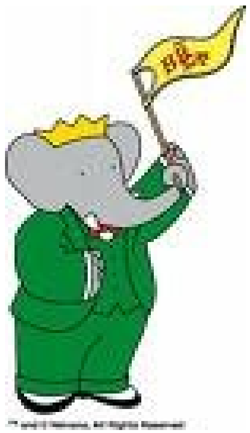
Workshop Meson 2008, Jun 7th 2008

Charmless B Decays at BaBar



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Motivation

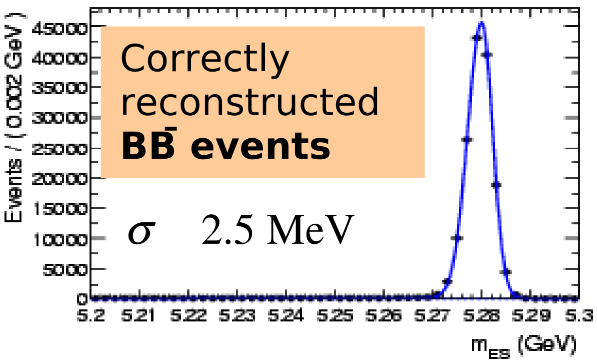
- Charmless 3 body B decays $K\pi\pi$, $KK\pi$ and KKK
- Spectroscopy: $\pi\pi$, $K\pi$ and KK mass spectra.
- Mainly contributing diagrams: $b\to s$ loop, $b\to u$ tree and $b\to d$ loop. (good place to look for New Physics).
- CKM Physics:
  - Testing CKM constraints from charmless modes: γ and β measurements.
  - Compare with global CKM fits.

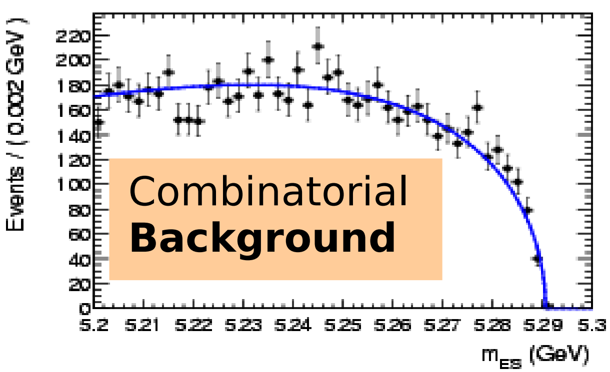
Experimental Issues

- Small S/B ratio, mostly continuum ($e^+e^- \to q\bar{q}$, $q \neq b$) background.
- Use kinematical and event-shape variables to discriminate:

Beam-energy substituted mass

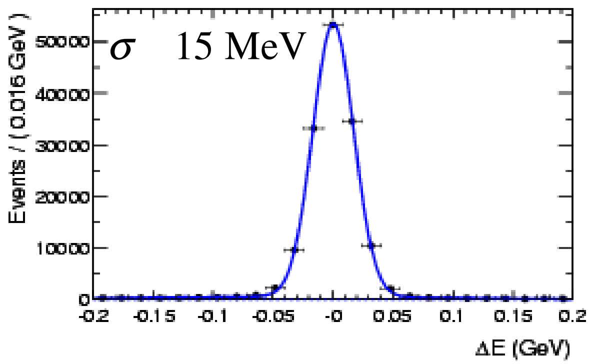
$$m_{ES} = \sqrt{E_{beam}^{*\,2} - p_B^{*\,2}}$$

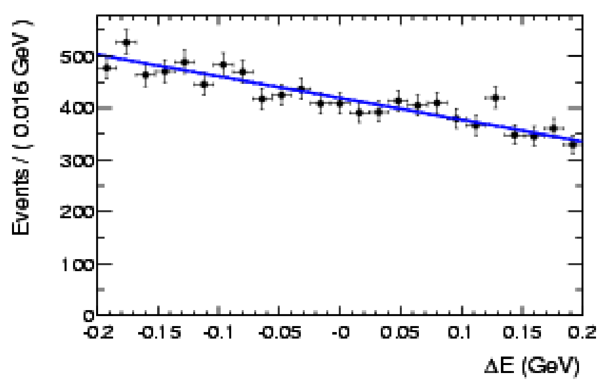




Energy difference

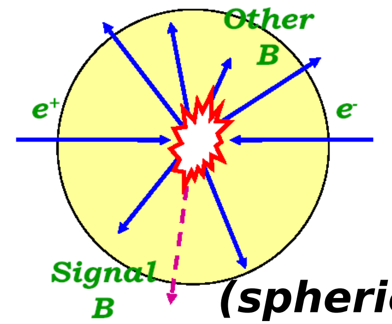
$$\Delta E = E_B^* - E_{beam}^*$$



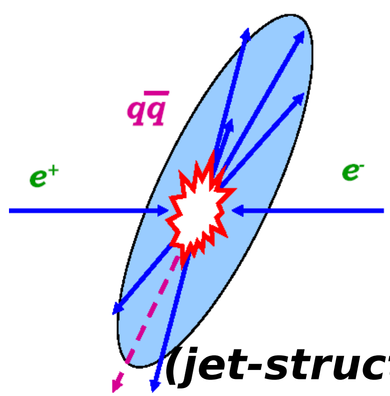


Event topology

(multivariate methods)



(spherical)



(jet-structure)

Time-dependent Dalitz Plot Analyses

- Parameterizing signal PDF using Isobar Model

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \bar{A}(DP) = \sum \bar{a}_j \bar{F}_j(DP) \end{cases}$$

Shapes of intermediates states over DP

Time-dependent DP PDF

$$f(\Delta t, DP, q_{tag}) \propto \left(|A|^2 + |\bar{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau} \left(1 + q_{tag} \frac{2\,\mathrm{Im}[\bar{A} A^*]}{|A|^2 + |\bar{A}|^2} \sin(\Delta m_d \Delta t) - q_{tag} \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} \cos(\Delta m_d \Delta t)\right)$$

CP violation varies over DP

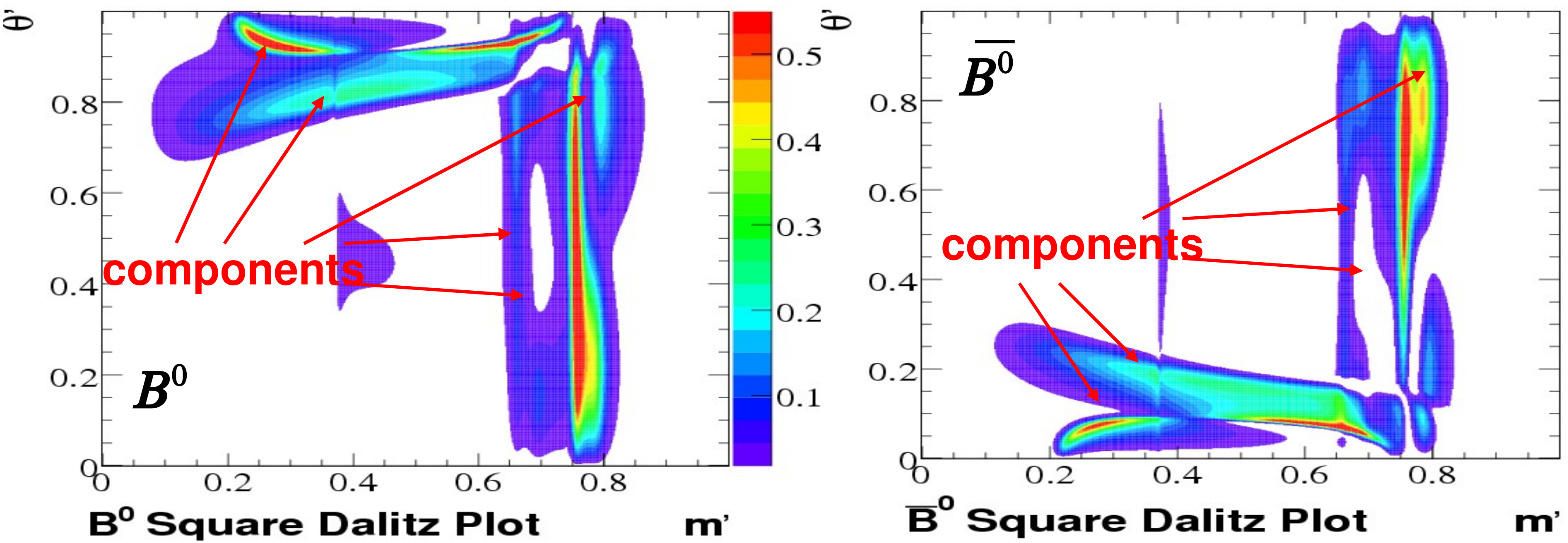
Complex amplitudes a_j and $\bar{a}_j$ determine DP interference pattern.
Module and phase con be directly fitted on data.

Time-dependent CPV parameters:

$$C_j = \frac{|a_j|^2 - |\bar{a}_j|^2}{|a_j|^2 + |\bar{a}_j|^2} \quad S_j = \frac{2\,\mathrm{Im}[a_j \bar{a}_j^*]}{|a_j|^2 + |\bar{a}_j|^2}$$

Interference helps disentangling strong and weak phases and thus raises the degeneracy on the phases.

Time-dependent Dalitz Plot Analyses



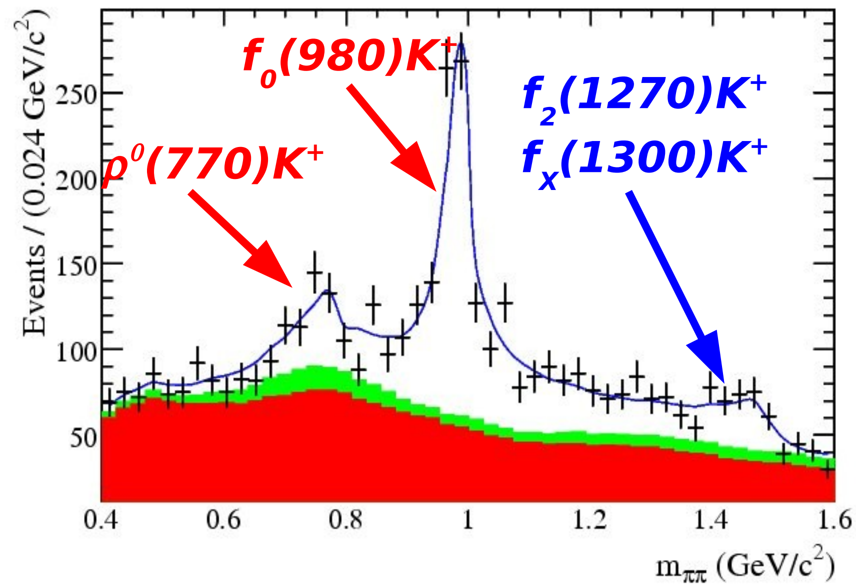
Spectroscopy: $\pi\pi$, $K\pi$ and KK mass spectra

Dalitz analysis of $B^+ \to K^+\pi^-\pi^+$

- Some resonances are wide, they overlap and interfere (e.g. ρ^0K^+ and f_0K^+) ⇒ $B^+ \to K^+\pi^-\pi^+$ Dalitz-plot (DP) analysis (time-integrated) is needed: magnitudes and relative phases of amplitudes are directly fitted.
- Sensitive to DCPV in decay rate asymmetry and in relative phase asymmetry.
- Largest S/B ratio among $B \to K\pi\pi$ decays ⇒ Used to study $\pi\pi$ and $K\pi$ mass spectra.

- $\pi\pi$ mass spectrum: use $f_0(980)K^+$, $\rho^0(770)K^+$, $f_2(1270)K^+$ and a scalar $f_X(1300)K^+$ with

$$\begin{cases} m = 1479 \pm 8 \text{ MeV}/c^2 \text{ and} \\ \Gamma = 80 \pm 19 \text{ MeV}/c^2 \end{cases}$$



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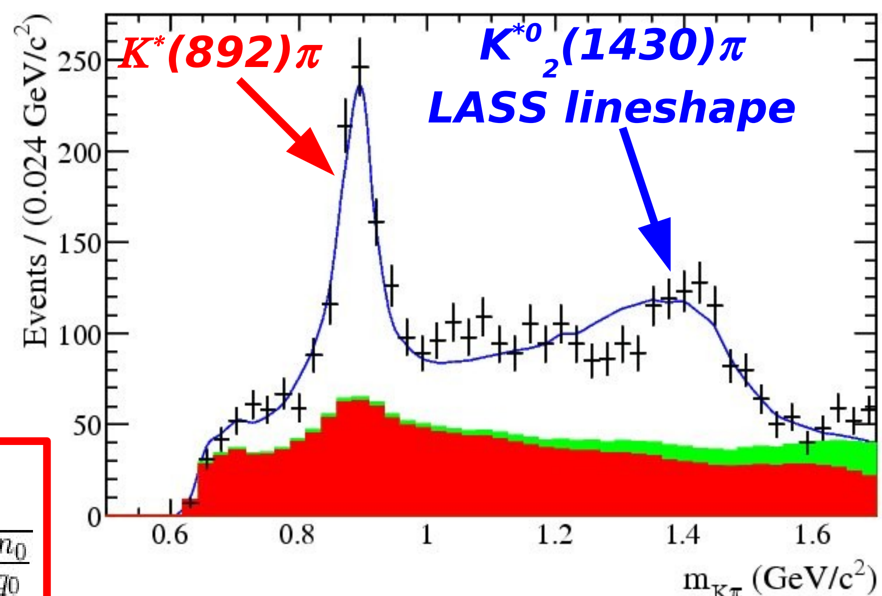
- Largest S/B ratio among $B \to K\pi\pi$ decays $\Rightarrow$ Used to study $\pi\pi$ and $K\pi$ mass spectra.

- $K\pi$ mass spectrum: use $K^{*0}(892)$, $K^{*0}_2(1430)$

  LASS lineshape used for describing $K\pi$ S-wave.

Nucl. Phys., B296:493, 1988

$$R_j(m_{K\pi}) = \frac{m_{K\pi}}{q\cot\delta_B - iq} + e^{2i\delta_B}\frac{m_0\Gamma_0\frac{m_0}{q_0}}{(m_0^2 - m_{K\pi}^2) - im_0\Gamma_0\frac{q}{m_{K\pi}}\frac{m_0}{q_0}}$$



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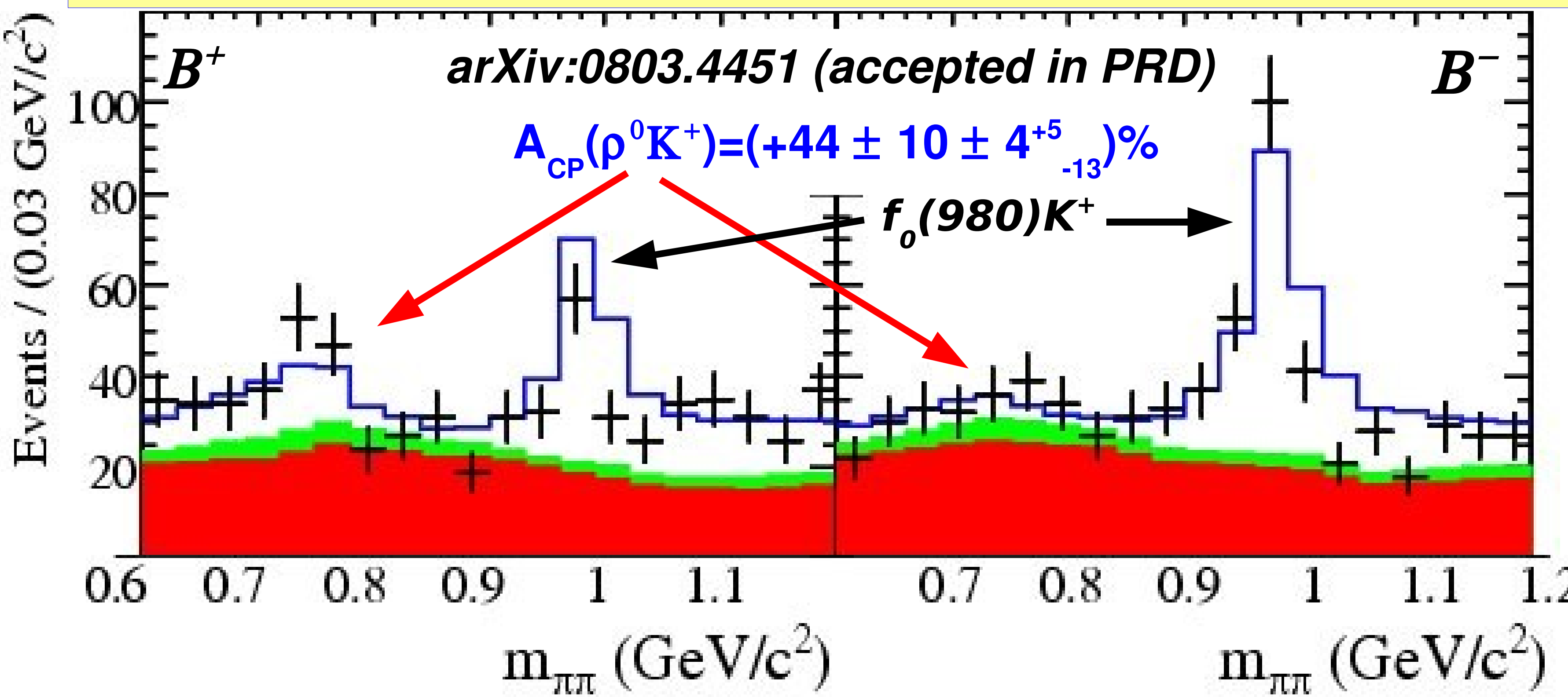
- **Sensitive to DCPV in decay rate asymmetry and in relative phase asymmetry**
- **a.**

- **$A_{CP}(K^{*0}\pi^+) \sim 0$ (as expected in SM).**
- **Evidence of DCPV in decay rate and relative phase for $B^+ \to \rho^0K^+$ at 3.7σ**



Dalitz analysis of $B^+ \to K^+\pi^-\pi^+$

- Some resonances are wide, they overlap and interfere (e.g. $\rho^0 K^+$ and $f_0 K^+$) ⇒ $B^+ \to K^+\pi^-\pi^+$ Dalitz-plot (DP) analysis (time-integrated) is needed: magnitudes and relative phases of amplitudes are directly fitted.
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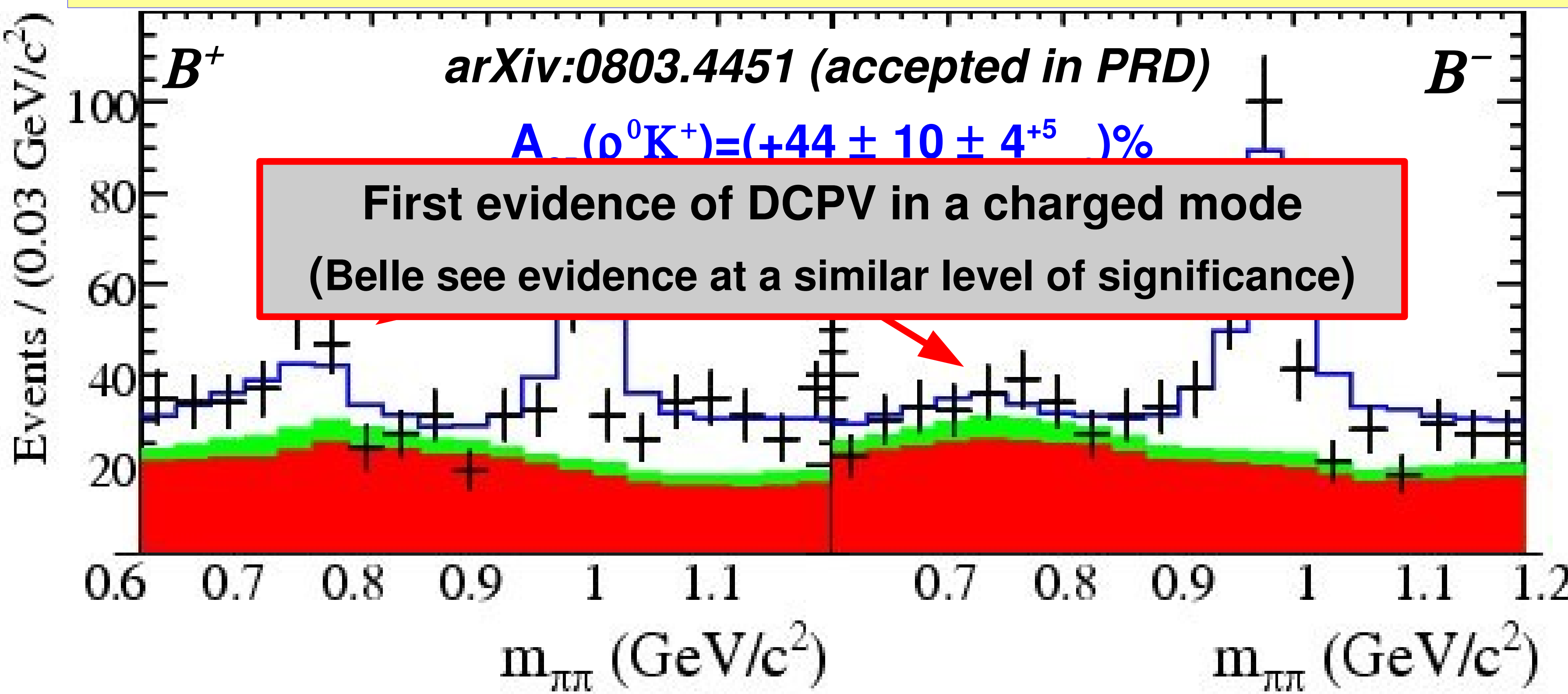


First evidence of DCPV in a charged mode

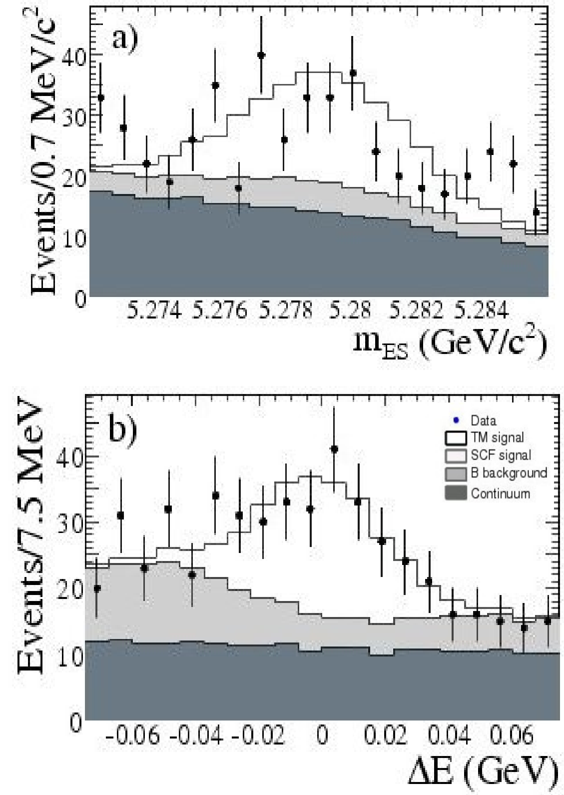
(Belle see evidence at a similar level of significance)

KK S-wave from $K^+K^-\pi^+$ & $K^+K^-K^0$

- Observation of $B^+ \to K^+K^-\pi^+$ at 9.6σ:

  BR = $(5.0 \pm 0.5 \pm 0.5) \times 10^{-6}$

  (429 ± 43 events)



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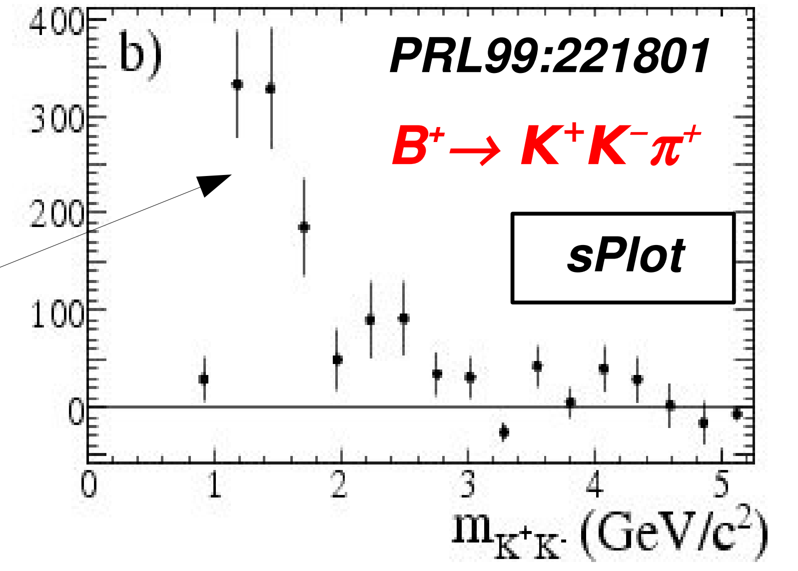
- Broad peak at ~1.5GeV/c² in KK mass
- $\phi(s\bar{s}) \to$ peak not seen

  (as expected in SM)



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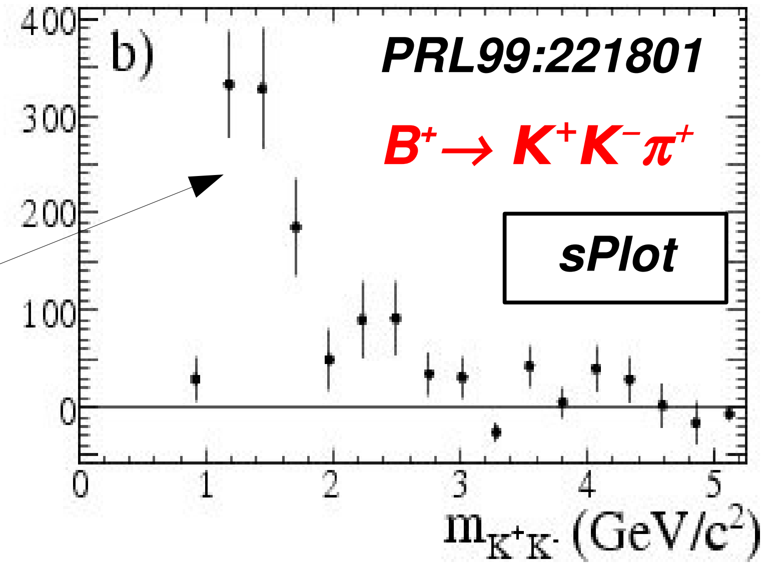
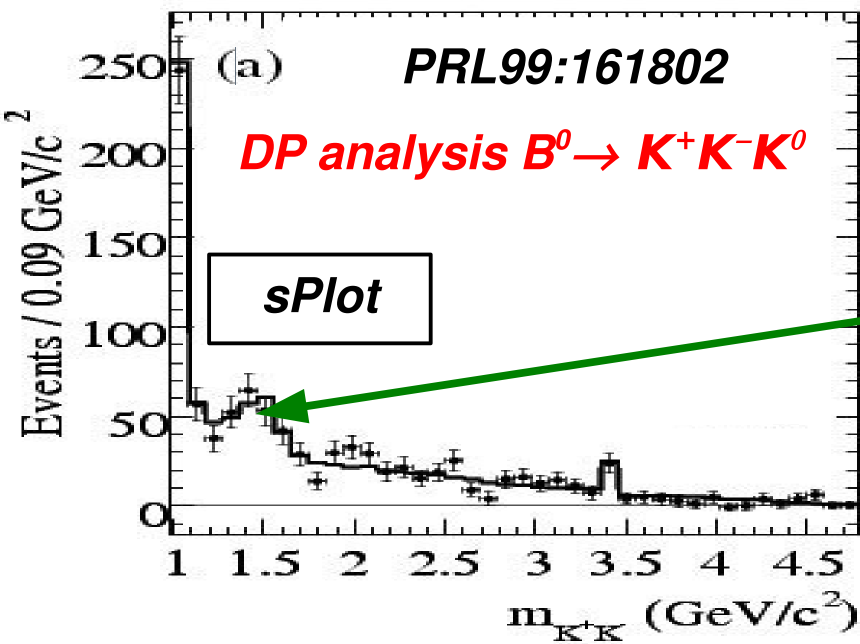




- Broad peak at ~1.5GeV/c^2 in KK (scalar) also seen in other modes:

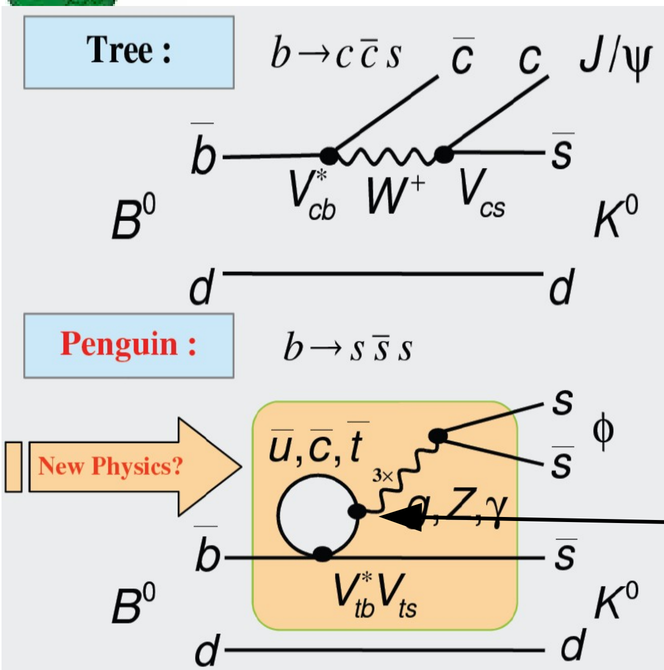
  $B^0 \to K^+K^-K^0$

  $m = 1539 \pm 20$MeV/c^2, $\Gamma = 257 \pm 33$MeV/c^2

- $B^0 \to KKK$ modes dominated by non-resonant component

CKM physics: γ and β measurements

$b \to s q\bar{q}$ penguins: loop-dominance



- **$b \to s c\bar{c}$:**
  - "golden" modes for $\sin(2\beta)$, i.e. $J/\psi\ K^0_S$
  - tree-dominated decays
  - penguins carry same weak phase
- **$b \to s q\bar{q}$:**
  - pure "internal" or "flavor-singlet" penguins, i.e. ϕK^0_S
  - dominant phase, same CKM factors as $b \to s c\bar{c}$
  - BSM particles could contribute in loops
  - **A window to New Physics**

Standard Model:

$S_{scc} = S_{sss} + \Delta S_{SM} = \sin(2\beta)$

$C_{scc} \approx C_{sss} \approx 0$

New Physics:

$S_{scc} \neq S_{sss} + \Delta S_{SM}$

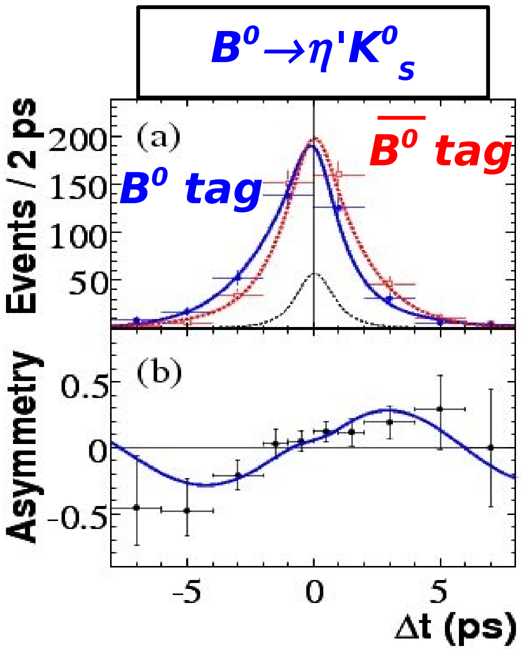
$C_{scc} \neq C_{sss}$

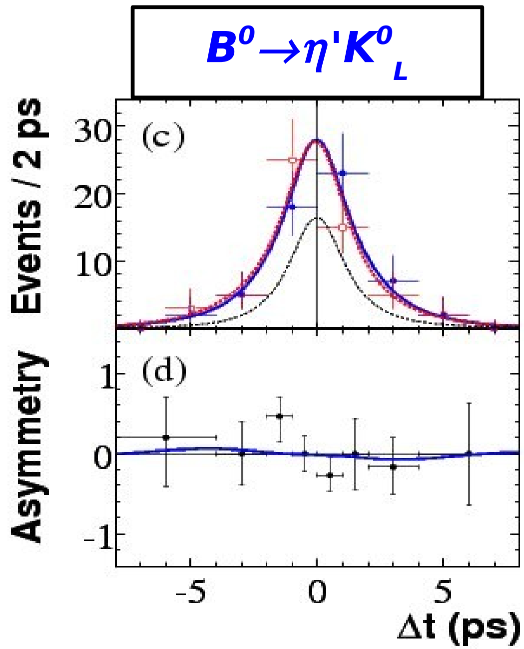
Theoretical issue: evaluate ΔS_{SM} for each mode

identify clean modes (with small ΔS_{SM})

$\sin(2\beta_{eff})$ from $B^0 \to \eta' K^0$

- Experimentally clean: largest BR among $b \to s$ penguin modes
  kinematical identification of η'
  $\eta' K^0_L$ adds 50% more events
- Theoretically clean: negligible tree contributions
- First $b \to s q\bar{q}$ mode to establish CP violation;
  results in agreement with $b \to s c\bar{c}$





PL98:031801 (2007)

Measurements:

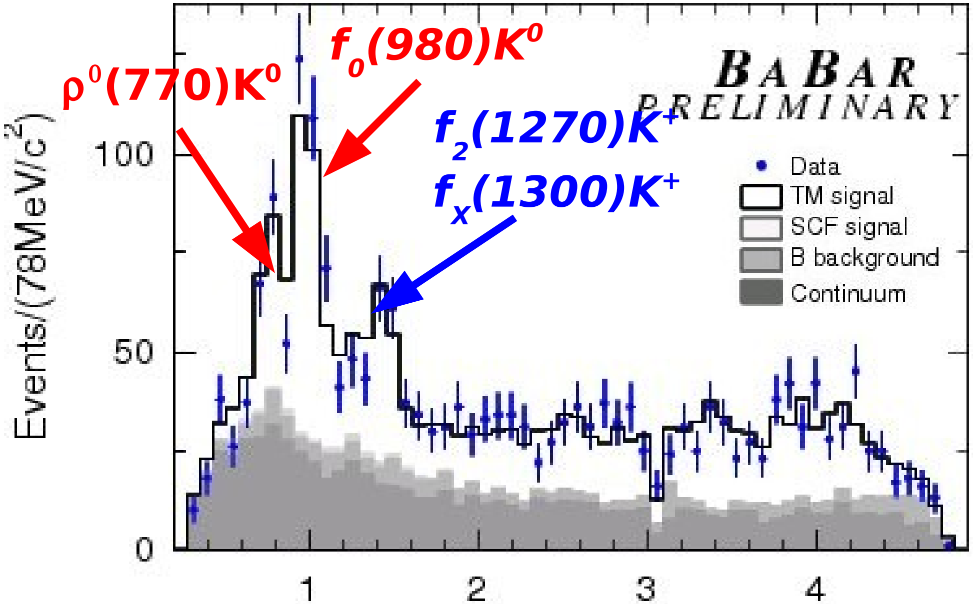
$C = -0.16 \pm 0.07 \pm 0.03$

$S = 0.58 \pm 0.10 \pm 0.03$

Observed mixing-induced CPV at 5.5σ level

β_{eff} from time-dependent DP analysis: $K^0_S\pi^+\pi^-$

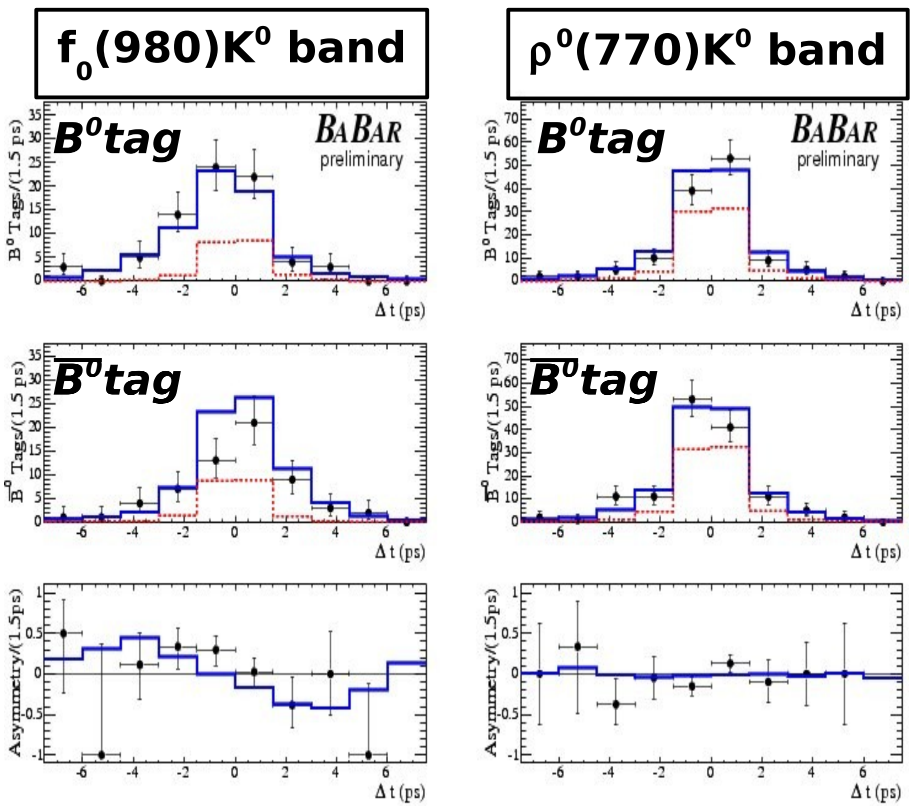
- **$\pi\pi$ spectrum:** as in $B^+ \to K^+\pi^-\pi^+$, $f_2(1270)K^0_S$ and a scalar $f_X(1300)K^0_S$
- Amplitude analysis for $f_0(980)K^0$ and $\rho^0(770)K^0$: measure of $2\beta_{eff}$ instead of $\sin(2\beta_{eff})$



Signal enhanced projection

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

Time dependent asymmetries:



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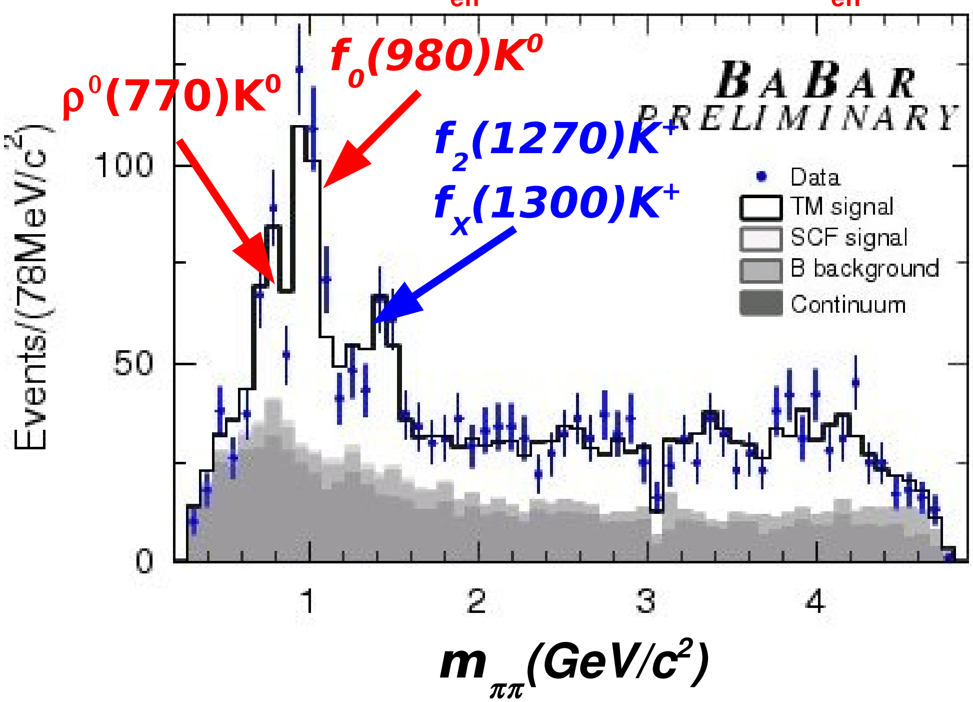
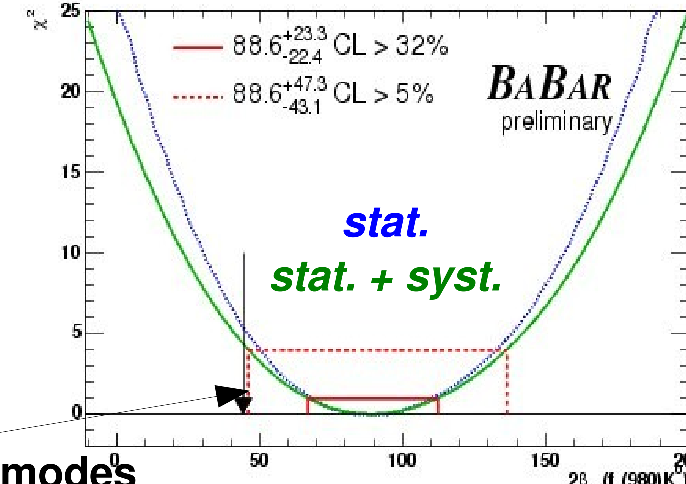
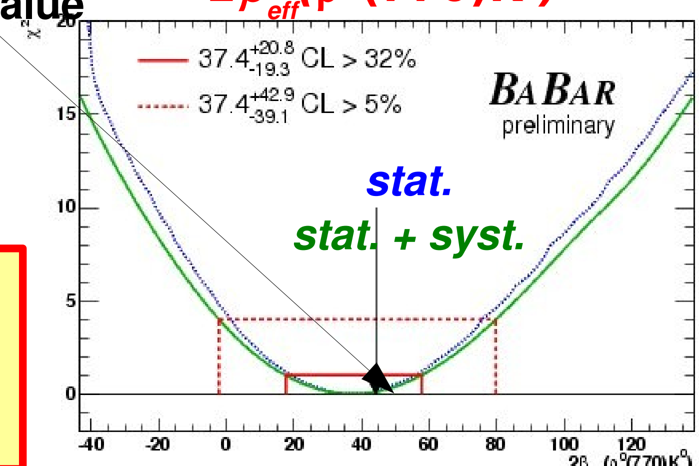


$2\beta_{eff}(f_0(980)K^0)$



golden modes 2β value

$2\beta_{eff}(\rho^0(770)K^0)$



arXiv:0708.2097

$2\beta_{eff}(f_0(980)K^0) = (88.6^{+23.3}_{-22.4})^\circ$ (stat. + syst.)

$2\beta_{eff}(\rho^0(770)K^0) = (37.4^{+20.8}_{-19.3})^\circ$ (stat. + syst.)

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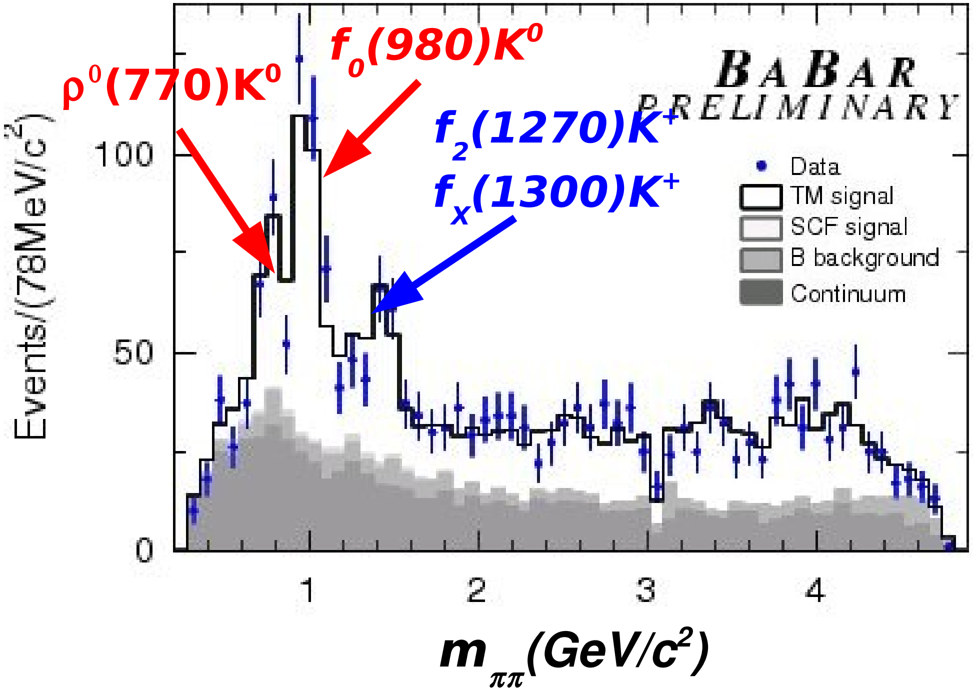

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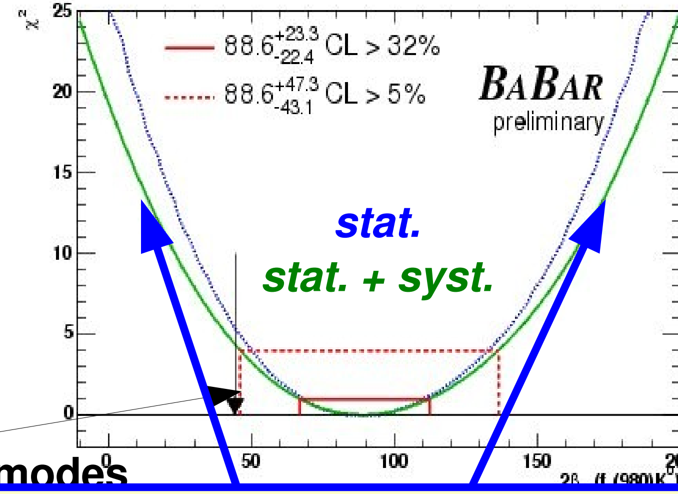
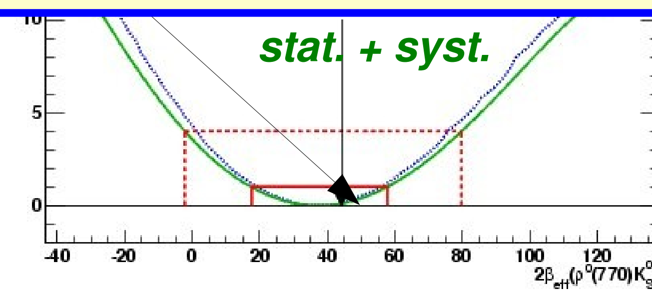


golden modes
2β

Non-gaussian result for $f_0K^0_S$
$2\beta_{eff}(f_0(980)K^0) = 0\ (=180)$ excluded at $4.3\sigma\ (3.9\sigma)$



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β_{eff} from time-dependent DP analysis: $K^+K^-K^0$

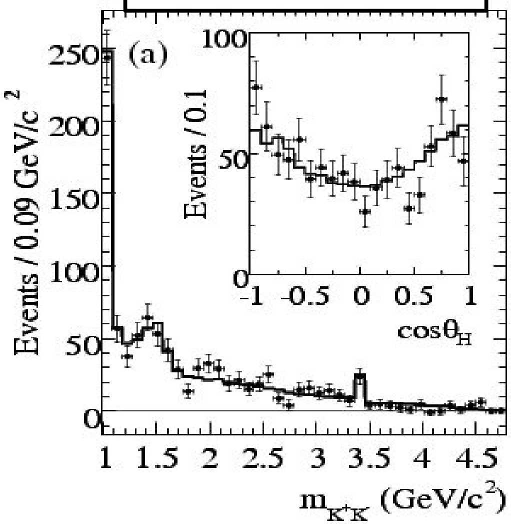
- **Fit strategy:**

  fit on the whole phase space. Average CPV parameters (same β_{eff})

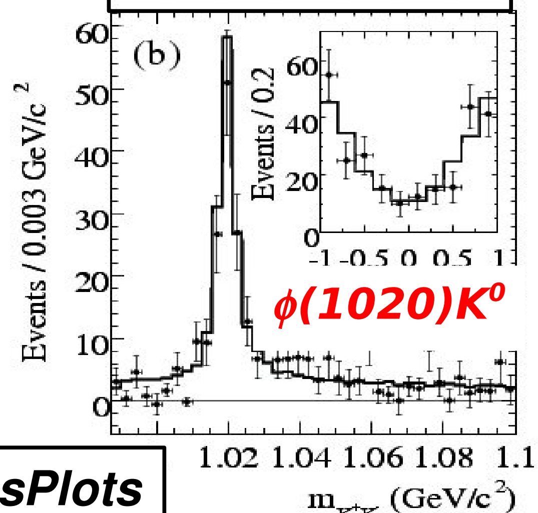
  fit on low KK mass (mostly $f_0(980)K^0_S$ and $\phi(1020)K^0_S$ components).

  fit on high KK mass (mostly non-resonant component).

whole KK mass



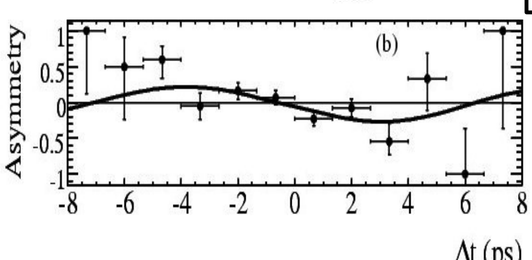
low KK mass

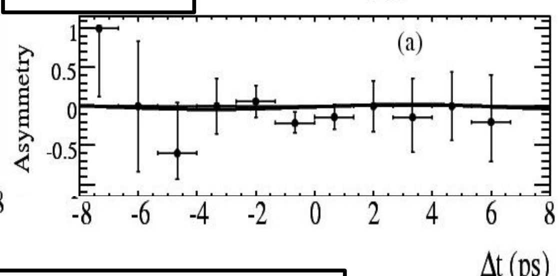


PRL99:161802

	A_{CP}	β_{eff} (rad)
Whole DP	$-0.015 \pm 0.077 \pm 0.053$	$0.352 \pm 0.076 \pm 0.026$
High-mass	$-0.054 \pm 0.102 \pm 0.060$	$0.436 \pm 0.087 ^{+0.055}_{-0.031}$
(1) ϕK^0	$-0.08 \pm 0.18 \pm 0.04$	$0.11 \pm 0.14 \pm 0.06$
(1) $f_0 K^0$	$0.41 \pm 0.23 \pm 0.07$	$0.14 \pm 0.15 \pm 0.05$
(2) ϕK^0	-0.11 ± 0.18	0.10 ± 0.13
(2) $f_0 K^0$	-0.20 ± 0.31	3.09 ± 0.19

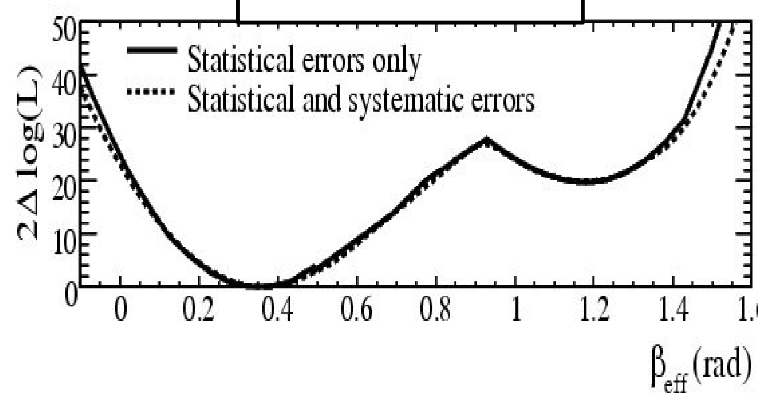
sPlots





time-dependent asymmetries

Likelihood scan



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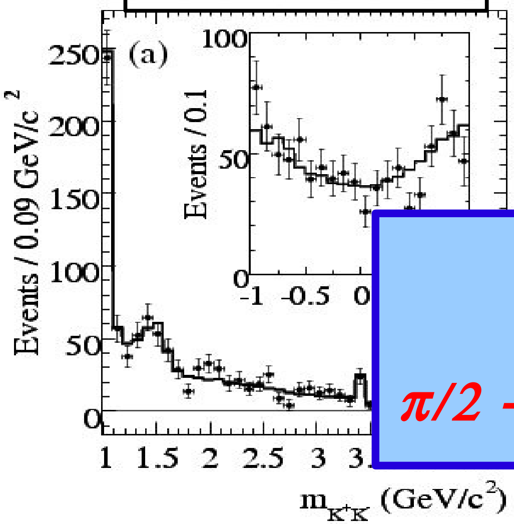
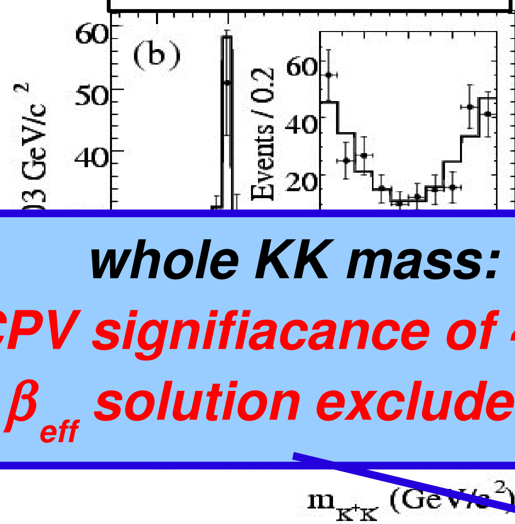


low KK mass



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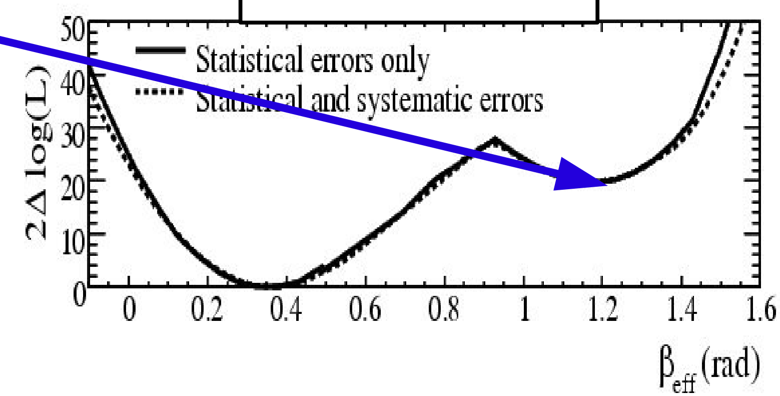
[illegible]	$-0.08 \pm 0.18 \pm 0.04$	$0.11 \pm 0.14 \pm 0.06$
[illegible]	$0.41 \pm 0.23 \pm 0.07$	$0.14 \pm 0.15 \pm 0.05$
[illegible]	-0.11 ± 0.18	0.10 ± 0.13
[illegible]	-0.20 ± 0.31	3.09 ± 0.19

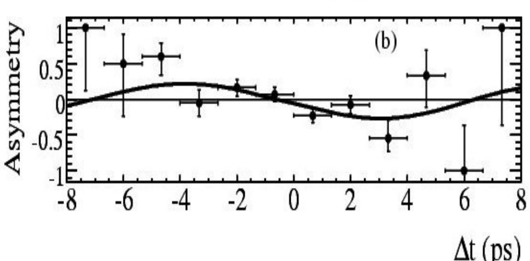
whole KK mass:

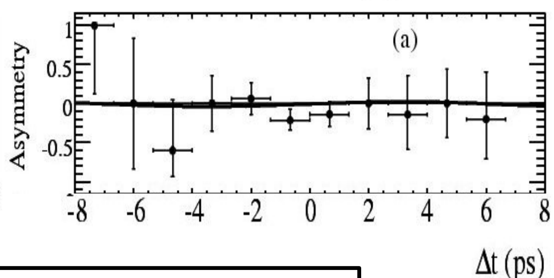
CPV signifiacance of 4.8σ

$\pi/2 - \beta_{eff}$ solution excluded at 4.5σ

Likelihood scan







time-dependent asymmetries

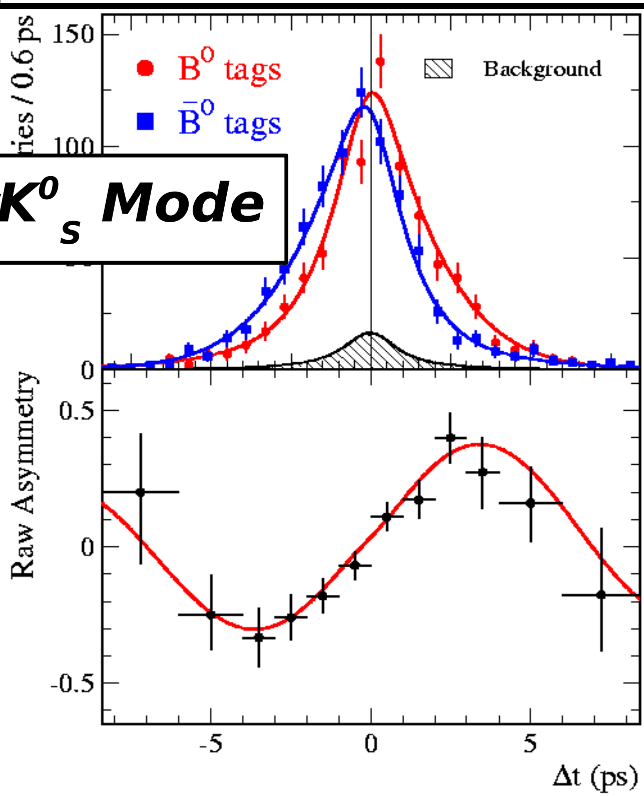
β_{eff} (loop $b \to s$) vs β (tree $b \to s$)

golden modes:

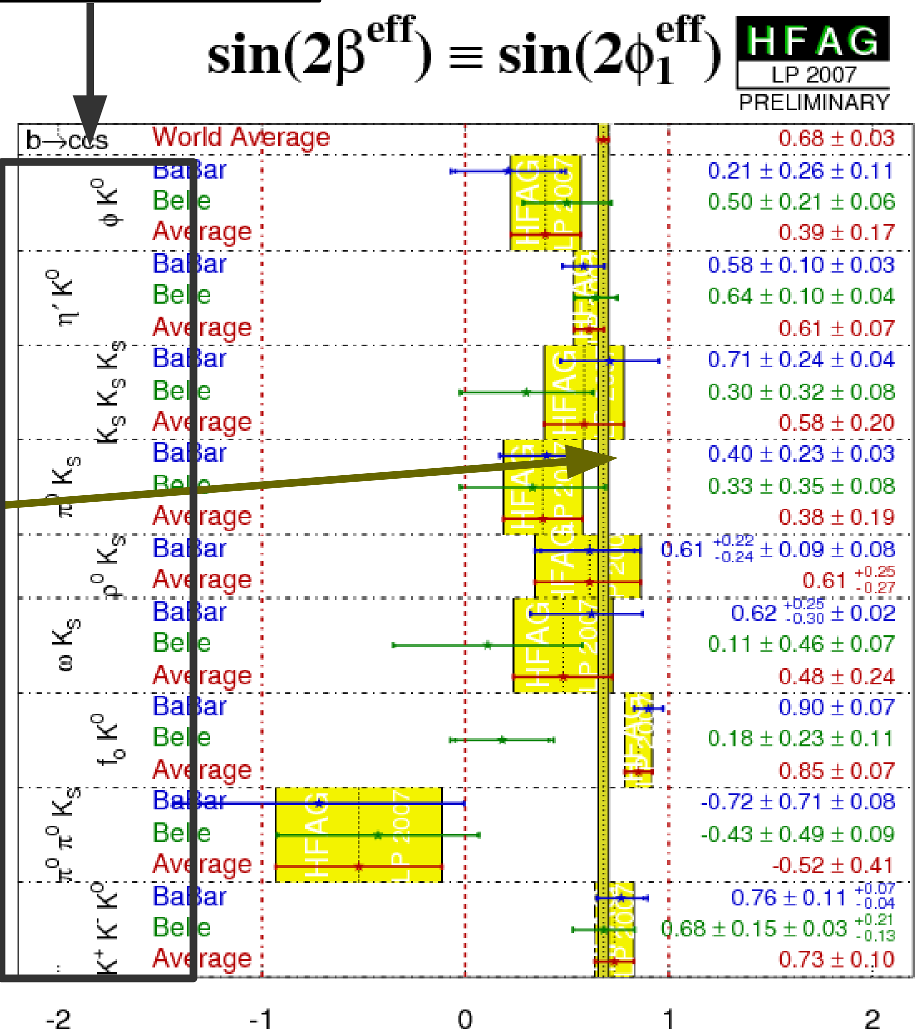
$\sin(2\beta) = 0.680 \pm 0.025$

(HFAG average)

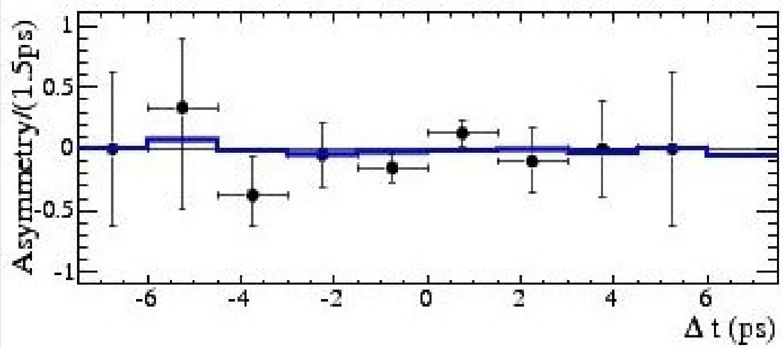
$J/\psi K^0_s$ Mode



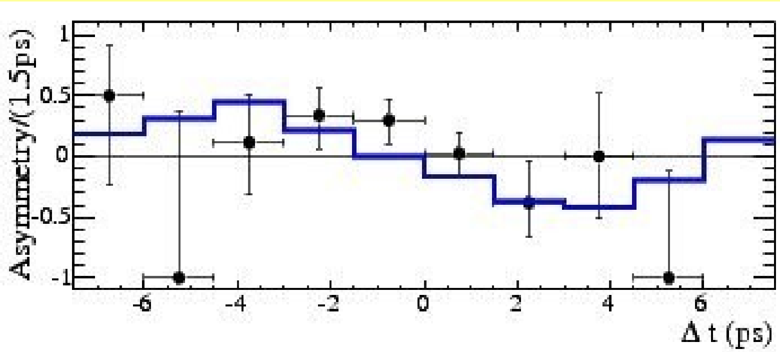
9 $b \to s q\bar{q}$ modes

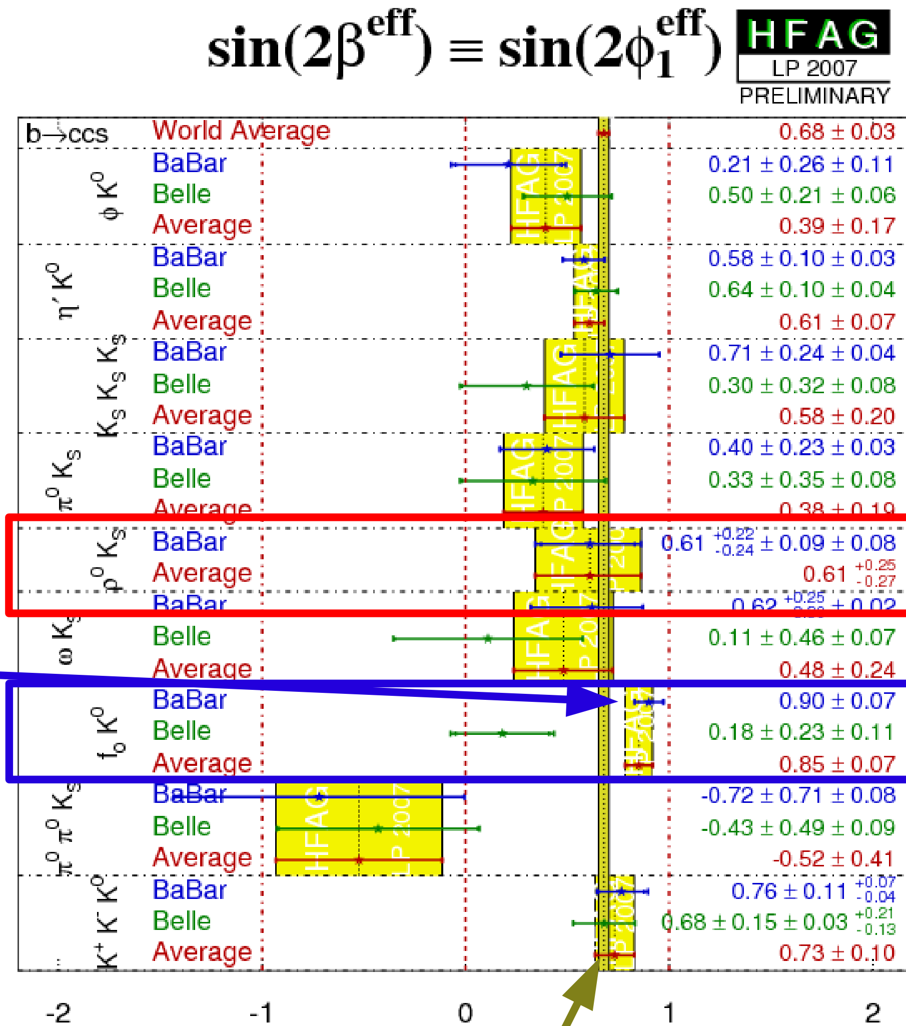


β_{eff} (loop b→s) vs β (tree b→s)



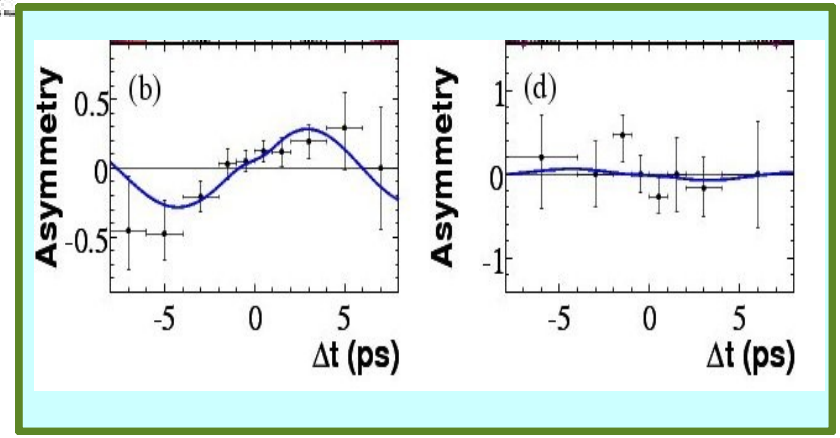
S(f_0(980)K^0) BaBar measurement
2.1σ above from golden modes value

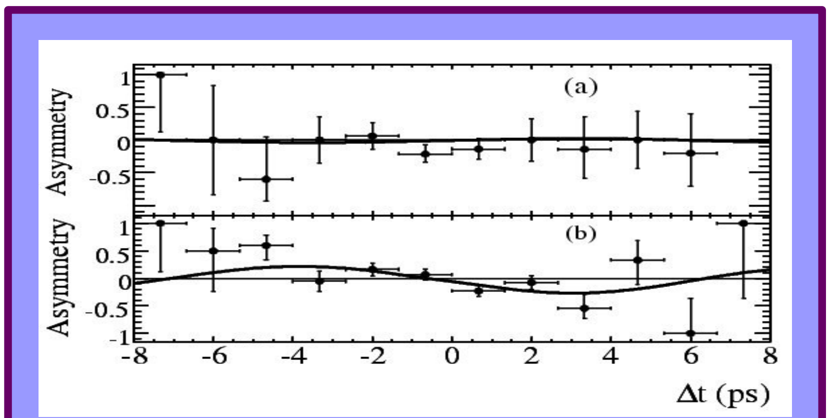


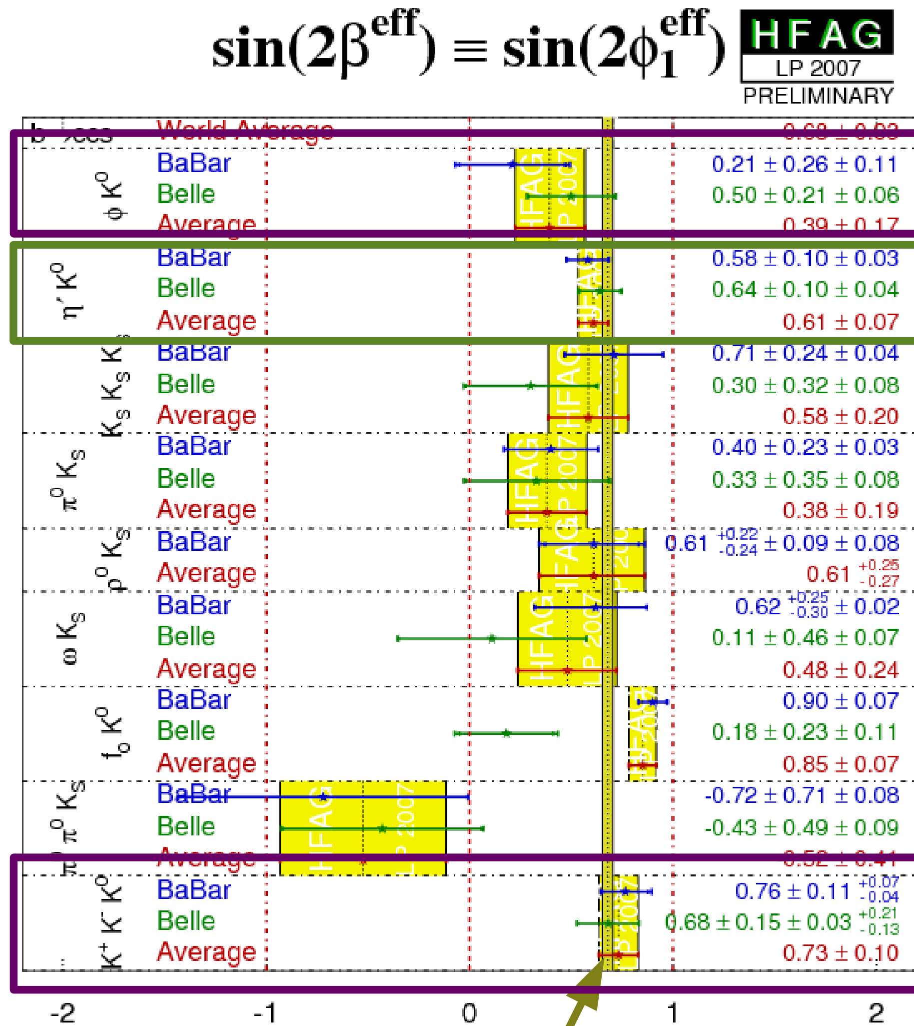


S golden modes value

β_{eff} (loop b→s) vs β (tree b→s)







S golden modes value

"γ" (CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

$K^*\pi$ Isospin relations:

$$A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0 \to K^{*+}\pi^-) + \sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0} \to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0} \to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

CPS PRD74:051301
GPSZ PRD75:014002

Direct access to γ CKM angle

"γ" (CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

$K^*\pi$ Isospin relations:

$$A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0 \to K^{*+}\pi^-) + \sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0} \to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0} \to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

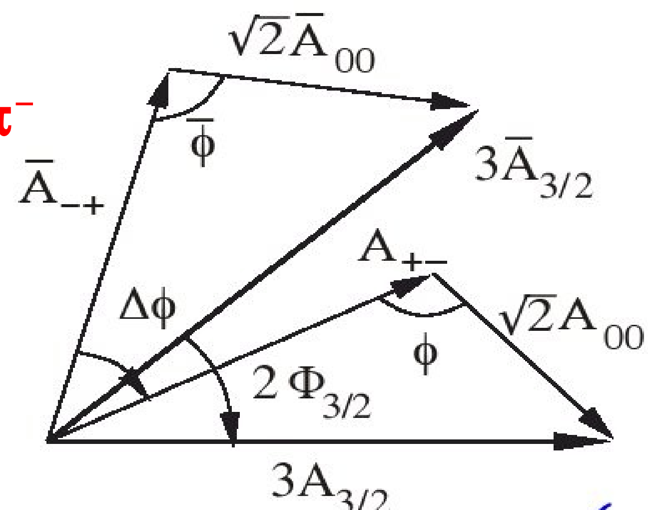
CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

Measurable from $K^+\pi^-\pi^0$ and $K^0_S\pi^+\pi^-$

- $|A(B^0 \to K^{*+}\pi^-)|$ and $|A(B^0 \to K^{*0}\pi^0)|$
- $|\overline{A}(B^0 \to \overline{K}^{*-}\pi^+)|$ and $|\overline{A}(\overline{B^0} \to \overline{K}^{*0}\pi^0)|$

Through BRs



"γ" (CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_s\pi^+\pi^-$

$K^*\pi$ Isospin relations:

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

CPS PRD74:051301
GPSZ PRD75:014002

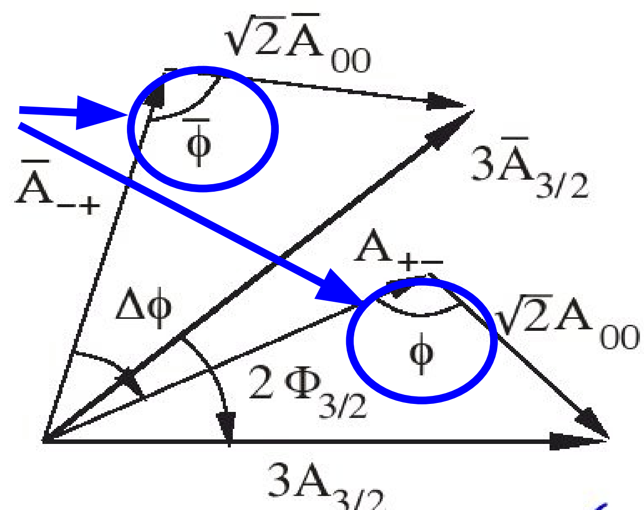
From experiment:

Measurable from $K^+\pi^-\pi^0$

$$\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(B^0\to K^{*0}\pi^0))$$

$$\overline{\phi} = \arg(\overline{A}(\overline{B^0}\to K^{*-}\pi^+)\overline{A}^*(\overline{B^0}\to \overline{K}^{*0}\pi^0))$$

Through interference



"γ"(CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

$K^*\pi$ Isospin relations:

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

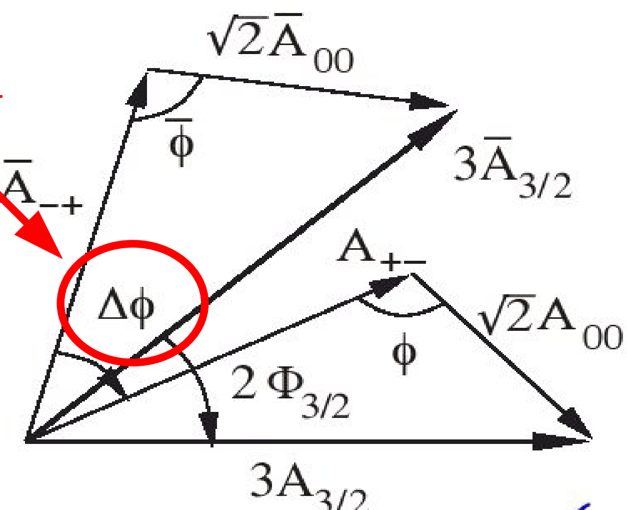
CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

Measurable from $K^0_S\pi^+\pi^-$

$$\Delta\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(\overline{B^0}\to K^{*-}\pi^+))$$

Through interference



"γ"(CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

$K^*\pi$ Isospin relations:

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

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Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

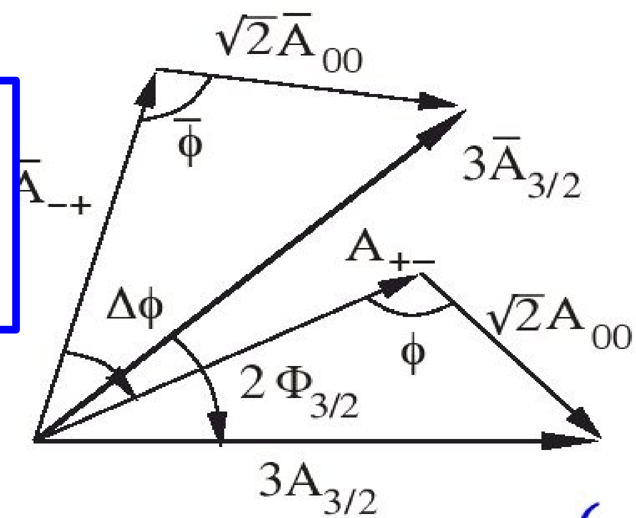
$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

CPS PRD74:051301
GPSZ PRD75:014002

With non zero P_{EW},

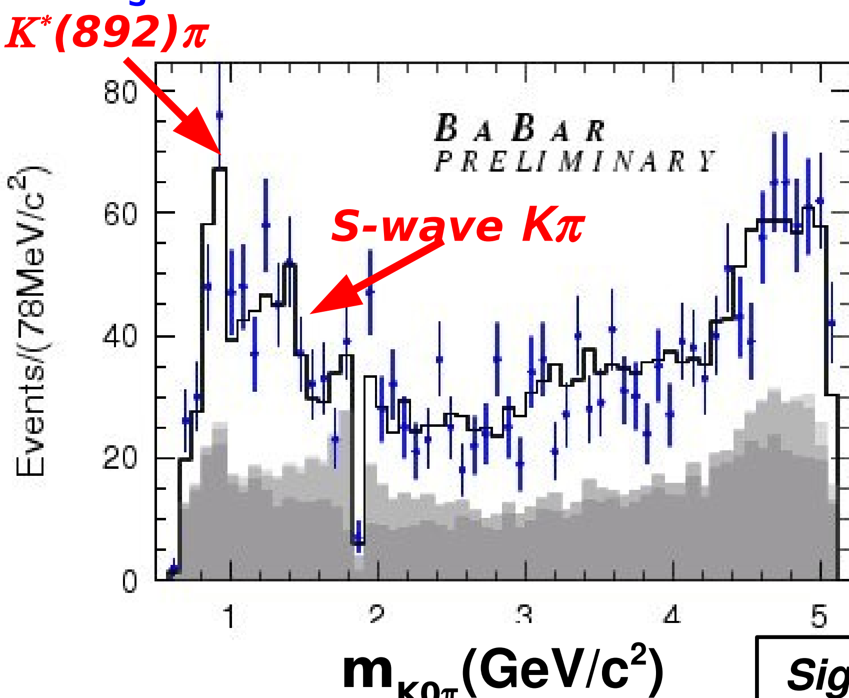
non-trivial constraint in $(\overline{\rho}-\overline{\eta})$



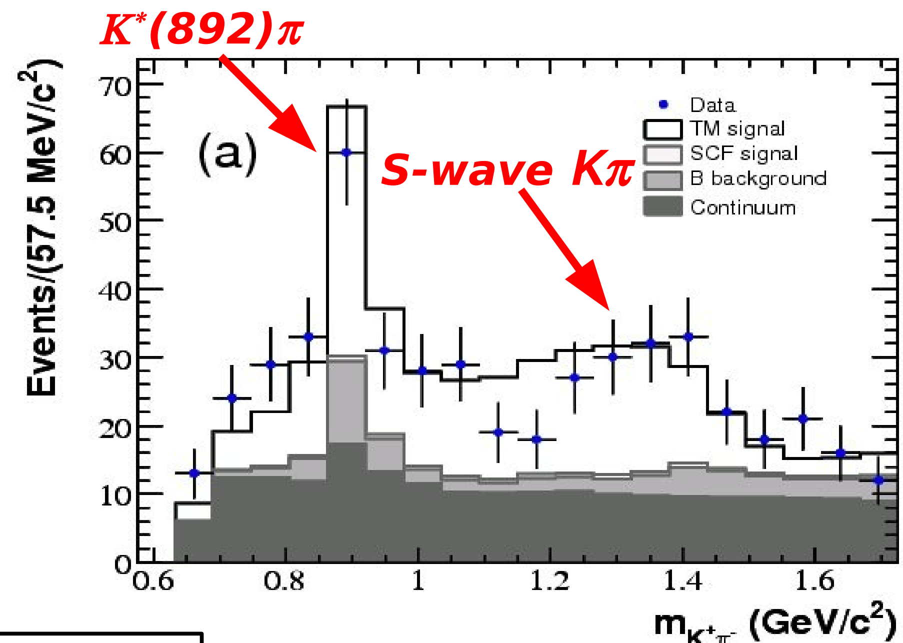
"γ"(CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

- **Kπ spectrum:** as in the $B^+\to K^+\pi^-\pi^+$ using **LASS lineshape to describe S-wave Kπ.** No significant $K^{*0}_2(1430)$ contribution

$K^0_S\pi^+\pi^-$ time-dependent DP analysis



$K^+\pi^-\pi^0$ time-integrated DP analysis

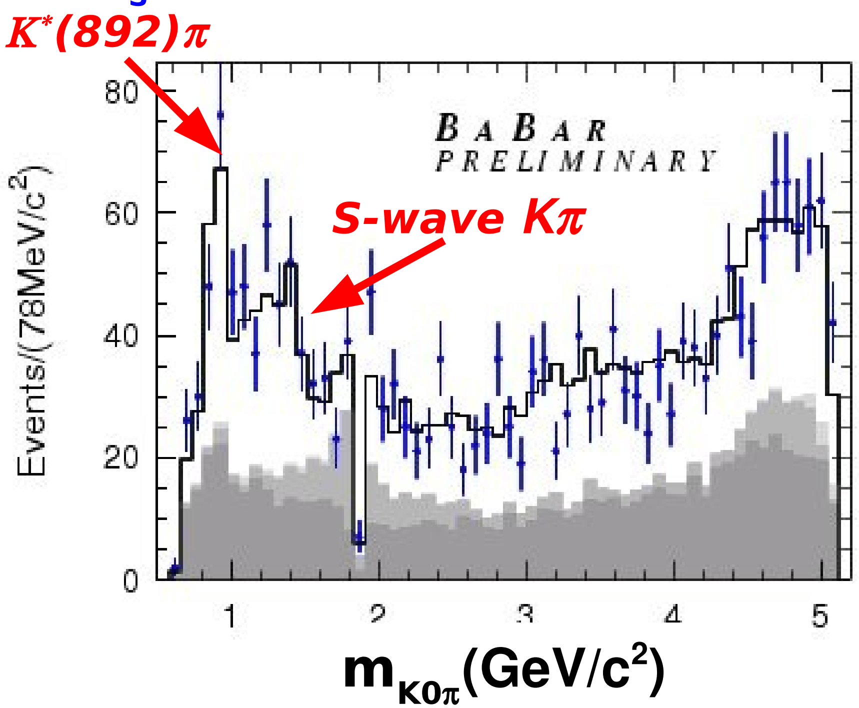


Signal enhanced projections

"γ" (CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_s\pi^+\pi^-$

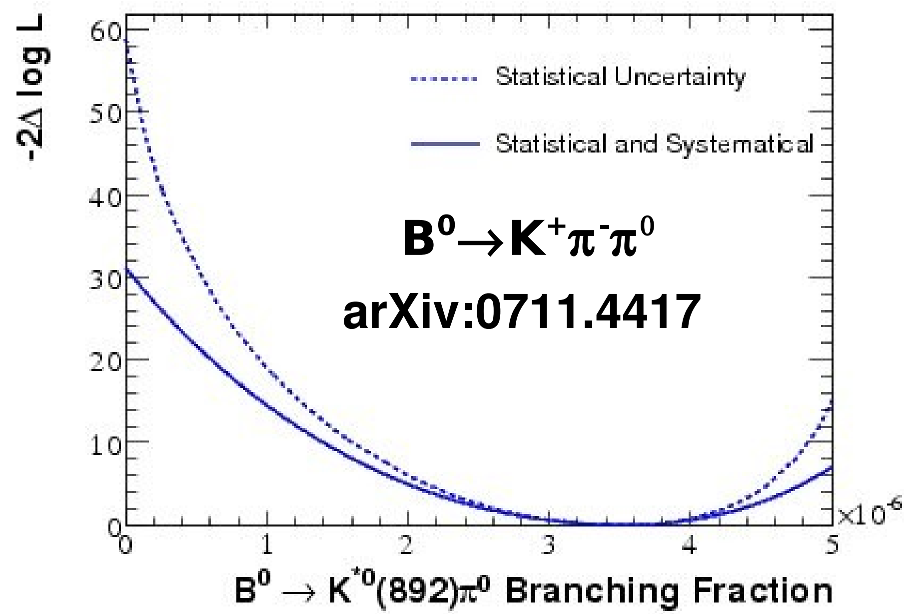
- **Kπ spectrum:** as in the $B^+\to K^+\pi^-\pi^+$ using **LASS lineshape to describe S-wave Kπ.** No significant $K^{*0}_2(1430)$ contribution

$K^0_s\pi^+\pi^-$ time-dependent DP analysis



$K^+\pi^-\pi^0$ time-integrated DP analysis

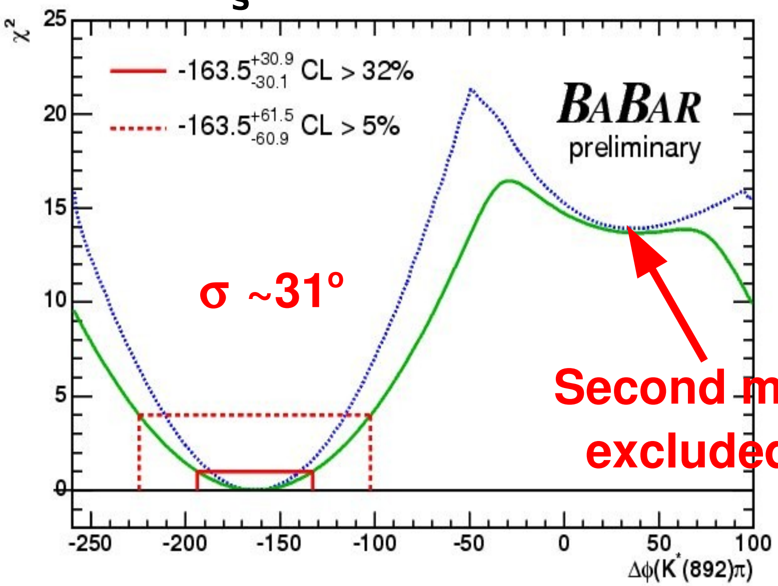
Obervation at 5.6σ of $B^0\to K^{*0}(892)\pi^0$ decay
$BF(B^0\to K^{*0}(892)\pi^0) = (3.6^{+0.7}_{-0.8} \pm 0.4)\times10^{-6}$

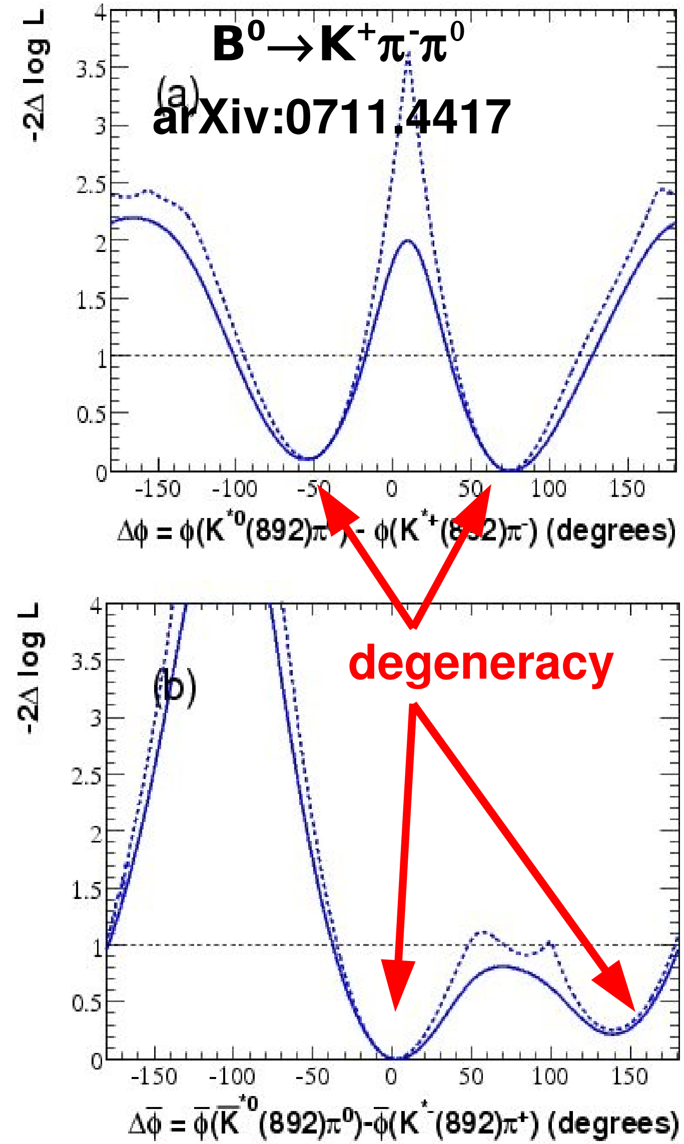


"γ" (CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_s\pi^+\pi^-$

- $|A_{ij}| \leftrightarrow$ BRs well measured
- $\Delta\varphi$ obtained from Dalitz $B^0 \to K^0_s\pi^+\pi^-$:
  - Single likelihood min, error ~31°
- φ and $\overline{\varphi}$ obtained from Dalitz $B^0 \to K^+\pi^-\pi^0$:
  - 2 minima close in Likelihood units, ~1σ.
  - Phases weakly constrained

$B^0 \to K^0_s\pi^+\pi^-$, arXiv:0708.2097

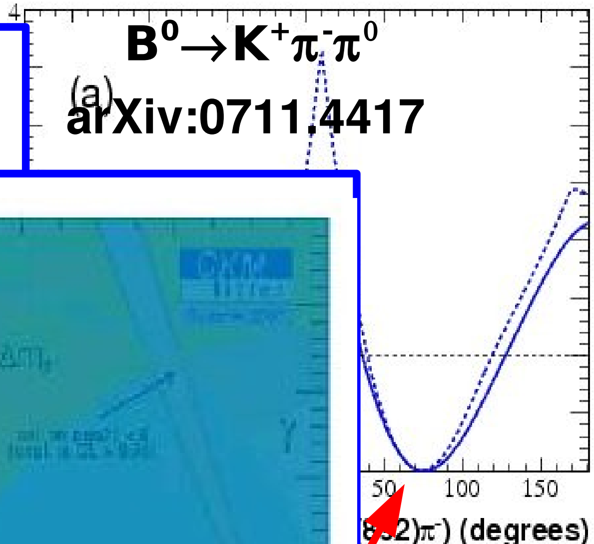




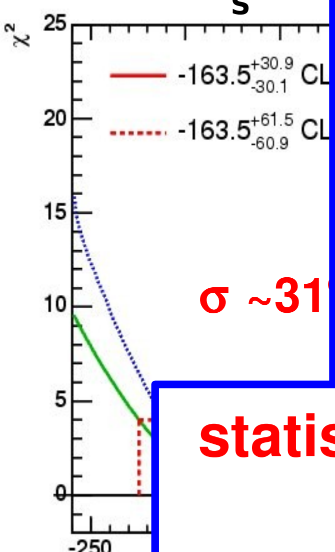
“γ ”(CPS/GPSZ) from $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$

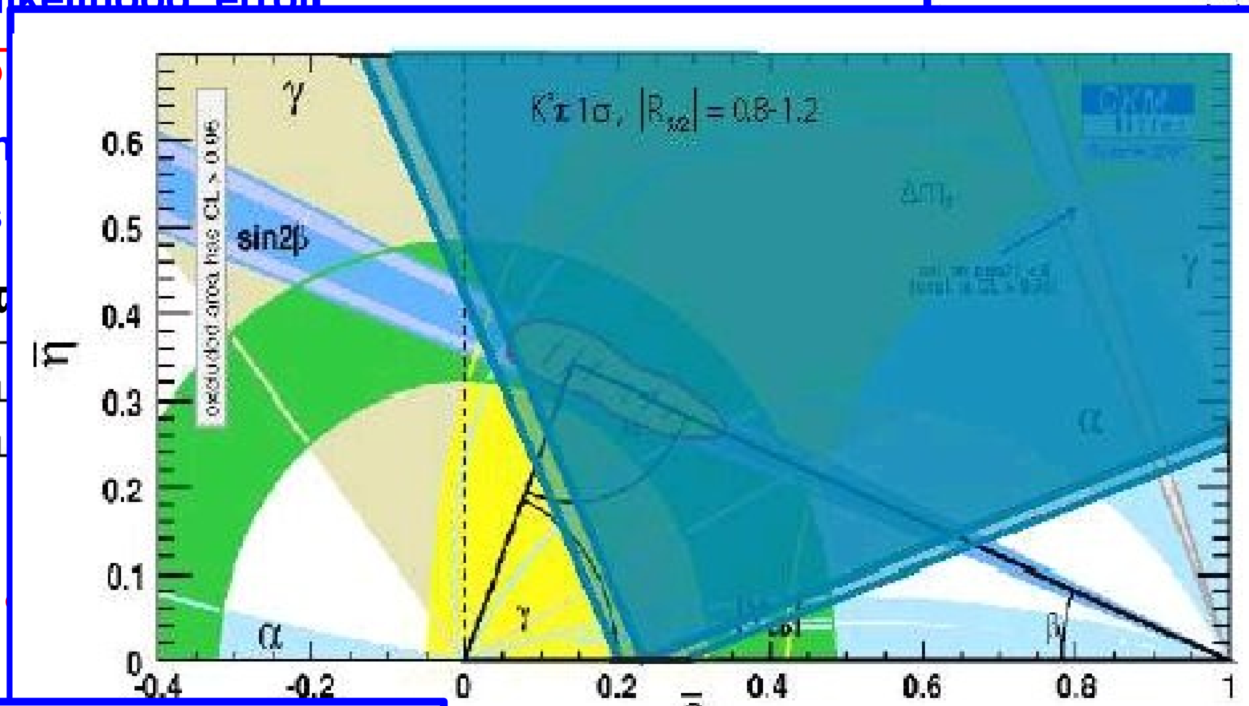
- $|A_{ij}| \leftrightarrow$ BRs well measured
- Δφ obtained from Dal
  - Single likelihood, error
- φ and $\overline{\varphi}$
  - 2 minim
  - Phases

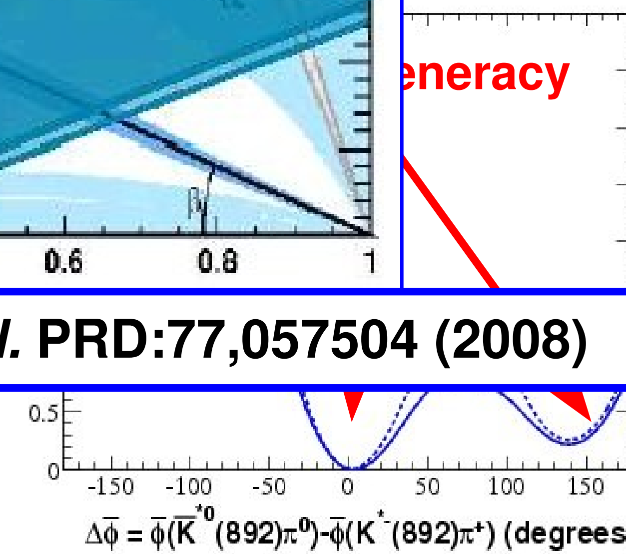
All ingredients for CPS/ GPSZ are there!



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







statistically limited constraint

Gronau *et. al.* PRD:77,057504 (2008)

Conclusions

- BaBar is exploring many interesting topics in Charmless B decays:
  - Probing $\pi\pi$ and $K\pi$ mass spectrum with: $B^+ \to K^+\pi^-\pi^+$
  - Evidence of DCPV: $B^+ \to K^+\pi^-\pi^+$ (3.7σ in $\rho^0 K^+$)
  - Probing KK mass spectrum with:

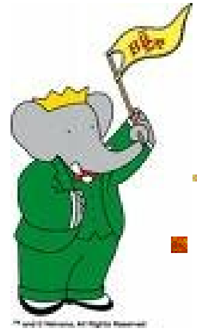
    $B^+ \to K^+K^-\pi^+$ & $B^0 \to K^+K^-K^0$
  - $\sin(2\beta_{eff})$ from $\eta' K^0_s$, results compatible with $b \to sc\bar{c}$
  - β_{eff} from time-dependent DP analyses:

    $\rho^0 K^0_s$, $f_0 K^0_s$, ϕK^0_s & high mass $K^+K^-K^0$
  - "γ" via CPS/GPSZ: $B^0 \to K^+\pi^-\pi^0$, $B^0 \to K^0_s\pi^-\pi^+$, non-trivial constraint in $(\bar{\rho}-\bar{\eta})$ plane

Backup

Outline

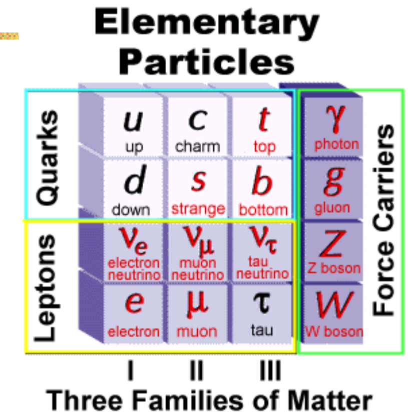
- Dalitz analysis of $B^+ \to K^+\pi^-\pi^+$:
  - $\pi\pi$ mass spectrum.
  - $K\pi$ mass spectrum.
  - Large Direct CP Violation (DCPV).
- KK S-wave from $B^+ \to K^+K^-\pi^+$ & $B^0 \to K^+K^-K^0$
- $b \to sq\bar{q}$ penguin-dominated charmless decays.
  - $b \to sq\bar{q}$ penguins and new physiscs.
  - $\sin(2\beta_{eff})$ from $B^0 \to \eta' K^0$ (Q2B analysis)
  - Dalitz analyses: $2\beta_{eff}$ from $B^0 \to K^0_S\pi^+\pi^-$ & $B^0 \to K^+K^-K^0$
- "γ" (CPS/GPSZ) from $B^0 \to K^+\pi^-\pi^0$ & $B^0 \to K^0_S\pi^+\pi^-$ Dalitz analyses.
- Conclusions



The Standard Model and the CKM Matrix

- **SM:** gauge theory of **strong** and **electroweak** interations. With the simetry group,

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$



In the quark sector:
mass eigenstates
≠
gauge eigenstates

$$\begin{cases} L_{CC} = g V^{ij}_{CKM} \bar{u}^i_L \gamma_\mu d^j_L W^{\mu -} + h.c. \\ CP^{-1} L_{CC} CP = g (V^T_{CKM})^{ij} \bar{d}^i_L \gamma_\mu u^j_L W^{\mu -} + h.c. \end{cases}$$

V_{CKM} **Complexe** → **CP violation in SM**

$V_{CKM} V^{\dagger}_{CKM} = I$ → **Quarks mixing described by 3 real parameters and one phase**

λ power expansion until λ³ with λ =sin(θ$_{cabibbo}$) ≈ 0.22

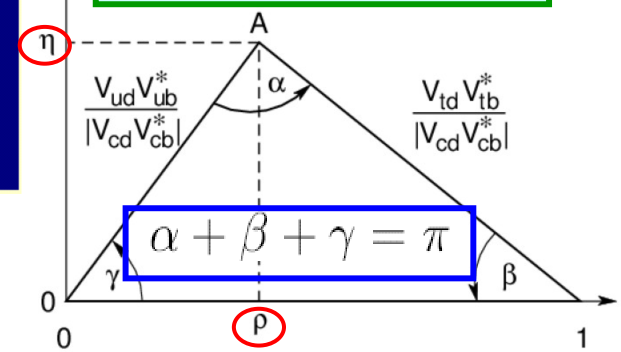
CKM matrix — Wolfenstein parameterization:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

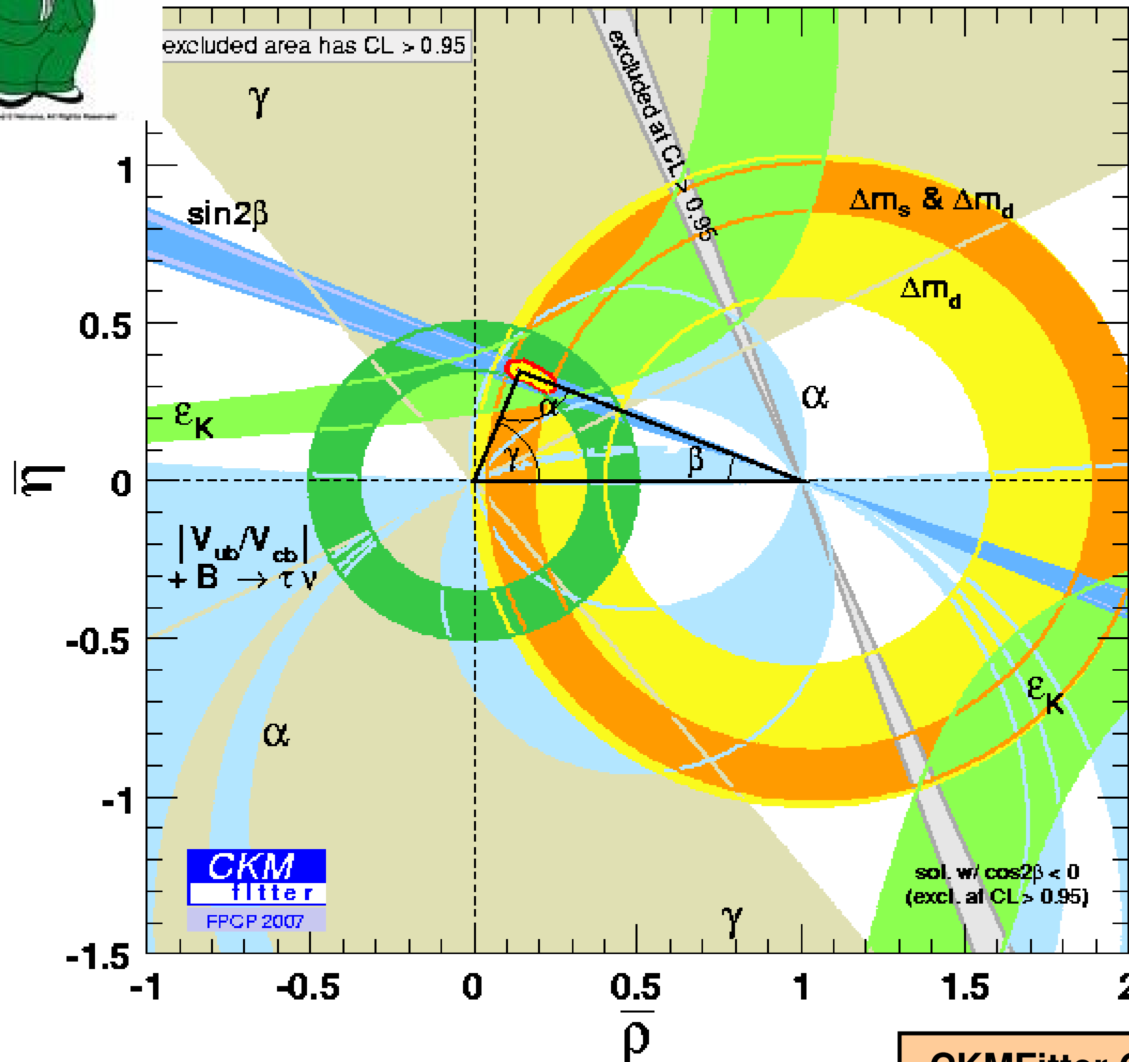
Experimental hierarchic structure

CP violation possible in the SM only if η≠0

Unitarity Triangle



CKM Matrix: Current knowledge



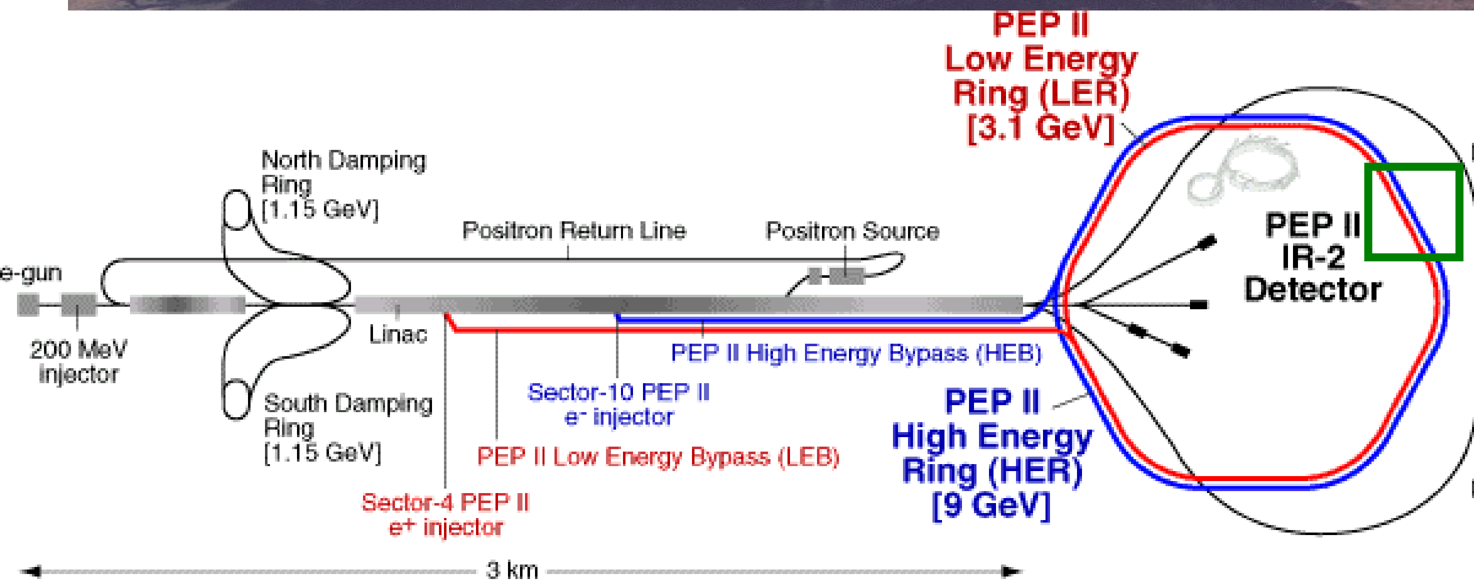
All measurement compatible between each other

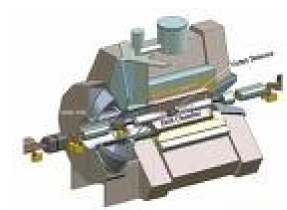
(Compatible with SM)

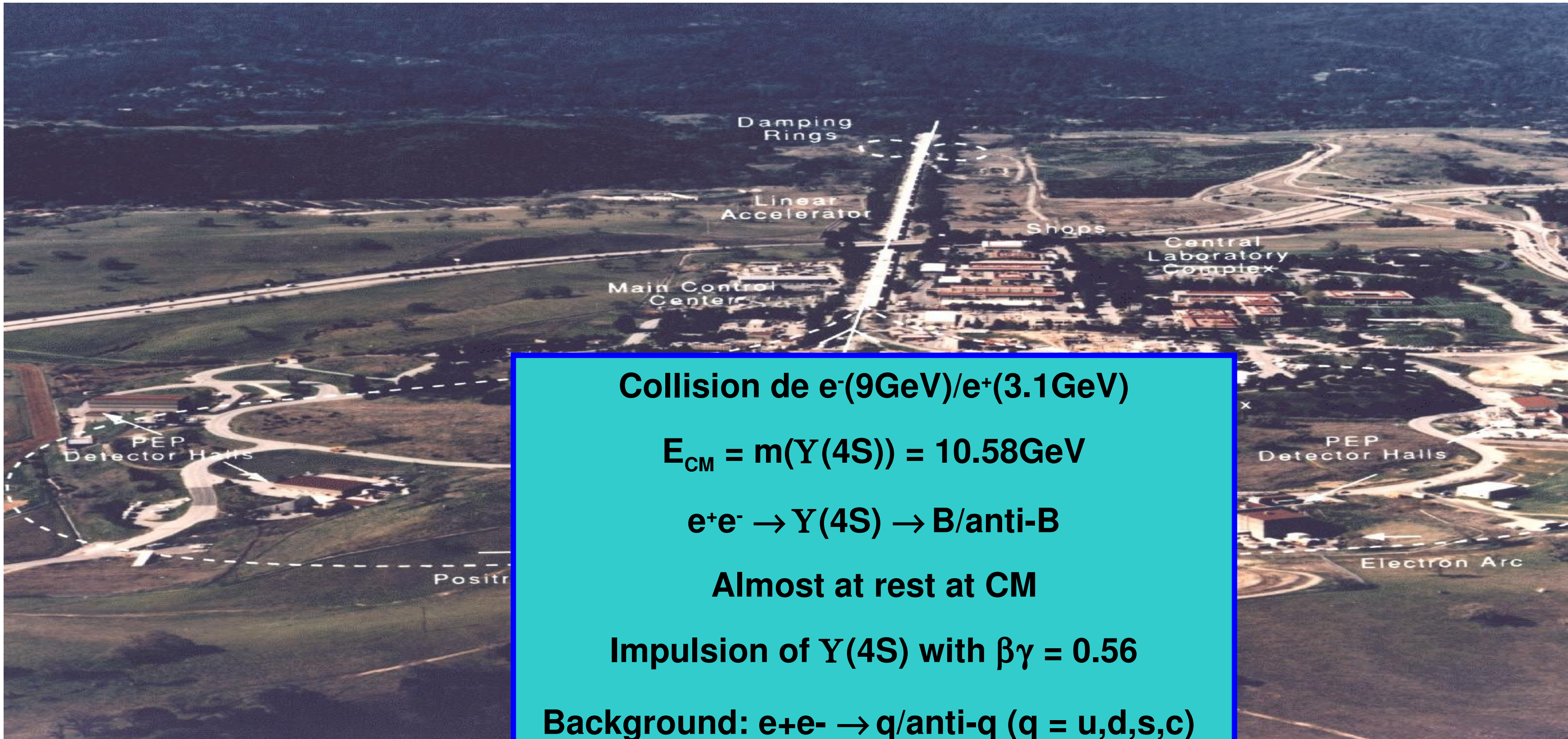
Compare "pure tree" measurements with "pure loop" measurements

CKMFitter Group (J. Charles et al.) Eur. Phys. J. C41, 1-131 (2005)


Damping Rings
Linear Accelerator
Shops
Central Laboratory Complex
Main Control Center
End Station B
End Station A
SSRL Complex
PEP Detector Halls
PEP Detector Halls
Positron Arc
Electron Arc
Collider Experimental Hall


PEP II Low Energy Ring (LER) [3.1 GeV]
North Damping Ring [1.15 GeV]
Positron Return Line
Positron Source
e-gun
PEP II IR-2 Detector
200 MeV injector
Linac
PEP II High Energy Bypass (HEB)
South Damping Ring [1.15 GeV]
Sector-10 PEP II e⁻ injector
PEP II High Energy Ring (HER) [9 GeV]
PEP II Low Energy Bypass (LEB)
Sector-4 PEP II e+ injector
3 km





Collision de e^-(9GeV)/e^+(3.1GeV)

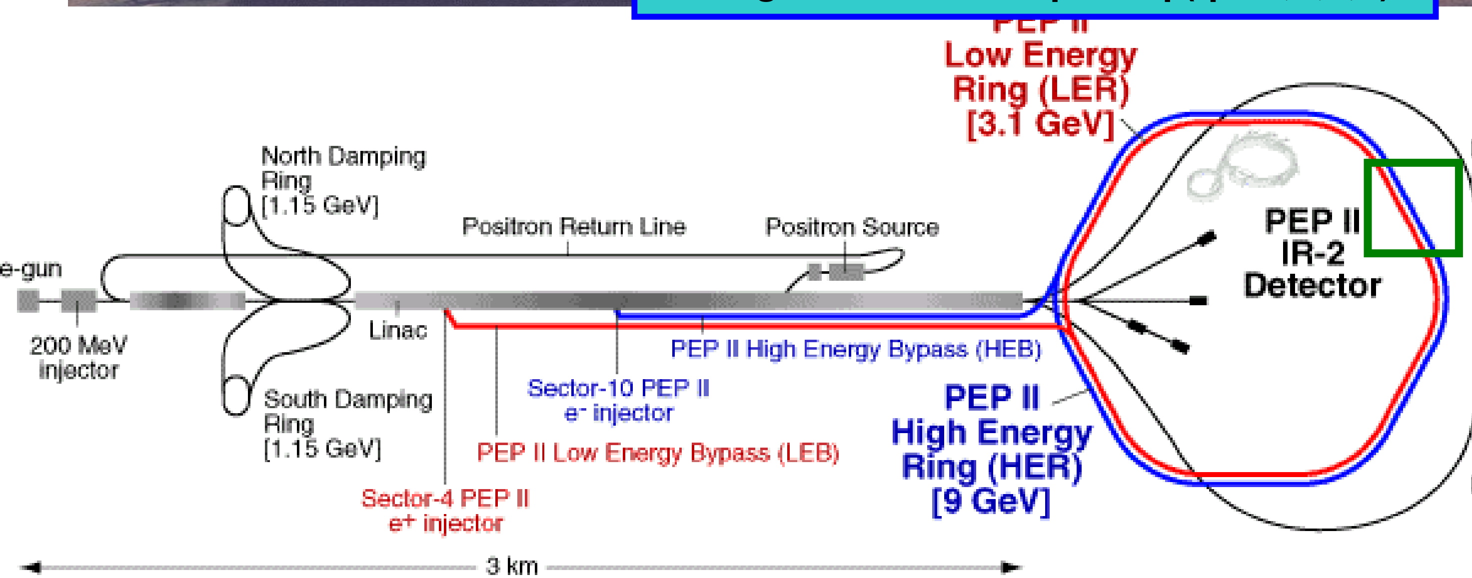
$E_{CM} = m(\Upsilon(4S)) = 10.58$GeV

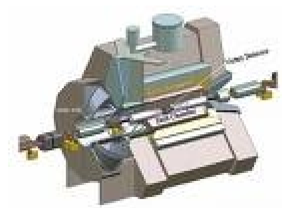
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow$ B/anti-B

Almost at rest at CM

Impulsion of $\Upsilon(4S)$ with $\beta\gamma = 0.56$

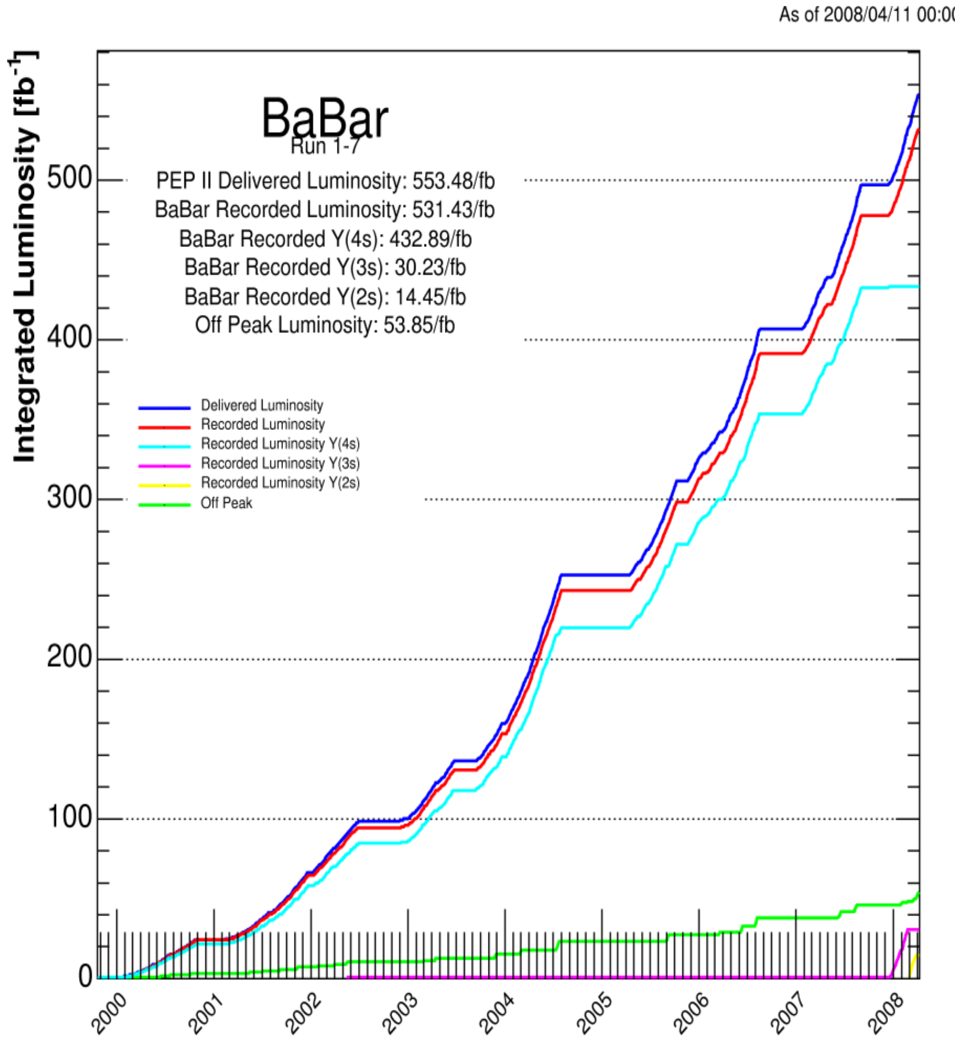
Background: e+e- $\rightarrow$ q/anti-q (q = u,d,s,c)





The BaBar Experiement

- $\Upsilon(4S)$ data taking ended Dec 2007 ~ 465 M B anti-Bs.
- Have recorded ~ 30/fb on $\Upsilon(3S)$ and ~15/fb on $\Upsilon(2S)$.
- Routinely collected data at 40MeV below $\Upsilon(4S)$ peak (off-peak data) for background characterization.
- Finished running on April 8th

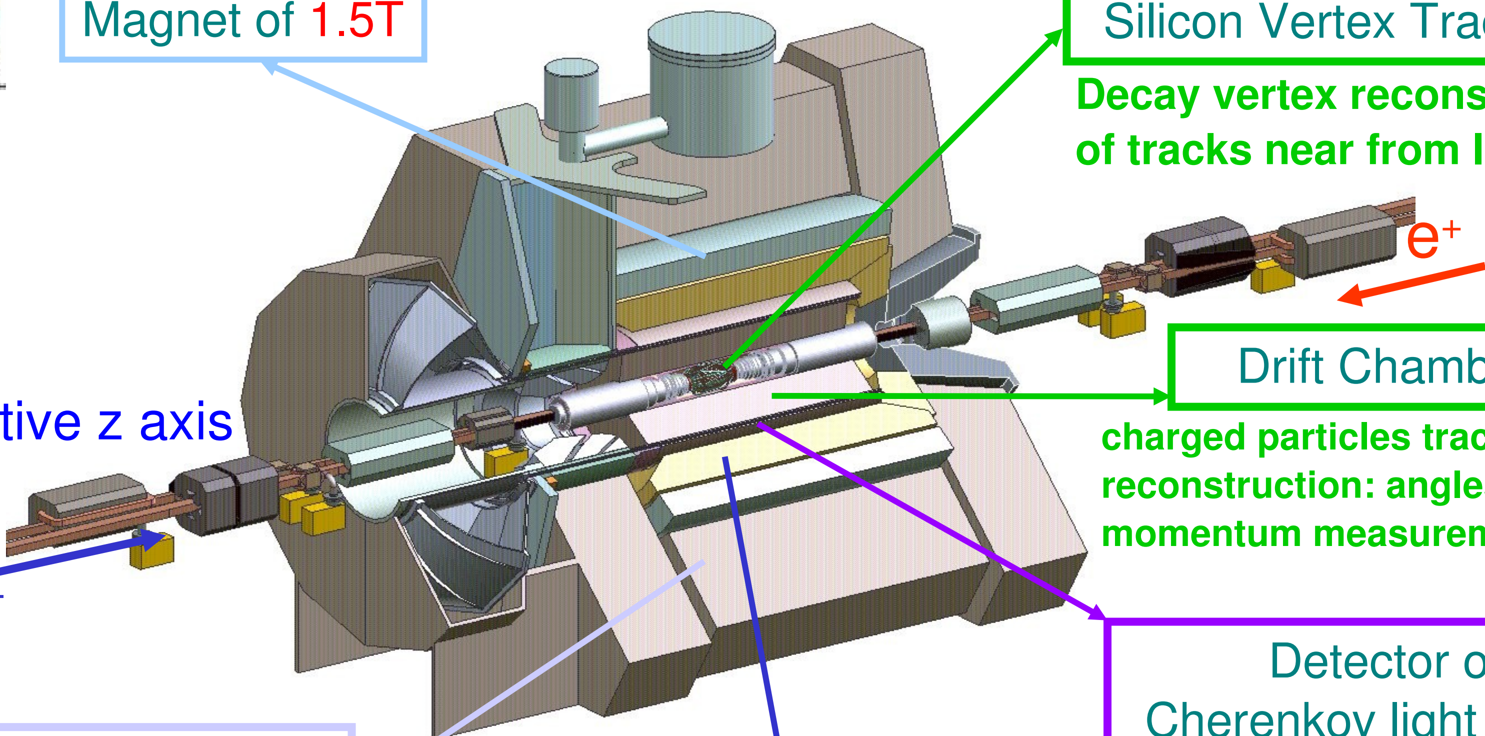


The BaBar Detector

Magnet of 1.5T

Silicon Vertex Tracker (SVT)

Decay vertex reconstruction of tracks near from IP



e^+

positive z axis

e^-

Drift Chamber (DCH)

charged particles tracks deviation reconstruction: angles and momentum measurements.

Detector of Cherenkov light (DIRC)

Charged particles ID

K/π separation >2.5σ until 4GeV/c^2

Intrumented flux return (IFR)

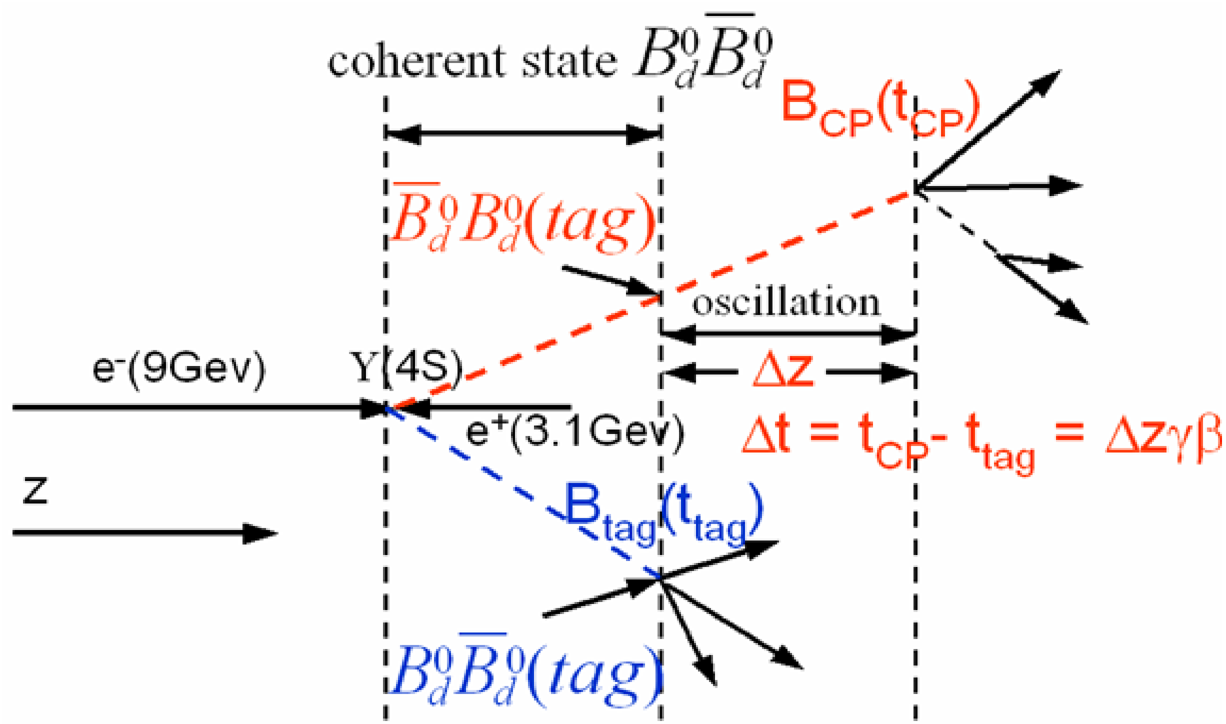
$\mu^{+/-}$ Identification

Electromagnetic calorimeter (EMC)

Detection of γ, e^- identification and $\pi^0 \rightarrow \gamma\gamma$ reconstruction, Measurements of Energy

The Δt and tagging measurement

- The neutral B mesons are produced in a coherent B^0 anti-B^0 state
- Flavor B tagging is made with B parner
- Δt measurement from Δz



The Dalitz Plot

- 2 degrees of freedom in $B \rightarrow P_1P_2P_3$, usually m^2_{P1P2} and m^2_{P1P3}:
  3 daughters x 3 p comp – 4 (E, p conservation) - 3 Euler angles

Resonances, bands of constant m^2_{12}, m^2_{23} or m^2_{13}

Overlap $\rightarrow$ interference

$\rightarrow$sensitive to relative phase

Observe intensity $|A|^2$,

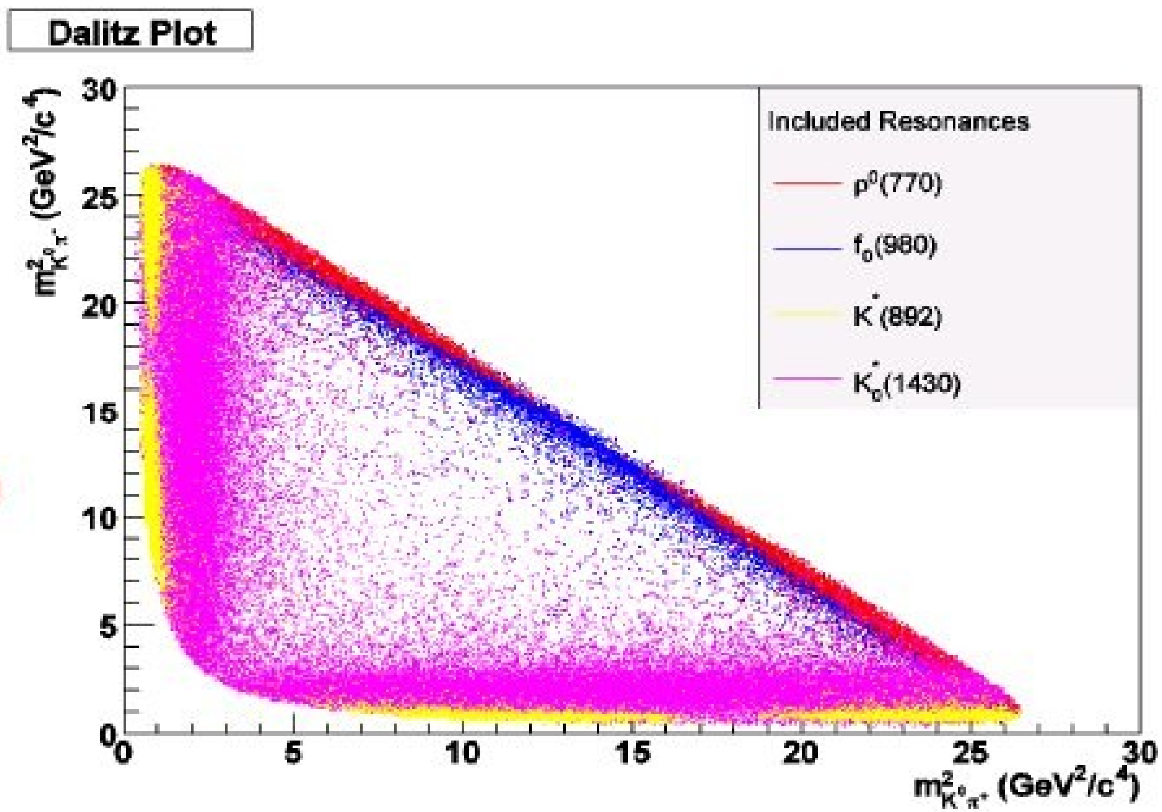
with $A \sim \sum c_i BW_i$ (Isobar)

c_i characterize model

so $|A|^2 \sim c_k^* c_l BW_k^* BW_l$

$k, l > 1$ lift degeneracies

Ideal to measure phases!



Δt-Dalitz Plot PDF

Time Dalitz Plot and tagging Pdf

$$f(\Delta t, DP, q_{tag}) \propto (|A|^2 + |\overline{A}|^2)\frac{e^{-|\Delta t|/\tau}}{4\tau}\left(1 + q_{tag}\frac{2\,\mathrm{Im}[\overline{A}A^*]}{|A|^2 + |\overline{A}|^2}\sin(\Delta m_d \Delta t) - q_{tag}\frac{|A|^2 - |\overline{A}|^2}{|A|^2 + |\overline{A}|^2}\cos(\Delta m_d \Delta t)\right)$$

Dalitz Plot Isobar Model

$$A(DP) = \sum a_j F_j(DP)$$

$$\overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP)$$

← shapes of intermediate states over DP

CP violation varies over the DP

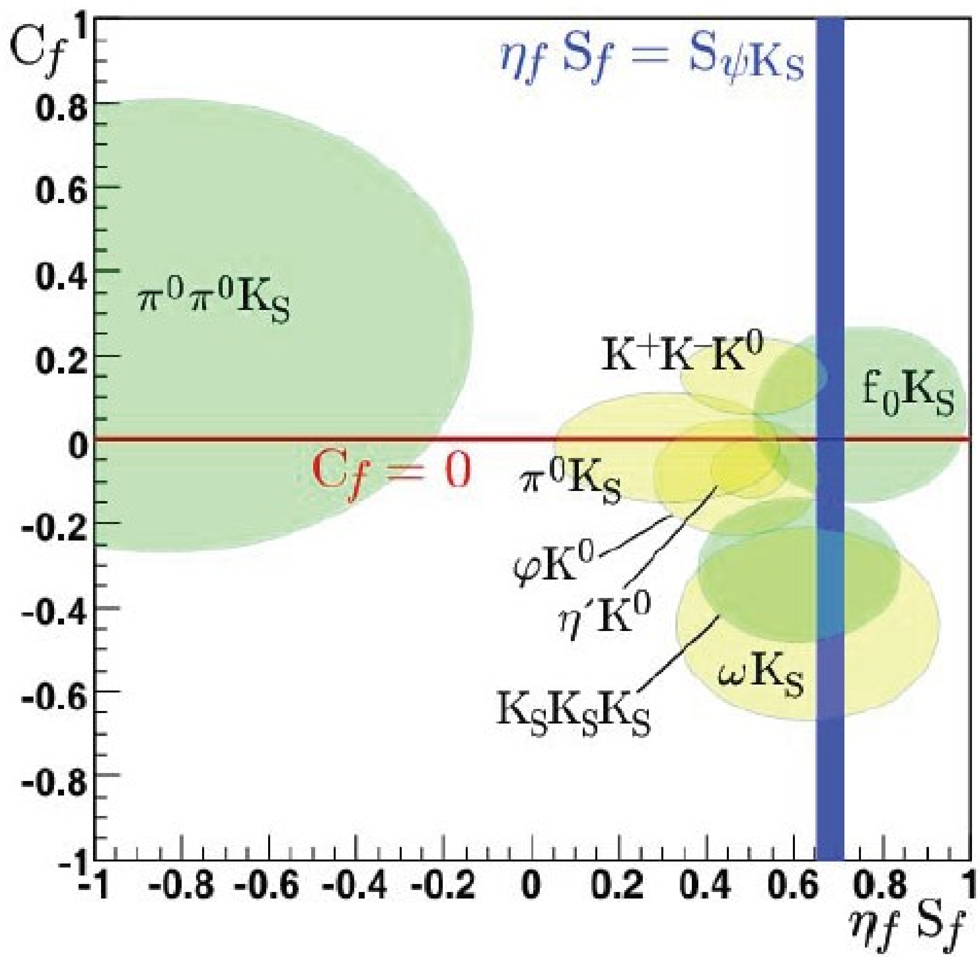
Amplitudes a_j and $\overline{a}_j$ determine DP interference pattern.

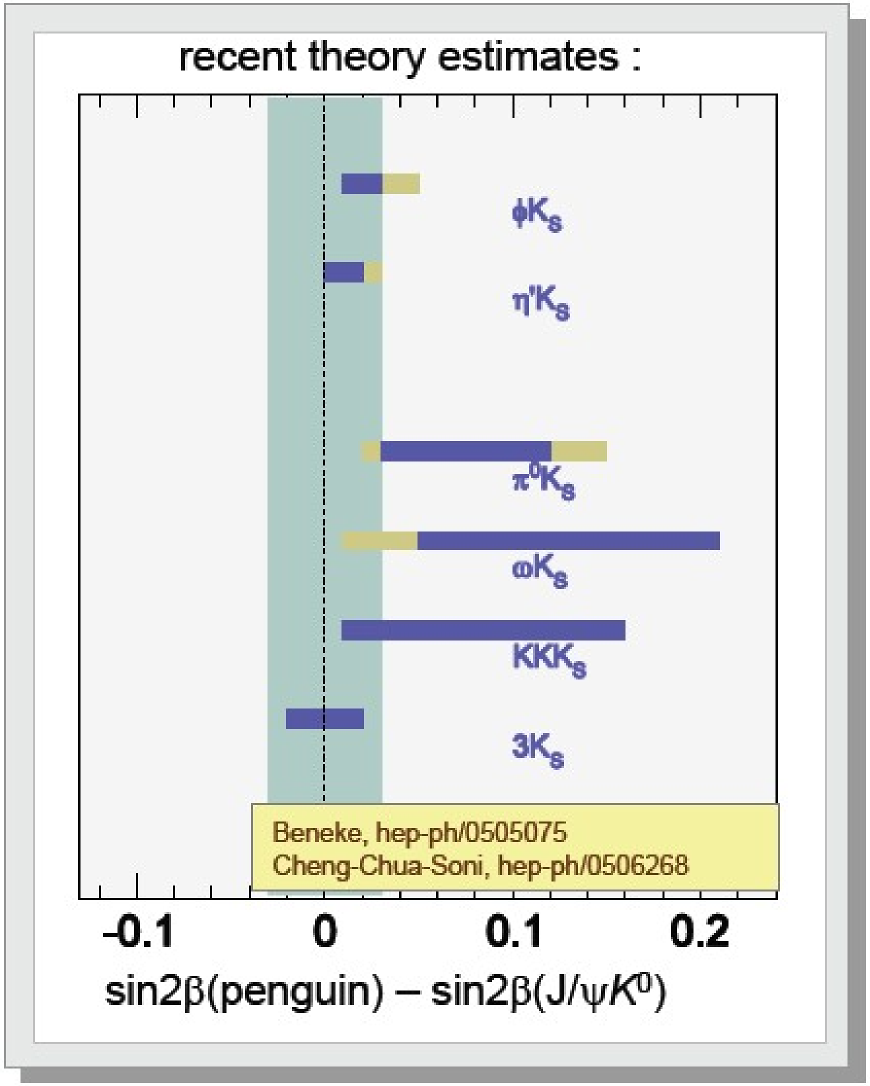
Time-Dependent CP Parameters:

$$C_j = \frac{|a_j|^2 - |\overline{a}_j|^2}{|a_j|^2 + |\overline{a}_j|^2} \qquad S_j = \frac{2\,\mathrm{Im}[\overline{a}_j a_j^*]}{|a_j|^2 + |\overline{a}_j|^2}$$

interference helps
disentangling strong and weak phases, and
thus raises the degeneracy in the
time-dependent CP parameter S

b→s penguins : summary



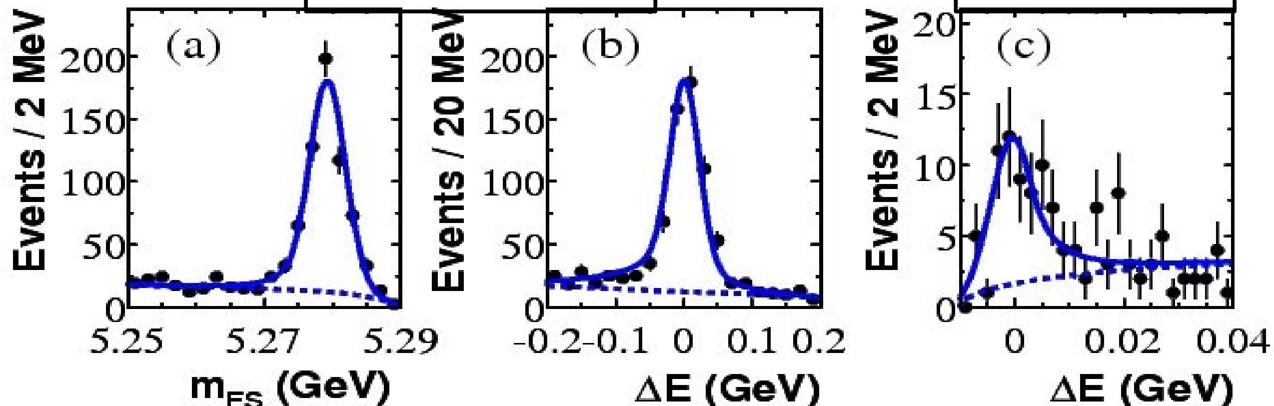


$\sin(\beta_{eff})$ from $B^0 \to \eta' K^0$

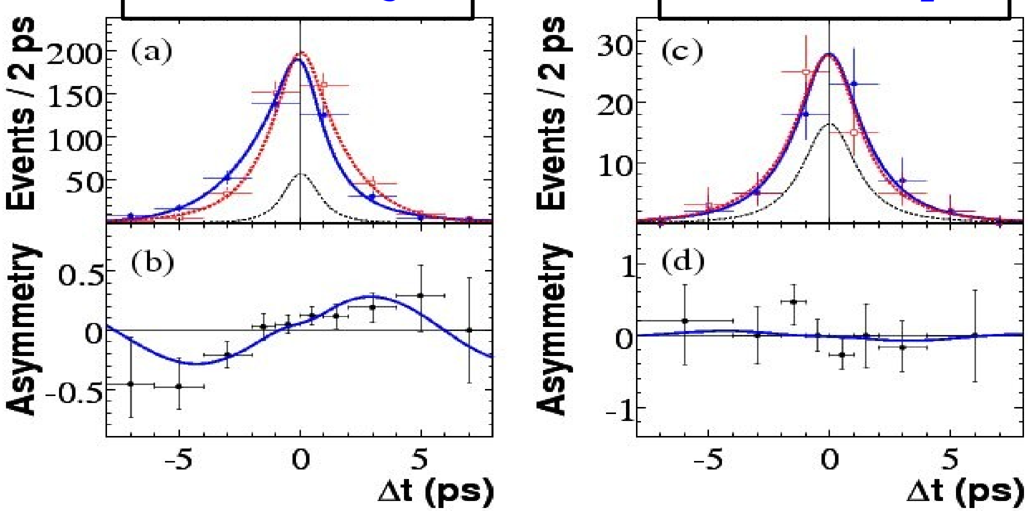
- **Channel have access only to $\sin(\beta_{eff})$**

- **Samples of:**
  $B^0 \to \eta' K^0_S$ and
  $B^0 \to \eta' K^0_L$ used.

$B^0 \to \eta' K^0_S$ | $B^0 \to \eta' K^0_L$



$B^0 \to \eta' K^0_S$ | $B^0 \to \eta' K^0_L$



Measurements:

$C = -0.16 \pm 0.07 \pm 0.03$

$S = 0.58 \pm 0.10 \pm 0.03$

Observed mixing-induced CPV at 5.5σ level