Recent « charmonium » results

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On behalf of BABAR collaboration

Talk outline

- Study of two-body decays B ➔KX : Inclusive view of the charmonium

  Preliminary update with 2 times more statistics than

  Phys. Rev. Letters 96 052002 (2006) based on 210 fb^{-1}

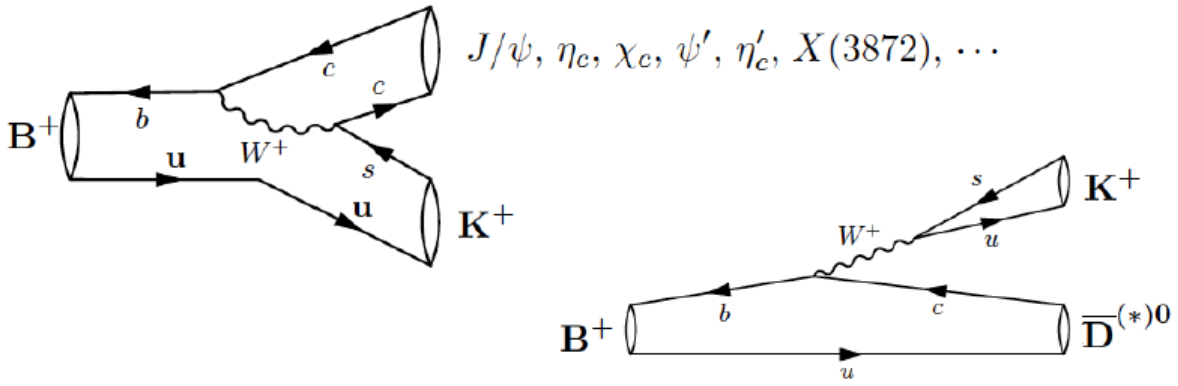
- Dalitz decays of $J/\psi \rightarrow K^0 K^{\pm} \pi^{\mu}$: First Dalitz analysis for this decay mode of J/ψ

  Phys. Rev. D95(2017) 072007. arxiv 1702.01551

- Y(1S) decays to $\gamma\pi^+\pi^-$ and γK^+K^-: properties of « glueball -like » mesons

  arxiv 1804.04044 accepted for PRD publication

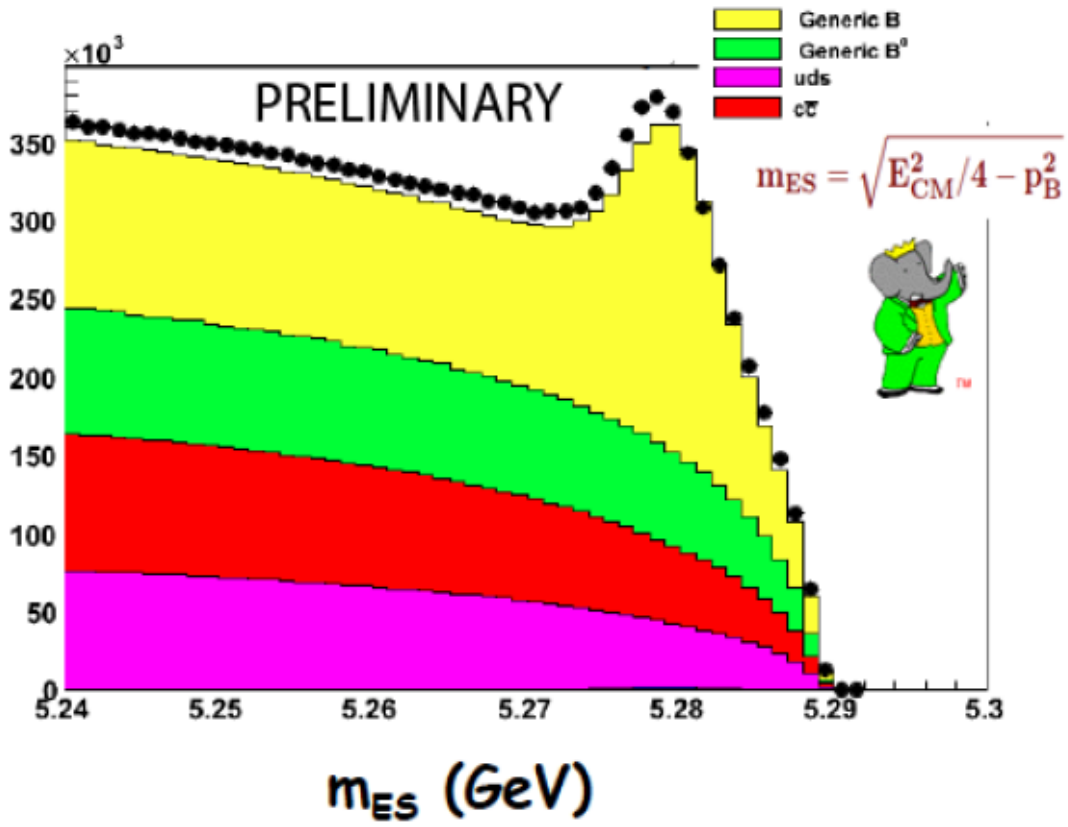
Two-body decays $B^{\pm} \rightarrow K^{\pm} X^0$



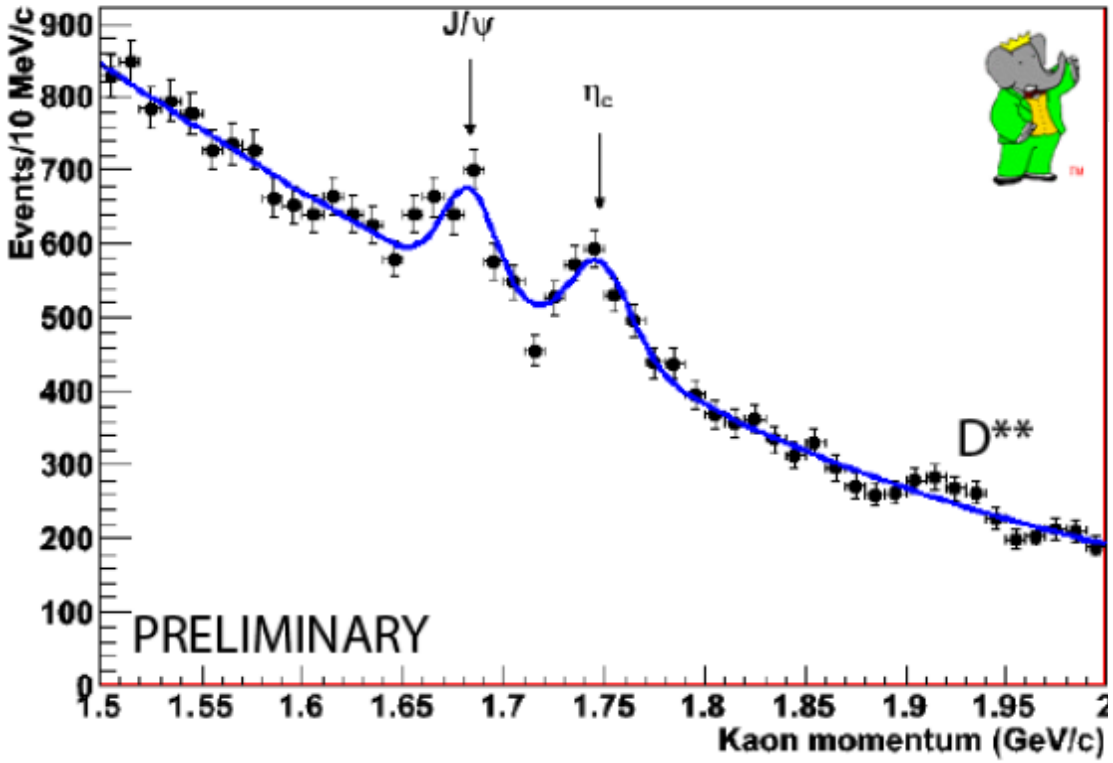
Measurements of the inclusive production of charm(-onium) states in the quasi-two-body decays

$B \rightarrow X + K$

Preliminary results

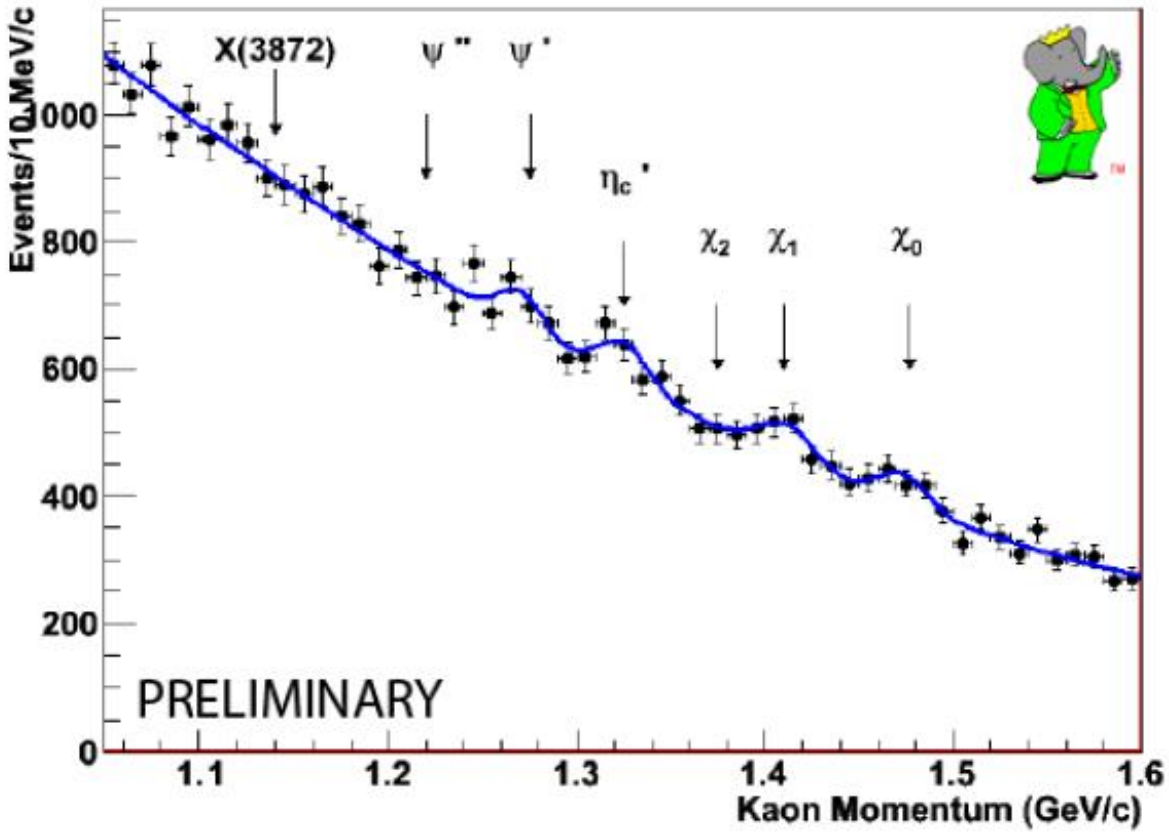


$K^{\pm}$ momentum recoil in the B center-of-mass



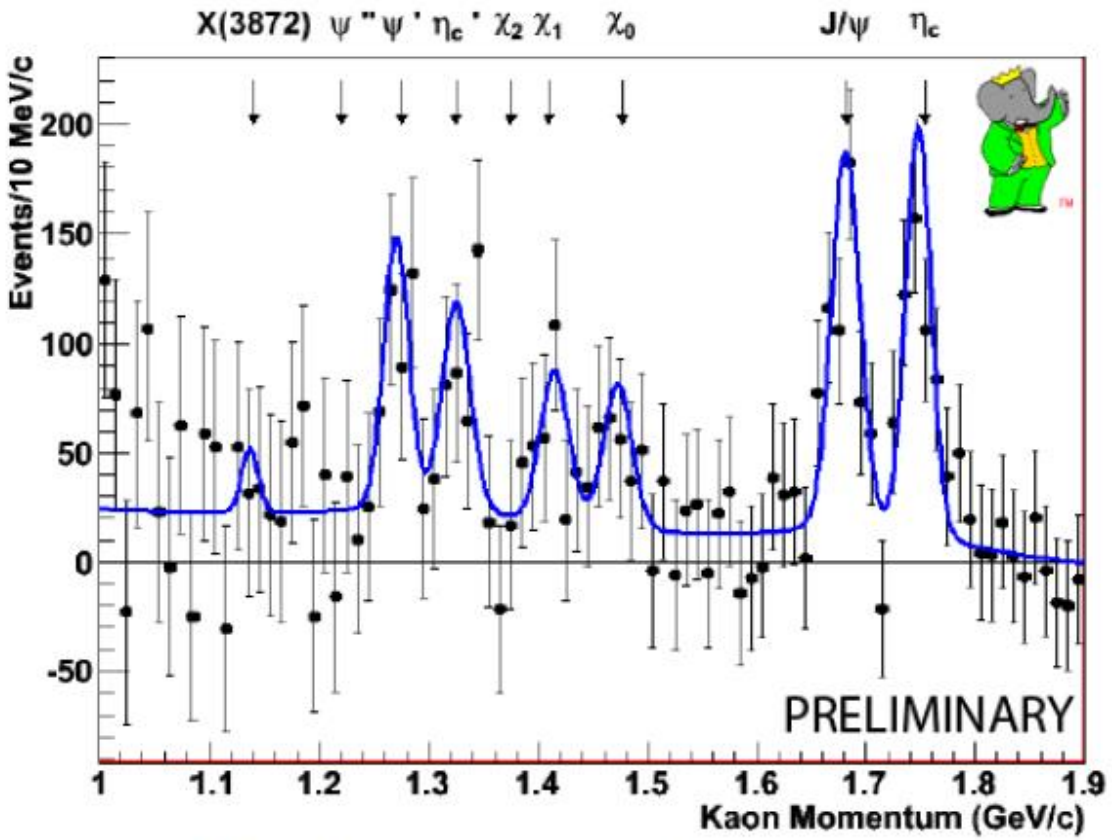
High momentum region (not blinded)

Low momentum region (blinded)



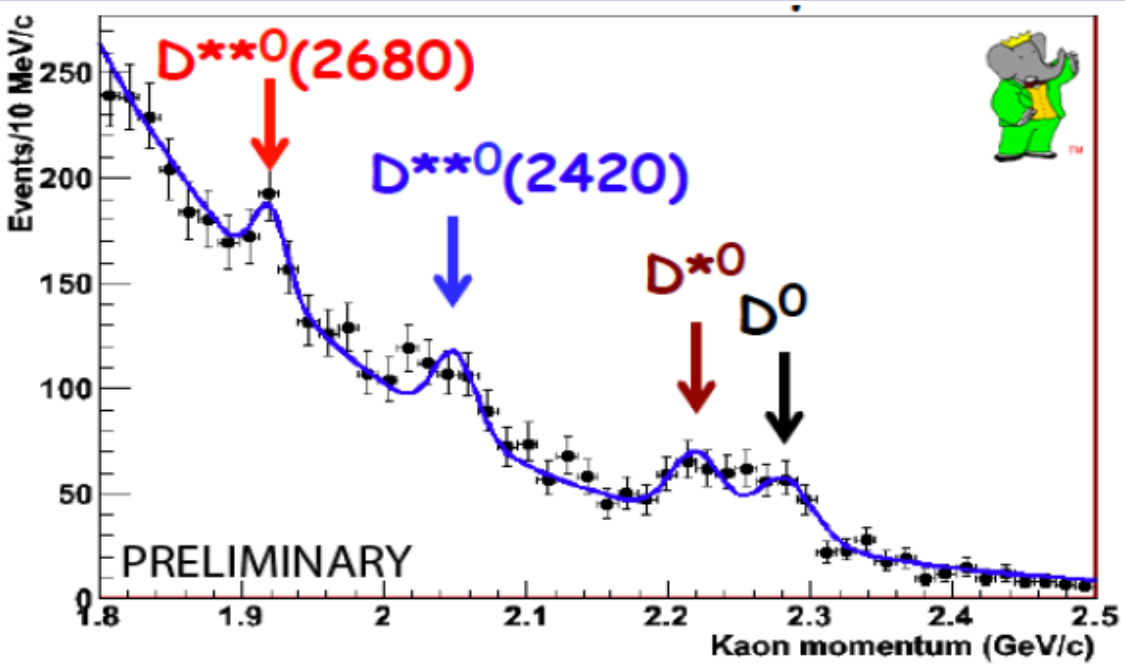
$B^{\pm} \to K^{\pm} X^0$; Full charmonium mass region

The charmonium spectrum … almost ..an Hydrogen atom spectrum!!



After background subtraction

$B^{\pm} \to K^{\pm} X^0$; Lower charmonium mass region, Search for Neutral D^*



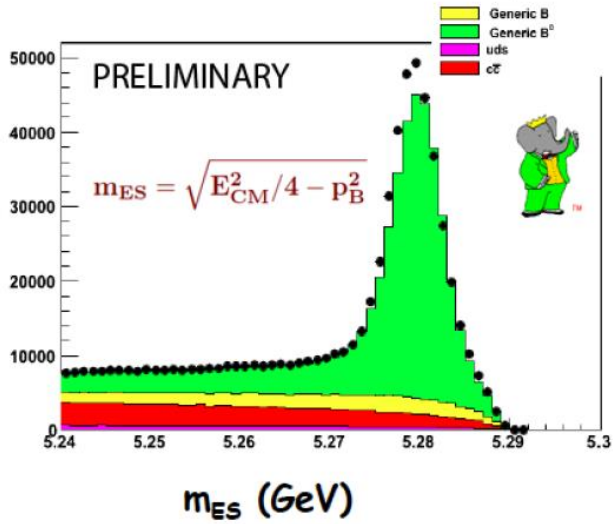
Very high K momentum region (blinded)

Statistical significance of the $D^{**}(2680) \sim 3.3\sigma$

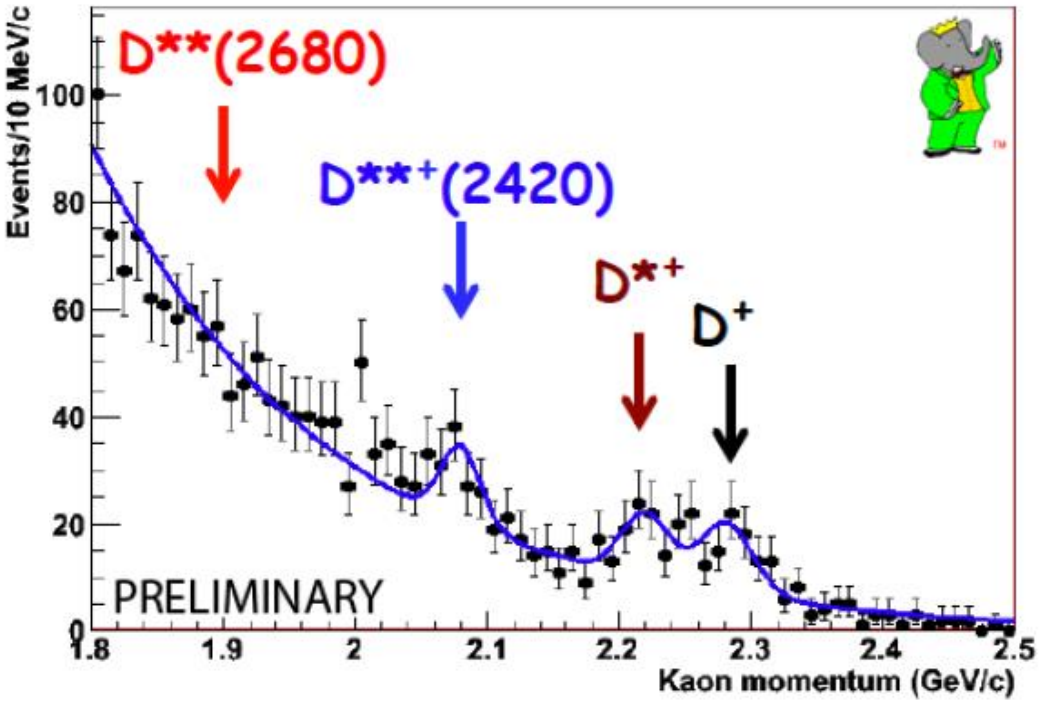
Particle	Yield	Peak Position	$BF(10^{-4})$	PDG 2014
D^0	126 ± 20		3.5 ± 0.5 ± 0.3	3.7 ± 0.17
D^{*0}	126 ± 21		3.5 ± 0.5 ± 0.3	4.2 ± 0.34
$D_1(2420)^0$	97 ± 25		2.1 ± 0.5 ± 0.3	-
$D^{**0}(2680)$	95 ± 29	2.68 ± 0.003	2.1 ± 0.6 ± 0.3	-

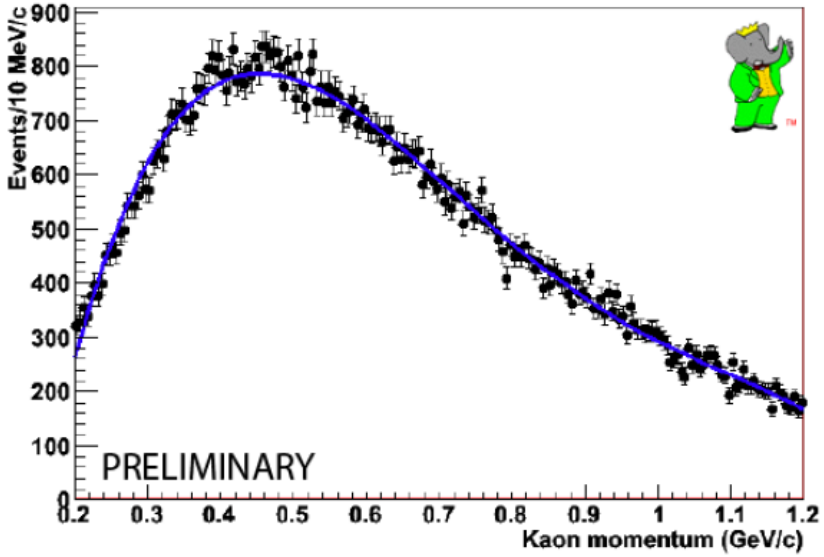
The branching fractions are consistent with PDG 2014 values.

Two-body decays $B^0 \rightarrow K^- X^+$



Very high Kaon momentum region





No observation of narrow charged« charmonium » states in the mass range 3.7 -4.7 GeV

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Summary results

- Improvements in $BF(B^{\pm} \to K^{\pm} X_{c\bar{c}})$ for all channels

Consistent with PDG (ie our previous results!)

Particle	Yield	Peak Position	Width	BF(10^{-4})	
J/ψ	516±67			9.6±1.2(sta)±0.8(sys)	8.9+-0.6+-0.5
η_c	655±77	2982±5	<43	13.3±1.8(stat)±0.4(sys)±0.3(ref)	12.0+-0.8+-0.7
χ_{c0}	218±76			4.4±0.9	2.0+0.9+-0.1
χ_{c1}	192±35			7.0±1.3(stat)±1.0(sys)	5.8+-0.9+0.5
χ_{c2}	0±32			<1.2	
η_c (2S)	283±94	3632±0.007	<33	6.0±2.1(stat)±0.4(sys)	4.8+_1.1+-0.3
ψ'	293±90			6.2±2(stat)±0.6(sys)	6.4+-1.0+-0.4
$\psi(3770)$	0±49			<2.0	<2.3
X(3872)	75±81			1.4±1.5 or < 4.4	1.2+-1.1+-0.1 <2.6

Recent BELLE-2 measurements

Phys.Rev.D97(2018)012005

Results from the fits of the K momentum spectrum in the charmonium mass region for 1.67 M reconstructed $B^{\pm}$ events

Note : The X(3872) limit is not improved when multiplying statistics by 2

Summary results

- Analysis extendend to D mass region

NEW

Particle	Yield	Peak Position	BF(10^{-4})	PDG 2014
D^0	126±20		3.5±0.5(sta)±0.3(sys)	3.7±0.17
D^{*0}	126±21		3.5±0.5(stat)±0.3(sys)	4.2±0.34
$D_1(2420)^0$	97±25		2.1±0.5(stat))±0.3(sys)	-
$D^{**0}(2680)$	95±29	2.68±0.003	2.1±0.6(stat)±0.3(sys)	-
$D^{\pm}$	44±10		3.3±0.8(sta)±0.3(sys)	2.0±0.21
$D^{*\pm}$	40±10		3.0±0.8(stat)±0.3(sys)	2.1±0.16
$D^*(2420)^{\pm}$	52±13		3.9±1.0(stat))±0.3(sys)	-

PDG 2017
3.74±0.16

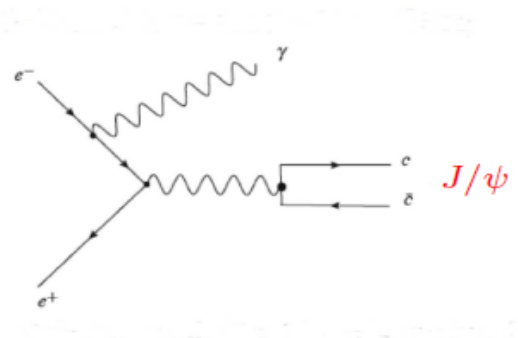
1.86±0.20
2.12±0.15

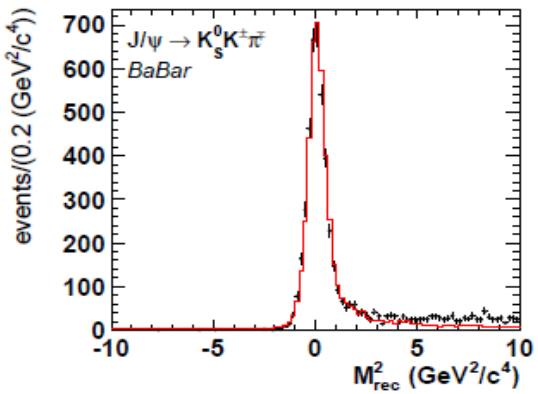
Results from the fits of the K momentum spectra in the D region mass, performed for $B^{\pm}$ and B^0 samples of 1.67 M and 0.8 M reconstructed B events, respectively.

Dalitz plot analysis of $J/\psi \to K^0_S K^\pm \pi^\mp$

- We use the Initial State Radiation (ISR) process to obtain clean J/ψ samples.
- We reconstruct events having a (mostly undetected) fast forward γ_{ISR}.

$$e^+e^- \to \gamma_{\rm ISR}\ K^0_S K^\pm \pi^\mp,$$





- Only $J^{PC} = 1^{--}$ states can be produced. We compute:

$$M^2_{\rm rec} \equiv (p_{e-} + p_{e+} - p_K - p_{K^0_S} - p_\pi)^2$$

- This quantity should peak near zero for ISR events.
- Plot of $M^2_{\rm rec}$ in the J/ψ signal region, In red is Monte Carlo simulation.

(Phys.Rev. D95 (2017) 072007, arXiv:1702.01551)

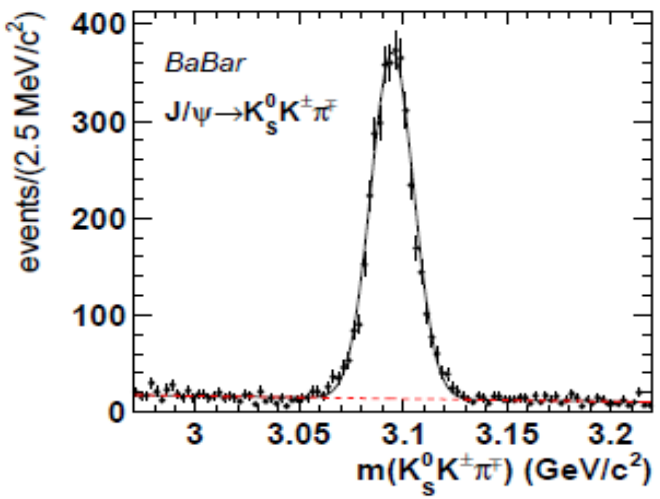
$J/\psi \rightarrow K^0_S K^{\pm}\pi^{\mp}$ Dalitz plot analysis

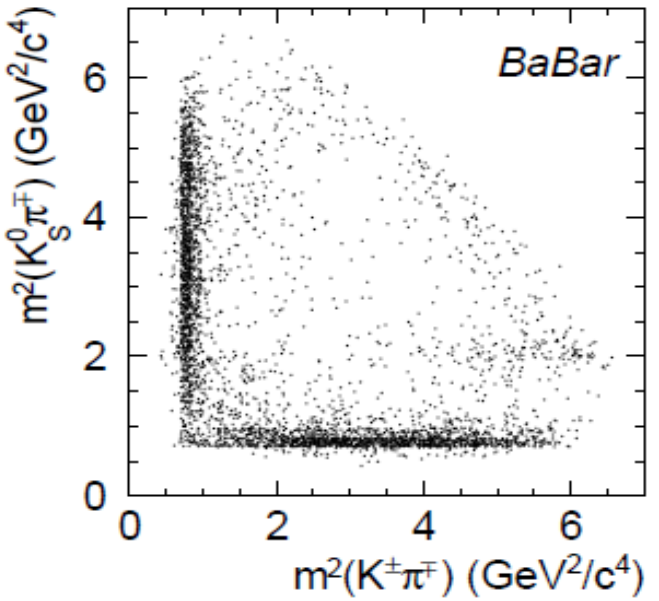
- We select events in the ISR region by requiring ($|M^2_{\rm rec}| < 1.5\ GeV^2/c^4$) and obtain 3694 ± 64 events with $(93.1 \pm 0.4\ \%)$ purity.

- Dalitz plot analysis performed using Isobar Model using Zemach tensors;

C. Zemach, Phys Rev. **133**, B1201 (1964),C. Dionisi et. al., Nucl. Phys. **B169**, 1 (1980).

- $J/\psi \rightarrow K^0_S K^{\pm}\pi^{\mp}$ Dalitz plot analysis performed here for the first time.
- J/ψ signal and Dalitz plot: dominated by K^* bands





- Significant improvement by leaving free the $K^*(892)$ mass and width parameters.

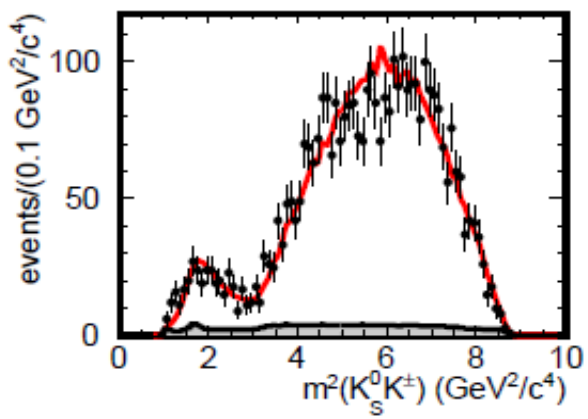
$$m(K^*(892)^+) = 895.6 \pm 0.8 \text{ MeV}/c^2, \Gamma(K^*(892)^+) = 43.6 \pm 1.3 \text{ MeV}$$

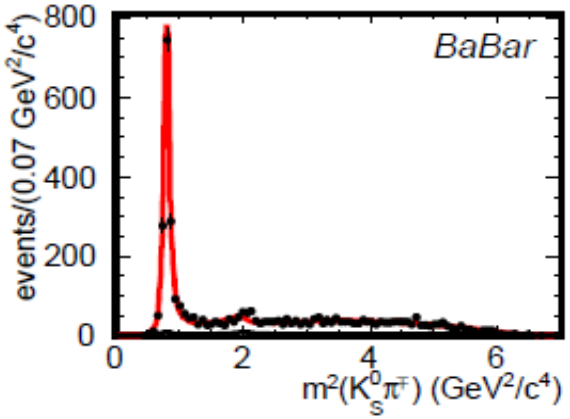
$$m(K^*(892)^0) = 898.1 \pm 1.0 \text{ MeV}/c^2, \Gamma(K^*(892)^0) = 52.6 \pm 1.7 \text{ MeV}$$

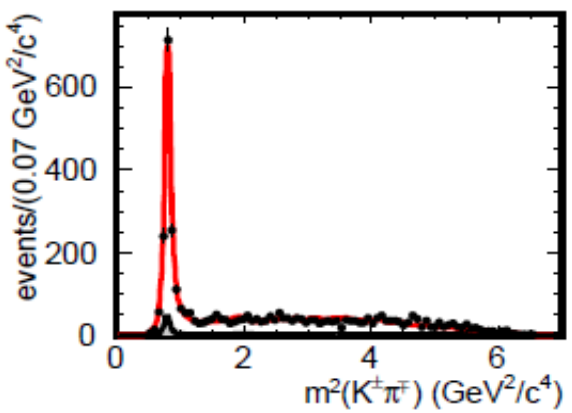
- The $K^*(892)^+$ measured parameters in good agreement with those measured in τ lepton decays.

Final state	fraction (%)	phase (radians)
$K^*(892)\bar{K}$	$90.5 \pm 0.9 \pm 3.8$	0.
$\rho(1450)^{\pm}\pi^{\mp}$	$6.3 \pm 0.8 \pm 0.6$	$-3.25 \pm 0.13 \pm 0.21$
$K_1^*(1410)\bar{K}$	$1.5 \pm 0.5 \pm 0.9$	$1.42 \pm 0.31 \pm 0.35$
$K_2^*(1430)\bar{K}$	$7.1 \pm 1.3 \pm 1.2$	$-2.54 \pm 0.12 \pm 0.12$
Total	105.3 ± 3.1	
χ^2/ν	$274/217 = 1.26$	

- Dalitz plot projections:







Y(1S) decays to γππ and γKK

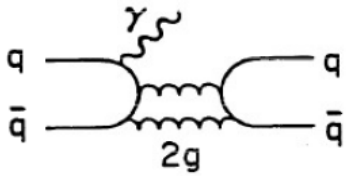
Physics Motivations

- The search for gluonium states is still a hot topic for QCD.

- Lattice QCD calculations predict the lightest gluonium states to have quantum numbers $J^{PC} = 0^{++}$ and 2^{++} and to be in the mass region below 2.5 GeV/c^2 [PRD73 014516].

- Possible candidate for the $J^{PC} = 0^{++}$ glueball is the $f_0(1710)$. For this resonance early analyses assigned $J^{PC} = 2^{++}$.

There are a lot of sources for the production of f-like states. Among them – radiative decay of J/ψ, ψ(2S) or Υ(1S):



- So, it is important to improve the precision of the parameters of f-like mesons and to check complementarity of beauty and charm hadron physics in the radiative decays.

- Used integrated luminosities of 13.6 fb^{-1} and 28.0 fb^{-1} at the Υ(2S) and Υ (3S) resonances

- We use the following full reconstructed decay chains:

$$\Upsilon(2S)/\Upsilon(3S) \to \pi_s^+\pi_s^-\Upsilon(1S)$$
$$\to \gamma h^+h^-$$

where h = π, K.

- The chain of the "reference" decay

$$\Upsilon(2S)/\Upsilon(3S) \to \pi_s^+\pi_s^-\Upsilon(1S)$$
$$\to \mu^+\mu^-$$

- We consider only events containing exactly four well-measured tracks with transverse momentum greater than 0.1 GeV/c

- We also require exactly one well-reconstructed γ in the calorimeter having an energy greater than 2.5 GeV

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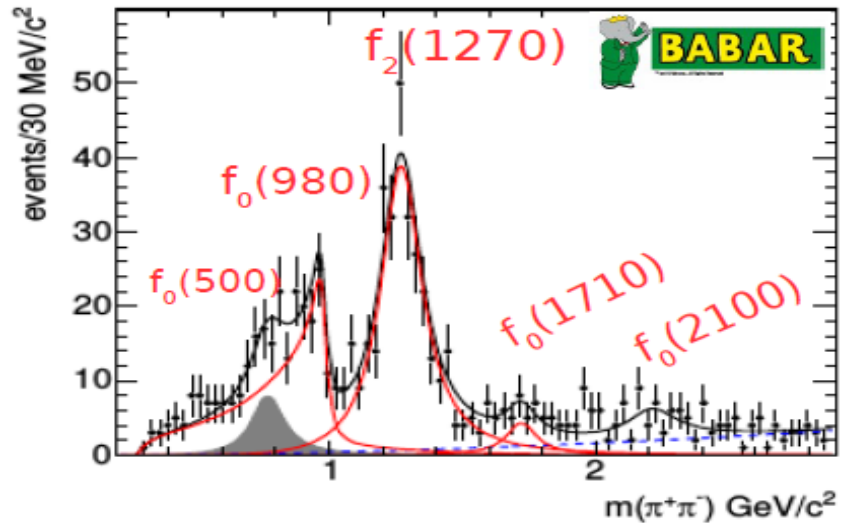
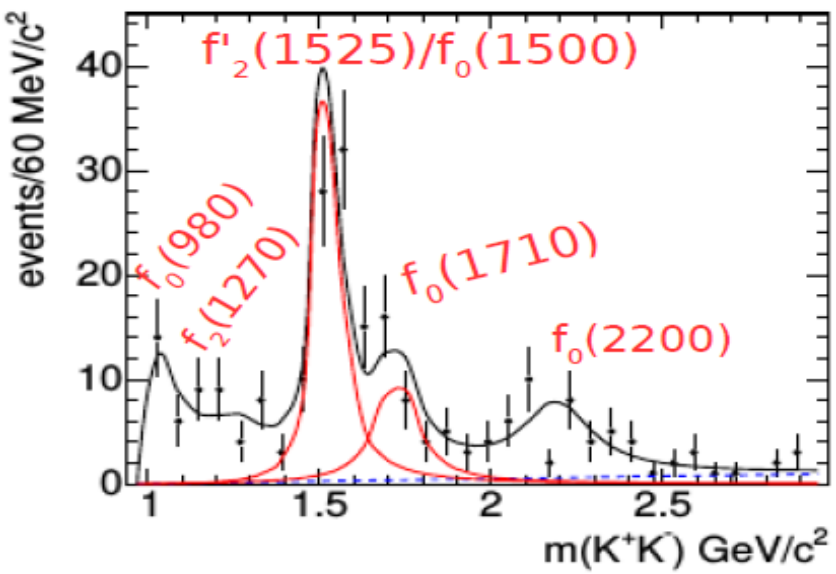
STUDY OF THE $\pi^+\pi^-$ AND K^+K^- MASS SPECTRA



- 16 free parameters
- χ^2/ndf = 182/152, P(χ^2) = 5%
- For the Y(3S) data we also include $\rho(770)^0$ background.
- S-wave = $|BW[f_0(500)(m)] + c \cdot BW[f_0(980)(m)e^{i\varphi}]|^2$
- The fraction of S-wave events associated with the $f_0(500)$ is $(27.7 \pm 3.1)\%$
- $m(f_0(500)) = 0.856 \pm 0.086$ GeV/c²
  $\Gamma(f_0(500)) = 1.279 \pm 0.324$ GeV
- $m(f_0(2100)) = 2.208 \pm 0.068$ GeV/c².

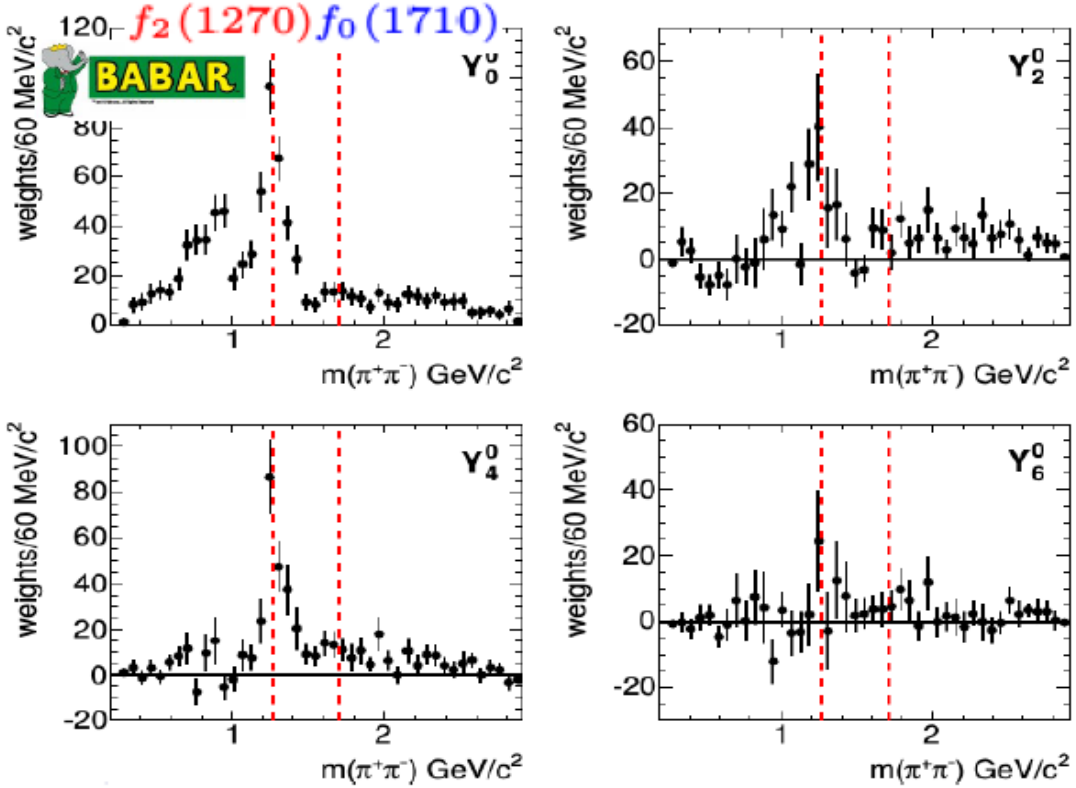


- 6 free parameters
- χ^2/ndf = 35/29, P(χ^2) = 20%
- Fits with only $f_2'(1525)$ and $f_0(1500)$ are performed. We label this contribution as $f_J(1500)$.

Two pions and two kaons invariant mass spectra

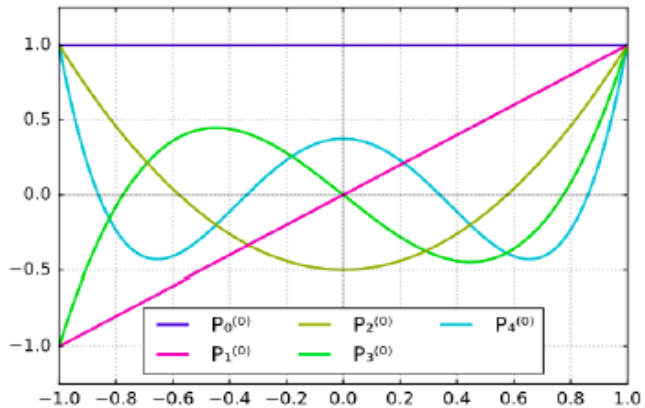
Legendre polynomial moments, $\pi^+\pi^-$.

- Efficiency corrected $\pi^+\pi^-$ mass spectrum weighted by Legendre polynomial moments:



$$\sqrt{4\pi} < Y_0^0 >= S^2 + D^2$$
$$\sqrt{4\pi} < Y_2^0 >= 2SD\cos\phi_{SD} + 0.639D^2$$
$$\sqrt{4\pi} < Y_4^0 >= 0.857D^2$$

$$Y_{\ell,m}(\theta,\phi) = \sqrt{\frac{(2\ell+1)(\ell-m)!}{4\pi(\ell+m)!}}\, P_\ell^m(\cos\theta)\, e^{im\phi}$$



- Y_2^0 is related to the S-D interference, clearly visible at the $f_2(1270)$ mass.
- Y_4^0 is related to D-wave, clearly visible at the $f_2(1270)$ mass.

STUDY OF THE $\pi^+\pi^-$ AND K^+K^- MASS SPECTRA

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Resonances $(\pi^+\pi^-)$	Yield $\Upsilon(2S)$	Yield $\Upsilon(3S)$	Significance
S-wave	$133 \pm 16 \pm 13$	87 ± 13	12.8σ
$f_2(1270)$	$255 \pm 19 \pm 8$	$77 \pm 7 \pm 4$	15.9σ
$f_0(1710)$	$24 \pm 8 \pm 6$	$6 \pm 8 \pm 3$	2.5σ
$f_0(2100)$	33 ± 9	8 ± 15	
$\rho(770)^0$		54 ± 23	
Resonances (K^+K^-)	**Yield $\Upsilon(2S) + \Upsilon(3S)$**		**Significance**
$f_0(980)$	47 ± 9		5.6σ
$f_J(1500)$	$77 \pm 10 \pm 10$		8.9σ
$f_0(1710)$	$36 \pm 9 \pm 6$		4.7σ
$f_2(1270)$	15 ± 8		
$f_0(2200)$	38 ± 8		

Resonances yields and statistical significances from the fits.

- The observation of a significant S-wave was not possible in the study of J/ψ radiative decay to $\pi^+\pi^-$ because of the presence of a irreducible background from J/ψ $\rightarrow \pi^+\pi^-\pi^0$ [PRD 35, 2077 (1987)].
- Systematic uncertainties are dominated by the uncertainties on resonances parameters

Branching fractions

- We compute branching fraction *B(R)* for resonance R using the expression

$$\mathcal{B}(R) = \frac{N(\Upsilon(nS)\to\pi^+\pi^-\Upsilon(1S)(\to R\gamma))}{N(\Upsilon(nS)\to\pi^+\pi^-\Upsilon(1S)(\to\mu^+\mu^-))} \cdot \mathcal{B}(\Upsilon(1S)(\to\mu^+\mu^-))$$

where N indicates the efficiency corrected yield for the given resonance.

Resonance	$\mathcal{B}(10^{-5})$
$\pi\pi$ S-wave	$4.63 \pm 0.56 \pm 0.48$
$f_2(1270)$	$10.15 \pm 0.59\ ^{+0.54}_{-0.43}$
$f_0(1710)\to\pi\pi$	$0.79 \pm 0.26 \pm 0.17$
$f_J(1500)\to KK$	$3.97 \pm 0.52 \pm 0.55$
$f_2'(1525)$	$2.13 \pm 0.28 \pm 0.72$
$f_0(1500)\to K\bar{K}$	$2.08 \pm 0.27 \pm 0.65$
$f_0(1710)\to KK$	$2.02 \pm 0.51 \pm 0.35$

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Γ_{34}	$\gamma f_0(980)$	< 3	$\times 10^{-5}$	90%
Γ_{35}	$\gamma f_2'(1525)$	$(3.7\ ^{+1.2}_{-1.1}) \times 10^{-5}$		
Γ_{36}	$\gamma f_2(1270)$	$(1.01 \pm 0.09) \times 10^{-4}$		
Γ_{38}	$\gamma f_0(1500)$	< 1.5	$\times 10^{-5}$	90%
Γ_{39}	$\gamma f_0(1710)$	< 2.6	$\times 10^{-4}$	90%
Γ_{40}	$\gamma f_0(1710) \to \gamma K^+ K^-$	< 7	$\times 10^{-6}$	90%

PDG

- We correct the efficiency corrected yields for isospin and for PDG measured branching fractions.

- $\dfrac{\mathcal{B}(f_0(1710)\to\pi\pi)}{\mathcal{B}(f_0(1710)\to K\bar{K})} = 0.64 \pm 0.27_{\text{stat}} \pm 0.18_{\text{sys}}$

$0.41\ ^{+0.11}_{-0.17}$

BES2 $e^+e^- \to J/\psi \to \gamma\pi^+\pi^-$

Conclusion

- BABAR is still producing many interesting results!
- Update of the 2005 pioneering study of B➔ $K^{\pm}$ X
  - Improved BRs for classical charmonium
  - Same upper limit for B➔ $K^{\pm}$ X(3872)
  - BELLE-2 recent results in very good agreement
- Study of J/ψ ➔ $K^0K^{\pm}\pi^{\mu}$
  - First Dalitz plot analysis- Precise determination of K^{*0} dominance

    Phys. Rev. D95(2017) 072007. arxiv 1702.01551
- Study of « glueball-like » mesons in the decay Y(1S) ➔ $\gamma\pi\pi$ and γKK
  - $\pi\pi$ channel : $f_2(1270)$ dominance, S wave measured for the first time
  - KK channel : $f_2(1710)$ present, ratio $\pi\pi$/KK measured, BR in agreement with glueball candidate

    arxiv 1804.04044 accepted for PRD publication