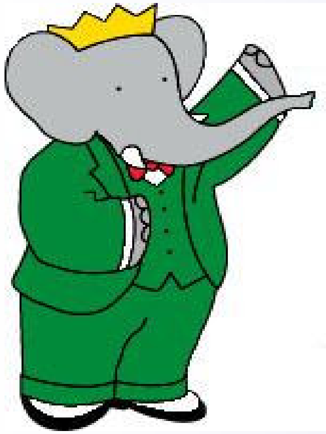

Hadronic Charmless Three-body B decays at BABAR

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23 September 2008

Euroflavour 08, Durham

Outline

- Introduction
- Recent results:
  - $B^+ \to K^+\pi^+\pi^-$
  - $B^0 \to K_S\pi^+\pi^-$
  - $B^0 \to K^+\pi^-\pi^0$
- The UT angle γ
- Conclusion

B $\rightarrow$ K$\pi\pi$ decays

Charmless B decays – no c quark involved:

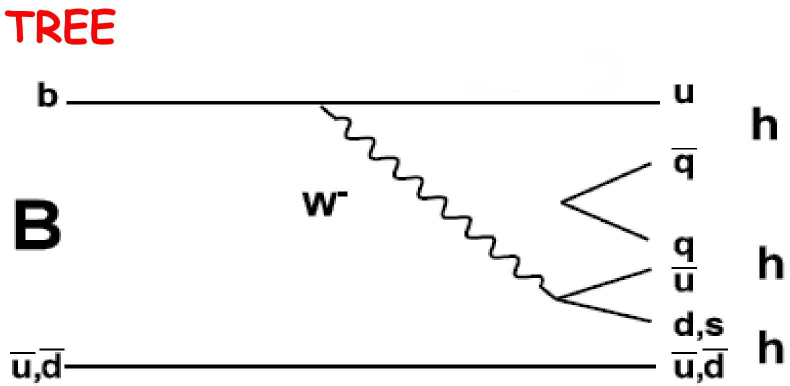
- Rare decays Bf ~ 10^{-6}

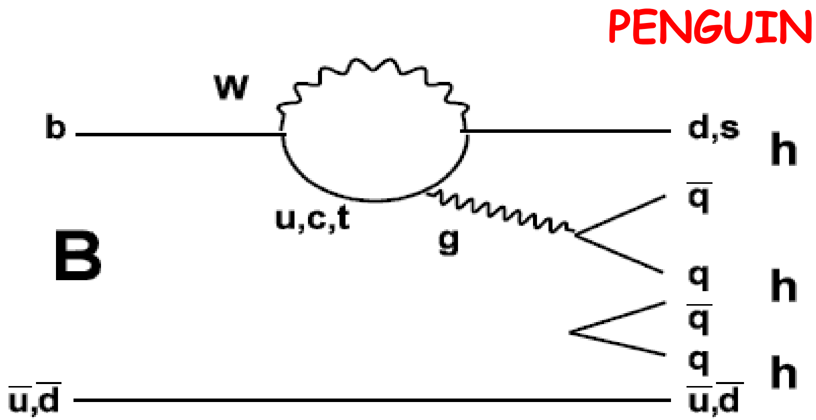
Rich Dalitz plot structure

- ($\pi\pi$) and (Kπ) intermediate resonant states
- $\sin(2\beta_{eff})$ in B^0 decays to CP eigenstates ($\rho^0 K_S$ and $f_0 K_S$)

b$\rightarrow$u (tree) and b$\rightarrow$s (penguin) processes

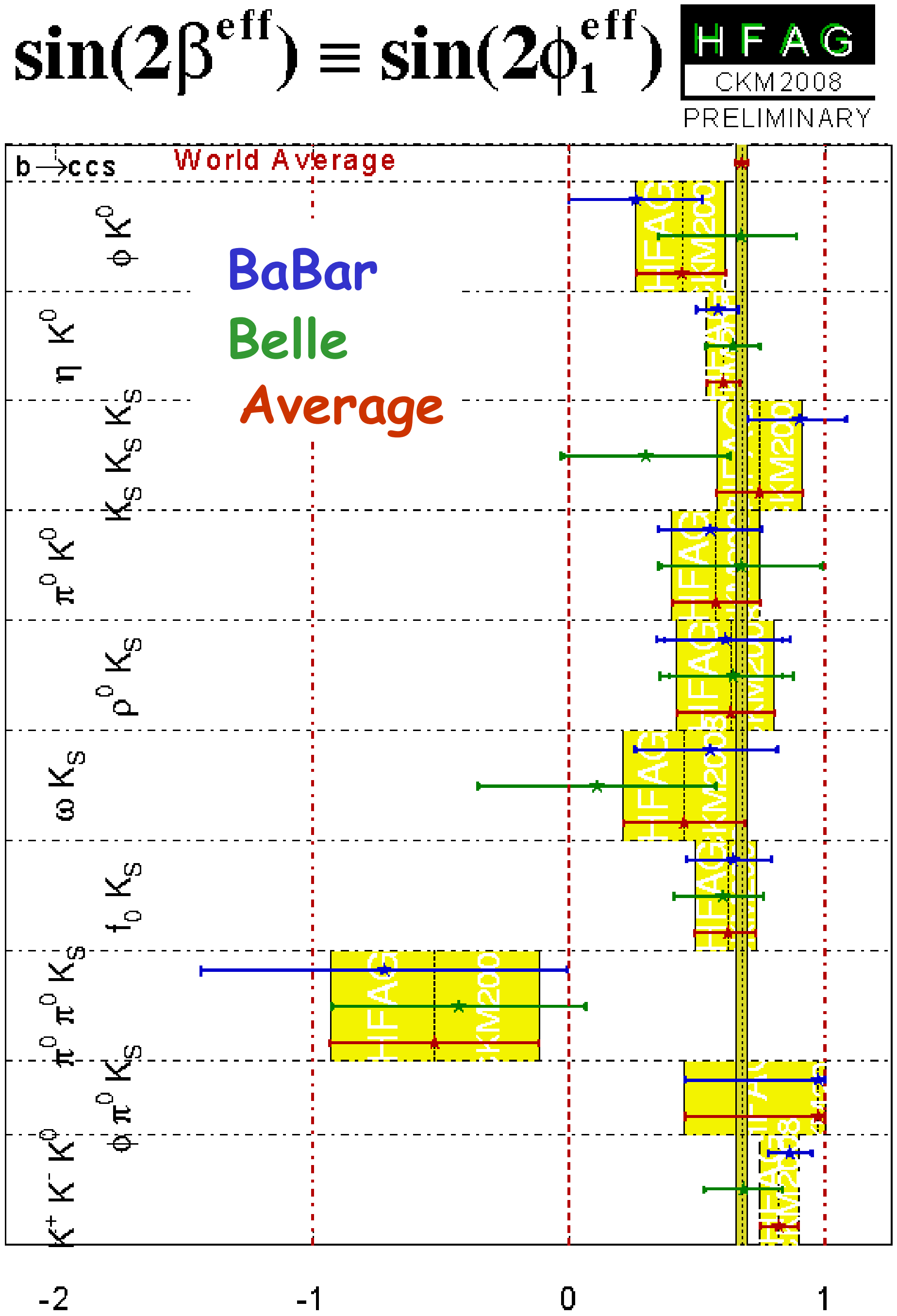
- Possible direct CP violation
- tree & penguin relative phase $\Rightarrow \gamma$



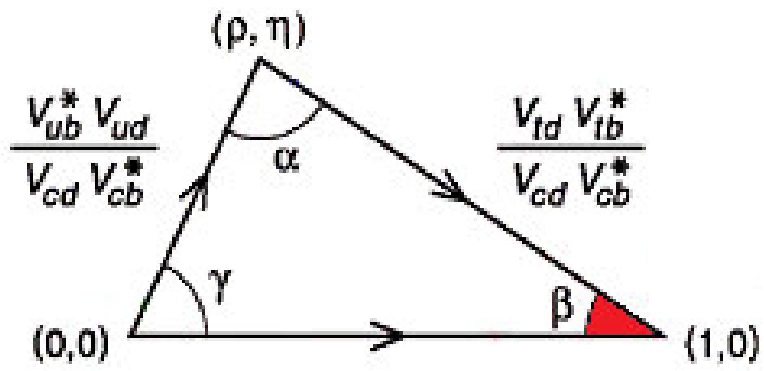


B → Kππ decays

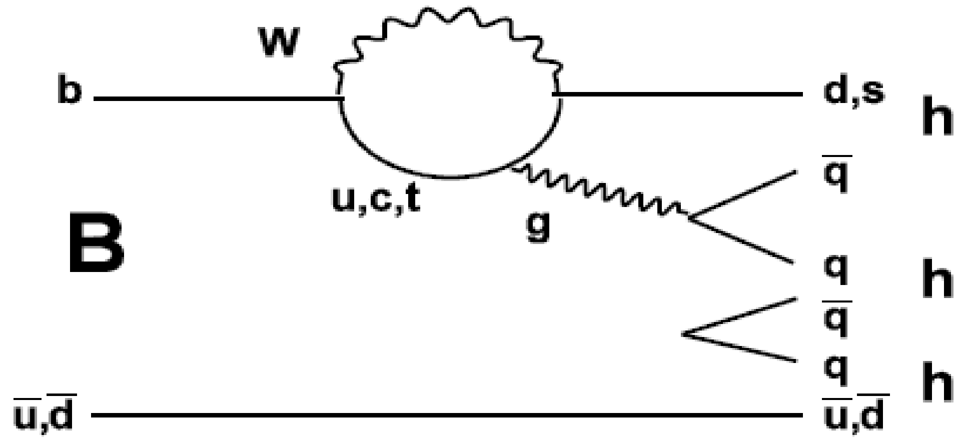
$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$



- Possibility to measure the UT angle β



Sensitivity to possible new physics effects



$B \to K\pi\pi$ decays

- Possibility to measure the UT angle γ

Use χ_{c0} resonance

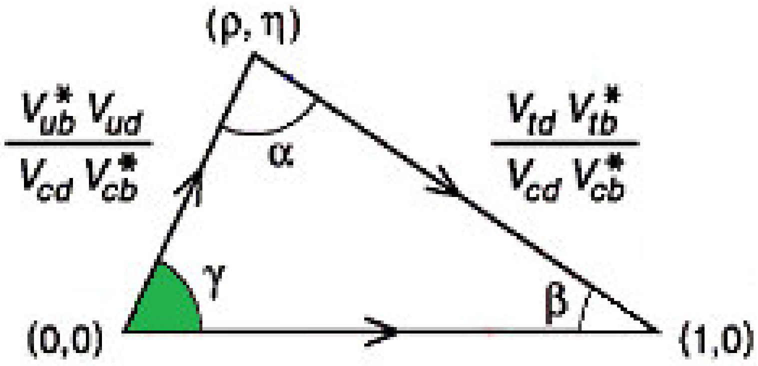
•Interference between the χ_{c0} and the nonresonant or other resonant states in $B^+ \to \pi^+\pi^+\pi^-$ or $K^+\pi^+\pi^-$ could, in principle, allow a determination of γ

Eilam et al., Phys. Rev. Lett. 74, 4984 (1995)

Bediaga et al., Phys. Rev. Lett. 81, 4067 (1998)

Blanco et al., Phys. Rev. Lett. 86, 2720 (2001)

• Small BF of $B \to \chi_{c0}K/\pi$!!!



Use $K^*\pi$ resonance

•Main method involves $K^+\pi^-\pi^0$ and $K_S\,\pi^+\pi^-$ DPs

Ciuchini et al., Phys. Rev. D74, 051301 (2006)

Gronau et al., Phys. Rev. D75, 014002 (2007)

Gronau et al., Phys. Rev. D77, 057504 (2008) and D78, 017505 (2008)

$B \to K\pi\pi$ decays and the UT angle γ

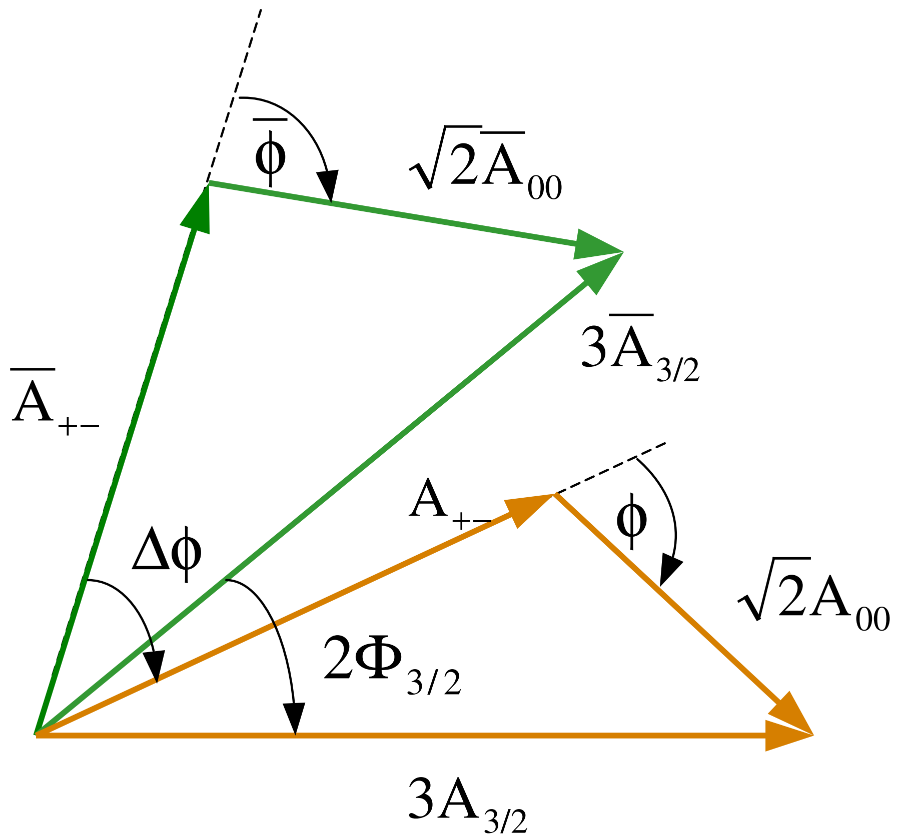
$A_{ij} = A(B^0 \to K^{*i}\pi^j)$

- Method from Ciuchini et al. and Gronau et al.
- Write the amplitudes for $B^0 \to K^*\pi$ modes using the isospin symmetry
- Use them to cancel penguin contribution
- Form isospin triangles ($B^0 \to K^{*+}\pi^-$ and $B^0 \to K^{*0}\pi^0$)
- $\Phi_{3/2} = \gamma$ (up to correction from EW penguins)

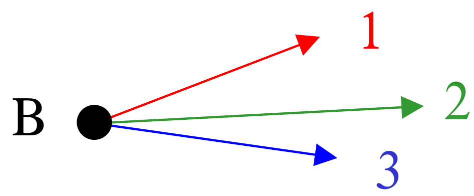
$$\gamma = \Phi_{3/2} \equiv -\frac{1}{2}\arg(R_{2/3})$$

$$R_{2/3} \equiv \frac{\overline{A}_{3/2}}{A_{3/2}}$$

- The amplitude magnitudes as well as ϕ, $\overline{\phi}$ and $\Delta\phi$ can be measured from Dalitz-plot analyses of $K^+\pi^-\pi^0$ and $K_s\pi^+\pi^-$



Analysis Method – Dalitz Plot

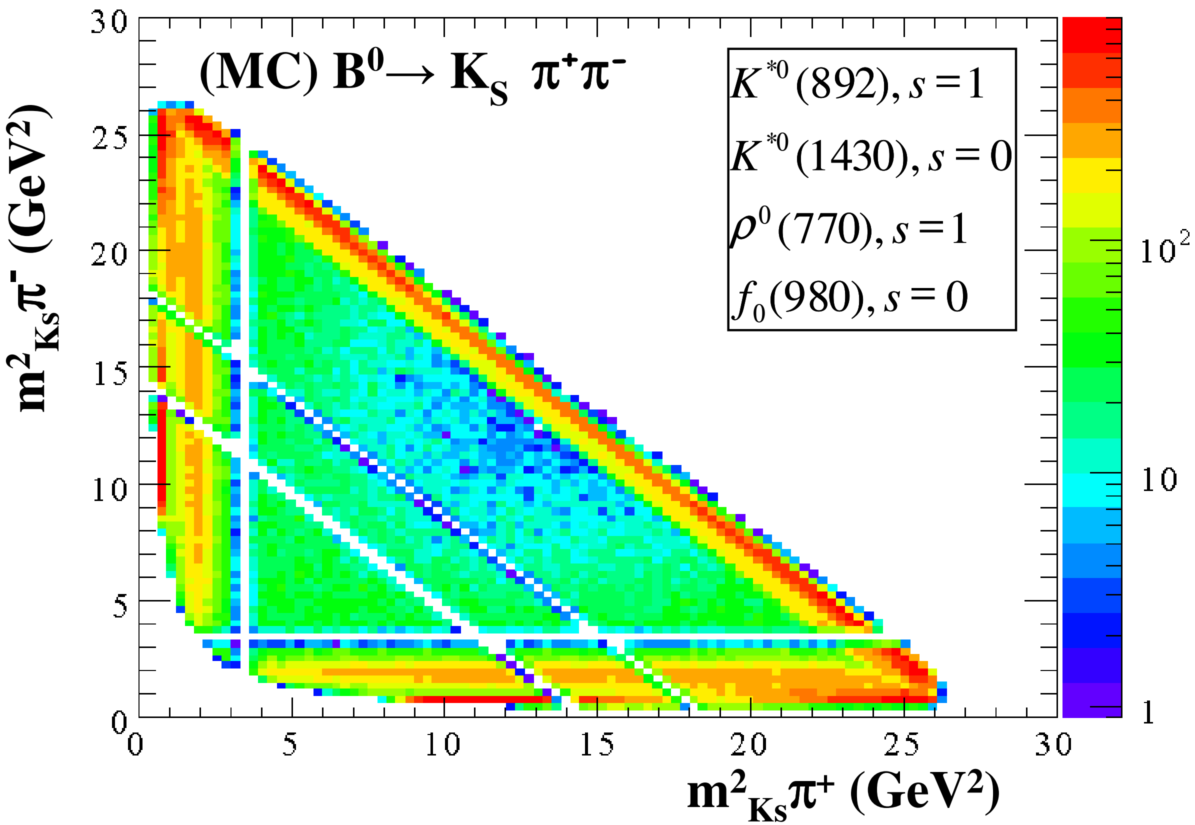


4 vectors	12
conservation laws	-4
meson masses	-3
free rotation	-3
total	**2**

- Invariant mass of combined ij particle
- Decay rate:

$$\Gamma \propto |M|^2 dm_{12}^2 dm_{23}^2$$ (M – invariant amplitude)

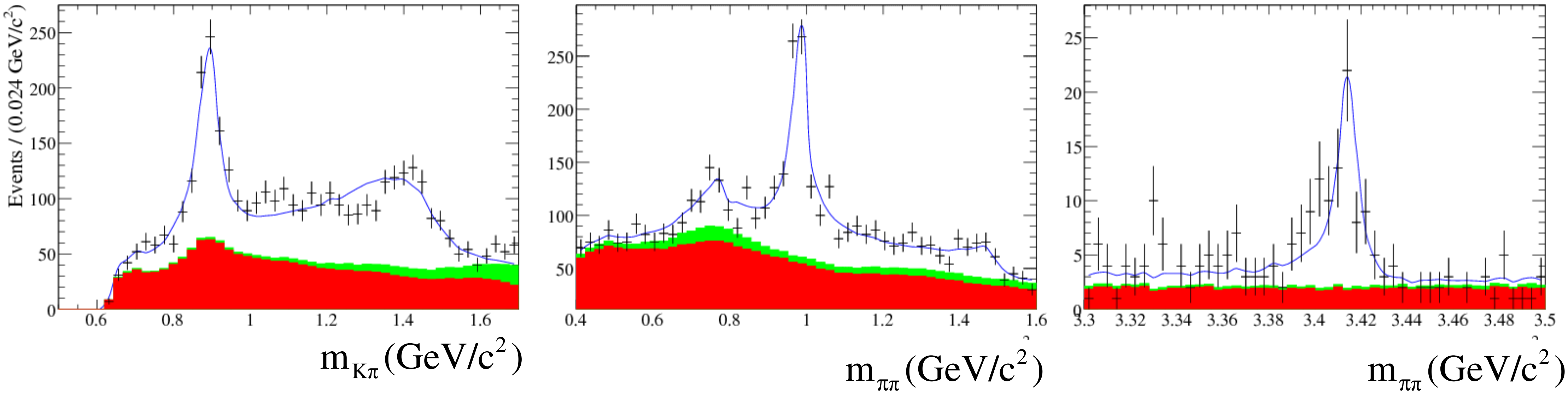
Dalitz plot - visualisation of the 3 body phase space



- **Interference between resonances**
- **DP analysis sensitive to phases**
- Measurements of $2\beta_{eff}$ (rather than just **sin($2\beta_{eff}$)**)
- Penguin – tree relative phase:
  - **UT angle γ**

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

- Results not directly used in main γ method
- Highest (BF x ε) of all $K\pi\pi$ modes!!!
  - Help determine signal DP model for other modes
- Possible large A_{CP} in $\rho^0 K^+$
  - Establishes that tree and penguin magnitudes are comparable and hence sensitivity to γ



Results $B^+ \to K^+\pi^+\pi^-$ decays

Mode	Fit Fraction (%)	$\mathcal{B}(B^+ \to \text{Mode})(10^{-6})$	A_{CP} (%)	DCPV Sig.
$K^+\pi^-\pi^+$ Total		$54.4 \pm 1.1 \pm 4.5 \pm 0.7$	$2.8 \pm 2.0 \pm 2.0 \pm 1.2$	
$K^{*0}(892)\pi^+$; $K^{*0}(892) \to K^+\pi^-$	$13.3 \pm 0.7 \pm 0.7\,^{+0.4}_{-0.9}$	$7.2 \pm 0.4 \pm 0.7\,^{+0.3}_{-0.5}$	$+3.2 \pm 5.2 \pm 1.1\,^{+1.2}_{-0.7}$	0.9σ
$(K\pi)^{*0}_0\pi^+$; $(K\pi)^{*0}_0 \to K^+\pi^-$	$45.0 \pm 1.4 \pm 1.2\,^{+12.9}_{-0.2}$	$24.5 \pm 0.9 \pm 2.1\,^{+7.0}_{-1.1}$	$+3.2 \pm 3.5 \pm 2.0\,^{+2.7}_{-1.9}$	1.2σ
$\rho^0(770)K^+$; $\rho^0(770) \to \pi^+\pi^-$	$6.54 \pm 0.81 \pm 0.58\,^{+0.69}_{-0.26}$	$3.56 \pm 0.45 \pm 0.43\,^{+0.38}_{-0.15}$	$+44 \pm 10 \pm 4\,^{+5}_{-13}$	3.7σ
$f_0(980)K^+$; $f_0(980) \to \pi^+\pi^-$	$18.9 \pm 0.9 \pm 1.7\,^{+2.8}_{-0.6}$	$10.3 \pm 0.5 \pm 1.3\,^{+1.5}_{-0.4}$	$-10.6 \pm 5.0 \pm 1.1\,^{+3.4}_{-1.0}$	1.8σ
$\chi_{c0}K^+$; $\chi_{c0} \to \pi^+\pi^-$	$1.29 \pm 0.19 \pm 0.15\,^{+0.12}_{-0.03}$	$0.70 \pm 0.10 \pm 0.10\,^{+0.06}_{-0.02}$	$-14 \pm 15 \pm 3\,^{+1}_{-5}$	0.5σ
$K^+\pi^-\pi^+$ nonresonant	$4.5 \pm 0.9 \pm 2.4\,^{+0.6}_{-1.5}$	$2.4 \pm 0.5 \pm 1.3\,^{+0.3}_{-0.8}$	—	—
$K^{*0}_2(1430)\pi^+$; $K^{*0}_2(1430) \to K^+\pi^-$	$3.40 \pm 0.75 \pm 0.42\,^{+0.99}_{-0.13}$	$1.85 \pm 0.41 \pm 0.28\,^{+0.54}_{-0.08}$	$+5 \pm 23 \pm 4\,^{+18}_{-7}$	0.2σ
$\omega(782)K^+$; $\omega(782) \to \pi^+\pi^-$	$0.17 \pm 0.24 \pm 0.03\,^{+0.05}_{-0.08}$	$0.09 \pm 0.13 \pm 0.02\,^{+0.03}_{-0.04}$	—	—
$f_2(1270)K^+$; $f_2(1270) \to \pi^+\pi^-$	$0.91 \pm 0.27 \pm 0.11\,^{+0.24}_{-0.17}$	$0.50 \pm 0.15 \pm 0.07\,^{+0.13}_{-0.09}$	$-85 \pm 22 \pm 13\,^{+22}_{-2}$	3.5σ
$f_X(1300)K^+$; $f_X(1300) \to \pi^+\pi^-$	$1.33 \pm 0.38 \pm 0.86\,^{+0.04}_{-0.14}$	$0.73 \pm 0.21 \pm 0.47\,^{+0.02}_{-0.08}$	$+28 \pm 26 \pm 13\,^{+7}_{-5}$	0.6σ

- statistical, systematic and model-dependent errors; Significance of DCPV is statistical only.

PRD 78, 012004 (2008) – 383 million BB

$A_{CP}(\rho^0 K^+) = (+44 \pm 10 \pm 4 \pm {}^{5}_{13})\%$

Very good agreement with the Belle result

HFAG Average

$A_{CP}(\rho^0 K^+) = (+42 \pm {}^{8}_{10})\%$

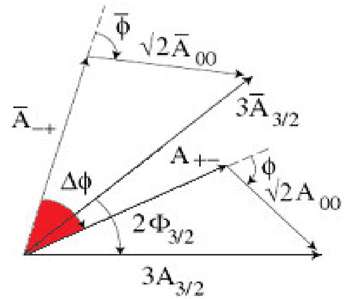
~ 4 σ significance

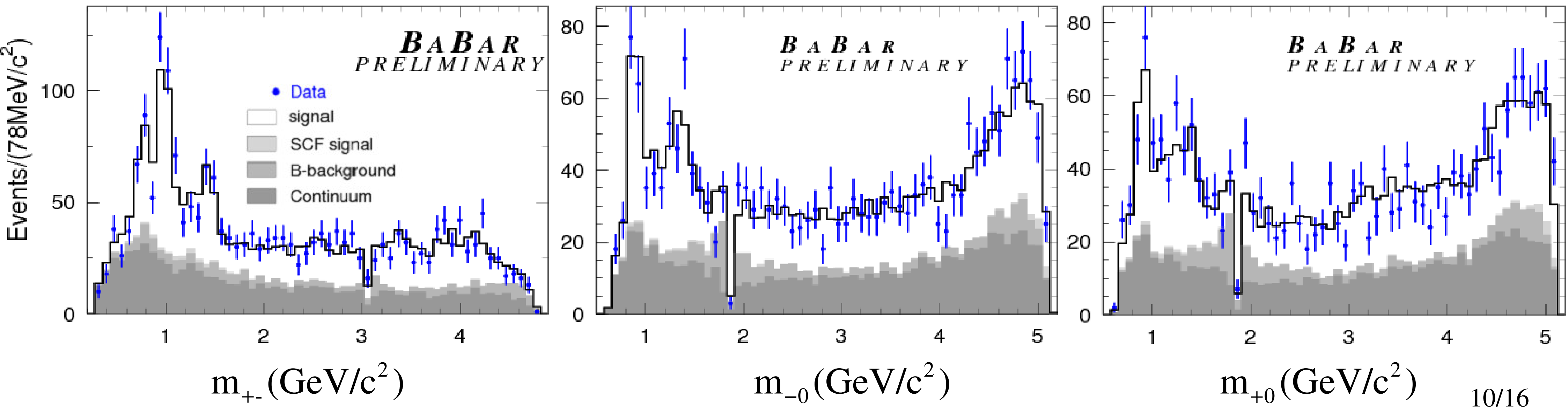
(systematic and model dependent uncertainties)

Results $B^0 \rightarrow K_S\pi^+\pi^-$ decays

arXiv: 0708.2097 [hep-ex]

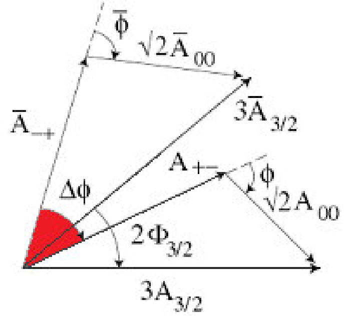
- Phase $\Delta\phi$ can be determined from this DP from interference between:
  - $K^{*+}\pi^-$ and $\rho^0 K_S$ (or $f_0 K_S$) in the B^0 decay
  - $K^{*-}\pi^+$ and $\rho^0 K_S$ (or $f_0 K_S$) in the $\bar{B}^0$ decay
- Does not require tagging or time-dependent analysis
- However, BABAR (Lepton-Photon '07) has performed time-dependent analyses of this mode
- Time-dependent analyses also allow measurement of β_{eff} from $\rho^0 K_S$, $f_0 K_S$ etc.



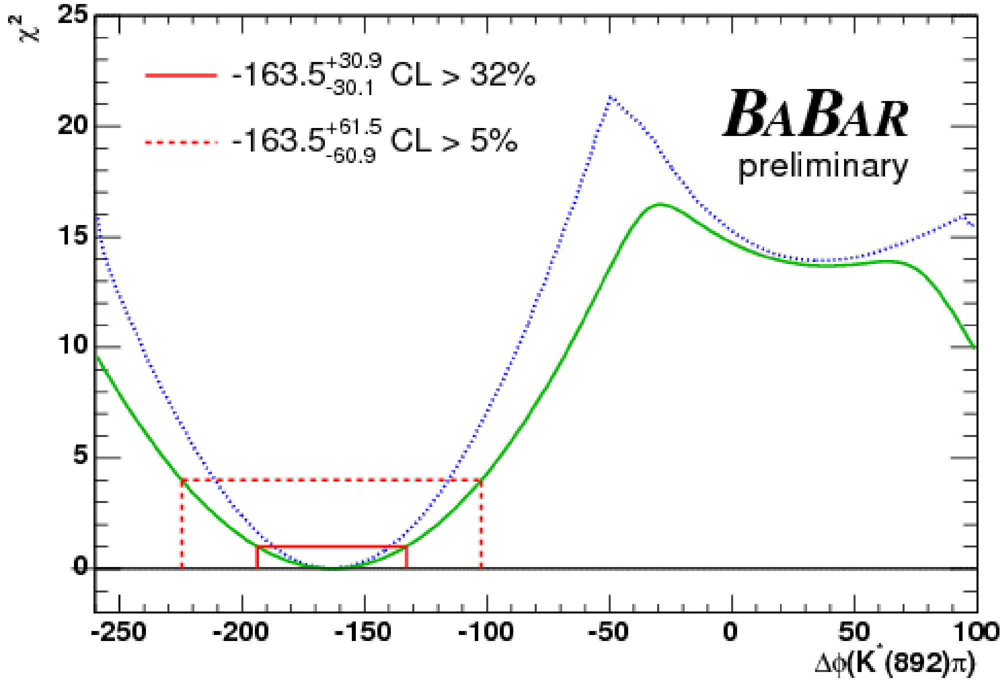


Results $B^0 \to K_S\pi^+\pi^-$ decays

arXiv: 0708.2097 [hep-ex]



- BABAR preliminary result from 383 million $B\bar{B}$ gives:
  $\Delta\phi = (-164 \pm 24 \pm 12 \pm 15)°$
  (stat, syst, model)



- This phase difference includes the $B^0\bar{B}^0$ mixing phase (-2β)

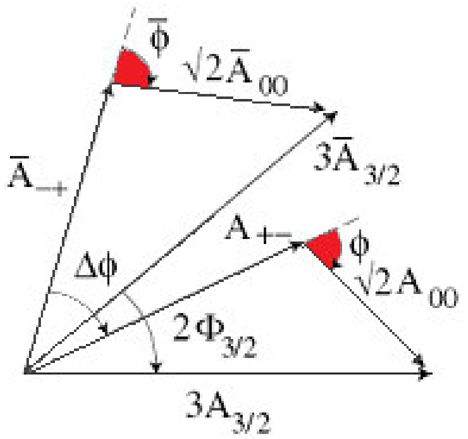
- Secondary solution excluded at >3σ

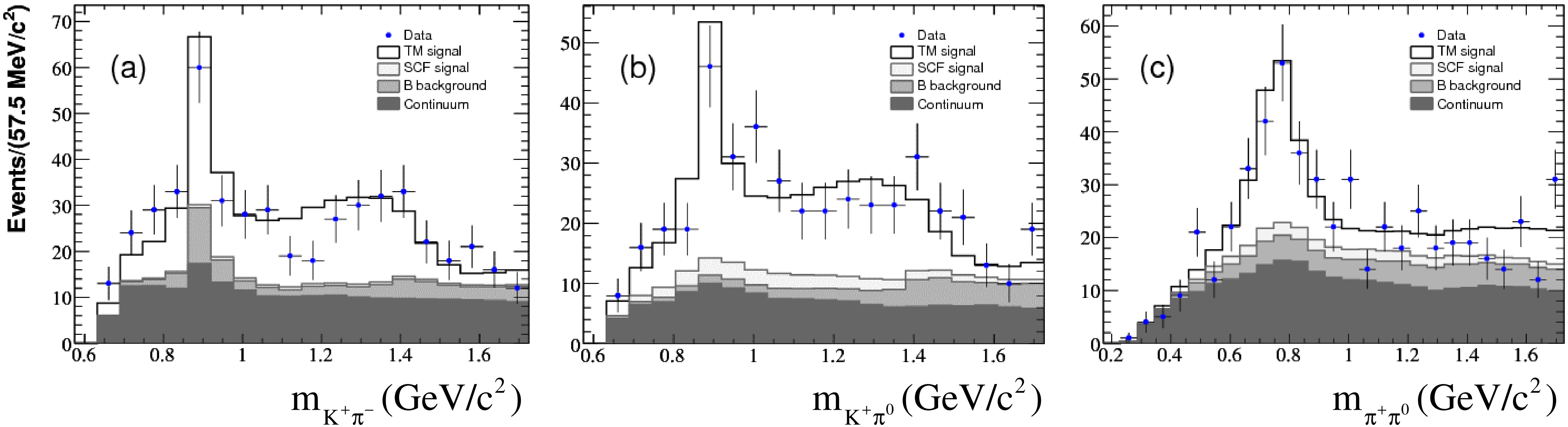
- Mixing phase, direct and mixing-induced CP asymmetries

Resonances	$2\beta_{eff}$ (degrees)	C	S
$f_0(980)K^0_S$	$89^{+22}_{-20} \pm 5 \pm 8$	$0.35 \pm 0.27 \pm 0.07 \pm 0.04$	$-0.94\,^{+0.07+0.05}_{-0.02-0.03} \pm 0.02$
$\rho^0(770)K^0_S$	$37^{+19}_{-17} \pm 5 \pm 6$	$0.02 \pm 0.27 \pm 0.08 \pm 0.06$	$0.61\,^{+0.22}_{-0.24} \pm 0.09 \pm 0.08$
$K^*(892)\pi$		$-0.18 \pm 0.10 \pm 0.03 \pm 0.03$	

Results $B^0 \to K^+\pi^-\pi^0$ decays

- Can determine the phases ϕ and $\overline{\phi}$ from this Dalitz plot
- Mode is self-tagging (from charge of kaon)-analysis does not involve flavour tagging or time-dependence
- BABAR have results from 232 million $B\overline{B}$
- Also preliminary results from 454 million $B\overline{B}$



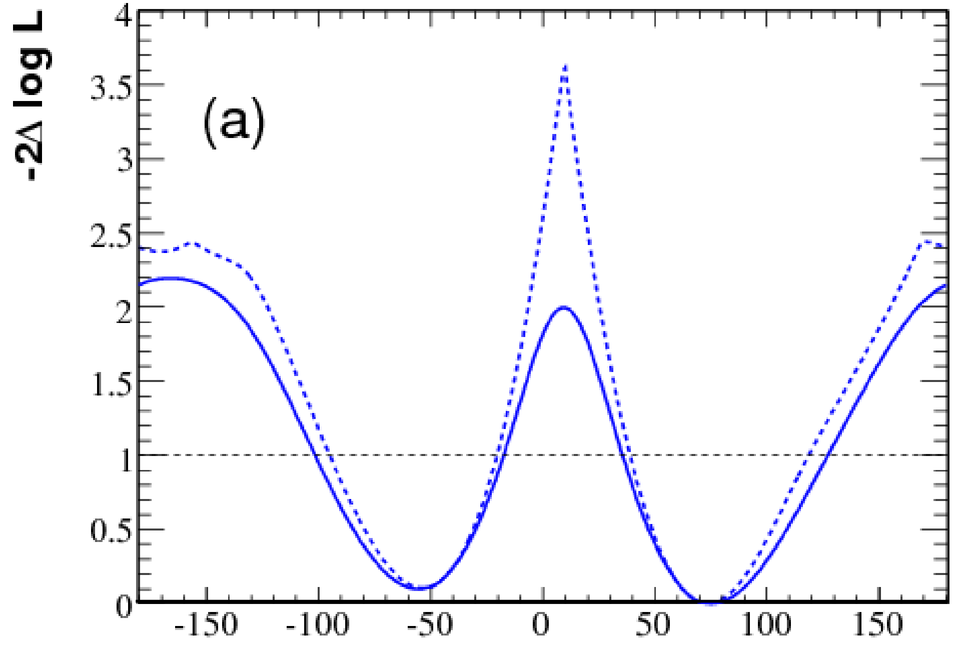


Results $B^0 \to K^+\pi^-\pi^0$ decays

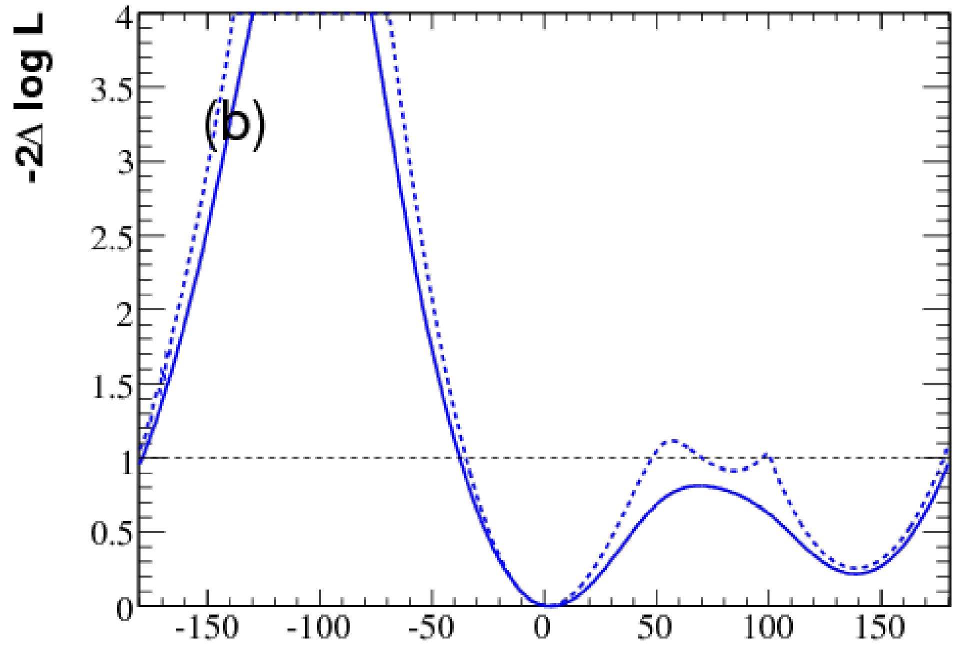
- BABAR results from 232 M $B\bar{B}$
- Published by PRD

–PRD 78, 052005 (2008)

- Scans opposite show the results for $\bar{\phi}$ and ϕ
- Presence of multiple solutions reduces precision of constraint
- Preliminary results on 454 M $B\bar{B}$ indicate much better separation between solutions
  - Likelihood scans of phase differences not yet completed
  - arXiv:0807.4567 [hep-ex]



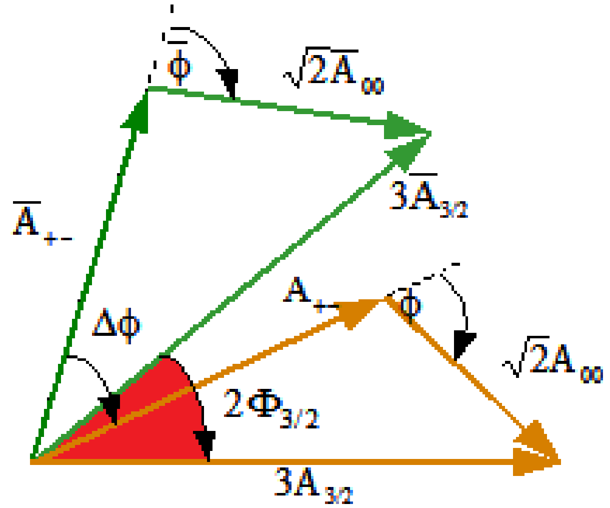
$\phi = \phi(K^{*0}(892)\pi^0) - \phi(K^{*+}(892)\pi^-)$ (^{0})

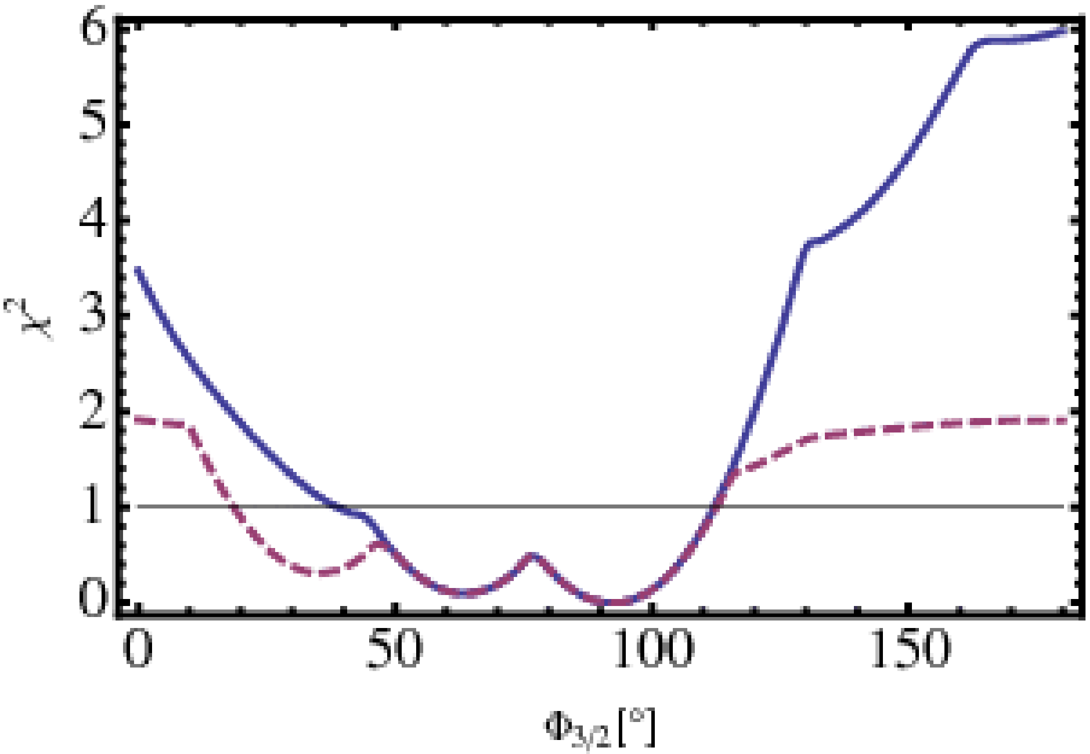


$\bar{\phi} = \bar{\phi}(\bar{K}^{*0}(892)\pi^0) - \bar{\phi}(K^{*-}(892)\pi^+)$ (^{0})

Combining results

- BABAR results from:
  - $K_S\,\pi^+\pi^-$ (arXiv:0708.2097)
  - $K^+\pi^-\pi^0$ (PRD 78, 052005 (2008))
- Gronau et al.
  - Phys. Rev. D77, 057504 (2008) and D78, 017505 (2008)





$39° < \Phi_{3/2} < 112°$ (68% CL)

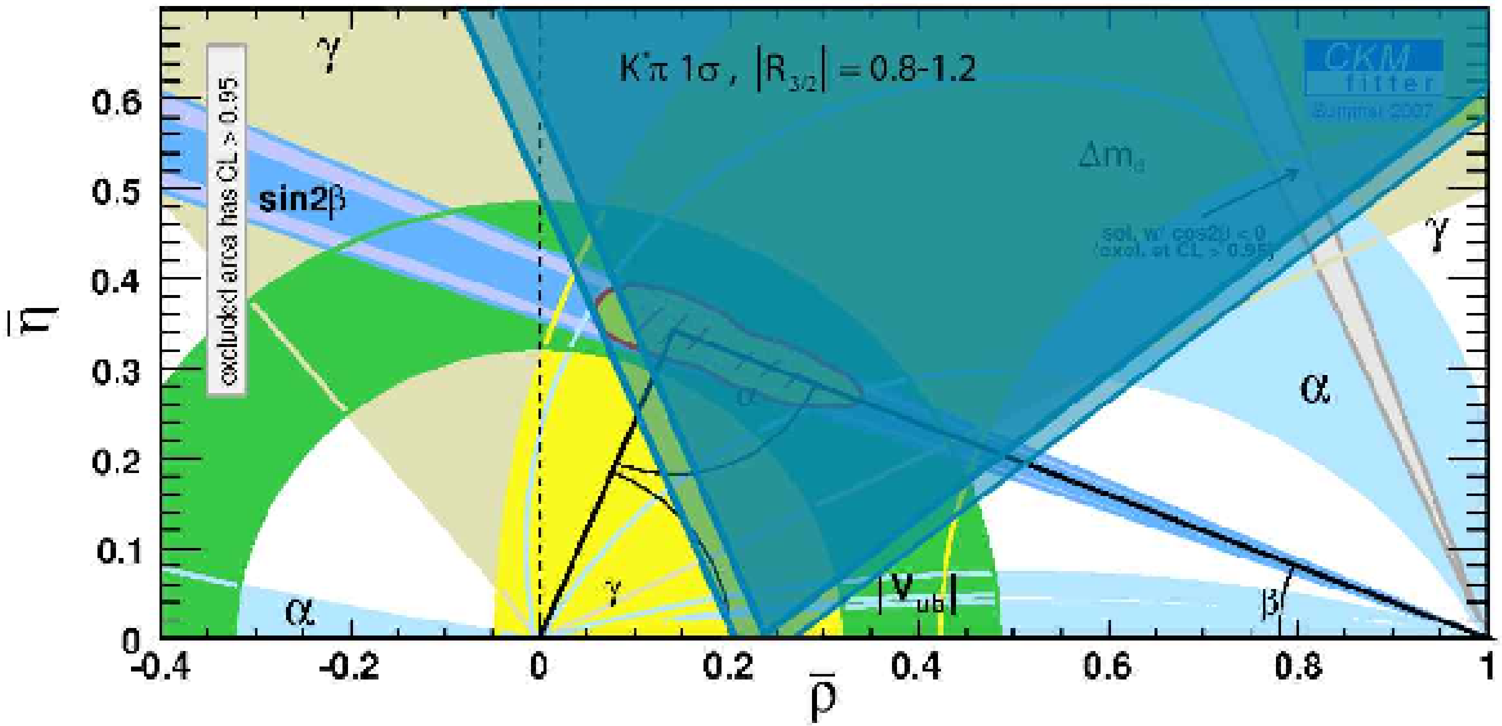
Dotted purple line – unconstrained $|R_{3/2}|$
Solid blue line – $0.8 < |R_{3/2}| < 1.2$

$$R_{2/3} \equiv \frac{\overline{A}_{3/2}}{A_{3/2}}$$

Combining results

- CKM constraint in presence of EW penguins:

$$\boxed{\bar{\eta} = \tan\Phi_{3/2}\left[\bar{\rho} - 0.24 \pm 0.03\right]}$$

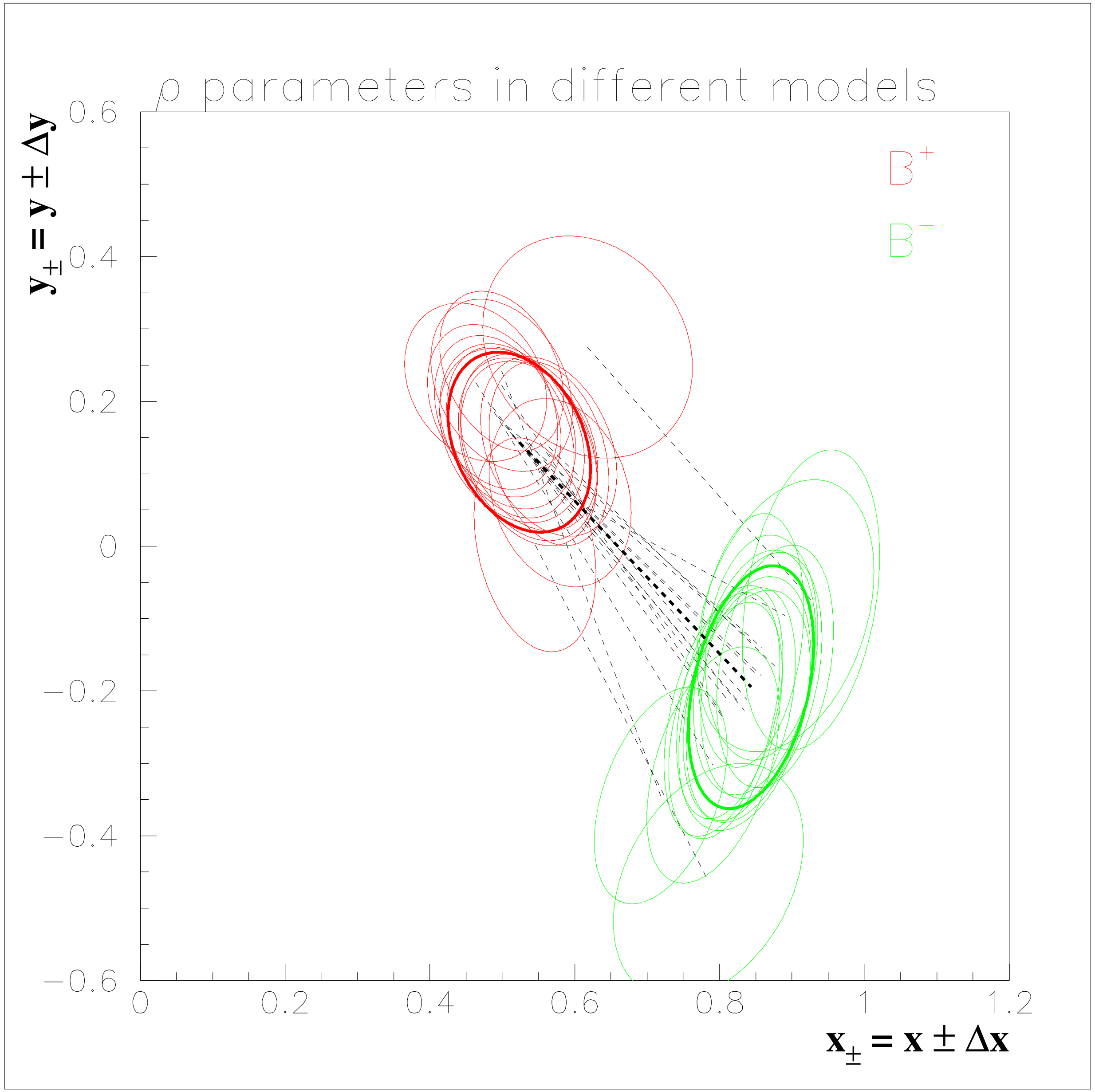


Summary

- BaBar has reacted quickly to the theoretical developments in this area
- Results available allow CKM constraint to be formed
- Updated results on ϕ and $\bar{\phi}$ from $K^+\pi^-\pi^0$ expected soon
  - Should help to resolve ambiguities
- Measurements from other $K\pi\pi$ modes, such as $K_S\pi^+\pi^0$, could help improve the precision
- Very promising method for future experiments

Backup slides

$B^+ \to K^+\pi^+\pi^-$ DCPV signifucance – ρ^0



$B^0 \to K_S\pi^+\pi^-$ decays

- Signal model:
  - $K^{*+}(892)$ – Relativistic Breit-Wigner
  - $K\pi$ S-wave – LASS
  - $\rho^0(770)$ – Gounaris-Sakurai
  - $f_0(980)$ – Flatté
  - $f_2(1270)$ – RBW
  - $f_X(1300)$ – RBW (m and Γ consistent $f_0(1500)$)
  - χ_{c0} – RBW
  - Phase-space nonresonant

Resonance Name	$\lvert c_\sigma \rvert$	ϕ[degrees]	$\lvert \bar{c}_\sigma \rvert$ ($\lvert \overline{c_{\overline{\sigma}}} \rvert$)	$\bar{\phi}$[degrees]
$f_0(980)K_S^0$	4.0	0.0	2.8 ± 0.7	-88.6 ± 21.3
$\rho^0(770)K_S^0$	0.10 ± 0.02	58.6 ± 16.4	0.09 ± 0.02	21.3 ± 21.2
$f_0(1300)K_S^0$	1.9 ± 0.4	117.6 ± 22.6	1.1 ± 0.3	-15.2 ± 23.8
Nonresonant	3.0 ± 0.6	13.8 ± 14.3	3.7 ± 0.5	-16.2 ± 17.3
$K^{*+}(892)\pi^-$	0.136 ± 0.021	-60.7 ± 18.5	0.113 ± 0.018	102.6 ± 22.9
$K^{*+}(1430)\pi^-$	4.9 ± 0.7	-82.4 ± 16.8	7.1 ± 0.9	79.2 ± 20.5
$f_2(1270)K_S^0$	0.011 ± 0.004	62.9 ± 23.3	0.010 ± 0.003	-73.9 ± 27.8
$\chi_{c0}(1P)K_S^0$	0.34 ± 0.15	68.7 ± 31.1	0.40 ± 0.11	154.5 ± 28.6

Results $B^0 \to K_S\pi^+\pi^-$ decays

Table 4: *Summary of results for the Q2B parameters. The first quoted error is statistical, the second is systematic and the third is DP signal model uncertainty. Parameters for which the statistical error have been obtained from a likelihood scan are marked by †. Phases are in degrees and relative fractions in %.*

Parameter	Value	Parameter	Value
$C(f_0(980)K_S^0)$	$0.35 \pm 0.27 \pm 0.07 \pm 0.04$	$C(\rho^0(770)K_S^0)$	$0.02 \pm 0.27 \pm 0.08 \pm 0.06$
$^\dagger 2\beta_{\rm eff}(f_0(980)K_S^0)$	$(89^{+22}_{-20} \pm 5 \pm 8)^\circ$	$^\dagger 2\beta_{\rm eff}(\rho^0(770)K_S^0)$	$(37^{+19}_{-17} \pm 5 \pm 6)^\circ$
$^\dagger S(f_0(980)K_S^0)$	$-0.94^{+0.07+0.05}_{-0.02-0.03} \pm 0.02$	$^\dagger S(\rho^0(770)K_S^0)$	$0.61^{+0.22}_{-0.24} \pm 0.09 \pm 0.08$
$f(f_0(980)K_S^0)$	$14.3^{+2.8}_{-1.8} \pm 1.5 \pm 0.6$	$f(\rho^0(770)K_S^0)$	$9.0 \pm 1.4 \pm 1.1 \pm 1.1$
$A_{CP}(K^{*+}(892)\pi^-)$	$-0.18 \pm 0.10 \pm 0.03 \pm 0.03$	$^\dagger \Delta\phi(f_0 K_S^0, \rho^0 K_S^0)$	$(-59^{+16}_{-17} \pm 6 \pm 6)^\circ$
$^\dagger \Delta\phi(K^*(892)\pi)$ [a]	$(-164 \pm 24 \pm 12 \pm 15)^\circ$		
$f(K^*(892)\pi)$	$11.7 \pm 1.3 \pm 1.3 \pm 0.6$		
$f(K^*(1430)\pi)$	$38.9 \pm 2.5 \pm 0.7 \pm 1.3$	$f(NR)$	$25.6 \pm 2.5 \pm 1.9 \pm 0.5$
$f(f_0(1300)K_S^0)$	$6.3 \pm 1.3 \pm 0.6 \pm 0.3$	$f(f_2(1270)K_S^0)$	$2.1 \pm 0.8 \pm 0.0 \pm 0.2$
$f(\chi_{c0}(1P)K_S^0)$	$1.2 \pm 0.5 \pm 0.0 \pm 0.1$		

Results $B^0 \to K^+\pi^-\pi^0$ decays

- Signal model:
  - $K^{*+}(892)$ – Relativistic Breit-Wigner
  - $K^{*0}(892)$ – Relativistic Breit-Wigner
  - $(K\pi)^+$ S-wave – LASS
  - $(K\pi)^0$ S-wave – LASS
  - $\rho^-(770)$ – Gounaris-Sakurai
  - Phase-space nonresonant

isobar j	FF_j (%)	$\mathcal{B}_j$ (10^{-6})	A^j_{CP}
$K^{*+}(892)\pi^-$	$11.8^{+2.5}_{-1.5} \pm 0.6$	$4.2^{+0.9}_{-0.5} \pm 0.3$	$-0.19^{+0.20}_{-0.15} \pm 0.04$
$K^{*0}(892)\pi^0$	$6.7^{+1.3+0.7}_{-1.5-0.6}$	$2.4 \pm 0.5 \pm 0.3$	$-0.09^{+0.21}_{-0.24} \pm 0.09$
$(K\pi)^{*+}_0\pi^-$	$26.3^{+3.1+2.1}_{-3.8-2.0} \pm 4.9$	$9.4^{+1.1+1.4}_{-1.3-1.1} \pm 1.8$	$+0.17^{+0.11}_{-0.16} \pm 0.09 \pm 0.20$
$(K\pi)^{*0}_0\pi^0$	$24.3^{+3.0+3.7}_{-2.6-3.0} \pm 6.7$	$8.7^{+1.1+1.8}_{-0.9-1.3} \pm 2.2$	$-0.22 \pm 0.12^{+0.13}_{-0.11} \pm 0.27$
$\rho^-(770)K^+$	$22.5^{+2.2}_{-3.7} \pm 1.2$	$8.0^{+0.8}_{-1.3} \pm 0.6$	$+0.11^{+0.14}_{-0.15} \pm 0.07$
N.R.	$12.4 \pm 2.6^{+1.3}_{-1.2}$	$4.4 \pm 0.9 \pm 0.5$	$+0.23^{+0.19+0.11}_{-0.27-0.10}$
Total	$102.3^{+7.1}_{-4.0} \pm 4.1$	$35.7^{+2.6}_{-1.5} \pm 2.2$	$-0.030^{+0.045}_{-0.051} \pm 0.055$