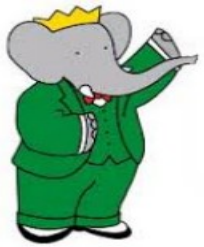


Search for exotic charmonium at BABAR

August 28th, 2014 | Elisabetta Prencipe(*), Forschungszentrum Jülich (Germany) | PANIC 2014, Hamburg (Germany)

(*) Previously addressed at JGU University of Mainz (Germany)

Outline

Recent results will be introduced.
Selected topics of this talk:

- Analysis of the rare decay $B^{\pm,0} \rightarrow J/\psi\ KKK^{\pm,0}$

  arXiV: 1407.7244 [hep-ex]
  Submitted to PRD (2014)

- Analysis of $B^0 \rightarrow J/\psi\phi$

- Analysis of $\eta_c \rightarrow K\ K\ \eta$ and $\eta_c \rightarrow K\ K\ \pi^0$ via 2-photon interactions

  PRD 89, 112004 (2014)

- Radiative transitions involving $\chi_{bJ}(1P, 2P)$ Draft in prepration

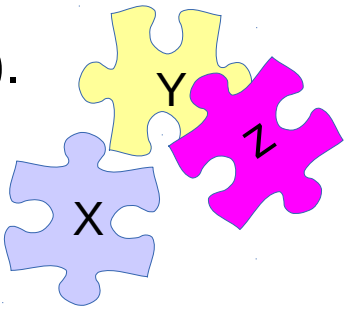
Introduction

- Exciting time to study exotic states using the full ***BABAR*** dataset.
- How many *charmonium(-like)* states can we count? CERN Yellow Report http://arxiv.org/abs/hep-ph/0412158

So many!

unexpected but found, expected and not found, controversial claims...

- 2014: 50th anniversary of CP violation discovery. Much progress thanks to the B-factories!
- 2014: 11 years after the observation of the unexpected X(3872).



⇩

QUESTION: What have we understood?

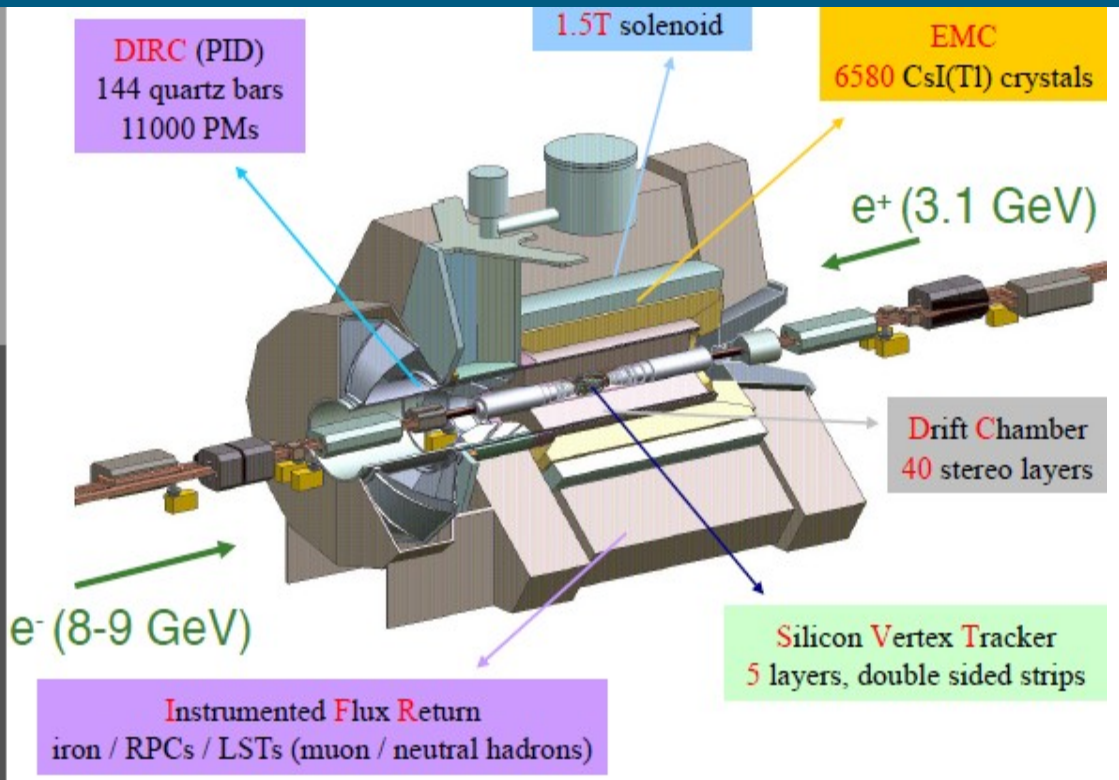
- The systems of $J/\psi\pi\pi$, $J/\psi\pi\pi\pi^0$ prove to be rich sources of information: still under study.
- What about $J/\psi KK$ (strangeness in charmonium)? Recently (partially) covered

Strangeness in Charmonium

$b \to c\bar{c}s$

(suppressed B decays)

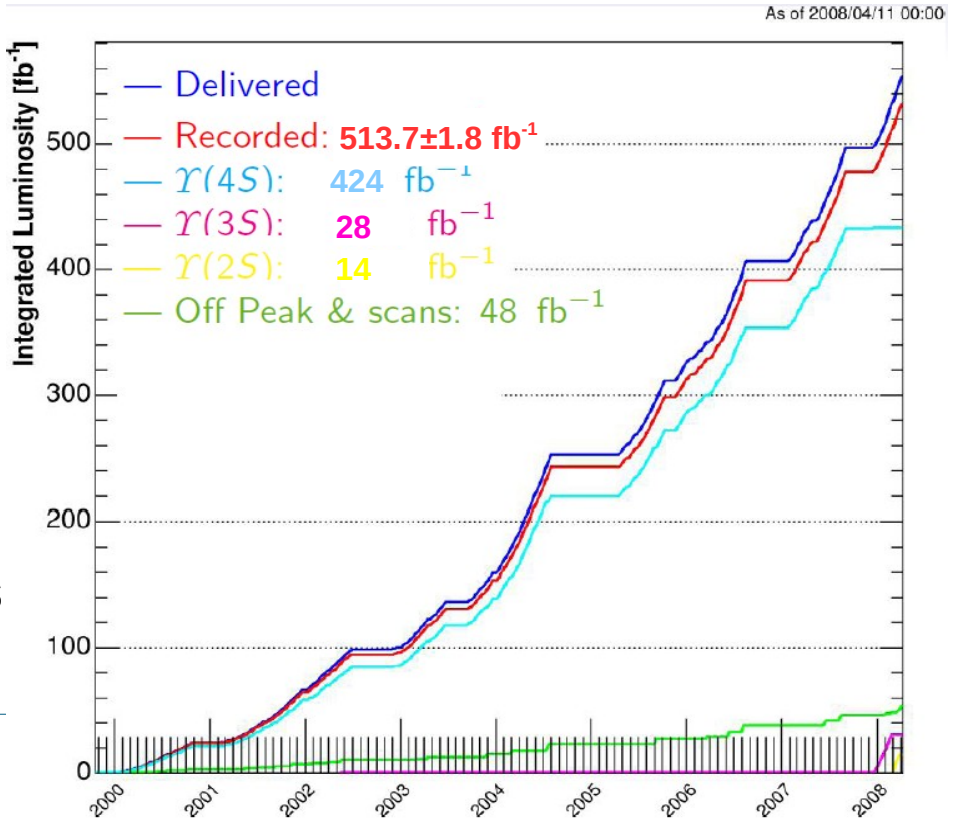
The BABAR experiment



- Located at SLAC (California)
- Runs: from 1999 to 2008
- e+e- asymmetric collider

$$-0.9 < \cos\theta^* < 0.85$$

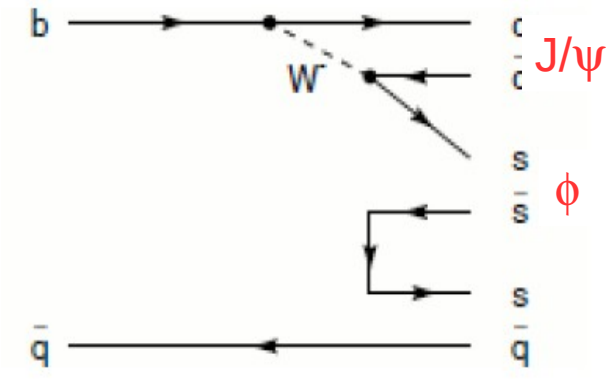
operating at the c.m. energy of Y(4S), then Y(2S) and Y(3S).



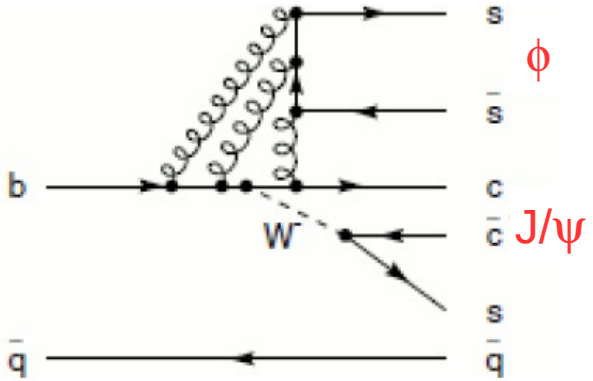
- Optimized for studies of CP violation
- High luminosity achieved ⇨ rare decay studies
- High production rate of $c\bar{c}$ ⇨ charmonium studies
- Run at Y(2S) and Y(3S) ⇨ bottomonium studies

Analysis $B \rightarrow J/\psi KK(K)$: motivation

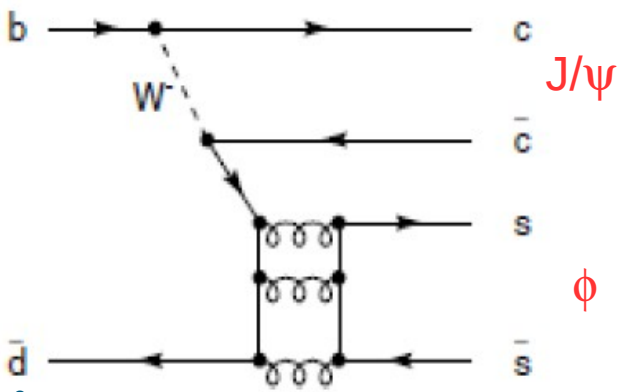
- $B \rightarrow J/\psi$ K K K: rare B decay, Cabibbo suppressed, predicted BF ~10^{-5}
- K^+K^- contribution expected to be dominated from ϕ [BF($\phi \rightarrow K^+K^-$) ~49.5%]
- $B \rightarrow J/\psi\, \phi$ K: three body decay, gluon rich process ⇒ ideal place to look for exotics
- It could proceed also via quasi-2-body decay, $B \rightarrow Y_g(\bar{c}c\bar{s}s)K$, $Y_g \rightarrow J/\psi\phi$
- If any Y_g exists, expected mass < 4.3 GeV/c^2 (threshold DD^{**})
- $B^0 \rightarrow J/\psi\phi$: transition $b\bar{d} \rightarrow \bar{c}c\bar{s}s$ rescattering process ⇒ no signal expected



B →J/ψϕK via strange sea quark



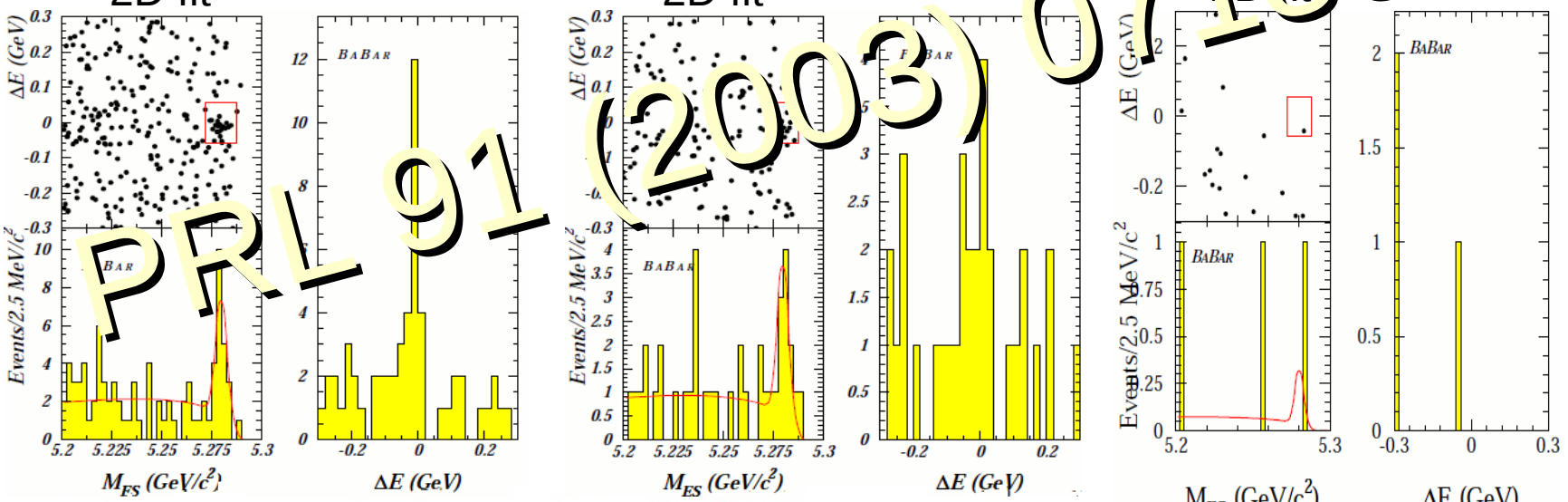
B →J/ψϕK via gluon coupling



$B^0 \rightarrow J/\psi\phi$: rescattering diagram

Analysis B → J/ψKK(K): "old" measurements

- Old BaBar publication: PRL 91 (2003) 071801, 51 fb^{-1}
- Today: 424 fb^{-1}, 470M B$\bar{B}$: expected much higher precision in BF measurements, and possibility to look at the invariant mass distributions



Experiment	Channel	B.R. (10^{-5})	PDG12 average (10^{-5})
BaBar	$B^{\pm} \to J/\psi\phi K^{\pm}$	$4.4 \pm 1.4 \pm 0.5$	5.2 ± 1.7
CLEO-II		$8.8^{+3.5}_{-3.0} \pm 1.3$	
BaBar	$B^{0} \to J/\psi\phi K^{0}$	$10.2 \pm 3.8 \pm 1.0$	9.4 ± 2.6
CLEO-II		$8.8^{+3.5}_{-3.0} \pm 1.3$	

$B^0 \to J/\psi\phi$ UL<9.2 * 10^{-6}

← No update until 2014!

← BaBar measurements dominate the PDG measurements since 2003

$B \to J/\psi KK(K)$: BF strategy

- B channels under study : $B^{\pm}$ and B^{0}
- K^+K^- invariant mass in the full range [0.98;1.69] GeV/c^2

PDG2012

decay channel	BR	J^G (J^{PC})
$a_0(980) \to K^+K^-$	seen	$1^-(0^{++})$
$f_0(980) \to K^+K^-$	seen	$0^+(0^{++})$
$\phi(1020) \to K^+K^-$	$(48.9 \pm 0.5)\%$	$0^-(1^{--})$
$f_2(1270) \to K^+K^-$	$(4.6 \pm 0.4)\%$	$0^+(2^{++})$
$a_2(1320) \to K^+K^-$	$(4.9 \pm 0.8)\%$	$1^-(2^{++})$
$f_2'(1525) \to K^+K^-$	$(88.8 \pm 3.1)\%$	$0^+(2^{++})$
$\phi(1680) \to K^+K^-$	seen	$0^-(1^{--})$

Several resonant states decaying to K^+K^-.
Expected dominant meson ($\to K^+K^-$) in these B decays: ϕ

- Measurement of BFs:
  - blind analysis (large MC samples) to check consistency of fit methods
  - unbinned maximum likelihood fit of m_{ES} (gaussian fit for signal yield; Argus function to parametrize the background). Double check with ΔE fit is performed

$$m_{ES} = \sqrt{E^*_{beam} - p^*_{beam}} \qquad \Delta E = E^*_{beam} - \sqrt{s}/2$$

  - K^+K^- invariant mass in the full range, then we restrict to the ϕ mass region
- J/ψ reconstructed to e^+e^- and $\mu^+\mu^-$; mass constrained

$B \to J/\psi KKK$: fits for BF measurements

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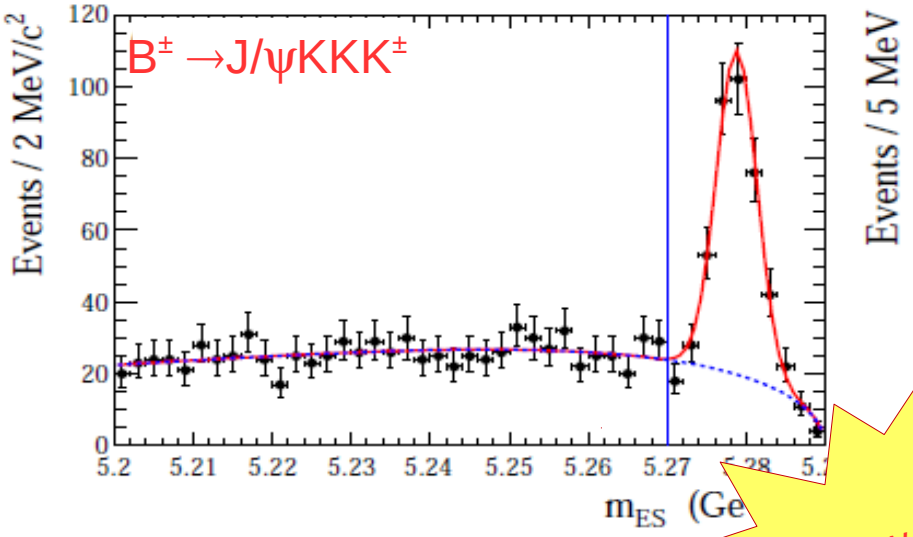
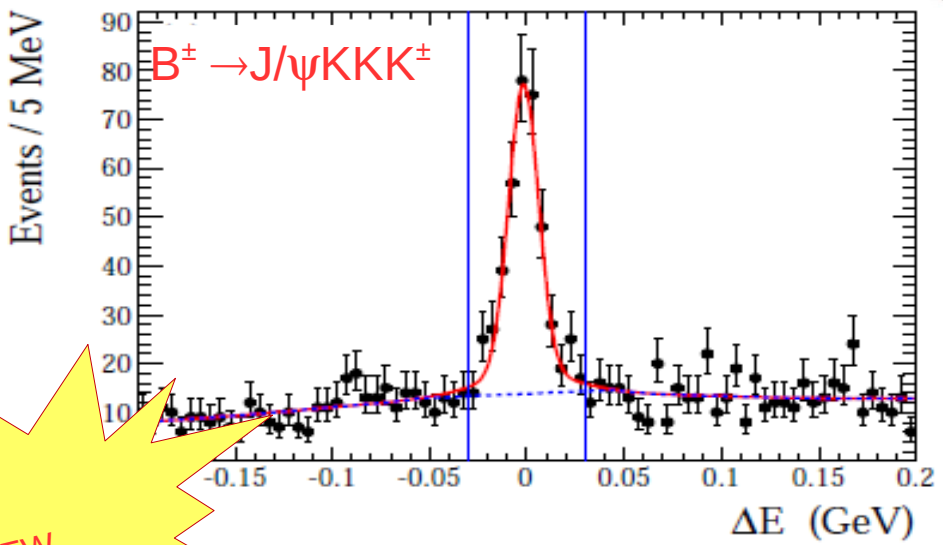
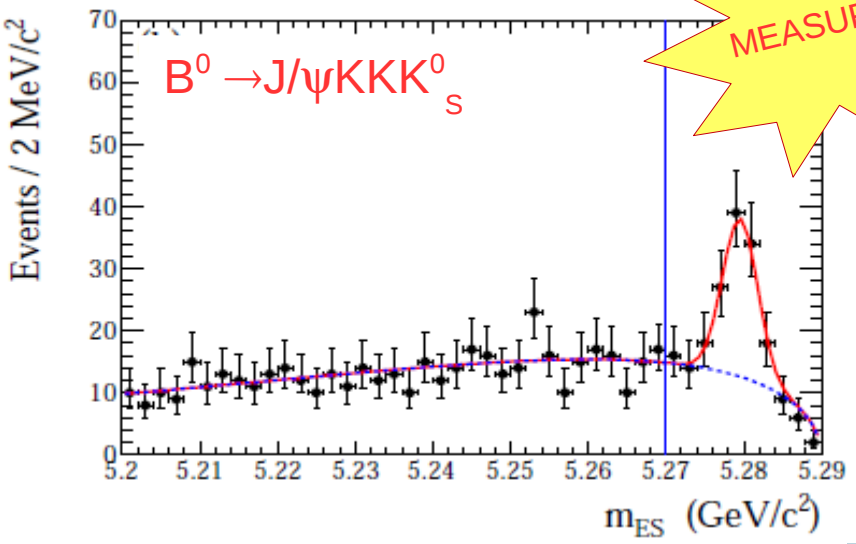
Submitted to PRD

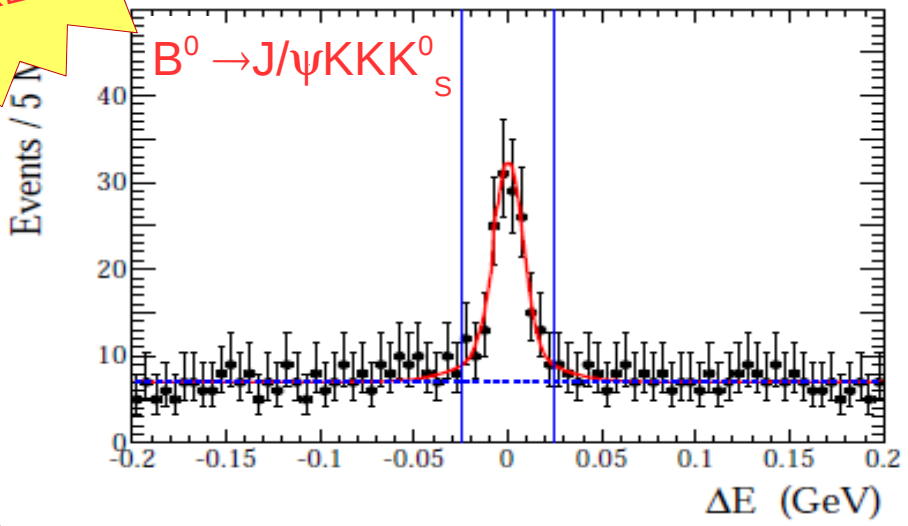
- No BF measurements in the PDG until 2014





NEW MEASUREMENTS





K^+K^- invariant mass

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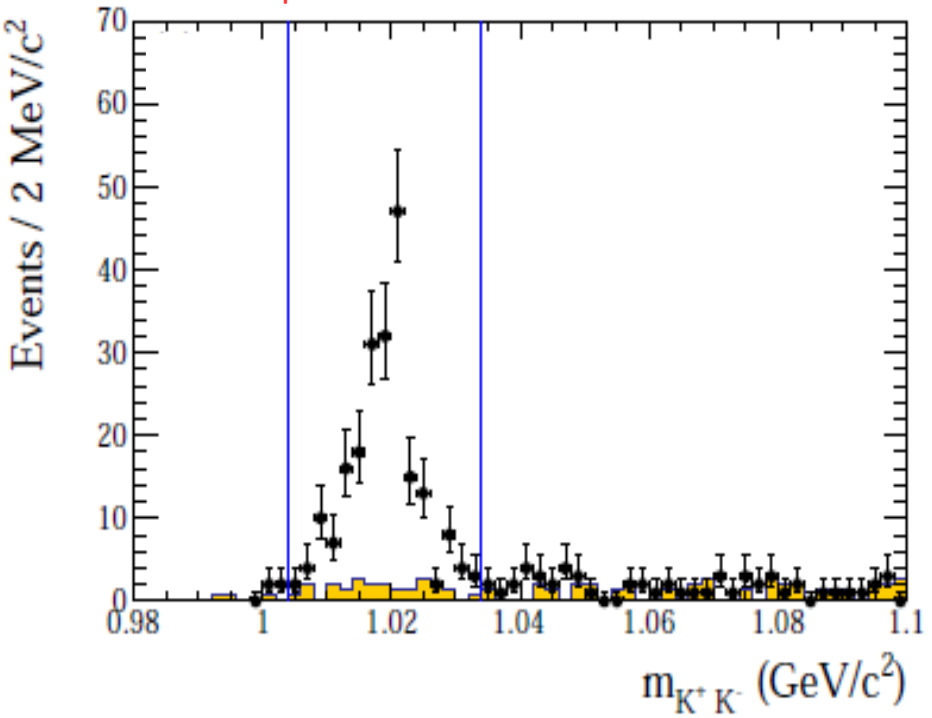
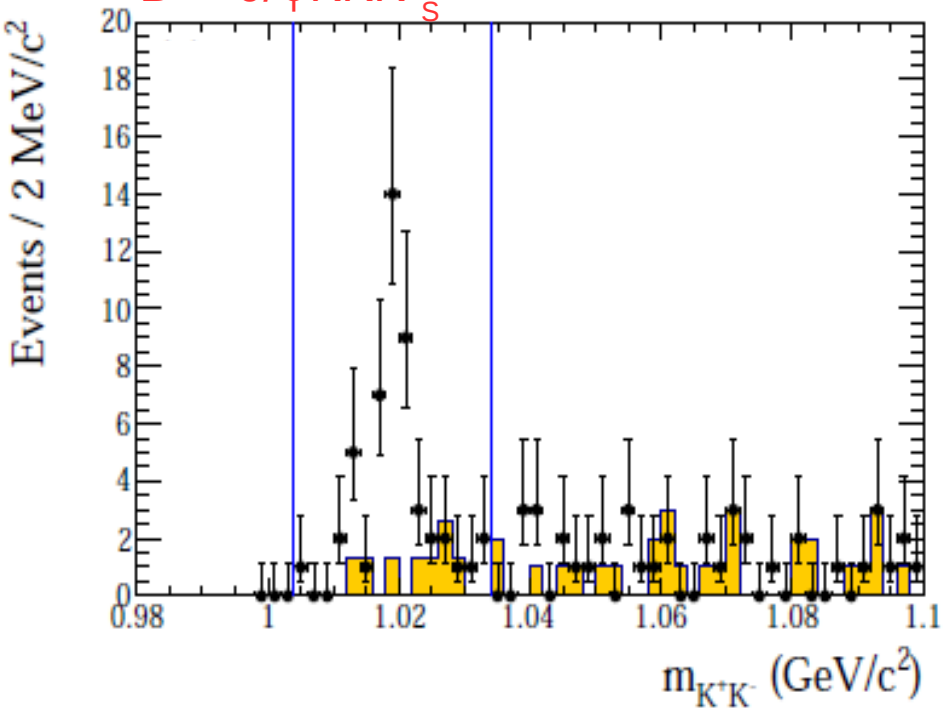
$B^{\pm} \rightarrow J/\psi KKK^{\pm}$



$B^0 \rightarrow J/\psi KKK^0_S$



- ϕ mass region selected to study $B \rightarrow J/\psi\phi K$
- ϕ meson dominant over the K^+K^- combinations
- One-to-one correspondence between B candidate and ϕ candidate
- Observation of good signal, small background

$B \to J/\psi\phi(K)$: fits for BF measurements

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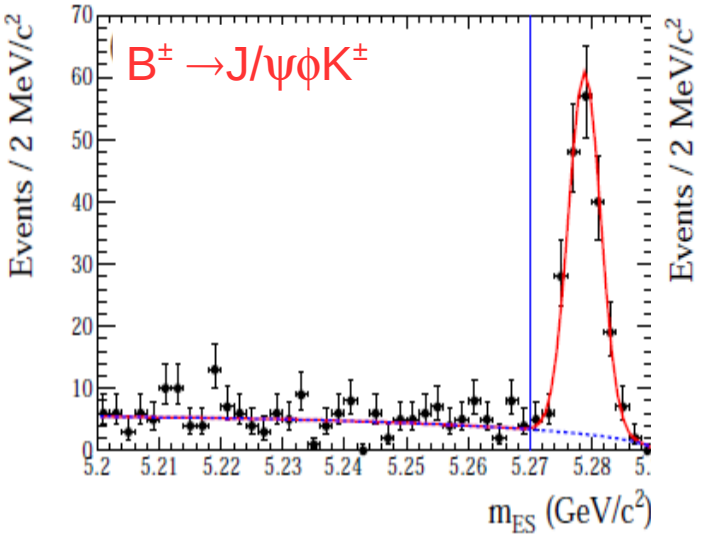

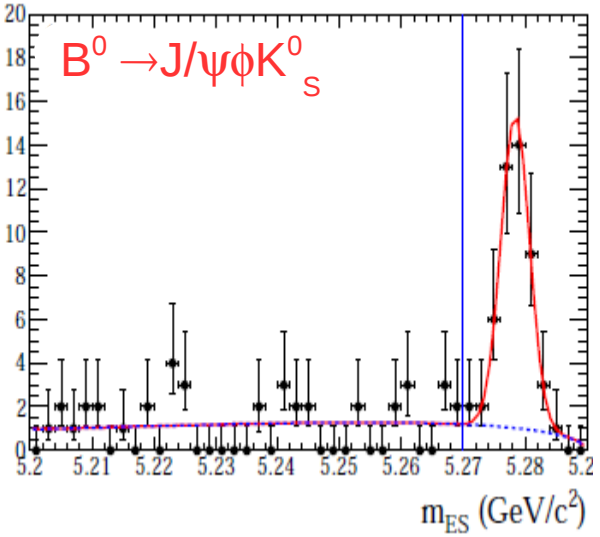

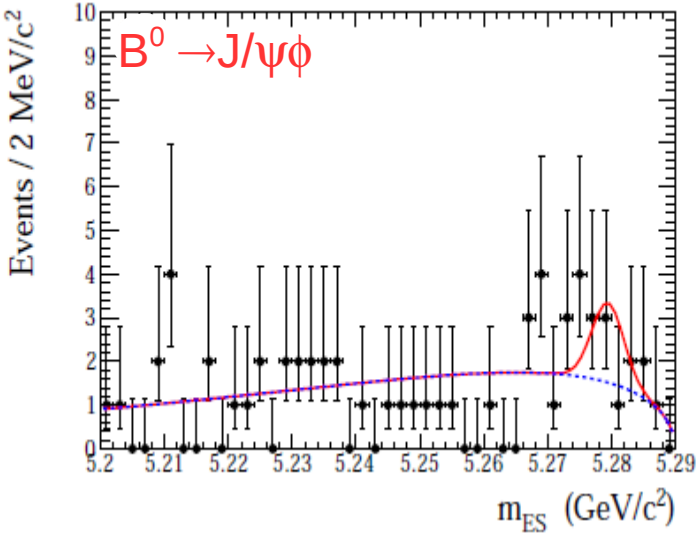

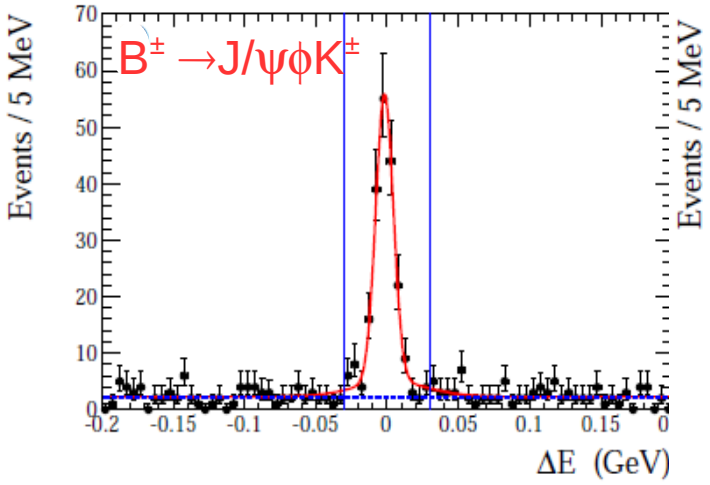

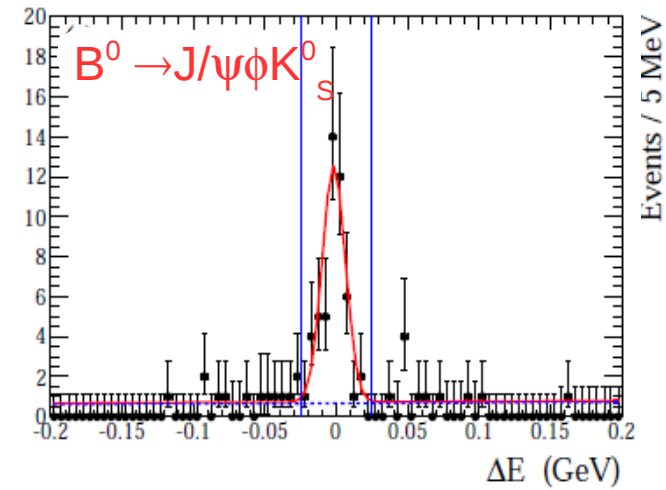

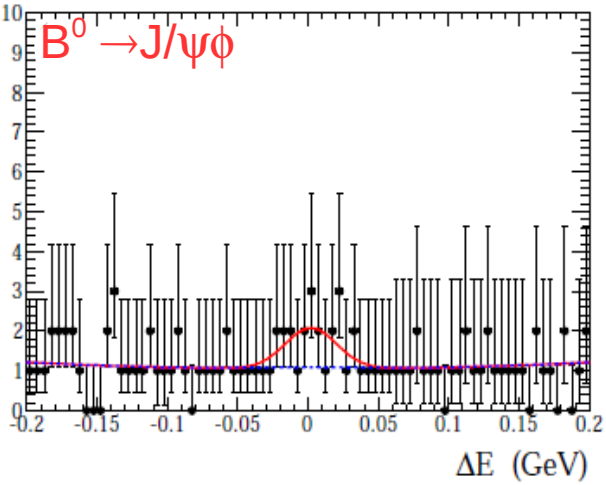

$B \to J/\psi KK(K)$: BF results

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TABLE I: Event yields, BF measurements ($\mathcal{B}$) and efficiencies (ϵ) for the different final states. The yields re-weighted by the average efficiency ($\bar{\epsilon}$) evaluated on PHSP MC distributions, and the yields re-weighted by the efficiency from the Dalitz plots (ϵ_D) are reported. BF measurements with the two different efficiency methods are compared for the channel $B^+ \to J/\psi K^+K^-K^+$ (B^+_{KKK}), $B^+ \to J/\psi\phi K^+$ ($B^+_{\phi K}$), $B^0 \to J/\psi K^-K^+K^0_S$ ($B^0_{KKK_S}$), and $B^0 \to J/\psi\phi K^0_S$ ($B^0_{\phi K_S}$). The $B^0 \to J/\psi\phi$ (B^0_ϕ) UL at 90% c.l. is listed at the end of the table.

B channel	Event yield	$\bar{\epsilon}$ (%)	Corrected yield ($\bar{\epsilon}$)	Corrected yield (ϵ_D)	Case A: $\mathcal{B}$ ($\times 10^{-5}$) calculated with $\bar{\epsilon}$	Case B: $\mathcal{B}$ ($\times 10^{-5}$) calculated with ϵ_D
B^+_{KKK}	290±22	17.96±0.04	1615±122	1904±144	5.86±0.44 (stat)±0.24 (sys)	6.91±0.52 (stat)±0.28 (sys)
$B^+_{\phi K}$	189±14	16.28±0.04	1161± 86	1396±103	4.21±0.31 (stat)±0.13 (sys)	5.06±0.37 (stat)±0.15 (sys)
$B^0_{KKK_S}$	68±13	11.31±0.04	586±115	639±125	3.07±0.59 (stat)±0.13 (sys)	3.35±0.66 (stat)±0.15 (sys)
$B^0_{\phi K_S}$	41± 7	10.73±0.04	382± 65	406± 69	2.00±0.34 (stat)±0.05 (sys)	2.13±0.36 (stat)±0.06 (sys)
B^0_ϕ	6 ± 4	31.12±0.07	19 ± 13	–	< 0.101	–

- The difference between the case A) and B) is due to the K^+K^- correction in the Dalitz structure

$B \to J/\psi KKK$: non-resonant contribution

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$$R_+ = \frac{\mathcal{B}(B^+ \to J/\psi K^+K^-K^+)}{\mathcal{B}(B^+ \to J/\psi \phi K^+)} = 1.39 \pm 0.15 \pm 0.07$$

$$R_0 = \frac{\mathcal{B}(B^0 \to J/\psi K^+K^-K^0_s)}{\mathcal{B}(B^0 \to J/\psi \phi K^0_s)} = 1.54 \pm 0.40 \pm 0.08$$

$$R_\phi = \frac{\mathcal{B}(B^0 \to J/\psi \phi K^0_s)}{\mathcal{B}(B^+ \to J/\psi \phi K^+)} = 0.48 \pm 0.09 \pm 0.02$$

$$R_{2K} = \frac{\mathcal{B}(B^0 \to J/\psi K^+K^-K^0_s)}{\mathcal{B}(B^+ \to J/\psi K^+K^-K^+)} = 0.52 \pm 0.09 \pm 0.03$$

- BFs in agreement with the prediction of the quark spectator model
- K^+K^- contribution to BFs outside the ϕ mass region: first measurement
- Old Babar measurement on $B \to J/\psi\phi K$ confirmed, now with >4 times precision
  ⇨ currently highest world precision of these BF measurements!

$B \to J/\psi KKK$: search for exotics

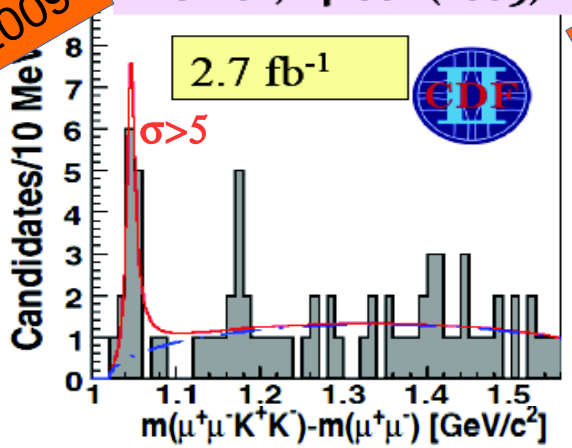
- Signal box selected: m_{ES}>5.27 GeV/c^2; |ΔE|<30 MeV ($B^{\pm}$) and |ΔE|<25 MeV (B^0)
- Mass resolution at the J/ψϕ threshold: 2 MeV/c^2
- Search for resonant states in J/ψKK, J/ψK, KKK
- J/ψϕ invariant mass gained more attention because of several recent publications
- J/ψ and ϕ are **vectors**: high spin contribution expected
- Efficiency as function of the invariant mass must be taken into account
- In our fit: mass and width fixed to the CDF values (first publication on res. structure)

Experiment	ref	$M_{X(4140)}$ [MeV/c^2]	$\Gamma_{X(4140)}$ [MeV]	
CDF	PRL102.242002(2009)	$4143.0 \pm 2.9 \pm 1.2$	$11.7^{+8.3}_{5.0} \pm 3.7$	OBSERVATION
CDF	arXiv:1101.6058	$4143.4^{+2.9}_{-3.0} \pm 0.6$	$15.2^{+10.4}_{6.1} \pm 2.5$	
LHCb	PRD85,091103(2012)	-	-	NO EVIDENCE
CMS	PRB734,261(2014)	$4148.0 \pm 2.4 \pm 6.3$	$28^{+15}_{-11} \pm 19$	OBSERVATION
D0	PRD89,012004(2014)	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6^{+1.0}_{-8.0}$	EVIDENCE
		$M_{X(4270)}$ [MeV/c^2]	$\Gamma_{X(4270)}$ [MeV]	
CDF	arXiv:1101.6058	$4274.4^{+8.4}_{-6.7} \pm 1.9$	$32.3^{+21.1}_{15.3} \pm 7.6$	EVIDENCE
LHCb	PRD85,091103(2012)	-	-	NO EVIDENCE
CMS	PRB734,261(2014)	$4313.8 \pm 5.3 \pm 7.3$	$38^{+30}_{-15} \pm 16$	OBSERVATION
D0	PRD89,012004(2014)	≈ 4360	30(*fixed*)	NO EVIDENCE, but BETTER FIT

The controversial picture of $m_{J/\psi\phi}$

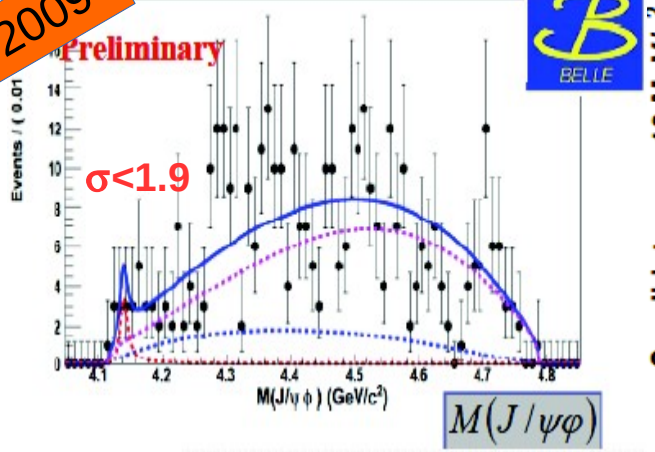
2009

PRL 102, 242002 (2009)



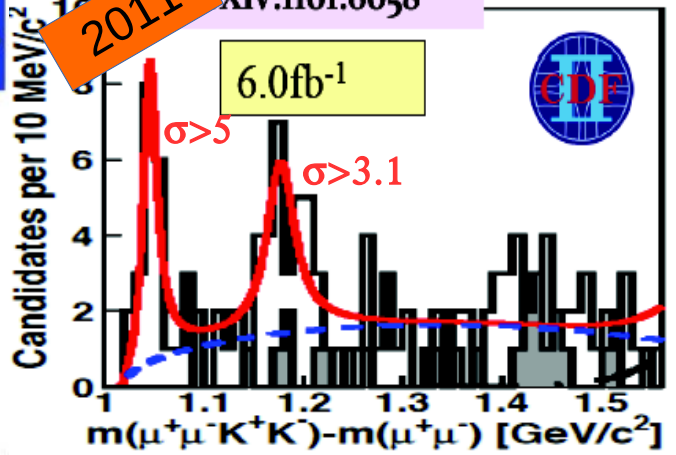
2009

Conference LP09



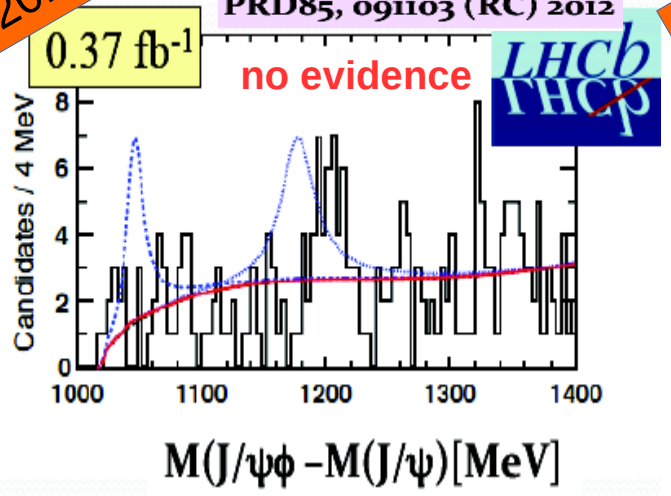
2011

Xiv:1101.6058



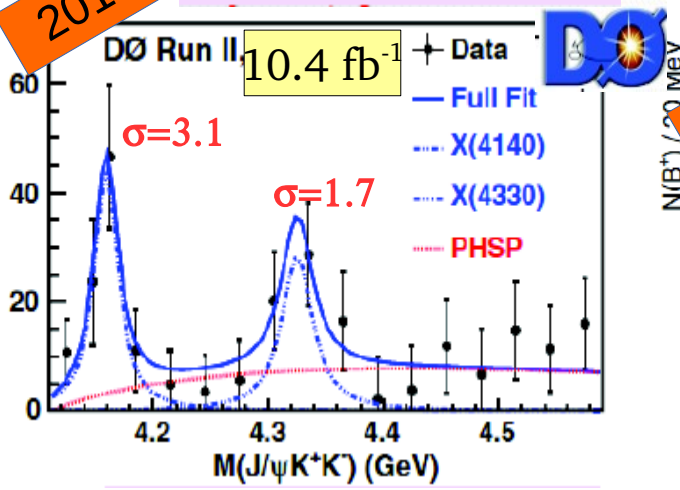
2012

PRD85, 091103 (RC) 2012



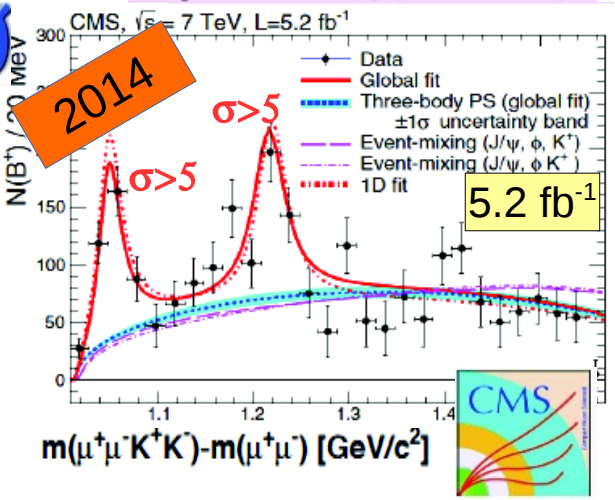
2014

PRD89, 012004 (2014)



2014

Phys. Lett. B 734, 261 (2014)



$B \to J/\psi\phi K$: reconstruction efficiency

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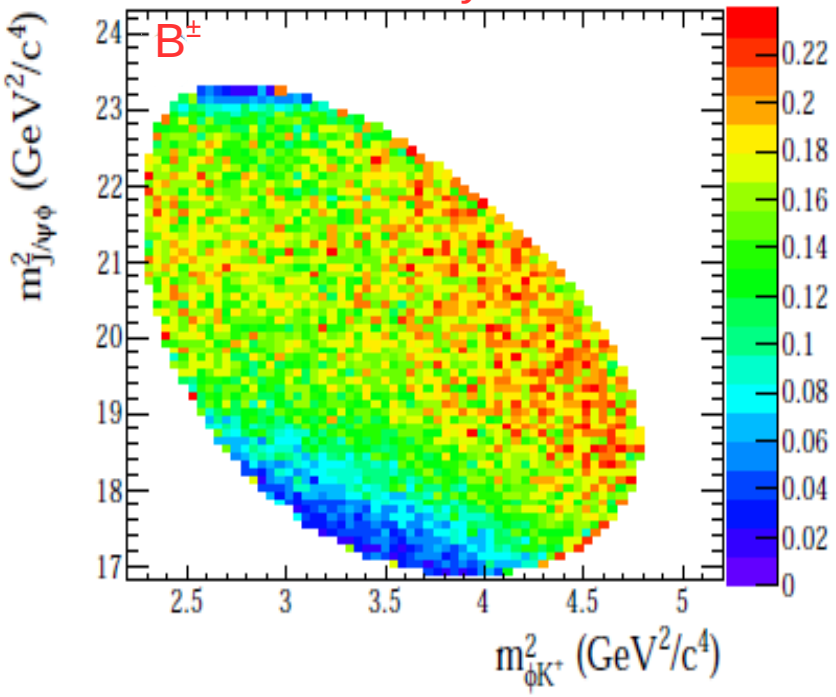
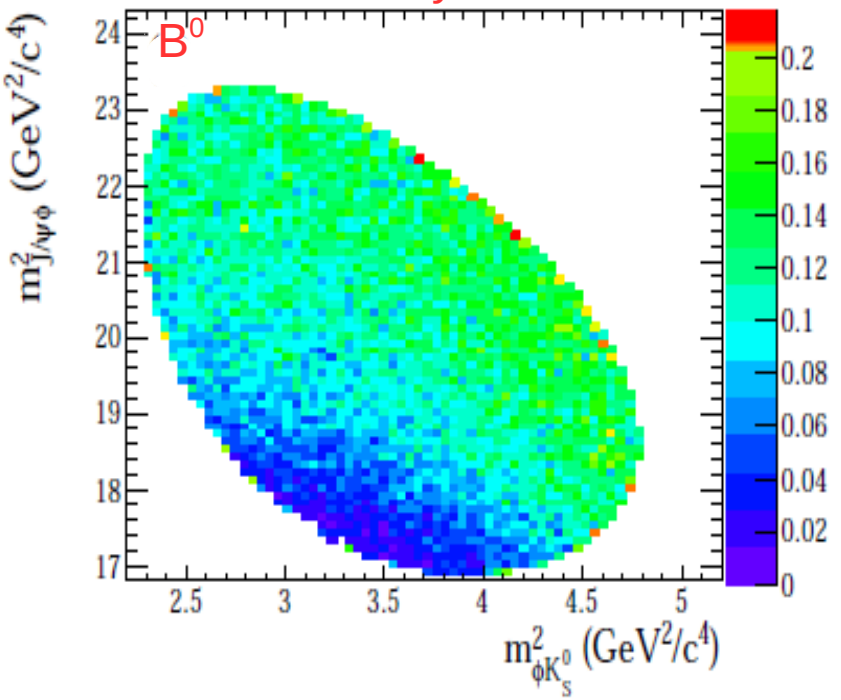
- Efficiency lower at the $J/\psi\phi$ mass threshold due to the difficulty to reconstruct low momentum kaon
- Charged B channel more sensitive to the efficiency change at the $J/\psi\phi$ threshold compared to B^0 channel, due to the poorer ϕ ($\to K^+K^-$)reconstruction

MC efficiency



MC efficiency



$B \to J/\psi\phi K$: invariant mass fit

- **Unbinned maximum likelihood fit**
- Central value and width of the Breit-Wigners are fixed in the fit
- 2 Breit-Wigner + PHSP function re-weighted by 2D-efficiency map from **Dalitz plots**
- Background estimated from ΔE sidebands

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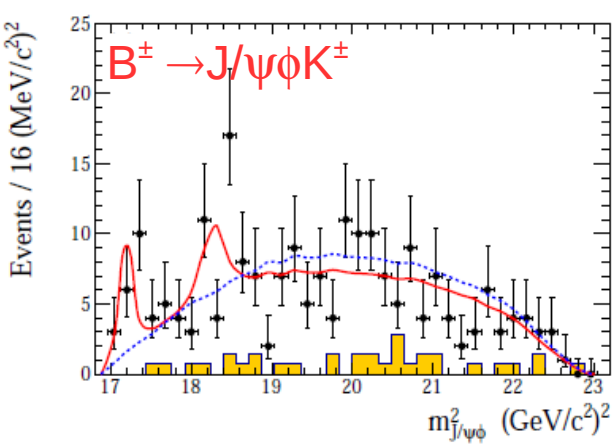
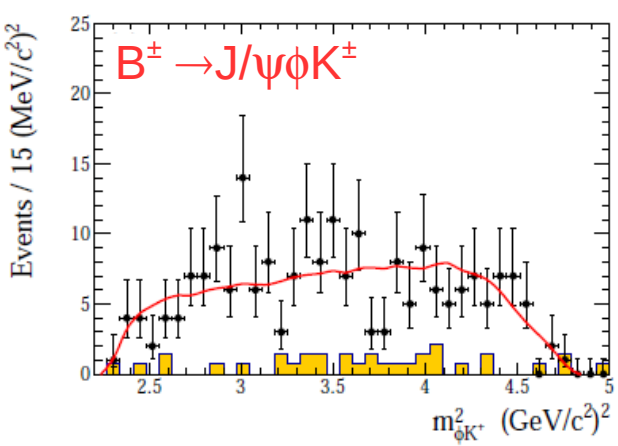
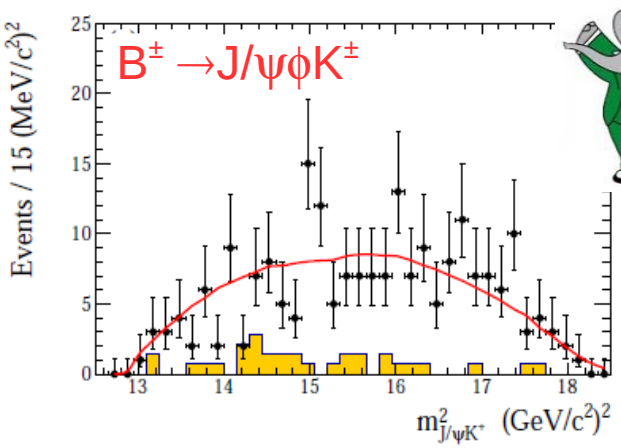
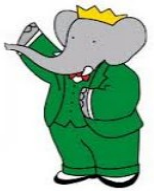
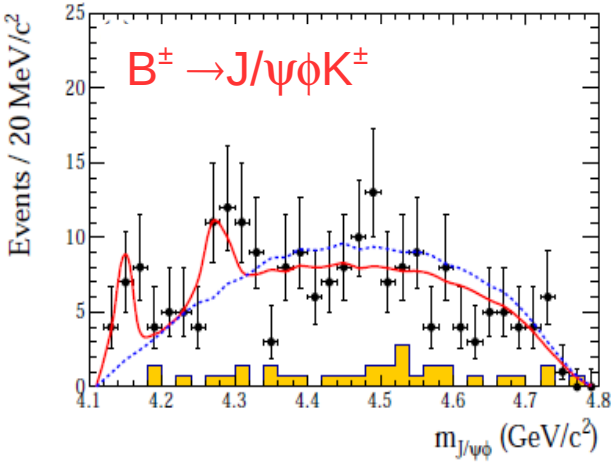
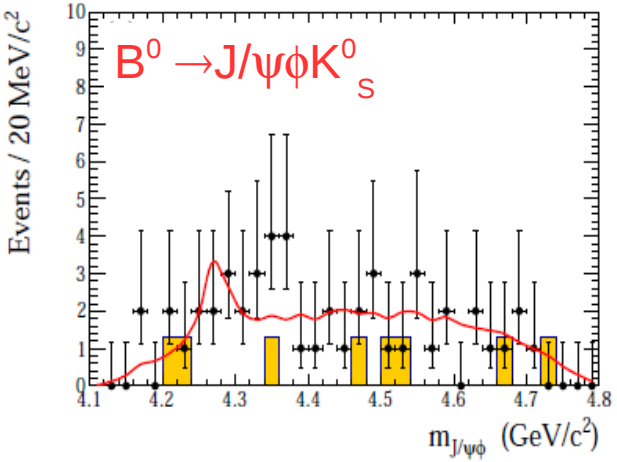


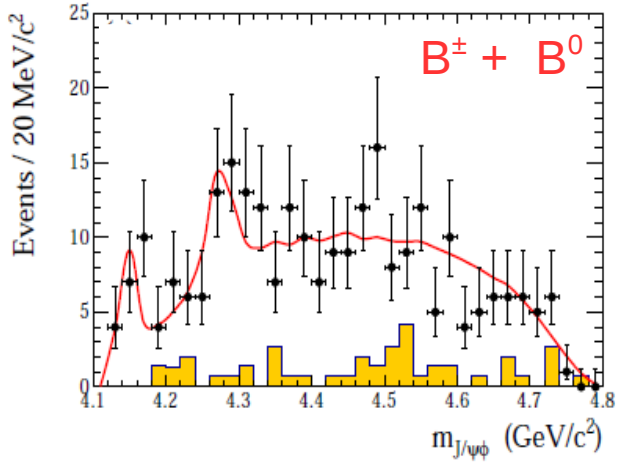












Background evaluated with ΔE sidebands

$B \to J/\psi\phi K$: mass fit results

Channel	Fit	$f_{X(4140)}(\%)$	$f_{X(4270)}(\%)$	2D χ^2/ν	1D χ^2/ν
B^+	A	9.2 ± 3.3	10.6 ± 4.8	12.7/12	6.5/20
	B	9.2 ± 2.9	0.	17.4/13	15.0/17
	C	0.	10.0 ± 4.8	20.7/13	19.3/19
	D	0.	0.	26.4/14	34.2/18
$B^0 + B^+$	A	7.3 ± 3.8	12.0 ± 4.9	8.5/12	15.9/19

arXiV: 1407.7244 [hep-ex]
Submitted to PRD

- These results are background corrected.
- Small background: purity 89% ($B^{\pm}$) and 82% (B^0)
- χ^2 of fits acceptable in all cases: no hypothesis should be rejected

Our fit:

– S-wave relativistic Breit-Wigners;

– non-resonant contribution represented by a constant term;

– no interference allowed between the fit components;

– small bkg from ΔE sidebands, consistent with PHSP behavior (incorporated in the non-resonant PHSP term);

– high spin contribution expected, but angular term non included due to poor statistics (we assume that the resonances decay isotropically)

fit without resonances (phase space): $\chi^2/\mathrm{ndof} = 26.4/14$

fit with two resonances (parameters fixed to CDF) : $\chi^2/\mathrm{ndof} = 12.7/12$

$f_{X(4140)} = (9.2 \pm 3.3 \pm 4.7)\%$, $f_{X(4270)} = (10.6 \pm 4.8 \pm 7.1)\%$ Parameters fixed to the CDF values PRL102,242002(2009)

$f_{X(4140)} = (13.2 \pm 3.8 \pm 6.8)\%$, $f_{X(4270)} = (10.9 \pm 5.2 \pm 7.3)\ \%$ Parameters fixed to the CMS values PLB734,261(2014)

$B \to J/\psi\phi K$: fractions

arXiV: 1407.7244 [hep-ex]
Submitted to PRD

$$\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\,\phi) / \mathcal{B}(B^+ \to J/\psi\,\phi K^+) < 0.135$$
$$\mathcal{B}(B^+ \to X(4270)K^+) \times \mathcal{B}(X(4270) \to J/\psi\,\phi) / \mathcal{B}(B^+ \to J/\psi\,\phi K^+) < 0.184$$

U.L. @ 90% c.l.

X(4140) and X(4270) on 422.5 fb^{-1} integrated luminosity: <2σ effect (within sys. uncertainties)

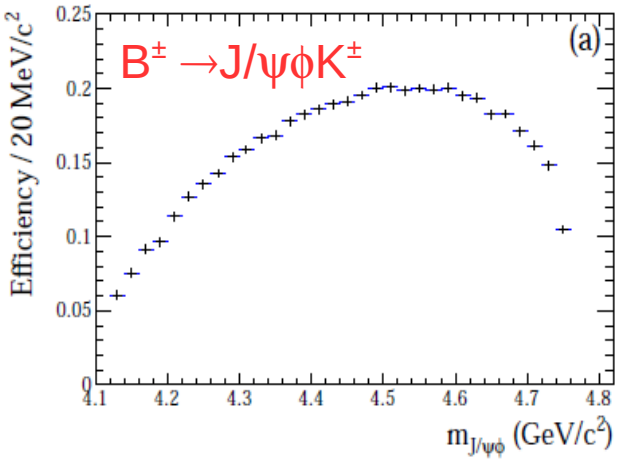
No additional structures are shown in the other invariant mass systems

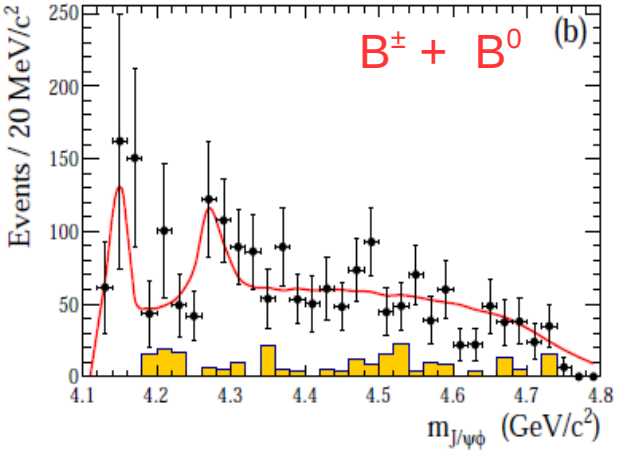
Experiment	ref	$f_{X(4140)}$ [%]
CDF	PRL102.242002(2009)	-
CDF	arXiv:1101.6058	$14.9 \pm 2.9 \pm 2.4$
LHCb	PRD85,091103(2012)	< 7
CMS	PRB734,261(2014)	13.4 ± 3.0
D0	PRD89,012004(2014)	$19 \pm 7 \pm 4$
		$f_{X(4270)}$ [%]
CDF	arXiv:1101.6058	-
LHCb	PRD85,091103(2012)	< 8
CMS	PRB734,261(2014)	18.0 ± 7.3
D0	PRD89,012004(2014)	-

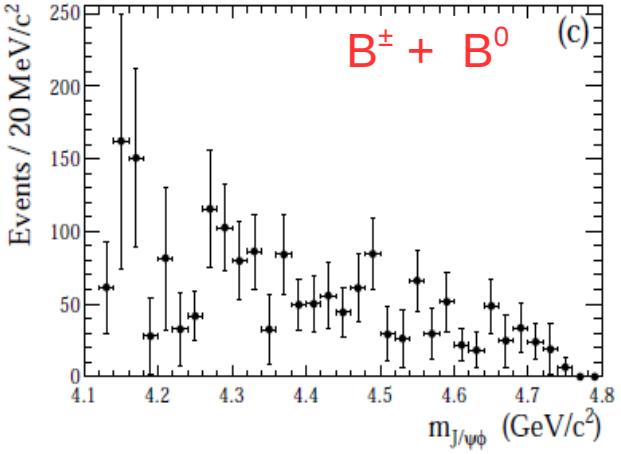
$B \to J/\psi\phi K$: BABAR re-weighted data

arXiV: 1407.7244 [hep-ex]
Submitted to PRD

- What happens if we re-weight data (not the fit function) by the Dalitz efficiency?







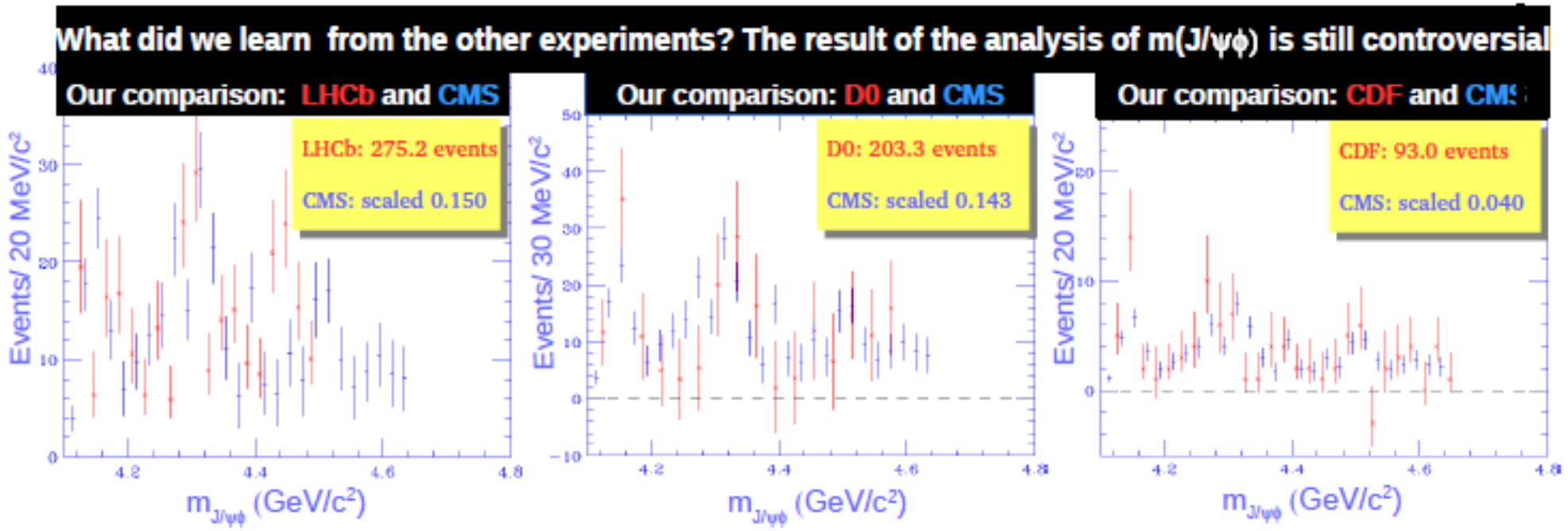
(a) Average efficiency distribution as a function of the $J/\psi\phi$ mass for $B^+ \to J/\psi\phi K^+$

(b) Efficiency corrected $J/\psi\phi$ for the combined B^+ and B^0 samples

(c) Efficiency corrected and background subtracted $J/\psi\phi$ mass spectrum for the combined B^+ and B^0 samples

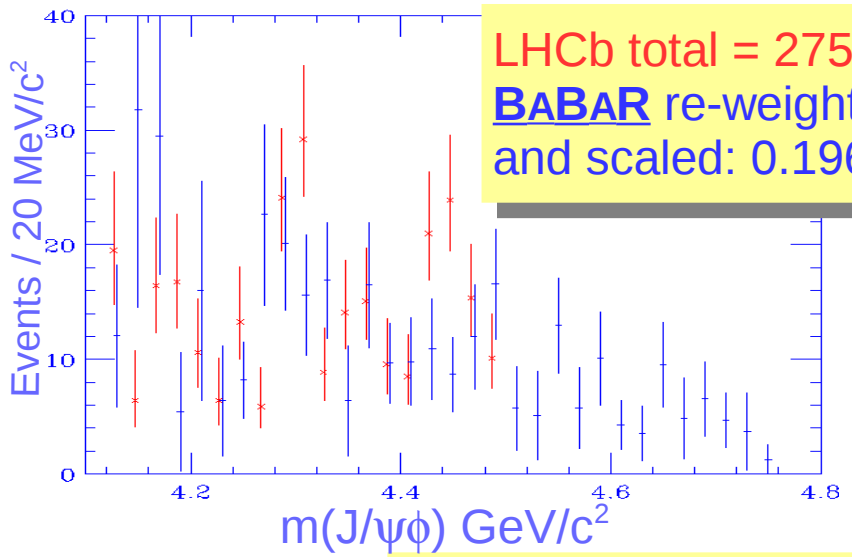
Significance < 2 σ within systematic uncertainties

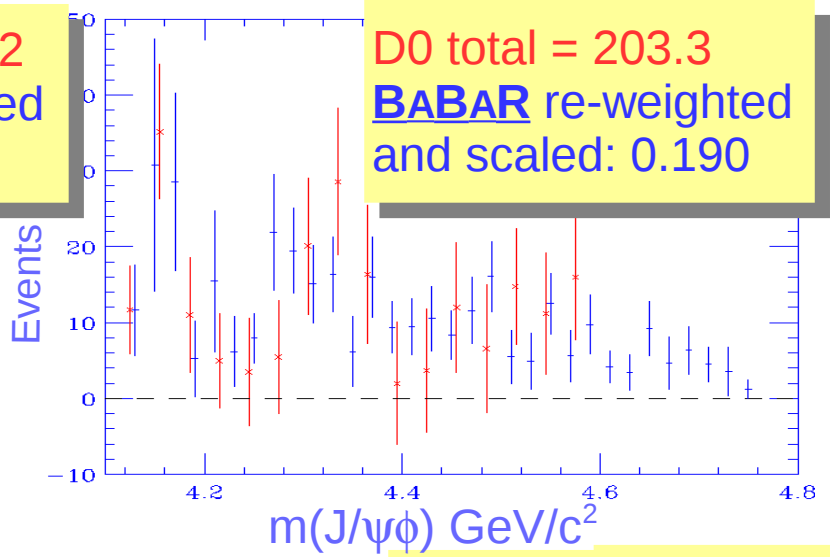
$B \rightarrow J/\psi\phi K$: comparison (I)

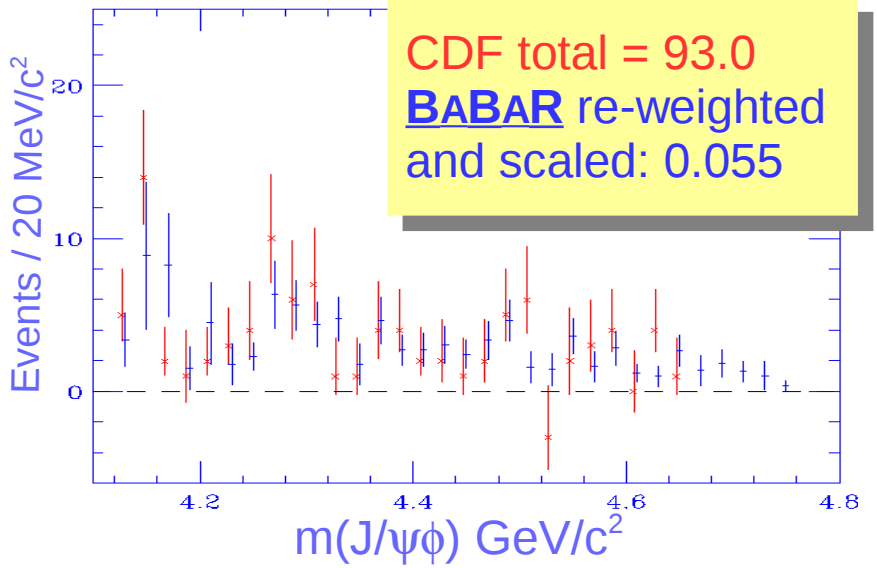


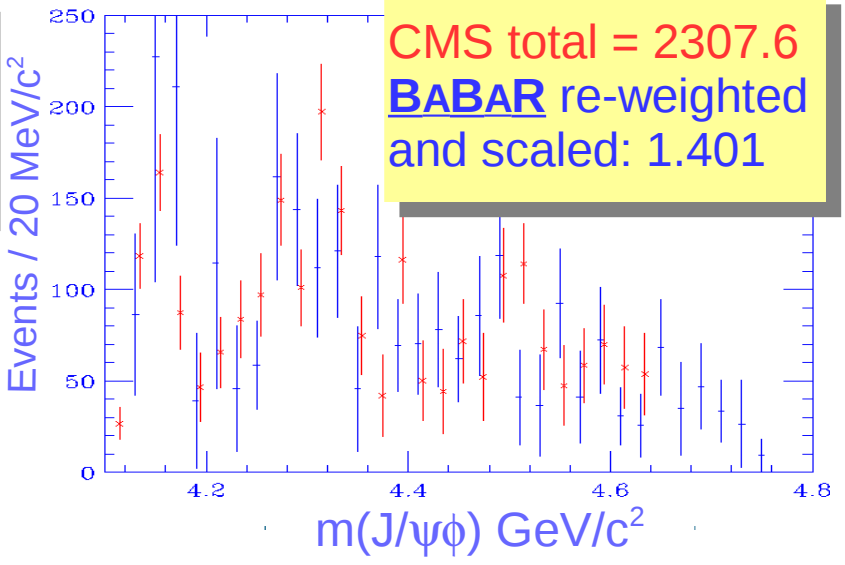
CDF Coll., PRL 102, 242002 (2009); LHCB Coll., PRD 85, 091103 (2010); D0 Coll., PRD 89, 012004 (2014); CMS Coll., PRB 734, 261 (2014)

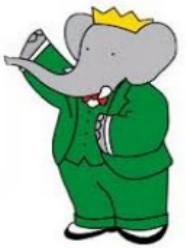
$B \to J/\psi\phi K$: comparison (II)





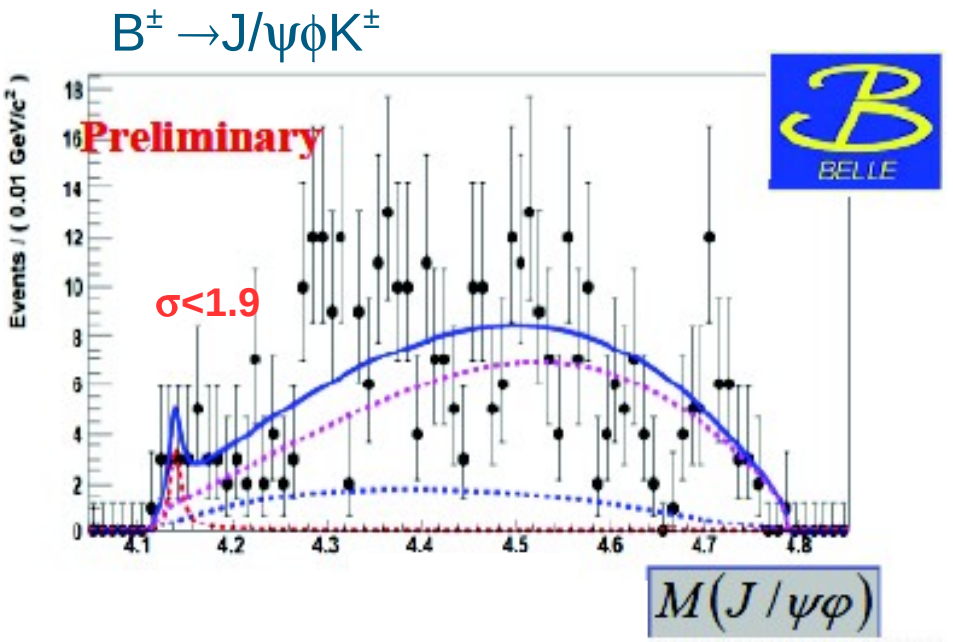


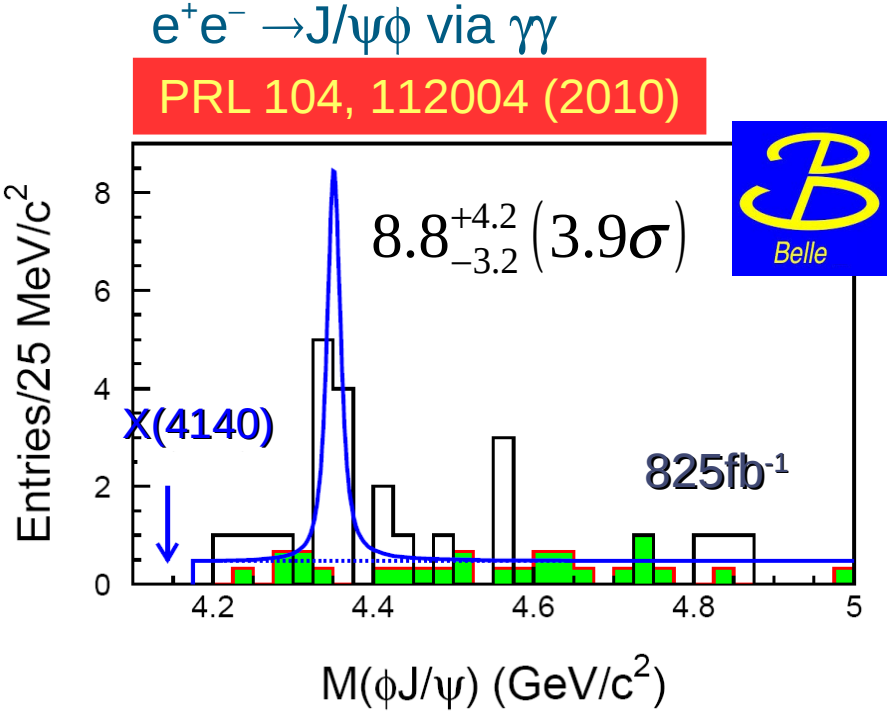




Note: BABAR re-weighed data ($B^0 + B^{\pm}$); other experiments: only $B^{\pm}$, only $J/\psi \to \mu\mu$

Search for exotics in m(J/ψφ) – Belle





No evidence for Y(4140) and/or Y(4270)!

...indeed hint of a new resonant state is found...

- X(4140) and X(4270), after 5 years of discussions and search in several modes, are <u>not observed in any other decay mode</u>, except m(J/ψφ) in B^+, with $J/\psi \to \mu^+\mu^-$ only

- <u>Not all experiments confirm</u> their observation, neither evidence in some cases. Are they real resonances?

Remarks on X(4140)

- No evidence in BABAR, in B decays, with $J/\psi \to e^+e^-$ and $\mu^+\mu^-$
- BABAR data reweighted by efficiency: $<2\sigma$ within systematic effects, on 469 M $B\bar{B}$
- THE BABAR UL is consistent with what was published from other experiments.
- BABAR and BELLE show the same efficiency behaviour at threshold of m($J/\psi\phi$): poorer ϕ reconstruction; in BABAR this effect is taken into account in the fit.
- No experiment shows additional decay mode for Y(4140) until now.

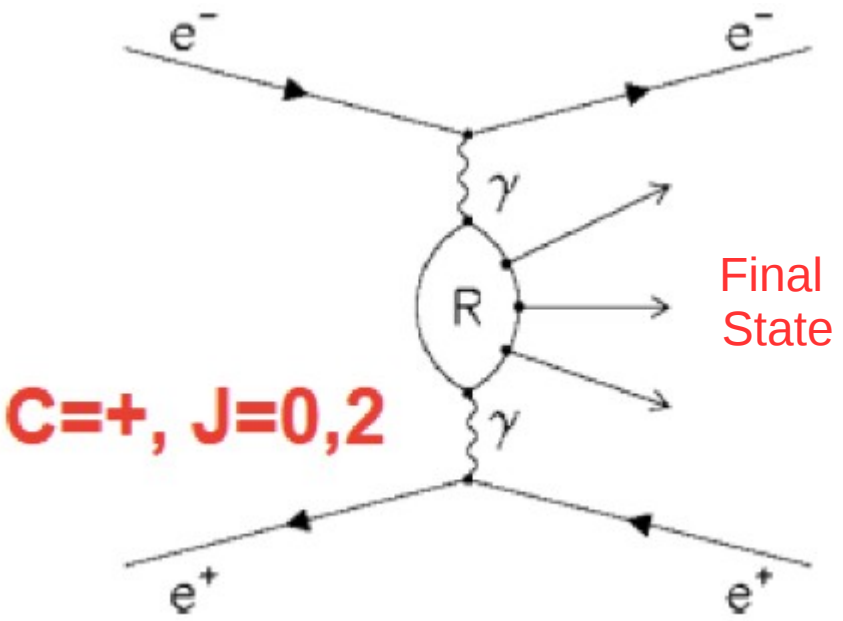
So:

- All experiments agree that the invariant mass system of $J/\psi\phi$ cannot be simply described by PHSP
- 2 vectors can be polarized: need full Dalitz analysis and higher statistics
- "*Enhancements*" does not mean only new resonant state!
  If real resonance, would expect to be seen in different decay modes

- B^+: controversial interpretation of data of the inv. mass distribution of $J/\psi\phi$;
- B^0: no evidence for Y(4140) and Y(4270) in BABAR and LHCb ($\rightarrow$x20 statistics)

Search for new resonances via $\gamma\gamma$ interactions

Dalitz analysis $\eta_c \to K^+K^-\eta/\pi^0$



- 2-photon interactions:
  e^+e^- interact and emit a quasi-real photon, which can form resonances.
- Clear signature: $J=0^{\pm},2^{\pm}$, ... ;
  the resonant state (if any) cannot be vector
- In BABAR resonant states are observed in 2-photon interactions: X(3915), ...
- Low p_t respect to the beam axis
- Final state emitted along the beam direction

- η_c(nS) decays not well known

$$\sum \mathcal{B}(\eta_c(1S)) \approx 20\%; \qquad \sum \mathcal{B}(\eta_c(2S)) \approx 5\%$$

- Advantage of this search in BaBar: large event yield
- Excellent S/B: non-resonant hadronic cross section is small

Search for exotic states in η_c decays

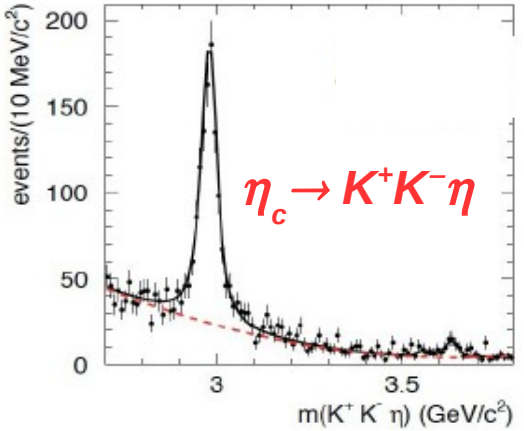
PRD 89, 112004 (2014)

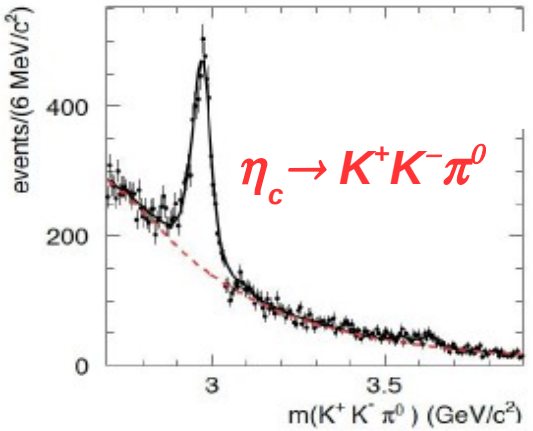
- BES III showed:
  - 6.7 ± 3.2 events for $\eta_c(nS) \to K^+K^-\eta$
  - 54.9 ± 9.2 events for $\eta_c(nS) \to K^+K^-\pi^0$

PRD 86 (2012) 010001

- No publication exists on Dalitz plot analysis of η_c to 3 pseudo-scalar mesons
  - $\eta_c(1S) \to K^+K^-\eta$: 1145 events
    First observation
  - $\eta_c(2S) \to K^+K^-\eta$: 47 events
    First evidence
  - $\eta_c(1S) \to K^+K^-\pi^0$: 4518 events
  - $\eta_c(2S) \to K^+K^-\pi^0$: 178 events

Resonance	Mass (MeV/c^2)	Γ (MeV)
$\eta_c \to K^+K^-\eta$	$2984.1 \pm 1.1 \pm 2.1$	$34.8 \pm 3.1 \pm 4.0$
$\eta_c \to K^+K^-\pi^0$	$2979.8 \pm 0.8 \pm 3.5$	$25.2 \pm 2.6 \pm 2.4$
$\eta_c(2S) \to K^+K^-\eta$	$3635.1 \pm 5.8 \pm 2.1$	11.3 (fixed)
$\eta_c(2S) \to K^+K^-\pi^0$	$3637.0 \pm 5.7 \pm 3.4$	11.3 (fixed)





BF measurements

PRD 89, 112004 (2014)

Channel	Event yield	Weights	$\mathcal{R}$	Significance
$\eta_c \to K^+K^-\pi^0$	$4518 \pm 131 \pm 50$	17.0 ± 0.7		$32\ \sigma$
$\eta_c \to K^+K^-\eta\ (\eta \to \gamma\gamma)$	$853 \pm 38 \pm 11$	21.3 ± 0.6		$21\ \sigma$
$\mathcal{B}(\eta_c \to K^+K^-\eta)/\mathcal{B}(\eta_c \to K^+K^-\pi^0)$			$0.602 \pm 0.032 \pm 0.065$	
$\eta_c \to K^+K^-\eta\ (\eta \to \pi^+\pi^-\pi^0)$	$292 \pm 20 \pm 7$	31.2 ± 2.1		$14\ \sigma$
$\mathcal{B}(\eta_c \to K^+K^-\eta)/\mathcal{B}(\eta_c \to K^+K^-\pi^0)$			$0.523 \pm 0.040 \pm 0.083$	
$\eta_c(2S) \to K^+K^-\pi^0$	$178 \pm 29 \pm 39$	14.3 ± 1.3		$3.7\ \sigma$
$\eta_c(2S) \to K^+K^-\eta$	$47 \pm 9 \pm 3$	17.4 ± 0.4		$4.9\ \sigma$
$\mathcal{B}(\eta_c(2S) \to K^+K^-\eta)/\mathcal{B}(\eta_c(2S) \to K^+K^-\pi^0)$			$0.82 \pm 0.21 \pm 0.27$	
$\chi_{c2} \to K^+K^-\pi^0$	$88 \pm 27 \pm 23$			$2.5\ \sigma$
$\chi_{c2} \to K^+K^-\eta$	$2 \pm 5 \pm 2$			$0.0\ \sigma$

η_c(1S)

$$\mathcal{R}(\eta_c) = \frac{\mathcal{B}(\eta_c \to K^+K^-\eta)}{\mathcal{B}(\eta_c \to K^+K^-\pi^0)} = 0.571 \pm 0.025 \pm 0.051$$

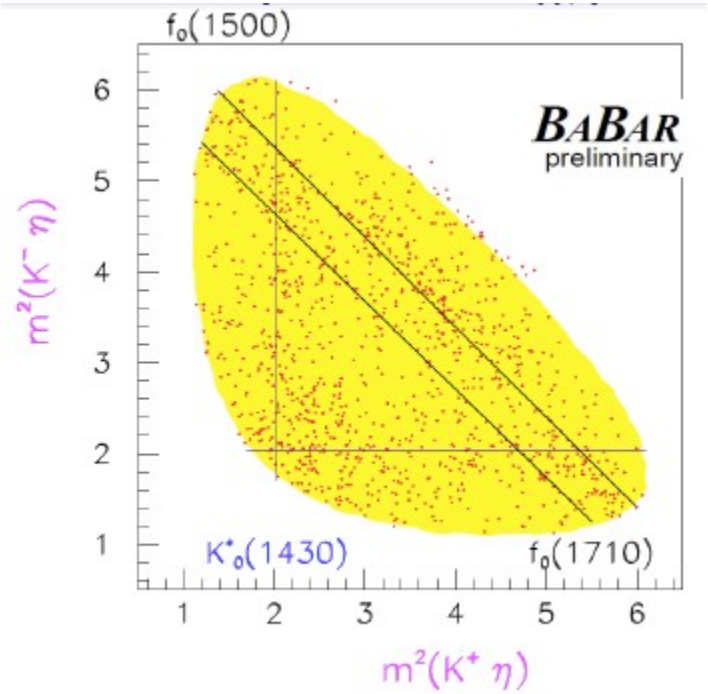
BESIII: 0.46 ± 0.24

η_c(2S)

$$\mathcal{R}(\eta_c(2S)) = \frac{\mathcal{B}(\eta_c(2S) \to K^+K^-\eta)}{\mathcal{B}(\eta_c(2S) \to K^+K^-\pi^0)} = 0.82 \pm 0.21 \pm 0.27$$

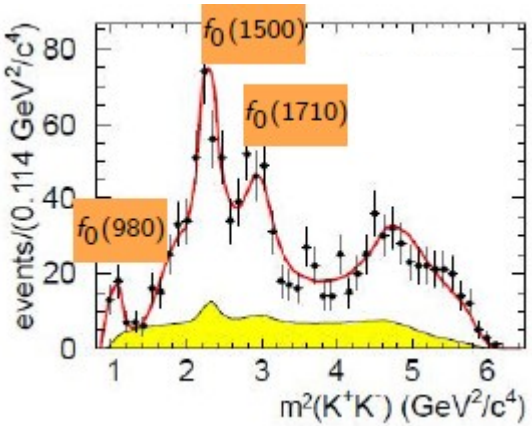
Dalitz plot: $\eta_c(1S) \rightarrow K^+K^-\eta$

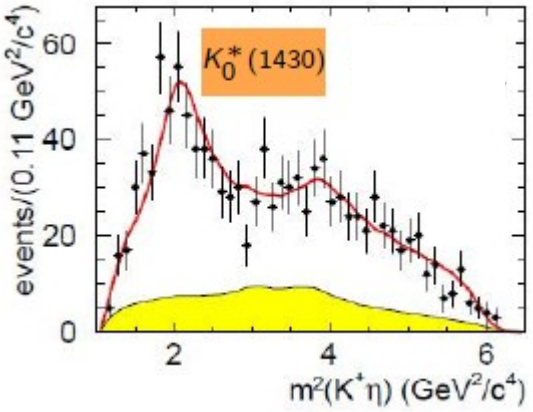
PRD 89, 112004 (2014)

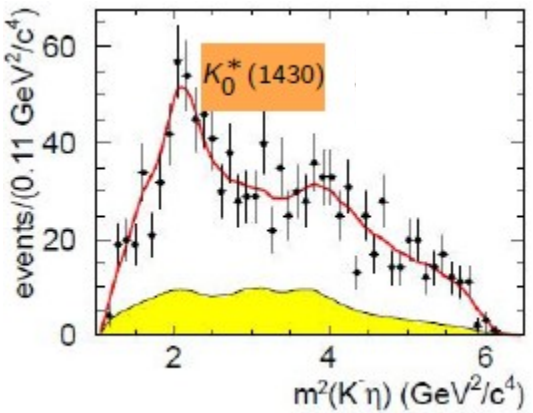


Final state	Fraction %	Phase (radians)
$f_0(1500)\eta$	$23.7 \pm 7.0 \pm 1.8$	0.
$f_0(1710)\eta$	$8.9 \pm 3.2 \pm 0.4$	$2.2 \pm 0.3 \pm 0.1$
$K_0(1430)^+K^-$	$16.4 \pm 4.2 \pm 1.0$	$2.3 \pm 0.2 \pm 0.1$
$f_0(2200)\eta$	$11.2 \pm 2.8 \pm 0.5$	$2.1 \pm 0.3 \pm 0.1$
$K_0^*(1950)^+K^-$	$2.1 \pm 1.3 \pm 0.2$	$-0.2 \pm 0.4 \pm 0.1$
$f_2'(1525)\eta$	$7.3 \pm 3.8 \pm 0.4$	$1.0 \pm 0.1 \pm 0.1$
$f_0(1350)\eta$	$5.0 \pm 3.7 \pm 0.5$	$0.9 \pm 0.2 \pm 0.1$
$f_0(980)\eta$	$10.4 \pm 3.0 \pm 0.5$	$-0.3 \pm 0.3 \pm 0.1$
NR	$15.5 \pm 6.9 \pm 1.0$	$-1.2 \pm 0.4 \pm 0.1$
Sum	$100.0 \pm 11.2 \pm 2.5$	
χ^2/ν	87/65	

$f_0(1500)$ and $f_0(1710)$ gluonium candidates



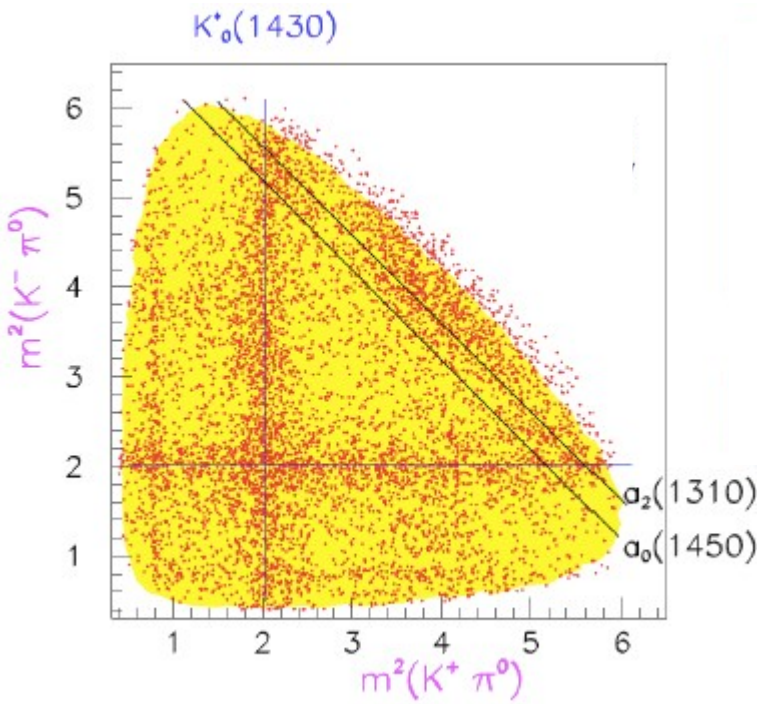




First evidence of $K_0^*(1430)^\pm \rightarrow K^\pm\eta$ seen as a peak

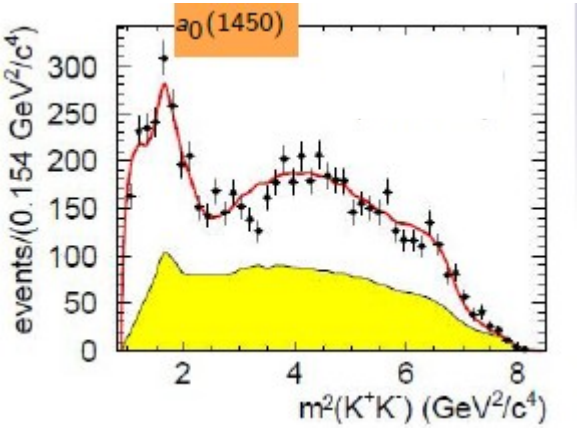
Dalitz plot: $\eta_c(1S) \rightarrow K^+K^-\pi^0$

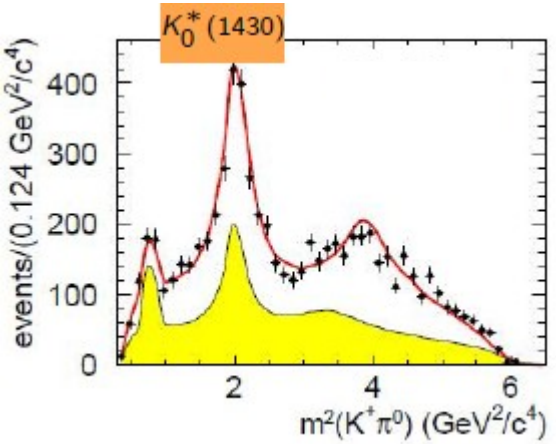
PRD 89, 112004 (2014)

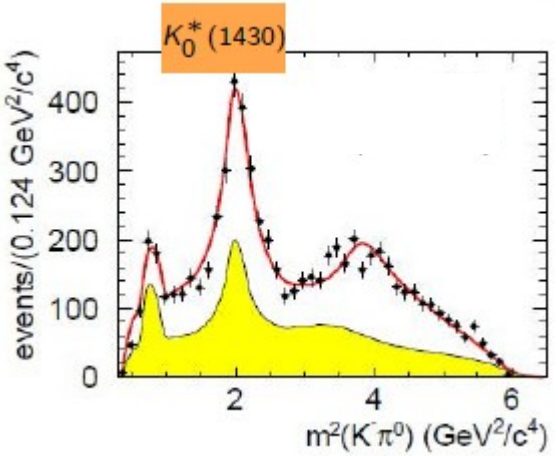


Final state	Fraction %	Phase (radians)
$K_0^*(1430)^+K^-$	$33.8 \pm 1.9 \pm 0.4$	0.
$K_0^*(1950)^+K^-$	$6.7 \pm 1.0 \pm 0.3$	$-0.67 \pm 0.07 \pm 0.03$
$a_0(980)\pi^0$	$1.9 \pm 0.1 \pm 0.2$	$0.38 \pm 0.24 \pm 0.02$
$a_0(1450)\pi^0$	$10.0 \pm 2.4 \pm 0.8$	$-2.4 \pm 0.05 \pm 0.03$
$a_2(1320)\pi^0$	$2.1 \pm 0.1 \pm 0.2$	$0.77 \pm 0.20 \pm 0.04$
$K_2^*(1430)^+K^-$	$6.8 \pm 1.4 \pm 0.3$	$-1.67 \pm 0.07 \pm 0.03$
NR	$24.4 \pm 2.5 \pm 0.6$	$1.49 \pm 0.07 \pm 0.03$
Sum	$85.8 \pm 3.6 \pm 1.2$	
χ^2/ν	212/130	

$K^{\pm}\pi^0$ dominated by $K_0^*(1430)$

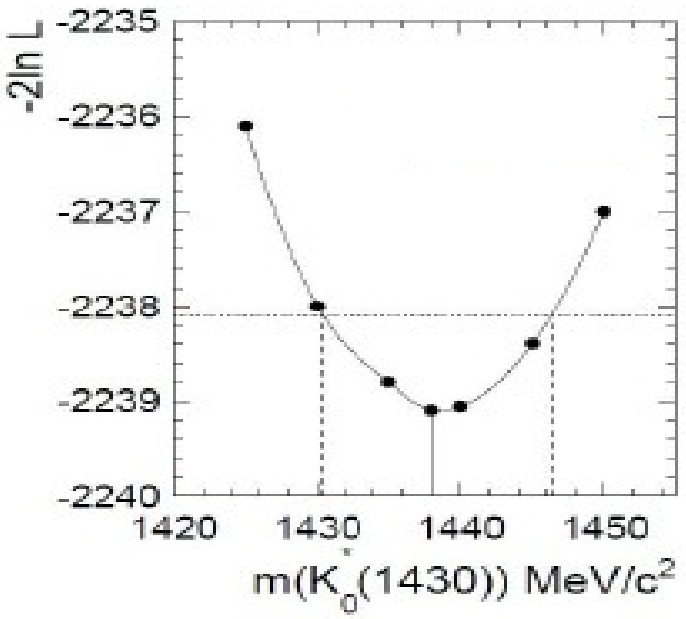






$K_0^*(1430)$ properties

PRD 89, 112004 (2014)

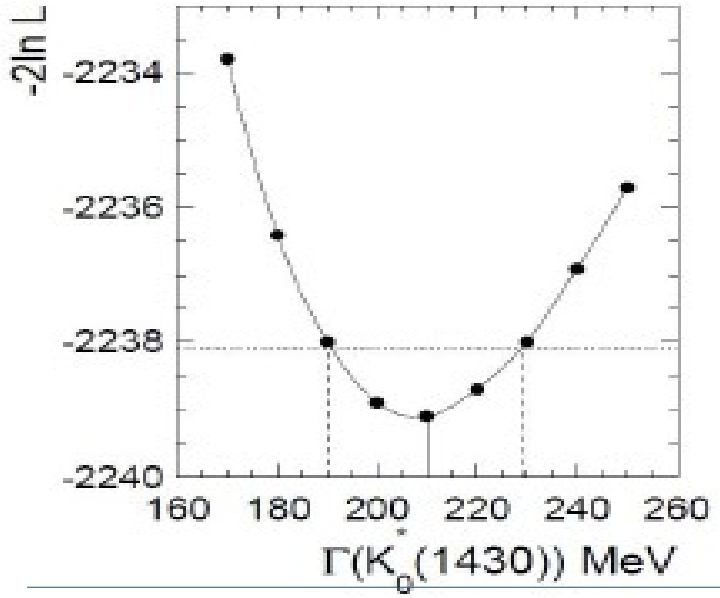


- $M = 1438 \pm 8 \pm 4\ \mathrm{MeV}/c^2$
  in agreement with LASS

  Nucl. Phys. B 296 (1988) 493

- $\Gamma = 210 \pm 20 \pm 12\ \mathrm{MeV}$
  $\approx 3\sigma$ smaller than LASS result

  294±23 LASS
  270±80 (PDG average)



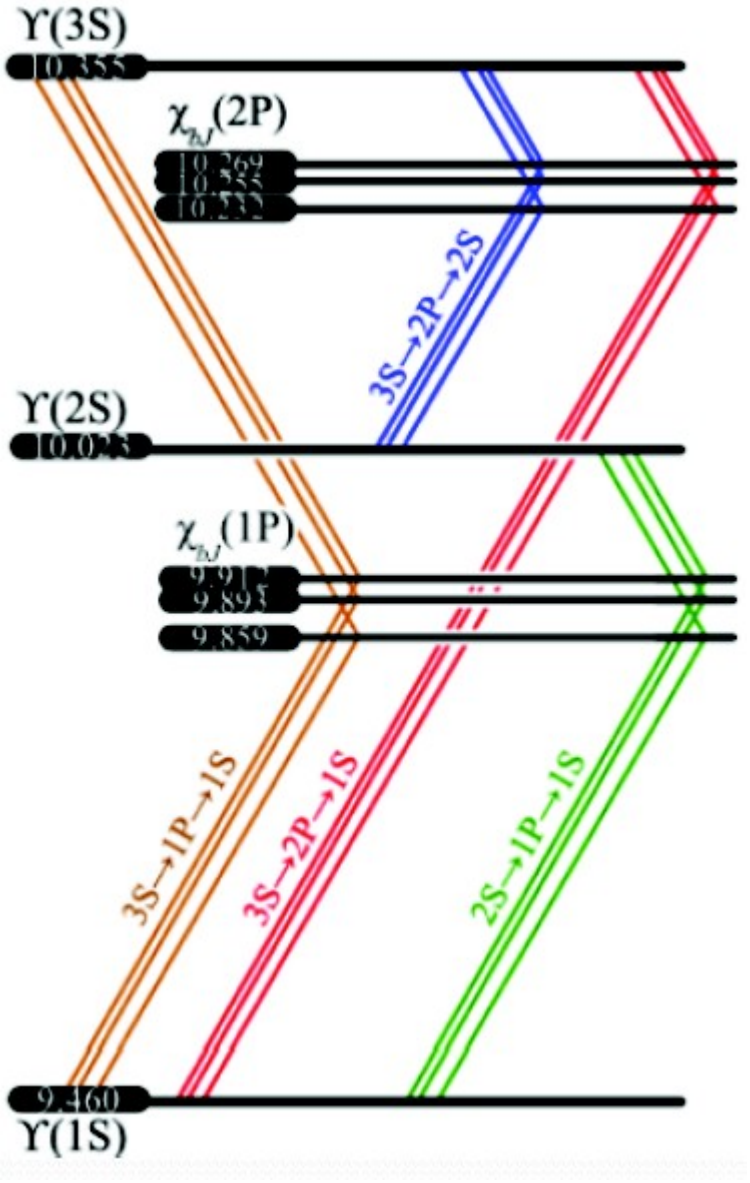
- $\frac{\mathcal{B}(K_0^* \to \eta K)}{\mathcal{B}(K_0^* \to \pi K)} = 0.092 \pm 0.025^{+0.010}_{-0.025}$

Implication: pseudoscalarmeson mixing angle is calculated as $\theta_p = (3.1^{+3.3}_{-5.0})^o$

It differs 2.9σ from the result obtained from $K^*_0(1430)$ BR.

Radiative Y(nS) transitions

Radiative $\Upsilon(nS)$ decays: motivation



- Generally well predicted from phenomenological models PRD 84 (2011) 094501
- Measure BF and mass splitting for radiative transition using BaBar $\Upsilon(2S)$ and $\Upsilon(3S)$ data

  BaBar sample: 14 fb^{-1} $\Upsilon(2S)$; 28 fb^{-1} $\Upsilon(3S)$
- Analysis measure:

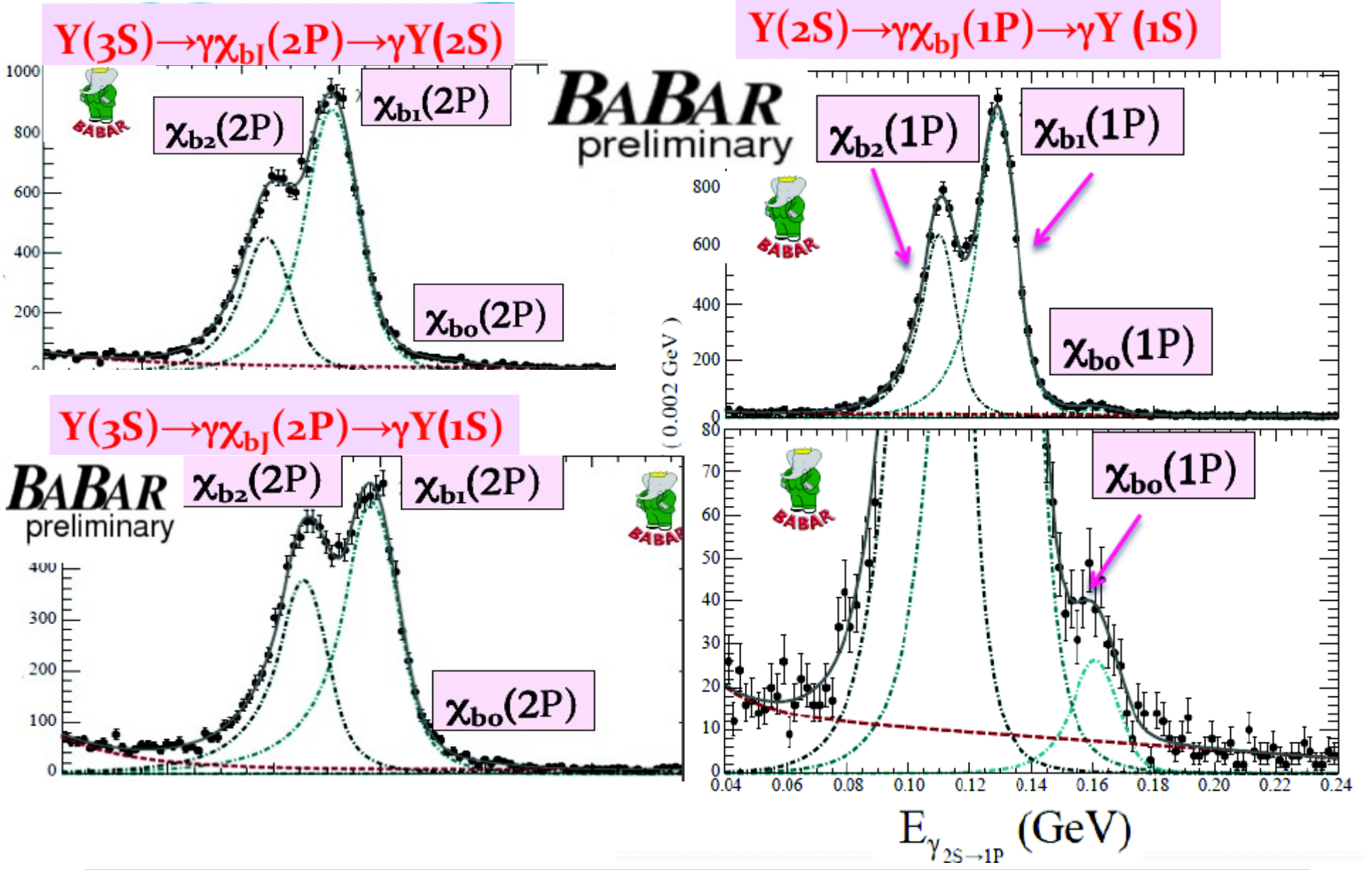
$\Upsilon(3S) \to \gamma\chi_{bJ}(2P), \chi_{bJ}(2P) \to \gamma\Upsilon(1S,2S)$
$\Upsilon(1S,2S) \to \mu^+\mu^-$ **3S→2P→1S, 3S→2P→1S**

$\Upsilon(2S) \to \gamma\chi_{bJ}(1P), \chi_{bJ}(1P) \to \gamma\Upsilon(1S), \Upsilon(1S) \to \mu^+\mu^-$
2S→1P→1S

$\Upsilon(3S) \to \gamma\chi_{bJ}(1P), \chi_{bJ}(1P) \to \gamma\Upsilon(1S), \Upsilon(1S) \to \mu^+\mu^-$
3S→1P→1S

- Event samples:
  - 2 calorimeter photons;
  - 1 calorimenter γ, one γ from conversion

2 calorimeter photons



1 γ from conversion, 1 γ from calorimeter

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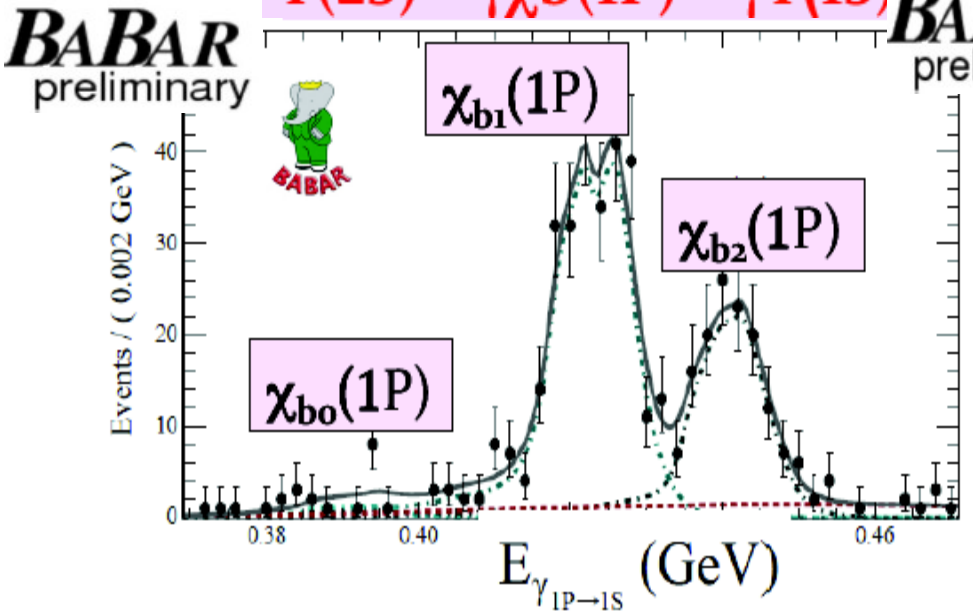
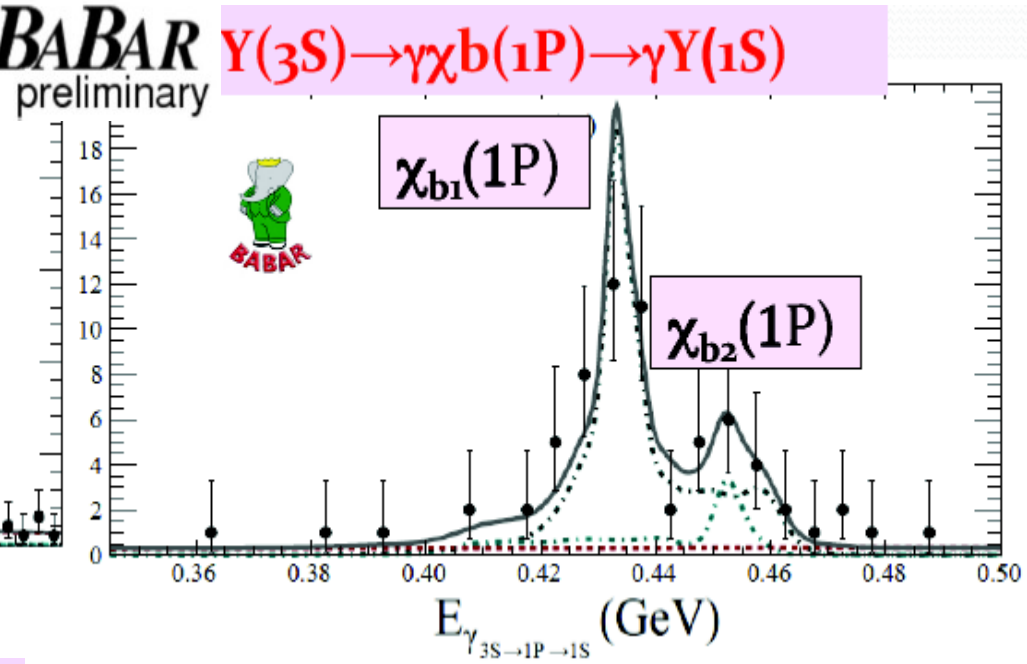
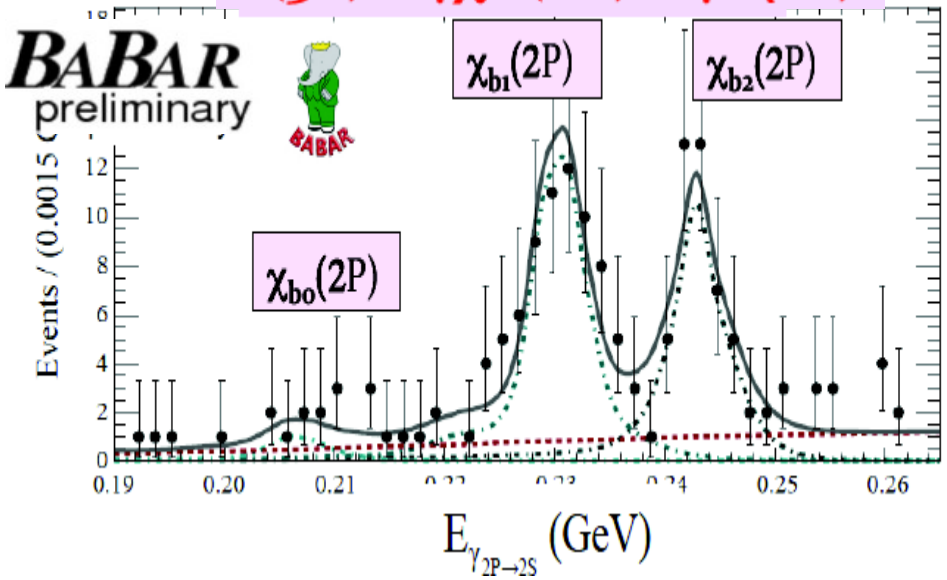
Υ(2S)→γχb(1P)→γΥ(1S)



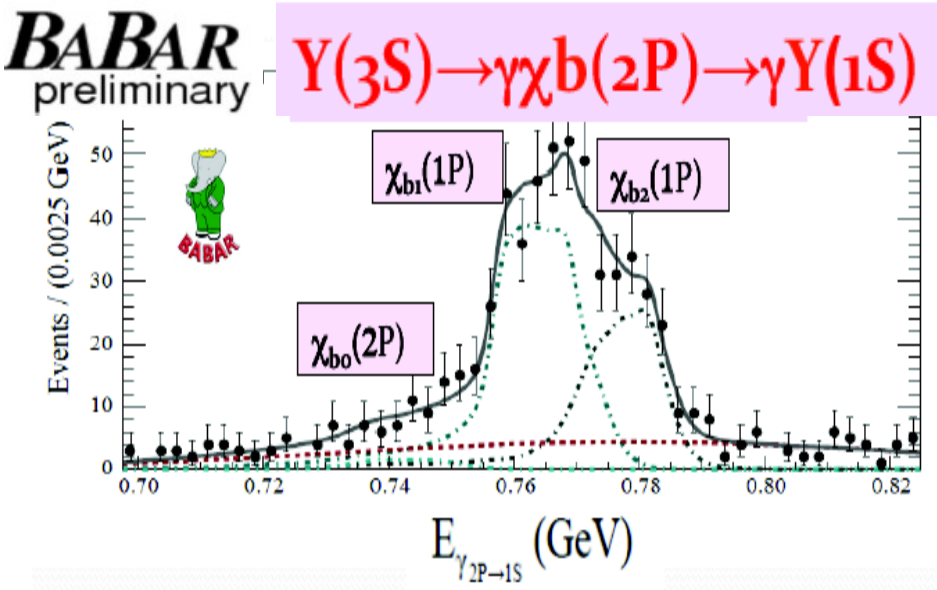
Υ(3S)→γχb(1P)→γΥ(1S)



Υ(3S)→γχb(2P)→γΥ(2S)



Υ(3S)→γχb(2P)→γΥ(1S)



Summary

- New exciting results from BABAR in charmonium and bottomonium spectroscopy

- Search for hybrids in the B decays: $B^{\pm,0} \rightarrow J/\psi KKK^{\pm,0}$ (charged and neutral B)
  All K^+K^- inv mass range under exam for the first time: no main structure is evident
  K^+K^- inv mass restricted to ϕ meson in [1.004;1.034] GeV/c^2:
  - $J/\psi K$ and KKK systems PHSP distributed;
  - $J/\psi\phi$ system shows a non-PHSP behaviour
- Search for X(4140) and X(4270) in $J/\psi\phi$ inv mass system: no evidence.
- UL are set up compatible with what published from other experiments.
- Interpretation of $J/\psi\phi$ inv mass system is difficult, because:
  - dynamics of J/ψ and ϕ (vectors) interaction is complicated: full Dalitz analysis needed;
  - different hypotheses for explaining the presence of a non-PHSP behavior at the threshold.
- Currently highest world precision in BR and UL measurements.
- Non resonant K^+K^- contribution to the BF of $B \rightarrow J/\psi KKK$: first measurement

- First observation of $K_0^*(1430)$ in the Dalitz analysis of $\eta_c \rightarrow KK\eta/\pi^0$ via $\gamma\gamma$ interaction

- Best evidence for $\chi_{bJ}(nP) \rightarrow \gamma\Upsilon$ transition

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Thank you for your attention!

Back up slides

$B \to J/\psi\phi K$: comparison

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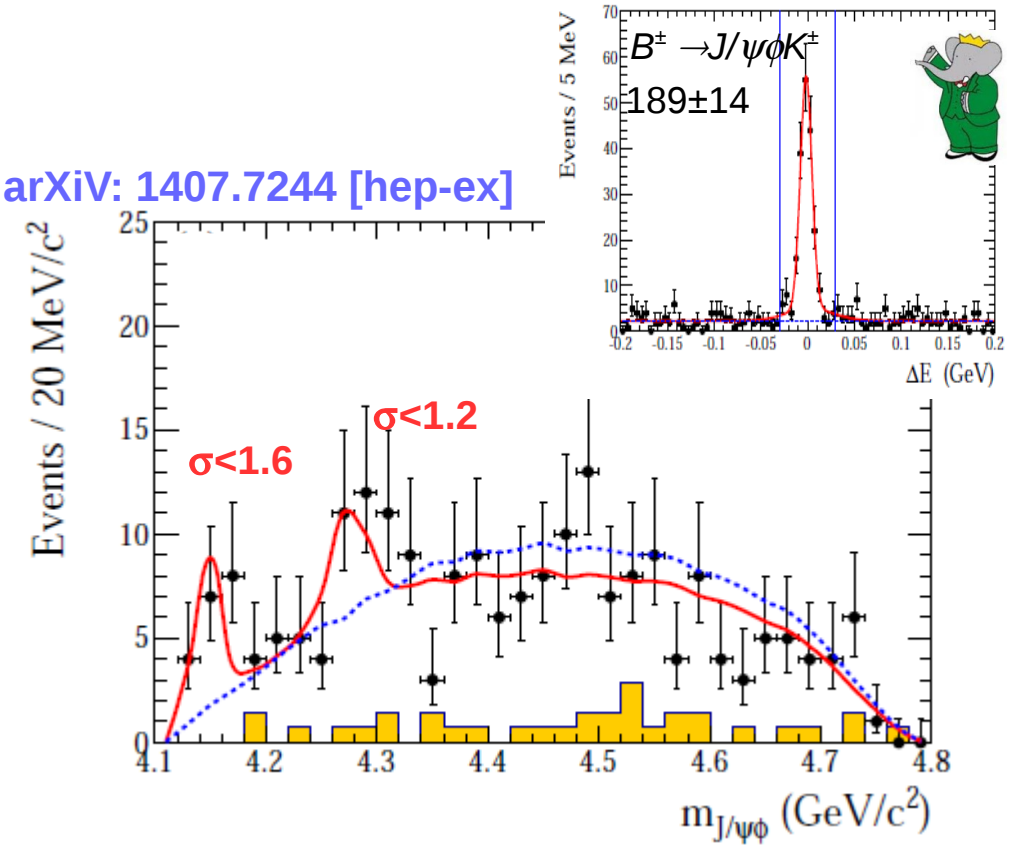
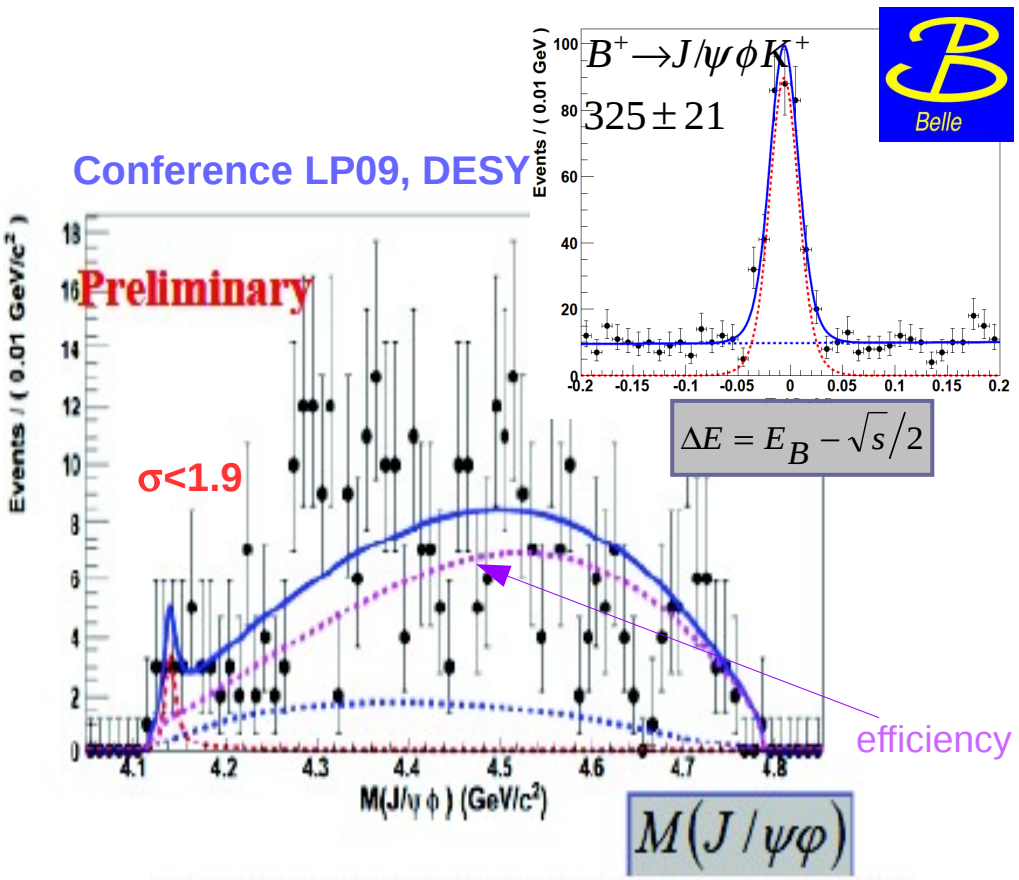


Conference LP09, DESY



NOTE: Significance is evaluated after re-weighting *pdf* by 2D-efficiency + systematic uncertainties are included

$Br(B^+ \to X(4140)K^+, X \to J/\psi\phi) < 5.7 \times 10^{-6}$ @90%*C.L.*

$Br(B^+ \to X(4140)K^+, X \to J/\psi\phi) < 6 \times 10^{-6}$ @90%*C.L.*

Consistency!