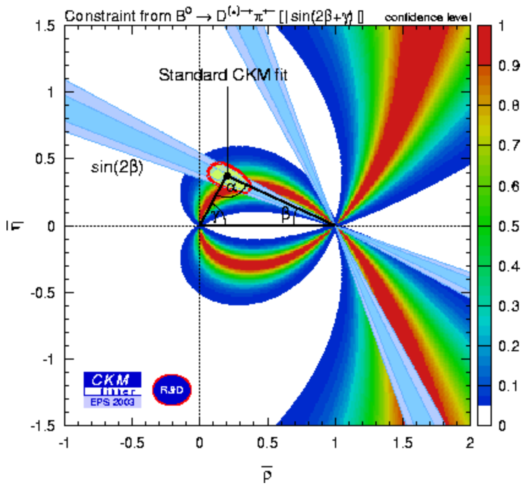
La misura di γ : status e prospettive
per le B factories



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Outline

- Introduction
- $\sin(2\beta+\gamma)$ with $B \to D^{(*)}\pi$
- B->DK
- Conclusions

IFAE 04, 14-16 Aprile 2004, Torino

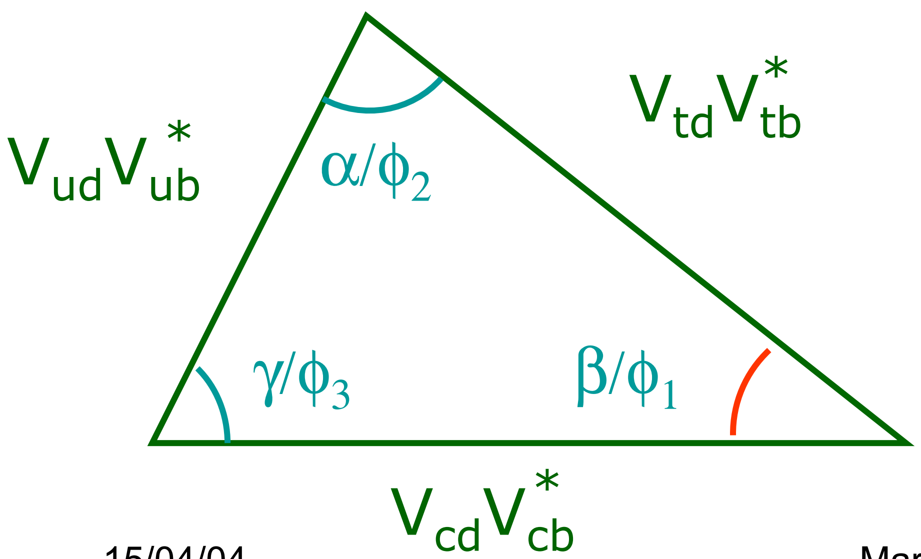
CP Violation in Standard Model

Standard Model with 3 generations accommodates CP violation through a phase in CKM matrix

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Unitarity of the CKM Matrix

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



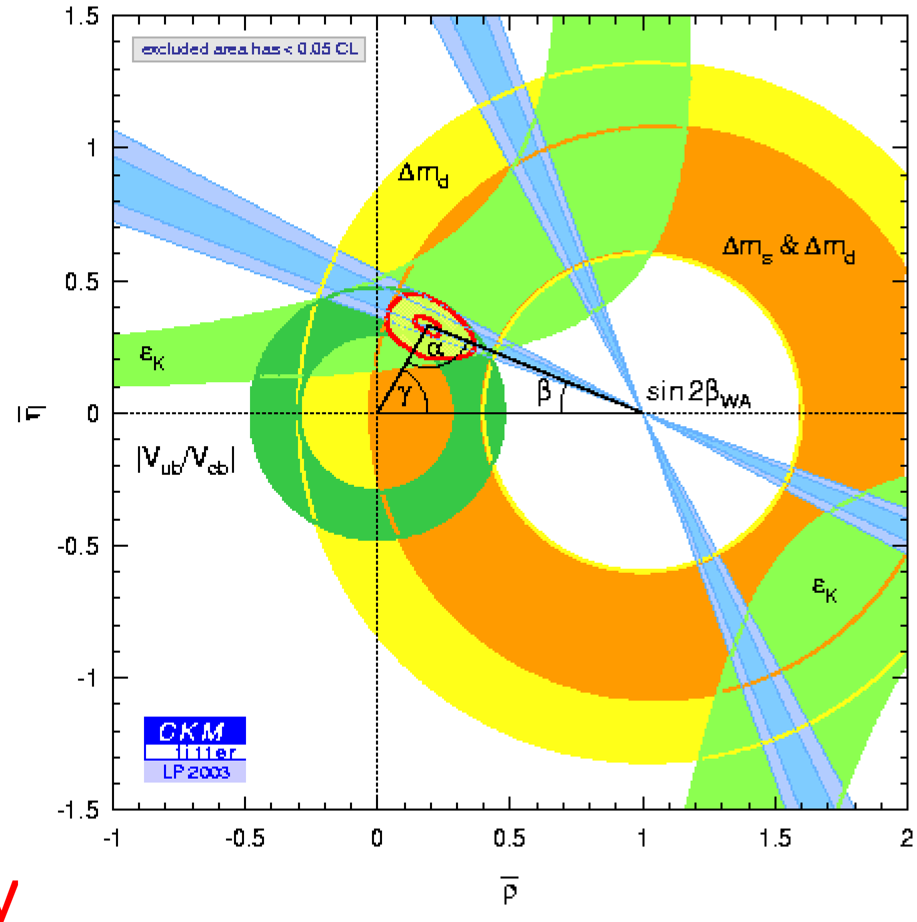
Aim of B factories :
Measure precisely the angles and the sides to overconstrain the unitarity triangle. Test of the SM in the CP violating sector

Current Constraints on the CKM Angles

World Average
sin2β = 0.736 ± 0.049

95% CL intervals with CKM Fitter:

$$19.4^\circ < \beta < 26.5^\circ$$
$$77^\circ < \alpha < 122^\circ$$
$$37^\circ < \gamma < 80^\circ$$

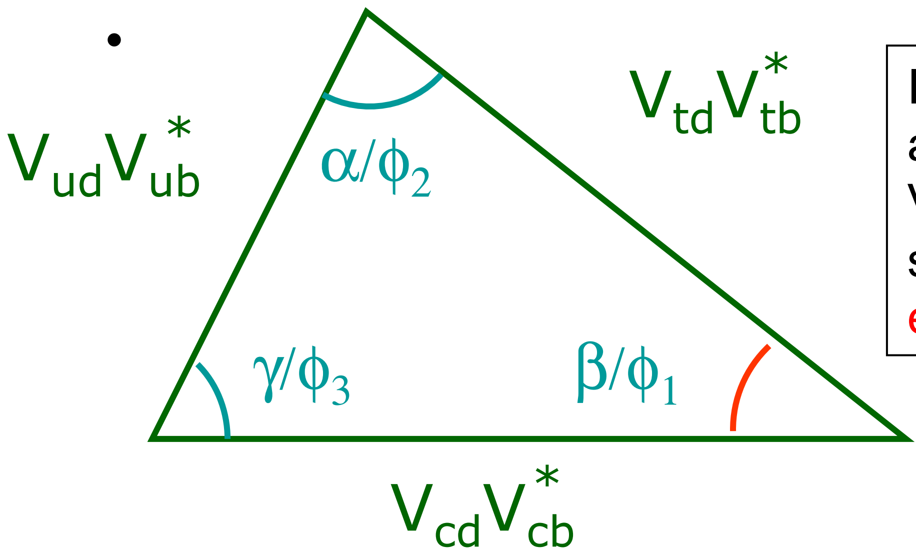


Direct measurement of γ is crucial step in the B factory program!

Method in A. Hoecker et al, Eur. Phys. Jour. C21 (2001) 225, [hep-ph/0104062]

Why measuring γ is difficult ?

•



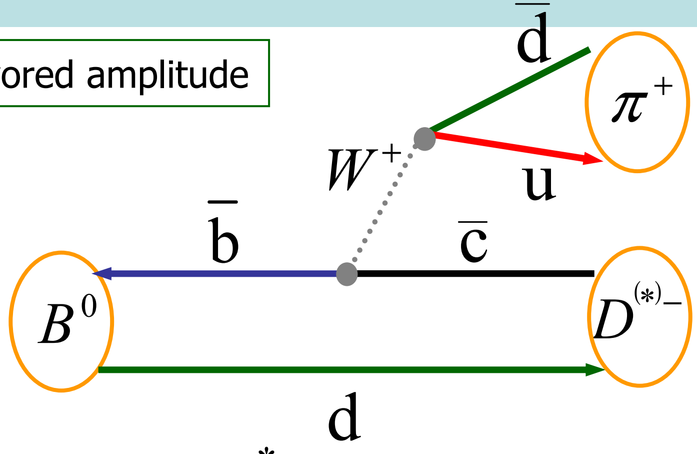
In the Wolfenstein phase convention, γ is the angle between V_{ub} and V_{cb}. The ratio V_{ub}/V_{cb} enters all interference terms sensitive to γ : small asymmetry or few events !

Strategies :

1. $B \to D(^*)\pi$ Small asymmetry : partial + full reconstruction
2. B->DK : (GLW) Small asymmetry : many modes
3. B->DK (ADS) Large asymmetry : few events
4. B->DK Dalitz plot analysis
5. B->πK difficult theory uncertainties ! (not covered in this talk)

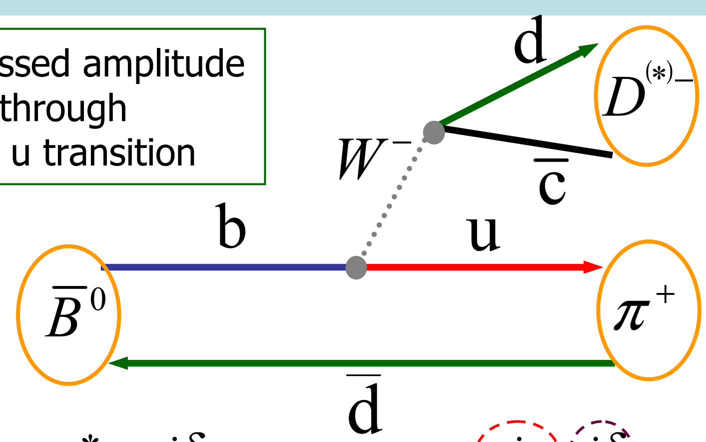
Measurement of sin(2β+γ) in $B^0 \to D^{(*)}\pi$

Favored amplitude



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

Suppressed amplitude through b → u transition



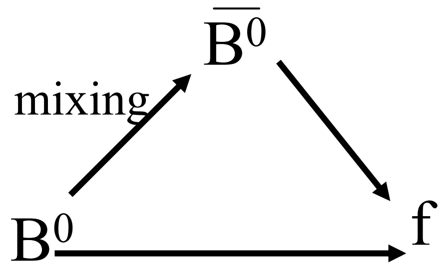
$$V_{ub}V_{cd}^* e^{i\delta} = r_{(*)} \; A \, e^{-i\gamma} e^{i\delta}$$

CKM angle

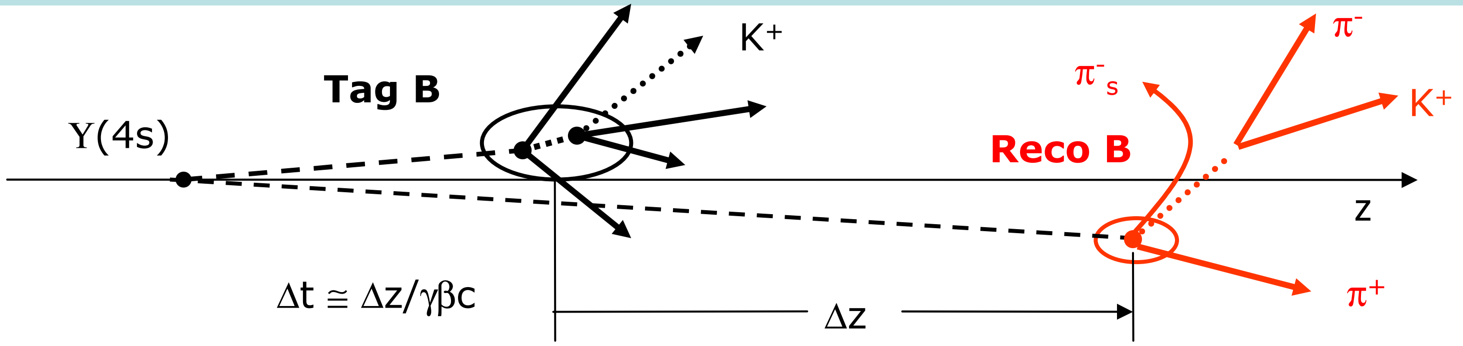
Strong phase difference

- CP violation from interference of mixing (weak phase= 2β) and decay (weak phase γ) ⇒ interference terms measures sin(2β+γ)
- Theoretically clean : no penguin contribution, strong phase measurable
- Small time dependent asymmetry (o(4%))
- r is an external input

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



$B^0 \to D^{(*)}\pi$ Time-dependent decay rate distributions



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

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

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

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

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

- Measurement of S and $\overline{\mathrm{S}}$ determine $2\beta+\gamma$ and δ
- Using $D\pi$ and $D^*\pi$ removes some ambiguities

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

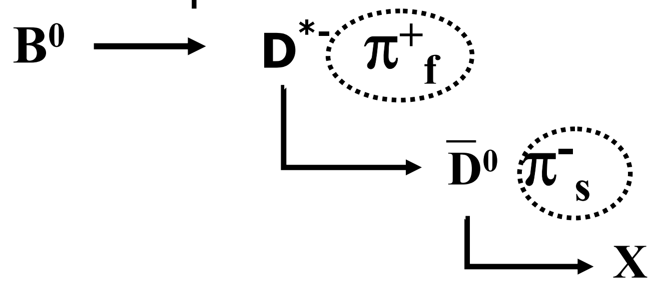
$$\overline{S}^{(*)} = \frac{2r_{(*)}}{1 + r_{(*)}^2}\sin(2\beta + \gamma + \delta^{(*)})$$

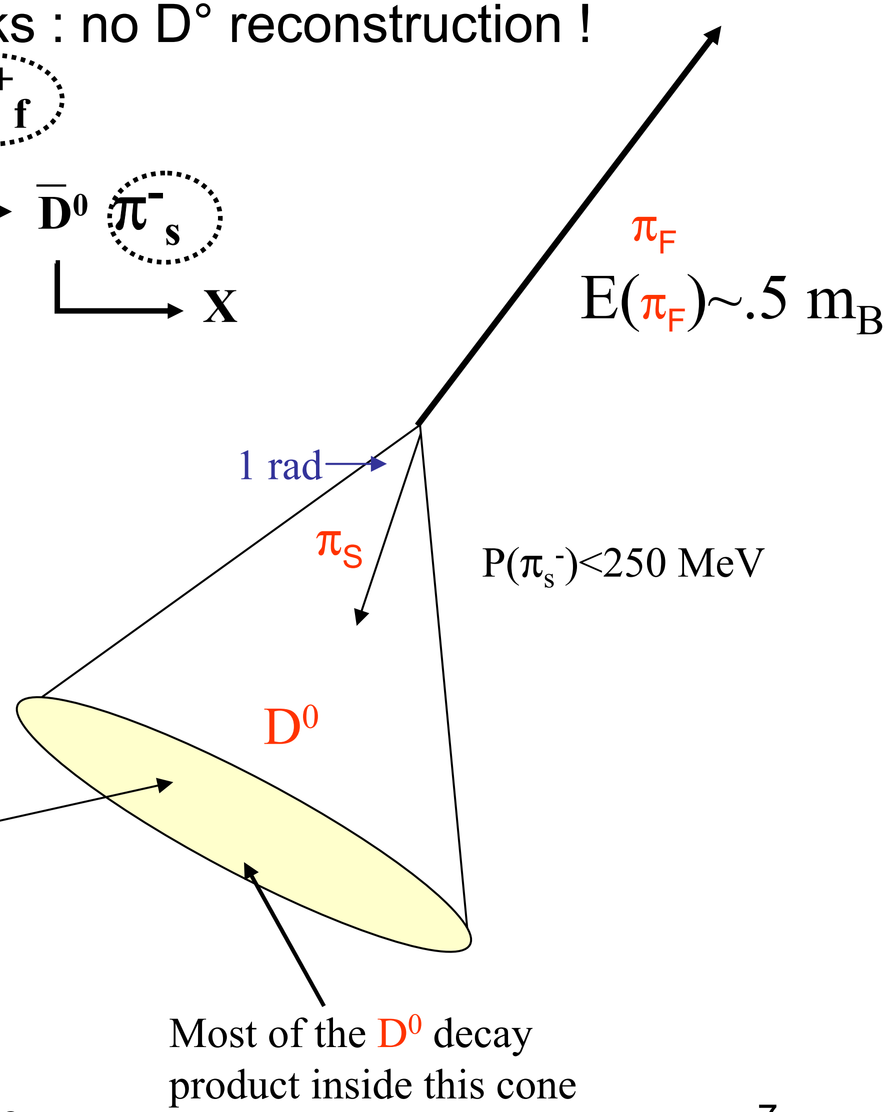
$\approx [-0.04 : 0.04]$

4 ambiguities on $2\beta+\gamma$

$B^0 \rightarrow D^{(*)}\pi$:partial reconstruction (BaBar)

- Use only the fast and soft pion tracks : no D° reconstruction !





- Combine the fast pion (2.1<p<2.4 GeV/c) with a slow pion (p<250 MeV).
- Compute the mass Mmiss of the recoiling object (r.m.s. 3 MeV)

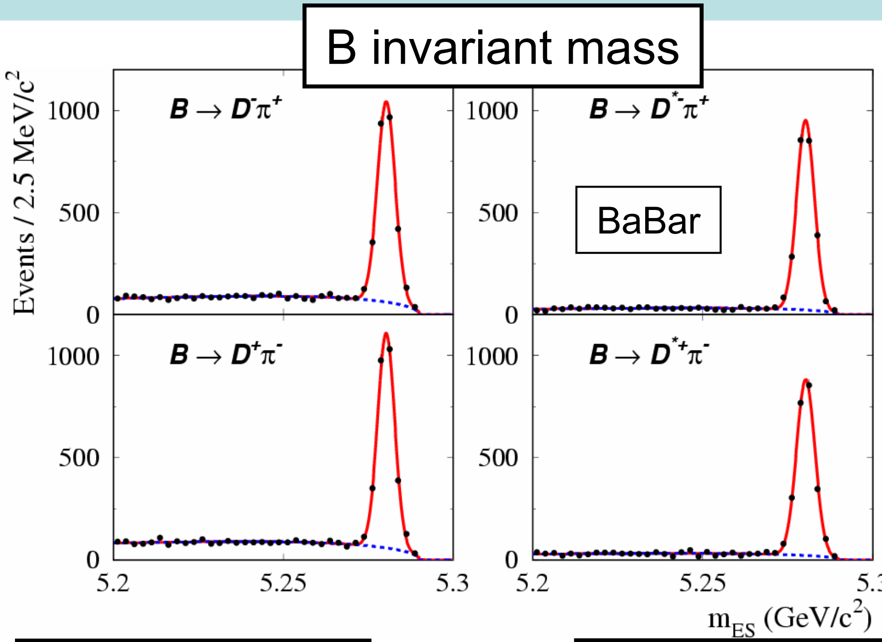
The unreconstructed D^0 complicates vertexing and tagging

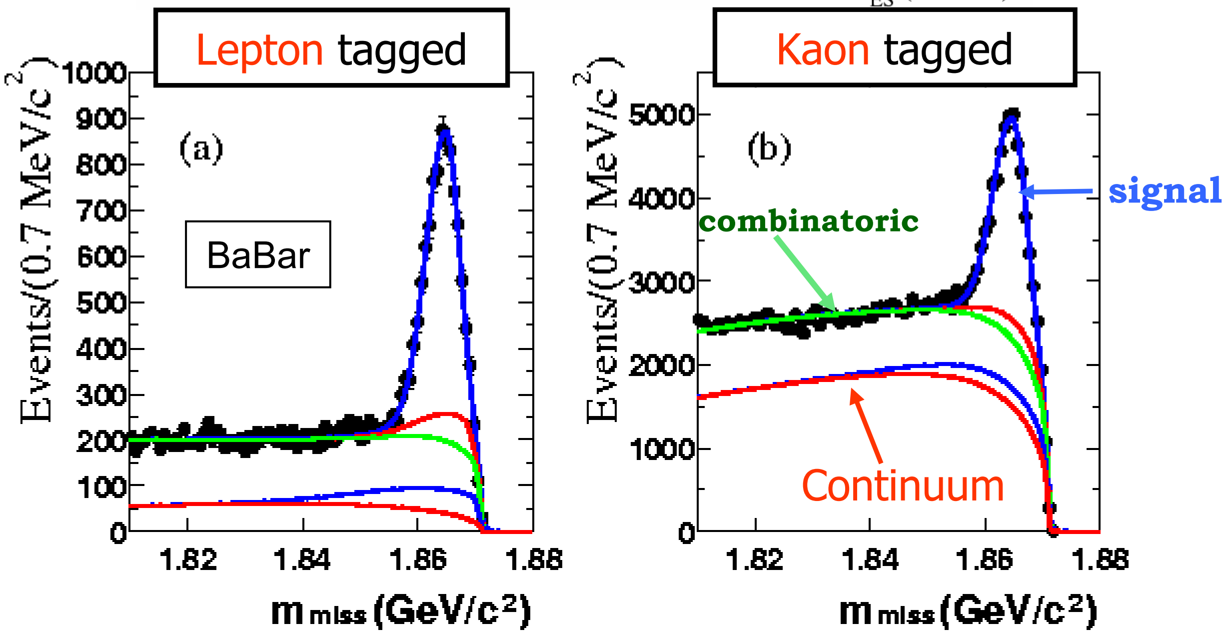
$B^0 \to D^{(*)}\pi$:the BaBar event sample

Exclusive reconstruction(ER) :
N($D\pi$)=5200 N($D^*\pi$)=4700

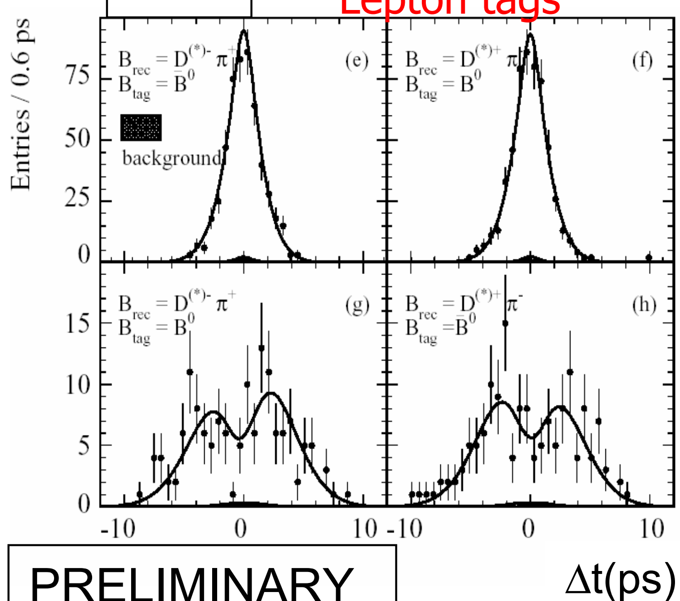
Based on a 81 fb^{-1} sample

Partial reconstruction(PR) :
N($D^*\pi$)=6400 (lepton tag)
N($D^*\pi$)=25100 (kaon tag)



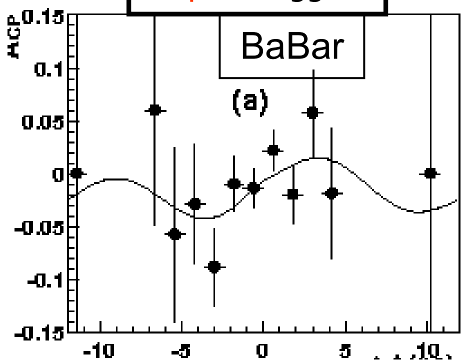


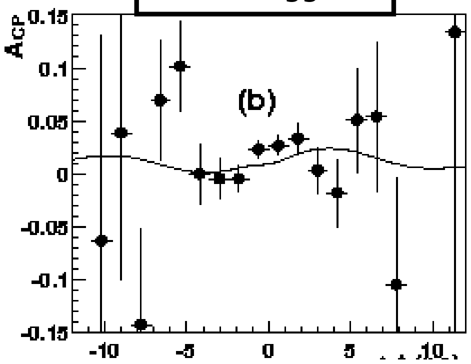
$B^0 \to D^{(*)}\pi$:BaBar results



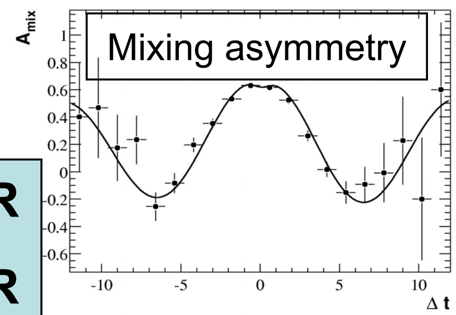
PRELIMINARY
hep-ex/0309017
hep-ex/0310037

CP asymmetry $A_{CP} = \frac{\left(N_{B^0_{tag}} - N_{\bar{B}^0_{tag}}\right)}{\left(N_{B^0_{tag}} + N_{\bar{B}^0_{tag}}\right)}$ $\propto$ **2 r* sin(2β+γ) cos(δ*)** sin(Δm Δt)





2.3 σ significance !



Used as a cross-check

2 r* sin(2β+γ) cos(δ*) = -0.063 ± 0.024 (stat.) ± 0.014 (syst.) PR

2 r* sin(2β+γ) cos(δ*) = -0.068 ± 0.038 (stat.) ± 0.020 (syst.) ER

2 r sin(2β+γ) cos(δ) = -0.022 ± 0.038 (stat.) ± 0.020 (syst.) ER

There is also a Belle result with excl. Reco. hep-ex/0308048

$B^0 \to D^{(*)}\pi$:Interpretation

• Need the value of r(*) to interpret the results in terms of sin(2β+γ)

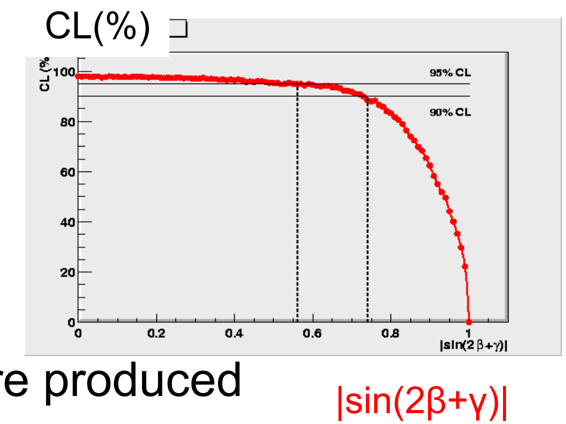
• Use (I. Dunietz, PLB 427,179 (1988)) the measured (BaBar+Belle) $Br(B \to D^{(*)}_s \pi)$ + SU(3) + decays constants to get

• $r = 0.019 \pm 0.004$ and $r^* = 0.017^{+0.005}_{-0.007}$

• Derive the combined confidence level as a function of sin(2β+γ) using the Feldman-Cousins method with toy MC

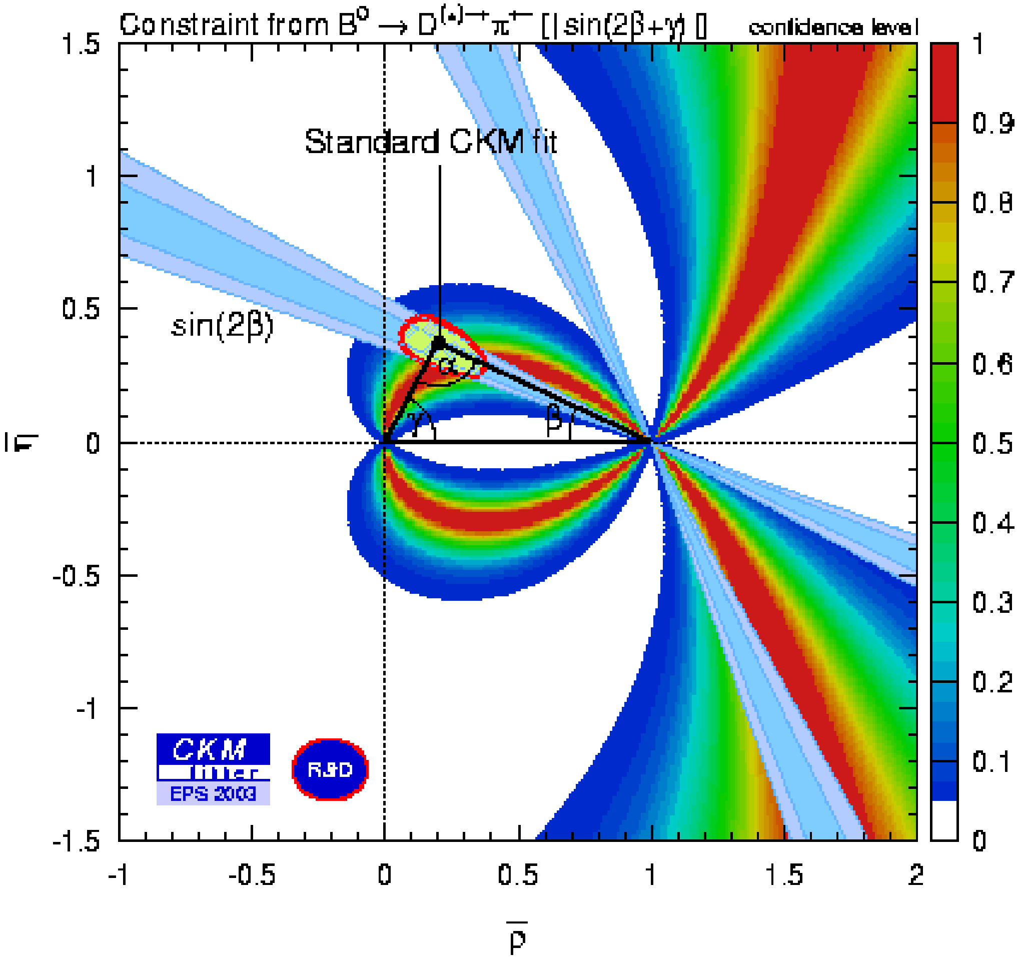
|sin(2β+γ)|>0.87 (68% CL)

|sin(2β+γ)|>0.58 (95% CL)

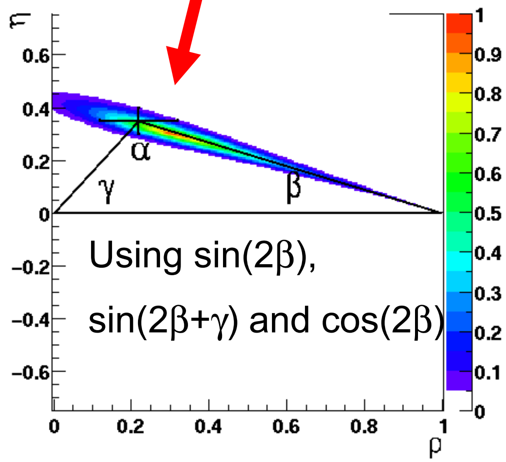


• With a similar method limits on |sin(2β+γ)| versus r* are produced

Constraints on the Unitarity Triangle from BaBar



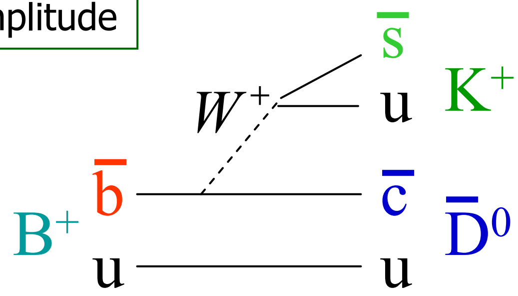
- •Despite limited statistics already interesting constraint !
- •Complementary to β
- •Excludes two sin(2β) branches
- • Start constraining the triangle only with CP violation in the B sector !



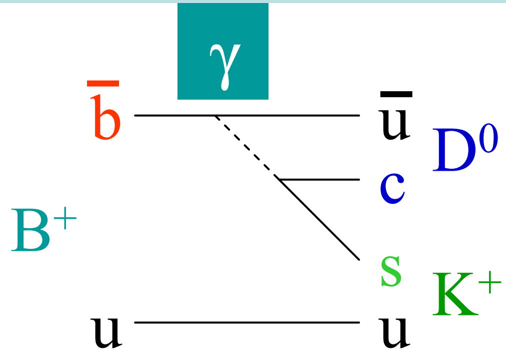
Thanks to Ch. Yeche

γ with $B^- \to D^0 K^-$ decays

Favored amplitude



Suppressed amplitude:
b → u transition
Color suppression



$$r \equiv \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \bar{D}^0 K^+)|} \sim 0.2$$

- Interference (and direct CP violation) may occur if D° and $\bar{D}$° decay in the same final state f :
  - f can be CP eigenstate ($\pi^+\pi^-$, K^+K^-, $K_S\pi^\circ$ …) Gronau, London, Wyler (GWL) method
  - f =DCSD for D° ($K^+\pi^-$) and CFD for $\bar{D}$° ($K^+\pi^-$) Atwood, Dunietz, Soni (ADS)
  - or f=3 body final state : Dalitz plot analysis (Giri, Grossman, Soffer, Zupan)

DCSD : Doubly Cabibbo Suppressed Decay
CFD : Cabibbo Favoured Decay

GLW method

$$R_{\pm} \equiv 2\frac{\Gamma(B^- \to D_{\pm}K^-)+\Gamma(B^+ \to D_{\pm}K^+)}{\Gamma(B^- \to D^0K^-)+\Gamma(B^+ \to D^0K^+)} = 1 + r^2 \pm 2r\cos\delta\cos\gamma$$

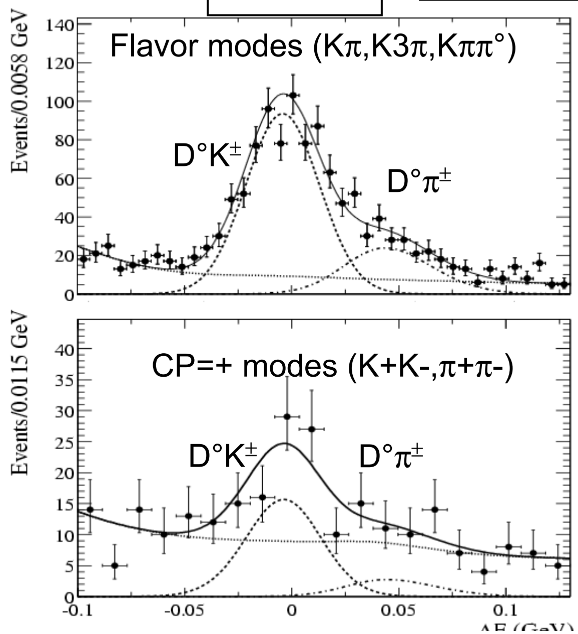
$$A_{\pm} \equiv \frac{\Gamma(B^- \to D_{\pm}K^-)-\Gamma(B^+ \to D_{\pm}K^+)}{\Gamma(B^- \to D_{\pm}K^-)+\Gamma(B^+ \to D_{\pm}K^+)} = \frac{\pm 2r\cos\delta\cos\gamma}{R_{\pm}}$$

$$r \equiv \frac{|A(B^+ \to D^0K^+)|}{|A(B^+ \to \bar{D}^0K^+)|} \sim 0.2$$

- Measure $A_{\pm}$ and $R_{\pm}$ and solve for r,δ,γ
- Four observables and three unknowns
- Based on o(20) ev. for the CP eigenstate modes
- Analysis of CP=- modes by BaBar in progress
- No constraint on γ yet

Hep-ex/0311032

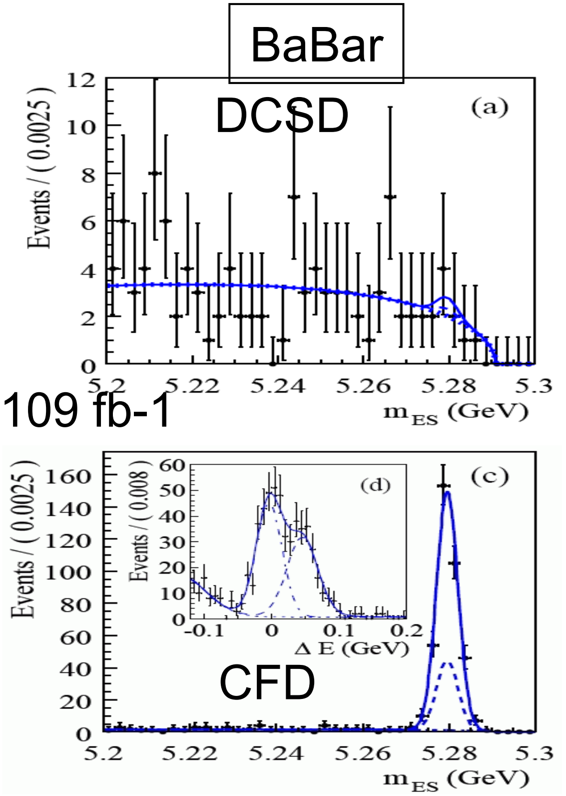
BaBar 82 fb-1



ΔE(GeV)

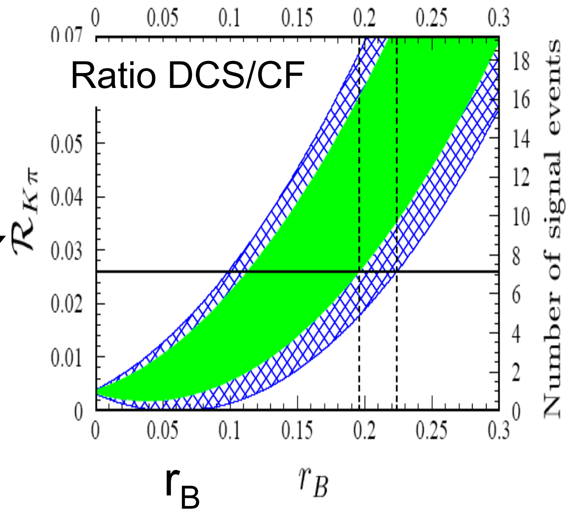
	R+	A+	R-	A-
Belle	1.21±0.25 ±0.14	0.06±0.19 ±0.04	1.41±0.27 ±0.15	-0.19±0.17 ±0.05
BaBar	1.06±0.19 ±0.06	0.07±0.17 ±0.06		

ADS method



- ADS method : Measure $B^+ \rightarrow [K^- \pi^+]_D K^+$
- Only O(5-20) DCSD events expected
- Requires powerful background rejection
- Use favored modes as control sample
- N $(B^+ \rightarrow [K^- \pi^+]_D K^+) = 1.1 \pm 3.0$ (DCSD) vs 261 ± 22 (CFD)
- $r_B < 0.22$ (90% CL)
- Excludes most favorable scenario for the sensitivity of this method

$$R_{K\pi} \equiv \frac{\Gamma(B^{\pm} \rightarrow [K^{\mp}\pi^{\pm}]_D K^{\pm})}{\Gamma(B^{\pm} \rightarrow [K^{\pm}\pi^{\mp}]_D K^{\pm})} = r_B^2 + r_D^2 \pm 2 r_B r_D \cos\delta \cos\gamma$$



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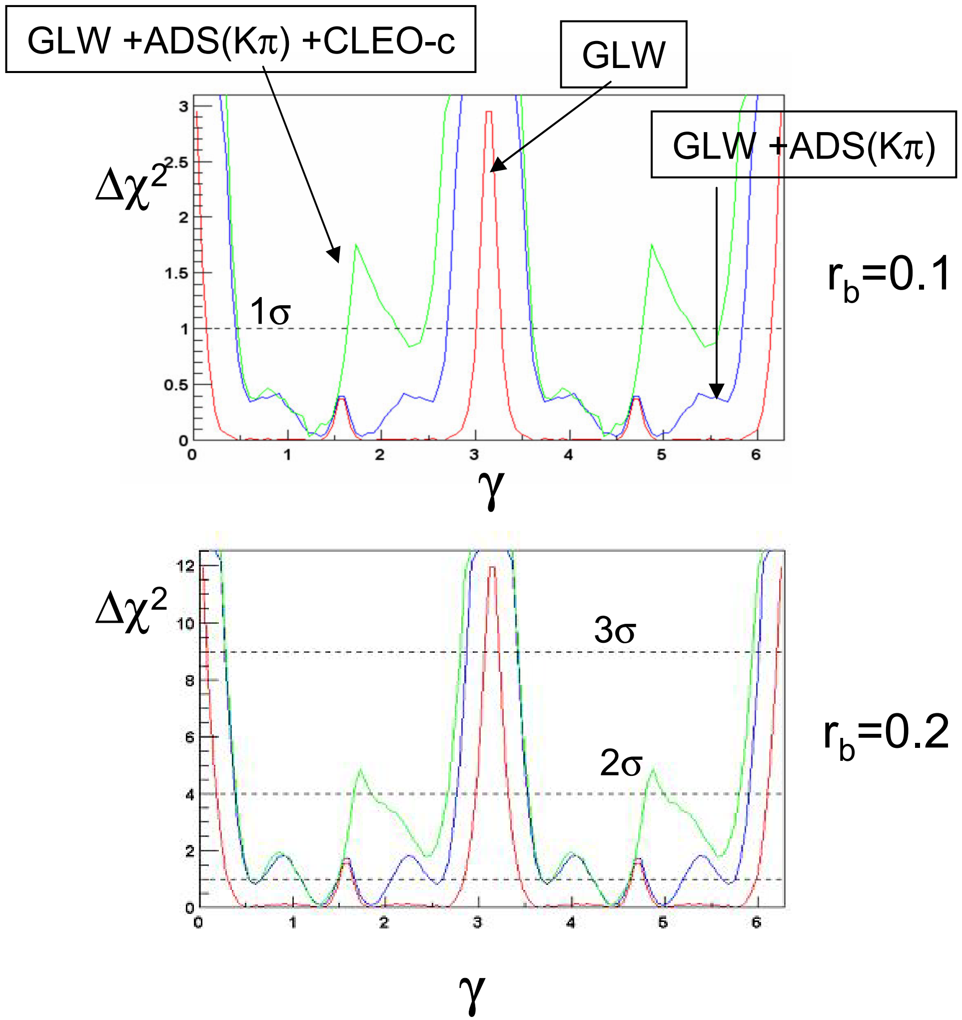
GLW-ADS method : expected sensitivity

- Toy MC with 500 fb-1
- Strong dependence on r
- Prospect not so bright for r=0.1



Study by C. Campagnari et al.

Belle: Dalitz plot method-1

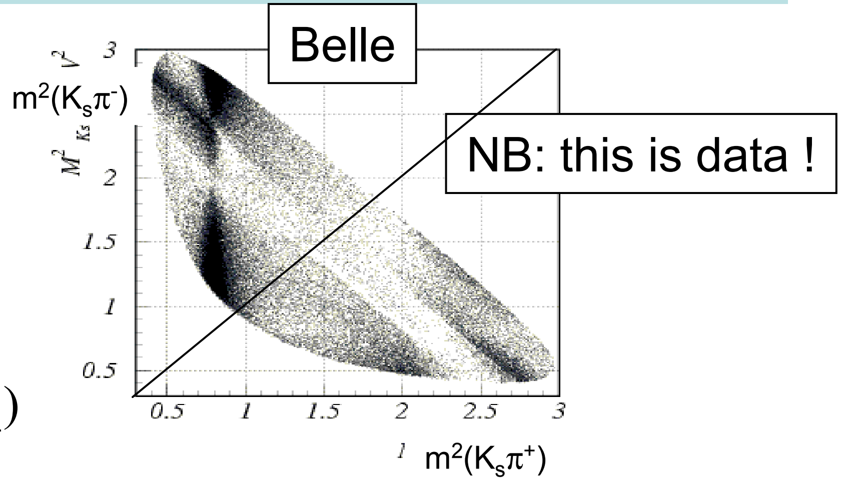
Hep-ex/0308043

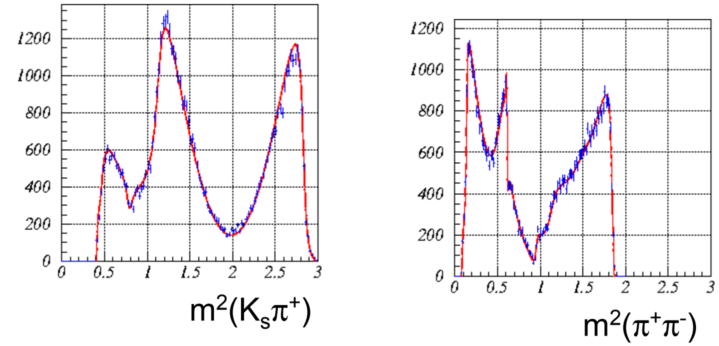
- Proposed by Giri et al. (hep-ph/0303187)
- Uses Cabibbo-allowed mode $K_s \pi^+ \pi^-$
- The Dalitz plot amplitude can be written as

$$M_+ = f(m_+^2, m_-^2) + re^{i(\gamma+\delta)} f(m_-^2, m_+^2)$$

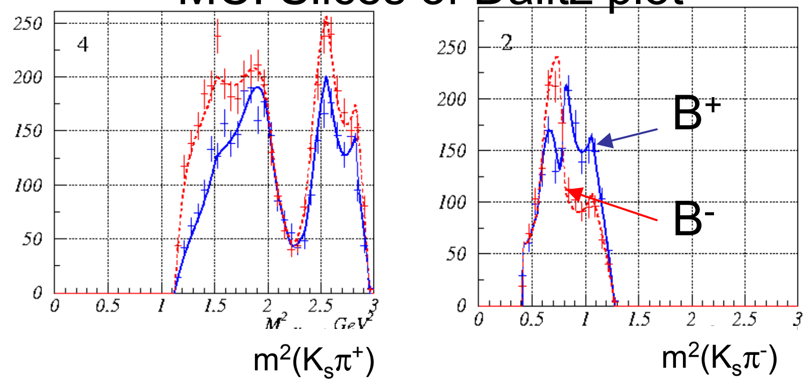
$$M_- = f(m_-^2, m_+^2) + re^{i(-\gamma+\delta)} f(m_+^2, m_-^2)$$

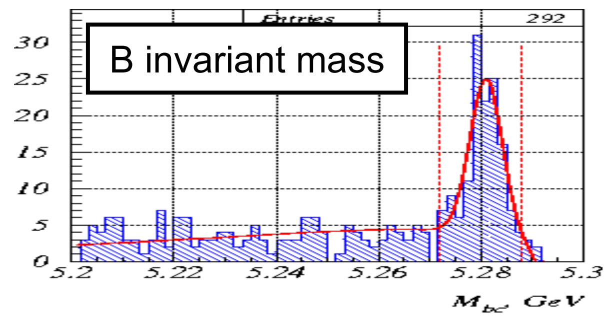
- Where $|f|^2$ can be fitted in D* tagged D° decays (57800 evt !!) and r,γ and δ are fitted in the Dalitz plot of $B^- \to D^0 K^-$ decays
- $B^- \to D^0 \pi^-$ is used as a control sample





MC: Slices of Dalitz plot





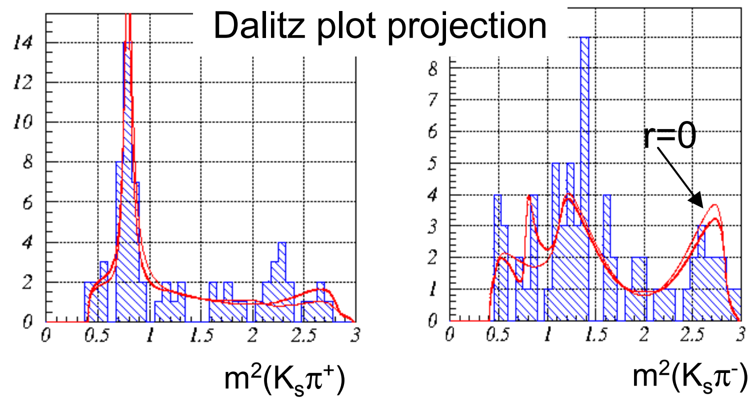
107 signal ev. are selected on 140 fb-1

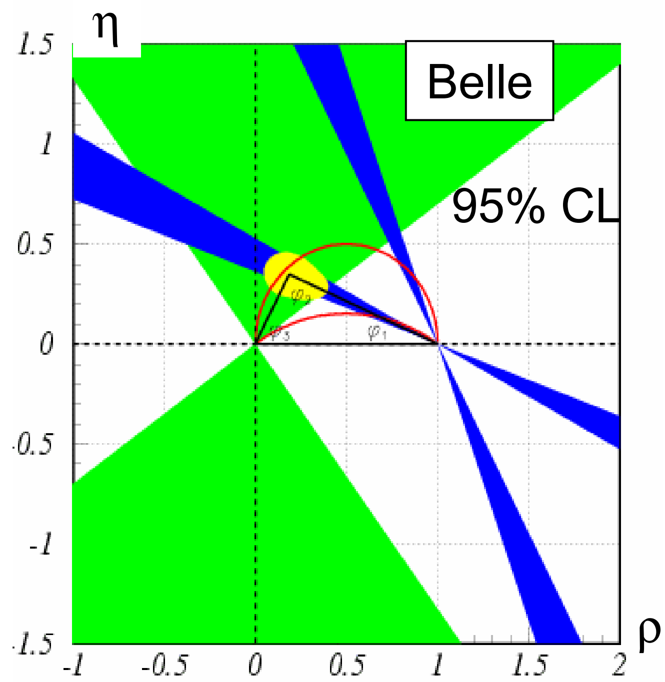
Belle: Dalitz plot method-2

$B^+ \to D^0 K^+$ and $B^+ \to D^{*0} K^+$, $D^0 \to K_s \pi^+ \pi^-$
$\gamma = \varphi_3 = 81° \pm 19° \pm 13°(\text{syst}) \pm 11°(\text{model})$ from combined fit, r=0.31±0.11
95% CL interval from combined fit: $35° < \varphi_3 < 127°$

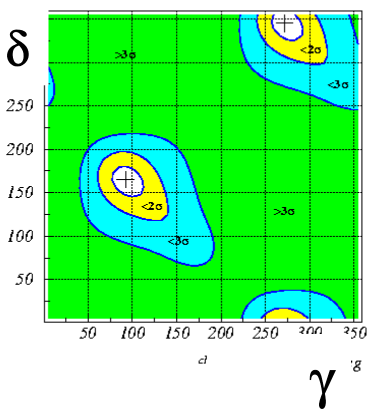
Caveat :

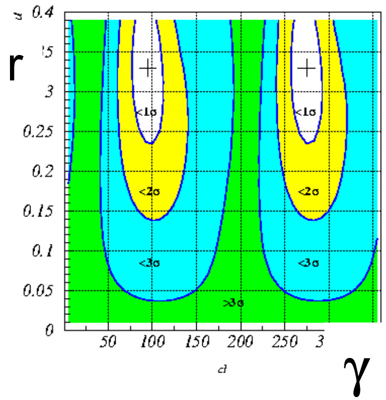
- model dependence of Dalitz amplitude
- Unexpectedly large value of r (r=0.13 exp.)





A. Poluektov at Moriond EW 2004





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Outlook

- BaBar : 200 fb^{-1} expected by summer 2004, 500 fb^{-1} by 2006

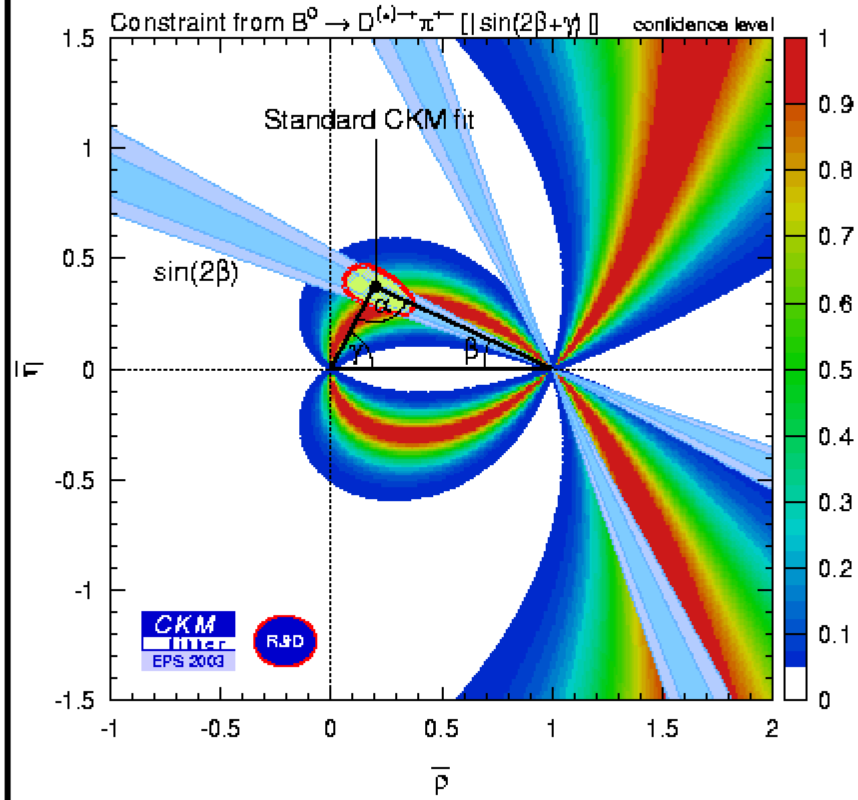
- $\sin(2\beta+\gamma)$: add new modes like $D\rho$, $D^*\rho$

- $B^- \rightarrow D^\circ K$: add many modes : drops in the bucket concept

- Dalitz plot analysis : r value ? Model independent approach

Conclusions

- First measurements of sin(2β+γ) and γ are available for CKM fitters !
- Many more methods and modes currently explored mainly B→ DK
- Already interesting constraints in the ρ-η plane
- The rapid increase of luminosity will be extremely beneficial to these difficult measurements
- Improved and complementary measurements of γ in 2004-2005 at the B-factories experiments



$B^0 \rightarrow D^{(*)}\pi$: Full result list

$2\, r^* \sin(2\beta+\gamma) \cos(\delta^*) = -0.063 \pm 0.024$ (stat.) $\pm\, 0.014$ (syst.) PR

$2\, r^* \cos(2\beta+\gamma) \sin(\delta^*) = -0.004 \pm 0.037$ (stat.) $\pm\, 0.020$ (syst.) PR

$2\, r^* \sin(2\beta+\gamma) \cos(\delta^*) = -0.068 \pm 0.038$ (stat.) $\pm\, 0.020$ (syst.) ER

$2\, r^* \sin(2\beta+\gamma) \cos(\delta^*) = 0.031 \pm 0.070$ (stat.) $\pm\, 0.033$ (syst.) ER

$2\, r \sin(2\beta+\gamma) \cos(\delta) = -0.022 \pm 0.038$ (stat.) $\pm\, 0.020$ (syst.) ER

$2\, r \cos(2\beta+\gamma) \sin(\delta) = -0.025 \pm 0.068$ (stat.) $\pm\, 0.033$ (syst.) ER

$B^0 \to D^{(*)}\pi$: CP violation on the tag side for kaon tagged events

Due to presence of Doubly Cabibbo Suppressed Decays on the tag side

⇒ We introduce r' and δ' in the coefficients relevant to the sin(Δm.t) term

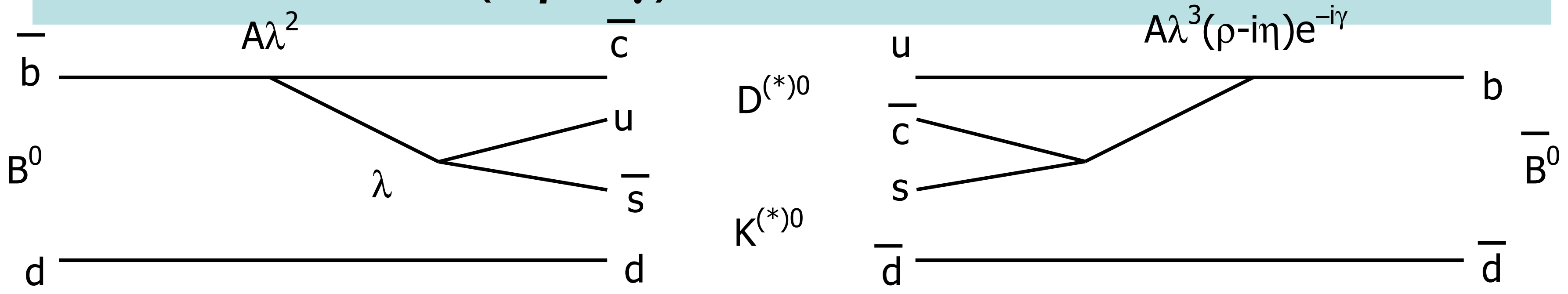
	Reco	Tag	$\sin(\Delta m \Delta t)$ coefficient
S_1	$(D^{*-}\pi^+)$	$B^0(K^+)$	$-2\lambda\sin(2\beta+\gamma-\delta)+2\lambda'\sin(2\beta+\gamma-\delta')$
S_2	$(D^{*-}\pi^+)$	$\overline{B}^0(K^-)$	$2\lambda\sin(2\beta+\gamma-\delta)+2\lambda'\sin(2\beta+\gamma+\delta')$
S_3	$(D^{*+}\pi^-)$	$B^0(K^+)$	$-2\lambda\sin(2\beta+\gamma+\delta)-2\lambda'\sin(2\beta+\gamma-\delta')$
S_4	$(D^{*+}\pi^-)$	$\overline{B}^0(K^-)$	$2\lambda\sin(2\beta+\gamma+\delta)-2\lambda'\sin(2\beta+\gamma+\delta')$

ABC parametrization* to restrict the set of fit variables to 3

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

* : O. Long, M. Baak, R.N. Cahn, and D. Kirkby, SLAC-PUB-9687, hep-ex/0303030

$\sin(2\beta+\gamma)$ in $B^0 \to D^{(*)0}K^{(*)0}$



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

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

Strong phase difference

- Similar to D(*)π: interference between decay and mixing, but…
  - Advantages:
    - Much larger asymmetries:
    - CP violation from tag-side not significant

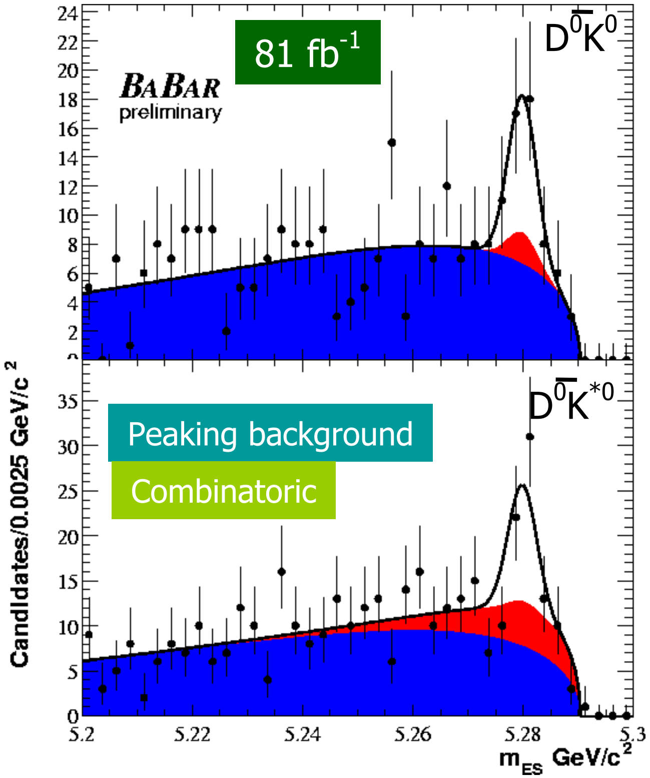
$$r = \left|\frac{A\left(B^0 \to D^0 K^{(*)0}\right)}{A\left(B^0 \to \bar{D}^0 K^{(*)0}\right)}\right| = \left|\frac{V_{ub}V_{cs}^*}{V_{cb}V_{us}^*}\right| \sim 0.4$$

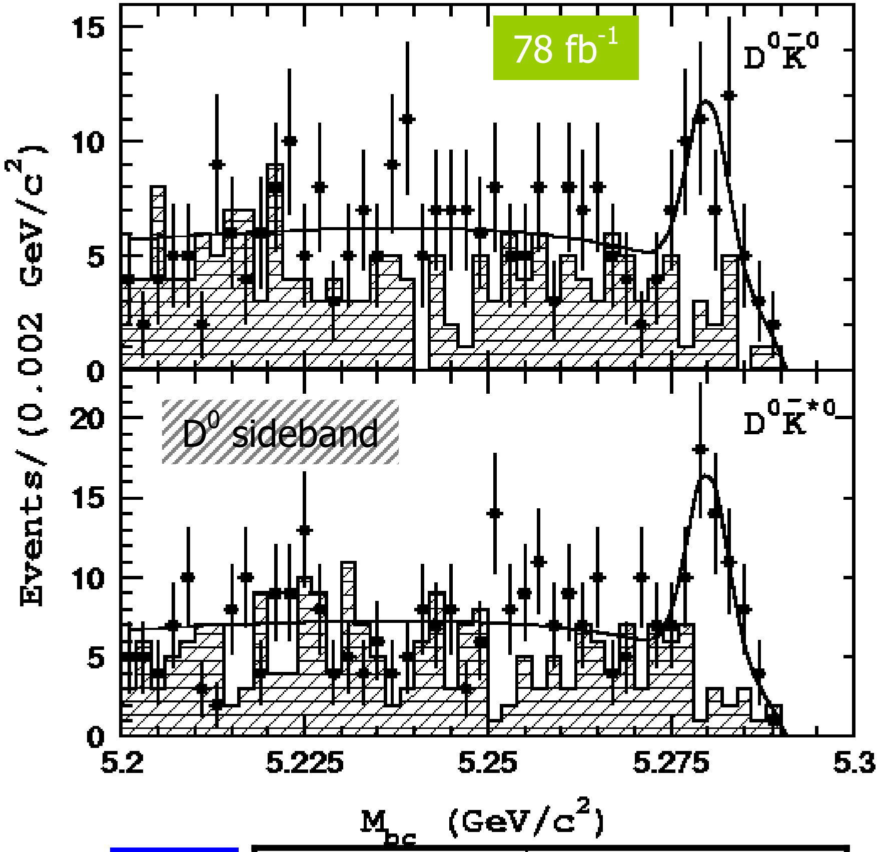
Measure r with $K^{*0} \to K^-\pi^+$

  - Disadvantages:
    - Color suppressed decays: Smaller branching fractions
    - Possible competing effects from Doubly-Cabibbo-suppressed D^0 decays
    - Requires tagging for time-dependent studies: 70% tagging efficiency

Kayser, London, PRD 61, 116013
Atwood, Soni, hep-ph/0206045

Current measurements and limits in $B^0 \to \bar{D}^{(*)0}K^{(*)0}$





Mode	Br(x10^{-5}) Belle	Br(x10^{-5}) BaBar
$B^0 \to D^0K^{*0}$	4.8 ±1.1 ±0.5	3.0 ±1.3 ±0.6
$B^0 \to D^0K^0$	5.0 ±1.3 ±0.6	3.4 ±1.3 ±0.6

BELLE

$B^0 \to \bar{D}^{*0}K^0$	<6.6 (90% c.l.)
$B^0 \to \bar{D}^{*0}K^{*0}$	<6.9 (90% c.l.)
$B^0 \to D^0K^{*0}$	<1.8 (90% c.l.)
$B^0 \to D^{*0}K^{*0}$	<4.0 (90% c.l.)

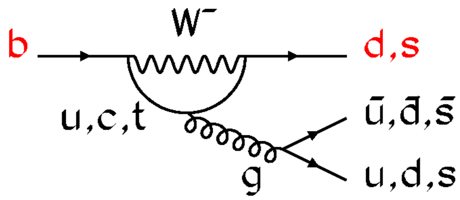
V_{ub}

V_{ub} contribution necessary for measurement of γ not observed yet!

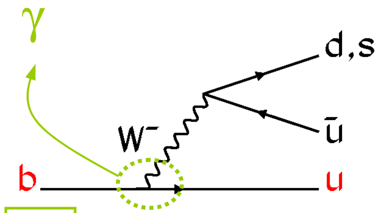
γ in Charmless B → PP,PV decays

$$A(B\to f)=\left(|P|e^{i\delta}+|T|e^{+i\gamma}\right)$$

$$\bar{A}(\bar{B}\to\bar{f})=\left(|P|e^{i\delta}+|T|e^{-i\gamma}\right)$$



P $V_{cb}^{*}V_{cs} \sim \lambda^2$



T $V_{ub}^{*}V_{us} \sim \lambda^4$

- Tree amplitude suppressed in Standard Model — Possible window on New Physics
  - Penguin contributions large: $\frac{B\to K\pi}{B\to\pi\pi}\approx 4$ ← 5% if neglecting penguins
  - Interference between Tree and Penguin

⇒ Branching fractions and CP asymmetries sensitive to γ

$$BF\propto 1+2\left|\frac{P}{T}\right|\cos\delta\cos\gamma+\left|\frac{P}{T}\right|^2$$

$$A_{CP}=-2\left|\frac{P}{T}\right|\sin\delta\sin\gamma$$

- Main Challenges
  - Background suppression
  - Contribution of EW penguins
  - Effects of Final State Interaction
  - **Requires estimate of |P/T|**

A_{CP} alone not sufficient

Need also BF to have a handle on δ