Prospects of γ Measurement Using $B^0 \rightarrow D^0 K^{*0}$ Decays at LHCb

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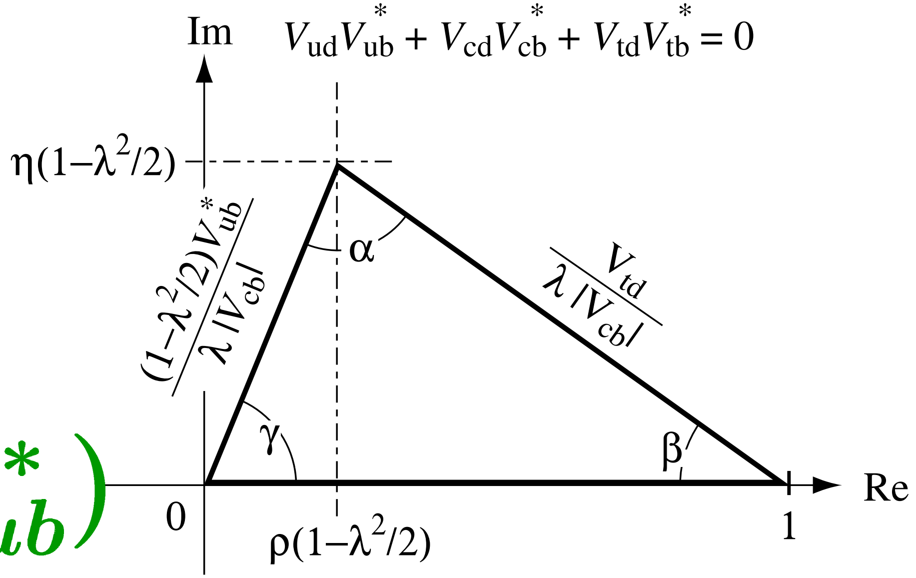
- ✓ **CP Violation**
- ✓ **How to extract γ using $B^0 \rightarrow D^0 K^{*0}$ decays**
- ✓ **The LHCb experiment**
- ✓ **MC data analysis**
- ✓ **Sensitivity Studies**

CP Violation

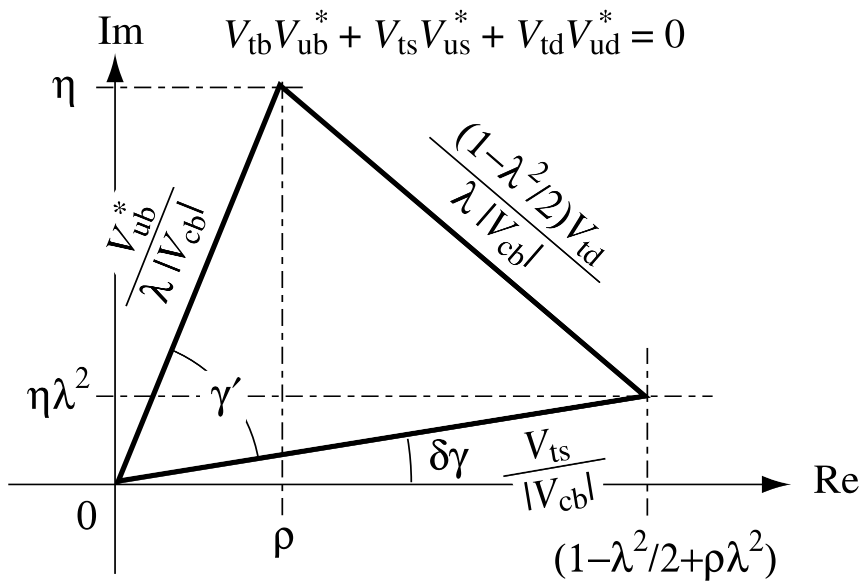
CKM Matrix

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



$$\gamma = \arg(V_{ub}^*)$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0,$$
$$V_{td}V_{ud}^* + V_{ts}V_{us}^* + V_{tb}V_{ub}^* = 0.$$



$50^\circ < \gamma < 72^\circ$ (CKM Fit)

How to extract γ

$$A_1 \equiv A(\mathrm{B}^0 \rightarrow \overline{\mathrm{D}}^0 \mathrm{K}^{*0}) \propto V_{cb}^* V_{us} e^{i\delta_1} \mathcal{A}_1$$
$$A_2 \equiv A(\mathrm{B}^0 \rightarrow \mathrm{D}^0 \mathrm{K}^{*0}) \propto V_{ub}^* V_{cs} e^{i\delta_2} \mathcal{A}_2$$

$$\Rightarrow |A_1| = (\rho^2 + \eta^2)^{-\frac{1}{2}} e^{i\gamma} e^{i\delta_2 - i\delta_1} |A_2|$$

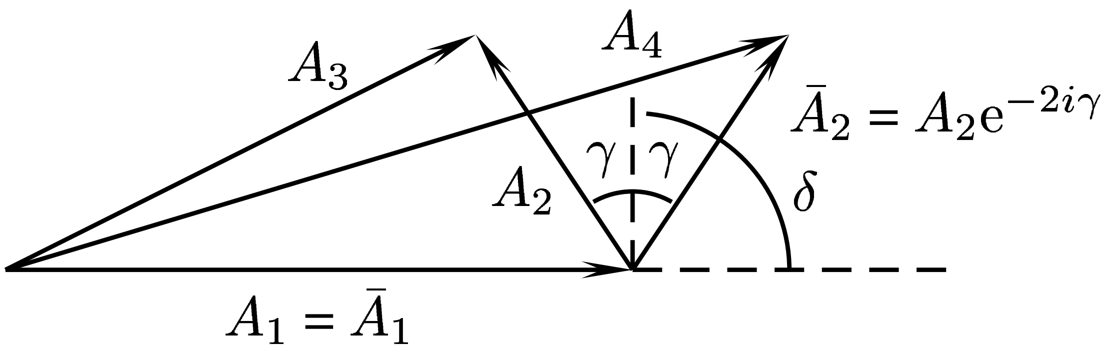
$$\mathrm{D}^0 \rightarrow \mathrm{K}^+\mathrm{K}^-, \pi^+\pi^- \leftarrow \overline{\mathrm{D}}^0$$
$$\mathrm{D}^0 \rightarrow \mathrm{D}_{\mathrm{CP}} \leftarrow \overline{\mathrm{D}}^0$$
$$\mathrm{D}_{\mathrm{CP}} = \frac{1}{\sqrt{2}}(\mathrm{D}^0 + \overline{\mathrm{D}}^0)$$

How to Extract γ

$$A(\mathrm{B}^0 \to \mathrm{D}_{\mathrm{CP}}\mathrm{K}^{*0}) = \frac{1}{\sqrt{2}}[A(\mathrm{B}^0 \to \overline{\mathrm{D}}^0\mathrm{K}^{*0}) + A(\mathrm{B}^0 \to \mathrm{D}^0\,\mathrm{K}^{*0})]$$
$$= \frac{1}{\sqrt{2}}[A_1 + A_2 \mathrm{e}^{i(\delta+\gamma)}] \equiv \frac{1}{\sqrt{2}}A_3$$

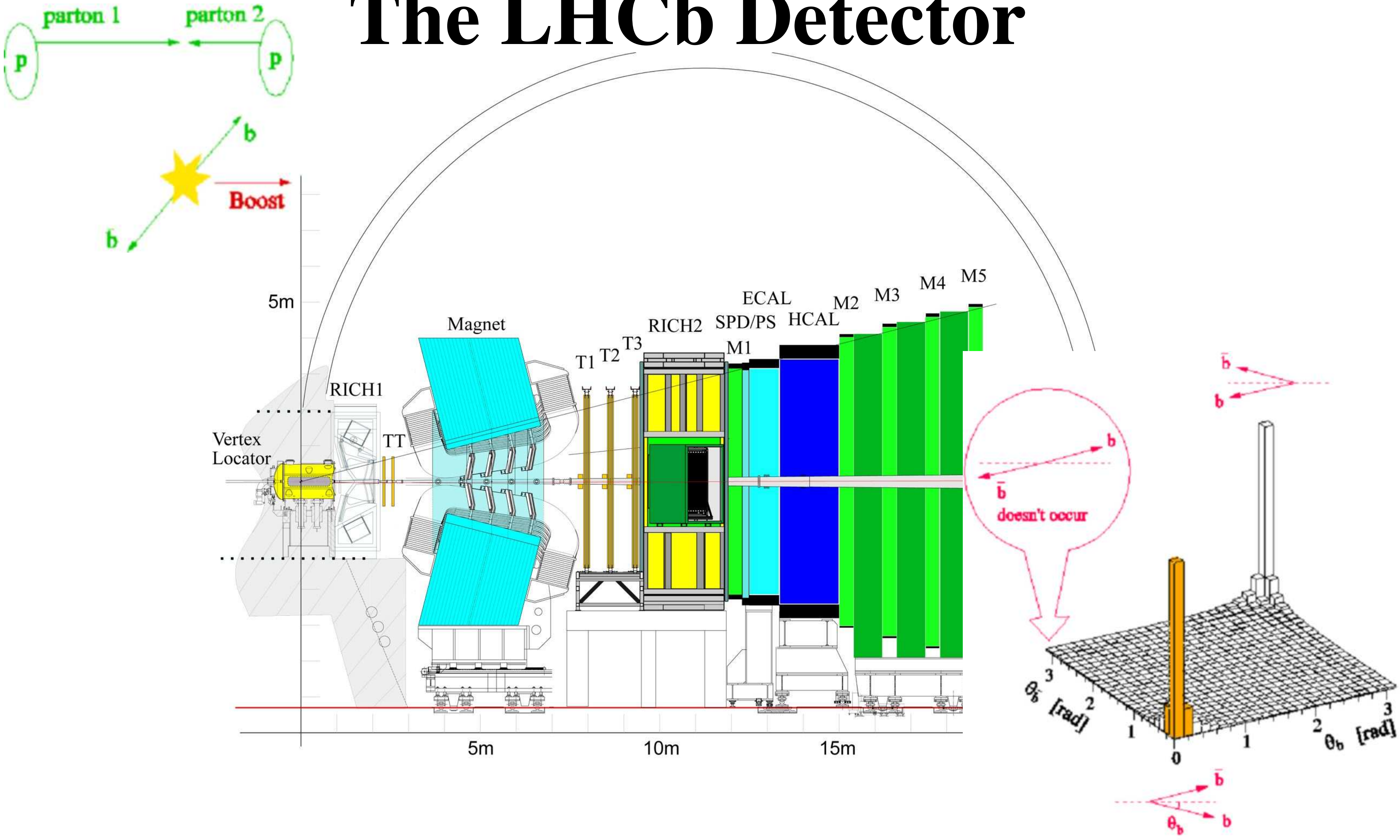
$$A(\overline{\mathrm{B}}^0 \to \mathrm{D}_{\mathrm{CP}}\overline{\mathrm{K}}^{*0}) = \frac{1}{\sqrt{2}}[A(\overline{\mathrm{B}}^0 \to \mathrm{D}^0\overline{\mathrm{K}}^{*0}) + A(\overline{\mathrm{B}}^0 \to \overline{\mathrm{D}}^0\overline{\mathrm{K}}^{*0})]$$
$$= \frac{1}{\sqrt{2}}[A_1 + A_2 \mathrm{e}^{i(\delta-\gamma)}] \equiv \frac{1}{\sqrt{2}}A_4$$

$$\cos(\delta+\gamma) = \frac{A_3^2 - A_1^2 - A_2^2}{2A_1A_2}$$
$$\cos(\delta-\gamma) = \frac{A_4^2 - A_1^2 - A_2^2}{2A_1A_2}$$



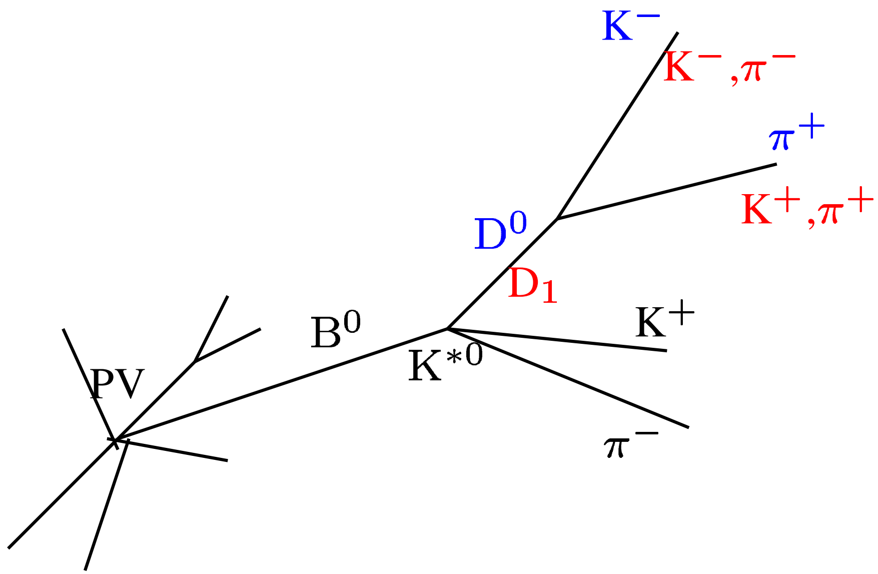
It's possible to extract γ measuring only decay rates!

The LHCb Detector



B^0 Reconstruction

- 3 Different sets of cuts
  to select the different D^0 final states
- Reconstructed K^{*0} and D^0 tracks
  to fit a vertex with a maximum χ^2
- Kinematical cuts are done
  to require this event topology
- B^0 has to come from the PV
- K^{*0}, D^0, K, π are required not to come from the PV



Selection Results

Channel	Analised	$\varepsilon_{\rm tot}$ (%)	Event per year	B/S
$B^0 \rightarrow \overline{D}^0(K^+\pi^-)K^{*0}$	49.5k	0.31(3)	3.0(3)k	[0, 0.58]
$B^0 \rightarrow D_{CP}(K^+K^-)K^{*0}$	49k	0.35(3)	0.540(45)k	[0, 2.93]
$B^0 \rightarrow D_{CP}(\pi^+\pi^-)K^{*0}$	30k	0.41(4)	0.221(22)k	[0, 8.51]

0 events selected out of 10M $b\overline{b}$ *inclusive* sample
in a $\pm$ 500 MeV/c^2 mass window, around known B^0 mass.
this corresponds to 4 min of real data taking!

γ Sensitivity Studies

- Two different approaches were used to estimate the sensitivity on γ:

  Fast Monte Carlo

  Joint Probability density function

- the uncertainty on the amplitudes is given by:

$$\sigma_A = \frac{1}{2}\sqrt{1 + B/S}\,\frac{1}{\sqrt{S}}A,$$

  were we assume background rate at half of the B/S upper limit.

- A_3 and A_4, and their uncertainties are obtained with a γ and δ first guess.

- The $\mathrm{B}^0 \rightarrow \mathrm{D_{CP}}(\mathrm{K}^+\mathrm{K}^-)\mathrm{K}^{*0}$ and $\mathrm{B}^0 \rightarrow \mathrm{D_{CP}}(\pi^+\pi^-)\mathrm{K}^{*0}$ are statistically combined to give the best estimate on the $\mathrm{B}^0 \rightarrow \mathrm{D_{CP}}\mathrm{K}^{*0}$ amplitude

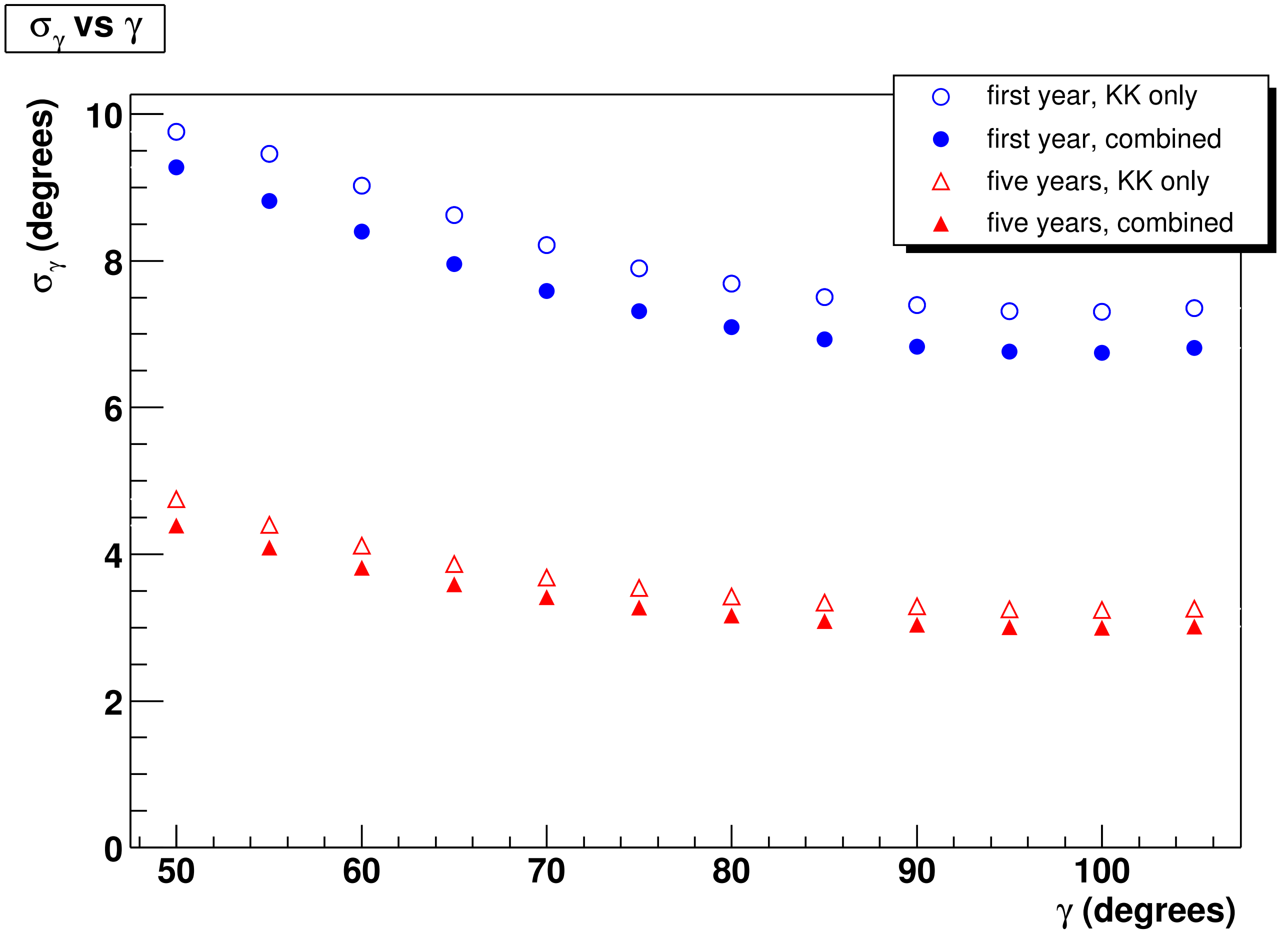
Fast Monte Carlo

- ✗ A random number based on a gaussian is added to each amplitude according to its respective uncertainty.
- ✗ γ is then extracted using:

$$\gamma = \frac{1}{2}\left\{ \cos^{-1}\left(\frac{A_3^2 - A_1^2 - A_2^2}{2A_1A_2}\right) - \cos^{-1}\left(\frac{A_4^2 - A_1^2 - A_2^2}{2A_1A_2}\right)\right\},$$

- ✗ this procedure is repeated 100000 times
- ✗ A gaussian fit is performed to the final γ distribution and the uncertainty is obtained from the width.
- ✗ IF $|\cos(\delta + \gamma)|$ or $|\cos(\delta - \gamma)|$ are greater than 1 the event is counted as a failure.

γ Uncertainty for different γ guesses



Joint Probability Density Function

The Joint Probability Density Function (JPDF) of γ and δ is obtained from the χ^2 function of the 4 independent sides of the triangle.

$$\chi^2(A_1, A_2, A_3, A_4) = \sum_{i=1}^{4} \Big(\frac{A_i - \bar{A}_i}{\sigma(\bar{A}_i)}\Big)^2,$$

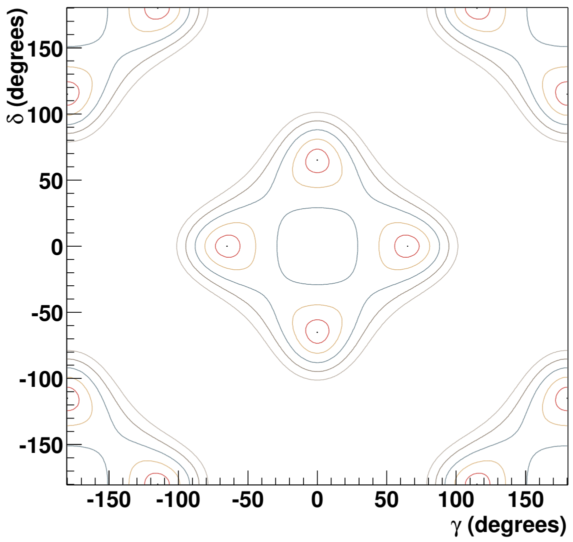
Where $\bar{A}_i$ represent the expected values A_i given a fixed γ and δ value. For each γ and δ a numerical integration is performed to obtain the JPDF:

$$\mathcal{J}(\gamma, \delta) = N \int dA_1 \int dA_2 \mathrm{e}^{-\frac{1}{2}\chi^2(A_1, A_2, \gamma, \delta)}$$

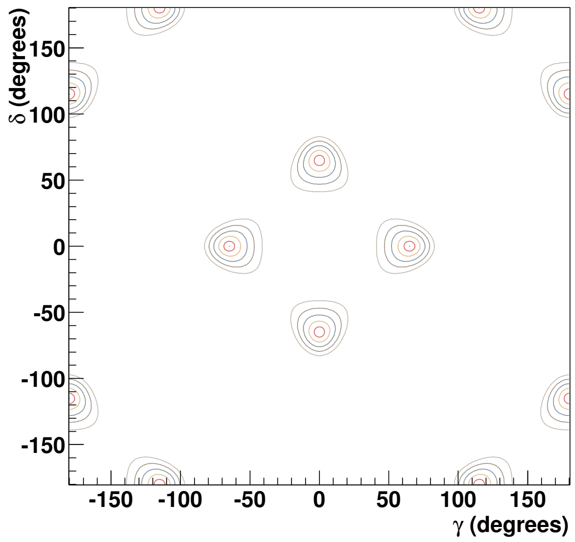
The results are plotted as the 3rd coordinate of a 2D histogram, δ vs γ. The $n\sigma$ contours are given by:

$$C_n = \mathcal{J}_{max} \mathrm{e}^{-\frac{1}{2}\mathrm{n}^2}$$

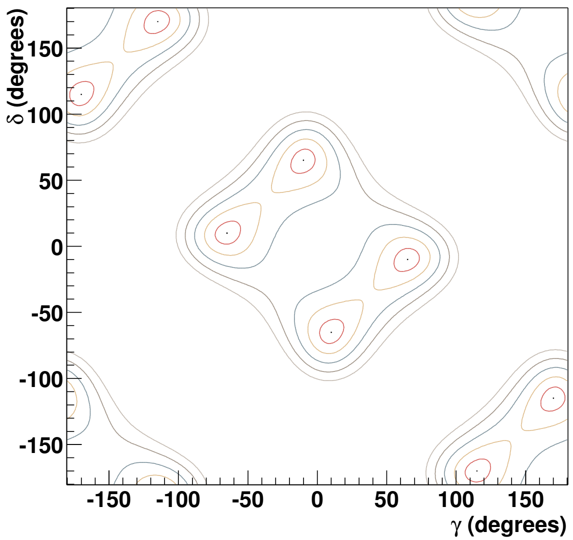
JPDF Results



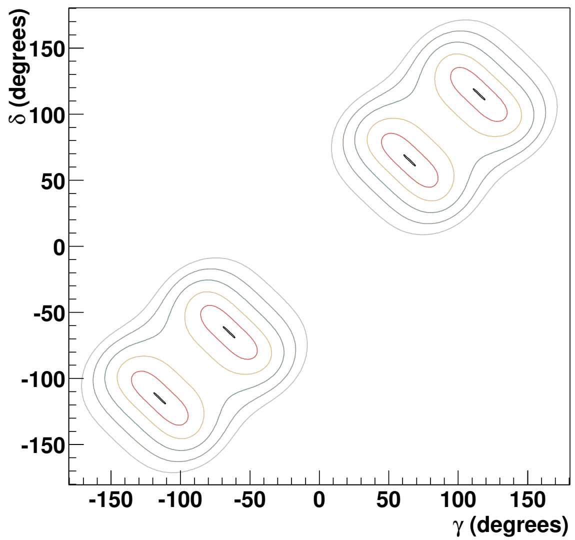
γ=65°
δ=0°
1 year



γ=65°
δ=0°
5 years



γ=65°
δ=-10°
1 year



γ=65°
δ=65°
1 years

Results Summary

γ	55°	65°	75°	85°	95°	105°
1 year						
MC σ_γ	8.9°	8.0°	7.3°	6.9°	6.7°	6.8°
JPDF σ_γ	10.1°	8.4°	8.1°	7.6°	7.4°	7.5°
5 years						
MC σ_γ	4.0°	3.6°	3.3°	3.1°	3.0°	3.0°
JPDF σ_γ	4.5°	3.9°	3.6°	3.4°	3.3°	3.4°

Conclusion

✓ We estimate that LHCb will be able to reconstruct correctly: ≈ 3000 $B^0 \rightarrow \overline{D}^0(K^+\pi^-)K^{*0}$, ≈ 540 $B^0 \rightarrow D_{CP}(K^+K^-)K^{*0}$ and ≈ 221 $B^0 \rightarrow D_{CP}(\pi^+\pi^-)K^{*0}$ per year

✓ Two methods were used to estimate the uncertainty on γ, giving compatible results.

✓ The overall precision to measure γ is about from 7° to 8° for the first year of data taking and from 3° to 4° in 5 years.