Исследование боттомония в эксперименте Белле

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коллаборация Белле

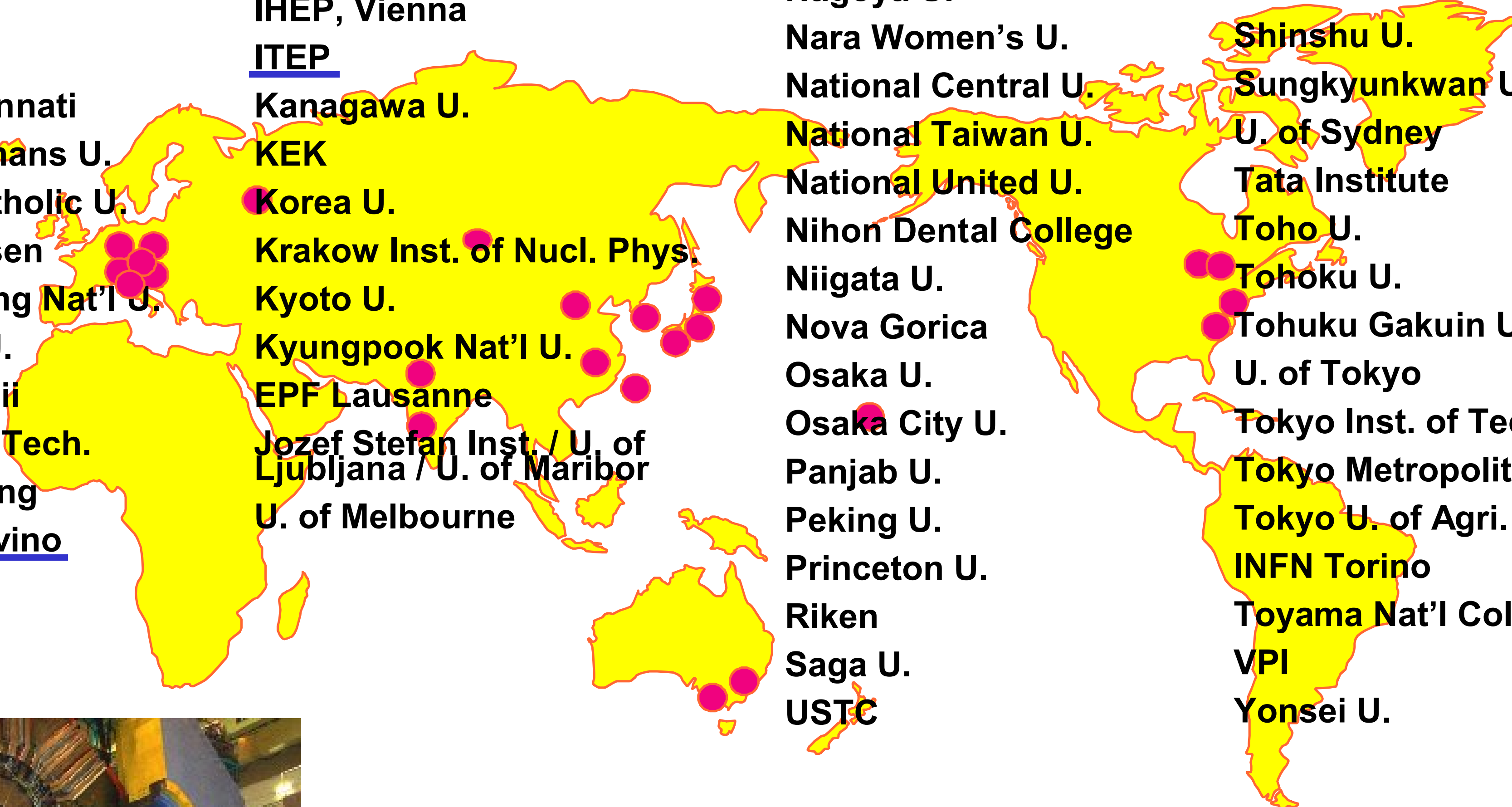
Семинар ИФВЭ

20.11. 2008

Содержание

- Об эксперименте Белле
- Метод наблюдения перехода $\Upsilon(4S)\to\Upsilon(1S)$
- Измерение ширины распада $\Upsilon(4S)\to\Upsilon(1S)\pi^+\pi^-$
- Изучение переходов $\Upsilon(5S)\to\Upsilon(nS)$
- Результаты сканирования энергии в районе пика $\Upsilon(5S)$
- Планы по изучению боттомония на B-фабриках
- Набор статистики боттомониев $\Upsilon(1S)$, $\Upsilon(1S)$, $\Upsilon(3S)$ в экспериментах BaBar, Belle

International Collaboration: Belle



BINP
Chiba U.
U. of Cincinnati
Ewha Womans U.
Fu-Jen Catholic U.
U. of Giessen
Gyeongsang Nat'l U.
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Protvino

IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
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U. of Melbourne

Nagoya U.
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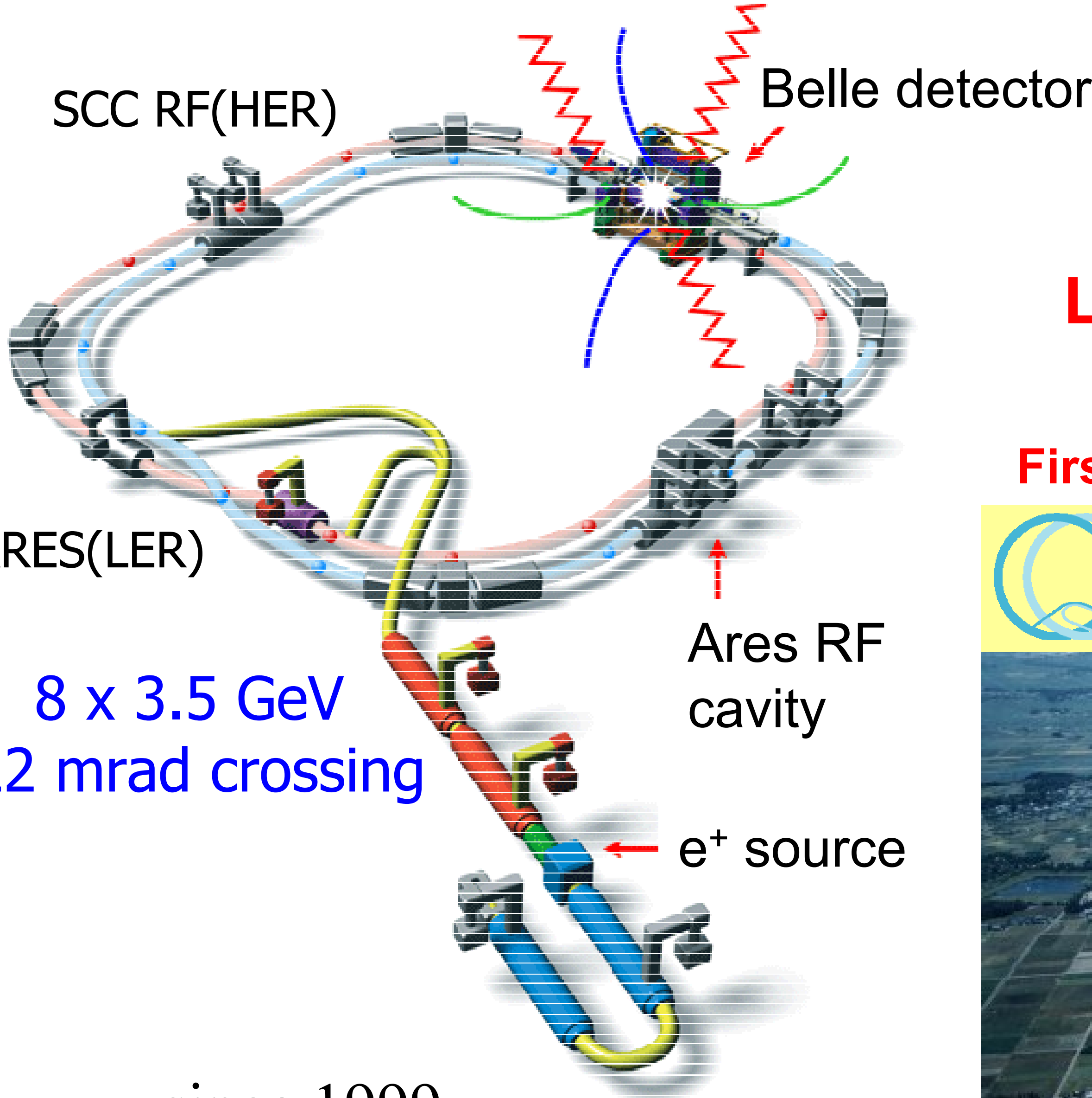
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries, 55 institutes, ~400 collaborators

The KEKB Collider



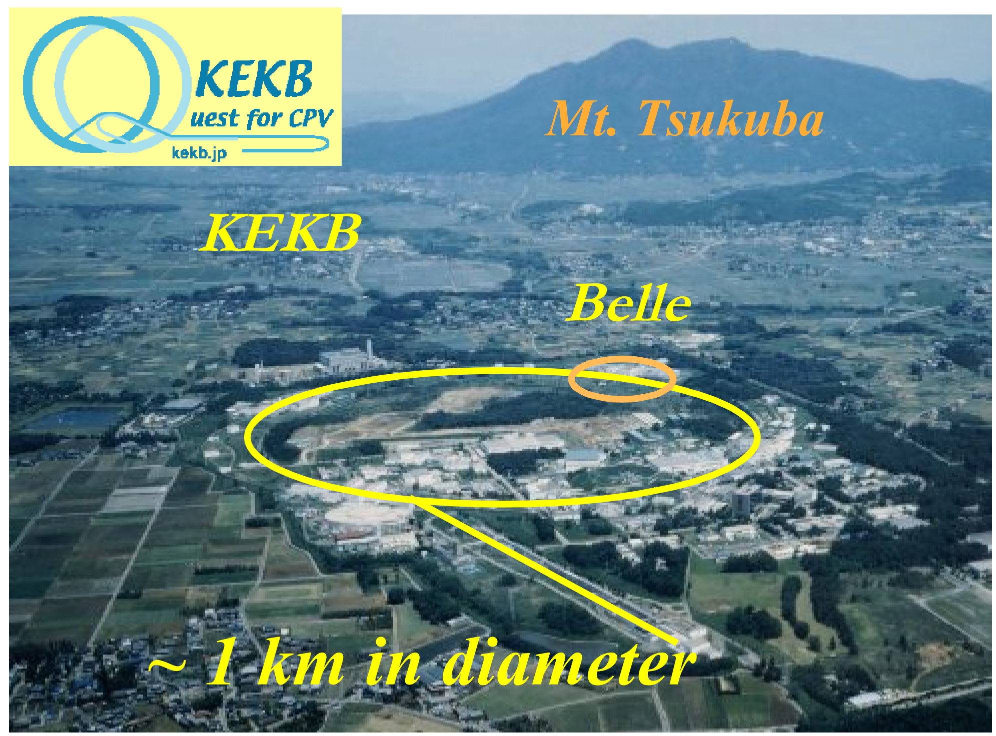
8 x 3.5 GeV
22 mrad crossing

since 1999

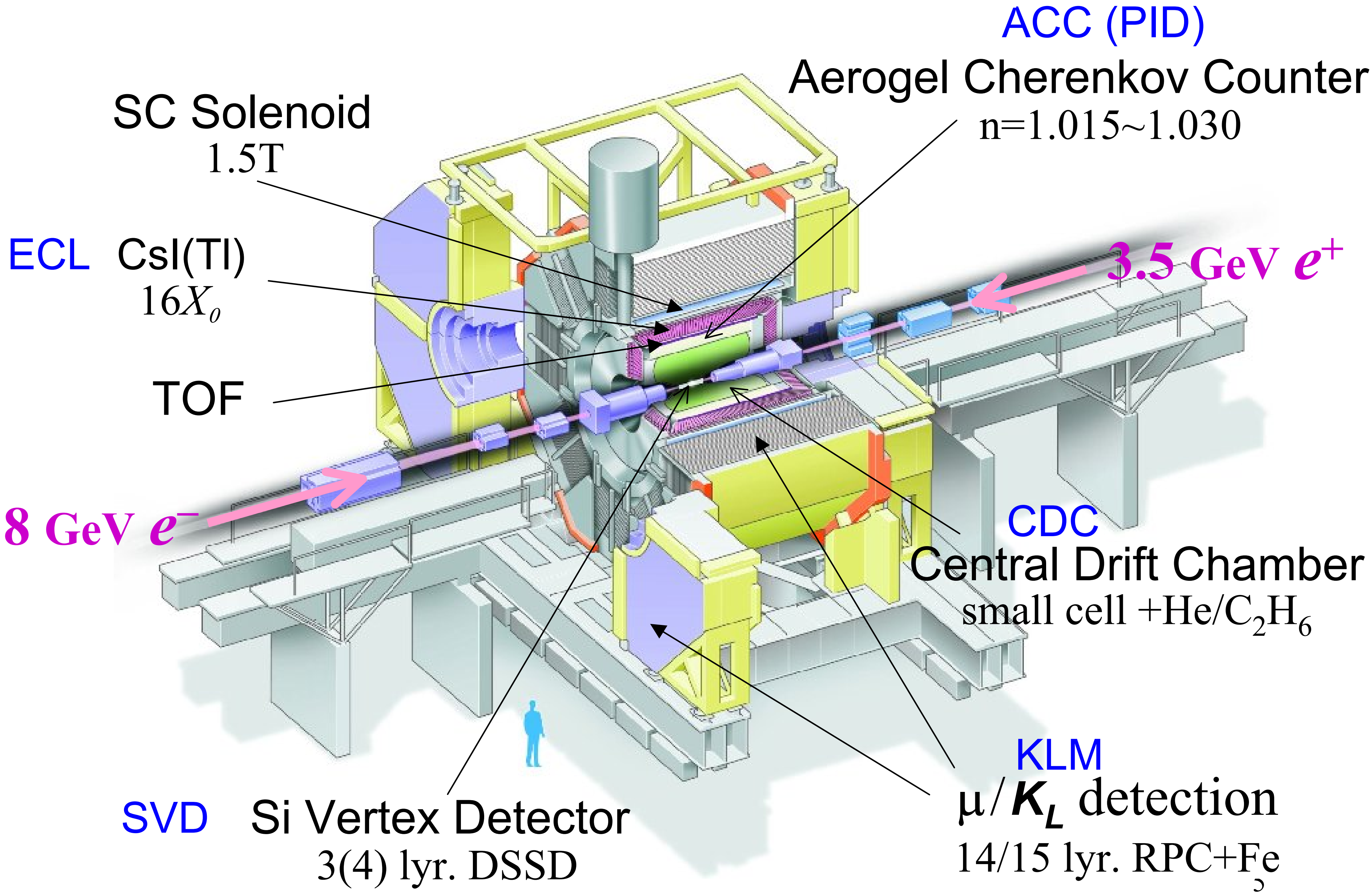
World record:

$L = 1.7118 \times 10^{34}/cm^2/sec$

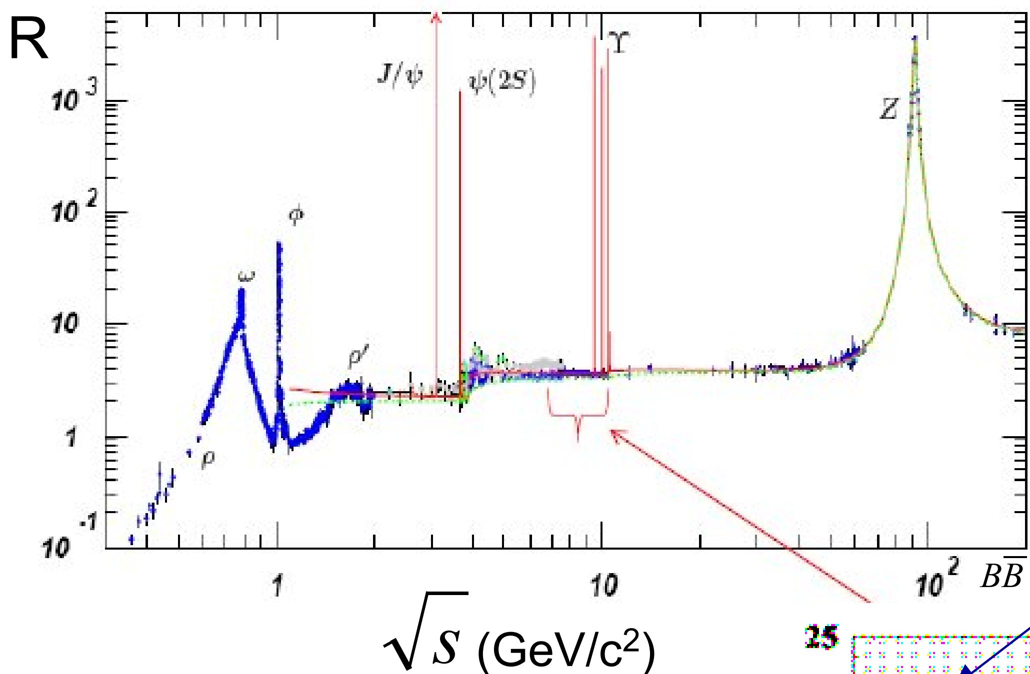
First successful op. of Crab cavities

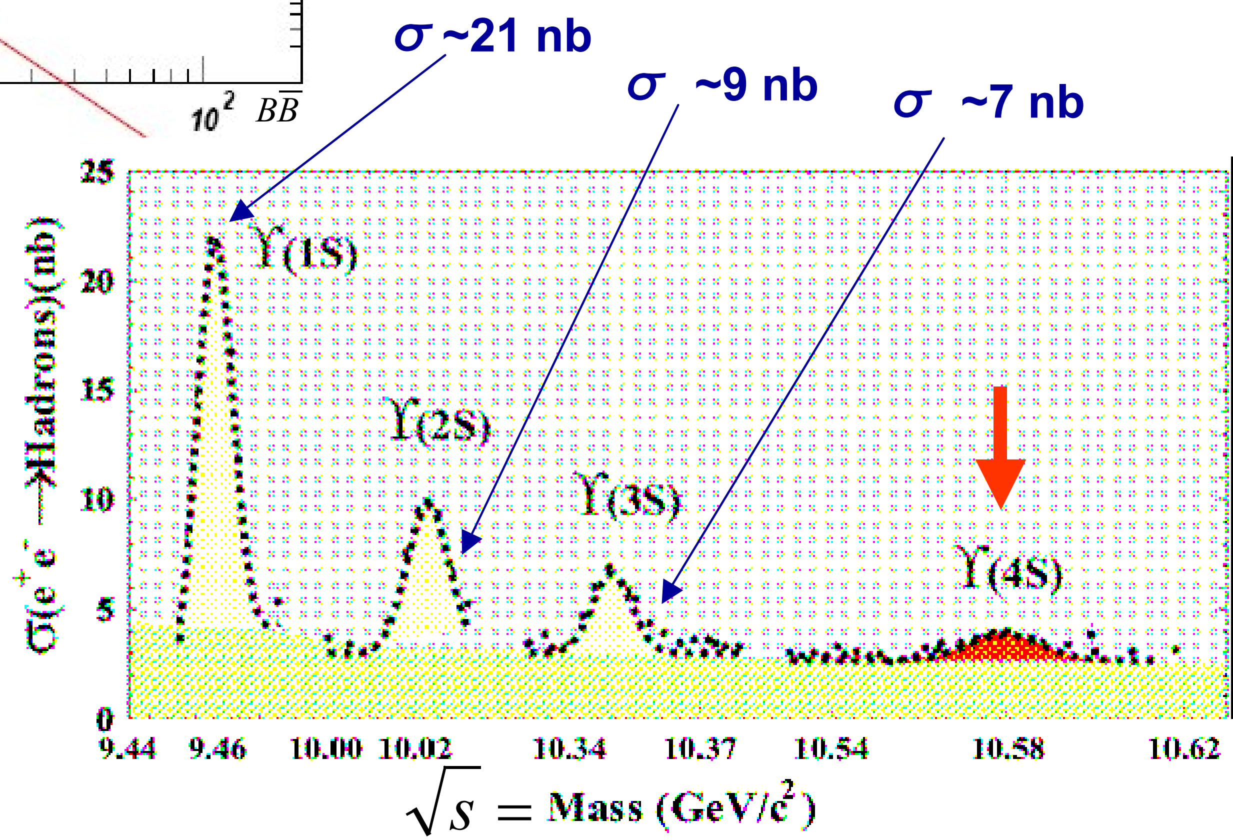


Belle Detector



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





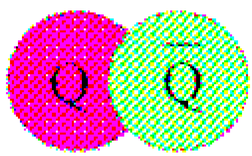
Study of e^+e^- interactions at $\sqrt{s} \sim M(\Upsilon(4S))$

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

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

Motivation

Heavy quark symmetry

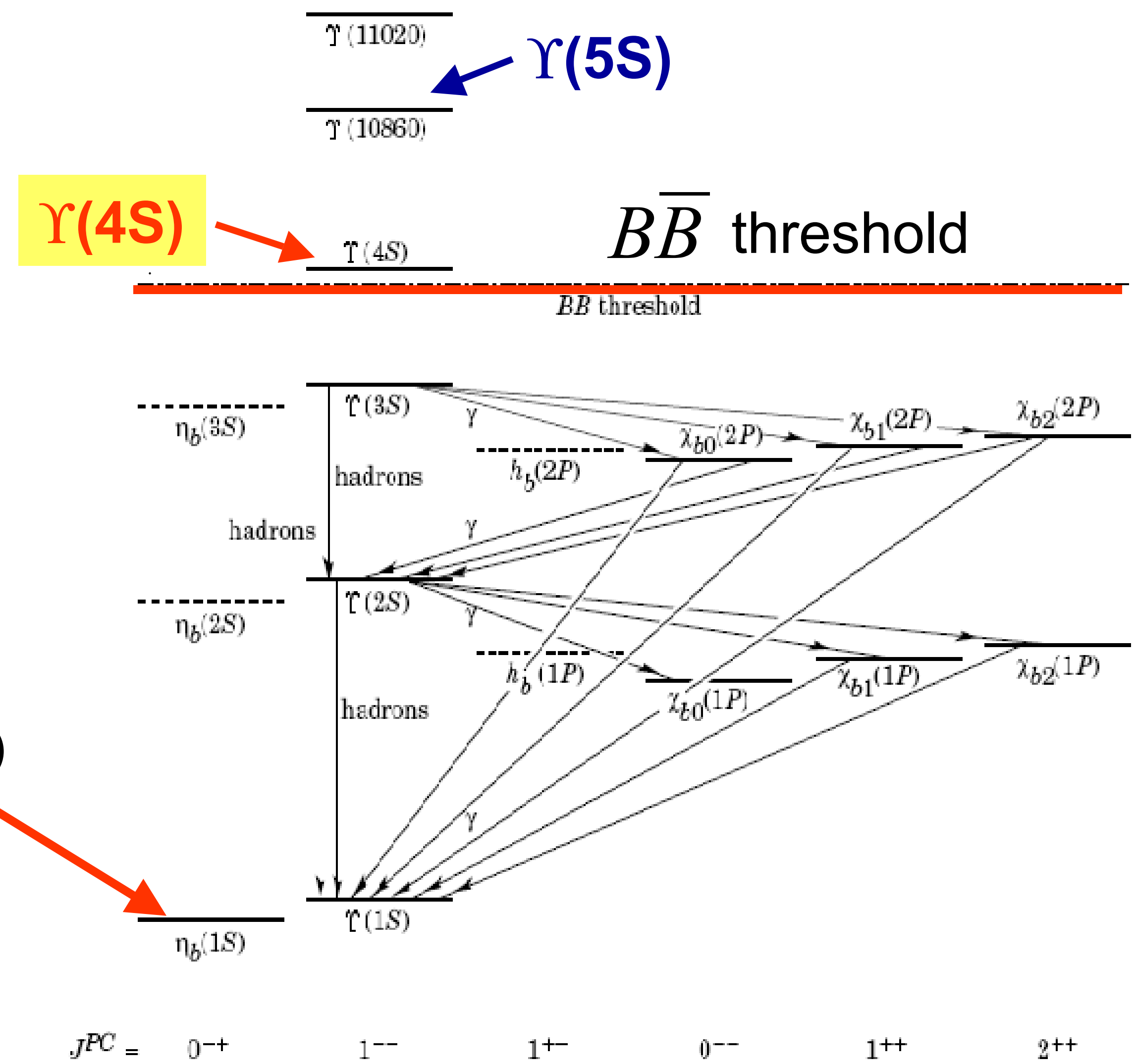


Q = b or c

Rich spectroscopy, various production schemes, interesting decay scenarios, many important states not yet observed

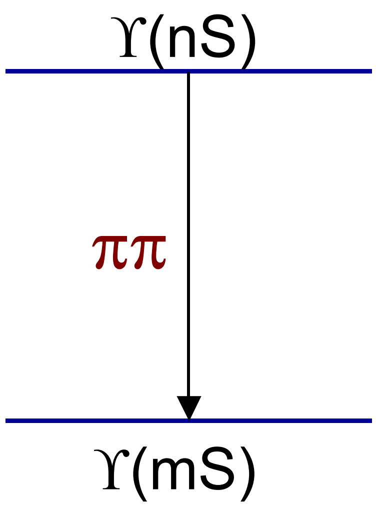
Search for bottomonium states which are not seen in experiments (η_b ...)

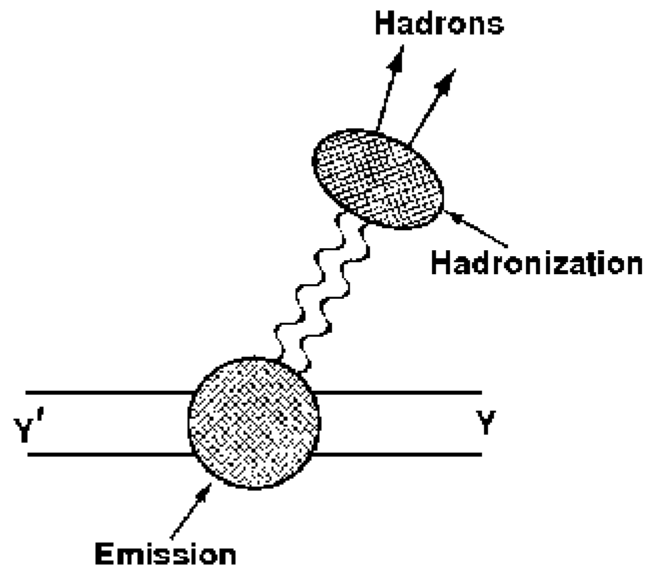
Measuring of their parameters helps to specify corresponding models.



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)

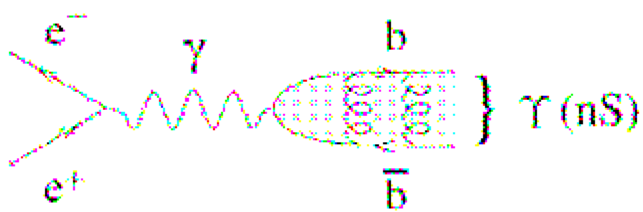
Most common process (known for decades):

Dipion transition between $^3S_1$ states,

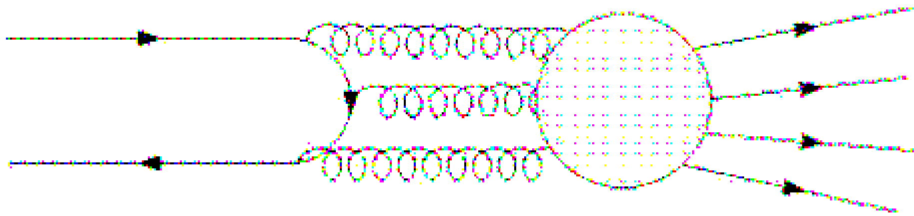
e.g., **$\Upsilon(mS) \rightarrow \pi\pi\, \Upsilon(nS)$, m>n**

(BR ≈ 50% in cc, BR ≈ 5 - 20 % in bb)

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

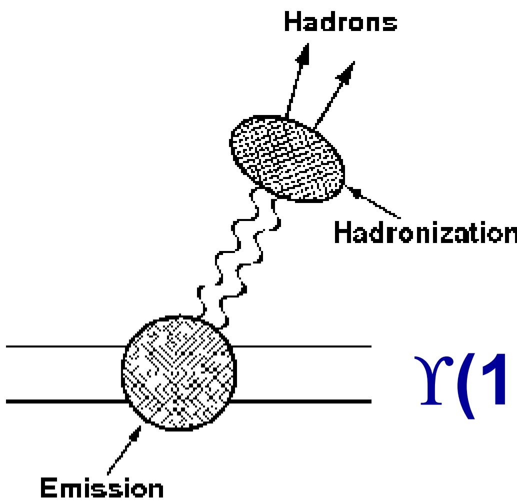


$e^+e^- \to \Upsilon(4S)$



$\Upsilon(4S) \to B\bar{B}$

$\Upsilon(4S)$



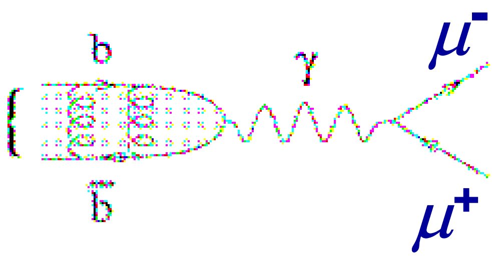
$\Upsilon(1S)$

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

$\downarrow$

$\mu^+\mu^-$

$\Upsilon(1S)$



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

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

Motivation: search for new bottomonium states, transitions.

Data sample: $\mathcal{L}$=605 fb^{-1}, $\Upsilon(4s)$
657×10^6 $B\bar{B}$ – on-resonance

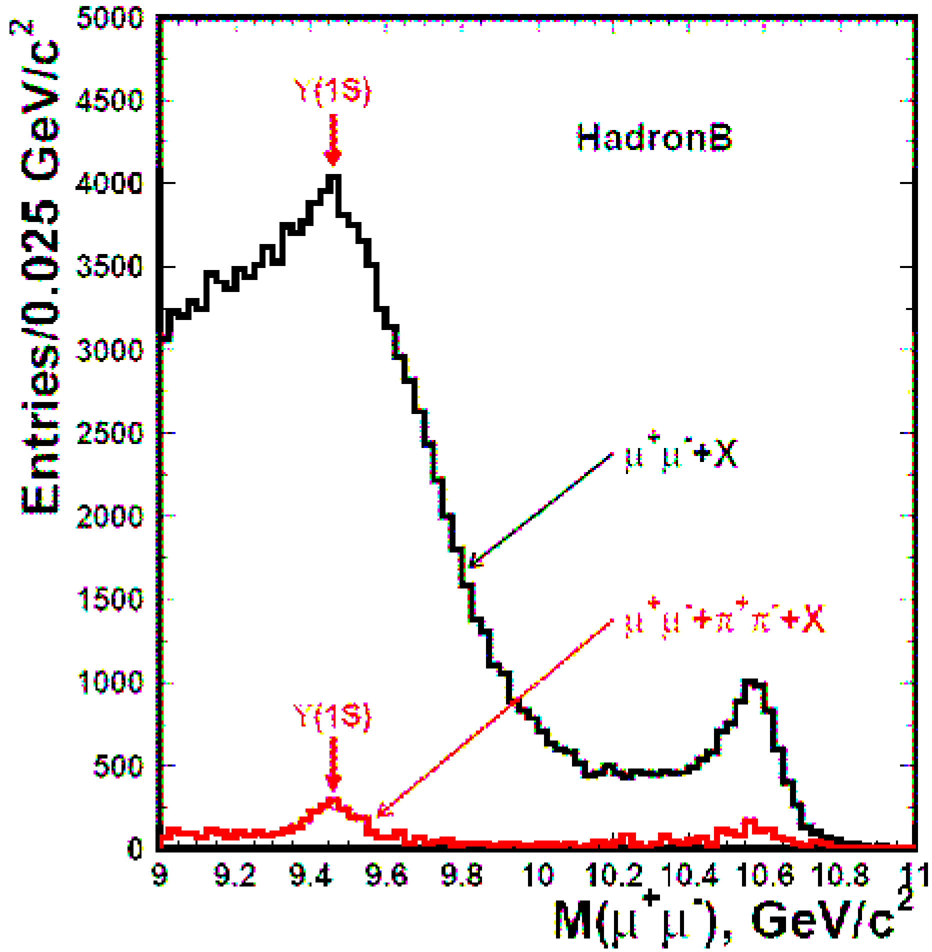
$N(\mu^+\mu^-)$ = 161000

Data sample: $\mathcal{L}$=427 fb^{-1}, $\Upsilon(4s)$
A.Sokolov *et al*. (Belle collaboration)
Phys.Rev. D75, 071103® (2007)

Primary event selection

$\Upsilon(1S)\to\mu^+\mu^-$

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



Event selection

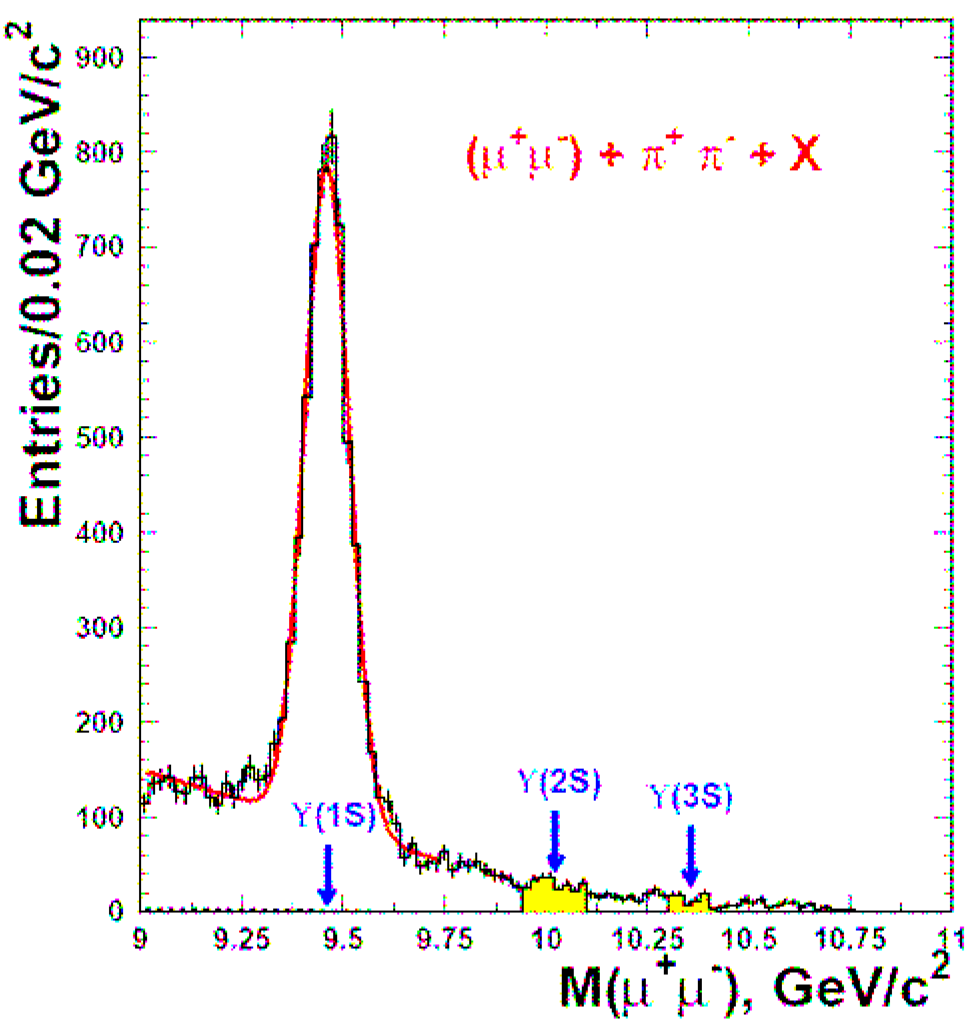
$N(\mu^+\mu^-\pi^+\pi^-X) = 9655$

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

- $M(\mu^+\mu^-)$>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 $\pi^\pm$



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

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

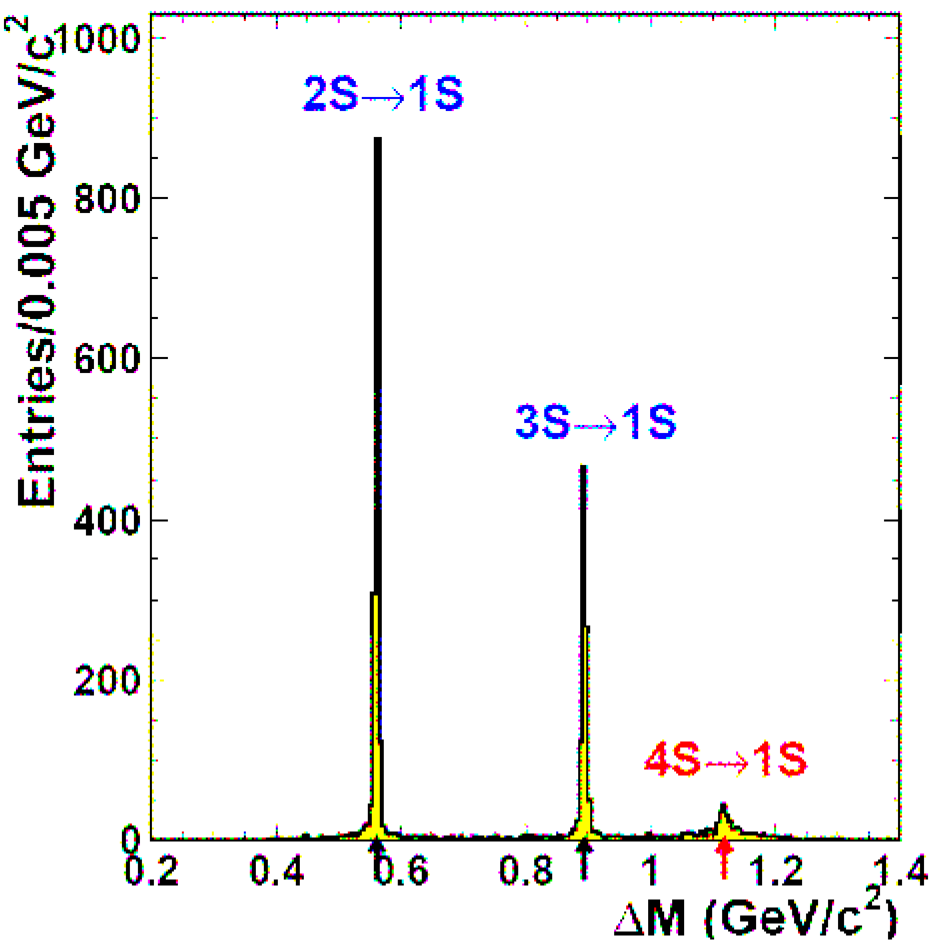
$\Upsilon(2S,3S) \to \Upsilon(1S)\,\pi^+\pi^-$

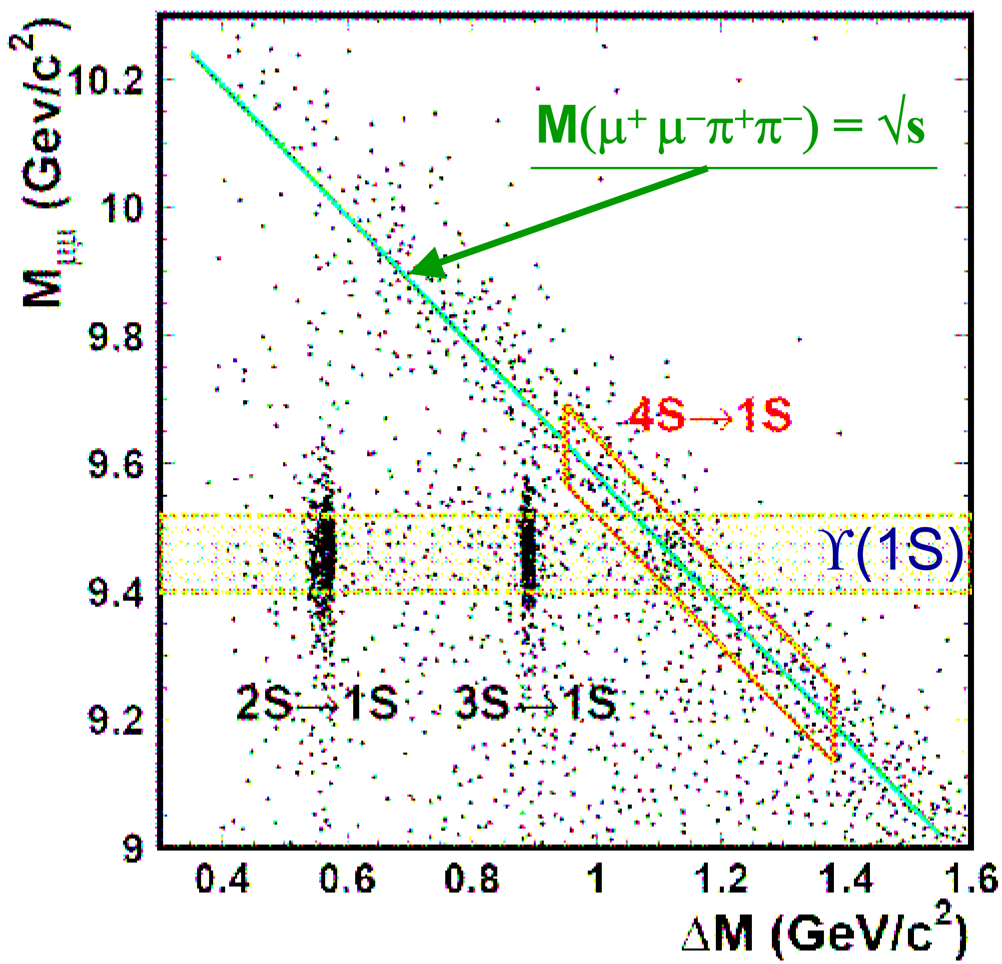
$N_{ev} = 0.9 \div 1.8 \times 10^6$, $\mathcal{L}$=605 fb^{-1}

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

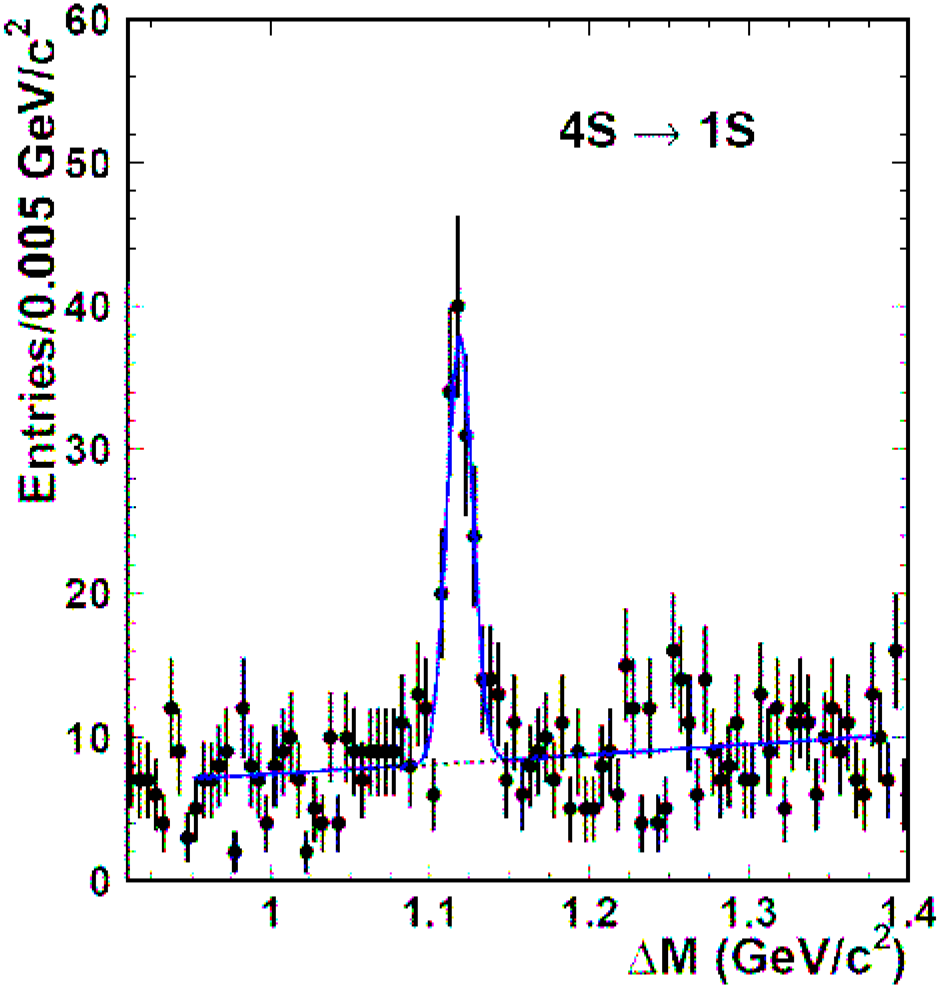
Distribution of $\Delta M = [M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)]$

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





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)%

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

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

Preliminary

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

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

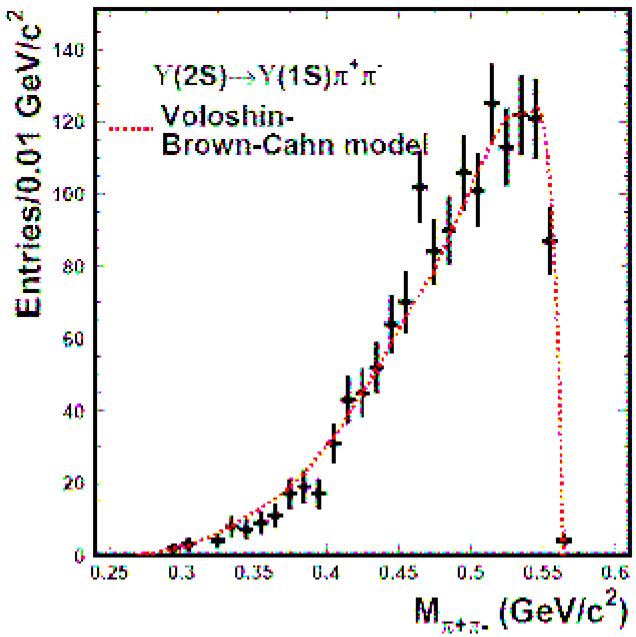
$(\sim 11.6\sigma)$

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

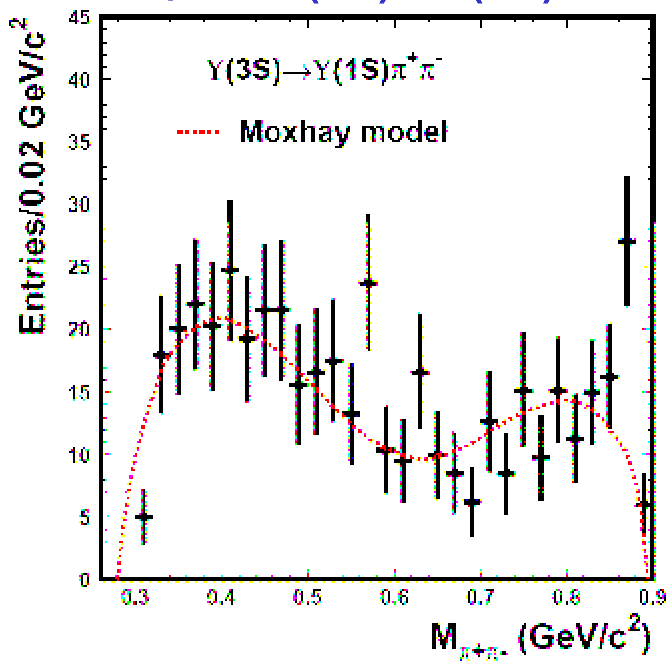
$\Gamma(\Upsilon(2S)) = 6.0$ keV $\Gamma(\Upsilon(3S)) = 0.9$ keV

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

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

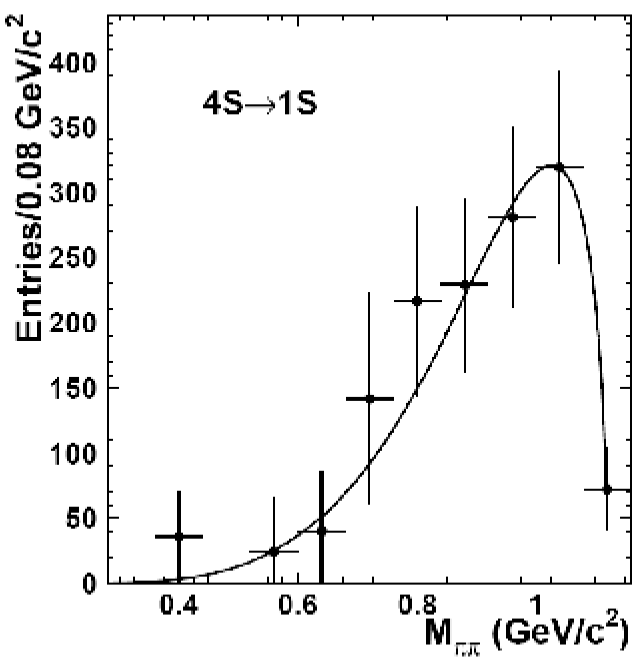


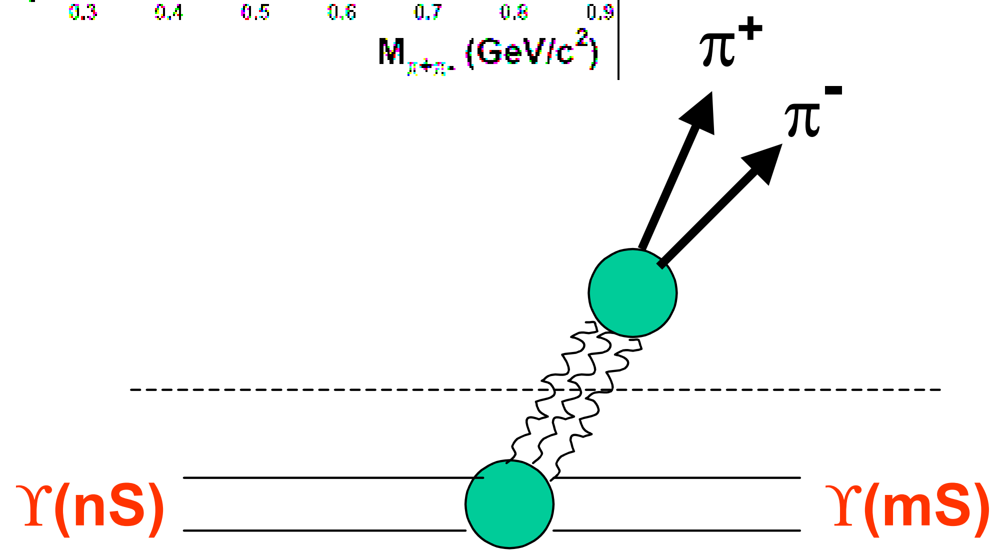
2nd peak $\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-$



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

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





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

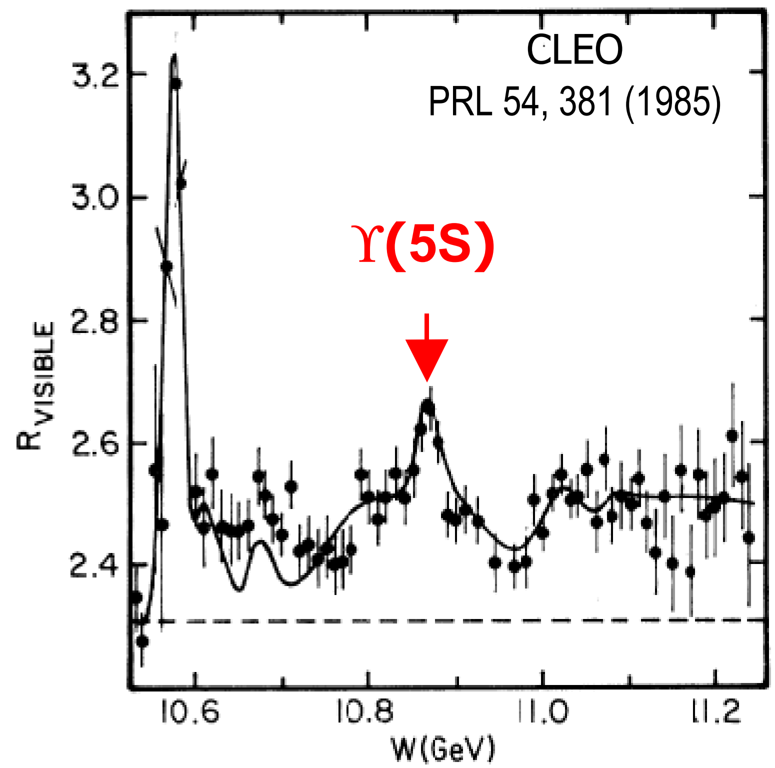
L.S.Brown and R.N.Cahn, Phys.Rev.Lett., **35**, 1(1975)

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 $\Upsilon(5S)\to\Upsilon(nS)$ transitions

Data sample:

Exp. 53, 5S_scan,

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

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

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

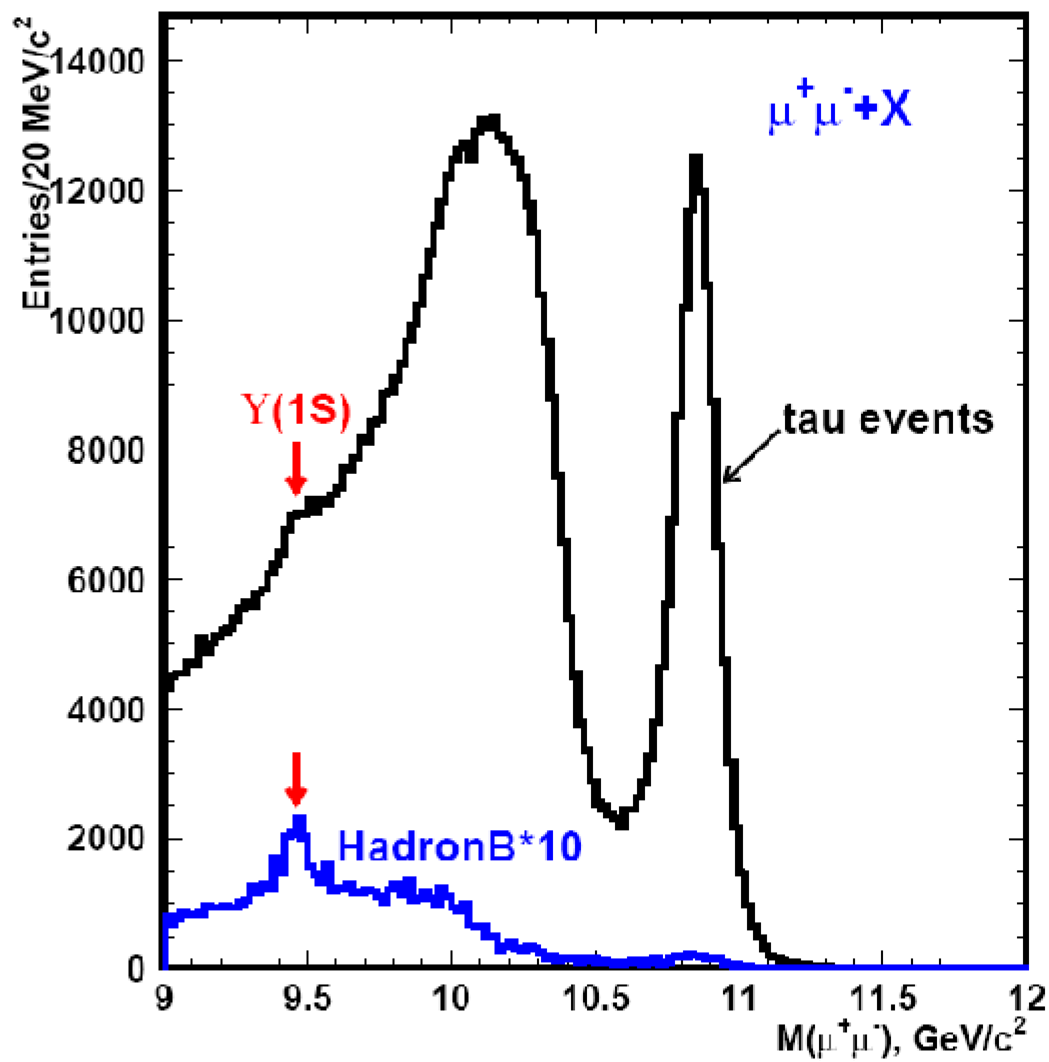
Primary event selection

- HadronB
  &
  tau skim

- There is exist a $(\mu^+\mu^-)$ - pair with a $M(\mu^+\mu^-) > 9\ GeV/c^2$

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

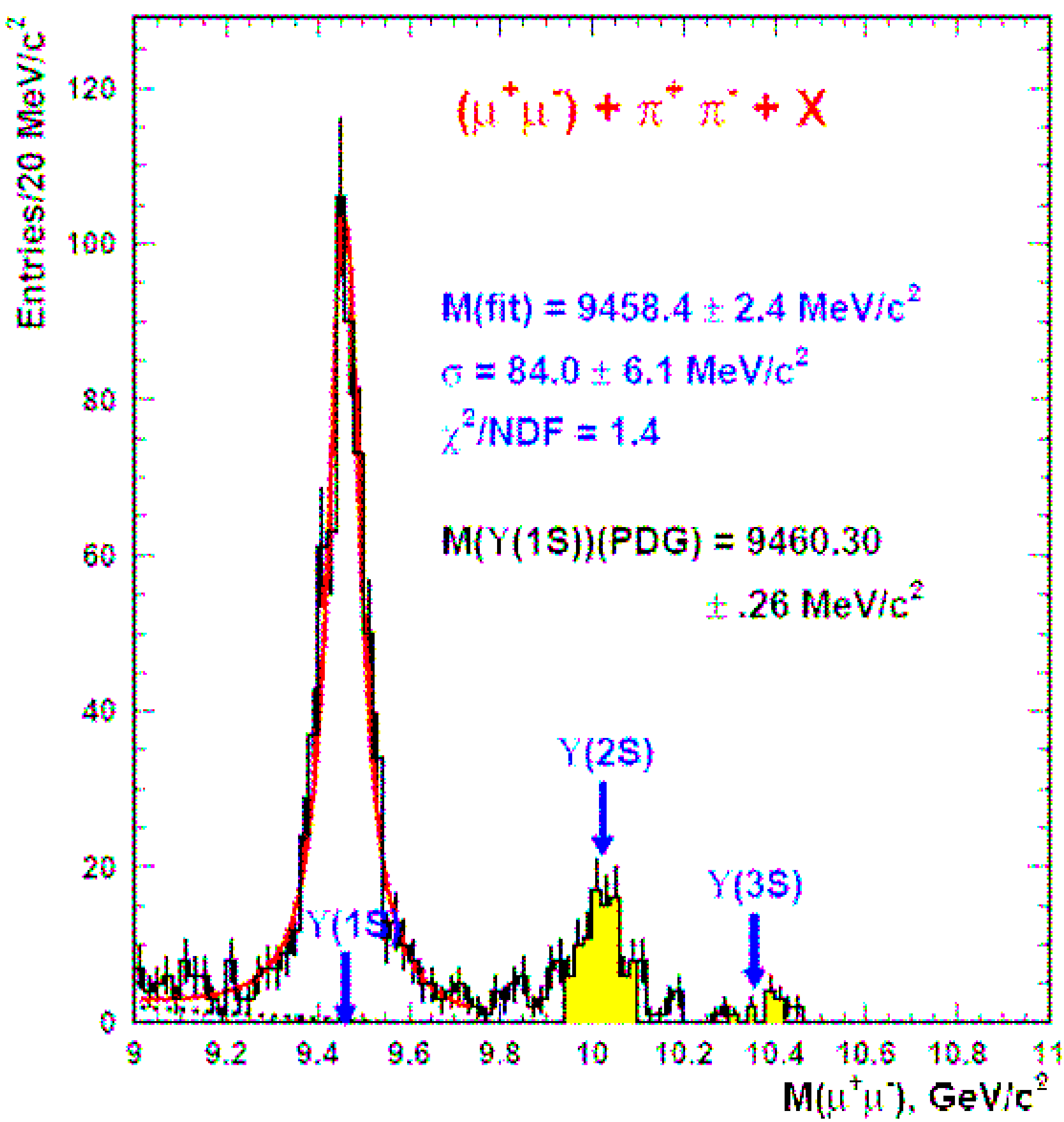
N(tau events) = 762000
N(HB) = 7300



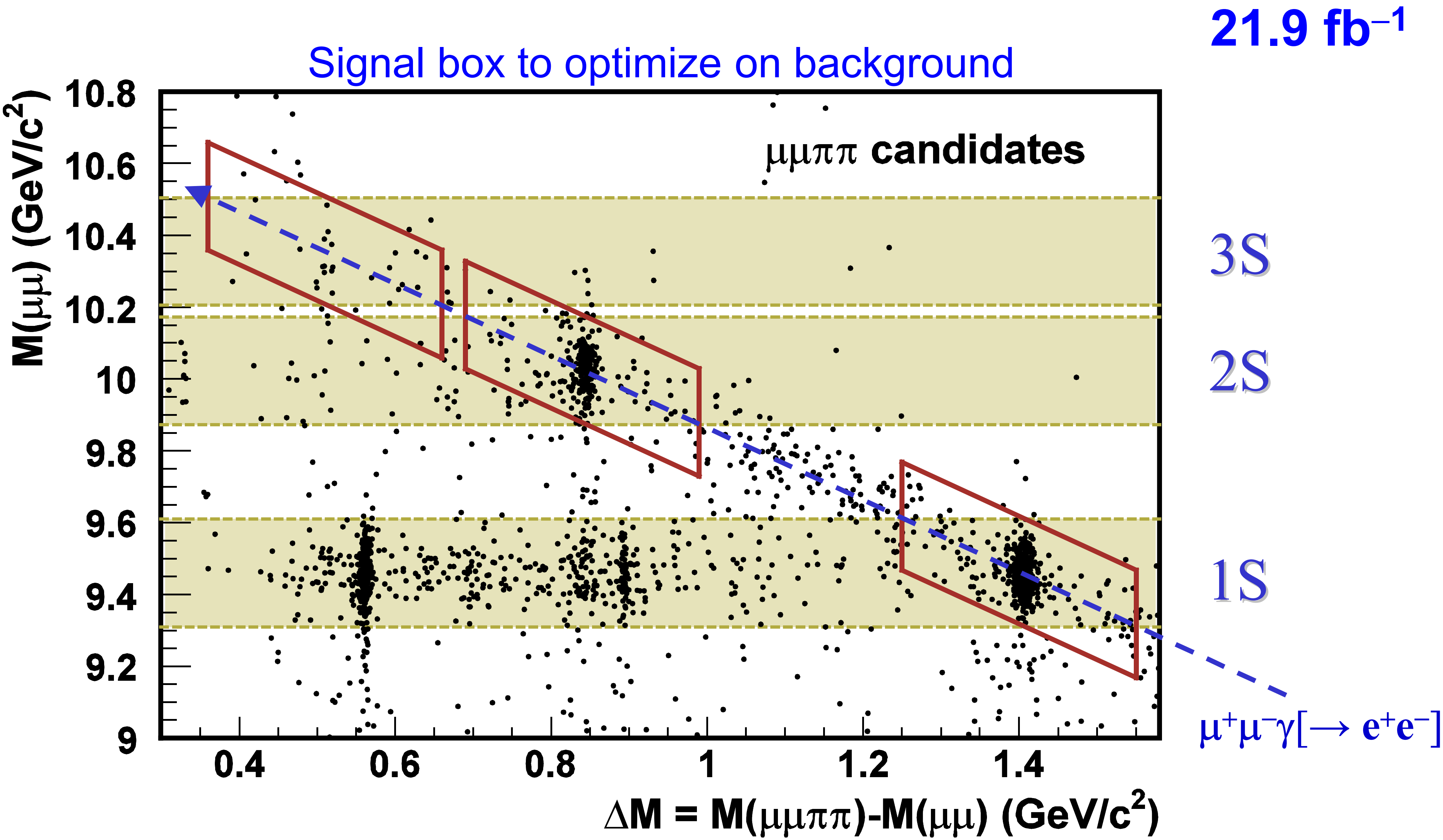
Event selection

$N(\mu^+\mu^-\pi^+\pi^-X) = 1876$ (tau)
$N(\mu^+\mu^-\pi^+\pi^-X) = 705$ (HB)

- HadronB & tau skim
- $\mu^+\mu^- + \pi^+\pi^- + X$
- $M(\mu^+\mu^-) > 9\ \mathrm{GeV}/c^2$
- 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 $\pi^\pm$

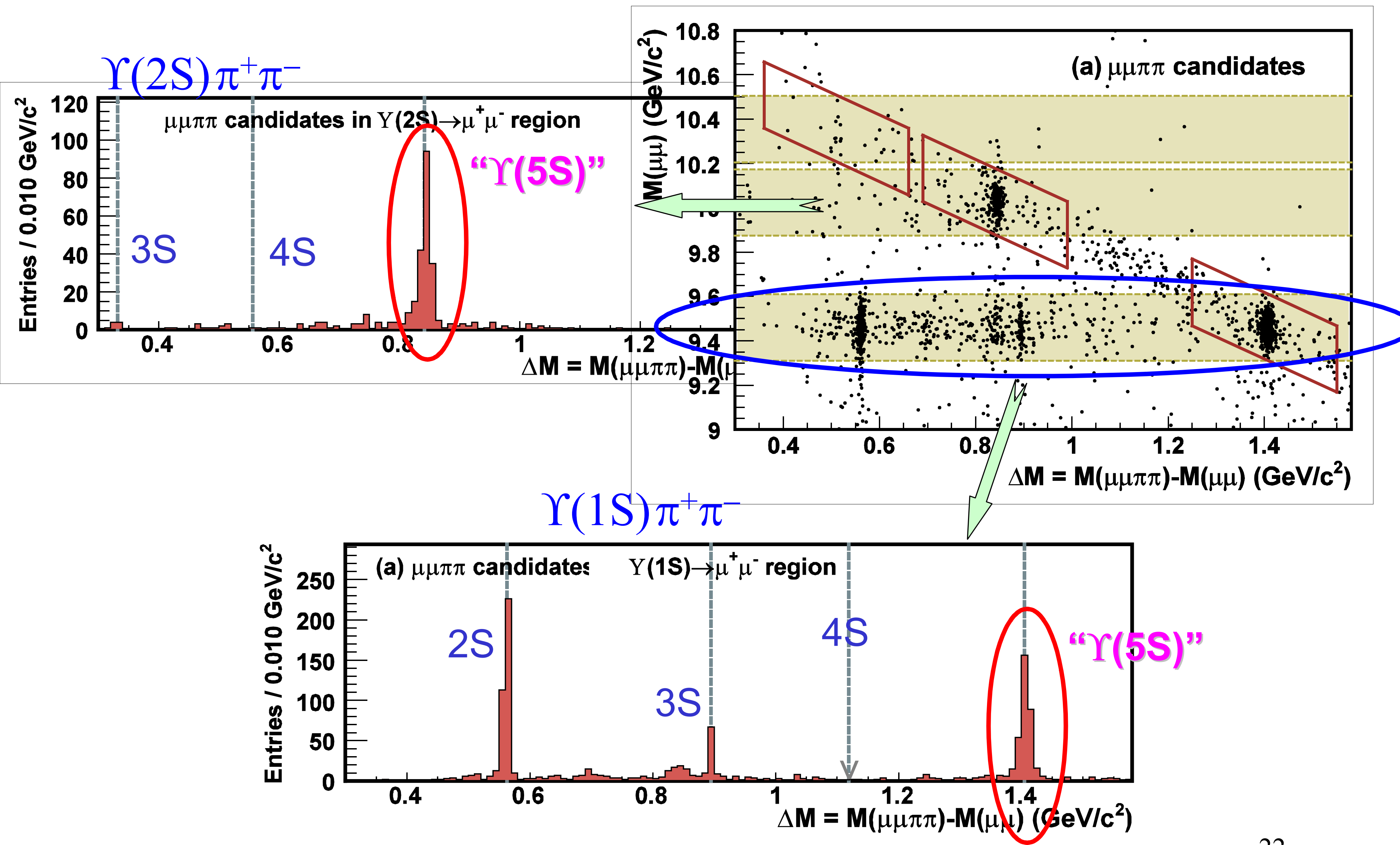


$e^+e^- \to \Upsilon(nS)h^+h^-$ at 10.87 GeV

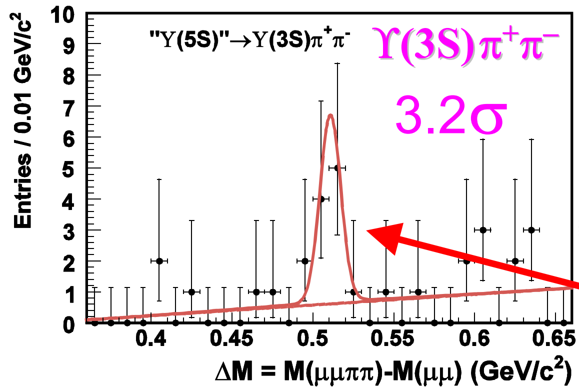


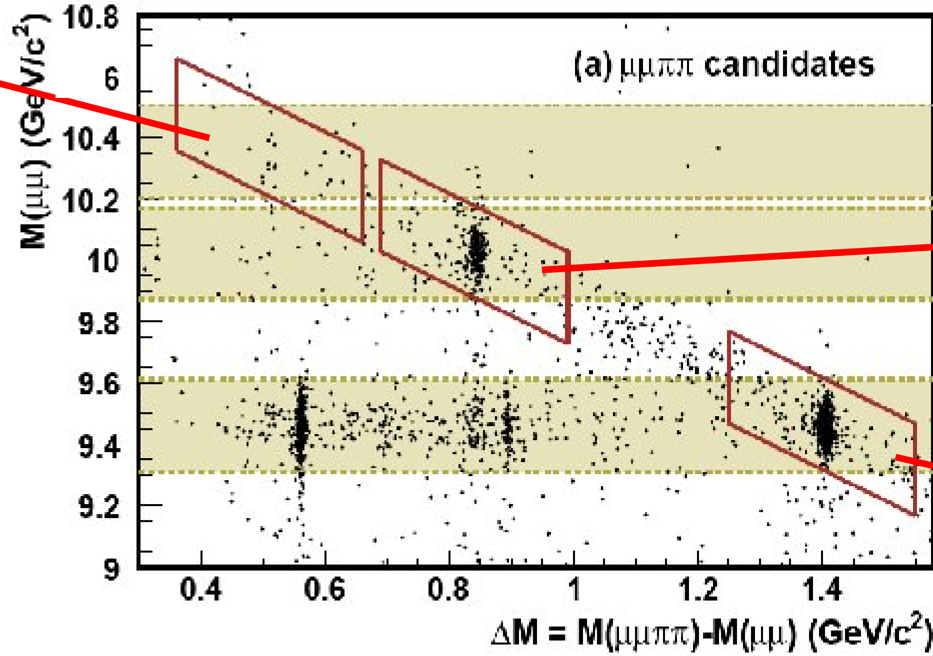
Results

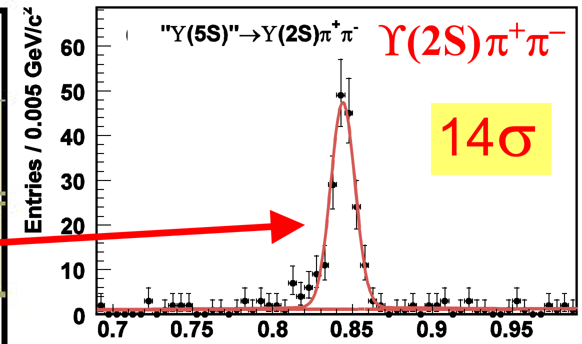
"$\Upsilon(5S)$" $\to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$

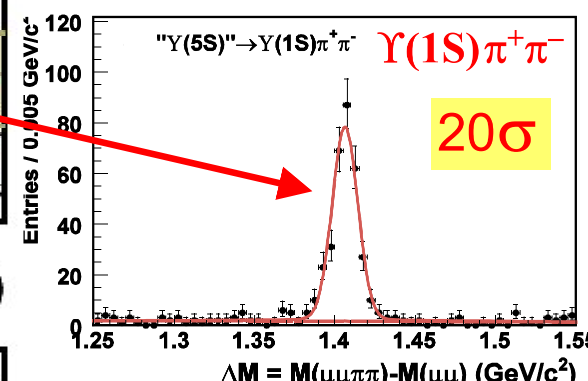


“$\Upsilon(5S)$” $\rightarrow \Upsilon(nS)\pi^+\pi^-$, $\Upsilon(1S)K^+K^-$

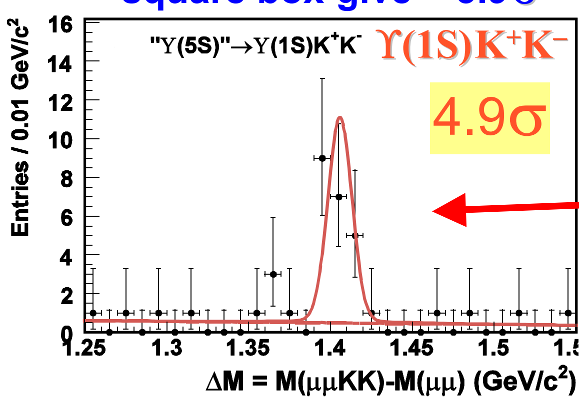


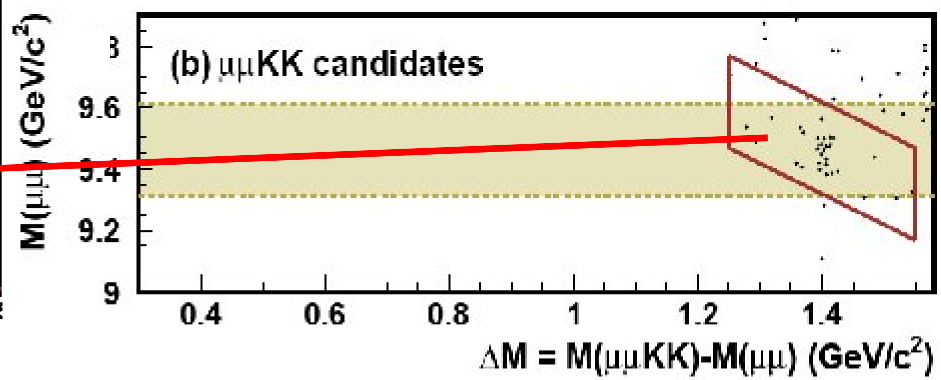




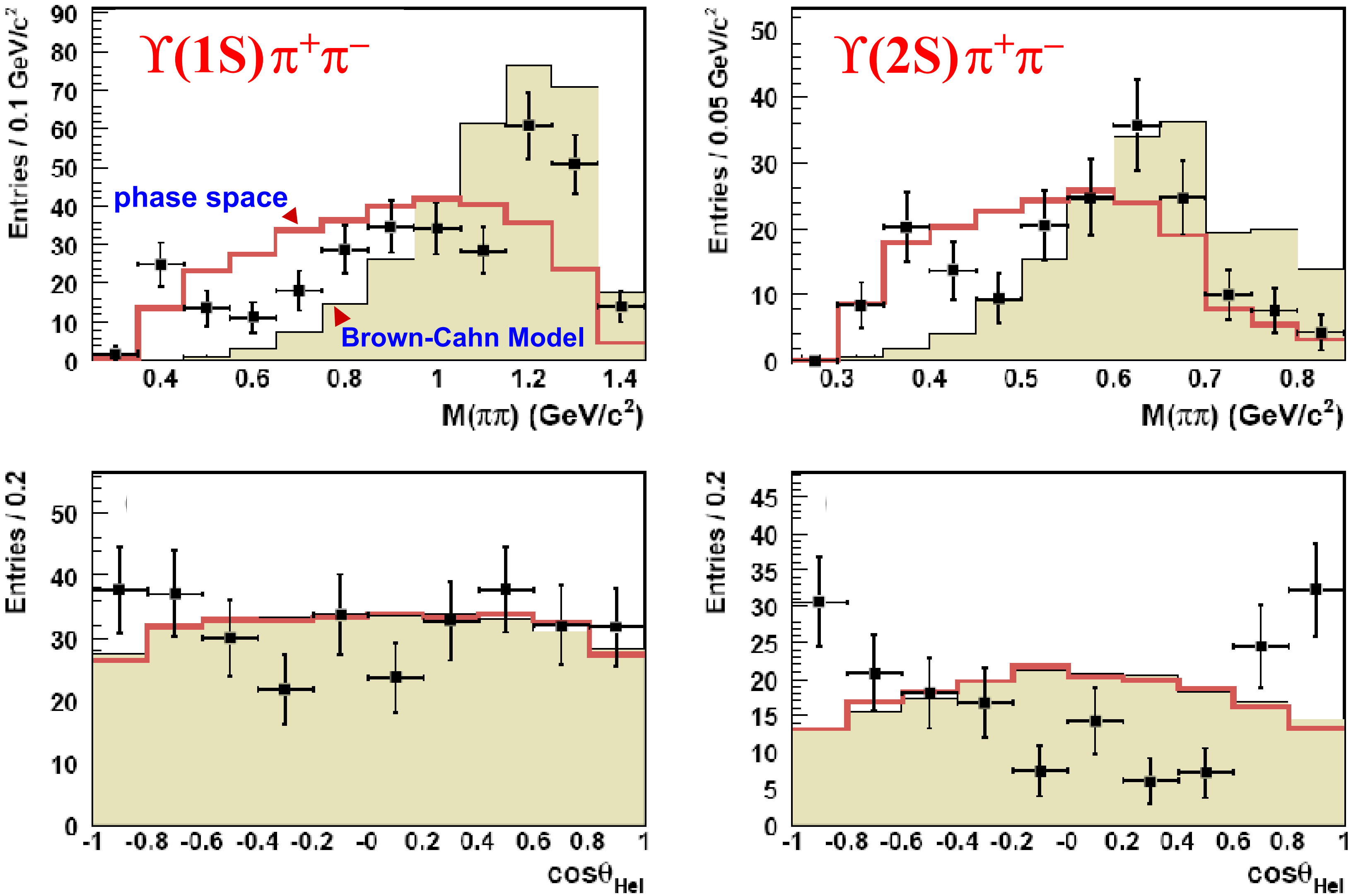


square box give ~ 3.9σ





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

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

- 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}

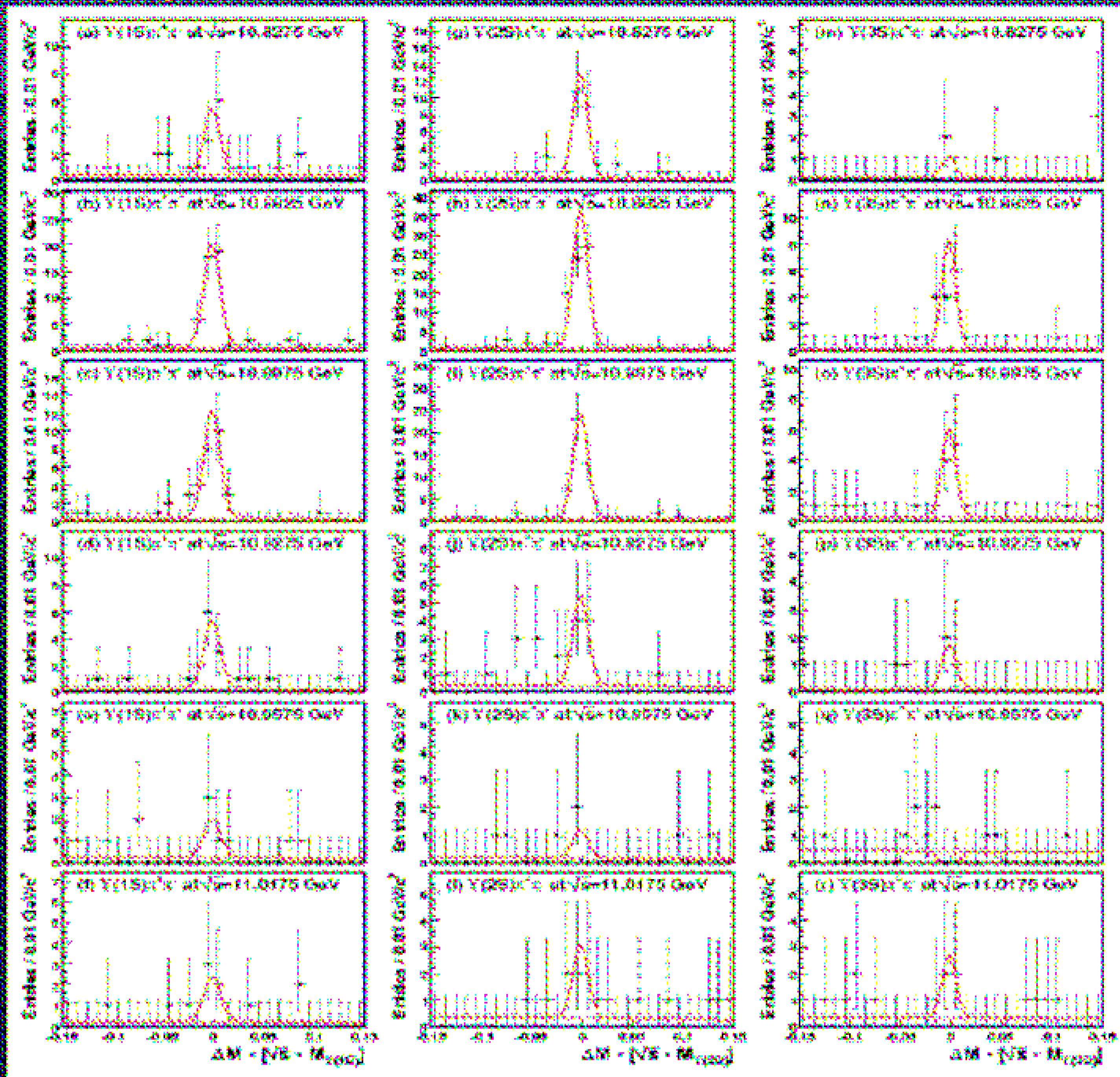
Ecm = 10957.5

$\mathcal{L}$= 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(Υ(1S)$\pi\pi$)	325^{+20}_{-19}
ε(Υ(1S)$\pi\pi$)	37.4%
σ(Υ(1S)$\pi\pi$)	1.61 ± 0.16
N(Υ(2S)$\pi\pi$)	186 ± 15
ε(Υ(2S)$\pi\pi$)	18.9%
σ(Υ(2S)$\pi\pi$)	2.35 ± 0.37
N(Υ(3S)$\pi\pi$)	$10.5^{+4.0}_{-3.3}$
ε(Υ(3S)$\pi\pi$)	1.5%
σ(Υ(3S)$\pi\pi$)	$1.44^{+0.58}_{-0.49}$

2006 Υ(5S) data (Exp 53)

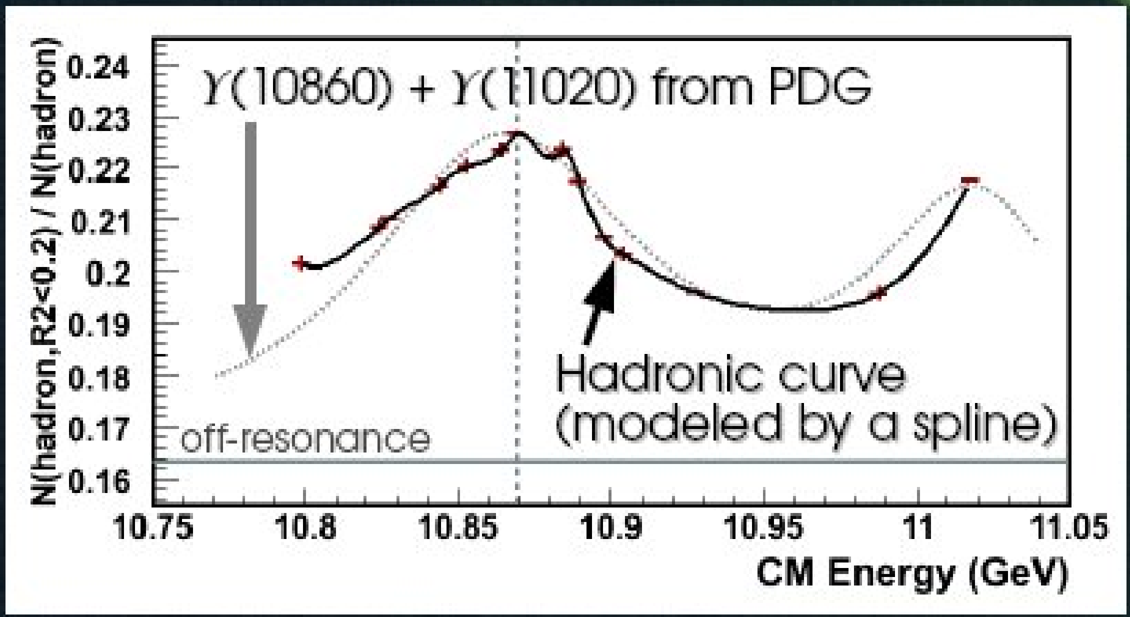
- Efficiency for 3S$\pi\pi$ increases dramatically due to the "ypipi" skims.

Point	10829	10884	10899	10929	10959	11019
int(L) (pb^{-1})	1683.48	1832.86	1407.58	1138.80	1007.30	856.02
N(Υ(1S)$\pi\pi$)	$10.6^{+4.0}_{-3.3}$	$43.5^{+7.2}_{-6.5}$	$26.3^{+5.8}_{-5.1}$	$11.2^{+4.0}_{-3.3}$	$3.9^{+2.6}_{-1.9}$	$4.9^{+2.8}_{-2.1}$
ε(Υ(1S)$\pi\pi$)	43.8%	43.1%	43.2%	42.6%	42.5%	42.0%
σ(Υ(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(Υ(2S)$\pi\pi$)	$24.0^{+5.6}_{-4.9}$	$68.9^{+9.0}_{-8.3}$	$45.5^{+7.4}_{-6.7}$	$9.7^{+3.8}_{-3.1}$	$2.0^{+2.0}_{-1.3}$	$5.5^{+3.1}_{-2.4}$
ε(Υ(2S)$\pi\pi$)	34.9%	35.4%	35.6%	35.9%	36.4%	36.0%
σ(Υ(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(Υ(3S)$\pi\pi$)	$1.8^{+1.9}_{-1.1}$	$14.9^{+4.4}_{-3.7}$	$10.3^{+3.7}_{-3.1}$	$2.9^{+2.2}_{-1.5}$	$-1.8^{+2.5}_{-3.0}$	$4.3^{+2.6}_{-1.9}$
ε(Υ(3S)$\pi\pi$)	20.5%	24.5%	25.7%	27.5%	29.4%	32.7%
σ(Υ(3S)$\pi\pi$)	$0.24^{+0.24}_{-0.15}$	$1.52^{+0.44}_{-0.38}$	$1.31^{+0.47}_{-0.39}$	$0.42^{+0.32}_{-0.22}$	$-0.28^{+0.39}_{-0.47}$	$0.71^{+0.43}_{-0.31}$

Hadronic Ratios

2nd 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):



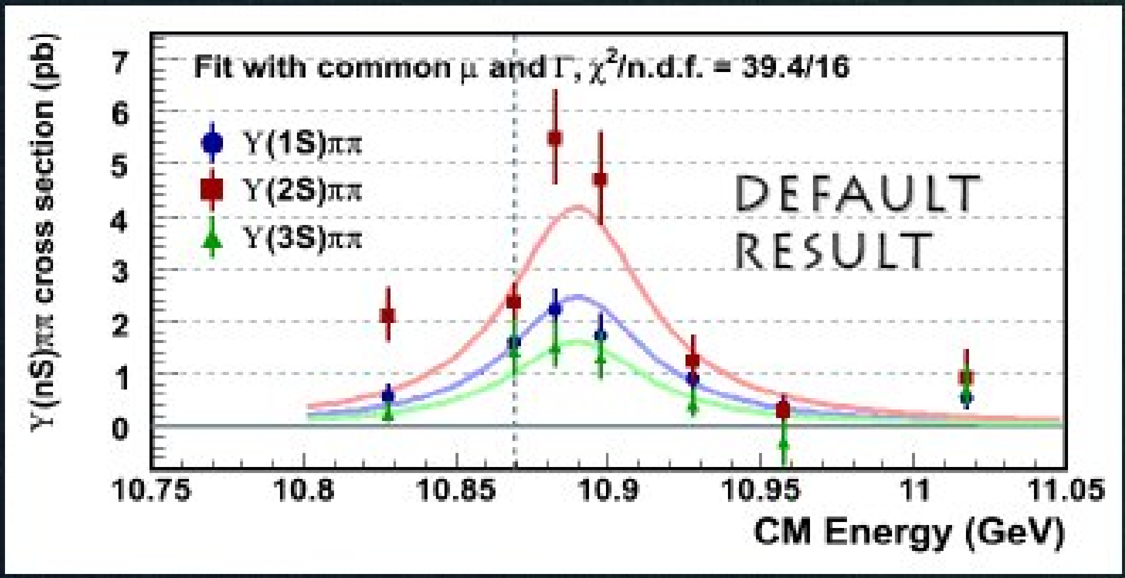
*I would like to avoid providing a very accurate number but without systematic error in the publication.
(e.g. M = 10860.7 ± 0.2 MeV from a poor χ^2 fit to these points)*

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.*

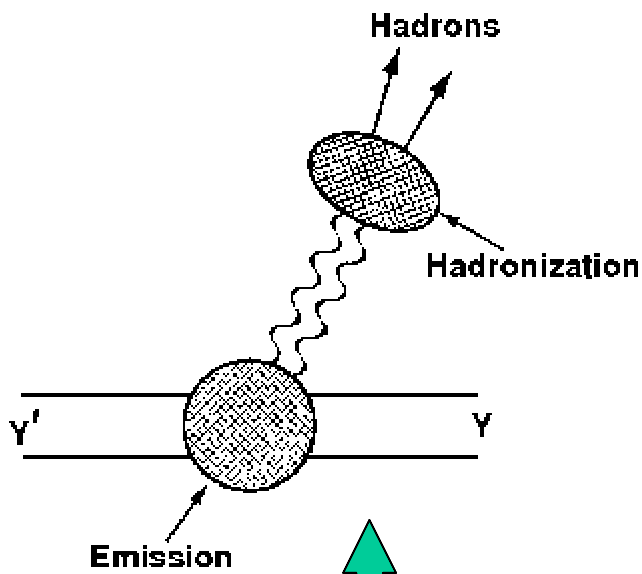
Дальнейшее изучение боттомония

- 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

$$\Upsilon(mS)$$

$$\psi'$$



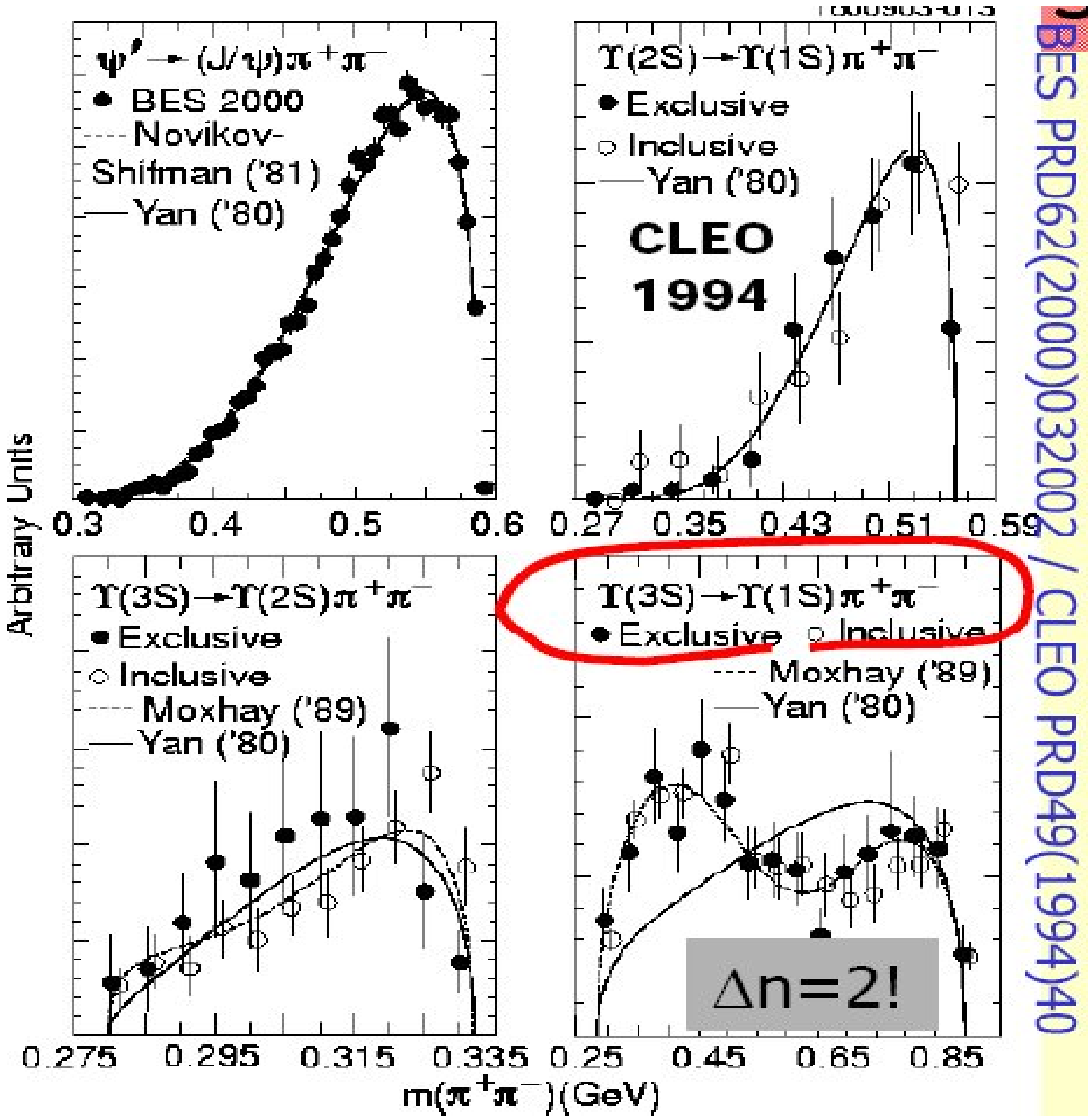
$$\Upsilon(nS)$$

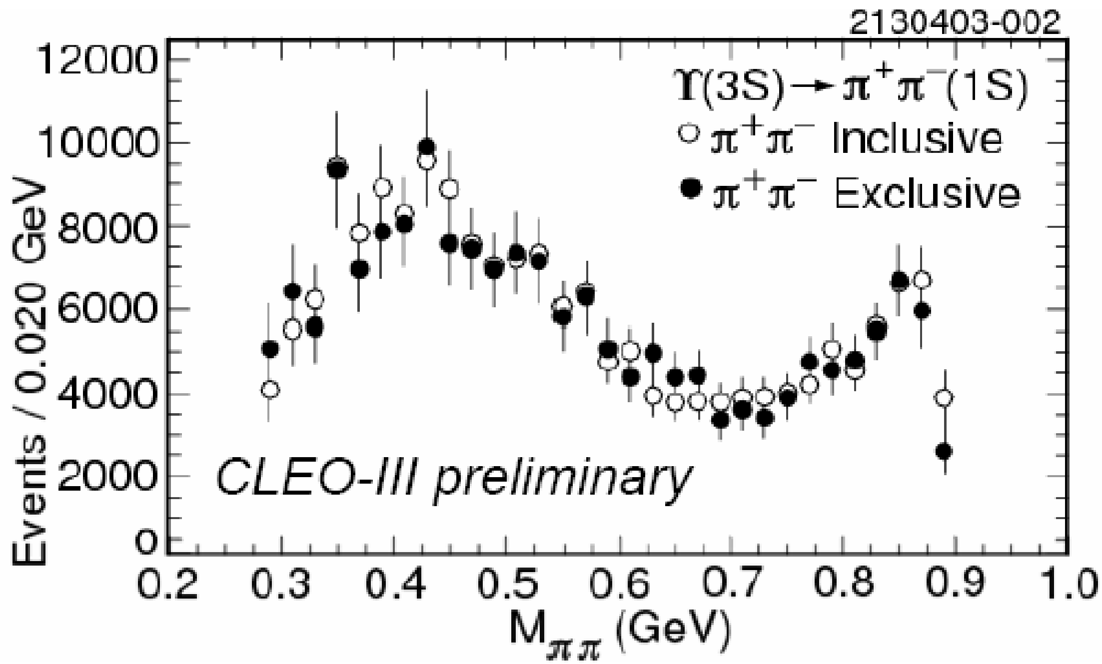
$$\psi$$

“QCD Multipole Expansion”

Распады для случая m-n > 1 ?

Most famous ancient mystery (1994-2000)





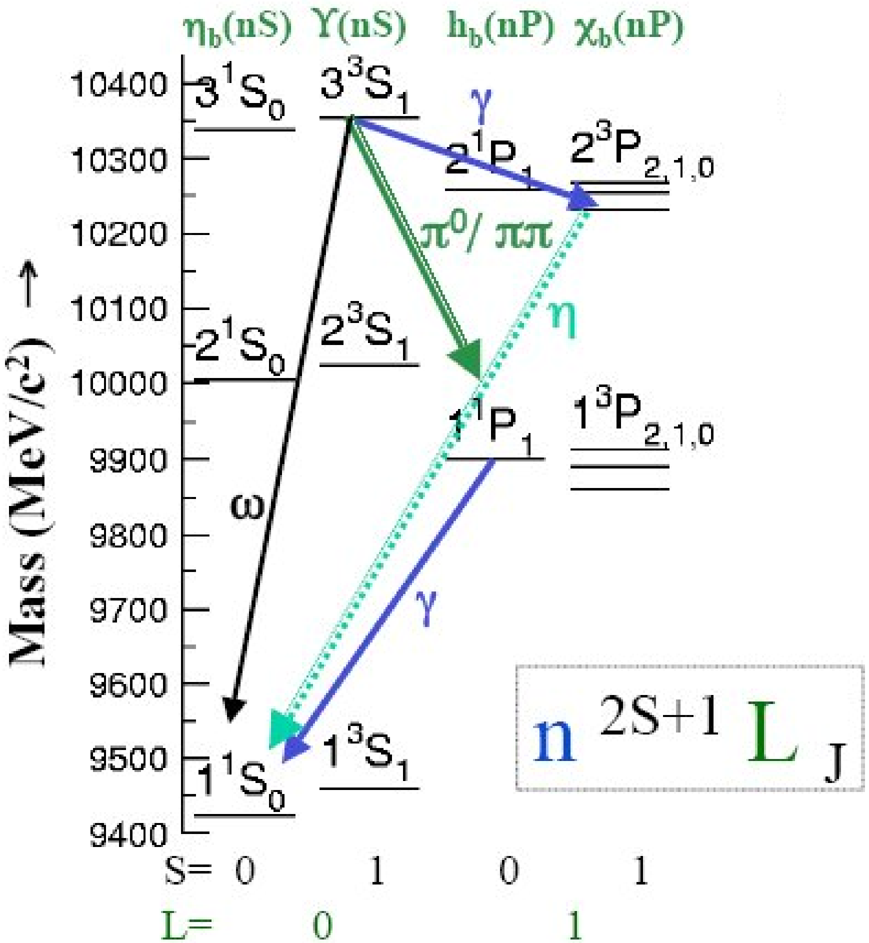
Возможные теоретические объяснения

- 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)]

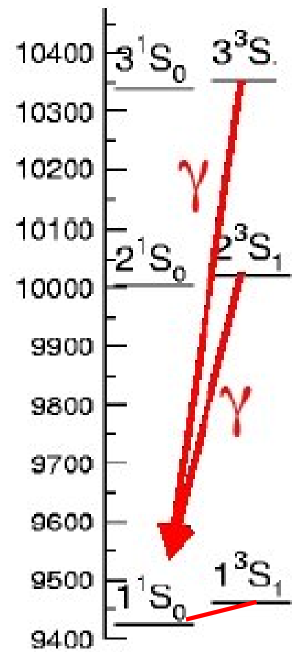
Необходима большая статистика данных и более детальный анализ

Где основное состояние боттомония η_b ?

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



Direct M1 transitions



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

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

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

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

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

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

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

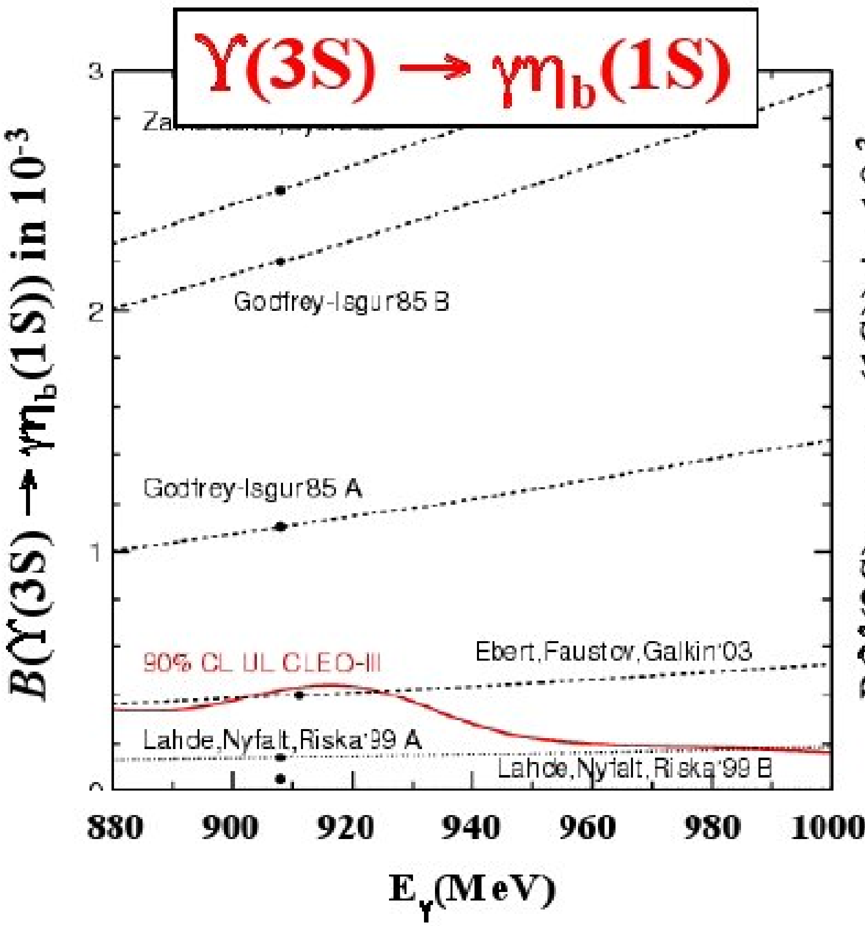
$\rightarrow$ $B(\Upsilon(2S) \to \eta_b(1S)\,\gamma) < 5.1\times10^{-4}$

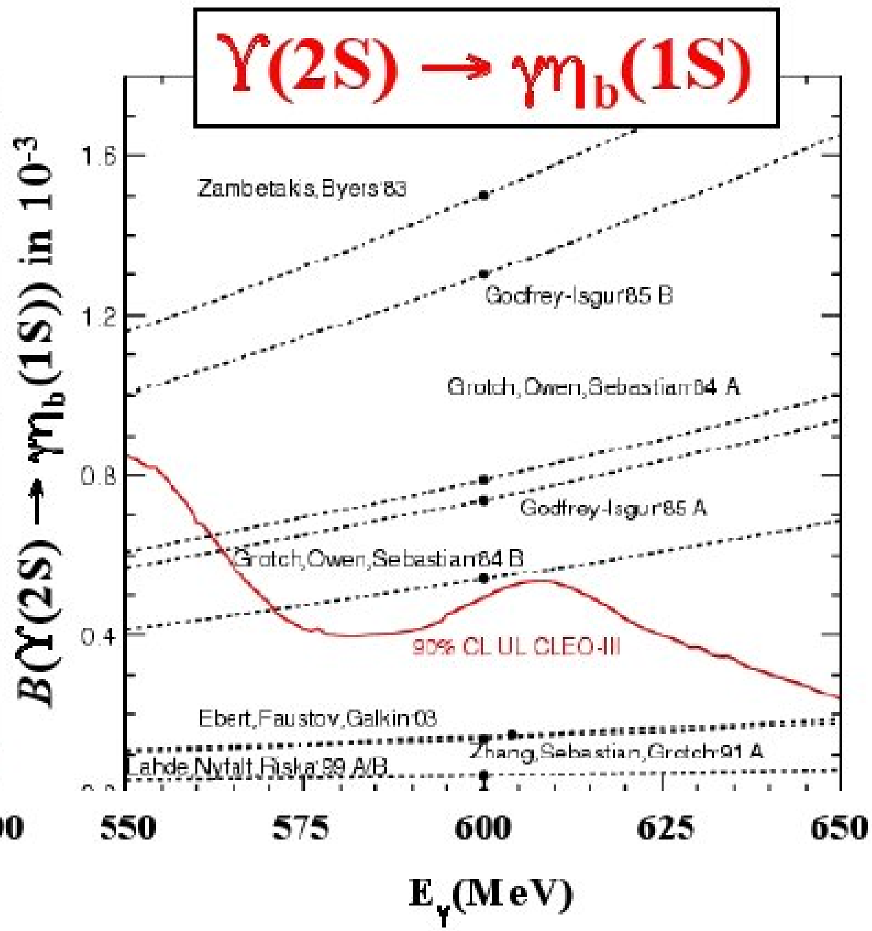
$B(\Upsilon(3S) \to \eta_b(1S)\,\gamma) < 4.3\times10^{-4}$

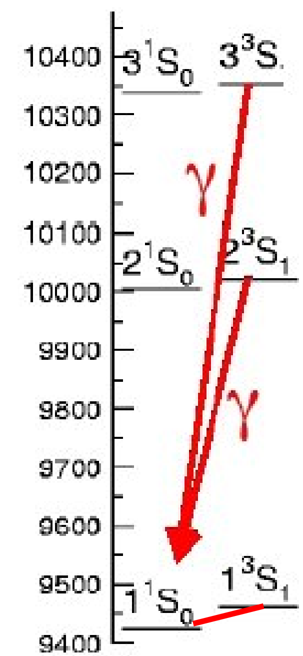
$B(\Upsilon(3S) \to \eta_b(2S)\,\gamma) < 6.2\times10^{-4}$

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

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







Тест pQCD в распадах Υ

Из pQCD → "12% rule"

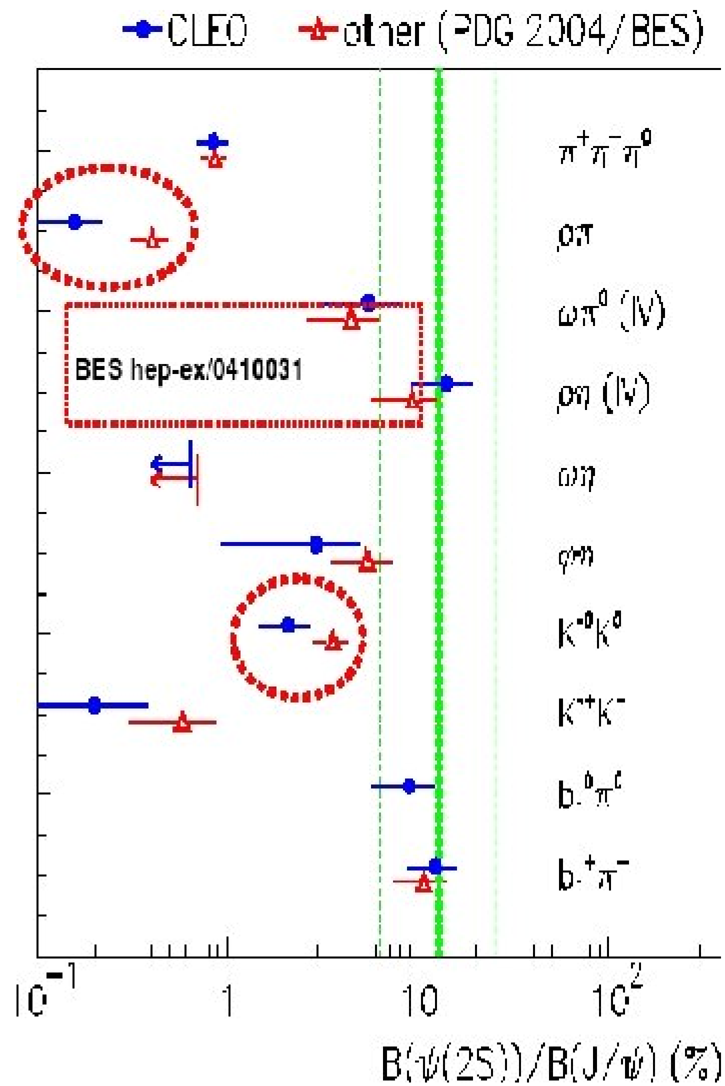
$$Q_\psi = \frac{\mathcal{B}_{\psi(2S)\to h}}{\mathcal{B}_{J/\psi\to h}} = \frac{\mathcal{B}_{\psi(2S)\to e^+e^-}}{\mathcal{B}_{J/\psi\to e^+e^-}} \approx 12\% \,.$$

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

<u>Для проверки необходимо иметь **_N(Υ(1S) ~ N(Υ(2S) ~ N(Υ(3S)_**</u>

$\Upsilon \to$ 2-Body Results

Channel	$\Upsilon(1S)$ BR (10^{-6})	$\Upsilon(1S)$ Sig.	$\Upsilon(2S)$ BR (10^{-6})	$\Upsilon(2S)$ Sig.	$\Upsilon(3S)$ BR (10^{-6})	$\Upsilon(3S)$ 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	-

Боттомоний: поиск хиггсовского бозона

Next-to-Minimal Supersymmetric Model (NMSSM)

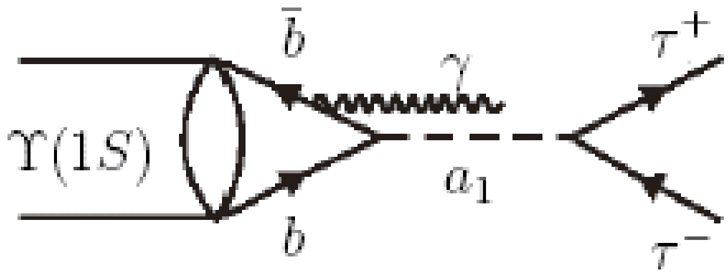
Данные LEP менее ограничивают массу хиггсовского бозона (*M_H~100 ГэВ*).
Возможно существование легкого хиггсовского бозона a_1 ($m(a_1) < 2m(b)$).
(R. Dermisek, J. Gunion, B. McElrath, hep-ph/0612031)

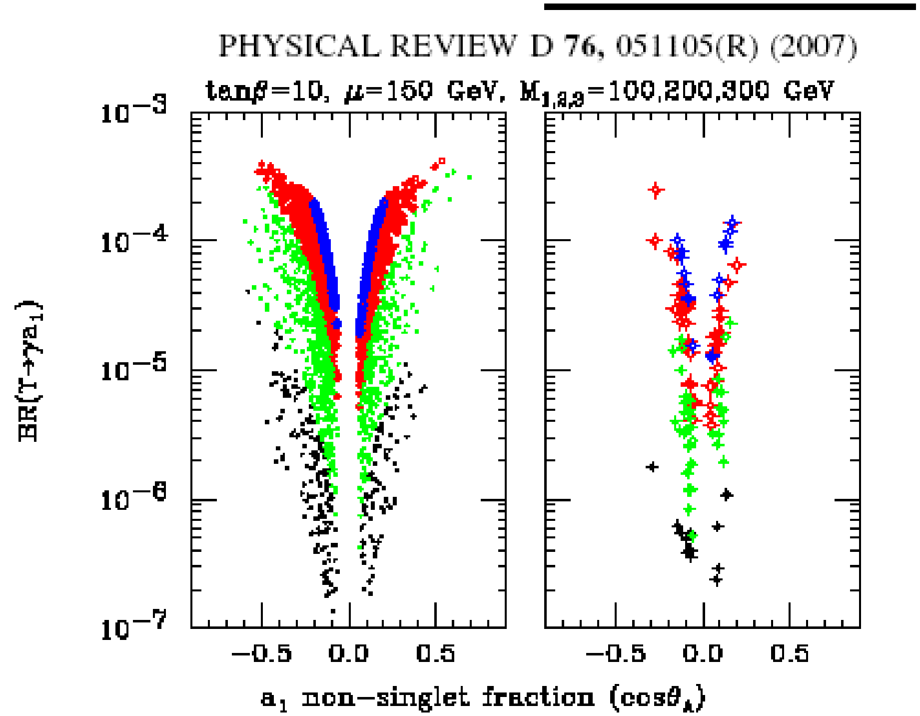
Основная мода распада $H \to a_1 a_1 \to (\tau^+\tau^-)(\tau^+\tau^-)$

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

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 $\Upsilon(3S)$.

A_κ, A_λ, κ, λ 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.

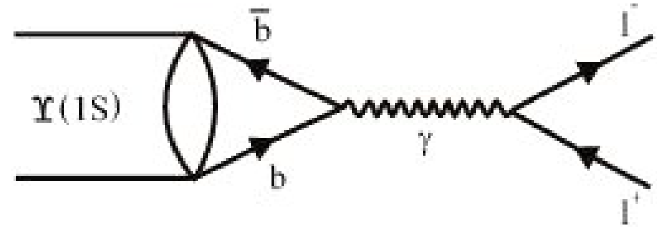
Поиск монохроматического γ-кванта

CLEO limits from 20M Y(1S) decays

Testing Lepton Universality

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

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



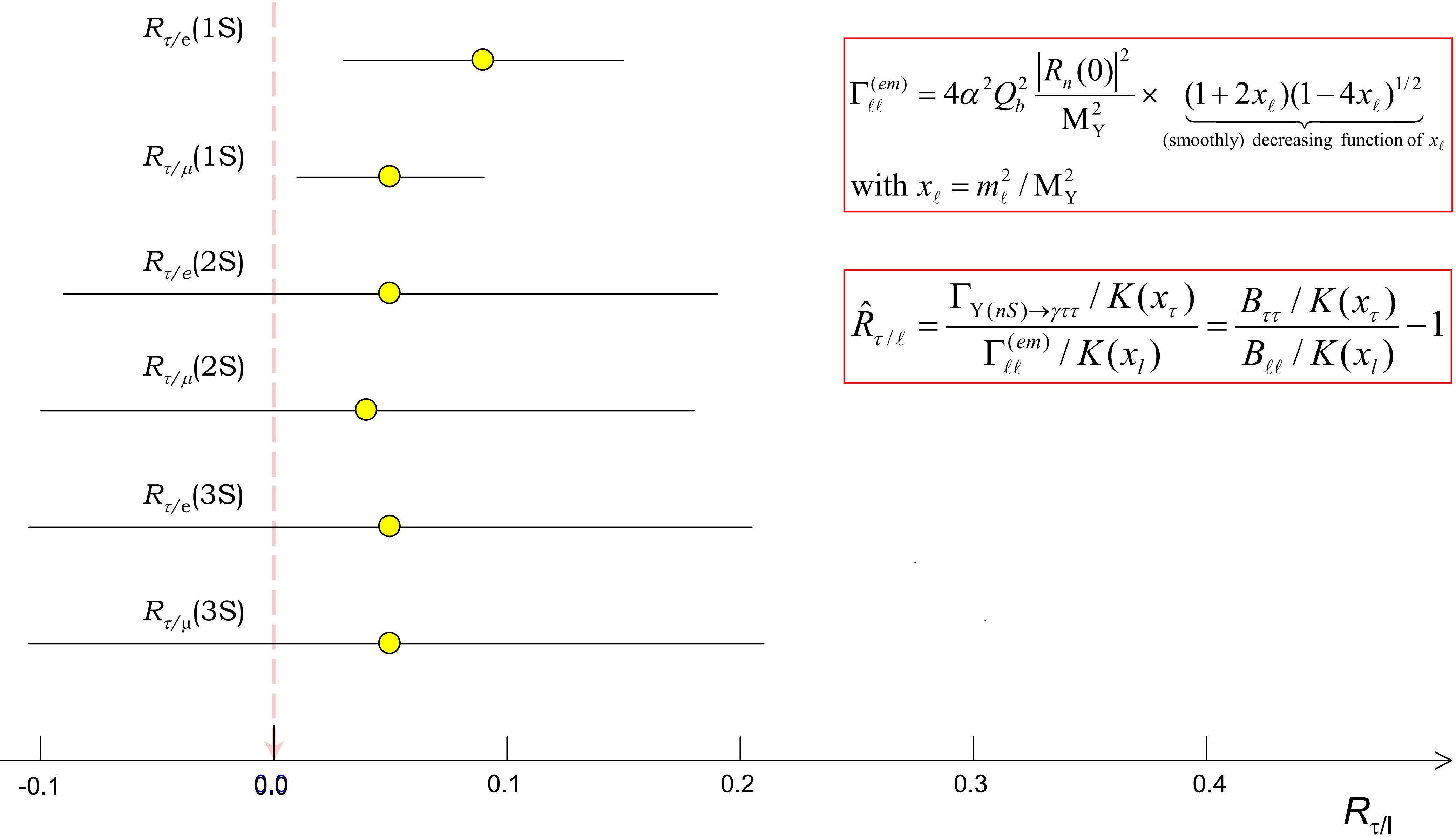
Channel: *	BF[e^+e^-]	BF[$\mu^+\mu^-$]	BF[$\tau^+\tau^-$]	$R_{\tau/l}$
$\Upsilon(1S)$	2.38 ± 0.11 %		2.60 ± 0.10 %	0.09 ± 0.06
$\Upsilon(1S)$		2.48 ± 0.05 %	2.60 ± 0.10 %	0.05 ± 0.04
$\Upsilon(2S)$	1.91 ± 0.16 %		2.00 ± 0.21 %	0.05 ± 0.14
$\Upsilon(2S)$		1.93 ± 0.17 %	2.00 ± 0.21 %	0.04 ± 0.14
$\Upsilon(3S)$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

* From PDG '07

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

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

Lepton Universality Breaking?



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

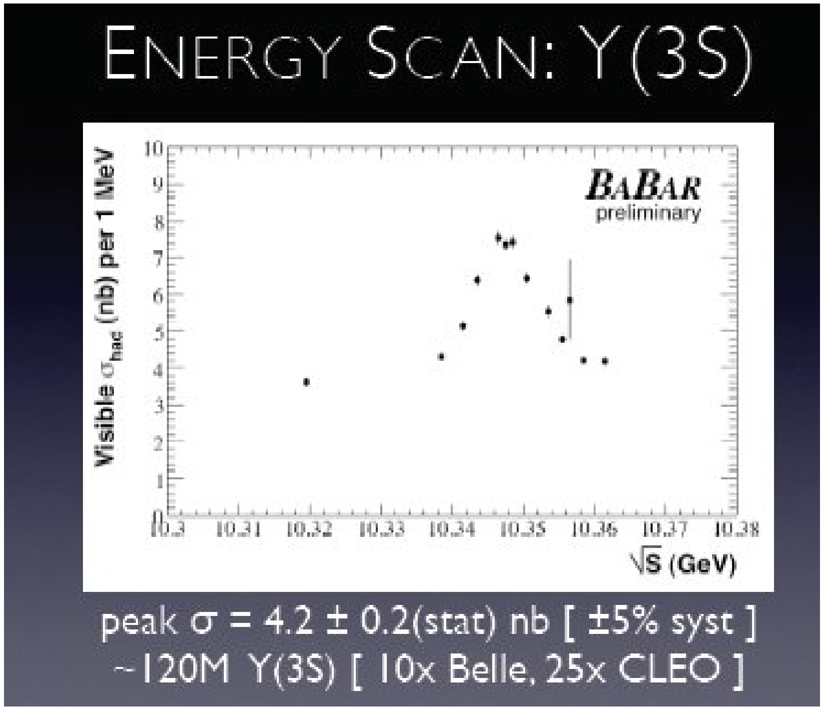
with $x_\ell = m_\ell^2 / M_\Upsilon^2$

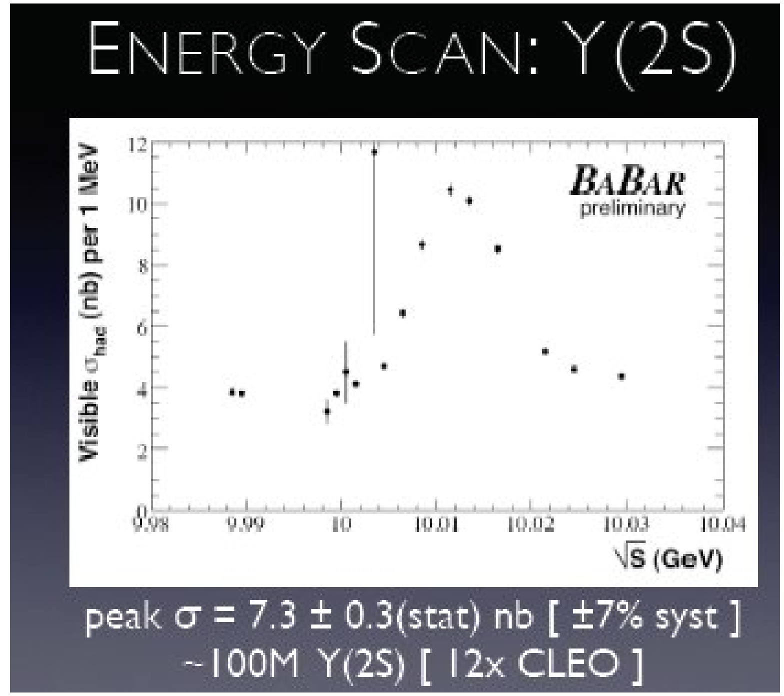
$$\hat{R}_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma\tau\tau} / K(x_\tau)}{\Gamma_{\ell\ell}^{(em)} / K(x_l)} = \frac{B_{\tau\tau} / K(x_\tau)}{B_{\ell\ell} / K(x_l)} - 1$$

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's final run





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

$\Upsilon(1S)$ Run at KEK

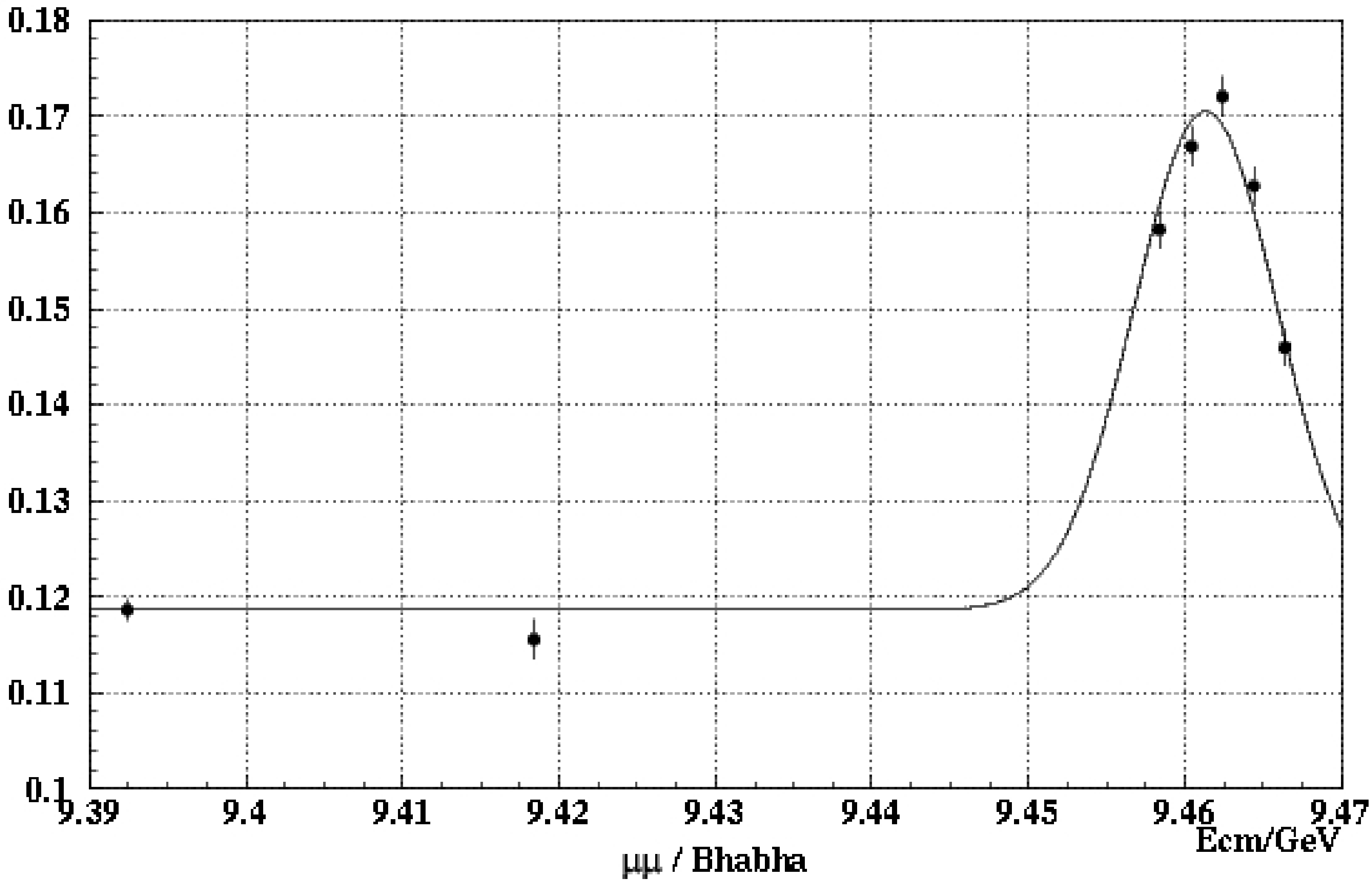
- study of pQCD rule in bottomonium decays
- search for η_b in $\Upsilon(1,2,3S)$ decays
- search for light Higgs a_1 in $\tau^+\tau^-$ decays
- search for H^0 dibaryon in $\Upsilon(1S)$ decays

	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,

no 2S recorded

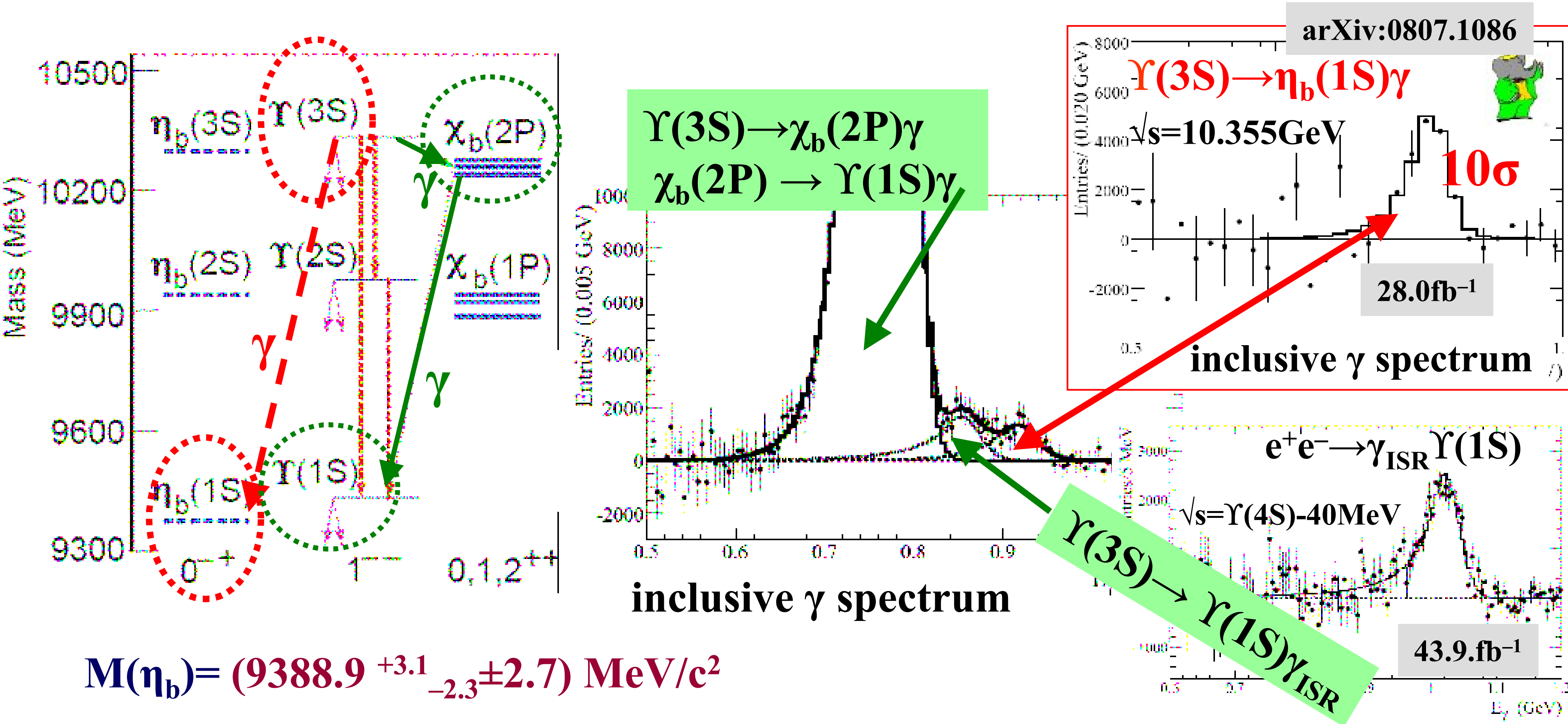
In 2008 - 2009:

$\sqrt{s}$ (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 $\Upsilon(3S) \rightarrow \eta_b(1S)\,\gamma$



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

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

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

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

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. $\leq$ 49)
event selection criteria

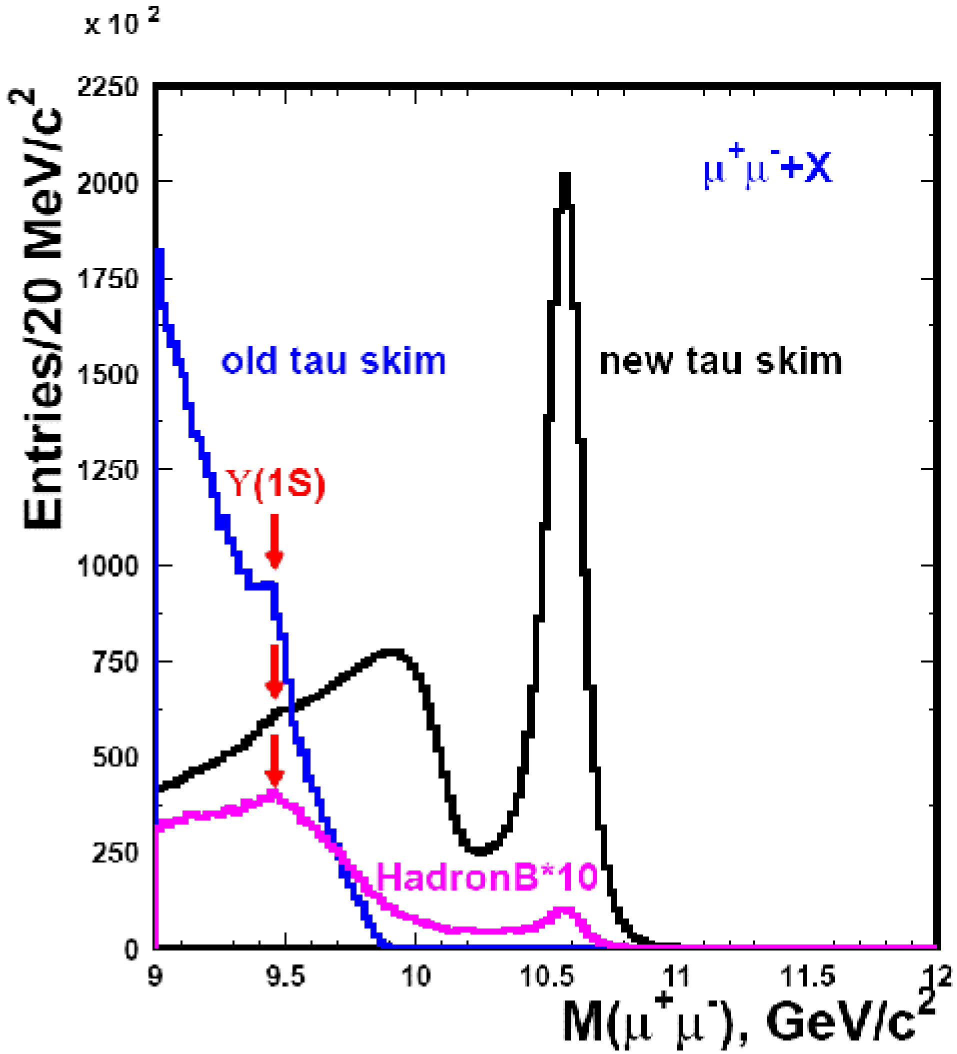
$$\Sigma|P(ch.tr.)| \leq 10 \text{ GeV/c}$$

New τ skim (Exp. $\geq$ 51)

selection criteria

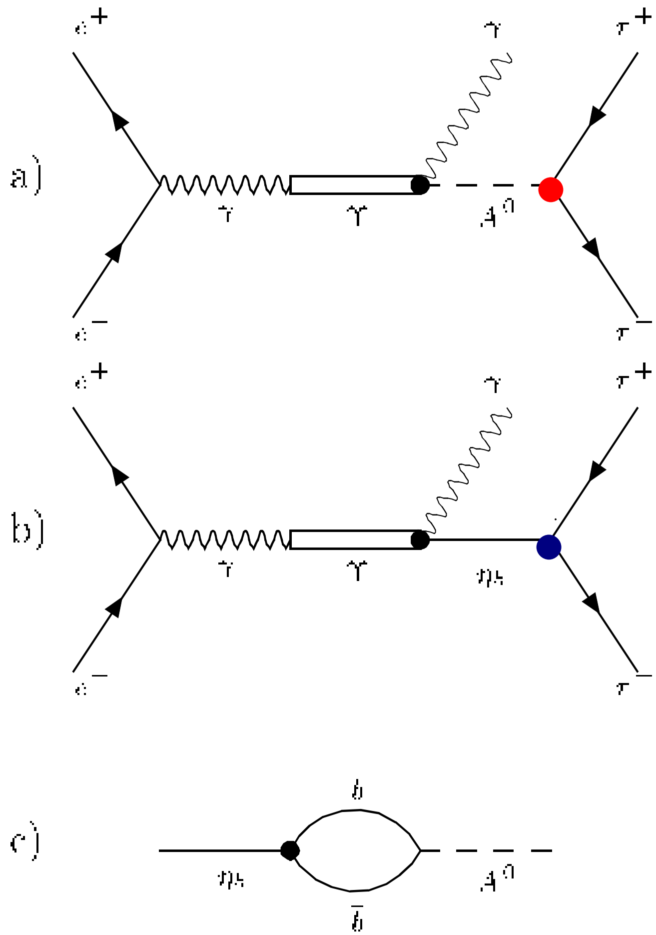
$$\Sigma|P(ch.tr.)| \leq 10 \text{ GeV/c}$$

is removed



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

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



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

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

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

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

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

0

0

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

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

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

hep-ph/0610046

- <u>With the machine sitting on the $\Upsilon(3S)$</u>

Final state & BF

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

BF ~ 2-4 x 10^{-2} $\quad$ BF ~ 2 x 10^{-2} $\quad$ BF ~ 4 - 8 x 10^{-4}

Compare rates

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

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

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

BF ~ 2 x 10^{-2} $\quad$ BF ~ 2 x 10^{-2}

Compare rates

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

$l^+ l^- X$

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

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

Systematic error ≤ 0.037

- <u>With the machine sitting on the $\Upsilon(4S)$</u>

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

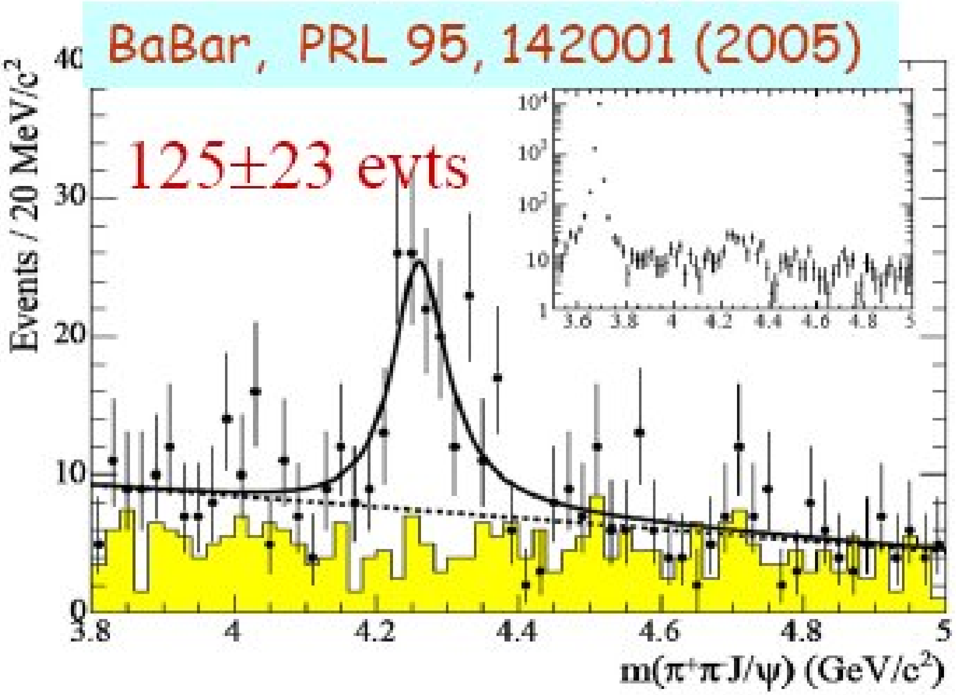
BF ~ 10^{-4} $\quad$ BF ~ 2 x 10^{-2} $\quad$ BF ~ 2 x 10^{-6}

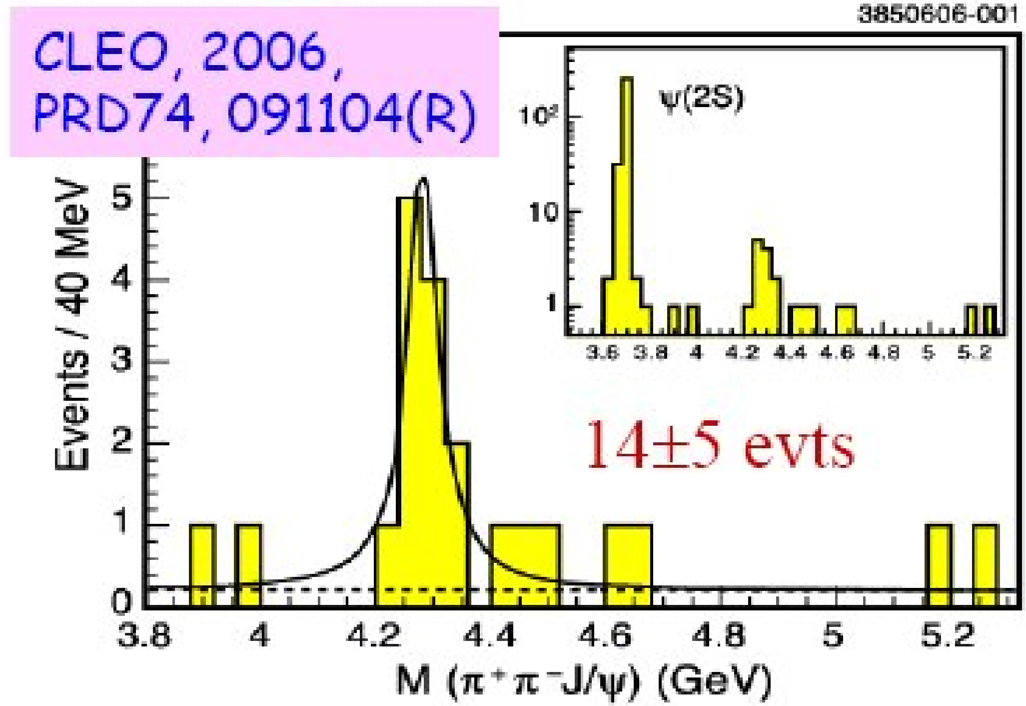
Compare rates

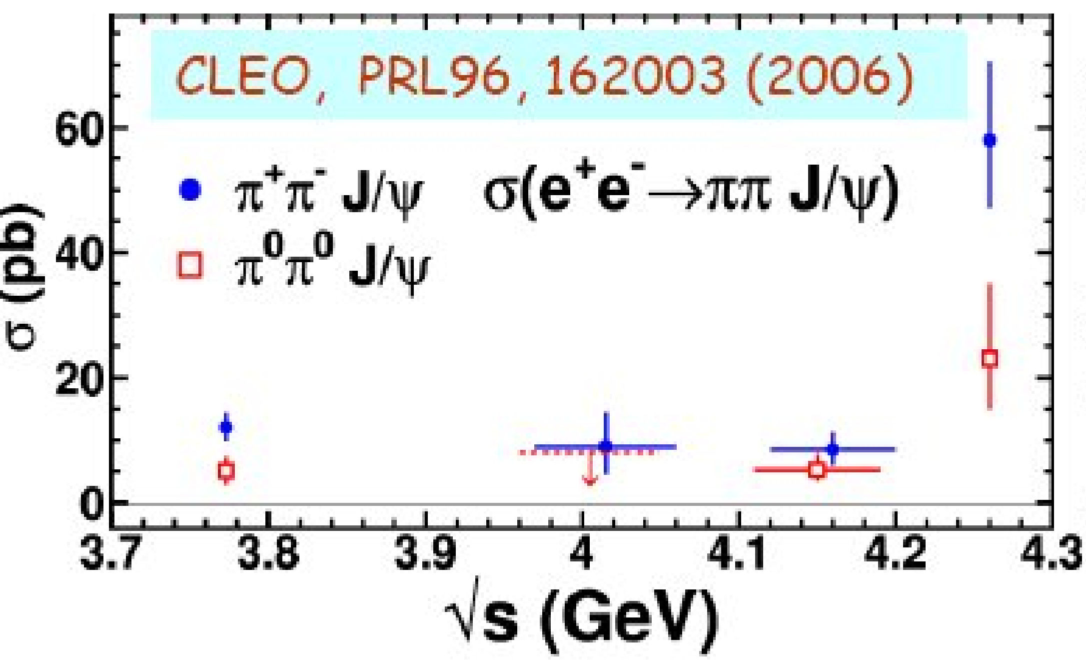
$\Upsilon(4S) \to \pi^+ \pi^- \Upsilon(1S, 2S) \to \tau^+ \tau^-$ $\quad$ $\pi^+ \pi^- l^+ l^- X$

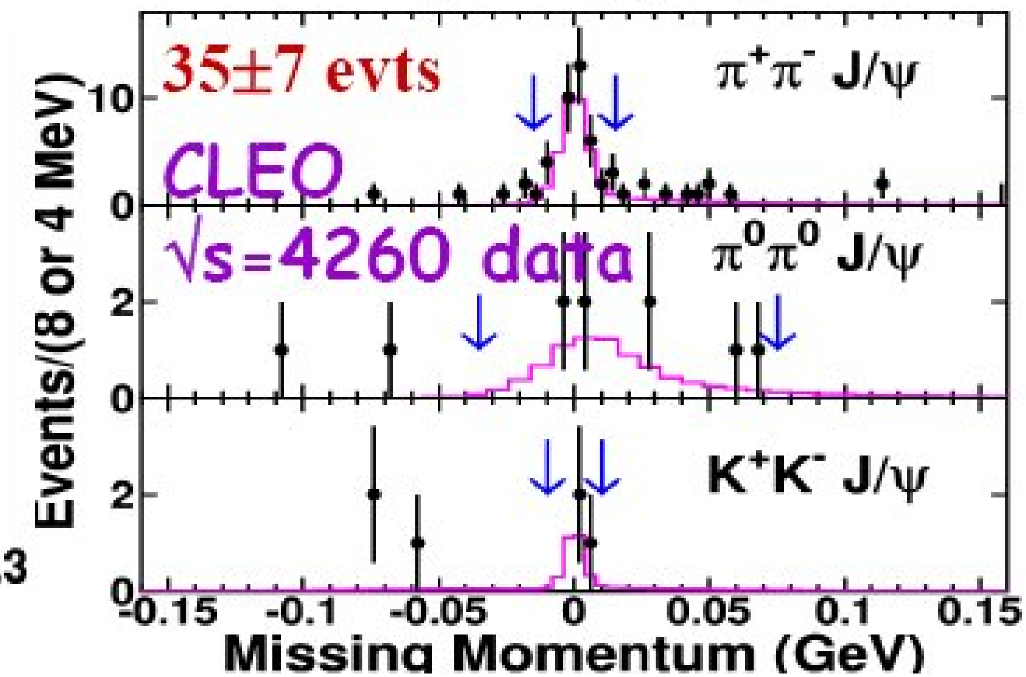
BF ~ 10^{-1} $\tau^+ \tau^- \to l^+ l^- X, l = e, \mu$ $\quad$ BF ~ 2 x 10^{-7}

Y(4260) in other experiments









Y(4260) in other experiments

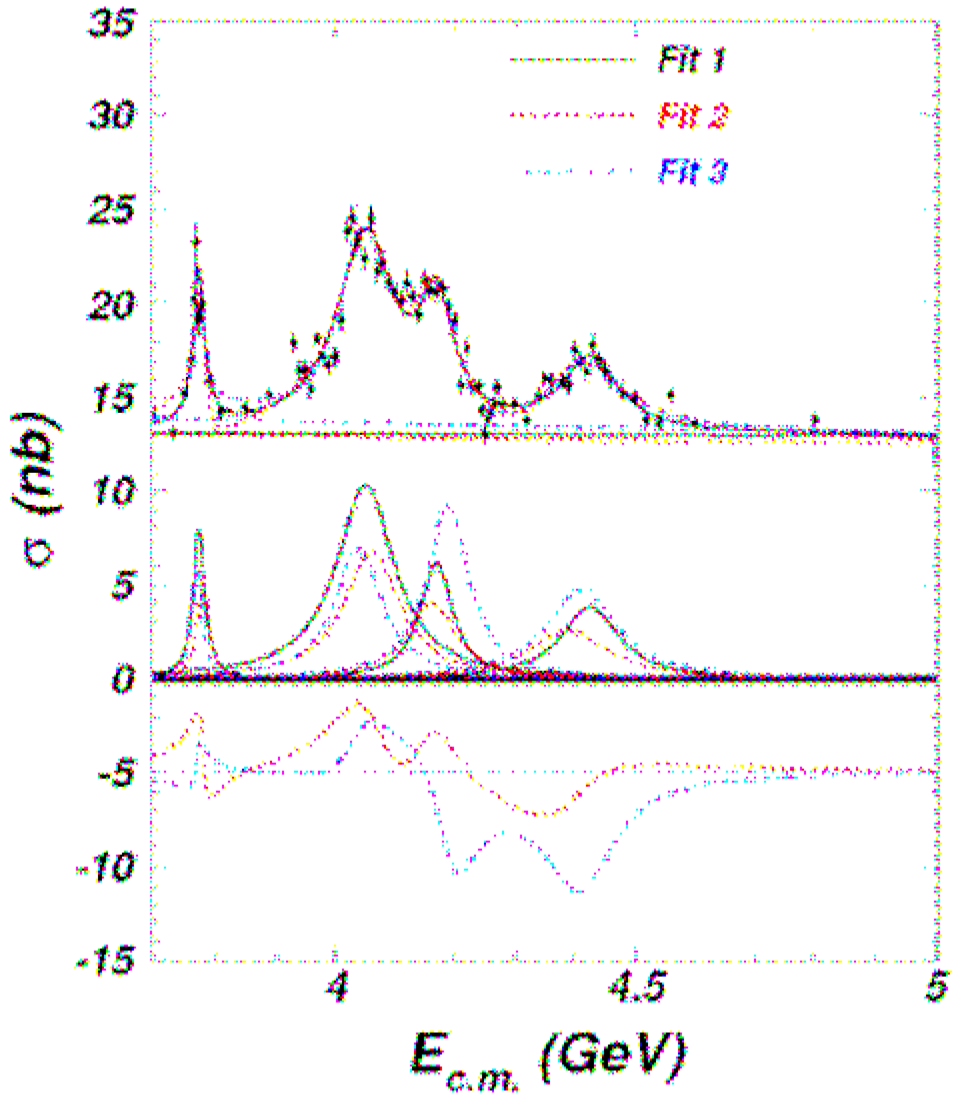
X.H. Mo et al, PLB **640**, 182 (2006)
Using R-values from BES experiment.
Γ_{ee}<580 eV @90% C.L.

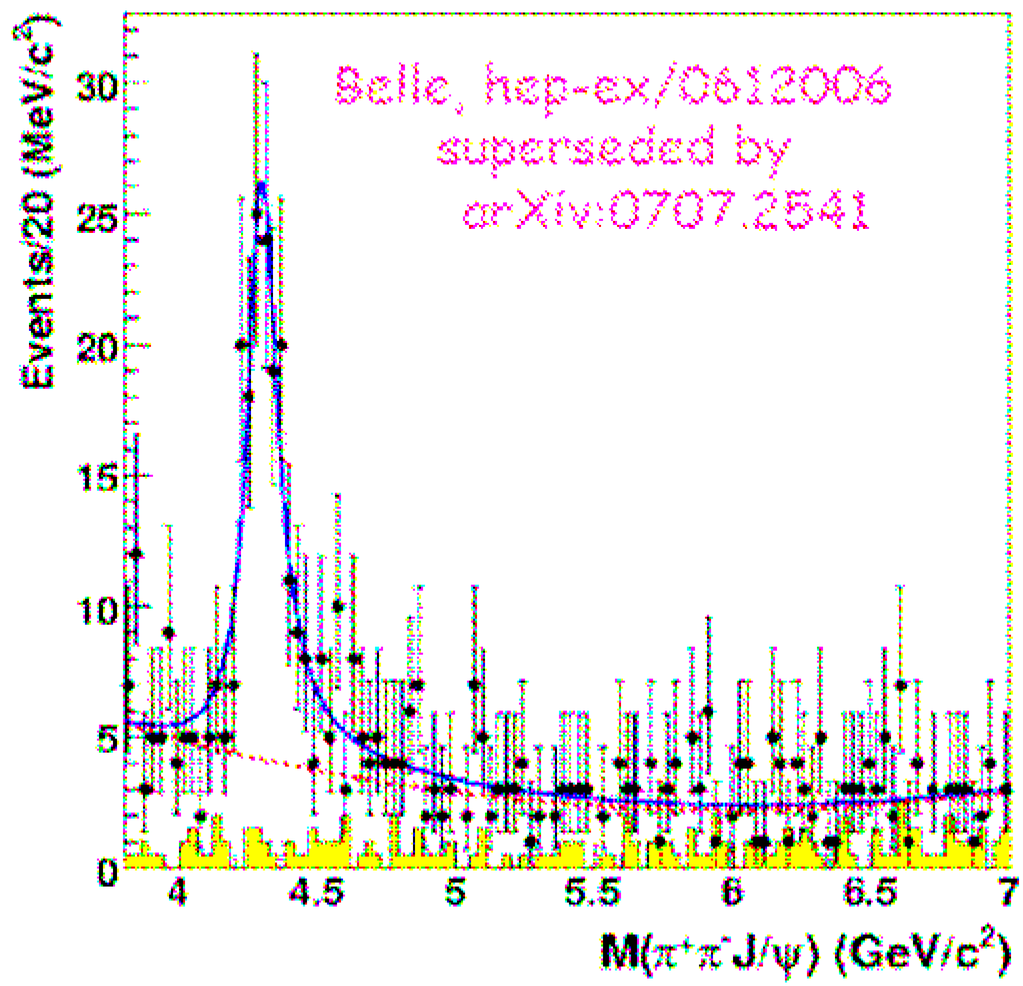
$N = 165 \pm 24$

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

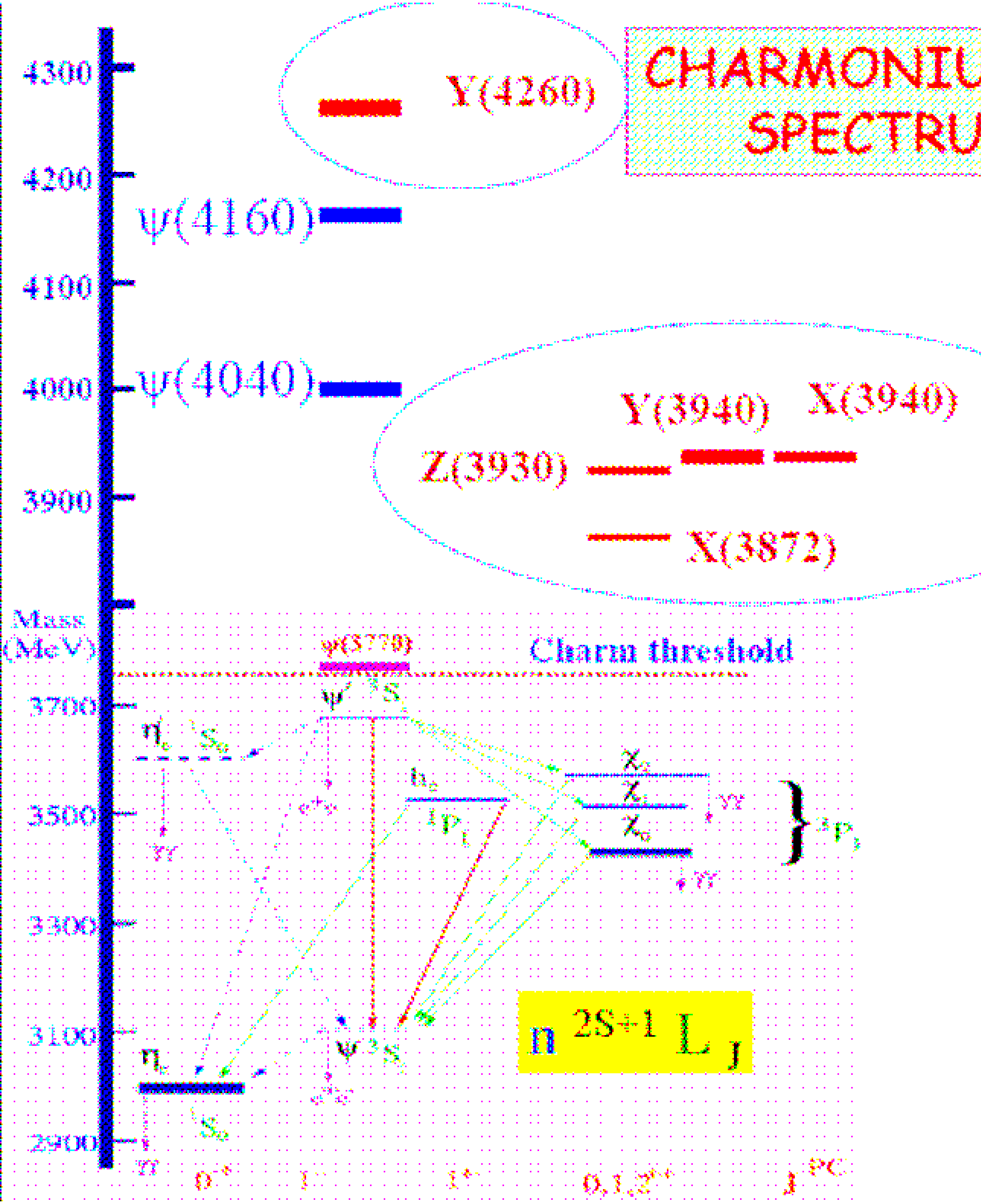
$\Gamma = 133 \pm 26^{+13}_{-6}$ MeV

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





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

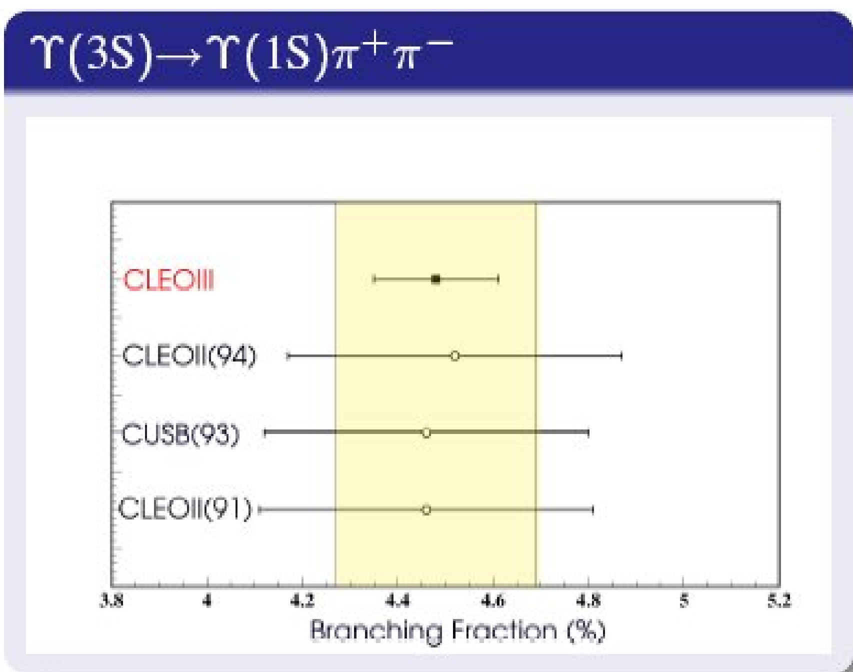
Inclusive : $\mathcal{B}(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) = (4.48 \pm 0.01 \pm 0.14)\%$

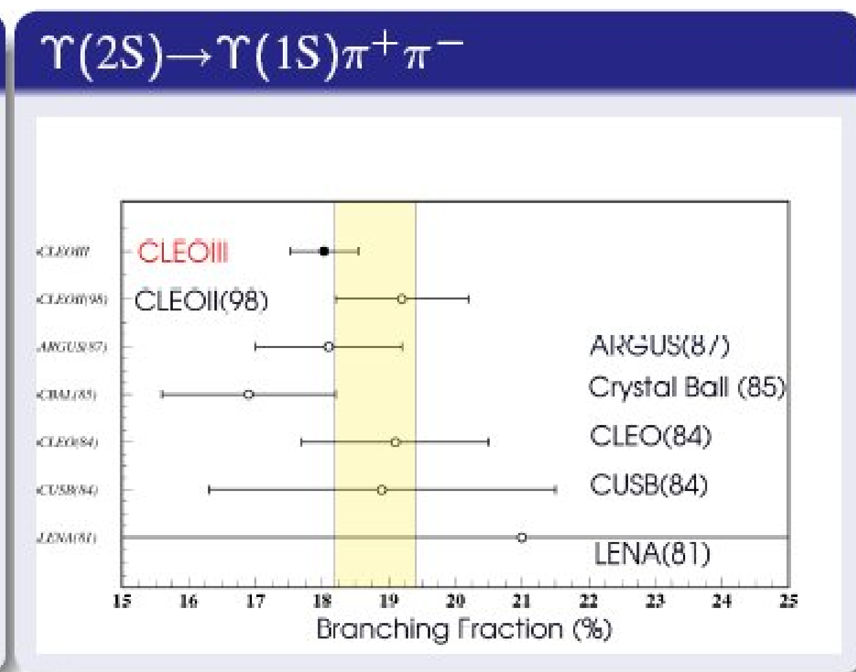
Average: $\mathcal{B}(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) = (4.48 \pm 0.13)\%$

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

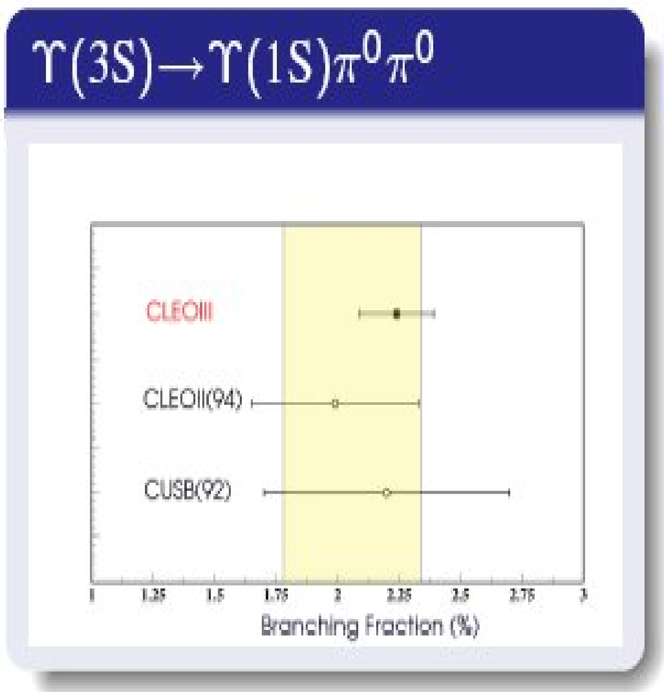


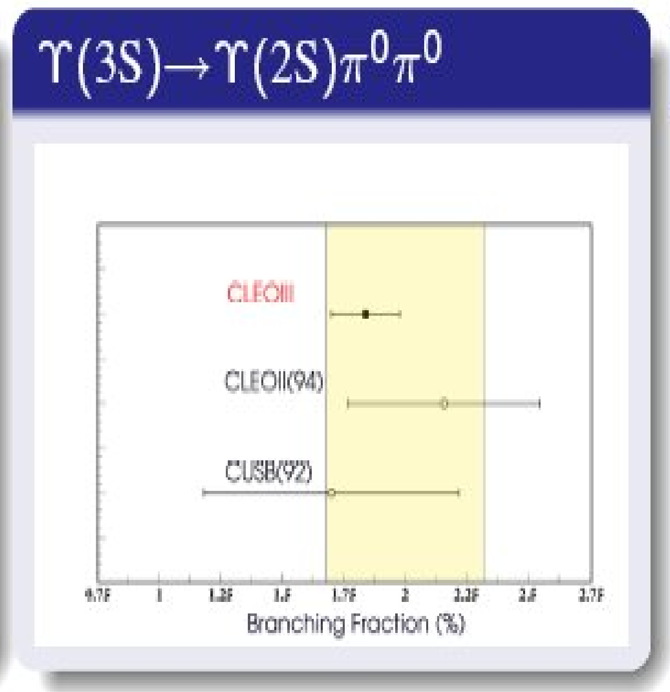


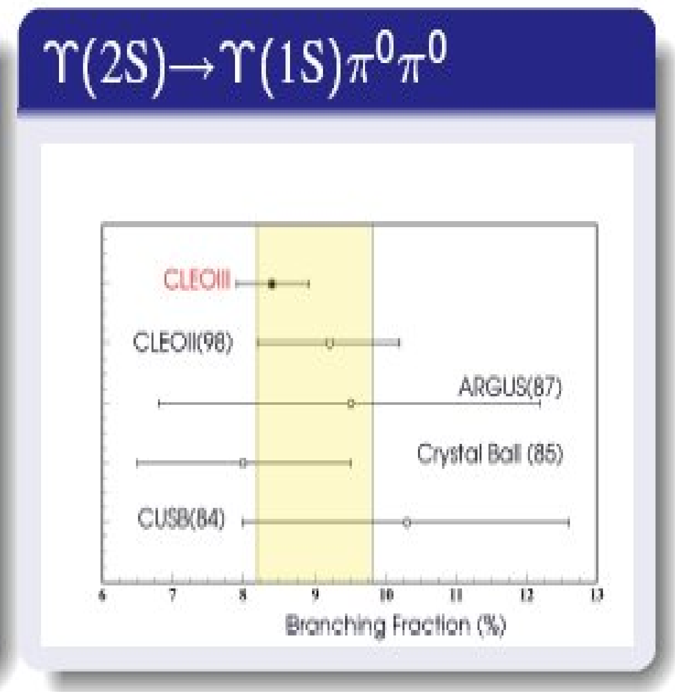
New Measurements of Upsilon(3S) Branching Fractions (CLEO)

PRELIMINARY

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



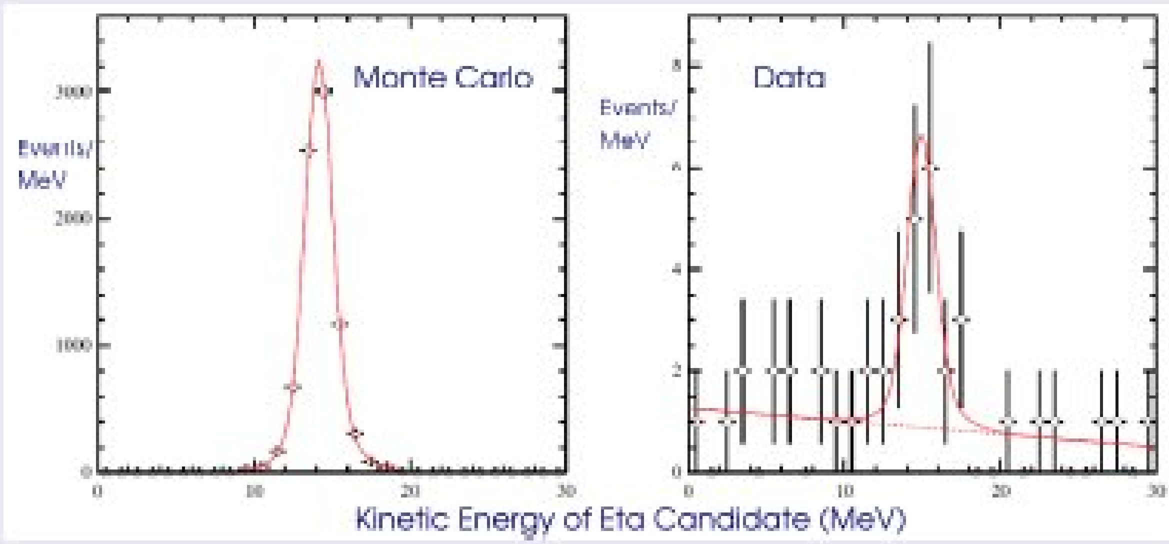




CLEO's first evidence for $\Upsilon(2S) \rightarrow \Upsilon(1S)\ \eta$

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,

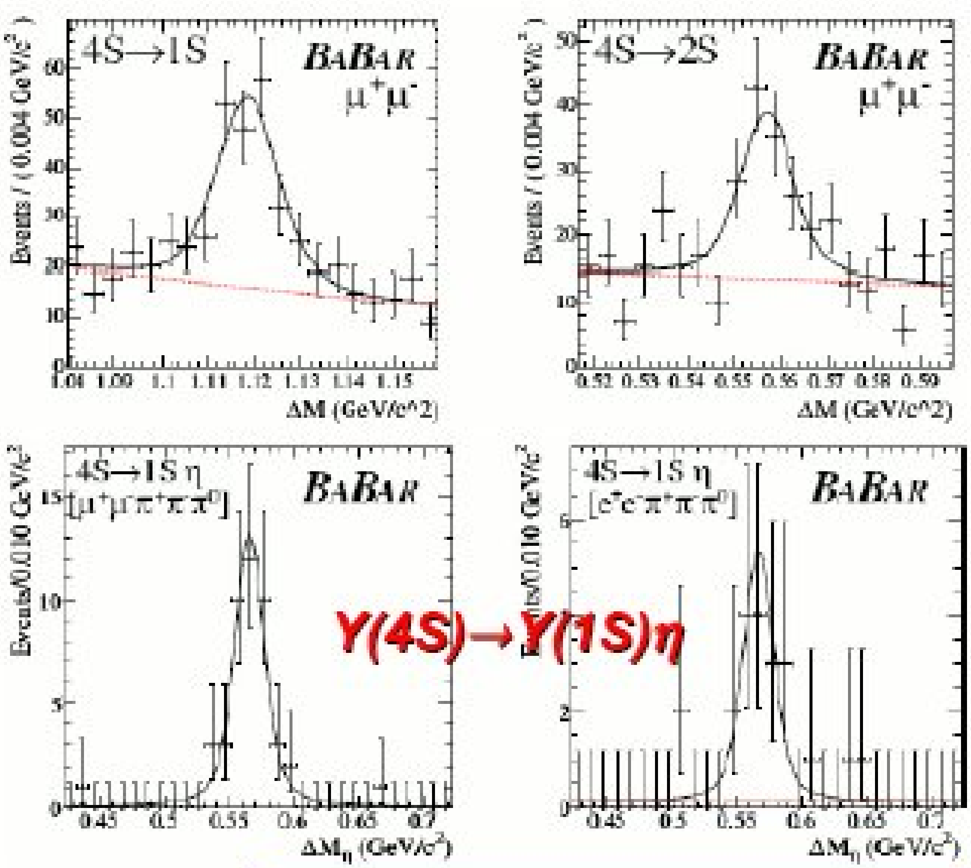
$$BF(\Upsilon(2S) \to \Upsilon(1S)\pi^0) < 1.6 \times 10^{-4}$$

Expect this is 16% of the η mode

BaBar discovers Y(4S)→Y(1S)η

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

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



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

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

Unexpected result:

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

E1M2/
E1E1

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

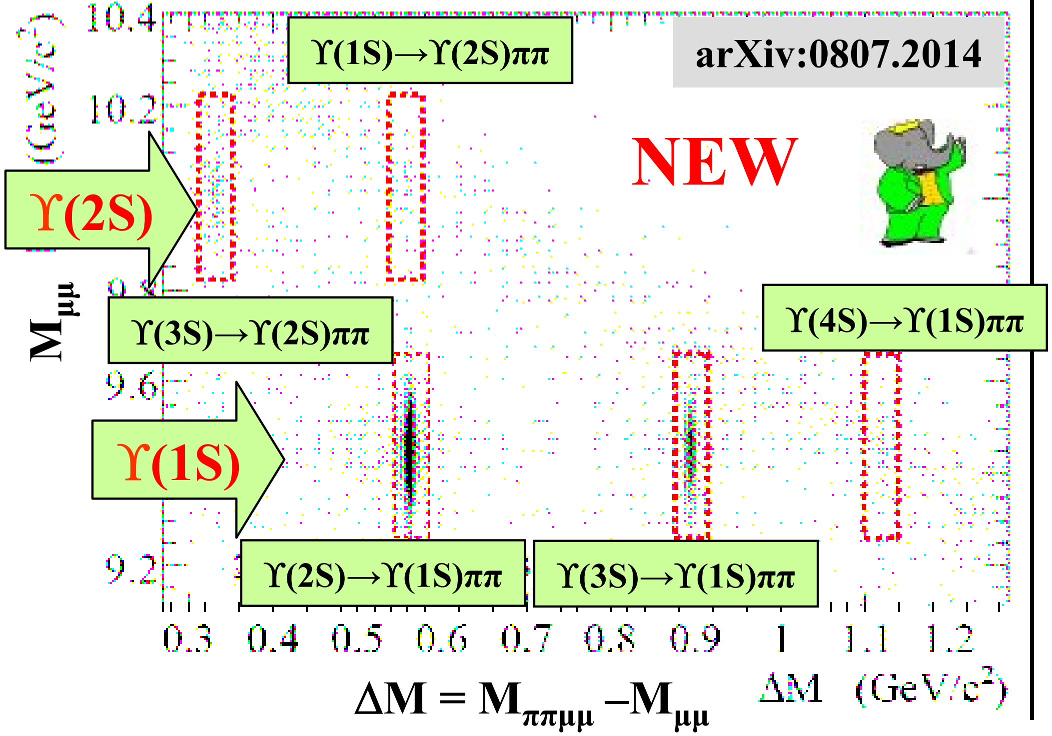
preliminary

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

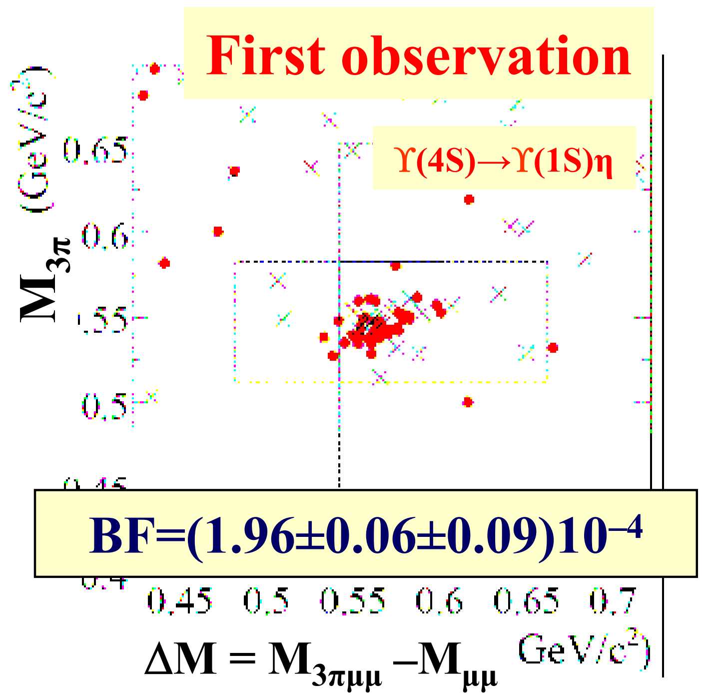
Hadronic transition between Υ states

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

$\Upsilon(nS)\rightarrow l^+l^-\quad l^+l^- = \mu^+\mu^-, e^+e^-$



$\Upsilon(mS)\rightarrow\Upsilon(nS)\eta,\ \ \eta\rightarrow\pi^+\pi^-\pi^0$



				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	$2.41\pm0.40\pm0.12$	–