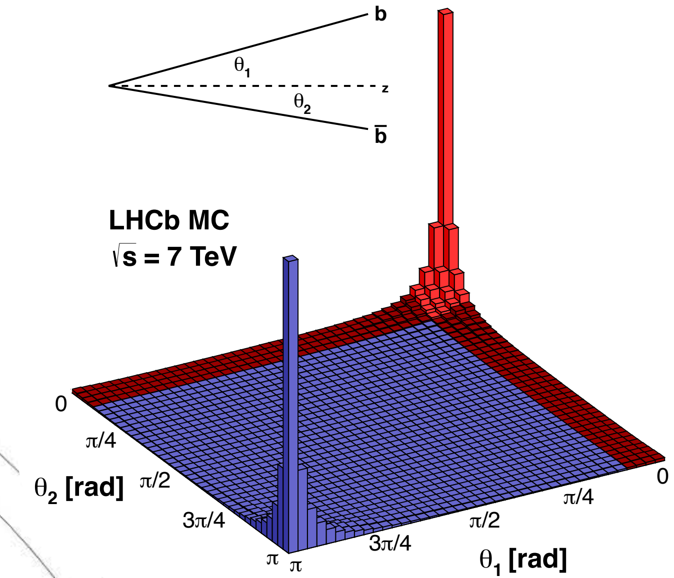
technische universität dortmund

Bundesministerium für Bildung und Forschung

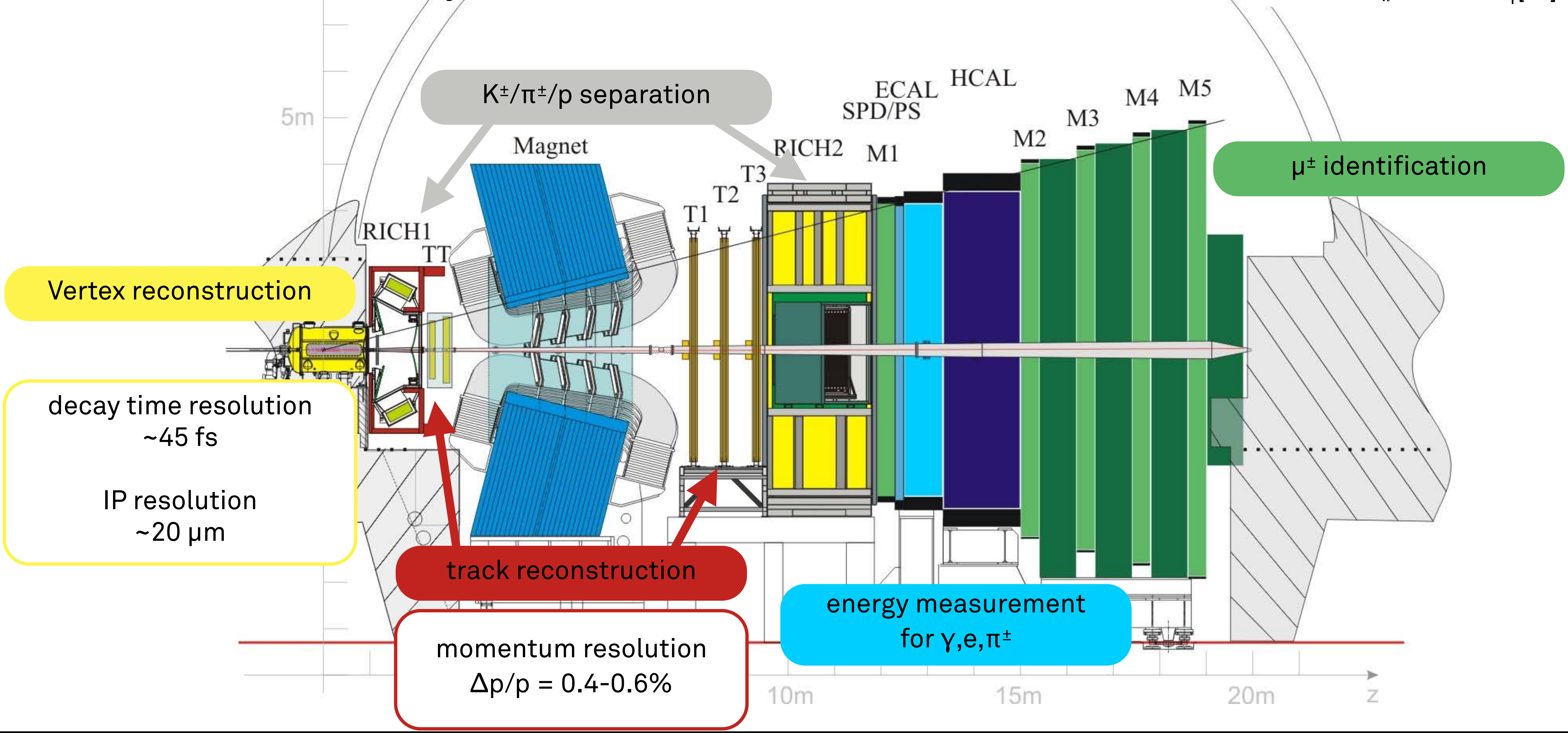
Flavour tagging and flavour oscillation measurements at LHCb

Epiphany 2013 Conference
7–9 January 2013 – Cracow, Poland
Christophe Cauet – on behalf of the LHCb collaboration

The LHCb detector

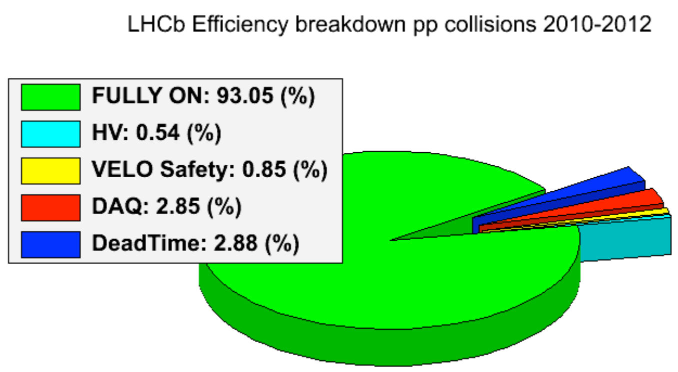


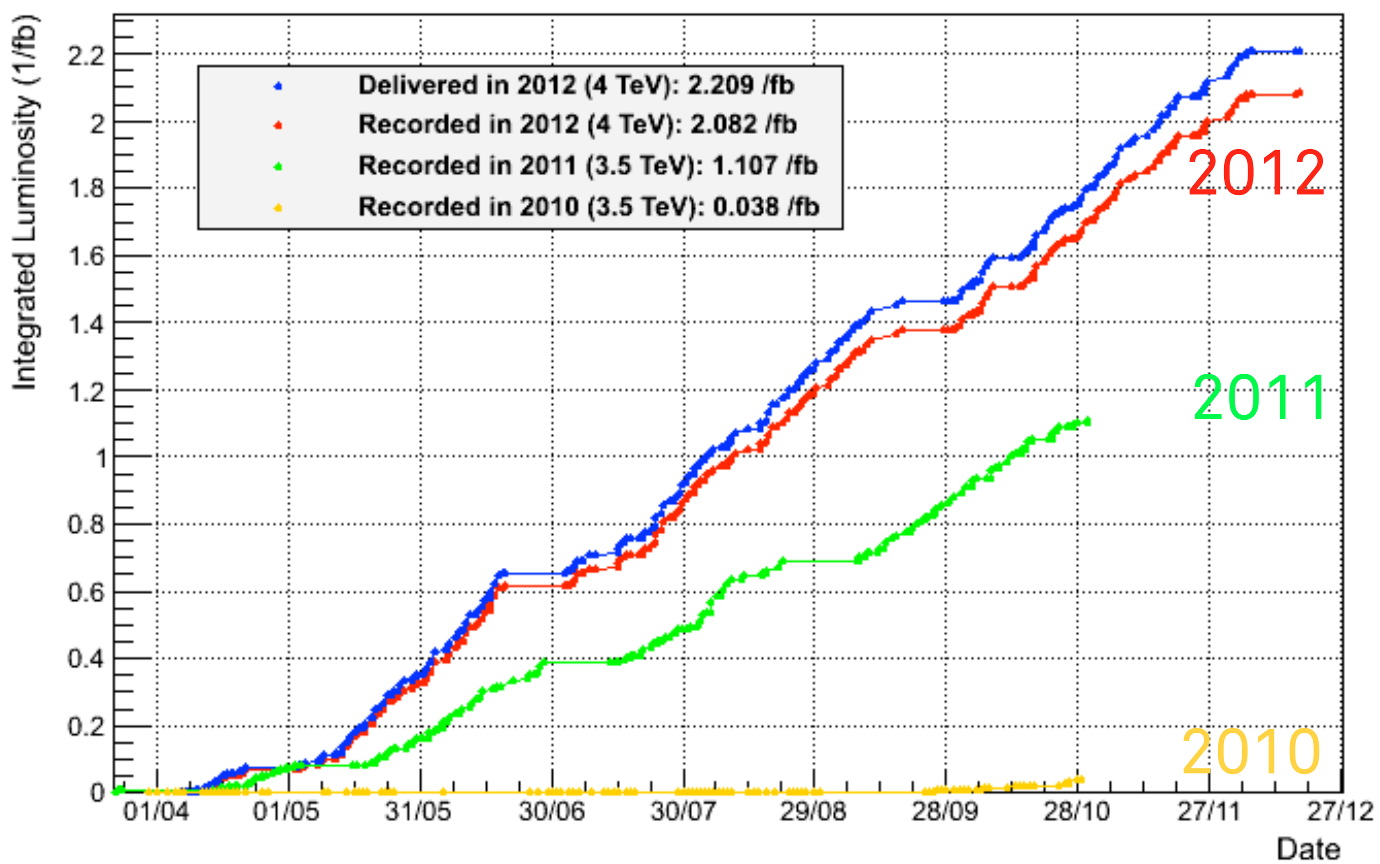
- single arm spectrometer ($2 < \eta < 5$)
- correlated (incoherent) production of *b* quark pairs in *pp*-collisions
  - harsh hadronic environment requires efficient triggers
  - dedicated for the study of *b* and *c* hadrons



The LHCb detector

- 1.0 fb^{-1} of pp collisions at a center-of-mass energy of 7 TeV in 2011
  - (2.1 fb^{-1} at 8 TeV in 2012)
- data taking efficiency >90%
- trigger: 20 MHz collision rate reduced to 4 kHz output rate
  - 90% efficient for dimuon channels
  - 30% efficient for multi-body hadronic final states





A brief reminder: flavour oscillations

- Neutral mesons can oscillate between matter and anti-matter states because mass-eigenstates differ from flavour-eigenstates.
- Mixing is well established in the (Kaon and) *B* meson system, while it's almost unexplored in the *D* meson system.
- Mixing is characterized by the mass difference and the decay width difference of the two mass eigenstates.

$$\Delta m \equiv m_H - m_L \qquad x \equiv \frac{\Delta m}{\Gamma}$$

$$\Delta\Gamma \equiv \Gamma_H - \Gamma_L$$

$$\Gamma \equiv (\Gamma_H + \Gamma_L)/2 \qquad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

- e.g. the B_q-$\overline{B}_q$ oscillation frequency is measured by the asymmetry

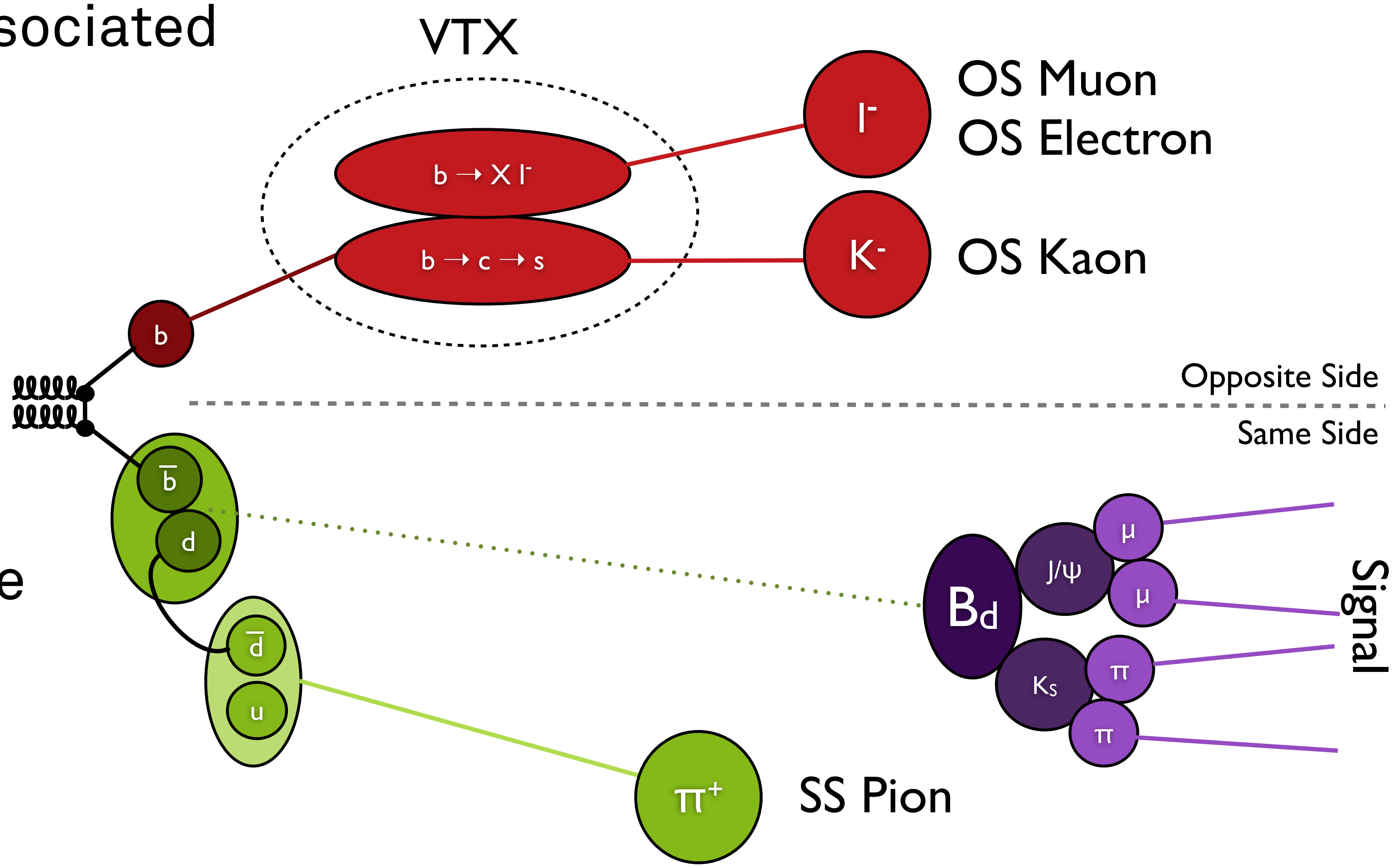
$$\mathcal{A}_q(t) = \frac{N^{sig}_{\text{unmixed}}(t) - N^{sig}_{\text{mixed}}(t)}{N^{sig}_{\text{unmixed}}(t) + N^{sig}_{\text{mixed}}(t)} = \mathcal{D} \cos \Delta m_q t$$

Flavour Tagging @LHCb

- Investigate the initial flavour of the signal *B* meson

- OS tagging exploits decay of associated *b* hadron
  - lepton taggers
  - kaon tagger
  - inclusive reconstruction of secondary vertex

- SS tagging uses remnants of the signal *b* hadronization
  - SS Pion for B^0 and B^+ mesons
  - SS Kaon for B_s mesons



Flavour Tagging @LHCb

Eur. Phys. J. C (2012) 72:2022
LHCb-CONF-2012-033

- Tagging performance
  - tagging efficiency
  - mistag fraction
  - tagging power

$$\varepsilon_{\text{tag}} = \frac{N_{\text{tagged}}}{N_{\text{tagged}} + N_{\text{untagged}}}$$

$$\omega = \frac{N_{\text{wrong tagged}}}{N_{\text{right tagged}} + N_{\text{wrong tagged}}}$$

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

- Each tagging algorithm determines
  - a tag decision d_i and
  - a mistag probability estimate η_i
    (based on neural net trainend on MC)
    - necessary step: calibrate η on data to fit the true mistag fraction ω
- combination of all taggers (OST+SST) or just OST gives a combined *d* and η

Flavour Tagging @LHCb

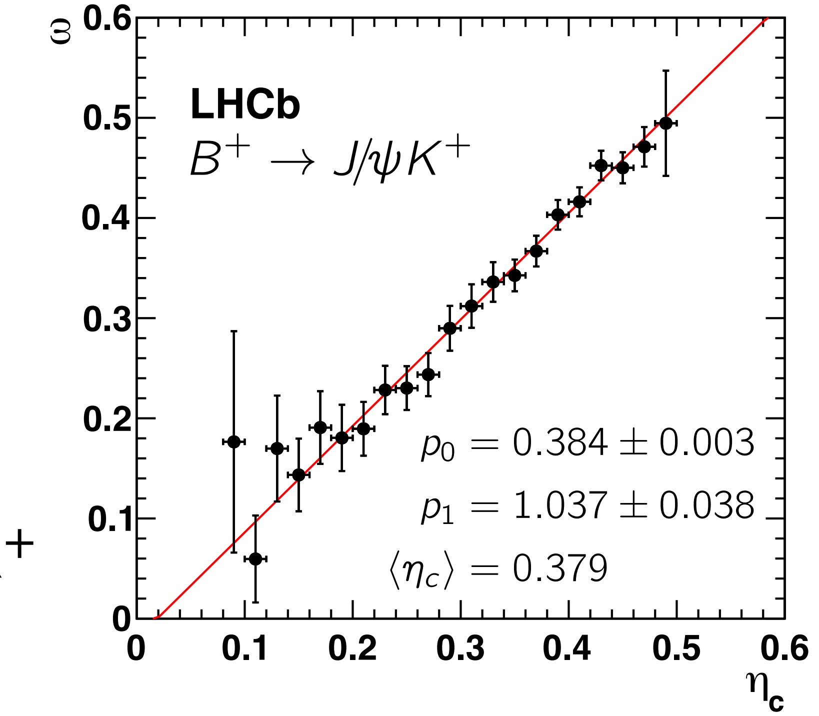
Eur. Phys. J. C (2012) 72:2022
LHCb-CONF-2012-033

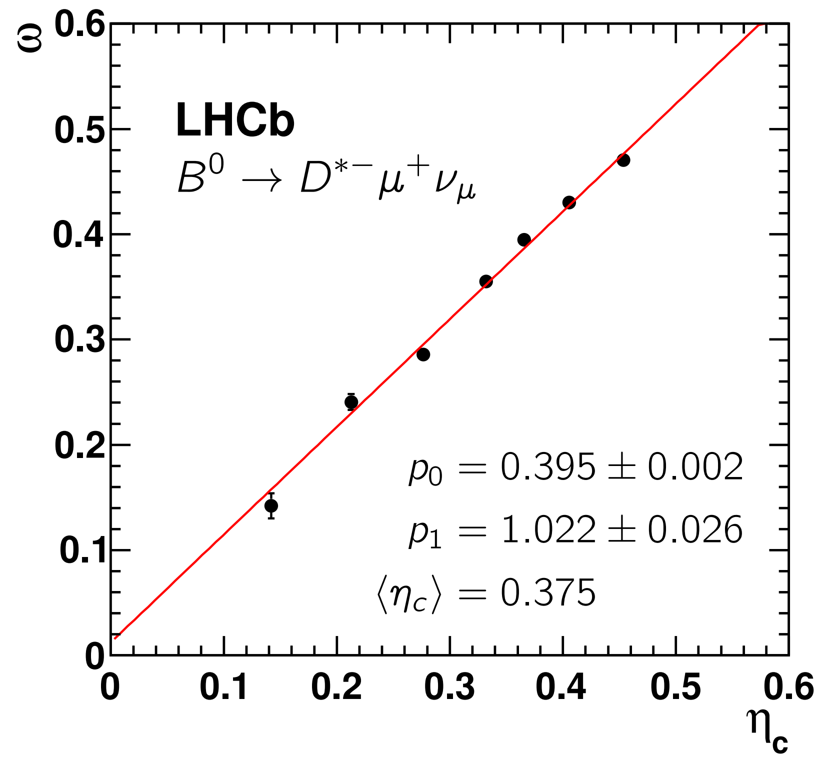
- Use the self-tagging channels $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ and, $B^0 \to D^{*-}\mu^+\upsilon_\mu$ to measure the tagging performance
- Optimize tagging power and calibrate the mistag probability prediction using the channel $B^+ \to J/\psi K^+$
- Linear calibration function

$$\omega(\eta_c) = p_0 + p_1(\eta_c - \langle\eta_c\rangle)$$

- perfect calibration if $p_1=1$ and $p_0=\langle\eta_c\rangle$
- OST tagging power in the $B^+ \to J/\psi K^+$ channel

$$\varepsilon_{\rm eff} = \varepsilon_{\rm tag}\mathcal{D}^2 = (2.10 \pm 0.08 \pm 0.24)\%$$





Measurement of Δm_d

- Status as of summer 2012
  - World average (HFAG)

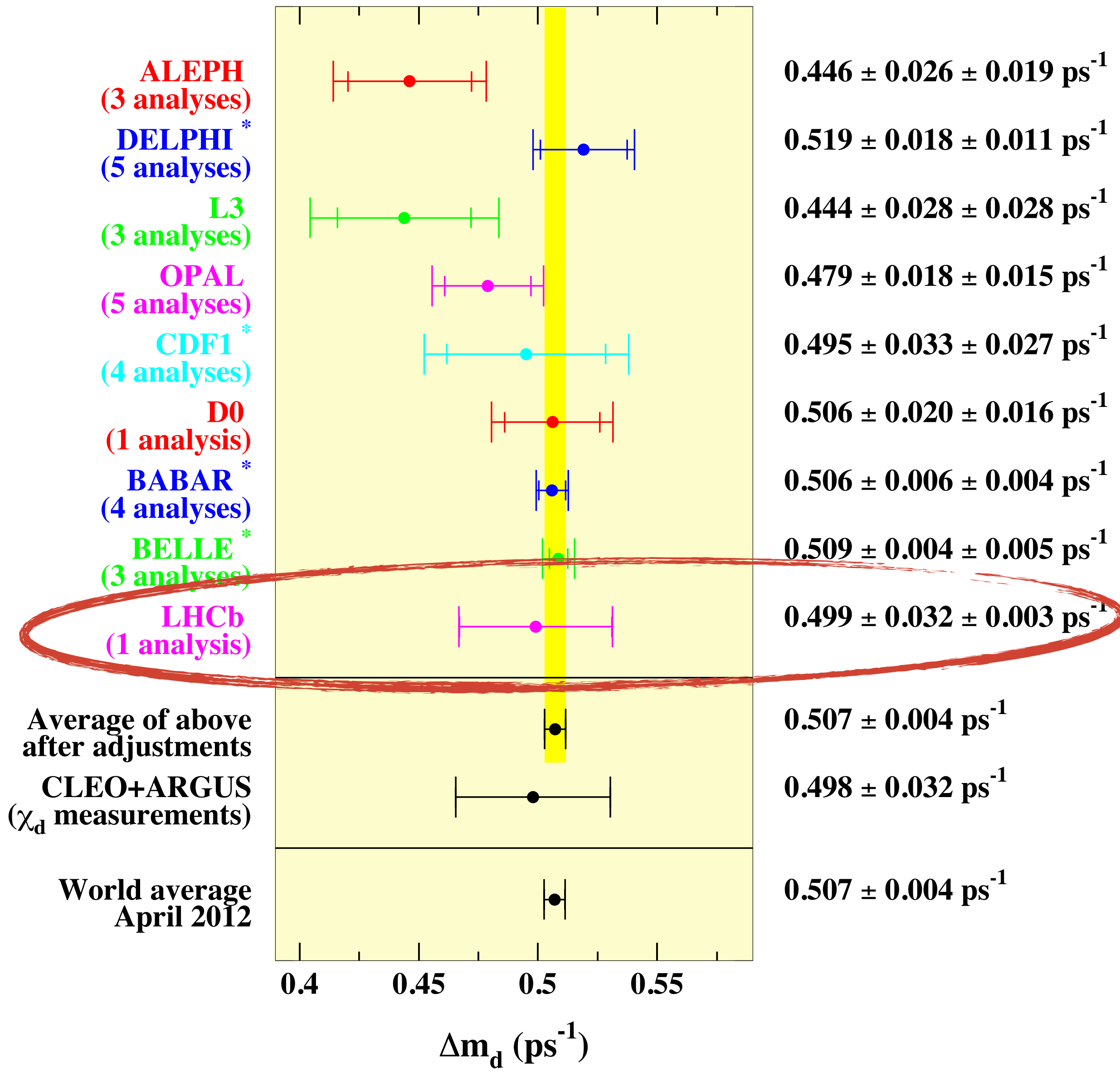
    $\Delta m_d = 0.507 \pm 0.004\,\mathrm{ps}^{-1}$

  - Best single measurement by Belle

    $\Delta m_d = 0.511 \pm 0.005 \pm 0.006\,\mathrm{ps}^{-1}$

  - LHCb measurement with 37.7 pb^{-1} (2010)

    $\Delta m_d = 0.499 \pm 0.032 \pm 0.003\,\mathrm{ps}^{-1}$



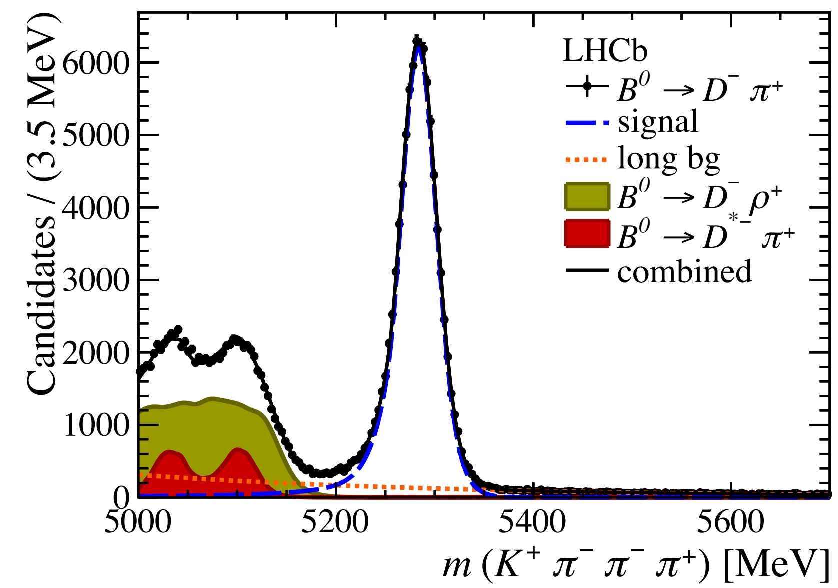
Measurement of Δm_d

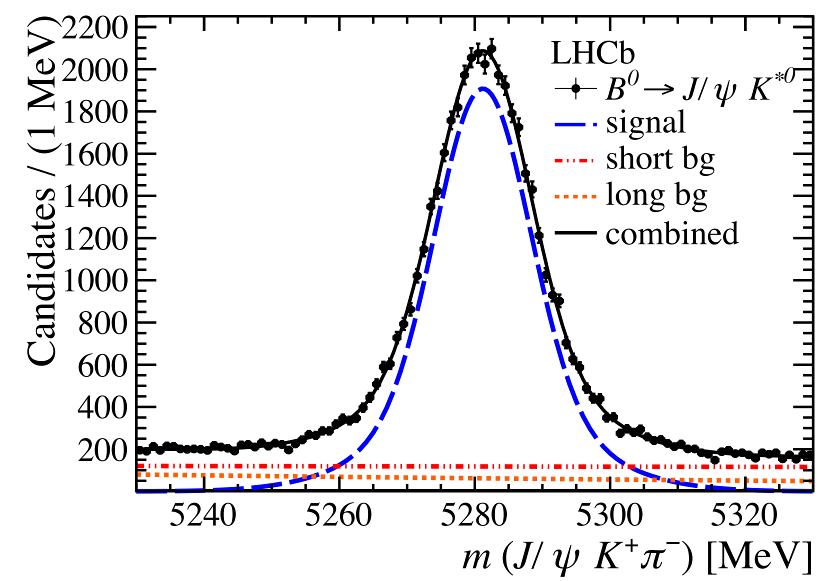
Submitted to Phys. Lett. B
LHCb-PAPER-2012-032
arxiv:1210.6750

- Time-dependent mixing asymmetry

$$\mathcal{A}_d(t) = \frac{N^{sig}_{\text{unmixed}}(t) - N^{sig}_{\text{mixed}}(t)}{N^{sig}_{\text{unmixed}}(t) + N^{sig}_{\text{mixed}}(t)} = \mathcal{D}\cos\Delta m_d t$$

- data sample
  - ~88k $B^0 \to D^- \pi^+$
  - ~39k $B^0 \to J/\psi\, K^{*0}$
- OST+SSπ combination used with per-event mistag probability
- Major systematic uncertainty from background modeling





Measurement of Δm_d

Submitted to Phys. Lett. B
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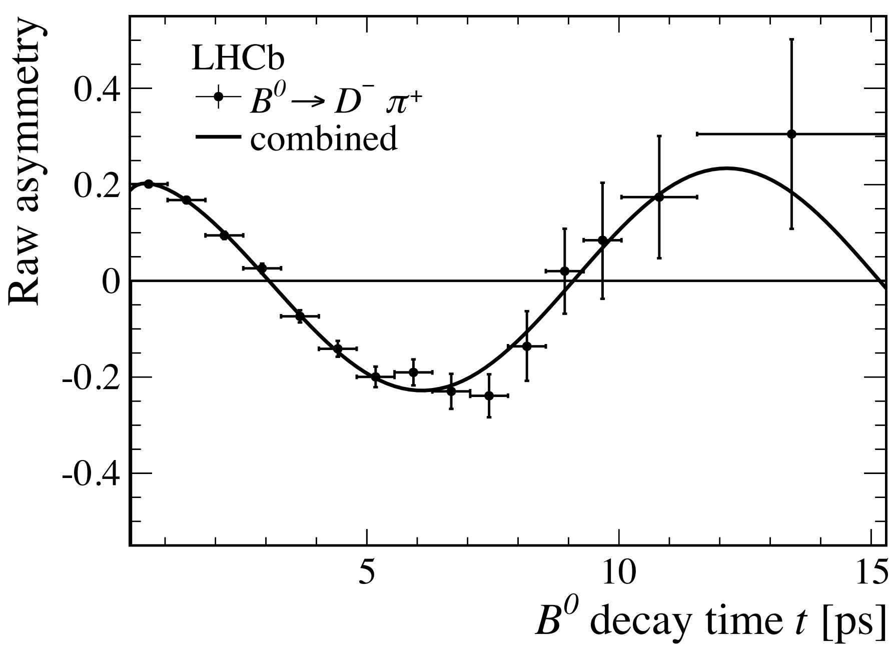
arxiv:1210.6750

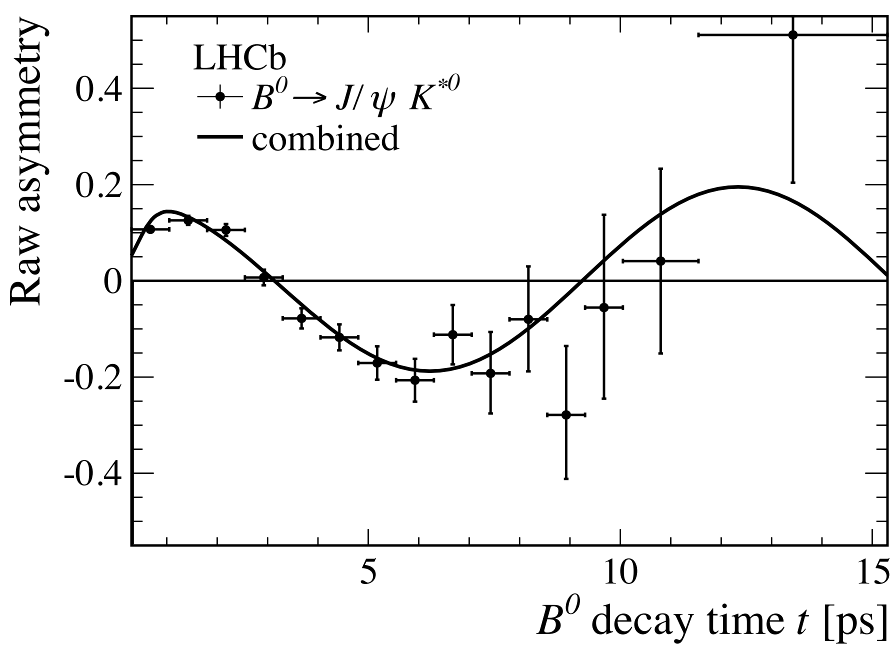
- Results

$$\Delta m_d(B^0 \to D^- \pi^+) = 0.5178 \pm 0.0061(stat.) \pm 0.0037(syst.)\,\text{ps}^{-1}$$
$$\Delta m_d(B^0 \to J/\psi K^{*0}) = 0.5096 \pm 0.0114(stat.) \pm 0.0022(syst.)\,\text{ps}^{-1}$$

- Combined

$$\Delta m_d = 0.5156 \pm 0.0051(stat.) \pm 0.0033(syst.)\,\text{ps}^{-1}$$





- Belle: $\Delta m_d = 0.511 \pm 0.005 \pm 0.006\,\text{ps}^{-1}$ HFAG: $\Delta m_d = 0.507 \pm 0.004\,\text{ps}^{-1}$

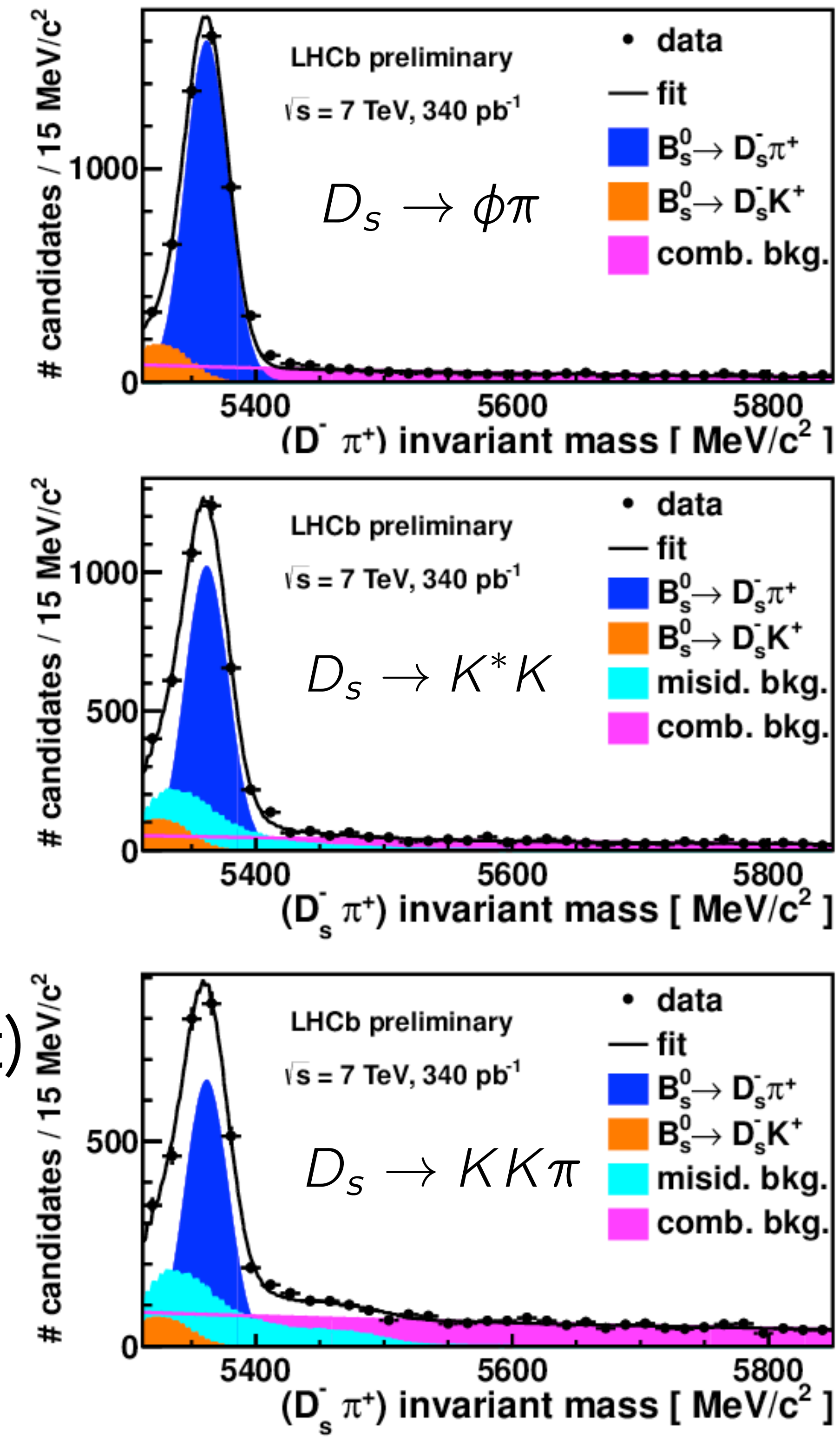
Measurement of Δm_s

Phys. Lett. B709 (2012)
LHCb-CONF-2011-050

- Status as of summer 2012
  - measurement by CDF

    $$\Delta m_s = 17.77 \pm 0.10 \pm 0.07\,\mathrm{ps}^{-1}$$

  - best single measurement by LHCb preliminary (see the CONF note)
- Dataset 340 pb^{-1} (⅓ 2011 data)
  - 9189 $B_s \rightarrow D_s \pi^+$ decays
    - $D_s \rightarrow \Phi\pi^-$, $D_s \rightarrow K^*K^-$, $D_s \rightarrow K^+K^-\pi^-$ (non-resonant)
  - OST per-event mistag probability and SSK tagging

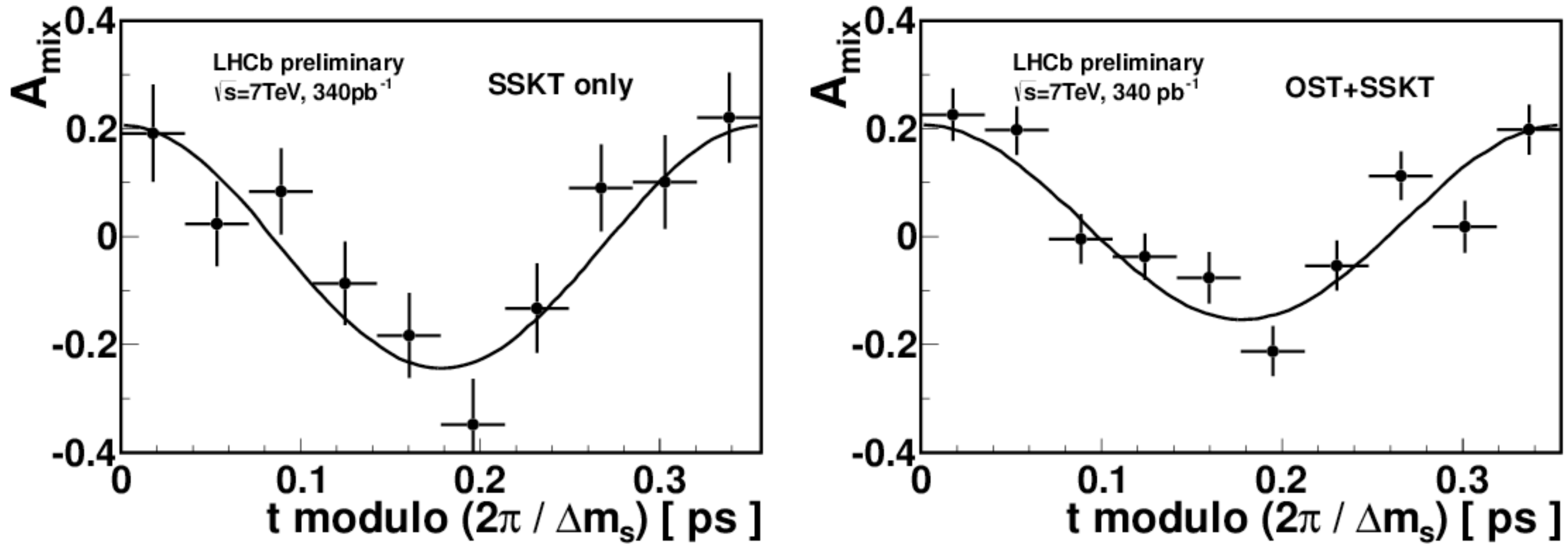


Measurement of Δm_s

Phys. Lett. B709 (2012)
LHCb-CONF-2011-050

- Result

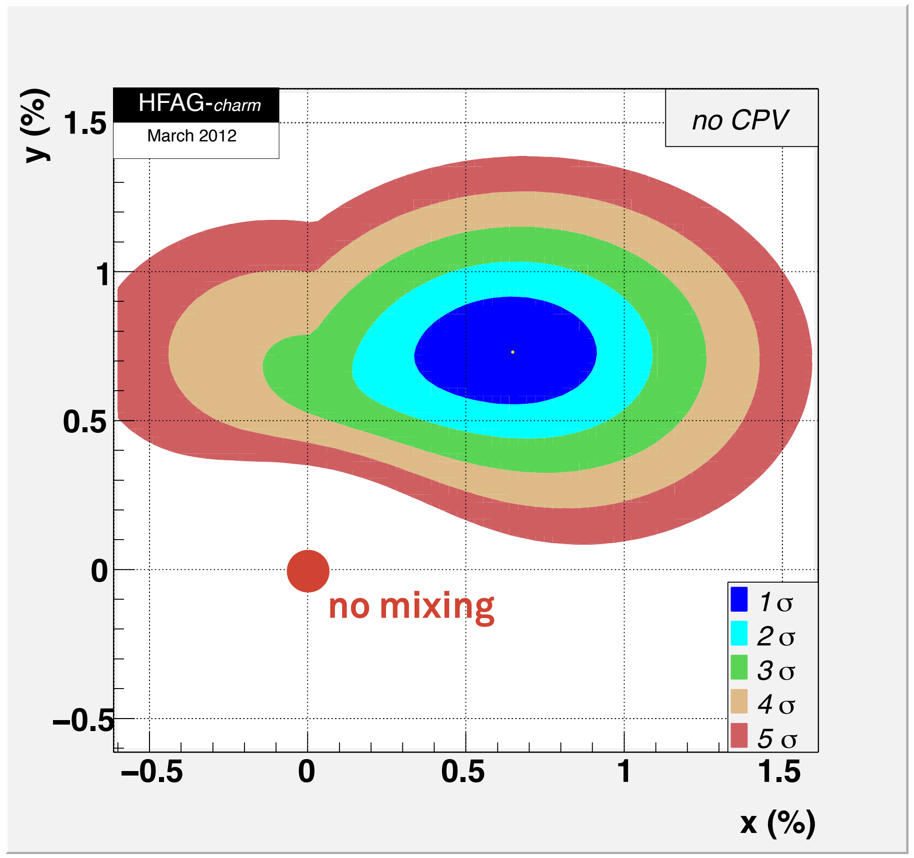
$$\Delta m_s = 17.725 \pm 0.041(stat.) \pm 0.026(syst.)\,\text{ps}^{-1}$$



- Largest systematic uncertainty from length-scale
- Update with larger dataset is in progress

Charm oscillations

- Until now only the combination of BaBar, Belle, and CDF measurements confirms the existence of D meson oscillations.



$$x \equiv \frac{\Delta m}{\Gamma}$$

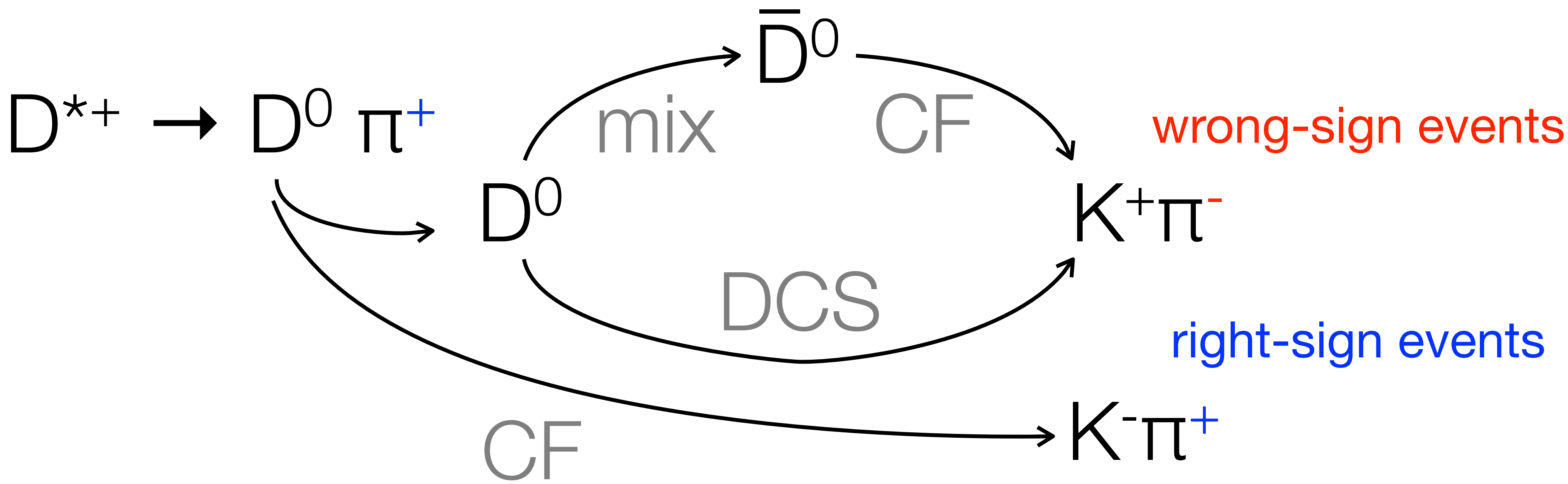
$$y \equiv \frac{\Delta \Gamma}{2\Gamma}$$

- Very low standard model rate with $|x|, |y| \leq O(10^{-2})$
  - potentially interesting for BSM physics searches

Charm oscillations with $D^0 \to K^+\pi^-$

Submitted to PRL
LHCb-PAPER-2012-038
arXiv:1211.1230

- Exploit interference between mixing and doubly-Cabibbo-suppressed decay amplitudes



Thanks to Angelo Di Canto for the illustration

- With no CPV, and $|x|$ and $|y| \ll 1$

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} \approx R_D + \sqrt{R_D}\,y'\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

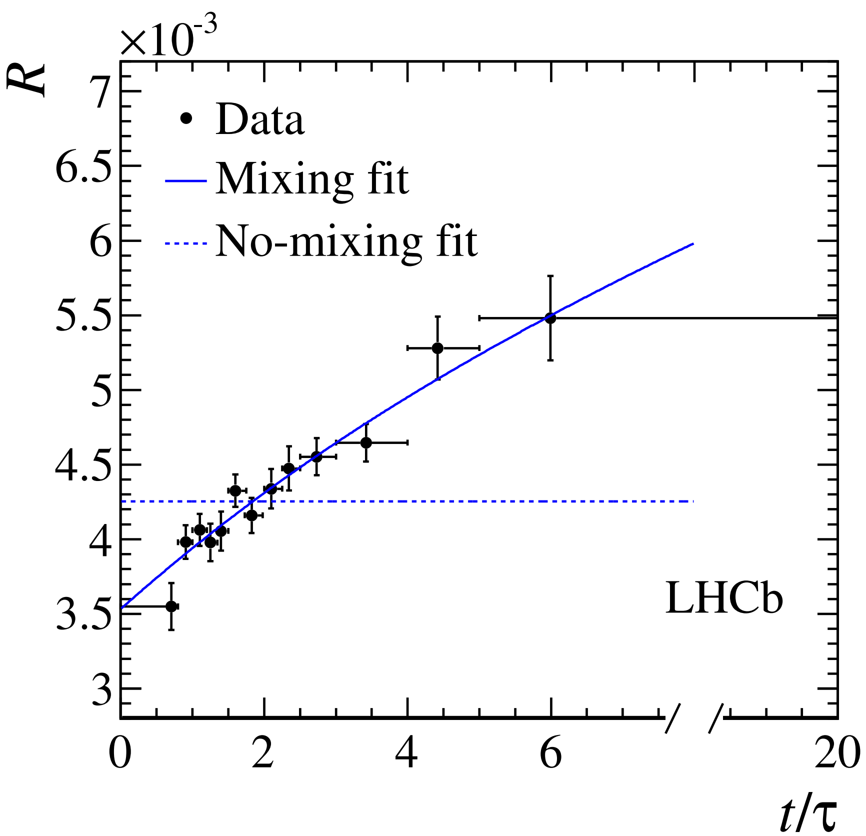
$$x' = x\cos\delta + y\sin\delta, \quad y' = y\cos\delta - x\sin\delta$$

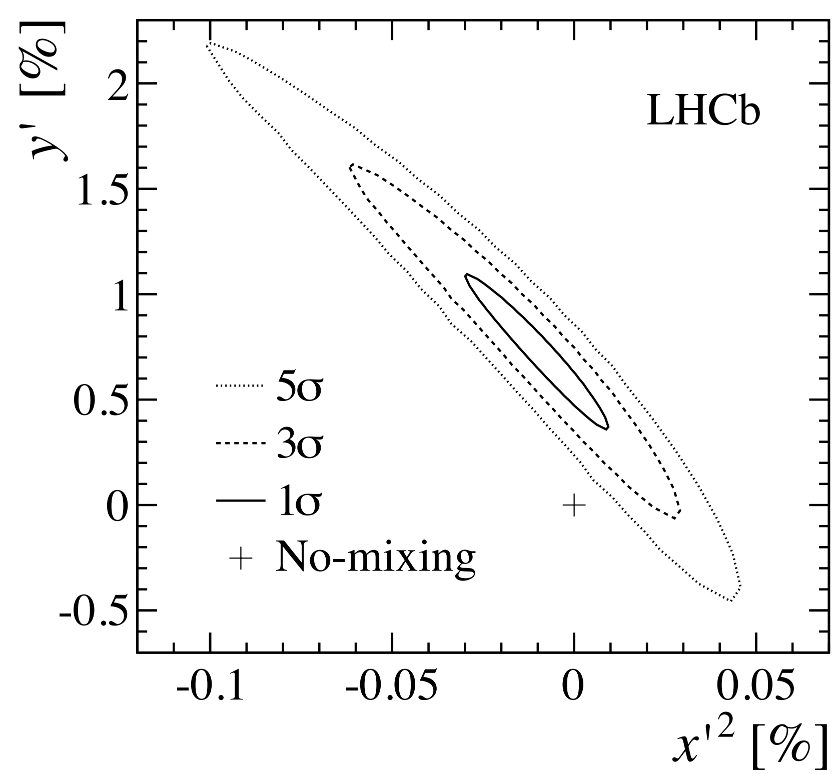
R_D ratio of DCS to CF decay rates
δ strong phase difference between the DCS and CF amplitudes

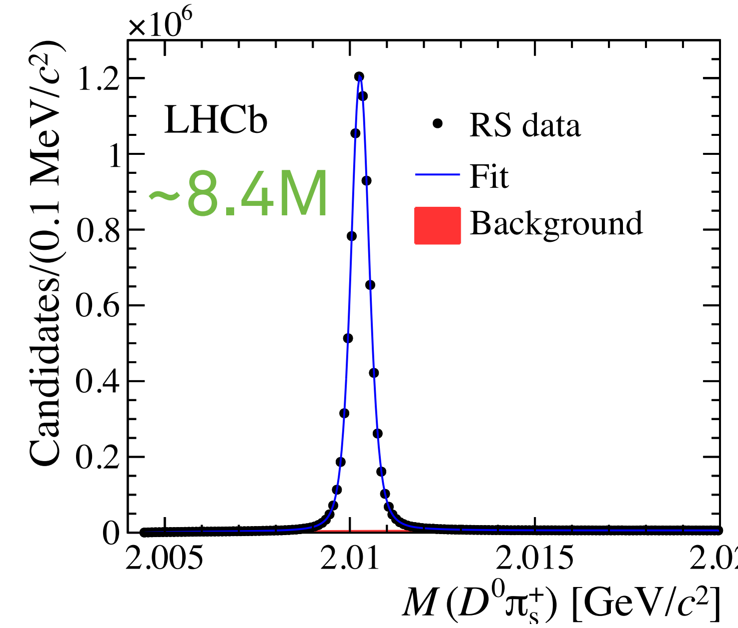
Charm oscillations with $D^0 \to K^+\pi^-$

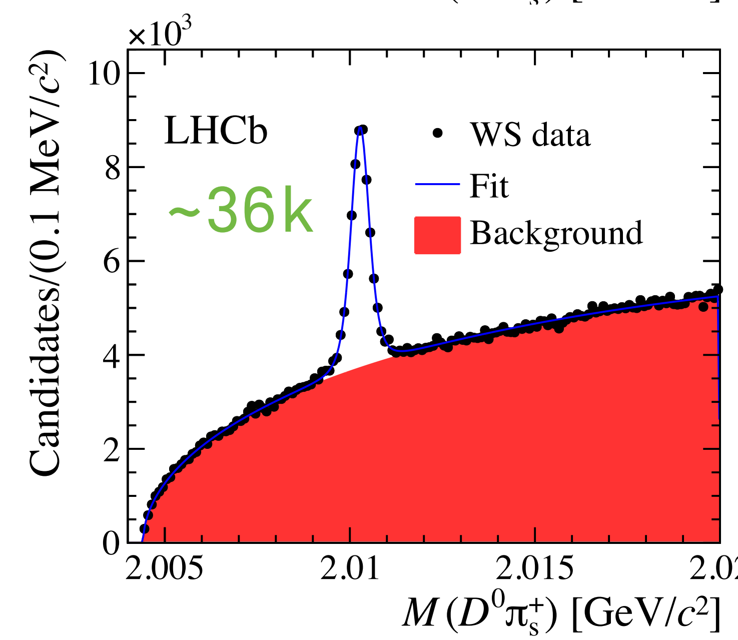
Submitted to PRL
LHCb-PAPER-2012-038
arXiv:1211.1230

- 1.0 fb^{-1} of 2011 LHCb data
- Count WS and RS events in bins of decay time
- Fit the ratio of yields vs decay time









- Dominant systematic uncertainties are treated within the fit procedure
- no-mixing hypothesis excluded at 9.1 σ

Conclusion

- LHCb features
  - clean signals
  - excellent decay time resolution
  - flavour tagging understood and under control
- Best measurements of Δm_d and Δm_s

$$\Delta m_s = 17.77 \pm 0.10(stat.) \pm 0.07(syst.)\,\mathrm{ps}^{-1}$$

340 pb^{-1} — Phys. Lett. B709 (2012), LHCb-CONF-2011-050

$$\Delta m_d = 0.511 \pm 0.005(stat.) \pm 0.006(syst.)\,\mathrm{ps}^{-1}$$

1.0 fb^{-1} — LHCb-PAPER-2012-032, arxiv:1210.6750

- First observation of charm oscillations from a single measurement

$$x'^2 = (-0.9 \pm 1.3) \times 10^{-4}$$
$$y' = (7.2 \pm 2.4) \times 10^{-3}$$
$$R_D = (3.52 \pm 0.15) \times 10^{-3}$$

1.0 fb^{-1} — LHCb-PAPER-2012-038, arXiv:1211.1230

- Now we recorded a total of 3 fb^{-1}
  - Updates are in progress, stay tuned...