Measurement of the CP-violating phase ϕ_s with $B_s \to J/\Psi\,\Phi$ decays at LHCb

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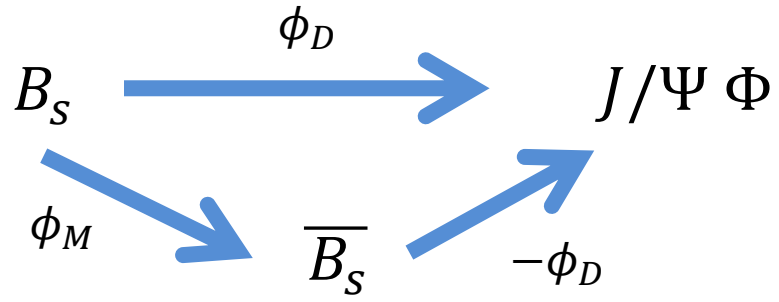
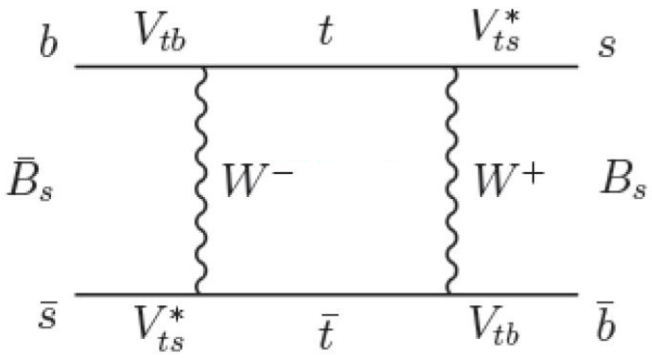
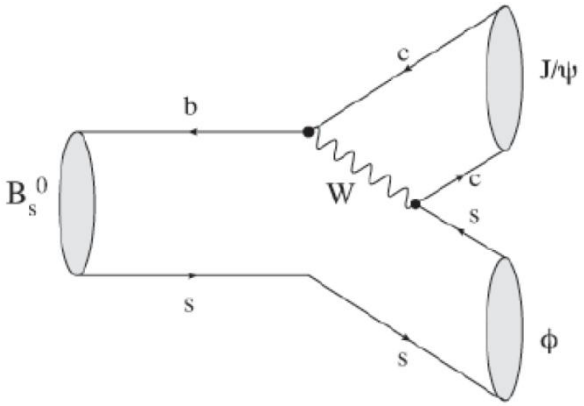
CP-violation in B_s mixing

Interference between mixing and decay:
→ CP violating phase $\phi_s = \phi_M - 2\,\phi_D$





$$\phi_s = -2\arg[-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}]$$



tree-level transition dominant
(penguin contribution $\sim 10^{-4} - 10^{-3}$)

ϕ_s in Standard Model well predicted and small: -0.0363 ± 0.0017 rad

[CKMfitter Eur.Phys.J.C41 1-131 (2005)]

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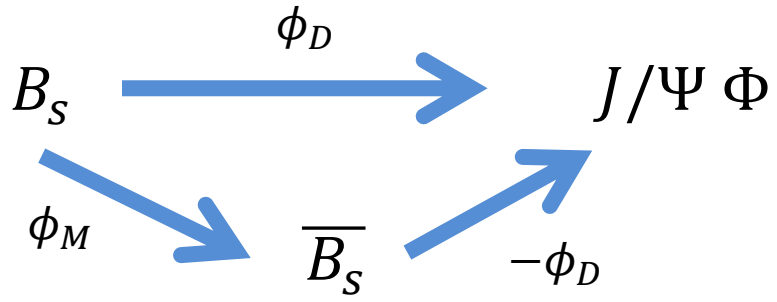

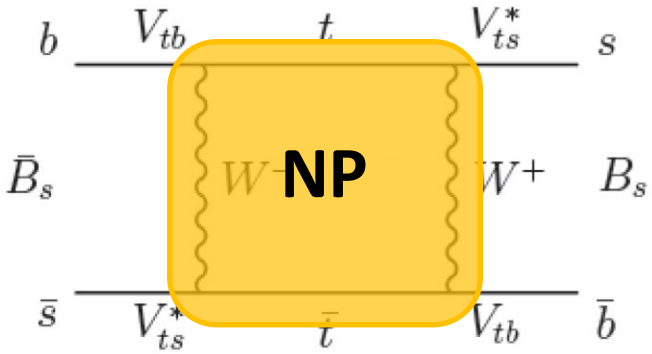

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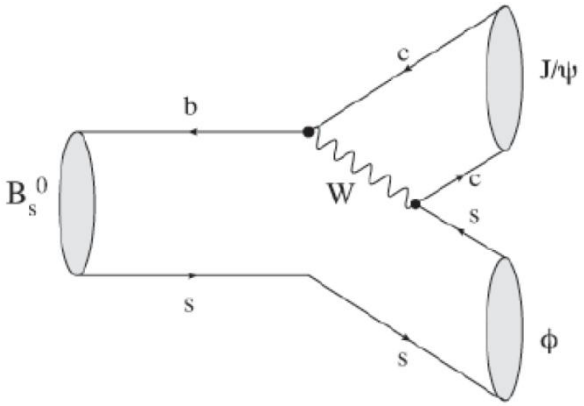

New Physics: $\phi_s = \phi_s^{SM} + \phi_s^{NP}$

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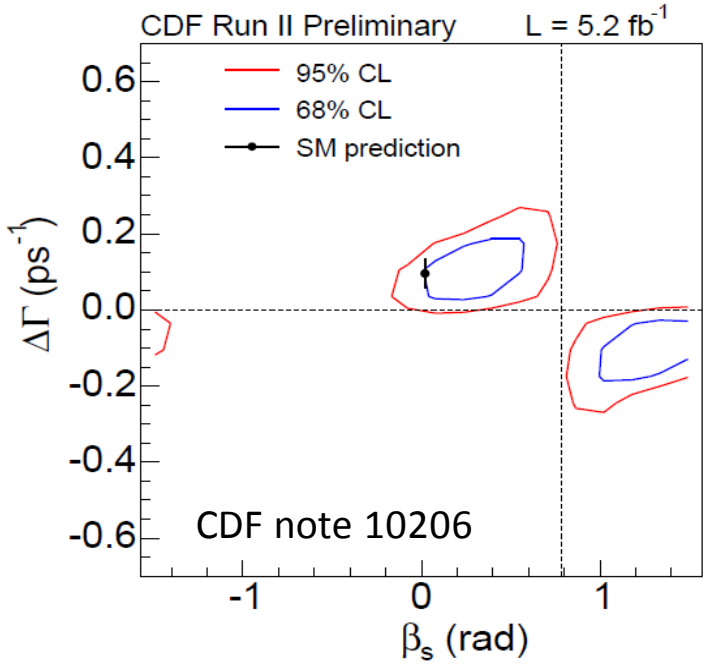
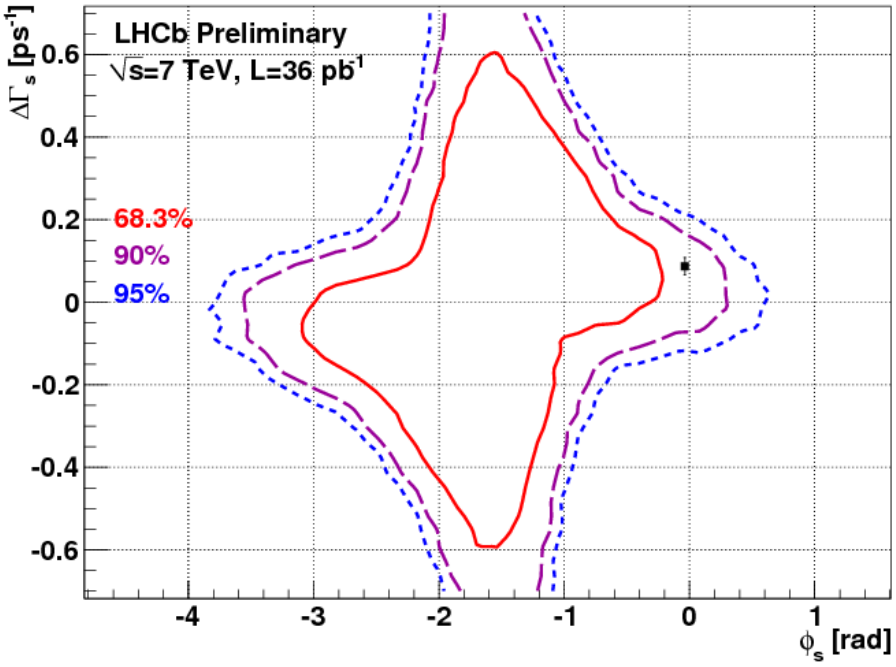
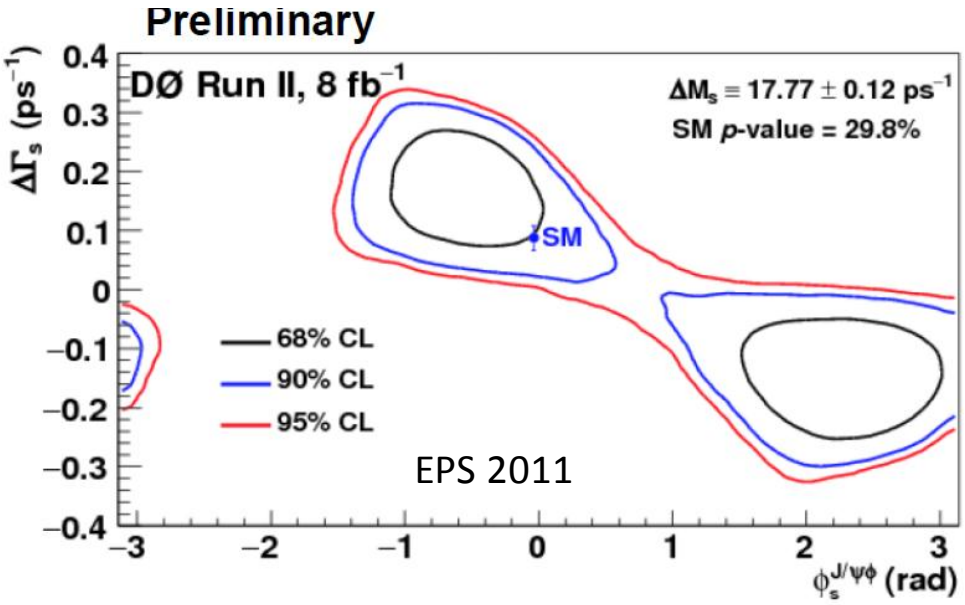
Experimental status in spring 2011

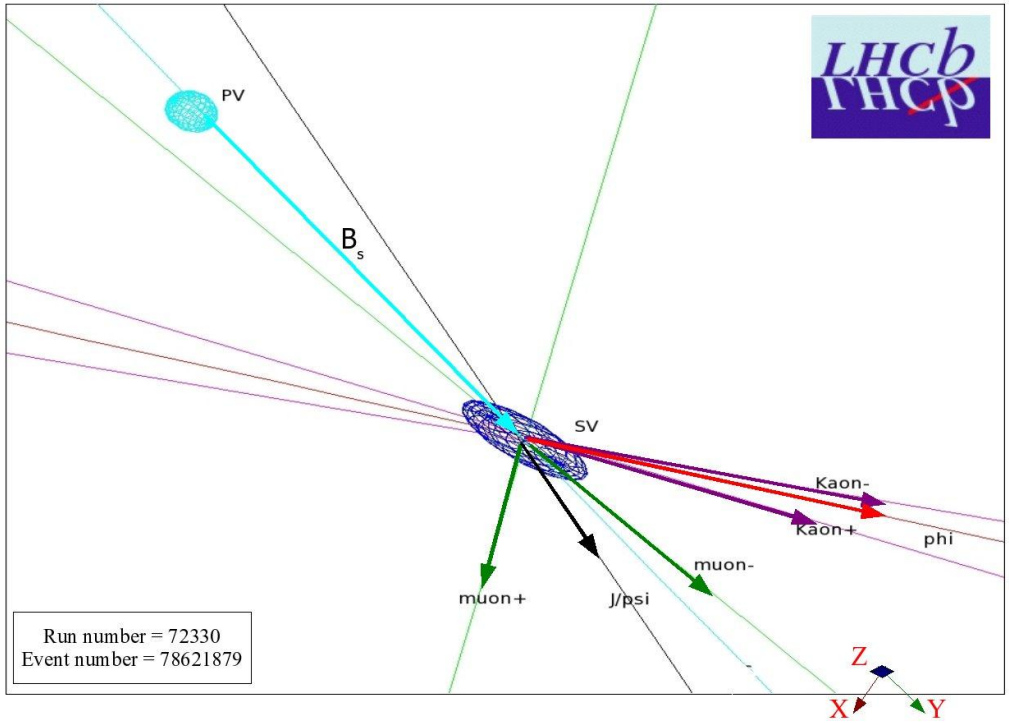
- Measurements from CDF and D0, first measurement of LHCb
- Still large uncertainties on ϕ_s and $\Delta\Gamma_s$

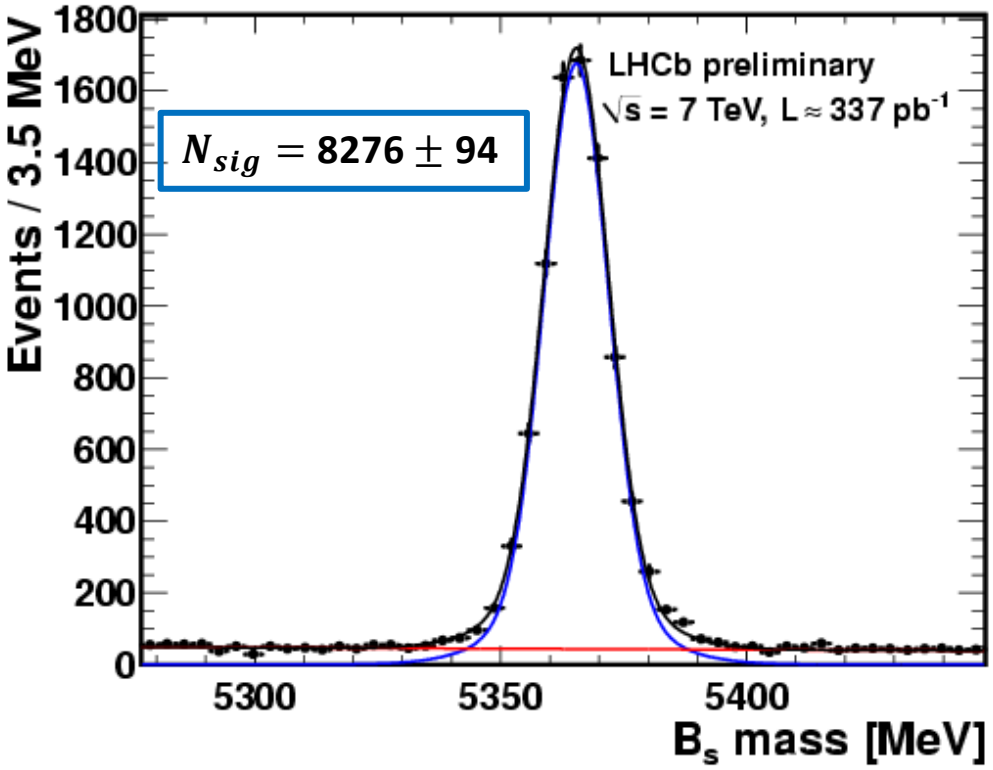






$B_s \to J/\Psi\,\Phi$ at LHCb





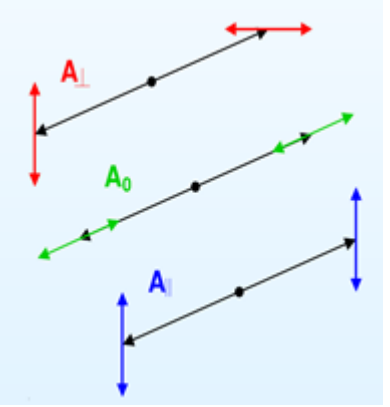
- Single and dimuon trigger lines
- Cut on proper time $t > 0.3$ ps to suppress prompt background
- Low background level: S/B $\approx$ 11 in 3σ mass window
- Background mostly from real J/Ψ decays

ϕ_s in $B_s \rightarrow J/\Psi\,\Phi$

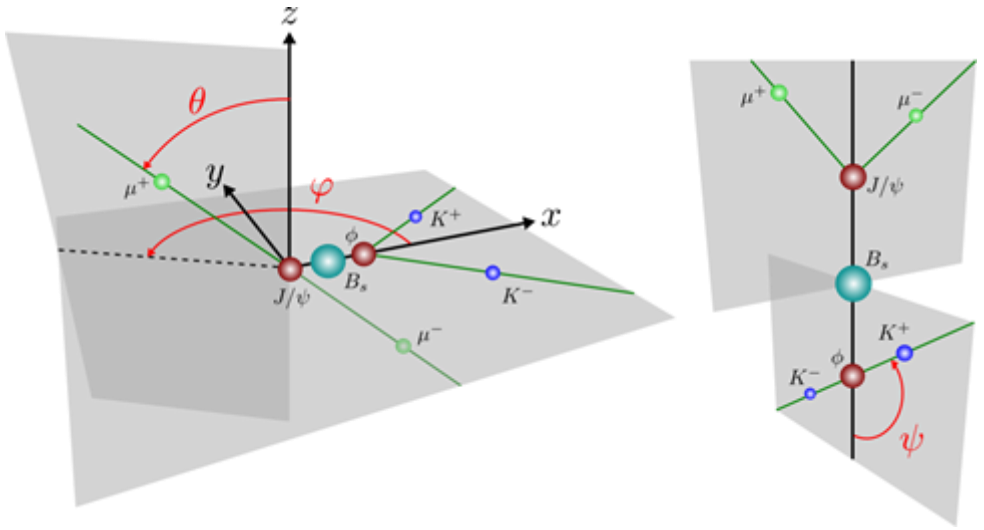
P -> VV decay:
final state is mixture of CP even and CP odd eigenstates

Described by three polarization amplitudes:

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



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



→ Statistical separation of CP eigenstates

Analysis strategy

Perform unbinned maximum likelihood fit in mass, proper time, transversity angles:

$$P(\lambda; m, t, \Omega) = f_{sig} \cdot S(\lambda; m)\, S(\lambda; t, \Omega) + \left(1 - f_{sig}\right) \cdot B(\lambda; m)\, B(\lambda; t)\, B(\lambda; \Omega)$$

signal **background**

$$S(\lambda, t, \Omega) = \epsilon(t, \Omega) \cdot \left(\frac{1+qD}{2} \cdot P_B(\lambda, t, \Omega) + \frac{1-qD}{2} \cdot \overline{P_B}\,(\lambda, t, \Omega) \right) \otimes R_t$$

Ingredients:

Proper time and angular acceptance — tagging — Proper time resolution

Physics parameters:

$\Gamma_s, \Delta\Gamma_s, \phi_s,\ |A_0|^2, |A_\perp|^2, \delta_\perp, \delta_\parallel,$

$|A_s|^2, \delta_s$ non-resonant $K^+ K^-$ s-wave

Proper time acceptance and resolution

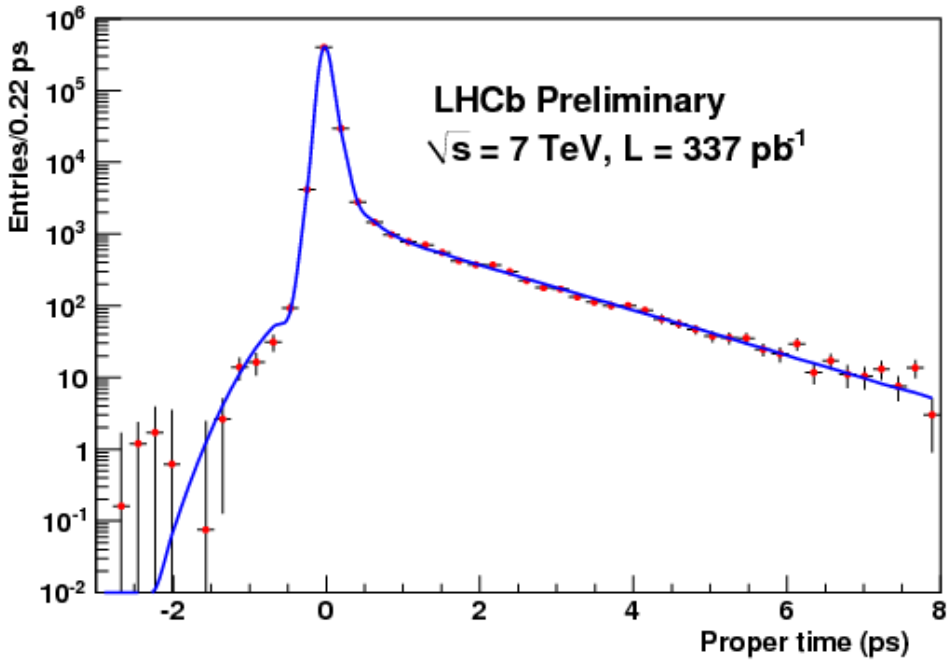
Acceptance and resolution measured on data:

- Non-flat proper time acceptance due to lifetime biasing cuts in trigger:
  acceptance parameters directly fitted using $B_s \rightarrow J/\Psi\,\Phi$ events
  cross-checked by comparing biased and unbiased trigger lines

- Resolution determined from prompt J/Ψ peak in data (triple Gaussian model)

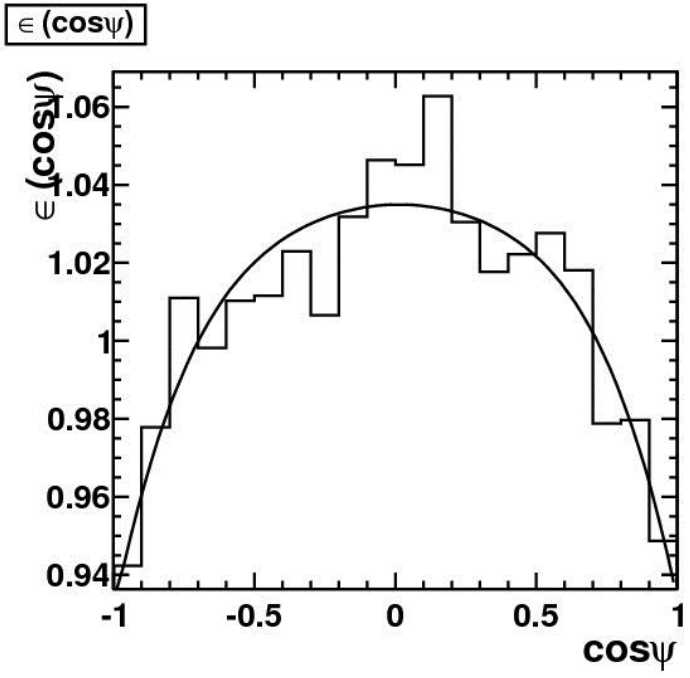
Effective proper time resolution: ~ 50fs

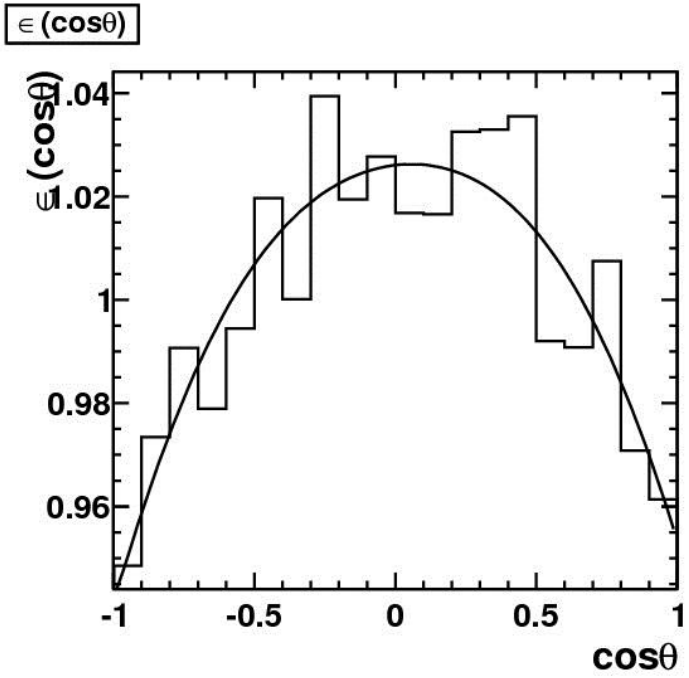
Dilution: $< D^{reso} >_{eff} = 0.673 \pm 0.013$

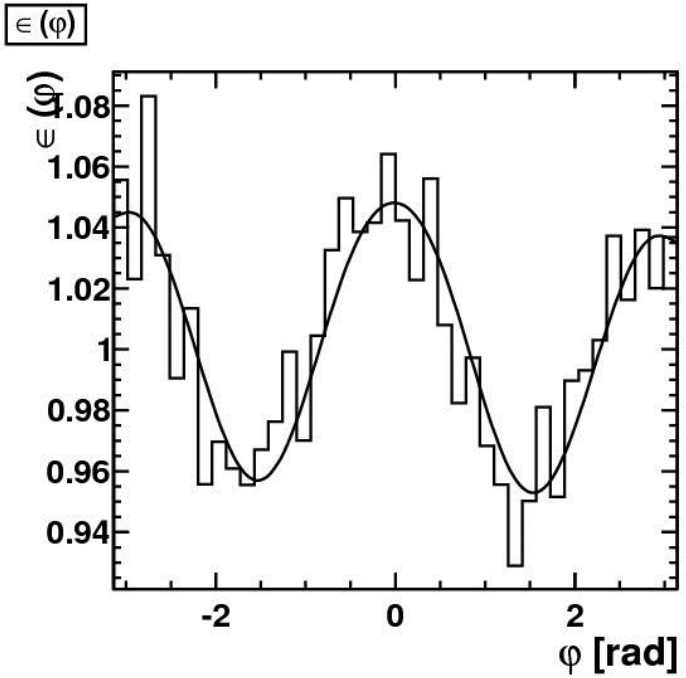


Angular acceptance

- Angular acceptance changes composition of CP even and CP odd eigenstates
- Acceptance determined on MC and cross-checked on data
- 3d description necessary to account for correlation





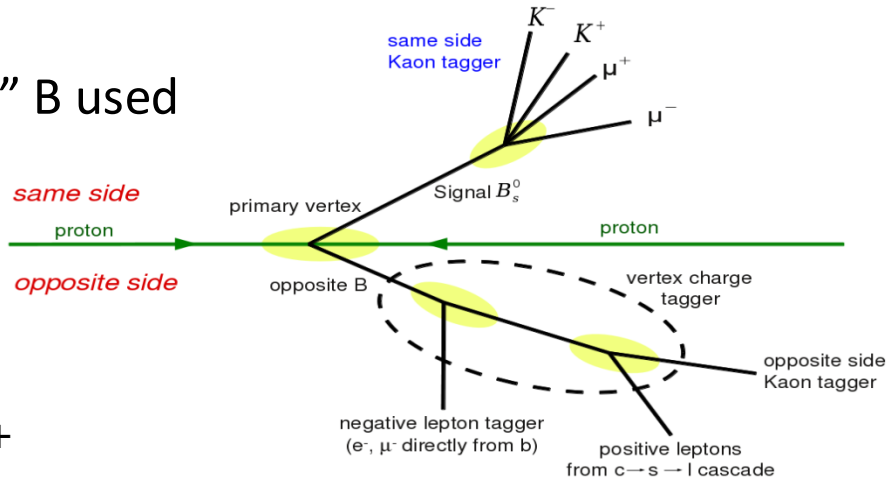


- maximal deviations $\sim 5\%$:
  mainly due to angular coverage of the detector and reconstruction effects

Flavour tagging

- Only tagging information from the "opposite side" B used

  Efficiency of OS tagger: $\sim 17.5\%$



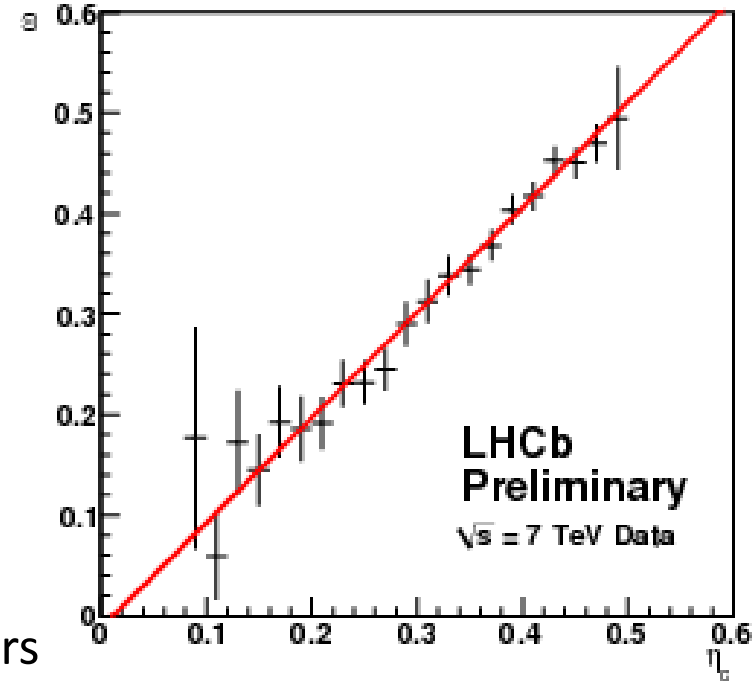
- OS tagger calibrated on data with $B^+ \rightarrow J/\Psi\, K^+$

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

For $B_s \rightarrow J/\Psi\, \Phi$:

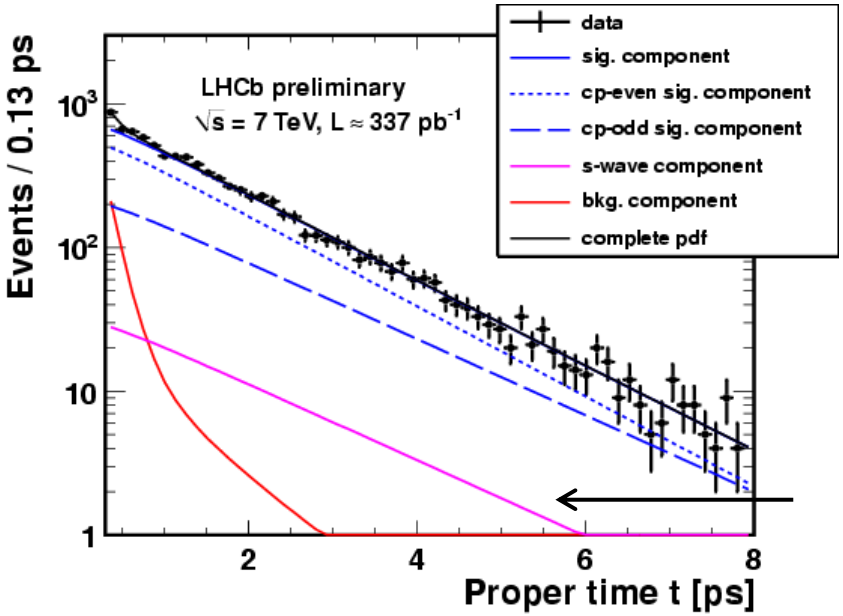
Dilution: $D_{eff} = (27.7 \pm 1.1 \pm 2.5)\%$

Tagging Power: $\epsilon D_{eff}^2 = (2.08 \pm 0.17 \pm 0.37)\%$

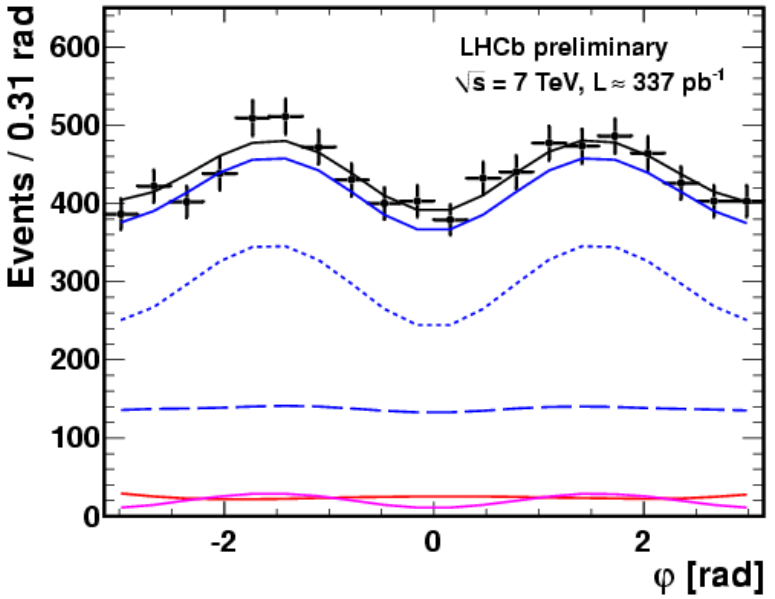


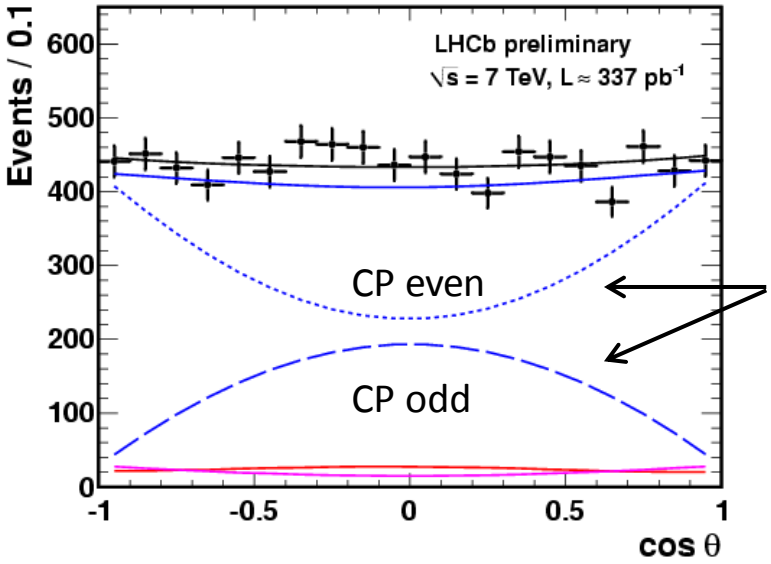
- Calibration parameters p_0, p_1 floated in fit within errors

Fit projections

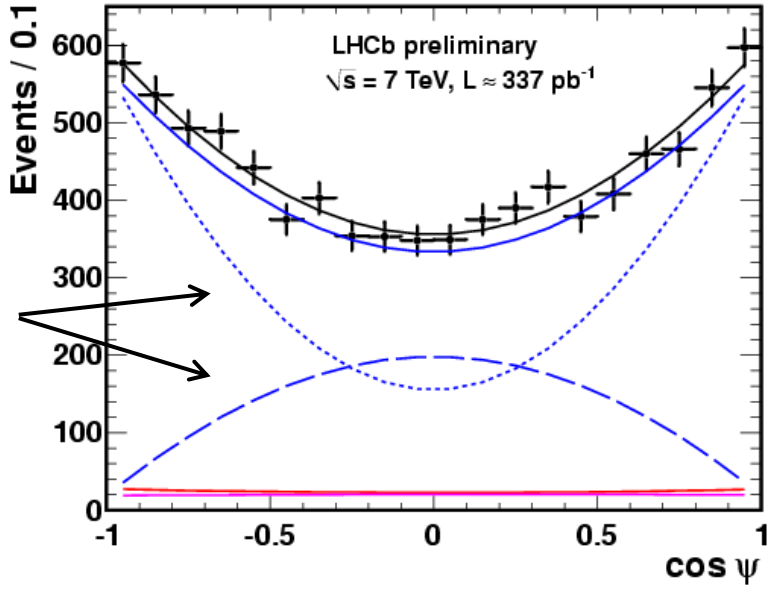


Non-resonant
S-wave component





Separation between
CP eigenstates



Systematic uncertainties

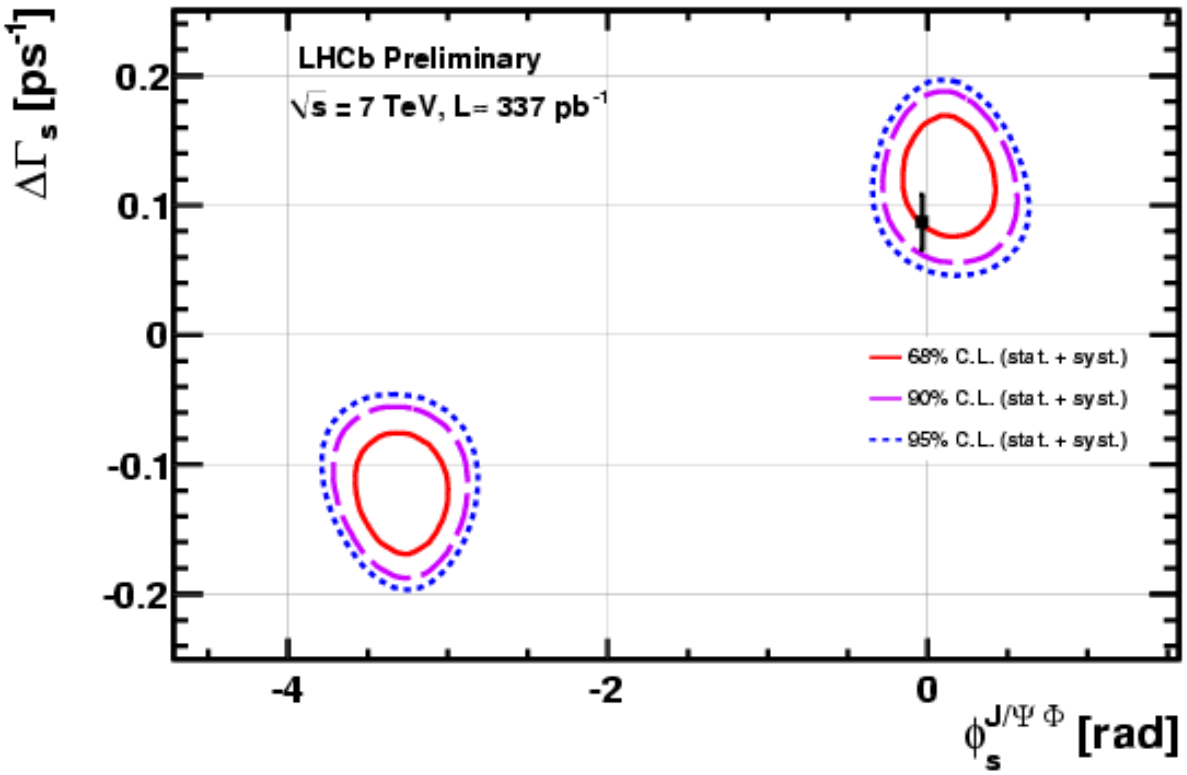
Source	$\phi_s^{J/\psi\phi}$[rad]	$\Delta\Gamma_s$ [ps^{-1}]
Description of background	0.06	0.004
Angular acceptances	0.004	0.008
z and momentum scale	–	0.002
Production asymmetry ($\pm$ 10%)	< 0.01	< 0.001
CPV in mixing & decay ($\pm$ 5%)	< 0.03	< 0.006
Quadratic sum	0.07	0.011

- Tagging, proper time resolution, mixing frequency: floated in fit
- Background description: different treatments in fit
- Angular acceptance: toy studies with reweighted MC acceptance
- Nuisance asymmetries:
  Production asymmetry, CPV decay/mixing simulated in toy experiments
- S-wave: toy studies and parameterization cross-checks

Systematic uncertainties ~40% of statistical error on ϕ_s, ~ 30% on $\Delta\Gamma_s$

Final results

Parameter	Value	Stat.	Syst.
$\phi_s\ [rad]$	0.13	0.18	0.07
$\Delta\Gamma_s\ [ps^{-1}]$	0.123	0.029	0.011
$\Gamma_s\ [ps^{-1}]$	0.656	0.009	0.008
$\lvert A_\perp(0)\rvert^2$	0.238	0.015	0.011
$\lvert A_0(0)\rvert^2$	0.497	0.013	0.031
$\lvert A_s(0)\rvert^2$	0.041	0.016	0.019
$\delta_\perp\ [rad]$	2.94	0.37	0.12
$\delta_s\ [rad]$	3.00	0.36	0.12



$\delta_\parallel \in$ **[3.01, 3.36] @ 68% C.L.**

- Most precise measurement on Γ_s, $\Delta\Gamma_s$ and ϕ_s
- first direct experimental significant evidence of non-zero $\Delta\Gamma_s$
- good agreement with SM predictions

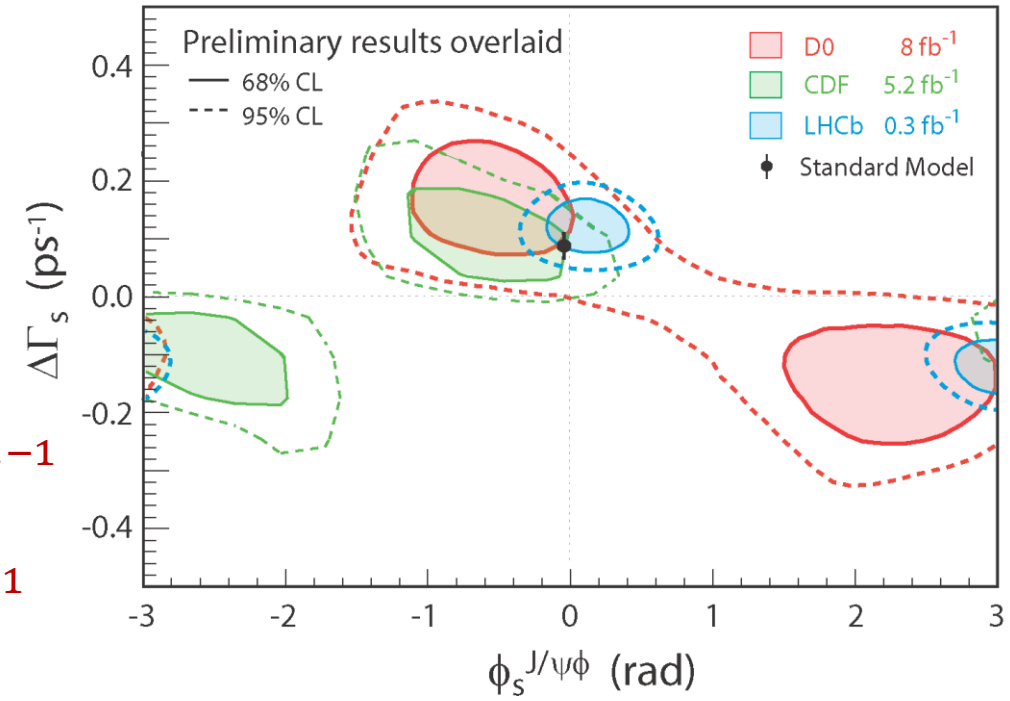
Summary

- Tagged time-dependent angular analysis of $B_s \to J/\Psi\ \Phi$ decays at LHCb
- $\sim$ 8300 signal candidates corresponding to $L \approx 337\ pb^{-1}$
- Effective proper time resolution of 50 fs
  tagging power $\epsilon D^2 = (2.1 \pm 0.4)\%$
- Most precise measurement of

$\phi_s = 0.13 \pm 0.18\ (stat) \pm 0.07\ (sys)$ rad

$\Delta\Gamma_s = 0.123 \pm 0.029\ (stat) \pm 0.008\ (sys)\ ps^{-1}$

$\Gamma_s = 0.656 \pm 0.009\ (stat) \pm 0.008\ (sys)\ ps^{-1}$



BACKUP