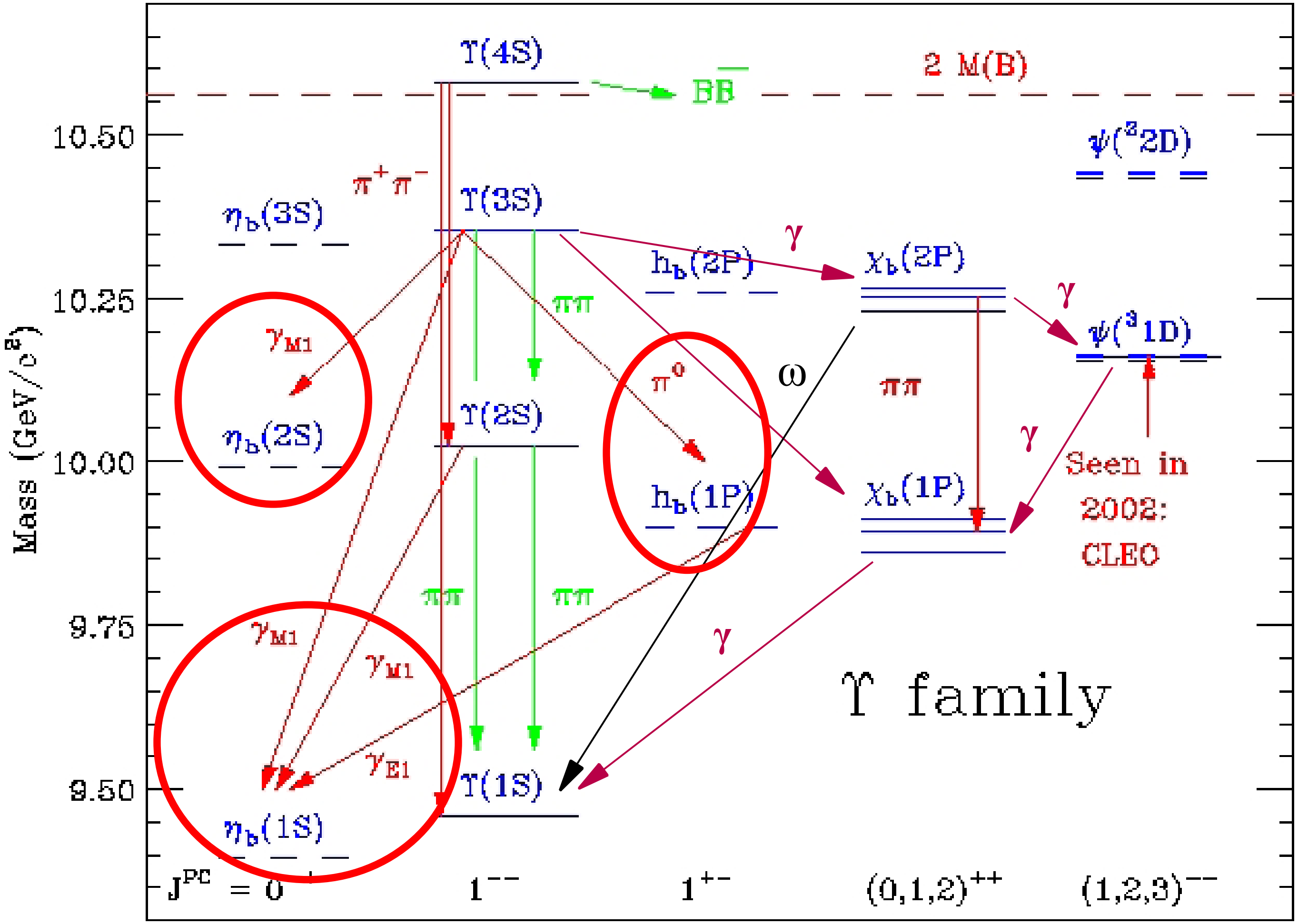
Υ(3S) Standard Model Physics

Claudia Patrignani
Università and INFN Genova

Outline

- "standard" bottomonium measurements
- missing states
- interesting measurements

Bottomonium spectrum



Priority n.1 : find η_b (1S)!!

- Spectrum of spin triplets with L=0 and L=1 below $b\bar{b}$ threshold is complete
- All spin singlets still to be discovered
- A rich cascade from the Y(3S):

almost all states virtually accessible

- Even for known states few decay modes mesured so far...

$\eta_b(1S)$, $\eta_b(2S)$ and $h_b(1P)$

$h_b(1P)$ mass within few MeV from the center of gravity of $\chi_b(1P)$ (~9900 MeV)

"large" radiative (E1) decay to $\eta_b(1S)$ with a photon of E~500 MeV

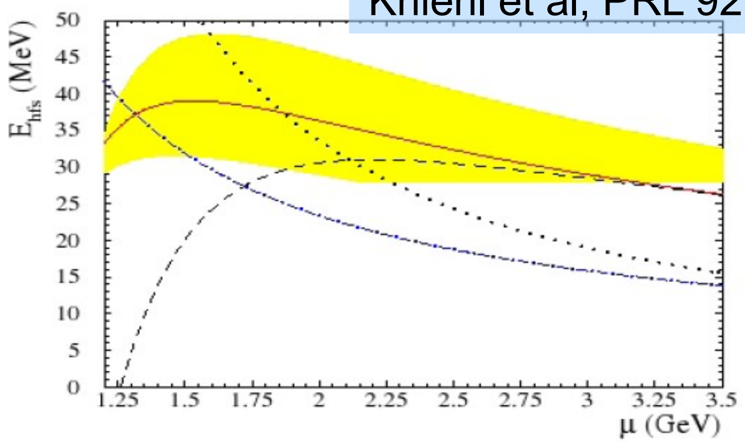
Hyperfine splittings in 3S,2S, and 1S states predicted by lattice and other approaches to be ~60, 30, 20 MeV

$M(\eta_b(1S))$ at NLL:
$9421 \pm 10 \pm 9$ MeV/c^2

$\Gamma(\eta_b(1S) \to \gamma\gamma)$ at NNLL:
$659 \pm 89 \pm 18 \pm 15$ eV

Penin et al, NPB 699(2004) 183

Kniehl et al, PRL 92(2004)242001



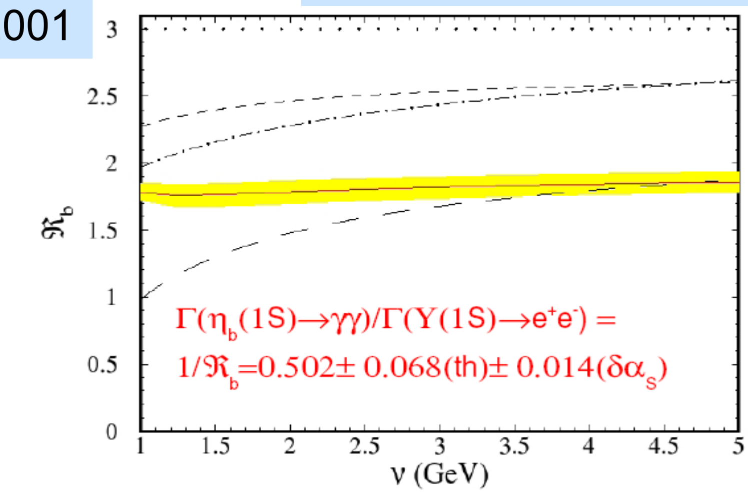
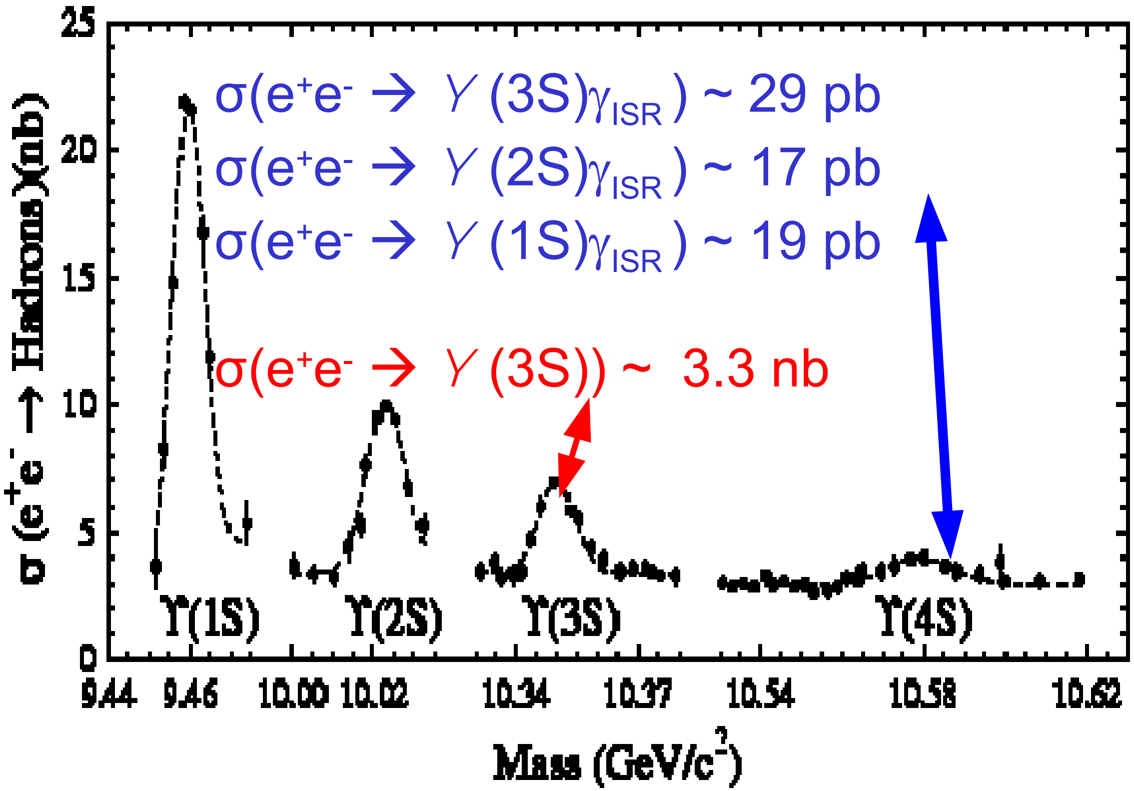
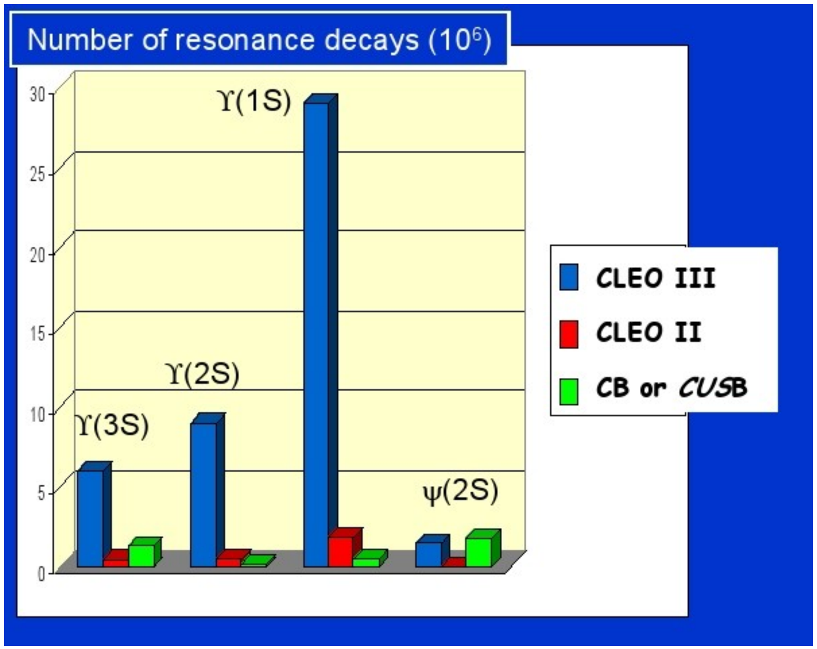


FIG. 1: HFS of 1S bottomonium as a function of the renormalization scale μ in the LO (dotted line), NLO (dashed line), LL (dot-dashed line), and NLL (solid line) approximations. For the NLL result, the band reflects the errors due to $\alpha_s(M_Z) = 0.118 \pm 0.003$.

Figure 3: The spin ratio as the function of the renormalization scale ν in LO≡LL (dotted line), NLO (short-dashed line), NNLO (long-dashed line), NLL (dot-dashed line), and NNLL (solid line) approximation for the bottomonium ground state with $\nu_h = m_b$. For the NNLL result the band reflects the errors due to $\alpha_s(M_Z) = 0.118 \pm 0.003$.

Some numbers...





B factories also produce narrow Υs in ISR:
in 500 fb^{-1} ~9M Υ(1S), ~8M Υ(2S), ~13M Υ(3S)
OK for fully reconstructed final states or
for inclusive analyses detecting γ_{ISR} or tagging using $\pi^+\pi^-$

SuperB in 50 ab^{-1} at the Υ(4S) will have
900M Υ(1S) 800M Υ(2S) 1,300 M Υ(3S)
and in 50 ab^{-1} at the Υ(5S) will have
700M Υ(1S) 500M Υ(2S) and 600M Υ(3S)

Quite respectable, even paying a factor >10 for tagging

CLEO: ~ 1.2 fb^{-1} at each resonance
30M Υ(1S), 8M Υ(2S), 6M Υ(3S)

Belle: 2.9 fb^{-1} at the Υ(3S): ~11M Υ(3S)

Present B factories could aim at
~100 M Υ(nS) "on peak"
SuperB with 3 ab^{-1} ~10 B Υ(3S)

what measurements would require so many?

Tagged ISR samples vs on-peak

ISR will provide samples of unprecedented size for study of exclusive, fully reconstructed, final states

Tagging the ISR photon would allow to determine the Υ(nS) momentum yielding samples "almost equivalent" to on-peak that could be used also for semi-exclusive or inclusive searches

But the expected number of "photon tagged" Υ(nS) in 50+50 ab^{-1} at the Υ(4S)+Υ(5S) is just ~ 200 M

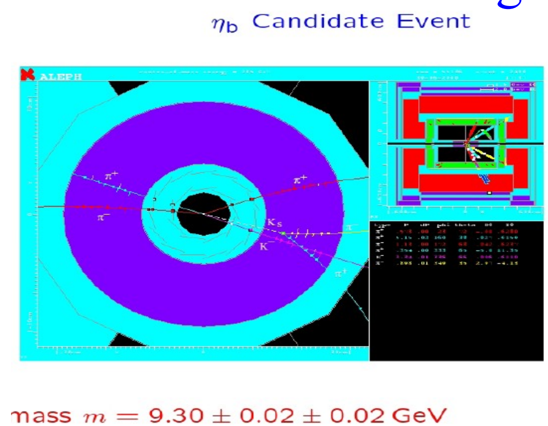
equivalent to just ~ 60 fb^{-1} on-peak... is it worth the effort?

Much cleaner even a short run on peak...

ISR samples just for exclusive final states...

$\eta_b(1S)$ searches in exclusive final states

In 50+50 ab^{-1} at the Y(4S)+Y(5S) there will be BILLIONS untagged Y(nS) from ISR
i.e. if $\mathcal{B}(Y(nS)\rightarrow \eta_b(1S)\,\gamma)\sim10^{-4}$ overall in all transitions order of 1M $\eta_b(1S)$
could search exclusive $\eta_b(1S)$ BR as low as 10^{-4} without a dedicated running

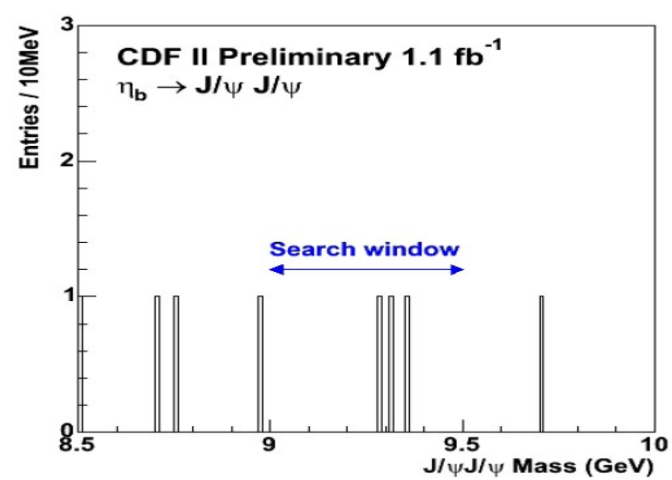


LEP searched for $\gamma\gamma\rightarrow\eta_b$ in 4-6 prongs
few events, compatible with backgrounds

Large hadronic backgrounds, but it could
be possible to sum many exclusive 2-4-6 prong modes

How about. $\eta_b \rightarrow J/\psi J/\psi$?
predictions range from 10^{-4} to 10^{-8}

CDF has few candidates but $\sim10^9$ η_b /fb^{-1}
(Braaten et al PRD 63(2001)094006



Even with dedicated 3 ab^{-1} at the Y(3S)
only ~1 M $\eta_b(1S)$...
Could use semiexclusive strategy
$Y(3S) \rightarrow \gamma\,\eta_b \rightarrow \gamma\, J/\psi\, X$
but still unlikely unless $\mathcal{B}\sim10^{-3}$

Measurements in exclusive final states

in 50+50 ab^{-1} at the Υ(4S)+Υ(5S) (or x10 more for on-peak running...)

Υ(mS)→ππ Υ(nS)

- 600 k reconstructed $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(2S)\to\pi^+\pi^-\mu^+\mu$
- 400 k reconstructed $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)\to\pi^+\pi^-\mu^+\mu$

matrix elements in the transition

$\Upsilon(mS)\to\gamma\,\chi_j(nP)\to\gamma\gamma\Upsilon(kS)\to\gamma\gamma\mu\mu$ hundred thousands each

multipole amplitudes in radiative transitions

measure $\Upsilon(3S)\to\gamma\,\chi_b(1P)$

$\Upsilon(3S)\to\gamma\,\chi_{b1,2}(2P)\to\gamma\,\pi\pi\,\chi_{b1,2}(1P)$

dipion transition in P states

in on-peak or with ISR photon tagging could select $\chi_{b1,2}(1P)$

recoiling againts γ ππ

$\Upsilon(3S)\to\gamma\,\chi_{b1,2}(2P)\to\gamma\,\omega\,\Upsilon(1S)$ thousands

$\Upsilon(3S)\to\gamma\,\Upsilon(1D)\to\gamma\,\gamma\,\gamma\,\gamma\,\ell\ell$ (confirm CLEO observation)

Υ(1D)→ππ Υ(1S)

……

More measurements

- χ_b decays to open charm (CLEO prel. Heltsey@QWG5)

Need on-peak

- Search for LFV $\Upsilon(nS)$ decays
- exclusive BR in $p\bar{p}$, LH..., baryons
- radiative $\Upsilon(nS)$ decays to LH
- η_b, χ_b decays to $\varphi\varphi$
- χ_b decays to $\eta\eta^{(\prime)}$
- inclusive and exclusive decays to charmonium

Need on-peak

- ... new states in $b\bar{b}$ exclusive and inclusive decays??
- ....

$\eta_b(nS)$ search in inclusive photon spectra

CLEO, PRL94(2005)032001

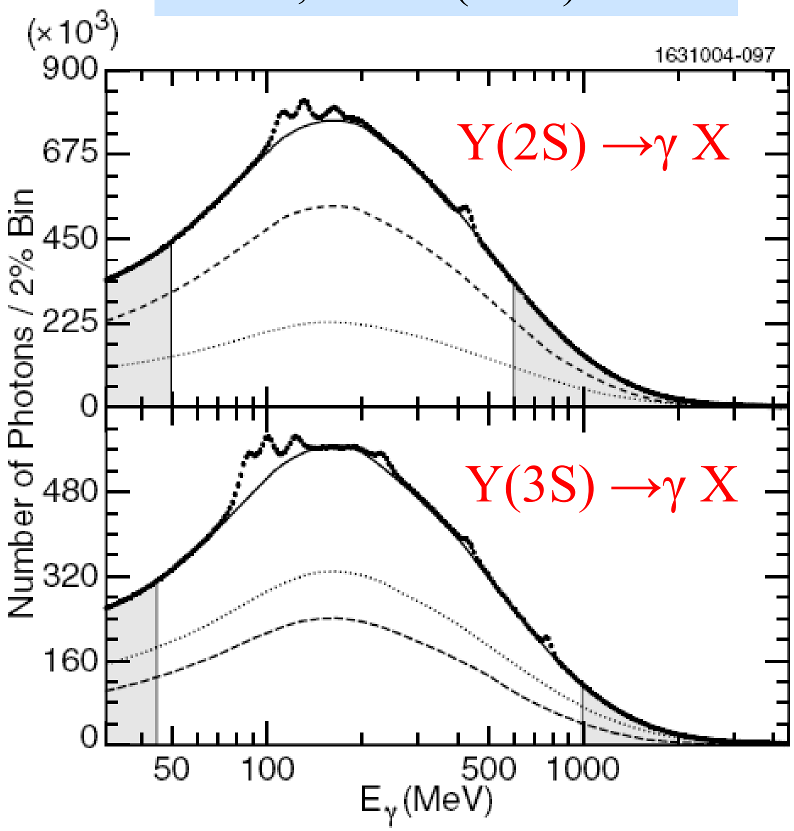
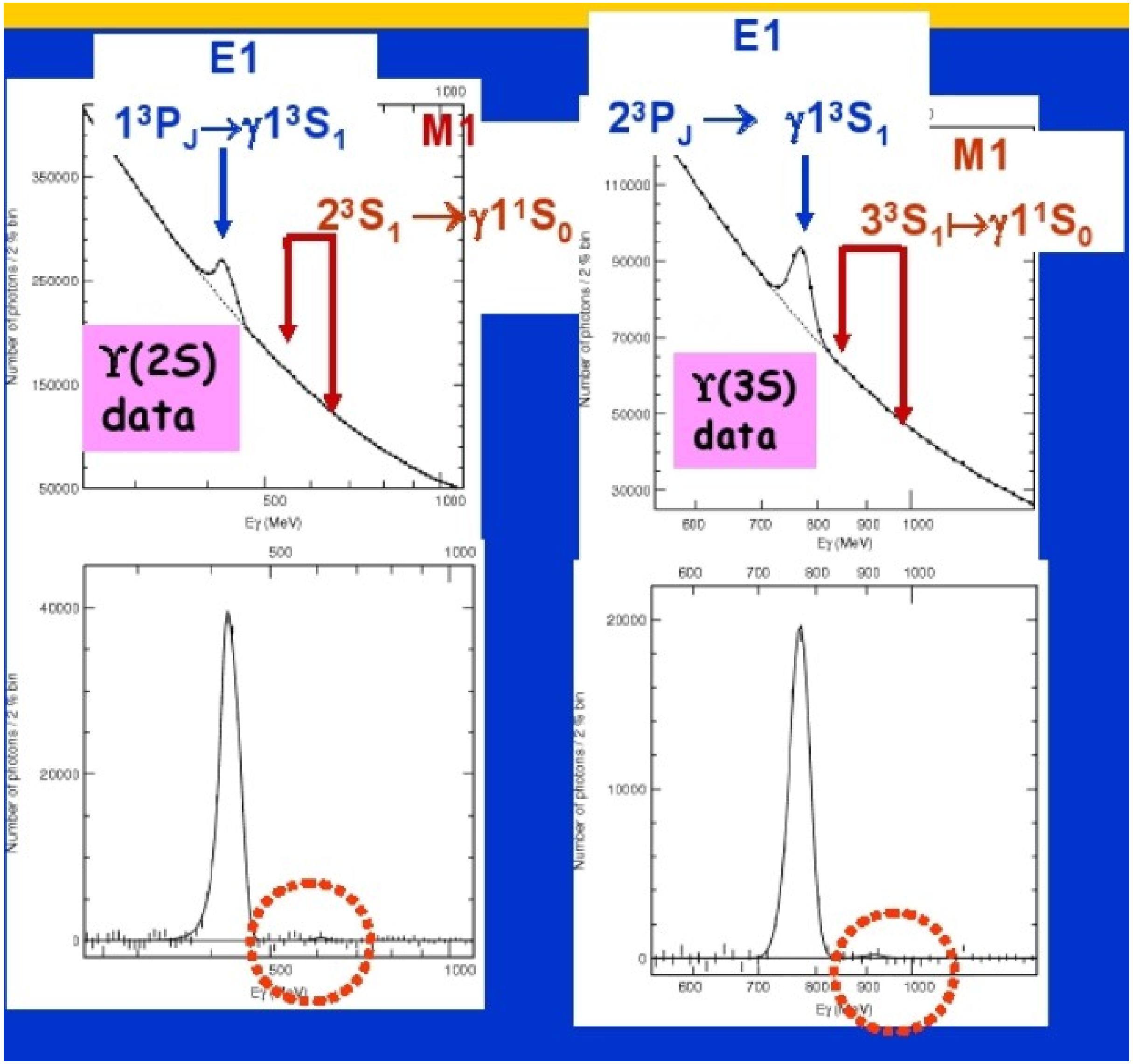


FIG. 1. Fit of the off resonance and $\Upsilon(1S)$ photon spectra to photon backgrounds in the $\Upsilon(2S)$ (top) and $\Upsilon(3S)$ (bottom) data. The energy regions used in the fit are shaded. The total fitted background is represented by the solid line. The $\Upsilon(2S)$ and $\Upsilon(3S)$ data are shown by points. The fitted contributions of the off resonance (dashed line) and $\Upsilon(1S)$ spectra (dotted line) are also shown. See the text for explanation of various photon lines observed in the data.



Already challenging predictions...

Experiment (90%CL)

CLEO, PRL94(2005)032001

$$\mathcal{B}(\Upsilon(3S) \to \gamma\eta_b(2S)) < 6.2 \times 10^{-4}$$

$$\mathcal{B}(\Upsilon(2S) \to \gamma\eta_b(1S)) < 4.3 \times 10^{-4}$$

$$\mathcal{B}(\Upsilon(3S) \to \gamma\eta_b(1S)) < 5.1 \times 10^{-4}$$

Predictions

$\mathcal{B}(\Upsilon(3S) \to \gamma\eta_b(1S))$

- 15-30 10^{-4} — Godfrey,Rosner PRD 64(2001)074011
- 5.2 10^{-4} — Ehbert et al,PRD 67(2003)014027
- 3.6 10^{-4} — Lähde, NPA 714(2003)183

If background level and efficiencies
are comparable to CLEO
the expected UL scales as $\approx\sqrt{N}$
100M could set UL at $\approx 10^{-4}$

Measuring these BR with a precision
of 10-20% is a SuperB job!

Even if found at present B factories
mass and width measurements likely statistics limited....

$h_b(1P)$: double search strategy

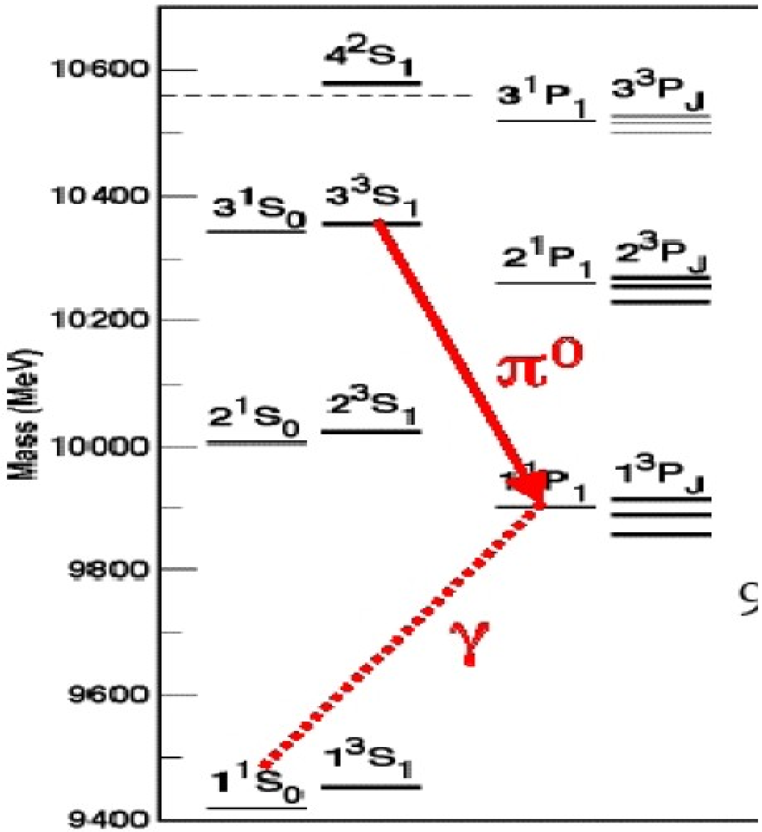
Strategy similar to what CLEO used for the h_c:

Look for the cascade $\Upsilon(3S) \to \pi^0 h_b(1P)$

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

$\hookrightarrow \gamma\, \eta_b(1S)$

Voloshin (86) and Kuang(81) predictions ranging from ~$0.5\ 10^{-3}$ — $5\ 10^{-3}$



CLEO's sensitivity with 6M 3S(Rosner@QWG4)

$B(\Upsilon(3S) \to \pi^0 h_b(1P)) \times B(h_b(1P) \to \gamma\, \eta_b(1S)) \approx 10^{-3}$

Dedicated running at current B factories could have sensitivity to product BR at most ~ 10^{-4}
at best handful of events: mass and width measurements likely statistically limited!

for singlet statess the key measurement is the mass splitting

Other possibilities (Rosner's talk at QWG4)

$$3S \to \pi^+\pi^- h_b \to \pi^+\pi^-\gamma\eta_b$$ 4/6

Inclusive search for $3S \to \pi^+\pi^- h_b$: still need to quantify upper limit.

CLEO II limit: $\mathcal{B}[\Upsilon(3S) \to \pi^+\pi^- h_b] < 0.18\%$ for $(465 \pm 31) \times 10^3$ produced $\Upsilon(3S)$ [F. Butler *et al.*, PR D **49**, 40 (1994)]. (Factor of ~ 2 better including $h_b \to \gamma\eta_b$).

With 5.88 M $\Upsilon(3S)$, scaling by $1/\sqrt{N}$, should set an upper limit at least as good as 0.05% (ultimate goal)

This is within range predicted by Y.-P. Kuang but still above Voloshin's

CLEO II: $\mathcal{B}[\Upsilon(3S) \to \pi^0 h_b] :< 0.27\% \to 0.08\%$ if scale as $1/\sqrt{N}$

$$3S \to \gamma\chi'_{b0} \to \gamma\eta\eta_b$$

Early search (2004): No obvious signal. Voloshin: Independent suggestion

Can one see inclusive η? Look in $\Upsilon(3S) \to \eta\Upsilon(1S)$

No $\Upsilon(3S) \to \eta\Upsilon(1S) \to \eta\ell^+\ell^-$ signal $\Rightarrow \mathcal{B}[\Upsilon(3S) \to \eta\Upsilon(1S)] < 2.2 \times 10^{-3}$

Scaling from $\mathcal{B}[\psi(2S) \to \eta J/\psi] \simeq 3\%$ suggests this should be detectable.

SuperB: over 3 B Y(3S) in each ab^{-1} x1000 more stat!!

Conclusions

Even after current B-factories there will likely be still crucial measurements in particular on singlet states

ISR will anyway provide samples that are one order of magnitude larger than what collected at B-factories

These samples can be used for studying exclusive final states

Inclusive measurements would be possible using tagged ISR, but they would certainly be much cleaner in on-peak running

... and do not forget bottomonium decays of Y(4S) and Y(5S)...