Highlights and Perspectives at BESIII

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for the BESIII collaboration

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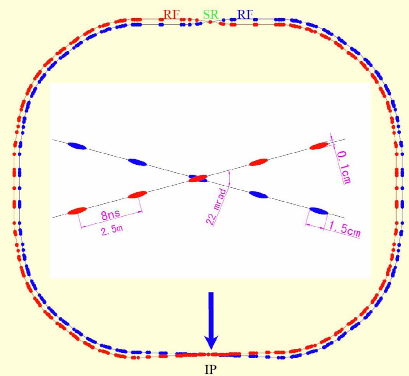
SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

MENU 2013
1st October 2013

BEPCII and BESIII

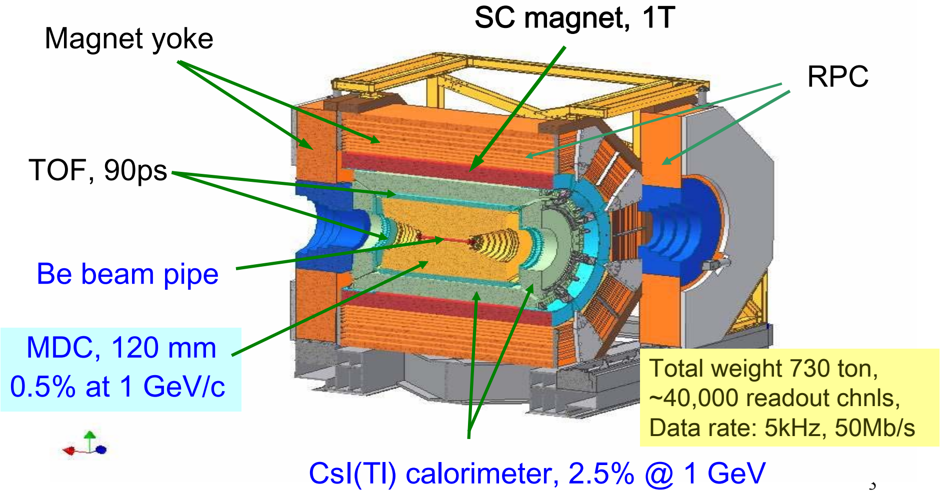
BEPCII storage rings: a τ-charm factory



Upgrade of BEPC (started 2004, first collisions July 2008)
Beam energy 1 . . . 2.3 GeV
Optimum energy 1.89 GeV
Single beam current 0.91 A
Crossing angle: ± 11 mrad

Design luminosity: $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Achieved: $7 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Beam energy measurement:
Laser compton backscattering
$\Delta E / E \approx 5 \times 10^{-5}$
($\approx$ 50 keV at τ threshhold)

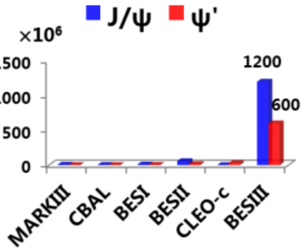
BESIII detector

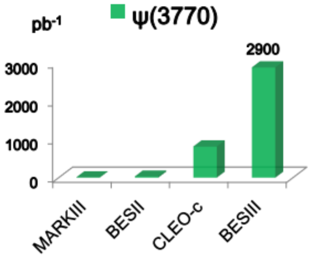


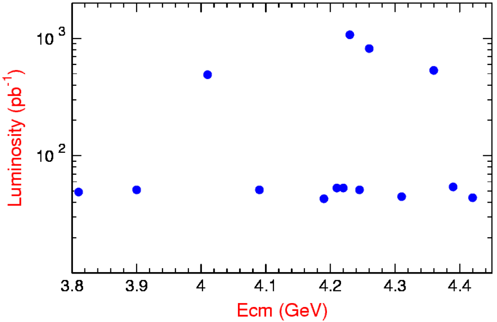
Completely new detector

Comparable performance to CLEO-c, + muon ID

BESIII data sets







Direct production of 1^{--} states studied with world's largest scan dataset

Today's 

BESIII at BEPCII

Light hadron spectroscopy

- $p\bar{p}$ threshold enhancement
- Nucleon resonances

Charmonium spectroscopy

- $\eta_c(1S)$ properties

XYZ

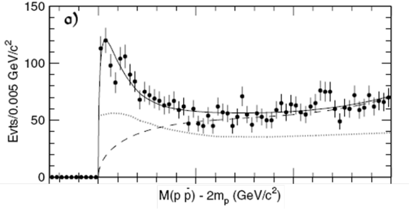
- $e^+e^- \to J/\psi\,\pi^+\pi^-$ and $h_c\pi^+\pi^-$
- A variation of Z_c
- $e^+e^- \to \gamma X(3872)$

Light Hadron Spectroscopy

$J/\psi \to \gamma p\bar{p}$ threshold enhancement

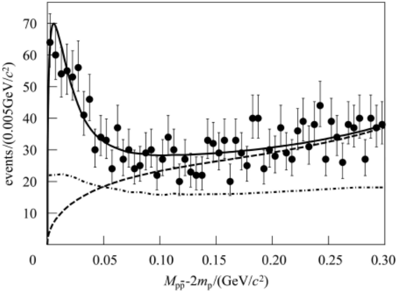
normal meson? $p\bar{p}$ bound state? multiquark? glueball? FSI?

BESII Phys. Rev. Lett. **91**, 022001 (2003)



BESIII CPC 34, 421 (2010)

using J/ψ from 106 M $\psi(3686)$



$$M = (1860^{+3}_{-10}{}^{+5}_{-25})\,\mathrm{MeV}/c^2$$

$$\Gamma < 38\,\mathrm{MeV} \quad (90\%\,C.L.)$$

Compatible with S-wave BW

$$M = (1861^{+6}_{-13}{}^{+7}_{-26})\,\mathrm{MeV}/c^2$$

$$\Gamma < 30\,\mathrm{MeV} \quad (90\%\,C.L.)$$

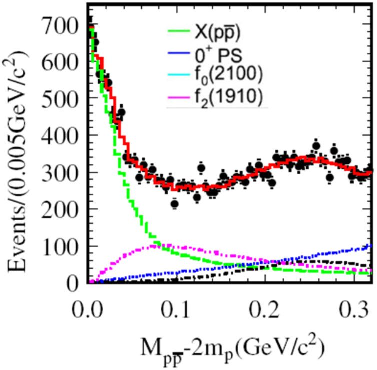
Compatible with S-wave BW

Spin-parity analysis essential to determine nature

PWA of $J/\psi \to \gamma p\bar{p}$ at $M(p\bar{p}) < 2.2\,\mathrm{GeV}/c^2$

PRL **108**, 112003

- PWA of $J/\psi \to \gamma p\bar{p}$: never done before
- best solution: $X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$ fixed at PDG, 0^{++} phase space, S-wave ($I = 0$) FSI
- Systematics:
  - $f_2(2150)$, $f_2(1950)$, other resonances from PDG, 0^{-+} phase space
  - FSI model dependence



Result:

$J^{PC} = 0^{-+}$, preferred over other J^{PC} assignments with $> 6.8\sigma$

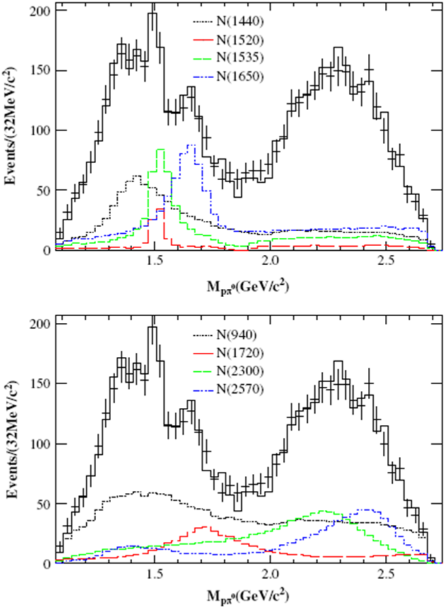
$$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19(\mathrm{mod})\ \mathrm{MeV}/c^2$$

$$\Gamma = 13 \pm 39^{+10}_{-13} \pm 4(\mathrm{mod})\ \mathrm{MeV} \qquad \Gamma < 76\,\mathrm{MeV}/c^2 \quad (90\%\,C.L.)$$

$\psi(2S) \to p\bar{p}\pi^0$

PRL **110**, 022001

- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation:
  Δ suppressed
- using 108 M $\psi(2S)$
- best solution:
  N(1440), N(1520), N(2090),
  N(1535), N(1650), N(1720)
  $N(2300)[\frac{1}{2}^+]$
  $N(2570)[\frac{5}{2}^-]$
- No need for
  N(1885), N(2065)
  $p\bar{p}$ $[1^{--}]$ enhancement
- Systematics:
  additional possible resonances



$\psi(2S) \to p\bar{p}\pi^0$

PRL **110**, 022001

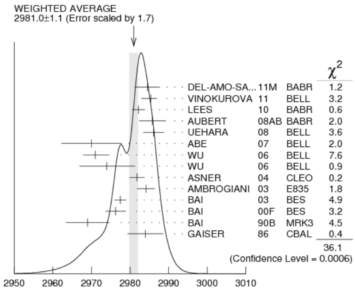
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$

$N(2300)[\frac{1}{2}^+]$
$N(2570)[\frac{5}{2}^-]$
never seen before

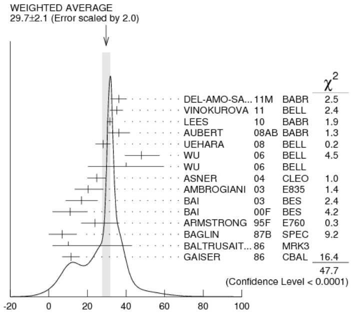
Charmonium Spectroscopy

Mass and width of $\eta_c(1S)$

Ground state charmonium ($c\bar{c}$), but mass and width not well known:
Tension between radiative J/ψ transitions and production in $\gamma\gamma$, $p\bar{p}$, B decays



$\eta_c(1S)$*mass*



$\eta_c(1S)$*width*

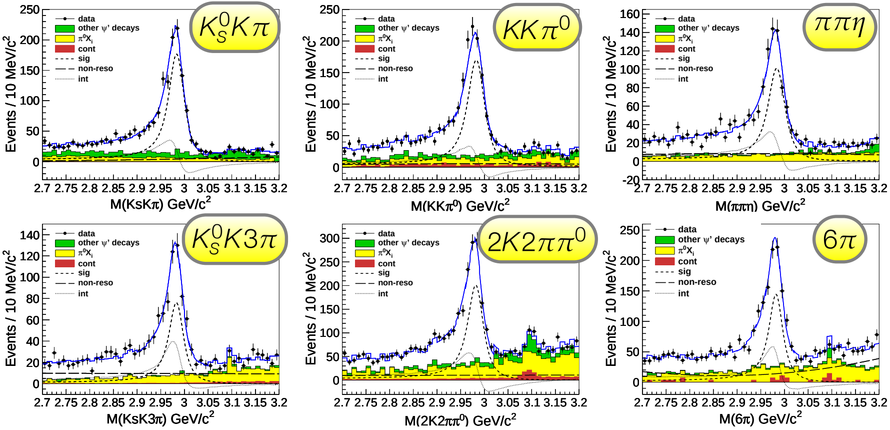
PDG '12

CLEO-c found distortion in $\eta_c(1S)$ line shape — Phys. Rev. Lett. **102**,011801

$c\bar{c}$ hyperfine splitting: $\Delta m_{hf}(1S) \equiv m(J/\psi) - m(\eta_c)$
important experimental input for Lattice QCD, dominated by $\Delta m(\eta_c)$

$\psi(3686) \to \gamma\eta_c(1S)$, η_c exclusive decays

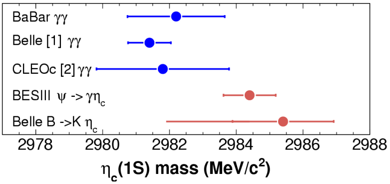
PRL **108**, 222002
using 106 M $\psi(3686)$

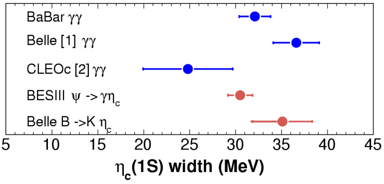


Interference with non-resonant decay important! All decay channels show same relative phase within $3\sigma \Rightarrow$ fix to common value in fit

$$m(\eta_c) = 2984.3 \pm 0.6 \pm 0.6\,\mathrm{MeV}/c^2$$
$$\Gamma(\eta_c) = 32.0 \pm 1.2 \pm 1.0\,\mathrm{MeV}$$
$$\phi = 2.40 \pm 0.07 \pm 0.08\,\mathrm{rad} \quad \text{or}$$
$$= 4.19 \pm 0.03 \pm 0.09\,\mathrm{rad}$$

$\eta_c(1S)$ mass and width

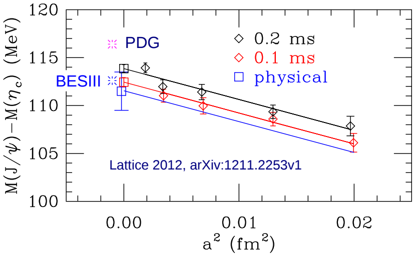




plots: S. Olson

Consistent with results from *B* factories in other production mechanisms.

Line shape, interference with non-resonant decays important



Hyperfine splitting

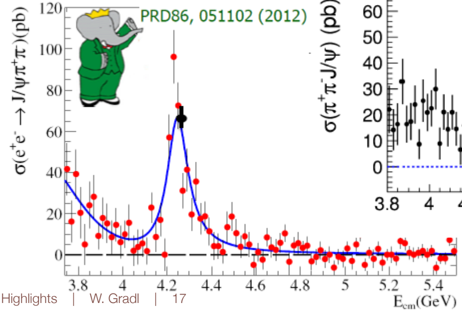
$\Delta m(1S) = 112.6 \pm 0.8\ \text{MeV}/c^2$

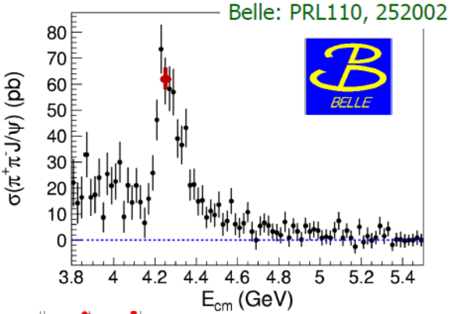
➡ in better agreement with LQCD and quark model predictions

Exotic charmonium-like states

$e^+e^- \to J/\psi\,\pi^+\pi^-$ at 4.26 GeV

- 1^{--} resonance $Y(4260)$ seen in ISR production at e^+e^-
  BABAR, PRL **95**, 142001 (2005); CLEO, PRD **74**, 091104 (2006); Belle, PRL **99**, 182004 (2007)
- No obvious place in charmonium spectrum; unexpectedly large decay rate into $J/\psi\,\pi^+\pi^-$ for charmonium state
- BESIII: take large datasets ($500 - 1000\,\mathrm{pb}^{-1}$) at interesting $\sqrt{s}$
- $\sigma^B(e^+e^- \to J/\psi\,\pi^+\pi^-) = (62.9 \pm 1.9 \pm 3.7)\,\mathrm{pb}$
  in good agreement with BABAR and Belle

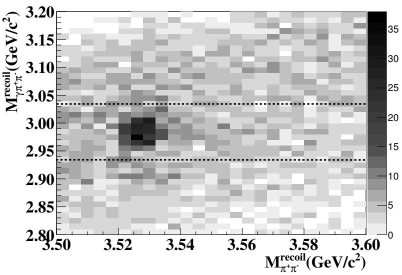


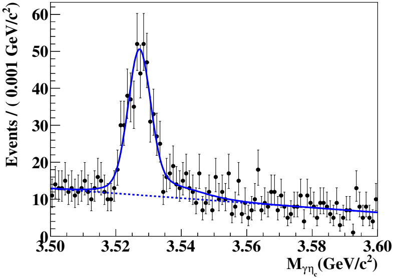


$e^+e^- \to h_c(1P)\pi^+\pi^-$

BESIII **preliminary**, arXiv:1309.1896 (2013)

Reconstruct $h_c \to \gamma\eta_c$, $\eta_c \to 16$ exclusive hadronic modes





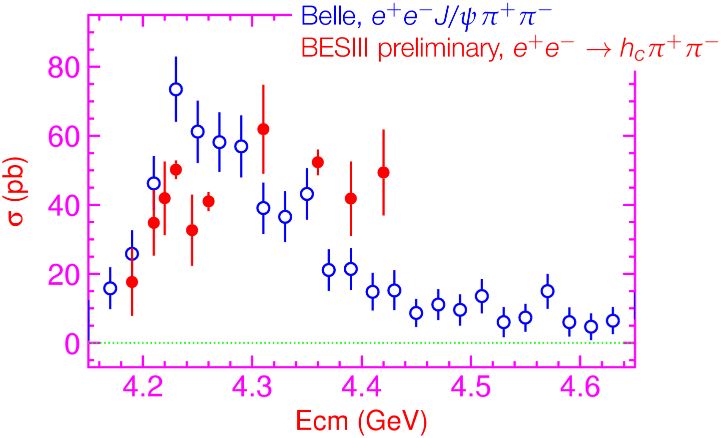
at $\sqrt{s} = 4.26$ GeV

$h_c\pi^+\pi^-$ sample sizes

$\sqrt{s}$	$\mathcal{L}_{int}$	N_{cand}
4.23	1090	859
4.26	827	568
4.36	545	469

Purity $\sim$ 65%

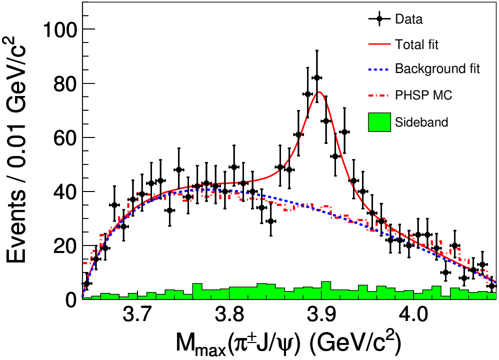
Cross section comparison



- $\sigma(e^+e^- \to h_c\pi^+\pi^-) \approx \sigma(e^+e^- \to J/\psi\,\pi^+\pi^-)$, but different line shape
- Local maximum around 4.23 GeV?
- Broad structure around 4.4 GeV?

$Z_c(3900)^{\pm} \to J/\psi\,\pi^{\pm}$

BESIII, PRL **110**, 252001 (2013)

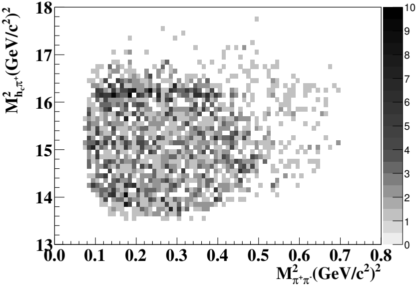


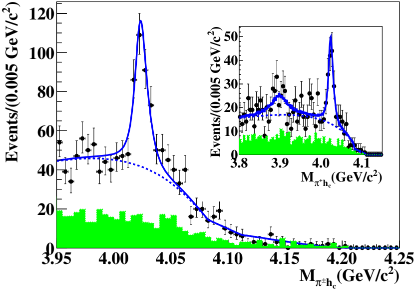
- 1D fit to extract resonance parameters,
  S-wave Breit Wigner with phase space factor & efficiency corr.
- $M = (3899.0 \pm 3.6 \pm 4.9)\,\mathrm{MeV}/c^2$, $\Gamma = (46 \pm 10 \pm 20)\,\mathrm{MeV}$
- Significance $> 8\sigma$
- Confirmed by Belle PRL **110**, 252002 and with CLEOc data arXiv:1304.3036

$Z_c(4020) \to h_c\pi^+$

BESIII **preliminary**, arXiv:1309.1896 (2013)

- Using data taken at 4.23 GeV, 4.26 GeV 4.36 GeV (total 2.4 fb^{-1})
- See structure in $h_c\pi^\pm$ spectrum, close to $D^*\bar{D}^*$ threshold :



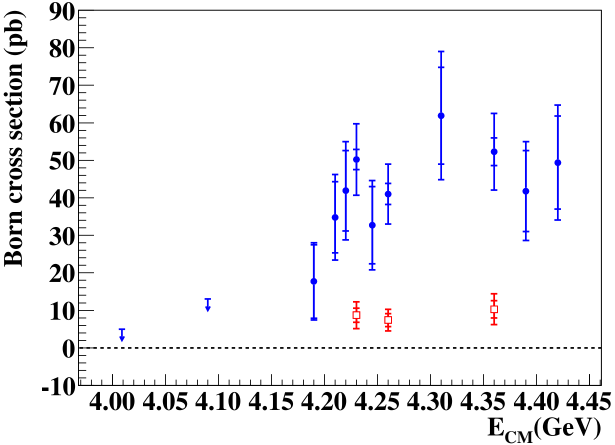


$$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7\,\text{MeV}/c^2$$
$$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6\,\text{MeV}$$

No significant signal $Z_c(3900) \to h_c\pi^+$ seen

$e^+e^- \to Z_c(4020)^+\pi^- \to h_c\pi^+\pi^-$ cross section

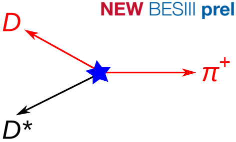
BESIII **preliminary**, arXiv:1309.1896 (2013)



Systematics mainly from h_c and η_c branching fraction
95% of syst. uncertainty common to all data points

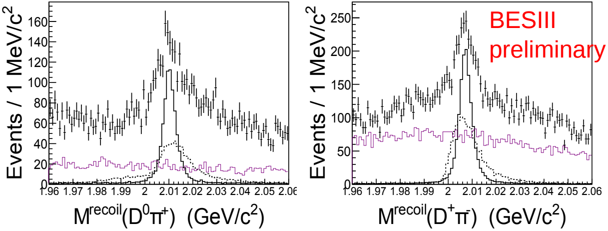
$e^+e^- \to \pi^\pm(D\bar{D}^*)^\mp$

NEW BESIII **preliminary**



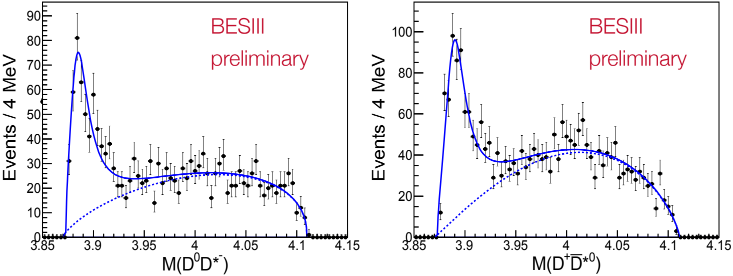
Single tag analysis:

- reconstruct 'bachelor' π^+ and $D^0 \to K^-\pi^+$ or $D^- \to K^+\pi^-\pi^-$
- require D^* in missing mass
- veto $e^+e^- \to (D^*\bar{D}^*)^0$
- apply kinematic fit; look in mass recoiling against π^+ : see clear D^* signal over smooth background



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

NEW BESIII **preliminary**



- Fit with rel. Breit Wigner (*S*-wave), extract pole position.
- Background modelled with empirical smooth function
- $D^0 D^{*-}$ and $D^+ \bar{D}^{*0}$ give compatible result ➡ average:

$$M = 3883.9 \pm 1.5 \pm 4.2\,\mathrm{MeV}/c^2$$

$$\Gamma = 24.8 \pm 3.3 \pm 11.0\,\mathrm{MeV}$$

$$\sigma \times \mathcal{B} = 83.5 \pm 6.6 \pm 22.0\,\mathrm{pb}$$

$Z_c(3885)^+$ Quantum numbers?

NEW BESIII **preliminary**

- $\cos\theta_\pi$: angle between bachelor pion and beam axis in CMS

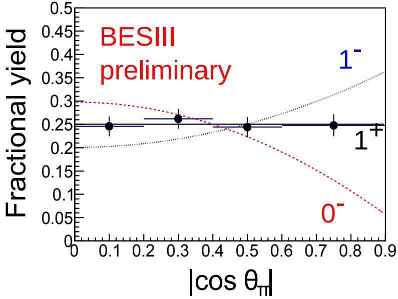
0^+ excluded by parity conservation

0^- π and $Z_c(3885)$ in P-wave, with $J_z = \pm 1$ ➡ $dN/d\cos\theta_\pi \propto \sin^2\theta_\pi$

1^- π and $Z_c(3885)$ in P-wave ➡ $dN/d\cos\theta_\pi \propto 1 + \cos^2\theta_\pi$

1^+ π and $Z_c(3885)$ in S or D wave. Assume D wave small near threshold: flat distribution in $\cos\theta_\pi$.

Event yield in 4 bins in $|\cos\theta_\pi|$



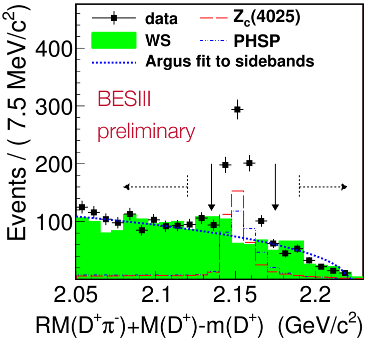
data clearly favour $J^P = 1^+$ for $D\bar{D}^*$ structure

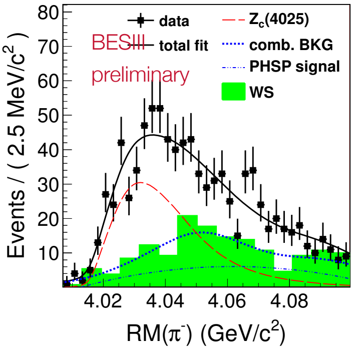
first measurement of J^P for one of the Z_c

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

BESIII **preliminary**, arXiv:1308.2760 (2013)

Partial reconstruction technique:
reconstruct π^-, D^+ and one π^0 from $D^{*+} \to D^+\pi^0$ or $D^{*0} \to D^0\pi^0$





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

$$M = 4026.3 \pm 2.6 \pm 3.7\,\mathrm{MeV}/c^2,\ \Gamma = 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}$$

Summary of "Z states"

Channel	Mass [MeV/c^2]	Width [MeV]
$J/\psi\,\pi^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$(D\bar{D}^*)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
$h_c\pi^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$

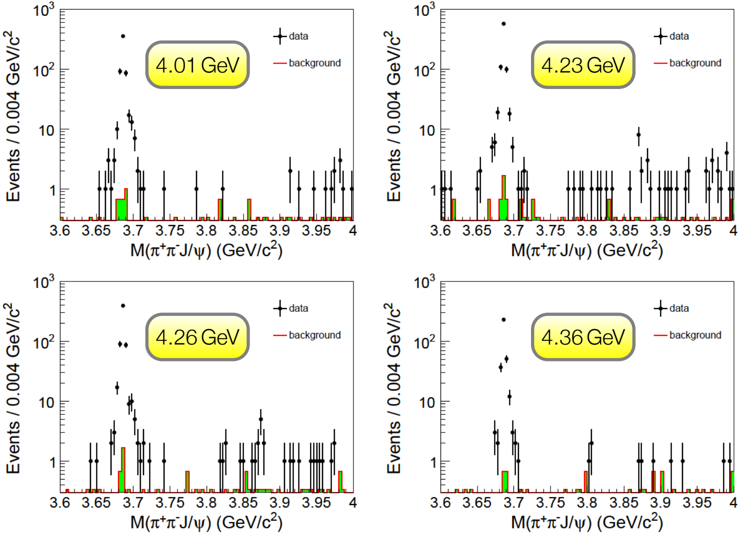
Suggestively grouped the four states — but are they related in this way?

Nature of these states?

- Tetraquark L. Maiani, A. Ali et al.
- Hadronic molecule U.-G. Meissner, F.K. Guo et al.
- Hadro-charmonium M. B. Voloshin
- Meson loop Q. Zhao et al.
- ISPE model X. Liu et al.
- …

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

BESIII **preliminary**

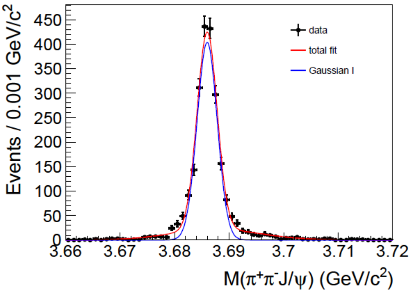


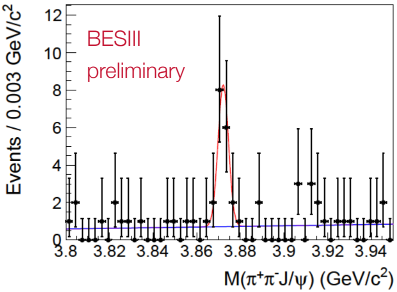
Clear ISR $\psi(3686)$ signal for validation

$X(3872)$ signal around 4.23 – 4.26 GeV

$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma J/\psi\,\pi^+\pi^-$

BESIII **preliminary**





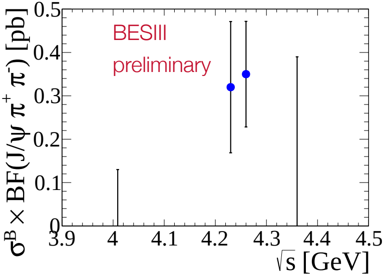
- Plots show partial dataset at $\sqrt{s} = 4.23\,\text{GeV}$
- Use ISR $\psi(3686)$ signal for calibration of rate, mass and mass resolution
- Model signal peak with MC signal width $\otimes$ Gaussian with σ_M

$\psi(3686)$ $N = 1242$; $M = (3685.96 \pm 0.05)$ MeV; $\sigma_M = (1.84 \pm 0.06)$ MeV

X(3872) $N = 15.0 \pm 3.9$; $M = (3872.1 \pm 0.8 \pm 0.3)$ MeV
significance $> 5.3\,\sigma$

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

BESIII **preliminary**



$\sqrt{s}$ [GeV]	$\sigma^B \times \mathcal{B}$ [pb]
4.01	< 0.13
4.23	$0.32 \pm 0.15 \pm 0.02$
4.26	$0.35 \pm 0.12 \pm 0.02$
4.36	< 0.39

Suggestive: radiative decay $Y(4260) \to \gamma X(3872)$, not from continuum

Combined with $\sigma^B(e^+e^- \to J/\psi\,\pi^+\pi^-) = (62.9 \pm 4.2)$ pb

$$\frac{\sigma^B[e^+e^- \to \gamma X(3872)] \times \mathcal{B}(X \to J/\psi\,\pi^+\pi^-)}{\sigma^B(e^+e^- \to J/\psi\,\pi^+\pi^-)} = (5.6 \pm 2.0) \times 10^{-3}$$

Assuming $\mathcal{B}(X \to J/\psi\,\pi^+\pi^-) \approx 5\%$: large transition ratio

$$\frac{\sigma^B[e^+e^- \to \gamma X(3872)]}{\sigma^B(e^+e^- \to J/\psi\,\pi^+\pi^-)} \approx 11\%$$

Perspectives

- Precise determination of resonance parameters
- Spin-parity assignment: angular analysis / PWA
- More decay modes: $\psi(3686)\pi$, $\eta_c\rho$, open charm …
- Production mechanisms, production rates
- Test various models
- Search for neutral partners
- Excited Z_c, Z_c' states? $Z_{cs} \to J/\psi K$?
- Other XYZ states?
- More data at 4.26 GeV and higher energies

Summary

- Rich physics programme at BESIII with large and unique data sets J/ψ, $\psi(3686)$, $\psi(3770)$, XYZ
- Light hadron spectroscopy:
- Precision measurements of charmonia
- Discovery of new, exotic (!) states $Z_c(3900)$ …
- Not shown today: precise measurements of
  - τ mass
  - hadronic cross sections
  - transition form factors
  - open charm decays
  - …
- Many new exciting results on their way