Flavour-specific asymmetry and LHCb

Robert W. Lambert

On behalf of the LHCb collaboration

Introduction

- DØ exclusive asymmetry hep-ex 0904.3907

$$B_s^0 \to D_s^{\mp} \mu^{\pm} \nu_{\mu} X^0 \qquad a_{fs}^s = [1.7 \pm 9.1(\text{stat}) \,^{+1.4}_{-1.5}(\text{syst})] \times 10^{-3}$$

- DØ Inclusive asymmetry hep-ex 1005.2757

$$b\bar{b} \to \mu^{\pm}\mu^{\pm}\ldots \qquad A^b = [-9.57 \pm 2.51(\text{stat}) \pm 1.46(\text{syst})] \times 10^{-3}$$

- What can we do at LHCb?

Literature

- Reading material:
  - LHCb
    - CERN-LHCb-2007-054 Public note from old Monte Carlo
    - CERN-THESIS-2008-045 Paul's Thesis
    - CERN-THESIS-2009-001 Rob's Thesis
    - CERN-THESIS-2010-076 Ken's Thesis
  - Theory
    - hep-ph 0406300 U. Nierste
    - hep-ph 0612167 [JHEP] A. Lenz, U. Nierste
    - hep-ph 0605028 [PRL] Y. Grossman *et al*.
    - hep-ph 0604112 [PRL] Z. Ligeti *et al.*
  - Other measurements
    - hep-ex 0505017 [PRD] Belle
    - hep-ex 0202041 [PRL] Babar
    - hep-ex 0101006 [PRL] Cleo
    - Note 9015 CDF inclusive

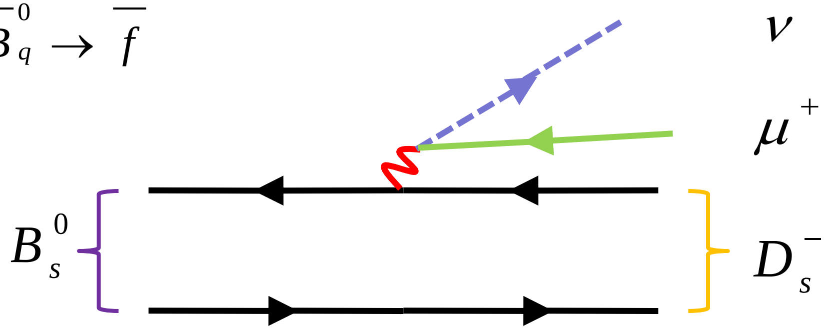
Outline

1. Theory .. from an experimentalist
2. Experimental Status
3. Complications at LHCb
4. Why LHCb?
5. Measurements at LHCb
6. Real data highlights
7. Outlook and Prospects
8. Conclusions

Flavour-specific asym.

- Flavour-specific decays
  - Favoured/Allowed $B_q^0 \longrightarrow f$
  - Not allowed at tree $B_q^0 \longrightarrow \overline{f}$
  - Through mixing $B_q^0 \to \overline{B}_q^0 \to \overline{f}$

$$B_s^0 \to D_s^- \mu^+ \nu$$
$$B_s^0 \to D_s^- \pi^+$$
$$B_d^0 \to D^- \mu^+ \nu$$



- Flavour specific asymmetry, a_{fs}, parameterises CPV in mixing

$$a_{fs}^q \propto A_{fs}^q(t) = \frac{\Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to \overline{f}\right) - \Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to f\right)}{\Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to \overline{f}\right) + \Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to f\right)}$$

The whole shebang

- Three different parameters fully constrain b-mixing

$$i\frac{d}{dt}\begin{pmatrix}\left|B_q^0(t)\right\rangle \\ \left|\overline{B}_q^0(t)\right\rangle\end{pmatrix} = \left(\underline{\underline{M}}_q - \frac{i}{2}\underline{\underline{\Gamma}}_q\right)\begin{pmatrix}\left|B_q^0(t)\right\rangle \\ \left|\overline{B}_q^0(t)\right\rangle\end{pmatrix}$$

$$\Delta\Gamma_q = \left(\Gamma_H^q - \Gamma_L^q\right) = 2\left|\Gamma_{12}^q\right| \arg\left\{\frac{\Gamma_{12}^q}{M_{12}^q}\right\}, \quad \Delta m_q = \left(M_H^q - M_L^q\right) = 2\left|M_{12}^q\right|, \quad a_{fs}^q = \mathrm{Im}\left\{\frac{\Gamma_{12}^q}{M_{12}^q}\right\}$$

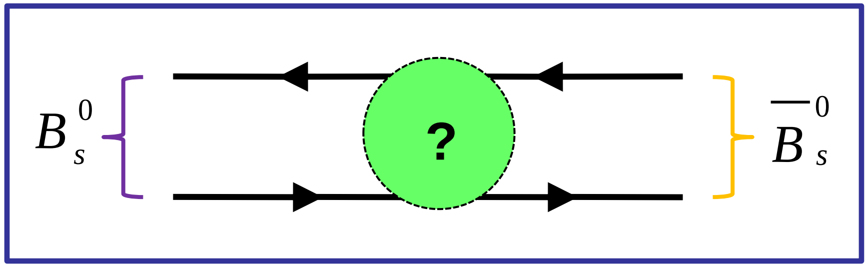
- a_{fs} is very small in the standard model

$$\left(a_{fs}^d\right)^{SM} = -(5.0 \pm 1.1) \times 10^{-4}$$

$$\left(a_{fs}^s\right)^{SM} = (2.1 \pm 0.4) \times 10^{-5}$$

Discovery Potential

- a_{fs} is sensitive to new physics (NP):
  - Sensitive to loop contributions
  - Sensitive to new CPV phases

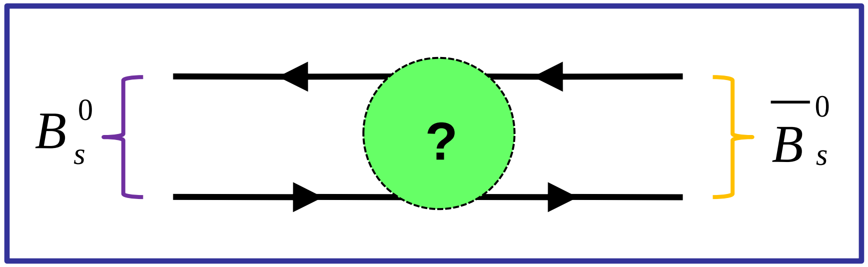


- If we allow a single NP phase in the mixing Θ

$$a^{NP} \approx \mathrm{Im}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\sin\Theta$$

Discovery Potential

- a_{fs} is sensitive to new physics (NP):
  - Sensitive to loop contributions
  - Sensitive to new CPV phases

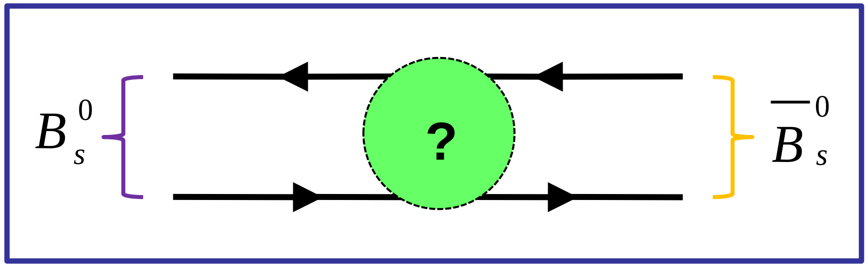


- If we allow a single NP phase in the mixing Θ

$$a^{NP} \approx a_{fs}^{SM} \cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\sin\Theta$$

Discovery Potential

- a_{fs} is sensitive to new physics (NP):
  - Sensitive to loop contributions
  - Sensitive to new CPV phases



- If we allow a single NP phase in the mixing Θ

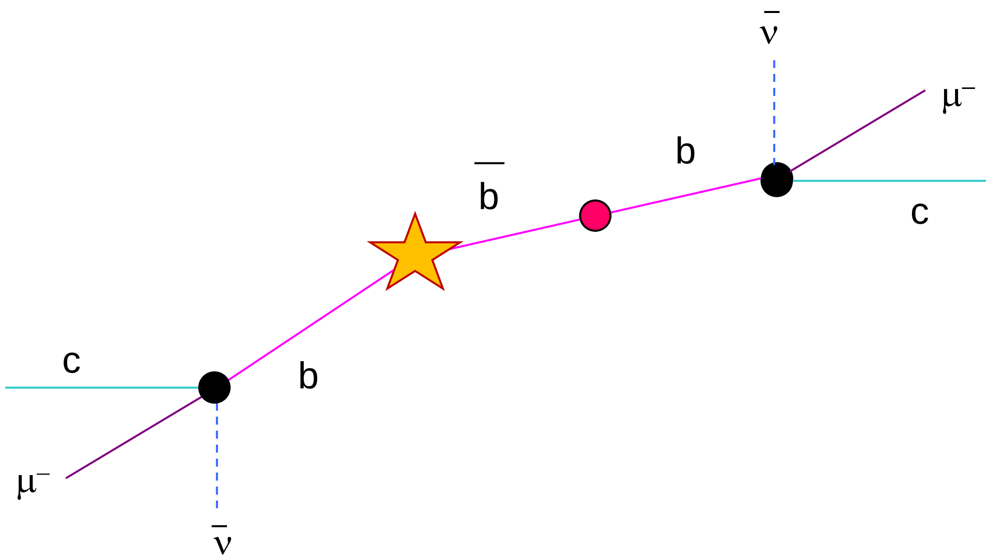
$$a^{NP} \approx 2.1\times10^{-5}\cos\Theta + 4.0\times10^{-3}\sin\Theta$$

- Up to **200-times** the SM ... but ... $(4\text{x}10^{-3})<$ DØ measurement

Experimental Status

B-factories

- Babar, Belle, Cleo all use the di-muon sample [hep-ph 0605028]
  - Know the initial state $\Upsilon(4S)$
  - Time-integrated number-counting of di-muons
  - Possible muon detector asymmetry is important to measure



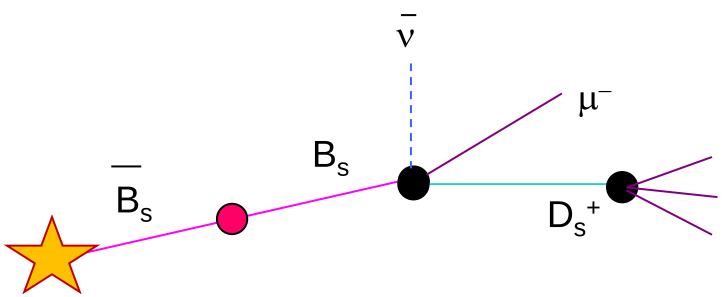
$$N^{++} = N(b\bar{b} \rightarrow Xl^{+}l^{+})$$

$$A_{SL} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = a^{d}_{fs}$$

$$\left(a^{d}_{fs}\right)^{b-fact} = -(1.1 \pm 5.5) \times 10^{-3}$$

Exclusive measurement

- DØ have also made an exclusive measurement hep-ex 0904.3907
  - Search for the full decay chain in the data
  - Requires full reconstruction
  - Flavour-tagging provides extra information
  - ✓ Lower and more easily understood backgrounds
  - x Extra detector asymmetry
  - x Lower statistics



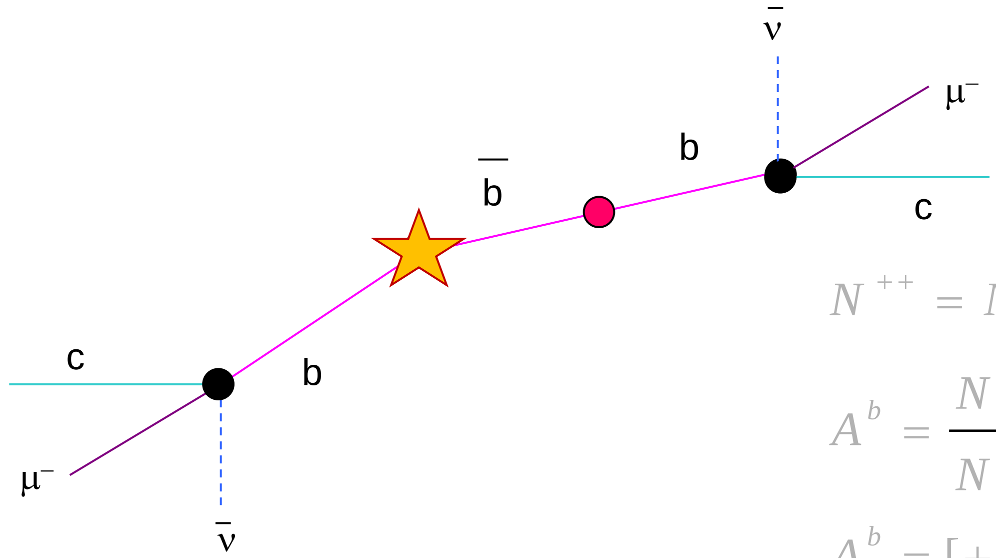
$$A_{SL} = \frac{\Gamma(\bar{B}_s^0 \to f) - \Gamma(B_s^0 \to \bar{f})}{\Gamma(\bar{B}_s^0 \to f) + \Gamma(B_s^0 \to \bar{f})} = a_{fs}^s$$

$$a_{fs}^s = [1.7 \pm 9.1(\text{stat})\ {}^{+1.4}_{-1.5}(\text{syst})] \times 10^{-3}$$

CDF Inclusive

Note 9015

- CDF use only the di-muon sample
  - Don't know the initial state ($p\bar{p}$)
  - Time-integrated number-counting
  - Possible muon detector asymmetry is important to measure



$$N^{++} = N(b\bar{b} \to Xl^{+}l^{+})$$

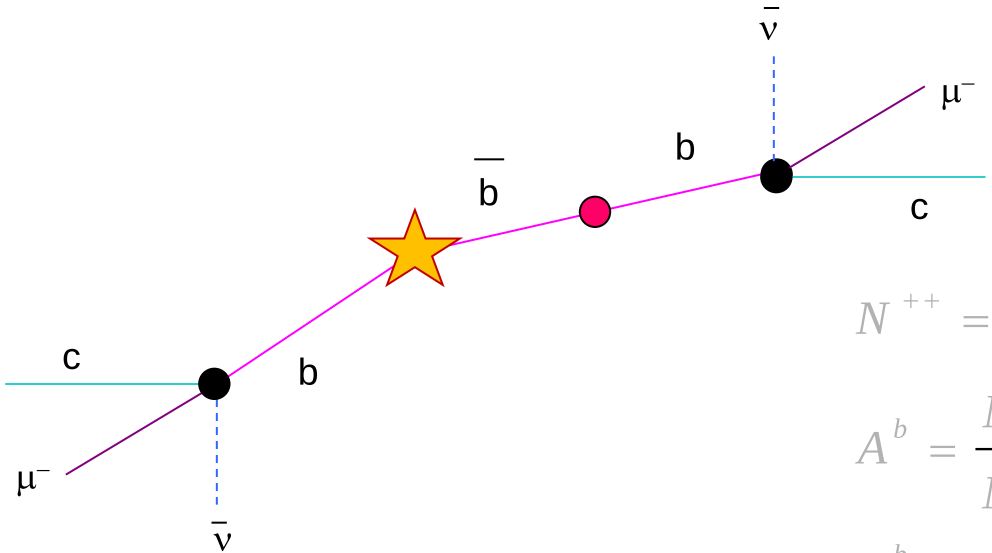
$$A^{b} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.418)a^{s}_{fs} + (0.582)a^{d}_{fs}$$

$$A^{b} = [+8.0 \pm 9.0(\mathrm{stat}) \pm 6.8(\mathrm{syst})] \times 10^{-3}$$

$$\left(a^{s}_{fs}\right)^{\text{using b-fact}} = -(2.0 \pm 2.1(\mathrm{stat}) \pm 1.6(\mathrm{syst}) \pm 0.9(\mathrm{ip})) \times 10^{-2}$$

New DØ inclusive

- DØ used primarily the di-muon sample hep-ex 1005.2757
  - Don't know the initial state ($p\bar{p}$)
  - Time-integrated number-counting
  - Possible muon detector asymmetry is important to measure



$$N^{++} = N(b\bar{b} \to Xl^{+}l^{+})$$

$$A^{b} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.494)a^{s}_{fs} + (0.506)a^{d}_{fs}$$

$$A^{b} = [-9.57 \pm 2.51(\text{stat}) \pm 1.46(\text{syst})] \times 10^{-3}$$

$$\left(a^{s}_{fs}\right)^{\text{using b-fact}} = -(1.46 \pm 0.75) \times 10^{-2}$$

New DØ inclusive

- Key Systematics (it's difficult to be inclusive!) hep-ex 1005.2757
  - Kaons decaying in-flight
  - Punch-through of hadrons to muons
- Key methods
  - Rely on real data, cross-check with well-tuned Monte Carlo
  - Use the inclusive single muon sample to get extra information
  - Reverse magnets to remove most detector asymmetry
  - Do many many cross-checks in different phase-space regions
- Result, **3.2σ !**

$$SM = \left(-2.3^{+0.5}_{-0.6}\right)\times 10^{-4} \qquad A^{b} \approx +(1 \pm 0.3)\ \%$$

Summary

- Before the New DØ Inclusive Measurement
  - A lot of measurements
  - All consistent with SM +/- 1%
- The New DØ Inclusive Measurement
  - First evidence of departure from the SM
  - Statistics-limited, so may improve over the next year
- A lot of theory interest ☺, so, how will LHCb help?
- ... The situation is significantly more complicated ...

Complications

The simple formula

$$A_{fs}^{q}(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$$

$$A_{fs}^{q}(t) = \frac{a_{fs}^{q}}{2} \qquad - \left(\frac{a_{fs}^{q}}{2} \qquad \right) \frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)}$$

10^{-3} -> 10^{-5}

The ~~simple~~ Very Complicated formula

$$A^q_{fs}(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$$

$$A^q_{fs}(t) = \frac{a^q_{fs}}{2} - \frac{\delta^q_c}{2} - \left(\frac{a^q_{fs}}{2} + \frac{\delta^q_p}{2}\right)\frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} + \frac{\delta^q_b}{2}\left(\frac{B}{S}\right)^q$$

10^{-3} -> 10^{-5} **10^{-2}** **10^{-2}** **10^{-3}**

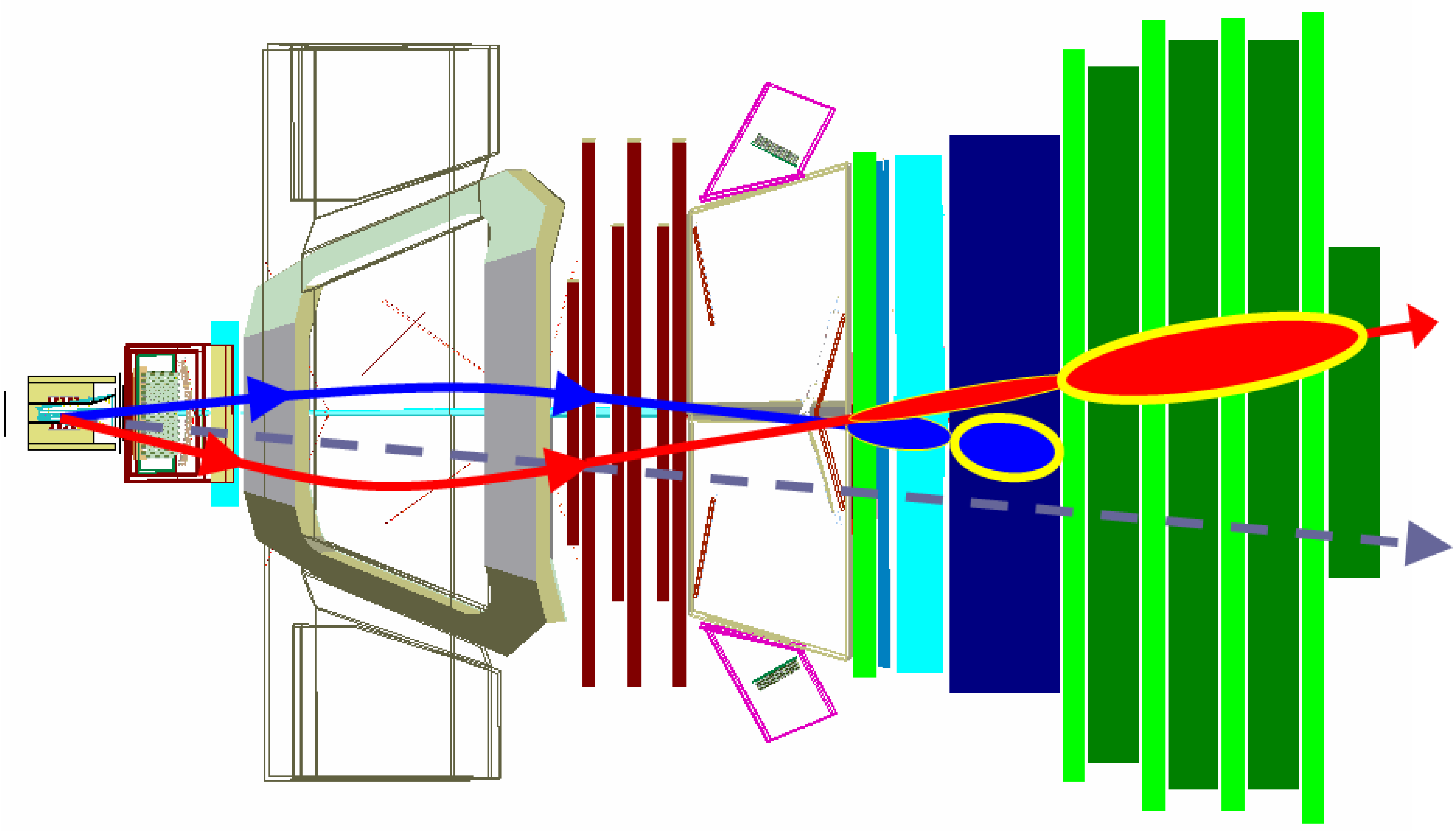
$$\delta_c = \frac{\varepsilon(\bar{f}_i)}{\varepsilon(f_i)} - 1$$

$$\delta_p = \frac{N(\bar{I}_0)}{N(I_0)} - 1$$

$$\delta_b = \frac{\overline{B}/\overline{S}}{B/S} - 1$$

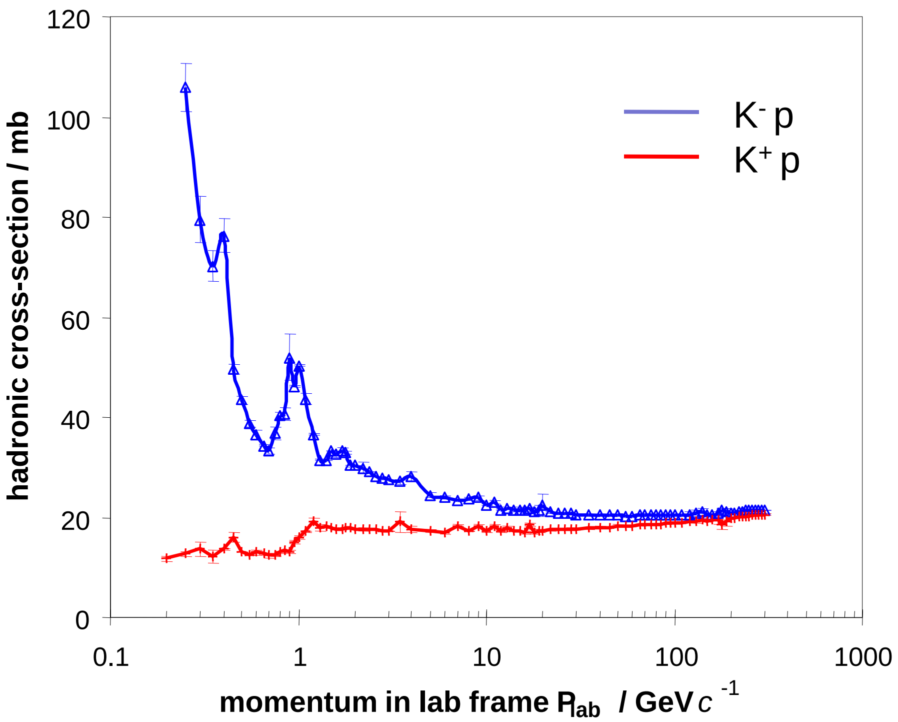
- Polluting asymmetries are much larger than a_{fs}
  - Detector asymmetry δ_c ~(10^{-2})
  - Production asymmetry δ_p ~(10^{-2})
  - Background asymmetry δ_b ~(10^{-3})

LHCb

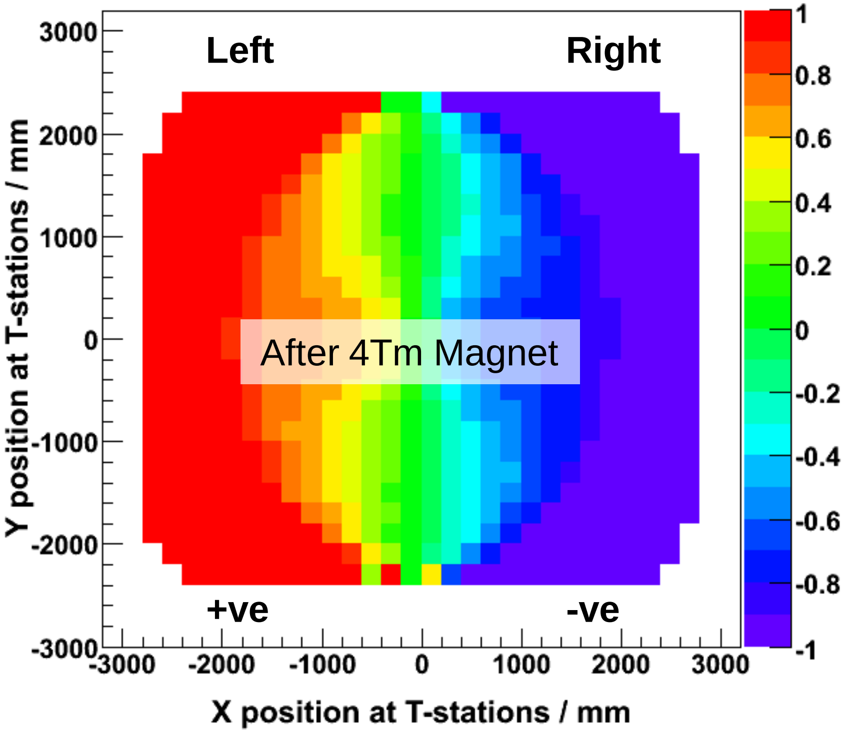


Detector Asymmetry, δ_c

Kaon interaction cross-section



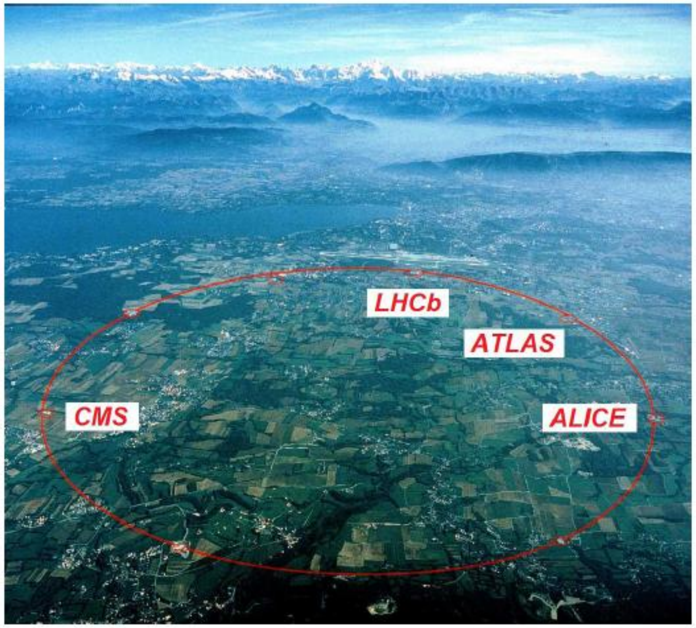
MC Asymmetry in Muons

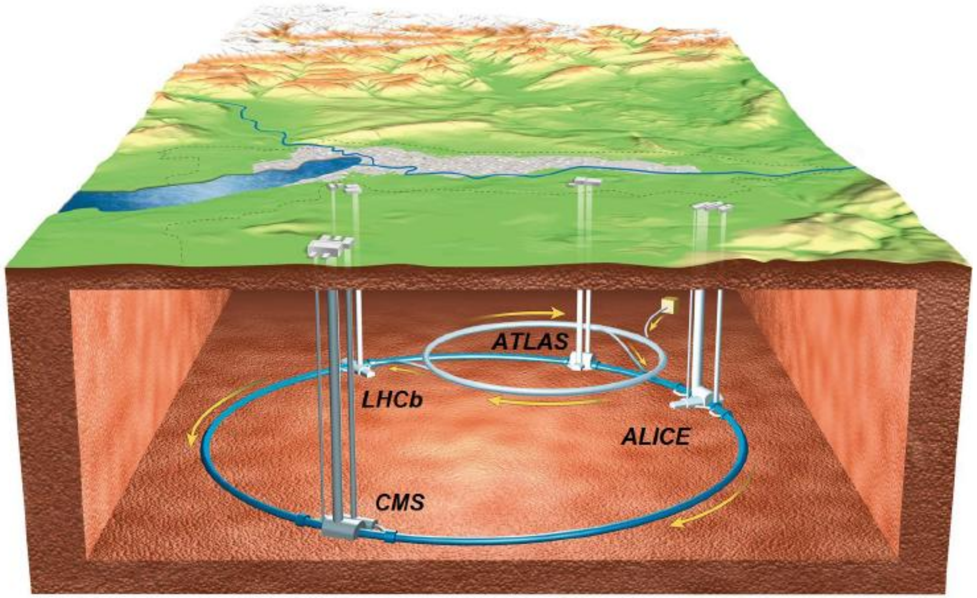


- Matter detector → hadronic interactions are asymmetric
- Magnet divides +/- charge, allowing +/- detector asymmetry
  - We need to reverse the magnet regularly

LHC

- An amazing machine

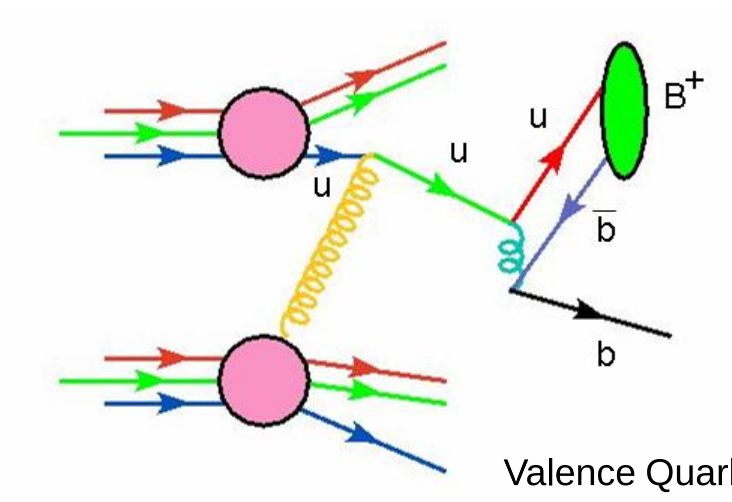




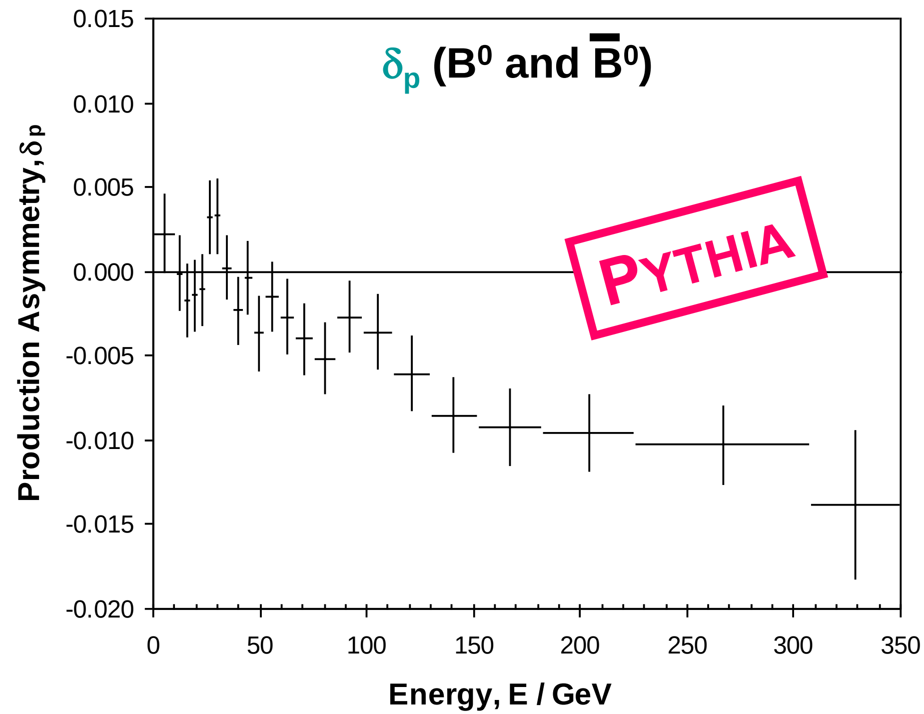
- Unfortunately also not CP symmetric

Production Asymmetry, δ_p

Explicitly asymmetric at LHC



Valence Quark Scattering

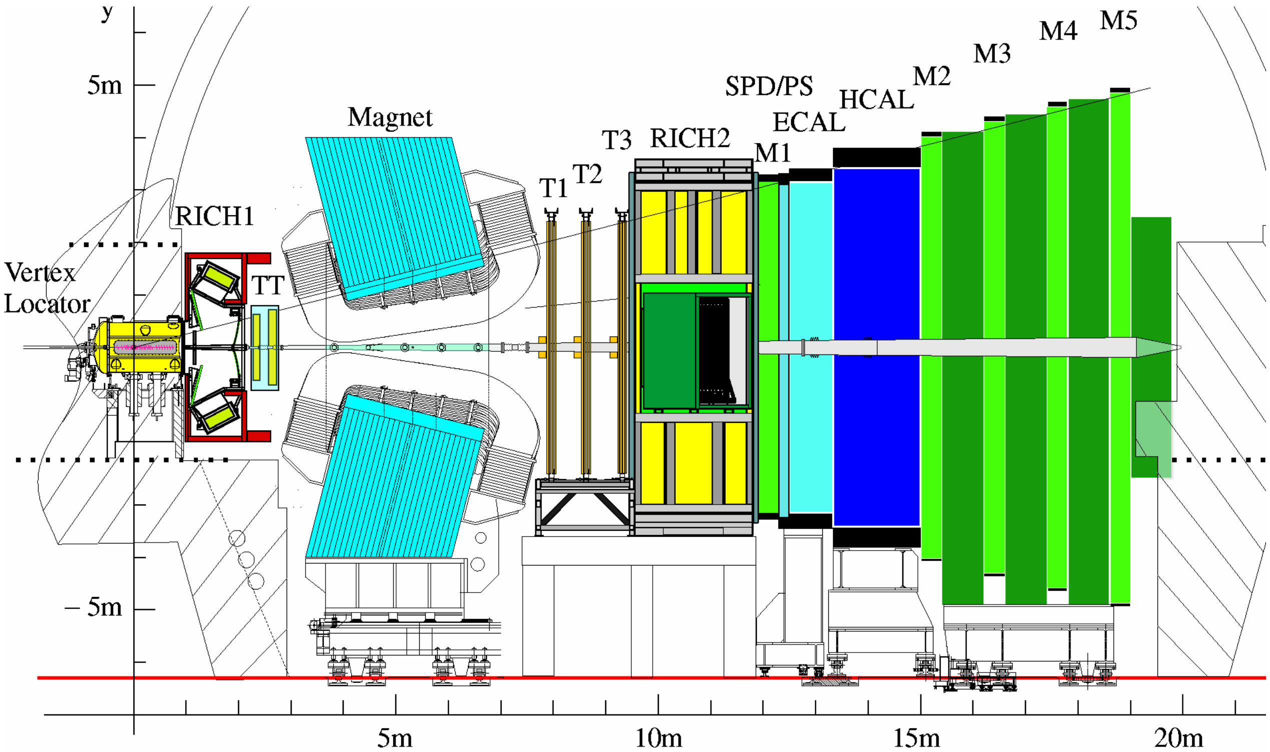


- LHC is a proton-proton collider: not CP-symmetric
- LHCb is at high rapidity where production asymm. are largest
- There is never a simple control channel to measure δ_p

Why LHCb?

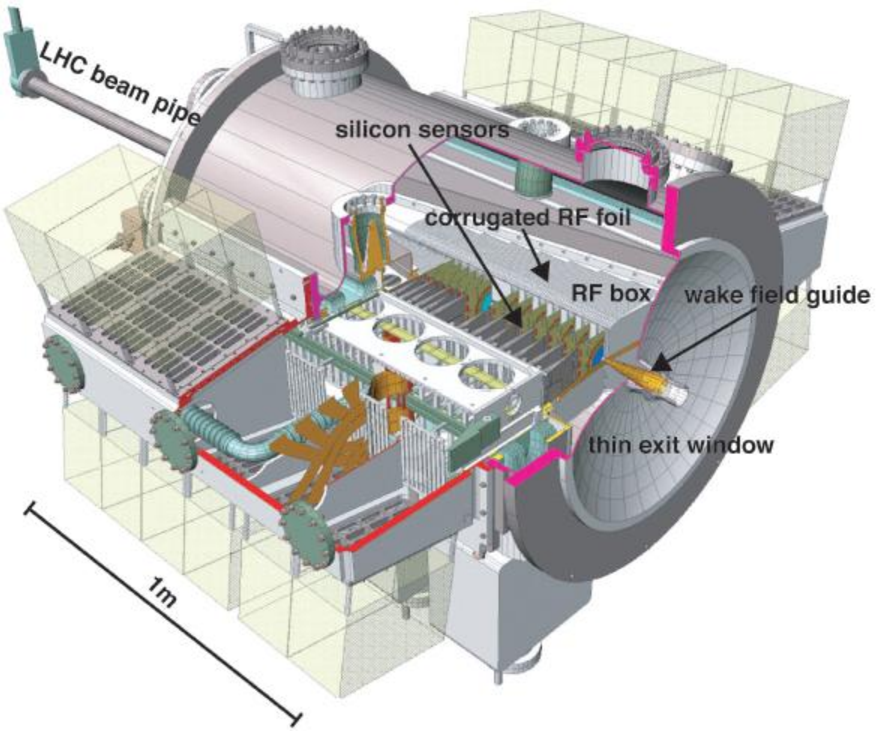
Why LHCb?

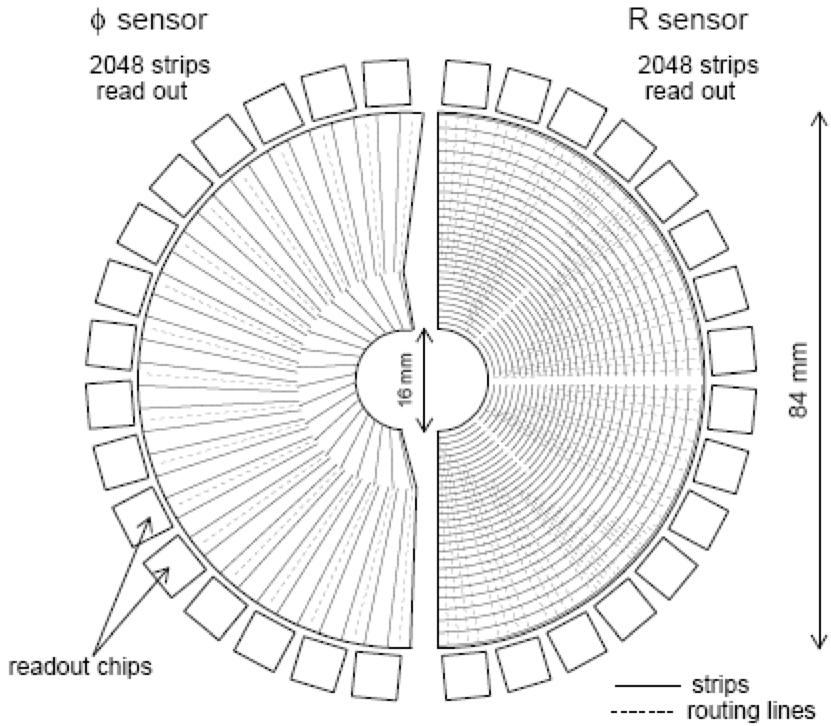
- LHCb is a dedicated, precision, *b*-physics experiment
- More statistics: we're in the forward region, and at LHC



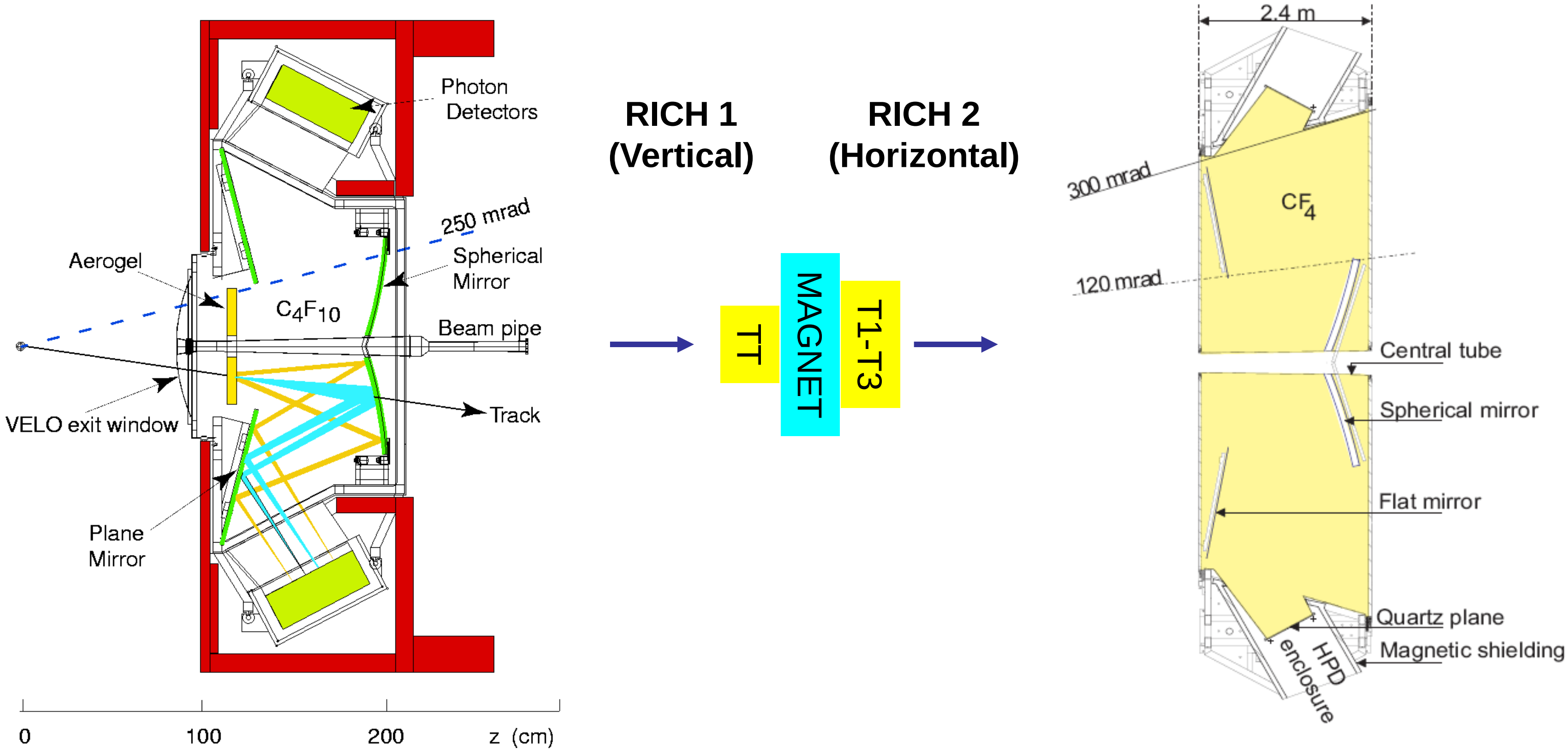
Being Timely

- Proper Time: LHCb Velo precise down to 35 fs!



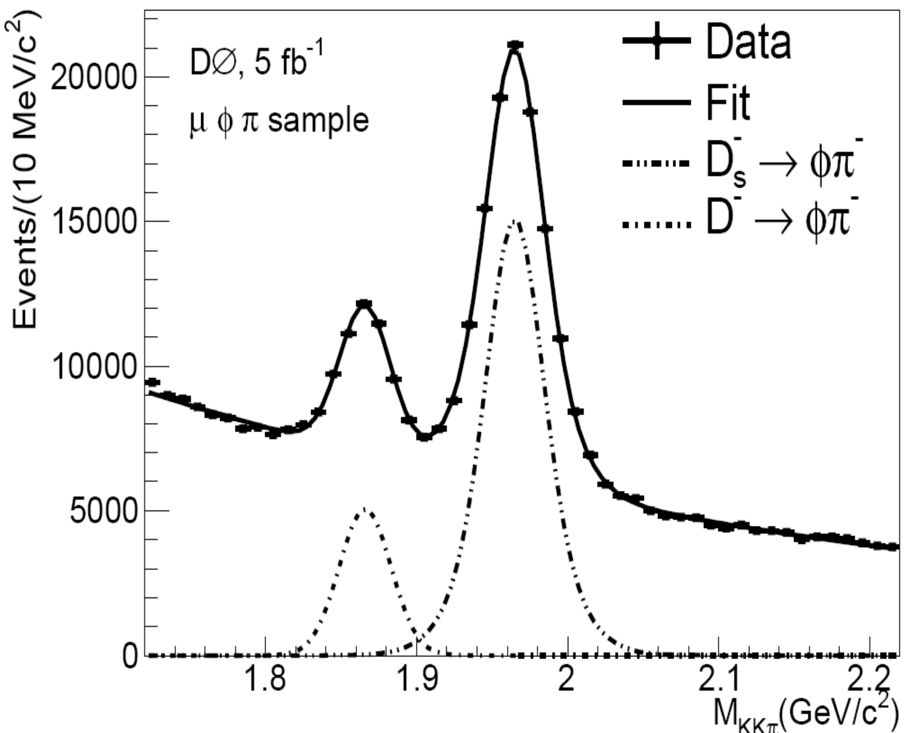


- Particle ID: separation handled by dedicated subdetectors
- Two RICHes, Calorimetry and Muon system

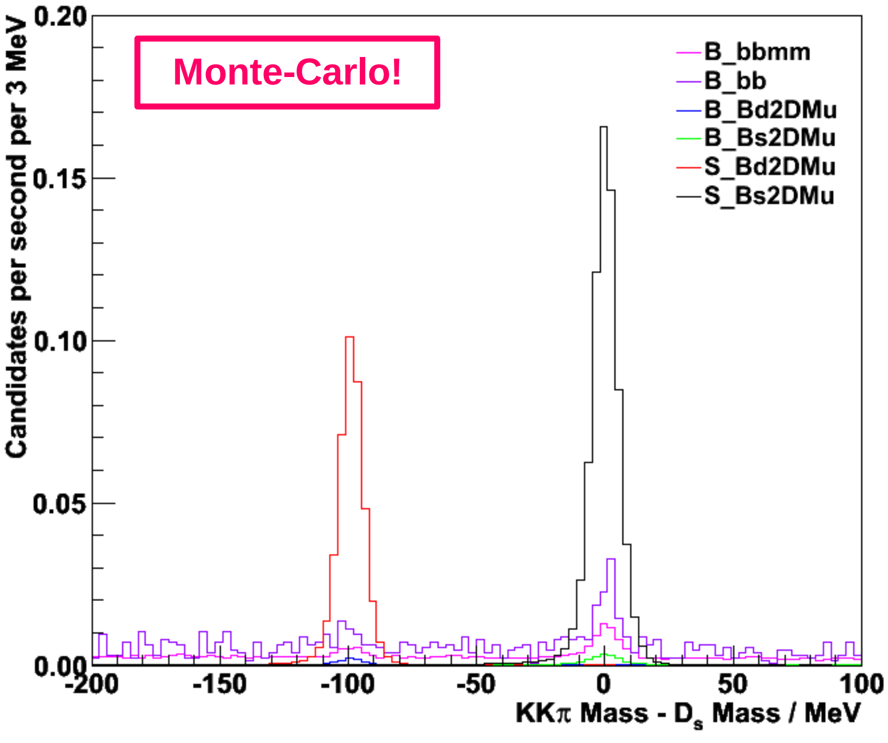


Being Exclusive

- Our forte: exclusive, reconstructed, *b*-decays
- In particular, time-dependent measurements



~100k D_s in 5 fb^{-1}



~100k D_s in 0.05 fb^{-1}

Measurements

Measurements

- Inclusive

$$b\bar{b} \rightarrow \mu^{\pm}\mu^{\pm}...$$

- Exclusive

$$B_s^0 \rightarrow D_s^{\mp}\pi^{\pm}$$

$$B_d^0 \rightarrow D^{\mp}\mu^{\pm}\nu_{\mu}X^0$$

$$B_s^0 \rightarrow D_s^{\mp}\mu^{\pm}\nu_{\mu}X^0$$

- Subtraction method

combine $B_s^0 \rightarrow D_s^{\mp}\mu^{\pm}\nu_{\mu}X^0$ and $B_d^0 \rightarrow D^{\mp}\mu^{\pm}\nu_{\mu}X^0$

Inclusive at LHCb

- Channel

$$b\bar{b} \rightarrow \mu^{\pm}\mu^{\pm}\ldots$$ ~10^8 per fb^{-1}

- Measured by DØ (see earlier)

$$A^b \approx \frac{a^s_{fs} + a^d_{fs}}{2} \qquad SM = \left(-2.3^{+0.5}_{-0.6}\right)\times 10^{-4}$$

- Complications
  - Physics!
  - Production asymmetry: N(b)≠N(anti-b) [in acceptance]
  - PYTHIA predicts $\delta_p(b) = \left(+3.4 \pm 0.3\right)\times 10^{-3}$
- Mitigating factors
  - None, difficult to interpret this measurement

Inclusive at LHCb

- Channel

$$b\bar{b} \rightarrow \mu^{\pm}\mu^{\pm}\ldots \qquad \sim 10^{8} \text{ per fb}^{-1}$$

- Measured by DØ (see earlier)

$$A^{b} \approx \frac{a_{fs}^{s} + a_{fs}^{d}}{2} \qquad SM = \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4}$$

- Complications
  - Physics!
  - Production asymmetry: N(b)≠N(anti-b) [in acceptance]
  - PYTHIA predicts $\delta_p(b) = \left(+3.4 \pm 0.3\right) \times 10^{-3}$

- Mitigating factors
  - None, difficult to interpret this measurement

Hadronic at LHCb

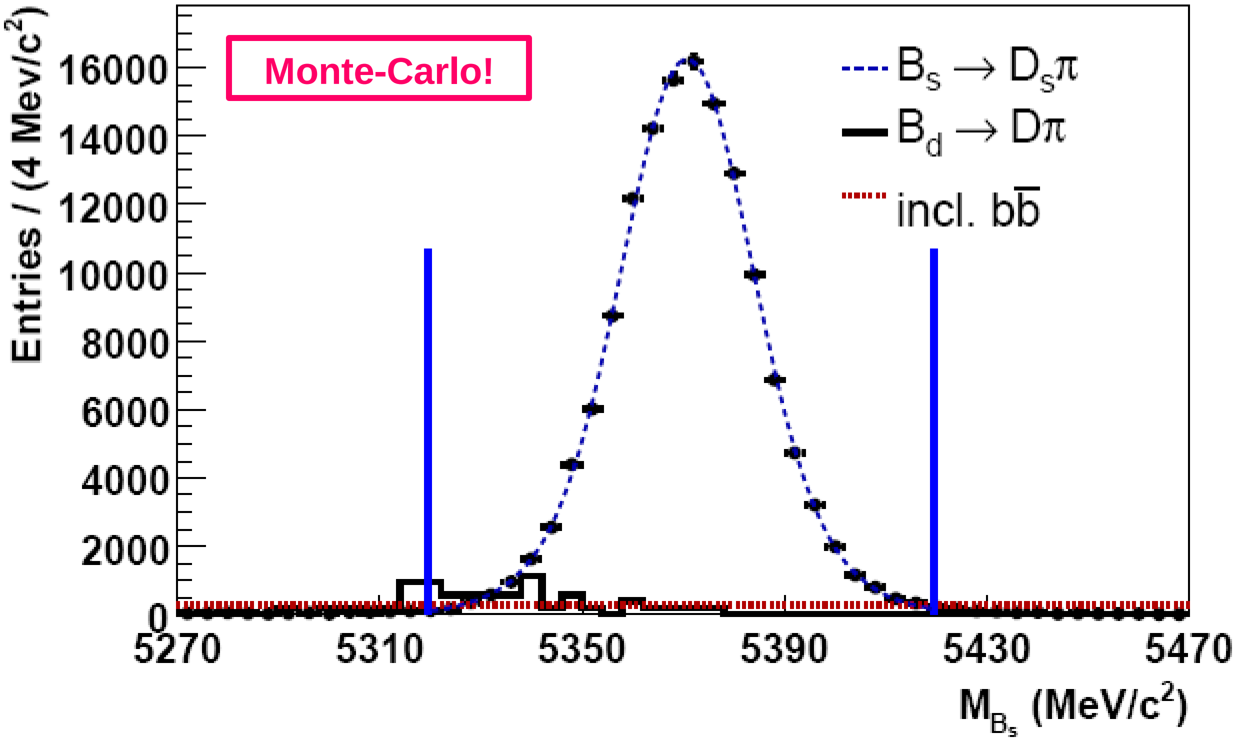
- Channel

CERN-THESIS-2008-045

CERN-LHCb-2007-017

$$B_s^0 \to D_s^{\mp}\left(K^+K^-\pi^{\mp}\right)\pi^{\pm}$$

~10^5 per fb^{-1}



Hadronic at LHCb

CERN-THESIS-2008-045

CERN-LHCb-2007-054

- Channel

$$B_s^0 \to D_s^{\mp}\left(K^+K^-\pi^{\mp}\right)\pi^{\pm}$$

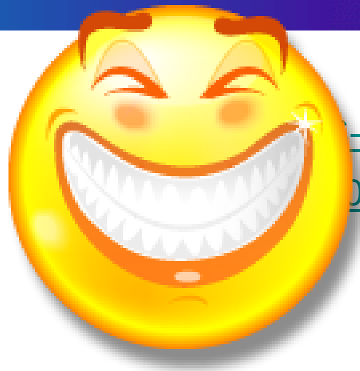
~10^5 per fb^{-1}

- Measures

$$A_{fs}^s(t) = \frac{a_{fs}^s}{2} - \frac{\delta_c^s}{2} - \left(\frac{a_{fs}^s}{2} + \frac{\delta_p^s}{2}\right)\frac{\cos\left(\Delta m_s t\right)}{\cosh\left(\Delta\Gamma_s t/2\right)} + \frac{\delta_b^s}{2}\left(\frac{B}{S}\right)^s$$

- Complications
  - Must fix either δ_c or δ_p in the fit – (δ_b can be fit beforehand)
- Mitigating factors
  - Detector asymmetry small ~10^{-4}
  - Fit a_{fs} and δ_p. – With excellent proper time resolution (35 fs)

Hadronic at LHCb



-2008-045

07-054

- **Channel**

$$B_s^0 \to D_s^{\mp}\left(K^+K^-\pi^{\mp}\right)\pi^{\pm} \qquad \sim 10^5 \text{ per fb}^{-1}$$

- **Measures**

$$A_{fs}^s(t) = \frac{a_{fs}^s}{2} - \frac{\delta_c^s}{2} - \left(\frac{a_{fs}^s}{2} + \frac{\delta_p^s}{2}\right)\frac{\cos(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2)} + \frac{\delta_b^s}{2}\left(\frac{B}{S}\right)^s$$

- **Complications**
  - Must fix either δ_c or δ_p in the fit – (δ_b can be fit beforehand)
- **Mitigating factors**
  - Detector asymmetry small $\sim 10^{-4}$
  - Fit a_{fs} and δ_p. – With excellent proper time resolution (35 fs)

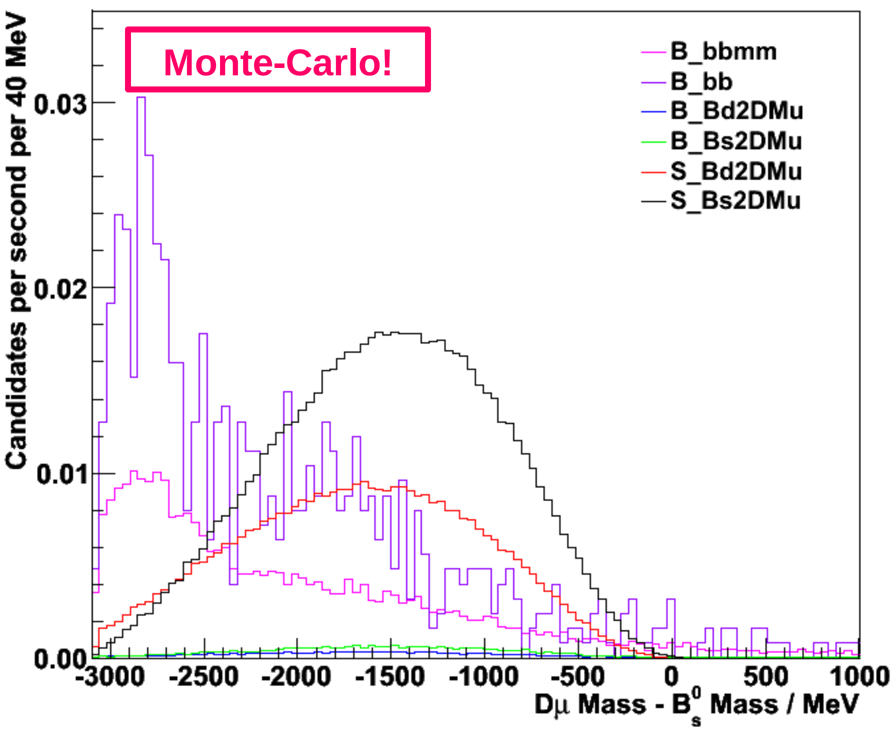
Semi-leptonic

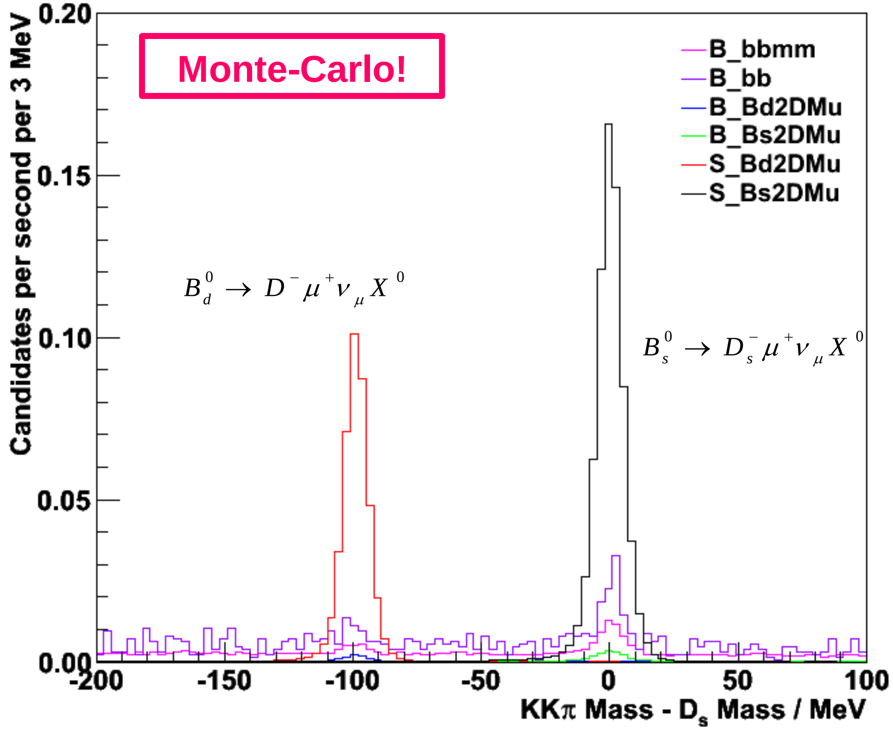
- Channel (q = s/d)

CERN-LHCb-2007-054

$$B_q^0 \to D_q^{\mp} \mu^{\pm} \nu_{\mu} X^0$$

~10^6 per fb^{-1}





Semi-leptonic

- Channel (q = s/d)

CERN-LHCb-2007-054

$$B_q^0 \to D_q^{\mp} \mu^{\pm} \nu_\mu X^0$$

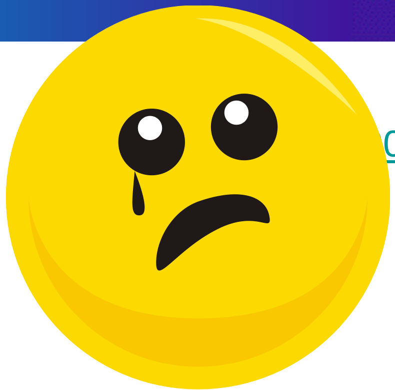
~10^6 per fb^{-1}

- Measures

$$A_{fs}^q(t) = \frac{a_{fs}^q}{2} - \frac{\delta_c^q}{2} - \left(\frac{a_{fs}^q}{2} + \frac{\delta_p^q}{2}\right) \frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} + \frac{\delta_b^q}{2}\left(\frac{B}{S}\right)^q$$

- Complications
  - Missing neutrino makes proper-time resolution worse (≥120 fs?)
  - Detector asymmetry large and difficult to measure
- Mitigating factors
  - Lots of statistics, but this makes δ_c even more important

Semi-leptonic



07-054

- Channel (q = s/d)

$$B_q^0 \rightarrow D_q^{\mp} \mu^{\pm} \nu_{\mu} X^0$$

~10^6 per fb^{-1}

- Measures

$$A_{fs}^q(t) = \frac{a_{fs}^q}{2} - \frac{\delta_c^q}{2} - \left(\frac{a_{fs}^q}{2} + \frac{\delta_p^q}{2}\right)\frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} + \frac{\delta_b^q}{2}\left(\frac{B}{S}\right)^q$$

- Complications
  - Missing neutrino makes proper-time resolution worse (≥120 fs?)
  - Detector asymmetry large and difficult to measure

- Mitigating factors
  - Lots of statistics, but this makes δ_c even more important

The subtraction method

- Take B_s/B_d with the same final states (f=KKπ μ)
  - ✓ Background asymmetry: 2D fit in mass spectra
  - ✓ Production asymmetry: fit with proper-time dependence
  - ✓ Detector asymmetry: the same in each decay…
- Do a simultaneous time-dependent fit
- Measure the **difference** between B_s and B_d

$$\Delta A_{fs}^{s,d} \approx \frac{(a_{fs}^{s} - \delta_c) - (a_{fs}^{d} - \delta_c)}{2} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2}$$

$$SM = \left(+2.5_{-0.6}^{+0.5}\right) \times 10^{-4}$$

- Very comparible to the DØ measurement, but orthogonal to it!

The subtraction method

- Take B_s/B_d with the same final states (f=KK
  - ✓ Background asymmetry: 2D fit in mass spect
  - ✓ Production asymmetry: fit with proper-time depe
  - ✓ Detector asymmetry: the same in each decay…
- Do a simultaneous time-dependent fit
- Measure the **difference** between B_s and B_d

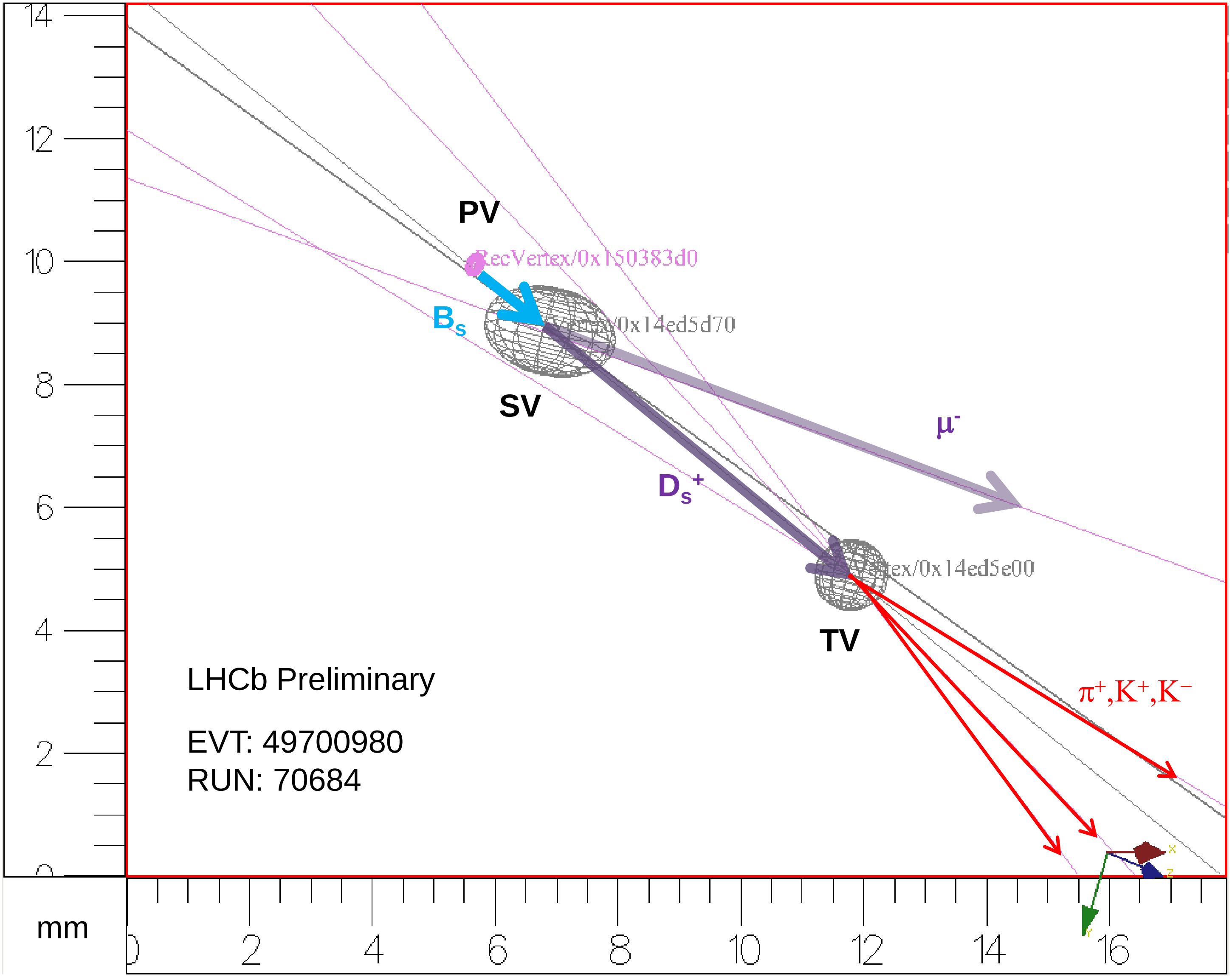
$$\Delta A_{fs}^{s,d} \approx \frac{(a_{fs}^{s} - \delta_c) - (a_{fs}^{d} - \delta_c)}{2} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2}$$

$$SM = \left(+2.5^{+0.5}_{-0.6}\right) \times 10^{-4}$$

- Very comparible to the DØ measurement, but orthogonal to it!

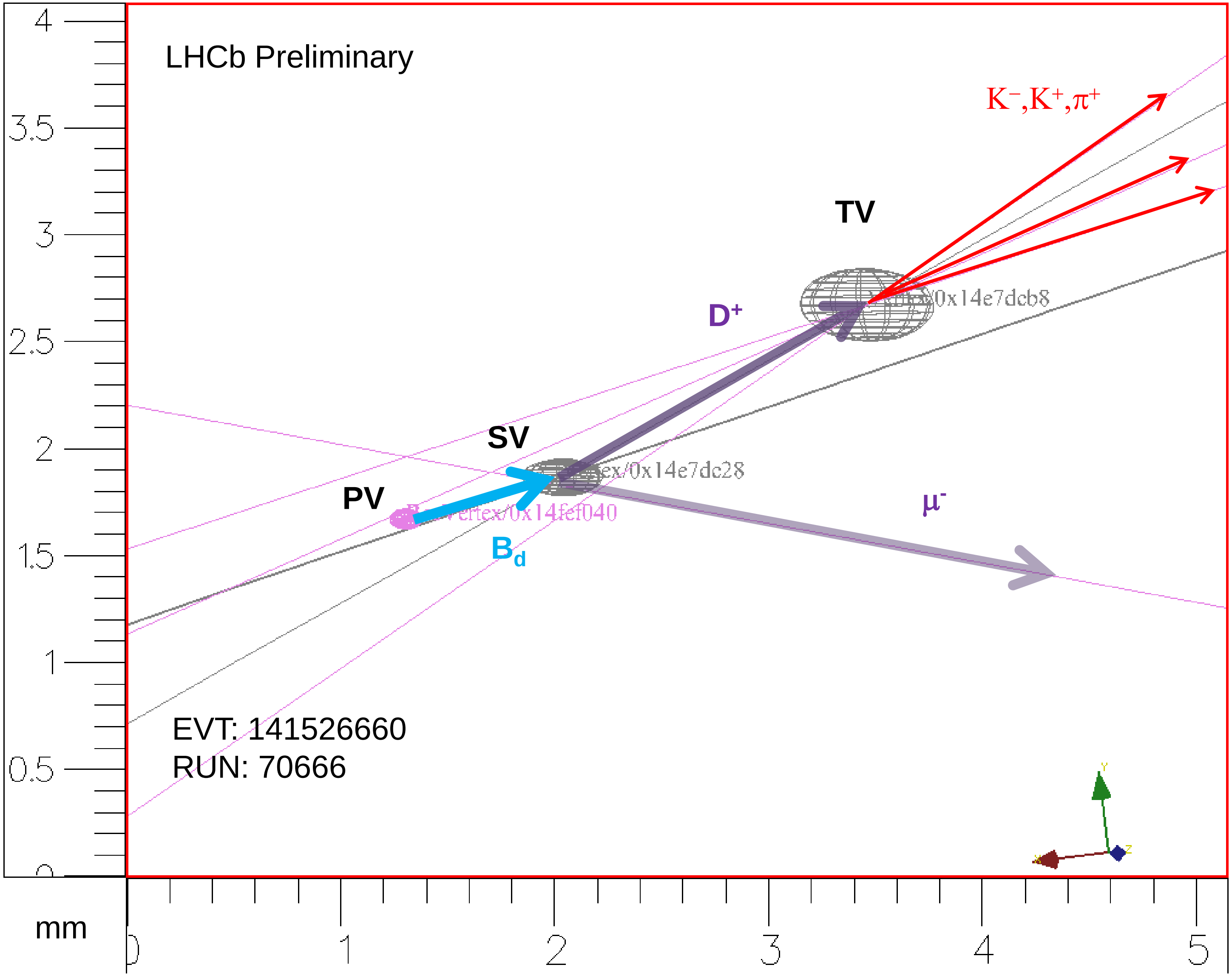
Real data highlights

Real Data B_s



~800 μb^{-1}

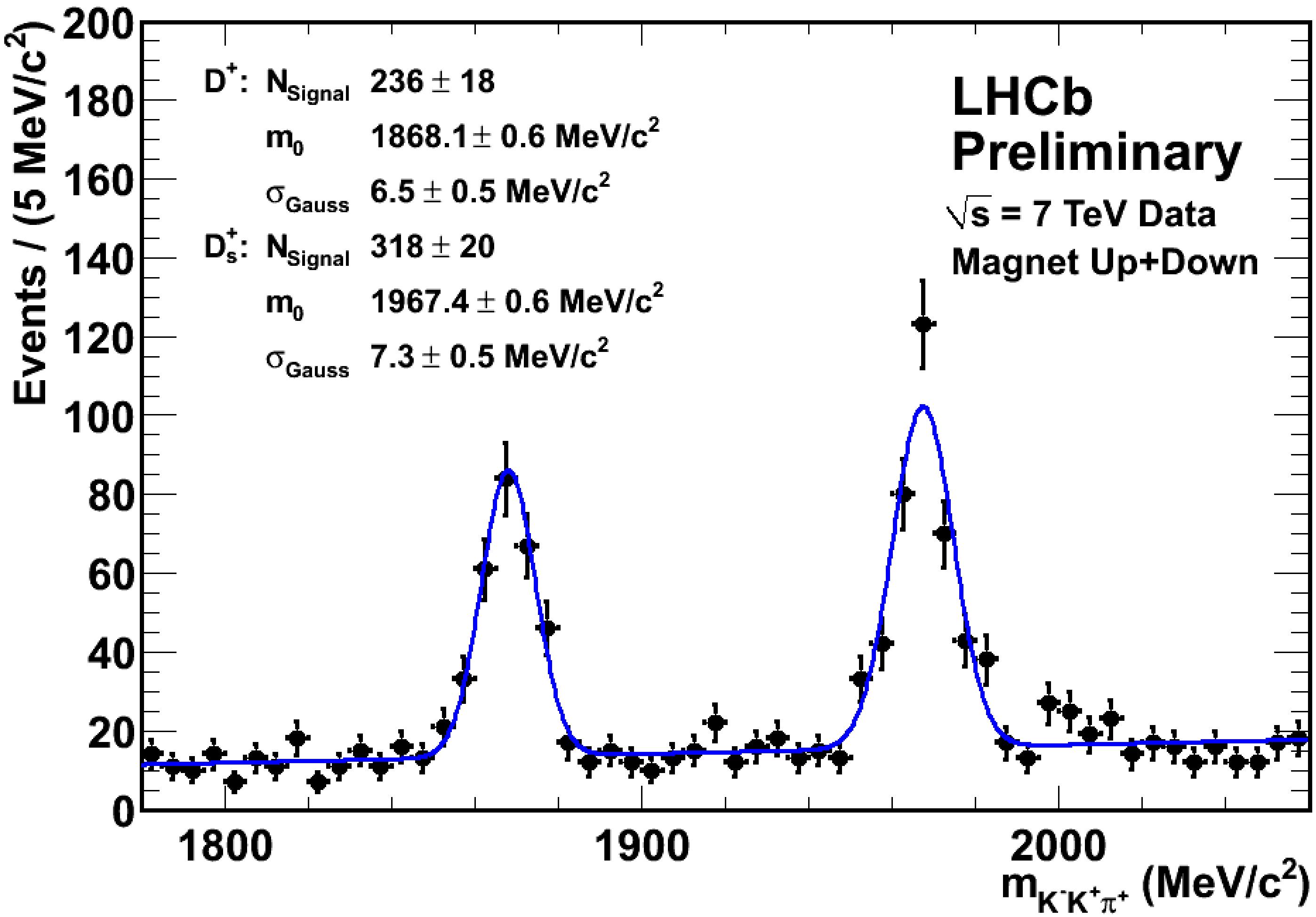
Real Data B_d



~800 μb^{-1}

All $D_{(s)}$->KKπ

~2.6 nb^{-1}

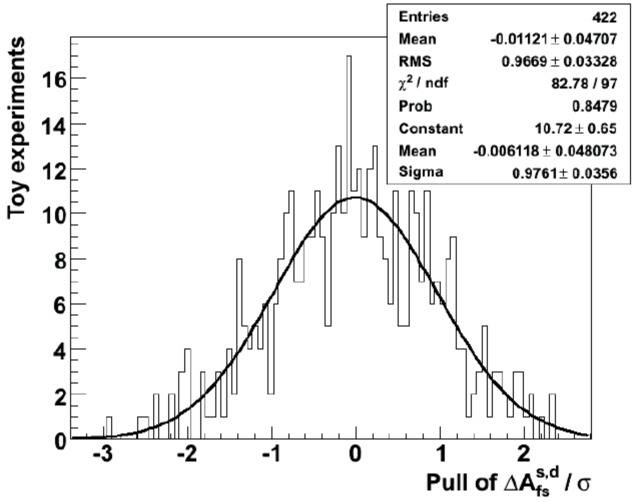


n.b. Selection with no requirement for a muon (need ~40 nb^{-1})

Sensitivities and Outlook

Sensitivity estimates

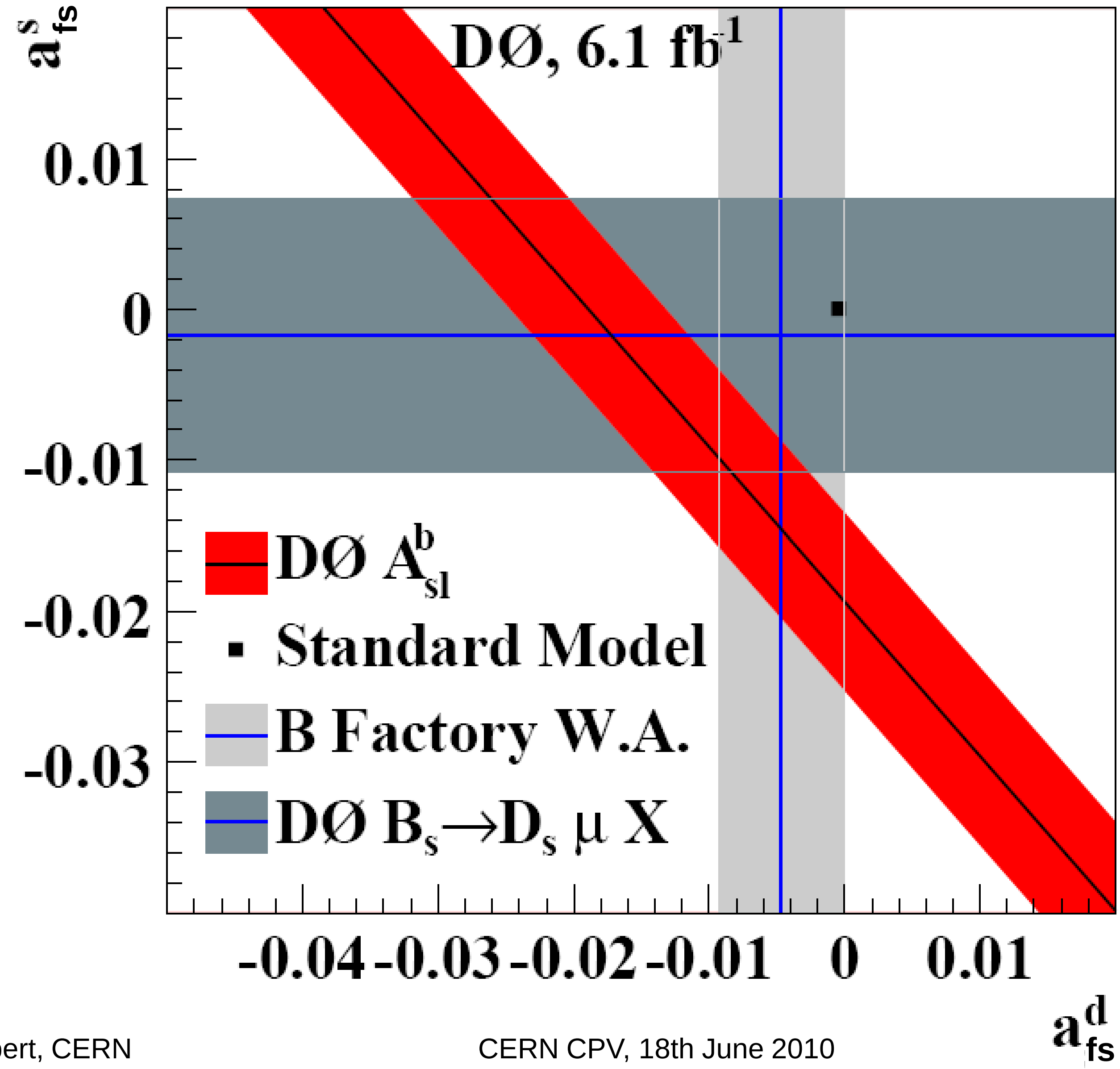
- Full MC used to tune toy MC
- Massive toy MC studies done in:
  - CERN-LHCb-2007-054
  - CERN-THESIS-2008-045
  - CERN-THESIS-2009-001
- Scaled to:
  - Latest Monte Carlo efficiencies
  - $\sigma(bb)$ = 500 μb



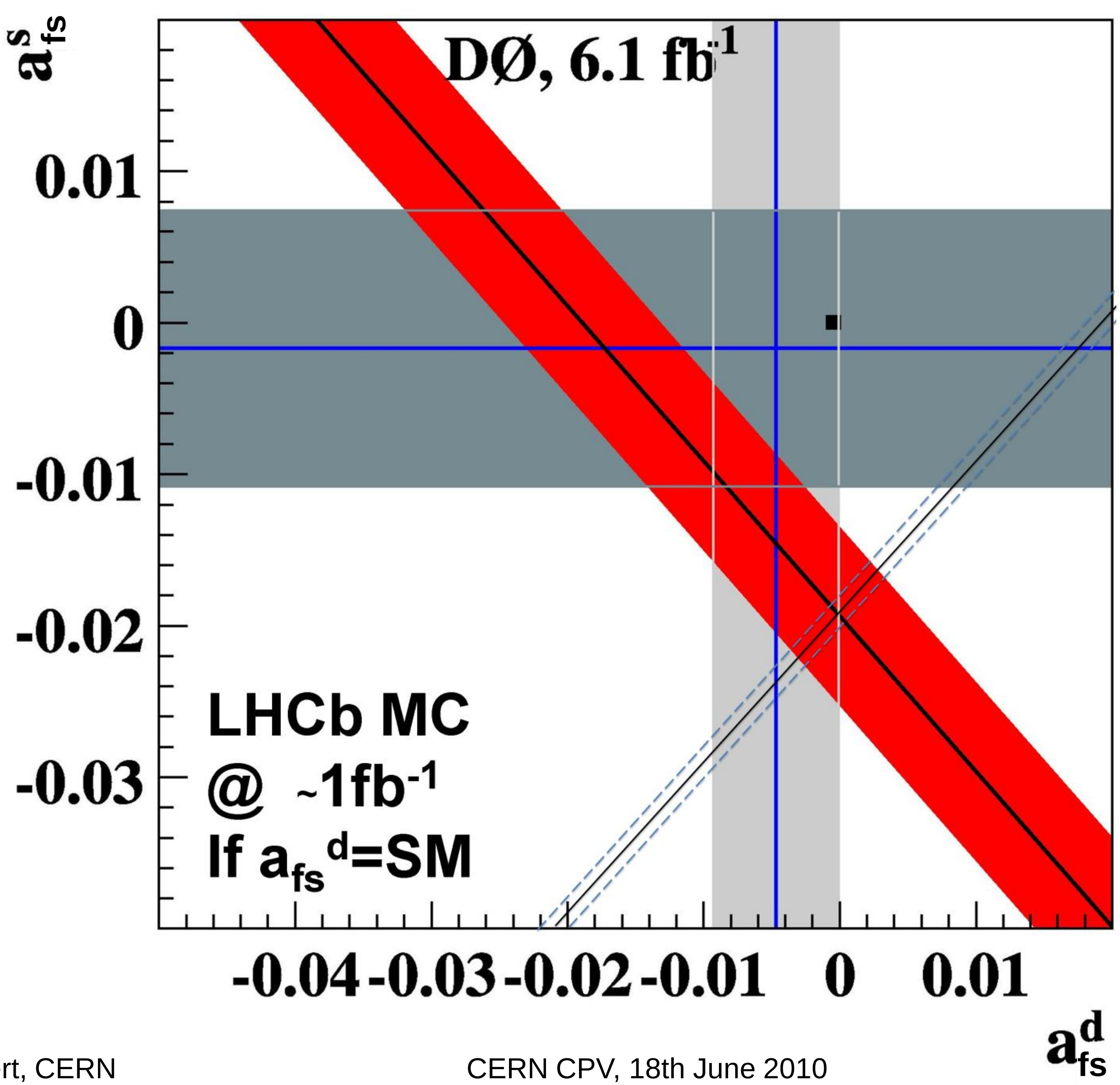
Stat. Error (500 μb)	100 pb^{-1}	1fb^{-1}
a_{fs}^{s} (D_s π)	2.1 x10^{-2}	6.8 x10^{-3}
ΔA_{fs} (D_q $\mu\nu$)	2.0 x10^{-3}	6.3 x10^{-4}

All MC predictions!!
Real data will be worse

Current Results



After 1fb^{-1} of LHCb



Assume
A^b central value
and no NP in B_d

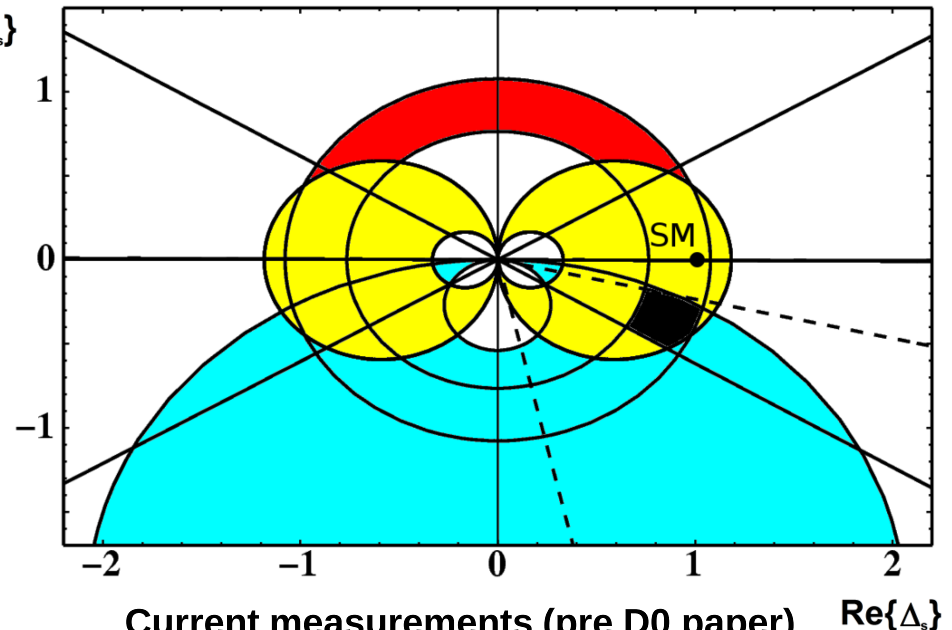
c.f. J/Ψ Φ

hep-ph 0612167

- $B_s^0 \to J/\psi\ \Phi$
  - Directly Measure sin ϕ_s
  - $\sigma(\phi_s) = 0.05^c$ in 1 fb^{-1}
- a_{fs}^s
  - Effectively Measures

$$\mathrm{Im}\left\{\frac{\Gamma_{12}}{M_{12}}\right\}\cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}}{M_{12}}\right\}\sin\Theta$$

  - $\sigma(\Theta) = 0.5^c$ in 1 fb^{-1}

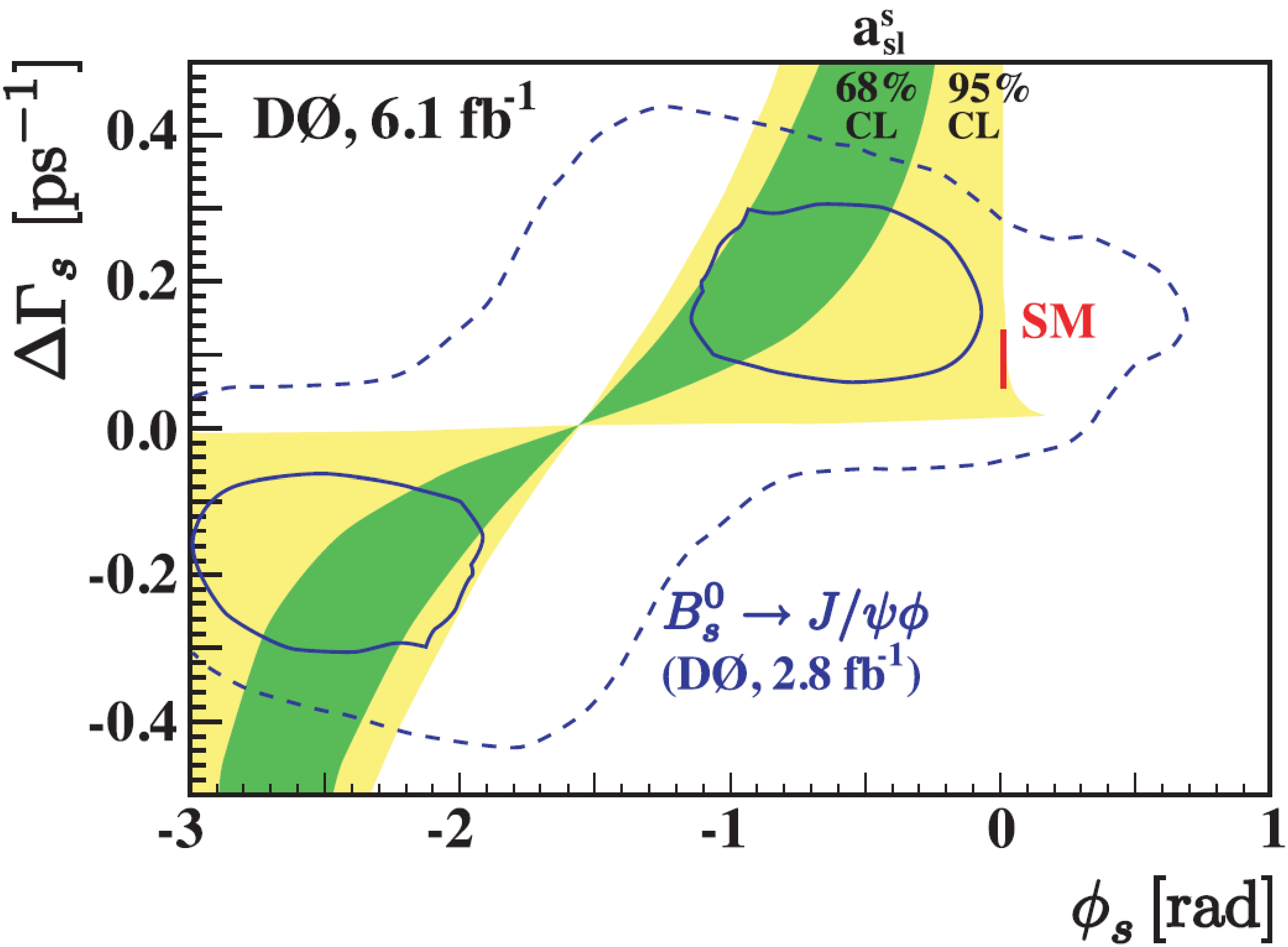


Current measurements (pre D0 paper)

Red : Δm_s
Yellow: $\Delta\Gamma_s$
Black: ϕ_s
Blue: a_{fs}

- But they constrain NP differently
  - Effective power enhanced
  - NB physical limit of a_{fs} is at 4×10^{-3} < current DØ result!

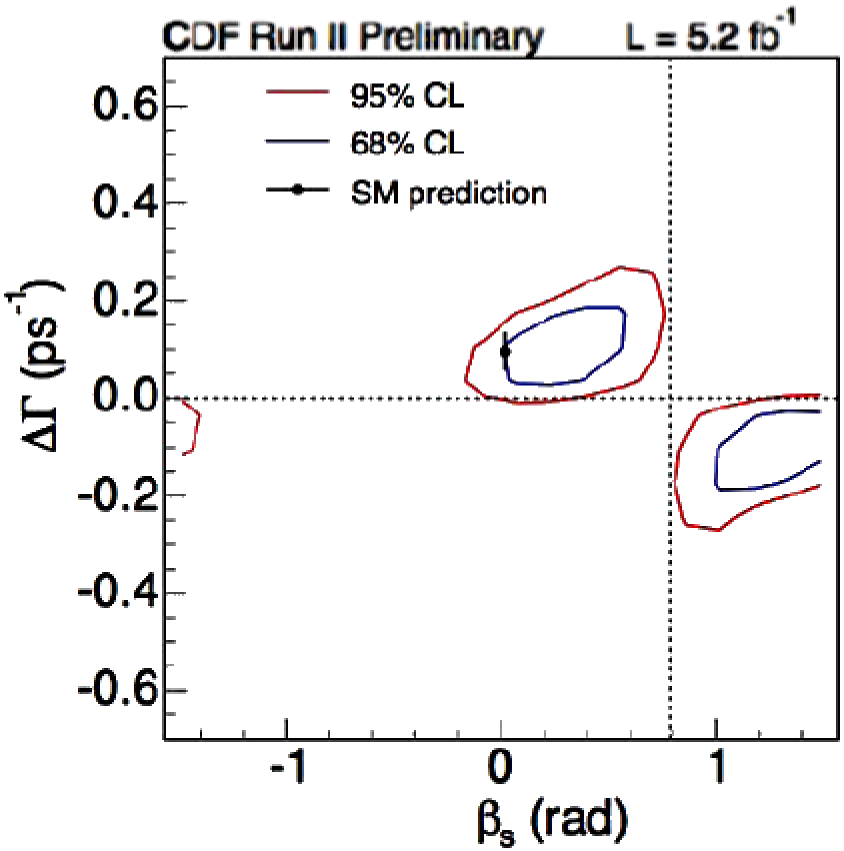
Combining DØ

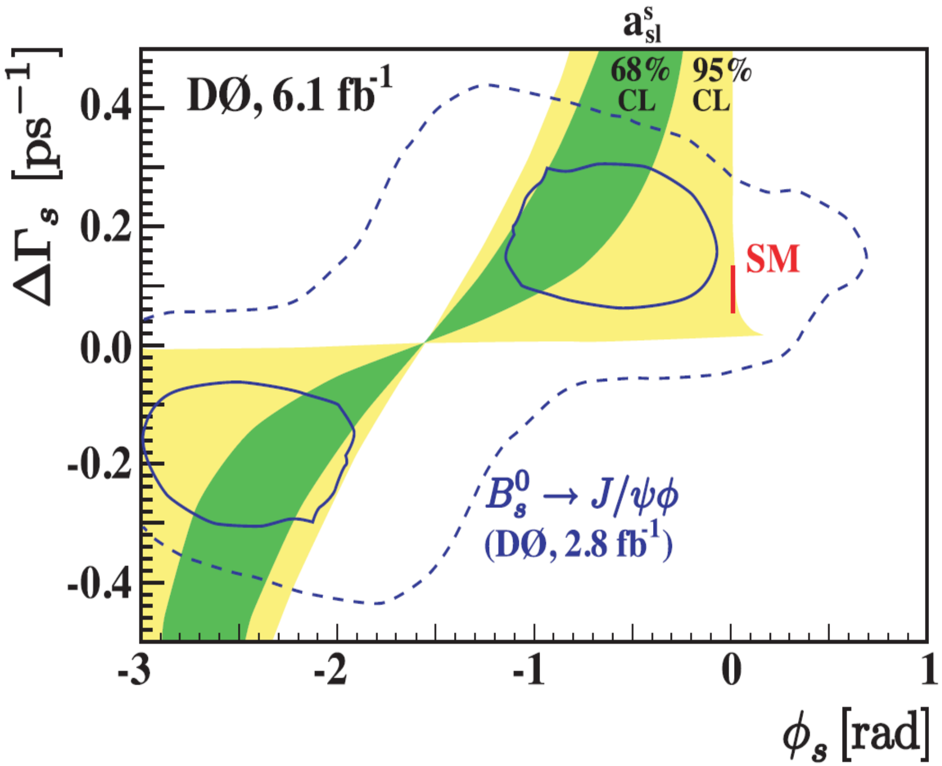


DØ and CDF

- $-2\beta_s = \phi_s$

FPCP 2010

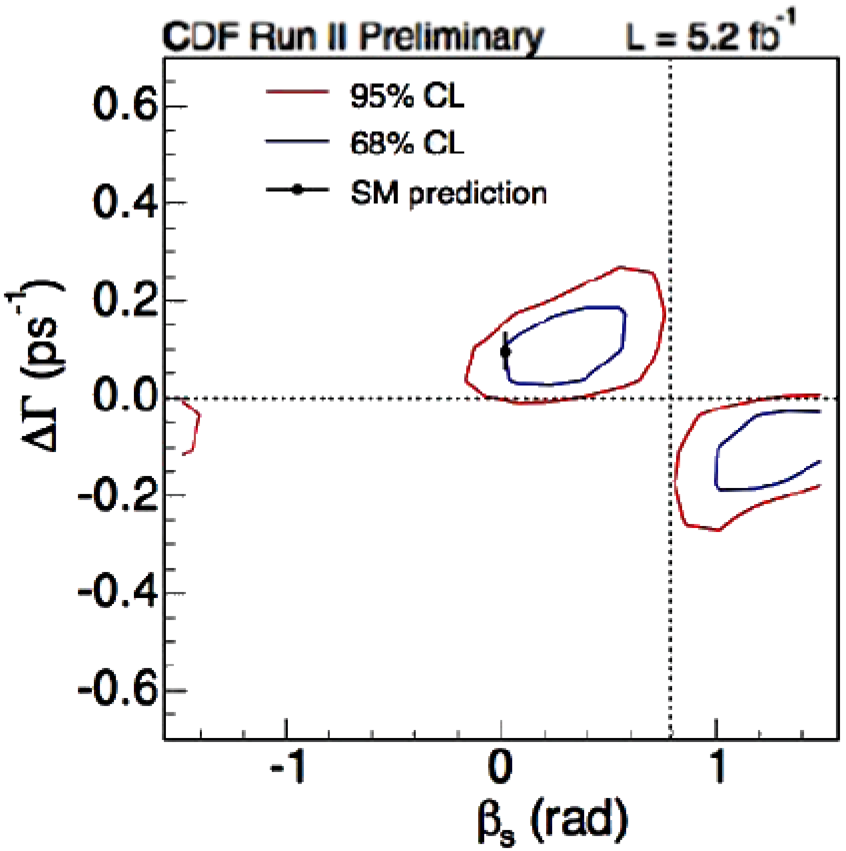


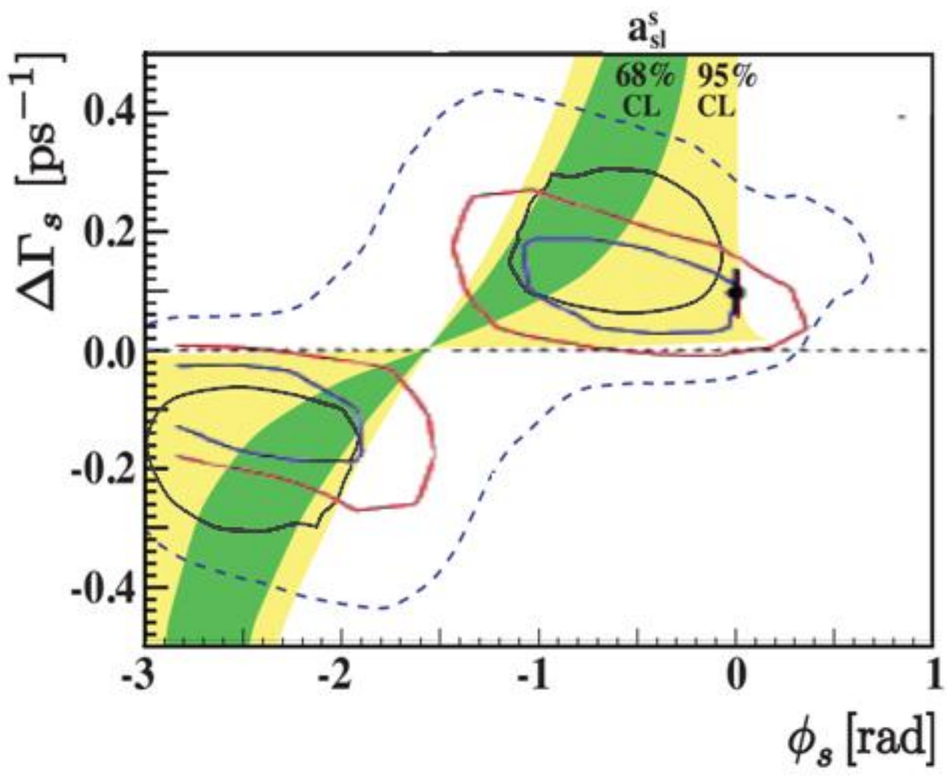


DØ and CDF

- (add my own personal merging)

FPCP 2010





Conclusion

- DØ have made an astounding new measurement (3.2 σ!)

$$A^b = [-9.57 \pm 2.51(\text{stat}) \pm 1.46(\text{syst})] \times 10^{-3}$$

- At LHCb the environment is more hostile, concentrate on:

(a) a^s_{fs} from $B^0_s \to D^{\mp}_s \pi^{\pm}$

✓ Low detector asymmetry, great proper time resolution

(b) $\Delta A^{s,d}_{fs}$ from $B^0_q \to D^{\mp}_q \mu^{\pm} \nu_{\mu} X^0$

✓ Detector and production asymmetries fitted with the data

Stat. Error (500 μb)	100 pb^{-1}	1fb^{-1}
a_{fs}^s (D_s π)	2.1 x10^{-2}	6.8 x10^{-3}
ΔA_{fs} (D_q μν)	2.0 x10^{-3}	6.3 x10^{-4}

All MC predictions!!
Real data will be worse

End

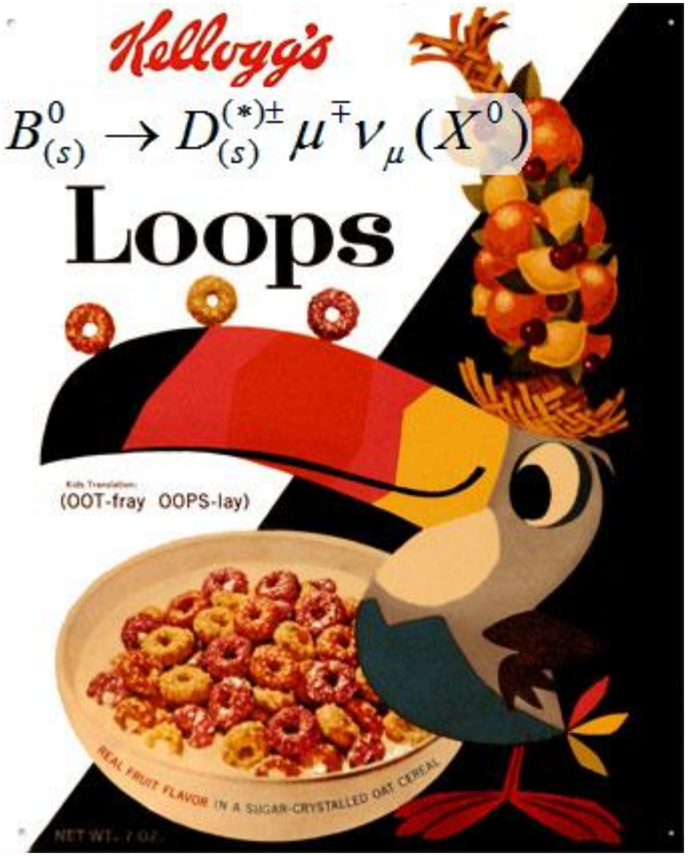
- Backups are often required

Cereal loops

New Physics in special boxes!

Two exciting flavours!

A_{fs} $\Delta\Gamma$ and Δm_s in every box!



Now in bitesize-chunks!

Act now and get your first 10^5 decays free!

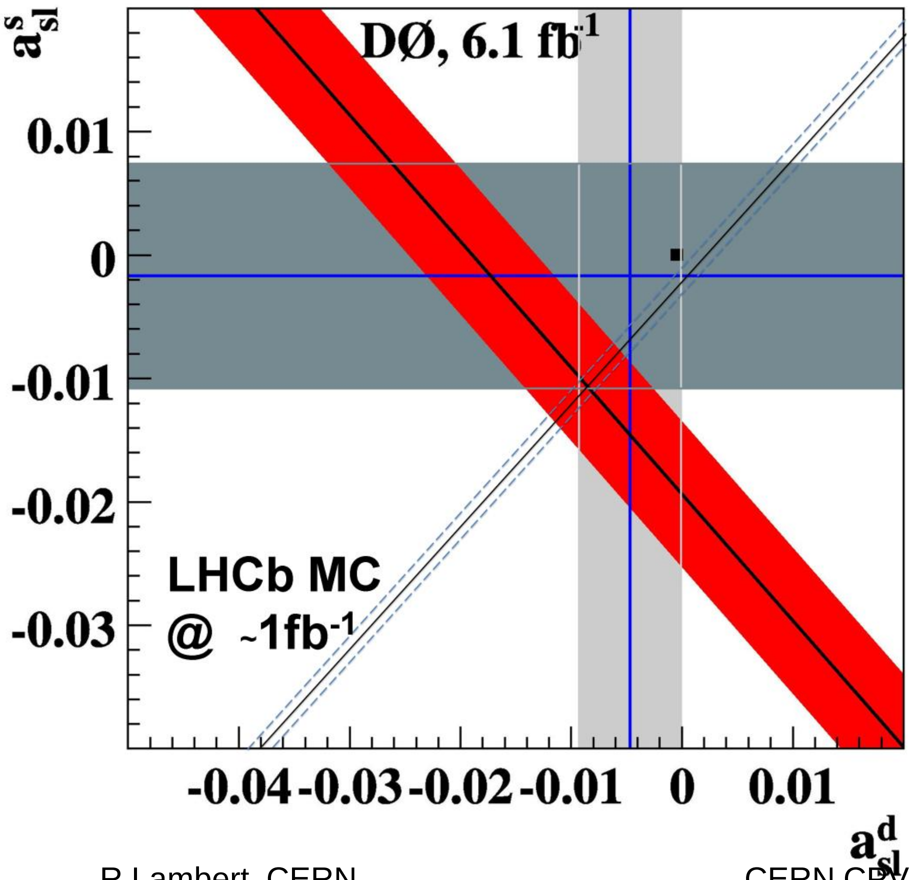
Nomenclature

- A decay to a given state which cannot be reached by the anti-flavour state (at tree level) = flavour-specific
- CP-violating asymmetry in mixing, manifests directly in flavour-specific decays = A_{fs}/a_{fs} flavour-specific asymmetry
- Since this is most readily observed in semi-leptonic decays it is also referred to as A_{sl}
- f a final state of given flavour. $\bar{f}$ its charge conjugate.

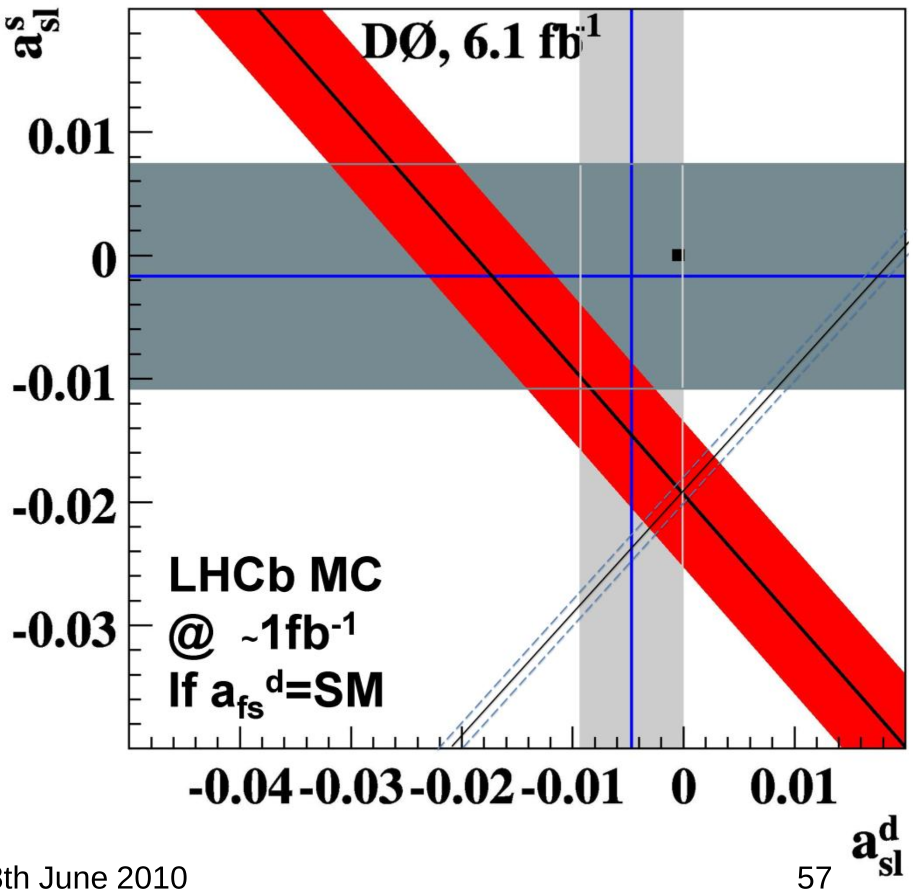
After 1fb^{-1} of LHCb

- LHCb measurement cuts at right-angles
  - really depends what the value is, and if there is NP!

current favoured value

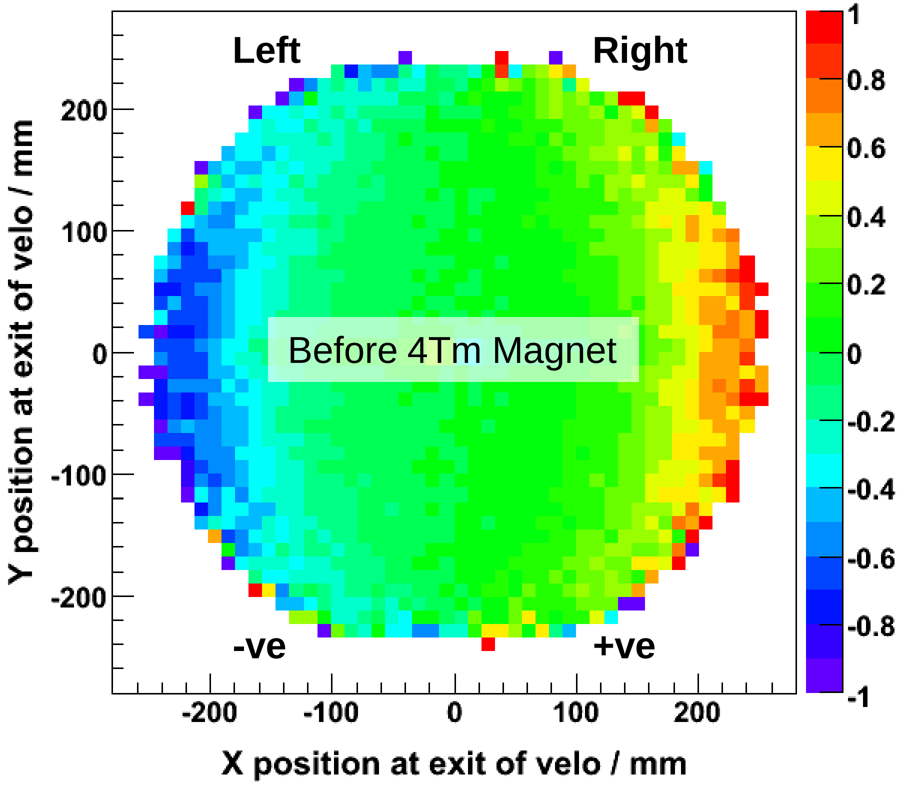


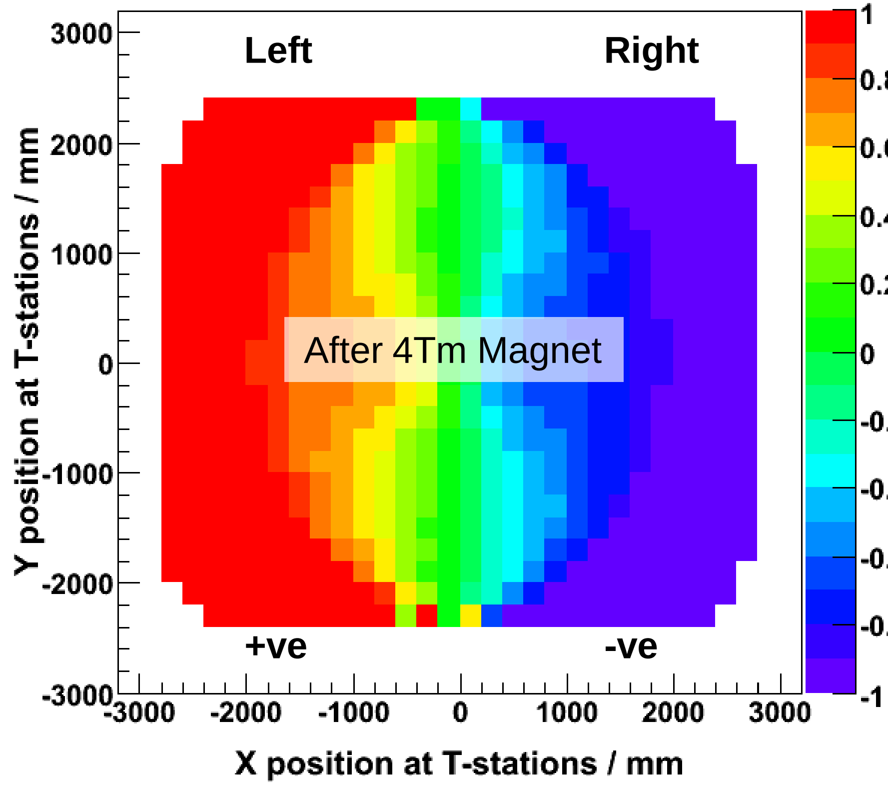
A^b central value and no NP in Bd



Detector Asymmetry, δ_c

Asymmetry from Long Muon Tracks Reconstructed in MC

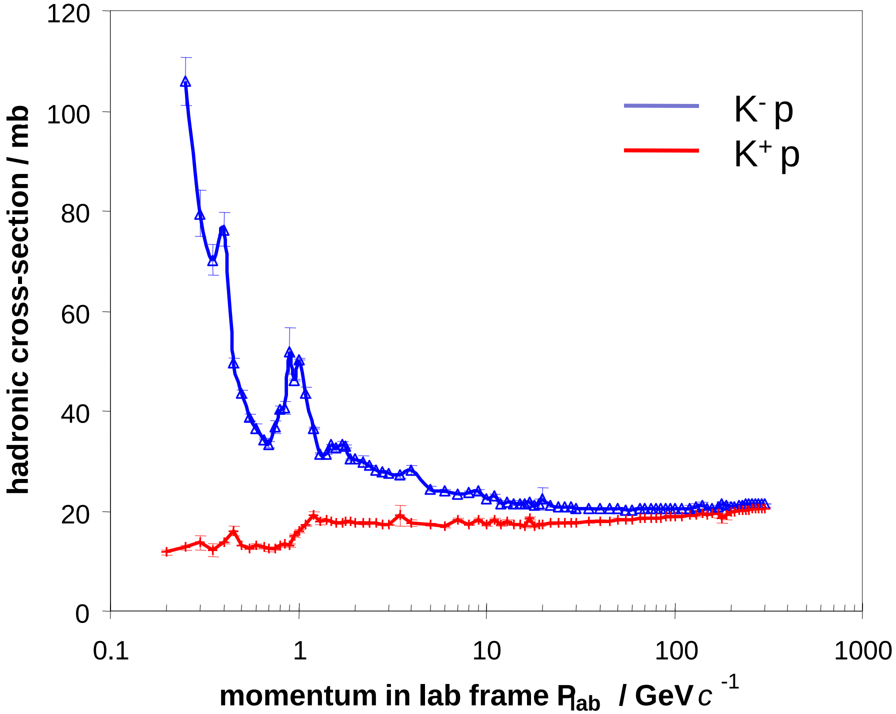




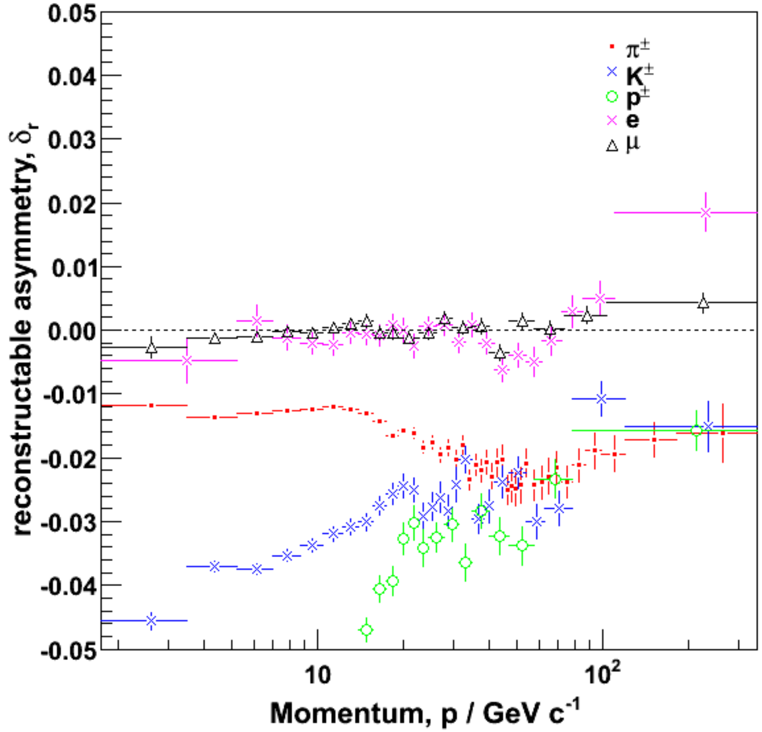
- Magnet divides +/- charge, allowing +/- asymmetry
- by reversing magnet in D0: δ_c reduced from 3% -> ~0.1%

Detector Asymmetry, δ_c

Kaon interaction cross-section



Resultant charge asymmetry (MC)



- ➢ Matter detector → hadronic interactions are asymmetric
- ➢ Dominant systematic at order 1%

Systematics (1)

- $B_s^0 \to D_s^{\mp} \pi^{\pm}$

1. Detector asymmetry
   - **Expect** second order, so < 10^{-4}
   - **Know** the magnitude in real data from the pi momentum spectra
   - **Detect** any bias by binning in momentum
   - **Correct** with MC: Assuming the magnet is reversed!!
2. Production asymmetry
   - **Separate** using the time-dependence
   - **Detect** large bias from this by binning in eta
   - **Measure** production asymmetry, possible but very coarse
3. Background asymmetry
   - **Fit** simultaneously, simply, in the B-mass spectrum

Systematics (2)

- $B_q^0 \rightarrow D_q^{\mp} \mu^{\pm} \nu_{\mu} X^0$

1. Detector asymmetry only second order, so < 10^{-4}
   - **Know** the magnitude in real data from the daughter momenta
   - **Detect** any bias by binning in momentum
   - **Correct** with MC: Assuming the magnet is reversed!!
2. Production asymmetry
   - **Separate** using the time-dependence
   - **Detect** large bias from this by binning in eta
   - **Measure** in $B_s^0 \rightarrow D_s^{\mp} \pi^{\pm}$ can help quantify any bias
3. Background asymmetry
   - **Suppressed** by the effective B/S < 0.1, in the signal region
   - **Fit** simultaneously, 2D fit, in the B-mass and D-mass spectra
   - **Cancel** detector-related part also, only production remains
   - **Detect** bias by binning in eta

The subtraction method

- Take B_s/B_d with the same final states (f=KKπ μ)

$$\Gamma(f) = Ne^{-\Gamma t}\left[(1+x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2+x_3)\cos(\Delta m t)\right]$$

$$\Gamma(\bar{f}) = Ne^{-\Gamma t}\left[(1-x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2-x_3)\cos(\Delta m t)\right]$$

$$\text{where:}\quad x_1 = A_c + a_{fs} \qquad x_2 = 2A_cA_p \qquad x_3 = 2A_p - a_{fs}$$

- All production asymmetry is in x_2/x_3, just throw it away

- Measure the **difference** between B_s and B_d

$$\Delta A_{fs}^{s,d} = \frac{x_1^s - x_1^d}{2} = \frac{a_{fs}^s - a_{fs}^d}{2} \qquad SM = \left(+2.5^{+0.5}_{-0.6}\right)\times 10^{-4}$$

Subtraction method

CERN-THESIS-2009-001
CERN-LHCb-2007-054

- Channel (q = s/d)

$$B_q^0 \to D_q^{\mp} \mu^{\pm} \nu_{\mu} X^0 \qquad D_q^{\pm} \to K^+ K^- \pi^{\pm}$$

- Measures

$$\Delta A_{fs} \approx \frac{a_{fs}^s - a_{fs}^d}{2} \qquad SM = \left(+2.5^{+0.5}_{-0.6}\right) \times 10^{-4}$$

- Complications
  - Requires weak constraints on $\Delta\Gamma$ and Δm
- Mitigating factors
  - Production asymmetry fit simultaneously
  - Detector asymmetry cancelled

Production Asymmetry

- Tuned Pythia samples

δ_p **x1000**	Min Bias (10M)*	bb – inclusive (10M)*	$B_s^0 B_d^0$ (20M) †
Pions	-(4.23 0.16)	-(2.16 0.09)	-(2.27 0.07)
Kaons	-(17.0 0.5)	-(7.73 0.26)	-(8.2 0.2)
Muons	--	+(2.0 1.2)	+(1.0 0.9)
Ds	--	-(1.6 1.1)	-(1.6 1.1)
Bs	--	-(1.9 1.3)	-(1.5 0.8)
Bd	--	-(3.2 0.7)	-(3.2 0.4)

*=standard decays, †=Stable Bd+Bs

- Asymmetries agree with generic bb events