



Semileptonic b Decays at LHCb

Alessandra Borgia
Syracuse University

US LHC Users Organization
FNAL, Batavia, Illinois

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Goals for Semileptonic B Decay Measurements at LHCb

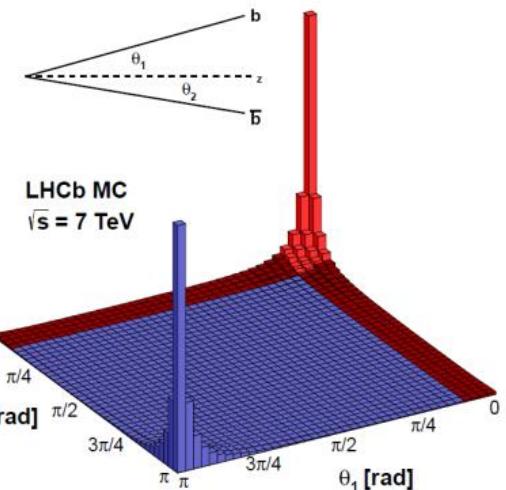
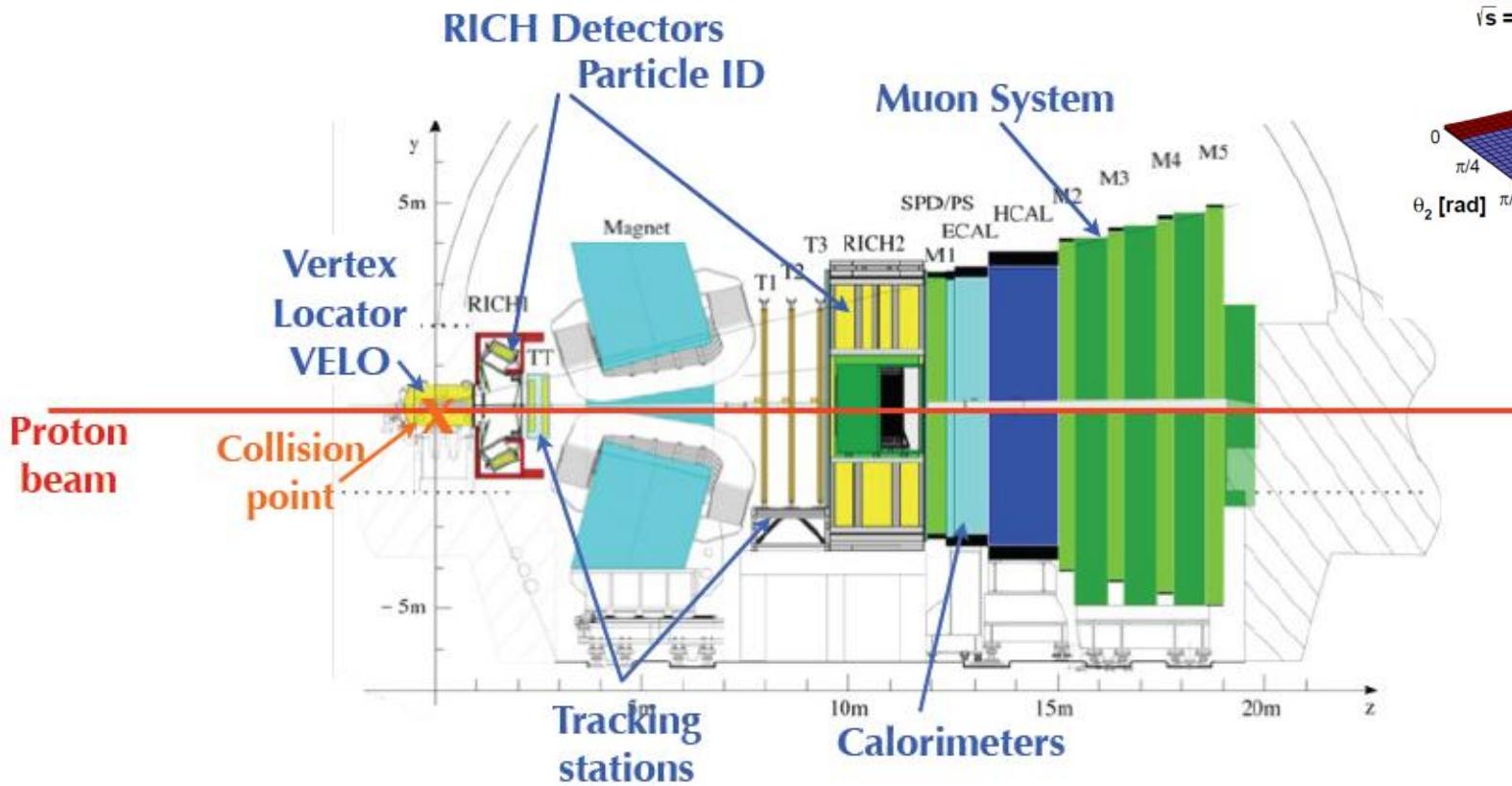
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- Cross section of $b\bar{b}$ production → Phys. Lett. B 694 (2010) 209-216
- Hadronization studies → Physical Review D 85, 032008 (2012)
 - » B^0, B^+, B_s, Λ_b production fractions
- Semileptonic Asymmetry, a_{sl}^s → LHCb-conf-2012-022
- Exclusive semileptonic decays (Cabibbo favored/Cabibbo suppressed)
 - » Composition of inclusive semileptonic width, form factors and CKM parameters

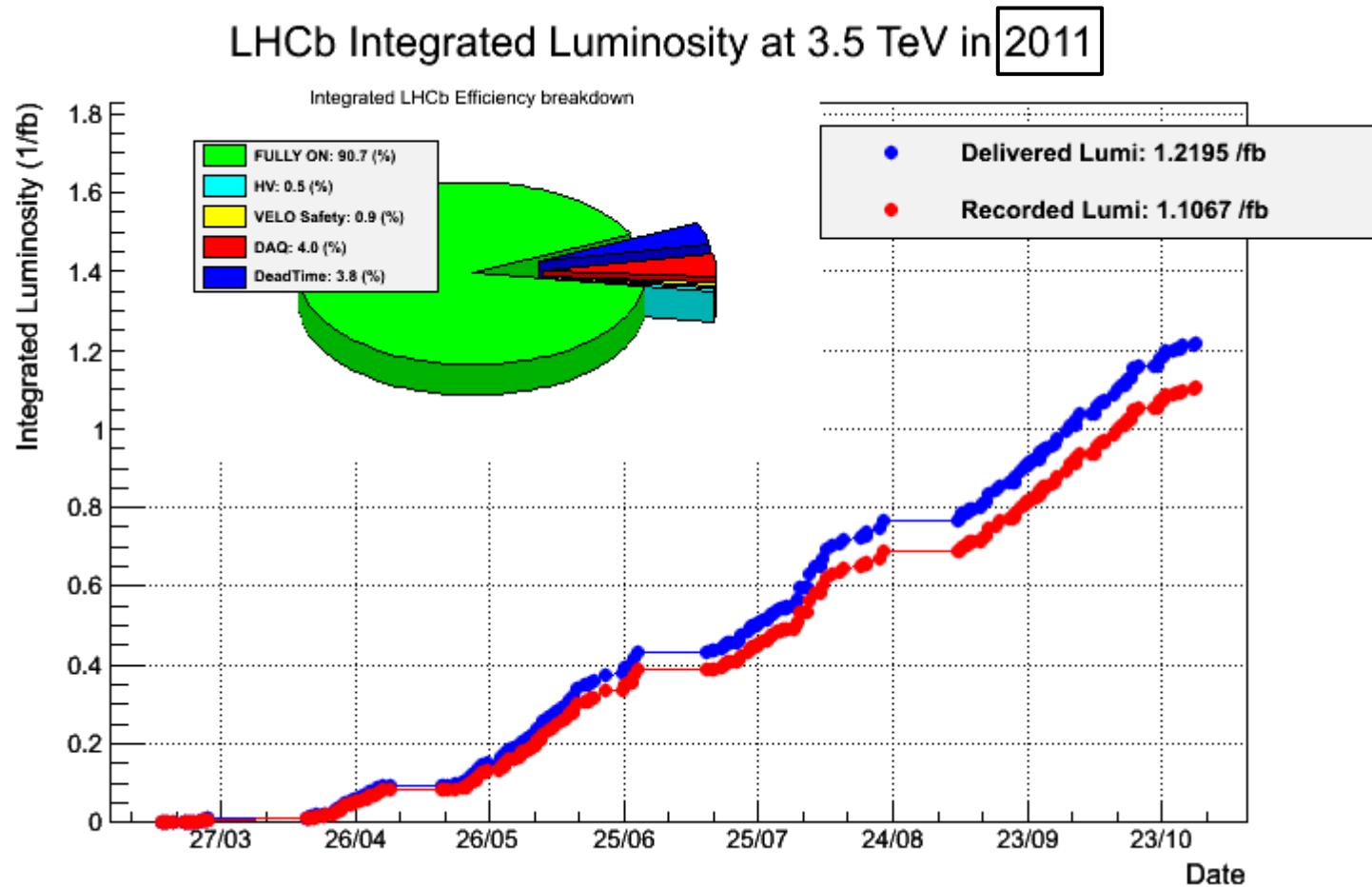
The LHCb Detector

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Dedicated precision b-physics experiment
Covers forward region
Acceptance: $2 < \eta < 5$



LHCb Data Sets

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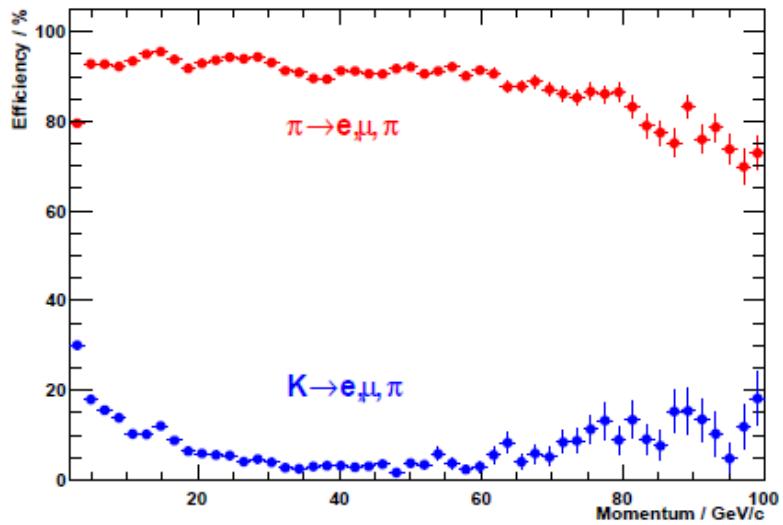
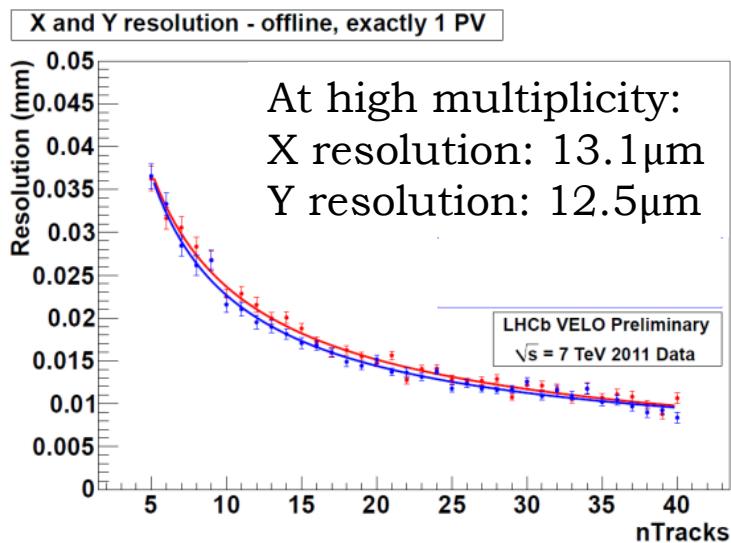
2011: 1.0 fb^{-1} @ $\sqrt{s} = 7 \text{ TeV}$

→ 2012: Already reached goal of 1.5 fb^{-1} @ $\sqrt{s} = 8 \text{ TeV}!$

Key Elements

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- Great b reconstruction
 - » Separation of primary, secondary and tertiary vertices.
 - » Precise b-flight direction
- Excellent momentum, mass and time resolutions
- Good particle identification



b-hadron Production Fractions

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- Many absolute branching fractions of B^- and B^0 decays have been measured at e^+e^- colliders
 - » Enough to measure the ratio of B_s production to either B^- or B^0 **to perform precise absolute B_s branching fraction measurements.**
- Fragmentation processes cannot be reliably predicted due to strong dynamics in the nonperturbative regime
 - » Improvement of knowledge of b production

b-hadron Production Fractions

[Physical Review D 85, 032008 \(2012\)](#)

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Measurement of b-hadron fractions using inclusive B semileptonic decays:

$$f_s/(f_u + f_d) \text{ and } f_{\Lambda b}/(f_u + f_d)$$

where $f_q \equiv \mathcal{B}(b \rightarrow B_q)$

Signal channels: $D^+ X \mu\nu$, $D^0 X \mu\nu$, $D_s^+ X \mu\nu$, $\Lambda_c^+ X \mu\nu$

Get cross feeds, e.g.:

$B_s \rightarrow D_s^{**} X \mu\nu$ with $D_s^{**} \rightarrow D^0 K^+$, $D^+ K^0$, \Rightarrow must measure $D^0 K^+ X \mu\nu$.

Other cross feed channels:

D^0 , $D^\pm K \mu\nu$ (B^0, B^+, B_s)
 $D_s^- K \mu\nu$ (B^0, B^+, B_s)
 $D^0 p(n) \mu\nu$ (B^0, B^+, Λ_b)

Channel	BF(%)	Error(%)
$D^0 \rightarrow K^- \pi^+$	3.89 ± 0.05	1.3
$D^+ \rightarrow K^- \pi^+ \pi^+$	9.14 ± 0.20	2.2
$D_s^+ \rightarrow K^- K^+ \pi^+$	5.50 ± 0.27	4.9
$\Lambda_c^+ \rightarrow p K^- \pi^+$	5.0 ± 1.3	26

b-hadron Production Fractions: Key idea

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$$\frac{f_s}{f_u + f_d} = \frac{n_{\text{corr}}(\bar{B}_s^0 \rightarrow D_s \mu)}{n_{\text{corr}}(B \rightarrow D^0 \mu) + n_{\text{corr}}(B \rightarrow D^+ \mu)} \frac{\tau_{B^-} + \tau_{\bar{B}^0}}{2\tau_{\bar{B}_s^0}}$$

n_{corr} = corrected yields for detection efficiencies
and cross feeds

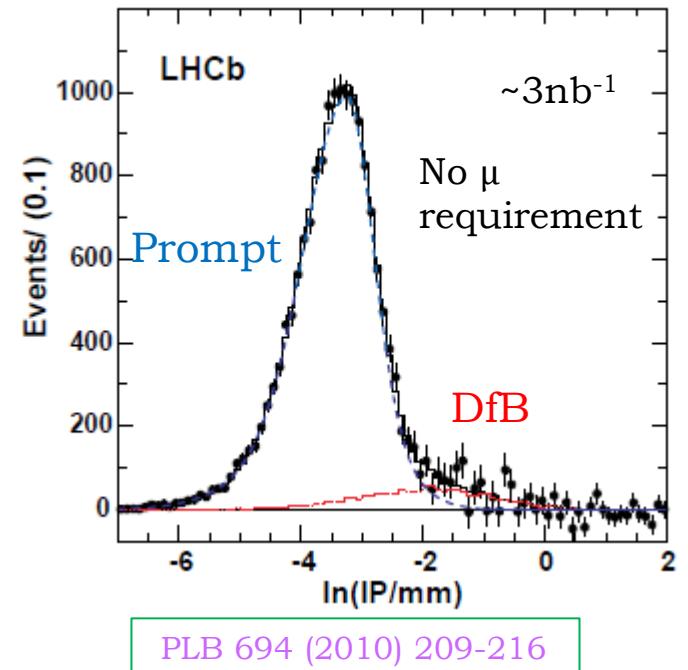
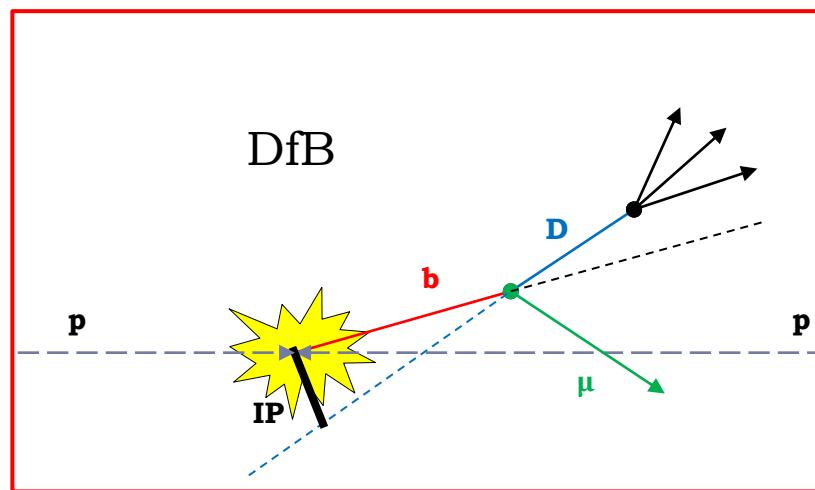
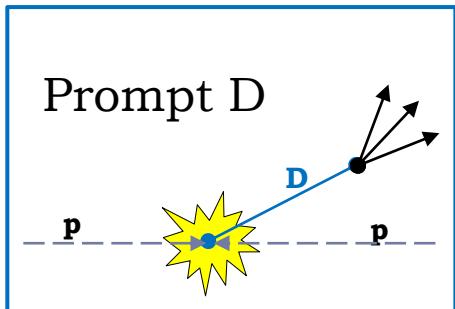
Equality of semileptonic widths assumed and justified by HQET

arXiv:1105.4574 (hep-ph)

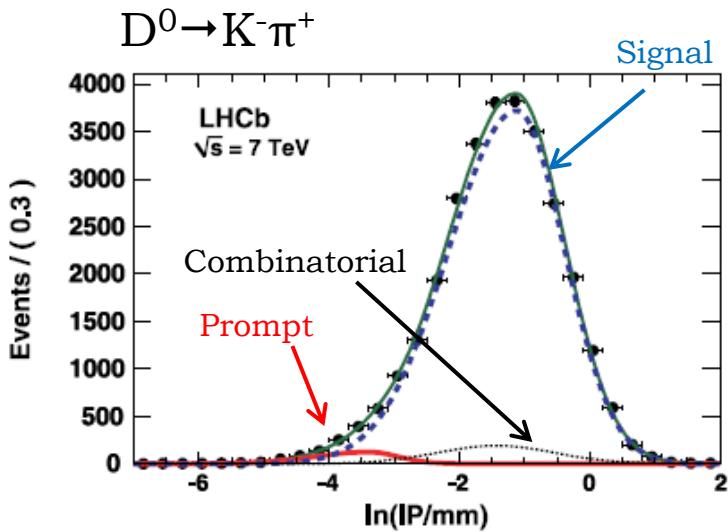
Fit Method to Determine Yields

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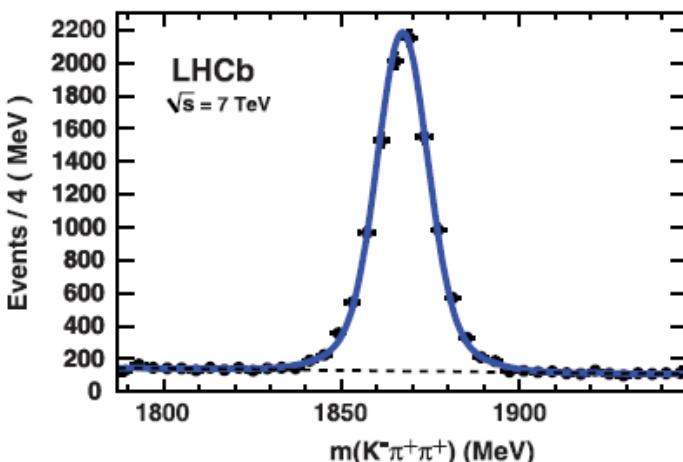
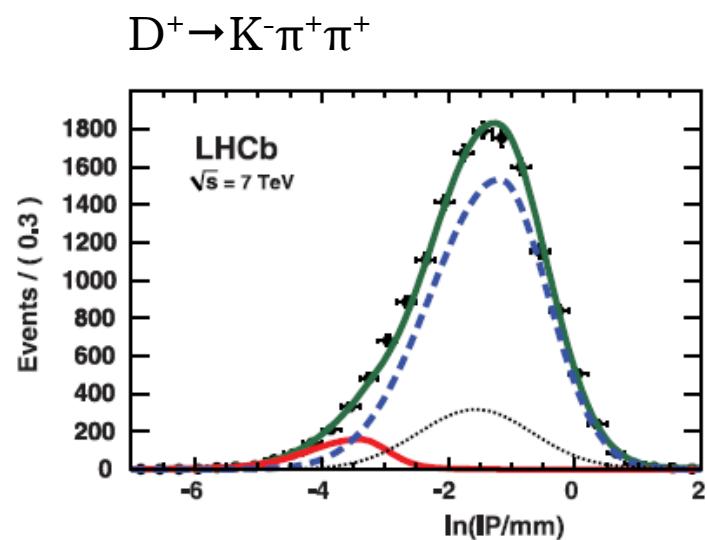
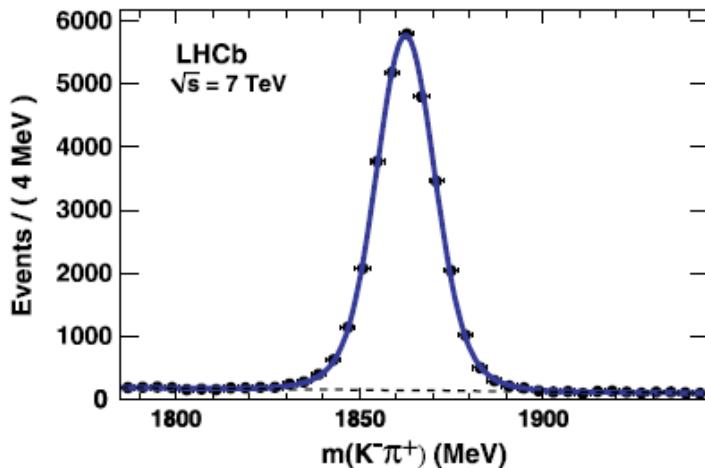
- 2-dimensional fit in $\ln(\text{IP})$ and charm mass.
 - » “Prompt D” separated from signal (DfB).
 - » Fit in bins of Pt (charm- μ) and η .



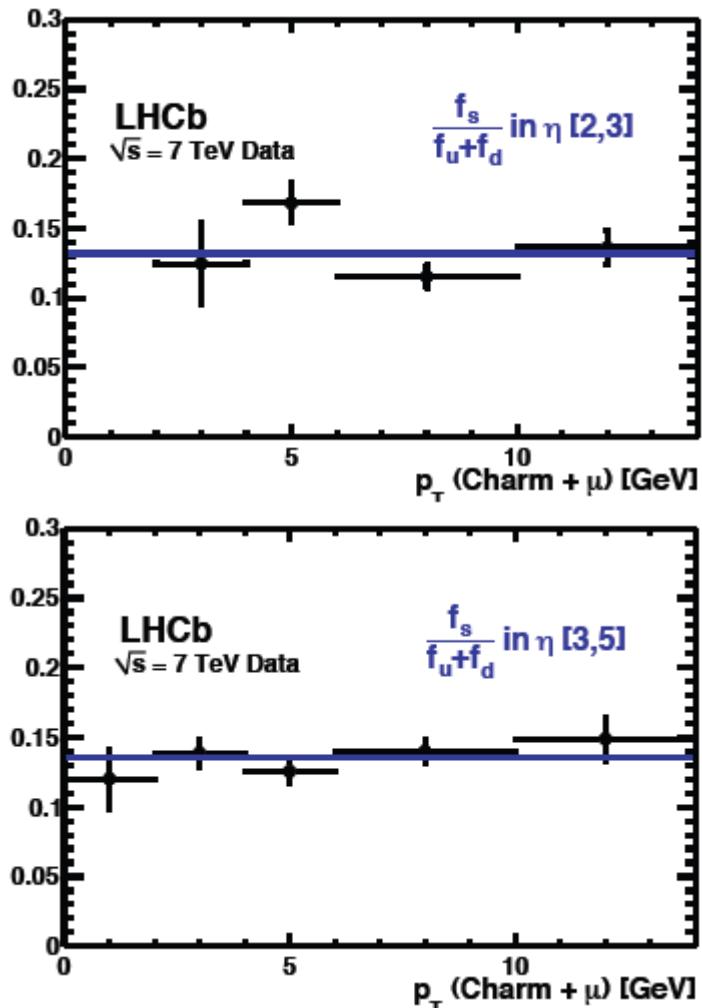
Fit Results:

 $B^+ \rightarrow D^0 X \mu \nu$ and $B^0 \rightarrow D^\pm X \mu \nu$ SYRACUSE
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Physical Review D 85, 032008 (2012)



b-hadron Production Fractions: $f_s/(f_u+f_d)$

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Physical Review D 85, 032008 (2012)

$$f_s/(f_u+f_d) = 0.134 \pm 0.004(\text{stat.}) \quad {}^{+0.012}_{-0.011}(\text{sys.})$$

LEP: 0.128 ± 0.012

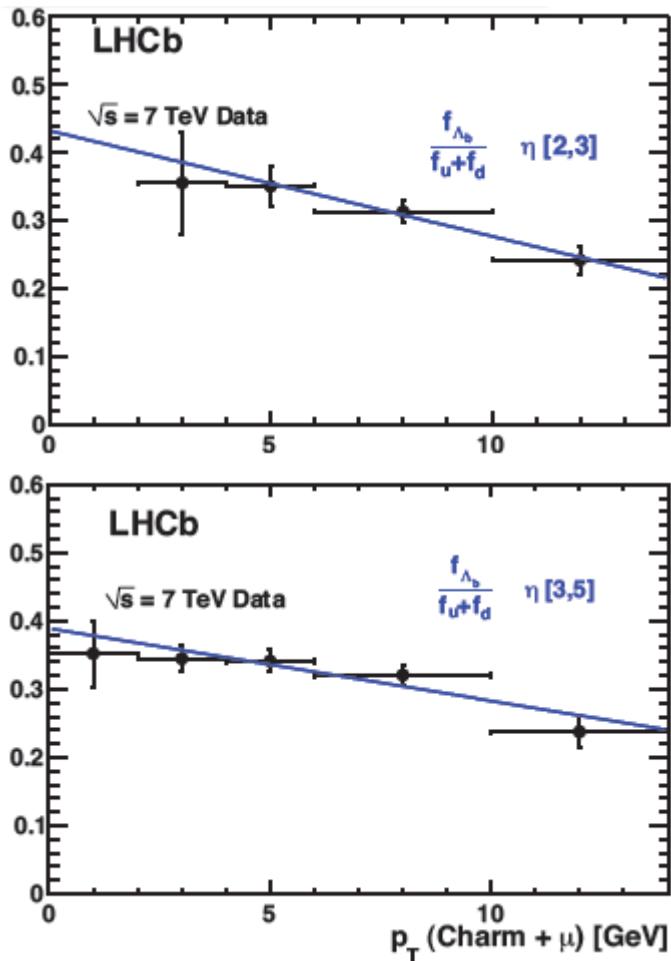
Tevatron: 0.164 ± 0.026 (HFAG PDG 2012)

$f_s/(f_u+f_d)$ does not depend on η or $Pt(\text{charm}-\mu)$ at this level of statistics over the limited Pt range

Systematic error breakdown

Source	Error (%)
Bin dependent errors	1.0
Charm hadron branching fractions	5.5
B_s semileptonic decay modeling	3.0
Backgrounds	2.0
Tracking efficiency	2.0
Lifetime ratio	1.8
PID efficiency	1.5
$\overline{B}_s^0 \rightarrow D^0 K^+ X \mu^- \bar{\nu}$	${}^{+4.1}_{-1.1}$
$(B^-, \overline{B}^0) \rightarrow D_s^+ K X \mu^- \bar{\nu}$	2.0
Total	${}^{+8.6}_{-7.7}$

b-hadron Production Fractions: $f_{\Lambda_b}/(f_u + f_d)$



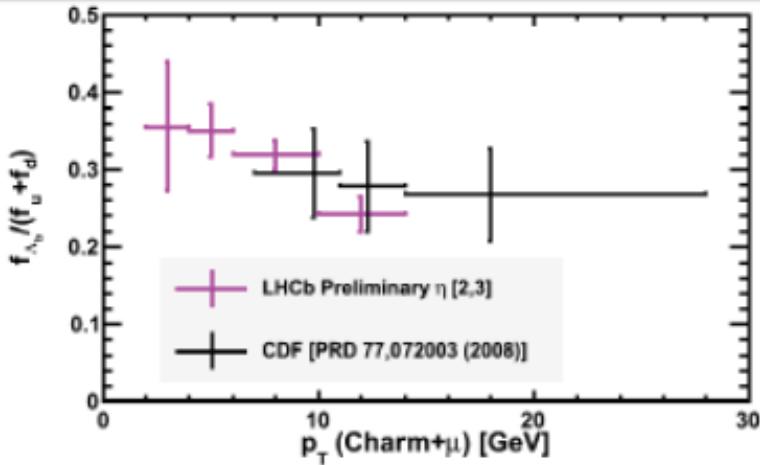
[Physical Review D 85, 032008 \(2012\)](#)

$f_{\Lambda_b}/(f_u + f_d)$ not consistent with flat over p_T
If we fit with straight line, we get

$$\frac{f_{\Lambda_b}}{f_u + f_d} = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T / \text{GeV}]$$

Excluded to 4 σ

Systematic error on the scale 26% from $\mathcal{B}(\Lambda_c \rightarrow p K \pi)$



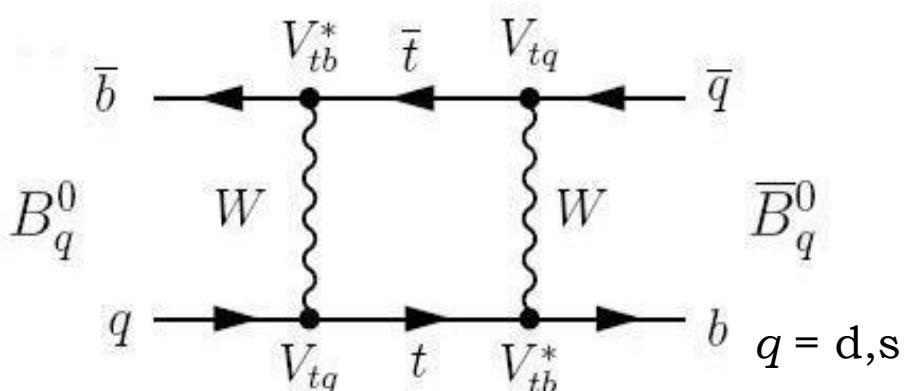
CDF: $(0.281 \pm 0.012)^{+0.011}_{-0.056} {}^{+0.128}_{-0.086}$
Phys. Rev. D 77,072003 (2008)

LEP: 0.110 ± 0.035
arXiv:1010.1589

$\langle p_T \rangle_{\text{CDF}} \approx 14.1 \text{ GeV}$

$\langle p_T \rangle_{\text{LEP}} \approx 40 \text{ GeV}$

CP Violation in B_s^0 Mixing



- Measurements of mixing induced CP violation in B_s^0 decays are important in probing **new physics**
- Can show up in flavor asymmetries

$$|B_{sL}^0\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$$

$$|B_{sH}^0\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$$

- Off diagonal terms are related to important observable quantities
 - Mass differences
 - Width differences

Also:

$$a_s = 1 - \left| \frac{q}{p} \right|^2 = \text{Im} \left(\frac{\Gamma_{12}^s}{M_{12}^s} \right) + O \left(\left(\text{Im} \left(\frac{\Gamma_{12}^s}{M_{12}^s} \right) \right)^2 \right) = \left| \frac{\Gamma_{12}^s}{M_{12}^s} \right| \sin \phi_{12}^s$$

$$\phi_{12}^s = \arg \left(-\frac{M_{12}^s}{\Gamma_{12}^s} \right)$$

- B_s time dependent decays are governed by 2x2 complex Hamiltonian

$$i \frac{d}{dt} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M_{11}^s - i \frac{\Gamma_{11}^s}{2} & M_{12}^s - i \frac{\Gamma_{12}^s}{2} \\ M_{12}^{s*} - i \frac{\Gamma_{12}^{s*}}{2} & M_{22}^s - i \frac{\Gamma_{22}^s}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

First DØ Result

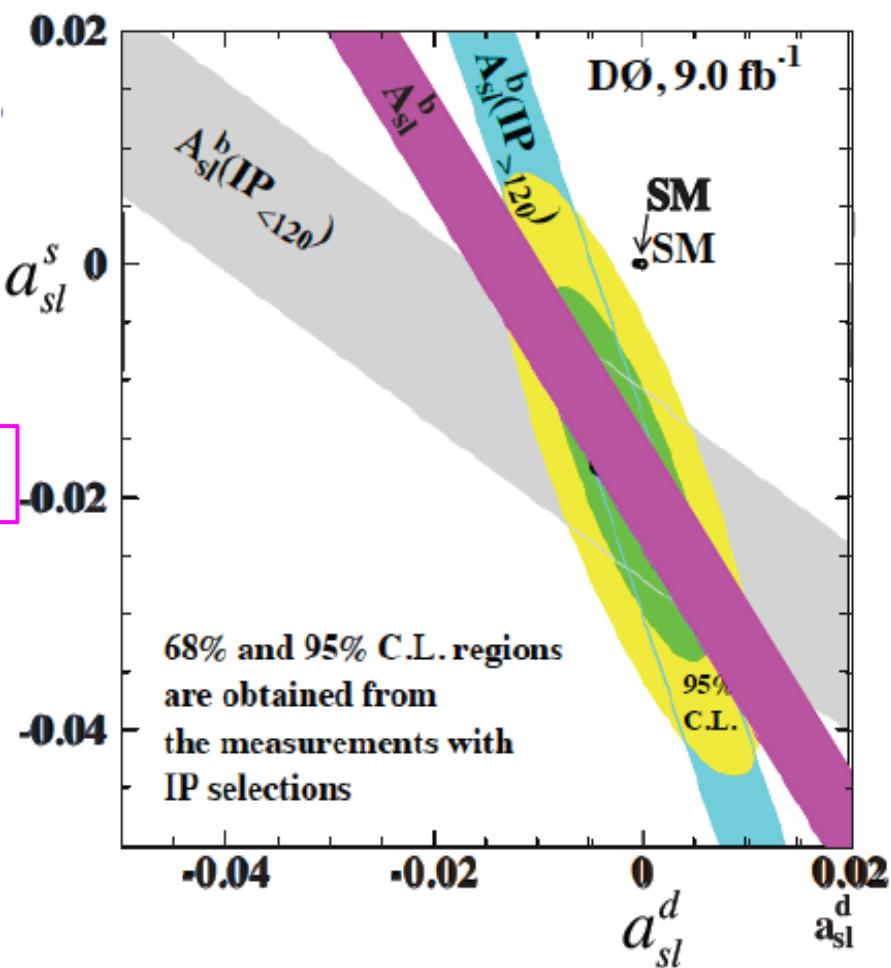
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DØ's result with
dimuon analysis:

$$a_{sl}^s = (-0.108 \pm 0.72 \pm 0.17)\%$$
$$a_{sl}^d = (0.93 \pm 0.45 \pm 0.14)\%$$

and $A_{sl}^b = (-0.787 \pm 0.172 \pm 0.093)\%$

→ 3.9 σ from SM.



$a_{s\text{ sl}}^s$ at LHCb

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Measurement is asymmetry between $D_s^+\mu^-\bar{\nu}$ and $D_s^-\mu^+\nu$.

Final state included is $D_s^+ \rightarrow \varphi(1020)\pi^+$ only.

Our measured quantity

$$A_{\text{meas}} = \frac{\Gamma(D_s^-\mu^+\nu) - \Gamma(D_s^+\mu^-\bar{\nu})}{\Gamma(D_s^-\mu^+\nu) + \Gamma(D_s^+\mu^-\bar{\nu})} = \frac{a_{fs}^s}{2} + \left(a_p - \frac{a_{fs}^s}{2} \right) \frac{\int_{t=0}^{\infty} e^{-\Gamma t} \cos(\Delta M t) \epsilon(t) dt}{\int_{t=0}^{\infty} e^{-\Gamma t} \cosh(\frac{\Delta\Gamma}{2} t) \epsilon(t) dt}$$

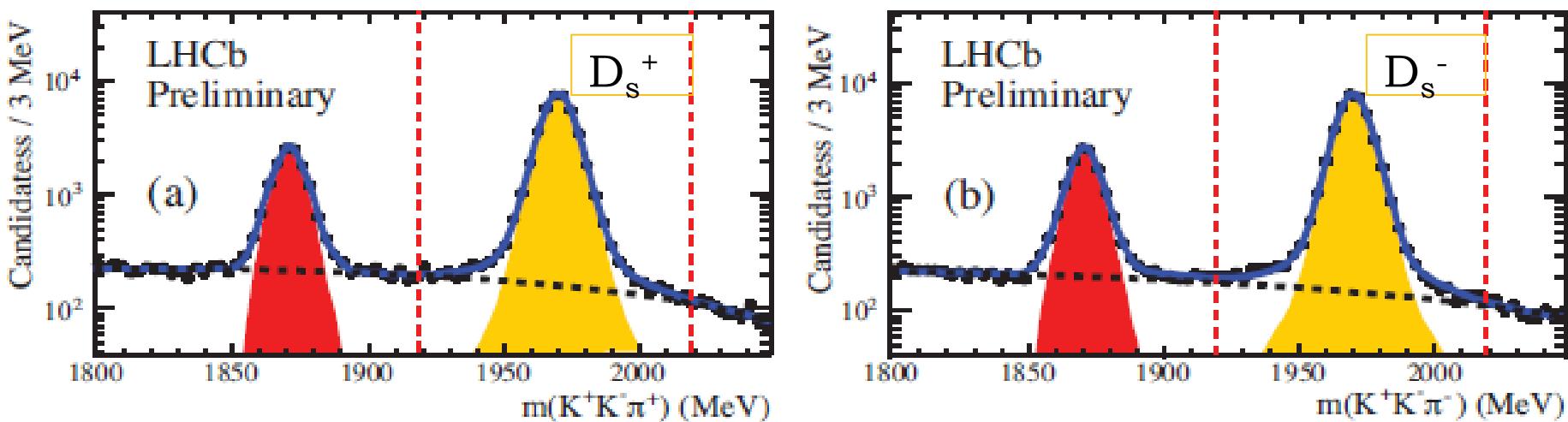
B_s^0/\bar{B}_s^0
Production
asymmetry ~1%

Acceptance integral is small
in B_s case because of rapid
oscillations. (~0.2%)

LHCb-conf-2012-022

The Measurement

- Measure yields with mass fits
 - » Fit D and D_s simultaneously with double Gaussians and 2nd order polynomial background.
 - » Also fit in 50 muon p-px-py bins to reduce kinematic biases.

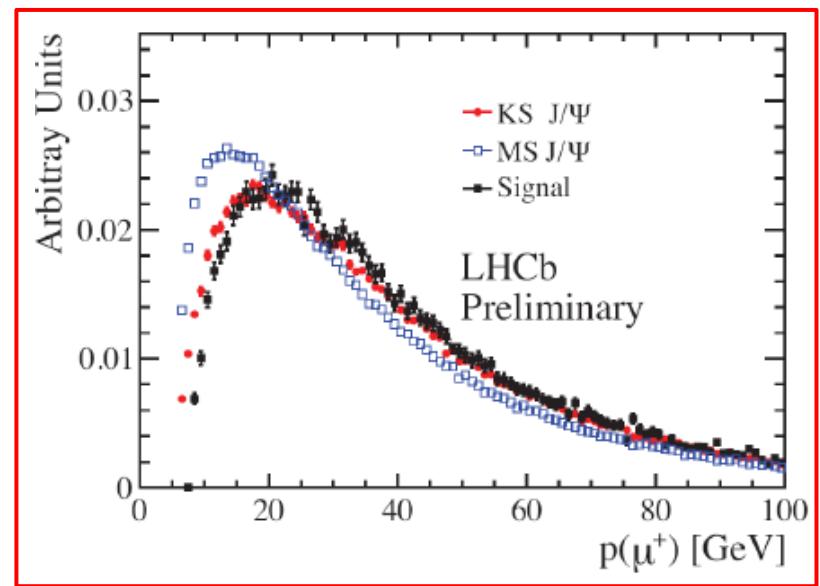
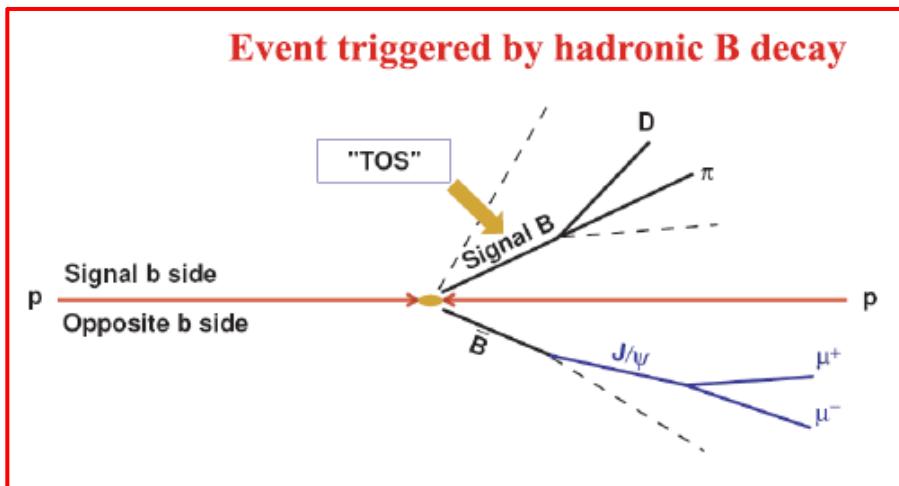


	Magnet up	Magnet down
Mass fitting		
$D_s^- \mu^+$	40945 ± 285	55755 ± 278
$D_s^+ \mu^-$	39849 ± 239	56447 ± 294

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The Measurement (cont'd)

- Measure detection, trigger and tracking efficiencies with calibration samples.
 - » J/ψ , D^{*+}



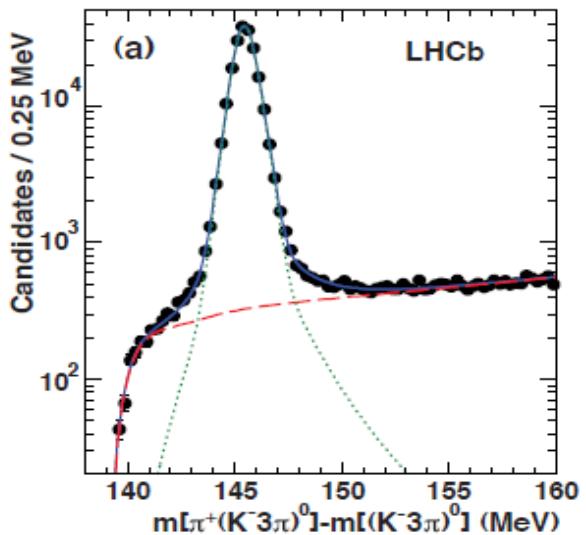
- $J/\psi \rightarrow \mu^+ \mu^-$ selected in events triggered by b-hadron **not** decaying into a J/ψ , using only kinematic selections.
- Used to determine $\epsilon(\mu^+)/\epsilon(\mu^-)$ for the muon identification algorithm and muon dependent triggers.

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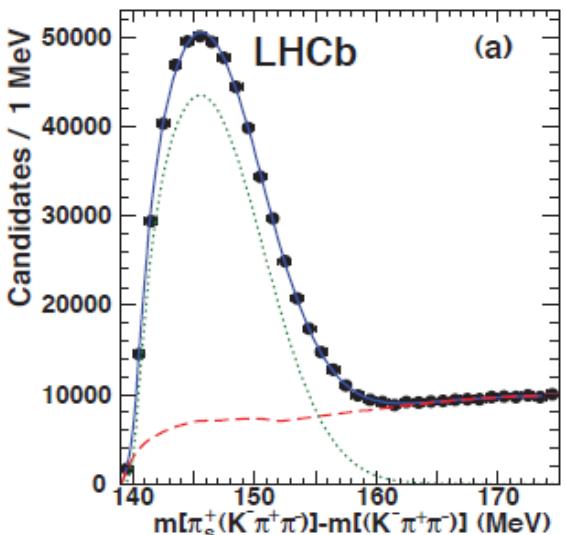
Pion Efficiency

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Full

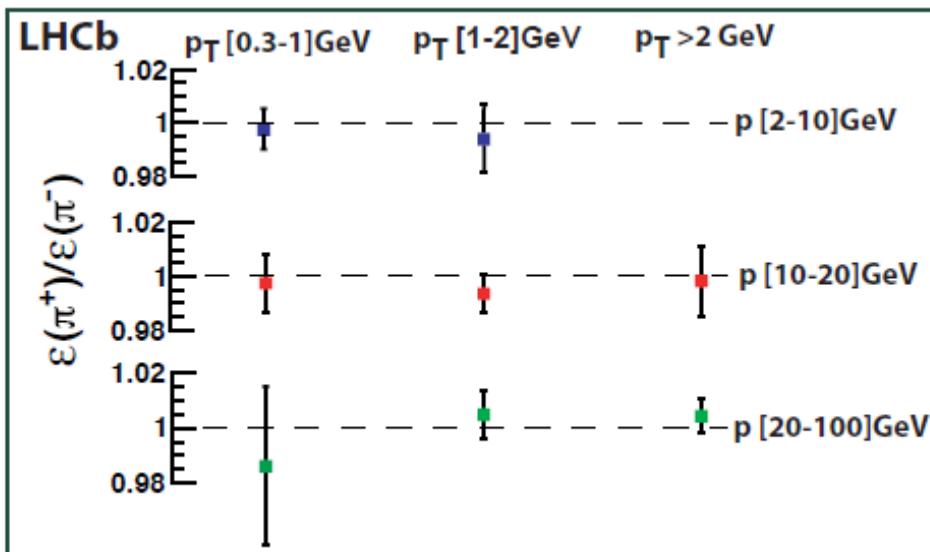


Partial



[PLB-D-12-00693R1](#)

- From D^{*+} calibration sample
- Used to measure the momentum dependent efficiency ratios.
- No momentum dependence found.

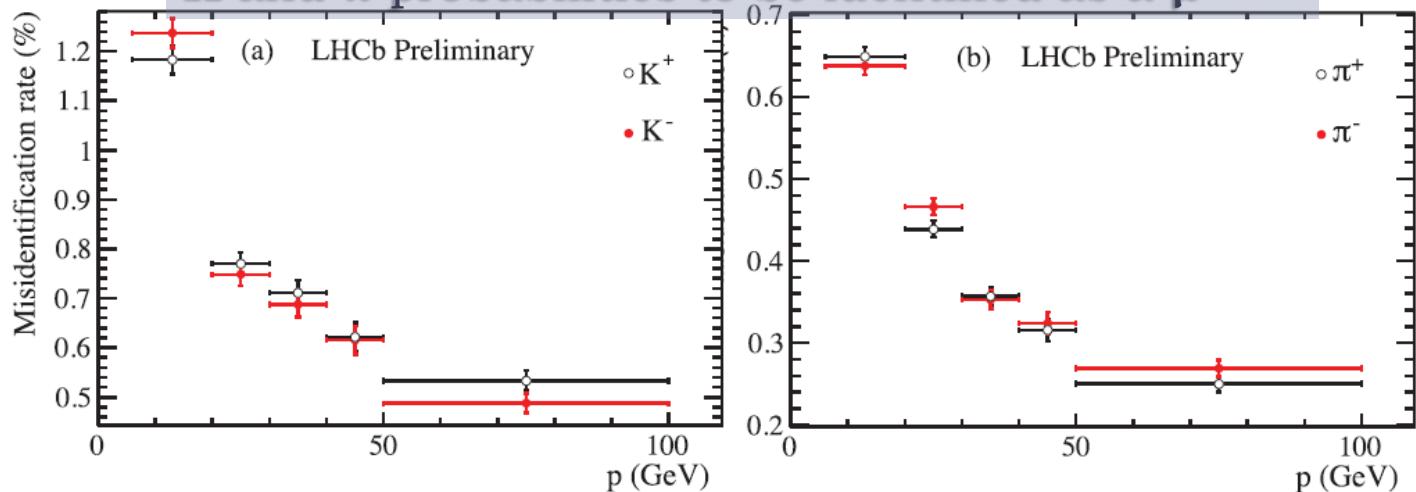


Systematic Uncertainties

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Sources	$\sigma(A_{\text{meas}}) (\%)$
Signal modelling in D_s^+ mass fit	0.06
Background from other b hadrons	0.05
Momentum difference between π and μ	0.06
Momentum difference between the same sign and opposite sign kaons	0.02
Muon corrections	0.05
Varying run conditions between field-up and field-down	0.01
Muon mis-identification	0.01
HLT2 bias in μ -topological trigger	0.05
Statistical uncertainty on the efficiency ratios	0.10
Total	0.16

K and π probabilities to be identified as a μ



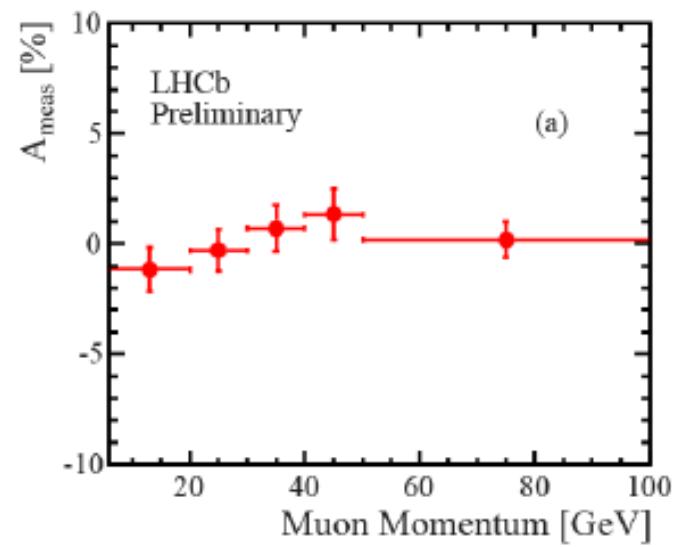
**Small differences
between opposite
signs**

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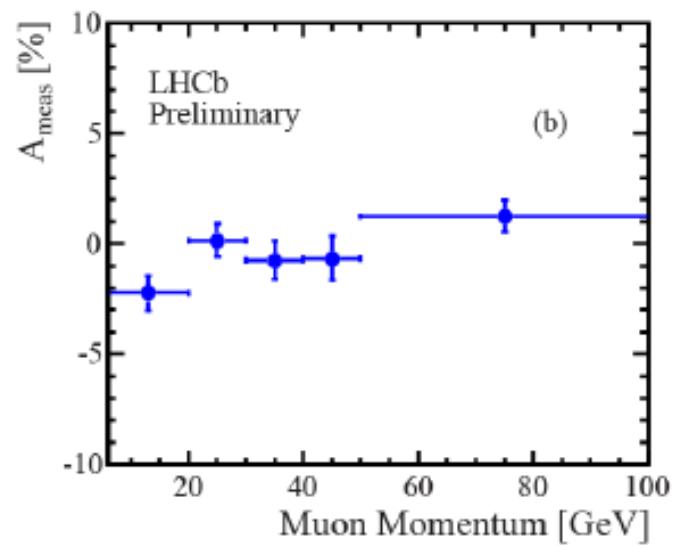
Measured Result, A_{meas}

SYRACUSE
UNIVERSITY**Magnet Up
Preliminary**

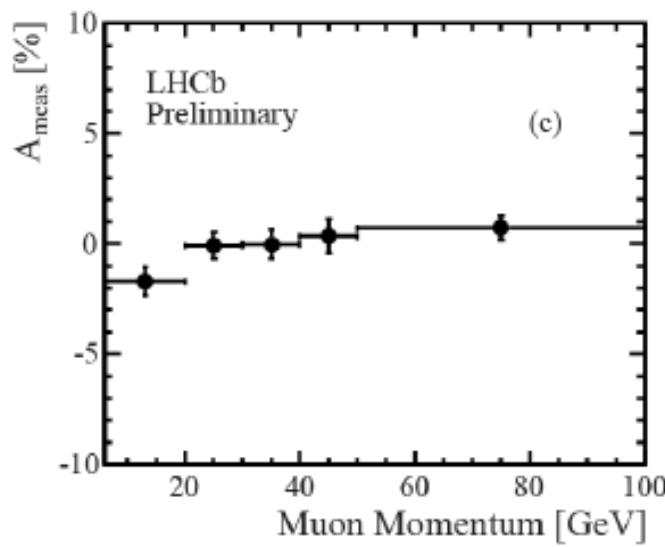
$$A_{\text{meas}} = (0.10 \pm 0.41 \pm 0.15)\%$$

**Magnet Down
Preliminary**

$$A_{\text{meas}} = (-0.34 \pm 0.35 \pm 0.13)\%$$

**Average
Preliminary**

$$A_{\text{meas}} = (-0.12 \pm 0.27 \pm 0.10)\%$$

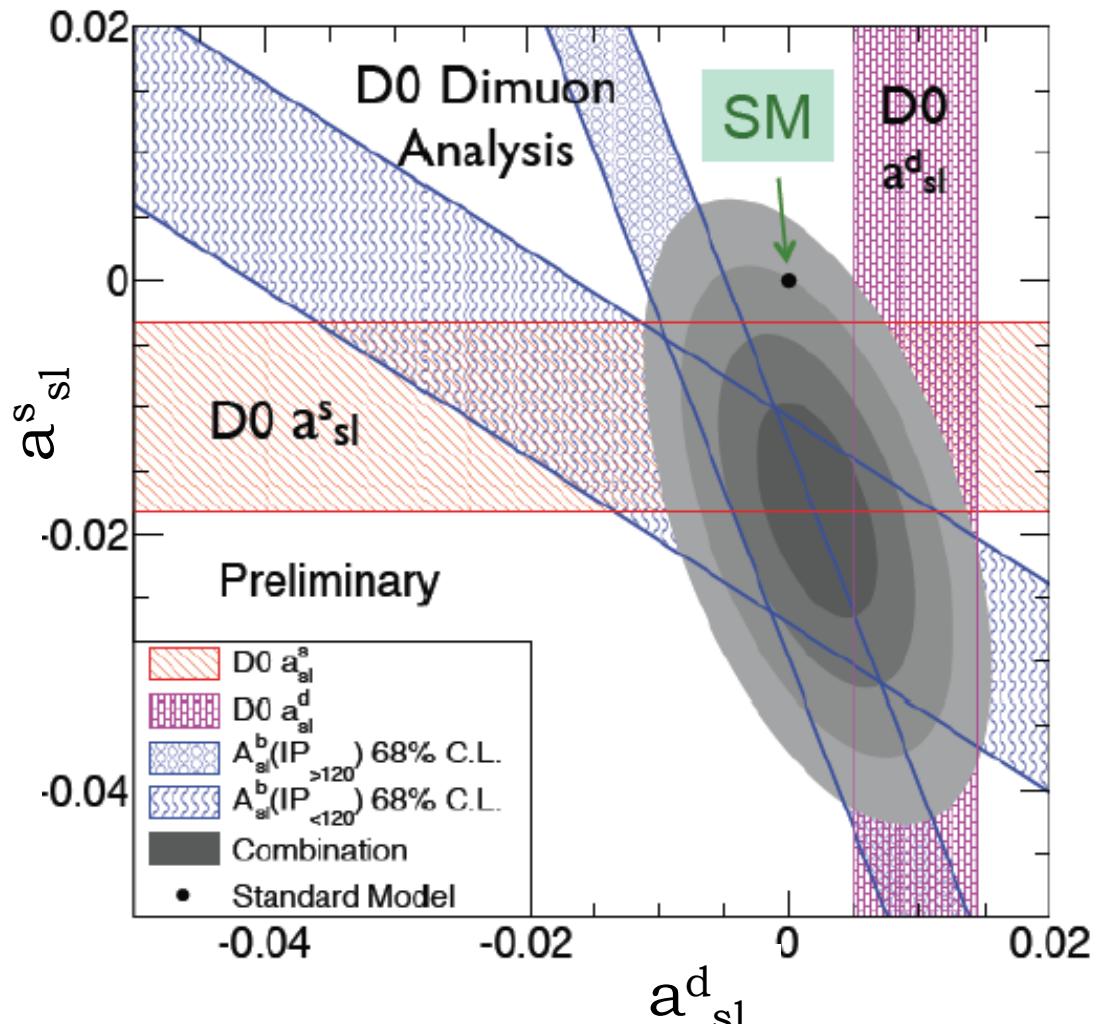


LHCb-conf-2012-022

DØ Results

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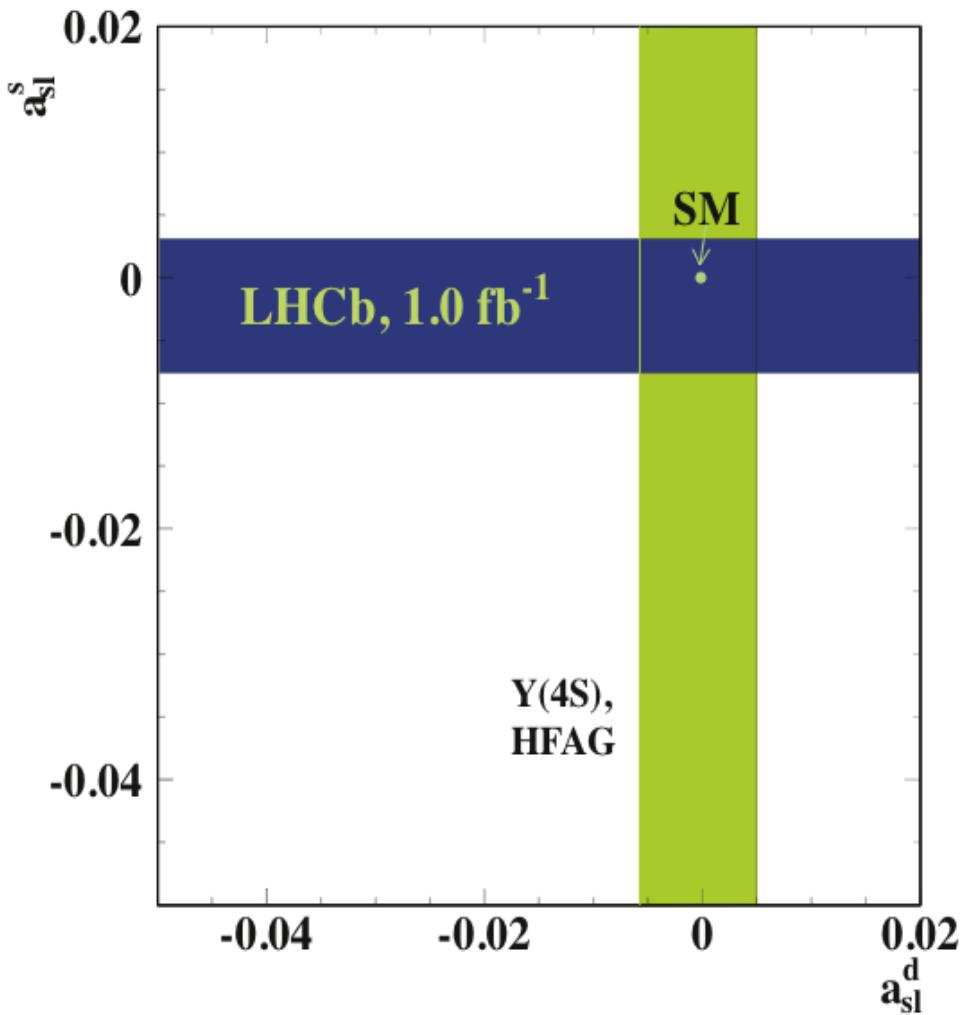
- $a_{sl}^s = (-1.81 \pm 0.56)\%$
- $a_{sl}^d = (-0.22 \pm 0.30)\%$



arXiv:1207.1769 [hep-ex]

LHCb Preliminary Result

- $a_{\text{sl}}^{\text{s}} = 2A_{\text{meas}}$
- $\mathbf{a_{\text{sl}}^{\text{s}} = (-0.24 \pm 0.54 \pm 0.33)\%}$
- Most precise measurement of a_{sl}^{s}
- **In agreement with Standard Model's prediction**
(Lenz, arXiv:1205.1444)
 - » $a_{\text{sl}}^{\text{s}} = (0.0019 \pm 0.0003)\%$
 - » $a_{\text{sl}}^{\text{d}} = (-0.041 \pm 0.0006)\%$



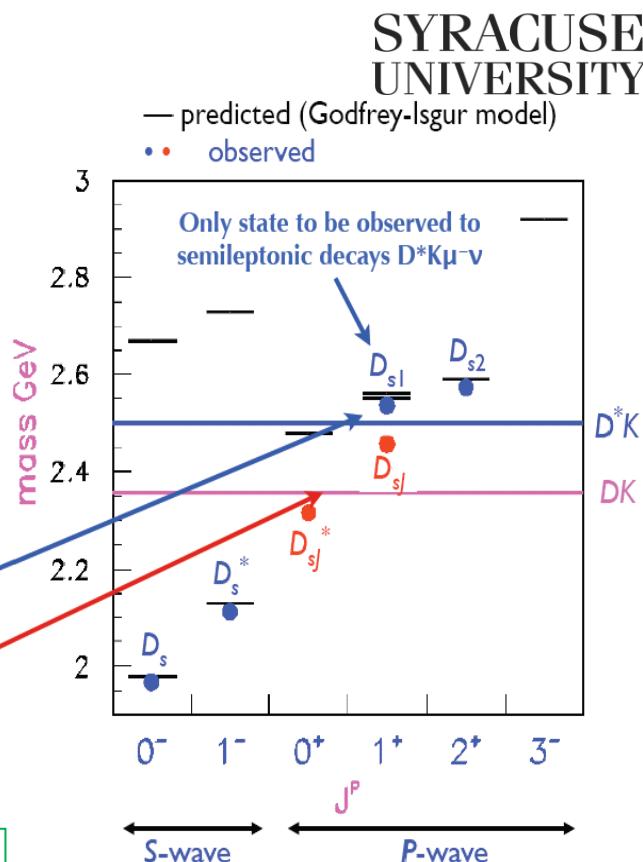
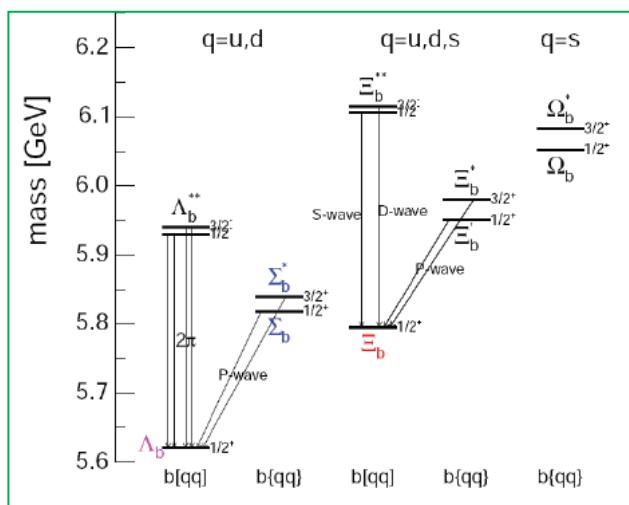
Towards CKM Parameters Studies

- Ultimate goal: measure V_{cb} and V_{ub} in B_s and Λ_b decays
- On the way: form factor studies and hadron mass spectra
 - » HQET validation in B_s and Λ_b semileptonic decays
- Better modeling of B_s semileptonic decays
- Understanding the Cabibbo favored semileptonic width, may allow V_{ub} determination from $B_s \rightarrow K(K^*)\mu\nu$

B_s and Λ_b Semileptonics

- B_s → D_sXμν Exclusive
 - » Only two final states have been observed
 - » Measurements of D^(*)K will constrain B_s → D_s^{**1}ν
 - First observation of $\bar{B}_s^0 \rightarrow D_{s2}^{+*} \mu^- \bar{\nu}$
- Λ_b⁰ → Λ_c⁺ Xμ⁻ ν
 - » Several exclusive measurements exist, but *no inclusive*.
 - » Λ_b⁰ → Λ_c⁺ Xμ⁻ ν form factors measured at DELPHI: $\rho^2 = 2.03 \pm 0.5 \pm 1.0$

$\Lambda_c^+ 1^- \nu$	$= (5.0^{+1.9}_{-1.4})\%$
$\Lambda_c^+ \pi^+ \pi^- 1^- \nu$	$= (5.6 \pm 3.1)\%$
$\Lambda_c(2595)^+ 1^- \nu$	$= (0.6^{+0.4}_{-0.3})\%$
$\Lambda_c(2625)^+ 1^- \nu$	$= (1.1^{+0.6}_{-0.4})\%$

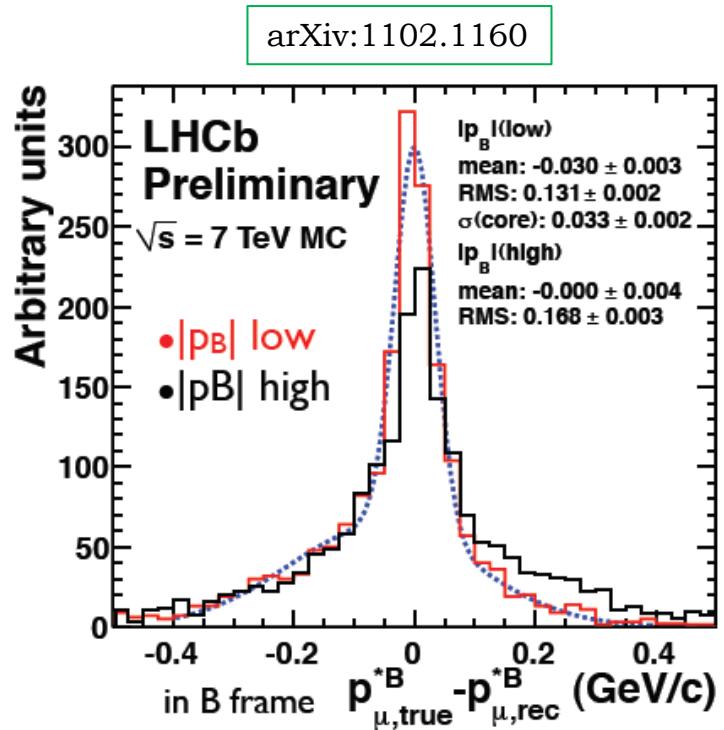
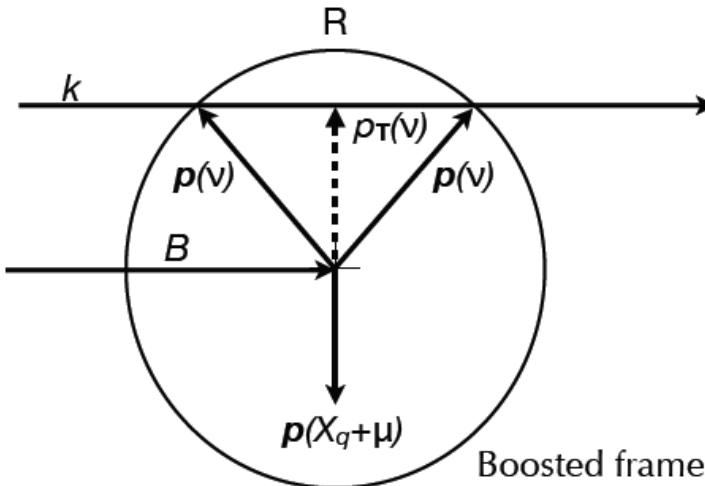


How We Infer the Neutrino 4-vector

Neutrino information and $|p_B|$ in semileptonic decays can be determined with a two-fold ambiguity.

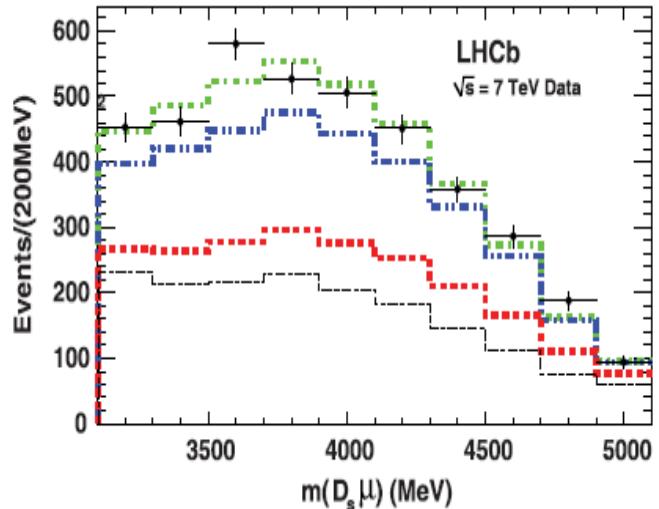
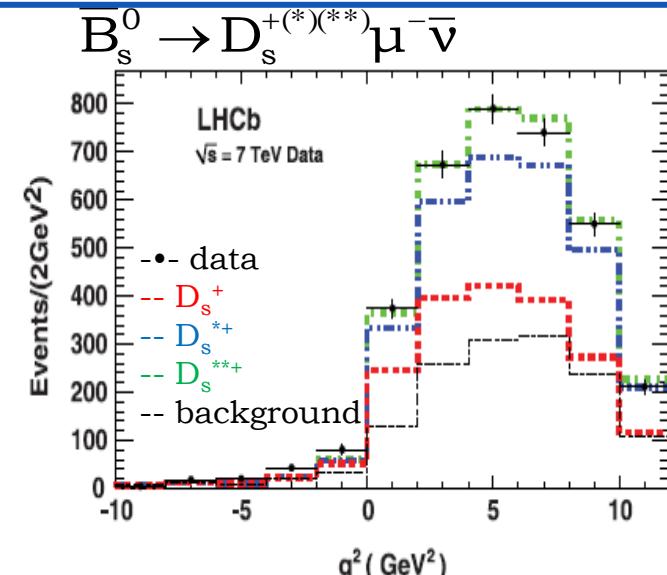
B direction determined from vertex displacement.

$$\left[\left(\frac{\hat{p}_B \cdot \vec{p}_{X_q\mu}}{E_{X_q\mu}} - 1 \right) \right] \rho^2 + \left[\frac{M^2 \rho \hat{p}_B \cdot \vec{p}_{X_q\mu}}{E_{X_q\mu}^2} \right] \rho + \left[\left(\frac{M^2}{2E_{X_q\mu}} \right)^2 - m_B^2 \right] = 0$$



Example of q^2 Fits

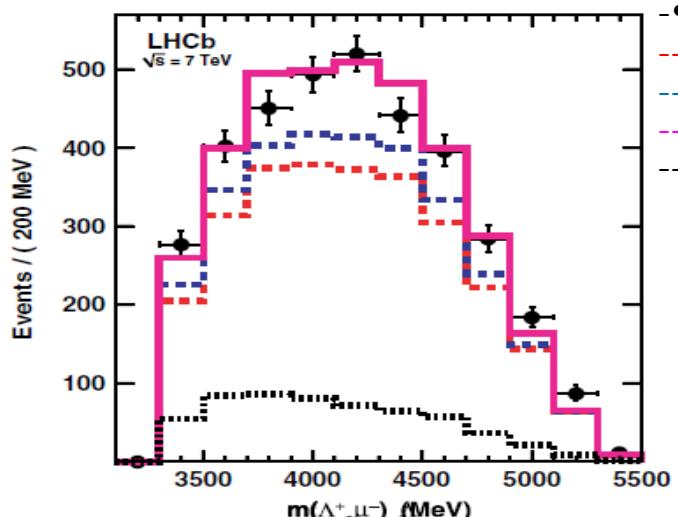
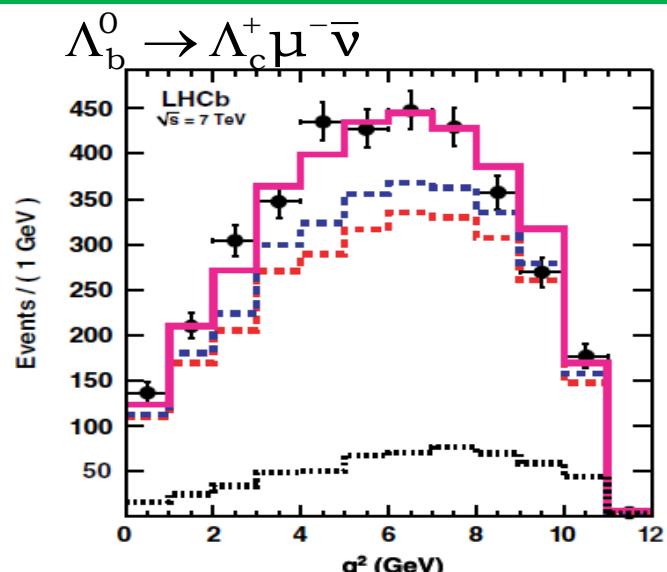
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Signal predictions for D_s and D_s^* based on D and D^{*+} form factors.

Relative fractions based on $D^*/D = 2.42$

[Physical Review D 85, 032008 \(2012\)](#)



$\Lambda_c^+(2595) / \Lambda_c^+(2625)$ ratio fixed to its predicted value.

[Phys. Rev. C 72 035201 \(2005\)](#)

Conclusions

- Measurement of the b-hadron production fractions done to very good precision.

$$f_s/(f_u + f_d) = 0.134 \pm 0.004(\text{stat.})^{+0.012}_{-0.011} (\text{sys.})$$

$$\frac{f_{A_b}}{f_u + f_d} = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T/\text{GeV}]$$

- Using similar techniques from previous measurements, LHCb is able to measure a_{sl}^s :

$$a_{\text{sl}}^s = (-0.24 \pm 0.54 \pm 0.33)\%$$

- » More data to be added as well as more D_s final states
- Studies of exclusive semileptonic B_s and Λ_b decays in progress

Thank you!

BACKUP

b-hadron production fraction

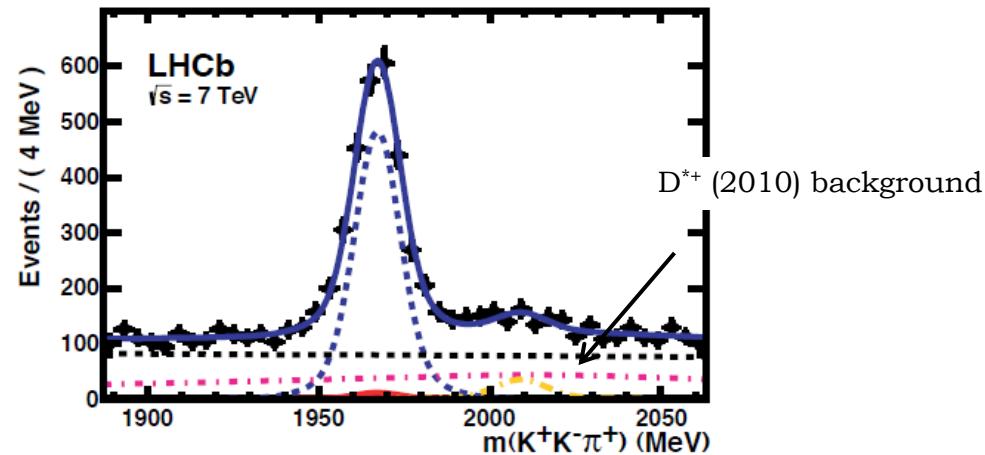
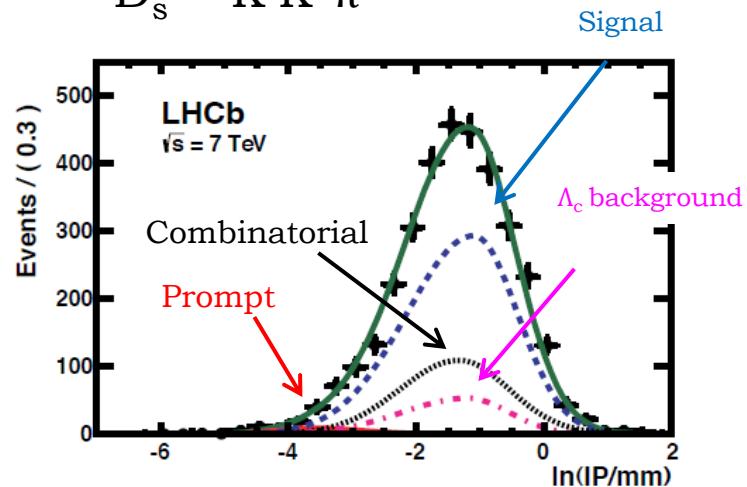
Further Fit Results:

$B_s^0 \rightarrow D_s^\pm X \mu \nu$ and $\Lambda_b \rightarrow \Lambda_c^\pm X \mu \nu$

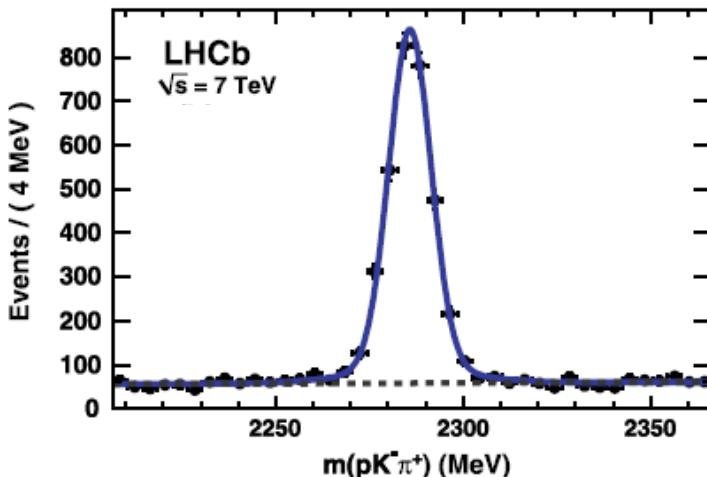
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$D_s^+ \rightarrow K^- K^+ \pi^+$

Physical Review D 85, 032008 (2012)



$\Lambda_c^+ \rightarrow p K^- \pi^+$

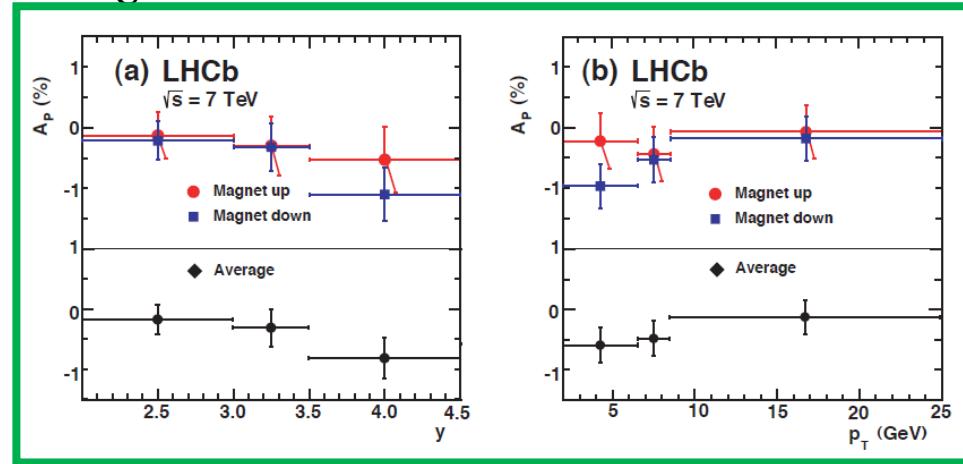


Pion Tracking Efficiency Method

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- Data driven method
- Applied for the first time to measure the production asymmetry of $D_s^+ - D_s^-$
 - » $A_p = (-0.33 \pm 0.22 \pm 0.10)\%$

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- Method
 - » $D^{*+} \rightarrow \pi_s^+ D^0$, with $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$
 - » **Partially** reconstruct decay ignoring a π
 - Examine mass difference:

$$\Delta m_{prt} = m(\pi_s^+ K^- \pi^+ \pi^-) - m(K^- \pi^+ \pi^-)$$

- » **Fully** reconstruct decay

$$\Delta m_{full} = m(\pi_s^+ K^- \pi^+ \pi^- \pi^+) - m(K^- \pi^+ \pi^- \pi^+)$$

- » $\epsilon_{reco} = \frac{N_{Full}(D^0 \pi_s^+)}{N_{partial}(D^0 \pi_s^+)}$