Heavy flavor mesons

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New or recent results from B factories on

- Charm mesons
- Charmonium
- Bottomonium

Heavy flavor meson spectrum: why bother?

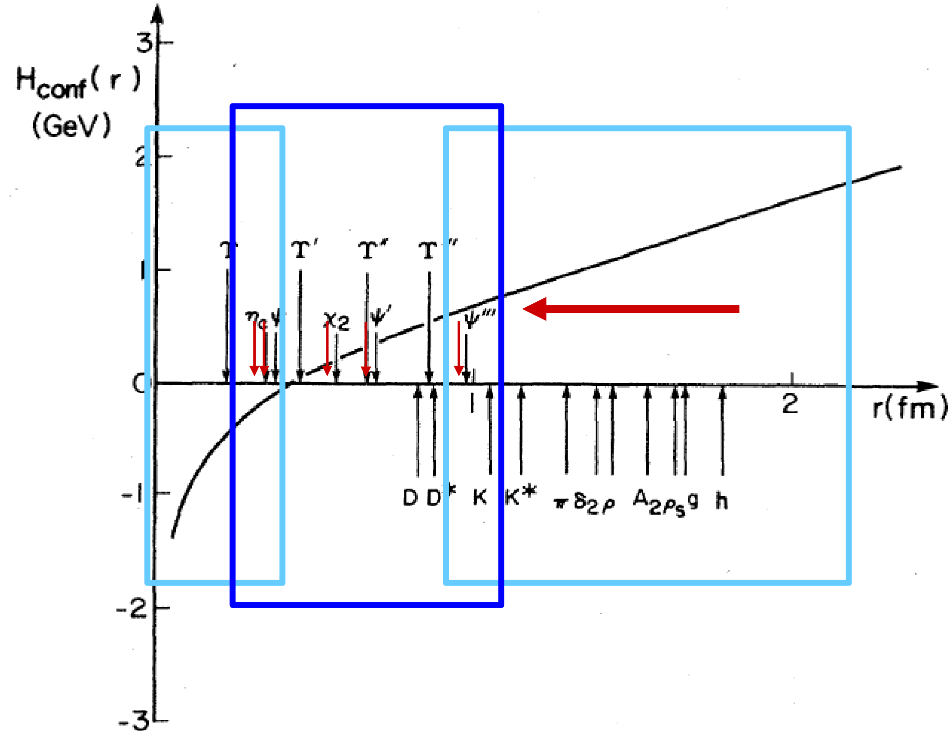
Naive picture of $q\bar{q}$ potential

Coulomb-like term:
- small distance
- one-gluon exchange
- asymptotic freedom

low radial excitations
of heavy-heavy mesons

linear term
- large distance
- confinement

"perturbative regime"

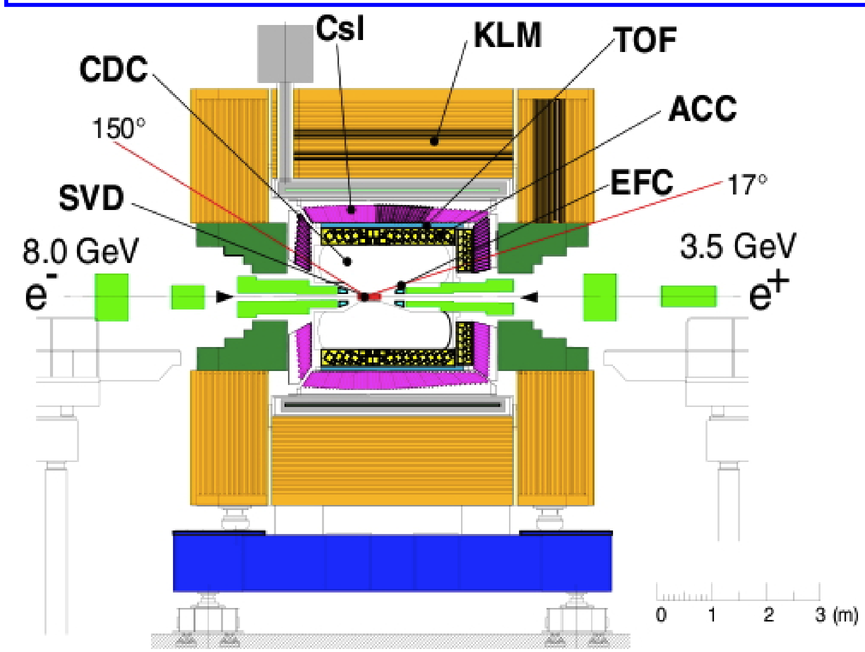


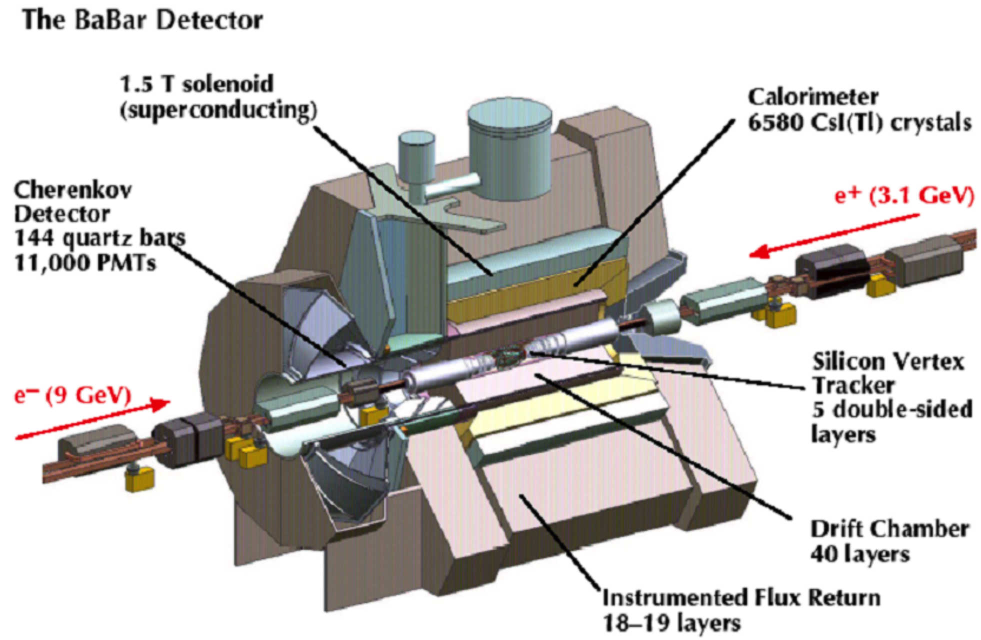
The "meat" is in-between:

- heavy-light
- higher radial excitations

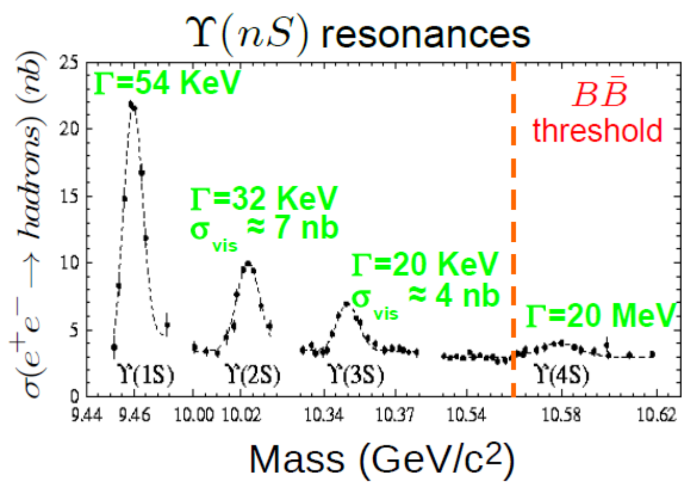
radiative (hadronic) transitions "probe"
$q\bar{q}$ wave-functions

BaBar and Belle





Samples	Υ(1S)	Υ(2S)	Υ(3S)	Υ(4S)	Υ(5S)
BaBar		14 fb^{-1}	30 fb^{-1}	433 fb^{-1}	3.2 fb^{-1} (scan)
Belle	6 fb^{-1}	24 fb^{-1}	3 fb^{-1}	711 fb^{-1}	121 fb^{-1}

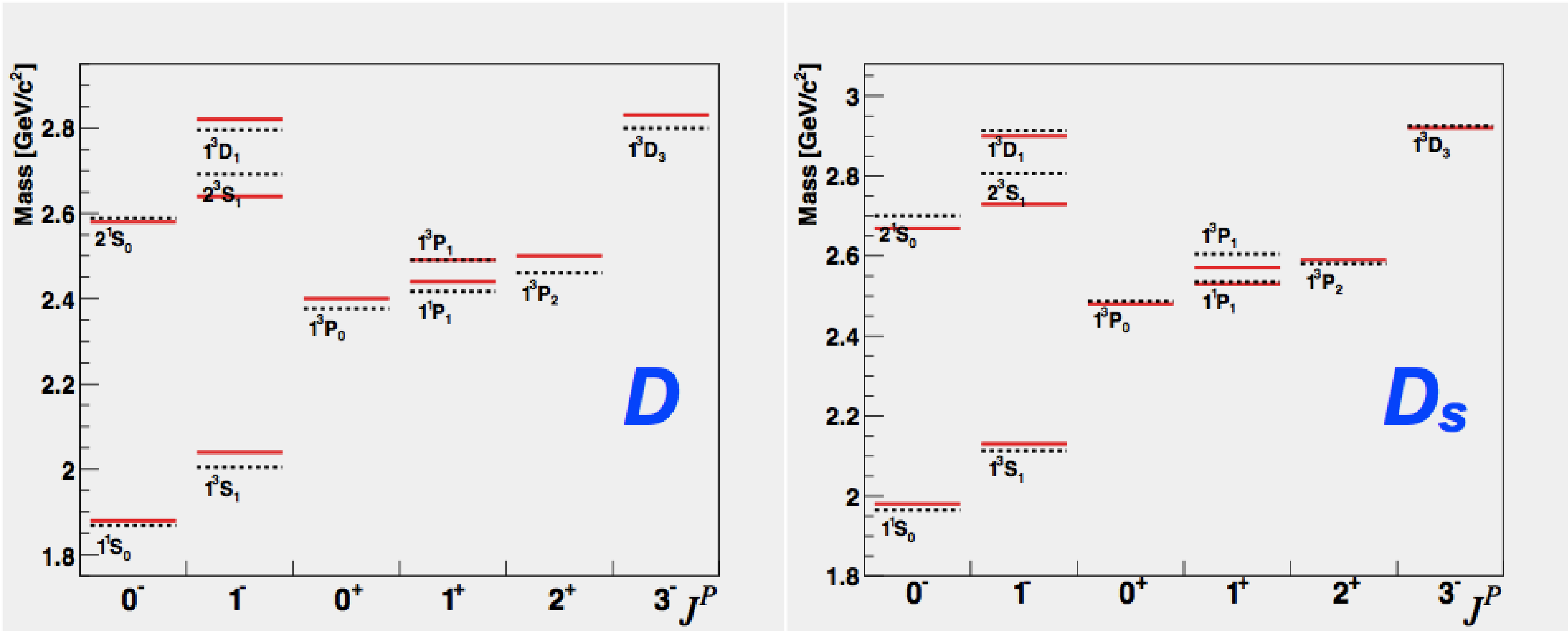


Large samples of Υ(nS) and B mesons

also very large samples of charm mesons and charmonium:

- $\sigma(e^+e^- \to c\bar{c}) \sim 1.3$ nb
- Charm meson and charmonium in b→c decays
- charmonium in ISR and γγ processes

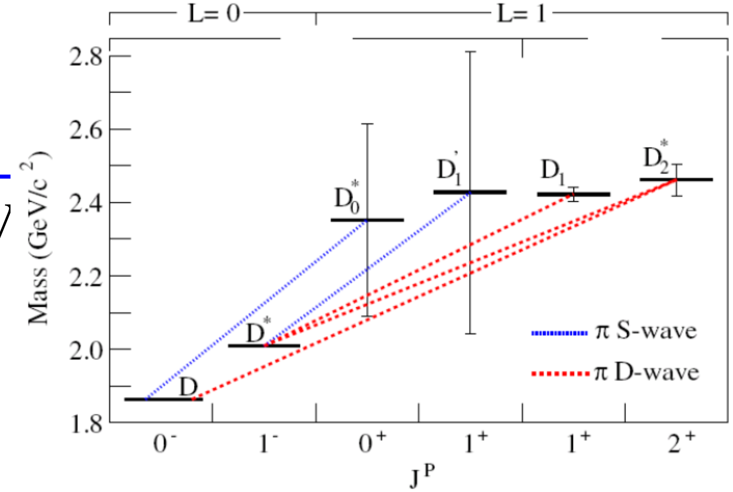
Charm meson spectrum



S. Godfrey, N. Isgur, Phys. Rev. D 32, 189 (1985)
M. Di Pierro, N. Eitchen, Phys. Rev. D 64, 114004 (2001)

- qualitative overall agreement
- discrepancies for some higher states, not all observed or well measured

New excited D states

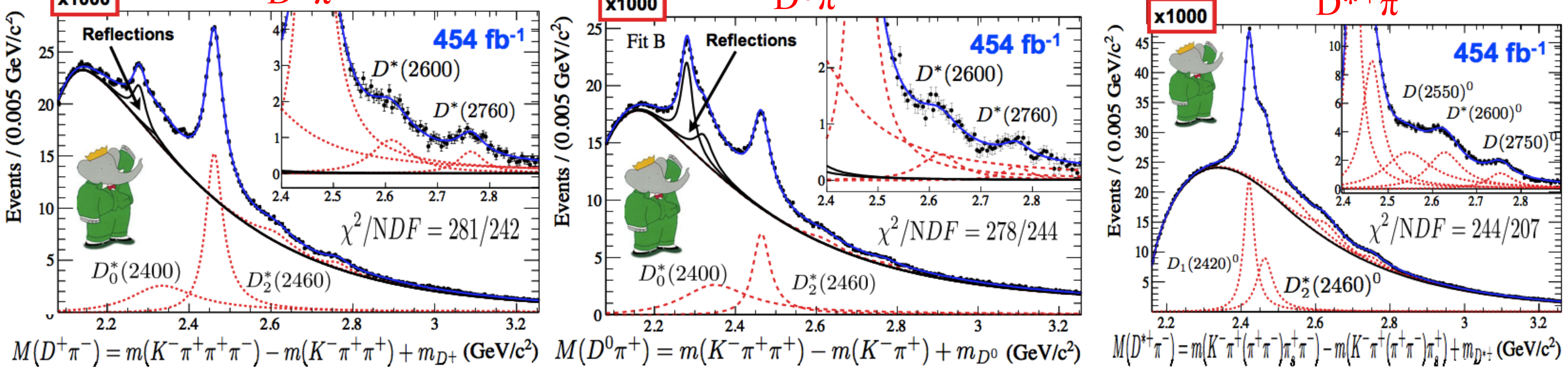


4 states with L=1 — two with D-wave decays, Γ~40 MeV; two S-wave decay, Γ~300 MeV

Inclusive search at BaBar: [Phys. Rev. D 82, 111101 (2010)]

$$e^+e^- \rightarrow c\bar{c} \rightarrow D^{**}X \rightarrow D^{(*)}\pi X$$

$D^+\pi^-$ $D^0\pi^+$ $D^{*+}\pi^-$

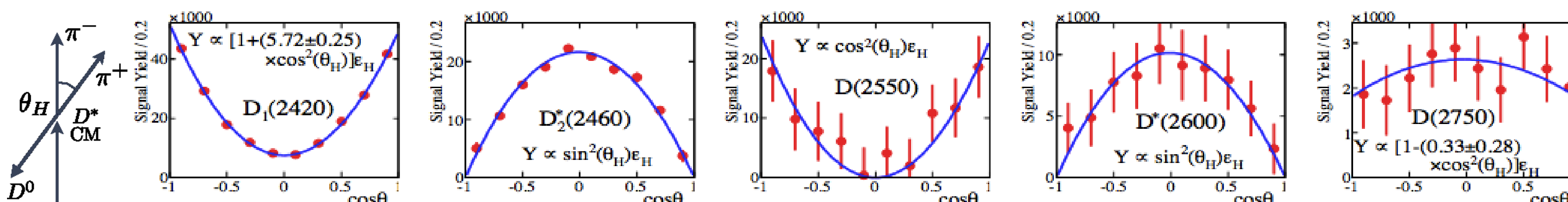


Resonance	Mass (MeV/c^2)	Signif.
$D^*(2600)^0$	$2608.7 \pm 2.4 \pm 2.5$	3.9σ
$D^*(2760)^0$	$2763.3 \pm 2.3 \pm 2.3$	8.9σ

Resonance	Mass (MeV/c^2)	Signif.
$D^*(2600)^+$	$2621.3 \pm 3.7 \pm 4.2$	2.8σ
$D^*(2760)^+$	$2769.7 \pm 3.8 \pm 1.5$	3.5σ

Resonance	Mass (MeV/c^2)	Signif.
$D(2550)^0$	$2539.4 \pm 4.5 \pm 6.8$	3.0σ
$D(2750)^0$	$2752.4 \pm 1.7 \pm 2.7$	4.2σ

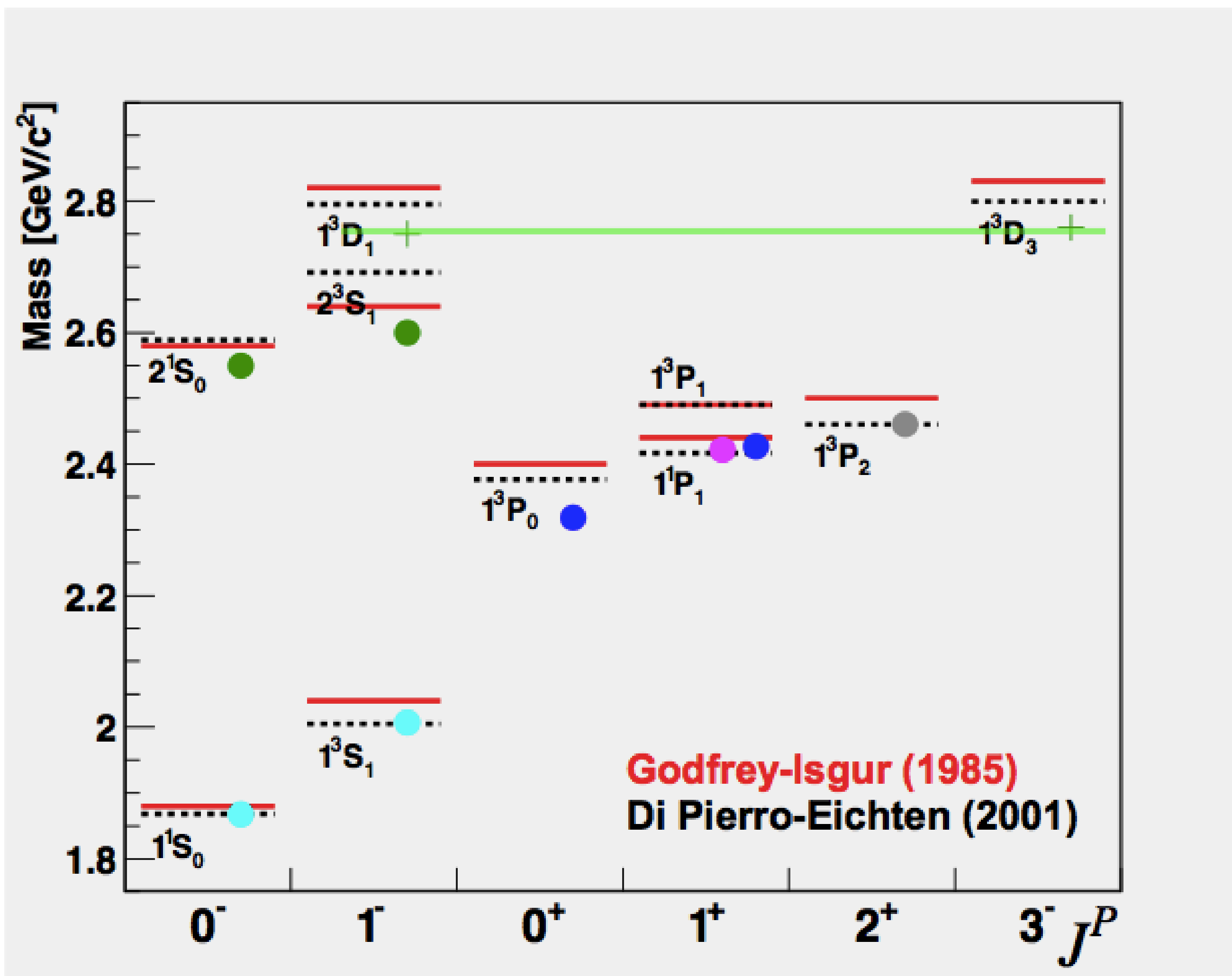
Helicity angle distribution



Consistent with HERA [Eur.Phys. J. C 60, 25 (2009)]

J^P assignment: 1^3P_2 2^1S_0 2^3S_1 ?

Charm meson spectrum today

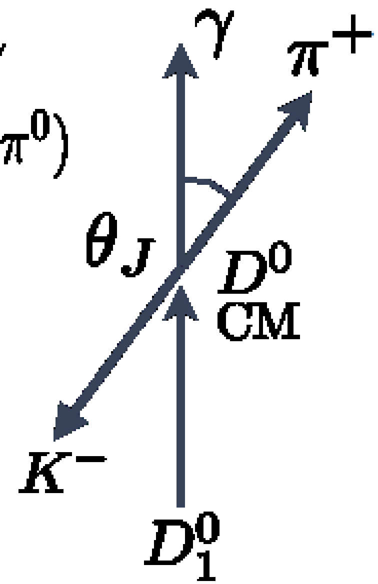


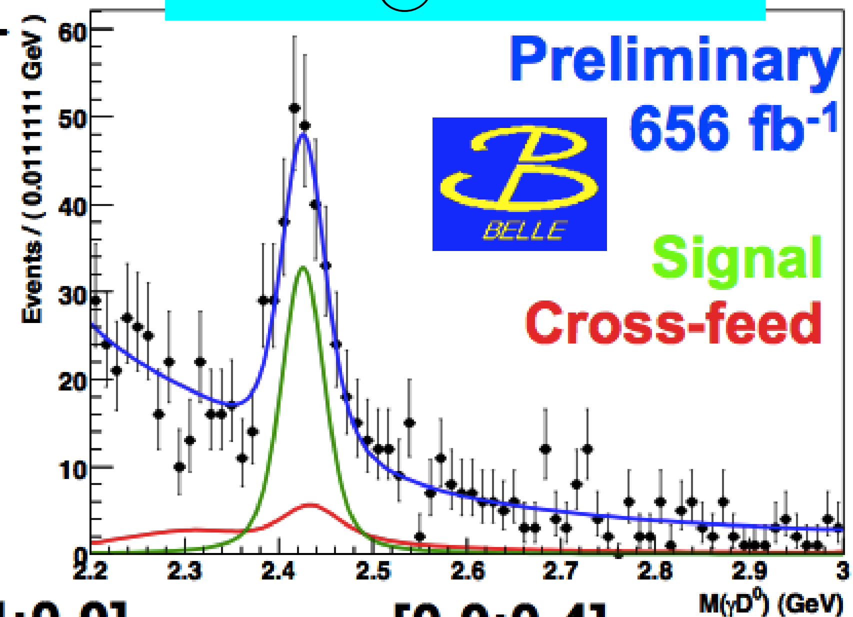
$n^{2S+1}L_J$	Name(Mass)	1st Obs.(Year)
1^1S_0	D	Mark I (1975)
1^3S_1	D^*	Mark I (1977)
1^3P_1	$D_1(2420)$	ARGUS (1986)
1^3P_2	$D_2(2460)$	TPS (1989)
1^3P_0	$D_0^*(2400)$	BELLE (2004)
1^1P_1	$D_1^*(2430)$	
2^1S_0	$D(2550)$	BaBar (2010)
2^3S_1	$D^*(2600)$	
$1^?D_?$	$D(2750)$	
$1^?D_?$	$D^*(2760)$	

$D_1(2420)^0 \to D^0\gamma$ radiative transition

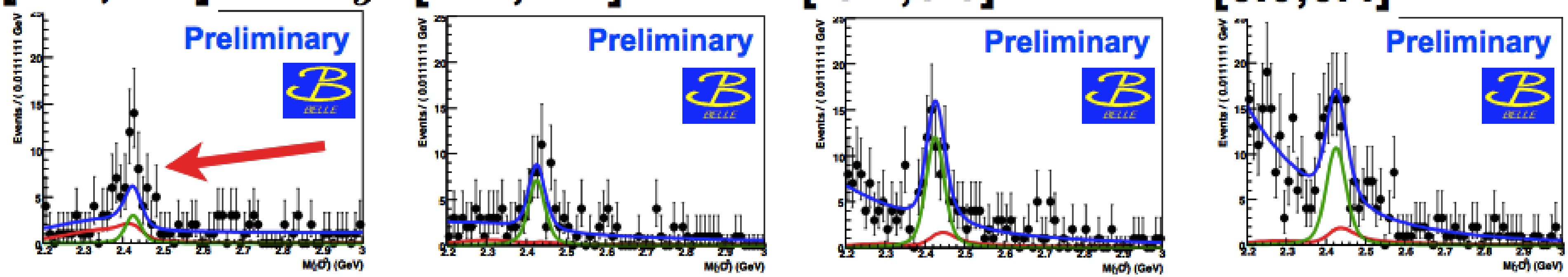
Watson@ICHEP2010

- $B^- \to \pi^- D_1^0,\ D_1^0 \to D^0\gamma$
- Bkg from $B^- \to \pi^- D_{0/2}^0 (\to D^0\pi^0)$ with different angular distribution
- Fit in different regions of $\cos\theta_J$
- Disagreement in low bin





[-1.0;-0.7] $\cos\theta_J$ [-0.7;-0.4] [-0.4;0.0] [0.0;0.4]



$$\mathcal{B}(B^- \to \pi^- D_1^0) \times \mathcal{B}(D_1^0 \to D^0\gamma) = (5.0 \pm 0.5(\text{stat}) \pm 1.5(\text{syst})) \times 10^{-5}$$

Using BR($B^- \to D_1^0\pi^-$) = 0.102% and $\Gamma(D_1^0)$ = 20.4 MeV

Belle obtains : BR($D_1^0 \to D^0\gamma$) = 5.0% (Godfrey, PRD72 (2005) 054029: 2.8%)

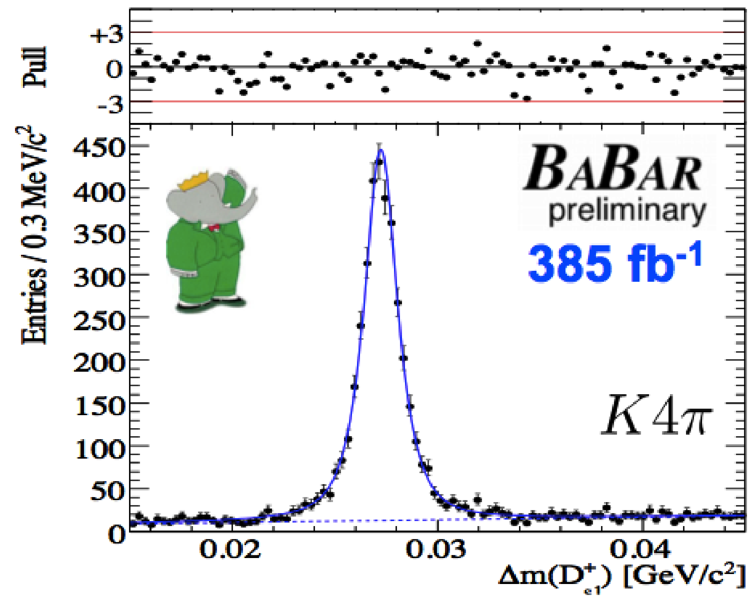
Ds1(2536) properties

- **Inclusive reconstruction:**
  $D_{s1} \to D^{*+} K^0_S, \quad D^{*+} \to D^0 \pi^+$
  $D^0 \to K^- \pi^+ (\pi^+ \pi^-)$
- $\Delta m(D^+_{s1})$ **has a better resolution**
  $\Delta m(D^+_{s1}) = m(D_{s1}) - m(D^{*+}) - m(K^0_S)$

$m(D^+_{s1}) = 2535.08 \pm 0.01 \pm 0.15\,\mathrm{MeV}/c^2$

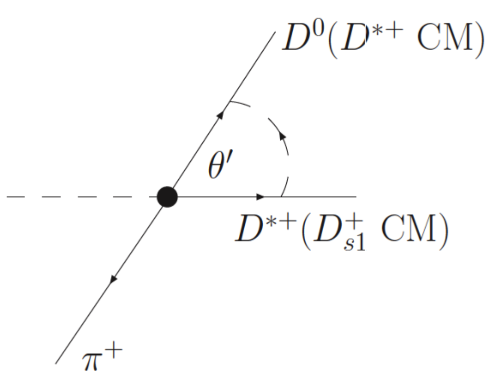
$\Gamma(D^+_{s1}) = 0.92 \pm 0.03 \pm 0.04\,\mathrm{MeV}$, **1st Meas.**

$m(D^+_{s1}) - m(D^{*+}) = 524.83 \pm 0.01 \pm 0.04\,\mathrm{MeV}/c^2$

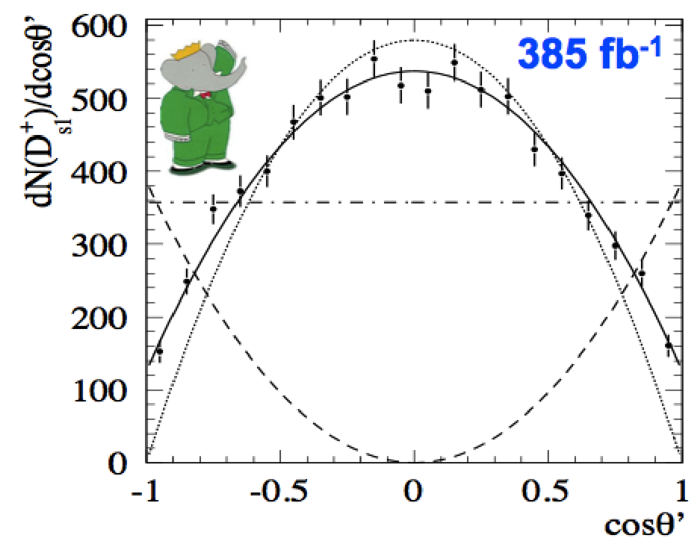


PRD 83 072003 (2011)

Helicity angle distribution confirms unnatural parity

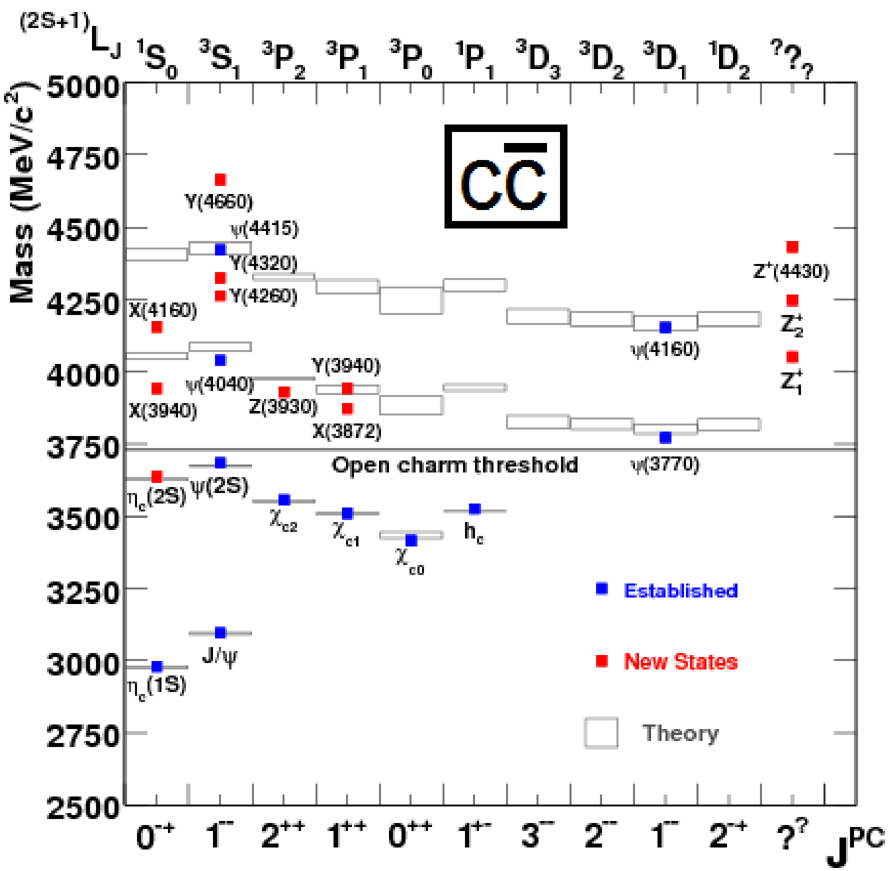


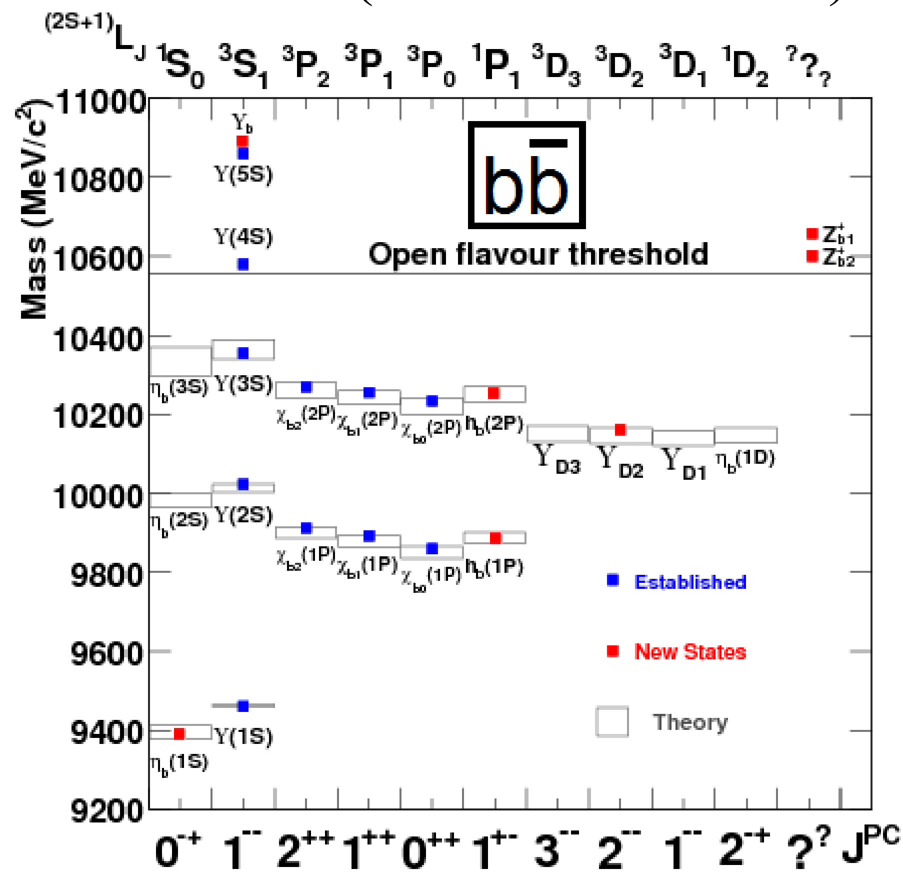
J^P	$dN(D^+_{s1})/d\cos\theta'$	χ^2/NDF	Legend
0^-	$a\cos^2\theta'$	4578.0/19	
$1^-, 2^+, 3^-$	$a\sin^2\theta'$	190.9/19	
$1^+, 2^-, 3^+, ...$	$a(\sin^2\theta' + \beta\cos^2\theta')$ $\beta = 1$ (fixed)	802.5/19	
$1^+, 2^-, 3^+, ...$	$a(\sin^2\theta' + \beta\cos^2\theta')$ $\beta = 0.23 \pm 0.02$	14.7/18	



Quarkonium spectrum

B-factories contributed in filling the empty slots
... and found a few more: the XYZ states (see Eidelman talk)





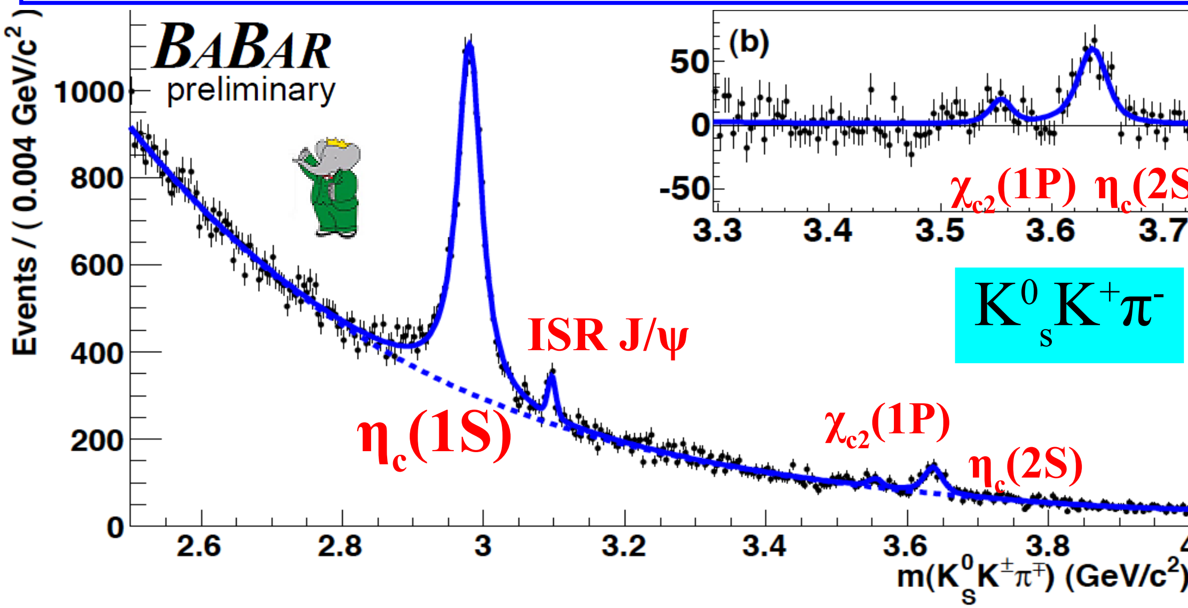
Recent progresses in conventional quarkonia:

- new measurements of η_c(nS) masses and widths, η_c(2S) decay modes
- observation of bottomonium singlet states h_b(1P) and h_b(2P)
- improved measurements of radiative and hadronic transitions of ϒ(nS) and χ_b(nP)

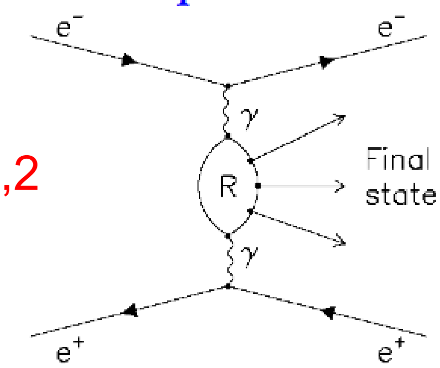
$\eta_c(1S)$,$\eta_c(2S)$ and $\chi_{cJ}(1P)$in $\gamma\gamma$ at BaBar

arXiv:1103.3971

519 fb^{-1}

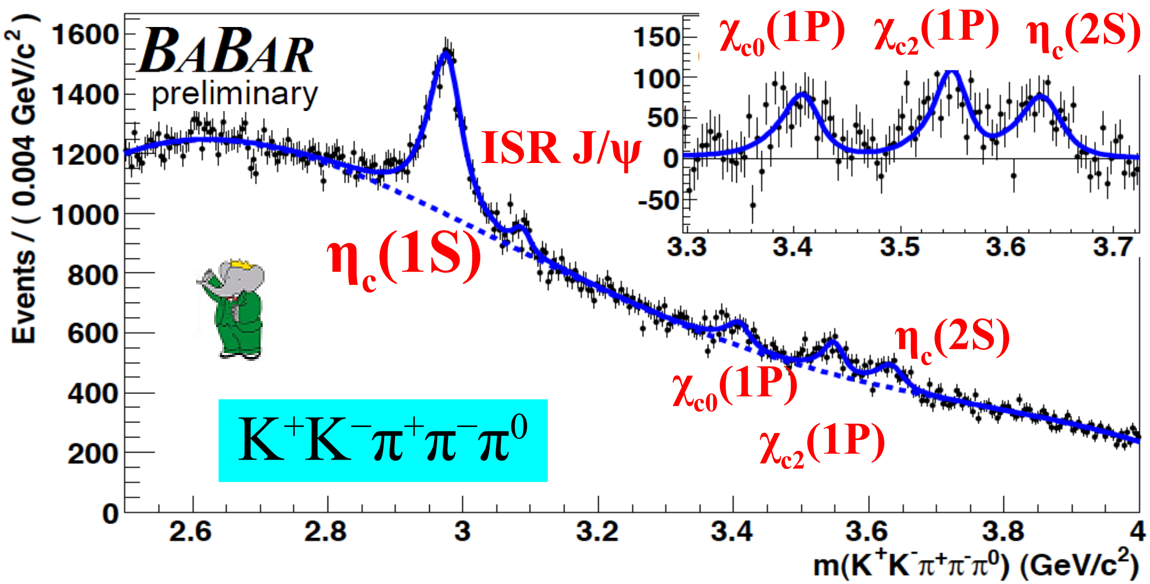


two-photon fusion



C=+, J=0,2

e+e- along beam pipe: undetected
resonance formed at low pt



- $K^0_S K^+\pi^-$ forbidden for $\chi_{c0}(1P)$
- $K^+K^-\pi^+\pi^-\pi^0$ new mode

from $K^0_S K^+\pi^-$ decay mode:

$m(\eta_c(1S))=2982.5\pm0.4\pm1.4$ MeV/c^2
$\Gamma(\eta_c(1S))=32.1\pm1.1\pm1.3$ MeV

$m(\eta_c(2S))=3638.5\pm1.5\pm0.8$ MeV/c^2
$\Gamma(\eta_c(2S))=13.4\pm4.6\pm3.2$ MeV

(see also Santoro talk in Quarkonium 4 parallel session)

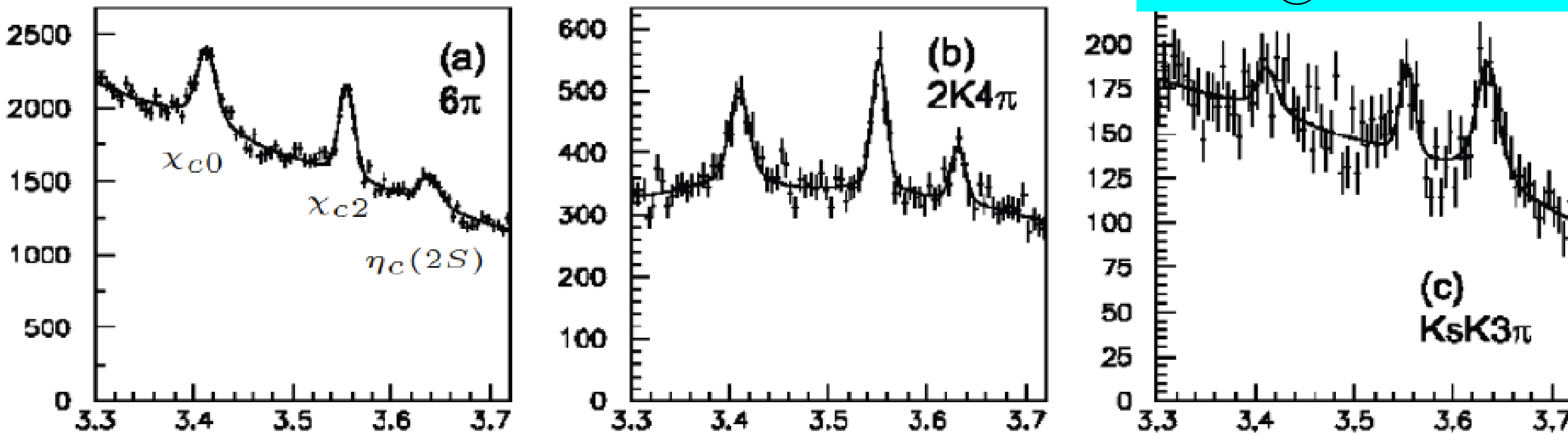
includes syst. from interference with continuum

$\eta_c(2S)$ and $\chi_{cJ}(1P)$in $\gamma\gamma$ reactions at Belle

Belle studied $\eta_c(2S)$ and $\chi_{cJ}(1P)$ to 6 charged tracks in $\gamma\gamma$

new modes

Belle @ICHEP2010



	M, MeV	Γ, MeV	Signif.	$\Gamma_{\gamma\gamma}\mathcal{B}$, eV
6π	$3638.9 \pm 1.6 \pm 2.3$	10.7 ± 4.9	8.5σ	$20.1 \pm 3.7 \pm 3.2$
$2K4\pi$	$3634.7 \pm 1.6 \pm 2.8$	< 13 @ 90% CL	6.2σ	$10.2 \pm 2.3 \pm 3.4$
$K_S K 3\pi$	$3636.5 \pm 1.8 \pm 2.4$	15.9 ± 5.7	8.7σ	$30.7 \pm 3.9 \pm 3.7$

$$M(\eta_c(2S))=3636.9\pm1.1\pm2.5 \pm5.0 \text{ MeV}/c^2$$
$$\Gamma(\eta_c(2S))=9.9\pm3.2\pm2.6 \pm2.0 \text{ MeV}$$

systematic due to interference with continuum

η_c(1S) and η_c(2S) in B decays from Belle

$B^+ \to K^+(K_S K\pi)^0$

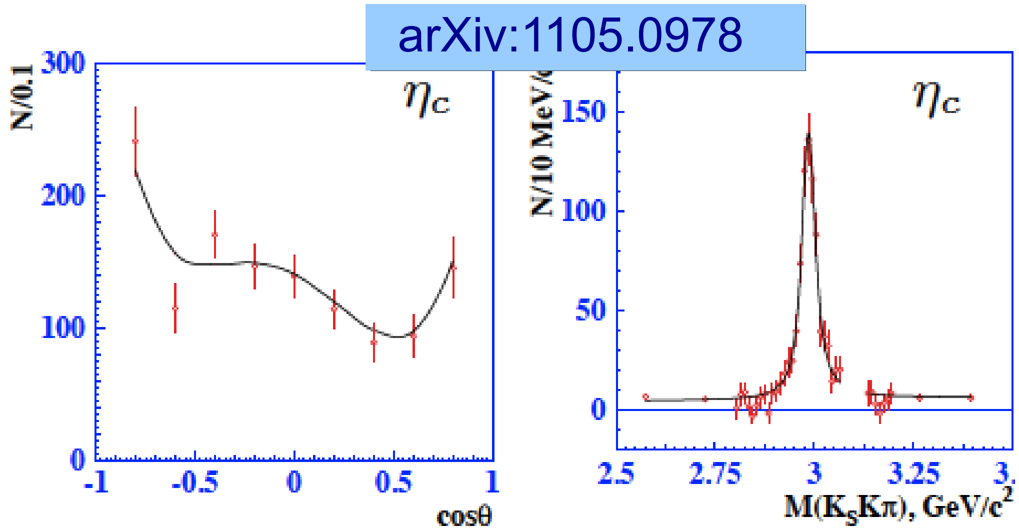
Interference with
non-res. $B^+ \to K^+(K_S K\pi)^0$.

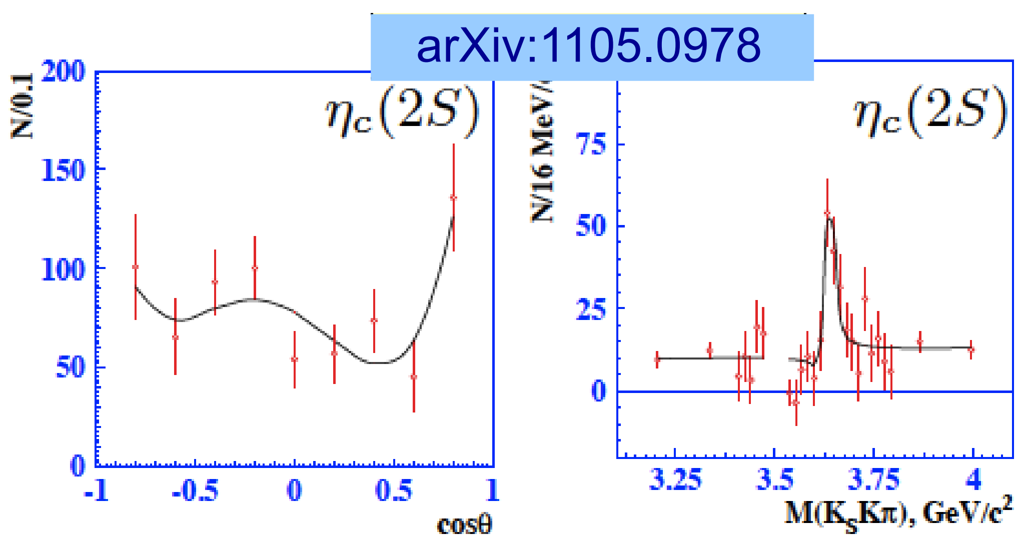
2D fit: $\angle(K^+, K_S)$–$M(K_S K\pi)$.

$M_{\eta_c} = 2985.4 \pm 1.5^{+0.2}_{-2.0}$ MeV
$\Gamma_{\eta_c} = 35.1 \pm 3.1^{+1.0}_{-1.6}$ MeV
$M_{\eta_c(2S)} = 3636.1^{+3.9}_{-4.1}{}^{+0.5}_{-2.0}$ MeV
$\Gamma_{\eta_c(2S)} = 6.6^{+8.4}_{-5.1}{}^{+2.6}_{-0.9}$ MeV

No interference:
$\Gamma_{\eta_c(2S)} = 41.1 \pm 12.0^{+6.4}_{-10.9}$ MeV

Significant effect for $\eta_c(2S)$ width!

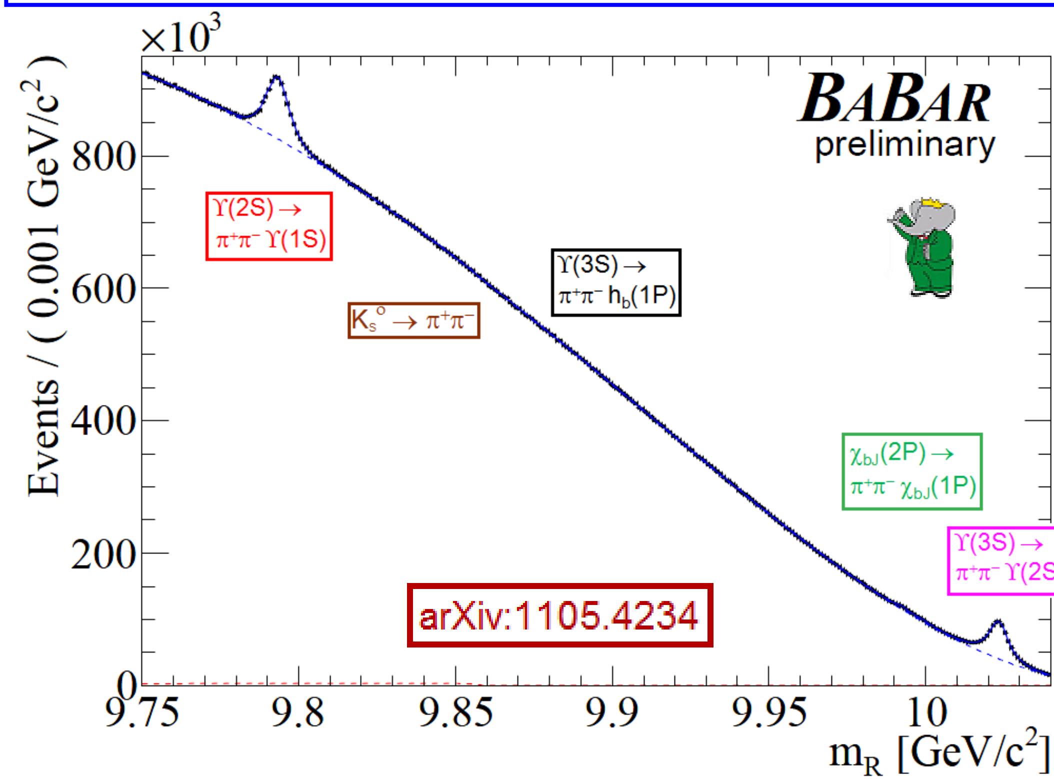




Interference with continuum is important!

Search for $h_b(1P)$ in $\Upsilon(3S) \to \pi^+\pi^- (X)$

122 M $\Upsilon(3S)$



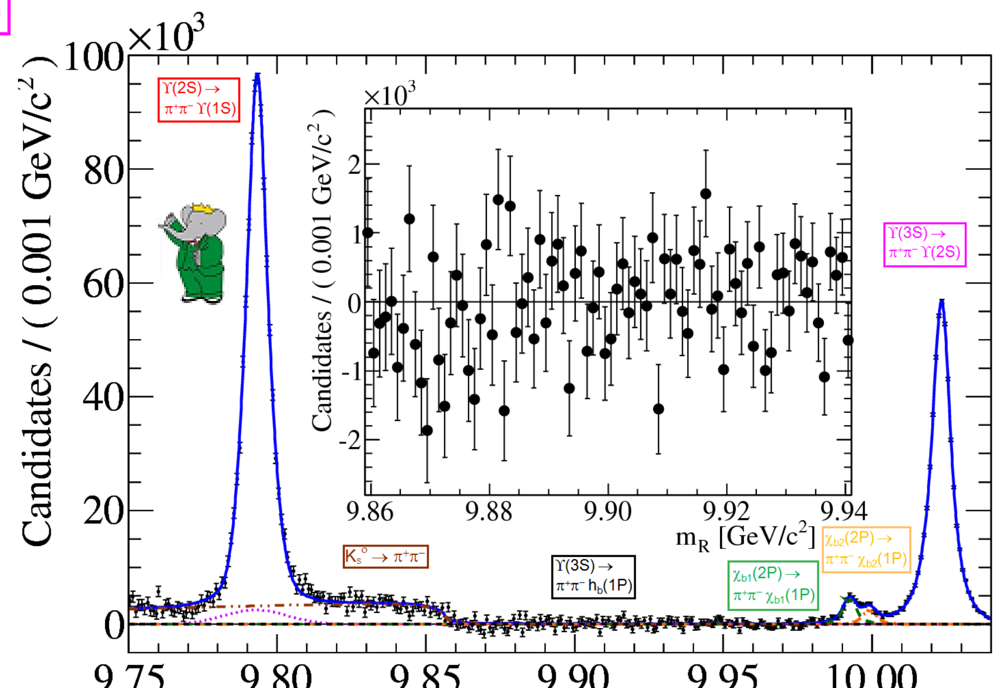
mass recoiling against the $\pi^+\pi^-$

$$m_R^2 = (m_{\Upsilon(3S)} - E_{\pi\pi})^2 - P_{\pi\pi}^2$$

expected to be within ~MeV of

$$m_{CoG} = (m_{\chi_{b0}(1P)} + 3m_{\chi_{b1}(1P)} + 5m_{\chi_{b2}(1P)}) / 9$$

$$m_{h_b(1P)} \approx 9900$$



smooth background subtracted

m_R [GeV/c²]

Fit to signal components

- $\Upsilon(3S) \to \pi^+\pi^- h_b(1P)$
- $\Upsilon(3S) \to \pi^+\pi^- \Upsilon(2S)$
- $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$
- $\chi_b(2P) \to \pi^+\pi^- \chi_b(1P)$

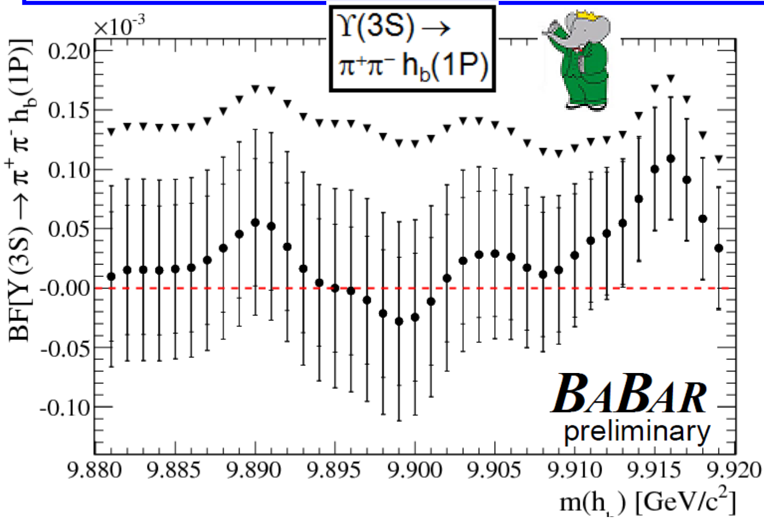
plus smooth background

- non-peaking combinatorial
- $K^0 \to \pi\pi$

Bottomonium dipion transitions

arXiv:1105.4234

122 M $\Upsilon(3S)$



central value and 90% CL UL as a function of h_b mass

No evidence for $\Upsilon(3S)\to\pi^+\pi^- h_b(1P)$:

$\mathcal{B}(\Upsilon(3S)\to\pi^+\pi^- h_b(1P)) < 1.8\times10^{-4}$ (90%CL)

over the whole search region

x10 improvement over previous CLEO limit PRD 43,1448(1991)

Precise measurements on other transitions

$$\mathcal{B}[\Upsilon(3S)\to\pi^+\pi^-\Upsilon(2S)] = (3.00\pm0.02(\text{stat.})\pm0.14(\text{syst.}))\%$$

$$\mathcal{B}[\Upsilon(3S)\to X\chi_{b1}(2P)]\times\mathcal{B}[\chi_{b1}(2P)\to\pi^+\pi^-\chi_{b1}] = (1.16\pm0.07\pm0.12)\times10^{-3}$$

$$\mathcal{B}[\Upsilon(3S)\to X\chi_{b2}(2P)]\times\mathcal{B}[\chi_{b2}(2P)\to\pi^+\pi^-\chi_{b2}] = (0.64\pm0.05\pm0.08)\times10^{-3}$$

$$\mathcal{B}[\Upsilon(3S)\to X\Upsilon(2S)]\times\mathcal{B}[\Upsilon(2S)\to\pi^+\pi^-\Upsilon] = (1.78\pm0.02\pm0.11)\%$$

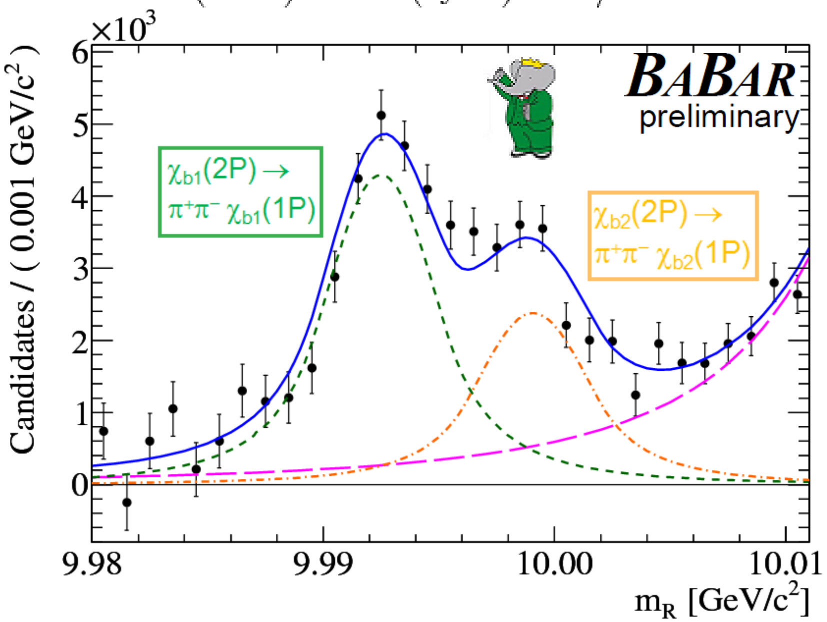
$$\Delta m[\Upsilon(3S)\text{-}\Upsilon(2S)] = 331.50\pm0.02(\text{stat.})\pm0.13(\text{syst.})\ \text{MeV}/c^2$$

dipion transitions between $\chi_{b1,2}$ states clearly separated for the first time

$\mathcal{B}(\chi_{b1}(2P)\to\pi^+\pi^-\chi_{b1}(1P)) = (9.2\pm0.6\pm0.9)\times10^{-3}$

$\mathcal{B}(\chi_{b2}(2P)\to\pi^+\pi^-\chi_{b2}(1P)) = (4.9\pm0.4\pm0.6)\times10^{-3}$

consistent with the CLEO measurement (the two transitions were not resolved) PRD 73, 012003 (2006)



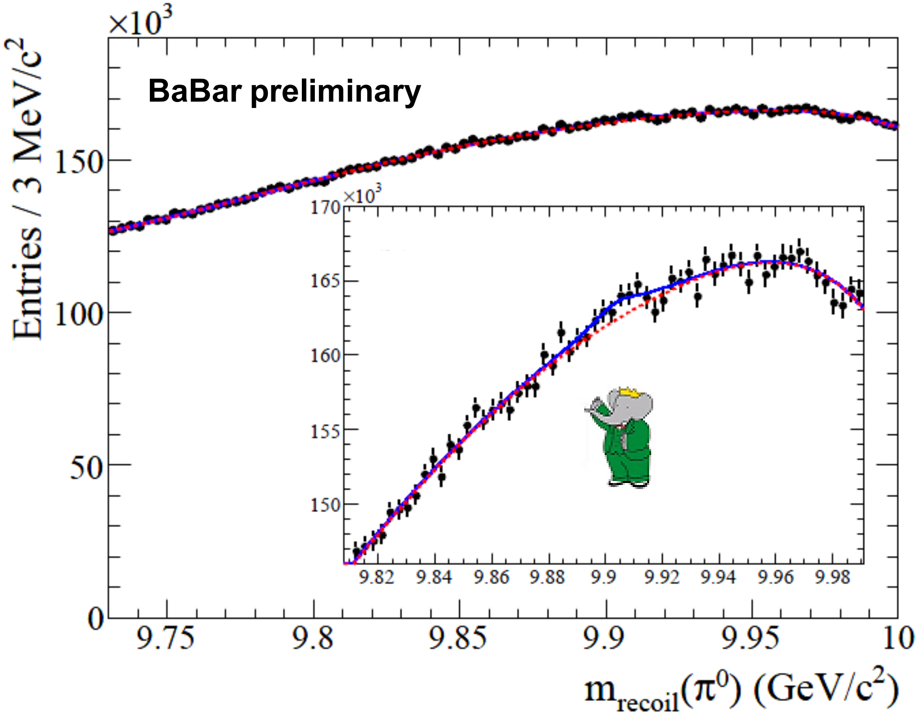
Evidence for $\Upsilon(3S)\to\pi^0 h_b(1P)$ Preliminary

122 M $\Upsilon(3S)$

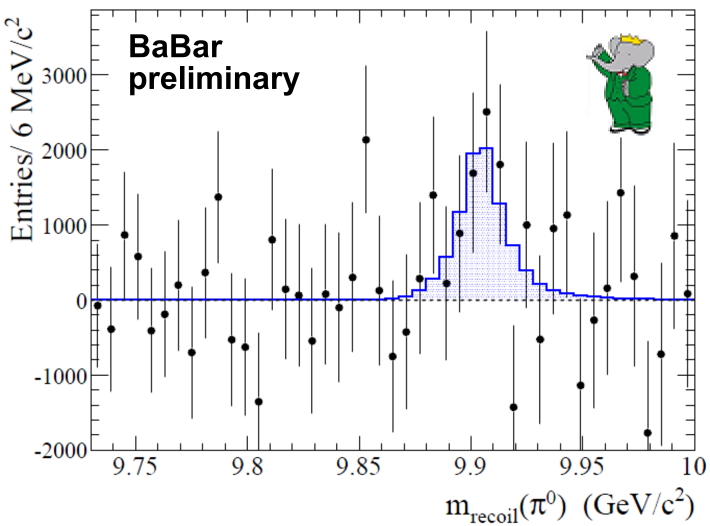
Select events with a π^0 and a photon compatible with $h_b\to\gamma\eta_b(1S)$ (dominant decay mode)

In each bin of $m_{recoil}{}^2 = (m_{\Upsilon(3S)} - E^*_{\pi^0})^2 - P^{*2}_{\pi^0}$ # of ev with real π^0 from $\gamma\gamma$ inv. mass dist.

arXiv:1102.4565



$m_{recoil}(\pi^0)$ background subtracted



9145±2804 signal events

$M(h_b)$= (9902±4(stat)±1(syst)) MeV/c^2 consistent with predictions

$\mathcal{B}(\Upsilon(3S)\to\pi^0 h_b(1P))\times\mathcal{B}(h_b(1P)\to\gamma\eta_b(1S))$=(3.7±1.1±0.7) $\times10^{-4}$

Statistical significance (from $\sqrt{\Delta\chi^2}$): 3.2 σ

evaluated at the expected mass value $M(h_b)$=9900 MeV/c^2

including systematic error: 3.0 σ

(see also talk at Quarkonium 3 parallel session)

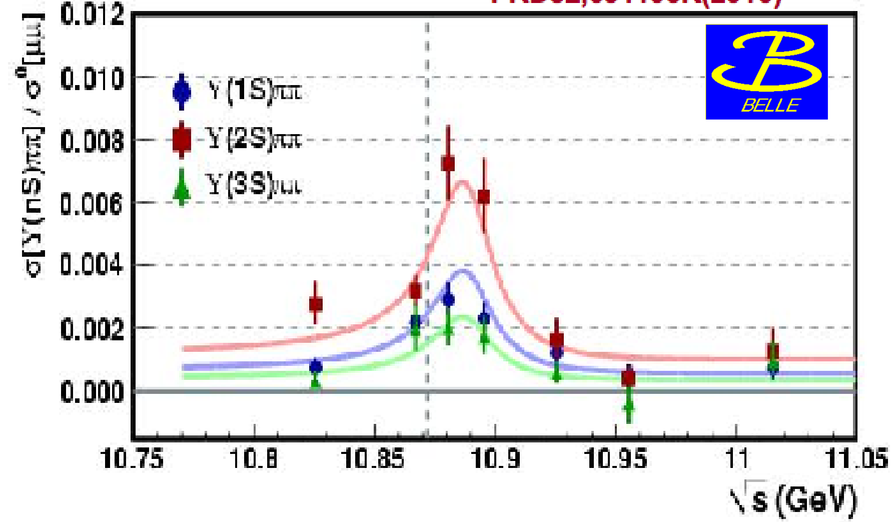
Bottomonium decays of $\Upsilon(5S)$

In 2008 Belle reported a surprisingly high production of $\Upsilon(nS)\,\pi^+\pi^-$ at the $\Upsilon(5S)$ energy with 21.7 fb^{-1}

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

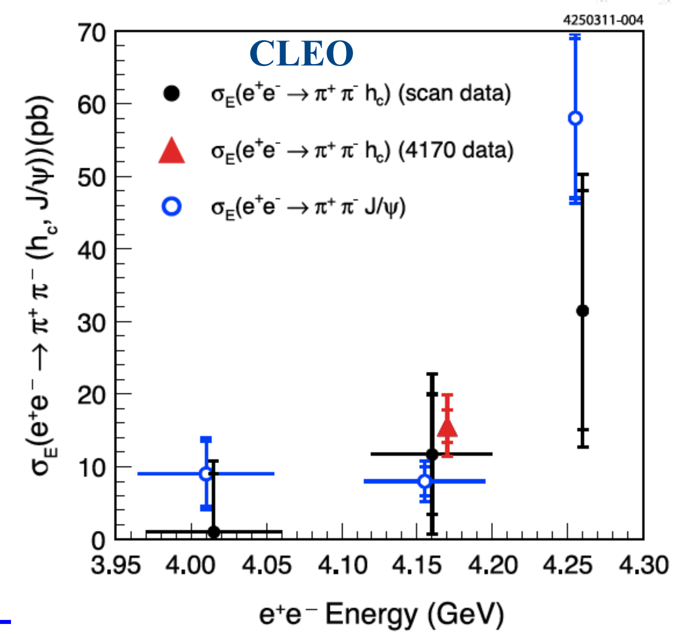
PRD82,091106R(2010)



Is it $\Upsilon(5S)$ or Y_b partner of Y(4260)?

arXiv:1104.2025

Observation of $e^+e^- \to \pi^+\pi^-\, h_c$ by CLEO



Enhancement of $\sigma(h_c\,\pi^+\pi^-)$@ Y(4260)

is the $\sigma(h_b\,\pi^+\pi^-)$enhanced at the Y_b?

$\Upsilon(5S)\to\pi\pi X$

Large data sample collected by Belle to study B*, Bs .. but not only

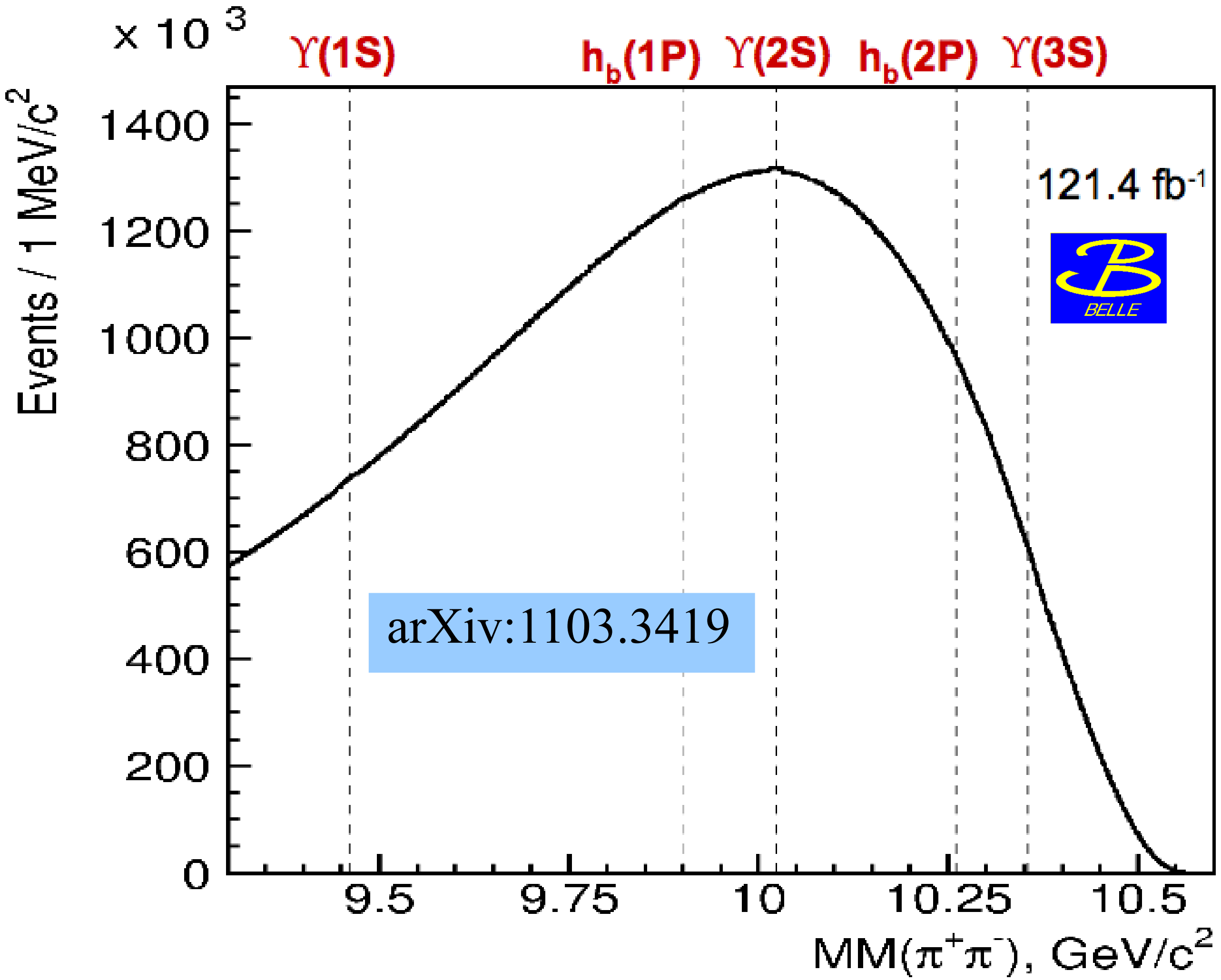
mass recoiling against the $\pi^+\pi^-$

$MM(\pi^+\pi^-)^2 = (P_{\Upsilon(5S)} - P_{\pi\pi})^2$

continuum events have "jet-like" shape:

select events with R2<0.3

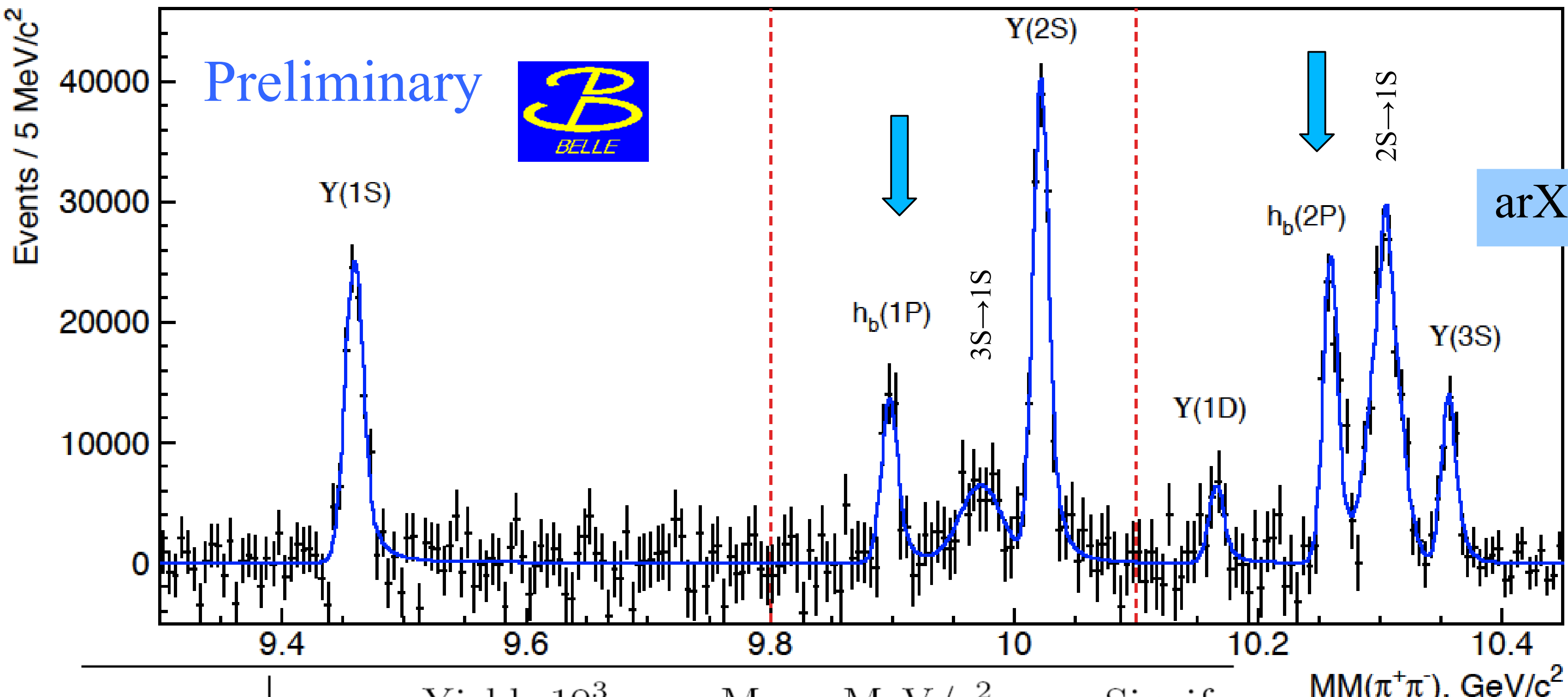
(Ratio of Fox-Wolfram moments)



$\Upsilon(5S)\to\pi\pi$ X: observation of $h_b(1P)$ and $h_b(2P)$

121.4 fb^{-1}

arXiv:1103.3419



	Yield, 10^3	Mass, MeV$/c^2$	Signif.
$\Upsilon(1S)$	$105.2 \pm 5.8 \pm 3.0$	$9459.42 \pm 0.53 \pm 1.02$	$18.2\,\sigma$
$h_b(1P)$	$50.4 \pm 7.8^{+4.5}_{-9.1}$	$9898.25 \pm 1.06^{+1.03}_{-1.07}$	$6.2\,\sigma$
$3S \to 1S$	55 ± 19	9973.01	$2.9\,\sigma$
$\Upsilon(2S)$	$143.4 \pm 8.7 \pm 6.8$	$10022.25 \pm 0.41 \pm 1.01$	$16.6\,\sigma$
$\Upsilon(1D)$	22.1 ± 7.8	10166.2 ± 2.4	$2.4\,\sigma$
$h_b(2P)$	$84.4 \pm 6.8^{+23.}_{-10.}$	$10259.76 \pm 0.64^{+1.43}_{-1.03}$	$12.4\,\sigma$
$2S \to 1S$	$151.6 \pm 9.7^{+9.0}_{-20.}$	$10304.57 \pm 0.61 \pm 1.03$	$15.7\,\sigma$
$\Upsilon(3S)$	$44.9 \pm 5.1 \pm 5.1$	$10356.56 \pm 0.87 \pm 1.06$	$8.5\,\sigma$

Significance w/ systematics

$h_b(1P)$ 5.5σ

$h_b(2P)$ 11.2σ

$h_b(1P)$ and $h_b(2P)$

arXiv:1103.3419

Deviations from CoG of χ_{bJ} masses

$h_b(1P)$ 1.62 ± 1.52 MeV/c^2

$h_b(2P)$ $0.48^{+1.57}_{-1.22}$ MeV/c^2

} consistent with zero, as expected

Ratio of production rates

spin-flip

$$\frac{\Gamma[\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-]}{\Gamma[\Upsilon(5S) \to \Upsilon(2S)\,\pi^+\pi^-]} = \begin{cases} 0.407 \pm 0.079^{+0.043}_{-0.076} & \text{for } h_b(1P) \\ 0.78 \pm 0.09^{+0.22}_{-0.10} & \text{for } h_b(2P) \end{cases}$$

no spin flip $S(\Upsilon) = 1$ $S(h_b) = 0$

Process with spin-flip of heavy quark is not suppressed

- exotic ?
- rescattering? **Simonov JETP Lett 87,147(2008), D. Bugg, arXiv:1101.1659**

No h_b signal at $\Upsilon(4S)$

Bottomonium radiative transitions with converted photons

arXiv:1104.5254

Goals: search for η_b and measure the hindered E1 transitions

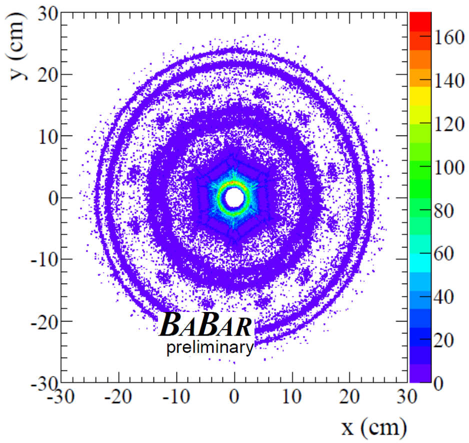
$\Upsilon(3S)\rightarrow\chi_{bJ}(1P)$, $\chi_{bJ}(2P)\rightarrow\Upsilon(1S)$

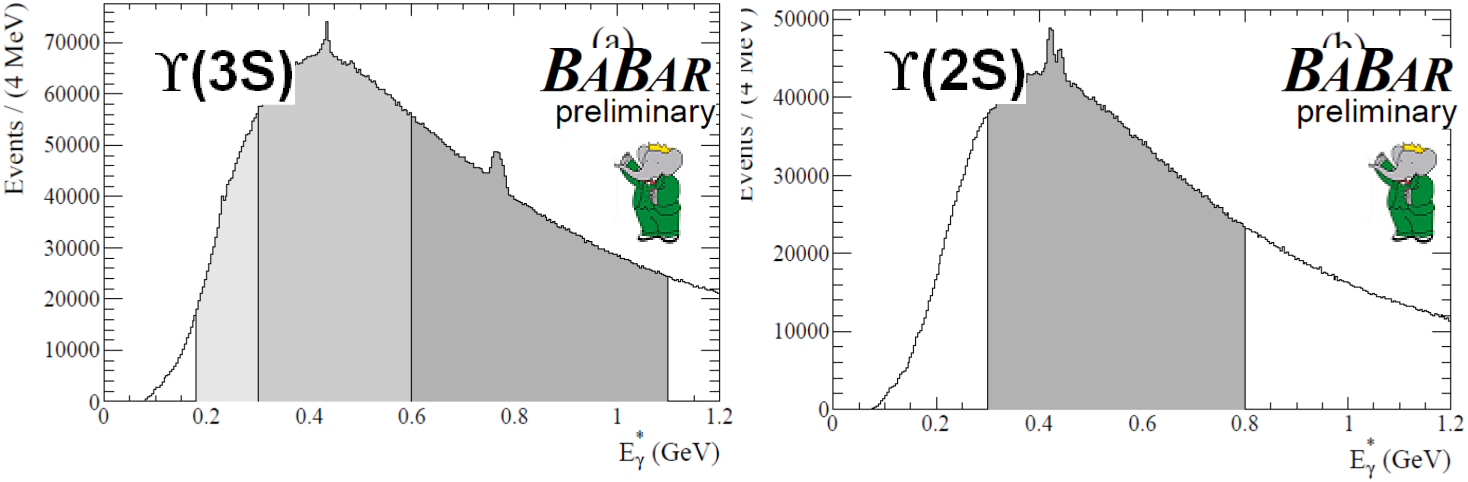
Rates generally phenomenologically well-predicted

For some of these transitions the photons are in the same energy range "overlapping" due to Doppler broadening and detector resolution

Use converted photons ($\gamma\rightarrow e^+e^-$) to improve resolution (e.g.: 25 → 5 MeV)

Price: efficiency (0.1÷2.5)% (depending on energy)

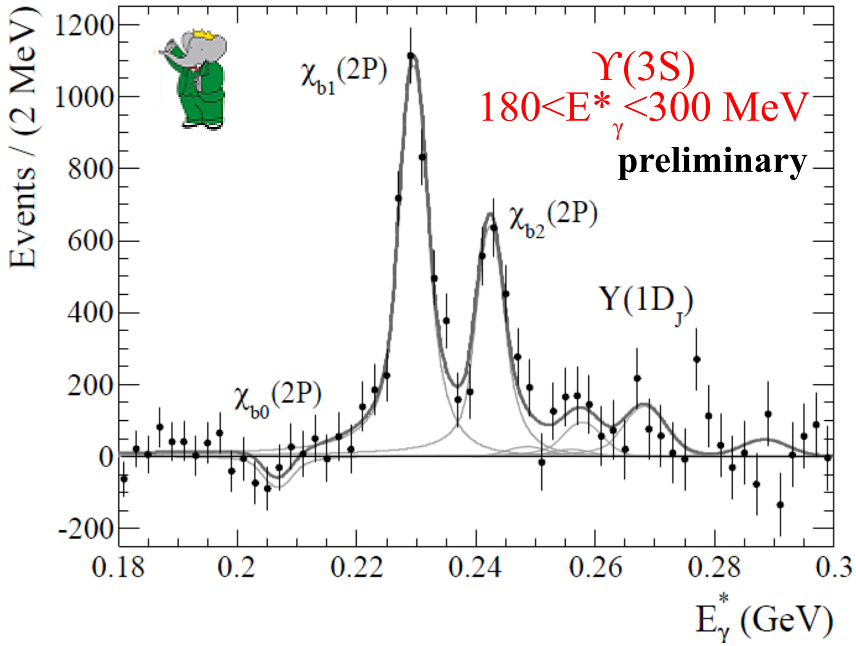


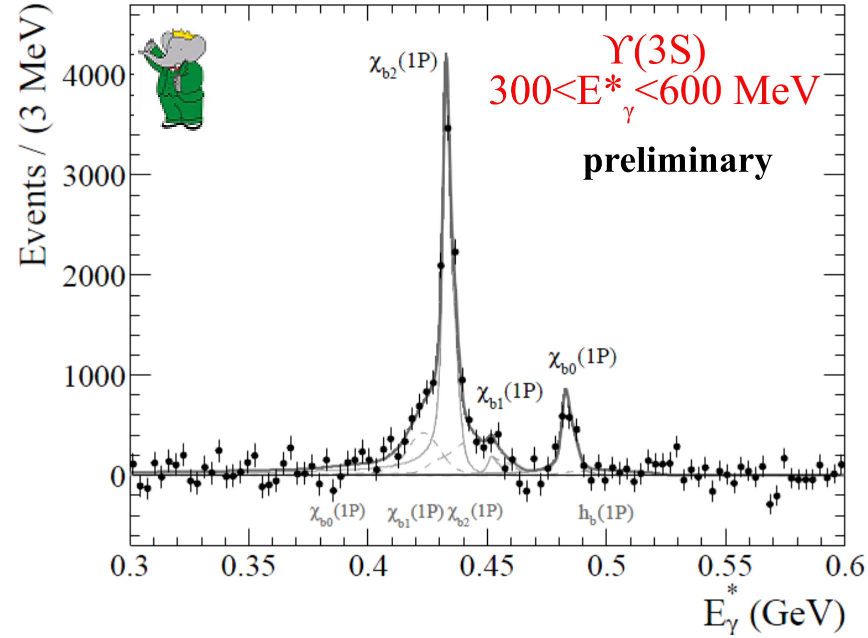


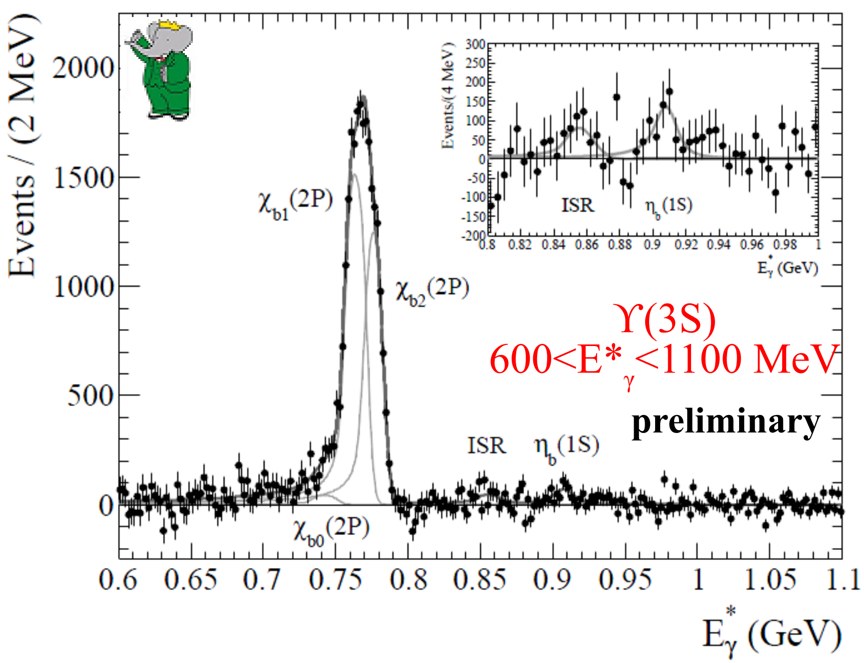
Fit the E^*_γ spectrum in 4 regions of interest

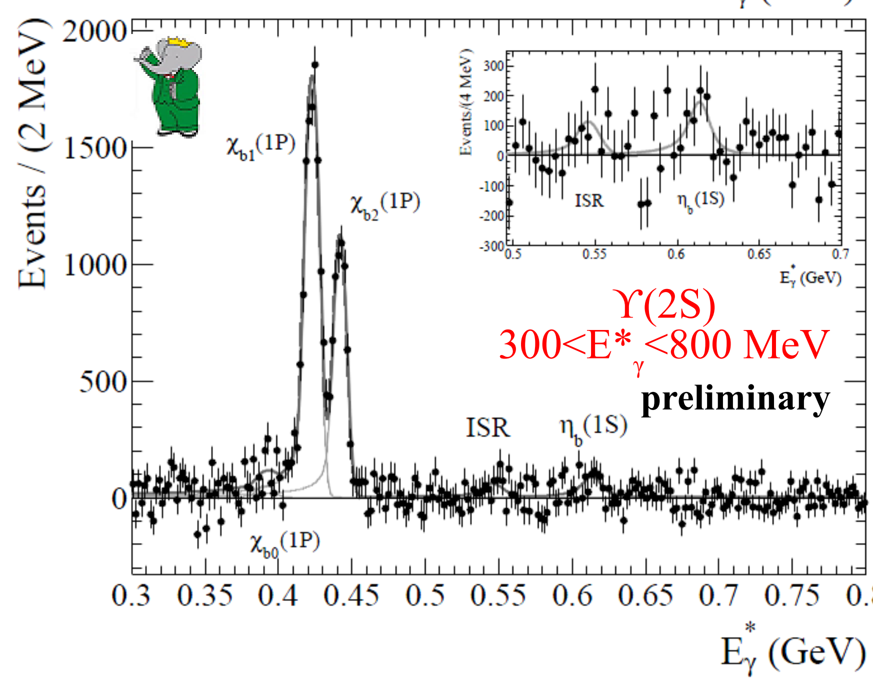
Background subtracted spectra

arXiv:1104.5254









see talk in Quarkonium 3 parallel session

Results

BABAR
CLEO: PRD 83,054003 (2011)

Most precise measurements to date in most cases

Transition	E^*_γ (MeV)	Yield	ϵ (%)	Derived Branching Fraction (%) BABAR	CUSB	CLEO
$\chi_{b0}(2P) \to \gamma\Upsilon(2S)$	205.0	-347 ± 209	0.105	$-4.9 \pm 2.9^{+0.7}_{-0.8} \pm 0.5\ (< 2.9)$	3.6 ± 1.6	< 5.2
$\chi_{b1}(2P) \to \gamma\Upsilon(2S)$	229.7	4294 ± 251	0.152	$19.5 \pm 1.1^{+1.1}_{-1.0} \pm 1.9$	13.6 ± 2.4	21.1 ± 4.5
$\chi_{b2}(2P) \to \gamma\Upsilon(2S)$	242.3	2462 ± 243	0.190	$8.6^{+0.9}_{-0.8} \pm 0.5 \pm 1.1$	10.9 ± 2.2	9.9 ± 2.7

Transition	E^*_γ (MeV)	Yield	ϵ (%)	Derived Branching Fraction ($\times 10^{-3}$) BABAR	CLEO
$\Upsilon(3S) \to \gamma\chi_{b2}(1P)$	433.1	9699 ± 318	0.794	$10.6 \pm 0.3 \pm 0.6$	7.7 ± 1.3
$\Upsilon(3S) \to \gamma\chi_{b1}(1P)$	452.2	483 ± 315	0.818	$0.5 \pm 0.3^{+0.2}_{-0.1}\ (< 1.1)$	1.6 ± 0.5
$\Upsilon(3S) \to \gamma\chi_{b0}(1P)$	483.5	2273 ± 307	0.730	$2.7 \pm 0.4 \pm 0.2$	3.0 ± 1.1

No evidence in BaBar for $\Upsilon(3S) \to \gamma\chi_{b1}(1P)$

3S→1P rates differ from the expected $E_\gamma^3(2J+1)$ pattern

Transition	E^*_γ (MeV)	Yield	ϵ (%)	Derived Branching Fraction (%) BABAR	CB	CUSB	CLEO
$\chi_{b0}(1P) \to \gamma\Upsilon(1S)$	391.5	391 ± 267	0.496	$2.3 \pm 1.5^{+1.0}_{-0.7} \pm 0.2\ (< 4.6)$	< 5	< 12	1.7 ± 0.4
$\chi_{b1}(1P) \to \gamma\Upsilon(1S)$	423.0	12604 ± 285	0.548	$36.2 \pm 0.8 \pm 1.7 \pm 2.1$	34 ± 7	40 ± 10	33.0 ± 2.6
$\chi_{b2}(1P) \to \gamma\Upsilon(1S)$	442.0	7665^{+270}_{-272}	0.576	$20.2 \pm 0.7^{+1.0}_{-1.4} \pm 1.0$	25 ± 6	19 ± 8	18.5 ± 1.4
$\Upsilon(2S) \to \gamma\eta_b(1S)$	$613.7^{+3.0+0.7}_{-2.6-1.1}$	1109 ± 348	1.050	$0.11 \pm 0.04^{+0.07}_{-0.05}\ (< 0.22)$	-	-	-

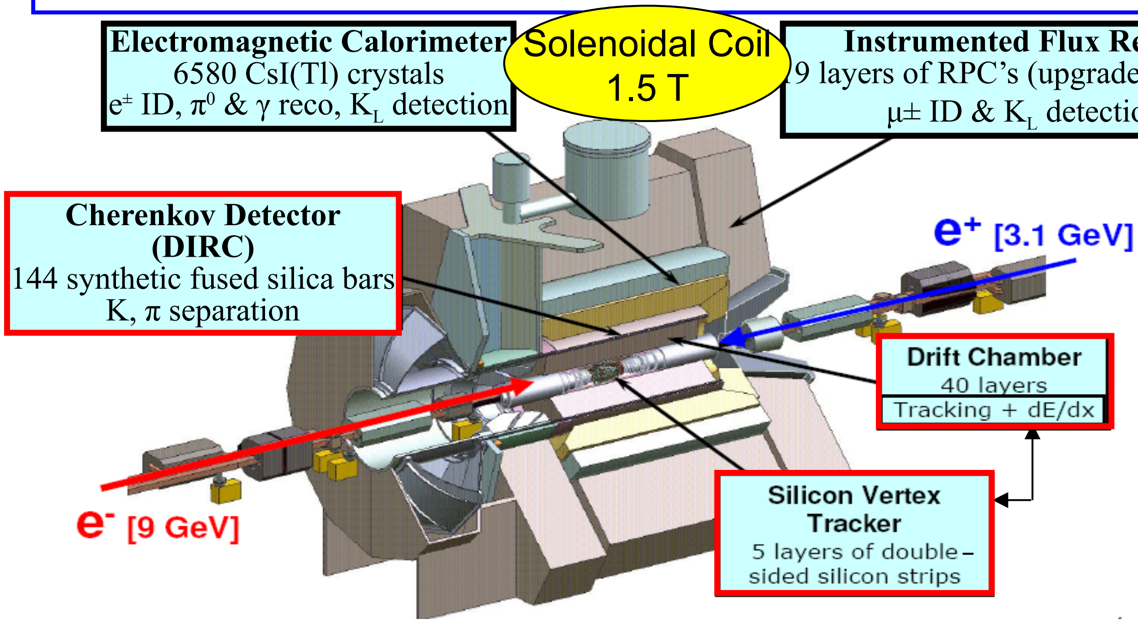
Transition	E^*_γ (MeV)	Yield	ϵ (%)	Derived Branching Fraction (%) BABAR	CUSB	CLEO
$\chi_{b0}(2P) \to \gamma\Upsilon(1S)$	742.7	469^{+260}_{-259}	1.025	$0.7 \pm 0.4^{+0.2}_{-0.1} \pm 0.1\ (< 1.2)$	< 1.9	< 2.2
$\chi_{b1}(2P) \to \gamma\Upsilon(1S)$	764.1	14965^{+381}_{-383}	1.039	$9.9 \pm 0.3 \pm 0.4 \pm 0.9$	7.5 ± 1.3	10.4 ± 2.4
$\chi_{b2}(2P) \to \gamma\Upsilon(1S)$	776.4	11283^{+384}_{-385}	1.056	$7.1 \pm 0.2 \pm 0.3 \pm 0.9$	6.1 ± 1.2	7.7 ± 2.0
$\Upsilon(3S) \to \gamma\eta_b(1S)$	$907.9 \pm 2.8 \pm 0.9$	933^{+263}_{-262}	1.388	$0.059 \pm 0.016^{+0.014}_{-0.016}$	-	-

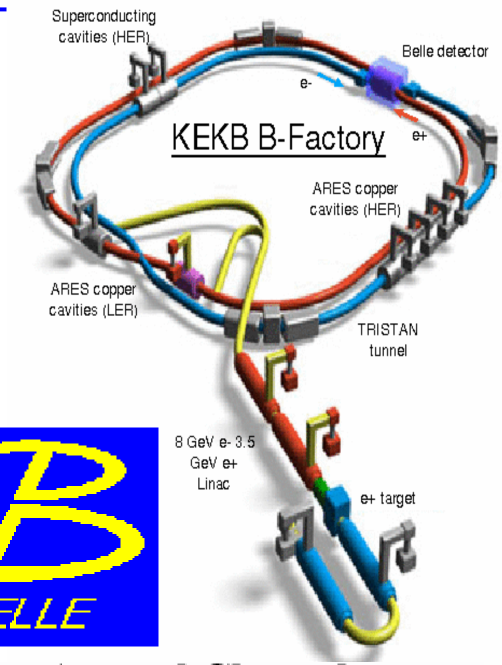
Conclusions

- B factories gave a dramatic contribution to heavy flavor spectroscopy
  - conventional states and a number of puzzling new states
  - bottomonium singlet state finally observed
  - precision mesurements of bottomonium radiative and hadronic transitions
  - still actively analizing data, expect more results from B factories
  - yet some measurements are statistics limited
    - more precise measurements on bottomonia will likely have to wait superB or Belle II
- BES-III already providing exciting data on charmonia and D states
- LHC starting to exploit their data
  - unique gateway to Bs and Bc spectra

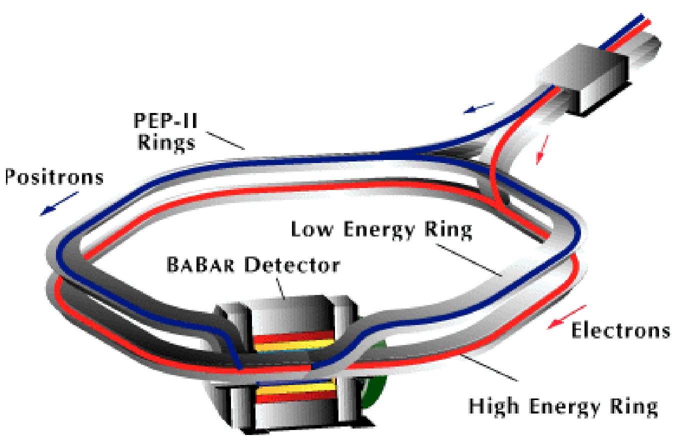
Additional slides

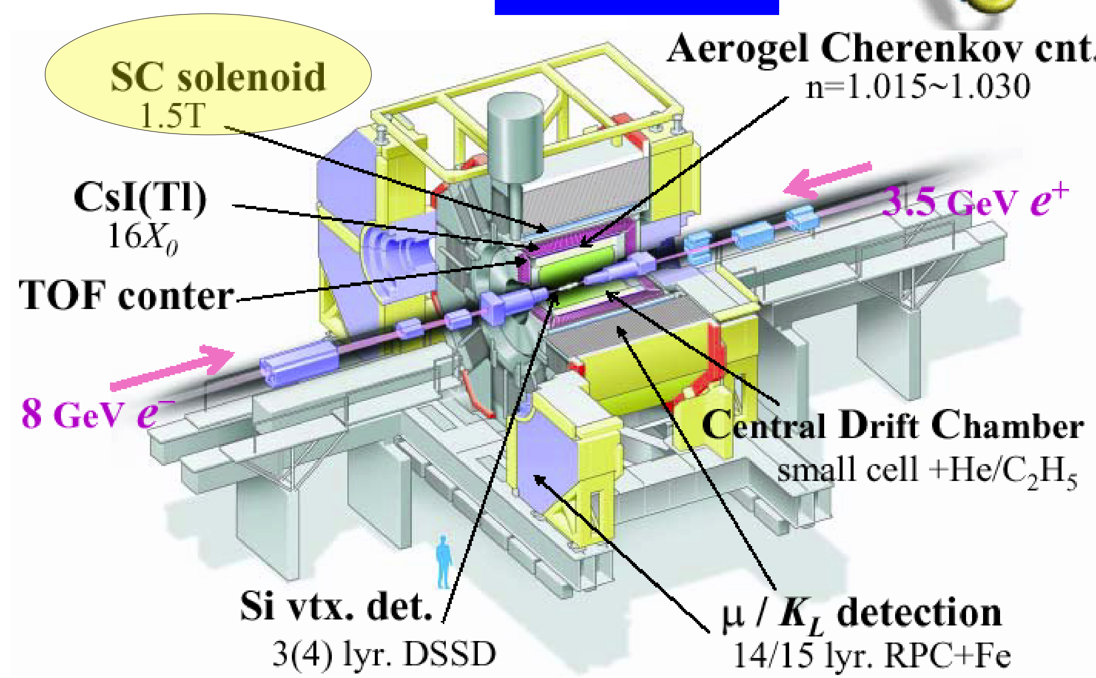
BaBar and Belle





BELLE





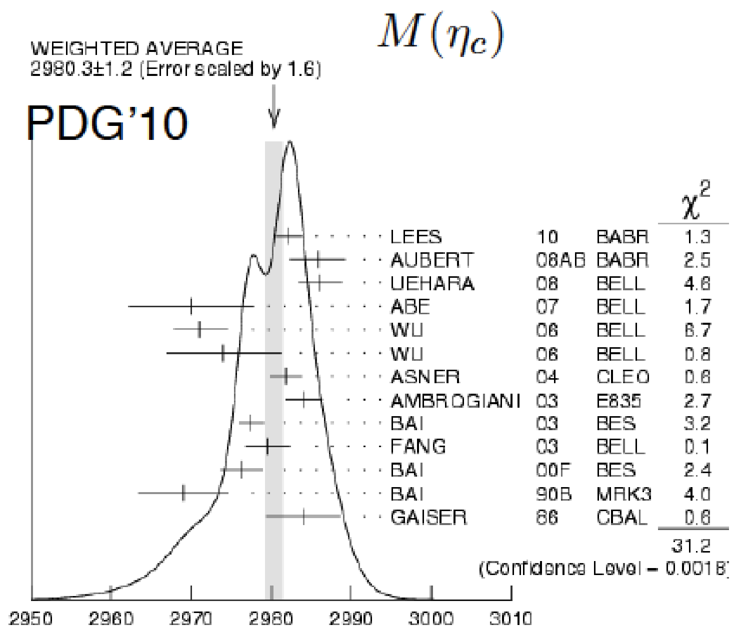
BABAR™

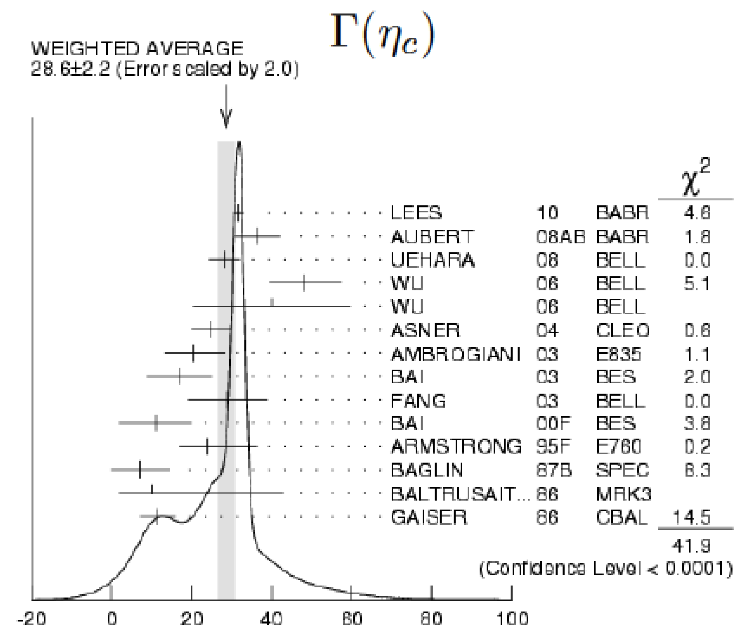
Charm mesons at B-factories

- **Inclusive production,** mesons are fully reconstructed in $c\bar{c}$ events:
  - $b\bar{b}$ and $c\bar{c}$ cross sections are comparable at their CM energy (~1 nb)
  - Rejecting candidates with CM momentum larger than 2.6 GeV/c removes candidates from B decays and reduces combinatoric background
- **Exclusive production,** mesons are reconstructed in B decays:
  - Charm mesons are really abundant in B decays, almost one for each decay
  - B candidates are selected using the mass and CM energies

$e^+e^- \to$	Cross section (nb)	BaBar (0.55 ab^{-1})	Belle (1 ab^{-1})
$c\bar{c}$	1.30	0.7B evts	1.3B evts
$b\bar{b}$	1.05	0.55B evts	1B evts

Singlet S states parameters





Large spread in mass and widths measured by different techniques

Widths measured in radiative J/ψ decays tend to be lower than the values measured in B decays or γγ reactions

η_c(2S) parameters not well known, decay modes largely unknown