CKM2010

THE UNIVERSITY OF WARWICK

Determination of γ from $B \to K^* \pi$ decays and related modes

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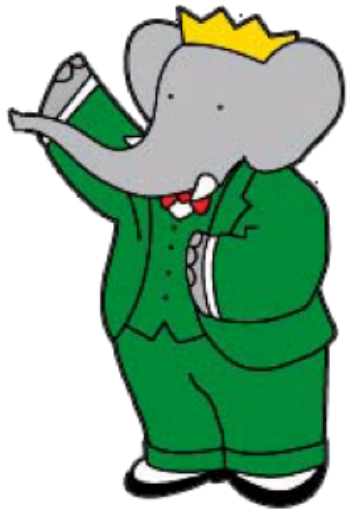
The BaBar Collaboration



Overview

- Motivation
- Experimental issues
- Recent results in $K^+\pi^-\pi^0$ and $K_S\pi^+\pi^-$
- Issues with interpretation
  - Phase conventions
  - EW penguin contributions
- Conclusion

Measuring γ in $B \to K^* \pi$ decays

- At tree level $B \to K^* \pi$ sensitive to γ:

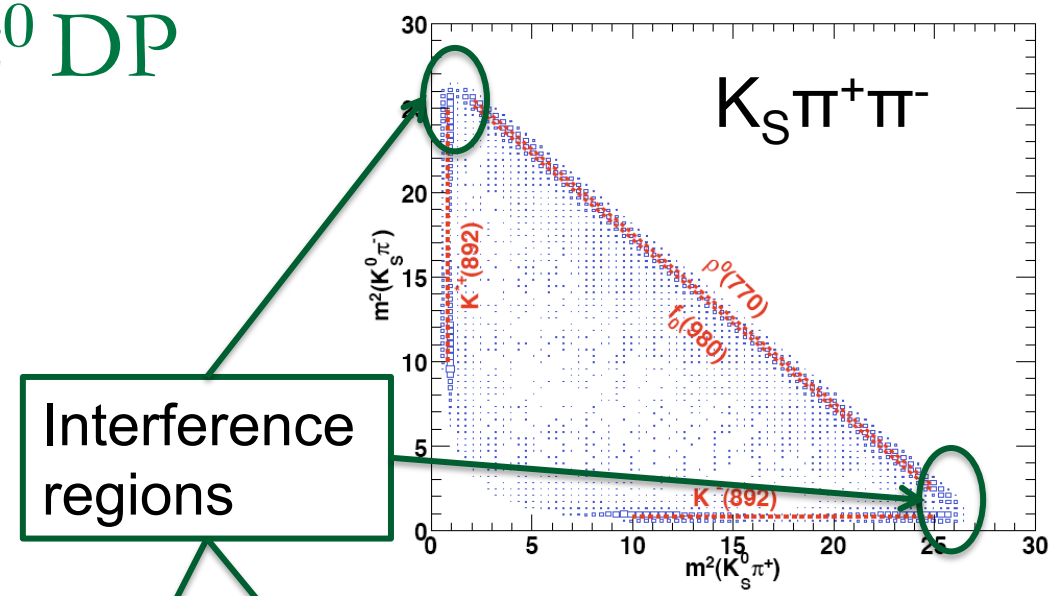
$$e^{-2i\gamma} = \frac{A\left(K^{*-}\pi^{+}\right) + \sqrt{2}A\left(\overline{K}^{*0}\pi^{0}\right)}{A\left(K^{*+}\pi^{-}\right) + \sqrt{2}A\left(K^{*0}\pi^{0}\right)}$$

- Need to measure magnitude and phases of amplitudes

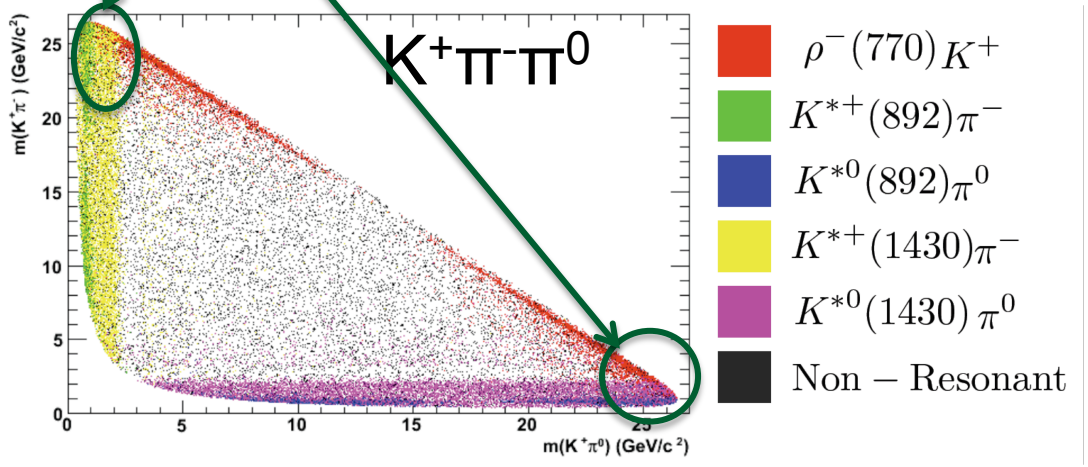
- In $B \to K\pi\pi$ can measure interference pattern in Dalitz plot (DP) from $B \to K^* \pi$ and $B \to K\rho$ to determine:
  - Magnitude of amplitudes,
  - Relative phases between amplitudes.

$K_S\pi^+\pi^-$ and $K^+\pi^-\pi^0$ DP structure

- Relative phases determined at interference regions
- Overlap region of resonances small
  - Effect on event density is subtle
  - Crucial to understand backgrounds and efficiencies in interference regions.



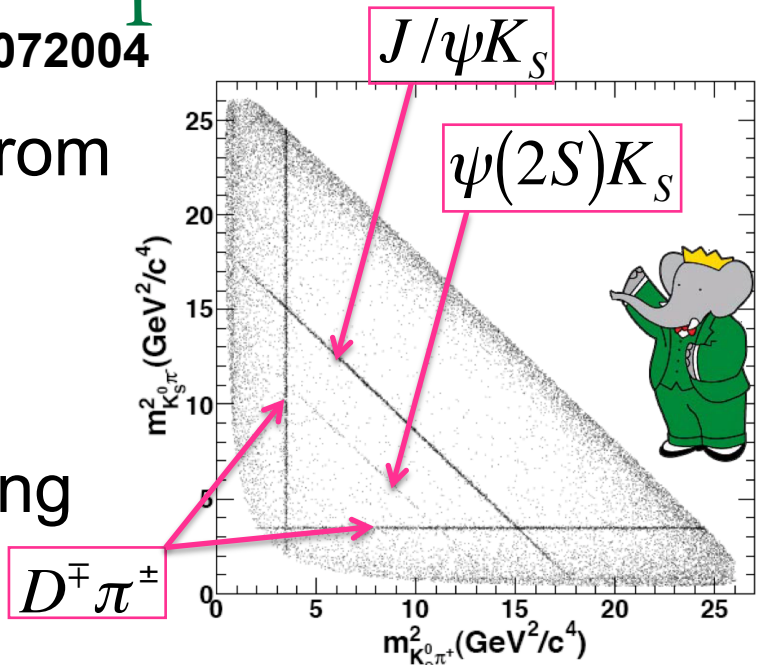
Characteristic MC DP distributions



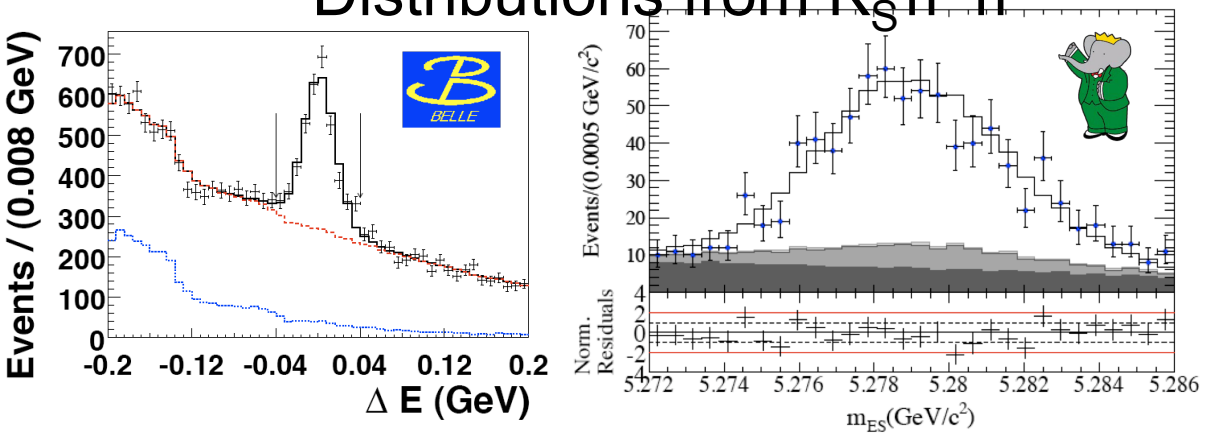
Signal and background separation

Phys. Rev. D80, 112001 & Phys. Rev. D79, 072004

- Main background contribution from continuum events
  - A Neural Network is used to reject most of the continuum
- Main B backgrounds in remaining events from $D^{-}\pi^{+}$, $J/\psi K_s$ and $\psi(2S)K_s$
- Projection plots for m_{ES} and ΔE after vetoes and event selection



Distributions from $K_S\pi^+\pi^-$

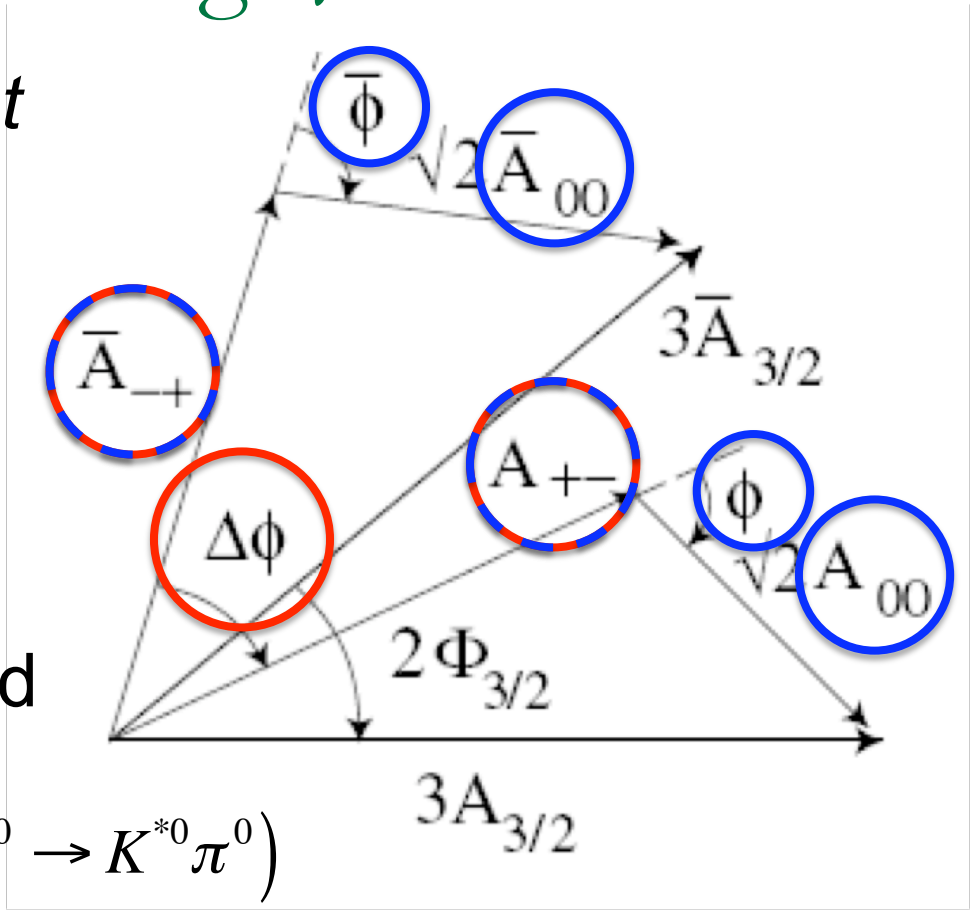


Determining γ from $K\pi\pi$ DPs

- 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 & D78, 017505 (2008)
  - Gronau et al., Phys. Rev. D81, 094011 (2010)
- Other methods use $K_S\pi^+\pi^0$, $K^+\pi^+\pi^-$ & $K_S\pi^+\pi^-$, and B_s decays to $K^+\pi^-\pi^0$ & $K_S\pi^+\pi^-$
  - Ciuchini et al., Phys. Rev. D74, 051301 (2006)
  - Bediaga et al., Phys. Rev. D76, 073011 (2007)
  - Ciuchini et al., Phys. Lett. B645, 201 (2007)

Method for determining γ from $K\pi\pi$

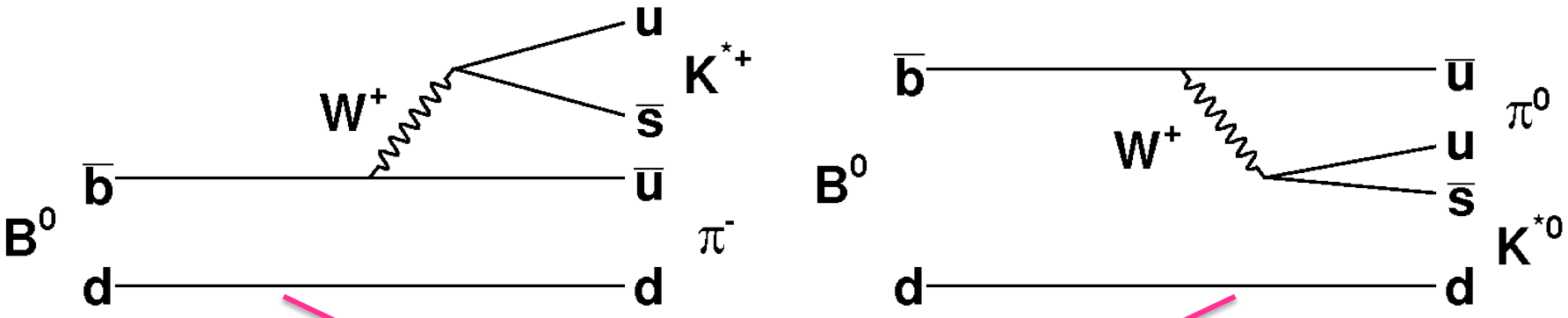
- Method from Ciuchini *et al.* and Gronau *et al.*
- Form isospin triangles from $K^*\pi$ modes:
  - From $B^0 \to K^+\pi^-\pi^0$
  - From $B^0 \to K_S\pi^+\pi^-$
- Resultant amplitude and phase:



$$3A_{\frac{3}{2}} = A\left(B^0 \to K^{*+}\pi^-\right) + \sqrt{2}A\left(B^0 \to K^{*0}\pi^0\right)$$

$$\Phi_{\frac{3}{2}} = \frac{1}{2}\left(\phi - \bar{\phi} - \Delta\phi_{K^*\pi}\right) \approx \gamma$$ up to correction from EW penguins

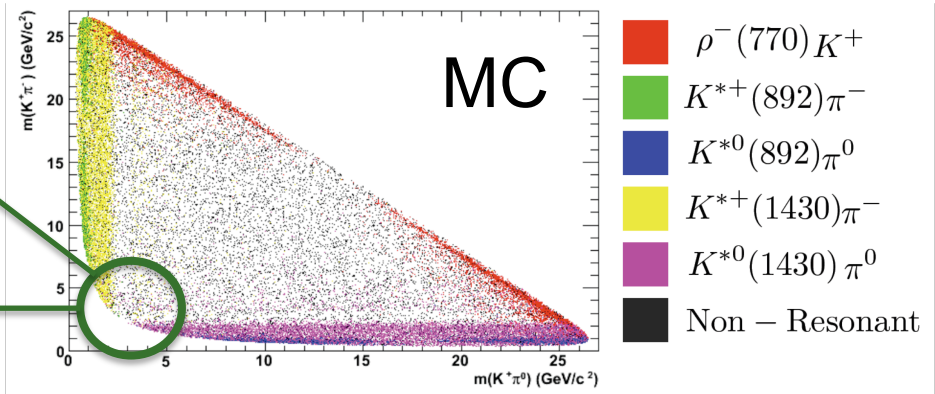
$K^{*0}\pi^0$ and $K^{*+}\pi^-$ phase difference



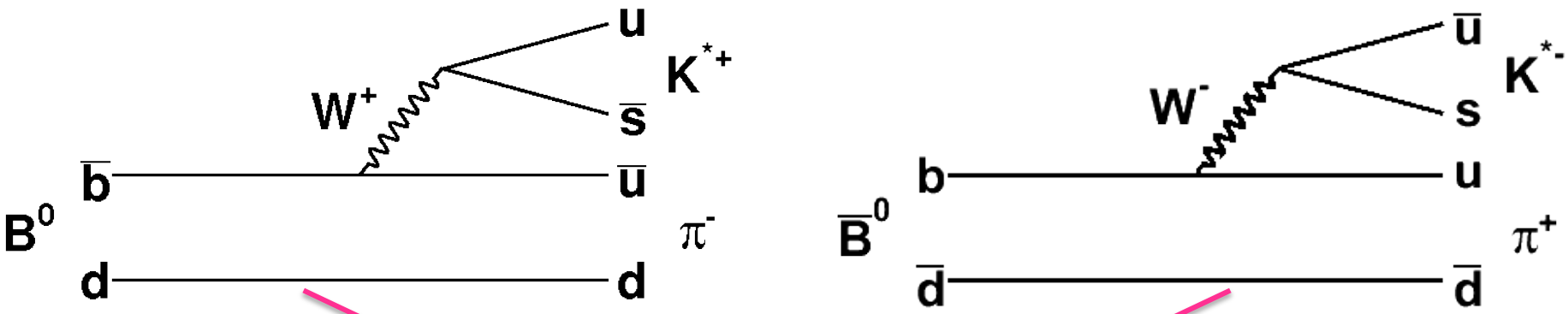
$$B^0 \to K^+\pi^-\pi^0$$

$$\overline{\phi} = \overline{\phi}_{K^{*0}\pi^0} - \overline{\phi}_{K^{*-}\pi^+}$$

$$\phi = \phi_{K^{*0}\pi^0} - \phi_{K^{*+}\pi^-}$$



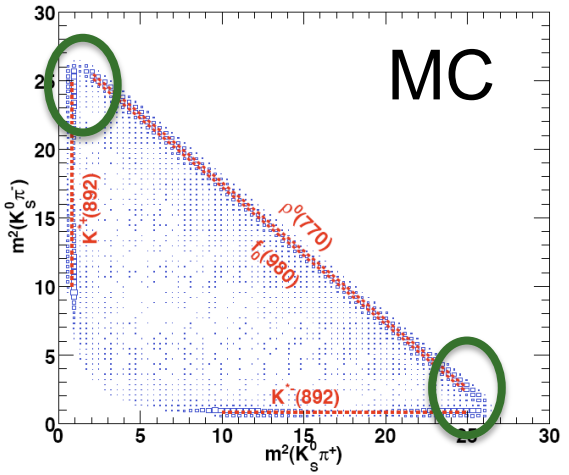
$K^{*+}\pi^-$ and $K^{*-}\pi^+$ phase difference



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

$$\Delta\phi_{K^*\pi} = \bar{\phi}_{K^{*-}\pi^+} - \phi_{K^{*+}\pi^-}$$

- Measure $K^*\pi$ phases relative to each other due to mixing
  - Additional phase of -2β needs to be accounted for.

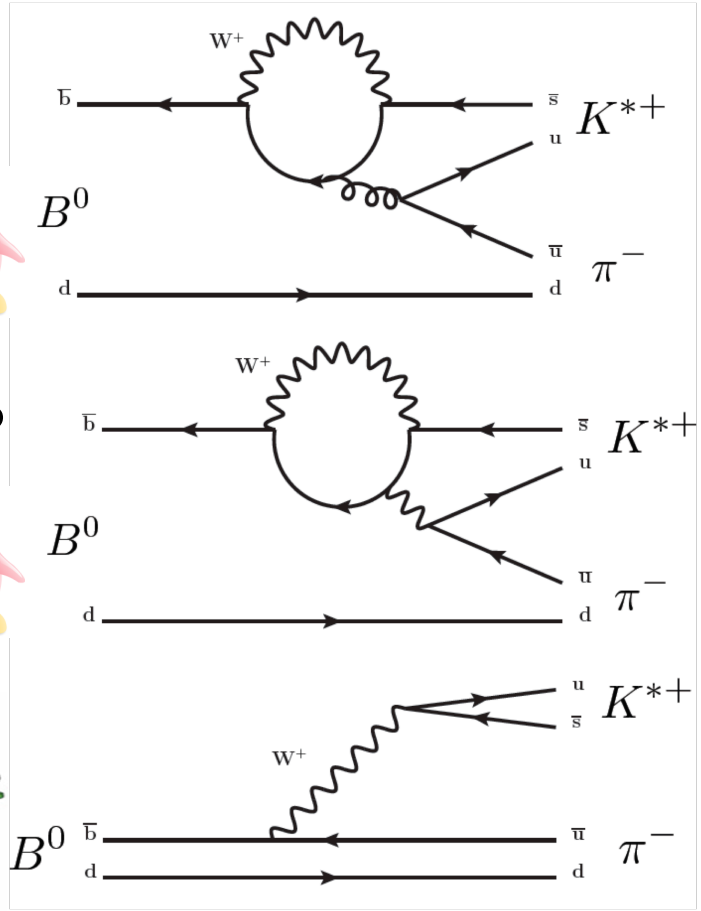


$K^*\pi$ Amplitudes and penguins

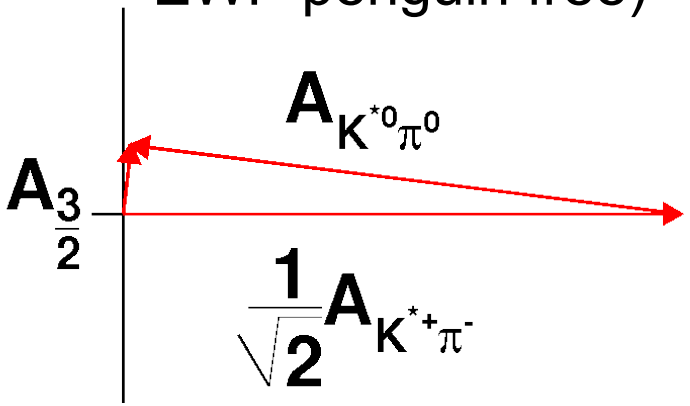
$$A_{\frac{3}{2}} = \frac{1}{\sqrt{2}} A\left(B^0 \to K^{*+}\pi^-\right) + A\left(B^0 \to K^{*0}\pi^0\right)$$

QCD

EWP



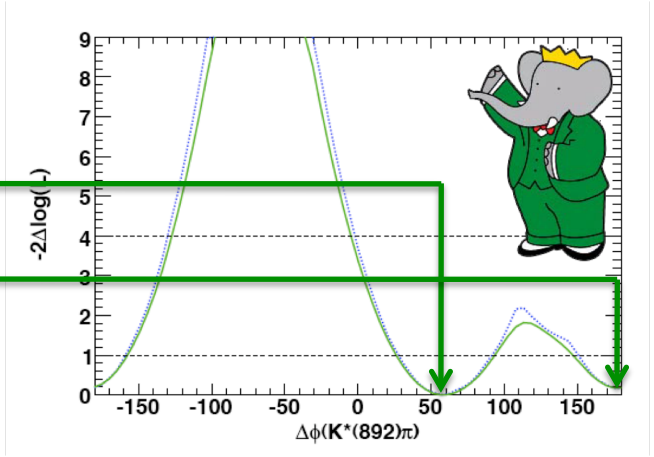
- Tree component expected to be small compared to dominant QCD penguin in $K^*\pi$ amplitudes
- QCD penguin contributions cancel in the sum of $A_{K^*\pi}$
  - $A_{3/2}$ is QCD penguins free (not EWP penguin free)



Results from time dependent $B^0 \to K_S\pi^+\pi^-$

- BaBar result from 383 million $B\bar{B}$ events gives:
  - $\Delta\phi = (58.3 \pm 32.7 \pm 4.6 \pm 8.1)°$
  - $\Delta\phi = (176.6 \pm 28.8 \pm 4.6 \pm 8.1)°$

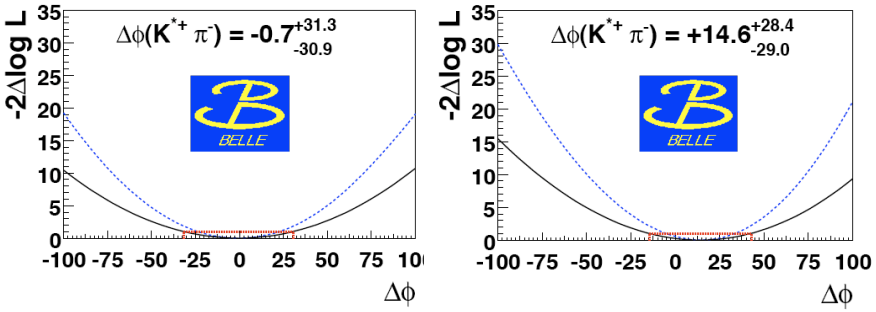
  (errors are stat, syst, model)



B.Aubert *et al.,* Phys. Rev. D80, 112001

- Belle results from 657 million $B\bar{B}$:
  - $\Delta\phi = (-0.7 \pm {}^{24}_{23} \pm 11 \pm 18)°$
  - $\Delta\phi = (+14.6 \pm {}^{19}_{20} \pm 11 \pm 18)°$

  (errors are stat, syst, model)
- Difference between solutions is interference between $K_0^{*\pm}(1430)$ and NR

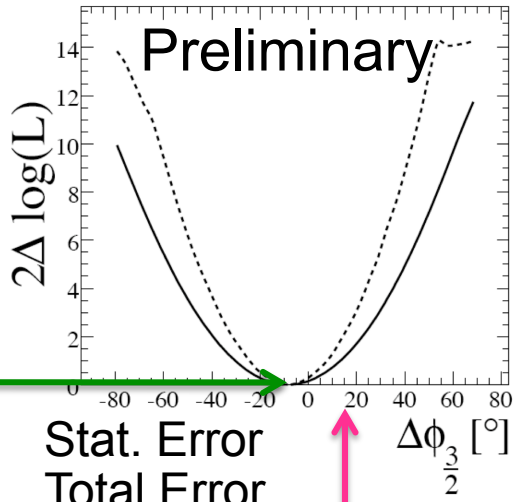


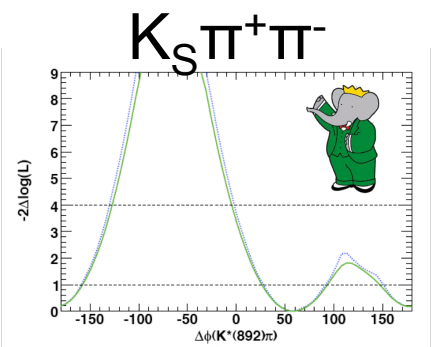
J.Dalseno *et al.,* Phys. Rev. D79, 072004

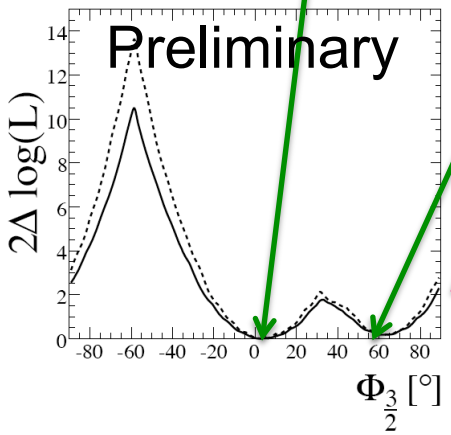
- This phase difference includes the $B^0\bar{B}^0$ mixing phase (-2β)

Preliminary results from $B^0 \to K^+\pi^-\pi^0$

- Results taken from A. Wagner, PhD Thesis, BaBar graduate student, SLAC-R-942
- From BaBar data of 454 million BB events gives:
  - $\Delta\Phi_{3/2} = (-7\ ^{+15}_{-18} \pm 15)°$
  - $\Phi_{3/2} = (1 \pm 21)°, (60 \pm 18)°$







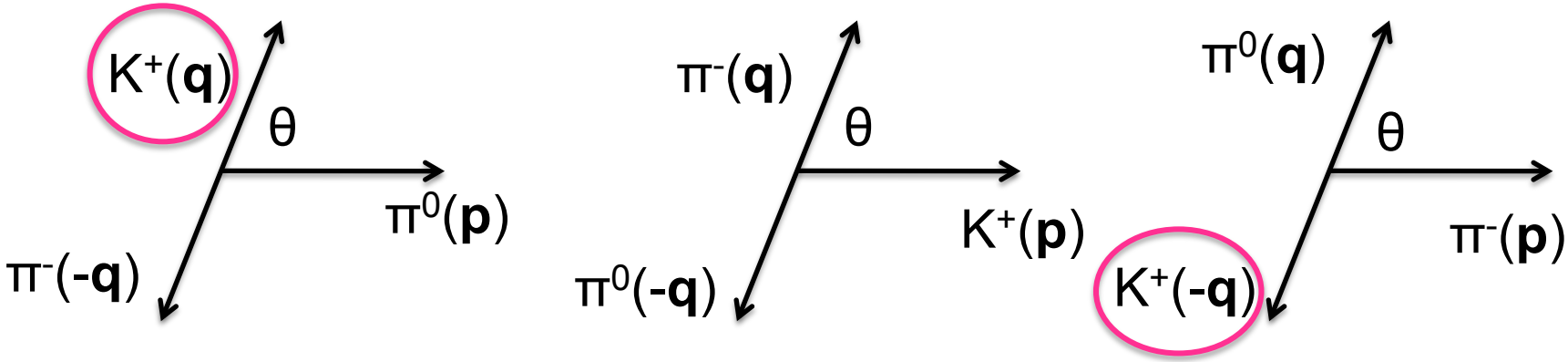
$$\Phi_{\frac{3}{2}} = \frac{1}{2}\left(\arctan\left(\frac{\sin\Delta\Phi}{\frac{|A_{K^{*+}\pi^-}|}{\sqrt{2}|A_{K^{*0}\pi^0}|}+\cos\Delta\Phi}\right) - \arctan\left(\frac{\sin\Delta\bar{\Phi}}{\frac{|\bar{A}_{K^{*+}\pi^-}|}{\sqrt{2}|\bar{A}_{K^{*0}\pi^0}|}+\cos\Delta\bar{\Phi}}\right) - \Delta\phi_{K^*\pi}\right)$$

- Two bands in $\Phi_{3/2}$ from ambiguity in $B^0 \to K_S\pi^+\pi^-$

Issue 1 - Phase conventions

- Each quasi-two body subsystem of Kππ in the vector meson rest frame contains:
  - Two pseudoscalar decay products with momentum **q** and **–q**
  - The bachelor pseudoscalar with momentum **p**
- Choice of which resonance daughter is defined to have positive momentum defines the phase convention
- Alternative choice induces a 180° flip of the phase
- Whichever choice is made it must be correctly accounted for when combining amplitudes to obtain the constraint on the UT apex
- See Gronau *et al.*, Phys.Rev.D**81**, 094026(2010)

Phases in $K^+ \pi^- \pi^0$



Helicity convention 180° out of phase for K^* resonances.

- Two K^* resonances have opposite conventions
- Appropriate Clebsch Gordon coefficients should be chosen when constructing the amplitudes from results of the DP fit

Defining phase conventions

- Can use any phase convention but:
  - important to include phase convention used in documentation
- Provide convention-independent information:
  - Useful cross check for understanding phase conventions and making comparison between experiments.
  - Using interference fraction can help identify constructive or destructive

Issue 2 - EWP contributions

$$A_{\frac{3}{2}} = Te^{i\gamma} - P_{EWP}$$

EWP

Gronau *et al.*, Phys.Rev.D75, 014002

$$A_{\frac{3}{2}} \propto \left(\bar{\rho} + i\bar{\eta}\right)\left(1 + r_{\frac{3}{2}}\right) + C\left(1 - r_{\frac{3}{2}}\right)$$

SU(3) decomposition of operators gives good approximation:

Wilson coeff, λ ≈ -0.27

Ratio of hadronic matrix elements

$$r_{\frac{3}{2}} = \frac{\left[A_{\rho^+\pi^0} - A_{\rho^0\pi^+}\right] - \sqrt{2}\left[A_{K^{*+}\bar{K}^0} - A_{K^+\bar{K}^{*0}}\right]}{A_{\rho^+\pi^0} + A_{\rho^0\pi^+}}$$

Estimating $r_{3/2}$

Decay Mode	BF(x10^{-6})	A_{CP}
$B^+ \to \rho^0\pi^+$	$8.3\ ^{+1.2}_{-1.3}$	$0.18\ ^{+0.09}_{-0.17}$
$B^+ \to \rho^+\pi^0$	$10.9\ ^{+1.4}_{-1.5}$	0.02 ± 0.11
$B^+ \to K^+\overline{K}^{*0}$	0.68 ± 0.19	-
$B^+ \to K_S K_S \pi^+$	< 0.51	-

BFs are well measured

Amplitudes small but relative phases unknown

Experimental numbers from HFAG Winter 2010, www.slac.stanford.edu/xorg/hfag/

Strategy – Separate into well-measured components and systematic uncertainty

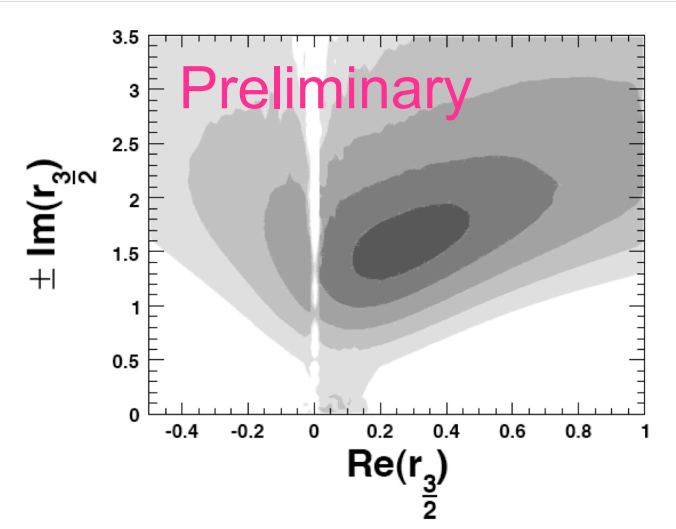
K*K Systematic

$$r_{\frac{3}{2}} = \frac{A_{\rho^+\pi^0} - A_{\rho^0\pi^+}}{A_{\rho^+\pi^0} + A_{\rho^0\pi^+}} \pm \sqrt{2}\,\frac{A_{K^{*+}\overline{K}^{*0}} - A_{K^+\overline{K}^{*0}}}{A_{\rho^+\pi^0} + A_{\rho^0\pi^+}} \pm 30\%SU(3)$$

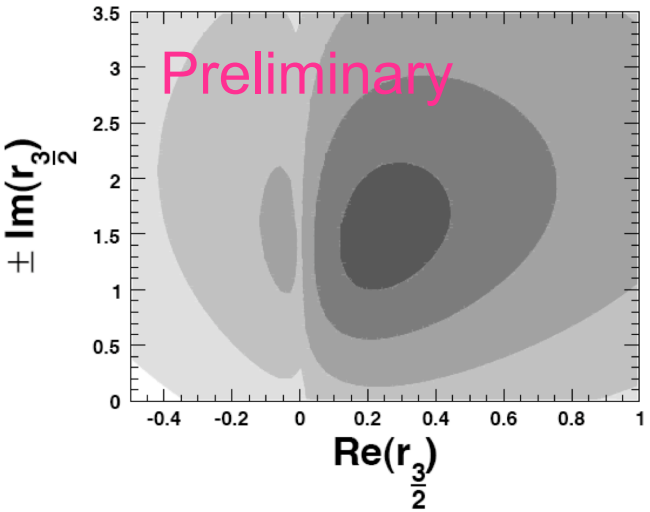
$$\frac{m_s}{\Lambda_{QCD}} \approx 30\%$$

Measurement of $r_{3/2}$

3% SU(3) breaking



30% SU(3) breaking



Contours darkest to lightest:
1, 2, 3, 4, 5σ

$$r_{\frac{3}{2}} \equiv \frac{A_{\rho^+\pi^0} - A_{\rho^0\pi^+}}{A_{\rho^+\pi^0} + A_{\rho^0\pi^+}}$$

A. Wagner, PhD Thesis, SLAC-R-942

- K^*K contribution added as a systematic.

Preliminary results for $r_{3/2}$ and P_{EWP}

A. Wagner, PhD Thesis, SLAC-R-942

- Preliminary results for $r_{3/2}$:

$$\mathrm{Re}(r_{\frac{3}{2}}) = 0.21 \pm 0.13\ (\mathrm{stat.}) \pm 0.77\ (\mathrm{syst.}) \pm 0.06\ (\mathrm{theo.}),$$

$$\pm\mathrm{Im}(r_{\frac{3}{2}}) = 1.45 \pm 0.35\ (\mathrm{stat.}) \pm 0.77\ (\mathrm{syst.}) \pm 0.44\ (\mathrm{theo.}).$$

- Preliminary results for the ratio of EW penguin to tree amplitudes:

$$\mathrm{Re}(P_{\mathrm{EWP}}/T) = -0.21 \pm 0.13\ (\mathrm{stat.}) \pm 0.29\ (\mathrm{syst.}) \pm 0.16\ (\mathrm{theo.}),$$

$$\pm\mathrm{Im}(P_{\mathrm{EWP}}/T) = -0.54 \pm 0.05\ (\mathrm{stat.}) \pm 0.29\ (\mathrm{syst.}) \pm 0.04\ (\mathrm{theo.}).$$

- Systematic is dominant source of error in this measurement:
  - Only eliminated by measuring relative phases for $K^{*+}\overline{K}^{0}$ and $K^{+}\overline{K}^{*0}$

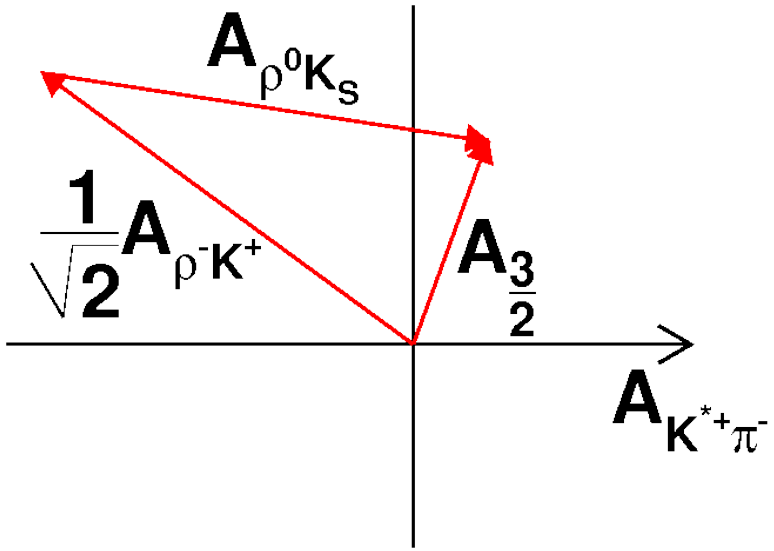
Conclusion

- BaBar results for $K^+\pi^-\pi^0$ in process of being finalised.
- Results to be combined soon to form CKM constraint.
- Measuring γ from $B \to \rho K$ via phase difference of ρK and $K^*\pi$
  - Tree/QCD penguin ratio expected to be larger than $K^*\pi$
  - Potentially better sensitivity to γ
- Promising method for future experiments:
  - At a Super B factory errors can expect errors to scale by 7% compared to BaBar results.
  - LHCb could also have potential for these measurements and additionally study the constraint in the B_s decays.

BACKUP SLIDES

Determining γ from $B \to \rho K$

- Another method involves using $B \to \rho K$ with $K^+\pi^-\pi^0$ and $K_S\pi^+\pi^-$
- Subtle difference with $K^*\pi$: relative phase not measured directly:
  - ρ^+K^- measured from $K^+\pi^-\pi^0$
  - ρ^0K_S measured from $K_S\pi^+\pi^-$
- $A_{3/2}$ determined from difference between the phases relative to $K^{*+}\pi^-$



- EW penguin contributions follow again from $\rho\pi$ like in $K^*(892)\pi$ case

Interference fractions

$$FF_{ij} = \frac{\int_{\mathrm{DP}} 2\,\mathrm{Re}\left[c_i c_j^* F_i(m_+^2, m_-^2) F_j^*(m_+^2, m_-^2)\right] d(m_+^2) d(m_-^2)}{\int_{\mathrm{DP}} \left|\sum_j c_j F_j(m_+^2, m_-^2)\right|^2 d(m_+^2) d(m_-^2)}$$

- Gives the extent of the interference effect between two resonances as measured in the fit.
- It's a convention independent representation of the event population of the DP
  - $+FF_{ij}$ = constructive interference
  - $-FF_{ij}$ = destructive interference