CKM Workshop
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$2\beta+\gamma$ from $\overline{B}^0 \to D^+ K^0 \pi^-$ at BaBar

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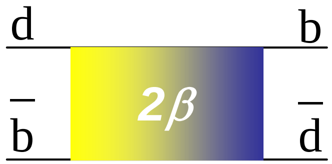
$2\beta+\gamma$ IN $B^0 \rightarrow D^- K^0 \pi^+$ DECAYS

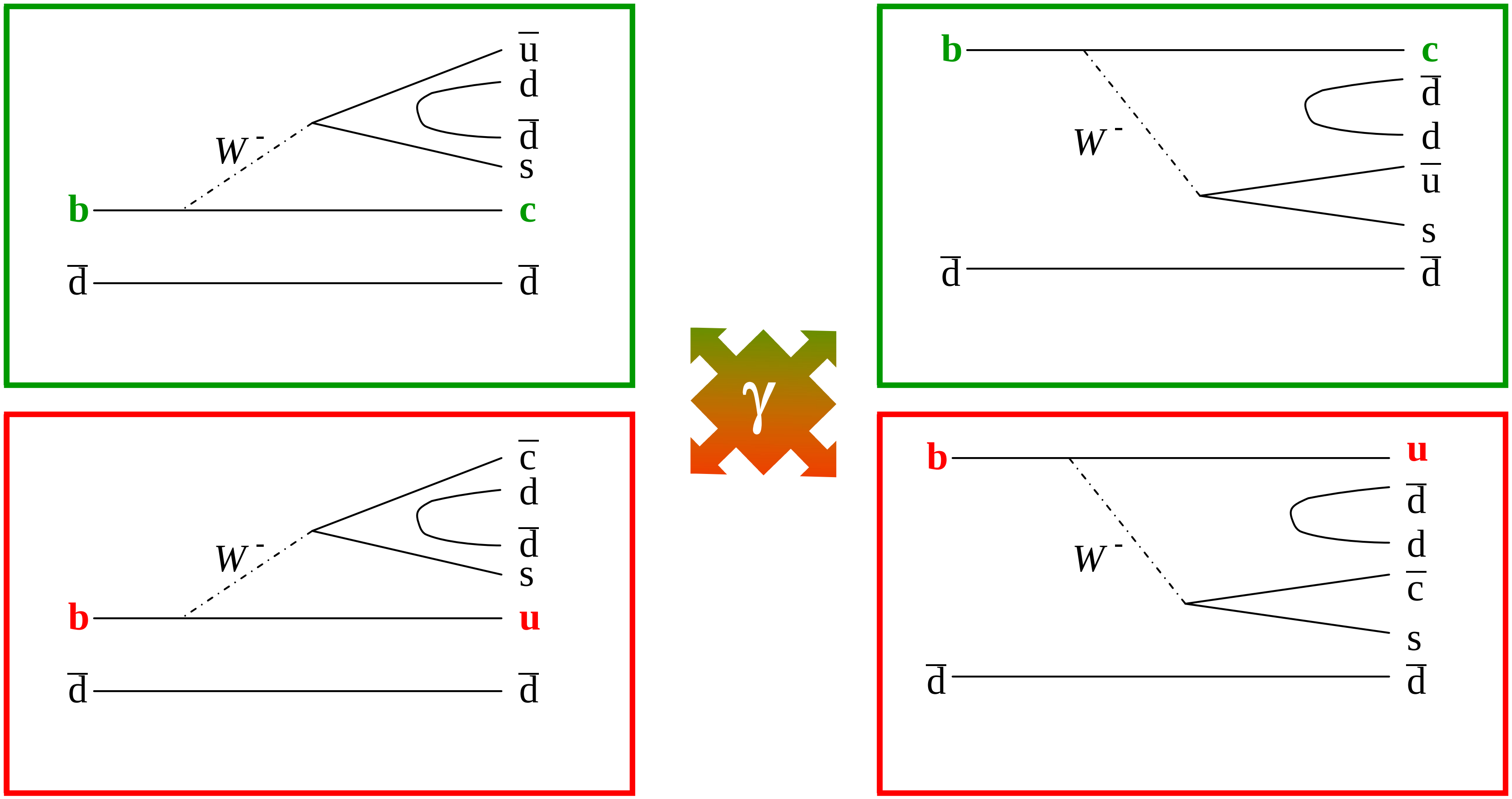
Interference of V_{cb} e V_{ub} amplitudes to the same final state ➔ **sensitivity to γ**

Mixing $\overline{B^0}B^0$ ➔ **sensitivity to 2β**



(see: R. Aleksan, T. C. Petersen, A. Soffer, *Phys. Rev. D67 (2003) 096002*

R. Aleksan, T. C. Petersen, *hep-ph/0307371* (CKM workshop 2003, numerical analysis))



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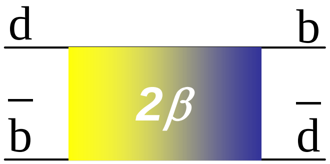

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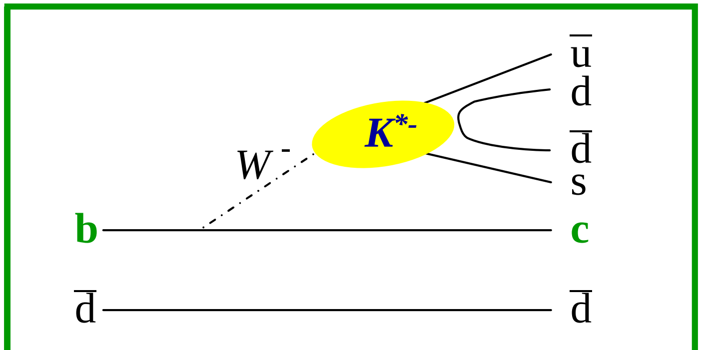
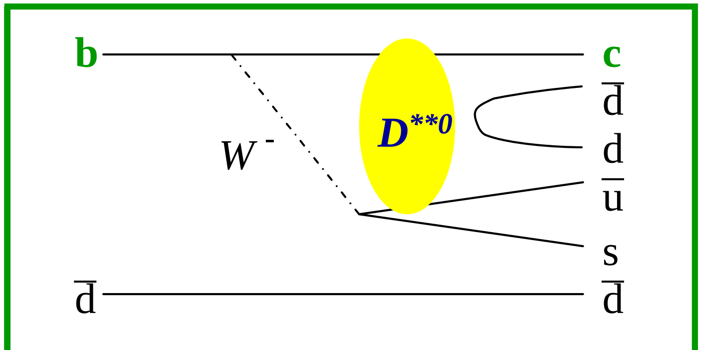
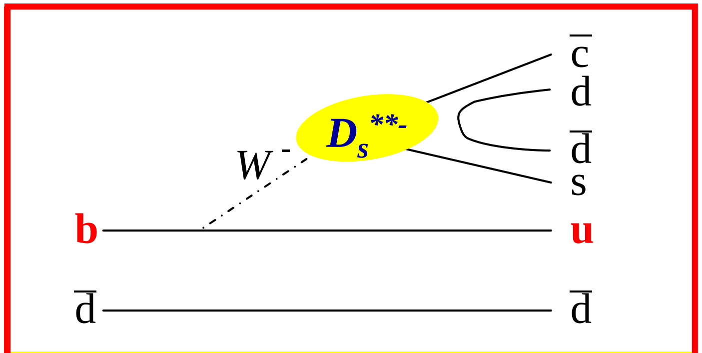


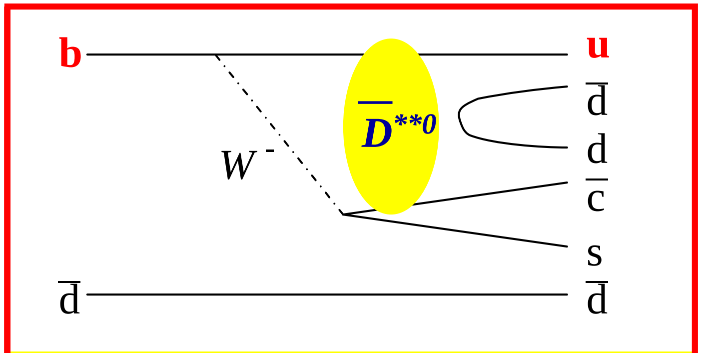
$\overline{B^0} \rightarrow D^+ K^{*-}$ $(K^{*-} \rightarrow K^0 \pi^-)$



$\overline{B^0} \rightarrow D^{**0} K^0$ $(D^{**0} \rightarrow D^+ \pi^-)$



$\overline{B^0} \rightarrow D_s^{**-} \pi^+$ $(D_s^{**-} \rightarrow D^- K^0)$

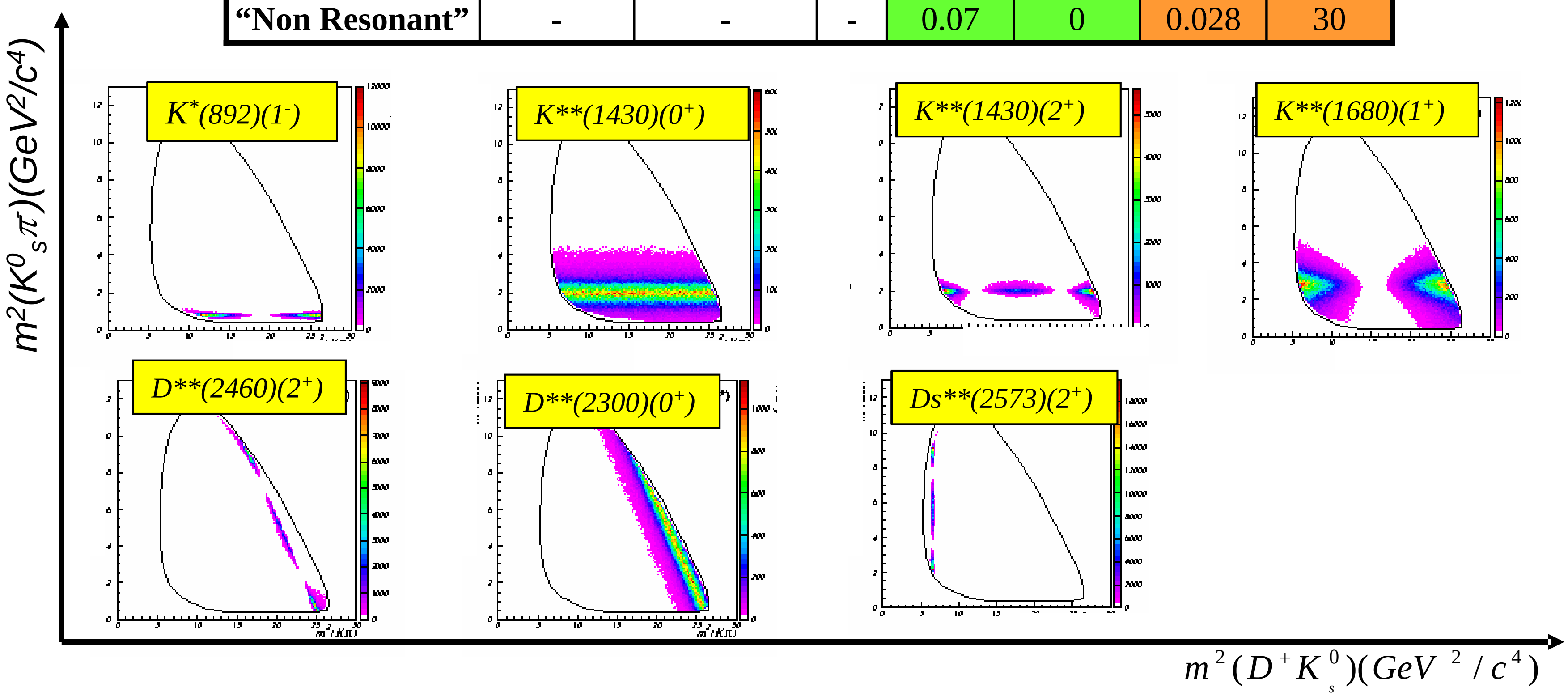


$\overline{B^0} \rightarrow \overline{D}^{**0} K^0$ $(\overline{D}^{**0} \rightarrow D^- \pi^+)$

3-body decay* ➔ *Intermediate resonances* ➔ *Dalitz analysis

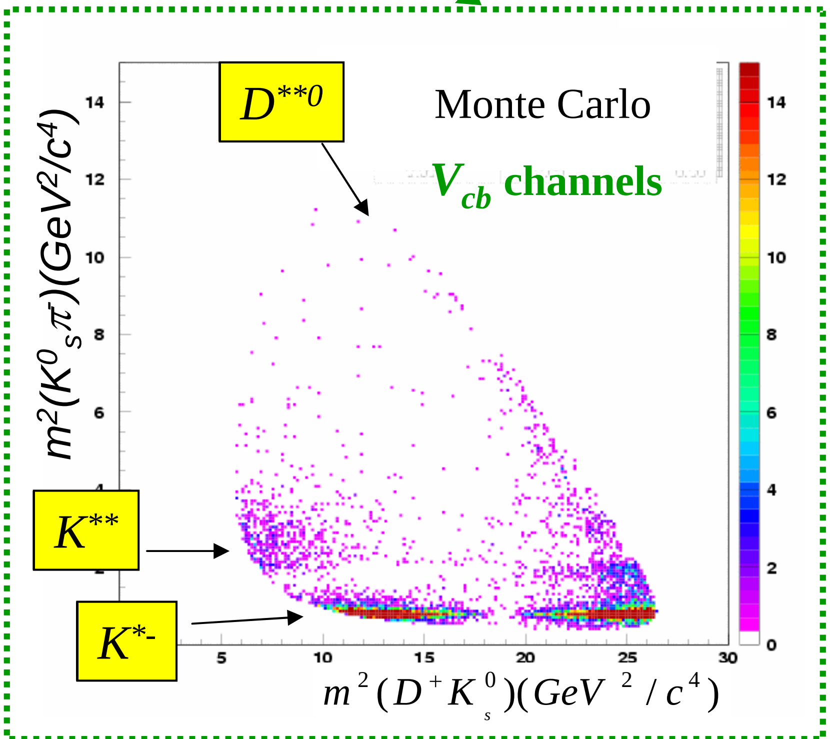
DALITZ MODEL

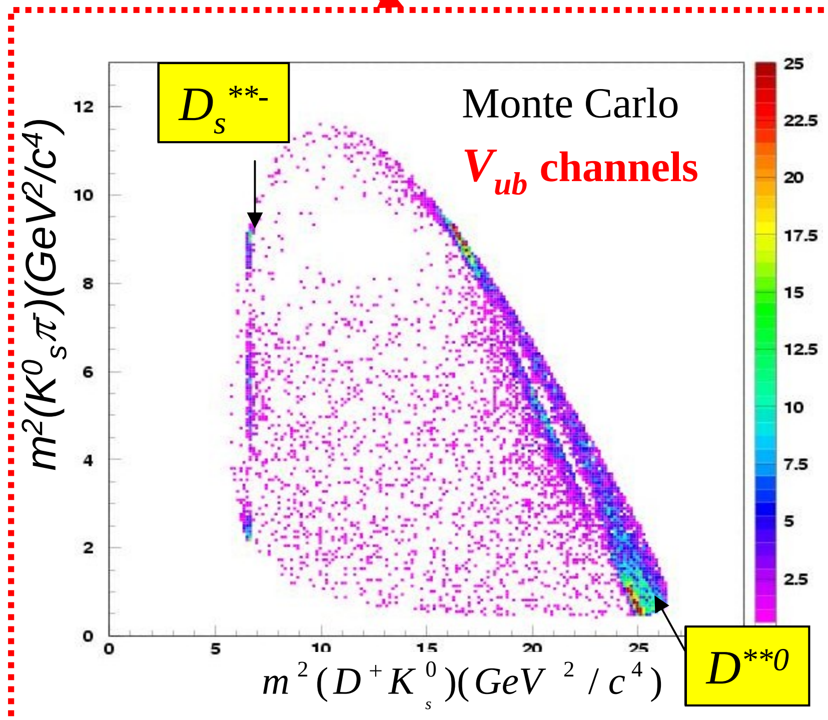
Isobar model is assumed.	*Mass (GeV/c^2)*	*Width (Gev/c^2)*	J^P	$a(V_{cb})$	$\phi(V_{cb})^o$	$a(V_{ub})$	$\phi(V_{ub})^o$
$D_{s2}(2573)^{\pm}$	2.572	0.015	2+	-	-	0.02	
$D_2^*(2460)^0$	2.461	0.046	2+	0.12	30	0.048	30
$D_0(2308)^0$	2.308	0.276	0+	0.12	70	0.048	90
$K^*(892)^{\pm}$	0.89166	0.0508	1-	1	0	-	-
$K_0^*(1430)^{\pm}$	1.412	0.294	0+	0.6	80	-	-
$K_2^*(1430)^{\pm}$	1.4256	0.0985	2+	0.2	0	-	-
$K^*(1680)^{\pm}$	1.717	0.322	1-	0.3	30	-	-
"Non Resonant"	-	-	-	0.07	0	0.028	30



INTERFERENCE IN THE DALITZ

INTERFERENCE



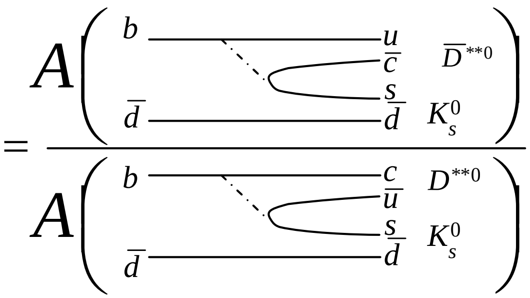


ADVANTAGES OF THE METHOD

- **Theoretically clean (no need of assuming SU(3) or neglect diagrams)**

- **r_i varies on the Dalitz plot, no need to determine it** if all the V_{ub} e V_{cb} amplitudes and phases are determined;

- in some regions **r is expected to be high (*)**:

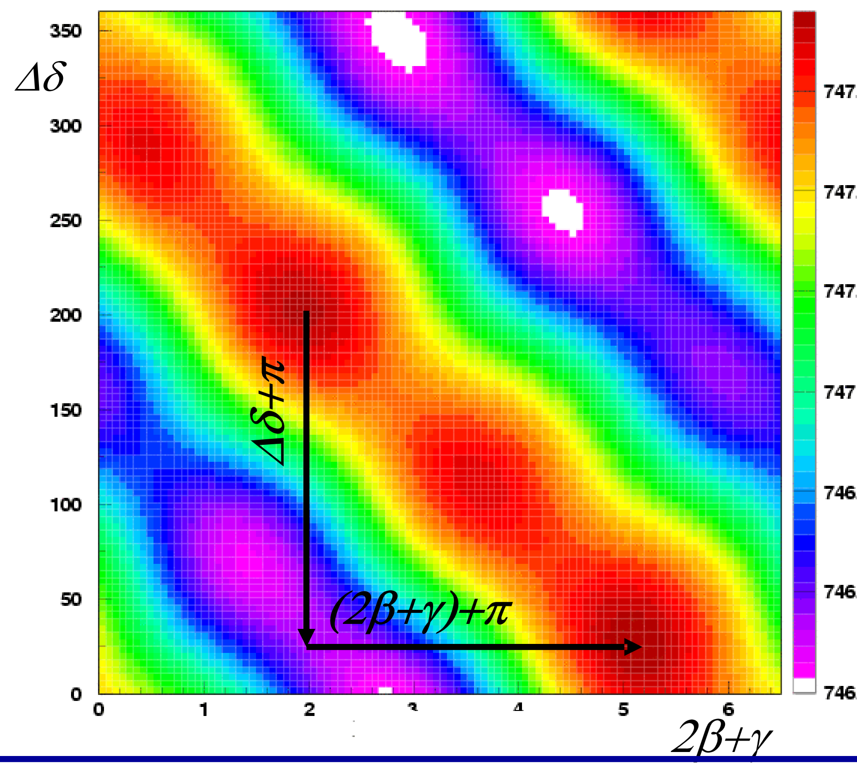


$$r_B = \frac{A(\ldots)}{A(\ldots)} \approx \frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

- The presence of some wide resonances ensures **only 2 ambiguities (due to the irreducible S_π) !**
(In $D^{(*)}\pi(\rho)$ there are 4 ambiguities…)

$$S_{\pi/2}:\ 2\beta+\gamma \to \pi/2 - \Delta\delta,\quad \Delta\delta \to \pi/2 - (2\beta+\gamma)$$
$$S_-\ :\ 2\beta+\gamma \to -(2\beta+\gamma),\quad \Delta\delta \to \pi - \Delta\delta$$
$$S_\pi\ :\ 2\beta+\gamma \to 2\beta+\gamma+\pi,\quad \Delta\delta \to \Delta\delta + \pi$$

Example of the likelihood with a wide resonance D^{**0}: only two ambiguities are present!



(*): see also B.Aubert et al., [BABAR Collaboration], Phys.Rev. D74, 031101, (2006)
http://ckm2005.ucsd.edu/WG/WG5/thu2/Sordini-WG5-S3.pdf

TIME DEPENDENT DALITZ PDF

In the case of $B^0 \to D^+\pi^-$:

$$B_{tag} = \begin{cases} B^0 \Rightarrow (\eta = -1) \\ \overline{B}^0 \Rightarrow (\eta = +1) \end{cases}$$

$$P_{\eta}^{TAG}(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau}}}{4\tau}\left\{1 - \eta S_f \sin(\Delta m \cdot \Delta t) + \eta C \cos(\Delta m \cdot \Delta t)\right\}$$

$$r_{D+\pi-} \equiv \frac{q}{p}\frac{\overline{A}_{D+\pi-}}{A_{D+\pi-}} = |r_{D+\pi-}|\, e^{-i(2\beta+\gamma+\Delta\delta)}$$

$$\begin{cases} C_{D^+\pi^-} = \dfrac{1-|r_{D^+\pi^-}|^2}{1+|r_{D^+\pi^-}|^2} \\ S_{D^+\pi^-} = \dfrac{2\,\mathrm{Im}(r_{D^+\pi^-})}{1+|r_{D^+\pi^-}|^2} \end{cases}$$

In the case of $B^0 \to D^+K_s\pi^-$:

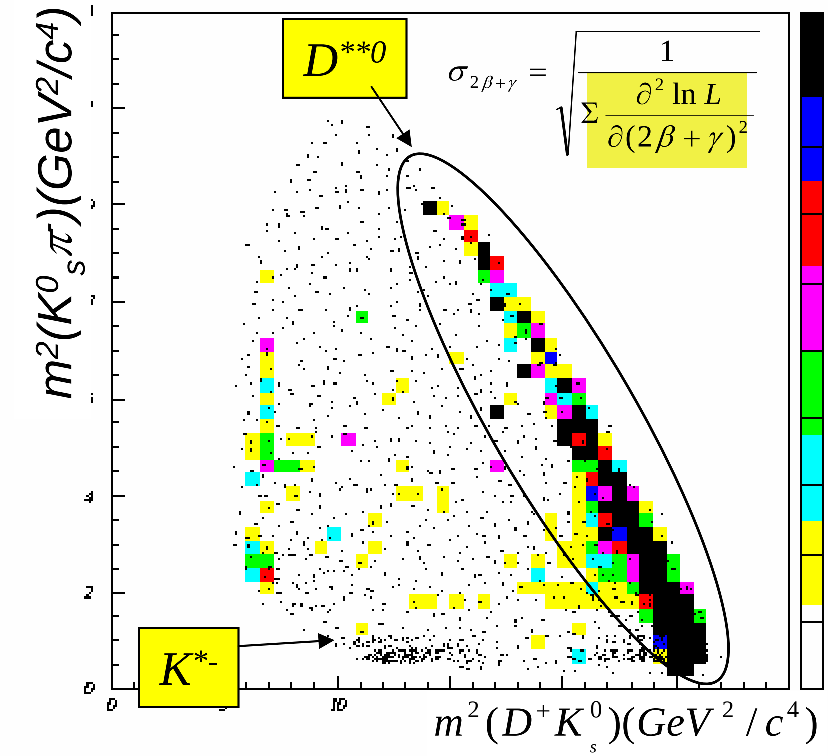
$$P_{\eta,k}^{TAG}(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau}}}{4\tau}\frac{A_{c_k}^2 + A_{u_k}^2}{2}\left\{1 - \eta S_f^k \sin(\Delta m \cdot \Delta t) + \eta C^k \cos(\Delta m \cdot \Delta t)\right\}$$

$$C^k = \frac{A_{c_k}^2 - A_{u_k}^2}{A_{c_k}^2 + A_{u_k}^2} \qquad S^k_{D^+K_S^0\pi^-} = \frac{2\,\mathrm{Im}(A_{c_k} A_{u_k} e^{i(2\beta+\gamma)+i(\delta_{c_k}-\delta_{u_k})})}{A_{c_k}^2 + A_{u_k}^2}$$

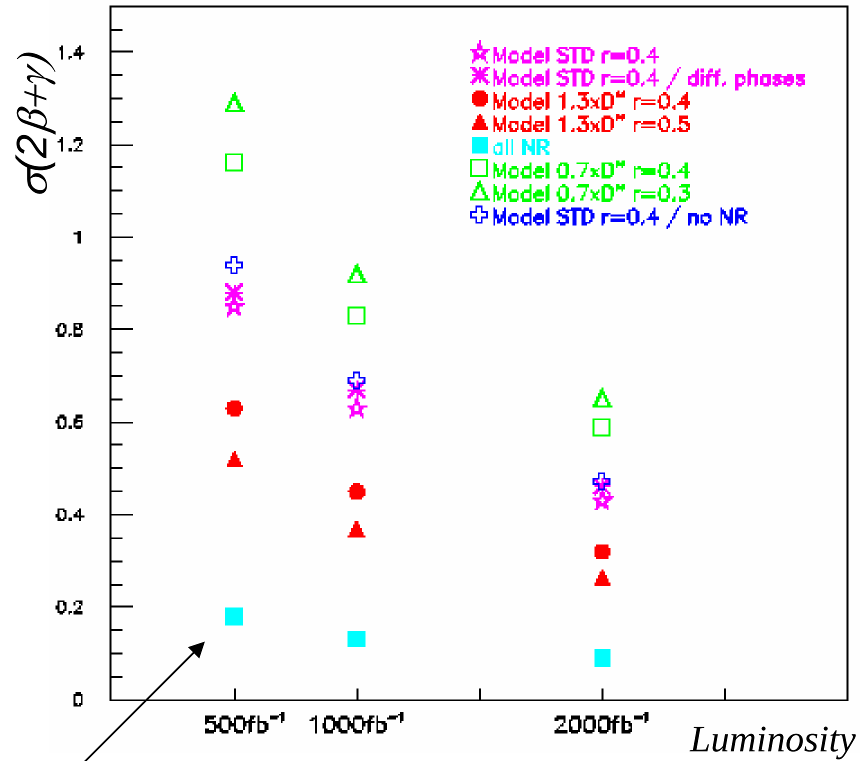
- ***Moreover untagged*** events are included in the fit since they help in the amplitudes and phases determination. They corresponds to $\eta=0$.

SENSITIVITY

Simulated distribution of the events in the Dalitz plot is weighted by a factor $\sigma_{2\beta+\gamma}$



Variations as a function of the model and the luminosity.

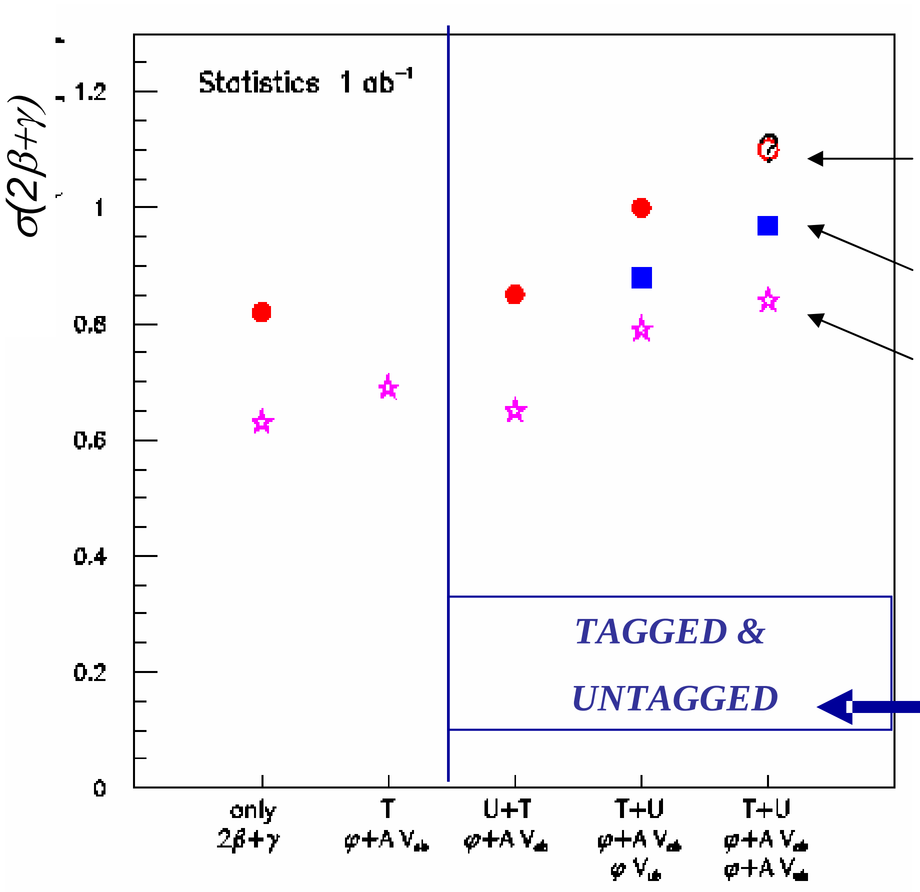


Previous feasibility study had an optimistic assumption on the Dalitz model, thus underestimating the error.

F.Polci, M.H.Schune, A.Stocchi
hep/ph 0605129

BACKGROUND EFFECT

- ***The effect of a BACKGROUND uniform in the Dalitz plot has been evaluated.***
- ***The use of untagged events helps.***



50% of background

30% of background

no background

Projection at 1ab^{-1}

•Amplitudes and phases V_{cb} are determined with an error of 20%-30%

•All the parameters can be determined with a purity > 50%

THE TIME DEPENDENT DALITZ LIKELIHOOD

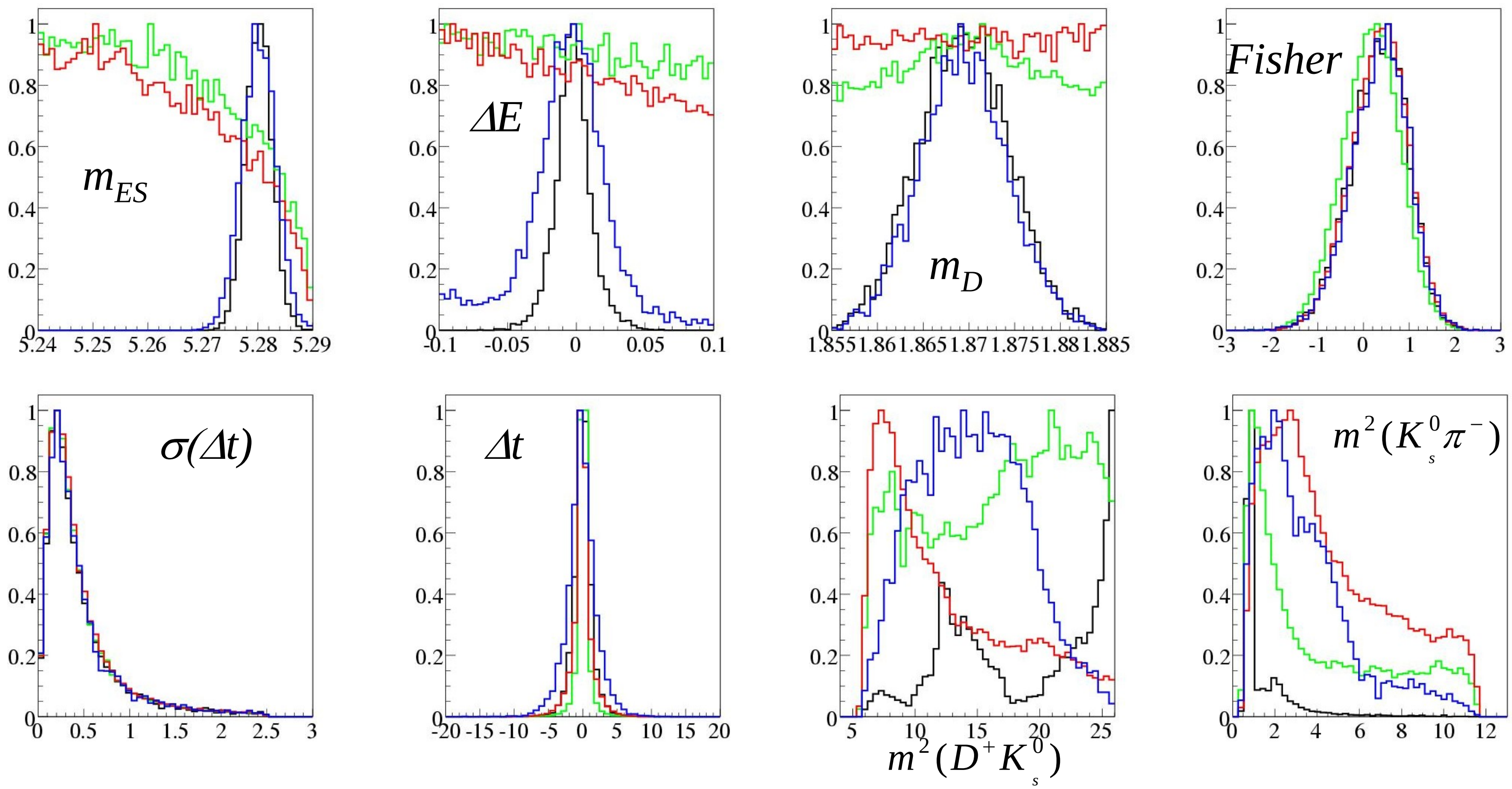
A simulation has been performed using realistic estimation of background levels and including resolution effects from studies on BaBar data.

- $\boldsymbol{Y} = Y(m_{ES}, \Delta E, Fisher, m_D)$
- $\boldsymbol{T} = T(\Delta t) \otimes R(\Delta t, \sigma(\Delta t))$
- $\boldsymbol{D} = D(m^2(D^+K^0_s), m^2(K^0_s\pi^-))$

Signal pdf
Continuum pdf
BB pdf
Peaking pdf

$$L^i_{\pm} = N^i_{sig}(TD)^i_{\pm,sig}Y_{sig} + N^i_{Cont}T^i_{\pm,Cont}D^i_{\pm,Cont}Y_{Cont} + N^i_{BBComb}T^i_{\pm,BBComb}D^i_{\pm,BBComb}Y_{BBComb} + N^i_{Peak}T^i_{\pm,Peak}D^i_{\pm,Peak}Y_{Peak}$$

Simulated variables distributions:



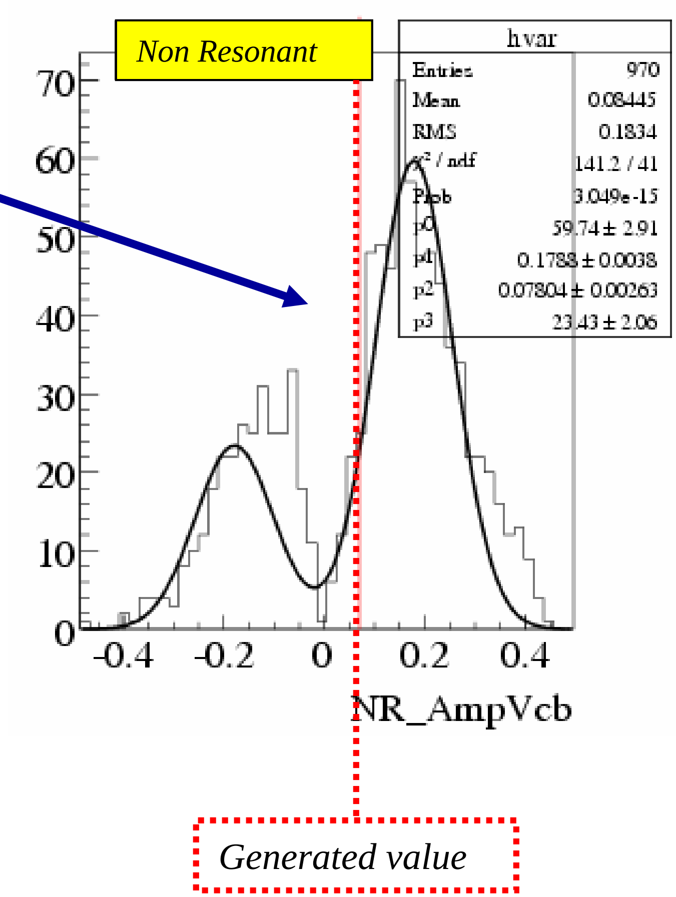
CP FIT: CONFIGURATION AT 354 fb^{-1}

Monte Carlo simulations show that *the statistic is not yet sufficient* to extract all amplitudes and phases from the fit.

Problems with Non Resonant amplitude. Probably confusion with background. At such a low statistics the NR amplitude needs to be fix on data.

The fit can be performed in the following configuration:

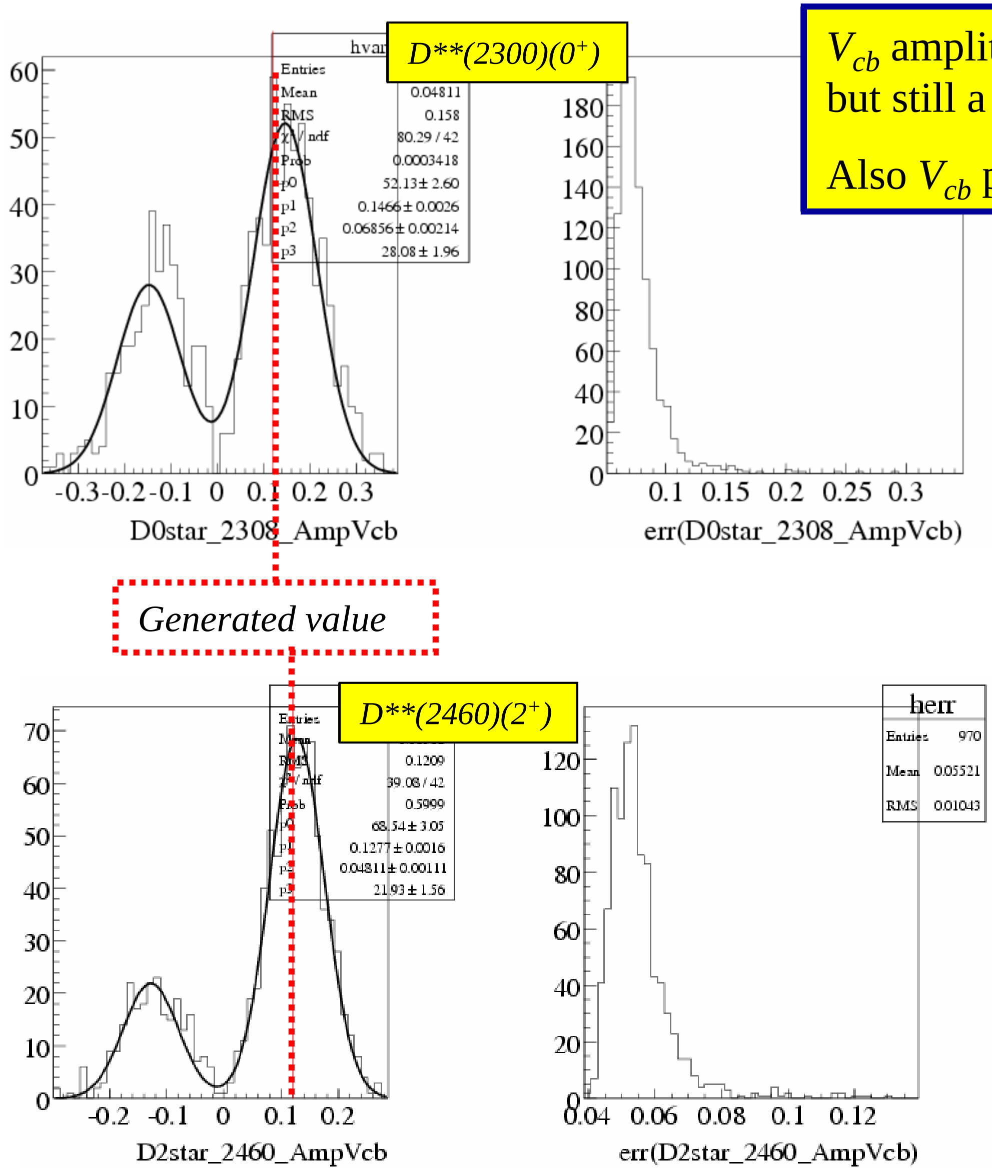
- A parameter ***r = 0.3*** is defined as the ratio between the V_{ub} and V_{cb} amplitudes.
- The *non resonant* amplitude and phase must be fixed to the values in the model.
- The D^{*}_{s} amplitude and phase are fixed to the model values.
- All the V_{ub} *phases* are fixed to the model values.



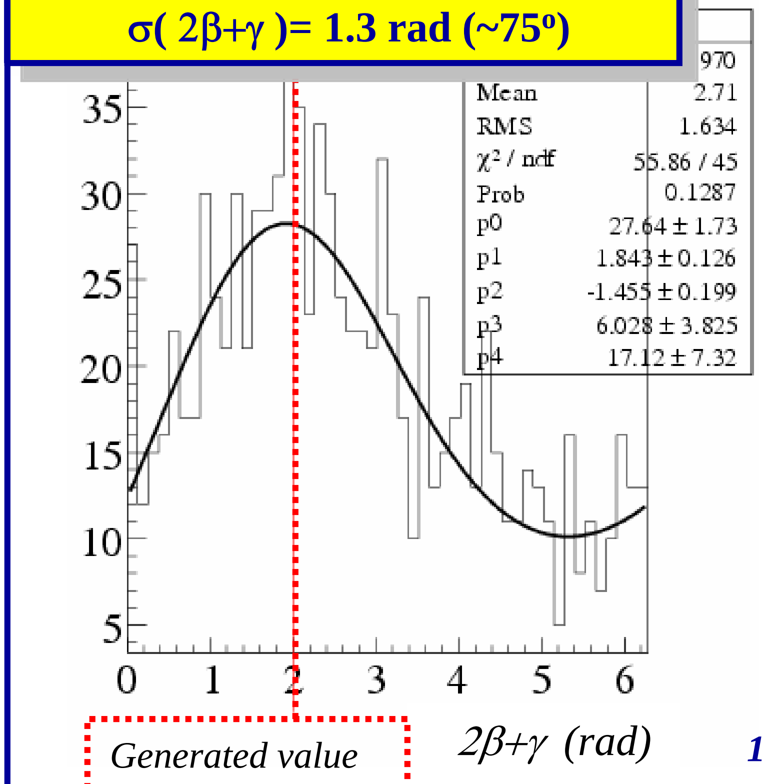
TOY MONTECARLO @ 354 fb^{-1}

V_{cb} amplitudes are determined with ~30% error, but still a bias for *D**(2300)(0⁺)*.

Also V_{cb} phases are determined.

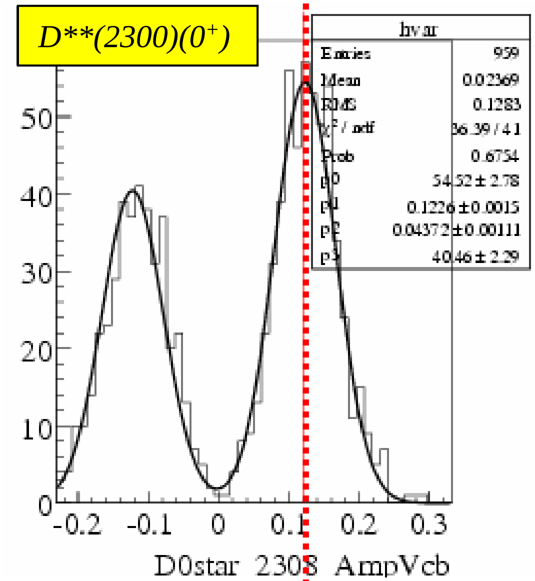


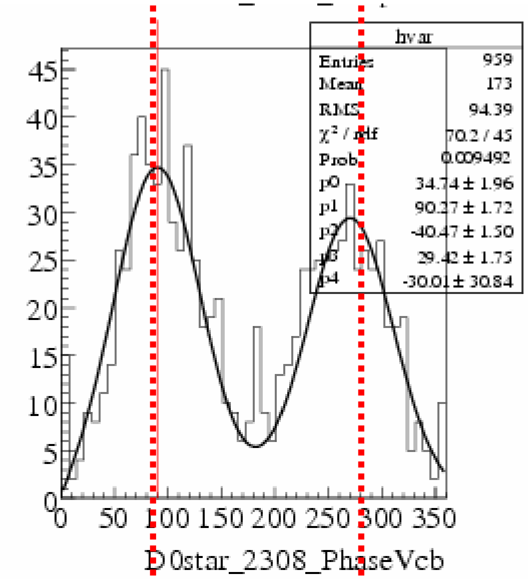
The error on 2β+γ is:
σ(2β+γ)= 1.3 rad (~75º)



TOY MONTECARLO @ ~1 ab^{-1}

*D**(2300)(0^+)*

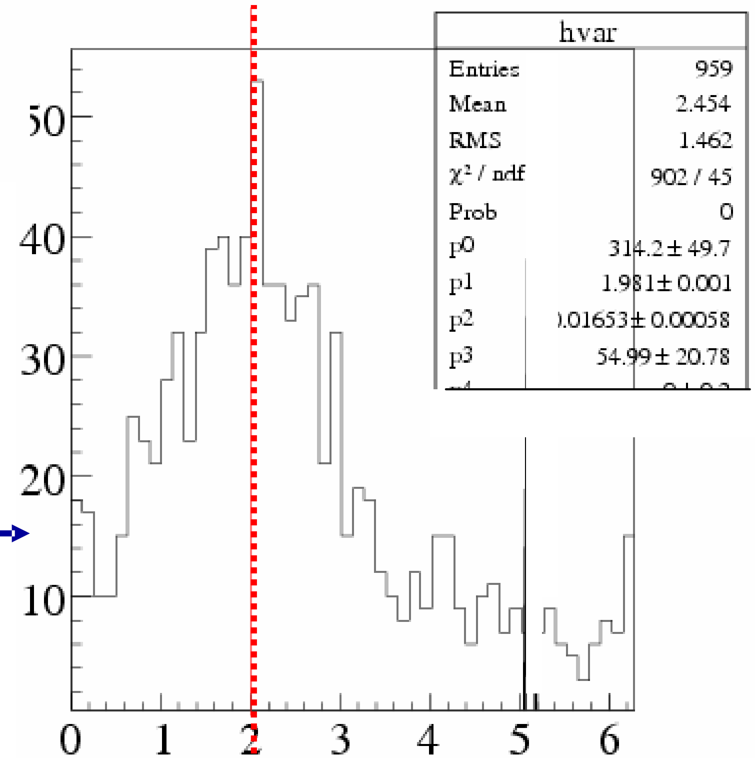




Generated values

No significant biases in amplitudes and phases determination.

The error on 2β+γ is:
$\sigma(2\beta+\gamma) = 1$ rad (~57°)



Generated value

TOY MONTECARLO @ ~10 ab^{-1} !!!

All amplitudes and phases are correctly determined.

	Fitted values				*Generation values*			
	$a(V_{cb})$	$\phi(V_{cb})^o$	$a(V_{ub})$	$\phi(V_{ub})^o$	$a(V_{cb})$	$\phi(V_{cb})^o$	$a(V_{ub})$	$\phi(V_{ub})^o$
$D_{s2}(2573)^{\pm}$	-	-	0.002 ± 0.011	0. ± 155	-	-	0.02	
$D_2^*(2460)^0$	-0.111 ± 0.010	207 ± 7	0.046 ± 0.019	46 ± 26	0.12	30	0.048	30
$D_0(2308)^0$	-0.128 ± 0.017	252 ± 11	0.047±0.023	38 ± 31	0.12	70	0.048	90
$K^*(892)^{\pm}$	fixed	fixed	-	-	1	0	-	-
$K_0^*(1430)^{\pm}$	0.602 ± 0.024	81 ± 2.2	-	-	0.6	80	-	-
$K_2^*(1430)^{\pm}$	0.197 ± 0.035	0. ± 2	-	-	0.2	0	-	-
$K^*(1680)^{\pm}$	0.301 ± 0.011	28 ± 3.6	-	-	0.3	30	-	-
"Non Resonant"	0.093 ± 0.019	357 ± 13	0.070 ± 0.030	48 ± 24	0.07	0	0.028	30

$$2\beta+\gamma = (1.93 \pm 0.25)\ rad$$
$$= (111 \pm 14)^o$$

Reality could be different, depending on the real relative abundances of the intermediate resonances contributing to the final state…

CONCLUSIONS

The time dependent Dalitz analysis of the $B^0 \to D^- K^0 \pi^+$ decays allows to bound the weak phase $2\beta+\gamma$.

- This measurement does not rely, at high statistic, on any theoretical assumption.
- $2\beta+\gamma$ can be determined with only 2 fold ambiguities.
- The interference could be large in some regions of the Dalitz plot.
- The analysis will give the knowledge of the V_{cb} and V_{ub} parts of the Dalitz plot.

Crucial points for a precise determination are:

- The contribution of the $D^{**}(2300)(0^+)$, $D^{**}(2460)(2^+)$.
- The level of backgrounds.

BACKUP

SIGNAL TIME-DALITZ LIKELIHOOD

	$D^- K^0 \pi^+$ final state	$D^+ K^0 \pi^-$ final state
V_{cb} contribution	$< D^- K^0 \pi^+ \vert T \vert B^0 >= A_{c_i} e^{i\delta_{c_i}}$	$< D^+ K^0 \pi^- \vert T \vert \overline{B}^0 >= A_{c_i} e^{i\delta_{c_i}}$
V_{ub} contribution	$< D^- K^0 \pi^+ \vert T \vert \overline{B}^0 >= A_{u_i} e^{i\delta_{u_i} - i\gamma}$	$< D^+ K^0 \pi^- \vert T \vert B^0 >= A_{u_i} e^{i\delta_{u_i} + i\gamma}$

Amplitude — strong phase — Breit Wigner of resonance

$$A_{c_i(u_i)} e^{i\delta_{c_i(u_i)}} = \sum_j a_j \cdot e^{i \cdot \delta_j} \cdot BW_j(m, \Gamma, s)$$

$$\Pr\left(B^0 \to D^+ K_s^0 \pi^- \right) = \frac{|A_{c_i}|^2 + |A_{u_i}|^2}{2} e^{-\Gamma t} \left\{ 1 + C_i \cos(\Delta m \cdot t) + S_i^+ \sin(\Delta m \cdot t) \right\}$$

$$\Pr\left(\overline{B}^0 \to D^+ K_s^0 \pi^- \right) = \frac{|A_{c_i}|^2 + |A_{u_i}|^2}{2} e^{-\Gamma t} \left\{ 1 - C_i \cos(\Delta m \cdot t) - S_i^+ \sin(\Delta m \cdot t) \right\}$$

$$\Pr\left(B^0 \to D^- K_s^0 \pi^+ \right) = \frac{|A_{c_i}|^2 + |A_{u_i}|^2}{2} e^{-\Gamma t} \left\{ 1 - C_i \cos(\Delta m \cdot t) + S_i^- \sin(\Delta m \cdot t) \right\}$$

$$\Pr\left(\overline{B}^0 \to D^- K_s^0 \pi^+ \right) = \frac{|A_{c_i}|^2 + |A_{u_i}|^2}{2} e^{-\Gamma t} \left\{ 1 + C_i \cos(\Delta m \cdot t) - S_i^- \sin(\Delta m \cdot t) \right\}$$

$$C_i = \frac{|A_{c_i}|^2 - |A_{u_i}|^2}{|A_{c_i}|^2 + |A_{u_i}|^2} \qquad S_i^+ = \frac{2\,\mathrm{Im}(A_{c_i} A_{u_i}^* e^{i(2\beta+\gamma)})}{|A_{c_i}|^2 + |A_{u_i}|^2} \qquad S_i^- = \frac{2\,\mathrm{Im}(A_{c_i}^* A_{u_i} e^{i(2\beta+\gamma)})}{|A_{c_i}|^2 + |A_{u_i}|^2}$$

TIME DEPENDENT DALITZ PDF

Finale state	$D^- K^0 \pi^+$	$D^+ K^0 \pi^-$
V_{cb} **contribution**	$< D^- K^0 \pi^+ \mid T \mid B^0 >= A_{c_k} e^{i\delta_{c_k}}$	$< D^+ K^0 \pi^- \mid T \mid \overline{B}^0 >= A_{c_k} e^{i\delta_{c_k}}$
V_{ub} **contribution**	$< D^- K^0 \pi^+ \mid T \mid \overline{B}^0 >= A_{u_k} e^{i\delta_{u_k} - i\gamma}$	$< D^+ K^0 \pi^- \mid T \mid B^0 >= A_{u_k} e^{i\delta_{u_k} + i\gamma}$

Amplitude Strong phase Breit Wigner

$$A_{c_k(u_k)} e^{i\delta_{c_k(u_k)}} = \sum_j a_j \cdot e^{i\cdot\delta_j} \cdot BW_{jk}(m, \Gamma, s)$$

$$P^{TAG}_{\eta,k}(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau}}}{4\tau} \frac{A^2_{c_k} + A^2_{u_k}}{2} \left\{ 1 - \eta S^k_f \sin(\Delta m \cdot \Delta t) + \eta C^k \cos(\Delta m \cdot \Delta t) \right\}$$

$$B_{tag} = \begin{cases} B^0 \Rightarrow (\eta = -1) \\ \overline{B}^0 \Rightarrow (\eta = +1) \end{cases}$$

$$C^k = \frac{A^2_{c_k} - A^2_{u_k}}{A^2_{c_k} + A^2_{u_k}} \qquad S^k_{D^+ K^0_S \pi^-} = \frac{2\,\mathrm{Im}(A_{c_k} A_{u_k} e^{i(2\beta+\gamma)+i(\delta_{c_k} - \delta_{u_k})})}{A^2_{c_k} + A^2_{u_k}} \qquad S^k_{D^- K^0_S \pi^+} = \frac{2\,\mathrm{Im}(A_{c_k} A_{u_k} e^{i(2\beta+\gamma)-i(\delta_{c_k} - \delta_{u_k})})}{A^2_{c_k} + A^2_{u_k}}$$

Untagged events are included in the fit since they help in the amplitudes and phases determination.

$$P^{UNTAG}_k(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau}}}{4\tau} \frac{A^2_{c_k} + A^2_{u_k}}{2}$$