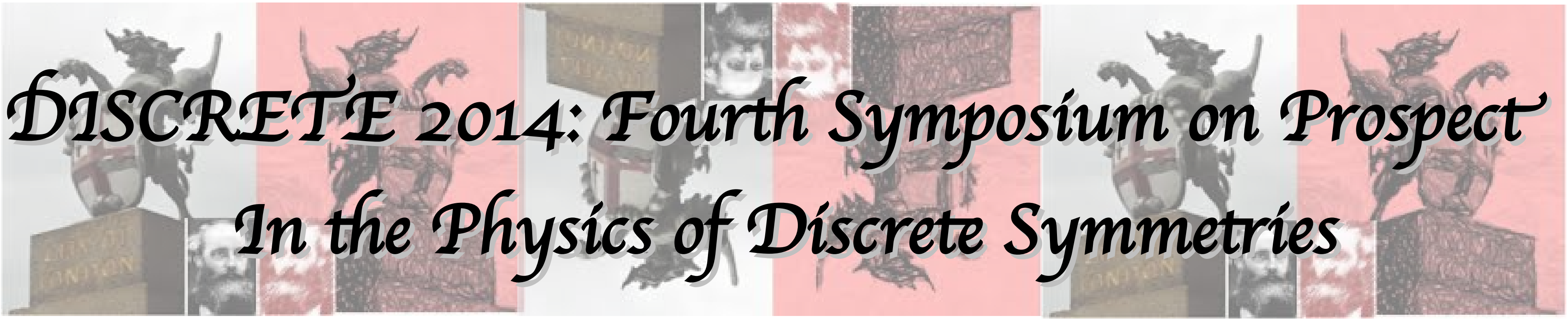


Recent results, status and prospects for the BESIII experiment

Isabella Garzia, INFN-Ferrara
Representing the BESIII Collaboration

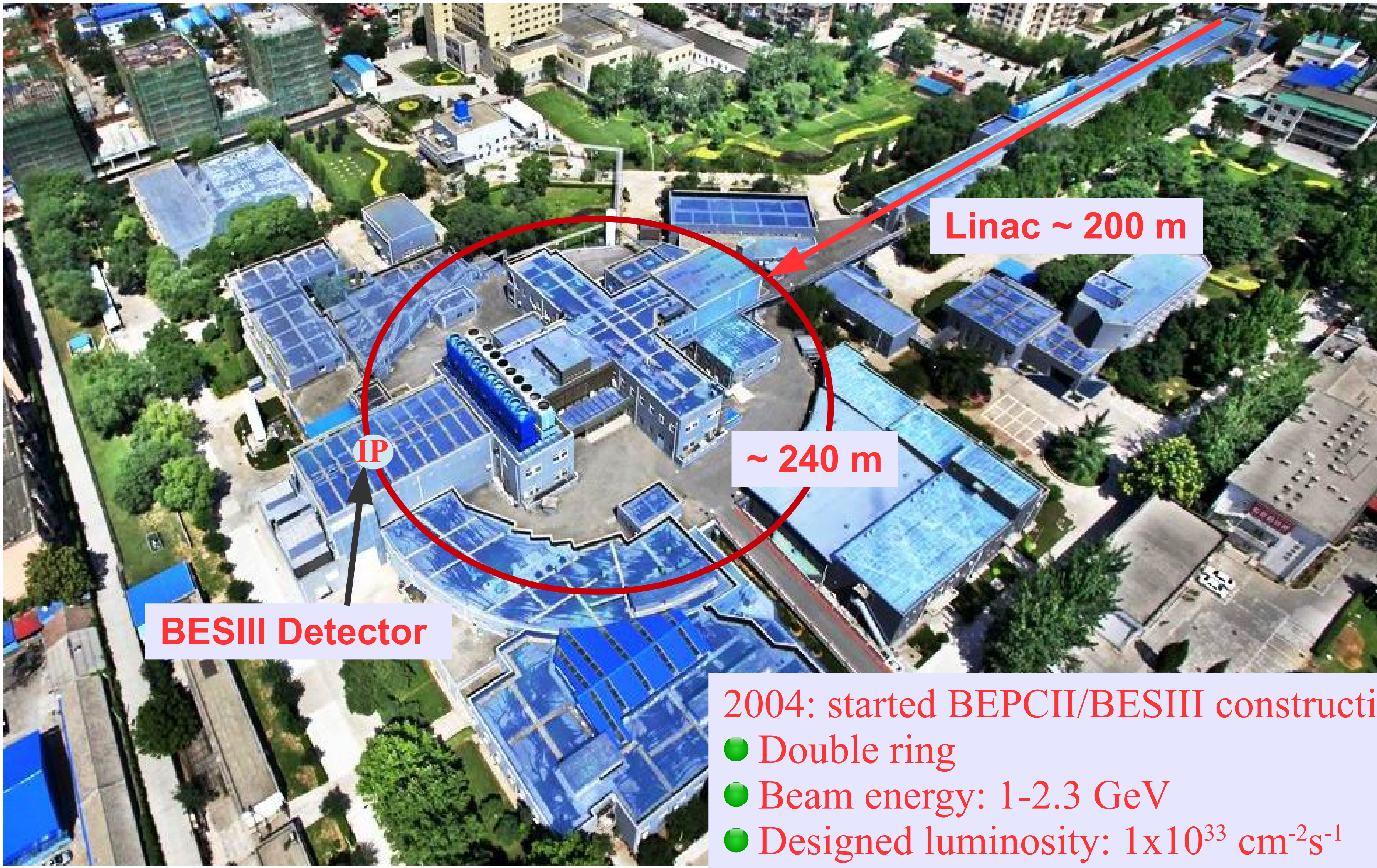
INFN
Istituto Nazionale
di Fisica Nucleare

2-6 December 2014
King's College London

OUTLINE

- **The BES III experiment**
  - BEPC-II and the BESIII detector
- **PART I: CP violation in the charm sector**
  - Measurement of y_{CP}
  - Measurement of the strong phase $\delta_{K\pi}$
- **PART II: Charmonium spectroscopy**
  - Charmonium spectrum
  - Z states
    - $Z_c(3900)$, $Z_c(4020)$
    - Study of $(D\overline{D}^*)^\pm$ and $(D^*\overline{D}^*)^\pm$ systems
- **Conclusion and Outlook**

Beijing Electron Positron Collider II



2004: started BEPCII/BESIII construction

- Double ring
- Beam energy: 1-2.3 GeV
- Designed luminosity: 1×10^{33} $cm^{-2}s^{-1}$

2008: test run

2009 – today: BESIII physics run

The BESIII Detector

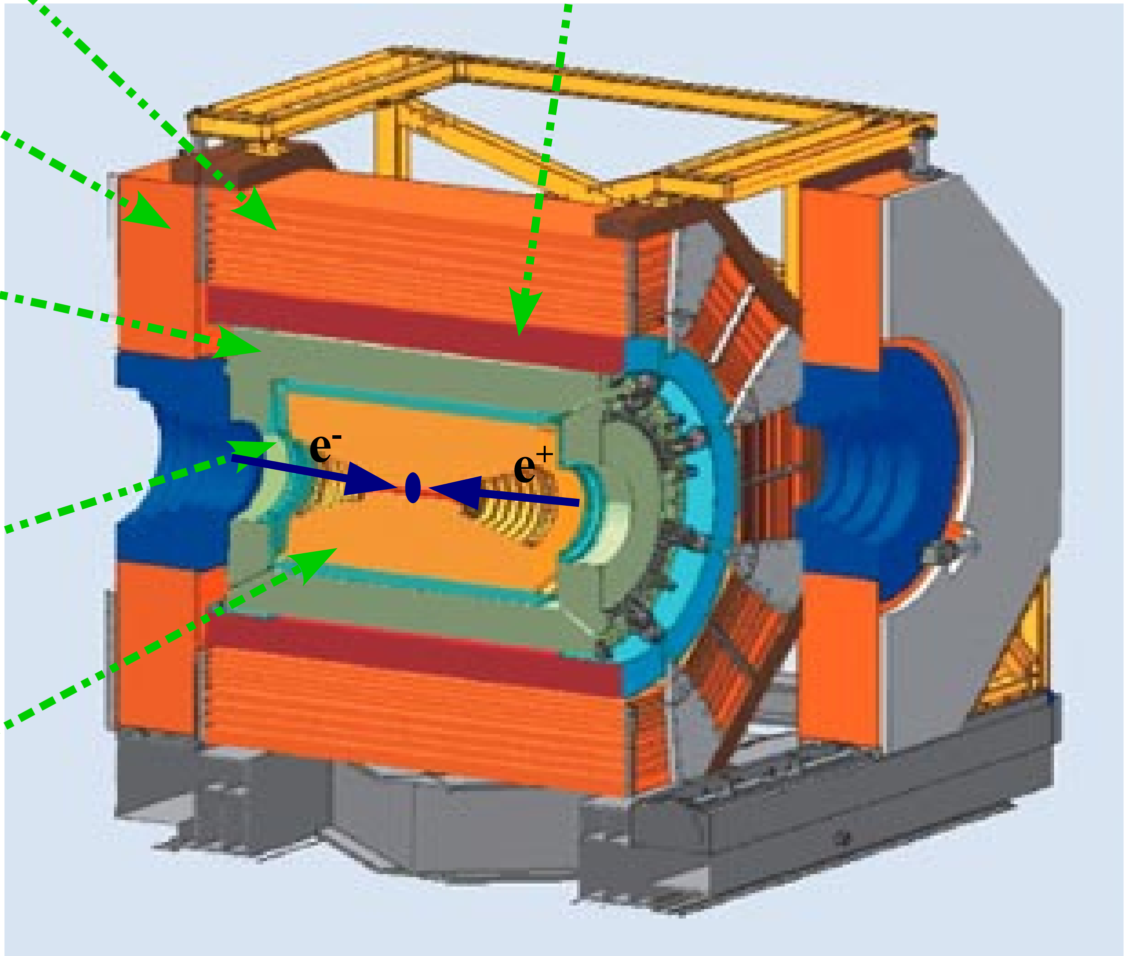
RPC Muon Detector
8 layers (end caps) +
9 layers (barrel)
$\Delta\Omega/4\pi = 93\%$

Superconducting solenoid (1T)

Electromagnetic CsI(Tl) Calorimeter
$\sigma_E/E < 2.5\%$ @ 1GeV
σ_{xy}=6mm/$E^{1/2}$ @ 1GeV

Time of Flight System
σ_t = 90 ps (barrel)
σ_t = 120 ps (end caps)

Drift Chamber
$\sigma_{r\phi}$ = 130 μm (single wire)
σ_{pt}/p_t = 0.5% at 1 GeV



Nucl. Instr. Meth. A614, 345 (2010)

The BESIII Collaboration

Europe
13 institutions:

Bochum University,Budker Instituteof Nuclear Physics,Ferrara University,GSI Darmstadt, Helmholtz Institute Mainz,INFN, Laboratori Nazionali di Frascati, Johannes Gutenberg University of Mainz, Joint Institute for Nuclear Research (JINR), KVI/University of Groningen,Turkish Accelerator Center Particle Factory Group (TAC-PF),Universitaet Giessen, University of Turin,Uppsala University

China
30 institutions:

Beihang University, China Center of Advanced Science and Technology, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Institute of High Energy Physics, Lanzhou University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, Peking University, Shanxi University, Sichuan University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Science and Technology of China, University of South China, Wuhan University, Zhejiang University, Zhengzhou University

USA
5 institutions:

Carnegie Mellon University,Indiana University, University of Hawaii, University of Minnesota, University of Rochester

OTHER IN ASIA
4 institutions:

COMSATS Institute of Information Technology (CIIT), Tokyo University,Seoul National University, University of the Punjab

http://bes3.ihep.ac.cn

Data Samples

Data sample	E_{cm}	years
1.3×10^9	J/Ψ @ 3.097 GeV	2009 (0.225×10^9) + 2012
0.5×10^9	Ψ' @ 3.686 GeV	2009 (0.106×10^9) + 2012
2.92 fb^{-1}	Ψ(3770) @ 3.773 GeV	2010+2011
0.5 fb^{-1}	Ψ(4040) @ 4.009 GeV	2011
0.024 fb^{-1}	τ mass scan at around 3.554 GeV	2011
1.9 fb^{-1}	Y(4260) @ 4.23 GeV and 4.26 GeV	2013
0.5 fb^{-1}	Y(4360) @ 4.36 GeV	2013
0.5 fb^{-1}	Y(4260) and Y(4360) scan	2013
0.8 fb^{-1}	R scan, 104 energy points between 3.85 and 4.59 GeV	2014
1 fb^{-1}	@ 4.42 GeV	2014
0.1 fb^{-1}	@ 4.47 GeV	2014
0.1 fb^{-1}	@ 4.53 GeV	2014
0.04 fb^{-1}	@ 4.575 GeV	2014
0.5 fb^{-1}	@ 4.60 GeV	2014

D decays; flavor physics

Charmonium spectroscopy

Flavor mixing and CP violation in Charm sector

The time evolution of the D^0 system is described by the Schroedinger equation:

$$\frac{\delta}{\delta t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = -i(M - i\frac{\Gamma}{2})\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$$

M and Γ are Hermitian matrices

Mixing occurs when flavour eigenstates differ from mass eigenstates:

$$D_{1,2} = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

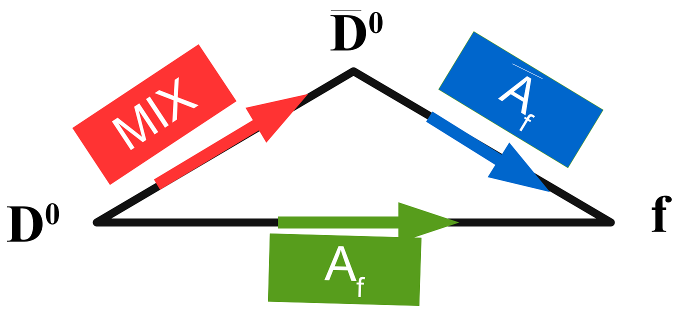
Mixing parameters

$$x = \frac{M_1 - M_2}{\Gamma_D} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma_D}$$

$M_{1,2}$ and $\Gamma_{1,2}$ are mass and width of $|D_{1,2}>$, and $\Gamma=(\Gamma_1+\Gamma_2)/2$

CP violation (CPV) can occur in three ways:

- in decay: $|A_f| \neq |\bar{A}_{\bar{f}}|$
- in mixing: $r_m=|q/p| \neq 1$
- in the interference: $\varphi_f \neq 0$



$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = \left|\frac{q}{p}\right|\left|\frac{\bar{A}_f}{A_f}\right| e^{i(\delta_f+\varphi_f)}$$

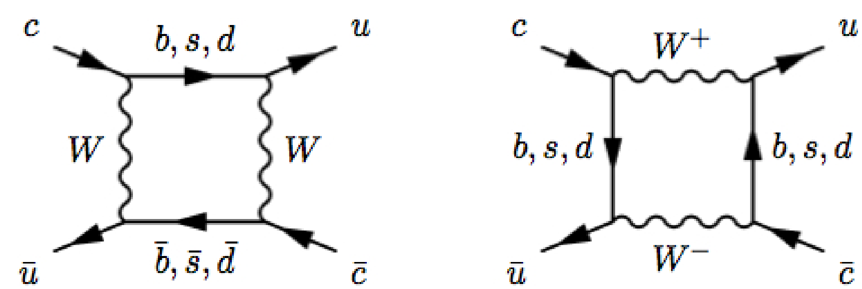
Strong+weak phase

$$\bar{A}_{\bar{f}} = \langle\bar{D}^0|\mathcal{H}|\bar{f}\rangle,\ \bar{A}_f = \langle\bar{D}^0|\mathcal{H}|f\rangle,\ A_f = \langle D^0|\mathcal{H}|f\rangle$$

Neutral D meson oscillation

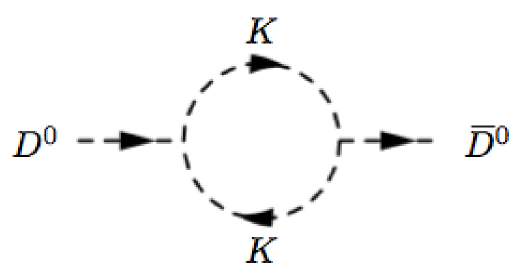
Short distance contributions:

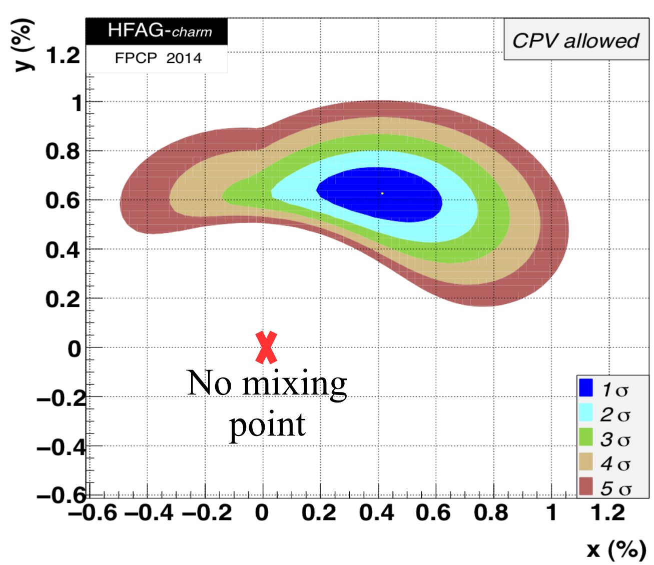
- virtual down type quark involved in mixing loop (only in D system)
- b contribution CKM suppressed; s and d contribution GIM suppressed
- small D-mixing in the Standard Model (SM) ~ 10^{-6} → New Physics (NP) contributions might manifest in the loop



Large distance contributions:

- from transition to final state *f* that are accessible to both D^0 and $\overline{D}^0$
- long range contribution expected to be dominant ~ 10^{-3}
- non-perturbative contribution → large theoretical uncertainties on their estimation





...experimental situation

- First evidence of CPV in the charm sector:
  - LHCb: $\Delta A_{CP}(D^0 \to KK - D^0 \to \pi\pi) = (-0.82 \pm 0.21^{stat} \pm 0.11^{syst})$ PRL **108**,111602 (2012)
  - CDF: $\Delta A_{CP}(D^0 \to KK - D^0 \to \pi\pi) = (-0.62 \pm 0.21^{stat} \pm 0.10^{syst})$ CDF note10784 (2012)
- No straightforward interpretation: NP contribution?
- Exclusion of no-mixing point (x=y=0) @ >12σ when CPV is allowed

http://www.slac.stanford.edu/xorg/hfag/charm/FPCP14/results_mix+cpv.html

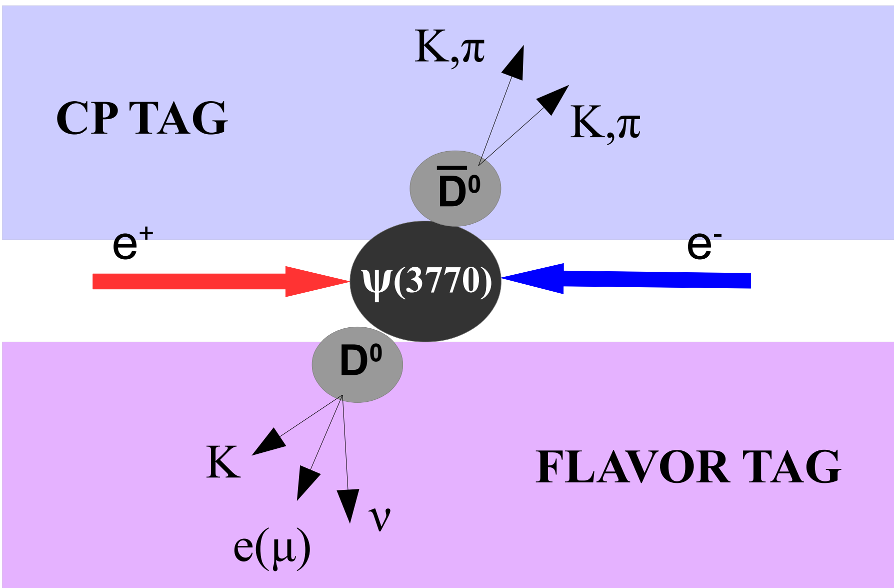
Measurement of y_{CP} at BESIII

We measure y_{CP} using CP-tagged semileptonic D decays, which allows to access CP asymmetry in mixing and decays:

- data sample of 2.92 fb^{-1}@ $\sqrt{s}$=3.773 GeV
- quantum-correlated $D^0\overline{D}^0$ pair in a C=-1 state
- two D mesons with opposite CP eigenstates

$$y_{CP} = \frac{\Gamma_{CP+} - \Gamma_{CP-}}{\Delta\Gamma} = \frac{|q/p| - |p/q|}{2} y\cos\phi - \frac{|q/p| + |p/q|}{2} x\sin\phi$$

$$\phi = \arg(q/p)$$



Single tag decay rate (ST)

♦ full reconstruction of D meson into a CP eigenstate
- ♦ CP+: K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$
- ♦ CP-: $K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$

$$\mathcal{B}_{CP\pm} \propto |A_{CP\pm}|^2(1 \mp y)$$

Double tag (DT) decay rate (CP tag + flavor tag)

♦ $D^0 \to K^{-/+}e^{+/-}\nu$ and $K^{-/+}\mu^{+/-}\nu$

$$\mathcal{B}_{l,CP\pm} = \frac{N_{l,CP\pm}}{N_{CP\pm}} \cdot \frac{\epsilon_{CP\pm}}{\epsilon_{l,CP\pm}} \propto |A_l|^2|A_{CP\pm}|^2$$

► $y_{CP} \neq 0$ if $\tau_{CP} \neq \tau_{flavor}$

► From the semileptonic branching fraction we can determine y_{CP} as:

$$y_{CP} \sim \frac{1}{4}\left(\frac{\mathcal{B}_{l,CP-}}{\mathcal{B}_{l,CP+}} - \frac{\mathcal{B}_{l,CP+}}{\mathcal{B}_{l,CP-}}\right)$$

y_{CP} signal extraction

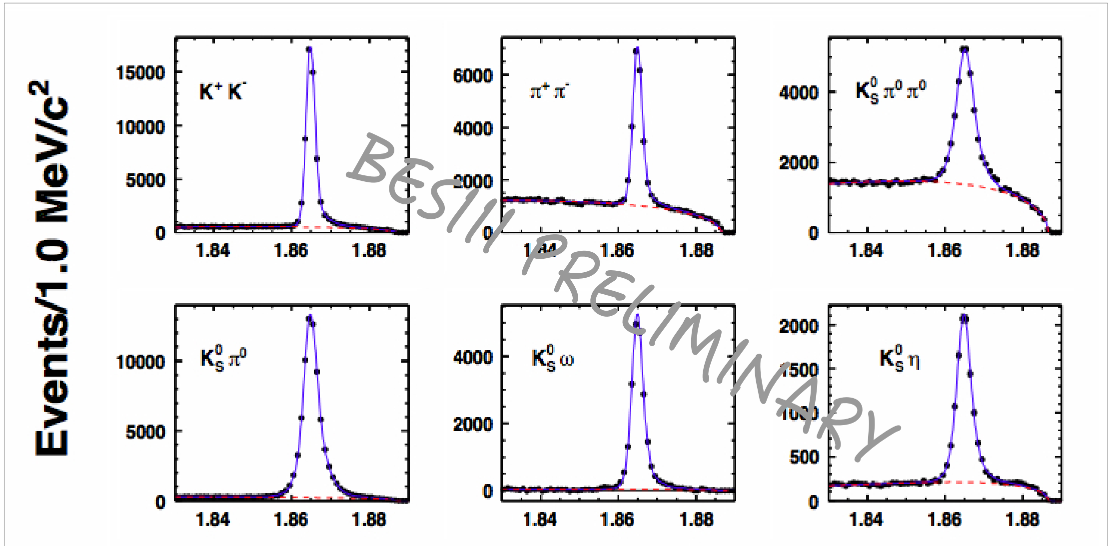
Single tag yields extraction:

- M_{BC} and ΔE to identify the reconstruct D candidates
- Signal shape: MC ⊗ bifurcated Gaussian
- Backgrounds: ARGUS function

Double tag yields extraction:

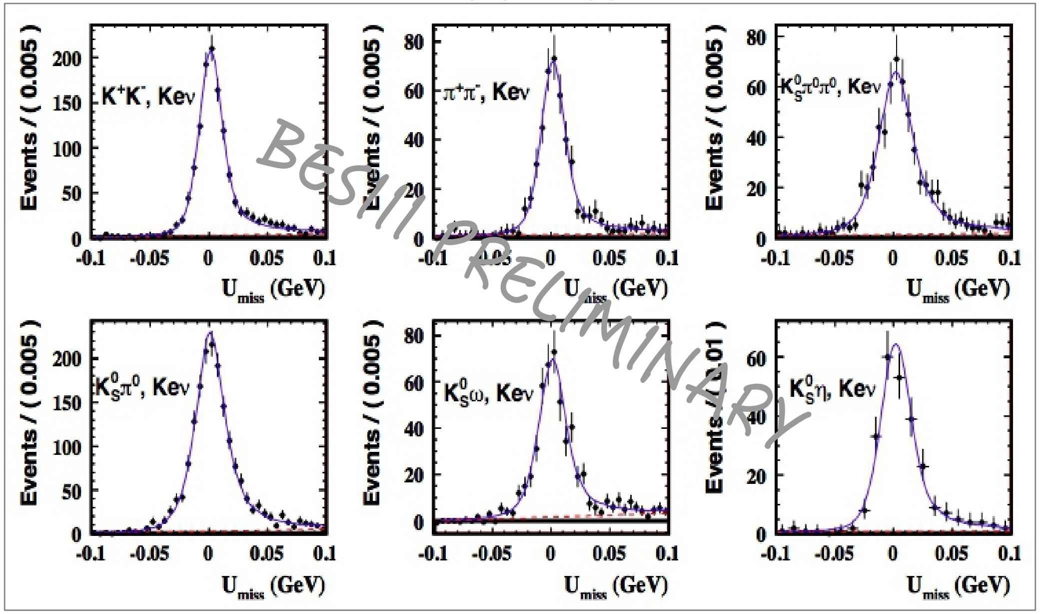
- $U_{miss}=E_{miss}-|p_{miss}|$ (~0 for signal)
- Signal shape: MC ⊗ bifurcated Gaussian
- Backgrounds Keν: first order polynomial
- Backgrounds Kμν: $D\to K\pi\pi^0$ from data + Keν from MC + first order polynomial

CP STs

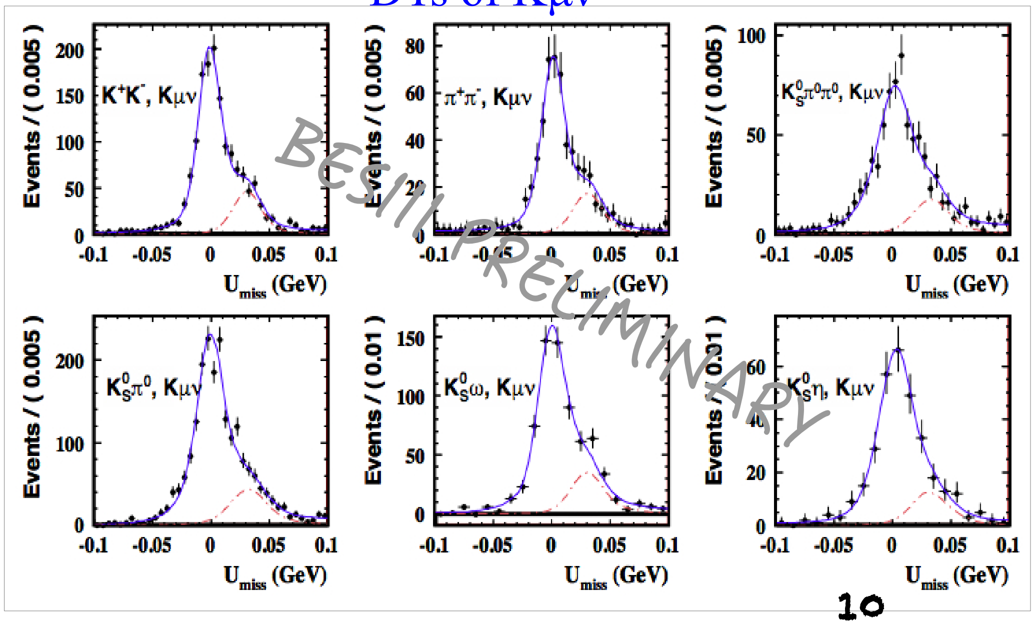


$$M_{BC}=\sqrt{E_{beam}^2-|\vec{p}_D|^2}$$

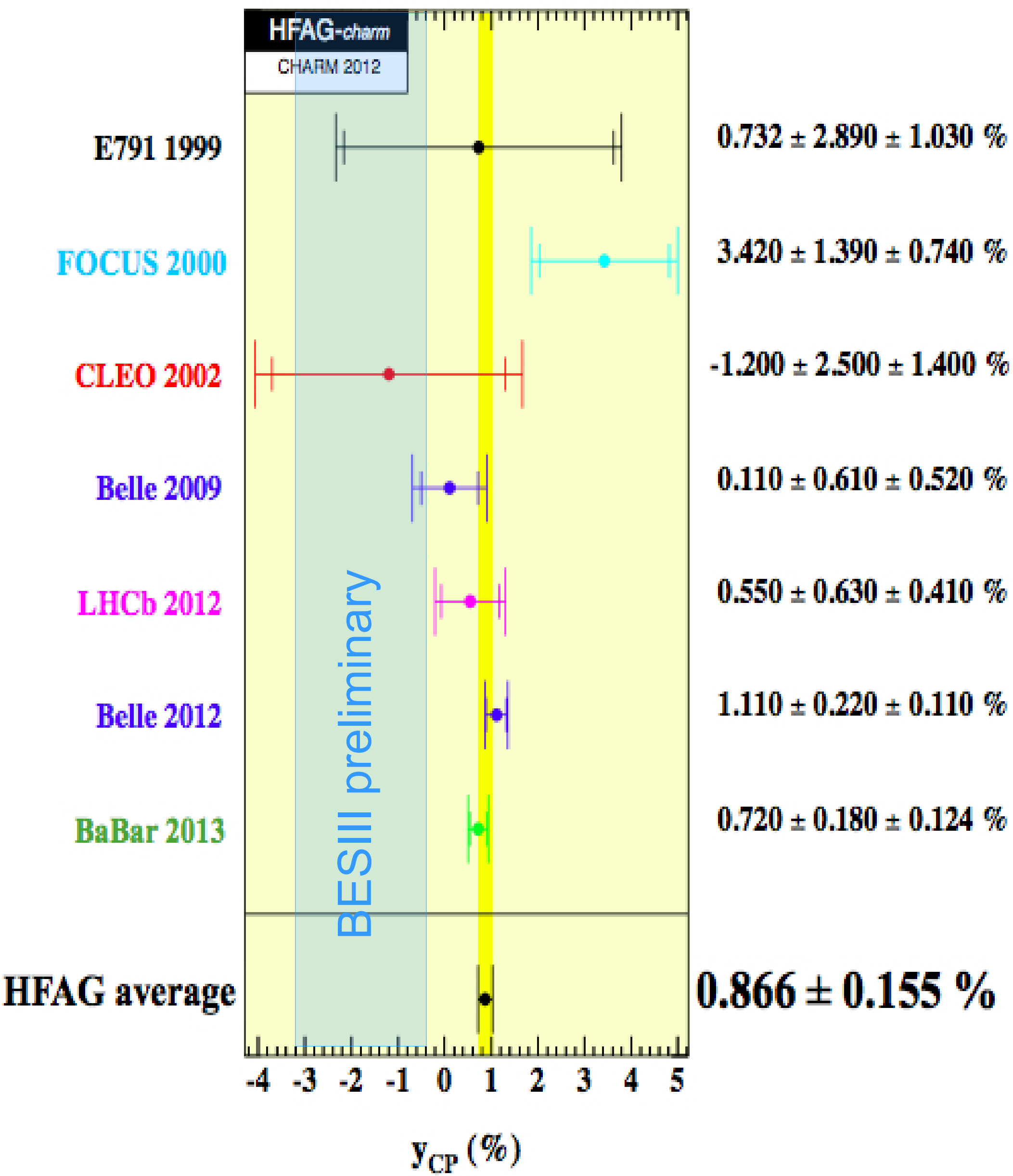
DTs of Keν



DTs of Kμν



y_{CP} results



Assuming Gaussian uncertainties and no correlation between experiments, the combined result is:

$$y_{CP}=(0.866 \pm 0.155)\%$$

- Most precise measurements from B-factories
- In the limit of no CPV, $y_{CP}=y$

BESIII preliminary results

$$\mathbf{y_{CP}=(-1.7 \pm 1.3 \pm 0.6)\%}$$

- Result is statistically limited
- Systematic uncertainty is relatively small

PAPER CLOSE TO SUBMISSION

Strong phase $\delta_{K\pi}$ measurement

The measurement of the time-dependent decay rate of $D^0 \to K^- \pi^+$ process is sensitive to

$$y' = y\cos\delta_{k\pi} - x\sin\delta_{k\pi}, \quad x' = x\cos\delta_{k\pi} + y\sin\delta_{k\pi}$$

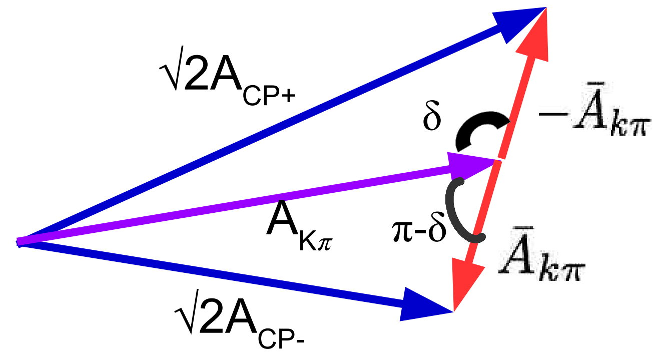
Strong phase difference between the doubly Cabibbo-suppressed (DCS) amplitude for $\overline{D}^0 \to K^- \pi^+$ and the corresponding Cabibbo-favored (CF) amplitude for $D^0 \to K^- \pi^+$

$$\frac{\langle K^- \pi^+ | \bar{D}^0 \rangle}{\langle K^- \pi^+ | D^0 \rangle} = -re^{-i\delta_{K\pi}} \quad \text{with} \quad \mathrm{r} = \left| \frac{\langle \mathrm{K}^- \pi^+ | \bar{\mathrm{D}}^0 \rangle}{\langle \mathrm{K}^- \pi^+ | \mathrm{D}^0 \rangle} \right|$$

The neutral D meson CP eigenstates are:

$$\langle K\pi | D_{CP\mp} \rangle = \frac{\langle K\pi | D^0 \rangle \pm \langle K\pi | \bar{D}^0 \rangle}{\sqrt{2}}$$

$$\to \sqrt{2} A_{CP\mp} = A_{K\pi} \pm \bar{A}_{K\pi}$$



Using cosine laws and the relation $\mathcal{B}_{CP\pm} \sim A^2_{CP\pm}(1 \mp y)$:

$$2r \cdot \cos\delta_{K\pi} \sim \mathcal{A}_{CP\to K\pi} \equiv \frac{\mathcal{B}(D_{CP-} \to K\pi) - \mathcal{B}(D_{CP+} \to K\pi)}{\mathcal{B}(D_{CP-} \to K\pi) + \mathcal{B}(D_{CP+} \to K\pi)}$$

Strong phase $\delta_{K\pi}$ at threshold

PL B734, 227 (2014)

Signal reconstruction:

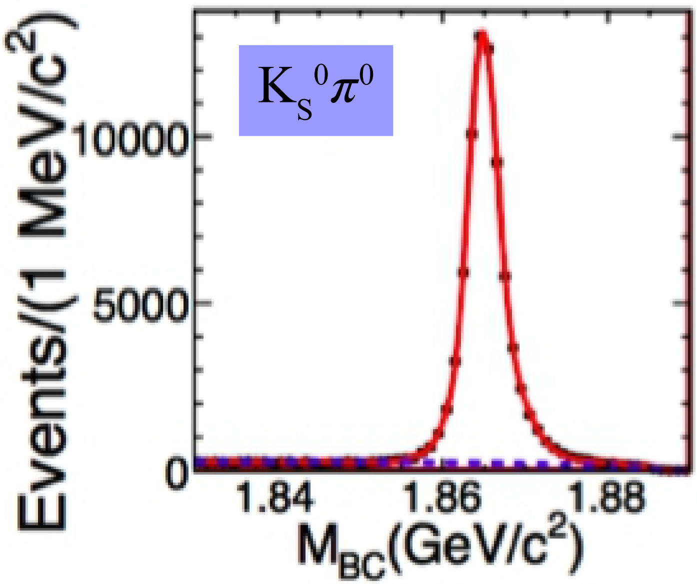
- **2.92 fb^{-1} @ 3.773 GeV**
- ST modes: CP tags
  - 5 CP+ tag modes: K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$, $\pi^0\pi^0$, $\rho^0\pi^0$
  - 3 CP- tag modes: $K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$
- DT modes: CP tag + flavour tag ($K^+\pi^-$ or $K^-\pi^+$)
- Kinematic variable: beam constrained mass M_{BC}
- Signal shape derived from MC ⊗ Gaussian function
- Background shape: ARGUS function

$$\star\ \mathcal{B}(D_{CP\pm} \to K\pi) = \frac{n_{K\pi,CP\pm}}{n_{CP\pm}} \cdot \frac{\epsilon_{CP\pm}}{\epsilon_{K\pi,CP\pm}}$$

- $n_{k\pi,CP\pm}$ and $n_{CP\pm}$ are the yields for DT and ST from M_{BC} fit, respectively
- $\varepsilon_{k\pi,CP\pm}$ and $\varepsilon_{CP\pm}$ are the detection efficiencies of DT and ST from MC simulation, respectively
- Most systematic uncertainties cancel in the ratio

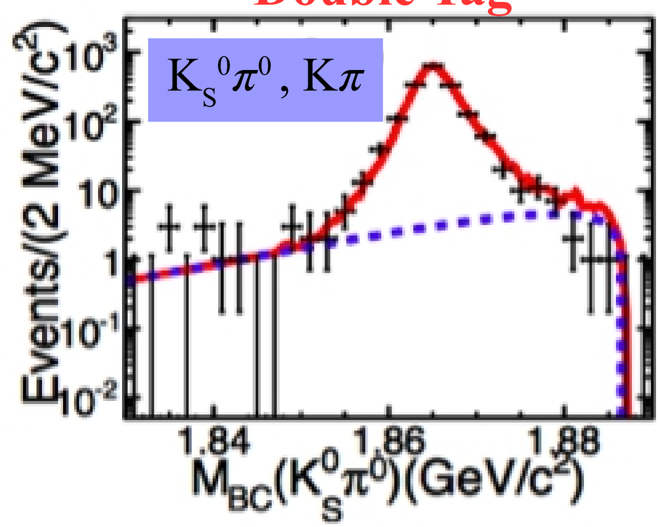
BESIII results: $\mathcal{A}_{CP}$=(12.7±1.3±0.7) × 10^{-2}

Single Tag



$$M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_D|^2}$$

Double Tag



Strong phase $\delta_{K\pi}$ result

Taking into account lowest order mixing effect:

PL B734, 227 (2014)

$$2r\cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot \mathcal{A}_{CP\to K\pi}$$

where $R_{WS} \equiv \frac{\Gamma(\bar{D}^0 \to K^-\pi^+)}{\Gamma(D^0 \to K^-\pi^+)}$ is the decay rate ratio of the "wrong sign" to the "right sign" process

Using external input from HFEG (http://www.slac.stanford.edu/xorg/hfag/charm/CHARM13/) and PDG: $r^2 = (3.50 \pm 0.04) \times 10^{-3}$, $y = (6.7 \pm 0.9) \times 10^{-3}$, $R_{ws} = (3.80 \pm 0.05) \times 10^{-3}$

BESIII results: $\cos\delta_{K\pi} = (1.02 \pm 0.11 \pm 0.06 \pm 0.01)$ (stat. / syst. / input par.)

CLEO-c results @ √s=3.773 GeV [PRD 86,112001 (2012)]

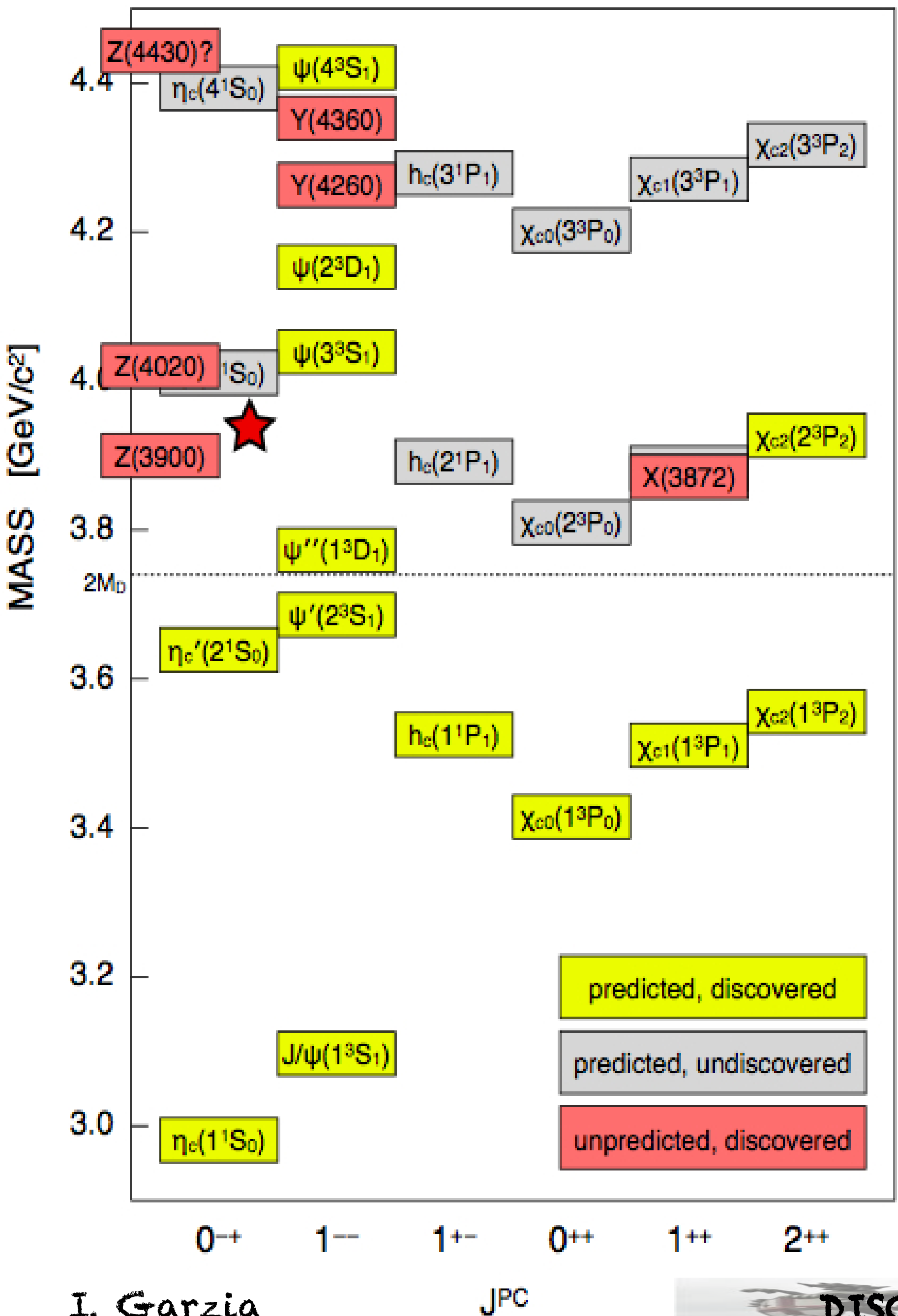
$\cos\delta_{K\pi} = 0.81^{+0.22+0.07}_{-0.18-0.05}$ using CLEO-c parameters

$\cos\delta_{K\pi} = 1.15^{+0.19+0.00}_{-0.17-0.08}$ using external parameters from global fit

- Precision limited by the statistical error
- **BESIII: word best precision**
- 10 fb^{-1} will be accumulated in the next 5 years ⇒ stat. ~ 0.06 expected

Charmonium spectroscopy at BESIII

Charmonium Spectrum



- Below the open charm threshold the spectrum is well understood
  - very good agreement between predicted and discovered states
- Above the threshold the situation in more complex
  - only few of the predicted states have been found
  - in the last decades many new states have been observed with properties that are not consistent with expectations for charmonium: X, Y, Z

X states:

➲ charmonium-like states with $J^{PC} \neq 1^{--}$

➲ Observed in B decays, pp and $p\bar{p}$ collisions

Y states:

➲ charmonium-like states **with $J^{PC} = 1^{--}$**

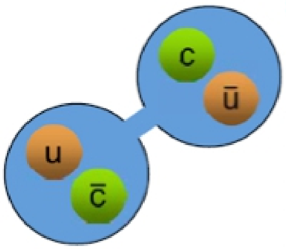
➲ Observed in direct e^+e^- annihilation or in ISR

Z states:

➲ charmonium-like states **carrying electric charge**

➲ Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair

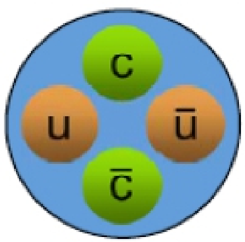
Nature of X, Y and Z states



Molecular state:

Loosely bound state of a pair of meson. The dominant binding mechanism should be pion exchange

NA Tornqvist PLB 590, 209 (2004)
ES Swanson PLB 598,197 (2004)
E Braaten & T Kusunoki PRD 69 074005 (2004)
CY Wong PRC 69, 055202 (2004)
MB Voloshin PLB 579, 316 (2004)
F Close & P Page PLB 578,119 (2004) …..



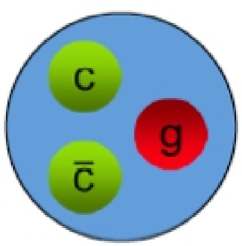
L Maiani et al PRD 71,014028 (2005)
T-W Chiu & TH Hsieh PRD 73, 111503 (2006)
D Ebert et al PLB 634, 214 (2006)
…

Tetraquark:

Bound state of four quark, i.e. diquark-antidiquark

Distinctive feature of multi-quark picture with respect to charmonium:

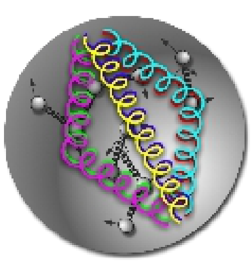
- Prediction of many new states
- Possible existence of new states wit non-zero charge, strangeness, or both



Charmonium hybrids

States with an exited gluonic degree of freedom. Lattice and model predictions found that the lowest charmonium hybrid lies around 4200 MeV

P Lacock et al (UKQCD) PLB 401, 308 (1997)
SL Zhu PLB 625, 212 (2005)
FE Close, PR Page PLB 628, 215 (2005)
E Kou, O Pene PLB 631, 164 (2005)
…

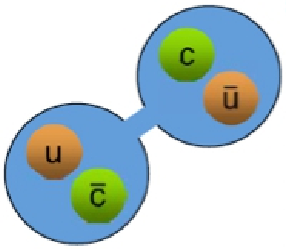


Glueballs

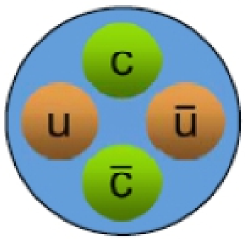
Bound states of gluons

Heavy quarkonium: progress, puzzles, and opportunities
N. Brambilla et. All, Eur.Phys.J.C71:1534,2011

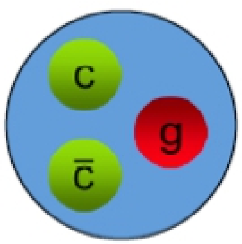
Nature of X, Y and Z states



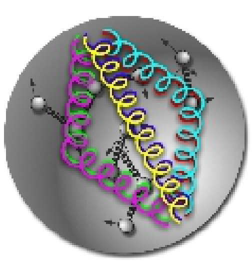
1) Establish the spectrum: search for more X, Y and Z states, determine masses, widths, and quantum numbers and investigate the decays



2) Build connections: looks for transition between states (i.e. radiative transitions)



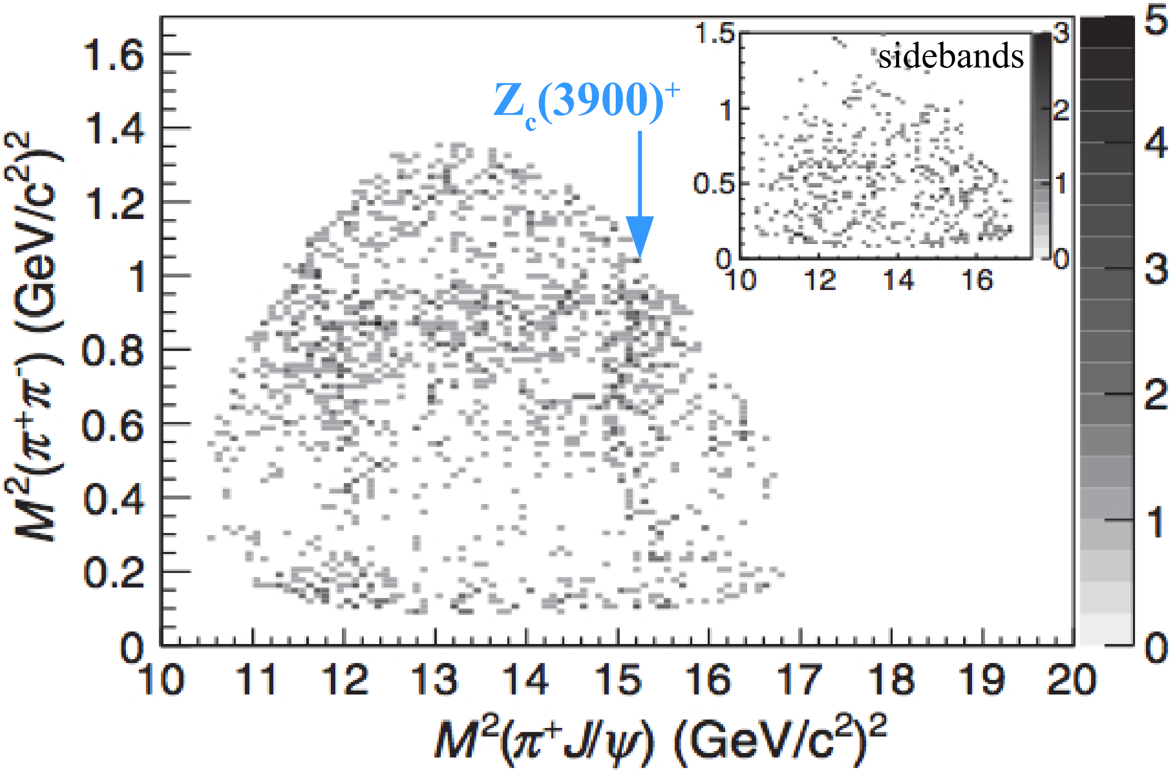
BESIII dedicated program started in 2012

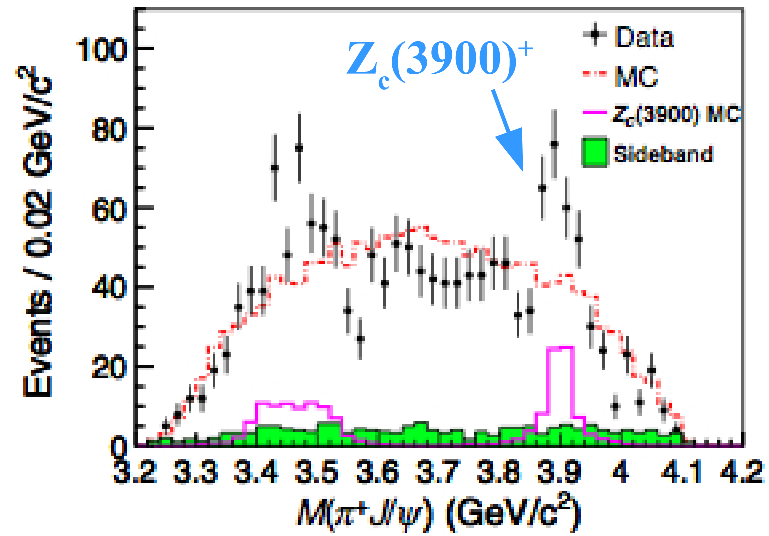


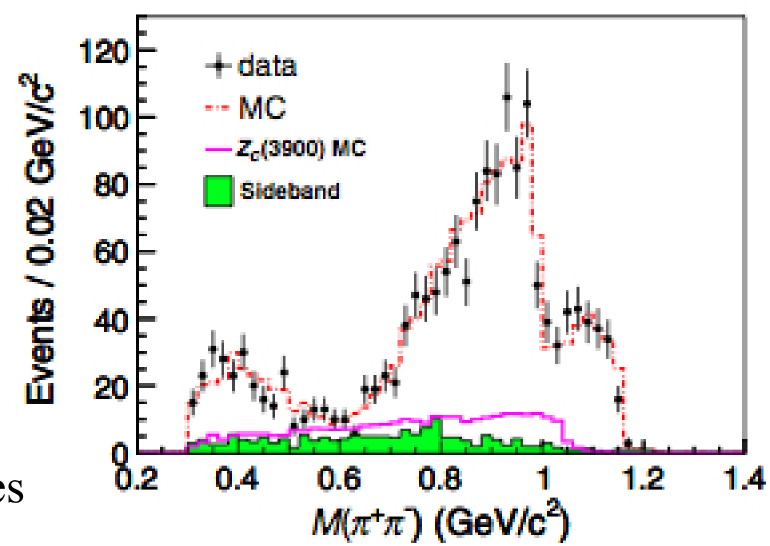
Discovery of $Z_c(3900)^+$

PRL 110, 252001 (2013)

- Study the $e^+e^- \to \pi^+\pi^- J/\psi$ process at center-of-mass energy of 4.260 GeV using ~0.5 fb^{-1}
- **Cross section: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb**
- Study the substructure in the $Y(4260) \to \pi^+\pi^- J/\psi$
  - Dalitz plot analysis: structures in the $\pi^+\pi^-$ and $J/\psi\pi^+$ systems







MC includes $\sigma(500)$, $f_0(980)$, and non-resonant $\pi^+\pi^-$ amplitudes

Discovery of $Z_c(3900)^+$

PRL 110, 252001 (2013)

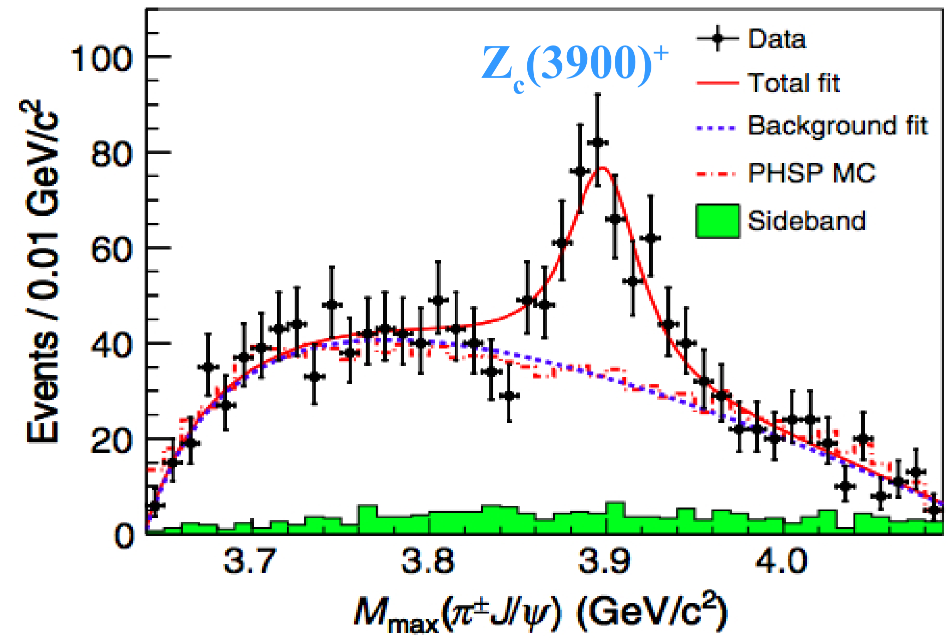
- Choosing the heavier J/ψ combination per events removes reflection at 3.45 GeV/c²
- **Significance greater than 8σ**

$$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$$

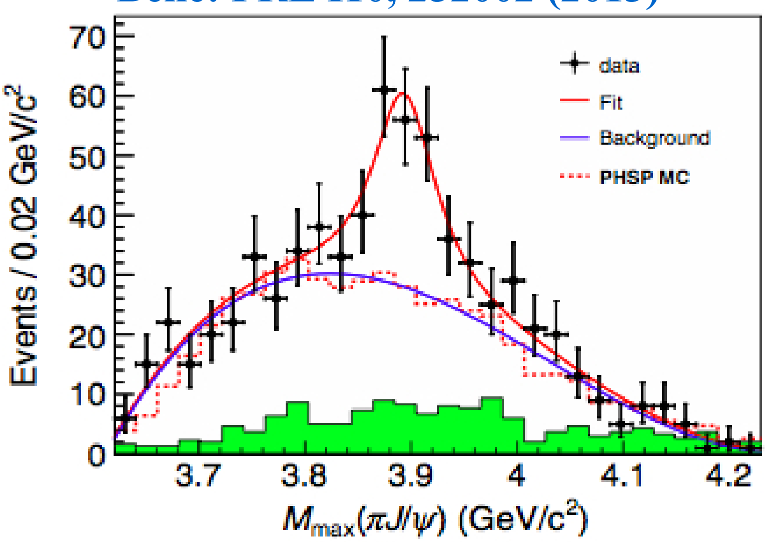
$$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$$

- Mass close to the $D\overline{D}^*$ threshold
  - Decay to J/ψ ⇒ $c\overline{c}$
  - Electric charge ⇒ contains ud

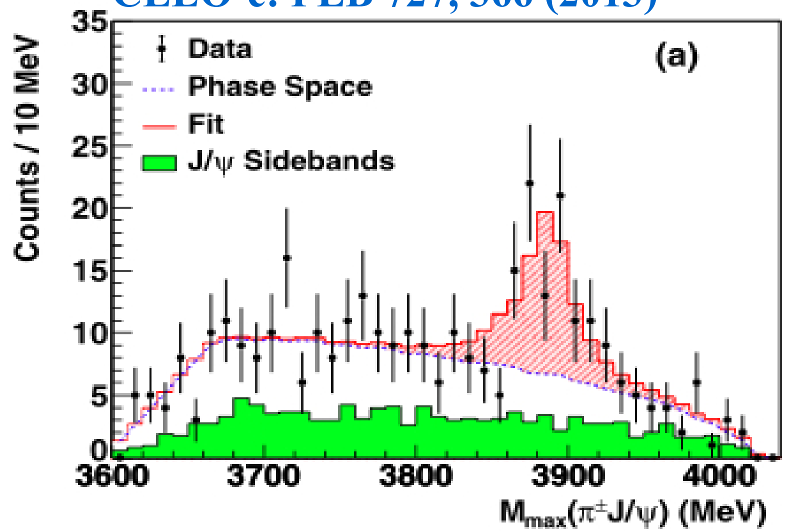
4-quark state!?



Belle: PRL 110, 252002 (2013)



CLEO-c: PLB 727, 366 (2013)



Belle:

$$e^+e^- \to \gamma_{ISR} J/\psi \pi^+\pi^-$$

$$m = (3894.5 \pm 6.6 \pm 4.5)\ \mathrm{MeV}/c^2$$

$$\Gamma = (63 \pm 24 \pm 26)\ \mathrm{MeV}$$

CLEO-c:

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

at √s=4.17 GeV

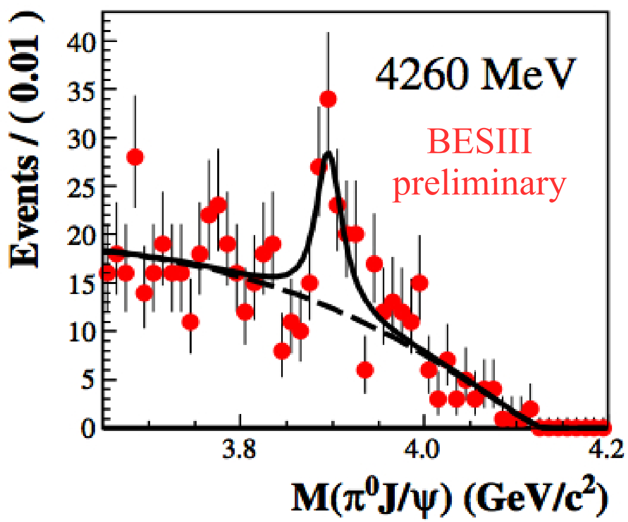
$$m = (3886 \pm 4 \pm 2)\ \mathrm{MeV}/c^2$$

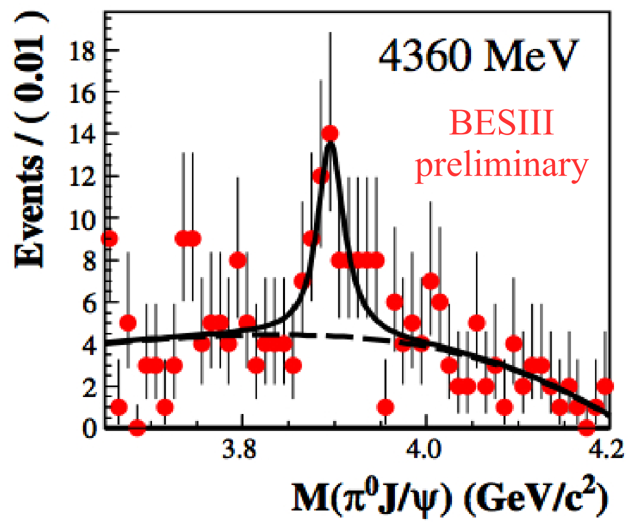
$$\Gamma = (37 \pm 4 \pm 8)\ \mathrm{MeV}$$

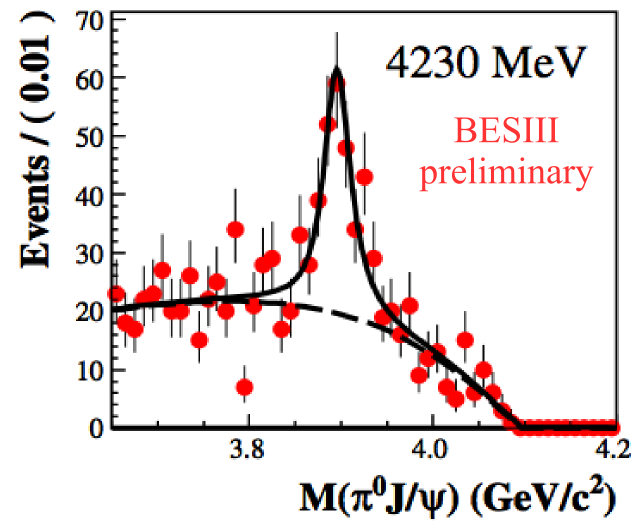
Search for a neutral $Z_c(3900)$ isospin partner

BESIII preliminary

- New BESIII analysis: observation of the $Z_c(3900)^0$ decaying into $J/\psi\pi^0$ in $e^+e^- \to \pi^0\pi^0 J/\psi$
- ~2.8 fb^{-1} data distributed in the center-of-mass energy region of [4.19-4.420] GeV







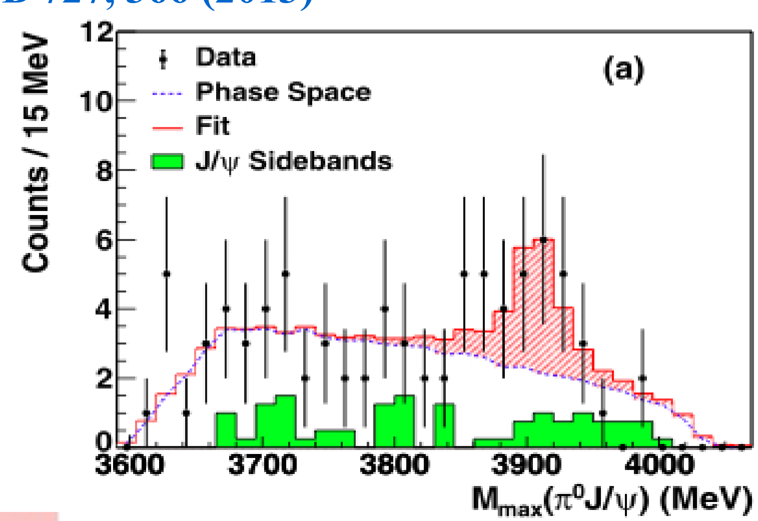
- New structure into $J/\psi\pi^0$ observed:
  - Mass=3894.8±2.3 MeV/c^2
  - Width=29.6±8.2 MeV
- **Significance greater than 10σ**

Isospin triplet is established!

CLEO-c: PLB 727, 366 (2013)

First observed by CLEO-c:

- M=3904±10 MeV/c^2
- Width=37 MeV (fixed)
- **Significance = 3.5σ**

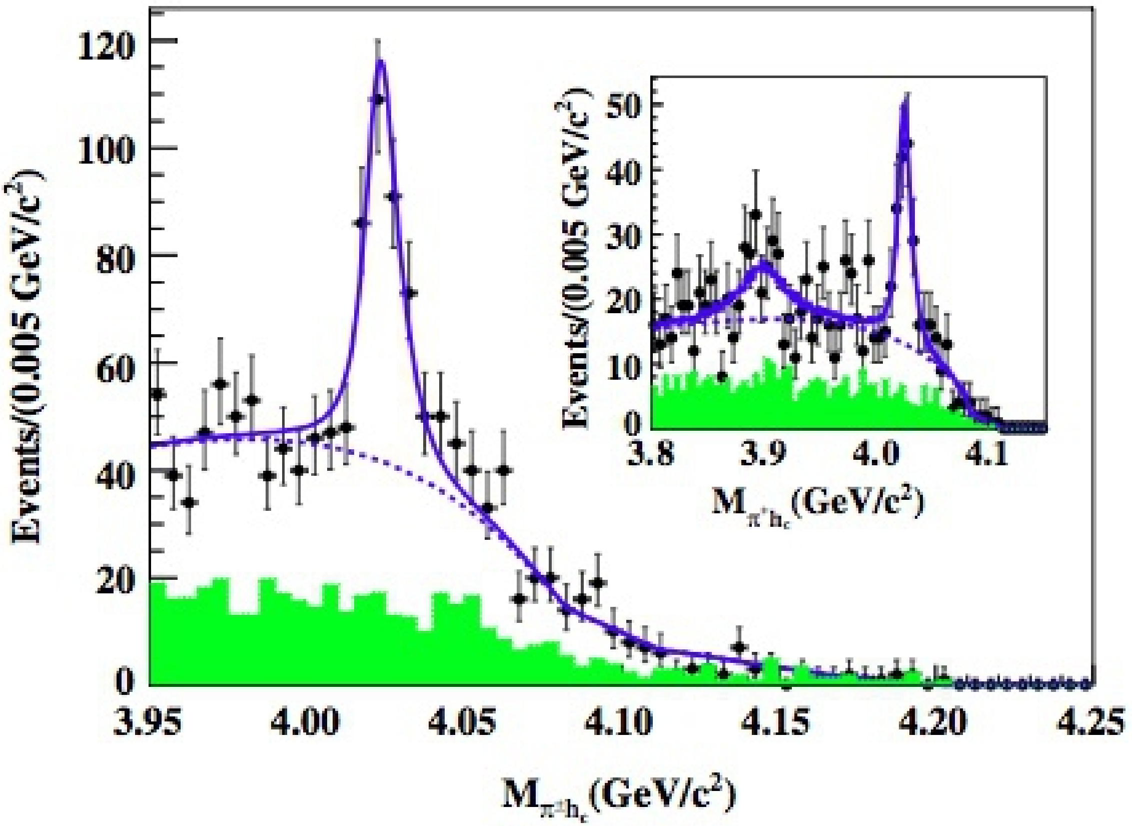


Study of $e^+e^- \to h_c\, \pi^+\pi^-$: observation of $Z_c(4020)^+$

PRL 111, 242001 (2013)

- First observation of $Z_c(4020)^+ \to h_c\pi^+$ in $e^+e^- \to h_c\pi^+\pi^-$
- 13 center-of-mass energies from 3.900 to 4.420 GeV
- Reconstruction of $h_c \to \gamma\eta_c$ including 16 hadronic η_c decay modes

$\sqrt{s}$ = 4.23, 4.26 and 4.36 GeV



$Z_c(4020)^+$

- Significant peak at around 4.02 GeV/c^2
- Mass=(4022.9±0.8±2.7) MeV/c^2
- Width=(7.9±2.7±2.6) MeV
- Close to $(D^*\bar{D}^*)^\pm$ threshold
- **Significance greater than 8.9σ**

$Z_c(3900)^+$

- $Z_c(3900)^+$ significance of 2.1σ (with mass and width fixed)
- Upper limit on $Z_c(3900)^+$ production cross section at $\sqrt{s}$=4.26 GeV:

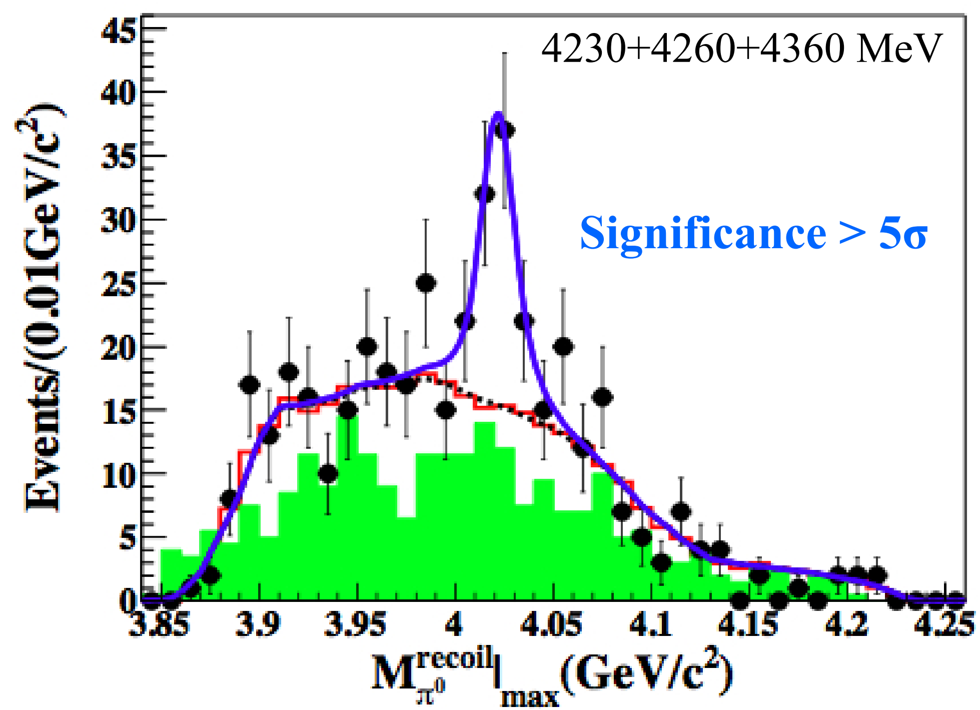
$$\sigma(e^+e^- \to Z_c(3900)^+\pi^- \to h_c\pi^+\pi^-) < 11\,\text{pb} \quad \text{(at 90\% CL)}$$

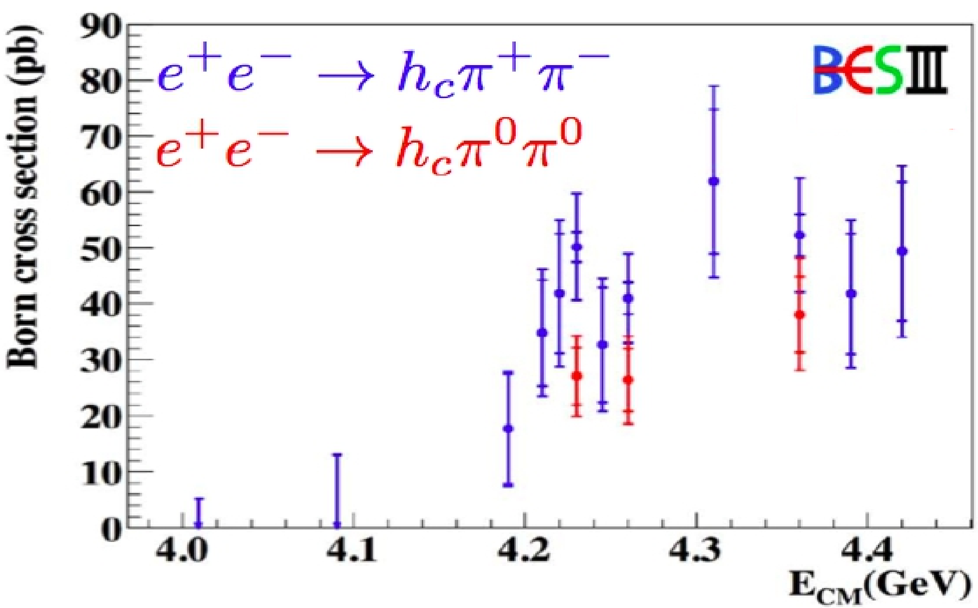
Evidence of the neutral isospin partner: $Z_c(4020)^0$

PRL 113, 212002 (2014)

- Study of the process $e^+e^- \to h_c\pi^0\pi^0$
- $\sqrt{s}$= 4.23, 4.26, and 4.36 GeV
- Reconstruction of $h_c \to \gamma\eta_c$ including 16 hadronic η_c decay modes
- A structure in the $h_c\pi^0$ invariant mass spectrum is observed:
  - Mass = (4023.9±2.2±3.8) MeV/c^2
  - Width = fixed to be the same as its charged partner

Isospin triplet is established!





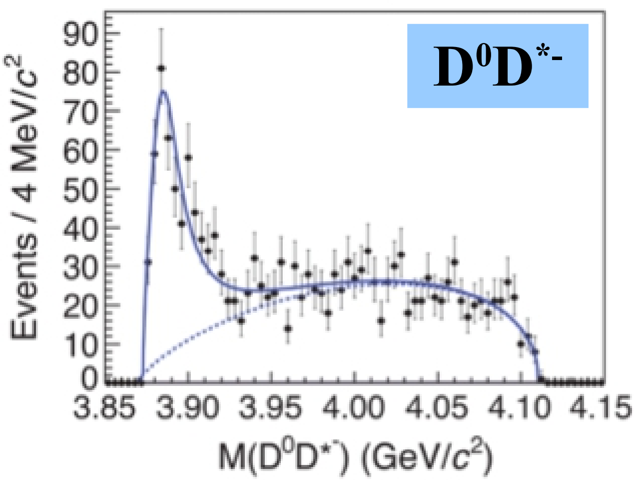
Cross sections for $e^+e^- \to h_c\pi^+\pi^-$ and $e^+e^- \to h_c\pi^0\pi^0$ are in agreement with isospin conservation within 2σ: $R_{\pi\pi hc}$=0.63±0.09

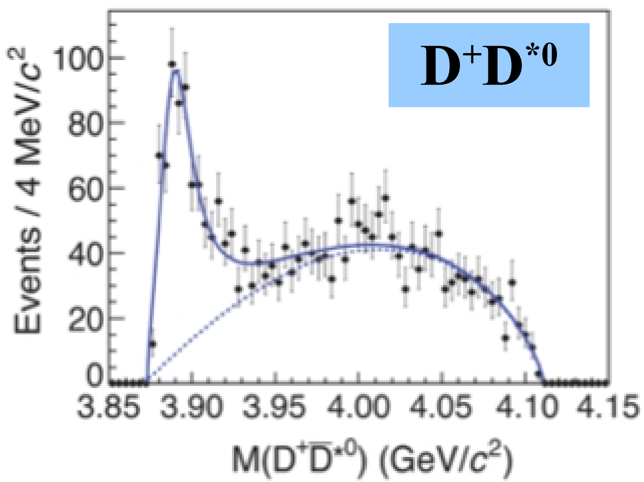
Study of $(D\bar{D}^*)^\pm$ system

PRL 112, 022001 (2014)

The $Z_c(3900)$ mass is 24 MeV/c^2 above the $D\bar{D}^*$ mass threshold

- Study the $e^+e^-\to D^0D^{*-}\pi^+$, $D^+D^{*0}\pi^-$ at $\sqrt{s}$=4.26 GeV (525 pb^{-1})
- $D^0\to K\pi$ and $D^+\to K^-\pi^+\pi^+$
- Identify the D^* in the $D\pi$ recoil mass





Enhancement at (DD^*) threshold

- Fit function: Breit-Wigner + smooth threshold function

Mass = (3883.9±1.5±4.2) MeV/c^2
Width = (24.8±3.3±11.0) MeV
$\sigma \times \mathcal{B}$ = (83.5±6.6±22.0) pb

Parameters very similar to $Z_c(3900)$ ⇒ same state? A J^P quantum number determination for the $Z_c(3900)$ needed

Fit to angular distribution favours $J^P=1^+$

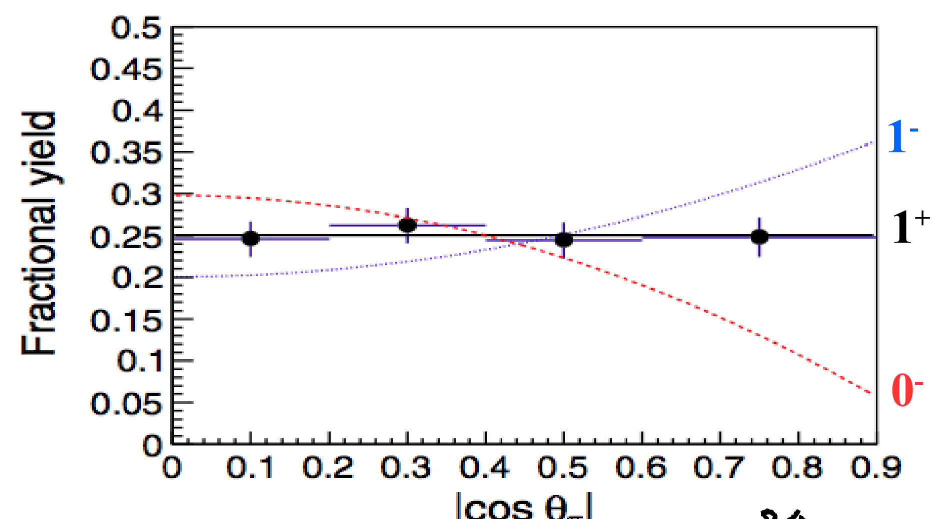
If this is $Z_c(3900)^+$, open charm decays are suppressed:

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

to be compared with

$$\frac{\mathcal{B}(\psi(3770)\to D\bar{D})}{\mathcal{B}(\psi(3770)\to J/\psi\pi^+\pi^-)} = 482 \pm 84$$

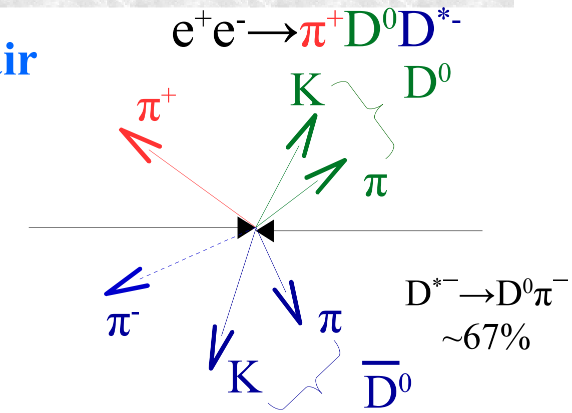
Different dynamics in the Y(4260)-Z_c(3900) system!!!



NEW PRELIMINARY

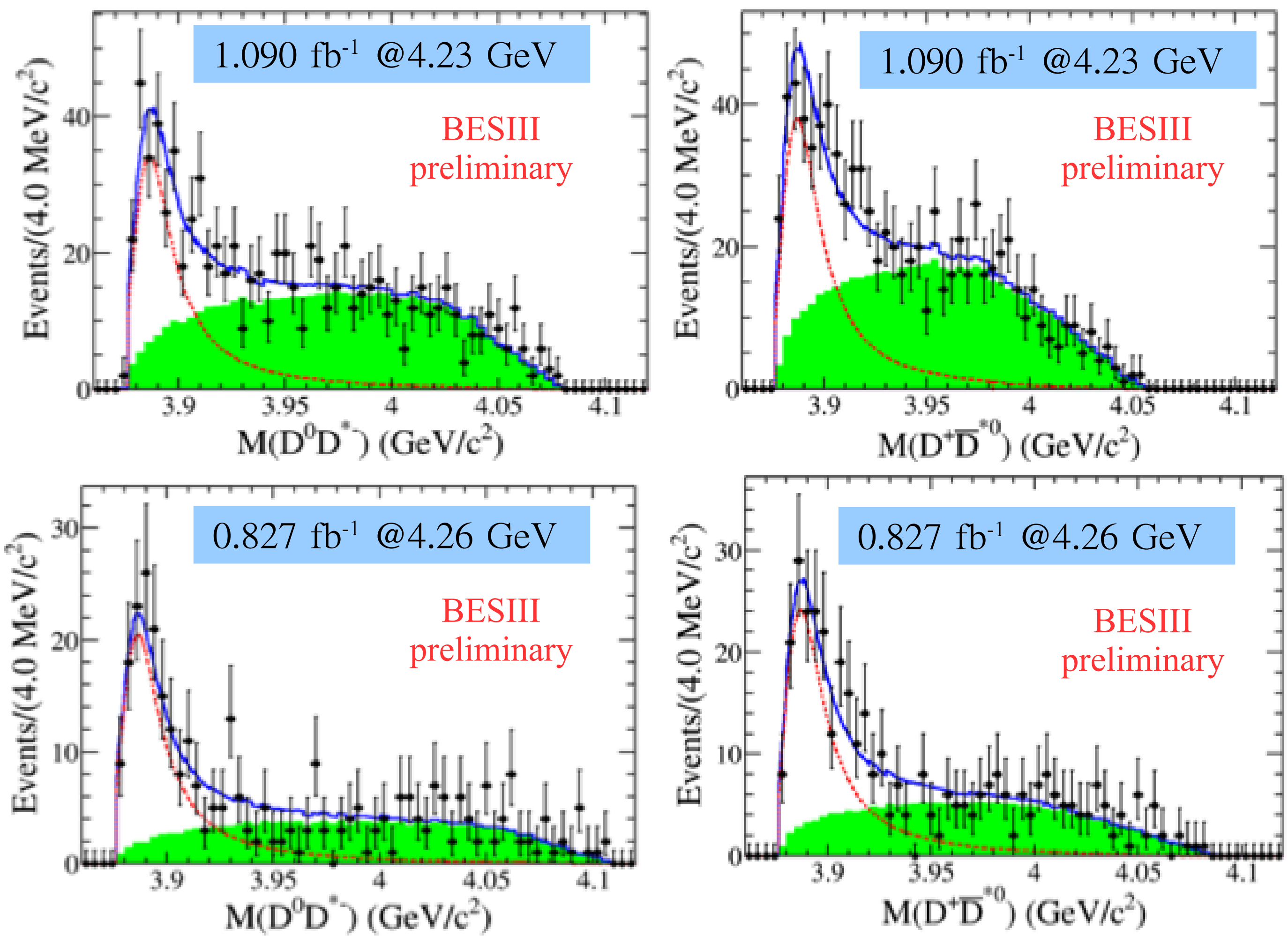
Study of $(D\bar{D}^*)^\pm$ system

- **Double tag method: reconstruction of the bachelor π and $D\bar{D}$ pair**
- D^0 final states: $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K^-\pi^+\pi^+\pi^-\pi^0$
- D^- final states: $K^+\pi^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $K^0_s\pi^-$, $K^0_s\pi^-\pi^0$, $K^0_s\pi^+\pi^-\pi^-$, $K^+K^-\pi^-$



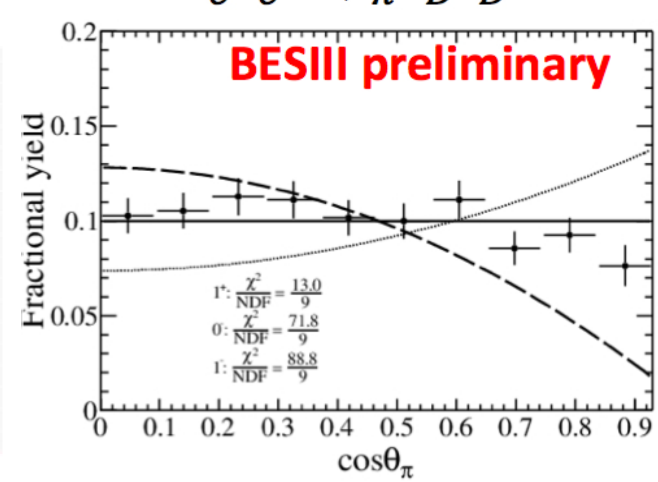
Mass = (3884.3±1.2±1.5) MeV/c² Width = (23.8±2.1±2.5) MeV

$\sigma\times\mathcal{B}$ = (88.0±6.1±7.9) pb @ 4.26 GeV



- The results are consistent with and more precise that BESIII previous observation
- The data agree well with $J^P=1^+$ quantum numbers

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



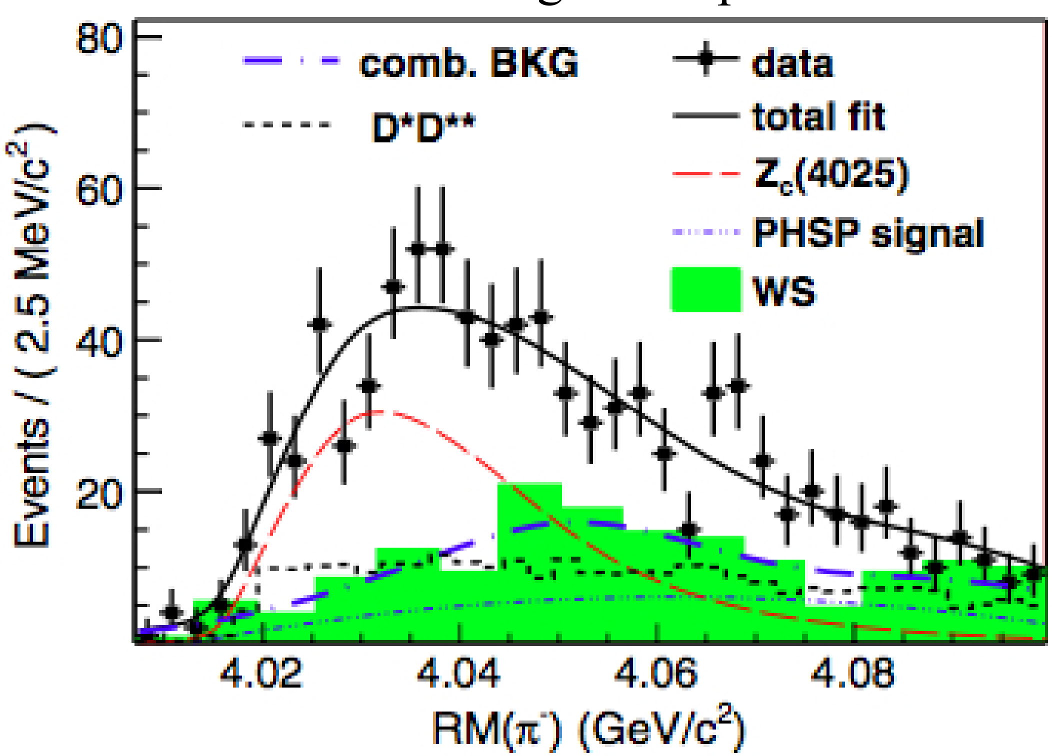
Study of $(D^*\bar{D}^*)^\pm$ system

PRL 112, 132001 (2014)

Study of $e^+e^-\to D^{*+}D^{*0}\pi^-$, $D^{*-}D^{*0}\pi^+$ at $\sqrt{s}$=4.26 GeV (827 pb^{-1})

- $D^+\to K^-\pi^+\pi^+$ (dominant yield and low backgrounds)
- Additional π^0 from $D^{*+(-)}$ or D^{*0}

π^- recoiling mass spectra



Enhancement observed near the $D^{*+}D^{*0}$ threshold ($Z_c(4025)^+$)

(fitting with a Breit-Wigner function)

Mass=(4026.3±2.6±3.7) MeV/c^2
Width=(24.8±5.6±7.7) MeV
Significance of 10σ

Parameters are very similar to $Z_c(4020)^+$ ⇒ to identify whether both state are the same, one needs a rigorous spin analysis on a larger data sample

Summary of Z_c states at BESIII

State	Channel	Mass m [MeV/c^2]	Width Γ [MeV]	Reference
$Z_c(3900)$, I=1	$J/\psi\pi^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	**PRL 110, 252001**
	$J/\psi\pi^0$	3894.8 ± 2.3	29.6 ± 8.2	**BESIII Preliminary**
$Z_c(3885)$, $J^P=1^+$	$D^+\bar{D}^{*0}$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$	**PRL 112, 022001**
		3884.3±1.2±1.5	23.8±2.1±2.5	**BESIII Preliminary**
$Z_c(4020)$, I=1	$h_c\pi^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	**PRL 111, 242001**
	$h_c\pi^0$	$4023.6 \pm 2.2 \pm 3.9$	fixed	**PRL 113, 212002**
$Z_c(4025)$, $J^P=1^+$	$D^{*+}\bar{D}^{*0}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	**PRL 112, 132001**

- States must contain at least 4 quarks
- What is the exact nature?
- Many theoretical interpretations:
  - Thetraquarks (L. Maiani et al., PRD71,014028)
  - Hadronic molecules (Dubynskiy et al., PLB666,344)
  - Hadro-charmonia (Voloshin, arXiv:1304.0380)

I. Determine J^P

II. Perform coupled channel analysis of open/hidden charm channels

Conclusions and Outlook

- Data at charm threshold provide unique ingredient on identifying D-$\overline{D}$ oscillation and CPV in the charm sectors
  - 2.92 fb^{-1} at 3.773 GeV
  - quantum-correlated D$\overline{D}$ production on threshold provide an unique way to measure the strong phase difference and charm mixing parameters
  - y_{CP} compatible with the word average, but still statistically limited

BESIII preliminary y_{CP}=(-1.7±1.3±0.6)%	$\cos\delta_{K\pi} = (1.02 \pm 0.11 \pm 0.06 \pm 0.01)$ NPB 734,227

More charm data will be collected at BESIII

- In 2012, BESIII has started a dedicated program toward understanding X, Y, Z states
  - Study the transitions between states
  - Surprising discoveries: $Z_c(3900)$ and $Z_c(4020)$
  - New data in the region above 4.2 GeV (~2 fb^{-1})

- Many new results will come out soon

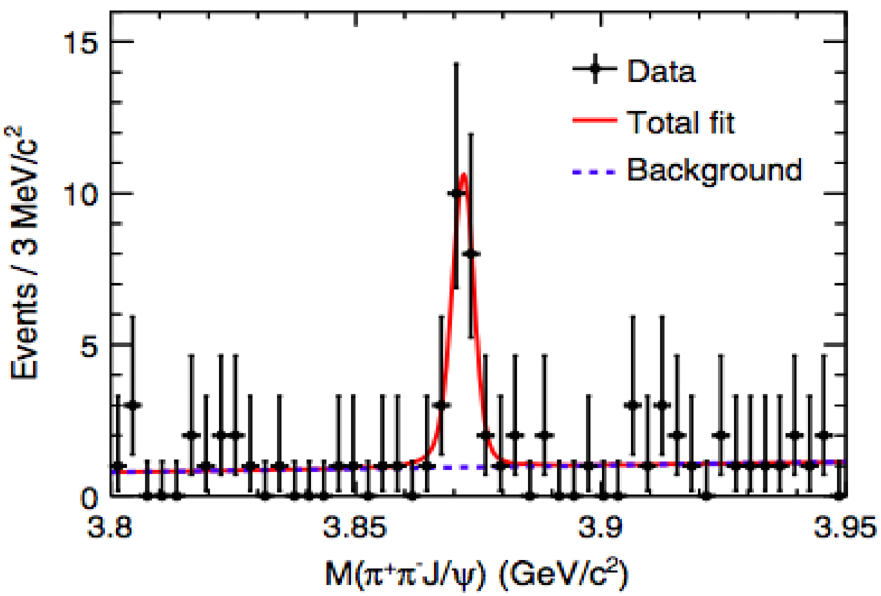
Stay Tuned

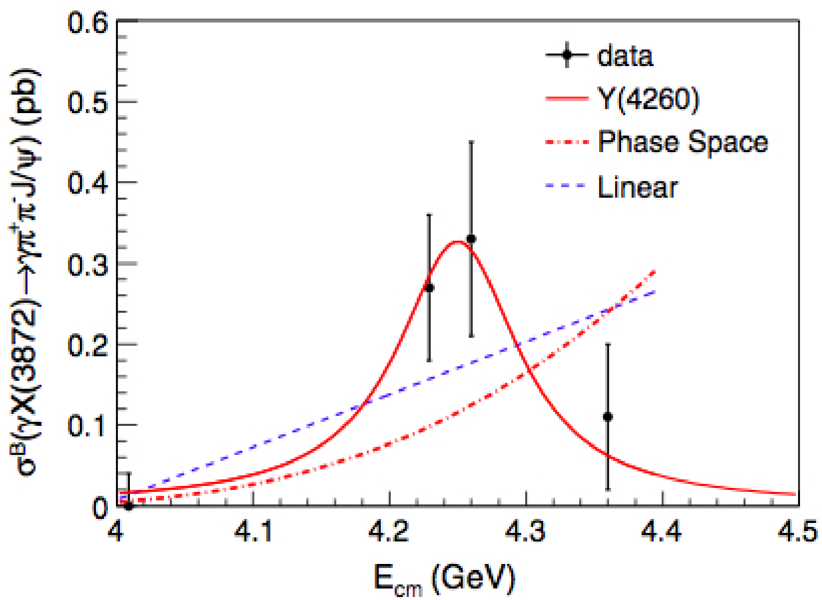
BK slides

First observation of gamma X(3872)

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

PRL 112, 132001 (2014)





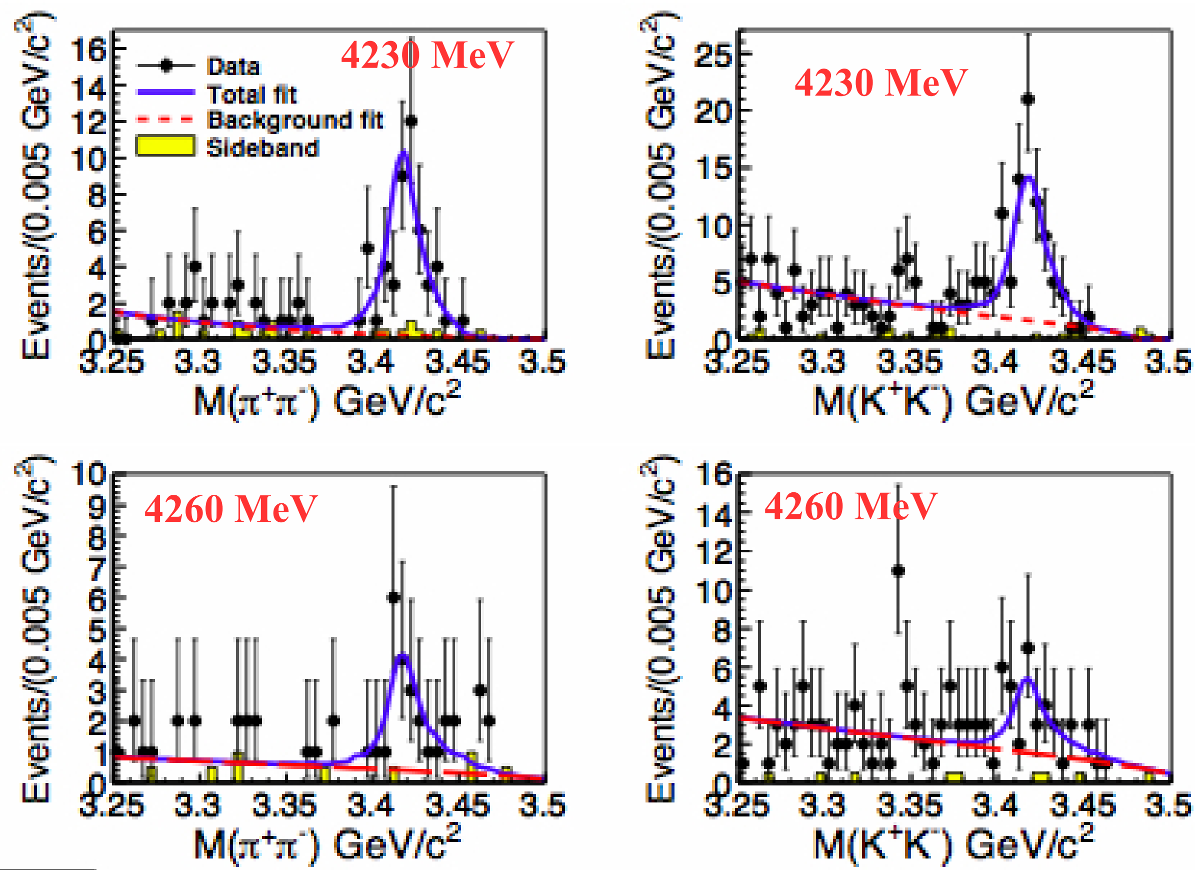
Significance = 6.3σ
N = 20.1 ± 4.5 events
M = 3871.9 ± 0.7 ± 0.2 MeV
Γ consistent with detector resolution

The resonant contribution with Y(4260) line shape provides a better description of the data than either a linear continuum or a E1-transition phase space distribution

The Y(4260)→γX(3872) could be another previously unseen decay mode of the Y(4260) resonance

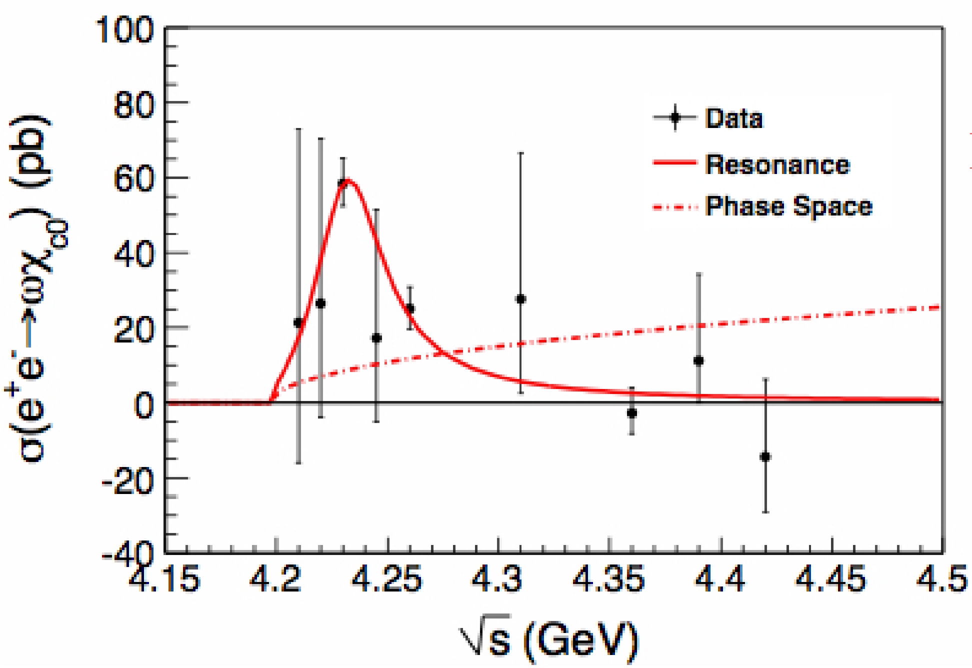
First observation of $e^+e^- \to \omega\chi_{c0}$

ArXiv:1410.6538 (2014)



The events are reconstructed exclusively:

- $\omega \to \pi^+\pi^-\pi^0$
- $\chi_{c0} \to \pi^+\pi^-$, K^+K^-



FIRST OBSERVATION OF THIS PROCESS

- The observed $\omega\chi_{c0}$ signals are unlikely from Y(4260)
  - Fit with a single Breit-Wigner yields mass lower than Y(4260)
- No significant signal observed for $\omega\chi_{c1,2}$