LHCb Results on Semileptonic $B/B_s/\Lambda_b$ Decays

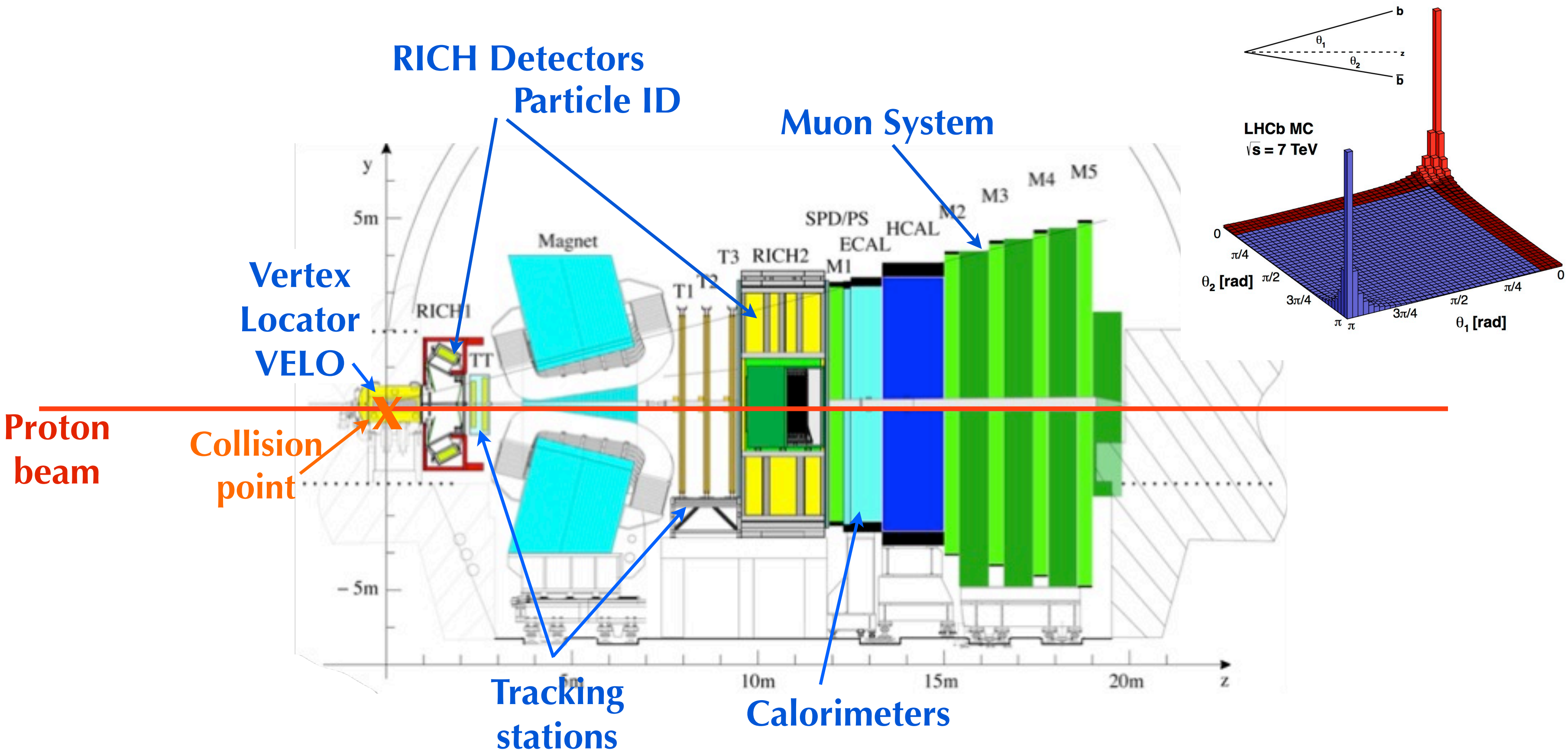
Concezio Bozzi, INFN Sezione di Ferrara

on behalf of the LHCb Collaboration

Outline

- The LHCb detector and data sample
- Semileptonic decays at LHCb
- Results on b production fractions and B_s decays
- Outlook: form factors, CKM and decays with taus

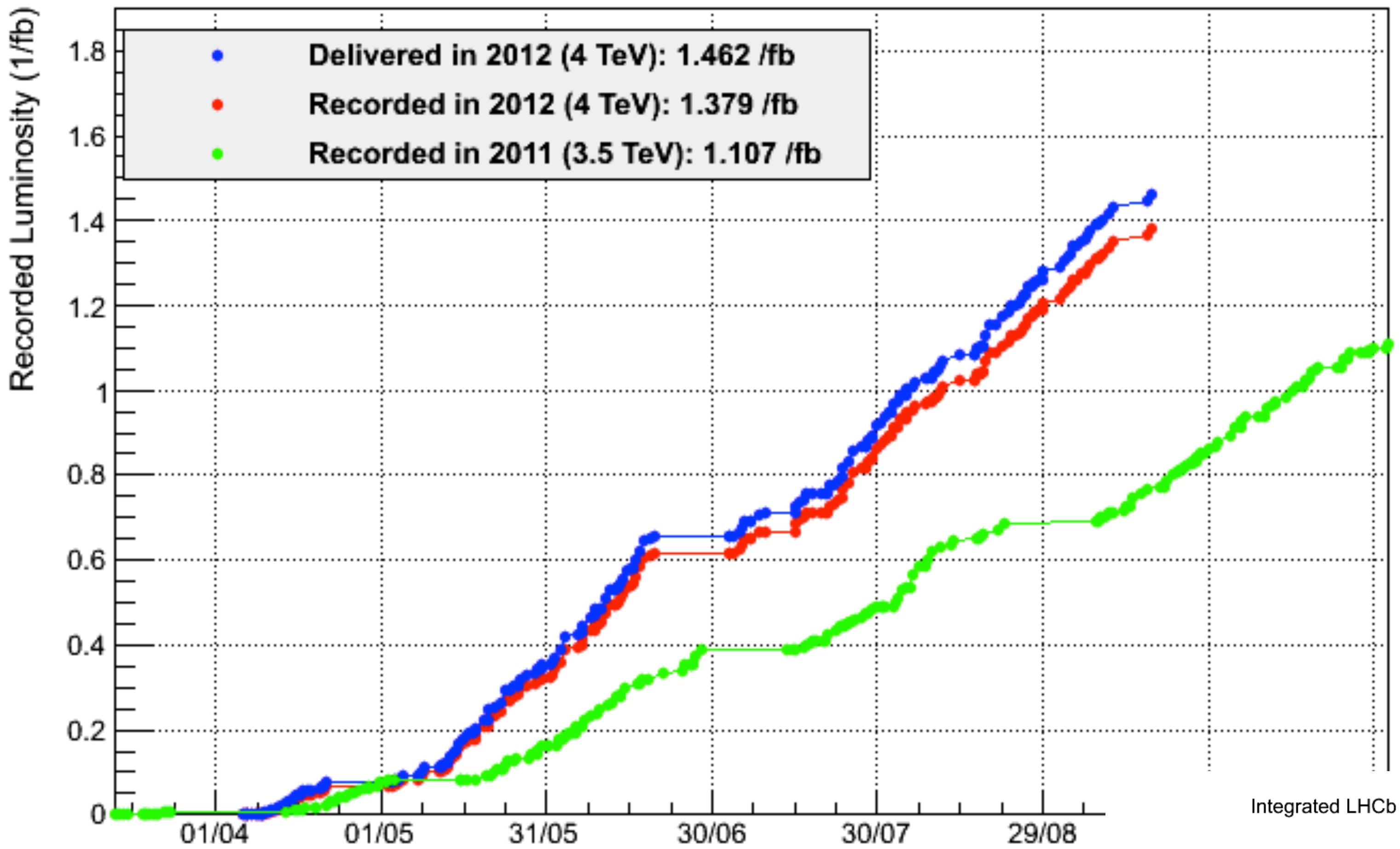
The LHCb detector

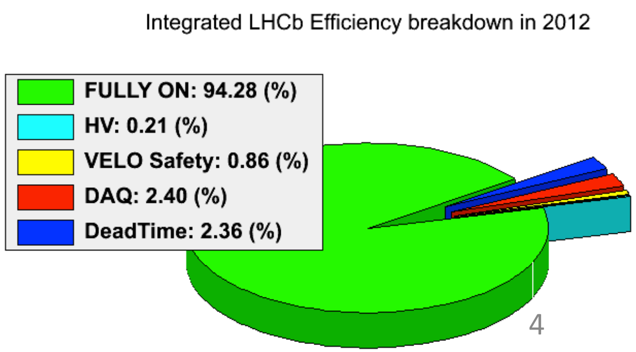


$\sigma(pp \to b\bar{b}X) = (284 \pm 20 \pm 49)\ \mu b$ @ √s=7 TeV
(obtained on a sample of semileptonic decays!)
Phys. Lett. B 694 (2010) 209

All b hadrons produced
B^0, B^+, B_s, B^{**}, Λ_b, Σ_b, …

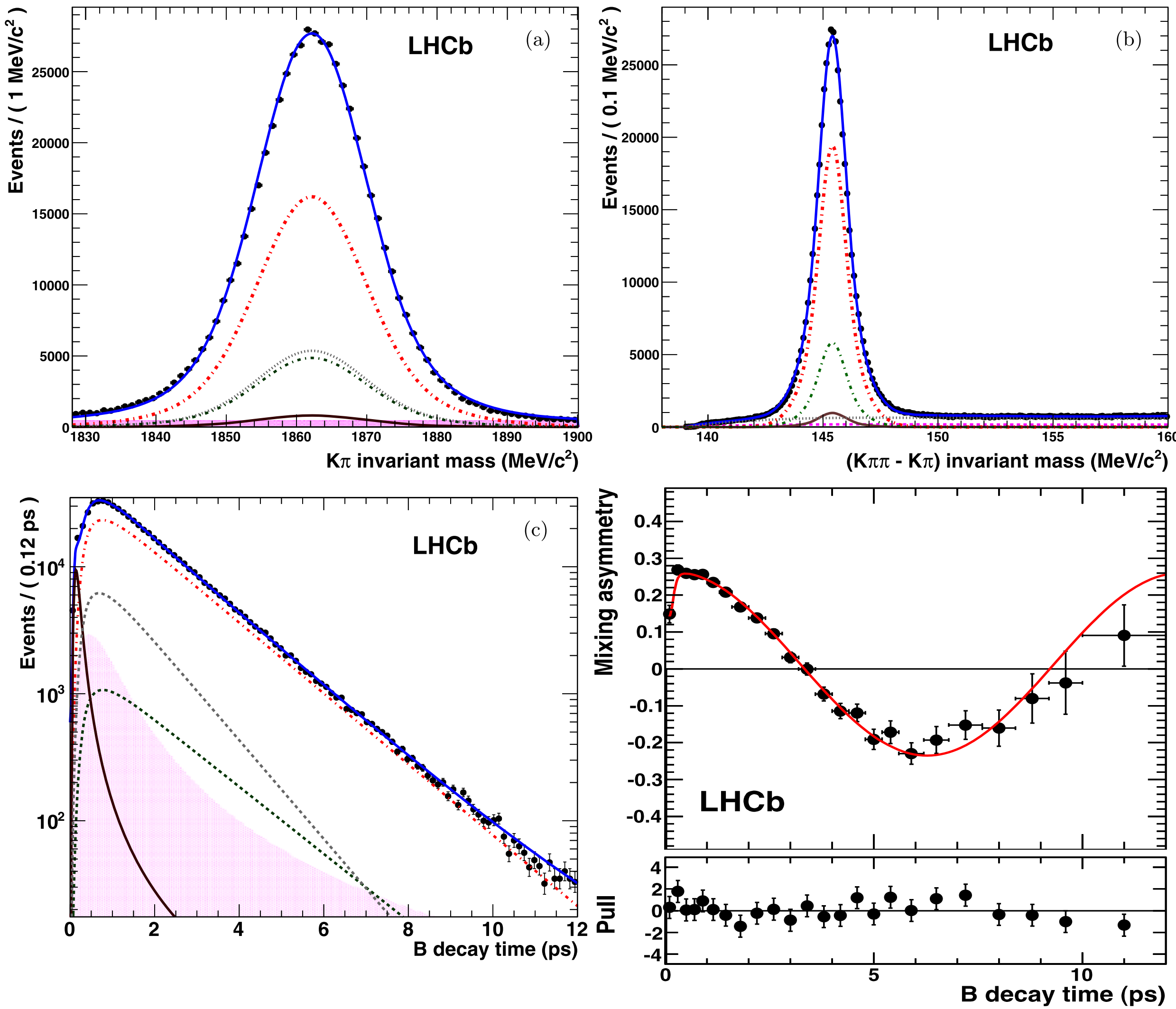
Great LHC(b) performance!





Currently taking data @ L = 4 x 10^{32} cm^{-2} s^{-1} (flat)
(design luminosity: 2 x 10^{32})

Large and clean samples



Eur. Phys. J. C (2012) 72:2022

$$\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu$$
$$\hookrightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$

370 pb^{-1}

500k events

Δm compatible with world average

Semileptonic B decays at LHCb

- "Calibration tool" and hadronization studies
  - $b\bar{b}$ cross section — Phys. Lett. B 694 (2010) 209
  - flavour tagging performance — Eur. Phys. J. C (2012) 72:2022
  - production fractions of B, B_s, Λ_b — PRD 85, 032008 (2012)

- CP Violation through semileptonic asymmetries
  → see Zhou's talk in WG IV

- Exclusive decays of B_s and Λ_b — Phys. Lett. B 698 (2011) 14; PRD 85, 032008 (2012)
  - Composition of the inclusive SL width
  - Improved systematic uncertainties on CP asymmetries
  - Measurement of form factors
  - Measurements of CKM parameters $|V_{ub}|/|V_{cb}|$ (e.g. $B_s \rightarrow K^{(*)}\mu\nu$)

Semileptonic B decays at LHCb

- Experimental signature:
  charm-hadron + muon
- Use large IP wrt to primary vertex to suppress "prompt" charm background
- Use charm to tag b hadron species:

  $B^+/B^0/\mathbf{B_s}/\Lambda_b$

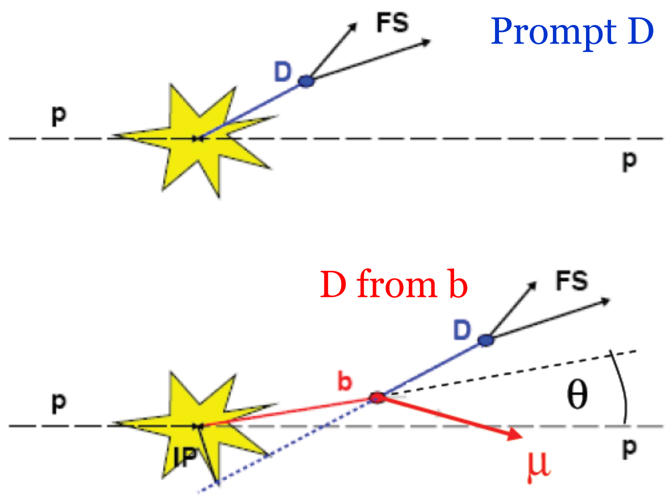
  $\rightarrow D^0 X \mu^- \nu$ $\quad$ $\rightarrow \mathbf{D_s X \mu^- \nu}$

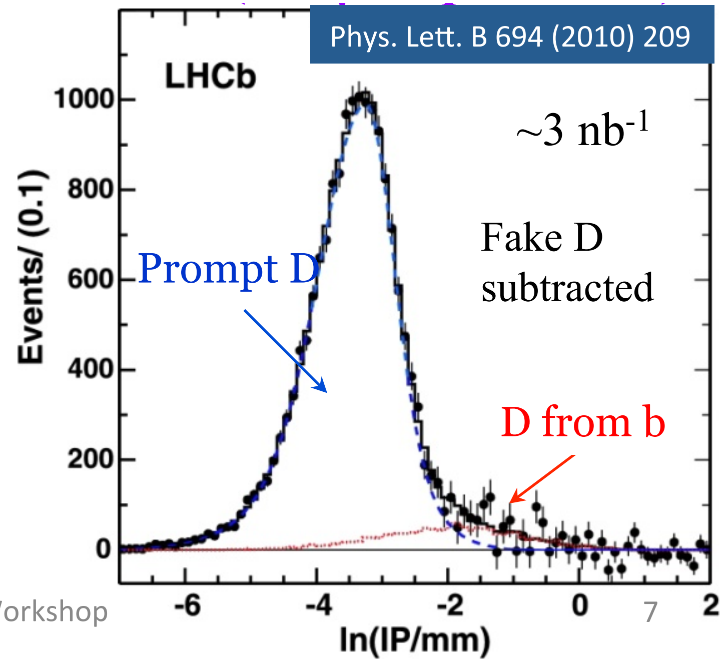
  $\rightarrow D^+ X \mu^- \nu$ $\quad$ $\rightarrow \Lambda_c X \mu^- \nu$

- Subtract cross-feed, e.g.

  $B_s \rightarrow (D_s^{**} \rightarrow DK) X \mu^- \nu \rightleftarrows B^{0/+} \rightarrow D_s K X \mu^- \nu$

  - D^0K, D^0p final states
  - other available measurements





b-hadron production fractions

- Production fractions directly related to yields of different charmed hadrons, after correcting for cross-feeds i.e.

$f_q = BR(b \to B_q)$

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

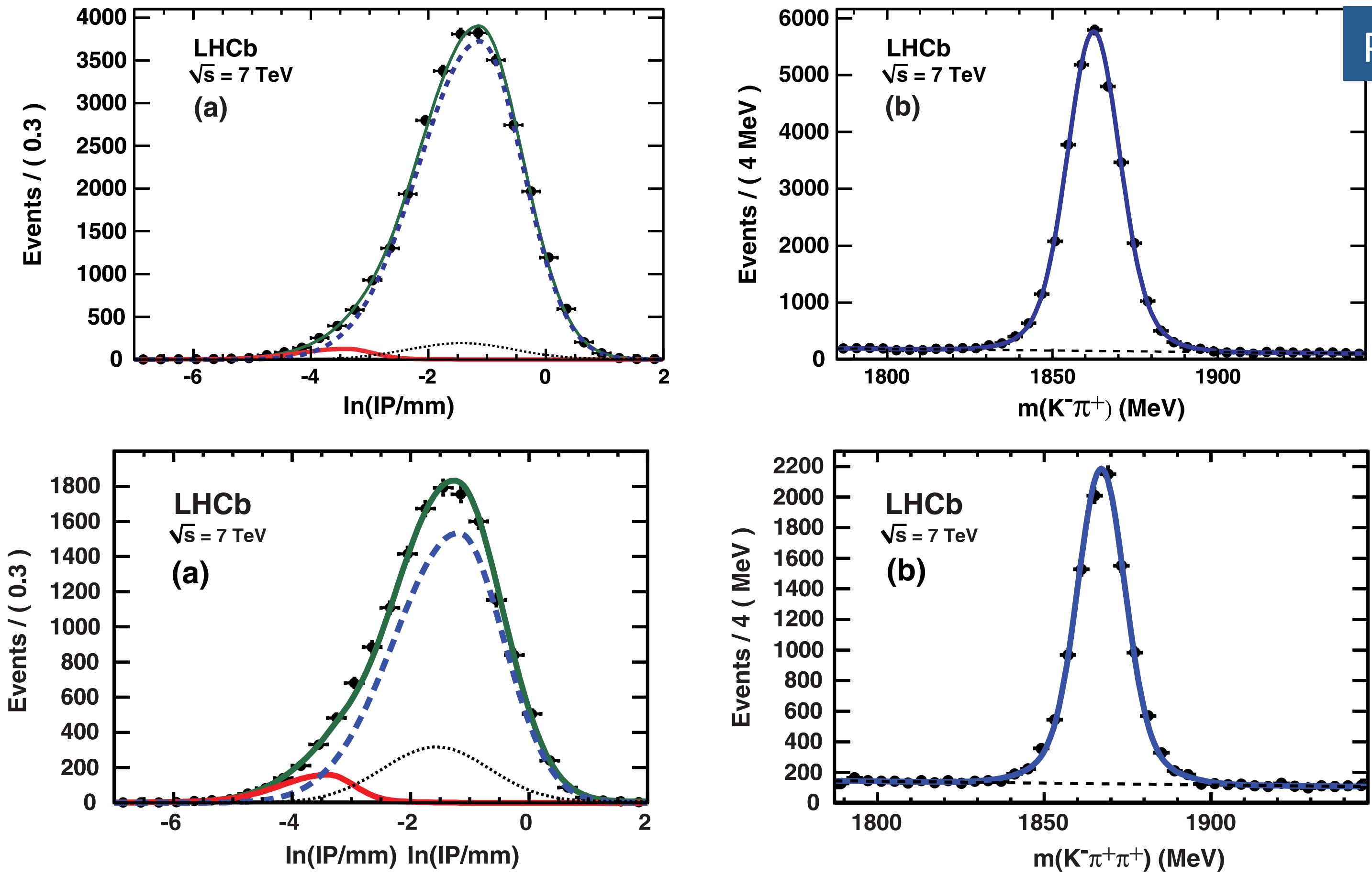
$$\frac{f_{\Lambda_b}}{f_u + f_d} = \frac{n_{\rm corr}(\Lambda^0_b \to D\mu)}{n_{\rm corr}(B \to D^0\mu) + n_{\rm corr}(B \to D^+\mu)} \times \frac{\tau_{B^-} + \tau_{\bar{B}^0}}{2\tau_{\Lambda^0_b}}(1 - \xi).$$

- Determine cross-feeds with D^0K and D^0p control samples. For instance:

$$n_{\rm corr}(\Lambda^0_b \to D\mu) = \frac{n(\Lambda^+_c\mu^-)}{\mathcal{B}(\Lambda^+_c \to pK^-\pi^+)\epsilon(\Lambda^0_b \to \Lambda^+_c)} + 2\frac{n(D^0p\mu^-)}{\mathcal{B}(D^0 \to K^-\pi^+)\epsilon(\Lambda^0_b \to D^0p)},$$

- Perform analysis in 3 (η) x 5 (p_T) bins, $2<\eta<5$, $p_T \leq 14$ GeV
- Measurements based on single-muon, low-p_T (1GeV) trigger
- Efficiencies depend on hadronic composition
  - Determine different contributions directly on data (see later)

D^0 and D^+ samples



PRD 85, 032008 (2012)

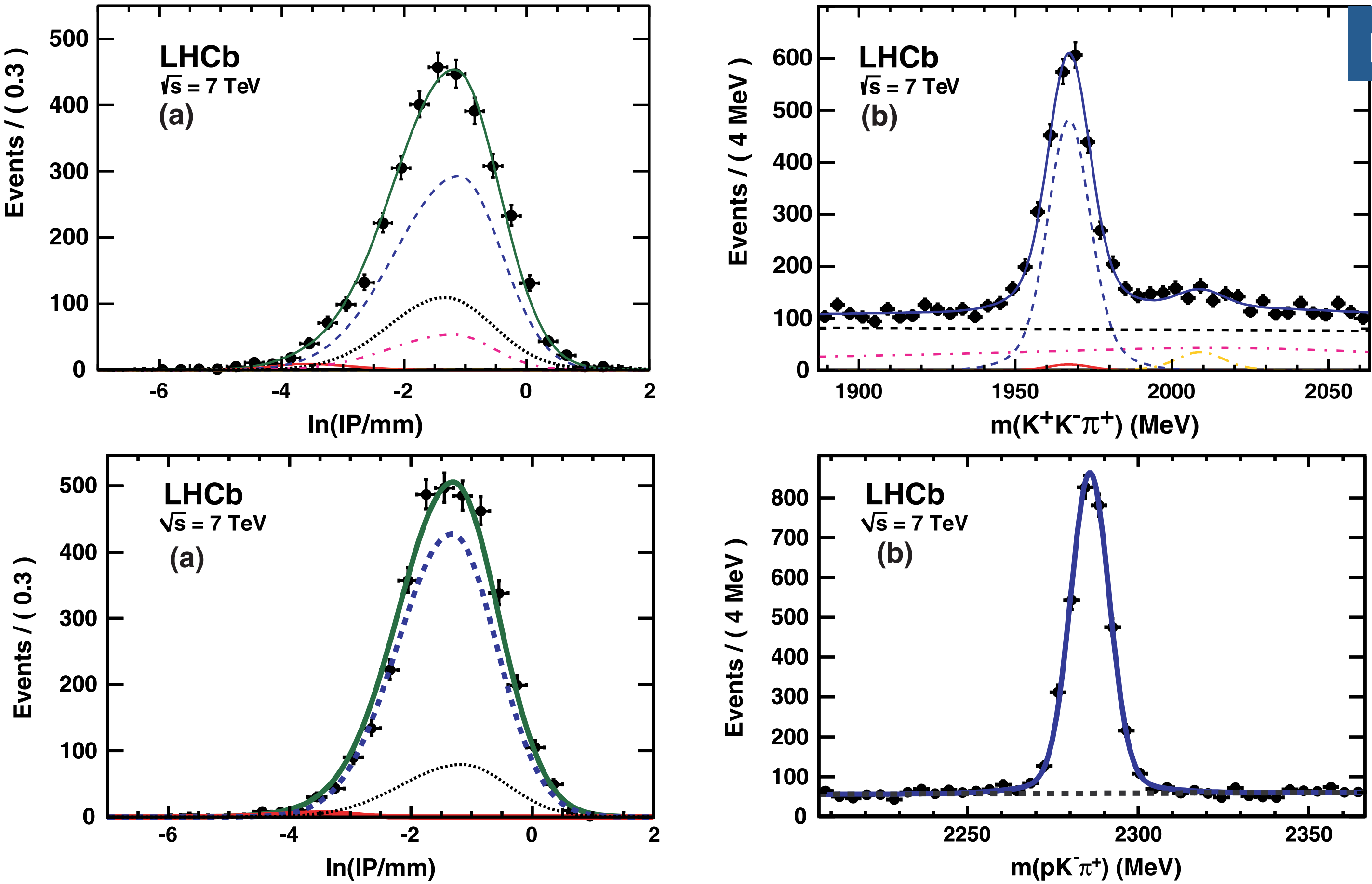
3 pb^{-1}

2D fit to ln(IP/mm) and charm hadron invariant mass

Channel	Signal (RAW)	Prompt D	Combinatorial
$D^0\mu\nu X$	27666 ± 167	695 ± 43	1492 ± 30
$D^+\mu\nu X$	9257 ± 110	362 ± 34	1150 ± 22

Use also wrong charm-lepton charge correlations for background estimates

D_s and Λ_c samples



PRD 85, 032008 (2012)

3 pb^{-1}

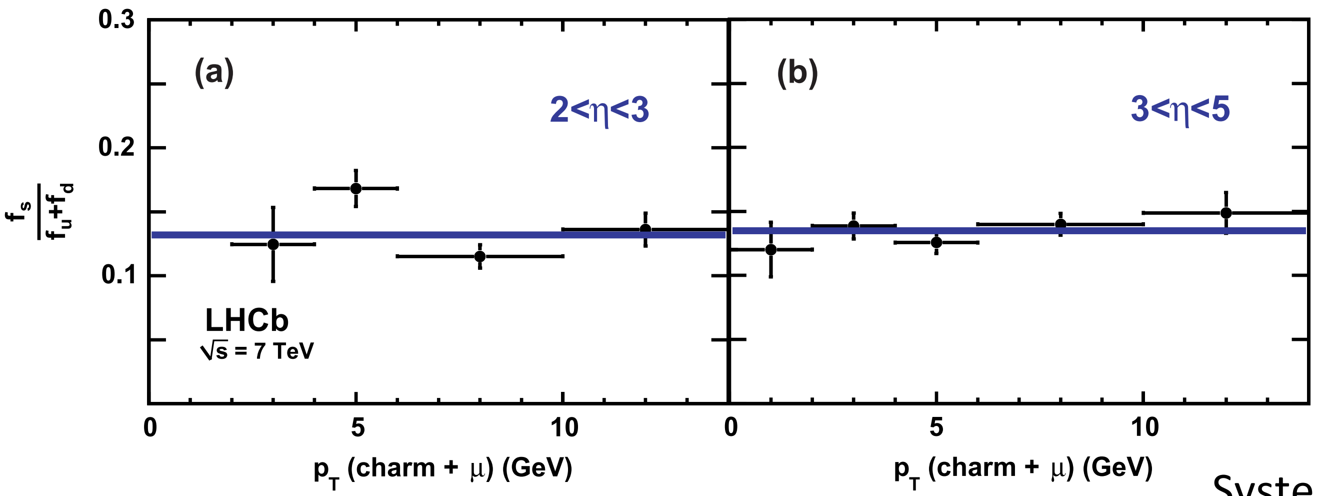
2D fit to ln(IP/mm) and charm hadron invariant mass

Channel	Signal (RAW)	Prompt D	Combinatorial	Λ_c reflection
$D_s \mu \nu X$	2192 ± 64	63 ± 16	985 ± 145	387 ± 132
$\Lambda_c \mu \nu X$	3028 ± 112	43 ± 17	589 ± 27	

Use also wrong charm-lepton charge correlations for background estimates

Results: f_s

PRD 85, 032008 (2012)



3 pb^{-1}

No p_T dependence

$$\frac{f_s}{f_u + f_d} = 0.134 \pm 0.004^{+0.011}_{-0.010}$$

Compare with:

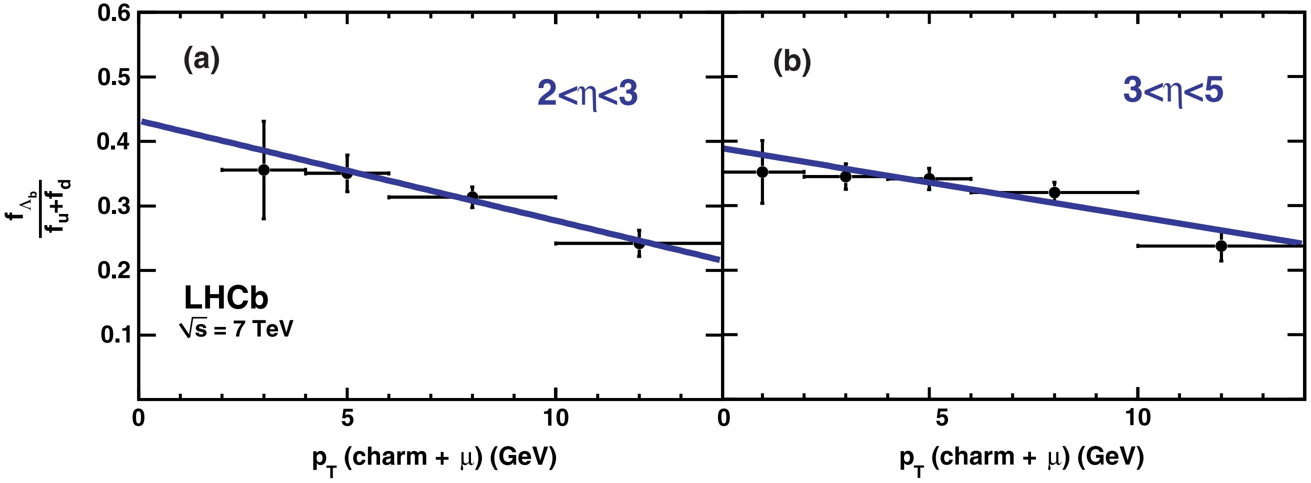
$$\frac{f_s}{f_u + f_d} = 0.128 \pm 0.012 \quad (LEP)$$

$$= 0.164 \pm 0.026 \quad (Tevatron)$$

Systematic uncertainties

Source	Error (%)
Bin-dependent errors	1.0
$\mathcal{B}(D^0 \to K^-\pi^+)$	1.2
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	1.5
$\mathcal{B}(D_s^+ \to K^-K^+\pi^+)$	4.9
$\bar{B}_s^0$ semileptonic decay modelling	3.0
Backgrounds	2.0
Tracking efficiency	2.0
Lifetime ratio	1.8
PID efficiency	1.5
$\bar{B}_s^0 \to D^0 K^+ X \mu^- \bar{\nu}$	$^{+4.1}_{-1.1}$
$\mathcal{B}((B^-, \bar{B}^0) \to D_s^+ K X \mu^- \bar{\nu})$	2.0
Total	$^{+8.6}_{-7.7}$

Results: f_{Λ_b}



PRD 85, 032008 (2012)

3 pb^{-1}

Not flat over p_T !

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

Systematically dominated (26%) by BF($\Lambda_c \to pK\pi$)

Consistent with CDF in same kinematic region

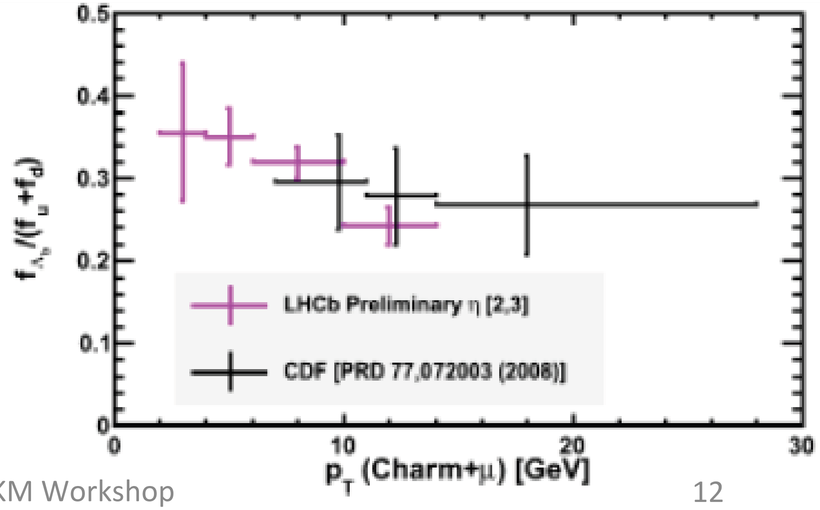
Baryon fraction higher at low p_T

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

$\langle p_T \rangle_{CDF} \approx 14.1\,\mathrm{GeV}$

LEP: 0.110 ± 0.035
arXiv:1010.1589

$\langle p_T \rangle_{LEP} \approx 40\,\mathrm{GeV}$

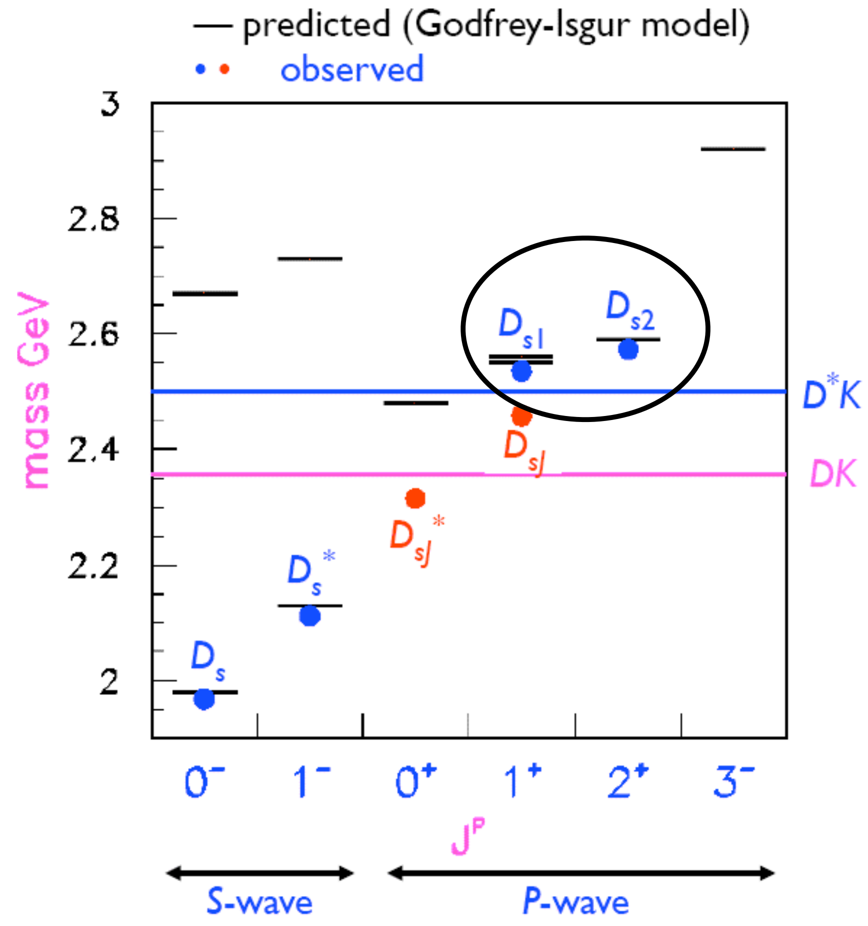


B_s exclusive SL decays

- Contrary to lighter B mesons, not much is known experimentally on exclusive B_s decays
- Final states with D^0K can be used to measure $B_s \rightarrow D_s^{**} l\nu$

$$D'_{s1}, D^*_{s2} \rightarrow D^{(*)}K$$

$$D^{(*)}_{sJ} \rightarrow D^{(*)+}_s + n(\pi^0 \; or \; \gamma)$$



First observation: $\bar{B}_s \to D_{s2}^{*+} X \mu^- \bar{\nu}$

$D_{s1}(2536)^+ \to D^*(2007)^0 K^+$

(missed π^0 or γ)

$D_{s2}(2573)^+ \to D^0 K^+$

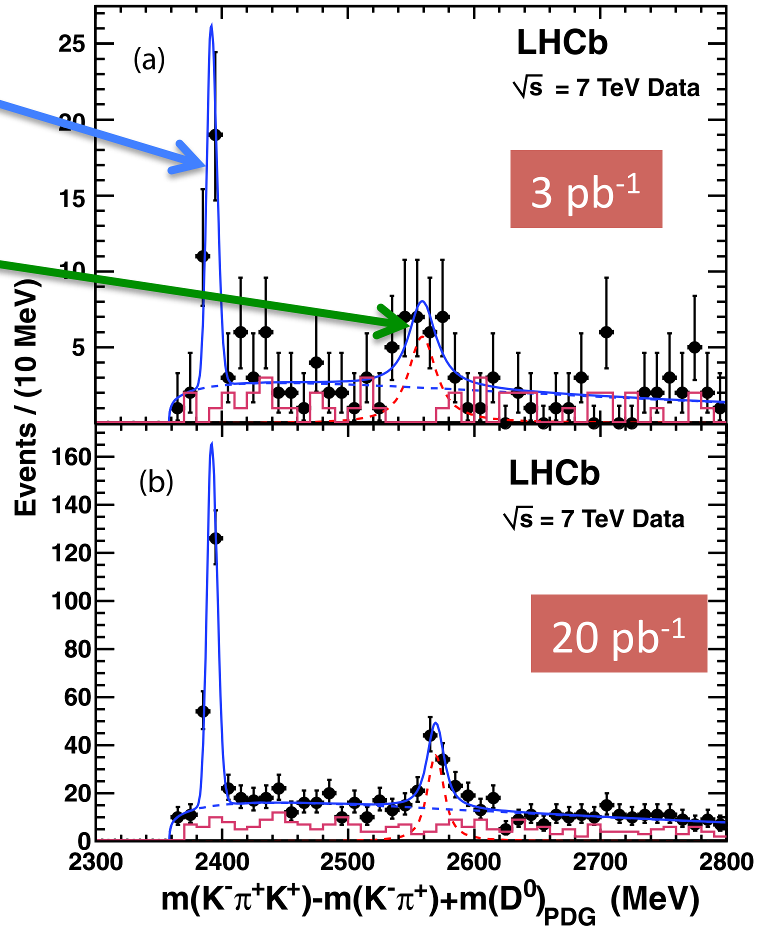
Significance: 8.3 σ

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

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

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

Phys. Lett. B 698 (2011) 14

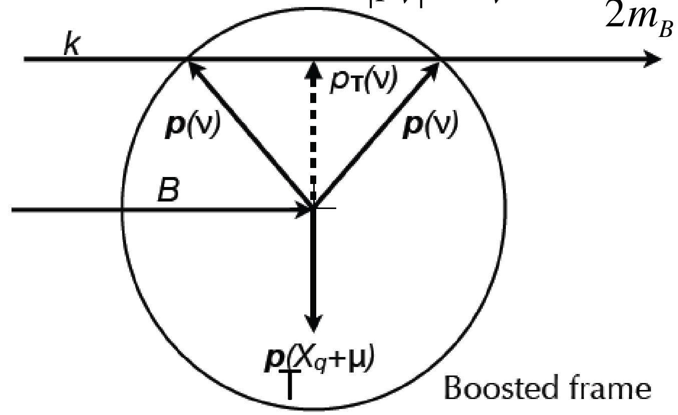


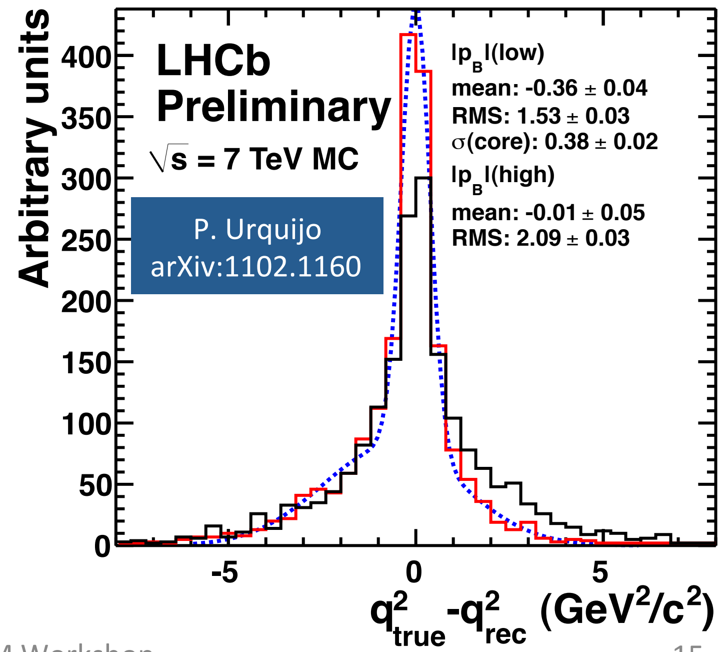
Most precise measurements of $B_s \to D_s^{**} l\nu$ decays!

$|V_{xb}|$ with exclusive decays?

- Need to reconstruct rest frame observables
- Neutrino reconstruction:
  - Determine B flight direction vector from the separation of primary and B decay vertices
  - Get neutrino momentum with two-fold ambiguity
  - Resulting q^2 resolution is similar to that observed in B factories
- First steps: measure BFs and form factors in B_s and Λ_b decays
- Ultimate goal: measure $|V_{ub}|$ in exclusive B_s and Λ_b decays
- Input from lattice/LCSR needed

$$R = |\vec{p}_\nu| = E_\nu = \frac{m_B^2 - m_{X_q+\mu}^2}{2m_B}$$

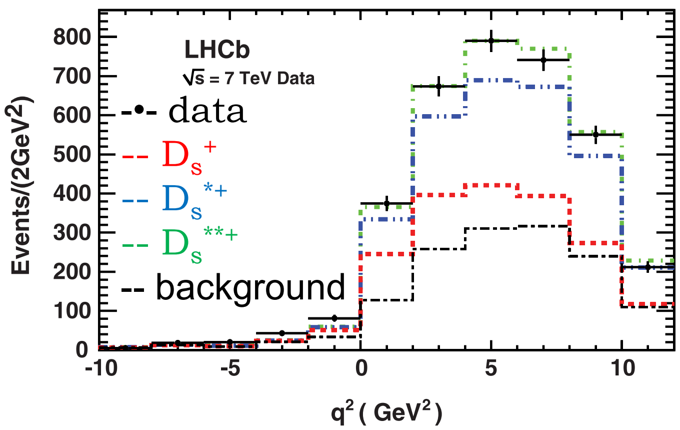


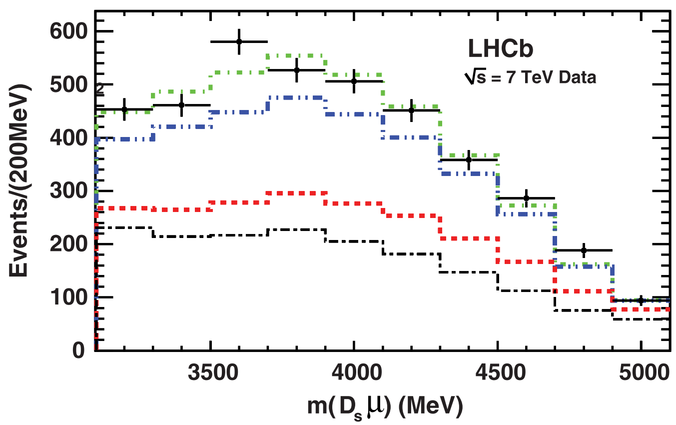


Proof of principle

PRD 85, 032008 (2012)

$$\overline{B}_s^0 \rightarrow D_s^{+(*)(**)} \mu^- \overline{\nu}$$

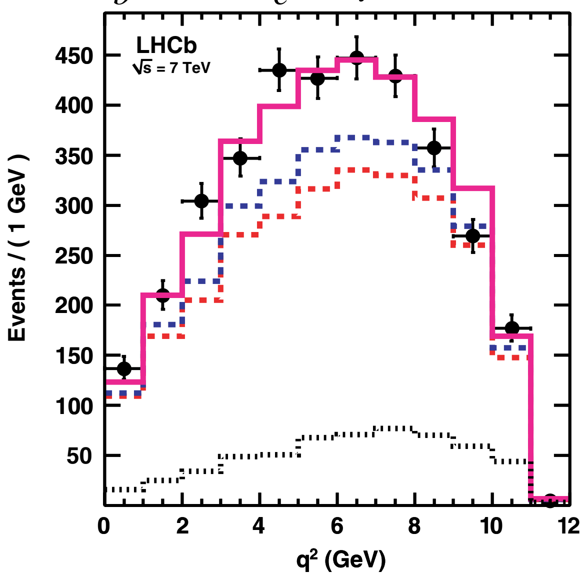


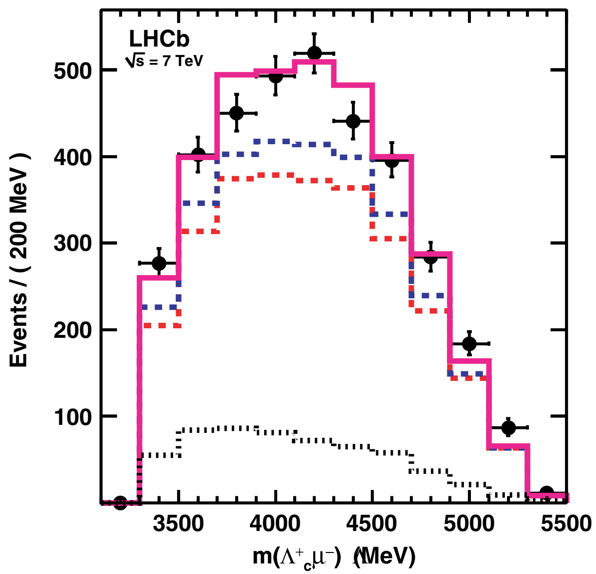


Use D and D*+ form factors for D_s and D_s*

Constrain relative fractions $D_s^*/D_s = D^{*+}/D = 2.42$

$$\Lambda_b^0 \rightarrow \Lambda_c^{+(**)} \mu^- \overline{\nu}$$



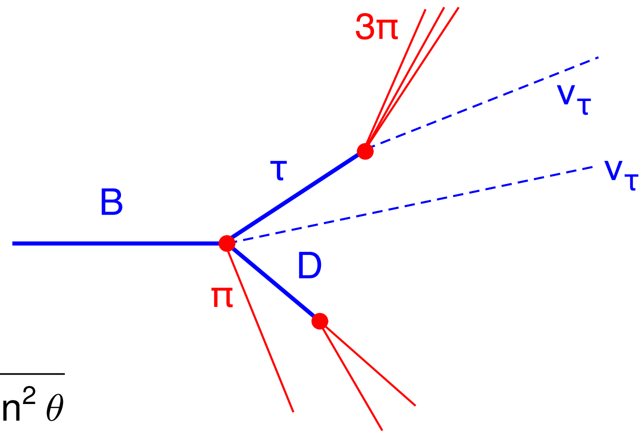


-•- data
-- Λ_c^+
-- Λ_c^+ (2595)
-- Λ_c^+ (2625)
-- background

Fix $\Lambda_c(2595)^+/\Lambda_c(2625)^+$ ratio to value predicted in Phys. Rev. C 72 035201 (2005)

$B \rightarrow D^{(*)}\tau\nu$?

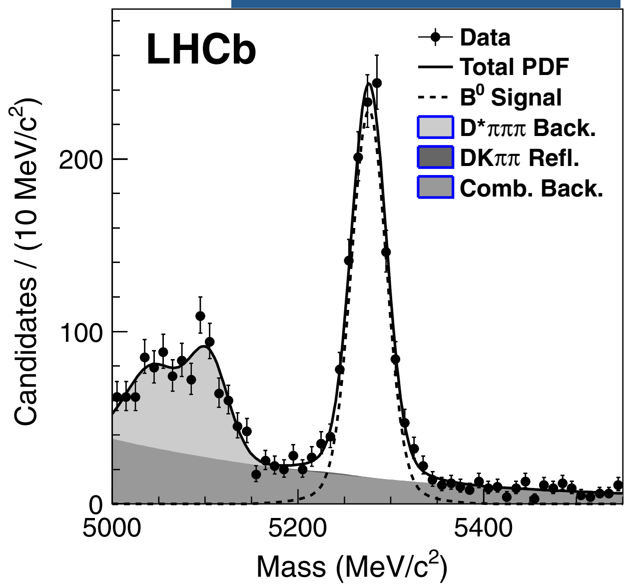
- Neutrino reconstruction outlined above not appropriate on $\tau \rightarrow \mu\nu\nu$ (too many neutrinos!)
- Try to kinematically reconstruct 3-prong decays $\tau^\pm \rightarrow \pi^+\pi^-\pi^\pm\nu_\tau$



$$|\vec{p}_\tau| = \frac{(m_{3\pi}^2 + m_\tau^2)|\vec{p}_{3\pi}|\cos\theta \pm E_{3\pi}\sqrt{(m_{3\pi}^2 - m_\tau^2)^2 - 4m_\tau^2|\vec{p}_{3\pi}|^2\sin^2\theta}}{2(E_{3\pi}^2 - |\vec{p}_{3\pi}|^2\cos^2\theta)}$$

- Main problems: two-fold ambiguity (four-fold when going to B), non-physical solutions due to momentum and vertex resolutions
- High track multiplicities should not be a problem, see e.g. $B_{(s)} \rightarrow D_{(s)}\pi\pi\pi$

PRD 84, 092001 (2011)

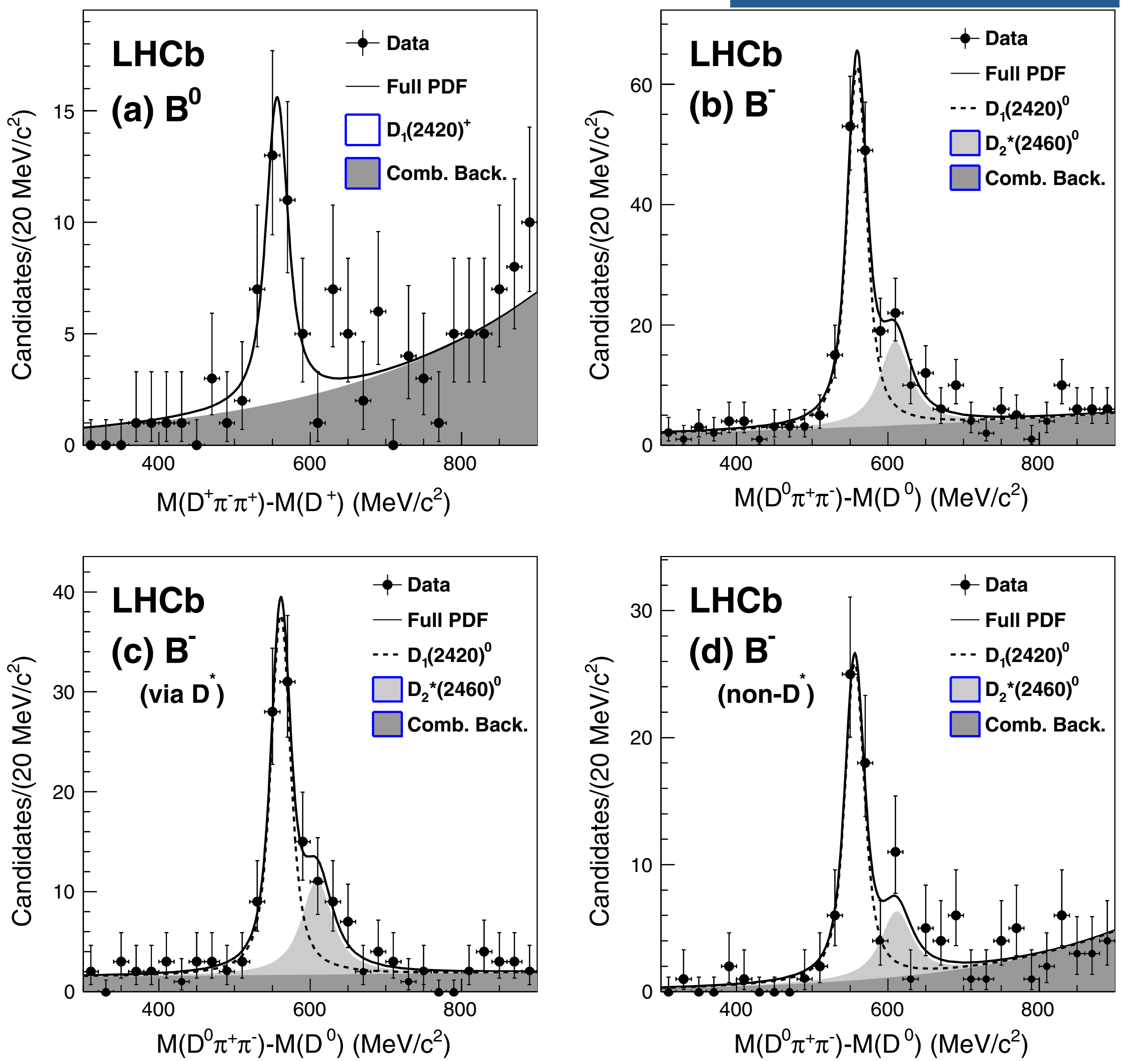


More on D** states

PRD 84, 092001 (2011)

B→Dπππ analysis clearly shows $D_1(2420)$ and $D^*_2(2460)$ signals, confirming and extending Belle's evidence for 3-body decays of D** mesons

→Search for radial excitations $D^{(*)\prime}$



Conclusion

Semileptonic $B/B_s/\Lambda_b$ decays are an important part of the LHCb physics program

- Precise measurements of production fractions
- Improving knowledge of exclusive decays
- Neutrino reconstruction will allow for form factor measurements and eventually to determine $|V_{cb}|$, $|V_{ub}|$ with B_s/Λ_b decays
- Measurements of $B \rightarrow D^{(*)}\tau\nu$ through 3-prong τ decays should be viable