CP violation in B_s decays @ LHCb

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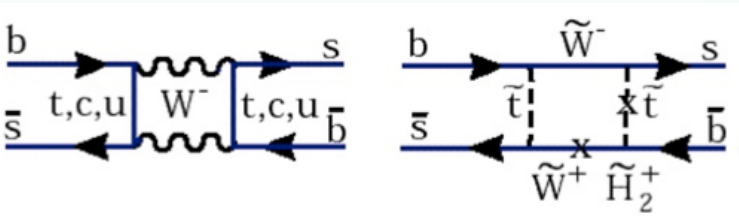
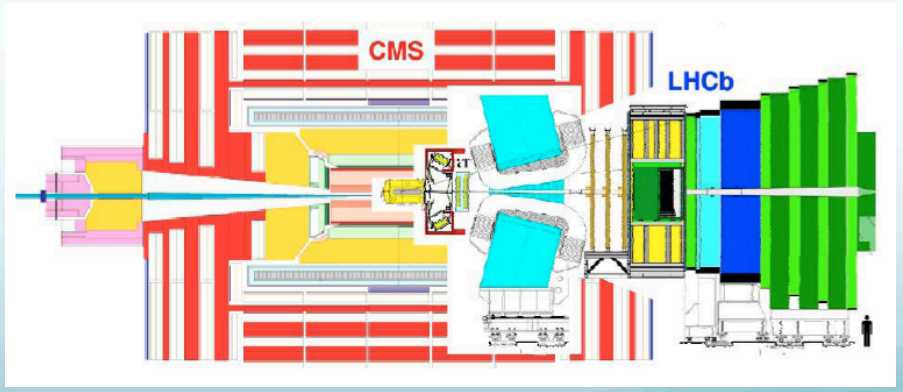
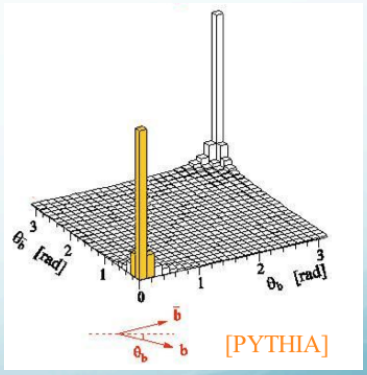
HCP 2011 – 14/11/2011 - Paris

LHCb experiment

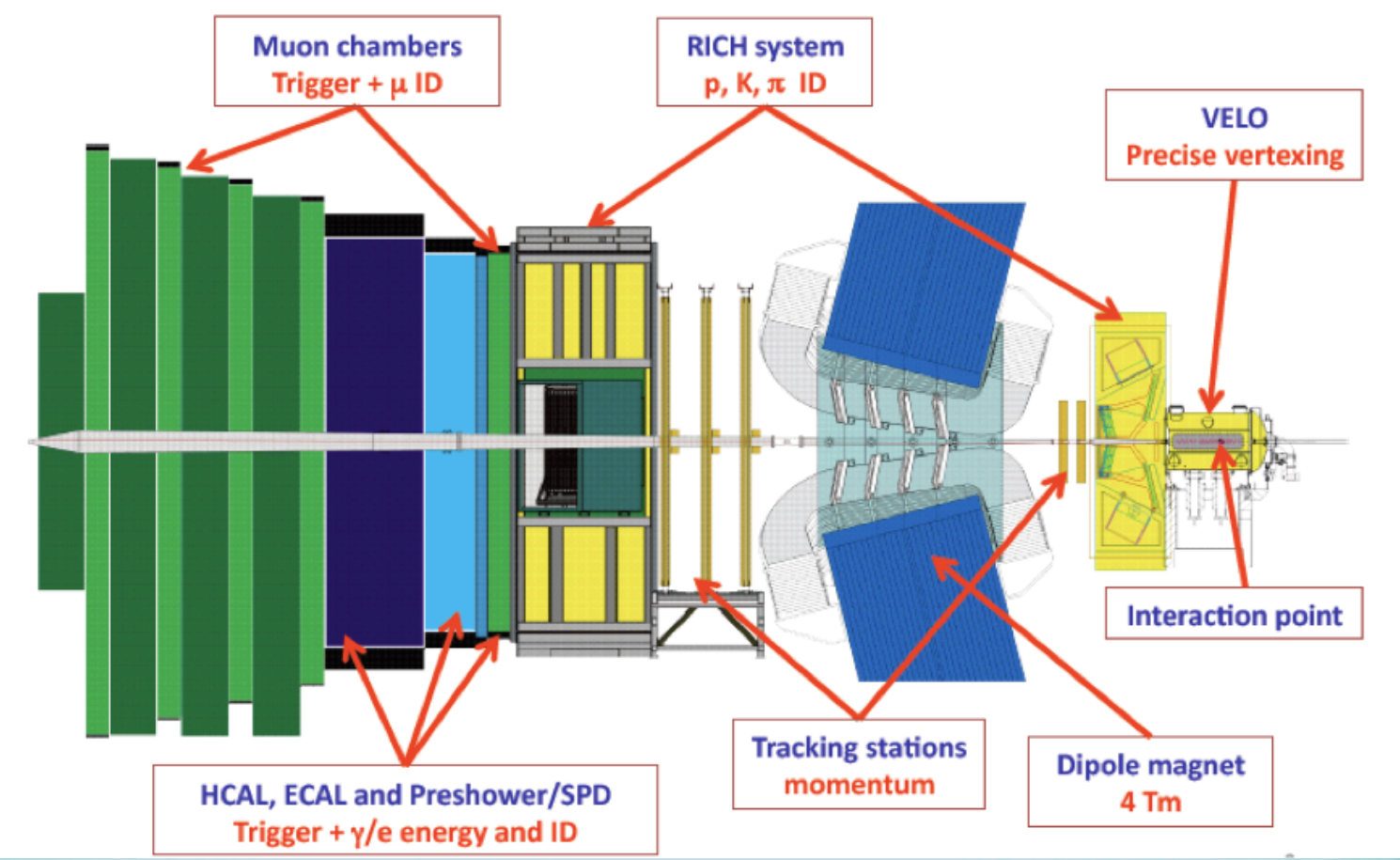
- Complementary to B Factories (look for B_s sector)
- Complementary to ATLAS and CMS
  - Dedicated to flavour physics in B (and D) sector(s)
  - LHCb searches for indirect effect of New Physics through loop diagrams sensitive to higher mass scales
  - Forward spectrometer as $b\bar{b}$ are boosted along beam axis $2 < \eta < 5$







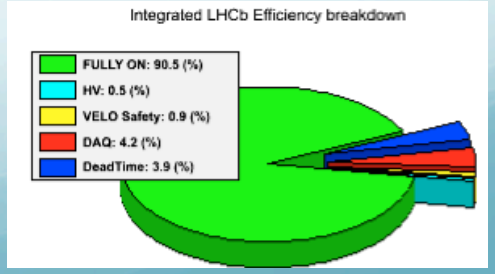
LHCb experiment



LHCb performance

[PLB 694 209]

- $b\bar{b}$ cross section in pp collisions at √s= 7TeV with 2010 data (284±53) μ b
- VELO silicon planes gets closer (8 mm) to beam in collision mode
  - Resolution of IP of ~12 μ m and proper time of ~40fs
- 2 RICH detectors give better particle identification (p/K/π) separation 2-100GeV/c
- Tracking system gives a resolution of σ p/p ~0.5% (2-100GeV/c)
- Allows a B mass resolution of ~7MeV/c^2 (ATLAS/CMS of ~20MeV/c^2)
- In 2011: over 1 fb^{-1} recorded: ~3.10^{11} *bb* pairs produced
- Analysis presented today use up to ~350 pb^{-1}



CP in $B_s \rightarrow hh$

- Direct integrated CP asymmetry

$$A_{CP} = \frac{\Gamma(\overline{B_s} \rightarrow K^+\pi^-) - \Gamma(B_s \rightarrow K^-\pi^+)}{\Gamma(\overline{B_s} \rightarrow K^+\pi^-) + \Gamma(B_s \rightarrow K^-\pi^+)}$$

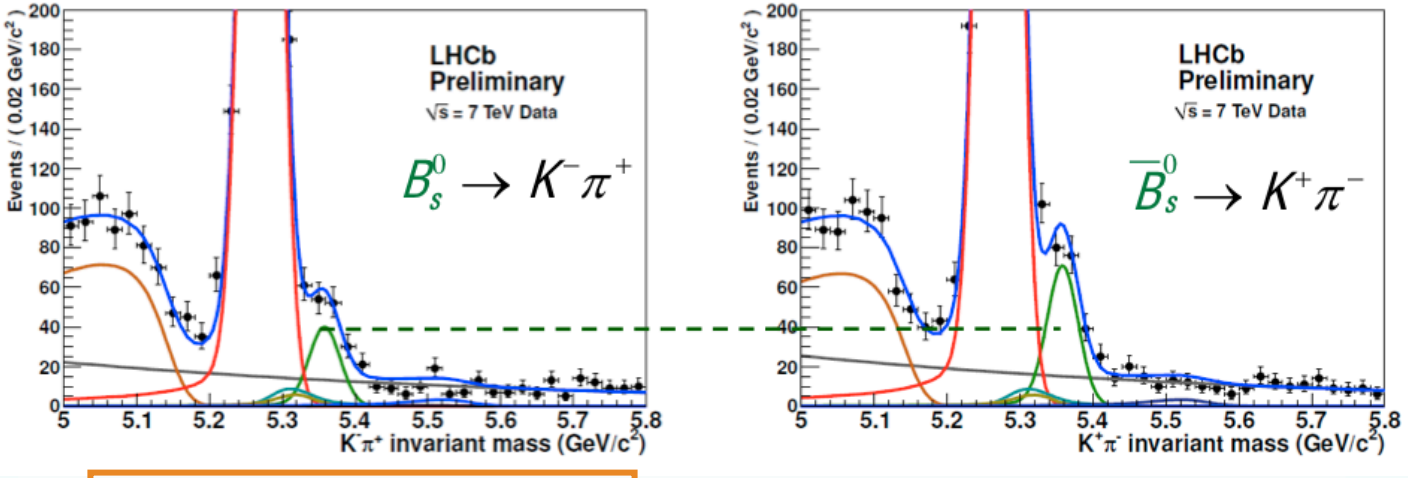
- Correct for detection (magnet polarity) and production asymmetries

$$A_{CP} = A_{RAW} - A_D - \kappa A_P$$

- A_D extracted from $D^{*+} \rightarrow D^0(K\pi)\pi^+$ and $D^{*+} \rightarrow D^0(KK)\pi^+$
- A_P measured in $B^0 \rightarrow J/\psi K^*(K\pi)$ and κ =0.03 is due to different mixing and proper time acceptance

A_{CP} in $B_s \rightarrow K^-\pi^+$

- With 320 pb^{-1}



$$A_{CP} = (27 \pm 8 \pm 2)\%$$

(previous CDF result of A_{CP}=(39±15±8)%)
PRL 106, 181802

- First 3σ measurement of ~~CP~~ in B_s system
- Future goal (besides improving measurement with 1 fb^{-1}) to measure γ in time dependent $B_s \rightarrow KK$ analysis

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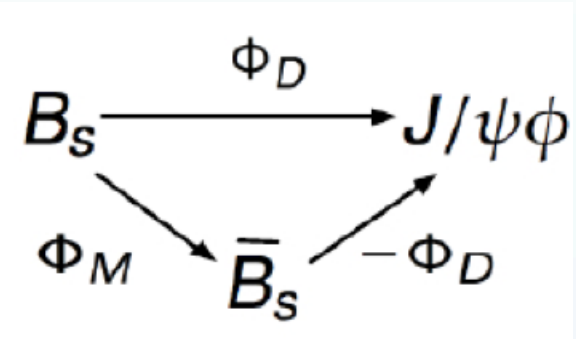
$\not{CP}$ in mixing

- When both B_s and $\overline{B}_s$ have the same final state we can have CP asymmetry in the interference between decay and mixing



- To measure it we need to
  - Have good proper time resolution
  - Measure Δm_s
  - Know the original flavour of the meson

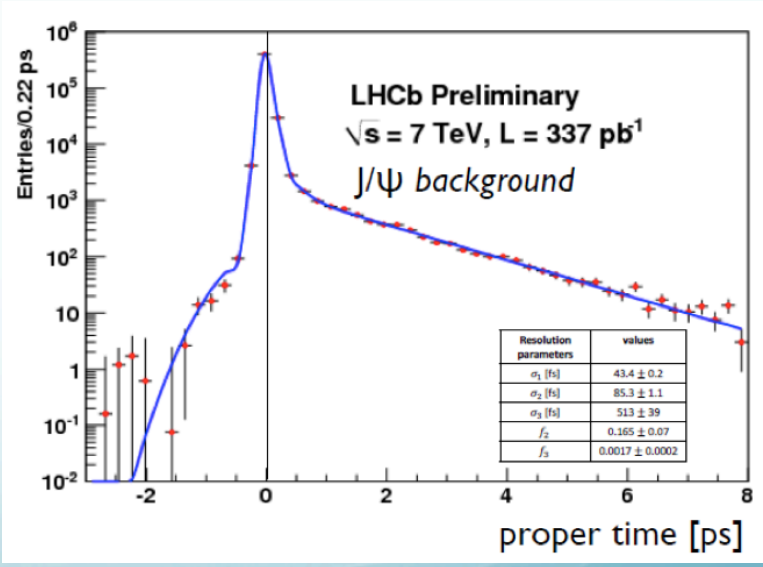
$$\Phi_s = \Phi_M - 2\Phi_D$$

↓

Flavour tagging

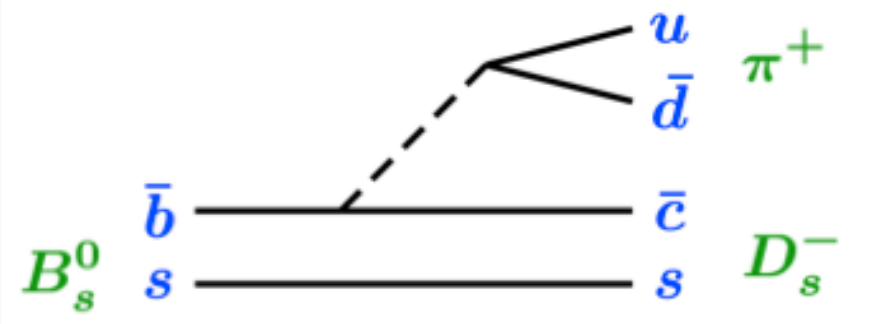
Proper time resolution

- As B mesons are highly boosted along beam axis only z-axis resolution matters
- PV resolution depends on number of tracks 0.05-0.2 mm
- z resolution of secondary vertex ~0.3 mm
- Proper time resolution is modeled as triple gaussian with effective resolution of σ_t of 40-50 fs
- From $B_s \rightarrow J/\psi \Phi$

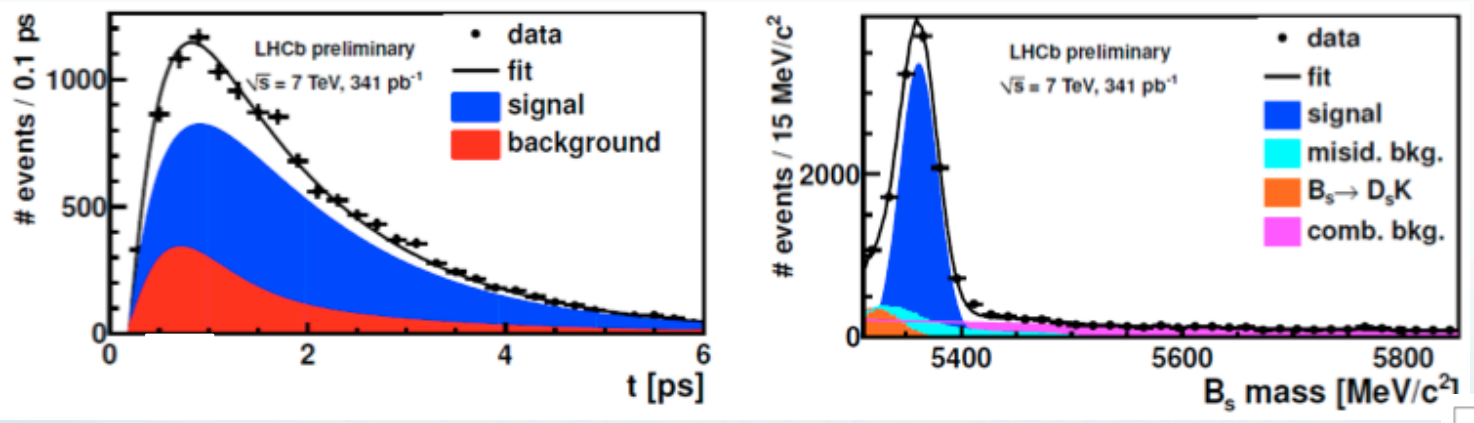


Δm_s measurement

- Mixing much faster than in B_d
- Use $B_s \rightarrow D_s^-(K^+K^-\pi^-)\pi^+$
- Maximum Likelihood fit

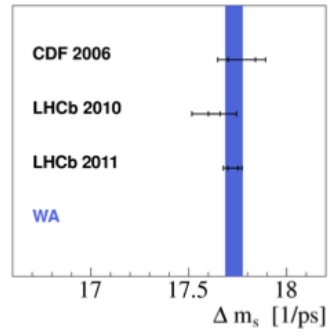


340 pb^{-1}



$$\Delta m_s = (17.725 \pm 0.041 \pm 0.026)\, ps^{-1}$$

World average
$\Delta m_s = (17.731 \pm 0.045) ps^{-1}$



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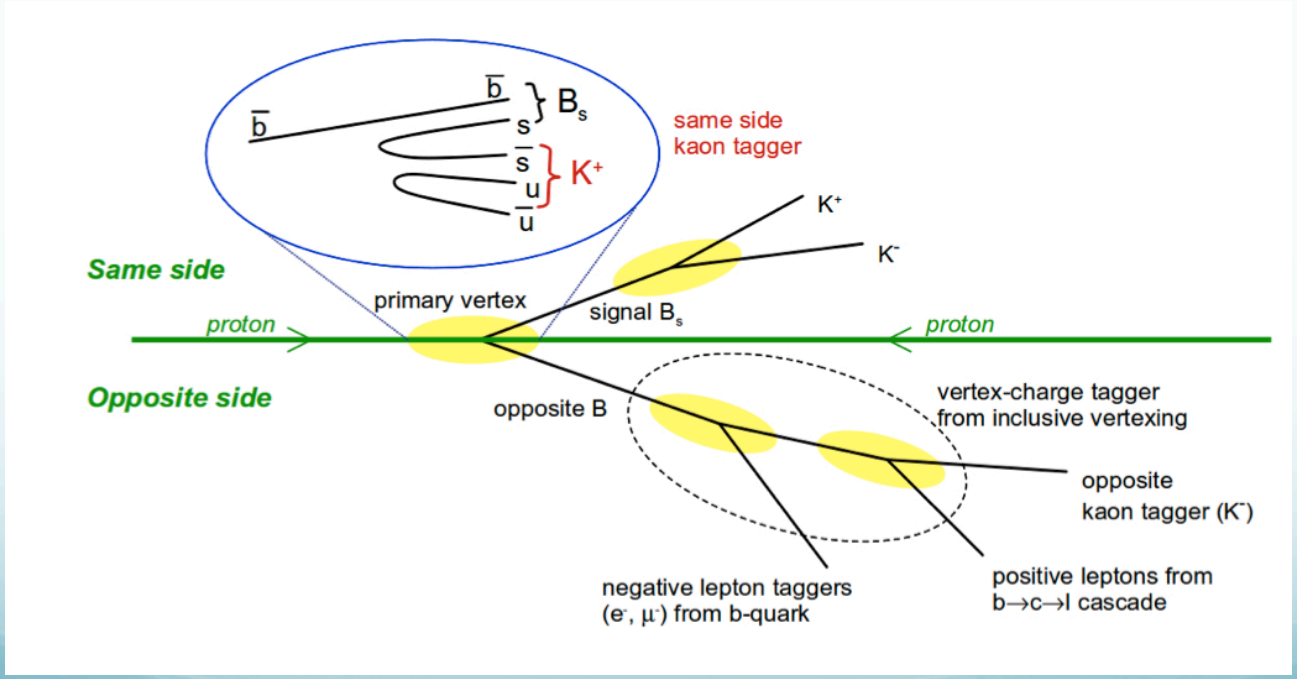
Tagging system

- Flavour Tagging is the procedure to determine the flavour of the reconstructed B meson at production
- Neural net to combine the taggers per event



Tagging system

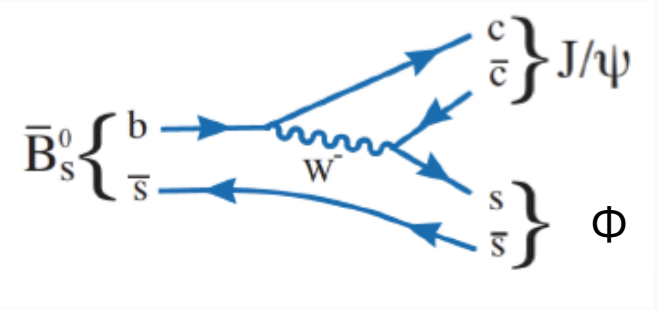
- Calibrate tagging using flavour specific decays as $B^+ \rightarrow J/\psi K^+$

$$\varepsilon_{tag} = \frac{N_R + N_W}{N_R + N_W + N_U} \qquad \omega = \frac{N_W}{N_R + N_W}$$

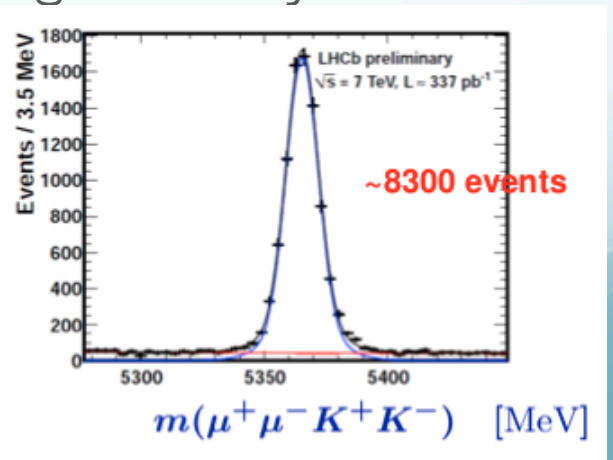
$$\varepsilon_{eff} = \varepsilon_{tag}(1 - 2\omega)^2$$

- Dilution depends on final state
- Only using opposite side taggers for $B_s \rightarrow J/\psi X$ CP analysis
- Typical tagging power $\varepsilon_{eff} = (2.1 \pm 0.4)\%$ (for $B_s \rightarrow J/\psi \Phi$)

$B_s \rightarrow J/\psi\,\Phi$

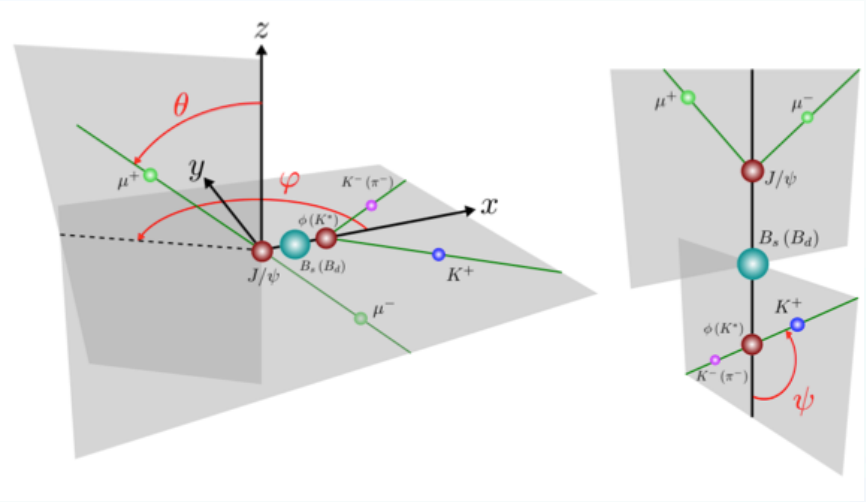


- Golden mode for Φ_s (Analogue in B_s sector to $B^0 \rightarrow J/\psi K_S$)
- Very small and well predicted in SM
  $\Phi_s = -2\beta_s = (-0.036 \pm 0.002)$ rad (CKM fitter)
- New Physics can add large terms to Φ_s
- VV final state: Is not a CP eigenstate and needs to separate CP odd and even components with angular analysis
- $J/\psi \rightarrow \mu^+\mu^-$ and $\Phi \rightarrow K^+K^-$



$B_s \rightarrow J/\psi\,\Phi$

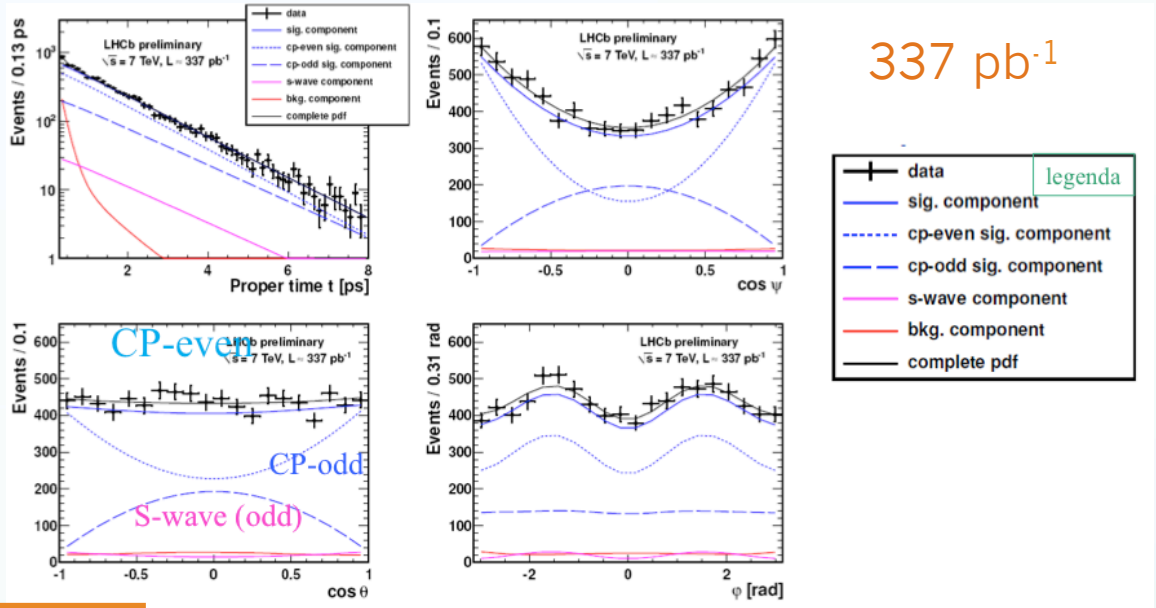
- Described using transversity basis
  - l=0,2 CP even
  - l=1 CP odd
- Polar angles θ, ψ and φ azimuthal angle of final states



- Parameters are extracted in a simultaneous multidimensional unbinned extended maximum likelihood fit: $\Delta\Gamma_s$, Γ_s and Φ_s
- Observables: reconstructed B_s mass and proper time, flavour tagging decision and angles

$B_s \rightarrow J/\psi \Phi$ fit results

- Main systematics due to acceptance of the angles
- Ambiguity in
  - $\Phi_s \rightarrow \pi - \Phi_s$
  - $\Delta\Gamma_s \rightarrow -\Delta\Gamma_s$

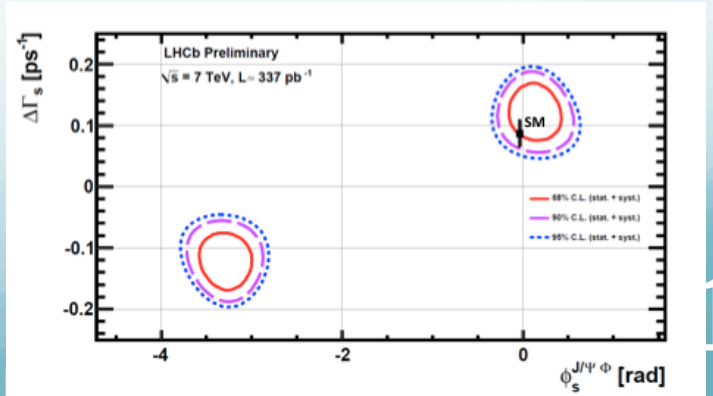


$$\phi_s^{J/\psi\phi} = (0.13 \pm 0.18 \pm 0.07) rad$$

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

$$\Delta\Gamma_s = (0.123 \pm 0.029 \pm 0.011) ps^{-1}$$

Most precise result from single experiment
Compatible with SM (-0.036±0.002)



First 4σ non-zero $\Delta\Gamma_s$

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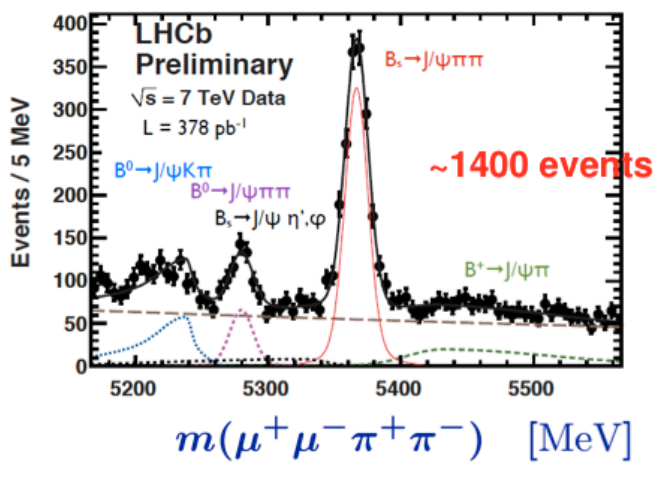
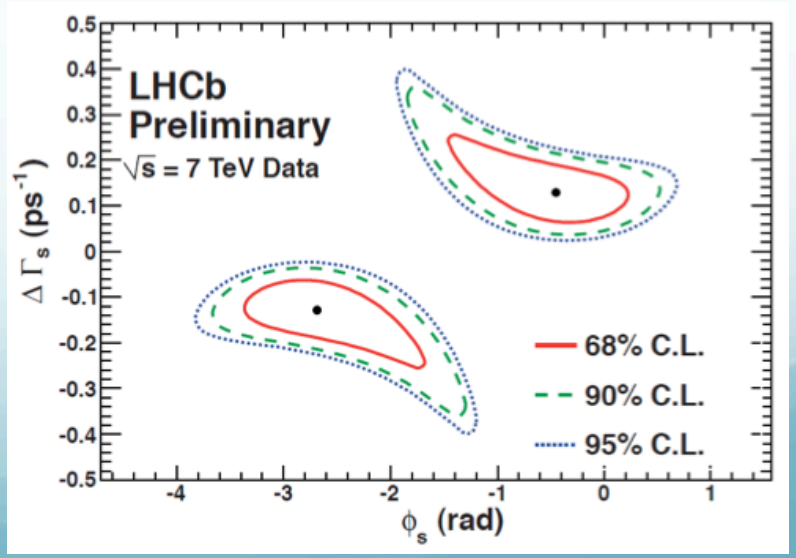
$B_s \rightarrow J/\psi f_0$

- Same phases of $B_s \rightarrow J/\psi \Phi$
- $f_0 \rightarrow \pi^+\pi^-$
- Smaller yield but is CP eigenstate (no need for angular analysis)
- First observed by LHCb in 2011
- Similar fit to m and t
- Γ_s from $B_s \rightarrow J/\psi \Phi$
- Δm_s from $B_s \rightarrow D_s\pi$

$$\phi_s^{J/\psi f_0} = (-0.44 \pm 0.44 \pm 0.02)rad$$





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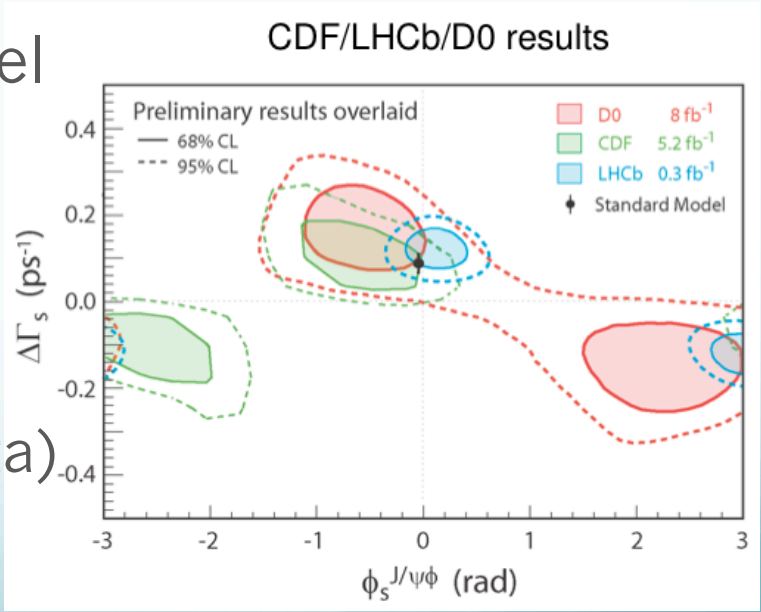
Combining results

- Simultaneous fit to both $B_s \rightarrow J/\psi \Phi$ and $B_s \rightarrow J/\psi f_0$ samples

$$\phi_s = (0.03 \pm 0.16 \pm 0.07) rad$$

+ambiguous solution

- Compatible with Standard Model
- Next steps (2012 winter)
  - Solve ambiguity fitting for S-wave phase
  - Include more data (3x more data)
  - Include SS kaon tagging



LHCB-CONF-2011-056

CDF Public Note 10206
D0 CONF Note 6093

Conclusion

- Neutral meson mixing in channels with small Branching Fractions:
  - Precise predictions for SM small CP phases
  - Very sensitive to New Physics
  - B_s sector not as well measured as B_d
- LHCb can (and is already) measure precisely those asymmetries
- Detector is performing according to specifications
- Many B_s sector WA CP measurements already dominated by LHCb
  - First non-zero 3σ of direct ~~CP~~ in $B_s \rightarrow K^-\pi^+$
  - Δm_s from $B_s \rightarrow D_s\pi$
  - First 4σ non-zero $\Delta \Gamma s$ from $B_s \rightarrow J/\psi\, \Phi$
  - Φs combining $B_s \rightarrow J/\psi\, \Phi$, $B_s \rightarrow J/\psi\, f0$

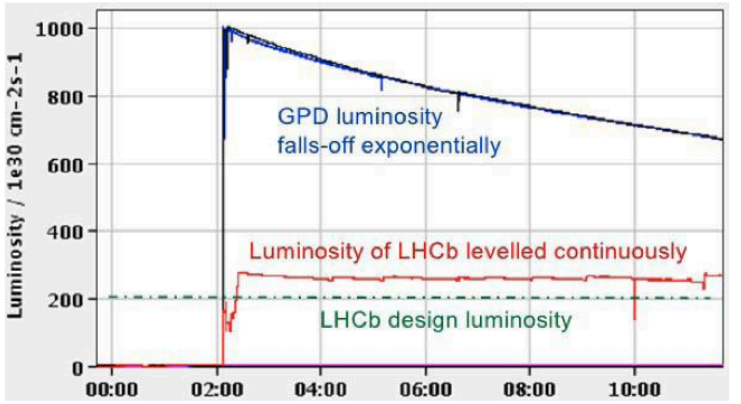
Prospects

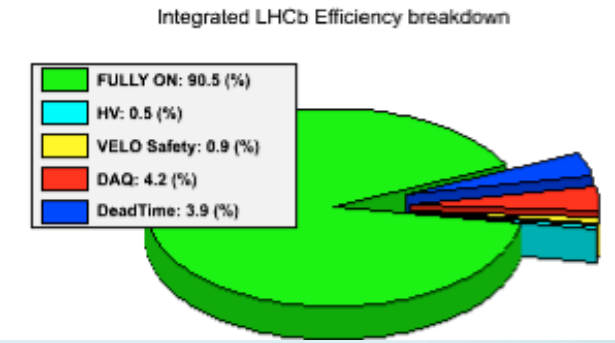
- So far good agreement with Standard Model
- Update those results in near future (data sample recorded is 3x larger) and much more:
  - Solve ambiguity in Φ_s and $\Delta\Gamma_s$
  - Similar analysis for penguin mode $B_s \rightarrow \phi\phi$ (even smaller CP in SM than $B_s \rightarrow J/\psi\phi$)
  - Measure γ from time dependent $B_s \rightarrow K^+K^-$
- Another $\sqrt{s}$=7 TeV run in 2012

Backup

Data and trigger

- Nominal luminosity of 2×10^{32} cm^{-2}s^{-1}
- Operating above nominal and still don't lose lumi during the fill
- Trigger uses typical B decay signatures (high transverse momentum and impact parameter)
- In 2011: over 1 fb^{-1} recorded (37 pb^{-1} in 2010)
- About 3.10^{11} $b\bar{b}$ pairs produced
- Analysis presented today use up to ~350 pb^{-1}





Tagging calibration

- For each event an estimated probability of the tagging decision to be correct (η) is given by a neural net.

  Calibration of η is needed to obtain an ω event per event

- Use per event mistag as observable $\omega = p_0 + p_1 \cdot (\eta - \bar{\eta})$

- $B^+ \to J/\psi\, K^+$ used for calibration, and the kinematically similar $B^0 \to J/\psi\, K^*$ is used as crosscheck

  MC ω distribution/calibration totally compatible with $B^0 \to J/\psi\, K_s$

  Study correction function between actual mistag and calibrated mistag

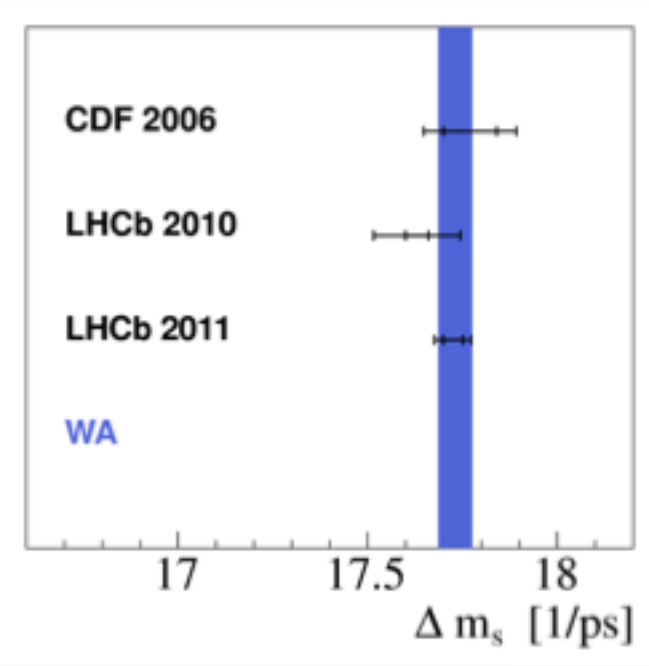
Expected	Obtained
$p_0 = \bar{\eta} = 0.35$	$p_0 = 0.333 \pm 0.025$
$p_1 = 1$	$p_1 = 0.71 \pm 0.36$

8

Δm_s World Average

- World Average
  - $\Delta m_s = (17.731 \pm 0.045) ps^{-1}$
- Standard Model prediction
  - $\Delta m_s = (16.8^{+2.6}_{-1.5}) ps^{-1}$

PRD.83, 036004 (2011)



Φ_s

- In SM

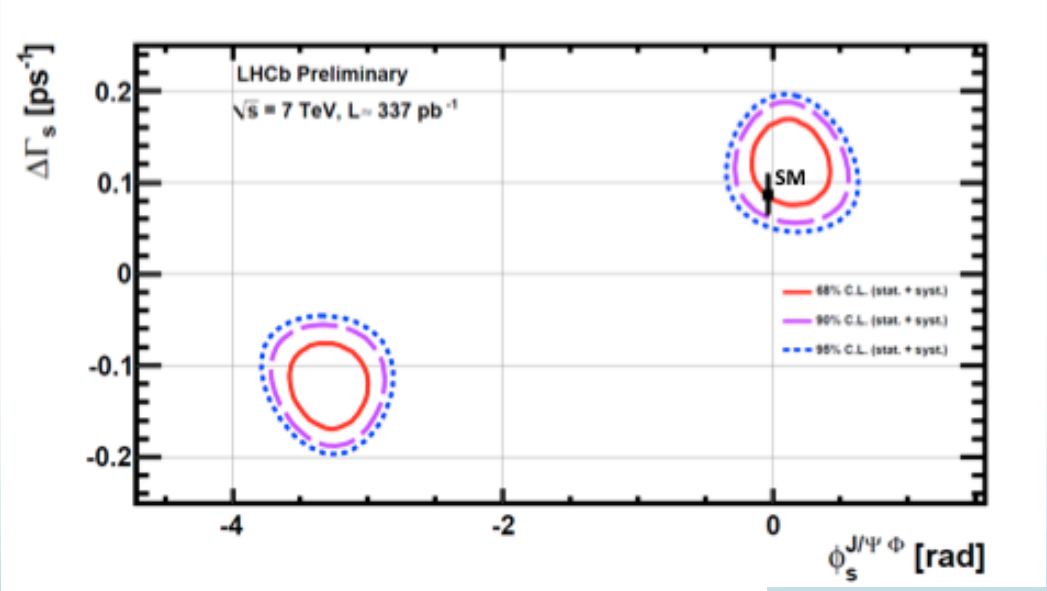
$$\phi_s = -2\beta_s = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = (-0.036 \pm 0.002)rad$$

- We measure $\phi_s = \phi_s^{SM} + \phi^{NP}$
- Many NP terms can be added to Φ_s due to mixing: eg. SUSY, extra dimensions, 4th generation

$B_s \rightarrow J/\psi \Phi$ Fit

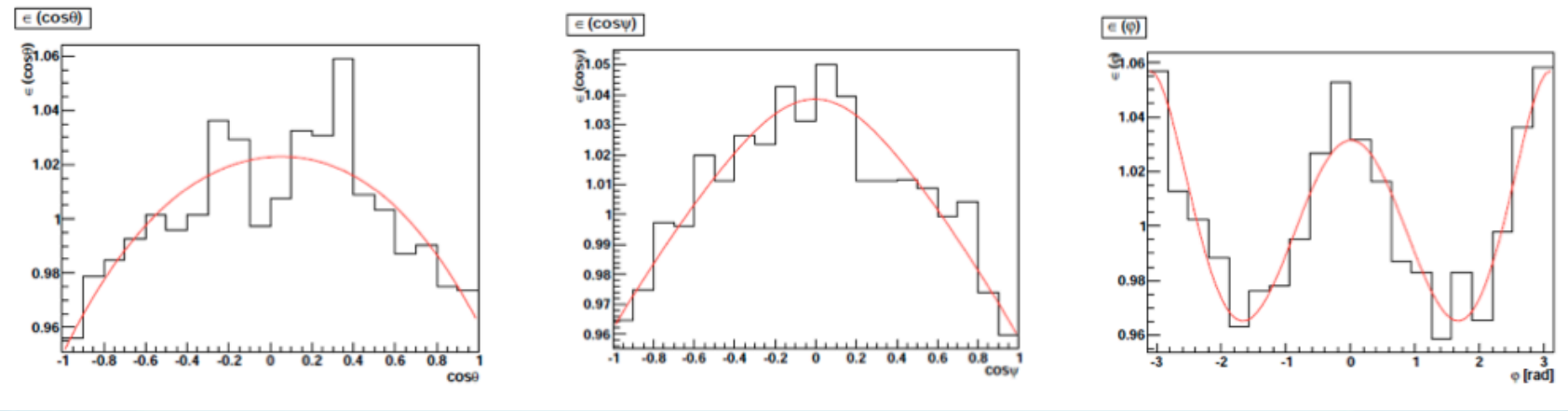
- Signal pdf depends on acceptance, flavour tagging andproper time resolution

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



Angles acceptance

- Polar and azimuthal angles from $B_s \rightarrow J/\psi\,\Phi$ final state acceptance obtained from MC
- Deviation from uniform within 5%



- Used in likehood fit