Some Topics in Hadron Spectroscopy:

Funny Things that Happen at Thresholds

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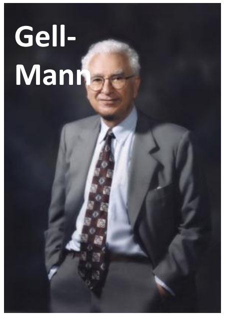
Seoul National University

Constituent Quark Model



The model was proposed independently by Gell-Mann and Zweig in 1964 with three fundamental building blocks:

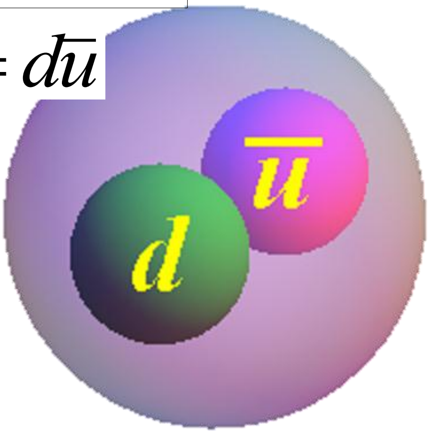
1960's $(p, n, \lambda) \Rightarrow$ 1970's (u,d,s):

<u>mesons</u> are bound states of a of quark and anti-quark:

$$\pi^+ = u\bar{d} \qquad \pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}) \qquad \pi^- = d\bar{u}$$

$$K^+ = u\bar{s} \qquad K^0 = d\bar{s} \qquad \bar{K}^0 = s\bar{d} \qquad K^- = s\bar{u}$$

$$\pi^- = d\bar{u}$$

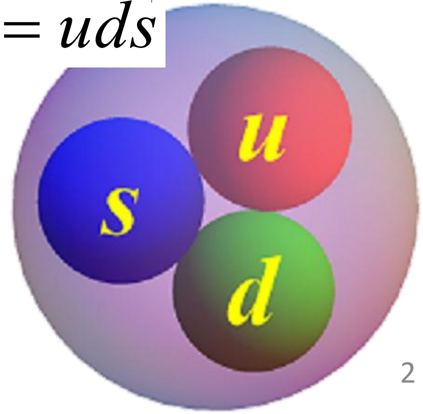


<u>baryons</u> are bound state of 3 quarks:

$$p = uud \qquad n = udd \qquad \Lambda = uds$$

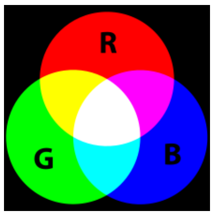
$$\bar{p} = \bar{u}\bar{u}\bar{d} \qquad \bar{n} = \bar{u}\bar{d}\bar{d} \qquad \bar{\Lambda} = \bar{u}\bar{d}\bar{s}$$

$$\Lambda = uds$$

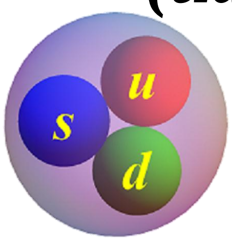


Superseded by QCD in the 1970s: observed particles are color singlets

3 primary colors → **white**

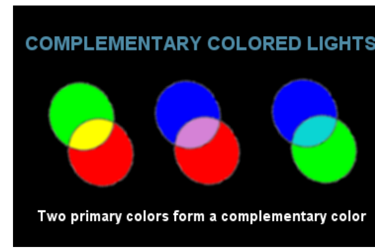


$$\Lambda = (uds)$$



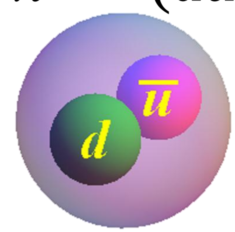
Baryons are red-blue-green triplets

color + complementary **color** → **white**



blue-yellow
green-magenta
red-cyan

$$\pi^- = (d\bar{u})$$



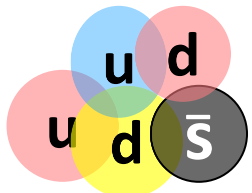
Mesons are color-anticolorpairs

What about other color-singlet combinations?

Other possible "white" combinations of quarks & gluons:

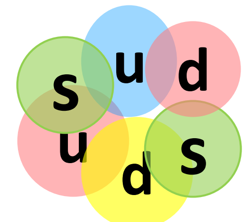
Pentaquark:

S=+1 Baryon



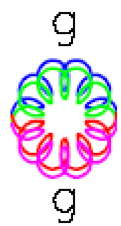
H-diBaryon

tightly bound
6-quark state



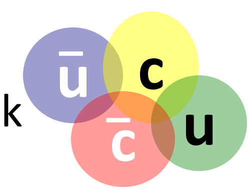
Glueball

Color-singlet multi-
gluon bound state

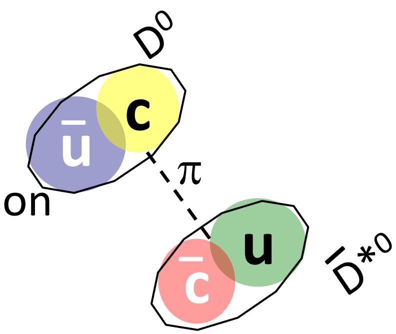


Tetraquark mesons

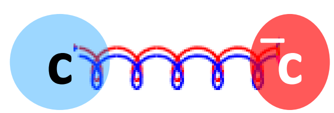
tightly bound
diquark-diantiquark



loosely bound
meson-antimeson
"molecule"

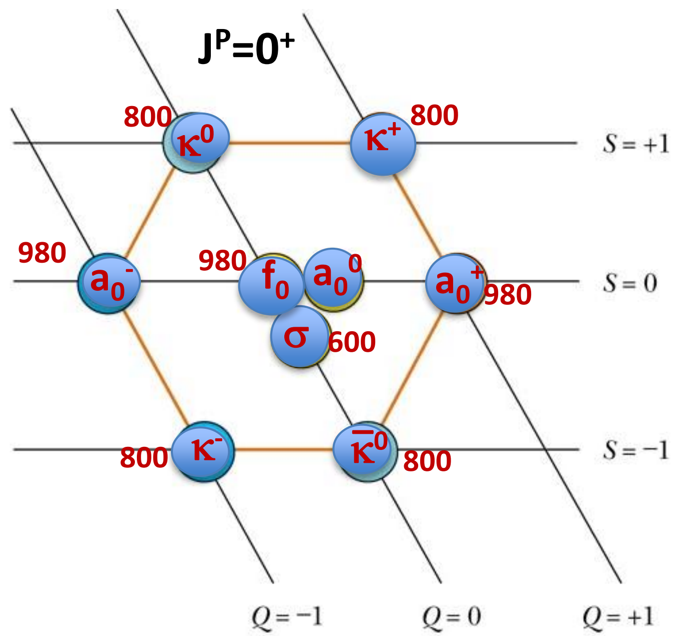


$q\bar{q}$-gluon hybrid mesons

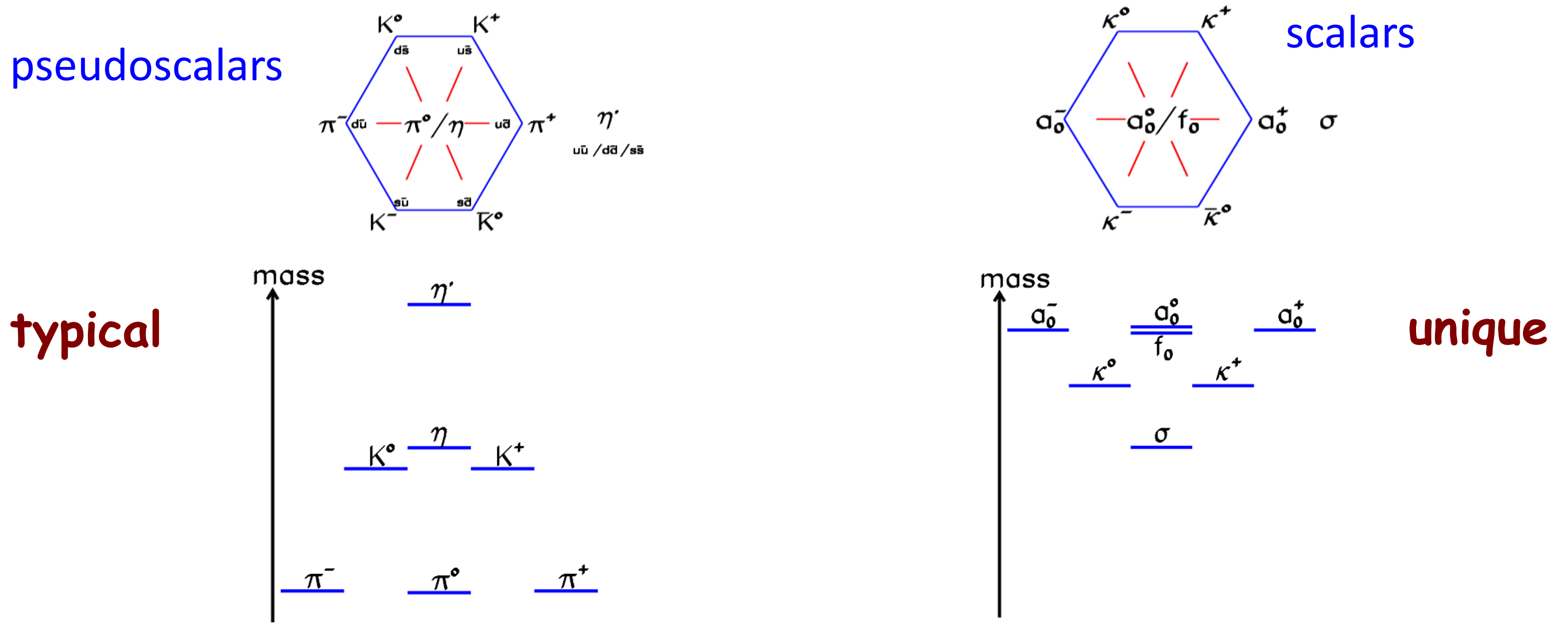


1st evidence for non-qq mesons

The "light" scalar-meson nonet??



light scalar nonet masses are inverted



Also:

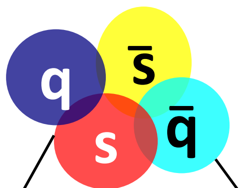
- No “light” $J^P=1^+$ and 2^+ partner nonets in the same mass range.
- In $q\bar{q}$ meson nonets, the I=0 state (here the $a_0(980)$) has no s-quarks.
- $m(f_0(980)) \approx m(a_0(980))$ implies “ideal” mixing & ***small*** s-quark content in $f_0(980)$.

  strong couplings of the $a_0(980)$ & the $f_0(980)$ to $K\bar{K}$ indicate strong OZI-rule violations

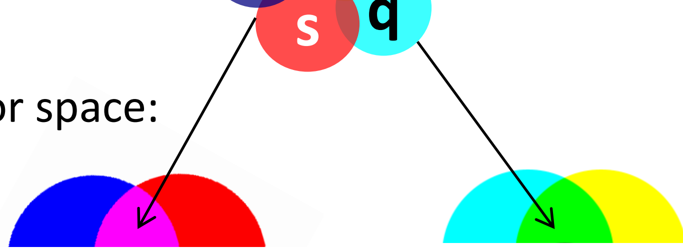
If not $q\bar{q}$, then what?

Possibilities that have been suggested:

tightly bound diquark-diantiquark



In color space:



red+blue=magenta
(antigreen)

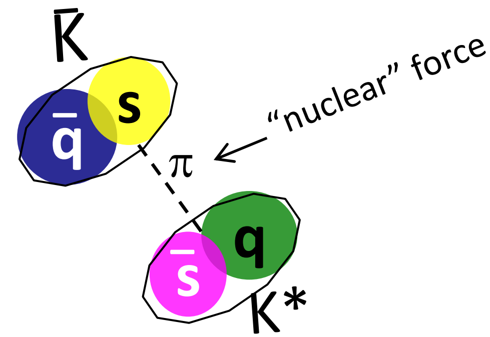
cyan+yellow=green
(antimagenta)

A colored diquark
is like a antiquark

A colored diantiquark
is like a quark

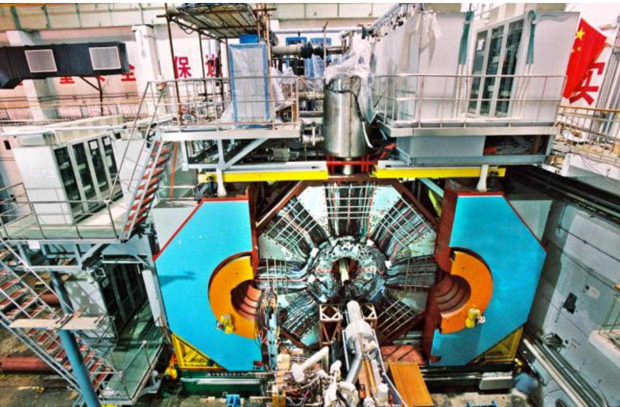
R.L.Jaffe PRD 15, 267 (1977)

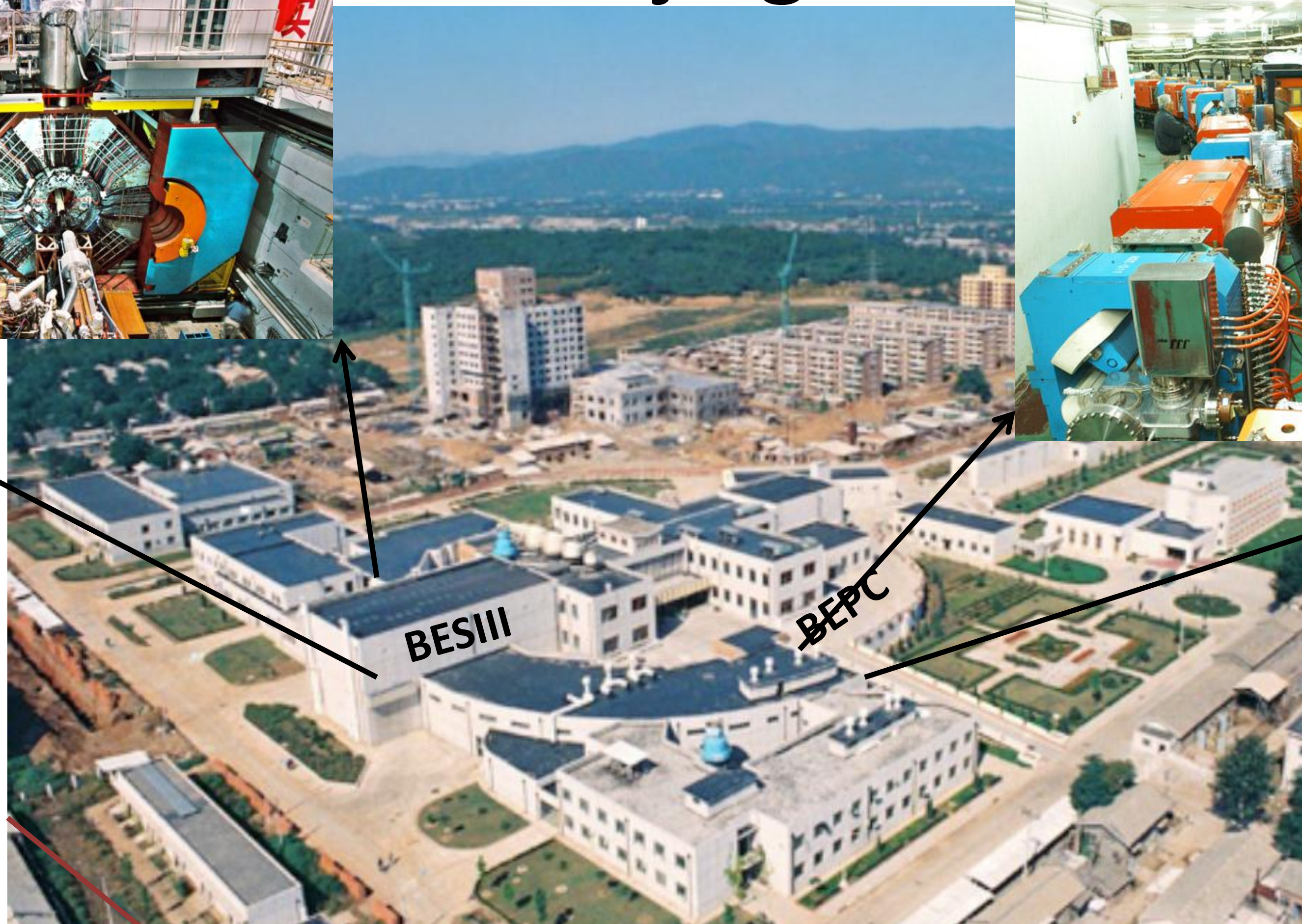
loosely bound meson-antimeson
"molecule"



J.D.Weinstein & N.Isgur PRD 27, 588 (1983)

Institute of High Energy Physics
-- Beijing --



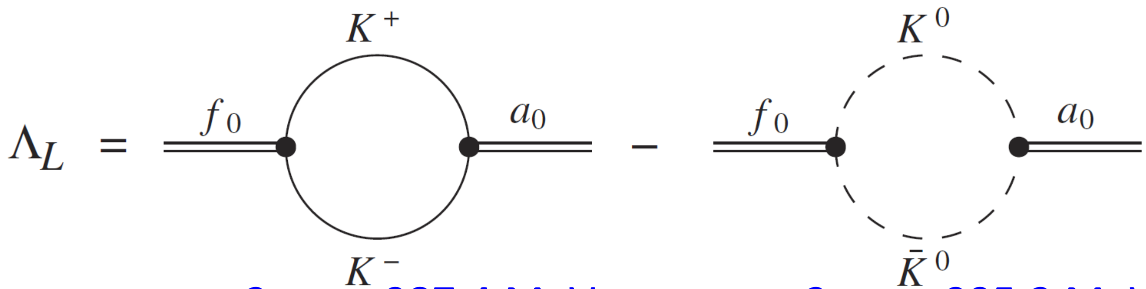


To Tiananmen Square (~10 km)

$a_0(980)^0 \longleftrightarrow f_0(980)$ mixing

N.N. Achasov, S.A. Devanin & G.N. Shestakov, Phys. Lett. B88, 367 (1979)

isospin violation enhanced by $K^0 - K^+$ mass difference

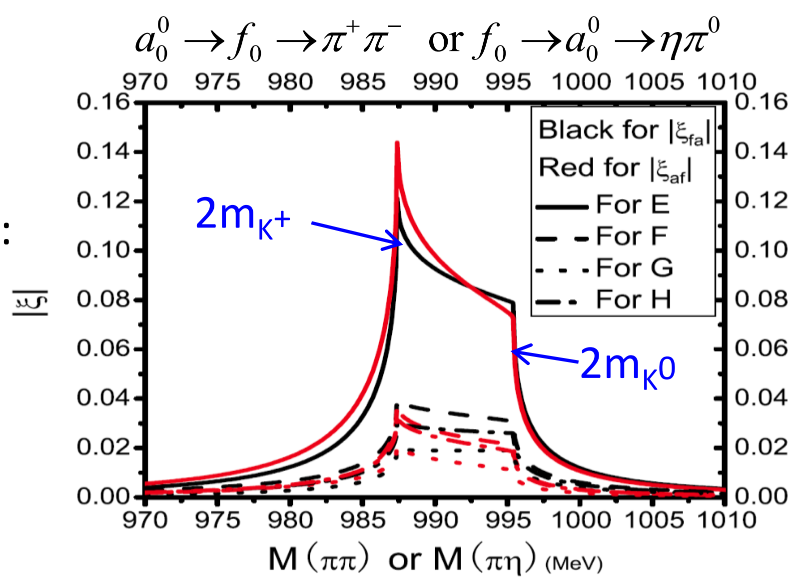


$2m_{K^+} = 987.4$ MeV

$2m_{K^0} = 995.2$ MeV

expect a narrow line shape:

$\Gamma \approx 2(m_{K^0} - m_{K^+}) = 7.8$ MeV



PDG2010:

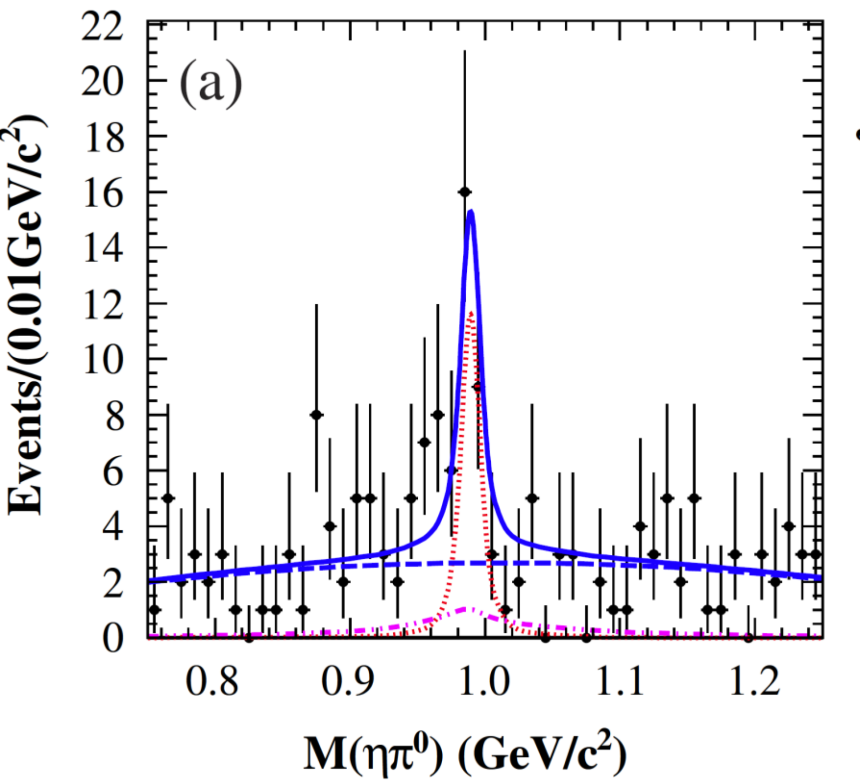
M_{f_0} = 980 ± 10 MeV
Γ_{f_0} = 40 ~ 100 MeV

M_{a_0} = 980 ± 20 MeV
Γ_{a_0} = 50 ~ 100 MeV

C. Hanhart, B. Kubis, and J.R. Pelaez, Phys. Rev. D **76**, 074028 (2007)
J.J. Wu and B.S. Zou, Phys. Rev. D **78**, 074017 (2007)

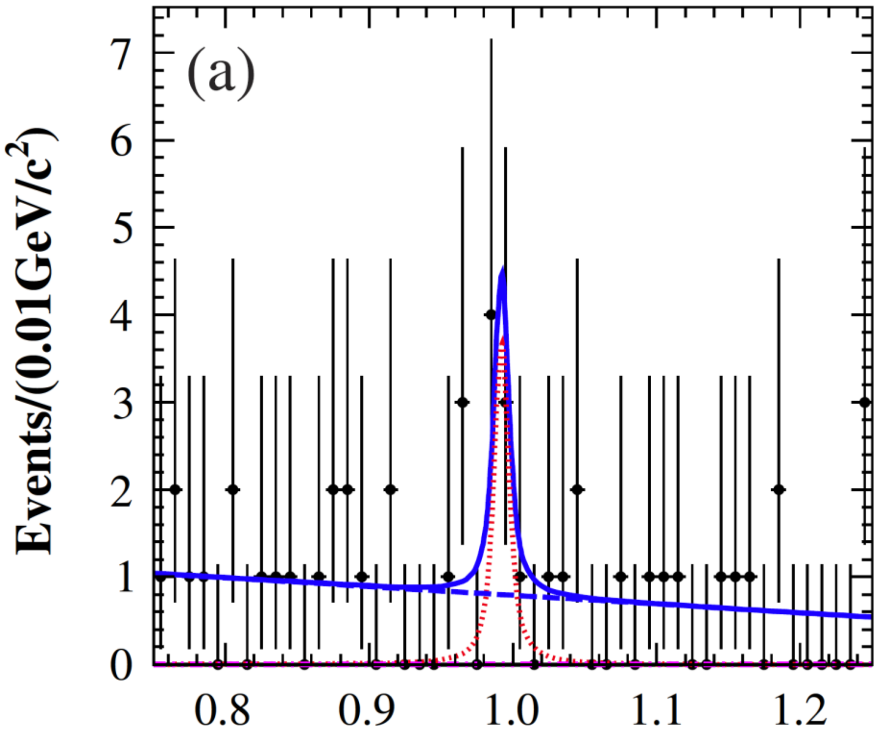
BES study of $a_0(980)^0 \longleftrightarrow f_0(980)$ mixing

$J/\psi \rightarrow \phi f_0 \rightarrow \phi a_0 \rightarrow K^+ K^- \eta \pi^0$



$\xi_{fa} = (0.60 \pm 0.20(\text{stat})) \pm 0.12(\text{sys}) \pm 0.26(\text{para})\%$

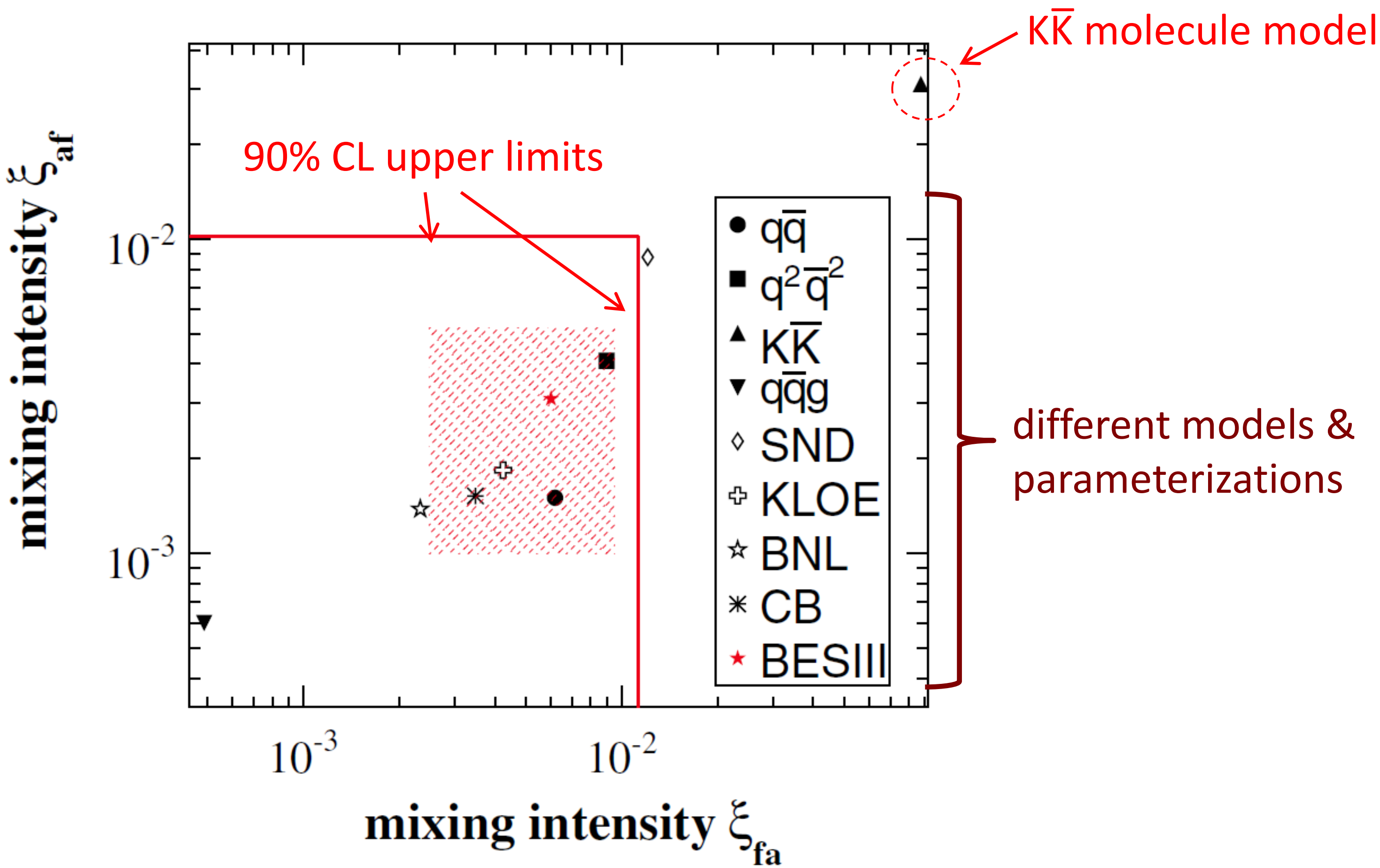
$\psi' \rightarrow \gamma \chi_{c1} \rightarrow \gamma \pi^0 a_0 \rightarrow \gamma \pi^0 f_0 \rightarrow \gamma \pi^o \pi^+ \pi^-$



$\xi_{af} = (0.31 \pm 0.16(\text{stat}) \pm 0.14(\text{sys}) \pm 0.03(\text{para}))\%$

BESIII PRD 83, 032003 (2011)

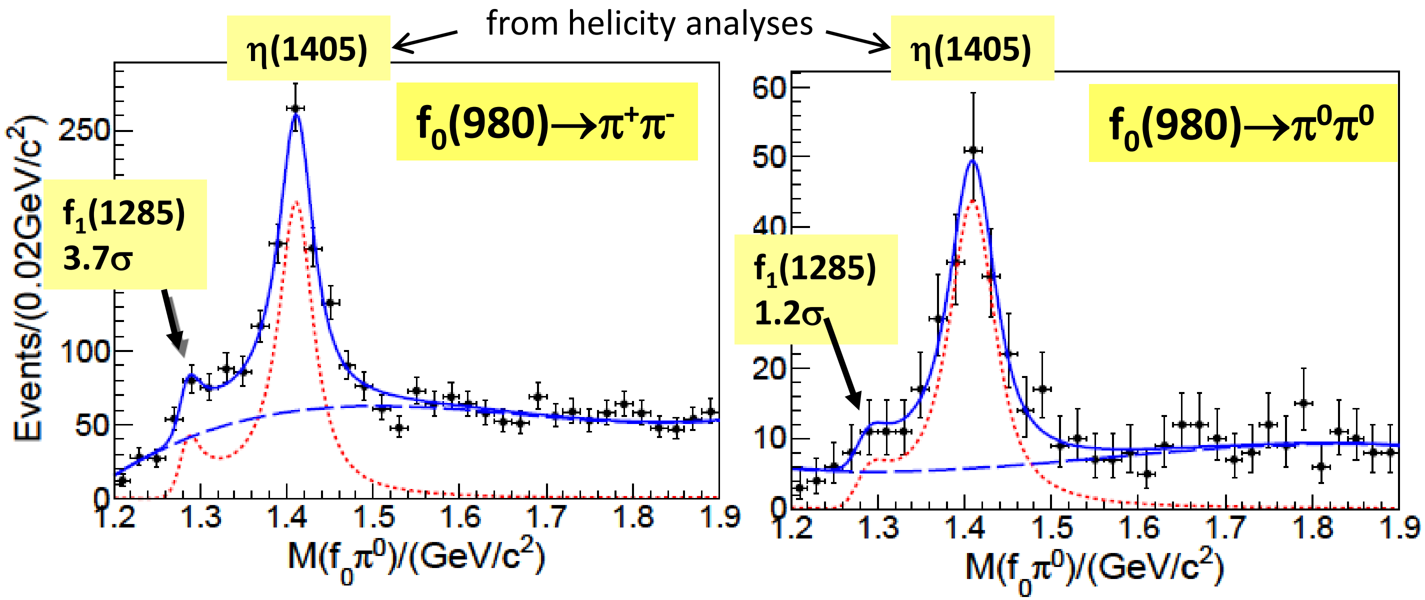
$a_0(980)^0 \longleftrightarrow f_0(980)$ mixing results



Statistics limited, but we should have lots more data soon

$J/\psi \to \gamma f_0(980)\pi^0, f_0(980) \to \pi\pi$

BESIII arXiv:1201:2737 (→PRL) ← last week!



1st observations: **$\eta(1405) \to f_0(980)\pi^0$**
& $J/\psi \to \gamma f_0(980)\pi^0$

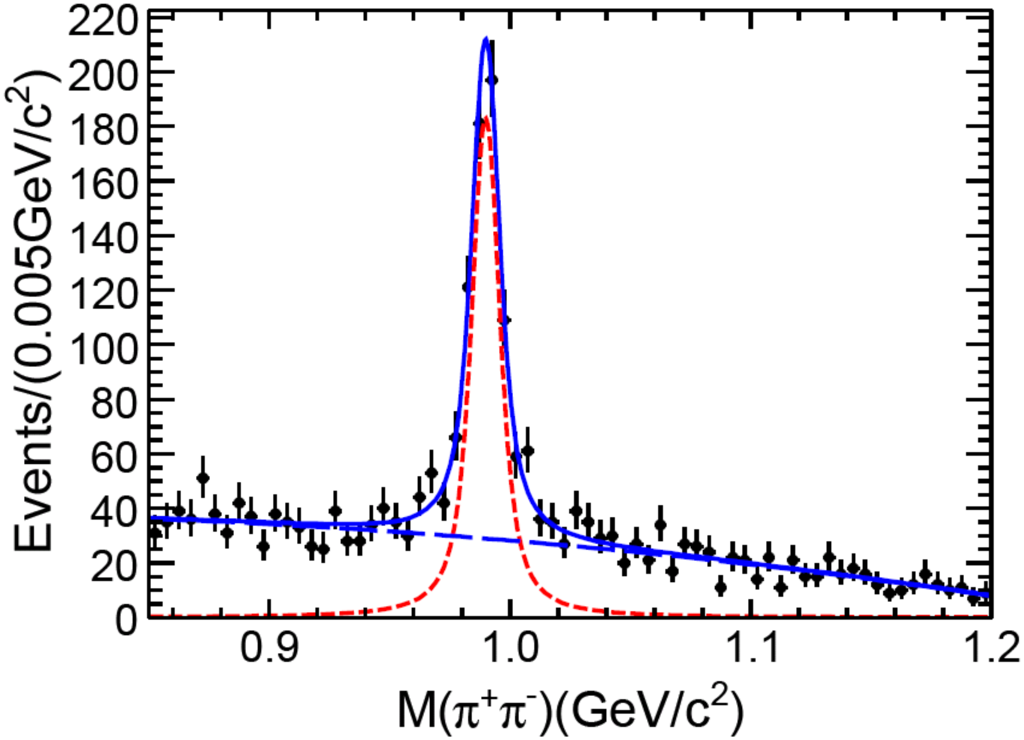
$$Bf(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-)$$
$$= (1.50 \pm 0.11(stat.) \pm 0.11(syst.)) \times 10^{-5}$$
$$Bf(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^0\pi^0)$$
$$= (7.10 \pm 0.82(stat.) \pm 0.72(syst.)) \times 10^{-6}$$

Large Isospin violation:

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} = 17.9 \pm 4.2\%$$

Anomalous $f_0(980)$ lineshape in $\eta(1405) \rightarrow f_0(980)\pi^0$

BESIII arXiv:1201:2737



Fitted mass:

$M_{\text{"}f_0\text{"}}$ = 989.9 $\pm$ 0.4 MeV

$\Gamma_{\text{"}f_0\text{"}}$ = 9.5 $\pm$ 1.1 MeV

The peak is midway between $2m_{K^0}$ & $2m_{K^+}$ & width ≈ $2(m_{K^0} - m_{K^+})$

PDG2010:

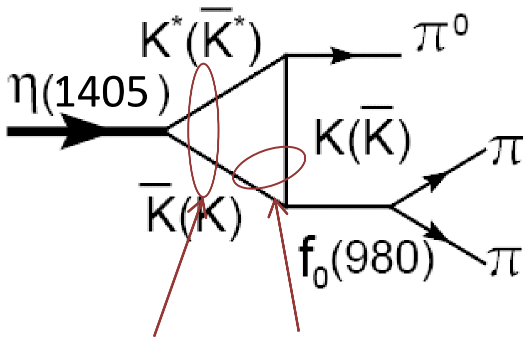
M_{f_0}= 980 $\pm$ 10 MeV

Γ_{f_0}=40 ~ 100 MeV

Effect of Triangle Singularity?

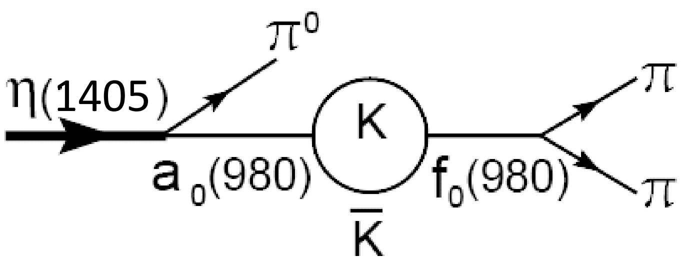
J.J.Wu et al, arXiv:1108.3772

Triangle Singularity (TS)



$K^*\bar{K}$ and $K\bar{K}$ are on shell enhancing TS contribution and isospin violation

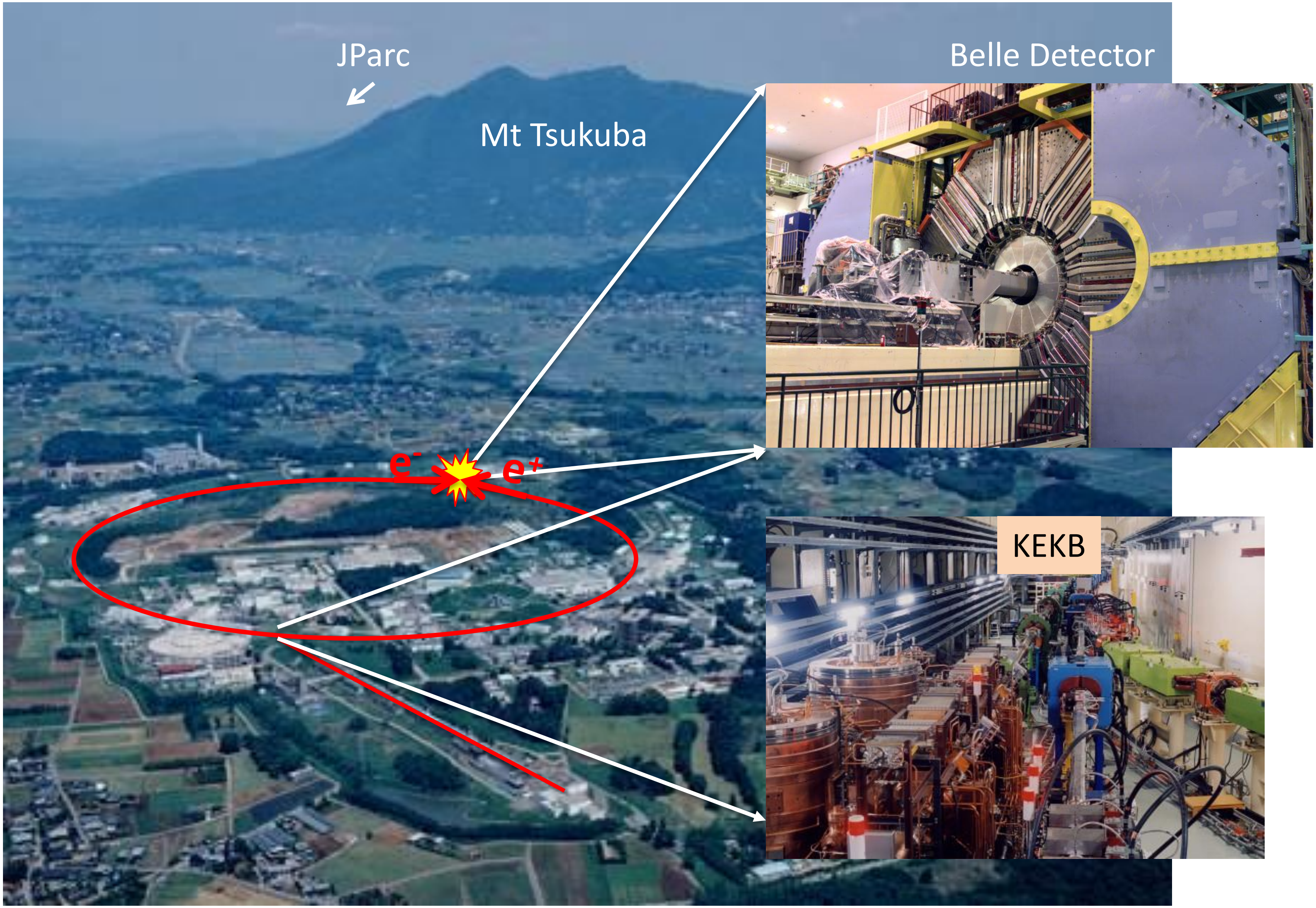
a_0—f_0 mixing



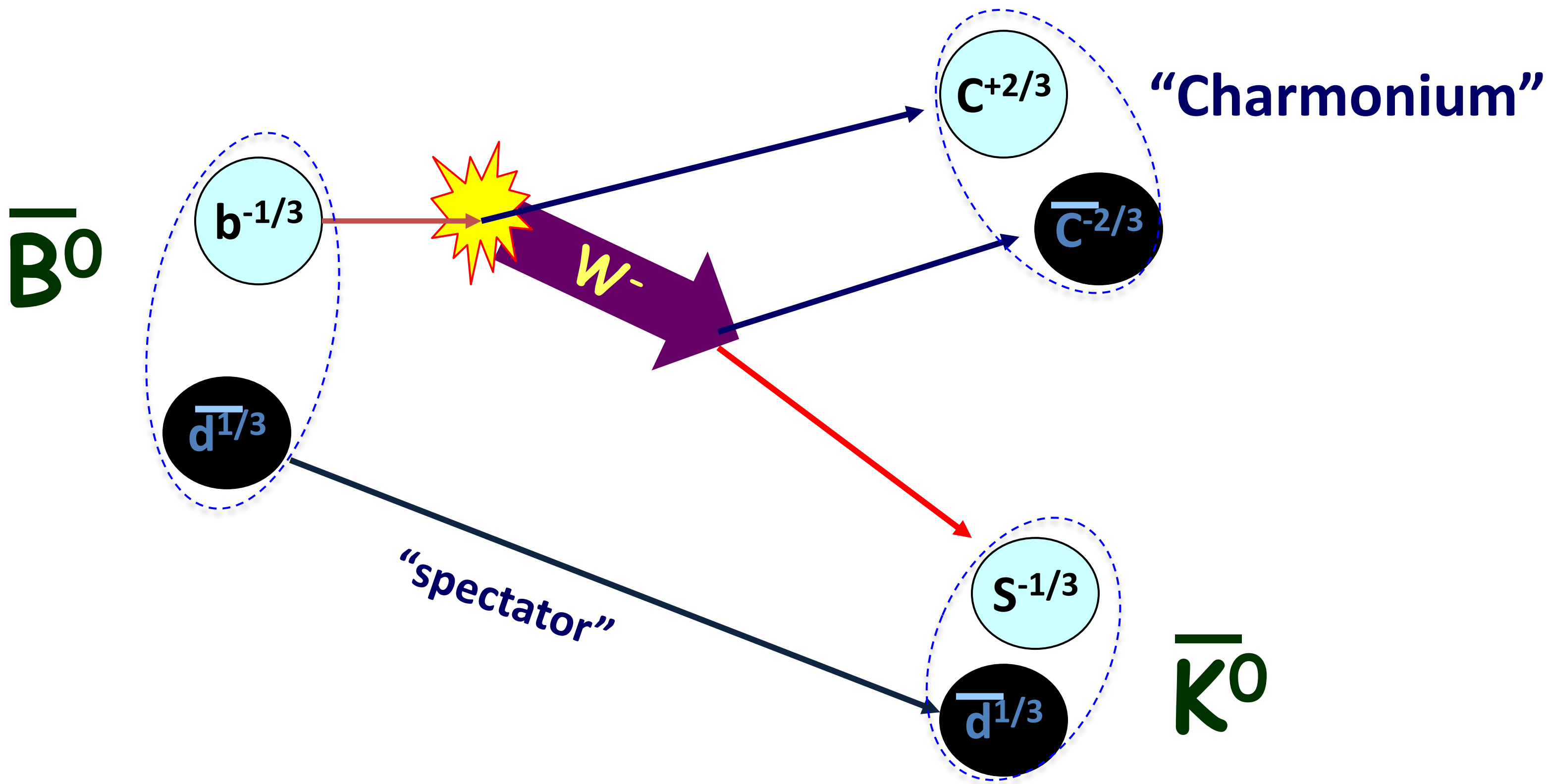
a_0—f_0 mixing is too small to explain anomaly by itself

The X(3872) & the $D\bar{D}^*$ open charm threshold

KEK Laboratory, Tsukuba Japan



c$\bar{c}$ meson production in B decays



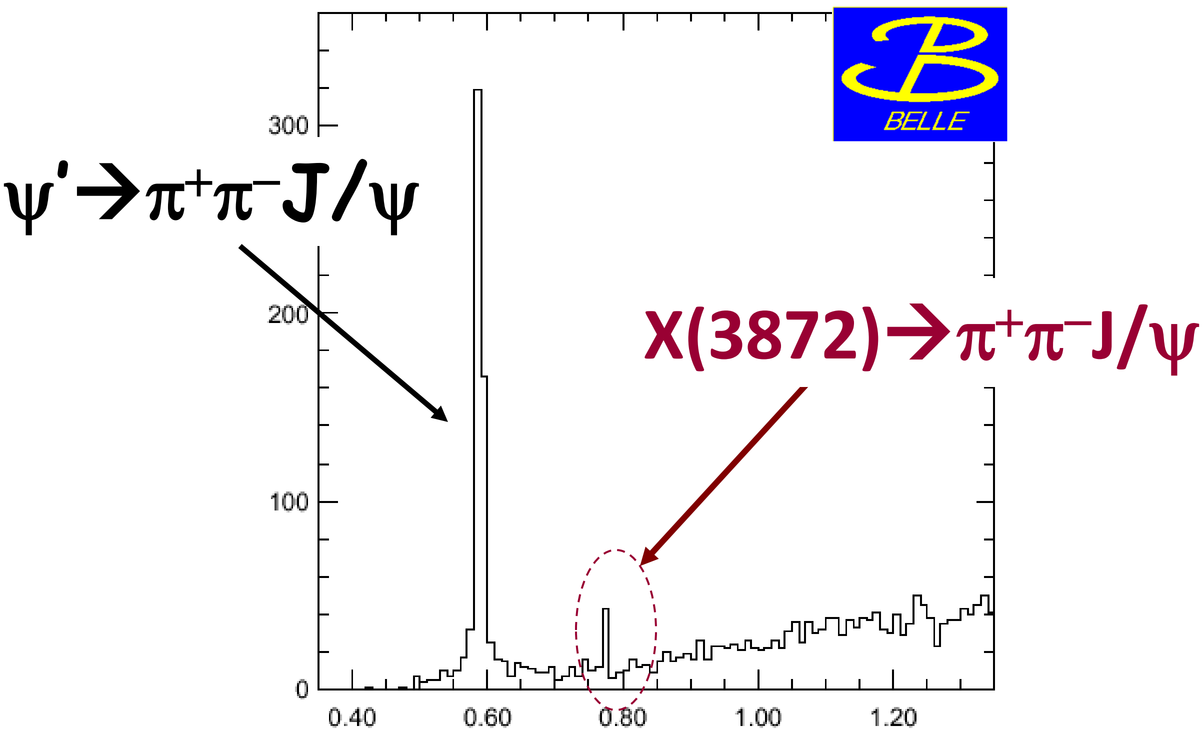
Belle's main purpose: Measure CP violations with B mesons that decay like this.

➔ Nobel prize for Kobayashi &Maskawa in 2008

The X(3872) in $B \rightarrow K \pi^+\pi^- J/\psi$

discovered by Belle (140/fb)

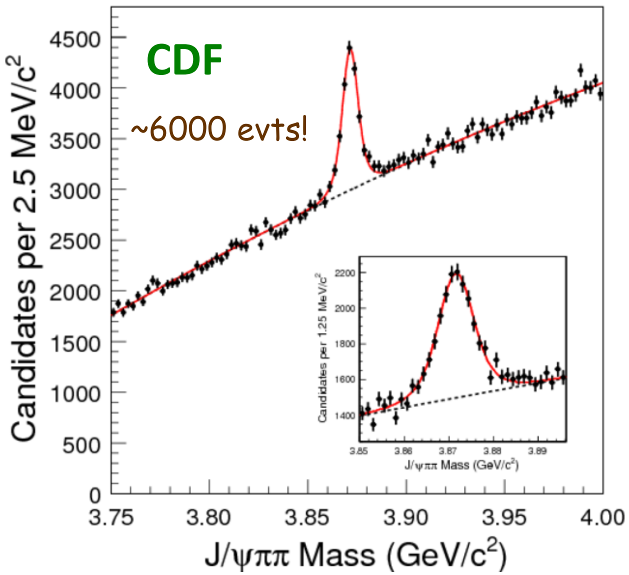
PRL 91, 262001 (2003)



$M(\pi\pi J/\psi) - M(J/\psi)$

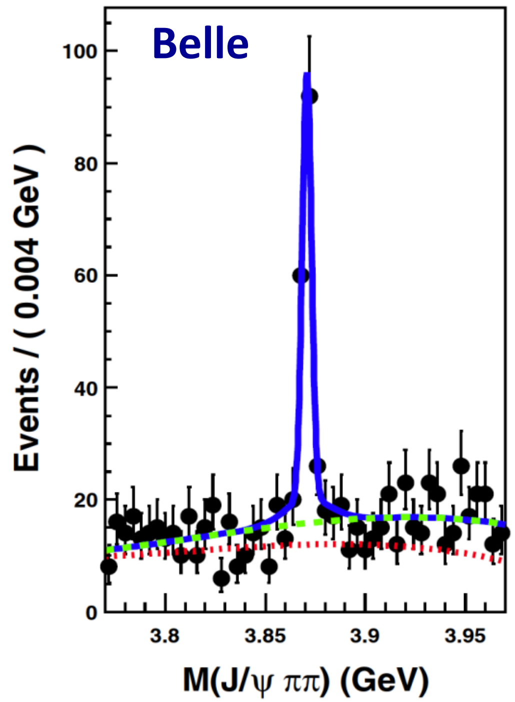
X(3872)→$\pi^+\pi^-$ J/ψ

recent results



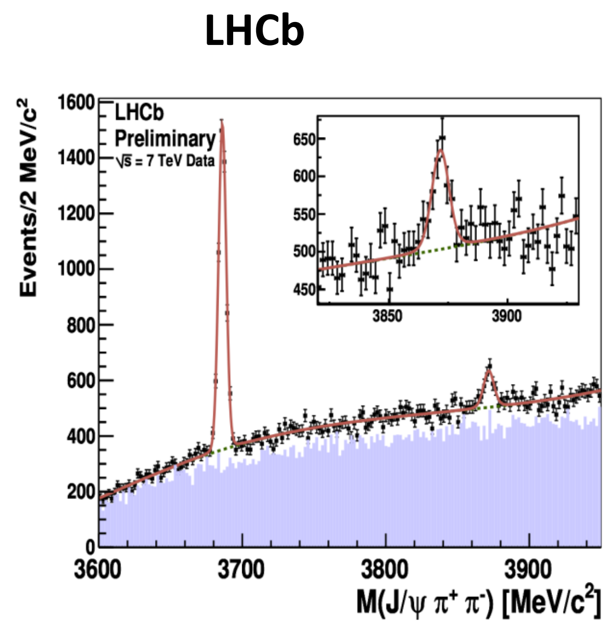
M_X = 3871.61 ± 0.16 ± 0.19 MeV

CDF: PRL 103 152001



M_X = 3871.85 ± 0.27 ± 0.19 MeV

Belle: PRD 84 052004



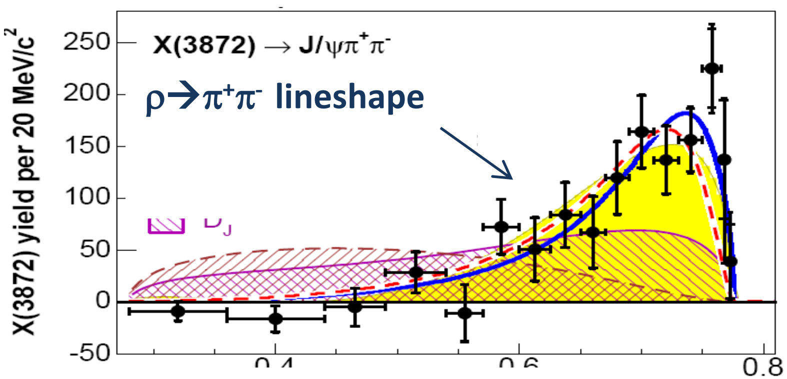
M_X = 3871.96 ± 0.46 ± 0.10 MeV

LHCb: arXiv:1112.5310

What is known about the X(3872)

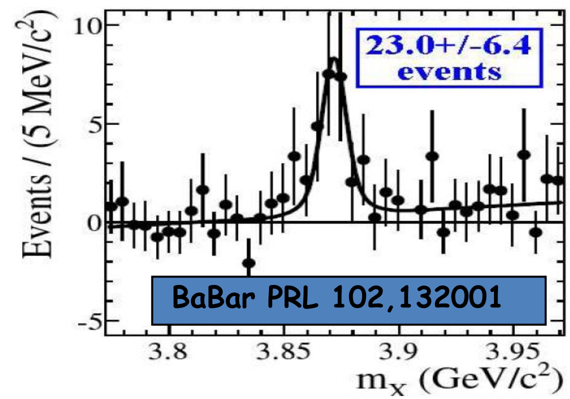
1) It has C=+1: X(3872)→$\rho J/\psi$ and →$\gamma J/\psi$ are well established

X→$\pi^+\pi^- J/\psi$



CDF: PRL 96 102002

X→$\gamma J/\psi'$

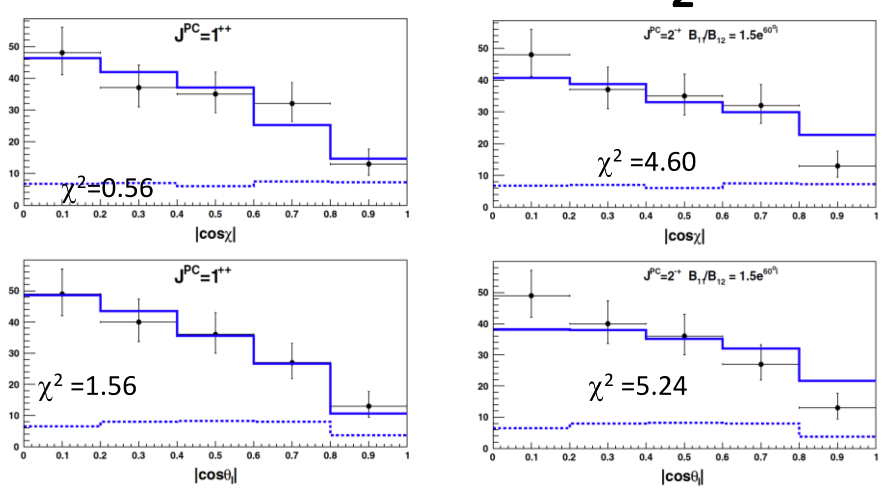


2) $J^{PC} = 1^{++}$ most likely

2^{-+} cannot be ruled out

Belle: PRD 84 052004

1^{++} 2^{-+}

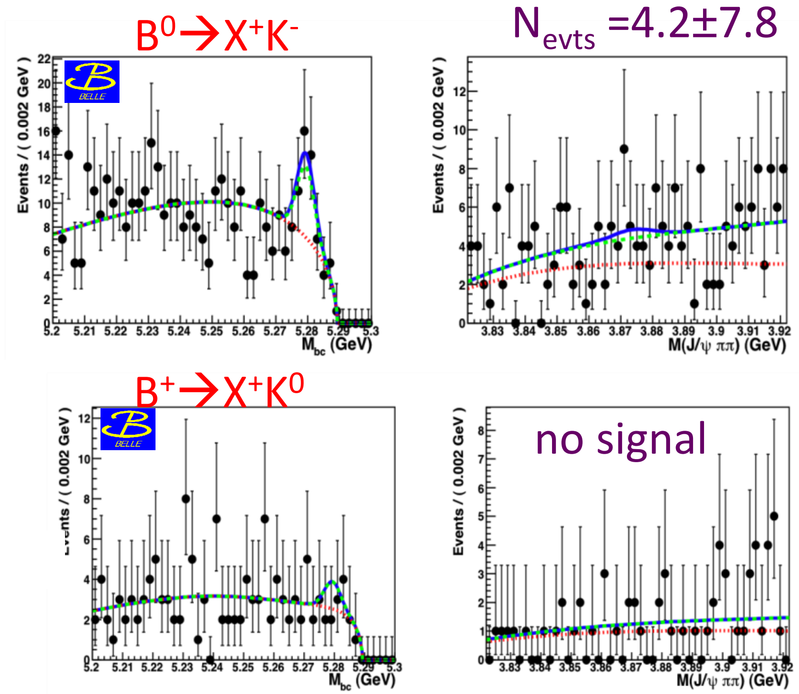


2^{-+} has higher χ^2 and fewer dof than 1^{++}

What is known, continued

3) Isospin = 0, probably…

No (narrow) charged partners are seen; limits are well below Ispin=1 expections

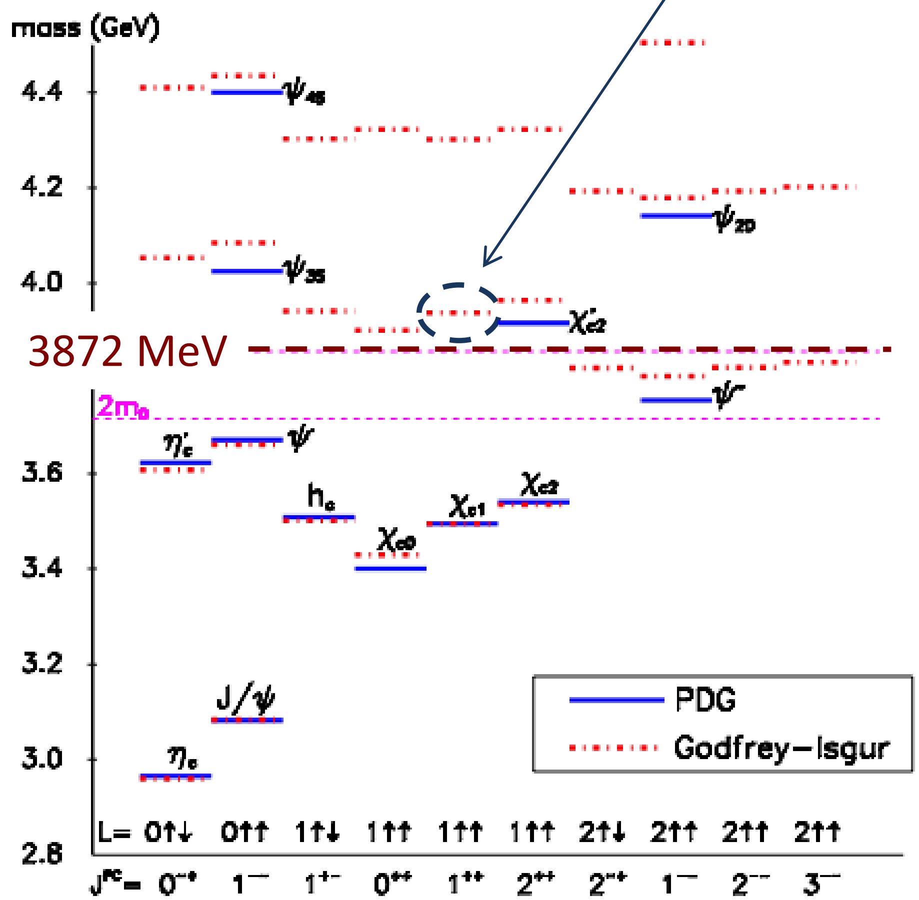


Belle: PRD 84 052004

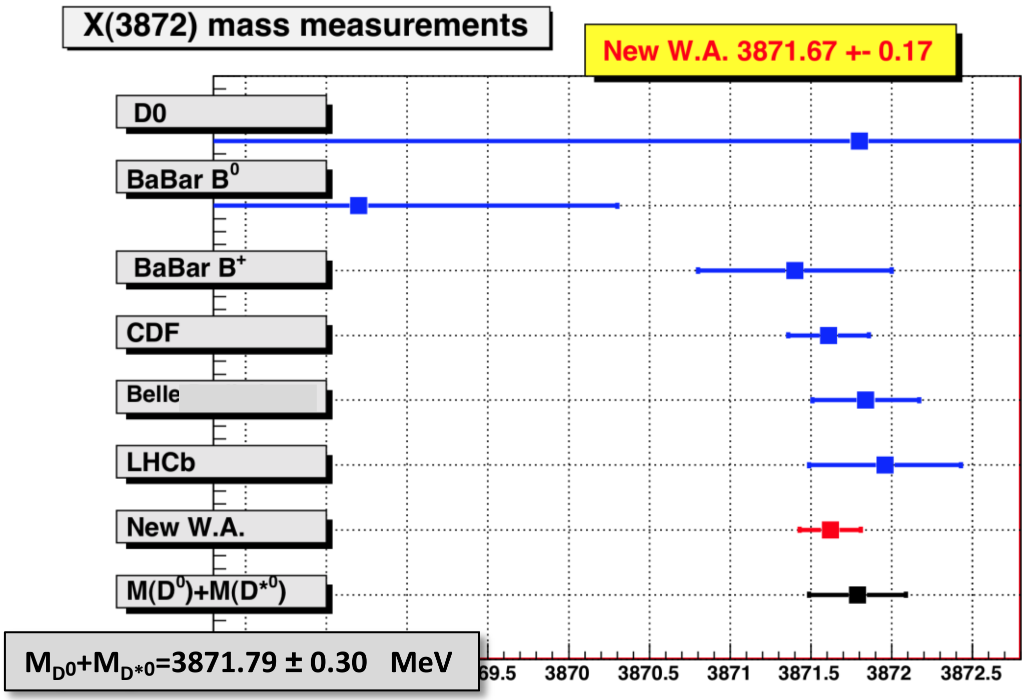
4) $X \rightarrow \pi^+\pi^- J/\psi$ (discovery mode), violates I-spin

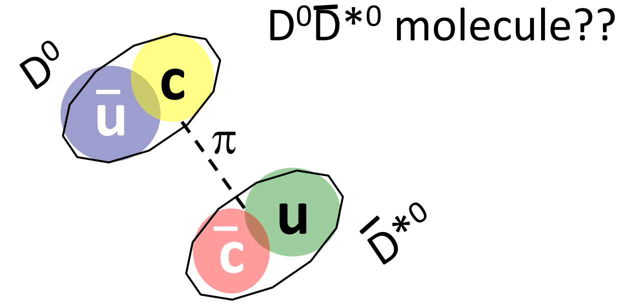
1^{++} $c\bar{c}$ assignment?

- Mass is too low?
  - 3872 *vs* 3905 MeV
  - n_r=2 splitting> n_r=1
- Scaling the Bf($\pi^+\pi^- J/\psi$) by $c\bar{c}$ theoretical value for $\Gamma(\gamma J/\psi)$ gives: $\Gamma(\pi^+\pi^- J/\psi) \approx$ 45 keV, ~100x larger than other $c\bar{c}$ Ispin violating widths.



X(3872) mass (in $\pi^+\pi^- J/\psi$ channel only)

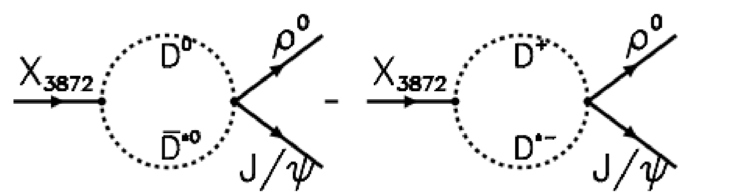




$M_{X(3872)} - (M_{D^0} + M_{\bar{D}^{*0}}) = -0.12 \pm 0.35$ MeV

$M_{X(3872)} - (M_{D^+} + M_{D^{*-}}) = -7.74 \pm 0.35$ MeV

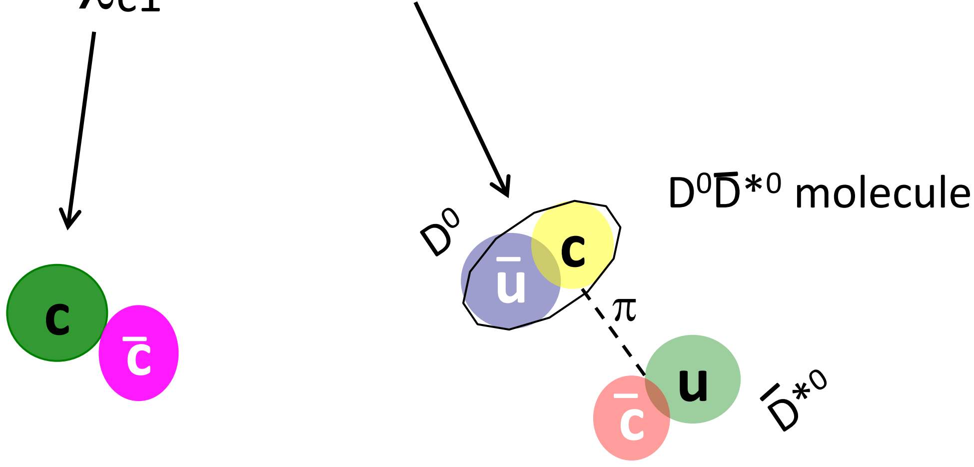
Isospin Violation in X(3872) decay:



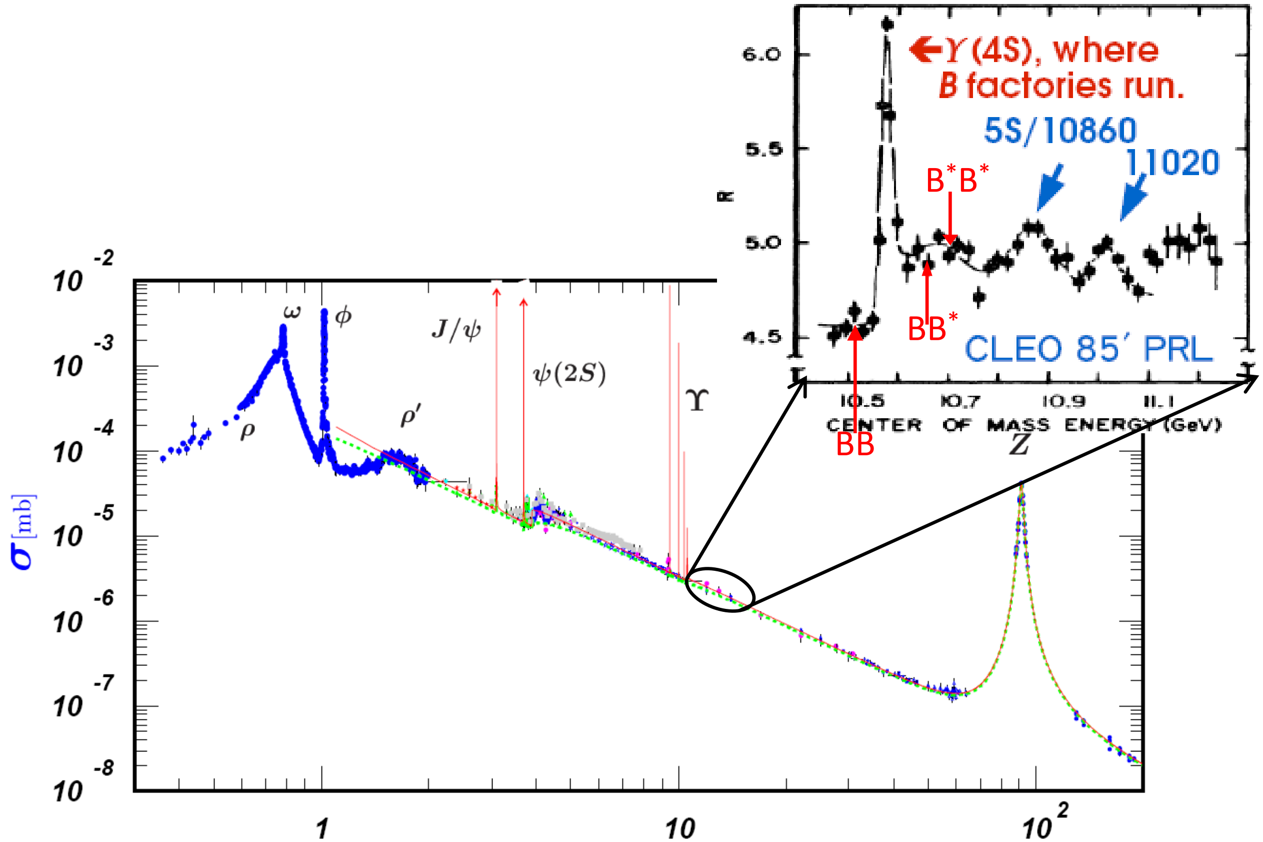
≈on mass shell ≈8 MeV off mass shell

Consensus (?)

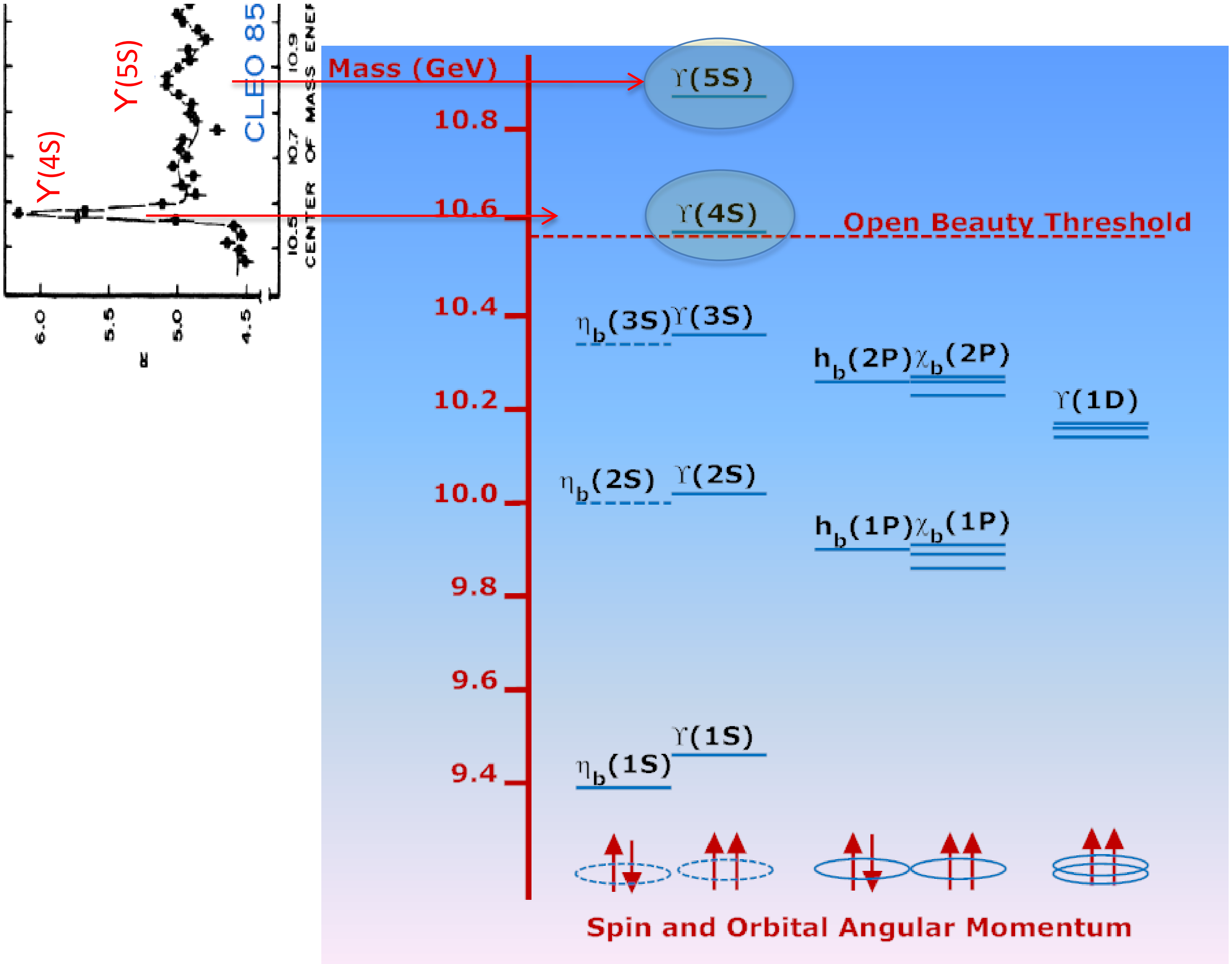
X(3872) is some kind of a mixture of the χ'_{c1} and a $D^0\bar{D}^{*0}$ Molecule.



B(*)B* threshold states



ϒ(4&5S) "bottomonium" $b\bar{b}$ mesons



$2M_B = 10358.7$ MeV

"ϒ(5S)" is very different from other ϒ states

Anomalous production of ϒ(nS) $\pi^+\pi^-$

Belle PRL100,112001(2008)

	Γ(MeV)
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019

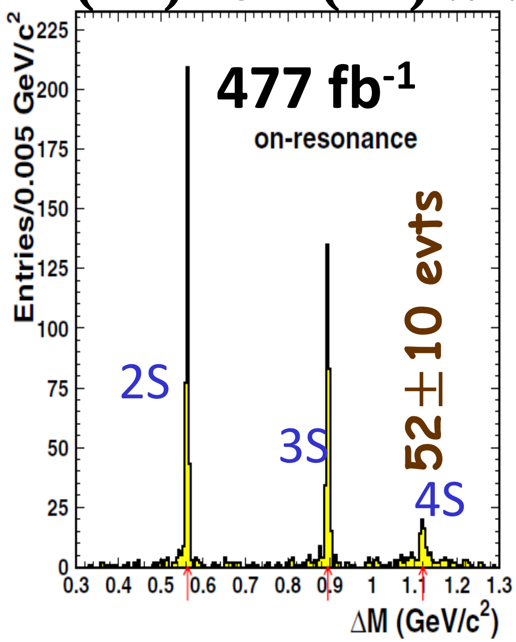
X10--2

$$Bf(\mathrm{Y}(4S) \to \pi^+\pi^-\mathrm{Y}(1S)) = (0.008 \pm 0.0003)\%$$

$$Bf(Y(5S) \to \pi^+\pi^-\mathrm{Y}(1S)) = (0.53 \pm 0.06)\%$$

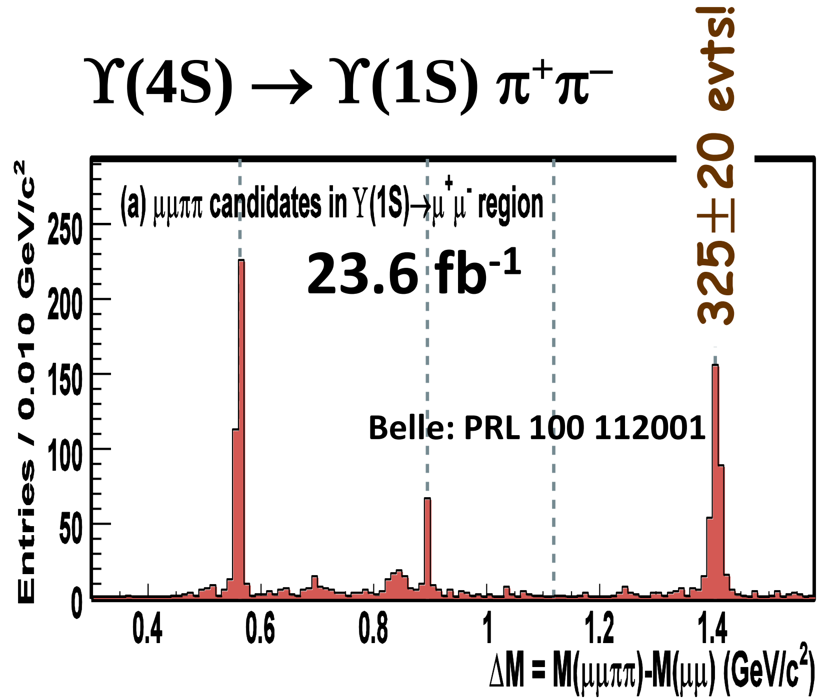
Belle: $\Gamma_{\Upsilon(4,5S) \to \pi^+\pi^- \Upsilon(1S)}$

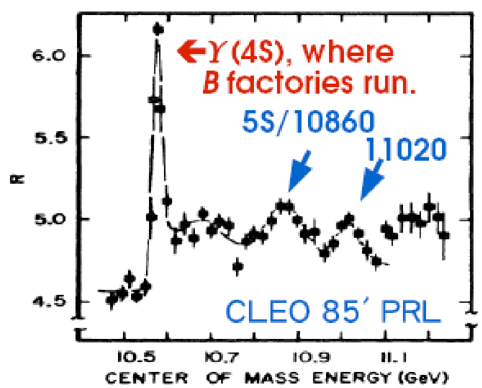
$\Upsilon(4S) \to \Upsilon(1S)\,\pi^+\pi^-$



Belle: PRD 75 071103

$\Upsilon(4S) \to \Upsilon(1S)\,\pi^+\pi^-$

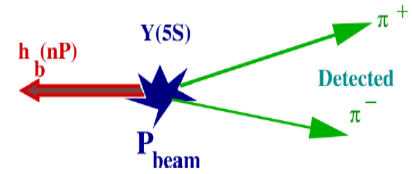


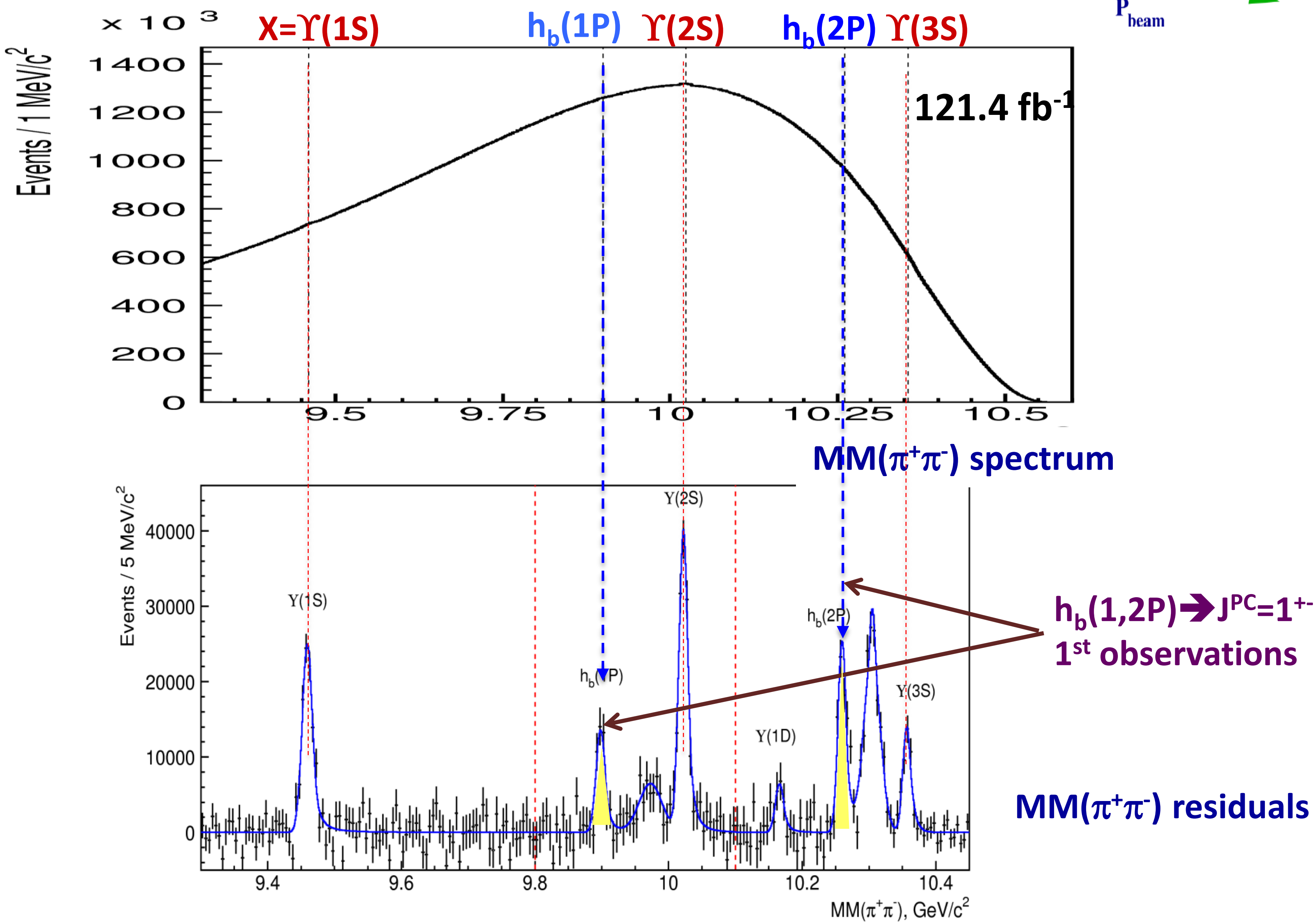


~1/20th the data

~1/5th the cross-section

Look at $\pi^+\pi^-$ ***recoil mass*** in $\Upsilon(5S) \rightarrow \pi^+\pi^- + X$





Belle: PRL 108 032001

$h_b(1,2P)$

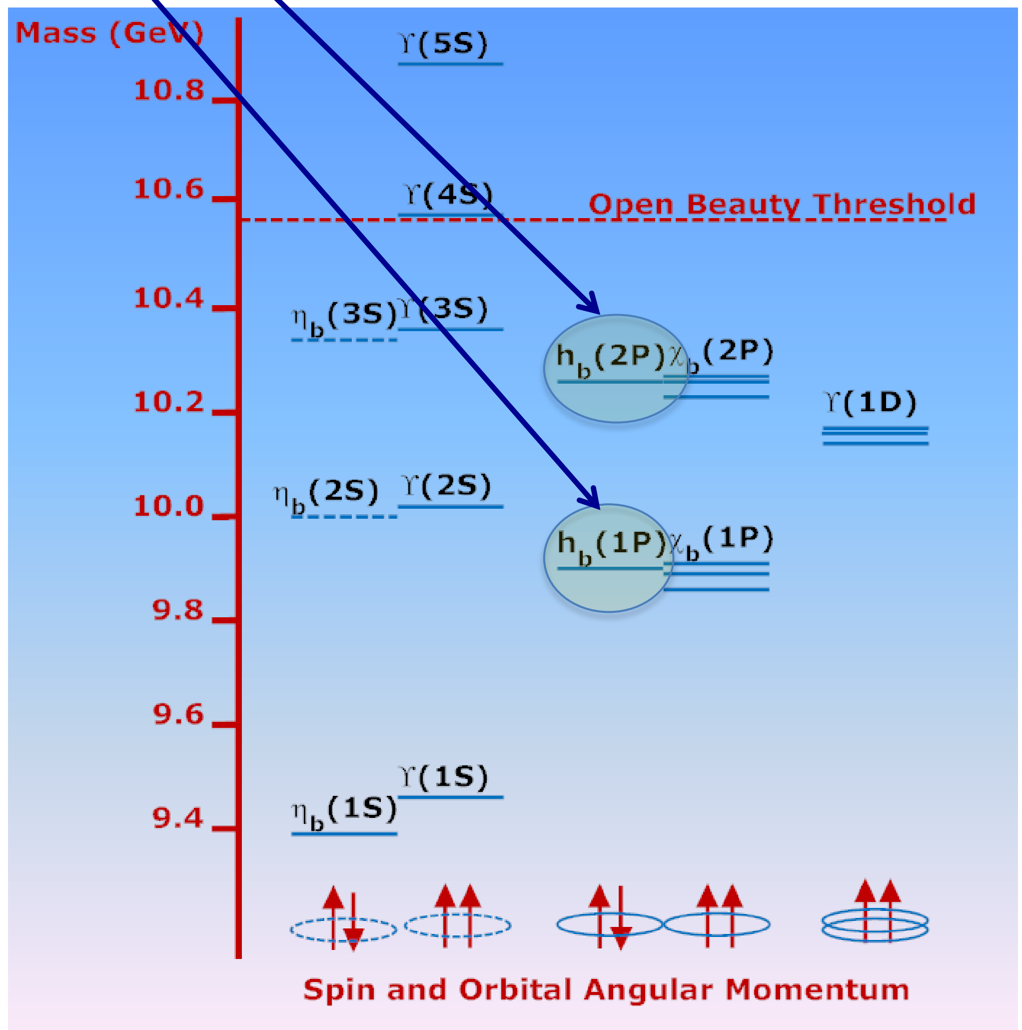
$(b\bar{b})$: S=0 L=1 $J^{PC}=1^{+-}$

Expected mass

$\approx (M\chi_{b0} + 3\,M\chi_{b1} + 5\,M\chi_{b2})\,/\,9$

$\Delta M_{HF} \Rightarrow$ test of hyperfine interaction

Belle PRL 108, 122001 ← January

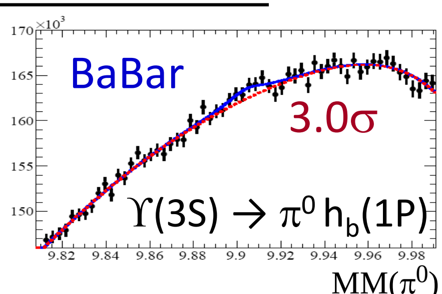


Deviations from CoG of χ_{bJ} masses

$h_b(1P)$	(1.6 ± 1.5) MeV/c^2
$h_b(2P)$	$(0.5\,^{+1.6}_{-1.2})$ MeV/c^2

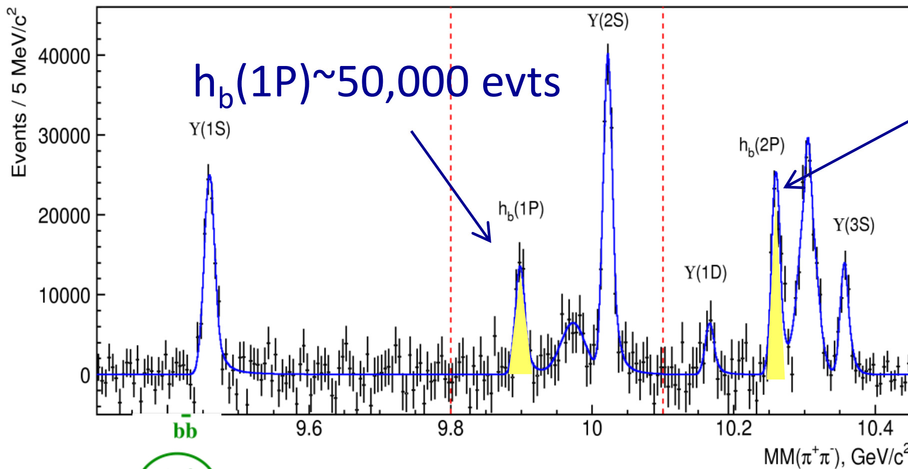
Agrees with expectations

Previous search



arXiv:1102.4565

$\Gamma[\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-]$ is large



$h_b(1P)$~50,000 evts

$h_b(2P)$~85,000 evts

spin-flip

$$\frac{\Gamma[\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-]}{\Gamma[\Upsilon(5S) \to \Upsilon(2S)\,\pi^+\pi^-]} = \begin{cases} 0.46 \pm 0.08^{+0.07}_{-0.12} & \text{for } h_b(1P) \\ 0.77 \pm 0.08^{+0.22}_{-0.17} & \text{for } h_b(2P) \end{cases}$$

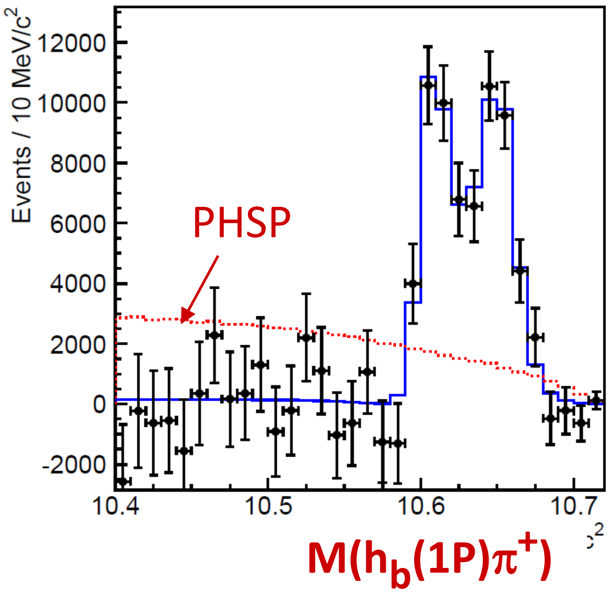
no spin-flip

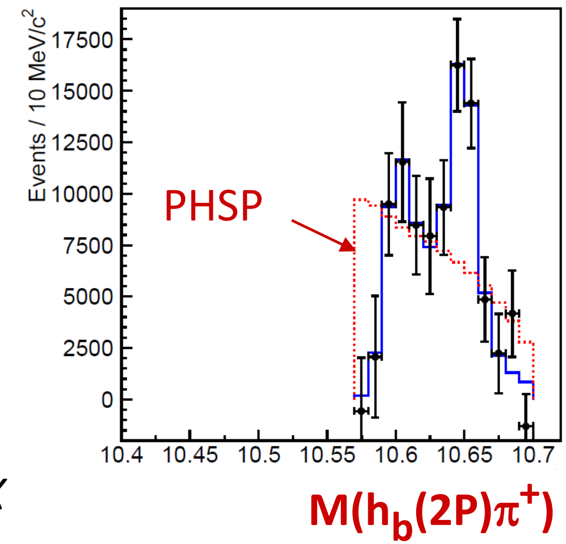
Process with spin-flip of heavy quark is not suppressed

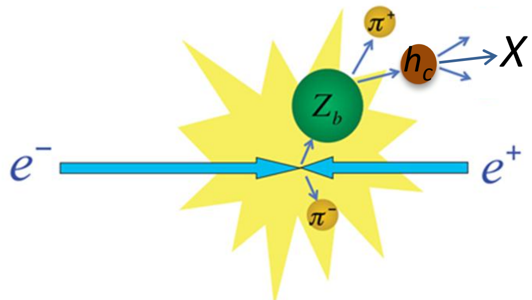
⇒ **Mechanism of $\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-$ decay is exotic**

Resonant structure of "$\Upsilon(5S)$" $\rightarrow h_b(nP)\pi^+\pi^-$

⇒measure $\Upsilon(5S)\rightarrow h_b\pi\pi$ yield in bins of $MM(\pi)$







$M_1 = 10605.1 \pm 2.2\,^{+3.0}_{-1.0}$ MeV/c²

$\Gamma_1 = 11.4\,^{+4.5}_{-3.9}\,^{+2.1}_{-1.2}$ MeV

~$B\bar{B}^*$ threshold

$10596 \pm 7\,^{+5}_{-2}$ MeV/c²

$16\,^{+16}_{-10}\,^{+13}_{-4}$ MeV

$M_2 = 10654.5 \pm 2.5\,^{+1.0}_{-1.9}$ MeV/c²

$\Gamma_2 = 20.9\,^{+5.4}_{-4.7}\,^{+2.1}_{-5.7}$ MeV

non-res.~0

~$B^*\bar{B}^*$ threshold

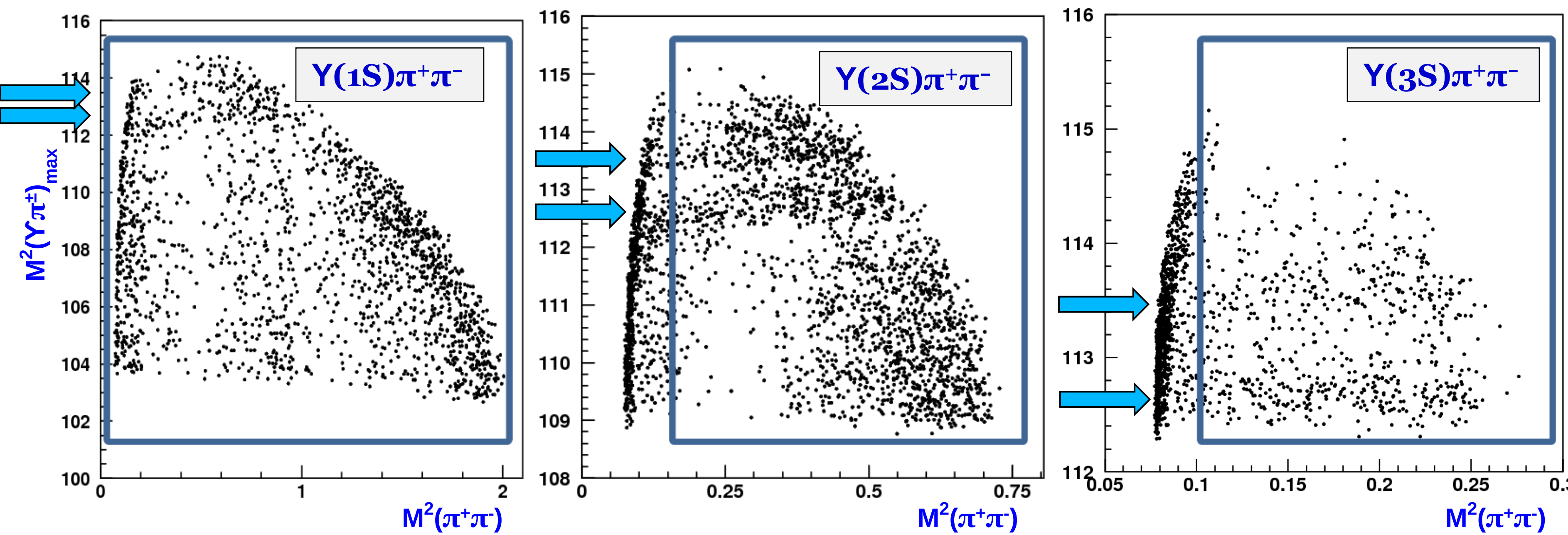
$10651 \pm 4 \pm 2$ MeV/c²

$12\,^{+11}_{-9}\,^{+8}_{-2}$ MeV

Look at "Υ(5S)"→Υ(nS) $\pi^+\pi^-$

Dalitz distributions for events in Υ(nS) signal regions.

9.43 GeV < $MM(\pi^+\pi^-)$ < 9.48 GeV   10.05 GeV < $MM(\pi^+\pi^-)$ < 10.10 GeV   10.33 GeV < $MM(\pi^+\pi^-)$ < 10.38 GeV

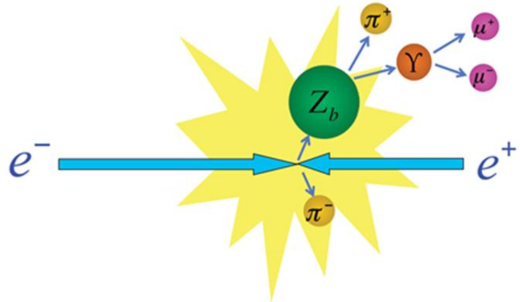


To exclude contamination from gamma conversions we require:

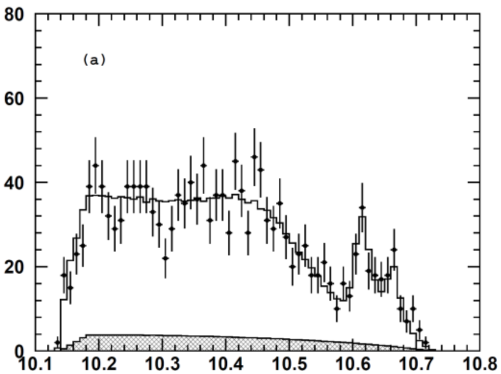
$M^2(\pi^+\pi^-) > 0.20\ GeV^2$ $M^2(\pi^+\pi^-) > 0.16\ GeV^2$ $M^2(\pi^+\pi^-) > 0.10\ GeV^2$

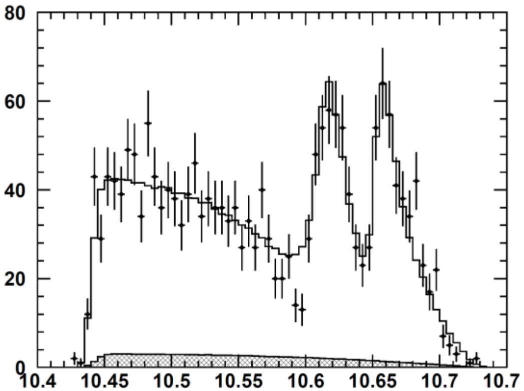
Belle PRL 108, 122001

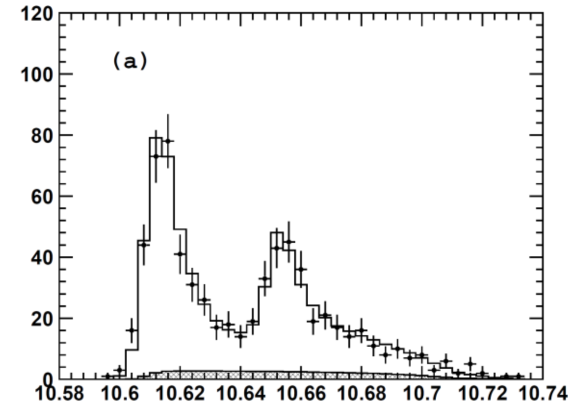
Fit results:



$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$

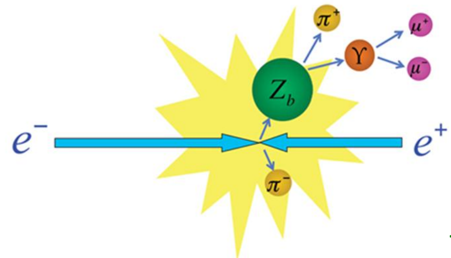


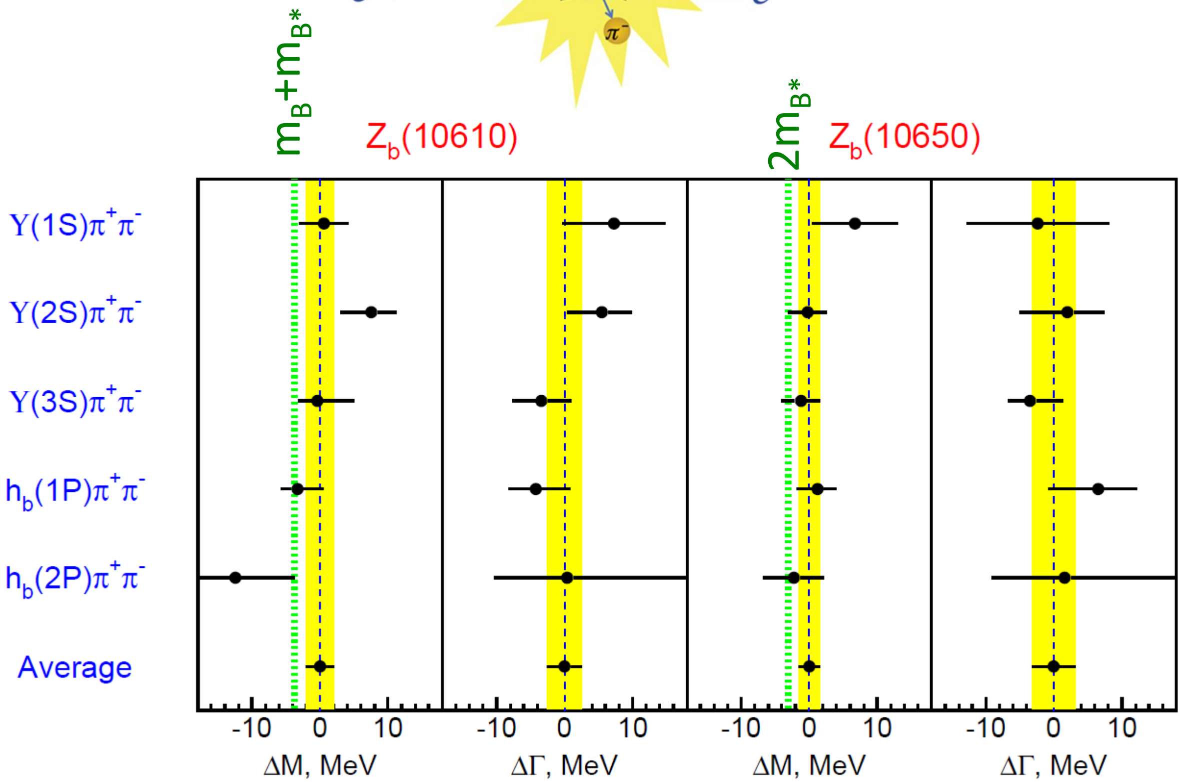




	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
Z_{b1}	M=10611±4±3 MeV Γ=22.3±7.7±4.0 MeV	M=10609±2±3 MeV Γ=24.2±3.1±3.0 MeV	M=10608±2±3 MeV Γ=17.6±3.0±3.0 MeV
Z_{b2}	M=10657±6±3 MeV Γ=16.3±9.8±6.0 MeV	M=10651±2±3 MeV Γ=13.3±3.3±4.0 MeV	M=10652±1±2 MeV Γ=8.4±2.0±2.0 MeV

Summary of parameter measurements





$Z_b(10610)$

M=10607.2±2.0 MeV

Γ=18.4±2.4 MeV

$Z_b(10650)$

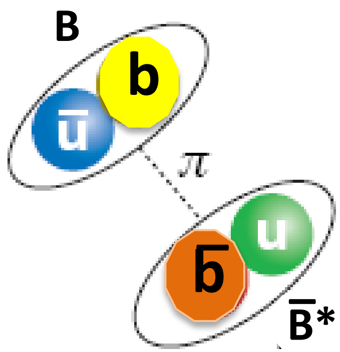
M=10652.2±1.5 MeV

Γ=11.5±2.2 MeV

Belle PRL 108, 122001 ← last month

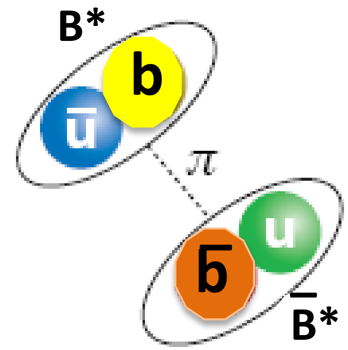
B-$\bar{B}$* & B*-$\bar{B}$* molecules??

$Z_b(106010)^{\pm}$



B-$\bar{B}$* "molecule"

$Z_b(106050)^{\pm}$



B*-$\bar{B}$* "molecule"

$M_{Z_b(106010)} - (M_B + M_{B*}) = +\ 3.6 \pm 1.8$ MeV

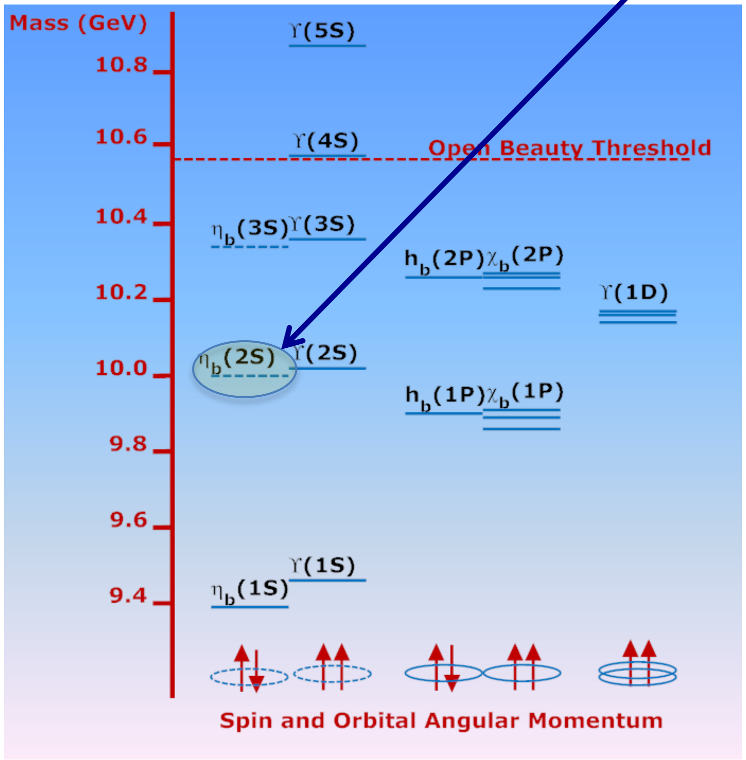
$M_{Z_b(106010)} - 2M_{B*} = +\ 3.1 \pm 1.8$ MeV

Slightly unbound threshold resonances??

Belle:	M=10608.1±1.7 MeV Γ=15.5±2.4 MeV	M=10653.3±1.5 MeV Γ=14.0±2.8 MeV
PDG:	$M_B + M_{B*} = 10604.5 \pm 0.6$ MeV	$M_{B*} + M_{B*} = 10650.2 \pm 1.0$ MeV

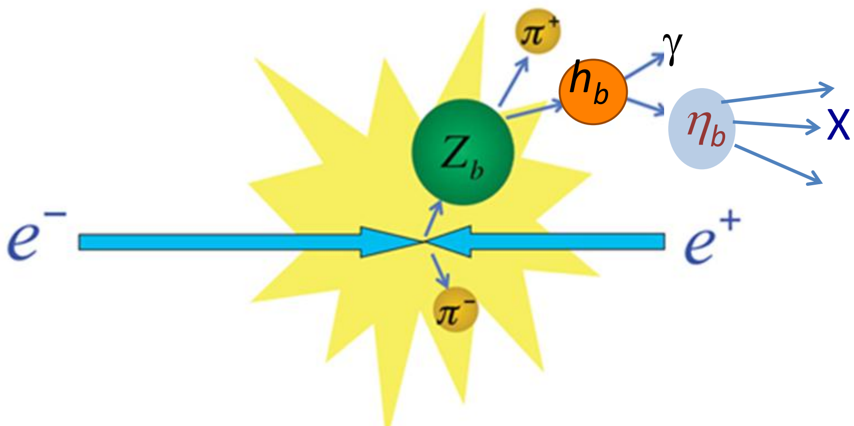
New result for IWHSS'12:

1[st] observation of the $\eta_b(2S)$



1st: $\eta_b(1S)$ signals from $h_b(nP) \rightarrow \eta_b(1S)$

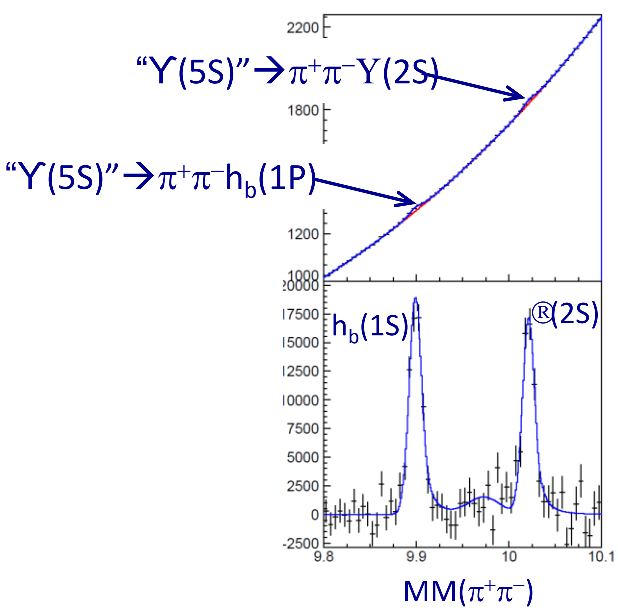
$h_b(1,2P) \rightarrow \gamma\eta_b(1S)$ are expected to be prominent (20%~50%)



Final state: $\pi^+\pi^-\gamma$ X

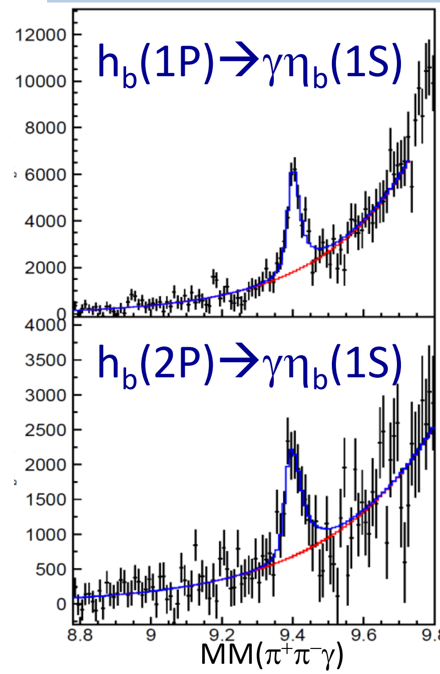
measure h_b yields in bins of $MM(\pi^+\pi^-\gamma)$

(require 10.59<$MM(\pi)$<10.67 GeV, *i.e.* =$M_{Z_{b1,2}}$)



Belle

Bondar, Mizuk (Belle) ArXiv 1110.2251



$\Delta M_{hfs}(1S) = 59.3 \pm 1.9^{+2.4}_{-1.4}$ MeV

$M[\eta_b(1S)] = 9401.0 \pm 1.9^{+1.4}_{-2.4}$ MeV

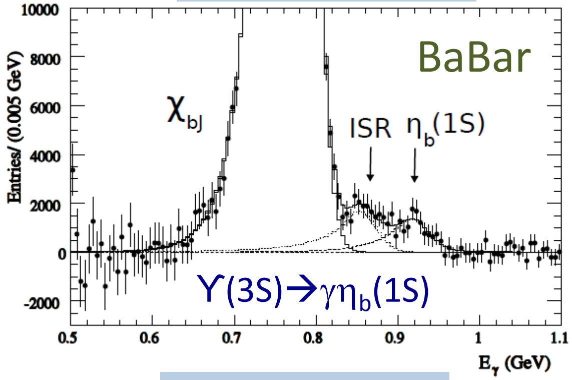
$\Gamma[\eta_b(1S)] = 12.4^{+5.5}_{-4.6}{}^{+11.5}_{-3.4}$ MeV

$Bf[h_b(1P) \rightarrow \gamma\eta_b(1S)] = 50^{+13}_{-9}$ %

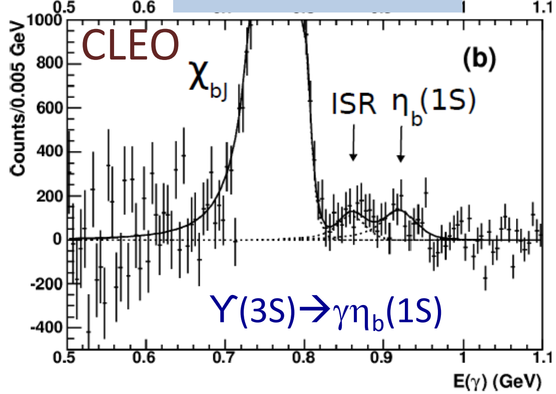
preliminary

Comparisons: $\eta_b(1S)$ results

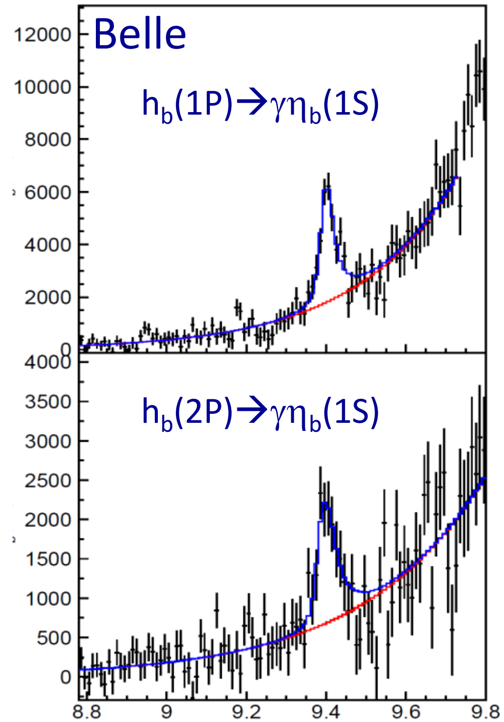
PRL 101, 182003 (2008)



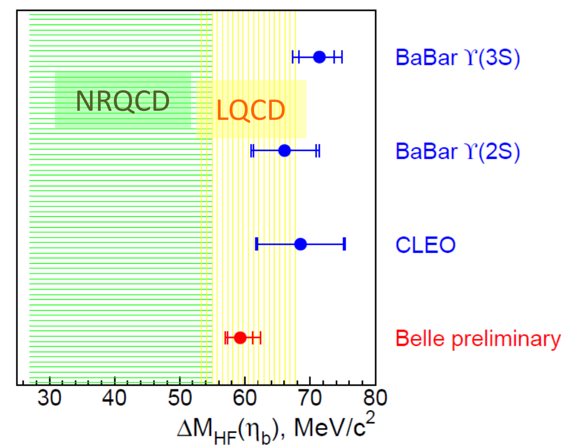
PRD 81, 031104 (2010)



Bondar, Mizuk, et al (Belle)ArXiv 1110.2251



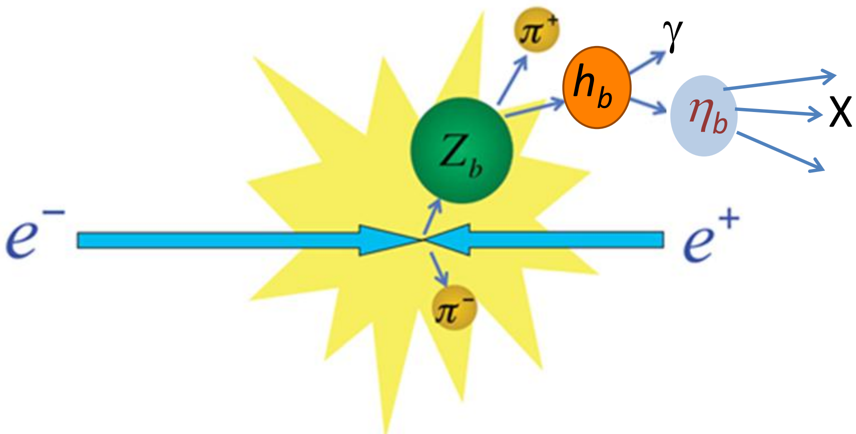
Expt	$\Delta M_{hfs}(1S)$ (MeV)
BaBar	$66.1\,^{+4.9}_{-4.8} \pm 2.0$
CLEO	$68.5 \pm 6.6 \pm 2.0$
Belle	$59.3 \pm 1.9\,^{+2.4}_{-1.4}$



Reasonable agreement among experiments and with theory

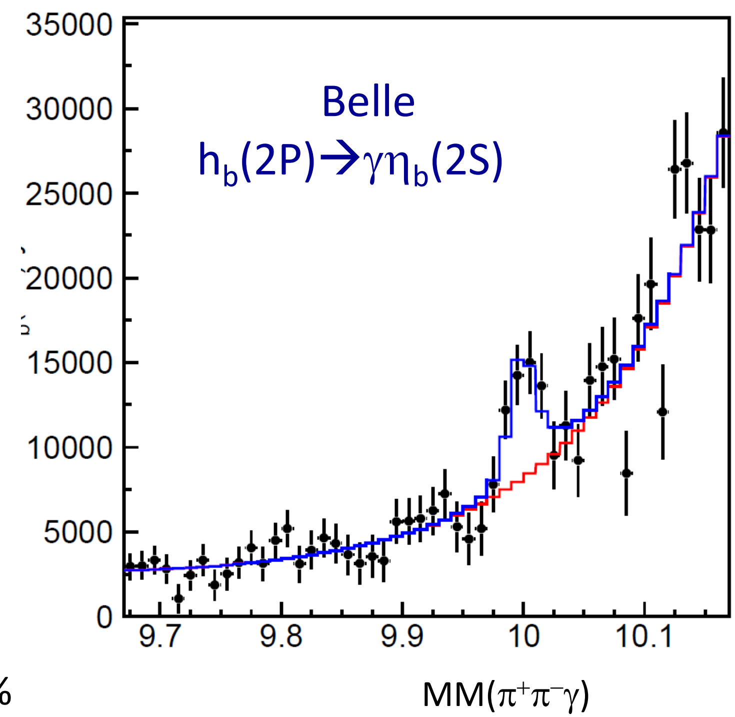
1^{st} observation of the $\eta_b(2S)$

$h_b(2P)\rightarrow\gamma\eta_b(2S)$ is expected to be the dominant decay mode (20%~50%)



Final state: $\pi^+\pi^-\gamma$ X

New!!!



measure $h_b(2P)$ yields in bins of $MM(\pi^+\pi^-\gamma)$
(require 10.59<$MM(\pi)$<10,67 GeV, *i.e.* =$M_{Z_{b1,2}}$)

$\Delta M_{hfs}(2S)=24.3\pm3.5^{+2.8}_{-1.9}$ MeV

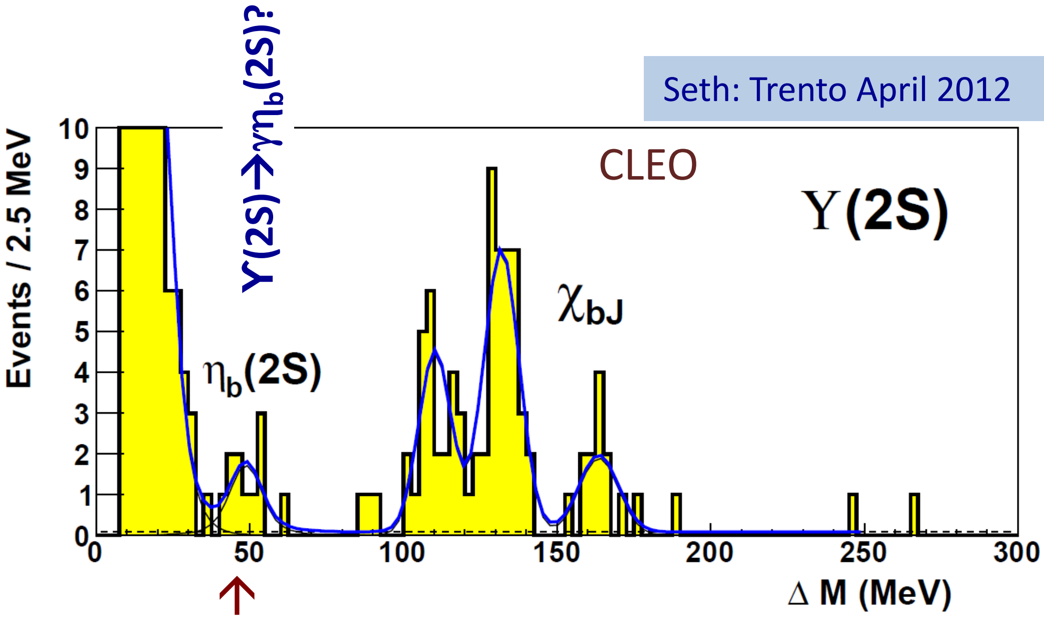
$M[\eta_b(2S)]=9999.0\pm3.5^{+2.8}_{-1.9}$ MeV

$Bf[h_b(2P)\rightarrow\gamma\eta_b(2S)]=47.5\pm10.5^{+6.6}_{-7.7}$ %

preliminary

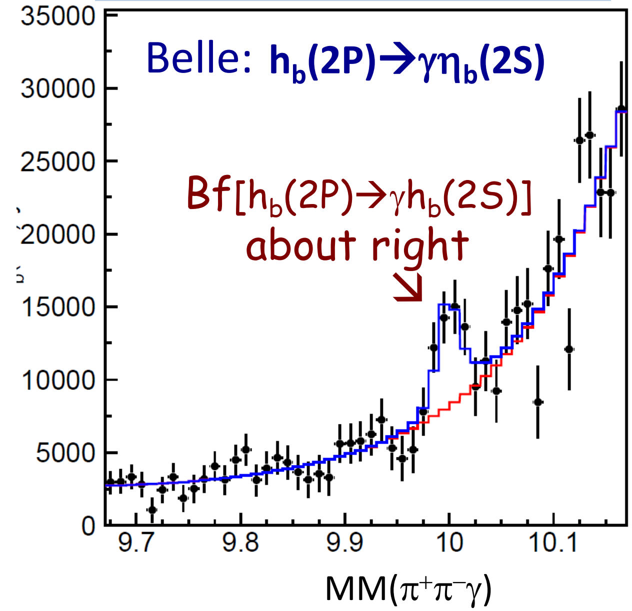
Comparison: $\eta_b(2S)$ “signals”

Seth: Trento April 2012



anomalously large production rate
($\sim 0.2\times\chi_{b1}$ rate)

Belle: IWHSS’12 April, 2012



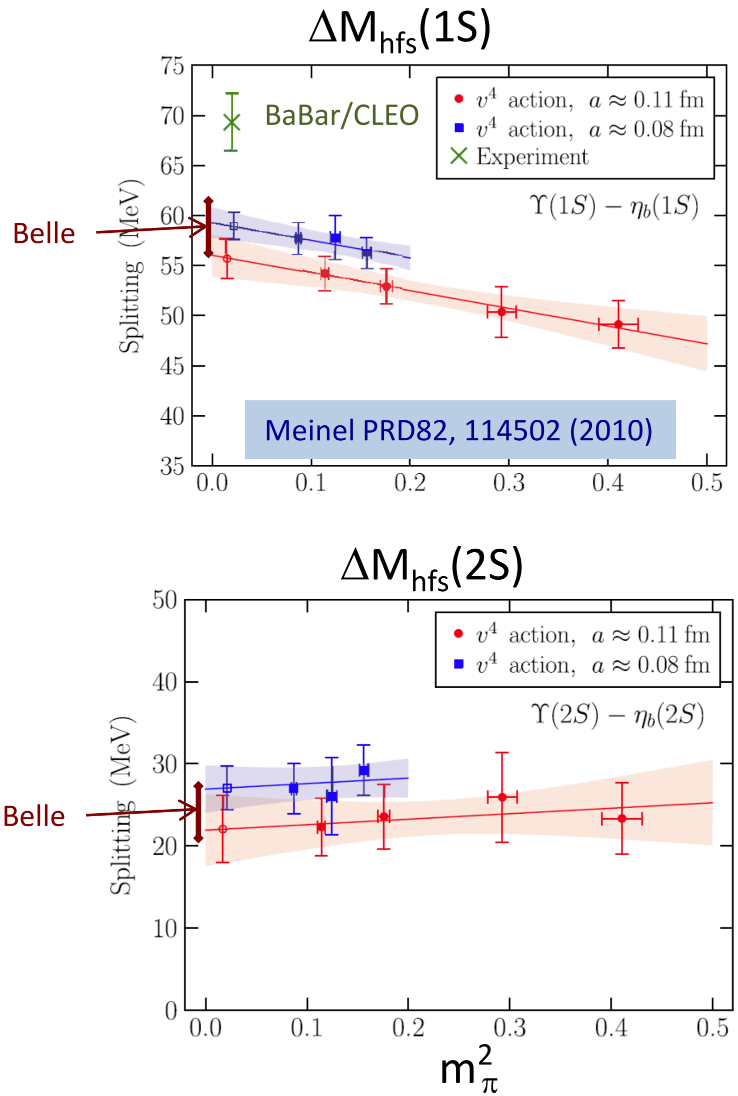
Expt	ΔM_{hfs} (2S) (MeV)
CLEO	48.7±2.7
Belle	24.3±4.3

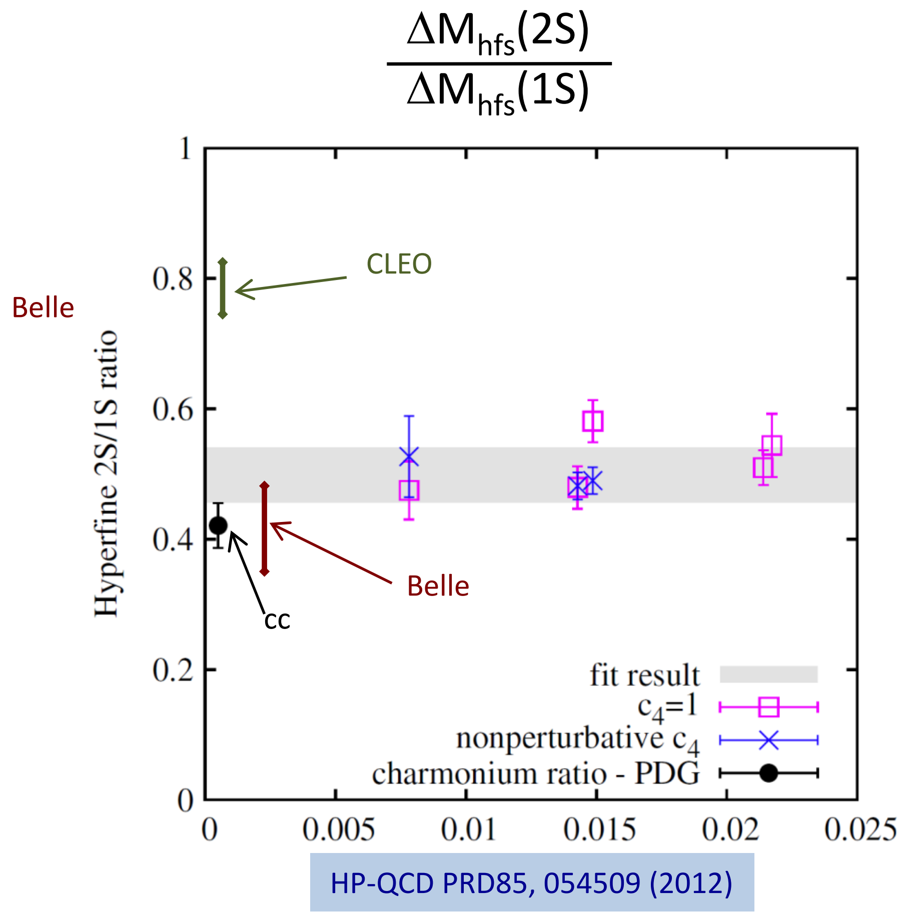
← strong disagreement with theory

← agrees with theory

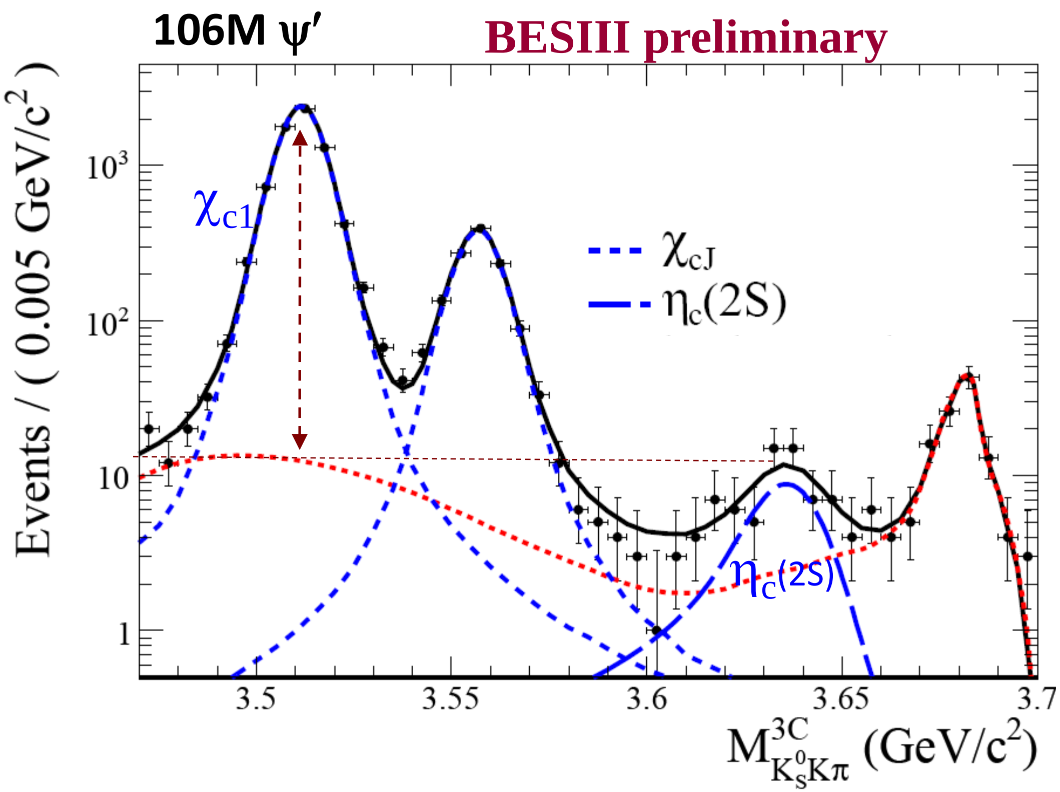
≈5σ discrepancy

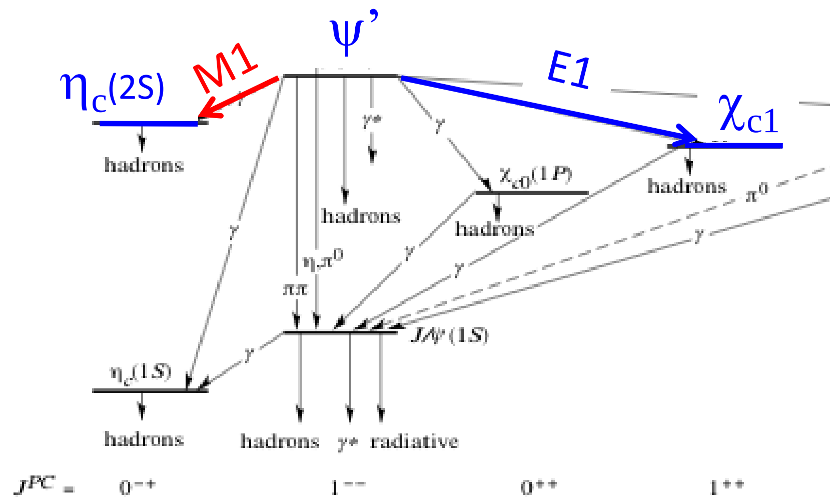
LQCD predictions for $\Delta M_{hfs}(1,2S)$





BESIII $\psi' \to \gamma\eta_c(2S) \to \gamma\,(K_s K^+ \pi^-)$





$BF(\psi' \to \gamma\eta_c(2S))$ = $(4.7 \pm 0.9 \pm 3.0) \times 10^{-4}$ BESIII preliminary

$BF(\psi' \to \gamma\chi_{c1})$= $9.2 \pm 0.4\%$ PDG

$\psi' \to \gamma\eta_c(2S)$ yield ≈ 0.005 $\psi' \to \gamma\chi_{c1}$ yield

Same M1 vs E1 suppression applies to $b\bar{b}$

Summary

-- open strange threshold --

- Strong evidence for $K\bar{K}$-mediated $a_0(980) \longleftrightarrow f_0(980)$ mixing reported by BESIII
  - below level expected for "pure" $K\bar{K}$ molecule picture

- Large (≈20%) Isospin violation seen in $\eta(1405) \rightarrow \pi^0 f_0(890)$ decays
  - anomalous $f_0(980)$ width ➔ influence of $K\bar{K}^*$ threshold & Triangle Singularity

-- open charm threshold --

- Properties of X(3872) consistent with expectations for $D\bar{D}^*$ S-wave molecule-like state
  - $J^{PC}=1^{++}$ favored (2^{-+} not ruled out) ➔ mixing with χ'_{c1}?
  - Mass = $M_{D0} + M_{\bar{D}^{*0}}$ ← to a part in ~10^4
  - no isospin partners are seen
  - Isospin-violating $X(3872) \rightarrow \rho J/\psi$ is a strong decay mode

-- open beauty threshold --

- "$\Upsilon(5S)$" $\rightarrow Z^+_{b_{1,2}}\pi^-$ with $Z^+_b \rightarrow \Upsilon(nS)\pi^+$ & $Z^+_b \rightarrow h_b\pi^+$ a source of $\pi^+\pi^-\Upsilon(nS)$ & $\pi^+\pi^- h_b(nP)$ at "$\Upsilon(5S)$"
  - M_{Zb_1}-($M_B + M_{\bar{B}^*}$) = +3.6 ±1.8 MeV; M_{Zb_2}- $2M_{B^*}$ = +3.1 ±1.8 MeV
  - S-wave $B\bar{B}^*$ and $B^*\bar{B}^*$ molecules? large widths to hidden beauty

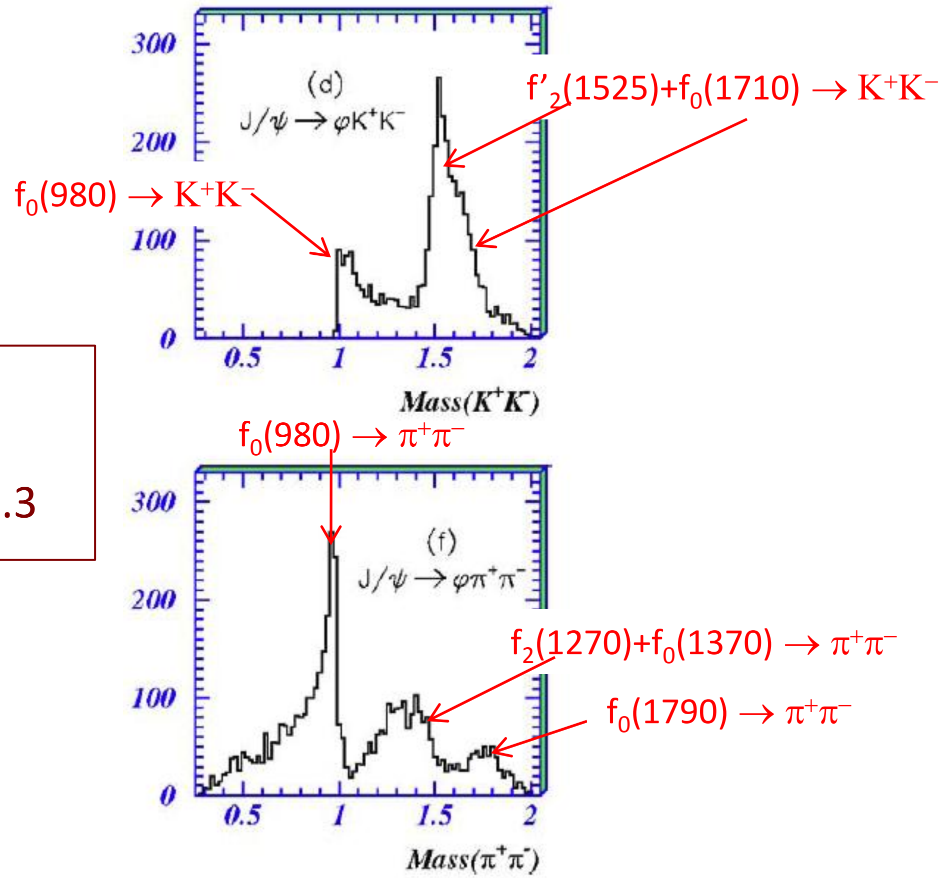
-- new from Belle --

- First observation of $\eta_b(2S)$
  - $\Delta M_{hfs}(2S)$ = 24.3±4.3 MeV Bf[$h_b(2P) \rightarrow \gamma\eta_b(2S)$] = 47±13% ← preliminary
  - no surprises

Signals for $f_0(980) \to \pi\pi$ & $\to K^+K^-$

Resonances in $J/\psi \to \phi\pi^+\pi^-$ and ϕK^+K^-

BESII PLB 607, 243 (2005)



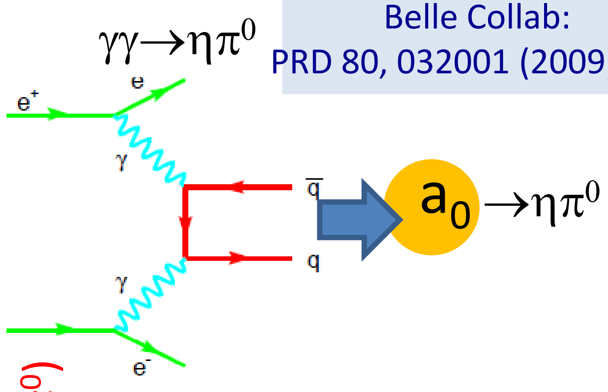
strong $f_0(980)$ coupling to $K\bar{K}$

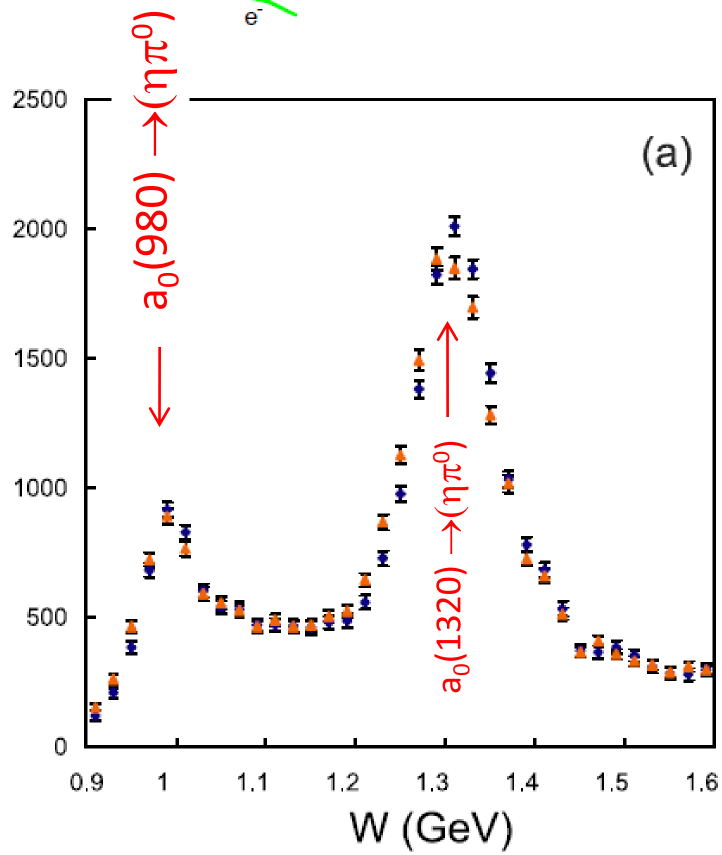
$$\frac{g_{KK}}{g_{\pi\pi}} = 4.2 \pm 0.3$$

$Bf(J/\psi \to \phi f_0(980)) = 0.32 \pm 0.09 \times 10^{-3}$

Signal for $a_0(980) \to \eta\pi$

Belle Collab:
PRD 80, 032001 (2009)



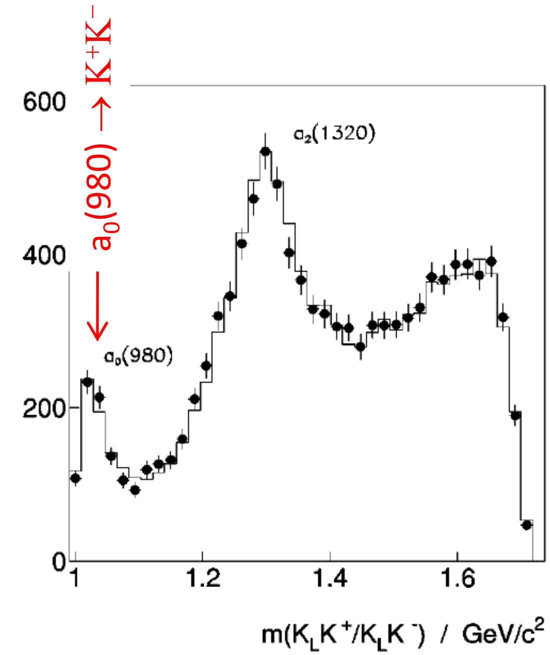


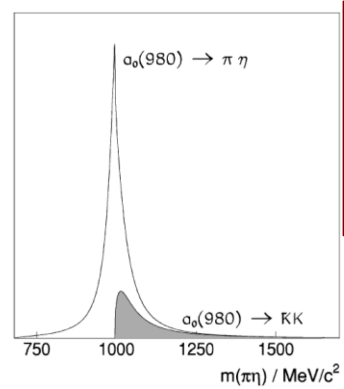
PHYSICAL REVIEW D **80**, 032001 (2009)

Signal for $a_0(980) \to K^+K^-$

$\bar{p}p$ ANNIHILATION AT REST INTO $K_L K^{\pm} \pi^{\mp}$

Crystal Barrel Collab: PRD 57, 3860 (1998)





strong $a_0(980)$ coupling to KK

$$\frac{g_{KK}}{g_{\pi\eta}} = 1.03 \pm 0.14$$

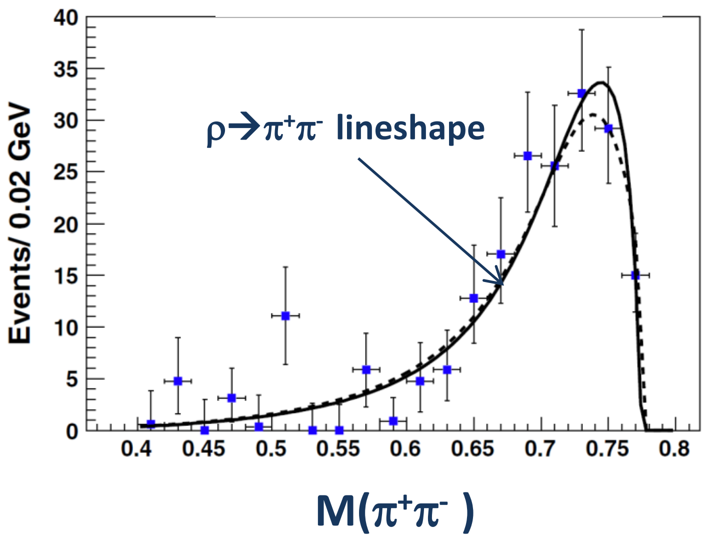
Thank you

Obrigado

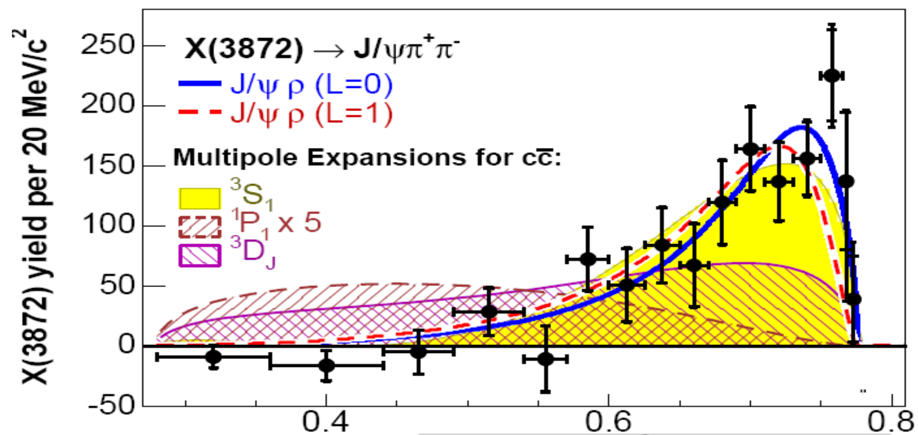
감사합니다

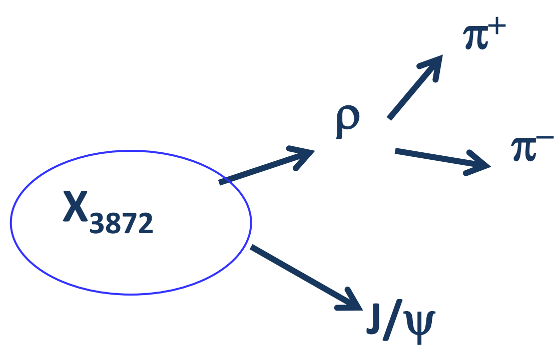
$\pi^+\pi^-$ system in X(3872)→$\pi^+\pi^-$J/ψ comes from ρ→$\pi^+\pi^-$

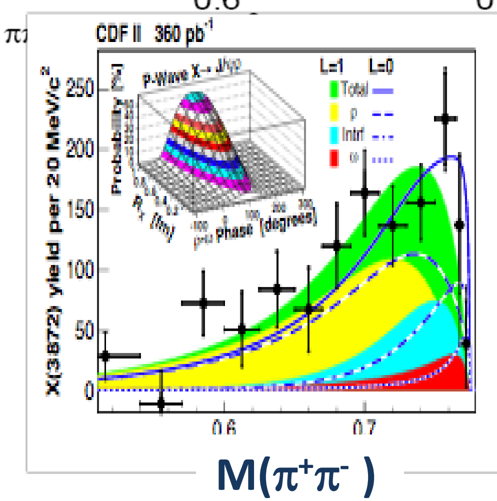
Belle: PRD 84 052004



CDF: PRL 96 102002







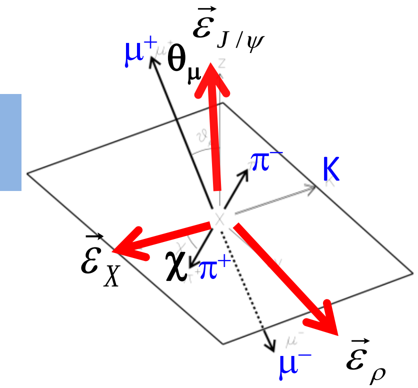
J^{PC} of the X(3872)

1^{++} fits well with no adjustable parameters

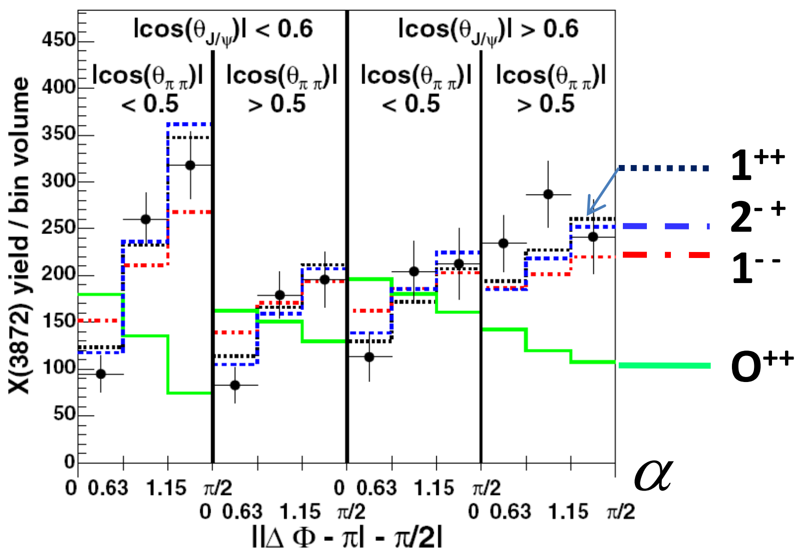
2^{-+} cannot be ruled out

J. Rosner PRD 70, 092023 (2004) for 1^{++}:

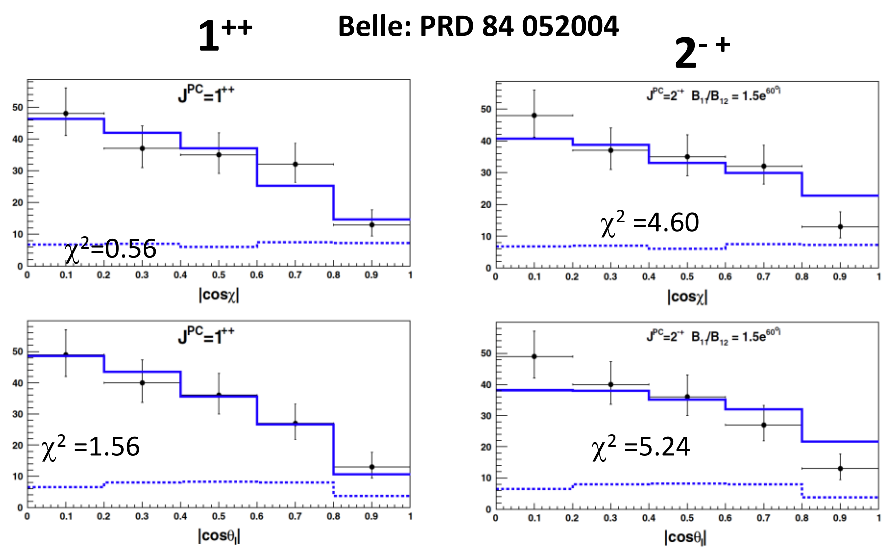
$$\mathcal{L}_{int} \propto \vec{\epsilon_X} \cdot \vec{\epsilon_{J/\psi}} \times \vec{\epsilon_\rho}$$



CDF: PRL 98 132002



Belle: PRD 84 052004



2^{-+} has higher χ^2 and fewer dof than 1^{++}

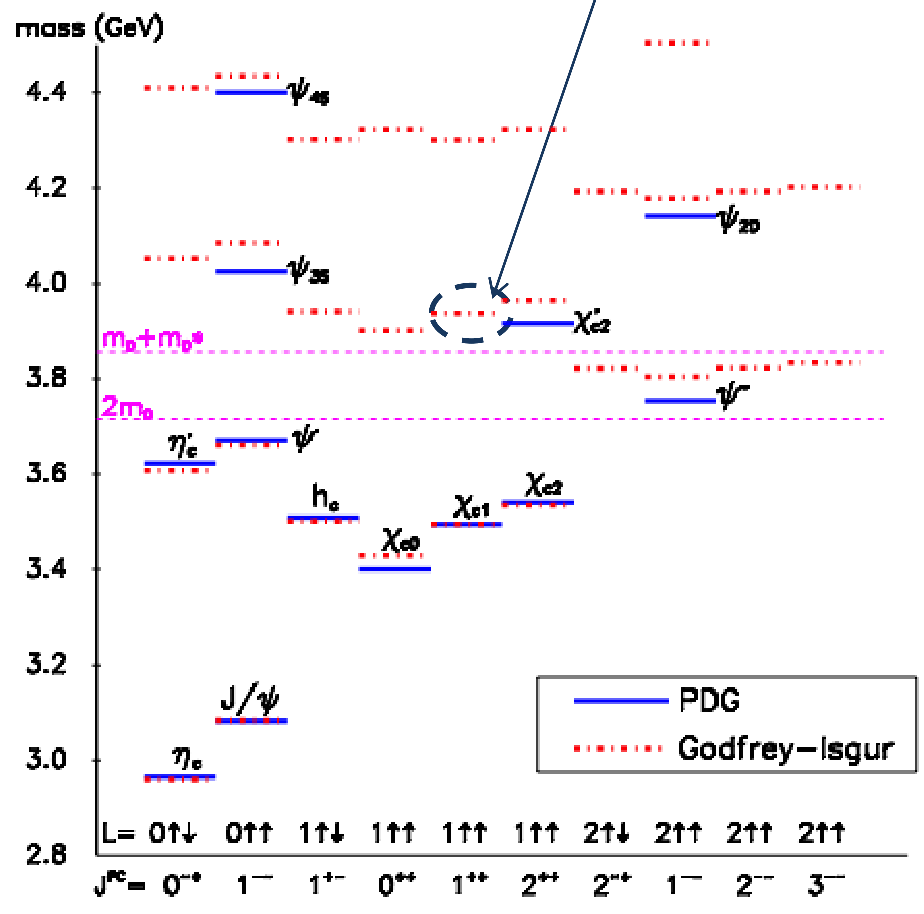
1^{++} $c\bar{c}$ assignment?

χ'_{c1}

pinned to: $M\chi'_{c2}$=3930 MeV

- Mass is too low?
  - 3872 *vs* 3905 MeV
  - n_r=2 splitting> n_r=1
- $\Gamma(\chi'_{c1} \rightarrow \gamma\psi')$ ~180 keV
  $\Gamma(\chi'_{c1} \rightarrow \gamma\ J/\psi)$ ~14 keV
  T.Barnes *et al* PRD 72, 054026
  - **$\Gamma(\chi_{c1} \rightarrow \gamma\psi')/\Gamma(\chi_{c1} \rightarrow \gamma\ J/\psi)$>>1**
  - **expt'l upper limit: <2.1**
- $\Gamma_{\pi+\pi-\ J/\psi}=(3.4\pm1.2)\Gamma_{\gamma J/\psi}$ ~45 keV

  huge for Isospin-violating decay
  c.f.: $\Gamma(\psi' \rightarrow \pi^0 J/\psi) \approx 0.4$ keV



Does the X(3872) have Ispin=1?

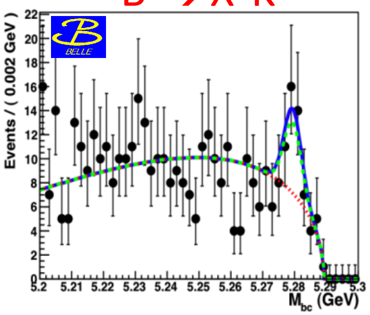
search for charged partners: $X^+(3872) \rightarrow \pi^+\pi^0 J/\psi$: Isospin triplet?

Isospin relations:

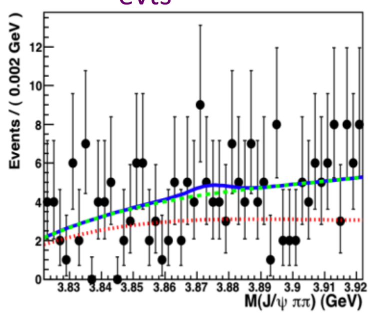
$$B(B^+ \to K^0 X(3872)^+) = 2 \times B(B^0 \to K^0 X(3872)^0)$$
$$B(B^0 \to K^- X(3872)^+) = 2 \times B(B^+ \to K^+ X(3872)^0)$$

2-dim fits:

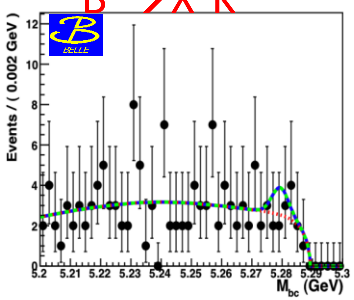
$B^0 \rightarrow X^+ K^-$

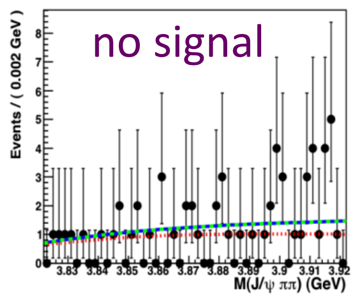


$N_{evts} = 4.2 \pm 7.8$



$B^+ \rightarrow X^+ K^0$





$\mathcal{B}(B^0 \rightarrow K^- X^+) \times \mathcal{B}(X^+ \rightarrow \pi^+\pi^0 J/\psi) < 3.9 \times 10^{-6}$

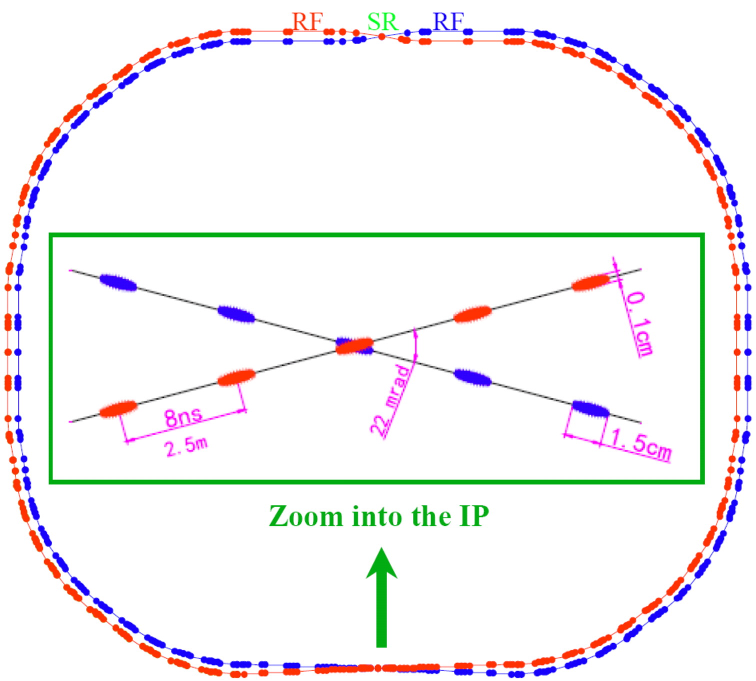
Rule out isospin triplet model

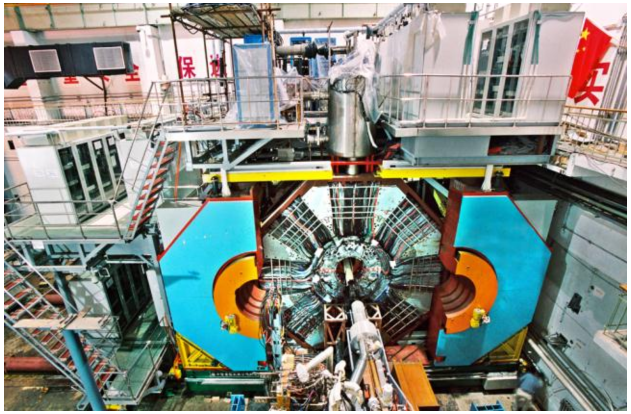
$\mathcal{B}(B^+ \rightarrow K^0 X^+) \times \mathcal{B}(X^+ \rightarrow \pi^+\pi^0 J/\psi) < 4.5 \times 10^{-6}$

not 2x larger!!

$$B(B^+ \to K^+ X(3872)^0) \times B(X(3872)^0 \to \pi^+\pi^- J/\psi) = (8.61 \pm 0.82 \pm 0.78) \times 10^{-6}$$
$$B(B^0 \to K^0 X(3872)^0) \times B(X(3872)^0 \to \pi^+\pi^- J/\psi) = (4.3 \pm 1.2 \pm 0.4) \times 10^{-6}$$

BEPCII storage rings





Beam energy: 1.0 − 2.3 GeV

Peak Luminosity:

Design: 1×10^{33} $cm^{-2}s^{-1}$

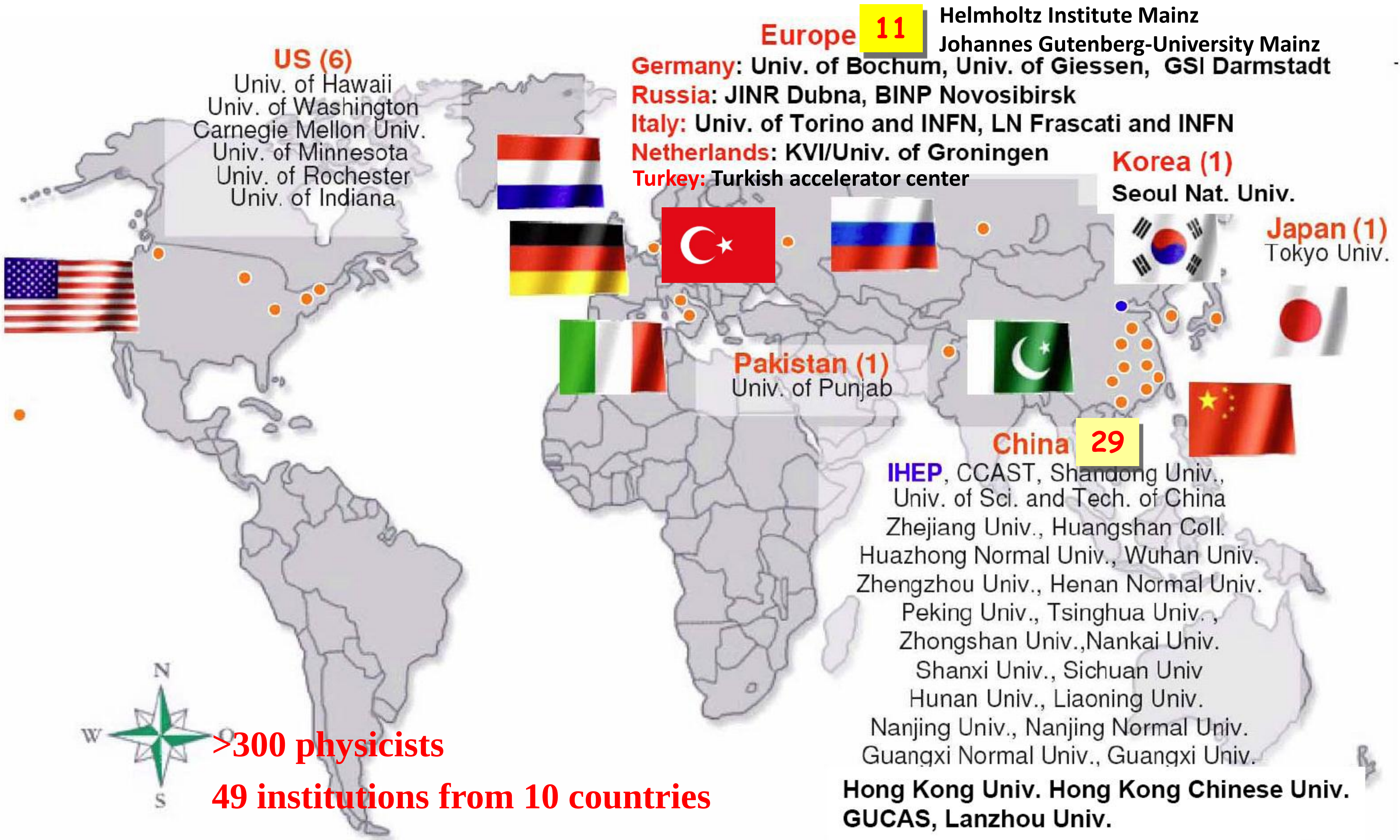
Achieved: 0.65×10^{33} $cm^{-2}s^{-1}$

Beam energy measurement: Using Compton backscattering technique.

Accuracy: $\delta E_{beam}/E_{beam} \approx 5 \times 10^{-5}$

➔ $\delta E_{beam} \approx 50$ KeV @ $E_{beam} \approx m_{\tau}$

BESIII Collaboration



>300 physicists

49 institutions from 10 countries