Recent BaBar results on *CP* violation in *B* decays

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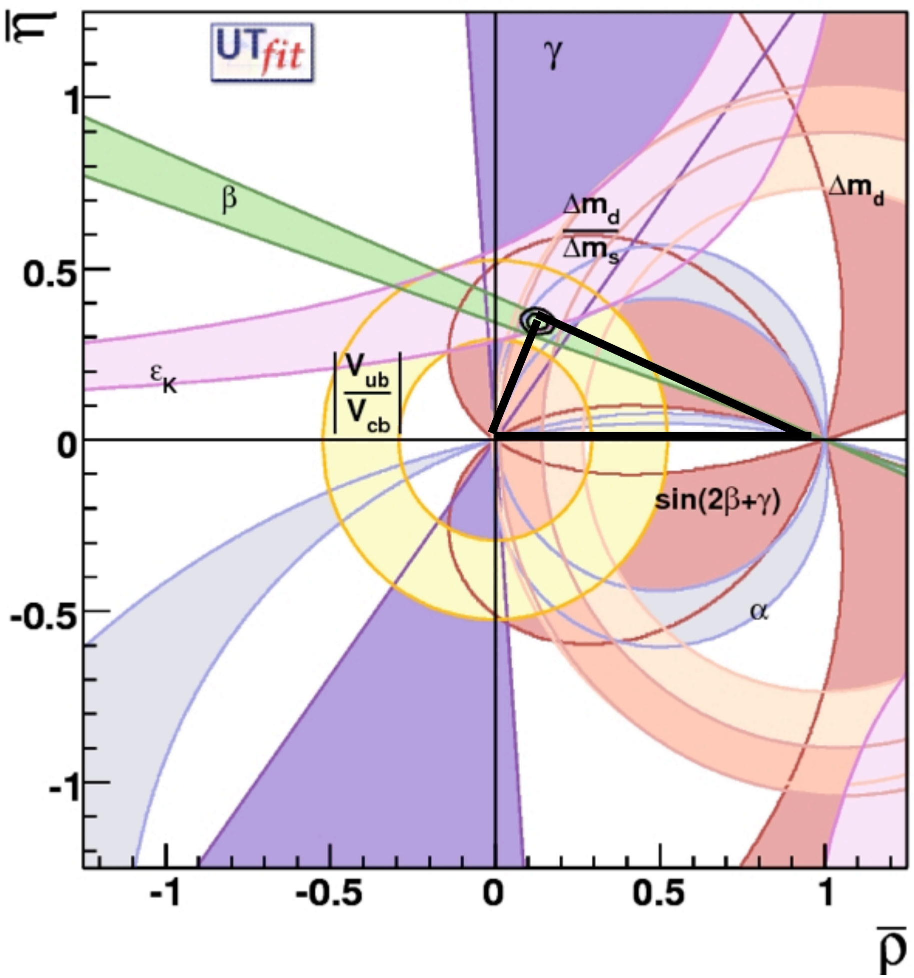
Motivation and outline



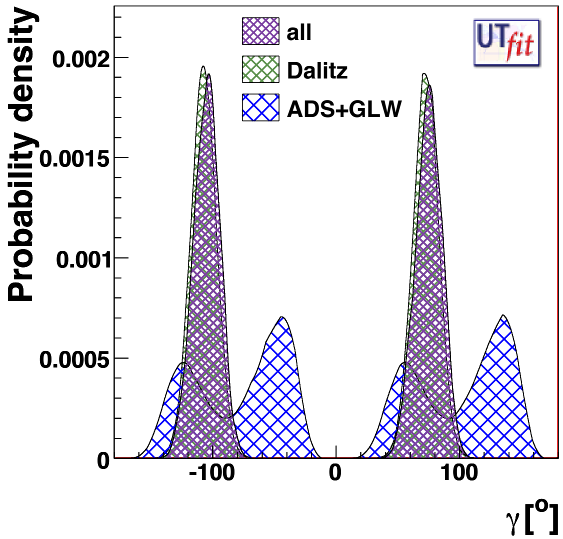
CP violation studies showed good agreement with the SM by now

3.1 GeV e^+
9 GeV e^-

L = 1.2 x 10^{34} $cm^{-2}s^{-1}$
$\int L\,dt \sim 430\ fb^{-1}$ @ Υ(4S)+off-resonance (~10%)

This talk is concentrated on

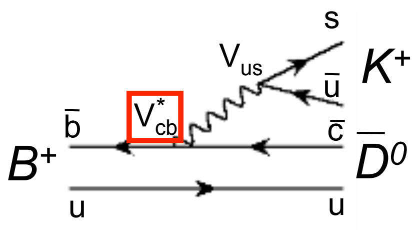
γ measurements

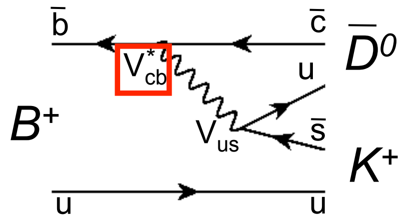


See other BaBar talks for more CPV results

γ measurements from $B \rightarrow D^{(*)}K^{(*)}$

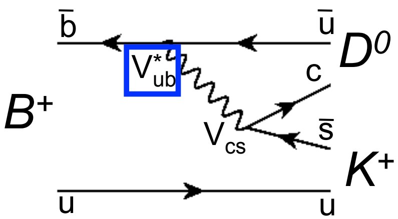
b→c

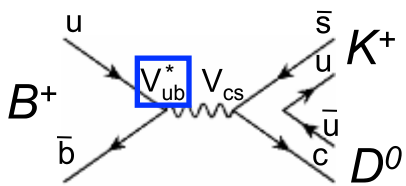




relative phase ~γ

b→u





Advantages:
- Only tree decays.
- Largely unaffected by the New Physics scenarios
- Clear theoretical interpretation

Disadvantages:
- Rare decays and low r_B

Related variables (depend on the *B* meson decay channel):

$$r_B = \frac{|A_{b\rightarrow u}|}{|A_{b\rightarrow c}|}$$

$r_B \sim 0.1$ For charged *B* mesons

$r_B \sim 0.3$ For neutral *B* mesons

δ_B strong phase (*CP* conserving)

Experimentally not easy to measure.
Three ways to extract the information:
- GLW
- ADS
- Dalitz

GLW Method

Many D^0 Modes reconstructed:

$$CP+ : D^0_{CP+} \to K^+K^-, \pi^+\pi^-$$

$$CP- : D^0_{CP-} \to K^0_s\pi^0, K^0_s\omega, K^0_s\phi$$

$$\text{CA} : D^0 \to K^-\pi^+$$

4 observables (3 independent):

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) - \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}$$

$$R_{CP\pm} = 2\frac{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \bar{D}^0K^+)}$$

3 unknowns:

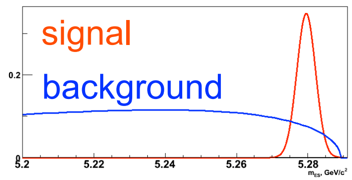
$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B$$

$$A_{CP\pm} = \frac{\pm 2r_B \cos\gamma\cos\delta_B}{R_{CP\pm}}$$

M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991)

Energy substituted mass

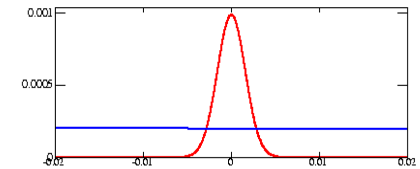
$$m_{ES} = \sqrt{E^2_{\text{beam}} - p_B^2}$$



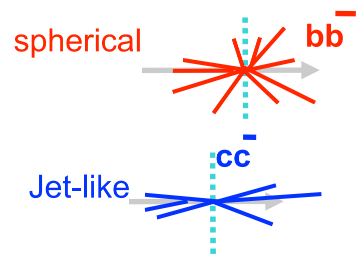
Typical experimental resolution ~2.6 MeV/c^2

Beam-energy difference

$$\Delta E = E_B - E_{\text{beam}}$$

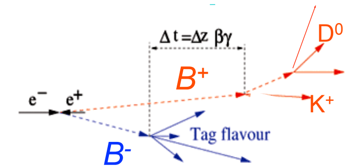


Typical experimental resolution [15-20] MeV



event shape moments

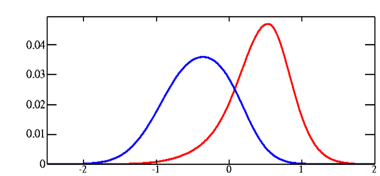
angles of thrust axes



proper time interval

non-signal B variables

Information is usually combined into Fisher discriminant or Neural Net

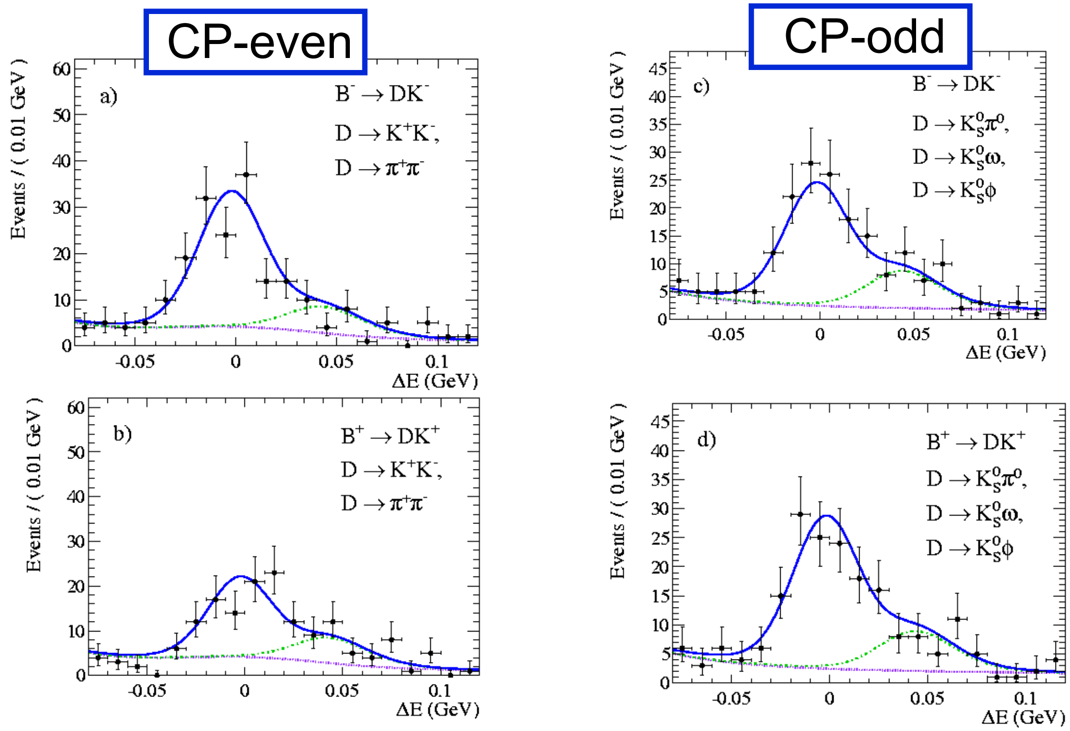


GLW method results

BaBar 425 fb^{-1}
(467 MBB)

ML fit to {m_{ES}, ΔE, Fisher(event shape variables)}

Simultaneous fit to the subsamples corresponding to different D decays



N_{CP+}=477±28

N_{CP-}=506±26

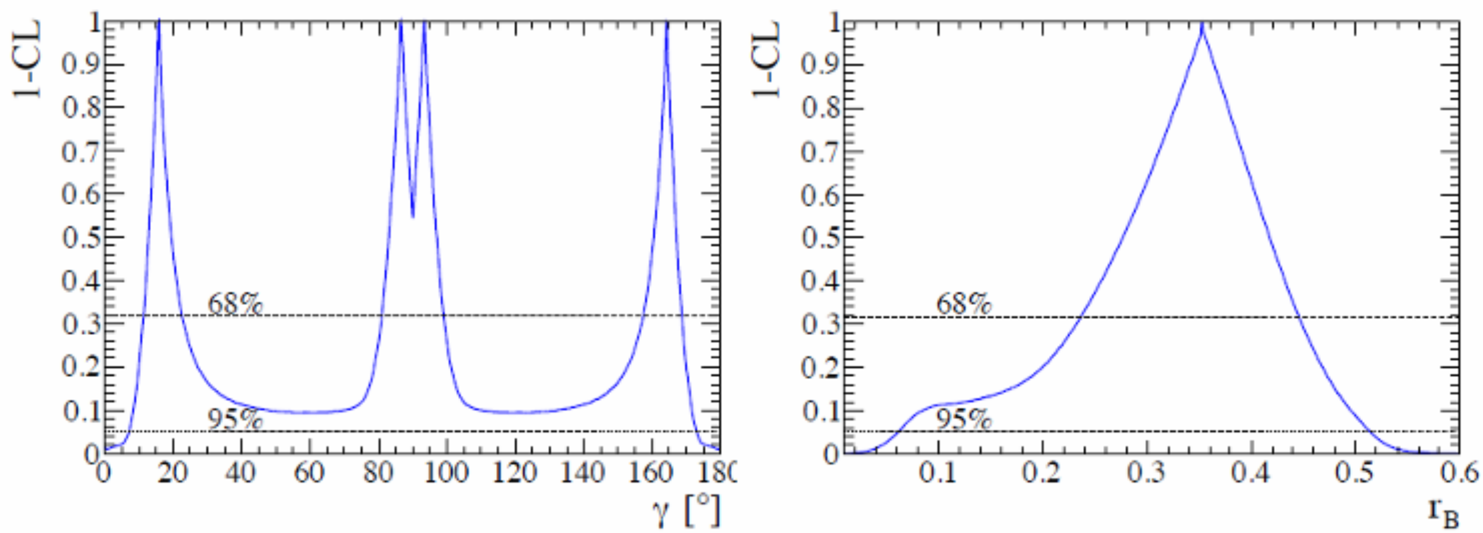
$A_{CP+} = 0.25 \pm 0.06 \pm 0.02$
$A_{CP-} = -0.09 \pm 0.07 \pm 0.02$
$R_{CP+} = 1.18 \pm 0.09 \pm 0.05$
$R_{CP-} = 1.07 \pm 0.08 \pm 0.04$

Direct CPV at 3.6σ
in $B \rightarrow D_{CP+}K$ decays !

PRD82:072004,2010

Frequentist interpretation gives:

	γ mod 180 [°]	r_B
68% CL	[11.3, 22.7]	[0.24, 0.45]
	[80.9, 99.1]	
	[157.3, 168.7]	
95% CL	[7.0, 173.0]	[0.06, 0.51]



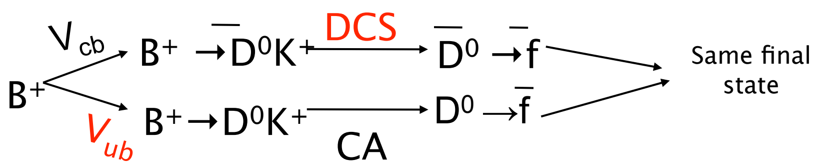
Large value of r_B is favored (but large uncertainty: less than 2σ from 0)

ADS Method

D. Atwood, I. Dunietz, A. Soni, PRL **78**, 3357 (1997).

D^0 Modes:
$K^+\pi^-$,
$K^+\pi^-\pi^0$

Interplay between Doubly-Cabibbo-Suppressed and Cabibbo allowed D meson decay



$$B^+ \to DK^+, D \to K^+\pi^-$$ Same sign

$$B^+ \to DK^+, D \to K^-\pi^+$$ Opposite sign

New set of variables:

$$R^+ = \frac{\Gamma([K^-\pi^-]K^+)}{\Gamma([K^+\pi^-]K^+)} = \left[\frac{\text{opposite sign events yield}}{\text{same sign events yield}}\right]_{B^+}$$

$$R^- = \frac{\Gamma([K^+\pi^-]K^-)}{\Gamma([K^-\pi^+]K^-)} = \left[\frac{\text{opposite sign events yield}}{\text{same sign events yield}}\right]_{B^-}$$

These variables do not suffer of mutual statistical correlations.

$$R^+ = r_B^2 + r_D^2 + 2r_B k_D r_D \cos(\delta_B + \delta_D + \gamma)$$

$$R^- = r_B^2 + r_D^2 + 2r_B k_D r_D \cos(\delta_B + \delta_D - \gamma)$$

Parameters:
$\{\gamma;\, r_B;\, \delta_B\}$

Can be measured by BaBar (and others)

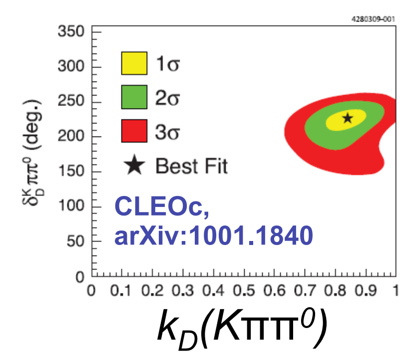
External Inputs:
$\{r_D;\, \delta_D;\, k_D\}$

$$r_D = \frac{|A_{c\to u}|}{|A_{c\to s}|}$$

$$k_D e^{i\delta_D} = \frac{\int A_D \bar{A}_D e^{i(\bar{\delta}(m)-\delta(m))} dm}{\sqrt{\int |A_D|^2 dm \int |\bar{A}_D|^2 dm}}$$

$$k_D(D \to K\pi) = 1$$

k_D and δ_D can be measured at charm factories using the Quantum-Correlated Measurements



ADS results ($D \to K\pi$)

BaBar 425 fb^{-1}
(467 MBB)

PRD82:072006,2010

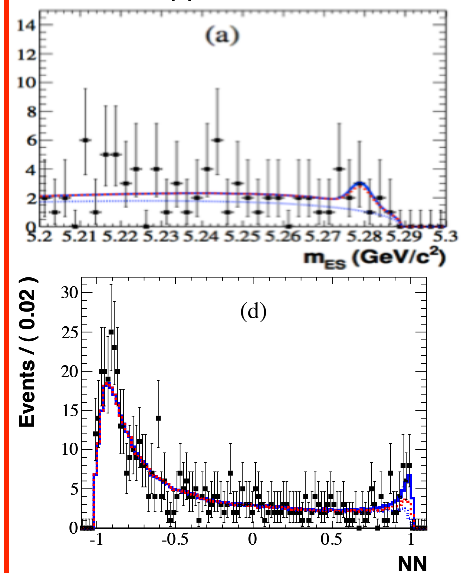
$$B^+ \to D^{(*)}K^+, D \to K\pi$$

Simultaneous fit to m_{ES} and NN (based on Event shape and tagging variables) for both decay chains.

$B^+ \to D^* K^+$ results:

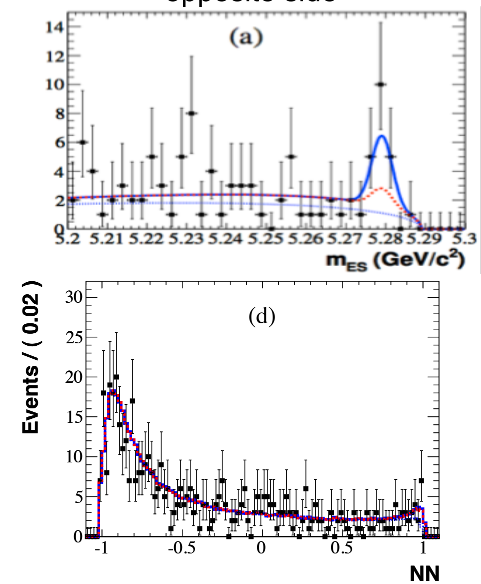
	$D^*_{D\pi^0}K$	$D^*_{D\gamma}K$
$\mathcal{R}^{(*)+}_{DK}$ (10^{-2})	0.5 ± 0.8	0.9 ± 1.6
$\mathcal{R}^{(*)-}_{DK}$ (10^{-2})	3.7 ± 1.8	1.9 ± 2.3

$B^- \to DK^-$
opposite side



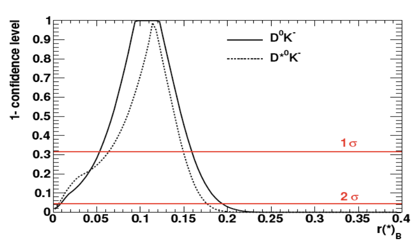
$$R^- = (0.2 \pm 0.6 \pm 0.2) \times 10^{-2}$$

$B^+ \to DK^+$
opposite side



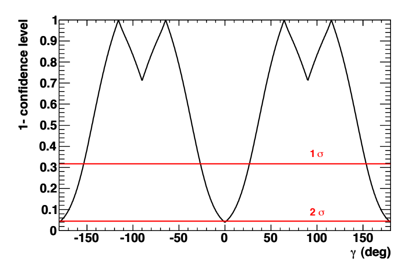
$$R^+ = (2.2 \pm 0.9 \pm 0.3) \times 10^{-2}$$

These measurements allowed us to reconstruct r_B and gamma



$$r_B = (9.5^{+5.1}_{-4.1})\%,$$
$$r^*_B = (9.6^{+3.5}_{-5.1})\%.$$

This can be interpreted as a limit r_B<16% @ 90% C.L.



ADS results ($D \rightarrow K\pi\pi^0$)

BaBar 431 fb^{-1}
(474 MBB)

PRD84:012002,2011

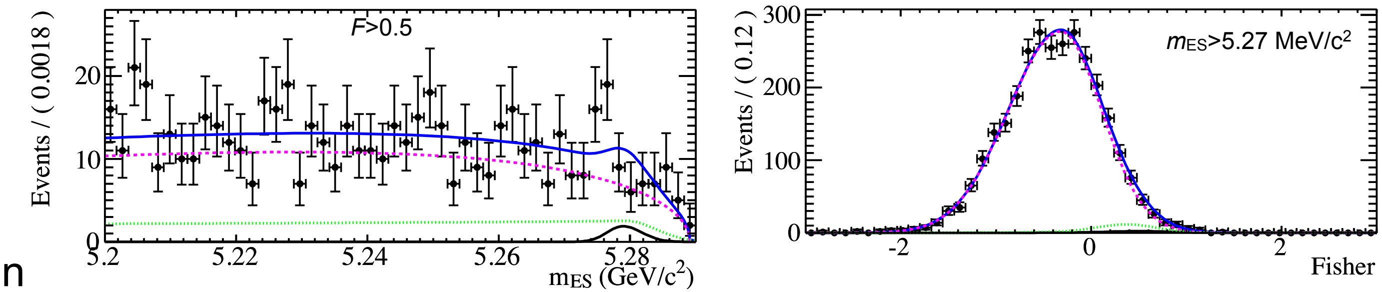
full fit | signal
continuum | BB | BBpeak

New result with the reprocessed data.

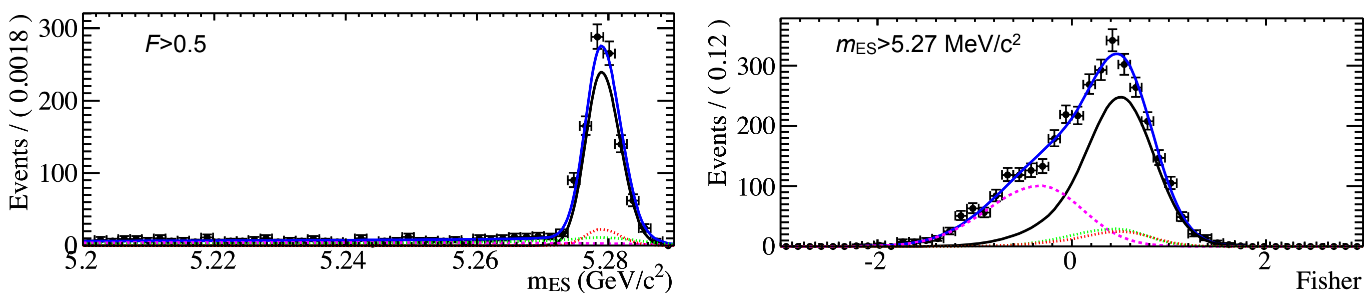
BaBar is the only experiment for a moment to use a π^0 in the ADS chain

Simultaneous fit to m_{ES} and *Fisher* (based on event shape and tagging variables) for both decay chains.

Opposite Sign events (~20 events)



Same Sign events (~2000 events)



ADS results ($D \to K\pi\pi^0$)

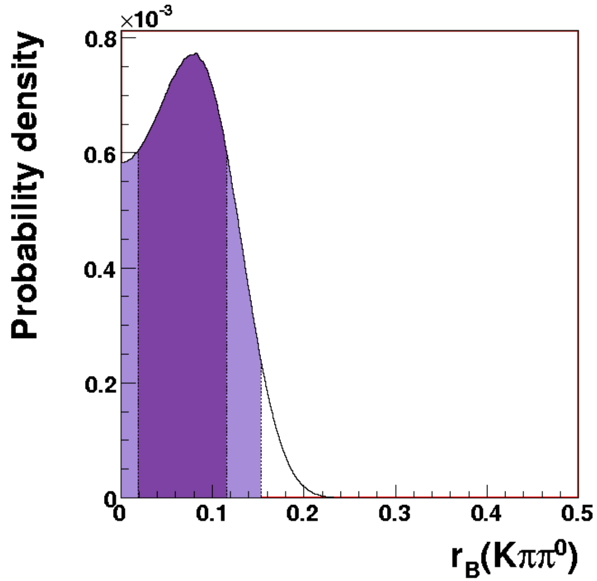
Fit	R^+	R^-
PDF	$+1.0 \cdot 10^{-3}$ $-1.8 \cdot 10^{-3}$	$1.1 \cdot 10^{-3}$
same sign peaking bkg	$2 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
opposite sign peaking bkg	$+0$ $-3.6 \cdot 10^{-3}$	$+0$ $-3.6 \cdot 10^{-3}$
Data-MC difference	$6 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
BR uncertainties	$2 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
Efficiency ratio	$1 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
os <-> ss crossfeed	$1 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
Total	$+1.2 \cdot 10^{-3}$ $-4.1 \cdot 10^{-3}$	$+1.6 \cdot 10^{-3}$ $-3.9 \cdot 10^{-3}$

We measured:

$$R^+ = (5\ ^{+12}_{-10}\ ^{+2}_{-4}) \times 10^{-2}$$

$$R^- = (12\ ^{+12}_{-10}\ ^{+3}_{-5}) \times 10^{-2}$$

Statistical errors dominate over systematical ones



This measurement allows us to put a limit r_B<14% at 90% probability, thus, making the results competitive with the channels without π^0

This channel is less precise for gamma measurements (subject to lower k_D)

Conclusions

CP violation in *B* decays from BaBar:

– The structure of SM is well confirmed by the experiment

– Several analyses completed recently

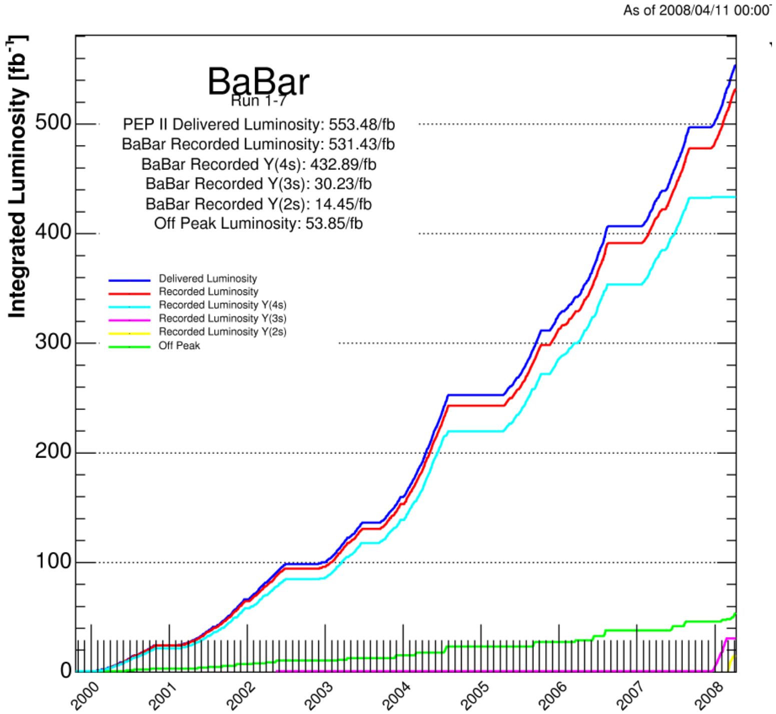
– The results are being updated to the full (and reprocessed) data sample

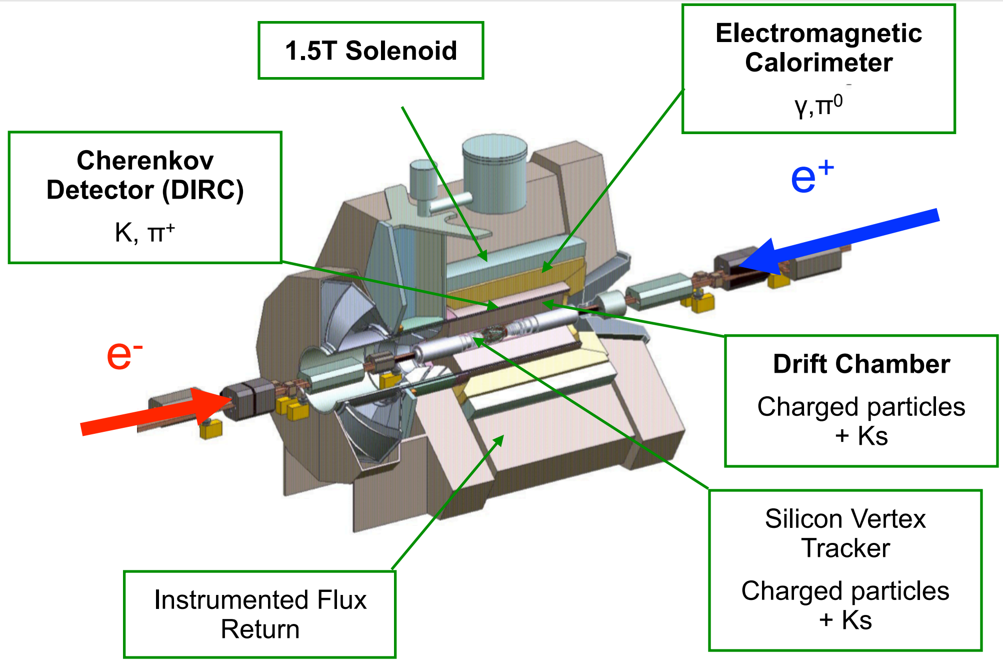
– Some results with more then 3 sigma evidence are obtained in gamma sector.

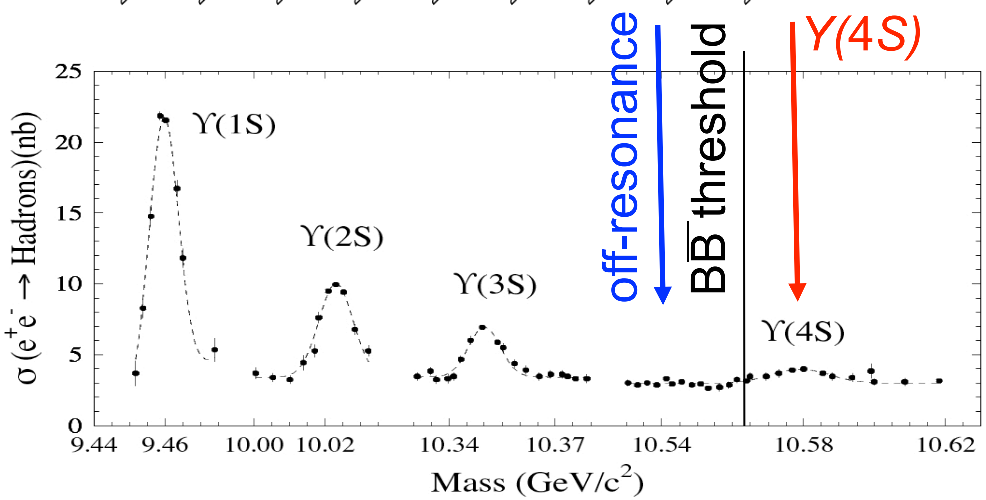
– More information in other BaBar talks.

Backup

BaBar detector and recorded luminosity







3.1 GeV e^+ & 9 GeV e^- beams

L = 1.2 x 10^{34} cm^{-2}s^{-1}

$\int L\,dt \sim 430$ fb^{-1} @ *Y(4S)* +

off-resonance (~10%)

with >96% *Y(4S)→BB*

(coherent production L=1)