Time dependent CP-violation measurements and related studies in B_s decays at LHCb

Christian Linn
Physikalisches Institut, Universität Heidelberg

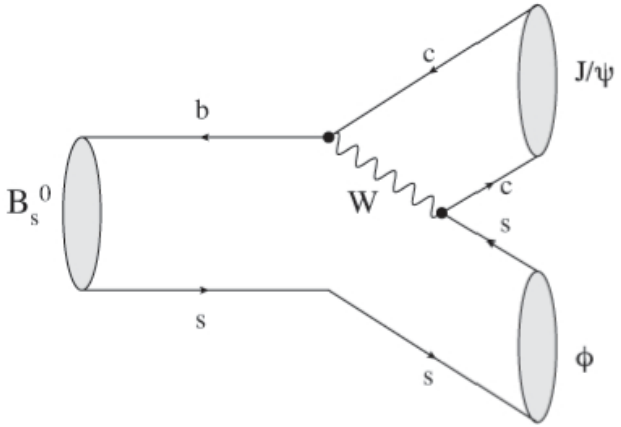
On behalf of the LHCb collaboration

Topics:

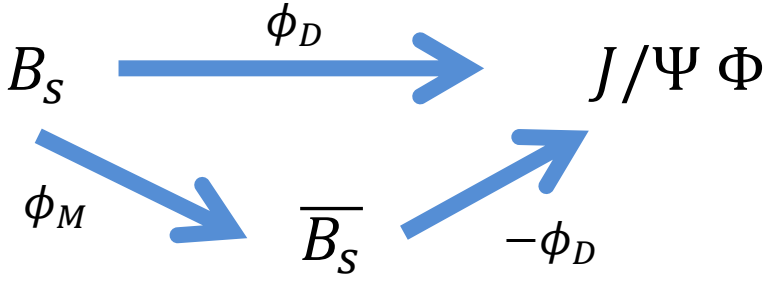
- Δm_s measurement
- ϕ_s from $B_s \to J/\Psi\, \Phi$
- $B_s \to K^+ K^-$ lifetime measurement

CP-violation in B_s mixing

$B_s \to J/\Psi\,\Phi$ dominated by tree-level transition
(small penguin contribution $\sim 10^{-4} - 10^{-3}$)

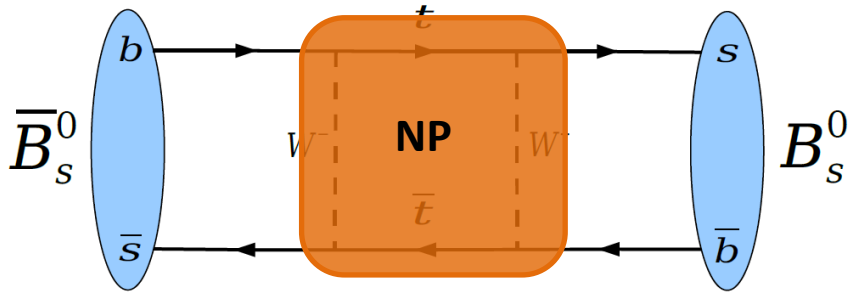


Interference between mixing and decay gives rise to CP violating phase $\phi_s = \phi_M - 2\,\phi_D$



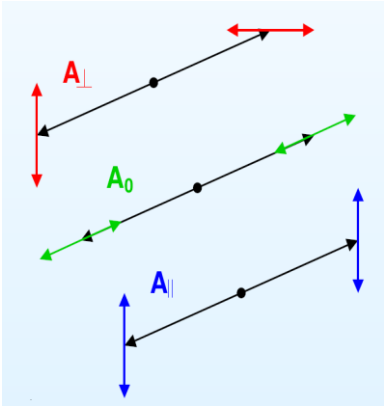
ϕ_s in Standard Model well predicted and small:
0.0363 ± 0.0017 rad
[CKMfitter Eur.Phys. J.C41 1-131 (2005)]

New Physics in mixing: $\phi_s = \phi_s^{SM} + \phi^{NP}$



Angular Analysis of $B_s \rightarrow J/\Psi\,\Phi$

P -> VV decay:
final state is mixture of CP even and CP odd eigenstates

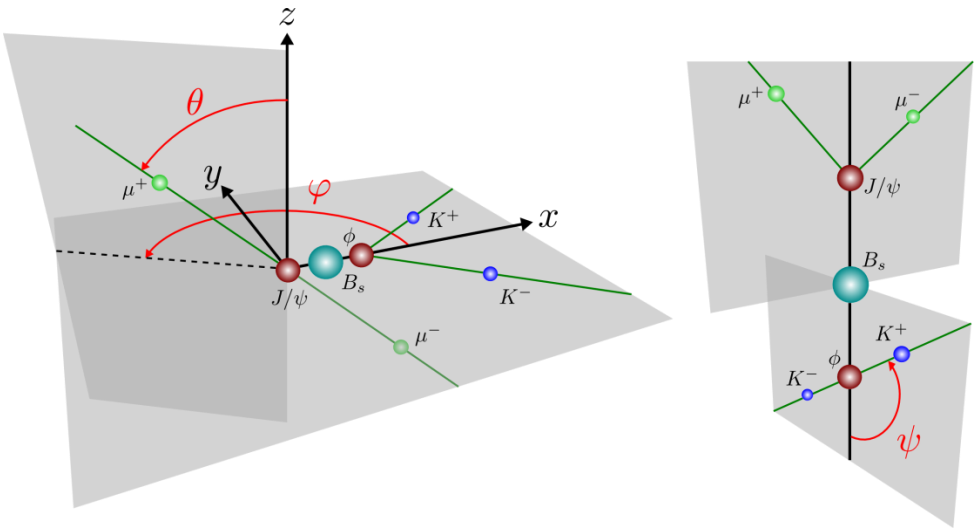


$$CP(J/\Psi\,\Phi) = \eta_{CP}(J/\Psi\,) \cdot \eta_{CP}\,(\Phi) \cdot (-1)^{l}$$

Described by three polarization amplitudes:

$A_\perp$ (CP-odd)
A_0 , $A_\parallel$ (CP-even)

Final states described by three transversity angles: $\Omega = \{\varphi,\ \theta,\ \psi\}$



Likelihood fit to disentangle CP states

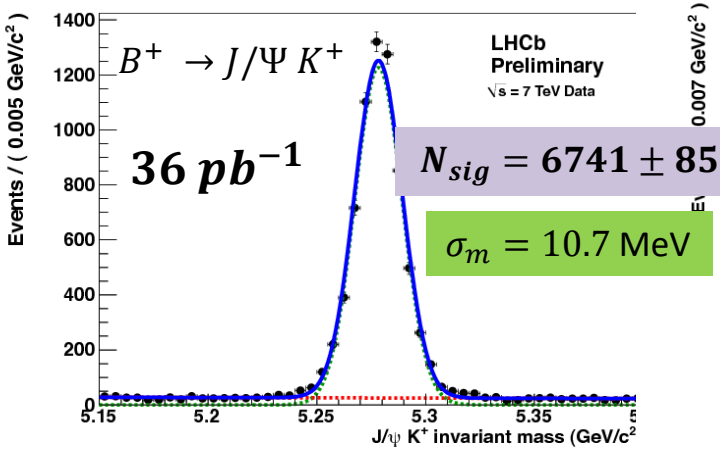
Physics Parameters:
$\Gamma_s, \Delta\Gamma_s, |A_0|^2, |A_\perp|^2, \delta_\parallel, \delta_\perp, \Delta m_s, \phi_s$

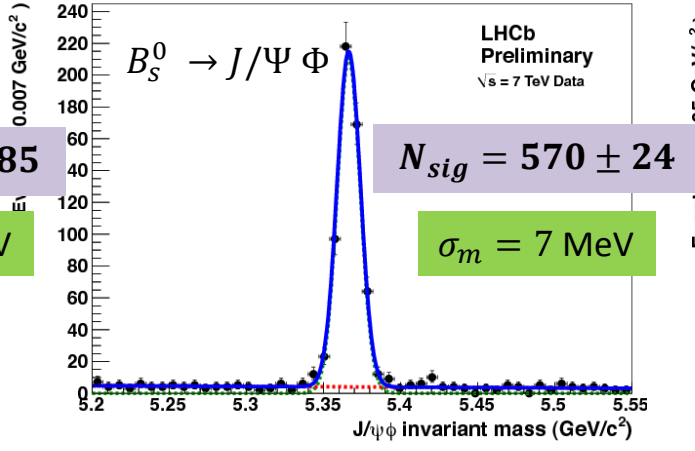
Only measurable with tagging information

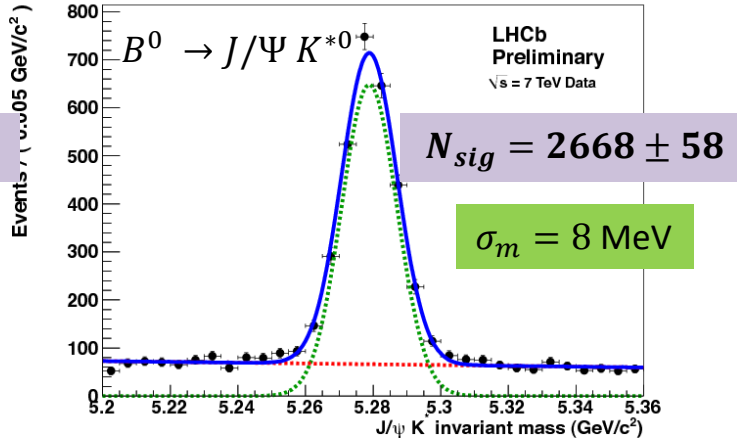
Selection of $B_s \rightarrow J/\Psi\,\Phi$ and control channels

Selection similar for all $B \rightarrow J/\Psi\,X$ channels

Single- and Di – μ unbiased trigger lines (no cuts on proper time, IP, …)







Cuts on kinematic , track and vertex quality variables

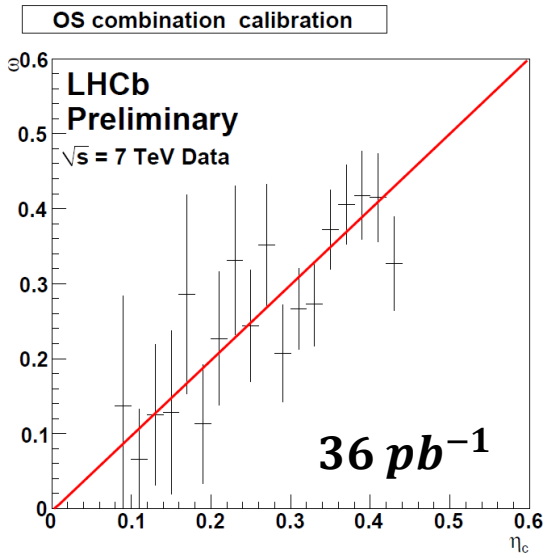
Cut at proper time t > 0.3 ps to suppress prompt background

LHCb-Conf-2011-01

Flavour tagging and Δm_s measurement

LHCb-Conf-2011-03

OS tagger calibration with B+ -> Jpsi K+

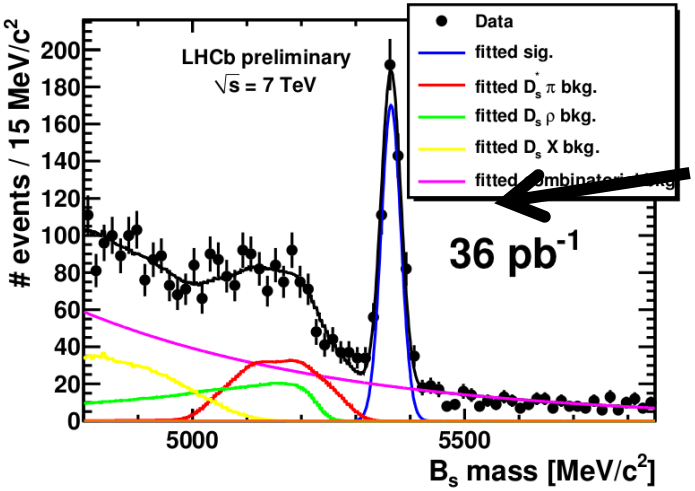


Per event mistag: $\omega_i = p_0 + p_1 \cdot (\eta_i - <\eta>)$

For $B_s \rightarrow J/\Psi\,\Phi$: $\omega_{eff} = 32 \pm 2\ \%$

(in 2010 data) $\epsilon D^2 = 2.2 \pm 0.5\%$ (tagging power)

Measurement of Δm_s using OS tagger:



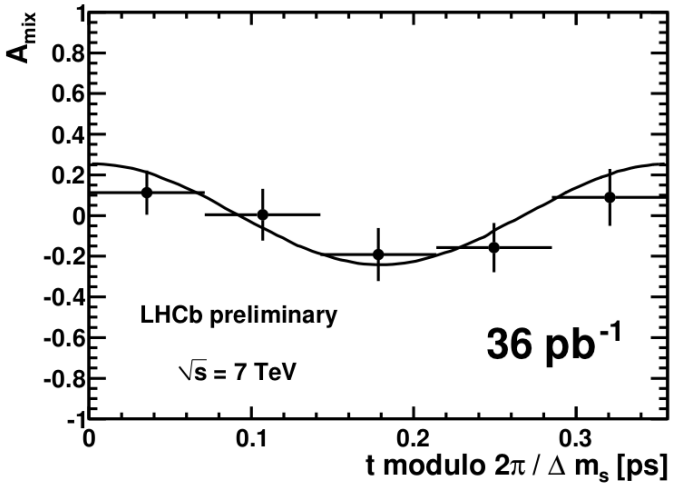
Different decay modes used:

$B_s \rightarrow D_s\,(\Phi\,\pi)\,\pi$ (515 ± 25)

$B_s \rightarrow D_s\,(\mathrm{K}^*\,K)\,\pi$ (338 ± 27)

$B_s \rightarrow D_s\,(\mathrm{K\,K}\,\pi)\,\pi$ (283 ± 27)

$B_s \rightarrow D_s\,(K\,K\,\pi)\,3\pi$ (245 ± 46)

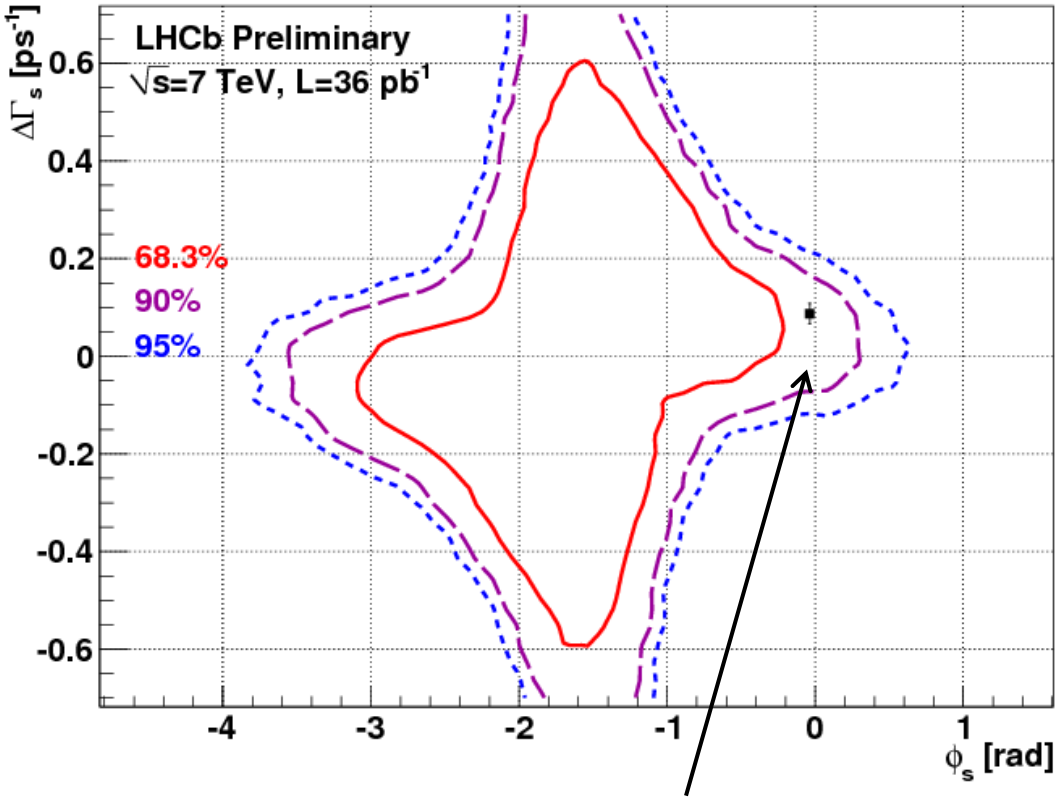


Unbinned 2d fit: $\Delta m_s = 17.63 \pm 0.11\,(stat) \pm 0.04\,(syst)$

LHCb-Conf-2011-05 CDF: $\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07(syst)$

Main systematics:
Momentum and z-scale

CP analysis of $B_s \rightarrow J/\Psi\,\Phi$



Standard Model p-value 22% (1.2σ)

757 $\pm$ 28 events

Point-estimate not meaningful with current statistics

Feldman-Cousins method to get confidence level contours in $\Delta\Gamma_s - \phi_s$ plane

Here: only statistical error

(systematics effects have been studied and are small compared to statistical uncertainty)

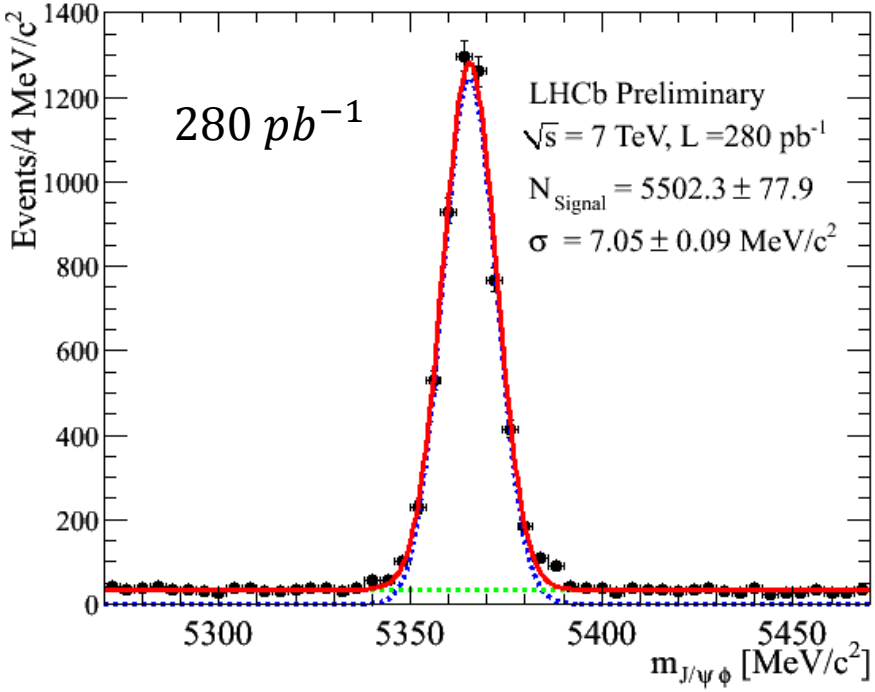
$$\phi_s \in [-2.7, -0.5]\ rad\ @\ 68\%\ CL$$

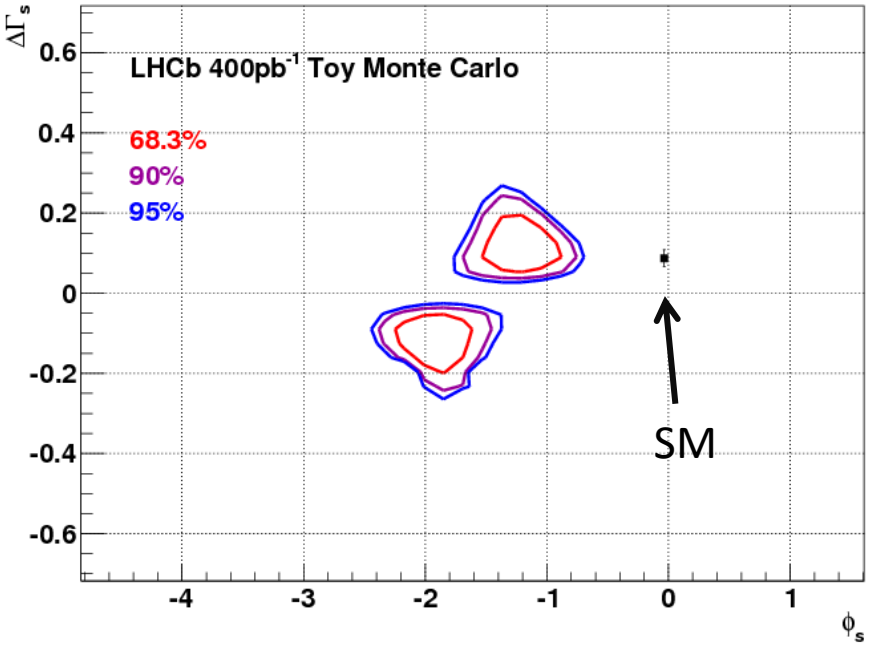
LHCb-Conf-2011-06

Prospects for $B_s \rightarrow J/\Psi\,\Phi$

Results for 10x more statistics ($350 - 400\ pb^{-1}$) very soon

→ expect world best measurement of ϕ_s





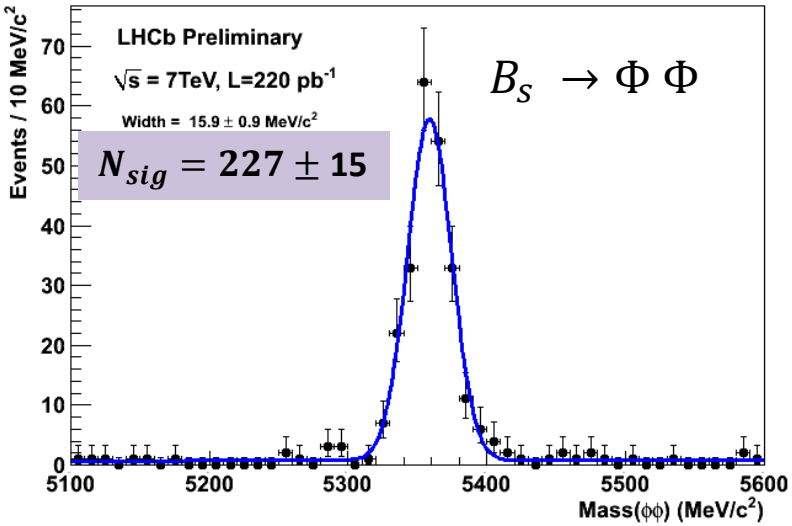
Central values from 2010 analysis as input

Assuming identical performance as 2010

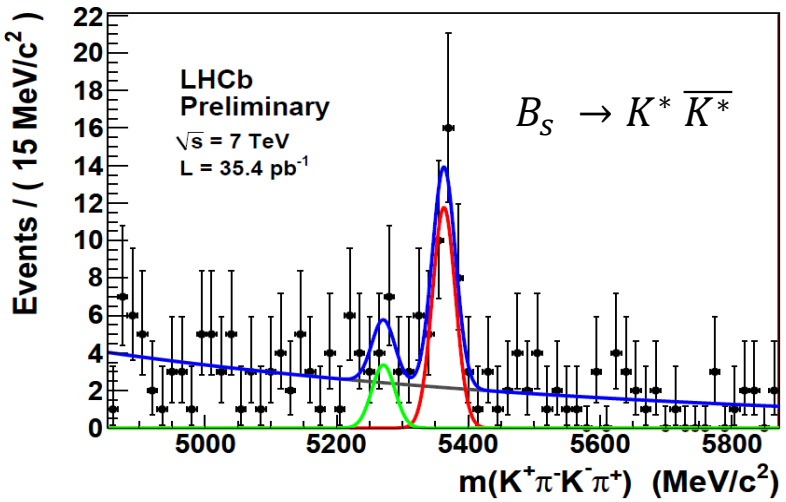
Effect of 10x more statistics

Additional interesting channels for ϕ_s

Pure Penguin decays
Can be used in the extraction of ϕ_s



First observation of $B_s \to K^* \overline{K^*}$: LHCb-Conf-2011-019



$$BR(B_s \to K^* \overline{K^*}) = (1.95 \pm 0.47(stat.) \pm 0.51(syst.) \pm 0.29(f_d/f_s)) \cdot 10^{-5}$$

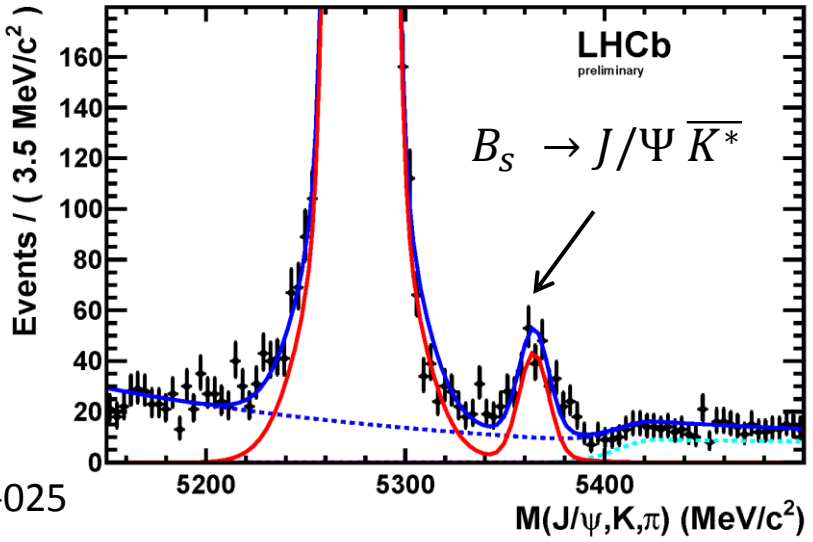
Branching ratio of $B_s \to J/\Psi\, K^*$:

Based on $36\ pb^{-1}$

Assumes all events are $K^* \to K\,\pi$ for $|m(K\pi) - m(K^*)| < 150$ MeV

$$BR(B_s \to J/\Psi\, \overline{K^*}) = \left(3.5^{+1.1}_{-1.0}\,(stat.) \pm 0.9(syst.)\right) \cdot 10^{-5}$$

for $\sim 300\ pb^{-1}$:



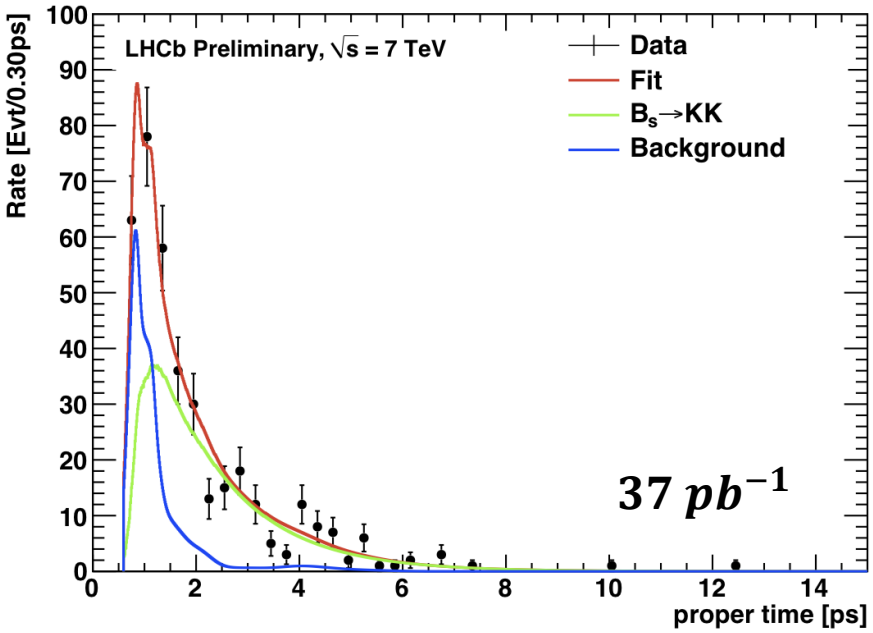
LHCb-Conf-2011-025

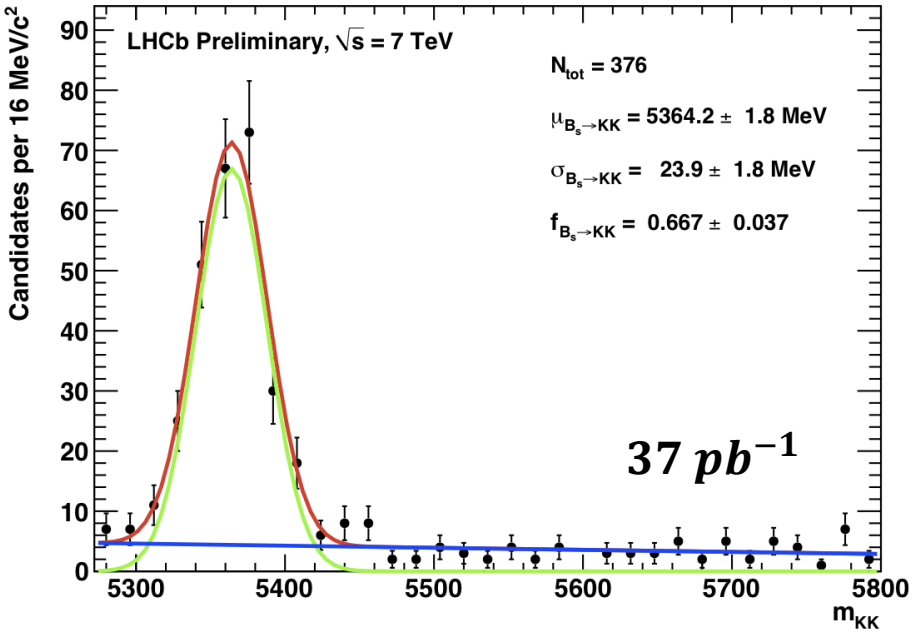
Lifetime measurement of $B_s \rightarrow K^+ K^-$

$B_s \rightarrow K^+ K^-$ decay dominated by penguin diagram

Can be used to put constraints on $\Delta\Gamma_s$ and the mixing phase ϕ_M

Fitting decay rate with single exponential gives effective lifetime





Two independent lifetime measurements:

1. Absolute measurement of lifetime
2. Relative measurement with respect to B_0 lifetime

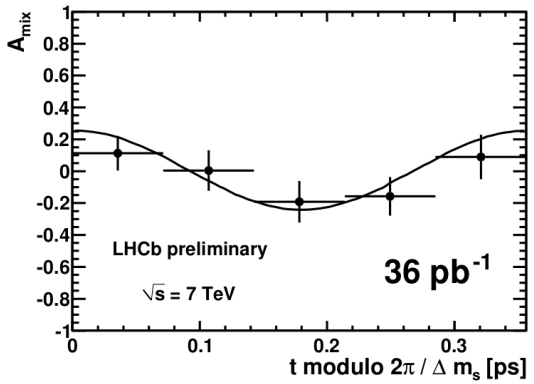
$\tau_{KK} = 1.440 \pm 0.096 \pm 0.008\ ps$
(absolute measurement)

LHCb-Conf-2011-018

CDF: $\tau_{KK} = 1.53 \pm 0.18(stat) \pm 0.02(syst)$ ps

Summary

LHCb has measured many interesting results with 36 pb^{-1}:

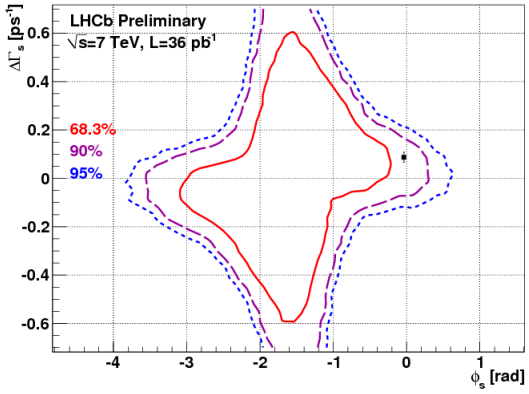


- World best measurement of Δm_s using $B_s \rightarrow D_s \pi$

$$\Delta m_s = 17.63 \pm 0.11\ (stat) \pm 0.04\ (syst)\ ps^{-1}$$

- Tagged analysis of $B_s \rightarrow J/\Psi\ \Phi$ allows to constrain ϕ_s

$$\phi_s \in [-2.7, -0.5]\ rad\ @\ 68\%\ CL$$



- Lifetime measurement of $B_s \rightarrow K^+ K^-$

$$\tau_{KK} = 1.440 \pm 0.096 \pm 0.008\ \text{ps}$$

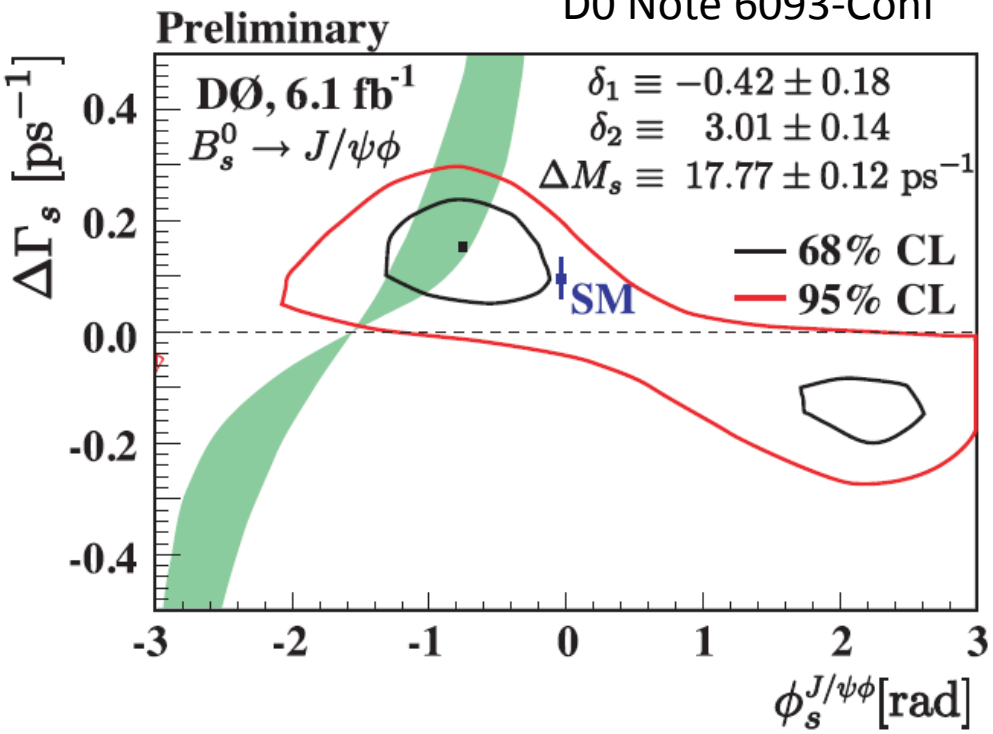
- first observation of $B_s \rightarrow K^* \overline{K^*}$, BR measurements, …

- **Expect world best measurement on ϕ_s soon …**
  … and many more interesting results with 2011 data

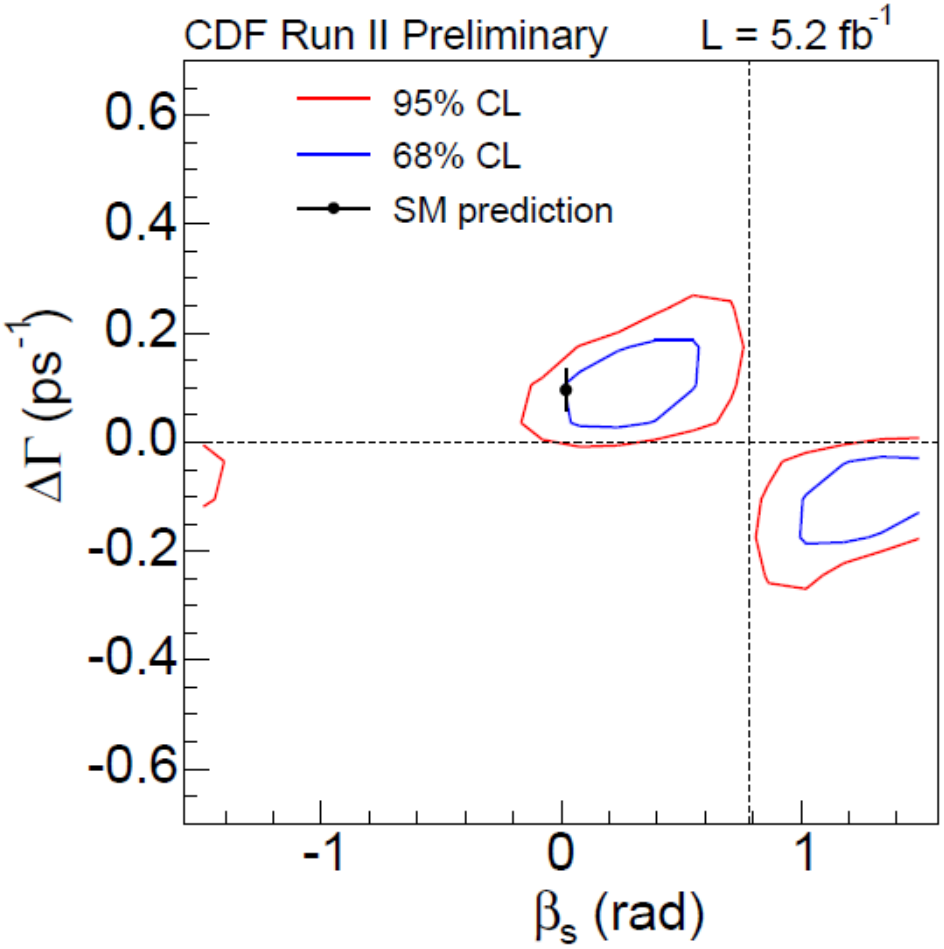
BACKUP

Tevatron results on ϕ_s

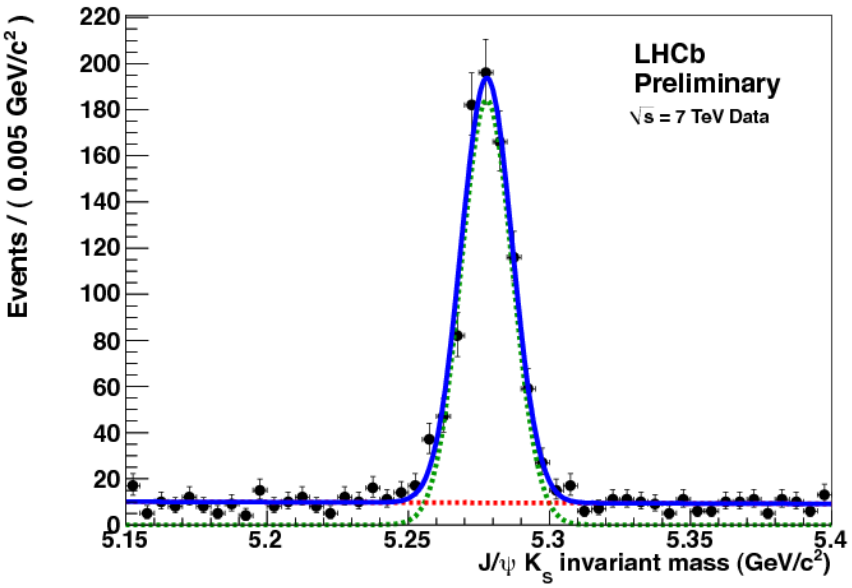
D0 Note 6093-Conf

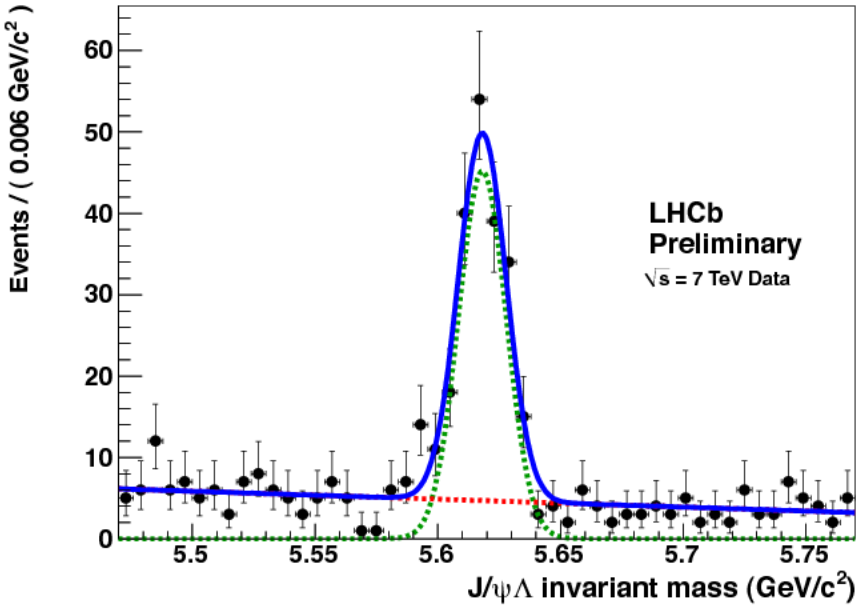


CDF note 1026

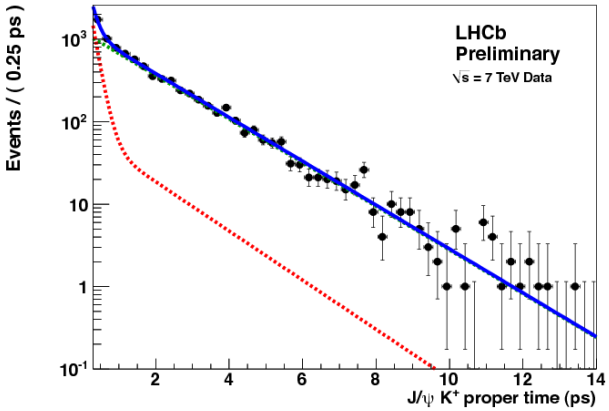


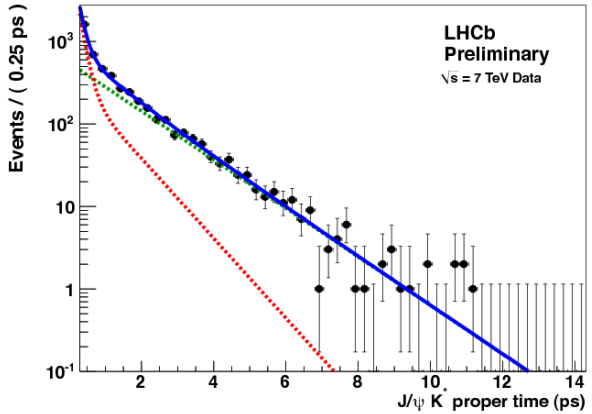
Control channels

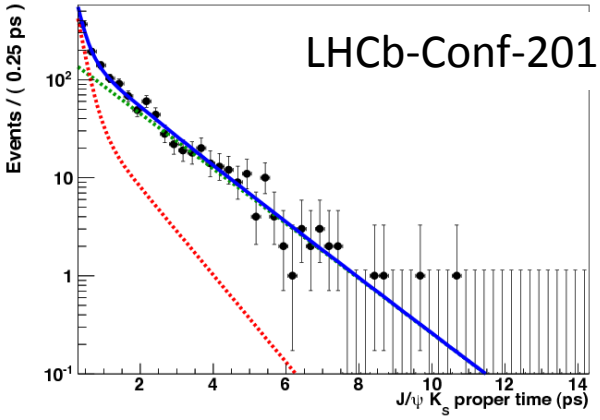




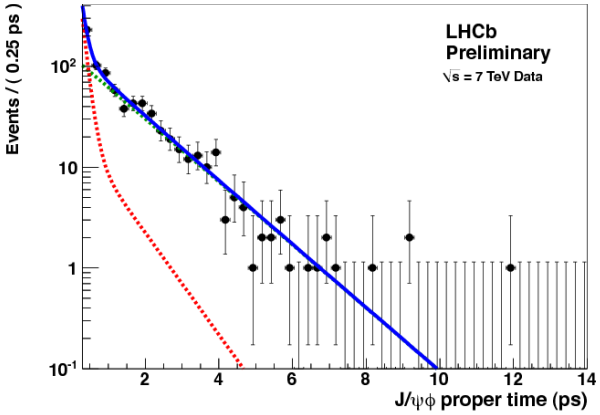
Lifetime measurements of $b \rightarrow J/\Psi\, X$ channels

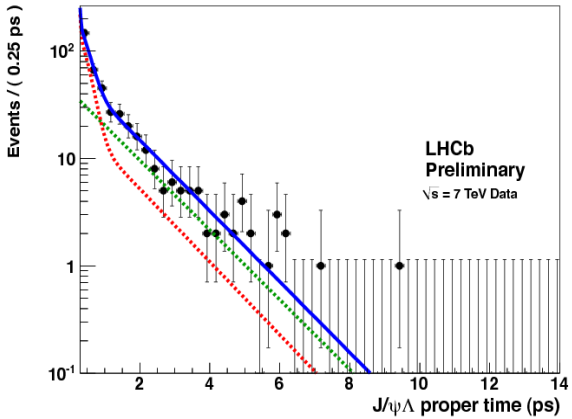






Fit single exponential

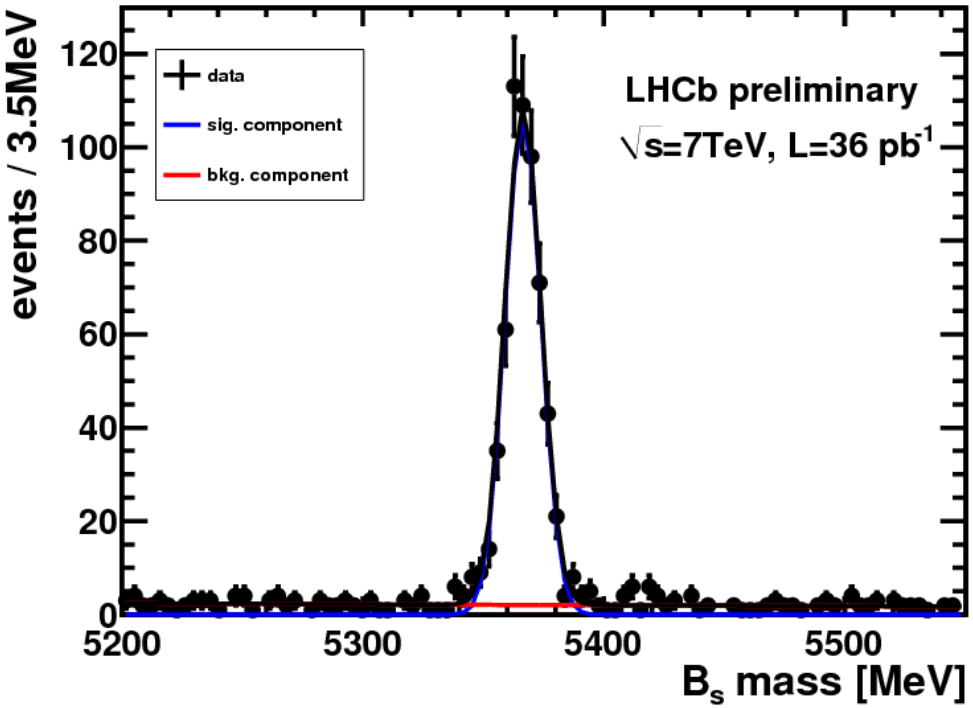


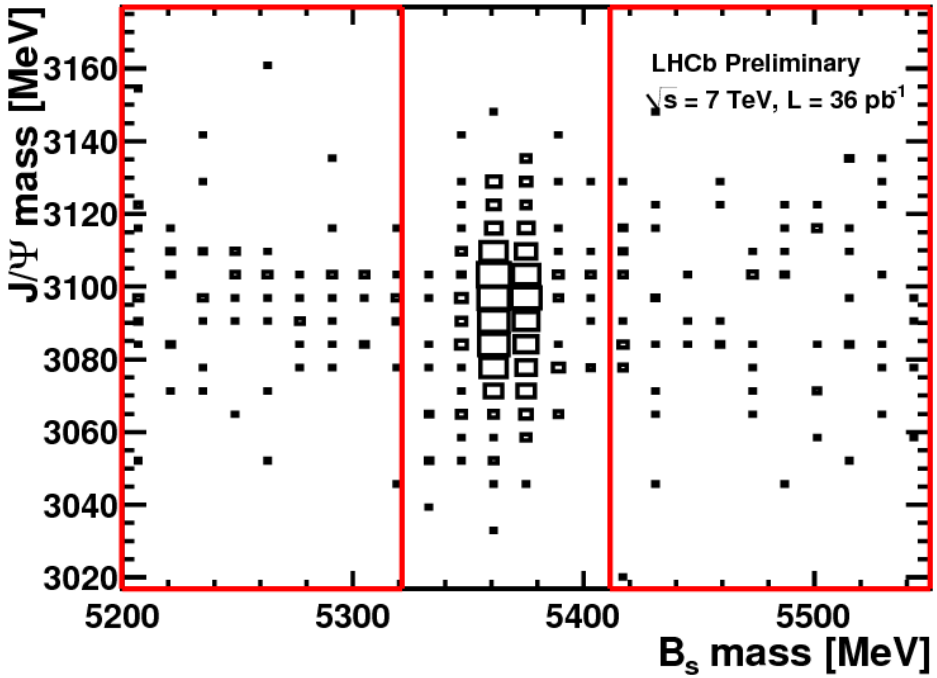


Main systematic: lifetime acceptance

Channel	LHCb Result $\pm$ stat. $\pm$ syst. [ps]	PDG lifetime [ps]
$B^+ \rightarrow J/\Psi\, K^+$	**$1.689 \pm 0.022 \pm 0.047$**	1.638 ± 0.011
$B^0 \rightarrow J/\Psi\, K^{*0}$	**$1.512 \pm 0.032 \pm 0.042$**	1.525 ± 0.009
$B^0 \rightarrow J/\Psi\, K_S^0$	**$1.558 \pm 0.056 \pm 0.022$**	1.525 ± 0.099
$B_s^0 \rightarrow J/\Psi\, \Phi$	**$1.447 \pm 0.064 \pm 0.056$**	1.477 ± 0.046
$\Lambda_b \rightarrow J/\Psi\, \Lambda$	**$1.353 \pm 0.108 \pm 0.035$**	$1.391^{+0.038}_{-0.037}$

Untagged $B_s \to J/\Psi\,\Phi$ plots

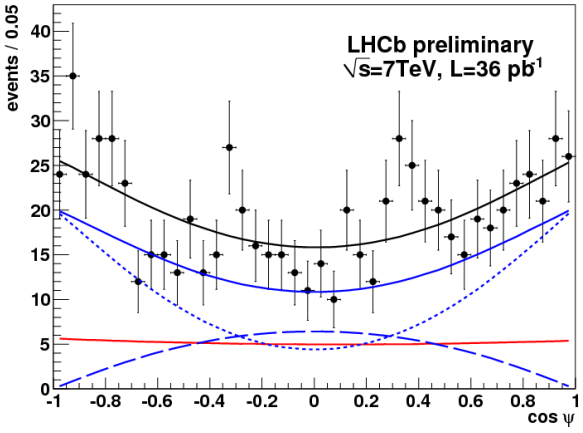


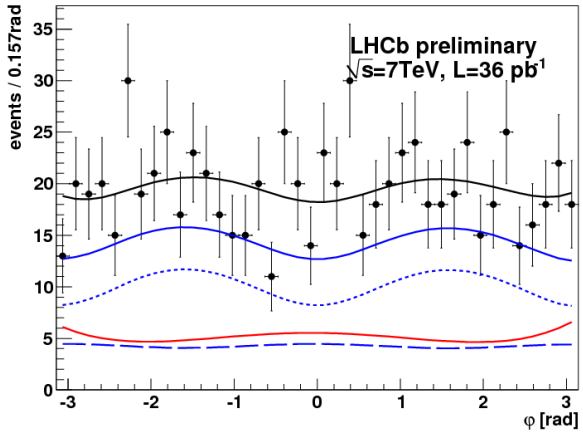


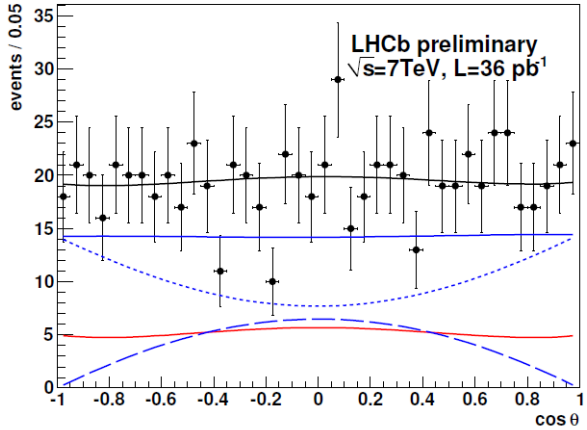
$B_s \rightarrow J/\Psi\,\Phi$ untagged

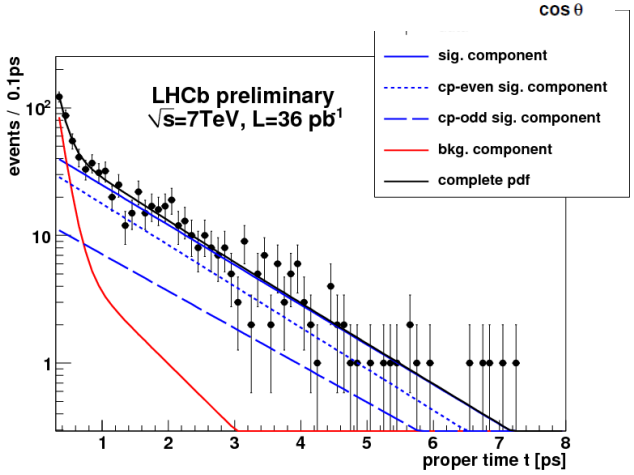
$\phi_s = 0$

Transversity angle distributions:









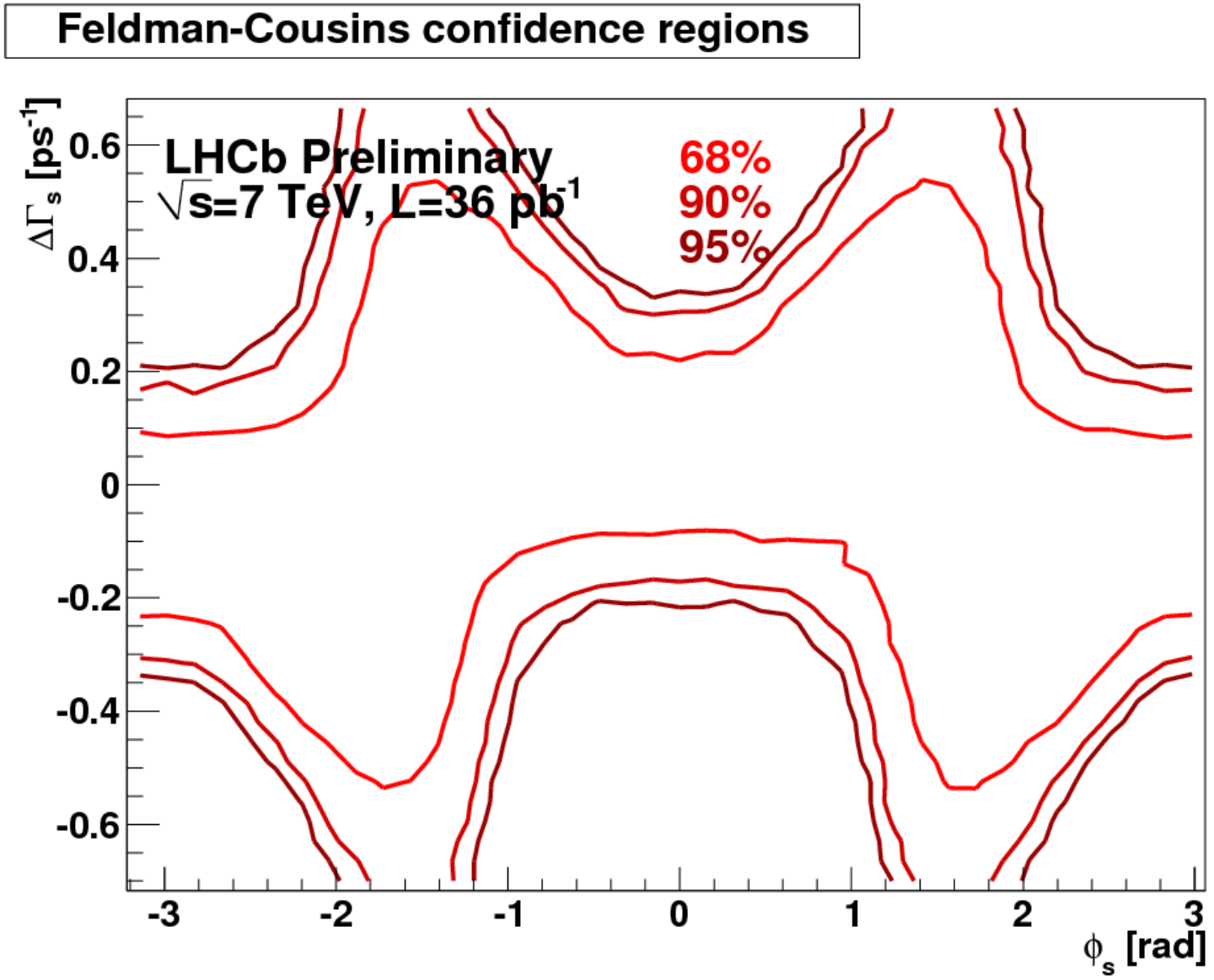
Angular analysis and acceptances cross-checked with $B^0 \rightarrow J/\Psi\,K^*$

Parameter	Result $\pm$ stat. $\pm$ syst.
Γ_s	$0.679 \pm 0.036 \pm 0.027$
$\Delta\Gamma_s$	$0.077 \pm 0.119 \pm 0.021$
$\lvert A_0(0)\rvert^2$	$0.528 \pm 0.040 \pm 0.028$
$\lvert A_\perp(0)\rvert^2$	$0.263 \pm 0.056 \pm 0.014$

Main systematics:
Background
Lifetime acceptance
S-wave

LHCb-Conf-2011-02

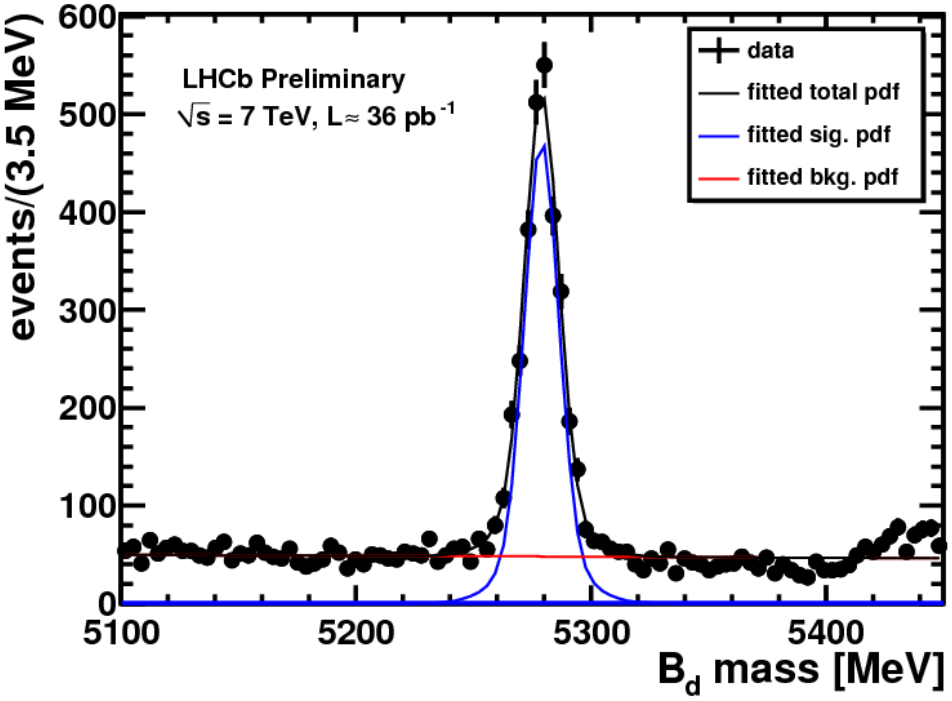
Untagged $B_s \to J/\Psi\,\Phi$ results

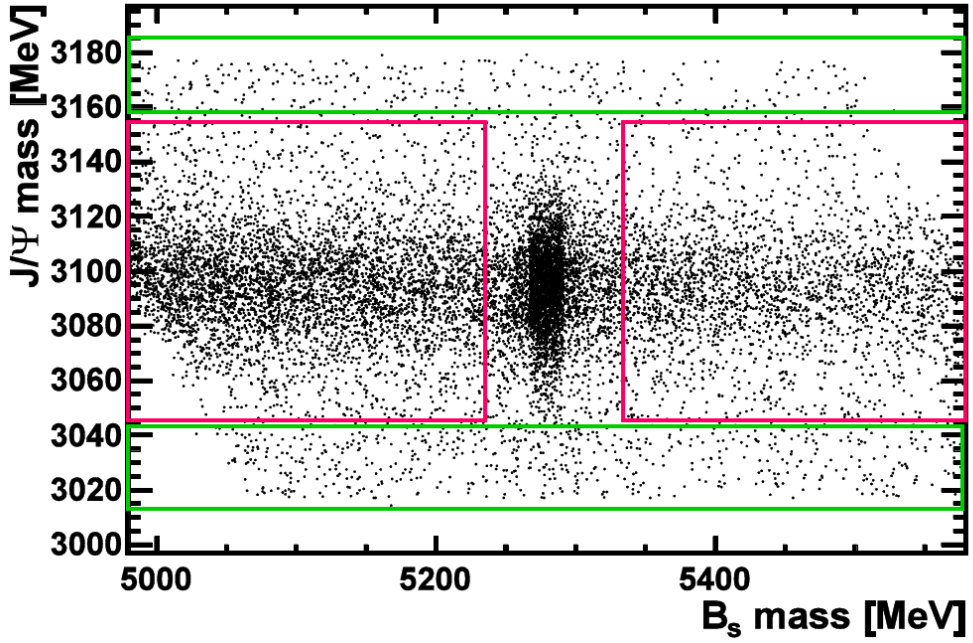


Untagged $B_s \to J/\Psi\,\Phi$ systematics

Systematic effect	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$\lvert A_\perp(0)\rvert^2$	$\lvert A_\parallel(0)\rvert^2$	$\cos\delta_\parallel$
Proper time resolution	0.0001	-	-	-	-
Angular acceptance	-	-	-	0.0007	-
Acceptance parametrisation	0.0002	0.001	0.0017	0.0013	-
Proper time acceptance	0.0272	0.001	0.0003	0.0002	-
S-wave treatment	0.003	0.003	0.013	0.028	0.09
Background treatment	0.0002	0.02	0.0016	0.0012	-
Mass model	0.0004	0.004	0.0032	0.0006	-
Total (quadratic sum)	0.0274	0.0206	0.0136	0.0281	0.09

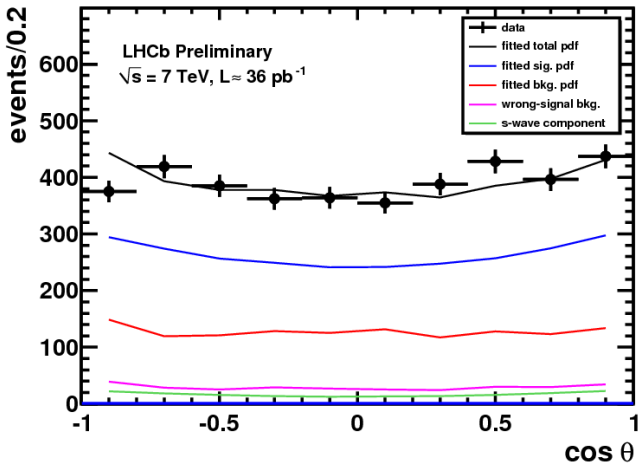
Untagged $B_d \rightarrow J/\Psi K^*$ plots

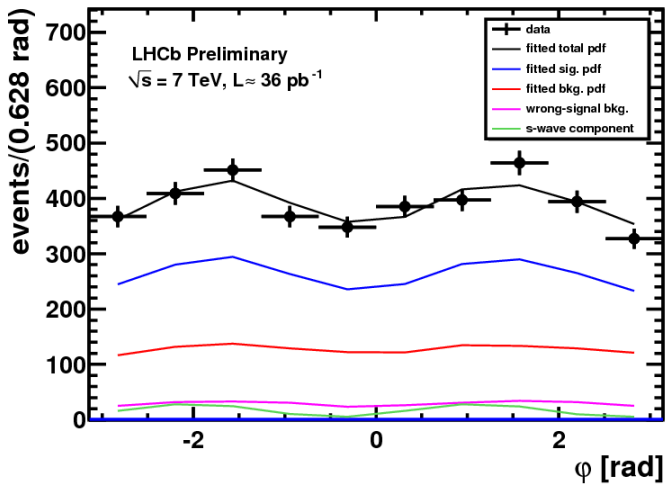




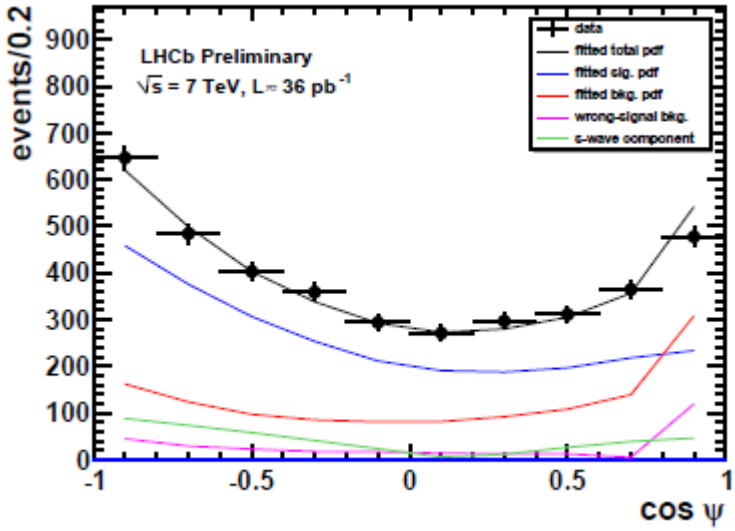
Untagged $B_d \to J/\Psi K^*$ results

parameter	results S-wave	results no S-wave
$\lvert A_\parallel \rvert^2$	0.252 ± 0.020	0.253 ± 0.020
$\lvert A_\perp \rvert^2$	0.178 ± 0.022	0.191 ± 0.019
$\delta_\parallel$	-2.87 ± 0.11	-2.82 ± 0.12
$\delta_\perp$	3.02 ± 0.10	3.07 ± 0.09
$\lvert A_s \rvert^2$	0.051 ± 0.022	–
δ_s	2.16 ± 0.15	–
Γ_d [ps^{-1}]	0.659 ± 0.015	0.661 ± 0.015

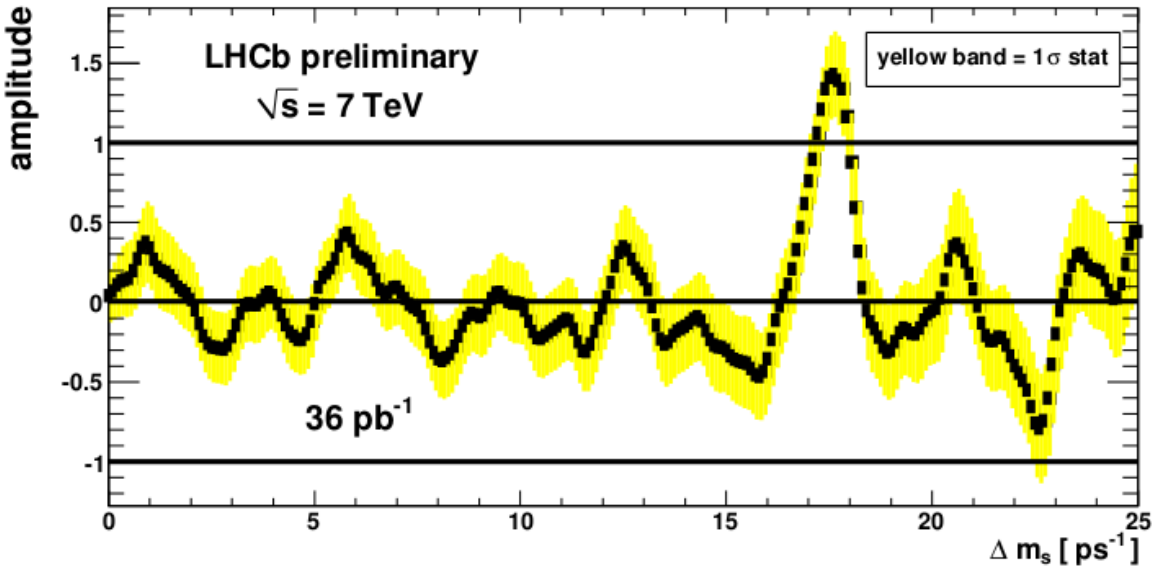




Systematic effect	$\lvert A_\parallel \rvert^2$	$\lvert A_\perp \rvert^2$	$\delta_\parallel$	$\delta_\perp$
proper time acceptance	-	-	-	-
data/MC differences	0.008	0.006	0.07	0.05
statistical error of acceptance	0.002	0.001	-	0.01
wrong-signal fraction	0.004	0.001	-	0.01
background treatment	0.002	0.008	0.04	0.01
statistical error of background	0.008	0.005	0.02	0.01
mass model	0.010	0.002	0.01	0.01
s-wave treatment	0.001	0.013	0.05	0.05
total (quadratic sum)	0.016	0.017	0.10	0.07

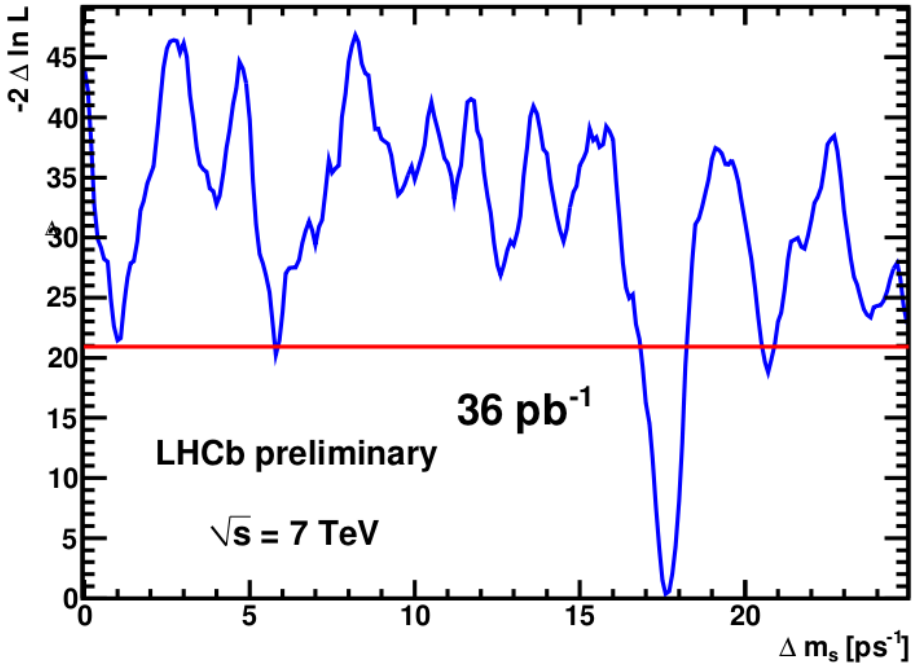


Δm_s results



parameter	result
Δm_s $[ps^{-1}]$	17.63 ± 0.11
$\epsilon_{sig,D_s\pi}$	0.236 ± 0.013
$\epsilon_{sig,D_s3\pi}$	0.176 ± 0.032
$\omega_{bkg,D_s\pi}$	0.527 ± 0.026
$\epsilon_{bkg,D_s\pi}$	0.255 ± 0.012
$\omega_{bkg,D_s3\pi}$	0.457 ± 0.037
$\epsilon_{bkg,D_s3\pi}$	0.236 ± 0.0016
ϵ_{eff} [%]	3.8 ± 2.1

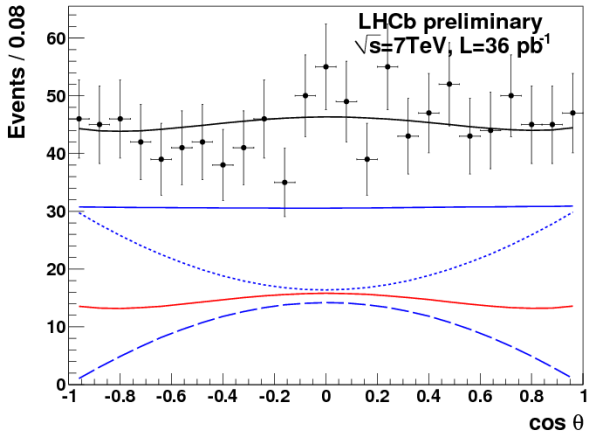
source	$\Delta_{\Delta m_s}$ [ps^{-1}]
proper time resolution	0.006
proper time resolution model	0.001
proper time acceptance function	0.000
fixed parameters floating	0.003
diff. background shape in mass fit	0.010
phys. bkg mass templates	0.002
variation of η_c and σ_t PDFs	0.026
z-scale	0.018
momentum scale	0.018
$\Delta\Gamma_s$	0.002
total systematic uncertainties	0.038

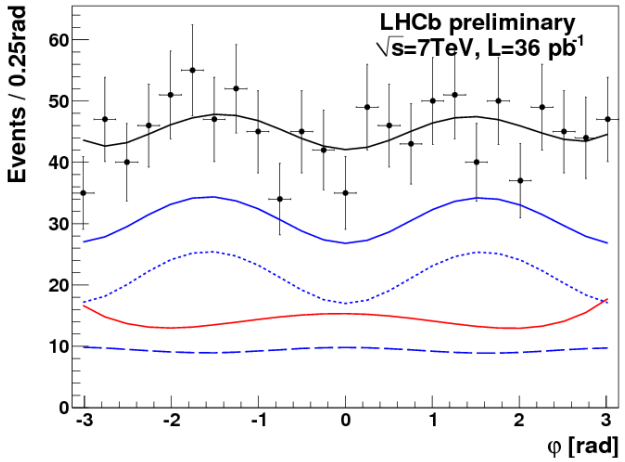


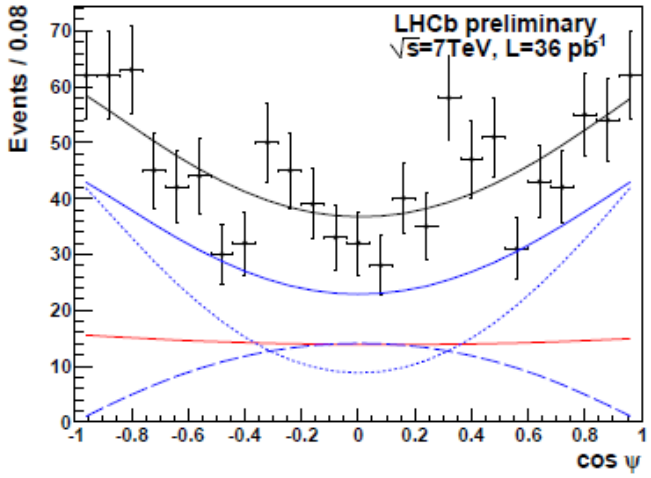
$B_s \to J/\Psi\,\Phi$ pdf

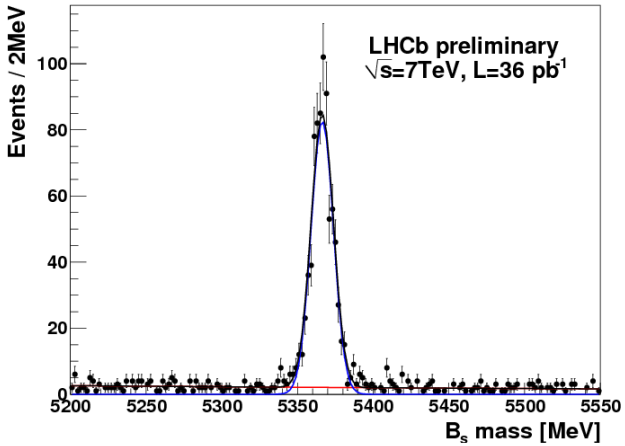
$$
\begin{aligned}
|A_0(t)|^2 &= |A_0(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\phi_s \sin(\Delta m_s t)\right], \\
|A_\parallel(t)|^2 &= |A_\parallel(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\phi_s \sin(\Delta m_s t)\right], \\
|A_\perp(t)|^2 &= |A_\perp(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - \sin\phi_s \sin(\Delta m_s t)\right], \\
\Im\{A_\parallel^*(t)A_\perp(t)\} &= |A_\parallel(0)||A_\perp(0)| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right. \\
&\quad \left. + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos\phi_s \sin(\Delta m_s t)\right], \\
\Re\{A_0^*(t)A_\parallel(t)\} &= |A_0(0)||A_\parallel(0)| e^{-\Gamma_s t}\cos\delta_\parallel\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right. \\
&\quad \left. + \sin\phi_s \sin(\Delta m_s t)\right], \\
\Im\{A_0^*(t)A_\perp(t)\} &= |A_0(0)||A_\perp(0)| e^{-\Gamma_s t}\left[-\cos\delta_\perp \sin\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right. \\
&\quad \left. + \sin\delta_\perp \cos(\Delta m_s t) - \cos\delta_\perp \cos\phi_s \sin(\Delta m_s t)\right].
\end{aligned}
$$

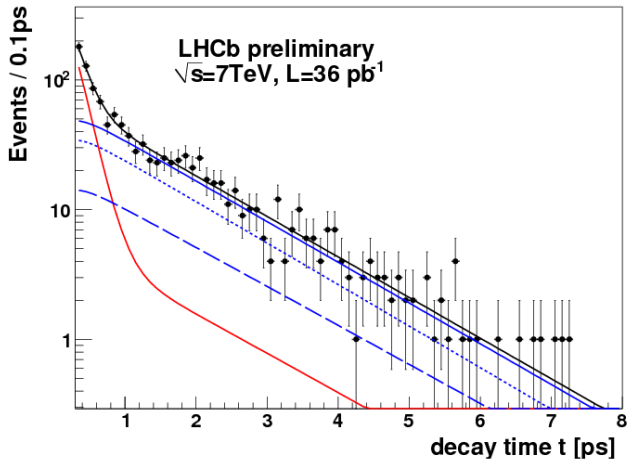
$B_s \to J/\Psi\,\Phi$ tagged projections



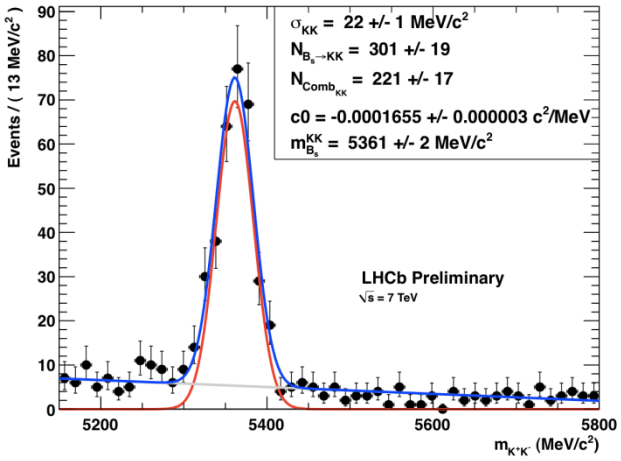


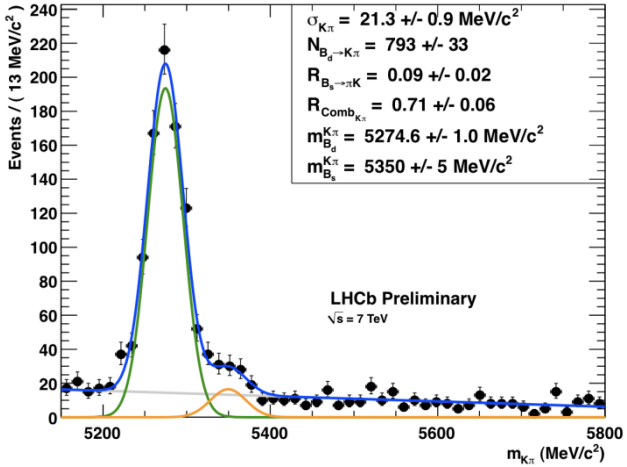


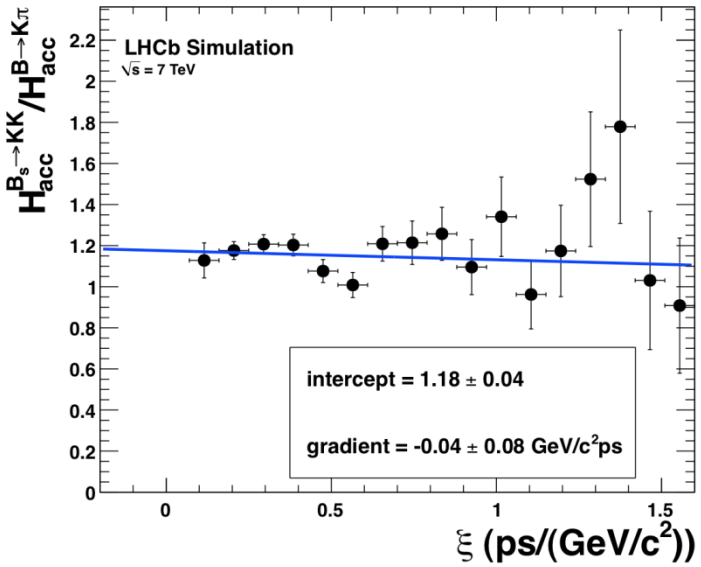




$B_s \to K^+ K^-$ relative measurement and systematics

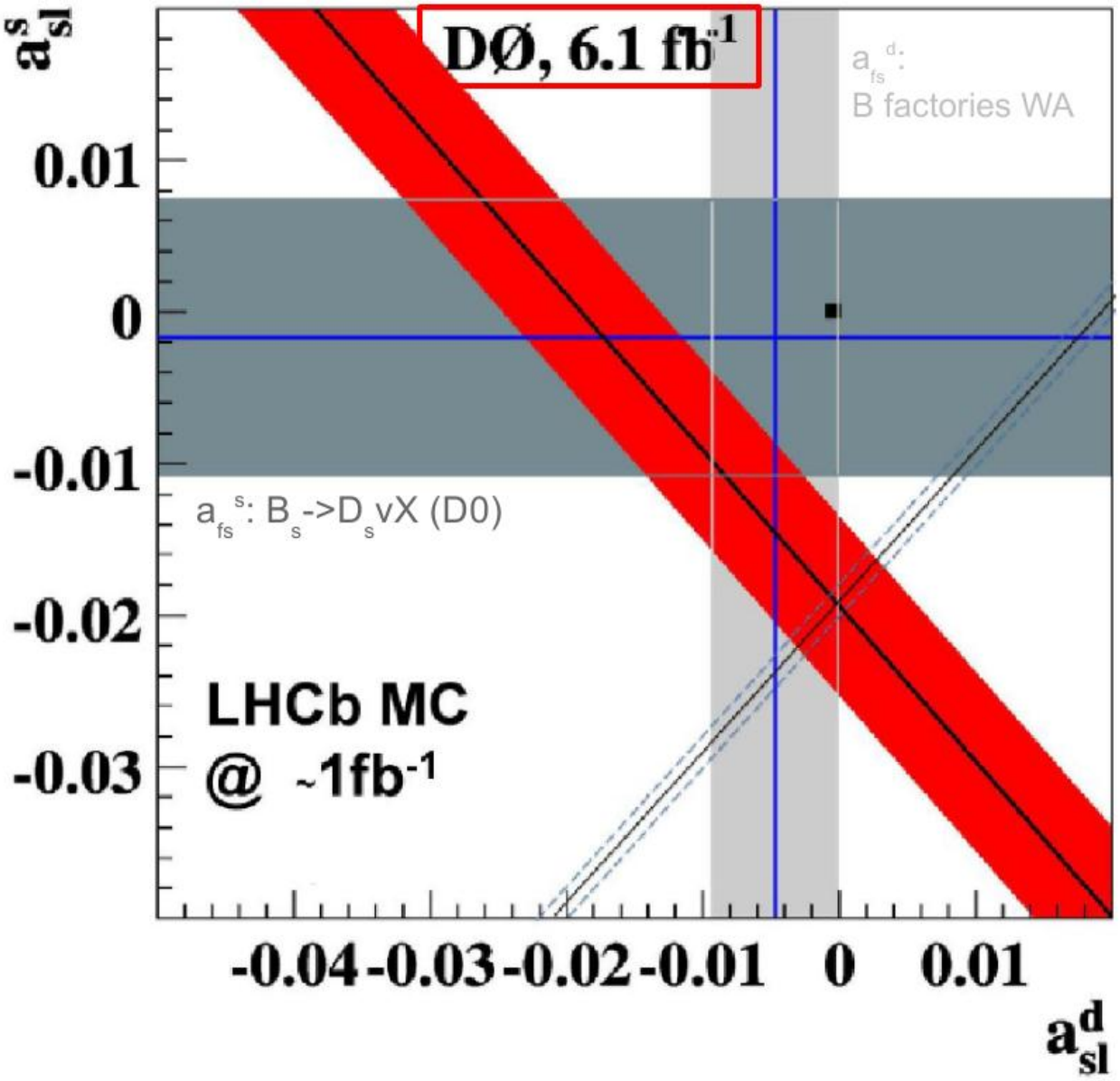






Source of uncertainty	Absolute Lifetime (fs)	Relative Lifetime (fs)
$B \to h^+h^-$ Background	2	4
Combinatorial Background	2	2
Acceptance Correction	6	0
Primary Vertex Association	6	6
Alignment	2	0
Minimum accepted lifetime	1	N/A
Signal parametrisation	N/A	5
Method and Verification	3	N/A
Total syst above (added in quadrature)	10	9
B^0 lifetime syst (external input)	N/A	9

LHCb MC prospect for a_{sl}



$B_d \to \Phi\, K^*$ in 2011 data