Y(4008)

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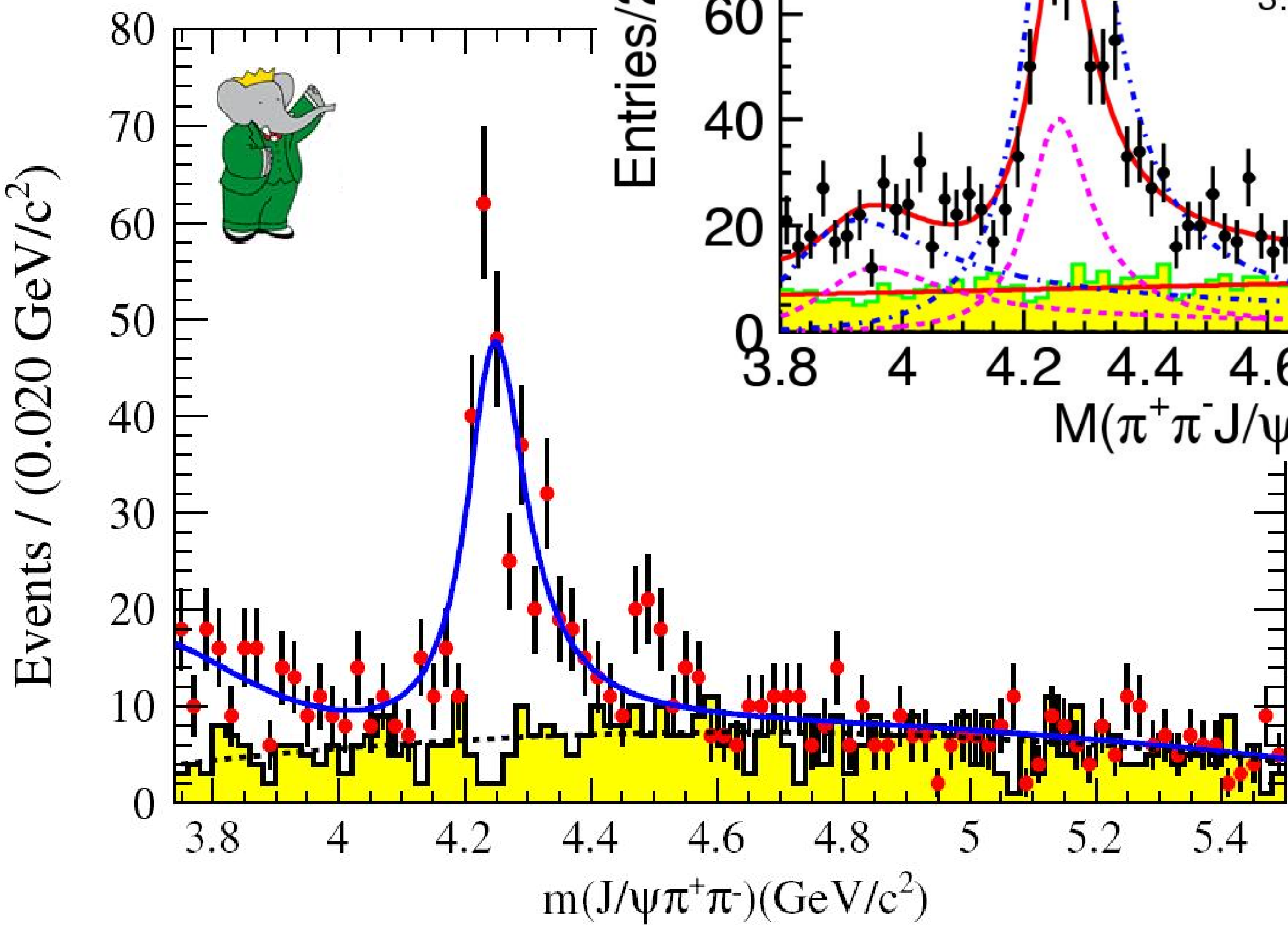
IHEP, Beijing

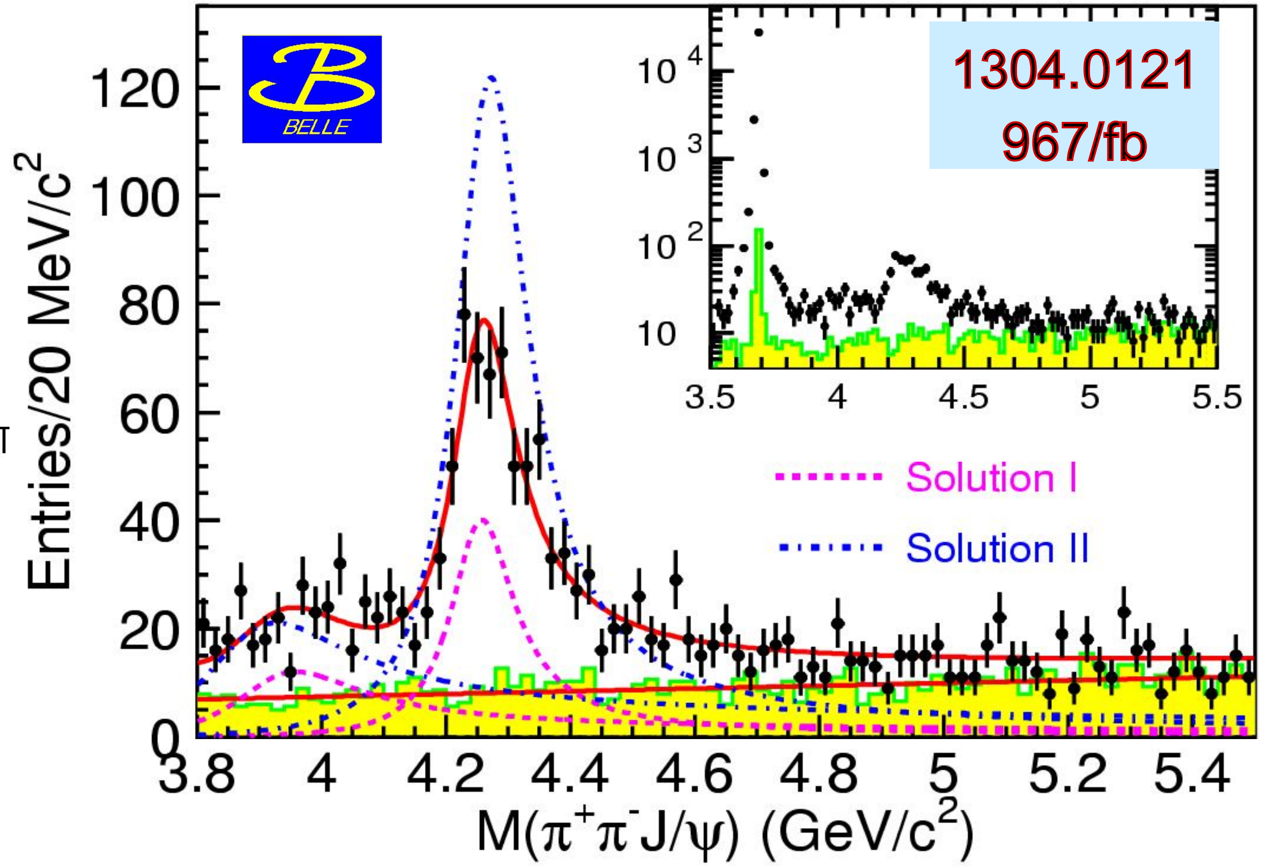
QWG 2013

Raw data

PRD86, 051102
454/fb



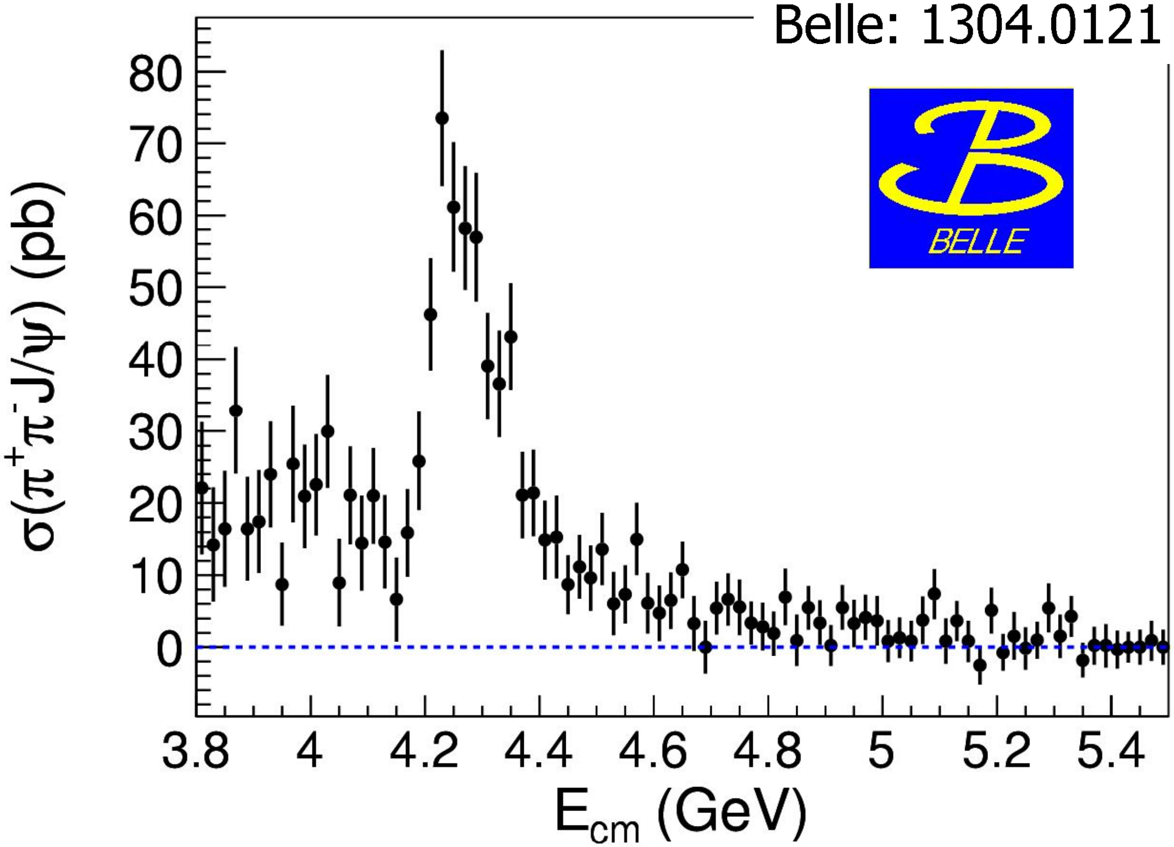
1304.0121
967/fb



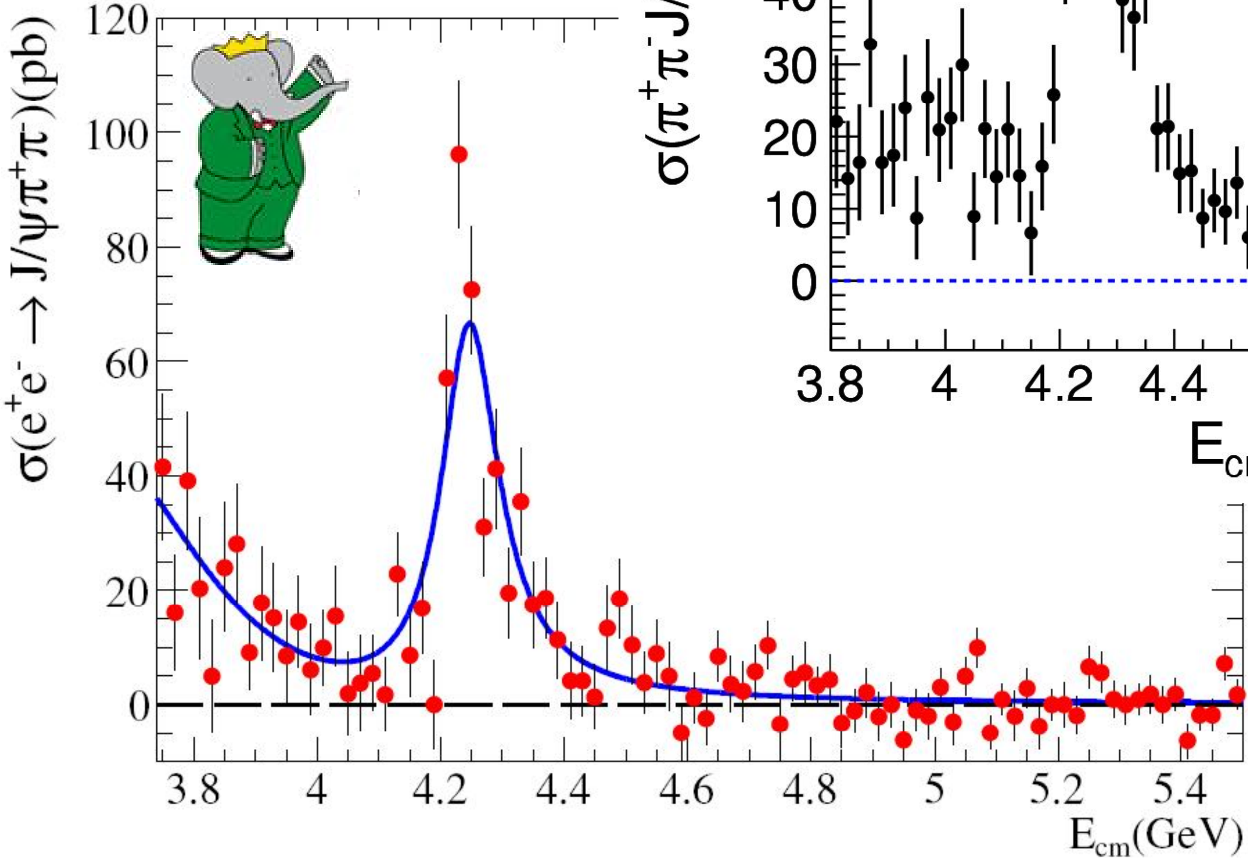
Lum ratio = 1:2
Same bin width
ψ' tail and ψ''?
Bkg estimation?

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

Belle: 1304.0121



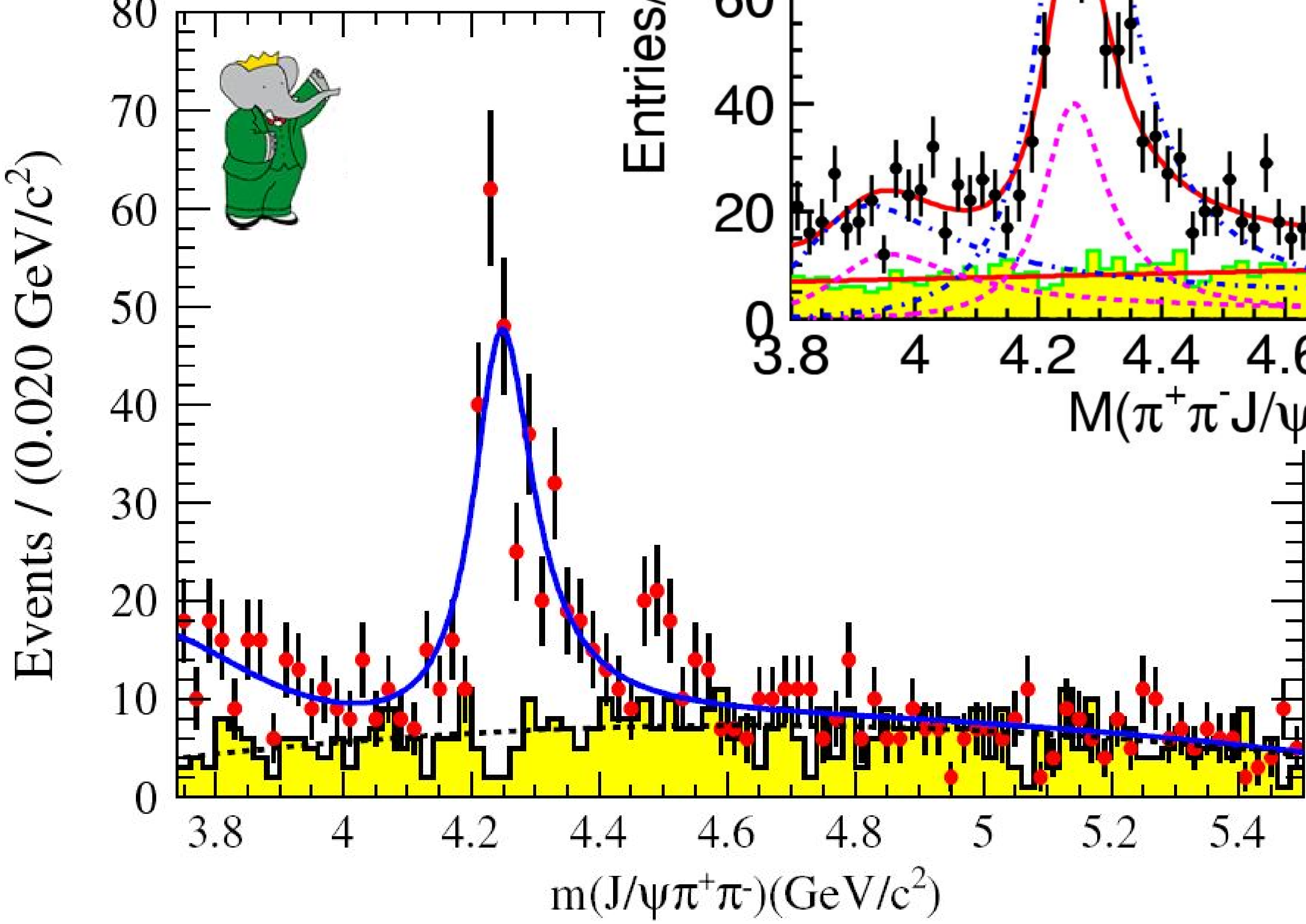
BaBar:
PRD86, 051102 (2012)

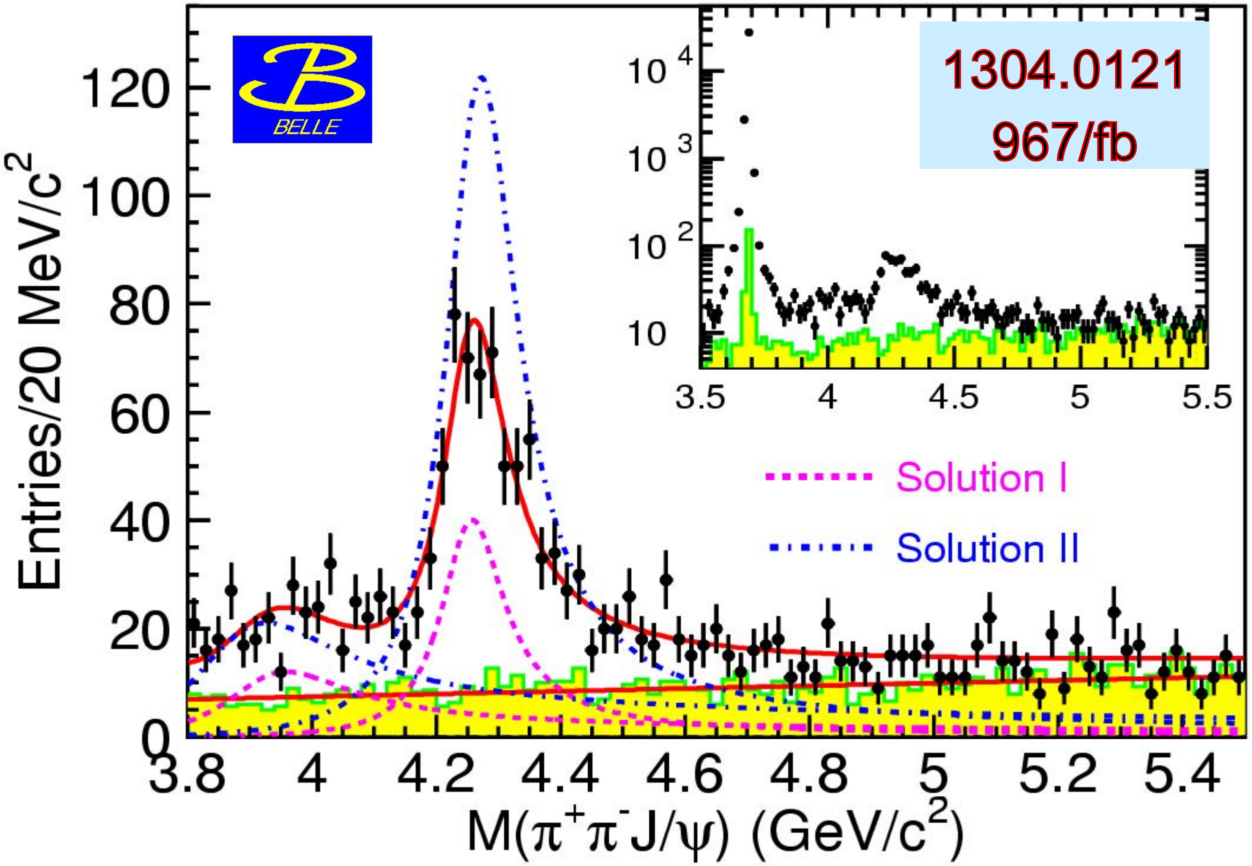


BESIII could be able to judge!

Fits with $|A_1+A_2|^2$

PRD86, 051102
454/fb





1304.0121
967/fb

Could be >1 amplitudes at around 4 GeV!

Conclusions?

- BESIII scans the cross section between 3.8 and 4.2 GeV with at least 50/pb per point

  n^{obs}=20 pb*50/pb*12%*0.5=60 !

- KEDR scan?

- BaBar+Belle ~ 25 signals+15 bkgs/[20 MeV]

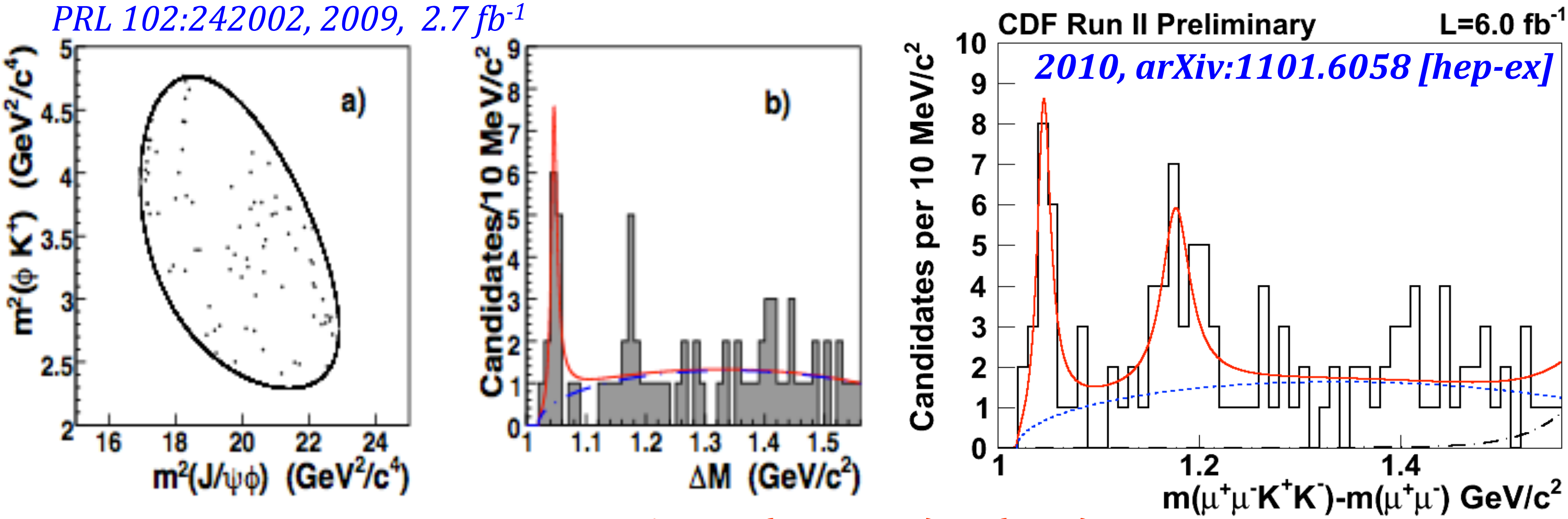
Y(4140) Status

Round table: XYZ: where do we stand

Kai Yi
University of Iowa

Structures in J/ψϕ Spectrum (CDF)

PRL 102:242002, 2009, 2.7 fb^{-1}



$\Delta M = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$

$Yield_1$ = 19±6; >5σ

M_1 = $4143.4^{+2.9}_{-3.0}$ (stat) ± 0.6 (syst) MeV

Γ_1 = $15.3^{+10.4}_{-6.1}$ (stat) ± 2.5(syst) MeV

$Yield_2$ = 22±8; 3.1σ

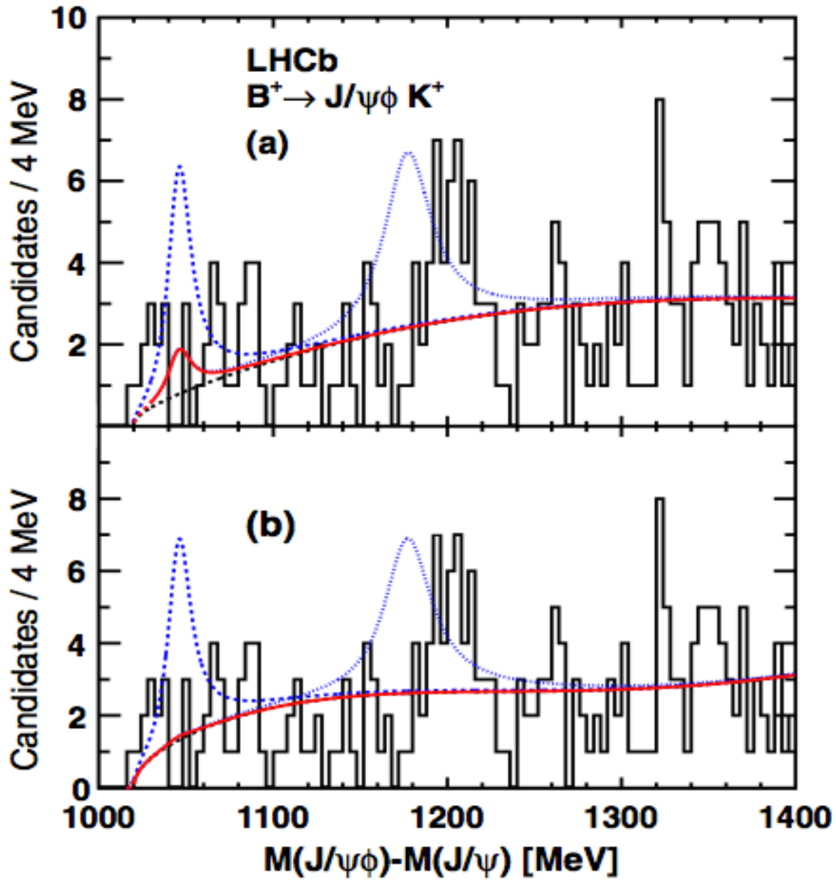
M_2 = $4277.4^{+8.4}_{-6.7}$ (stat) ± 1.9 (syst) MeV

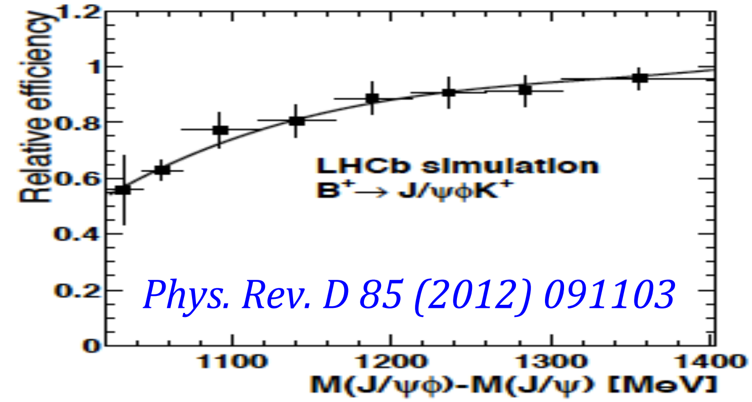
Γ_2 = $32.3.7^{+21.9}_{-15.3}$ (stat) ± 7.6(syst) MeV

Observed in exclusive $B^+ \rightarrow J/\psi \phi K^+$ decays

$$\frac{\mathcal{B}(B^+\to Y(4140)K^+, Y(4140)\to J/\psi\phi)}{\mathcal{B}(B^+\to J/\psi\phi K^+)} = 0.149 \pm 0.039(\mathrm{stat}) \pm 0.034(\mathrm{syst})$$

LHCb: does not confirm w/ 0.37 fb^{-1}





Phys. Rev. D 85 (2012) 091103

LHC_b confirms neither structure(s)
2.4σ disagreement with CDF measurement @90% CL:

$$\frac{\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\,\phi)}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.07.$$

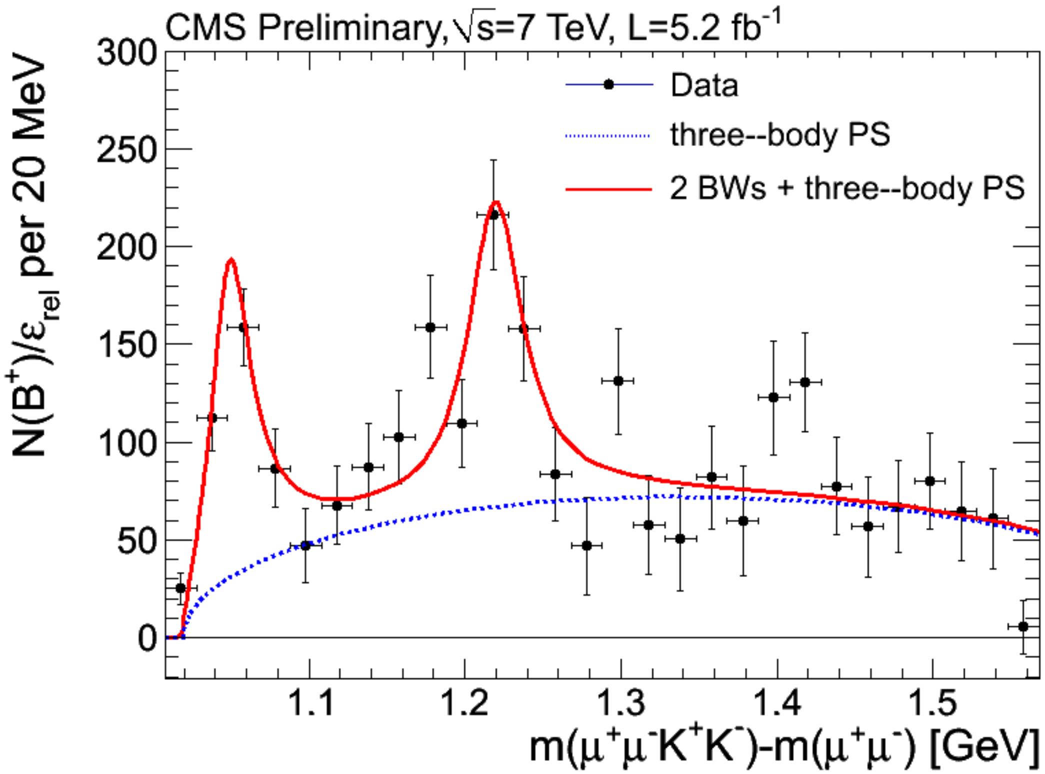
$$\frac{\mathcal{B}(B^+ \to X(4274)K^+) \times \mathcal{B}(X(4274) \to J/\psi\,\phi)}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.08$$

There was an unofficial LHCb result (1 fb^{-1}) in Workshop for New Results on Charmonium Production and Decays, March 6-8, 2013, Orsay France.

Waiting for LHCb official result w/ full dataset.
???

CMS Results on $J/\psi\,\phi$ Structures

- *The efficiency-corrected $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$*



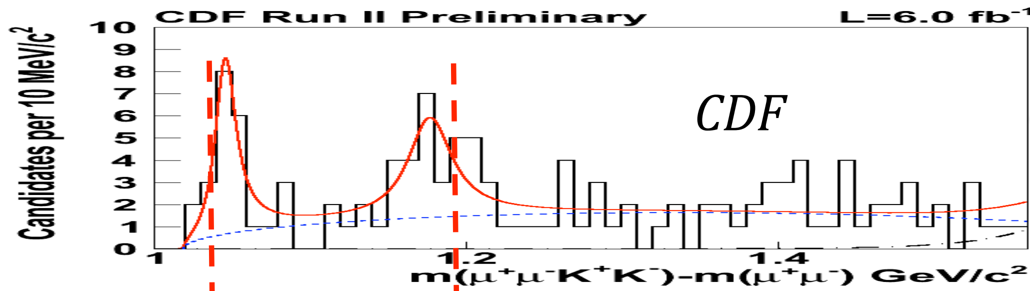
~20 times CDF statistics (115±12);
~7.2X LHCb statistics (346±20)

	Mass (MeV)	Signal Yield
First Peak	1051.5 ± 2.0	355 ± 46
Second Peak	1220.0 ± 3.0	445 ± 83

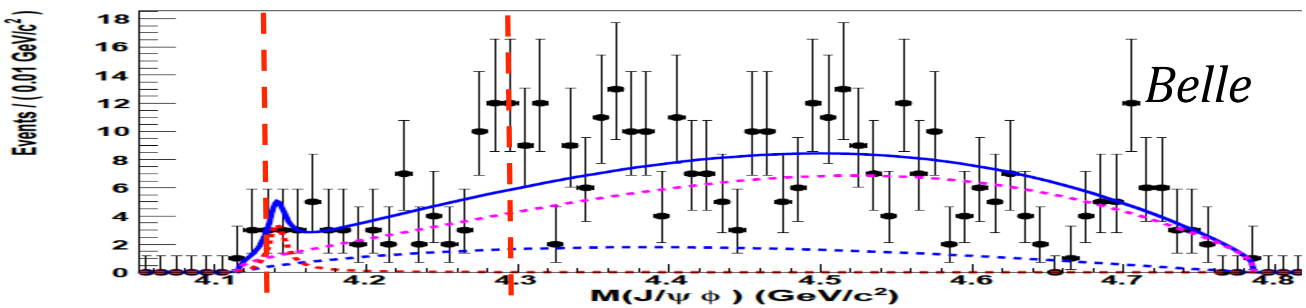
m_1= 4148.2±2.0(stat.)±4.6 (syst.) MeV
m_2= 4316.7±3.0(stat.)±7.3 (syst.) MeV

- *CMS observed a $J/\psi\phi$ structure at 4148MeV with a significance greater than 5σ consistent with CDF results on Y(4140)*

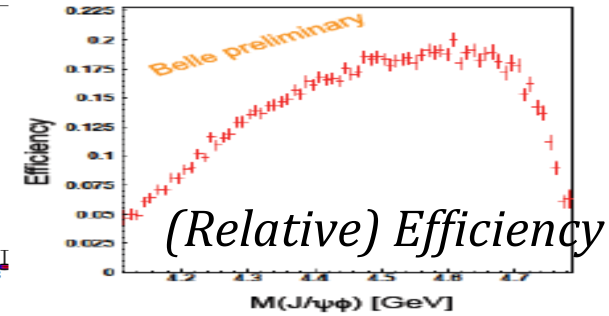
- *CMS finds evidence for a second structure at ~4317MeV*

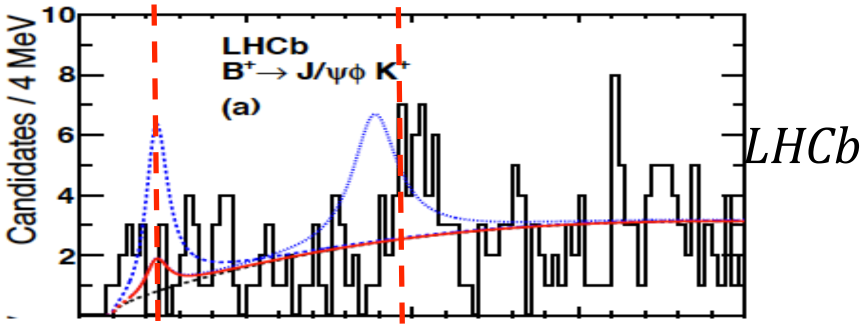


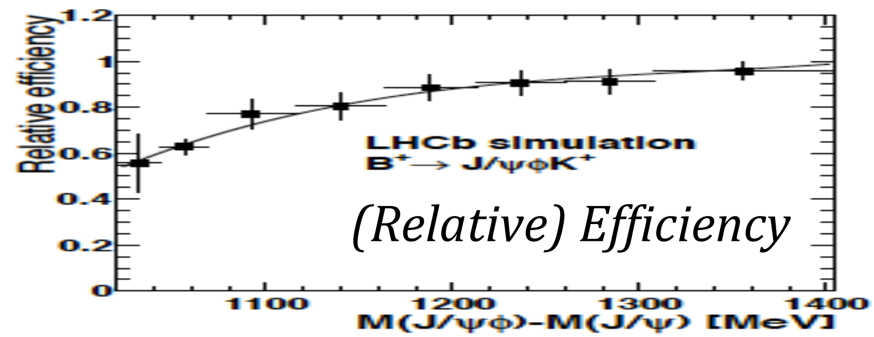
flat relative efficiency

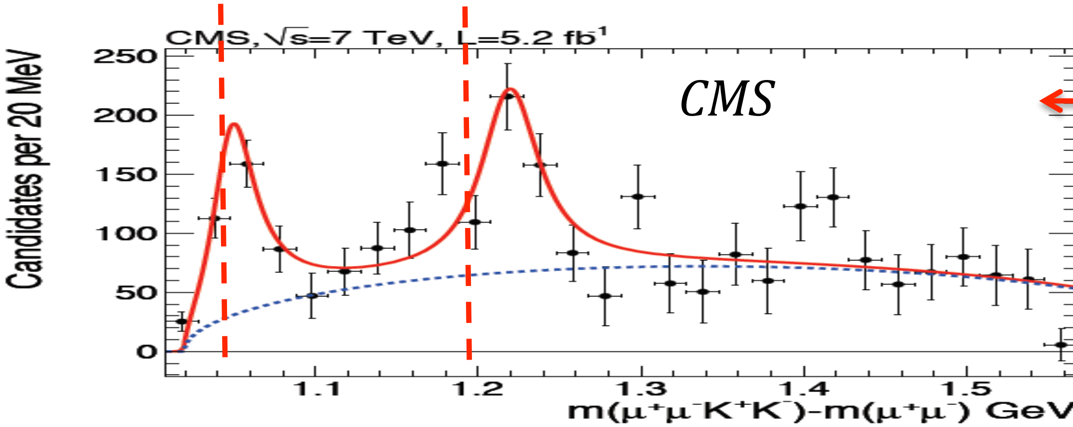


K. Miyabayashi, QWG 2010









relative efficiency corrected

CDF/BELLE/LHCb are raw distributions w/o efficiency correction

Summary of Y(4140) Status

- *CDF positive report*
- *Belle cannot confirm or deny it*
- *LHCb did not confirm w/ 0.37 fb^{-1} data*

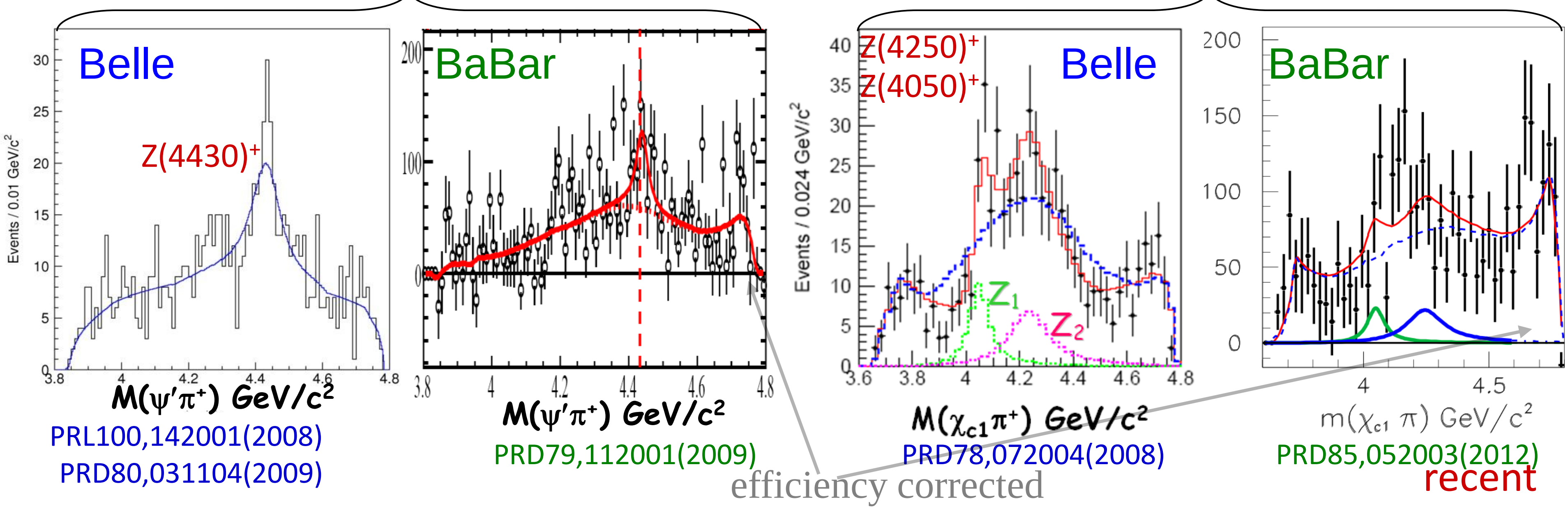
  (no official update, only unofficial plot w/ 1fb^{-1})
- *CMS confirms it w/ large statistics (7X LHCb)*
- *Apparent activity going on near the threshold*
- *ATLAS/CMS/LHCb can investigate its nature with more data*

- *A possible second structure, full amplitude analysis?*

Charged Z^+ in $\pi^+\chi_{c1}$ and $\pi^+\psi'$ systems ?

candidates for multiquark states

$B \to \psi'\pi K$ $B \to \chi_{c1}\pi K$



Belle : 3 charged states, BaBar : data are consistent with Belle, but no significant Z^+

Peaking structures are present in Belle and BaBar data

Different conclusions are due to <u>different analyses</u>

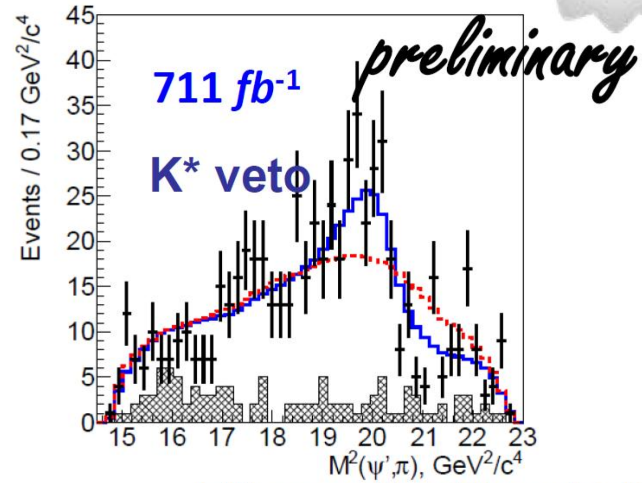
Belle – amplitude analysis of Dalitz plot, BaBar – moments of Legendre polynomials (same for Z(4430) and Z_1, Z_2 searches)

To settle Belle/BaBar controversy we need input from LHCb [Z(4430)] and Belle-II.

Talk by Chengping Shen on Monday

Measurement of $Z(4430)^+$ quantum numbers

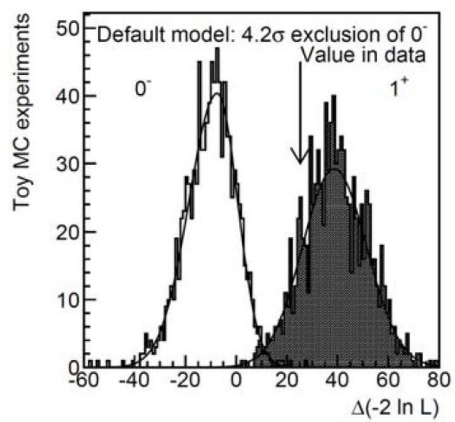
★ Amplitude analysis in 4D phase:
$(M^2_{K\pi}, M^2_{\psi'\pi}, \phi_{\psi' K^*}, \theta_{\psi'})$.
$\phi_{\psi' K^*}$: angle between Ψ' and K* decay planes
$\theta_{\psi'}$: Ψ' helicity angle



Fit result without Z^+
Fit result with Z^+ ($J^P=1^+$)

TABLE I: Fit results: $Z^+ \to \psi'\pi^+$.

J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV	4470 ± 20	4482 ± 4	4500 ± 12	4545 ± 2	4367 ± 2
Width, MeV	139 ± 36	10.9 ± 0.3	126 ± 20	11.2 ± 0.6	9.1 ± 0.6
Significance	4.4σ	1.2σ	6.1σ	2.3σ	2.6σ



- ★ **The 1^+ hypothesis is preferred**
- ★ Exclusion levels are calculated from toy MC
- ★ 0^- is not excluded; significance of 1^+ over 0^- is 2.9σ. 1^-,2^- and 2^+ are excluded at levels of 5.5σ, 4.3σ,and 5.4σ
- ★ **We also calculated some Brs:**

$$\mathcal{B}(\bar{B}^0 \to \psi' K^- \pi^+) = (5.50 \pm 0.15 \pm 0.42) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to \psi' K^*(892)) = (4.93^{+0.30+1.40}_{-0.23-0.43}) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to Z(4430)^+ K^-) \times \mathcal{B}(Z(4430)^+ \to \psi'\pi^+) =$$

$$(3.4^{+1.1+0.4}_{-0.7-1.3}) \times 10^{-5} \quad \text{for } J^P = 1^+ \text{ or}$$

$$(1.4^{+0.8+0.6}_{-0.7-0.2}) \times 10^{-5} \quad \text{for } J^P = 0^-.$$

Round table: XYZ: where do we stand

The 9th International Workshop on Heavy Quarkonium.

Beijing, April 26 2013

Participants

Theory

Gunnar Bali (*University of Regensburg*)

Estia Eichten (*FNAL*)

Christoph Hanhart (*IAS, Forschungszentrum Juelich*)

Bernd Kniehl (*II. ITP Univ. Hamburg*)

Wei Wang (*HISKP Universitaet Bonn*)

Experimental

Ryan Mitchell (*Indiana University*)

Roman Mizyuk (*ITEP Moscow*)

Kai Yi (*University of Iowa*)

Changzheng Yuan (*IHEP Beijing*)

Questions related to $Z_c(3900)$

1. Why does the $Z_c(3900)$ appear in $Y(4260)$ decays?
2. Why is there a single $Z_c(3900)$ state in charmonium and two ($Z_b(10610)$ and $Z_b(10650)$) states in bottomonium?
3. Can we understand why the width of Z_c is larger than the widths of Z_b's?
4. Do we expect $Z_c(3900)$ to decay to $h_c\pi^+$?
5. The mass of $Z_c(3900)$ is some 10MeV higher than the $DD*$ threshold. How this can be understood in the molecular picture?
6. If $Z_c^{\pm}$ and Z_c^0 form a triplet, can we expect an associated octed once strangeness is considered. From what we know about the triplet can we make any predictions for the masses of such states.

Round table discussion

Christoph Hanhart

Forschungszentrum Jülich

Questions

Why does the $Z_c(3900)$ appear in $Y(4260)$ decays?

IF $Y(4260)$ has a large $\bar{D}_1 D$ component (referring to previous talk)

$\rightarrow$ low energy $\bar{D}D^*$ pairs copiously produced

$\rightarrow$ perfect environment for formation of $\bar{D}D^*$ resonance

Why is there a single $Z_c(3900)$ state in charmonium and two ($Z_b(10610)$ and $Z_b(10650)$) states in bottomonium?

There should be another Z_c, but above mechanism not operative

$\rightarrow$ measurement at higher energies necessary

Can we understand why the width of Zc is larger than the widths of Zb's?

A resonance couples strongly to $\bar{D}D^*$

$\rightarrow$ width strongly correlated with pole position

Do we expect $Z_c(3900)$ to decay to $h_c\pi^+$?

Yes

Questions directed to experimentalist

7. What are the final states that are preferable/accessible for the experimental analysis, especially for Z_b or Z_c decays; what are the conditions?[Ryan Mitchell slide]
8. What prevents a combined analysis of different channels? Maybe one can measure various final states at once to ease this? Only a combined analysis of distinct final states offers the hope to disentangle the composition of states. [Roman Mizyuk]

From the talk of Zhiqing LIU…

Future XYZ plans at BESIII

Using ~2/fb data sample around 4.26 GeV:

- $Z_c(3900)$
- PWA analysis to determine J^P
- Precise mass, width and branching ratio measurements.
- potential topics ongoing:
- $\pi^+\pi^- h_c$
- $DD^*\pi$
- $D^*D^*\pi$
- $\pi^+\pi^-\psi(2S)$
- Search for $h_c(2P)$
- …

BESIII also has ~500pb^{-1} at 4.36 GeV
and smaller sets at a number of scan points…

The center of mass system is at rest, which allows us to access a wide variety of final states…

More ideas are welcome…

Questions related to the Z_b

9. $Z_b(10650)$ decays mainly to $B^*\bar{B}^*$ and with small probability (if any) to $B\bar{B}^*$, despite much larger phase space. Can this be considered a "smoking gun" for the $B^*\bar{B}^*$ wave-function of the $Z_b(10650)$? Can other approaches (tetraquark?) explain this? [Wei Wang slides]

Questions related to $X(3872)$

10. What are the implication of $X(3872)$ production cross-section measurement for its interpretation?

Z_b(10650) decays mainly to B*B*bar and with small probability (if any) to BB*bar, despite much larger phase space.

Can this be considered a "smoking gun" for the B*B*bar wave-function of the Zb(10650)? Can other approaches (tetraquark?) explain this?

Can tetraquark (diquark-antidiquark) explain the decay pattern of $Z_b(10650)$?

Molecule 

Tetraquark 

$|Z_{b(10610)}\rangle = (0_{b\bar q} \otimes 1_{\bar b q} + 1_{b\bar q} \otimes 0_{\bar b q})/\sqrt{2}$

$|Z_{b(10650)}\rangle = 1_{b\bar q} \otimes 1_{\bar b q}$

$|Z_{b(10610)}\rangle = (0_{[bq]} \otimes 1_{[\bar b\bar q]} - 1_{[bq]} \otimes 0_{[\bar b\bar q]})/\sqrt{2}$

$|Z_{b(10650)}\rangle = 1_{[bq]} \otimes 1_{[\bar b\bar q]}$

$\downarrow$ Fierz $\downarrow$

$|Z_{b(10610)}\rangle = 1^{-}_{b\bar q} \otimes 1^{-}_{q\bar b}$

$|Z_{b(10650)}\rangle = (1^{-}_{b\bar q} \otimes 0^{-}_{q\bar b} + 0^{-}_{b\bar q} \otimes 1^{-}_{q\bar b})/\sqrt{2}$

Molecule	Tetraquark
$Z_{b(10610)} \to B\bar B^* + B^*\bar B$	$Z_{b(10610)} \to B^*\bar B^*$
$Z_{b(10650)} \to B^*\bar B^*$	$Z_{b(10650)} \to B\bar B^* + B^*\bar B$

Can tetraquark(diquark-antidiquark) explain the decay pattern of $Z_b(10650)$?

Molecule

$|Z_{b(10610)}\rangle =$

$|Z_{b(10650)}\rangle =$

$\otimes 0_{[\bar{b}\bar{q}]})/\sqrt{2}$

[Belle Collaboration (2012)]

Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ± 3.6	
$B^{*+}\bar{B}^{*0}$		73.4 ± 7.0

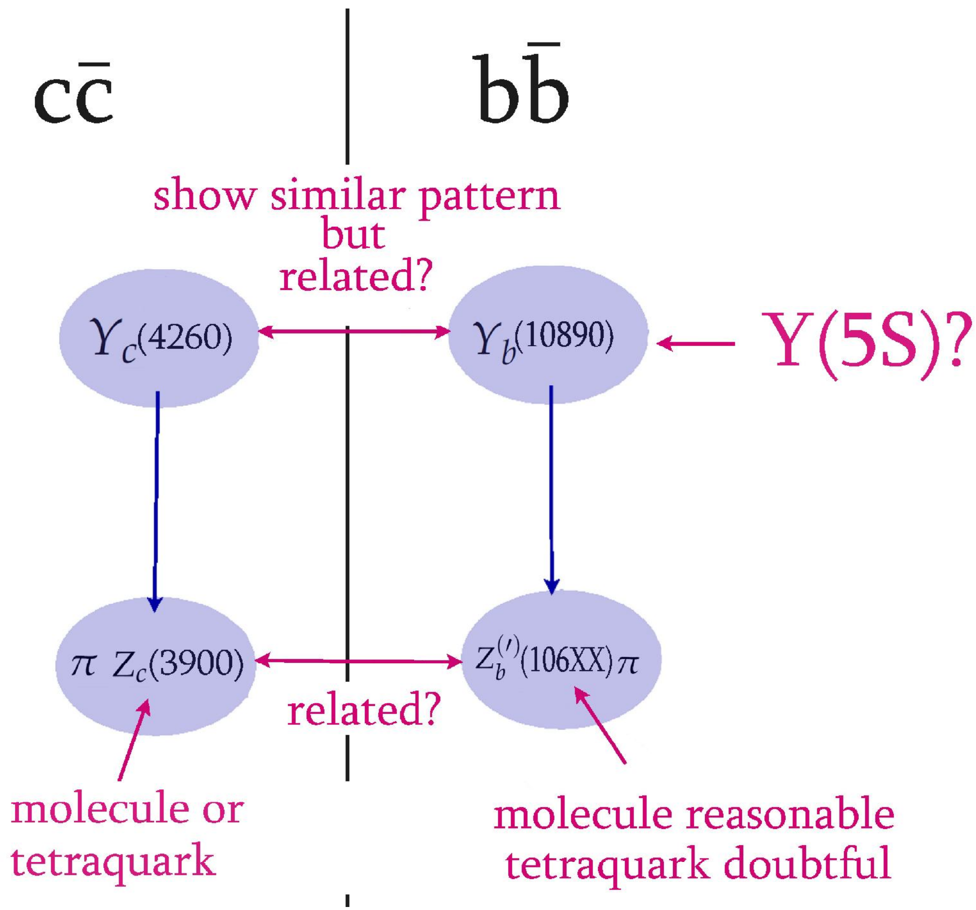
$|Z_{b(10650)}\rangle = (1^-_{b\bar{q}} \otimes 0^-_{q\bar{b}} + 0^-_{b\bar{q}} \otimes 1^-_{q\bar{b}})/\sqrt{2}$

$Z_{b(10610)} \to B\bar{B}^* + B^*\bar{B}$

$Z_{b(10650)} \to B^*\bar{B}^*$

$Z_{b(10610)} \to B^*\bar{B}^*$

$Z_{b(10650)} \to B\bar{B}^* + B^*\bar{B}$


$c\bar{c}$
$b\bar{b}$
show similar pattern
but
related?
$Y_c(4260)$
$Y_b(10890)$
Y(5S)?
$\pi\ Z_c(3900)$
$Z_b^{(\prime)}(106XX)\pi$
related?
molecule or
tetraquark
molecule reasonable
tetraquark doubtful

What are the implications of $X(3872)$ production cross section measurements for its interpretation?

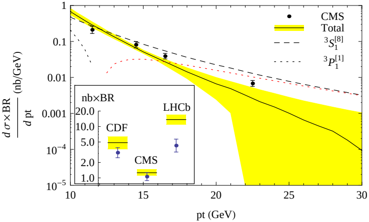
M. Butenschoen, Z. He, BK, 1303.3524 [hep-ph]

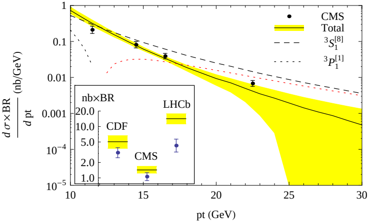
Test hypothesis $X(3872) \equiv \chi_{c1}(2P)$ in prompt hardoproduction at NLO in NRQCD

$$d\sigma(pp \to \chi_{c1}(2P)+X) = \sum_{i,j,n} \int dxdy\, f_{i/A}(x) f_{j/B}(y) \langle \mathcal{O}^{\chi_{c1}(2P)}[n] \rangle d\sigma(ij \to c\bar{c}[n]+X)$$

Fix $\langle \mathcal{O}^{\chi_{c1}(2P)}({}^3P_1^{[1]}) \rangle = (2J+1)\frac{3C_A}{2\pi}|R'_{2P}(0)|^2 = 0.438\ \mathrm{GeV}^5$.

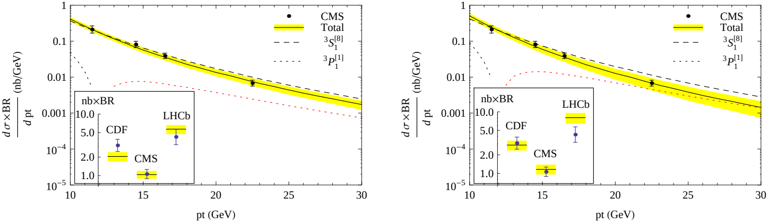
	w/ LHCb	w/o LHCb
$\langle \mathcal{O}^{\chi_{c1}(2P)}({}^3S_1^{[8]}) \rangle$ [GeV^3]	$(3.84^{+0.28}_{-0.24}) \times 10^{-3}$	$(4.30^{+0.30}_{-0.26}) \times 10^{-3}$
$\chi^2/\mathrm{d.o.f.}$	$79.1/5 = 15.8$	$16.7/4 = 4.18$





Two-parameter fit

	w/ LHCb	w/o LHCb	1304.6710 [hep-ph][1]
$\langle \mathcal{O}^{\chi_{c1}(2P)}(^3P_1^{[1]})\rangle$ [GeV^5]	$0.10^{+0.050}_{-0.050}$	$0.19^{+0.092}_{-0.094}$	0.17 ± 0.7
$\langle \mathcal{O}^{\chi_{c1}(2P)}(^3S_1^{[8]})\rangle$ [GeV^3]	$(3.84^{+0.28}_{-0.24}) \times 10^{-3}$	$(4.30^{+0.30}_{-0.26}) \times 10^{-3}$	$(3.34 \pm 1.69) \times 10^{-3}$
χ^2/d.o.f.	$4.26/4 = 1.07$	$0.63/3 = 0.21$	$0.52/2 = 0.26$



[1] C. Meng, H. Han, K.-T. Chao, 1304.6710 [hep-ph]

Fix $|R'_{2P}(0)|^2 = 0.075\ \mathrm{GeV}^5$ and fit $\langle \mathcal{O}^{\chi_{c1}(2P)}(^3S_1^{[8]})\rangle$ and overall factor $\frac{d\sigma(pp\to X(3872)+X)}{d\sigma(pp\to\chi_{c1}(2P)+X)}$ to CMS p_T distribution.

Related to other exotic states

11. There are many hadronic transitions from $\Upsilon(5\mathrm{S})$ to lower bottomonia with anomalously high partial widths $\Gamma \sim 1\mathrm{MeV}$. Also transitions with emission of eta are not suppressed relative to $\pi^+\pi^-$. How all these can be understood? What is $\Upsilon(5S)$? (bottomonium with admixture of molecule?)
12. All charmonium(-like) states above open flavor thresholds like to decay to lower charmonia with emission of light hadrons, with anomalous partial width $\Gamma > 1\mathrm{MeV}$. Is this of the same origin as hadronic transitions from the $\Upsilon(5S)$? Why charmonium(-like) states couple to one channel only (e.g. $Y(4360)$ and $Y(4660)$ decay to $\psi(2S)\pi^+\pi^-$, but not to $J/\psi\pi^+\pi^-$ etc).

Question about Large N_c arguments

13. Do large Nc arguments favor the molecular picture?

Comment for panel discussion

Estia Eichten
Fermilab

Comment

- Large hadronic transitions for states above threshold only occur when the decay of the initial quarkonium-like state can produce a ground state pair of heavy-light mesons that;
  - In a relative S-wave
  - Very low momentum in CM frame.
- The initial state decays into kinematically allowed associated pair of ground state and P-wave excited heavy light meson according to HQS.

For 1-- quarkonium state Φ allowed decays are:

Φ -> H(1-) (j^P = 1/2-) + H(0+) (j^P = 1/2+) S-wave
Φ -> H(0-) (j^P = 1/2-) + H(1+) (j^P = 1/2+) S-wave
Φ -> H(1-) (j^P = 1/2-) + H(1+) (j^P = 1/2+) S-wave
Φ -> H(1-) (j^P = 1/2-) + H(1+) (j^P = 3/2+) D-wave
Φ -> H(0-) (j^P = 1/2-) + H(2+) (j^P = 3/2+) D-wave
Φ -> H(1-) (j^P = 1/2-) + H(2+) (j^P = 3/2+) D-wave

H(0+) (j^P = 1/2+) -> π H(0-) (S-wave)

H(1+) (j^P = 1/2+) -> π H(1-) (S-wave)

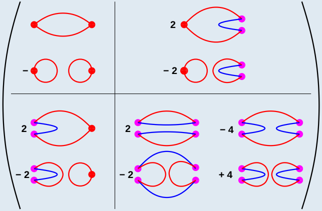
H(1+) (j^P = 3/2+) -> π H(1-) (D-wave)

H(2+) (j^P = 3/2+) -> π H(0-) (D-wave)
-> π H(1-) (D-wave)

- For hybrid states (Y(4260)) or molecular states, I assume the decays are some subset of the decay channels above. eg. hybrid -> H(0-) (j^P = 1/2-) + H(1+) (j^P = 1/2+, 3/2+) often used.
- Then it is simple kinematics to get the pattern of observed charged states in the bottom and charm system transitions.

Tetraquarks in large-N QCD (G Bali)

Wick contractions for mixing $c\bar{c}$ with $c\bar{q}q\bar{c}$ ($n_F = 2$):



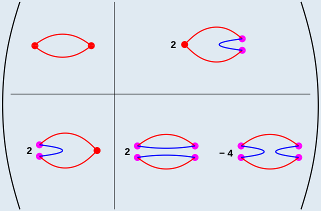
$$= \begin{pmatrix} \# + \#N & \frac{1}{\sqrt{N}}(\# + \#N) \\ \frac{1}{\sqrt{N}}(\# + \#N) & \frac{1}{N}(\# + \#N) \end{pmatrix}$$

Each closed line obtains a factor N. Usually each $M = \bar{q}q$ is divided by $\sqrt{N}$ so that the normalization of the propagator is N-independent. Mixing is governed by

$$\frac{C_{12}^2}{C_{11}C_{22}} = \frac{(\# + \#N)^2}{(\# + \#N)(\# + \#N)} \xrightarrow{N\to\infty} \text{const?}$$

At large N the disconnected contributions of C_{11} and C_{22} dominate. Their mixing with glueballs is $\mathcal{O}(1)$ and glueball propagators are also of $\mathcal{O}(N)$.

We have ignored that the different N-sectors decouple. If we look at the connected quarkonium alone (which is of $\mathcal{O}(1)$ in the N-counting) then we encounter the situation discussed recently by Weinberg:



$$= \begin{pmatrix} \# & \frac{1}{\sqrt{N}} \\ \frac{1}{\sqrt{N}} & \frac{1}{N}\,(\# + \# N) \end{pmatrix}$$

Now

$$\frac{C_{12}^2}{C_{11}\,C_{22}} = \mathcal{O}(1/N) \quad \text{or} \quad \mathcal{O}(1).$$

Mixing with disconnected $D\overline{D}$ is suppressed by $1/N$ but it can mix with a connected tetraquark (which is of the same order in N). $\Rightarrow$ Kinematical question: which one is lighter? If the tetraquark is lighter it will dominate. $\Rightarrow$ Calculation of $N = \infty$ charmonium and charmed tetraquark spectra could be interesting.