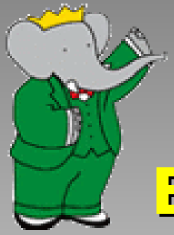
Charmonium Physics

in B decays

at

BaBar



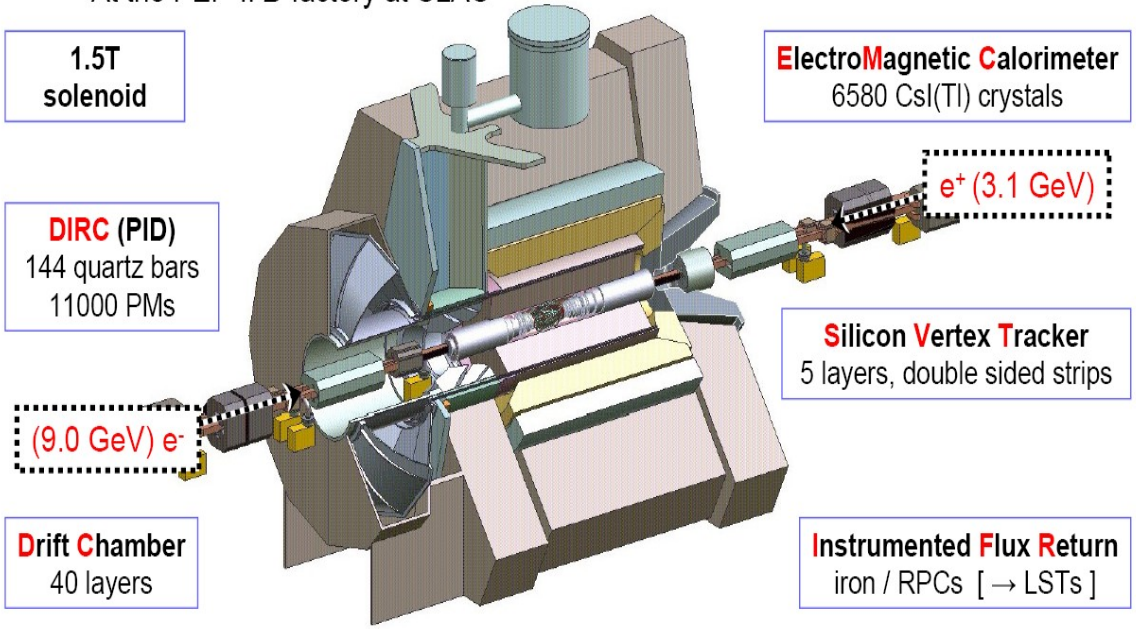
Elisabetta Prencipe

Overview

- The BaBar experiment
- Spectroscopy introduction
- Charmonium Physics at BaBar
- Charmonium Physics in B decay
  - $B \to X(3870)K$
  - $B \to YK$
  - $B \to Z(4430)K$
  - $B \to J/\psi\phi K$
- Overview on bottomonium studies at BaBar

BaBar: Who? Where? What?

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



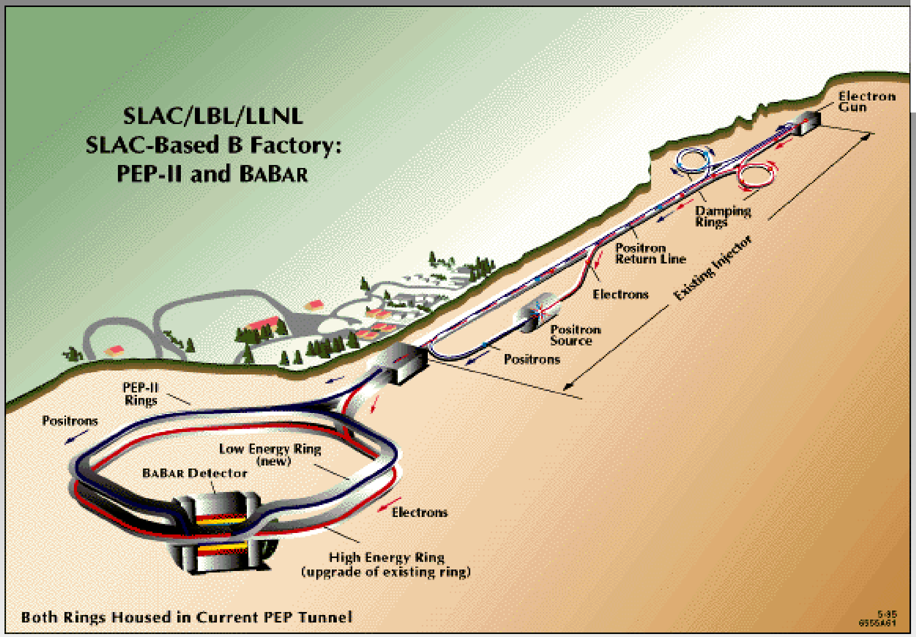
- *BABAR* collaboration consists : 11 countries and 630 physicists!

Asymmetric e^+e^- beam @ PEPII

Peak luminosity: $1.2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

>500 M $B\bar{B}$ produced

$\sqrt{s}$ = 10.58 GeV



Physics @ BaBar (I)

The BaBar detector has been optimized for:

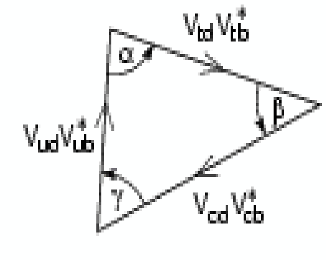
☒ study on CP violation in $B\bar{B}$ system

measurement of the angles and sides of the Unitarity Triangle

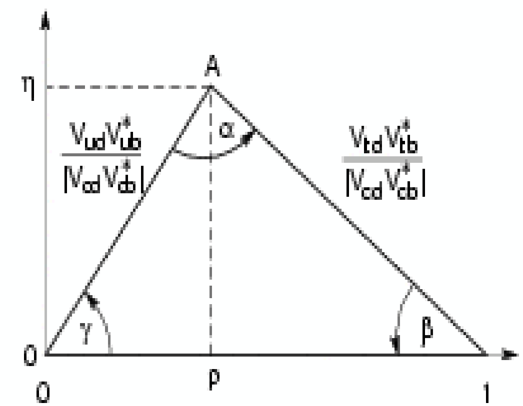
☒ rare B meson decays

(search for new Physics)

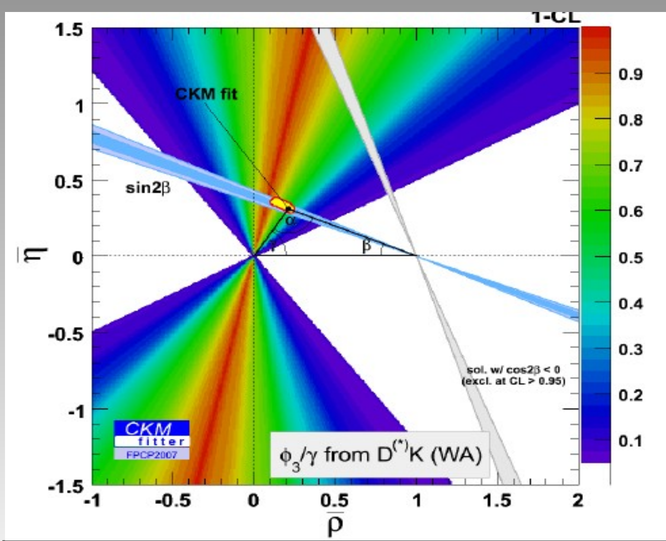
- Sides ~ λ^3
- CP violation ∝ triangle area
- Test the flavour sector of the SM

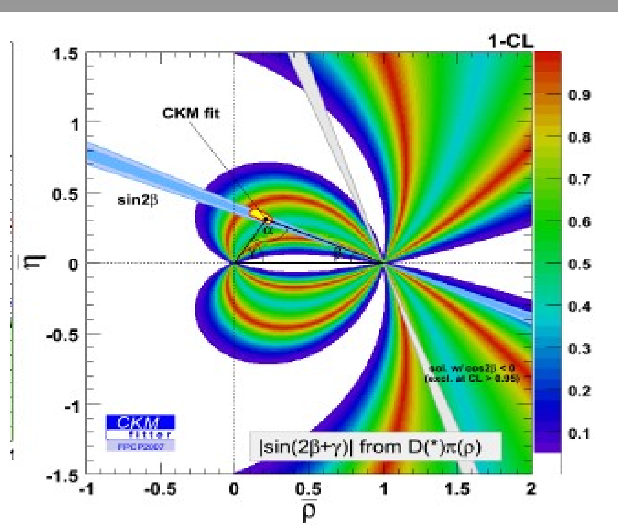


(a)



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$





Physics @ BaBar *(II)*

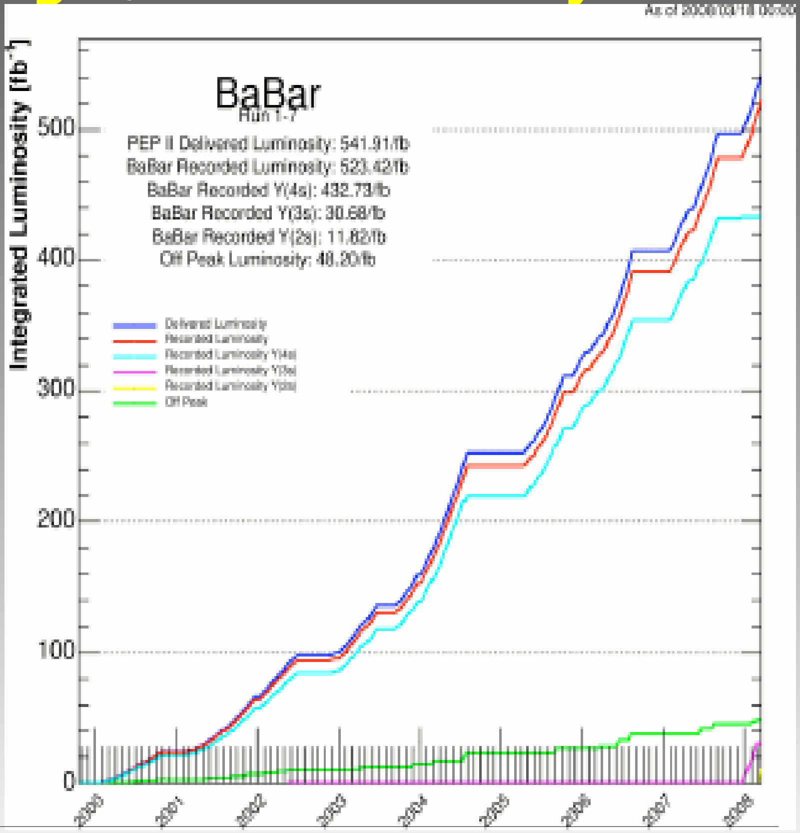
- ***BaBar*** is a B-factory:
  1999-2007 ☞ ~ 433fb^{-1} @ Υ(4S) (on-peak data)
  end of Dec07- end of Feb08 ☞ 30fb^{-1} @ Υ(3S)
  end of Feb08-6th of April08 ☞15fb^{-1} @ Υ(2S)
  scan around Υ(4S) (25pb^{-1} every 5 MeV)

- The main goal of the BaBar Physics has been the measurement of the sides and angles of the **Unitarity Triangle**, and **rare decays**.

- B-factories have been demonstrated to be also a ***huge source of $c\bar{c}$ production***.

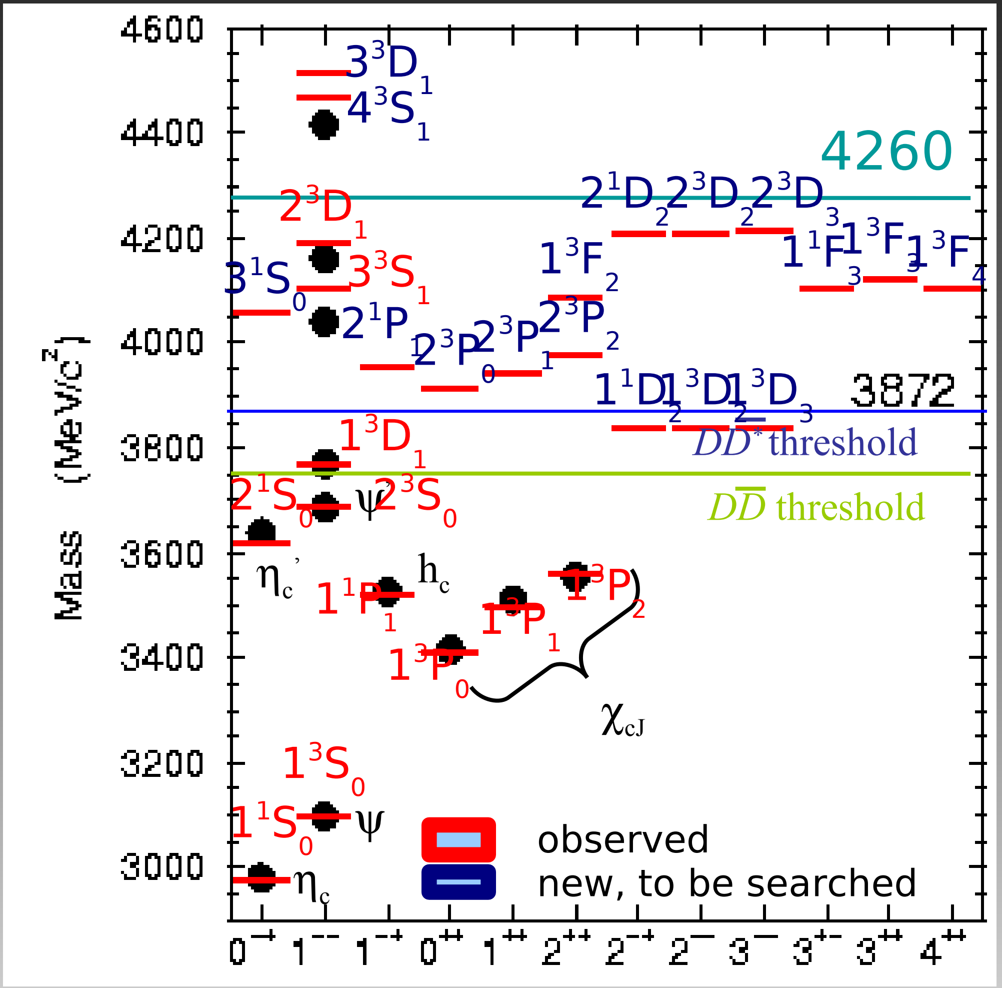
- The spectrum of Heavy Quarkonium states is an ideal place to provide precision tests of ***QCD***.

- Very accurate calculations are possible using Lattice techniques.
  $M_c \sim 1.5$ GeV/c^2 is high enough to try to describe **QCD** in term of NRPM.



Spectroscopy @BaBar

- Well known charmonium states below the $D\bar{D}$ threshold and some 1^{--} states above threshold
- States below the $D\bar{D}$ threshold are in good agreement with theoretical models
- New states recently observed at the B-factories **do not fit theoretical expectations**
- **QCD** foresees a more rich spectroscopy: hybrids, tetraquark, molecular states...
- BaBar is also working in this direction in order to interpret these new states...



Heavy Spectroscopy in e^+e^- interactions @Y(4S)

BABAR

- Production in continuum:
  - $e^+e^- \rightarrow \psi \; X$ (C_X=+)
  - $e^+e^- \rightarrow \gamma_{ISR} X$ (only $J^{PC}=1^{--}$)
  - $\gamma\gamma \rightarrow X$ ($J_X \neq 1$)
- Production B decays:
  - $b \rightarrow c$ (color suppressed decay)
  - open-charm and charmonium
    ($c\bar{s}$ and $c\bar{c}$ meson, cqq baryons; $c\bar{c}$ +…)

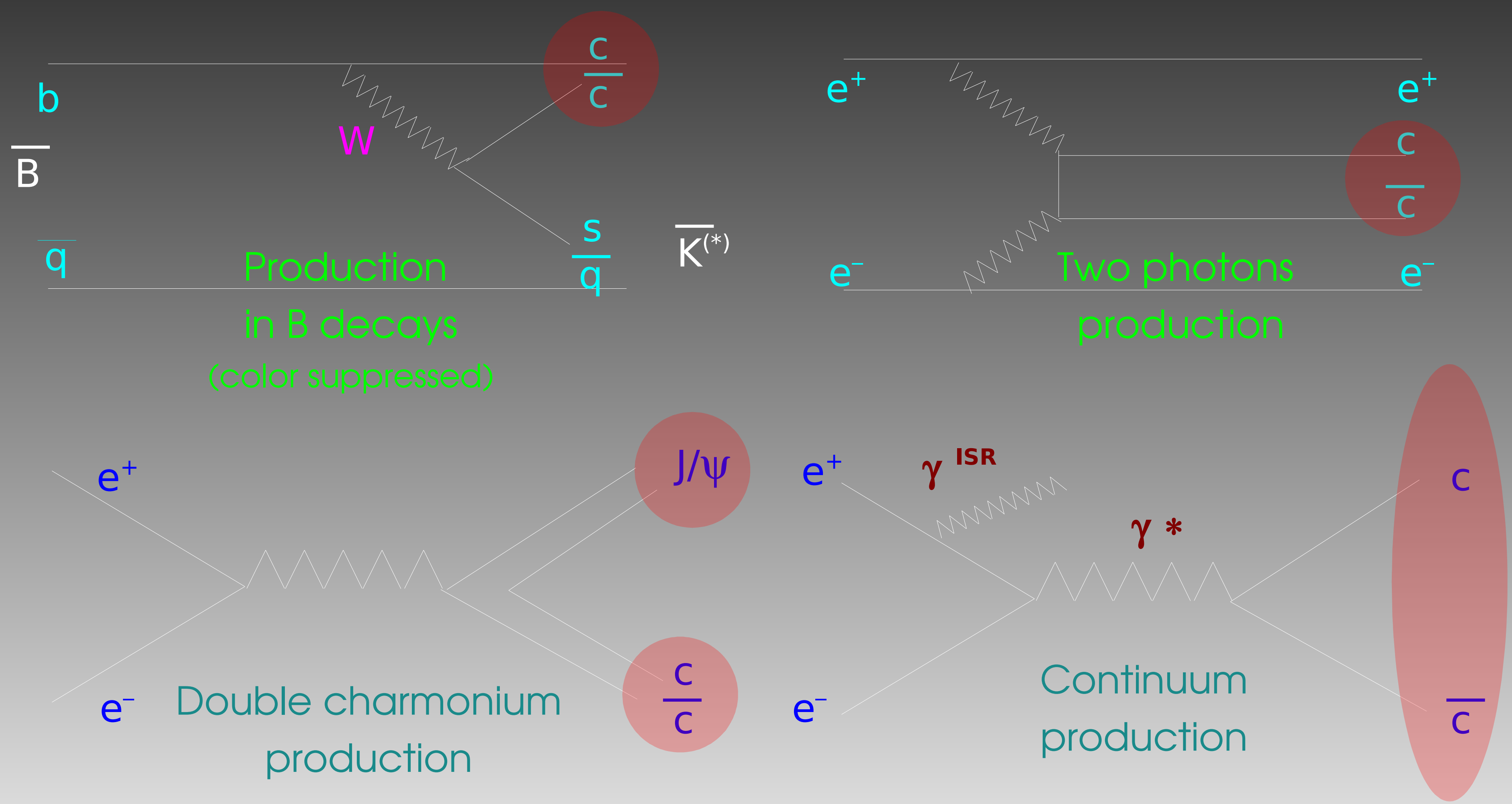
charm and charmonium spectroscopy

- Transition $\Upsilon(4S) \rightarrow \Upsilon(2S)\pi^+\pi^-$, $\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(4S) \rightarrow \Upsilon(1S)\eta$

bottomonium spectroscopy

The main goal of the physics @*Y(3S)* and @*Y(2S)* is the search of bottomonium states and light Higgs.

B-factory: charmonium production processes



Systematic program for the study of charmonia production in B decay

Some possibilities are investigated for the study of resonant structures in B decays (missing or new states, hybrids):

$[\ ] \rightarrow J/\psi[nx]\ K$

- $[\ ] \rightarrow B$
- $[\ ] \rightarrow ISR$

$[\,] \rightarrow J/\psi\ \pi^0\pi^0 K$

$[\,] \rightarrow J/\psi\ \pi^+\pi^-\ K$

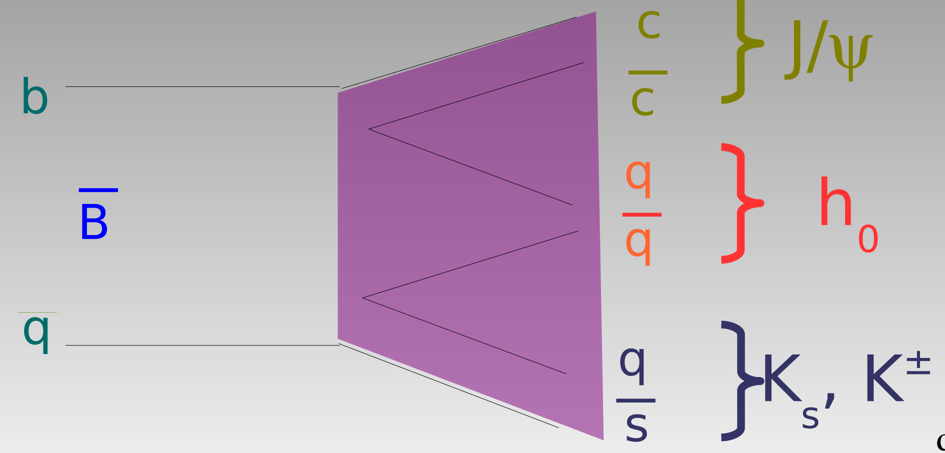
$[\,] \rightarrow J/\psi\ \pi^+\pi^-\pi^0\ K$

....

$B \rightarrow J/\psi\ h^0\ K$

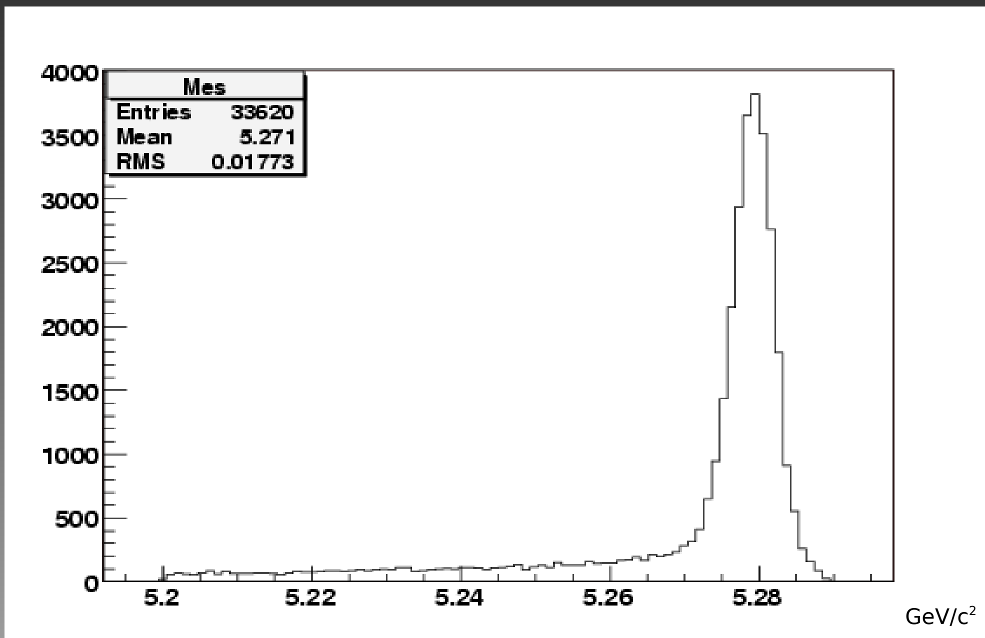
$h^0 = \pi^0, \omega, \phi, \rho^0, \eta, \eta'$

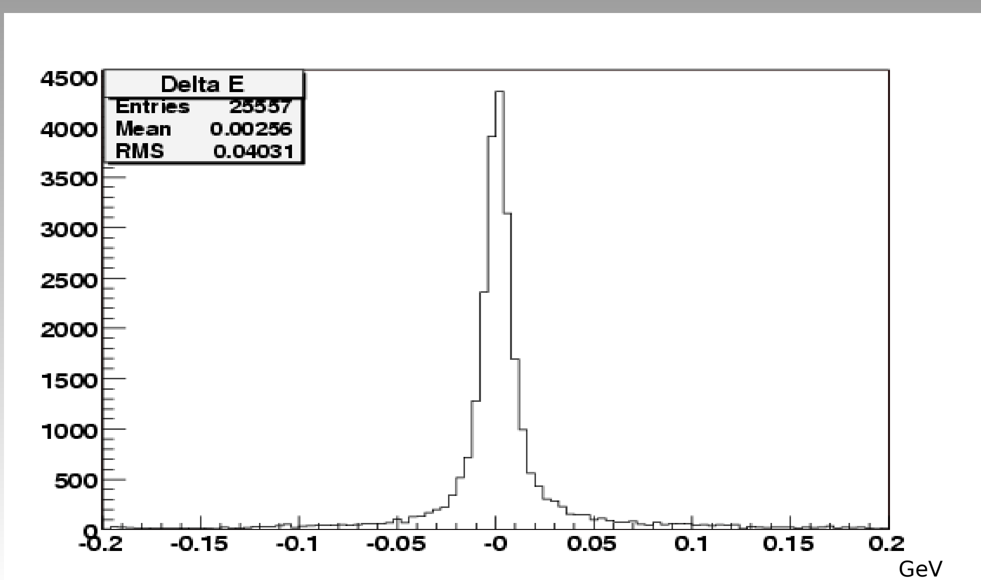
(neutral light mesons)



Selecting B mesons

For Charmonium studies in B decays most of the bkg is from combinatorics: use two uncorrelated variables reflecting momentum and energy conservation.





Main kinematic variables:

$$m_{ES} = \sqrt{\frac{\left(\frac{1}{2}s + \mathbf{p_0} \cdot \mathbf{p_B}\right)^2}{{E_0}^2} - p_B^2}$$

s = inv . mass of e^+e^- system;
$\mathbf{p_B}$, $\mathbf{p_0}$ = 3-momentum module of the B candidate and e^+e^- system respectively

$$\Delta E = \frac{(2 q_B q_0 - s)}{2\sqrt{s}}$$

s = inv . mass of e^+e^- system;
$\mathbf{q_B}$, q_0 = 4-momentum module of the B candidate and e^+e^- system respectively

X(3782)

- Discovered by BELLE in $B \to XK$, $X \to J/\psi\pi^+\pi^-$; confirmed by CDF, D0, (PRL 91, 262001 (2003), PRL 93, 072001 (2004), PRL 93, 162002 (2004)),and *BABAR* (PRD 71, 071103 (2004)[117 fb^{-1}], PRD 73, 011101 (2006) [211 fb^{-1}])

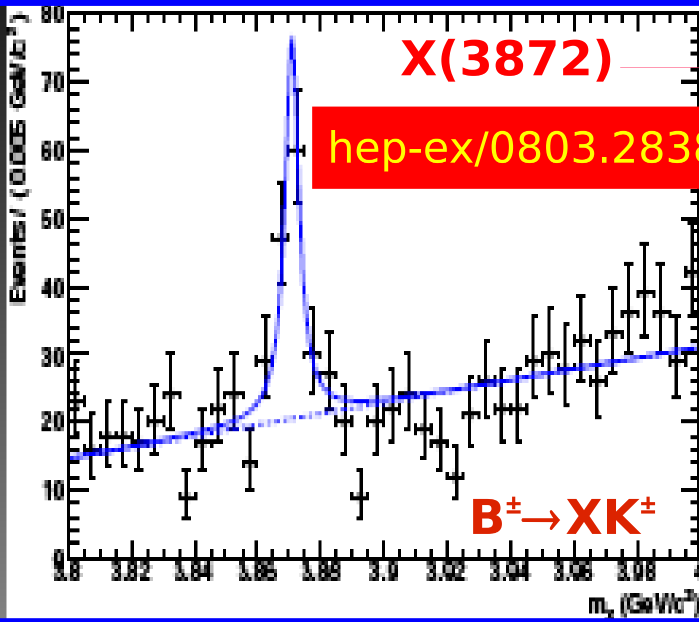
Exclusive searches @ BaBar: B→XK

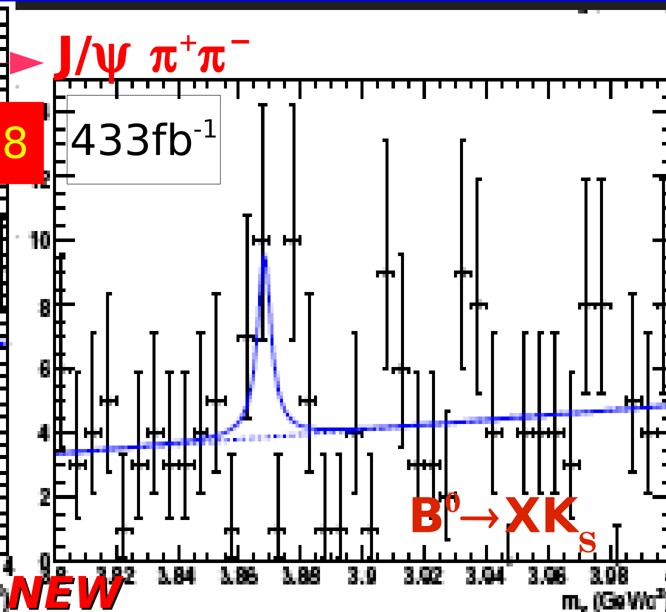
- Update on the study: B→XK, X→J/ψππ

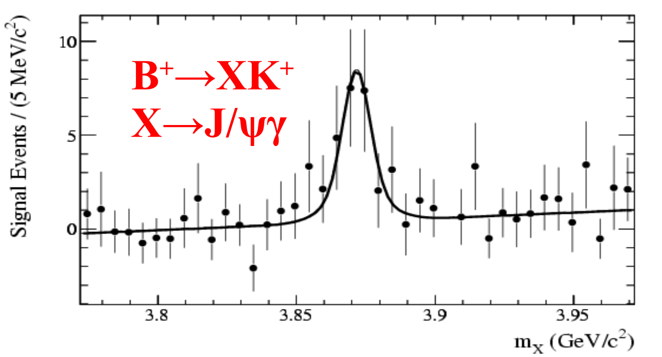
R($B^0/B^\pm$) = 0.41±0.24±0.05

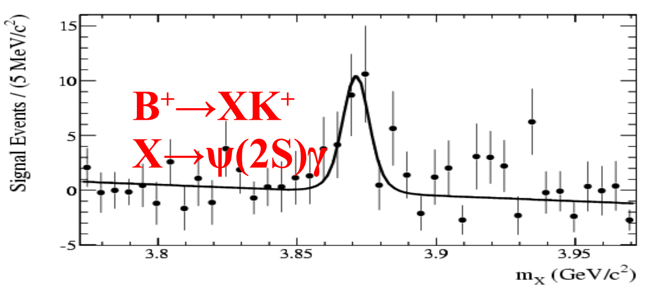
ΔM =(2.7±1.6±0.4) MeV/c^2

Γ < 3.3 MeV @90%CL









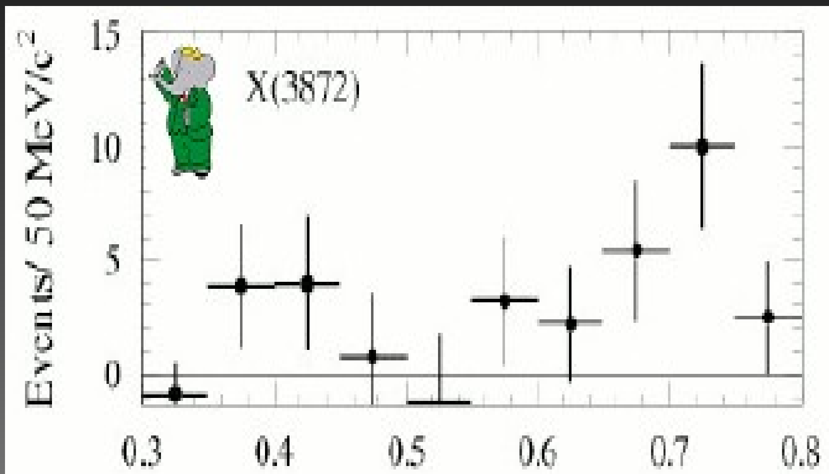
- $B^\pm \to J/\psi\, \gamma\, K^\pm$
  X→J/ψ γ

- $B^\pm \to \psi(2s)\, \gamma\, K^\pm$
  X→ψ(2s)γ

M =(3871.±0.6) MeV/c^2

What is this ***X(3872)*** *state?*

X(3872) study:

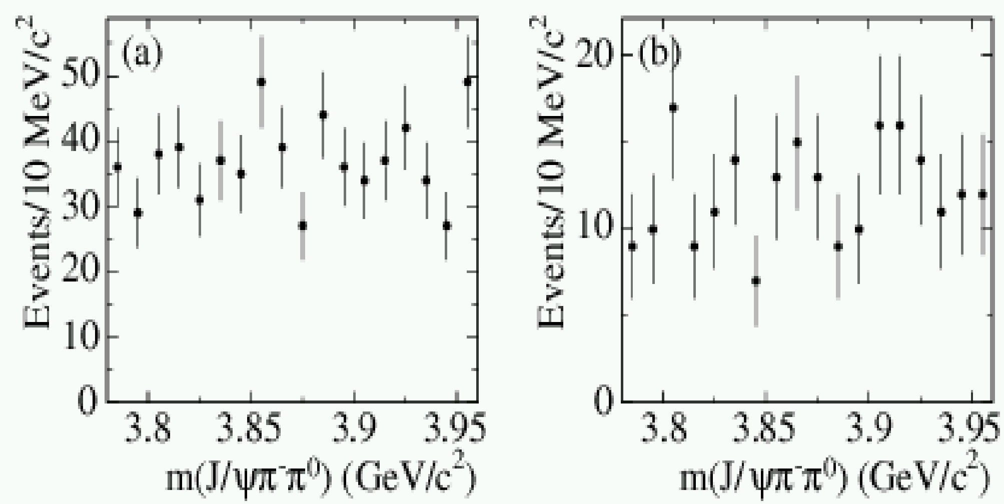


$m_{\pi\pi}$ (GeV/c²)

- Invariant 2π-mass in J/ψππ :
  S-wave J/ψρ favoured
  J^{++} favoured over J^{-+}

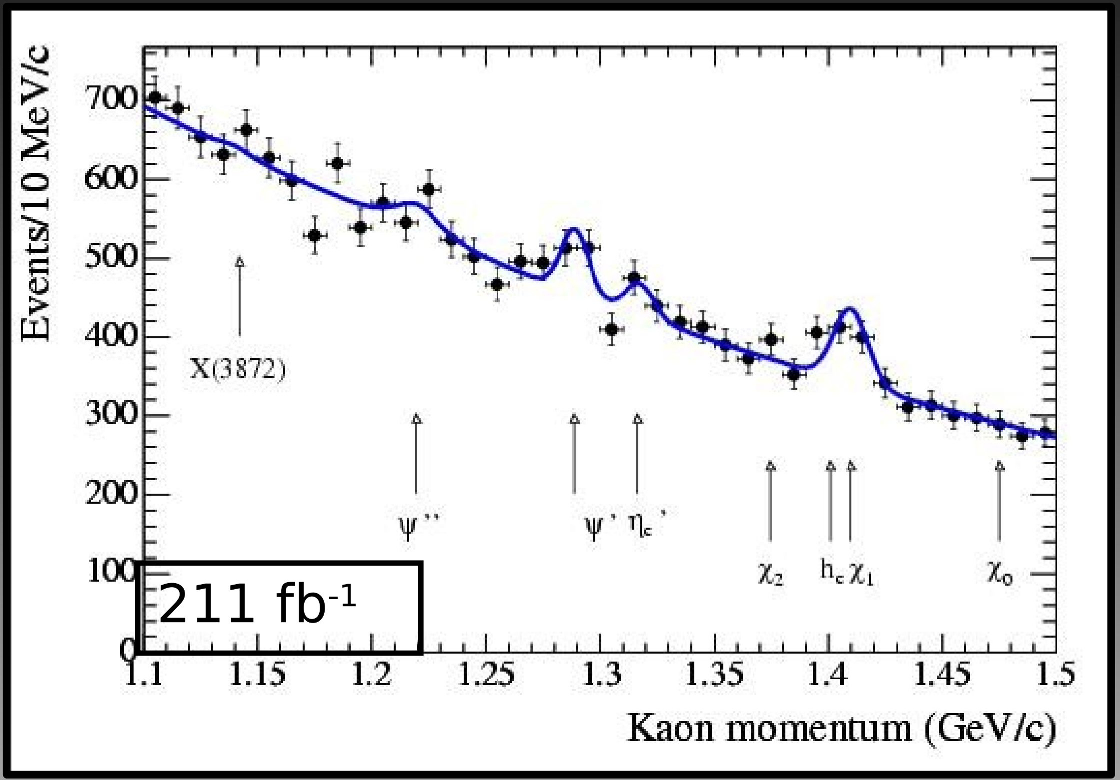
- **C=+** for the X(3872)
- I=1 for the (ππ) in $J/\psi\pi^+\pi^-$;
- forbidden $J/\psi\pi^0\pi^0$, $J/\psi\pi^0$, $J/\psi\eta$
- **I=0** favored for X(3872);
  the $J/\psi\pi^+\pi^-$ decay is
  I-violating (small width)
- Decay $X(3872)\rightarrow J/\psi\rho$ against charmonium hypothesis:
  <u>no charged partner found</u>!

PRD 71, 031501 (2005)

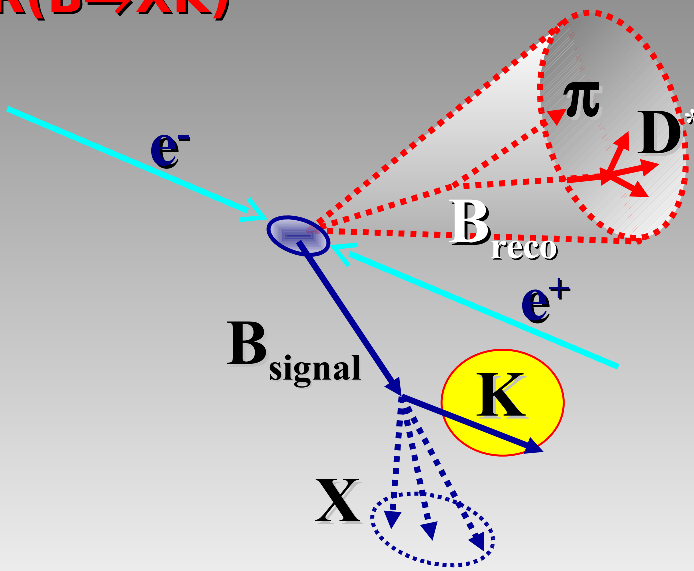


PRL96, 052002

Inclusive searches @ BaBar: $B \to XK$



- Fully reconstruct B_{reco} in hadronic modes
- The **X** mass distribution can be obtained from the momentum distribution of **$K^{\pm}$**
- Huge background due to secondary $K^{\pm}$ tracks
- Observation of X states independent from the decay mode
- **Absolute measurement of BR($B \to XK$)**



From BaBar-Belle average:

$BR(B^{\pm} \to X(3872)K^{\pm}, X(3872) \to J/\psi\pi^{+}\pi^{-}) =$
$= (13.3 \pm 2.5) \cdot 10^{-6}$

$BR(B^{\pm} \to X(3872)K^{\pm}) < 3.2 \cdot 10^{-4}$ at 90% CL
$BR(X(3872) \to J/\psi\pi^{+}\pi^{-}) > 4.2\%$ at 90% CL

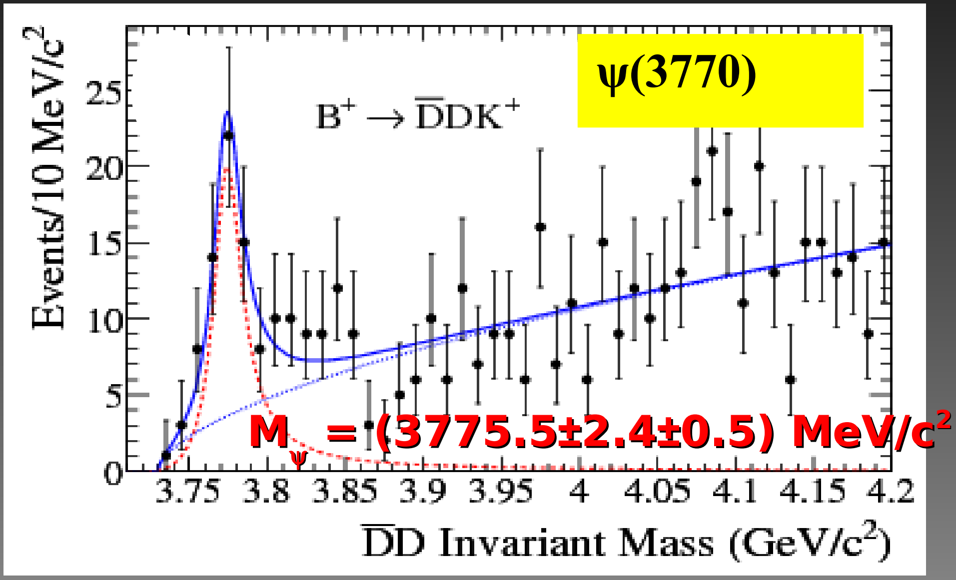
Still some surprises: $B \rightarrow (D\bar{D})_X K$

PRD77, 011102

347 fb^{-1}

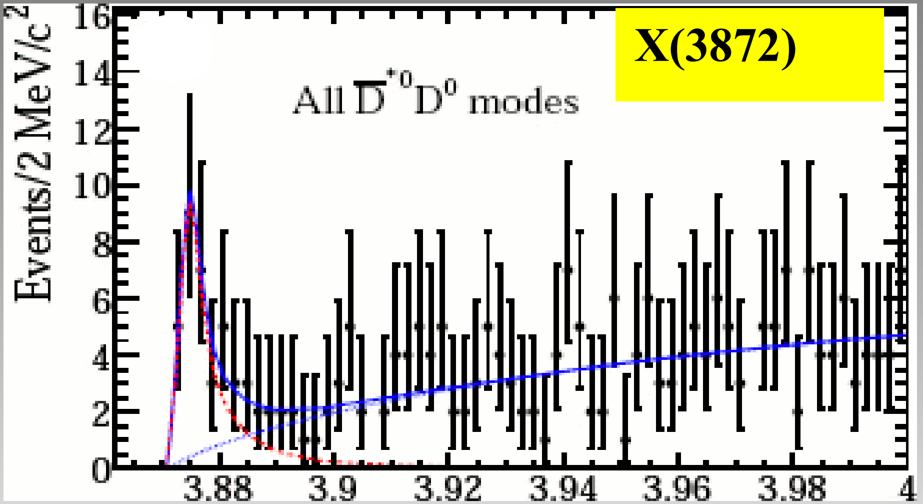
- BaBar studied the channels:

  $B^+ \rightarrow D^0 \bar{D}^{*0} K^+ + \bar{D}^{*0} D^0 K^+$
  $B^0 \rightarrow D^0 \bar{D}^{*0} K^0 + \bar{D}^{*0} D^0 K^0$
  $D^{*0} \rightarrow D^0\gamma$ and $D^0\pi$



- Measurements:

  - **$\Delta M = (0.2 \pm 1.6) MeV/c^2$**
  - **$R(B^0/B^\pm) = (1.33 \pm 0.69 \pm 0.43\ ) MeV/c^2$**
  - $R \left(\frac{X(3872) \rightarrow D^0\bar{D}^0\pi^0}{X(3872) \rightarrow D^0\bar{D}^0\gamma} \right)$ **$= 1.37 \pm 0.56$**



experiment	Mass (MeV/c^2)
BABAR	$3875.2^{+0.7}_{-0.5} \pm 0.5$
BELLE	$3875.2 \pm 0.7^{+0.3}_{-1.6} \pm 0.8$

M is ~4.5σ away from the world average in J/ψπ

R Expected: 1.3 for a state proceeding only via D^0D^{0*}

X(3872): interpretation

X(3872) likely NOT a charmonium state

Radial excitation of χ_{1c} (1^{++}) expected at 3950 MeV/c^2
No satisfactory $c\bar{c}$ assignment

Measurements:

- R(B0/B+) = 0.50±0.30±0.05 in $J/\psi\pi$
- R(B0/B+) = 1.33±0.69±0.52 in $D^0\bar{D}^{*0}$

BaBar: PRD73 (2006) 011101

BaBar preliminary

- Δm =2.7±1.3±0.2 MeV/c^2 in $J/\psi\pi$
- Δm =0.7±1.9±0.3 MeV/c^2 in $D^0\bar{D}^{*0}$

BaBar: PRD73 (2006) 011101

- M_X = 3871.4±0.6 MeV/c^2 in $J/\psi\pi$
- M_X= 3875±1.1 MeV/c^2 in $D^0\bar{D}^{*0}$

Is it a molecular state?

PRD71 (2005) 074005

Is it a 4-quark state?

PRD71 (2005) 014028

...what else?

Even more: $B \to YK$, $Y \to J/\psi\omega \to \pi^+\pi^-\pi^0$

$$M(Y) = (3914.6^{+3.8}_{-3.4}(stat)^{+1.9}_{-1.9}(syst))\ \mathrm{MeV}/c^2$$
$$\Gamma(Y) = (33^{+12}_{-8}(stat)^{+5}_{-5}(syst))\ \mathrm{MeV}$$

$B \to Y K$

$$\mathcal{B}(B^+) = (4.9^{+1.0}_{-1.0}(stat)^{+0.5}_{-0.5}(syst)) \times 10^{-5}$$
$$\mathcal{B}(B^0) = (1.5^{+1.4}_{-1.2}(stat)^{+0.2}_{-0.2}(syst)) \times 10^{-5}$$

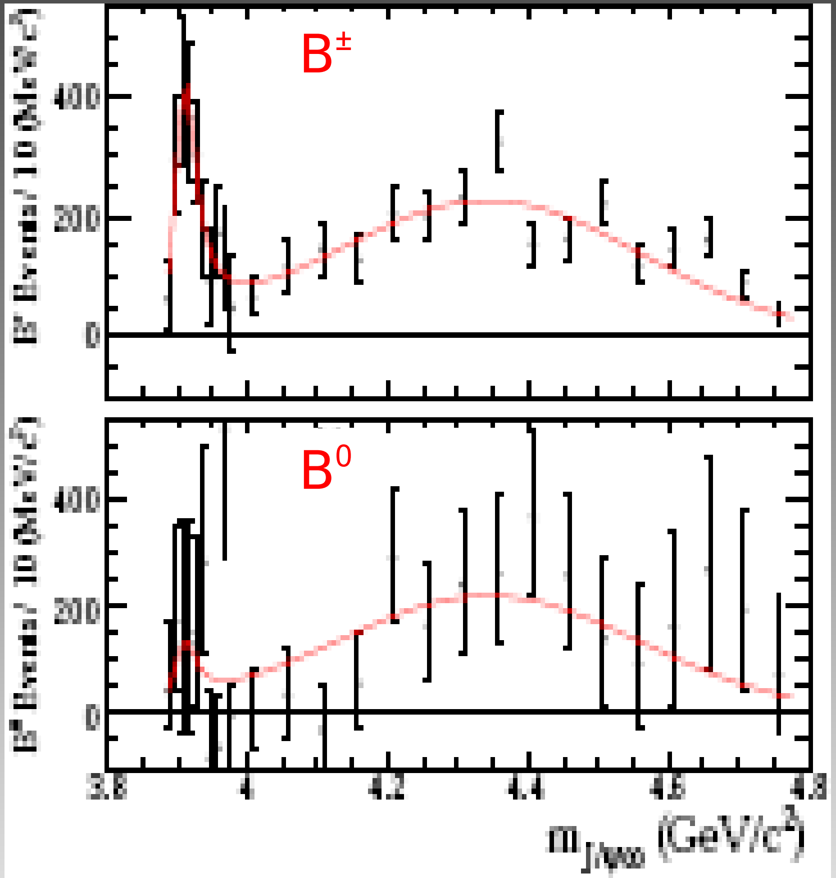
$B \to J/\psi\omega\ K$

$$\mathcal{B}(B^+_{tot}) = (3.5^{+0.2}_{-0.2}(stat)^{+0.4}_{-0.4}(syst)) \times 10^{-4}$$
$$\mathcal{B}(B^0_{tot}) = (3.0^{+0.6}_{-0.6}(stat)^{+0.3}_{-0.3}(syst)) \times 10^{-4}$$

$R_1(B^0/B^+) = 0.30^{+0.29}_{-0.24}(stat)^{+0.04}_{-0.01}(syst)$ signal region;

$R_2(B^0/B^+) = 0.94^{+0.23}_{-0.21}(stat)^{+0.03}_{-0.02}(syst)$ non resonant contribution

- The measured values are corrected for efficiency and resolution effects

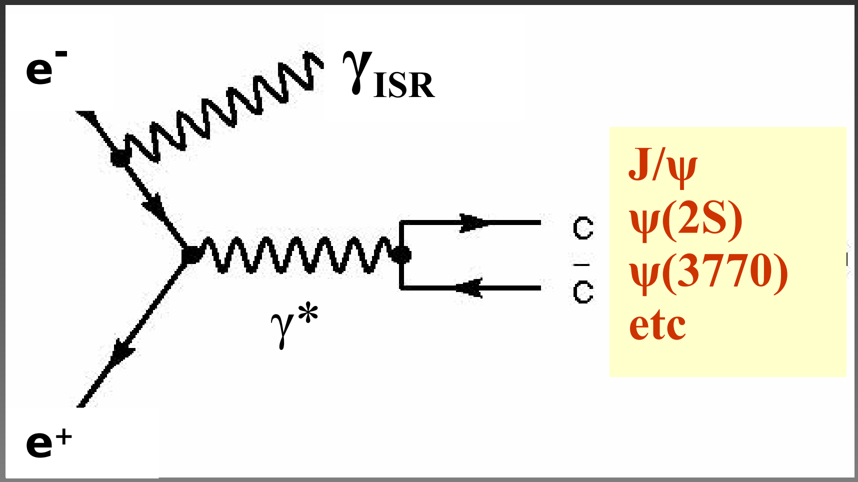


hep-ex/0711.2047 **347 fb^{-1}**

Study in ISR production

- What are these new structures?

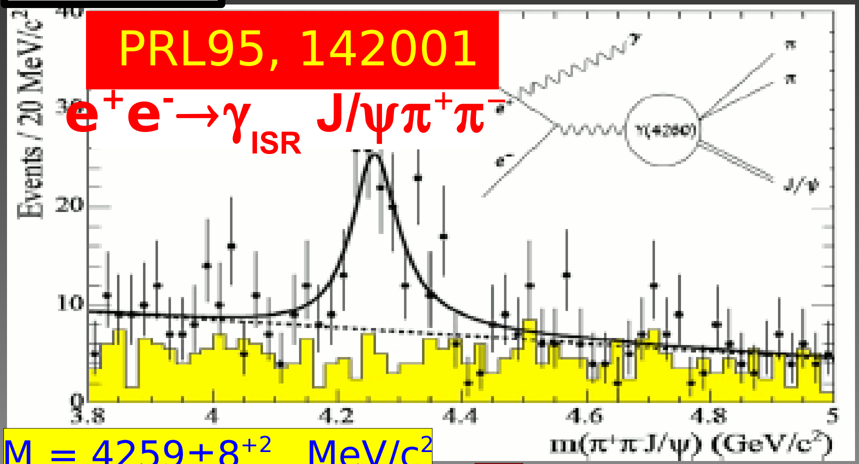
First observed at BaBar $J^{PC}=1^{--}$



233 fb^{-1}

PRL95, 142001

$e^+e^-\to\gamma_{ISR}\ J/\psi\pi^+\pi^-$



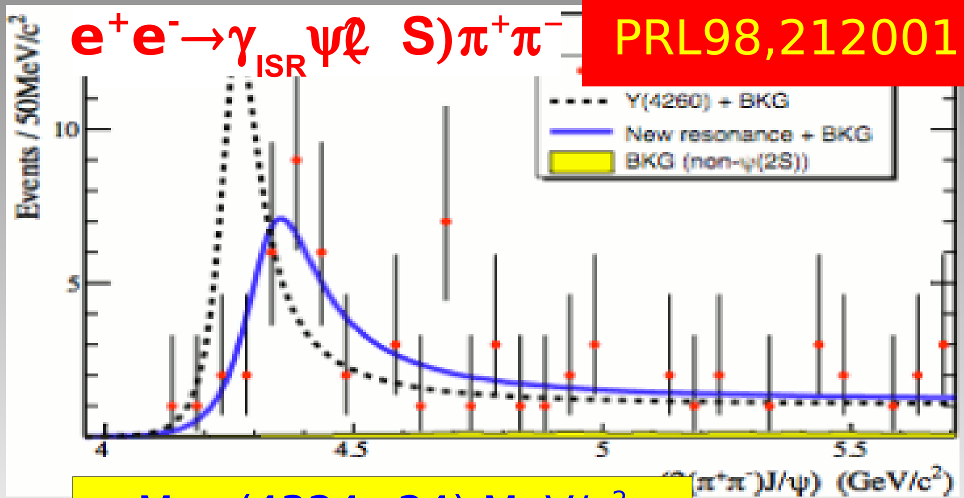
$M_Y = 4259\pm8^{+2}_{-6}$ MeV/c^2

$\Gamma_Y = 88\pm23^{+6}_{-4}$ MeV

298 fb^{-1}

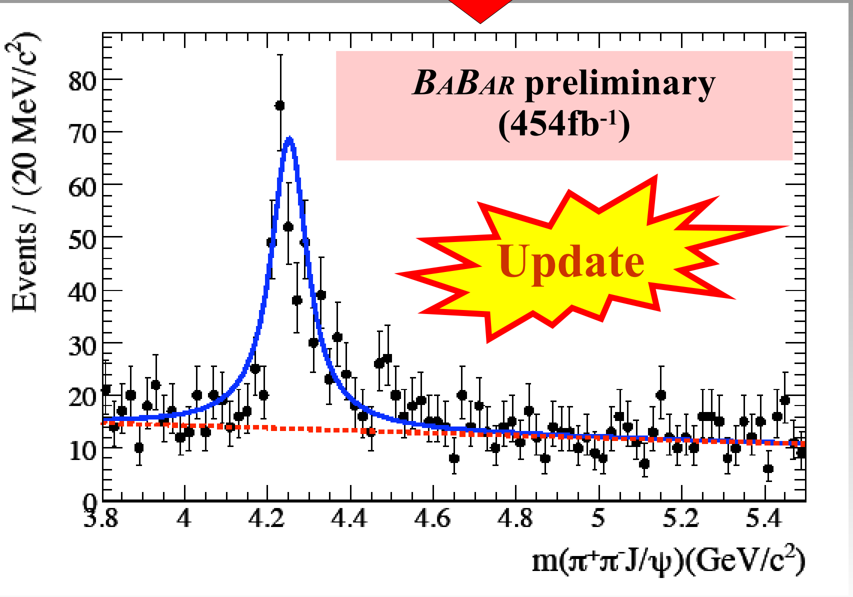
$e^+e^-\to\gamma_{ISR}\psi(2S)\pi^+\pi^-$

PRL98,212001



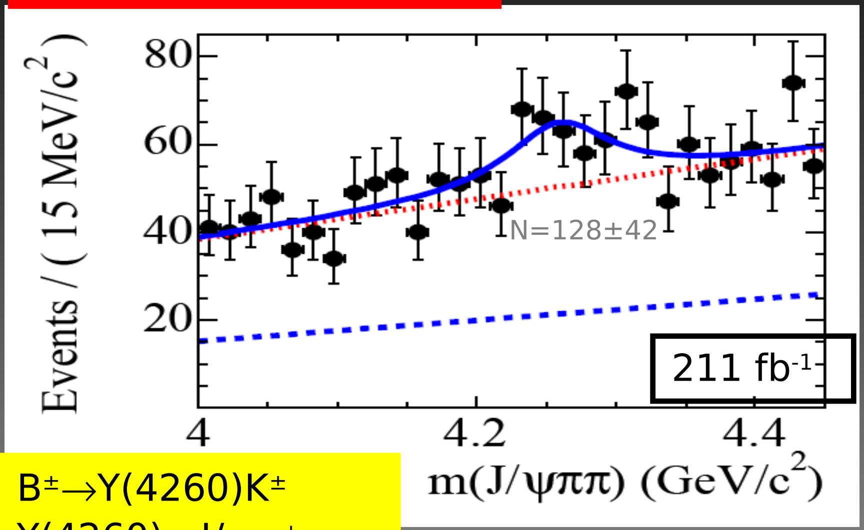
$M = (4324\pm24)$ MeV/c^2

$\Gamma = (172\pm33)$ MeV



Y(4260) in B decays

PRD 73,011101 (2006)



$B^{\pm} \to Y(4260)K^{\pm}$
$Y(4260) \to J/\psi\ \pi^+\pi^-$

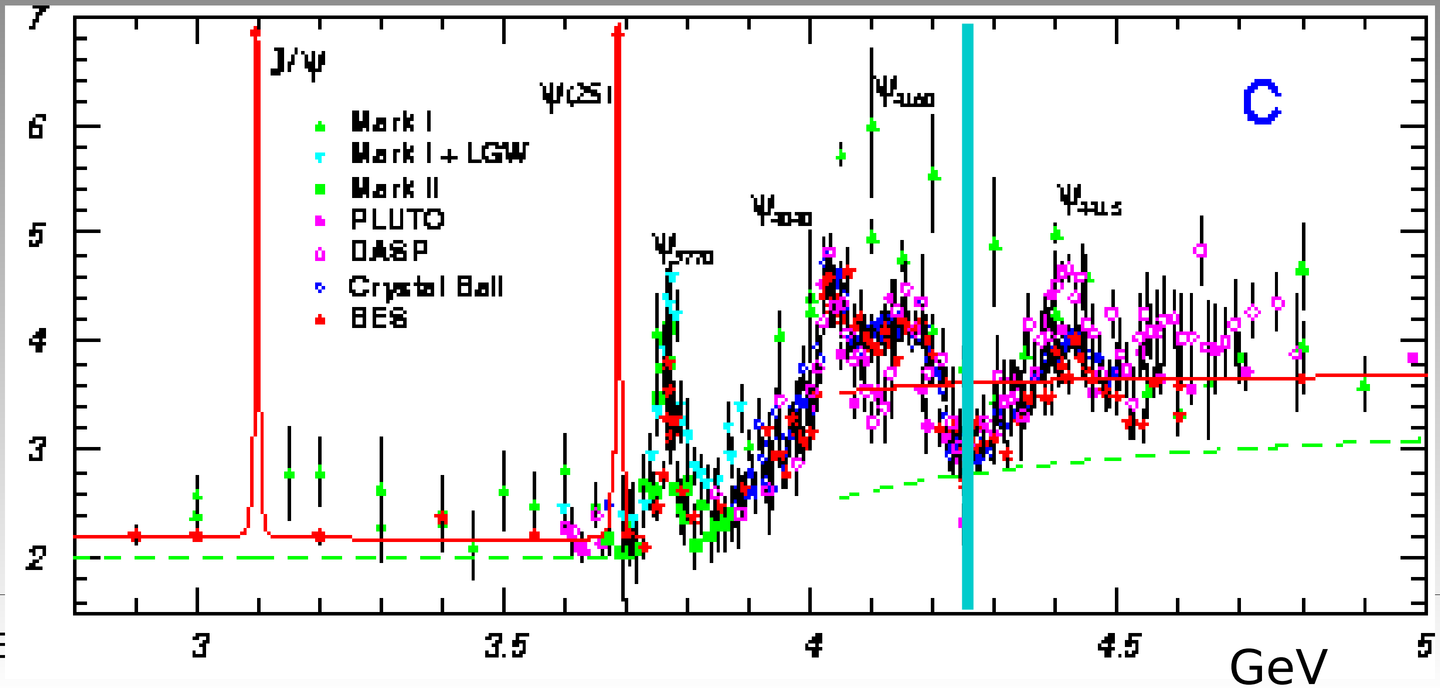
$\Gamma_{ee}^{Y} \times B(Y(4260) \to \pi^+\pi^-\varphi) < 0.4\,\mathrm{eV}\quad 90\%\,\mathrm{CL}$ No signal

$$\frac{B(Y(4260) \to D\bar{D})}{B(Y(4260) \to \pi^+\pi^-\psi)} < 7.6 \quad 95\%\,\mathrm{CL}$$ No signal

$$\frac{B(Y(4260) \to p\bar{p})}{B(Y(4260) \to \pi^+\pi^-\psi)} < 0.13 \quad 90\%\,\mathrm{CL}$$ No signal

$$B(B^- \to Y(4260)K^-) \times B(Y(4260) \to \psi\pi^+\pi^-) = \left(2.0 \pm 0.7 \pm 0.2\right) \times 10^{-5}$$ 3σ

R



Y(4260): interpretation

Interpretation of the Y(4260)

Hybrid interpretation most appealing:

- Dominant decay mode: $D\bar{D}_1$: threshold ≈ 4287… ?
- Is the Y(4260) a $D\bar{D}_1$ bound state
- Should be a multiplet

Charmonium ψ(4S):

- in some models, the Y mass consistent with predicted 4S state: 4^3S_1
- Some other models: 4S ≡Y(4415)

Tetraquark:

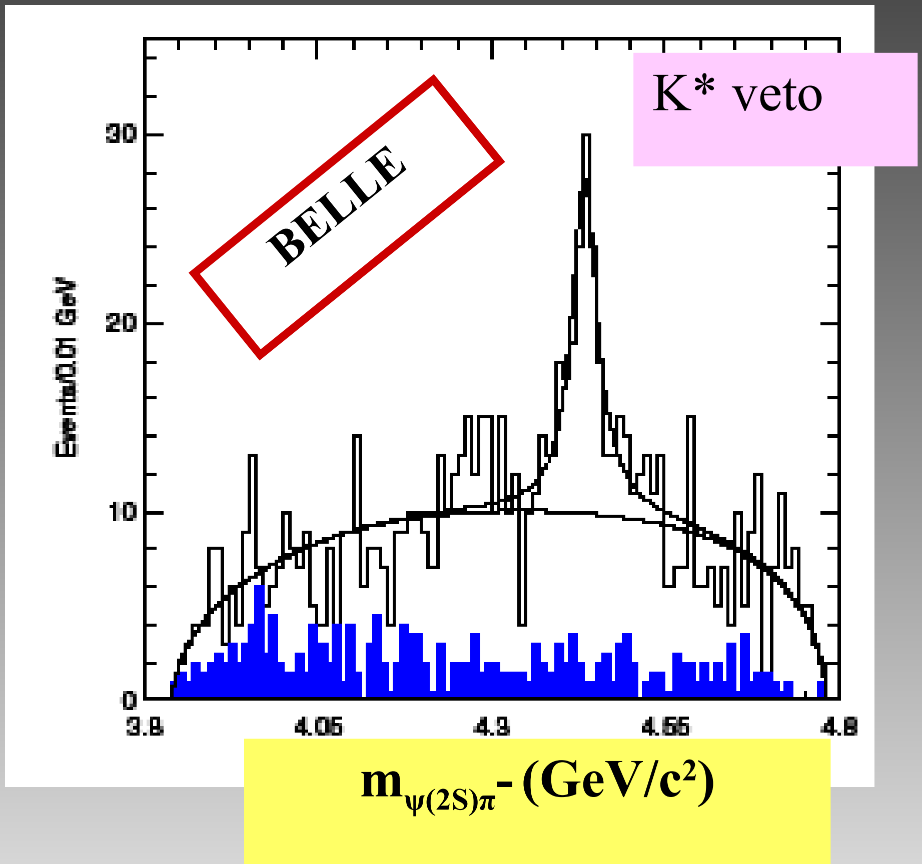
- How can we tell from hybrid?

The whole Family:

Y(4008), Y(4260), Y(4325), Y(4660)

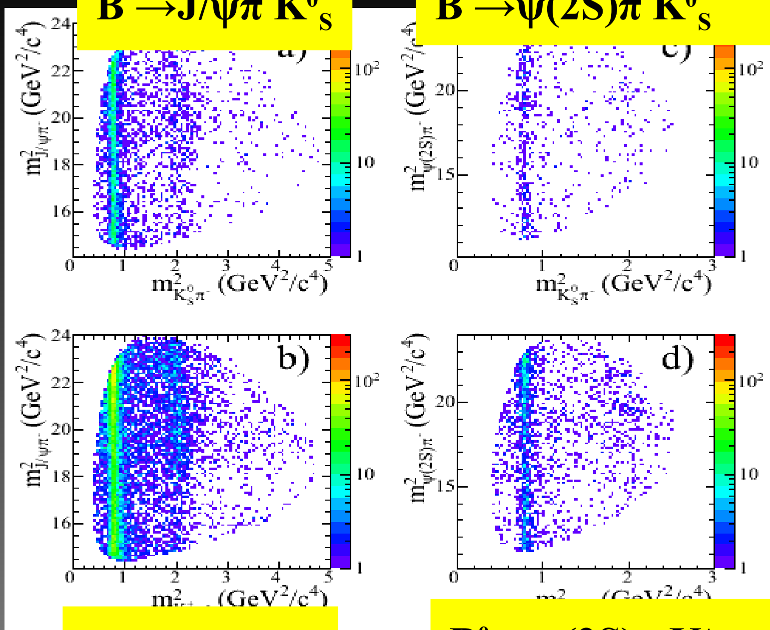
P. Grenier

Z(4430)$^-$

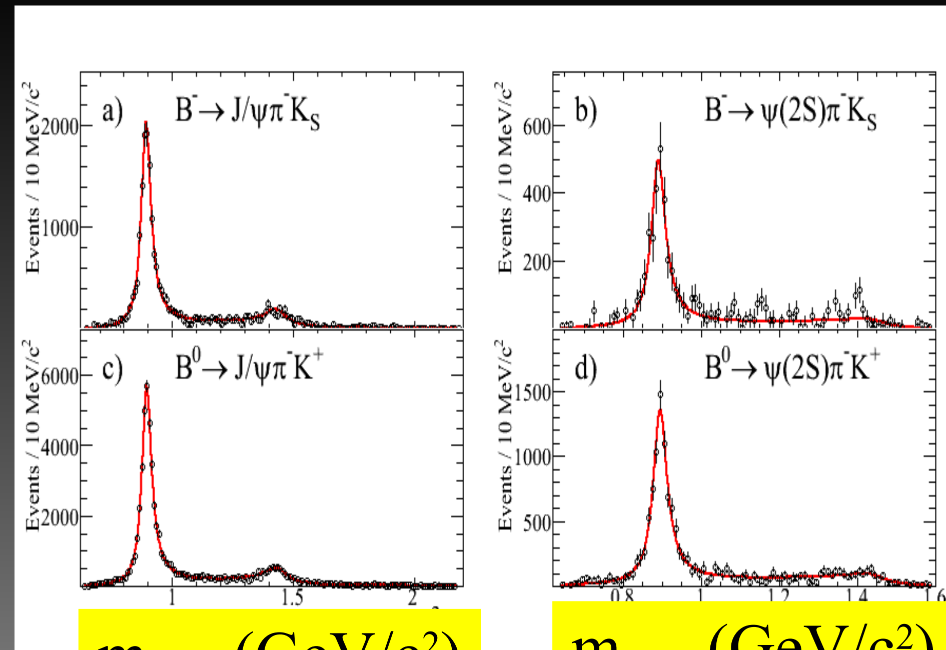


- BELLE has reported a new charged charmonium-like state in the decay: $B \to Z^- K$, $Z^- \to \psi(2S)\pi^-$ (PRL *100, 142001 (2008)*)
- The reported mass and width are:
  - **$m = 4433 \pm 4(stat) \pm 2(syst)$ MeV/c^2**
  - **$\Gamma = 45^{+18}_{-13}(stat)^{+30}_{-13}(syst)$ MeV**
- Significance: 6.5σ
- If this result is confirmed ➔ first observation of a genuine ccud "tetraquark" state, since it is charged and carries hidden charm
  (e.g. Maiani: 0708.3997 (hep-ph) ,
  Karliner & Lipkin arxiv: 0802.0649 (hep-ph))

$B^- \to J/\psi \pi^- K^0_S$ | $B^- \to \psi(2S) \pi^- K^0_S$



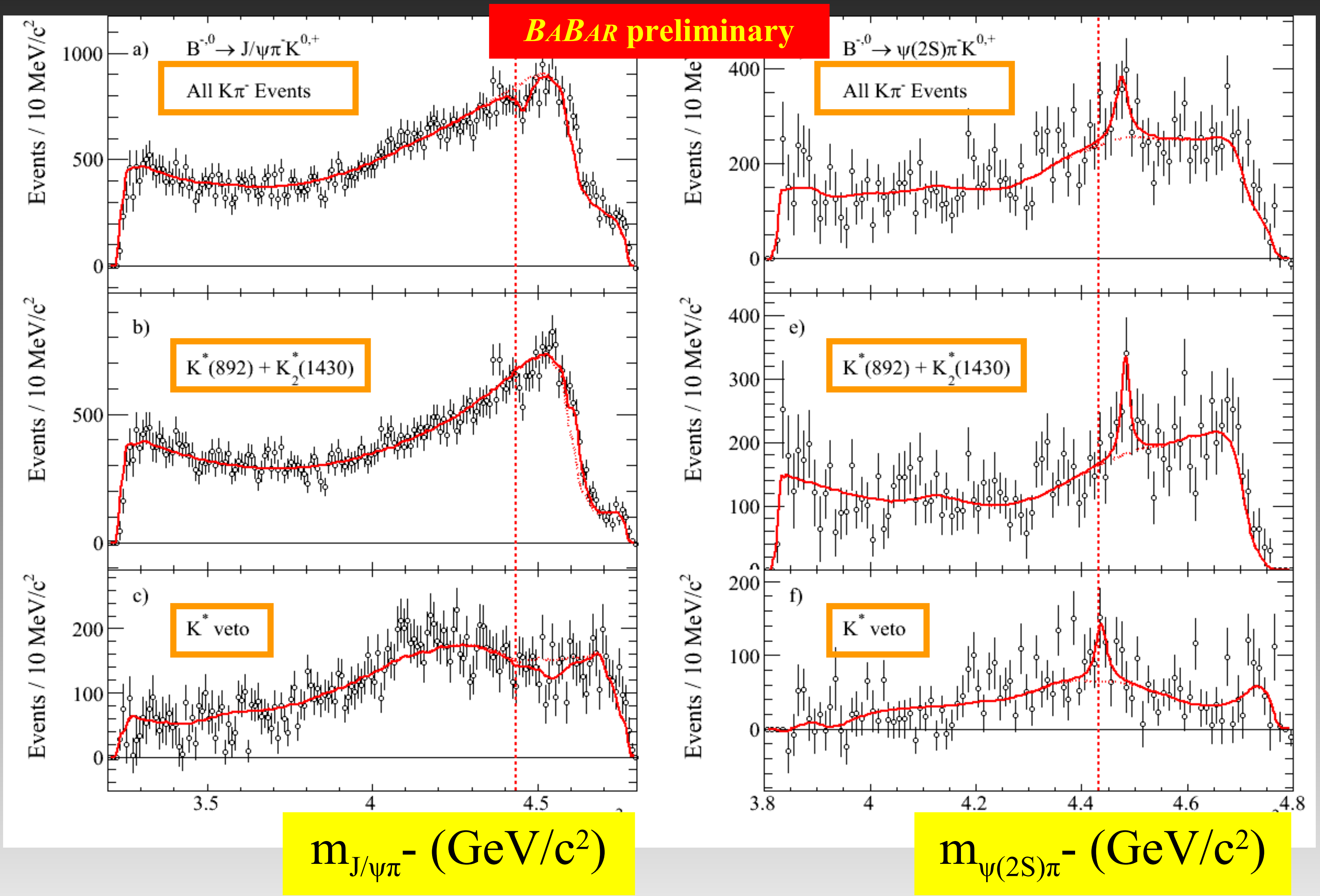
$B^0 \to J/\psi \pi^- K^+$ | $B^0 \to \psi(2S) \pi^- K^+$



$m_{K\pi^-}$ (GeV/c²) | $m_{K\pi^-}$ (GeV/c²)

Decay mode	$Z(4430)^-$ signal	Branching fraction ($\times 10^{-5}$)	Upper limit ($\times 10^{-5}$) (@95% C.L.)
$B^- \to Z^- K^0$, $Z^- \to J/\psi \pi^-$	-16 ± 140	-0.1 ± 0.8	<1.5
$B^0 \to Z^- K^+$, $Z^- \to J/\psi \pi^-$	-666 ± 203	-1.2 ± 0.4	<0.4
$B^- \to Z^- K^0$, $Z^- \to \psi(2S) \pi^-$	110 ± 118	1.3 ± 1.4	<3.8
$B^0 \to Z^- K^+$, $Z^- \to \psi(2S) \pi^-$	327 ± 170	1.4 ± 0.7	<2.6

Z(4430)$^-$: corrected distributions



no significant Z(4430)- signal was observed!

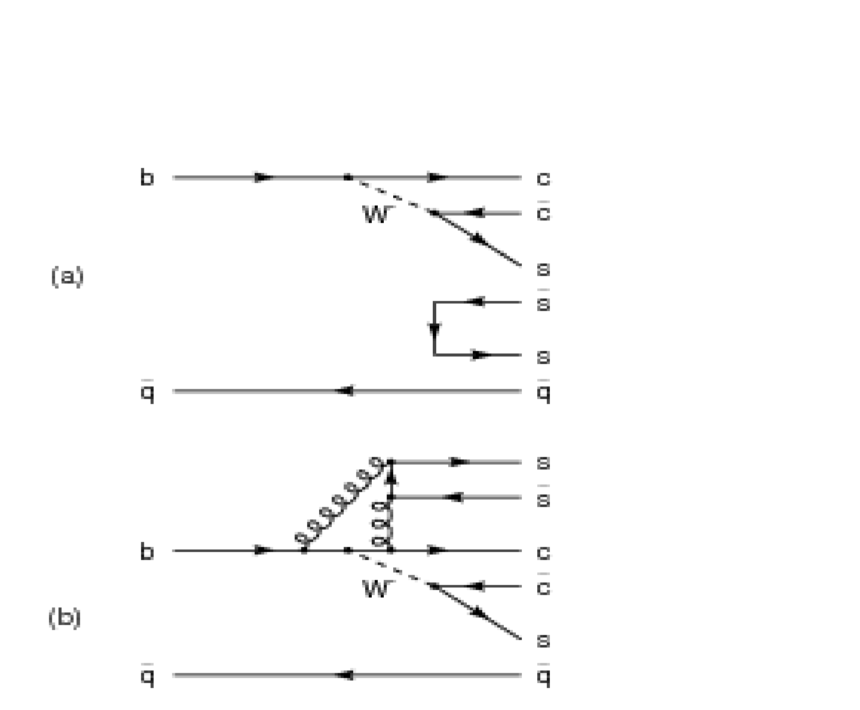
Looking for tetraquark....

...more recent....

....$B \rightarrow J/\psi\phi\ K$

Goals of the analysis:

$B \rightarrow J/\psi\phi\ \ K$



The proposal is:

- to measure the *BR* of the decay channel

$$B \rightarrow J/\psi\phi\ \ K,\ \ \phi \rightarrow K^+K^-$$

- to study the invariant masses of the B daughters, with particular attention to [J/ψ φ] in order to check if there is a new charmonium state decaying to these two mesons

The transition $B \rightarrow J/\psi\ \phi K$ most likely proceed as a 3-body decay.

Another possibility to be exploited is that this transition can proceed as a quasi-2-body decay, in which J/ψ and ϕ are daughters of an hybrid, charmonium state $Y_g(c\bar{c}s\bar{s})$.

The transition $b \rightarrow c\bar{c}s$ is a very promising place to observe observe Y_g.

If this state exists, and it decays in $J/\psi\phi$, the invariant mass will be *below 4.3 GeV/c²* (the DD* threshold), as above 4.3 GeV/c² the dominant decay should be $Y_g \rightarrow DD^*$.

A recent paper (arXiV:0801.2036) provides theoretical explanation for a model in *quenched-lattice QCD* giving for vector hybrids states masses:

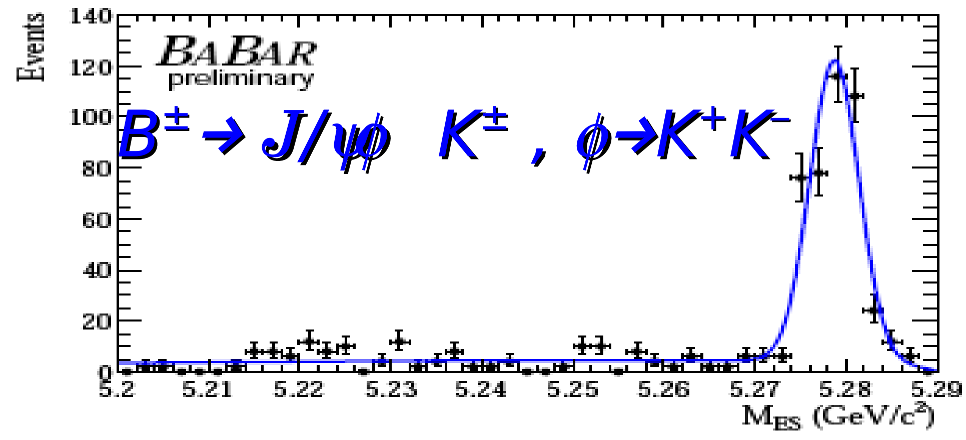
J^{PC}	0^{-+}	1^{-+}	2^{-+}	1^{--}
Mass	4.252	4.320	4.397	4.457

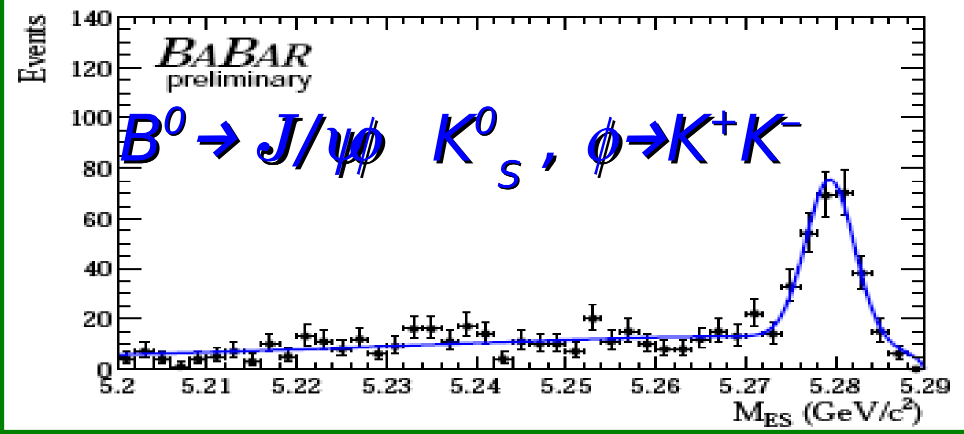
Y.S. Kalashnikova, A.V. Nefediev

As the [$J/\psi\phi$] invariant mass lies in the range [4.0;5.0] *GeV/c²*, we believe that the transition under examination is a very promising place to search for hybrids, new resonances.

MC Final Fit

Decay mode	PDF	Parameters
$B^{\pm} \to J/\psi\phi K^{\pm}$	gaussian + Argus	$\xi = -25 \pm 10$ $\bar{x} = 5.27921 \pm 0.0028$ $\sigma = (2.718 \pm 0.022) \times 10^{-3}$ $N_{peak} = 130 \pm 12$ $N_{bkg} = 127 \pm 13$ $\chi^2 = 0.66$
$B^0 \to J/\psi\phi K^0_S$	gaussian + Argus	$\xi = -44 \pm 10$ $\bar{x} = 5.28014 \pm 0.0070$ $\sigma = (3.08 \pm 0.022) \times 10^{-3}$ $N_{peak} = 69 \pm 9$ $N_{bkg} = 141 \pm 14$ $\chi^2 = 0.62$

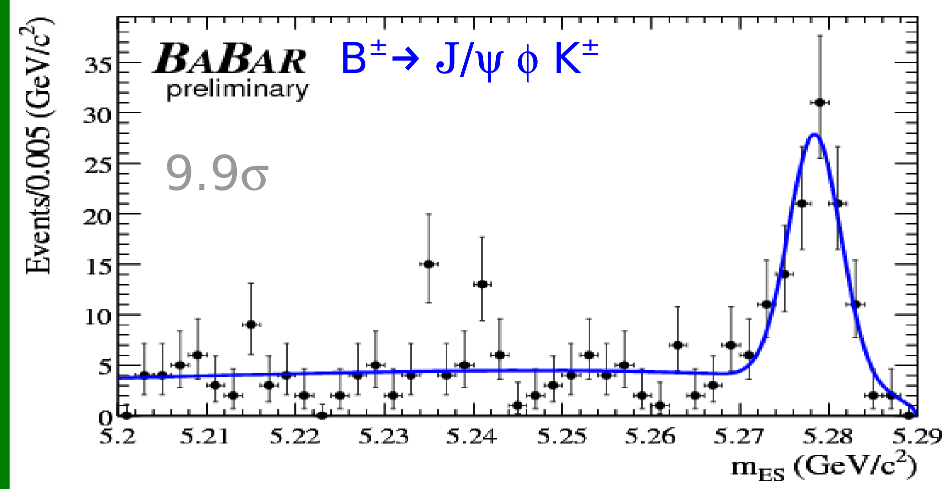


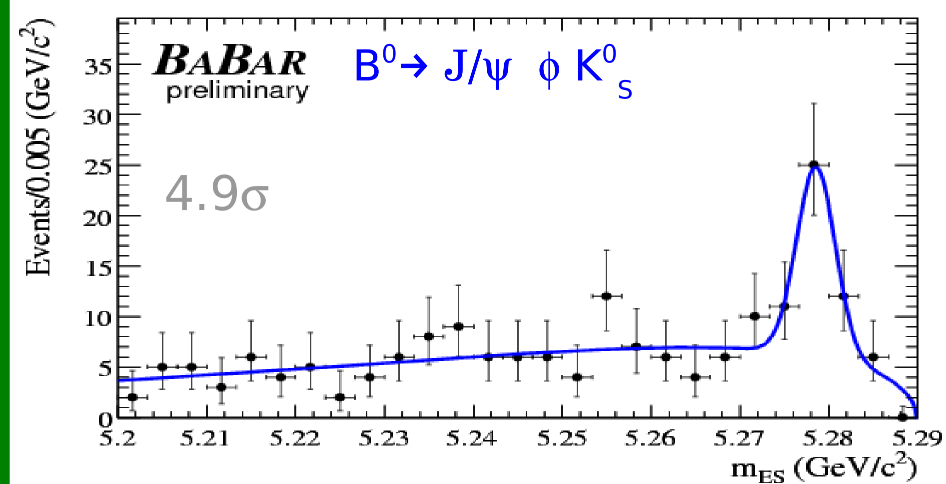


Channel	Expected events	Measured events	Efficiency	Expected B.R.	Measured B.R.
$B^{\pm} \to J/\psi\phi K^{\pm}$	127	130 ± 12	$(11.19 \pm 0.08)\%$	9×10^{-5}	$(9.23 \pm 0.85) \times 10^{-5}$
$B^0 \to J/\psi\phi K^0_S$	70	69 ± 9	$(8.91 \pm 0.07)\%$	4.5×10^{-5}	$(4.42 \pm 0.58) \times 10^{-5}$

DATA Final Fit

Decay mode	PDF	Parameters
$B^{\pm} \to J/\psi\phi K^{\pm}$	gaussian + Argus	$\xi = -33 \pm 11$ $\bar{x} = 5.2784 \pm 0.0042$ $\sigma = (2.88 \pm 0.40) \times 10^{-3}$ $N_{peak} = 79 \pm 12$ $N_{bkg} = 178 \pm 16$ $\chi^2 = 0.47$
$B^{0} \to J/\psi\phi K^{0}_{S}$	gaussian + Argus	$\xi = -42 \pm 10$ $\bar{x} = 5.27805 \pm 0.0053$ $\sigma = (2.235 \pm 0.063) \times 10^{-3}$ $N_{peak} = 43 \pm 10$ $N_{bkg} = 166 \pm 14$ $\chi^2 = 0.43$





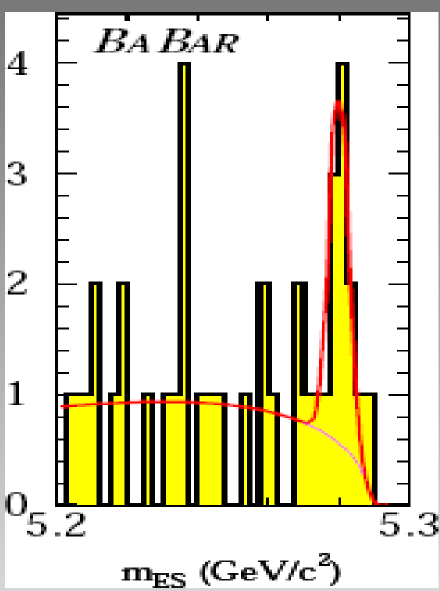
Channel	Measured events	Efficiency	B.R. (10^{-5})
$B^{\pm} \to J/\psi\phi K^{\pm}$	79 ± 12	$(11.19 \pm 0.08)\%$	(5.57 ± 0.85)
$B^{0} \to J/\psi\phi K^{0}_{S}$	42 ± 10	$(8.91 \pm 0.07)\%$	(2.69 ± 0.61)

BR measurements

OLD

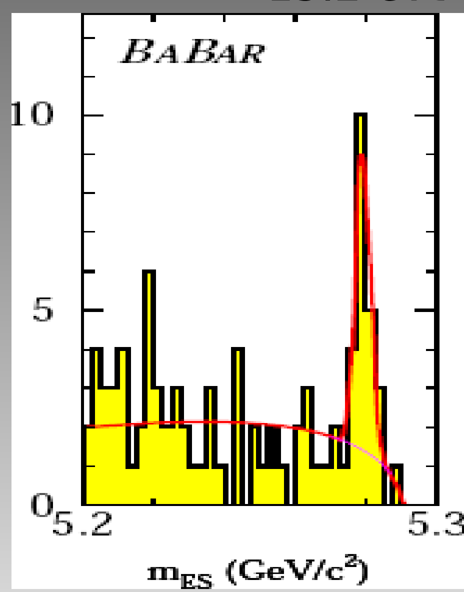
Experiment	Channel	$B.R.(10^{-5})$
BaBar	$B^{\pm} \to J\psi\phi K^{\pm}$	$4.4 \pm 1.4 \pm 0.5$
CLEO-2		$8.8^{+3.5}_{-3.0} \pm 1.3$
BaBar	$B^{0} \to J\psi\phi K^{0}$	$10.2 \pm 3.8 \pm 1.0$
CLEO-2		$8.8^{+3.5}_{-3.0} \pm 1.3$

9.7 evt



$B^0 \to J/\psi\ \phi\ K^0_S$

15.2 evt



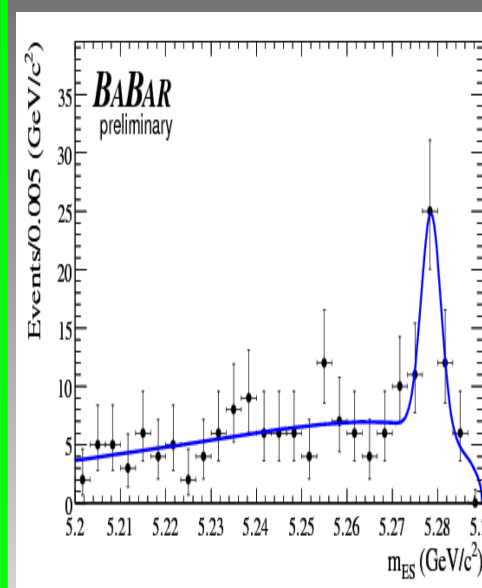
$B^{\pm} \to J/\psi\ \phi\ K^{\pm}$

PRL 91 071801

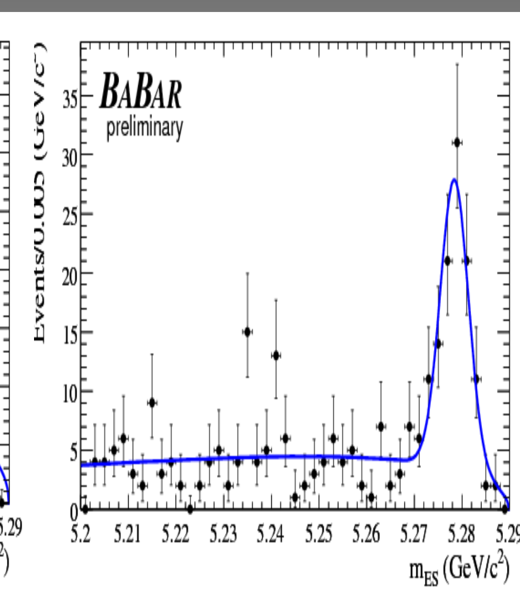
NEW

$$\mathcal{B}(B^{\pm} \to J/\psi\phi K^{\pm}) = (5.6 \pm 0.9(stat) \pm 0.3(sys)) \times 10^{-5}$$

$$\mathcal{B}(B^{0} \to J/\psi\phi K^{0}) = (5.4 \pm 1.2(stat) \pm 0.4(sys)) \times 10^{-5}$$



$B^0 \to J/\psi\ \phi\ K^0_S$

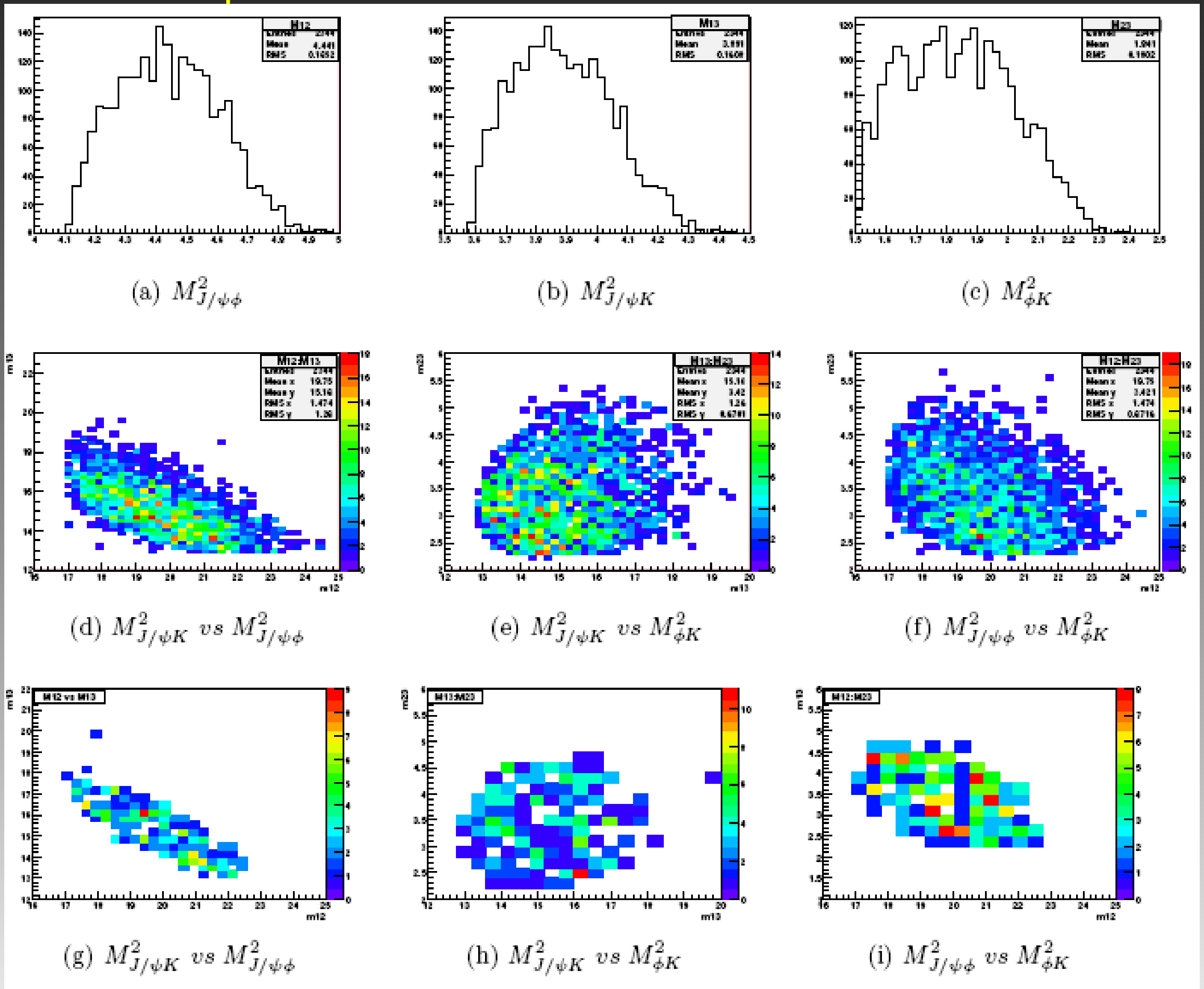


$B^{\pm} \to J/\psi\ \phi\ K^{\pm}$

hep-ex/....

Invariant masses study: $B^{\pm} \rightarrow J/\psi\phi\ K^{\pm}$

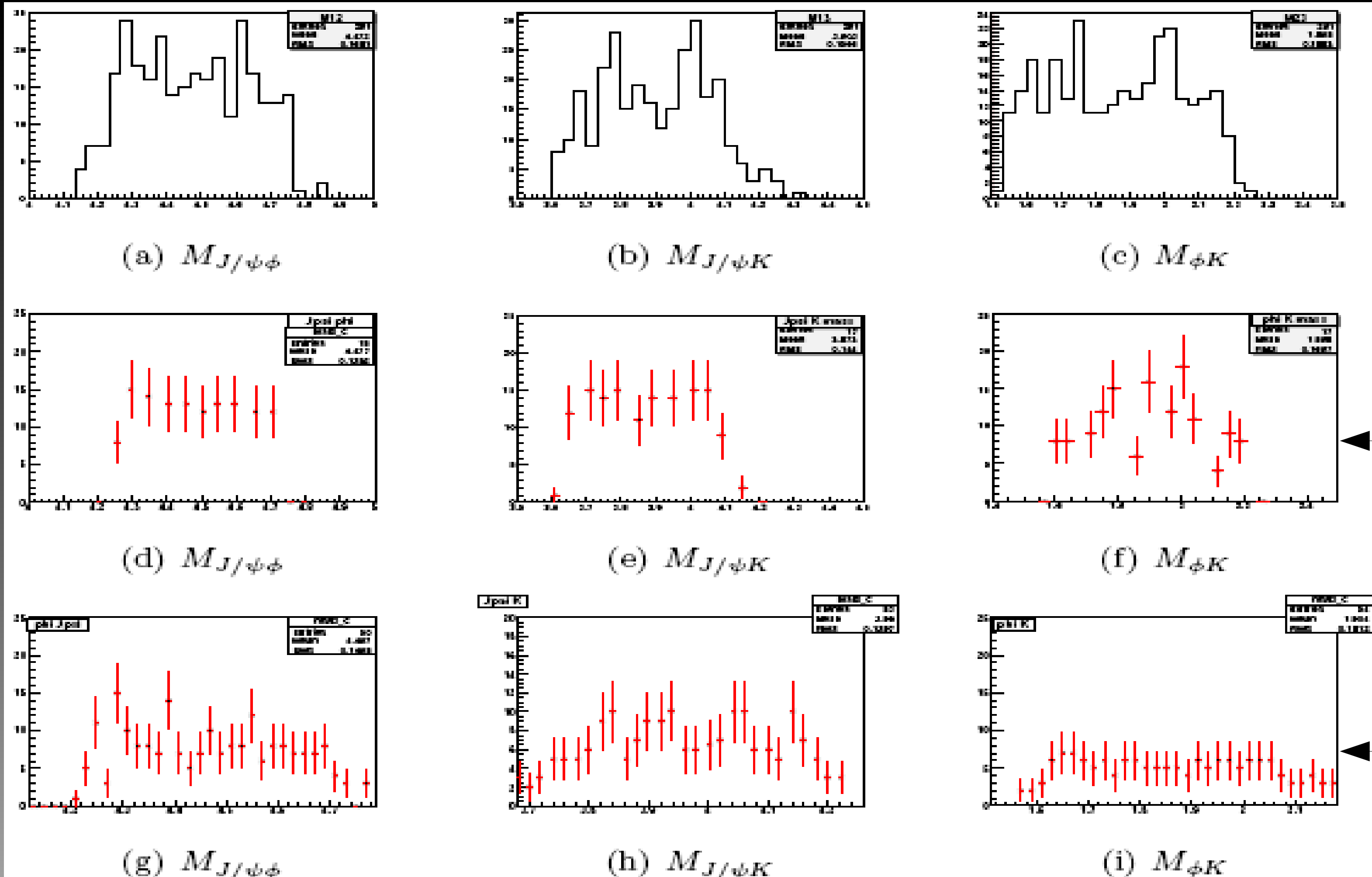
MC sample



In order to understand if new resonances lie in the masse range under examination, we analyze M_{ij}.

In the MC sample we do not expect to see any resonant structure , so we observe smooth distributions.

$B^{\pm} \rightarrow J/\psi\, \phi\, K^{\pm}$



(a) $M_{J/\psi\phi}$ (b) $M_{J/\psi K}$ (c) $M_{\phi K}$

(d) $M_{J/\psi\phi}$ (e) $M_{J/\psi K}$ (f) $M_{\phi K}$

(g) $M_{J/\psi\phi}$ (h) $M_{J/\psi K}$ (i) $M_{\phi K}$

50 MeV/c^2

20 MeV/c^2

- (a), (b), (c) are realized applying the selection cuts and requiring $M_{ES}>5.27$
- (d), (e), (f) are realized after the background subtraction
- A cut every 50/c^2 (20)MeV was put on the M_{ij} range

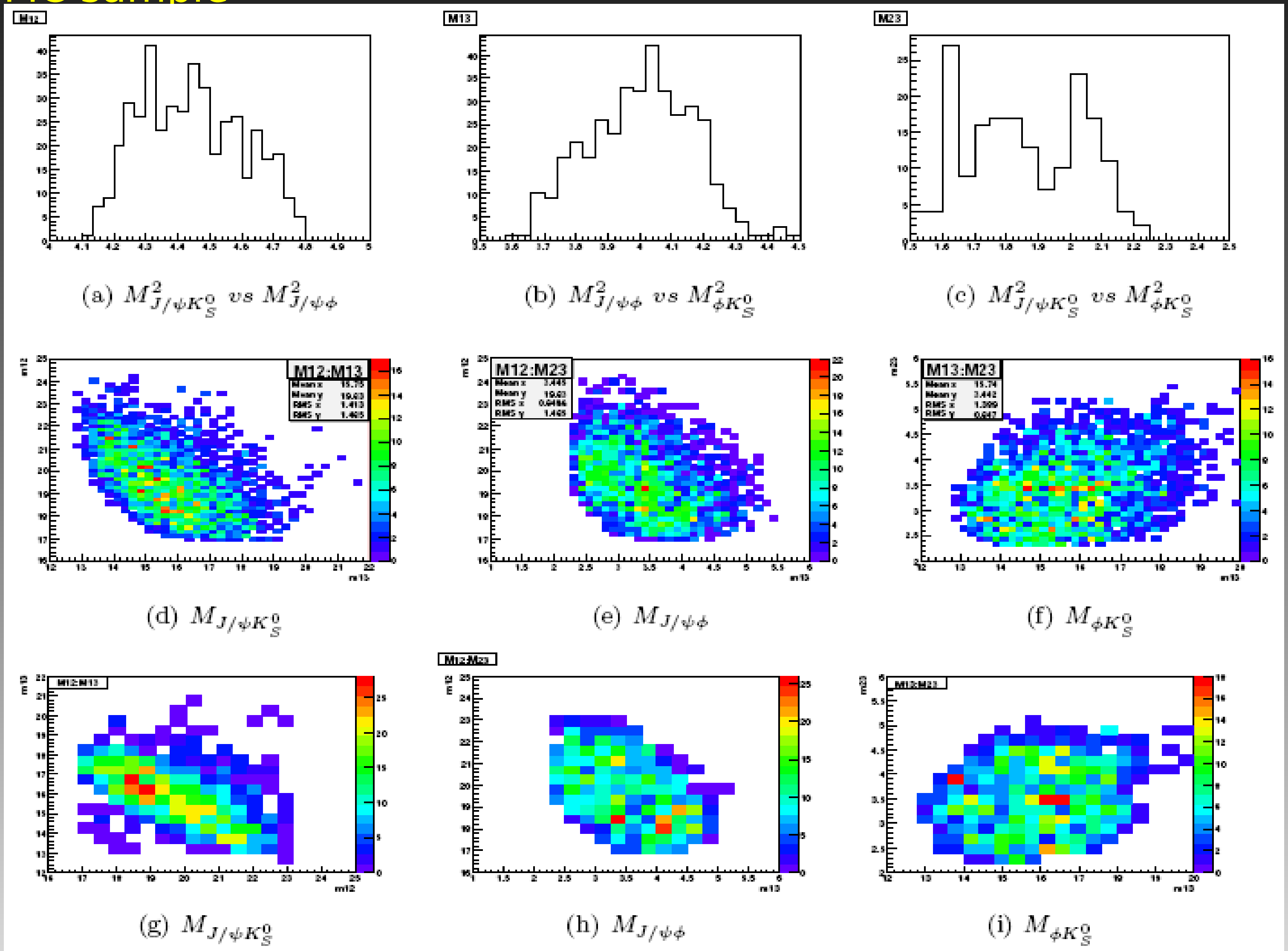
<u>Expected events</u>: 127

<u>Measured</u>: 125±15 $M_{J/\psi\phi}$
137±16 $M_{J/\psi K}$
119±16 $M_{\phi K}$

Invariant masses study

$B^0 \rightarrow J/\psi\, \phi\, K^0_S$

MC sample



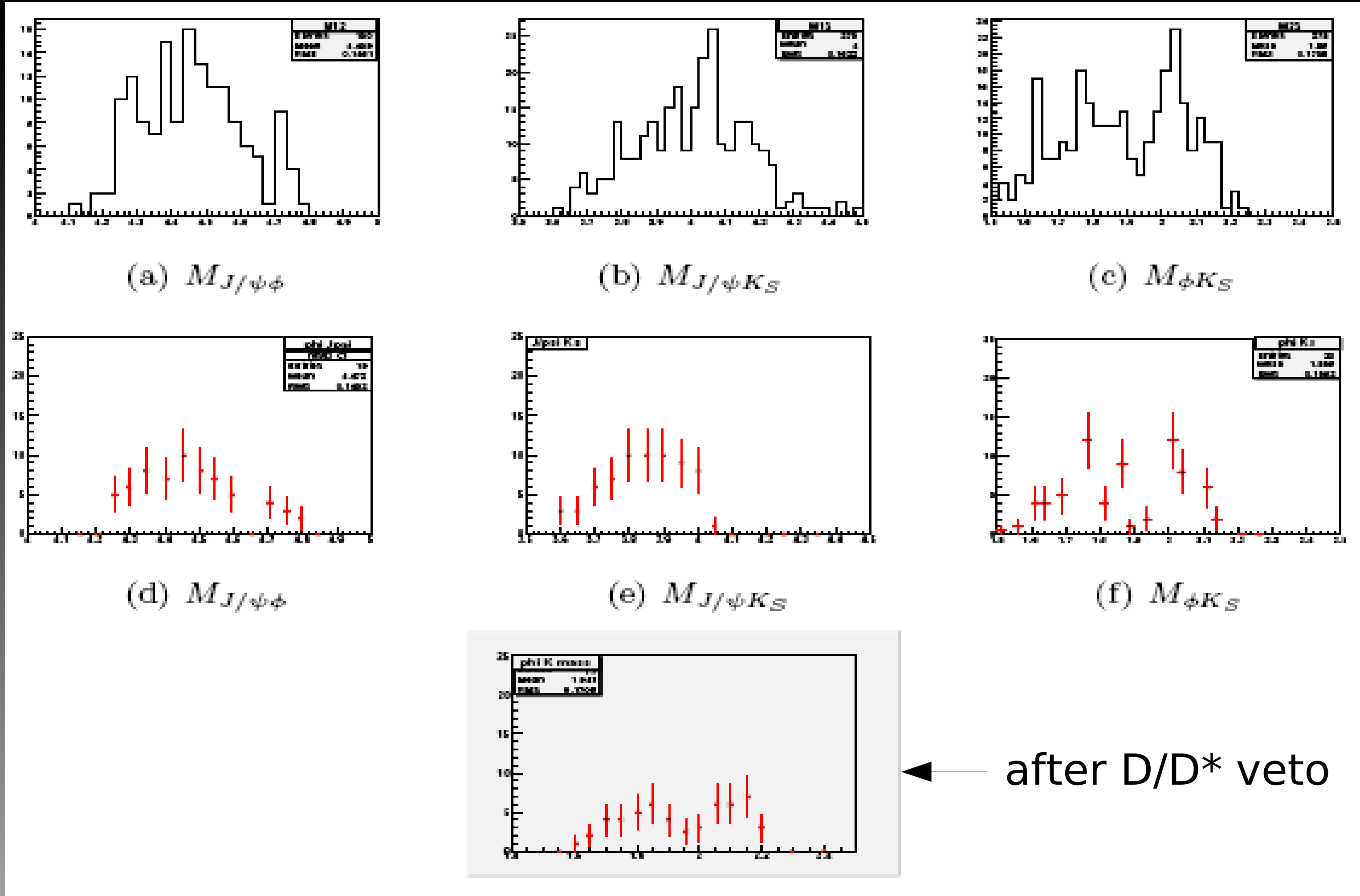
(a) $M^2_{J/\psi K^0_S}$ vs $M^2_{J/\psi\phi}$ (b) $M^2_{J/\psi\phi}$ vs $M^2_{\phi K^0_S}$ (c) $M^2_{J/\psi K^0_S}$ vs $M^2_{\phi K^0_S}$

(d) $M_{J/\psi K^0_S}$ (e) $M_{J/\psi\phi}$ (f) $M_{\phi K^0_S}$

(g) $M_{J/\psi K^0_S}$ (h) $M_{J/\psi\phi}$ (i) $M_{\phi K^0_S}$

The same study as described in Slide28 was done for the neutral B channel decay. In this case we used a larger MC sample of 1273 fb^{-1}

$B^0 \rightarrow J/\psi\,\phi\,K^0_S$



(a) $M_{J/\psi\phi}$ (b) $M_{J/\psi K_S}$ (c) $M_{\phi K_S}$

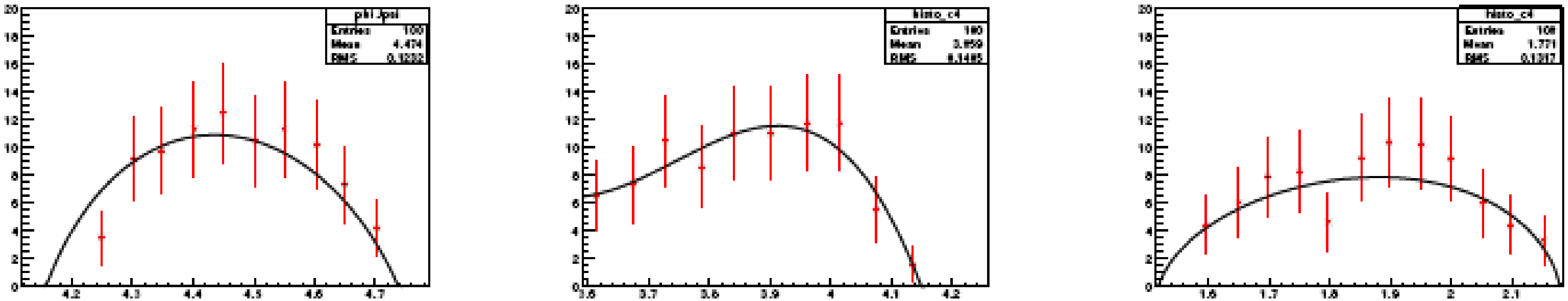
(d) $M_{J/\psi\phi}$ (e) $M_{J/\psi K_S}$ (f) $M_{\phi K_S}$

- (a), (b), (c) are realized applying the selection cuts and requiring $M_{ES}>5.27$
- (d), (e), (f) are realized after the background subtraction
- A cut every 50 MeV/c^2 was put on the M_{ij} range

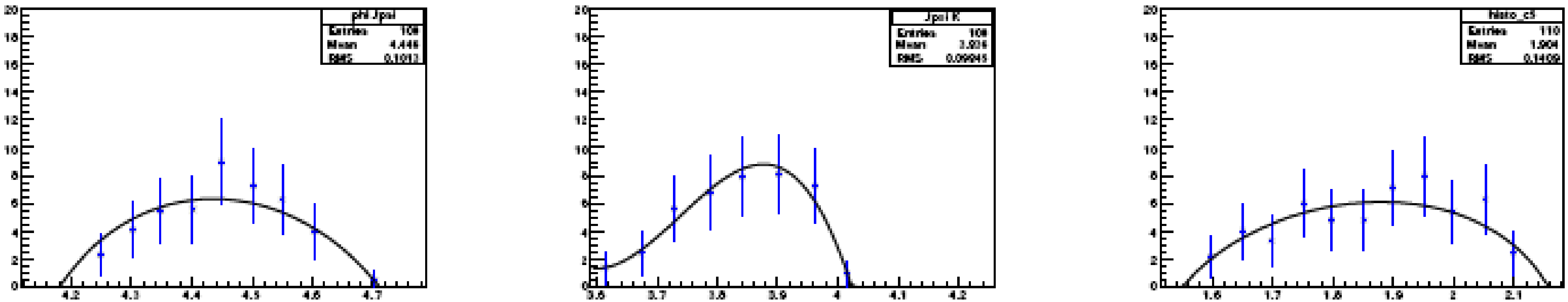
Expected events: 65

Measured: 58±13 $M_{J/\psi\phi}$
66±14 $M_{J/\psi K_S}$
60±14 $M_{\phi K_S}$

MC fit



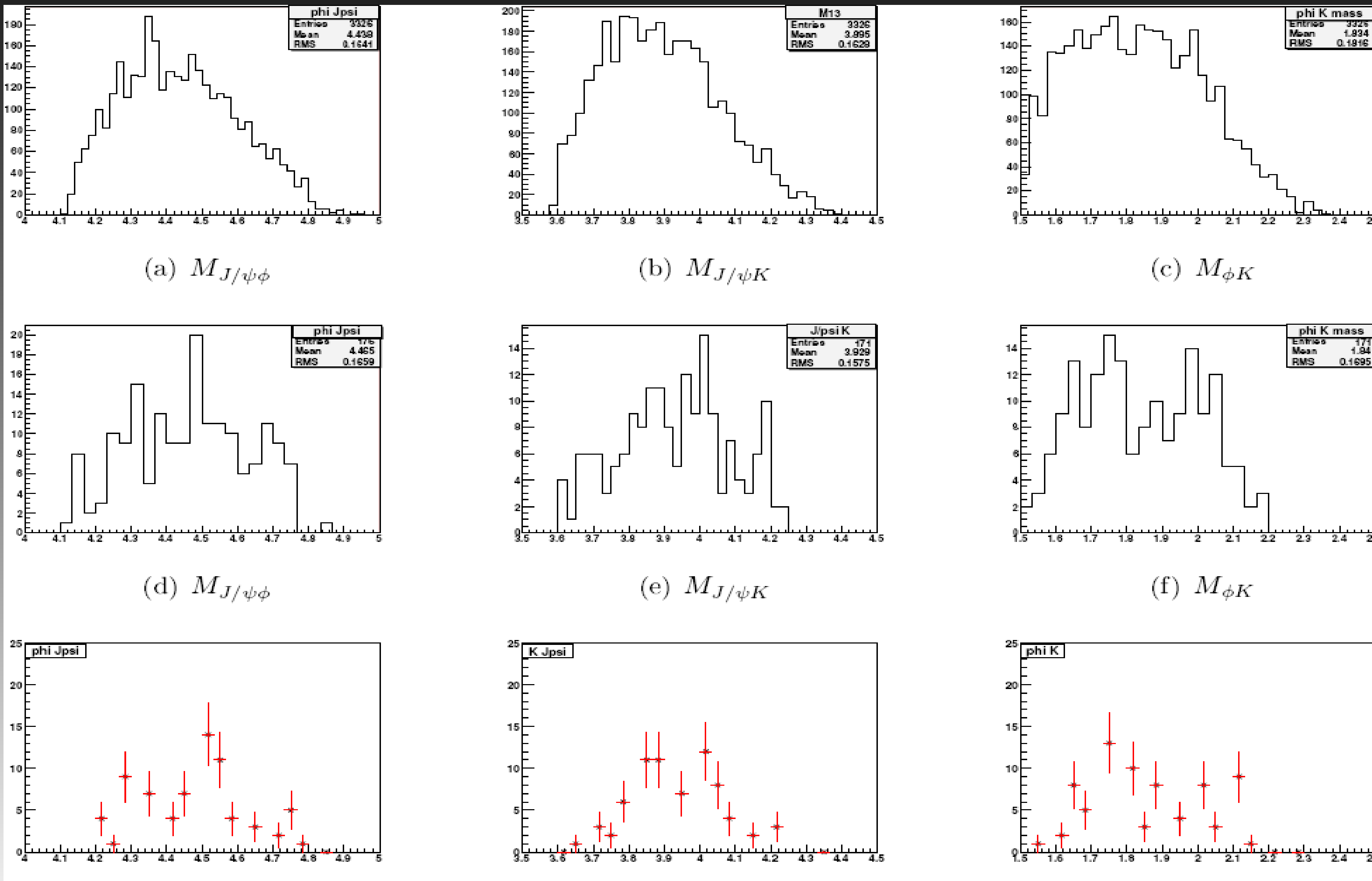
(a) $M_{J/\psi\phi}$, $B^\pm \to J/\psi\phi K^\pm$ (b) $M_{J/\psi K}$, $B^\pm \to J/\psi\phi K^\pm$ (c) $M_{\phi K}$, $B^\pm \to J/\psi\phi K^\pm$



(d) $M_{J/\psi\phi}$, $B^0 \to J/\psi\phi K^0_S$ (e) $M_{J/\psi K}$, $B^0 \to J/\psi\phi K^0_S$ (f) $M_{\phi K}$, $B^0 \to J/\psi\phi K^0_S$

$B^{\pm} \rightarrow J/\psi\, \phi\, K^{\pm}$

Results on DATA (I)



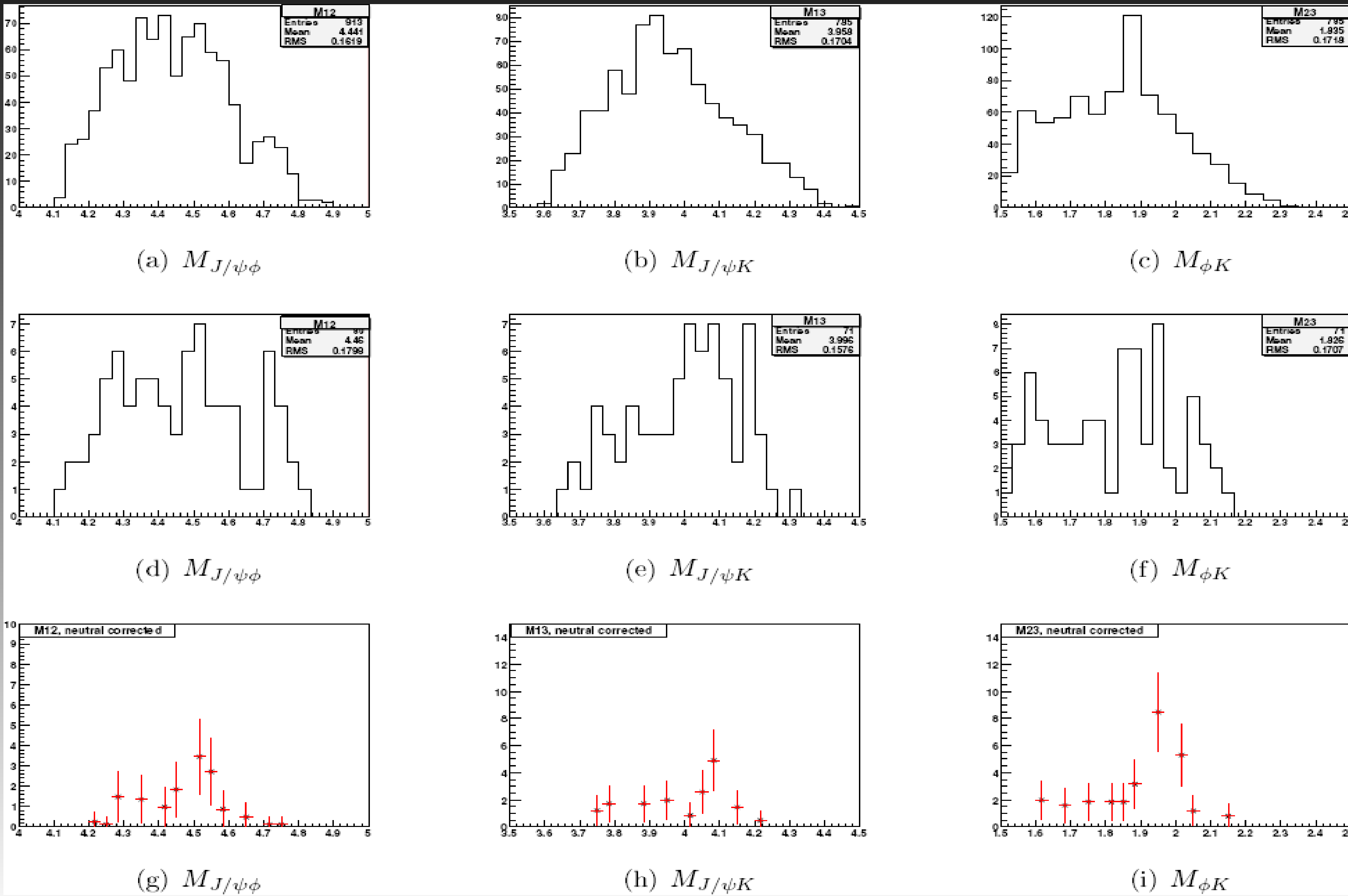
(a) $M_{J/\psi\phi}$ (b) $M_{J/\psi K}$ (c) $M_{\phi K}$

(d) $M_{J/\psi\phi}$ (e) $M_{J/\psi K}$ (f) $M_{\phi K}$

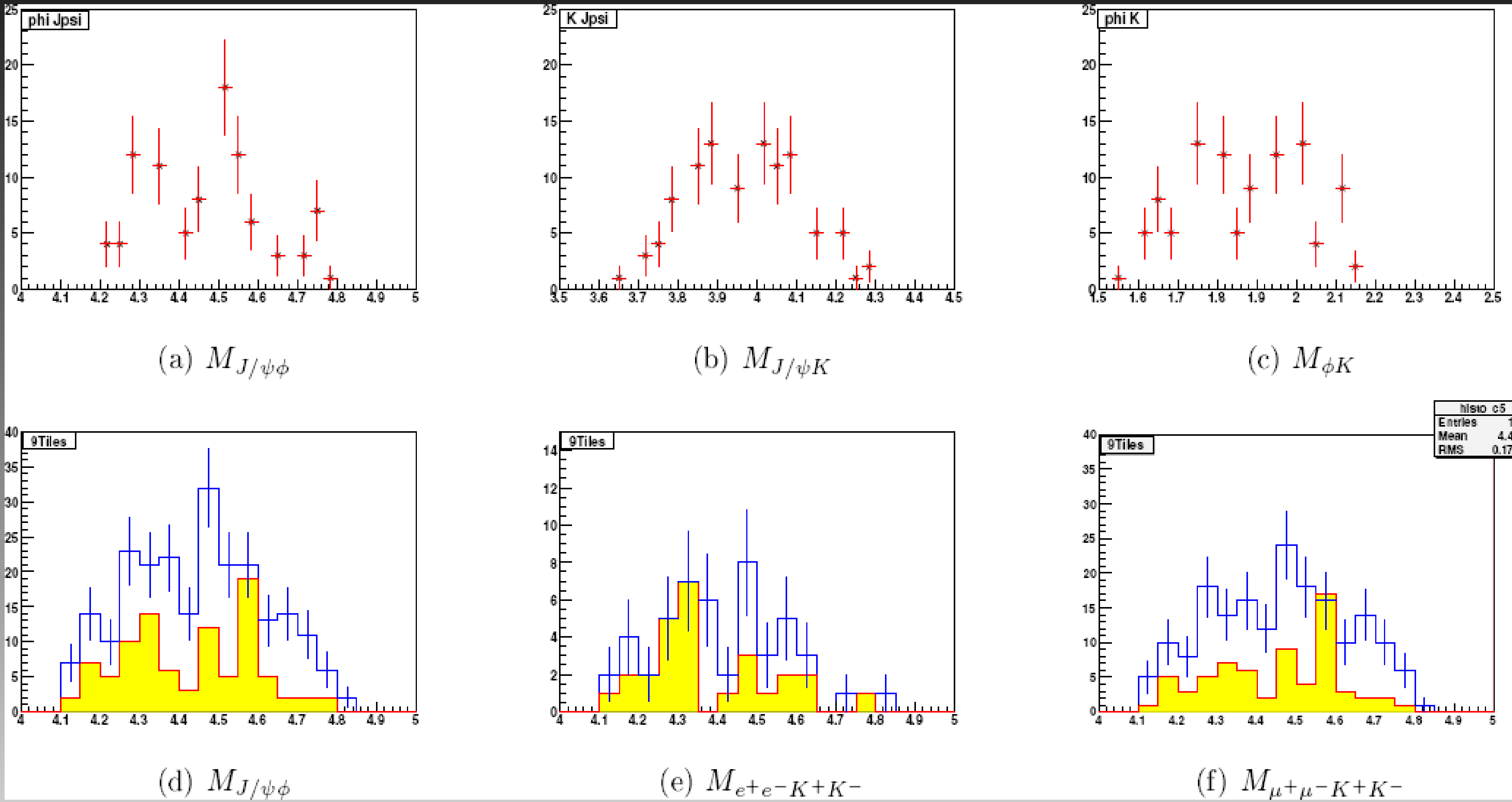
(g) $M_{J/\psi\phi}$ (h) $M_{J/\psi K}$ (i) $M_{\phi K}$

$B^0 \to J/\psi\,\phi\,K^0_s$

Results on DATA (II)



If we put together the charged and the neutral channel:

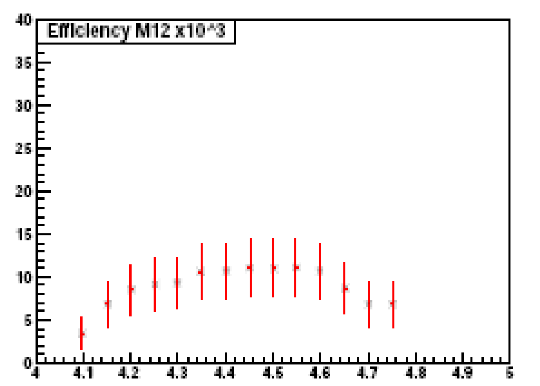


(a) $M_{J/\psi\phi}$ (b) $M_{J/\psi K}$ (c) $M_{\phi K}$

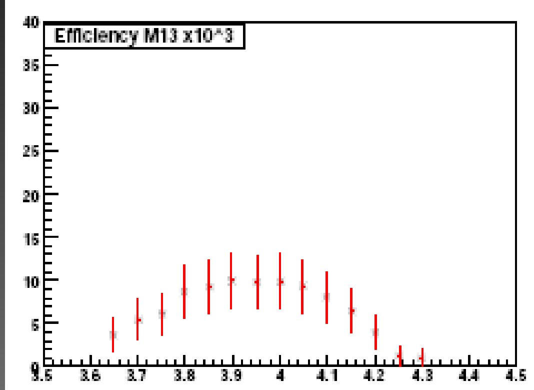
(d) $M_{J/\psi\phi}$ (e) $M_{e^+e^-K^+K^-}$ (f) $M_{\mu^+\mu^-K^+K^-}$

- (a), (b), (c) represent the *binned fit*
- (d), (e), (f) represent the $M_{J/\psi\phi}$ invariant mass plot using the *9-tiles method*

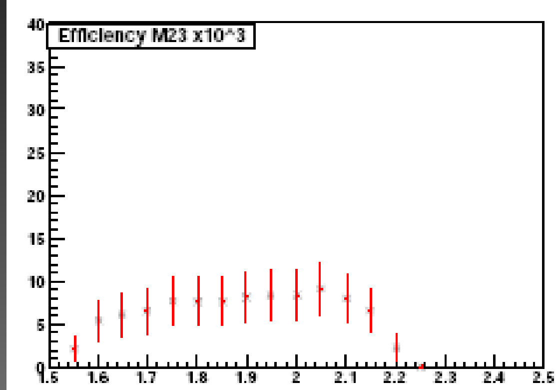
Efficiency corrections



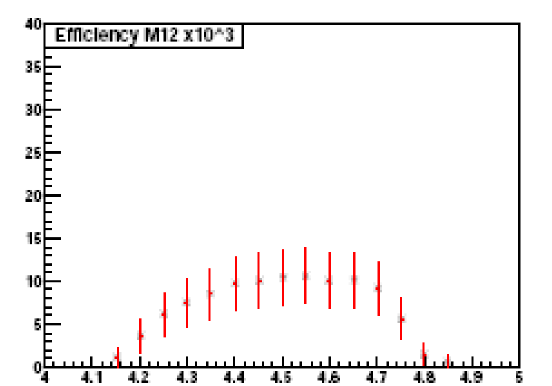
(a) ϵ vs $M_{J/\psi\phi}$, $B^{\pm} \to J/\psi\phi K^{\pm}$



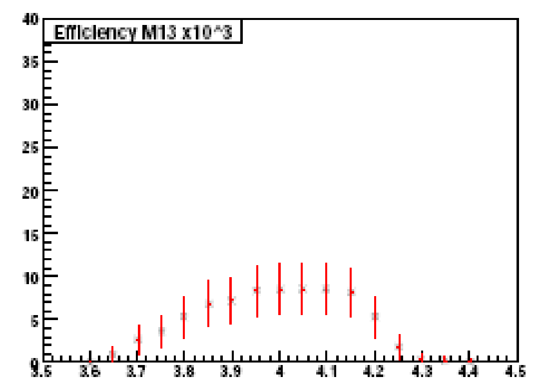
(c) ϵ vs $M_{J/\psi K}$, $B^{\pm} \to J/\psi\phi K^{\pm}$



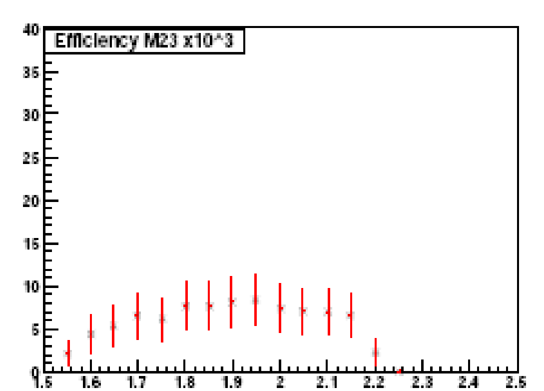
(e) ϵ vs $M_{\phi K}$, $B^{\pm} \to J/\psi\phi K^{\pm}$



(b) ϵ vs $M_{J/\psi\phi}$, $B^{0} \to J/\psi\phi K^{0}_{S}$



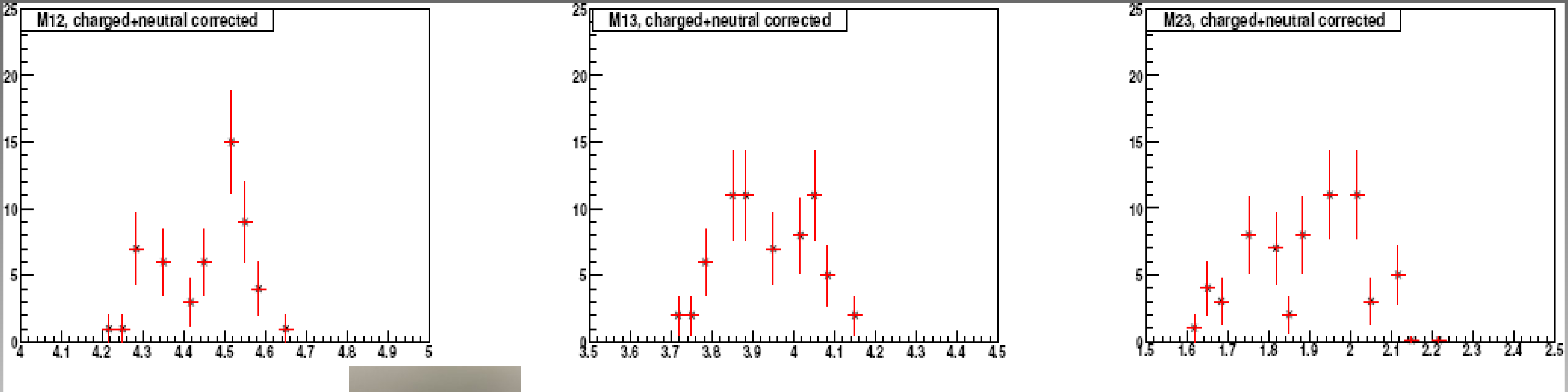
(d) ϵ vs $M_{J/\psi K}$, $B^{0} \to J/\psi\phi K^{0}_{S}$



(f) ϵ vs $M_{\phi K}$, $B^{0} \to J/\psi\phi K^{0}_{S}$

Final invariant mass plots

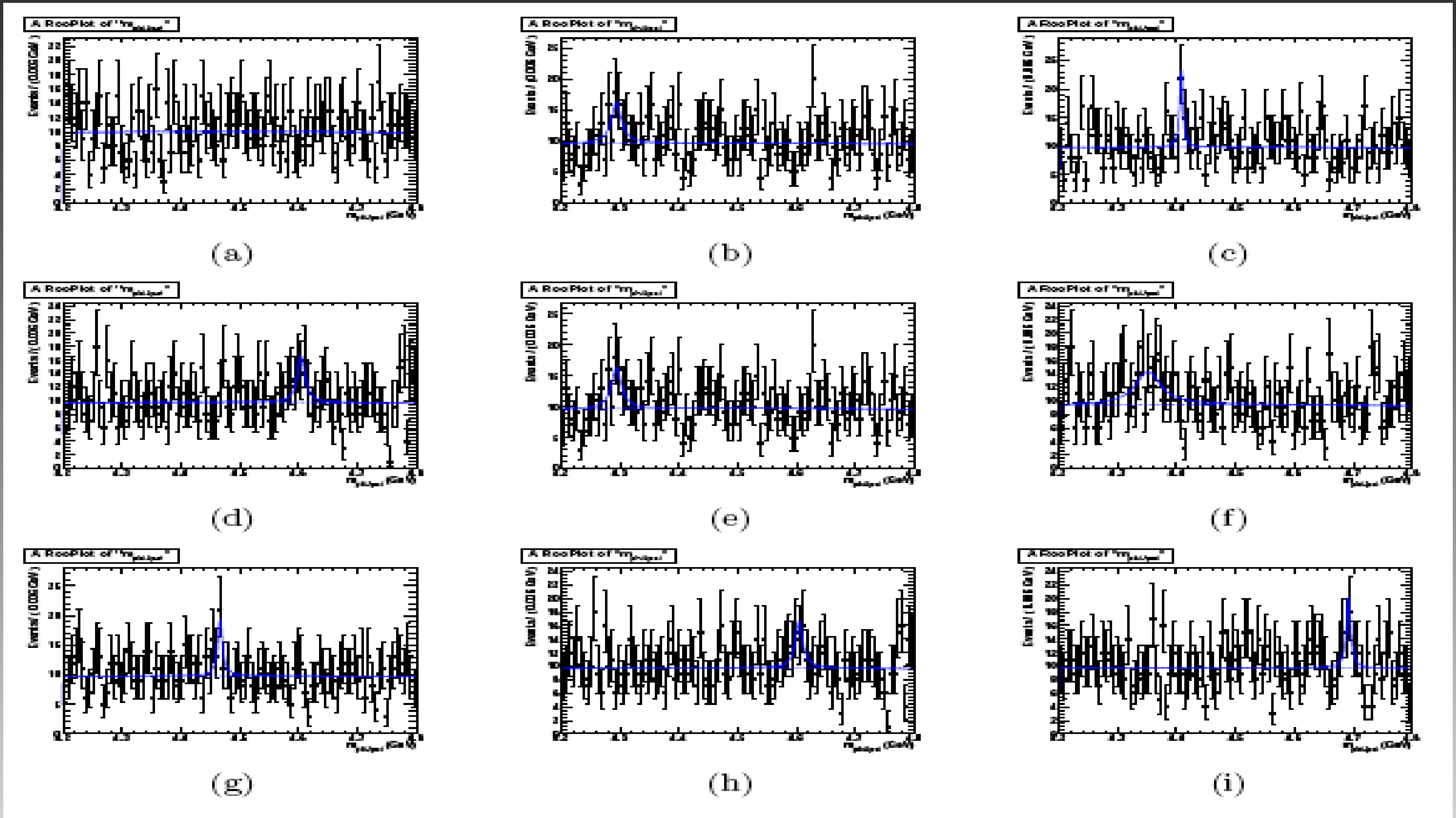
- Efficiency corrections applied
- Plots done on the full DATA sample: Bch + B0
- Excess of events seen around 4.50 GeV/c^2, but also compatible with flat distribution
- Need of more data and accuracy to understand the nature of this enhancement



(a) $M_{J/\psi\phi}$ (b) $M_{J/\psi K}$ (c) $M_{\phi K}$

What is it?

ToyMC study

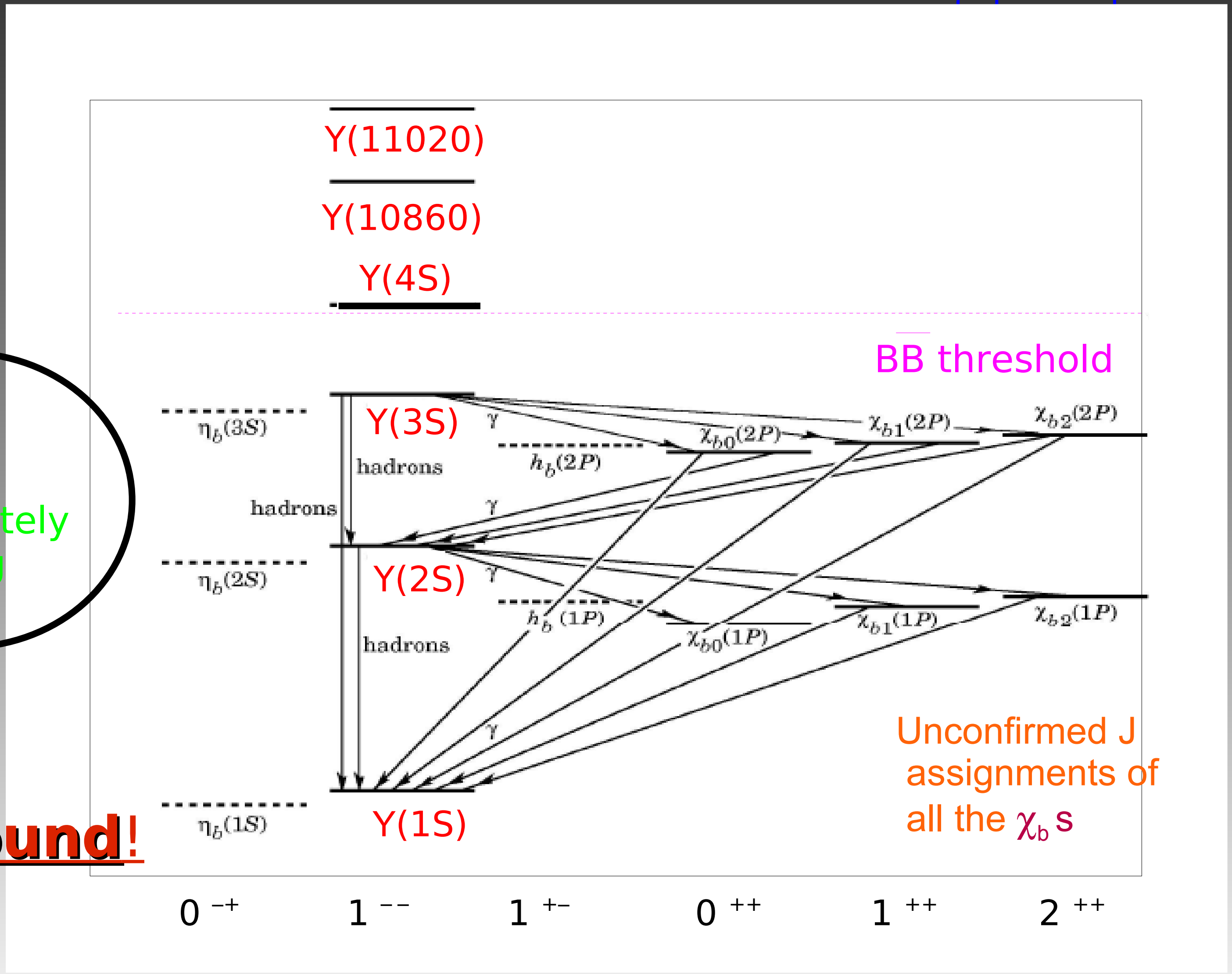


BOTTOMONIUM SPECTROSCOPY

2 h_b and 3 D wave states are narrow but

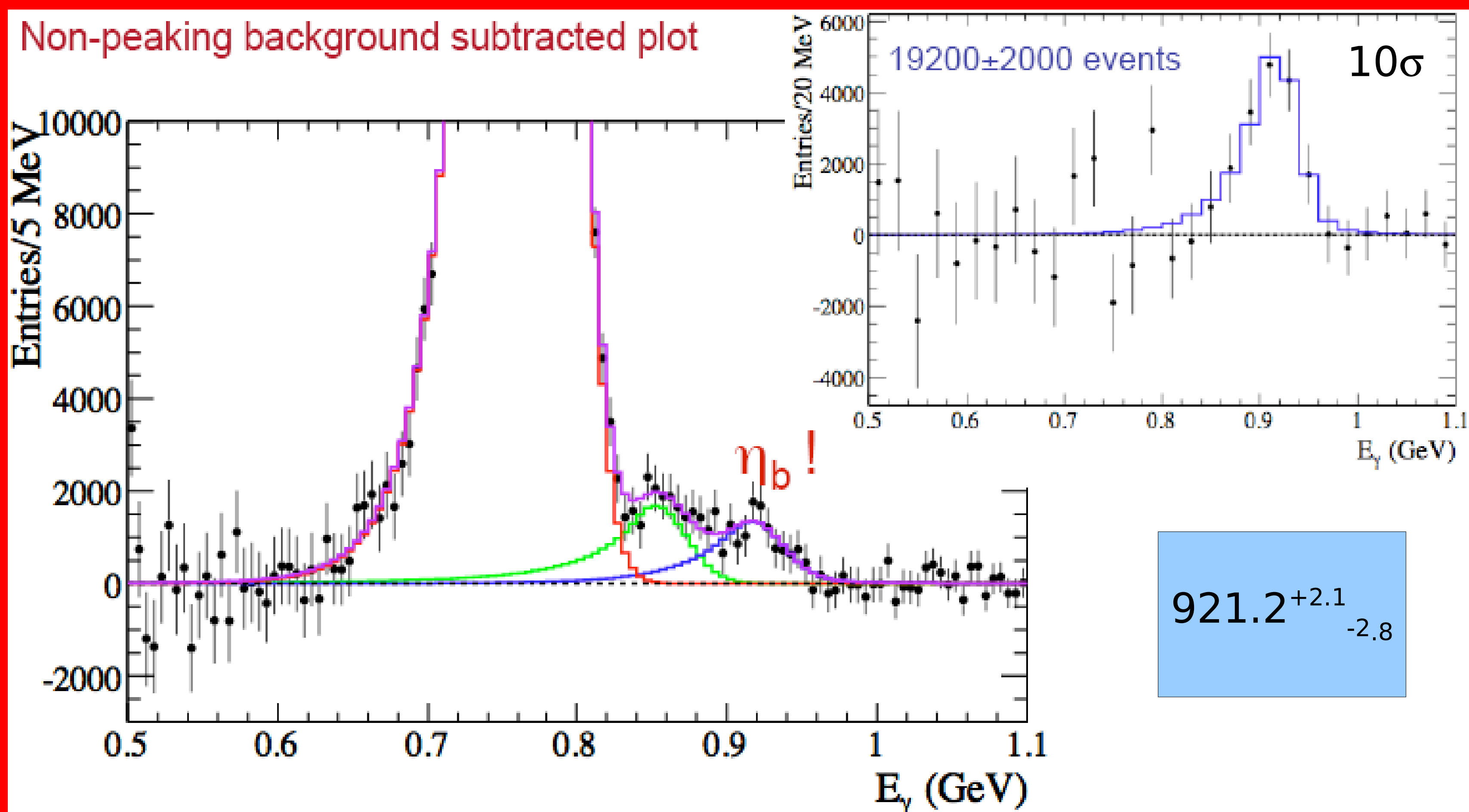
η_b completely missing

now **BaBar found**!



η_b

- $e^+e^- \rightarrow \Upsilon(3S) \rightarrow \gamma\eta_b$



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

$$BR = [4.8 \pm 0.5(\mathrm{stat}) \pm 1.2(\mathrm{syst})] \times 10^{-4}$$

under
bottomonium hypothesis

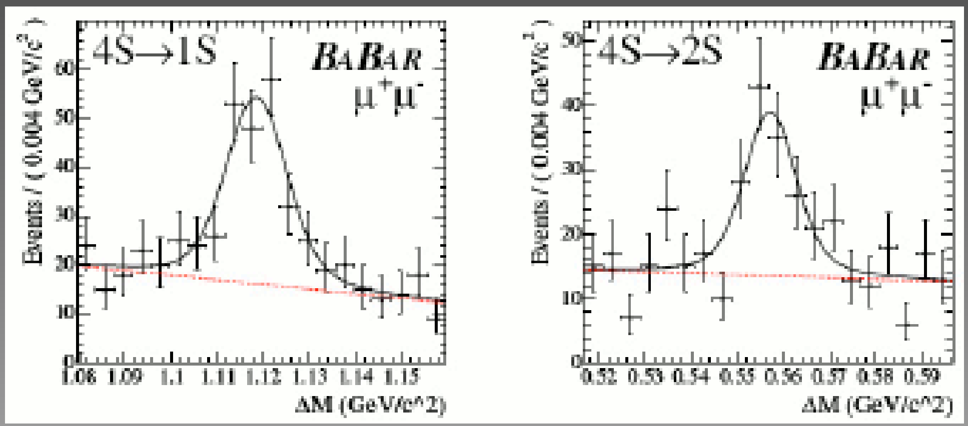
PRL96, 232001

230 M Y(4S)

Bottomonium @ Y(4S)

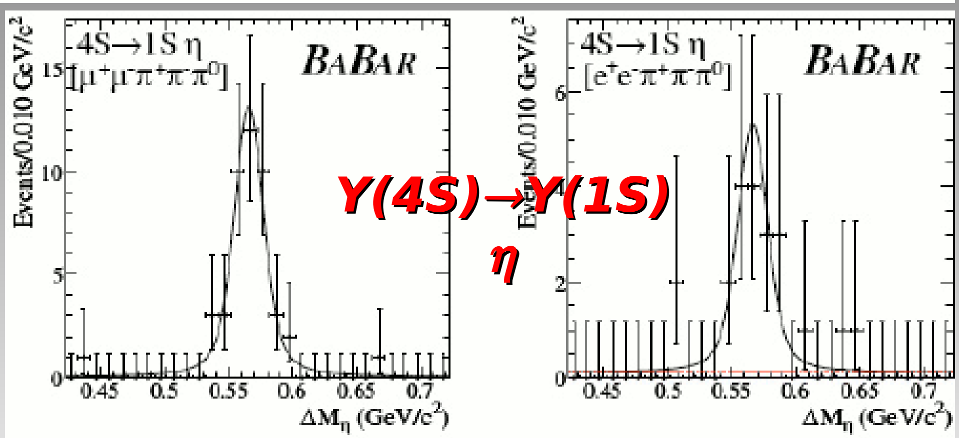
BABAR

- Non BB decays
- Transitions: **Y(4S) →Y(2S)$\pi^+\pi^-$**
  Y(4S) →Y(1S)$\pi^+\pi^-$



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

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



Y(4S)→Y(1S) η

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

Unexpected result:

$$\frac{\Gamma_{4S\to 1S\eta}}{\Gamma_{4S\to 1S\pi\pi}} = 2.41\pm0.40\pm0.12$$

E1M2/
E1E1

Summary

What is in the  *zoo?*

EXP	STATE	MASS (MeV/c^2)	Γ (MeV)	J^{PC}	DECAY MODE	PRODUCTION MECHANISM
Belle CDF, D0 BaBar	X(3872)	3871.2 ± 0.5	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$ $\pi^+\pi^-\pi^0 J/\psi$	B decays, $p\bar{p}$
Belle BaBar		$3875.4\pm0.7^{+1.2}_{-2.0}$ $3875.1^{+0.7}_{-0.5}\pm0.5$	$3.0^{+1.9}_{-1.4}\pm0.9$	$(2^{++}\ ?)$	$D^0\bar{D}^0\pi^0$ DD^*	B decays
Belle	Z(3930)	$3929\pm5\pm2$	$29\pm10\pm2$	2^{++}	$D^0\bar{D}^0$, D^+D^-	$e^+e^- \to J/\psi X$
Belle BaBar	Y(3940)	$3943\pm1.1\pm1.3$ $3914.6^{+3.8}_{-3.4}\pm1.9$	$87\pm22\pm26$ $33^{+12}_{-8}\pm5$	$?^{??}$	$\omega J/\psi$	B decays
Belle	X(3940)	$3942^{+7}_{-6}\pm6$	$37^{+25}_{-15}\pm8$	$?^{?+}$	DD^*	γ
Belle	Y(4008)	$4008\pm40^{+72}_{-28}$	$226\pm44^{+87}_{-79}$	1^{--}	$\pi^+\pi^- J/\psi$	B decays
Belle	Y(4160)	$4156^{+15}_{-20}\pm15$	$139^{+111}_{-61}\pm21$	$?^{?+}$	D^*D^*	$e^+e^- \to J/\psi X$
BaBar	Y(4175)	$2175\pm10\pm15$	$58\pm16\pm20$	1^{--}	$K^+K^-\pi\pi$	ISR
Babar CLEO Belle	Y(4260)	$4259\pm8^{+8}_{-6}$ $4284^{+17}_{-16}\pm4$ $4247\pm12^{+17}_{-32}$	$88\pm23^{+6}_{-4}$ $73^{+39}_{-25}\pm5$ $108\pm19\pm10$	1^{--}	$\pi^+\pi^- J/\psi$ $\pi^0\pi^0 J/\psi$ $K^+K^- J/\psi$	ISR
Babar Belle	Y(4350)	4324 ± 24 $4361\pm9\pm9$	172 ± 33 $74\pm15\pm10$	1^{--}	$\pi^+\pi^-\psi(2S)$	ISR
Belle	Z(4430)	$4433\pm4\pm1$	$44^{+17}_{-13}\,^{+50}_{-11}$	$?^{??}$	$\pi^+\psi(2S)$	B decays
Belle	Y(4620)	$4466\pm11\pm5$	$48\pm15\pm3$	1^{--}	$\pi^+\pi^-\psi(2S)$	ISR

confirmed now also from BES → Y(4175)

Theory still not clear.

Significant contribution from **BaBar** in these 9 years.

Important analyses are ongoing...