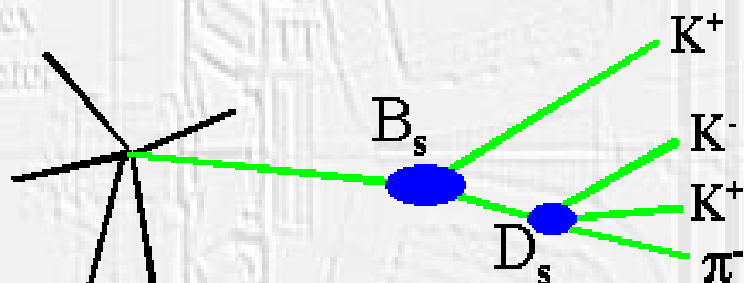


LHCb sensitivity to γ with $B_s \rightarrow D_s K$

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On behalf of the LHCb Experiment



I. Physics case

- CKM matrix
- extraction of γ from $B_s \rightarrow D_s K$ decays
- formalism

II. Event selection

- sources of background
- annual yields and B/S estimations

III. Sensitivity to γ

IV. Summary

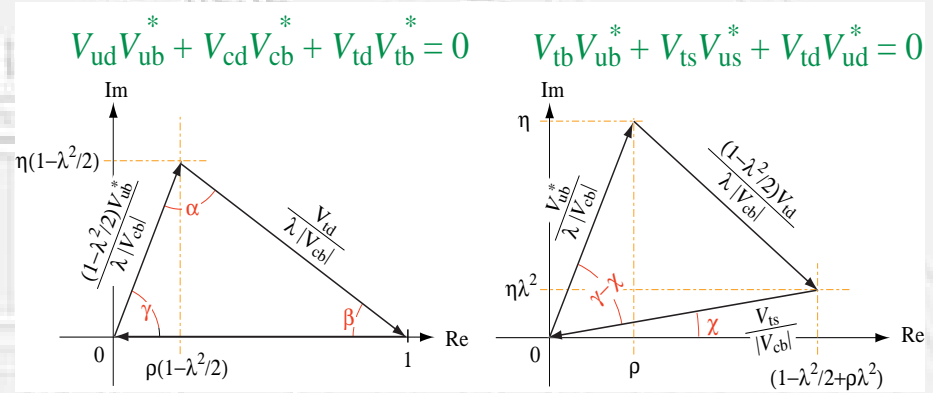
Physics at LHC

Vienna, Austria , 13-17 July 2004

Physics case

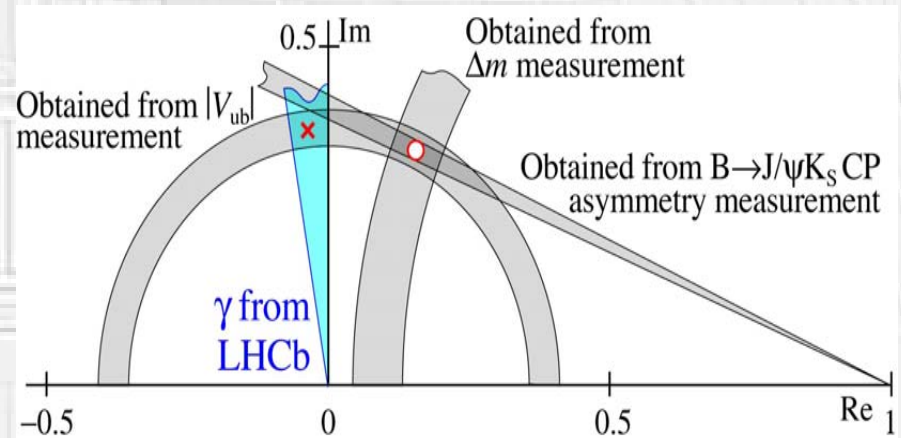
CKM matrix

- CP violation in the Standard Model
 - ↳ described by 1 complex phase
- 2 unitarity triangles (relations) relevant to B-physics / LHCb



γ from $B_s \rightarrow D_s K$

- one of several methods
- theoretically clean
- not sensitive to new physics
- in fact $\gamma - 2\chi$ is measured
 - ↳ χ from $B_s \rightarrow J/\Psi \phi$:
expect $\sigma(\sin 2\chi) \sim 0.06$ in 1 year
- large samples expected with LHCb, not accessible at B-factories
- no direct measurement of γ yet available



$$\gamma = -\arg(V_{ub})$$

↳ $50^\circ < \gamma < 80^\circ$ from CKM Fitter group [J. Charles et al., hep-ph/0406184]



Formalism

- 2 mass eigenstates

$$|B_{H(L)}\rangle = \frac{1}{\sqrt{p^2 + q^2}} [p|B\rangle + (-)q|\bar{B}\rangle]$$

- time evolution of B_s and c.c flavour eigenstates

$$\Gamma_{B \rightarrow f}(t) = \frac{|A_f|^2}{2} e^{-\Gamma_s t} [I_+(t) + I_-(t)]$$

$$\Gamma_{\bar{B} \rightarrow f}(t) = \frac{|A_f|^2}{2} \left| \frac{p}{q} \right|^2 e^{-\Gamma_s t} [I_+(t) - I_-(t)]$$

$$\Gamma_{\bar{B} \rightarrow \bar{f}}(t) = \frac{|\bar{A}_{\bar{f}}|^2}{2} e^{-\Gamma_s t} [\bar{I}_+(t) + \bar{I}_-(t)]$$

$$\Gamma_{B \rightarrow \bar{f}}(t) = \frac{|\bar{A}_{\bar{f}}|^2}{2} \left| \frac{q}{p} \right|^2 e^{-\Gamma_s t} [\bar{I}_+(t) - \bar{I}_-(t)],$$

A_f = instantaneous decay amplitude for $B_s \rightarrow f$



$\Gamma_s = (\Gamma_H + \Gamma_L) / 2$
 $\Delta\Gamma_s = \Gamma_H, \Gamma_L$ decay width difference
 $\Delta m_s = m_H, m_L$ mass difference

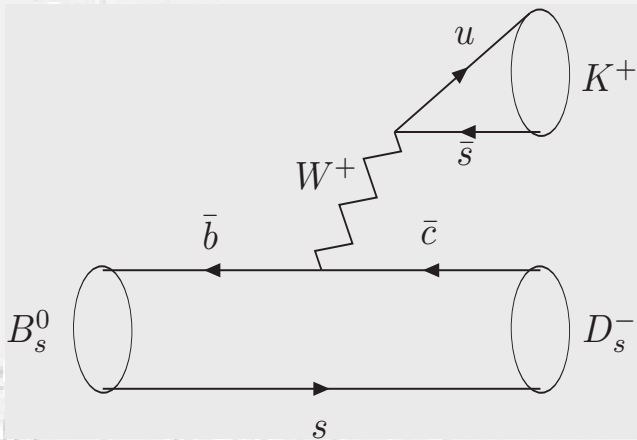
$$I_+(t) = (1 + |\lambda|^2) \cosh\left(\frac{\Delta\Gamma_s}{2} t\right) - 2\Re\lambda \sinh\left(\frac{\Delta\Gamma_s}{2} t\right)$$

$$I_-(t) = (1 - |\lambda|^2) \cos(\Delta m_s t) - 2\Im\lambda \sin(\Delta m_s t)$$

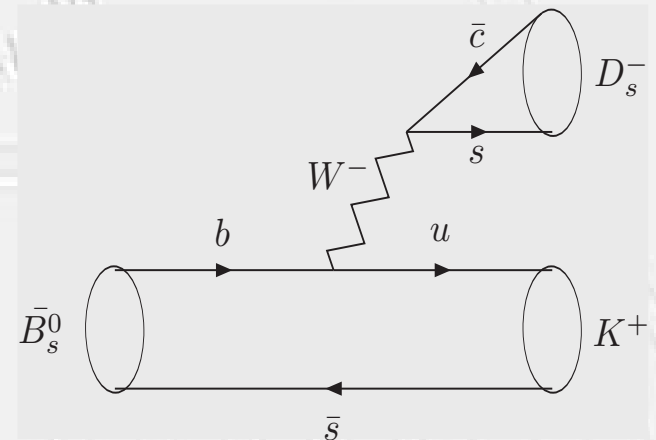
$$\lambda \equiv \frac{q}{p} \frac{\bar{A}_{\bar{f}}}{A_f}$$

$$\bar{\lambda} \equiv \frac{p}{q} \frac{A_{\bar{f}}}{\bar{A}_{\bar{f}}}$$

Case of $B_s \rightarrow D_s K$



B_s^0 as well as a \bar{B}_s^0 can decay to same final state



Interference between 2 tree diagrams via mixing \leftrightarrow CP asymmetry

- interference gives sensitivity to $\gamma - 2\chi$ and resolves strong phase difference Δ between 2 diagrams

- $D_s^- K^+$ asymmetry phase = $\Delta + (\gamma - 2\chi)$ (= arg λ -bar)
- $D_s^+ K^-$ asymmetry phase = $\Delta - (\gamma - 2\chi)$ (= arg λ)

- expected that

$$\frac{A_f}{|\lambda|} \approx \frac{\bar{A}_f}{|\bar{\lambda}|}$$

$$\left| \frac{A_f}{\bar{A}_f} \right| = \left| \frac{A_{\bar{f}}}{\bar{A}_{\bar{f}}} \right| = \left| \frac{V_{ub} V_{cs}}{V_{cb} V_{us}} \right| \approx 0.5$$

Large asymmetry expected



- 2 time-dependent rates (for f and f-bar) used to measure $\gamma - 2\chi$ and Δ

→ extraction of γ and Δ from A_f and charge conjugate



Case of $B_s \rightarrow D_s \pi$

➤ needs also to be considered here because:

↳ main source of background to $D_s K$ ($\text{Br}(D_s \pi) / \text{Br}(D_s K) \sim 12$)

↳ extraction of γ needs Δm_s , $\Delta \Gamma_s$ and wrong tag fraction from $D_s \pi$

➤ flavour-specific final state

↳ B_s decays to $D_s^- \pi^+$, but not to $D_s^+ \pi^-$

➤ one single tree diagram for B_s decay

$$A_{\bar{f}} = \bar{A}_f = 0 \quad \lambda = \bar{\lambda} = 0$$

➤ flavour asymmetry

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

D = convolution of dilution factor (tagging) and experimental resolution function



with $\left| \frac{p}{q} \right| = 1$

➔ possible extraction of Δm_s , $\Delta \Gamma_s$, wrong tag fraction

Event selection

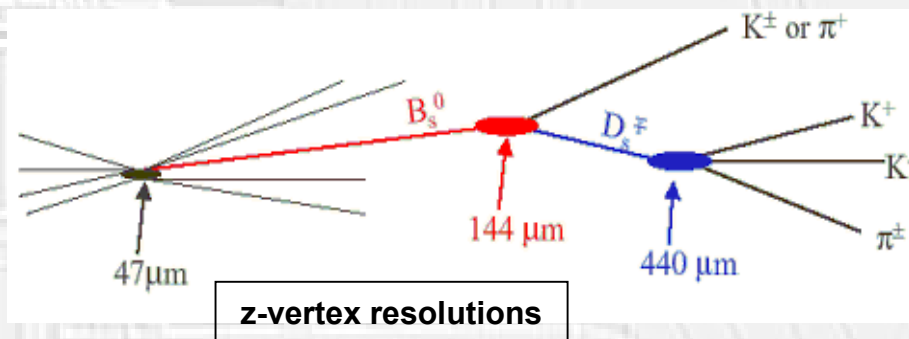
[LHCb Note 2003-127]

General – common selection for $B_s \rightarrow D_s K$ and $B_s \rightarrow D_s \pi$ (small kinematic difference)

- cuts on quality, IP and momentum for tracks
- (mass-constrained) vertex fits
- mass window cuts

D_s reconstruction

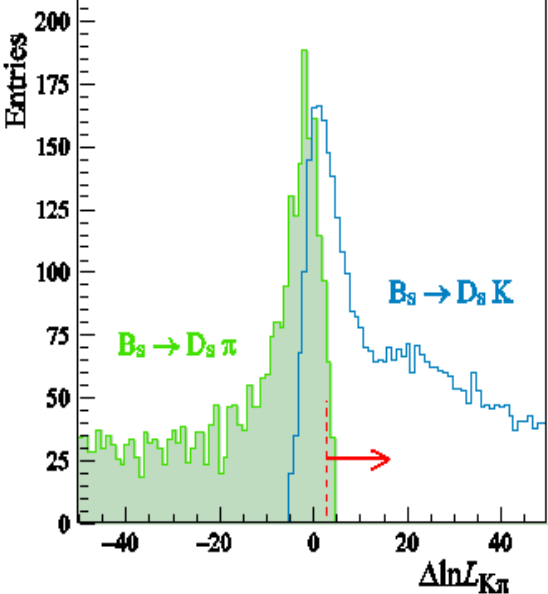
- D_s reconstructed in $D_s \rightarrow K K \pi$ mode
 - ↳ fully reconstructible, high-ish B.R. $\sim 4.4\%$
- the 3 tracks must satisfy $\Sigma p_T > 2.2 \text{ GeV}$
- vertex with $\chi^2 < 10$
- invariant mass window of $\pm 15 \text{ MeV}$ around the true D_s -mass



B_s reconstruction

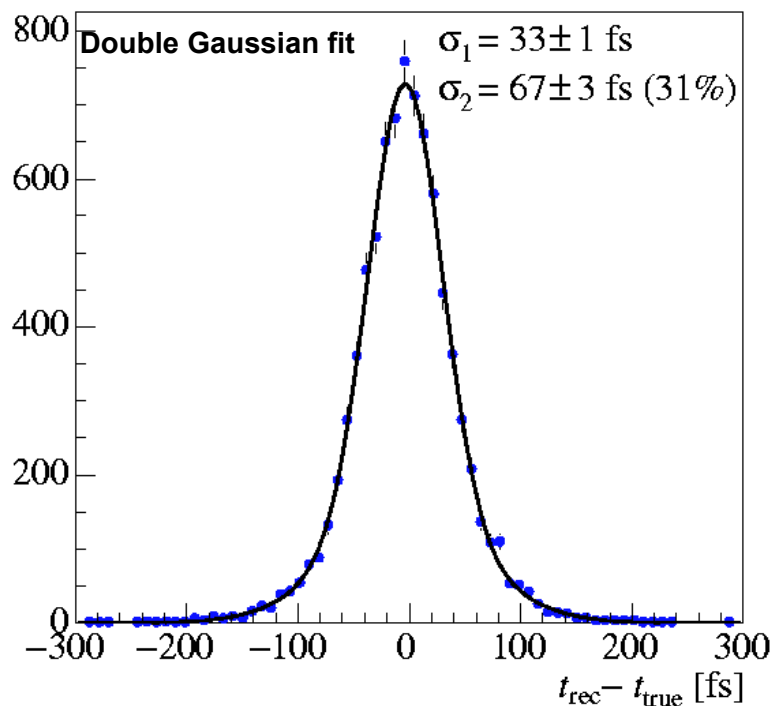
- bachelor particle identified with RICH PID information - crucial for K / π separation, i.e. for $D_s K / D_s \pi$ separation
- B_s vertex obtained from reconstructed D_s and bachelor particle
- quality criteria applied to D_s and B_s candidates and vertices

Reconstruction plots

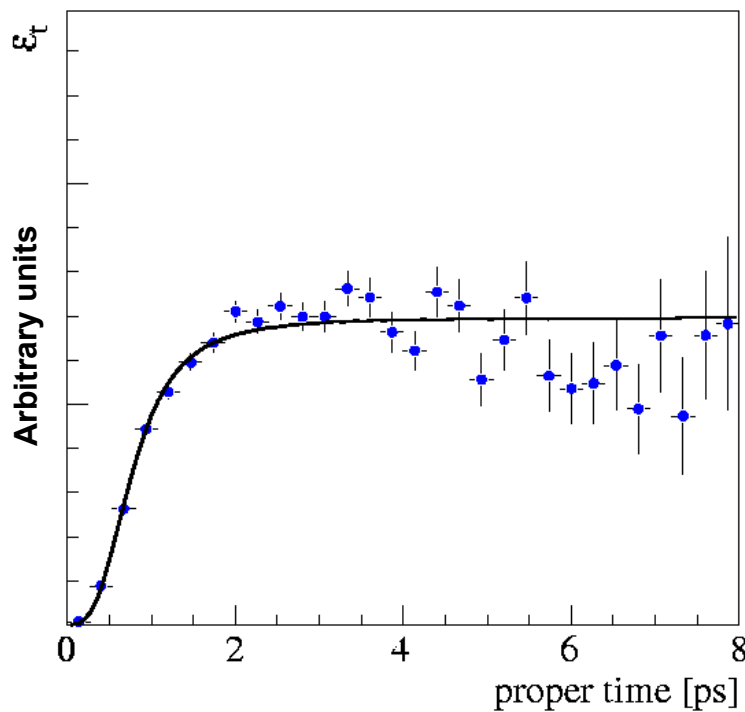


K/ π separation using log-likelihood from RICH PID hypotheses

Proper time resolution of B_s

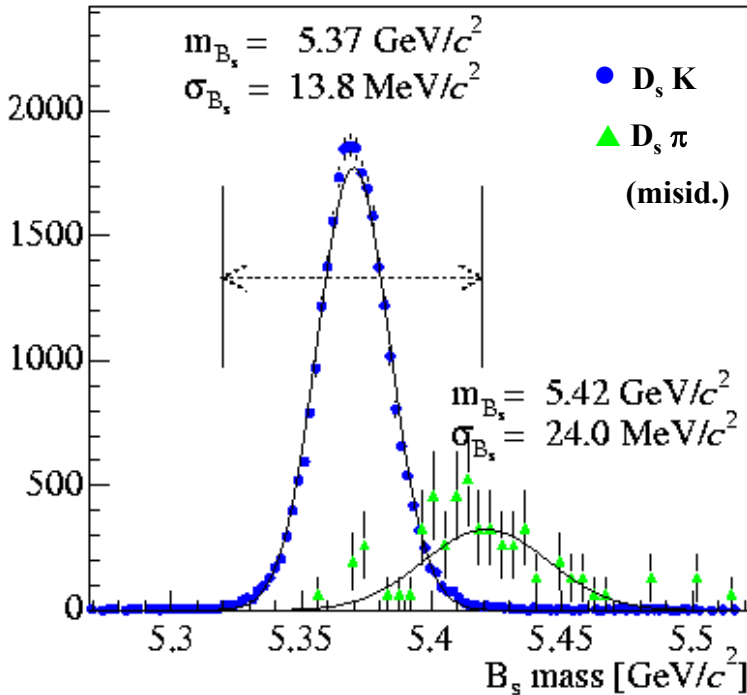


Time-dependent rec. + sel. + trig. efficiency



(not normalised plots)

Annual yields and B/S



B_s Mass resolution

(remaining $D_s \pi$ contamination $\sim 10\%$)

Sources of background

- pollution from $D_s \pi$ events
 - ↳ $\text{Br}(D_s \pi) / \text{Br}(D_s K) \sim 12$
- b-bbar background

Annual yield - untagged events

Decay	Untagged annual yield	B/S (90% C.L.)
$B_s \rightarrow D_s K$	$\sim 5.4 \text{ k}$	< 1.0
$B_s \rightarrow D_s \pi$	$\sim 82 \text{ k}$	0.32 ± 0.10

Sensitivity studies

[LHCb Note 2003-103]

Likelihood fit for extraction of γ

- ▶ events generated with parameterized (toy) MC for different settings of CP-parameters: $\gamma - 2\chi$, Δ , Δm_s , $\Delta\Gamma_s/\Gamma_s$
- ▶ full simulation MC info used for acceptance function, decay time uncertainty distribution, background fraction, etc.
- ▶ background events simulated with half the lifetime of the B_s , and with mass distribution observed in full simulation $R_{bkg}(t) = \Gamma e^{-\Gamma t}$
- ▶ $D_s K$ and $D_s \pi$ fitted simultaneously \leftrightarrow maximization of combined likelihood function

$$\mathcal{L}_{B \rightarrow f}(\vec{\alpha}) = \prod_i^{B_s \rightarrow D_s K} \text{Prob}(\tau_{rec}, \Delta\tau_{rec} | \vec{\alpha}, \omega_{tag}) \prod_i^{B_s \rightarrow D_s \pi} \text{Prob}(\tau_{rec}, \Delta\tau_{rec} | \vec{\alpha}, \omega_{tag})$$

- ▶ parameters for fit:

$$\vec{\alpha} = (\Gamma_s, \Delta\Gamma_s, \Delta m_s, \lambda, \bar{\lambda})$$

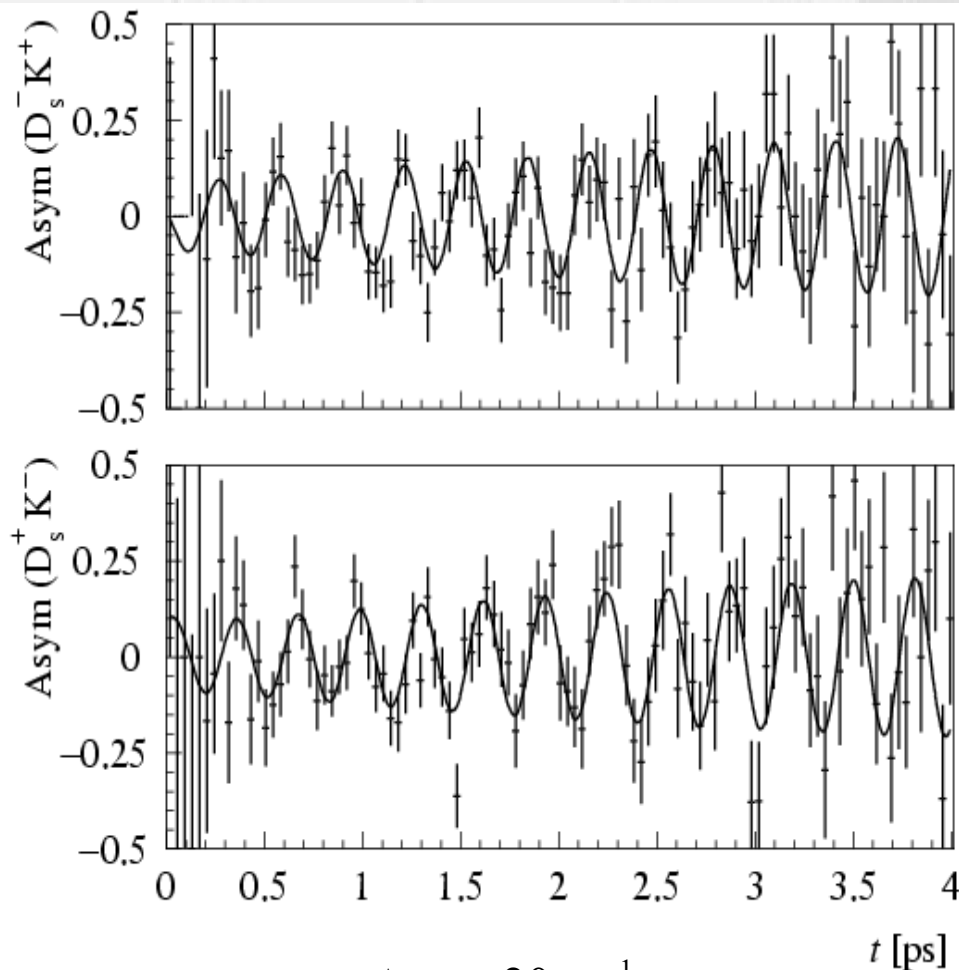
(per event proper time resolution)

- ▶ total likelihood:

$$\mathcal{L}(\vec{\alpha}) = \mathcal{L}_{B \rightarrow f}(\vec{\alpha}) \cdot \mathcal{L}_{\bar{B} \rightarrow f}(\vec{\alpha}) \cdot \mathcal{L}_{B \rightarrow \bar{f}}(\vec{\alpha}) \cdot \mathcal{L}_{\bar{B} \rightarrow \bar{f}}(\vec{\alpha})$$

Sensitivity studies

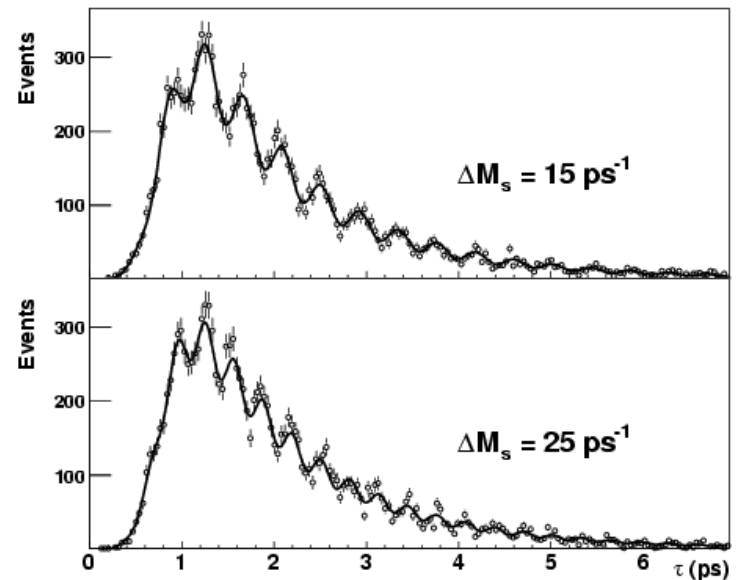
Asymmetries for 5 years of running



$$\Delta m_s = 20 \text{ ps}^{-1}$$

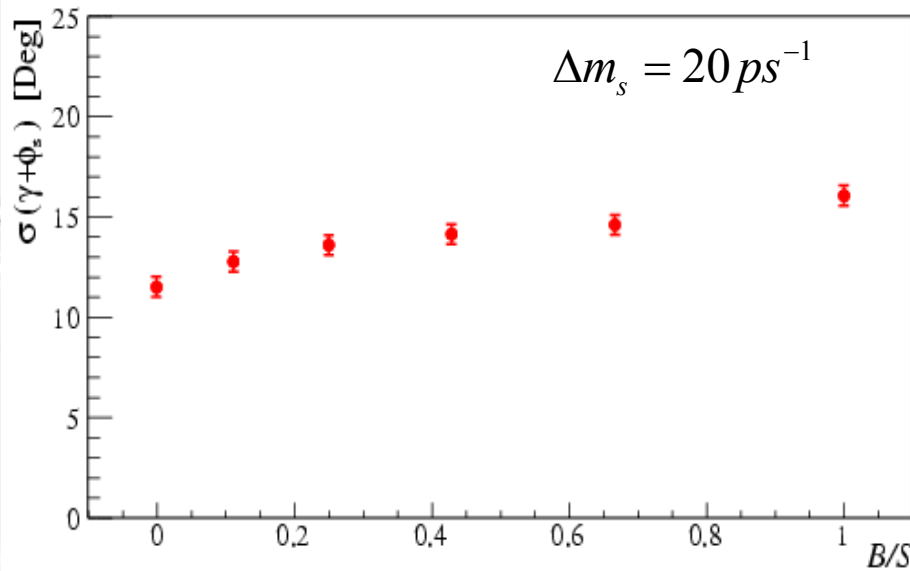
Simulated $B_s \rightarrow D_s \pi$ decay rate:

- contains only tagged and non-oscillated decays
- represents 1 year of data taking
- curve = prob. from likelihood maximization



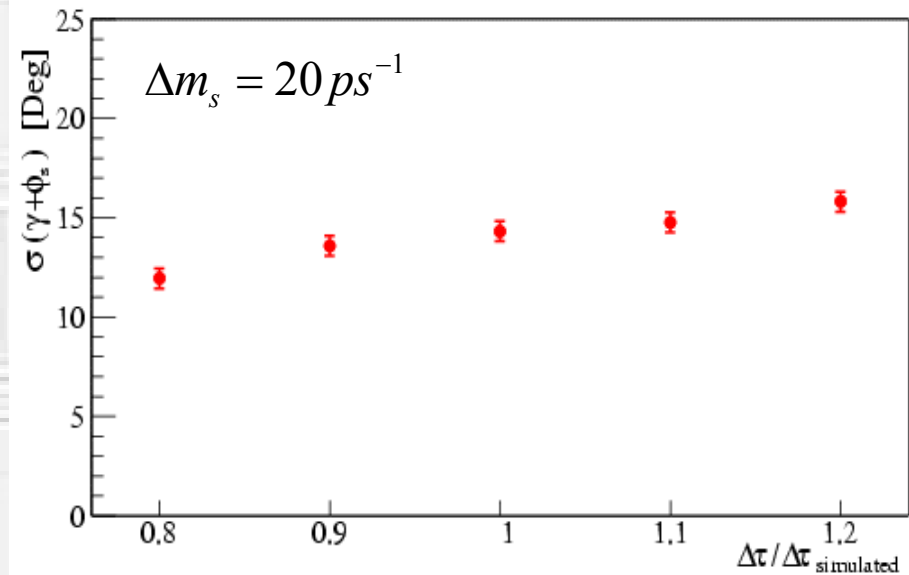
Sensitivity to reconstruction

Sensitivity to B/S ratio



Statistical uncertainties
for 1 year of data

Sensitivity to proper time resolution



$\phi_s = -2\chi$ in the Standard Model

Case the experimental uncertainty on the reconstructed proper (decay) time is wrong wrt simulation ...

Sensitivity summary

nominal values



Statistical precision (in degrees) on $\gamma-2\chi$ after **one** year

Δm_s :	15	20	25	30		
$\sigma(\gamma - 2\chi)$	12.1	14.2	16.2	18.3		
$\Delta\Gamma_s/\Gamma_s$:	0	0.1	0.2			
$\sigma(\gamma - 2\chi)$	14.7	14.2	12.9			
$\gamma - 2\chi$:	55	65	75	85	95	105
$\sigma(\gamma - 2\chi)$	14.5	14.2	15.0	15.0	15.1	15.2
$\Delta T_{1/T2}$:	-20	-10	0	10	20	
$\sigma(\gamma - 2\chi)$	13.9	14.1	14.2	14.5	14.6	

Statistical precision on Δm_s in ps^{-1} (**one** year):

Δm_s	15	20	25	30
$\sigma(\Delta m_s)$	0.009	0.011	0.013	0.016

Conclusions

- LHCb can exploit several methods of extraction of the γ angle
 - ↳ γ from $B_s \rightarrow D_s K$ method discussed
 - ↳ possibility of cross-checks between methods
 - ↳ different methods have different sensitivity to new physics
 - > detailed / sensitive description of CKM picture
- LHCb will provide large statistics for precision measurements
 - ↳ $\sim 5.4k D_s K$ events / year with LHCb
 - ↳ $\sim 80k D_s \pi$ events / year with LHCb
 - ↳ the B_s is not accessible at B-factories
- Performance in 1 year
 - ↳ $\sigma(\gamma) \sim 12-18^\circ$ for $\Delta m_s \sim 15-30 \text{ ps}^{-1}$
 - ↳ 5σ for Δm_s up to $\sim 65 \text{ ps}^{-1}$, $\sigma(\Delta m_s) \sim 0.01 \text{ ps}^{-1}$