LHCb SENSITIVITY TO γ WITH $B_s \to D_s K$

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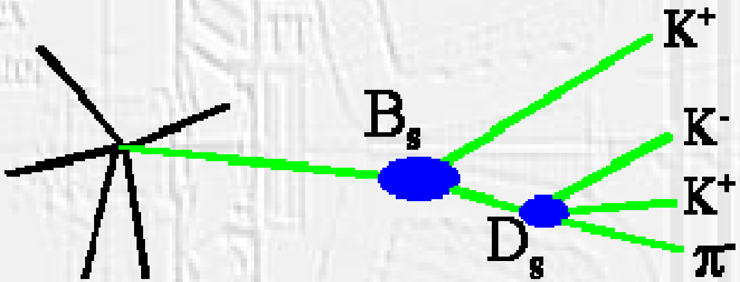
On behalf of the LHCb Experiment



I. Physics case

- CKM matrix
- extraction of γ from B_s -> 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

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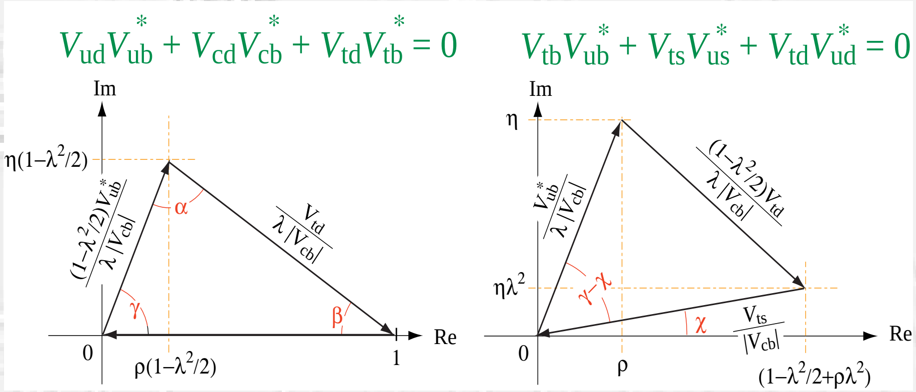
PHYSICS CASE

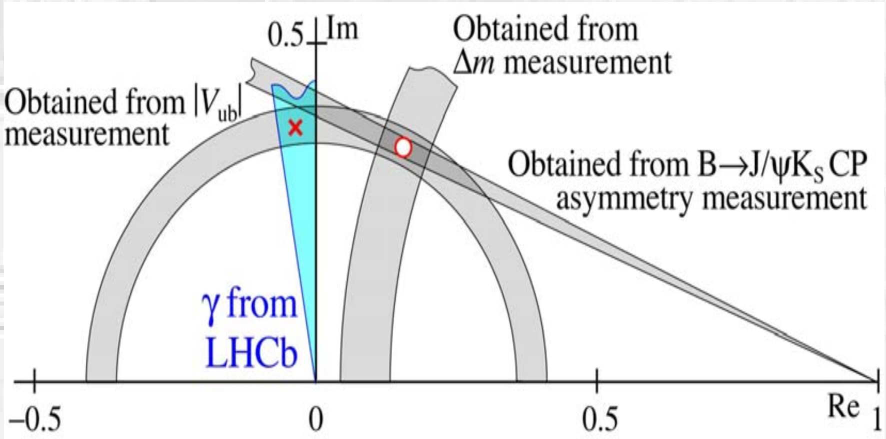
CKM matrix

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



γ from Bs -> D_s K

- one of several methods
- theoretically clean
- not sensitive to new physics
- in fact γ – 2χ is measured
  - ➥ χ from B_s -> J/Ψ φ :
    expect σ(sin2χ) ~ 0.06 in 1 year
- large samples expected with LHCb, not accessible at B-factories
- no direct measurement of γ yet available
  - ➥ $50^0 < \gamma < 80^0$ from CKM Fitter group [J. Charles et al., hep-ph/0406184]



γ = - arg(V_{ub})

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

A_f = instantaneous decay amplitude for B_s -> f

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

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

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

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

$\Gamma_s = (\Gamma_H + \Gamma_L) / 2$

$\Delta\Gamma_s = B_H , B_L$ decay width difference

$\Delta m_s = B_H , B_L$ mass difference

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

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

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

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

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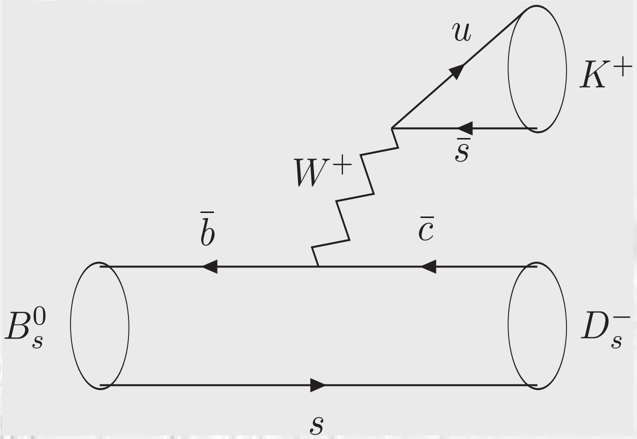
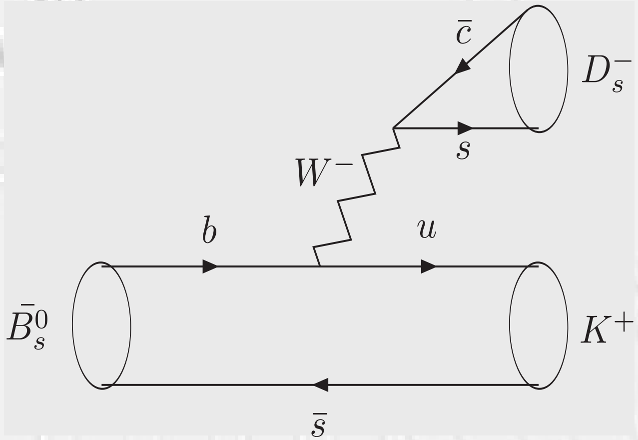
Case of $B_s \to D_s K$



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



Interference between 2 tree diagrams via mixing <-> 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

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

Large asymmetry expected

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

- 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 -> $D_s \pi$

- needs also to be considered here because:
  - main source of background to $D_s K$ ($Br(D_s\pi)$ / $Br(D_sK)$ ~ 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

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

$$\mathcal{A}^{flav} = \frac{\Gamma_{\bar{B}\to f} - \Gamma_{B\to f}}{\Gamma_{\bar{B}\to f} + \Gamma_{B\to f}} = -D \cdot \frac{\cos(\Delta m_s t)}{\cosh(\Delta\Gamma_s t)} \quad \text{with} \quad \left|\frac{p}{q}\right| = 1$$

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

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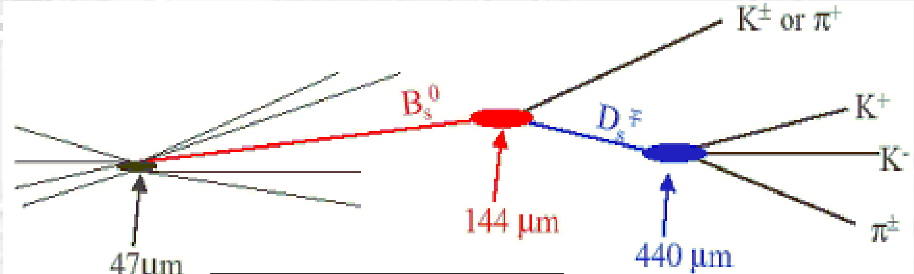
Event selection

[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



z-vertex resolutions

D_s reconstruction

- D_s reconstructed in $D_s \rightarrow K K \pi$ mode
  - ➥ fully reconstructible, high-ish B.R. ~ 4.4%
- the 3 tracks must satisfy $\Sigma p_T > 2.2$ GeV
- vertex with $\chi^2 < 10$
- invariant mass window of +/- 15 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

only non-common selection for $B_s \rightarrow D_s K$ and $B_s \rightarrow D_s \pi$

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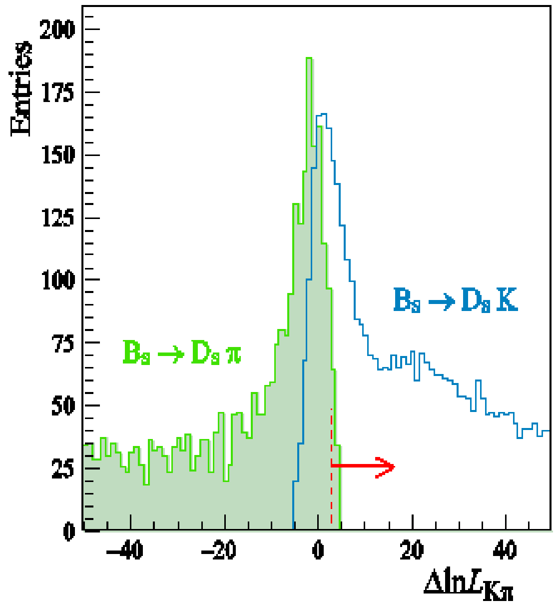
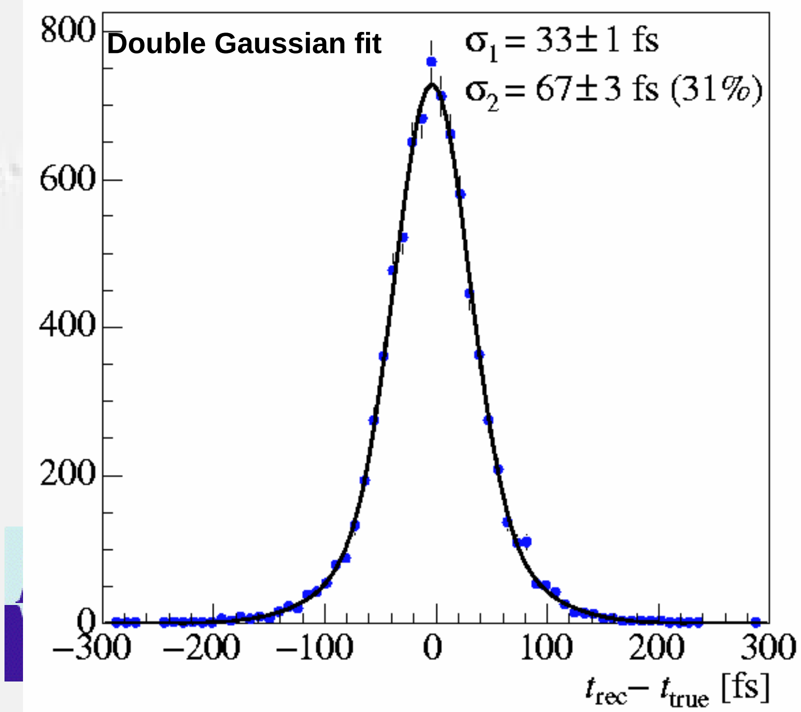
Reconstruction plots

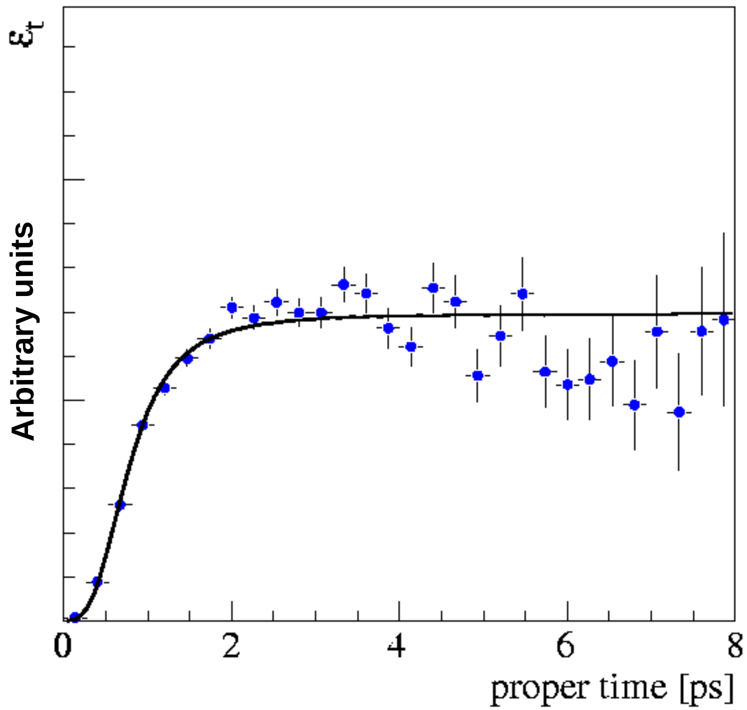


K/π separation using log-likelihood from RICH PID hypotheses

Proper time resolution of B_s

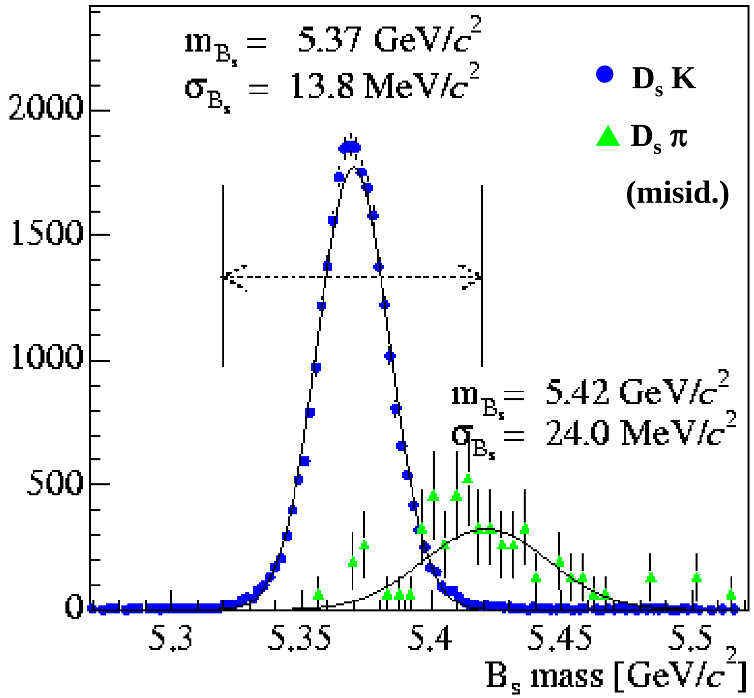


Time-dependent rec. + sel. + trig. efficiency



(not normalised plots)

Annual yields and B/S



B_s Mass resolution

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

Sources of background

- pollution from D_s π events
  - ➥ Br($D_s\pi$) / Br(D_sK) ~ 12
- b-bbar background

Annual yield – untagged events

Decay	Untagged annual yield	B/S (90% C.L.)
B_s -> D_s K	~ 5.4 k	< 1.0
B_s -> D_s π	~ 82 k	0.32 ± 0.10

Triggered & reconstructed & selected

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 π fitted simultaneously <-> maximization of combined likelihood function

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

(per event proper time resolution)

- parameters for fit:

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

- total likelihood:

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

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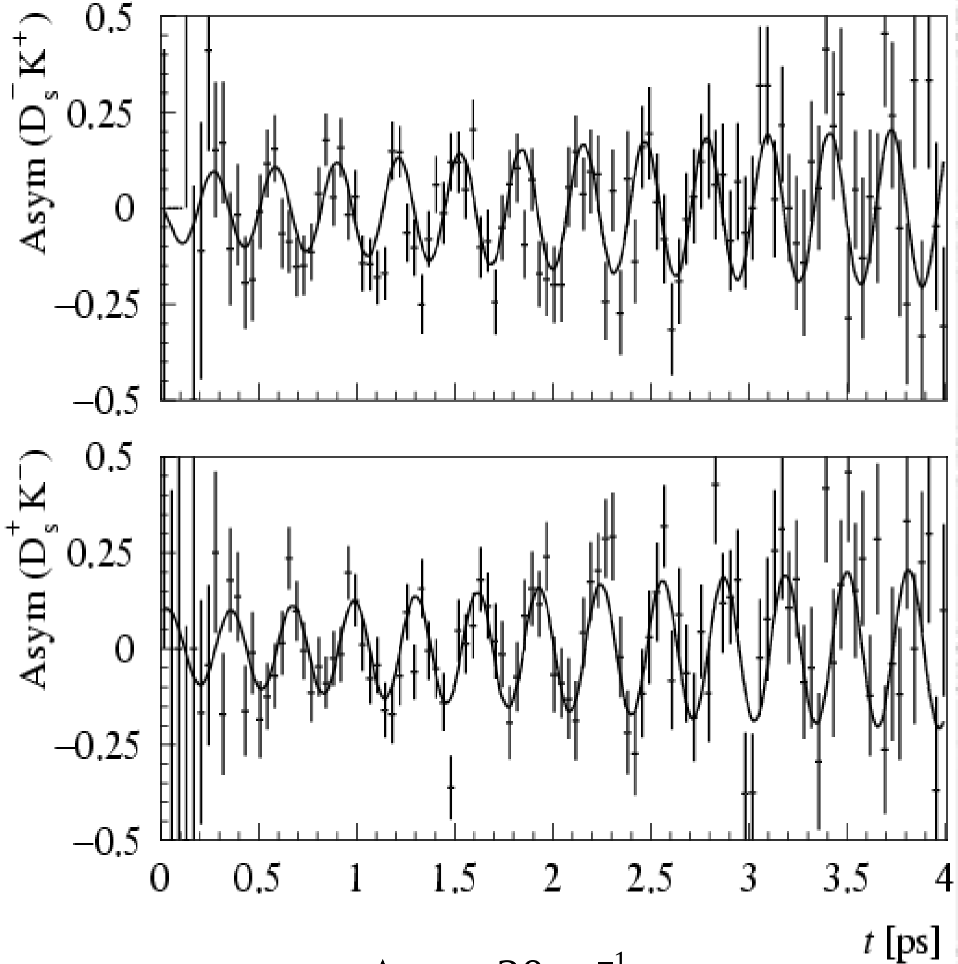
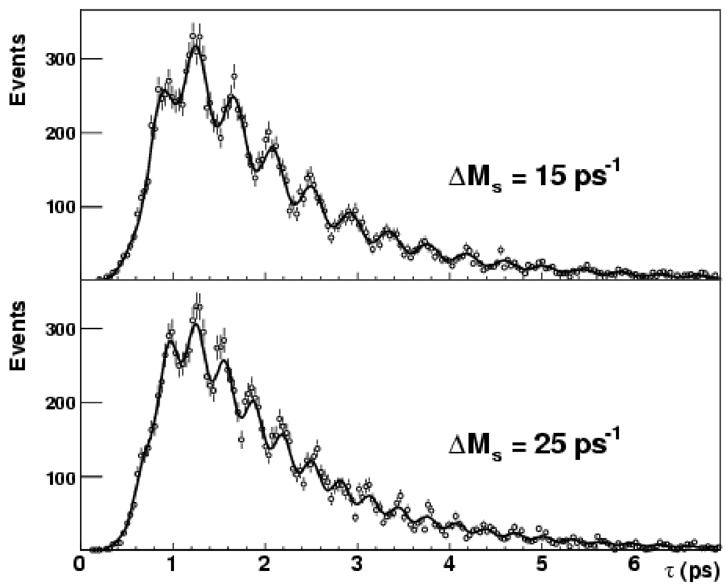
Sensitivity studies

Asymmetries for 5 years of running



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

Simulated B_s -> $D_s\ \pi$ decay rate:
- contains only tagged and non-oscillated decays
- represents 1 year of data taking
- curve = prob. from likelihood maximization



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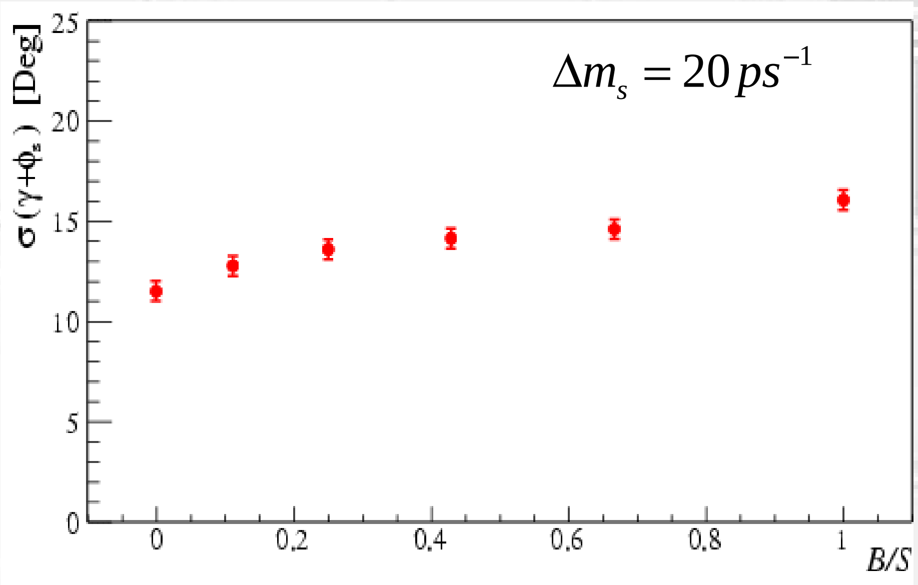
Sensitivity to reconstruction

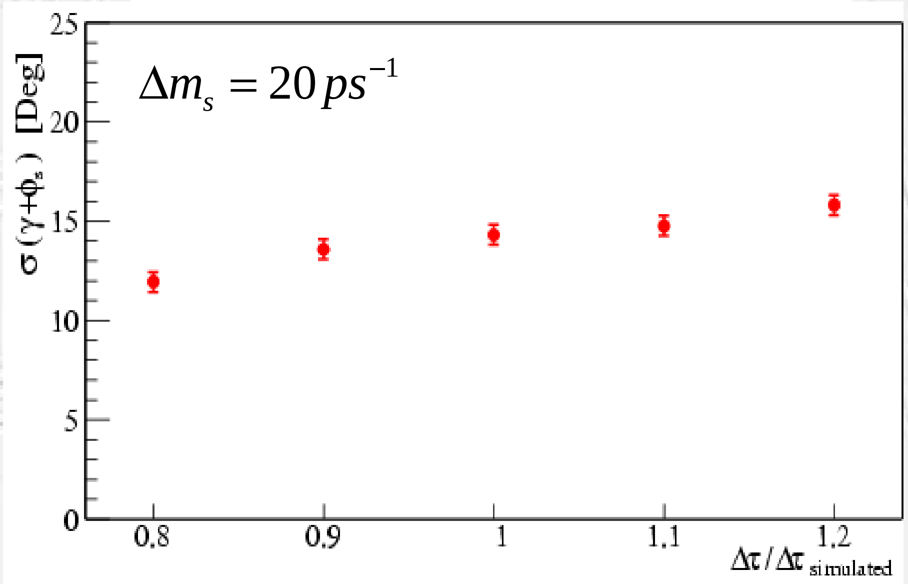
Sensitivity to B/S ratio



Statistical uncertainties for 1 year of data

ϕ_s = -2χ in the Standard Model

Sensitivity to proper time resolution



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

Sensitivity summary

nominal values

Statistical precision (in degrees) on γ-2χ 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

$\Delta_{T1/T2}$:	-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 -> 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
  - ~ 5.4k D_s K events / year with LHCb
  - ~ 80k $D_s \pi$ events / year with LHCb
  - the B_s is not accessible at B-factories

- Performance in 1 year
  - $\sigma(\gamma) \sim 12\text{-}18^0$ for $\Delta m_s \sim 15\text{-}30\ ps^{-1}$
  - 5σ for Δm_s up to ~ 65 ps^{-1} , $\sigma(\Delta m_s) \sim 0.01\ ps^{-1}$

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