Search for $Z(4430)^-$ at BaBar

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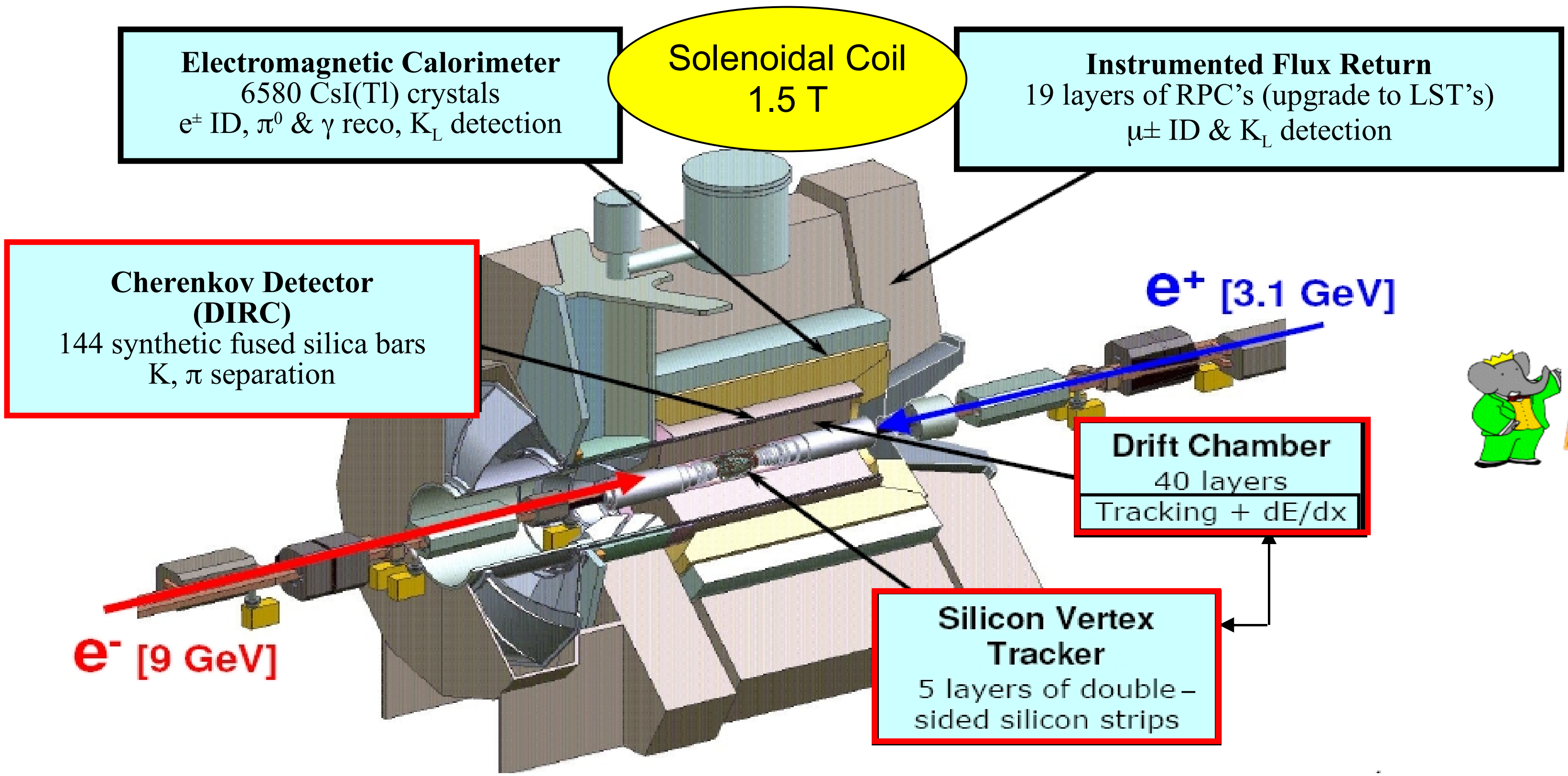
representing the BaBar collaboration

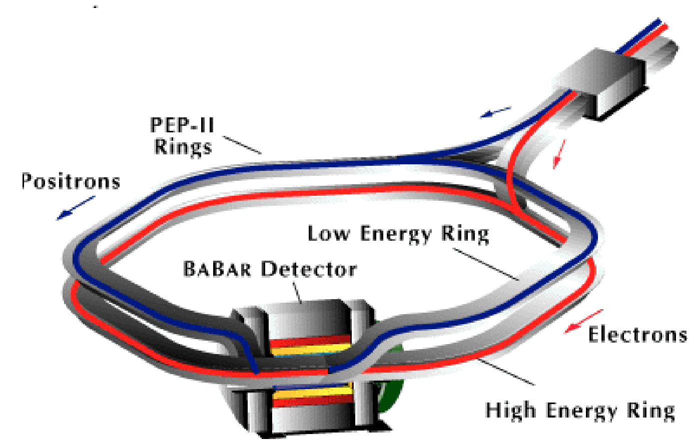
Charm 2009 -- Leimen (Germany) May 20-22, 2009

Outline:

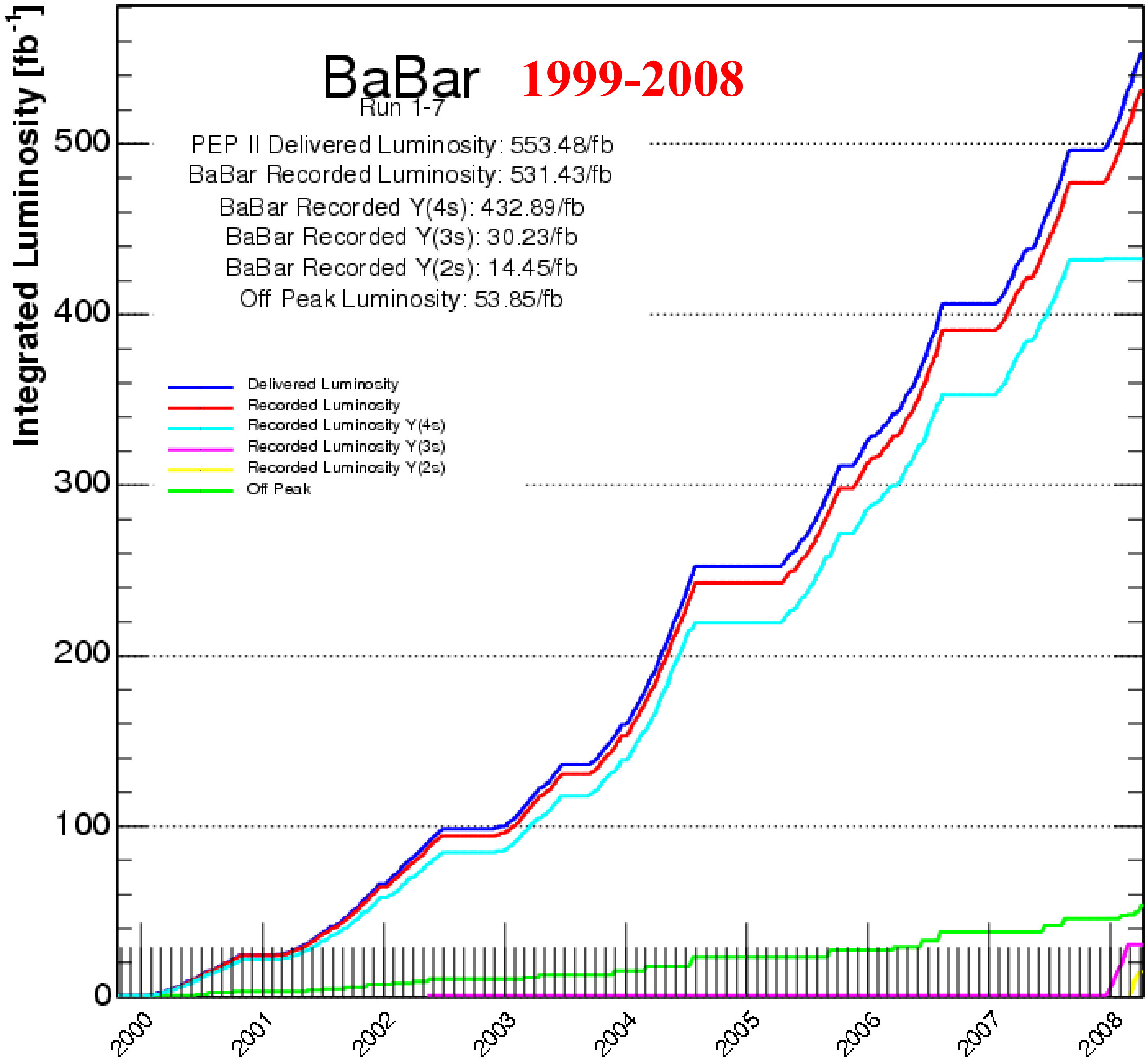
- Study $B^{-/0} \to J/\psi\ \pi^-\ K^{0/+}$ and $B^{-/0} \to \psi(2S)\ \pi^-\ K^{0/+}$
- describe $K\pi$ mass and angular structure
- search for $\psi\pi$ signal on top of $K\pi$ reflections
- results

BaBar and PEP-II





BaBar data



476 million Υ(4S)

122 million Υ(3S)

101 million Υ(2S)

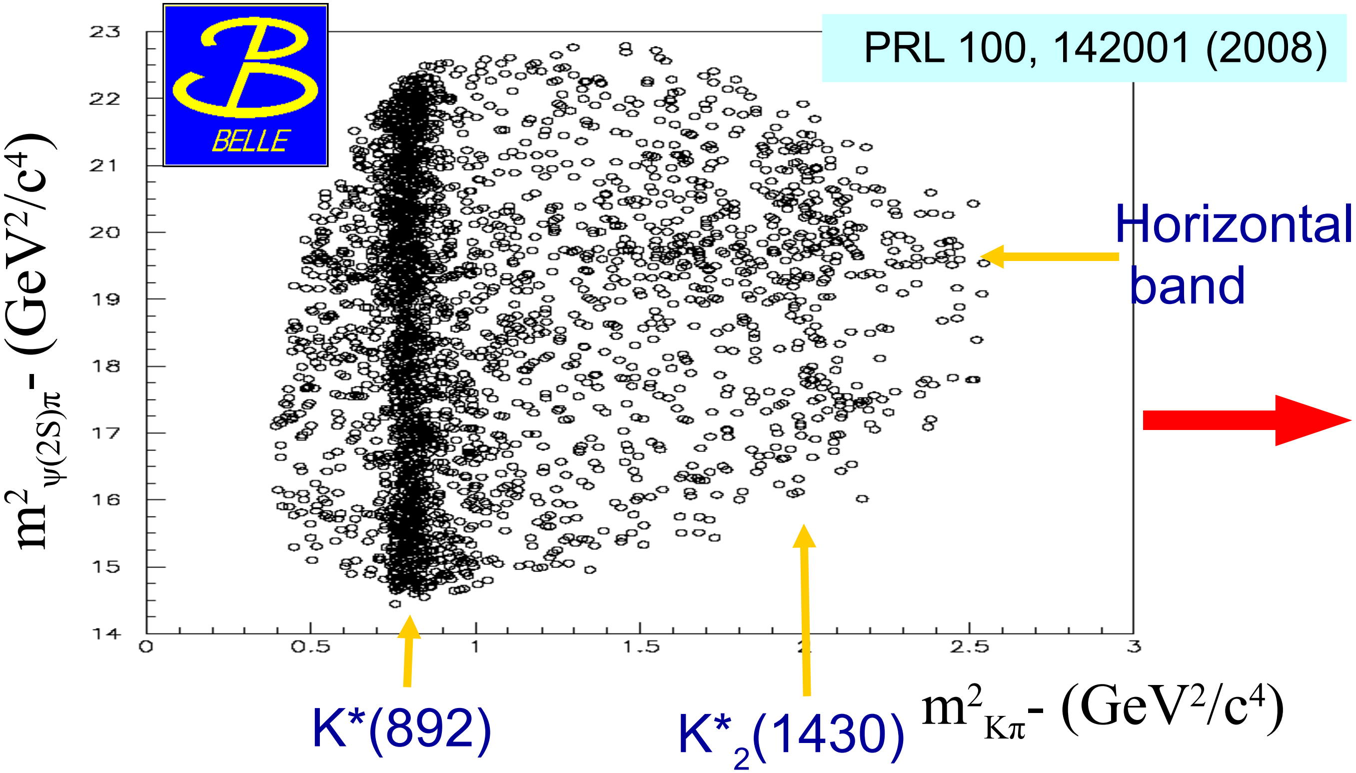
~ 50 fb^{-1} “off-peak” including scan above Υ(4S)

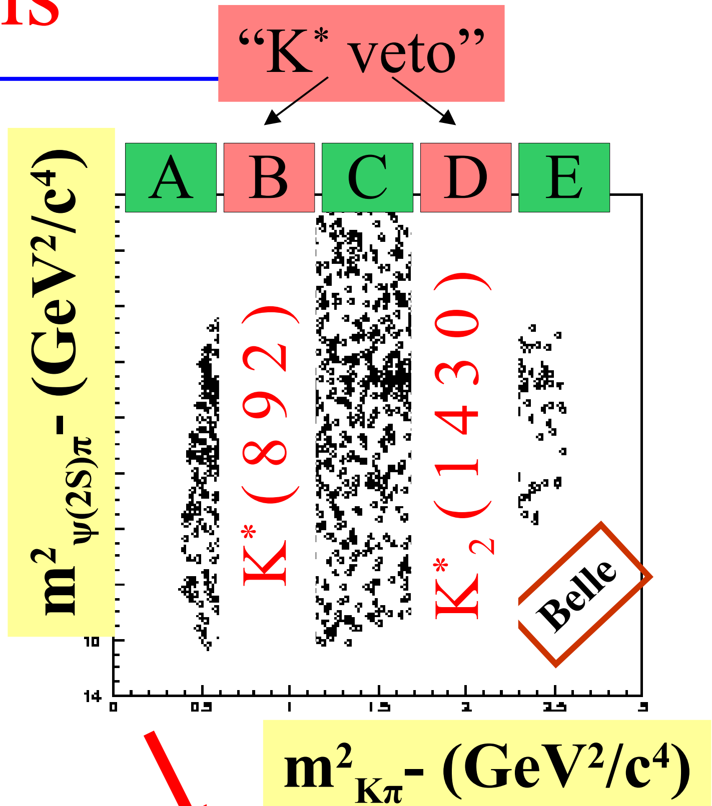
large samples of

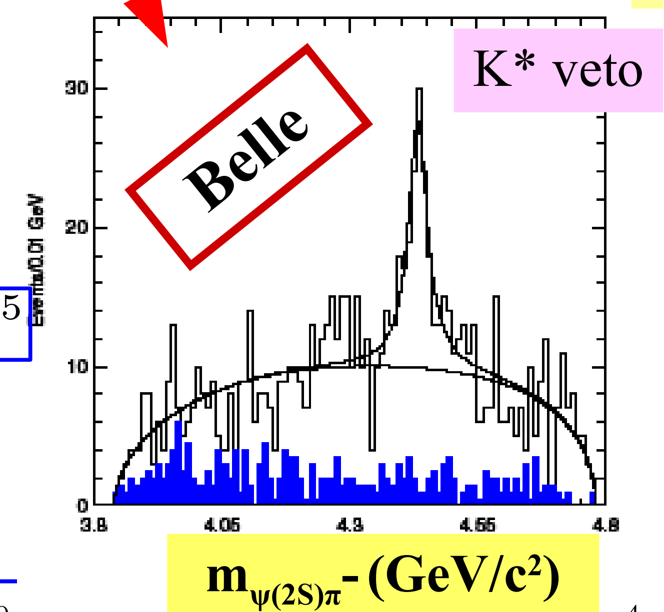
- charmed hadrons (mesons/baryons)
- $c\bar{c}$ mesons
- τ's

still working hard on PHYSICS....

$Z(4430)^-$ at Belle: the first analysis







121 ± 30 ev 6.5σ

$$M = 4433 \pm 4 \pm 2 \text{ MeV/c}^2$$

$$\Gamma = 43^{+18}_{-13}{}^{+30}_{-13} \text{ MeV}$$

$$\mathcal{B}(B^0 \to Z^- K^+)\mathcal{B}(Z^- \to \psi(2S)\pi^-) = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$

first genuine $c\bar{c}d\bar{u}$ "tetraquark" candidate:
charged and carries hidden charm

Search for $Z(4430)^-$ at BaBar

Search in four B decay modes:

$B^{-/0} \to J/\psi\ \pi^- K^{0/+}$

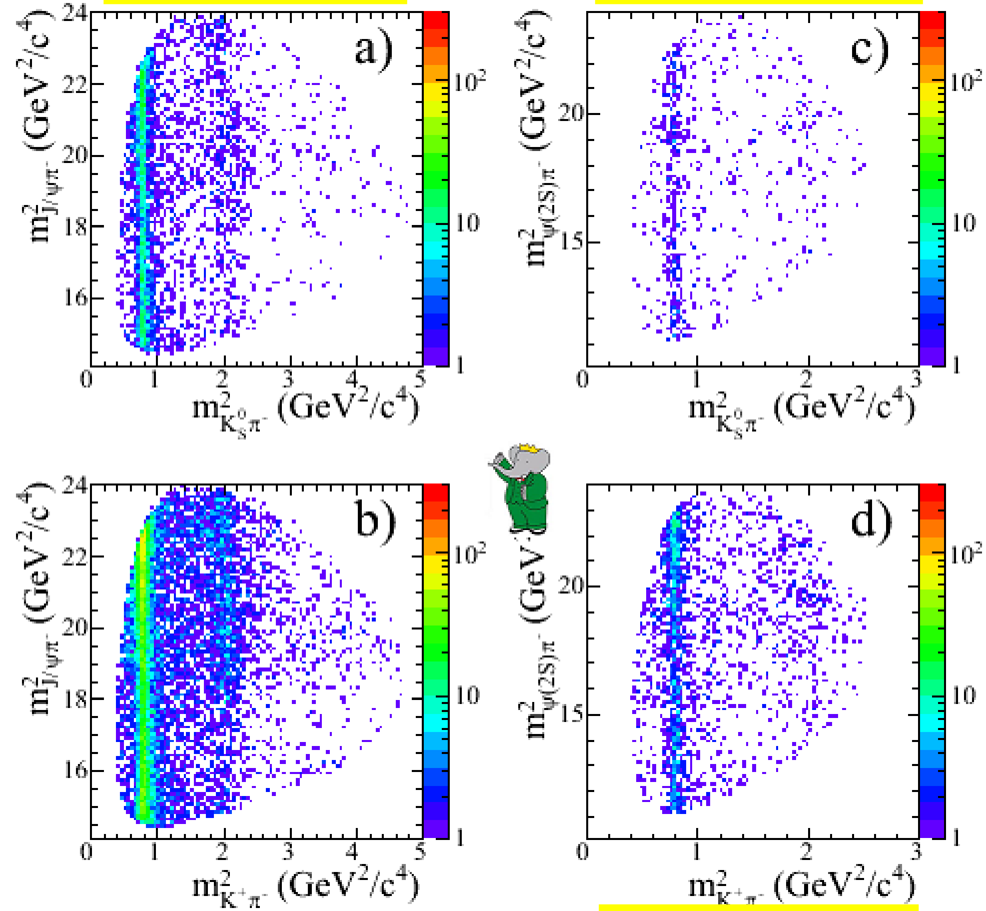
$B^{-/0} \to \psi(2S)\ \pi^- K^{0/+}$

[in the following ψ denotes J/ψ and $\psi(2S)$]

- subtract background (sidebands)
- correct for efficiency event by event
- describe in detail the $K\pi^-$ system
  - ➔ structures in the $K\pi^-$ mass and angular distributions dominate each Dalitz plot

Project each $K\pi^-$ description onto the relevant $\psi\pi^-$ mass distribution to investigate the need for $Z(4430)^-$ signal above this “ $K\pi^-$ background”

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

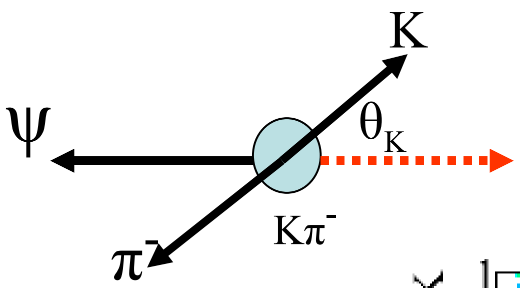


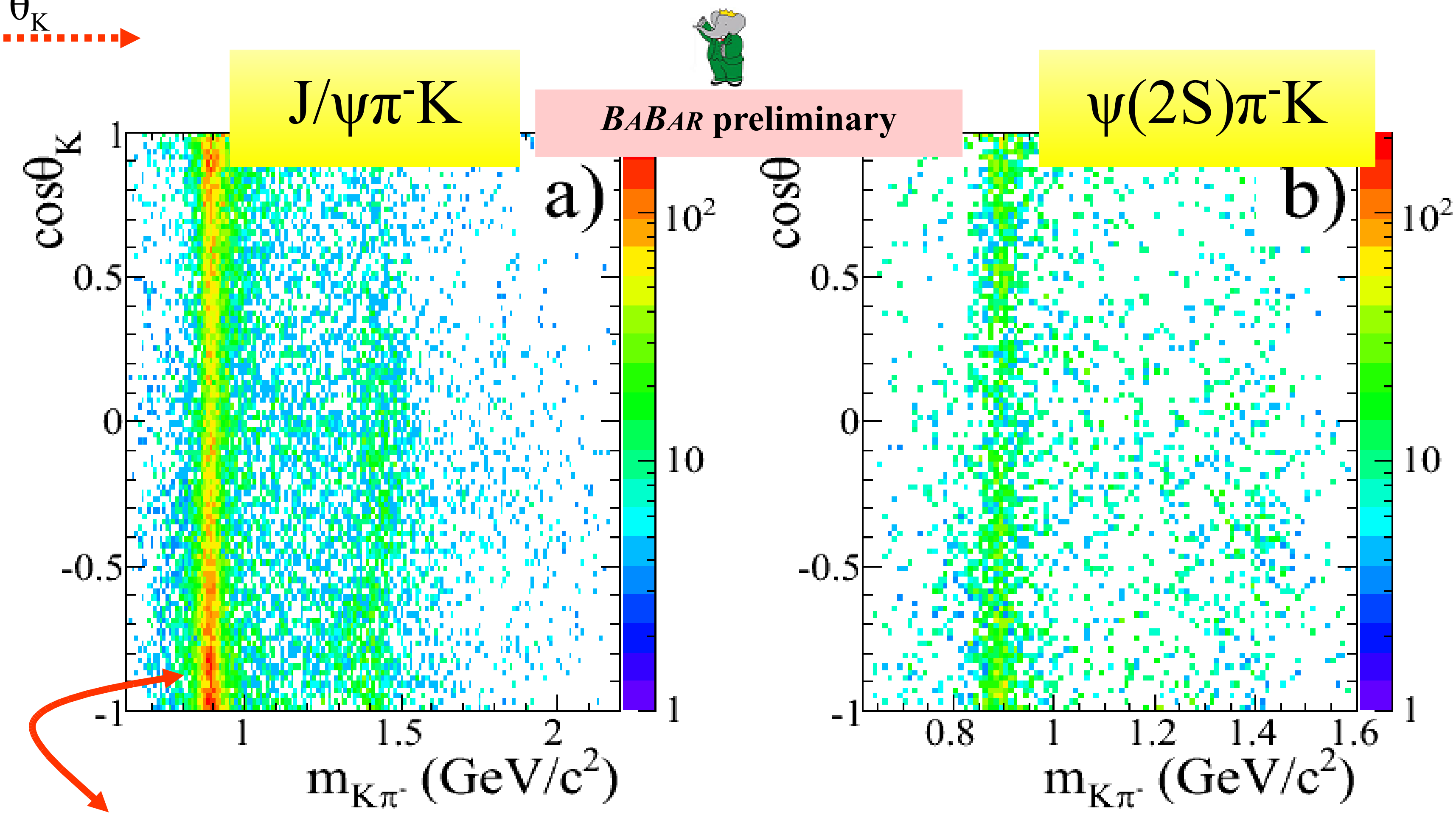
$B^0 \to J/\psi \pi^- K^+$ $B^0 \to \psi(2S) \pi^- K^+$

***BABAR* preliminary**

arXiv:0811.0564
accepted for publication in PRD

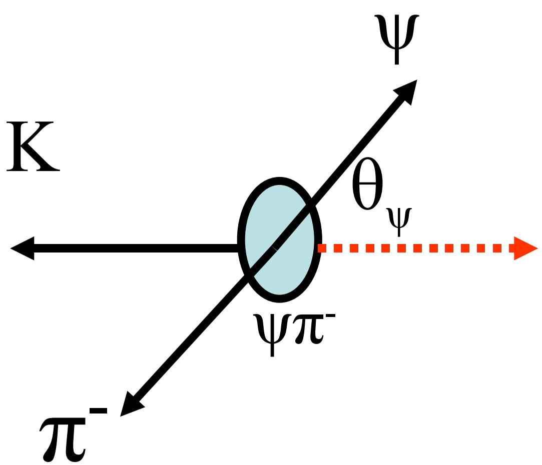
"Square" Dalitz plot





More backward than forward

Kπ reflections and the Z(4430)⁻



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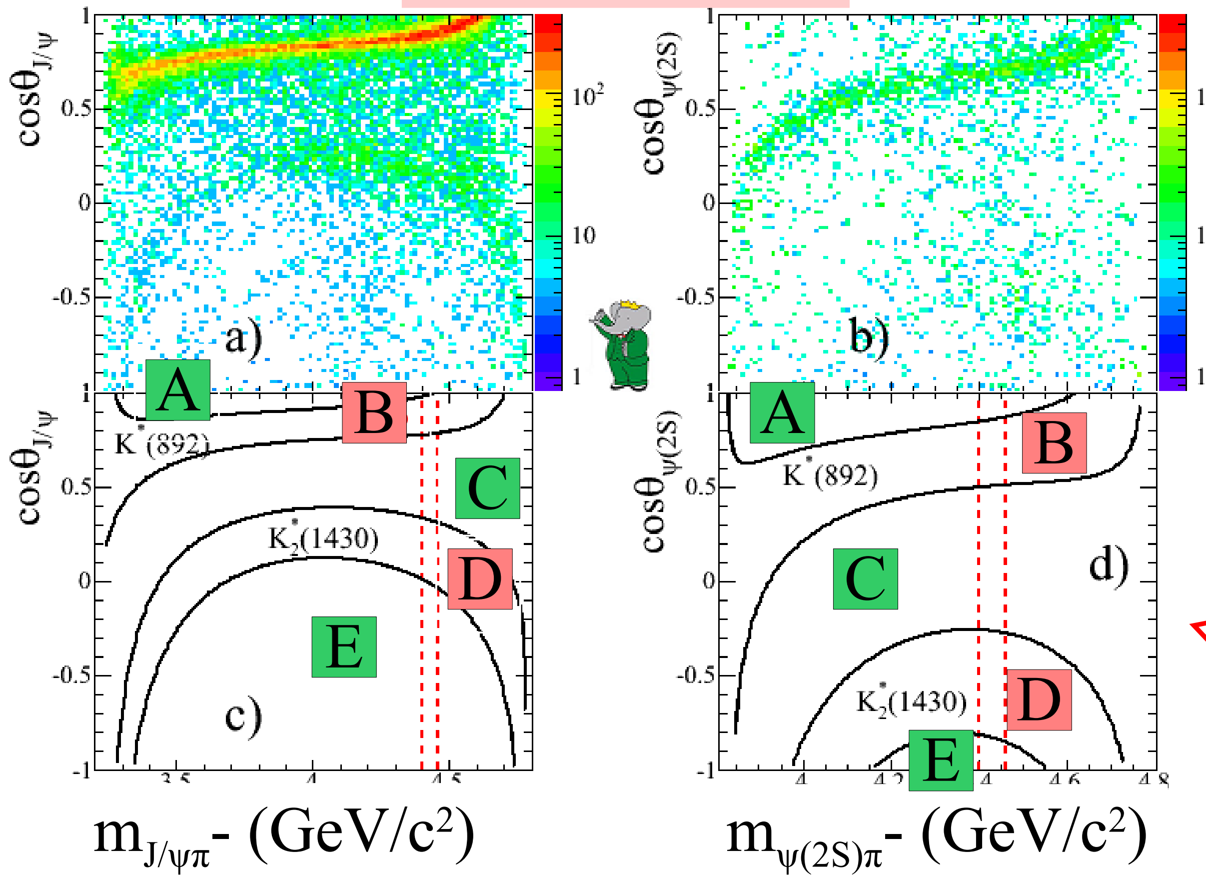


- $m_{\psi\pi}$ peaks at high values because of the asymmetry in the $\cos\theta_K$ distributions
- The K^* regions dominate, and affect different regions of $\cos\theta_\psi$ for J/ψ and $\psi(2S)$
- The K^* veto removes approximately half of the angular distribution at the $Z(4430)^-$

$K\pi^-$ description: S, P and D wave intensities

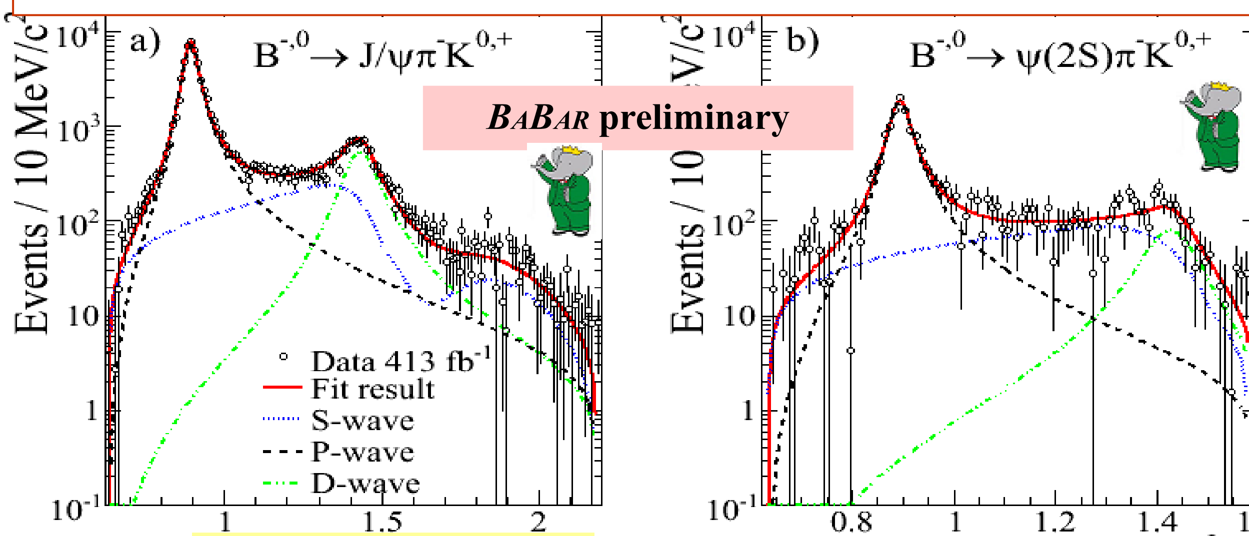
Fit with S- (LASS), P-, and D-wave intensity

Mode	Events	m(K*(892)) (MeV/c2)	Γ(K*(892)) (MeV)	S-wave (%)	P-wave (%)	D-wave (%)
$B^0 \to J/\psi\pi^- K^+$	57231±561	895.5±0.4	48.9±1.0	15.7±0.8	73.5±0.7	10.8±0.5
$B^- \to J/\psi\pi^- K^0_S$	20985±393	892.9±0.8	49.0±1.9	17.0±1.6	72.5±1.3	10.5±1.0
$B^0 \to \psi(2S)\pi^- K^+$	13237±377	895.8±1.0	43.8±3.0	25.4±2.2	68.2±2.0	6.4±1.2
$B^- \to \psi(2S)\pi^- K^0_S$	5016±292	891.6±2.1	44.8±6.0	23.4±4.5	71.3±4.4	5.3±2.7

compatible with being equal (first two rows)

compatible with being equal (last two rows)

It is justified to combine the K^0_S and K^+ modes



$m_{K\pi^-}$ (GeV/c^2) $m_{K\pi^-}$ (GeV/c^2)

B→ψ(Kπ): *S*-, *P*-, and *D*-wave moments

The expression of the angular distribution for B→ψπK is complicated
(see e.g. S. T'Jampens, Ph.D. Thesis, Universite Paris XI (2002), SLAC-R-838)

Integrating over the ψ decay angles: 5 observables, 7 amplitudes, 6 relative phases

$$N = S_0^2 + P_0^2 + D_0^2 + P_{+1}^2 + P_{-1}^2 + D_{+1}^2 + D_{-1}^2$$

Complete Kπ amplitude analysis of DP not possible without making assumptions

$$\langle P_1^U \rangle = S_0 P_0 \cos\left(\delta_{S_0} - \delta_{P_0}\right) + 2\sqrt{\frac{2}{5}} P_0 D_0 \cos\left(\delta_{P_0} - \delta_{D_0}\right) + \sqrt{\frac{6}{5}}\left[P_{+1} D_{+1} \cos\left(\delta_{P_{+1}} - \delta_{D_{+1}}\right) + P_{-1} D_{-1} \cos\left(\delta_{P_{-1}} - \delta_{D_{-1}}\right)\right]$$

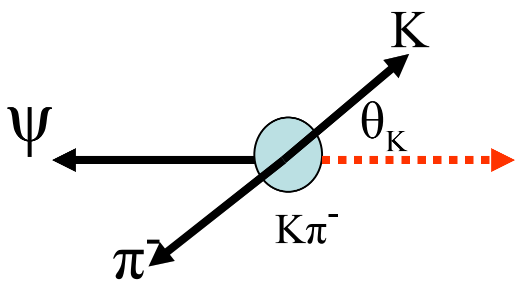
$$\langle P_2^U \rangle = \sqrt{\frac{2}{5}} P_0^2 + \sqrt{\frac{10}{7}} D_0^2 + \sqrt{2} S_0 D_0 \cos\left(\delta_{S_0} - \delta_{D_0}\right) - \left[\frac{1}{\sqrt{10}}\left(P_{+1}^2 + P_{-1}^2\right) + \frac{5\sqrt{10}}{28}\left(D_{+1}^2 + D_{-1}^2\right)\right]$$

$$\langle P_3^U \rangle = 3\sqrt{\frac{6}{35}} P_0 D_0 \cos\left(\delta_{P_0} - \delta_{D_0}\right) - 3\sqrt{\frac{2}{35}}\left[P_{+1} D_{+1} \cos\left(\delta_{P_{+1}} - \delta_{D_{+1}}\right) + P_{-1} D_{-1} \cos\left(\delta_{P_{-1}} - \delta_{D_{-1}}\right)\right]$$

$$\langle P_4^U \rangle = \frac{3\sqrt{2}}{7} D_0^2 - \frac{2\sqrt{2}}{7}\left(D_{+1}^2 + D_{-1}^2\right)$$

For Kπ scattering

Legendre polynomial moments description of $K\pi^-$ angular structure

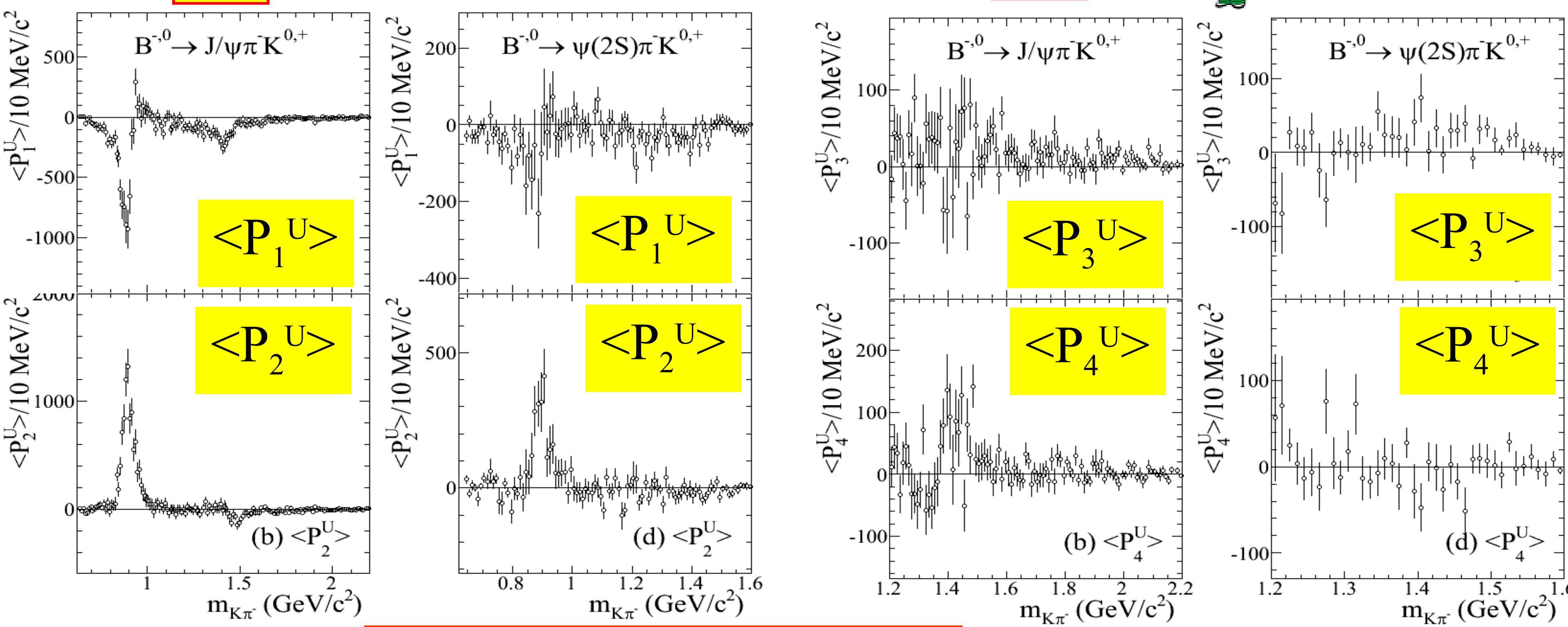


assume only S,P and D wave

$$\frac{dN}{d\cos\theta_K} = N\sum_{i=0}^{4} \langle P_i \rangle P_i(\cos\theta_K) = \frac{N}{2} + \sum_{i=1}^{4} \left(N\langle P_i\rangle\right) P_i(\cos\theta_K)$$

Unnormalized moment $\langle P_i^U \rangle$

J/ψ | ψ(2S) | J/ψ | ψ(2S)



$\langle P_1^U \rangle$ and $\langle P_2^U \rangle$ dominant

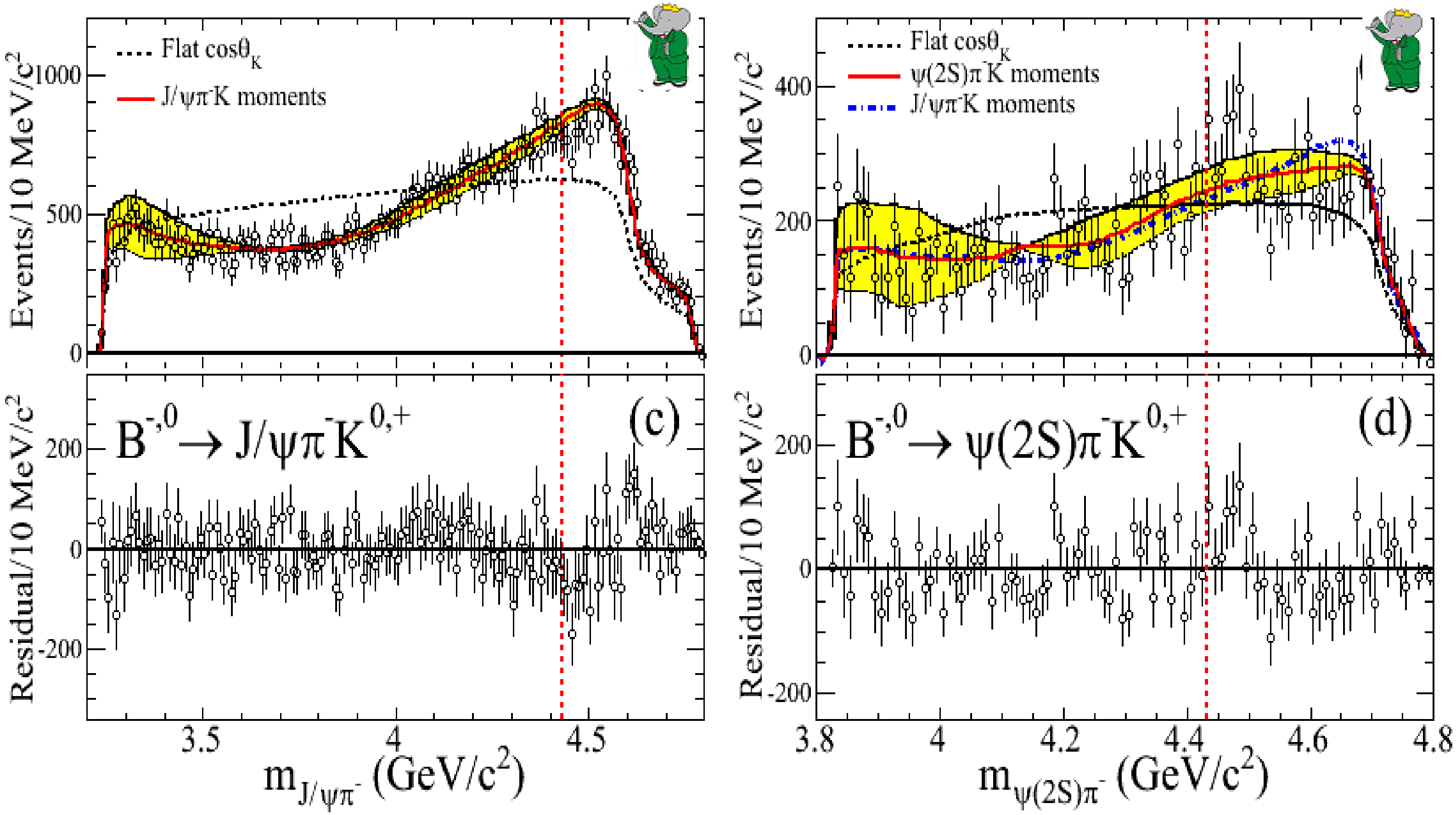
***BABAR* preliminary**

Kπ⁻ reflection onto the ψπ⁻ projection

10M events generated flat in $\cos\theta_K$ according to the $m_{K\pi^-}$ fit function

- Weight each event using Legendre moments: $w_j = 1 + \sum_{i=1}^{4} \langle P_i^N \rangle P_i(\cos\theta_{Kj})$

i^{th} **normalized** moment, obtained from data by linear interpolation → $\langle P_i^N \rangle = \frac{2}{N} \langle P_i^U \rangle$

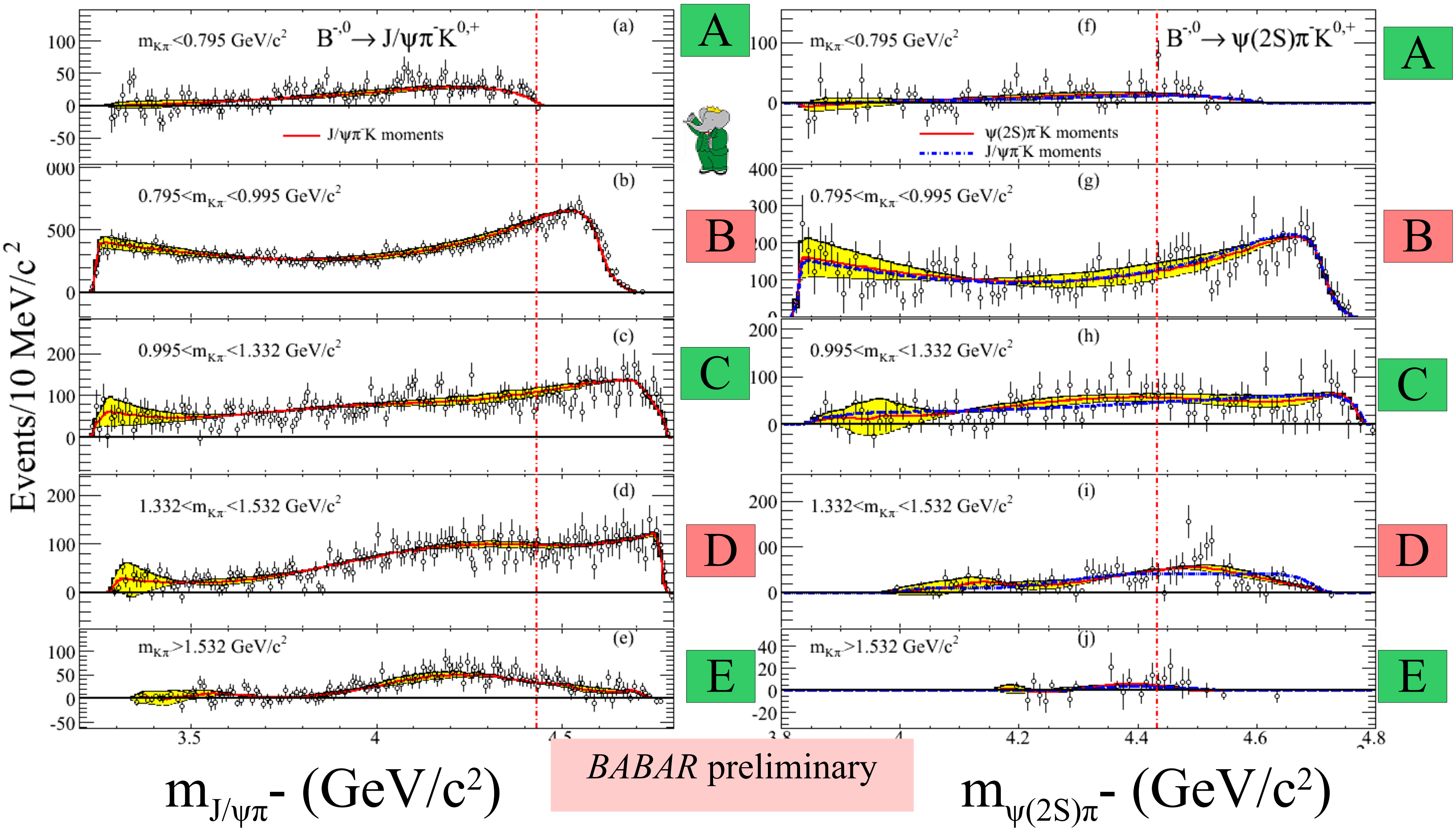


Compare $\psi\pi^-$ distribution in data after background subtraction and efficiency correction to what expected from $K\pi^-$ reflections

$K\pi^-$ reflections reproduce data

$m_{\psi\pi^-}$- mass distributions in intervals of $m_{K\pi}$

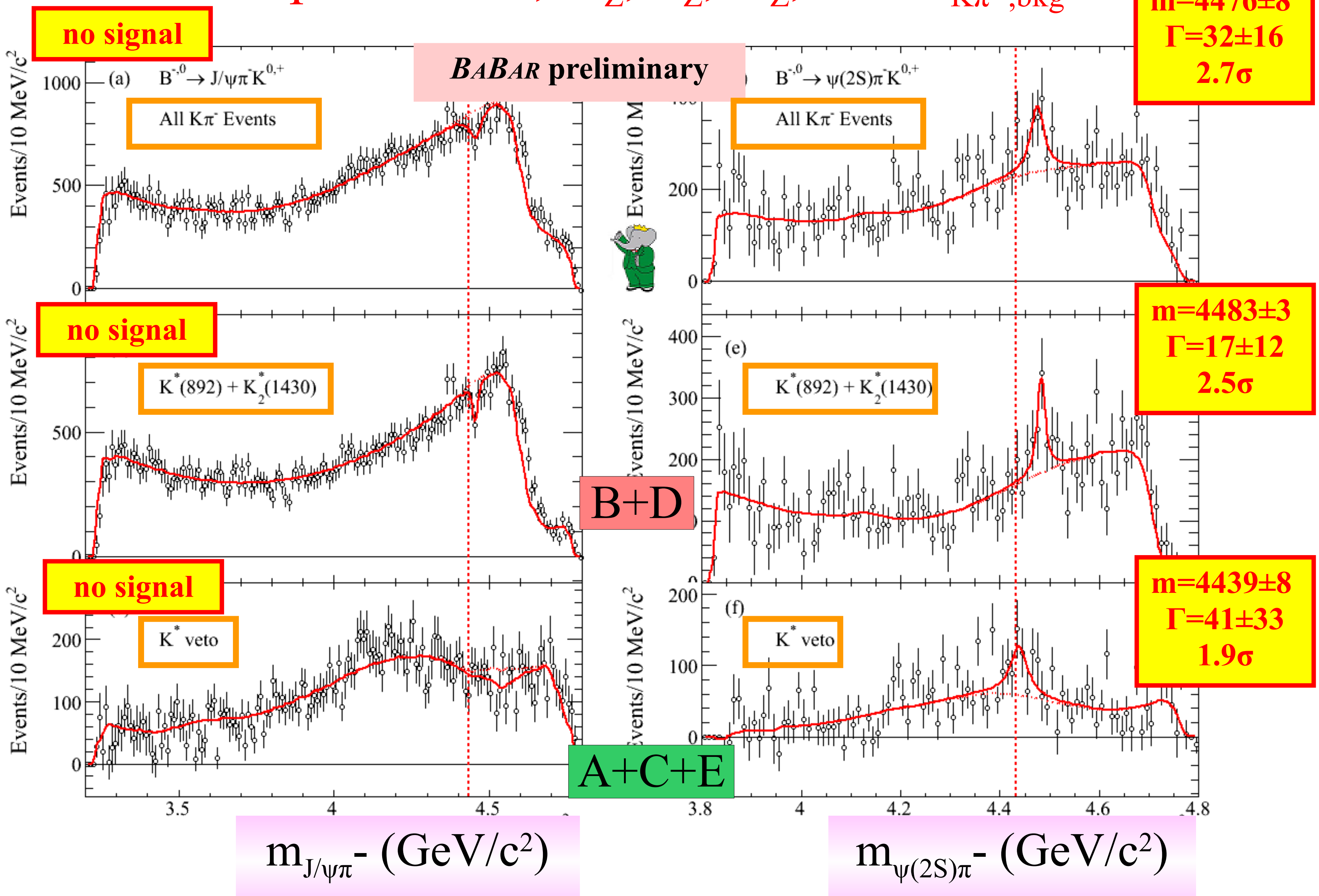
Five $K\pi^-$ intervals defined (A,B,C,D,E) by Belle K^* veto; **one normalization factor**



The $K\pi^-$ reflections reproduce the data in all mass intervals

Fit for a Z(4430)$^-$ signal in the $\psi\pi^-$ spectra

Four free parameters; m_Z, Γ_Z, N_Z, and $N_{K\pi^-,bkg}$



Fit results fixing m_Z and Γ_Z to Belle's values

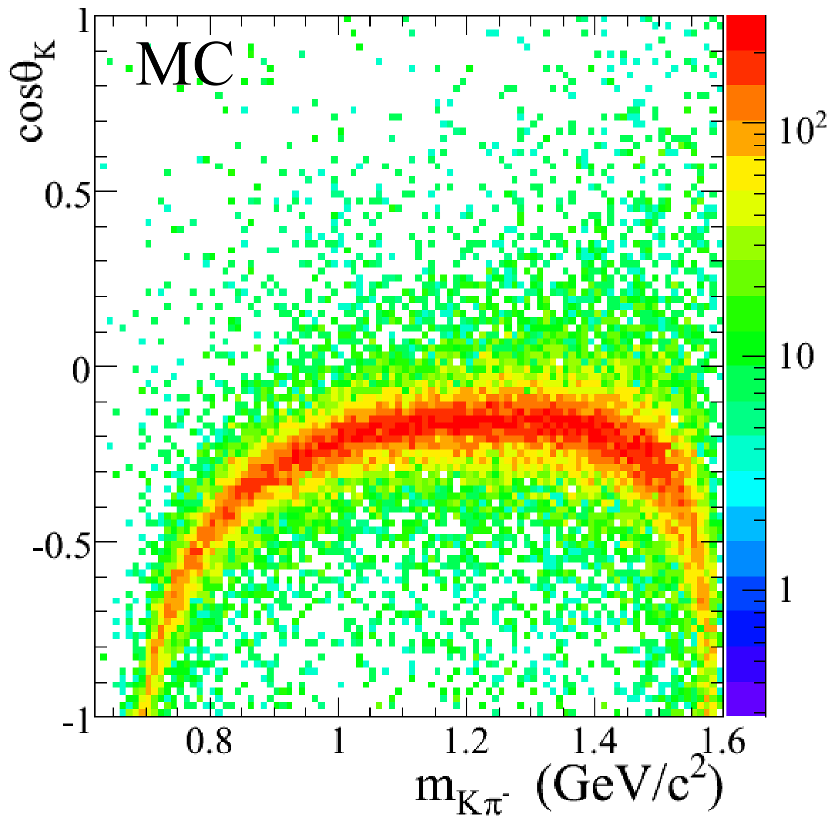
All $K\pi^-$ mass values

***BaBar* preliminary**

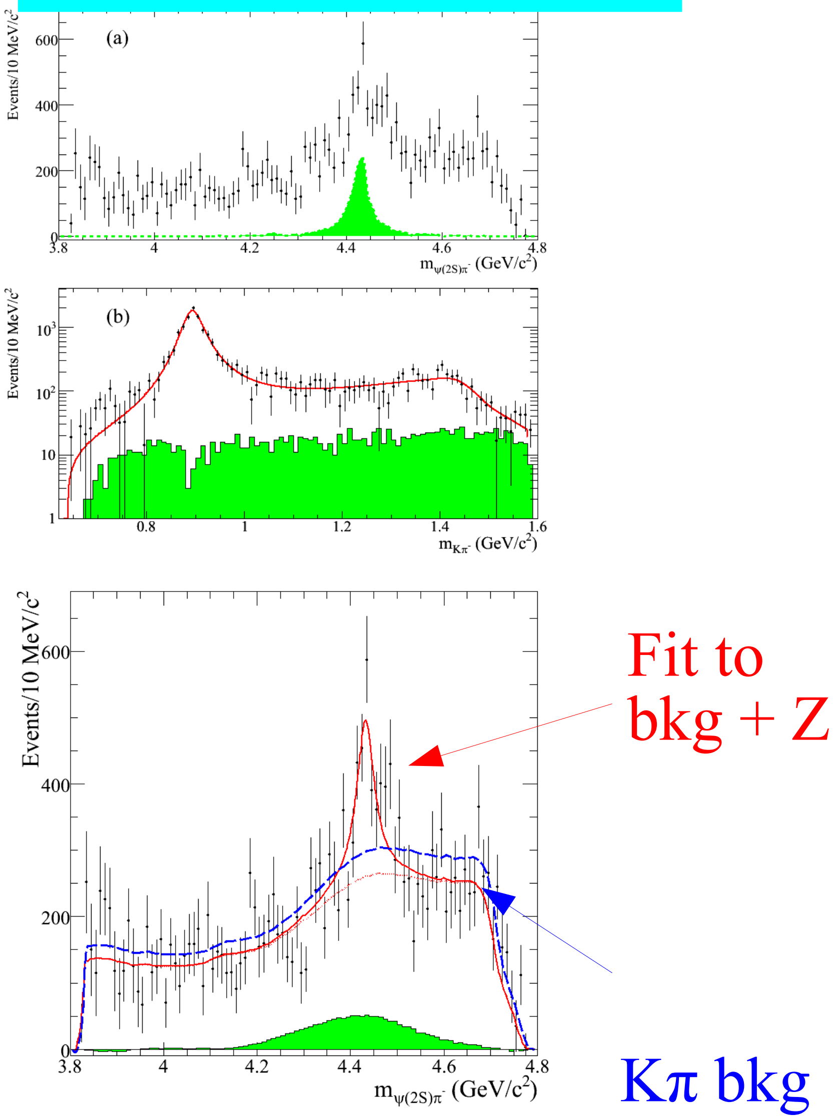
Decay mode	$Z(4430)^-$ signal	Branching fraction ($\times 10^{-5}$)	Upper limit ($\times 10^{-5}$) (@95% C.L.)
$B^- \to Z^- \bar{K}^0$, $Z^- \to J/\psi\pi^-$	-17 ± 140	-0.1 ± 0.8	< 1.5
$B^0 \to Z^- K^+$, $Z^- \to J/\psi\pi^-$	-670 ± 203	-1.2 ± 0.4	< 0.4
$B^- \to Z^- \bar{K}^0$, $Z^- \to \psi(2S)\pi^-$	148 ± 117	2.0 ± 1.7	< 4.7
$B^0 \to Z^- K^+$, $Z^- \to \psi(2S)\pi^-$	415 ± 170	1.9 ± 0.8	< 3.1

Belle: $BF(B^0 \to Z^- K^+, Z^- \to \psi(2S)\pi^-) = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$

Effect of adding a MC Z(4430)$^-$ signal



embed MC in ψ(2S)data



Adding an incoherent S-wave BW Z(4430)$^-$ signal

our procedure does not destroy it

Conclusions

- We have searched for the $Z(4430)^-$ with the full BaBar data sample in

$$B^{-/0}\to J/\psi\ \pi^-\ K^{0/+} \text{ and } B^{-/0}\to \psi(2S)\ \pi^-\ K^{0/+}$$

- The $K\pi^-$ system can be described by S-, P-, and D-wave intensity contributions
- The $m_{\psi\pi^-}$ distributions can be understood as reflections of the mass and angular structure of the $K\pi^-$ system
- No significant $Z(4430)^-$ signal is observed in any of the decay modes which have been studied

arXiv:0811.0564 accepted for publication in PRD

Backup slides

Fit result

- $B \rightarrow J/\psi \pi^- K$ (mass & width free) ➔ negative, or no, BW signal is obtained
- $B \rightarrow \psi(2S) \pi^- K$ (mass and width free):
  - Shifted mass enhancement for overall $K\pi^-$ range:

    $m = 4476 \pm 8$ MeV/c^2; $\Gamma = 32 \pm 16$ MeV; signal size: 2.7σ

  - Shifted mass enhancement in the $K^*(892)$ and $K^*_2(1430)$ region:

    $m = 4483 \pm 3$ MeV/c^2; $\Gamma = 17 \pm 12$ MeV; signal size 2.5σ

  - mass enhancement with the K* veto:

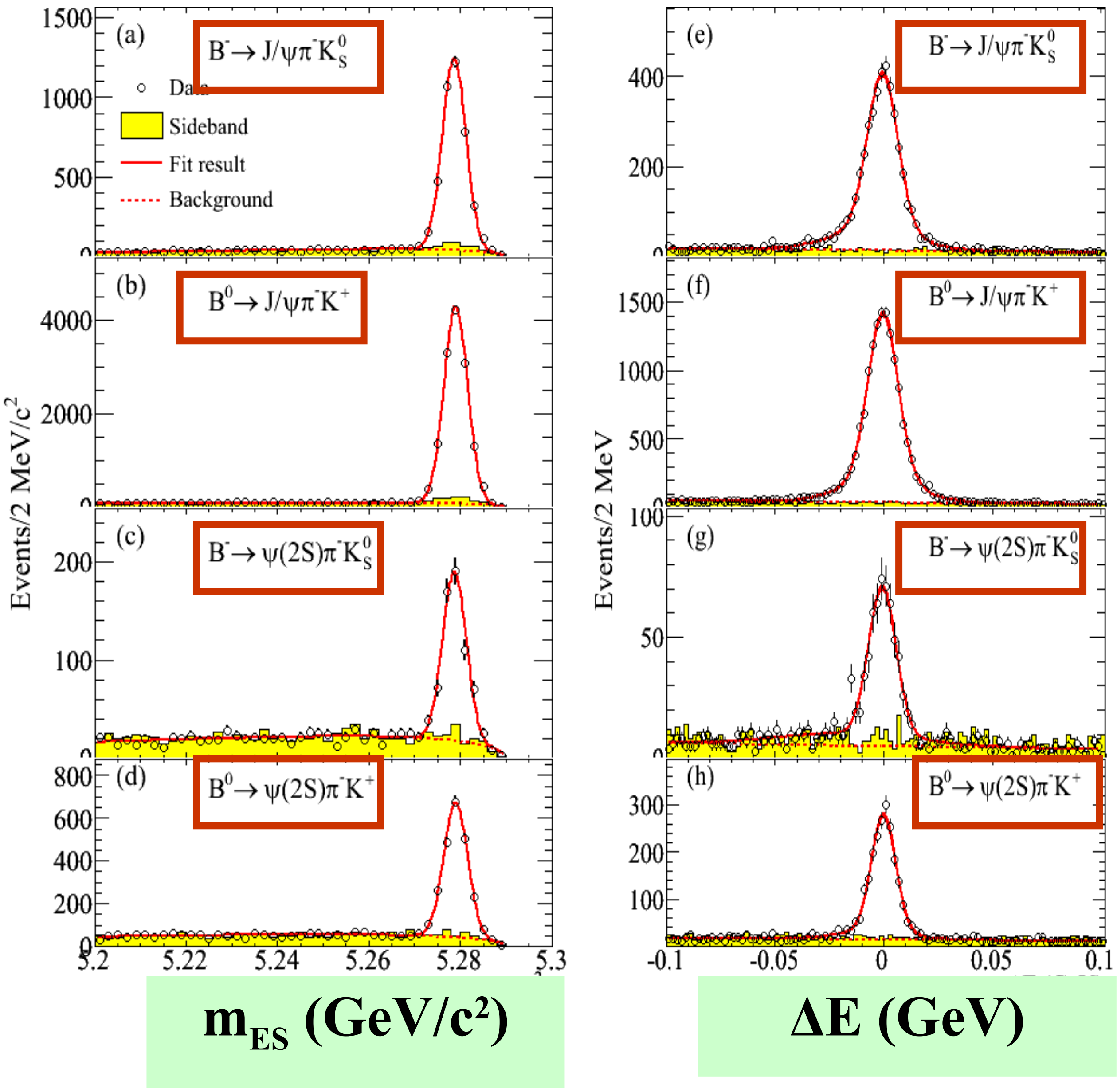
    $m = 4439 \pm 8$ MeV/c^2; $\Gamma = 41 \pm 33$ MeV; signal size 1.9σ

- No significant $Z(4430)^-$ signal is observed

Event selection criteria

Selection category	Criterion
$J/\psi \rightarrow e^+e^-$ mass **$J/\psi \rightarrow \mu^+\mu^-$ mass**	$2.95 < m(ee) < 3.14$ GeV/c^2 $3.06 < m(\mu\mu) < 3.14$ GeV/c^2 J/ψ mass constraint applied
$\psi(2S) \rightarrow e^+e^-$ mass **$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$** **$(J/\psi \rightarrow e^+e^-)$ mass**	$3.44 < m(ee) < 3.74$ GeV/c^2 $3.655 < m(J/\psi\pi\pi) < 3.715$ GeV/c^2
$\psi(2S) \rightarrow \mu^+\mu^-$ mass **$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$** **$(J/\psi \rightarrow \mu^+\mu^-)$ mass**	$3.64 < m(\mu\mu) < 3.74$ GeV/c^2 $3.655 < m(J/\psi\pi\pi) < 3.715$ GeV/c^2 $\psi(2S)$ mass constraint applied
$K_S \rightarrow \pi^+\pi^-$ mass **Flight length significance**	$472 < m(\pi\pi) < 522$ MeV/c^2 Flight distance $> +3\sigma$
m_{ES}	$5.272 < m_{ES} < 5.286$ GeV/c^2
ΔE	$\lvert\Delta E\rvert < 20$ MeV Side-band $30 < \lvert\Delta E\rvert < 50$ MeV

ΔE and m_{ES} distributions



Clear m_{ES} and ΔE signals in all four decay modes; low background

Mass resolution and efficiency

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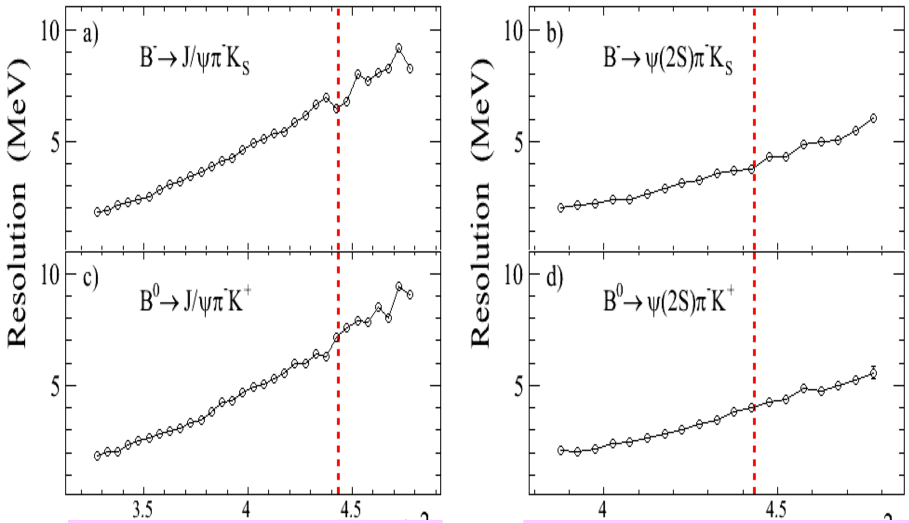
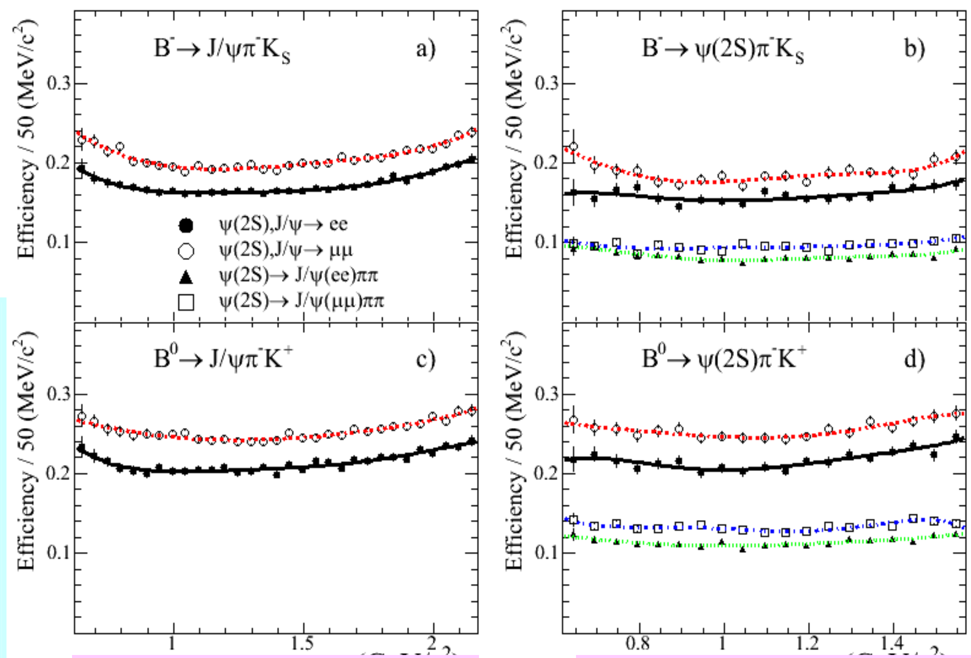


$m_{J/\psi\pi^-}$ (GeV/c^2) $m_{\psi(2S)\pi^-}$ (GeV/c^2)

- Mass resolution is ~7 (4) MeV/c2 in the decay modes with J/ψ (ψ(2S)) at m_Z
- same mass resolution at same Q-value

BABAR preliminary



$m_{K\pi^-}$ (GeV/c^2) $m_{K\pi^-}$ (GeV/c^2)

- The average efficiency is calculated separately for the different ψ decay modes (two modes for J/ψ and four for ψ(2S))
- The average efficiency is slightly higher for $\mu^+\mu^-$ than e^+e^-

Efficiency vs K/π momentum

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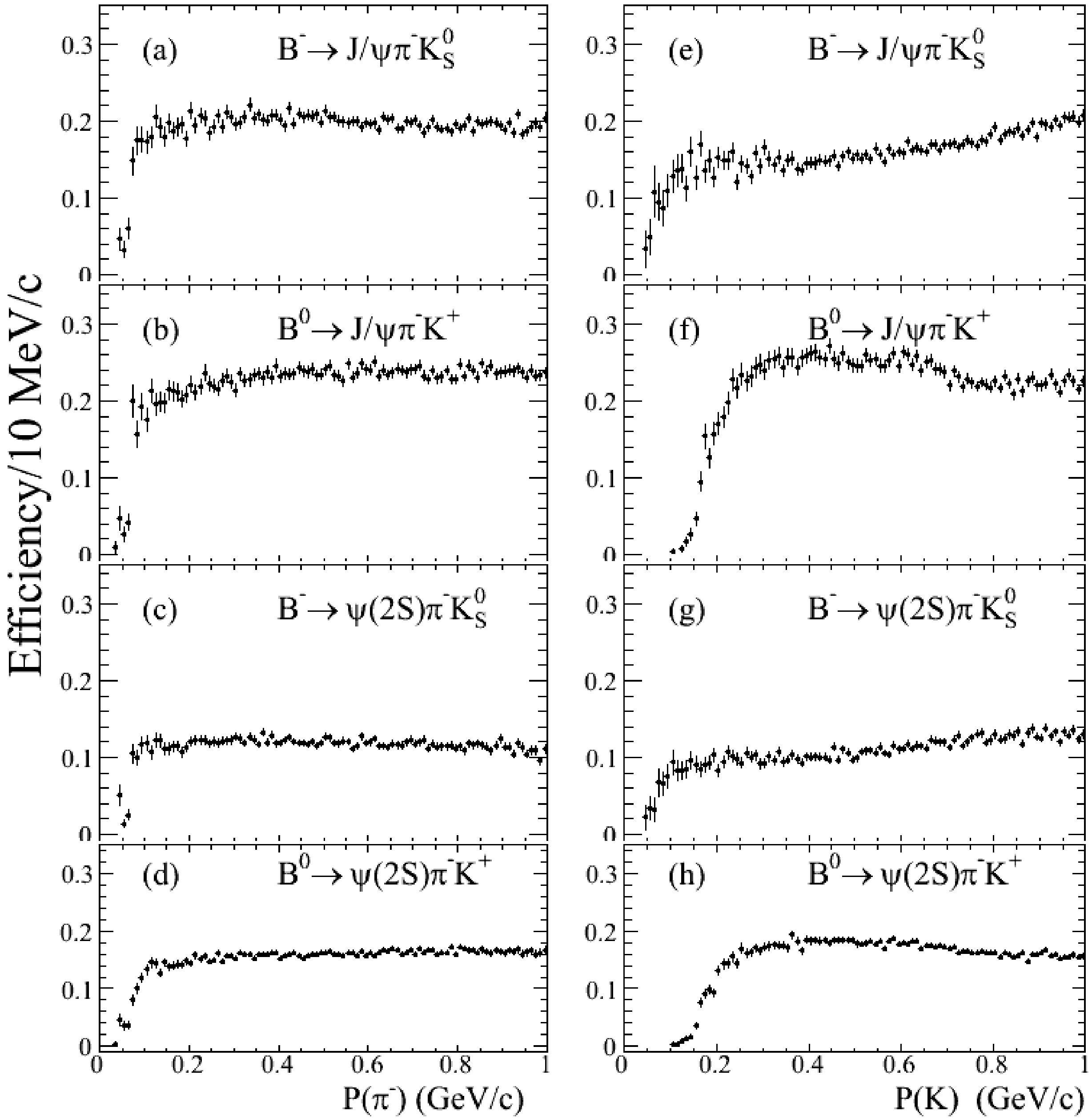
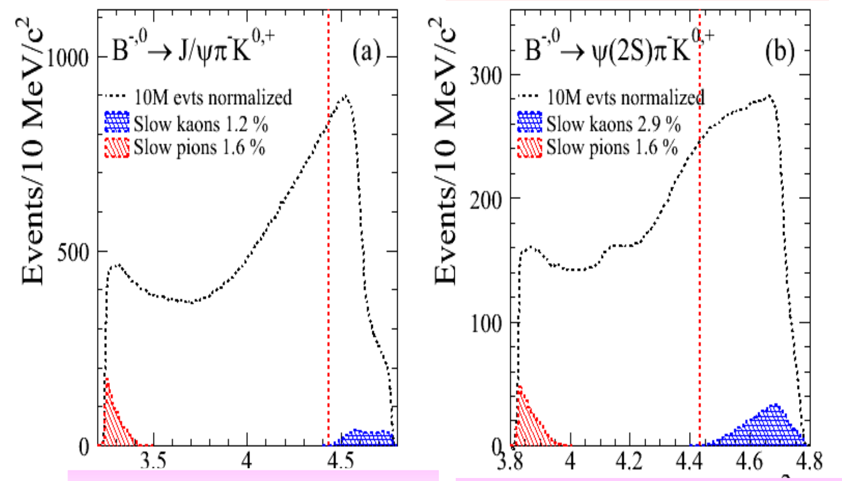




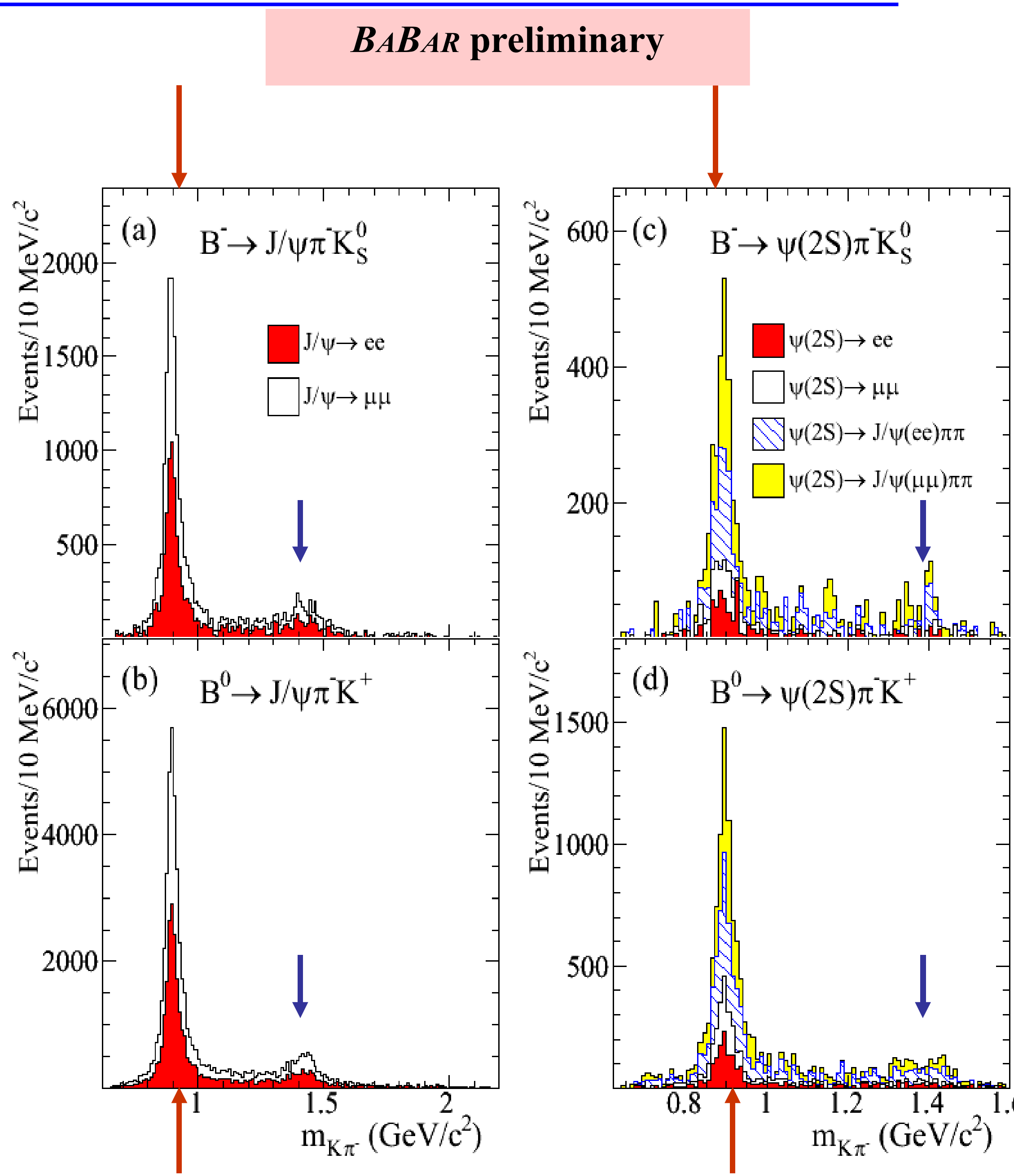
$m_{J/\psi\pi^-}$ (GeV/c²)

$m_{\psi(2S)\pi^-}$ (GeV/c²)

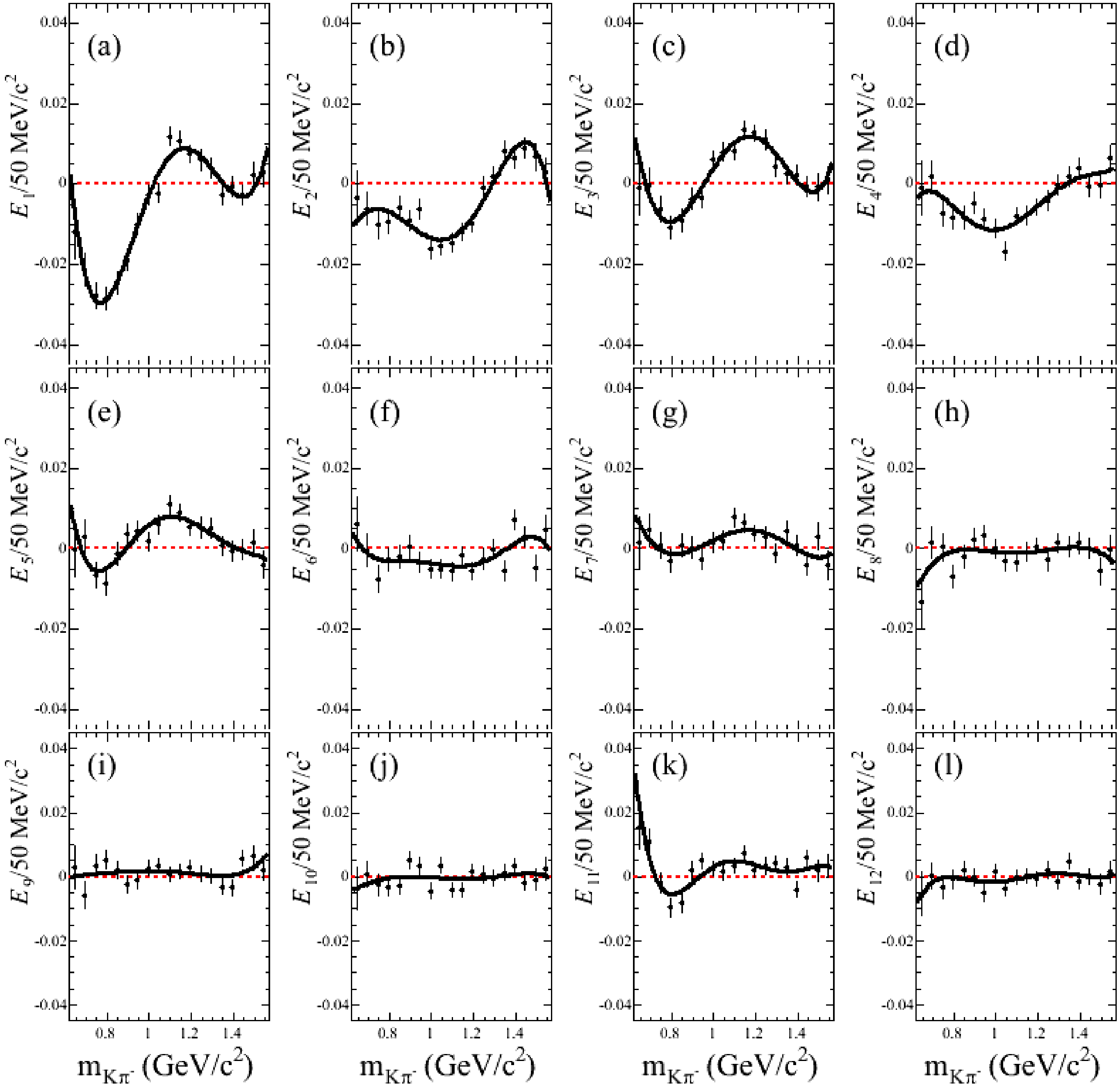
Efficiency losses due to slow π^-/K do not affect the $Z(4430)^-$ region

$K\pi$ mass distribution

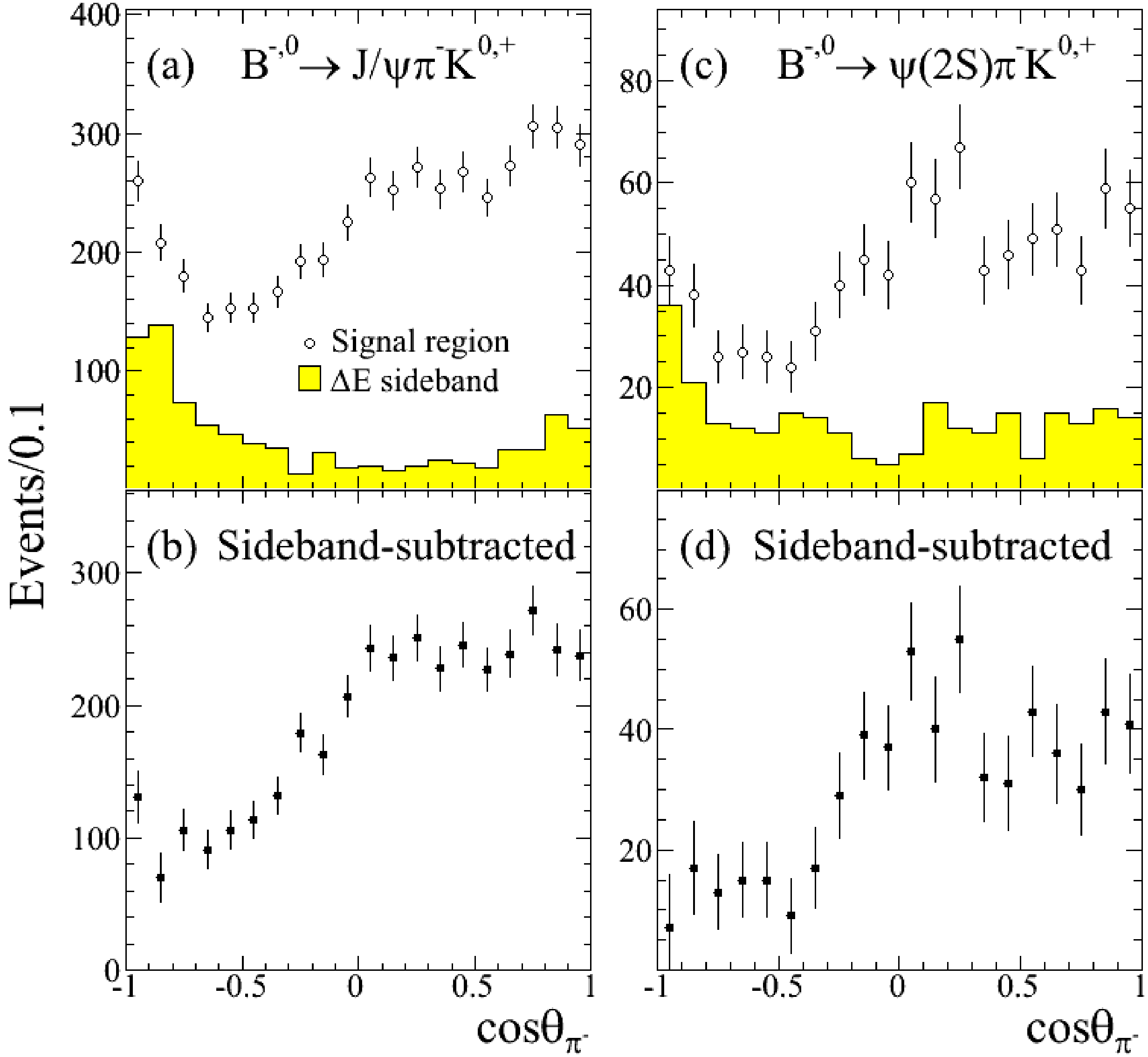
- The distributions are efficiency-corrected and side-band subtracted
- Clear $K^{*}(892)$ peaks are observed in all decay modes
- Clear $K^{*}_{2}(1430)$ peaks are obtained in the decay modes with J/ψ and consistent $K^{*}_{2}(1430)$ enhancements are obtained in the decay modes with ψ(2S)



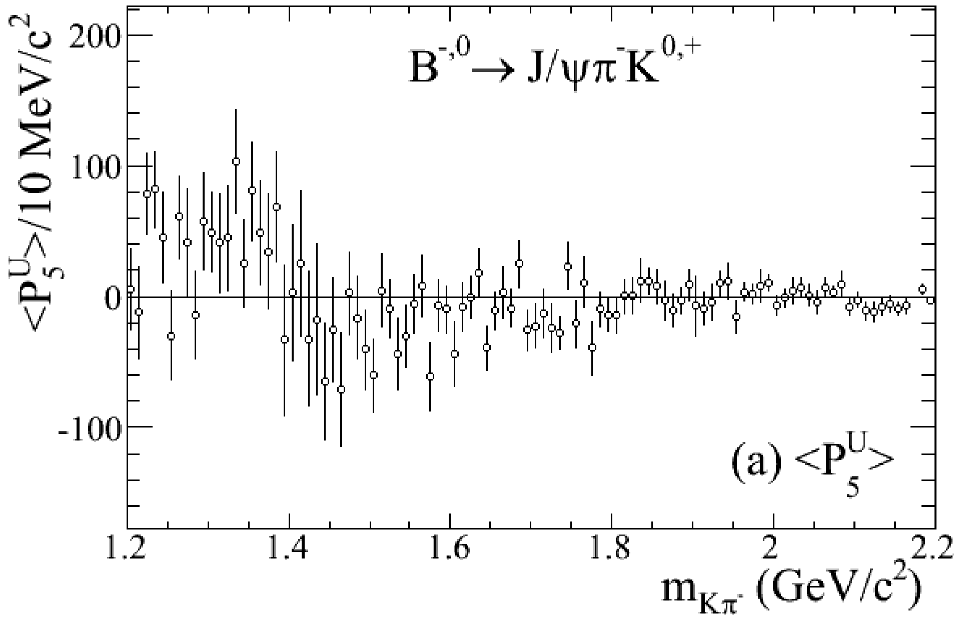
Efficiency correction: Kπ mass dependence of Legendre polynomial coefficients

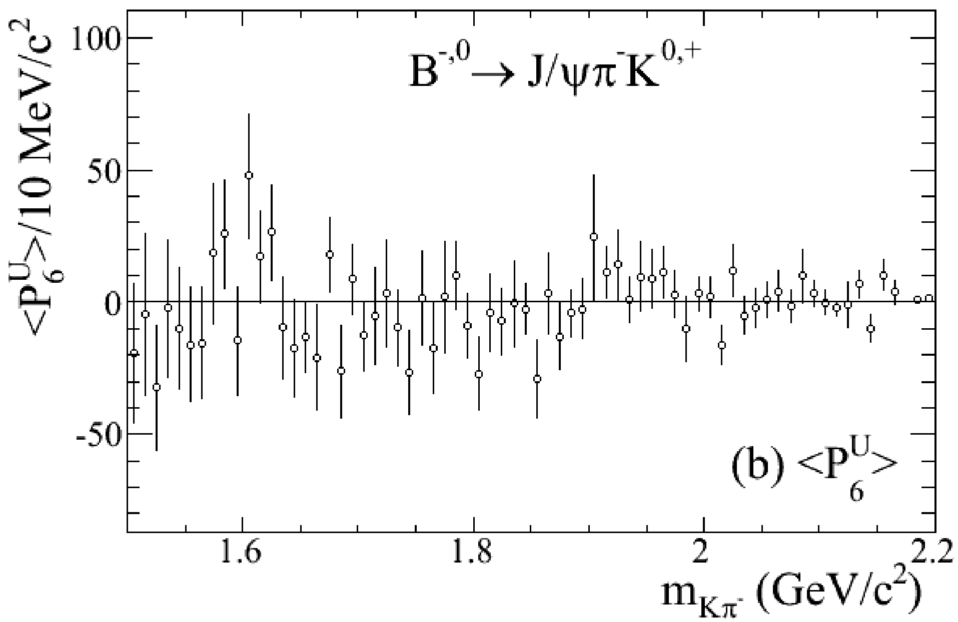


$\cos\theta_\pi$ distributions (K* veto)

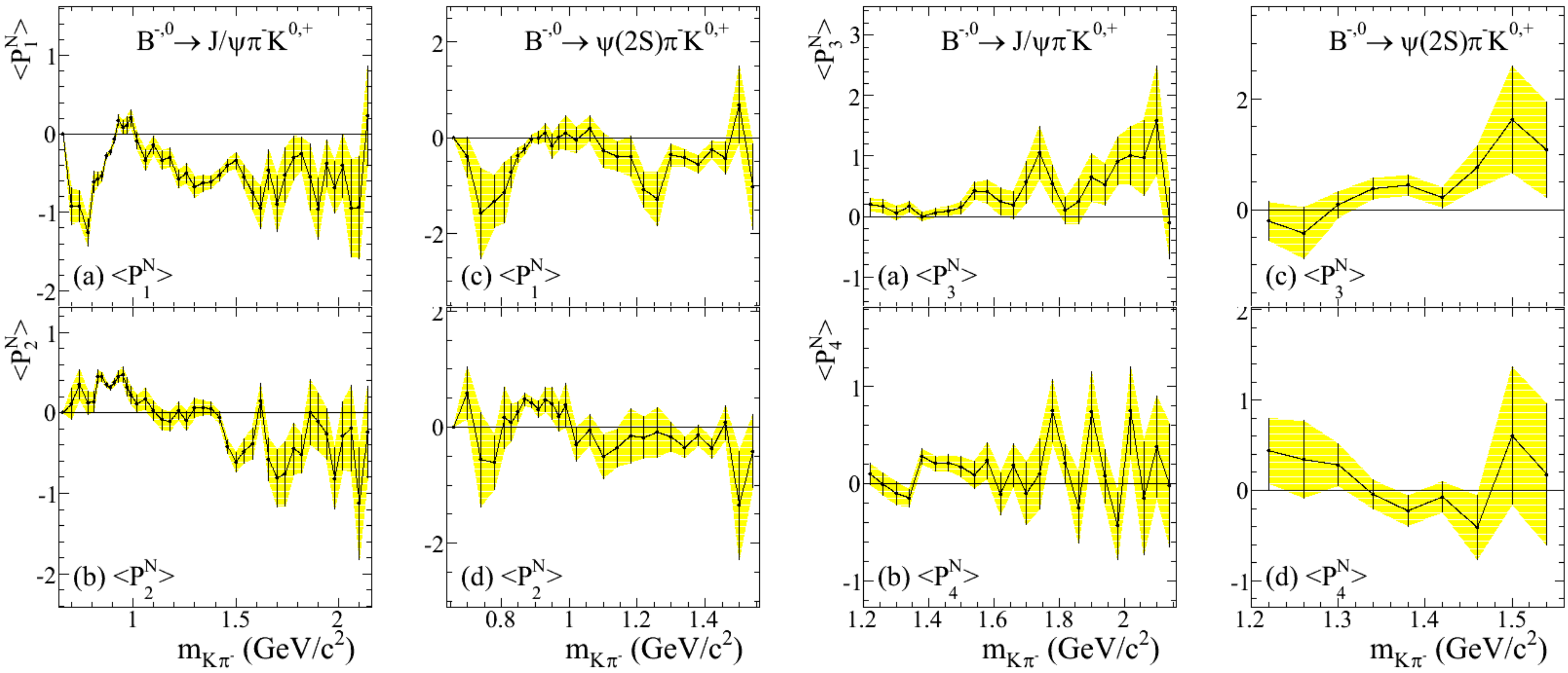


Unnormalized 5th and 6th moments (J/ψ)

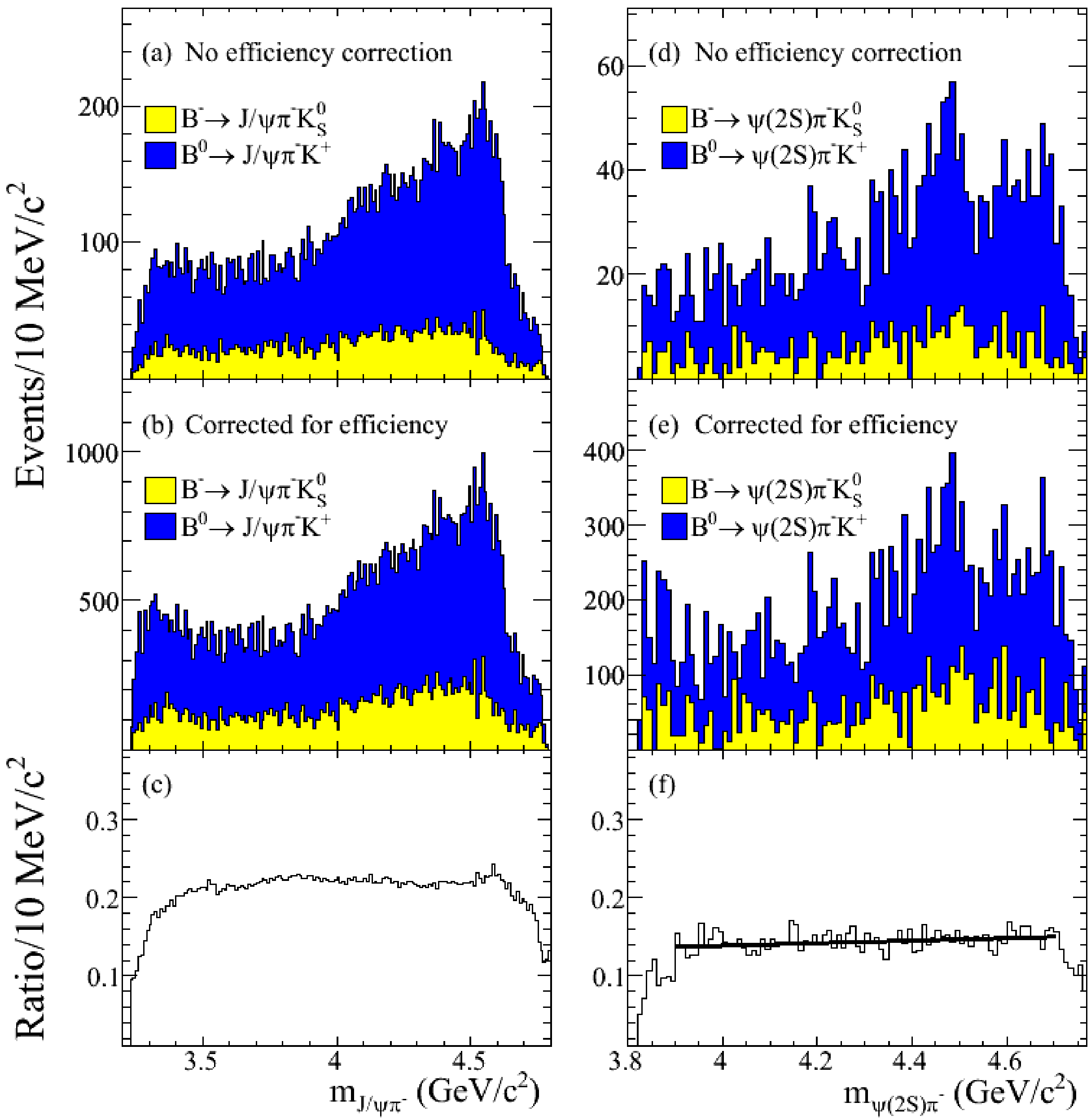




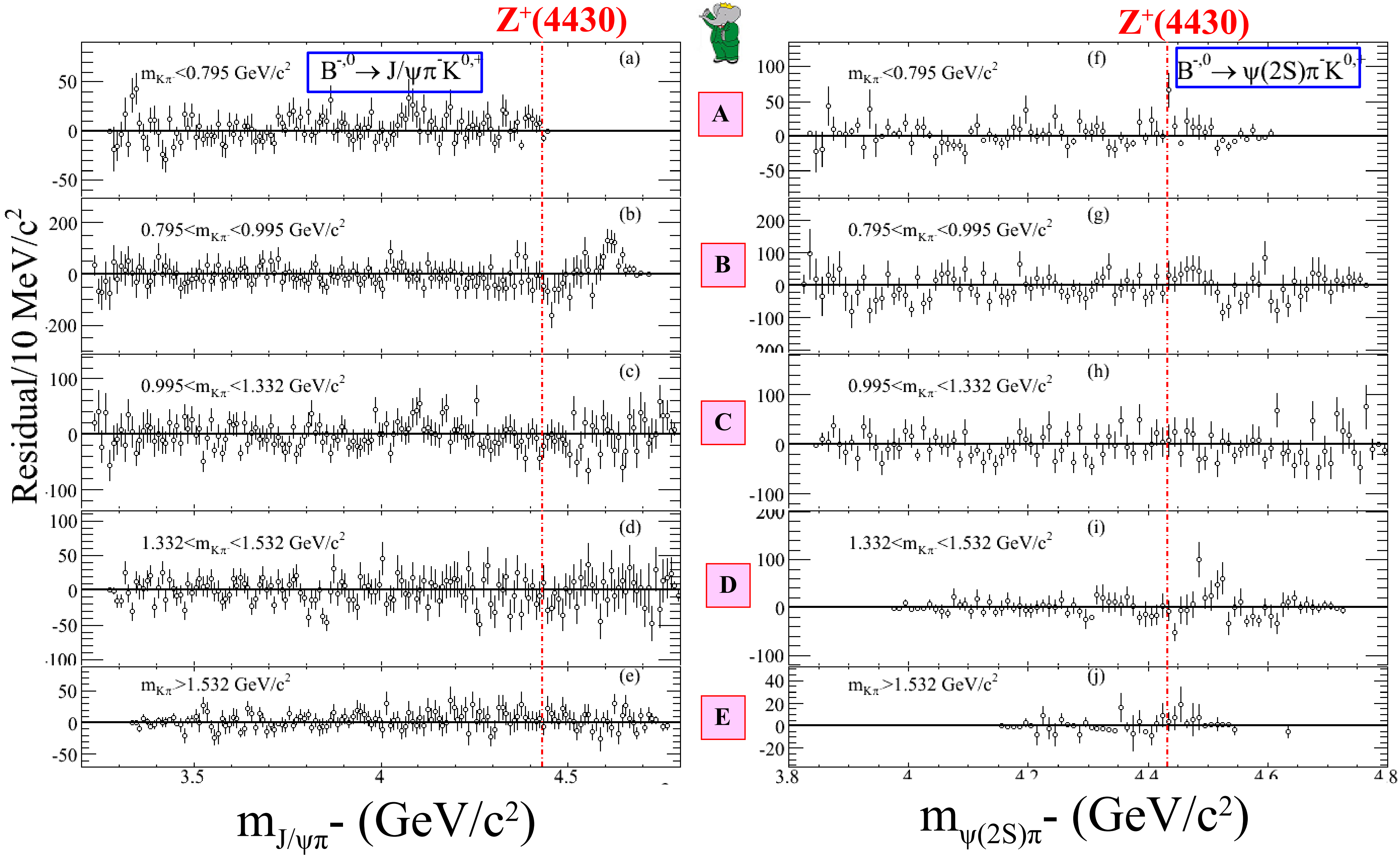
Normalized moments



Average efficiency as a function of ψπ mass

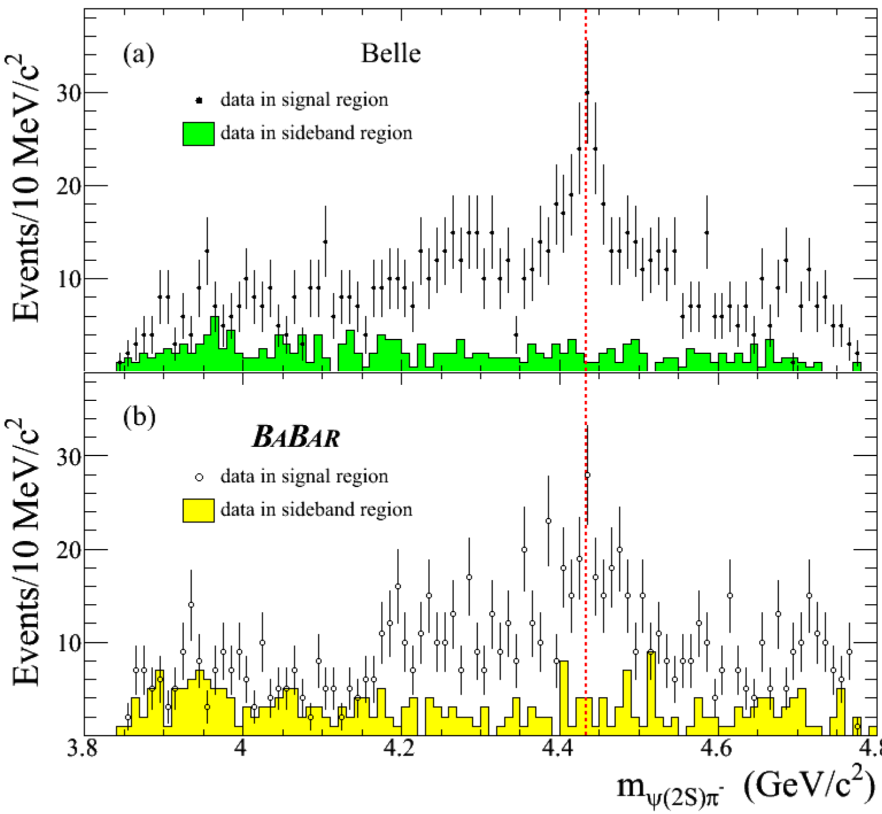


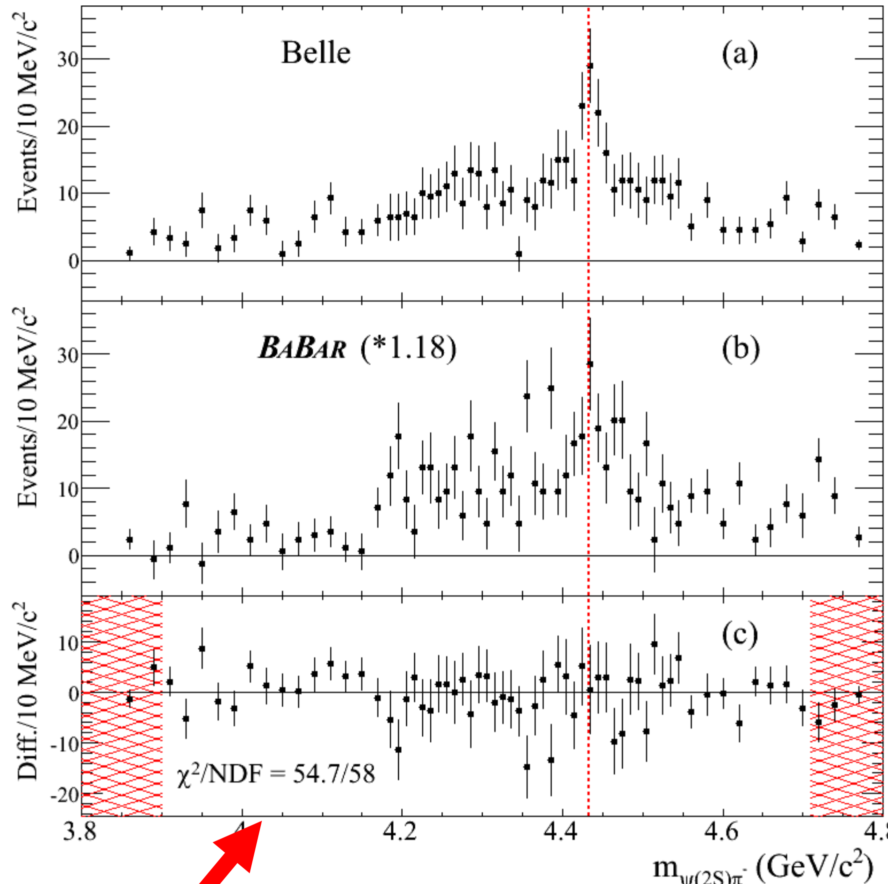
Residuals in $m_{K\pi}$ intervals



BaBar/Belle comparison

<u>Uncorrected</u> data in the K* veto region





- Both Belle and *BABAR* data are re-binned (to calculate χ^2) and side-band subtracted
- The *BABAR* data are normalized (*1.18) to the Belle sample; Luminosity ratio is 1.46

The data distributions are statistically consistent (χ^2=54.7/58)