Highlights of BESIII results

BESIII结果亮点

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on behalf of the BESIII collaboration

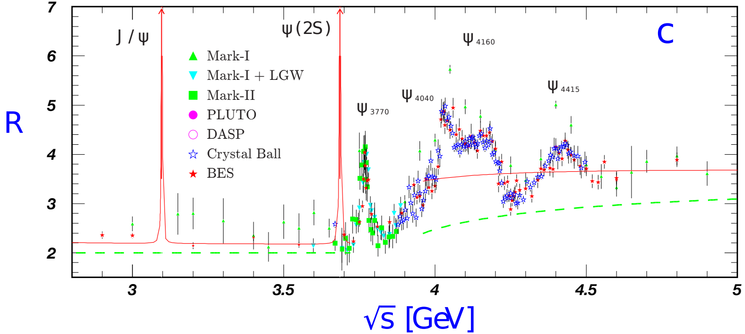
54th International Winter Meeting on Nuclear Physics
25th January 2016

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

PRISMA

τ-charm energy region



Rich in resonances: charmonia and charmed mesons

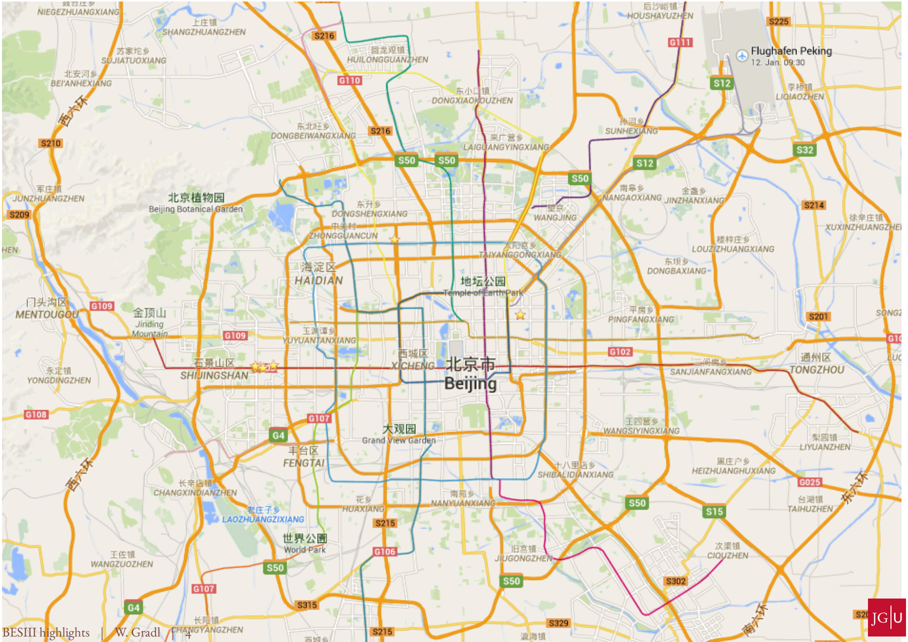
Threshold characteristics (pairs of τ, D, D_s, Λ_c …)

Transition region between continuum and resonances, perturbative and non-perturbative QCD

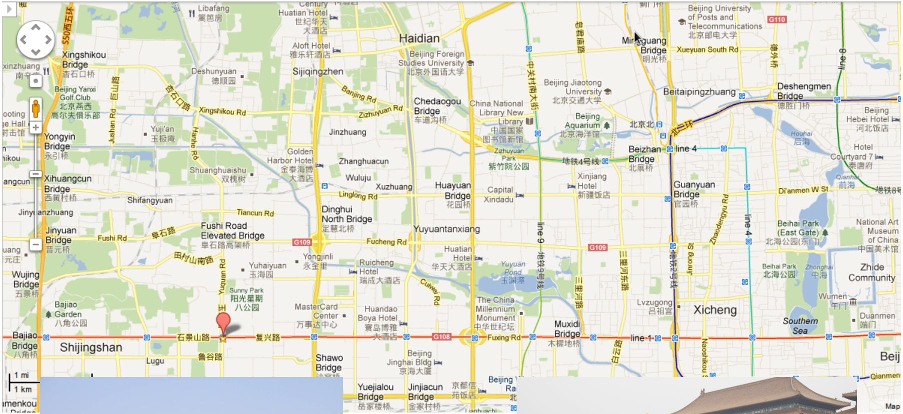
Location of new hadrons: glueballs, hybrids, multi-quark states


BESIII: a τ-charm factory

BEPCII and BESIII

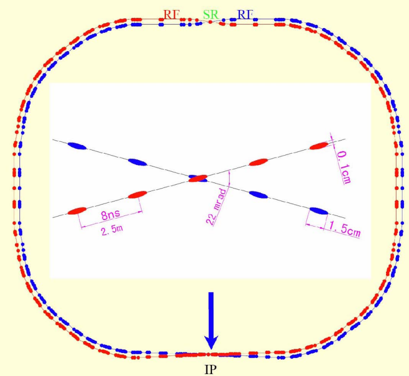


BEPCII and BESIII



BEPCII and BESIII

BEPCII storage rings: a τ-charm factory



Upgrade of BEPC (started 2004, first collisions July 2008)	
Beam energy	**$1 \cdots 2.3$ GeV**
Optimum energy	**1.89 GeV**
Single beam current	**0.91 A**
Crossing angle	**$\pm$11 mrad**

Design luminosity	**$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$**
Achieved	**$8 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$**

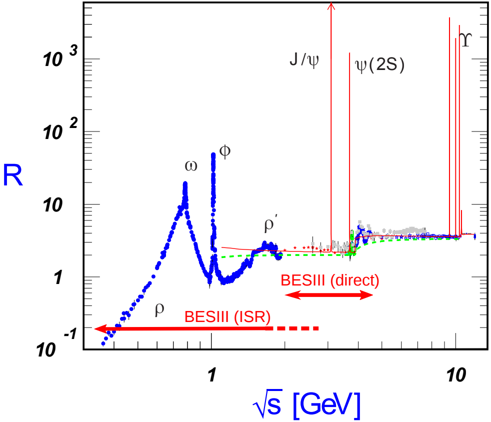
Beam energy measurement:

Laser Compton backscattering

$\Delta E/E \approx 5 \times 10^{-5}$

($\approx$ 50 keV at τ threshhold)

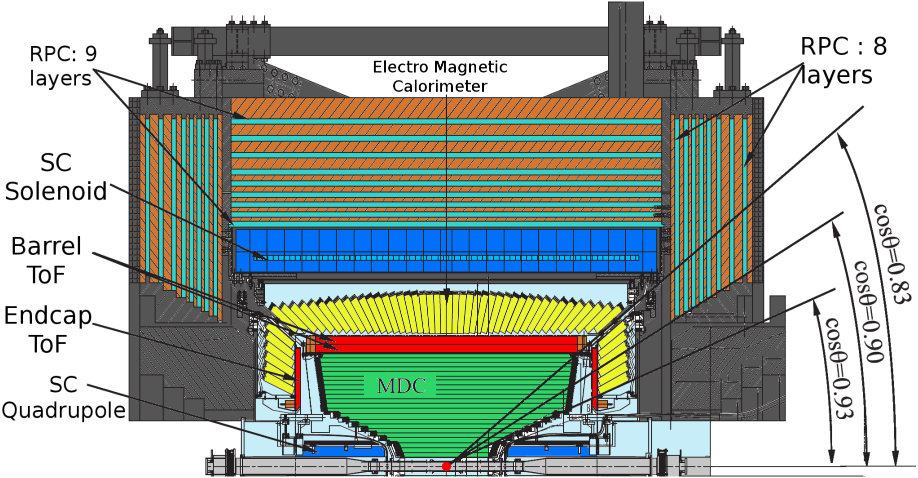
BEPC energy region



Direct production: span the interesting charmonium region

ISR: reach down to $\pi\pi$ threshold with decent statistics

BESIII detector

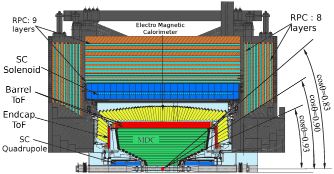


Completely new detector

Comparable performance to CLEO-c, + muon ID

BESIII detector performance

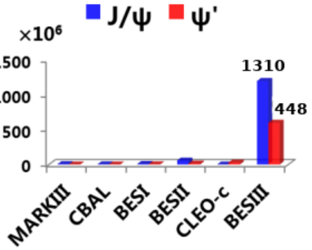
Expt.	MDC Wire resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO	110 μm	5%	2.2 – 2.4%
BABAR	125 μm	7%	2.67%
Belle	130 μm	5.6%	2.2%
BESIII	115 μm	$<$ 5%	2.3%

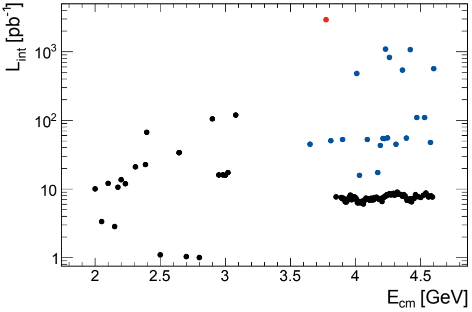


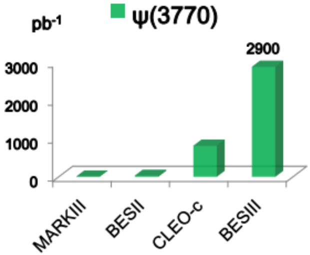
Expt.	TOF time resolution
CDF	100 ps
Belle	90 ps
BESIII	68 ps (Barrel) 100 ps (ETOF)

- 2015: Installation of new ETOF modules (MRPC, $\sigma_t \sim 60$ ps)
- Cylindrical GEM (CGEM) detector to replace inner part of MDC (Italy, IHEP, Germany, Sweden)
- Small-angle electron/photon tagger

Unique BESIII data set



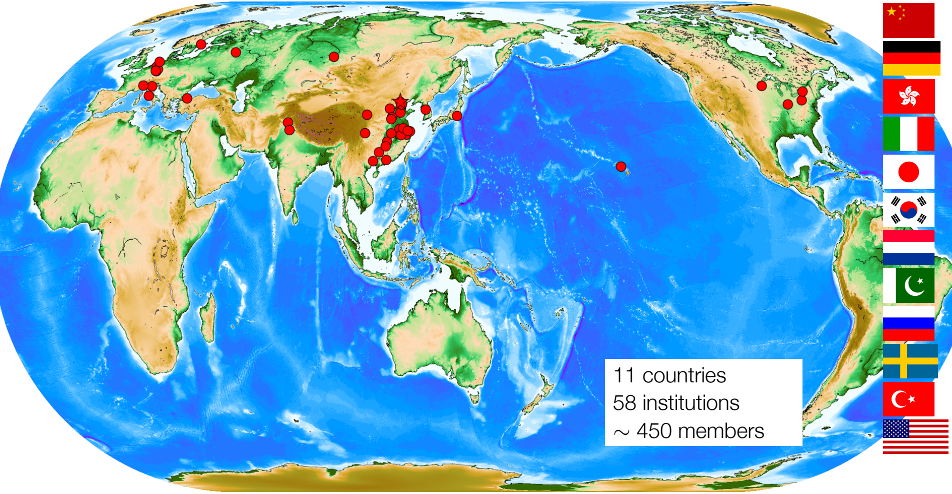




large data sets of $\approx 4\,\text{fb}^{-1}$ above 3.8 GeV for XYZ studies
$+$ 104 energy points between 3.85 and 4.59 GeV (R scan)
$+ \sim 20$ energy points between 2.0 and 3.1 GeV

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

The BESIII Collaboration



Physics programme

Light hadron physics

- meson and baryon spectroscopy
- multiquark states
- threshold effects
- glueballs & hybrids
- two-photon physics
- form-factors

QCD and τ

- precision R measurement
- τ decays
- hadron form factors and fragmentation fcts.

Charmonium physics

- precision spectroscopy
- transitions and decays

Charm physics

- semi-leptonic form factors
- decay constants f_D and f_{D_s}
- CKM matrix: $|V_{cd}|$, $|V_{cs}|$
- $D^0 - \bar{D}^0$ mixing, CPV
- strong phases
- Λ_c decays

Precision mass measurements

- τ mass
- D, D^* mass

XYZ meson physics

- $Y(4260)$, $Y(4360)$ properties
- $Z_c(3900)^+$, …

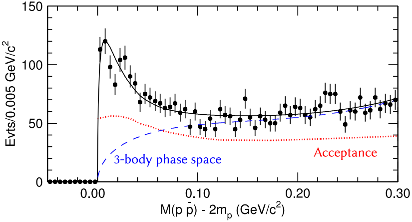
…


Light Hadron Spectroscopy

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

Seen by BES-II with 58M J/ψ

PRL **91**, 022001 (2003)



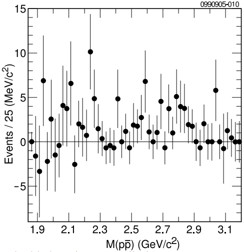
What could it be?

- FSI effect
- Baryonium (i.e. $p\bar{p}$ bound state)
- something of both?
- …

No similar structure observed in related channels:

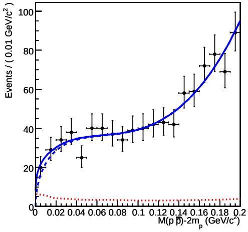
$\Upsilon(1S) \to \gamma p\bar{p}$ (CLEO)

PRD **73**,032001 (2006)



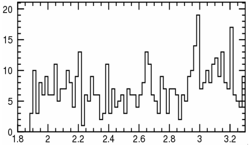
$J/\psi \to \omega p\bar{p}$ (BES-II)

EPJ C53, 15 (2007)



$\psi' \to \gamma p\bar{p}$ (BES-II)

Phys. Rev. Lett. **99**, 011820



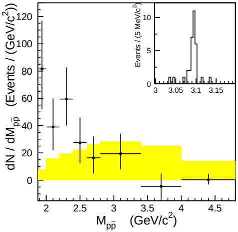
($\sim 2\sigma$ significance for threshold enhancement)

$p\bar{p}$ threshold enhancement in other reactions

BELLE, $B^+ \to K^+ p\bar{p}$

Phys. Rev. Lett. **88**,181803

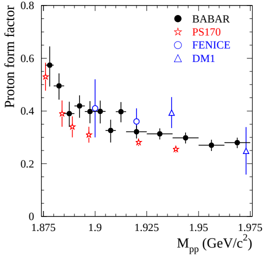
($29.4\,\mathrm{fb}^{-1}$)



BABAR, $e^+e^- \to \gamma p\bar{p}$

Phys. Rev. D **73**, 012005

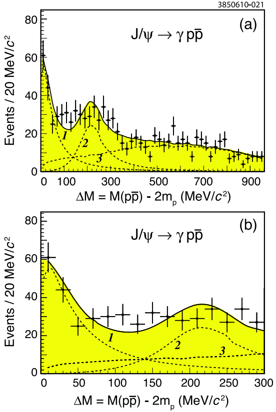
($231\,\mathrm{fb}^{-1}$)



CLEO, $\psi' \to \pi^+\pi^- J/\psi$

Phys. Rev. D **82**,092002

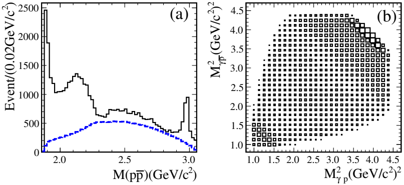
(24.5 M ψ')

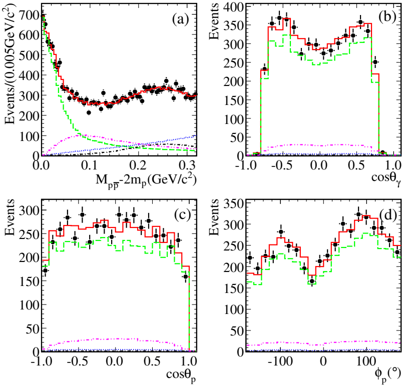


- Also seen in other *B* decays
- FSI? Sub-threshold resonance? …
- Not enough statistics!

BESIII: $J/\psi \to \gamma p\bar{p}$

BESIII, PRL **108**, 112003 (2012)





Using 225M J/ψ decays ($\approx 4\times$ BES-II)

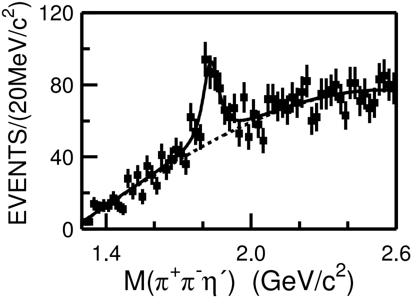
Apply PWA for $M(p\bar{p}) < 2.2\,\text{GeV}/c^2$
Fit with S-wave Breit-Wigner for $X(p\bar{p})$:

$$M = 1832^{+19}_{-5}\,(\text{stat.})^{+18}_{-17}\,(\text{syst.}) \pm 19\,(\text{model})\,\text{MeV}/c^2$$

$$\Gamma = 13 \pm 39\,(\text{stat.})^{+10}_{-13}\,(\text{syst.}) \pm 4\,(\text{model})\,\text{MeV}/c^2$$

Fit prefers $J^{PC} = 0^{-+}$ for $X(p\bar{p})$

X(1835) in $J/\psi \to \gamma\eta'\pi\pi$



BES-II, Phys. Rev. Lett. **95**, 262001

- Using 58 M J/ψ
- $m = 1833.7 \pm 6.1 \pm 2.7\,\mathrm{MeV}/c^2$
- $\Gamma = 67.7 \pm 20.3 \pm 7.7\,\mathrm{MeV}/c^2$
- Significance $\sim 7.7\sigma$

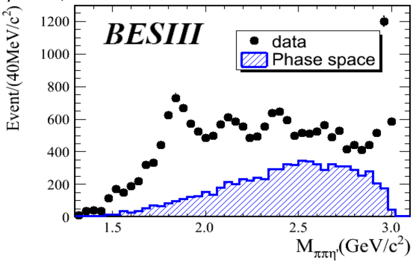
$p\bar{p}$ bound state? Pseudoscalar glueball? Radial excitation of η'?

- 0^{-+} glueball expected to have similar decay properties of η_c
- LQCD prediction for mass of 0^{-+} glueball $\sim 2.3\,\mathrm{GeV}/c^2$

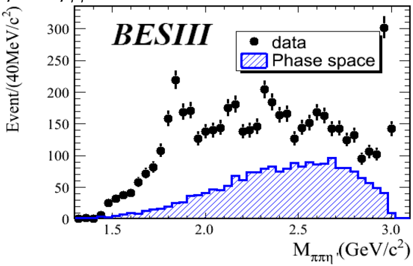
➠ With this statistics, impossible to measure quantum numbers of this $X(1835)$

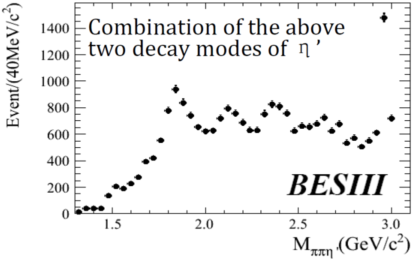
BESIII: Mass spectrum of $\eta' \pi^+ \pi^-$

$\eta' \to \gamma \pi^+ \pi^-$



$\eta' \to \eta_{\gamma\gamma} \pi^+ \pi^-$



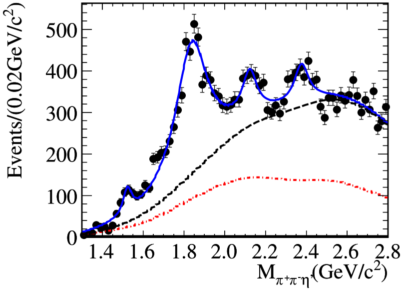


- 225 M J/ψ events
- η_c and $X(1835)$ visible
- More structure at ~ 2.1 and 2.3 GeV/c^2
- Bump at 1510 MeV/c^2: $f_1(1510)$?

Fit to $\eta'\pi^+\pi^-$ spectrum

BESIII, PRL **106**, 072002 (2011)

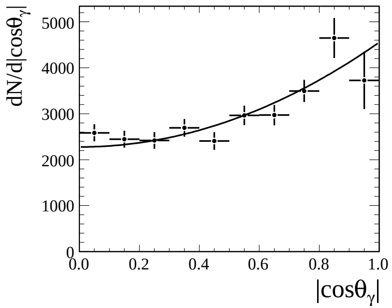
- Four resonances (rel. BW $\otimes$ Gauss, acceptance weighted)
- Non-resonant $\eta'\pi^+\pi^-$: from MC, incoherent
- Background components:
  - non-η' background estimated by η' sidebands
  - Mis-reconstructed $J/\psi \to \pi^0\eta'\pi^+\pi^-$: from data, reweight



Find three resonant structures in $\eta'\pi^+\pi^-$ mass spectrum:

	$m\,[\mathrm{MeV}/c^2]$	$\Gamma\,[\mathrm{MeV}/c^2]$
$X(1835)$	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$
$X(2120)$	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$
$X(2370)$	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$

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

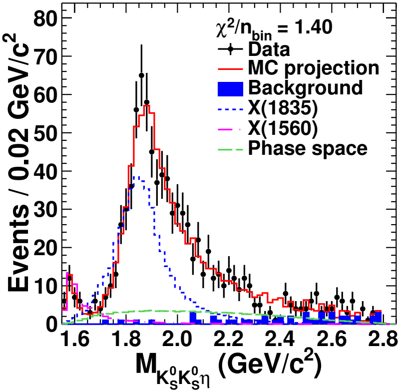


Angular distribution for events in $X(1835)$ peak $\propto 1 + \cos^2\theta_\gamma$
➠ supports $J^{PC} = 0^{-+}$

- $X(1835)$ mass consistent with BES-II msmt,
  width significantly larger
- Next step: PWA to determine spin-parity assignment
  allows to take interference into account
- Need to look
  - in reactions with recoil particles (ω, ϕ, …) instead of γ
  - in other related channels (e.g. $\eta\pi\pi$)

$X(1835)$ in $J/\psi \to \gamma\eta K_S^0 K_S^0$

BESIII, PRL **115**, 091803 (2015)



$M = 1844 \pm 9(\text{stat})^{+16}_{-25}(\text{syst})\ \text{MeV}/c^2$

$\Gamma = 192^{+20}_{-17}(\text{stat})^{+62}_{-43}(\text{syst})\ \text{MeV}$

See 0^{-+} structure in $p\bar{p}$, $\eta'\pi^+\pi^-$, and $\eta K_S^0 K_S^0$ at $\sim$ same mass
different decay modes of the same state?

Using full dataset of 1.3×10^9 J/ψ

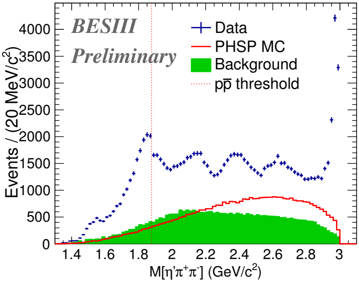
PWA results: $J^{PC} = 0^{-+}$ preferred for $X(1835) \to \eta K_S^0 K_S^0$

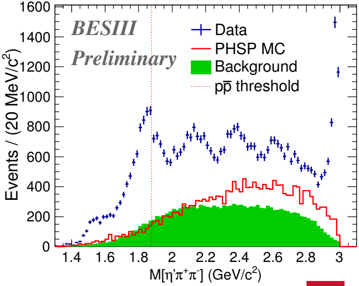
$X(1835) \to \eta K_S^0 K_S^0$ is dominated by $f_0(980)$

New: connection between $X(p\bar{p})$ and $X(1835)$

BESIII preliminary

- Using 1.09×10^9 J/ψ events collected in 2012
- $\eta' \to \gamma\pi^+\pi^-$ and $\eta(\gamma\gamma)\pi^+\pi^-$
- Clear peaks of $X(1835)$, $X(2120)$, $X(2370)$, η_C, and a structure near 2.6 GeV/c^2
- Significant distortion of the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold

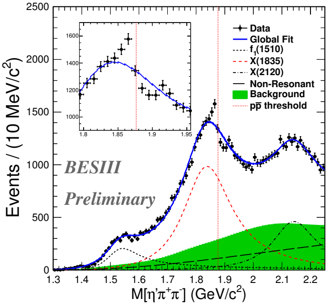




Fit to $\eta'\pi^+\pi^-$ mass spectrum

Simultaneous fits to two η' decay modes

- Simple Breit-Wigner function fails in describing the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold



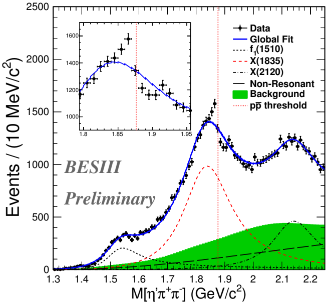
Fit to $\eta'\pi^+\pi^-$ mass spectrum

Simultaneous fits to two η' decay modes

- Simple Breit-Wigner function fails in describing the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold
- Two typical circumstances where an abrupt distortion of a resonance's line shape shows up:

➠ Threshold structure caused by the opening of an additional $p\bar{p}$ decay mode
Use the Flatté formula for the line shape (MODEL I)

➠ Interference between two resonances
Use coherent sum of two Breit-Wigner amplitudes for the line shape (MODEL II)



Fit to $\eta'\pi^+\pi^-$ mass spectrum: coupled channels

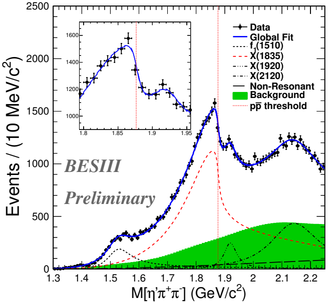
Using the Flatté formula for line shape

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

$$\text{with } \sum_k g_k^2 \rho_k \simeq g_0^2 \left(\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2} \rho_{p\bar{p}} \right)$$

- $\frac{g_{p\bar{p}}^2}{g_0^2}$: ratio between coupling strength to $p\bar{p}$ channel and sum of all other channels
- Fit result:

$g_0^2((\text{GeV}/c^2)^2)$	$93.7 \pm 35.4^{+47.6}_{-43.9}$
$g_{p\bar{p}}^2/g_0^2$	$2.31 \pm 0.37^{+0.83}_{-0.60}$
$M_{\text{pole}}(\text{MeV}/c^2)$	$1909.5^{+15.9+9.4}_{-15.9-27.5}$
$\Gamma_{\text{pole}}(\text{MeV})$	$273.5 \pm 21.4^{+6.1}_{-64.0}$



Significance for $g_{p\bar{p}}^2/g_0^2 > 0$ is larger than 7σ

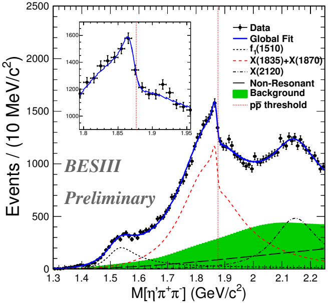
Fit to $\eta'\pi^+\pi^-$ mass spectrum: two resonances

Using two interfering resonances

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

- Fit result:

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

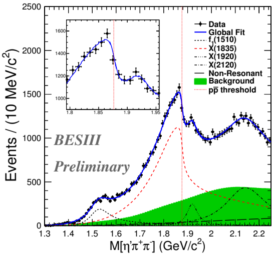


Significance for $X(1870)$ is larger than 7σ

$X(1920)$ not significant

$\eta'\pi^+\pi^-$ line shape near $p\bar{p}$ threshold

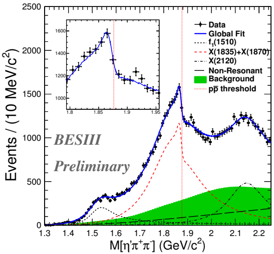
Significant distortion of $\eta'\pi^+\pi^-$ line shape near $p\bar{p}$ mass threshold observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$



Two models used to describe data:

- Flatté (coupled channels)
- two interfering resonances

Almost equal fit quality for both models:
cannot distinguish between them with current data



Suggest existence of one of

- a broad state with strong coupling to $p\bar{p}$
- narrow state just below $p\bar{p}$ mass threshold

$p\bar{p}$ molecule-like or bound state?

Study line shapes for other decay modes,
e.g. $\gamma p\bar{p}$, $\gamma\eta K^0_S K^0_S$ …


Charm physics

Charm physics

At 3.77 GeV ($\psi(3770)$) and above, produce $c\bar{c}$: charmed hadrons

Exploit threshold production of $D\bar{D}$, $D\bar{D}^*$, $D_s^+ D_s^-$ etc.

Clean events; use double-tag technique to measure absolute branching fractions

$\psi(3770) \to D^0\bar{D}^0$: quantum correlations between the D's
measure strong phases

See Li Lei's talk on Charm results on Wednesday afternoon

JG|U

Semileptonic decay of Λ_c^+

BESIII, PRL **115**, 221805 (2015)

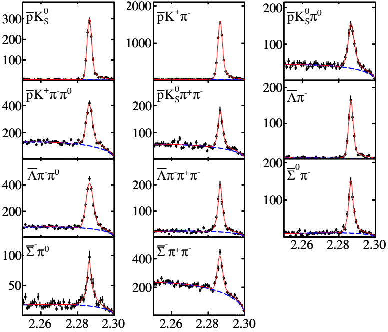
Run at highest energy, $\sqrt{s} = 4.6\,\text{GeV}$, for $567\,\text{pb}^{-1}$:

World's largest clean sample of $\Lambda_c^+ \bar{\Lambda}_c^-$

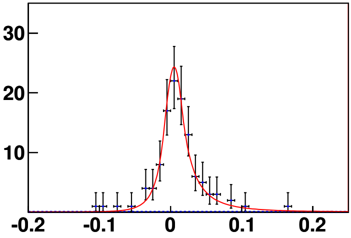
$\Lambda_c \sim udc$; ground state of baryons with charm

First result: absolute measurement of
$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu) = (3.63 \pm 0.38(\text{stat}) \pm 0.20(\text{syst}))\%$

Use double-tag technique:
reconstruct one Λ_c^+ in the event

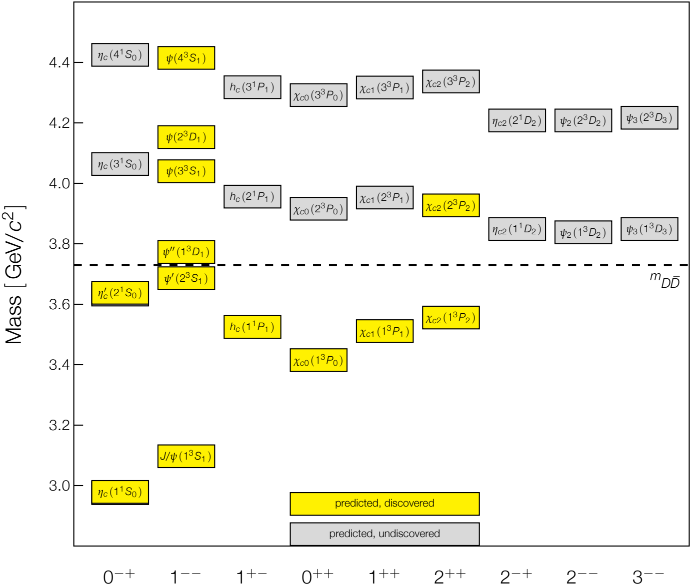


Search for SL decay in the remaining tracks
Identify SL decay with
$U_{\text{miss}} \equiv E_{\text{miss}} - |\vec{p}_{\text{miss}}|$



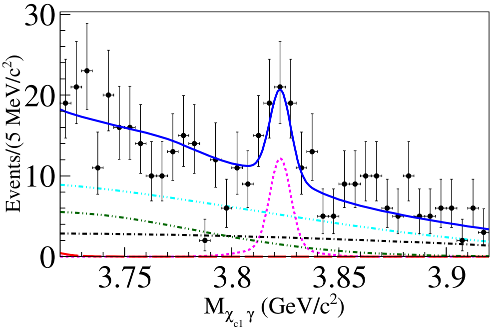
Conventional $c\bar{c}$ states

Higher charmonium states



The $X(3823)$ at Belle

PRL **111**, 032001 (2013)



Using full Belle data set of $772 \times 10^6 B\bar{B}$

$B \to K\gamma\chi_{c1}$
simultaneous fit to B^+ and B^0

3.8σ evidence

$M = 3823.1 \pm 1.8 \pm 0.7\,\text{MeV}$

very narrow

Mass (and width) compatible with $\psi_2(1^3D_2)$ state

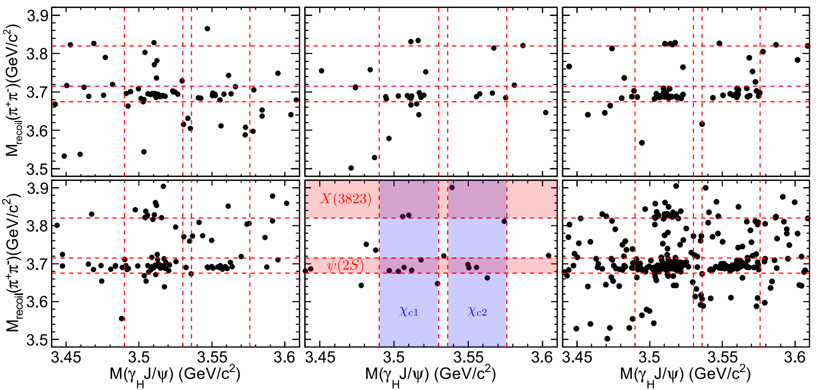
$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

PRL **115**, 011803

reconstruct $\chi_{c1,2} \to \gamma J/\psi \to \gamma\ell^+\ell^-$
look in mass recoiling against $\pi^+\pi^-$ system, $M_{\text{recoil}}(\pi^+\pi^-)$

Use 5 large data sets (total luminosity $\sim 4.1\ \text{fb}^{-1}$)

$\sqrt{s} = 4.23$ GeV | $\sqrt{s} = 4.26$ GeV | $\sqrt{s} = 4.36$ GeV

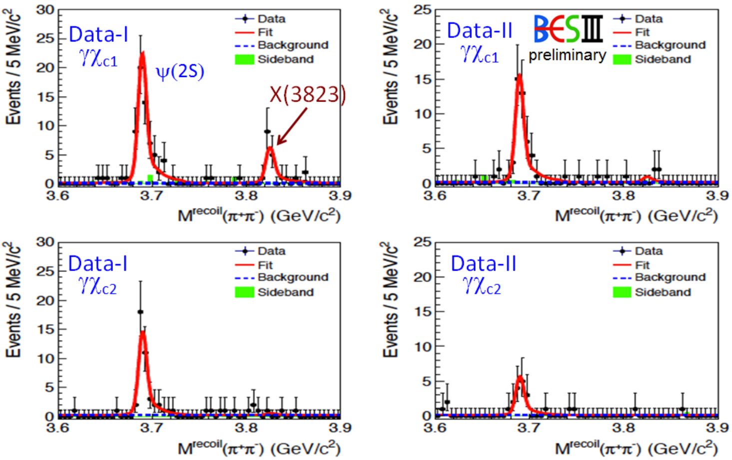


$\sqrt{s} = 4.42$ GeV | $\sqrt{s} = 4.60$ GeV | sum

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

PRL **115**, 011803

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



$M = 3821.7 \pm 1.3 \pm 0.7$ MeV,   significance 6.7σ

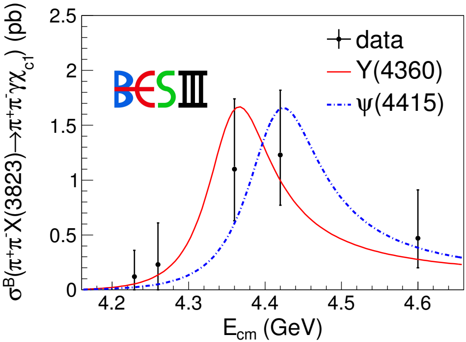
$\Gamma < 16$ MeV   at 90% C.L.

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

PRL **115**, 011803

Energy-dependent cross section for

$$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$$



$Y(4360)$ and $\psi(4415)$ line shapes to guide the eye

Mass and width $\sim$ in agreement with potential model prediction for 1^3D_2
predicted to be narrow!

Production ratio

$$R_{21} \equiv \frac{\mathcal{B}(X(3823) \to \gamma\chi_{c2})}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})}$$

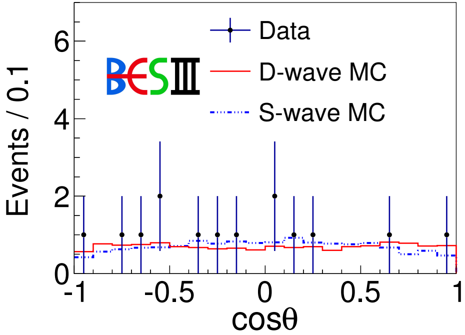
~ 0.2 prediction

< 0.43 at 90% C.L.

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

PRL **115**, 011803

Angular distribution $\theta \equiv \angle(\pi\pi, \psi_2)$
assuming $\pi\pi$ system in S-wave: $1 + \cos^2\theta$ for spin 2



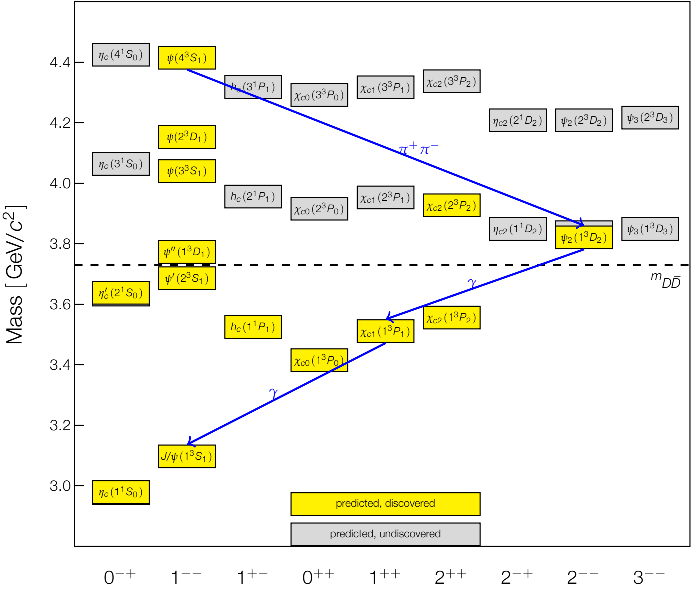
Mass and width $\sim$ in agreement with potential model prediction for 1^3D_2
predicted to be narrow!

J^P by exclusion:
$1^1D_2 \to \gamma\chi_{c1}$ forbidden
$1^3D_3 \to \gamma\chi_{c1}$ has zero amplitude

Good candidate for $\psi_2(1^3D_2)$

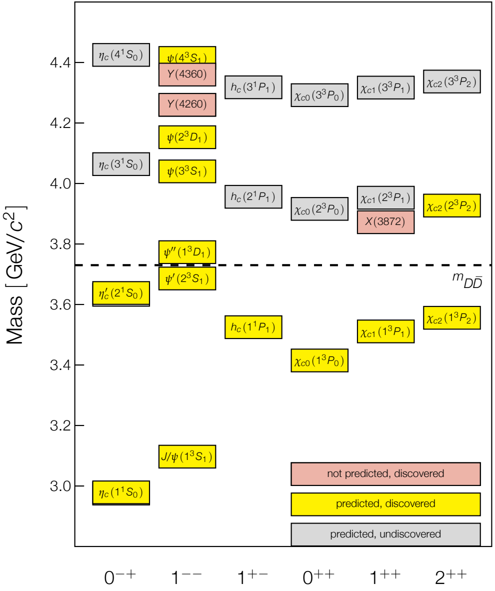
Not enough statistics to distinguish S and D wave from data

Higher charmonium states — a new family member!




Exotic states: the X and Y

$Y(4260) \to J/\psi\,\pi^+\pi^-$

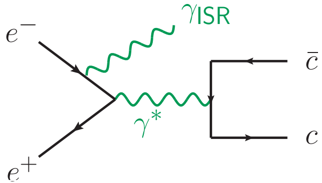


e^+e^- collisions near $\Upsilon(4S)$

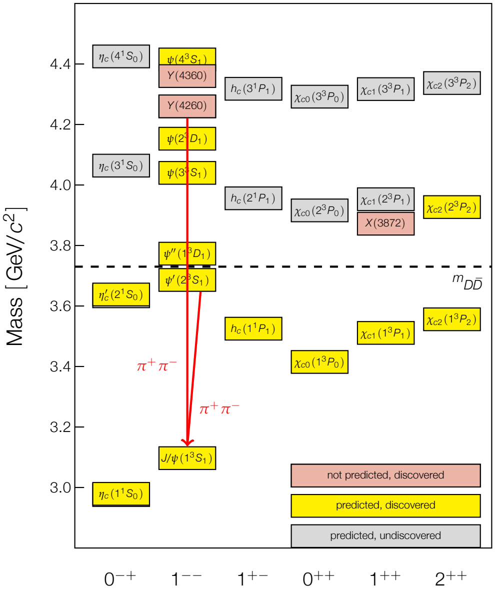
in ISR production

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

$\Rightarrow J^{PC} = 1^{--}$



$Y(4260) \to J/\psi\, \pi^+ \pi^-$



e^+e^- collisions near $\Upsilon(4S)$

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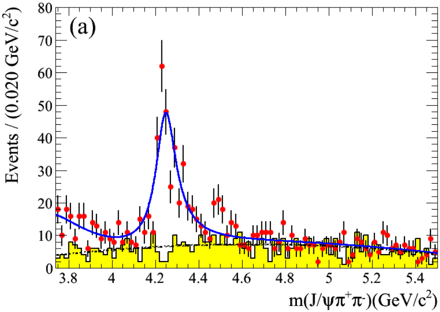
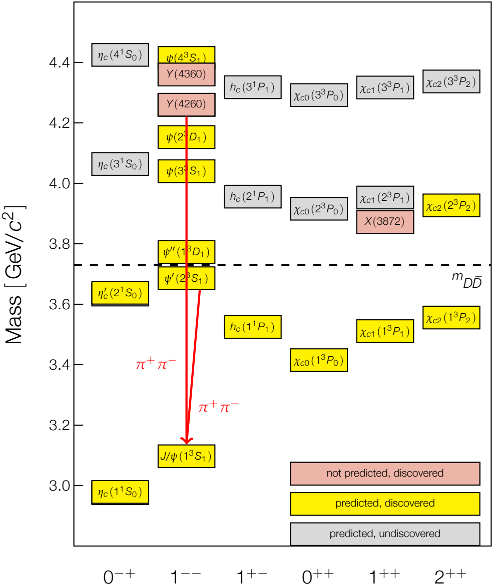
$e^+e^- \to \gamma_{ISR} J/\psi\, \pi^+\pi^-$

$\Rightarrow J^{PC} = 1^{--}$

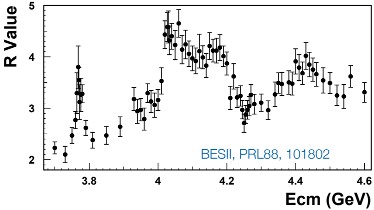


BABAR, PRD 86, 051102(R) (2012)

$Y(4260) \to J/\psi\,\pi^+\pi^-$



- $Y(4260) \to J/\psi\,\pi^+\pi^-$
- $Y(4360) \to \psi(2S)\pi^+\pi^-$
- additional state at 4660 MeV
- supernumerary states:
  all 1^{--} slots already taken
- ➡ do not correspond to peaks in $\sigma(e^+e^- \to \text{hadrons})$

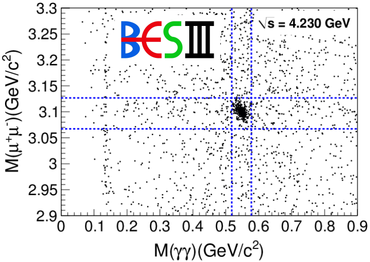


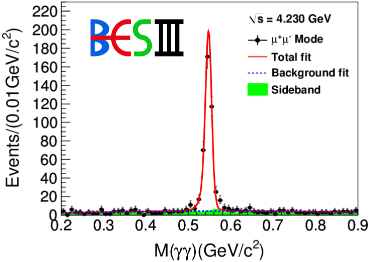
- ➡ produce them directly at BESIII!

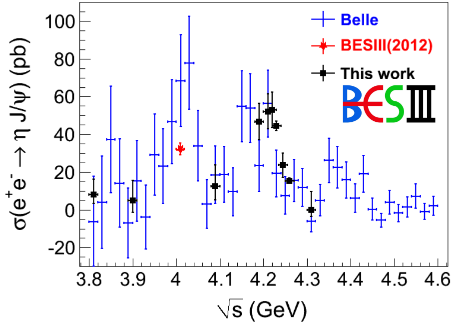
JG|U

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

BESIII, PRD **91**, 112005 (2015)







Compare to $e^+e^- \to \gamma_{\mathrm{ISR}}\eta J/\psi$ from
Belle, PRD **87**, 051101(R) (2013)

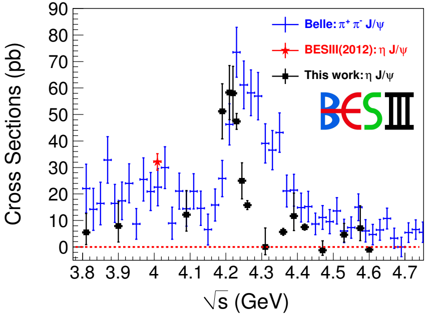
Good agreement,
significantly better precision

Cross section peaks around 4.2 GeV

Also searched for $e^+e^- \to \pi^0 J/\psi$:
no significant signal found

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

BESIII, PRD **91**, 112005 (2015)



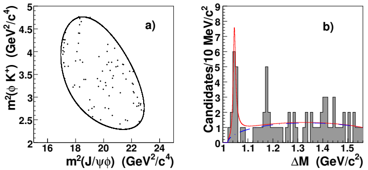
Compare to $e^+e^- \to \gamma_{\text{ISR}}\pi^+\pi^- J/\psi$ from Belle, PRL **110**, 252002 (2013)

Very different line shape

➡ Different dynamics at work in $e^+e^- \to \eta J/\psi$ compared to $e^+e^- \to \pi^+\pi^- J/\psi$

Search for $Y(4140) \to J/\psi\phi$

CDF first reported evidence for
$Y(4140) \to J/\psi\phi$ in $B^+ \to J/\psi\phi K^+$,
also claimed by D0 and CMS



CDF, PRL **102**, 242002, (2009)

Not seen by LHCb, Belle (B decays and $\gamma\gamma$ events),
or BABAR

$J/\psi\phi$ system has $C = +1$: search in radiative transitions of charmonium or $Y(4260)$

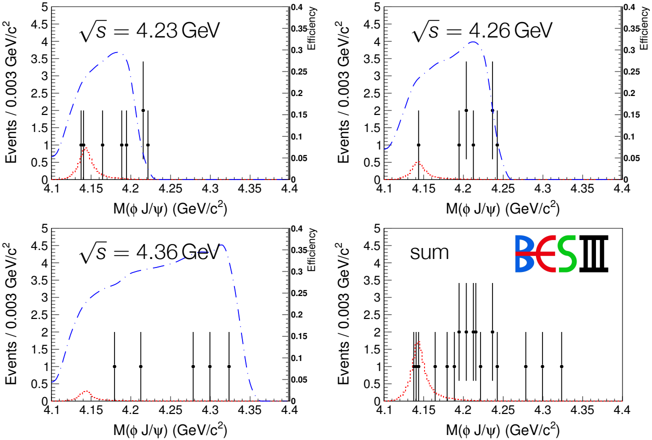
If both $Y(4260)$ and $Y(4140)$ are *charmonium hybrids*:
partial width of $Y(4260) \to \gamma Y(4140)$ may be up to several tens of keV
N. Mahajan, PLB **679**, 228 (2009)

Search for $Y(4140) \to J/\psi\,\phi$

BESIII, PRD **91**, 032002 (2015)

Use BESIII's large data samples from 4.23 – 4.36 GeV (2.47 fb^{-1} in total)

$$e^+e^- \to \gamma J/\psi\,\phi$$
$$J/\psi \to e^+e^-,\,\mu^+\mu^-,$$
$$\phi \to K^+K^-,\,K^0_S K^0_L,\,\pi^+\pi^-\pi^0$$



Search for $Y(4140) \to J/\psi\,\phi$

BESIII, PRD **91**, 032002 (2015)

No significant signal found; place upper limits on
$\sigma(e^+e^- \to \gamma Y(4140)) \times \mathcal{B}(Y(4140) \to J/\psi\,\phi)$

Compare sensitivity to $e^+e^- \to \gamma X(3872) \times \mathcal{B}(X(3872) \to J/\psi\,\pi^+\pi^-)$

$\sqrt{s}$ / GeV	4.23	4.26	4.36
$\sigma \times \mathcal{B}(X(3872))$/pb	0.27 ± 0.09	0.33 ± 0.12	0.11 ± 0.09
$\sigma \times \mathcal{B}(Y(4140))$/pb	< 0.35	< 0.28	< 0.33

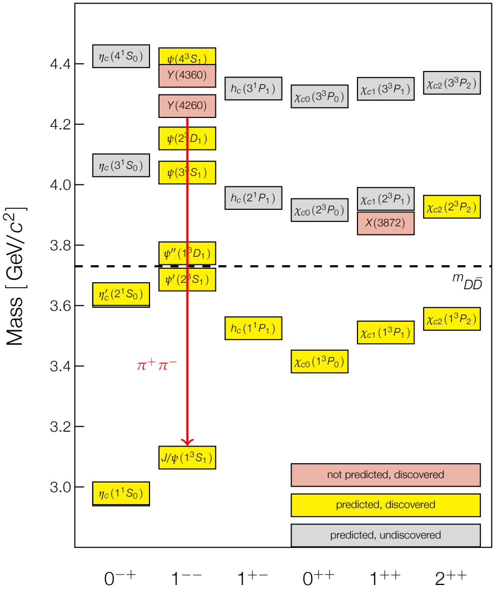
Assuming $\mathcal{B}(Y(4140) \to J/\psi\,\phi) \sim 30\%$ and $\mathcal{B}(X(3872) \to J/\psi\,\pi^+\pi^-) \sim 5\%$:

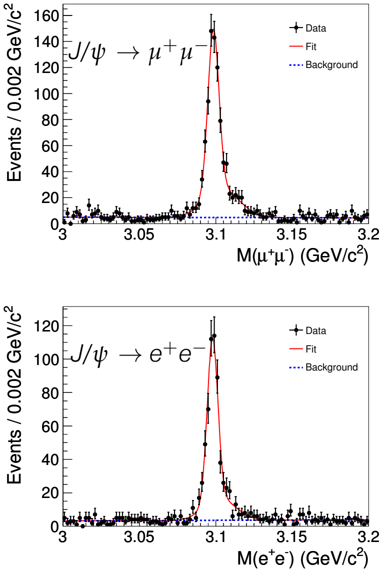
$$\frac{\sigma[e^+e^- \to \gamma Y(4140)]}{\sigma[e^+e^- \to \gamma X(3872)]} < 0.1 \quad \text{at 4.23, 4.26 GeV}$$


The Z_c family

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

BESIII, PRL **110**, 252001 (2013)
$525\ \mathrm{pb}^{-1}$ at 4.26 GeV

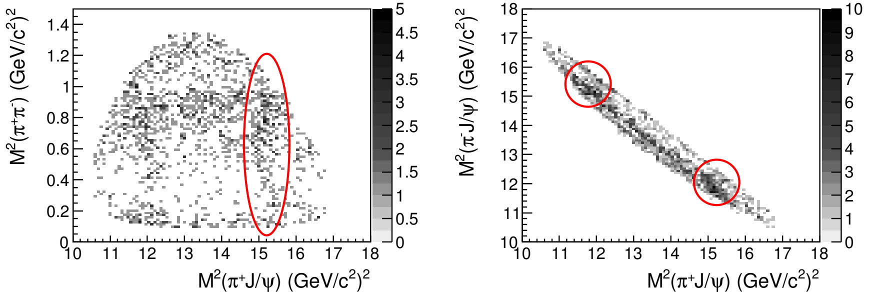


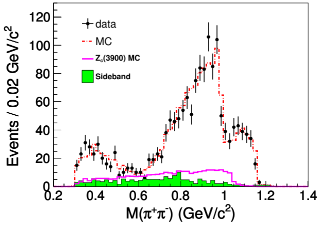


…have hundreds of events!

$J/\psi\,\pi^+\pi^-$ Dalitz plot

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

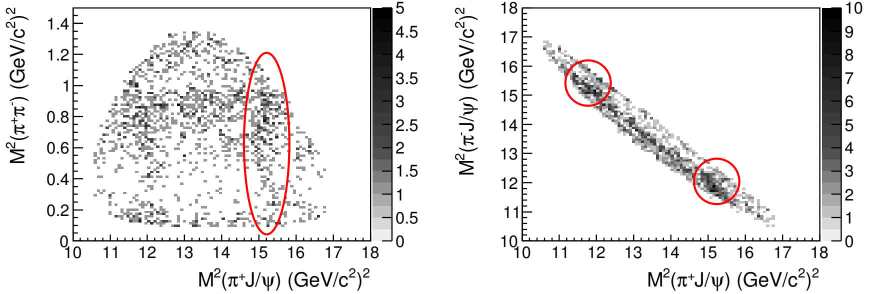


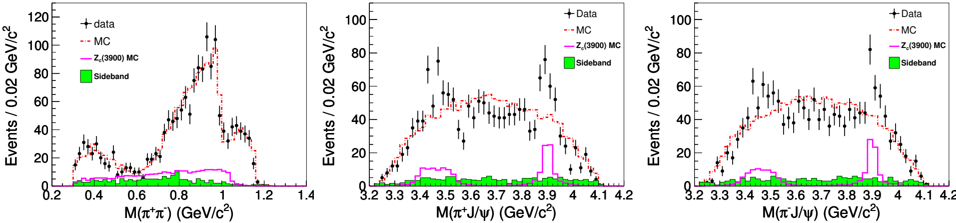


Model $\pi^+\pi^-$-system with known structure:
$f_0(500)$, $f_0(980)$, non-resonant
obtain good fit of $\pi^+\pi^-$ mass projection

$J/\psi\,\pi^+\pi^-$ Dalitz plot

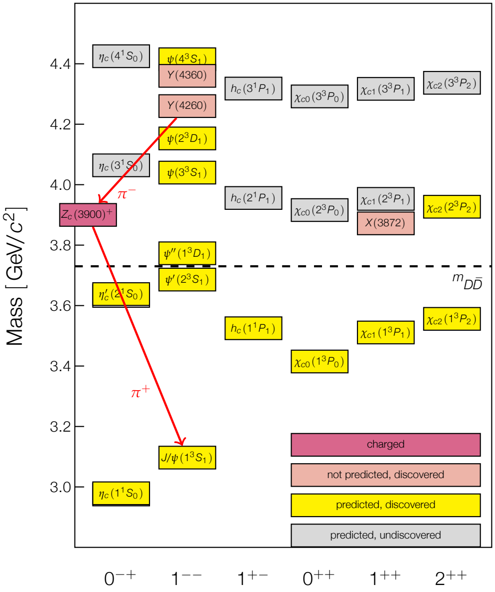
BESIII, PRL **110**, 252001 (2013)

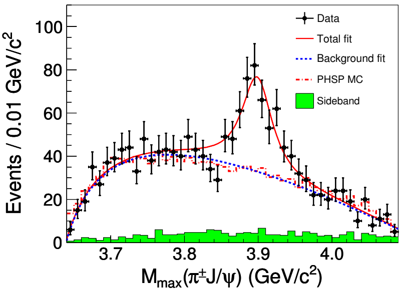




$e^+e^- \to J/\psi\,\pi^+\pi^-$ at 4.26 GeV

BESIII, PRL **110**, 252001 (2013)
525 pb^{-1} at 4.26 GeV





Charged charmonium-like structure

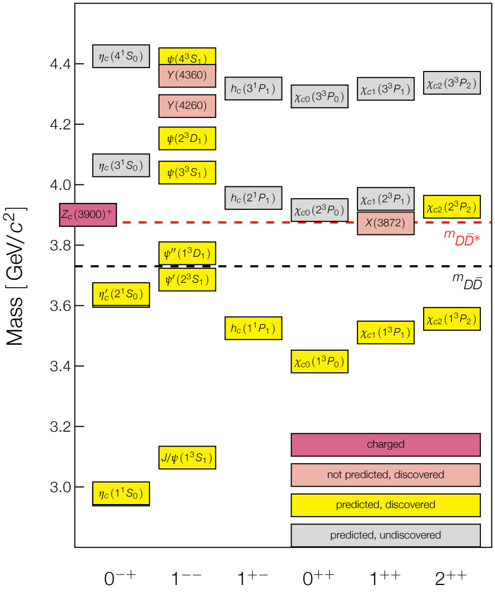
$$M = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$$
$$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$$

Confirmed by Belle PRL **110**, 252002
and with CLEOc data PLB 727, 366

Close to DD^* threshold
Interpretation?

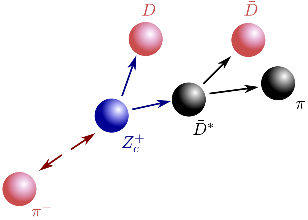
$Z_c(3900)^+$ at $D\bar{D}^*$ threshold

BESIII, PRD **92**, 092006 (2015)



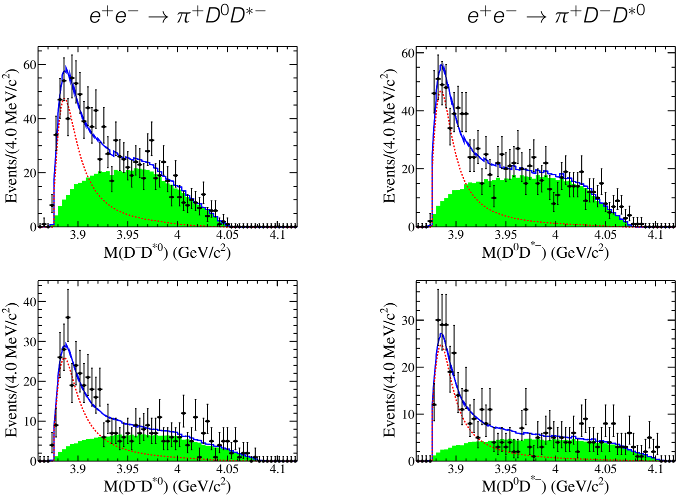
Decay mode $Z_c(3900)^+ \to (D\bar{D}^*)^+$?

- reconstruct 'bachelor' π^+
  and D^0, D^-
  in 4 or 6 decay modes
- kinematic fit, requiring π from D^*
  in missing mass
  essentially background-free D^*
- improved statistics,
  much better control over
  background shape,
  improved systematics
- $M^{\text{recoil}}(\pi^+) = M(D\bar{D}^*)$



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

BESIII, PRD **92**, 092006 (2015)



Simultaneous fit with phase space shape + $(BW \otimes \mathcal{R}) \times \varepsilon$

Compatible with, but significantly more precise, than single-tag analysis

JG|U

$e^+e^- \to \pi^+(D\bar{D}^*)^-$ with double tags: Results

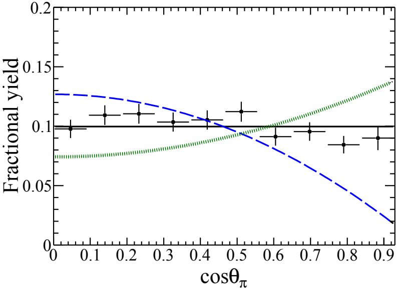
Single and double tag analyses only share $\sim 9\%$ of events:
samples statistically almost independent!

	$M_{\text{pole}}\,[\text{MeV}/c^2]$	$\Gamma_{\text{pole}}\,[\text{MeV}]$
Single D tags	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
Double D tags	$3881.7 \pm 1.6 \pm 2.6$	$26.6 \pm 2.0 \pm 2.3$
Combined	$3882.3 \pm 1.1 \pm 1.9$	$26.5 \pm 1.7 \pm 2.3$

$Z_c(3885)^+$ Quantum numbers?

θ_π: angle between bachelor pion and beam axis in CMS
Know initial state is 1^-, with $J_z = \pm 1$. Depending on J^P of Z_c:

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



Efficiency corrected event yield in 10 bins in $|\cos\theta_\pi|$

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

confirms J^P for $Z_c(3885)$ from single-tags

JG|U

A neutral partner to the $Z_c(3900)^+$?

BESIII, PRL **115**, 112003 (2015)

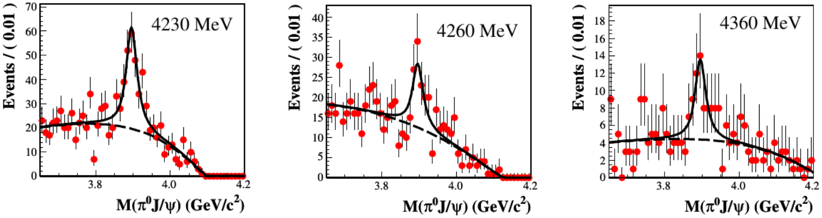
If interpretation of $Z_c(3900)^+$ as four-quark state is correct:
expect state completing isospin triplet, with decay $Z_c(3900)^0 \to \pi^0 J/\psi$

A neutral partner to the $Z_c(3900)^+$?

BESIII, PRL **115**, 112003 (2015)

If interpretation of $Z_c(3900)^+$ as four-quark state is correct:
expect state completing isospin triplet, with decay $Z_c(3900)^0 \to \pi^0 J/\psi$

Study $e^+e^- \to \pi^0\pi^0 J/\psi$ with large data sets at three different $\sqrt{s}$

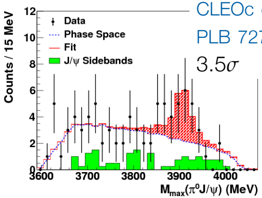


Structure in $\pi^0 J/\psi$ invariant mass clearly visible at all energies

$M = 3894.8 \pm 2.3 \pm 2.7\,\mathrm{MeV}/c^2$

$\Gamma = 29.6 \pm 8.2 \pm 8.2\,\mathrm{MeV}$

Significance 10σ



CLEOc data, PLB 727, 366 (2013)

3.5σ

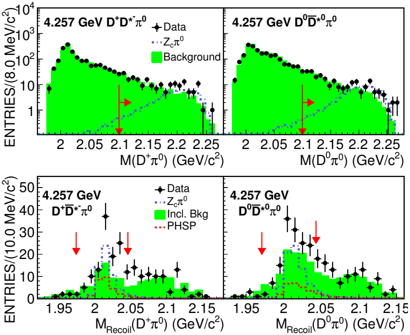
$Z_c(3885)^0$ in $e^+e^- \to (D\bar{D}^*)^0\pi^0$

BESIII, PRL **115**, 222002 (2015)

Partial reconstruction technique:

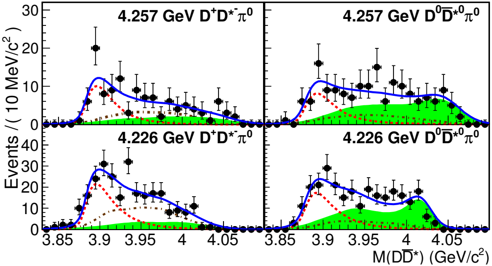
$$e^+e^- \to D^+D^{*-}\pi^0 \to D^+\bar{D}^0\pi^-\pi^0$$
$$e^+e^- \to D^0\bar{D}^{*0}\pi^0 \to D^0\bar{D}^0\pi^0\pi^0$$

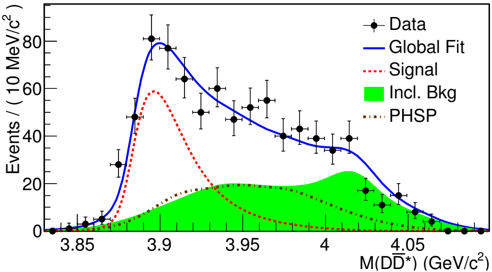
1. Reconstruct bachelor π^0
2. Reconstruct D^+ ($\bar{D}^0$) in one of five (three) hadronic decay modes
3. Infer presence of $\bar{D}^*$ by recoil mass



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

BESIII, PRL **115**, 222002 (2015)





Simultaneous fit to both charge combinations in two large datasets at $\sqrt{s} = 4.226$ and 4.257 GeV

Significance $> 10\sigma$

Pole parameters of rel. BW:

$$M = (3885.7^{+4.3}_{-5.7}(\text{stat.}) \pm 8.4(\text{syst.}))\ \text{MeV}/c^2$$

$$\Gamma = (35^{+11}_{-12}(\text{stat.}) \pm 15(\text{syst.}))\ \text{MeV}$$

$$\mathcal{R} = \frac{\mathcal{B}(Z_c(3885)^0 \to D^+D^{*-})}{\mathcal{B}(Z_c(3885)^0 \to D^0\bar{D}^{*0})} = 0.96 \pm 0.18 \pm 0.12$$

Comparison between $Z_c(3900)$ and $Z_c(3885)$

BESIII
NEW preliminary

	$Z_c(3885) \to D\bar{D}^*$	$Z_c(3900) \to \pi J/\psi$
Mass / MeV/c^2	$3882.3 \pm 1.1 \pm 1.9$	$3899.0 \pm 3.6 \pm 4.9$
Width / MeV	$26.5 \pm 1.7 \pm 2.3$	$46 \pm 10 \pm 20$
$\sigma \times \mathcal{B}$ / pb	$88.0 \pm 6.1 \pm 7.9$	$13.5 \pm 2.1 \pm 4.8$

Both are $J^P = 1^+$; mass and width compatible within $\sim 2\sigma$

If this is the same state decaying in two channels: open charm decays suppressed!

$$\frac{\mathcal{B}(\psi(4040) \to D^{(*)}\bar{D}^{(*)})}{\mathcal{B}(\psi(4040) \to J/\psi\,\eta)} = 192 \pm 27$$

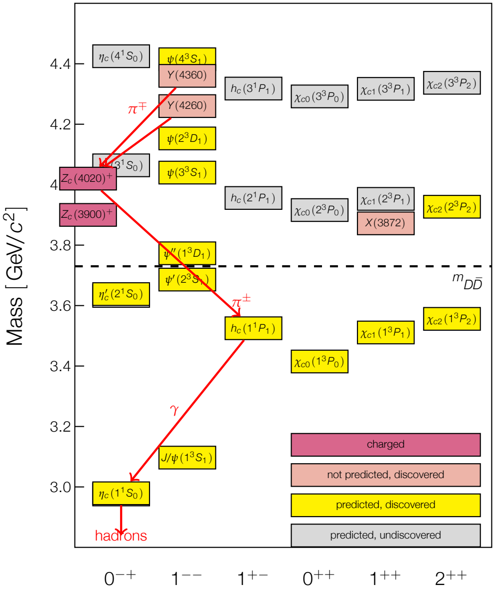
$$\frac{\mathcal{B}(Z_c \to D\bar{D}^*)}{\mathcal{B}(Z_c \to J/\psi\,\pi)} = 6.2 \pm 2.9$$

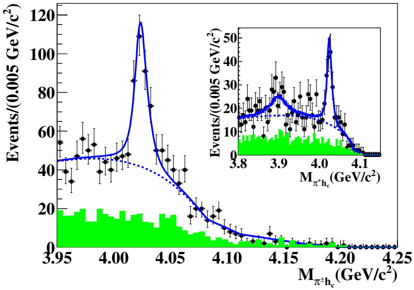
➡ Different dynamics at work in $Y(4260) - Z_c(3900)$ system

JG|U

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

BESIII, PRL **111**, 242001 (2013)





Charged charmonium-like structure close to $D^*\bar{D}^*$ threshold

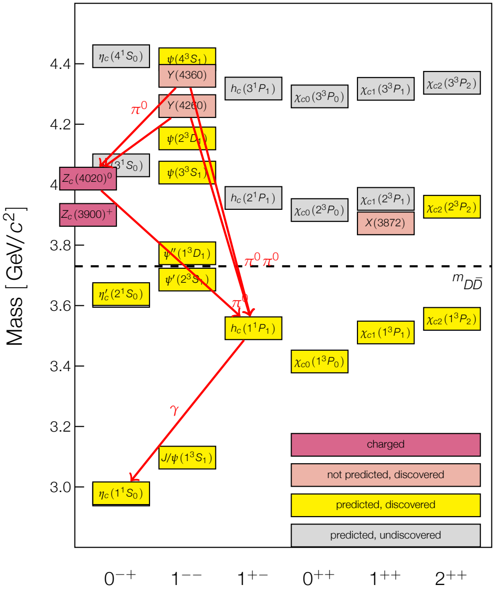
$$M = 4022.9 \pm 0.8 \pm 2.7\,\mathrm{MeV}/c^2$$

$$\Gamma = 7.9 \pm 2.7 \pm 2.6\,\mathrm{MeV}$$

Note: no significant signal for $Z_c(3900)^+ \to \pi^+ h_c$ seen!

$e^+e^- \to h_c(1P)\pi^0\pi^0$

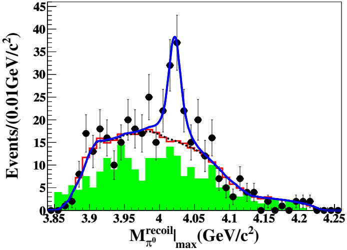
BESIII, PRL **113**, 212002 (2014)



Study $e^+e^- \to \pi^0\pi^0 h_c$ at 4.23, 4.26, 4.36 GeV

Observe structure in $h_c\pi^0$ mass distribution:

Neutral partner to $Z_c(4020)^+$



$M = 4023.6 \pm 4.5\,\mathrm{MeV}/c^2$

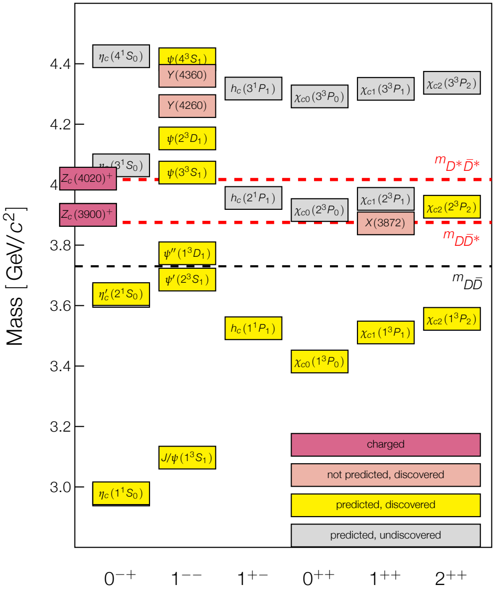
Γ fixed in the fit

Isospin triplet found!

Yet another mass threshold ...

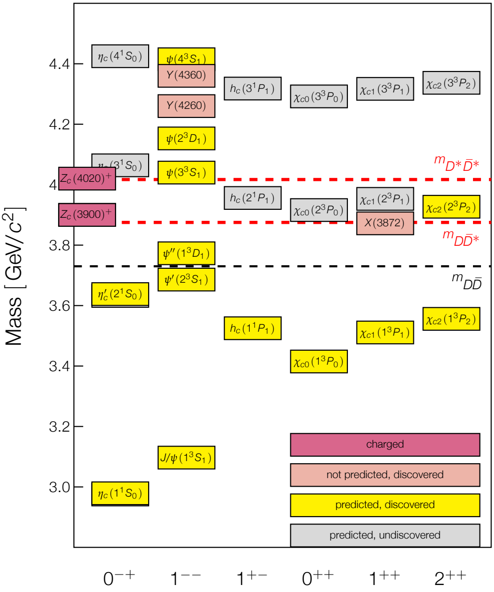
BESIII, PRL **112**, 132001 (2014)

$Z_c(4020)$ sits at D^*D^* threshold



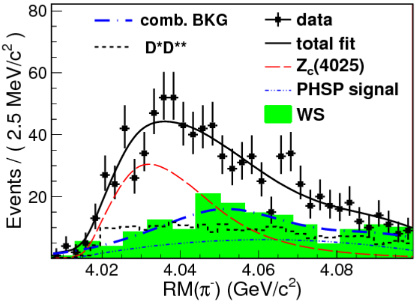
Yet another mass threshold ...

BESIII, PRL **112**, 132001 (2014)



$Z_c(4020)$ sits at D^*D^* threshold

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



…and BESIII sees structure in D^*D^*

$Z_c(4025)^+$

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

$$\Gamma = 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}$$

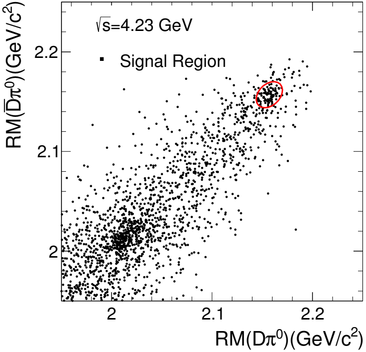
... and the neutral partner: $Z_c(4025)^0$

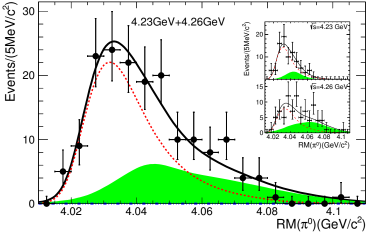
PRL **115**, 182002 (2015)

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

Use partial reconstruction technique:

- Reconstruct D, $\bar{D}$, and bachelor π^0
- Infer presence of D^* by selecting on mass recoiling against $\bar{D}^*\pi^0$





Combine data sets at $\sqrt{s} = 4.23, 4.26\,\text{GeV}$
Enhancement at threshold visible
No non-resonant process needed
Fit with $BW \otimes \mathcal{R}$, extract pole position

$$M_{\text{pole}} = (4025.5^{+2.0}_{-4.7} \pm 3.1)\,\text{MeV}/c^2$$
$$\Gamma_{\text{pole}} = (23.0 \pm 6.0 \pm 1.0)\,\text{MeV}$$

… and the neutral partner: $Z_c(4025)^0$

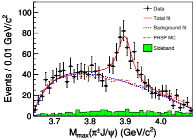
PRL **115**, 182002 (2015)

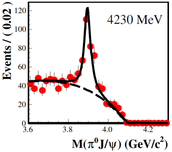
Comparison with the $Z_c(4025)^+ \to (D^*\bar{D}^*)^+$:

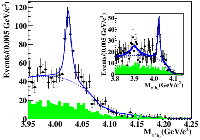
	Mass [MeV/c^2]	Width [MeV]	$\sigma(e^+e^- \to Z_c\pi \to D^*\bar{D}^*\pi)$ [pb]
$Z_c(4025)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$42.2 \pm 2.8 \pm 4.6$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$43.4 \pm 8.0 \pm 5.4$

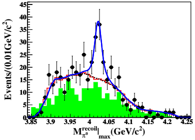
- Almost perfect agreement in resonance parameters
- and cross sections
- very small isospin violation?!

All the Z_Cs from BESIII near $\sqrt{s} = 4.3$ GeV

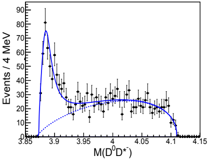


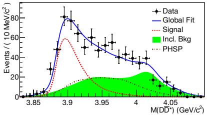




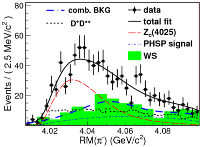


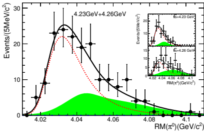
$e^+e^- \to \pi^-\pi^+J/\psi$ $\quad$ $e^+e^- \to \pi^0\pi^0 J/\psi$ $\quad$ $e^+e^- \to \pi^-\pi^+h_c$ $\quad$ $e^+e^- \to \pi^0\pi^0 h_c$





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





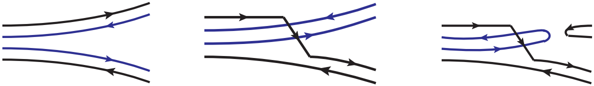
$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

$Z_C(3900)^+$? $\quad$ $Z_C(3900)^0$? $\quad$ $Z_C(4020)^+$? $\quad$ $Z_C(4020)^0$?

Nature of these states? Isospin triplets? (we got 'em all!)
Different decay channels (hidden-charm vs. open-charm) of the same states observed?
Other decay modes?

Other decay modes?

Exploring new decay modes can help to identify nature of structures close to threshold



open charm hidden charm light mesons

threshold effects!

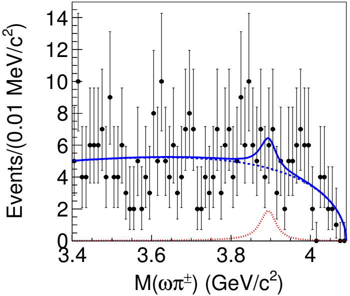
Decay modes with $c\bar{c}$ annihilation does not involve hidden or open charm final states!

If $c\bar{c}$ in S-wave, annihilation could be as 'easy' as for J/ψ …
but theoretical predictions very difficult,
order-of-magnitude only

$Z_c(3900)^+ \to \omega\pi^+ \to (\pi^+\pi^-\pi^0)\,\pi^+$

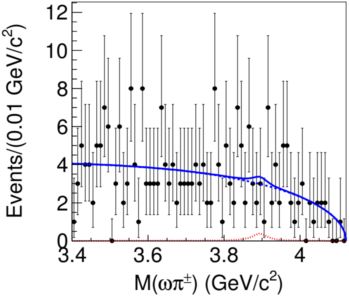
BESIII, PRD **92**, 032009 (2015)

$\sqrt{s} = 4.230\,\text{GeV}$



$\sigma(e^+e^- \to Z_c^+\pi^-, Z_c^+ \to \omega\pi^+) < 0.26\,\text{pb}$

$\sqrt{s} = 4.260\,\text{GeV}$



$\sigma(e^+e^- \to Z_c^+\pi^-, Z_c^+ \to \omega\pi^+) < 0.18\,\text{pb}$

Compared to sum of $Z_c^+ \to J/\psi\,\pi^+$ and $Z_c^+ \to (D\bar{D}^*)^+$:

$$\Gamma(Z_c^+ \to \omega\pi^+) < 0.2\%\Gamma_{\text{tot}}$$

Summary

Huge, clean data samples collected with BESIII

- Connection between $X(p\bar{p})$ and $X(1835)$?
- First absolute branching fractions of Λ_c
- New conventional charmonium state: $\psi_2(1^3D_2)$
- Progress in identifying *XYZ* states with (hidden) charm

Future is bright for BESIII:

- Currently taking data around $D_s D_s^*$ threshold
- Large data samples for future *XYZ* studies

Advertisement

Come and see

- Posters on
  Light Hadron Spectroscopy and
  progress in *XYZ* [Giulio MEZZADRI, Gianfranco MORELLO] (tonight)
- Talk on Charm physics at BESIII [LI Lei] (Wednesday afternoon)

謝謝！