Measurement of mixing parameters of the B_s meson at LHCb

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Swiss Physical Society meeting

February 20-21, 2007

Outline

- Physics motivation
- LHCb experiment
- Main steps of the study
- Results of sensitivity studies
- Conclusion

Motivation

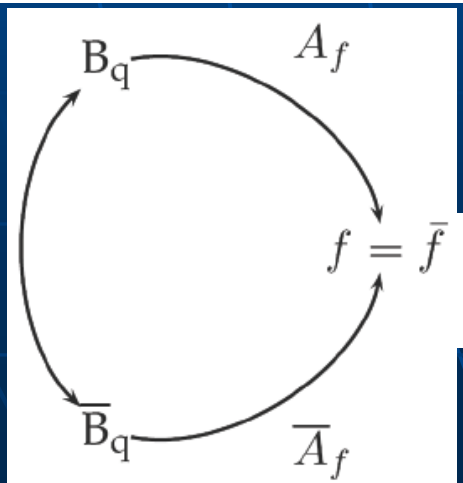
- LHCb Physics program: dedicated to b physics
  - All B_s mixing parameters: Δm_s , ϕ_s, $\Delta\Gamma_s$
    - $B_s \to D_s\pi$, b→c cbar s modes: J/ΨΦ, J/Ψη, $\eta_c\Phi$
  - CKM angles α β and γ
  - Rare B decays
    - Radiative, electroweak, gluonic penguins
    - $B_s \to \mu\mu$ (rare box diagram)

Sensitivity to new physics:

New particles in loop diagrams

- B_c , b-baryon physics, charm physics, etc…

B mixing and decays:



for CP eigenstates (e.g: J/ΨΦ, J/Ψη, ηcΦ)

For $B_s \to D_s^- \pi^+$, $f \neq \bar{f}$

Combined decays to CP eigen states and non CP eigen states to extract the mixing parameters:

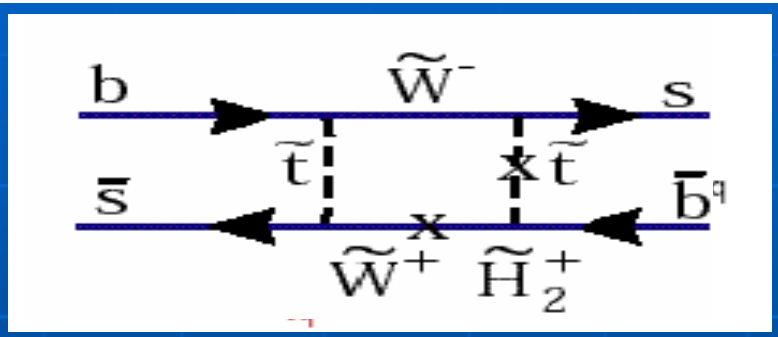
1. Precision measurement for Δm_s
2. ϕ_s measurement

Small $(\phi_s)_{SM}$ (-0.04): possible early detection of New Physics

Mixing and decay asymmetry for $b \to c\bar{c}s$ modes

Mixing: mass eigenstates ≠ CP eigenstates

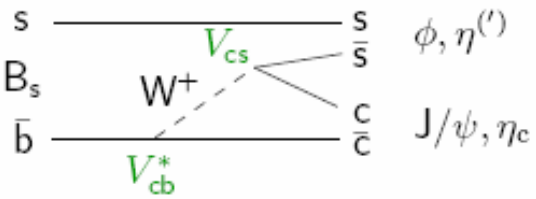
$$|B_{L/H}\rangle = p|B_q\rangle \pm q|\bar{B}_q\rangle, \Delta M_q = M_H - M_L, \Delta\Gamma_q = \Gamma_L - \Gamma_H$$

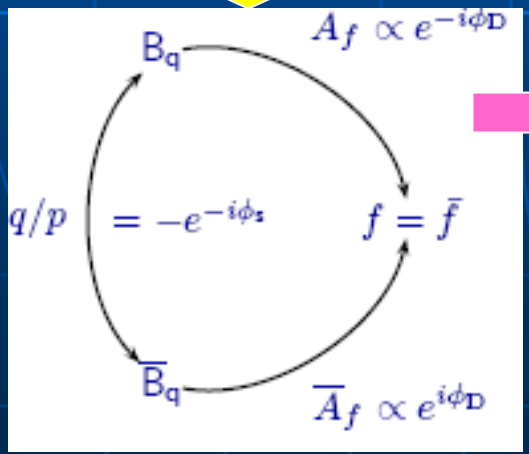


Mixing phase $\phi_s + \phi_{NP}$ with new physics

Decay

Amplitudes (A_f) dominated by 1 tree $\phi_D \equiv -\arg[V_{cb}^* V_{cs}] \approx 0$





Final phase for asymmetry ratio ≈ ϕ_s ($+\phi_{NP}$)

$$\mathcal{A}_{CP}(t) = \frac{\Gamma[\bar{B}_s(t) \to f] - \Gamma[B_s(t) \to f]}{\Gamma[\bar{B}_s(t) \to f] + \Gamma[B_s(t) \to f]}$$

$$\mathcal{A}_{CP}^{\text{mix-ind}}(t) = -\frac{\eta_f \sin\phi_s \sin(\Delta M_s\, t)}{\cosh(\Delta\Gamma_s\, t/2) - \eta_f \cos\phi_s \sinh(\Delta\Gamma_s\, t/2)}$$

Time dependent asymmetry: extraction of ϕ_s and $\Delta\Gamma_s$ (ΔM_s obtained from control sample $B_s \to D_s^- \pi^+$)

LHCb experiment

- **pp collisions @ 14 TeV**

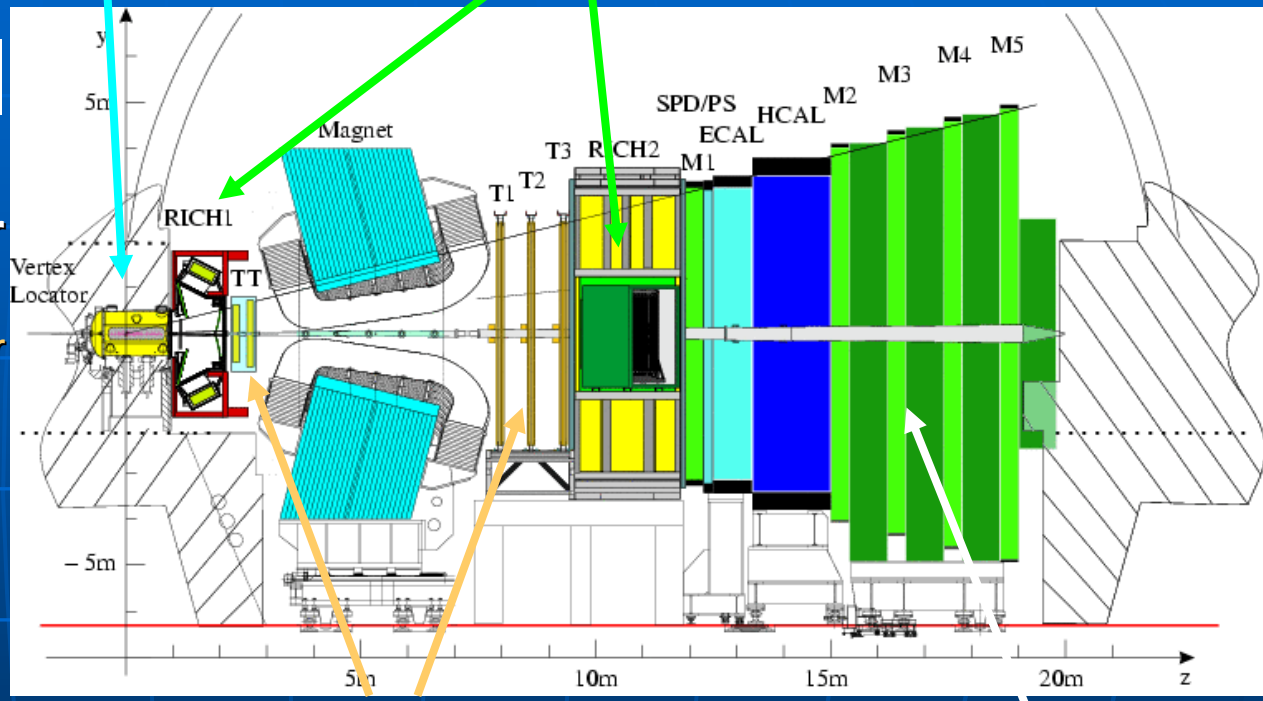
Correlated forward $b\bar{b}$ production $\sigma_b \approx 500\ \mu b$

- **Forward spectrometer**

Need prim. & b vertex reco for time measurements + subsequent decays separation

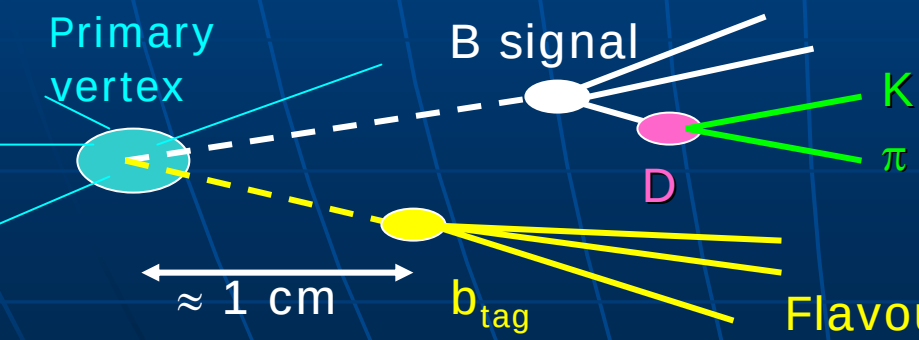
Vertexing

RICH system for PID



Tracking

Muon detector



PID to identify K/ π

Flavour tagging

Channels for mixing parameters determination

- Admixture of CP eigenstates (η_f = -1, +1)
  - $B_s \rightarrow J/\Psi(\mu^+\mu^-)\Phi(K^+K^-)$
    - Large yield but angular analysis to disentangle final states
- CP Even eigenstates (η_f = +1)
  - $B_s \rightarrow J/\Psi(\mu^+\mu^-)\eta(\gamma\gamma,\pi^+\pi^-\pi^0)$, $J/\Psi(\mu^+\mu^-)\eta'(\pi^+\pi^-\eta,\rho^0\gamma)$, $\eta_c(h^+h^-h^+h^-)\Phi(K^+K^-)$
    - Low yield, high background
  - $B_s \rightarrow D_s^+(K^+K^-\pi^+)D_s^-(K^+K^-\pi^-)$
    - Low yield, degradation of proper time resolution
- Extraction of ΔM_s using flavor-specific control channel
  - $B_s \rightarrow D_s^-(K^+K^-\pi^-)\pi^+$

Basic ingredients for the analyses

- Candidate selection
  - B_s mass resolution
- Proper time
  - Vertex/time resolution and time-dependent efficiency $\varepsilon(t)$
- Tagging
  - Mistag rate and tagging efficiency

Full Monte Carlo simulation results (based on 2 fb^{-1})

Parameters	$J/\psi\ \phi$	$\eta_c\ \phi$	D_sD_s	$J/\psi\eta(\gamma\gamma)$	$J/\psi\eta(\pi\pi\pi)$	$D_s\pi$	J/Ψ η'($\pi^+\pi^-$ η(γγ))
2 fb^{-1} yield [k events]	131	3	4	8.5	3	120	2.2
Background level B/S	0.12	0.6	0.3	2.0	3.0	0.4	1.0
Mass σ_{B_s} [MeV/c]	14	12	6	34	20	14	19
Mean $< \tau_{fit}^{err} >$ [fs]	29.5	26.2	44.4	30.4	25.5	32.9	33.0
Scale factor Σ_τ	1.22	1.16	1.26	1.22	1.32	1.21	19
Wrong tag ω_{tag} [%]	33	31	34	35	30	31	31
Tagging ε_{tag} [%]	57	66	57	63	62	63	64

$B_s \to D_s^- \pi^+$ decay rates and ΔM_s

Ideal rate

$$R(\overset{(-)}{B}_s(t) \to D_s\pi) \propto \frac{e^{-\Delta\Gamma_s t}}{2}\left(\cosh\frac{\Delta\Gamma_s t}{2} \pm \cos\Delta M_s t\right)$$

+ dilution from flavour tagging

$$R(\overset{(-)}{B}_s(t) \to D_s\pi) \propto \frac{e^{-\Delta\Gamma_s t}}{2}\left(\cosh\frac{\Delta\Gamma_s t}{2} \pm D\cos\Delta M_s t\right)$$

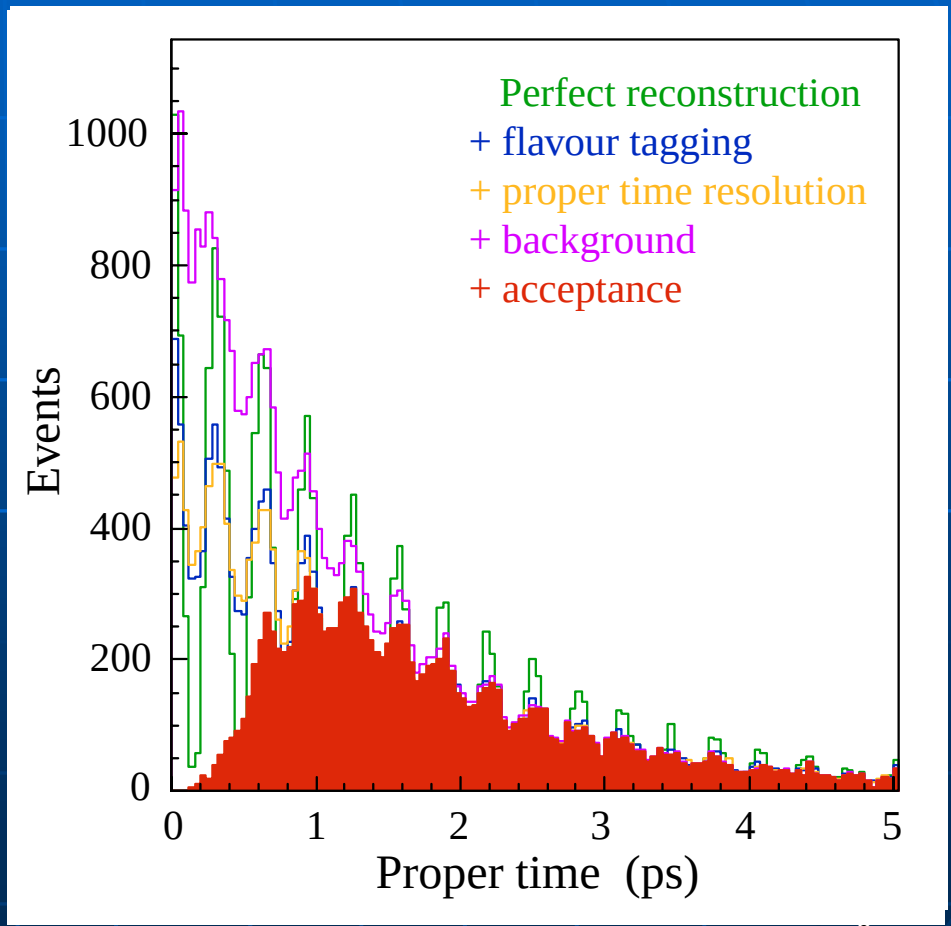
+ Proper time resolution ~40 fs

$$R(\overset{(-)}{B}_s(t^{true}) \to D_s\pi) \otimes G(t^{true} - t^{rec}, \Sigma_\tau \sigma_\tau)$$

+ Background S/B ~ 3

+ Acceptance

$$\varepsilon(t^{rec})\, R(\overset{(-)}{B}_s(t^{true}) \to D_s\pi) \otimes G(t^{true} - t^{rec}, \Sigma_\tau \sigma_\tau)$$



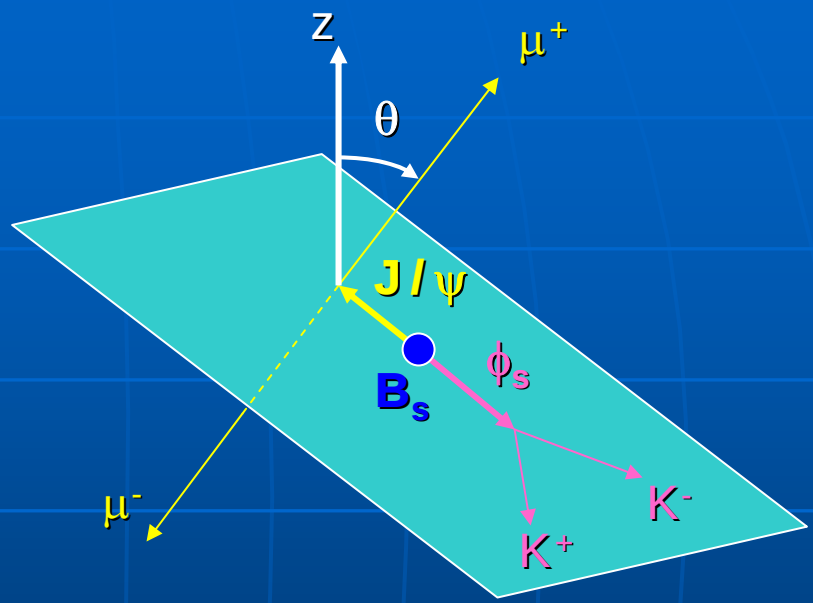
$B_s \to J/\Psi(\mu^+\mu^-)\Phi(K^+K^-)$ case

Transversity amplitudes:

A_0, $A_{//}$ (CP even) $A_\perp$ (odd)

CP-odd fraction $(t = 0)$:

$$R_T \equiv \frac{|A_\perp|^2}{\sum_{f=0,\|,\perp} |A_f|^2} \sim \mathcal{O}(0.2)$$



One angle distribution:

$$\frac{d\,\Gamma[B_s(t) \to f]}{d\cos\theta} \propto (|A_0(t)|^2 + |A_\|(t)|^2)\,\frac{3}{8}\,(1+\cos^2\theta) + |A_\perp(t)|^2\,\frac{3}{4}(1-\cos^2\theta)$$

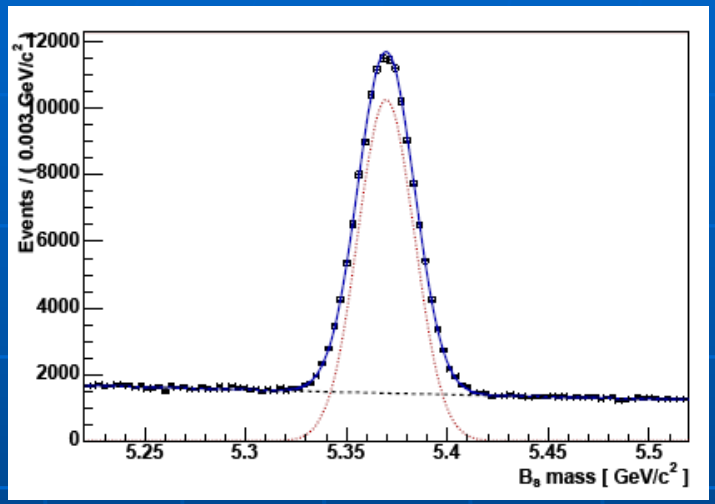
$$\Gamma(B_s(t) \to f) \propto (1-R_T)\,\Gamma(B_s(t) \to f_{even}) + R_T\,\Gamma(B_s(t) \to f_{odd})$$

Toy Monte Carlo sensitivity studies

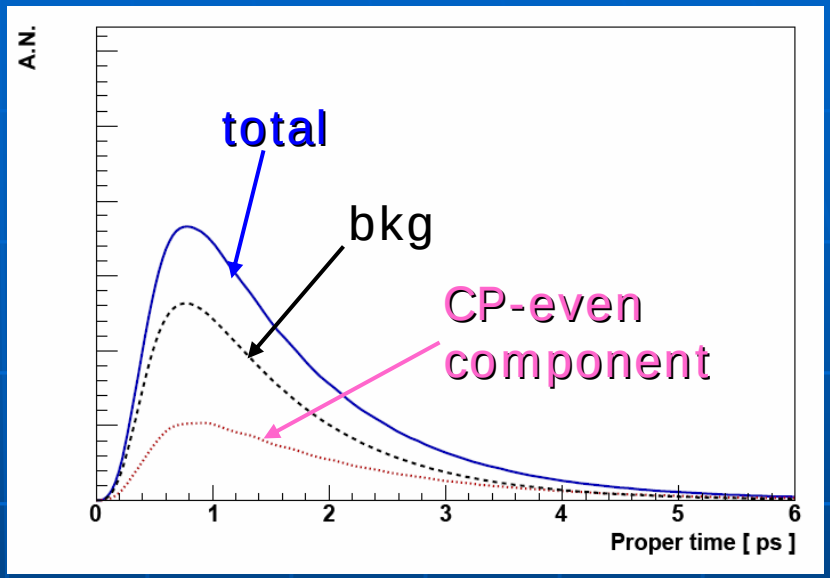
- From full MC, extract PDFs to model signal and background
  - Mass distributions
  - Proper time distributions (including acceptance, tagging, resolution model)
  - Transversity angle θ for $B_s \rightarrow J/\Psi\Phi$
- Generate ~ 200 toy experiments, each of them corresponds to 2 fb^{-1} of data
  - Likelihood maximized for $b \rightarrow c\,\bar{c}\,s$ modes simultaneously with control sample $B_s \rightarrow D_s\pi$
- Standard Model (or measured) values used for the input parameters:
  - $M(B_s) = 5369.6$ MeV/c^2, $\Delta M_s = 17.5$ ps^{-1}
  - $\phi_s = -0.04$ rad, $\Delta\Gamma_s/\Gamma_s = 0.15$, $\tau_s = 1/\Gamma_s = 1.45$ ps
  - $R_T = 0.2$ for $B_s \rightarrow J/\Psi\Phi$
- Fitted parameters: ϕ_s, ΔM_s, Γ_s , $\Delta\Gamma_s$ (+ R_T, ω_{tag})

PDF modeling, examples

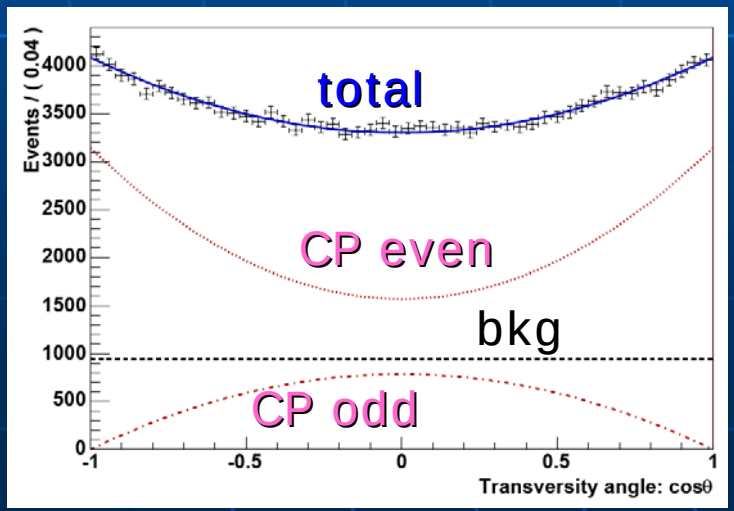
$B_s(\rightarrow D_s\pi)$ mass



Proper time model for $B_s\rightarrow J/\Psi\Phi$



Transversity angle for $B_s\rightarrow J/\Psi\Phi$



Proper time PDF: convolution

$(\varepsilon(t^{rec}).R(t^{true},\omega_{tag})$ (acceptance function×decay rate)

$\otimes$ $G(t^{rec} - t^{true}, \Sigma_\tau\sigma_\tau)$ (resolution function)

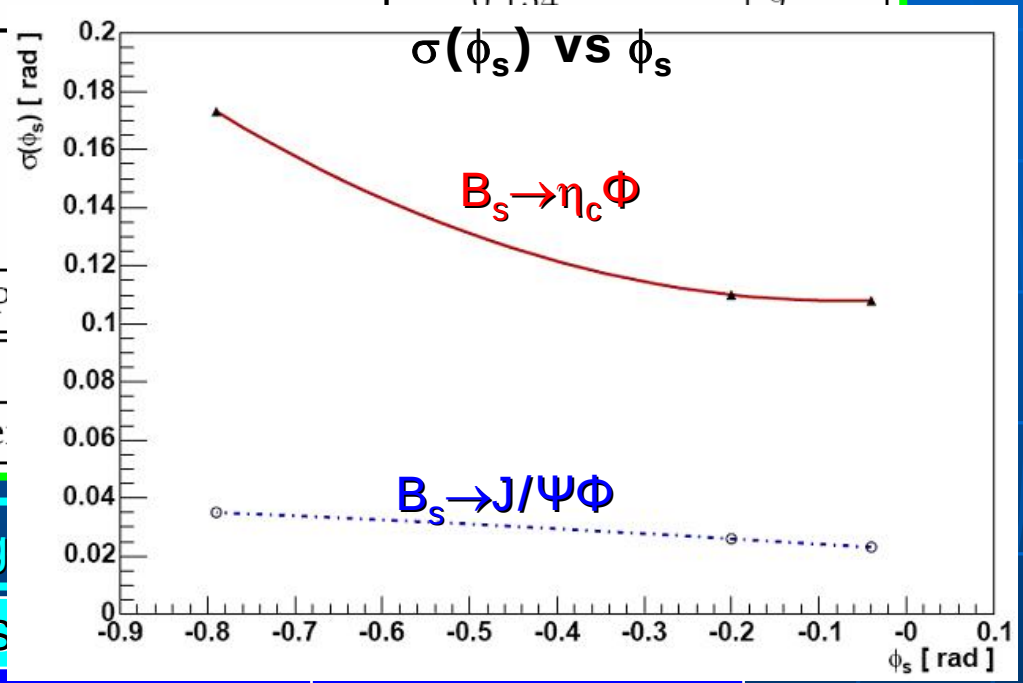
- σ_τ (per event) proper time error

- Σ_τ scaling factor to account for bad error estimation

Results for the sensitivities (2 fb^{-1})

ϕ_s sensitivity

Channels	$\sigma(\phi_s)$ [rad]	Weight [%]
$B_s^0 \to J/\psi\, \eta'(\pi^+\, \pi^-\, \eta)$	0.154	1.9
$B_s^0 \to J/\psi\, \eta(\pi^+\, \pi^-\, \pi^0)$		
$B_s^0 \to D_s\, D_s$		
$B_s^0 \to J/\psi\, \eta(\gamma\, \gamma)$		
$B_s^0 \to \eta_c\, \phi$		
Combined sensitivity for pure CP		
$B_s^0 \to J/\psi\, \phi$		
Combined sensitivity for all CP e		



Other mixing

Parameters	S	
$\Delta\Gamma_s/\Gamma_s$	0.0092	$B_s \to J/\Psi\Phi$
R_T	0.0004	$B_s \to J/\Psi\Phi$
ΔM_s	0.007 ps^{-1}	$B_s \to D_s\pi$
ω_{tag}	0.0036	$B_s \to D_s\pi$

Conclusions

- Precision measurement for ΔM_s
- ϕ_s is unmeasured (yet)
- LHCb combined statistical sensitivity to ϕ_s is 0.02 for 2 fb^{-1} (a 2σ measurement for a SM value)
  - Dominated by $B_s \rightarrow J/\Psi\Phi$
  - With the same statistics, ability to detect deviation due to new physics
  - First results expected for 2008. More precision afterwards
- More improvement to come
  - Adding $J/\Psi \rightarrow e^+e^-$ mode increases yield by ~ 20%
  - Full angular analysis for $B_s \rightarrow J/\Psi\Phi$
  - Optimize use of $B_s \rightarrow D_s\pi$ to determine the tagging performance of the $b \rightarrow c\ \bar{c}\ s$ modes
  - Systematics studies

Back up

Decay rates

$$R[\mathrm{B_s}(t) \to f] \propto e^{-\Gamma_s t}\left\{\cosh\frac{\Delta\Gamma_s\, t}{2} - \eta_f \cos\phi_s \sinh\frac{\Delta\Gamma_s\, t}{2} + \eta_f\, D \sin\phi_s \sin(\Delta M_s\, t)\right\},$$

$$R[\overline{\mathrm{B}}_s(t) \to f] \propto e^{-\Gamma_s t}\left\{\cosh\frac{\Delta\Gamma_s\, t}{2} - \eta_f \cos\phi_s \sinh\frac{\Delta\Gamma_s\, t}{2} - \eta_f\, D \sin\phi_s \sin(\Delta M_s\, t)\right\}.$$

$b \to c\ \bar{c}\ s$ modes

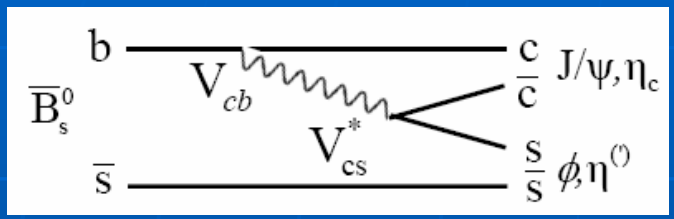
$$R[\mathrm{B_s}(t) \to f] \propto \frac{e^{-\Gamma_s t}}{2}\left[\cosh\frac{\Delta\Gamma_s\, t}{2} + D\cos(\Delta M_s\, t)\right]$$

$$R[\overline{\mathrm{B}}_s(t) \to f] \propto \frac{e^{-\Gamma_s t}}{2}\left[\cosh\frac{\Delta\Gamma_s\, t}{2} - D\cos(\Delta M_s\, t)\right]$$

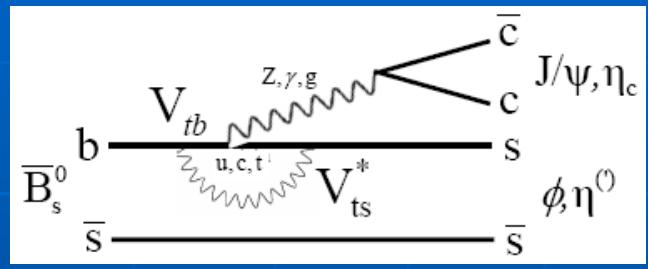
$B_s \to D_s^- \pi^+$

Decay diagrams

Dominant tree

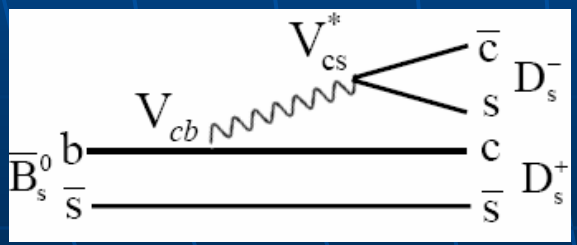


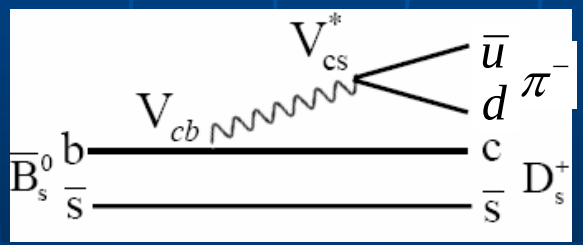
Penguin contribution



$$A(\bar{b} \to \bar{c}c\bar{s}) = V_{cs}V_{cb}^*(A_T + P_c) + V_{us}V_{ub}^* P_u + V_{ts}V_{tb}^* P_t = V_{cs}V_{cb}^*(A_T + P_c - P_t) + V_{us}V_{ub}^*(P_u - P_t)$$

$\propto \lambda^2$ $\propto \lambda^4$

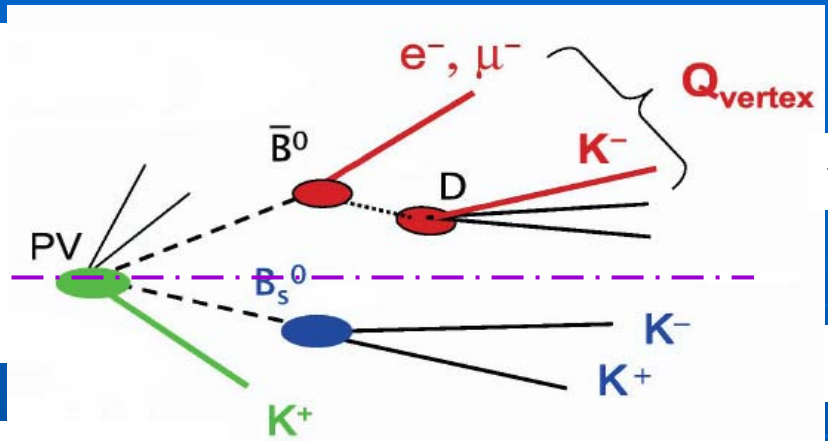




Tagging performance

e, μ from semi-leptonic decays
$K^{\pm}$ from the $b \to c \to s$
jet/vertex charge

same side π/K



Tagging power $\varepsilon D^2 = \varepsilon(1-2\omega_{tag})^2$ (in %)

Tag	εD^2
Muon	1.0
Electron	0.4
Kaon	2.4
Jet/vertex charge	1.0
Same side	2.1

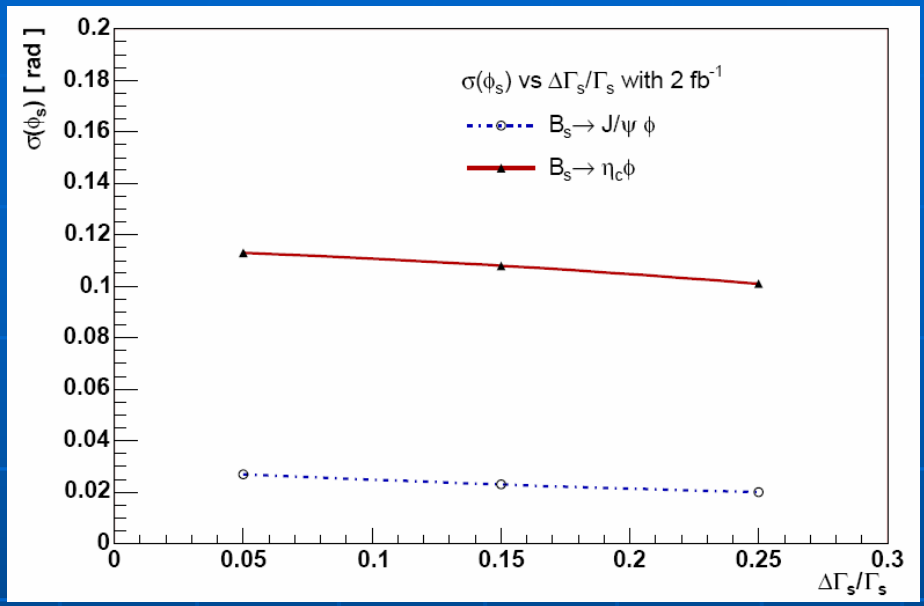
Combined tagging power for B_S in LHCb is ~ 6%

Note **~2%** at the Tevatron
~30% at B-Factories

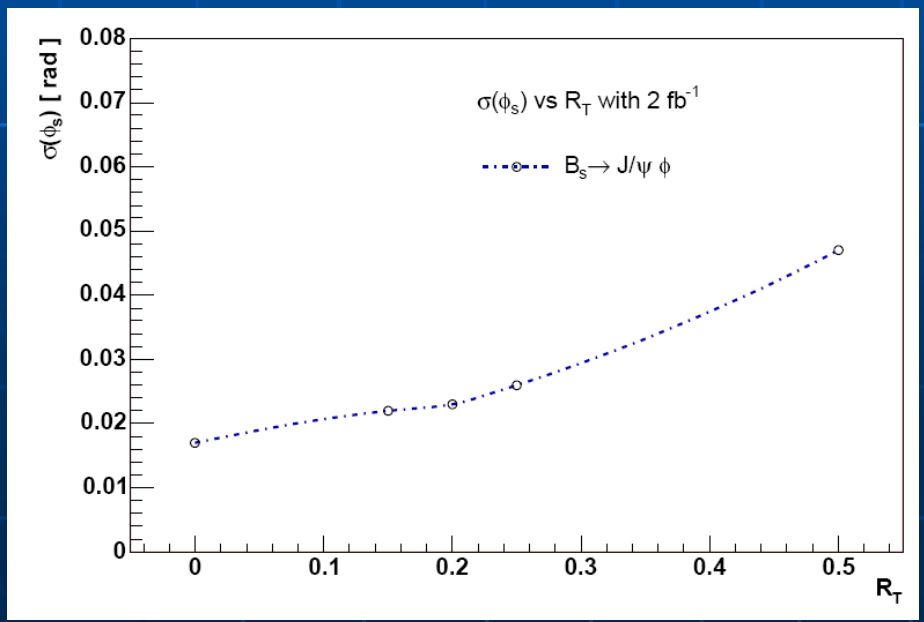
Tagging power for B^0 ~ 4%
(reduced same side tagging)

Recent Neural Network based study achieved 9% for B_S tagging!

More sensitivity plots



$\sigma(\phi_s)$ vs $\Delta\Gamma_s/\Gamma_s$



$\sigma(\phi_s)$ vs R_T