XYZ studies at BESIII

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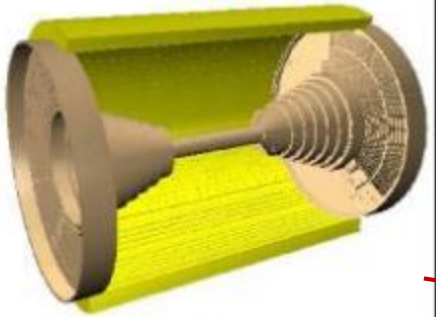
BESIII Detector

MDC

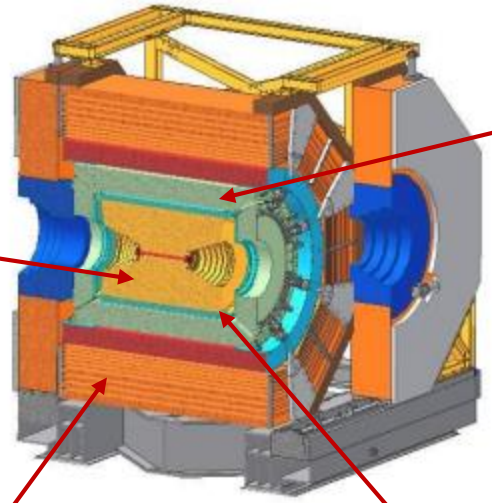


R inner: 63mm ;

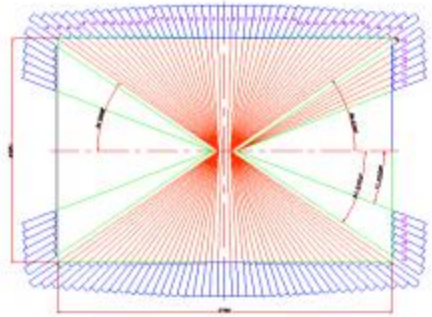
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



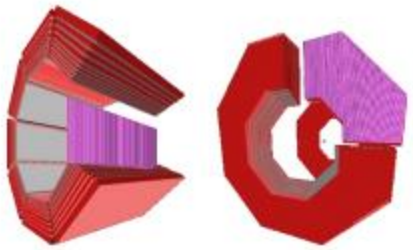
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

TOF

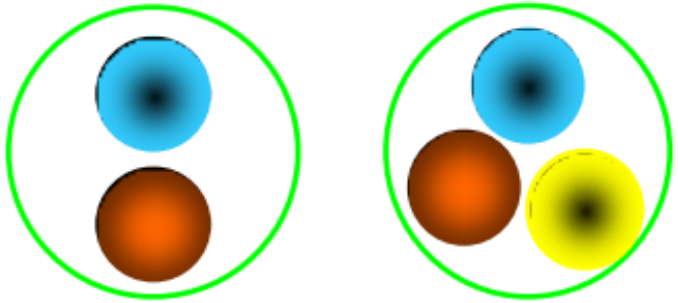
BTOF: two layers

ETOF: 48 crys. for each

Hadrons: normal & exotic

- Hadrons are composed from 2 (meson) quarks or 3 (baryon) quarks

Quark model



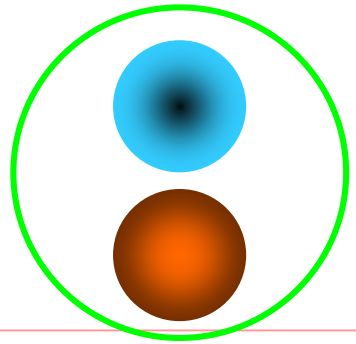
- QCD allows hadrons with $N_{quarks} \neq 2, 3$
  - glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - hybrid : $N_{quarks} = 2$ + excited gluon
  - multiquark state : $N_{quarks} > 3$
  - molecule : bound state of more than 2 hadrons

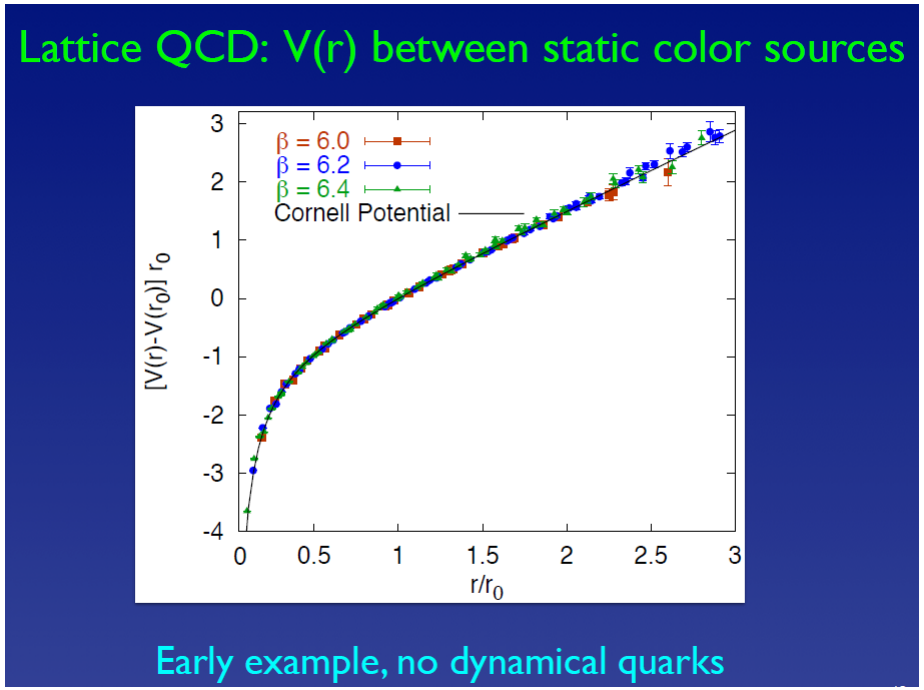
The heavy quarkonium system

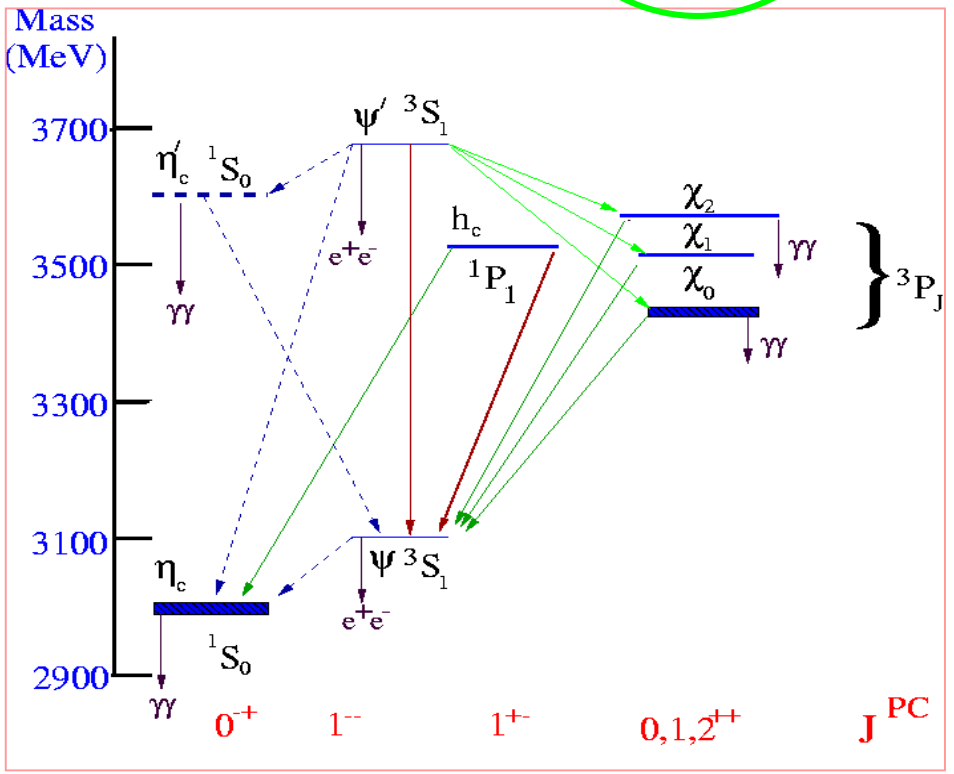
- At short distance

  Cornell model works pretty well

  $V(r) = -4\alpha_s/3r+kr$





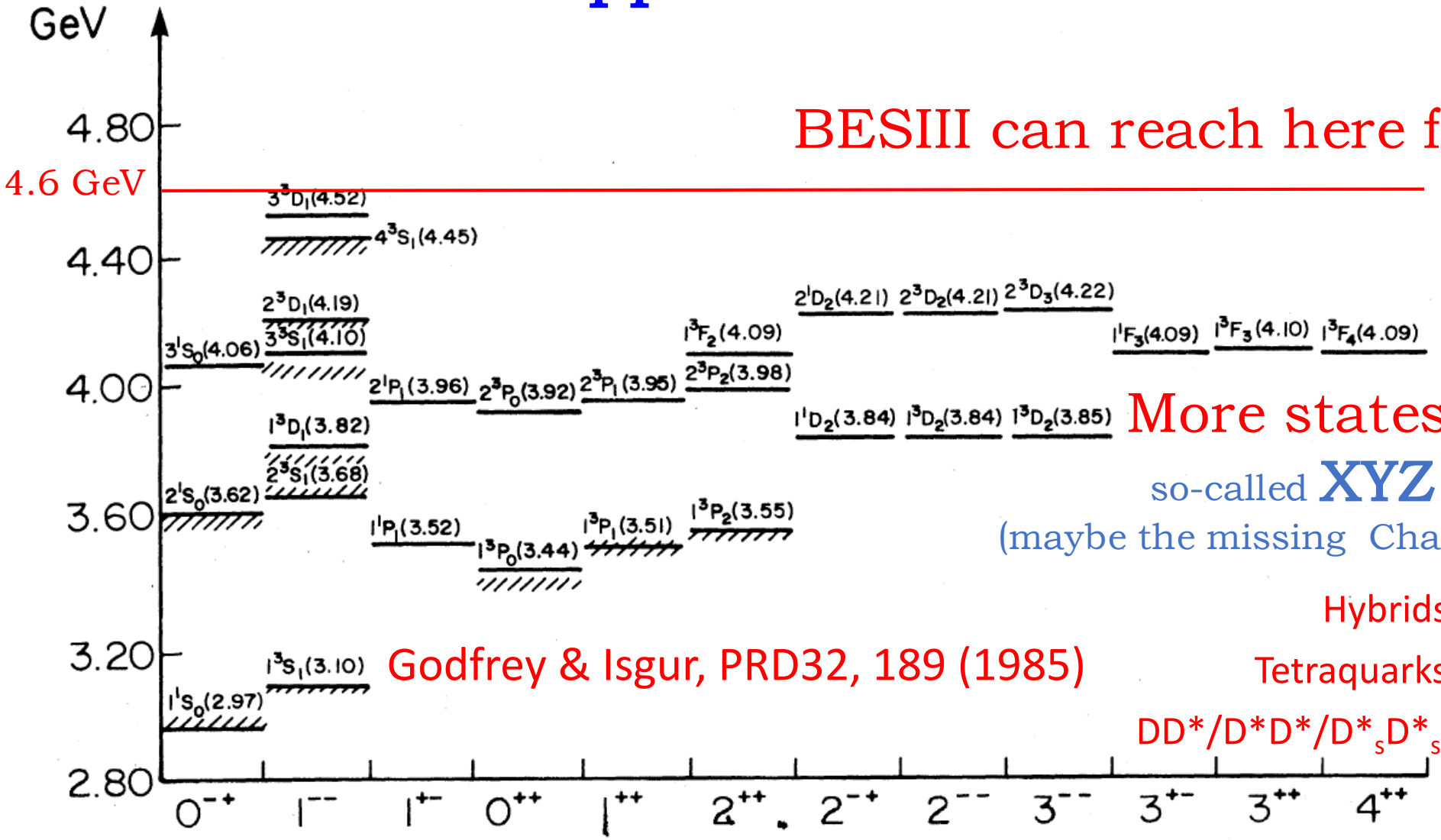


When distance becomes larger

Theory 1: let there be screened potential
Theory 2: let there be hybrids with excited gluons
Theory 3: let there be tetraquark states
Theory 4: let there be meson molecules
Theory 5: let there be cusps
Theory 6: let there be final state interaction
Theory 7: let there be coupled-channel effect
Theory 8: let there be mixing
Theory 9: let there be mixture of all these effects
Theories …

The world is not that good! Need data to develop theory.

All these happen in 4.0-4.7 GeV



4.6 GeV

BESIII can reach here for now

More states?

so-called **XYZ**

(maybe the missing Charmonium)

Godfrey & Isgur, PRD32, 189 (1985)

Hybrids ~ 4.2-4.5 GeV

Tetraquarks ~ 3.9-4.7 GeV

$DD^*/D^*D^*/D^*_sD^*_s/DD_1$ molecule ~ 3.9-4.4 GeV

XYZ states

Name	J^{PC}	Γ(MeV)	Decay modes	Experiments	interpretation
X(3872)	1^{++}	<1.2	$\pi\pi J/\psi$, $\gamma J/\psi$, DD*, …	Belle/CDF/D0/BaBar/LHCb	$\bar{D}D^*$ molecule?
X(3940)	$0^{?+}$	~37	DD* (not DD, $\omega J/\psi$)	Belle	η_c"(?)
Y(3940)	$?^{?+}$	~30	$\omega J/\psi$ (not DD*)	Belle/BaBar	
Y(4140)	$?^{?+}$	~11	$\phi J/\psi$	CDF & CMS & BaBar	ccss?
X(4160)	$0^{?+}$	~140	D*D* (not DD, DD*)	Belle	η_c"(?)
Y(4008)	1^{--}	~220	$\pi\pi J/\psi$	Belle (not Babar)	$\psi(4040)$?
Y(4260)	1^{--}	~80	$\pi\pi J/\psi$	BaBar/CLEO/Belle	ccg hybrid?
X(4350)	$?^{?+}$	~13	$\gamma\gamma$, $\phi J/\psi$	Belle	ccss?
Y(4360)	1^{--}	~75	$\pi\pi\psi(2S)$	BaBar/Belle	
Y(4660)	1^{--}	~50	$\pi\pi\psi(2S)$, $\Lambda_c\Lambda_c$ (?)	Belle/BaBar	

$Z^{\pm}(4430)$	1^{+}	~100	$\psi(2S)\pi^{\pm}$	Belle/LHCb	4-quark?
$Z^{\pm}(4050)$	1^{+}	~80	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(4250)$	1^{+}	~180	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(3900)$	1^{+}	~40	$J/\psi\pi^{\pm}$	BESIII/Belle/CLEOc	4-quark?
$Z^{\pm}(4020)$	$?^{?}$	~10	$h_c\pi^{\pm}$	BESIII	4-quark?

15

XYZ states

conventional quarkonium ($c\bar{c}$), meson molecule ($c\bar{q}+\bar{c}q$), tetraquark ($c\bar{c}q\bar{q}$), hybrid state ($c\bar{c}+g$ ...) et.al.

X: 1^{++}, et.al

Y: $J^{PC}=1^{--}$

Z: isospin triplet

radiative or hadronic transition from Y

e^+e^- annihilation

Hadronic transition from Y

$Y\to\gamma X(3872)$

$Y(4260)\to\pi Z_c$

Largest data sample around $Y(4260)$ at BESIII,
We can study the relations between X and Y.

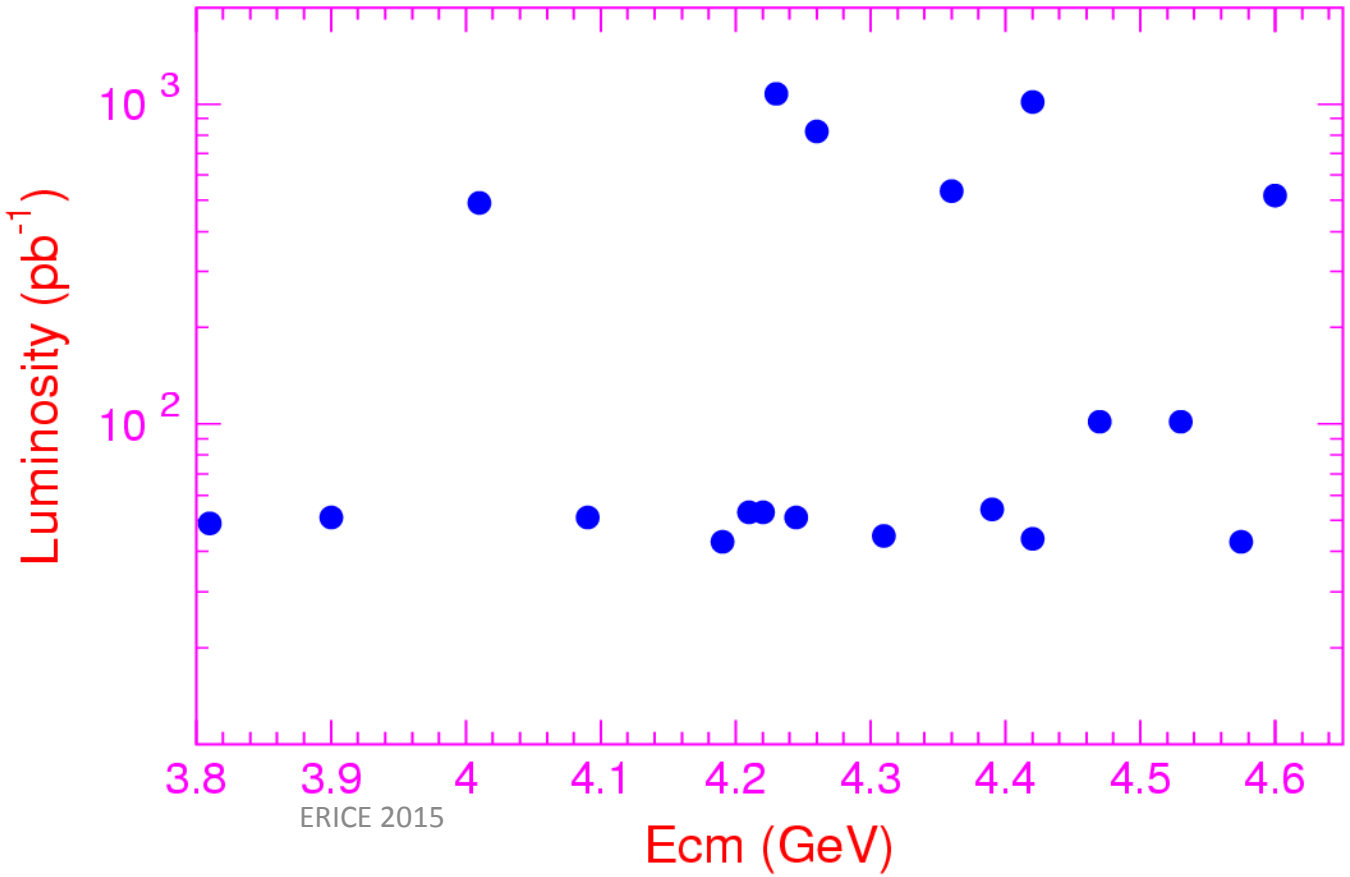
- # Published works

  - **Observation of the $e^+e^- \to \gamma X(3872)$** (PRL 112,092001)

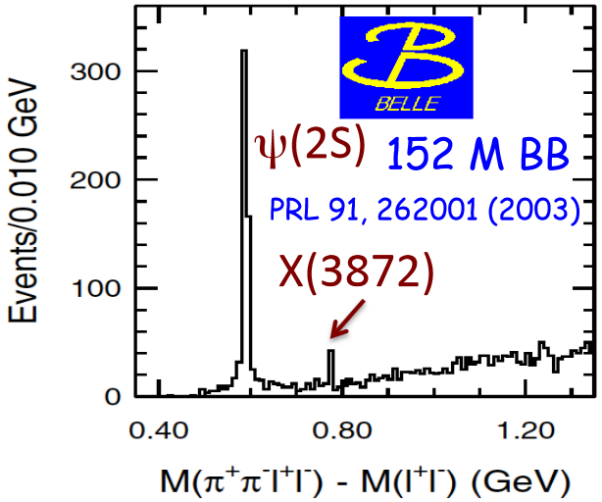
  - **Search for $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$** (PRD 91,032002)

~5 fb^{-1} data
$\sqrt{s} = 3.81 - 4.60$ GeV

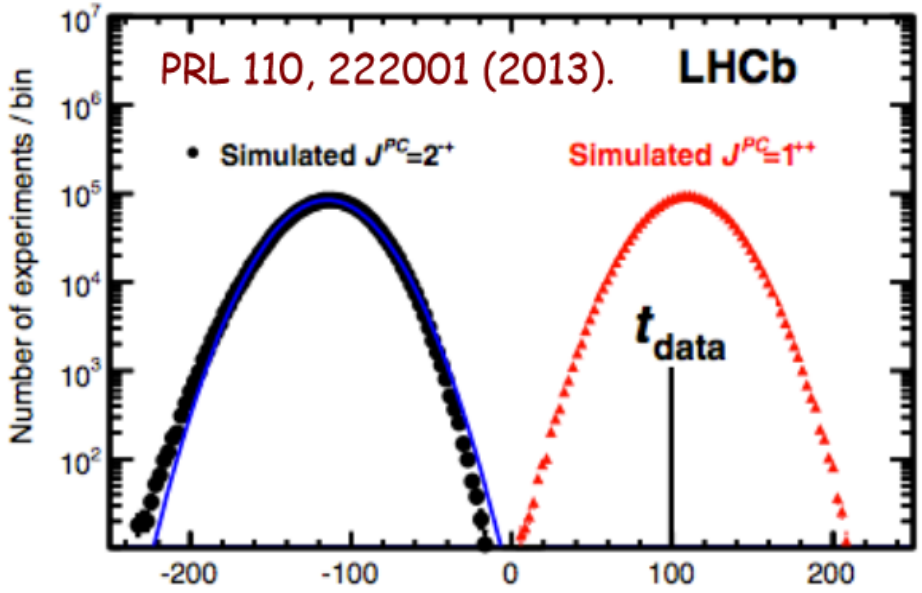
More will come soon.

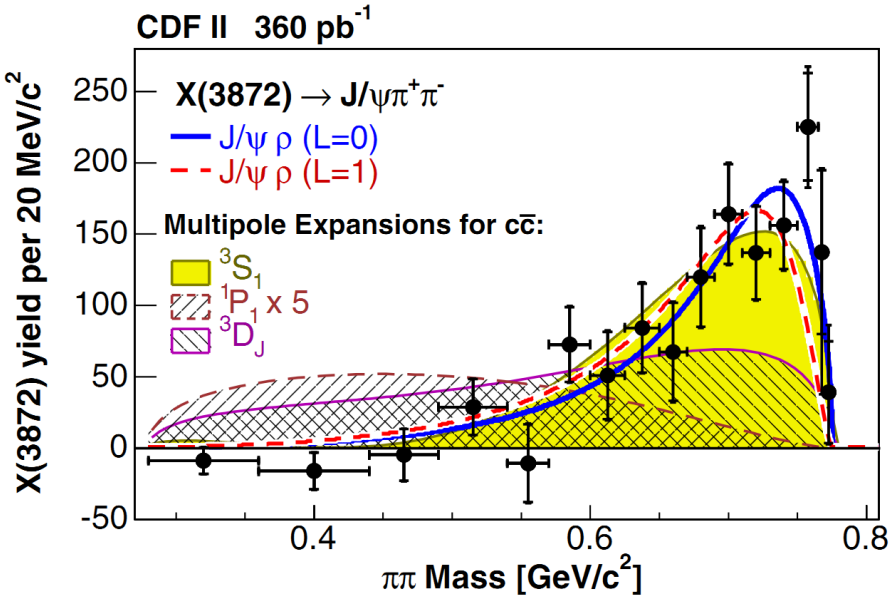


Observation of the $e^+e^- \to \gamma X(3872)$



- Observed by Belle, Babar, CDF, LHCb only from B decays and $p\bar{p}$ collision,
- Mass 3871.69±0.17 MeV
- very narrow (< 1.2 MeV)
- close to $D^{*0}D^0$ threshold (~3871.8)
- $J^{PC} = 1^{++}$ (LHCb)
- Hunt it through radiative transition





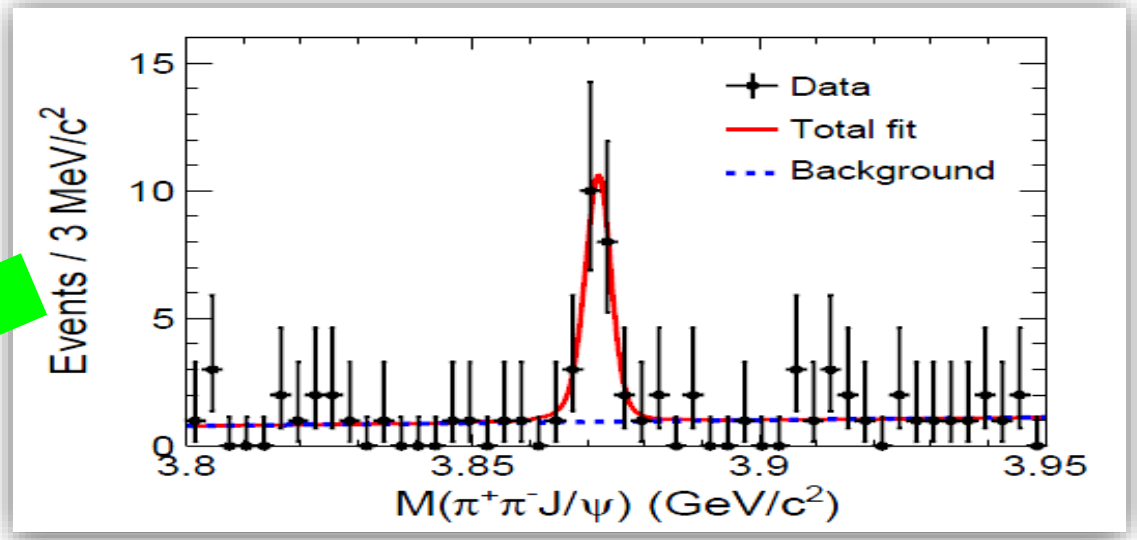
Observation of the $e^+e^- \to \gamma X(3872)$

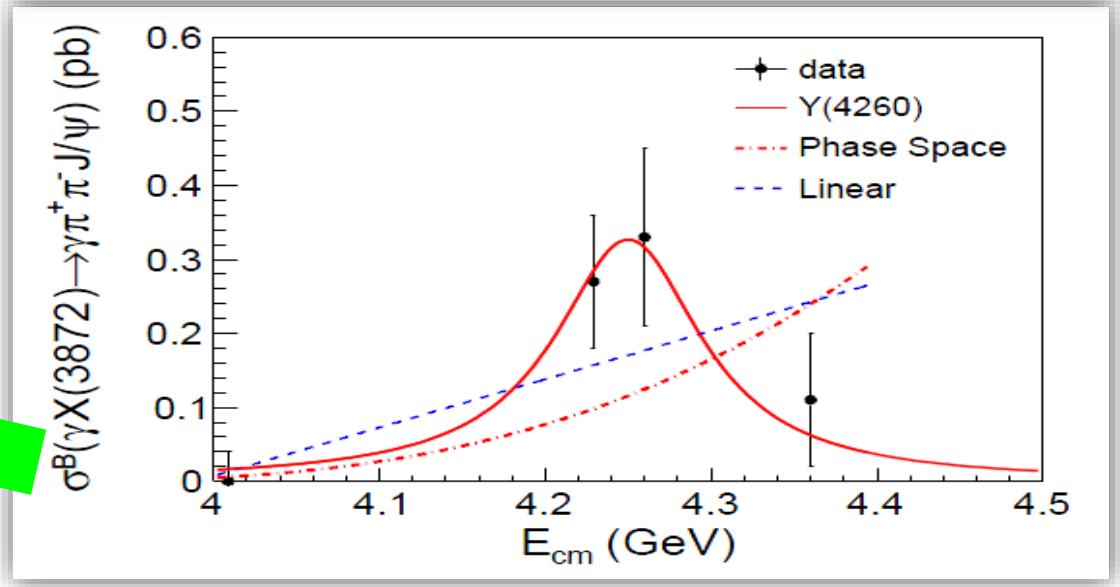
- M=3871.9±0.7 ± 0.2 MeV
- Summed over all data X(3872) significance = 6.3σ
- Production in Y(4260) decay suggestive,

  connect **X** and **Y** for the first time

$\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$=5% (arXiv:0910.3138)

$$R = \frac{\mathcal{B}(Y(4260) \to \gamma X(3872))}{\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)} = 0.1$$





[BESIII RPL112,092001]

Search for Y(4140) via $e^+e^- \to \gamma\phi J/\psi$

Exist

CDF (3.8σ) $B^+ \to \phi J/\psi K^+$

CDFII (>5 σ) $B^+ \to \phi J/\psi K^+$
6.0 fb^{-1} at $\sqrt{s} = 1.96$ TeV

CMS $B^+ \to \phi J/\psi K^+$
5.2 fb^{-1} at $\sqrt{s} = 7$ TeV

D0 (3.1σ) $B^+ \to \phi J/\psi K^+$
10.4 fb^{-1} at $\sqrt{s} = 1.96$ TeV

V.S.

or not?

Belle $\gamma\gamma \to \phi J/\psi$
825 fb^{-1} e^+e^- collider

Belle $B^+ \to \phi J/\psi K^+$ 772× 10^6 $\bar{B}B$

LHCb$B^+ \to \phi J/\psi K^+$
0.37 fb^{-1} at $\sqrt{s} = 7$ TeV
(2.4σ) disagreement with CDF

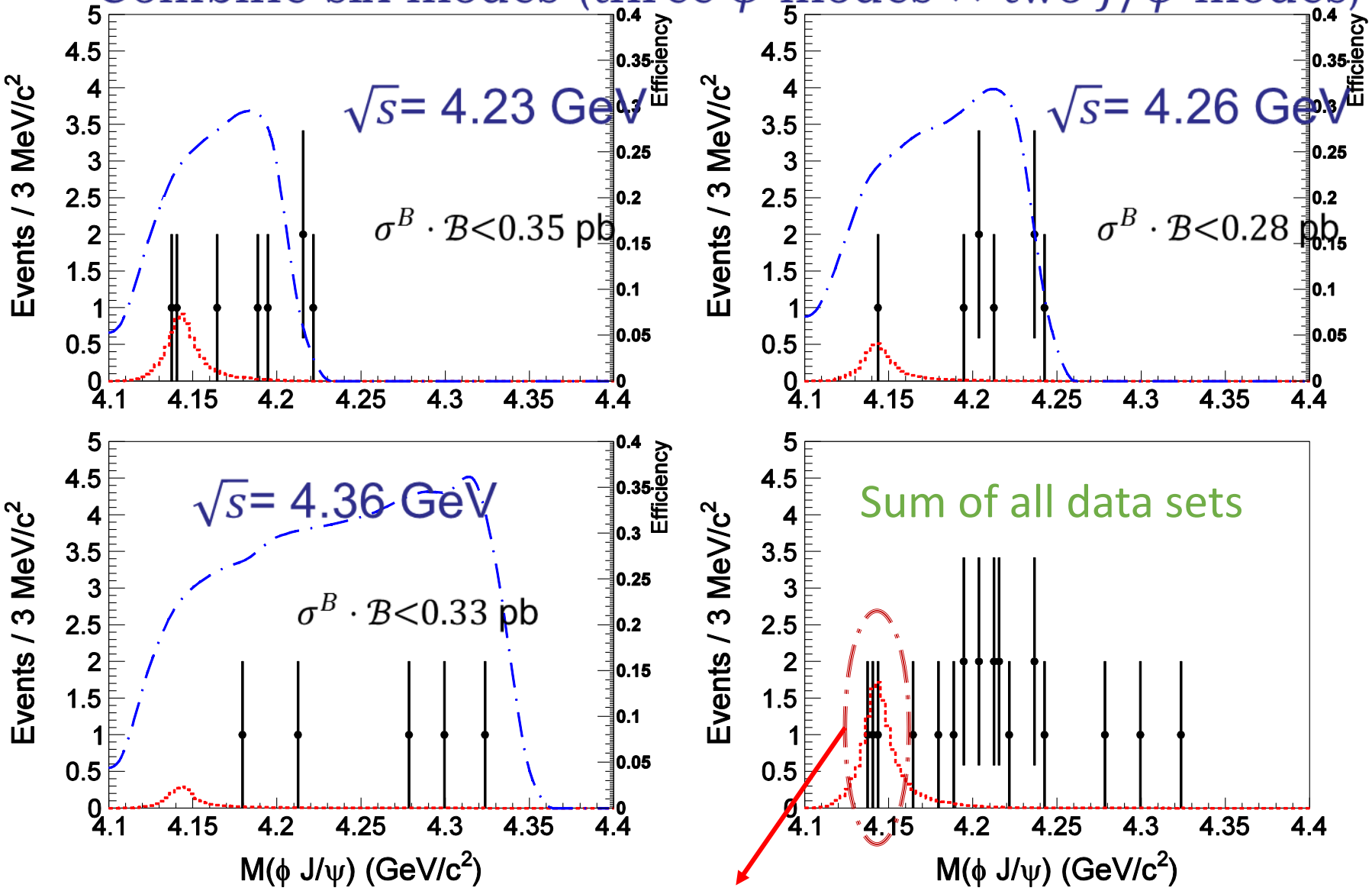
BABAR$B^+ \to \phi J/\psi K^+$ 469× 10^6 $\bar{B}B$

A good candidate for $D_s^*\overline{D_s^*}$ molecular.

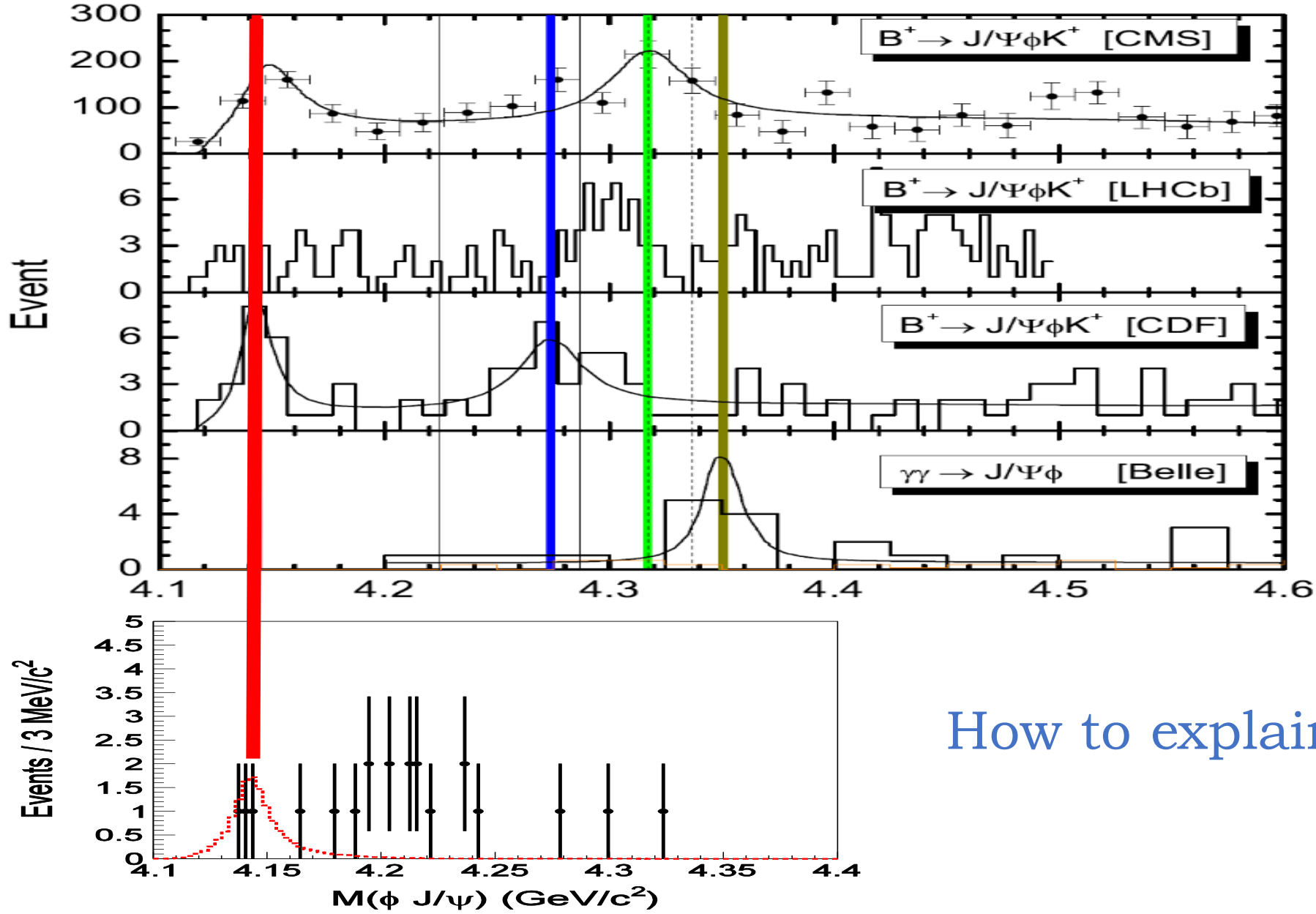
Positive C-parity,
radiative transition of 1^{--} charmonium (-like) states at BESIII?

$e^+e^- \to \gamma\phi J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$
with $\phi \to K^+K^-$ (one Kaon can be missing), $\phi \to K_SK_L$ (K_L is missing) and $\phi \to \pi^+\pi^-\pi^0$

Combine six modes (three ϕ modes × two J/ψ modes)



Three events seems like Y(4140).
No background from MC studies



How to explain?

Summary

Many states (XYZ) in charm sector do not fit quark model well.

- The $X(3872)$ is observed with significance 6.3σ via $e^+e^- \to \gamma X(3872)$.
- The Y(4140) is searched via $e^+e^- \to \gamma\phi J/\psi$, no obvious signal (three events).

On-going analysis (within collaboration)

$e^+e^- \to D_s D_s^*, D_s D_s^*$

$e^+e^- \to D_s^* D_{s0}(2317)\ D_{s1}(2460)$

$e^+e^- \to \eta Y(2175)$

Charmonium

M1 transition $J/\psi \to \gamma\eta_c, \psi' \to \gamma\eta_c(\eta_c(2S))$

With more data above 4.0 GeV at BESIII, more informations of XYZ particles will be uncovered. Hopefully we may understand the natures of them.

Thanks for your attention.