Time dependent measurements of gamma at LHCb

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on behalf of LHCb collaboration

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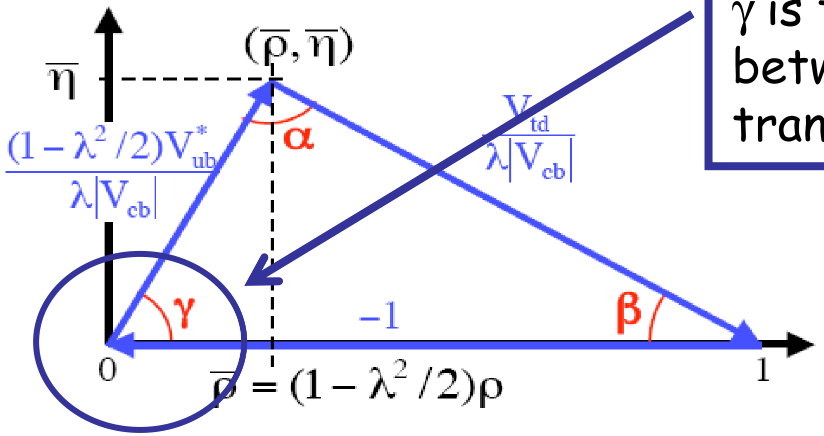
Overview

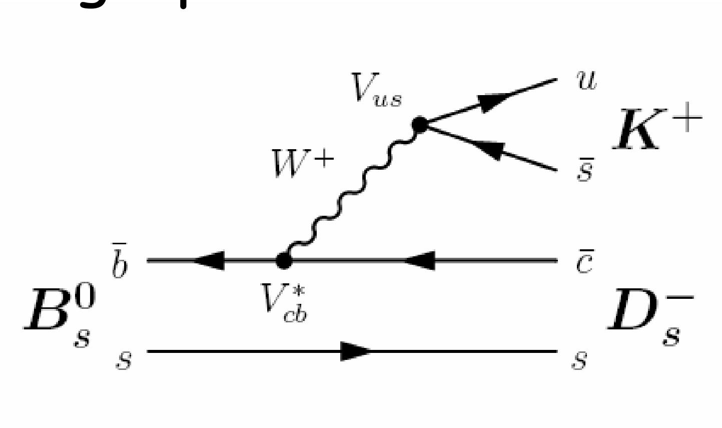
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



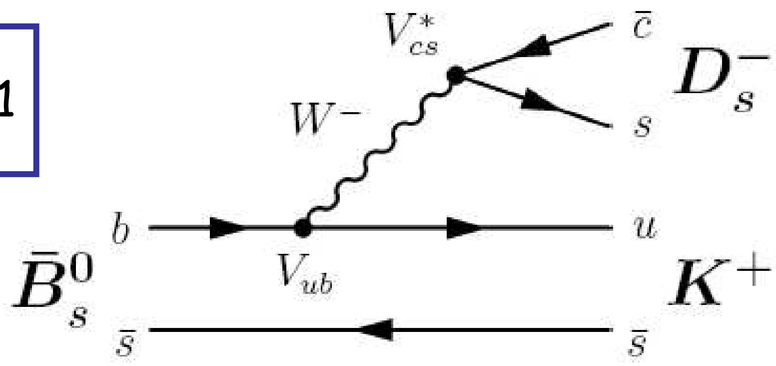
γ is the weak phase between b→u b→ c transition

- LHCb will explore different modes to measure γ through time dependent analysis
- Will present expected sensitivities from the decays:
  - $B_s \to D_sK$
  - $B^0 \to D\pi$
  - Combined $B_s \to D_sK$ and $B^0 \to D\pi$ under U-spin symmetry assumption
- Preliminary studies are also underway
  - $B_s \to D_sK^*$ and $B^0 \to D\rho$
  - $B_s \to D_sK\pi\pi$

- Consider tree diagrams +cc and the $B^0(s) \leftrightarrow \bar{B}^0(s)$ mixing graphs



T1



T2

- Interference between the tree diagrams will allows through a time dependent analysis a clean theoretical extraction of $\gamma+\phi_{d(s)}$
  - $\phi_{d(s)}$ is the week mixing phase associated with the mixing which can be measured with high precision
  - the mixing phases ϕ_d (ϕ_s) is (will be) precisely measured from $B_d \to J/\psi K_S$ ($B_s \to J/\psi\phi$, see Gaia Lanfranchi's talk)
- This allows to measure γ!

Asymmetries

- From four time decay rates is possible to construct two asymmetries for example in the $B_s \rightarrow D_s K$ case

$$\mathcal{A}_{CP}(D_s^+ K^-) \equiv \frac{B_s^0 \to D_s^+ K^- - \overline{B_s^0} \to D_s^+ K^-}{B_s^0 \to D_s^+ K^- + \overline{B_s^0} \to D_s^+ K^-} = \frac{C_s \cos \Delta m_s t + S_s \sin \Delta m_s t}{\cosh(\Delta\Gamma_s t/2) - A_{\Delta\Gamma} \sinh(\Delta\Gamma_s t/2)}$$

$$\mathcal{A}_{CP}(D_s^- K^+) \equiv \frac{B_s^0 \to D_s^- K^+ - \overline{B_s^0} \to D_s^- K^+}{B_s^0 \to D_s^- K^+ + \overline{B_s^0} \to D_s^- K^+} = \frac{\overline{C}_s \cos \Delta m_s t + \overline{S}_s \sin \Delta m_s t}{\cosh(\Delta\Gamma_s t/2) - \overline{A}_{\Delta\Gamma} \sinh(\Delta\Gamma_s t/2)}$$

- 6 Observables, S, $\overline{S}$, C, $\overline{C}$, $A_{\Delta\Gamma}$, $\overline{A}_{\Delta\Gamma}$
  - Using the untagged analysis is possible to measure $A_{\Delta\Gamma}$, $\overline{A}_{\Delta\Gamma}$
- For B_d case we only have 4 observables: C_d, S_d, $\overline{C}_d$, $\overline{S}_d$ ($\Delta\Gamma_d$ very small !)

Observables

- Observables are function of γ, ϕ_q, δ_q and x_q

$$S = \frac{2x_q \sin(\delta_q + \phi_q - \gamma)}{(x_q^2 + 1)} \qquad C_q = -\frac{1 - x_q^2}{1 + x_q^2}$$

- where

$$R_b = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

a_d,a_s are hadronic parameter of the order of 1

$$x_s = R_b a_s \approx 0.4 \qquad x_d = -\left(\frac{\lambda^2 R_b}{1-\lambda^2}\right) a_d \approx 0.02$$

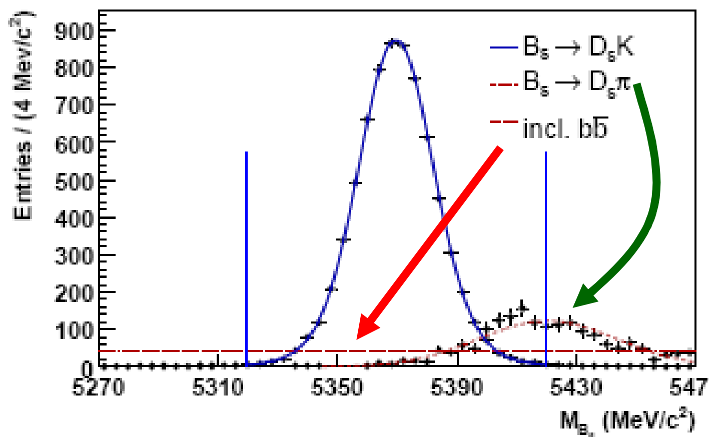
- In principle is possible to extract $x_{d,s}$ from the cosine term
  - x_s is large enough to be fitted from data
  - x_d must be constrained externally
    - Recent BaBar analysis of the decay B→Dπ has estimated x_d from the relation using SU(3) [hep-ex/0803.4296]
- In order to extract γ in this studies we consider an overall 20% theoretical error on x_d
- Improving the statistics and the theoretical knowledge, it is expected to have $\sigma(x_d)$~10% by the end of LHCb data taking

$B_s \rightarrow D_s h$ selection with full LHCb simulation

- Selection studies performed on PYTHIA/EVTGEN/GEANT4
- Simulated samples of signal and background events
- Selection criteria based on:
  - RICH $K^{\pm}$ $\pi^{\pm}$ ID
  - P_T and impact parameter of K and π
  - B_s and D_s invariant mass
  - B_s and D_s vertex quality
  - B_s and D_s impact parameter with respect all reconstructed primary verteces
  - B_s distance of flight

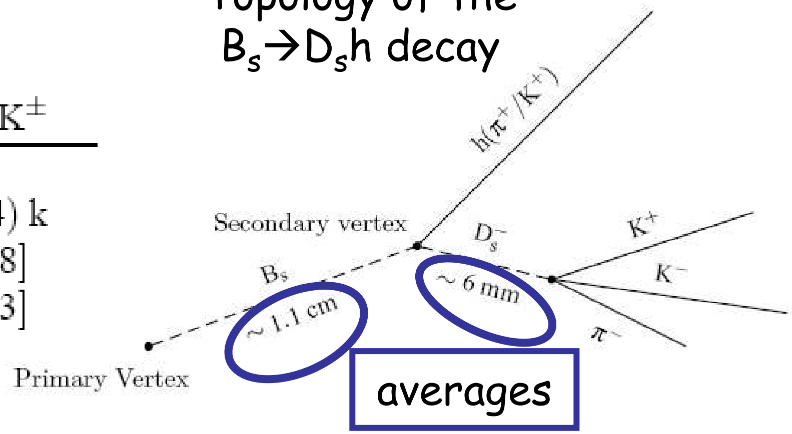
Impressive performance of RICH systems allows clean $B_s \rightarrow D_s K$ and $B_s \rightarrow D_s \pi$ separation

Reconstructed B_s invariant mass after the selection



Plot normalized to $2fb^{-1}$

Topology of the $B_s \rightarrow D_s h$ decay



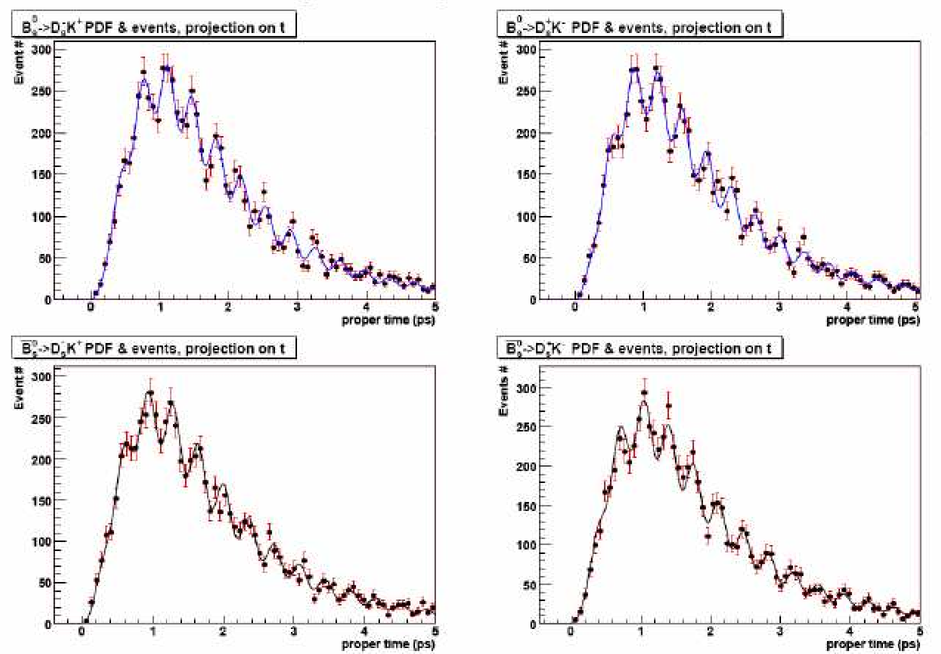
	$B_s \rightarrow D_s^- \pi^+$	$B_s \rightarrow D_s^{\mp} K^{\pm}$
Yield after trigger:	(140 ± 40) k	(6.2 ± 2.4) k
B/S at 90% CL ($b\bar{b}$ combinatorial)	$\in [0.014, 0.05]$	$\in [0, 0.18]$
B/S at 90% CL ($b\bar{b}$ specific)	$\in [0.08, 0.4]$	$\in [0.08, 3]$

$b\bar{b}$ specific background → $B_s \rightarrow D_s l \nu X$, $B_s \rightarrow D_s^* \pi/\rho$

Sensitivity studies on γ from $B_s \rightarrow D_s K$

- Fast Monte Carlo toys performed
  - Events are generated according to the toy MC model based on the LHCb experiment full simulation and selection studies results
- In order to obtained the expected uncertainty on $\gamma+\phi_s$ a simultaneous likelihood fit to the decay time distributions of $B_s \rightarrow D_s K$ and $B_s \rightarrow D_s \pi$ have been performed

Four proper time distributions $B_s \rightarrow D_s K$: generated events and maximized likelihood curves projected onto the proper time axis



	Sensitivity $2fb^{-1}$	Sensitivity $10fb^{-1}$
$\gamma+\phi_s$	10.3°	4.6°
Δm_s	0.007 ps^{-1}	0.003 ps^{-1}

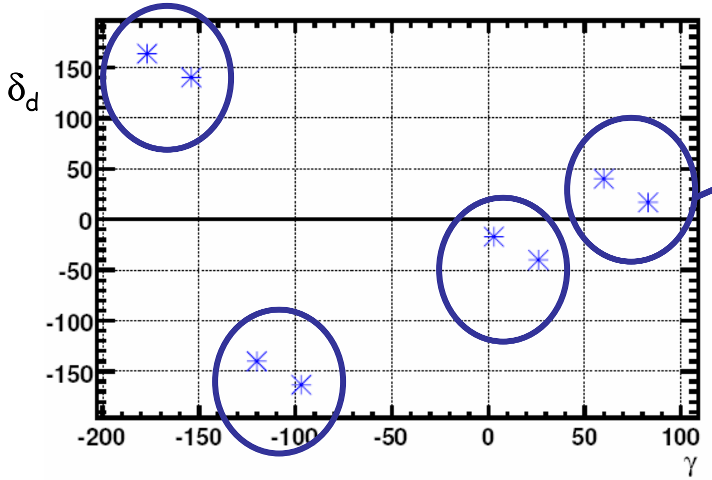
Input values

$\gamma+\phi_s$=60°

Δm_s=17.5 ps^{-1}

Sensitivity studies on γ from $B^0 \to D\pi$

- In addition to the theoretical uncertainties on x_d the extraction of γ from $B^0 \to D\pi$ suffers from a eightfold ambiguity on the extracted value of γ



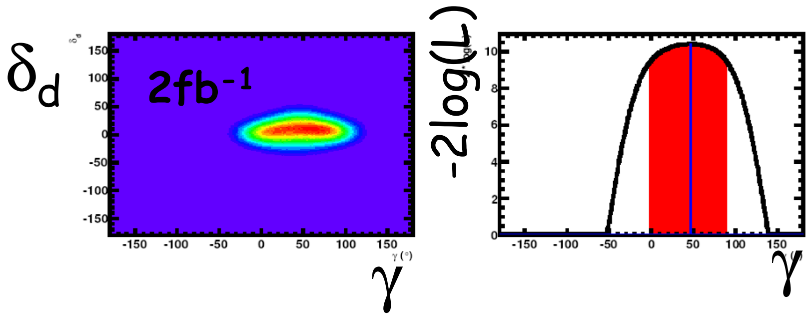
degeneracy of solutions decreases the precision on γ

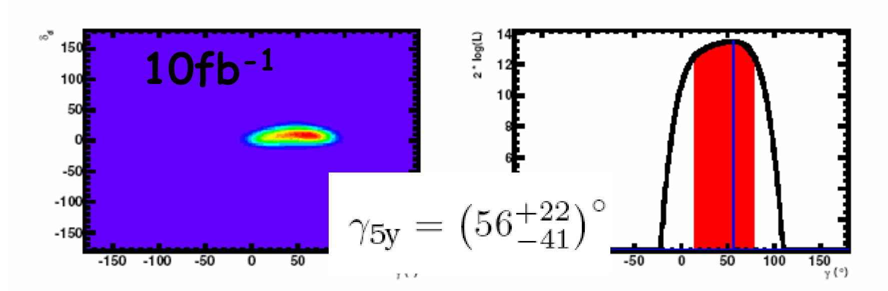
True value for this study γ=60°

- In order to resolve the degenerate solutions one can introduce information from the $B_s \to D_s K$ decay
  - U-spin symmetry can be use to related δ_d to δ_s → $\delta_d = \delta_s$
  - δ_s will be measured with γ from $B_s \to D_s K$ decay
  - The precision on δ_s it expected to be ~10°
  - In the next studies, when U-spin symmetry is used a conservative assumption on $\sigma(\delta_s)$ has been taken to account breaking effect
    - Error of 20° for 2fb^{-1} and 10° for 10fb^{-1}

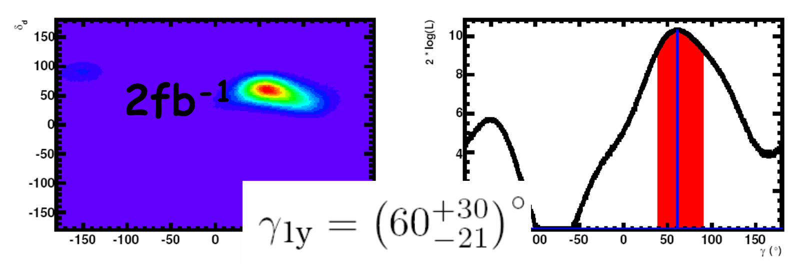
Sensitivity studies on γ from $B^0 \to D\pi$

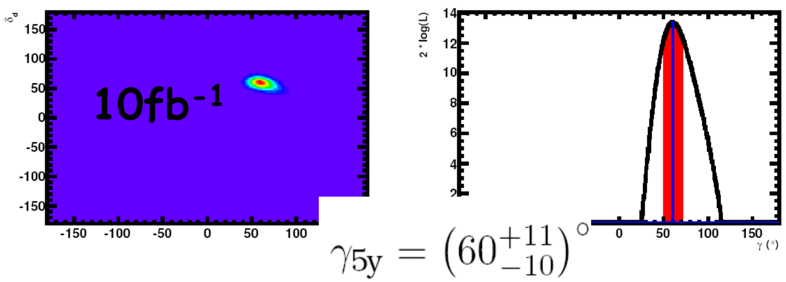
- Based on the full LHCb experiment simulation and signal selection studies toy Monte Carlo studies have been performed in order to evaluate γ sensitivity
  - *Background included*
  - *Assumed exact knowledge of mixing phase ϕ_d*
  - *Assumed U-spin symmetry*
- Scenario 1: γ=60° and δ_d=10°
  - *Small value of strong phase corresponding to factorization limit*





- Scenario 2: γ=60° and δ_d=60° (explores non-factorisable effects)



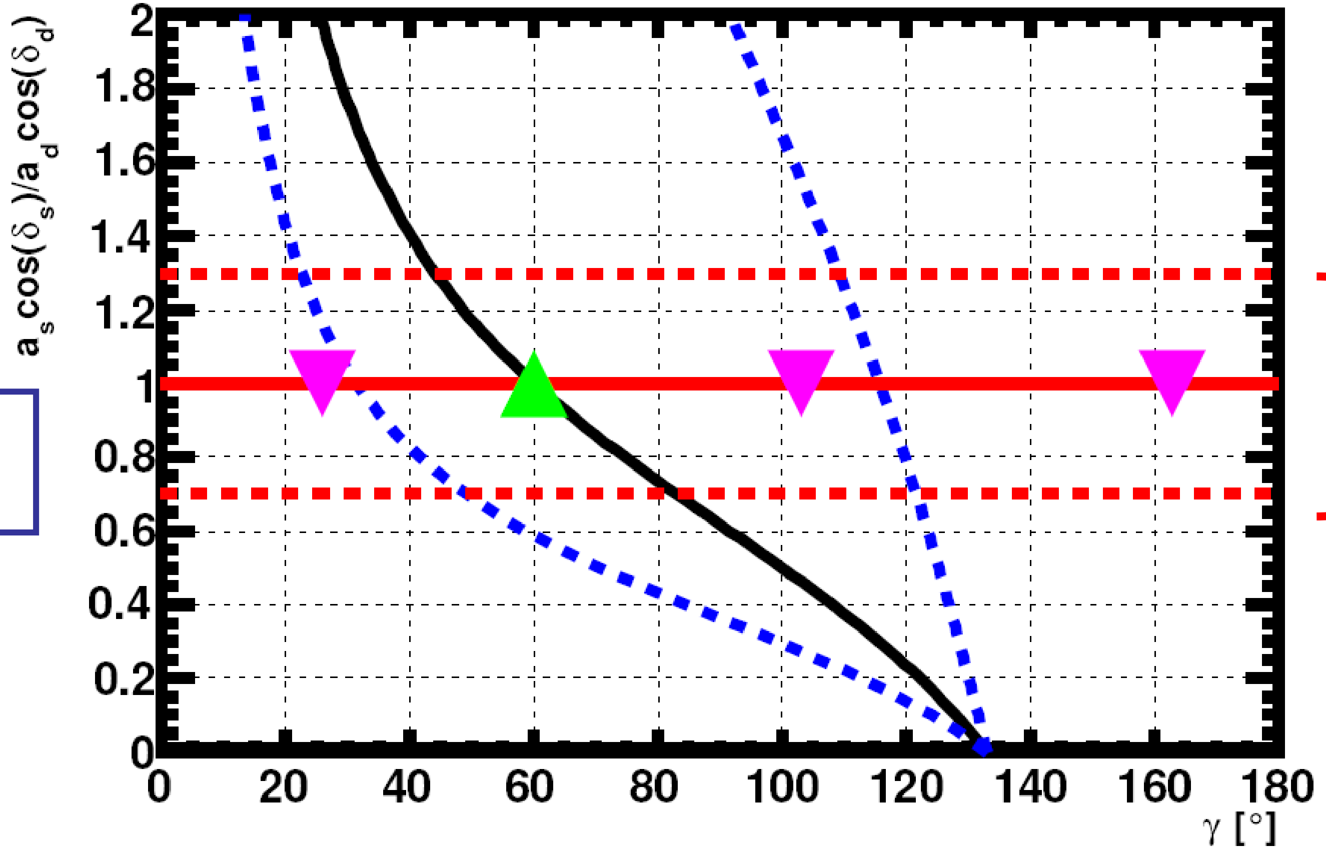


Combined extraction of γ from $B^0 \to D\pi$ and $B_s \to D_s K$

- The combined extraction of γ relies on the U-spin symmetry between the channels $B^0 \to D_d \bar{u}_d$ and $B_s \to D_s \bar{u}_s$
  - Replacing all down quarks in the decay by strange quarks
- It is possible to extract γ unambiguously without any external knowledge of x_d
- Three different scenarios can be considered
  - Strong U-spin assumption: equal strong amplitudes and phases → two relation to extract unambiguously γ
  - Amplitude U-spin assumption: equal strong amplitudes → one relation to extract unambiguously γ
  - Phases U-spin assumption: equal strong amplitudes → one relation to extract unambiguously γ

γ=60° and δ_d=60° (2fb^{-1})

U-spin breaking



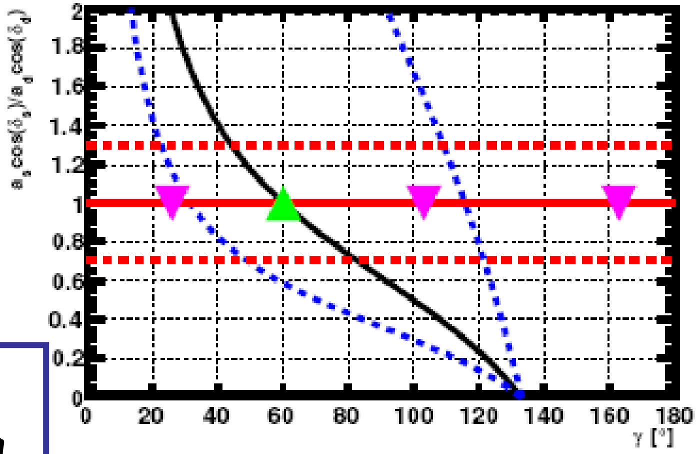
30% U-spin breaking

γ=60° and δ_d=60° (2fb^{-1})

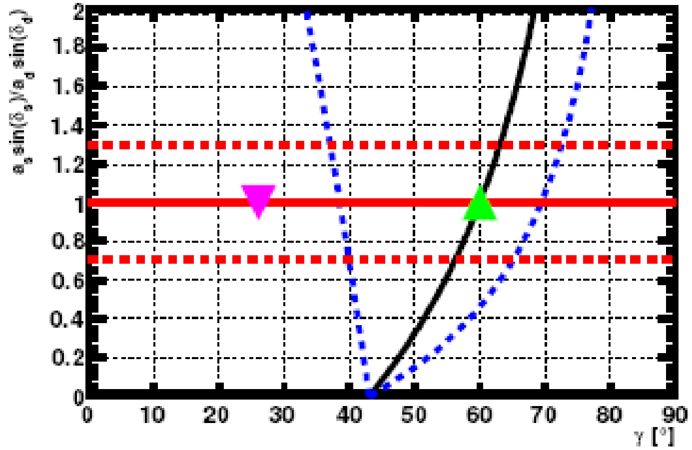
γ-U-spin breaking space

U-spin breaking

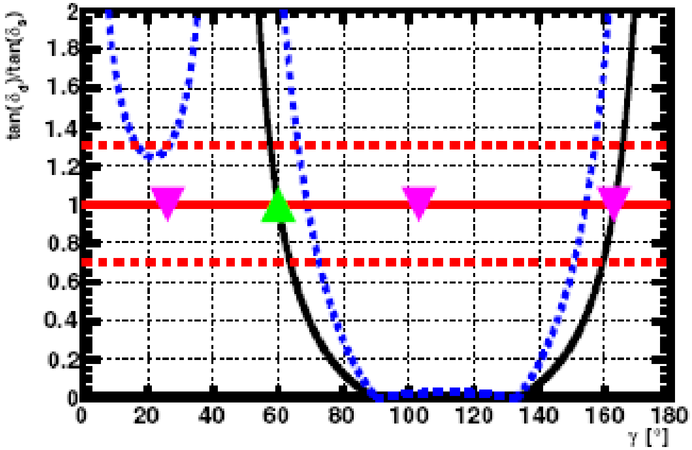
Strong U-spin assumption



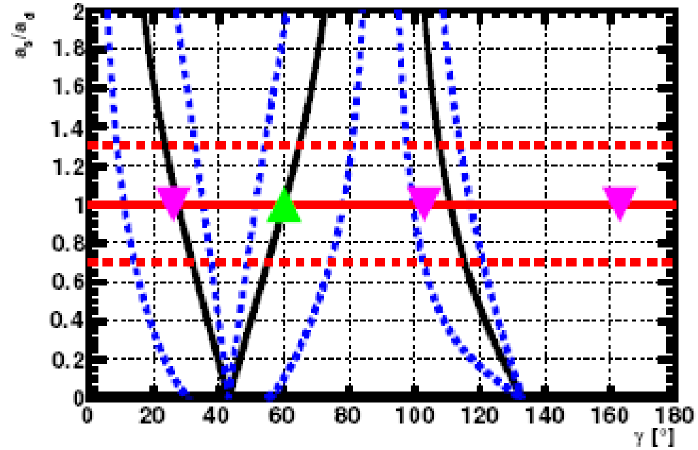
Strong U-spin assumption



Phase U-spin assumption



Amplitude U-spin assumption

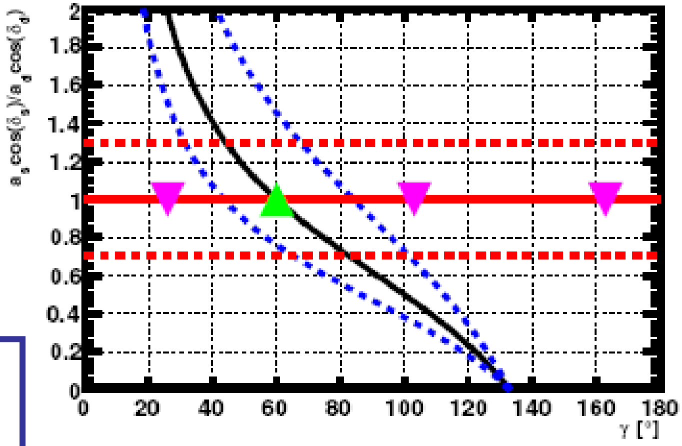


30% U-spin breaking

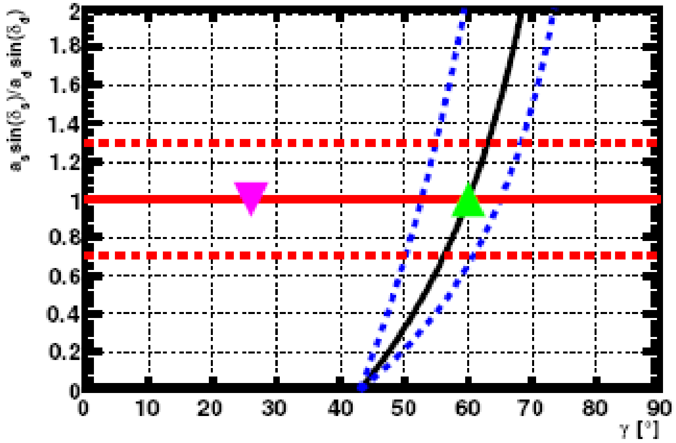
γ=60° and δ_d=60° (10fb^{-1})

γ-U-spin breaking space

Strong U-spin assumption

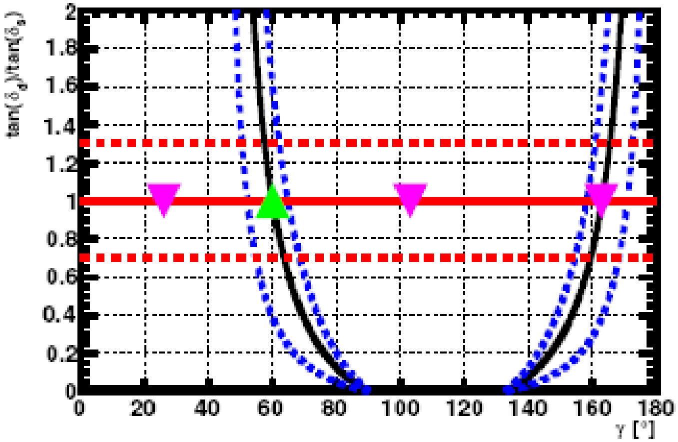


Strong U-spin assumption

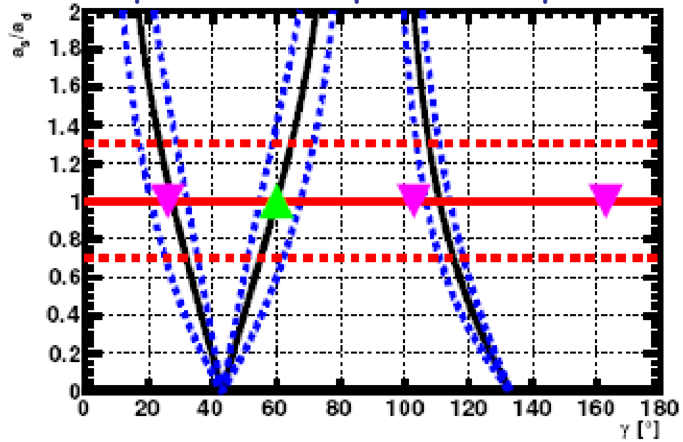


U-spin breaking

Phase U-spin assumption



Amplitude U-spin assumption



30% U-spin breaking

Summary of combined extraction of γ

- The combined U-spin analysis of the channels $B^0 \rightarrow D\pi$ and $B_s \rightarrow D_s K$ allows for an ambiguous extraction of γ under a variety of theoretical assumptions
  - It has the advantage of not requiring x_d to be known
- Performance on γ quoted considers the smallest upper error in any of the four U-spin assumption and similarly for the lower error
- Statistical and systematic error (30% of U-spin breaking) from the same U-spin assumption

	$\sigma_{1y}^{\rm stat}$ (2fb^{-1})	$\sigma_{1y}^{\rm syst}$ (2fb^{-1})	$\sigma_{5y}^{\rm stat}$ (10fb^{-1})	$\sigma_{5y}^{\rm syst}$ (10fb^{-1})
$\gamma = 60°, \delta_{s,d} = 60°$	$-9°, +9°$	$-4°, +3°$	$-5°, +5°$	$\pm 3°$
$\gamma = 60°, \delta_{s,d} = 10°$	$-20°, +30°$	$-10°, +22°$	$-8°, +12°$	$-15°, +4°$

- Even if this combined analysis is outperformed by other analyses at measuring γ it can be used to understand the scale of U-spin breaking
  - Any observable difference between the fitted values of γ can be used to constrain the U-spin breaking parameters

Additional channel: $B_s \to D_s K\pi\pi$

- The final state $B_s \to D_s K\pi\pi$ may contain a non-resonant and several resonant contributions in any given $M(K\pi\pi)$ mass window.
  - It is expected some region dominated by K1
- In general each point in the Dalitz plot has a strong phase difference between the b→c and b→u diagrams and depends on the $\mathcal{D}$ Dalitz plot position
  - Due to the strong phase variation an addition parameter needs to be fit (3 are in the $B_s \to D_s K$ case)
  - 6 observables and 4 unknowns

With the substitution: $A \to A(\mathcal{D}),\ \lambda \to \lambda(\mathcal{D}),\ \delta \to \delta(\mathcal{D})$.

$$\Gamma(B_s^0 \to D_S^- K^+ \pi^- \pi^+) = \int \frac{|A(\mathcal{D})|^2}{2} e^{-t/\tau}[(1+|\lambda(\mathcal{D})|^2)\cosh(\Delta\Gamma_s t/2) + (1-|\lambda(\mathcal{D})|^2)\cos(\Delta m_s t)$$
$$-2|\lambda(\mathcal{D})|\cos(\delta(\mathcal{D})+(\gamma+\phi_s))\sinh(\Delta\Gamma_s t/2) - 2|\lambda(\mathcal{D})|\sin(\delta(\mathcal{D})+(\gamma+\phi_s))\sin(\Delta m_s t)]d\mathcal{D}$$

After integration over the Dalitz plot, we get :

$$\Gamma(B_s^0 \to D_S^- K^+ \pi^- \pi^+) = \frac{|A_{eff}|^2}{2} e^{-t/\tau}[(1+|\lambda_{eff}|^2)\cosh(\Delta\Gamma_s t/2) + (1-|\lambda_{eff}|^2)\cos(\Delta m_s t)$$
$$-2|\lambda'|\cos(\delta_{eff}+(\gamma+\phi_s))\sinh(\Delta\Gamma_s t/2) - 2|\lambda'|\sin(\delta_{eff}+(\gamma+\phi_s))\sin(\Delta m_s t)]$$

Aleksan, Peterson and Soffer, hep-ph/0209194

where:

$$|A_{eff}|^2 = \int |A_f(\mathcal{D})|^2 d\mathcal{D}$$

$$|\lambda_{eff}(\mathcal{D})|^2 = \frac{\int |\lambda(\mathcal{D})|^2 |A_f(\mathcal{D})|^2 d\mathcal{D}}{\int |A_f(\mathcal{D})|^2 d\mathcal{D}}$$

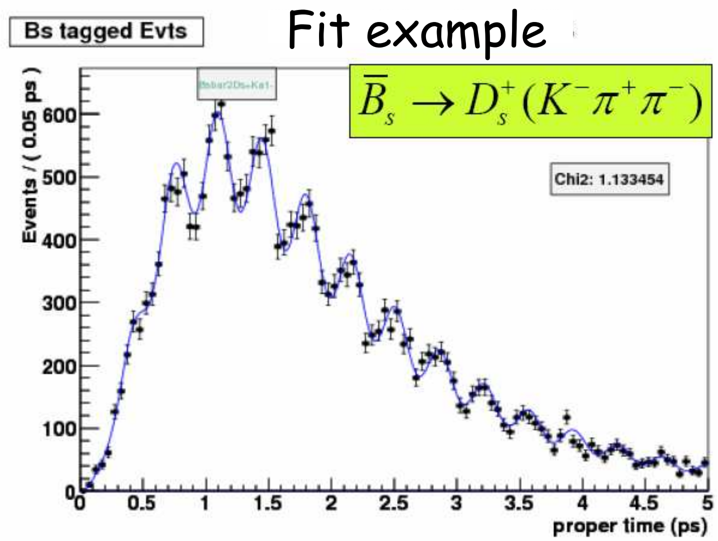
$$\cos\delta_{eff} = \frac{a}{c}, \quad \sin\delta_{eff} = \frac{b}{c}, \quad \lambda' = \frac{c}{|A_{eff}|^2}$$

where:

$$a \equiv \int |A_f(\mathcal{D})|^2 |\lambda(\mathcal{D})| \cos\delta(\mathcal{D}) d\mathcal{D}$$
$$b \equiv \int |A_f(\mathcal{D})|^2 |\lambda(\mathcal{D})| \sin\delta(\mathcal{D}) d\mathcal{D}$$
$$c \equiv \sqrt{a^2+b^2}$$

Additional channel: $B_s \to D_s(K\pi\pi)$

- Preliminary Monte Carlo studies show that is possible to collect with $2fb^{-1}$
  - 16k events if $BR(B_s \to D_s K\pi\pi)/B(B_s \to D_s K) \sim 3$
  - With B/S < 0.9 @ 90 % C.L.
- Preliminary toy MC studies show that $B_s \to D_s K\pi\pi$ looks to be a promising mode to include in the γ measurement
  - $\sigma(\gamma) \sim 5°$, for $B_s \to D_s K$ ($10fb^{-1}$) -vs-
    - $\sigma(\gamma) \sim 13°$, for $Bs \to DsK\pi\pi$ if $BR(B_s \to D_s K\pi\pi)/B(B_s \to D_s K) \sim 3$



$$\frac{B(B^0 \to D^- \pi^+ \pi^- \pi^+)}{B(B^0 \to D^- \pi^+)} \sim 3.0$$

$$\frac{B(B^0 \to D^- a_1(1260)^+, a_1(1260)^- \to \pi^+ \pi^- \pi^+)}{B(B^0 \to D^- \pi^+)} \sim 2.5$$

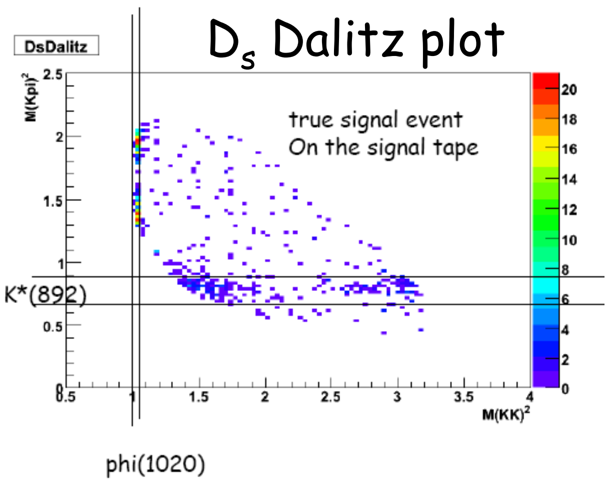
$$Guess \quad \frac{B(B_s \to D_s^- K_1(1270)^+, K_1(1270)^+ \to K^+ \pi^- \pi^+)}{B(B_s \to D_s^- K^+)} \approx 2.5 - 3.0$$

large uncertainties (experimental and theoretical) so a factor of the three enhancements is also considered

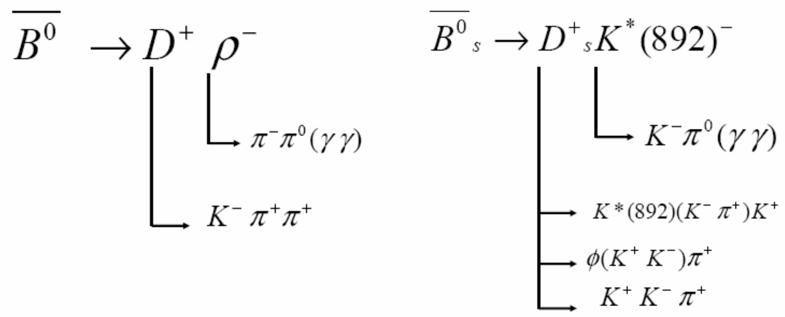
Additional channel: $B_s \to D_s K^*$ and $B \to D\rho$

- $B_s \to D_s K^*$ will be used to extracted γ the same way as $B_s \to D_s K$
- Combined with the $B \to D\rho$ is possible to extract γ with U-spin symmetry assumption in the same way as in $B_s \to D_s K$ and $B \to D\pi$
- Preliminary studies underway,with $2fb^{-1}$ will collect
  - 1M of $B \to D\rho$ with B/S ~ 1.4
  - 3k $B_s \to D_s K^*$ (need more MC statistics to evaluate B/S)

D_s Dalitz plot



Reconstructed modes



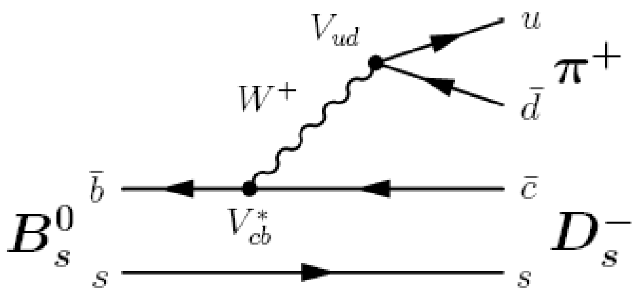
Conclusion

- Time dependent measurements of γ at LHCb are promising
- Sensitivity on γ expected to be 10° (5°) with $2fb^{-1}$ ($10fb^{-1}$) from the time dependent analysis of the decay $B_s \rightarrow D_s K$
  - *Measurements theoretically clear*
- U-spin symmetry relation between $B^0 \rightarrow D\pi$ and $B_s \rightarrow D_s K$ will be useful either to extract γ or understanding the U-spin breaking
- In case of large strong phases the sensitivity on γ is of 9°(5°) with systematic error from U-spin breaking effects of 4° (3°) and $2fb^{-1}$ ($10fb^{-1}$)
- Other modes will be use to measure γ
  - $B_s \rightarrow D_s K\pi\pi$
  - $B_s \rightarrow D_s K^*$ and $B \rightarrow D\rho$
  - $B \rightarrow D^*\pi$

BACKUP

Sensitivity studies on γ from $B_s \to D_s K$

- In order to measure γ from $B_s \to D_s K$, the $B_s \to D_s \pi$ mode can be use to constrain ΔM_s and the wrong tagging fraction
- For the $B_s \to D_s \pi$ only one tree decay exists
  - B_s can only decay instantaneously into $D_s^- \pi^+$ while the decay into $D_s^+ \pi^-$ can only occur after the mixing



- $S = A_{\Delta\Gamma} = 0$ and $C = 1$
- Using the flavour asymmetry

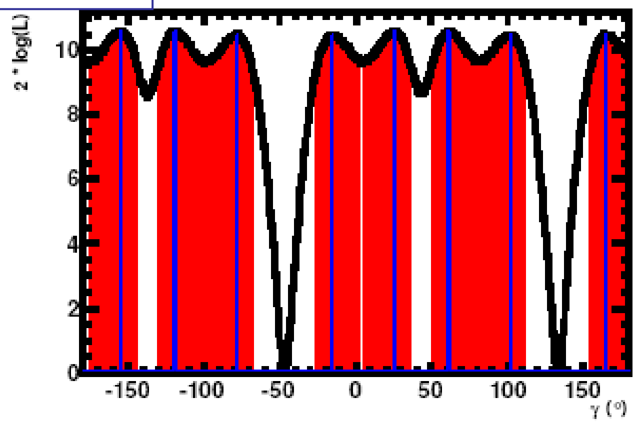
$$A^{flav} = \frac{\Gamma_{\bar{B}_s^0 \to f} - \Gamma_{B_s^0 \to f}}{\Gamma_{\bar{B}_s^0 \to f} + \Gamma_{B_s^0 \to f}} = -D \cdot \frac{cos(\Delta m_s t)}{cosh(\frac{\Delta\Gamma_s t}{2})}$$

- It is possible to measure the dilution factor $D=1-2\omega$ (ω=wrong tagging fraction) and ΔM_s
- Under the reasonable assumption that ω is the same in $B_s \to D_s \pi$ and $B_s \to D_s K$ one can fit all decay distributions simultaneously

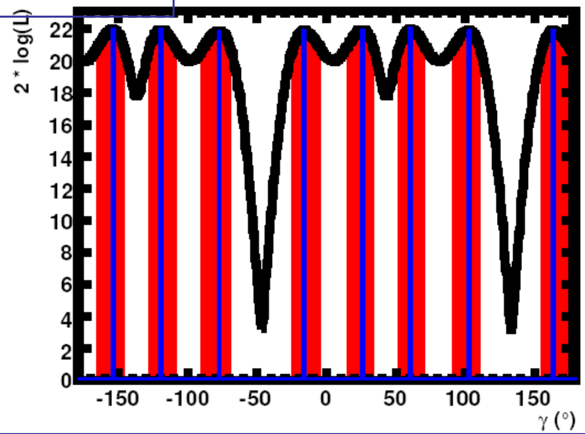
Including information from $B^0 \to D^*(D^0\pi^{\pm})\pi^{\mp}$

- Not needs of U-spin relation to resolve degenerate solution
- Decay mode depends on γ in an analogous way to $B^0 \to D\pi$
  - 206k fully triggered events expected to be collected by LHCb with $2fb^{-1}$
- From a theoretical point of view the strong phase is expected to be 180° different from the strong phases of $B^0 \to D\pi$
  - This allows the combined γ precision of the two modes to be better then the addition in quadrature
    - Better discrimination of ambiguous solutions

$10\ fb^{-1}$ — $B^0 \to D\pi$ alone



$10\ fb^{-1}$ — Combined $B^0 \to D\pi$ and $B^0 \to D^*\pi$



All the solutions are more than 1σ away each other

$$\gamma_{5y} = (61^{-8}_{+10})^{\circ}\,.$$