Исследование боттомония в эксперименте Белле

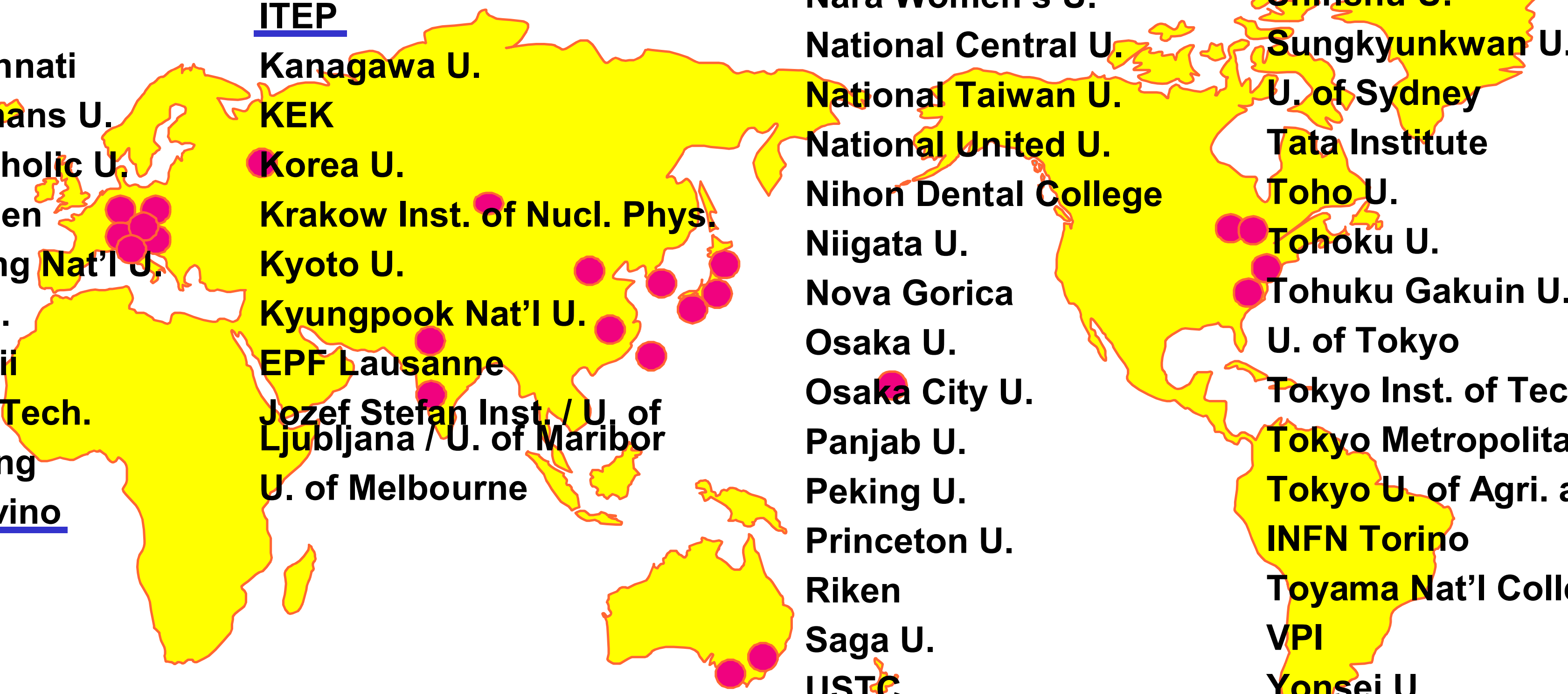
А. Соколов

ИФВЭ Протвино &
коллаборация Белле

Сессия ОЯФ РАН
22.12.2008

Содержание

International Collaboration: Belle



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Gyeongsang Nat'l U.
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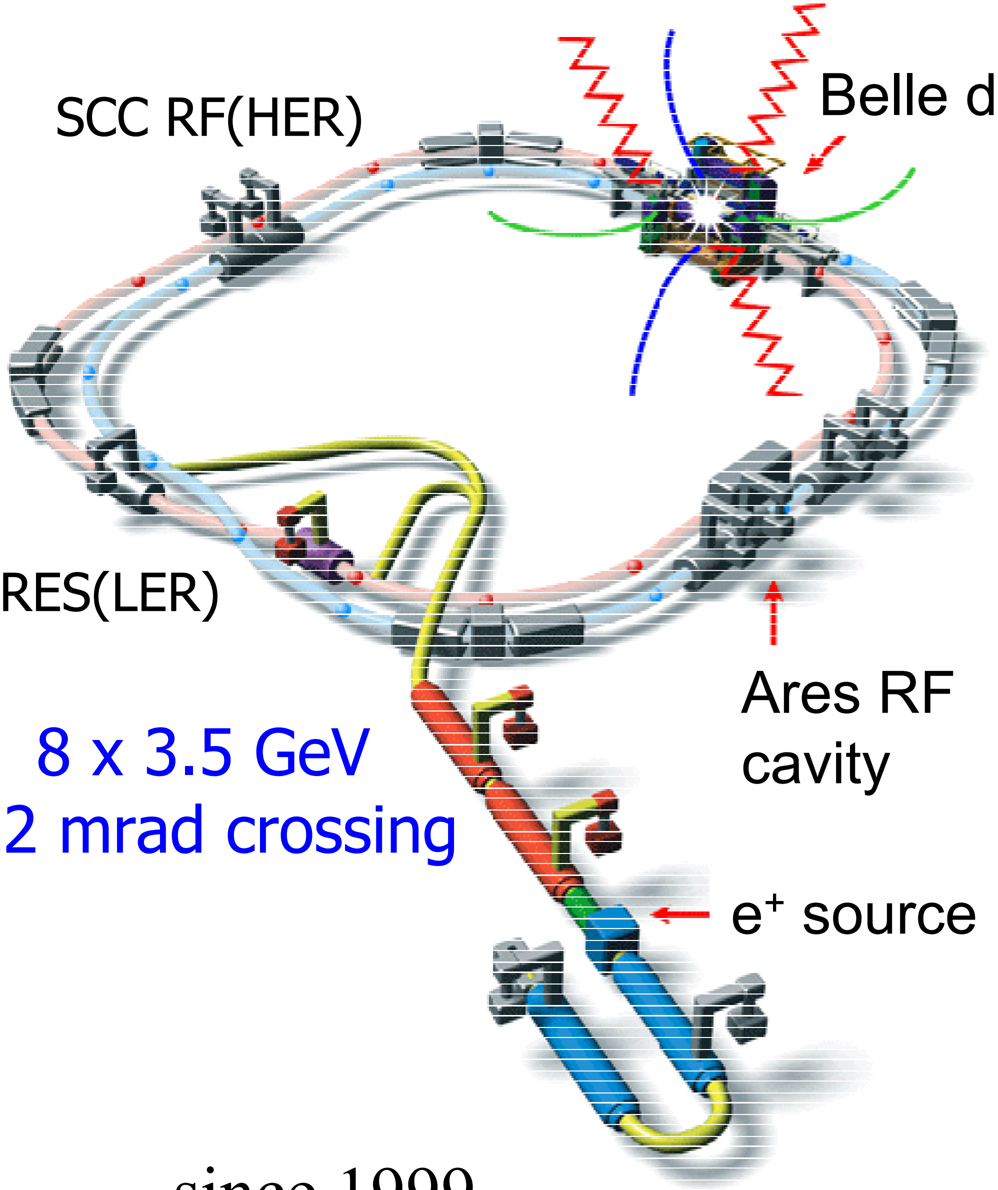
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries, 55 institutes, ~400 collaborators

The KEKB Collider



SCC RF(HER)

Belle detector

ARES(LER)

Ares RF cavity

e^+ source

8 x 3.5 GeV
22 mrad crossing

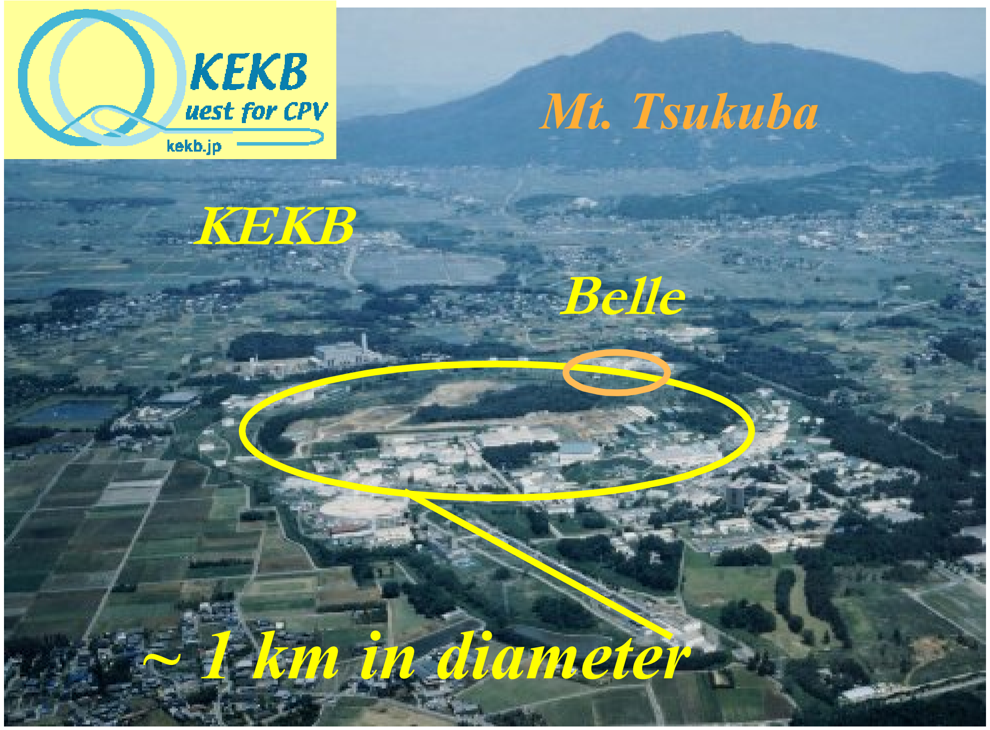
since 1999

World record:

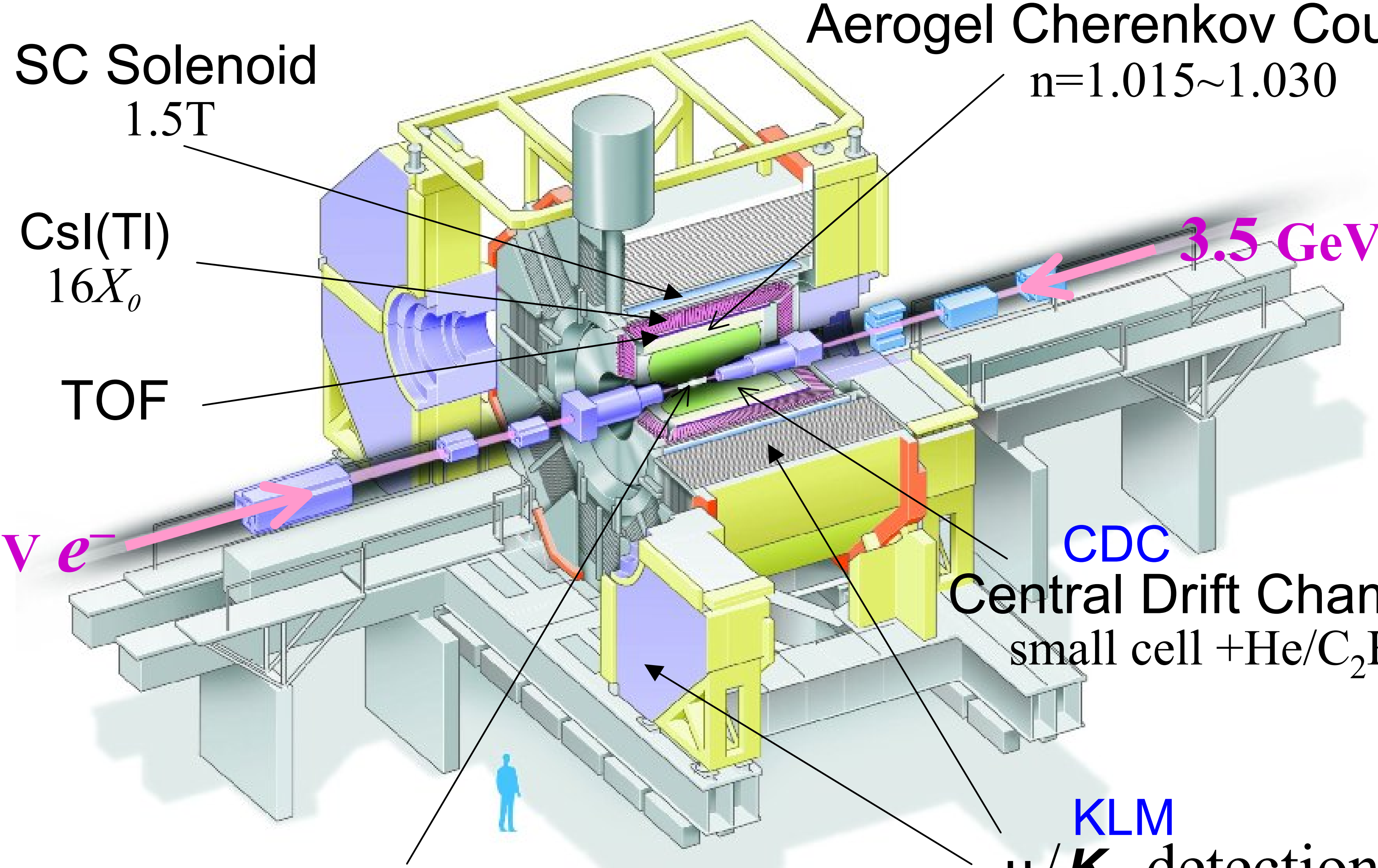
L = 1.7118 x 10^{34}/cm^2/sec

⇩

First successful op. of Crab cavities



Belle Detector



ACC (PID)
Aerogel Cherenkov Counter
n=1.015~1.030

SC Solenoid
1.5T

ECL CsI(Tl)
$16X_0$

TOF

3.5 GeV e^+

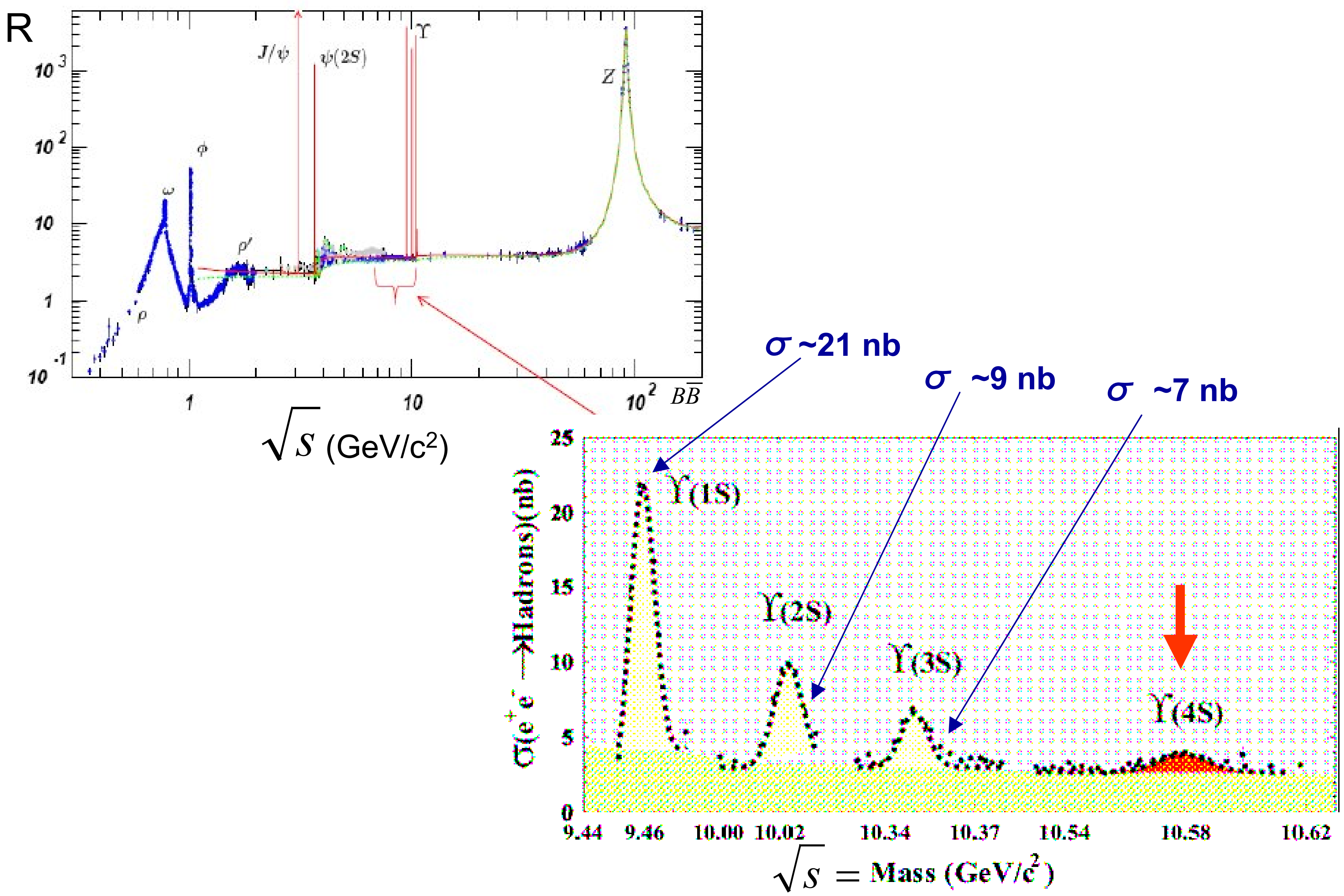
8 GeV e^-

CDC
Central Drift Chamber
small cell +He/C_2H_6

KLM
μ/K_L detection
14/15 lyr. RPC+Fe

SVD Si Vertex Detector
3(4) lyr. DSSD

$e^+e^- \rightarrow$ hadrons cross section



σ ~21 nb

σ ~9 nb

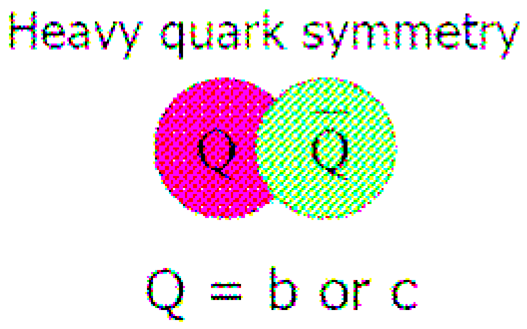
σ ~7 nb

Study of e^+e^- interactions at $\sqrt{s} \sim M(\Upsilon(4S))$

$\mathcal{L}$ ~860/fb (July 2008)

	σ, nb	N_{ev}
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ (Br($\Upsilon(4S) \to B\bar{B}$) >96%)	1.05	$\sim 900 \cdot 10^6$
$e^+e^- \to$ hadrons (continuum)	2.8	
$e^+e^- \to \tau^+\tau^-$	0.9	
$e^+e^- \to \mu^+\mu^-$	0.9	
$e^+e^- \to e^+e^-$	44	
$e^+e^- \to \gamma\,\gamma$	2.4	
$\gamma\,\gamma \to$ hadrons	15	
Σ	~67	

Motivation



u,d,s кварки

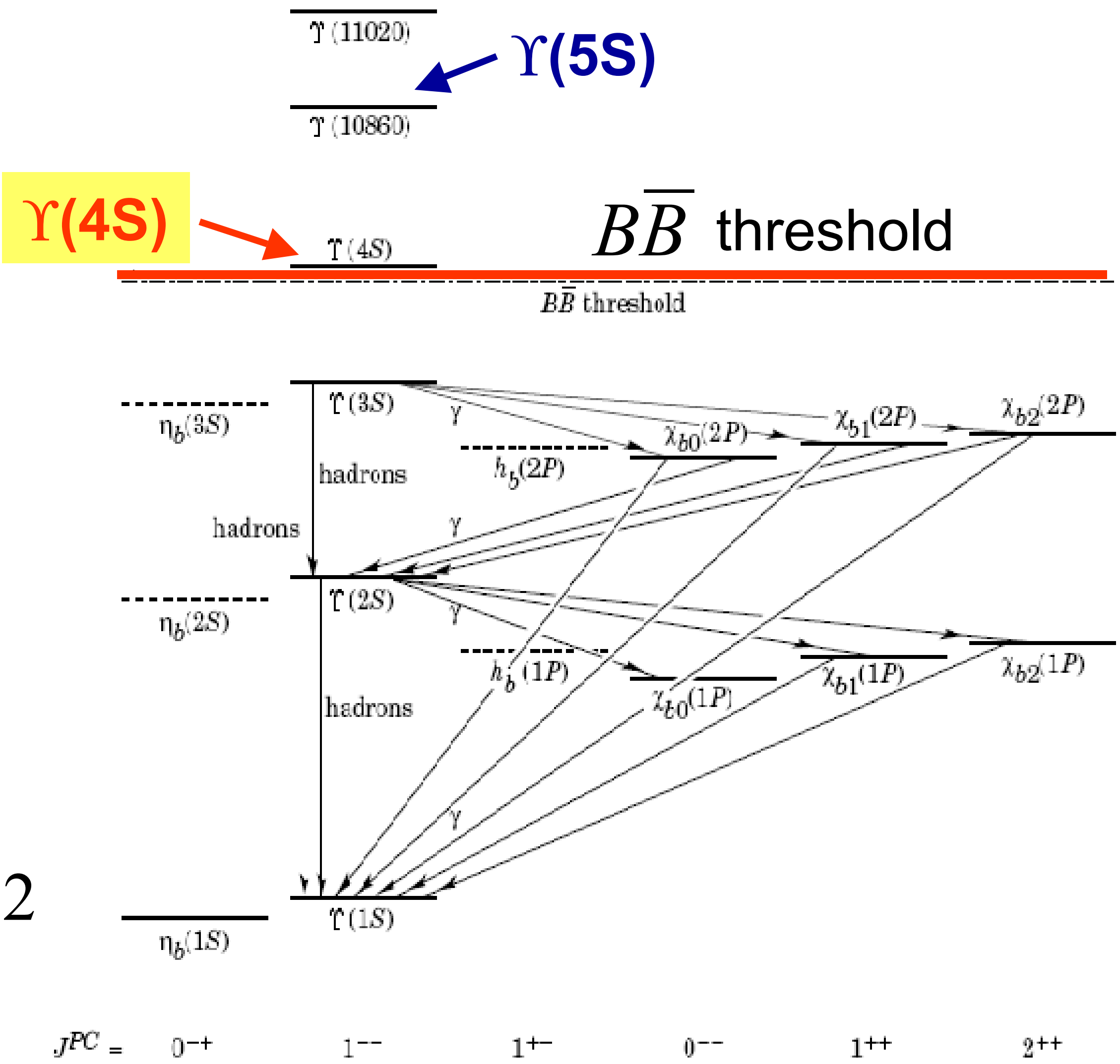
$$\left\langle v^{2} / c^{2} \right\rangle \sim 1 \qquad \alpha_{s} \geq 0.6$$

$$\Gamma_{tot} \approx 150 MeV > \Delta M$$

c,b кварки

$$\left\langle v^{2} / c^{2} \right\rangle \sim 0.1 - 0.2 \qquad \alpha_{s} \sim 0.1 - 0.2$$

$$\Gamma_{tot} \approx 0.1 - 10 MeV < \Delta M$$



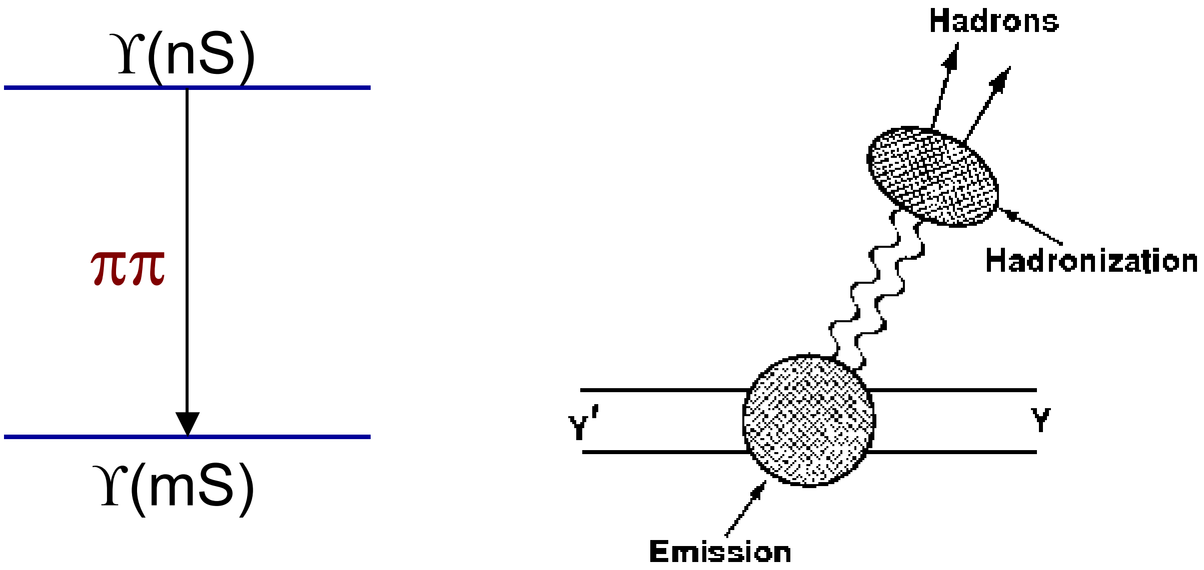
ϒ(5S)

ϒ(4S)

$B\overline{B}$ threshold

Search for $\Upsilon(4S)\rightarrow\Upsilon(nS)X$ transitions

Hadronic transitions between Upsilon states



Motivation:

Test of models of gluon (E1E1) emission

(e.g., Yan, Gottfried)

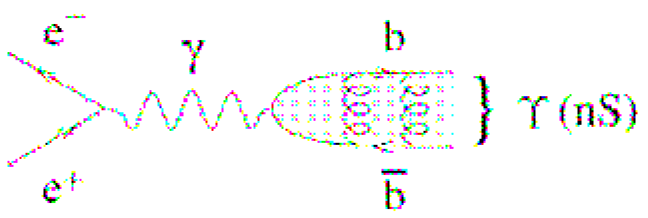
Most common process (known for decades):

Dipion transition between $^3S_1$ states,

e.g., **$\Upsilon(mS) \rightarrow \pi\pi\, \Upsilon(nS)$, m>n**

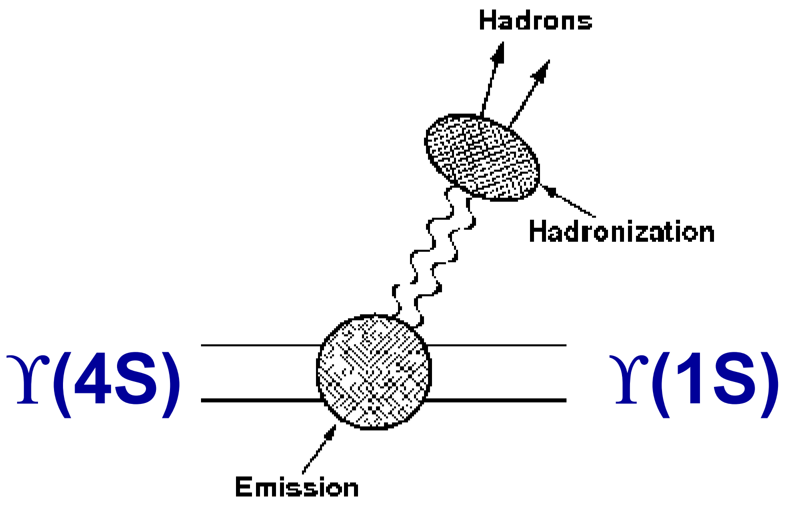
(BR ≈ 50% in cc, BR ≈ 5 - 20 % in bb)

Search for $\Upsilon(4S)\to\Upsilon(1S)\pi^+\pi^-$ decay



$e^+e^- \to \Upsilon(4S)$

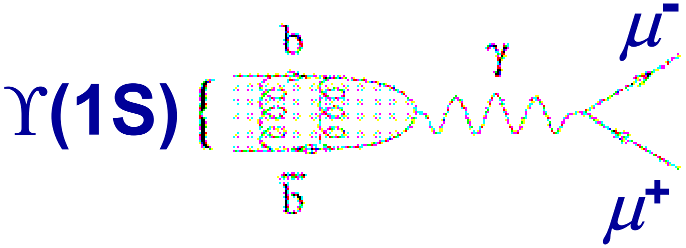
$\Upsilon(4S) \to B\bar{B}$ Br > 96%



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

$\downarrow$

$\mu^+\mu^-$



$e^+e^- \to \mu^+\mu^-\pi^+\pi^-$

Search for $\Upsilon(4S)\rightarrow\Upsilon(1S)\pi^{+}\pi^{-}$ decay

Motivation: search for new bottomonium states, transitions.

Data sample: $\mathcal{L}$=605 fb^{-1}, $\Upsilon(4s)$

657×10^{6} BB – on-resonance

$N(\mu^{+}\mu^{-})$ = 161000

Data sample: $\mathcal{L}$=427 fb^{-1}, $\Upsilon(4s)$

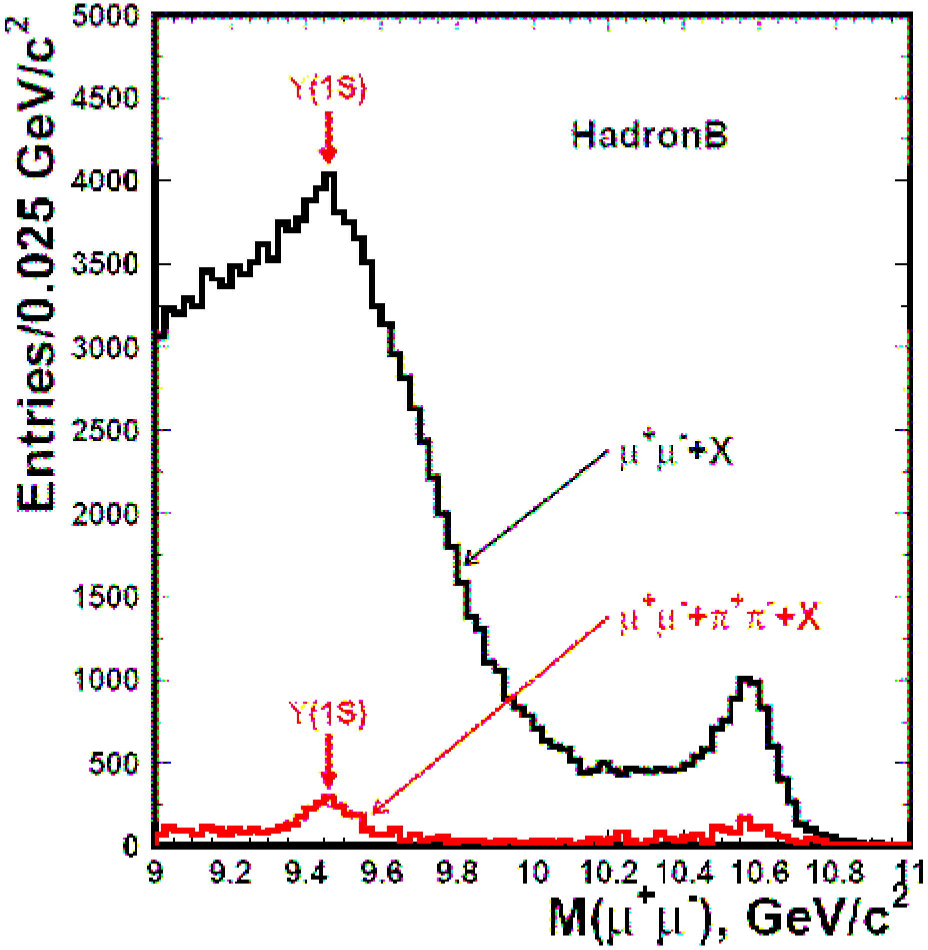
A.Sokolov *et al*. (Belle collaboration)

Phys.Rev. D75, 071103® (2007)

Primary event selection

$\Upsilon(1S)\rightarrow\mu^{+}\mu^{-}$

- There is exist a $(\mu^{+}\mu^{-})$-pair with a $M(\mu^{+}\mu^{-})>9$ GeV/c^2
- HadronB or tau event selection criteria



Event selection

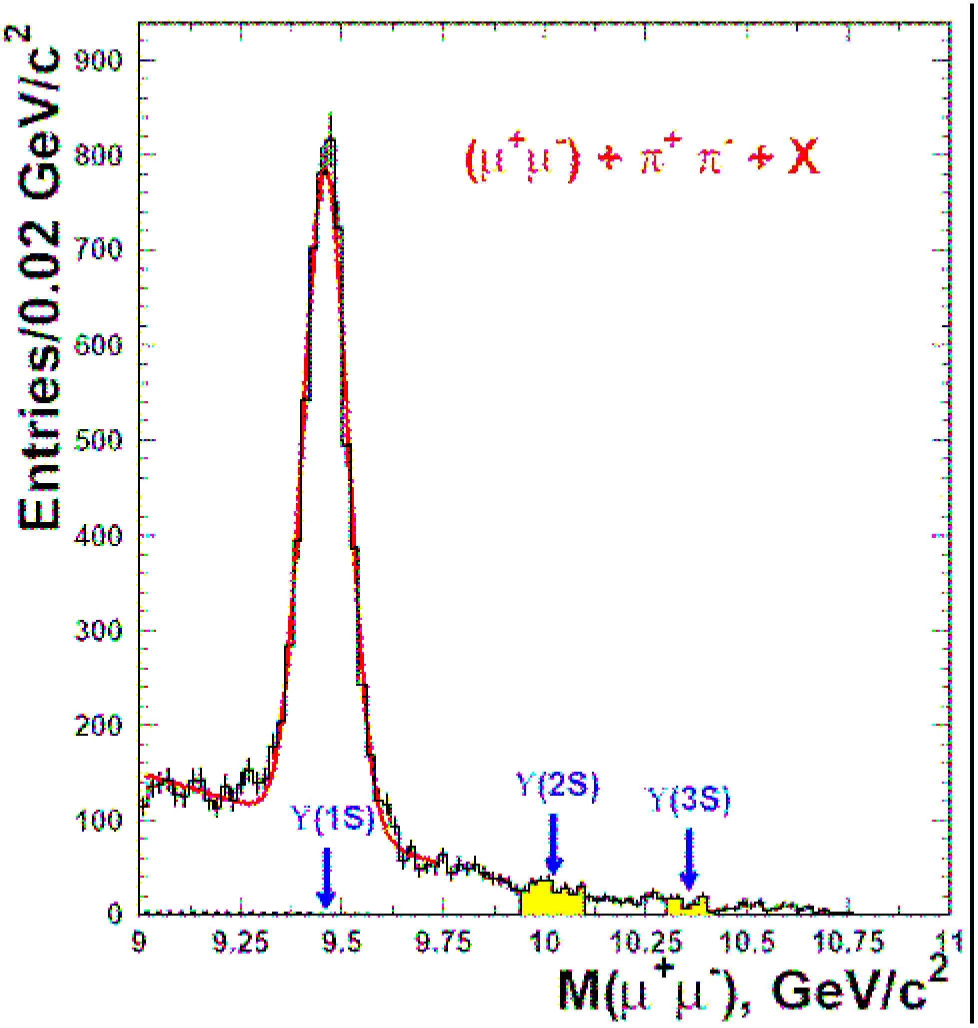
- $\mu^+\mu^- + \pi^+\pi^- + X$

- $M(\mu^+\mu^-) > 9$ GeV/c^2
  ($e^+e^- + \pi^+\pi^- + X$)-events with $M(e^+e^-) > 9$ GeV/c^2 are put down by the Belle trigger

- 10.5 GeV < Evis < 12.5 GeV

- $\cos\vartheta_{\pi\pi} < 0.95$
  reduce the bkg.
  $e^+e^- \to e^+e^-\gamma \to \Upsilon(1S)\gamma,\ \gamma \to e^+e^-$,
  $e^\pm$ are identified as $\pi^\pm$

$N(\mu^+\mu^-\pi^+\pi^-X) = 9655$



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

$e^+e^- \to e^+e^-\gamma \to \Upsilon(1S,2S,3S)\gamma$

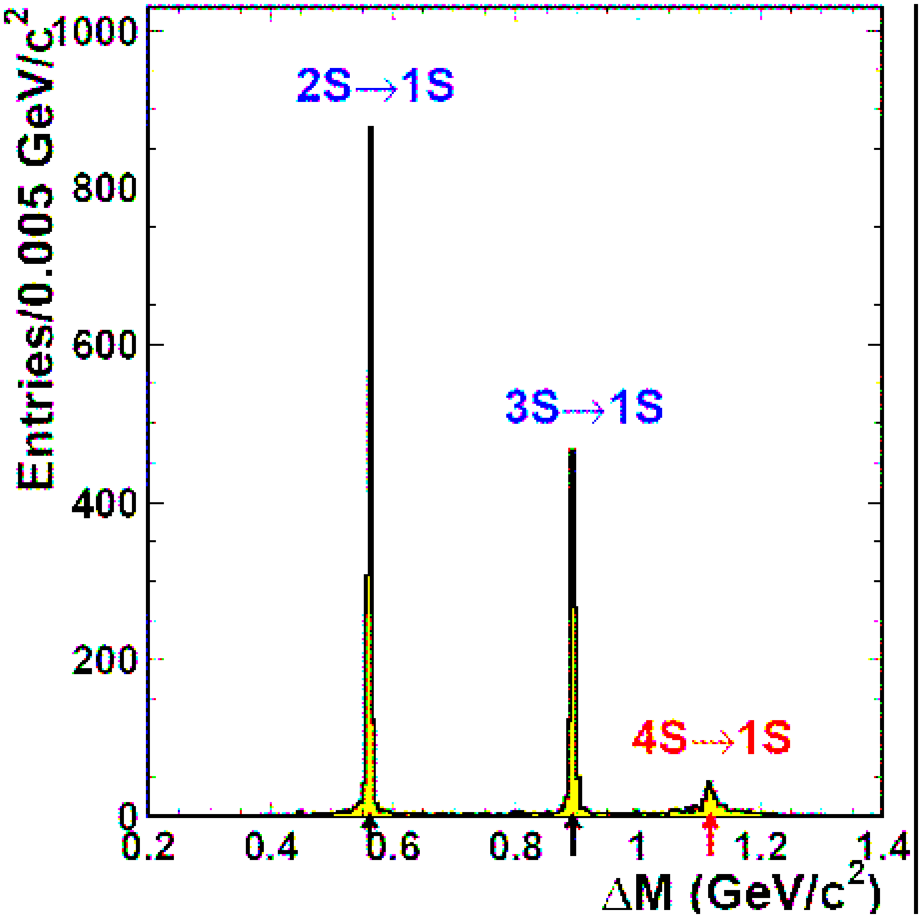
$\Upsilon(2S,3S) \to \Upsilon(1S)\ \pi^+\pi^-$

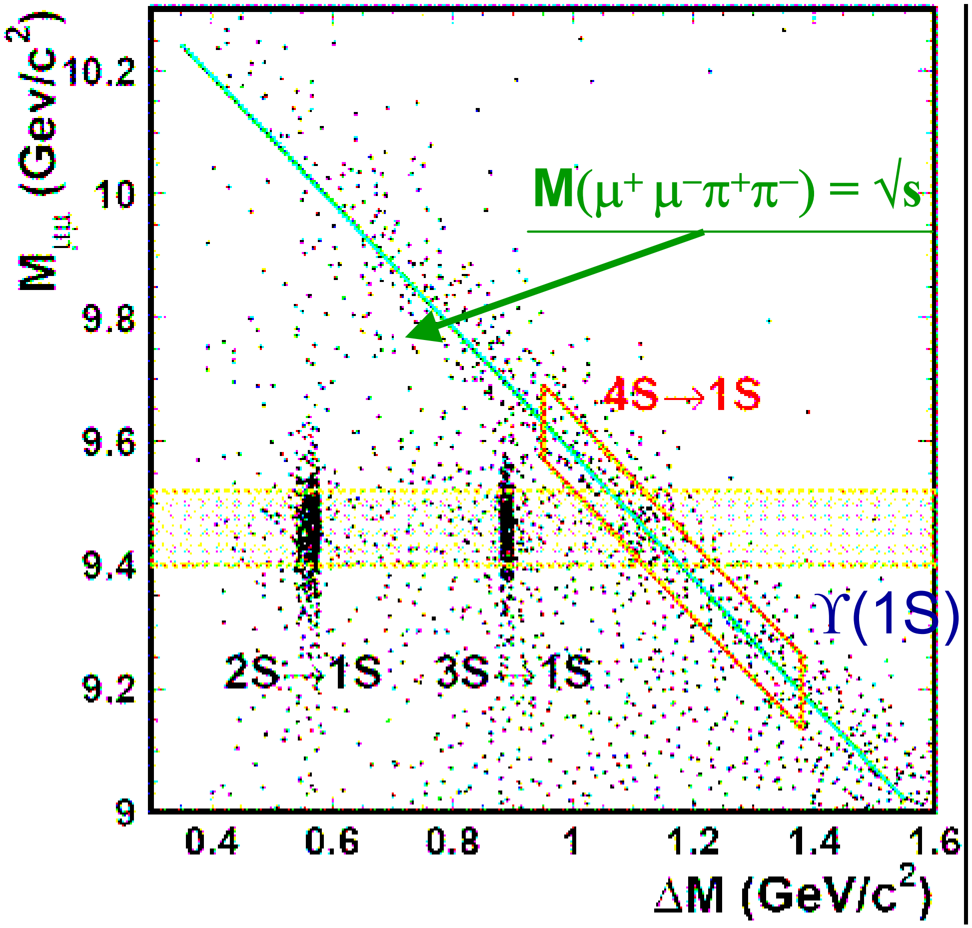
$N_{ev} = 0.9 \div 1.8 \times 10^6$, $\mathcal{L}$=605 fb^{-1}

Resonance decays in the $\Upsilon(1S)$ $\mu^+\mu^-$ state

Distribution of $\Delta M=[M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)]$

$|M(\mu^+\mu^-) - M(\Upsilon(1S)| < 60 \text{ MeV}/c^2$





2S → 1S

ΔM=561.60± 0.06 MeV

ΔM=563.0± 0.4 MeV (PDG)

3S → 1S

ΔM=893.7± 0.1 MeV

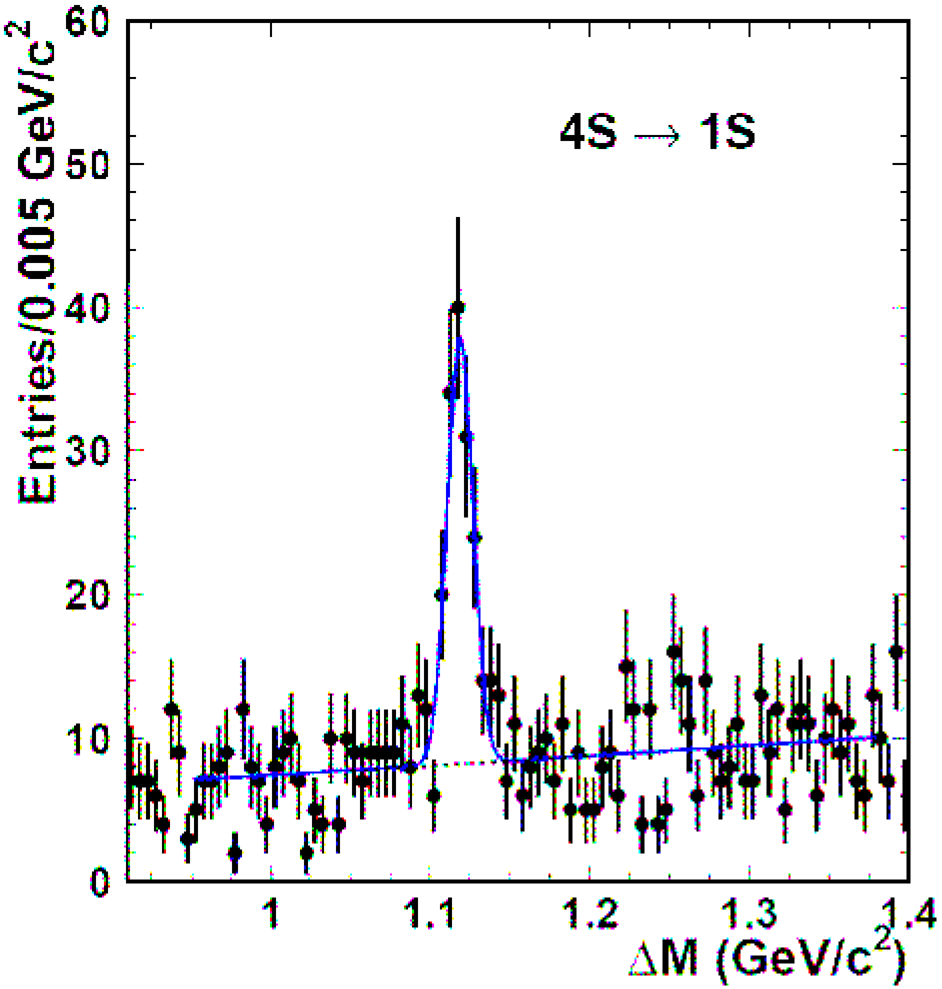
ΔM=894.9± 0.6 MeV (PDG)

4S → 1S

ΔM=1118.7± 1.2 MeV

ΔM=1120.0± 3.5 MeV (PDG)

Branching fraction of the $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$ decay



$Br(\Upsilon(4S) \to \Upsilon(1S)\,\pi^+\pi^-)$ =
N_{obs} /[$N_{tot} \cdot \varepsilon \cdot Br(\Upsilon(1S) \to \mu^+\mu^-)$]

- $N_{tot} = 657 \cdot 10^6$
- $\varepsilon = 0.048(0.251)$
- $Br(\Upsilon(1S) \to \mu^+\mu^-) = 0.0248$

Systematic ~ 10.2(6.5)%

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

= $(0.81 \pm 0.12(\text{stat.}) \pm 0.05(\text{syst.})) \times 10^{-4}$

Preliminary

$N_{peak} = 163$ $N_{bkg.} = 49.5$

$N_{\Upsilon(4S)} = 113.5 \pm 16.3$
(after bkg. subtraction)

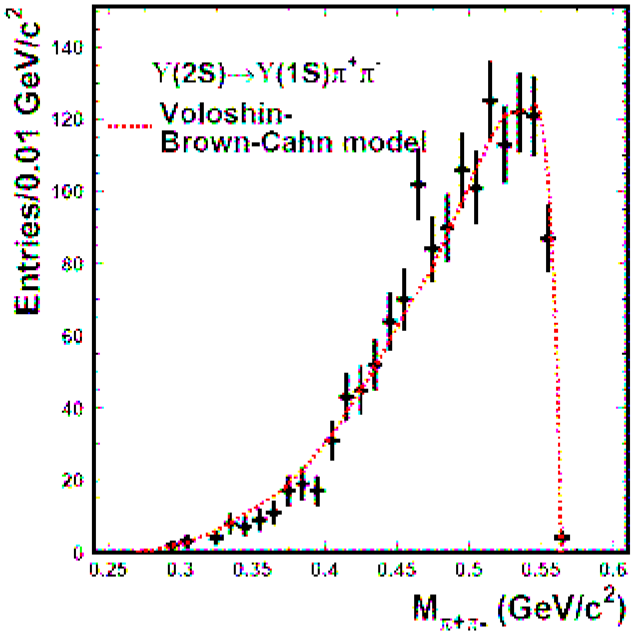
(~11.6σ)

$\Gamma(\Upsilon(4S) \to \Upsilon(1S)\,\pi^+\pi^-) = (1.67 \pm 0.24 \pm 0.23)$ keV

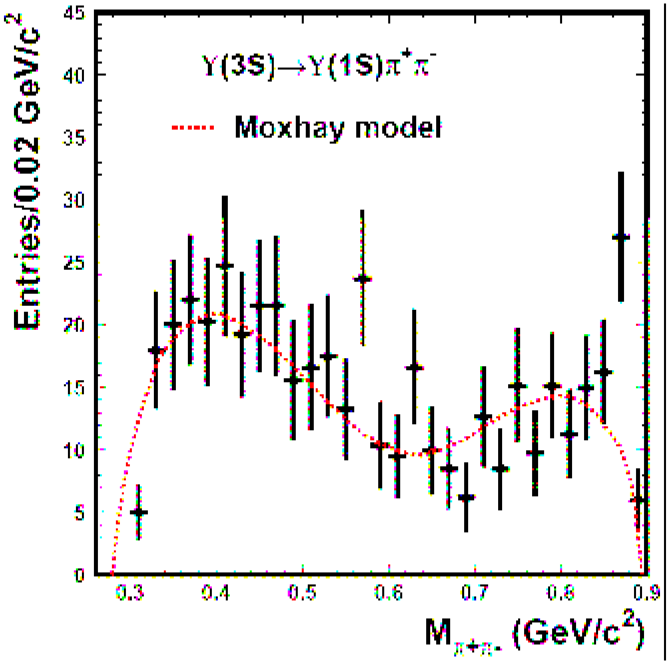
$\Gamma(\Upsilon(2S)) = 6.0$ keV $\Gamma(\Upsilon(3S)) = 0.9$ keV

Invariant mass of the $\pi^+\pi^-$ system

1st peak $\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^+\pi^-$

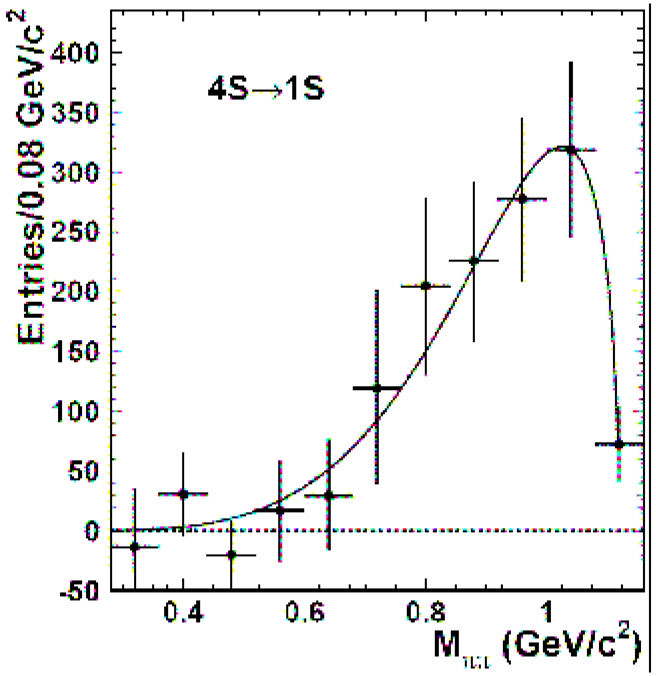


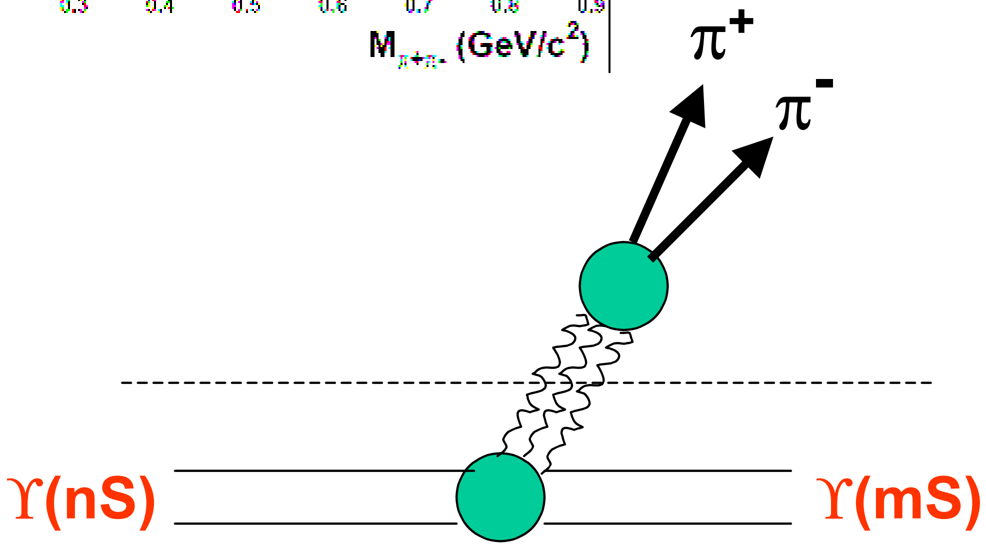
2nd peak $\Upsilon(3S)\rightarrow\Upsilon(1S)\pi^+\pi^-$



$\Upsilon(3S) \rightarrow B^*B^* \rightarrow$
$\rightarrow B^*B\ \pi \rightarrow BB\ \pi\ \pi \rightarrow$
$\rightarrow \Upsilon(1S)$

3d peak $\Upsilon(4S)\rightarrow\Upsilon(1S)\pi^+\pi^-$





M.B.Voloshin, JETP Lett., **21**, 347 (1975);

L.S.Brown and R.N.Cahn, Phys.Rev.Lett., **35**, 1(1975)

BaBar data for $Y(4S) \rightarrow Y(1S,2S)\ \pi^+\ \pi^-$

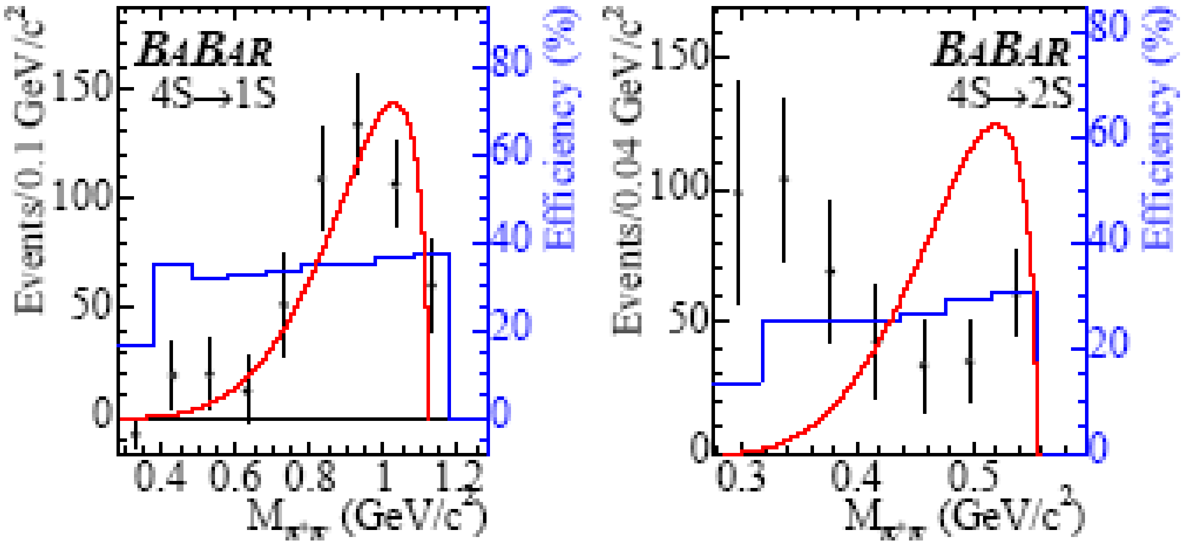
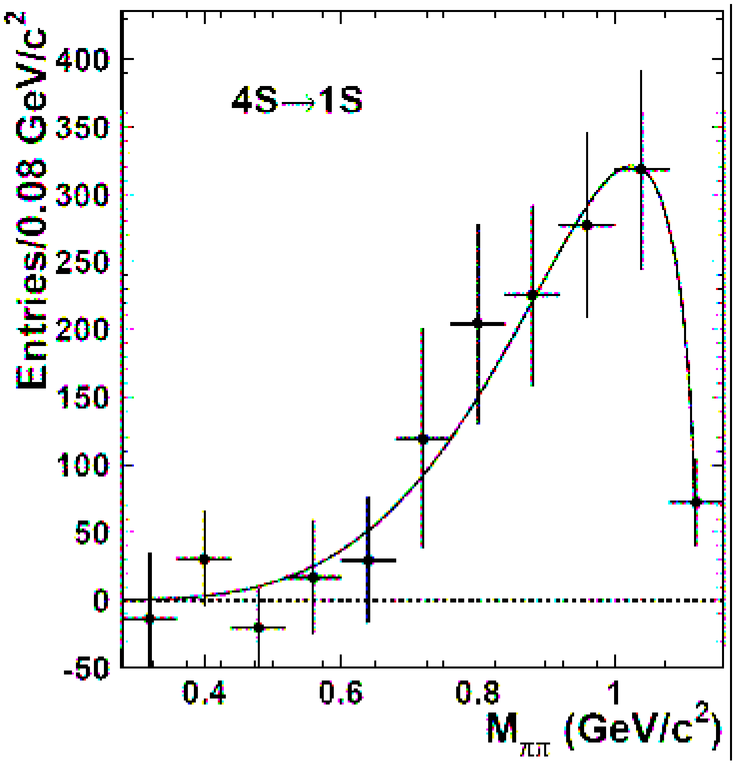


FIG. 3: The efficiency-corrected $M_{\pi^+\pi^-}$ distribution for $4S \rightarrow 1S$ transition (left) and $4S \rightarrow 2S$ transition (right). The solid line shows the distribution predicted in Ref. [2]. The dotted histogram shows the selection efficiency in each bin. The experimental resolution in $M_{\pi^+\pi^-}$ is less than 5 MeV/c^2, much smaller than the bin size.

PRL 96 (2006) 232001

Belle data

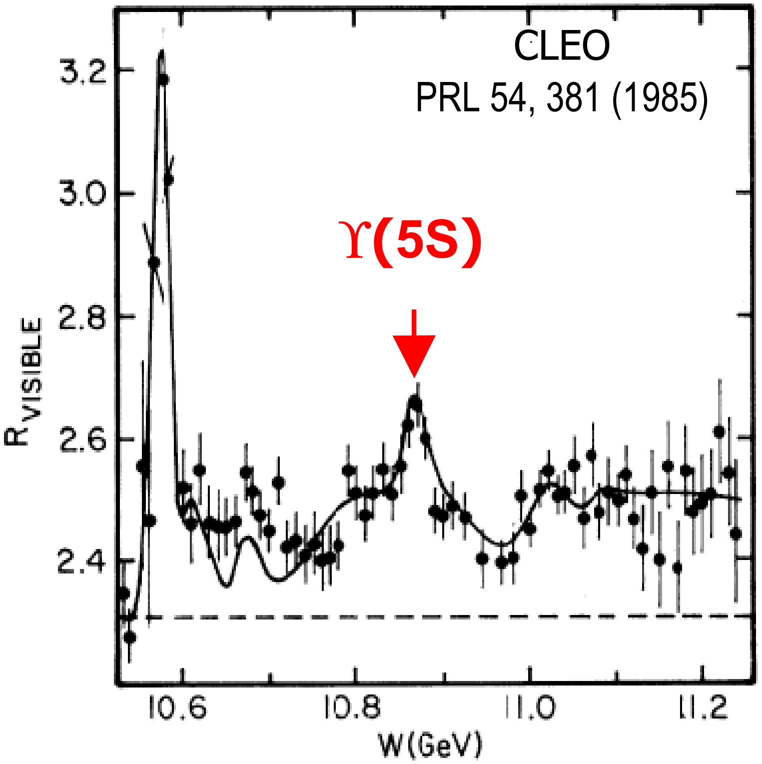


Dataset on $\Upsilon(5S)$

Dataset on $\Upsilon(5S)$

1985: CLEO,CUSB @ CESR ~ **116 pb^{-1}**

2003: CLEO III @ CESR **~ 0.42 fb^{-1}**



2005: Belle @ KEKB **~ 1.86 fb^{-1}**

enginering run

2006, June 9-31: Belle @ KEKB

~ 21.9 fb^{-1}

Search for ϒ(5S)→ϒ(nS) transitions

Data sample:

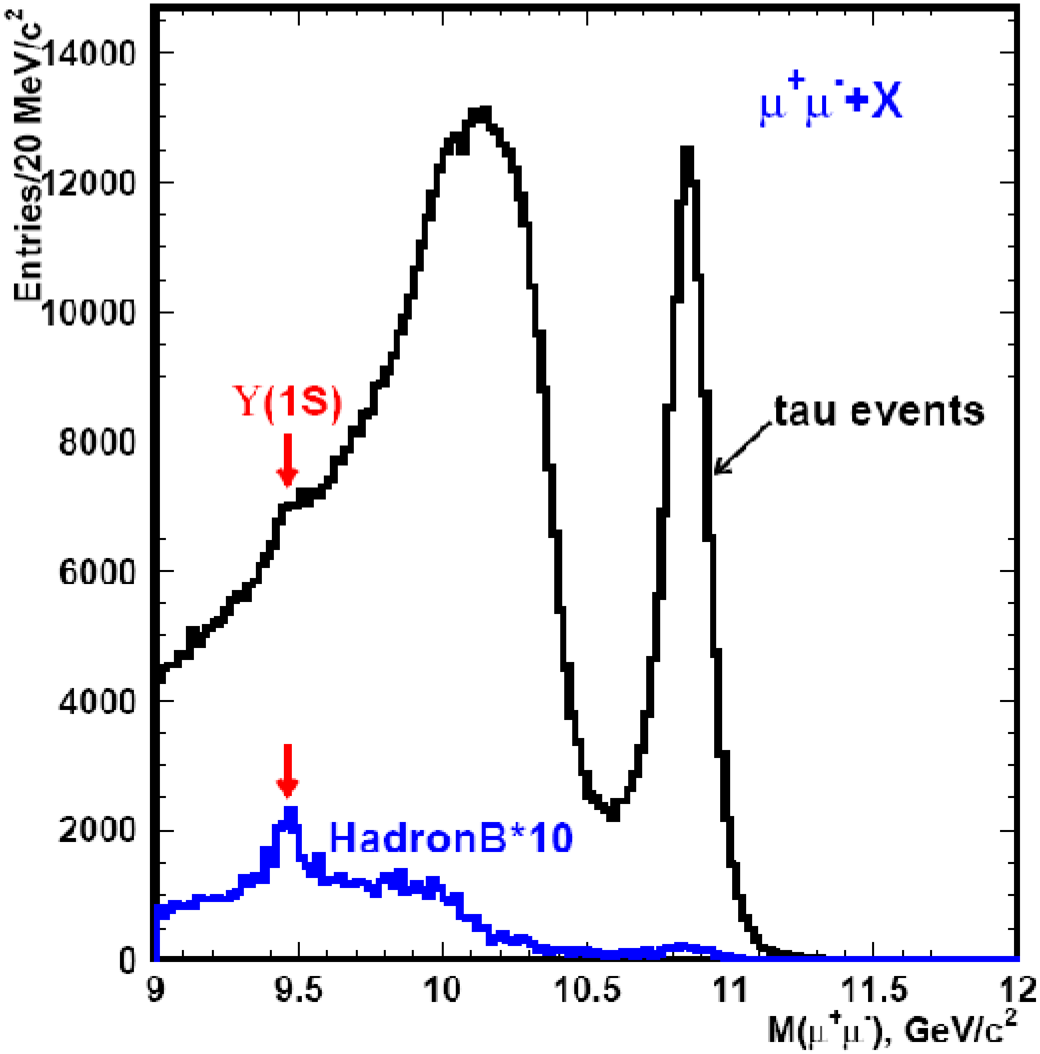
Exp. 53, 5S_scan,

$N_{tot}(5S) = \mathcal{L} \cdot \sigma = (6.60 \pm .33) \cdot 10^6$

$\mathcal{L} = 21.9\ \text{fb}^{-1}$,

$\sigma = (.302 \pm 0.015)$ nb (Belle)

N(tau events) = 762000
N(HB) = 7300



Primary event selection

- HadronB
  &
  tau skim
- There is exist a $(\mu^+\mu^-)$ - pair with a $M(\mu^+\mu^-) > 9$ GeV/c²

$(\Upsilon(nS) \to \mu^+\mu^-, e^+e^-)$

Event selection

$N(\mu^+\mu^-\pi^+\pi^-X)$ = 1876 (tau)

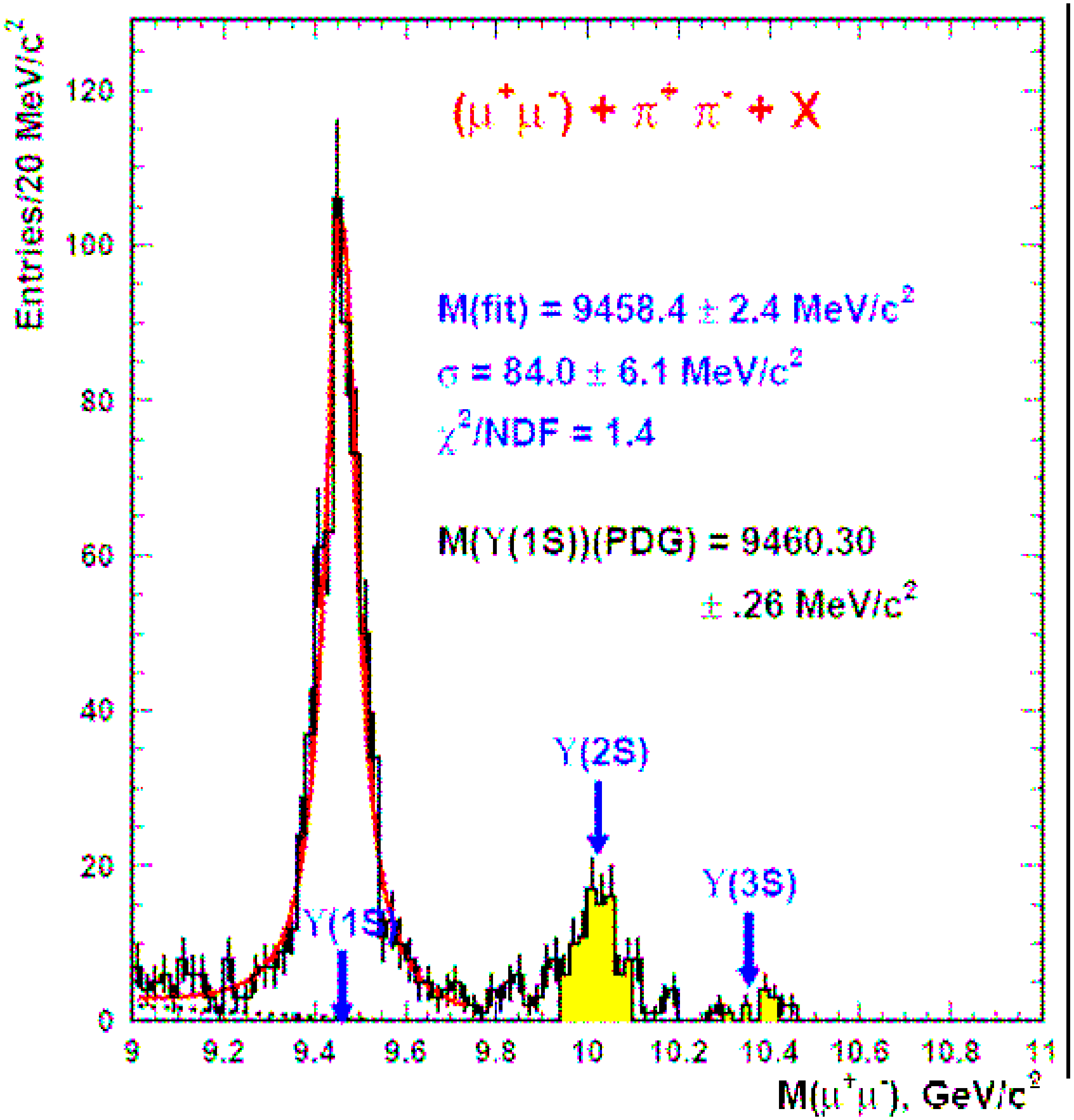
$N(\mu^+\mu^-\pi^+\pi^-X)$ = 705 (HB)

- HadronB & tau skim
- $\mu^+\mu^- + \pi^+\pi^- + X$
- $M(\mu^+\mu^-) > 9$ GeV/c^2
- 10.5 GeV < Evis < 12.5 GeV
- $\cos\vartheta_{\pi\pi} < 0.95$

  reduce the bkg.

  $e^+e^- \rightarrow \Upsilon(1S)\gamma,\ \gamma \rightarrow e^+e^-$,

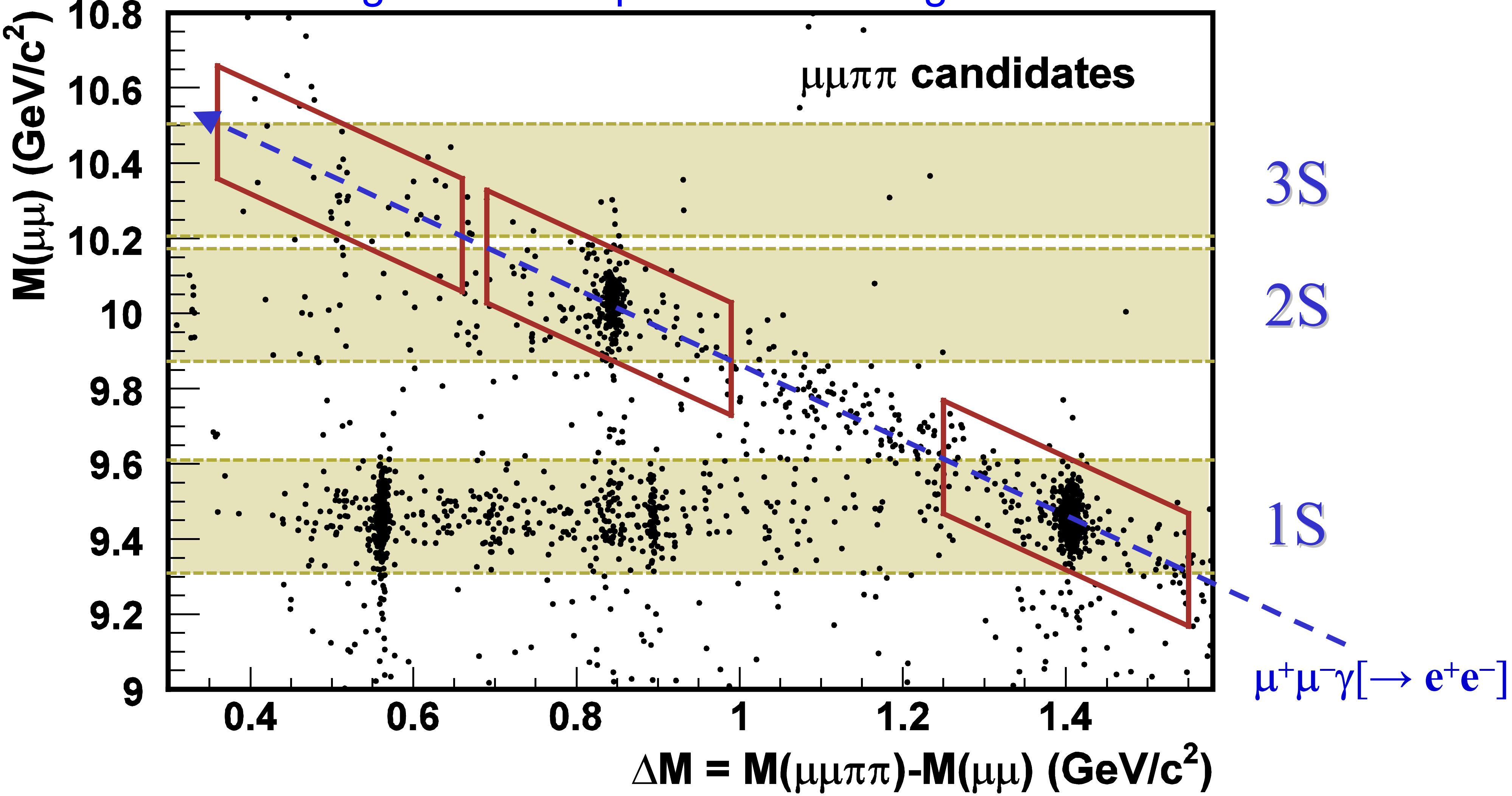
  $e^\pm$ are identified as $\pi^\pm$



$e^+e^- \to \Upsilon(nS)h^+h^-$ at 10.87 GeV

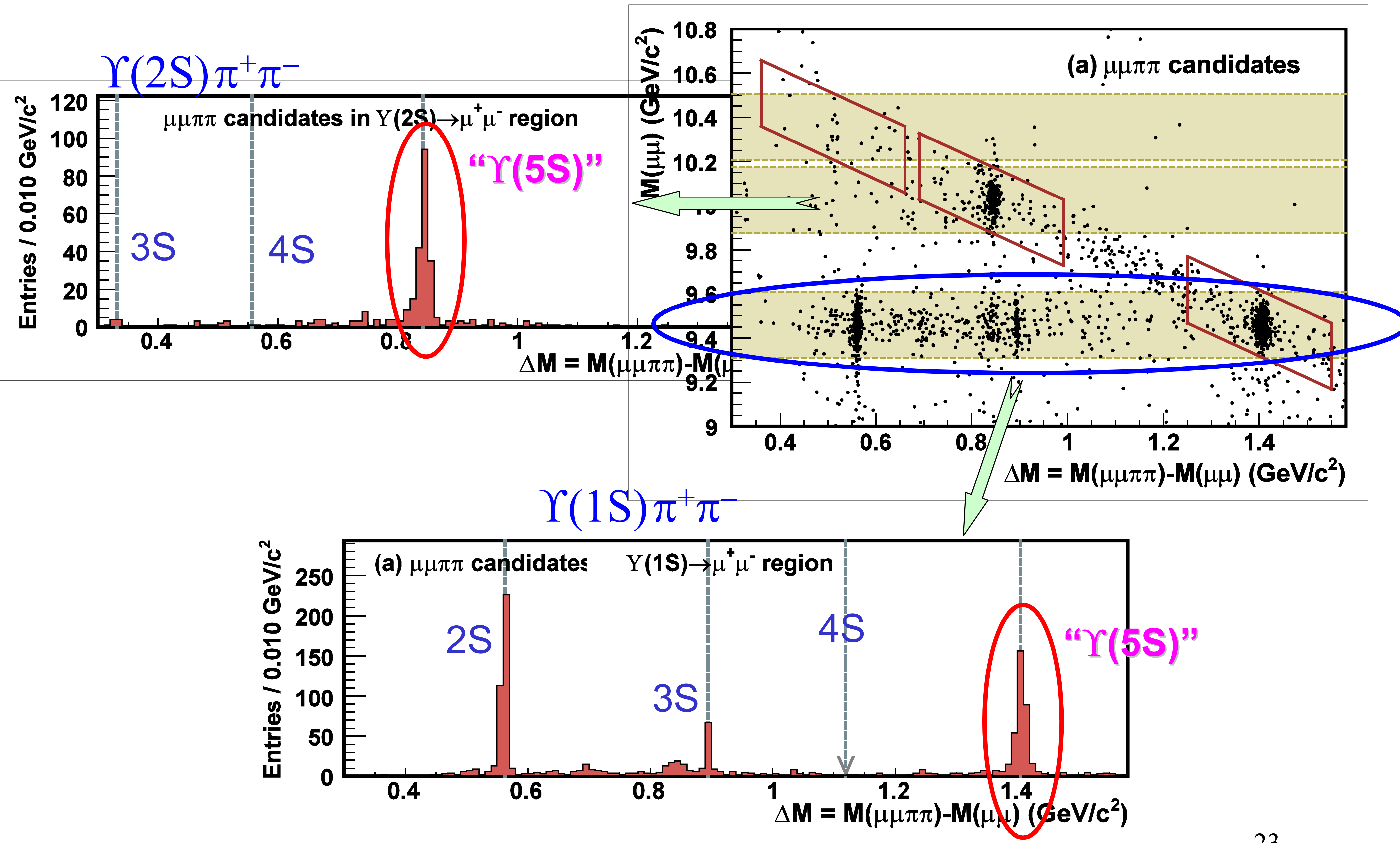
$21.9\ \mathrm{fb}^{-1}$

Signal box to optimize on background

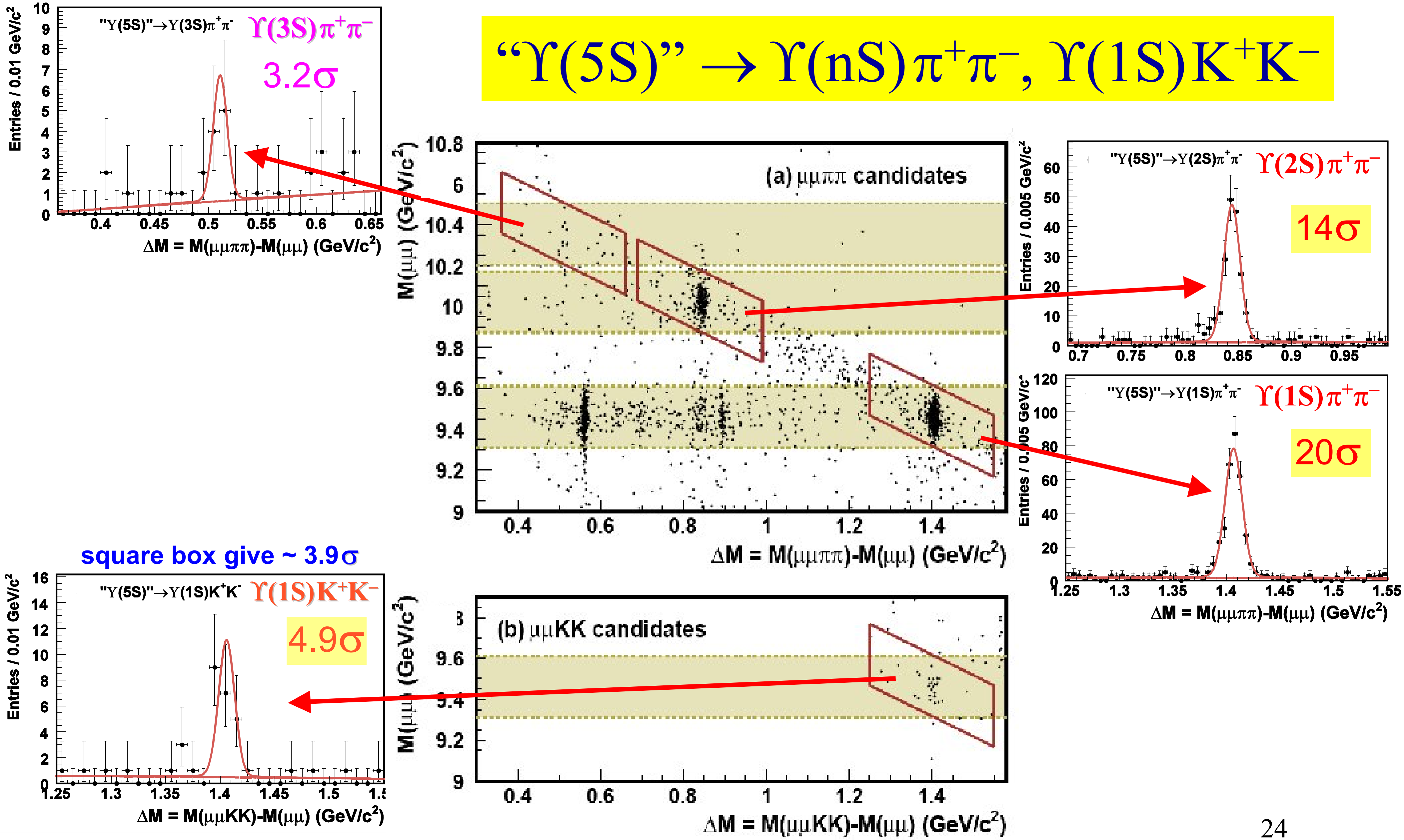


Results

“$\Upsilon(5S)$” → $\Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$

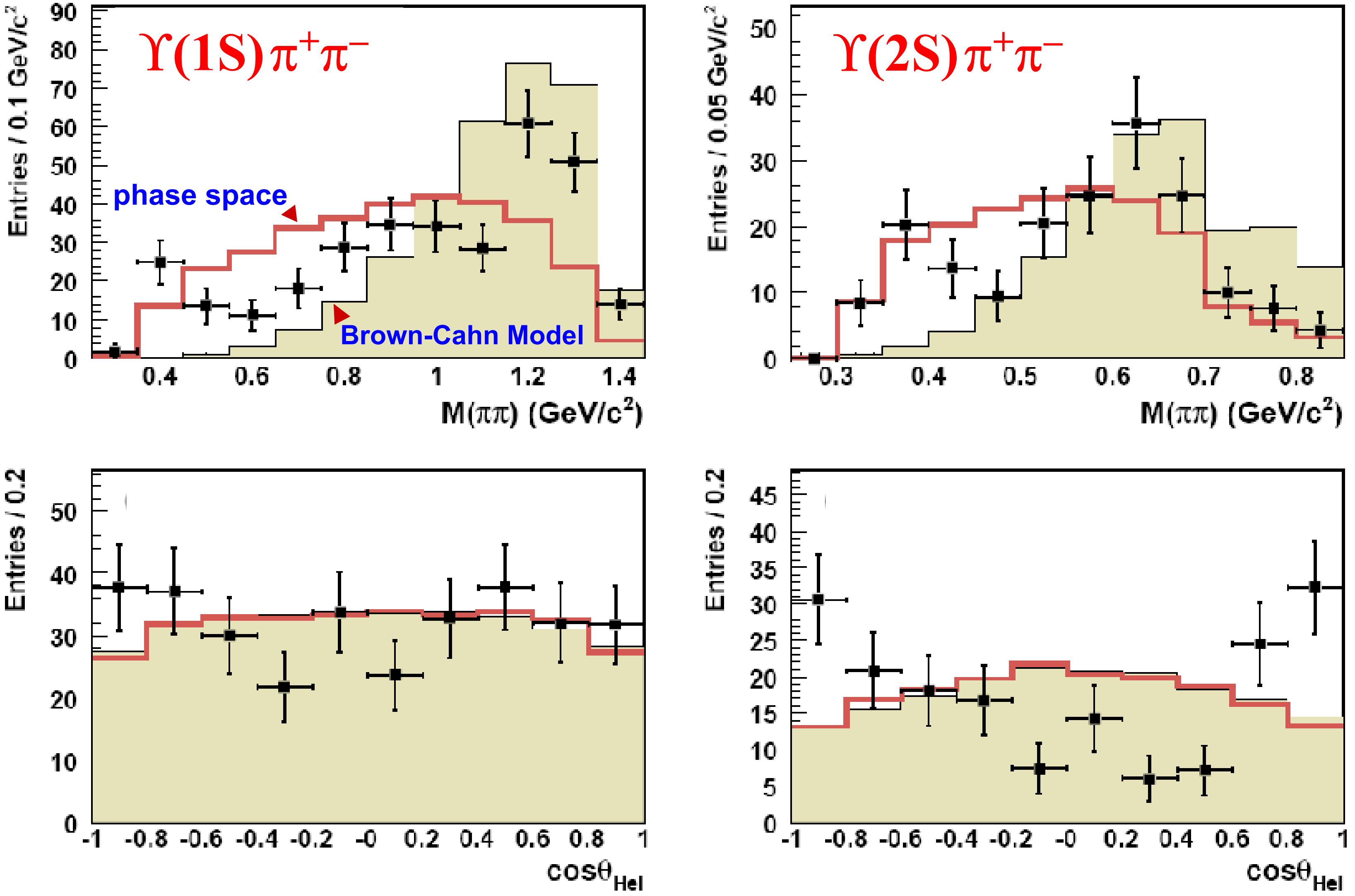


"$\Upsilon(5S)$" $\rightarrow \Upsilon(nS)\pi^+\pi^-$, $\Upsilon(1S)K^+K^-$



square box give ~ 3.9σ

$M(\pi\pi)$ and $\cos\theta_{Hel}$ Distributions



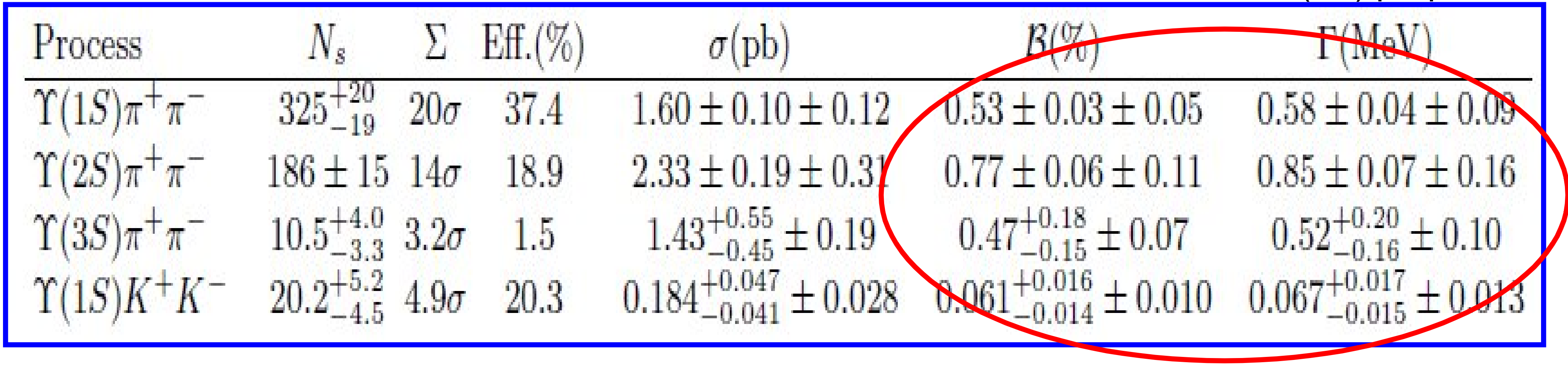
Efficiency estimate: re-weighted MC according to data

N.B. other two modes use B-C model due to limited statistics

Summary Table

Assume "Υ(5S)" = Υ(5S)

PDG value taken for Υ(nS) properties



Process	N_s	Σ	Eff.(%)	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	325^{+20}_{-19}	20σ	37.4	$1.60 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.58 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	186 ± 15	14σ	18.9	$2.33 \pm 0.19 \pm 0.31$	$0.77 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$10.5^{+4.0}_{-3.3}$	3.2σ	1.5	$1.43^{+0.55}_{-0.45} \pm 0.19$	$0.47^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.16} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$20.2^{+5.2}_{-4.5}$	4.9σ	20.3	$0.184^{+0.047}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

>100 times bigger!!

bb	*Γ(total)*	*$\Gamma(\Upsilon(1S)\pi\pi)$*	*cc*	*Γ(total)*	*$\Gamma(J/\psi\pi\pi)$*
Y(2S)	32 KeV	6.0 KeV	ψ(2S)	337 KeV	107 KeV
Y(3S)	20 KeV	0.9 KeV	ψ(3770)	23 MeV	44 KeV
Y(4S)	20.5 MeV	1.8 KeV	ψ(4040)	80 MeV	<320 KeV @90%
"Y(5S)"	110 MeV	~0.5 MeV!!	ψ(4160)	103 MeV	<309 KeV @90%
			Y(4260)	83 MeV	*O(>MeV)*

Предполагается, что резонанс при массе =10860 МэВ это состояние **$\Upsilon(5S)$**, но

$$\Gamma(\Upsilon(5S) \to \Upsilon(nS)\,\pi^+\pi^-) > 100 \times \Gamma(\Upsilon(2S,3S,4S) \to \Upsilon(1S)\,\pi^+\pi^-)$$

Возможные механизмы:

- аналог состояния Y(4260) (гибридное состояние $c\bar{c}g$?)
  Wei-Shu Hou, PR D74, 017504 (2006)

- переход через тетракварк $b\bar{b}ud$ (< M($B\bar{B}$))
  Karliner & Lipkin, 0802.0649 [hep-ph]
  (аналог состояния Y(4430))

$$\Upsilon(mS) \to T^{\pm}_{b\bar{b}}\pi^{\mp} \to \Upsilon(nS)\pi^{+}\pi^{-}$$

- непертурбативный подход
  Yu.A.Simonov, JETP Lett. **87**, 147 (2008)

$$\frac{\Gamma_{K^+K^-}(5S\to 1S)}{\Gamma_{\pi^+\pi^-}(5S\to 1S)} \sim \left(\frac{\mu_K}{\mu_\pi}\right)^7 = 0.104$$

- взаимодействие в конечном состоянии
  C.Meng & K.T.Chao, Phys.Rev. D **77**, 074003 (2008)

Сканирование энергии в районе пика Υ(5S)

K.F. Chen et al (Belle) arXiv:0808.2445

Results

Ecm = 10827.5

$\mathcal{L}$= 1.7 fb^{-1}

Ecm = 10882.5

$\mathcal{L}$= 1.8 fb^{-1}

Ecm = 10897.5

$\mathcal{L}$= 1.4 fb^{-1}

Ecm = 10927.5

$\mathcal{L}$= 1.1 fb^{-1}

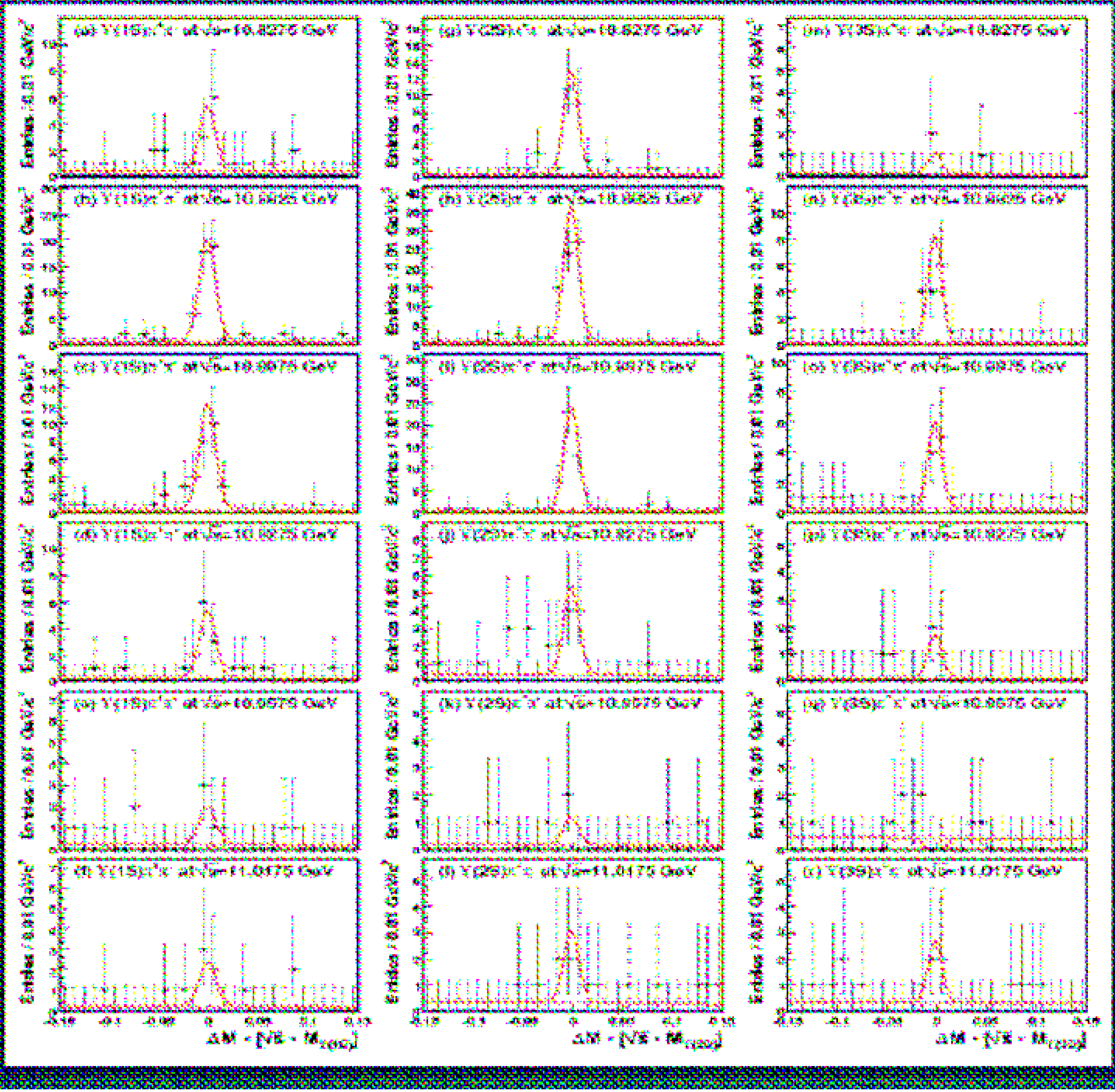
Ecm = 10957.5

$\mathcal{L}$= 1.0 fb^{-1}

Ecm = 11017.5

$\mathcal{L}$= 0.9 fb^{-1}

$\Upsilon(1S)\pi\pi$ $\Upsilon(2S)\pi\pi$ $\Upsilon(3S)\pi\pi$



Results

Yields & Cross Sections

Point	10869
int(L) (pb^{-1})	21744
$N(\Upsilon(1S)\pi\pi)$	325^{+20}_{-19}
$\varepsilon(\Upsilon(1S)\pi\pi)$	37.4%
$\sigma(\Upsilon(1S)\pi\pi)$	1.61±0.16
$N(\Upsilon(2S)\pi\pi)$	186±15
$\varepsilon(\Upsilon(2S)\pi\pi)$	18.9%
$\sigma(\Upsilon(2S)\pi\pi)$	2.35±0.37
$N(\Upsilon(3S)\pi\pi)$	$10.5^{+4.0}_{-3.3}$
$\varepsilon(\Upsilon(3S)\pi\pi)$	1.5%
$\sigma(\Upsilon(3S)\pi\pi)$	$1.44^{+0.58}_{-0.49}$

← 2006 Υ(5S) data
(Exp 53)

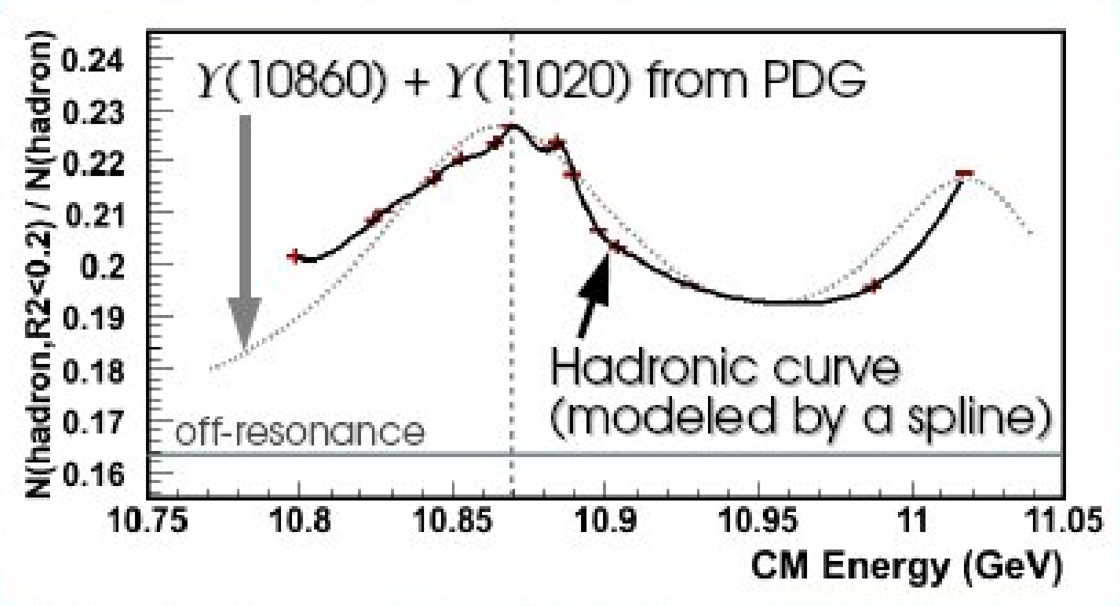
- Efficiency for 3S$\pi\pi$ increases dramatically due to the "ypipi" skims.

Point	10829	10884	10899	10929	10959	11019
int(L) (pb^{-1})	1683.48	1832.86	1407.58	1138.80	1007.30	856.02
$N(\Upsilon(1S)\pi\pi)$	$10.6^{+4.0}_{-3.3}$	$43.5^{+7.2}_{-6.5}$	$26.3^{+5.8}_{-5.1}$	$11.2^{+4.0}_{-3.3}$	$3.9^{+2.6}_{-1.9}$	$4.9^{+2.8}_{-2.1}$
$\varepsilon(\Upsilon(1S)\pi\pi)$	43.8%	43.1%	43.2%	42.6%	42.5%	42.0%
$\sigma(\Upsilon(1S)\pi\pi)$	$0.58^{+0.22}_{-0.18}$	$2.22^{+0.37}_{-0.33}$	$1.73^{+0.39}_{-0.34}$	$0.93^{+0.33}_{-0.27}$	$0.36^{+0.24}_{-0.18}$	$0.55^{+0.31}_{-0.24}$
$N(\Upsilon(2S)\pi\pi)$	$24.0^{+5.6}_{-4.9}$	$68.9^{+9.0}_{-8.3}$	$45.5^{+7.4}_{-6.7}$	$9.7^{+3.8}_{-3.1}$	$2.0^{+2.0}_{-1.3}$	$5.5^{+3.1}_{-2.4}$
$\varepsilon(\Upsilon(2S)\pi\pi)$	34.9%	35.4%	35.6%	35.9%	36.4%	36.0%
$\sigma(\Upsilon(3S)\pi\pi)$	$2.11^{+0.49}_{-0.43}$	$5.49^{+0.72}_{-0.66}$	$4.69^{+0.77}_{-0.69}$	$1.23^{+0.48}_{-0.39}$	$0.28^{+0.28}_{-0.18}$	$0.92^{+0.52}_{-0.40}$
$N(\Upsilon(3S)\pi\pi)$	$1.8^{+1.9}_{-1.1}$	$14.9^{+4.4}_{-3.7}$	$10.3^{+3.7}_{-3.1}$	$2.9^{+2.2}_{-1.5}$	$-1.8^{+2.5}_{-3.0}$	$4.3^{+2.6}_{-1.9}$
$\varepsilon(\Upsilon(3S)\pi\pi)$	20.5%	24.5%	25.7%	27.5%	29.4%	32.7%
$\sigma(\Upsilon(3S)\pi\pi)$	$0.24^{+0.24}_{-0.15}$	$1.52^{+0.44}_{-0.38}$	$1.31^{+0.47}_{-0.39}$	$0.42^{+0.32}_{-0.22}$	$-0.28^{+0.38}_{-0.47}$	$0.71^{+0.43}_{-0.31}$

Hadronic Ratios

2^{nd} order of Fox-Wolfram momentum
2-jet events R2~1

- Would like to extract the shapes for $\Upsilon(5S)$ from the ratios:
  N(hadron, R2<0.2) / N(hadron,total)
  N(Bhabha) or N($\mu\mu$) seems to have small efficiency difference between different experiments (need some extra calibration?).
- Model the hadronic curve by a simple spline connecting all the data points (without a fit):



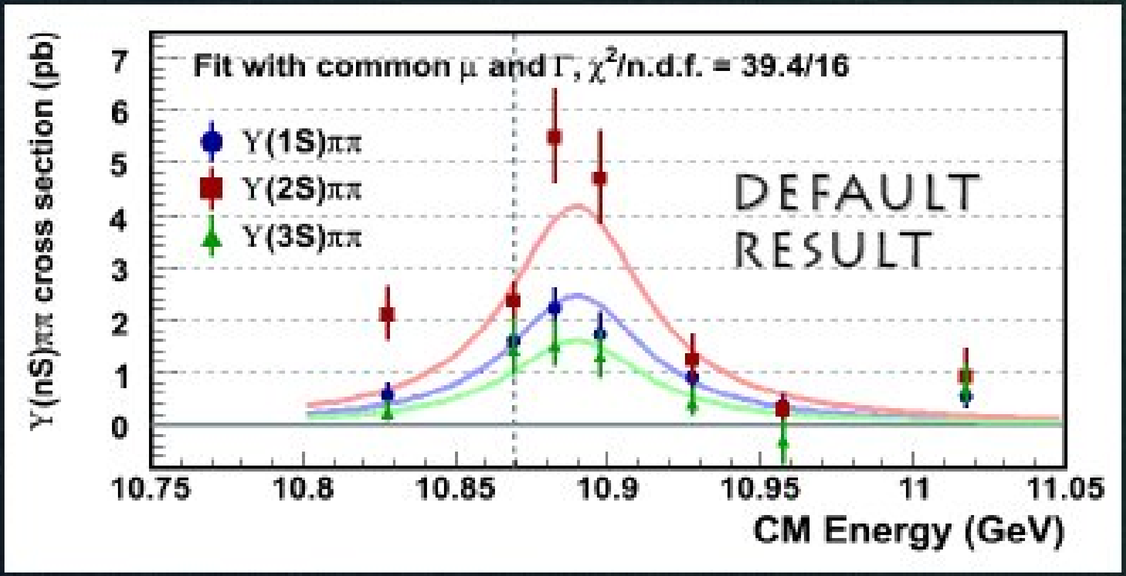
I would like to avoid providing a very accurate number but without systematic error in the publication.
(e.g. M = 10860.7 ± 0.2 MeV from a poor χ^2 fit to these points)

Results

Default Resonance Fits

- Simple χ^2 fit to the measured cross sections.
- Default fit: a common(*) Breit-Wigner (floated mean & width) with floated 3 normalizations (for 1S, 2S, and 3S).
- The results from previous publication are included in the fit.

(7 energies x 3 states = 21 points).



Peak(1S) = $2.46^{+0.27}_{-0.25}$ pb

Peak(2S) = $4.18^{+0.49}_{-0.46}$ pb

Peak(3S) = $1.61^{+0.31}_{-0.28}$ pb

Mean = 10889.6 ± 1.8 MeV

Width = $54.7^{+0.85}_{-0.72}$ MeV

χ^2/n.d.f. = 39.4 /16

(*) *Since the resonance parameters are quite similar for 3 final states.*

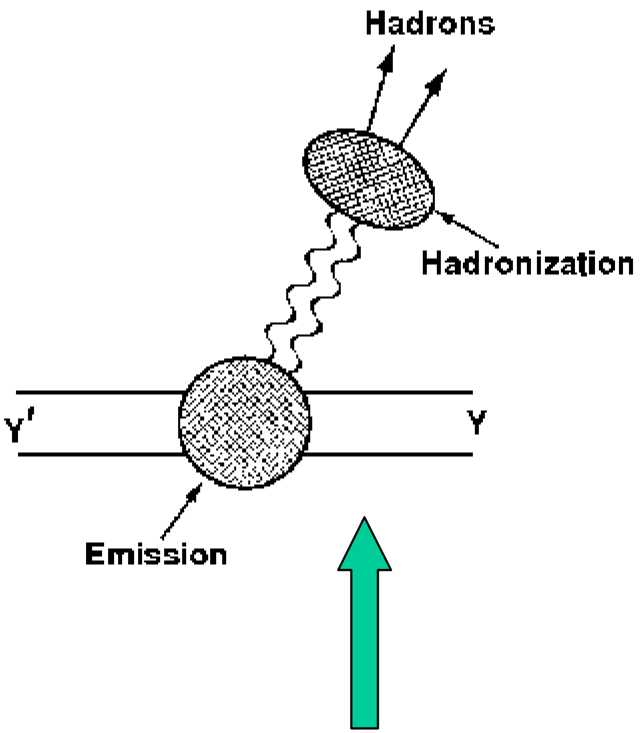
Дальнейшее изучение боттомония

- детальное изучение распадов боттомония
- поиск η_b в распадах Υ(1,2,3S)
- изучение правил pQCD в распадах боттомония
- поиск легкого хиггсовского бозона a_1 в распадах на $\tau^+\tau^-$
- поиск дибариона в распадах Υ(1S)

Боттомоний – невыясненные детали распада

$$\Upsilon(mS)$$

$$\psi^{'}$$



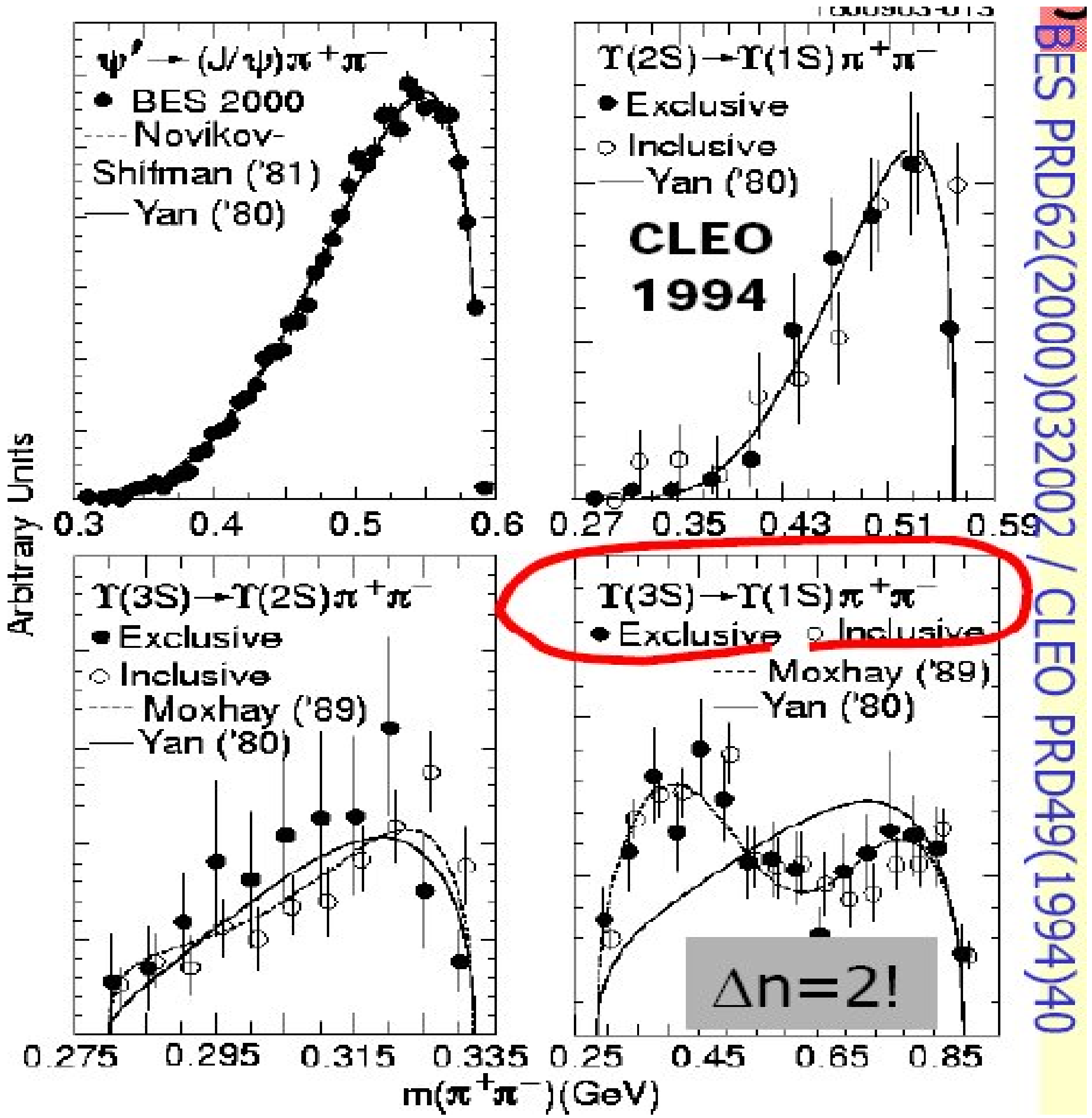
$$\Upsilon(nS)$$

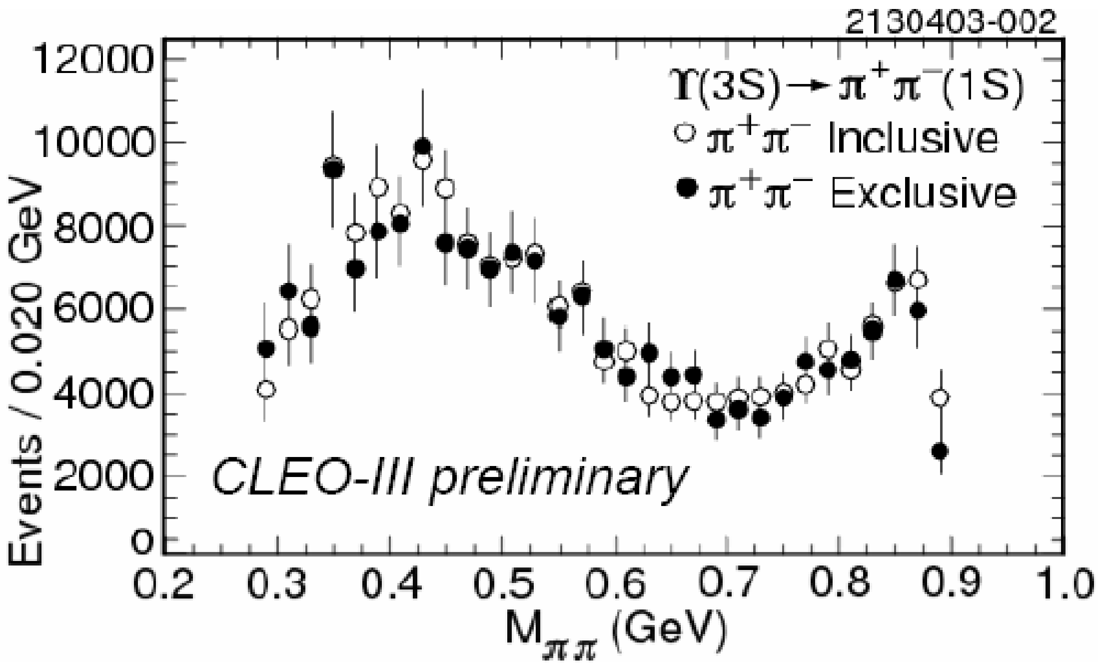
$$\psi$$

“QCD Multipole Expansion”

Распады для случая m-n > 1 ?

Most famous ancient mystery (1994-2000)





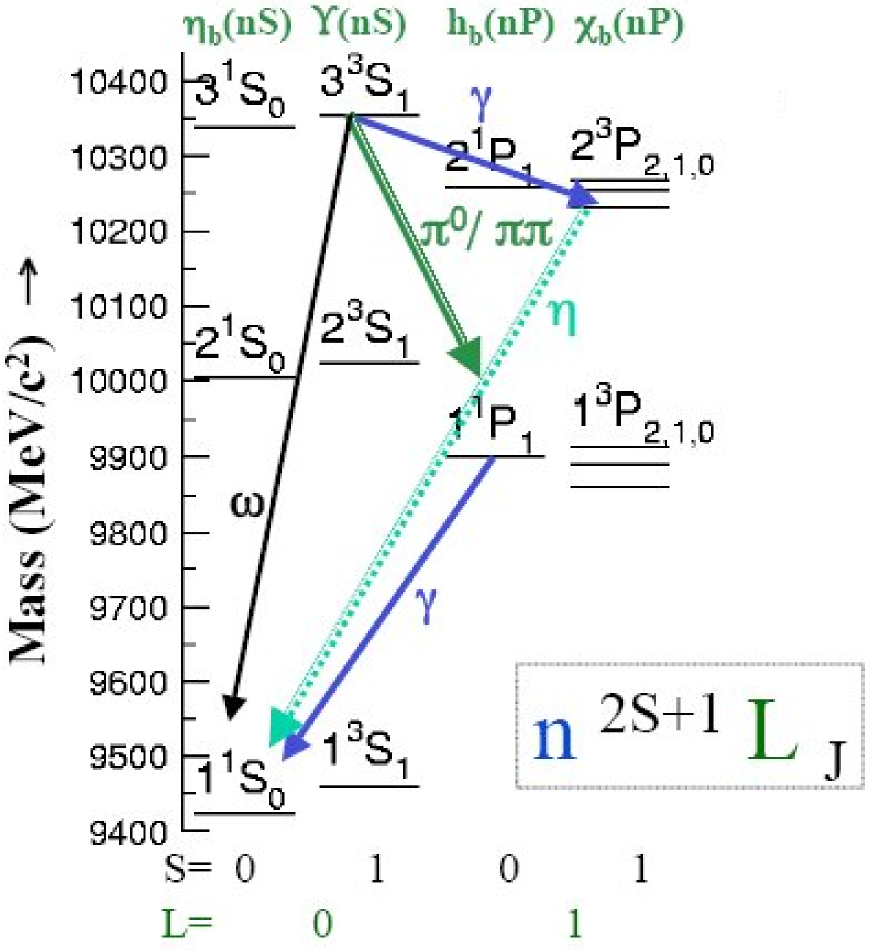
Возможные теоретические объяснения

- Large final state interactions [Belanger,DeGrand,Moxhay,PR,D39,257(89);Chakravarty,Kim,Ko,PR,D50,389(94)]
- σ-meson in $\pi\pi$ system [Komada,Ishida,Ishida,PL,B508,31(01);PL,B518,47(01);Uehara Prog.Theor.Phys.109,265(03)]
- Exotic $\Upsilon\pi$ resonance [Voloshin,JTEP Lett.,37,69(83);Belanger et al ,PR,D39,257(89); Anisovich,Bugg,Sarantsev,Zhou,PR,D51,4619(95); Guo,Shen,Chiang,Ping,NP,A761,269(05).]
- Ad hoc constant term in amplitude [Moxhay,PR,D39,3497(89)]
- Coupled channel effects [Lipkin,Thuan,PL,B206,349(88);Zhou,Kuang,PR,D44,756(91)]
- 3^3S_1-n^3D_1 mixing [Chakravarty,Kim,Ko,PR,D48,1212(93)]
- Relativistic corrections [Voloshin,PR,D74,054022(06)]

Необходима большая статистика данных и более детальный анализ

Где основное состояние боттомония η_b ?

Тест теории (высший приоритет группы по изучению боттомония (QWG))



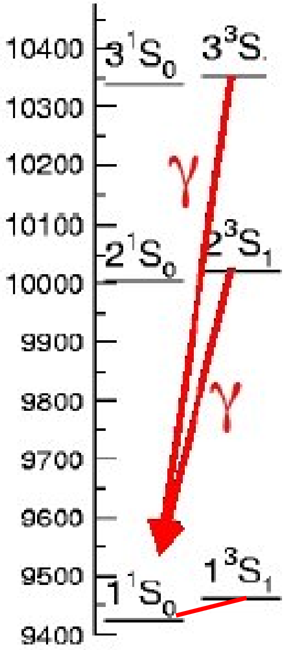
$$\Upsilon(3S) \to \gamma\chi_b(2P) \to \gamma(\eta\eta_b)$$

(Voloshin, Mod. Phys. Lett. A 19, 2895 (2004))

$$\Upsilon(3S) \to \pi^0 h_b, h_b \to \gamma\eta_b$$

(Godfrey, Rosner, PRD66, 014012 (2002))

Direct M1 transitions

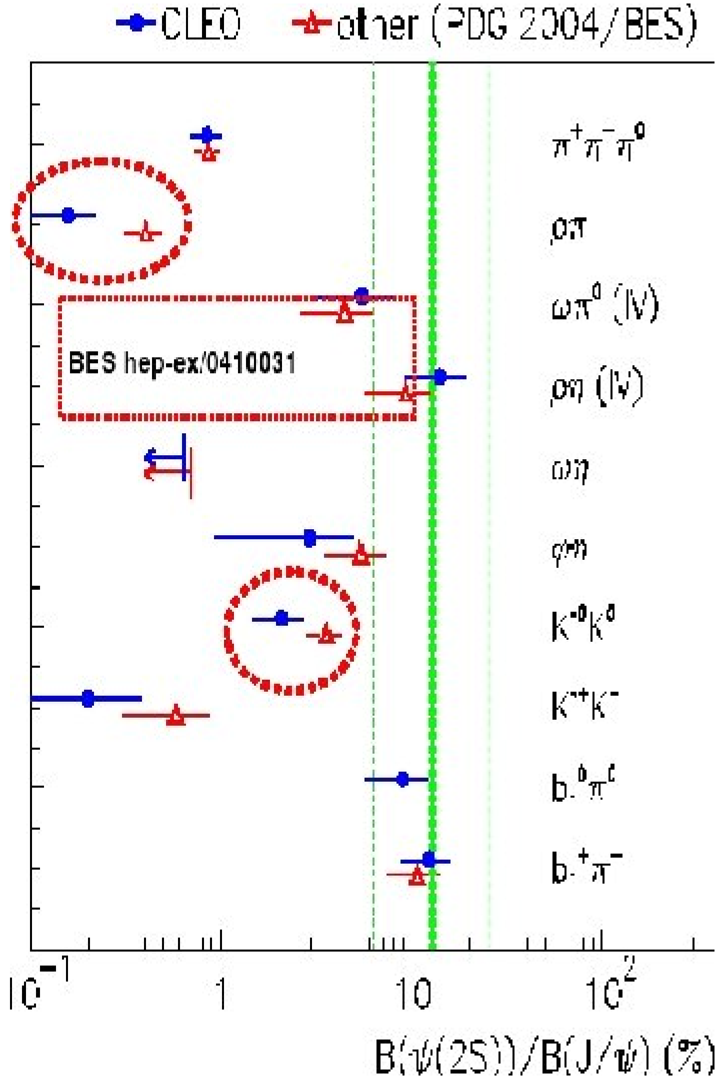


$$\Upsilon(1S,2S,3S) \to \gamma\eta_b$$

Тест pQCD в распадах Υ

Из pQCD → “12% rule”

$$Q_{\psi} = \frac{\mathcal{B}_{\psi(2S)\to h}}{\mathcal{B}_{J/\psi\to h}} = \frac{\mathcal{B}_{\psi(2S)\to e^+e^-}}{\mathcal{B}_{J/\psi\to e^+e^-}} \approx 12\% \ .$$



Нарушается в чармонии,
когда *h=Pseudoscalar +Vector.*

$$Q_{21} = \frac{\mathcal{B}_{\Upsilon(2S)\to h}}{\mathcal{B}_{\Upsilon(1S)\to h}} = \frac{\mathcal{B}_{\Upsilon(2S)\to e^+e^-}}{\mathcal{B}_{\Upsilon(1S)\to e^+e^-}} = 0.80 \pm 0.08,$$

$$Q_{31} = \frac{\mathcal{B}_{\Upsilon(3S)\to h}}{\mathcal{B}_{\Upsilon(1S)\to h}} = \frac{\mathcal{B}_{\Upsilon(3S)\to e^+e^-}}{\mathcal{B}_{\Upsilon(1S)\to e^+e^-}} = 1.14 \pm 0.15,$$

$$Q_{32} = \frac{\mathcal{B}_{\Upsilon(3S)\to h}}{\mathcal{B}_{\Upsilon(2S)\to h}} = \frac{\mathcal{B}_{\Upsilon(3S)\to e^+e^-}}{\mathcal{B}_{\Upsilon(2S)\to e^+e^-}} = 0.92 \pm 0.10.$$

Необходимо проверить аналогичное сотношение в боттомонии

Для проверки необходимо иметь ***N(Υ(1S) ~ N(Υ(2S) ~ N(Υ(3S)***

Боттомоний: поиск хиггсовского бозона

Next-to-Minimal Supersymmetric Model (NMSSM)

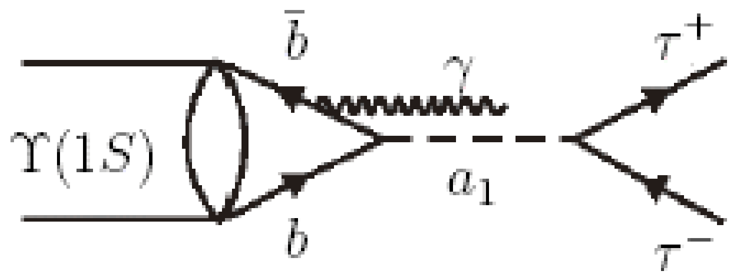
Данные LEP менее ограничивают массу хиггсовского бозона (*M_H~100 ГэВ*).
Возможно существование легкого хиггсовского бозона *a_1 ($m(a_1)$ <2m(b)).*
(R. Dermisek, J. Gunion, B. McElrath, hep-ph/0612031)

Основная мода распада $H \to a_1 a_1 \to (\tau^+\tau^-)(\tau^+\tau^-)$

$$e^+ e^- \to \Upsilon \to \gamma\, a_1 \to \gamma\, \tau^+ \tau^-$$

Распады боттомония могут использоваться для поиска a_1

Боттомоний: поиск хиггсовского бозона (2)



The best mode:

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

with

$$\sigma_{eff} = 179\,pb.$$

To limit

$$Br(\Upsilon(1S) \to \gamma a_1) \lesssim 10^{-6}$$

we need

$5.6 fb^{-1}/\epsilon$ collected on $\Upsilon(3S)$.

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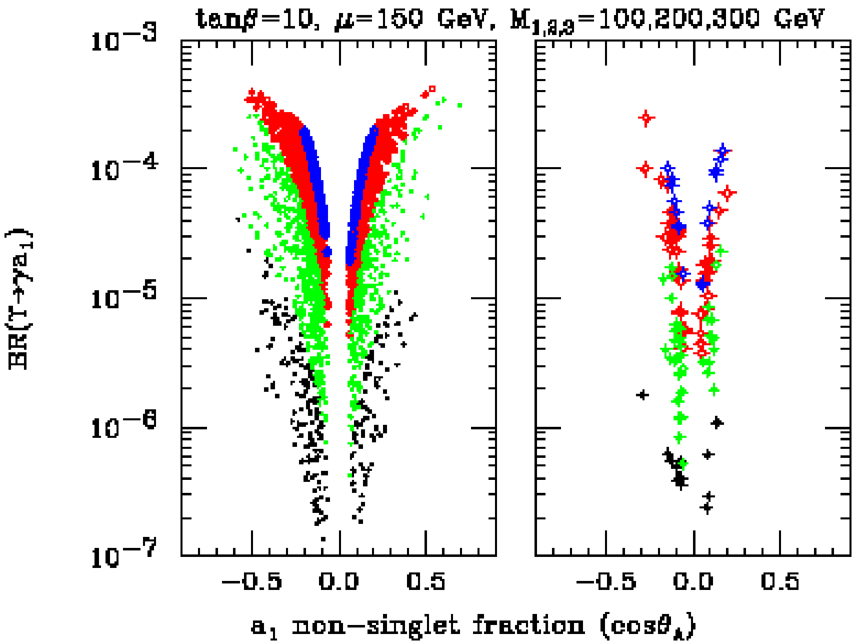


$A_\kappa, A_\lambda, \kappa, \lambda$ scan $\quad$ $F < 15$ scan

$m_{a_1} < 2m_\tau$

$2m_\tau < m_{a_1} < 7.5\,GeV$

$7.5\,GeV < m_{a_1} < 8.8\,GeV$

$8.8\,GeV < m_{a_1} < 9.2\,GeV$

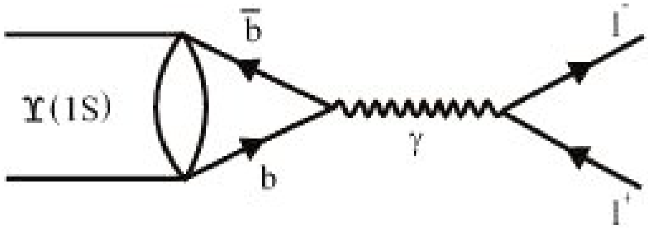
One motivation for BaBar's 30 fb^{-1} Y(3S) run.

Поиск монохроматического γ-кванта

Testing Lepton Universality

$$\mathrm{BF}(\Upsilon \to e^+e^-) = \mathrm{BF}(\Upsilon \to \mu^+\mu^-) = \mathrm{BF}(\Upsilon \to \tau^+\tau^-)$$

$$\Gamma_{ee} = \Gamma_{\mu\mu} = \Gamma_{\tau\tau}$$



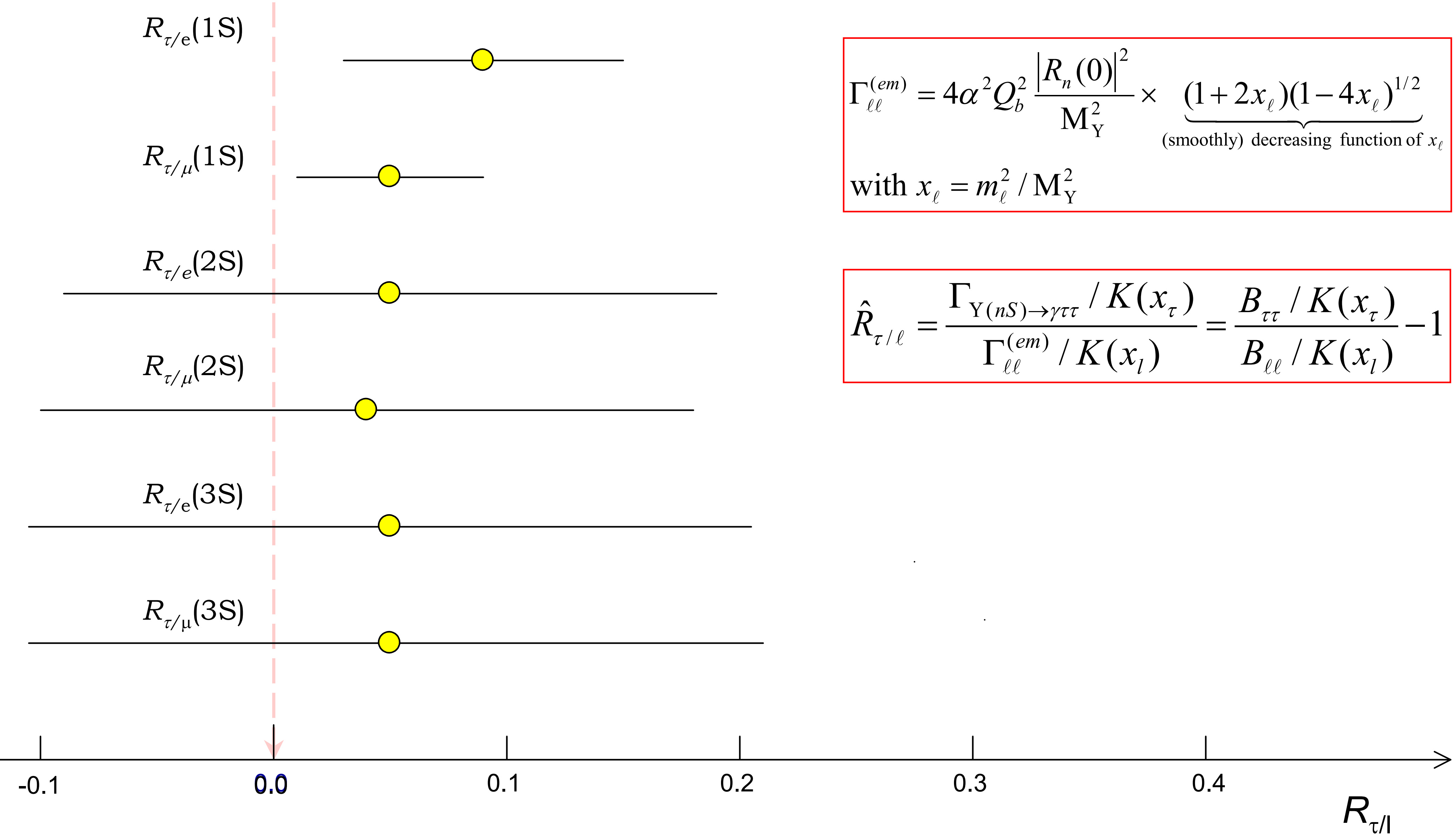
Channel: *	BF[e$^+$e$^-$]	BF[μ$^+$ μ$^-$]	BF[τ$^+$τ$^-$]	$R_{\tau/l}$
Υ(1S)	2.38 ± 0.11 %		2.60 ± 0.10 %	0.09 ± 0.06
Υ(1S)		2.48 ± 0.05 %	2.60 ± 0.10 %	0.05 ± 0.04
Υ(2S)	1.91 ± 0.16 %		2.00 ± 0.21 %	0.05 ± 0.14
Υ(2S)		1.93 ± 0.17 %	2.00 ± 0.21 %	0.04 ± 0.14
Υ(3S)	2.18 ± 0.20 %		2.29 ± 0.30 %	0.05 ± 0.16
Υ(3S)		2.18 ± 0.21 %	2.29 ± 0.30 %	0.05 ± 0.16

* From PDG ‘07

$$R_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma_s\tau\tau}}{\Gamma_{\ell\ell}^{(em)}} = \frac{B_{\tau\tau} - B_{\ell\ell}}{B_{\ell\ell}} = \frac{B_{\tau\tau}}{B_{\ell\ell}} - 1$$

Lepton Universality in Upsilon decays implies $\langle R_{\tau/l} \rangle = 0$

Lepton Universality Breaking?



$$\Gamma_{\ell\ell}^{(em)} = 4\alpha^2 Q_b^2 \frac{|R_n(0)|^2}{M_\Upsilon^2} \times \underbrace{(1+2x_\ell)(1-4x_\ell)^{1/2}}_{\text{(smoothly) decreasing function of } x_\ell}$$

with $x_\ell = m_\ell^2 / M_\Upsilon^2$

$$\hat{R}_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma\tau\tau} / K(x_\tau)}{\Gamma_{\ell\ell}^{(em)} / K(x_l)} = \frac{B_{\tau\tau} / K(x_\tau)}{B_{\ell\ell} / K(x_l)} - 1$$

Боттомоний: набранная статистика

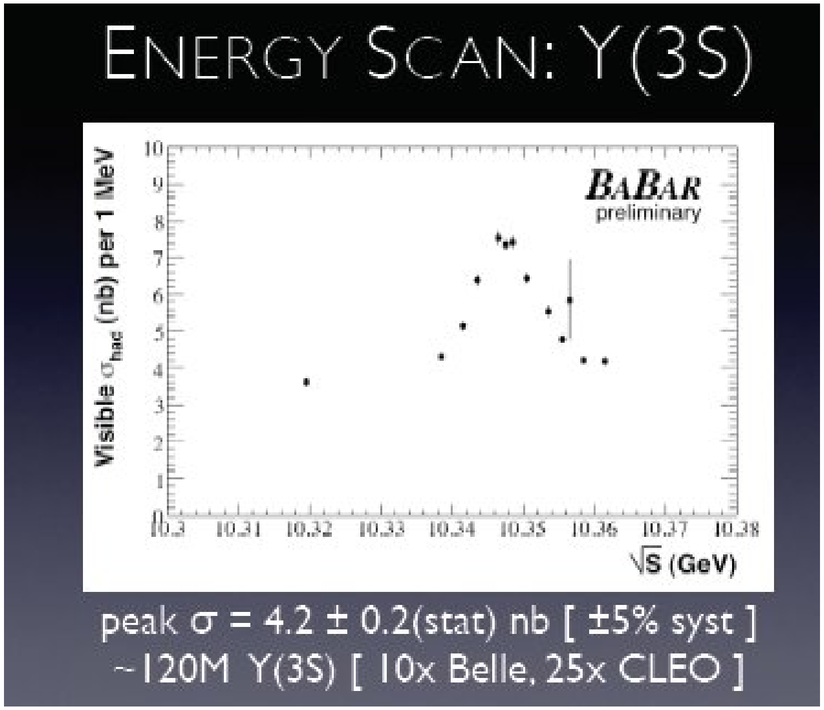
	CLEO-III		BaBar		Belle	
	$\mathcal{L}$ (fb^{-1})	N_{ev} 10^6	$\mathcal{L}$ (fb^{-1})	N_{ev} 10^6	$\mathcal{L}$ (fb^{-1})	N_{ev} 10^6
$\Upsilon(3S)$	**1.2(0.1)**	**6**	**30.3**	**120**	**2.9**	**11**
$\Upsilon(2S)$	**1.2(0.4)**	**9**	**14.4**	**100**	**-**	**-**
$\Upsilon(1S)$	**1.2(0.2)**	**21**	**-**	**-**	**5.7(1.7)**	**~100**

"***BaBar*** *has decided that they can optimize their science output by moving to the Upsilon 3S to generate a unique data set rather than only marginally adding to the existing Upsilon 4S data set. We started running on the Upsilon 3S just before Christmas. We will terminate B-factory operations at the beginning of March, after completing a run of approximately 30 inverse femtobarns on the Upsilon 3S resonance.*"

Persis Drell , All Hands Meeting , Jan.7, 2008

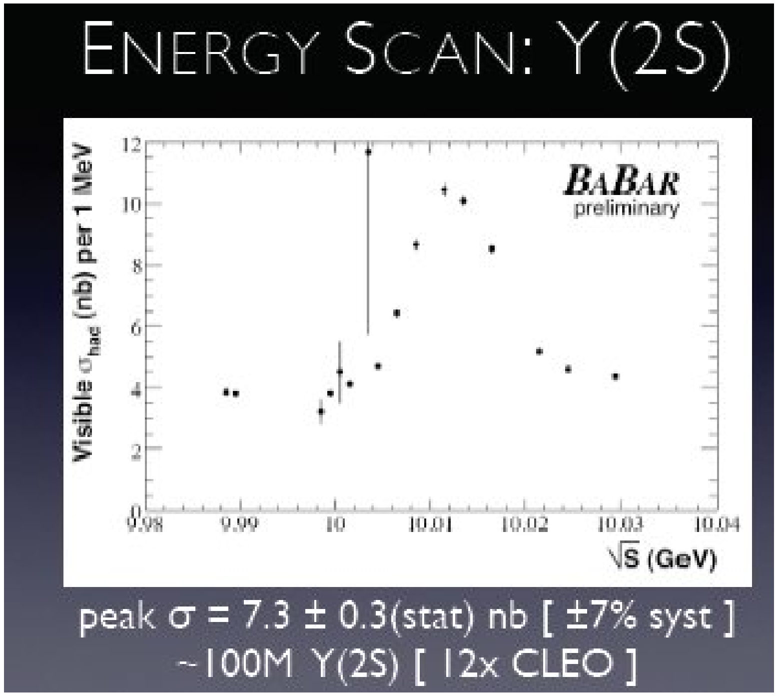
(http://today.slac.stanford.edu/feature/2008/All-Hands-010708.asp)

BaBar's final run



ENERGY SCAN: $\Upsilon(3S)$

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



ENERGY SCAN: $\Upsilon(2S)$

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

Expect compelling results on bottomonium from BaBar (and perhaps Belle) in the near future.

$\Upsilon(1S)$ Run at KEK

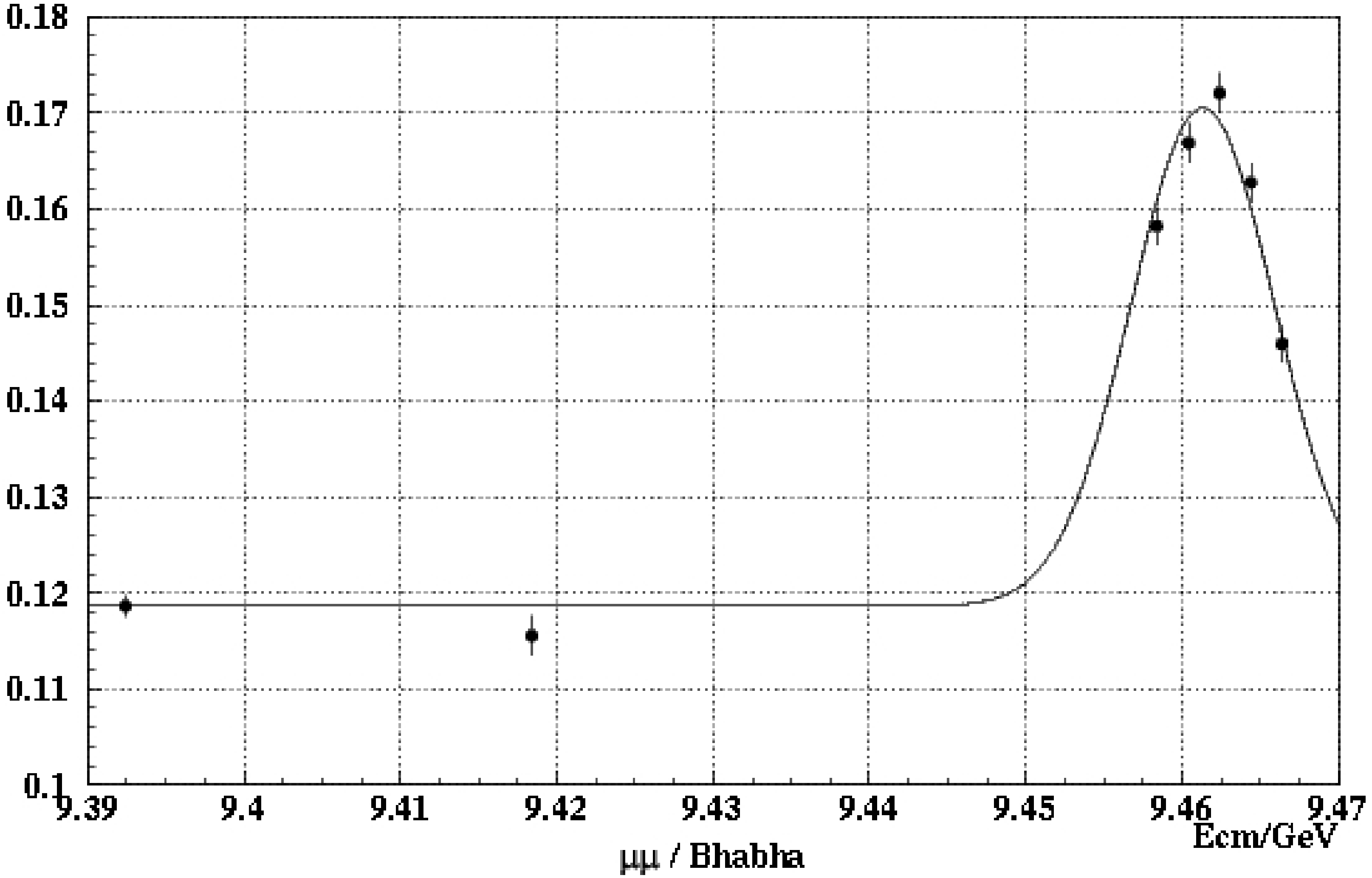
- study of pQCD rule in bottomonium decays
- search for η_b in $\Upsilon(1,2,3S)$ decays
- search for light Higgs a_1 in $\tau^+\tau^-$ decays
- search for H^0 dibaryon in $\Upsilon(1S)$ decays

	On Resonance (fb^{-1})	**Off Resonance (fb^{-1})**
Belle	5.7	1.7
CLEO	1.1	0.19

~5x CLEO data set, ~10x continuum;

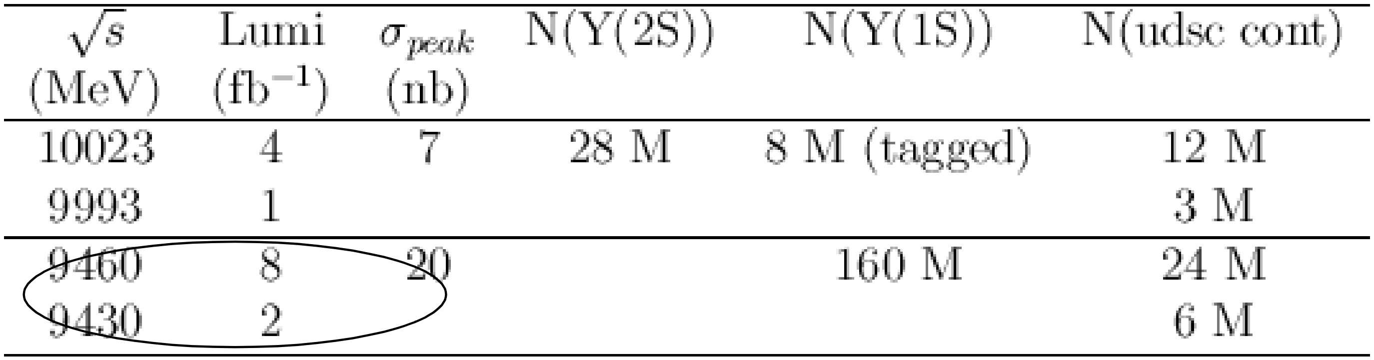
estimate ~100million $\Upsilon(1S)$ events.

Y(1S) Run: Estimate



Upsilon(1S,2S,3S) options

Original Plan before summer **(Belle)**



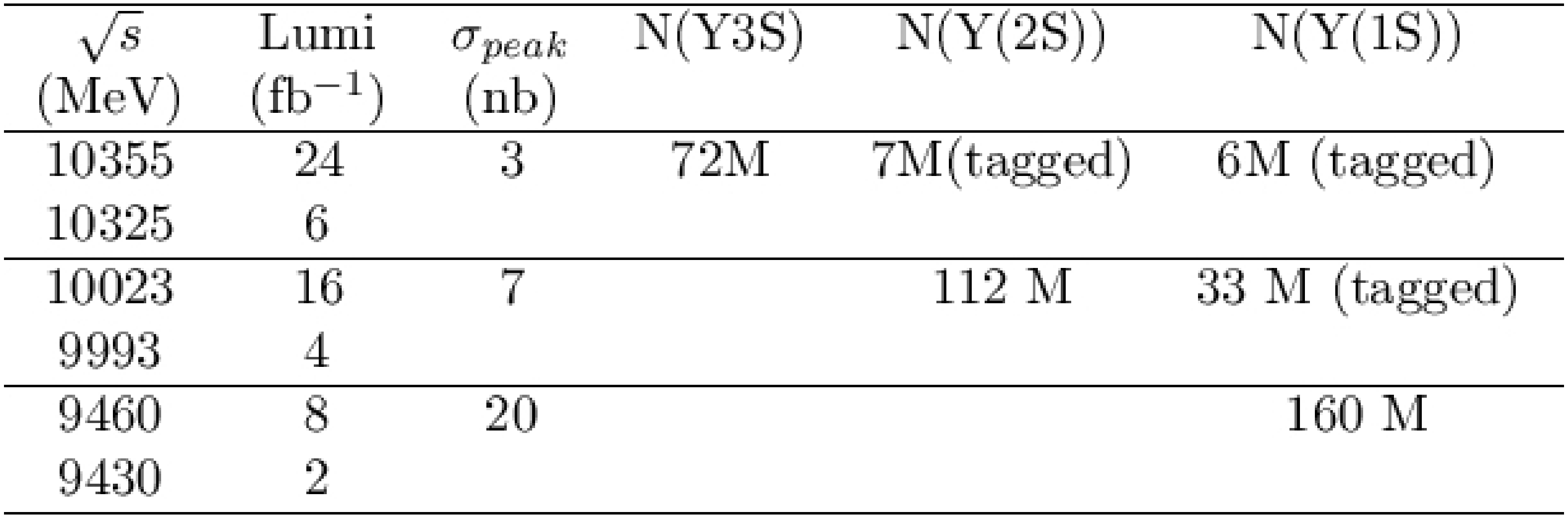
$\sqrt{s}$ (MeV)	Lumi (fb^{-1})	σ_{peak} (nb)	N(Y(2S))	N(Y(1S))	N(udsc cont)
10023	4	7	28 M	8 M (tagged)	12 M
9993	1				3 M
9460	8	20		160 M	24 M
9430	2				6 M

Actually recorded $5.7\ fb^{-1}$ on 1S,

$1.7\ fb^{-1}$ below 1S,

2S is recorded now

In 2008 - 2009:

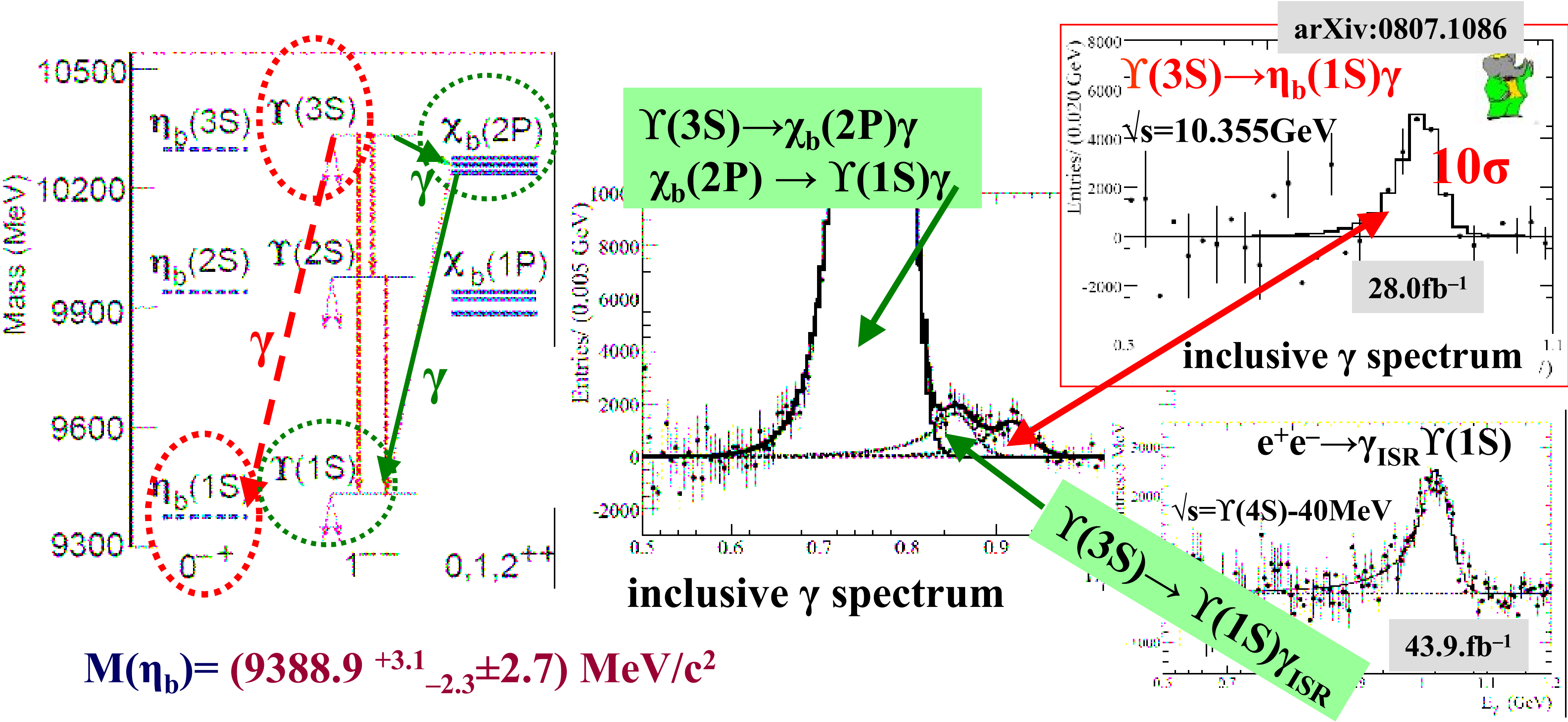


$\sqrt{s}$ (MeV)	Lumi (fb^{-1})	σ_{peak} (nb)	N(Y3S)	N(Y(2S))	N(Y(1S))
10355	24	3	72M	7M(tagged)	6M (tagged)
10325	6				
10023	16	7		112 M	33 M (tagged)
9993	4				
9460	8	20			160 M
9430	2				

May modify to aim for ~40 fb^-1 on the Upsilon(2S): better for eta_b search and 3 x BaBar sample

Последние результаты

Observation of $\Upsilon(3S) \rightarrow \eta_b(1S)\,\gamma$



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

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

Larger than potenail models predict
Agrees with lattice 61±14MeV (S.Godfrey and J.L.Rosner)

$B(\Upsilon(3S) \rightarrow \eta_b(1S)\gamma) = (4.8 \pm 0.5 \pm 1.2) \times 10^{-4}$

Summary

- Изучение переходов боттомониев
  $\Upsilon(4S) \rightarrow \Upsilon(1S, 2S)\pi^+\pi^-$, $\Upsilon(5S) \rightarrow \Upsilon(1S, 2S, 3S)\pi^+\pi^-(K^+K^-)$
  на B-фабриках (эксперименты Belle, BaBar) позволило получить новые интересные результаты.

- Набрана (набирается) новая статистика боттомониев $\Upsilon(1S)$, $\Upsilon(1S)$,$\Upsilon(3S)$ в экспериментах BaBar, Belle, на порядок превосходящая предыдущую.
  Ожидается получение новых результатов.

Backup

New τ skim

$N(\mu^+ \mu^-) = 4.8 \times 10^6$

HadronB, Exp.7÷49

HadronB & tau, Exp.51,55

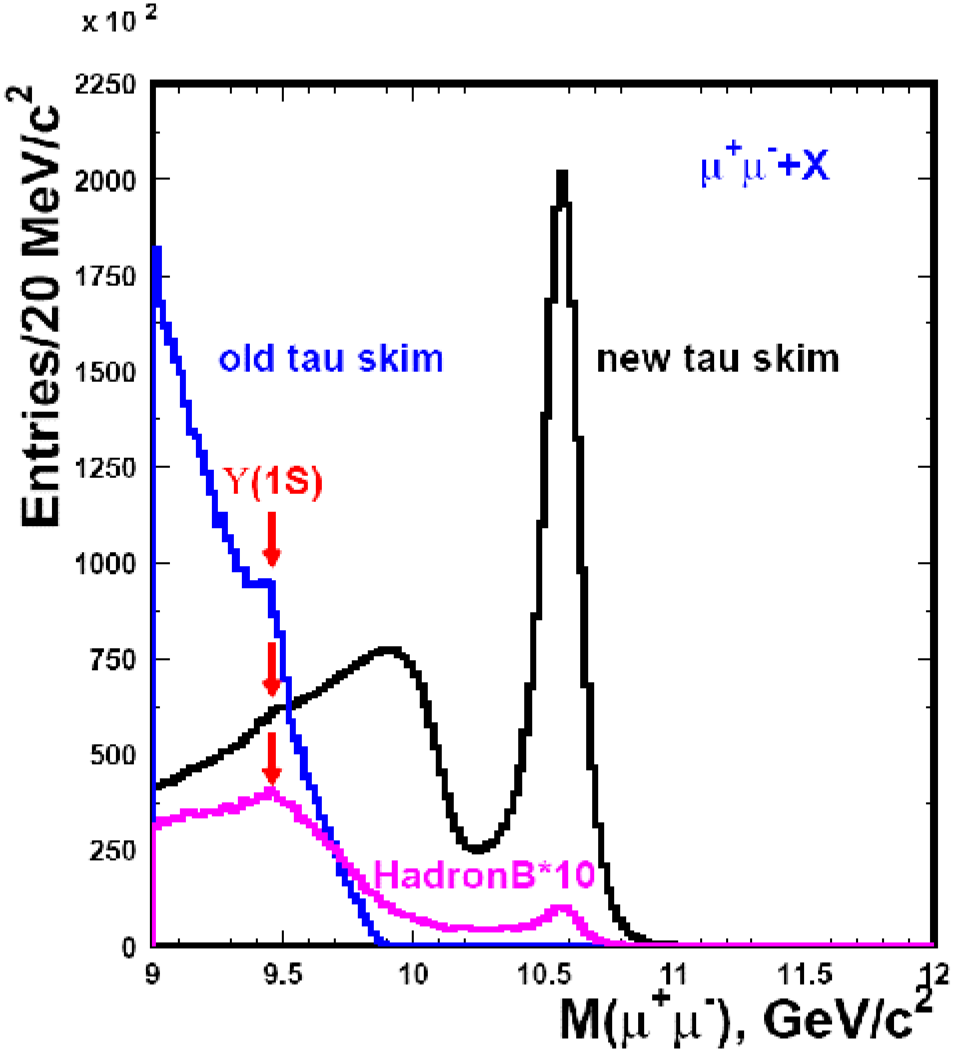
Important **old τ skim** (Exp. ≤ 49)
event selection criteria

$\Sigma|P(ch.tr.)| \leq 10$ GeV/c

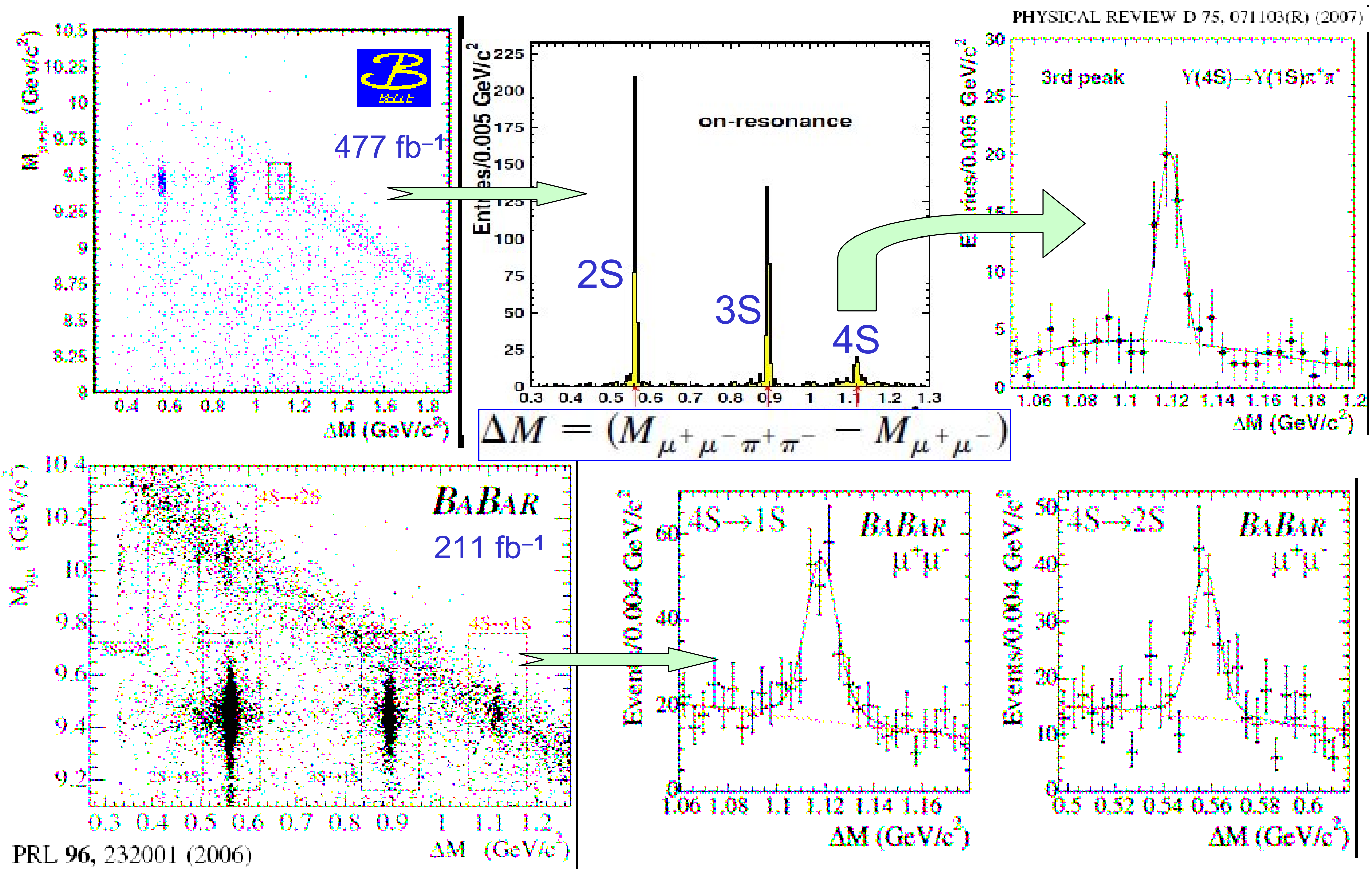
New τ skim (Exp. ≥ 51)

selection criteria
$\Sigma|P(ch.tr.)| \leq 10$ GeV/c

is removed



$\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ Template



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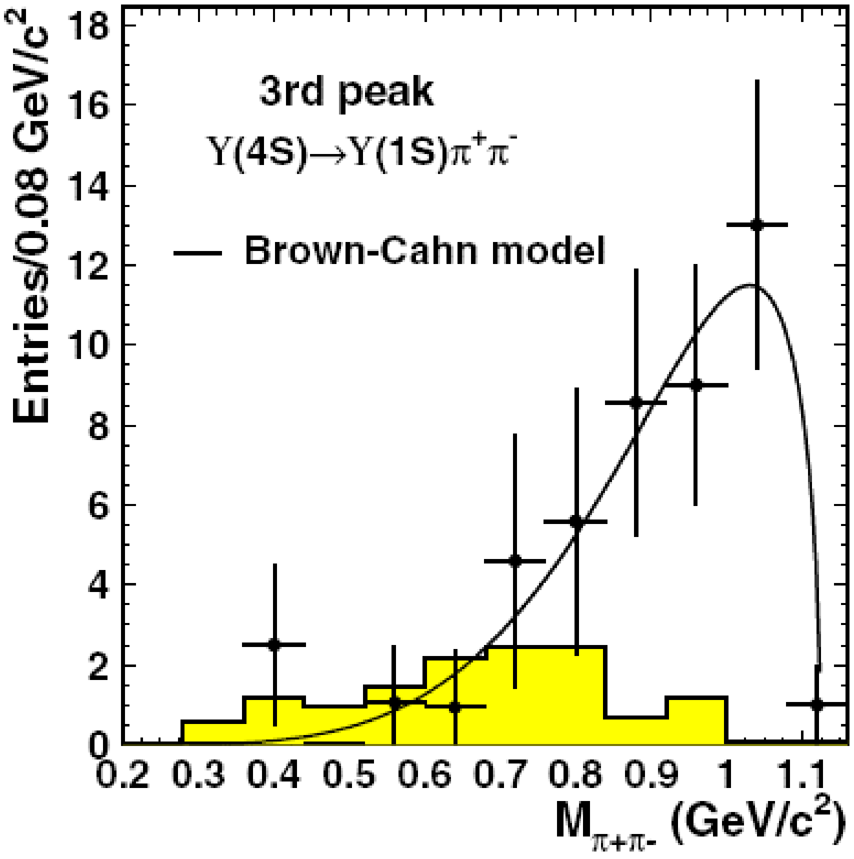
$$\Delta M = (M_{\mu^+\mu^-\pi^+\pi^-} - M_{\mu^+\mu^-})$$

PRL 96, 232001 (2006)

BaBar data for $\Upsilon(4S) \rightarrow \Upsilon(1S,2S)\ \pi^+\ \pi^-$

Belle data



PRD 071103 (R) 2007

Non-B
Bbar decay

BaBar data

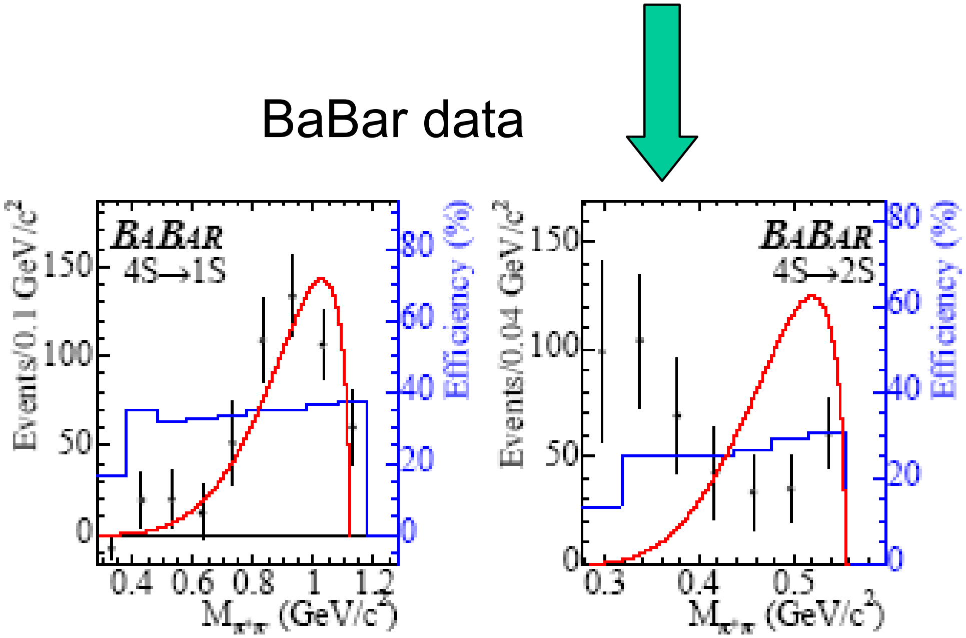


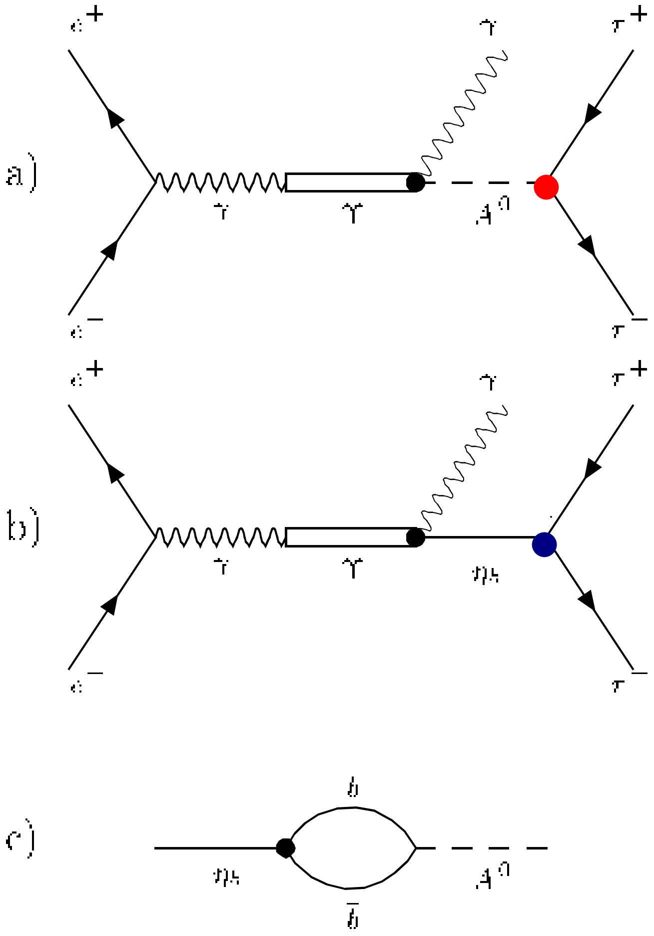
FIG. 3: The efficiency-corrected $M_{\pi^+\pi^-}$ distribution for $4S \rightarrow 1S$ transition (left) and $4S \rightarrow 2S$ transition (right). The solid line shows the distribution predicted in Ref. [2]. The dotted histogram shows the selection efficiency in each bin. The experimental resolution in $M_{\pi^+\pi^-}$ is less than 5 MeV/c^2, much smaller than the bin size.

PRL 96 (2006) 232001

$$\mathcal{B}\,(\Upsilon(4S) \rightarrow \pi^+\pi^-\Upsilon(1S)) = (0.90 \pm 0.15) \times 10^{-4},$$
$$\mathcal{B}\,(\Upsilon(4S) \rightarrow \pi^+\pi^-\Upsilon(2S)) = (1.29 \pm 0.32) \times 10^{-4},$$
$$\Gamma(\Upsilon(4S) \rightarrow \pi^+\pi^-\Upsilon(1S)) = (1.8 \pm 0.4)\ \mathrm{keV},$$

Mixing of a pseudoscalar Higgs A^0 and a η_b resonance

$e^+ e^- \rightarrow \Upsilon \rightarrow \gamma\, \tau^+ \tau^-$



$$\delta m^2 \approx \left(\frac{3m_{\eta_b}^3}{4\pi v^2}\right)^{1/2} |R_{\eta_b}(0)| \times X_d$$

$$\mathbf{M}^2 = \begin{pmatrix} m_{A_0}^2 - i m_{A_0}\Gamma_{A_0} & \delta m^2 \\ \delta m^2 & m_{\eta_{b0}}^2 - i m_{\eta_{b0}}\Gamma_{\eta_{b0}} \end{pmatrix}$$

$\sin 2\alpha \approx \delta m^2$

A_0^0 , η_{b0}
unmixed states

$$A^0 = \cos\alpha\ A_0^0 + \sin\alpha\ \eta_{bo}$$

$$\eta_b = \cos\alpha\ \eta_{b0} - \sin\alpha\ A_0^0$$

A^0 , η_b
mixed (physical)
states

$$g_{A^0\tau\tau} = \cos\alpha\ g_{A_0^0\tau\tau} + \sin\alpha\ \cancelto{0}{g_{\eta_{bo}\tau\tau}}$$

$$g_{\eta_b\tau\tau} = \cos\alpha\ \cancelto{0}{g_{\eta_{b0}\tau\tau}} - \sin\alpha\ g_{A_0^0\tau\tau}$$

$$\Gamma_{A^0} = |\cos\alpha|^2\ \Gamma_{A_0^0} + |\sin\alpha|^2\ \Gamma_{\eta_{bo}}$$

$$\Gamma_{\eta_b} = |\cos\alpha|^2\ \Gamma_{\eta_{b0}} + |\sin\alpha|^2\ \Gamma_{A_0^0}$$

$\mathbf{X_d = \cos\theta_A \tan\beta}$ $\longleftarrow$ Smaller coupling strength than in the MSSM

Proposal of testing lepton universality (to the percent level) @ a (Super) B factory

hep-ph/0610046

- With the machine sitting on the $\Upsilon(3S)$

Final state & BF

$\Upsilon(3S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S) \rightarrow \mu^+ \mu^-$ $\quad \pi^+ \pi^- \mu^+ \mu^-$

BF ~ 2-4 x 10^{-2} BF ~ 2 x 10^{-2} BF ~ 4 - 8 x 10^{-4}

$\Upsilon(3S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S) \rightarrow \tau^+ \tau^-$ $\quad \pi^+ \pi^- l^+ l^-$

BF ~ 10^{-1} $\tau^+ \tau^- \rightarrow l^+ l^- X, l = e, \mu$ BF ~ 5 - 10 x 10^{-5}

Compare rates

- $\Upsilon(3S) \rightarrow \mu^+ \mu^-$ $\quad \mu^+ \mu^-$

BF ~ 2 x 10^{-2} BF ~ 2 x 10^{-2}

$\Upsilon(3S) \rightarrow \tau^+ \tau^-$

$l^+ l^- X$

$\rightarrow l^+ l^- X, l = e,$

Compare rates

Statistical error ≈ 0.07 / √ # fb^{-1}

Systematic error ≤ 0.037

- With the machine sitting on the $\Upsilon(4S)$

$\Upsilon(4S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S) \rightarrow \mu^+ \mu^-$ $\quad \pi^+ \pi^- \mu^+ \mu^-$

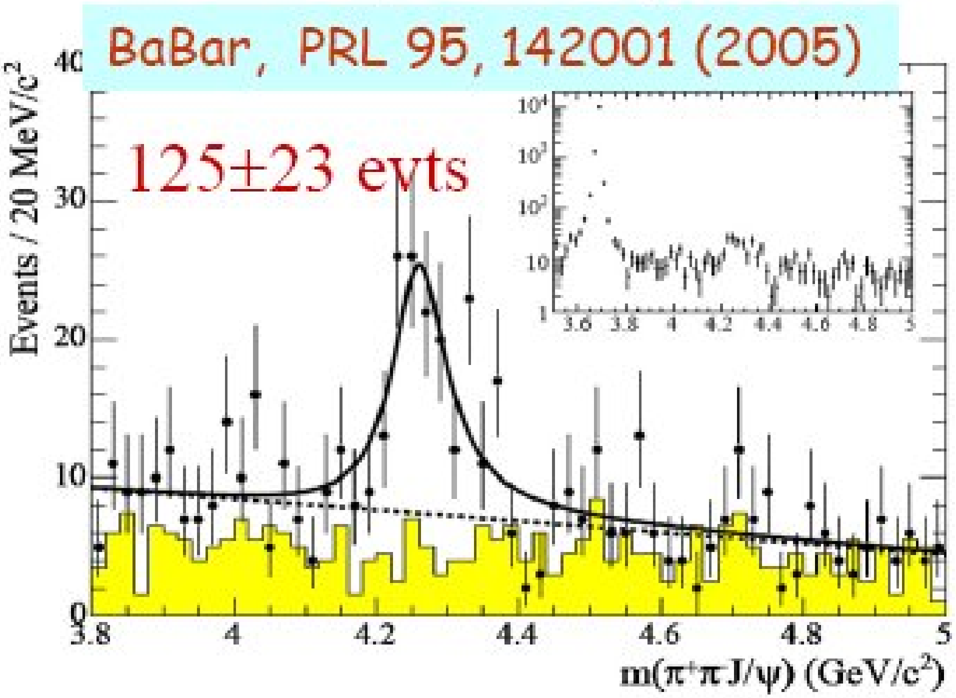
BF ~ 10^{-4} BF ~ 2 x 10^{-2} BF ~ 2 x 10^{-6}

$\Upsilon(4S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S) \rightarrow \tau^+ \tau^-$ $\quad \pi^+ \pi^- l^+ l^- X$

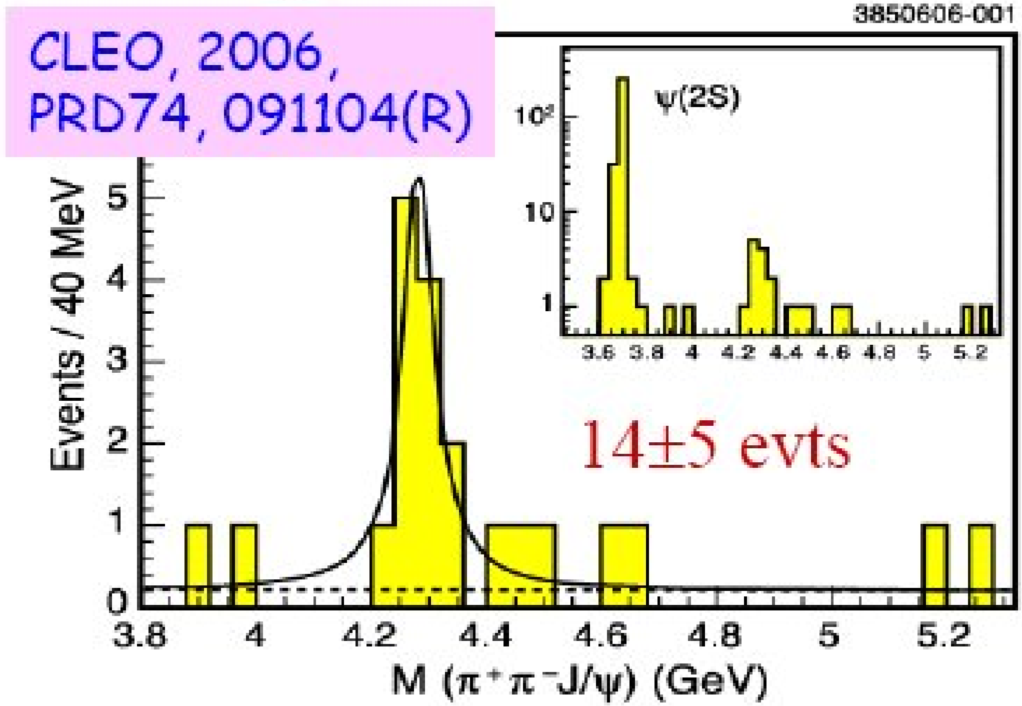
BF ~ 10^{-1} $\tau^+ \tau^- \rightarrow l^+ l^- X, l = e, \mu$ BF ~ 2 x 10^{-7}

Compare rates

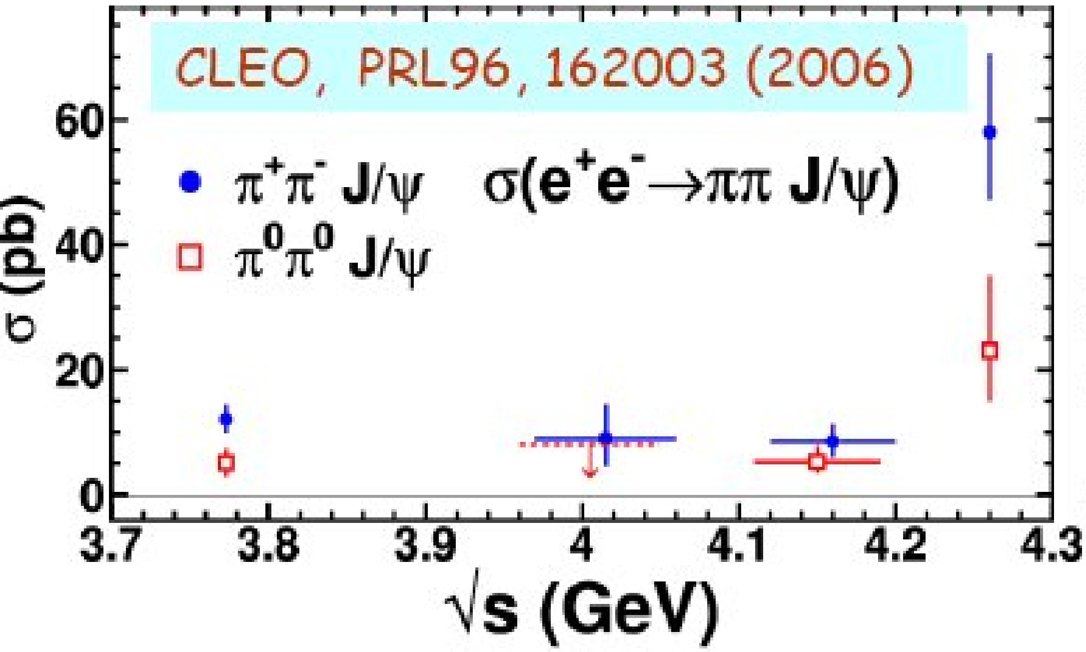
Y(4260) in other experiments



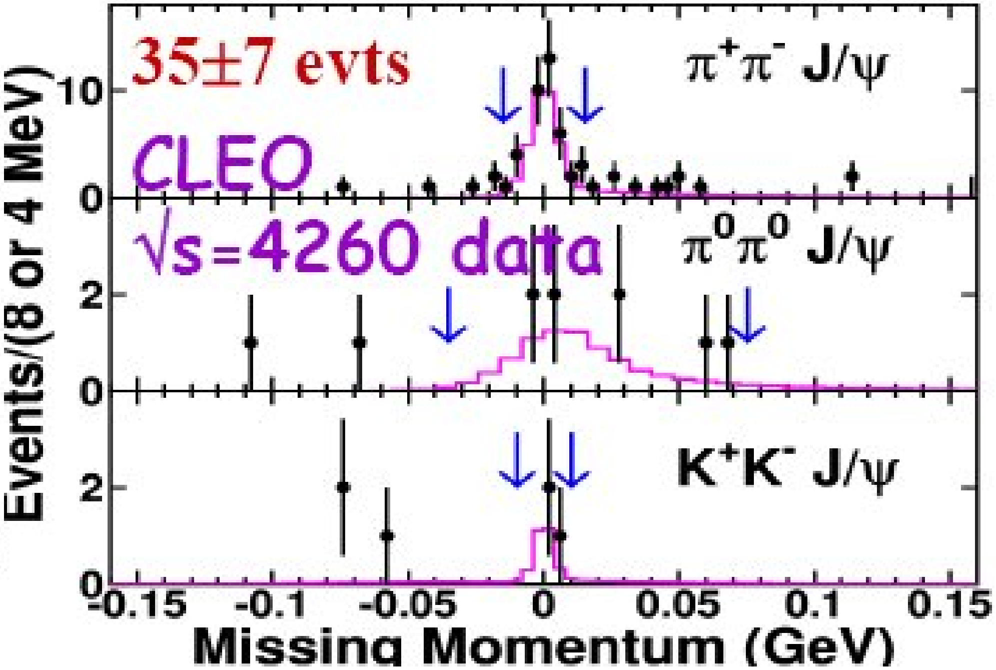
BaBar, PRL 95, 142001 (2005)



CLEO, 2006, PRD74, 091104(R)



CLEO, PRL96, 162003 (2006)



Y(4260) in other experiments

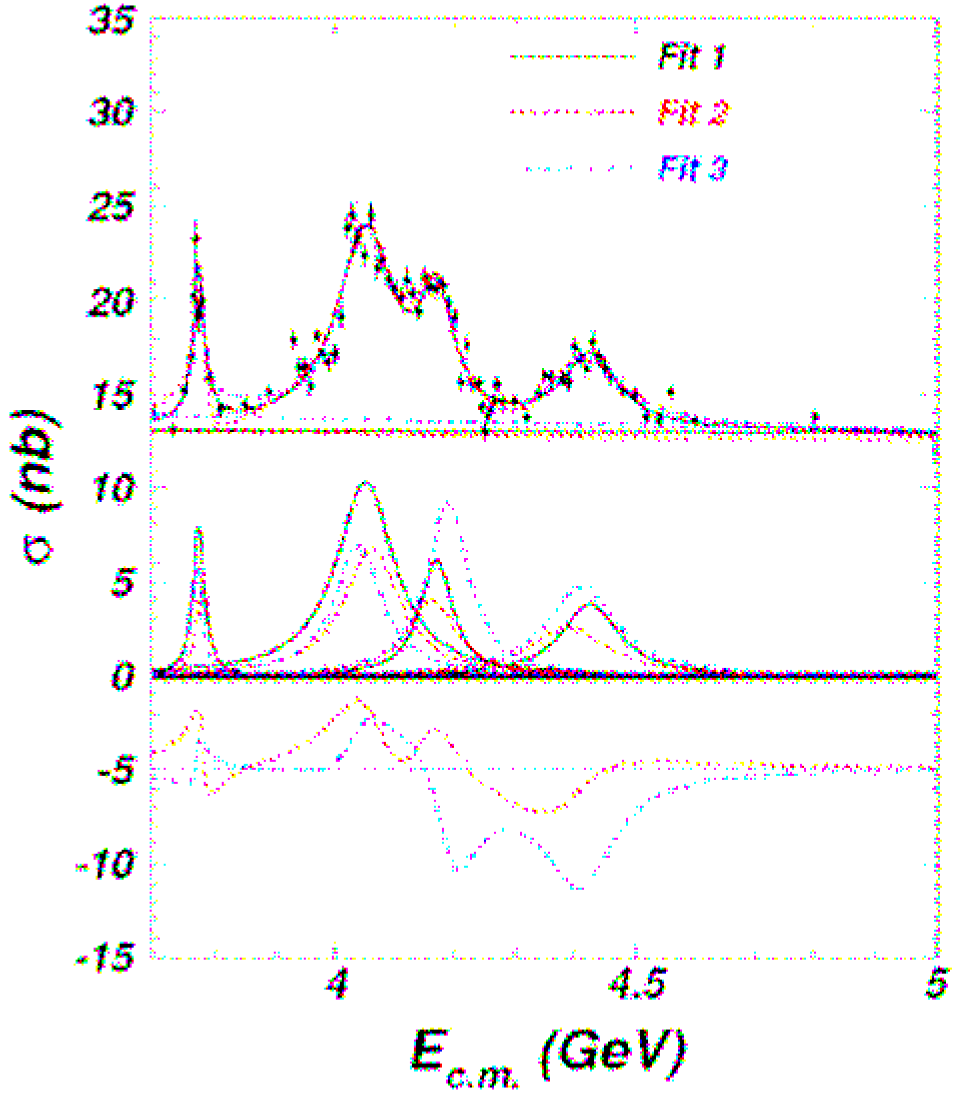
X.H. Mo et al, PLB **640**, 182 (2006)
Using R-values from BES experiment.
Γ_{ee}<580 eV @90% C.L.

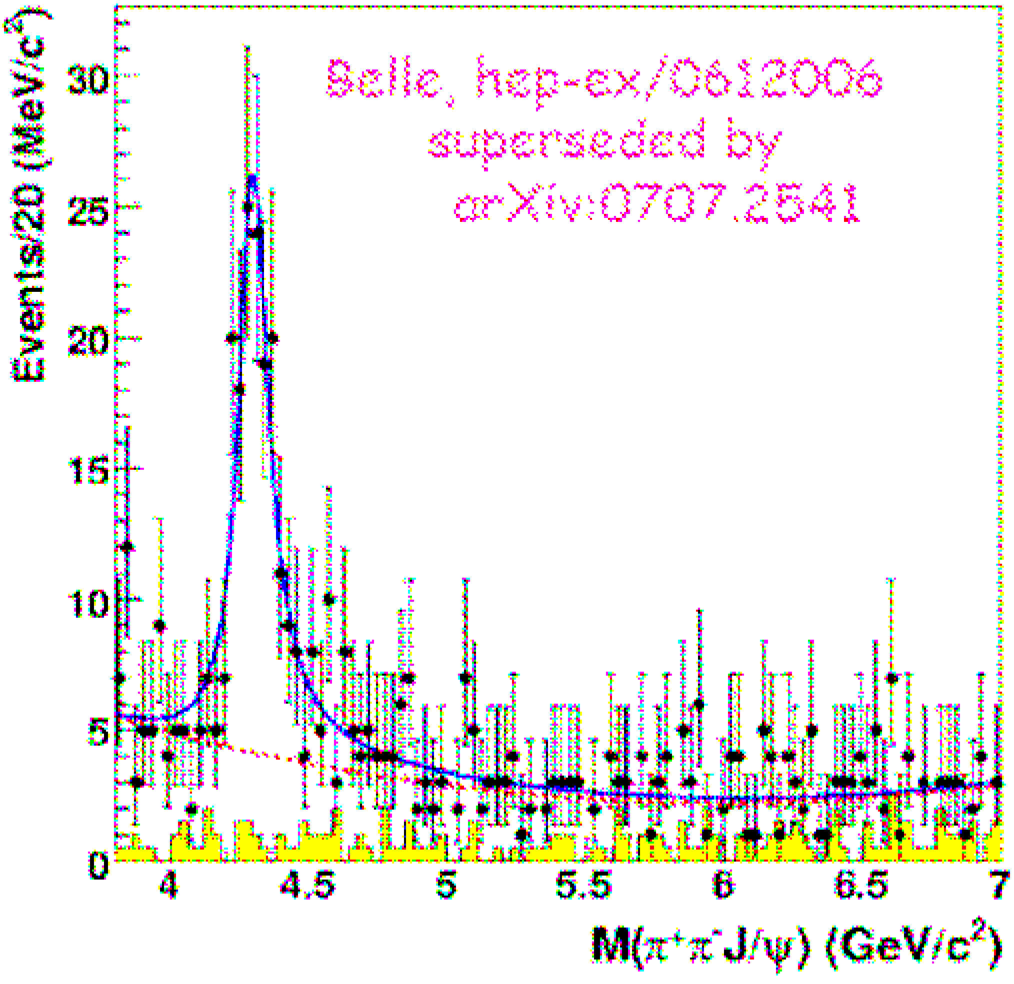
$N = 165 \pm 24$

$M = 4295 \pm 10^{+10}_{-5}$ MeV

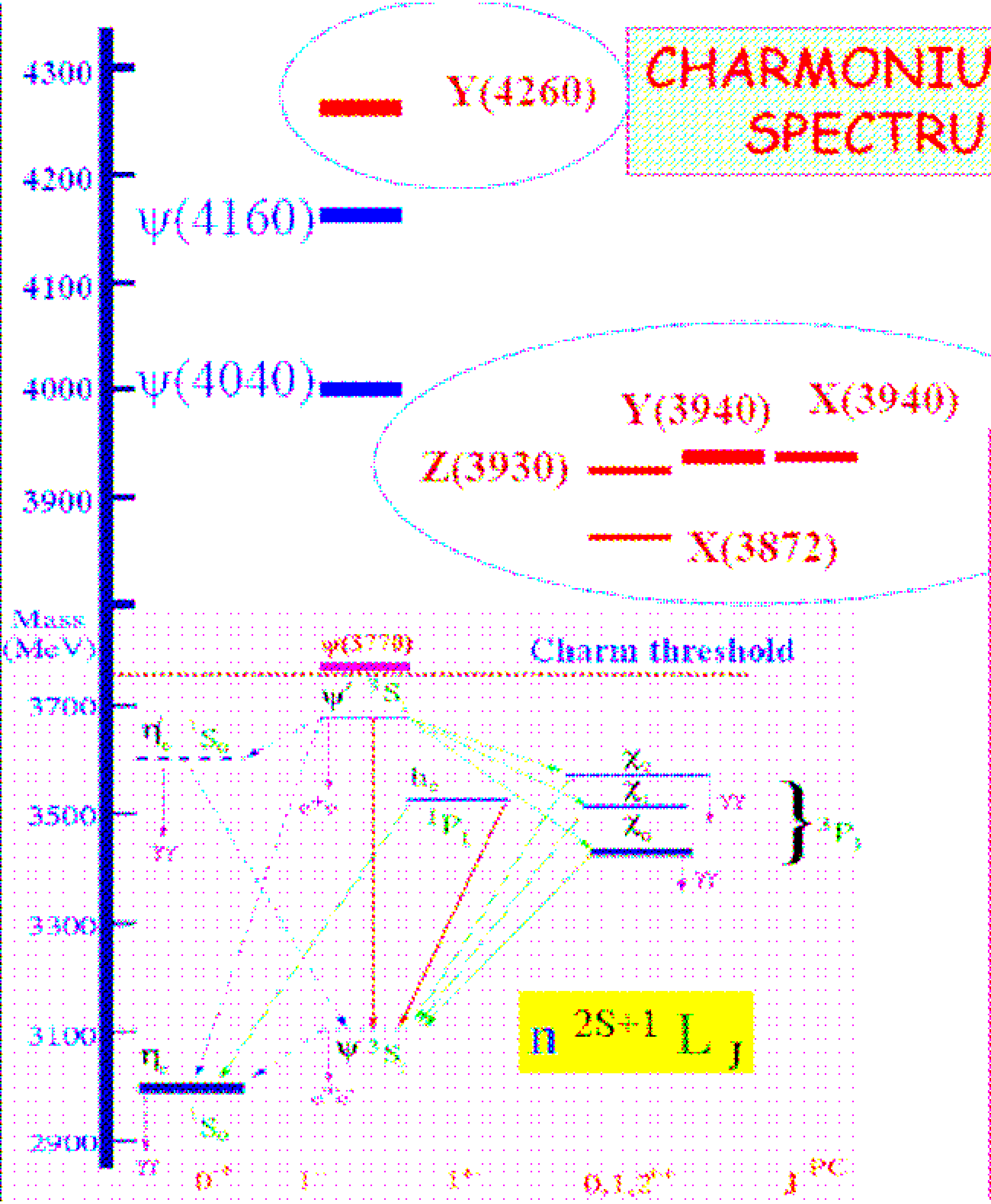
$\Gamma = 133 \pm 26^{+13}_{-6}$ MeV

$\Gamma_{ee} \cdot B(Y \to \pi^+\pi^- J/\psi) = 8.7 \pm 1.1^{+0.3}_{-0.9}$ eV




Belle, hep-ex/0612006
superseded by
arXiv:0707.2541

CHARMONIUM (?) SPECTRUM



Less known states:

- ψ(4040)
- ψ(4160)
- ψ(4415)

New states from B-factories:

- X(3872)=DD* (?)
- X(3940)=η_c(3S) (?)
- Y(3940)=?
- Z(3930)=χ_{c2}(2P)
- Y(4008)= ψ(3S) (?)
- X(4160)=χ_{c0}(3P) (?)
- Y(4260)=hybrid (?)
- Y(4324)/Y(4360)=?
- Z(4430)=tetraquark(?)
- Y(4660)= ψ(5S) (?)

New states every year!

What are they?

Charmonia? Exotic states?

New Measurements of Upsilon(3S) Branching Fractions (CLEO)

PRELIMINARY

Exclusive : $\mathcal{B}(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) = (4.46 \pm 0.06 \pm 0.11 \pm 0.13)\%$

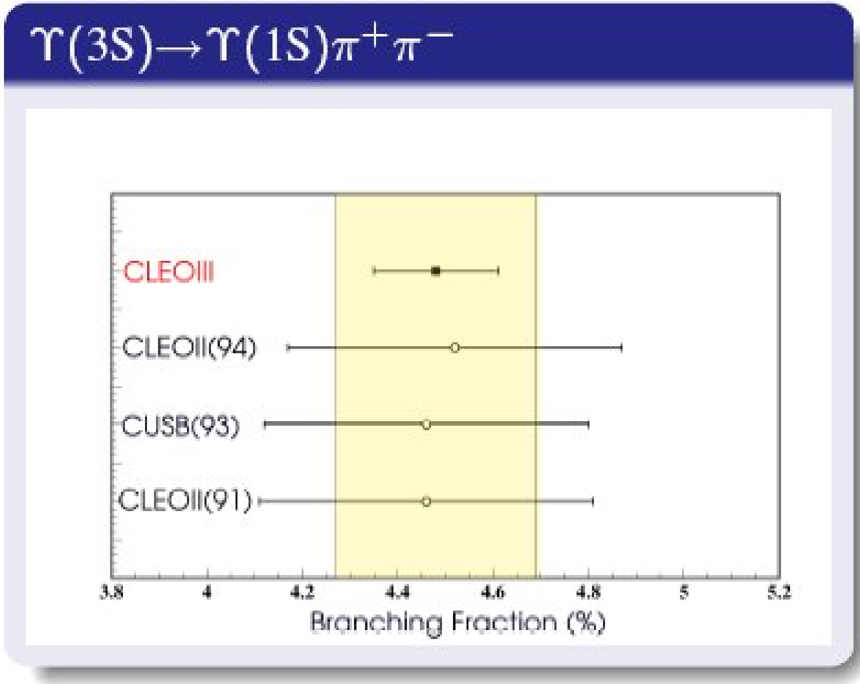
Inclusive : $\mathcal{B}(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) = (4.48 \pm 0.01 \pm 0.14)\%$

Average: $\mathcal{B}(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) = (4.48 \pm 0.13)\%$

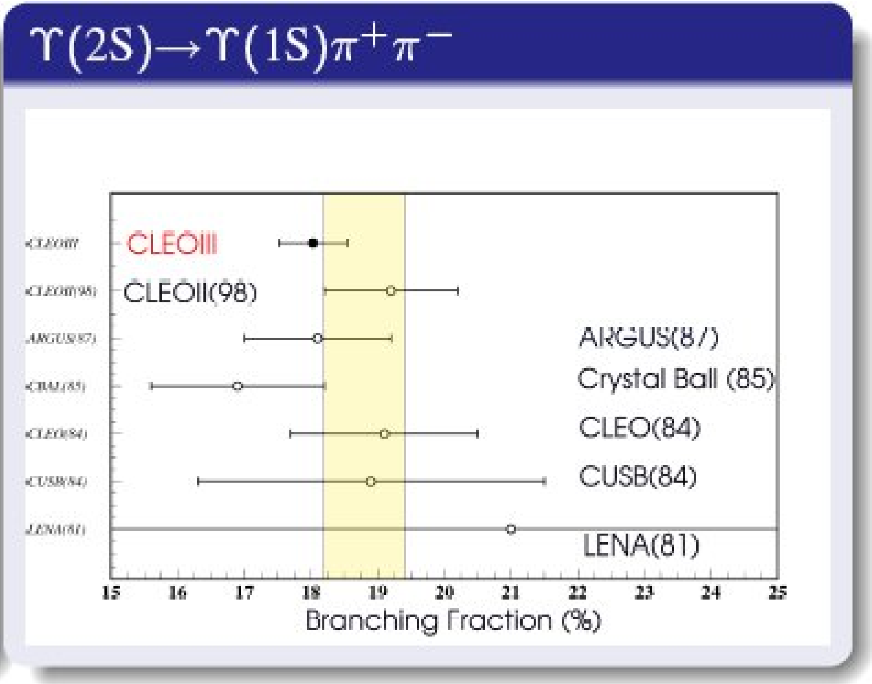
Exclusive: $\mathcal{B}(\Upsilon(2S)\to\Upsilon(1S)\pi^+\pi^-) = (18.22 \pm 0.11 \pm 0.76 \pm 0.53)\%$

Inclusive: $\mathcal{B}(\Upsilon(2S)\to\Upsilon(1S)\pi^+\pi^-) = (18.03 \pm 0.02 \pm 0.59)\%$

Average: $\mathcal{B}(\Upsilon(2S)\to\Upsilon(1S)\pi^+\pi^-) = (18.03 \pm 0.51)\%$



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



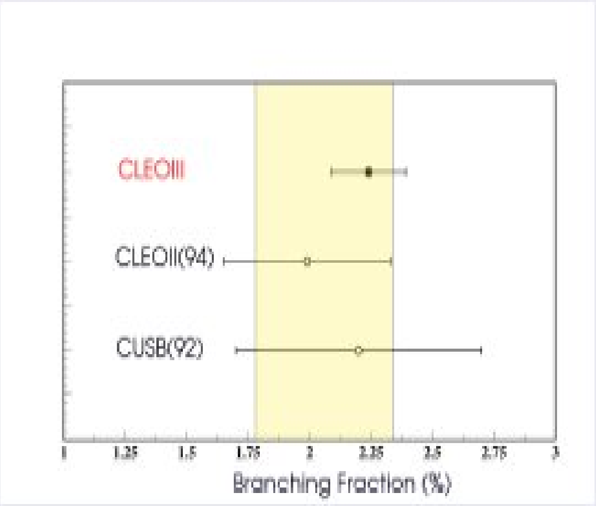
$\Upsilon(2S)\to\Upsilon(1S)\pi^+\pi^-$

New Measurements of Upsilon(3S) Branching Fractions (CLEO)

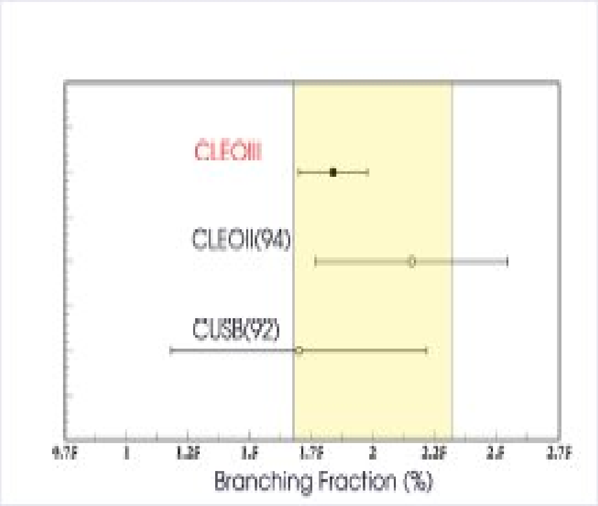
PRELIMINARY

$$\mathcal{B}(\Upsilon(3S)\rightarrow\Upsilon(1S)\pi^0\pi^0) = (2.24 \pm 0.09 \pm 0.11 \pm 0.06)\%$$
$$\mathcal{B}(\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^0\pi^0) = (8.41 \pm 0.16 \pm 0.46 \pm 0.24)\%$$
$$\mathcal{B}(\Upsilon(3S)\rightarrow\Upsilon(2S)\pi^0\pi^0) = (1.84 \pm 0.09 \pm 0.08 \pm 0.07)\%$$

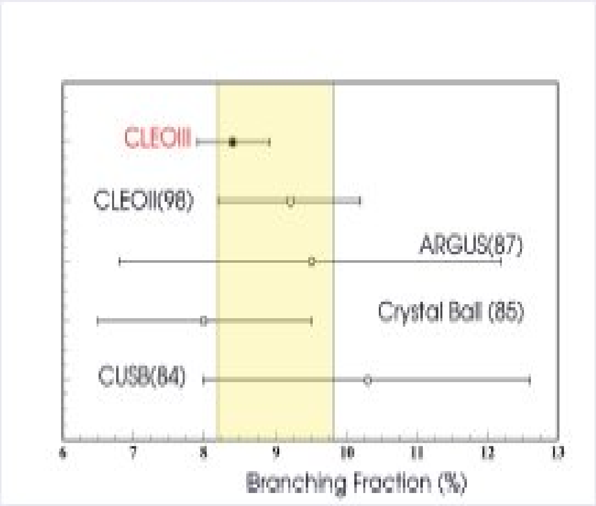
$\Upsilon(3S)\rightarrow\Upsilon(1S)\pi^0\pi^0$



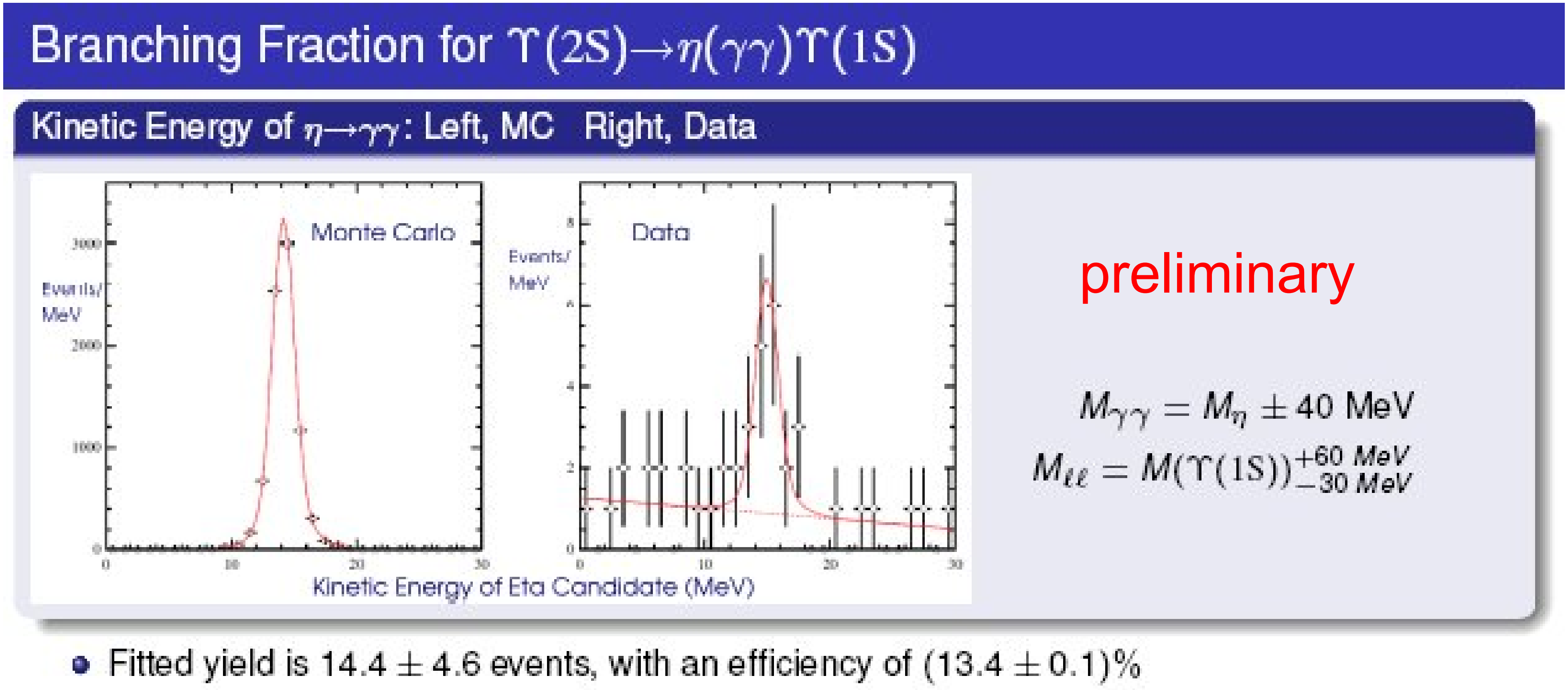
$\Upsilon(3S)\rightarrow\Upsilon(2S)\pi^0\pi^0$



$\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^0\pi^0$



CLEO's first evidence for Υ(2S)→Υ(1S) η



Branching Fraction for $\Upsilon(2S)\to\eta(\gamma\gamma)\Upsilon(1S)$

Kinetic Energy of $\eta\to\gamma\gamma$: Left, MC Right, Data

preliminary

$$M_{\gamma\gamma} = M_\eta \pm 40\text{ MeV}$$

$$M_{\ell\ell} = M(\Upsilon(1S))^{+60\text{ MeV}}_{-30\text{ MeV}}$$

- Fitted yield is 14.4 ± 4.6 events, with an efficiency of $(13.4 \pm 0.1)\%$

$$BF(\Upsilon(2S)\to\Upsilon(1S)\eta) = (2.31 \pm 0.74)\times 10^{-4}$$

4.6σ

One candidate is found,

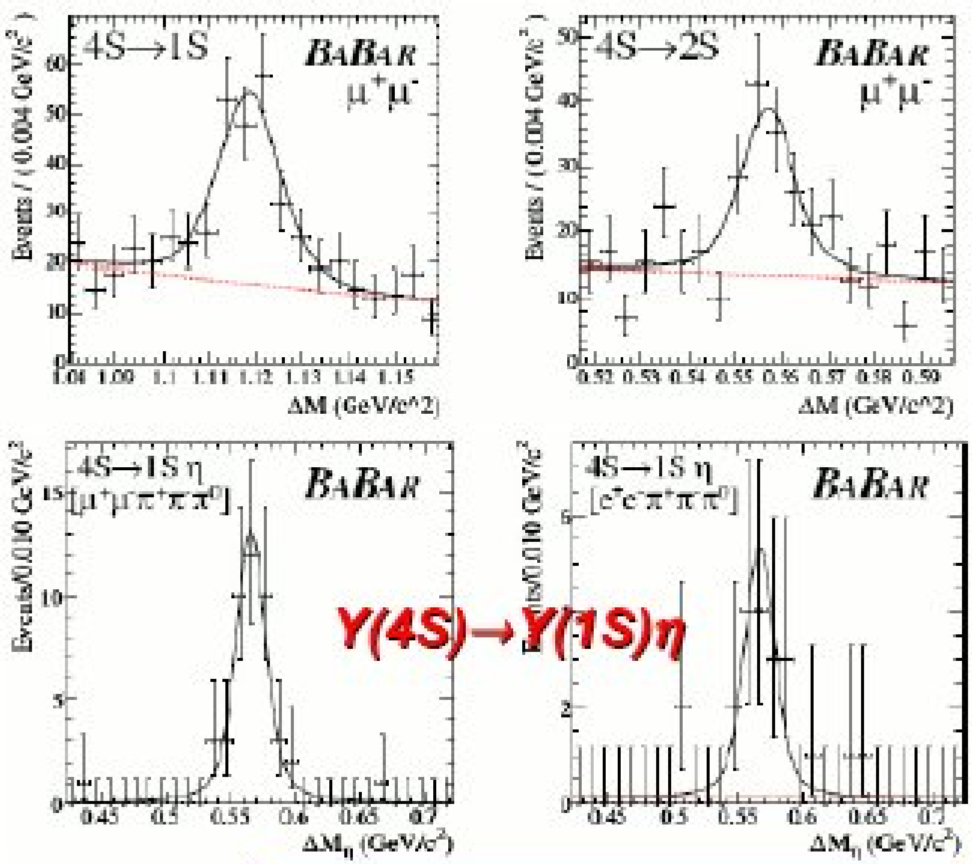
$$BF(\Upsilon(2S)\to\Upsilon(1S)\pi^0) < 1.6\times 10^{-4}$$

Expect this is 16% of the η mode

BaBar discovers Y(4S)→Y(1S)η

- Transitions: **$Y(4S) \to Y(2S)\pi^+\pi^-$**
  $Y(4S) \to Y(1S)\pi^+\pi^-$

These are examples of non-B Bbar decays that have been observed by BaBar and Belle.



$Y(4S) \to Y(1S)\eta$

$B_{4S\to 2S} = (1.29 \pm 0.32)\times 10^{-4}$
$\Gamma_{4S\to 2S} = (2.7 \pm 0.8)$ keV

$B_{4S\to 1S} = (0.90 \pm 0.15)\times 10^{-4}$
$\Gamma_{4S\to 1S} = (1.8 \pm 0.4)$ keV

$B_{4S\to 1S\eta} = (1.96 \pm 0.060.09)\times 10^{-4}$

preliminary

Unexpected result:

$$\frac{\Gamma_{4S\to 1S\eta}}{\Gamma_{4S\to 1S\pi\pi}} = 2.41 \pm 0.40 \pm 0.12$$

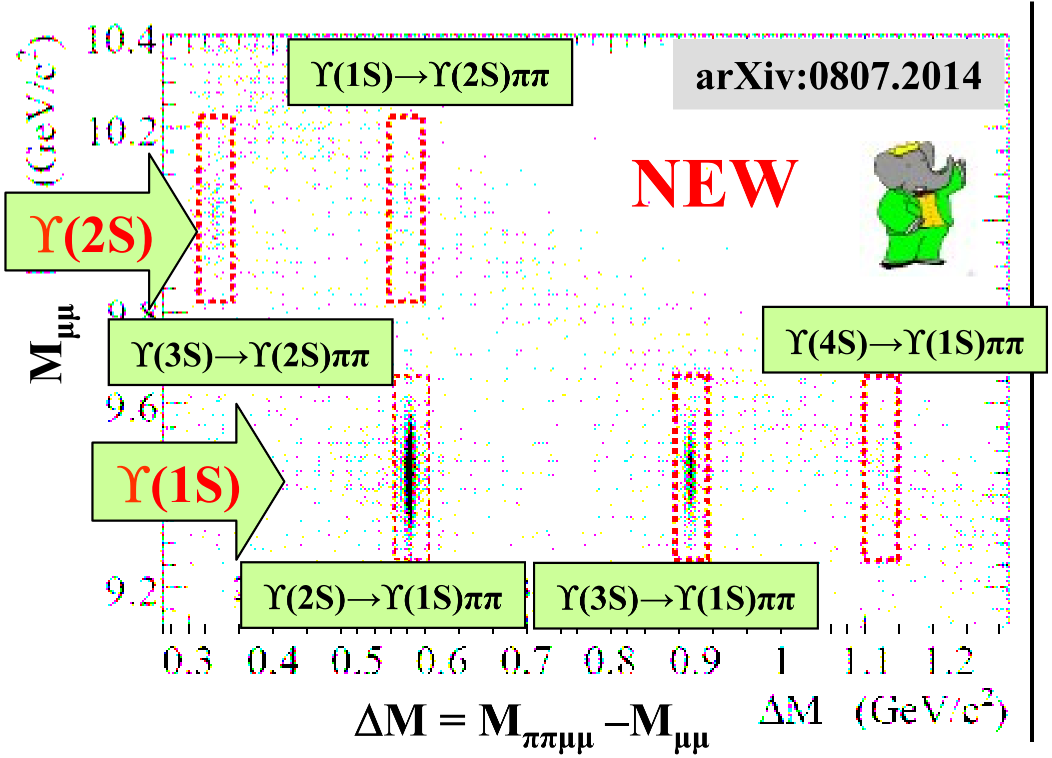
E1M2/
E1E1

$$\frac{\Gamma(\Upsilon(2S)\to\Upsilon(1S)\eta)}{\Gamma(\Upsilon(2S)\to\Upsilon(1S)\pi^+\pi^-)} = (1.3 \pm 0.5)\times 10^{-3}$$

Hadronic transition between Υ states

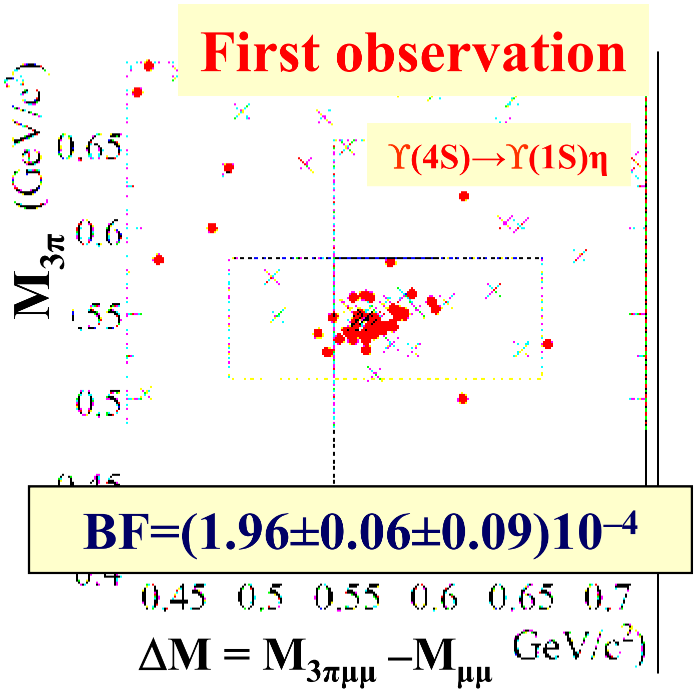
Υ(mS)→Υ(nS) $\pi^+\pi$

Υ(nS)→l^+l^- l^+l^- =$\mu^+\mu^-$,e^+e^-



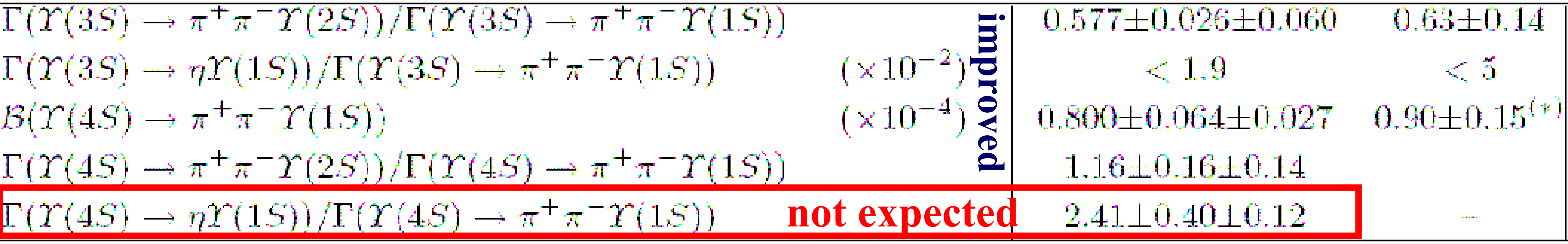
arXiv:0807.2014

Υ(mS)→Υ(nS)η, η → $\pi^+\pi^-\pi^0$



First observation

BF=(1.96±0.06±0.09)10^{-4}



				PDG
$\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S))/\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$		improved	$0.577\pm0.026\pm0.060$	0.63 ± 0.14
$\Gamma(\Upsilon(3S) \to \eta\Upsilon(1S))/\Gamma(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$	$(\times10^{-2})$		< 1.9	< 5
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$	$(\times10^{-4})$		$0.800\pm0.064\pm0.027$	$0.90\pm0.15^{(*)}$
$\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S))/\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$			$1.16\pm0.16\pm0.14$	
$\Gamma(\Upsilon(4S) \to \eta\Upsilon(1S))/\Gamma(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$	not expected		$2.41\pm0.40\pm0.12$	–

CLEO has looked for $\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$ inclusively.

No signals were seen, set ULs @ 90% C.L. (PRL94,032001(2005))

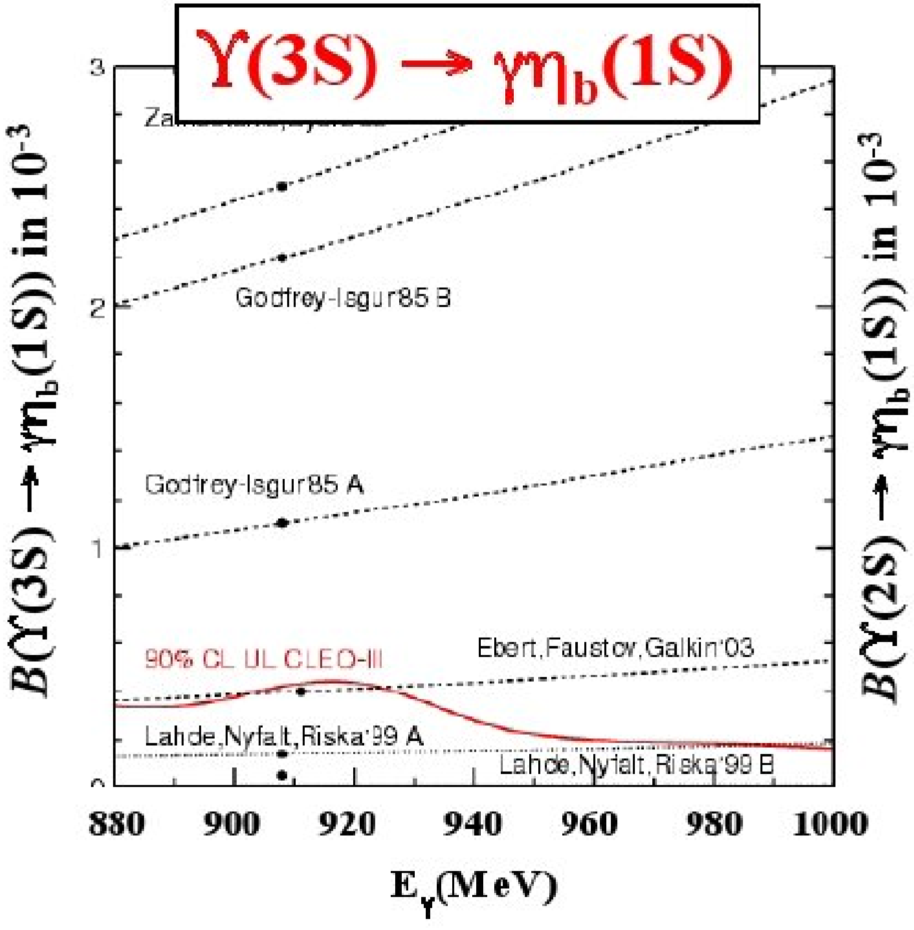
→ $\mathcal{B}(\Upsilon(2S) \rightarrow \eta_b(1S)\,\gamma) < 5.1\times10^{-4}$

$\mathcal{B}(\Upsilon(3S) \rightarrow \eta_b(1S)\,\gamma) < 4.3\times10^{-4}$

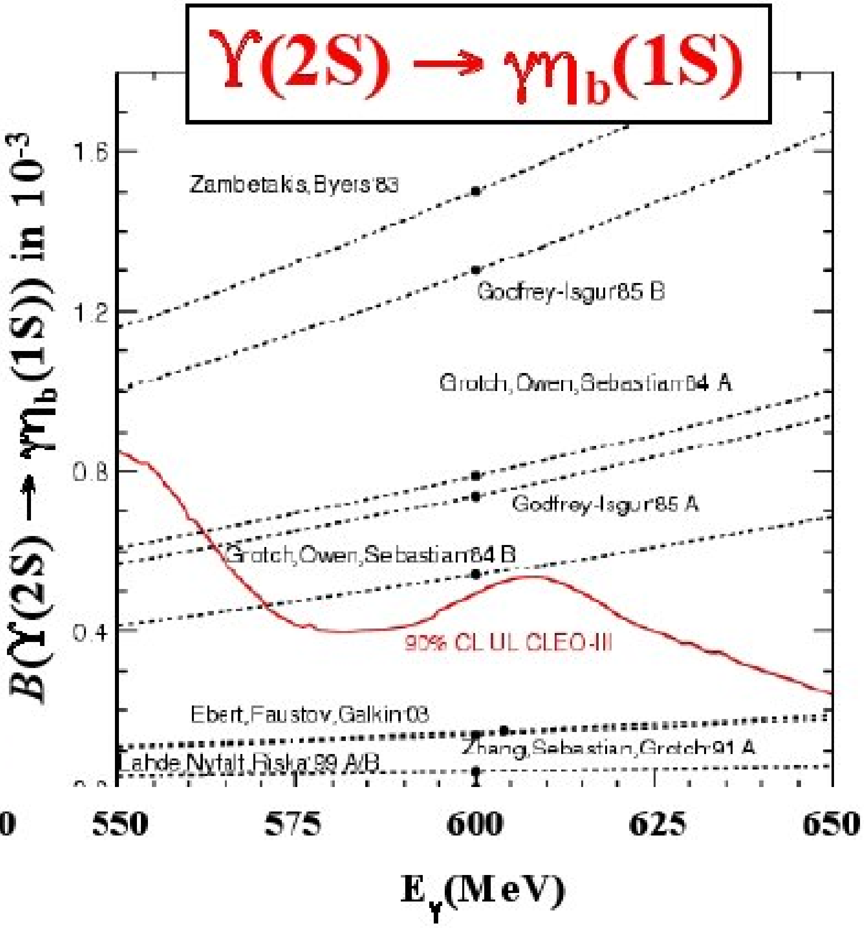
$\mathcal{B}(\Upsilon(3S) \rightarrow \eta_b(2S)\,\gamma) < 6.2\times10^{-4}$

Predictions vary: $\mathcal{B}(\Upsilon(2,3S) \rightarrow \eta_b(1S)\,\gamma) \sim 10^{-6} \sim 10^{-3}$

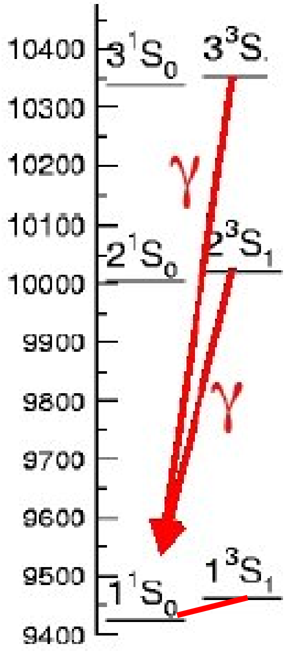
See S. Godfrey and J. L. Rosner PRD64,074011(2001).



$\Upsilon(3S) \rightarrow \gamma\eta_b(1S)$



$\Upsilon(2S) \rightarrow \gamma\eta_b(1S)$



$\Upsilon \rightarrow$ 2-Body Results

Channel	$\Upsilon(1S)$		$\Upsilon(2S)$		$\Upsilon(3S)$	
	BR (10^{-6})	Sig.	BR (10^{-6})	Sig.	BR (10^{-6})	Sig
$\rho\pi$	<4	-	<11	-	<22	-
K^*K	$6^{+3}_{-2}\pm1$	3.6	<8	-	<14	-
ρa_2	$9\pm4\pm1$	3.0	<24	-	<30	-
ωf_2	<7	-	<11	-	<8	-
$\phi f_2'$	$7^{+3}_{-2}\pm1$	5.5	$6^{+6}_{-3}\pm1$	3.0	<14	-
$K^*K_2^*$	$9^{+5}_{-4}\pm1$	3.0	<32	-	<28	-
$b_1\pi$	<8	-	<12	-	<18	-
$K_1(1270)K$	<8	-	<11	-	<17	-
$K_1(1400)K$	$14^{+3}_{-2}\pm2$	5.6	<33	-	<22	-

CLEO limits from 20M Υ(1S) decays