Meson Spectroscopy at BESIII

Wolfgang Gradl
for the BESIII collaboration

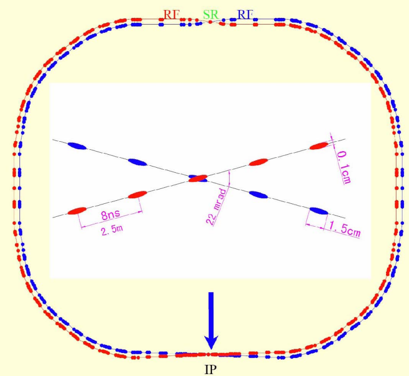
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

MENU 2013
1st October 2013

BEPCII and BESIII

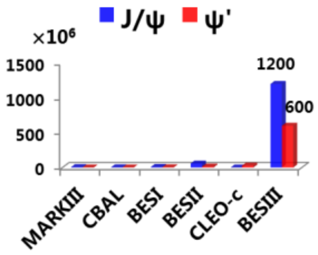
BEPCII storage rings: a τ-charm factory

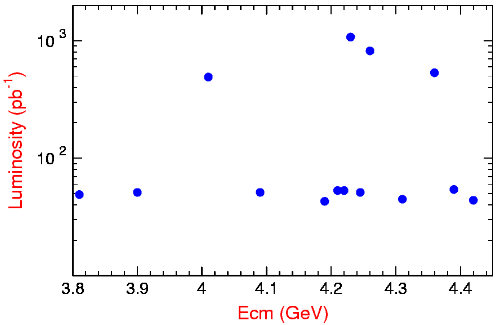


Upgrade of BEPC (started 2004,
first collisions July 2008)
Beam energy $1\ldots2.3$ GeV
Optimum energy 1.89 GeV
Single beam current 0.91 A
Crossing angle: ±11 mrad

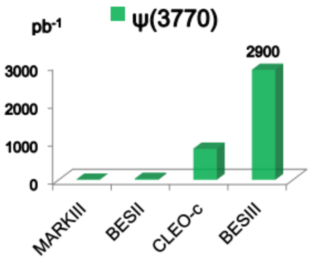
Design luminosity: $10^{33}\,\text{cm}^{-2}\text{s}^{-1}$
Achieved: $7\times10^{32}\,\text{cm}^{-2}\text{s}^{-1}$
Beam energy measurement:
Laser compton backscattering
$\Delta E/E \approx 5\times10^{-5}$
($\approx$ 50 keV at τ threshhold)

BESIII data sets





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



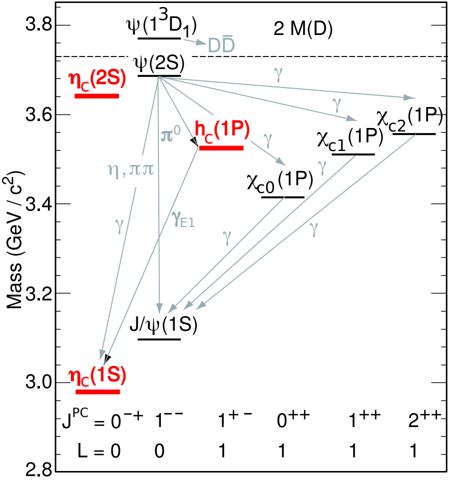
Charmonium states

Below threshold charmonium spectrum

…all states established, but spin singlet states least well known:

$\eta_c(1S)$ mass, width measurements inconsistent

$\eta_c(2S)$, $h_c(1P)$ properties not well known



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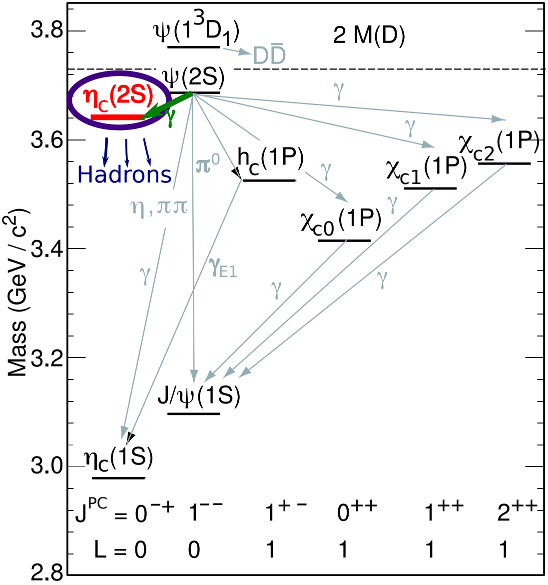
Observation of $\psi(3686) \to \gamma\eta_c(2S)$



Observation of $\psi(3686) \to \gamma\eta_c(2S)$

First seen in Crystal Ball at SLAC in recoil spectrum of $\psi(3686) \to \gamma X$, using 1.8M $\psi(3686)$, with $m = 3495 \pm 5\,\mathrm{MeV}/c^2$ Phys. Rev. Lett. **48**, 70 (1982)

Observed by Belle in $B^\pm \to K^\pm\eta_c(2S)$, $\eta_c(2S) \to K^0_S K^\pm\pi^\mp$, also seen by BABAR and CLEO in $\gamma\gamma$ production

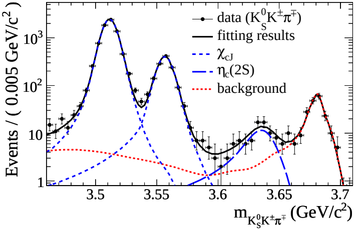
Experiment	Process	$m\,[\mathrm{MeV}/c^2]$	$\Gamma\,[\mathrm{MeV}]$
Belle	$B^\pm \to K^\pm\eta_c(2S) \to K^\pm K^0_S K^\pm\pi^\mp$	$3654 \pm 6 \pm 8$	—
CLEO	$\gamma\gamma \to \eta_c(2S) \to K^0_S K^\pm\pi^\mp$	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$
BABAR	$\gamma\gamma \to \eta_c(2S) \to K^0_S K^\pm\pi^\mp$	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$
BABAR	$e^+e^- \to J/\psi c\bar{c}$	$3645.0 \pm 5.5^{+4.9}_{-7.8}$	—
PDG '12		3638.9 ± 1.3	10 ± 4

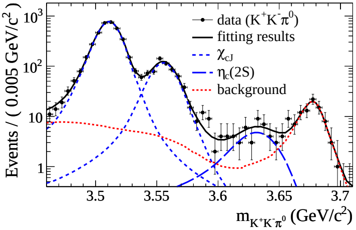
M1 transition $\psi(3686) \to \gamma\eta_c(2S)$ with exclusive reconstruction of $\eta_c(2S)$ not yet observed. Exploit factor 60 in statistics: 108 M $\psi(3686)$

Experimentally challenging: $E_\gamma \sim 50\,\mathrm{MeV}$

$\psi(3686) \to \gamma\eta_c(2S)$ with $\eta_c(2S) \to K^0_S K\pi, KK\pi^0$

BESIII, Phys. Rev. Lett. **109**, 042003 (2012)





Mass and width

Simultaneous fit yields:

$$m(\eta_c(2S)) = 3637.6 \pm 2.9 \pm 1.6\,\text{MeV}/c^2$$

$$\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8\,\text{MeV}$$

Combined significance $> 10\sigma$

Branching fraction

Using BABAR's Phys. Rev. D **78**, 012006

$$\mathcal{B}(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$$

$$\mathcal{B}(\psi(3686) \to \gamma\eta_c(2S)) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$$

cf. CLEO-c: $< 7.4 \times 10^{-4}$

Phys. Rev. D **81**,052002

$h_c(1\,^1P_1)$

Spin singlet P wave ($S = 0$, $L = 1$)

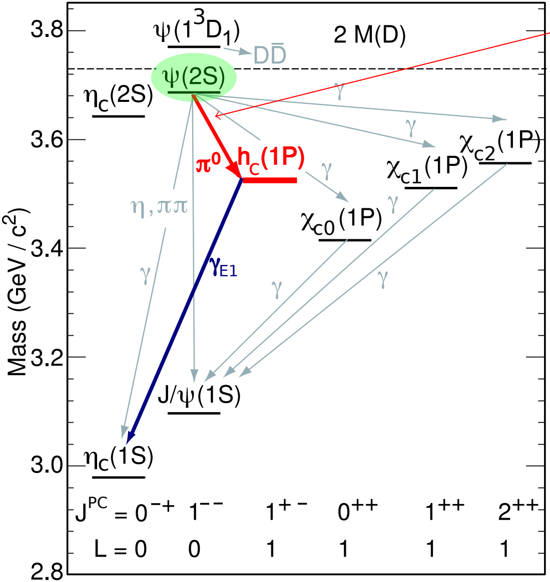
Potential model:
P wave hyperfine splitting non-zero if P-wave spin-spin interaction non-zero:

$$\Delta m_{hf}(1P) = m(1\,^1P_1) - \left\langle m(1^3P_J)\right\rangle \neq 0$$

$$\text{with } \left\langle m(1^3P_J)\right\rangle = \frac{1}{9}\left(m(\chi_{c0}) + 3m(\chi_{c1}) + 5m(\chi_{c2})\right)$$

First observation by CLEO-c in $e^+e^- \to \psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$
$\Delta m_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12\,\mathrm{MeV}/c^2$, consistent with zero HFS

h_c: Spin-singlet $^1P_1$ state

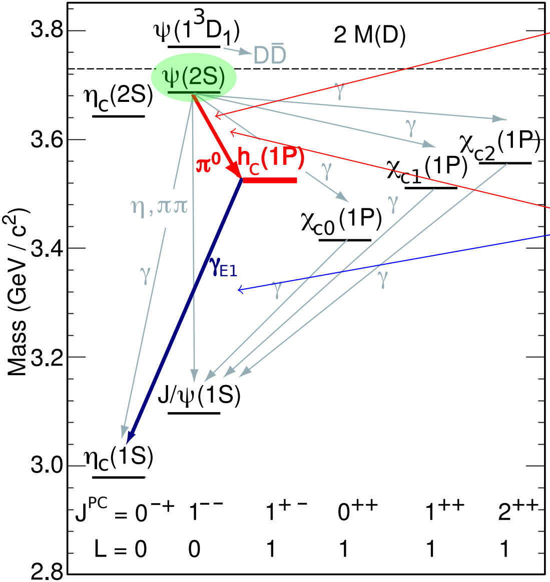


only detect π^0 : "inclusive"

compute m_{h_c} from kinematics

Rate $\propto \mathcal{B}(\psi(3686) \to \pi^0 h_c)$

h_c: Spin-singlet $^1P_1$ state



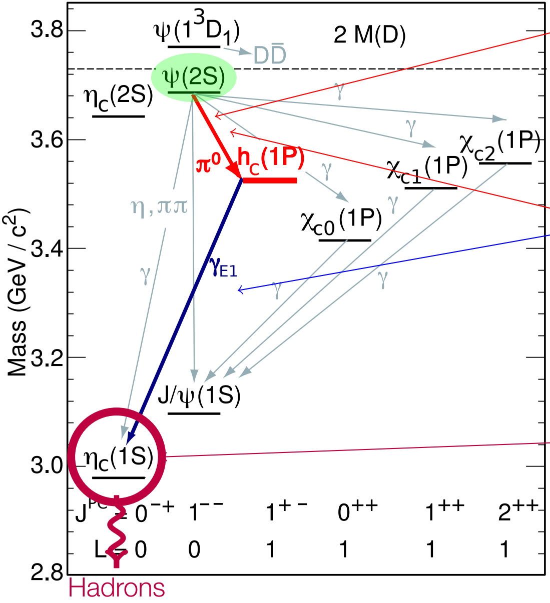
only detect π^0 : "inclusive"
compute m_{h_c} from kinematics

Rate $\propto \mathcal{B}(\psi(3686) \to \pi^0 h_c)$

detect π^0 and γ: "E1 tagged"
compute m_{h_c} from kinematics

Rate $\propto \mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c)$

h_c: Spin-singlet $^1P_1$ state



only detect π^0 : "inclusive"
compute m_{h_c} from kinematics
Rate $\propto \mathcal{B}(\psi(3686) \to \pi^0 h_c)$

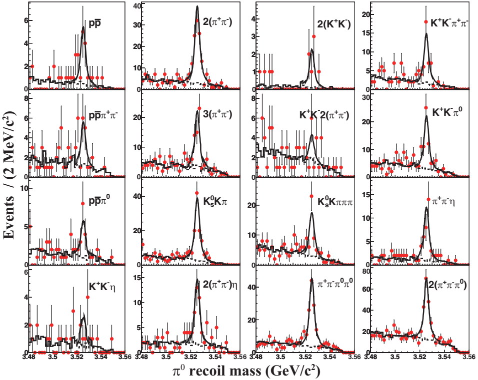
detect π^0 and γ: "E1 tagged"
compute m_{h_c} from kinematics
Rate $\propto \mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c)$

detect π^0, γ and $\eta_c \to X$ decay products: "exclusive"
m_{h_c} from 4C kin. fit
Rate $\propto \mathcal{B}(\psi' \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to X)$

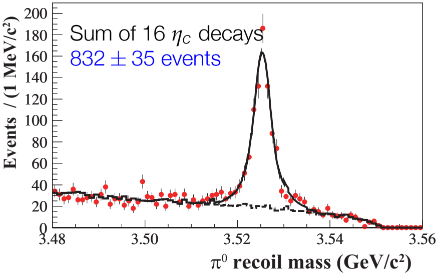
$\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c, \eta_c$ exclusive decays

BESIII, Phys. Rev. D **86**, 092009 (2012)

106M $\psi(3686)$ events



16 different η_c decay channels



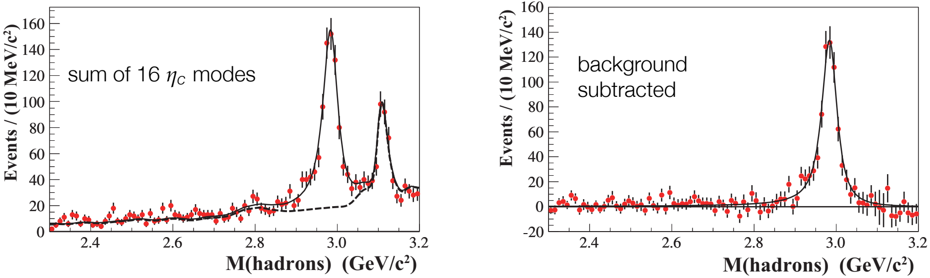
Simultaneous fit to π^0 recoil mass;
results consistent with E1-tagged BESIII Phys. Rev. Lett. **104**, 132002 (2010)

$$m = 3525.31 \pm 0.11 \pm 0.14\,\mathrm{MeV}/c^2$$

$$\Gamma = 0.70 \pm 0.28 \pm 0.22\,\mathrm{MeV}$$

η_c lineshape from $h_c \to \gamma\eta_c$

BESIII, Phys. Rev. D **86**, 092009 (2012)



Use $\psi(3686) \to \pi^0 h_c \to \pi^0 \gamma\eta_c$ as source for η_c

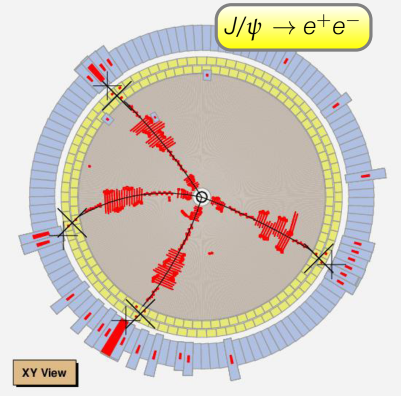
η_c lineshape in these decays not as distorted as in $\psi(3686) \to \gamma\eta_c$; smaller (non-existent?) non-resonant interfering contributions.

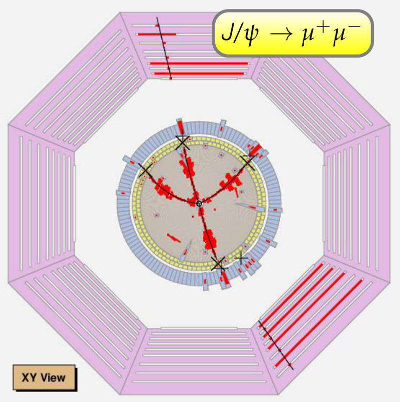
Eventually, best channel to determine η_c resonance parameters (with enough statistics …)

Exotic charmonium states

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

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

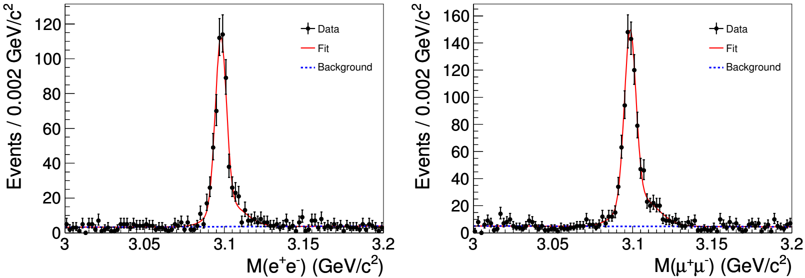




- Running at $\sqrt{s} = 4260\,\text{MeV}$: simple and straightforward
- $J/\psi\,(\to \ell^+\ell^-)\pi^+\pi^-$: four charged tracks
- very clean sample, high efficiency, reliable MC simulation
- dominant background: continuum $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

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

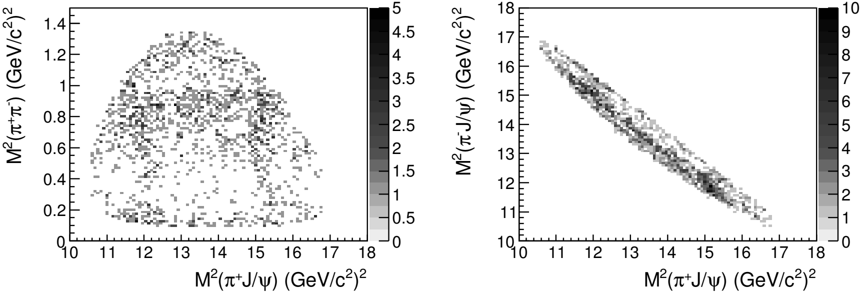
BESIII, PRL **110**, 252001 (2013)



- Based on $525\,\mathrm{pb}^{-1}$ at 4.26 GeV collected between Dec 2012 and Jan 2013
- Peak position of $Y(4260) \to J/\psi\,\pi^+\pi^-$ cross section
- $N(e^+e^-) = 595 \pm 28$, $N(\mu^+\mu^-) = 882 \pm 33$, purity $\approx 90\%$
- $\sigma^B(e^+e^- \to J/\psi\,\pi^+\pi^-) = (62.9 \pm 1.9 \pm 3.7)\,\mathrm{pb}$
  in good agreement with BABAR and Belle
- More data and more energy points being analysed

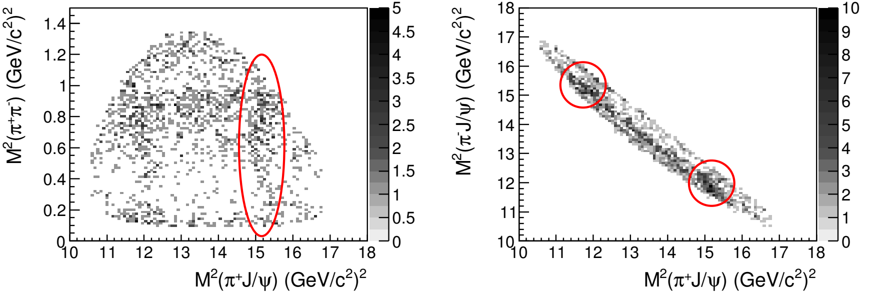
$J/\psi\,\pi^+\pi^-$ Dalitz plot

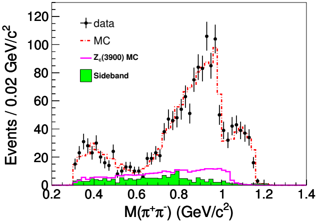
BESIII, PRL **110**, 252001 (2013)



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

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

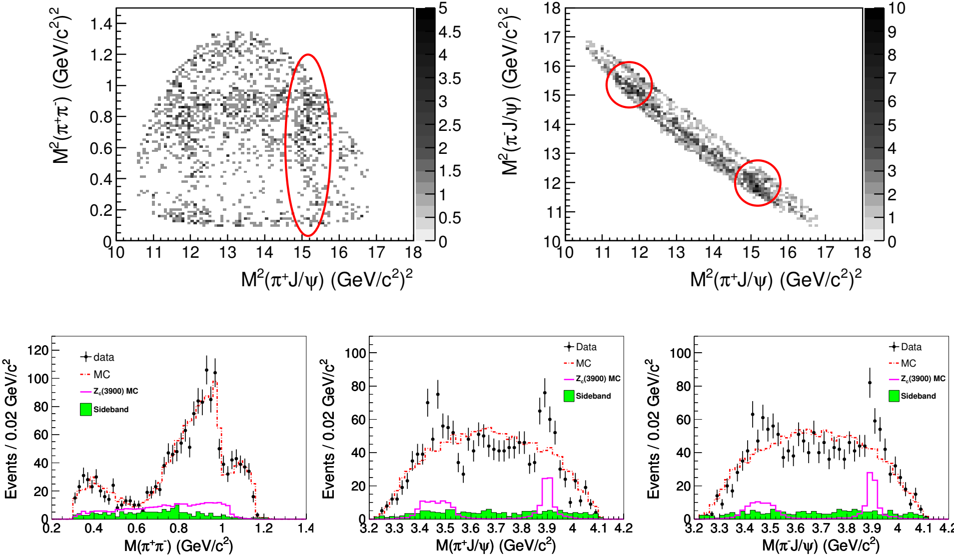




Model $\pi^+\pi^-$-system with known structure:
$f_0(500)$, $f_0(980)$, non-resonant
obtain good fit of $\pi^+\pi^-$ mass projection

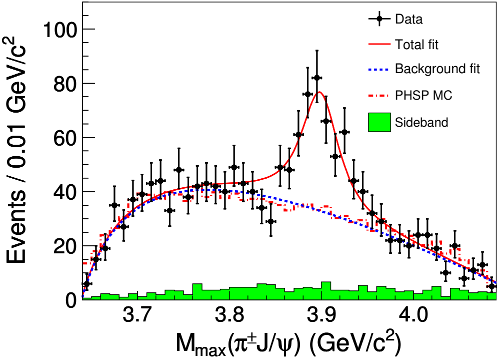
$J/\psi\,\pi^+\pi^-$ Dalitz plot

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



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

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



- Fit $M_{\mathrm{max}}(J/\psi\,\pi^{\pm})$ ⇔ fold Dalitz plot around diagonal
- 1D fit to extract resonance parameters,
  S-wave Breit Wigner with phase space factor & efficiency corr.
- $M = (3899.0 \pm 3.6 \pm 4.9)$ MeV, $\Gamma = (46 \pm 10 \pm 20)$ MeV
- Significance $> 8\sigma$

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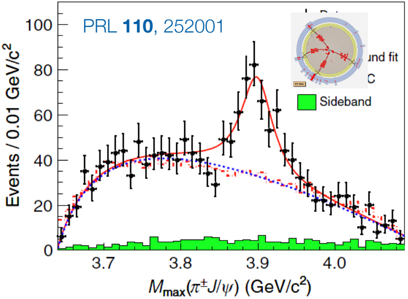
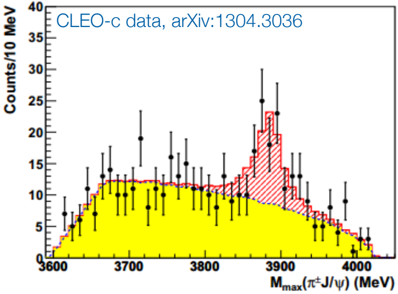
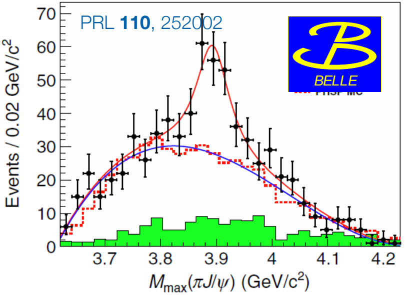
$Z_c(3900)^+$ in other datasets?



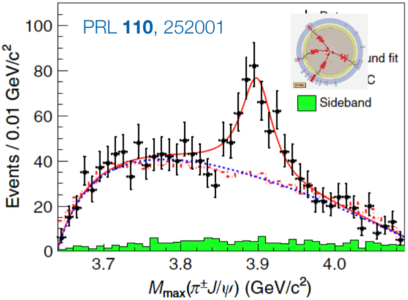


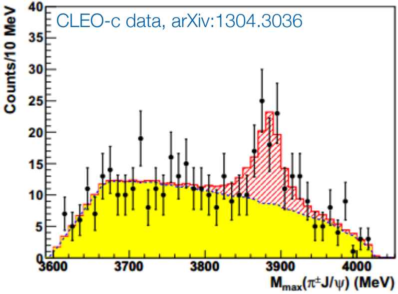


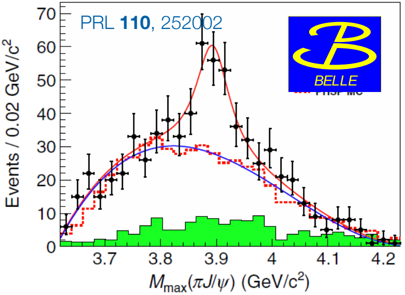
	m / MeV	Γ / MeV
BESIII	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
Belle	$3894.5 \pm 6.6 \pm 4.5$	$63 \pm 24 \pm 26$
CLEOc	$3885 \pm 5 \pm 1$	$34 \pm 12 \pm 4$

Belle: $e^+e^- \to \gamma_{ISR} J/\psi \pi^+\pi^-$,
in $Y(4260)$ region
CLEOc data: $\sqrt{s} = 4.170$ GeV

$Z_c(3900)^+$ in other datasets?



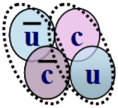


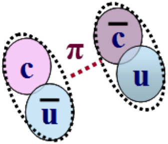


- $Z_c(3900)^+ \to J/\psi\,\pi^+$ seen at BESIII, Belle, and with CLEO-c data
- Masses and widths compatible within uncertainties

Nature of the $Z_c(3900)^+$?

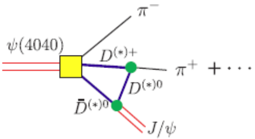
- Mass close to $D\bar{D}^*$ threshold
- Couples to $c\bar{c}$
- Has electric charge
- If new particle: contains at least 4 quarks

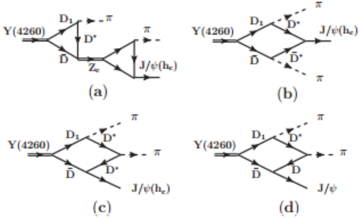




So, what is it?

- 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.
- …

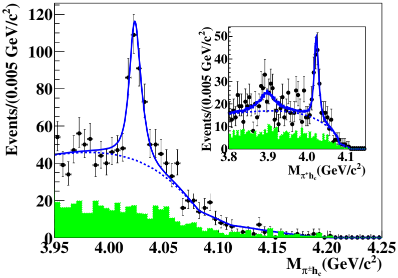




$e^+e^- \to h_c\pi^+\pi^-$

BESIII preliminary, arXiv:1309.1896 [hep-ex]

- Using data taken at 4.23 GeV, 4.26 GeV, and 4.36 GeV (total 2.4 fb^{-1})
- Reconstruct $h_c \to \gamma\eta_c$ with $\eta_c \to$ 16 exclusive hadronic final states
- 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 (significance $\sim 2\sigma$)

Summary

- BES-III successfully taking data since 2008
  world's largest data samples at J/ψ, $\psi(3686)$, $\psi(3770)$, $\psi(4040)$,
  large dataset above 4 GeV for XYZ studies

- **Charmonium transitions**
  first observation of $\psi(3686) \to \gamma\eta_c(2S)$
  fully reconstructed $h_c \to \gamma\eta_c$

- **Exotic charmonium-like states**
  Discovery of two states with charge which couple to charmonium:
  $Z_c(3900) \to J/\psi\,\pi^+$, $Z_c(4020) \to h_c\pi^+$
  Close to thresholds?
  Neutral partners?
  Other decay modes (e.g. DD^*, D^*D^*)? [see talk on Friday]
  More data will be taken

- Interesting times ahead

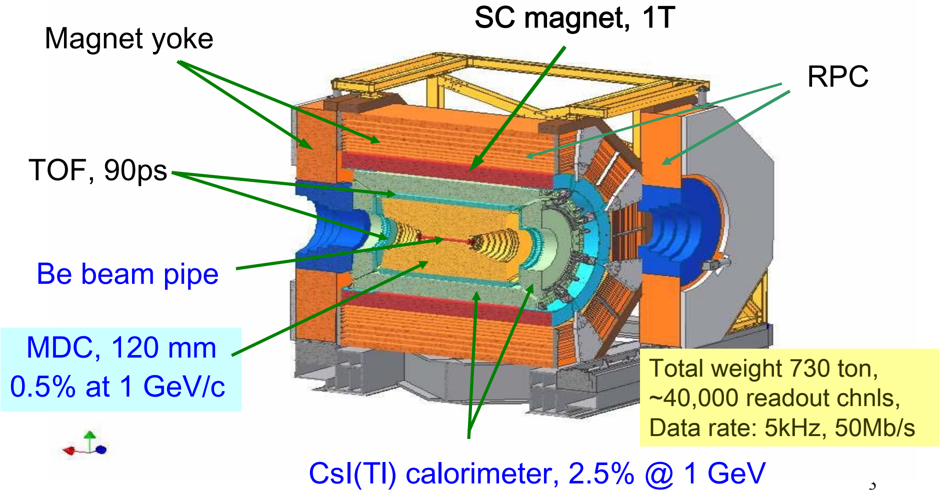
JG|U

谢谢！


Extra slides

The BESIII Collaboration

BESIII detector



Comparable performance to CLEO-c, + muon ID

BESIII detector