Bottomonium decays at Belle

$\Upsilon(5S) \rightarrow \eta\, \Upsilon(1,2\ S)$
Two-meson decays
Hyperon and baryon production

Umberto Tamponi
tamponi@to.infn.it

INFN, Sezione di Torino
University of Torino

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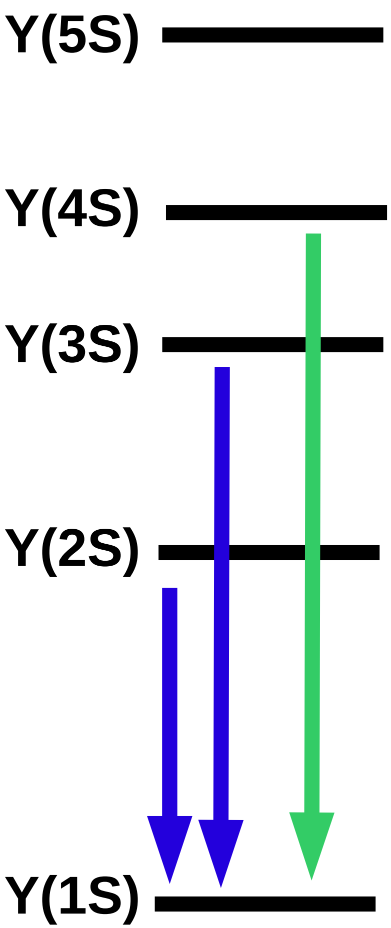
Part I

$\Upsilon(5S) \rightarrow \eta\ \Upsilon(1,2\ S)$

$\Upsilon(nS) \to \eta\Upsilon(mS)$



BF(2S → 1S) = (**3.57** ± 0.25 ± 0.21) x **10^{-4}** Belle PRD 87, 011104(R)

(**2.39** ± 0.31 ± 0.14) **x 10^{-4}** BaBar PRD 84, 092003

(**2.1** ± 0.7 ± 0.3) x **10^{-4}** CLEO PRL 101:192001

3-4 x 10^{-4} Theory Prog. Part. Nucl. Phys. 61, 455

Front. Phys. China 1, 19 (2006)

BF(3S → 1S) < **1** x **10^{-4}** BaBar PRD 84, 092003

5-10 x 10^{-4} Theory

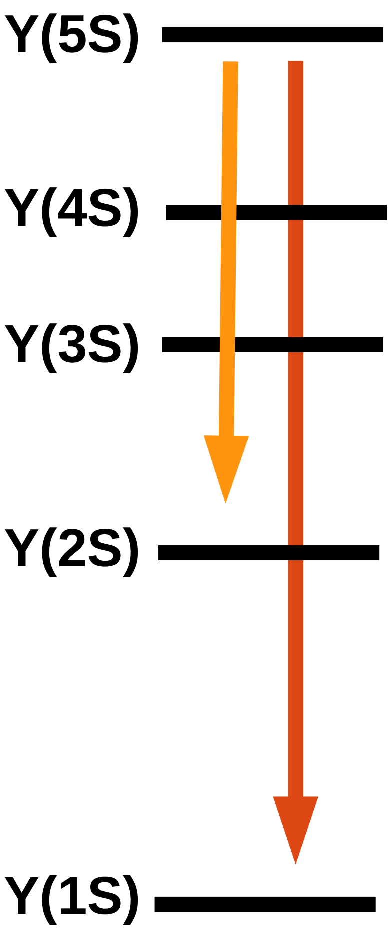
$BF(\eta)/BF(\pi^+\pi^-) \sim 10^{-3}$

BF(4S → 1S) = (**1.96** ± 0.06 ± 0.09) x **10^{-4}** BaBar PRD 78,112002

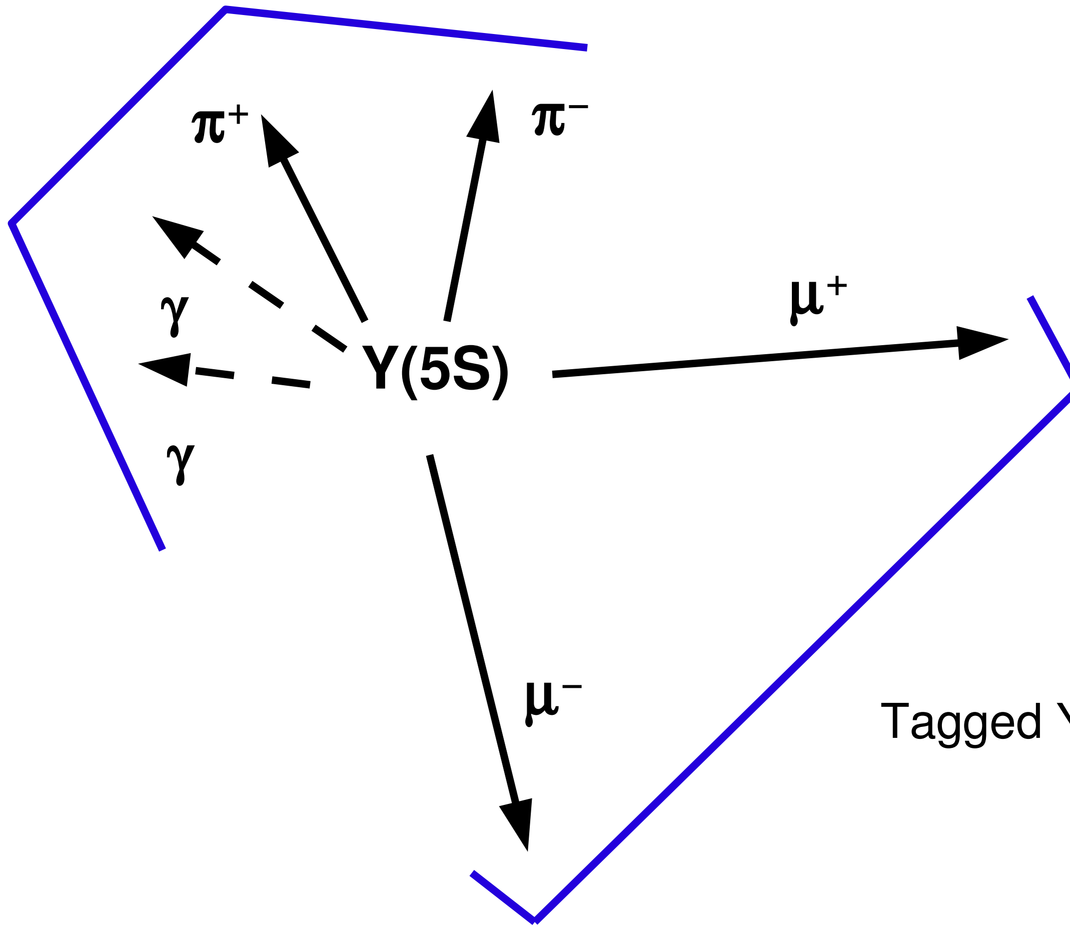
$BF(\eta)/BF(\pi^+\pi^-) \sim 2.5$

Υ(5S)→ ηΥ(1,2S)

Preliminary. First shown at Moriond QCD 2012



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

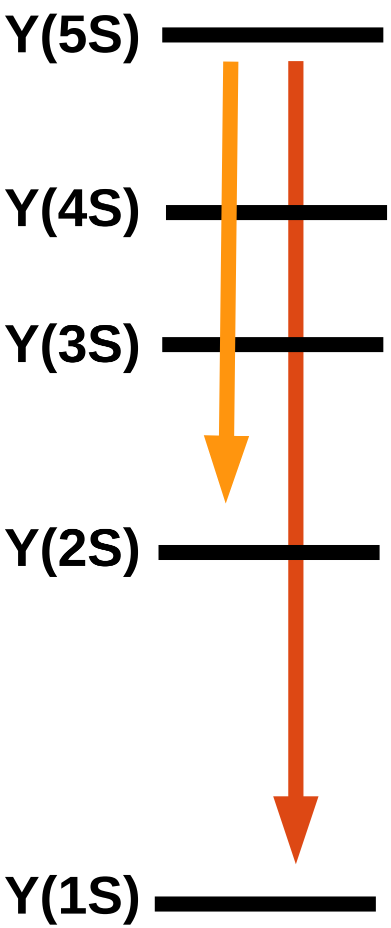


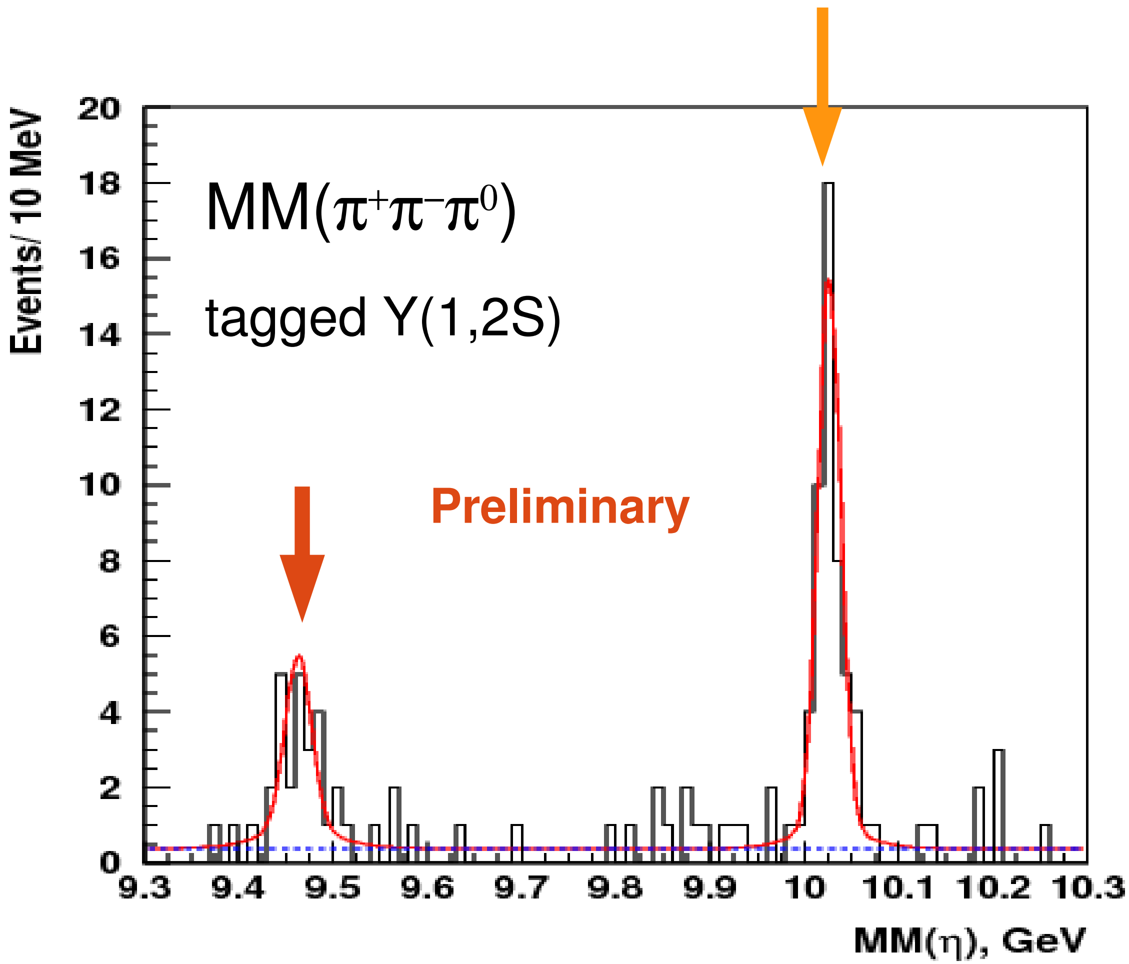
Tagged Υ(1,2S) → $\mu^+\mu^-$

Cross check: Υ(2S) → Υ(1S)$\pi^+\pi^-$ + $\eta \to \gamma\gamma$

$\Upsilon(5S) \to \eta\Upsilon(1,2S)$

Preliminary. First shown at Moriond QCD 2012

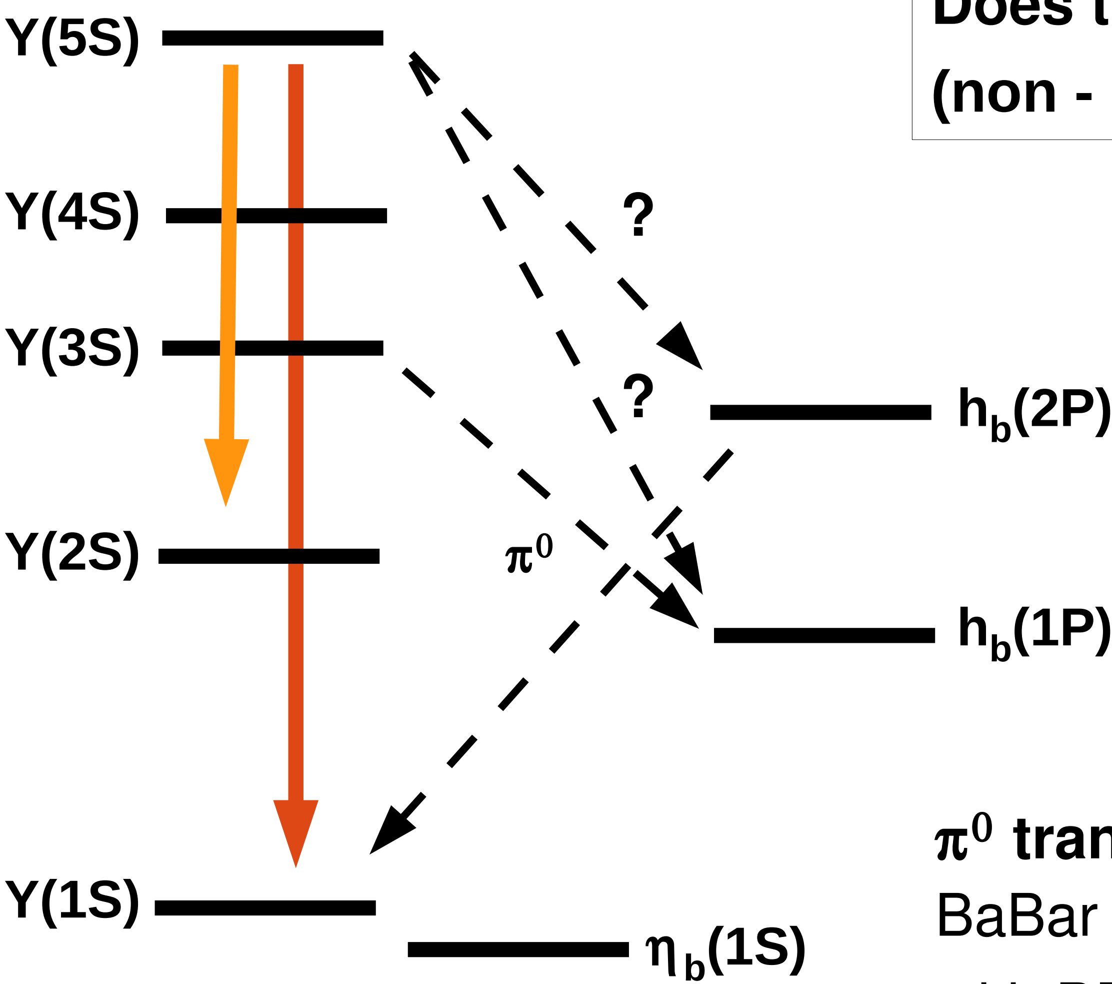




BF[5S → 1S] = $(7.3 \pm 1.6 \pm 0.8) \times 10^{-4}$ **BF(η)/BF(π+π−) = 0.16**

BF[5S → 2S] = $(38 \pm 4 \pm 5) \times 10^{-4}$ **BF(η)/BF(π+π−) = 0.48**

$\Upsilon(nS) \to \eta\Upsilon(mS)$: open questions



Does the $\Upsilon(5S)$ decay to $\eta\ h_b(2P)$ (non - spin - flipping)?

π^0 transitions?

BaBar **$\Upsilon(3S) \to \pi^0\ h_b(1P)$** at 3.1σ

with BF > 10 x BF[$\Upsilon(3S) \to \eta\ \Upsilon(1S)$]

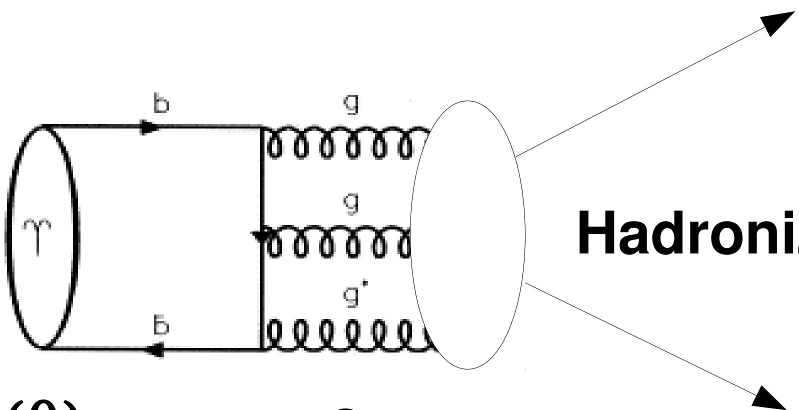
Part II

Two-meson decays

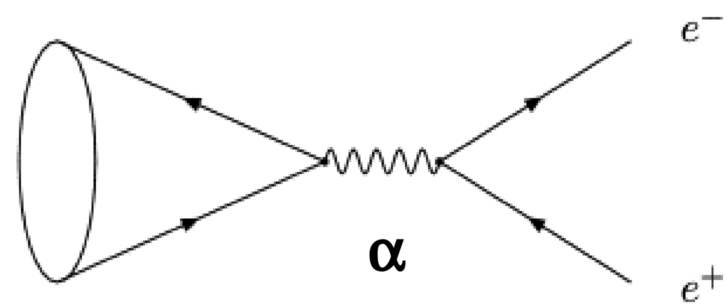
Υ(1,2S)→ light hadrons: 77% rule

OZI- suppressed quarkonium decays: $(b\bar{b}), (c\bar{c}) \rightarrow ggg$

12% rule in charmonium: violated in some VT and VP final states ($\rho\pi$ puzzle)



$\psi(0)$ αs



$\psi(0)$

$\Psi'(0)$, αs, had. $\Psi'(0)$, α

$$Q_c = \frac{B[\psi' \rightarrow \text{hadrons}]}{B[J/\psi \rightarrow \text{hadrons}]} = \frac{B[\psi' \rightarrow e^+e^-]}{B[J/\psi \rightarrow e^+e^-]} = 12\%$$

$\Psi(0)$, αs, had. $\Psi(0)$, α

$$Q_Y = \frac{B[Y(2S) \rightarrow \text{hadrons}]}{B[Y(1S) \rightarrow \text{hadrons}]} = \frac{B[Y(2S) \rightarrow e^+e^-]}{B[Y(1S) \rightarrow e^+e^-]} = 77\%$$

From non-relativistic QCD.
Expected to work better
but to be tested

$\Upsilon(1,2S) \rightarrow$ light hadrons

Preliminary and Phys. Rev. D 86, 031102(R) (2012)

2 body decay

Phys. Rev. D 86, 031102(R) (2012)

$\phi f'_2$	ρa_2	Vector-
ωf_2	$K^{*0}\overline{K}_2{}^0$	Tensor

$K_1(1270)^+ K^-$	Axial-
$K_1(1400)^+ K^-$	Pseudoscalar
$b_1(1235)^+ \pi^-$	

New

$K^*\overline{K}^0$	
$K^{*-}K^+$	Vector-
$\omega\pi^0$	Pseudoscalar
$\rho\pi$	

$\Upsilon(1,2S) \to$ light hadrons

2-body decay

Phys. Rev. D 86, 031102(R) (2012)

$\phi f'_2$ ρa_2
ωf_2 $K^{*0}\overline{K}_2{}^0$
Vector-Tensor

$K_1(1270)^+ K^-$
$K_1(1400)^+ K^-$
$b_1(1235)^+ \pi^-$
Axial-Pseudoscalar

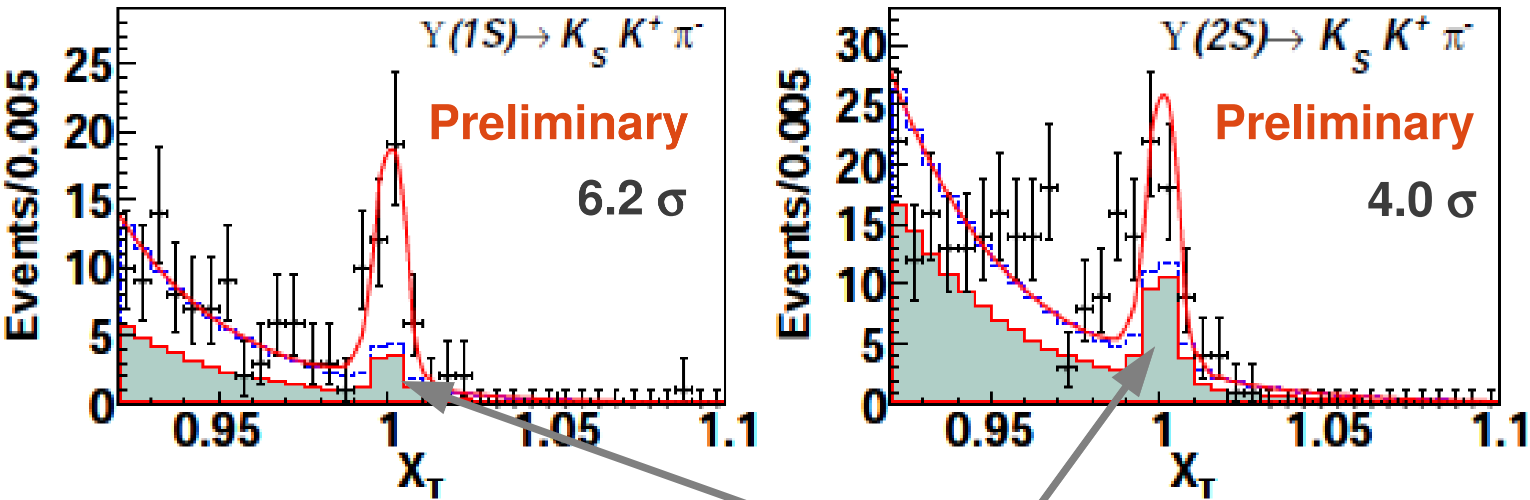
$K^*\overline{K}^0$
$K^{*-}K^+$
$\omega\pi^0$
$\rho\pi$
New
Vector-Pseudoscalar

3-, 4-bodies final state (f)

$K^{*0}K^-\pi^+$
$\omega\pi^+\pi^-$
ϕK^-K^+

$K_s{}^0K^-\pi^+$
$\pi^+\pi^-\pi^0\pi^0$
$\pi^+\pi^-\pi^0$
New

Υ(1,2S)→ 3, 4 bodies



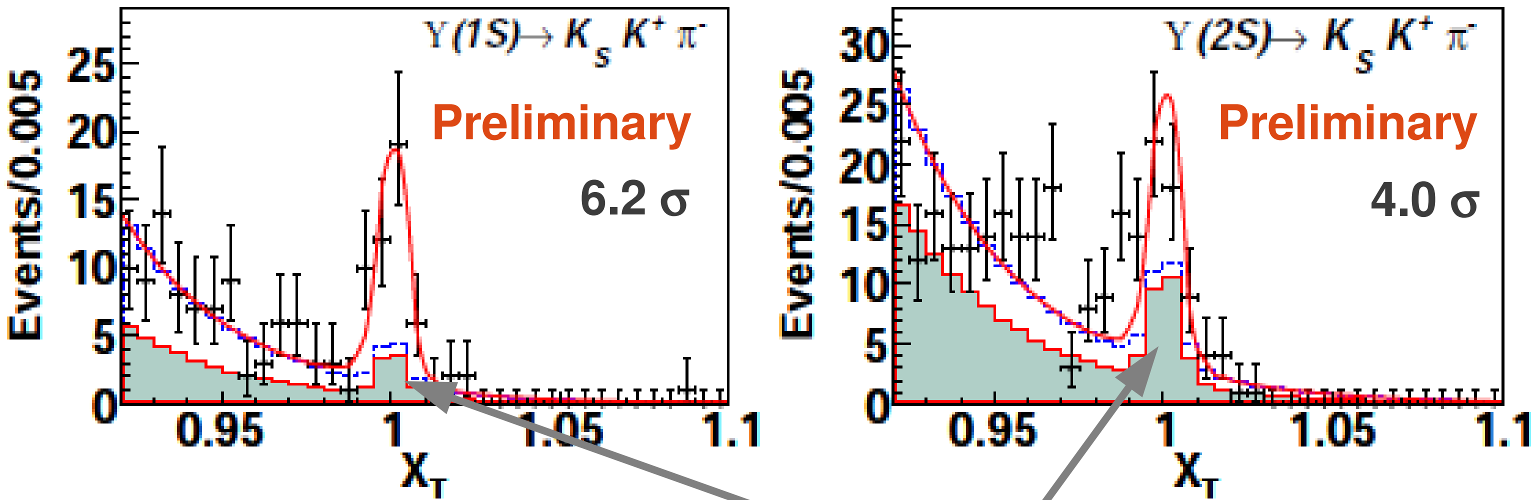
$$X_T = \frac{\sum E_i}{\sqrt{s}}$$

$e^+e^- \rightarrow q\bar{q} \rightarrow f$

Estimated with data below Υ(4S)

Υ(1,2S)→ 3, 4 bodies

Phys. Rev. D 86, 031102(R) (2012)



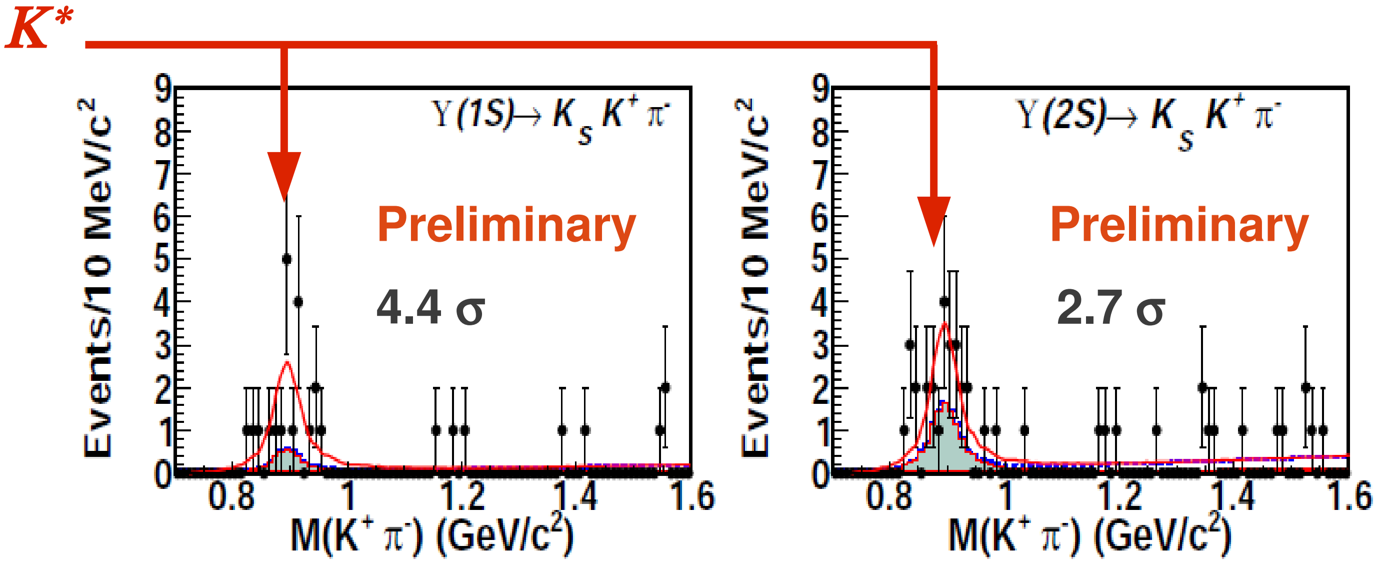
$$X_T = \frac{\sum E_i}{\sqrt{s}}$$

$e^+e^- \to q\bar{q} \to f$ — Estimated with data below Υ(4S)

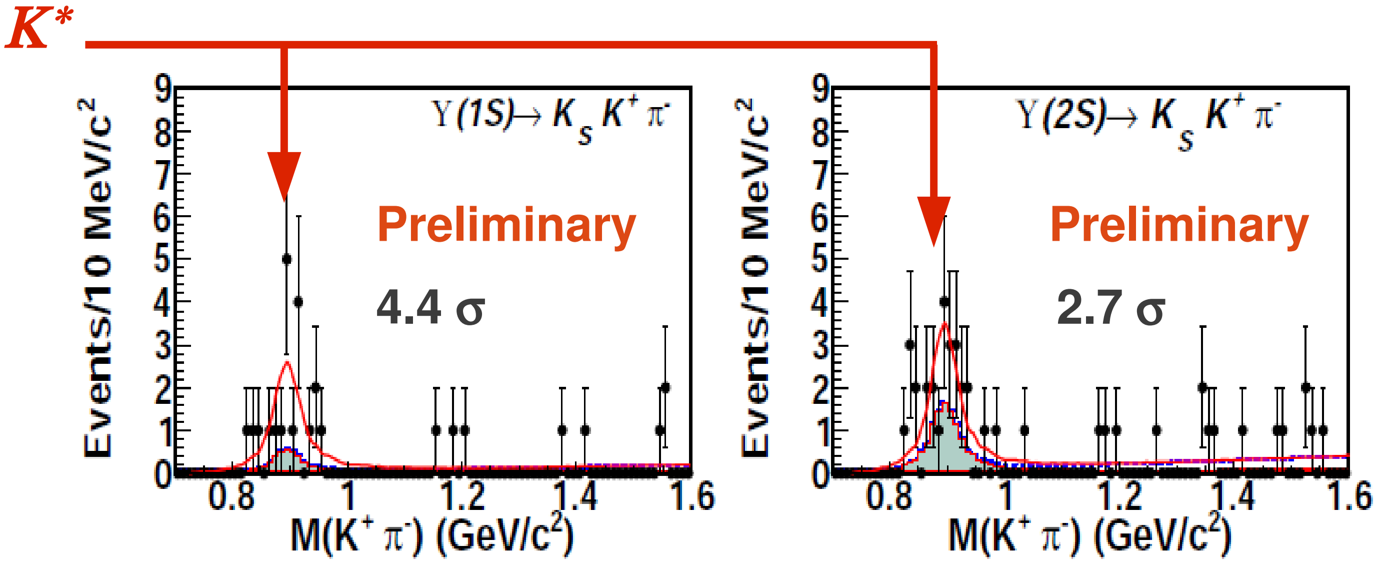
Branching ratios x 10^6

	Channel	$\mathcal{B}[\Upsilon(1S) \to f]$	$\mathcal{B}[\Upsilon(2S) \to f]$	Q
	$K^{*0}K^-\pi^+$	$4.42 \pm 0.50 \pm 0.58$	$2.32 \pm 0.40 \pm 0.54$	$0.52 \pm 0.11 \pm 0.14$
	$\omega\pi^-\pi^+$	$4.46 \pm 0.67 \pm 0.72$	< 2.58	< 0.55 ←
	ϕK^+K^-	$2.36 \pm 0.37 \pm 0.29$	$1.58 \pm 0.33 \pm 0.18$	$0.67 \pm 0.18 \pm 0.11$
Prel.	$K_sK^+\pi^-$	$1.59 \pm 0.33 \pm 0.18$	$1.14 \pm 0.30 \pm 0.13$	$0.72 \pm 0.24 \pm 0.09$
Prel.	$\pi^-\pi^+\pi^0$	$2.14 \pm 0.72 \pm 0.34$	< 0.80	< 0.42 ←
Prel.	$\pi^-\pi^+\pi^0\pi^0$	$12.8 \pm 2.01 \pm 2.27$	$13.0 \pm 1.86 \pm 2.08$	$1.01 \pm 0.22 \pm 0.23$

$\Upsilon(1,2S) \to$ AT, VT, VP



Υ(1,2S)→ AT, VT, VP



	Channel	$\mathcal{B}[\Upsilon(1S) \to X]$	$\mathcal{B}[\Upsilon(2S) \to X]$	Q
VT	$\phi f_2'$	< 1.63	< 1.33	
	ωf_2	< 1.79	< 0.57	
	ρa_2	< 2.24	< 0.88	
	$K^{*0} \bar{K}_2^{*0}$	$3.02 \pm 0.68 \pm 0.34$	$1.53 \pm 0.52 \pm 0.19$	$0.50 \pm 0.21 \pm 0.07$
AP	$K_1(1270)^+ K^-$	< 2.41	< 3.22	
	$K_1(1400)^+ K^-$	$1.02 \pm 0.35 \pm 0.33$	< 0.83	< 0.77
	$b_1(1235)^+ \pi^-$	< 1.25	< 0.40	
VP	→ $K^{*0}(892) \bar{K}^0$	$2.92 \pm 0.85 \pm 0.37$	< 4.22	< 1.20
	$K^{*-}(892) \bar{K}^+$	< 1.11	< 1.45	
	$\omega \pi^0$	< 3.90	< 1.68	
	$\rho \pi$	< 3.68	< 1.16	

Branching ratios x 10^6

PRD 86, 031102(R)

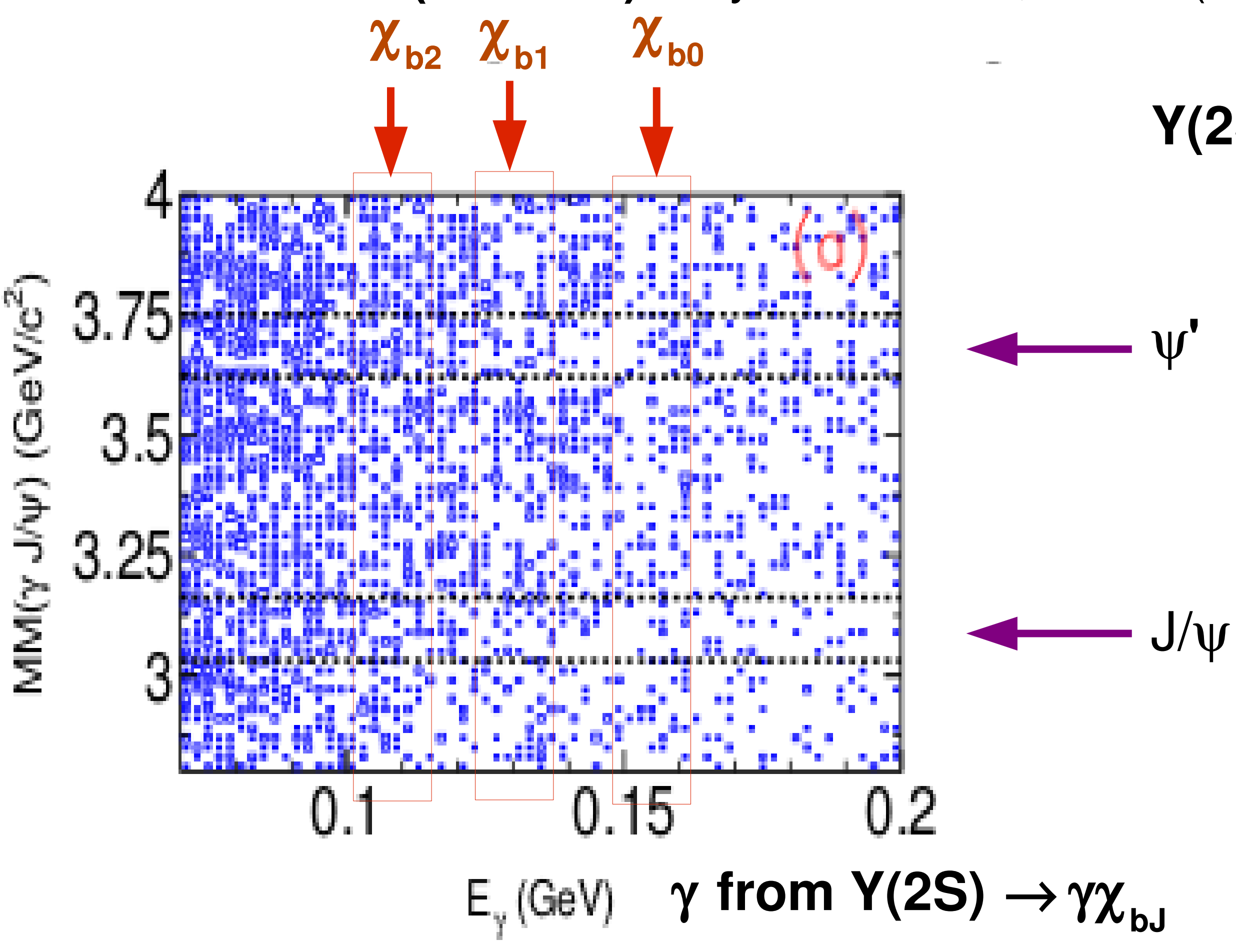
Preliminary

$\chi_b(1P) \rightarrow$ double charmonium

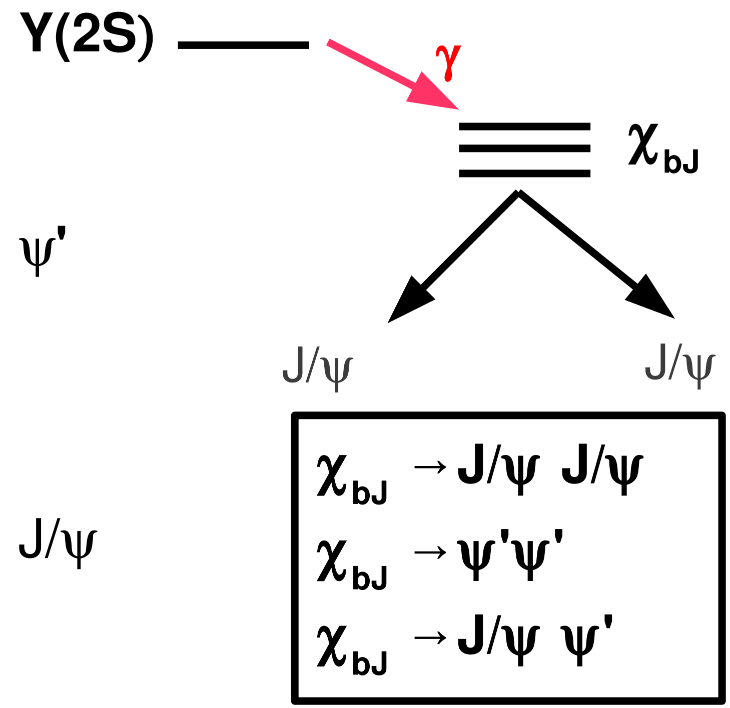
Phys. Rev. D 85, 071102(R), (2012)

Chance to compare different predictions:

Light Cone formalism (LC): Phys. Rev. D 80, 094008 (2009) Erratum-ibid. D85 (2012) 119901
Potential QCD (pQCD) : Phys. Rev. D 72, 094018 (2005)
Non relativistic QCD (NRQCD): Phys. Rev. D 84,094031(2011)

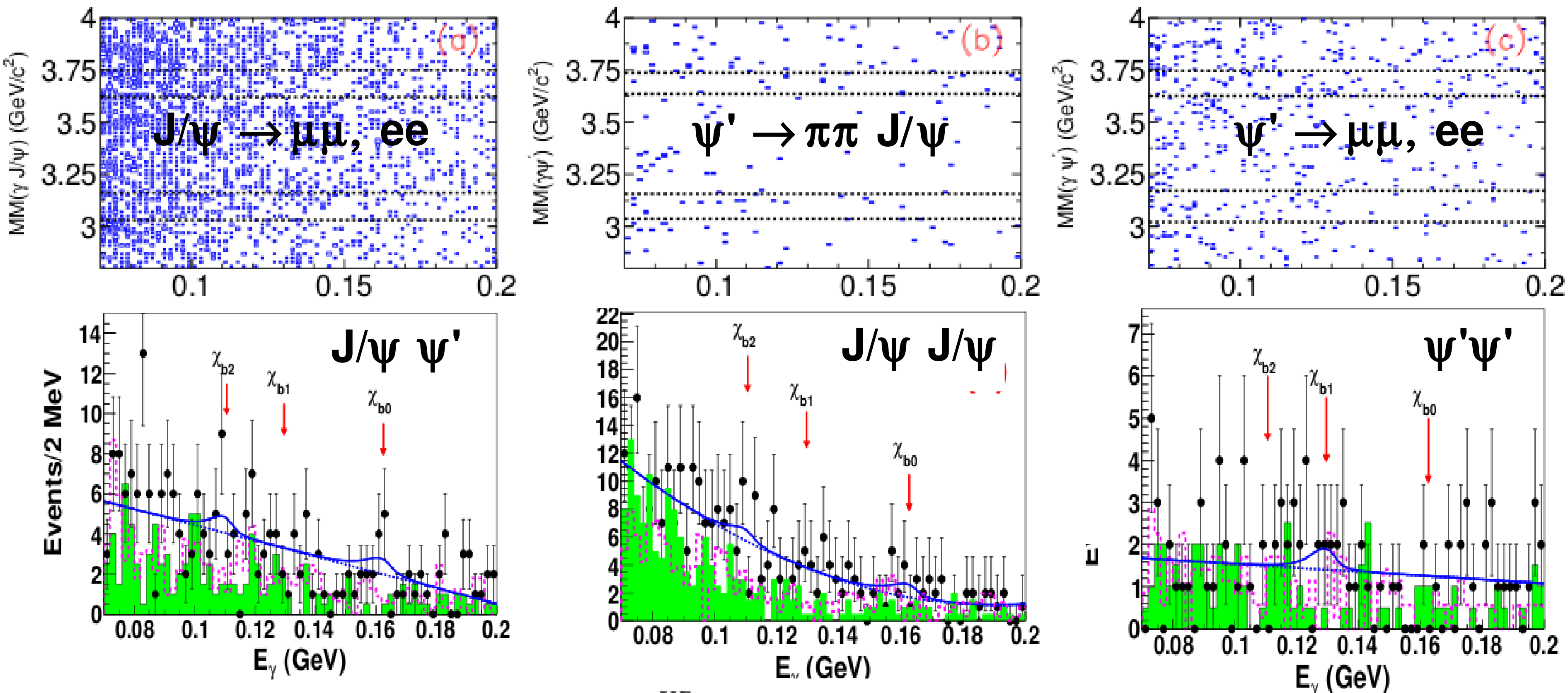


γ from $\Upsilon(2S) \rightarrow \gamma\chi_{bJ}$



$J/\psi \rightarrow \mu^+\mu^-, e^+e^-$
$\psi' \rightarrow \pi^+\pi^- J/\psi,\ \mu^+\mu^-, e^+e^-$

$\chi_b(1P) \rightarrow$ double charmonium



Channel	$n^{\rm up}$	$\varepsilon(\%)$	$\sigma_{\rm sys}(\%)$	$\mathcal{B}^{\rm UP}$
$\chi_{b0} \rightarrow J/\psi J/\psi$	21	5.8	16	7.1×10^{-5}
$\chi_{b1} \rightarrow J/\psi J/\psi$	13	6.3	30	2.7×10^{-5}
$\chi_{b2} \rightarrow J/\psi J/\psi$	22	5.9	27	4.5×10^{-5}
$\chi_{b0} \rightarrow J/\psi \psi'$	20	3.4	17	1.2×10^{-4}
$\chi_{b1} \rightarrow J/\psi \psi'$	5.8	3.8	15	1.7×10^{-5}
$\chi_{b2} \rightarrow J/\psi \psi'$	17	3.5	16	4.9×10^{-5}
$\chi_{b0} \rightarrow \psi' \psi'$	3.0	2.1	20	3.1×10^{-5}
$\chi_{b1} \rightarrow \psi' \psi'$	12	2.2	17	6.2×10^{-5}
$\chi_{b2} \rightarrow \psi' \psi'$	3.3	2.1	12	1.6×10^{-5}

Upper Limits in agreement with NRQCD and LC predictions

→ See V.V. Braguta's talk

Part III

Baryon production from Y(1,2S)

$\Upsilon(1,2S) \rightarrow \Lambda + X$

Hyperon production is **enhanced** in Y decays with respect to the nearby continuum and is **large**.

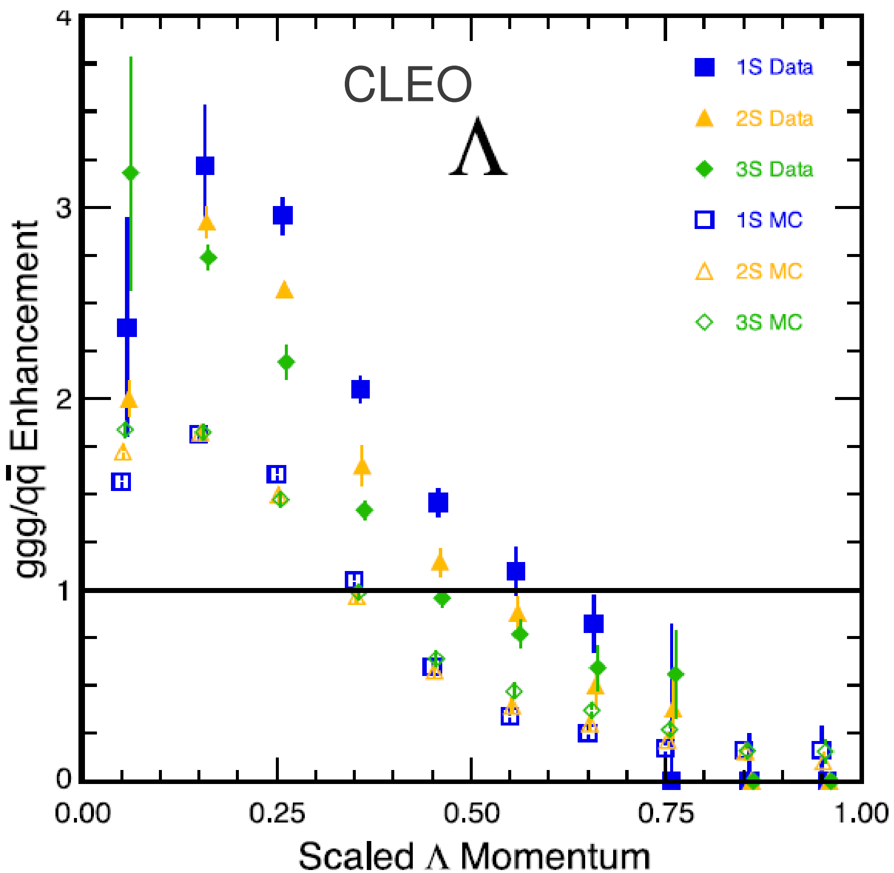
BF(Y(1S) → Λ + X) ~ 10%

BF(Y(1S) → $\Lambda\bar{\Lambda}$ + X) ~ 3%

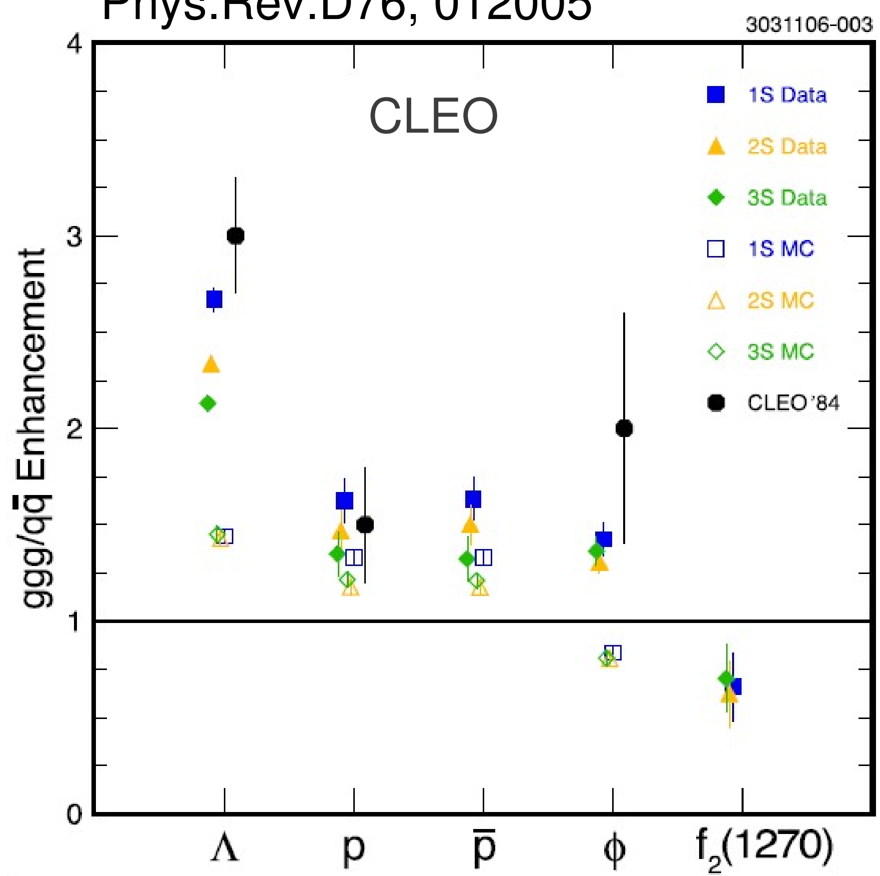
Enhancement for baryon $\mathcal{B}$:

$$\frac{\sigma[e^+e^- \rightarrow \Upsilon(nS) \rightarrow \mathcal{B} + X]}{\sigma[e^+e^- \rightarrow q\bar{q} \rightarrow \mathcal{B} + X]}$$

Phys.Rev.D76, 012005



Phys.Rev.D76, 012005



Production of anti-deuteron

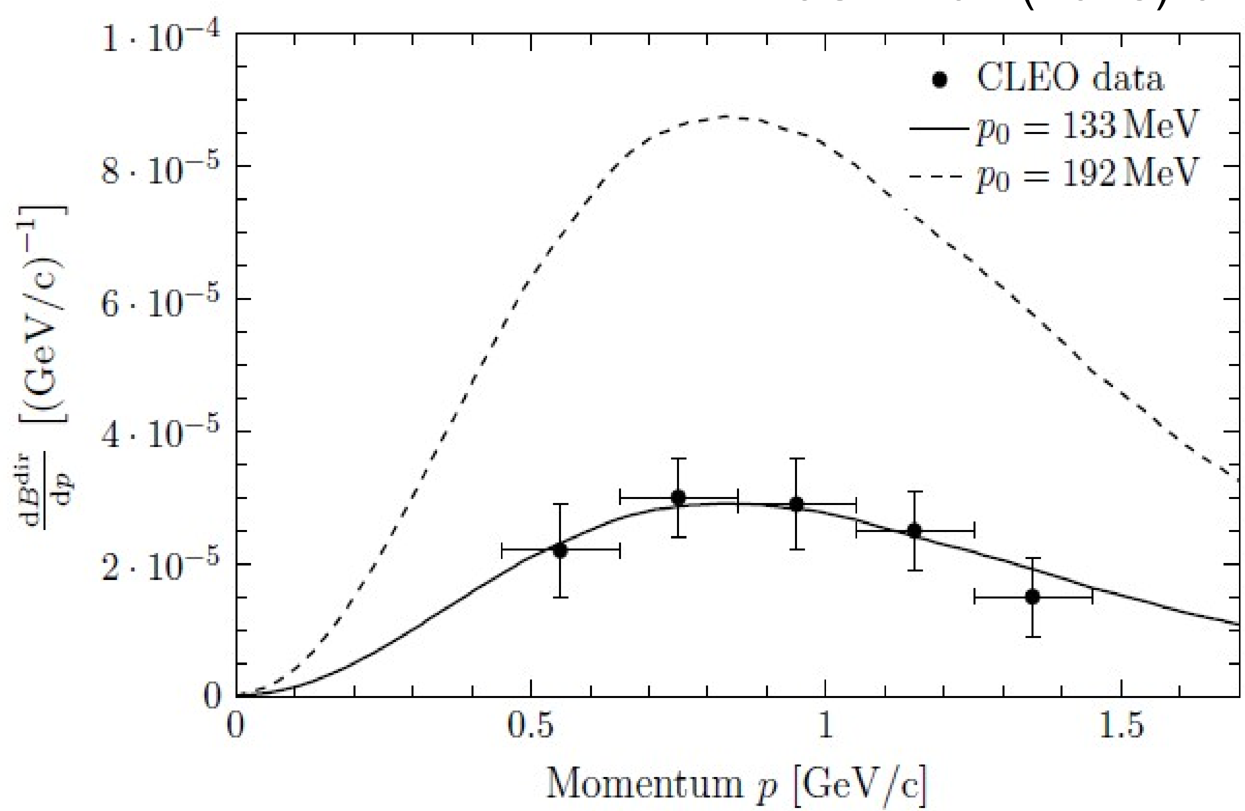
From early studies by Argus $\bar{d}$ can be produced in Y(nS) decays

BF[Y(1S) → d +X] =(**2.86** ± 0.19 ± 0.21) x **10^{-5}**
BF[Y(2S) → d +X] =(**3.37** ± 0.50 ± 0.25) x **10^{-5}** PRD, 75 012009 ,(2007)
σ[e^+e^- → $q\bar{q}$ → d +X] < **0.031 pb**

Coalescent production

p-n bound if $|p_p - p_n| < p_0$ = 133 MeV/c

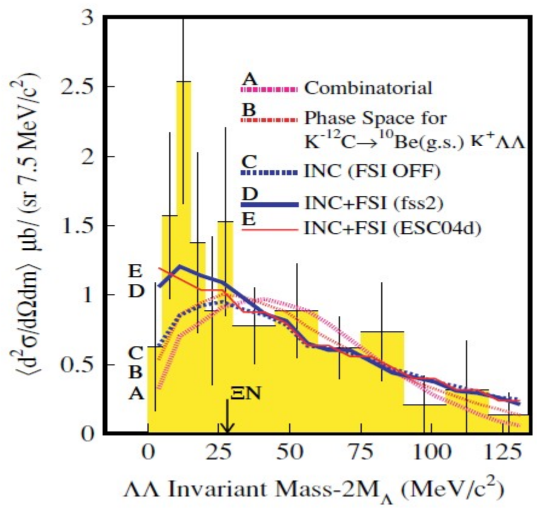
JCAP 02 (2013) 021



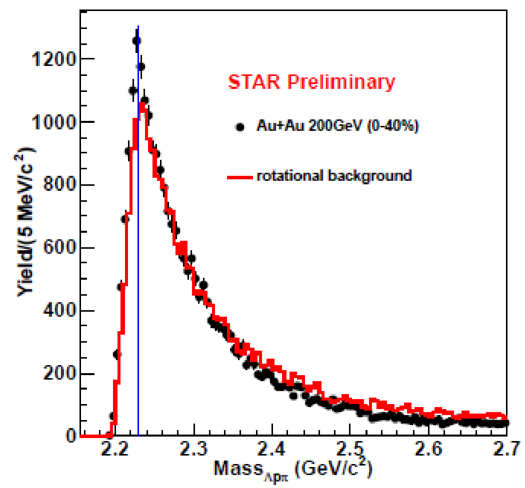
Search for H dibaryon

arXiv:1302.4028v1

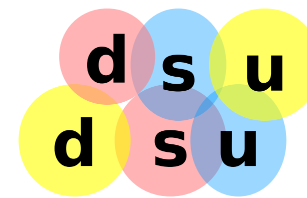
Exotic state (Jaffe, 1977)
→ completely

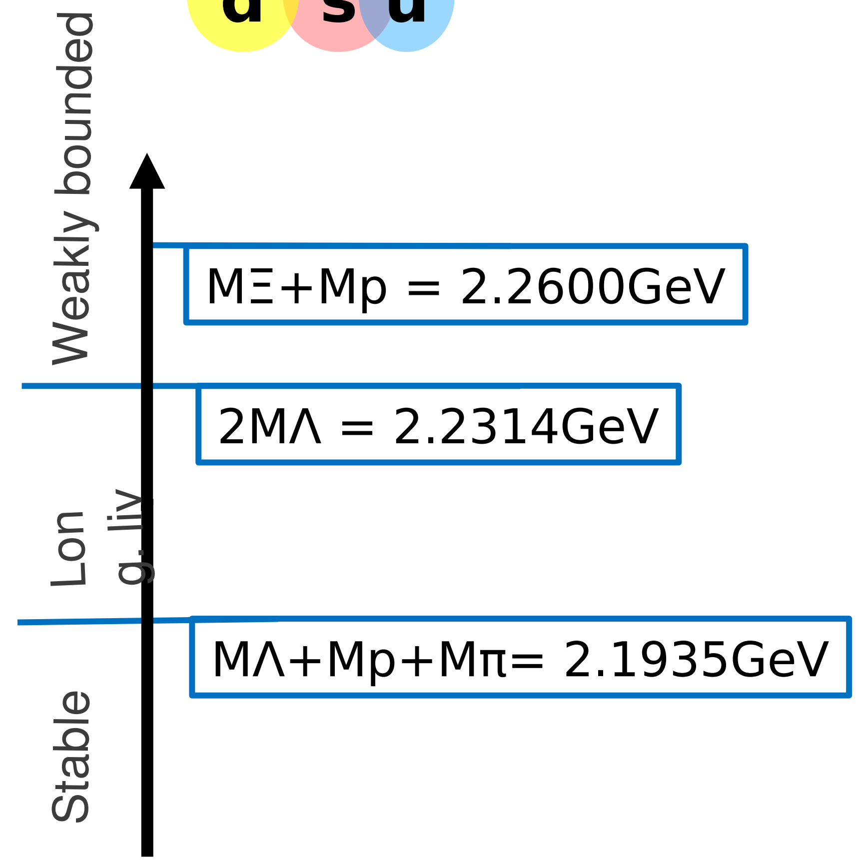


KEK-PS E522(2007)



RHIC-STAR (2011)





Y(nS) can produce **bound baryon-baryon states**

high yield of low momentum Λ .

→ can the H^0 be produced also?

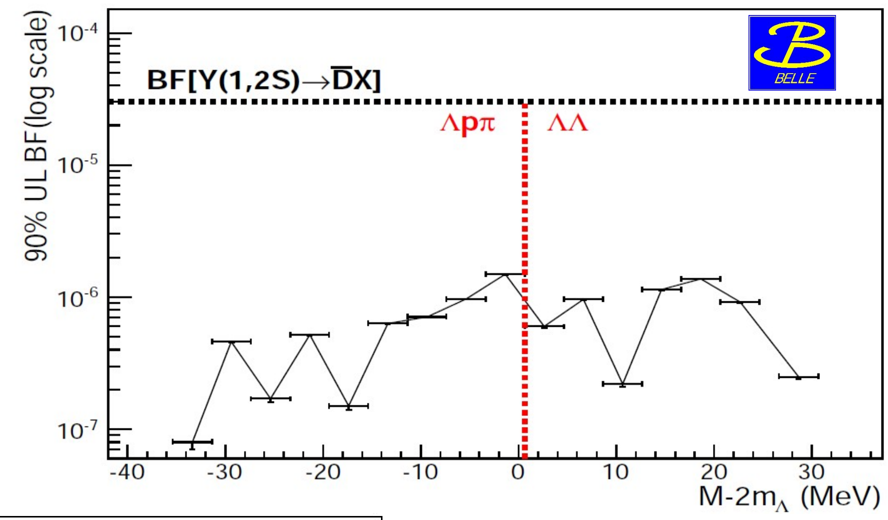
Search for H dibaryon

arXiv:1302.4028v1

Analysis strategy:

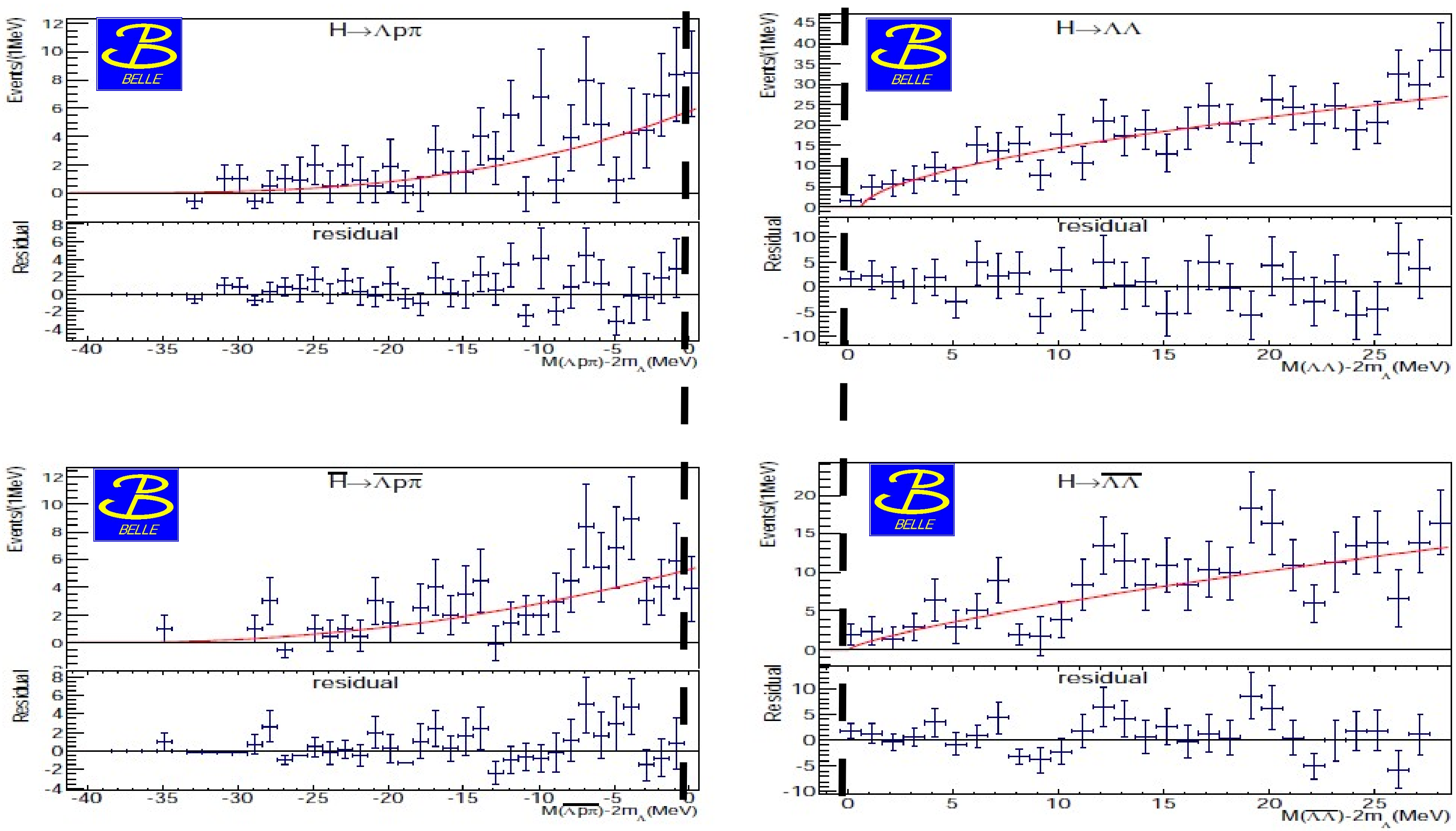
→ Inclusive reconstruction in Y(1S) and Y(2S) sample

→ Decays with **H** → **ΛΛ, H** → **Λpπ⁻**



2M(Λ)

2M(Λ)



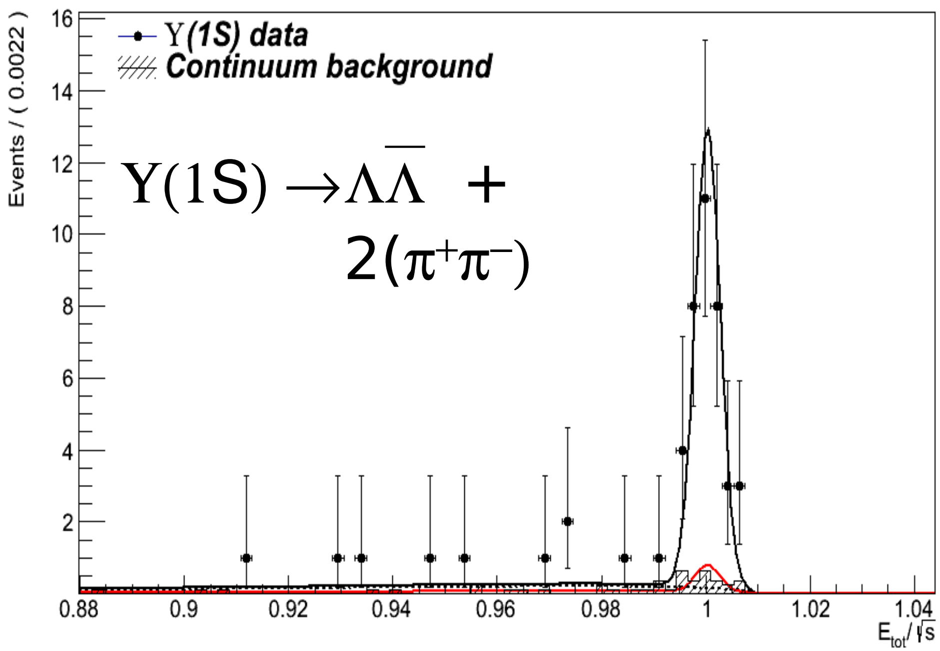
$\Upsilon(1,2S) \rightarrow$ exclusive $\Lambda\bar{\Lambda}$ + X

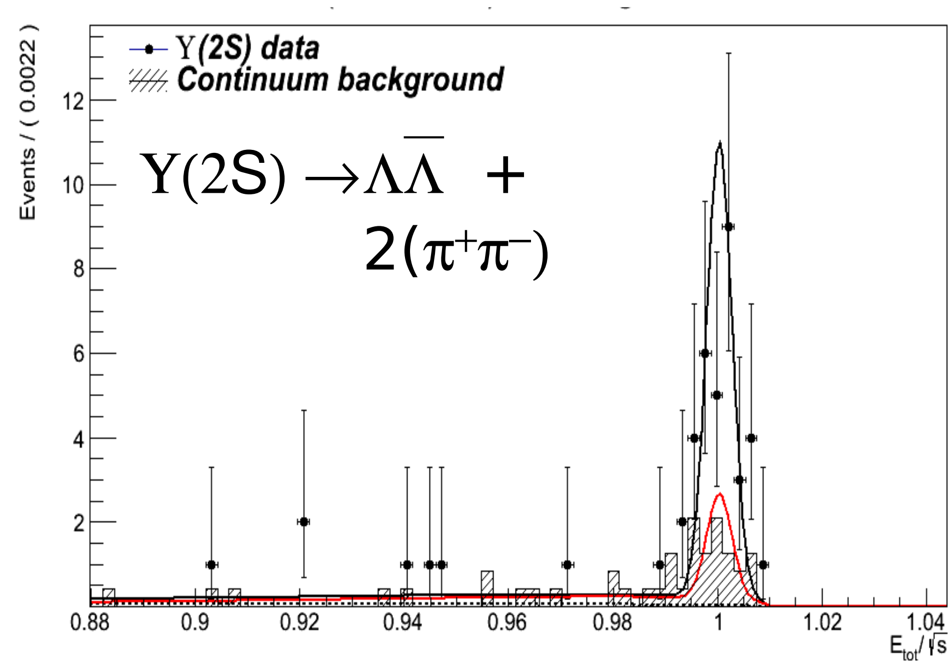
New!

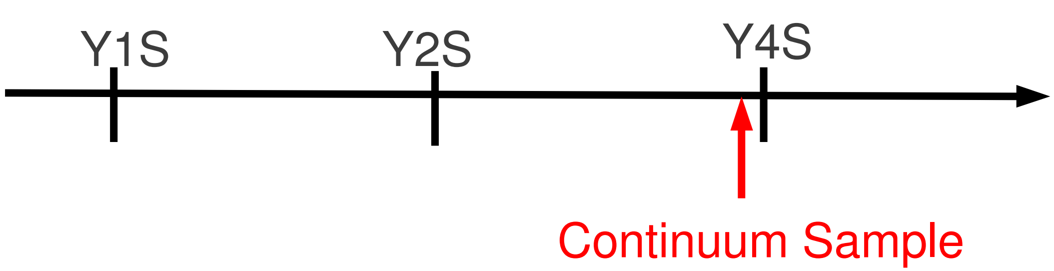
Preliminary

X = combination of K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ and π^0

Max 9 bodies, Max one π^0 → 48 channels







Full event reconstruction
Kinematic Fit of displaced vertexes

Side result: / Feedback: **first measurement of exclusive $\Lambda\bar{\Lambda}$ + X cross sections in continuum**

suppression (p ... 50

$\Upsilon(1,2S) \to$ exclusive $\Lambda\bar{\Lambda}$ + X

Preliminary

$$\sum_X BF[\Upsilon(1S) \to X] \simeq 2 \times 10^{-4}$$

$$\sum_X BF[\Upsilon(2S) \to X] \simeq 0.7 \times 10^{-4}$$

The large inclusive BF is not due to simple, low multiplicity decays

Channel	$\mathcal{B}[\Upsilon(1S) \to X]$ [$\times 10^{-6}$]	$\mathcal{B}[\Upsilon(2S) \to X]$ [$\times 10^{-6}$]	Q
$\Lambda\bar{\Lambda} + \pi^+\pi^-$	$1.43 \pm 0.48 \pm 0.23$		
$\Lambda\bar{\Lambda} + K^+K^-$	$1.29 \pm 0.51 \pm 0.20$	$1.27 \pm 0.47 \pm 0.20$	$0.98 \pm 0.53 \pm 0.11$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	$6.99 \pm 1.28 \pm 1.11$	$3.81 \pm 0.97 \pm 0.61$	$0.55 \pm 0.17 \pm 0.06$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-$	$11.83 \pm 2.01 \pm 1.87$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}$	$2.99 \pm 0.86 \pm 0.47$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)$	$13.14 \pm 2.36 \pm 2.10$	$4.72 \pm 1.64 \pm 0.75$	$0.36 \pm 0.14 \pm 0.04$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	$18.99 \pm 3.60 \pm 3.04$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	$6.03 \pm 1.67 \pm 0.96$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)$		$2.93 \pm 1.49 \pm 0.47$	
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	$2.00 \pm 0.97 \pm 0.34$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	$13.86 \pm 3.96 \pm 2.35$	$9.76 \pm 3.06 \pm 1.66$	$0.70 \pm 0.30 \pm 0.08$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	$18.26 \pm 4.68 \pm 3.11$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$	$5.85 \pm 2.35 \pm 0.99$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	$52.83 \pm 8.93 \pm 9.07$	$23.35 \pm 5.97 \pm 4.02$	$0.44 \pm 0.14 \pm 0.05$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78 \pm 9.35 \pm 5.54$	$30.70 \pm 8.60 \pm 5.36$	$0.97 \pm 0.39 \pm 0.12$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95 \pm 5.81 \pm 2.76$		

$\Upsilon(1,2S) \rightarrow$ exclusive $\Lambda\bar{\Lambda}$ + X

New!

BELLE

Preliminary

2.2 σ below 0.77

2.8 σ below 0.77

Compatible with 0.77

Channel	$\mathcal{B}[\Upsilon(1S) \to X]$ $[\times 10^{-6}]$	$\mathcal{B}[\Upsilon(2S) \to X]$ $[\times 10^{-6}]$	Q
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$\Lambda\bar{\Lambda} + K^+K^-$	$1.29 \pm 0.51 \pm 0.20$	$1.27 \pm 0.47 \pm 0.20$	$0.98 \pm 0.53 \pm 0.11$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	$6.99 \pm 1.28 \pm 1.11$	$3.81 \pm 0.97 \pm 0.61$	$0.55 \pm 0.17 \pm 0.06$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-$	$11.83 \pm 2.01 \pm 1.87$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}$	$2.99 \pm 0.86 \pm 0.47$		
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$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	$18.99 \pm 3.60 \pm 3.04$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	$6.03 \pm 1.67 \pm 0.96$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)$		$2.93 \pm 1.49 \pm 0.47$	
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	$2.00 \pm 0.97 \pm 0.34$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	$13.86 \pm 3.96 \pm 2.35$	$9.76 \pm 3.06 \pm 1.66$	$0.70 \pm 0.30 \pm 0.08$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	$18.26 \pm 4.68 \pm 3.11$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$	$5.85 \pm 2.35 \pm 0.99$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	$52.83 \pm 8.93 \pm 9.07$	$23.35 \pm 5.97 \pm 4.02$	$0.44 \pm 0.14 \pm 0.05$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78 \pm 9.35 \pm 5.54$	$30.70 \pm 8.60 \pm 5.36$	$0.97 \pm 0.39 \pm 0.12$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95 \pm 5.81 \pm 2.76$		

$\Upsilon(1,2S) \rightarrow \Lambda\bar{\Lambda} + X$ New!

Preliminary

Lowest multiplicity : N = 4, BF ~ 1.3 x 10^{-6}

BF(Υ(1S) → $\Lambda\bar{\Lambda}$) < 0.35 x 10^{-6}
BF(Υ(2S) → $\Lambda\bar{\Lambda}$) < 0.03 x 10^{-6}
$\sigma(e^+e^- \rightarrow \Lambda\bar{\Lambda})$ < 0.59 fb

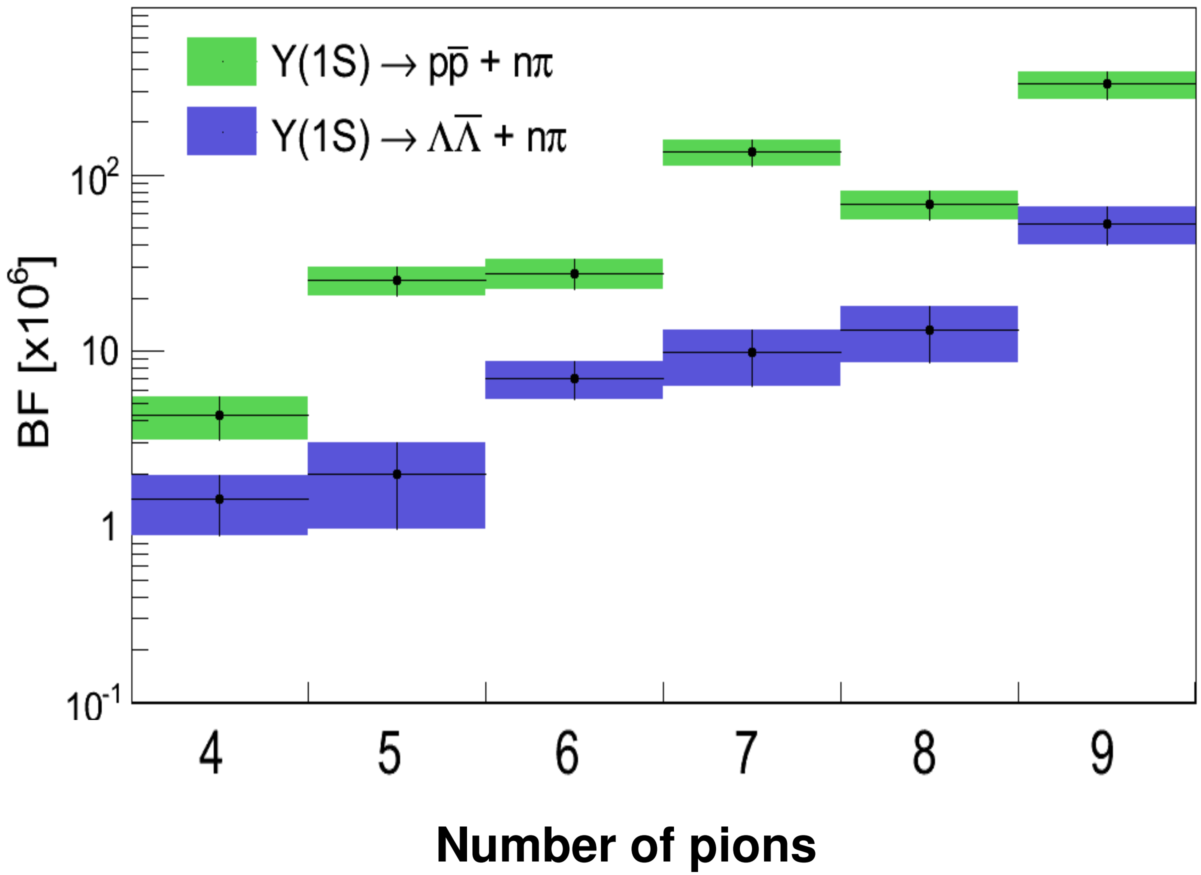
Channel	$\mathcal{B}[\Upsilon(1S) \rightarrow X]$ [$\times 10^{-6}$]	$\mathcal{B}[\Upsilon(2S) \rightarrow X]$ [$\times 10^{-6}$]	Q
$\Lambda\bar{\Lambda} + \pi^+\pi^-$	$1.43 \pm 0.48 \pm 0.23$		
$\Lambda\bar{\Lambda} + K^+K^-$	$1.29 \pm 0.51 \pm 0.20$	$1.27 \pm 0.47 \pm 0.20$	$0.98 \pm 0.53 \pm 0.11$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	$6.99 \pm 1.28 \pm 1.11$	$3.81 \pm 0.97 \pm 0.61$	$0.55 \pm 0.17 \pm 0.06$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-$	$11.83 \pm 2.01 \pm 1.87$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}$	$2.99 \pm 0.86 \pm 0.47$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)$	$13.14 \pm 2.36 \pm 2.10$	$4.72 \pm 1.64 \pm 0.75$	$0.36 \pm 0.14 \pm 0.04$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	$18.99 \pm 3.60 \pm 3.04$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	$6.03 \pm 1.67 \pm 0.96$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)$		$2.93 \pm 1.49 \pm 0.47$	
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	$2.00 \pm 0.97 \pm 0.34$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	$13.86 \pm 3.96 \pm 2.35$	$9.76 \pm 3.06 \pm 1.66$	$0.70 \pm 0.30 \pm 0.08$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	$18.26 \pm 4.68 \pm 3.11$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$	$5.85 \pm 2.35 \pm 0.99$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	$52.83 \pm 8.93 \pm 9.07$	$23.35 \pm 5.97 \pm 4.02$	$0.44 \pm 0.14 \pm 0.05$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78 \pm 9.35 \pm 5.54$	$30.70 \pm 8.60 \pm 5.36$	$0.97 \pm 0.39 \pm 0.12$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95 \pm 5.81 \pm 2.76$		

$\Upsilon(1,2S) \rightarrow \Lambda\bar{\Lambda} + X$ New!

Preliminary

Multiplicity Hierarchy?

$p\bar{p}$ results from Dobbs et Al. arXiv:1205.5070



Final states with > 9 bodies seems to be favoured

→ but reconstruction efficiency decreases constantly

Baryon – anti-baryon events occur with high multiplicity

Baryon – anti-baryon pairs have low relative momentum → they can interact

Summary

Quarkonium decays create a dense gluonic state:

→ First measurement of **16 exclusive modes Υ(nS) → $\Lambda\bar{\Lambda}$ +X**

→ Data indicates a **strong dependence of BF from the multiplicity**

→ Stringent upper limits on non stable H dibaryon production

Is the NRQCD the best model that we have for the decays?

Υ(1,2S) → light hadrons: Ratio Q in agreement with theory

χ(1P) → double charmonium: Upper limits compatible with LC and NRQCD

Υ(nS) → η Υ(mS)

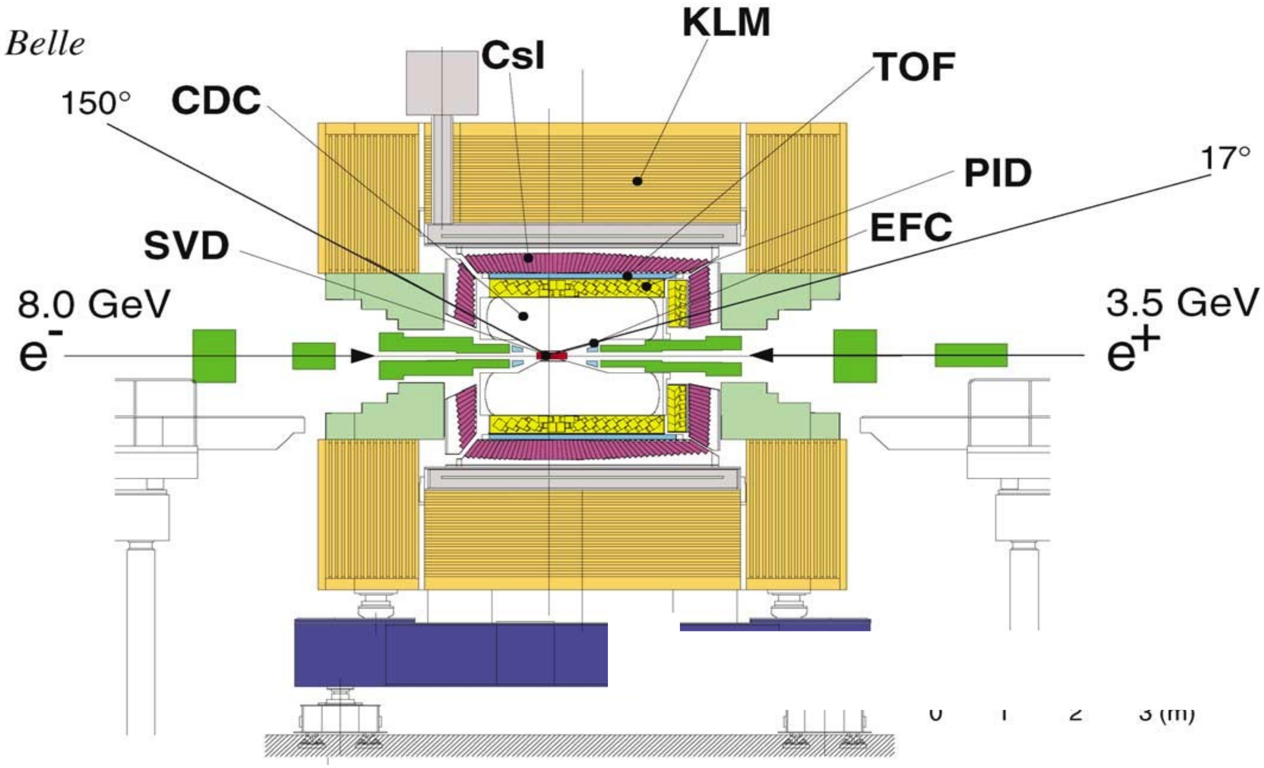
→ **What is happening above BB threshold?**

→ See E.Eichten's talk

→ For other Υ(5S) results, see R. Mizuk's talk tomorrow

Backup

Belle

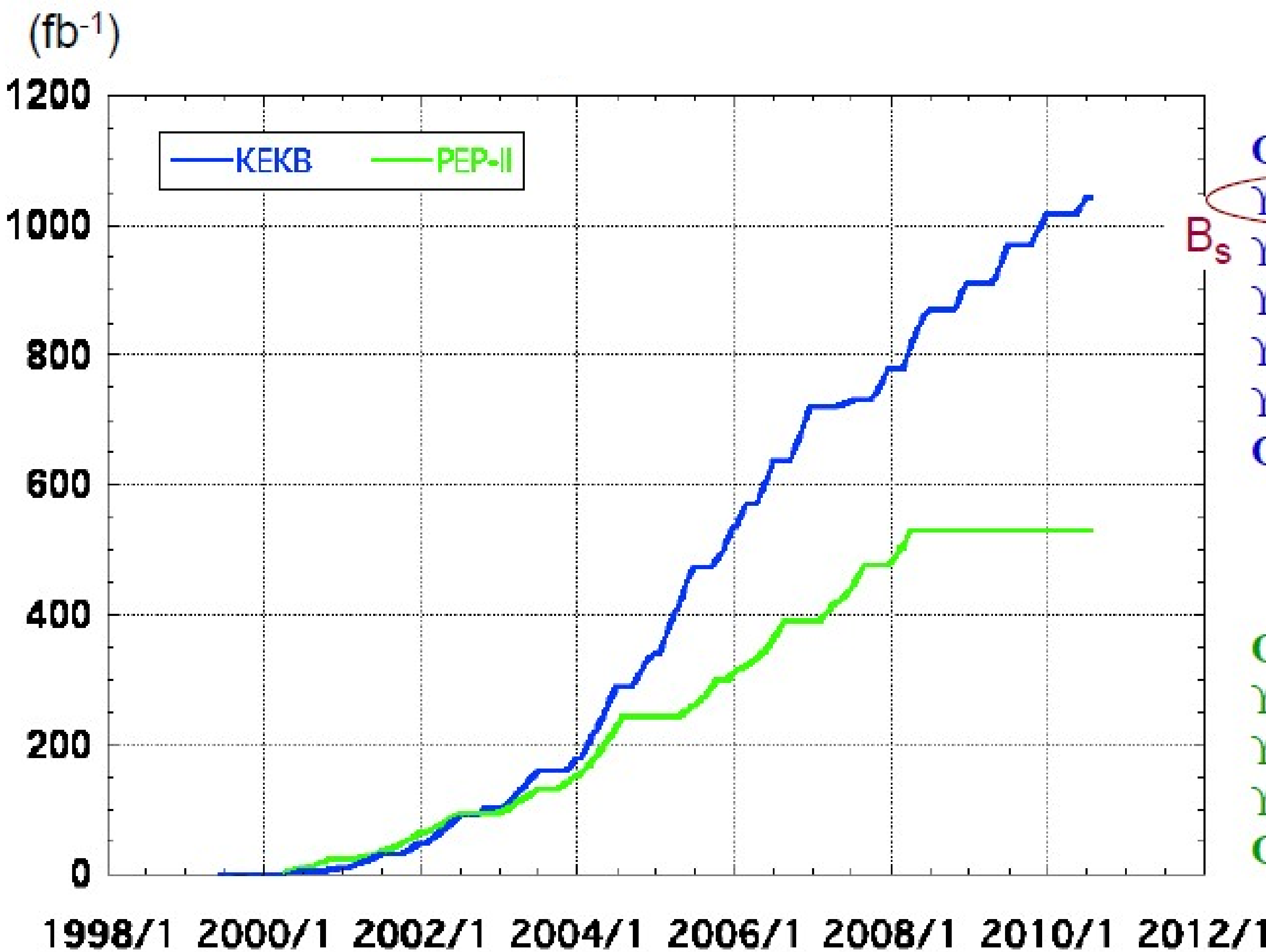


asymmetric e^+e^- **collider @Υ(nS) energies (KEKB at KEK)**

- **Study of B mesons (~770 M of BB pairs at Belle, ~470 M at BaBar)**
- **World largest samples of Υ(1,2 S)**
- **Unique sample of Υ(5S) for Bs and quarkonium studies**

- Complete knowledge of initial state
- Can compute Center-of-mass quantity
- Missing mass

Luminosity



> 1 ab^{-1}

On resonance:

B$_s$ ϒ(5S): 121 fb^{-1}

ϒ(4S): 711 fb^{-1}

ϒ(3S): 3 fb^{-1}

ϒ(2S): 24 fb^{-1}

ϒ(1S): 6 fb^{-1}

Off reson./scan :

~100 fb-1

BELLE

530 fb^{-1}

On resonance:

ϒ(4S): 433 fb^{-1}

ϒ(3S): 30 fb^{-1}

ϒ(2S): 14 fb^{-1}

Off reson./scan :

~54 fb-1

$\Upsilon(nS) \to \eta\Upsilon(mS)$

E1E1 transition

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

No Spin Flip

E1M2 transition

$\Upsilon(nS) \to \eta,\ \pi^0\ \Upsilon(mS)$

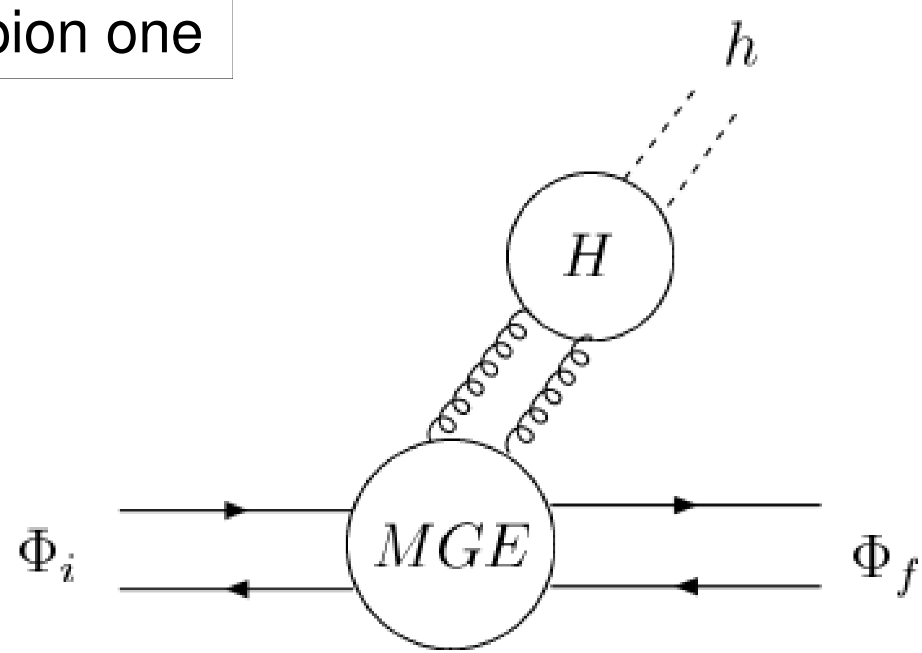
Spin Flip

The η transition is predicted to be suppressed with respect to the dipion one

The η transition requires a spin flip

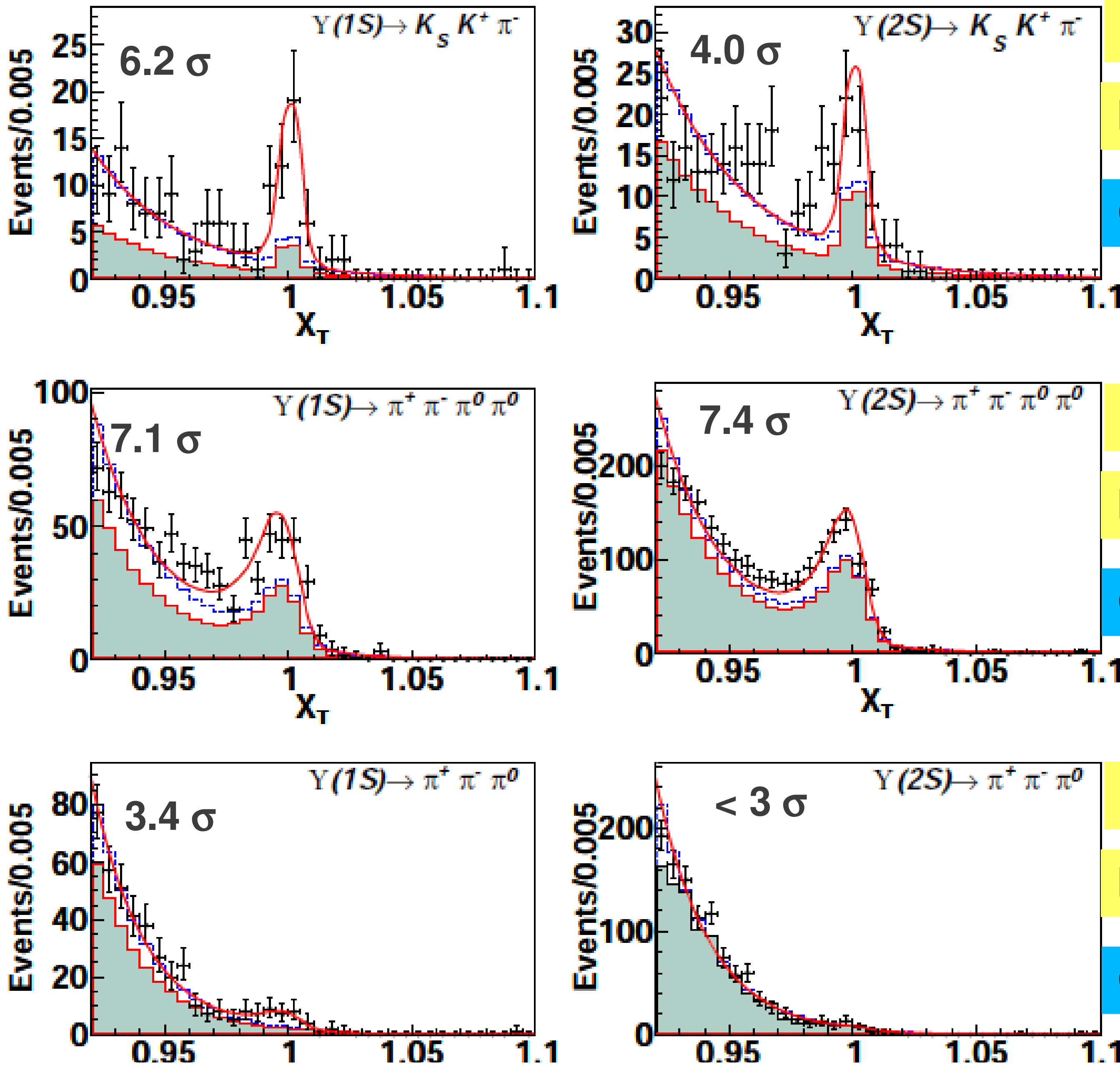
QCD **multipole expansion**: spin flip amplitude proportional to $(m_b)^{-2}$

Kuang Front.Phys.China 1, 19 (2006)



Υ(1,2S)→ VP → 3, 4 bodies

Preliminary



BF X 10^6

BF(1S) = 1.53 ± 0.32 ± 0.17

BF(2S) = 1.05 ± 0.52 ± 0.19

Q=0.50 ± 0.21 ± 0.07

BF(1S) = 12.8 ± 2.01 ± 2.27

BF(2S) = 13.0 ± 1.86 ± 1.95

Q=1.01 ± 0.22 ± 0.23

BF(1S) = 2.14 ± 0.72 ± 0.34

BF(2S) < 0.8

Q <0.42

$\Upsilon(1,2S) \to$ VP, AT, VT

Preliminary

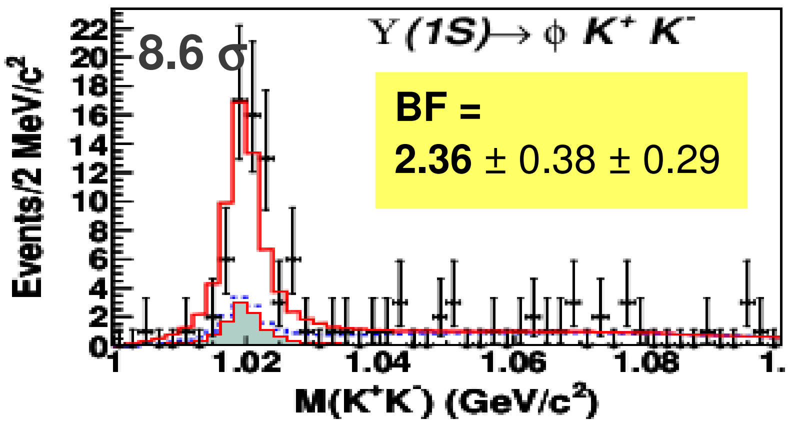
Channel	$\Upsilon(1S)$						$\Upsilon(2S)$							
	N_{sig}	N_{sig}^{UP}	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{UP}$	N^{sig}	N_{sig}^{UP}	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{UP}$	Q_{Υ}	Q_{Υ}^{UP}
$K_S^0 K^+ \pi^-$	37.2 ± 7.6	—	22.96	6.2	$1.59 \pm 0.33 \pm 0.18$	—	39.5 ± 10.3	—	21.88	4.0	$1.14 \pm 0.30 \pm 0.13$	—	$0.72 \pm 0.24 \pm 0.09$	—
$\pi^+\pi^-\pi^0\pi^0$	143.2 ± 22.4	—	11.20	7.1	$12.8 \pm 2.01 \pm 2.27$	—	260.7 ± 37.2	—	12.98	7.4	$13.0 \pm 1.86 \pm 2.08$	—	$1.01 \pm 0.22 \pm 0.23$	—
$\pi^+\pi^-\pi^0$	25.5 ± 8.6	—	11.86	3.4	$2.14 \pm 0.72 \pm 0.34$	—	-2.1 ± 9.5	15	13.19	—	$-0.10 \pm 0.46 \pm 0.02$	0.80	$-0.05 \pm 0.21 \pm 0.02$	0.42
$K^{*0}(892)\bar{K}^0$	16.1 ± 4.7	—	16.23	4.4	$2.92 \pm 0.85 \pm 0.37$	—	14.7 ± 6.0	30	15.59	2.7	$1.79 \pm 0.73 \pm 0.30$	4.22	$0.61 \pm 0.31 \pm 0.12$	1.20
$K^{*-}(892)K^+$	2.0 ± 1.9	6.3	18.92	1.3	$0.31 \pm 0.30 \pm 0.04$	1.11	5.7 ± 3.4	13	18.77	2.0	$0.58 \pm 0.35 \pm 0.09$	1.45	$1.87 \pm 2.12 \pm 0.33$	5.52
$\omega\pi^0$	2.5 ± 2.1	6.8	2.11	1.6	$1.32 \pm 1.11 \pm 0.14$	3.90	0.1 ± 2.2	4.6	2.32	0.1	$0.03 \pm 0.68 \pm 0.01$	1.63	$0.02 \pm 0.50 \pm 0.01$	1.68
$\rho\pi$	11.3 ± 5.9	22	6.41	2.2	$1.75 \pm 0.91 \pm 0.28$	3.68	-1.4 ± 8.6	14	8.66	—	$-0.11 \pm 0.64 \pm 0.03$	1.16	$-0.06 \pm 0.38 \pm 0.02$	0.94

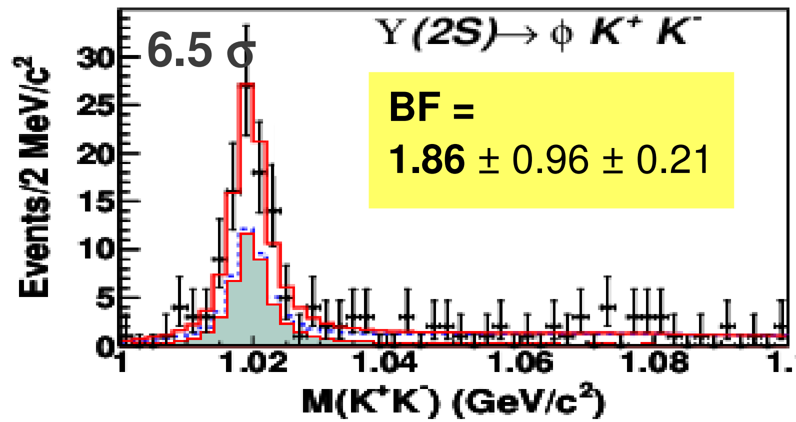
Channel	$\Upsilon(1S)$						$\Upsilon(2S)$							
	N^{sig}	N_{sig}^{UP}	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{UP}$	N^{sig}	N_{sig}^{UP}	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{UP}$	Q_{Υ}	Q_{Υ}^{UP}
ϕK^+K^-	56.3 ± 8.7		47.9	8.6	$2.36 \pm 0.37 \pm 0.29$		58 ± 12		47.8	6.5	$1.58 \pm 0.33 \pm 0.18$		$0.67 \pm 0.18 \pm 0.11$	
$\omega\pi^+\pi^-$	63.6 ± 9.5		15.7	8.5	$4.46 \pm 0.67 \pm 0.72$		29 ± 12	51	15.9	2.5	$1.32 \pm 0.54 \pm 0.45$	2.58	$0.30 \pm 0.13 \pm 0.11$	0.55
$K^{*0}K^-\pi^+$	173 ± 20		28.7	11	$4.42 \pm 0.50 \pm 0.58$		135 ± 23		27.5	6.4	$2.32 \pm 0.40 \pm 0.54$		$0.52 \pm 0.11 \pm 0.14$	
$\phi f_2'$	6.9 ± 3.9	15	48.8	2.1	$0.64 \pm 0.37 \pm 0.14$	1.63	8.3 ± 6.0	18	49.0	1.6	$0.50 \pm 0.36 \pm 0.19$	1.33	$0.77 \pm 0.70 \pm 0.33$	2.54
ωf_2	5.2 ± 4.0	13	17.7	1.5	$0.57 \pm 0.44 \pm 0.13$	1.79	-0.4 ± 3.3	6.1	17.5		$-0.03 \pm 0.24 \pm 0.01$	0.57	$-0.06 \pm 0.42 \pm 0.02$	1.22
ρa_2	29 ± 11	49	17.4	2.7	$1.15 \pm 0.47 \pm 0.18$	2.24	10 ± 11	30	17.3	0.9	$0.27 \pm 0.28 \pm 0.14$	0.88	$0.23 \pm 0.26 \pm 0.12$	0.82
$K^{*0}\bar{K}_2^{*0}$	42.2 ± 9.5		30.8	5.4	$3.02 \pm 0.68 \pm 0.34$		32 ± 11		29.6	3.3	$1.53 \pm 0.52 \pm 0.19$		$0.50 \pm 0.21 \pm 0.07$	
$K_1(1270)^+K^-$	3.7 ± 4.9	13	23.6	0.8	$0.54 \pm 0.72 \pm 0.21$	2.41	11.0 ± 4.4	26	23.5	1.2	$1.06 \pm 0.42 \pm 0.32$	3.22	$1.96 \pm 2.71 \pm 0.84$	4.73
$K_1(1400)^+K^-$	23.8 ± 8.2		27.3	3.3	$1.02 \pm 0.35 \pm 0.22$		9.2 ± 8.2	24	26.9	0.5	$0.26 \pm 0.23 \pm 0.09$	0.83	$0.26 \pm 0.25 \pm 0.10$	0.77
$b_1(1235)^+\pi^-$	14.4 ± 6.9	28	16.7	2.4	$0.47 \pm 0.22 \pm 0.13$	1.25	1.2 ± 3.5	13	17.0	0.2	$0.02 \pm 0.07 \pm 0.01$	0.40	$0.05 \pm 0.16 \pm 0.03$	0.35

$\Upsilon(1,2S) \to VT, AP \to$ 3 bodies

arXiv:1205.1246v1

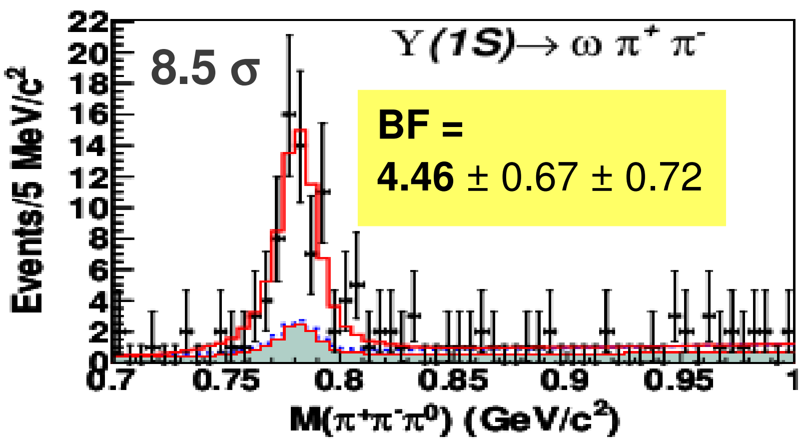
BF X 10^6

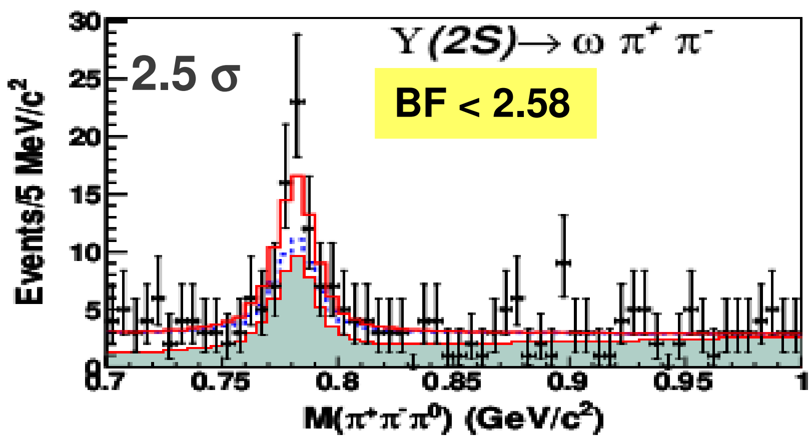




Q =
0.79 ± 0.54 ± 0.13

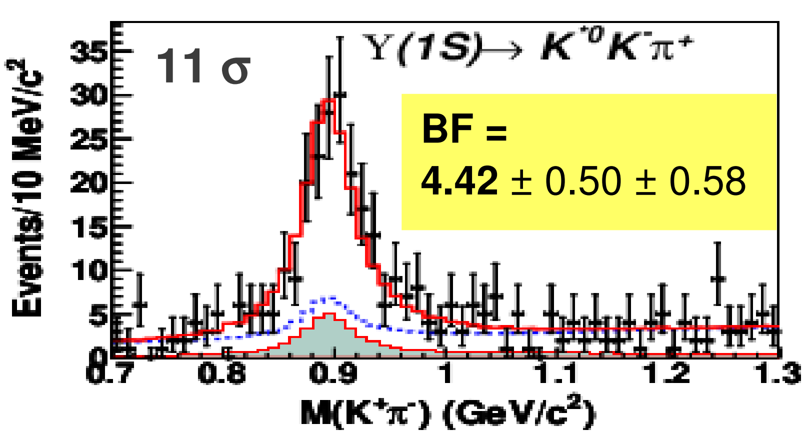
consistent

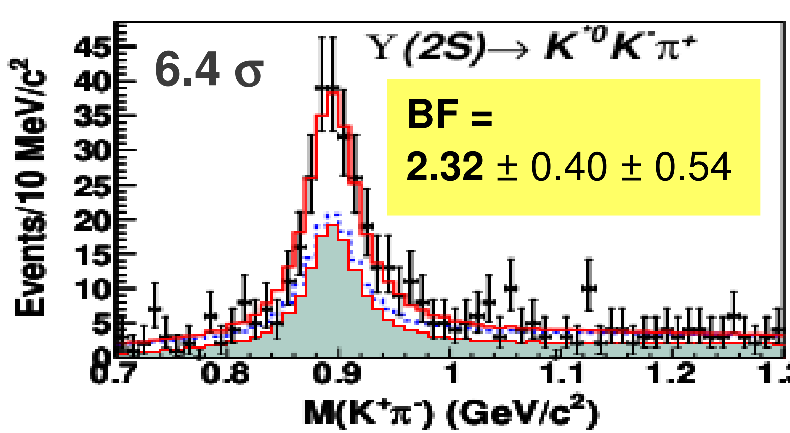




Q < 0.55

2.6 σ lower than prediction





Q =
0.52 ± 0.11 ± 0.14

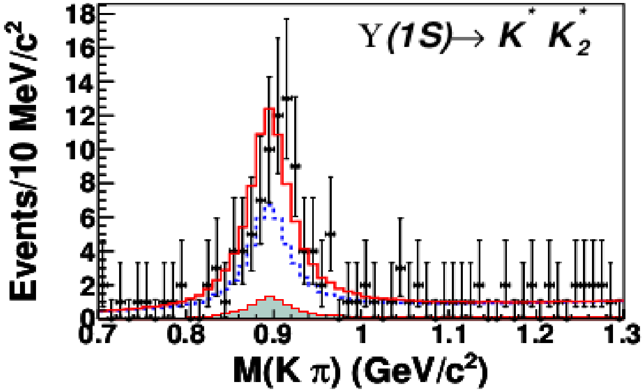
consistent

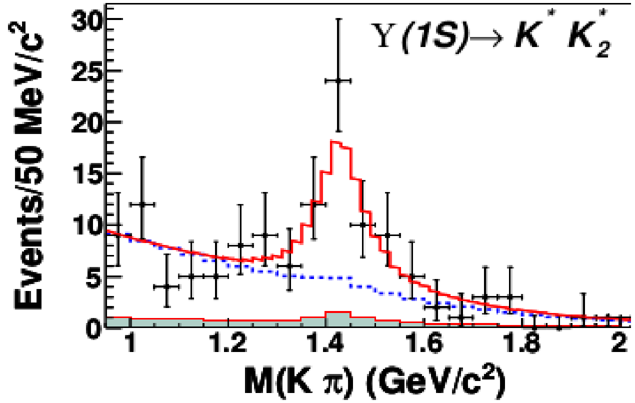
Υ(1,2S)→ VT, AP (observations)

arXiv:1205.1246v1

BF X 10^6

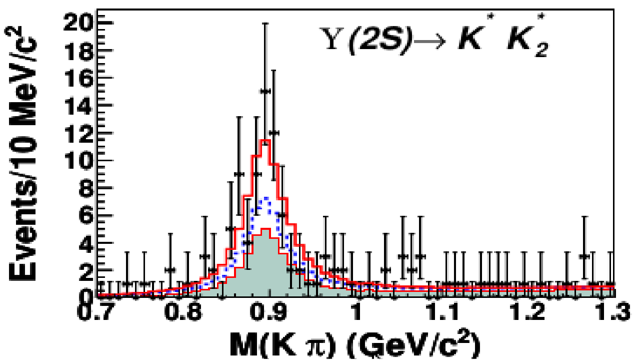
Signal from 2D fit of M(V,A) vs M(T) Dalitz plot → 1D projections

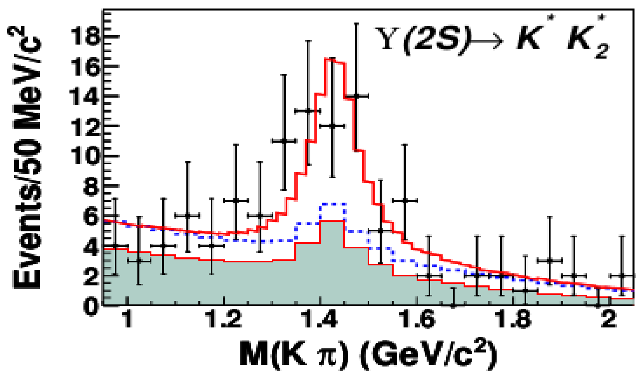




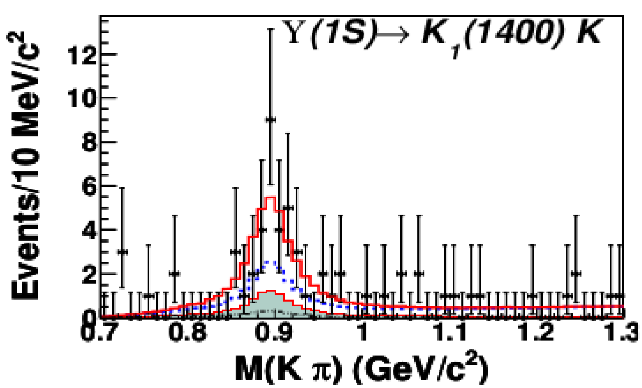
BF(1S) = 3.02 ± 0.68 ± 0.34

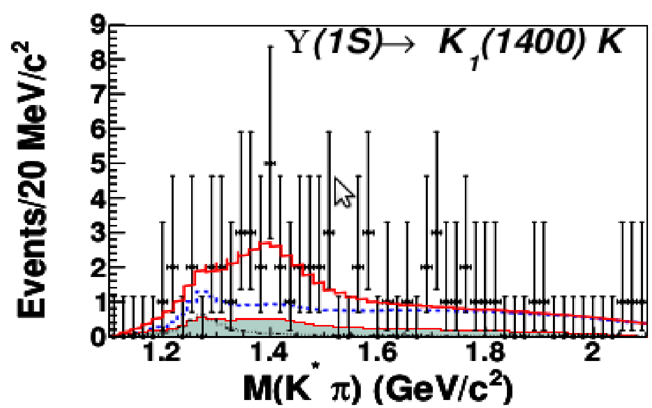
Q=0.50 ± 0.21 ± 0.07





BF(2S) = 1.53 ± 0.52 ± 0.19



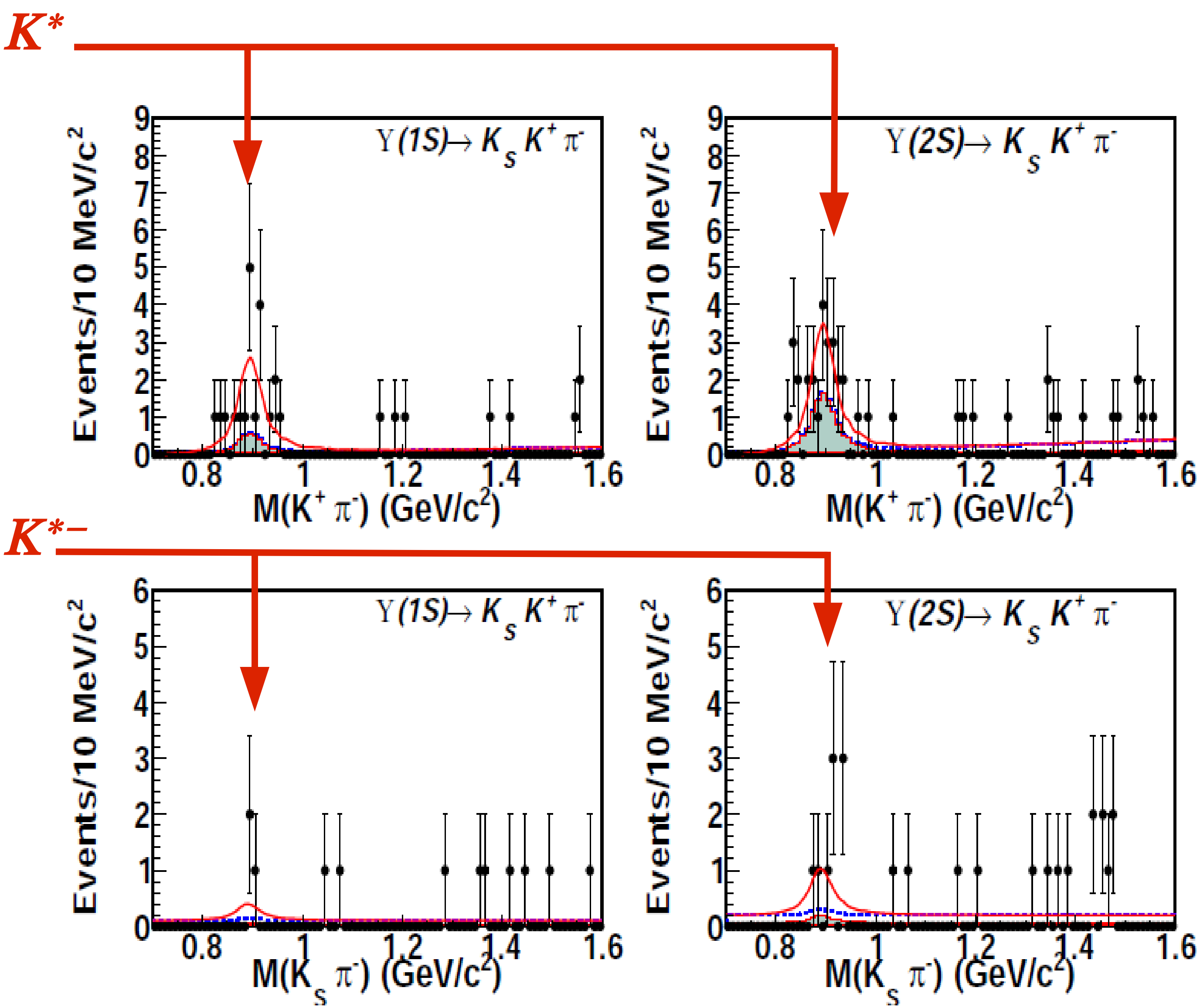


BF(1S) = 1.02 ± 0.35 ± 0.22

Q < 0.77

BF(2S) < 0.86

$\Upsilon(1,2S) \rightarrow K^{*}\overline{K}^{0}, \; K^{*-}K^{+}$



BF X 10^6

BF(1S) = 2.92 ± 0.85 ± 0.37

BF(2S) < 4.22

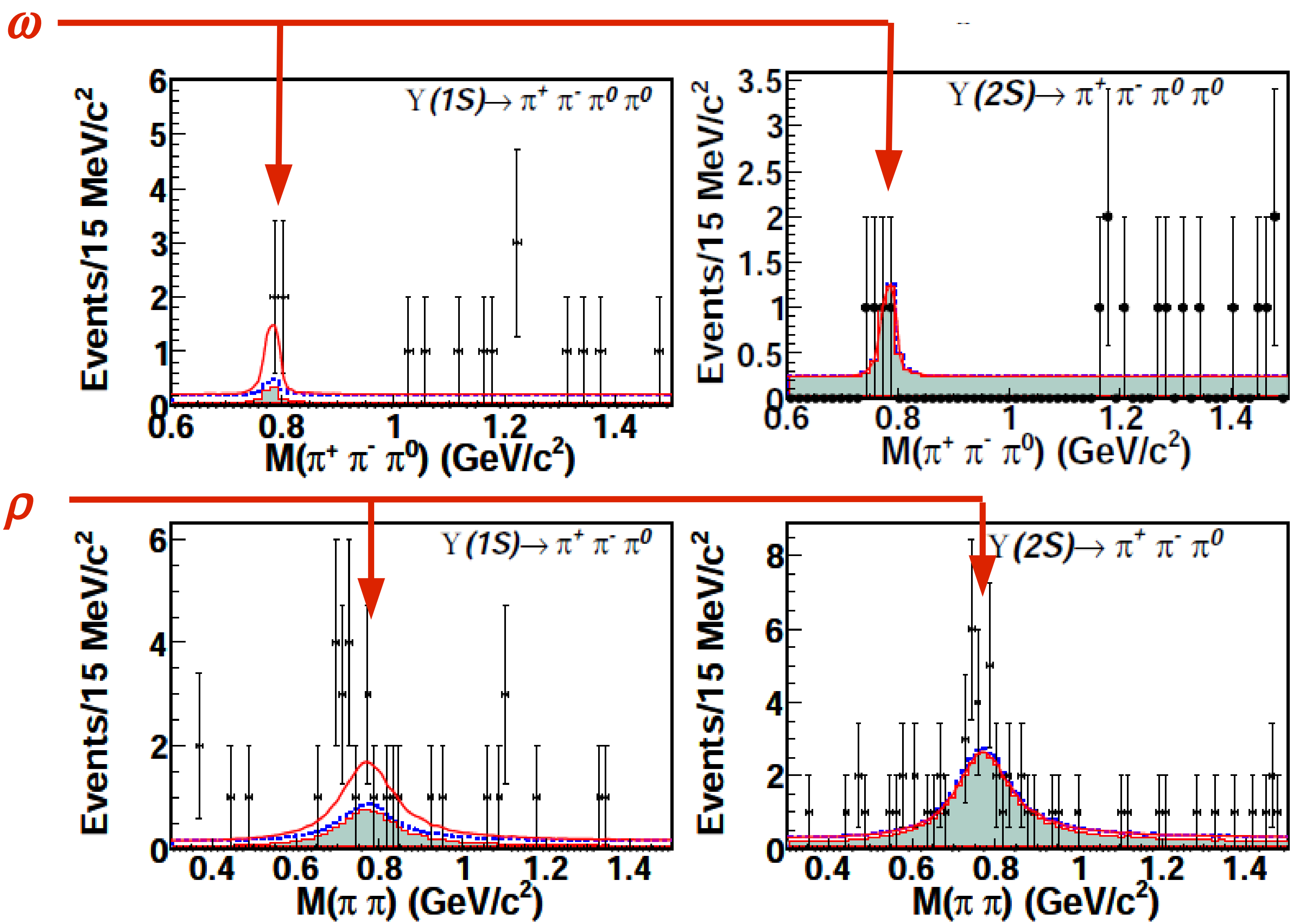
Q<1.20

BF(1S) < 1.11

BF(2S) < 1.45

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

BF X 10^6



BF(1S) < 3.90

BF(2S) < 1.63

BF(1S) < 3.68

BF(2S) < 1.16

Result statistically limited

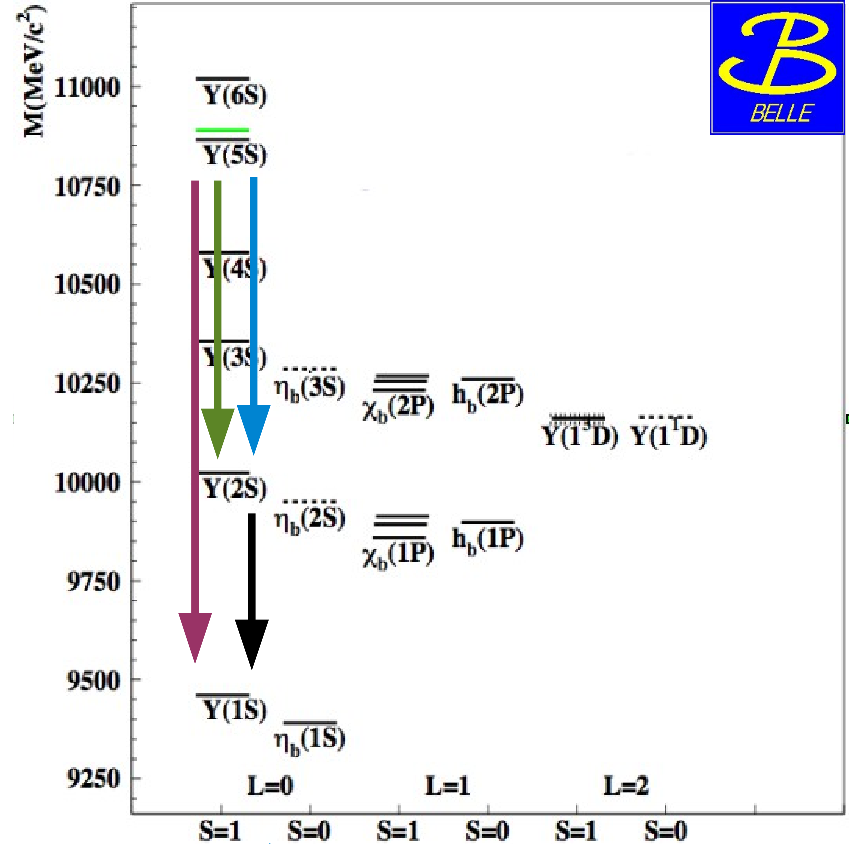
Υ(5S)→ η Υ(1,2S)

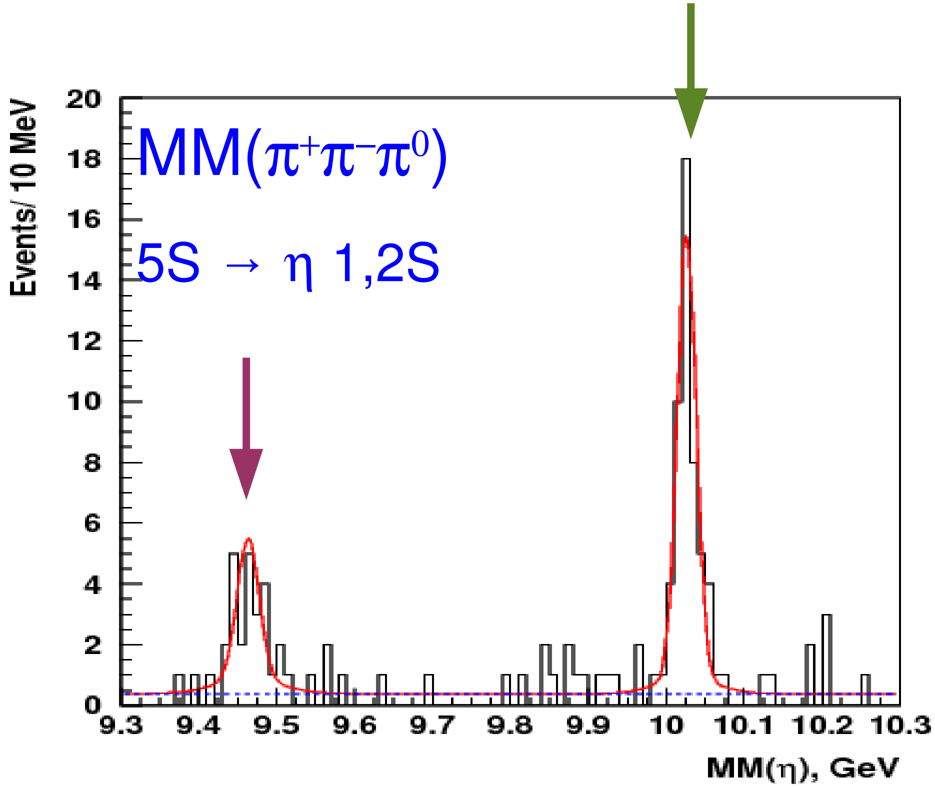
Exclusive reconstruction

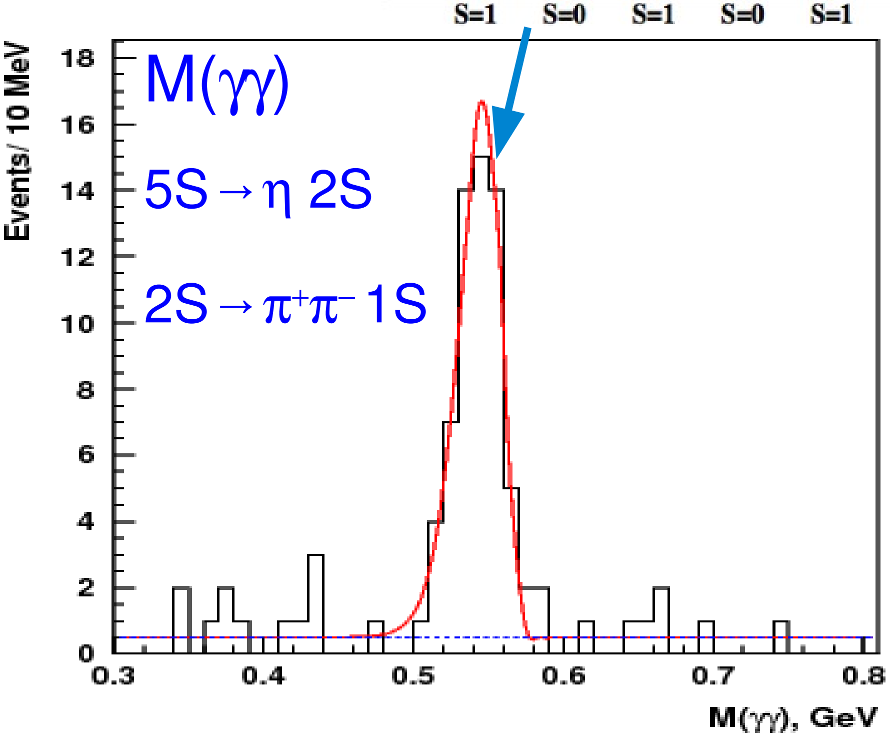
- $\Upsilon(1,2S) \to \mu^+\mu^- + \eta \to \pi^+\pi^-\pi^0$
- $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^- + \eta \to \gamma\gamma$

$B[\Upsilon(5S) \to \Upsilon(1S)\eta] = (7.3 \pm 1.6 \pm 0.8)\ 10^{-4}$

$B[\Upsilon(5S) \to \Upsilon(2S)\eta] = (38 \pm 4 \pm 5)\ 10^{-4}$



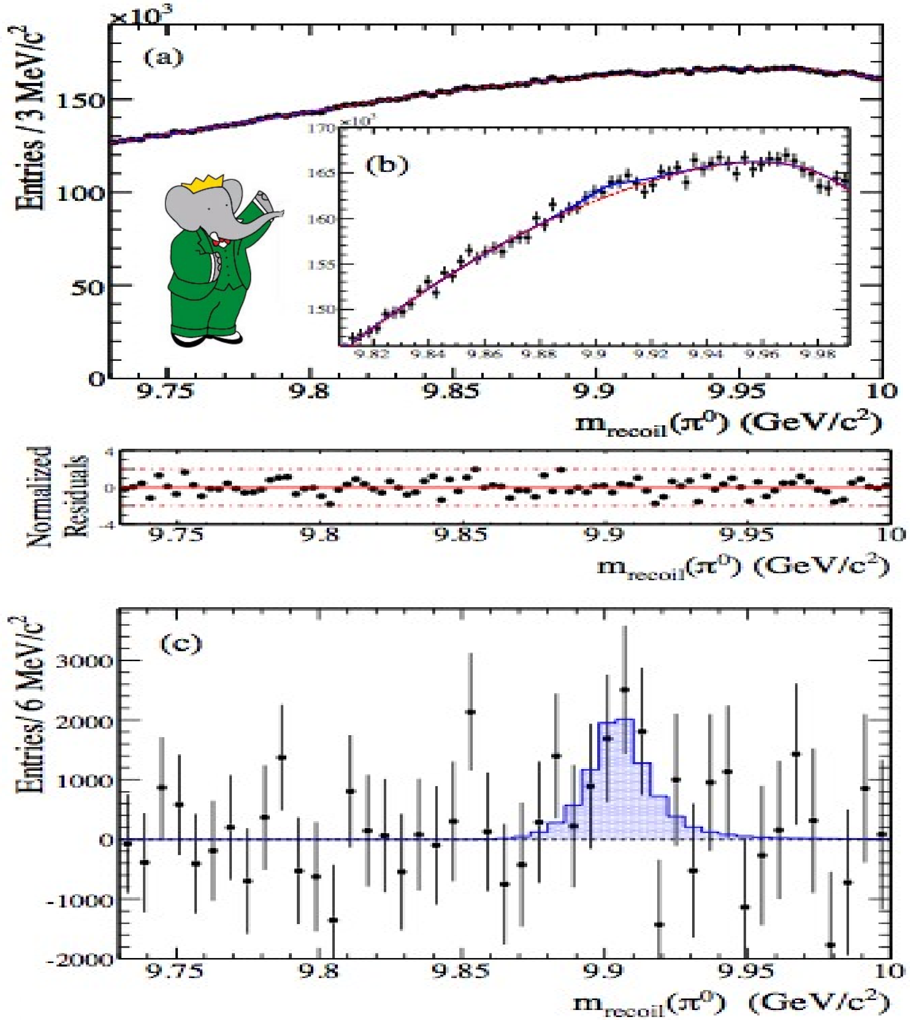




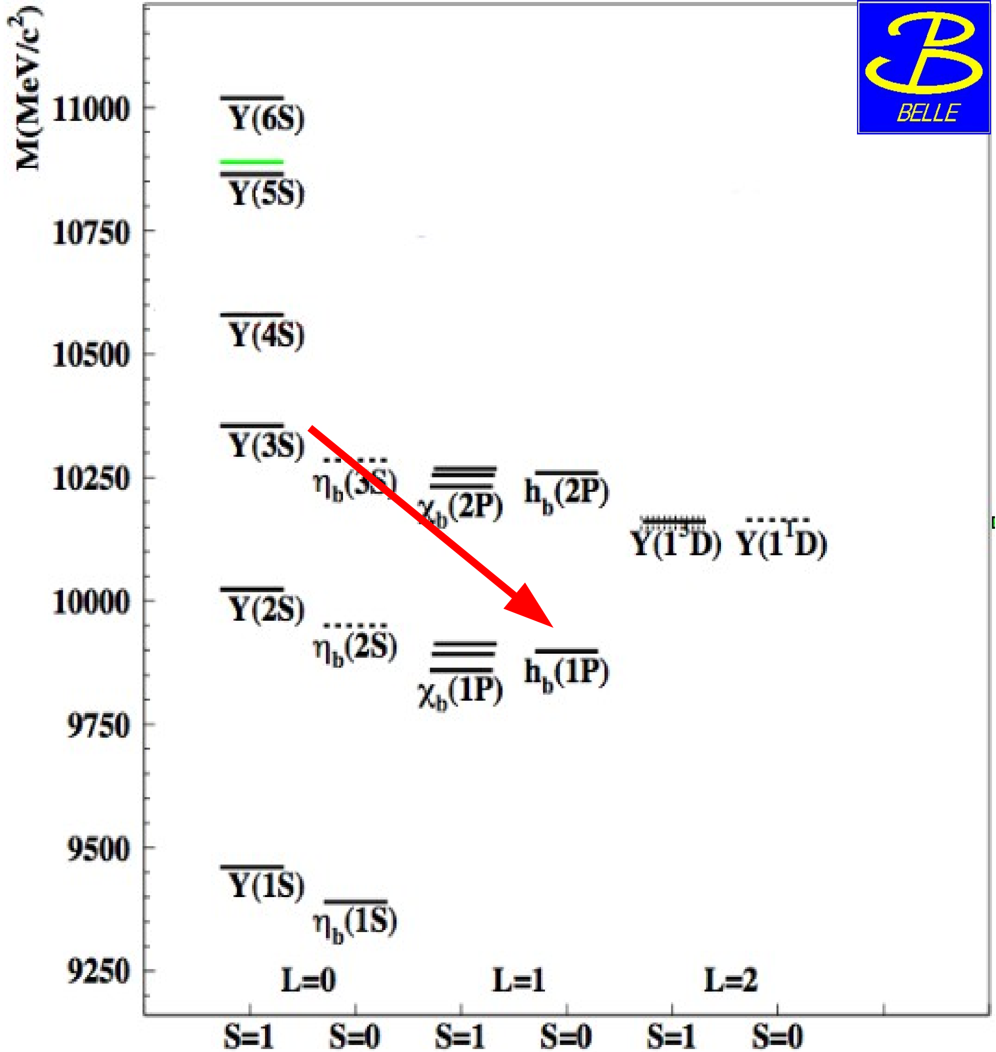
$h_b(1P)$ at BaBar

3 sigma evidence:

$e+e- \rightarrow Y(3S) \rightarrow \pi^0 h_b$

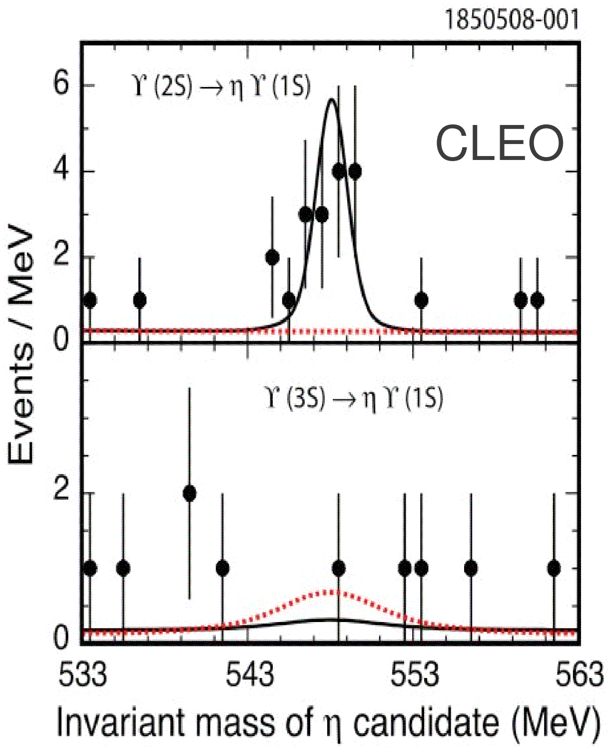


π^0 recoil mass (GeV/c^2)

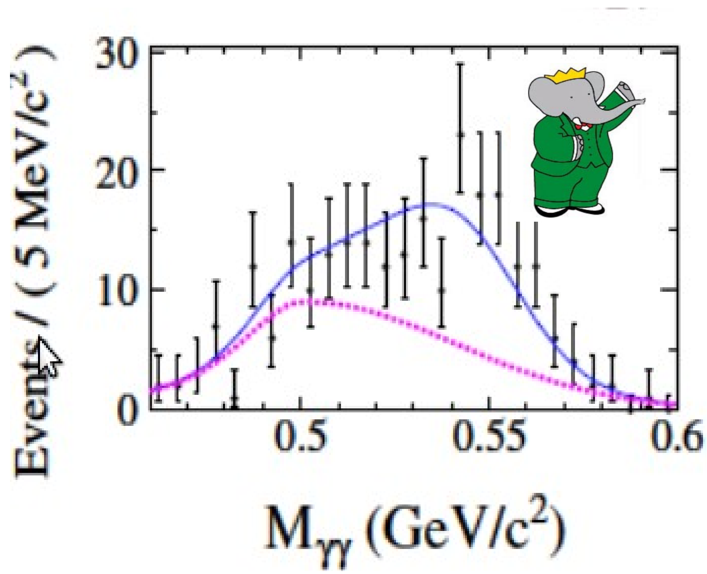


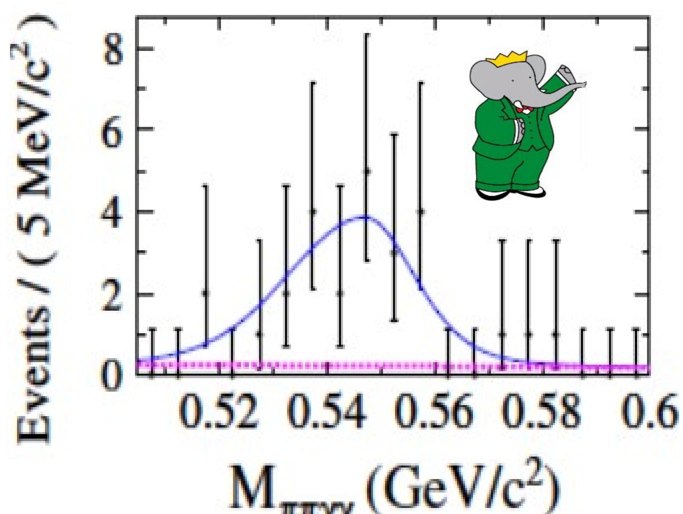
Phys.Rev.D 84 091101(R)

Υ(2S)→ η Υ(1S) @ BaBar and CLEO

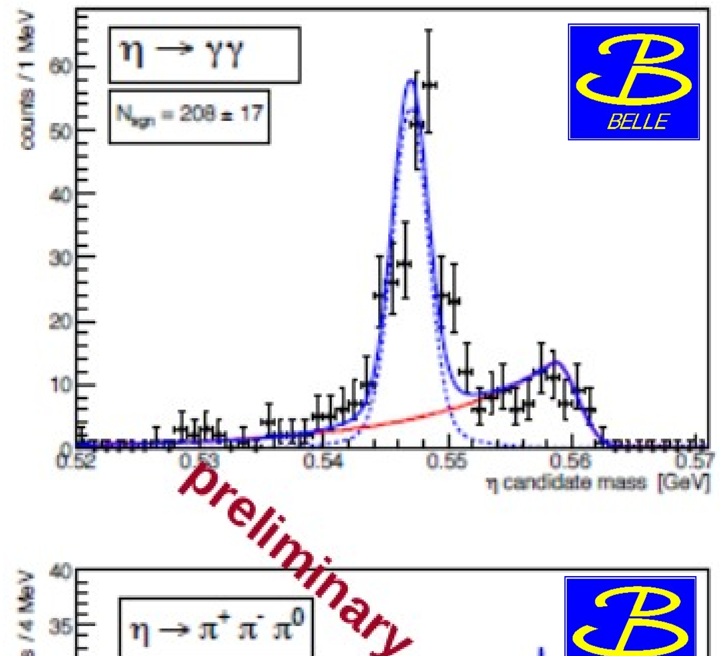


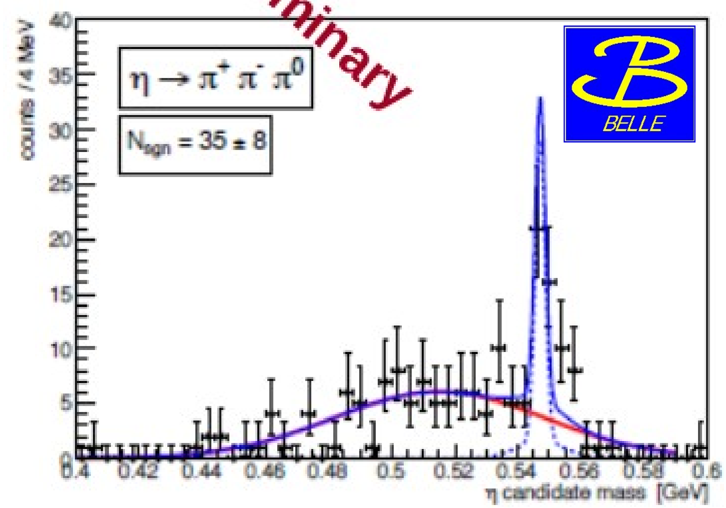
All modes summed





BF = (2.39 ± 0.31 ±0.14)×10^{-4}



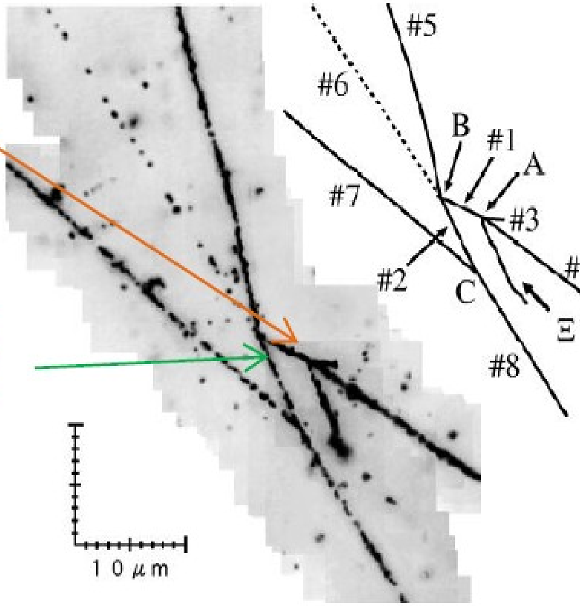


The Nagara event

Ξ^- beam on emulsion target (Phys. Rev. Lett. 87, 212502)

$\Xi^- + {}^{12}C \rightarrow {}_{\Lambda\Lambda}{}^{6}He(\#1) + t(\#4) + \alpha(\#3)$

${}_{\Lambda\Lambda}{}^{6}He(\#1) \rightarrow {}_{\Lambda}{}^{5}He(\#2) + p(\#5) + \pi(\#6)$



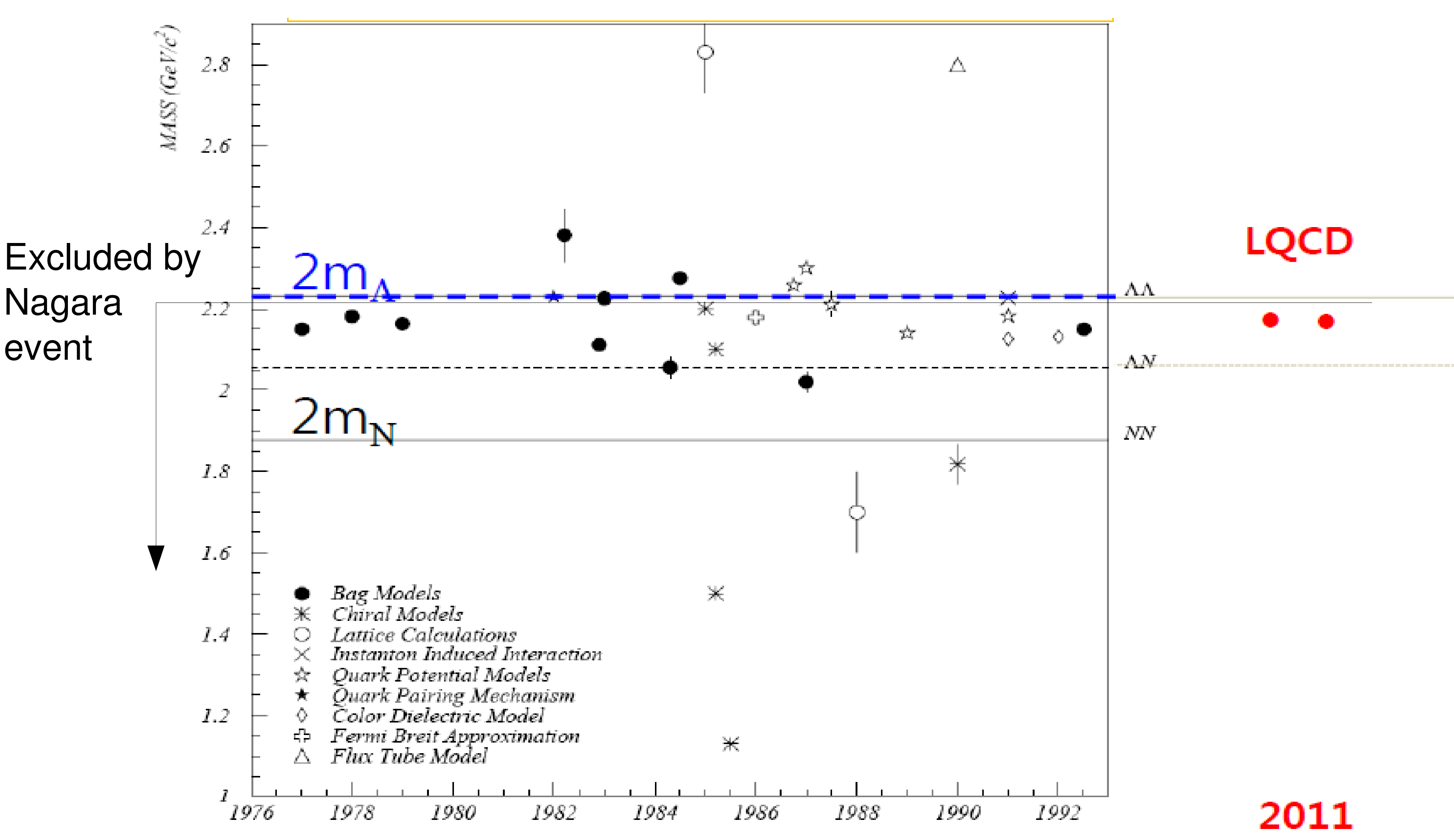
Event	Nuclide	$B_{\Lambda\Lambda}$ (MeV)	$\Delta B_{\Lambda\Lambda}$ (MeV)
1963	${}^{10}_{\Lambda\Lambda}Be$	17.7 ± 0.4	4.3 ± 0.4
1966	${}^{6}_{\Lambda\Lambda}He$	10.9 ± 0.5	4.7 ± 1.0
1991	${}^{13}_{\Lambda\Lambda}B$	27.5 ± 0.7	4.8 ± 0.7
NAGARA	${}^{6}_{\Lambda\Lambda}He$	7.13 ± 0.87	1.0 ± 0.2
MIKAGE	${}^{6}_{\Lambda\Lambda}He$	10.06 ± 1.72	3.82 ± 1.72
DEMACHIYANAGI	${}^{10}_{\Lambda\Lambda}Be$	11.90 ± 0.13	-1.52 ± 0.15
HIDA	${}^{11}_{\Lambda\Lambda}Be$	20.49 ± 1.15	2.27 ± 1.23
	${}^{12}_{\Lambda\Lambda}Be$	22.23 ± 1.15	–
E176	${}^{13}_{\Lambda\Lambda}Be$	23.3 ± 0.7	0.6 ± 0.8

← **ΛΛ binding energy = 7 MeV**

M(H) > 2223.7 MeV (90% CL)

2M(Λ) = 2231.36 MeV

H-dibaryon mass



$e^+e^- \to \Lambda\bar{\Lambda} + X$ (no π^0)

Channel	Significance	N_{meas}	N_{UL}	σ_{sys} [%]	σ [fb]	σ_{UL} [fb]
$\Lambda\bar{\Lambda}$		0	2.08	15.70		0.59
$\Lambda\bar{\Lambda}+\pi^+\pi^-$	5.18 σ	7± 3.00		15.81	2.09± 0.90	
$\Lambda\bar{\Lambda}+K^+K^-$		2± 2.00	5.65	15.83		2.83
$\Lambda\bar{\Lambda}+p\bar{p}$		0	2.92	15.81		1.14
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)$	8.62 σ	24± 5.00		15.90	10.05± 2.09	
$\Lambda\bar{\Lambda}+2(K^+K^-)$		1± 1.00	4.36	15.98		4.43
$\Lambda\bar{\Lambda}+2(p\bar{p})$		0	2.44	15.91		1.43
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-$	10.18 σ	26± 5.00		15.94	16.81± 3.23	
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}$	5.55 σ	8± 3.00		15.90	3.53± 1.32	
$\Lambda\bar{\Lambda}+K^+K^-p\bar{p}$		0	2.44	15.94		1.87
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)$	11.37 σ	36± 6.00		16.03	25.72± 4.29	
$\Lambda\bar{\Lambda}+3(K^+K^-)$		1± 1.00	4.36	16.31		11.57
$\Lambda\bar{\Lambda}+3(p\bar{p})$		0	2.44	16.37		7.42
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-$	9.68 σ	27± 5.00		16.12	32.54± 6.03	
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}$	7.09 σ	11± 3.00		16.04	8.87± 2.42	
$\Lambda\bar{\Lambda}+\pi^+\pi^-2(K^+K^-)$		2± 1.00	4.91	16.22		10.30
$\Lambda\bar{\Lambda}+\pi^+\pi^-2(p\bar{p})$		1± 1.00	4.36	16.09		5.53
$\Lambda\bar{\Lambda}+2(K^+K^-)p\bar{p}$		0	2.44	16.25		5.65
$\Lambda\bar{\Lambda}+K^+K^-2(p\bar{p})$		0	2.44	16.29		6.14
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-p\bar{p}$		0	2.44	16.18		4.44
$\Xi^+\Xi^-$		0	2.44	15.82		1.86
$\Xi^+\Xi^-+\pi^+\pi^-$		0	2.33	15.94		1.71
$\Omega^+\Omega^-$		0	2.44	15.91		7.04
$\Omega^+\Omega^-+\pi^+\pi^-$		0	2.44	16.06		6.94

$e^+e^- \rightarrow \Lambda\bar{\Lambda} + X + \pi^0$

Channel	Significance	N_{meas}	N_{UL}	σ_{sys} [%]	σ [fb]	σ_{UL} [fb]
$\Lambda\bar{\Lambda} + \pi^0$		0	2.44	16.75		2.26
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	3.40 σ	5$\pm$ 2.00	9.63	16.89	4.49$\pm$ 1.80	10.40
$\Lambda\bar{\Lambda} + K^+K^-\ \pi^0$	3.52 σ	4$\pm$ 2.00	7.92	16.96	5.07$\pm$ 2.54	12.09
$\Lambda\bar{\Lambda} + p\bar{p}\ \pi^0$		0	2.44	16.90		2.76
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	7.03 σ	21$\pm$ 5.00		17.03	26.95$\pm$ 6.42	
$\Lambda\bar{\Lambda} + 2(K^+K^-)\ \pi^0$		2$\pm$ 1.00	4.98	17.32		17.78
$\Lambda\bar{\Lambda} + 2(p\bar{p})\ \pi^0$		0	2.44	17.15		5.82
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	5.29 σ	12$\pm$ 4.00		17.18	25.50$\pm$ 8.50	
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$		3$\pm$ 2.00	5.98	17.07		10.76
$\Lambda\bar{\Lambda} + K^+K^-p\bar{p}\ \pi^0$		0	2.44	17.21		6.78
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	8.96 σ	25$\pm$ 5.00		17.31	62.24$\pm$ 12.45	
$\Lambda\bar{\Lambda} + 3(K^+K^-)\ \pi^0$		0	2.44	18.44		27.49
$\Lambda\bar{\Lambda} + 3(p\bar{p})\ \pi^0$		0	2.44	21.17		84.13
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	6.94 σ	16$\pm$ 4.00		17.63	69.39$\pm$ 17.35	
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$		1$\pm$ 1.00	4.21	17.44		16.73
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)\ \pi^0$		1$\pm$ 1.00	4.36	17.91		32.11
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(p\bar{p})\ \pi^0$		0	2.44	17.90		17.67
$\Lambda\bar{\Lambda} + 2(K^+K^-)p\bar{p}\ \pi^0$		0	2.44	18.56		29.79
$\Lambda\bar{\Lambda} + K^+K^-2(p\bar{p})\ \pi^0$		0	2.44	19.03		38.86
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-p\bar{p}\ \pi^0$		0	2.44	17.92		18.00
$\Xi^+\Xi^- + \pi^0$		0	2.44	16.90		4.71
$\Xi^+\Xi^- + \pi^+\pi^-\ \pi^0$		0	2.01	17.14		4.67
$\Omega^+\Omega^- + \pi^0$		0	2.44	17.06		17.86
$\Omega^+\Omega^- + \pi^+\pi^-\ \pi^0$		0	2.44	17.45		22.83