LHCb semileptonic highlights from 2010 and prospects for 2011

Robert W. Lambert

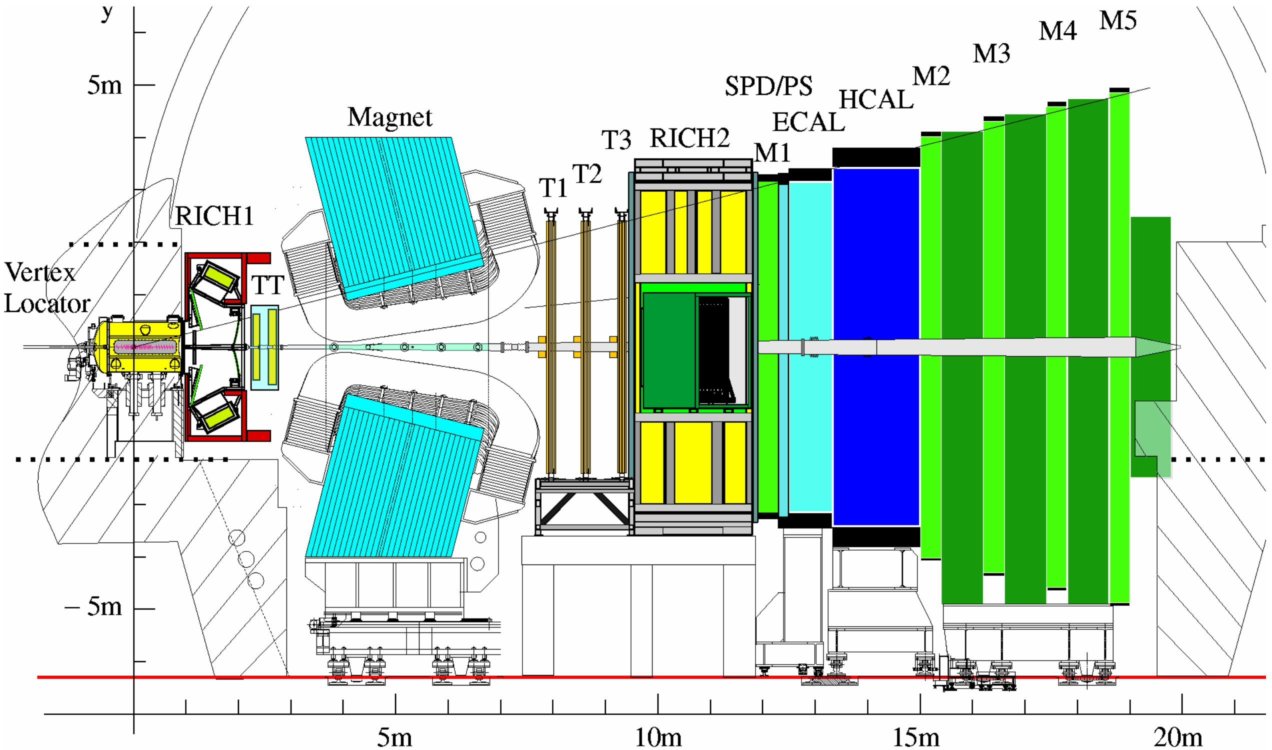
on behalf of the LHCb Collaboration

Outline

- LHC and LHCb
- Semileptonics in general
- Motivation and measurement of $B_s^0 \rightarrow D_{s1,2}^{*\pm} \mu^{\mp} \nu X^0$
- Flavour specific asymmetry

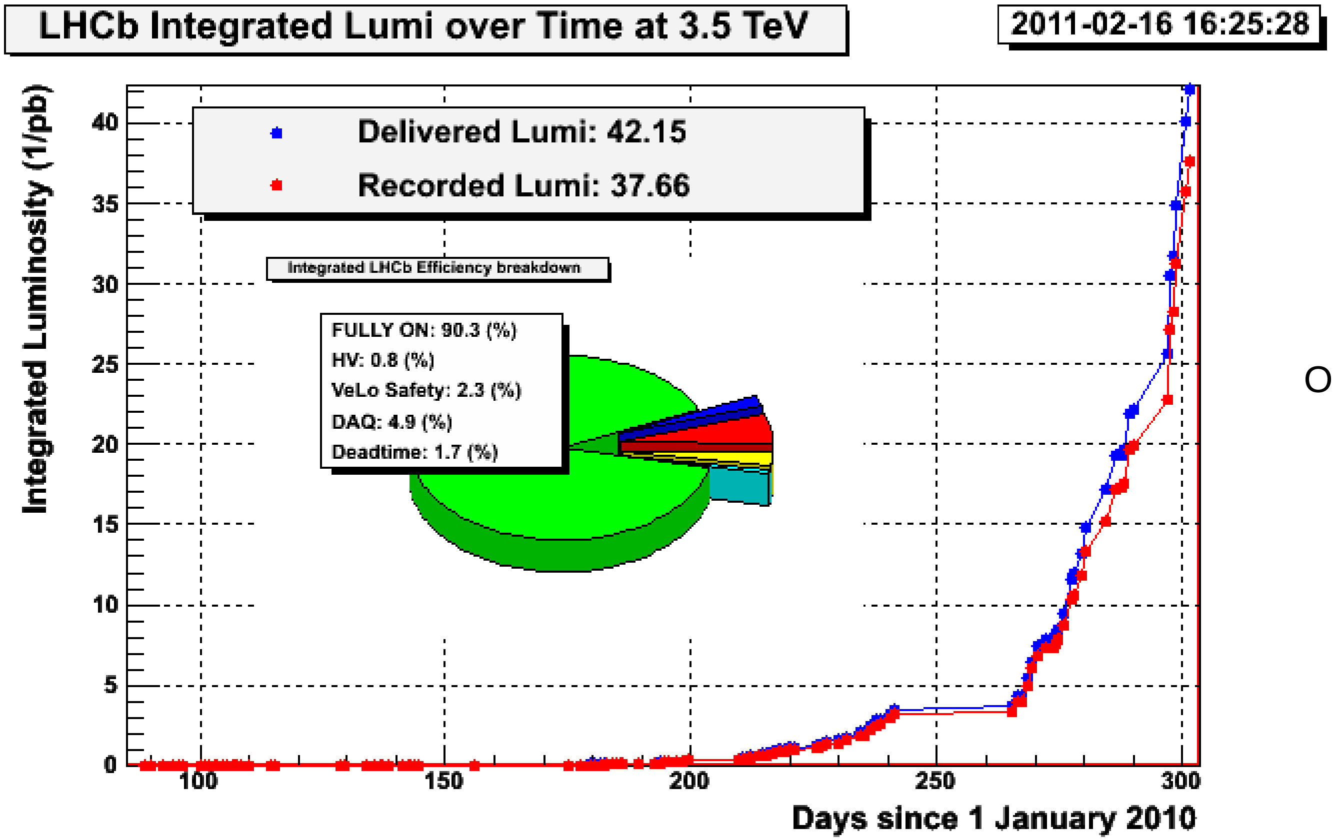
LHCb

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



LHC

- The LHC delivered ~40 pb^{-1} in 2010



Online Luminosity
Estimate

LHC

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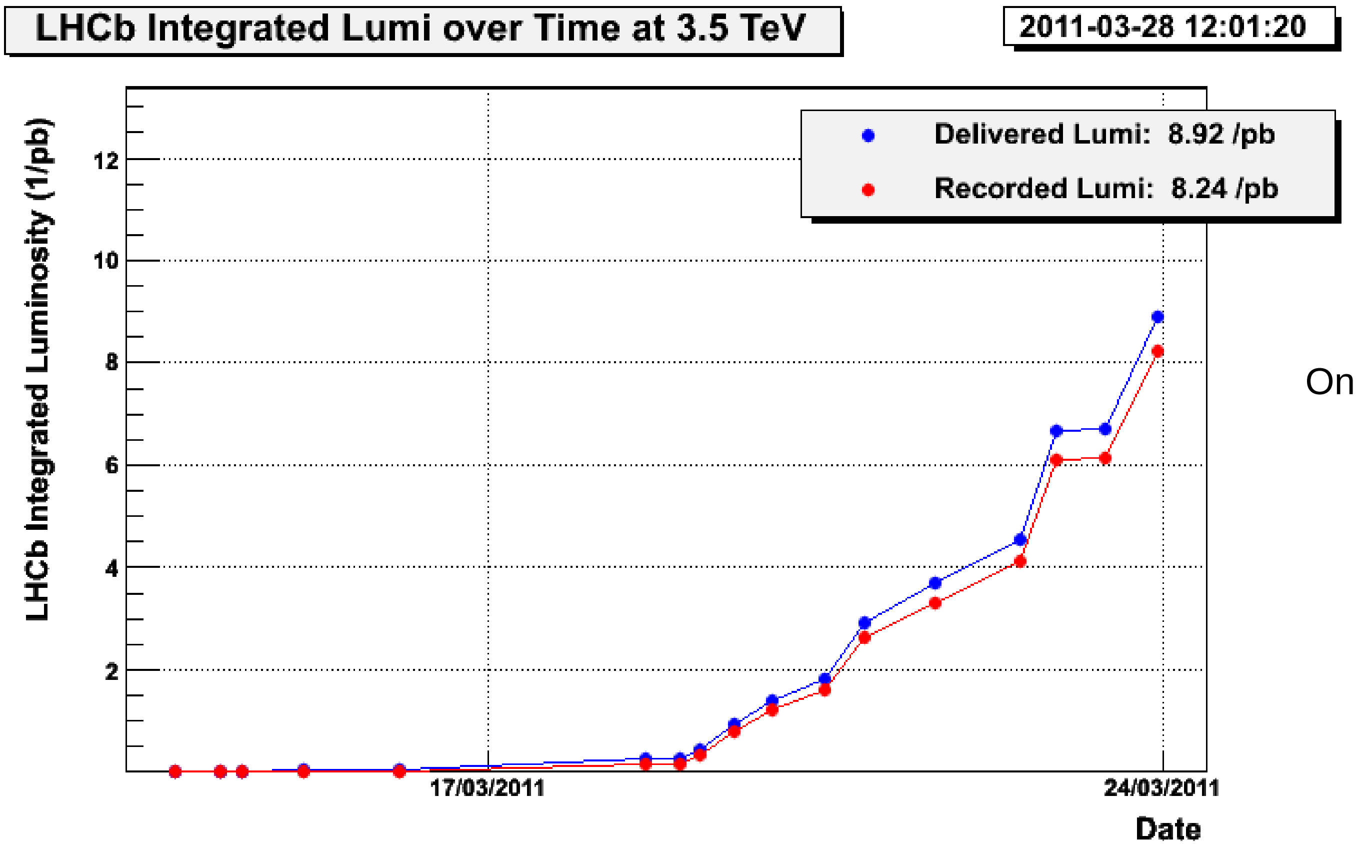


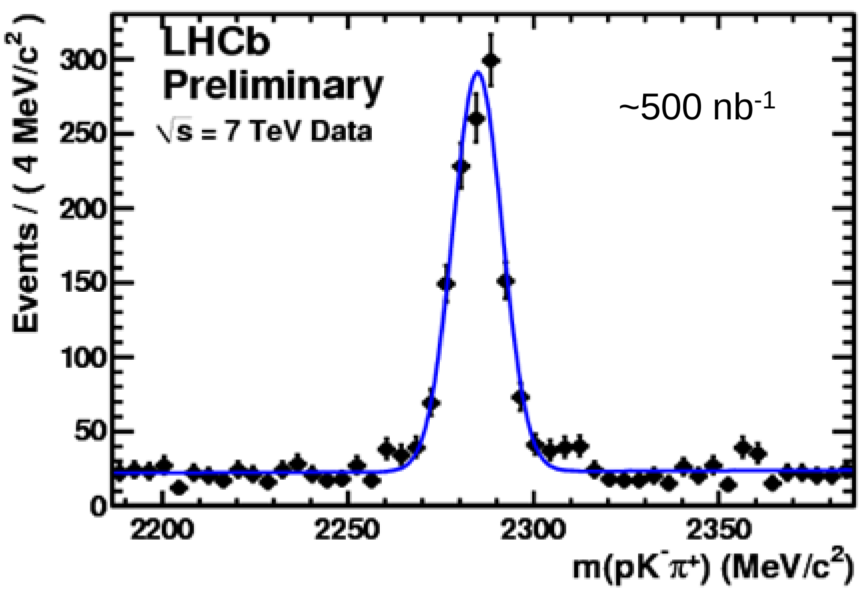
Online Luminosity
Estimate

- 25% more already in 2011!

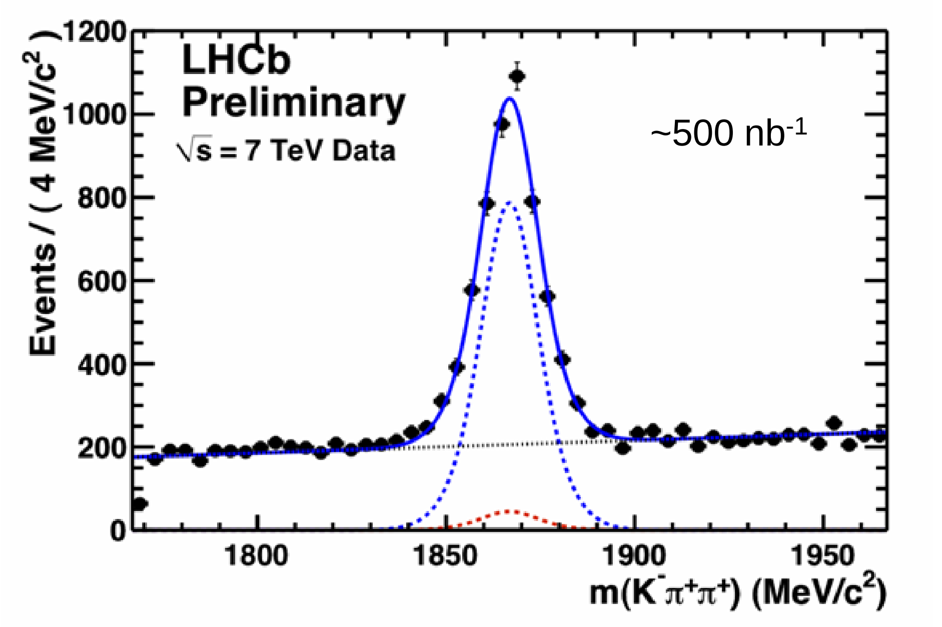
Semileptonic decays

- LHCb reconstructs charmed and charmless B-decays
  - Backgrounds from open charm and other light mesons

$\Lambda_b \rightarrow \Lambda_c \mu \upsilon X$



$X_b \rightarrow D^+ \mu \upsilon X$



- … just a sample of the many reconstructed moded

Semileptonic Program

Production and decay

- Spectroscopy
- Hadronization fractions
- Form factors
- V_{cb}, V_{ub}

B-meson mixing

- Lifetime
- Mass difference
- Width difference
- Flavour-specific asymmetry

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2010, 2011

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B-meson mixing

- Lifetime
- Mass difference
- Width difference
- Flavour-specific asymmetry

2010, 2011

Highlights to cover here:

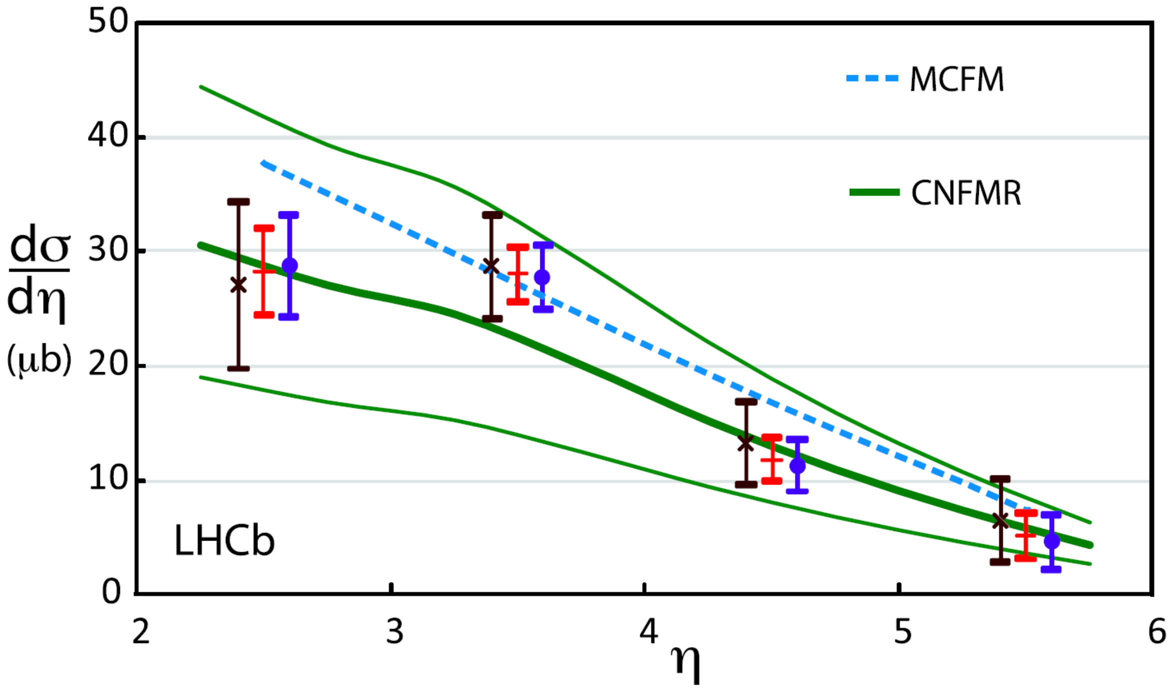
- **First LHC *b*-physics paper**
- **New D** decays of *B*-mesons**
- **Prospects for flavour-specific asymmetry**

See Niels Tuning from Tuesday, and Stefania Vecchi from Monday

$b\bar{b}$ cross-section

Phys. Lett. B 694 pp. 209
arxiv:1009.2731

- First LHCb *b*-physics paper, $\mathcal{L}$=(15.0±1.5)nb^{-1}
- $\sigma_{b\bar{b}}$ from semileptonic decays of the form $X_b \rightarrow D^0 \mu \upsilon X$



See Niels Tuning from Tuesday

- Scale to full rapidity: $\sigma\left(pp \rightarrow b\bar{b}X\right) = \left(284 \pm 20 \pm 49\right)\mu b$

$b\bar{b}$ cross-section

Phys. Lett. B 694 pp. 209
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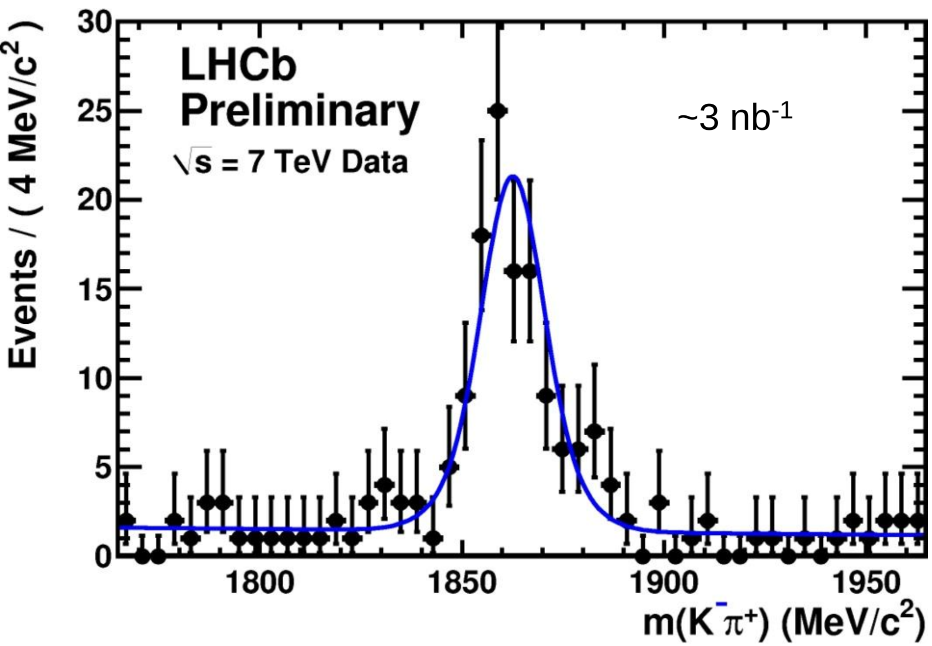
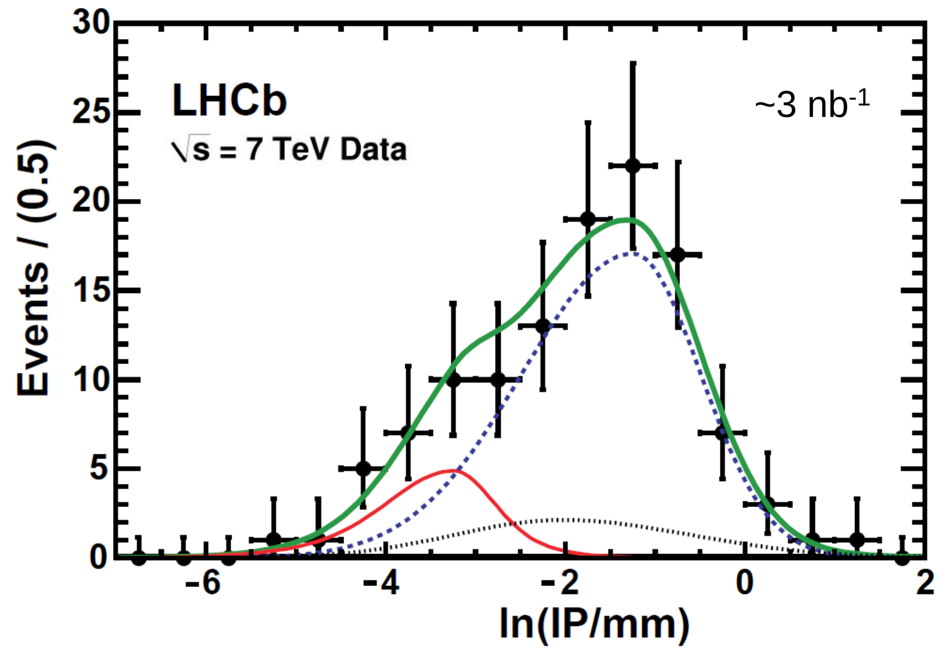




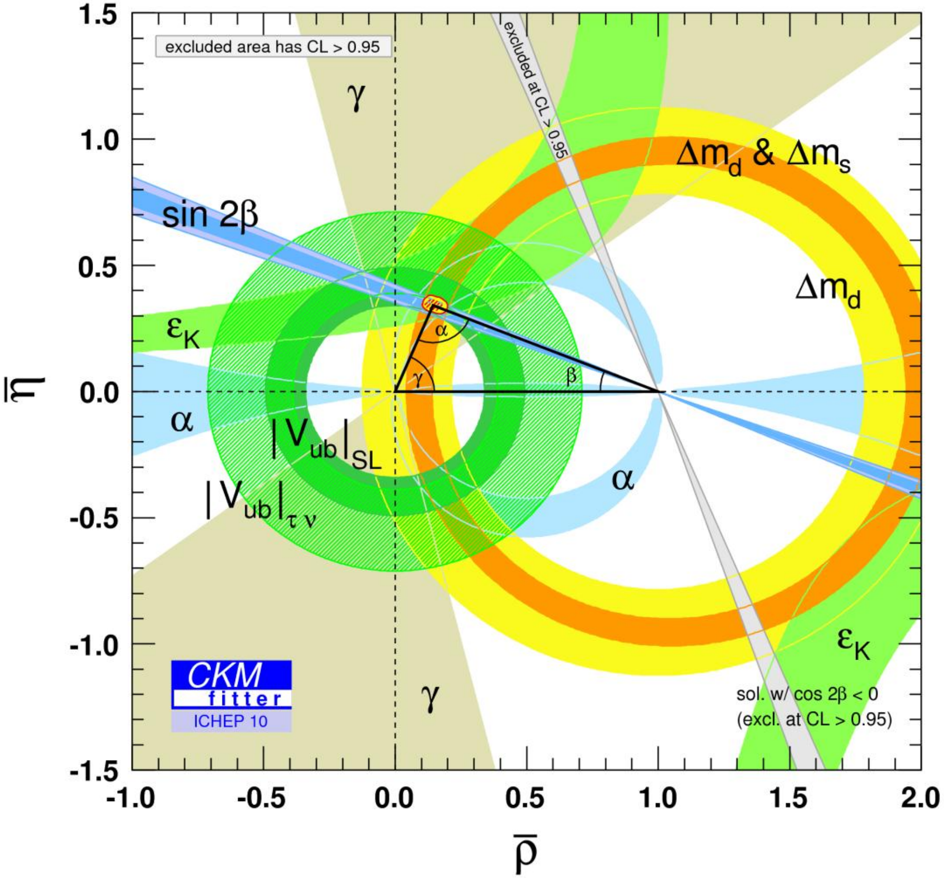
- ln(IP) distribution used to discriminate prompt contribution

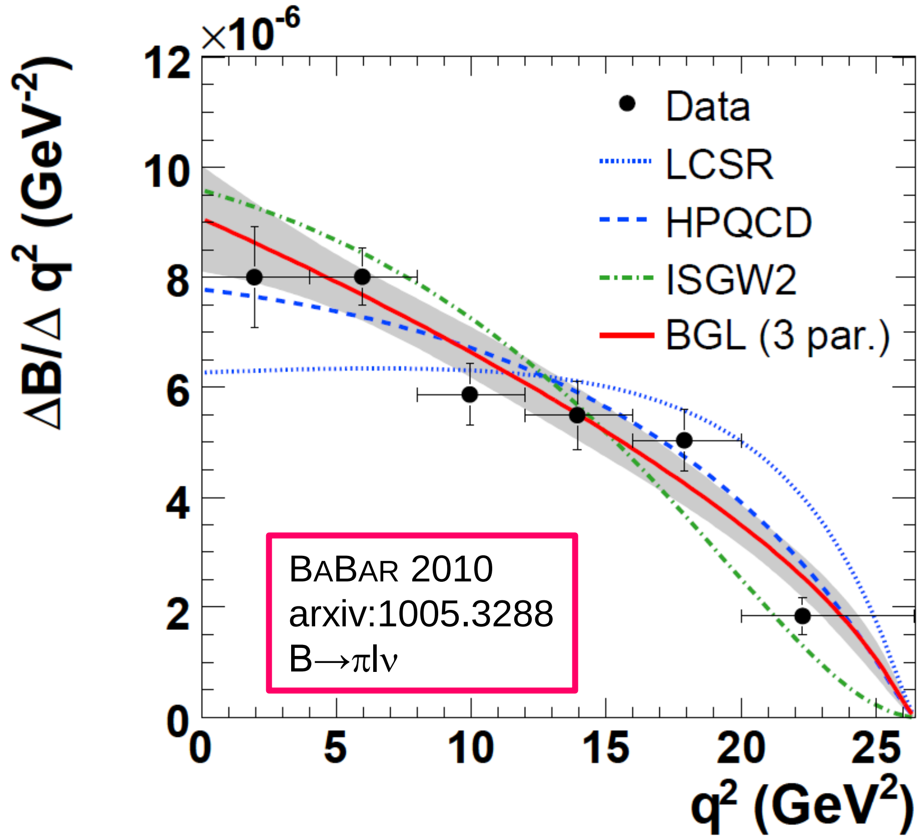
Progress towards $V_{(u/c)b}$

Measurement of $B_s^0 \to D_{s1,2}^{*\pm} \mu^{\mp} \nu X^0$

First Motivation: $V_{(u/c)b}$

- Constrains UT and/or measures form factors





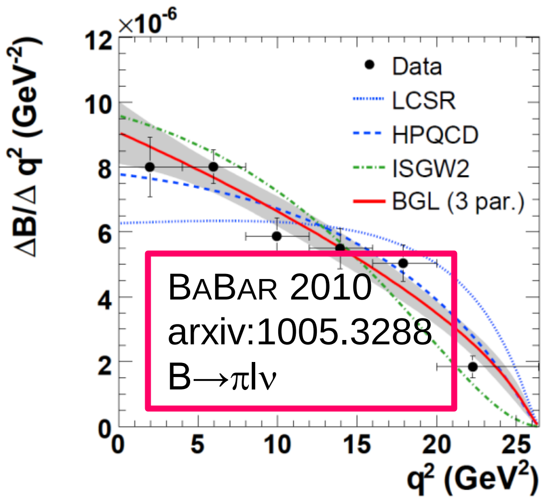
- LHCb also probes $V_{(u/c)b}$ in the B_s system

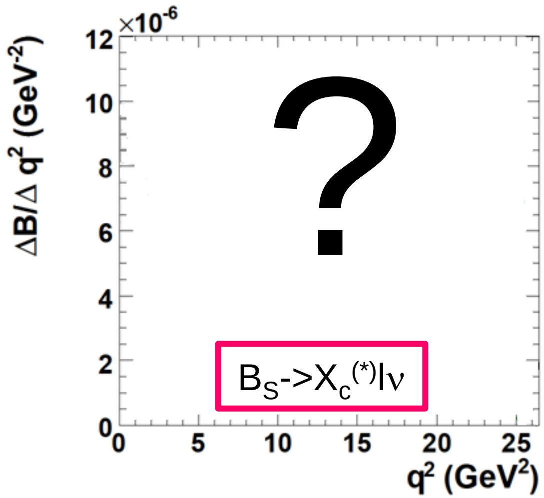
Complementarity

➢ To determine V_{ub}, we must first understand V_{cb}

X In the B_s system, very little is known phenomenologically

- X Form factors unknown, expected to differ in q^2 shape





✓ Theory interest and input encouraged

Complementarity

- To determine V_{ub}, we must first understand V_{cb}

X In the B_s system, very little is known experimentally

  X Excited D resonances unknown

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D \ell^+ \nu_\ell$ anything		(9.3 ± 0.9) %		–
$D^- \ell^+ \nu_\ell$	[nnn]	(2.17 ± 0.12) %		2309
$D^- \tau^+ \nu_\tau$		(1.1 ± 0.4) %		1909
$D^*(2010)^- \ell^+ \nu_\ell$	[nnn]	(5.01 ± 0.12) %		2257
$D^*(2010)^- \tau^+ \nu_\tau$		(1.5 ± 0.5) %	S=1.3	1837
$\overline{D}^0 \pi^- \ell^+ \nu_\ell$		$(4.3 \pm 0.6) \times 10^{-3}$		2308
$D_0^*(2400)^- \ell^+ \nu_\ell \times$ B$(D_0^{*-} \to \overline{D}^0 \pi^-)$		$(3.0 \pm 1.2) \times 10^{-3}$	S=1.8	–
$D_2^*(2460)^- \ell^+ \nu_\ell \times$ B$(D_2^{*-} \to \overline{D}^0 \pi^-)$		$(2.2 \pm 0.6) \times 10^{-3}$		2067
$\overline{D}^{(*)} n\pi \ell^+ \nu_\ell (n \geq 1)$		(2.3 ± 0.5) %		–
$\overline{D}^{*0} \pi^- \ell^+ \nu_\ell$		$(4.9 \pm 0.8) \times 10^{-3}$		2256
$D_1(2420)^- \ell^+ \nu_\ell \times$ B$(D_1^- \to \overline{D}^{*0} \pi^-)$		$(2.80 \pm 0.28) \times 10^{-3}$		–
$D_1'(2430)^- \ell^+ \nu_\ell \times$ B$(D_1'^- \to \overline{D}^{*0} \pi^-)$		$(3.1 \pm 0.9) \times 10^{-3}$		–
$D_2^*(2460)^- \ell^+ \nu_\ell \times$ B$(D_2^{*-} \to \overline{D}^{*0} \pi^-)$		$(1.2 \pm 0.5) \times 10^{-3}$	S=2.7	2067
$\rho^- \ell^+ \nu_\ell$	[nnn]	$(2.47 \pm 0.33) \times 10^{-4}$		2583
$\pi^- \ell^+ \nu_\ell$	[nnn]	$(1.34 \pm 0.08) \times 10^{-4}$		2638

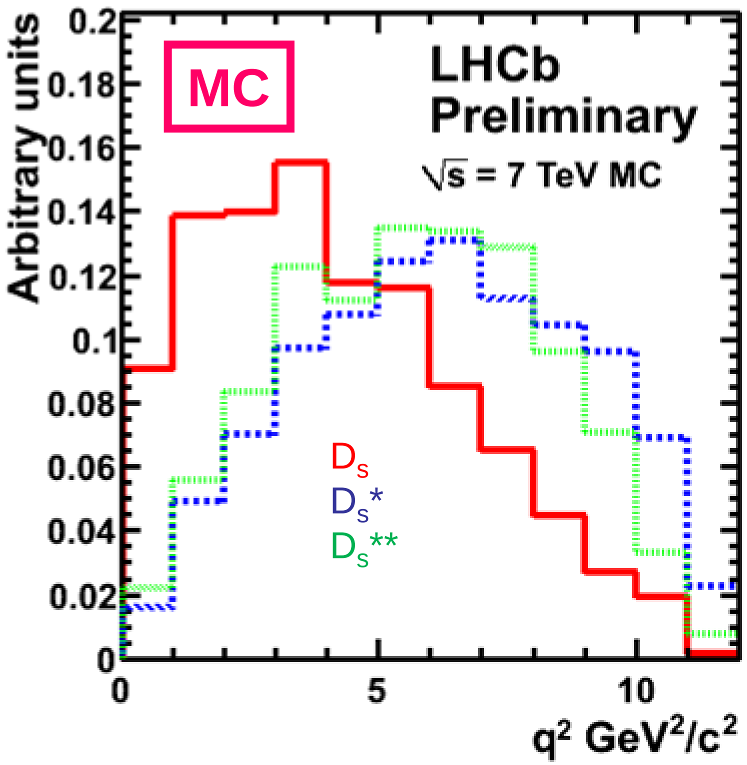
(my copy of the PDG 2010)

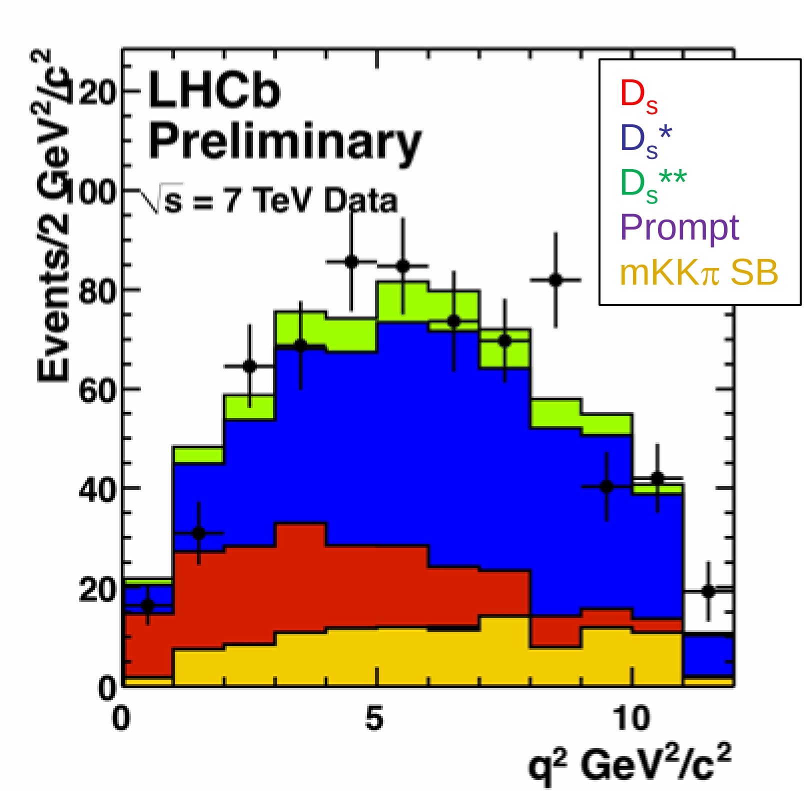
B_s^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
D_s^- anything		(93 ± 25) %		–
$D_s^- \ell^+ \nu_\ell$ anything	[gggg]	(7.9 ± 2.4) %		–
$D_{s1}(2536)^- \mu^+ \nu_\mu X \times$ B$(D_{s1}^- \to D^{*-} K_S^0)$		$(2.4 \pm 0.7) \times 10^{-3}$		–
$D_s^- \pi^+$		$(3.2 \pm 0.5) \times 10^{-3}$		2320
$D_s^- \pi^+ \pi^+ \pi^-$		$(8.4 \pm 3.3) \times 10^{-3}$		2301
$D_s^\mp K^\pm$		$(3.0 \pm 0.7) \times 10^{-4}$		2292
$D_s^+ D_s^-$		(1.04 ± 0.35) %		1823
$D_s^{*+} D_s^-$		< 12.1 %	90%	1742
$D_s^{*+} D_s^{*-}$		< 25.7 %	90%	1655

✓ There are many more resonances to be found!

Interplay

- The form factors in q^2 differ for the different excited states
  - Neither branching ratios nor form factors are well known!





- Need to experimentally constrain ratio of D** : D*

D** branching ratios

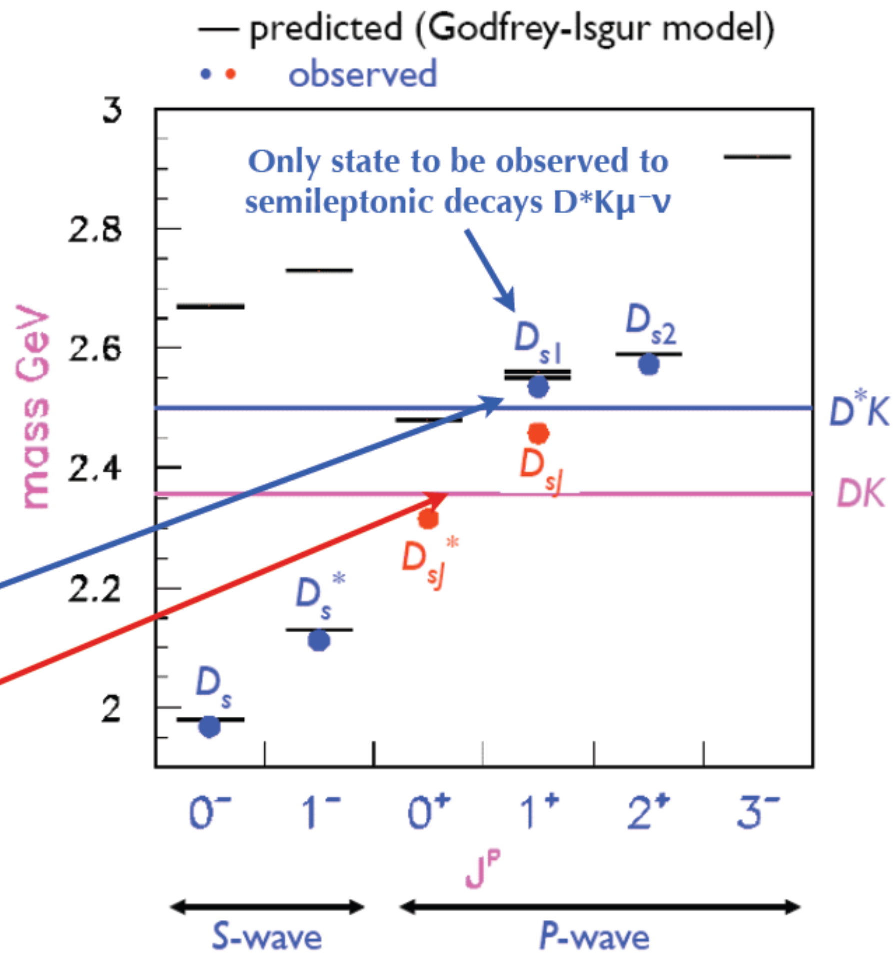
Phys. Rev. D 32, pp. 189–231 (1985)

- Spectroscopy of D_s states is very rich

✓ D_{s1}, D_{s2} decay to $D^{(*)}K$

∴ $D^{(*)}K$ resonance search

- Can measure relative BR



D_{s1}', D_{s2}^{*} → $D^{(*)}$ K, small $D_s^{(*)+}$ n π contribution

$D_{sj}^{(*)}$ → $D_s^{(*)+}$ n π^0/γ

Analysis strategy

Phys. Lett. B 698 pp.14-20,2011
arXiv:1102.0348

- Quickly changing 2010 conditions
- Need to subdivide into two datasets
  - 3 pb^{-1}, small pileup, inclusive single-muon trigger
  - 20 pb^{-1}, larger pileup, any trigger (hadronic, muonic, random)

1. Observe D^0K modes in both samples
2. Measure significance, widths and masses in 20 pb^{-1}
3. Determine ratio of D^0K yields in 20 pb^{-1}
4. Normalize to total SL-width within the 3 pb^{-1}
   - (due to the inclusive triggering)

1: Observe D^0K modes

Phys. Lett. B 698 pp.14-20,2011
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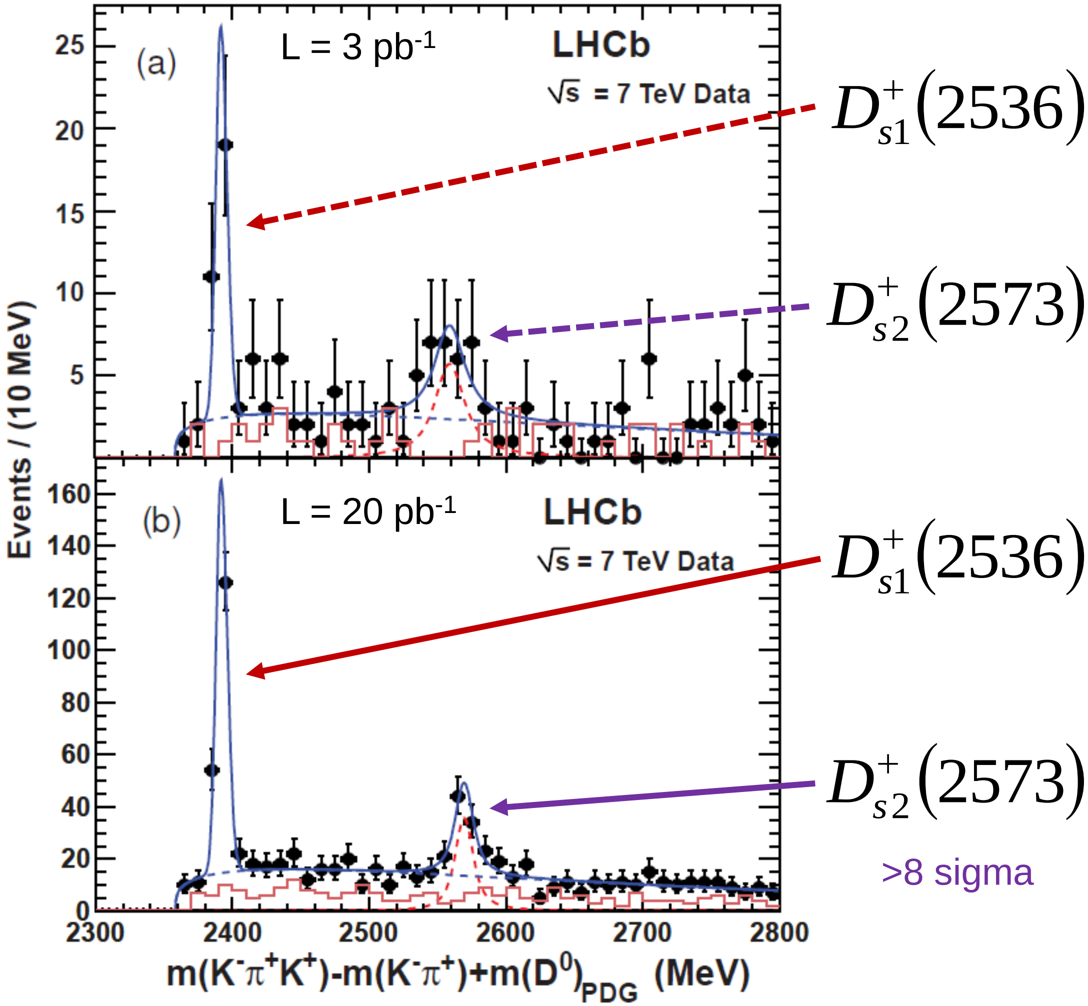
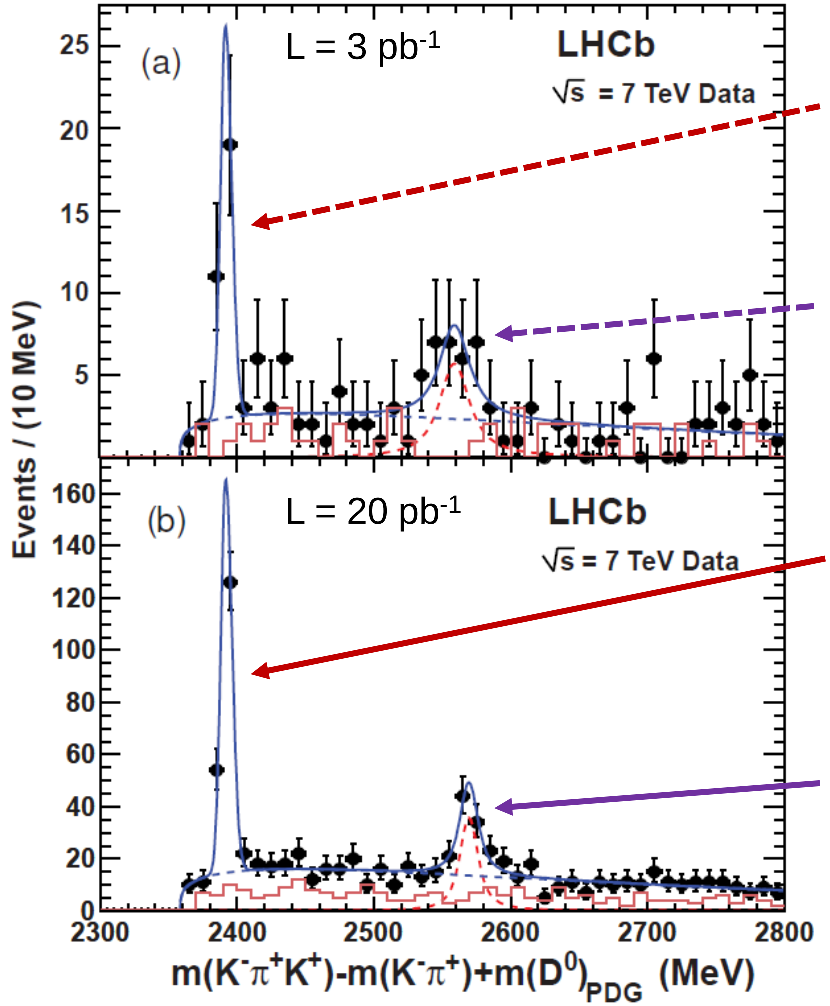


>8 sigma

2: Masses and widths

Phys. Lett. B 698 pp.14-20,2011
arXiv:1102.0348



$D_{s1}^{+}(2536)$

Axial vector … need an extra π^0/γ
Lower mass from missing π^0/γ
MC prediction 2392 $MeVc^{-2}$

$D_{s2}^{+}(2573)$

No need for extra π^0/γ
Almost at PDG mass (~2570)

$D_{s1}^{+}(2536)$

Events	155	±	15
Mass [$MeVc^{-2}$]	2391.6	±	0.5
Width [$MeVc^{-2}$]	4.0	±	0.4

$D_{s2}^{+}(2573)$

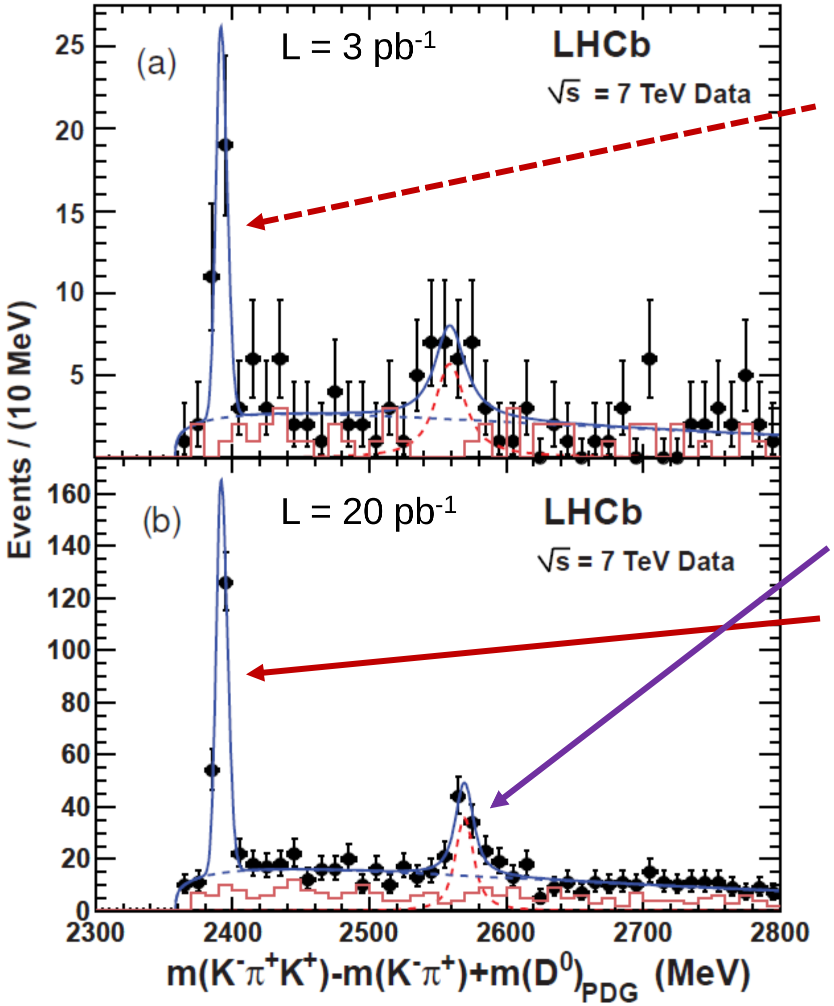
>8 sigma

Events	82	±	17
Mass [$MeVc^{-2}$]	2569.4	±	1.6
Width [$MeVc^{-2}$]	12.1	±	4.5

(stat errors)

3: Ratio Measurements

Phys. Lett. B 698 pp.14-20,2011
arXiv:1102.0348



Measure BR:

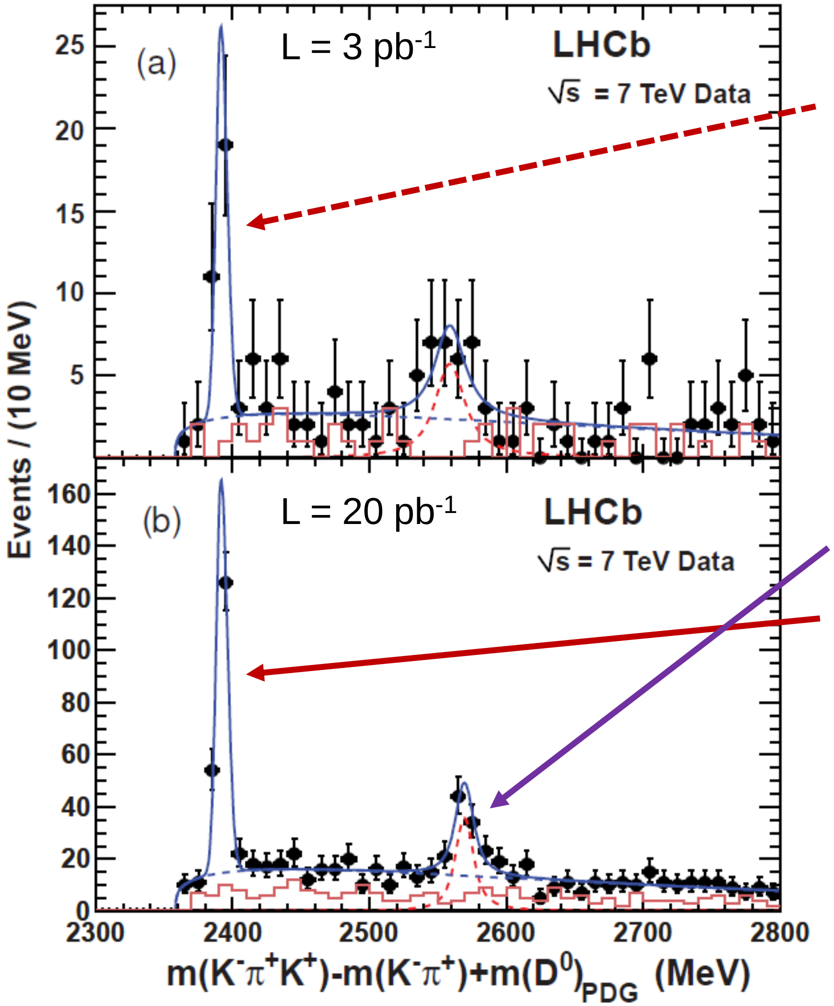
$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_{s1}^+ X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}_s^0 \to X \mu^- \overline{\nu})} = (5.4 \pm 1.2 \pm 0.5)\%$$

Relate both exclusive BR:

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_{s2}^{*+} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}_s^0 \to D_{s1}^+ X \mu^- \overline{\nu})} = 0.61 \pm 0.14 \pm 0.05$$

4: Branching Ratios

Phys. Lett. B 698 pp.14-20,2011
arXiv:1102.0348



Measure BR:

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^+_{s1} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = (5.4 \pm 1.2 \pm 0.5)\%$$

X

Relate both exclusive BR:

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to D^+_{s1} X \mu^- \overline{\nu})} = 0.61 \pm 0.14 \pm 0.05$$

=

Calculated exclusive BR:

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = (3.3 \pm 1.0 \pm 0.4)\%$$

Partial Summary

- From:

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^+_{s1} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = (5.4 \pm 1.2 \pm 0.5)\%$$

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to D^+_{s1} X \mu^- \overline{\nu})} = 0.61 \pm 0.14 \pm 0.05$$

- We constrain the D** branching ratios
  - ✓ Important for the attempt on V_{cb}
- We now use these measurements in our MC
  - ✓ Important for MC-corrections of missing neutrino
  - ∴ Important for many other SL measurements
  - … such as …

Flavour-specific asymmetry

Surprise!

Fermilab-Pub-10/114-E

Evidence for an anomalous like-sign dimuon charge asymmetry

V.M. Abazov,[36] B. Abbott,[74] M. Abolins,[63] B.S. Acharya,[29] M. Adams,[49] T. Adams,[47] E. Aguilo,[6] G.D. Alexeev,[36] G. Alkhazov,[40] A. Alton[a],[62] G. Alverson,[61] G.A. Alves,[2] L.S. Ancu,[35] M. Aoki,[48] Y. Arnoud,[14] M. Arov,[58] A. Askew,[47] B. Åsman,[41] O. Atramentov,[66] C. Avila,[8] J. BackusMayes,[81] F. Badaud,[13] L. Bagby,[48] B. Baldin,[48] D.V. Bandurin,[47] S. Banerjee,[29] E. Barberis,[61] A.-F. Barfuss,[15] P. Baringer,[56] J. Barreto,[2] J.F. Bartlett,[48] U. Bassler,[18] S. Beale,[6] A. Bean,[56] M. Begalli,[3] M. Begel,[72] C. Belanger-Champagne,[41] L. Bellantoni,[48] J.A. Benitez,[63] S.B. Beri,[27] G. Bernardi,[17] R. Bernhard,[22] I. Bertram,[42] M. Besançon,[18] R. Beuselinck,[43]

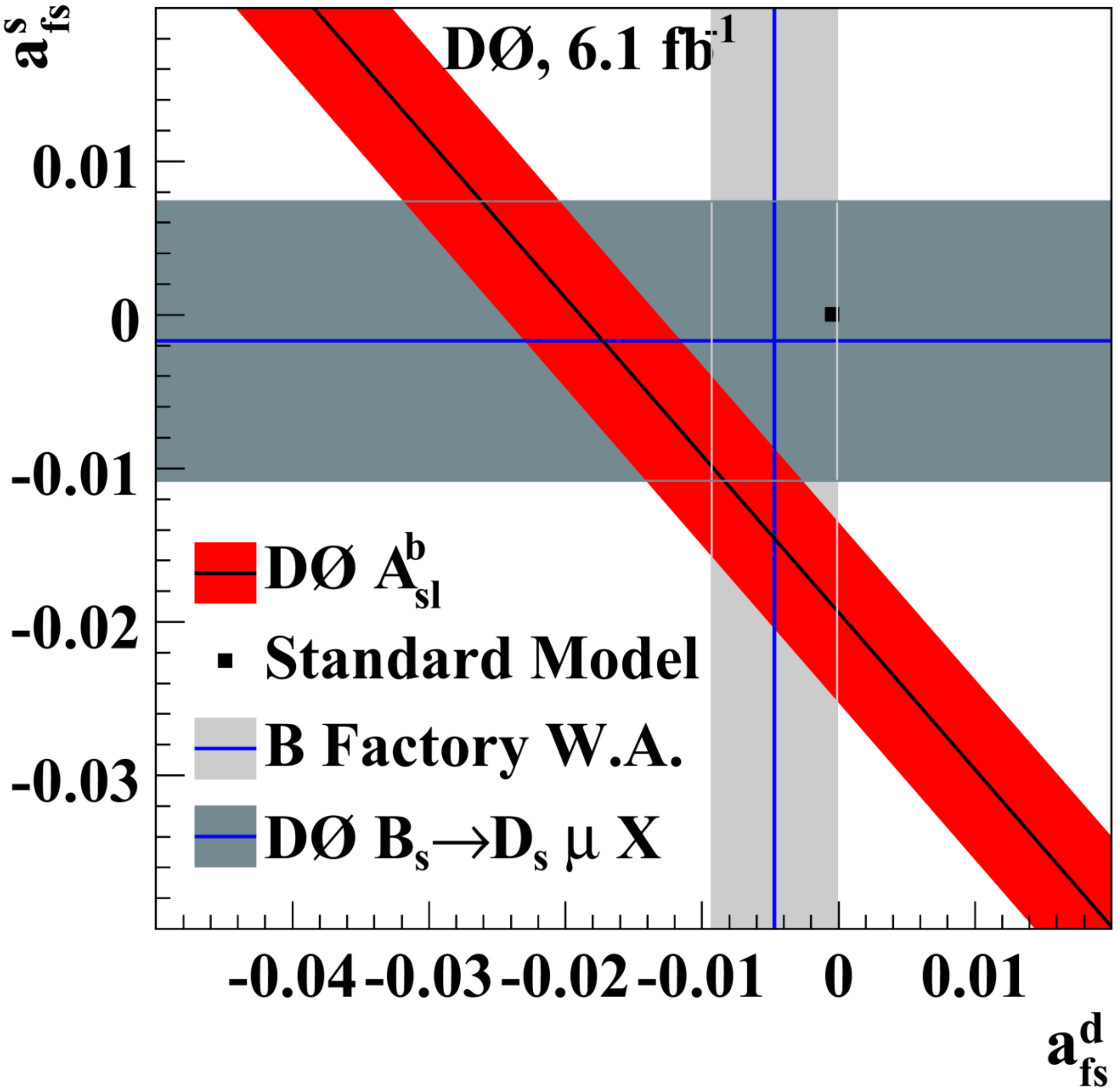
...

We measure the charge asymmetry A of like-sign dimuon events in 6.1 fb^{-1} of $p\overline{p}$ collisions recorded with the D0 detector at a center-of-mass energy $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron collider. From A, we extract the like-sign dimuon charge asymmetry in semileptonic b-hadron decays: $A^b_{\rm sl} = -0.00957 \pm 0.00251$ (stat) ± 0.00146 (syst). This result differs by 3.2 standard deviations from the standard model prediction $A^b_{\rm sl}(SM) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ and provides first evidence of anomalous CP-violation in the mixing of neutral B mesons.

PACS numbers: 13.25.Hw; 14.40.Nd

See talks from Monday morning

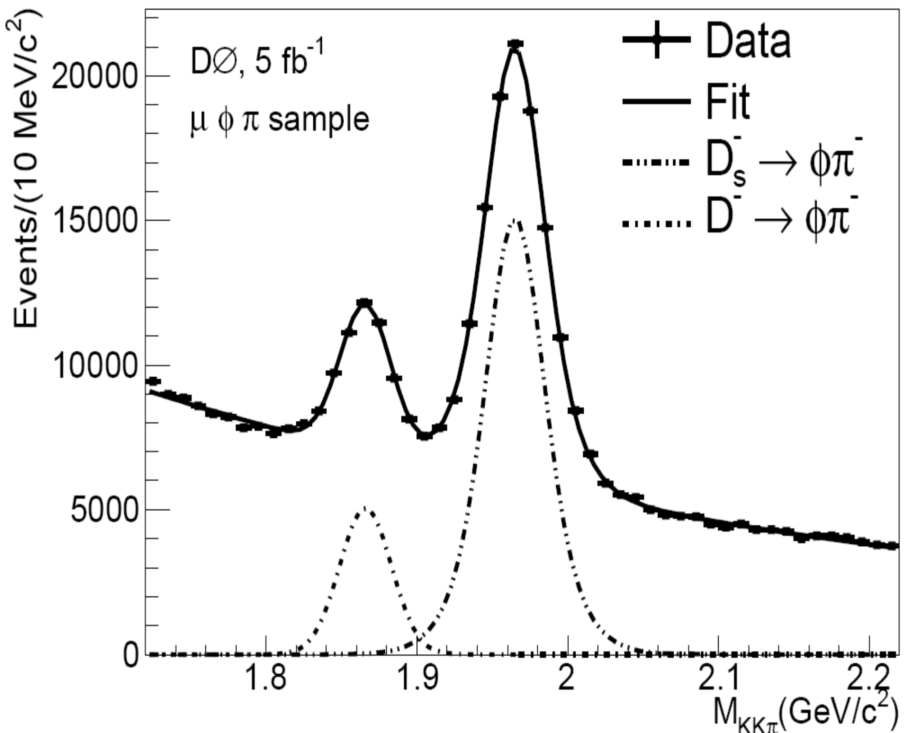
Hot Topic



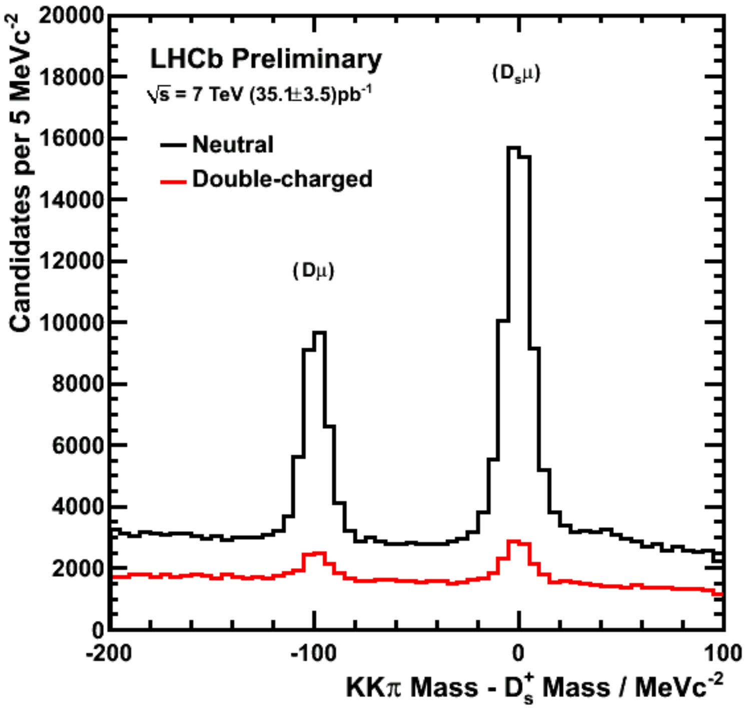
Situation could really be cleared up by LHCb

Current status

- LHCb is reconstructing both $B_s^0 \to D_s^{\mp} \mu^{\pm} \nu_\mu$ and $B_d^0 \to D_d^{\mp} \mu^{\pm} \nu_\mu$
- LHCb is catching up with DØ very quickly



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



~100k D_s in 0.2 fb^{-1}

Experimental Challenge

CERN-THESIS-2009-001

- LHC is a pp-collider, not a p$\bar{p}$-collider
- LHCb is in the forward region
  - Can't measure the same thing as DØ
  - Need a clever new method

NB: DØ
(inclusive)

$$\left(A^b \sim \frac{a_{fs}^s + a_{fs}^d}{2} \rightarrow -(2.0 \pm 0.3) \times 10^{-4} [S.M.] \right)$$

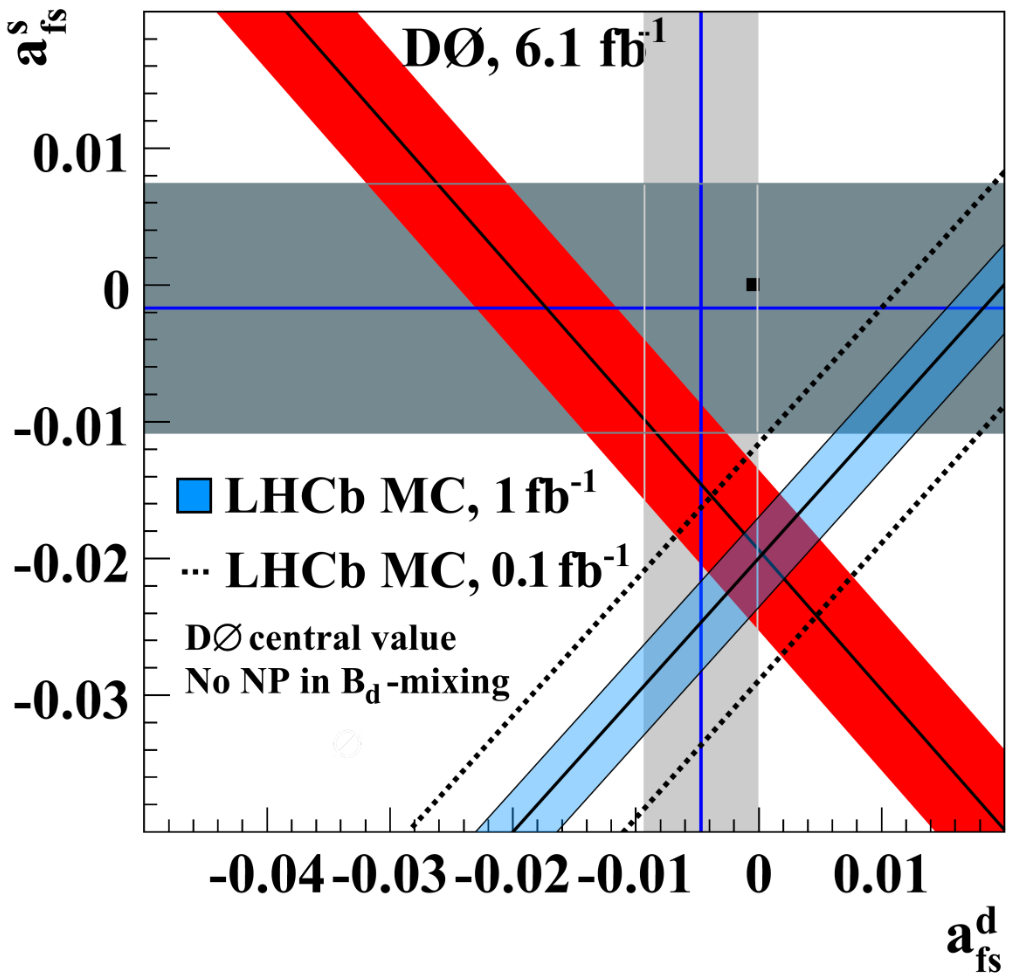
- Subtract two asymmetries to cancel main systematics

LHCb
(subtraction)

$$\Delta A_{fs} = \frac{a_{fs}^s - a_{fs}^d}{2} \rightarrow (2.1 \pm 0.3) \times 10^{-4} [S.M.]$$

After $1fb^{-1}$ of LHCb

- LHCb measurement cuts at right-angles to DØ



NB: This is MC, scaled to real data including an estimate of systematics…

Conclusions

- 2010 was a fantastic year for LHCb
- Semileptonics provide a excellent probe of the SM
  - Broad physics program
  - Already competitive with only ~37 pb^{-1}
- Already with 2010 data:
  - $b\bar{b}$ cross-section, re-discovery of B_d mixing
  - Measurement of $B_s^0 \to D_{s1,2}^{*\pm} \mu^{\mp} \nu X^0$
- Many other results in progress!
- In 2011 we expect 1fb^{-1}:
  - Form factors and $V_{(u/c)b}$
  - *B*-mixing including ΔA_{fs}

End

- Backups are often required

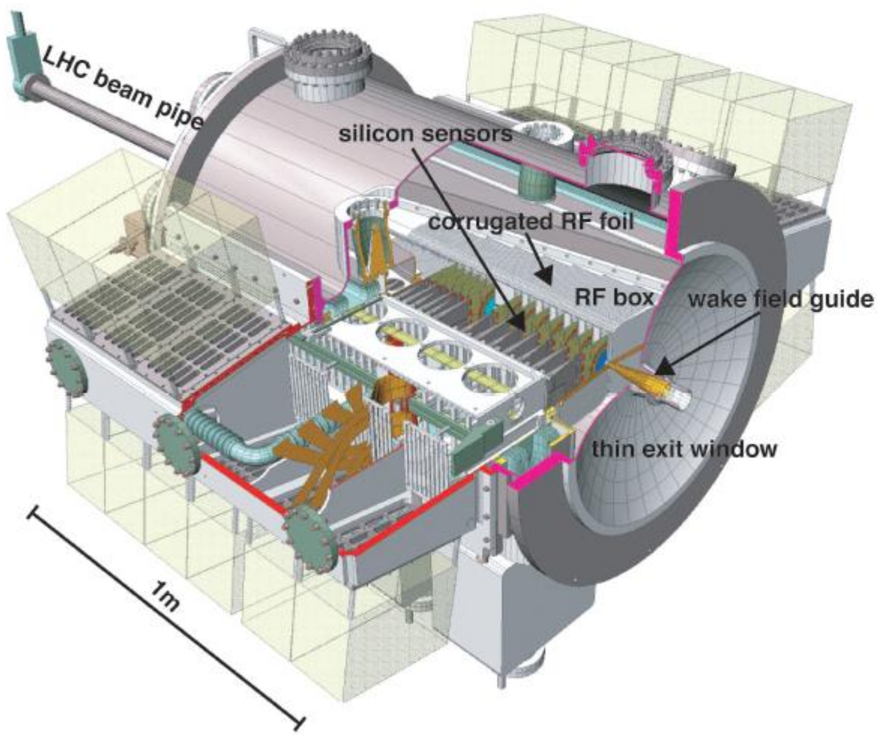
Acknowledgements

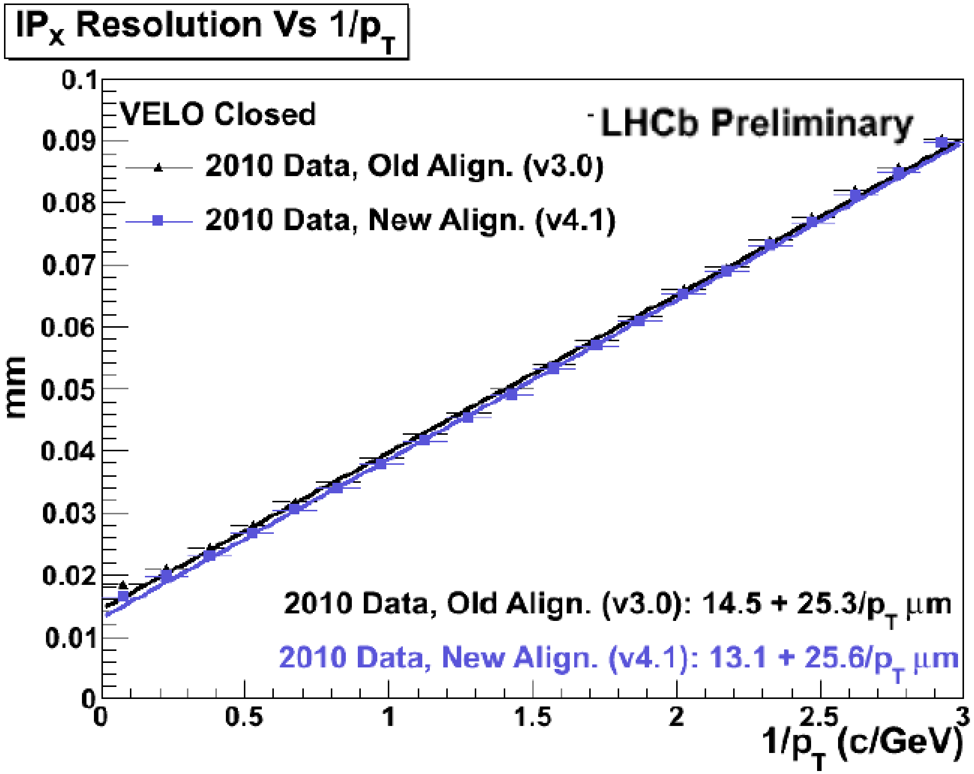
- Thanks to the LHC and the rest of the LHCb collaboration
- Specifically extra thanks to my colleagues:
  - Marina Artuso, Phillip Urquijo, Kim Vervink, Liming Zhang for direct contributions to this talk

- Theory predicts SL widths:
  - $D^{(*)*}$: D ~ 3 : 1
  - arXiv:1003.5576

Being Timely

➢ Proper Time: LHCb Velo precise down to ~50 fs

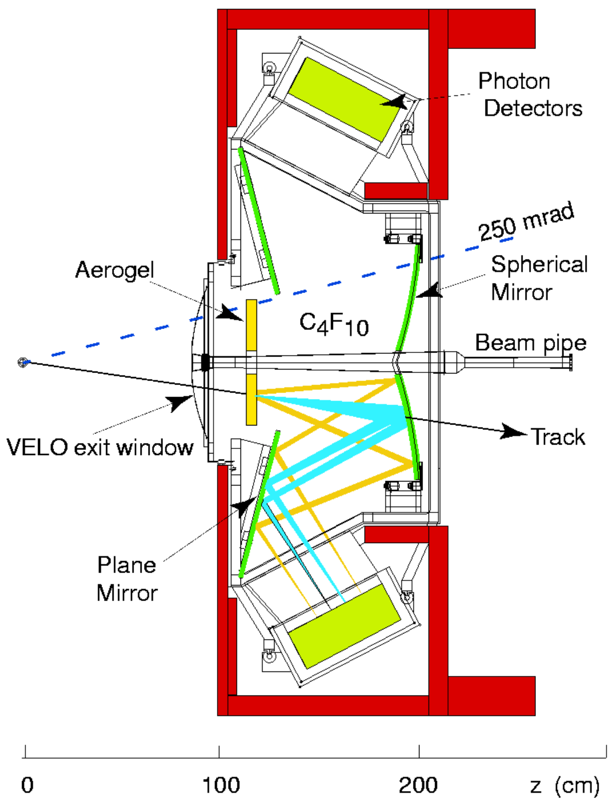


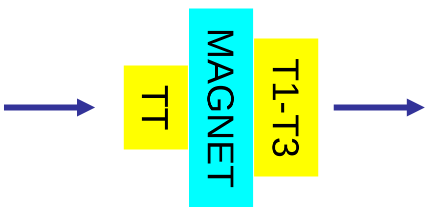


Being Precise

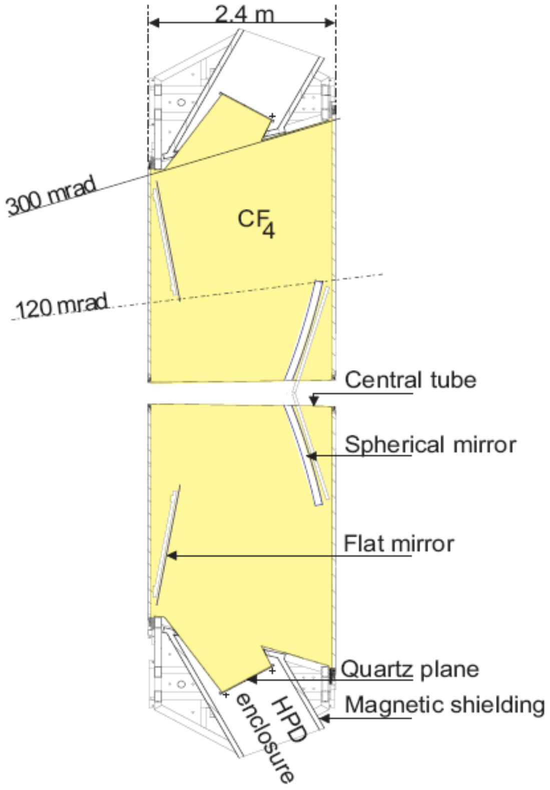
- Particle ID: separation handled by dedicated subdetectors
- Two RICHes, Calorimetry and Muon system

RICH 1 (Vertical)

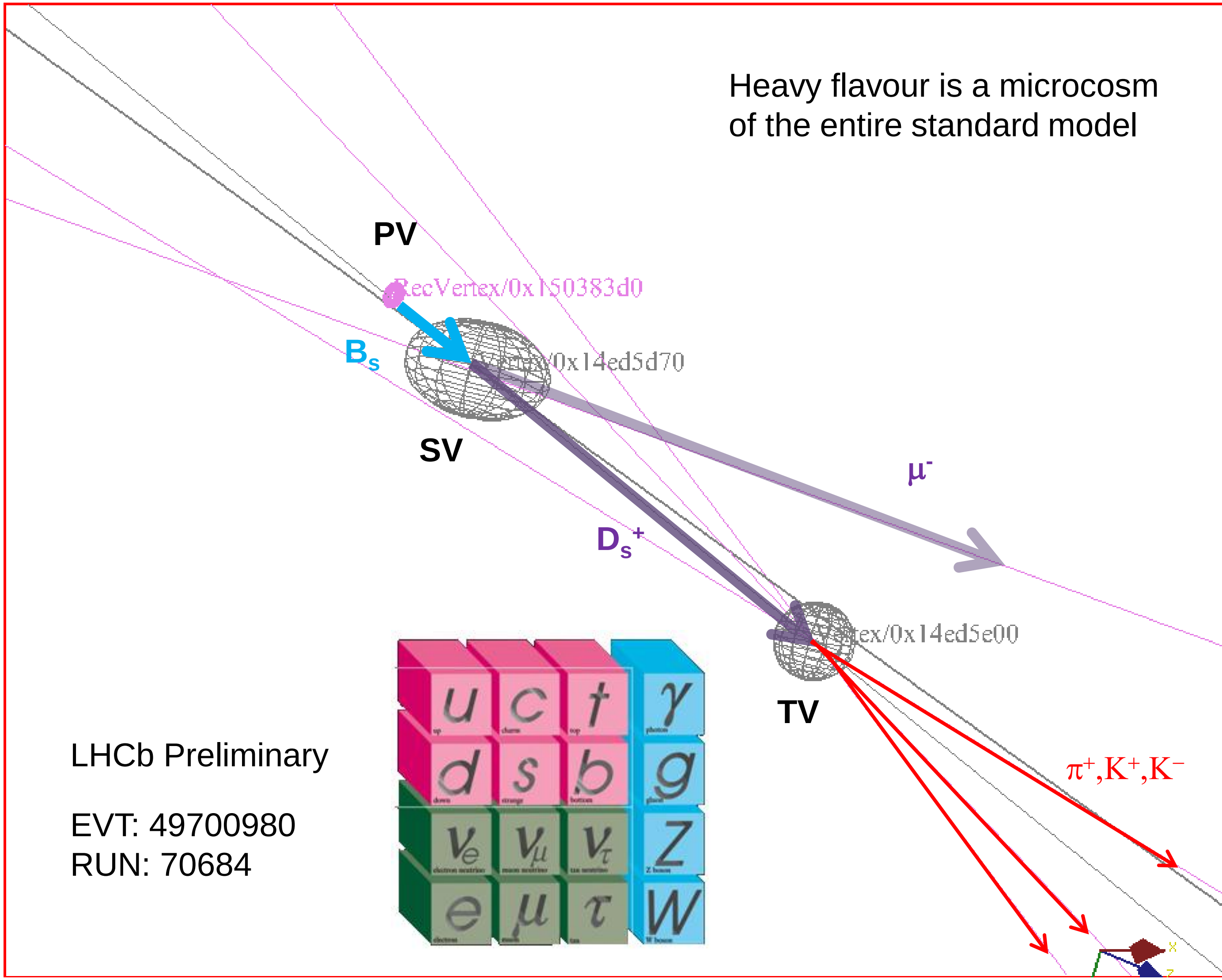




RICH 2 (Horizontal)

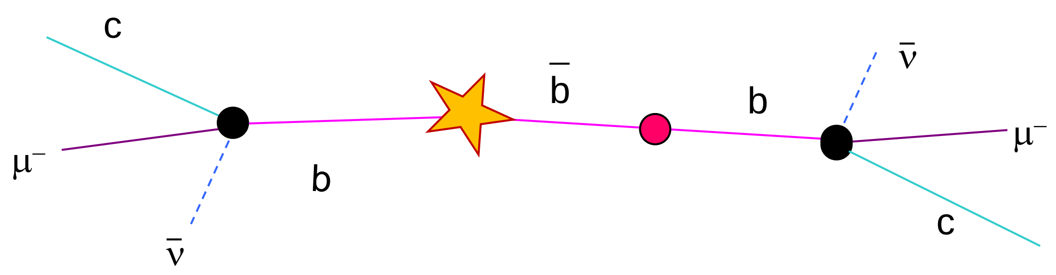


Reach of Semileptonics



Translate

- Very difficult measurement
- Observe $N(\mu^+\mu^+) \neq N(\mu^-\mu^-)$
- Flavour-specific asymmetry from B^0-mixing in the SM:



CP asymmetry in mixing, a_{fs}

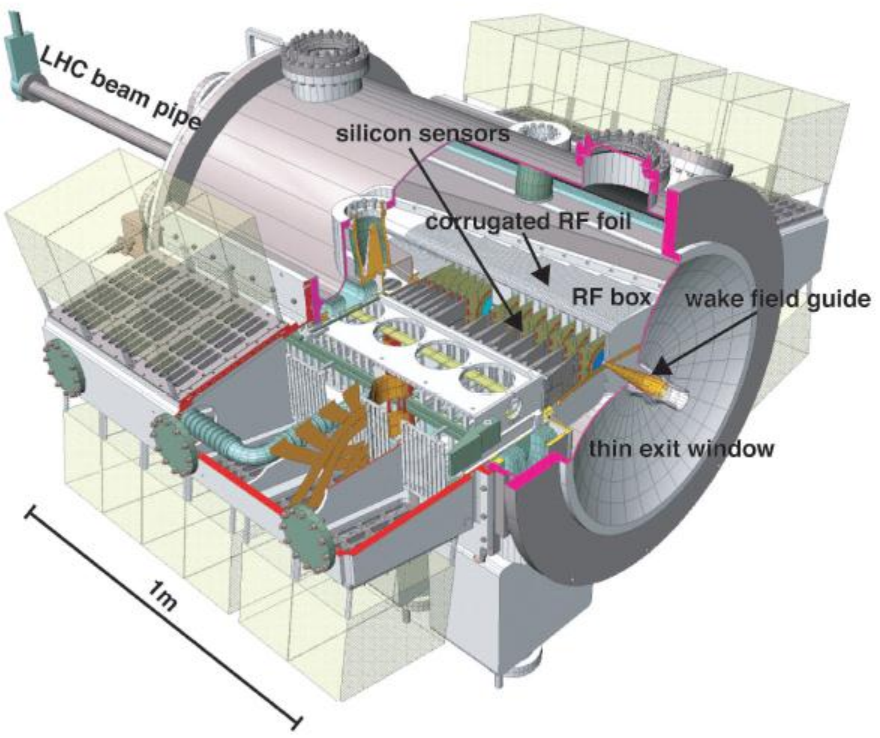
- **In the standard model a_{fs} is almost negligible**

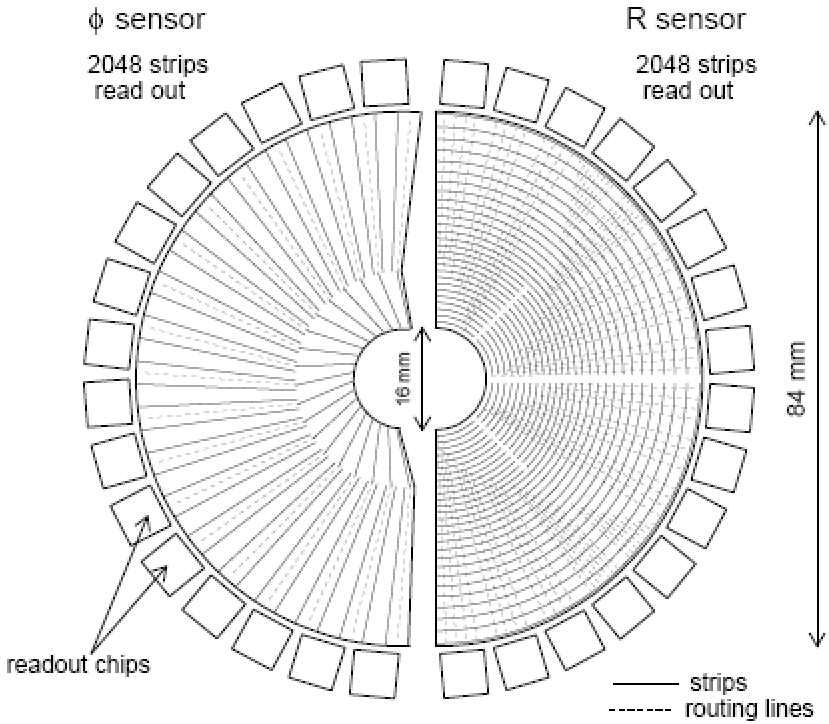
$$A^b \approx \frac{a^s_{fs} + a^d_{fs}}{2} \qquad SM = (-2.0 \pm 0.3) \times 10^{-4} \qquad D\emptyset \approx (-1 \pm 0.3)\%$$

Semileptonic Prospects

Being Timely

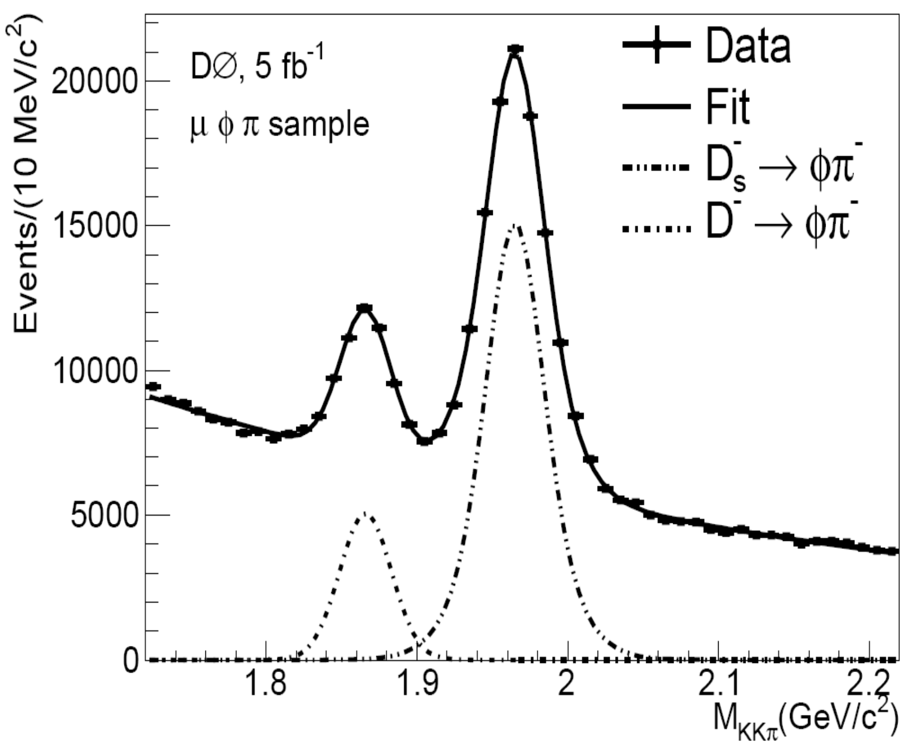
➢ Proper Time: LHCb Velo precise down to ~50 fs



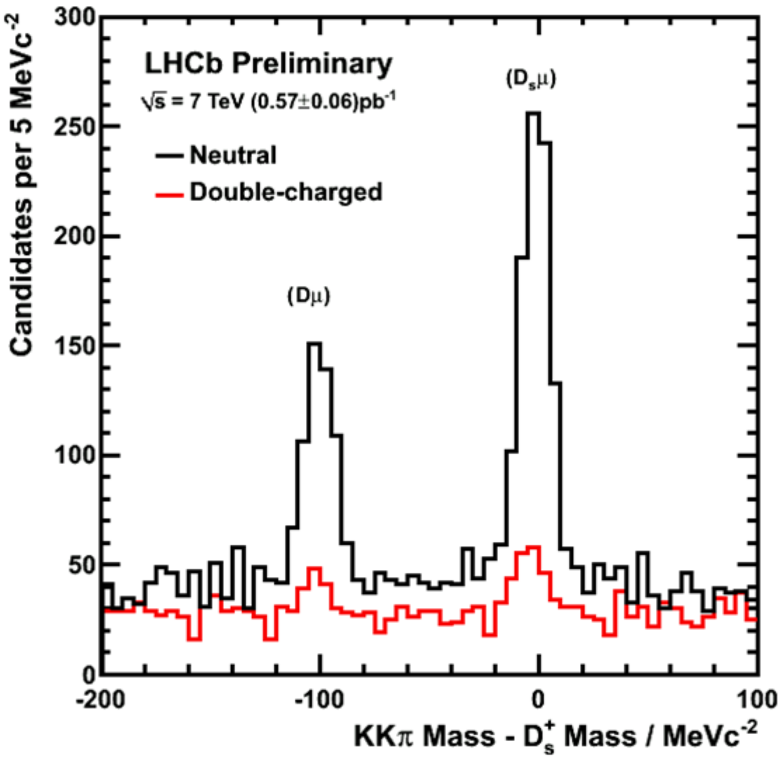


Being Exclusive

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



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



Estimate 100k D_s in 0.1 fb^{-1}

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}

Very Complicated ~~The simple formula~~

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

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

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

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

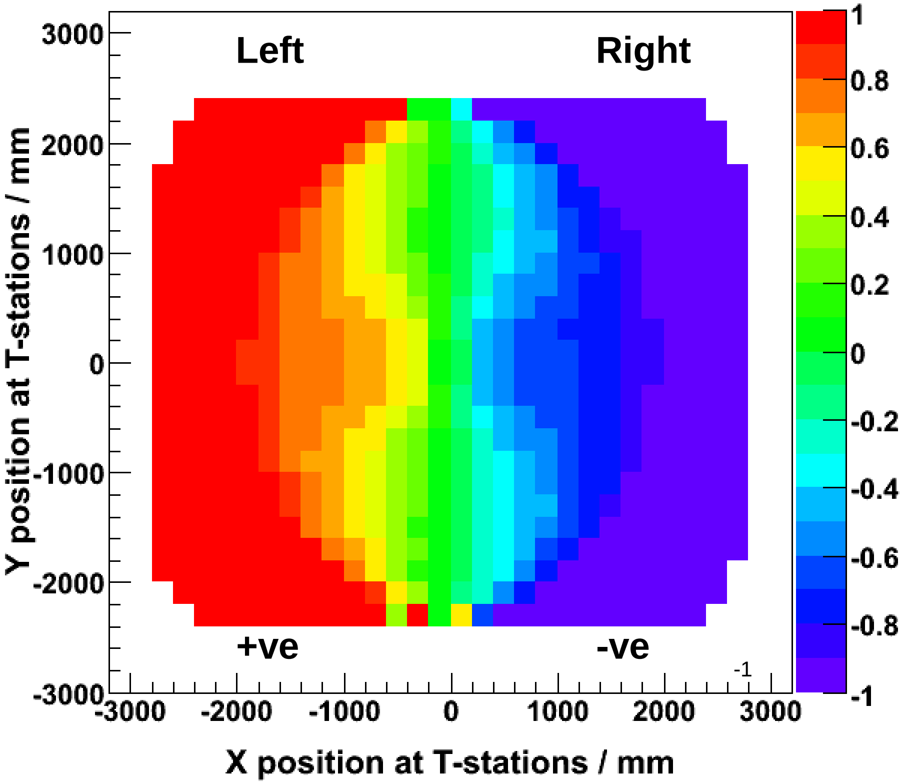
$$\delta_p=\frac{N(\bar{I}_0)}{N(I_0)}-1$$

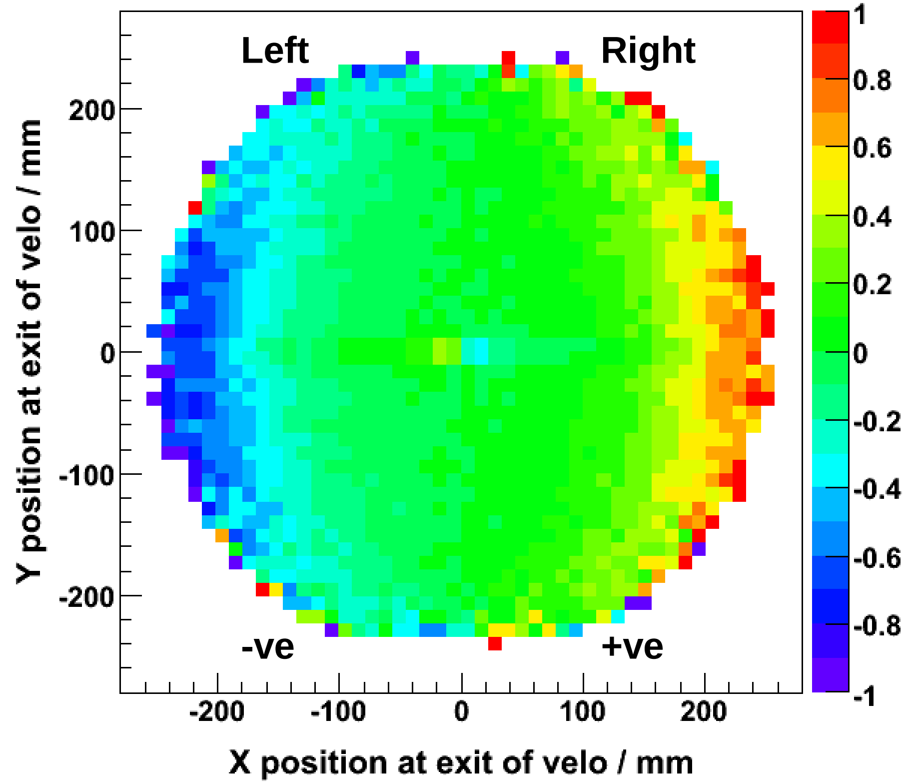
$$\delta_b=\frac{\overline{B}/\overline{S}}{B/S}-1$$

- 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})

Detector Asymmetry, δ_c

Asymmetry from Long Muon Tracks Reconstructed in MC

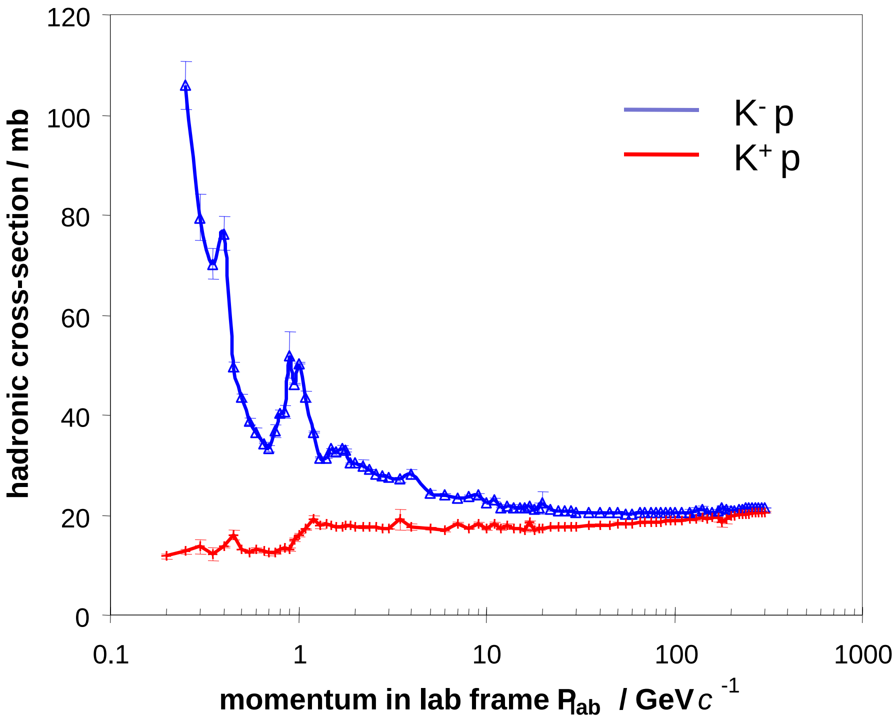




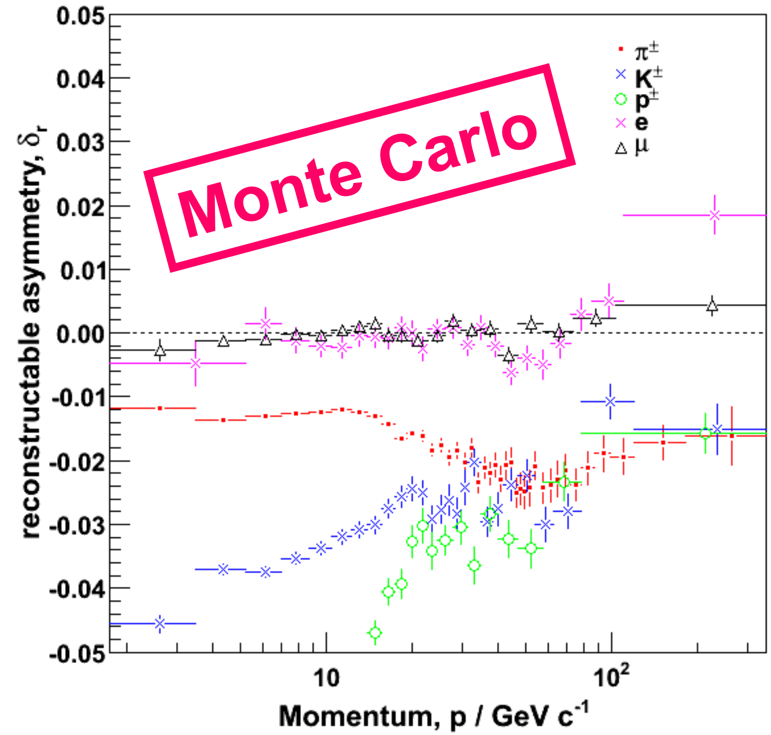
- ➢ Magnet divides +/- charge, allowing +/- asymmetry
- ➢ by reversing magnet in D0: δ_c reduced from 3% -> ~0.1%

Detector Asymmetry, δ_c

Kaon interaction cross-section



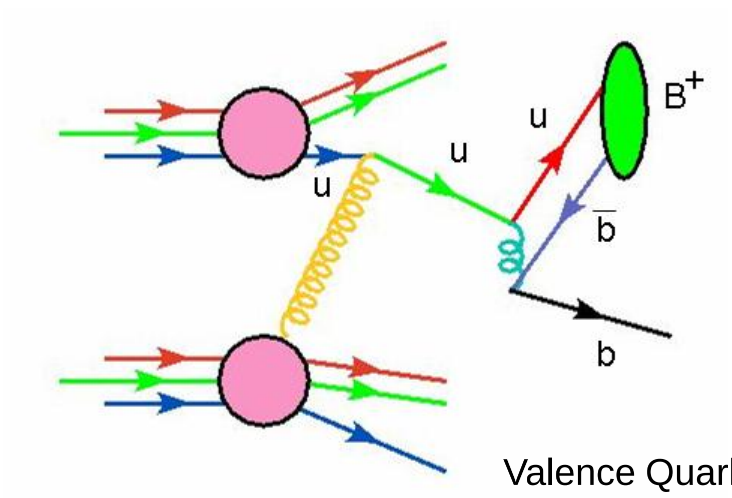
Resultant charge asymmetry (MC)



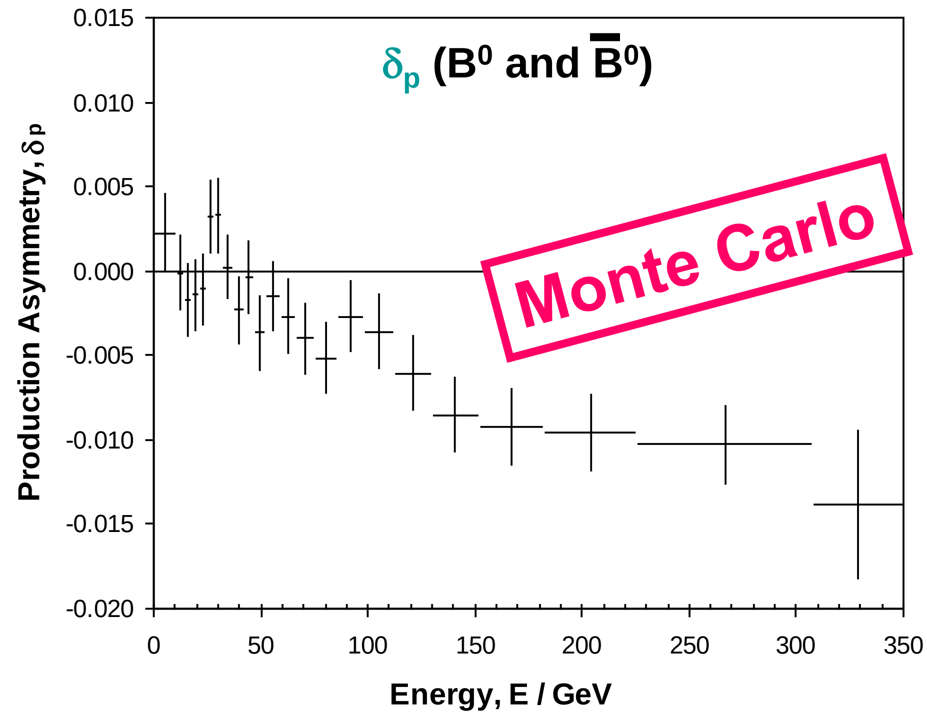
- Matter detector $\rightarrow$ hadronic interactions are asymmetric
- Dominant systematic at order 1%

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

The clever method

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

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

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

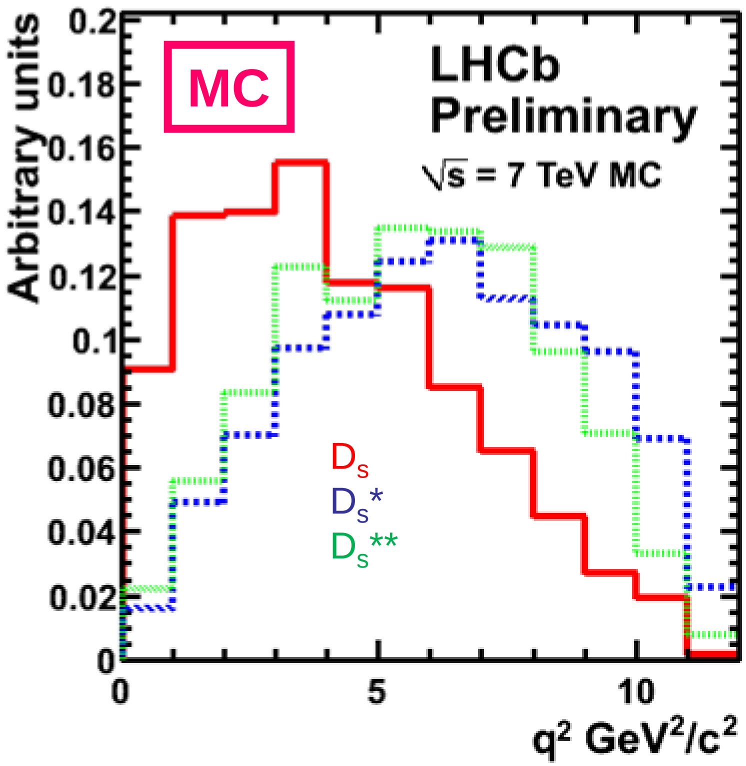
- All production asymmetry is in x_2/x_3, just throw it away
- Measure the **difference** between B_s and B_d

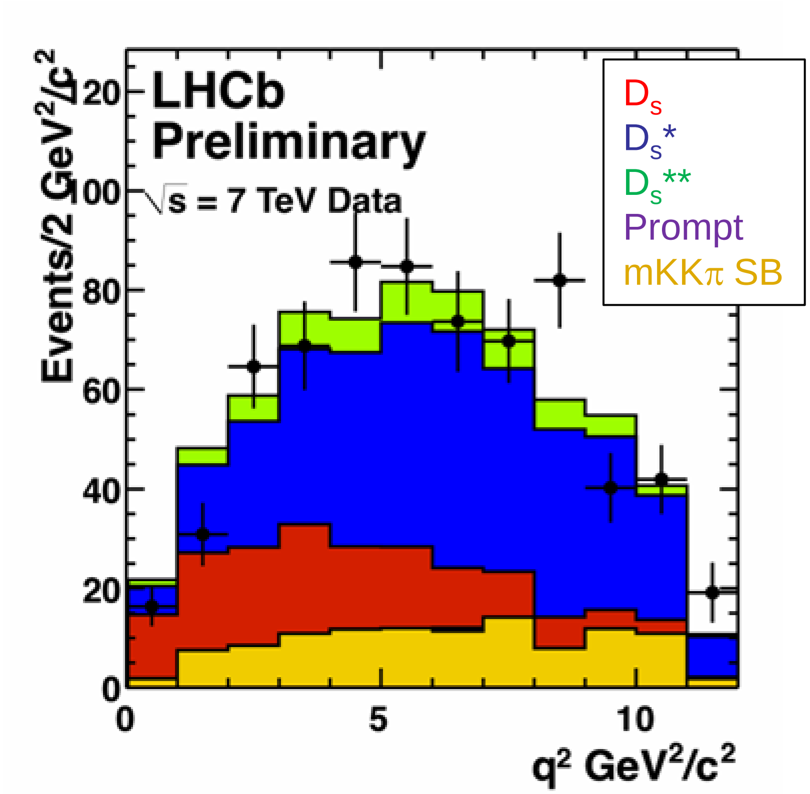
$$\Delta A_{fs}^{s,d} = \frac{x_1^s - x_1^d}{2} = \frac{a_{fs}^s - a_{fs}^d}{2}$$

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

V_{cb}

- Choose a set of form-factors for the LHCb MC (HQET2/ISGW2)
- Set the relative branching ratios from D/D*/D**, ~2.5:~6:~1

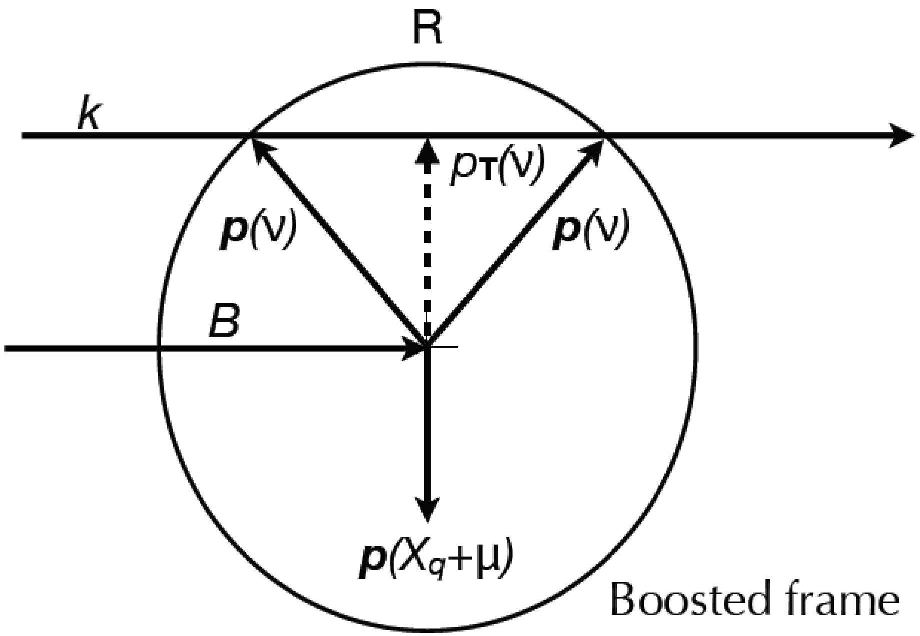


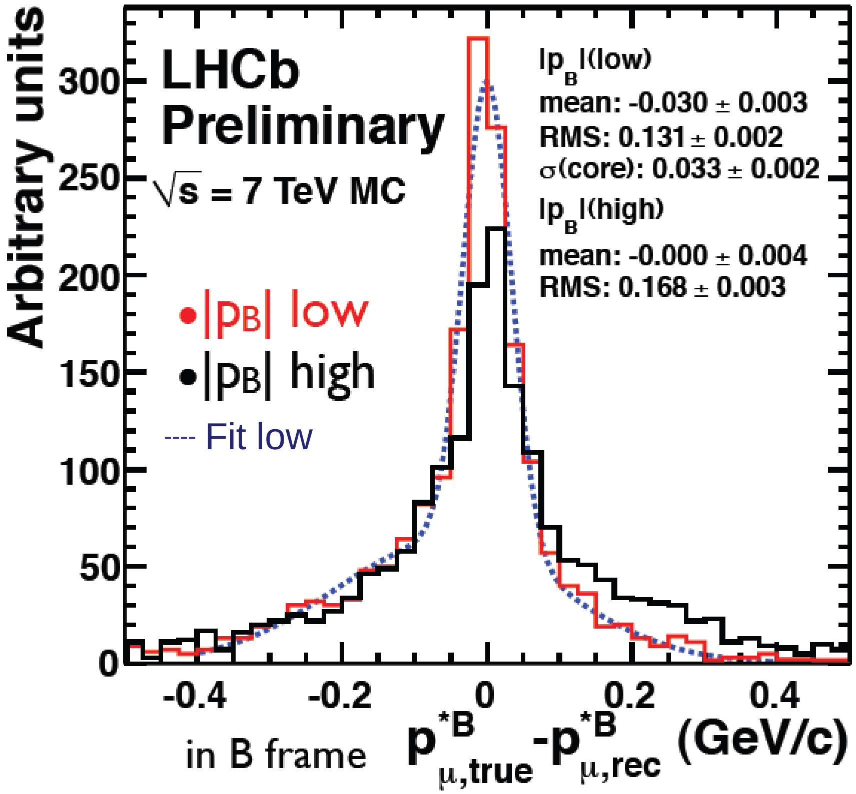


- 0.8 pb^{-1} examined so far, should become powerful in 50 pb^{-1}

Neutrino Reconstruction

- Use kinematics to calculate the neutrino momentum
  - Two ambiguous solutions, the lower momentum has lower error





Flavour-specific asymmetry

… a smoking gun for new physics??

Translate

1. pp̄-interactions within a symmetric experiment
2. Correct all experimental biases (magnets, mis-id …)
3. Observe $N(\mu^+\mu^+) \neq N(\mu^-\mu^-)$
4. In the SM, the favoured way to make charge asymmetry is if:

$$b\bar{b} \longrightarrow \mu^+\mu^+ \neq b\bar{b} \longrightarrow \mu^-\mu^-$$

5. Which comes from B^0-mixing:

$$b\bar{b} \Rightarrow \bar{B}^0 B^0 \sim \bar{B}^0 \bar{B}^0 \rightarrow \mu^+\mu^+ X \neq b\bar{b} \Rightarrow \bar{B}^0 B^0 \sim B^0 B^0 \rightarrow \mu^-\mu^- X$$

- **In the standard model it is almost negligible**

$$A^b \approx \frac{a^s_{fs} + a^d_{fs}}{2} \qquad SM = (-2.0 \pm 0.3) \times 10^{-4} \qquad D\varnothing \approx (-1 \pm 0.3)\%$$

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - Tree-level processes are SM-dominated
  - SM flavour structure
  - Unitary CKM
- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- Usual formula is modified:

$$a^{SM} \approx \mathrm{Im}\left\{ \frac{\Gamma_{12}^{SM}}{M_{12}^{SM}} \right\}$$

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- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- If we allow a single NP phase in the mixing Θ

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

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- If we allow a single NP phase in the mixing Θ
  - (first part is just the SM value)

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

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - Tree-level processes are SM-dominated
  - SM flavour structure
  - Unitary CKM
- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- If we allow a single NP phase in the mixing Θ
  - (first part is just the SM value)

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

- Up to **200-times** the SM!!! [[[... still... < DØ measurement]]]

Flavour-specific asymmetry

At LHCb

Experimental Challenge

- At the LHC we have extra complications in the measurement
- Polluting asymmetries, which are all much larger than a_{fs}
  - Production asymmetry δ_p ~(10^{-2})
  - Detector asymmetry δ_c ~(10^{-2})
  - Background asymmetry δ_b ~(10^{-3})
- Use a, time-dependent, untagged, simultaneous fit to B_s+B_d
- Subtract two asymmetries to eliminate detector component

$$\Delta A_{fs} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2} = (2.1 \pm 0.3) \times 10^{-4}$$

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$$\Delta A_{fs} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2} = (2.1 \pm 0.3) \times 10^{-4}$$

NB: DØ

$$\left(A^{b} \sim \frac{a_{fs}^{s} + a_{fs}^{d}}{2} \sim -(2.0 \pm 0.3) \times 10^{-4} \right)$$

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

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

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

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

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

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

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

Simplify

- We measure time-dependent decay rates:

$$\Gamma(f) = N e^{-\Gamma t}(1 + A_c)\left[(1 + A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (2A_p - A_{fs})\cos(\Delta m t)\right]$$

$$\rightarrow N e^{-\Gamma t}\left[(1 + A_c + A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (2A_p - A_{fs} + 2A_p A_c)\cos(\Delta m t)\right]$$

$$\Gamma(\bar{f}) \rightarrow N e^{-\Gamma t}\left[(1 - A_c - A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (A_{fs} - 2A_p + 2A_p A_c)\cos(\Delta m t)\right]$$

- A_c, A_p and A_{fs} are correlated and cannot be separately fitted
- First, reparameterise

Reparameterise

- Just to make it easier to see what we're doing…

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

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

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

- production asymmetry is an *initial state asymmetry*
- Changes the mixing amplitude, <u>does not</u> change the physics
- Fit for x_1 independently, which now only has detector asym

The subtraction method

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

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

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- All production asymmetry is in x_2/x_3, just throw it away
- Measure the **difference** between B_s and B_d

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

Projections

- MC sensitivities, Real data yields and systematics
  - 0.1 fb^{-1} $\sigma \sim 5 \times 10^{-3}$ ... First result (2011)
  - 1.0 fb^{-1} $\sigma \sim 2 \times 10^{-3}$ ... 5σ observation? (2012/2013)