20-30%

BESIII data taking status & plan (run ~ 8-10 years)

	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 Scan from 4.19 – 4.28, 10 MeV step, 500 pb^{-1}/point, 7 points	5-10 /fb
R scan & Tau	BESII	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)		100 pb^{-1}	
ψ(4160)		3 fb^{-1}	
J/ψ		6 – 8 Billion	

Thanks for your attention!

谢谢