Two and Three-body charmless B decays at BaBar

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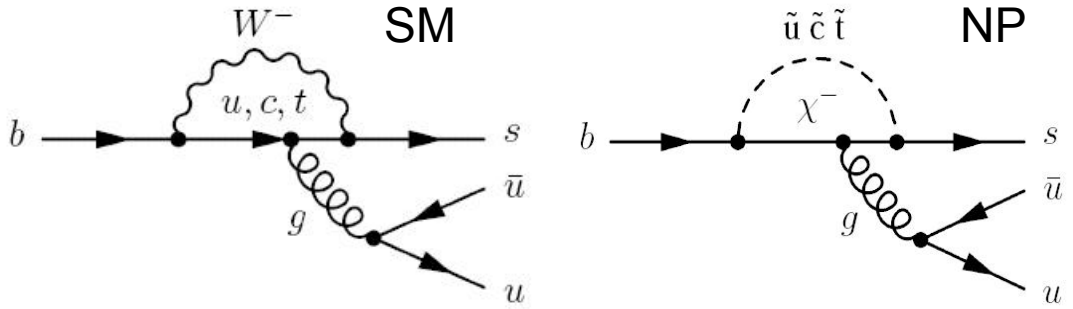
Introduction

- Rare charmless hadronic decays:
  - validate the CKM picture of CP violation by overconstraining the Unitarity Triangle
  - may reveal hints of New Physics (NP)
- In SM suppressed processes, NP may compete with SM
  - New couplings, including new (virtual) particles in loops



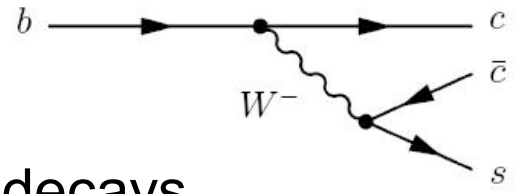
- NP probes include asymmetries and branching fractions
  - S~sin2β ($\eta'K^0$, ωK_S; $\eta' K_S K_S$, $\eta K_S K_S$, $\pi^0 K_S K_S$; $K_S\pi^+\pi^-$)
  - A_{CP} ($K^+\pi^-$ vs. $K^+\pi^0$)

} In this talk

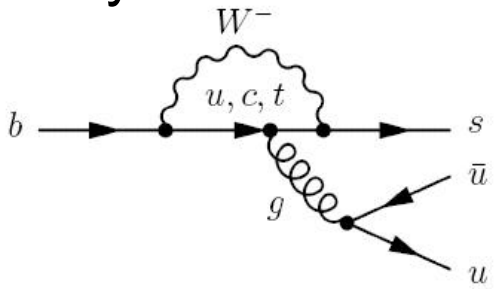
- Hadronic uncertainties can play a major role

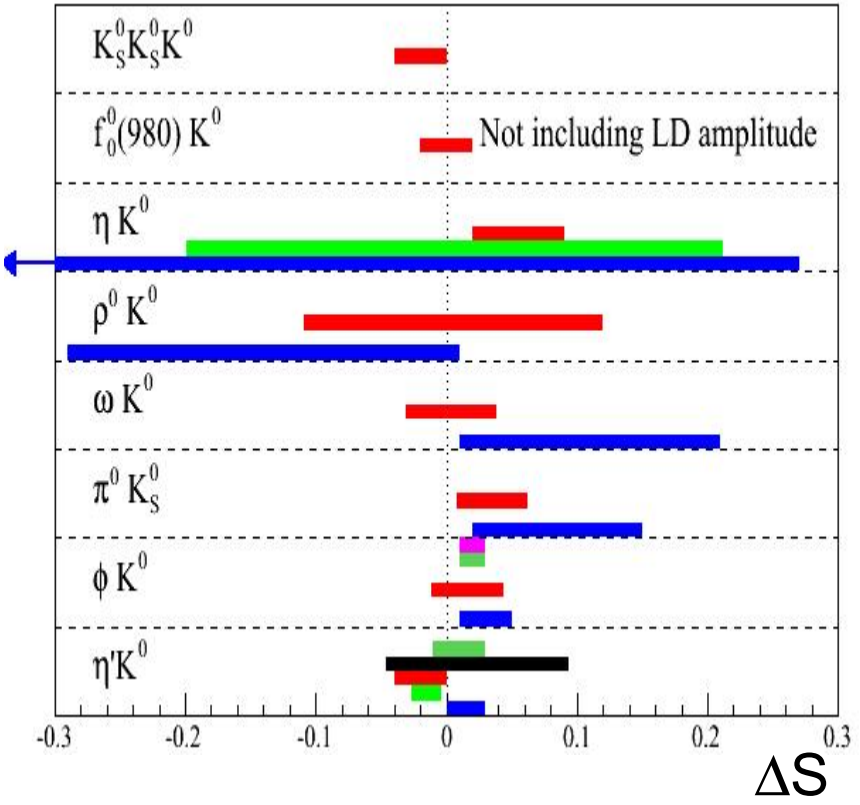
ΔS from $b \to s$ penguins

- $\sin 2\beta$ well measured in $b \to ccs$ tree decays
  - $S_{cc} = -\eta_{CP} \sin 2\beta$



- In penguin dominated decays
  - $S_{qq} = -\eta_{CP} \sin 2\beta_{eff}$
  - $\Delta S = S_{qq} - S_{cc}$
    - $\Delta S_{SM} > 0$ for most modes
      - λ suppressed tree contributions
    - In some model, $\Delta S_{NP} \sim O(1)$





- Theoretically cleanest modes
  - $K_S K_S K^0$, ϕK^0, $\eta' K^0$
- In recent HFAG average $\Delta S \leq 0$
  - $S_{qq} = 0.62 \pm 0.04$ (naïve) vs. $S_{cc} = 0.67 \pm 0.02$

QCDF Beneke, PLB**620**, 143(2005)
SCET/QCDF, Williamson and Zupan, PRD**74**, 014003 (2006)
QCDF Cheng, Chua and Soni, PRD**72**, 014006 (2005), PRD**74** 094001 (2006)
SU(3) Gronau, Rosner and Zupan, PRD**74**, 093003 (2006)
QCDF Buchalla, Hiller, Nir and Raz, JHEP**09**, 075 (2005)
pQCD Li and Mishima, PRD**74**, 094020 (2006)

$B^0 \to \eta' K^0$ and $B^0 \to \omega K_S$

- Last update uses the full BaBar dataset (+20% w.r.t. previous analysis)
- $\eta' K^0$ has a large BF(65×10^{-6}): 2500 signal events, most precise measurement of S in a penguin dominated mode
  - One additional η' decay channel added in $\eta' K_L$ analysis
  - $\eta' K_S$ and $\eta' K_L$ results combined with scans of -2 NLL
  - Main systematic from vertex resolution model
  - Decreased error on S and C by 20-25%
- 163 ωK_S signal events found
  - B daughters reconstructed in the main decay modes
  - ω mass and angular variables used in the fit
  - Main systematic from PDF characterization

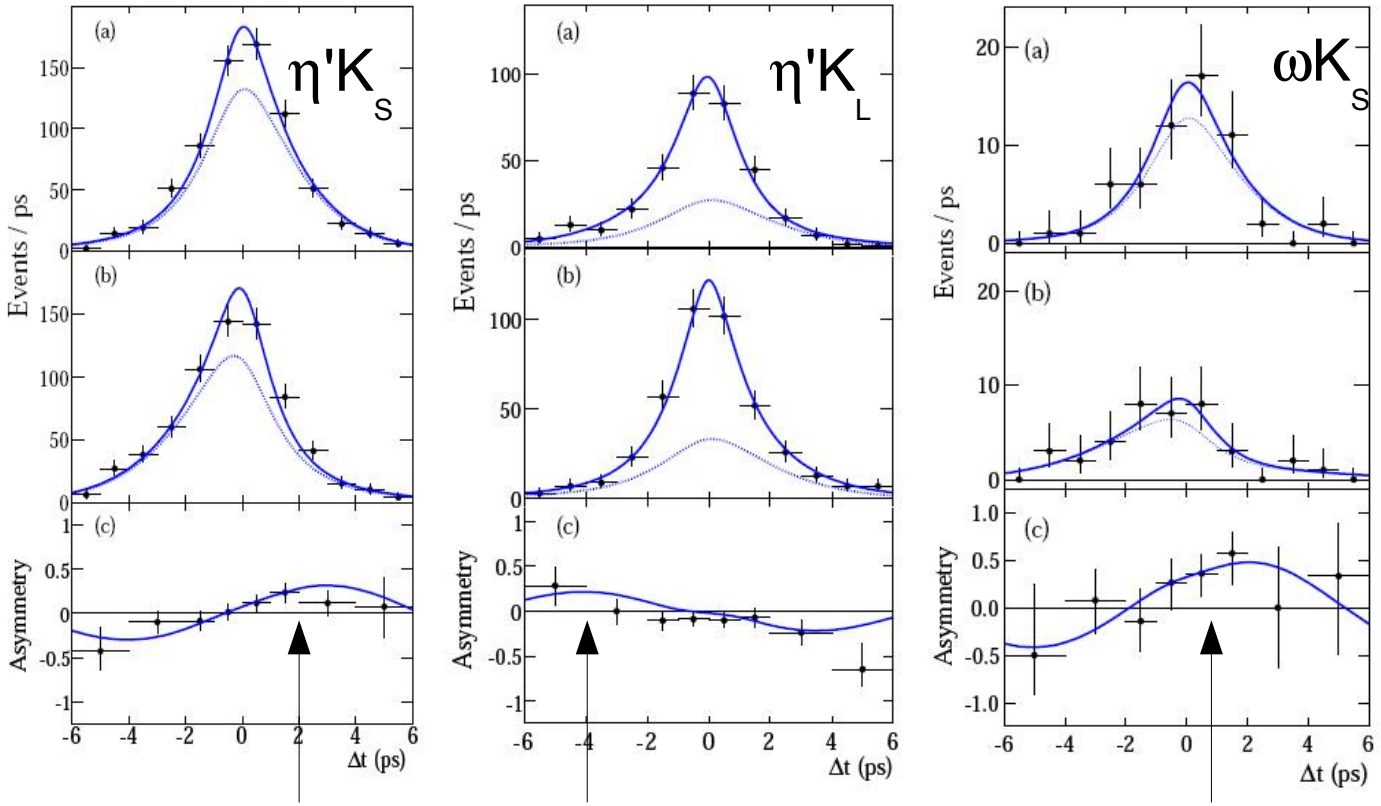
$B^0 \to \eta' K^0$ and $B^0 \to \omega K_s$ results

$S = 0.57 \pm 0.08 \pm 0.02$

$C = -0.08 \pm 0.06 \pm 0.02$

$S = 0.55\ ^{+0.26}_{-0.29} \pm 0.02$

$C = -0.52\ ^{+0.22}_{-0.20} \pm 0.03$ (2.5 σ)



B0

B0bar

asymmetry

PRD79, 052003 (2009)

$\eta_{CP} = -1$ $\eta_{CP} = +1$ $C \neq 0$

$\Delta S < 0$ but consistent with SM

More statistics needed in order to investigate $C \neq 0$

$B^0 \to \eta K_s K_s$, $\eta' K_s K_s$, $\pi^0 K_s K_s$

- Motivated by possibility for time-dependent CP asymmetry measurements

  Gershon, Hazumi, PLB 596, 163 (2004)

  - Final states are CP eigenstates
    - 3 CP eigenstate particles, 2 of which are equal
  - No need for isospin or Dalitz Plot analysis to separate the contributions
    - No dependence on intermediate resonant structure
- B daughters reconstructed in the main decay channels
- Maximum Likelihood fit to kinematical and topological variables
- No evidence of signal found

  arXiv:0905.0868, Accepted by PRD

  - No time-dependent analysis

	$\mathcal{B}(\times 10^{-6})$	90% CL UL $(\times 10^{-7})$
$\pi^0 K_S K_S$	$2.7^{+4.2}_{-3.7} \pm 0.6$	9
$\eta K_S K_S$	$2.1^{+4.7}_{-3.8} \pm 1.2$	10
$\eta' K_S K_S$	$5.7^{+8.0}_{-6.5} \pm 3.4$	20

Time-dependent DP $B^0 \to K_S \pi^+ \pi^-$ analysis

- Each intermediate resonance appears as a structure in the Dalitz plot according to its mass, width, spin
- Amplitude parameterization

$$\mathcal{A}(s_+, s_-) = \sum_{j=1}^{N} |c_j| e^{-i\phi_j} R_j(m) X_L(|\vec{p}^*| r') X_L(|\vec{q}| r) \Gamma_j(L, \vec{p}, \vec{q})$$

isobar amplitude, Breit-Wigner, barrier factors, angular distribution

- Δt model:

~ C ~ S ~ $e^{-2i\beta}$

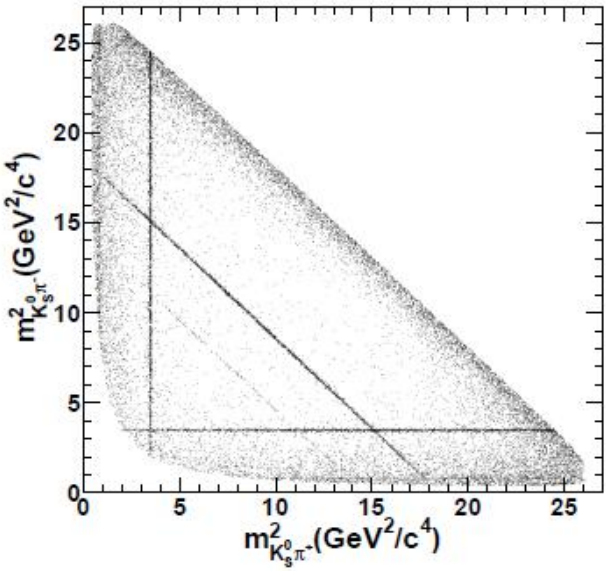
$$f(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{\tau} \left[|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2 \mp \left(|A|^2 - |\overline{\mathcal{A}}|^2 \right) \cos(\Delta m_d \Delta t) \pm \eta \, 2\mathrm{Im}\left[\overline{\mathcal{A}}\mathcal{A}^*\right] \sin(\Delta m_d \Delta t) \right]$$

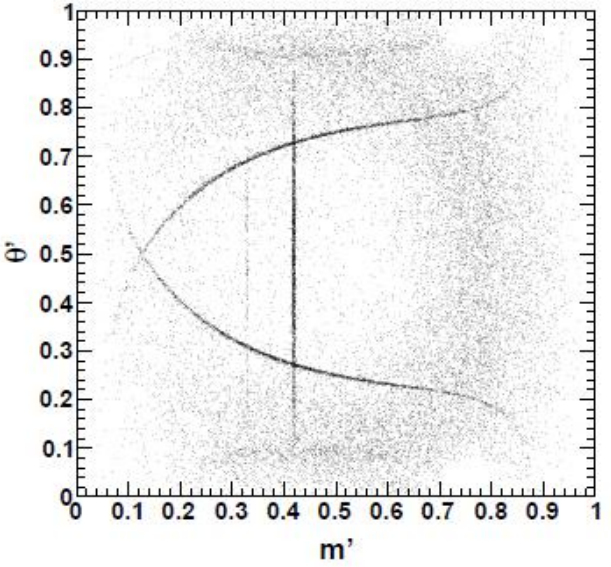
- The isobar amplitudes c_i are extracted from the fit
  - The other parameters (i.e. S, C, branching fractions) are calculated from them
- Interference of resonant contributions provides access to phases, without ambiguities from $\sin 2\beta_{\mathrm{eff}}$

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

- A square Dalitz plot is used

$$m' \equiv \frac{1}{\pi} \arccos\left(2\frac{m_0 - m_0^{\min}}{m_0^{\max} - m_0^{\min}} - 1\right), \quad \theta' \equiv \frac{1}{\pi}\theta_0$$





- Signal model includes:
  - $\pi\pi$ resonances: $\rho(770)$, $f_0(980)$, $f_2(1270)$, $f_X(1300)$, χ_{c0}
  - $K\pi$ resonances: K*(892), $K\pi$ S-wave
  - Non-resonant
- 15 complex isobar amplitudes
- 2182 events found

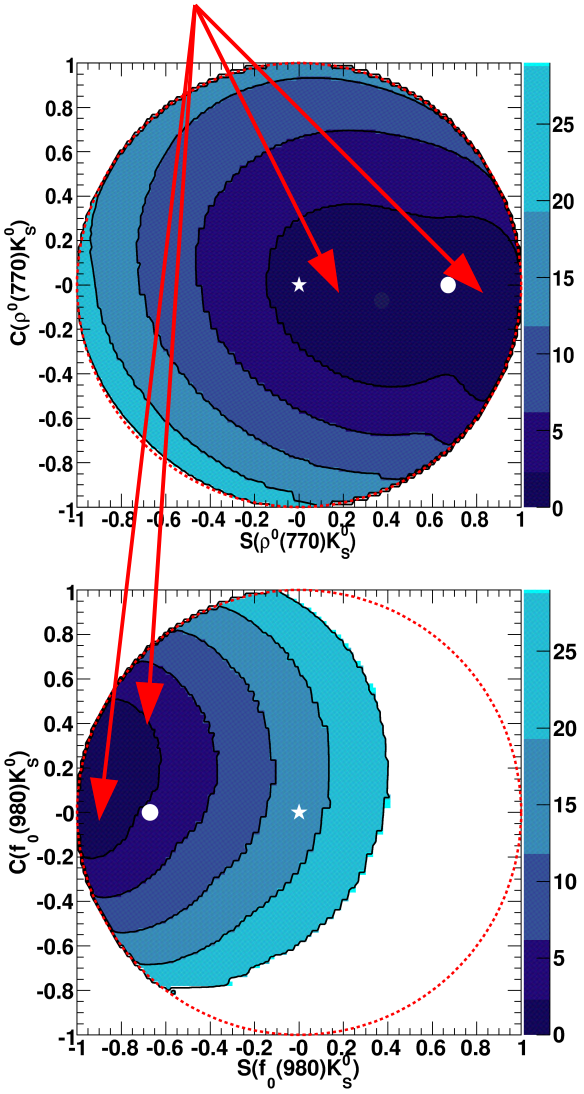
arXiv:0905.3615, Submitted to PRD

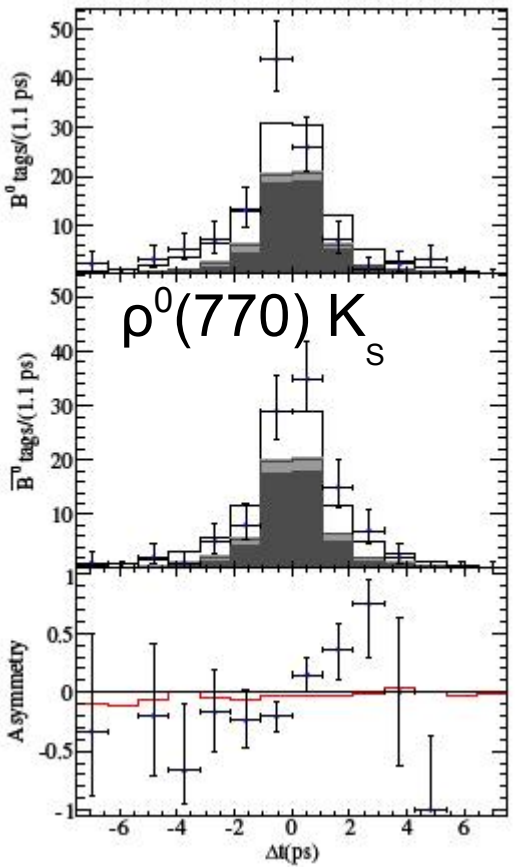
β_{eff} from $B^0 \to f_0 K_S$ and $B^0 \to \rho^0 K_S$

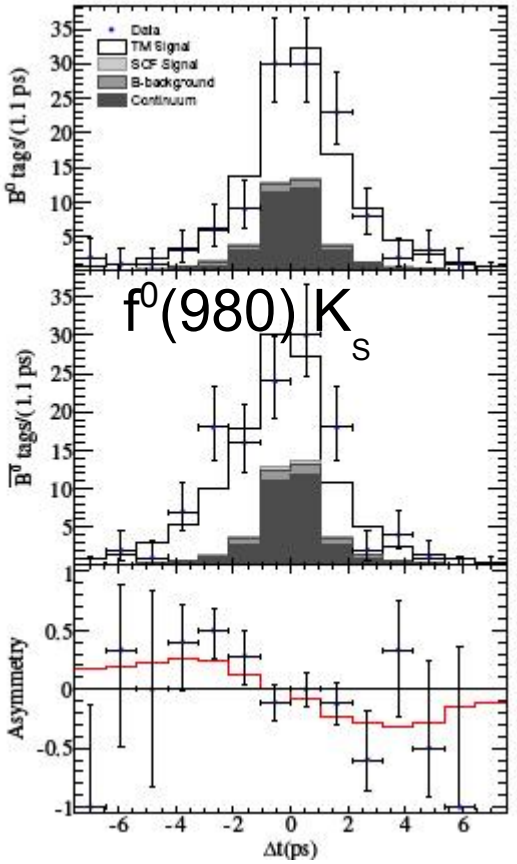
- Projections of the likelihood function on the S-C plane
- Two solutions, almost degenerate in likelihood (☆ is 0, ❍ is SM)
  - $18° < \beta_{eff}\ [f_0(980)\ K_S] < 76°$ (95% CL)
  - $-9° < \beta_{eff}\ [\rho_0(770)\ K_S] < 57°$ (95% CL)
  - S consistent with the SM

No ambiguity!

arXiv:0905.3615





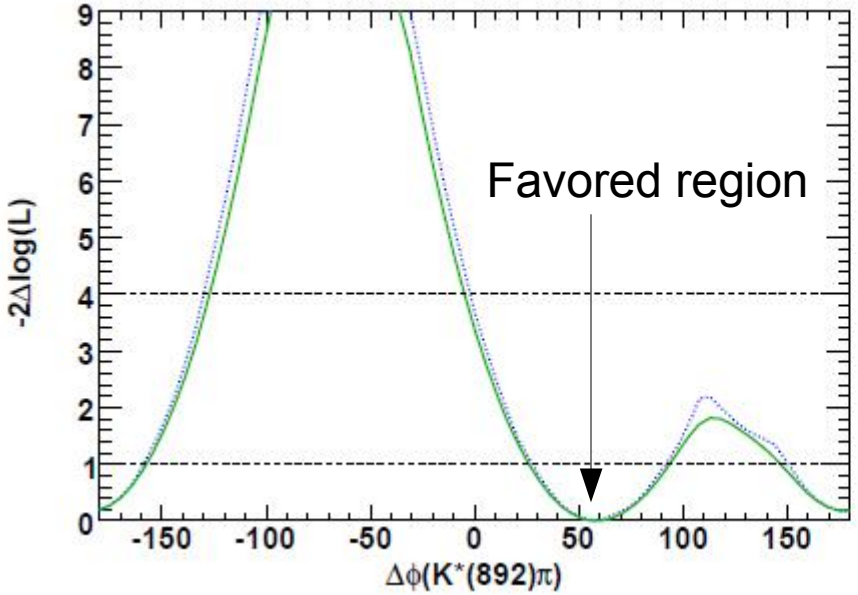


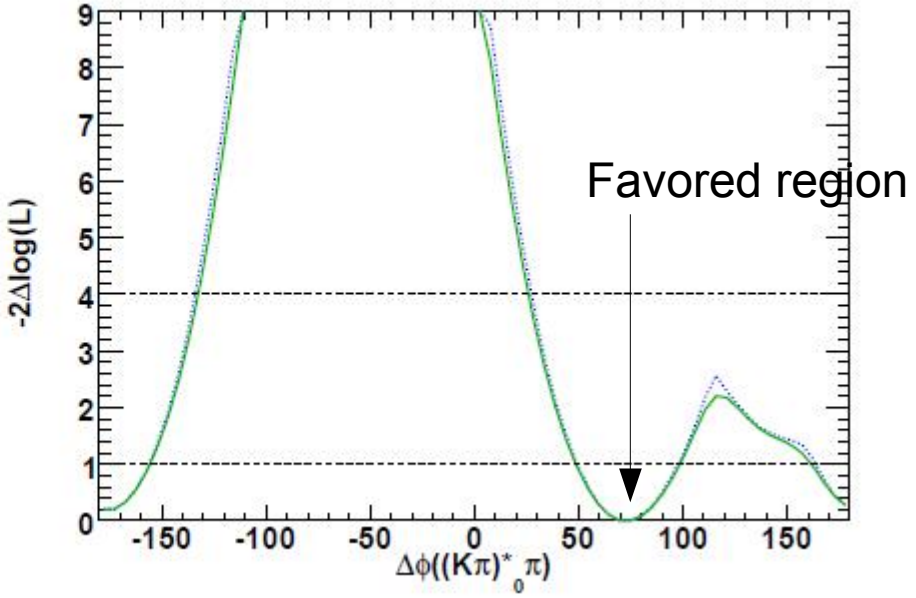
γ from $B^0 \to K^*\pi$ and $B^0 \to (K\pi)_{s\text{-wave}}\pi$

- The phase differences between the isobar amplitudes for $K^*\pi$ and $(K\pi)_S\pi$, $\Delta\phi_{K^*\pi} \equiv arg\, c_{K^{*+}\pi^-} - arg\, c_{K^{*-}\pi^+}$ and $\Delta\phi_{(K\pi)_S\pi}$ can be used to extract information about the CKM angle γ

Ciuchini, Pierini, Silvestrini, PRD74, 051301 (2006) Gronau, Pirjol, Soni, Zupan, PRD75, 014002 (2007)

- Projections of the likelihood function on the phase differences



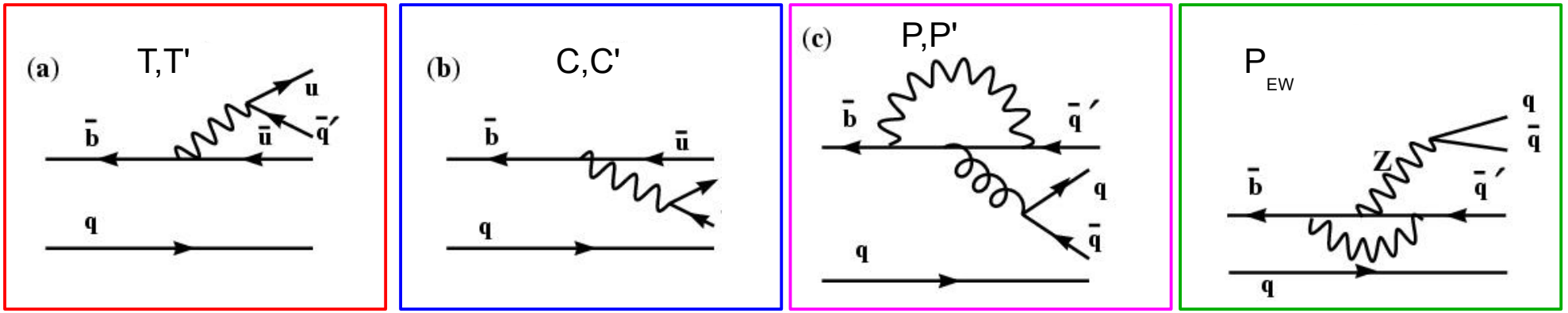


- $-137° < \Delta\varphi_{K^*\pi} < -5°$ excluded at 95% CL

arXiv:0905.3615

- Measurement still statistically limited
- Main source of systematic error is DP model

$\Delta A(K\pi)$



- $B \to K\pi$ decays receive contributions from tree (T), color suppressed tree (C), gluonic penguin (P) and electroweak penguin (P_{EW}) diagrams
- Gluonic penguin amplitudes are dominant
- Branching fractions and asymmetries could be sensitive NP probes
- In the standard model one naïvely expects $A_{CP}(K^{+,-}\pi^{-,+}) \sim A_{CP}(K^{+}\pi^{0})$

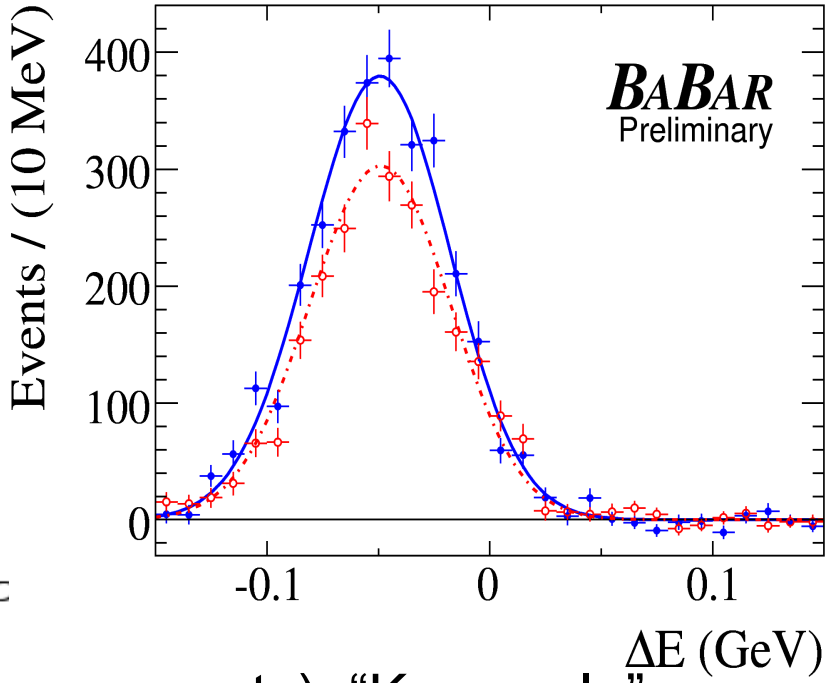
$B^0 \to K^+\pi^-$

- A_{CP} extracted from the fit in $B^0 \to h^+h^-$ (2008) measurement

arXiv:0807.4226, Contributed to ICHEP08

- Self tagging mode: event counting measurement

$$A_{CP} = \frac{N(\bar{B}^0 \to K^- \pi^+) - N(B^0 \to K^+ \pi^-)}{N(\bar{B}^0 \to K^- \pi^+) + N(B^0 \to K^+ \pi^-)}$$



- $A_{K\pi} = -0.107 \pm 0.016\ ^{+0.006}_{-0.004}$
  - 6.1 significance

$$A_{CP}(K^\pm\pi^\mp) = -0.098^{+0.012}_{-0.011} \quad [P' + T']$$

$$A_{CP}(K^\pm\pi^0) = +0.050 \pm 0.025 \quad [P' + T' + C' + F$$

  - $\Delta A_{K\pi} \sim 5\sigma$ (average including Belle measurements): "Kπ puzzle"

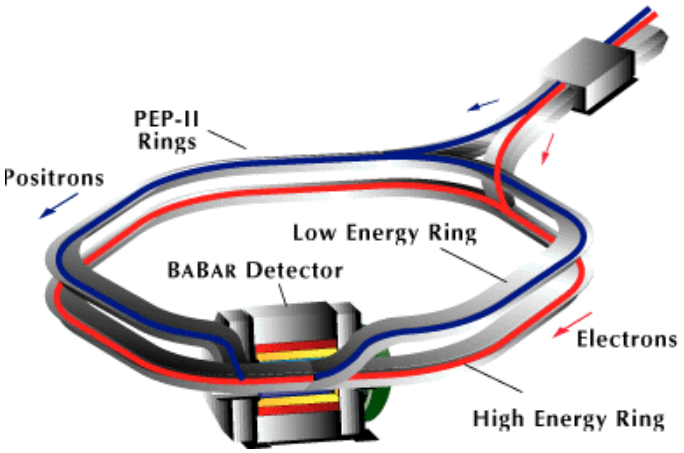
- Large C or P_{EW} is needed
  - P_{EW} could be due to New Physics
  - ... or C enhanced by nonperturbative (SM) effects

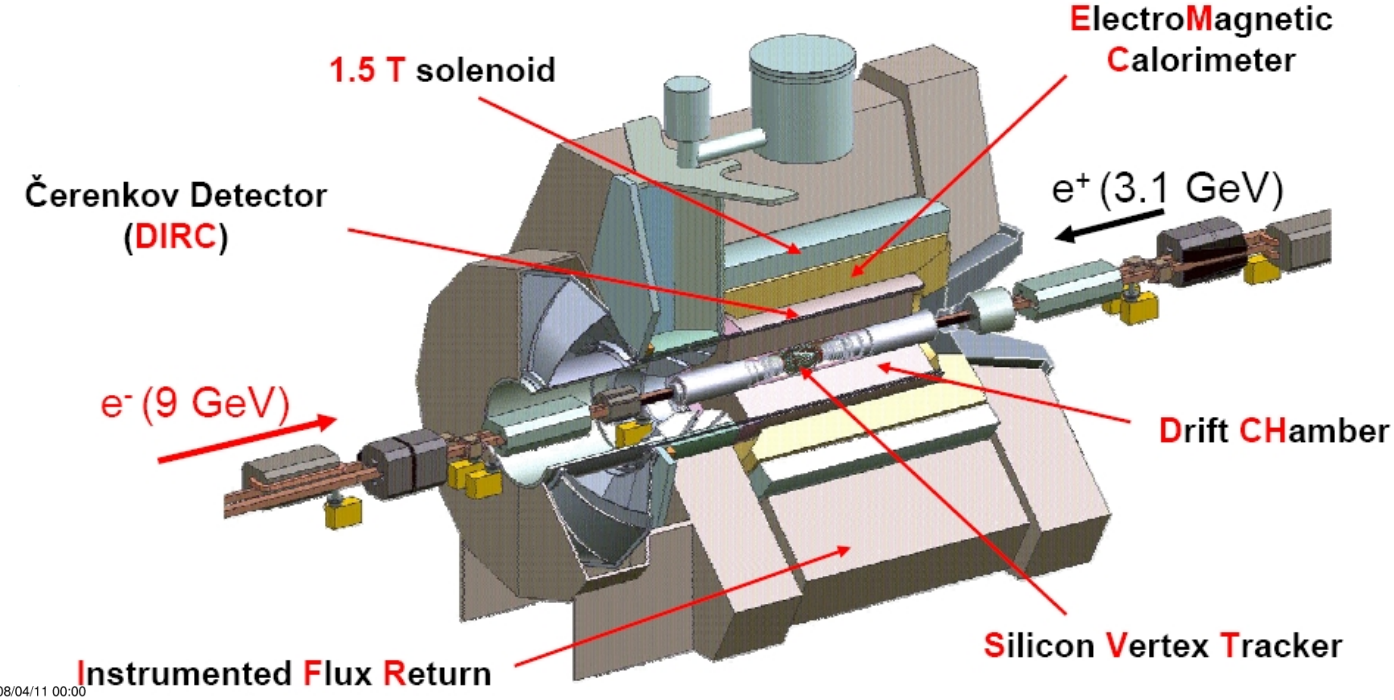
References in backup (too many!)

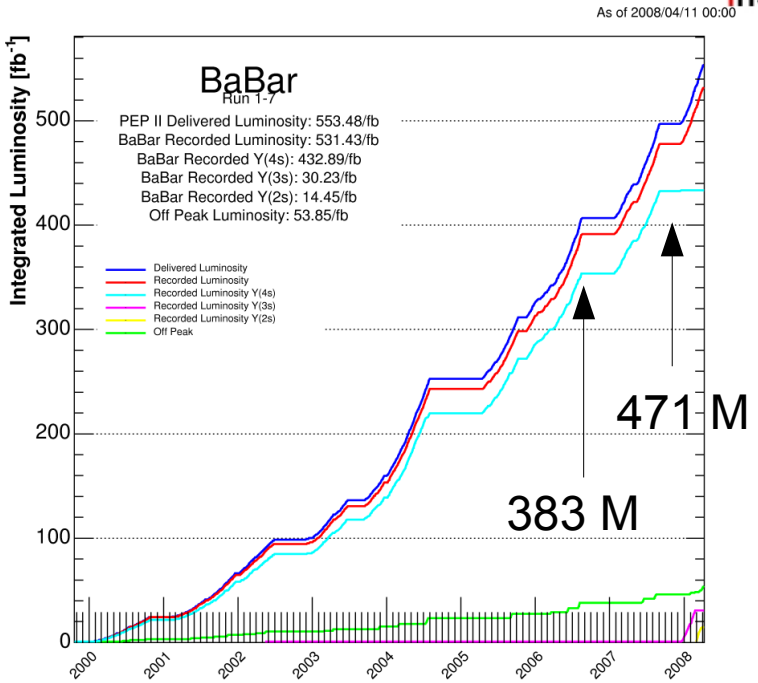
Conclusions

- Rare charmless hadronic B decays set non-trivial constraints on the UT
  - sin2β and γ
- Penguin dominated decays provide several observables to look for NP
  - No hint of NP found, most deviations are within 2σ from SM
  - Hadronic uncertainties may limit the impact of these measurements as NP probes
- Kπ puzzle, i.e. $\Delta A_{K\pi}$, is a “hot topic”
- More precision and more statistics needed
  - For cleanest b$\rightarrow$s modes, i.e. $B^0 \rightarrow \eta' K^0$, the experimental uncertainty on ΔS is dominant

BaBar detector and dataset



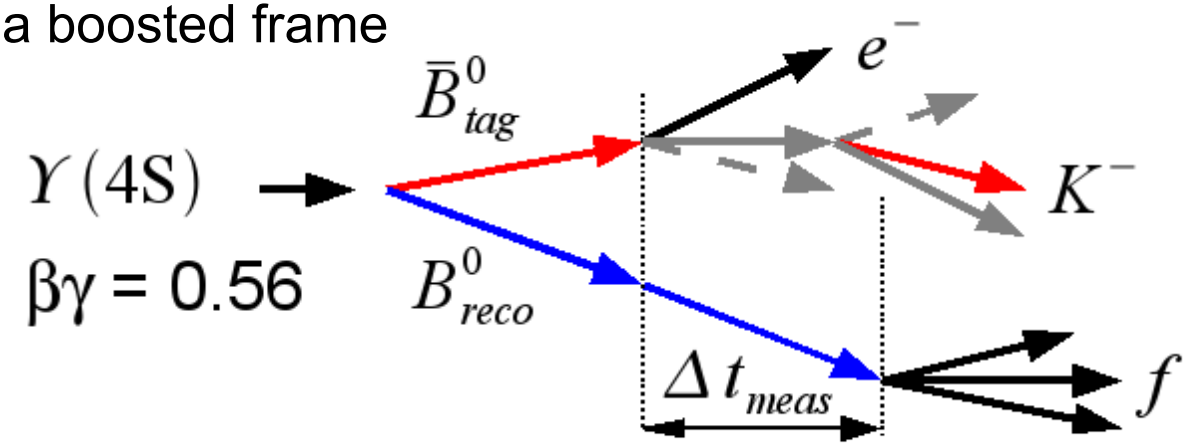




- Final sample @ $\Upsilon(4S)$:
  - 439 fb^{-1}
  - 471×10^6 BB pairs

Time-dependent analysis

B mesons are produced coherently in a boosted frame



Identify flavor and vertex of the other B: NN based tagging algorithm with 6 categories

Fully reconstruct signal final state

$$\Delta t_{meas} = t_{reco} - t_{tag} \qquad \Delta z = \beta\gamma c \Delta t_{meas} \approx 260\,\mu m$$

Include tagging performance: average mistagging probability and mistagging difference

$$F^{\pm}(\Delta t_{meas}) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left\{1 \mp \Delta w \pm (1-2w)\left[S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\right]\right\} \otimes R(\Delta t_{meas} - \Delta t, \sigma_{\Delta t})$$

Experimental resolution: convolution with triple Gaussian, with parameters obtained from a large sample of fully reconstructed B decays, and free to differ between tagging category

References for Kπ puzzle

- Large C or P_{EW} is needed
  - Enhancements of P_{EW} - could be due to New Physics

Yoshikawa, PRD68, 054023 (2003)
Mishima, Mashikawa, PRD70, 094024 (2004)
Buras et al., PRL92, 101804 (2004)
Buras et al., EPJC45, 701 (2006)
Baek, London, PLB653, 249 (2007)
Feldmann, Jung, Mannel, JHEP 0808,066 (2008)

  - Large C, nonperturbative (SM) contributions

Chiang et al., PRD70, 034020 (2004)
Li, Mishima, Sanda, PRD72, 114005 (2005)
Ciuchini et al., PLB674, 197 (2009)