Bottomonium Spectroscopy at B-Factories

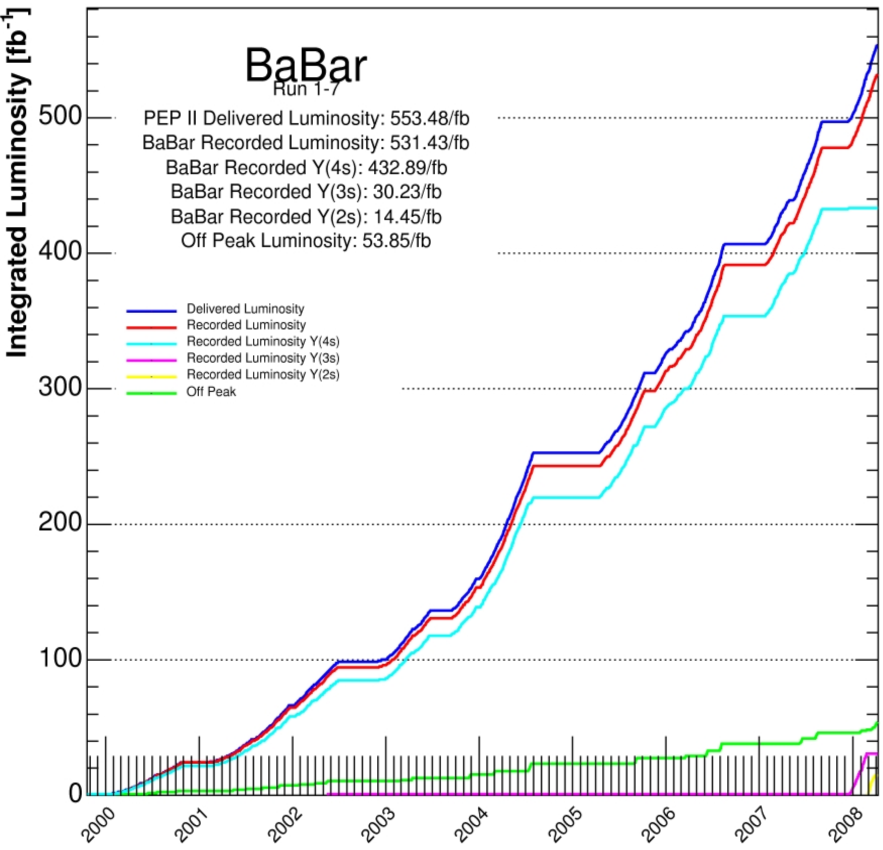
Roberto Mussa
INFN Torino

(on behalf of BELLE *and* *)*

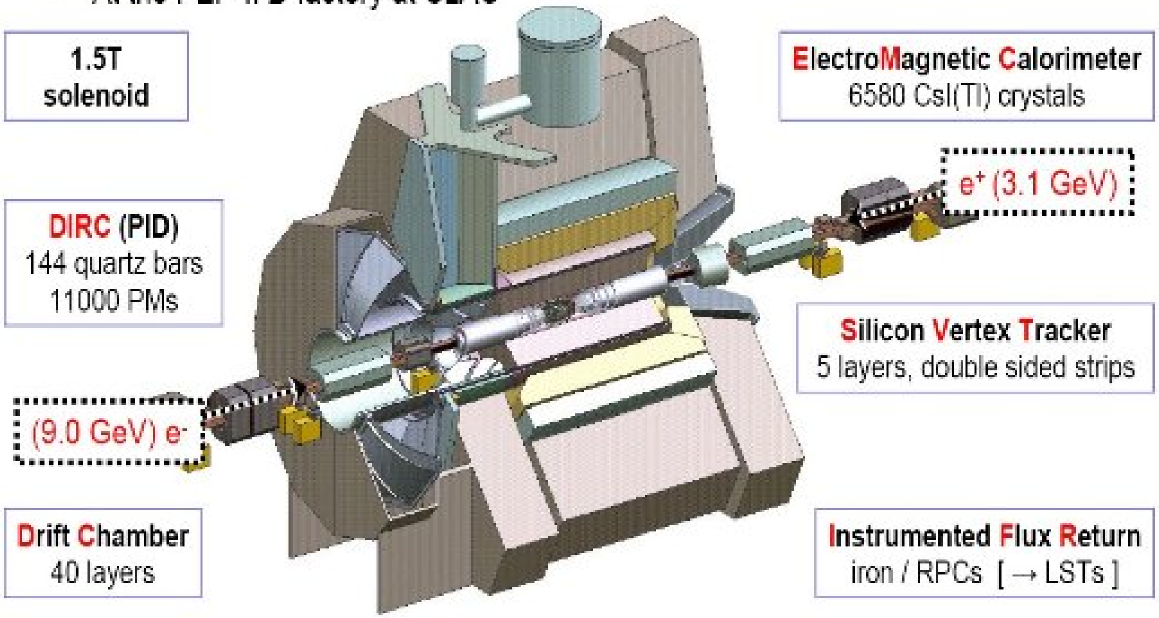
XXIII Rencontres de Physique de la Vallee d'Aoste, La Thuile, 3/4/2009

BaBar @ PEP-II

As of 2008/04/11 00:00



- At the PEP-II *B*-factory at SLAC



1.5T solenoid

DIRC (PID)
144 quartz bars
11000 PMs

(9.0 GeV) e^-

Drift Chamber
40 layers

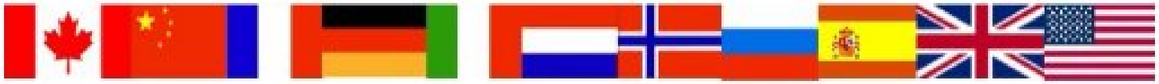
ElectroMagnetic Calorimeter
6580 CsI(Tl) crystals

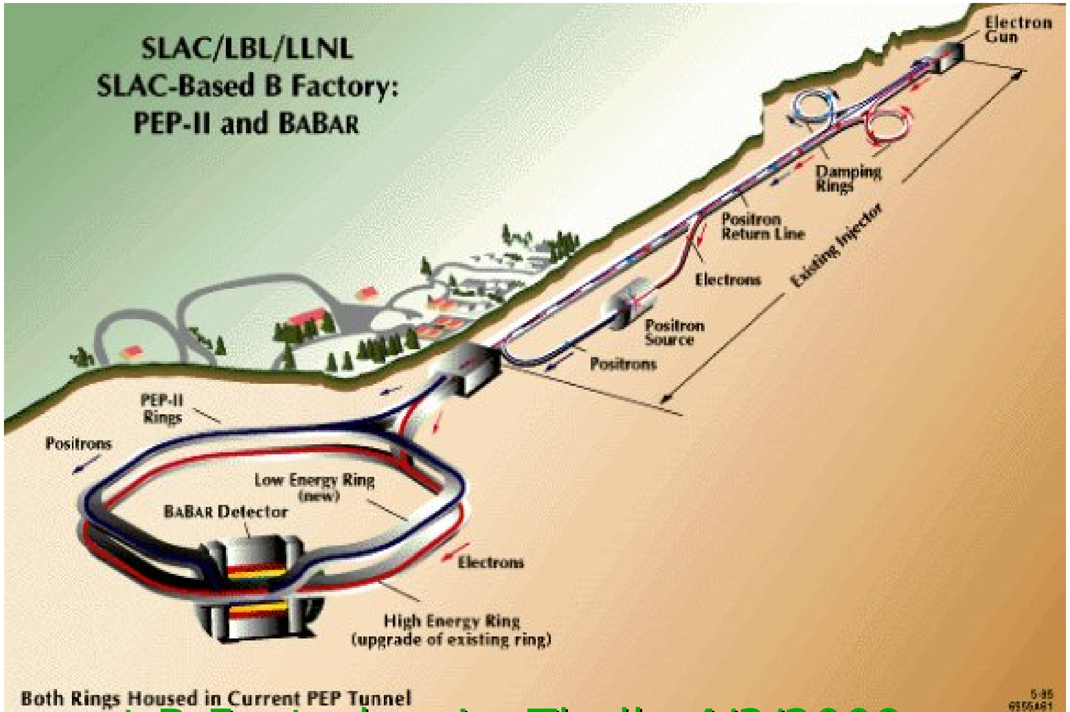
e^+ (3.1 GeV)

Silicon Vertex Tracker
5 layers, double sided strips

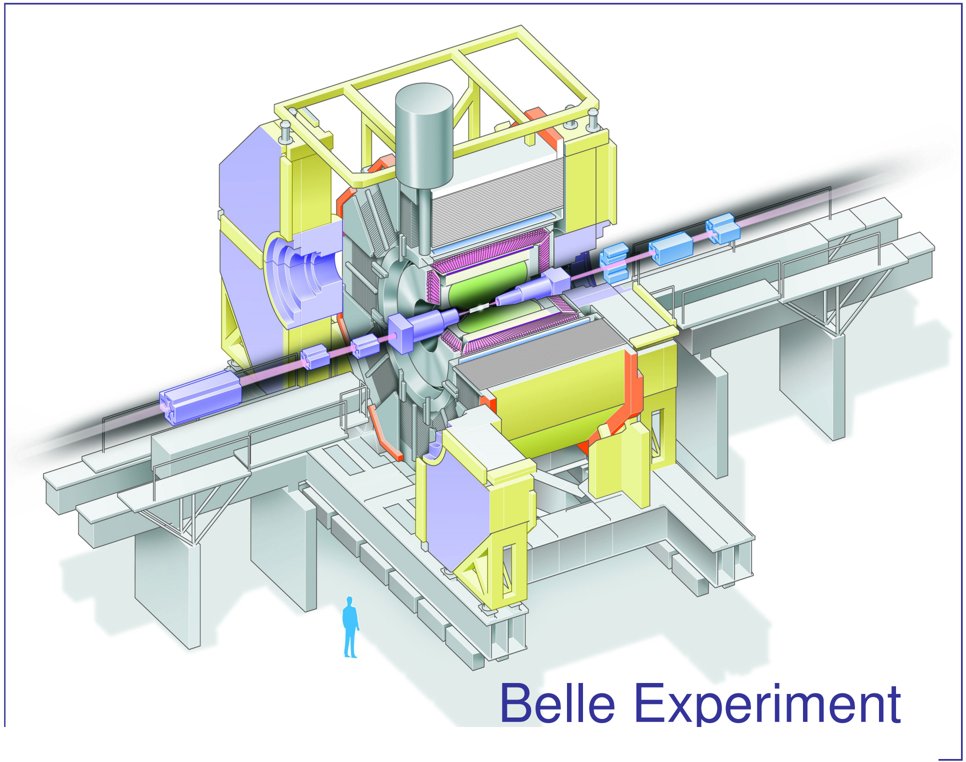
Instrumented Flux Return
iron / RPCs [→ LSTs]

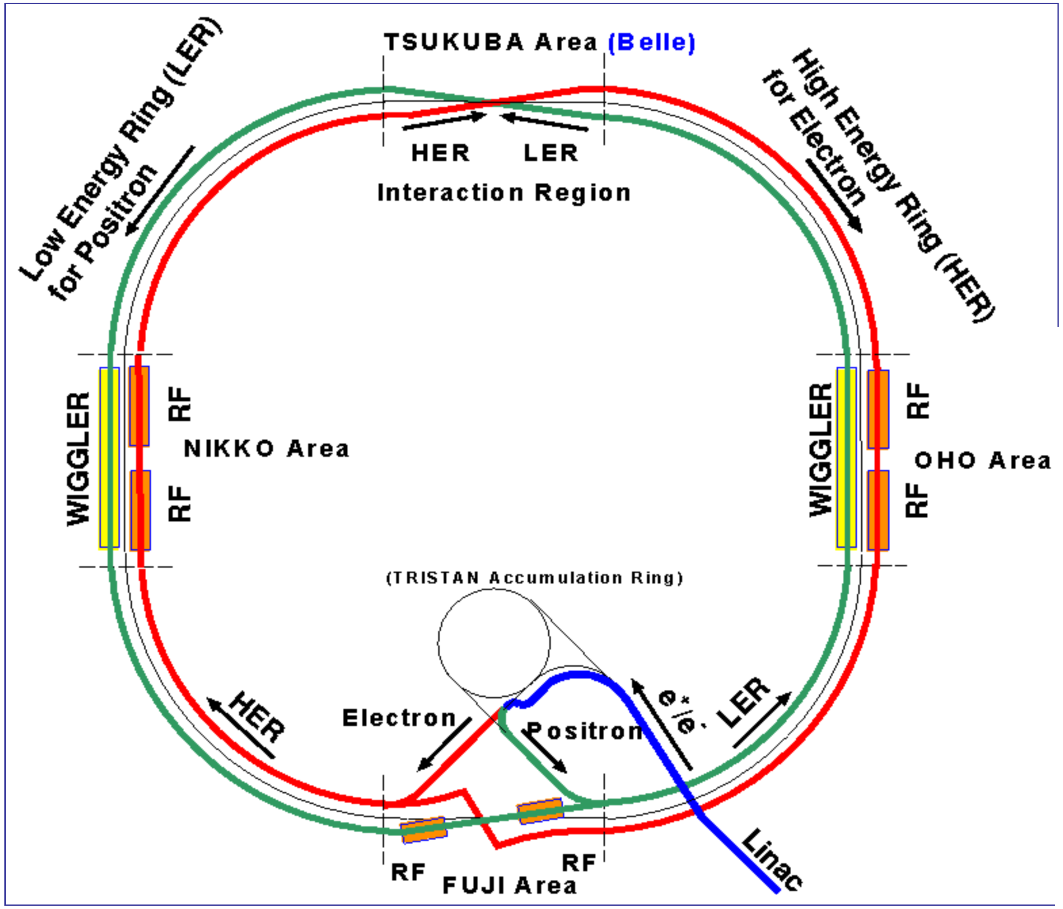
- *BABAR* collaboration consists 11 countries and 500 physicists!

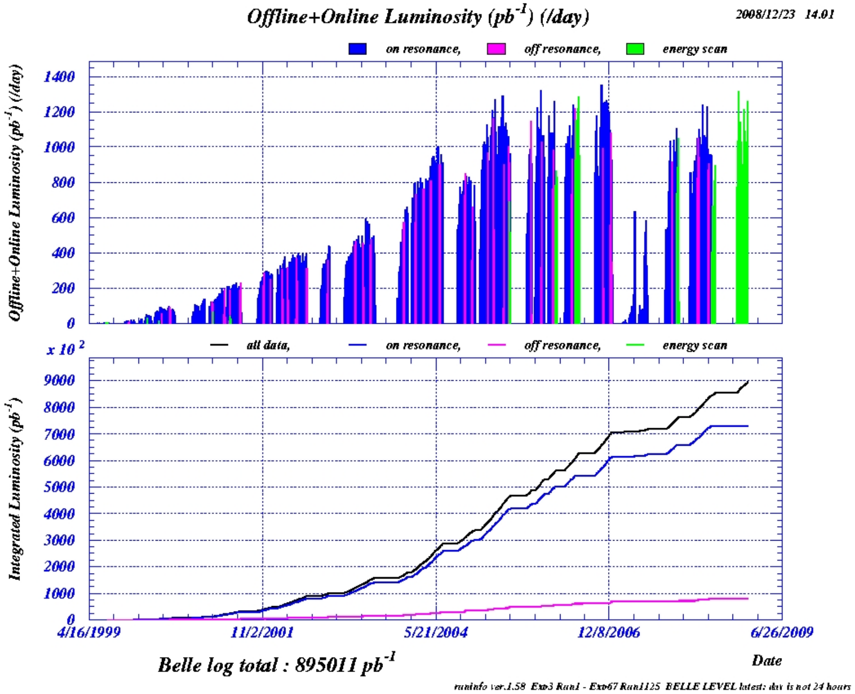


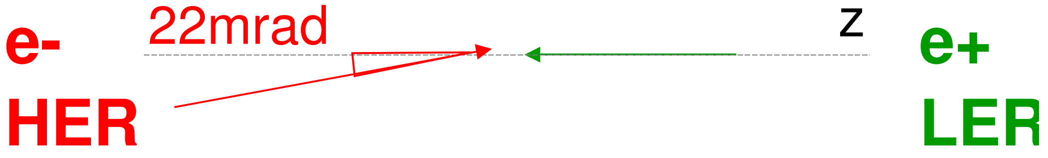


Belle @ KEKB


Belle Experiment


TSUKUBA Area (Belle)
HER
LER
Interaction Region
Low Energy Ring (LER)
for Positron
High Energy Ring (HER)
for Electron
WIGGLER
RF
RF
NIKKO Area
WIGGLER
RF
RF
OHO Area
(TRISTAN Accumulation Ring)
HER
Electron
Positron
e⁺/e⁻
LER
Linac
RF
RF
FUJI Area


Offline+Online Luminosity (pb⁻¹) (/day)
2008/12/23 14.01
on resonance,
off resonance,
energy scan
Offline+Online Luminosity (pb⁻¹) (/day)
1400
1200
1000
800
600
400
200
0
x 10²
all data,
on resonance,
off resonance,
energy scan
Integrated Luminosity (pb⁻¹)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
4/16/1999
11/2/2001
5/21/2004
12/8/2006
6/26/2009
Date
Belle log total : 895011 pb⁻¹
runinfo ver.1.58 Exp3 Run1 - Exp67 Run1125 BELLE LEVEL latest: day is not 24 hours


e-
HER
22mrad
z
e+
LER

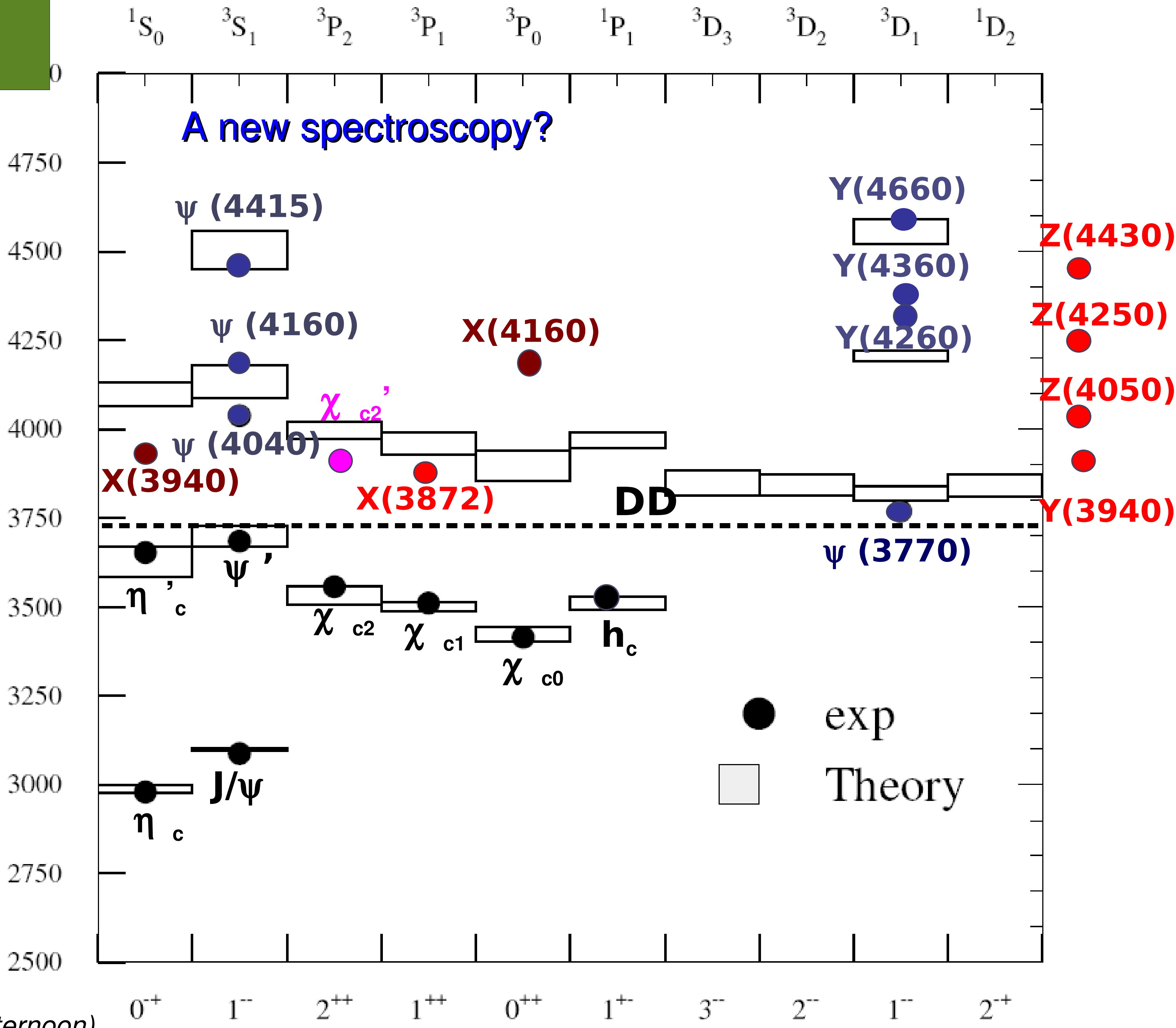
Charmonium

B-factories (CLEO, Babar, Belle) had a leading role in Charmonium Spectroscopy revival in the last decade.

Found missing paracharmonia. (η_c' and h_c)

Discovered >10 new states above threshold:
- narrow
- 3 charged
- large BR to $\psi(1,2S)+n\pi$

Many surprises!!!



(See R.Mizuk's talk this afternoon)

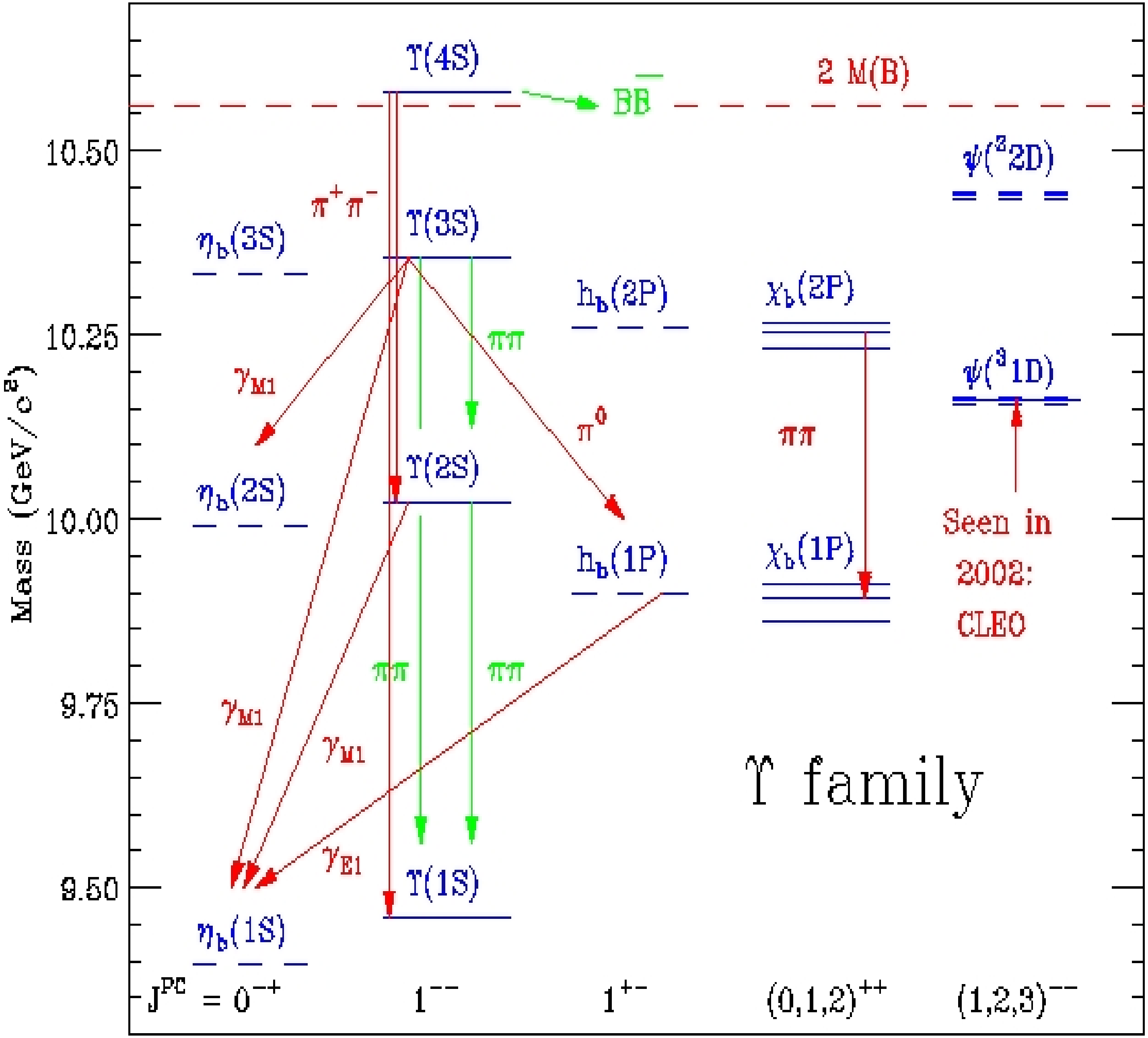
Bottomonium

What can B-factories do for bottomonium?

Action Items:

- find missing states below open bottom threshold:
  5 parabottomonia
  (in S,P wave)
  Y(1,2D) states

- find bottomonium analogues of most recent charmonium discoveries:
  X(3872)
  Y(4260)

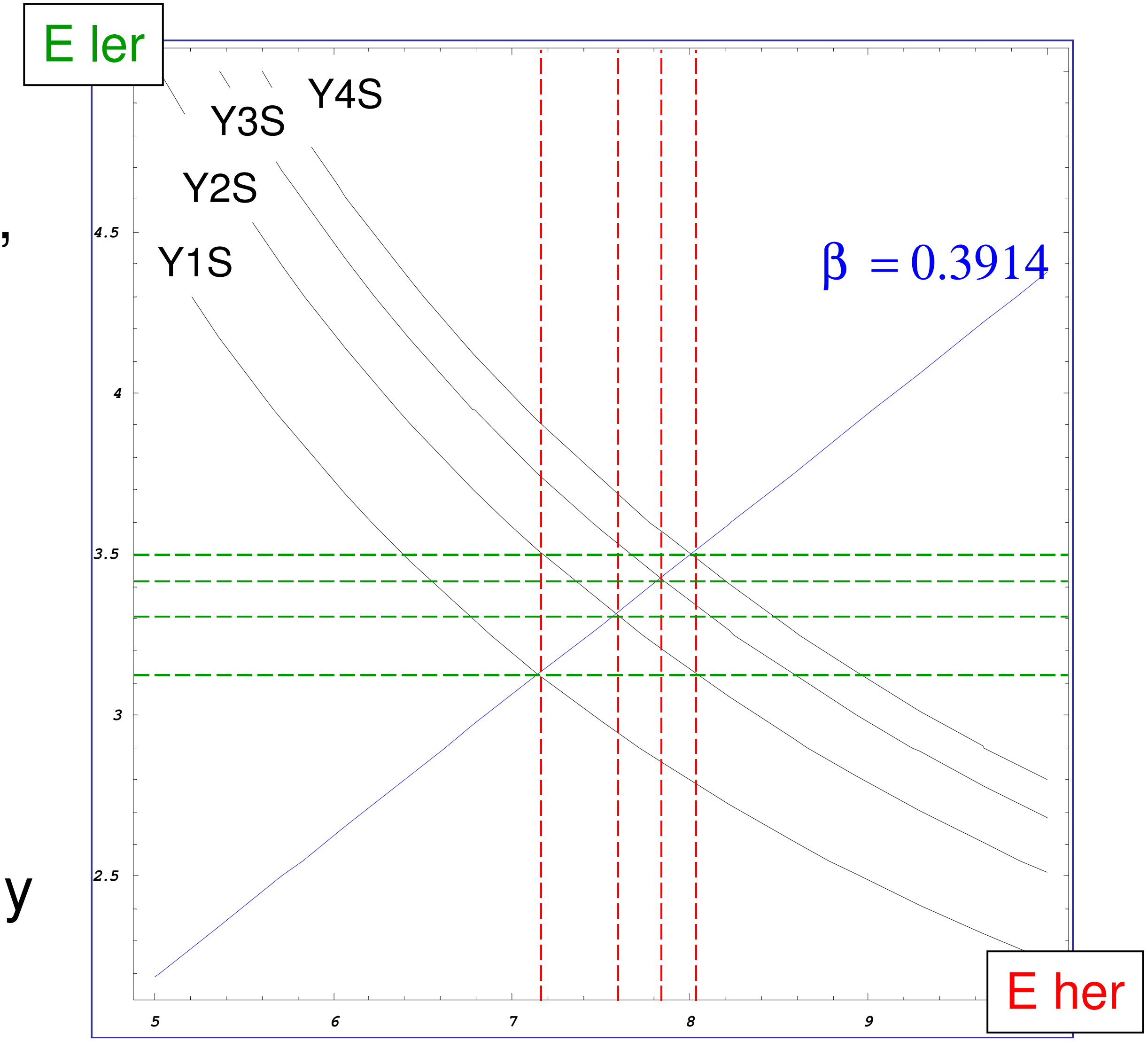


Kinematics

BELLE: Both HER and LER Energy are changed, keeping boost factor constant.

	Mass	Eher	Eler
Y(1S)	9460	7152	3128
Y(2S)	10023	7578	3314
Y(3S)	10355	7829	3424
Y(4S)	10580	7999	3499

BABAR: Only HER Energy is changed.



Data samples

Non-Y(4S) Data taken in 2008

BABAR:

- Jan-Feb 2008: 120 M Y(3S) decays
- March 2008: 100 M Y(2S) decays
- March 2008: 3.3 fb^{-1} scan from 10.54 to 11.2 GeV

BELLE:

- June 2008: 100 M Y(1S) decays
- Sep-Nov 2008: 30 fb^{-1} at Y(5S) peak
- Dec. 2008: 50 M Y(2S) decays

Overall summary on Y(1,2,3S) samples (units 10^6) :

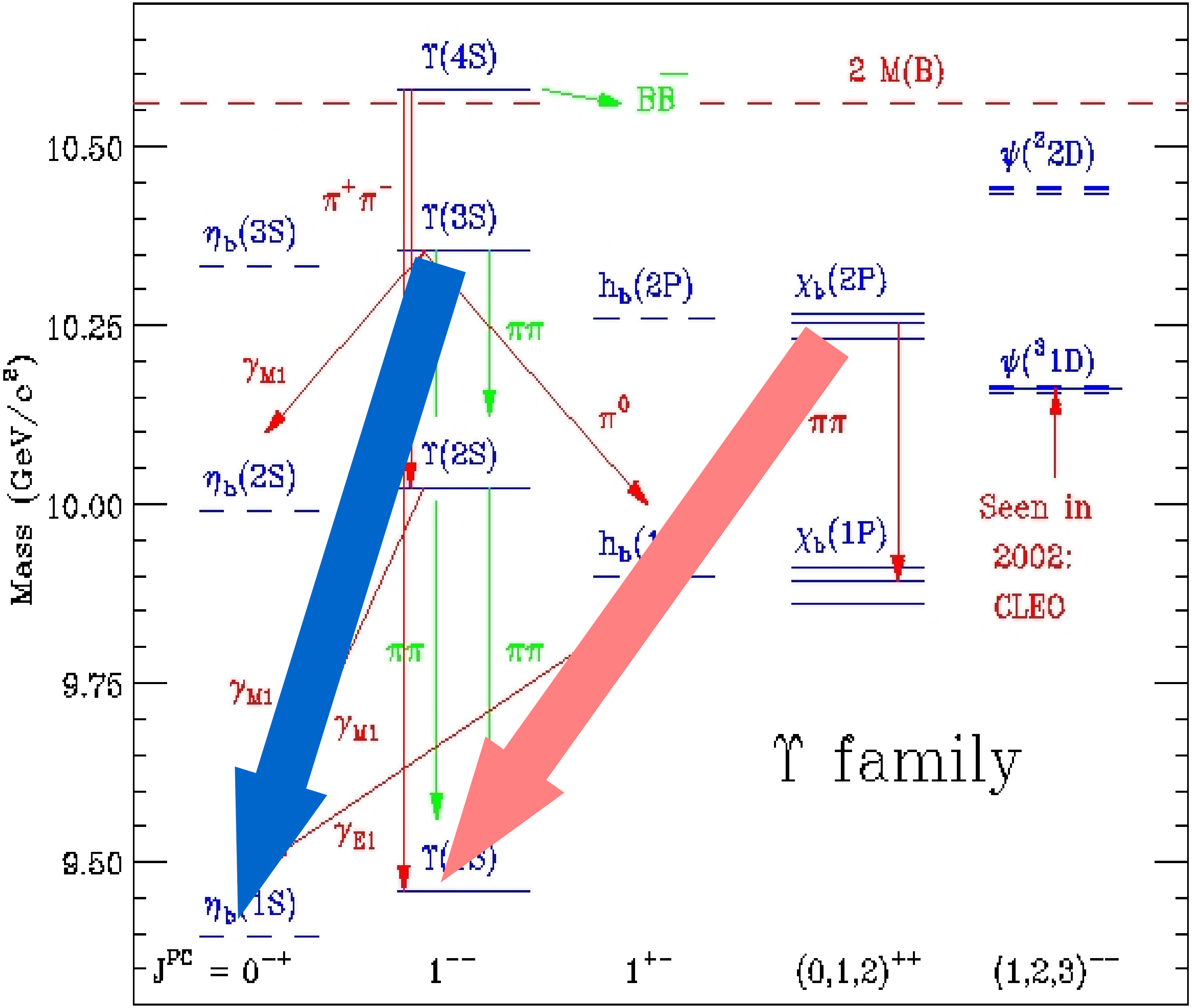
	CLEO-III	BABAR_ISR(a)	BABAR	BELLE_ISR(b)	BELLE
1S	20	6.80	-	11.8	100
2S	9	5.95	100	10.4	50
3S	6	10.0	120	17.4	11

(a) from 347.5/fb at Y(4S)
(b) from 604.5/fb at Y(4S)

η_b(1S) searches in Y(3S) decays

Peak hunting between 890 and 950 MeV in the single photon inclusive spectrum at Y(3S) peak.

Challenge: huge background from single photons from continuum and other Y(nS) transitions



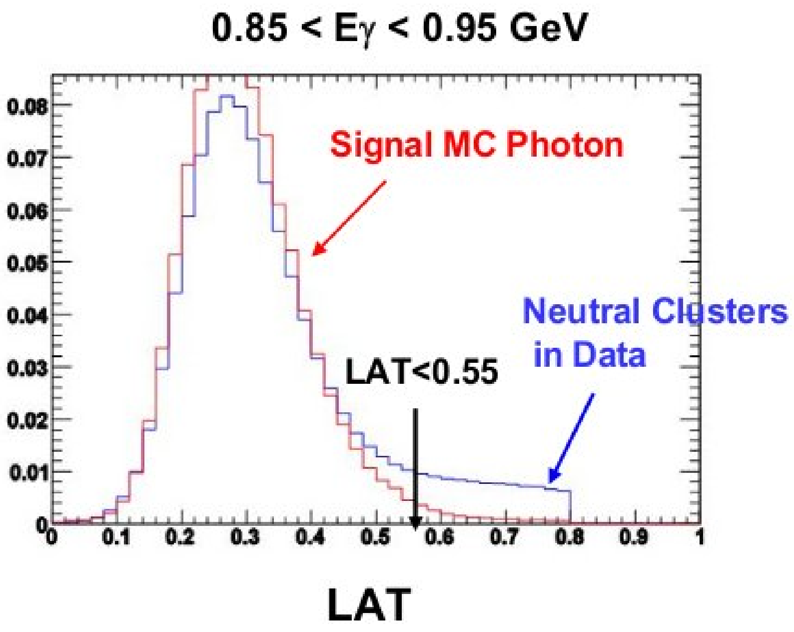
$\eta_b(1S)$ selection criteria

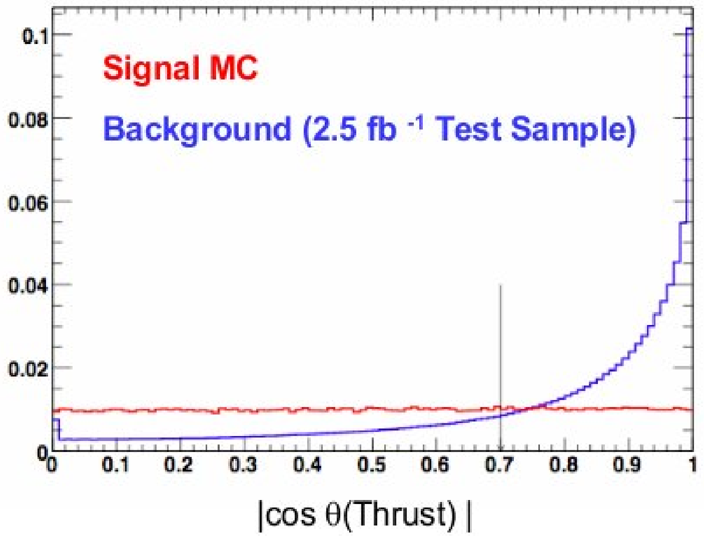
Cut tuning made on 1/10 of the sample

Hadronic Event Selection:
- Ntrk > 3
- R2 (Fox Wolfram)< 0.98

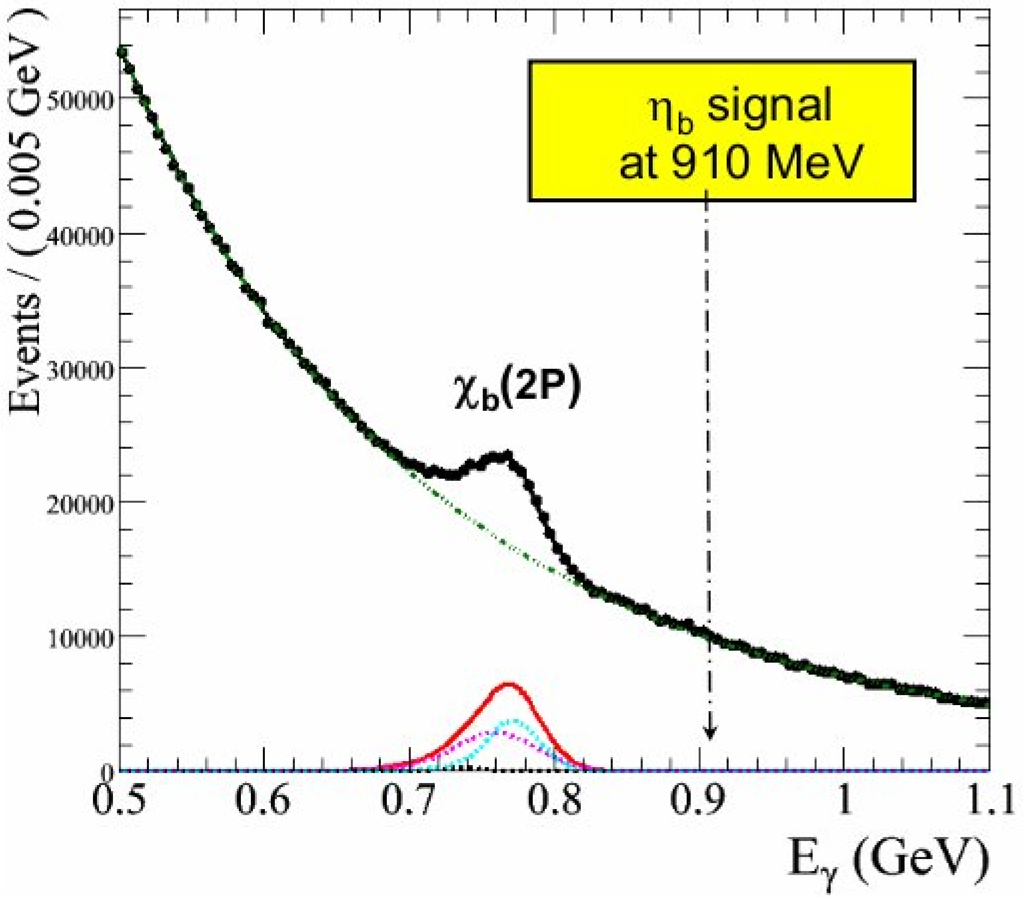
Photon candidates:
- Central Barrel: $-0.762 < \cos(\theta_{\gamma,lab}) < 0.89$
- Lateral shower shape cut: LAT<0.55
- no charged tracks in the proximity
- no other photons with E>50 MeV such that
  $|m(\gamma\gamma)-M(\pi^0)|<15$ MeV
- no correlation with thrust axis of recoil system:
  $|\cos\theta(\text{Thrust})|<0.7$

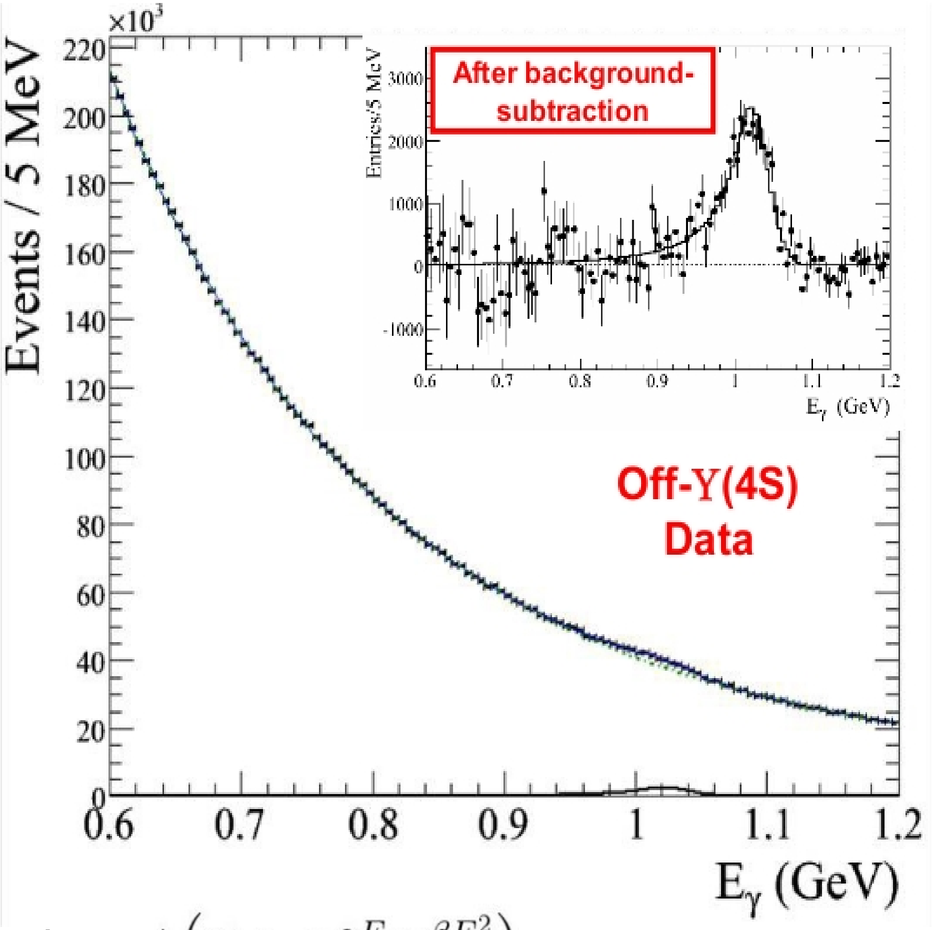
Efficiency (from MC):
- on signal: 37%
- on bkg: 6%
  - bkg=70% resonant
    - +30% continuum





Inclusive photon spectrum at Υ(3S)





Non peaking background fitted with 4 parameter function: $A\left(C + e^{-\alpha E_\gamma - \beta E_\gamma^2}\right)$

Peaking backgrounds:

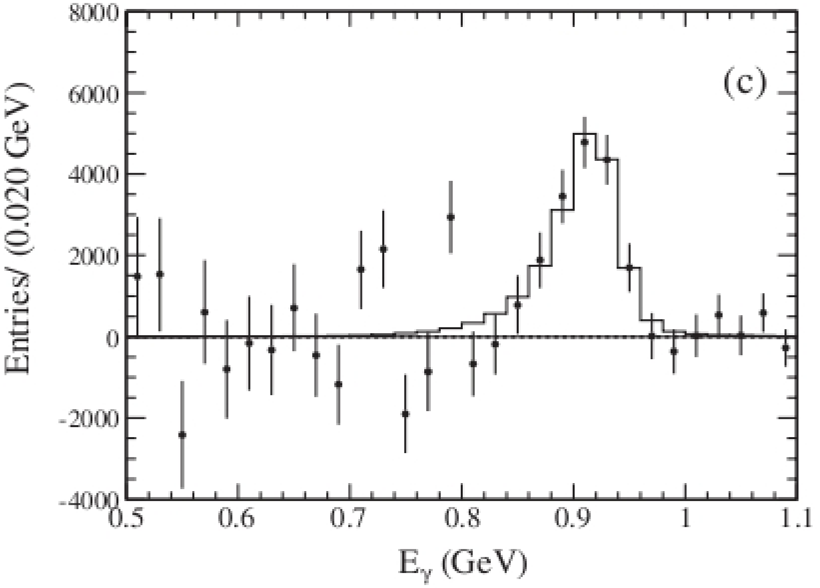
- on resonance: from Doppler broadened peaks from $\chi_{b1,2}(2P) \to \gamma\, Y(1S)$ (764-777 MeV)
- Modeled with resolution function (from MC): Signal PDF: Crystal Ball Fcn ⊗ BreitWigner

- on continuum: from ISR formation of Y(1S): $e^+e^- \to \gamma_{ISR} + \Upsilon(1S)$ (E=850 MeV at 3S)
- studied using 44 fb^{-1} at 10.54 GeV

BaBar result on $\Upsilon(3S)\rightarrow\gamma\,\eta_b(1S)$

$\Upsilon(3S) \rightarrow \gamma\ \eta_b$

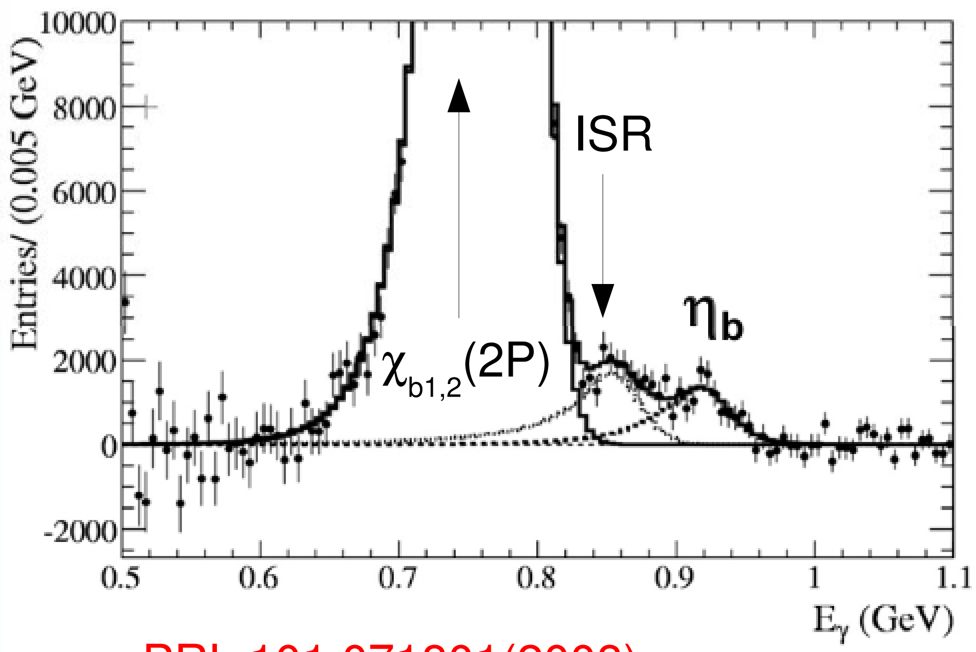
After subtracting the smooth and the peaking ($\chi_{b1,2}$(2P) and ISR) photon backgrounds:



the η_b yield is (19.2±2.0 ±2.1) ×10^3

[10 σ significance]

[30.2 fb^{-1} = 120 M Υ(3S), Jan-Feb.2008]



PRL 101,071801(2008)

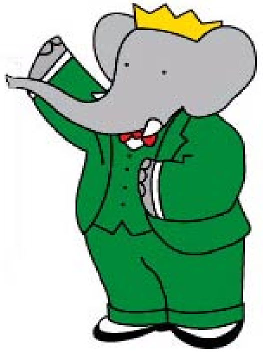
$$E_\gamma = 921.2^{+2.1}_{-2.8} \pm 2.4\ \text{MeV}$$

$$M(\eta_b) = 9388.9^{+3.1}_{-2.3} \pm 2.7\ \text{MeV}/c^2$$

$$M(\Upsilon(1S)) - M(\eta_b) = 71.4^{+2.3}_{-3.1} \pm 2.7\ \text{MeV}/c^2$$

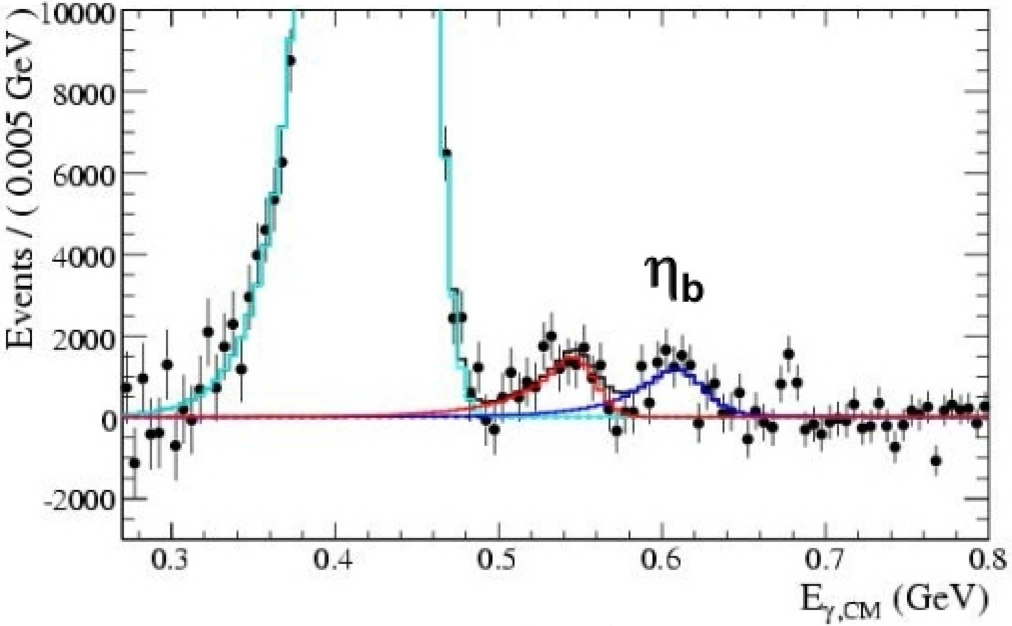
$$B(\Upsilon(3S) \rightarrow \gamma\,\eta_b) = [4.8 \pm 0.5 \pm 1.2] \times 10^{-4}$$

BaBar result on $Y(2S) \to \gamma\, \eta_b(1S)$



$Y(2S) \to \gamma\, \eta_b$

[14.5 fb^{-1} = 100 M Y(2S), Mar.2008]



Preliminary: shown at QWG2008, Nara (www-conf.kek.jp/qwg08/)

$$E_\gamma = 610.5^{+4.5}_{-4.3} \pm 1.8 \text{ MeV}$$

$$M(\eta_b) = 9392.9^{+4.6}_{-4.8} \pm 1.8 \text{ MeV}/c^2$$

$$M(\Upsilon(1S)) - M(\eta_b) = 67.4^{+4.8}_{-4.5} \pm 1.9 \text{ MeV}/c^2$$

$$B(\Upsilon(2S) \to \gamma\, \eta_b) = [4.2^{+1.1}_{-1.0} \pm 0.9] \times 10^{-4}$$

Slightly different selection criteria :

π^0 cut: $E(\gamma_2)>40$ MeV

Thrust axis cut: $|\cos\theta(\text{Thrust})<0.8$

Efficiency : 35.8%

After removing backgrounds:

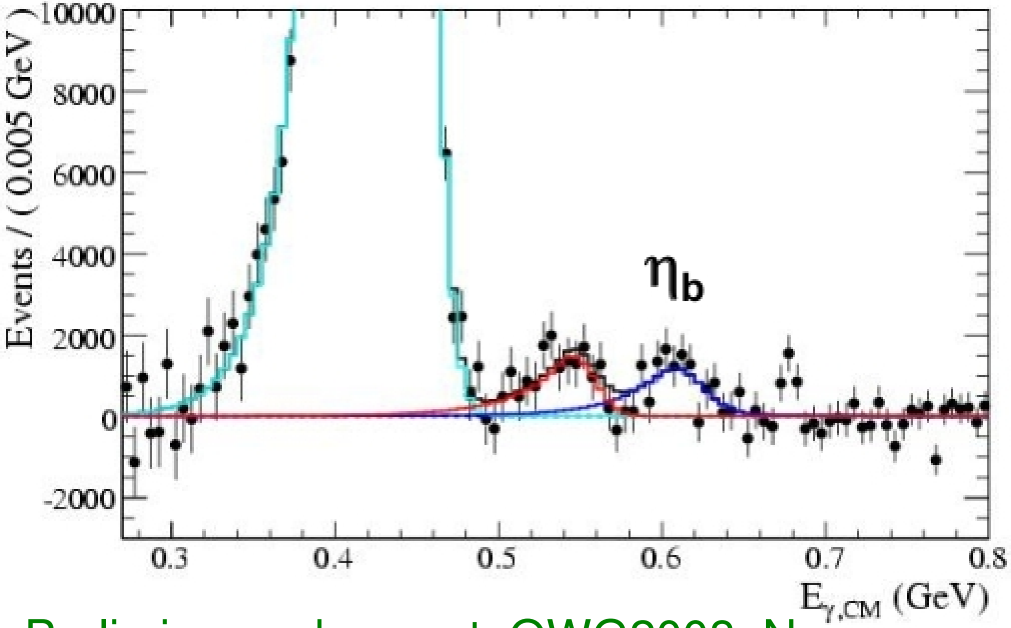
η_b yield is $(13.9 \pm 3.5 \pm ??) \times 10^3$

[> 3.5 σ significance]

BaBar results on $\Upsilon(2,3S)\rightarrow\gamma\,\eta_b(1S)$

$\Upsilon(2S) \rightarrow \gamma\,\eta_b$

[14.5 fb^{-1} = 100 M $\Upsilon(2S)$, Mar.2008]



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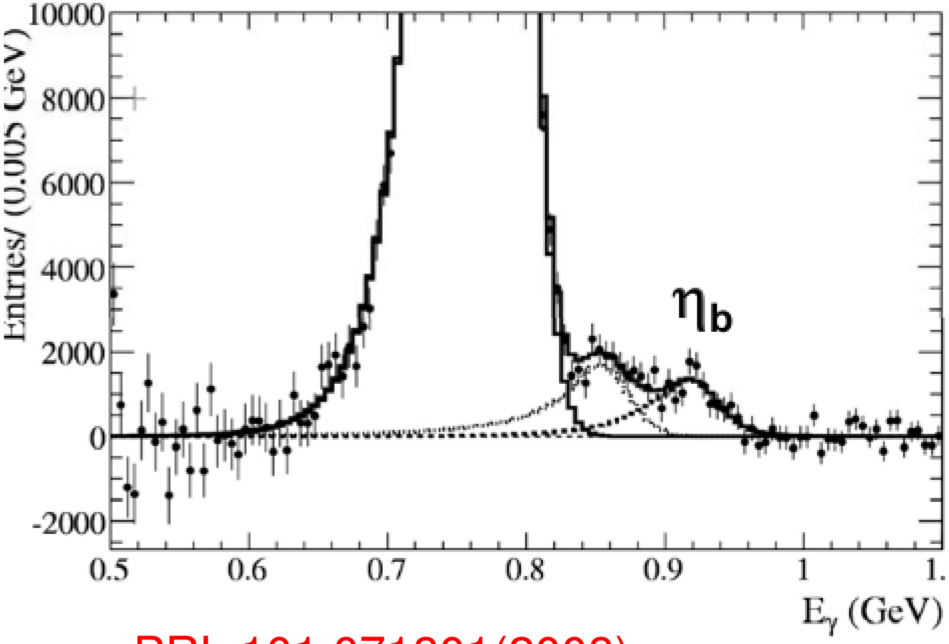
$\Upsilon(3S) \rightarrow \gamma\,\eta_b$

[30.2 fb^{-1} = 120 M $\Upsilon(3S)$, Jan-Feb.2008]



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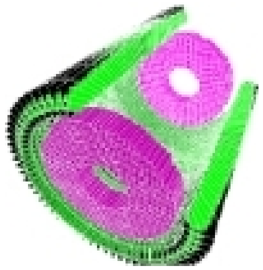
$$B(\Upsilon(3S) \rightarrow \gamma\,\eta_b) = [4.8 \pm 0.5 \pm 1.2] \times 10^{-4}$$

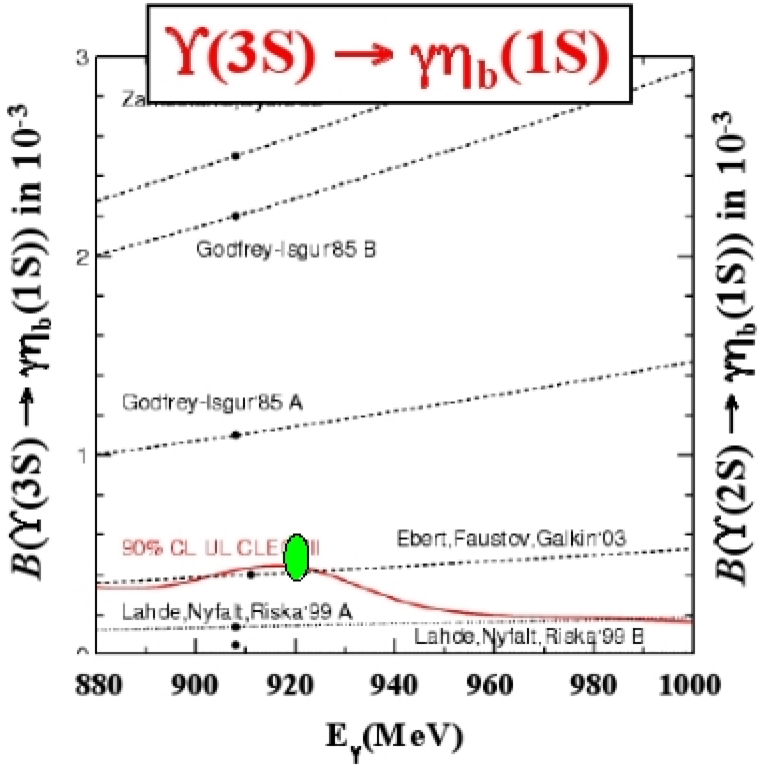
Did CLEO see the $\eta_b(1S)$?

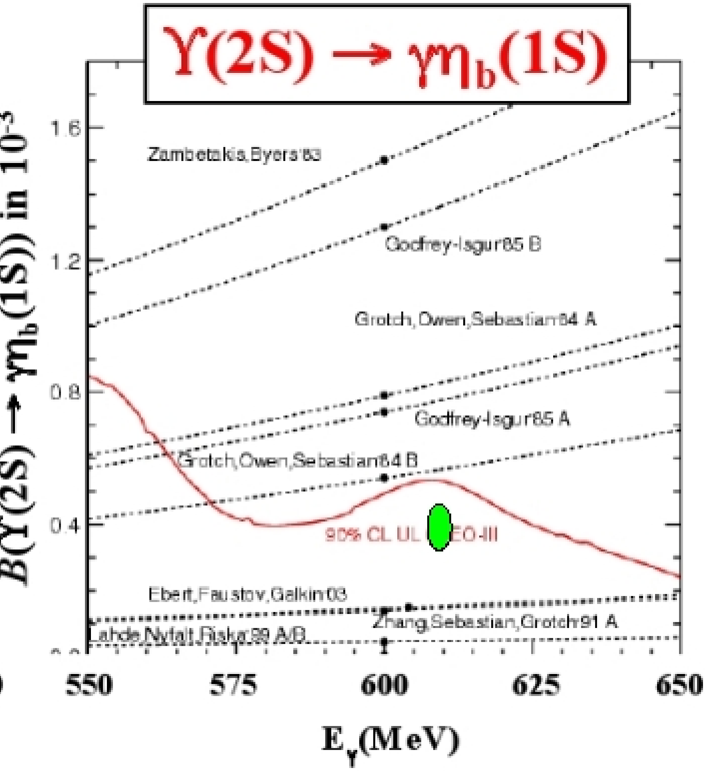


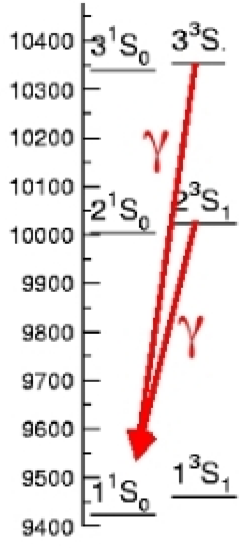
1/20 statistics

No cosθ(Thrust) cut

No ISR peak subtraction







Theory predictions

NRQCD:
NLL calculation of δM_{hf} :

δM_{hf}=39±10(th)±9($\delta\alpha_S$) MeV/c^2

Kniehl et al., PRL 92(2004),242001

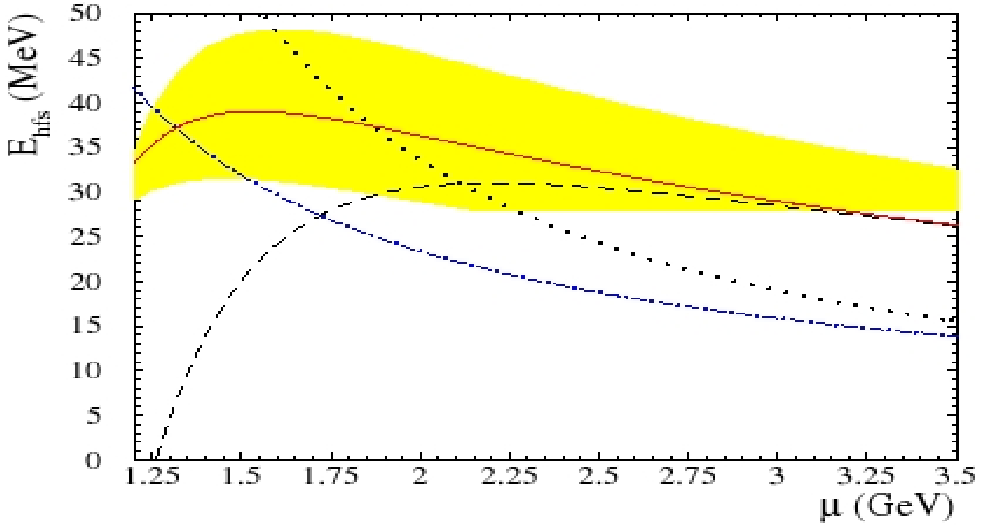


FIG. 1: HFS of 1S bottomonium as a function of the renormalization scale μ in the LO (dotted line), NLO (dashed line), LL (dot-dashed line), and NLL (solid line) approximations. For the NLL result, the band reflects the errors due to $\alpha_s(M_Z) = 0.118 \pm 0.003$.

Lattice QCD (δM_{hf} at LO)

M(Y1S)-M(η_b)=61±14 MeV/c^2

(th. error dominated by QCD radiative corrections)

Gray et al, PRD72(2005),094507

Experiment: (BABAR from Y3S)

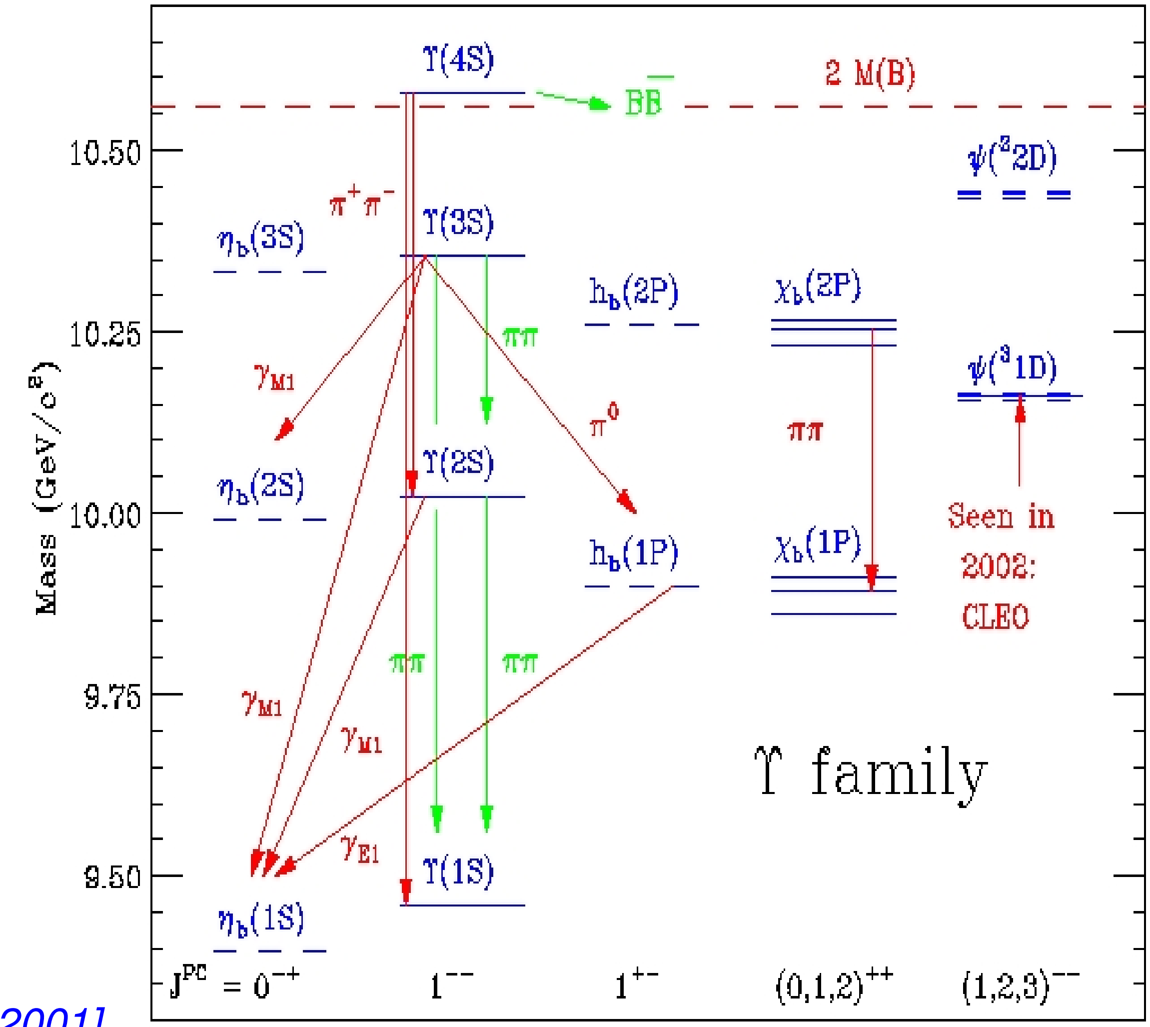
$$E_{\rm hfs}^{\rm exp} = 71.4 \pm 2.7\,({\rm syst})\,^{+2.3}_{-3.1}\,({\rm stat})\ {\rm MeV}$$

Rel.Quark Model, LO pQCD:

δM_{hf}=60 MeV/c^2

Godfrey,Isgur, PRD32(1985),189

Further searches



The remaining 4 S=0 states:

- Search for η_b(2S) from Y(3S)
- Y(3S)→π h_b(1P)→γη_b(1S)
- η_b(3S): exclusive modes?
- h_b(2P): decays from Y(5,6S)?

Y(1D) states

Narrow states at thresholds?

Y(nS) decays : searches for

charmonia *[CLEO:PRD70(2004)072001]*
nuclei *[CLEO:PRD75(2007)012009]*
DM candidates *[Belle:PRL98(2007)132001]*
light Higgs *(see S.Banerjee's talk on friday)*
LFV (eτ, μτ) *[Babar:arXiv:0812.1021]*

Exclusive modes

CLEO-III *Phys.Rev.D78:091103,2008*

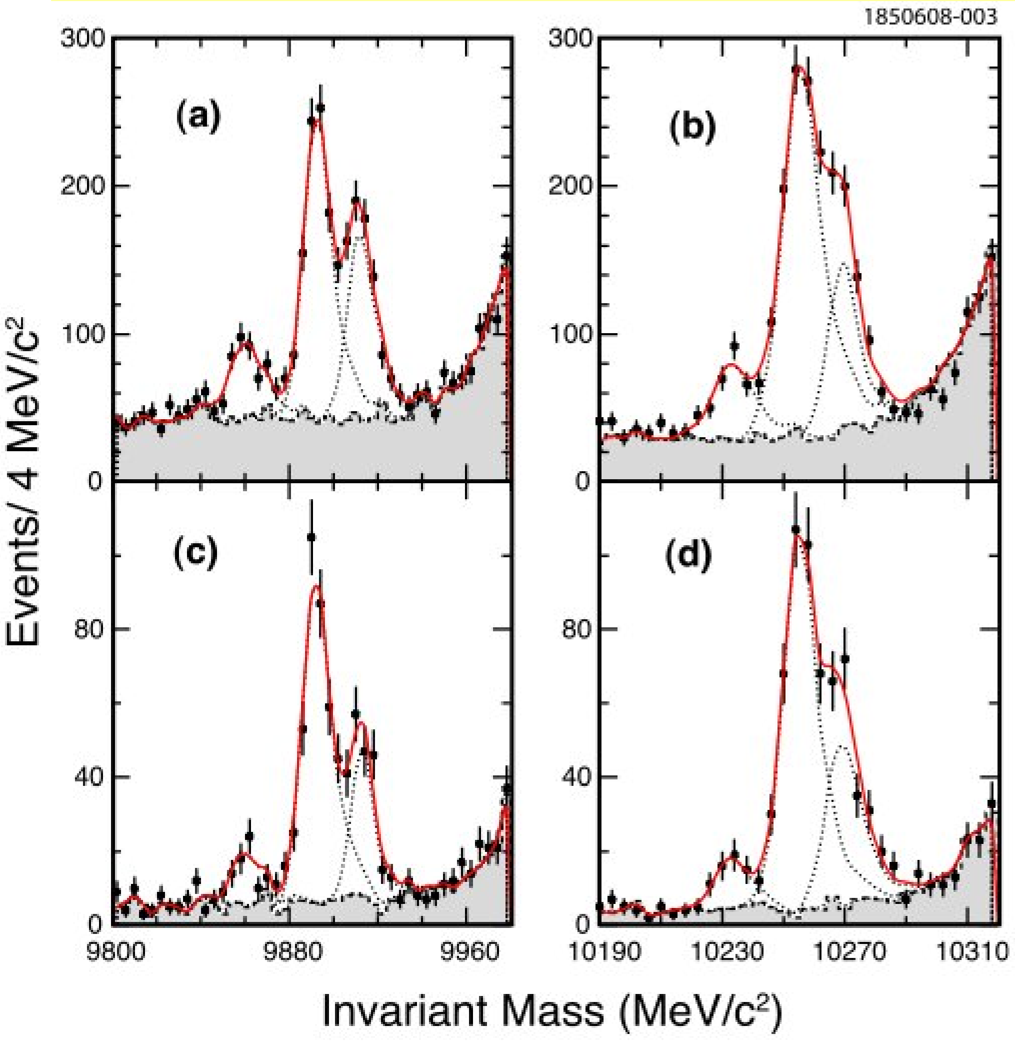
Full reconstruction of 659 exclusive $\chi_b(1,2P)$ decay modes from Y(2S,3S) radiative decays.

Only 14 decays modes detected with $>5\sigma$ significance

We might use them to tag exclusive $Y \rightarrow \gamma \eta_b$ transitions, BUT:

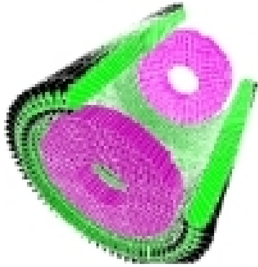
$BR(Y \rightarrow \gamma \eta_b) < 10^{-2} BR(Y \rightarrow \gamma \chi_b)$

$Y(2S) \rightarrow \gamma \chi_b(1P)$ $Y(3S) \rightarrow \gamma \chi_b(2P)$



Exclusive modes

CLEO-III *Phys.Rev.D78:091103,2008*



All Branching Ratios in 10^{-4} units

χ_b(nP)	J=0		J=1		J=2	
	2S → 1P	3S → 2P	2S → 1P	3S → 2P	2S → 1P	3S → 2P
$2\pi 2K 1\pi^0$	< 0.6	< 0.2	$1.4 \pm 0.3 \pm 0.3$	$3.9 \pm 0.8 \pm 0.9$	$0.6 \pm 0.3 \pm 0.2$	< 1.4
$3\pi 1K 1K_S^0$	< 0.2	< 0.3	$0.9 \pm 0.3 \pm 0.2$	$1.4 \pm 0.5 \pm 0.3$	< 0.7	< 1.2
$3\pi 1K 1K_S^0 2\pi^0$	< 1.8	< 1.3	< 4.2	$9.7 \pm 3.0 \pm 2.6$	$3.8 \pm 1.4 \pm 1.0$	< 8.7
$4\pi 2\pi^0$	< 0.8	< 1.4	$5.5 \pm 0.9 \pm 1.4$	$7.4 \pm 1.6 \pm 1.9$	$2.5 \pm 0.8 \pm 0.6$	$5.1 \pm 1.6 \pm 1.3$
$4\pi 2K$	$0.4 \pm 0.2 \pm 0.1$	< 0.9	$1.0 \pm 0.3 \pm 0.2$	$1.2 \pm 0.4 \pm 0.3$	$0.8 \pm 0.2 \pm 0.2$	$1.2 \pm 0.4 \pm 0.3$
$4\pi 2K 1\pi^0$	< 1.0	< 1.3	$2.4 \pm 0.6 \pm 0.6$	$6.9 \pm 1.3 \pm 1.7$	$1.5 \pm 0.5 \pm 0.4$	$3.2 \pm 1.1 \pm 0.8$
$4\pi 2K 2\pi^0$	< 2.0	< 6.3	$5.9 \pm 1.4 \pm 1.7$	$12.1 \pm 2.9 \pm 3.3$	$2.8 \pm 1.1 \pm 0.7$	$6.2 \pm 2.3 \pm 1.7$
$5\pi 1K 1K_S^0 1\pi^0$	< 0.6	< 3.9	$6.4 \pm 1.6 \pm 1.6$	$8.5 \pm 2.3 \pm 2.2$	< 3.6	< 5.8
6π	< 0.3	< 0.4	$1.3 \pm 0.3 \pm 0.3$	$1.5 \pm 0.4 \pm 0.3$	$0.5 \pm 0.2 \pm 0.1$	$1.2 \pm 0.4 \pm 0.3$
$6\pi 2\pi^0$	< 2.2	< 7.2	$11.9 \pm 1.8 \pm 3.2$	$15.0 \pm 3.0 \pm 4.0$	$7.3 \pm 1.6 \pm 2.0$	$15.9 \pm 3.3 \pm 4.3$
$6\pi 2K$	$0.9 \pm 0.4 \pm 0.2$	< 0.9	$1.8 \pm 0.4 \pm 0.4$	$2.5 \pm 0.7 \pm 0.6$	< 0.6	$1.9 \pm 0.7 \pm 0.5$
$6\pi 2K 1\pi^0$	< 3.7	< 4.3	$5.2 \pm 1.1 \pm 1.4$	$7.7 \pm 1.7 \pm 2.1$	$2.6 \pm 0.8 \pm 0.7$	$5.5 \pm 1.6 \pm 1.5$
8π	< 0.3	< 1.0	$1.8 \pm 0.4 \pm 0.5$	$2.2 \pm 0.6 \pm 0.5$	$0.6 \pm 0.2 \pm 0.2$	$1.2 \pm 0.5 \pm 0.3$
$8\pi 2\pi^0$	< 7.7	< 3.8	$9.6 \pm 2.4 \pm 2.9$	$24.1 \pm 4.7 \pm 7.2$	$13.2 \pm 3.1 \pm 4.0$	$16.5 \pm 4.6 \pm 5.0$

Modes in RED are the only ones above 10^{-3}

Modes with Nπ^0 favored on ones with 0 π^0

Dominant modes have 8,10 π's

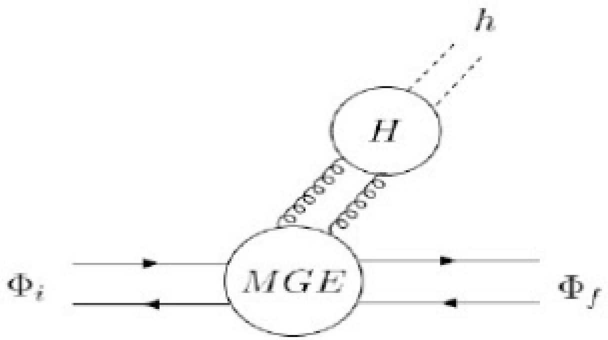
Sum of all BR's does not exceed 1%

Y(nS) →Y(mS) hadronic transitions

Hadronic transitions between heavy quarkonia are described by the QCD multiple expansion (QCDME) approach.

(Kuang and Yan, PRD24 (1981),2874)

Like in EM transitions, a perturbative series in ak , where a is the size of bound state and k is the gluon momentum, is used to calculate the transition amplitudes, classified in terms of cromoelectric and cromomagnetic multipoles.

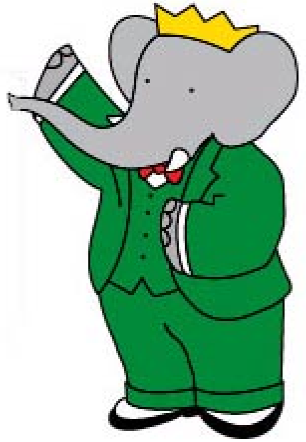


Y(nS) →ππY(mS) : E1E1

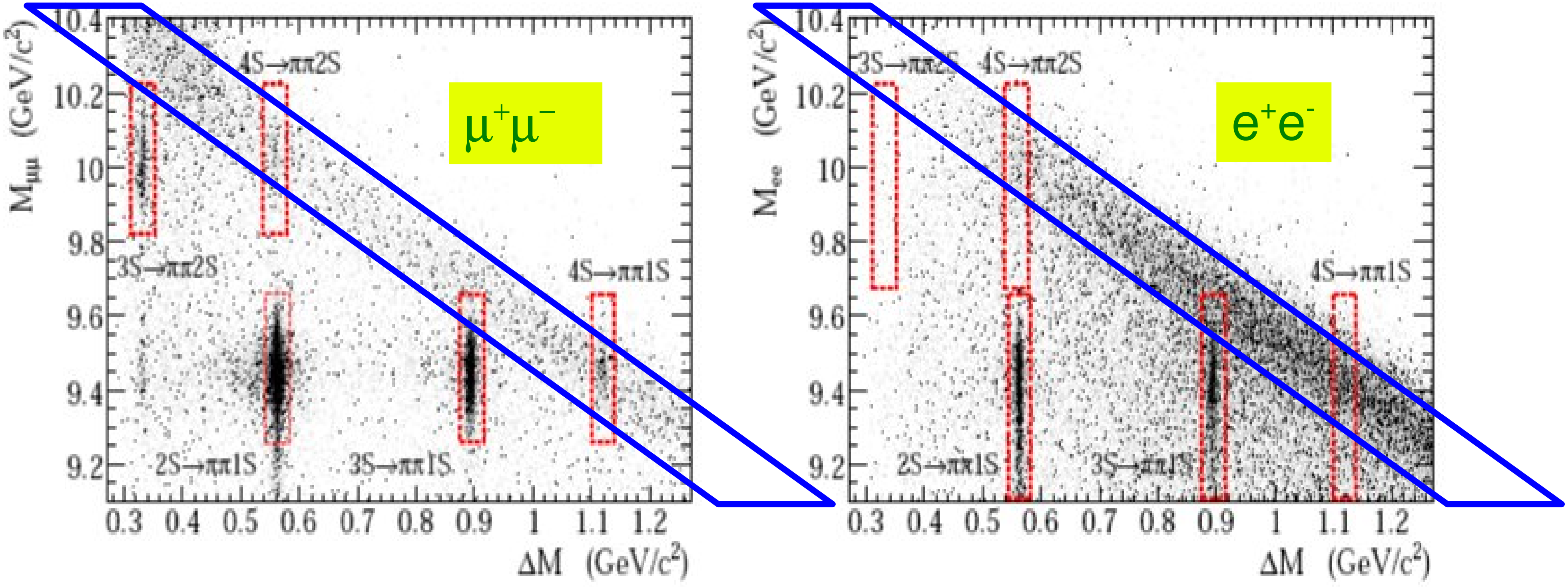
Y(nS) →ηY(mS): E1M2 or M1M1

Bottomonium offers a large variety of such transitions to be tested

$\Upsilon(4S) \to \Upsilon(nS)\pi\pi$



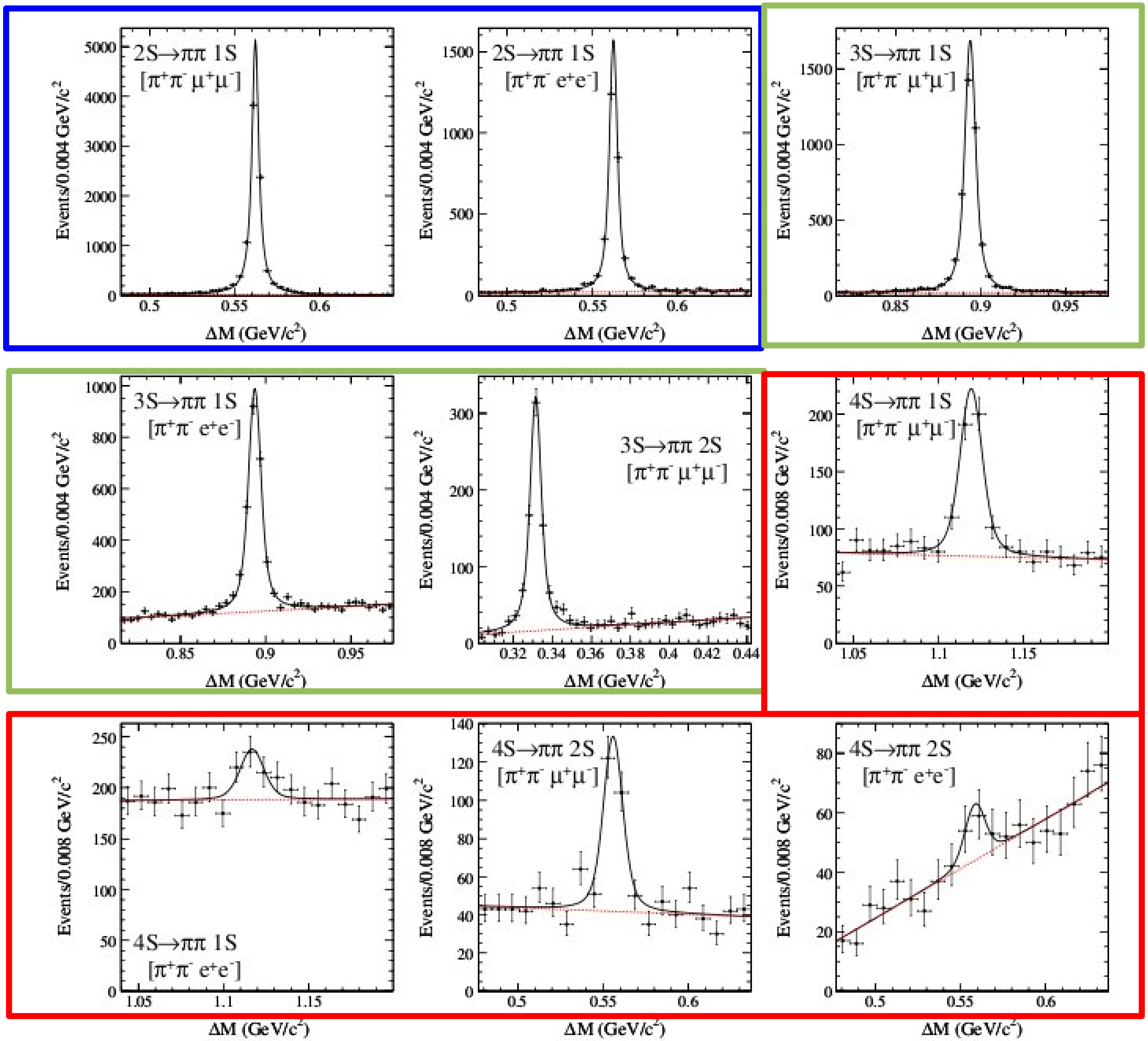
PRL96,232001: 230 M Y(4S)
PRD78,112002 (2008) : 382 MY(4S), 347.5 fb^{-1}

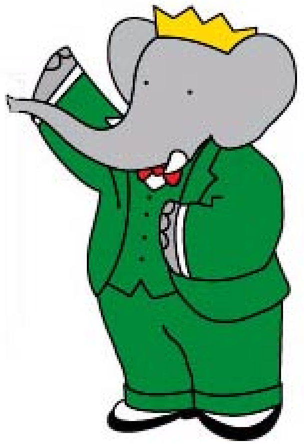


$M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)$ $M(e^+e^-\pi^+\pi^-) - M(e^+e^-)$

Events in the BLUE band are decays from the Y(4S) peak
Events on the left of the band are from ISR production of Y(2,3S)

$\Upsilon(mS) \rightarrow \Upsilon(nS)\pi\pi$





Transitions from 2S,3S,4S observed in both e^+e^- and $\mu^+\mu^-$ modes.

2S →1S

(17.22±0.17 ±0.75) %

3S →nS

1S: (4.17±0.06 ±0.19) %

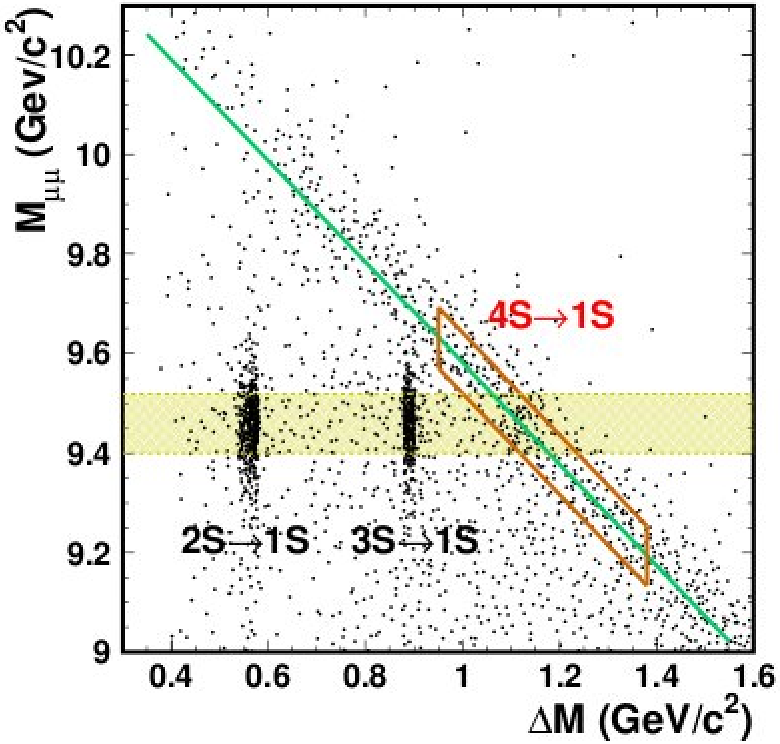
2S: (2.40±0.10 ±0.26)%

4S →nS

1S: $(0.80\pm0.06 \pm0.03) \times 10^{-4}$

2S: $(0.86\pm0.11 \pm0.07) \times 10^{-4}$

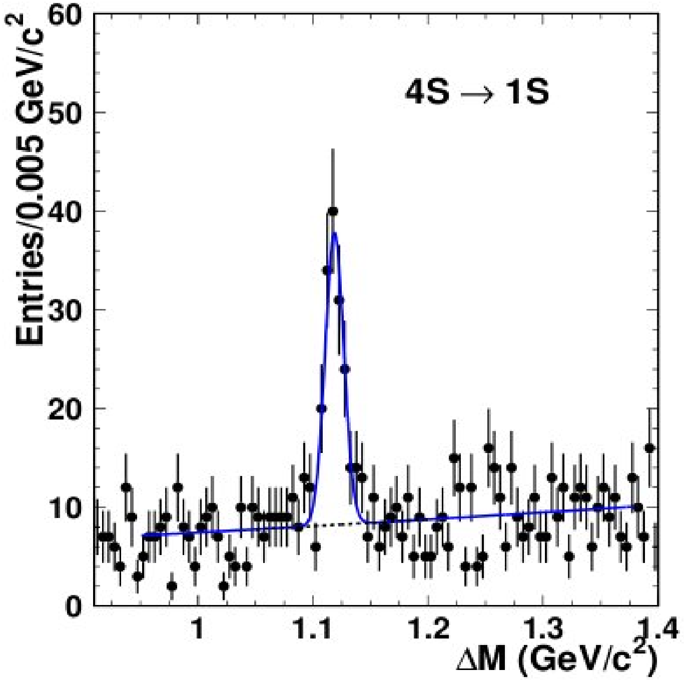
Y(4S) →Y(1S)ππ



ArXiv: 0901.1431

604.6 fb^{-1}

Y(1S) → $\mu^+\mu^-$ only



Data sample	$N_{\Upsilon(4S)}$, 10^6	N_{ev}	ε, %	$\mathcal{B}$, 10^{-4}
I	534.6±7.0	52.2±10.7	4.8±0.1	0.821±0.168
II	122.1±1.4	61.3±12.1	25.1±0.2	0.806±0.159

Efficiency loss in hadronic skim due to $E_{calo}/E_{cm} > 0.1$ cut.

Sample II from τ enriched skim : 6x more efficient.

B(Y(4S) →Y(1S)$\pi^+\pi^-$) = (0.81±0.12 ±0.05) ×10^{-4}

Γ(Y(4S) →Y(1S)$\pi^+\pi^-$) = (1.67±0.24 ±0.23) keV

Y(4S) →Y(nS)η

Phys.Rev.D78:112002,2008

$\eta\to\pi^+\pi^-\pi^0$ reconstructed

Y(2,3S) →ηY(1S) searched for in ISR sample (6M Y(2S), 10M Y(3S))

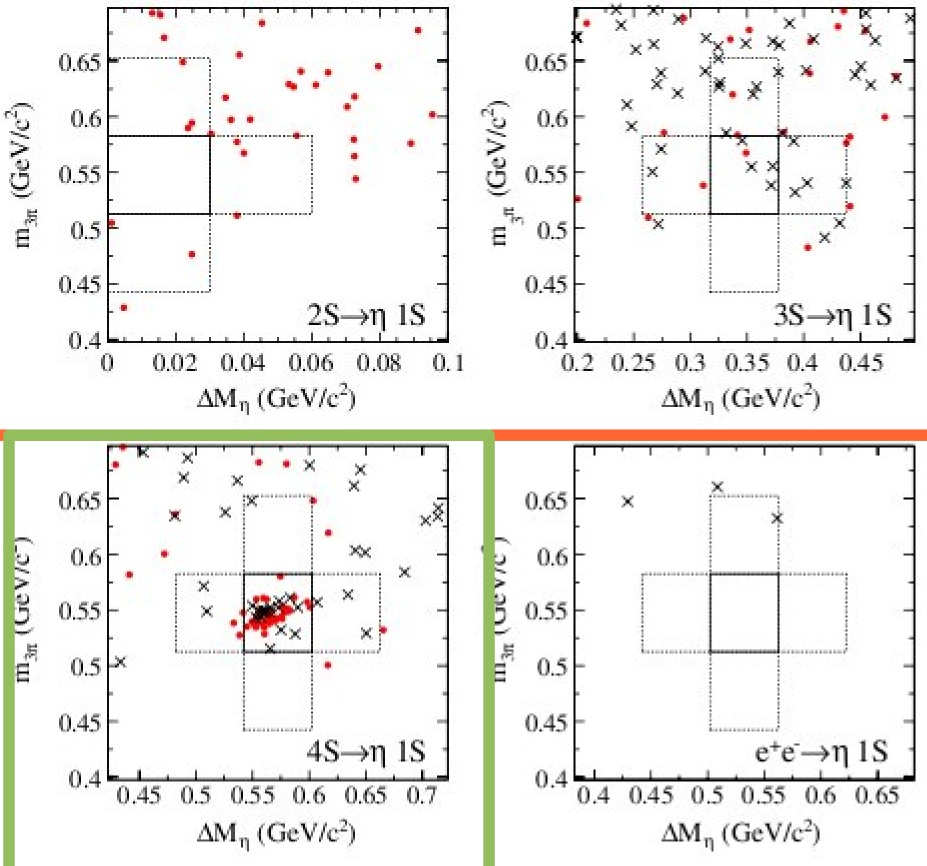
only upper limits:

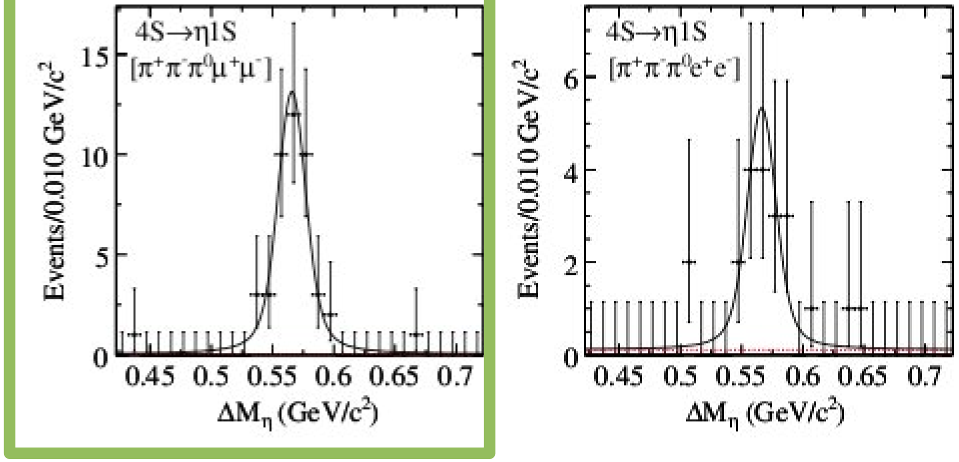
- BR(Y(2S) →ηY(1S))$<9\times10^{-4}$
- BR(Y(3S) →ηY(1S))$<8\times10^{-4}$

but ... unexpectedly:

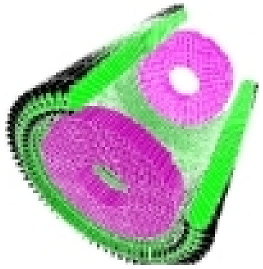
BR(Y(4S) →ηY(1S)) = $(1.96\pm0.06\pm0.09)\times10^{-4}$

2.4 times larger than Y(4S) →$\pi^+\pi^-$Y(1S)!!!

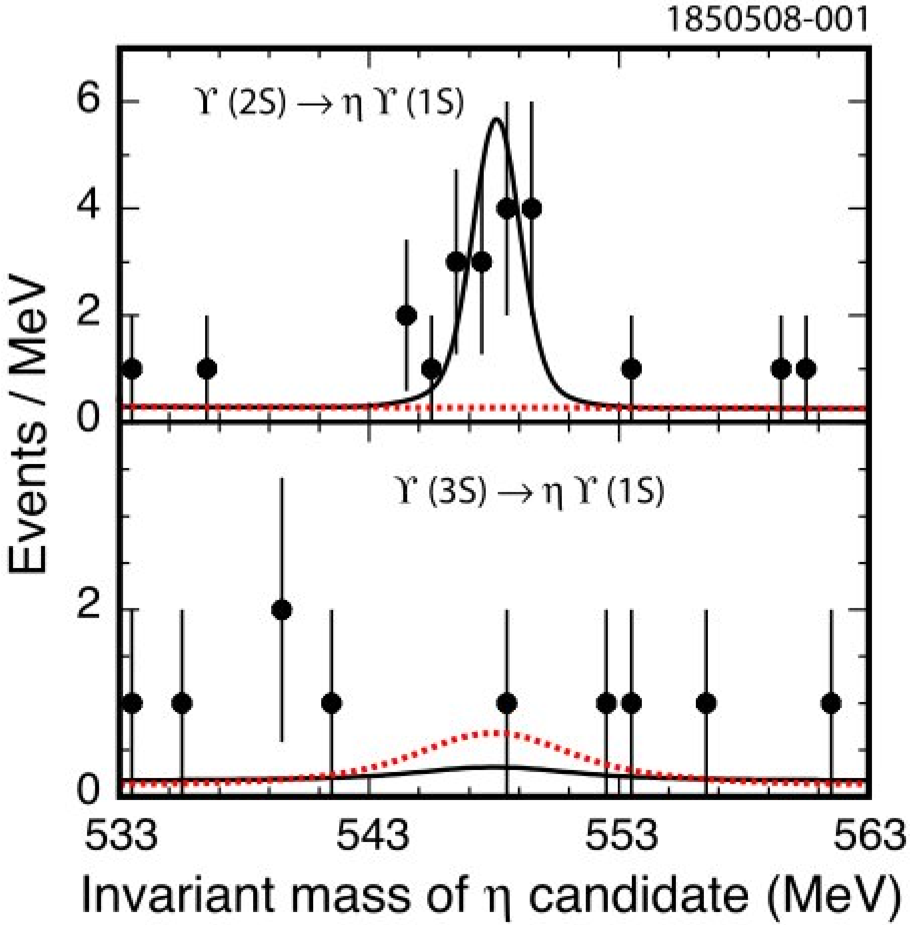




CLEO $\Upsilon(2,3S) \rightarrow \Upsilon(1S)\eta$



PRL101:192001,2008



$\eta \rightarrow \gamma\gamma$, $\pi^+\pi^-\pi^0$, $3\pi^0$ reconstructed

$BR(\Upsilon(2S) \rightarrow \eta\Upsilon(1S)) = (2.1^{+0.7}_{-0.6} \pm 0.5)\times 10^{-4}$

Theory: $\Gamma \sim (P_{cm})^3 / (m_Q)^4$

Scaling from charmonium we get:

$$\frac{\Gamma(\Upsilon(2S,3S) \to \eta\Upsilon(1S))}{\Gamma(\psi(2S) \to \eta J/\psi)} = (0.0025, 0.0013),$$

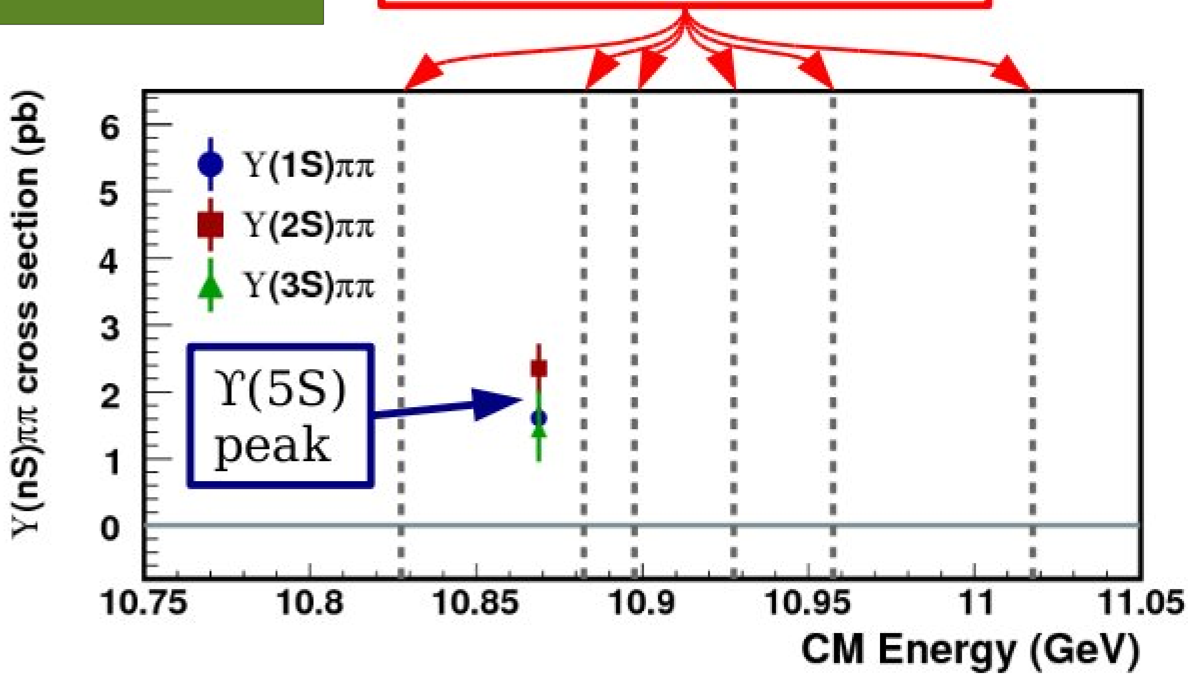
and then $BR(\Upsilon(2S) \rightarrow \eta\Upsilon(1S)) \sim 8\times 10^{-4}$

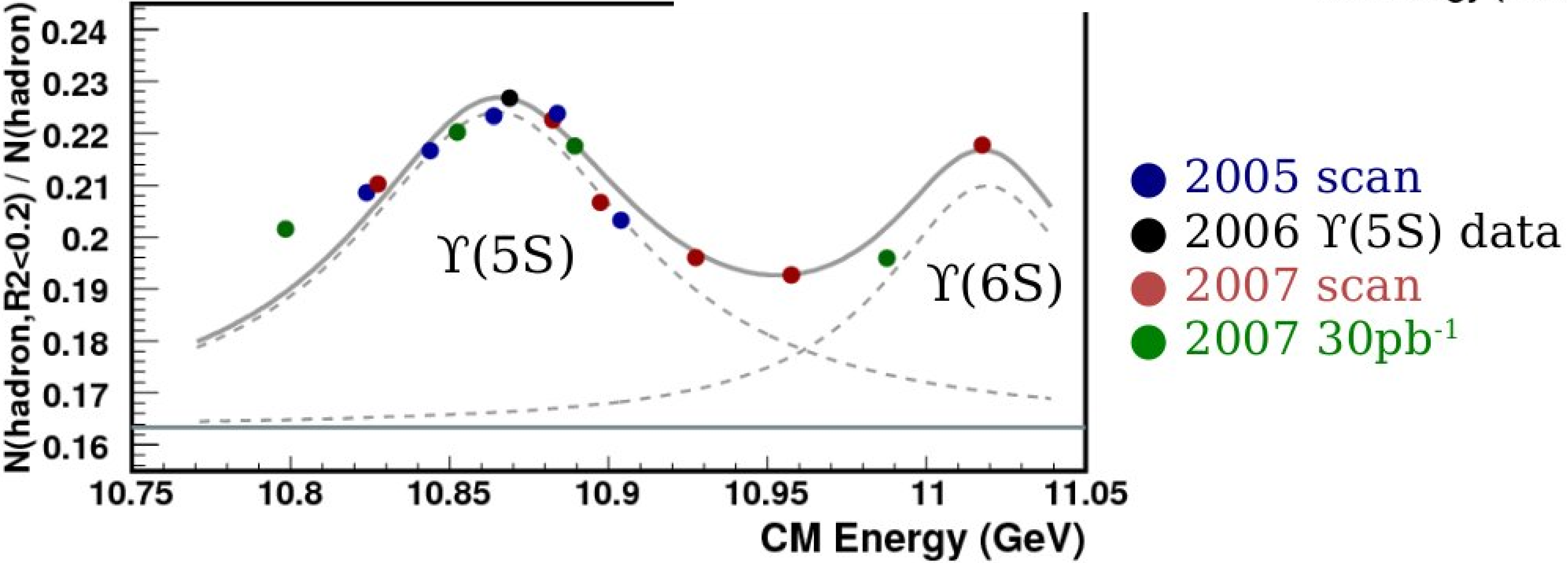
Scaling predictions for $\Upsilon(2S) \rightarrow \pi\Upsilon(1S)$:

$$\frac{\mathcal{B}(\Upsilon(2S,3S) \to \pi^0\Upsilon(1S))}{\mathcal{B}(\Upsilon(2S,3S) \to \eta\Upsilon(1S))} = (16 \pm 2, 0.42 \pm 0.04)\%.$$

Scan of the Υ(5S)-Υ(6S) region

6 points, ~1fb^{-1} each





Scan of the Υ(5S)-Υ(6S) region

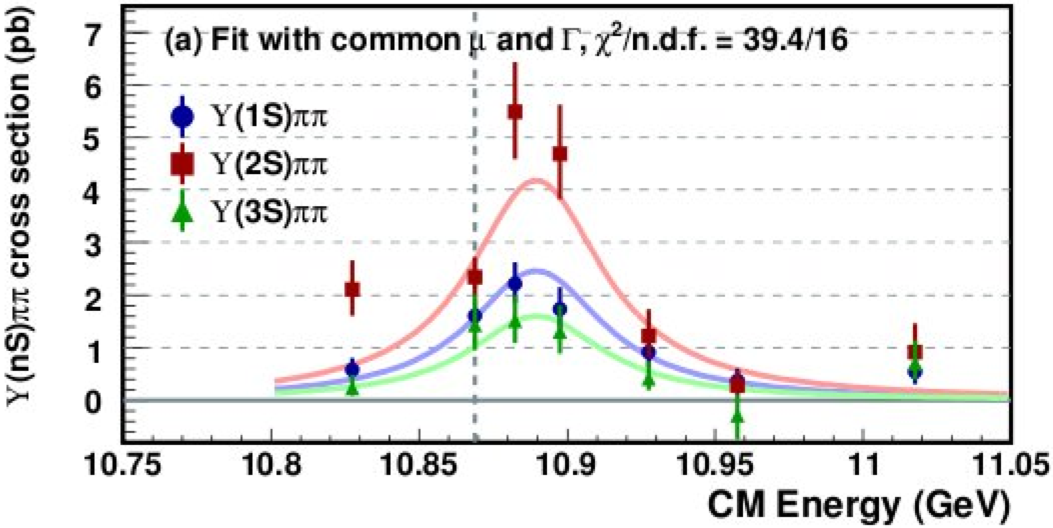
arXiv: 0808.2445

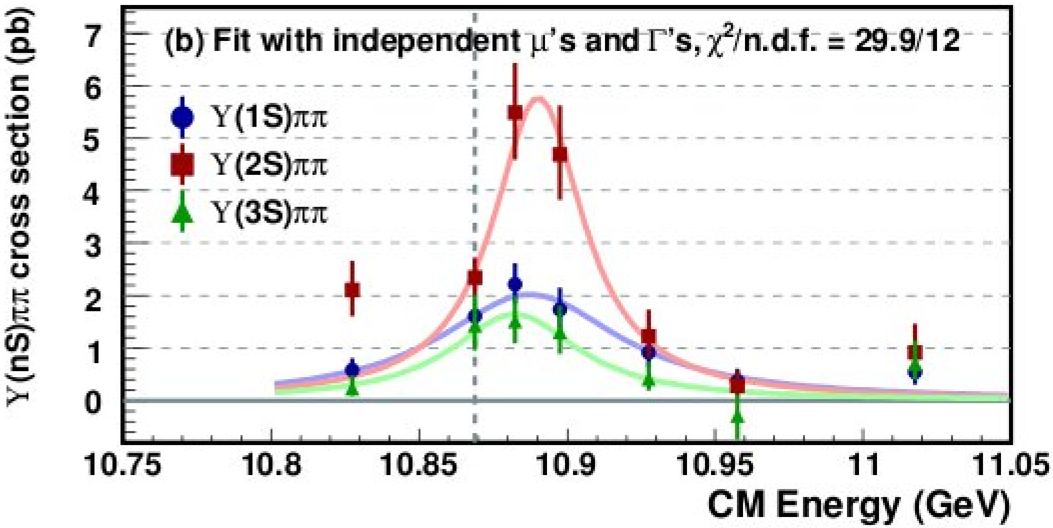
Fit with common μ and Γ

Process	Peak σ (pb)	μ (MeV)	Γ (MeV)
$\Upsilon(1S)\pi\pi$	$2.46^{+0.27}_{-0.25} \pm 0.18$	$10889.6 \pm 1.8 \pm 1.5$	$54.7^{+8.5}_{-7.2} \pm 2.5$
$\Upsilon(2S)\pi\pi$	$4.18^{+0.49}_{-0.46} \pm 0.55$		
$\Upsilon(3S)\pi\pi$	$1.61^{+0.31}_{-0.28} \pm 0.21$		

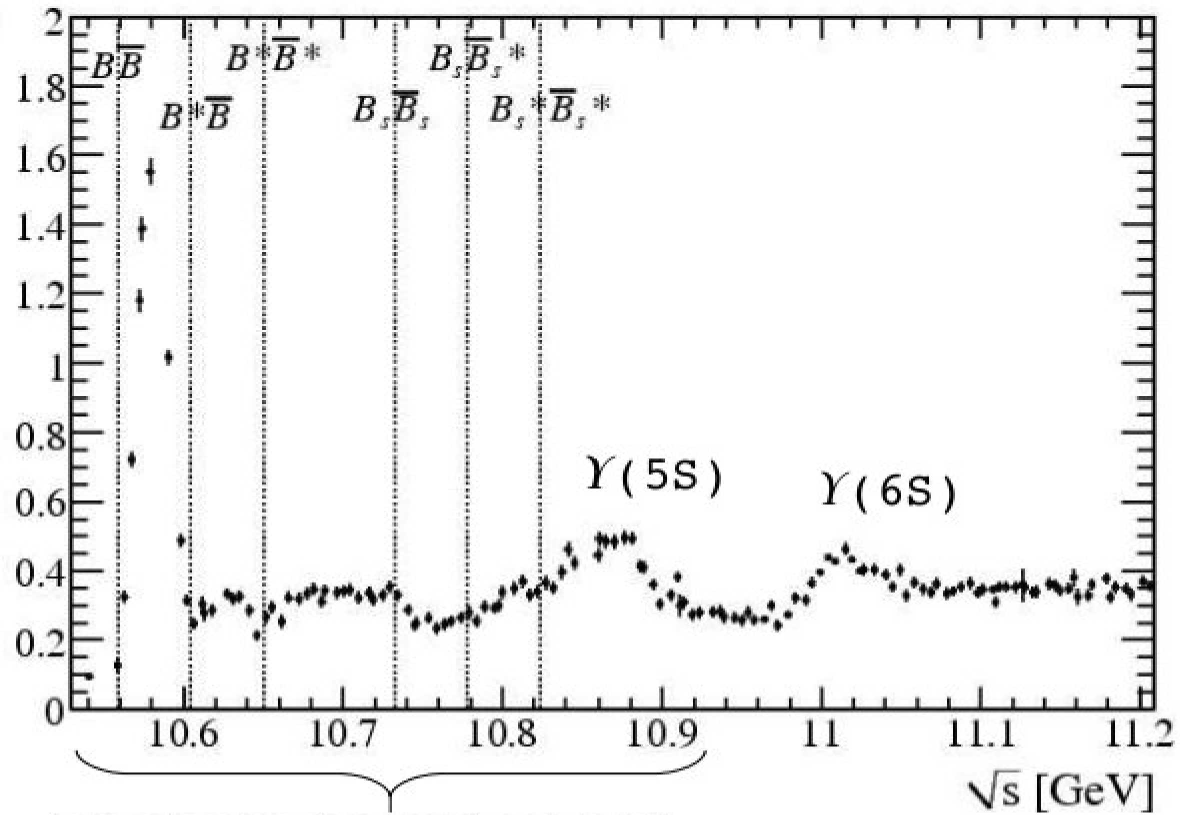
Fit with separate μ's and Γ's

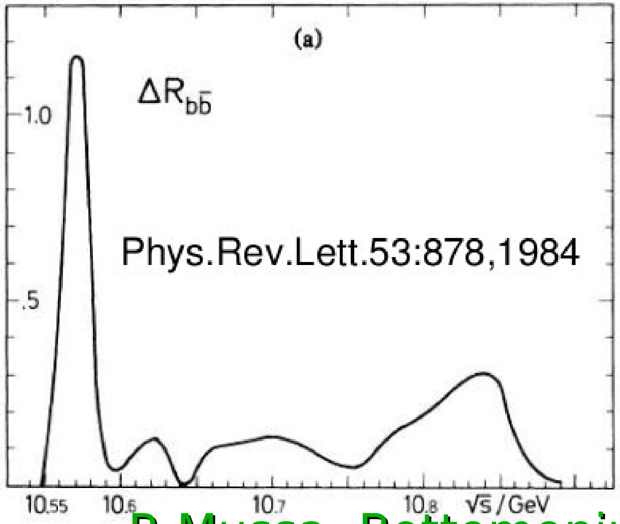
Process	Peak σ (pb)	μ (MeV)	Γ (MeV)
$\Upsilon(1S)\pi\pi$	$2.03^{+0.27}_{-0.22} \pm 0.15$	$10887.4^{+4.1}_{-4.5} \pm 1.6$	$74^{+19}_{-14} \pm 3$
$\Upsilon(2S)\pi\pi$	$5.77^{+0.90}_{-0.80} \pm 0.67$	$10890.3^{+2.3}_{-1.9} \pm 1.4$	$37.0^{+7.9}_{-6.2} \pm 3.1$
$\Upsilon(3S)\pi\pi$	$1.65^{+0.36}_{-0.32} \pm 0.21$	$10882.3^{+7.2}_{-7.3} \pm 1.5$	$52^{+20}_{-14} \pm 1$



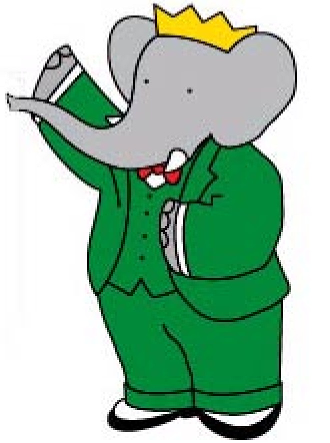


Scan of the Υ(5S)-Υ(6S) region





Phys.Rev.Lett.53:878,1984



Phys.Rev.Lett.102:012001,2009

Ldt 25 pb-1 per point,
E=10.54-11.2 ; dE=5 MeV
Total 3.3fb-1

Rb=σ(bb)/σ(μμ)

5S and 6S widths to be redefined, compare w/ PDG

Predicted by Tornqvist in 1984!!

Conclusions

Finally the ground state of bottomonium has been discovered!

The hyperfine splitting is 30 MeV larger than expected from theory.

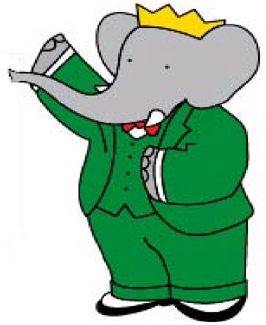
Many exclusive decay modes of χ_b states were measured and will hopefully help in detecting the direct M1 transitions to η_b's

Y(1,2,3S) decays may be useful also for charmonium spectroscopy, and for intriguing results in both old and new physics.

More results are about to come from analysis of record samples taken in 2008 on Y(1,2,3,5S). Stay tuned!!!

Backup

LFV in Y(3S) decays



arXiv: 0812.1021

EFTs estimate that Y(nS) → eτ,μτ allows to search for new physics phenomena at scale $\Lambda^{(1\tau)}$:

$$\frac{\Gamma(\Upsilon(3S) \to \ell^{\pm}\tau^{\mp})}{\Gamma(\Upsilon(3S) \to \ell^{+}\ell^{-})} = \frac{1}{2q_b^2}\left(\frac{\alpha_N^{(\ell\tau)}}{\alpha}\right)^2 \left(\frac{M_{\Upsilon(3S)}}{\Lambda^{(\ell\tau)}}\right)^4 \quad (\ell = e, \mu)$$

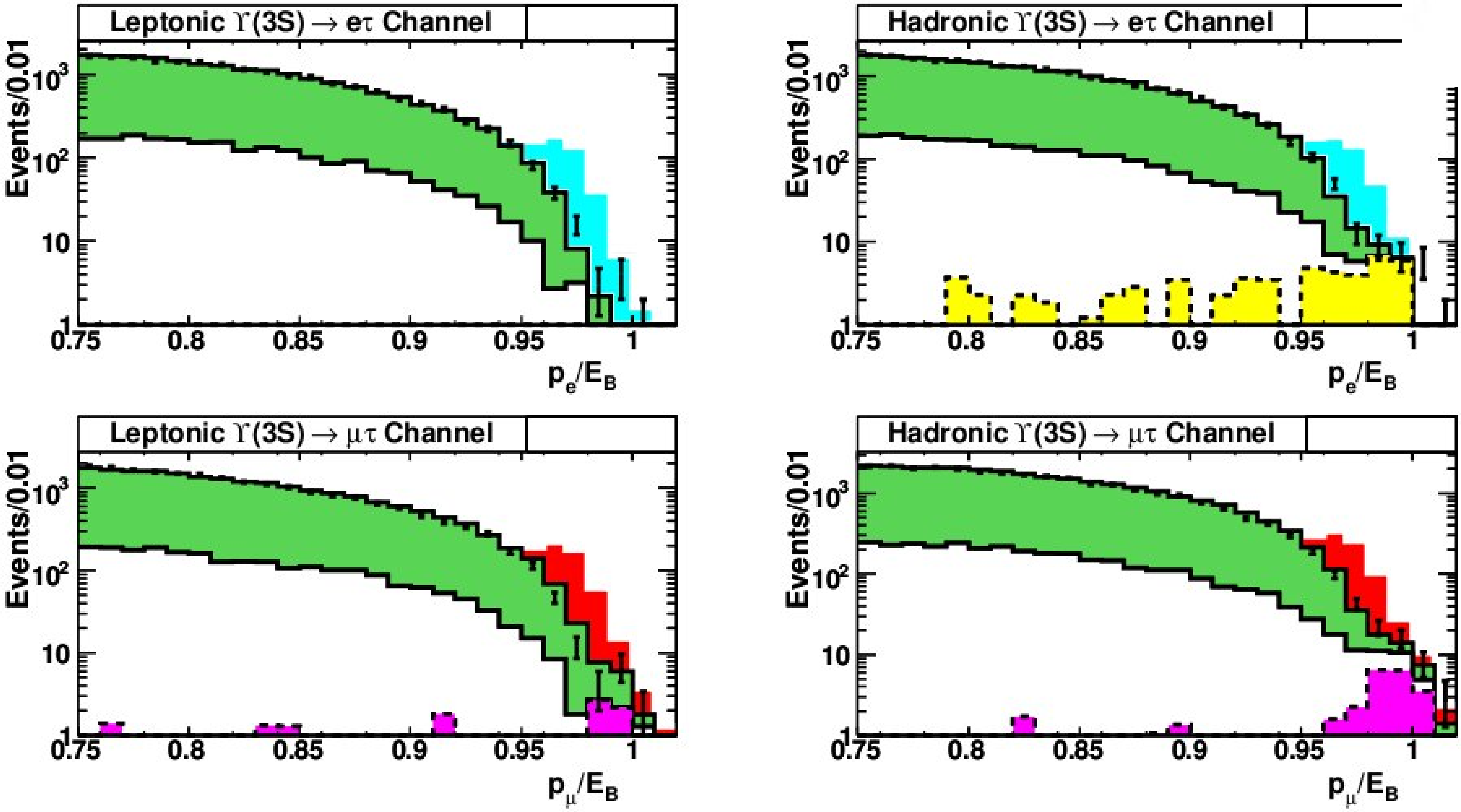
Signal :

- leptonic eτ: $Y(3S) \to e\tau$, $\tau \to \mu\nu\nu$
- hadronic eτ: $Y(3S) \to e\tau$, $\tau \to \pi^0\pi^-\nu, \pi^0\pi^0\pi^-\nu$
- leptonic μτ: $Y(3S) \to \mu\tau$, $\tau \to e\nu\nu$
- hadronic μτ: $Y(3S) \to \mu\tau$, $\tau \to \pi^0\pi^-\nu, \pi^0\pi^0\pi^-\nu$

Backgrounds:
ττ (continuum and resonant), ee, μμ

LFV in Υ(3S) decays

arXiv: 0812.1021



🟩 ττ (continuum)

🟨 Bhabha

🟦 τe (SIGNAL)

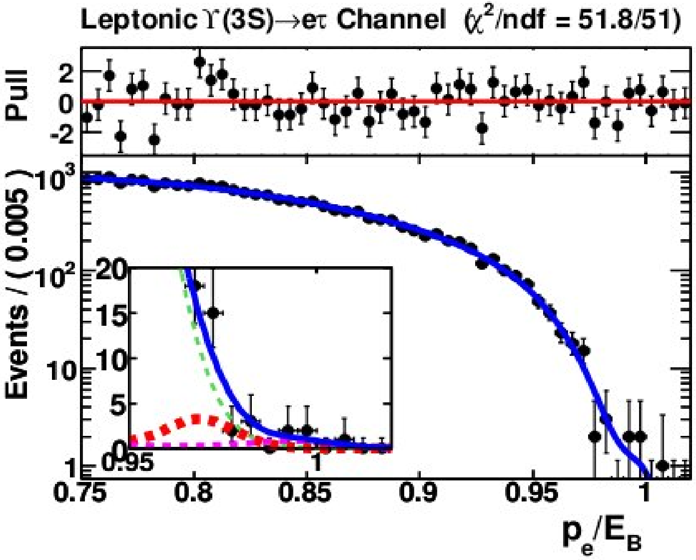
☐ ττ (resonant)

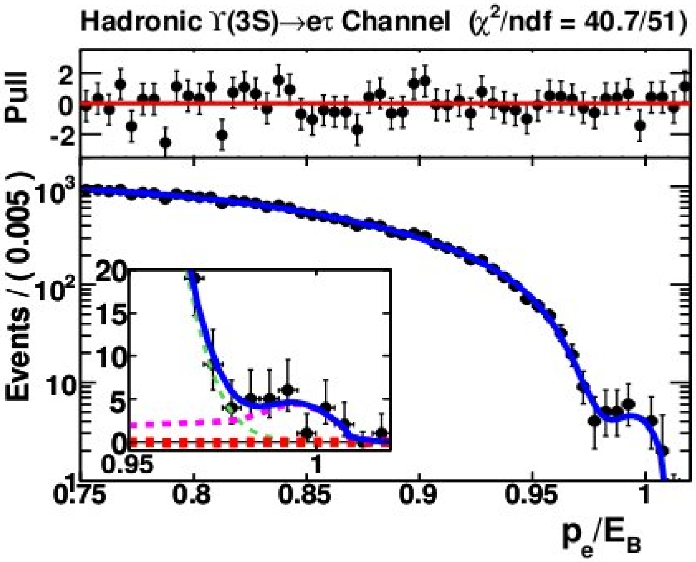
🟪 μμ

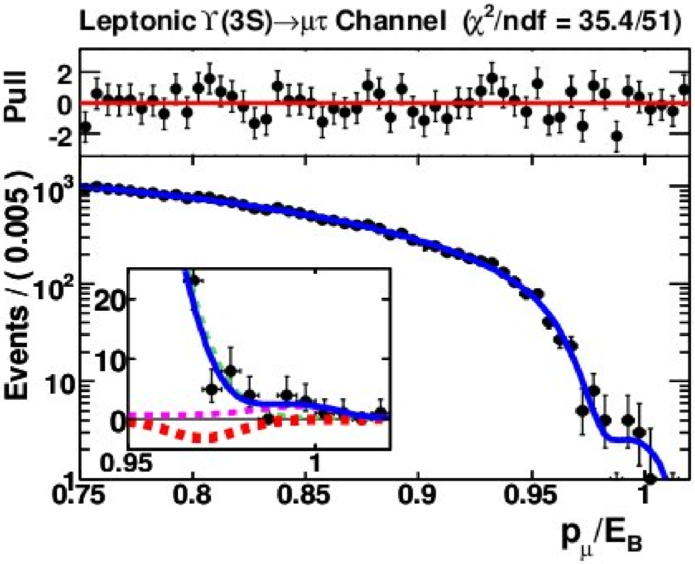
🟥 τμ (SIGNAL)

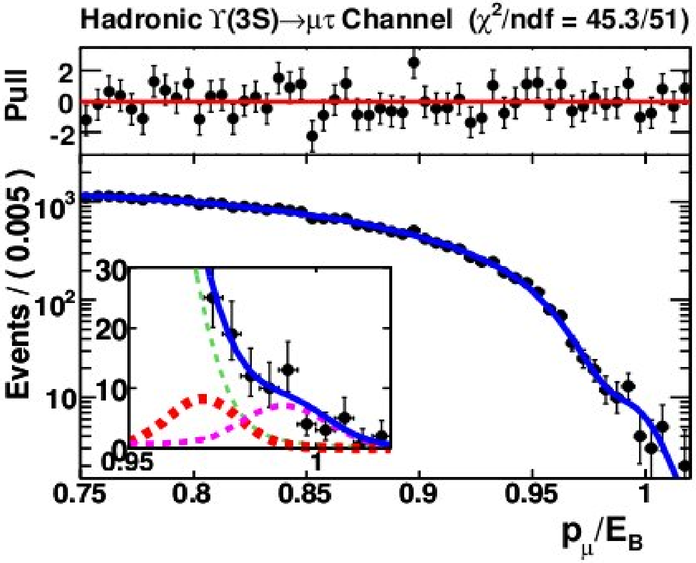
LFV in Y(3S) decays

arXiv: 0812.1021





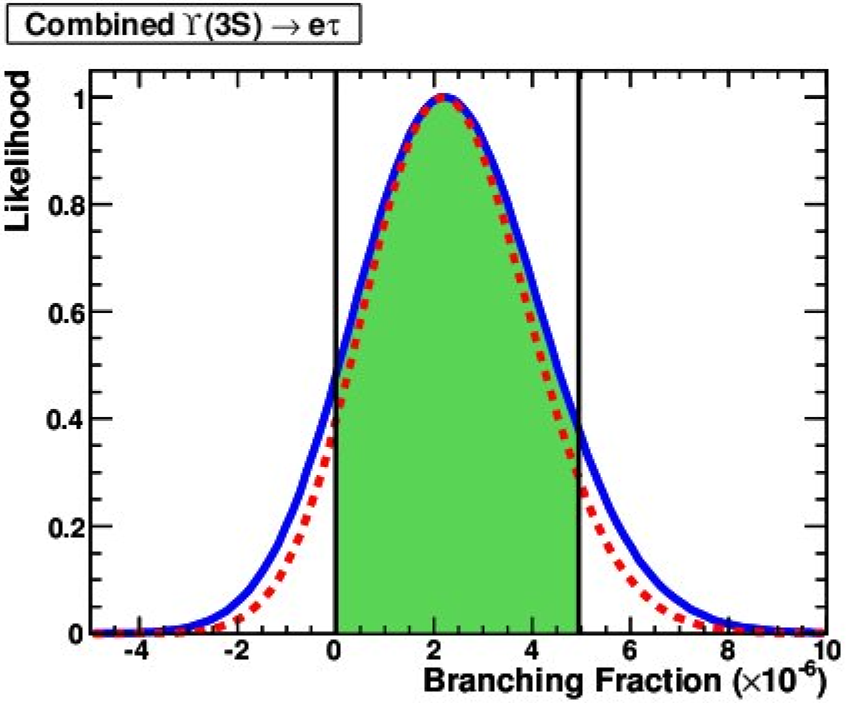


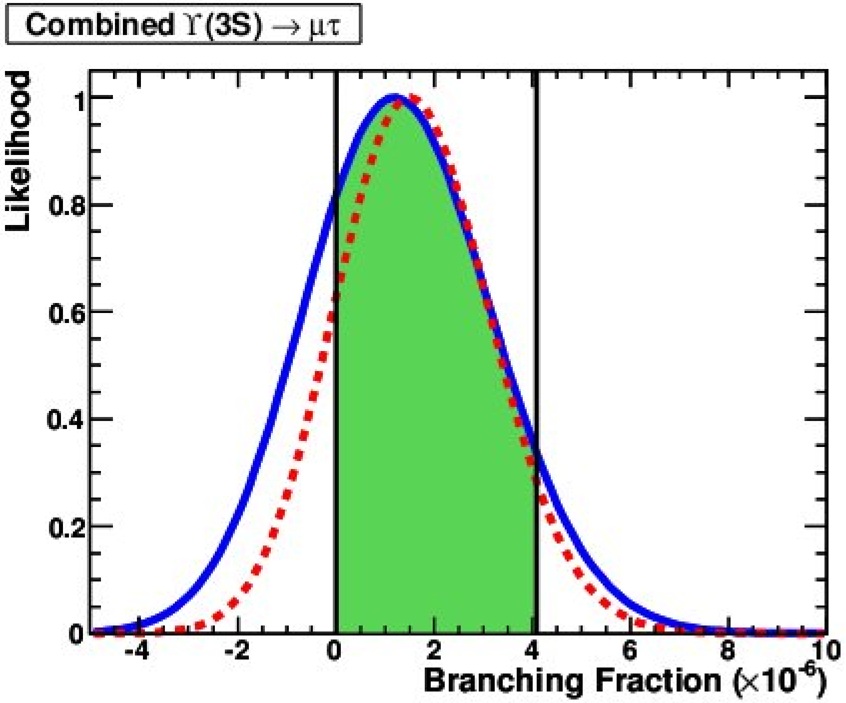


LFV in Y(3S) decays

arXiv: 0812.1021

	UL	MPV
$\mathrm{BF}(\Upsilon(3S) \to e^{\pm}\tau^{\mp})\ (\times 10^{-6})$	< 5.0	$2.2^{+1.9}_{-1.8}$
$\mathrm{BF}(\Upsilon(3S) \to \mu^{\pm}\tau^{\mp})\ (\times 10^{-6})$	< 4.1	$1.2^{+1.9}_{-1.9}$





Thrust Axis: Definition

THRUST is defined as :

$$\mathbf{MAX[}\quad t(\boldsymbol{n}) = \Sigma_i \, | \, p_i * \boldsymbol{n} \, | \, / \, \Sigma_i \, | \, p_i \, | \quad \mathbf{]}$$

n can be any versor on the unitary sphere

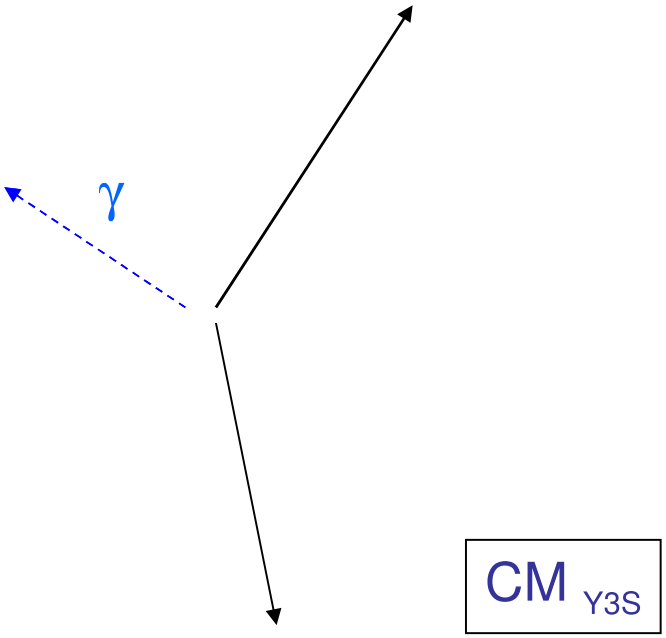
Thrust Axis is the direction of ***n*** which maximizes t(***n***)

Loop over all GOOD Gamma; for each of them:

1) the photon is excluded from the determination of **t(n)**

2) Max[t(n)] is calculated in the reference frame that recoils against the given photon

(*DOUBLE BOOST*)



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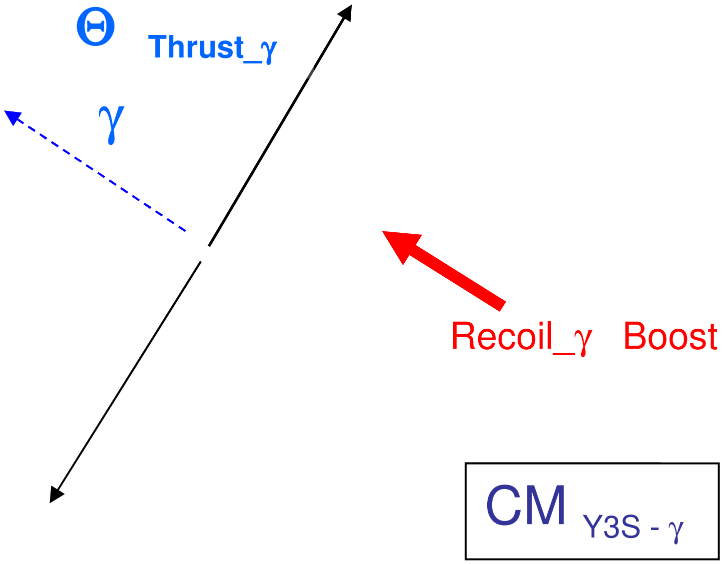
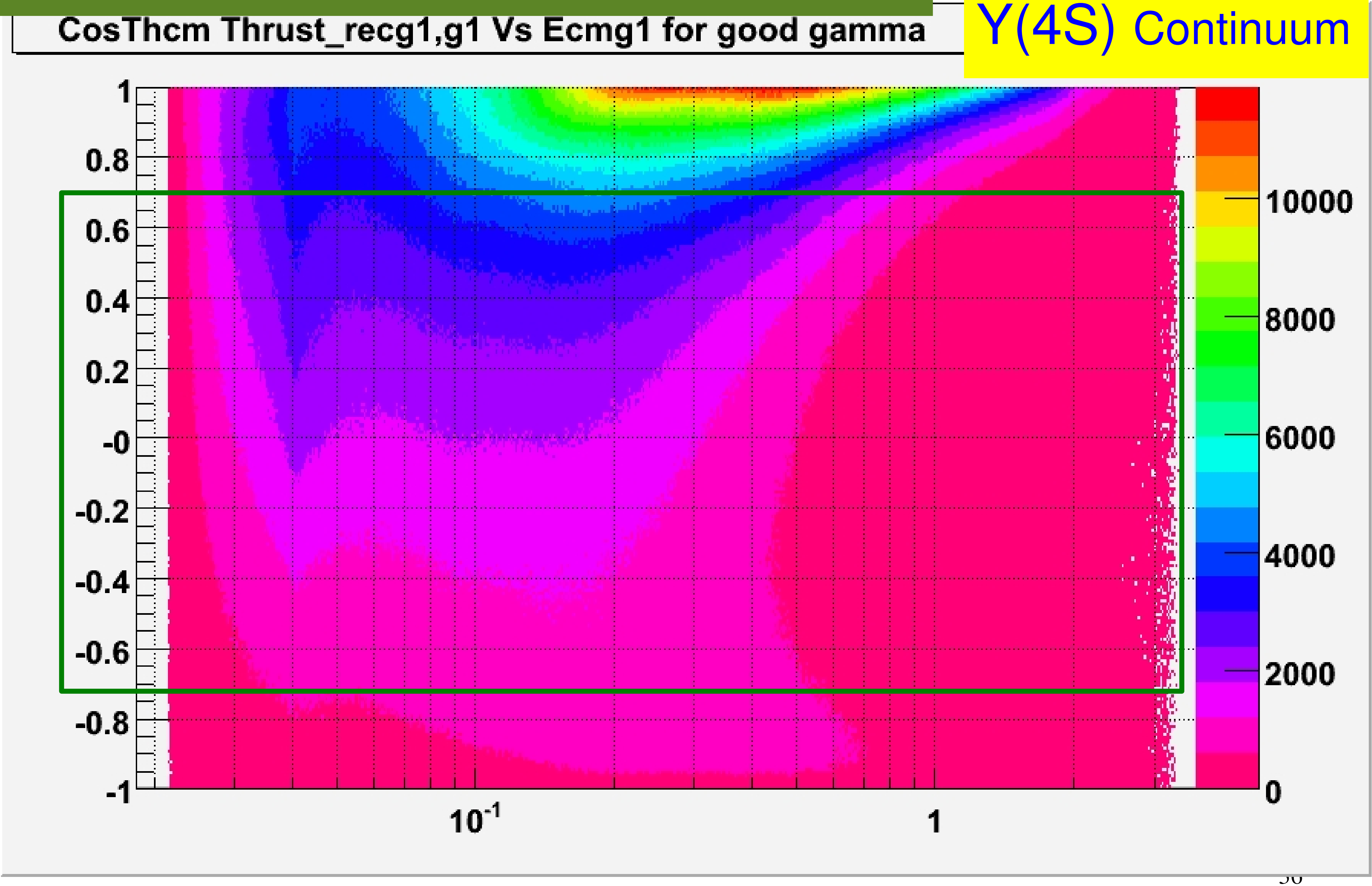
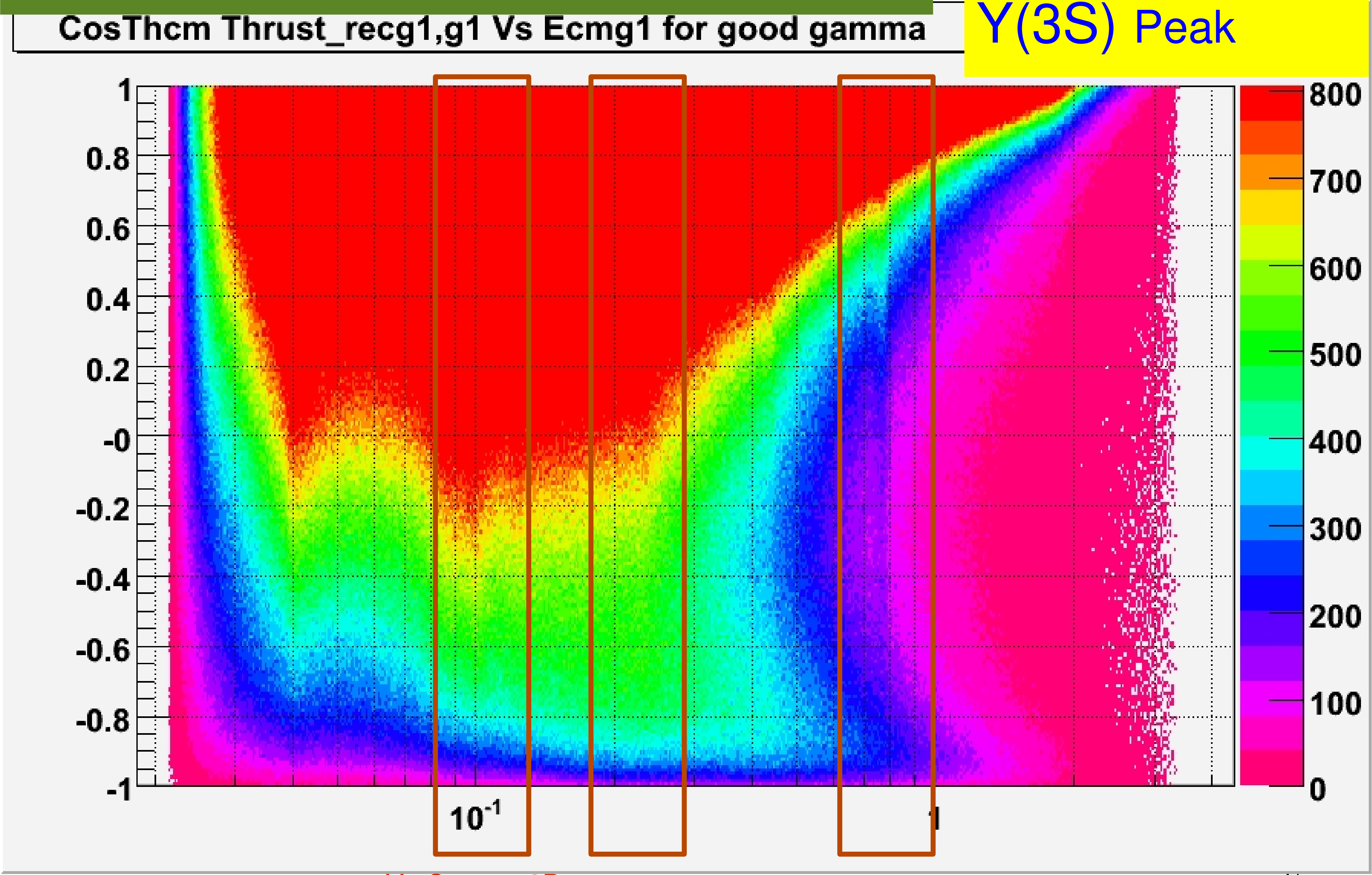


Cut on γ-Thrust angle



Y(4S) Continuum

Cut on γ-Thrust angle



Υ(3S) Peak

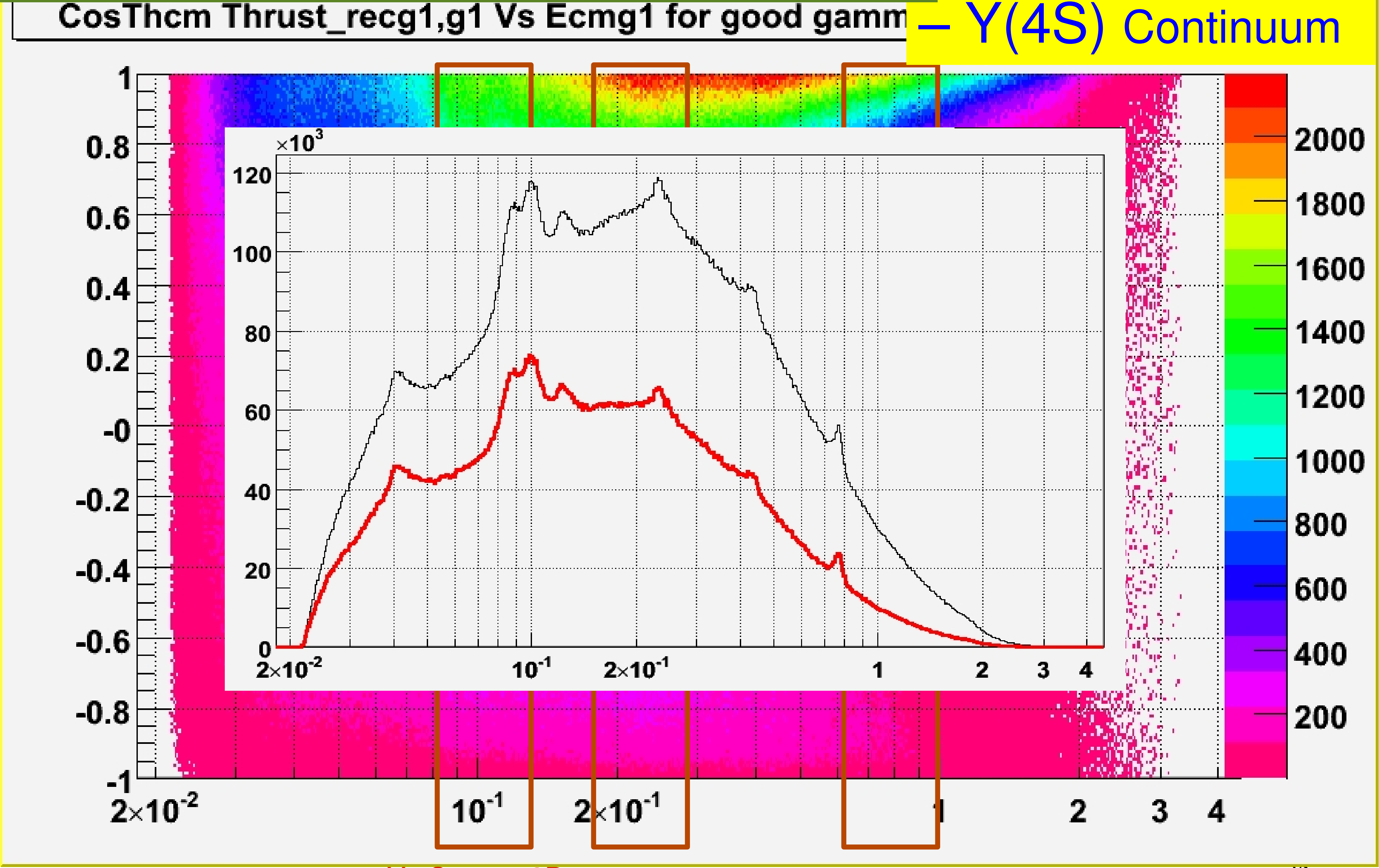
$\Upsilon(3S) \to \chi_{bJ}(2P)$

$\chi_{bJ}(2P) \to \Upsilon(2S)$

$\chi_{bJ}(2P) \to \Upsilon(1S)$

Cut on γ-Thrust angle

Y(3S) Peak
– Y(4S) Continuum



Y(3S)→χ_{bJ}(2P)

χ_{bJ}(2P)→Y(2S)

χ_{bJ}(2P)→Y(1S)

Crystal Ball Function

MC simulations with peaks smearing modeled as Crystal Ball Function (gaussian+ low energy tail described by power law)

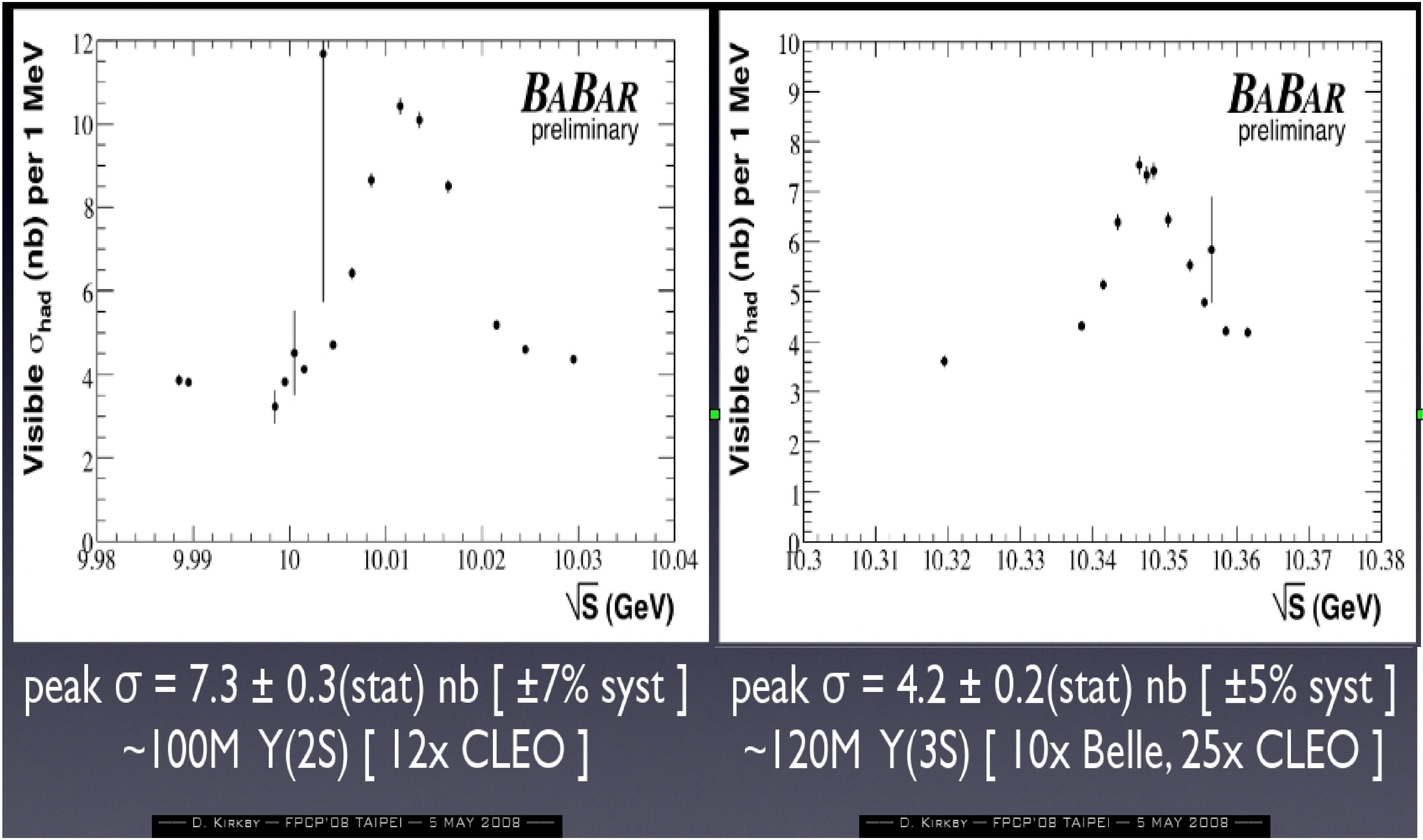
$$f_{CB}(N_0,\mu,\sigma,x) = \frac{N_0}{\sqrt{2\pi}\sigma} \times \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \qquad \text{per } t > -|\alpha|$$

$$f_{CB}(N_0,\mu,\sigma,\alpha,n,x) = N_0 \times A(\alpha,n) \times \left[B(\alpha,n) - \frac{x-\mu}{\sigma}\right]^{-n} \qquad \text{per } t < -|\alpha|, \tag{4.1}$$

con $t = \frac{x-\mu}{\sigma}$, $\alpha > 0$ e

$$A(\alpha,n) = \left(\frac{n}{|\alpha|}\right)^n \times \exp -\frac{|\alpha|^2}{2}, \qquad B(\alpha,n) = \frac{n}{|\alpha|} - |\alpha|\,. \tag{4.2}$$

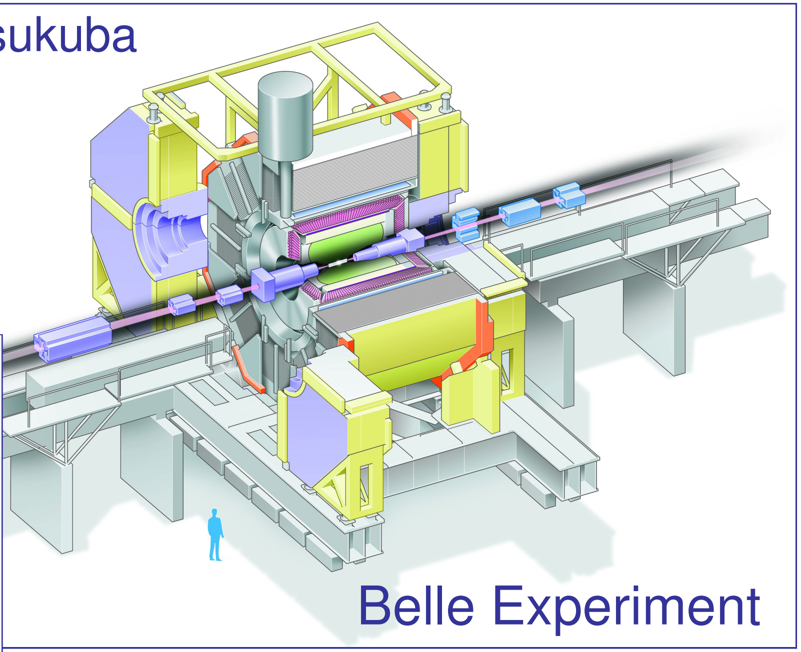
Babar data taking at Y(2,3S), Jan-Mar 2008

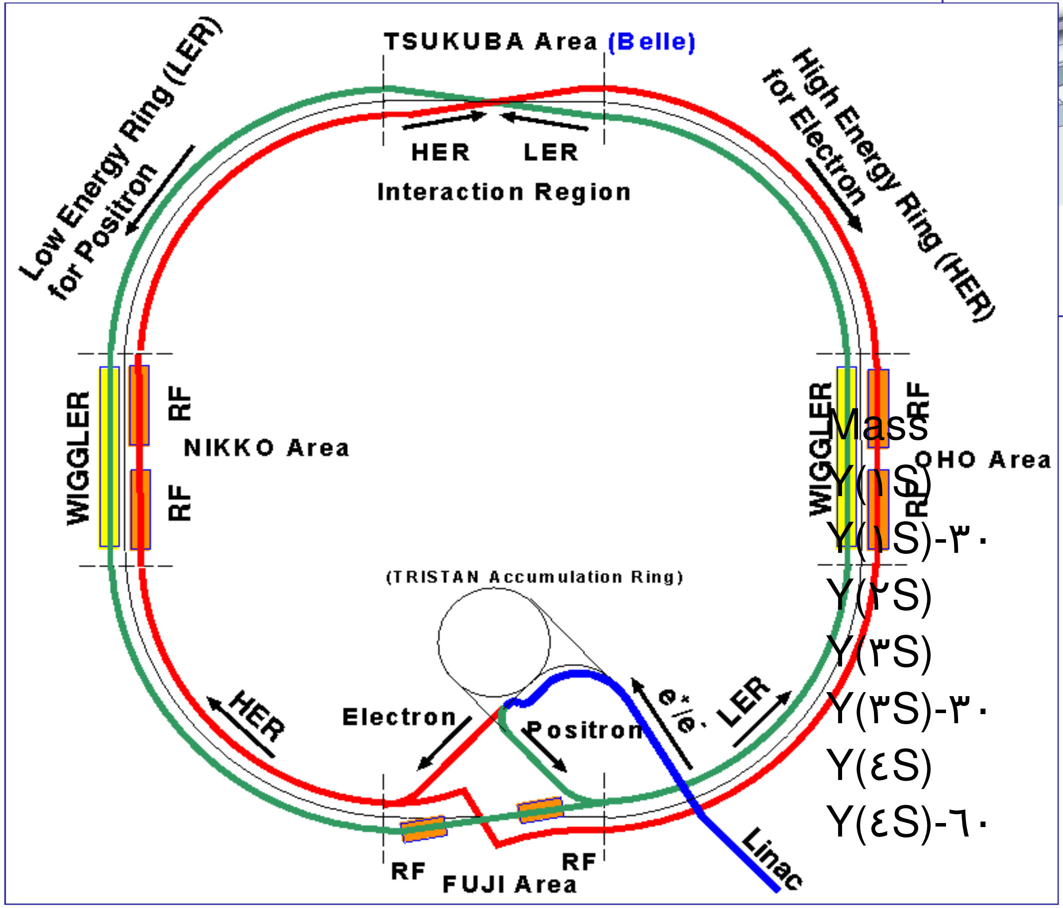


peak σ = 7.3 ± 0.3(stat) nb [±7% syst]
~100M Y(2S) [12x CLEO]

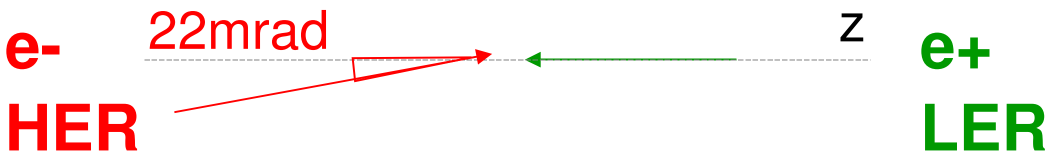
peak σ = 4.2 ± 0.2(stat) nb [±5% syst]
~120M Y(3S) [10x Belle, 25x CLEO]

Belle @ KEKB



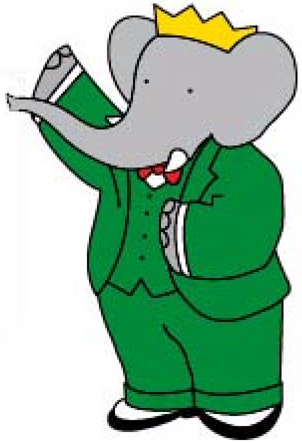


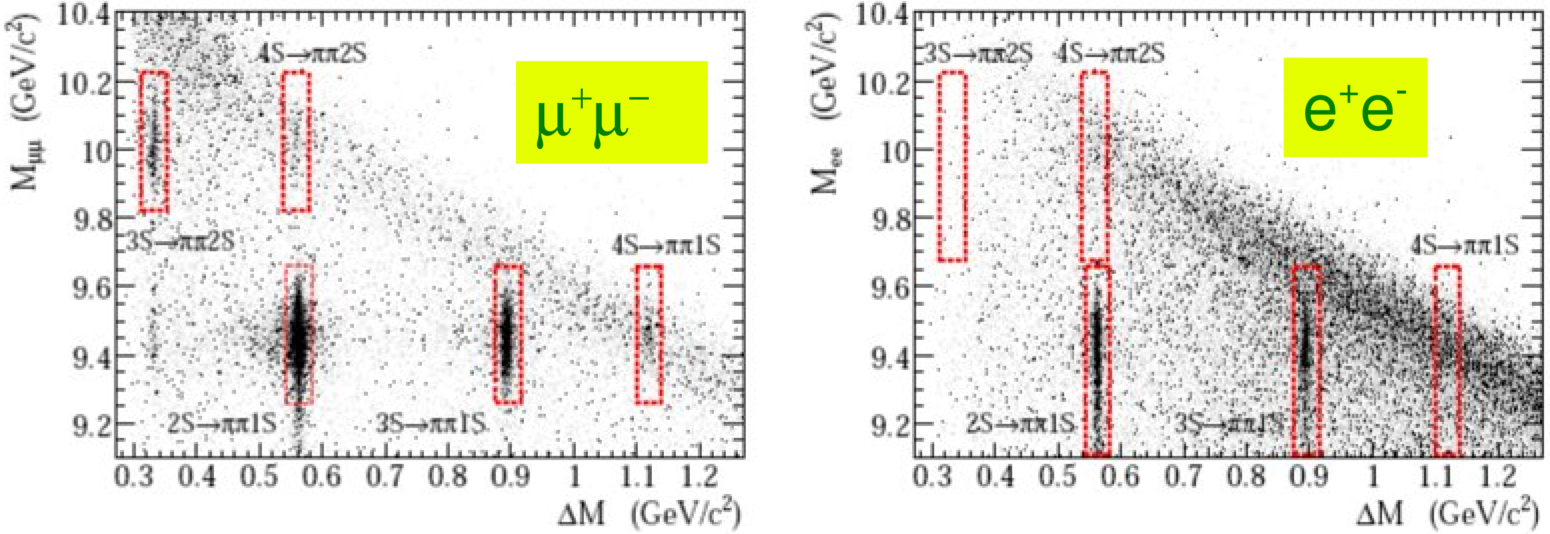
Mass	Lpeak	Ldt (fb-1)	Period
Y(١S)	٨.٨٠E+٣٣	٥.٧	June ٢٠٠٨
Y(١S)-٣٠	٨.٦٠E+٣٣	١.٧	June ٢٠٠٨
Y(٢S)	١.٣٤E+٣٤	٧.٥	Dec.٢٠٠٨
Y(٣S)	١.٥٠E+٣٤	٣.١	Feb.٢٠٠٦
Y(٣S)-٣٠	١.٥٠E+٣٤	٠.٢٧	Feb.٢٠٠٦
Y(٤S)	١.٧٠E+٣٤	٧٣٠	٢٠٠٠-٢٠٠٨
Y(٤S)-٦٠	١.٧٠E+٣٤	٦٨	٢٠٠٠-٢٠٠٨



Υ(mS) →Υ(nS)ππ

347.5 fb^{-1} *Phys.Rev.D78:112002,2008*

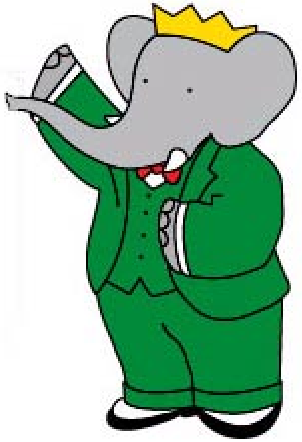


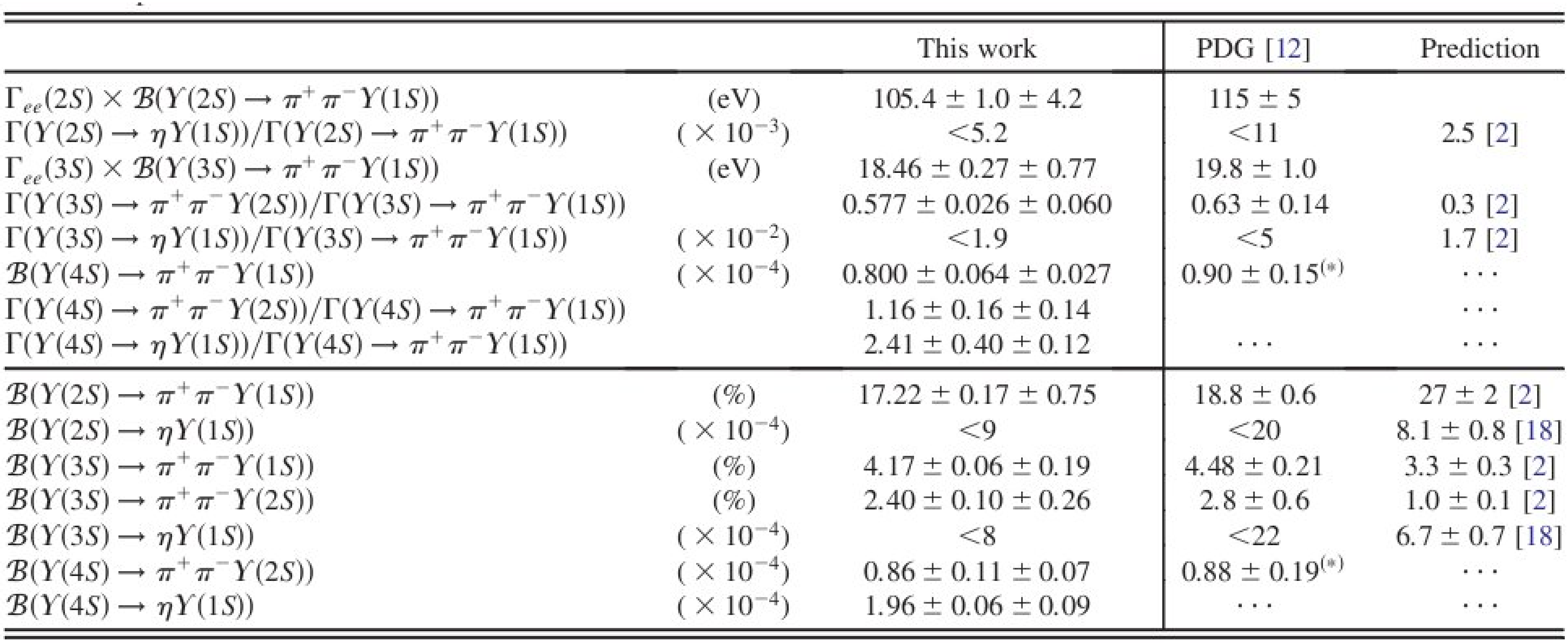


Transition	Selection efficiency (%)			
	$\mu\mu$		ee	
	$\varepsilon_{\rm PS}$	$\varepsilon_{\rm eff}$	$\varepsilon_{\rm PS}$	$\varepsilon_{\rm eff}$
$2S \rightarrow \pi\pi\ 1S$	34.46 ± 0.05	36.62 ± 0.08	11.17 ± 0.03	11.45 ± 0.14
$3S \rightarrow \pi\pi\ 1S$	41.23 ± 0.05	34.18 ± 0.20	24.48 ± 0.05	23.96 ± 0.24
$3S \rightarrow \pi\pi\ 2S$	14.76 ± 0.04	17.2 ± 0.6	≈ 0	$\cdots$
$4S \rightarrow \pi\pi\ 1S$	41.53 ± 0.23	44.2 ± 1.2	18.04 ± 0.18	19.7 ± 2.4
$4S \rightarrow \pi\pi\ 2S$	32.69 ± 0.22	30.2 ± 0.8	6.17 ± 0.12	7.9 ± 3.4
	ε		ε	
$2S \rightarrow \eta\ 1S$	8.25 ± 0.09		≈ 0	
$3S \rightarrow \eta\ 1S$	9.42 ± 0.10		3.91 ± 0.06	
$4S \rightarrow \eta\ 1S$	10.07 ± 0.10		3.77 ± 0.06	

$\Upsilon(4S) \to \Upsilon(nS)\pi\pi$

PRL96,232001: 230 M $\Upsilon(4S)$
PRD78,112002 (2008) : 382 M$\Upsilon(4S)$, 347.5 fb^{-1}





		This work	PDG [12]	Prediction
$\Gamma_{ee}(2S) \times \mathcal{B}(\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S))$	(eV)	$105.4 \pm 1.0 \pm 4.2$	115 ± 5	
$\Gamma(\Upsilon(2S) \to \eta\Upsilon(1S))/\Gamma(\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S))$	$(\times 10^{-3})$	<5.2	<11	2.5 [2]
$\Gamma_{ee}(3S) \times \mathcal{B}(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$	(eV)	$18.46 \pm 0.27 \pm 0.77$	19.8 ± 1.0	
$\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S))/\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$		$0.577 \pm 0.026 \pm 0.060$	0.63 ± 0.14	0.3 [2]
$\Gamma(\Upsilon(3S) \to \eta\Upsilon(1S))/\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$	$(\times 10^{-2})$	<1.9	<5	1.7 [2]
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$	$(\times 10^{-4})$	$0.800 \pm 0.064 \pm 0.027$	$0.90 \pm 0.15^{(*)}$	⋯
$\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S))/\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$		$1.16 \pm 0.16 \pm 0.14$		⋯
$\Gamma(\Upsilon(4S) \to \eta\Upsilon(1S))/\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$		$2.41 \pm 0.40 \pm 0.12$	⋯	⋯
$\mathcal{B}(\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S))$	(%)	$17.22 \pm 0.17 \pm 0.75$	18.8 ± 0.6	27 ± 2 [2]
$\mathcal{B}(\Upsilon(2S) \to \eta\Upsilon(1S))$	$(\times 10^{-4})$	<9	<20	8.1 ± 0.8 [18]
$\mathcal{B}(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$	(%)	$4.17 \pm 0.06 \pm 0.19$	4.48 ± 0.21	3.3 ± 0.3 [2]
$\mathcal{B}(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S))$	(%)	$2.40 \pm 0.10 \pm 0.26$	2.8 ± 0.6	1.0 ± 0.1 [2]
$\mathcal{B}(\Upsilon(3S) \to \eta\Upsilon(1S))$	$(\times 10^{-4})$	<8	<22	6.7 ± 0.7 [18]
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S))$	$(\times 10^{-4})$	$0.86 \pm 0.11 \pm 0.07$	$0.88 \pm 0.19^{(*)}$	⋯
$\mathcal{B}(\Upsilon(4S) \to \eta\Upsilon(1S))$	$(\times 10^{-4})$	$1.96 \pm 0.06 \pm 0.09$	⋯	⋯

Th.Ref.2: YPKuang, Front Phys China 1 (2006),19
Th.Ref.18: Eichten et al., Rev. Mod. Phys. 80 (2008),1161