Measurements related to sin(2β+γ) with the BaBar Detector

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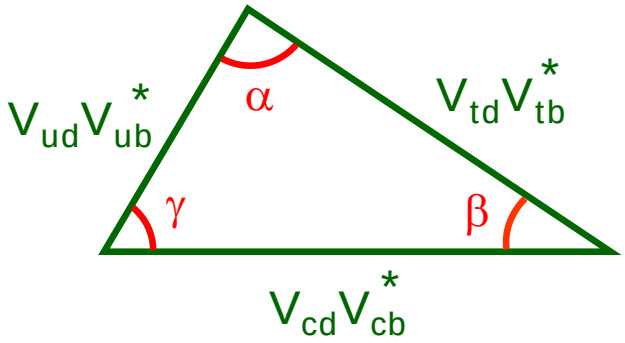
UC Riverside, California, 30 August 2004

CP Violation in Standard Model

CKM Matrix

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Unitarity Triangle



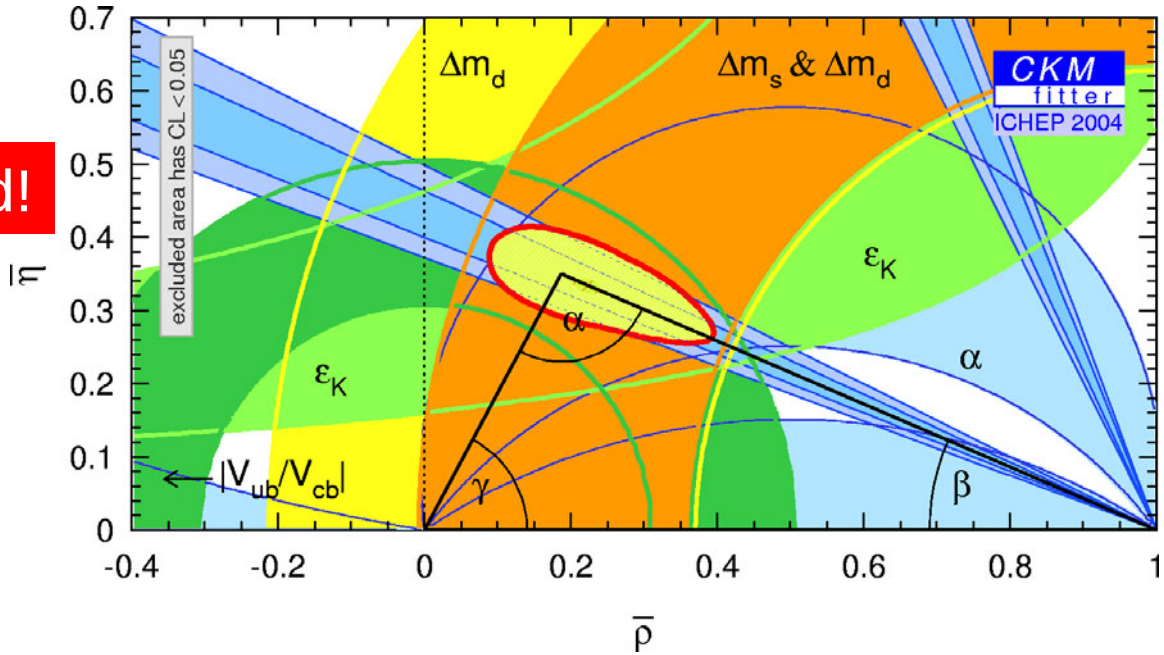
Precision Measurement of sin2β
World Average: 0.726 ± 0.037

ICHEP 2004

Experimental Constraints on α

Direct measurement of γ is needed!

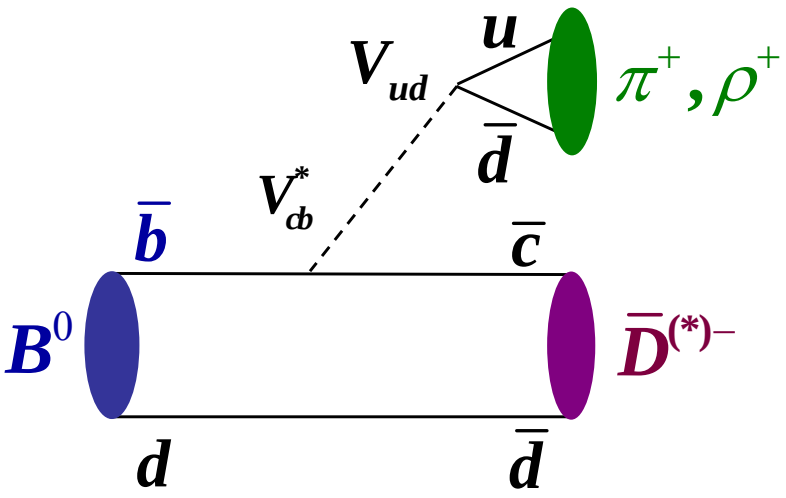
This Talk:
Time-dependent analysis to measure sin(2β+γ)



See also talks by G. Mancinelli and Y. Lau in this session for measurements related to γ

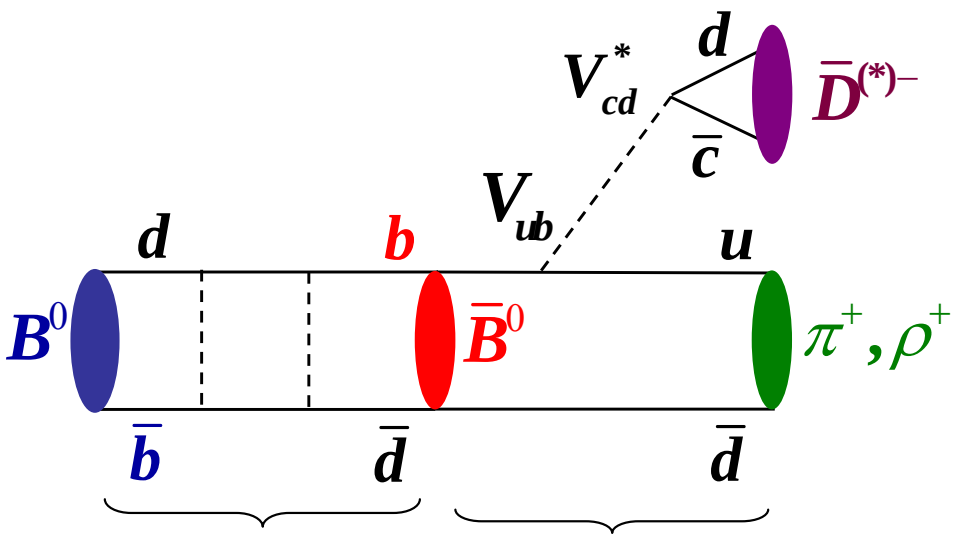
A. Hoecker et al, Eur. Phys. Jour. C21 (2001) 225 and hep-ph/0406184

CP violation from interference of decay and mixing with $B^0 \to D^{(*)}\pi/\rho$



Favored b → c decay

$$V_{cb} V_{ud}^* = A$$



Mixing: $e^{i2\beta}$

Suppressed b → u decay

$$V_{ub} V_{cd}^* e^{i\delta} = r^{(*)} A e^{-i\gamma} e^{i\delta}$$

Determines the sensitivity of the method

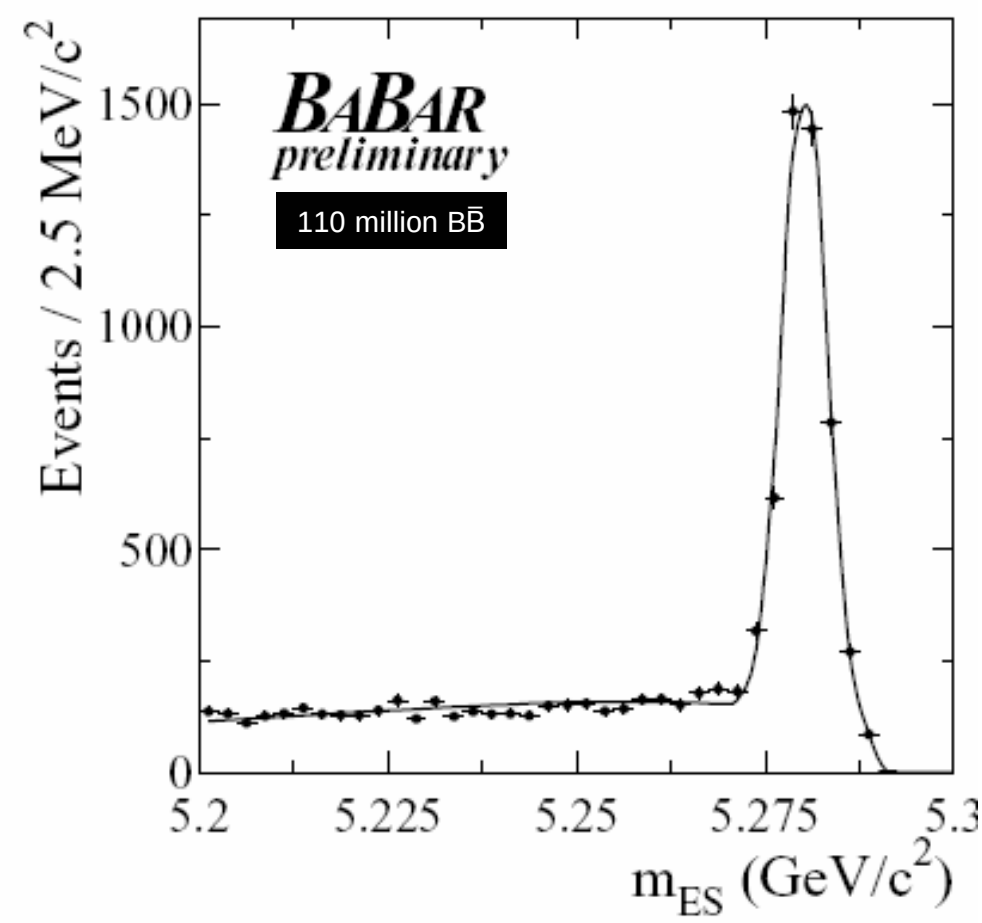
CKM angle

Strong phase difference

- Advantage: Large branching fraction for favored decay (~3 x 10^{-3})
- Disadvantage: Small BR for suppressed decay (~10^{-6}) → Small CP violating amplitude!

Fully and Partially Reconstructed B^0 Samples

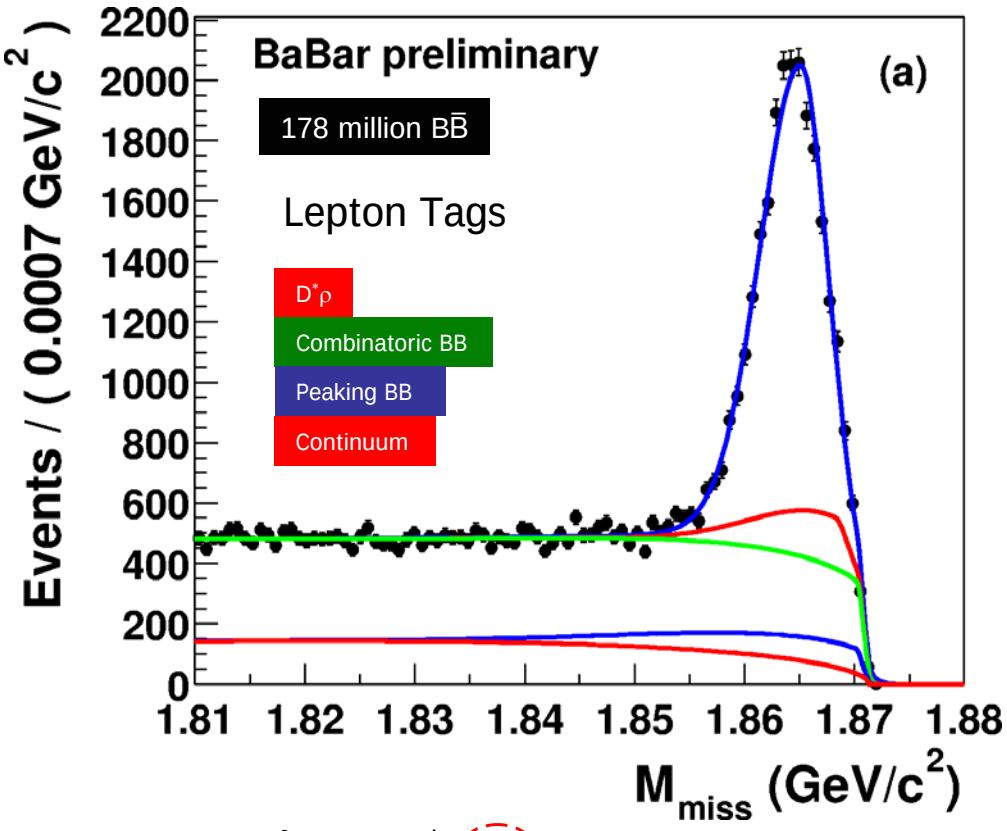
Fully Reconstructed $B^0 \to D\rho$



- Large sample with high purity

Sample	Yield	Purity
$B^0 \to D\pi$	7611 ± 97	91.4%
$B^0 \to D^*\pi$	7068 ± 89	95.8%
$B^0 \to D\rho$	4400 ± 79	87.3%

Partially Reconstructed $B^0 \to D^*\pi$



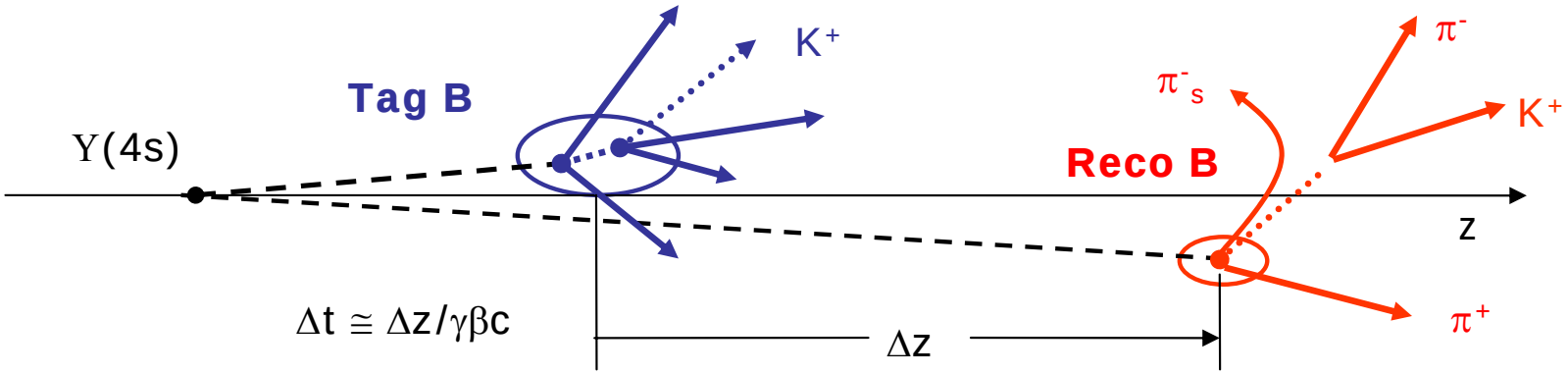
$B^0 \to D^{*-}\pi^+$, $D^{*-} \to \bar{D}^0\pi^-_{soft}$, $\bar{D}^0 \to X$

Use kinematic constraints to compute D^0 missing mass

- Modeling and characterization of background needed

Sample	Yield	Purity
Lepton Tags	16060 ± 210	54%
Kaon Tags	57480 ± 540	31%

Time-dependent Decay Time Distributions at Asymmetric e^+e^- Machines



$$f\left(B^0 \to D^{(*)-}\pi^+, \Delta t\right) = N e^{-\Gamma|\Delta t|}\left\{1 + C^{(*)}\cos\left(\Delta m_d \Delta t\right) + S^{(*)}\sin\left(\Delta m_d \Delta t\right)\right\}$$

$$f\left(\overline{B}^0 \to D^{(*)-}\pi^+, \Delta t\right) = N e^{-\Gamma|\Delta t|}\left\{1 - C^{(*)}\cos\left(\Delta m_d \Delta t\right) - S^{(*)}\sin\left(\Delta m_d \Delta t\right)\right\}$$

$$f\left(\overline{B}^0 \to D^{(*)+}\pi^-, \Delta t\right) = N e^{-\Gamma|\Delta t|}\left\{1 + C^{(*)}\cos\left(\Delta m_d \Delta t\right) - \overline{S}^{(*)}\sin\left(\Delta m_d \Delta t\right)\right\}$$

$$f\left(B^0 \to D^{(*)+}\pi^-, \Delta t\right) = N e^{-\Gamma|\Delta t|}\left\{1 - C^{(*)}\cos\left(\Delta m_d \Delta t\right) + \overline{S}^{(*)}\sin\left(\Delta m_d \Delta t\right)\right\}$$

Direct CP Violation

$$C^{(*)} = \frac{1 - r_{(*)}^2}{1 + r_{(*)}^2} \approx 1$$

Indirect CP Violation

Sensitivity on sin(2β+γ) depends on value of r

$$S^{(*)} = \frac{2r_{(*)}}{1 + r_{(*)}^2}\sin(2\beta + \gamma - \delta^{(*)})$$

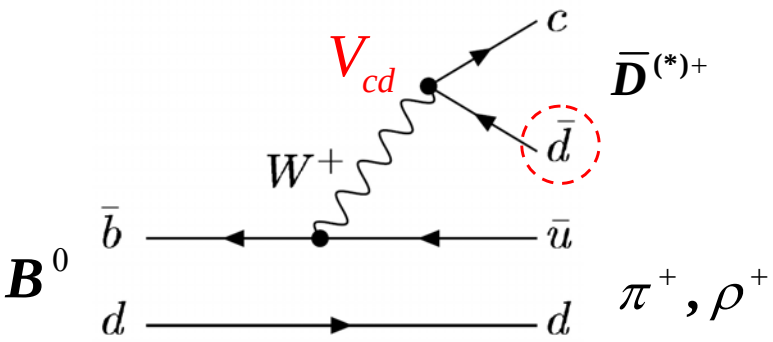
$$\overline{S}^{(*)} = \frac{2r_{(*)}}{1 + r_{(*)}^2}\sin(2\beta + \gamma + \delta^{(*)})$$

Estimate of r from $D_s^{(*)}\pi/\rho$ Branching Fractions

- Not sufficient data to measure ratio r of decay amplitudes

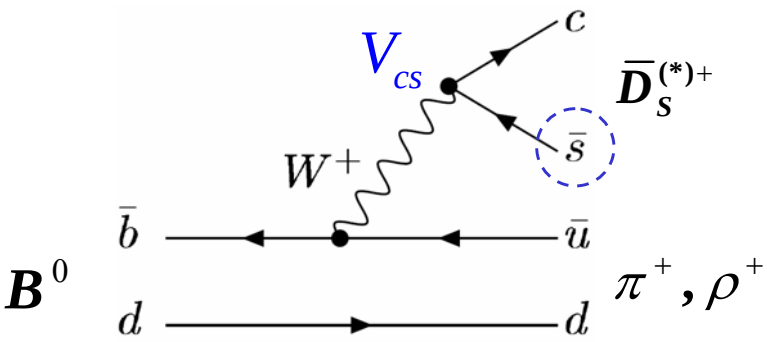
$$r\left(D^{(*)}\pi\right) = \left|\frac{A\left(B^0 \to D^{(*)+}\pi^-\right)}{A\left(B^0 \to D^{(*)-}\pi^+\right)}\right| \approx 0.02$$

- Use SU(3) symmetry to estimate from branching fraction in data



30% Theoretical Uncertainty

SU(3) ?



$$B^0 \to D^{(*)+}\pi^- \qquad r\left(D^{(*)}\pi\right) \approx \frac{f_{D^{(*)}}}{f_{D_S^{(*)}}}\left|\frac{V_{cd}}{V_{cs}}\right|\sqrt{\frac{BF\left(B^0 \to D_S^{(*)+}\pi^-\right)}{BF\left(B^0 \to D^{(*)+}\pi^-\right)}}$$

$$B^0 \to D^{(*)+}\rho^- \qquad r\left(D\rho\right) \approx \frac{f_D}{f_{D_S}}\left|\frac{V_{cd}}{V_{cs}}\right|\sqrt{\frac{BF\left(B^0 \to D_S^{+}\rho^-\right)}{BF\left(B^0 \to D^{+}\rho^-\right)}}$$

Measurement of $B^0 \to D^{(*)}_s \pi$ and Search for $B^0 \to D_s \rho$

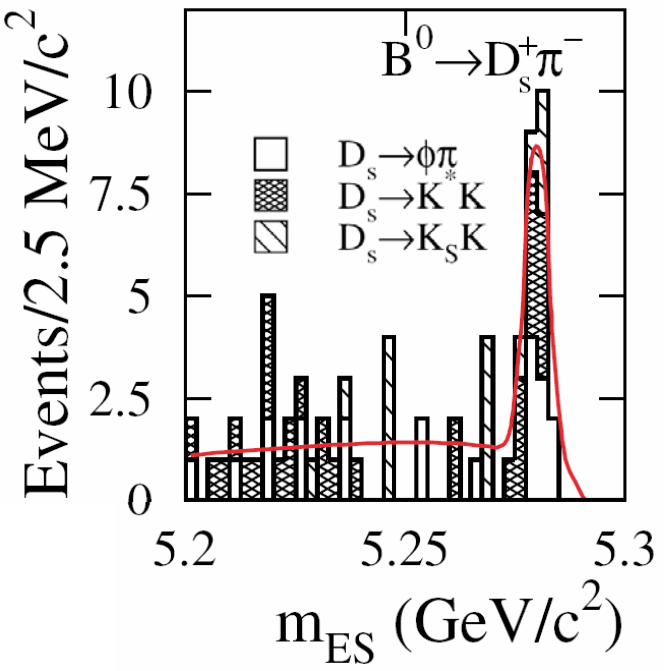
PRL 92, 251801

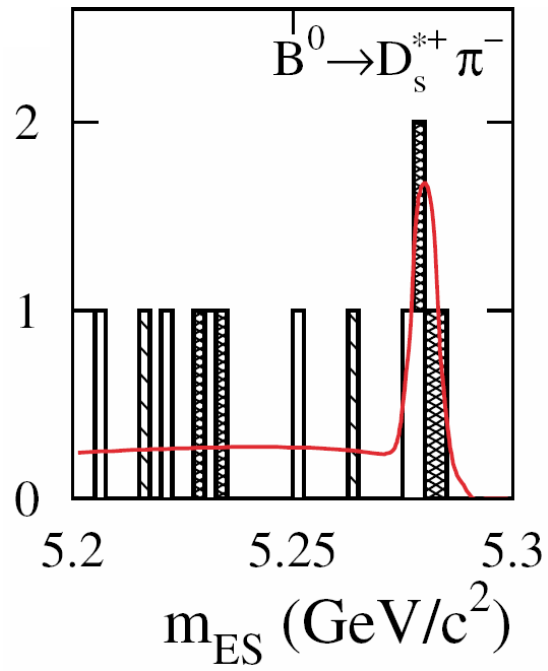
84 million B$\bar{B}$

$$r = 0.019 \pm 0.004$$

$$r^* = 0.017^{+0.005}_{-0.007}$$

Additional 30% Theoretical Uncertainty on estimated r





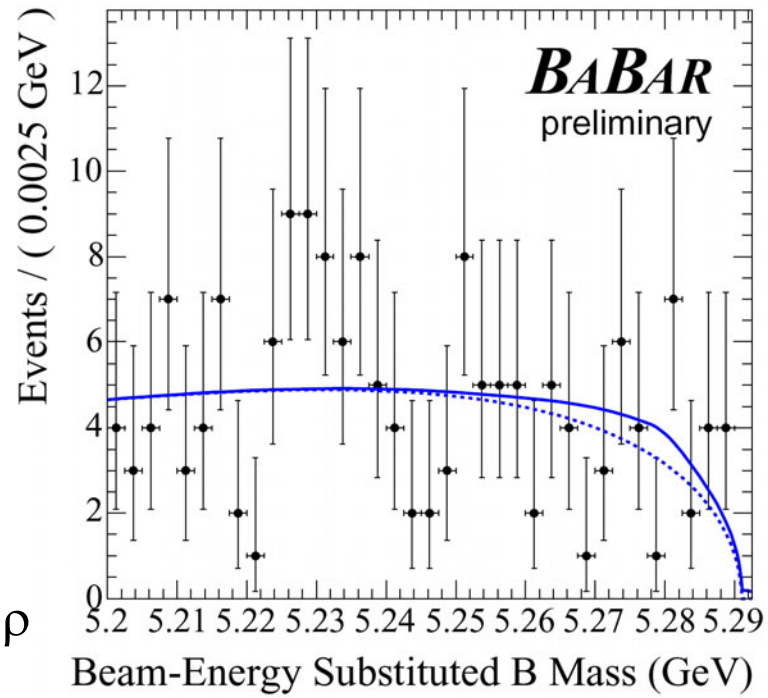
Search for $B^0 \to D_s \rho$

90 million B$\bar{B}$

hep-ex/0408029

$$\mathcal{B}(B^0 \to D_s^+ \rho^-) < 1.9 \times 10^{-5}$$

$$r(D\rho) < 9.5 \times 10^{-3} \text{ (at 90\% C.L.)}$$

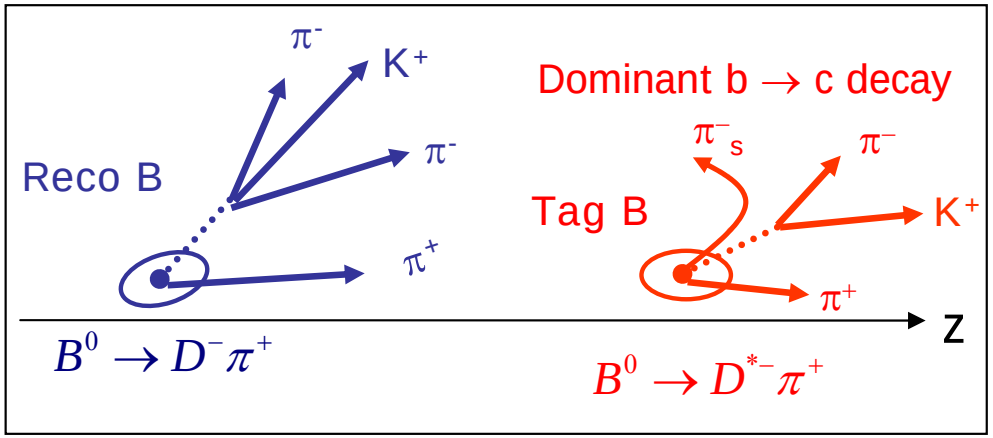


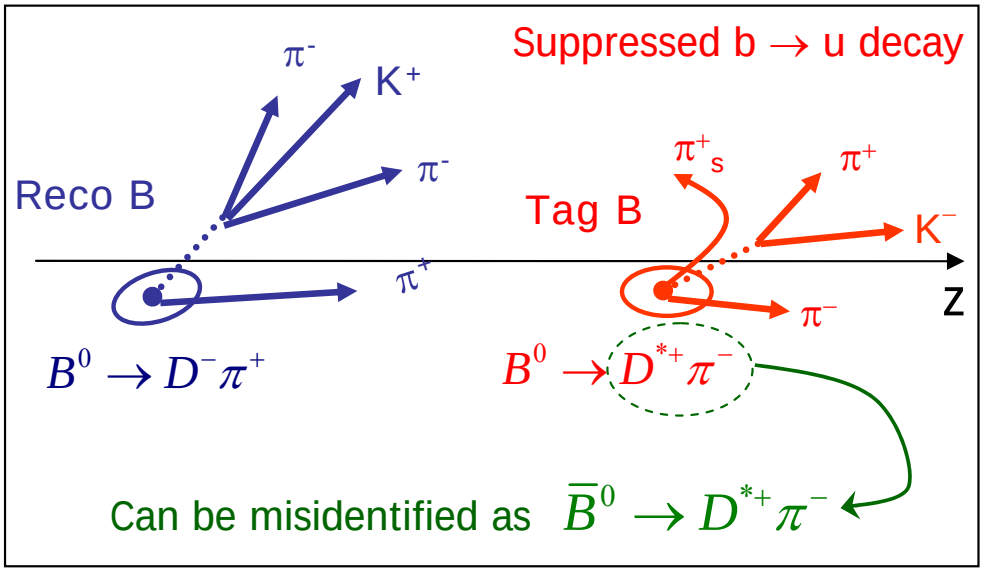
Not great news for CP violation measurement with Dρ

Impact of CP Violation on tag side

Long, Baak, Cahn, Kirkby
PRD68, 034010

- Potential competing CP violating effects in B decays used for flavor tagging





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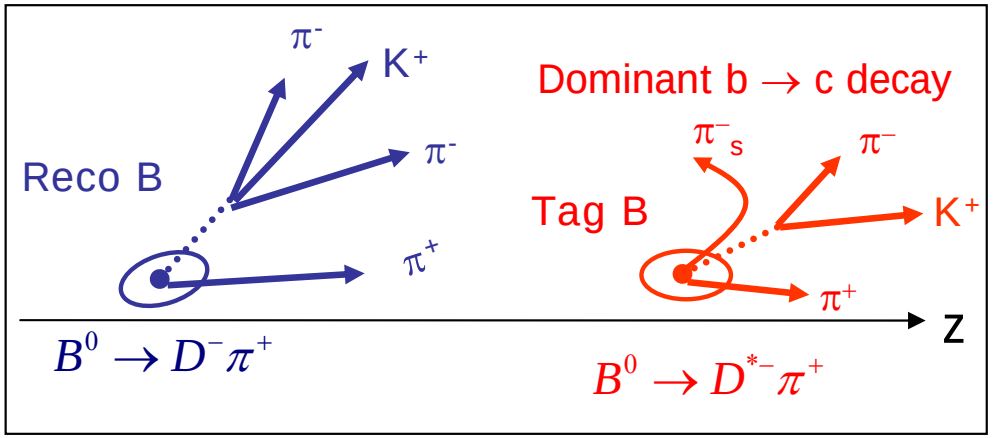

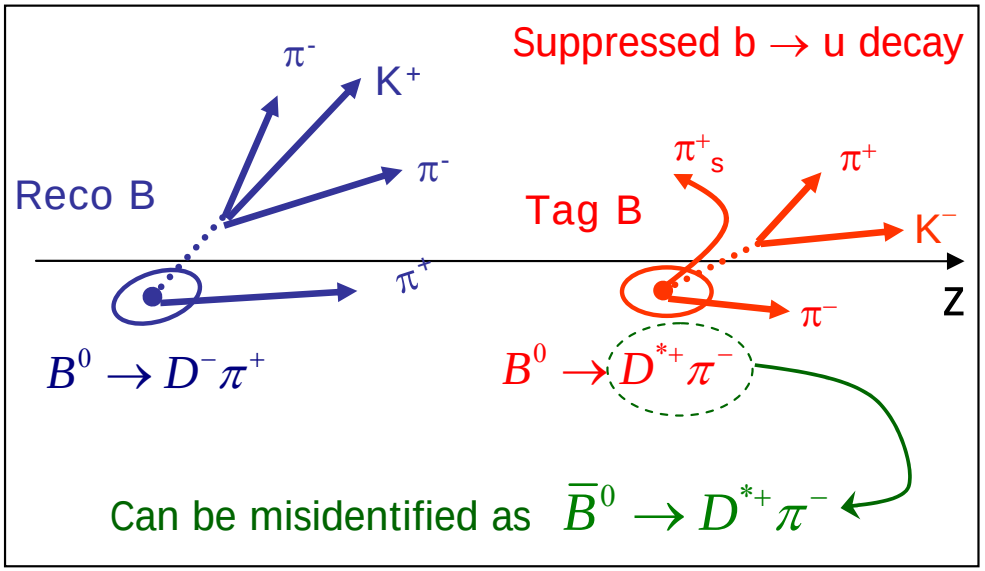

- Modified time distributions :

$$f\left(D^{(*)-}\pi^+, \Delta t\right) \propto 1 + C^{(*)} \cos\left(\Delta m_d \Delta t\right) + \sin\left(\Delta m_d \Delta t\right) \left[\pm 2r \sin(2\beta + \gamma + \delta) + 2r' \sin(2\beta + \gamma \pm \delta')\right]$$

Impact of CP Violation on tag side

Long, Baak, Cahn, Kirkby PRD68, 034010

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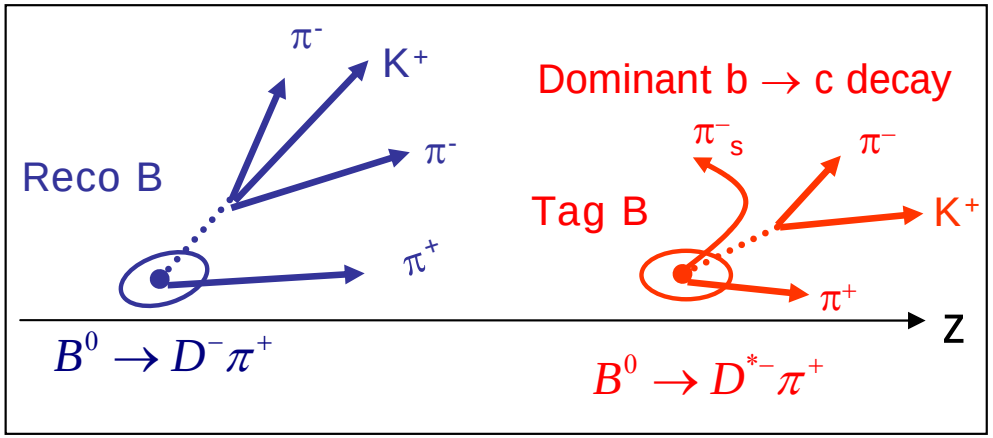

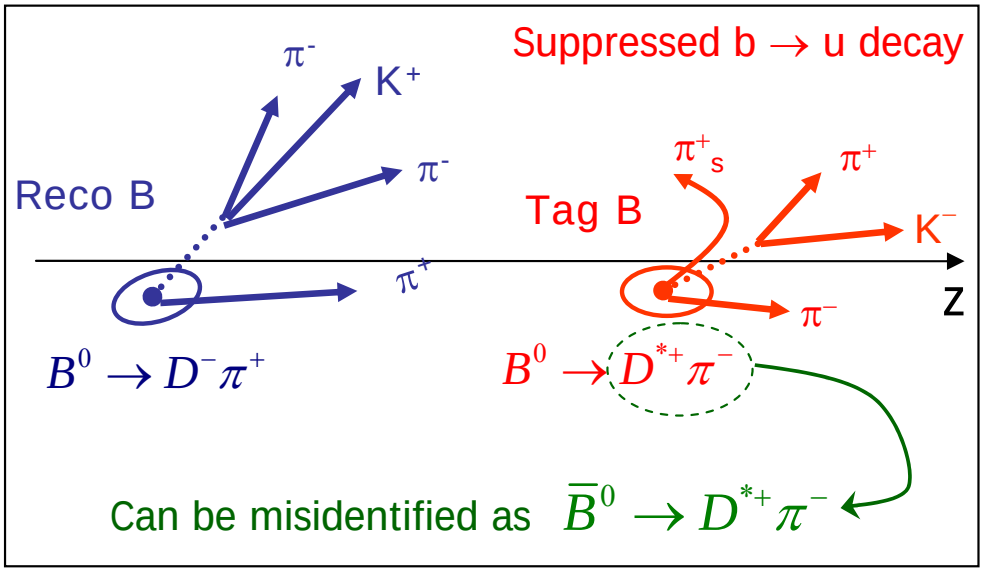

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- Re-parameterize sine coefficients S and $\bar{S}$ as sum of 3 new coefficients
  - 1 term unchanged

2 terms absorb the tag-side effect

Lepton flavor tags

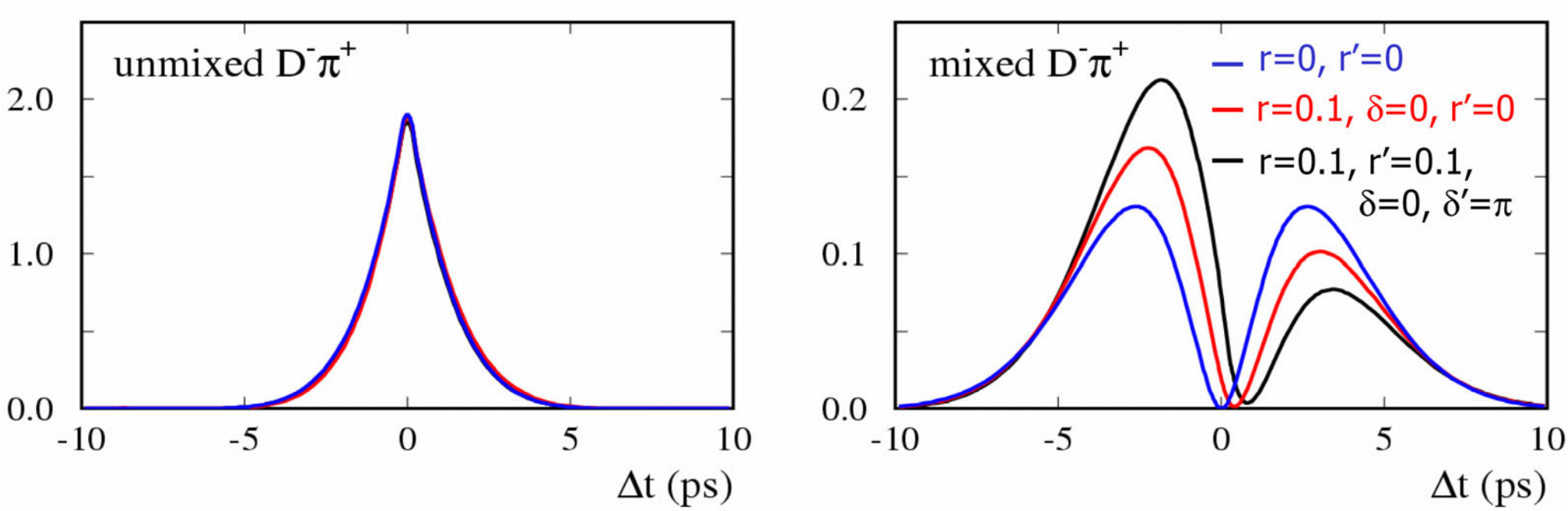
$$\begin{cases} a \equiv 2r \sin(2\beta+\gamma)\cos\delta \\ b \equiv 0 \\ c_{lep} \equiv 2r \cos(2\beta+\gamma)\sin\delta \end{cases}$$

No corresponding V_{ub} amplitude in semileptonic decays

Kaon and other flavor tags

$$\begin{cases} a \equiv 2r \sin(2\beta+\gamma)\cos\delta \\ b \equiv 2r' \sin(2\beta+\gamma)\cos\delta' \\ c \equiv 2\cos(2\beta+\gamma)(r\sin\delta - r'\sin\delta') \end{cases}$$

sin(2β+γ) in Pictures



No Interference → CP Violation

CP Violation only in fully reconstructed B^0: $r \neq 0$

CP Violation in both tag and fully reconstructed B^0s: $r \neq 0$ and $r' \neq 0$

- *r* exaggerated (x5 expectation) to enhance visual effect
  - Small values of *r* significantly reduce sensitivity of the method

CP Asymmetries in $B^0 \to D^{(*)}\pi/\rho$

$$a = 2r\sin(2\beta+\gamma)\cos\delta \qquad c_{lep} = 2r\cos(2\beta+\gamma)\sin\delta$$

110 million $B\bar{B}$
Exclusive Reconstruction

$$a^{D\pi} = -0.032 \pm 0.031\ (\text{stat.}) \pm 0.020\ (\text{syst.})$$
$$a^{D^*\pi} = -0.049 \pm 0.031\ (\text{stat.}) \pm 0.020\ (\text{syst.})$$
$$a^{D\rho} = -0.005 \pm 0.044\ (\text{stat.}) \pm 0.021\ (\text{syst.})$$

$$c_{lep}^{D\pi} = -0.059 \pm 0.055\ (\text{stat.}) \pm 0.033\ (\text{syst.})$$
$$c_{lep}^{D^*\pi} = +0.049 \pm 0.054\ (\text{stat.}) \pm 0.033\ (\text{syst.})$$
$$c_{lep}^{D\rho} = -0.147 \pm 0.074\ (\text{stat.}) \pm 0.035\ (\text{syst.})$$

Preliminary

hep-ex/0408059

178 million $B\bar{B}$
Partial Reconstruction

$$a_{lep}^{D^*\pi} = -0.048 \pm 0.022\ (\text{stat.}) \pm 0.010\ (\text{syst.})$$
$$a_{K}^{D^*\pi} = -0.033 \pm 0.023\ (\text{stat.}) \pm 0.015\ (\text{syst.})$$

$$c_{lep}^{D^*\pi} = -0.015 \pm 0.036\ (\text{stat.}) \pm 0.019\ (\text{syst.})$$
$$c_{K}^{D^*\pi} = +0.019 \pm 0.023\ (\text{stat.}) \pm 0.016\ (\text{syst.})$$

Preliminary

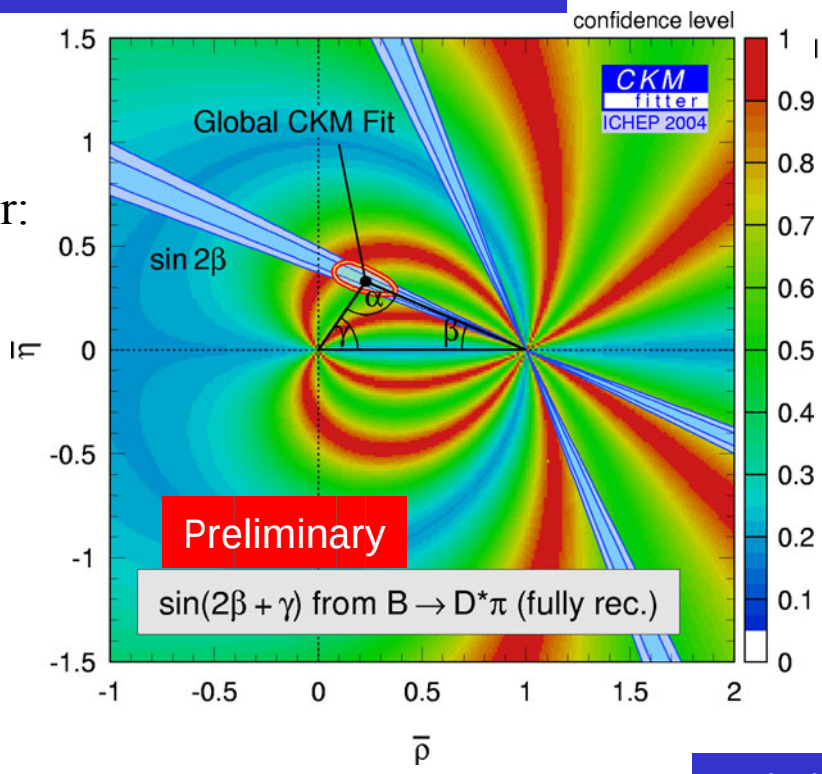
hep-ex/0408038

- No significant deviation from zero in measured asymmetries

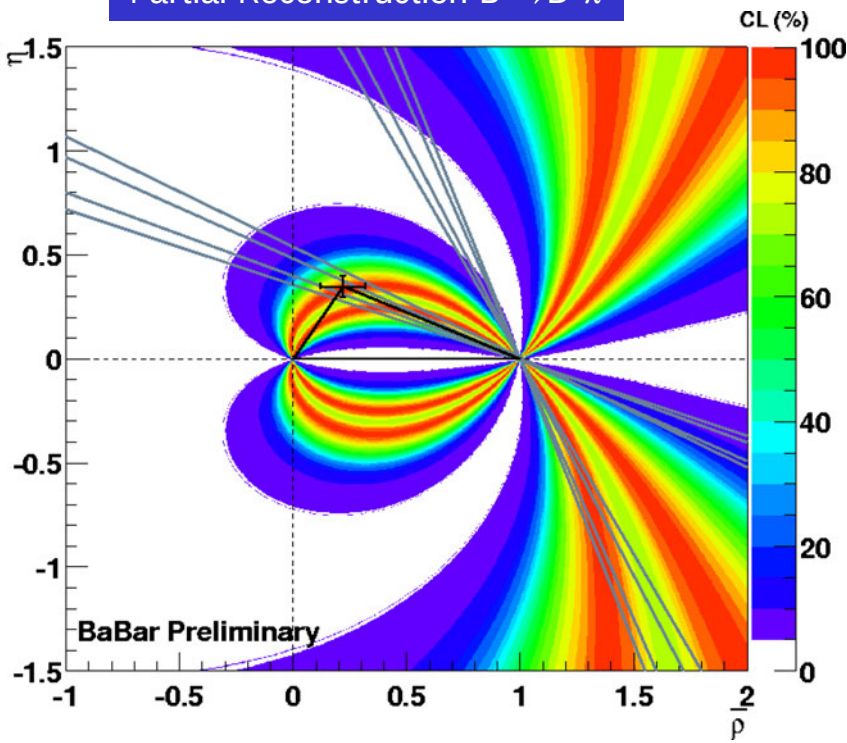
Constraints on Unitarity Triangle from BaBar Results

CKM Fitter: ckmfitter.in2p3.fr
A. Hoecker et al.,
Eur. Phys. Jour.
C21(2001) 225

Exclusive Reconstruction $B^0 \to D^{(*)}\pi$



Partial Reconstruction $B^0 \to D^*\pi$



Updated estimate of r:

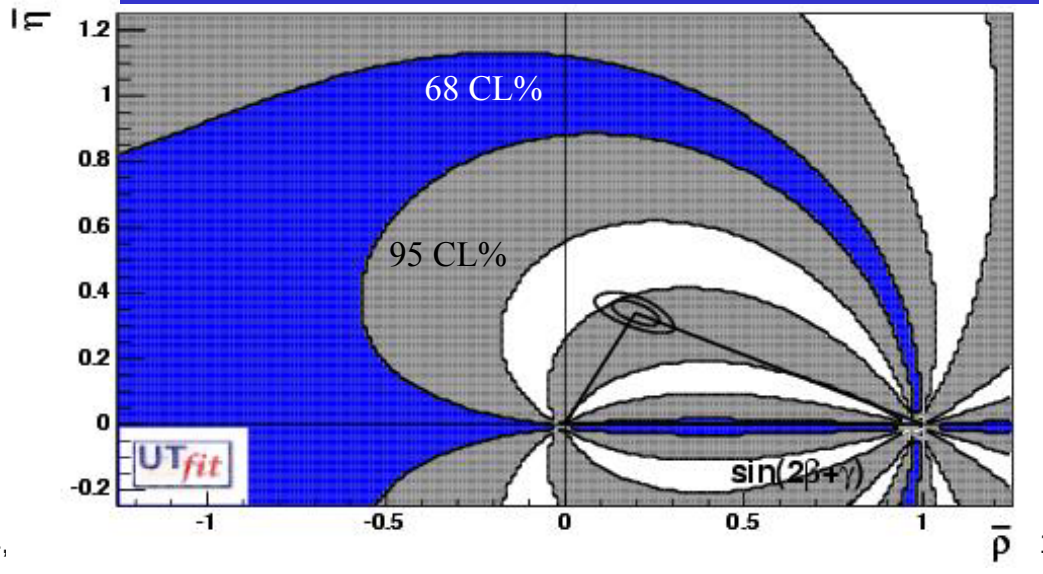
$$r\left(D^*\pi\right) = 0.015^{+0.004}_{-0.006}$$

from improved

$$BF(D_S^+ \to \phi\pi^+)$$

Exclusive Reco. $B^0 \to D^{(*)}\pi$, $D\rho$ and Partial Reco. $B^0 \to D^{(*)}\pi$

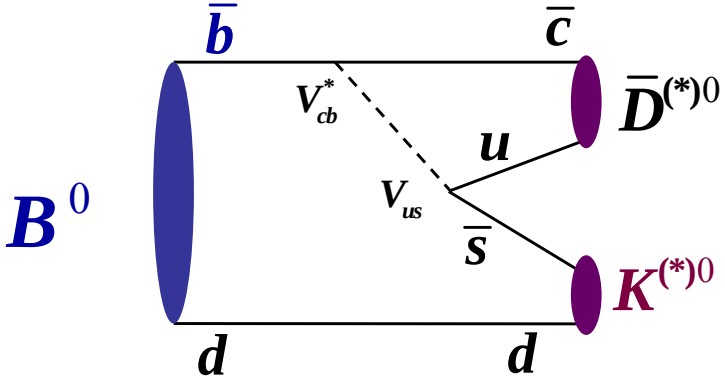
UTfit: www.utfit.org
M. Bona et al.,
hep-ph/0408079

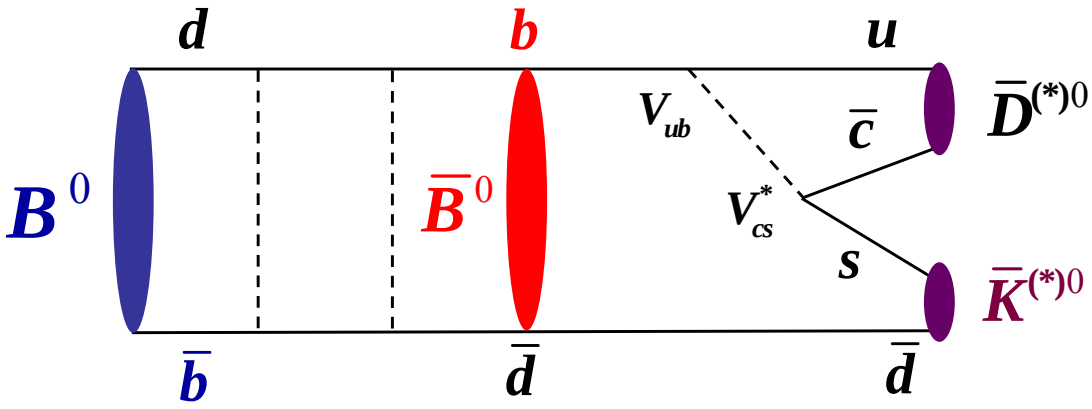


Does not use SU(3) symmetry to estimate *r*

Use flat a-priori in range [0.0--0.1]

Measurement of $\sin(2\beta+\gamma)$ with $B^0/\bar{B}^0 \to D^{(*)0}K^{(*)0}$





$$V_{cb}V_{us}^{*} = A$$

$$V_{ub}V_{cs}^{*}\, e^{i\delta} = r_B \; A\, e^{-i\gamma}\, e^{i\delta}$$

Strong phase difference

- Interference between decay and mixing as in $D^{(*)}\pi$
  - Advantages:
    - Expected large asymmetries

$$r_B = \left|\frac{A\left(B^0 \to D^0 K^{(*)0}\right)}{A\left(B^0 \to \bar{D}^0 K^{(*)0}\right)}\right| = \left|\frac{V_{ub}V_{cs}^{*}}{V_{cb}V_{us}^{*}}\right| \sim 0.4$$

    - Time-dependent measurement with $K^0 \to K_S$
    - Probe r_B in self-tagging final state $K^{*0} \to K^{-}\pi^{+}$
  - Disadvantages:
    - Color suppressed decays: Smaller branching fractions than $D^{(*)}\pi$
    - Possible competing effects from Doubly-Cabibbo-suppressed D^0 decays

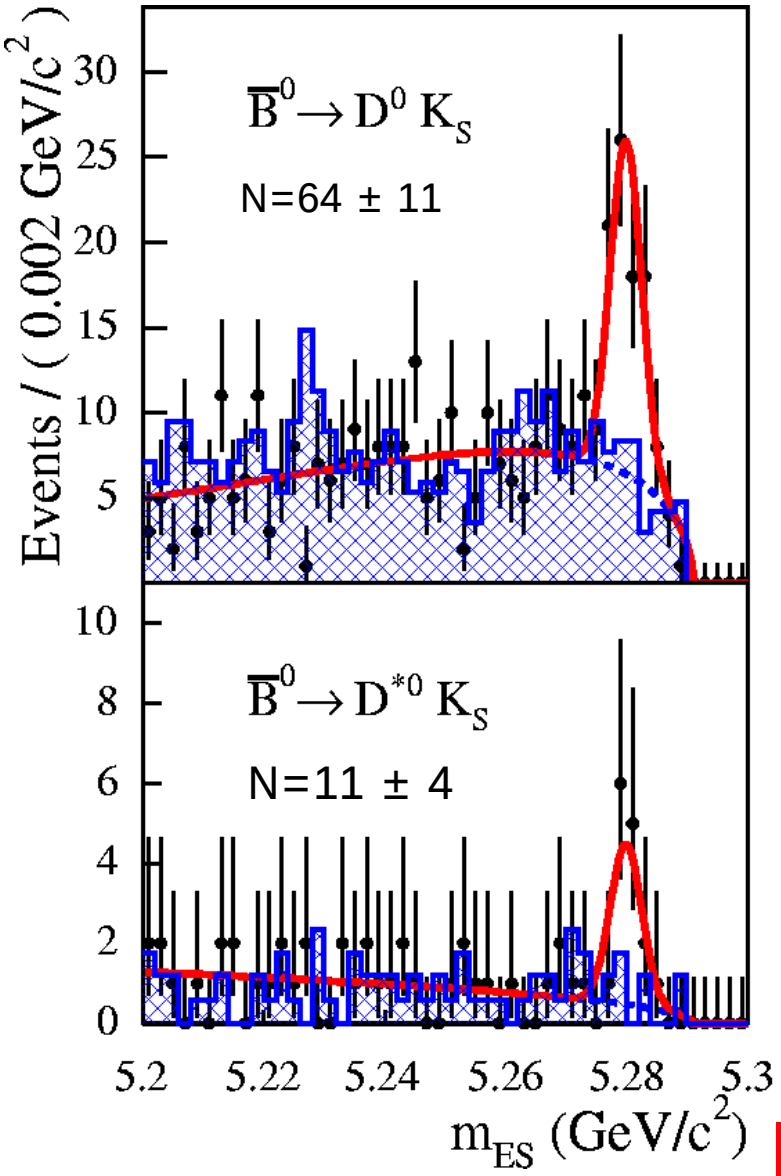
Study of $B^0/\bar{B}^0 \to D^{(*)0}K_S$ Decays

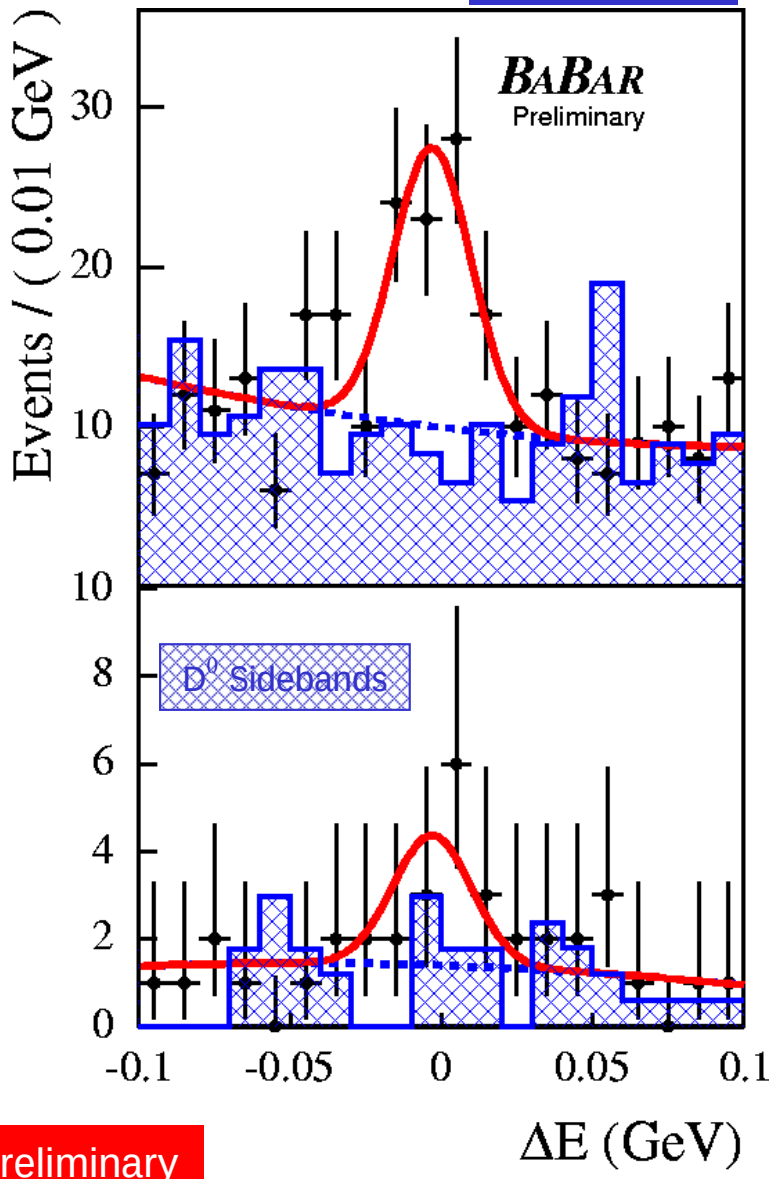
124 million $B\bar{B}$

hep-ex/0408052

Cannot distinguish B^0 from $\bar{B}^0$

Hidden strangeness with K_S in final state





First Evidence

Preliminary

Mode	BF (10^{-5})
$\bar{B}^0 \to D^0\bar{K}^0$	6.2 ±1.2 ±0.4
$\bar{B}^0 \to D^{*0}\bar{K}^0$	4.5 ±1.9 ±0.5

Uncertainty on $\sin(2\beta+\gamma)$ ~ 0.6 with D^0K_s in 500 fb^{-1}

Caveat: assuming r ~ 0.4

Self-Tagging $\bar{B}^0 \to D^0 \bar{K}^{*0}$ and limit on r_B

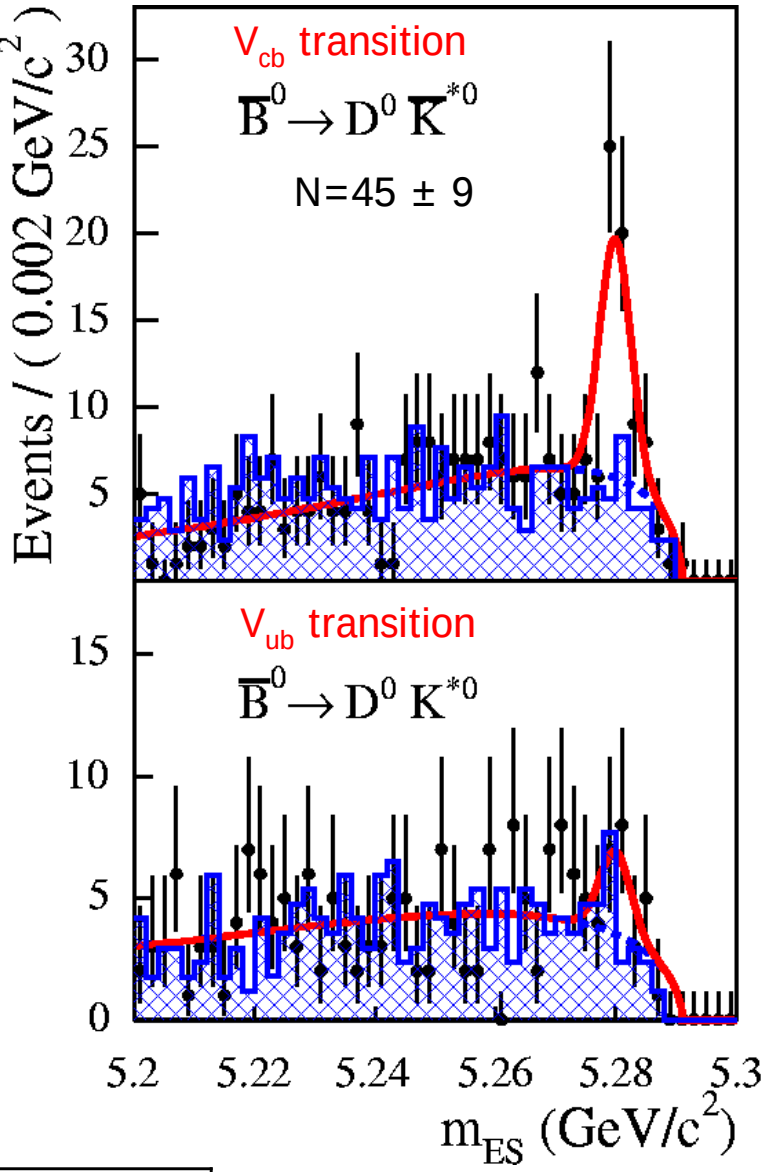
124 million $B\bar{B}$

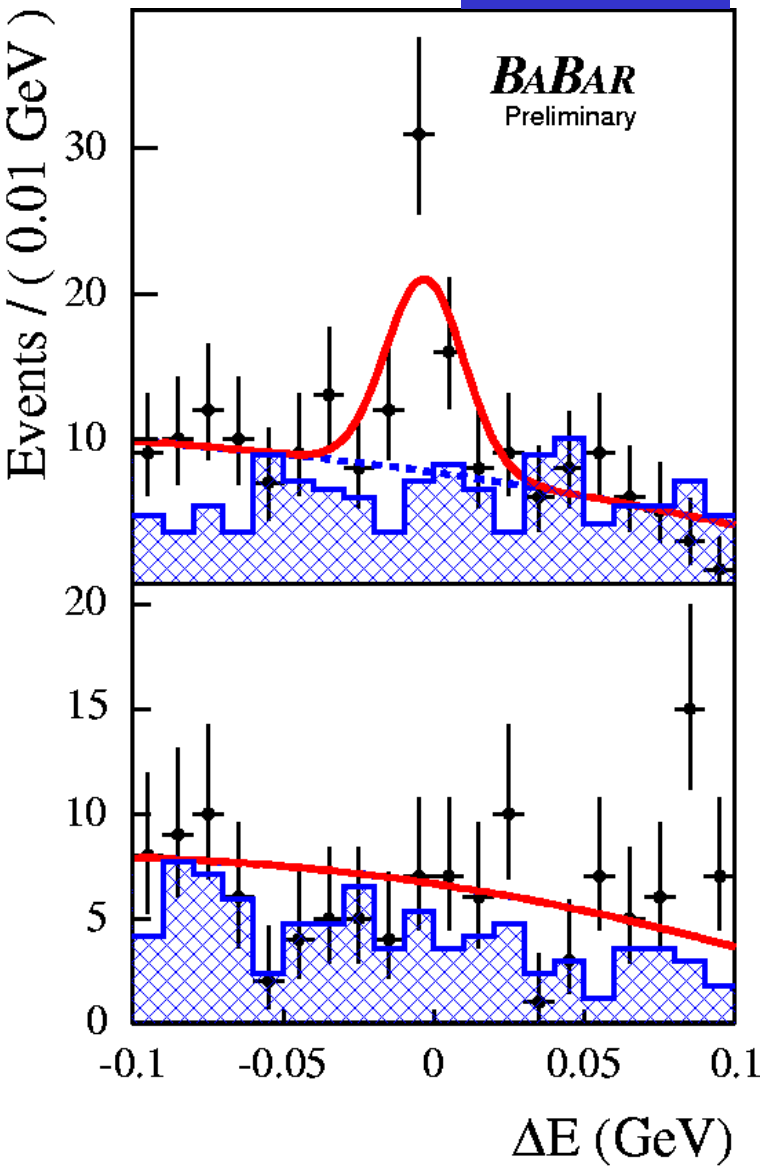
Charge correlation to separate B^0 from $\bar{B}^0$

$$\bar{B}^0 \to D^0 \bar{K}^{*0}$$
$$D^0 \to K^- X^+$$
$$\bar{K}^{*0} \to K^- \pi^+$$

$$\bar{B}^0 \to \bar{D}^0 \bar{K}^{*0}$$
$$\bar{D}^0 \to K^+ X^+$$
$$\bar{K}^{*0} \to K^- \pi^+$$

No Signal in V_{ub} mediated Decay





Preliminary

Mode	BF (10^{-5})
$\bar{B}^0 \to D^0 \bar{K}^{*0}$	6.2 ±1.4 ±0.6
$\bar{B}^0 \to D^0 K^{*0}$	< 4.1 @ 90% CL

V_{ub} contribution necessary for measurement of γ!

$$r_B < 0.8 \ @ \ 90\% \text{ C.L.}$$

Summary and Outlook

- Limits on $|\sin(2\beta+\gamma)|$ with time-dependent analysis of $B^0 \to D^{(*)}\pi$
  - Good agreement with constraints derived from other observables
  - Similar measurement with $B^0 \to D\rho$ complicated by current limit on r_B

Preliminary

$$r_B = \frac{\left|A\left(\bar{B}^0 \to D^- \rho^+\right)\right|}{\left|A\left(B^0 \to D^- \rho^+\right)\right|} < 0.0095 \ @ \ 90\% \text{ C.L.}$$

90 million $B\bar{B}$

- $B \to D^{(*)0}K^{(*)0}$ can also provide constraints via time-dependent analysis
  - No signal yet for V_{ub} transition

Preliminary

$$BF\left(\bar{B}^0 \to D^0 K^{*0}\right) < 4.1\times10^{-5} \ @ \ 90\% \text{ C.L.}$$

124 million $B\bar{B}$

  - Feasibility of this method strongly depends on the values of r

$$r_B = \frac{\left|A\left(\bar{B}^0 \to \bar{D}^0 \bar{K}^{*0}\right)\right|}{\left|A\left(\bar{B}^0 \to D^0 \bar{K}^{*0}\right)\right|} < 0.8 \ @ \ 90\% \text{ C.L.}$$