Physics goals for data taking at $\Upsilon(3S)$

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Outline

Experiment	Scans/Off. Res.	$\Upsilon(5S)$ 10876 MeV		$\Upsilon(4S)$ 10580 MeV		$\Upsilon(3S)$ 10355 MeV		$\Upsilon(2S)$ 10023 MeV		$\Upsilon(1S)$ 9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

Physics with 600 M Υ(3S):

- **The η,π transitions**
- **Hindered E1 transitions**
- **M1 transitions to η_b(1,2S)**
- **D waves**
- **Υ(3S) → ππ Υ(1,2S)**
- Antinuclei from Υ(3S)

Target Ldt: 150 fb^{-1}

All during BEAST-2 Phase?
Or
50 during BEAST-2, and 100 while taking first Υ(4S) data (3 ab^{-1})

Alternative scenarios:

Running at Υ(4S) and continuum point
Running at Υ(6S), 30 fb^{-1} = 6x Belle-I

Scan of $\Upsilon(1^3D_1)$, 7x2fb^{-1} points , 14 total
Scan of $\Upsilon(2^3D_1)$, 10x1.5fb^{-1} points , 15 total

Can we do them during BEAST-2 Phase?

Luminosity ramp-up scenarios:
- at L1 = $1x10^{34}$, 0.75 fb^{-1} / day
  How many days to reach L1?
  How long will Phase-II last?

Krakow B2TIP: WG7

R.Mizuk(ITEP), *R.Mussa (INFN Torino)*, C.P.Shen(Beihang),
Y.Kiyo(Juntendo), A.Polosa (Roma), S.Prelovsek (Ljubljana)

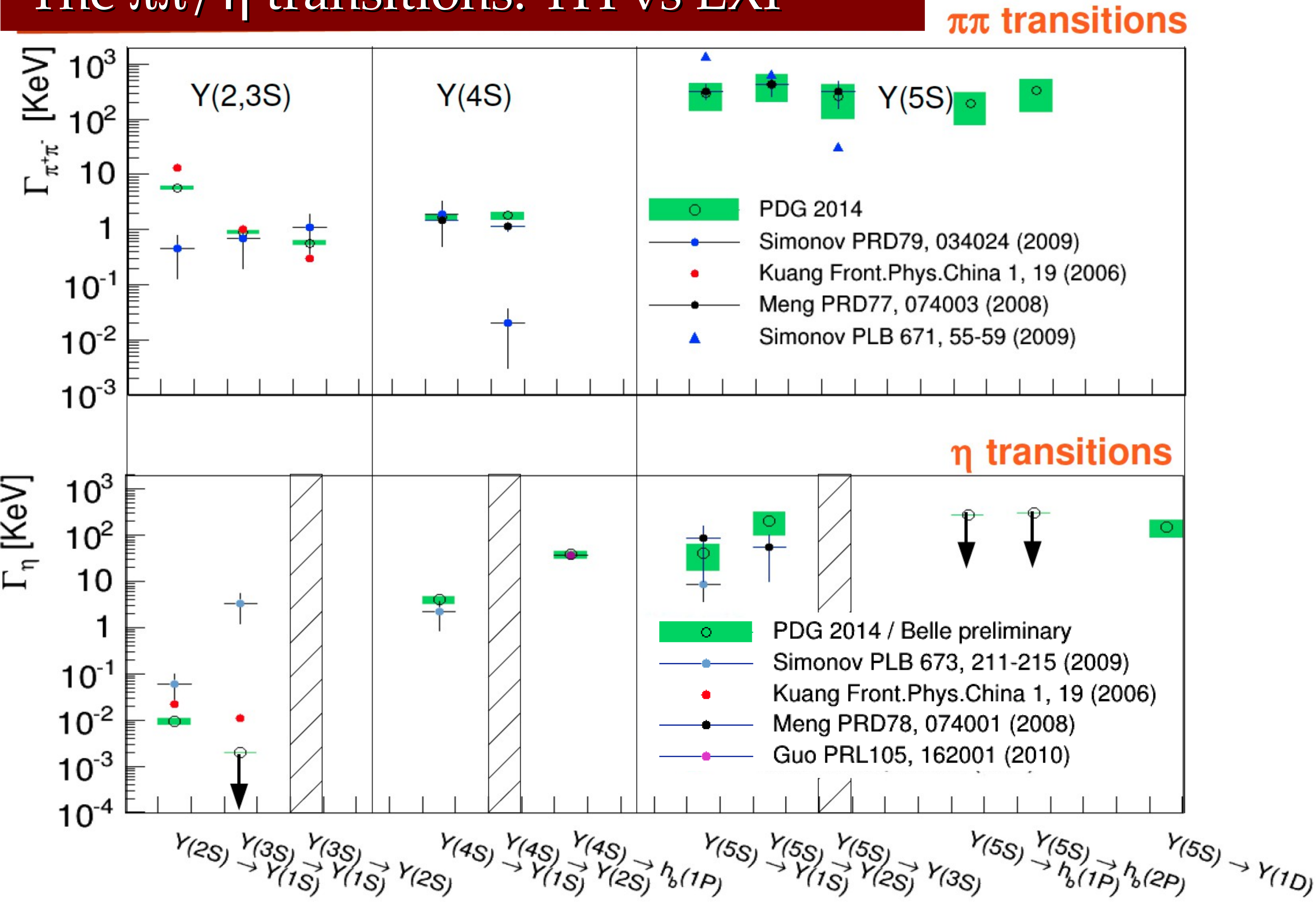
Theory:

Maiani,Guerrieri: *Charmed (and light) Tetraquarks*
Ali: *Beauty,charmed and light Tetraquarks*
Guo: *Molecules*
Eichten: *Hadronic Transitions in* $c\bar{c}$ *and* $b\bar{b}$
Vairo: *Radiative Transitions in* $c\bar{c}$ *and* $b\bar{b}$

Experiment:

Mizuk: *Running at 6S, scanning 10.95 to 11.25*
Mussa: *Running at 3S, scanning Y(1,2D)*
Tamponi: *MC Generators*

The ππ / η transitions: TH vs EXP



Hadron transition puzzle: solved?

From Eichten's talk at Krakow

- Above heavy flavor production threshold the usual QCDME fails.
  - The transitions rate are much larger than expected.
  - The factorization assumption fails. Heavy quark and light hadronic dynamics interact strongly due to heavy flavor meson pair (four quark) contributions to the quarkonium wavefunctions. Magnetic transitions not suppressed.
  - A new mechanism for hadronic transitions is required.
- A new mechanism, in which the dynamics is factored differently, is purposed.
  - It requires an intermediate state containing two narrow heavy-light mesons nearby and near threshold (v -> zero). This is the factor. Other light hadrons may be present or not.
    - The production of this state from the initial state is calculated using familiar strong dynamics of coupled channels.
    - The evolution of this threshold system into the final quarkonium state and light hadrons requires a new threshold dynamics.
- HQS as well as the usual SU(3) and chiral symmetry expectations are recovered.
- Resolves the puzzles in η transitions.

Hadron transitions: a new paradigm?

From Eichten's talk at Krakow

For lower states, QCDME works:

$$R_{Q\bar{Q}}(n \to m) \equiv \frac{\Gamma(n^3S_1 \to m^3S_1 + \eta)}{\Gamma(n^3S_1 \to m^3S_1 + \pi^+\pi^-)} :$$

Ratio	theory	experiment
$R^{c\bar{c}}(2 \to 1)$	3.29×10^{-3}	9.78×10^{-2}
$R^{b\bar{b}}(2 \to 1)$	1.16×10^{-3}	1.16×10^{-3}
$R^{b\bar{b}}(3 \to 1)$	4.57×10^{-3}	$< 4.13 \times 10^{-3}$
$R^{b\bar{b}}(4 \to 1)$	2.23×10^{-3}	2.45
$R^{b\bar{b}}(4 \to 2)$	5.28×10^{-4}	

~ 30 > theory
sets $C_3/C_1 = 0.143 \pm 0.024$
related to ππ suppression

~ 1000 > theory

$2M(D^0)\text{-}M(\psi') = 53.11\ \mathrm{MeV}/c^2$ $\quad 2M(B^0)\text{-}M(\Upsilon 3S) = 204\ \mathrm{MeV}/c^2$

$2M(D^+)\text{-}M(\psi') = 43.57\ \mathrm{MeV}/c^2$ $\quad 2M(B^+)\text{-}M(\Upsilon 3S) = 204\ \mathrm{MeV}/c^2$

$2M(D_s)\text{-}M(\psi') = 250.5\ \mathrm{MeV}/c^2$ $\quad 2M(B_s)\text{-}M(\Upsilon 3S) = 378\ \mathrm{MeV}/c^2$

Large enhancement of $\psi' \to \eta\psi$ explained by the proximity of the $D\bar{D}$,$D_s\bar{D}_s$ thresholds.

Large isospin violation in $\psi' \to \pi h_c$ due to the large D^0-D^+ mass difference

In bottomonium , degenerate $B^0\bar{B}^0$ / B^+B^- threshold → no isospin violation

The eta transition 3S to 1S is still in the ballpark: wavefunction overlaps can suppress is , like it happens in hindered E1 transitions. **We ought to measure it, and (precisely) the E1 hindered transitions from 3S to 1P states.**

The η transitions

Testing QCD multipole expansion
In low mass region:
Y' → ηY : M2*E1+M1*M1
Y' → ππY : E1*E1
(Y' → ηY)/(Y' →ππY) ~ $(\Lambda_{QCD}/m_b)^2$

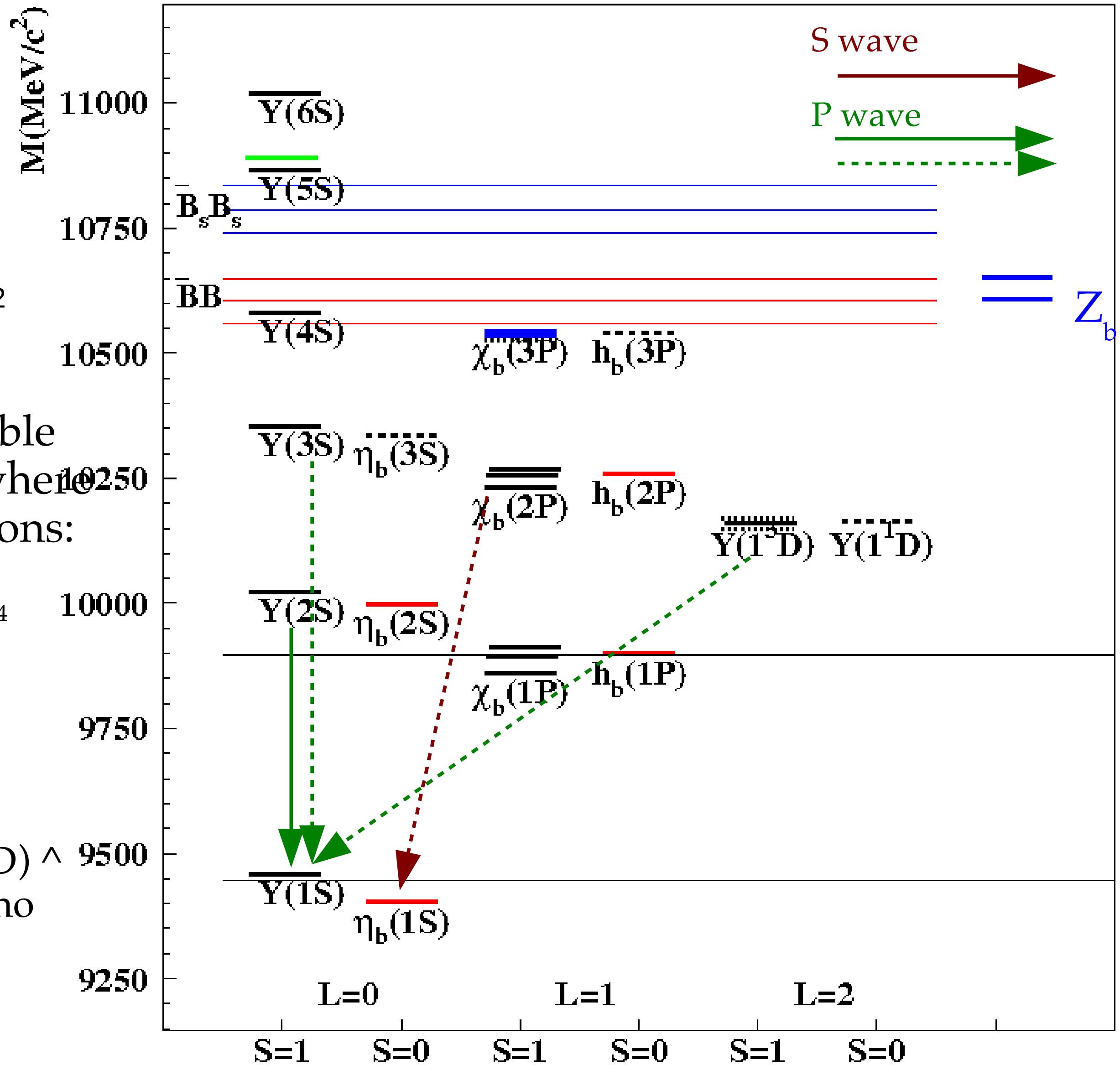
Three more transitions should be visible from Y(3S) but experimental limits, where available, are below theory expectations:

- B(Y(3S) → ηY(1S))   theory: 5-10× 10^{-4}
BaBar PRD84,42003(2011)   <1x10^{-4}

- Y(1D) → ηY(1S)
Voloshin: PLB 562, 68(2003)
QCD Axial Anomaly should enhance Y(1D) ^ ηY(1S) with respect to Y(1D) ^ ππY(1S): no quantitative estimates available.

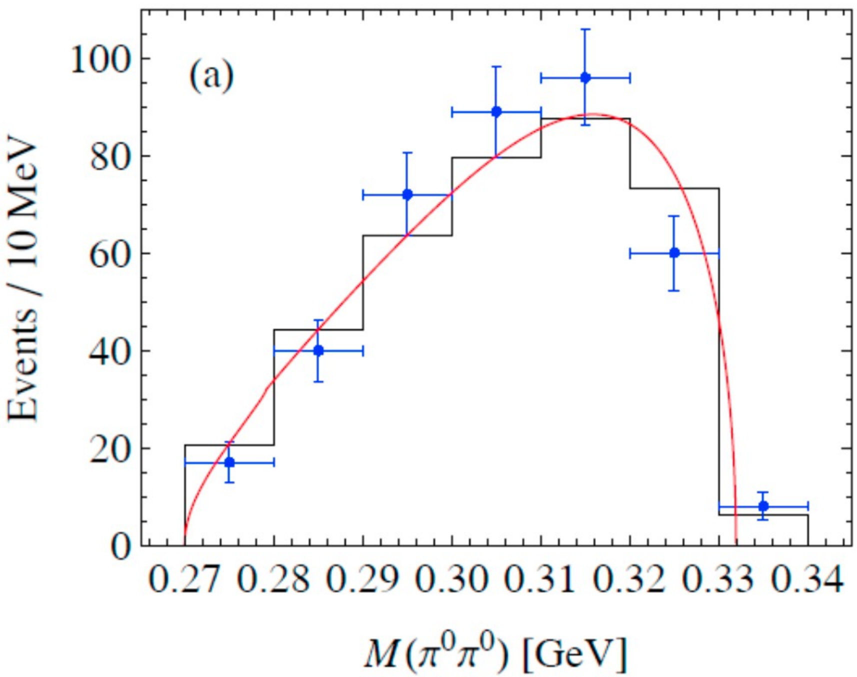
- B(χ_{b0}(2P) → η η_b)~ few 10^{-3} (S-wave)
Voloshin: Mod.Phys.Lett. A19, 2895(2004)

$$\frac{\Gamma(\chi_{b0}(2P)\to\eta\eta_b)}{\Gamma(\chi_{b0}(2P)\to\gamma\Upsilon)} \approx \frac{\pi^3}{3\alpha}\,\frac{p_\eta f_\eta^2 m_\eta^4}{\omega_\gamma^3 m_b^2\Delta^2} \approx 0.2\left(\frac{f_\eta}{0.16\ \text{GeV}}\right)^2\left(\frac{1\ \text{GeV}}{\Delta}\right)^2$$



$\Upsilon(3S) \to \Upsilon(2S)\,\pi^0\,\pi^0$

CLEO: Bhari et al. PRD79,011103 (2009)
Sample: 6M 3S decays, excl for neutrals, incl+excl for charged
Assuming Υ(2S) to ee+uu = 4.06%



Analysis	Efficiency-corrected Yield	$\mathcal{B}(\%)$
$3S\to1S\pi^0\pi^0$	6584 ± 274	$2.24 \pm 0.09 \pm 0.11$
$3S\to2S\pi^0\pi^0$	4391 ± 207	$1.82 \pm 0.09 \pm 0.12$
$2S\to1S\pi^0\pi^0$	38069 ± 727	$8.43 \pm 0.16 \pm 0.42$

Analysis	Data Yield	Efficiency (%)	$\mathcal{B}$ (%)
3S Excl.	5215 ± 72	39.7 ± 0.1	$4.47 \pm 0.06 \pm 0.18$
3S Incl.	184760 ± 430	69.9 ± 0.2	$4.46 \pm 0.01 \pm 0.14$
Average			$4.46 \pm 0.01 \pm 0.13$
2S Excl.	26417 ± 163	32.0 ± 0.1	$18.26 \pm 0.11 \pm 0.81$
2S Incl.	824418 ± 908	50.3 ± 0.1	$17.99 \pm 0.02 \pm 0.59$
Average			$18.02 \pm 0.02 \pm 0.61$

	$\Upsilon(3S)\to$				$\Upsilon(2S)\to$		
Contribution	$\Upsilon(1S)\pi^+\pi^-$ Excl.	$\Upsilon(1S)\pi^+\pi^-$ Incl.	$\Upsilon(1S)\pi^0\pi^0$	$\Upsilon(2S)\pi^0\pi^0$	$\Upsilon(1S)\pi^+\pi^-$ Excl.	$\Upsilon(1S)\pi^+\pi^-$ Incl.	$\Upsilon(1S)\pi^0\pi^0$
$\pi^\pm/\pi^0$	1.2	2.4	3.2	3.2	1.2	2.4	3.2
ℓ Tracks	1.0	N/A	1.0	1.0	1.0	N/A	1.0
Luminosity	1.7	1.7	1.7	1.7	1.5	1.5	1.5
ℓ Type	2.5	N/A	2.5	2.5	2.5	N/A	2.5
MC Modelling	0.2	0.4	0.5	2.2	2.3	1.4	0.2
$\ell\ell$ BR	2.0	N/A	2.0	4.2	2.0	N/A	2.0
Other Sources	0.35	0.8	1.0	1.0	0.1	0.8	1.0
Total	4.0	3.1	5.1	6.6	4.5	3.3	5.0

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

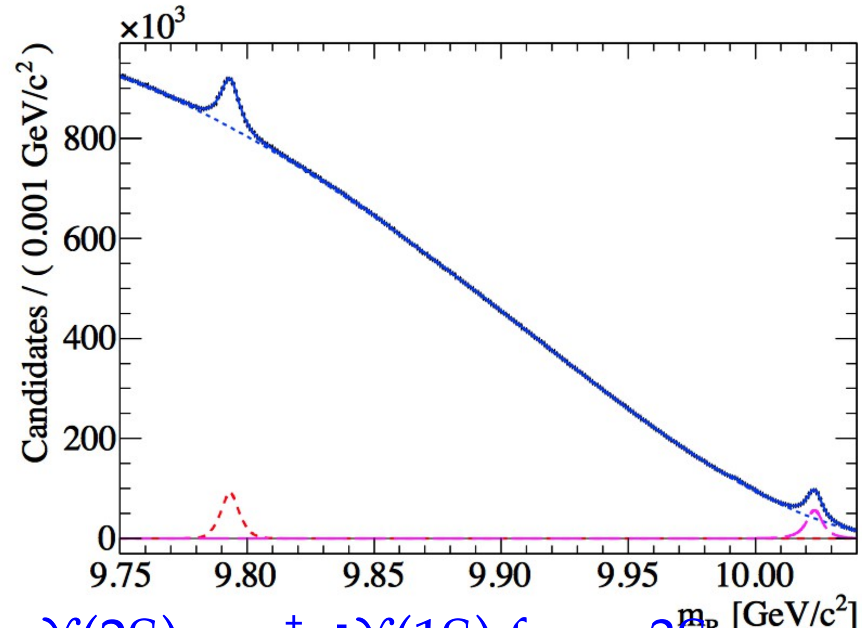
Babar: two analyses:
- Aubert et al., PRD78, 112002 (2008)

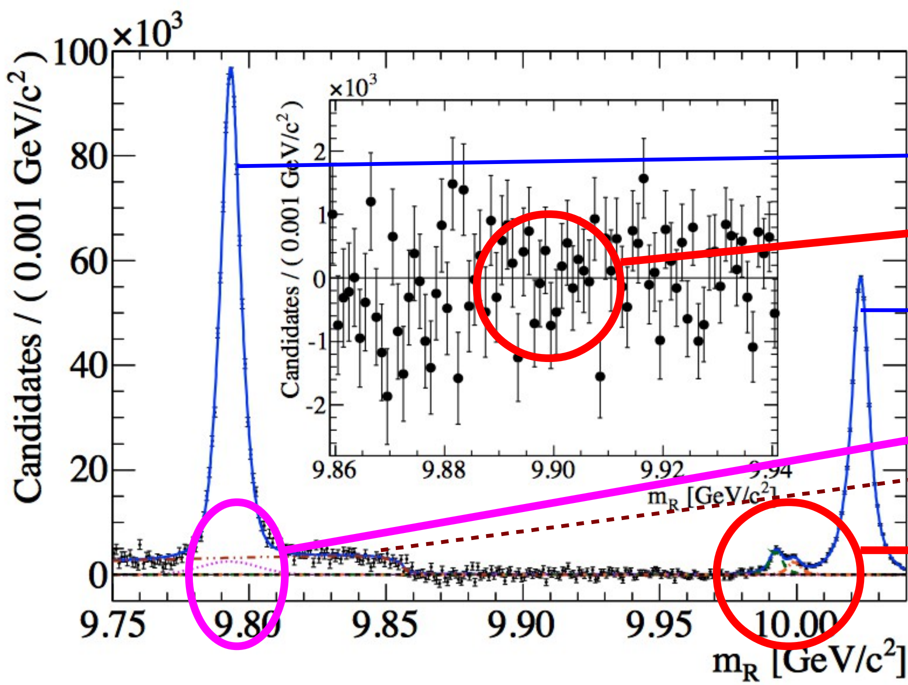
Using data from Y(4S): ISR exclusive decays
- Lees et al, PRD84, 011104 (2011)

Inclusive dipion transitions from 108 M Y(3S)

Systematics dominated:

Value (10^{-2})	EVTS		Document ID		TECN
(28.2 ± 1.8) × 10^{-1}	**OUR AVERAGE**	Error includes scale factor of 1.6.			
3.00 ±0.02 ±0.14	543k		LEES	2011C	BABR
2.40 ±0.10 ±0.26	800	1	AUBERT	2008BP	BABR
3.12 ±0.49	980	2, 3	BUTLER	1994B	CLE2
2.13 ±0.38	974	4	BROCK	1991	CLEO





- $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ from 3S
- No $\Upsilon(3S) \to \pi^+\pi^- h_b(1P)$
- $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S)$
- $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ from ISR
- $K_s \to \pi^+\pi^-$
- $\chi_{b1,2}(2P) \to \pi^+\pi^-\chi_{b1,2}(1P)$

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

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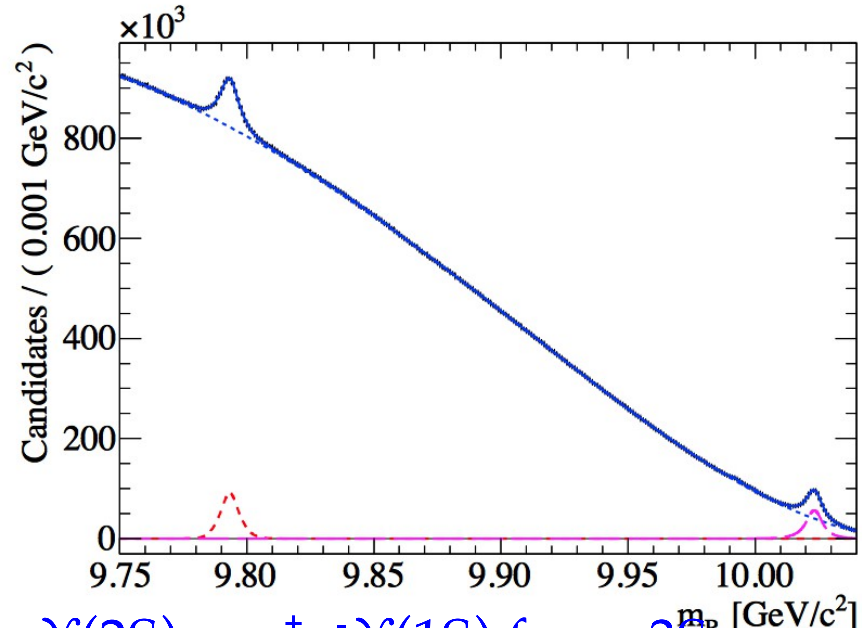

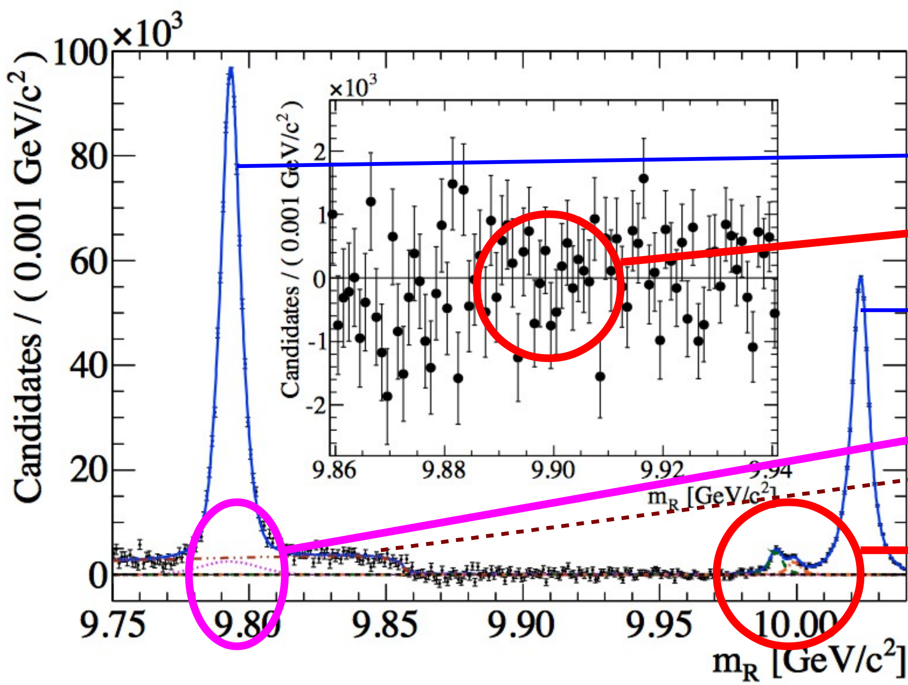

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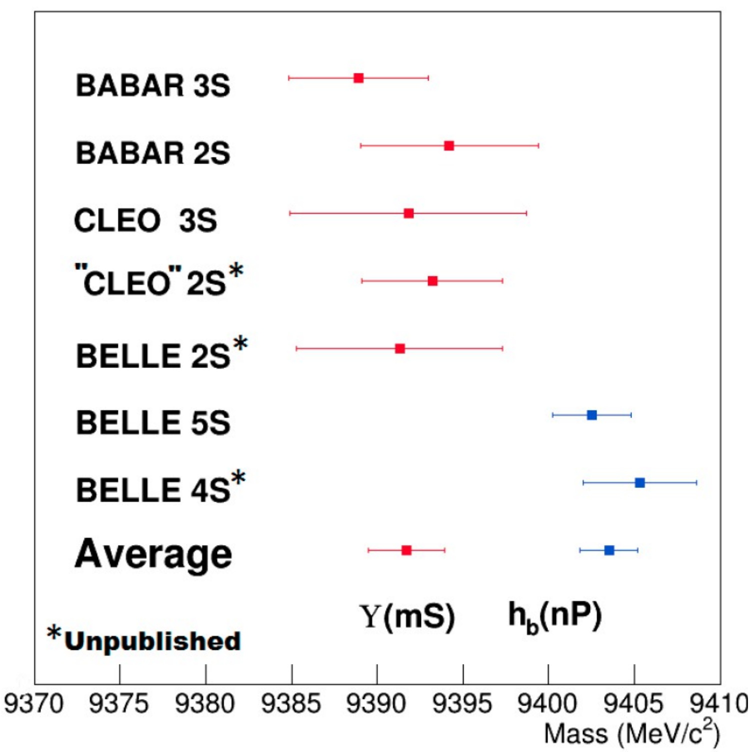
- $\chi_{b1,2}(2P) \to \pi^+\pi^- \chi_{b1,2}(1P)$

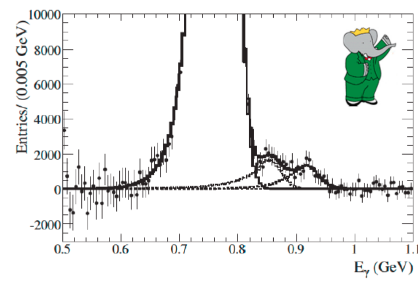
Belle-II startup

M1-E1 Discrepancy in $\eta_b(1S)$ mass measurements

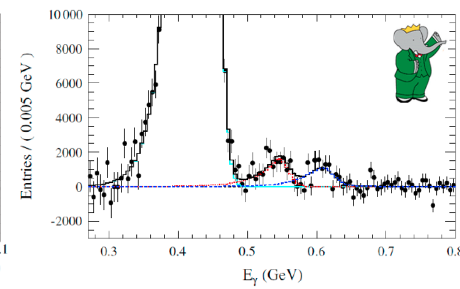
M1 transitions: inclusive from 3S (Babar,CLEO) and 2S (Babar, Belle)
E1 transitions: inclusive from hb(1,2P) produced in Y(4,S) decays (Belle)
Lineshape Skewness, as in the case of charmonium? Width = 10 MeV vs 30 in cc
In any case : we must improve the error on the M1 radiative width:

PNRQCD@NLL PRL92,242001(2004)
Lattice QCD PRD82,114502(2010)

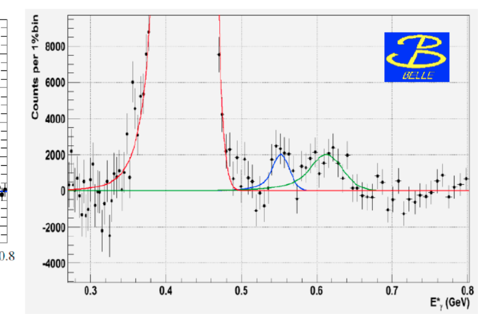




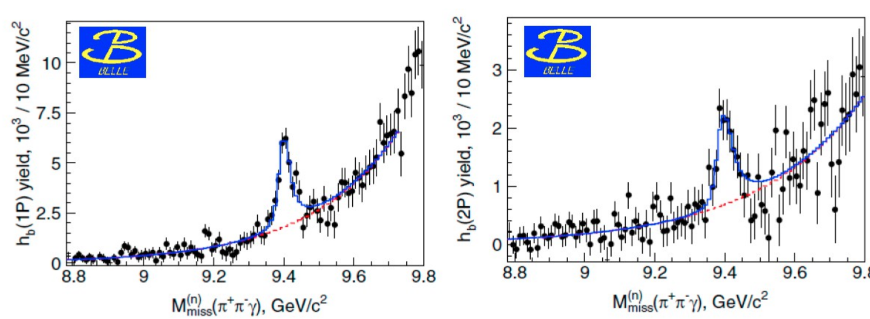
PRL 101, 071801 (2008)



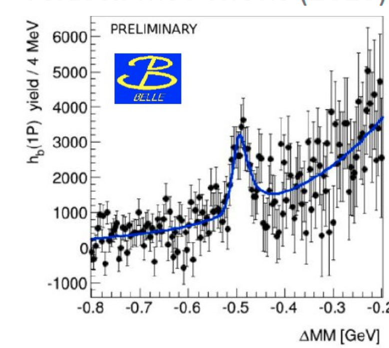
PRL 103, 161801 (2009)



Verzetti MSc Thesis (2010)



PRL 109, 232002 (2012)



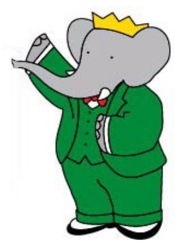
ICHEP 2014

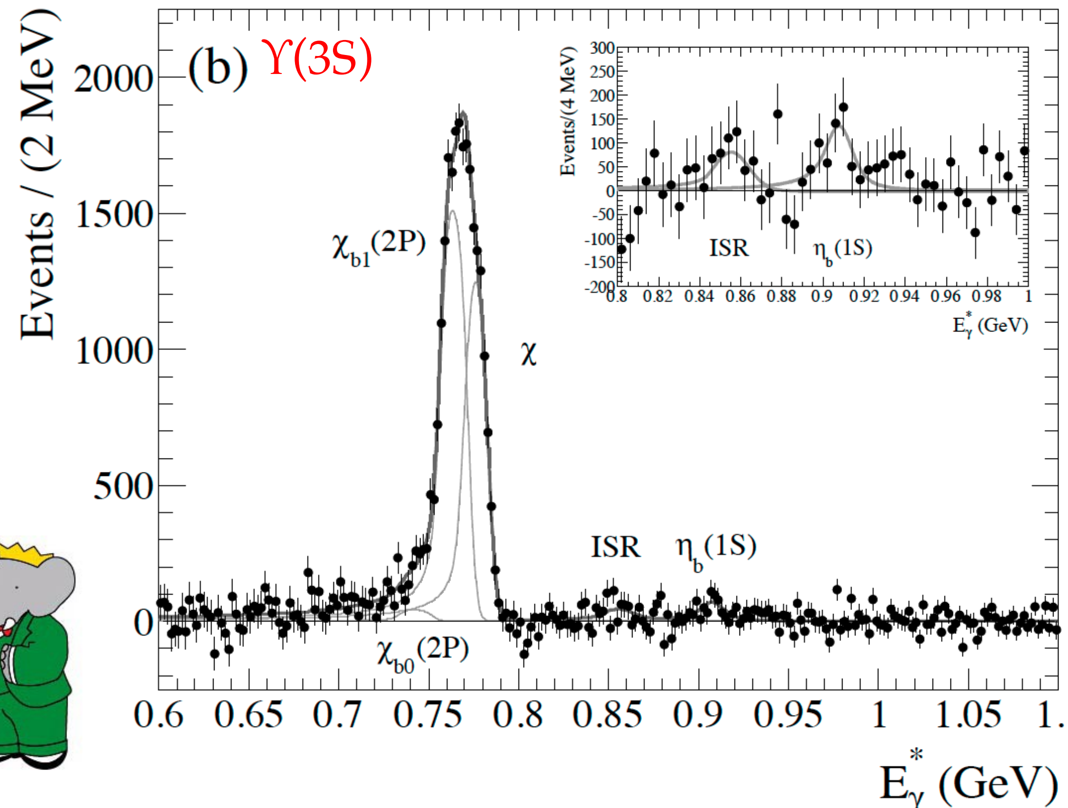
Converted photons for $\eta_b(1S)$ mass measurements

Energy resolution improves from 25% to 5% : ISR peak and η_b peak are better resolved. Width+lineshape measurement can be possible.

Selecting conversions in the inner CDC wall reduces multiple scattering and allows further improvement of the resolution.

BEAST-2 material can favor conversions, increasing the Vee sample.





Perfect understanding of material budget is key.

Phys.Rev. D84 (2011) 072002

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	$9.9 \pm 0.3^{+0.5}_{-0.4} \pm 0.9$	7.5 ± 1.3	10.4 ± 2.4
$\chi_{b2}(2P) \to \gamma\Upsilon(1S)$	776.4	11283^{+384}_{-385}	1.056	$7.0 \pm 0.2 \pm 0.3 \pm 0.9$	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	$0.058 \pm 0.016^{+0.014}_{-0.016}$ (< 0.085)	-	-

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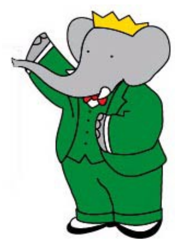

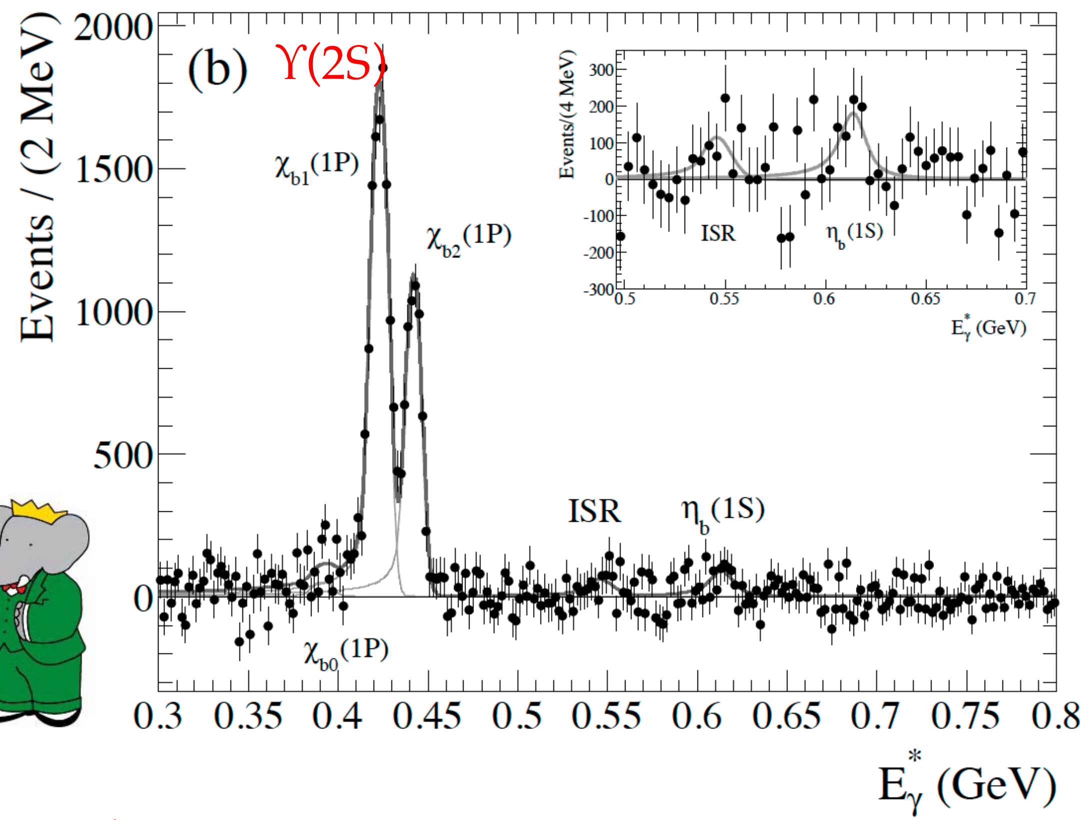

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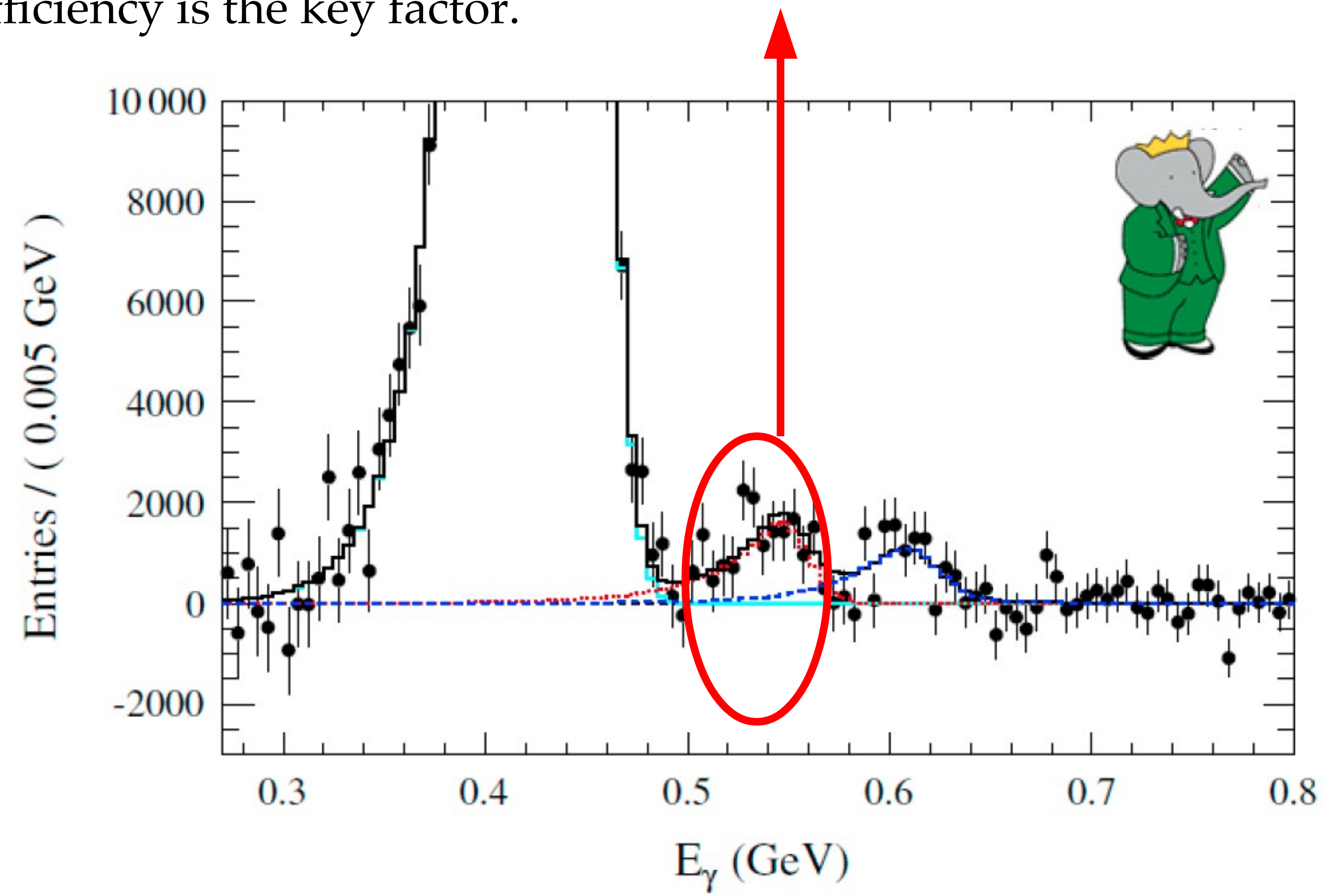
Phys.Rev. D84 (2011) 072002

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	$2.2 \pm 1.5^{+1.0}_{-0.7} \pm 0.2$ (< 4.6)	< 5	< 12	1.7 ± 0.4
$\chi_{b1}(1P) \to \gamma\Upsilon(1S)$	423.0	12604 ± 285	0.548	$34.9 \pm 0.8 \pm 2.2 \pm 2.0$	34 ± 7	40 ± 10	33.0 ± 2.6
$\chi_{b2}(1P) \to \gamma\Upsilon(1S)$	442.0	7665^{+270}_{-272}	0.576	$19.5 \pm 0.7^{+1.3}_{-1.5} \pm 1.0$	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	$0.11 \pm 0.04^{+0.07}_{-0.05}$ (< 0.21)	-	-	-

More $\eta_b(1S)$ pathways

Can we improve systematics and resolution removing the ISR peak?
From 600M Υ(3S) , we have 3% dipion tagged Υ(2S) , i.e. 18M , about 1/8 (1/6) of the Belle (Babar) sample, with 30% less combinatorial contamination (from qq continuum)
Again, the slow pion efficiency is the key factor.



M1 transitions to $\eta_b(2S)$?

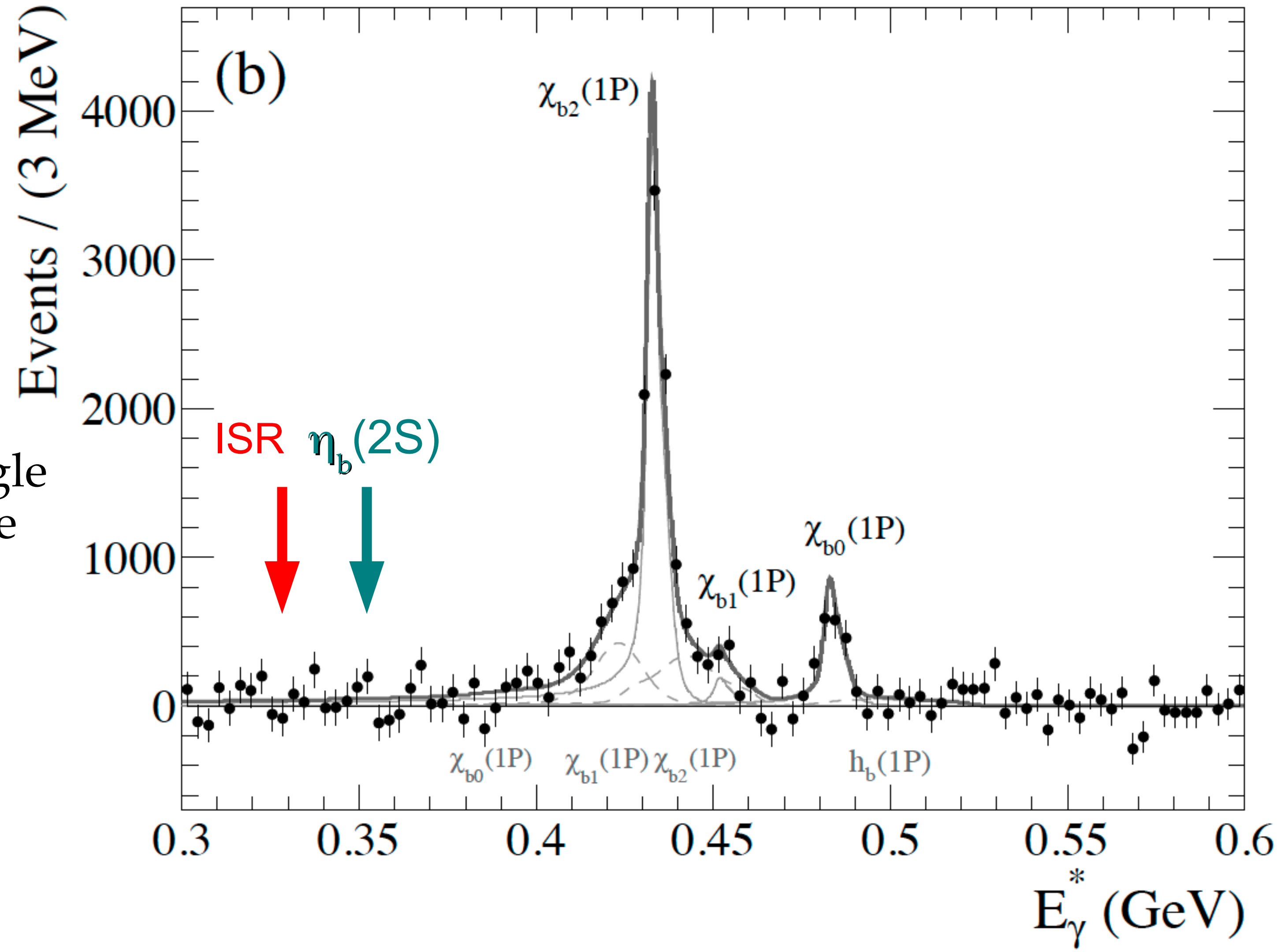
Best limits on Y(3S) to $\eta_b(2S)$:

Photons:
CLEO $<6.4\times10^{-4}$

Conversions:
Babar $< 13\times10^{-4}$

With 600 M decays:
UL $< 10^{-5}$?

Hints of signal from single Photon spectrum in Belle Data (unpublished)



Radiative E1 Widths: direct

Precise pNRQCD calculations on direct E1 transitions are now available to be compared with phenomenological models.

process	Γ^{LO}_{pNRQCD}/keV	Γ^{NLO}_{pNRQCD}/keV	Γ_{mod}/keV	Γ^{PDG}_{exp}/keV
$\chi_{b0}(1P) \to \Upsilon(1S)\gamma$	31.8	29.7 ± 3.1	25.7-27.0	-
$\chi_{b1}(1P) \to \Upsilon(1S)\gamma$	40.3	35.8 ± 4.0	29.8-31.2	-
$\chi_{b2}(1P) \to \Upsilon(1S)\gamma$	45.9	40.6 ± 4.6	33.0-34.2	-
$h_b(1P) \to \eta_b(1S)\gamma$	60.8	44.3 ± 6.1	-	-
$\Upsilon(2S) \to \chi_{b0}(1P)\gamma$	1.52	1.13 ± 0.15	0.72-0.73	1.22 ± 0.16
$\Upsilon(2S) \to \chi_{b1}(1P)\gamma$	2.26	1.94 ± 0.23	1.62-1.65	2.21 ± 0.22
$\Upsilon(2S) \to \chi_{b2}(1P)\gamma$	2.34	2.19 ± 0.23	1.84-1.93	2.29 ± 0.22
$\chi_{b0}(2P) \to \Upsilon(2S)\gamma$	12.6	13.0 ± 1.3	10.6-11.4	-
$\chi_{b1}(2P) \to \Upsilon(2S)\gamma$	17.1	16.3 ± 1.7	11.9-12.5	-
$\chi_{b2}(2P) \to \Upsilon(2S)\gamma$	20.4	18.1 ± 2.0	12.9-13.1	-
$\Upsilon(3S) \to \chi_{b0}(2P)\gamma$	1.44	1.05 ± 0.14	1.07-1.09	1.20 ± 0.16
$\Upsilon(3S) \to \chi_{b1}(2P)\gamma$	2.38	2.05 ± 0.24	2.15-2.24	2.56 ± 0.34
$\Upsilon(3S) \to \chi_{b2}(2P)\gamma$	2.53	2.35 ± 0.25	2.29-2.44	2.66 ± 0.41

The direct E1 transitions are already systematics limited.

The 1P to 1S transitions can be compared to theory only measuring total widths: best candidate is χ_{b0}(1P): 30 keV / 0.02 = 1.5 MeV?

Hindered E1 Widths

Hindered E1 transition widths are the most sensitive to relativistic corrections on wavefunctions, which are essential for the calculations on hadronic transitions.

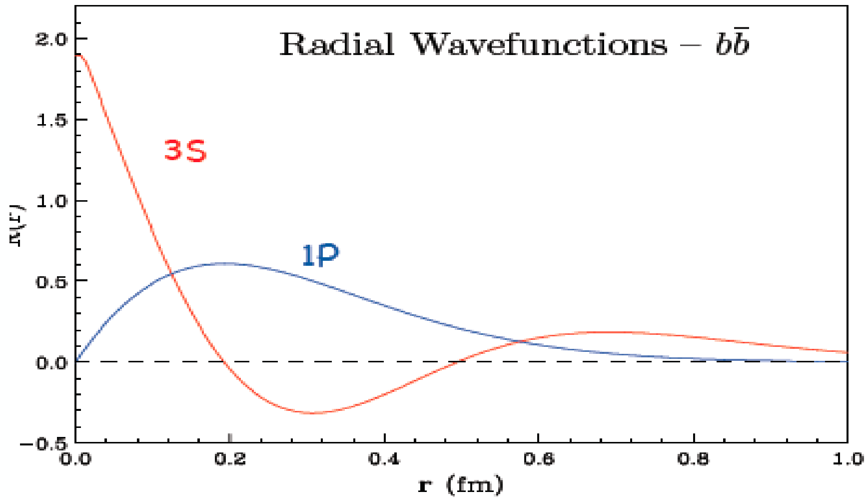


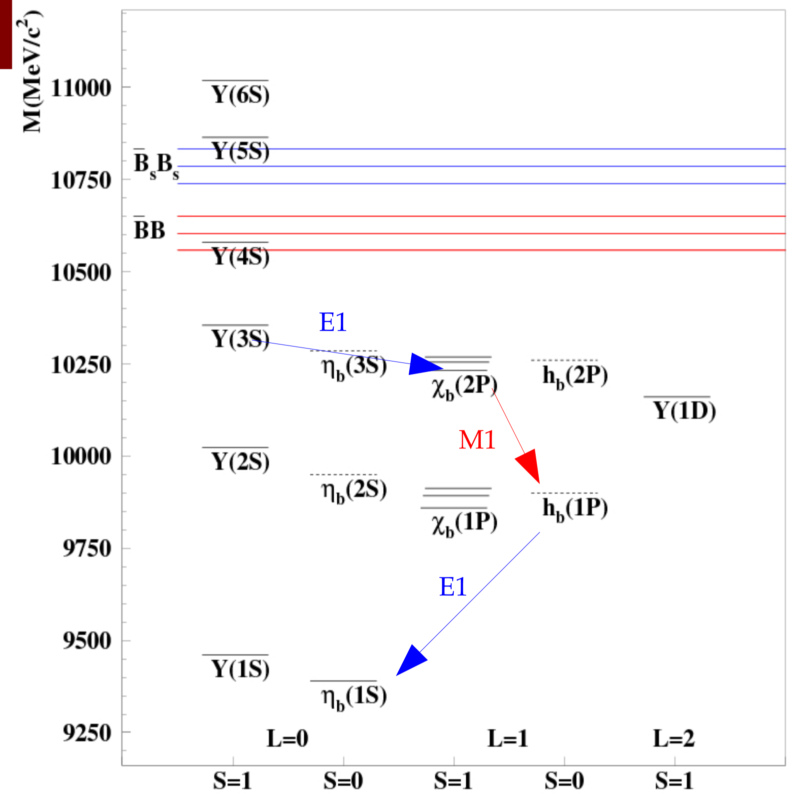
Table 1: Cancellations in $\mathcal{E}_{if}$ by node regions.

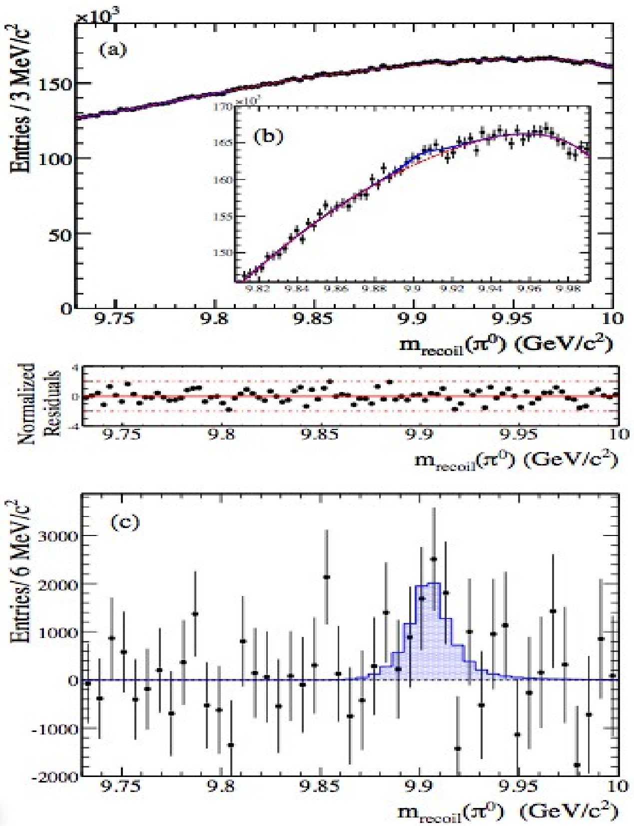
	$\Gamma_{J=0}$ (eV)	$\Gamma_{J=1}$ (eV)	$\Gamma_{J=1}/\Gamma_{J=0}$	$\Gamma_{J=2}$ (eV)	$\Gamma_{J=2}/\Gamma_{J=0}$	$\Gamma_{J=2}/\Gamma_{J=1}$
Moxhay–Rosner (1983)	25	25	1.0	150	6.0	6.0
Gupta *et al.* (1984)	1.2	3.1	2.6	4.6	3.8	1.5
Grotch *et al.* (1984) (a)	114	3.4	0.03	194	1.7	57
Grotch *et al.* (1984) (b)	130	0.3	0.002	430	3.3	1433
Daghighian–Silverman (1987)	42	(c)	(c)	130	3.1	(c)
Fulcher (1990)	10	20	2.0	30	3.0	1.5
Lähde (2003)	150	110	0.7	40	0.3	0.4
Ebert *et al.* (2003)	27	67	2.5	97	3.6	1.4
$E_\gamma^3 \times (2J+1)$			2.4		3.6	1.5

(a) Scalar confining potential. (b) Vector confining potential.
(c) The authors did not provide a prediction for $\Gamma[\Upsilon(3S) \to \gamma\chi_{b1}(1P)]$.

Hindered M1 between P waves

Idea: search for the first hindered M1 transition between P-wave bottomonia, in MM($\gamma\gamma\gamma$) replacing the π^0 mass constraint with the requirement that MM(γ_{low}) = M(χ_b).





π^0 recoil mass (GeV/c^2)

Theory papers on hindered P-wave M1 transitions in bottomonium do not exist; for charmonium see Guo, ***PoS ConfinementX (2012) 136*** *)*

Urgently need theory calculations on this topic: Vairo , Pineda ?

Spectrum below threshold

Below threshold:

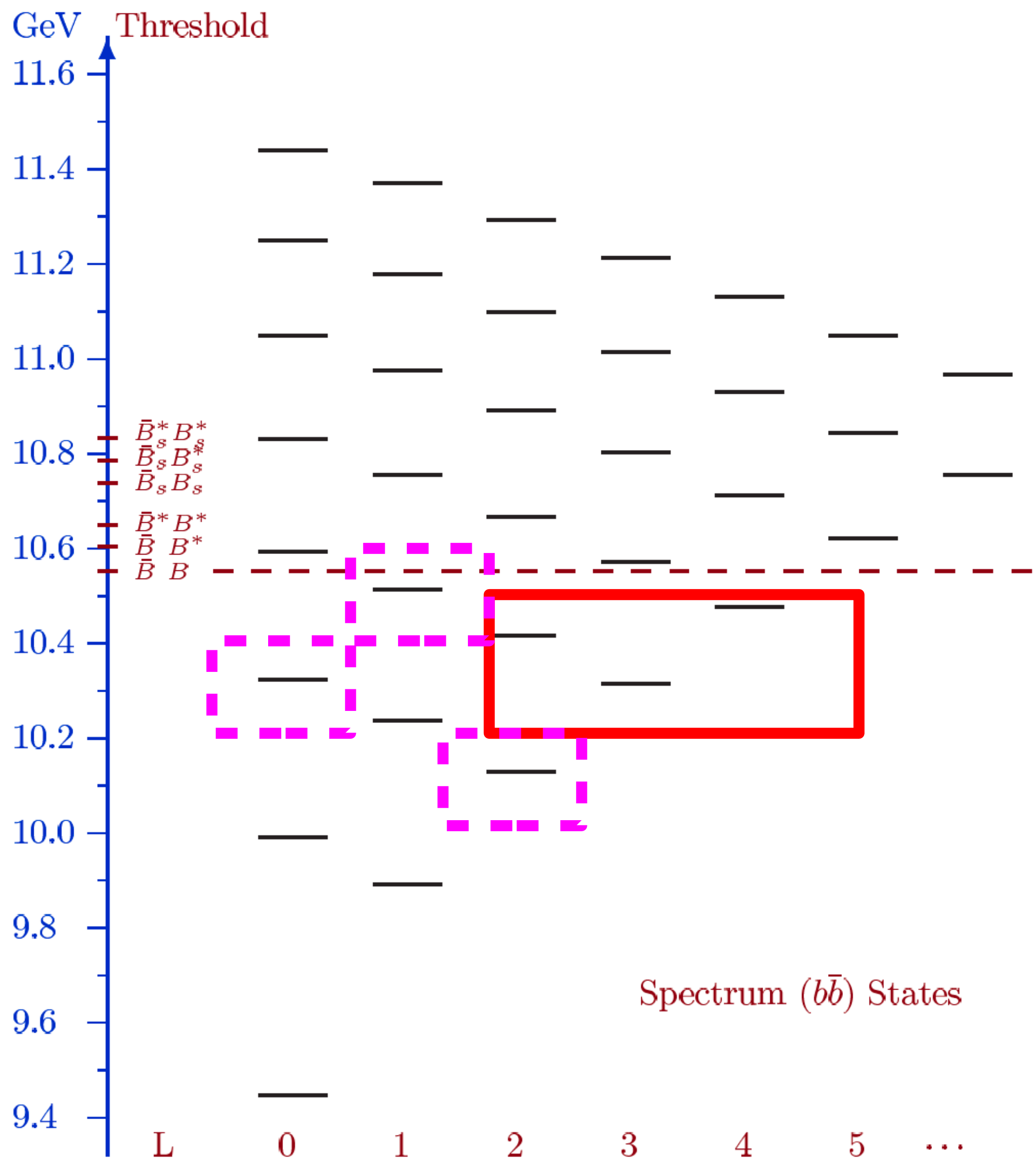
* 3S: $\eta_b(3S)$ not yet observed by anyone, maybe reachable from $h_b(3P)$?
* 3P: $\chi_b(3P)$ discovered at LHC, not yet resolved, we may eventually study them from 4S

  $h_b(3P)$: too high to be reached from 5S via Z_b, maybe from 6S? How?

* 1D states : S=1 states BEST STUDIED from 3S, S=0 maybe reachable from $h_b(2P)$

* 2D, 1F, 1G: totally unknown

We propose to search for the lowest member of the 2D triplet with a scan. The others may be reached from 6S. The 1F triplet $2,3,4^{++}$ is very close in mass to Y3S, but may be reached from the 2D triplet via E1 radiative transitions.

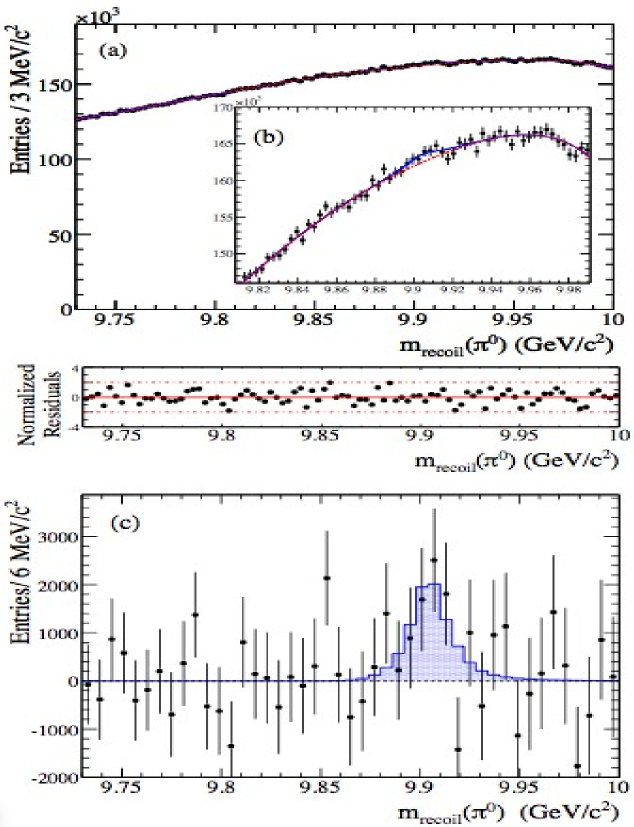


A puzzling π^0 transition

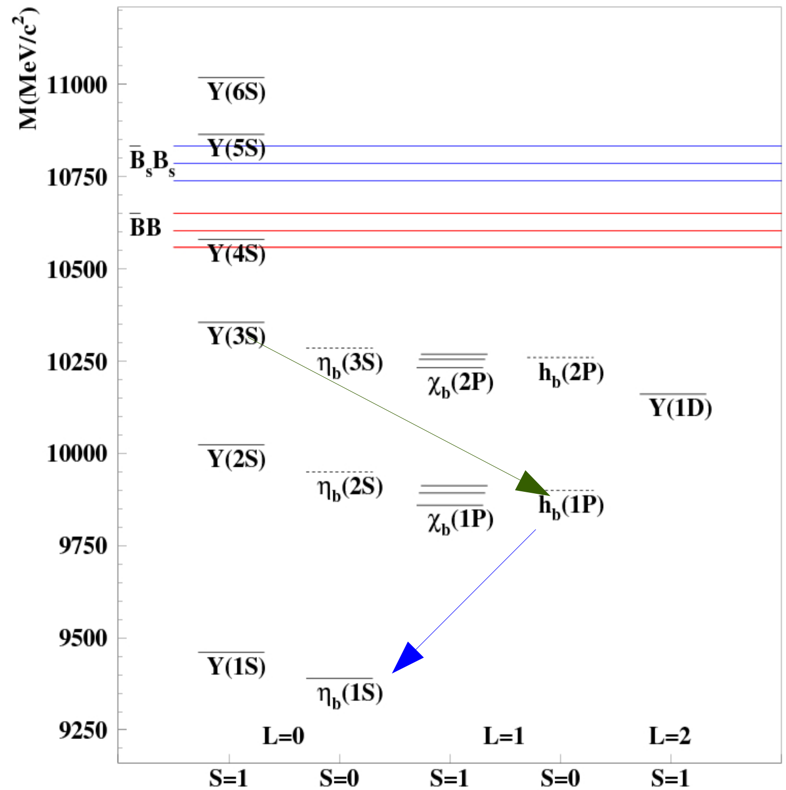
Babar: PRD 84 (2011)091101

3 sigma evidence of h_b from the inclusive search of

$e^+e^- \rightarrow \Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \pi^0 \gamma \eta_b$



π^0 recoil mass (GeV/c^2)



In charmonium:

$$\frac{\Psi \rightarrow \pi^0 h_c(1P)}{\Psi \rightarrow \eta J/\psi} = \frac{8.4\ 10^{-4}}{3.3\ 10^{-2}} = 2.5\ 10^{-2}$$

In bottomonium:

$$\frac{\Upsilon(3S) \rightarrow \pi^0 h_b(1P)}{\Upsilon(3S) \rightarrow \eta\ \Upsilon(1S)} = \frac{8.6\ 10^{-4}}{< 10^{-4}} > 8.6$$

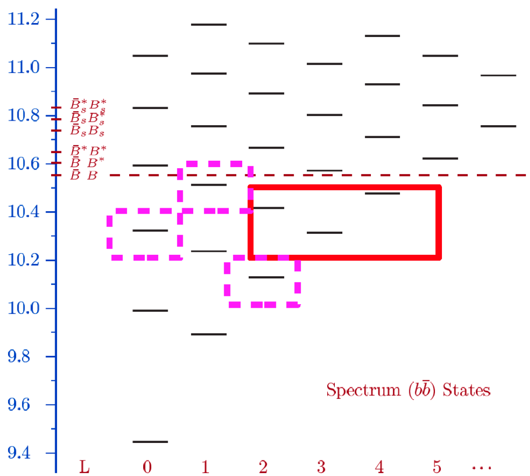
PRD 84 (2011)091101

PRD 84 (2011)042003

Isospin violating transition strongly favored?

Theory on Υ(1,2D)

Spectrum open items:



CoG of Υ(1,2D) systems in potential models:
Godfrey/Rosner, PRD 64, 097501 (2001)

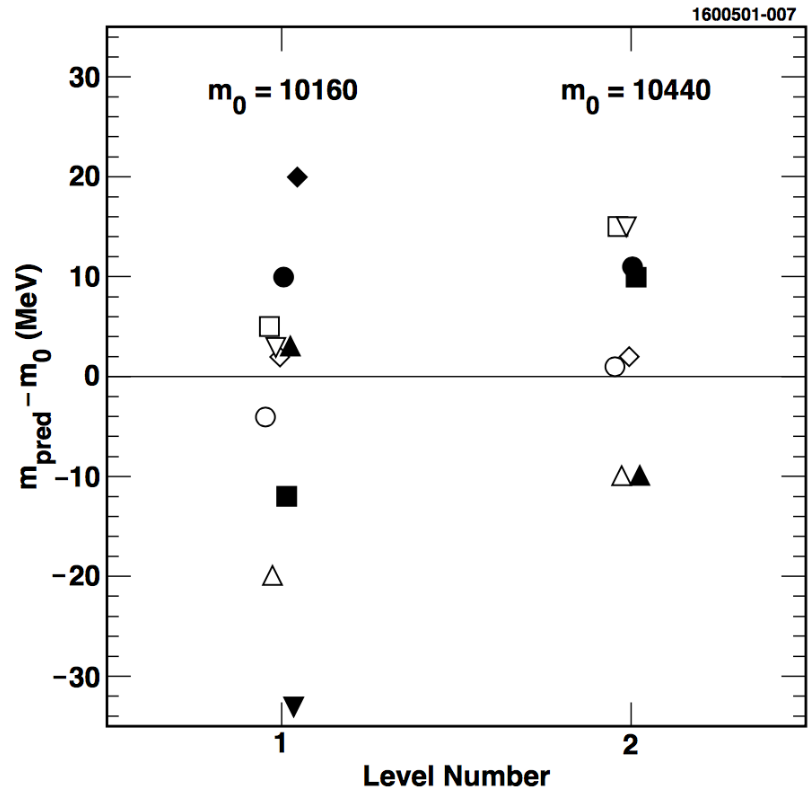
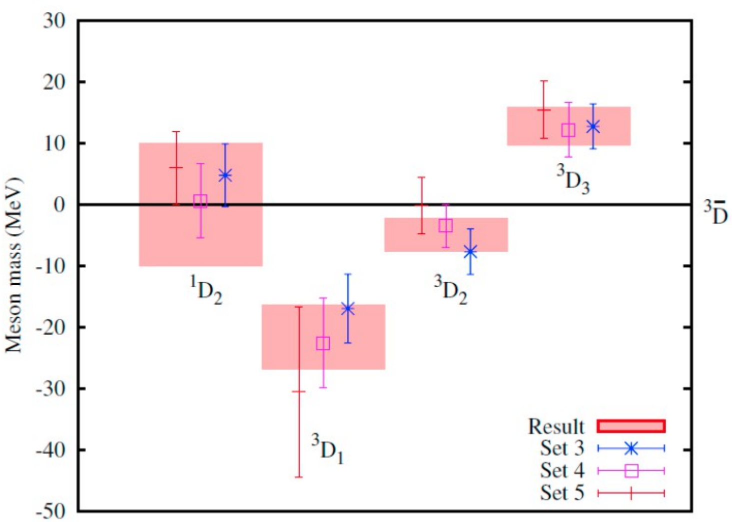
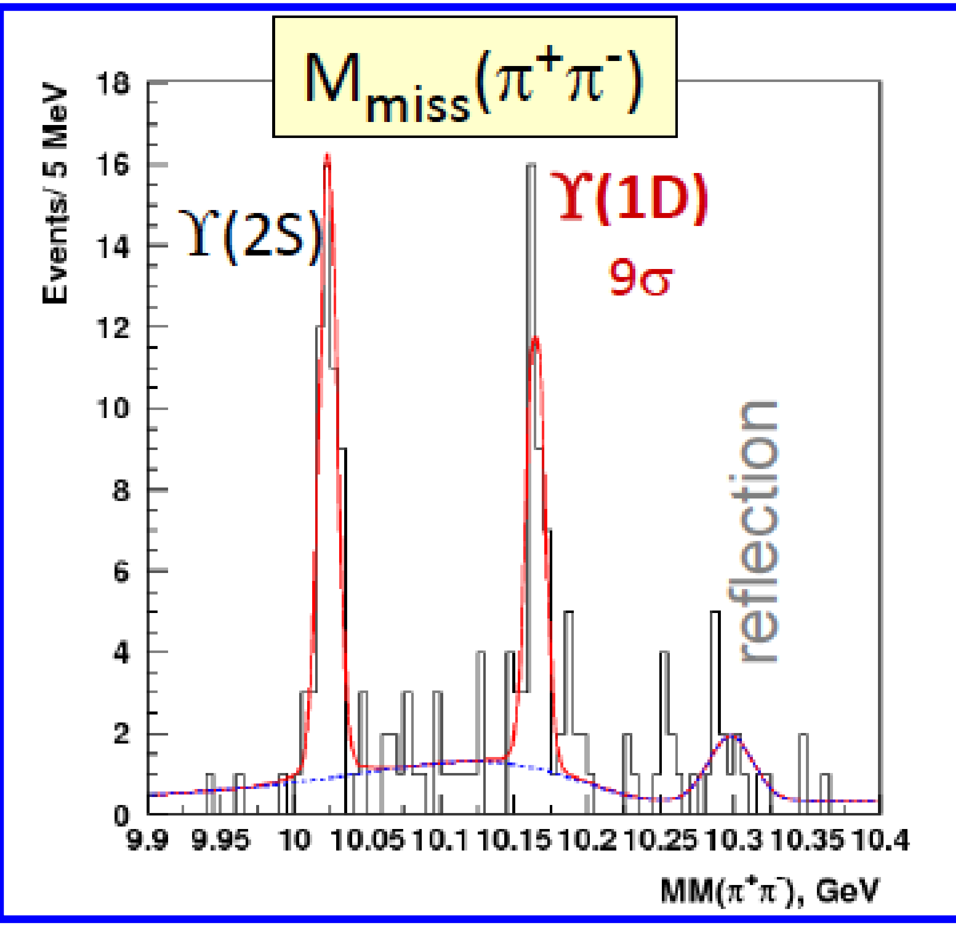


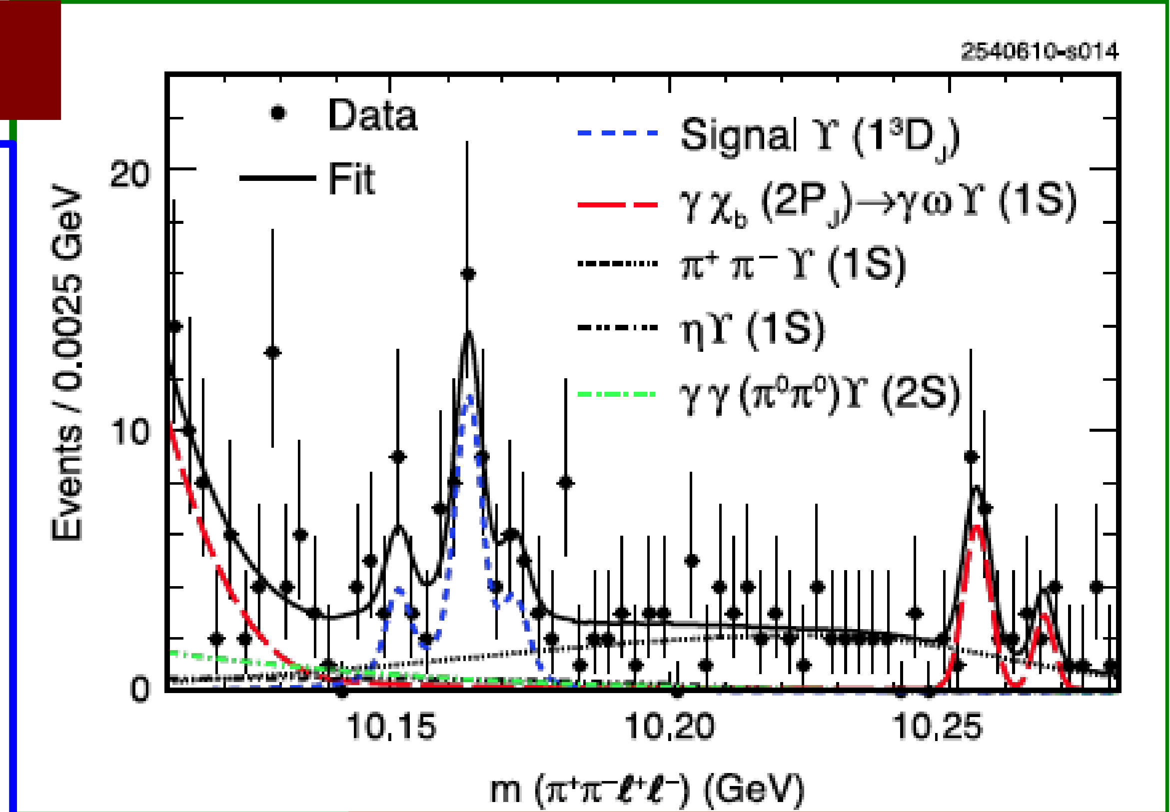
Figure 1: Predictions for the spin-weighted averages of ^3D_J $b\bar{b}$ states. Open circle (○): KR [3] (inverse scattering); open square (□): Cornell [6] (QCD-based potential); open triangle (△): BT [7] (QCD-based potential; published masses only quoted to nearest 10 MeV); open inverted triangle (▽): Gupta *et al.* [8] (QCD-based potential); open diamond (◇): MR [9] (QCD-based potential); solid circle: MB [10] (relativistic corrections; mass of $^3D_1$ plotted); solid square: GI [11] (QCD-based potential, masses calculated to nearest MeV); solid triangle: Grant *et al.* [12] (power-law potential); solid inverted triangle: EQ [13] (QCD-based potential [7], quoted for $n = 1$): solid diamond: lattice [14] (quenched approximation with $\beta = 6.0$, quoted for $n = 1$).

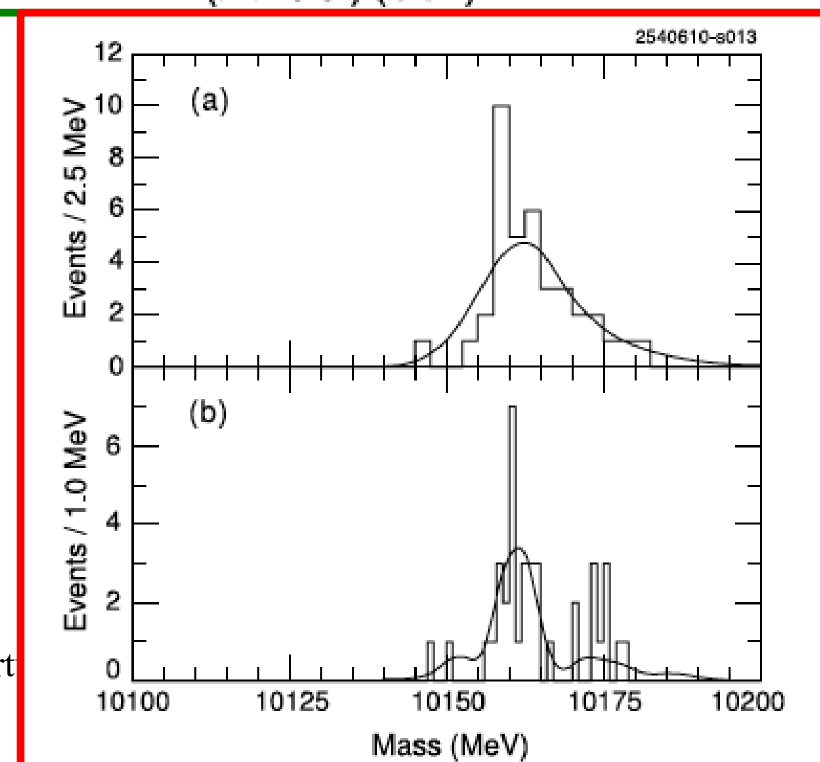
Lattice predictions on 1D splittings:
Daldrop et al., PRL 108, 102003 (2012)



Bottomonium D waves







Belle $10164.7 \pm 1.4 \pm 1.0$ MeV

BaBar $10164.5 \pm 0.8 \pm 0.5$ MeV

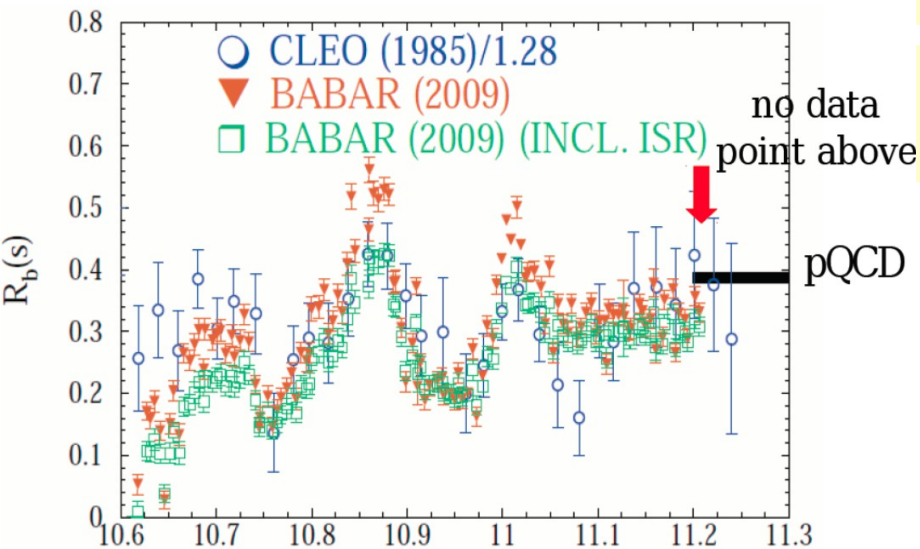
CLEO $10161.1 \pm 0.6 \pm 1.6$ MeV

Tetraquark-mania

From Ali's talk
at Krakow

Label	J^{PC}	charmonium-like State	Mass [MeV]	bottomonium-like State	Mass [MeV]
X_0	0^{++}	—	3756	—	10562.2
X_0'	0^{++}	—	4024	—	10652.2
X_1	1^{++}	$X(3872)$	3890	—	10607.2
Z	1^{+-}	$Z_c^+(3900)$	3890	$Z_b^{+,0}(10610)$	10607.2
Z'	1^{+-}	$Z_c^+(4020)$	4024	$Z_b^+(10650)$	10652.2
X_2	2^{++}	—	4024	—	10652.2
Y_1	1^{--}	$Y(4008)$	4024	$Y_b(10891)$	10891.1
Y_2	1^{--}	$Y(4260)$	4263	$Y_b(10987)$	**10987.5**
Y_3	1^{--}	$Y(4290)$ (or $Y(4220)$)	4292	—	**10981.1**
Y_4	1^{--}	$Y(4630)$	4607	—	11135.3
Y_5	1^{--}	—	6472	—	13036.8

SuperKEK Limits



Voloshin PRD84, 031502 (2011)

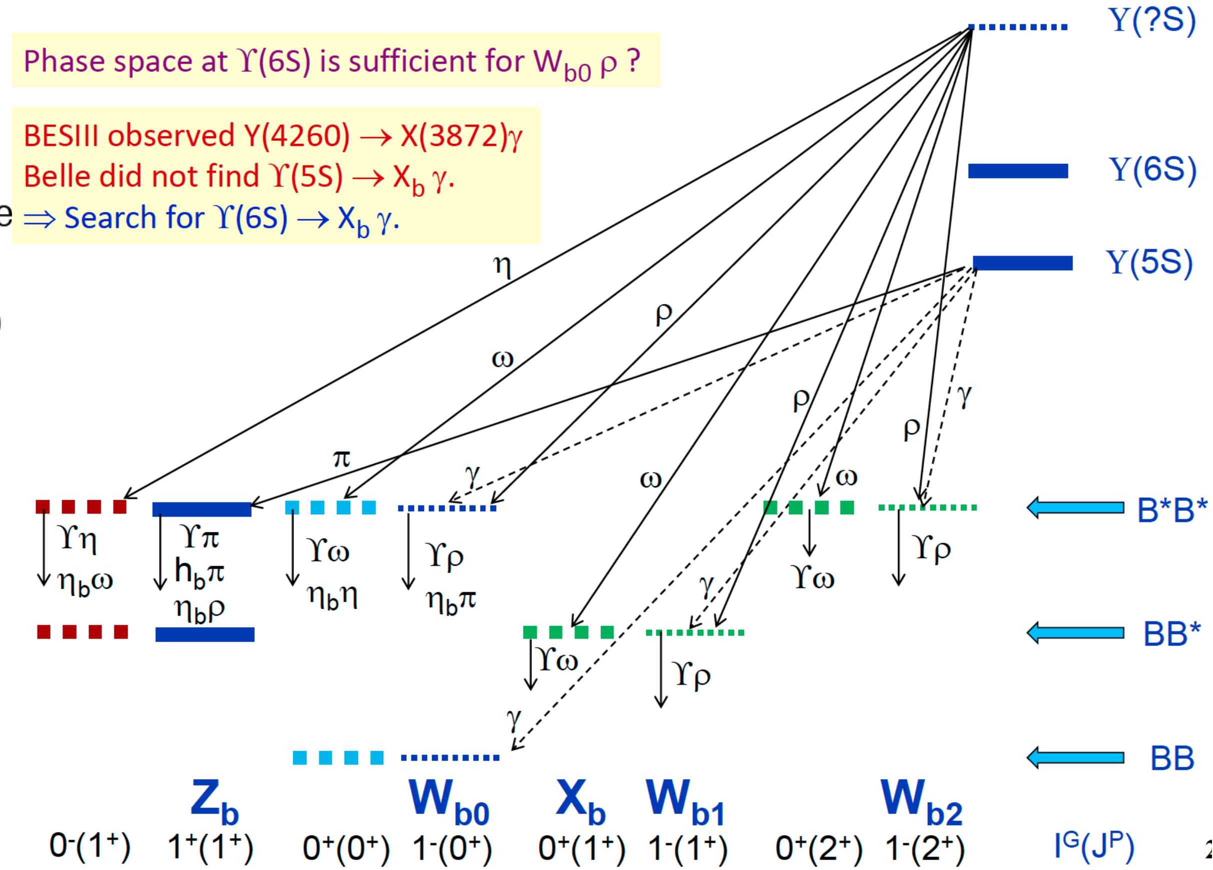
12GeV

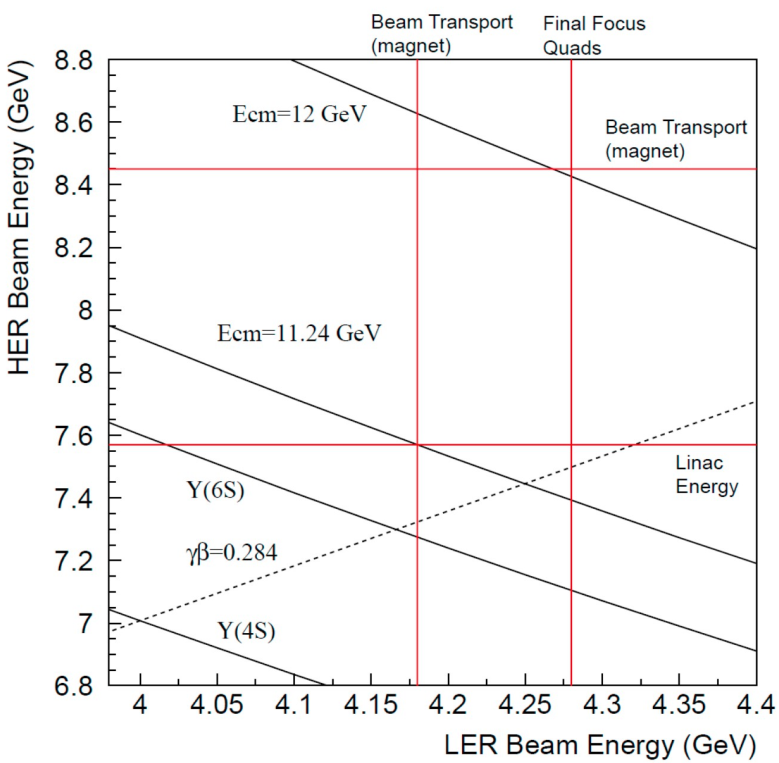
Phase space at $\Upsilon(6S)$ is sufficient for $W_{b0}\,\rho$?

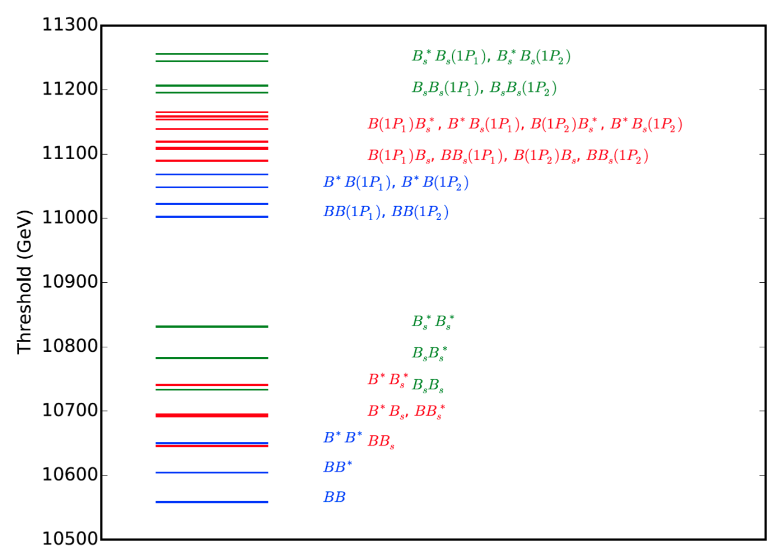
BESIII observed $Y(4260) \to X(3872)\gamma$

Belle did not find $\Upsilon(5S) \to X_b\,\gamma$.

$\Rightarrow$ Search for $\Upsilon(6S) \to X_b\,\gamma$.







Wrap-up (in italiano)

Fisica durante BEAST-II dipende da:
- Ldt integrabile
- Rapida definizione del material budget

Y(3S) e' la best option per > 100 fb^{-1}
First papers most likely from :
- eta transitions
- radiative (hindered) transitions
- 4-photon cascades , for D states
- 3S to 1S dipion transitions

Y(6S) e' buona per <60 fb^{-1} (10x Belle-I)

Scans alla Y(1,2D) non realistici per il 2017
Alternative: prese dati sul continuo? DarkPhoton?

Backup

Cusp in $K^+ \to \pi^+ \pi^0 \pi^0$

In 2006, NA48/2 measured the ππ scattering length using 60 M K+ decays, fitting the cusp observed at M=2m(π±) in the neutral dipion mass spectrum.

At low energy the ππ interaction is described by two scattering lengths who vanish in the chiral limit:

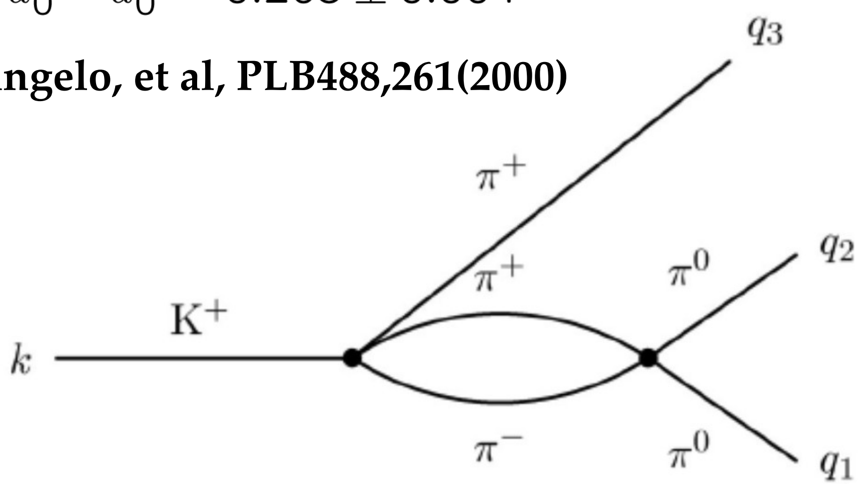
$$a_0^0 = \frac{7M_\pi^2}{32\pi F_\pi^2} + \mathcal{O}(m_q^2) \qquad a_0^2 = -\frac{M_\pi^2}{16\pi F_\pi^2} + \mathcal{O}(m_q^2)$$

Weinberg, PRL17,616(1966)

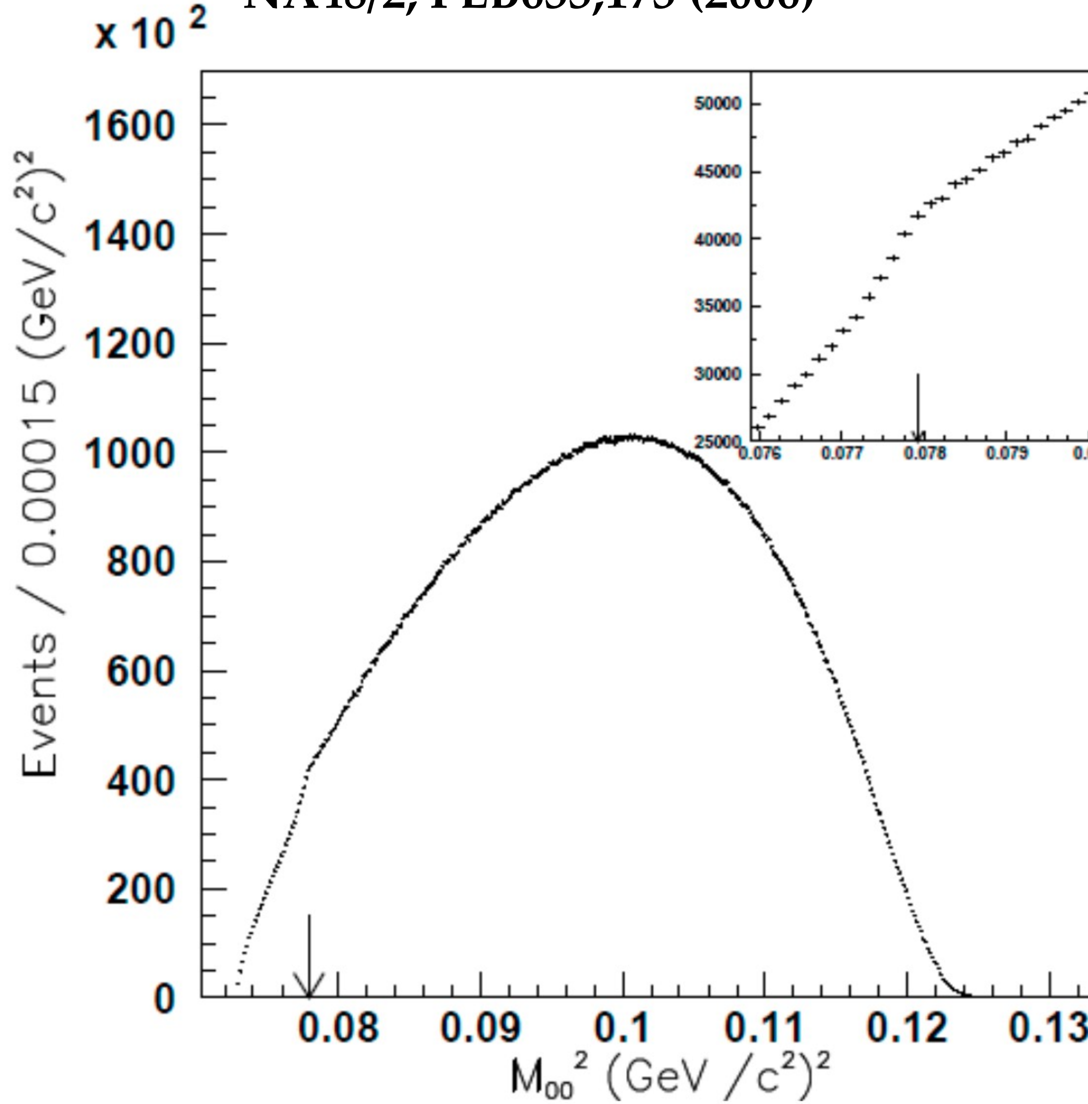
Using ChPT, theory predicts:

$$a_0^0 - a_0^2 = 0.265 \pm 0.004$$

Colangelo, et al, PLB488,261(2000)



NA48/2, PLB633,173 (2006)

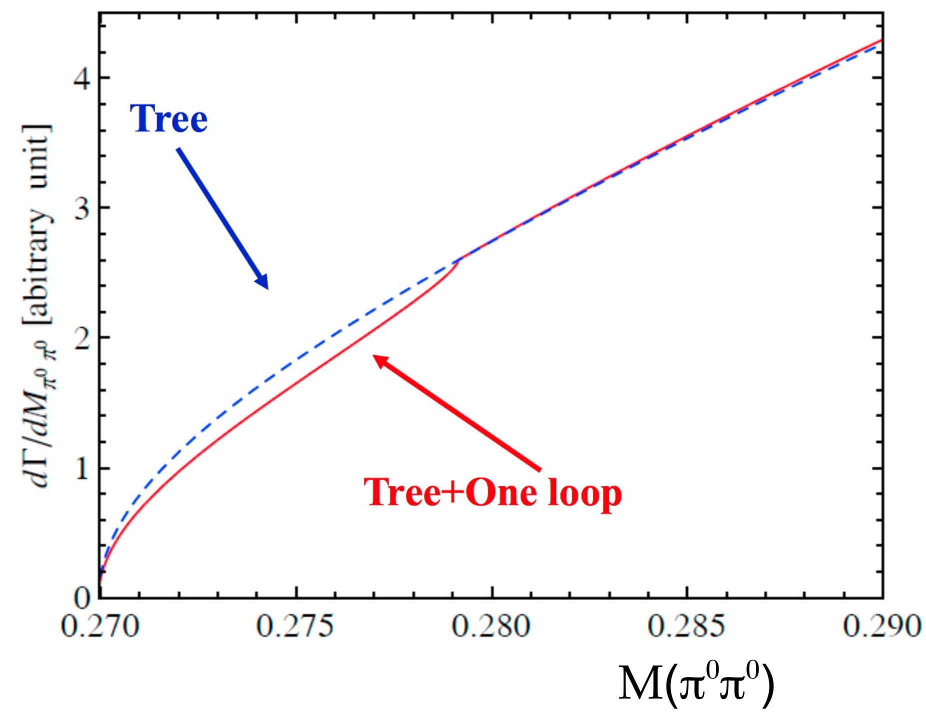


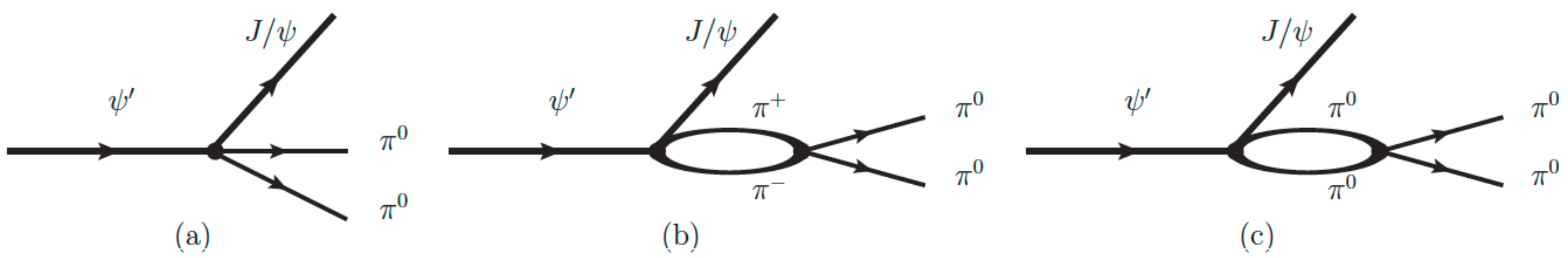
Cusp in $\Upsilon(3S) \to \Upsilon(2S)\, \pi^+ \pi^-$

The cusp effect was calculated using NREFT. **Liu et al,EPJC73, 2284 (2013)**

The reduction on the number of events is 9% in this process.
(13% in K+ decay, 8% in $\eta' \to \eta\pi\pi$)

Can we measure it with 600M Υ(3S) decays ?



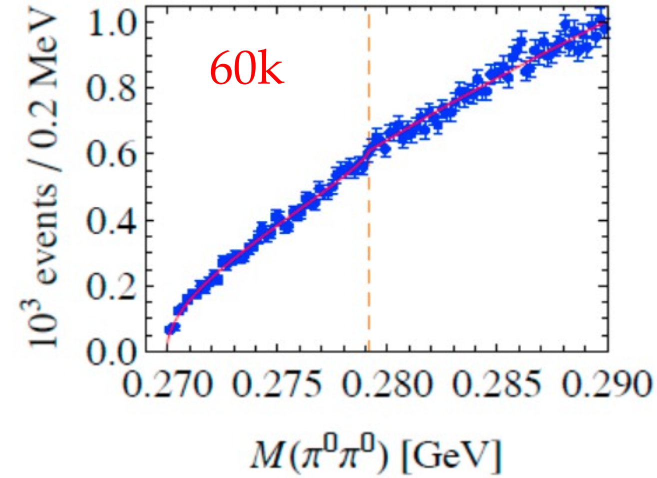


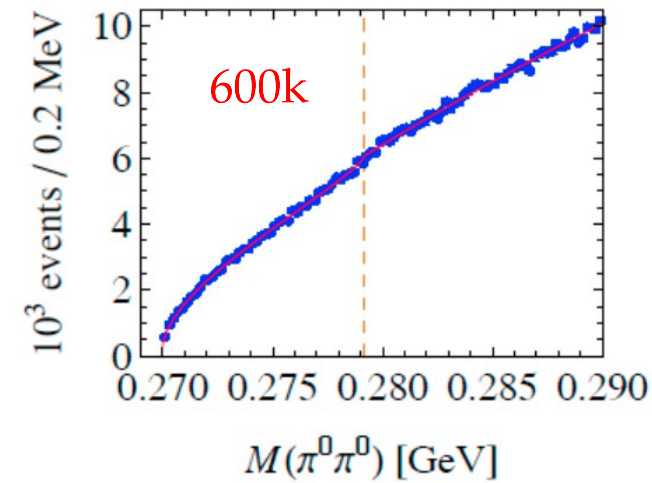
Cusp in $\Upsilon(3S) \rightarrow \Upsilon(2S)\, \pi^+ \pi^-$

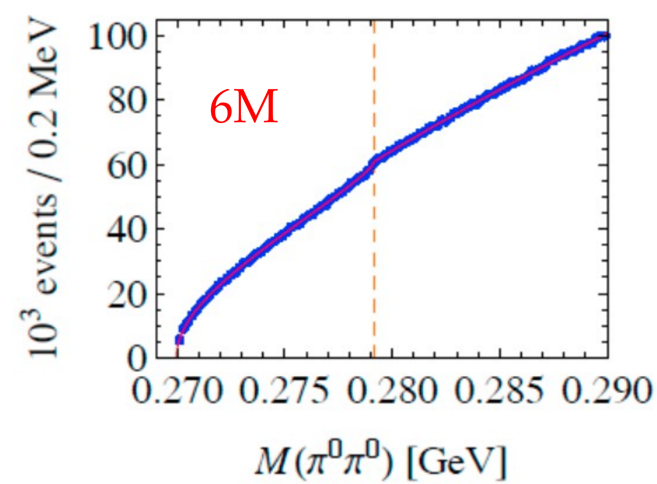
The effect was simulated assuming to have 60k,600k,6M events in the range $M(\pi^0\pi^0)$=0.27-0.29, 1/6 of the total.

Assuming 600M decays with 10% dipion acceptance, we have 0.1*1.85%/6 ~ 185 k decays in that range.

Can we use all events under the Υ(2S) peak in $MM(\pi^0\pi^0)$?
Penalty for extra clean Υ(2S) decays:
- exclusive dilepton : 4%*αε
- charge dipion recoil: 20%*αε







Bin width	Events	6×10^4	6×10^5	3×10^6	6×10^6
0.1 MeV	χ^2/dof	1.21	1.09	1.16	0.88
	$a_0 - a_2$	0.293 ± 0.036	0.260 ± 0.012	0.2717 ± 0.0048	0.2661 ± 0.0036
0.2 MeV	χ^2/dof	0.72	1.15	1.05	1.12
	$a_0 - a_2$	0.286 ± 0.035	0.251 ± 0.014	0.2722 ± 0.0048	0.2621 ± 0.0038
0.5 MeV	χ^2/dof	0.93	0.54	1.27	1.30
	$a_0 - a_2$	0.262 ± 0.026	0.256 ± 0.012	0.2659 ± 0.0051	0.2693 ± 0.0035
1 MeV	χ^2/dof	1.05	0.78	1.17	0.69
	$a_0 - a_2$	0.221 ± 0.054	0.291 ± 0.010	0.2658 ± 0.0054	0.2661 ± 0.0037
2 MeV	χ^2/dof	0.59	1.06	1.05	1.37
	$a_0 - a_2$	0.260 ± 0.040	0.262 ± 0.012	0.2592 ± 0.0055	0.2632 ± 0.0037

Total widths of $c\bar{c}$ and $b\bar{b}$ even P waves

TABLE III: Two-gluon decay widths of the p-wave heavy quarkonium states.

	$\Gamma_{2g}^{\chi_{c0}}$ (MeV)	$\Gamma_{2g}^{\chi_{c2}}$ (MeV)	$\Gamma_{2g}^{\chi_{b0}}$ (keV)	$\Gamma_{2g}^{\chi_{b2}}$ (keV)	$\Gamma_{2g}^{\chi'_{b0}}$ (keV)	$\Gamma_{2g}^{\chi'_{b2}}$ (keV)
PDG[a] [1]	10.4 ± 0.7	1.98 ± 0.11				
This work	$11.9^{+0.7}_{-0.9}$	$1.74^{-0.08}_{+0.09}$	431^{+45}_{-49}	214^{-0}_{+1}	122^{+4}_{-6}	$92.3^{+17.7}_{-14.8}$
Wang [6, 7]	10.3	2.64	887	220	914	248
Laverty[b] [8]	4.68(4.88)	1.72(0.69)	960(2740)	330(250)	990(2740)	350(260)
Gupta[c] [9]	13.44(17.10)	1.20(2.39)	2150(2290)	220(330)		
Bodwin [19]	4.8 ± 0.7	1.98 ± 0.18				
Barbieri [4]	2.4	0.64				
Godfrey [12]	6.25	0.774	672	123	672	137
Ebert [11]			653	109	431	76

[a] $\Gamma_{\text{tot}} \cong \Gamma_{2g}$.
[b] The values are obtained by the perturbative (nonperturbative) calculation.
[c] The values are obtained by the QCD potential (alternative treatment).

Υ(3S) in PDG nutshell

Υ(3S) MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
10355.2±0.5	[1] ARTAMONOV 00	MD1	$e^+e^- \to$ hadrons

203 MeV below the lowest $B\bar{B}$ threshold

Υ(3S) WIDTH

VALUE (keV)	DOCUMENT ID
20.32±1.85 OUR EVALUATION	See the Note on "Width Determinations of the Υ States"

The narrowest vector quarkonium
Annihilation width to light hadrons ~10 keV

Υ(3S) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\Upsilon(2S)$anything	(10.6 ±0.8) %	
Γ_2	$\Upsilon(2S)\pi^+\pi^-$	(2.82±0.18) %	S=1.6
Γ_3	$\Upsilon(2S)\pi^0\pi^0$	(1.85±0.14) %	
Γ_4	$\Upsilon(2S)\gamma\gamma$	(5.0 ±0.7) %	
Γ_5	$\Upsilon(2S)\pi^0$	$< 5.1 \times 10^{-4}$	CL=90%
Γ_6	$\Upsilon(1S)\pi^+\pi^-$	(4.37±0.08) %	
Γ_7	$\Upsilon(1S)\pi^0\pi^0$	(2.20±0.13) %	
Γ_8	$\Upsilon(1S)\eta$	$< 1 \times 10^{-4}$	CL=90%
Γ_9	$\Upsilon(1S)\pi^0$	$< 7 \times 10^{-5}$	CL=90%
Γ_{10}	$h_b(1P)\pi^0$	$< 1.2 \times 10^{-3}$	CL=90%
Γ_{11}	$h_b(1P)\pi^0 \to \gamma\eta_b(1S)\pi^0$	$(4.3 \pm 1.4) \times 10^{-4}$	
Γ_{12}	$h_b(1P)\pi^+\pi^-$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{13}	$\tau^+\tau^-$	(2.29±0.30) %	
Γ_{14}	$\mu^+\mu^-$	(2.18±0.21) %	S=2.1
Γ_{15}	e^+e^-	seen	
Γ_{16}	hadrons		
Γ_{17}	ggg	(35.7 ±2.6) %	
Γ_{18}	γgg	$(9.7 \pm 1.8) \times 10^{-3}$	

Radiative decays

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_{19}	$\gamma\chi_{b2}(2P)$	(13.1 ±1.6) %	S=3.4
Γ_{20}	$\gamma\chi_{b1}(2P)$	(12.6 ±1.2) %	S=2.4
Γ_{21}	$\gamma\chi_{b0}(2P)$	(5.9 ±0.6) %	S=1.4
Γ_{22}	$\gamma\chi_{b2}(1P)$	$(9.9 \pm 1.3) \times 10^{-3}$	S=2.0
Γ_{23}	$\gamma A^0 \to \gamma$hadrons	$< 8 \times 10^{-5}$	CL=90%
Γ_{24}	$\gamma\chi_{b1}(1P)$	$(9 \pm 5) \times 10^{-4}$	S=1.9
Γ_{25}	$\gamma\chi_{b0}(1P)$	$(2.7 \pm 0.4) \times 10^{-3}$	
Γ_{26}	$\gamma\eta_b(2S)$	$< 6.2 \times 10^{-4}$	CL=90%
Γ_{27}	$\gamma\eta_b(1S)$	$(5.1 \pm 0.7) \times 10^{-4}$	
Γ_{28}	$\gamma X \to \gamma + \geq 4$ prongs	[a] $< 2.2 \times 10^{-4}$	CL=95%
Γ_{29}	$\gamma a_1^0 \to \gamma\mu^+\mu^-$	$< 5.5 \times 10^{-6}$	CL=90%
Γ_{30}	$\gamma a_1^0 \to \gamma\tau^+\tau^-$	[b] $< 1.6 \times 10^{-4}$	CL=90%

Systematics dominates already dipion 1,2S transitions and direct E1 transitions

Goal of Commissioning Phase 2

Many group working with different goals during phase 2. Beam background measurements are just a small part of the overall program

- Beam commissioning to start collision (machine group: KCG)
  - Forward luminosity monitors(ZDLM) for knob tuning
- BG measurements and mitigation (KEK Belle group: BCG)
  - BG studies of each component to check consistency with simulation
  - Studies of relation between VXD hits and monitor hits
  - Beam collimators control study
  - Neutron measurement (fast and slow)
- Belle II commissioning with partial VXD sensors (Belle II shift)
  - Full Belle II DAQ
  - Slow control (also communication with machine)
  - PXD RoI finding with CDC+SVD tracking data
  - Detector noise check
  - **And investigation and confirmation to install the full VXD**
- Optimization of interlock system
  - Slow info. Some alarms or abort by environmental or rad. monitors
  - First info.: beam abort by hard wired signals

Goal of Commissioning Phase 2 (part II)

- Beam injection BG study (VXD group)
  - BG damping time measurement for Trigger veto gate
    - requiring storing veto gate width to condition database
    - With moderate update timing
- First try of CO2 cooling system for VXD sensors (VXD group)
  - Checking water vapor level by sucking air
  - cold and warm dry volume
- Detailed characterization of beam backgrounds (BEAST group)
  - Target luminosity at phase-2 is L ~ 10^{34} cm^{-2} s^{-1} , and BG structure is not exactly same as phase-3. We need somehow extrapolation to expect phase-3 beam BG.
    - how to extrapolate it?
      - We have a lot of monitor sensors, diamond sensors, 64 PIN diodes, FE-I4, CLOWS.
      - Effect from each BG component has to be studied separately by BG MC.
      - This extrapolation can be done only after the BG is will controlled by collimator studies.
      - Deferent BG components have different dependence for collimator setting. We can separate the BG components by using this feature.

BEAST-II inventory

Feb. 4, 2015

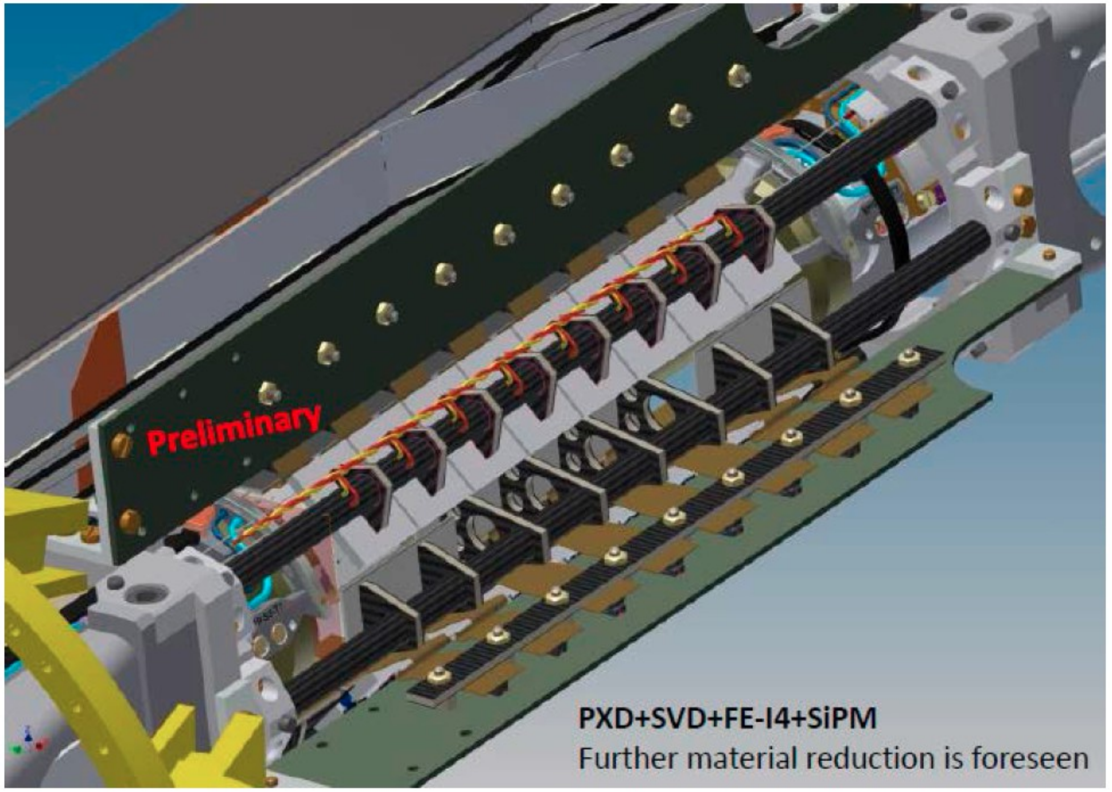
Phase-2 sensors in VXD volume

sensor	contact person	number	location	DAQ	note
PXD + SVD	C. Marinas K. Nakamura	2 PXD ladders 4 SVD ladders	decided +X	Belle II DAQ	
diamond w/ PIN diode (beam BG, abort)	L. Vitale	4 diamonds 64 PIN diodes	diamond: decided	Belle II monitor DB (EPICS)	PIN diode location: around diamond and beam pipe
FE-I4 pixels (Synchrotron rad. and track multiplicity)	C. Marinas	3 arms	decided (90, 180, 270)	?	arm design has to be fixed
CLAWS (beam BG)	C. Marinas	2 ladders	decided (135 and 225)	?	
Scintillator PIN diode (beam BG)	H. Nakayama K. Nakamura	~60 (scintillator) ? (PIN diode)	not decided	?	Basically put them around QCS
BGO (Bhabha events)	J. Liau	8 (if space allows)	under discussion	BEAST DAQ	Acceptance is overlapped with PXD cooling block.
temperature (NTC), humidity (DMT242B) (crosscheck for FOS)	L. Vitale	not decided	not decided	Belle II monitor DB	
FOS + L-shape (temp. and humidity)	I. Vila D. Moya	?	?	?	sensor on outer cover?
PLUME (beam BG)	I. Ripp-Baudot	1 ladder	not decided	EPICS DB BEAST DAQ?	baseline: PLUME-2 (hopefully PLUME-3)

See backup slides for more on these systems.

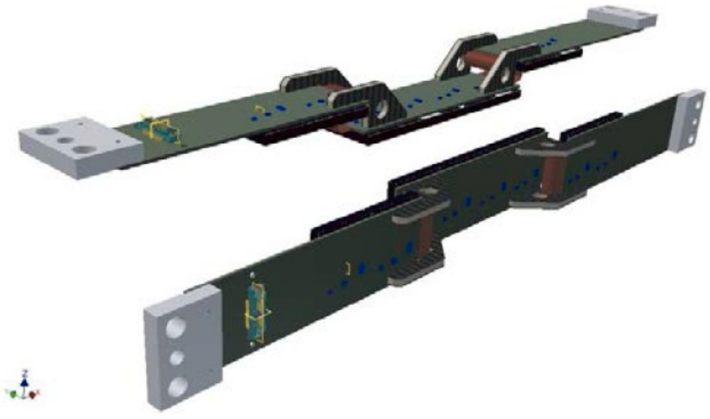
Phase 2 Detectors

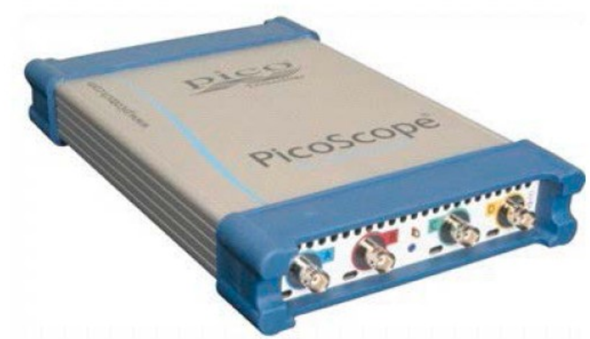
- VXD BEAST assembly
  - SVD, PXD ladders
  - Dedicated background and environment sensors (see next page)
- Scintillators and PIN diodes around QCS
- Neutron detector in dock space



CLAWS (Scintillator + SiPM)

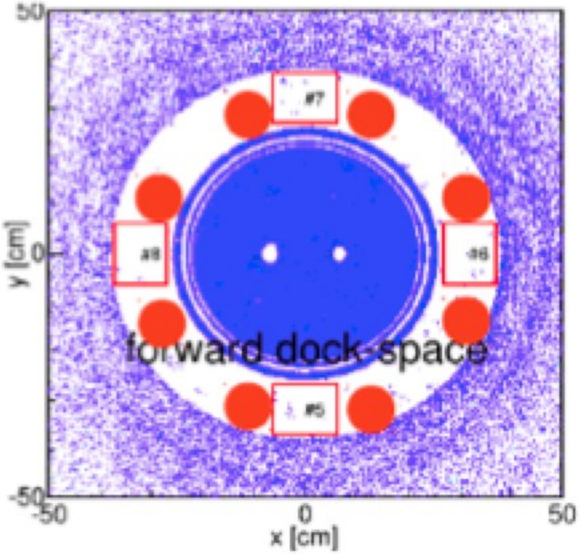
- **contact person**
  - C. Marinas
- **motivation and brief analysis plan**
  - spatial dependence of BG hits, injection BG
- **what kind of data to be stored on DAQ**
  - energy deposit, hit timing
- **designs of sensor/package/support**
  - Are they already fixed???
- **number and locations**
  - 2 ladders on 135 and 225 deg.
- **cables and space for service**
  - cables ???
- **readout system and DAQ**
  - 6404D (PICOTECH) DAQ???
- **request for dock boxes**
  - no
- **request for Belle II clock, trigger, injection timing?**
  - **how does it get injection timing?**

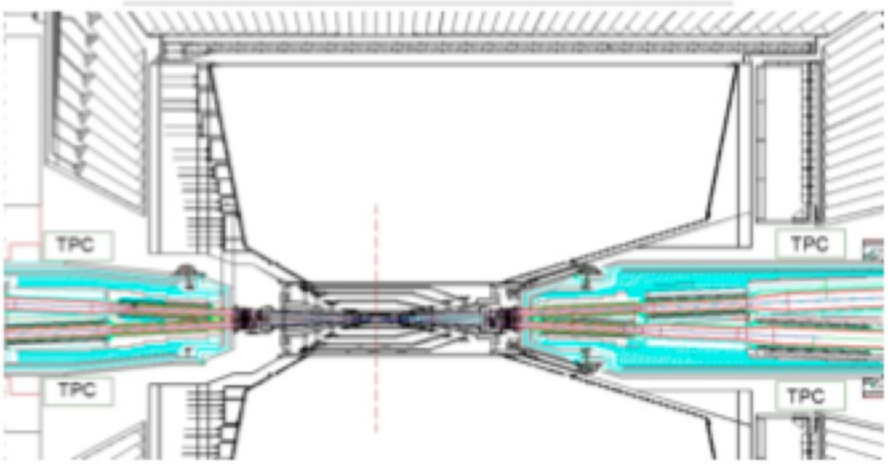




Neutron Detectors

- He-3 tubes and micro-TPCs in dock space
  - TPCs image direction of incoming fast neutrons, but detected rate is low
  - He-3 measure rate of thermal neutrons, which is high





Source	$\Upsilon(2S) \to$ $\pi^+\pi^-\Upsilon(1S)$	$\eta\Upsilon(1S)$ $\eta \to \pi^+\pi^-\pi^0$	$\eta \to \gamma\gamma$	$\Upsilon(3S) \to$ $\pi^+\pi^-\Upsilon(1S)$	$\eta\Upsilon(1S)$ $\eta \to \pi^+\pi^-\pi^0$	$\eta \to \gamma\gamma$
N_Υ		0.9			1.0	
Tracking	1.4	1.4	1.0	2.5	2.5	1.7
π^0/γ	$\cdots$	3.6	3.6	$\cdots$	3.6	3.6
Lepton identification		1.1		1.0 (1.2)	1.0 (1.2)	1.0
$\pi^+\pi^-$ model	0.5	$\cdots$	$\cdots$	0.4 (1.5)	$\cdots$	$\cdots$
Selection	0.4	2.6	5.5	0.9 (1.2)	4.4 (5.3)	5.6
PDFs	0.1	5.4	5.0	0.1	5.4	5.0
Total $\mathcal{B}$	2.9	7.6	8.7	3.6 (4.1)	8.6 (9.1)	8.1
Total ratio		7.2	8.3		8.3 (8.9)	7.8

Phase 2 is still a commissioning stage for the accelerator

- Accelerator goals
  - Opctics tuning
  - First beam background study
  - Increase of beam currents
  - Beam collision tuning
  - Luminosity tuning
  - Target luminosity: $\mathcal{L}_{peak}^{phase2} = 10^{34} cm^{-2} s^{-1}$
- BEAST II goals already mentioned in previous slide but study will be done only when target luminosity will be achieved
  - We requested two to three weeks
  - Belle II detectors will also be used with a random trigger

If acccelerator and BEAST II goals are achieved before summer shutdown: $\mathcal{L} = 16\ \mathrm{fb}^{-1}$ for physics available if $\mathcal{L}_{peak}$ constant