γ determination at LHCb

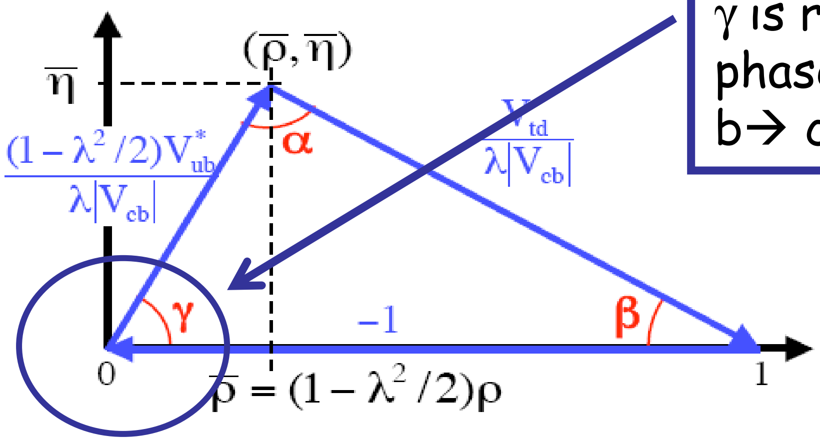
Angelo Carbone (INFN-Bologna)
on behalf of LHCb collaboration

Focus Week "B@LHC"

27th May 2008

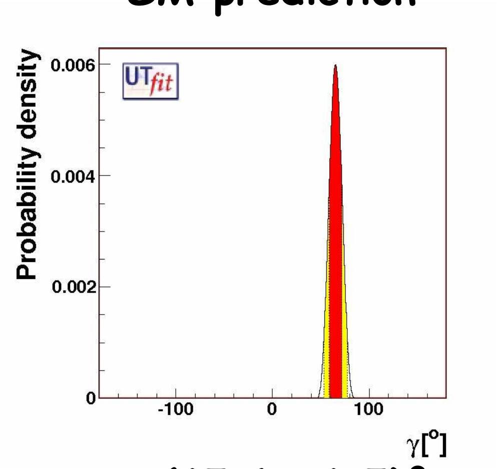
Overview

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



γ is related to the phase between b→u b→ c transition

SM prediction

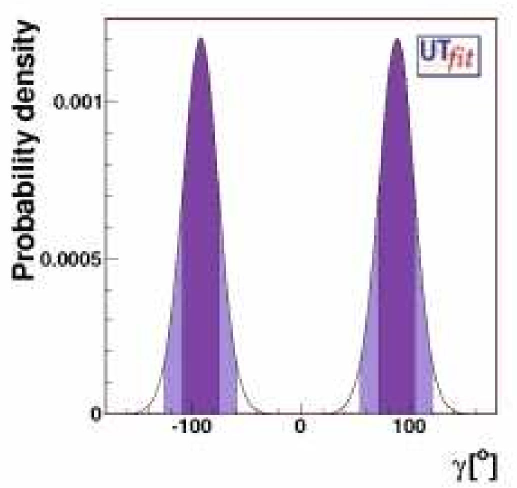


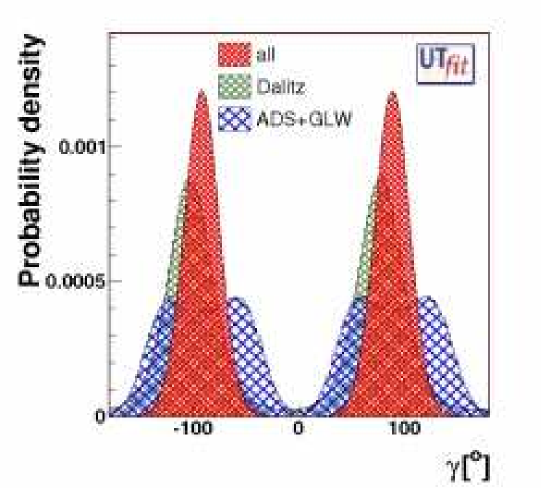
$\gamma = (65.1 \pm 6.5)^\circ$

- Unitary Triangle prediction of SM γ is ~7°
- LHCb goal is to measure γ in SM-clean way to match the precision of indirect measurements and check if the prediction is correct
  - Tree processes → very clean place to measure γ even if any New Physics effect in mixing will perturb the measurements
    - $B^\pm \to D^0 K^\pm$, $B^0 \to D^0 K^{0*}$
      - direct γ measurements using ADS, GLW and Dalitz methods
    - $B_s^0 \to D_s K^\pm$
      - measure γ-$2\beta_s$
  - Loop processes → a discrepancy between this and the tree-level measurements may point out New Physics in the loops
    - $B \to h^+h^-$
      - *Measure combination of γ , β and β_s using SU(3) symmetry*

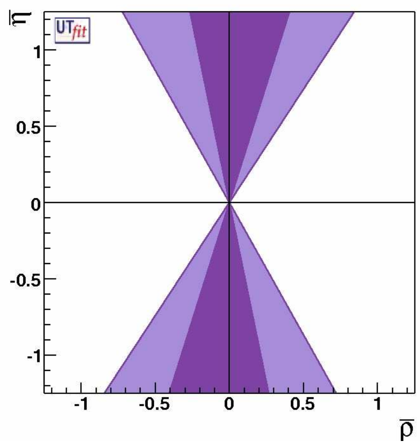
Current experimental status on γ from UTfit

Direct measurements from B→DK, D*K and DK*





bound from B → DK, D*K and DK* decays with present measurements using all the methods.

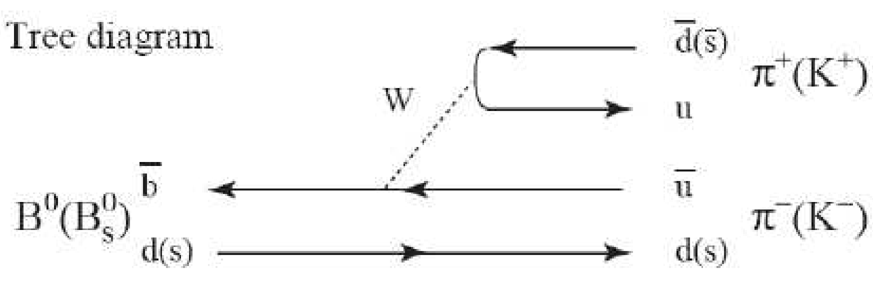


γ= (88 ± 16)° ([41,123] @ 95% Prob.)

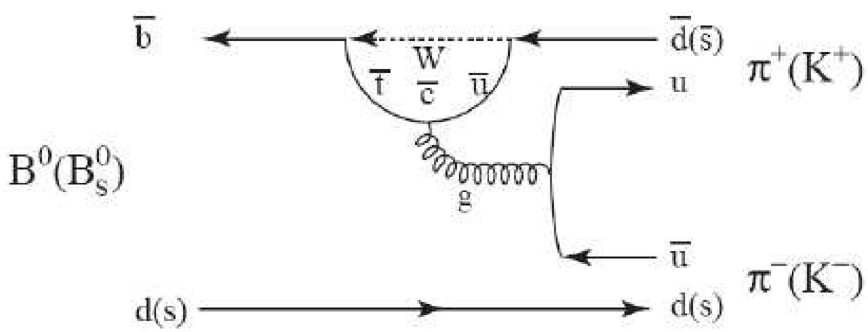
γ up to π ambiguity

Measuring γ from $B \to h^+h^-$

- $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ can be used to extract γ up to U-spin breaking conditions
- The presence of penguins is an addition opportunity to mixing to spot ot new physics
  - New Physics might show up also in loops of the penguin diagrams
  - CKM quantities from these modes can differ from the ones from tree-level modes, assuming they are unaffected from NP
- Can also be used to probe the size of U-spin breaking, together with $B_d \to K^+\pi^-$ and $B_s \to \pi^+K^-$



Example of penguin diagrams



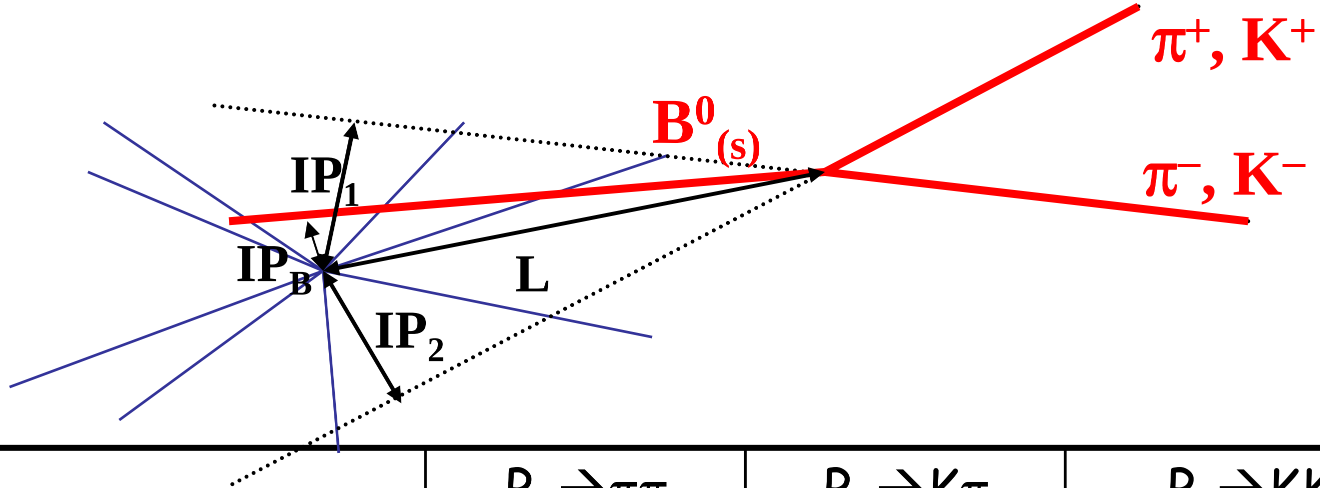
U-spin ($d \leftrightarrow s$ quark exchange) symmetric modes

$B_d \to \pi^+\pi^-$ $T+P+P^C_{EW}+PA+E$	$\Leftrightarrow$	$B_s \to K^+K^-$ $T+P+P^C_{EW}+PA+E$
$B_d \to \pi^+\pi^-$ $T+P+P^C_{EW}+PA+E$	$\Leftrightarrow$	$B_s \to \pi^+K^-$ $T+P+P^C_{EW}$
$B_s \to K^+K^-$ $T+P+P^C_{EW}+PA+E$	$\Leftrightarrow$	$B_d \to K^+\pi^-$ $T+P+P^C_{EW}$

T: tree
P: penguin
P^C_{EW}: colour suppressed electroweak penguin
PA: penguin annihilation
E: exchange

- Not all exactly U-spin symmetric, E and PA contributions missing from flavour specific decays
- E and PA contributions expected to be relatively small, and can be experimentally probed by measuring the still unobserved $B_s \to \pi^+\pi^-$ and $B_d \to K^+K^-$ branching ratios ($BR \sim 10^{-8}$)

Event yields at LHCb up to 2fb^{-1}

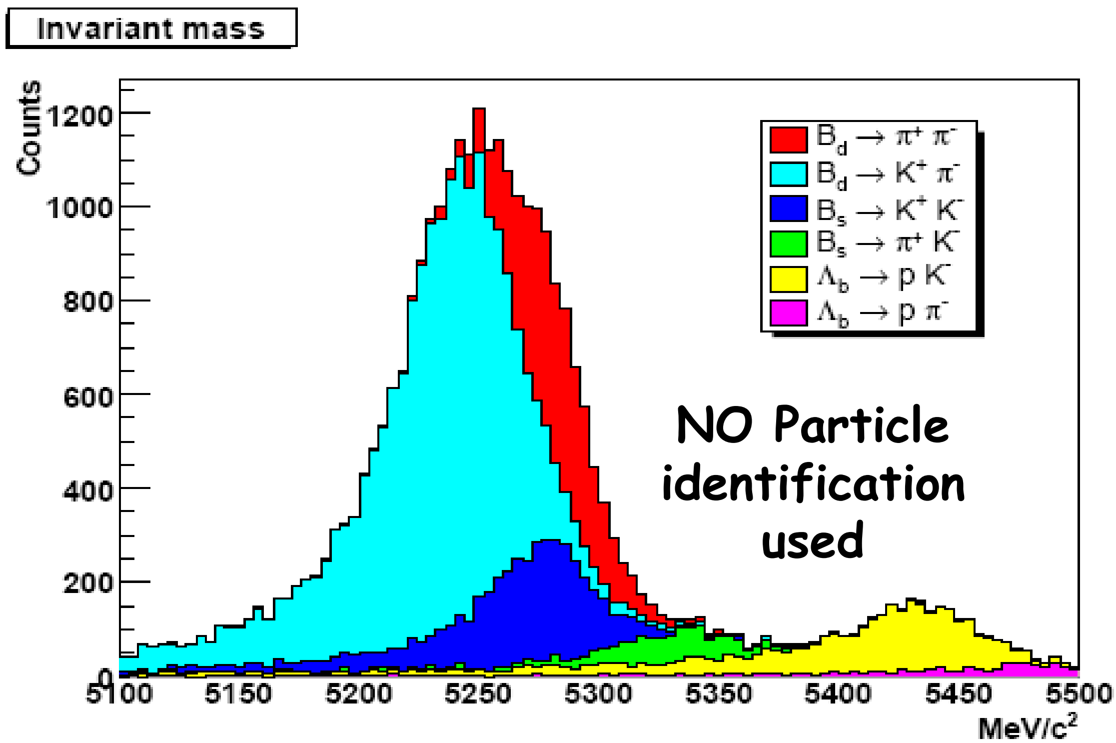


	$B_d \to \pi\pi$	$B_d \to K\pi$	$B_s \to KK$	$B_s \to \pi K$
L=0.01 fb^{-1}	0.18k	0.69k	0.18k	0.05k
L=0.5 fb^{-1}	9k	34.5k	9k	2.5k
L=2 fb^{-1}	36k	138k	36k	10k
B/S	0.5	<0.06	0.15	1.9

- LHCb will be statistically competitive with the final luminosity of Tevatron (assuming L=6fb^{-1}) already when approaching L=0.5fb^{-1}

Performance of hadron PID: invariant mass spectra

- One major advantage of LHCb with respect to the Tevatron (in addition to cross section of course): the particle identification system allows the different $B \rightarrow h^+h^-$ modes to be strongly separated



- Every $h^+h'^-$ channel is potentially a background for the other channels…

Performance of hadron PID: invariant mass spectra

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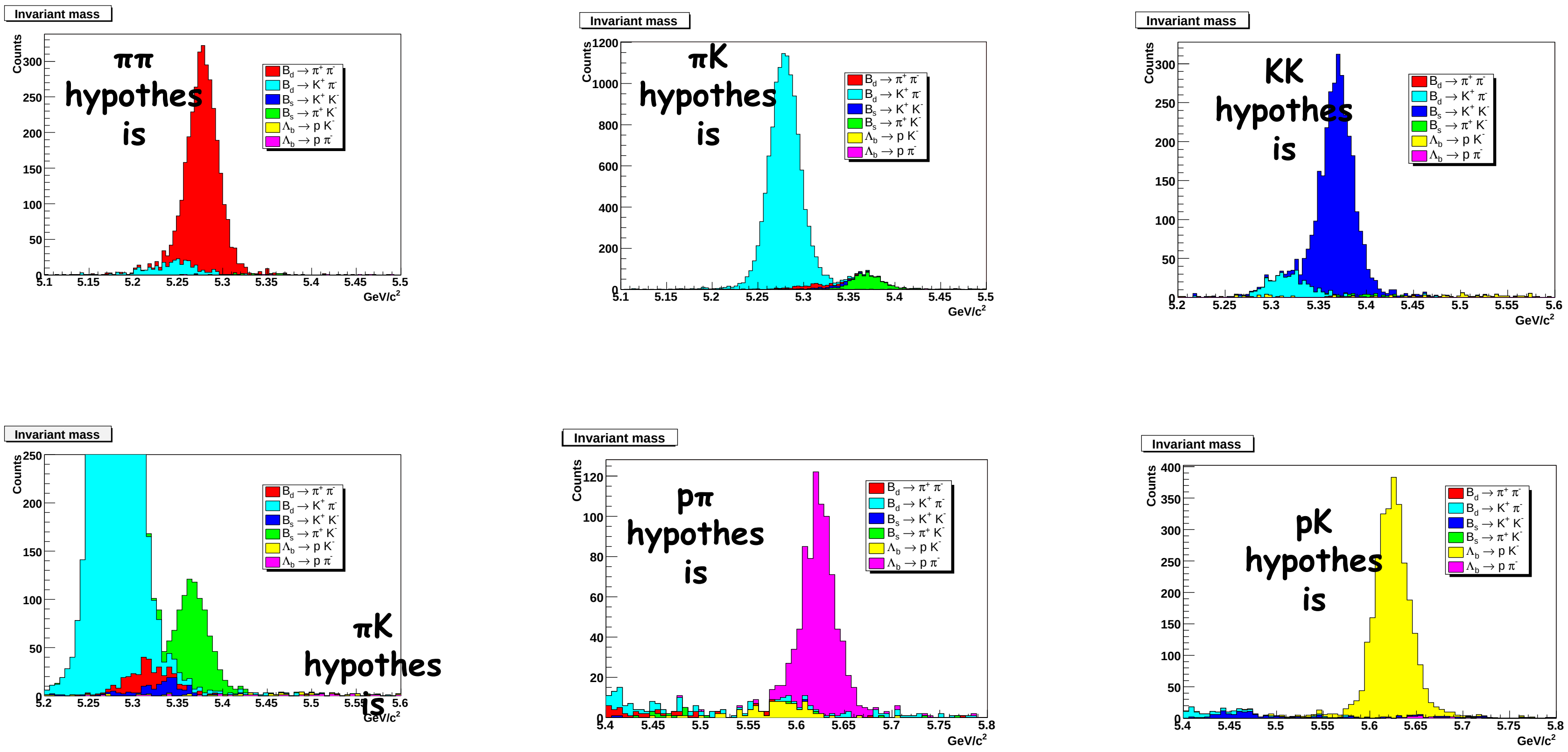

- …but impressive performance of RICH systems allows to select very clean samples

Tree, penguins and… γ

$$A_{\pi^+\pi^-} = V_{ub}^* V_{ud} \cdot T^u + V_{ub}^* V_{ud} \cdot P^u + V_{cb}^* V_{cd} \cdot P^c + V_{tb}^* V_{td} \cdot P^t$$

$$A_{\pi^+\pi^-} = C\left(e^{i\gamma} - d e^{i\vartheta}\right) \qquad \overline{A}_{\pi^+\pi^-} = C\left(e^{-i\gamma} - d e^{i\vartheta}\right)$$

$$C \equiv \lambda^3 A R_b \left(T^u + P^u - P^t\right) \qquad d e^{i\vartheta} \equiv \frac{1}{R_b}\left(\frac{P^c - P^t}{T^u + P^u - P^t}\right)$$

$$A_{K^+K^-} = V_{ub}^* V_{us} \cdot T'^u + V_{ub}^* V_{us} \cdot P'^u + V_{cb}^* V_{cs} \cdot P'^c + V_{tb}^* V_{ts} \cdot P'^t$$

$$A_{K^+K^-} = \frac{\lambda}{1-\lambda^2/2} C' \left(e^{i\gamma} + \frac{1-\lambda^2}{\lambda^2} d' e^{i\vartheta'}\right)$$

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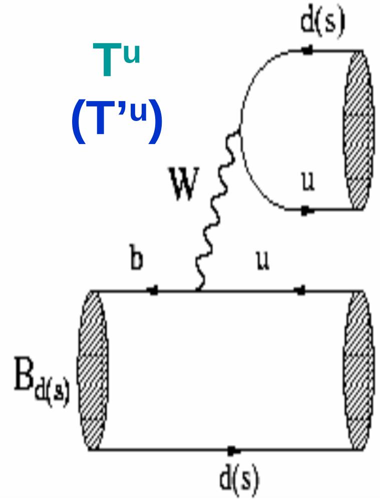
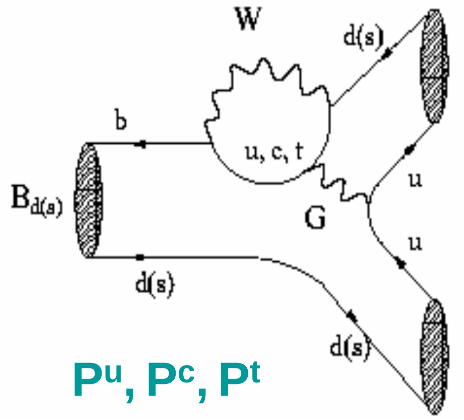
$$R_b \equiv \frac{1}{\lambda}\left(1 - \frac{\lambda^2}{2}\right)\left|\frac{V_{ub}}{V_{cb}}\right|$$

T^u
(T'^u)





P^u, P^c, P^t
(P'^u, P'^c, P'^t)

Using method and parameterization from
R. Fleischer, PLB 459 (1999) 306

Tree, penguins and… γ

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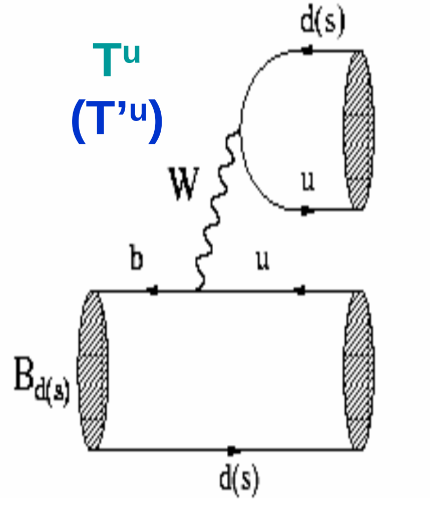

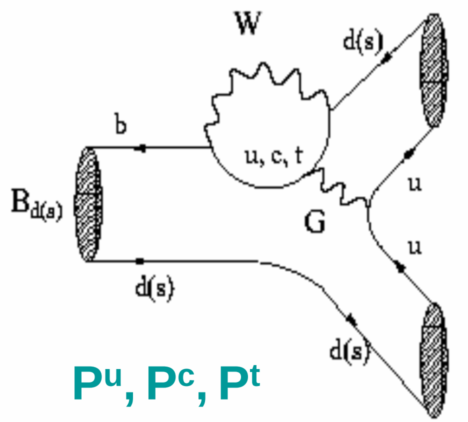

P^u, P^c, P^t

(P'^u, P'^c, P'^t)

d' is double Cabibbo enhanced… i.e. by a factor 20. For d' = 0.5 the weak CP-violating term in the amplitude - which is sensitive to γ - is 10 times less significant than the hadronic CP-conserving one

Tree, penguins and… γ

$$A_{\pi^+\pi^-} = V_{ub}^* V_{ud} \cdot T^u + V_{ub}^* V_{ud} \cdot P^u + V_{cb}^* V_{cd} \cdot P^c + V_{tb}^* V_{td} \cdot P^t$$

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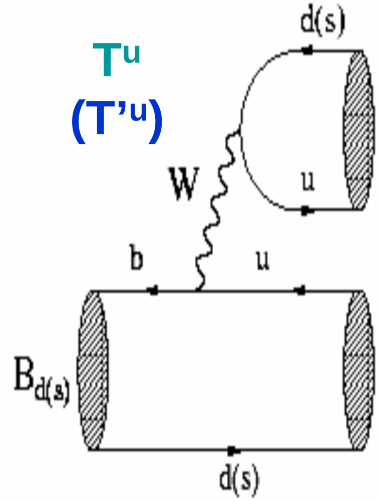
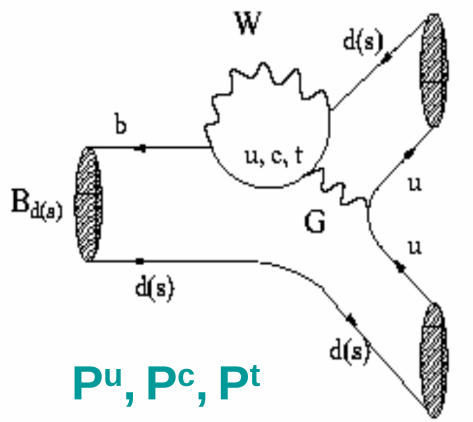
T^u
(T'^u)





P^u, P^c, P^t

(P'^u, P'^c, P'^t)

Relating by the U-spin symmetry the two amplitudes one gets $d = d'$ and $\theta = \theta'$

Extraction of γ from observables

$$C(B_d^0 \to \pi^+\pi^-) = f_1(d, \vartheta, \gamma)$$

$$S(B_d^0 \to \pi^+\pi^-) = f_2(d, \vartheta, \gamma, \phi_d)$$

$$C(B_s^0 \to K^+K^-) = f_3(d', \vartheta', \gamma)$$

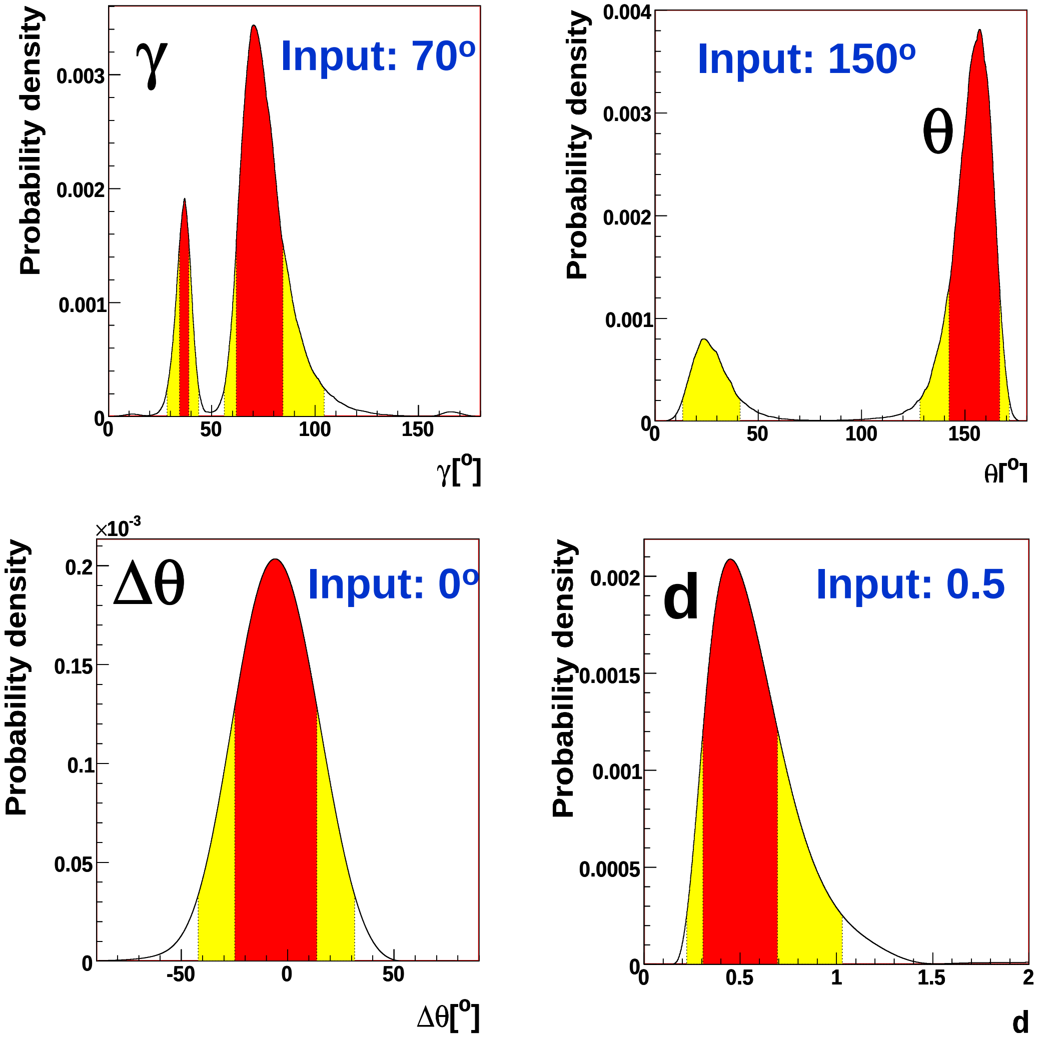
$$S(B_s^0 \to K^+K^-) = f_4(d', \vartheta', \gamma, \phi_s)$$

$$A_{CP}^{th}(\tau) = \frac{C \cdot \cos(\Delta M \cdot \tau) - S \cdot \sin(\Delta M \cdot \tau)}{\cosh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right) - A_{\Delta\Gamma} \cdot \sinh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right)}$$

- Once the direct and mixing-induced CP-violating terms are measured, one has a system of
  - 7 unknowns
- However, the mixing phase ϕ_d (ϕ_s) is (will be) precisely measured from $B_d \to J/\psi K_S$ ($B_s \to J/\psi\phi$)
  - 5 unknowns
- Finally, relying on U-spin symmetry one eliminates two further unknowns
  - $d=d'$, $\theta = \theta'$
  - 3 unknowns, system over-constrained, γ can be extracted unambiguously
  - one of the two U-spin relations can also be not used

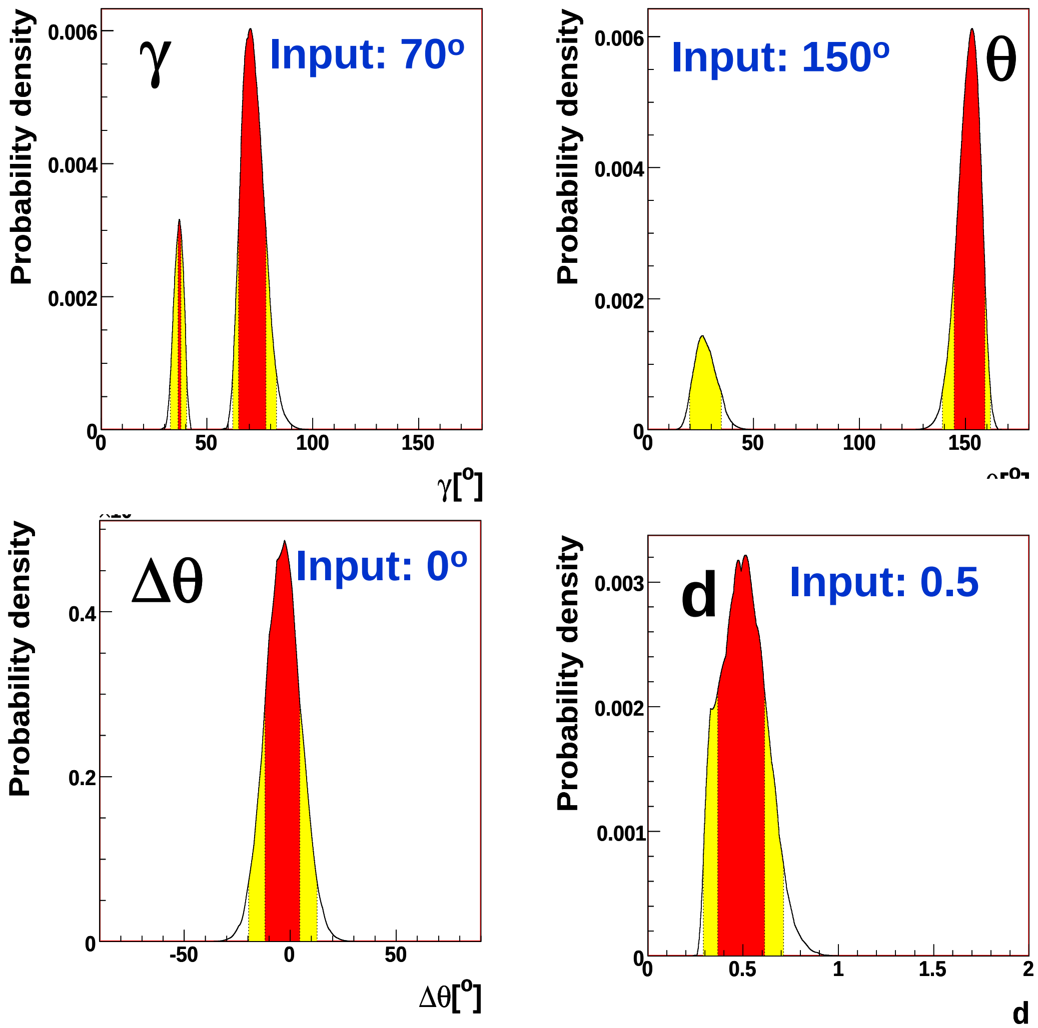
LHCb sensitivity on γ using time dependent measurements of $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ ($L=2fb^{-1}$)

- Weak use of U-spin assumption
  - Strong phases θ and θ' left free during the fit (no U-spin assumed)
  - Strong magnitude related by U-spin $d=d'$, but allowing for a 20% U-spin breaking
  - Fit results
    68% probability, excluding non-SM solution
  - $\sigma(\gamma) = 10^\circ$
  - $\sigma(\theta) = 9^\circ$
  - $\sigma(\Delta\theta) = 17^\circ$
  - $\sigma(d) = 0.18$



Same exercise, but with 5 years ($L=10fb^{-1}$)

- Fit results
  68% probability, excluding non-SM solution
  - $\sigma(\gamma) = 5^\circ$
  - $\sigma(\theta) = 5^\circ$
  - $\sigma(\Delta\theta) = 8^\circ$
  - $\sigma(d) = 0.09$

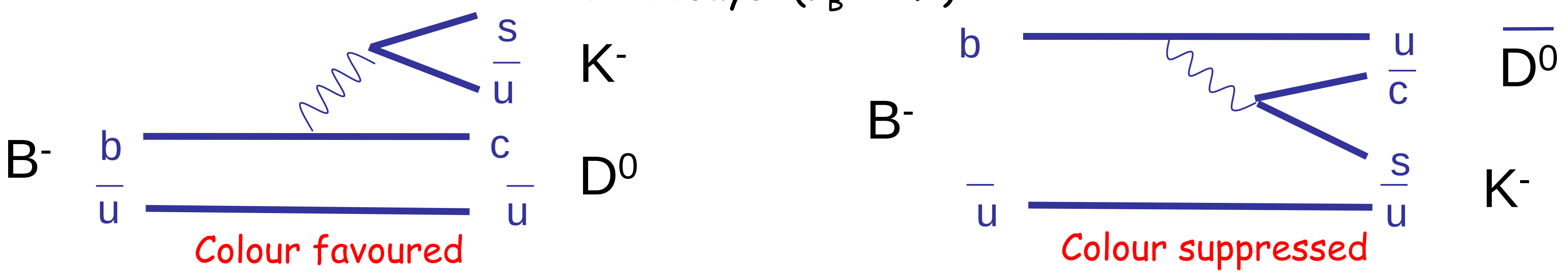


More details
CERN-LHCb-2007-059

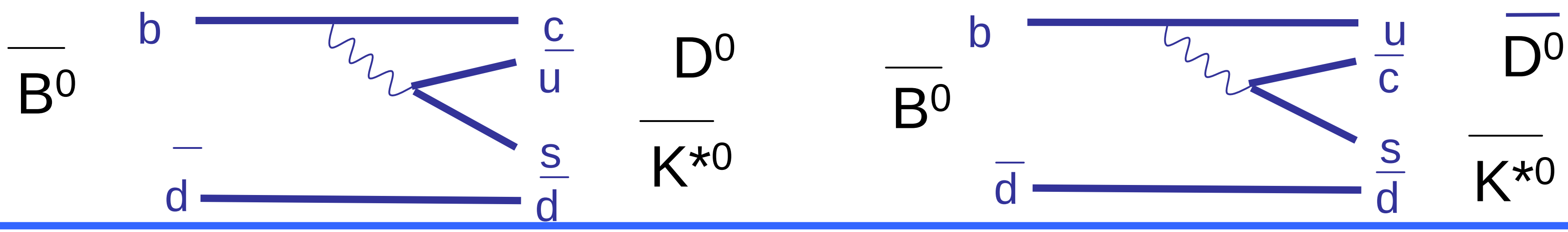
Measuring γ from $B\rightarrow DK$

- parameters for CKM favoured $B\rightarrow \bar{D}^0K$ and disfavoured $B\rightarrow D^0K$
- if D^0 and $\bar{D}^0$ are reconstructed in common final state than interference term involving gamma is accessed
- amplitude ratio $r_B = |A(B\rightarrow D^0K)|/|A(B\rightarrow \bar{D}^0K)|$
- δ_B, strong phases between amplitude → $A(B\rightarrow D^0K)=A(B\rightarrow \bar{D}^0K)\, r_B e^{i(\delta_B-\gamma)}$

$B^{\pm}$ decays ($r_B \sim 0.1$)



B^0 decays (both diagrams colour suppressed → $r_B \sim 0.4$)



Combining ADS+GLW

- GLW method → D^0 decays in CP eigenstate (h=K,π)

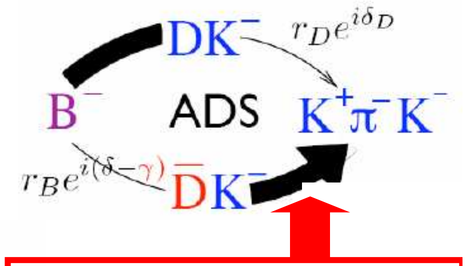
$$\Gamma(B^- \to (h^+h^-)_D K^-) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B - \gamma)),$$
$$\Gamma(B^+ \to (h^+h^-)_D K^+) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B + \gamma)).$$

$r_D = \dfrac{|A(D^0 \to K^+\pi^-)|}{|A(\overline{D^0} \to K^+\pi^-)|}$

$\delta_D^{K\pi}$ strong phase between amplitudes

- ADS method → D^0 decays in not CP eigenstate, Kπ

$$\Gamma(B^- \to (K^-\pi^+)_D K^-) = N^{K\pi}(1 + (r_B r_D) + 2r_B r_D\cos(\delta_B - \delta_D^{K\pi} - \gamma)$$
$$\Gamma(B^- \to (K^+\pi^-)_D K^-) = N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D\cos(\delta_B + \delta_D^{K\pi} - \gamma)).$$
$$\Gamma(B^+ \to (K^+\pi^-)_D K^+) = N^{K\pi}(1 + (r_B r_D) + 2r_B r_D\cos(\delta_B - \delta_D^{K\pi} + \gamma)$$
$$\Gamma(B^+ \to (K^-\pi^+)_D K^+) = N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D\cos(\delta_B + \delta_D^{K\pi} + \gamma))$$



interference enhanced

- Unknowns : r_B, δ_B, $d_D^{K\pi}$, γ, $N_{K\pi}$, N_{hh} (r_D=0.06 well measured)
- With knowledge of the relevant efficiencies and BRs, the normalisation constants ($N_{K\pi}$, N_{hh}) can be related to one another
- Important constraint from CLEO-c $\sigma(\cos(d_D^{K\pi}))$=0.1–0.2
- **Overconstrained: 6 observables and 5 unknowns**
- same relations in the neutral system but r_B expected to be ~0.4

Combining ADS+GLW

- GLW method → D^0 decays in CP eingenstate ($h=K,\pi$)

$$\Gamma(B^- \to (h^+h^-)_D K^-) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B - \gamma)),$$
$$\Gamma(B^+ \to (h^+h^-)_D K^+) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B + \gamma)).$$

$r_D = \dfrac{|A(D^0 \to K^+\pi^-)|}{|A(\overline{D^0} \to K^+\pi^-)|}$

$\delta_D^{K\pi}$ strong phase between amplitudes

- ADS method → D^0 decays in not CP eingenstate, $K\pi$

Only relative rates are measured, no flavour tagging id needed

full LHCb statistics can be used

- With knowledge of the relevant efficiencies and BRs, the normalisation constants ($N_{K\pi}$, N_{hh}) can be related to one another
- Important constraint from CLEO-c $\sigma(\cos(d_D^{K\pi}))$=0.1–0.2
- **Overconstrained: 6 observables and 5 unknowns**
- same relations in the neutral system but r_B expected to be ~0.4

Measuring γ from $B^{\pm}\rightarrow D^0K^{\pm}$ (ADS+GLW)

Integrated luminosity $2fb^{-1}$		
Modes	Signal Yield	B/S
$B\rightarrow D(K\pi)K$, favoured	56k	0.6
$B\rightarrow D(K\pi)K$, suppressed	0.71k	2
$B\rightarrow D(h^+h^-)K$	7.8k	1.8

- γ sensitivity of 10.8°-13.8° in $2fb^{-1}$, depending on the strong phase in the D decays
- input parameters:
  - r_B =0.01
  - δ_B = 130°
  - r_D =0.06
  - γ = 60°
- Cleo-c results on $\delta_D^{K\pi}$ included

More details
CERN-LHCb-2008-011

Measuring γ from $B^0 \to D^0 K^{*0}$ (ADS+GLW)

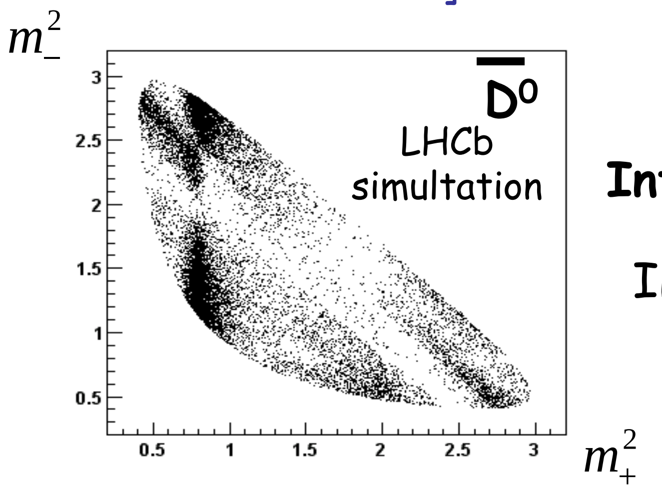
Integrated luminosity $2 fb^{-1}$		
Modes	Signal Yield	B/S (90%CL)
$B^0 \to D^0(K\pi)K^{*0}$, favoured	3.4k	[0.4, 2.1]
$B^0 \to D^0(K\pi)K^{*0}$, suppressed	0.5k	[2.2, 12.8]
$B^0 \to D(K^+K^-)K^{*0}$	0.5k	[0, 4.1]
$B^0 \to D(\pi^+\pi^-)K^{*0}$	0.1k	[0, 14]

- sensitivity of 9° with integrated luminosity of $2 fb^{-1}$
- input :
  - $rB_d = 0.4$
  - $\delta_B = 10°$
  - $\gamma = 60°$

More details
CERN-LHCb-2007-043

Measuring γ from $B^{\pm}\rightarrow D^0(K_s\pi^+\pi^-)K^{\pm}$

- amplitude analysis of the D^0 Dalitz plot leads to a determination of γ
  - Model-dependent [Giri, Grossman, Soffer, Zupan Phys. Rev. D68 054018 (2003)]
  - Model-independent [A. Bondar and A. Poluektov, Eur.Phys.J. C47 (2006) 347-353 and arXiv:0801.0840]



Integrated luminosity 2fb^{-1}

Input r_B= 0.10, γ = 60°

More details
CERN-LHCb-2007-048
CERN-LHCb-2007-141
CERN-LHCb-2007-142

Mode	Signal Yield	B/S
$B\rightarrow D(K_s\pi^+\pi^-)K$	5k	<0.7

Mode	sensitivity	Systematic error
$B\rightarrow D(K_s\pi^+\pi^-)K$ model-depen.	7°-12°	10° (model dependence)
$B\rightarrow D(K_s\pi^+\pi^-)K$ model-indepen.	9°-13°	3°-5° (Cleo-c statistics)

Sensitivity spread due to different background scenarios

Sensitivity on γ from ADS+GLW+Dalitz

- A global fit combining individual χ^2 from the different ADS/GLW rates and Dalitz model-independent has been performed
  - Use relative efficiencies and branching fractions to relate normalisation factors
  - Include constraints from CLEO-c as additional terms in the χ^2
  - Included in the global fit sensitivity from $B \to D(K3\pi)K$

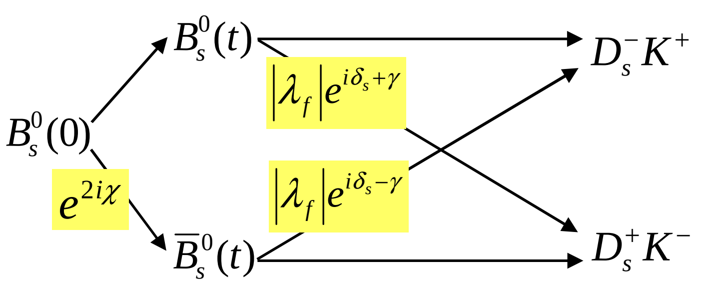
Integrated luminosity 2fb^{-1}

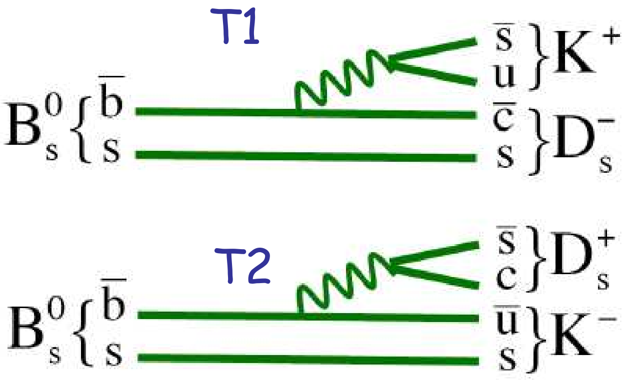
δ_B (°)	0	45	90	135	180
Combined B^+/B^0 ADS/GLW	4.6°	7.6°	6.3°	7.1°	4.6°
+ model independent Dalitz	**4.2°**	**5.7°**	**5.3°**	**5.7°**	**4.2°**

Measuring γ from $B_s \to D_s K^{\pm}$

- Tree level decay
  - Not affected by New Physics
- Need flavour tagging analysis to distinguish initial B^0 and $\bar{B}^0$
- Four time dependent decay rate

Interference between direct decay and decay after oscillation





Decay rates are sensitive to γ-2β_s and strong phases difference between T1 and T2

The mixing phase β_s will be precisely measured from $B_s \to J/\psi\phi$, hence we can determine gamma

Yields

- Estimated branching fraction for full B_s decay

$B_s \rightarrow D_s^- \pi^+$	$(3.4 \pm 0.7) \cdot 10^{-3}$
$B_s \rightarrow D_s^- K^+$ $B_s \rightarrow D_s^+ K^-$	$(2.0 \pm 0.6) \cdot 10^{-4}$ $(2.2 \pm 0.7) \cdot 10^{-5}$

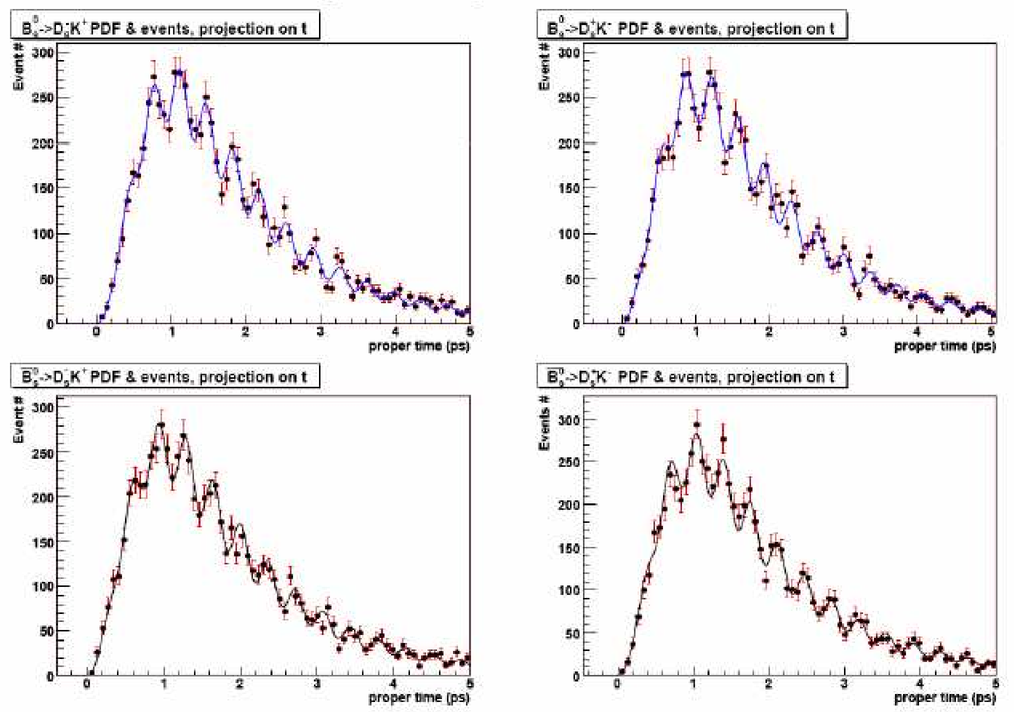
- Event yields

	$B_s \rightarrow D_s \pi$	$B_s \rightarrow D_s K$
L=0.01 fb^{-1}	0.7k	0.03k
L=0.5 fb^{-1}	35k	1.6k
L=2 fb^{-1}	140k	6.2k

- $B_s \rightarrow D_s \pi$: specific background
  - Not only background but is also a control channel for measuring tagging dilution.

Sensitivity studies on γ

- Unbinned likelihood fit on decay time distributions simultaneously on $B_s \to D_s K$ and $B_s \to D_s \pi$
  - Including $B_s \to D_s \pi$ events in a simultaneous fit to constrain $\Delta\Gamma_s$ and Δm_s
  - Used tagged and untagged sample



Integrated luminosity $2fb^{-1}$

	sensitivity	Input values
$\gamma-2\beta_s$	10.3°	60°
Δm_s	0.007 ps^{-1}	17.5 ps^{-1}
$\Delta_{T1/T2}$	10.3°	0°
$\lvert\lambda\rvert$	0.06	0.37

Sensitivity on γ (0.5 fb^{-1}, 10 fb^{-1})

Sensitivity on γ, global fit					
0.5 fb^{-1}					
δ_B (°)	**0**	**45**	**90**	**135**	**180**
$B \to DK$	9.2°	12.2°	10.5°	10.7°	8.6°
+ TDCPV	7.7°	9.3°	8.5°	8.6°	7.4°
10 fb^{-1}					
δ_B (°)	**0**	**45**	**90**	**135**	**180**
$B \to DK$	2.4°	3.5°	2.9°	3.4°	2.3°
+ TDCPV	2.1°	2.7°	2.4°	2.6°	2.0°

Sensitivity on γ with loops			
	0.5 fb^{-1}	10 fb^{-1}	Weak U-spin assumption
Loops	20°	5°	

Conclusion

- LHCb will be able to measure γ with a precision of 5° with 2fb^{-1} matching the precision of indirect measurements
  - Comparison between of γ measured at LHCb and indirect determination will become a stringent test of the SM
- Comparison between γ from trees and loops may show up New Physics in loops
- LHCb will be achieve a sensitivity of 2°-3° with 10 fb^{-1}
- LHCb's potential in charmless B->hhh (h=π or K) also under study ,
- Other modes under consideration:
  - B->D(K$\pi\pi^0$)K, D(K_sKK)K, D*K, D*π
  - $B^0 \rightarrow D^*\pi$, $B^0 \rightarrow D^*\rho$, $B^0 \rightarrow D^*a_1$, $B_s \rightarrow D_s^*K$ (time dependent)
    - U-spin combinations as well