LHCb performance for

$B_s \rightarrow J/\psi\ \phi$ and $B_d \rightarrow J/\psi\ K_s$

decays

Jeroen van Hunen

$B_s \to J/\psi\ \phi$ and $B_d \to J/\psi\ K_s$

$B_d \to J/\psi\ K_s$
$B_s \to J/\psi\ \phi$

} **CP eigenstate and a mixture of CP-odd and CP-even states**

$$\Rightarrow \qquad \lambda_{fcp} \equiv \frac{q}{p}\frac{\overline{A}_{fcp}}{A_{fcp}} = \eta_{fcp}\frac{q}{p}\frac{\overline{A}_{\bar{f}cp}}{A_{fcp}} \qquad \eta_{fcp} = \pm 1$$

$\left|\frac{\overline{A}_{\bar{f}}}{A_f}\right| = 1$ no CPV in decay → single weak phase

$\left|\frac{p}{q}\right| = 1$ no CPV in mixing

} CP-symmetry $\lambda_{fcp} = \eta_{fcp}$

If $\Im\lambda_{fcp} \neq 0$

$\Rightarrow$ CP violated

(interference mixing and decay)

CP - Asymmetry

$$A_f \equiv \frac{R_f(t) - \overline{R}_{\bar{f}}(t)}{R_f(t) + \overline{R}_{\bar{f}}(t)} = -\frac{(1-|\lambda_f|^2)\cos(\Delta m t) - 2\Im\lambda_f \sin(\Delta m t)}{(1+|\lambda_f|^2)\cosh(\Delta\Gamma t/2) - 2\Re\lambda_f \sinh(\Delta\Gamma t/2)}$$

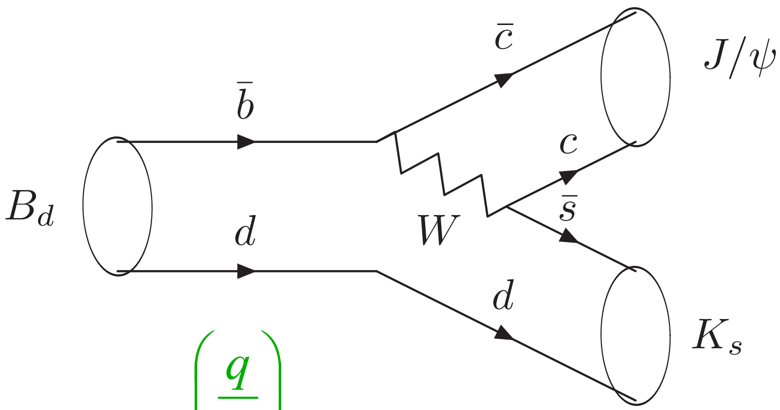
CP-eigenstate, $|\lambda_f| = 1$:

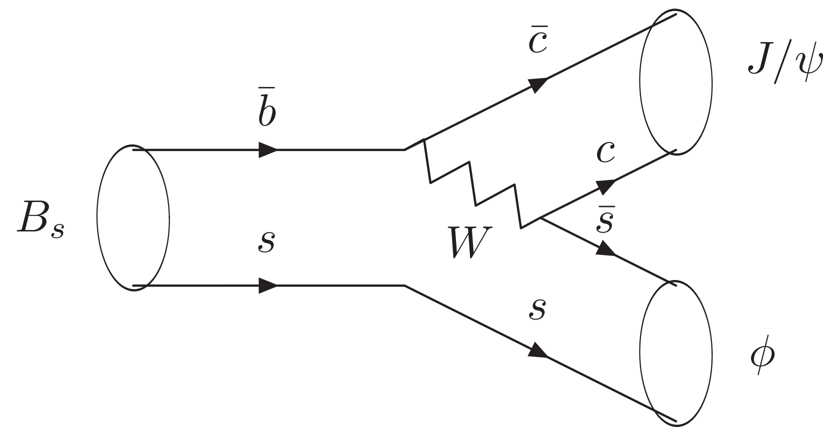
$$A_{fcp} = -\frac{\Im\lambda_{fcp}\sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) - \Re\lambda_{fcp}\sinh(\Delta\Gamma t/2)}$$

$\Delta\Gamma = 0$ (for B^0_d) :

$$A_{fcp} = -\Im\lambda_{fcp}\sin(\Delta m t)$$

$B_s \to J/\psi\,\phi$ and $B_d \to J/\psi\,K_s$





$\left(\frac{q}{p}\right)_{B_s}$ →

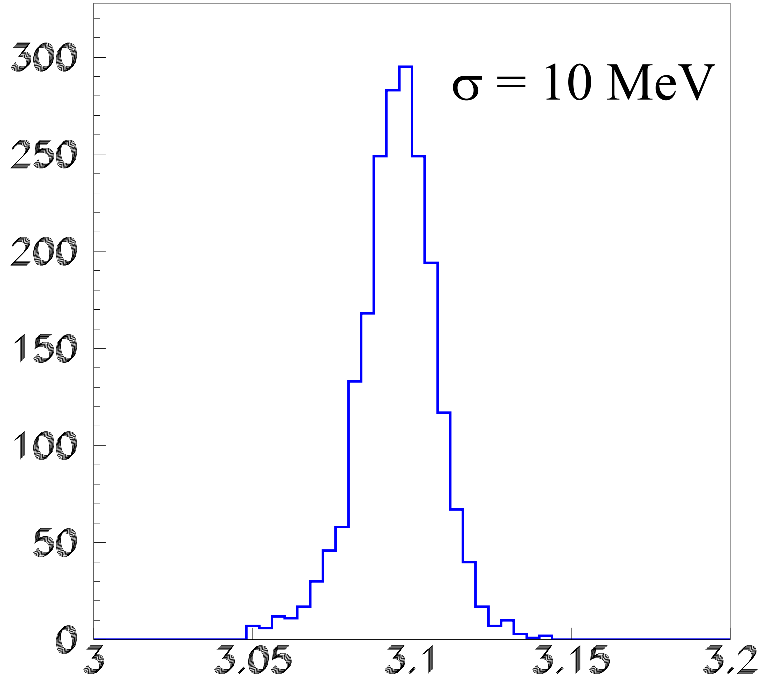
$$\lambda_{J/\psi\phi} = \eta_{J/\psi\phi}\left(\frac{V_{tb}^{*}V_{ts}}{V_{tb}V_{ts}^{*}}\right)\left(\frac{V_{cb}V_{cs}^{*}}{V_{cb}^{*}V_{cs}}\right) \quad \Rightarrow \Im\,\lambda_{J/\psi\phi} = \sin 2\beta_s$$

$$\lambda_{J/\psi K_s} = \eta_{J/\psi K_s}\left(\frac{V_{tb}^{*}V_{td}}{V_{tb}V_{td}^{*}}\right)\left(\frac{V_{cb}V_{cs}^{*}}{V_{cb}^{*}V_{cs}}\right)\left(\frac{V_{cd}^{*}V_{cs}}{V_{cd}V_{cs}^{*}}\right) \quad \Rightarrow \Im\,\lambda_{J/\psi K_s} = \sin 2\beta$$

$\left(\frac{q}{p}\right)_{B_d}$ ↗ ↖ $\left(\frac{q}{p}\right)_{K}$

$J/\psi \rightarrow \mu^+\mu^-$ selection

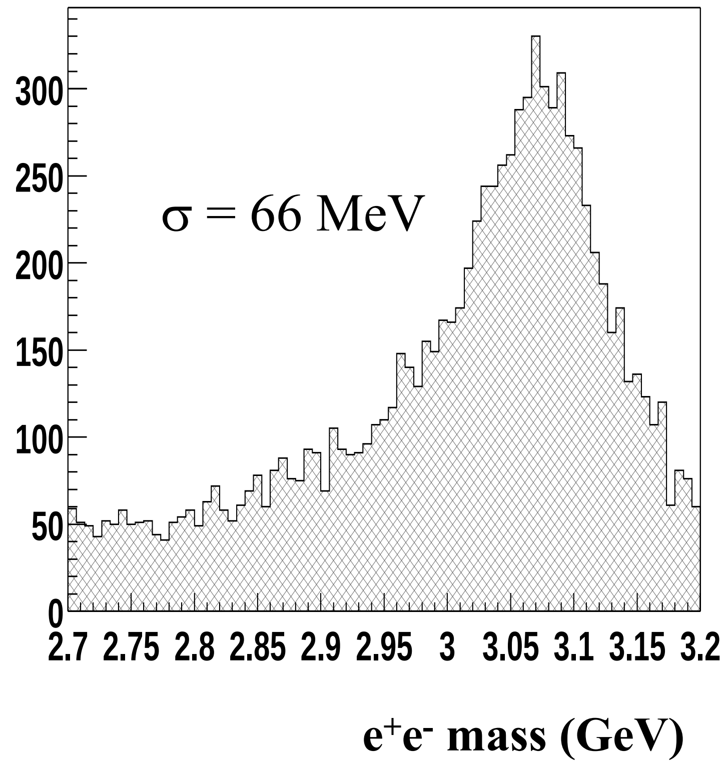
- Two opposite charged muons with :
- $P_t > 0.5$ GeV
- Vertex with a $\chi^2 < 9$
- Invariant mass within 50 MeV/c^2 of $m_{J/\psi}$



$\mu^+\mu^-$ mass (GeV)

$J/\psi \rightarrow e^+e^-$ selection

- Two opposite charged electrons one with $P_t > 0.8$ GeV/c and one with $P_t > 1.8$ GeV/c
- A vertex $\chi^2 < 6$
- vertex $|Z| < 150$ mm
- An invariant mass between 2.7 – 3.2 GeV/c^2



$\phi \rightarrow K^+K^-$ selection

• Two opposite charged kaons with $P_t > 0.5$ GeV, giving a vertex with a $\chi^2 < 9$, an invariant mass within 20 MeV/c^2 of m_ϕ, and $P_\phi >$ 12 GeV/c^2

$B_s \rightarrow J/\psi\ \phi$ selection

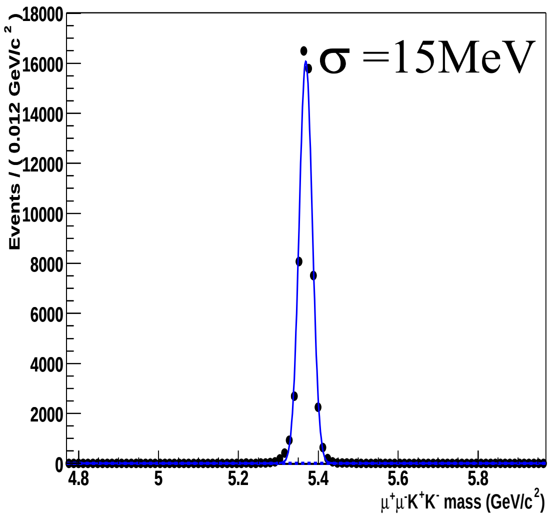
• Combine the J/ψ and ϕ if the four tracks form a vertex with $\chi^2 < 20$, then select the primary vertex with smallest IP (< 4mm)

$B_s \rightarrow J/\psi\,\phi$ selection

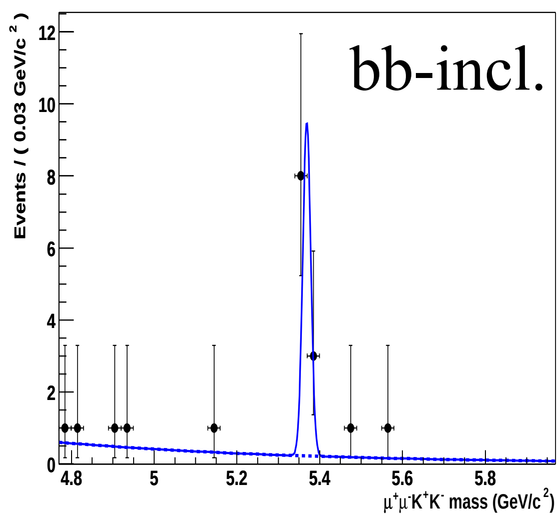
Other constraints on the B_s^0 :

- Proper time (consistency between the B_s^0 momentum and the vector between the production and decay vertex) significance > 5
- m_{B_s} within 50 MeV/c^2 of the nominal B_s^0 mass

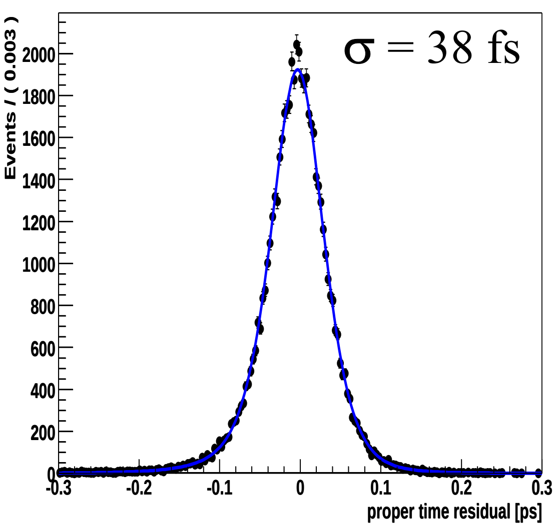
$\mu^+\mu^-K^+K^-$ Mass



$\mu^+\mu^-K^+K^-$ Mass



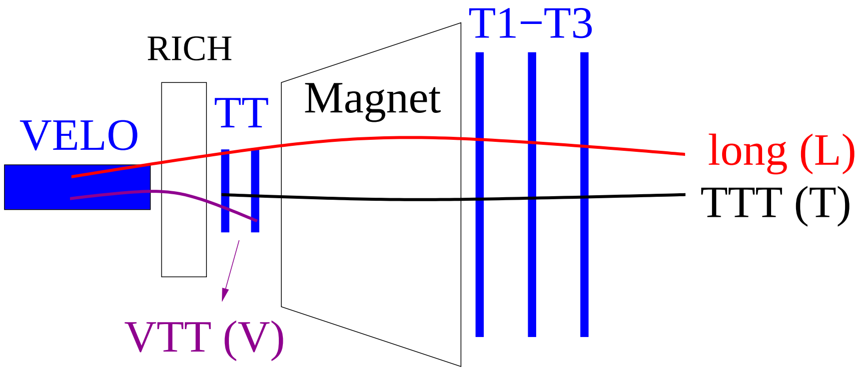
τ residual



$K_s \rightarrow \pi^+\pi^-$ selection

• Two oppositely charged pions, giving a vertex with a z position between 0 - 3 meter, invariant mass within 60 (100 for TT) MeV/c^2 of m_{K_S}, and a combined P_t >200 MeV/c.

category	fraction	vertex Z res.
LL	0.29	107 μm
LV	0.09	182 μm
TT	0.62	199 μm



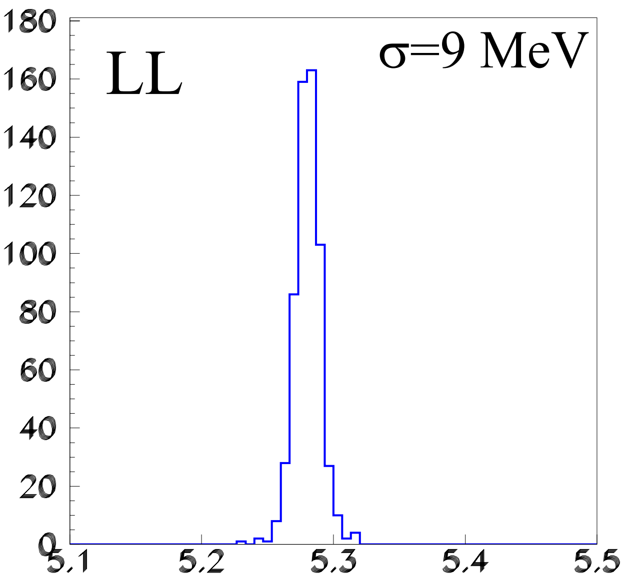
$B_d \to J/\psi\ (\mu^+\mu^-)K_s$ selection

B_d : combining J/ψ and K_s

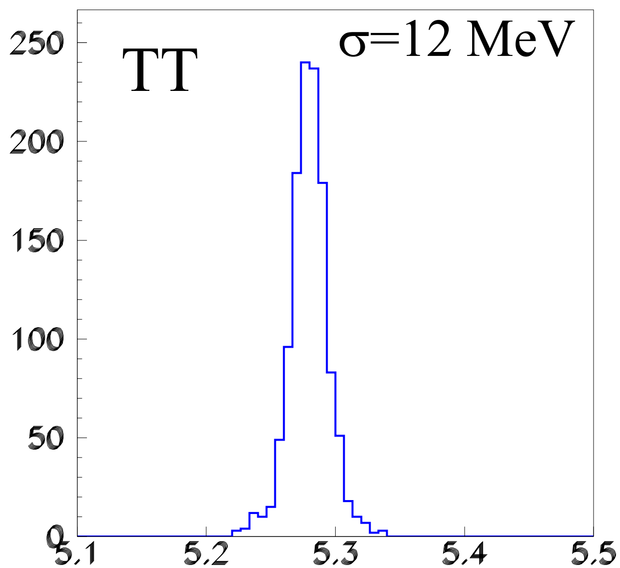
- J/ψ and K_s make a vertex with $\chi^2 < 50$
- IP significance of K_s with respect to J/ψ vtx < 3.5 (< 8 for TT)
- IP significance of Ks pions with respect to the primary vtx > 4 (2 for TT)
- significance of the distance between primary and J/ψ vtx $>$ 1.2(LL), 3.1(LV), 2.4(TT)
- B_d mass window 60 MeV/c^2

$B_d \rightarrow J/\psi\, K_s$ selection

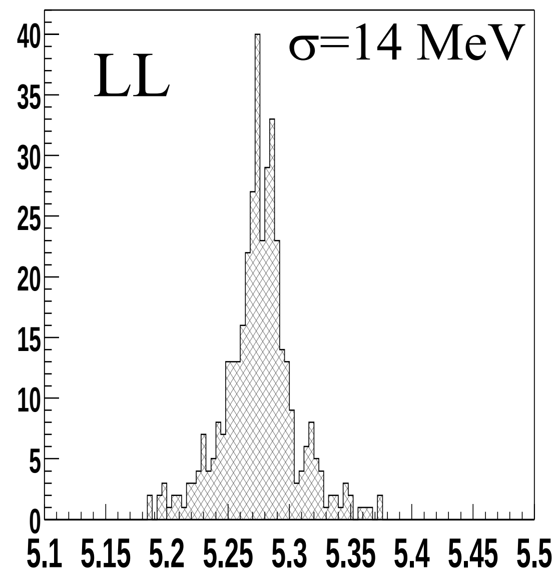
Results for the B_d^0 mass :



$J/\psi(\mu^+\mu^-)\, K_s$ (LL)



$J/\psi(\mu^+\mu^-)\, K_s$ (TT)



$J/\psi(e^+e^-)\, K_s$ (LL)

Annual yield and Background estimate for $B_s \to J/\psi\,\phi$ and $B_d \to J/\psi\,K_s$

Channel	Annual yield	B/S
$B_s \to J/\psi(\mu^+\mu^-)\,\phi$	100k	<0.3 (bb-incl) <0.7 (prompt J/ψ)
$B_s \to J/\psi(\mu^+\mu^-)\,K_s$	166k	0.6±0.1 (bb-incl) <0.4 (prompt J/ψ)
$B_s \to J/\psi(e^+e^-)\,K_s$	21k	<0.84 (prompt J/ψ) 3.4 ±0.5 (bb-incl)

Sensitivity studies for $B_s \rightarrow J/\psi\ \phi$ and $B_d \rightarrow J/\psi\ K_s$

Extracting β_s from $B_s \to J/\psi\ \phi$

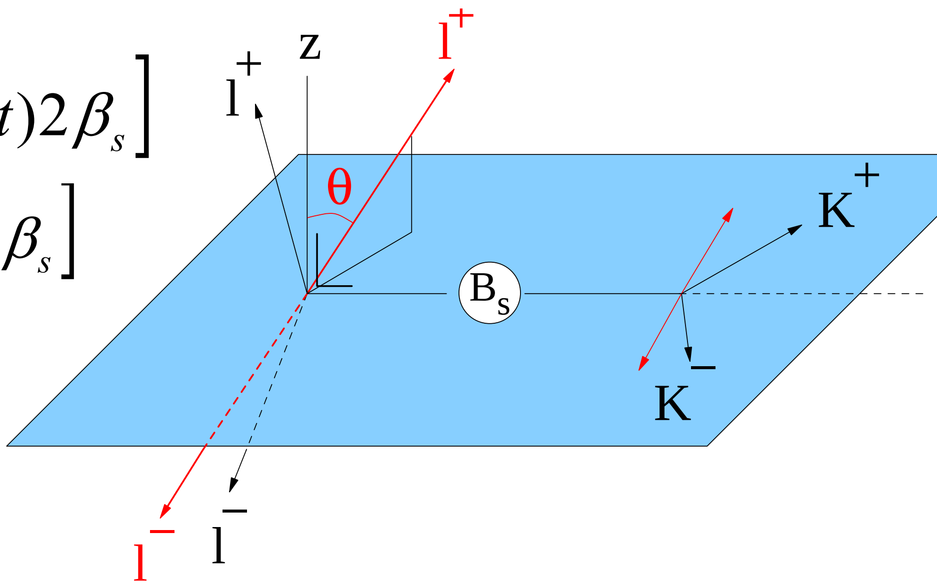
$$\frac{d\Gamma(t)}{d\cos(\theta)} \propto \left(|A_0(t)|^2 + |A_{\parallel}(t)|^2\right)\frac{3}{8}\left(1+\cos^2(\theta)\right) + |A_{\perp}(t)|^2\frac{3}{4}\sin^2(\theta)$$

$B_s \to J/\psi\ \phi$

$$|A_{0,\parallel}(t)|^2 = |A_{0,\parallel}(0)|^2\left[e^{-\Gamma_L t} - e^{-\bar{\Gamma} t}\sin(\Delta m_s t)2\beta_s\right]$$

$$|A_{\perp}(t)|^2 = |A_{\perp}(0)|^2\left[e^{-\Gamma_H t} + e^{-\bar{\Gamma} t}\sin(\Delta m_s t)2\beta_s\right]$$

$A_\perp$ = odd & $A_{0,\parallel}$ = even



$\bar{B}_s \to J/\psi\ \phi$

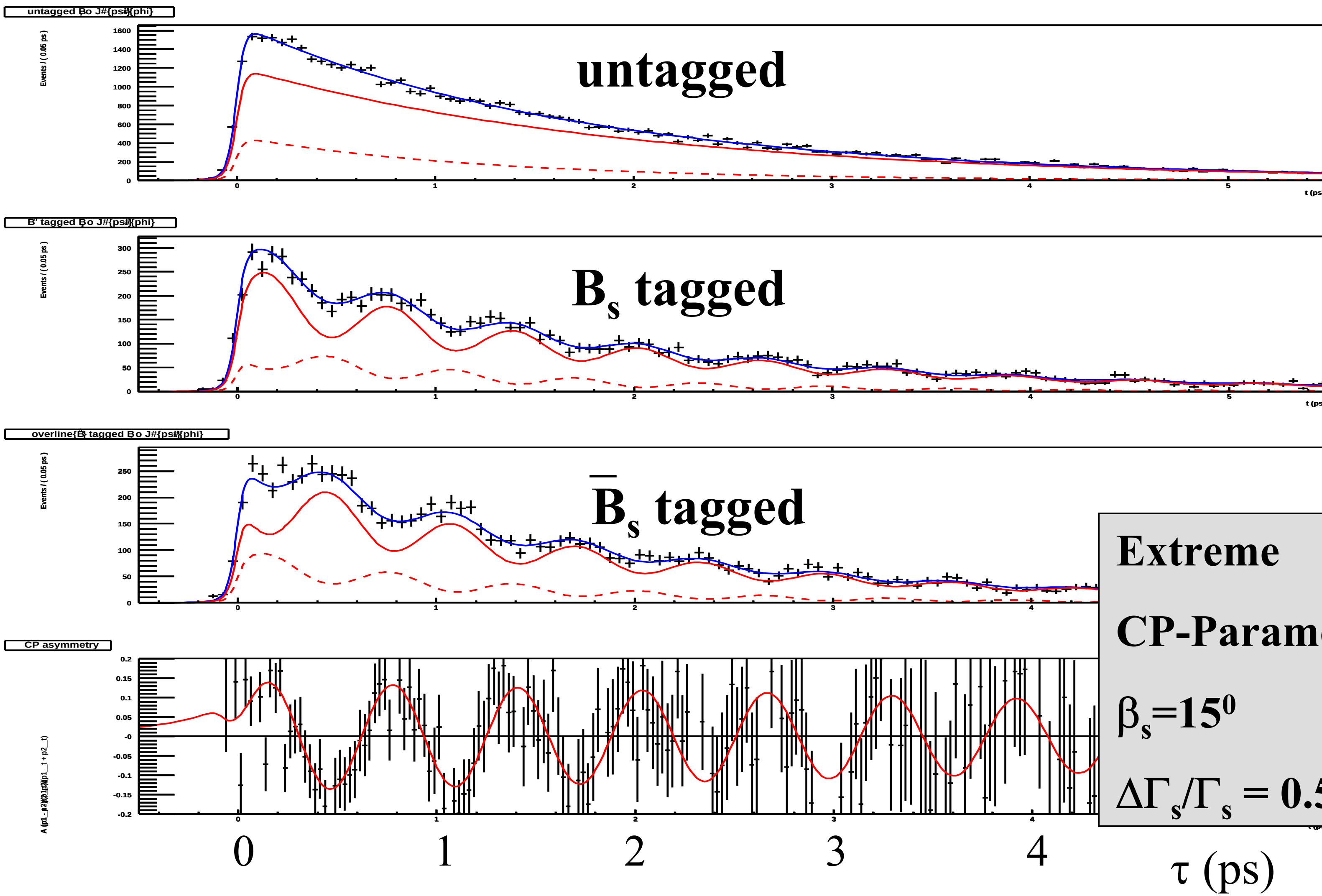
$$|A_{0,\parallel}(t)|^2 = |A_{0,\parallel}(0)|^2\left[e^{-\Gamma_L t} + e^{-\bar{\Gamma} t}\sin(\Delta m_s t)2\beta_s\right]$$

$$|A_{\perp}(t)|^2 = |A_{\perp}(0)|^2\left[e^{-\Gamma_H t} - e^{-\bar{\Gamma} t}\sin(\Delta m_s t)2\beta_s\right]$$

$2\beta_s \approx 0.03$ in SM :

A(t) $\propto$ two exponentials with lifetimes $1/\Gamma_H$ and $1/\Gamma_L$

Extracting β_s from $B_s \to J/\psi\ \phi$

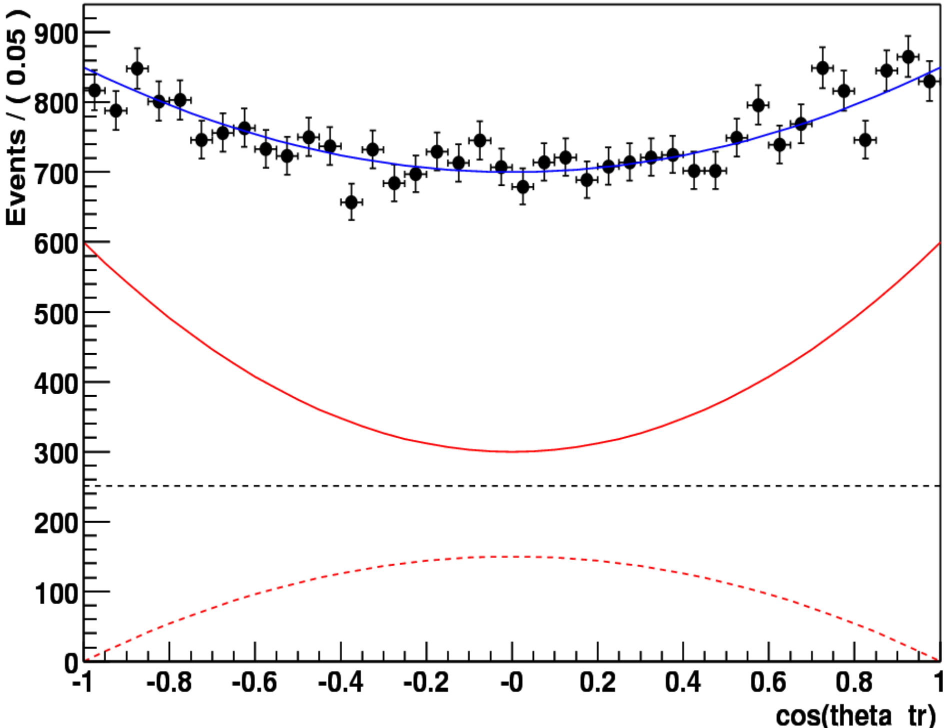


Extreme CP-Parameters:

$\beta_s = 15^0$

$\Delta\Gamma_s/\Gamma_s = 0.5$

Sensitivity for β_s from $B_s \rightarrow J/\psi\ \phi$



Angular analysis to determine the sensitivity for:

R($A_\perp$ fraction), $\Delta\Gamma_s$, τ_s and β_s

(for Δms and wrong tag fraction: fit $D_s\pi$ simultaneously)

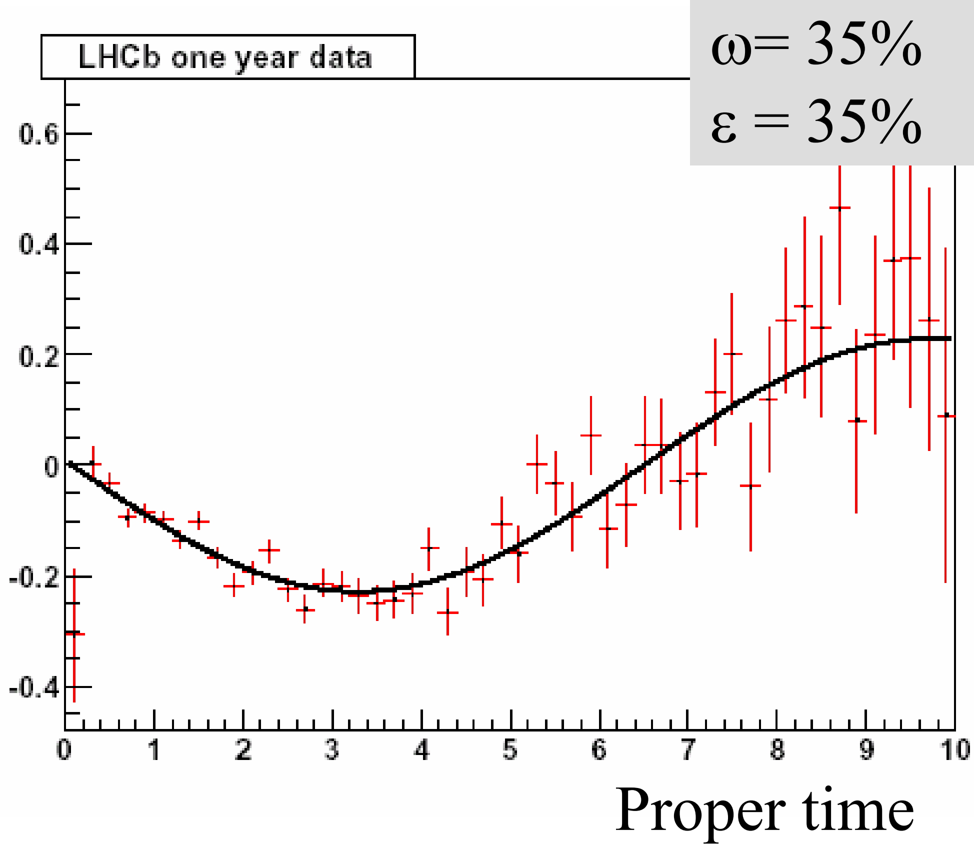
$$R = |A_\perp|^2/(|A_0|^2 + |A_{||}|^2 + |A_\perp|^2)$$

$$\omega = 35\% \ \& \ \varepsilon = 40\%$$

One year of LHCb data	β_s (Deg)	R -	τ_s (ps)	$\Delta\Gamma_s/\Gamma_s$ -	Δm_s (ps^{-1})
used	0.86^0	0.2	1.5	0.1	20
sensitivity	3.5^0	0.0085	0.011	0.026	0.038

Sensitivity for β from $B_s \rightarrow J/\psi\, K_s$

$$A_f = -\frac{(1-|\lambda_f|^2)\cos(\Delta m t) - 2\sin(2\beta)\sin(\Delta m t)}{1+|\lambda_f|^2}$$



$\omega = 35\%$

$\varepsilon = 35\%$

one year LHCb data		
	$\lvert\lambda\rvert$	β
used	**1**	**26.1^0**
sensitivity	**0.024**	**0.6^0**

Conclusions

Reconstruction of $B_s \rightarrow J/\psi\ \phi$ and $B_d \rightarrow J/\psi\ K_s$ decays :

- **Good mass (9-15 MeV/c^2) & vertex (107-199 μm) resolution**

⇒ Excellent proper time resolution (38 fs) allows to follow the oscillations of the decay rates accurately.

- **High annual yields with low background rates**

⇒ Precise determination of CKM angles β and β_s

Sensitivity for β and β_s One Year of LHCb Data	
β	β_s
0.6^0	3.5^0