Measurement of the Semileptonic CP Asymmetry in B_s-$\overline{B}_s$ Mixing

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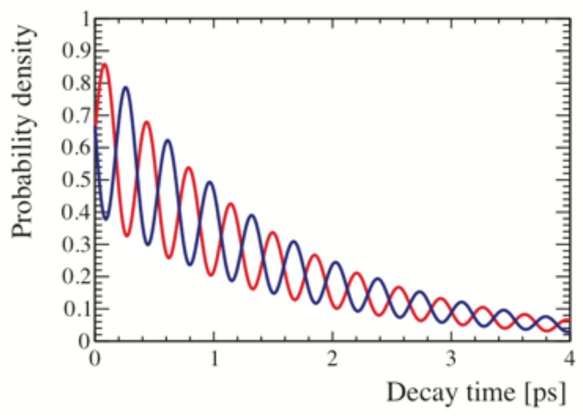
What

- Flavour eigenstates and mass eigenstates not aligned
- Quantum mechanics: neutral mesons mix over time:

$$i\frac{d}{dt}\begin{pmatrix}|B_q(t)\rangle\\|\overline{B}_q(t)\rangle\end{pmatrix}=\begin{pmatrix}M_{11}-i\frac{\Gamma_{11}}{2} & M_{12}-i\frac{\Gamma_{12}}{2}\\ M_{12}^*-i\frac{\Gamma_{12}^*}{2} & M_{22}-i\frac{\Gamma_{22}}{2}\end{pmatrix}\begin{pmatrix}|B_q(t)\rangle\\|\overline{B}_q(t)\rangle\end{pmatrix}$$

- Diagonalise to get mass eigenstates:

$$|B_q^{H,L}\rangle = p\,|B_q\rangle \pm q\,|\overline{B}_q\rangle$$
$$\Delta m_q = m_q^H - m_q^L$$
$$\Delta\Gamma_q = \Gamma_q^L - \Gamma_q^H$$



- CP-violation in mixing:

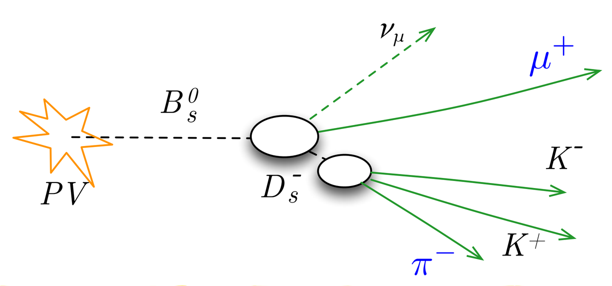
$$P(B_q \to \overline{B}_q) \neq P(\overline{B}_q \to B_q)$$

- Measure the flavour of the B_s at decay by a **flavour specific** final state: semileptonic decays. No CP violation in decay.

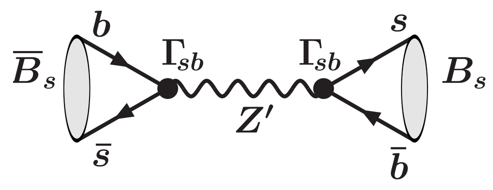
$$a_{sl}^s = \frac{\Gamma(\bar{B}_s \to B_s \to D_s^- \mu^+\nu) - \Gamma(B_s \to \bar{B}_s \to D_s^+\mu^-\nu)}{\Gamma(\bar{B}_s \to B_s \to D_s^- \mu^+\nu) + \Gamma(B_s \to \bar{B}_s \to D_s^+\mu^-\nu)}$$

- Production asymmetry negligible: only count the number of final-state $D_s^+\mu^-$ and $D_s^-\mu^+$! [1]

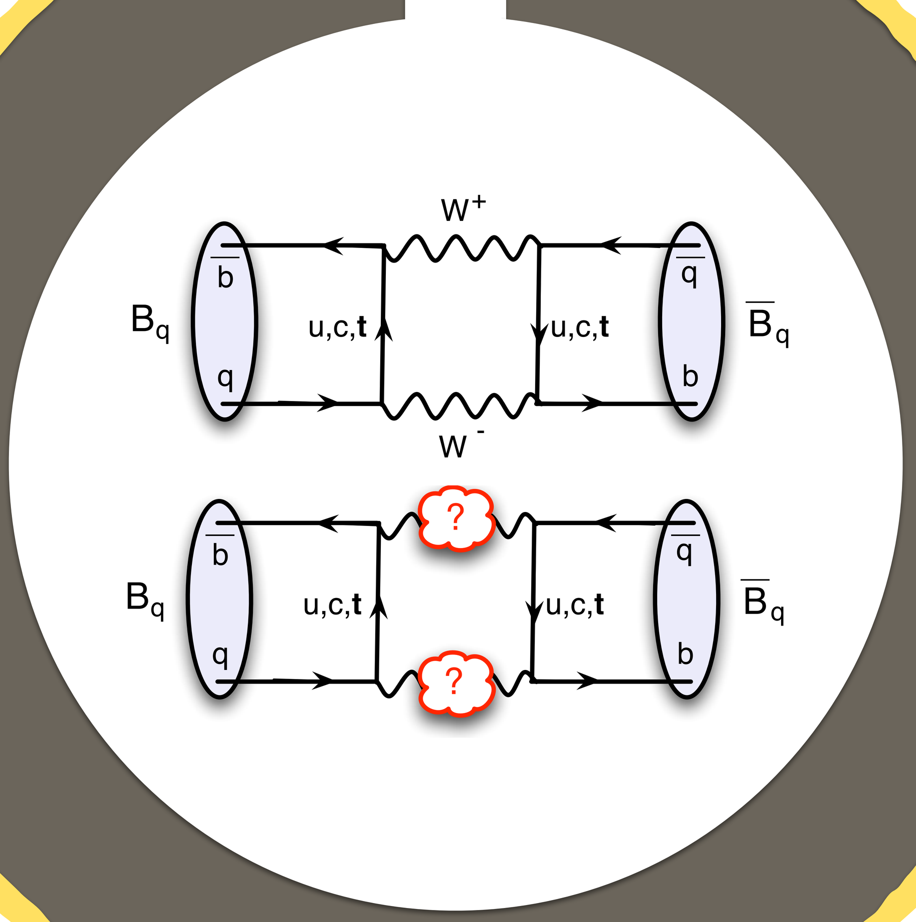
$$\frac{\Gamma[D_s^-\mu^+]-\Gamma[D_s^+\mu^-]}{\Gamma[D_s^-\mu^+]+\Gamma[D_s^+\mu^-]} = \frac{a_{sl}^s}{2} + \left[a_P - \frac{a_{sl}^s}{2}\right]\frac{\int_{t=0}^{\infty} e^{-\Gamma_s t}\cos(\Delta M_s t)\epsilon(t)dt}{\int_{t=0}^{\infty} e^{-\Gamma_s t}\cosh(\frac{\Delta\Gamma_s t}{2})\epsilon(t)dt}$$



Why



- CP-asymmetry in the Standard Model too small
- Are new particles enhancing CP violation?
- Mixing observables important constraint for Z' models
- CP violation in mixing sensitive to new physics in e.g. $B_s \to \tau\tau$ decays, little experimental constraints
- Other measurement for the B_s system: anomalous result?

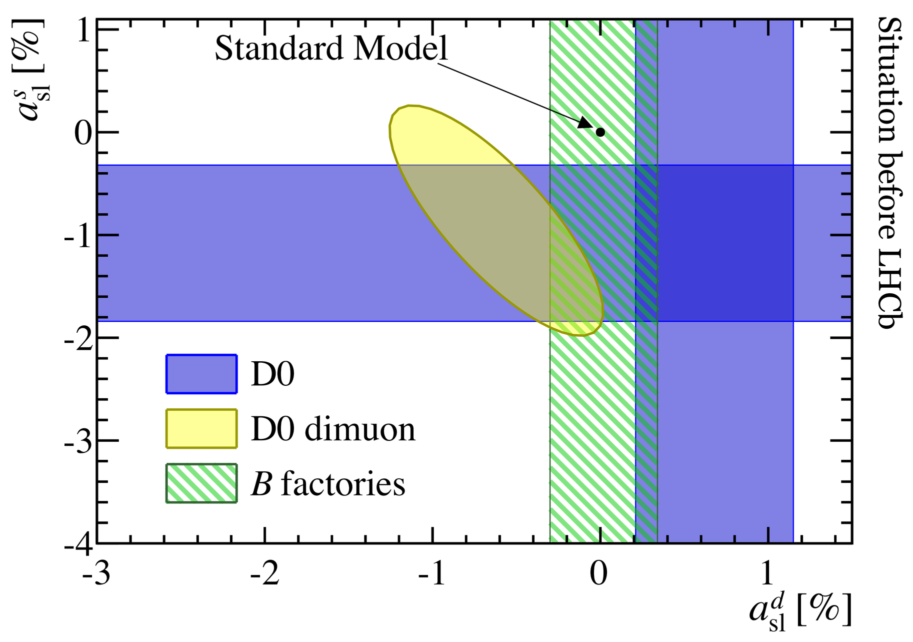


Prediction

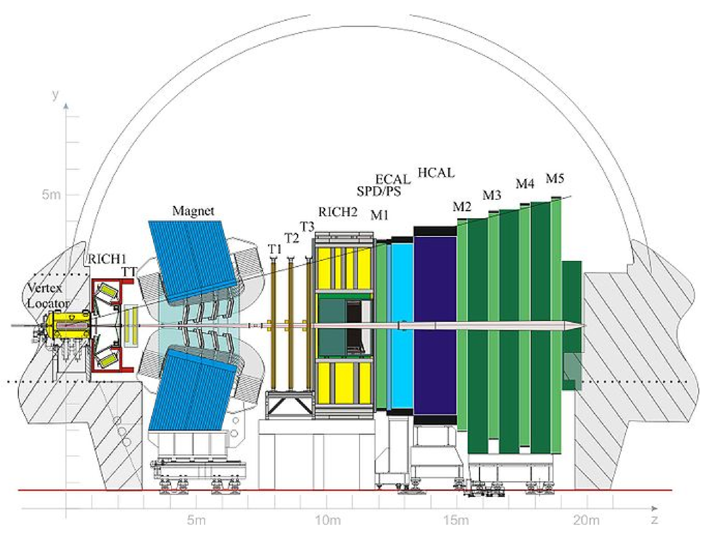
- Standard model prediction: extremely small[7]

$$a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4} \qquad a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5}$$

- Measurements by B-factories[2] (green) and D0[3] (blue)
- D0 dimuon result: 3.6σ deviation from Standard Model[4]



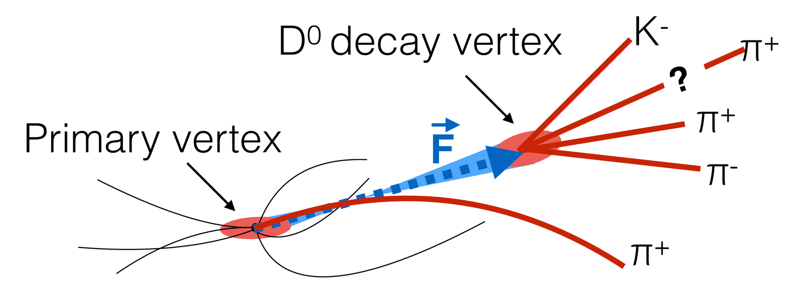
How

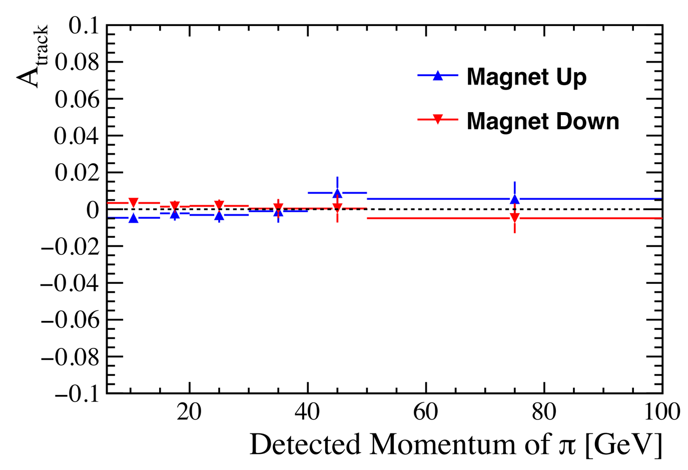


- The **LHCb detector** at CERN
  - High number of produced B_s: 93000 $D_s^+\mu^-$ candidates in 1 fb^{-1}
  - High momentum resolution, $\Delta p/p \sim (0.4\text{-}0.6)\%$
  - Excellent vertex detector to record the B_s decay vertex
  - Particle ID: separate K, π and p charged final state particles
    - Selected D_s^+ decay products, $K^+ K^- \pi^+$, are all well identified.
- Proton-proton collider: production asymmetry
  - ✓ Measured as percent-level[6]: $a_P(B_s) = (1.06 \pm 2.69)\%$

Detection asymmetries

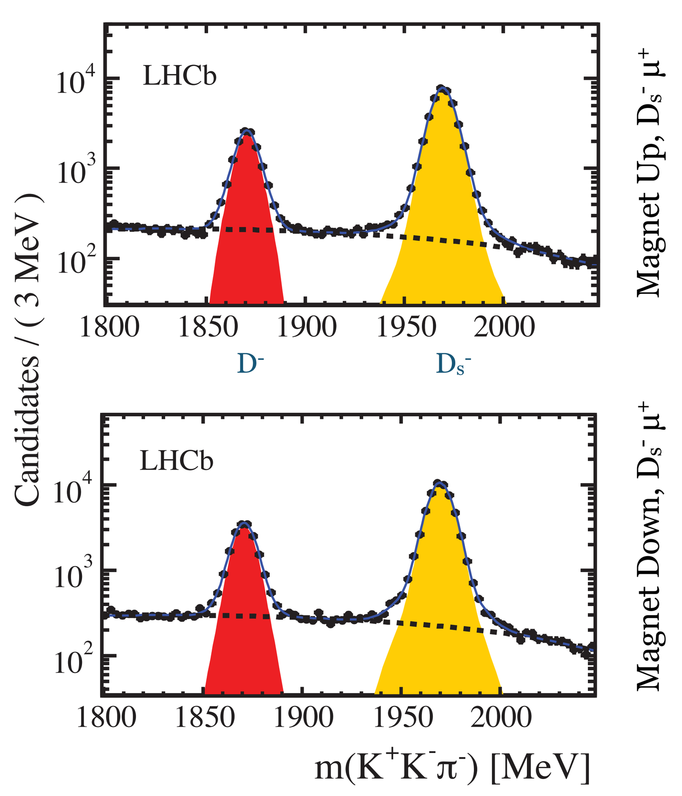
Magnet bends charged particles: charge asymmetry found in **left-right asymmetry**... but what if LHCb is not perfectly symmetric?





- Largest correction to the measurement.
- Measure and correct for asymmetries from tracking, trigger and particle ID
- Hadronic tracking asymmetries: prompt D^*-tagged D^0 daughters
  - Tag & probe: do we find all the tracks tracks, or do we miss one?
- Average magnet polarities: most detection asymmetry cancel

Results



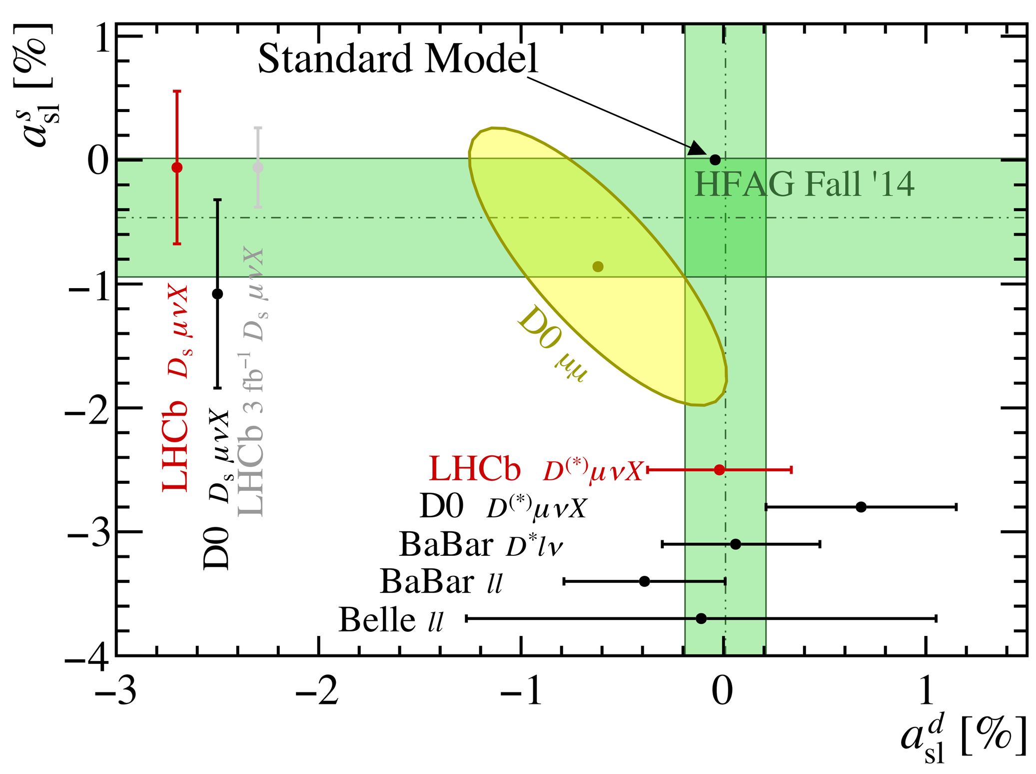
1 fb^{-1} a^s_{sl} published in 2014[1], 3 fb^{-1} a^d_{sl} result published in 2015[5]

$$a_{sl}^s = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\,\%$$
$$a_{sl}^d = (-0.02 \pm 0.19(\text{stat}) \pm 0.30(\text{syst}))\,\%$$

In progress: **improved** a^s_{sl} with 3 fb^{-1} (blinded result):

$$a_{sl}^s = X.XX\% \pm 0.25\% \pm 0.20\%$$

World's best measurement of both quantities!



[1] LHCb collaboration, R. Aaij *et al.*, Phys. Lett. B728 (2014) 607, arXiv:1308.1048
[2] Heavy Flavor Averaging Group, Y. Amhis *et al.*, arXiv:1412.7515
[3] D0 collaboration, V.M. Abazov *et al.*, Phys. Rev. D86 (2012) 072009, arXiv:1208.5813
[4] D0 collaboration, V.M. Abazov *et al.*, Phys. Rev. D89 (2014) 012002, arXiv:1310.0447
[5] LHCb collaboration, R. Aaij *et al.*, Phys. Rev. Lett. 114 (2015) 041601, arXiv:1409.8586
[6] LHCb collaboration, R. Aaij *et al.*, Phys. Lett. B739 (2014) 218, arXiv:1408.0275
[7] A. Lenz and U. Nierste, Theoretical update on B_s-$\bar{B}_s$ mixing, JHEP 0706 (2007) 072, arXiv:hep-ph/0612167

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Special thanks to Suzanne Klaver and Jacco de Vries