

Direct CP Violation and Charmless Branching Fractions with BABAR

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- Motivation
- Analysis procedure
- Results
- Summary and outlook



Introduction

- CP violation has been observed in Kaon system
- Measurement of $\sin(2\beta)$ with $(c\bar{c})K^0$ established CP violation in B^0 meson system arising from interference between mixing and decay amplitude
- We have not yet observed direct CP violation in B meson system arising from decay amplitude

$$A_{CP} \equiv \frac{|\bar{A}_f|^2 - |A_f|^2}{|\bar{A}_f|^2 + |A_f|^2} \neq 0 \rightarrow \text{Direct } CPV$$

It took more than 30 years to establish DCPV in Kaon system!

PRL 83, 22 (1999)

$$\text{Re}(\varepsilon' / \varepsilon) \sim 28 \times 10^{-4}$$

- Sources of direct CP asymmetries:

Interference between two decay amplitudes (A_i) with different strong (δ_i) and weak phases (ϕ_i)

$$A_{CP} = \frac{2 \sin(\phi_i - \phi_j) \sin(\delta_i - \delta_j)}{R + 1 / R + \cos(\phi_i - \phi_j) \cos(\delta_i - \delta_j)},$$

$$R \equiv \left| \frac{A_i}{A_j} \right|$$

Searching for Direct CPV in charmless B decay

- Competing amplitudes with different weak phases make large asymmetries possible
- Loop diagrams from New Physics (e.g. SUSY) can modify SM asymmetries/branching fractions
- Experimentally – look for charge asymmetries:

$$A_{CP} = \frac{Br(\bar{B} \rightarrow \bar{f}) - Br(B \rightarrow f)}{Br(\bar{B} \rightarrow \bar{f}) + Br(B \rightarrow f)}$$

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- Experimental challenge
 - Small branching fraction and large background from continuum (u, d, s, c) production
 - Charge bias
 - Detector: trigger, tracking, reconstruction
 - Event selection, particle ID, analysis
 - Asymmetries in background

Analysis Procedure

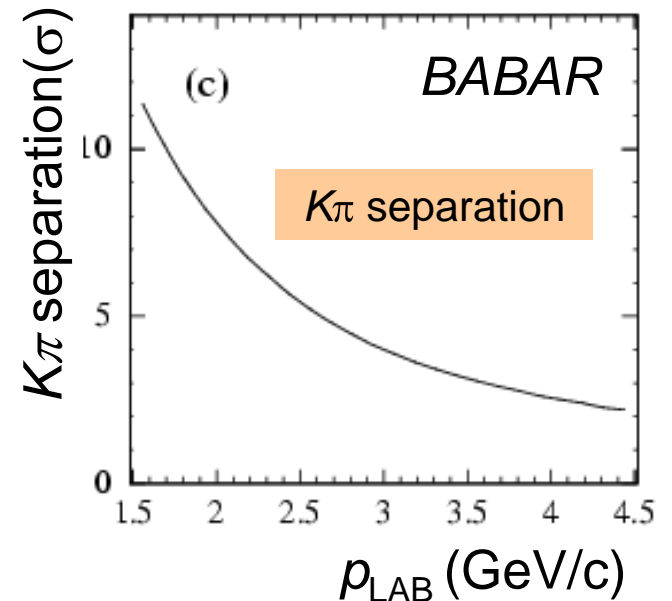
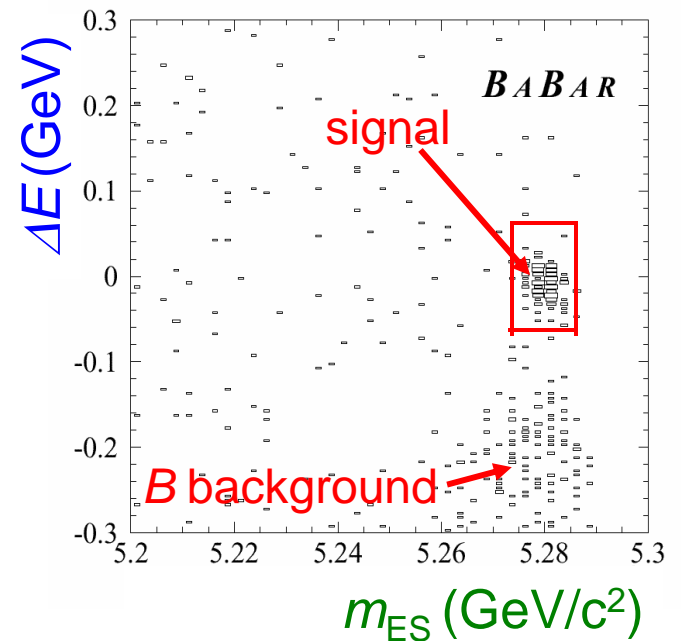
Event selection:

- ✓ Quality cuts for tracks and showers
- ✓ Continuum rejection using event shape variables
- ✓ Kinematic signal identification with m_{ES} and ΔE :

$$m_{ES} = \sqrt{E_{beam}^2 - p_B^{*2}} \quad \Delta E = E_{beam} - E_B^*$$

Maximum Likelihood Fit to determine yields and asymmetries simultaneously:

- ✓ B mass
 - ✓ B energy
 - ✓ Event shape
 - ✓ Particle ID
- } Separate signal from light quark background
→ Separate Kaon from Pion



Searching for Direct CPV in $B^0 \rightarrow K^+ \pi^-$

227x10⁶ B pairs

Motivation

- Both tree (T) and penguin (P) diagram contribute:

$$\text{amplitude} = \lambda^2 e^{i\gamma} T + P \quad A_{K\pi} \sim \sin(\gamma)$$

- Clean charmless mode with large BF:

$$BF(B^0 \rightarrow K^+ \pi^-) = (18.2 \pm 0.8) \times 10^{-6}$$

HFAG, March 2004

Method

- Extended ML fit simultaneously determines:

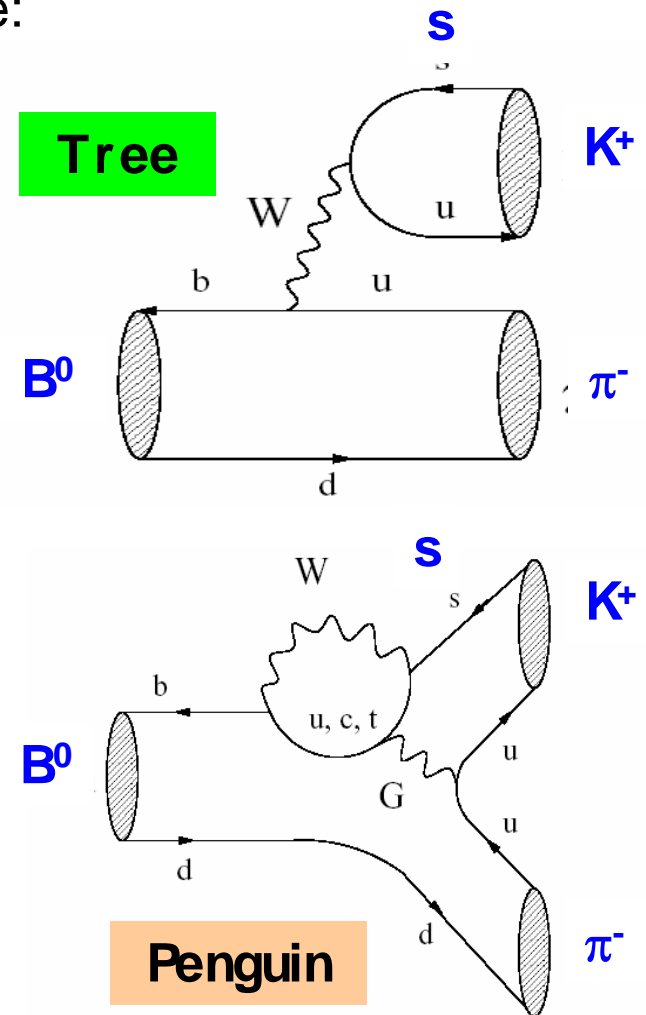
$$n_{\pi\pi}, n_{K\pi}, n_{KK}, A_{K\pi} \text{ and } A_{K\pi}^b$$

and uses:

$$m_{ES}, \Delta E, \text{Fisher}, \theta_c^+, \theta_c^-$$

- θ_c PDFs separately for $\{K^+, K^-, \pi^+, \pi^-\}$ from PID control sample

$$D^{*+} \rightarrow D^0 (K^- \pi^+) \pi^+$$



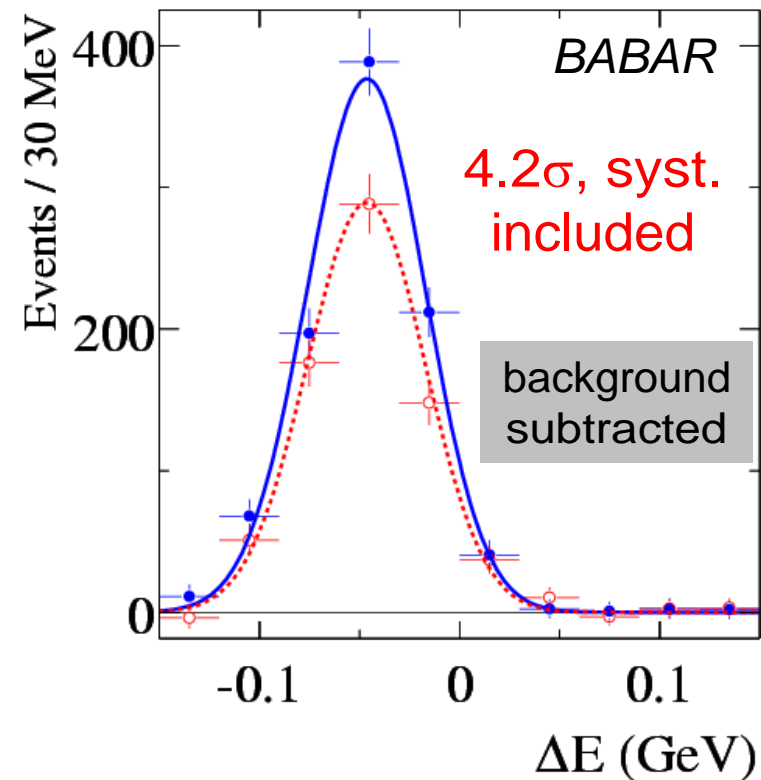
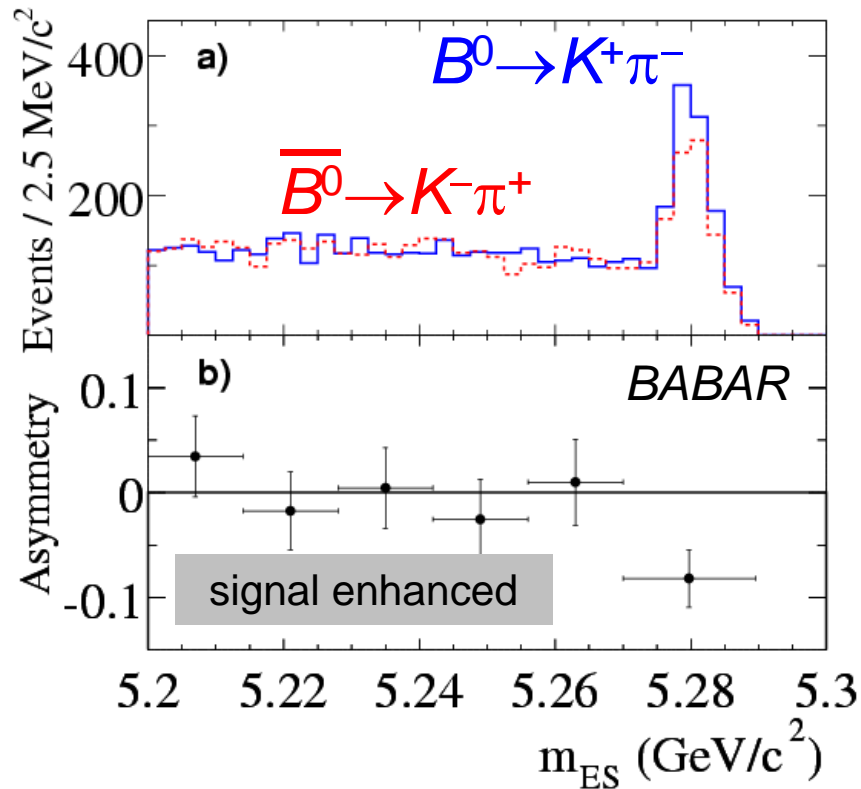
First Observation of Direct CPV in B decay

$$n_{K\pi} = 1606 \pm 51$$

$$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$$

$$n(B^0 \rightarrow K^+ \pi^-) = 910$$

$$n(\bar{B}^0 \rightarrow K^- \pi^+) = 696$$



$A_{K\pi}$: Systematics and Cross Checks

✓ CPV due to mixing ruled out

PRL 89, 281802 (2002)

- ✓ Asymmetries consistent in different Kaon momentum ranges
- ✓ Asymmetries consistent when including decay time information
- ✓ Asymmetries consistent in different running period
- ✓ Asymmetries consistent with SM predictions

Running period:

Sample	$N_{B\bar{B}}$	$n_{K\pi}$	$\mathcal{A}_{K\pi}$	$A_{K\pi}^b$
1999–2001	21.1	142 ± 15	-0.240 ± 0.102	0.006 ± 0.026
2002	66.4	479 ± 27	-0.102 ± 0.055	-0.008 ± 0.015
2003	34.1	241 ± 19	-0.109 ± 0.079	0.007 ± 0.021
2004	104.9	743 ± 33	-0.142 ± 0.044	0.004 ± 0.012

Systematics:

Source	Error
Signal fisher PDF	0.001
θ_c PDF	0.001
Potential MC bias	0.003
Potential Charge bias	0.008
Total	0.009

Background charge asymmetry free in the fit:

$$A_{K\pi}^b = 0.001 \pm 0.008$$

$B^+ \rightarrow K^+ \pi^- \pi^+, \pi^+ \pi^- \pi^+$

182x10⁶ B pairs

Motivation

- measure γ using a full Dalitz plot

PRL 86, 2720 (2001)

- look for direct CPV

Method

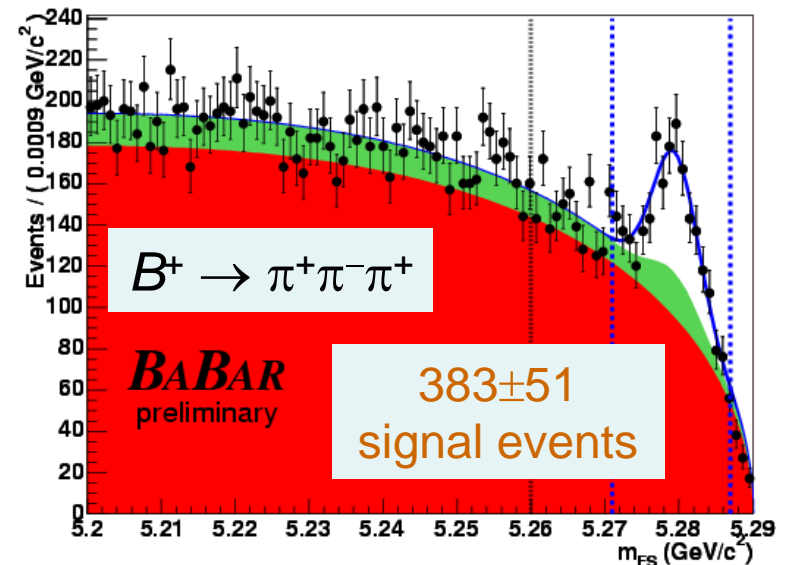
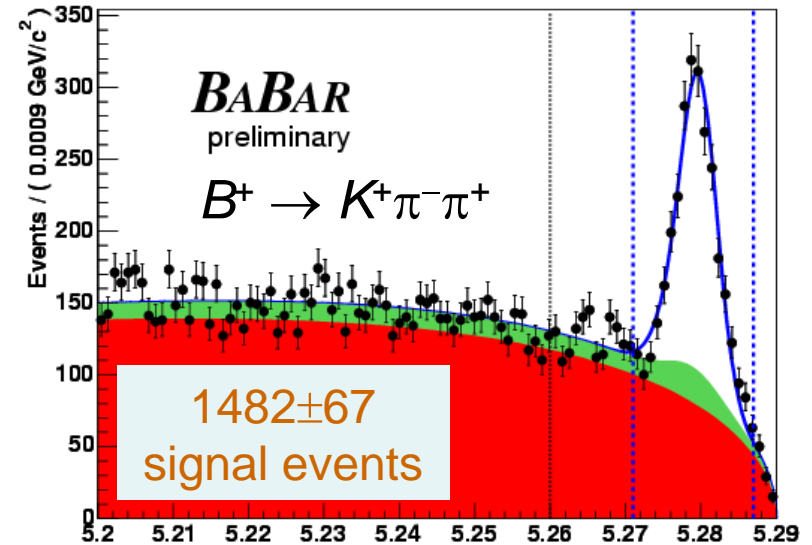
- full Dalitz plot analysis
- combined fit for B^+ and B^-
- Veto charm, charmonium decays: J/ψ , $\psi(2S)$, D^0
- Use relativistic Breit-Wigner lineshapes for resonances unless stated otherwise

$$Br(B^+ \rightarrow K^+ \pi^- \pi^+) = (61.4 \pm 2.4 \pm 4.5) \times 10^{-6}$$

$$Br(B^+ \rightarrow \pi^+ \pi^- \pi^+) = (16.2 \pm 2.1 \pm 1.3) \times 10^{-6}$$

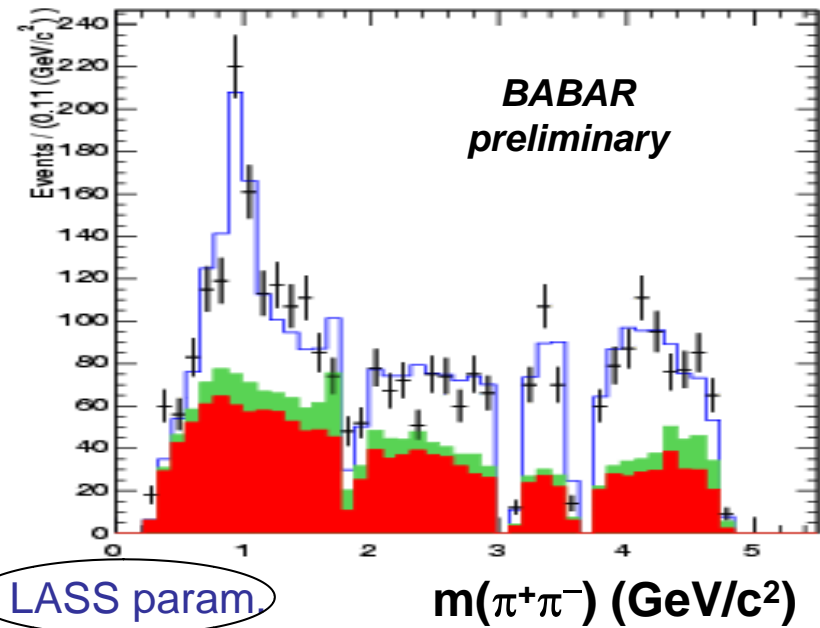
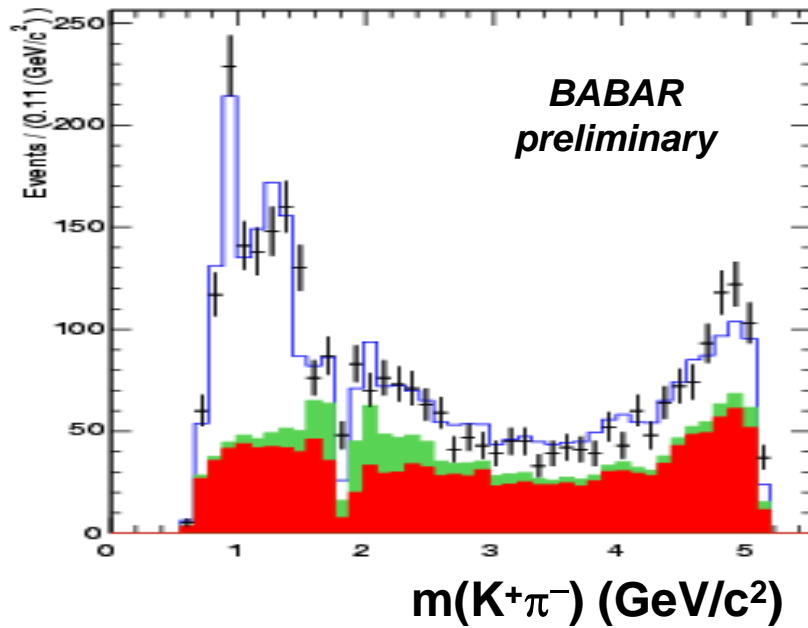
Syst. dominated by:

- bkg Dalitz plot characterization
- efficiency uncertainty on the DP



$B^+ \rightarrow K^+ \pi^- \pi^+$

182x10⁶ B pairs

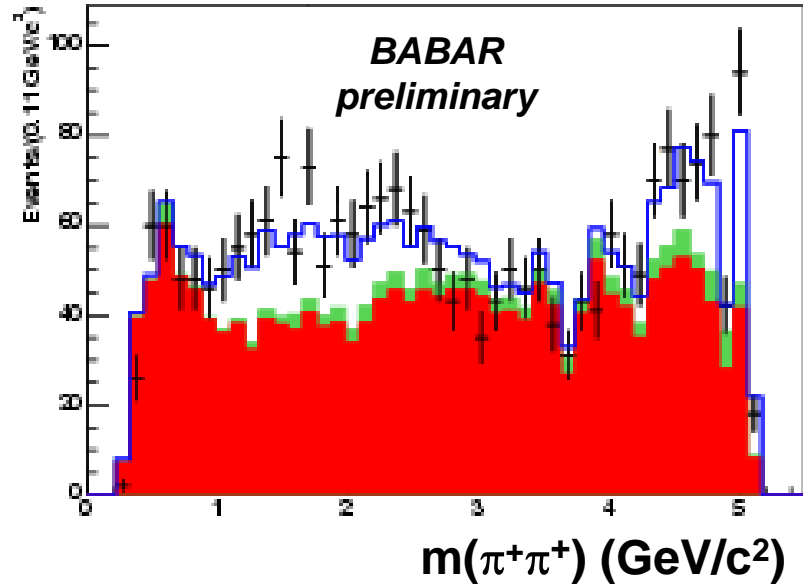
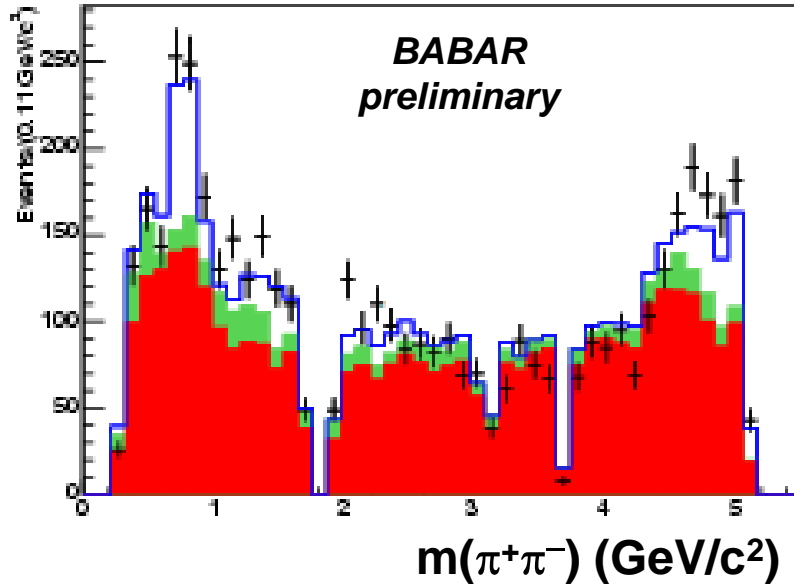


LASS param

	$K^*(892)^0\pi^+$	$K_0^*(1430)\pi^+$	$\rho(770)K^+$
fraction(%)	$11.4 \pm 2.0 \pm 1.5$	$52.6 \pm 2.3 \pm 4.0$	$8.5 \pm 1.9 \pm 1.1$
Phase (°)	0	$167.3 \pm 6.3 \pm 5.7$	$49 \pm 22 \pm 20$
	$f_0(980)K^+$	$\chi_{c0}K^+$	NR
fraction(%)	$15.0 \pm 2.4 \pm 1.3$	$1.45 \pm 0.27 \pm 0.23$	$7.9 \pm 0.9 \pm 2.3$
Phase (°)	$-32 \pm 18 \pm 23$	$9 \pm 19 \pm 12$	$29 \pm 14 \pm 14$

$B^+ \rightarrow \pi^+ \pi^- \pi^+$

182x10⁶ B pairs



	$\rho^0(770)\pi^+$	$\rho^0(1450)\pi^+$	$f_0(980)\pi^+$
fraction(%)	$58.2 \pm 2.9 \pm 6.0$	$13.6 \pm 2.8 \pm 2.0$	$2.0 \pm 1.3 \pm 2.8$
phase (°)	0	$34 \pm 22 \pm 10$	$140 \pm 35 \pm 11$

Flatte lineshape

	$f_2(1270)\pi^+$	NR
fraction(%)	$14.3 \pm 2.0 \pm 1.8$	$4.2 \pm 2.0 \pm 1.4$
phase (°)	$-154 \pm 20 \pm 10$	$35 \pm 32 \pm 11$

No evidence of:
' σ ', χ_{c0} and $f_0(1370)$

$B^0 \rightarrow K^+ \pi^- \pi^0$

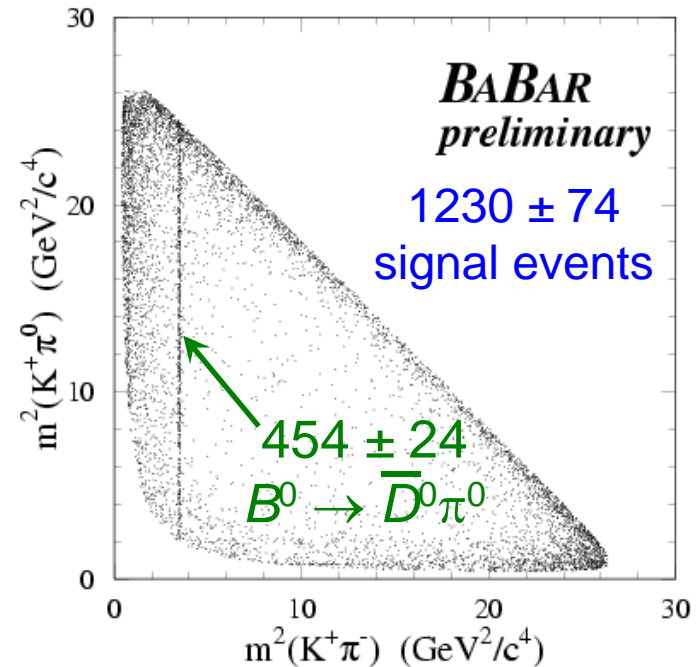
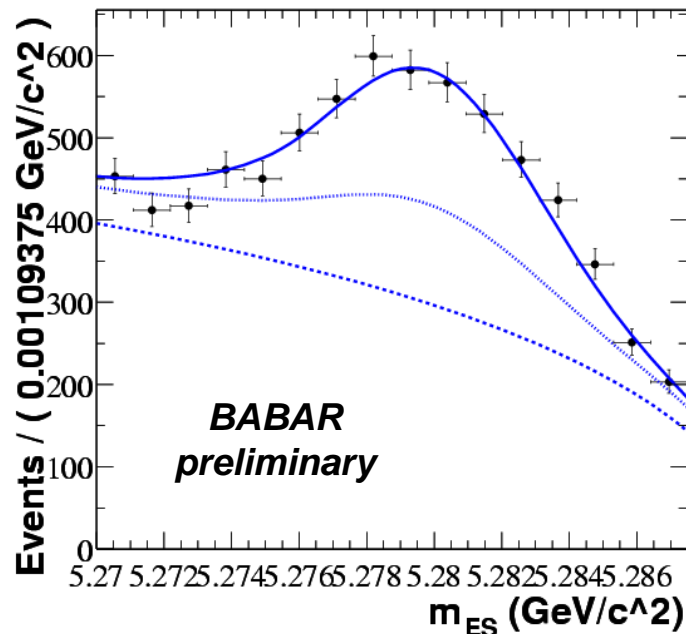
213x10⁶ B pairs

Motivation

- extract intermediate resonances
 - constrain penguins in $B \rightarrow \rho \pi$
 - constrain γ of the UT
- look for direct CPV

Method

- full Dalitz plot analysis
- separate fit for B^0 and \bar{B}^0
- 4-D convolution treatment for misreconstructed signal events
- fit $B^0 \rightarrow \bar{D}^0 \pi^0$ as cross check

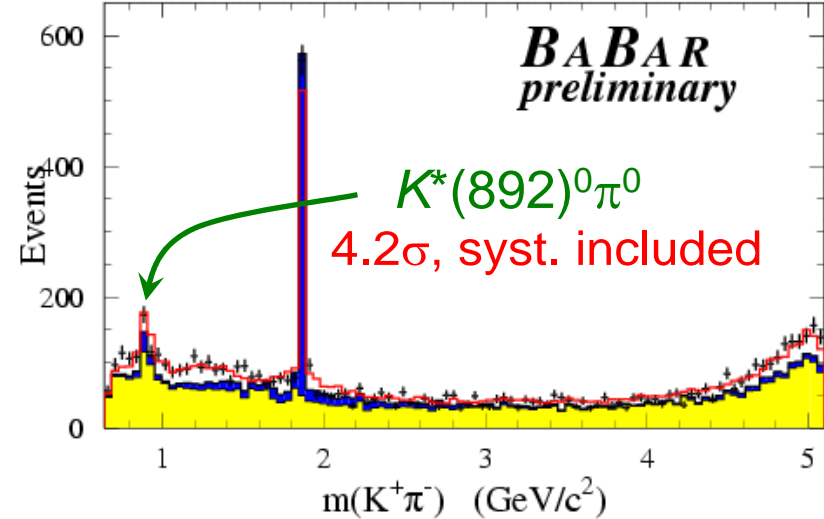
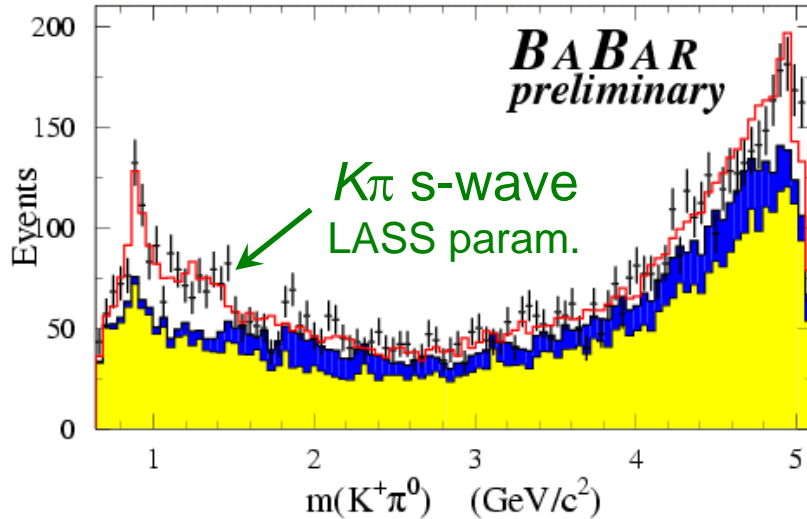


$$Br(B^0 \rightarrow K^+ \pi^- \pi^0) = (34.9 \pm 2.1 \pm 3.9) \times 10^{-6}$$

$$Br(B^0 \rightarrow \bar{D}^0 \pi^0) = (3.2 \pm 0.2 \pm 0.4) \times 10^{-4}$$

$B^0 \rightarrow K^+ \pi^- \pi^0$

213x10⁶ B pairs



	fraction(%)	phase ϕ	phase $\bar{\phi}$	A_{CP}
$\rho^-(770)K^+$	$24.6^{+3.6}_{-2.9} \pm 0.6$	0	0	$0.13^{+0.14}_{-0.17} \pm 0.04 \pm 0.13$
$K^*(892)^+\pi^-$	$10.4^{+2.1}_{-2.0} \pm 0.8$	138 ± 35	174 ± 42	$-0.25 \pm 0.17 \pm 0.02 \pm 0.02$
$K_0^*(1430)^+\pi^-$	$32.2 \pm 3.8 \pm 9.4$	115 ± 34	149 ± 35	$-0.07 \pm 0.12 \pm 0.06 \pm 0.05$
$K_0^*(1430)^0\pi^0$	$22.5 \pm 4.0 \pm 7.2$	-12 ± 40	8 ± 42	$-0.34 \pm 0.15 \pm 0.07 \pm 0.08$
$K^*(892)^0\pi^0$	$5.8^{+1.7}_{-1.5} \pm 0.6$	-160 ± 41	-144 ± 41	$-0.01^{+0.24}_{-0.22} \pm 0.07 \pm 0.11$
NR	$7.1^{+3.6}_{-2.9} \pm 0.1$	55 ± 28	79 ± 28	$-0.12^{+0.36}_{-0.37} \pm 0.20 \pm 0.07$

Syst. dominated by ignoring 'minor' intermediate states

Summary and outlook

- For other results, eg $B^0 \rightarrow \pi\pi$, $B^0 \rightarrow \rho\pi$, see talk by Markus
- First observation (4.2σ) of direct CP violation in B decay amplitude

$$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009 \quad \text{hep-ex/0407057} \\ \text{Submitted to PRL}$$

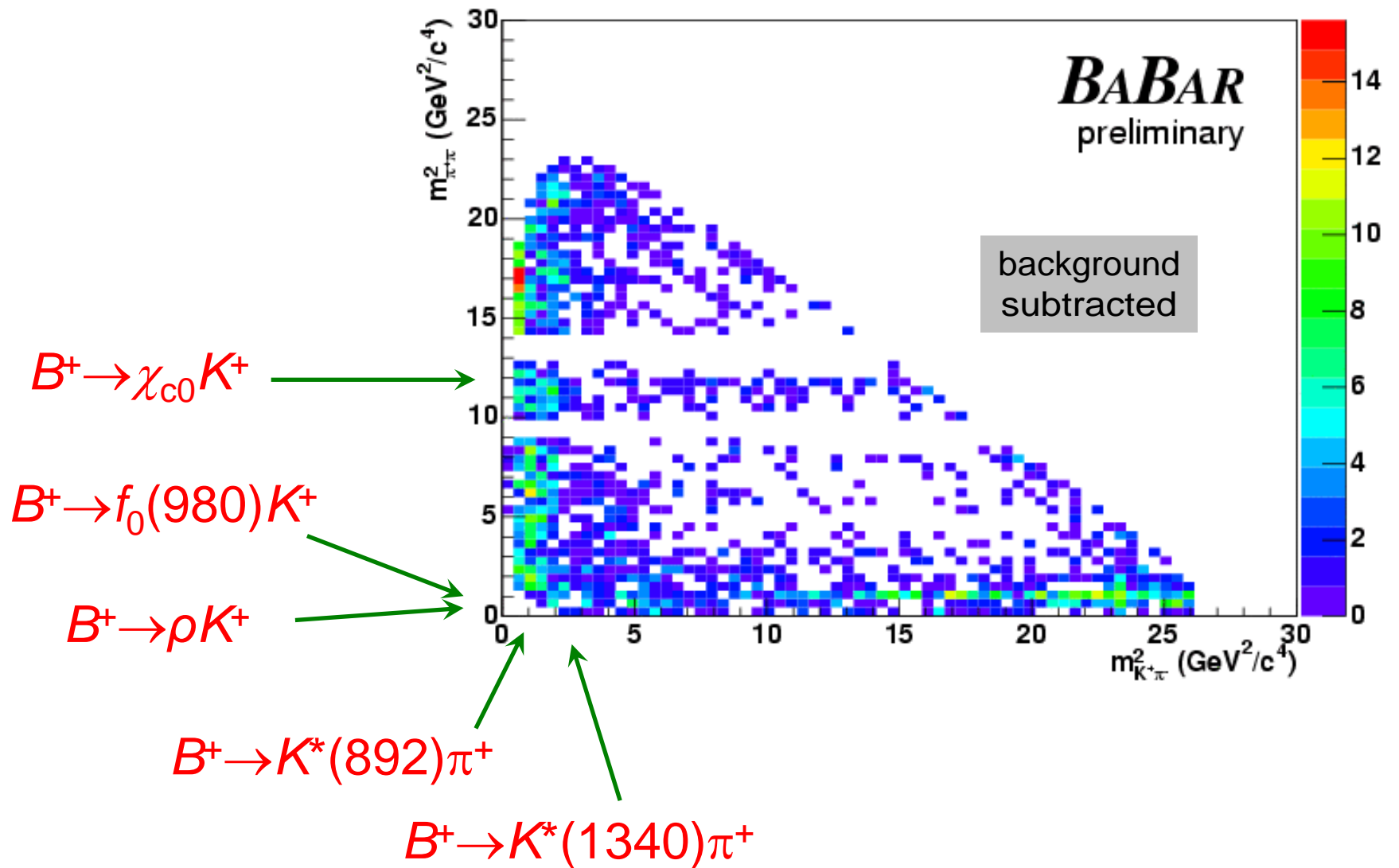
- Other results are preliminary
- Charmless three body B decays move the era of Dalitz plot analysis. Many branching fractions and A_{CP} measured, with new observations of:

$$B^+ \rightarrow f_2(1270)\pi^+, B^0 \rightarrow K^*(892)^0\pi^0$$

- A_{CP} precision achieved 3~25%, watch for future updates

Backup slides

$B^0 \rightarrow K^+ \pi^- \pi^+$



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