Les Rencontres de Physique de la Vallee d'Aoste
Results and Perspectives in Particle Physics
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New resonances at Belle

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Belle Collaboration

Introduction

B-factories ⇒

	EXP	M + i Γ (MeV)	J^{PC}	Decay Modes Observed	Production Modes Observed
X(3872)	Belle,CDF, D0, Cleo, BaBar	3871.2±0.5 + i(<2.3)	$1^{++},2^{-+}$	$\pi^+\pi^- J/\psi$, $\pi^+\pi^-\pi^0 J/\psi$, $\gamma J/\psi$	B decays, ppbar
	Belle BaBar	$3875.4\pm0.7^{+1.2}_{-2.0}$ $3875.6\pm0.7^{+1.4}_{-1.5}$		$D^0D^0\pi^0$	B decays
Z(3930)	Belle	3929±5±2 + i(29±10±2)	2^{++}	D^0D^0, D^+D^-	$\gamma\gamma$
Y(3940)	Belle BaBar	3943±11±13 + i(87±22±26) $3914.3^{+3.8}_{-3.4}$ ±1.6+ i(33^{+12}_{-8} ±0.60)	J^{++}	$\omega J/\psi$	B decays
X(3940)	Belle	$3942^{+7}_{-6}\pm6$ + i($37^{+26}_{-15}\pm8$)	J^{P+}	DD^*	e^+e^- (recoil against J/ψ)
Y(4008)	Belle	$4008\pm40^{+72}_{-28}$ + i($226\pm44^{+87}_{-79}$)	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
X(4160)	Belle	$4156^{+25}_{-20}\pm15$+ i($139^{+111}_{-61}\pm21$)	J^{P+}	D^*D^*	e^+e^- (recoil against J/ψ)
Y(4260)	BaBar Cleo Belle	$4259\pm8^{+8}_{-6}$ + i($88\pm23^{+6}_{-4}$) 4284^{+17}_{-16} ±4 + i($73^{+39}_{-25}\pm5$) $4247\pm12^{+17}_{-32}$ + i(108±19±10)	1^{--}	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $K^+K^- J/\psi$	e^+e^- (ISR), e^+e^-
Y(4350)	BaBar Belle	4324±24 + i(172±33) 4361±9±9 + i(74±15±10)	1^{--}	$\pi^+\pi^-\psi(2S)$	e^+e^- (ISR)
$Z^+(4430)$	Belle	$4433\pm4\pm1$+ i($44^{+17}_{-13}{}^{+30}_{-11}$)	J^P	$\pi^+\psi(2S)$	B decays
Y(4620)	Belle	4664±11±5 + i(48±15±3)	1^{--}	$\pi^+\pi^-\psi(2S)$	e^+e^- (ISR)

E. Eichten QWG -- 5th International Workshop on Heavy Quarkonia DESY October 17-20, 2007

Special place: $Z(4430)^\pm \to \psi(2S)\,\pi^\pm$ ⇔ minimal quark content $|c\bar{c}u\bar{d}\rangle$

⇐ can not be an ordinary meson

my talk

- Observation of $Z(4430)^\pm$
- Anything unexpected in bottomonium sector?
- Observation of anomalous $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ production near $\Upsilon(5S)$

$Z(4430)^{\pm}$

Observation of resonance-like structure in $\psi(2S)\pi^{\pm}$ mass spectrum for $B \to \psi(2S)K\pi^{+}$ decays

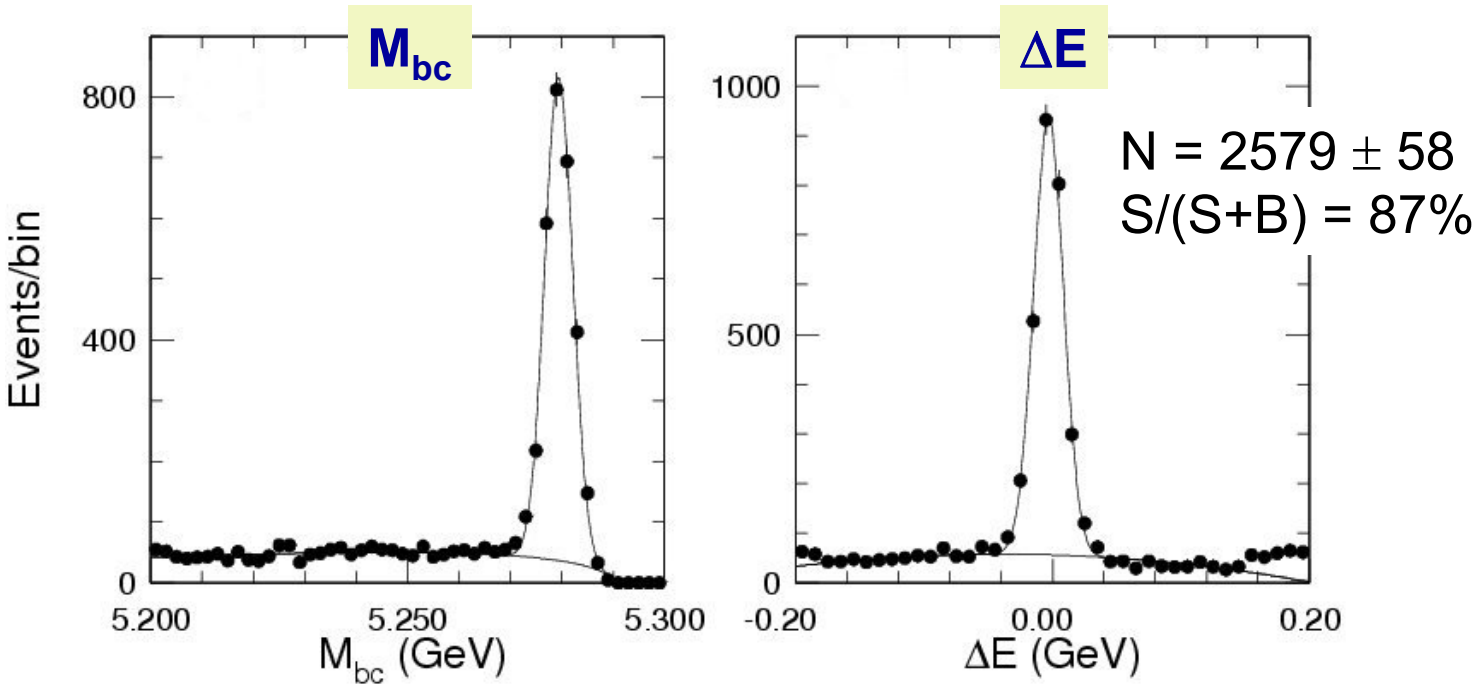
Reconstruction of B → ψ(2S) K π⁺

605fb^{-1}

K = K$^-$ or K$_S$ **ψ(2S) → J/ψ π$^+$π$^-$, μ$^+$μ$^-$, e$^+$e$^-$** **J/ψ → μ$^+$μ$^-$, e$^+$e$^-$**

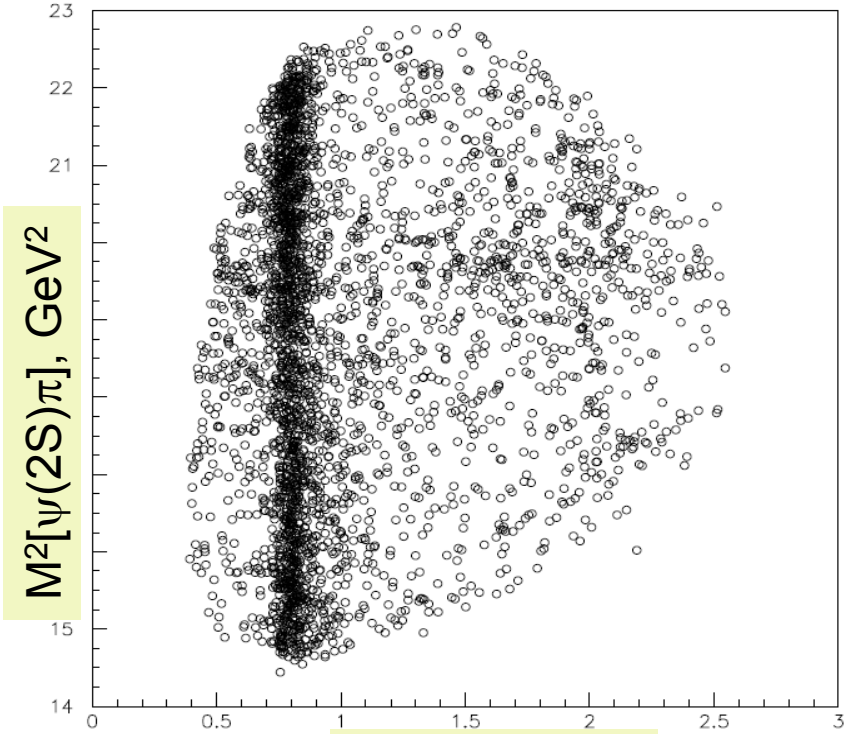
Use Υ(4S) → BB̲ decay kinematics

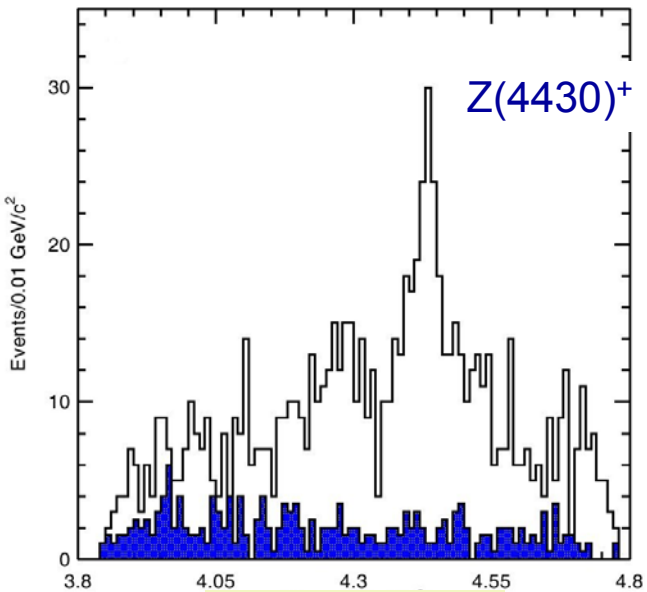
$$\begin{cases} \Delta E = E_{\rm beam} - E_B \\ M_{\rm bc} = \sqrt{E^2_{\rm beam} - p^2_B} \end{cases}$$

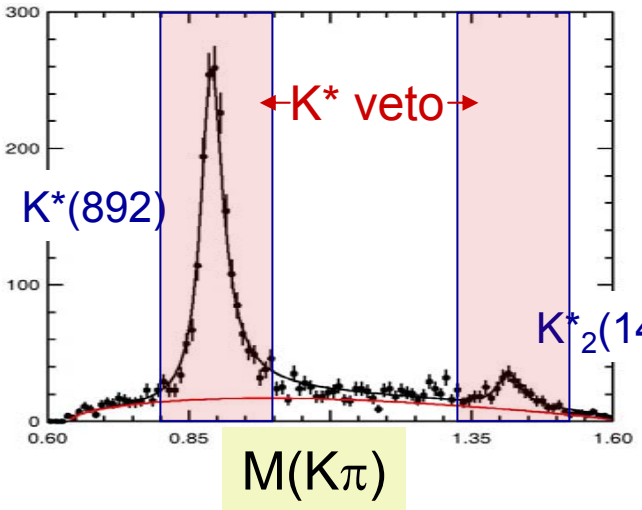


⇒ Clean B → ψ(2S) K π$^+$ signal.

Dalitz plot of B → ψ(2S) K π⁺



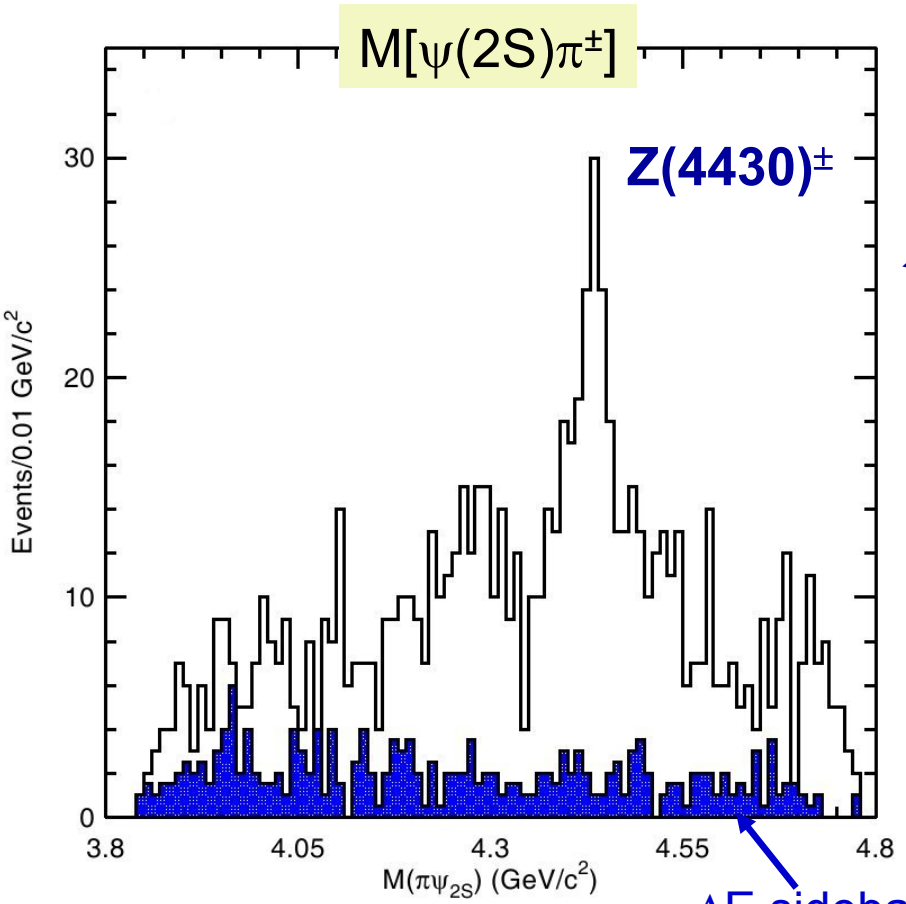




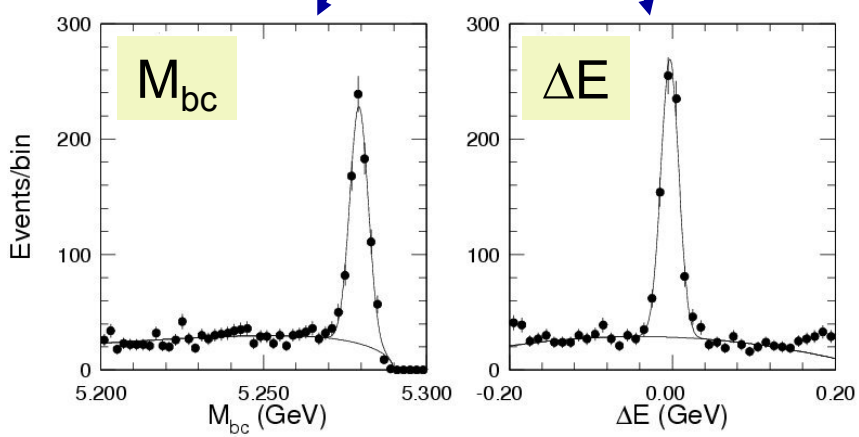
K*(890) = 1742 ± 59 evts

$K_2^*(1430)$ = 103 ± 36 evts

M[ψ(2S)π±] projection

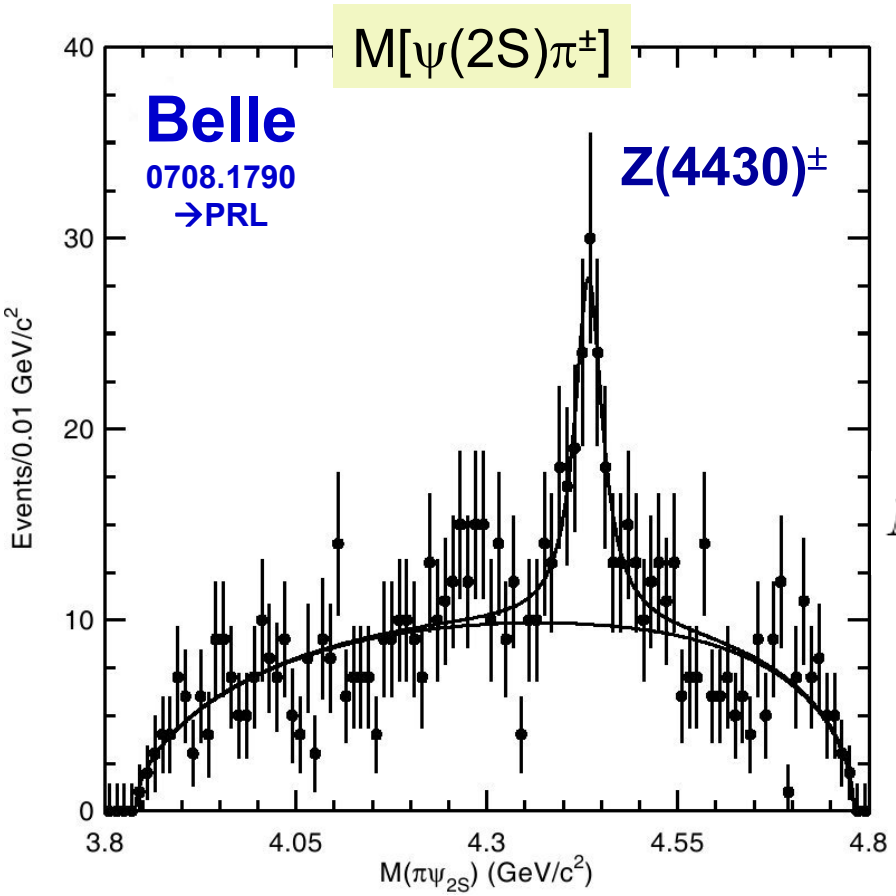


K*(892) and K*$_2$(1430) veto applied



⇒ Strong narrow signal in M[ψ(2S)π±] with very low background.

Fit results



Fit: S-wave BW
+ phase space-like function

$$f_{cont}(M) = \mathcal{N} q (Q^{1/2} + A_1 Q^{3/2} + A_2 Q^{5/2})$$

Significance 6.5σ (for 3 d.o.f.).

$$M = (4.433 \pm 0.004(\text{stat}) \pm 0.001(\text{syst}))\ GeV$$

$$\Gamma = (0.044^{+0.017}_{-0.012}(\text{stat})^{+0.030}_{-0.011}(\text{syst}))\ GeV$$

Cf	Γ, MeV
Y(3940)	33
Y(4260)	~90
Y(4350)	74
Y(4620)	48

$$\mathcal{B}(B \to K X(4430)) \times \mathcal{B}(X(4430) \to \pi^+ \psi') = (4.0 \pm 0.7 \pm 1.1) \times 10^{-5}$$

C.f. Y(3940) *BF*=7×10^{-5}

Cross-checks

Compare data subsamples $\Rightarrow$

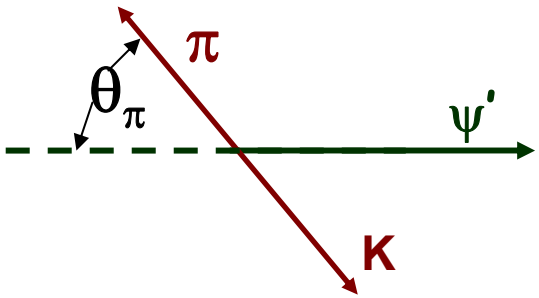
Subset	Mass (GeV)	Width (GeV)	Signif. (σ)	Constr. yield ($\Gamma = 0.045$GeV)
$\pi^+\pi^- J/\psi$	4.435 ± 0.004	$0.026^{+0.013}_{-0.008}$	4.5	64 ± 15
$\ell^+\ell^-$	4.435 ± 0.010	$0.094^{+0.042}_{-0.030}$	4.7	59 ± 13
e^+e^-	4.430 ± 0.009	$0.056^{+0.028}_{-0.020}$	3.5	41 ± 12
$\mu^+\mu^-$	4.434 ± 0.004	$0.038^{+0.023}_{-0.013}$	5.2	80 ± 16
$K^\pm\pi^\mp\psi'$	4.434 ± 0.005	$0.048^{+0.019}_{-0.014}$	6.0	102 ± 18
$K^0_S\pi^\mp\psi'$	4.430 ± 0.009	0.048-fixed	2.0	19 ± 8
K^* veto	4.437 ± 0.005	$0.063^{+0.024}_{-0.017}$	7.1	170 ± 26

$\Rightarrow$ Significant signals @ ~4433MeV in all subsets.

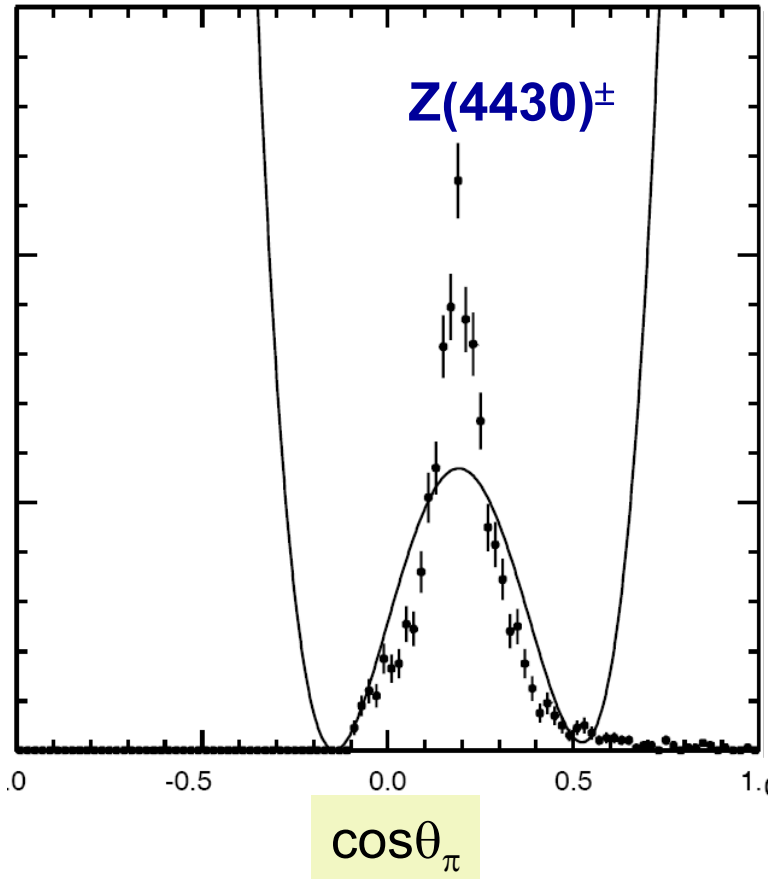
B generic MC $\Rightarrow$ not reflection.

Cross-checks (2)

Can interference of S-, P- and D-waves reproduce the peak?



M[ψ(2S)π] & $\cos\theta_\pi$ are tightly correlated



Not without introducing other, even more dramatic features at other $\cos\theta_\pi$ (&, ∴, other $M_{\psi'\pi}$) values.

Interpretation

$Z(4430)^{\pm}$ mass is close to $D^*\underline{D}_1(2420)$ threshold.

S-wave threshold effect — *Rosner, PRD76,114002*

$D^*\underline{D}_1(2420)$ molecule $J^P = 0^-, (1^-, 2^-)$ — *Meng, Chao, 0708.4222*; *Lee,Mihara,Navarra,Nielsen 0710.1029*; *Liu,Liu,Deng,Zhu, 0711.0494*

$Z(4430)^{\pm} \rightarrow D^*D^*\pi$

[c u] [c d] tetraquark $J^P = 1^+$ — *Maiani,Polosa,Riquer 0708.3997*

$Z(4430)^{\pm} \rightarrow DD^*, D^*D^*, J/\psi\pi, J/\psi\rho, \eta_c\rho\ \psi(2S)\pi$ ~~DD~~

$Z(4430)^0 \rightarrow \psi(2S)\ \pi^0/\eta, \eta_c(2S)\ \rho^0/\omega$

$Z(4340)^{\pm} \rightarrow \psi(2S)\pi$

We need more statistics to determine $Z(4430)^{\pm}$ spin and parity.
Hunting other decay modes is important.

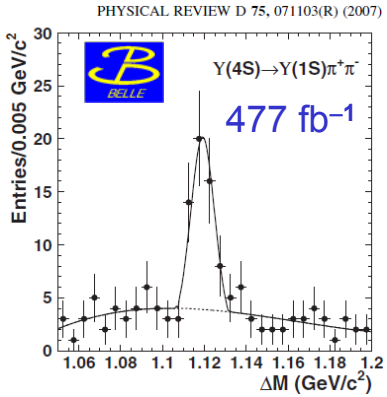
Observation of anomalous $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ production near $\Upsilon(5S)$

Introduction

Belle, BaBar operate at $\Upsilon(4S) \Rightarrow$

$$\Gamma(\Upsilon(4S) \to \Upsilon(1S)\,\pi^+\pi^-) = 1.8 \pm 0.4 \text{ keV}$$
$$\Upsilon(2S)\,\pi^+\pi^-) = 2.7 \pm 0.8 \text{ keV}$$

$BF \sim 10^{-4}$ PRL 96, 232001 (2006)



Belle collected 21.7fb^{-1} at $\Upsilon(5S)$ (June 9-31, 2006)
CLEO 0.42fb^{-1}

Primary goal – rare B_s decays. e.g. "Observation of $B_s \to \varphi\gamma$ and search for $B_s \to \gamma\gamma$ at Belle", 0712.2659 →PRL.

Is it possible to see $\Upsilon(5S) \to \Upsilon(nS)\,\pi^+\pi^-$ transitions?

$$\frac{21.7\text{fb}^{-1}}{477\text{fb}^{-1}}\ (\text{statistics})\quad \frac{20.5\text{MeV}}{110\text{ MeV}}\ (\text{width}) \quad \Rightarrow \text{expect limits only}$$

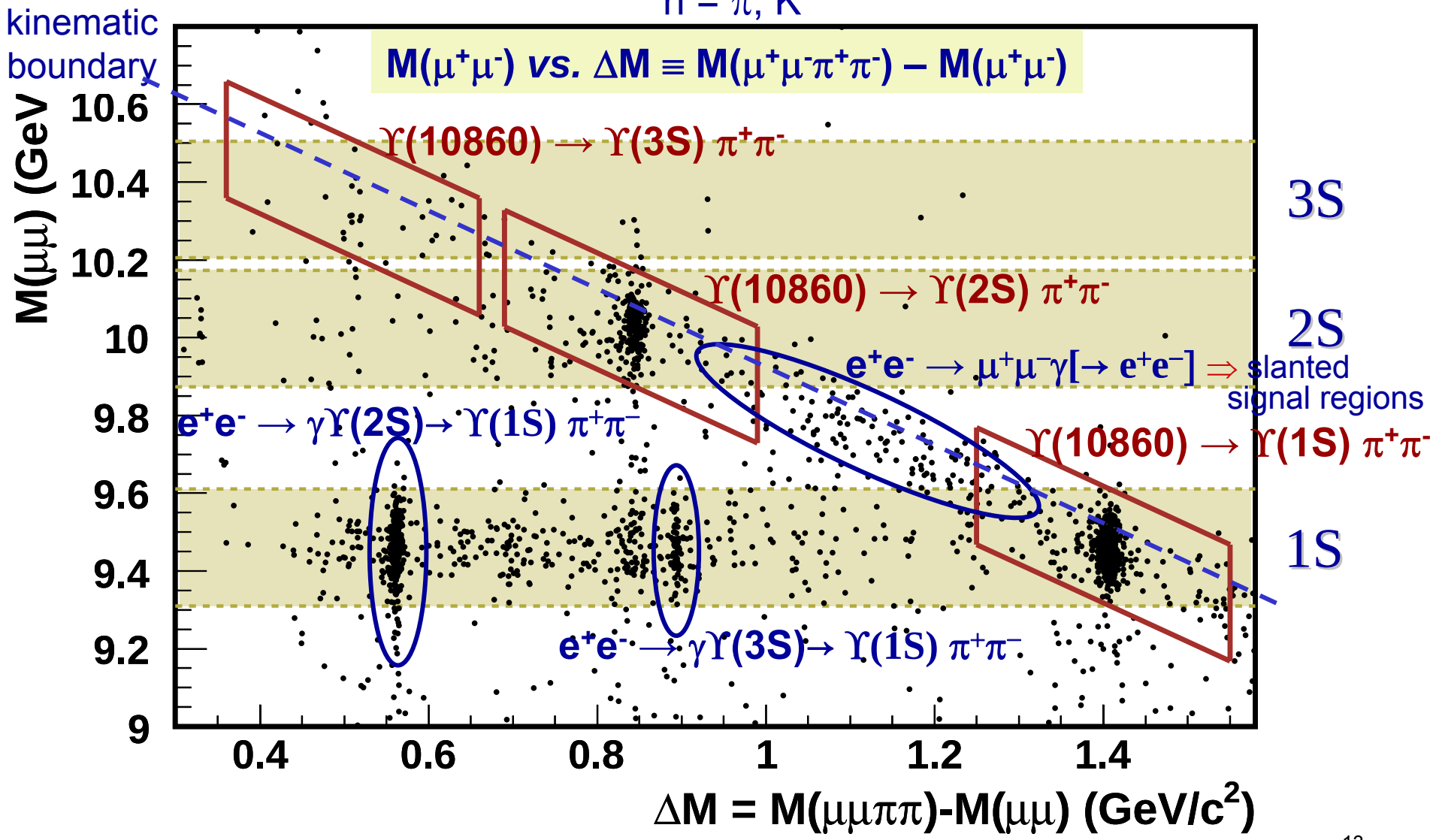
Reminder: $Y(2460) \to J/\psi\,\pi^+\pi^-$ rate is anomalously high.
If $\exists$ bottom counterpart of Y(2460) ($\equiv Y_b$) overlapping $\Upsilon(5S) \Rightarrow$ enhancement of $\Upsilon(nS)\,\pi^+\pi^-$ production @ $\Upsilon(5S)$. Hou, PRD 74, 017504 (2006)

Reconstruction of $\Upsilon(10860) \to \Upsilon(nS)\, h^+h^-$

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

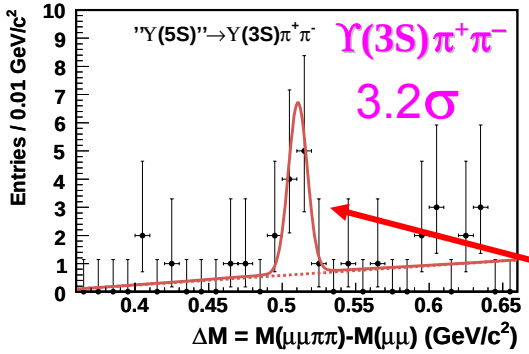
Select events $e^+e^- \to \mu^+\mu^- + h^+h^-$ (+ X^0

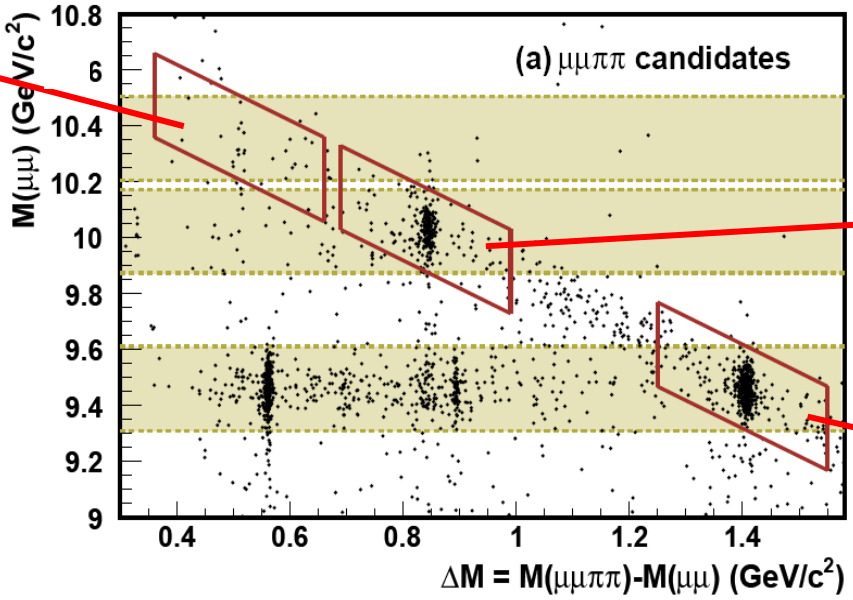
$h = \pi, K$

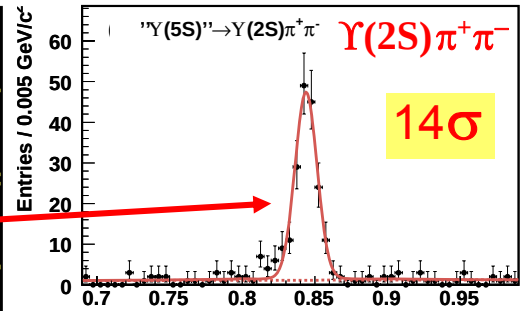


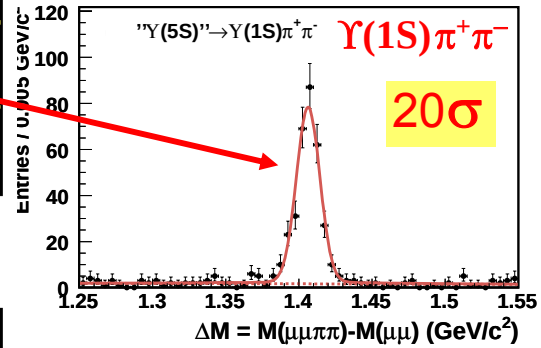
Signal extraction

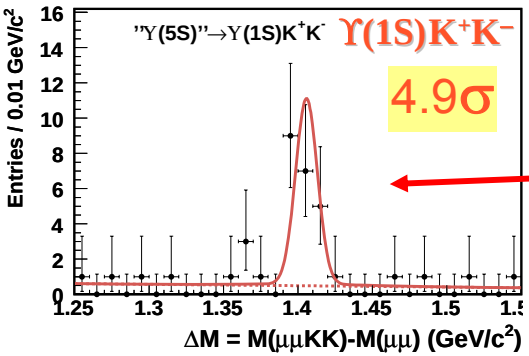
$$\Upsilon(1086) \to \Upsilon(nS)\pi^+\pi^-,\ \Upsilon(1S)K^+K^-$$

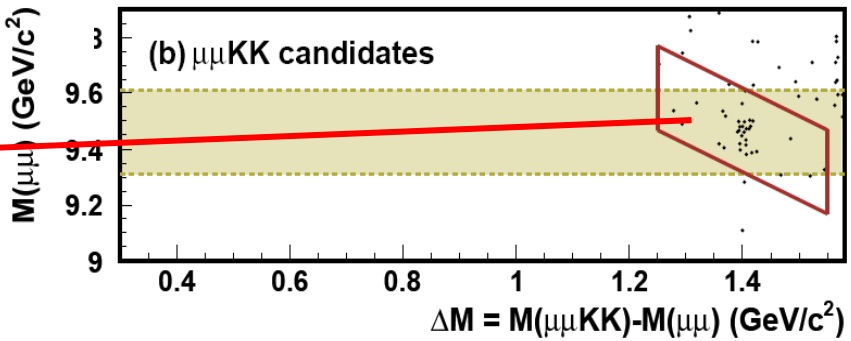












Results

Assume signal events come only from $\Upsilon(5S)$

Process	N_s	Σ	Eff.(%)	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	325^{+20}_{-19}	20σ	37.4	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	186 ± 15	14σ	18.9	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$10.5^{+4.0}_{-3.3}$	3.2σ	1.5	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$20.2^{+5.2}_{-4.5}$	4.9σ	20.3	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

Belle
0710.2577
→PRL

Cf
$\Upsilon(2S) \to \Upsilon(1S)\,\pi^+\pi^-$ ~ 6 keV
$\Upsilon(3S)$ 0.9 keV
$\Upsilon(4S)$ 1.8 keV

Is this $\Upsilon(5S)$, or the Y_b state? $\Rightarrow$ Need energy scan to tell.

Comparison between $\sigma(e^+e^- \to \Upsilon(nS)\pi^+\pi^-)$ and $\sigma(e^+e^- \to \text{hadrons})$.

Energy scan has been performed in Dec 6-17 2007 (7.9fb^{-1}, 6 energy points).

Results are coming soon!

Conclusions

Study of B → ψ(2S) K π⁺ decays ⇒ relatively narrow peak in M[ψ(2S)π±]

$$M = (4.433 \pm 0.004(\text{stat}) \pm 0.001(\text{syst}))\ GeV.$$

Significance 6.5σ.

$$\Gamma = (0.044^{+0.017}_{-0.012}(\text{stat})^{+0.030}_{-0.011}(\text{syst}))\ GeV$$

Peak is too narrow to be due to interference of (Kπ) resonances.

Candidate for multiquark state? ⇒ More experimental studies required.

First observation of Υ(1S) $\pi^+\pi^-$, Υ(2S) $\pi^+\pi^-$ transitions,
first evidence for Υ(2S) $\pi^+\pi^-$, Υ(1S) K^+K^- production near Υ(5S).

$\Gamma(\text{“}\Upsilon(5S)\text{”} \to \Upsilon(1S)\,\pi^+\pi^-) = 0.59 \pm 0.04 \pm 0.09$ MeV

$\Gamma(\text{“}\Upsilon(5S)\text{”} \to \Upsilon(2S)\,\pi^+\pi^-) = 0.85 \pm 0.07 \pm 0.16$ MeV

$\Gamma(\text{“}\Upsilon(5S)\text{”} \to \Upsilon(3S)\,\pi^+\pi^-) = 0.52^{+0.20}_{-0.17} \pm 0.10$ MeV

Two orders of magnitude higher than in other Υ(nS)!

Y_b is looming near? ⇒ energy scan in Dec 2007. Results to come.