



# CP violation and related issues

## Part 8: angle $\phi_3(\gamma)$

**Peter Križan**  
*University of Ljubljana and J. Stefan  
Institute*

May 17-25, 2005

Course at University of Barcelona

Peter Križan, Ljubljana



# Contents

How to measure  $\phi_3$ ?

$\phi_3$  from interference of a direct and colour  
suppressed decay

May 17-25, 2005

Course at University of Barcelona

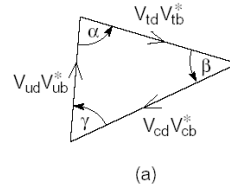
Peter Križan, Ljubljana



## How to measure $\phi_3$ ?

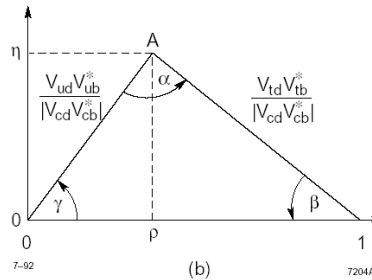
No easy (=tree dominated) channel to measure  $\phi_3$  through CP violation.

Any other idea? Yes.



(a)

$$\gamma \equiv \phi_3 \equiv \arg \left( \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right)$$



(b)

May 17-25, 2005

Course at University of Barcelona

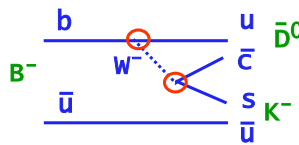
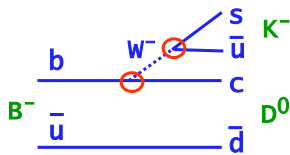
Peter Krizan, Ljubljana



## $\phi_3$ from interference of a direct and colour suppressed decay

Basic idea: use  $B^- \rightarrow K^- D^0$  and  $B^- \rightarrow K^- \bar{D}^0$  with  $D^0, \bar{D}^0 \rightarrow f$  interference  $\leftrightarrow \phi_3$

$f$ : any final state, common to decays of both  $D^0$  and  $\bar{D}^0$



$$T \sim V_{cb}^* V_{us} \sim A \lambda^3$$

$$T_C \sim V_{ub}^* V_{cs} \sim A \lambda^3 (\rho + i\eta)$$

$$(\rho + i\eta) \sim e^{i\phi_3}$$

May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana



## $\phi_3$ from interference of a direct and colour suppressed decay

Gronau, London, Wyler, 1991:  $B^- \rightarrow K^- D_{CP}^0$   
 Atwood, Dunietz, Soni, 2001:  $B^- \rightarrow K^- D^{0(*)} [K^+ \pi^-]$   
 Belle; Giri, Zupan et al., 2003:  $B^- \rightarrow K^- D^{0(*)} [K_S^0 \pi^+ \pi^-]$   
 Dalitz plot

Density of the Dalitz plot depends on  $\phi_3$

Matrix element:

$$M_+ = f(m_+^2, m_-^2) + r e^{i\phi_3 + i\delta} f(m_-^2, m_+^2),$$

Sensitivity depends on

$$r = \sqrt{\frac{Br(B^- \rightarrow \bar{D}^{(*)0} K^-)}{Br(B^- \rightarrow D^{(*)0} K^-)}} \approx 0.1 - 0.3$$

or any other common 3-body decay

May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana



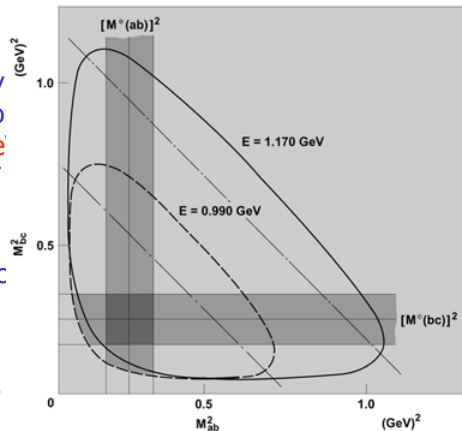
## What is a Dalitz plot?

Example: three body decay  $X \rightarrow abc$ .

$M_{ij}$  denotes the invariant mass of the two-particle system ( $ij$ ) in a three body decay. Kinematic boundaries: drawn for equal masses  $m_a = m_b = m_c = 0.14 \text{ Ge}$  and for two values of total energy  $E$  of the three-pion system. Resonance bands: drawn for states ( $ab$ ) and ( $bc$ ) corresponding to a (fictitious) resonance with  $M=0.5 \text{ GeV}$  and  $\Gamma=0.2 \text{ GeV}$ ; dot-dash lines show the locations a ( $ca$ ) resonance band would have for this mass of  $0.5 \text{ GeV}$ , for the two values of the total energy  $E$ .

The pattern becomes much more complicated, if the resonances interfere.

Richard H. Dalitz, "Dalitz plot", in AccessScience@McGraw-Hill, <http://www.accessscience.com>.



May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana

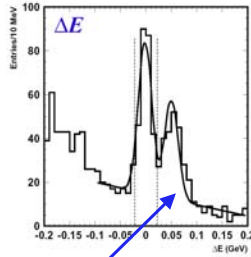


## $\phi_3$ from interference of a direct and colour suppressed decay

Reconstruct  $B^- \rightarrow D^0 K^-$  decays.

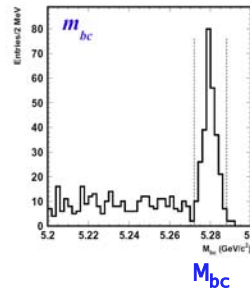
253 fb<sup>-1</sup>

$B^- \rightarrow D^0 K^-$  ;  
N = 209 ± 16  
75% pure



$B^- \rightarrow D^0 \pi^\pm$   
miss-id

$B^\pm \rightarrow D^0 K^\pm$   
 $D^0 \rightarrow K_S \pi^+ \pi^-$



Use continuum  $D^0$  from  $D^{*-} \rightarrow D^0 \pi^-$ ,  $D^0 \rightarrow K_S \pi^+ \pi^-$  decay to model Dalitz plot density.

May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana



## $\phi_3$ from interference of a direct and colour suppressed decay

Use  $D^0$  decays from  $D^{*-} \rightarrow D^0 \pi^-$ ,  $D^0 \rightarrow K_S \pi^+ \pi^-$  decay to model Dalitz plot density in two variables:

$$m^2(K_S \pi^+) = m_+^2 \quad \text{and} \\ m^2(K_S \pi^-) = m_-^2$$

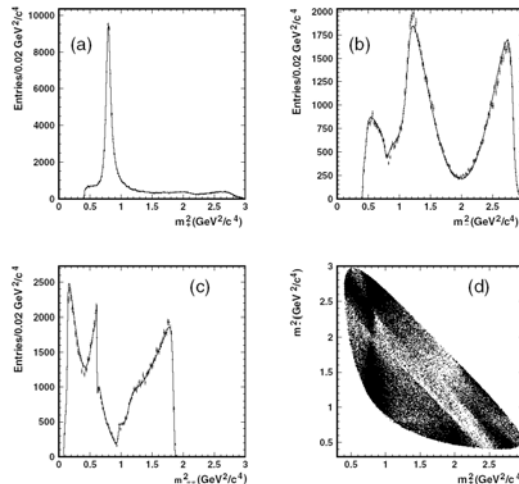


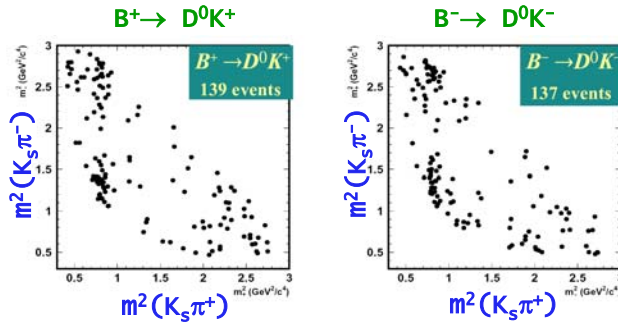
FIG. 5. (a)  $m_+^2$ , (b)  $m_-^2$ , (c)  $m_+^2 m_-^2$  distributions and (d) Dalitz plot for the  $D^0 \rightarrow K_S \pi^+ \pi^-$  decay from the  $D^{*\mp} \rightarrow D \pi_\mp^\pm$  process. The points with error bars show the data; the smooth curve is the fit result.

May 17-25, 2005

Course



## $\phi_3$ from interference of a direct and colour suppressed decay



➔ visible asymmetry  
Fit with  $\phi_3, \delta, r_B$  free

$$\phi_3 = (68 \pm 14_{15} \pm 13 \pm 11)^\circ$$

$$22^\circ < \phi_3 < 113^\circ \text{ @ 95\% C.L.}$$

$$r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$$

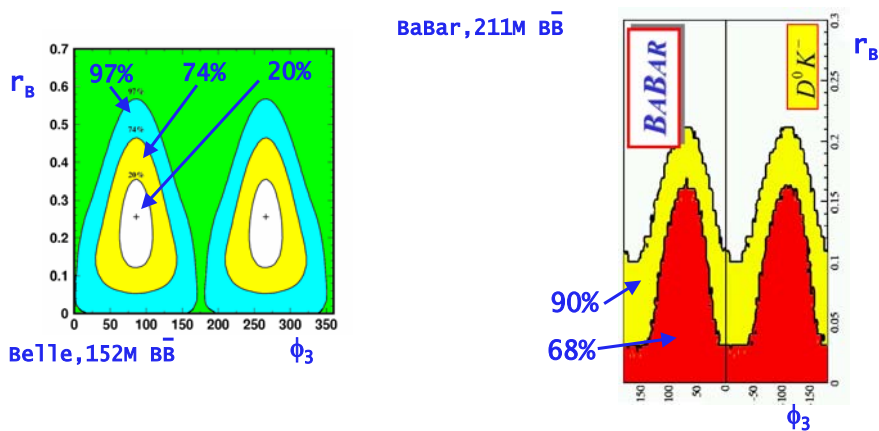
May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana



## $\phi_3$ vs. $r_B$ plots



May 17-25, 2005

Course at University of Barcelona

Peter Krizan, Ljubljana