New Results in Charmonium

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Outline

- **Study of $B^{0,\pm} \rightarrow J/\psi K^+K^-K_s^{0,\pm}$ and search for structure in the $J/\psi\phi$ system**

NEW BABAR RESULT SOON WILL BE SUBMITTED TO THE ARXiv

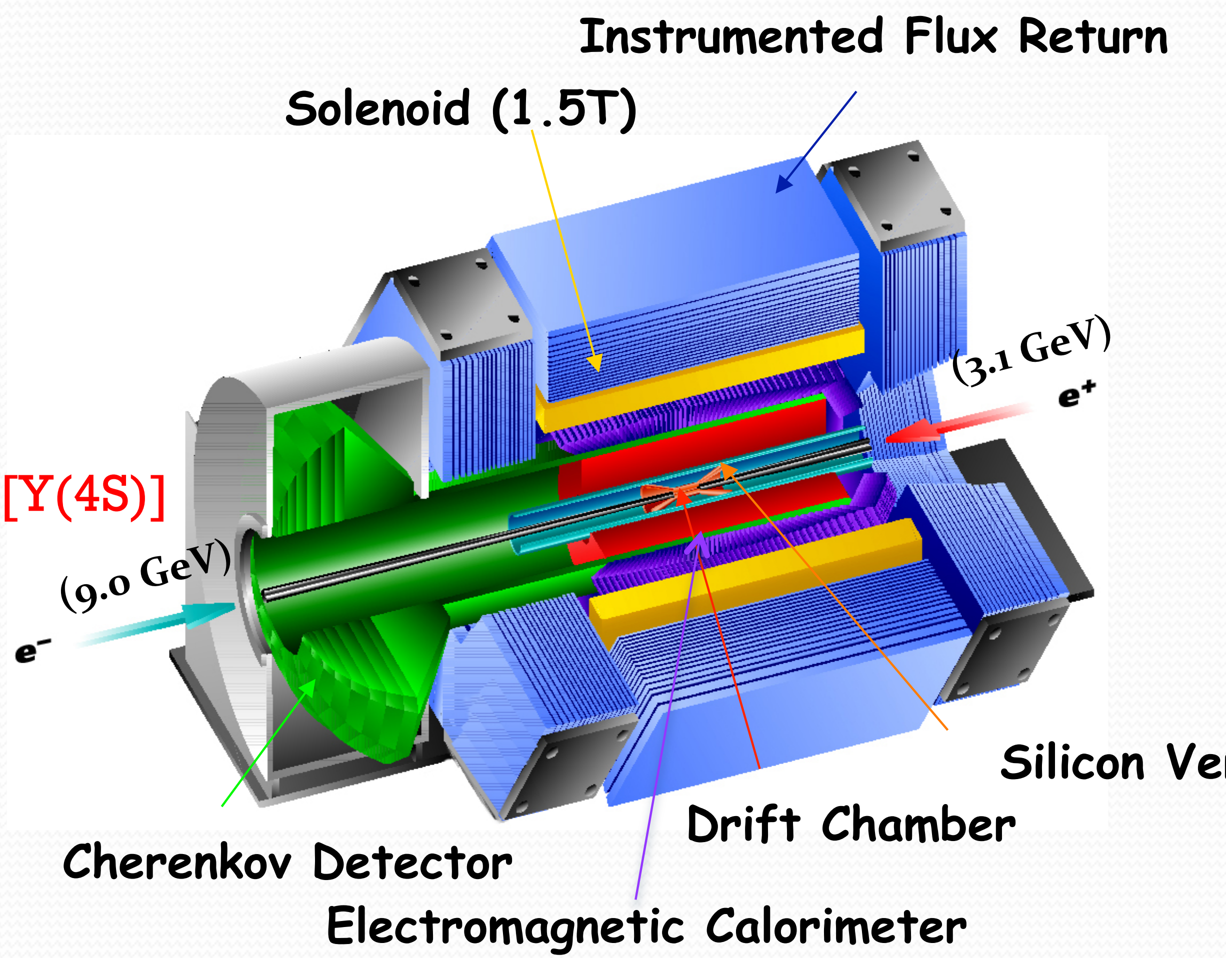
- **Dalitz plot analysis of $\eta_c \rightarrow K^+K^-\eta$ and $\eta_c \rightarrow K^+K^-\pi^0$ in two-photon interactions**

NEW BABAR RESULT SOON WILL BE SUBMITTED TO THE ARXiv

The BaBar detector and data sample

BaBar is a powerful *b* factory: 467 million BB pairs in the total data sample

BaBar is also a *c* factory: 1.3 million Charm events per fb^{-1}



Offpeak (10.54GeV) + Scan above Υ(4S): 53.9 fb^{-1}

Υ(4S): 432 fb^{-1}
Υ(3S): 30.2 fb^{-1}
Υ(2S): 14.5 fb^{-1}

Study of $B^{0,\pm} \to J/\psi K^+K^-K_s^{0,\pm}$ and search for structure in the $J/\psi\phi$ system

A little bit of history .....(1)

2011

CDF reported the study of the decay mode $B^+ \to J/\psi\ \phi\ K^+$,
$\phi \to K^+K^-$, $J/\psi \to \mu^+\mu^-$

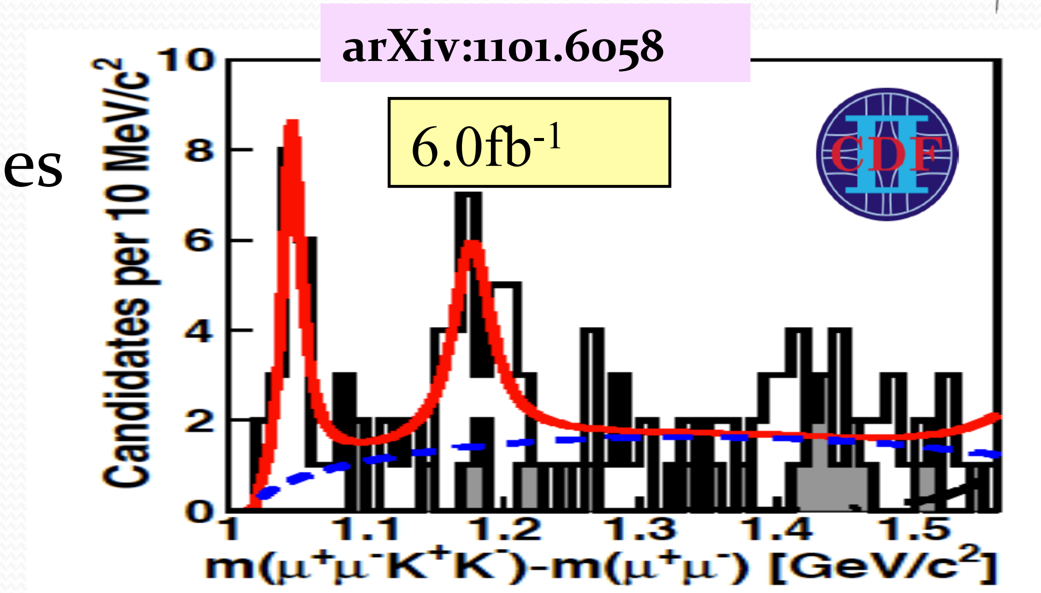
They observe two narrow peaks
that they interpreted as two resonances

$M_{Y4143} = 4143^{+2.9}_{-3.0} \pm 0.6$ MeV/c²

$\Gamma_{Y4143} = 15.3^{+10.4}_{-6.1} \pm 2.5$ MeV

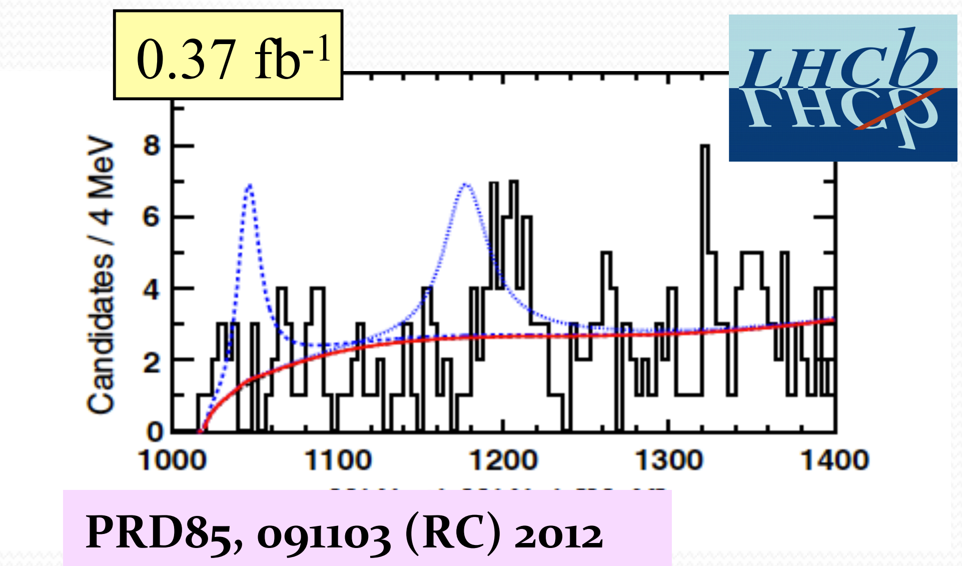
$M_{Y4274} = 4274.4^{+8.4}_{-6.7} \pm 1.9$ MeV/c²

$\Gamma_{Y4274} = 32.3^{+21.9}_{-15.3} \pm 7.6$ MeV



2012

A year after the CDF result LHCb shows its $J/\psi\phi$ mass spectrum.
They did not observe the two resonances



A little bit of history …..(2)

2013

CMS showed its $J/\psi\phi$ mass spectrum with 5.2 fb^{-1} and confirmed the presence of the two resonances

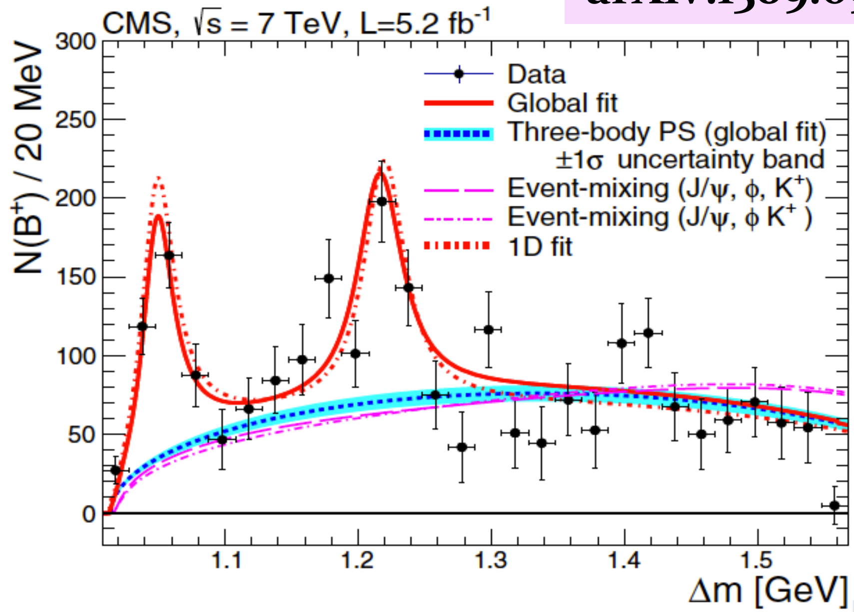
arXiv:1309.6920

M_{Y4143} = 4148± 2.4 ± 6.3 MeV/c²

$\Gamma_{Y4143} = 28\ ^{+15}_{-11} \pm\ 19$ MeV

M_{Y4313} = 4313± 5.3± 7.3 MeV/c²

$\Gamma_{Y4313} = 38\ ^{+30}_{-15} \pm\ 16$ MeV



2014

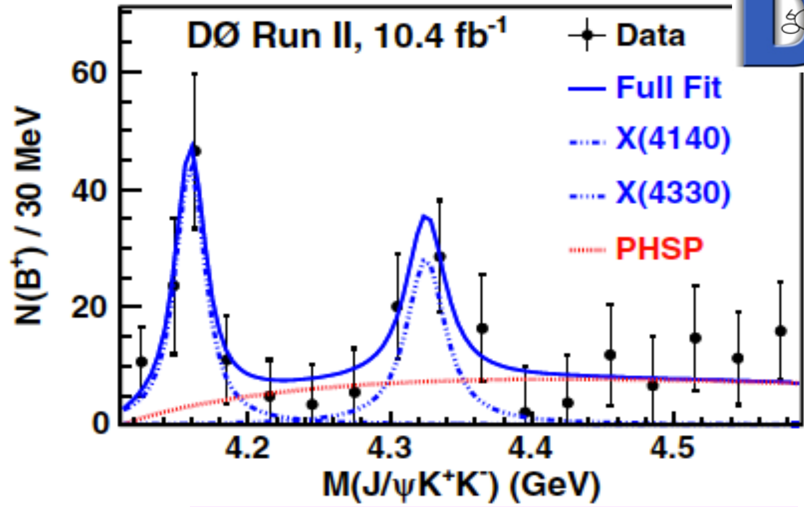
Recently DO has entered into the game With 10.4 fb^{-1} they observe the two Y resonances

M_{Y4143} = 4159± 4.3 ± 6.6 MeV/c²

Γ_{Y4143} = 19.9 ±4.3 ± 6.6 MeV

M_{Y4313} ~4.360

Γ_{Y4313} = fixed to 30 MeV



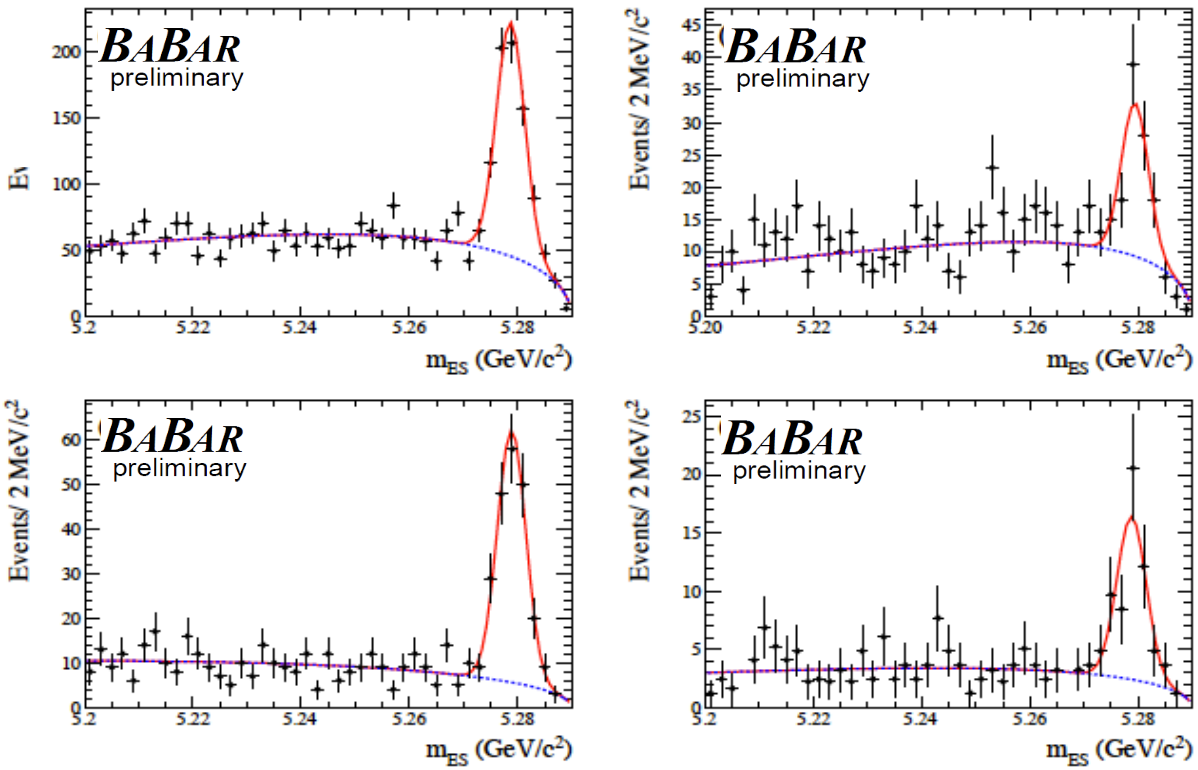
PRD89, 012004 (2014)

The BaBar Analysis (1)

Using the full Υ(4S) BaBar Data sample 424 fb^{-1}

We study the process $B^+ \to J/\psi K^+K^-K^+$, and $B^0 \to K^+K^- K^0_s$

$B^+ \to J/\psi K^+K^-K^+$ **$B^o \to J/\psi K^-K^+K^0_s$**



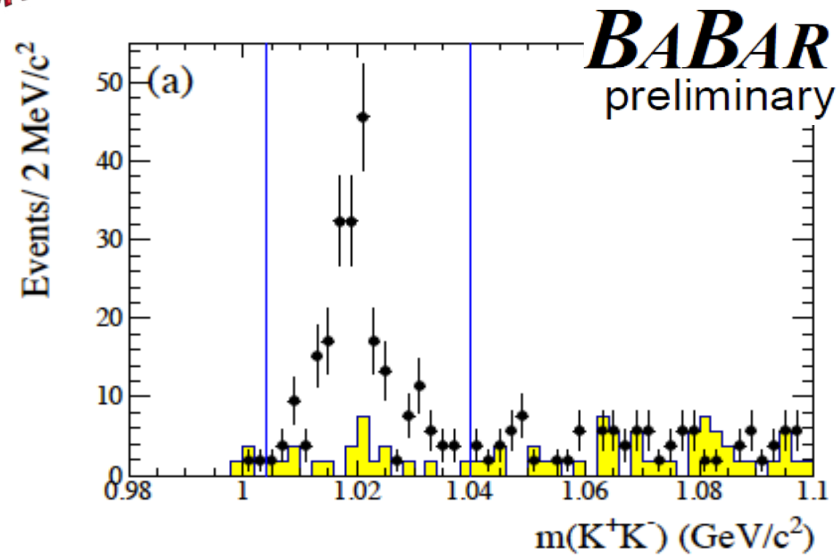
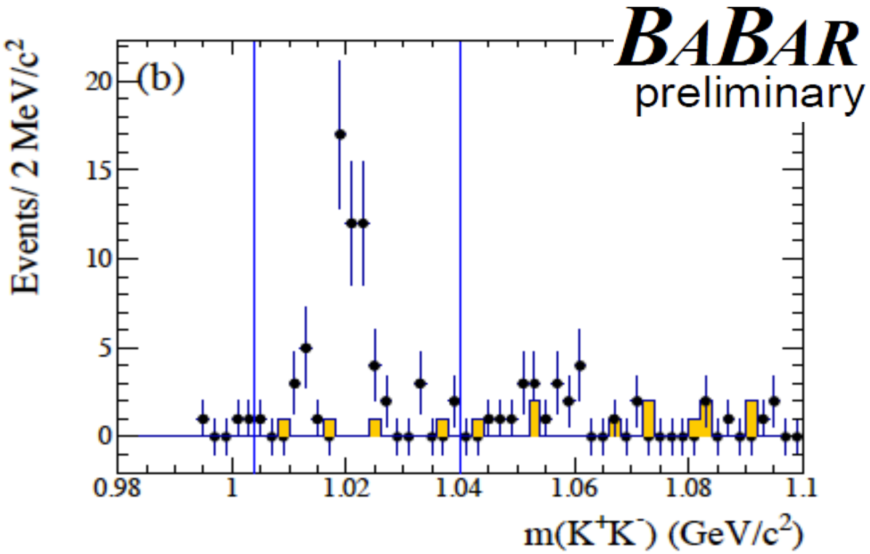
After φ selection

We performed an Unbinned Maximum likelihood fit to the m_{ES} distributions

$$m_{ES} = \sqrt{((s/2 + \vec{p}\cdot\vec{p}_b/E)^2 - \vec{p}_b^2}$$

with a Gaussian function for the signal and an ARGUS for the background shape

K^+K^- invariant mass and BR measurements

$B^+ \to J/\psi K^+K^-K^+$	$B^0 \to J/\psi K^-K^+K^0_s$
	

There is a small ϕ signal which does not saturate the K^+K^- channel

B channel	Event yield	$\mathcal{B}$ $(\times 10^{-5})$	Efficiency (%)
$B^+ \to J/\psi K^+K^-K^+$	595^{+32}_{-31}	6.05 ± 0.33 (stat) $\pm$ 0.24 (sys)	17.96 ± 0.08
$B^+ \to J/\psi \phi K^+$	200 ± 14	4.57 ± 0.32 (stat) $\pm$ 0.13 (sys)	16.20 ± 0.03
$B^0 \to J/\psi K^-K^+K^0_S$	74 ± 12	3.55 ± 0.57 (stat) $\pm$ 0.15 (sys)	11.31 ± 0.10
$B^0 \to J/\psi \phi K^0_S$	50 ± 7	2.53 ± 0.35 (stat) $\pm$ 0.09 (sys)	10.73 ± 0.04
$B^0 \to J/\psi \phi$	6 ± 4	< 0.101	31.12 ± 0.07

CDF, LHCb, DO and CMS do not obtain BF measurements

Search for resonances (1)

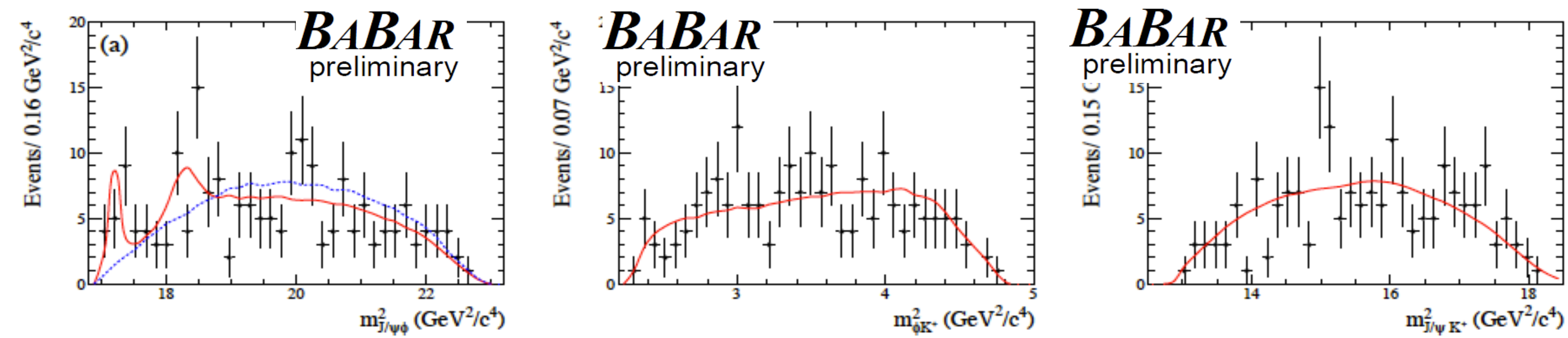
We searched for the resonant states claimed by CDF in the $J/\psi\phi$ mass spectrum

We perform an unbinned maximum fit using:

- a uniform distribution (i.e. phase space)
- two incoherent Breit –Wigner distributions with parameters values fixed to the values found by CDF **arXiv:1101.6058**

The fit function is weighted by the 2-D efficiency map over the Dalitz plot.

Mass Squared projections and fit results



Blue curve is phase space only

Search for resonances (2)

The fit fractions obtained in the fit with the assumption of two resonances are:

f(4140)=(7.3±2.5±3.8)%, UL @ 90% C.L. =12.1 %
f(4270)=(7.7±3.7±5.2)%, UL @ 90% C.L. =16.4 %

BABAR preliminary

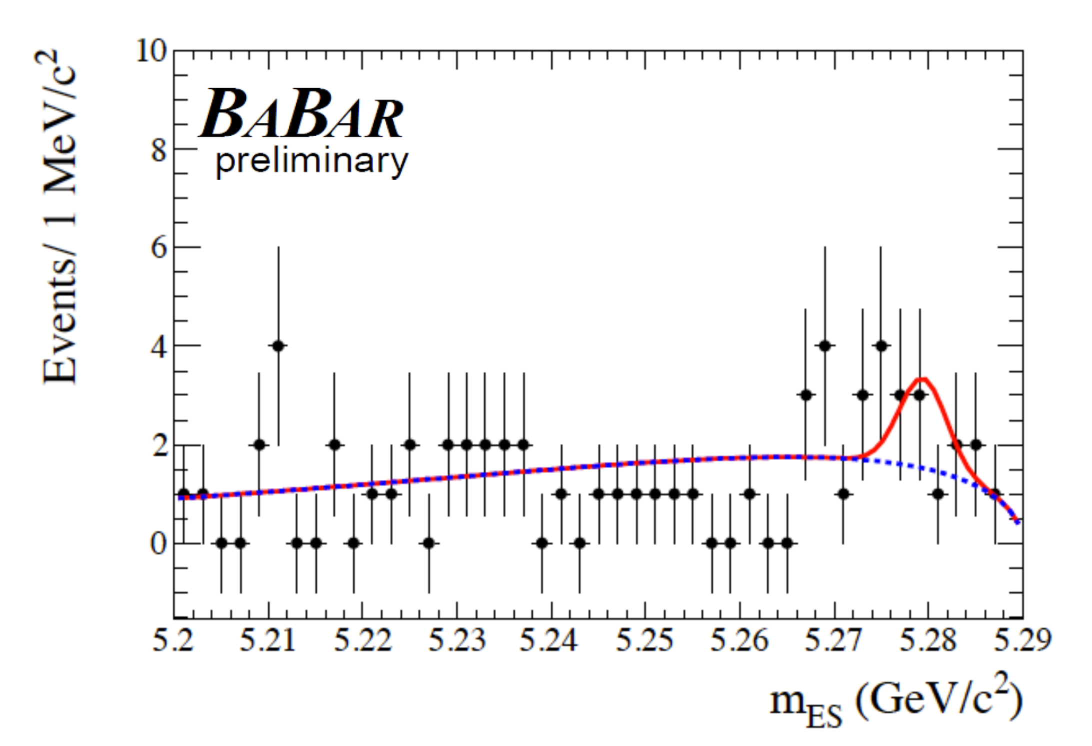
From the other experiments

Experiments	*f* (4140) [%]	*f* (4270) [%]
CDF	$14.9 \pm 2.9 \pm 2.4$	-
LHCb	<7	< 8
D0	$19 \pm 7 \pm 4$	-
CMS	13.4 ± 3.0 (*)	18.0 ± 7.3 (*)

(*) Estimated from the number of signal events quoted

With the present statistics we cannot access the presence of resonant behaviour, higher statistics and a full Dalitz plot analysis are needed

Search for the decay $B^0 \to J/\psi\phi$



BF($B^o \to J/\psi\ \phi$) <1.01 x 10^{-6} @ 90% C.L.

LHCb limit <1.9x 10^{-7} @ 90% C.L.

PRD 88, 072005 (2013)

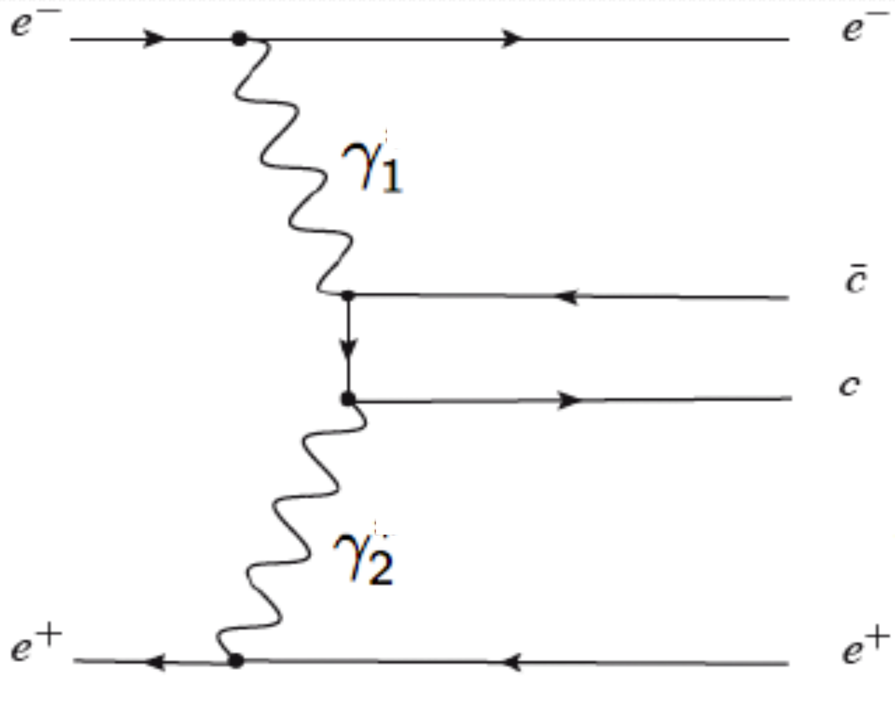
No evidence found for this decay mode

Dalitz Plot analyses of $\eta_c \to \eta K^+ K^-$ and $\eta_c \to K^+ K^- \pi^0$

Analysis strategy

With 519 fb^{-1} we study the reactions

$\gamma_1\gamma_2 \rightarrow K^+K^-\eta^+$ with $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\gamma_1\gamma_2 \rightarrow K^+K^-\pi^0$



Only states with even $J^{\pm+}$ or odd J^{++} with J>1 are allowed

$J^P = 0^+$ states cannot decay strongly to 3 pseudoscalar mesons

Final state e^+ and e^- produced at low angle

→ the γ_i are quasi-real

Outgoing e^+ and e^- are not detected

$\eta_c(1S)$ & $\eta_c(2S)$ current status

- Many $\eta_c(1S)$ and $\eta_c(2S)$ decays are still missing or studied with low statistics
- Even though the $\eta_c(1S)$ has been discovered more than 30 years ago the sum of its measured BFs is only ~20 % while for the $\eta_c(2S)$ is < 5%

- BESIII has obtained measurement of the η_c branching fraction via the decay $\psi(2S)\rightarrow\pi^0 h_c\rightarrow\gamma\eta_c$, but they obtained only

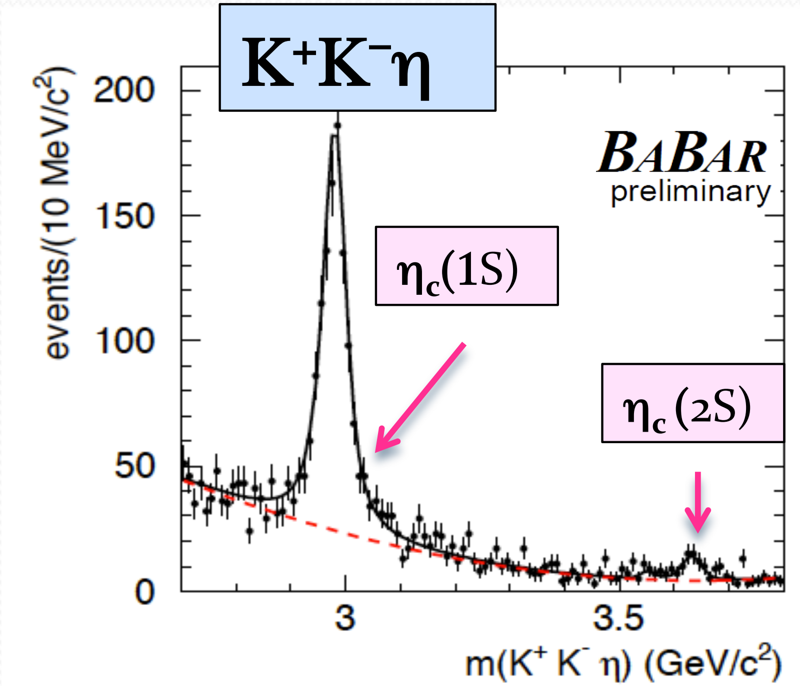
$N(\eta_c \rightarrow K^+K^-\eta)$ =6.7 ±3.2 events
$N(\eta_c \rightarrow K^+K^-\pi^0)$ =54.9 ±9.2 events

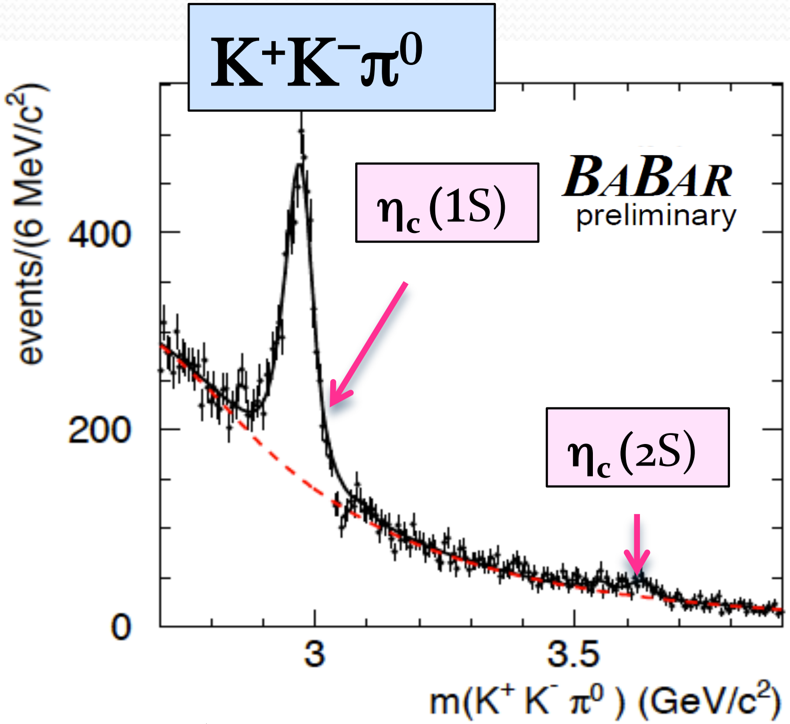
PRD 86, 010001 (2012)

- No Dalitz plot analysis has been published for η_c ($J^{PC}=0^{-+}$) three body decays
- Searches for gluonium state have been performed in the past using J/ψ decays

$K^+K^-\eta^+$ and $K^+K^-\pi^0$ mass spectra

After we applied the selection criteria we obtain the following mass spectra





- **Signal:** Breit-Wigner Convolved with resolution (the resolution functions are described by Crystal Ball for the **$K^+K^-\eta$** with **$\eta \rightarrow \pi^+\pi^-\pi^0$** and a sum of Crystal Ball and a Gaussian for the the **$K^+K^-\eta$** with **$\eta \rightarrow \gamma\gamma$** and **$K^+K\pi^0$** final state)
- **Background**: 2^{nd}-order polynomial

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

Branching-ratio Measurements

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		$4.9\ \sigma$
$\mathcal{B}(\eta_c(2S) \to K^+K^-\eta)/\mathcal{B}(\eta_c(2S) \to K^+K^-\pi^0)$			$0.82 \pm 0.21 \pm 0.27$	
$\chi_{c2} \to K^+K^-\pi^0$	$88 \pm 27 \pm 23$			$2.5\ \sigma$
$\chi_{c2} \to K^+K^-\eta$	$2 \pm 5 \pm 2$			$0.0\ \sigma$

Weighted mean of the BR values for the two η decay modes

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

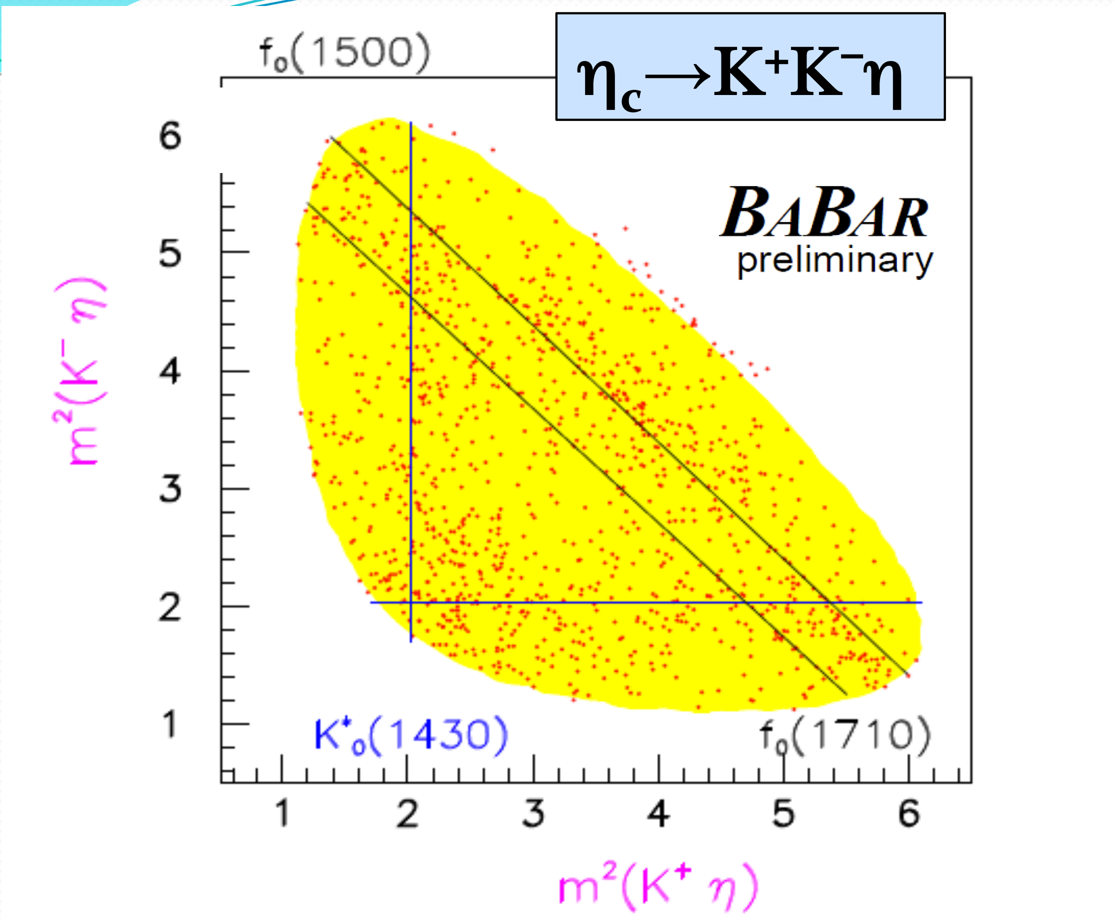
BESIII $\mathcal{R}(\eta_c)$ =0.46±0.24

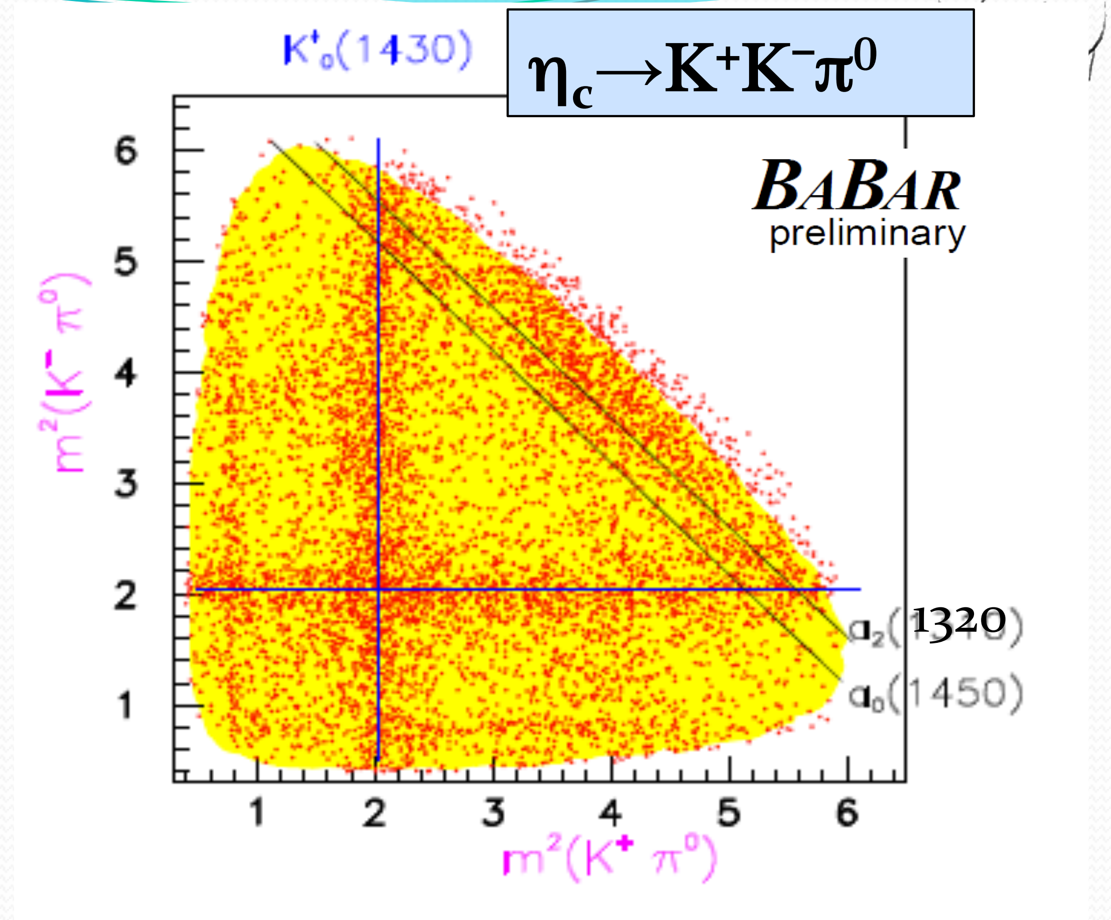
PRD 86, 092009 (2012)

For the η(2S) using only η→γγ

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

Dalitz plot analyses



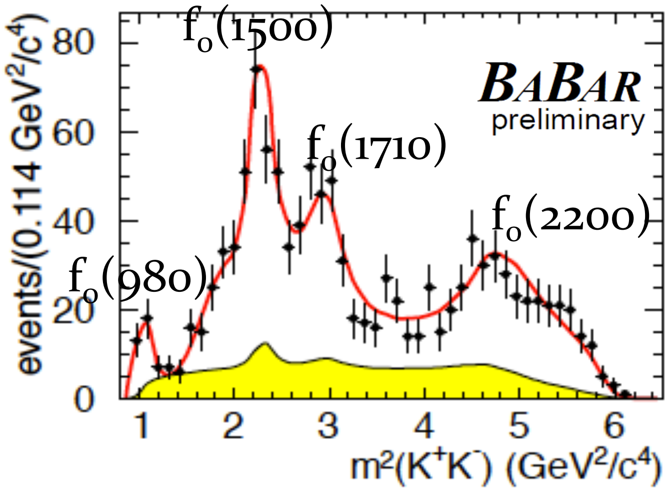


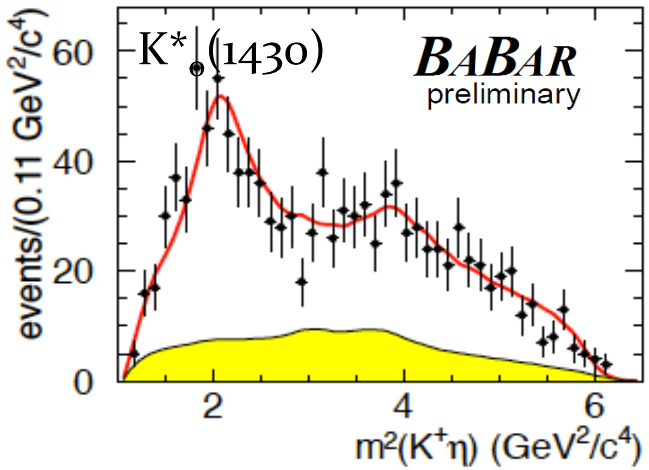
Signals for $f_0(1500)$, $K^*_0(1430)$ and $f_0(1710)$

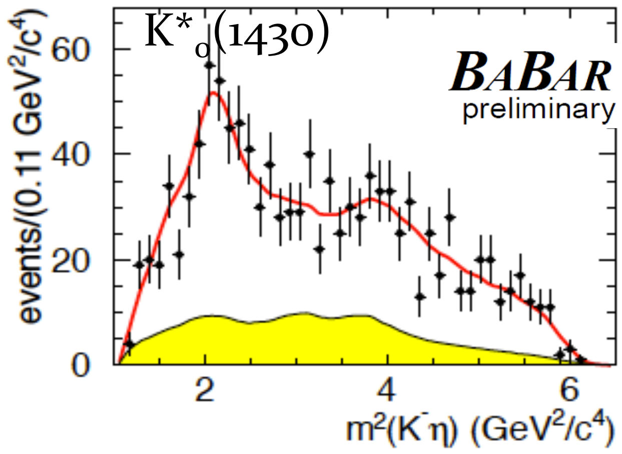
Signals for $a_0(980)$, $a_0(1450)$, $a_2(1320)$and $K^*_0(1430)$
$K^*(892)$ mostly from background

Dalitz plot analysis of $\eta_c \to K^+K^-\eta$: Fit Results

We perform an unbinned maximum likelihood fit which takes into account background from the η_c sideband regions (yellow histograms)







The K^+K^- amplitudes must have I=0

First evidence for the decay $K^*_0(1430)^\pm \to K^\pm\eta$

Observation of the $K^*_0(1430)$ as a Breit-Wigner peak

Not so in $K\pi$ scattering [see Fig. 12 in LASS Collaboration, NPB 296, 492 (1988)]

Results from the Dalitz plot analysis and fit projections

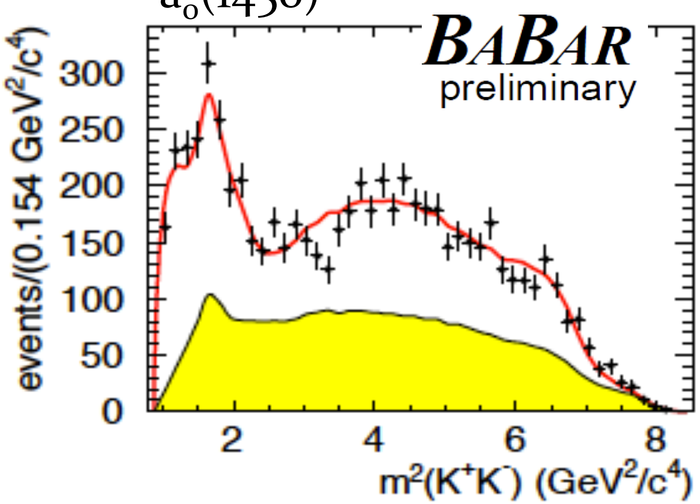
$f_0(1500)$ and $f_0(1710)$ are gluonium candidates

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	$87/65$	

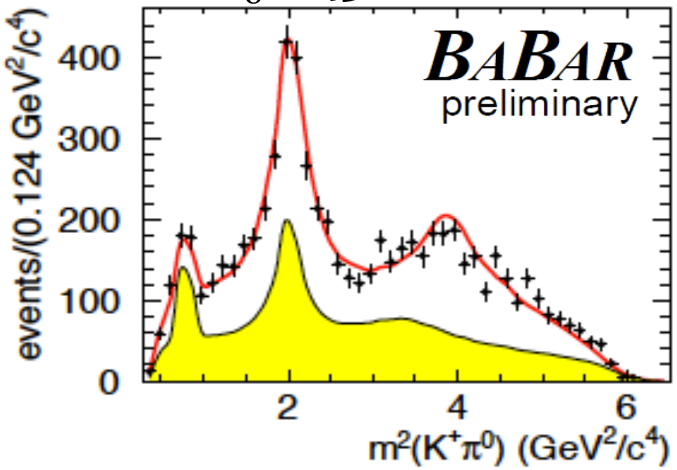
Dalitz plot analysis of $\eta_c \rightarrow K^+K^-\pi^0$: Fit Results

We perform an unbinned maximum likelihood fit which takes into account background from the η_c sideband regions (yellow histograms)

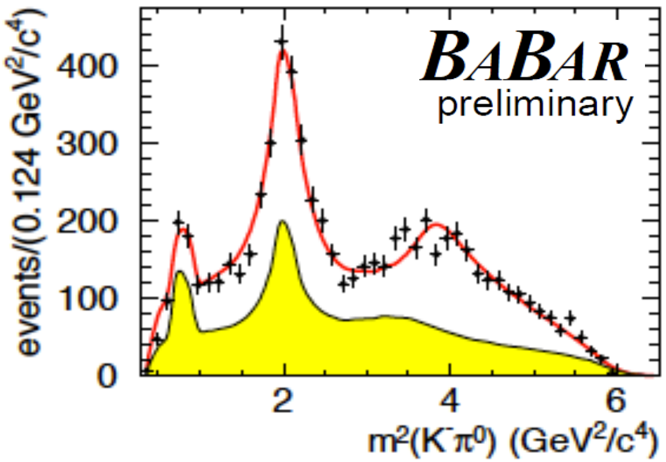
$a_0(1450)$



$K_0^*(1430)$



$K_0^*(1430)$



The K^+K^- amplitudes must have I=1

The $K^{\pm}\pi^0$ mass spectrum is dominated by the $K^*_0(1430)$ resonance

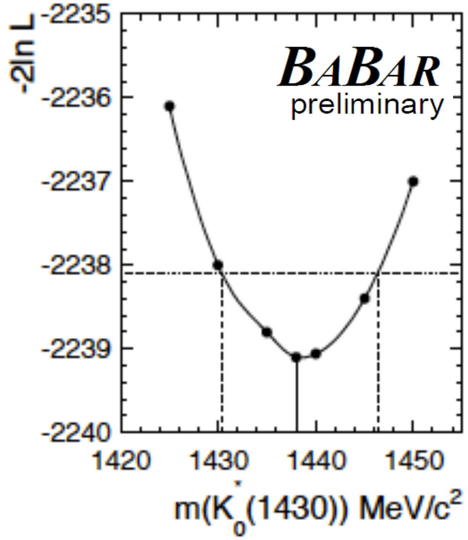
Results from the Dalitz plot analysis and fit projections

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

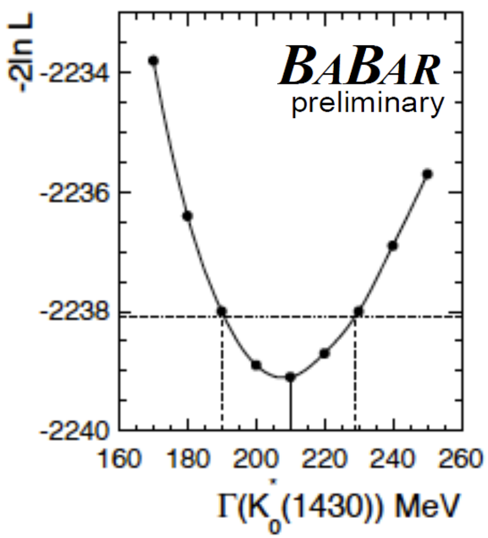
$K^*_0(1430)$ Branching Ratio

From the Dalitz plot analysis of $\eta_c \to K^+K^-\pi^0$ we perform a likelihood scan to obtain the best-fit parameter values for the $K^*_0(1430)$

$m(K^*_0(1430))$



$\Gamma(K^*_0(1430))$



$m(K^*_0(1430))=1438 \pm 8 \pm 4$ MeV/c^2
$\Gamma(K^*_0(1430))=210 \pm 20 \pm 12$ MeV

The mass value agrees well with that from the LASS experiment (Nucl. Phys. B 296, 493 (1988)), but the width is 3 sigma smaller than the LASS result

We obtain also the $K^*_0(1430)$ branching ratio:

$$\frac{B(K_0^*(1430) \to \eta K)}{B(K_0^*(1430) \to \pi K)} = 0.092 \pm 0.025^{+0.010}_{-0.025}$$

This negative systematic error is due to strong interference effects involving the ad hoc NR amplitude in the estimation of the $K\pi$ and ηK fractions

Conclusion

✓ We have presented new results on the **$B \to J/\psi K^+K^-K$** decay, measuring branching fractions and branching ratios and searching for **$J/\psi\phi$**

✓We perform for the first time Dalitz plot analyses of η_c decay to $K^+K^-\eta$ and to $K^+K^-\pi^0$

✓We observe a dominance of the decay

$\eta_c \to$ pseudoscalar + scalar

✓The decay $\eta_c \to K^+K^-\eta$ has a large contribution from $\eta_c \to f_0(1500)\eta$ ($f_0(1500)$ is a possible glueball candidate)

✓The $K^*_0(1430)$ has been observed for the first time as a BW peak in the $K^\pm\pi^0$ $K^\pm\eta$ mass distributions

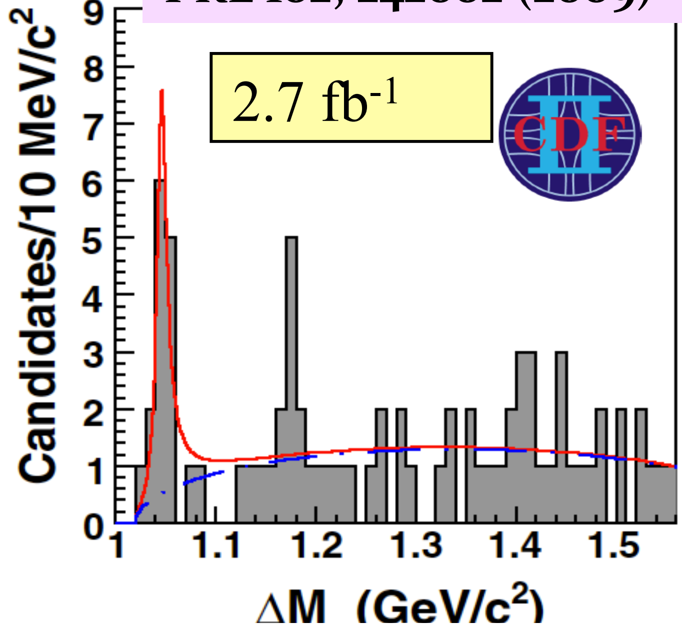
✓First observation of the decay $K^*_0(1430) \to K\eta$

BACK-UP SLIDES

2009

CDF reported the study of the decay mode $B^+ \rightarrow J/\psi\ \phi\ K^+$, $\phi \rightarrow K^+K^-$, $J/\psi \rightarrow \mu^+\mu^-$

PRL 102, 242002 (2009)



They observe a narrow peak near the threshold in the $J/\psi\ \phi$ mass spectrum

$M_{Y4143} = 4143 \pm 2.9 \pm 1.2\ MeV/c^2$

$\Gamma_{Y4143} = 11.7\ ^{+8.3}_{-5} \pm 3.7\ MeV$

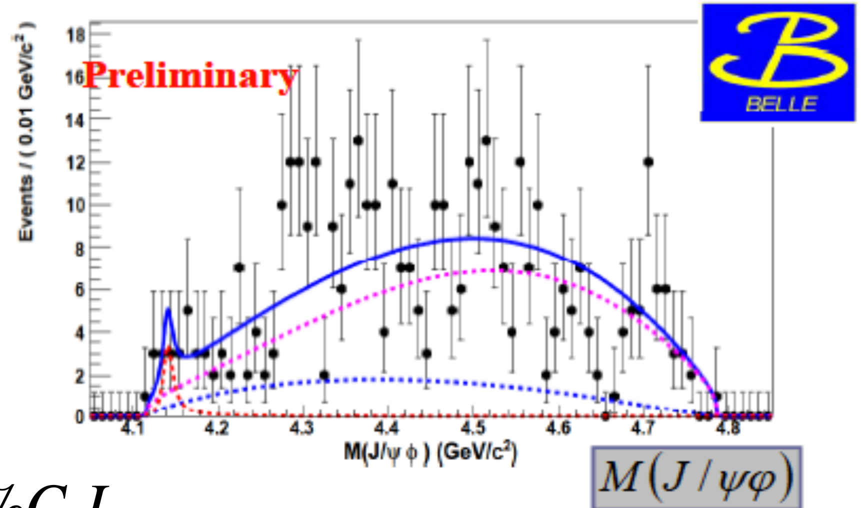
Soon after its discovery there were several theoretical interpretation about the nature of this state

arXiv: 0903:3107, 0903:2529 ecc…

Some months after the CDF result BELLE shows its $J/\psi\ \phi$ mass spectrum using 772 x10^6 $B\bar{B}$ pairs

NEVER PUBLISHED

They did not observe the Y(4140) in B decays or in two-photon production



$$B(B^+ \rightarrow Y(4140)K^+, Y(4140) \rightarrow J/\psi\phi) < 6 \cdot 10^{-6}\ @90\%C.L.$$