Measurements of CP Violation and Mixing in B_d Decays

Steve Playfer (Edinburgh) – on behalf of the LHCb Collaboration

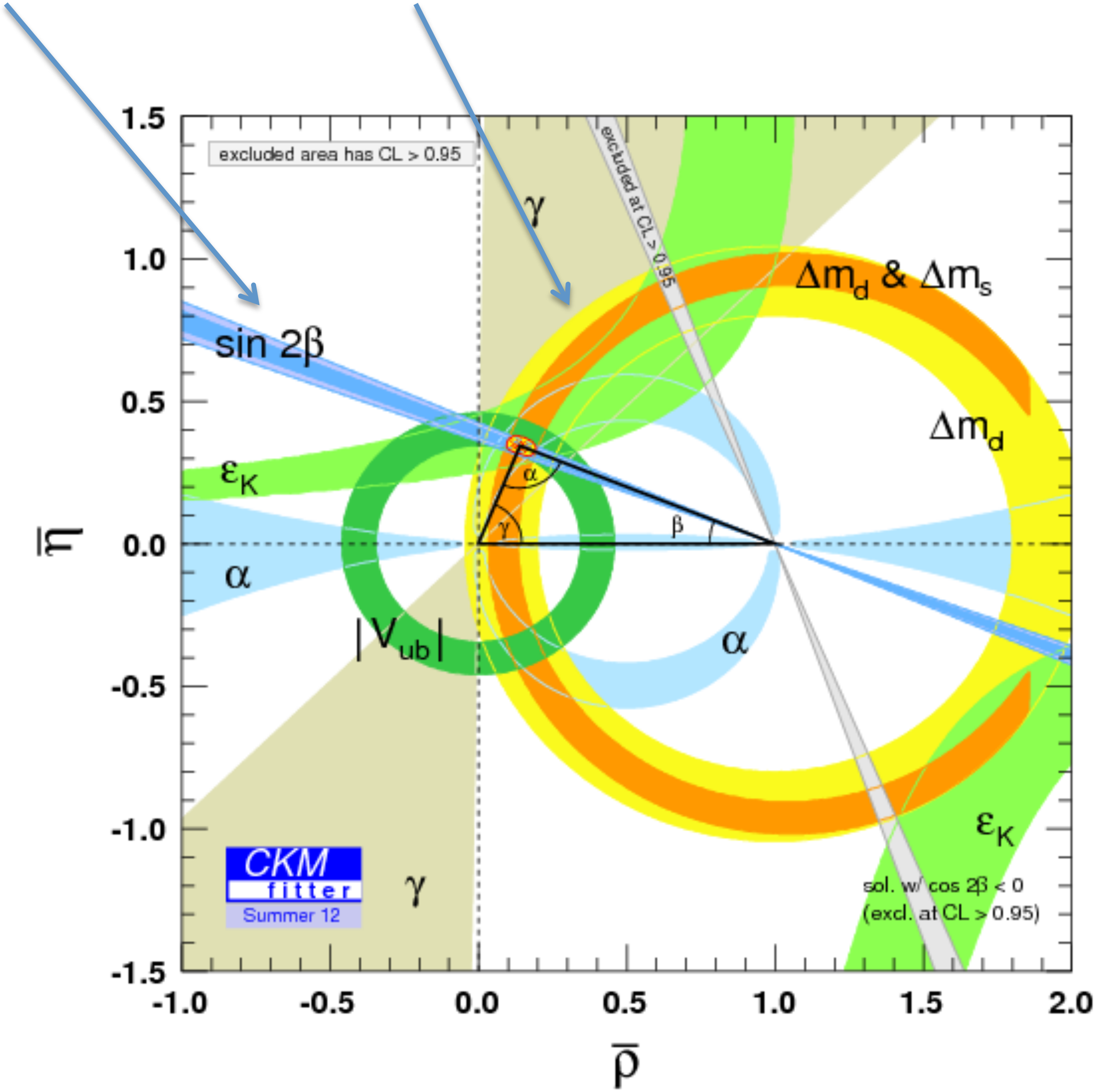
Sin 2β from $B_d \to J/\psi K_S$

Δm_d from $B_d \to J/\psi K^*$, $D\pi$

~~Direct CPV in $B_d \to J/\psi K^*$~~ ← Coming soon

Rare Decays $B_s \to J/\psi K_S$, $J/\psi K^*$

CP violation and mixing in B_d decays are well measured by B factories:

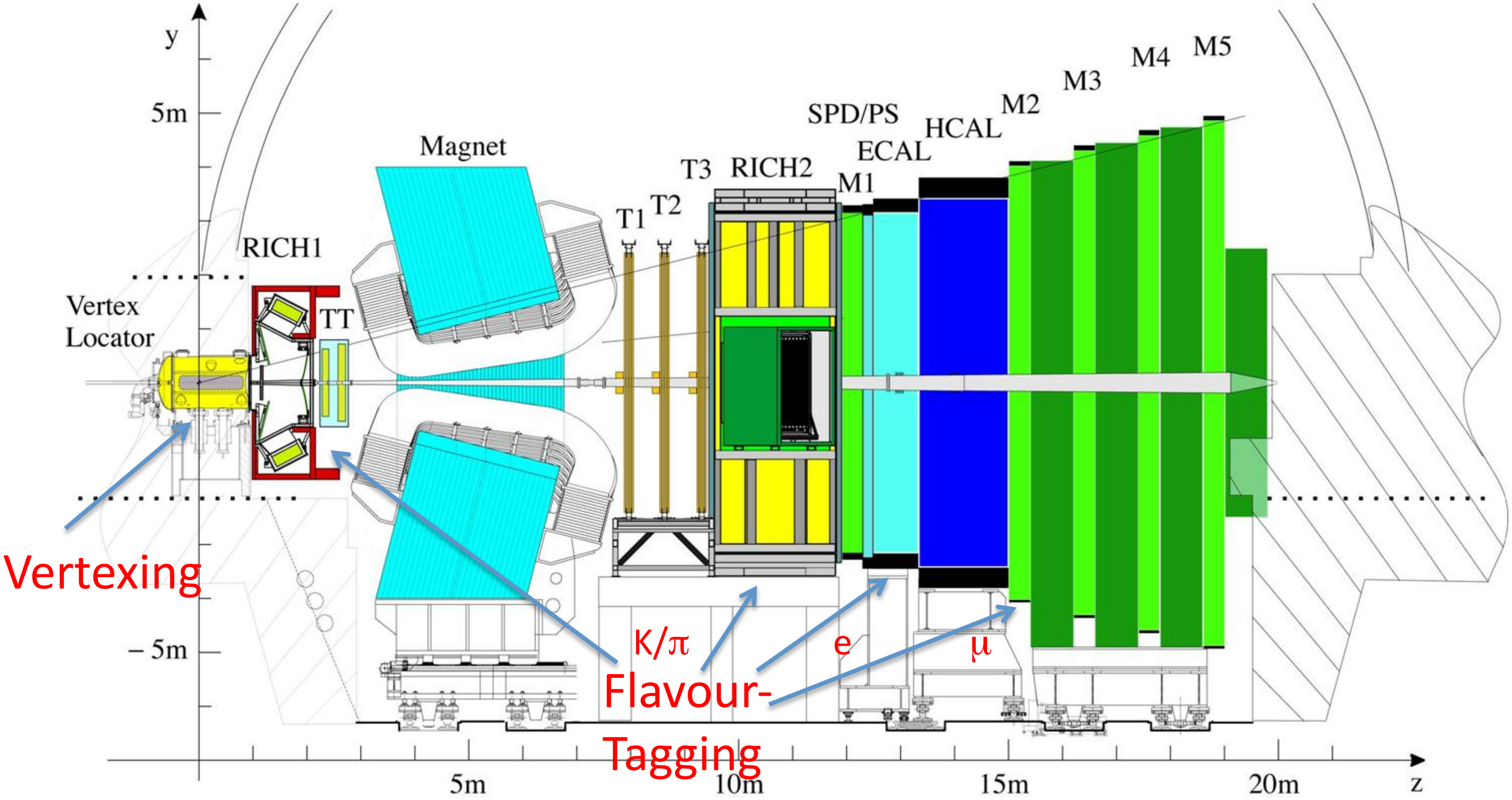


This is a challenge for LHCb

Can we reproduce the known results at a hadron collider?

Can we eventually improve on the B factories?

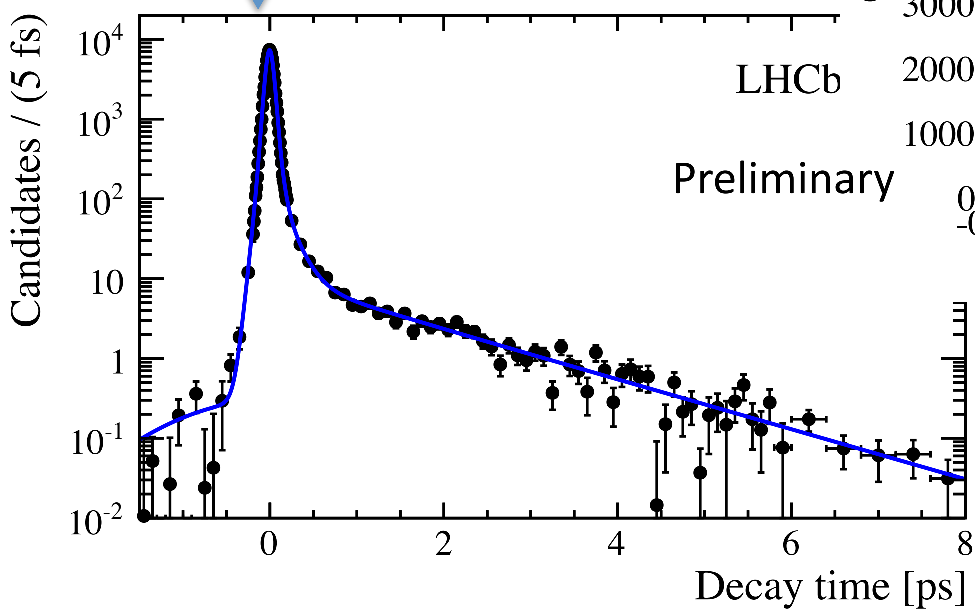
The LHCb Detector

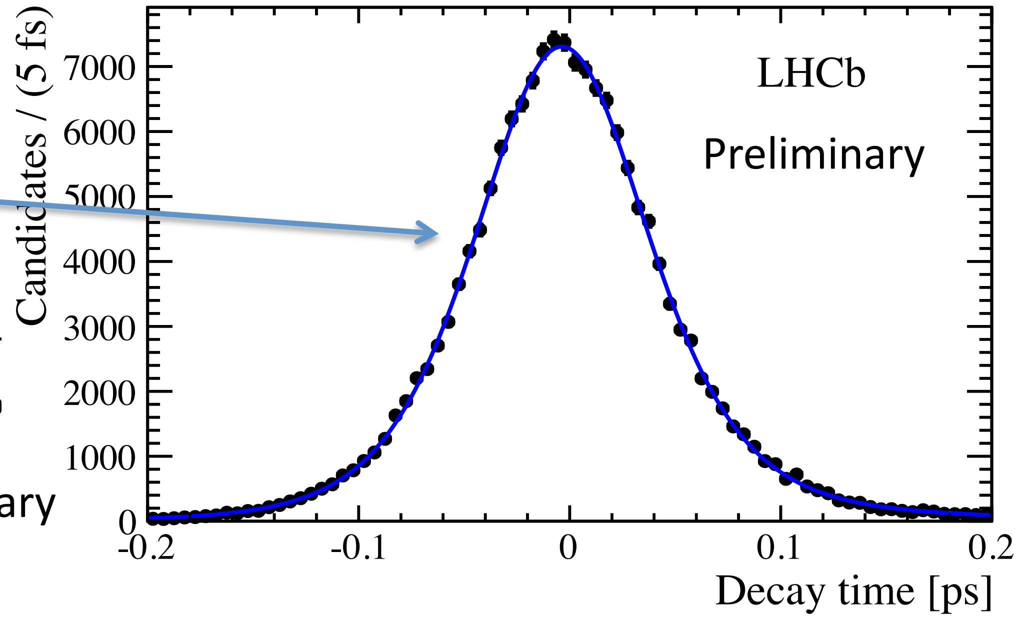


Forward detector ($2<\eta<5$) - need to understand acceptance
More than half of K_S decay after the Vertex Locator (VELO)

Vertexing Performance

Decay time resolution is determined from prompt J/ψ production





$\langle\sigma(t)\rangle = 45$ fs

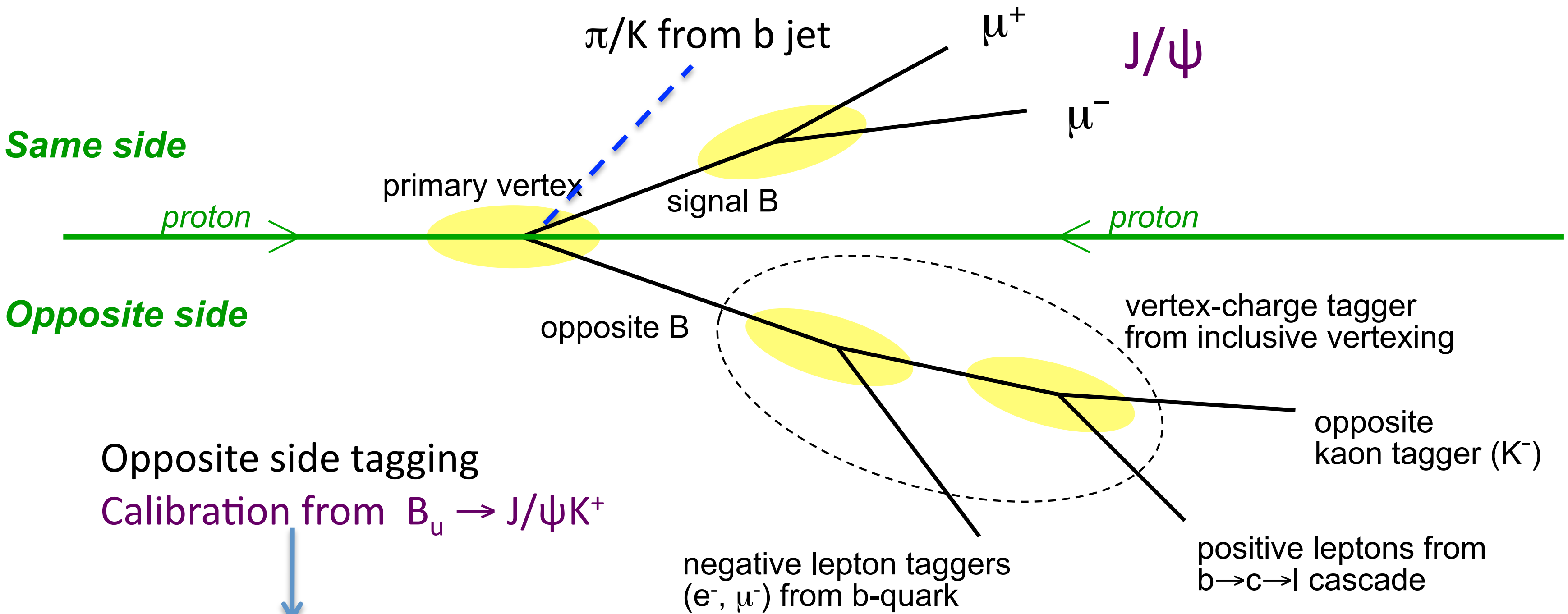
Analyses can either use average or per event decay time errors

Flavour-Tagging at LHCb

Same side Kaon tagging

Calibration from $B_s \rightarrow D_s\pi$

tagging efficiency ε_{tag} ~ 12%
effective mistag ω_{tag} ~ 35%
effective tagging power $\varepsilon_{tag}(1 - 2\omega_{tag})^2$ ~ 1.1%



Opposite side tagging

Calibration from $B_u \rightarrow J/\psi K^+$

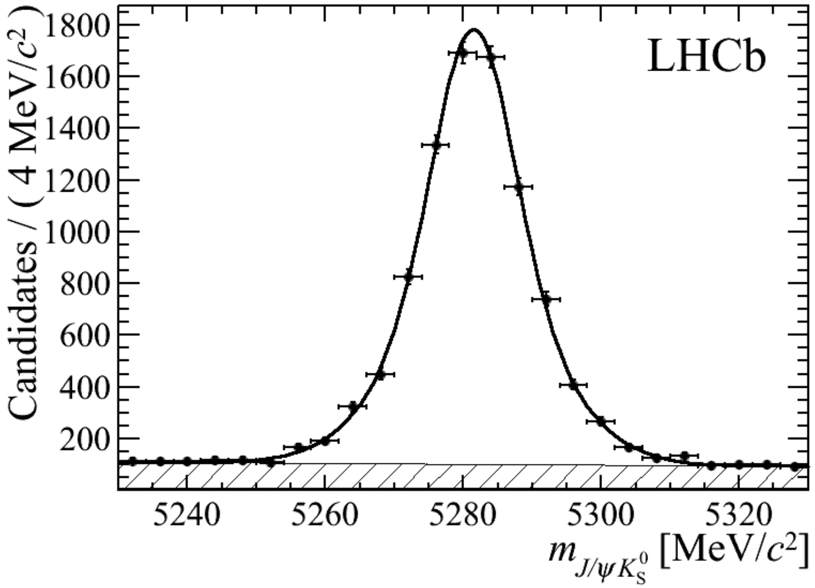
tagging efficiency ε_{tag} ~ 33%
effective mistag ω_{tag} ~ 36.8%
effective tagging power $\varepsilon_{tag}(1 - 2\omega_{tag})^2$ ~ 2.3%

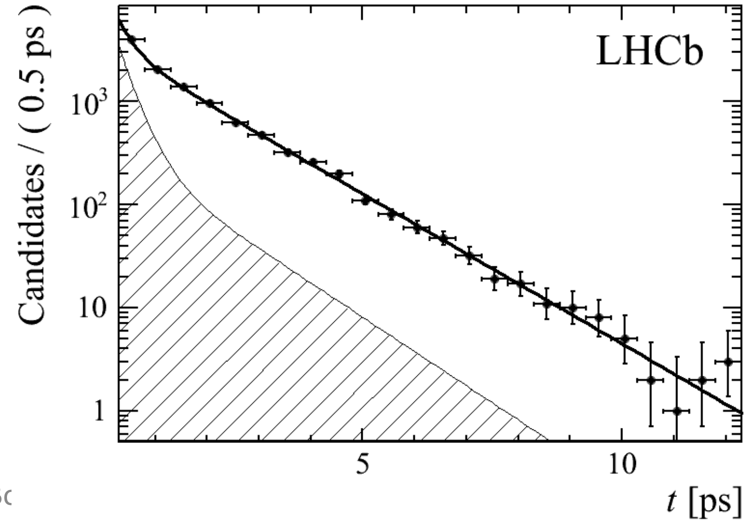
Analyses can either use average or per event tagging information

Measurement of sin2β

LHCb-PAPER-2012-035   Phys.Rev.Lett. 108(2012) 201601

- Reconstructed ~8000 tagged $B_d \rightarrow J/\psi K_S$ events with $J/\psi \rightarrow \mu^+\mu^-$ and $K_S \rightarrow \pi^+\pi^-$ in 1.0/fb (2011 data)
  Have another 2.1/fb (2012 data)
- Opposite side flavour-tagging only
- Magnet polarity reversed periodically to cancel detector asymmetries
- Need to correct for production asymmetry −1.5% (more b than $\bar{b}$ at p-p collider)
  Measured with $B_d \rightarrow J/\psi K^*$





Time-dependent Asymmetry

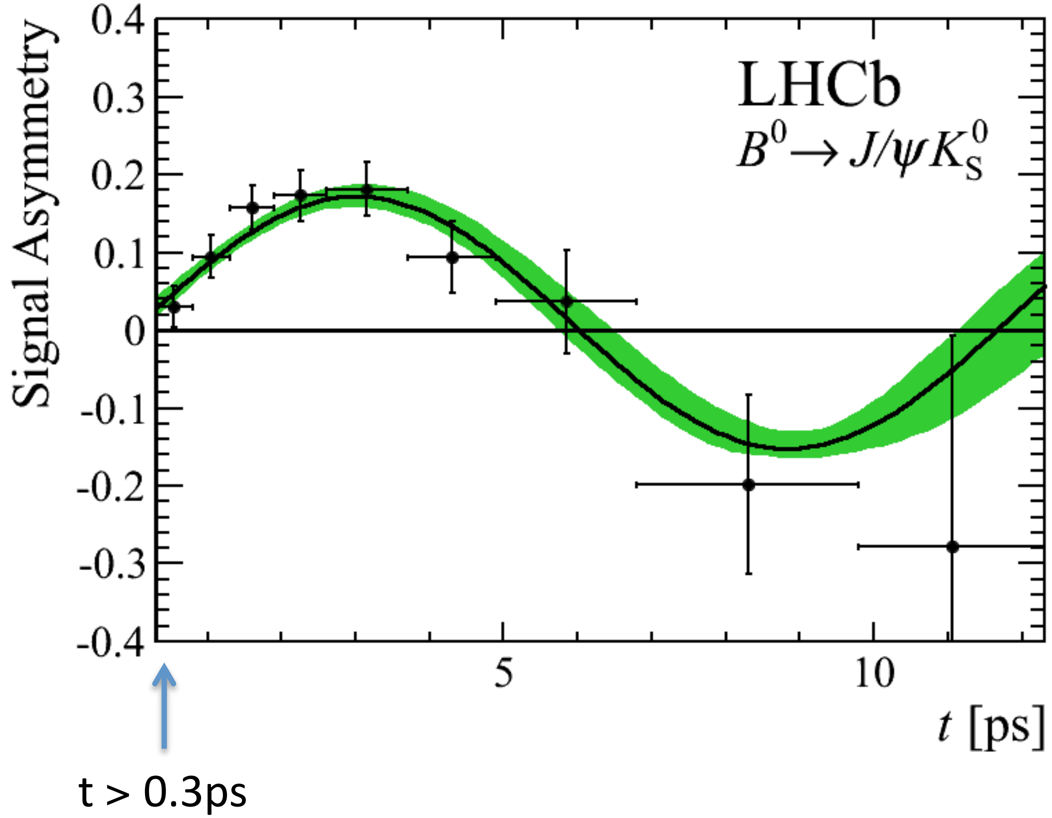
$$A(t) = \frac{\Gamma(\overline{B}) - \Gamma(B)}{\Gamma(\overline{B}) + \Gamma(B)}$$

$$A(t) = S \sin(\Delta m_d t) - C \cos(\Delta m_d t)$$

$\tau_d = 1.496 \pm 0.018$ ps

$\Delta m_d = 0.53 \pm 0.05$/ps

Agree with world averages



$S = 0.73 \pm 0.07(\text{stat.}) \pm 0.04(\text{syst.})$

$C = 0.030 \pm 0.090(\text{stat.}) \pm 0.012(\text{syst.})$

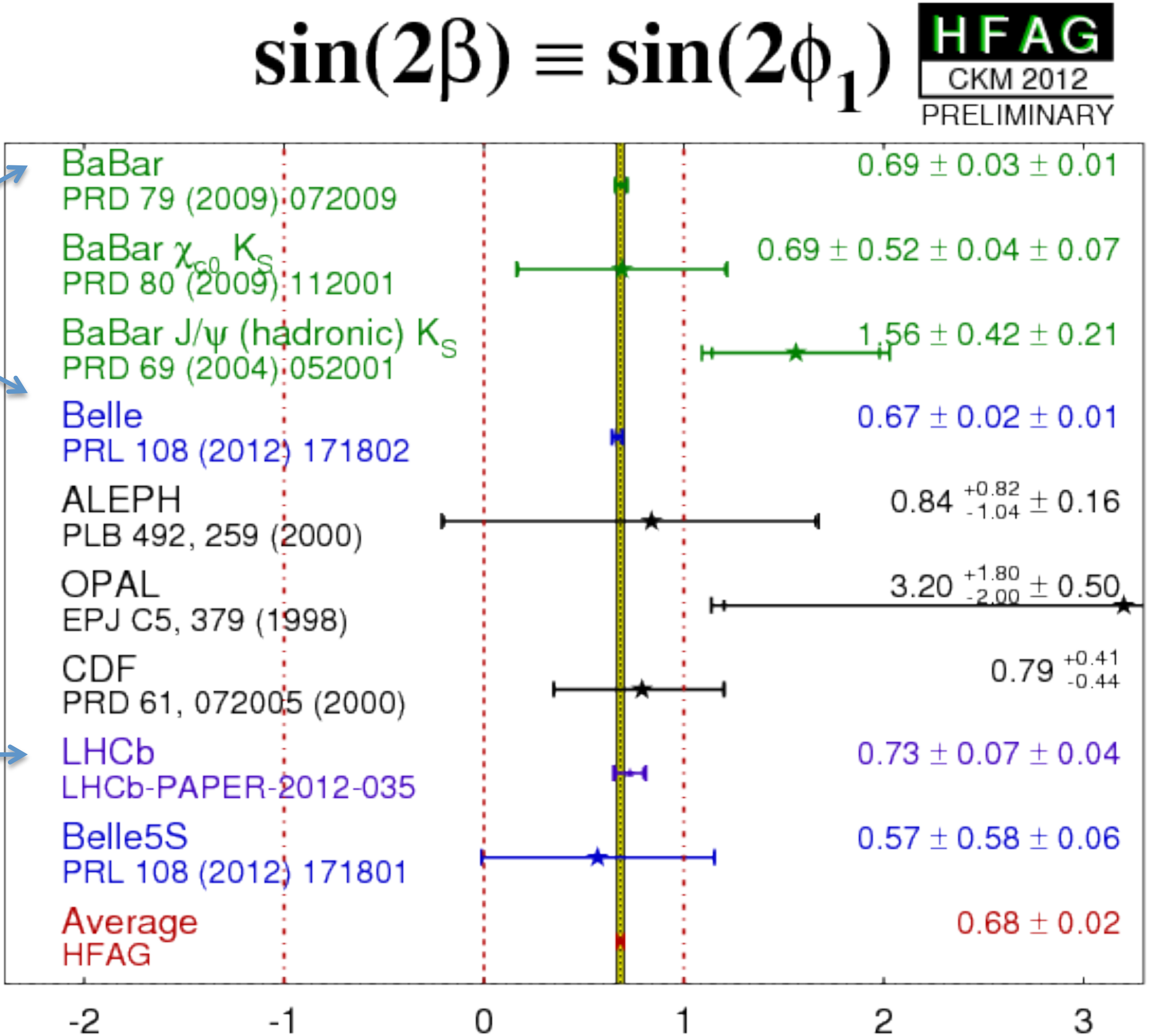
$S = 0.72 \pm 0.06$

$C \equiv 0$

Already within x3 of B-factory accuracy for $B_d \to J/\psi K_S$

(x2 with 2012 data)

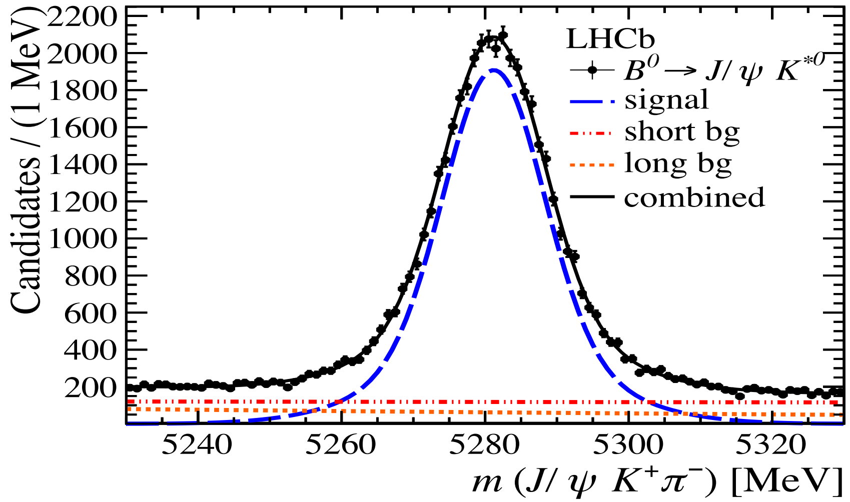
Best measurement at hadron collider



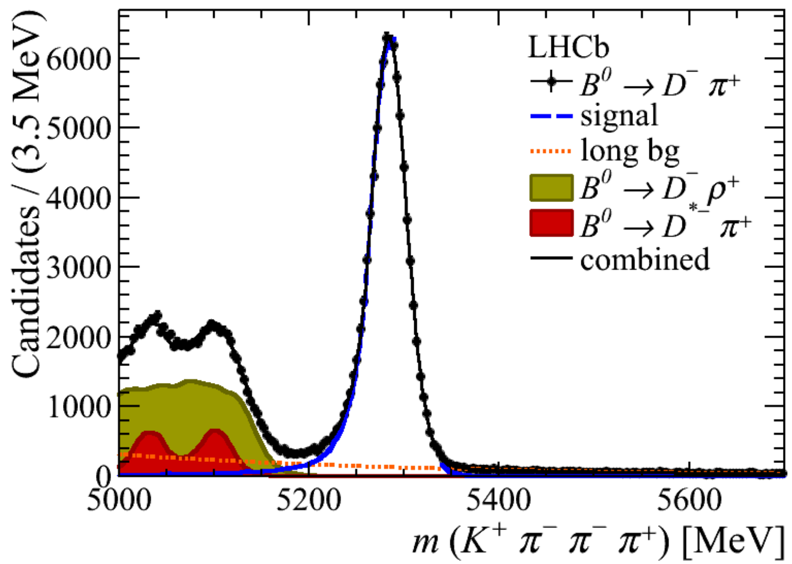
Measurement of Δm_d

LHCb-PAPER-2012-032 Phys.Lett.B 719(2013) 318

- Reconstructed ~39000 tagged $B_d \rightarrow J/\psi K^*$ events with $J/\psi \rightarrow \mu^+\mu^-$ and $K^{*0} \rightarrow K^+\pi^-$ or $\overline{K^{*0}} \rightarrow K^-\pi^+$ in 1.0/fb (2011 data)



- Reconstructed ~88000 tagged $\overline{B_d} \rightarrow D^+\pi^-$ or $B_d \rightarrow D^-\pi^+$ events in 1.0/fb (2011 data)

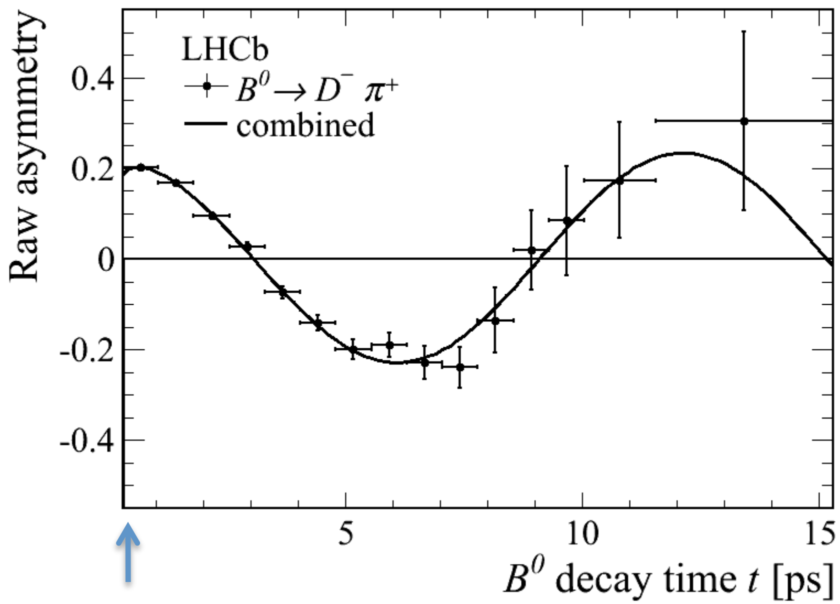


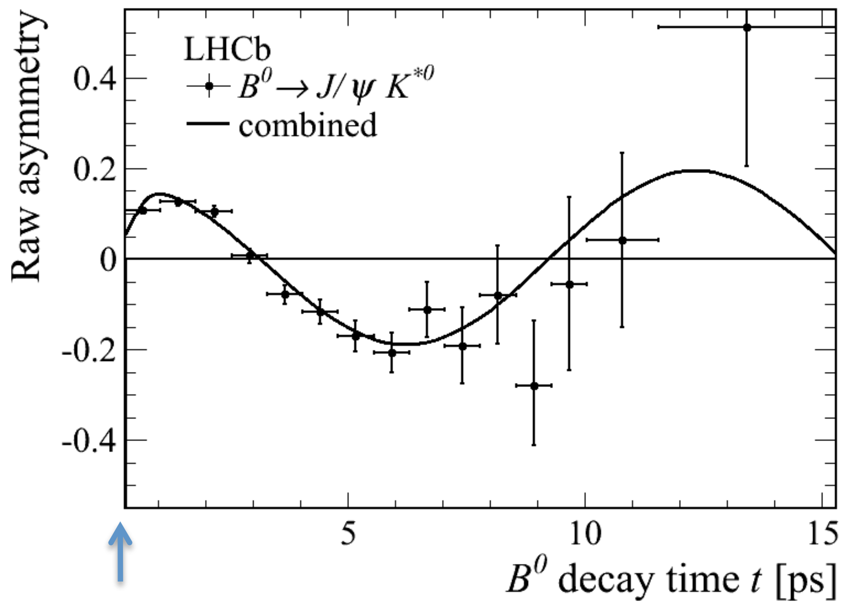
- Opposite side *and same-side* π flavour-tagging

- Magnet polarity reversed periodically to cancel detector asymmetries

Time-dependent B_d mixing

$$A(t) = \frac{N(\text{unmixed}) - N(\text{mixed})}{N(\text{unmixed}) + N(\text{mixed})} = A(0)\cos(\Delta m_d t)$$





t > 0.3ps

t > 0.3ps

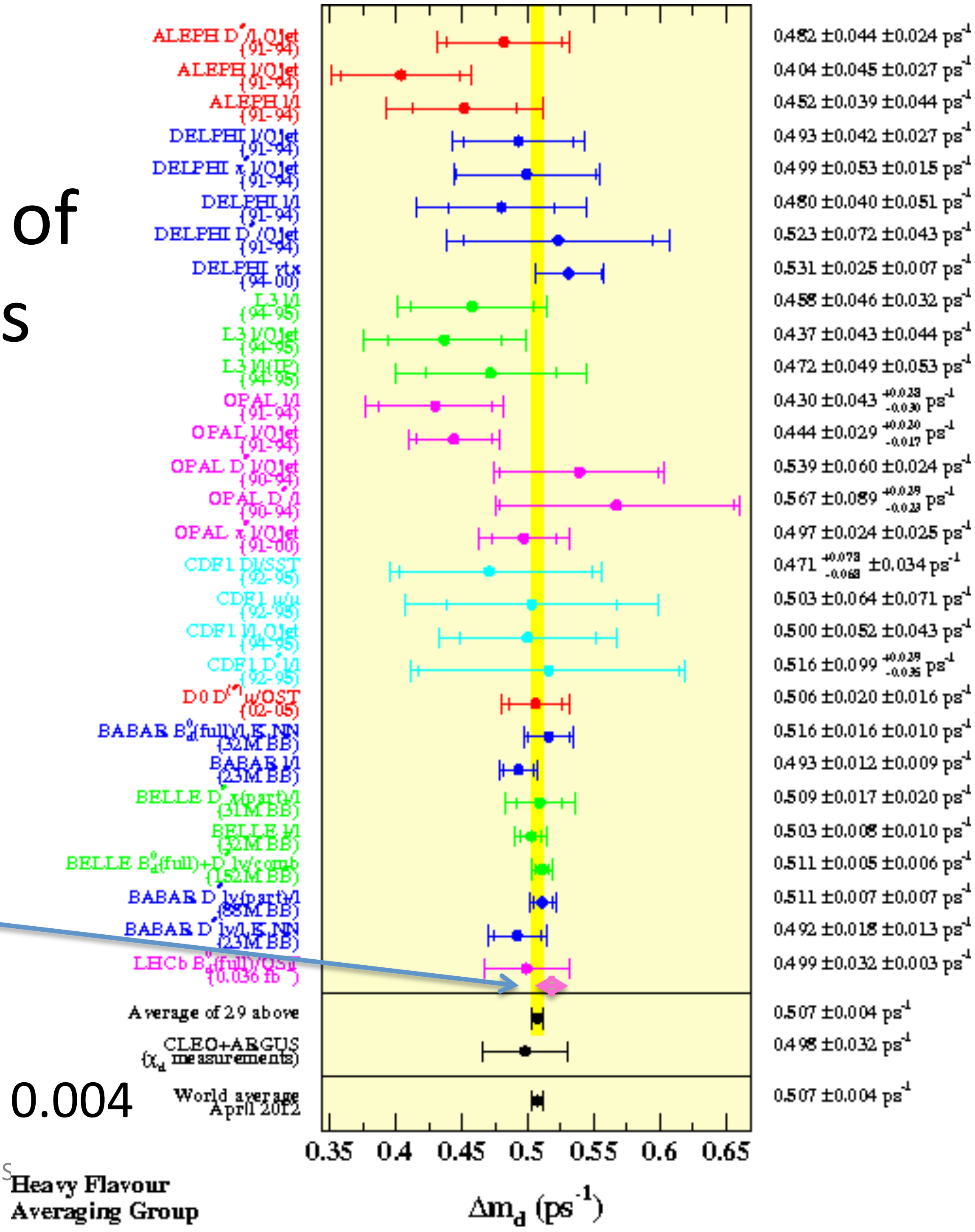
Δm_d = 0.518 ± 0.006(stat.) ± 0.004(syst.)/ps

Δm_d = 0.510 ± 0.011(stat.) ± 0.002(syst.)/ps

Combined

Δm_d = 0.516 ± 0.005(stat.) ± 0.003(syst.)/ps

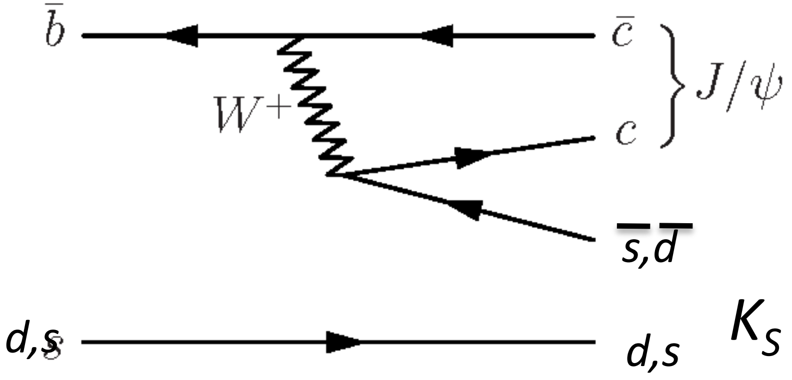
HFAG summary of B_d mixing results



Best measurement by a single experiment is new LHCb result:
$\Delta m_d = 0.516 \pm 0.006/\mathrm{ps}$

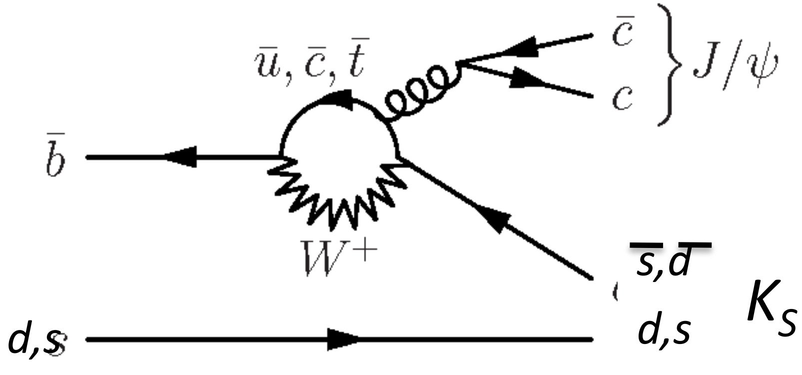
World average was 0.507 ± 0.004

Tree and Penguin Contributions



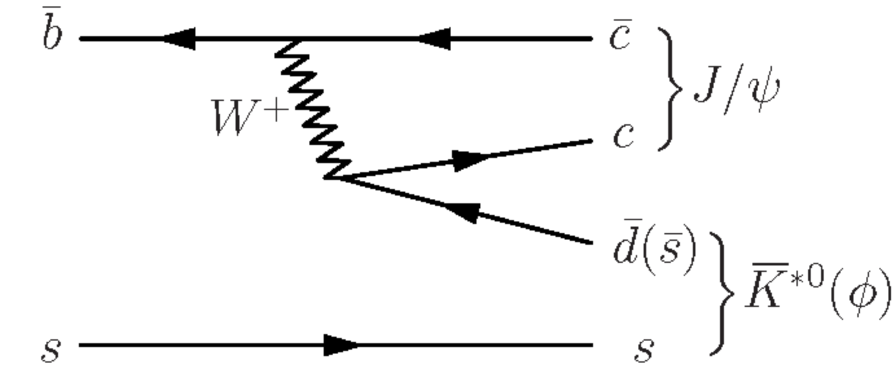
$B_s \rightarrow J/\psi K_s / B_d \rightarrow J/\psi K_s$

$\sim |V_{cd}/V_{cs}|^2 \sim 0.04$



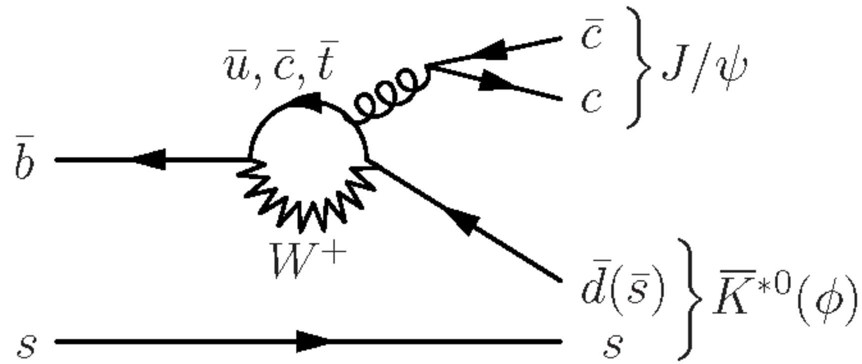
$B_s \rightarrow J/\psi K_s / B_d \rightarrow J/\psi K_s$

$\sim |V_{ts}/V_{td}|^2$



$B_s \rightarrow J/\psi K^* / B_s \rightarrow J/\psi \phi$

$\sim |V_{cd}/V_{cs}|^2 \sim 0.04$



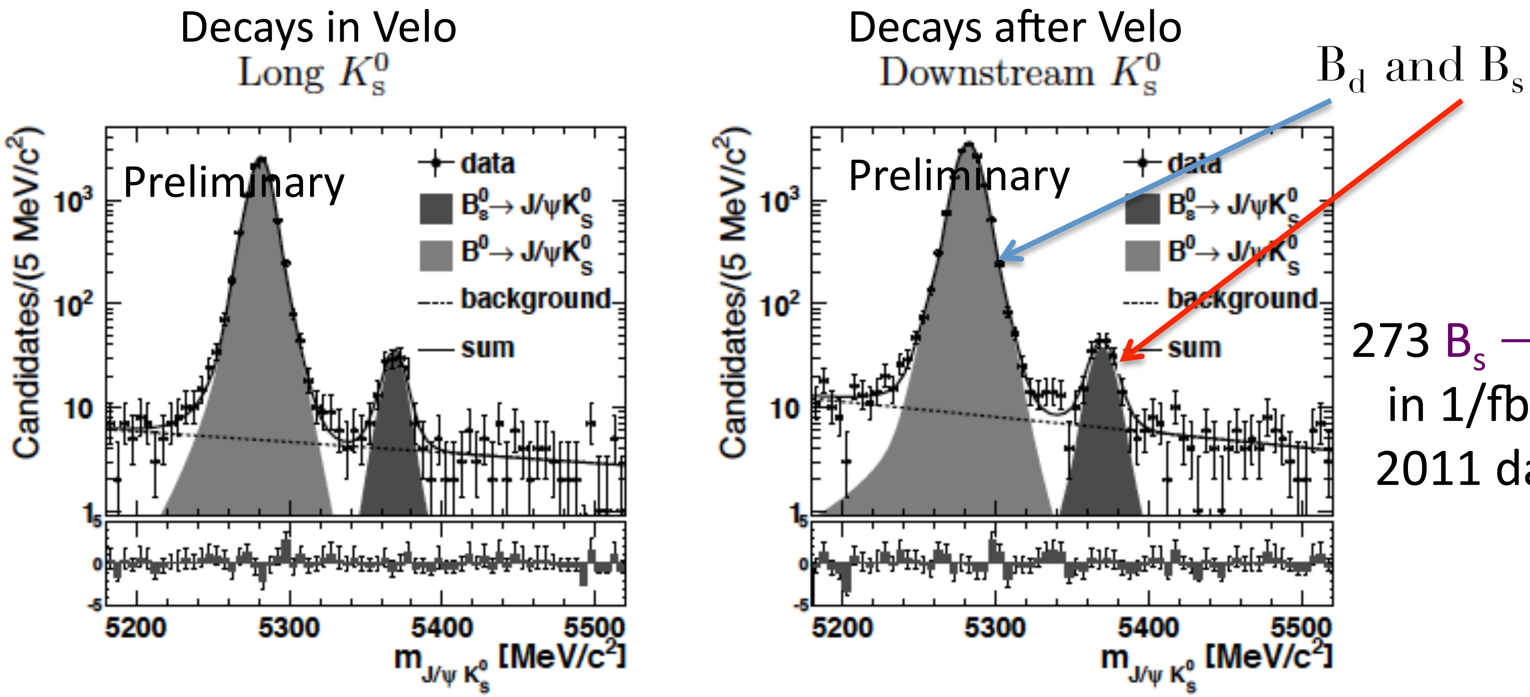
$B_s \rightarrow J/\psi K^* / B_s \rightarrow J/\psi \phi$

$\sim |V_{ts}/V_{td}|^2$

Rare Decay $B_s \to J/\psi K_S$

LHCb-PAPER-2013-015 (to be submitted to Nucl.Phys.B)

Useful as a U-spin constraint on penguin contributions to $B_d \to J/\psi K_S$ (Fleischer)



273 $B_s \to J/\psi K_S$ in 1/fb of 2011 data

- B_s/B_d Yield ratio R = 0.0116 ± 0.0008
- Production fractions f_s/f_d = 0.267 ± 0.020

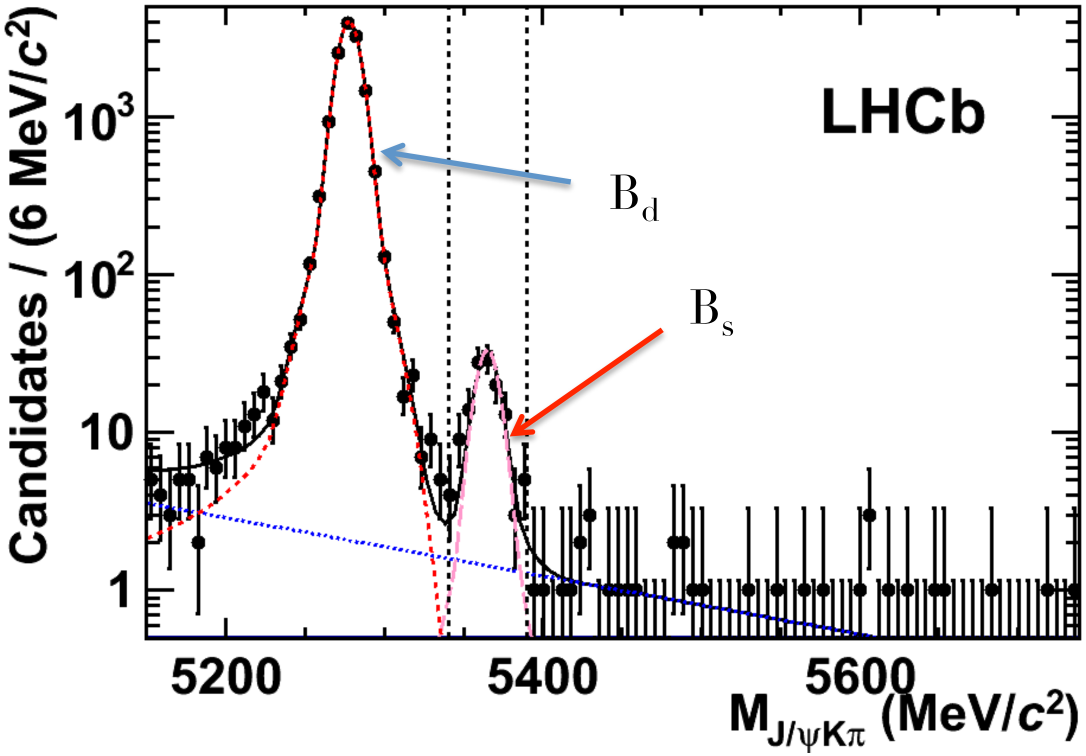
$BF(B_s \to J/\psi K_S)/BF(B_d \to J/\psi K_S)$ = 0.044± 0.003(stat)± 0.002(syst) ± 0.003(f_s/f_d)

Also measured effective lifetime $\tau_s (J/\psi K_S)$ = 1.75 ± 0.12(stat) ± 0.07(syst) ps

Rare Decay $B_s \to J/\psi K^*$

LHCb-PAPER-2012-014 Phys. Rev. D 86, 071102 (2012)

Useful as a U-spin constraint on penguin contributions to $B_s \to J/\psi\phi$ (Fleischer)



114 $B_s \to J/\psi K^*$ in 0.4/fb of 2011 data

- B_s/B_d Yield ratio R = 0.0085 ± 0.0009
- Production fractions f_s/f_d = 0.267 ± 0.020

BF($B_s \to J/\psi K^*$)/BF($B_d \to J/\psi K^*$) = 0.034± 0.004(stat)± 0.004(syst) ± 0.003(f_s/f_d)

Polarisation f_L = 0.50 ± 0.08(stat) ± 0.02(syst) $f_{||}$ = 0.19 ± 0.09(stat) ± 0.02(syst)

Summary

- With 8k tagged $B_d \to J/\psi K_S$ events from 1/fb:
  Measured $\sin 2\beta = 0.73 \pm 0.07(\text{stat.}) \pm 0.04(\text{syst.})$
  within x3 of B-factory accuracy

- With 39k tagged $B_d \to J/\psi K^*$ and 88k tagged $B_d \to D\pi$ events
  Measured $\Delta m_d = 0.516 \pm 0.005(\text{stat.}) \pm 0.003(\text{syst.})/\text{ps}$
  most accurate measurement (WA = $0.507 \pm 0.004/\text{ps}$)

- With 114 $B_s \to J/\psi K^*$ and 273 $B_s \to J/\psi K_S$ events:
  $BF(B_s/B_d \to J/\psi K^*) = 0.034 \pm 0.004(\text{stat}) \pm 0.004(\text{syst}) \pm 0.003(f_s/f_d)$
  $BF(B_s/B_d \to J/\psi K_S) = 0.044 \pm 0.003(\text{stat}) \pm 0.002(\text{syst}) \pm 0.003(f_s/f_d)$
  U-spin constraints on penguins in $B_d \to J/\psi K_S$, $B_s \to J/\psi\phi$

- LHCb is already competitive in B_d measurements
  … and world-leading in B_s measurements, see related LHCb talks:
  $B_s \to J/\psi\phi$, Δm_s (Frederic Dupertuis),
  $B \to h+h-$ (Aurelien Martens), $B_s \to \phi\phi$, ϕK^* (Paula Alvarez Cartelle)

Backup Slides

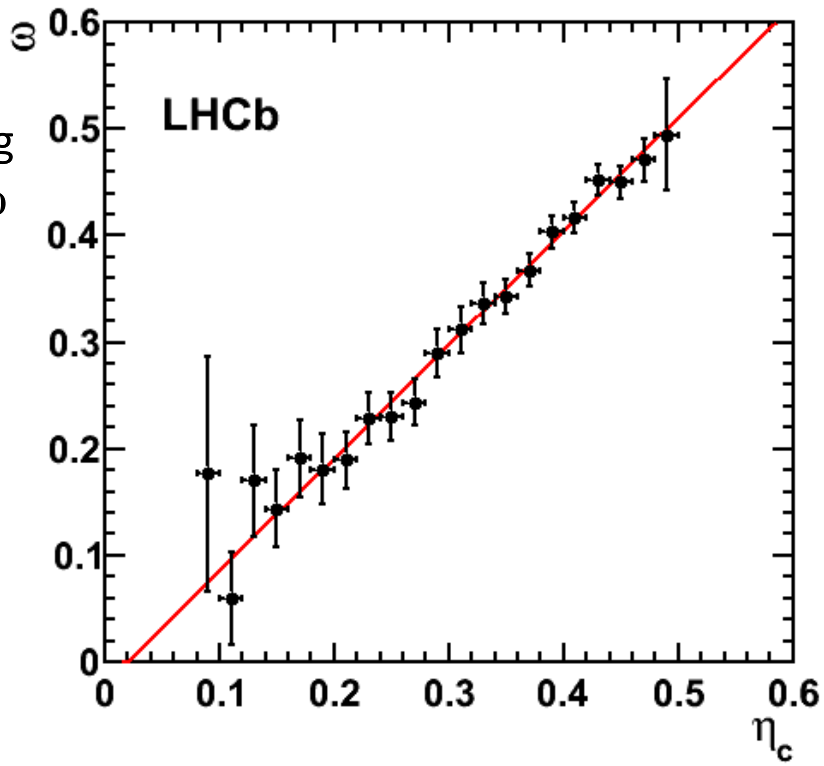
Calibration of Flavour-Tagging

Neural network output $\eta_c = p_0 + p_1 (\eta - <\eta>)$

p_0 and p_1 are calibration parameters

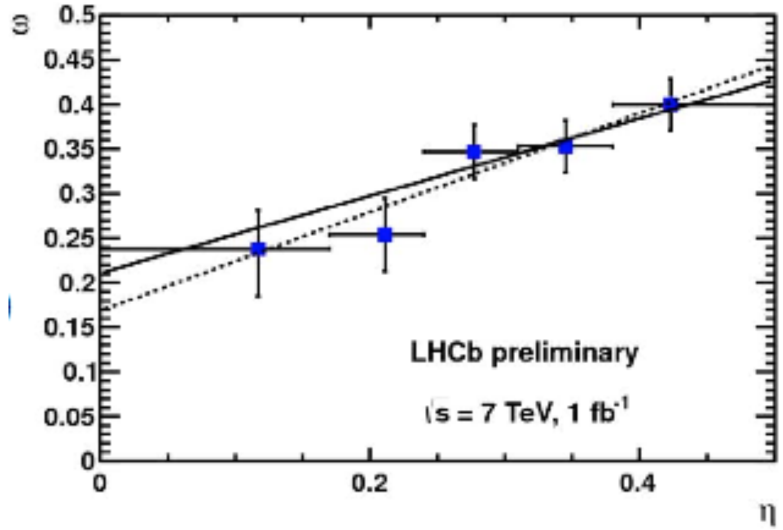
$B_u \rightarrow J/\psi K^+$

mistag rate ω



Opposite side tagger

$B_s \rightarrow D_s\pi$



Same side Kaon tagger

Systematics on $\sin 2\beta$

Source	Error on S	Error on C
Tagging calibration	0.0339	0.0013
Tagging efficiency	0.0018	0.0024
Decay time resolution	0.0014	0.0022
Decay time acceptance	0.0024	0.0062
Background model	0.0122	0.0088
Fit bias	0.0042	0.0045
TOTAL	0.036	0.012

Some of these errors are data driven
Tagging calibration and decay time resolution should improve with more statistics

Improvements also expected in understanding decay time acceptance and background

Systematics on Δm_d

Source	Error on Δm_d (J/ψK*)	Error on Δm_d (Dπ)
Decay time acceptance	0.0001	0.0004
Decay time resolution	0.0002	0.0002
Background model	0.0022	0.0037
Sum of uncorrelated errors	0.0022	0.0037
Detector z-scale	0.0005	0.0005
Tagging calibration	included in fit	included in fit
TOTAL	0.0023	0.0037

Tagging calibration is included in the statistical error
(free two parameter fit to mistag probability for each event)

Decay time resolution should improve with more statistics
Improvements also expected in understanding decay time acceptance and background