Semileptonic b decays at LHCb

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CKM Workshop 2010
Working Group II

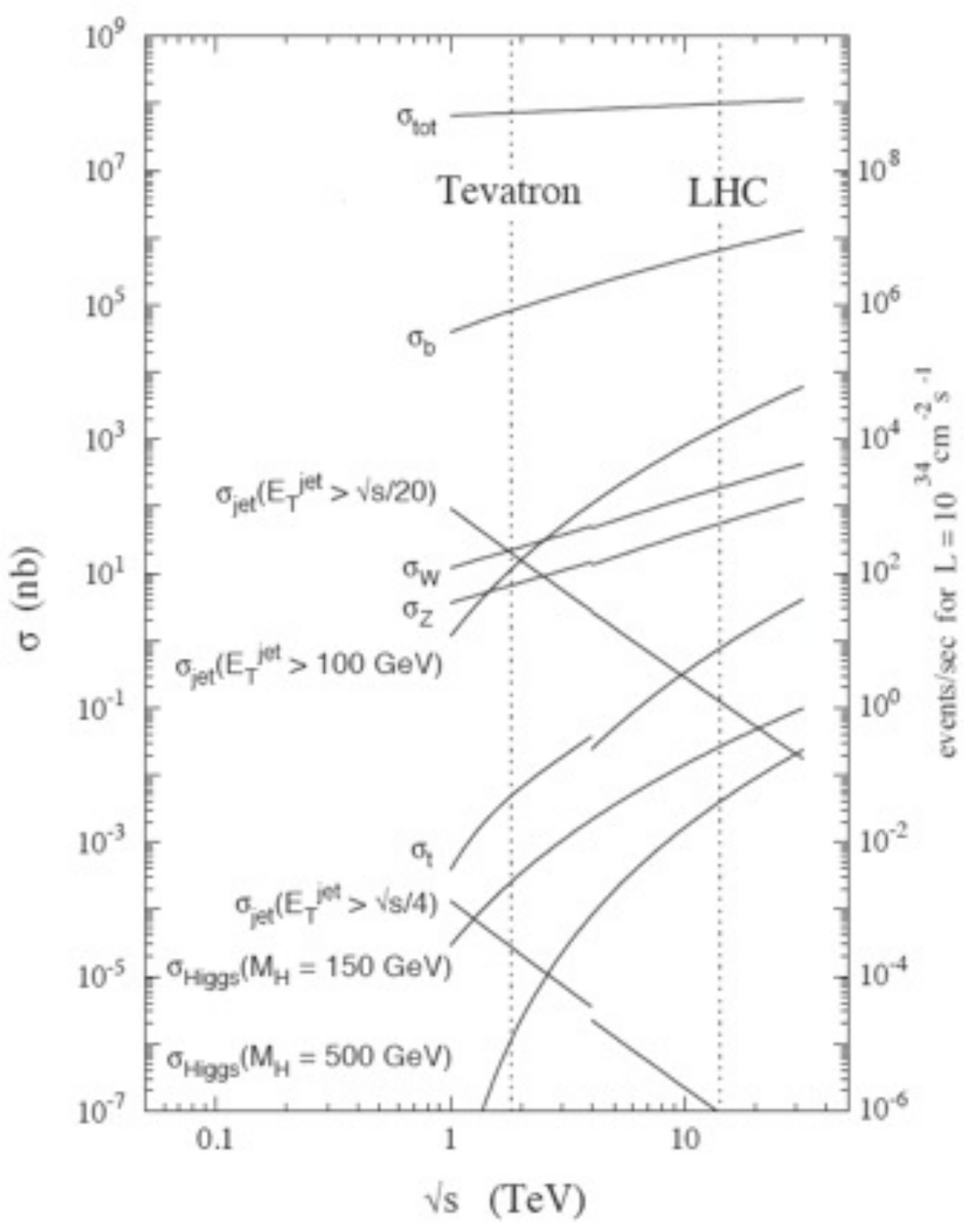
Introduction

- **Main goals for semileptonic decay measurements in LHCb:**
- Cross section for bb production
- Hadronisation studies: b ($B_d^0/B^+/B_s/\Lambda_b$) fractions
- Exclusive semileptonic decays (Cabibbo favoured/ Cabibbo suppressed):
    - Composition of the inclusive semileptonic width, form factors & CKM parameters: *HQET tests beyond the B^0/B^+.*
    - *Even Cabibbo suppressed decays are no longer rare at the LHC.*
- Semileptonic asymmetry, $\mathbf{A_{fs}}$

@CKM2010:

b-cross section measurement from semi inclusive $b\rightarrow D^0X\mu^-\nu$, measurements of $b\rightarrow D^+/D_s/\Lambda_c\, X\mu^-$ decays, and a first look at neutrino reconstruction @ LHCb.

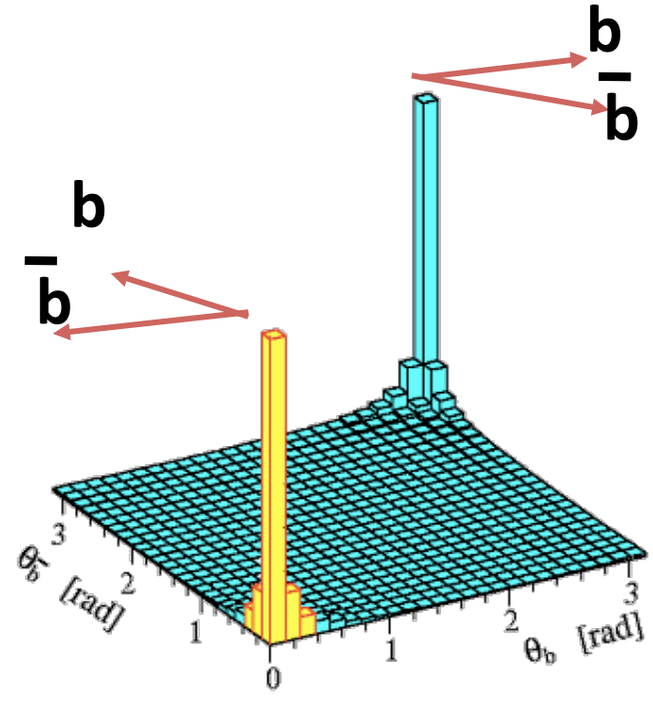
b Production Characteristics



Gluon-gluon fusion is prominent production mechanism.

If gluons do not have equal momenta, $b\bar{b}$ system can have significant momentum and go forward in the CM.

Both b-quarks will go in the same direction.



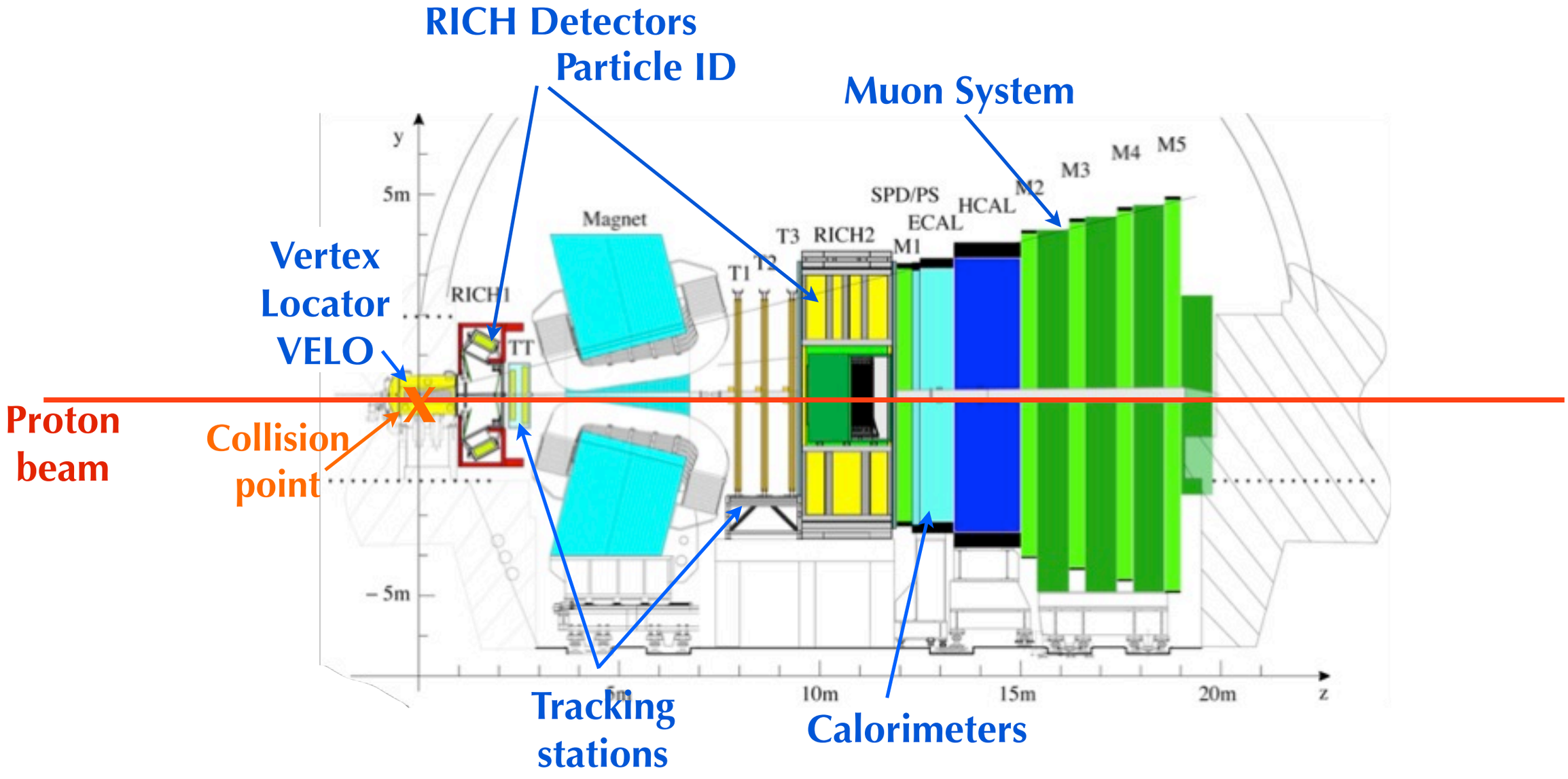
All b-hadron species produced

B_d, B_s, B_c, B^{**}, Λ_b, Σ_b, Ξ_b, …

$$\sigma(b\bar{b}) = 284 \pm 20 \pm 49\ \mu b\ @\ \sqrt{s} = 7\ \text{TeV}$$

LHCb ICHEP2010

The LHCb Detector



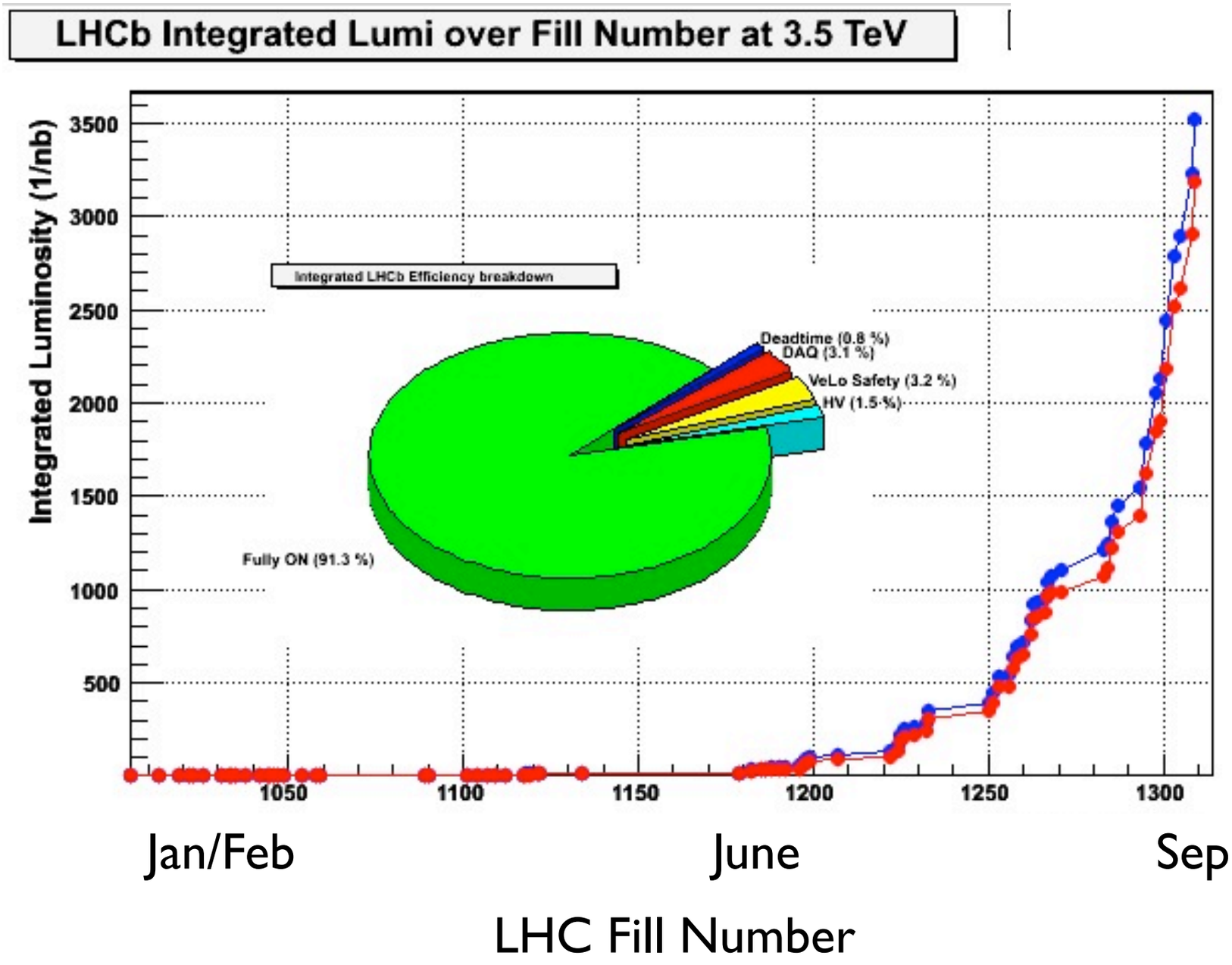
- LHCb deals with overwhelming QCD background with 3-level trigger.
- For semileptonic decays we can trigger as low as pT(muon)~1GeV (much lower than Tevatron)

LHC Performance

Exponential increase instantaneous luminosity at the LHC since Jan.

Current Luminosity of 1×10^{31} cm^2s^{-1}

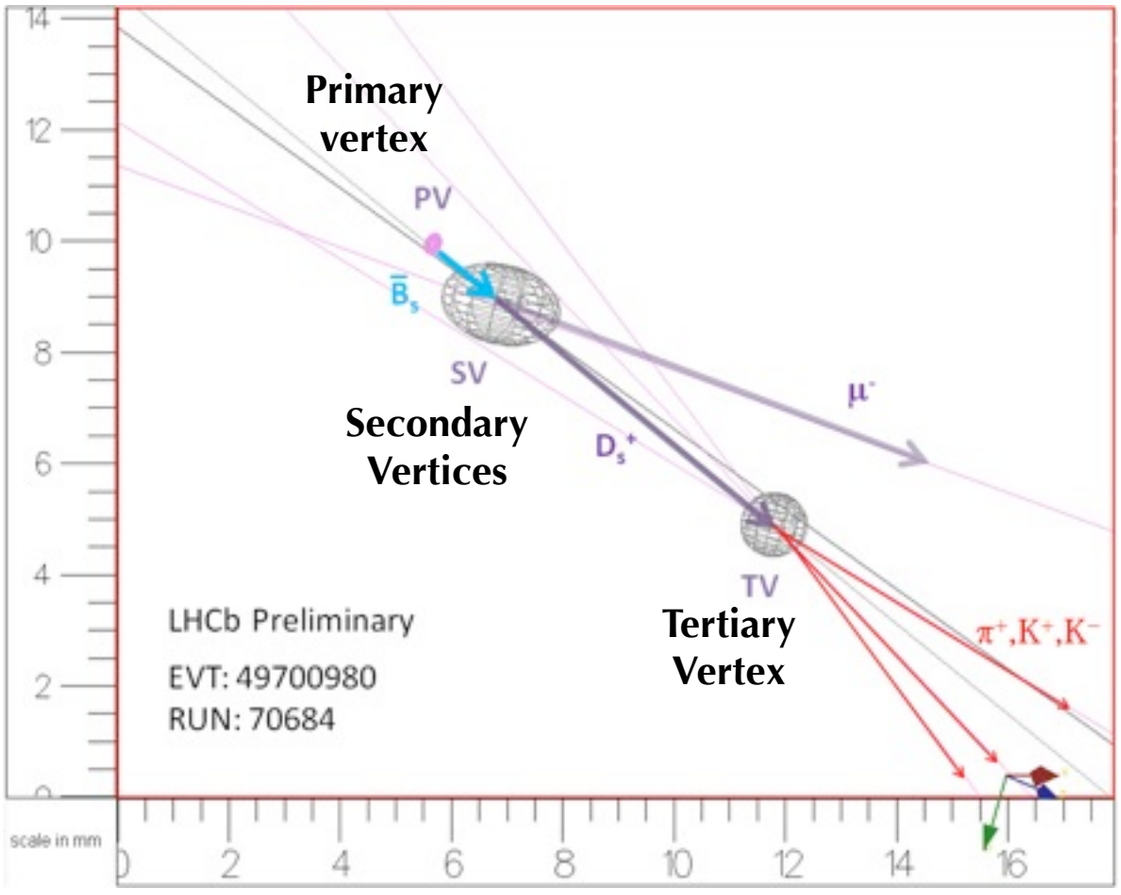
3.2 pb^{-1} collected by LHCb with a 91% data taking efficiency (Sep 1)

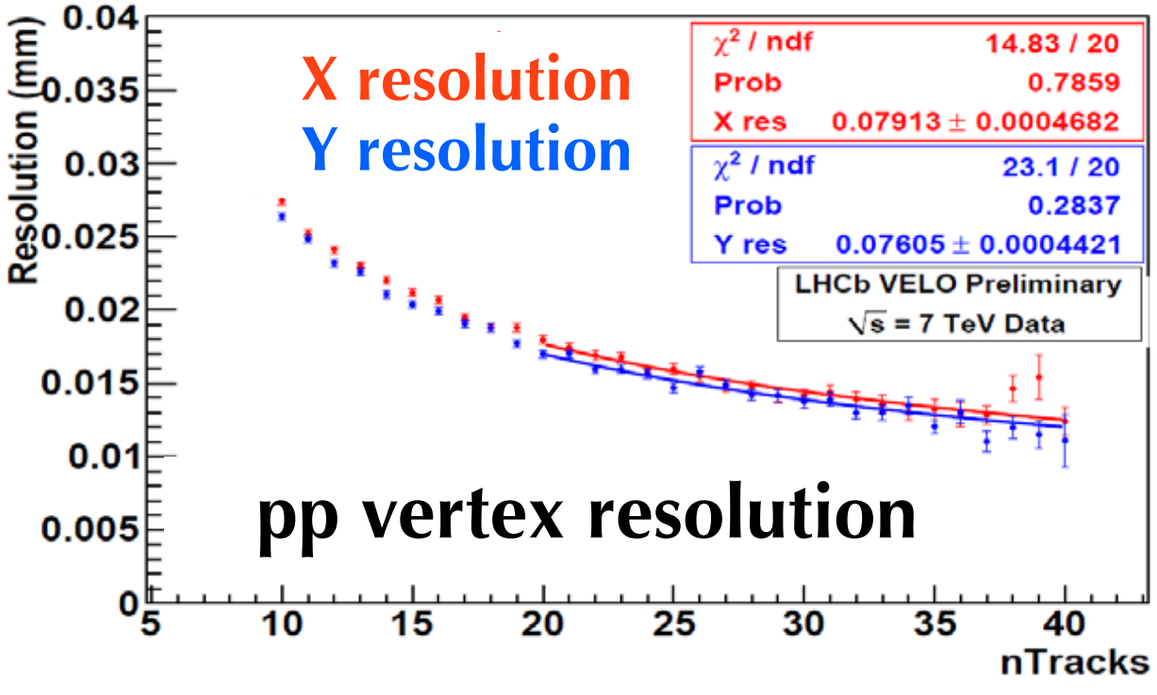


B Reconstruction

Fundamental: Vertex reconstruction.

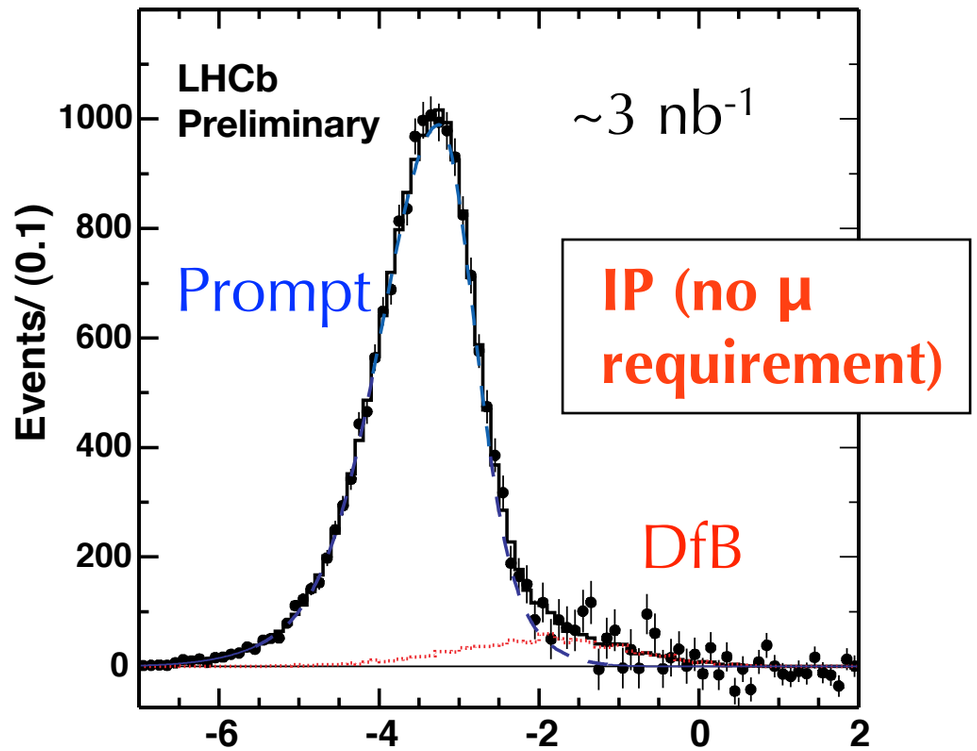
- Separation of primary, secondary, tertiary vertices
- Suppresses combinatoric background
- Measurement of proper decay times
- Precise B-flight direction allows reconstruction with neutrinos - semileptonic physics

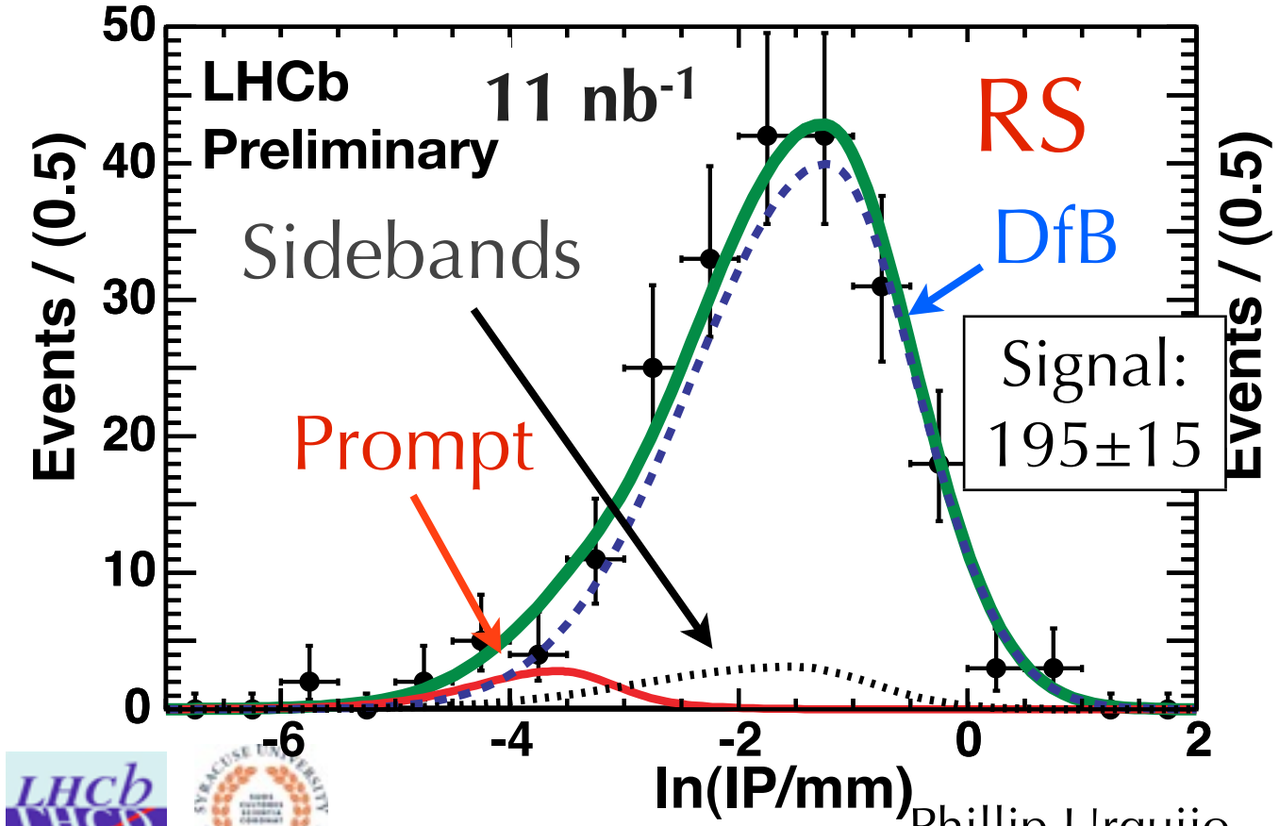


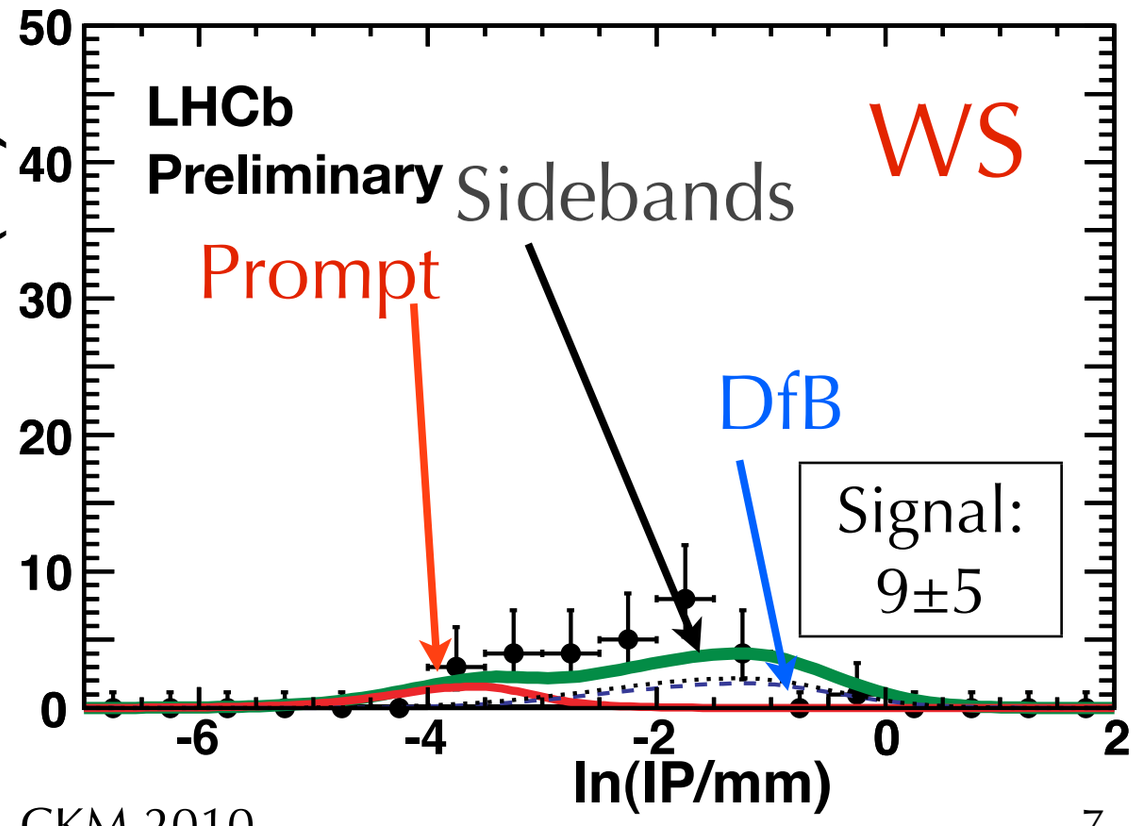


σ_{bb} from $b \to D^0 X \mu^- \nu$

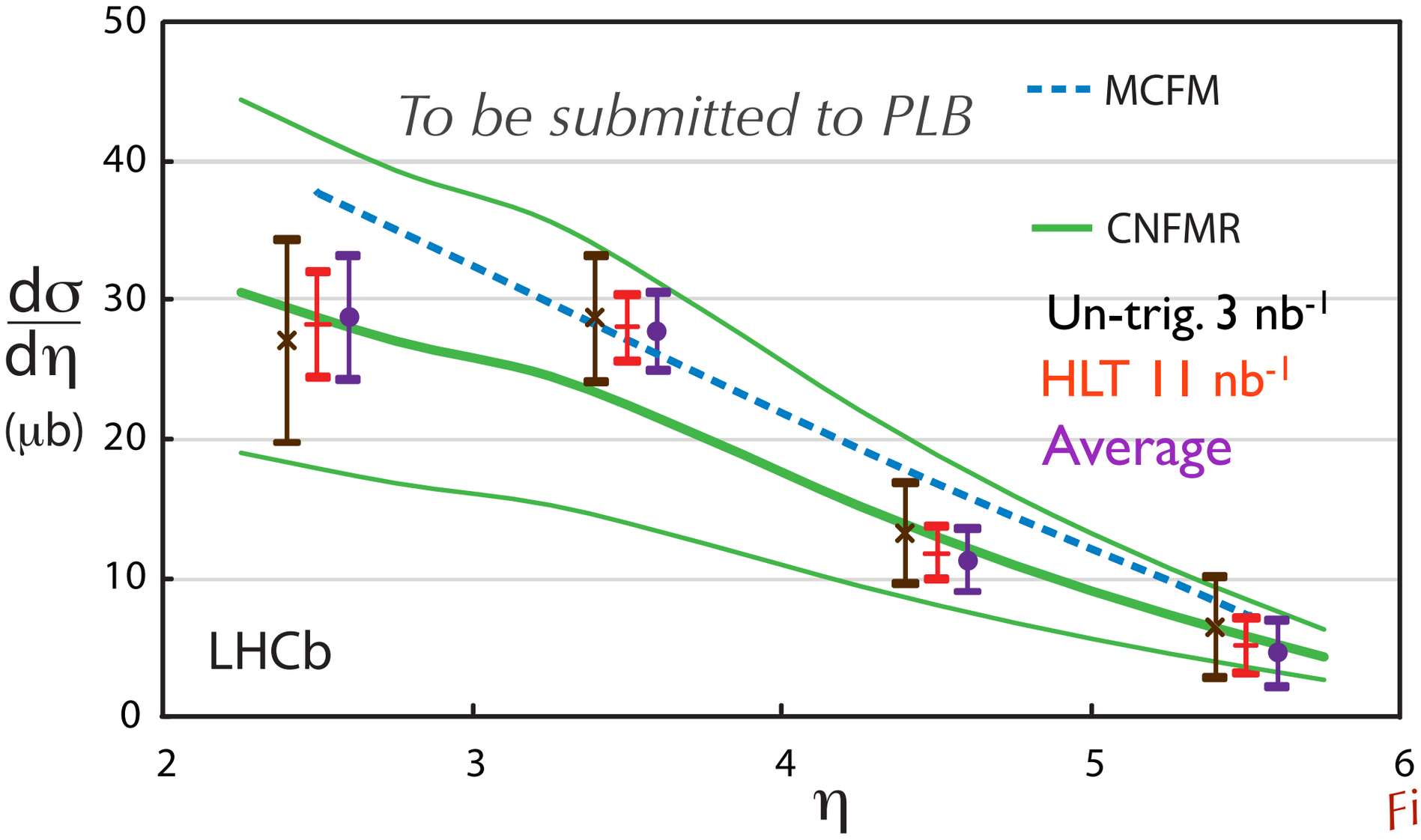
- Signal: $\mathbf{D^0\ \mu-}$ ($\mathbf{D^0 \to K^-\pi^+}$) using tracks which form a common vertex.
  - Background from "**Prompt**" D separated from Signal "**DfB**" using impact parameter (between D0 direction and primary vertex)
- 3nb^{-1} untriggered, 11 nb^{-1} triggered: pT(muon)>1.3GeV: trigger Efficiency ~50 %







b Cross Section



Extrapolated to full pseudo rapidity:

$$\sigma(pp \to b\bar{b}X) = (284 \pm 20 \pm 49)\ \mu\text{b} \quad \sqrt{s} = 7\ \text{TeV}$$

First b-physics paper from LHCb

Cross section systematics large due to dependence on absolute normalisation i.e. **luminosity 10%**, **tracking efficiency 10%**, **fragmentation fraction...**

$b \rightarrow D^+/D_s/\Lambda_c X \mu^- \nu$

- In fact there is a ***Large*** discrepancy on decay fractions to the different b species that must be resolved.

Species	LEP Z^0 fraction %	Tevatron fraction %
B^-	40.3±0.9	33.3±3.0
B^0	40.3±0.9	33.3±3.0
B_s	10.4±0.9	12.1±1.5
Λ_b	9.1±1.5	21.4±6.8

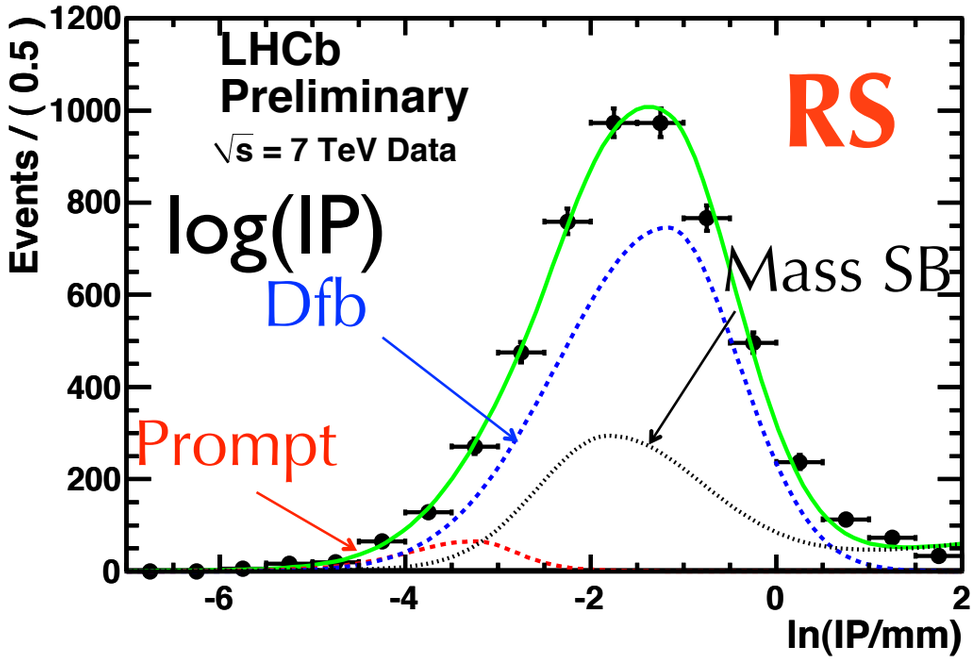
- ***All Preliminary*** results for CKM 2010:
  - 3-prong studies of $b \rightarrow D^+/D_s/\Lambda_c X \mu^- \nu$
  - ~800 nb^{-1} sample.
- Single muon triggers used at L0, Hlt1, Hlt2: p_T μ>1.3 GeV

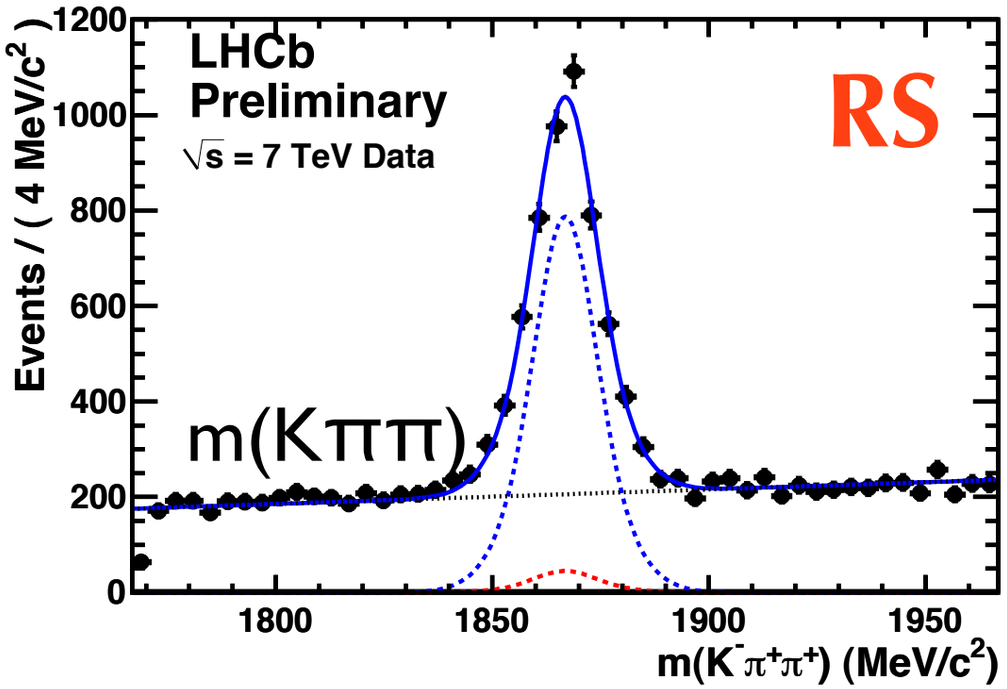
$b \to D^+ X \mu \nu$

Reconstruct $D^+ \to K\pi\pi$ Use as cross check of D_s^+ studies

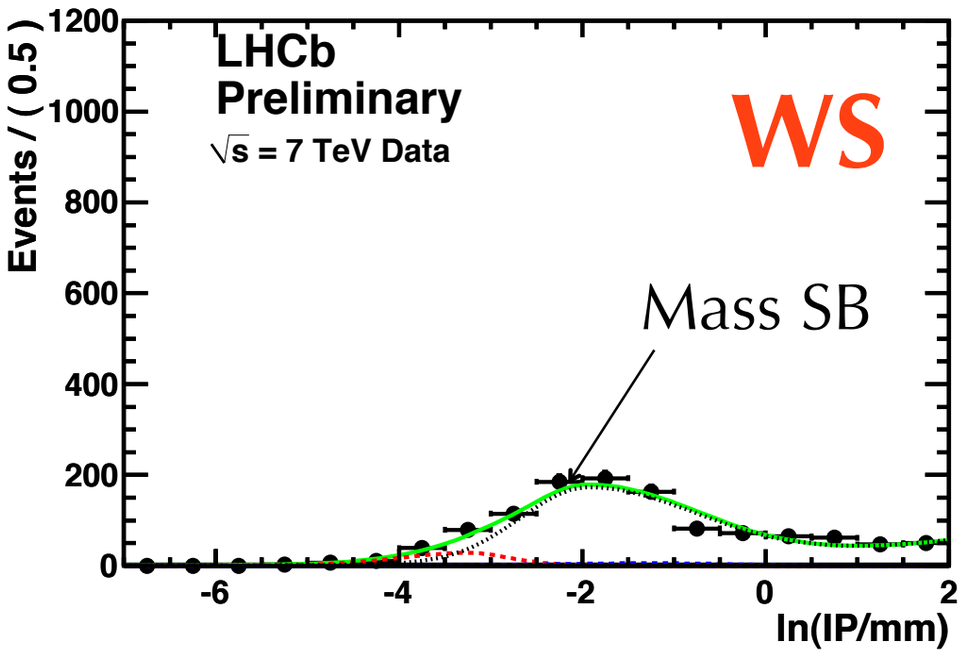
~800 nb^{-1}

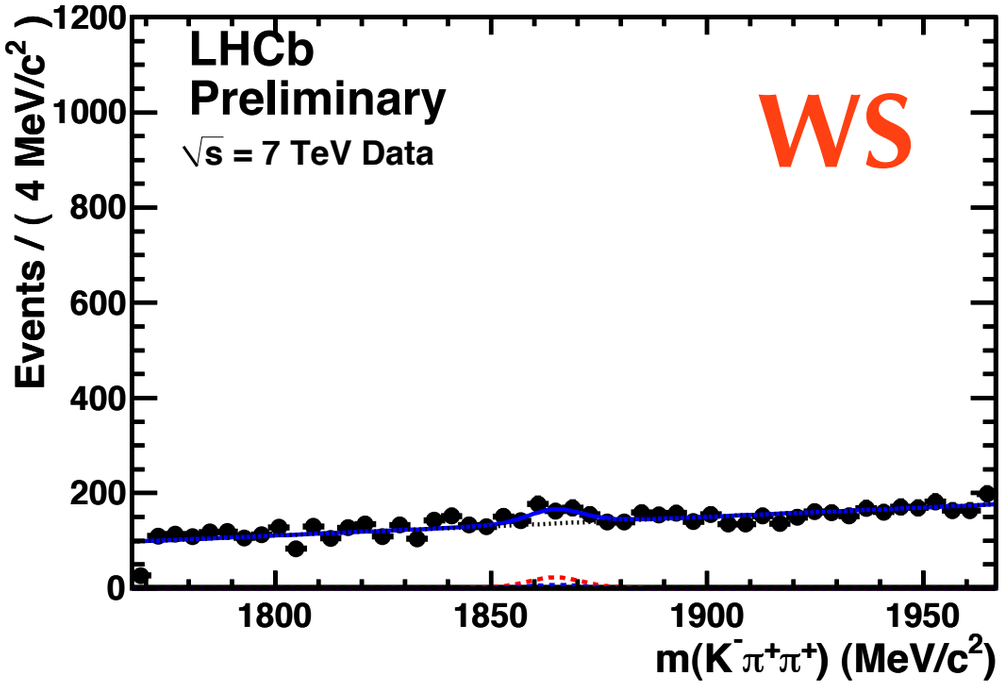
Signal:
3649±82



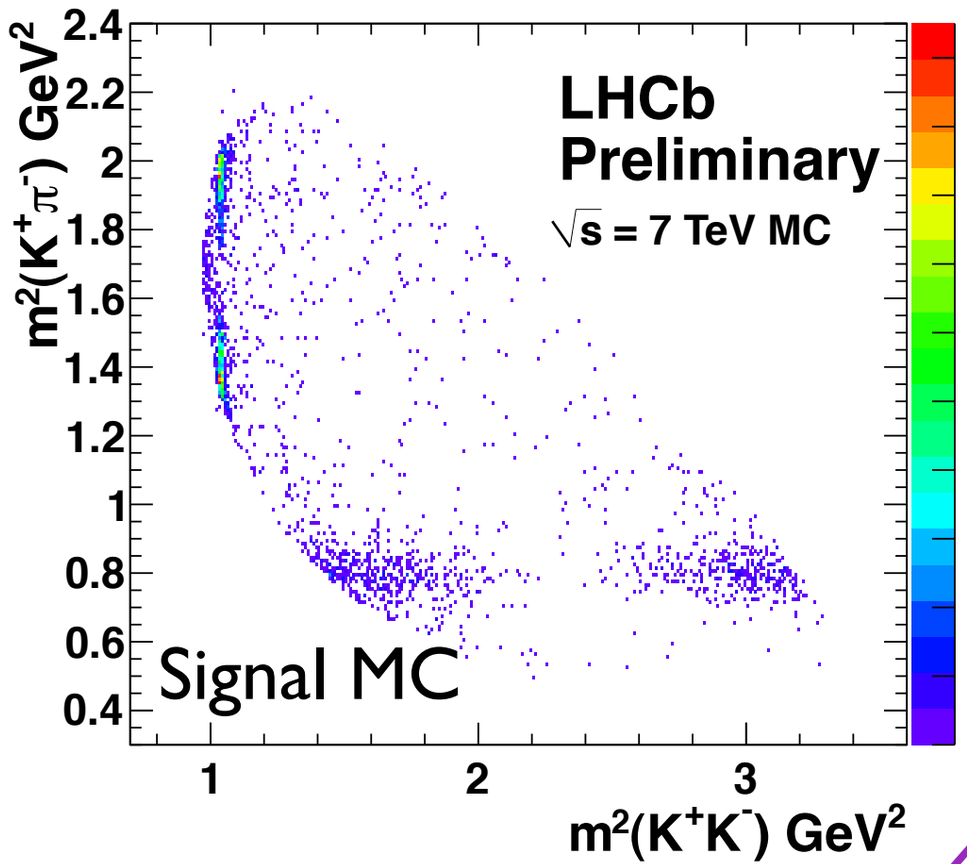


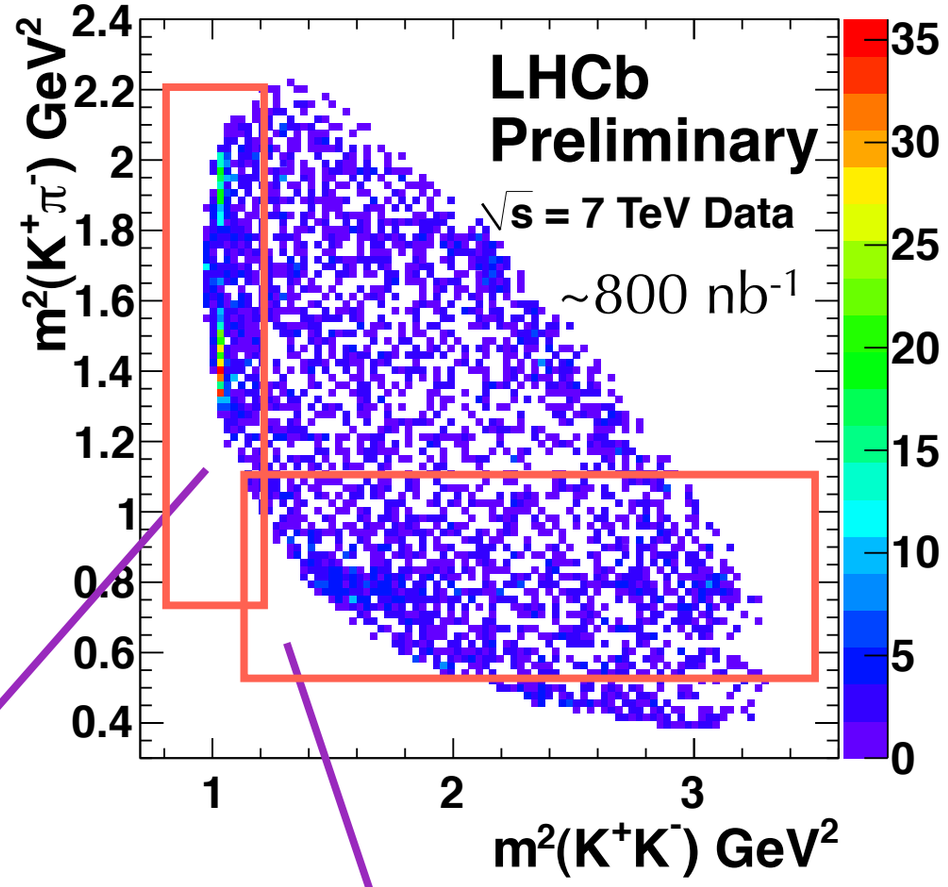
Signal:
28.2±30

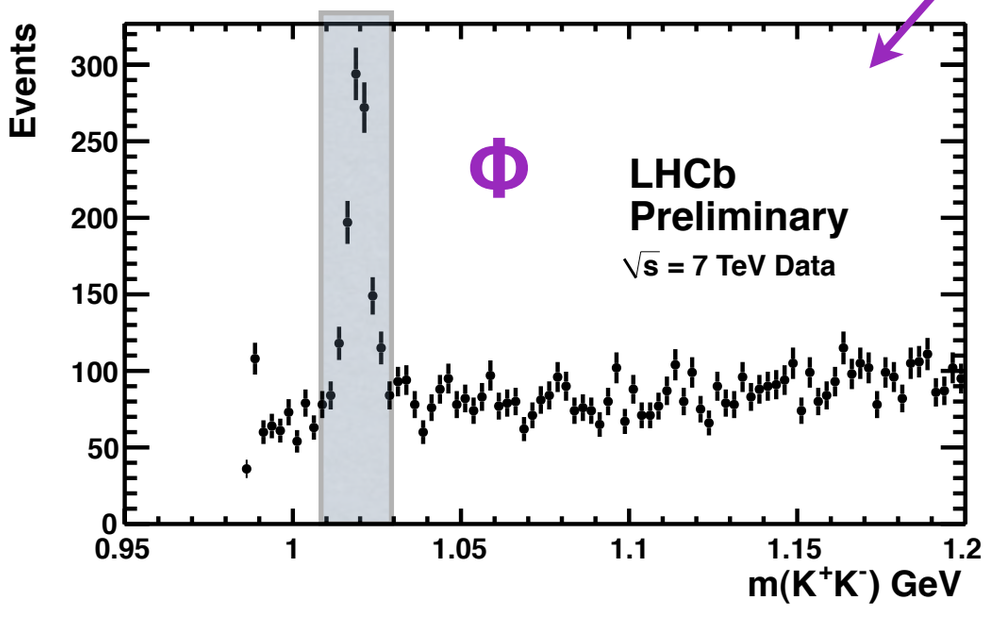


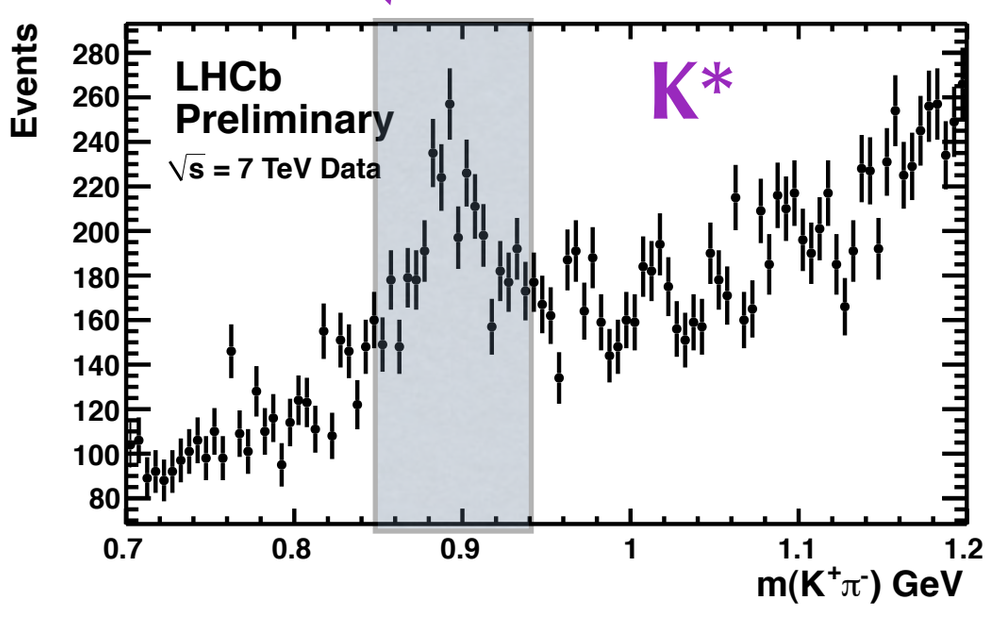


Dalitz: $b \to D_s X \mu^- \nu$







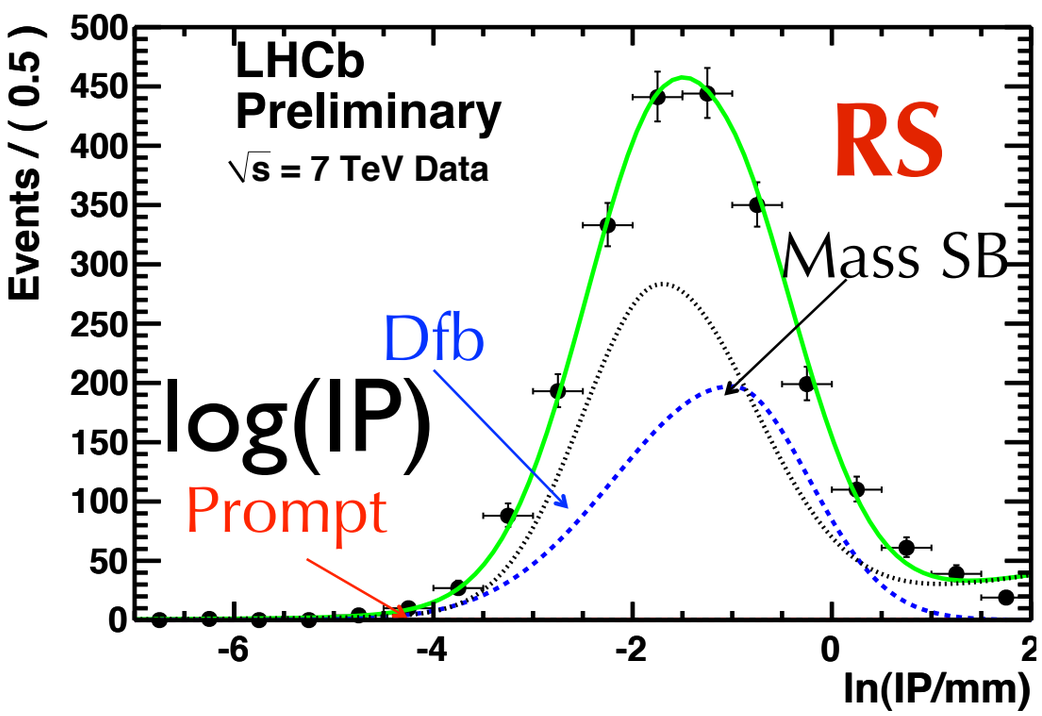


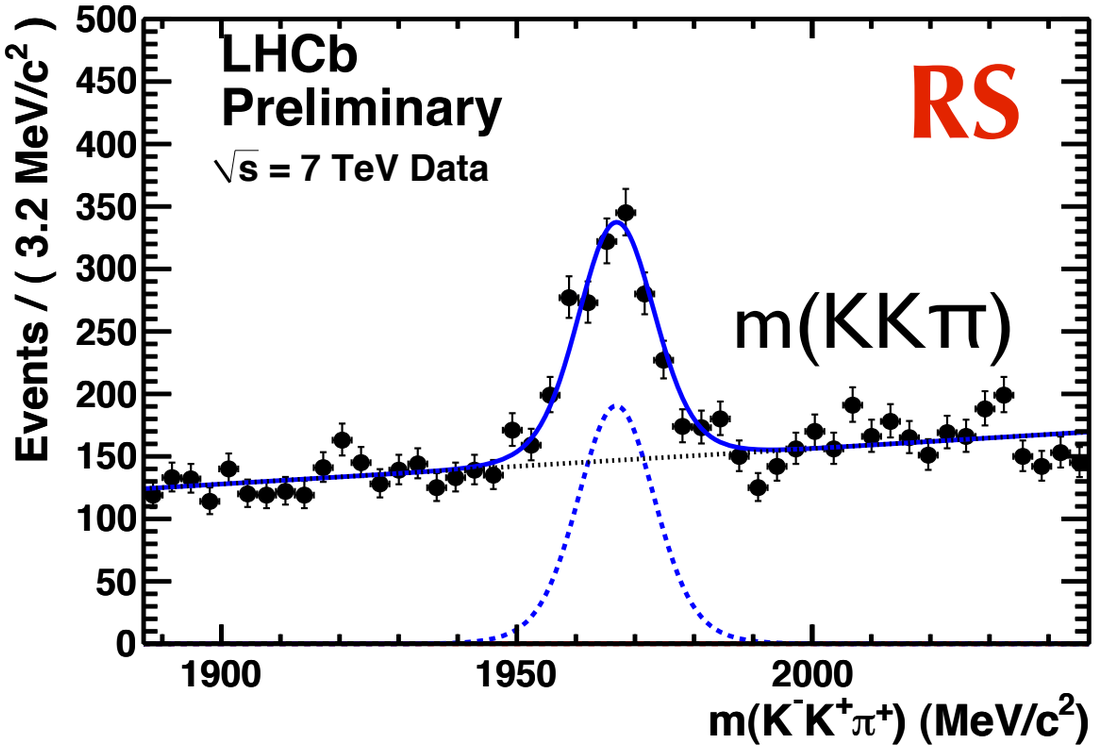
$b \to D_s X \mu^- \nu$

Inclusive Dalitz phase space selection.

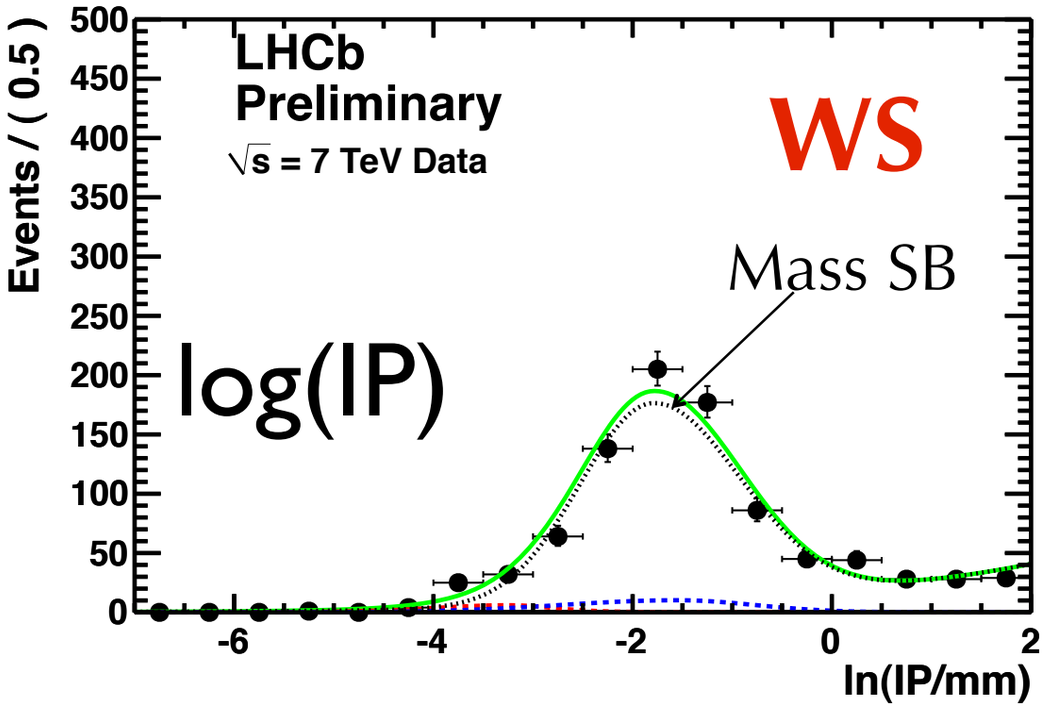
~800 nb^{-1}

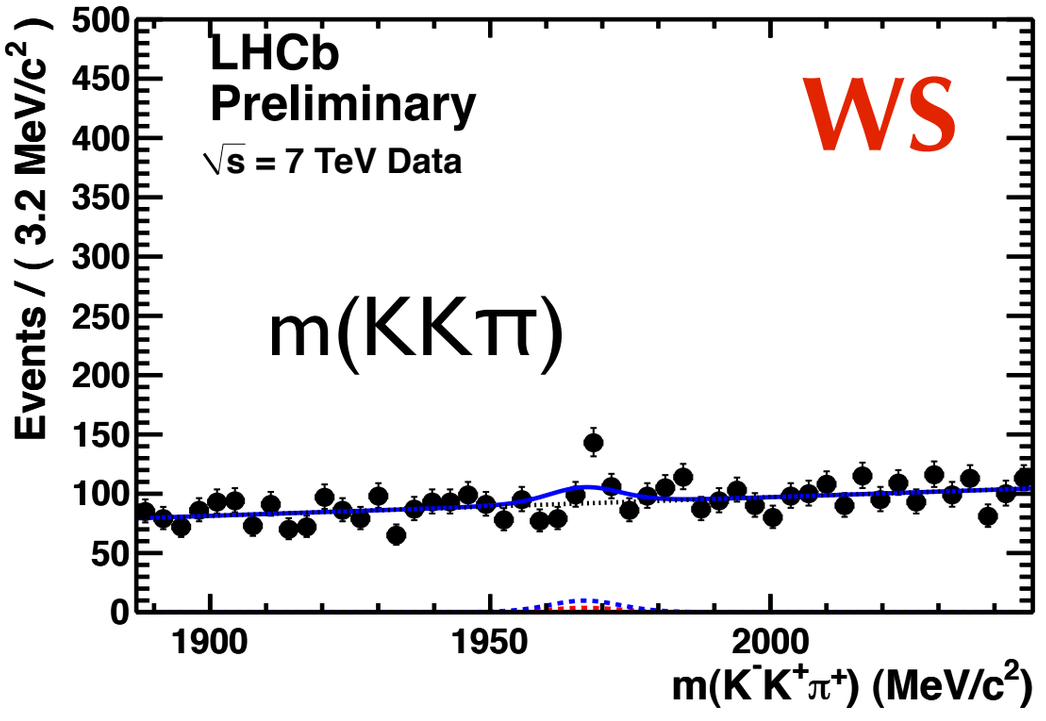
Signal
964±52





Signal:
50±32





Λ_b Semileptonics

Several exclusive measurements of Λ_b exist but not inclusive - infer from lifetime.

$\Lambda_c^+ l^- \nu = (5.0^{+1.9}_{-1.4}) 10^{-2}$

$\Lambda_c^+ \pi^+ \pi^- l^- \nu = (5.6 \pm 3.1) 10^{-2}$

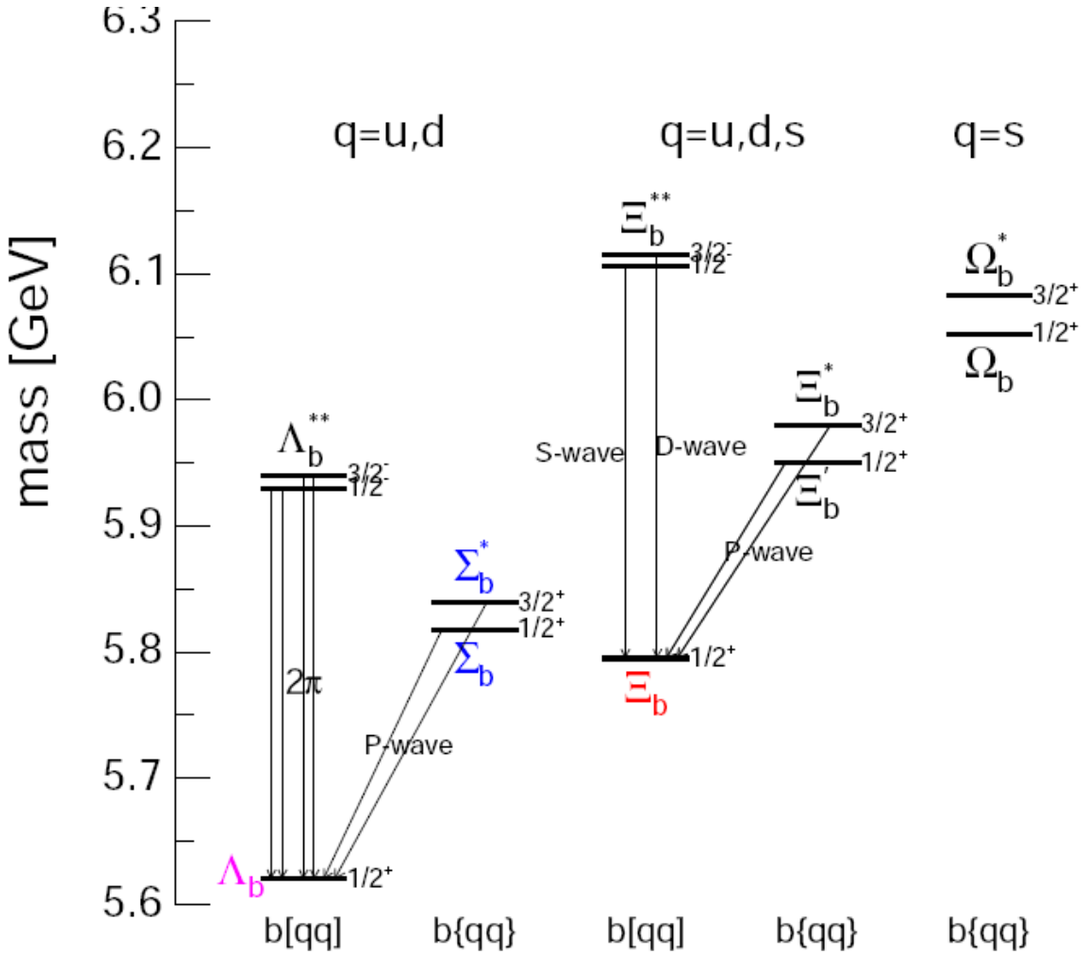
$BR(baryon_c \rightarrow \Lambda_c^+) = 1$

$\Lambda_c(2595)^+ l^- \nu = (6.3^{+4.0}_{-3.1}) 10^{-3}$

$\Lambda_c(2625)^+ l^- \nu = (1.1^{+0.6}_{-0.4}) 10^{-2}$

$\Sigma_c(2455)^0 \pi^+ l^- \nu$ **Upper limits from**

$\Sigma_c(2455)^{++} \pi^- l^- \nu$ **tevatron.**



$\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \nu$ form factors measured at DELPHI: $\rho^2 = 2.03 \pm 0.5 \pm 1.0$, some Lattice calculations exist.

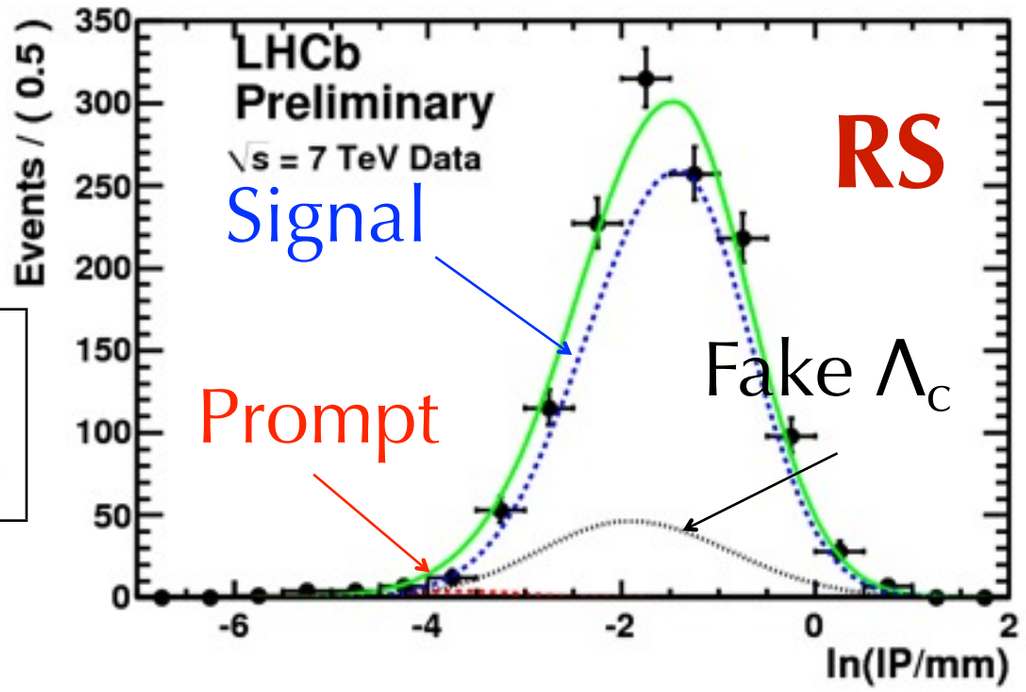
$b\bar{b}$ pairs with uud (from p) and forms Λ_b B^+ which may cause an asymmetry in $B/\bar{B}$, and $\Lambda_b/\bar{\Lambda}_b$ production.

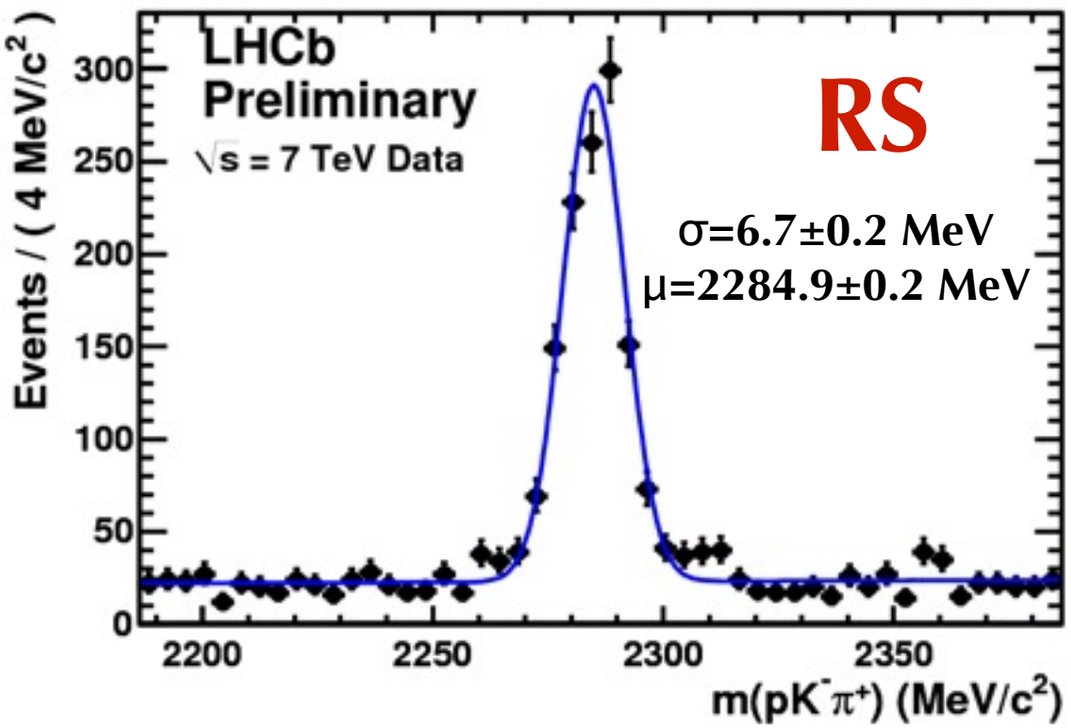
$\Lambda_b^0 \rightarrow \Lambda_c^+ X \mu^- \nu$

Reconstruct $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$ (BR=5.0±1.3%)

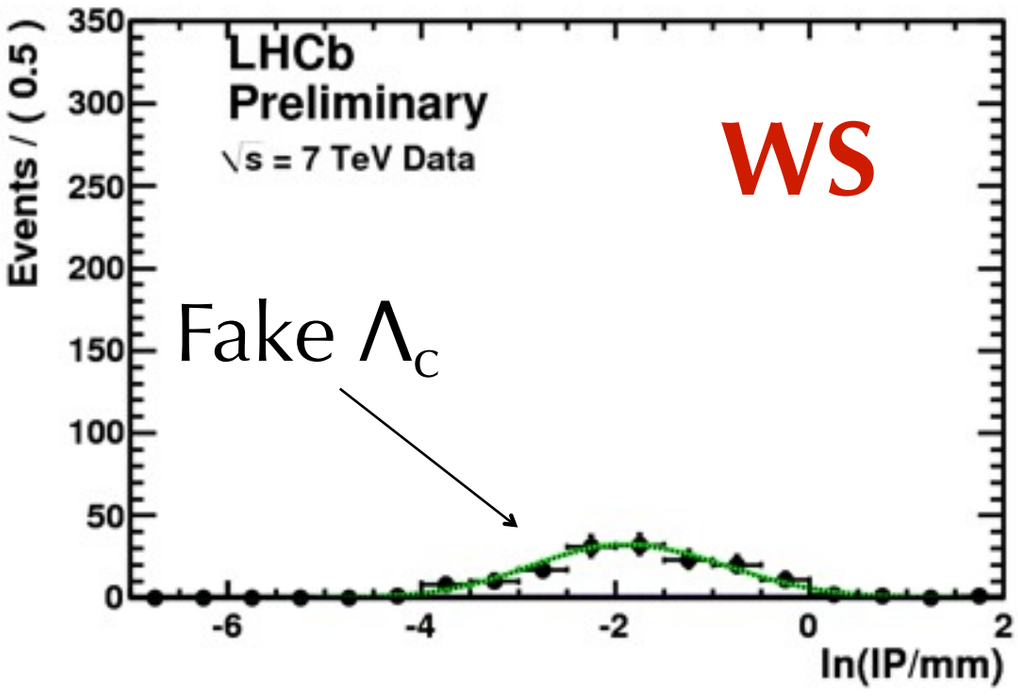
~800 nb^{-1}

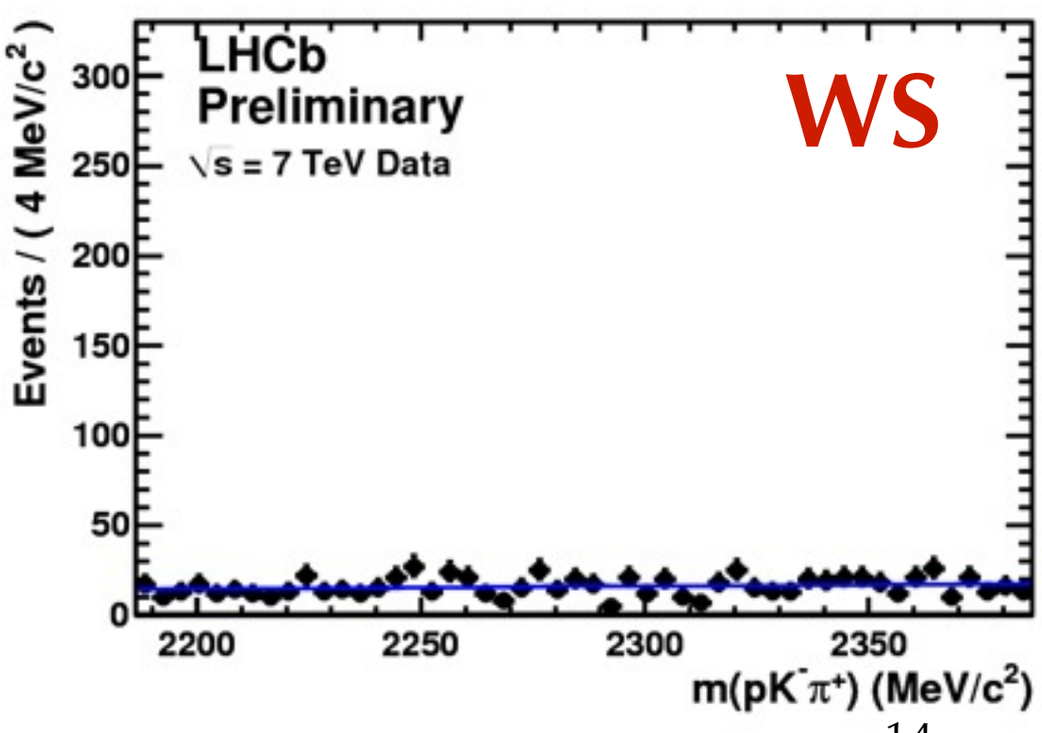
Signal:
1100 ± 38





Signal:
3 ± 10





$B_s \to D_s X \mu^- \nu$ Exclusive

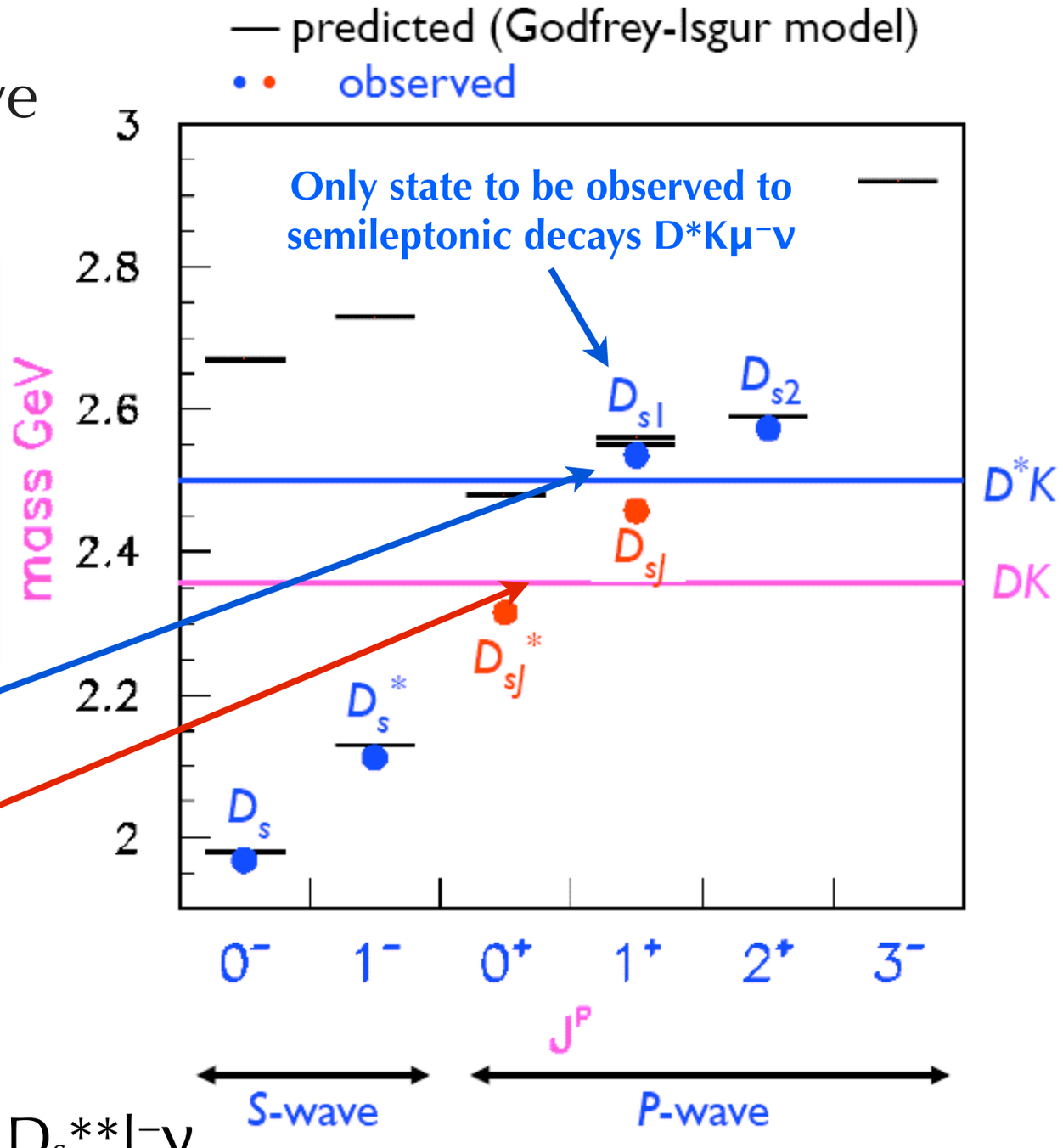
Exclusive $B_s \to D_s X \mu^- \nu$ states **have not been isolated**/observed but the inclusive B_s width has been measured by Belle.

Theory predicts Γs(sl)~90% Ds+Ds*+DsJ

$$Br(B_s \to D_s e \nu_e) = (2.85 \pm 0.35)\%$$

$$Br(B_s \to D_s^* e \nu_e) = (7.09 \pm 0.88)\%$$

arXiv:1003.5576



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

$D_{sj}^{(*)}$ → $D_s^{(*)+}$ n π^0/γ

Measurements of $D^{(*)}K$ will constrain $B_s \to D_s^{**} l^- \nu$

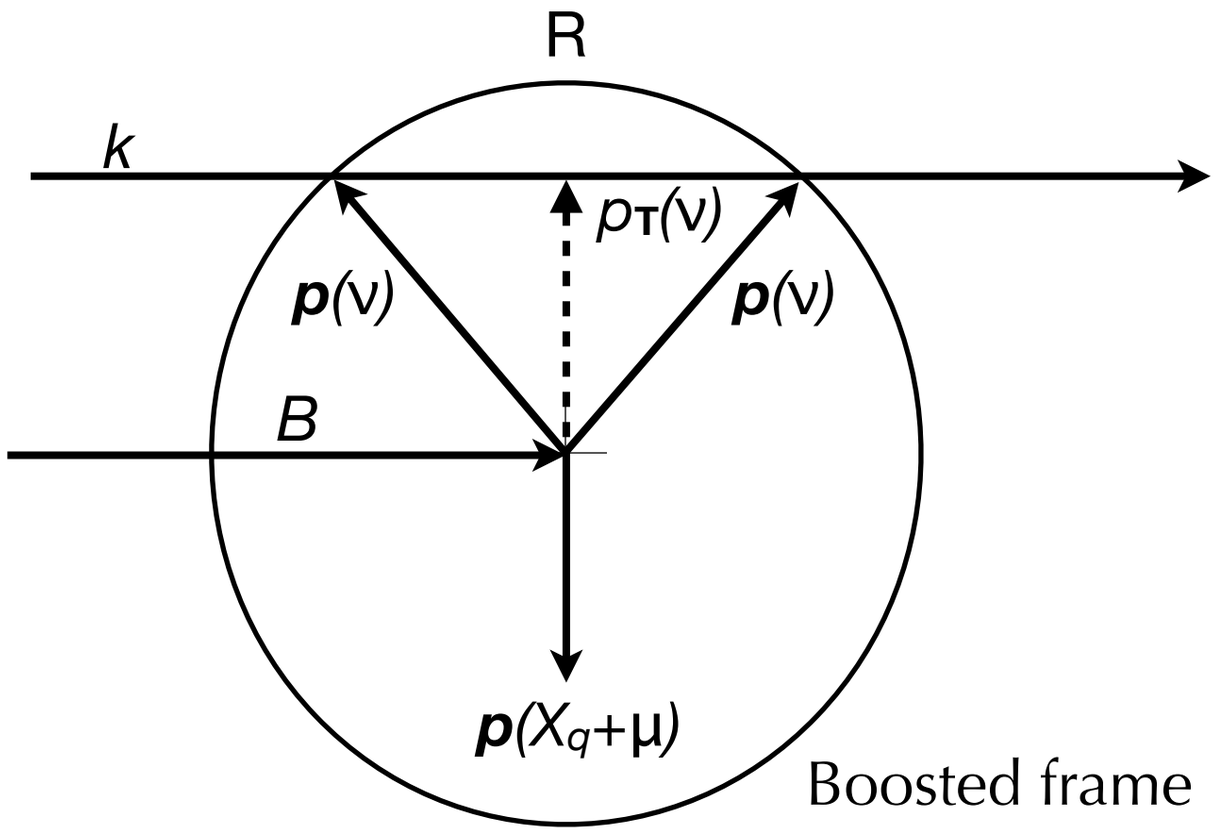
Towards V_{ub}/V_{cb} exclusive

Neutrino reconstruction.

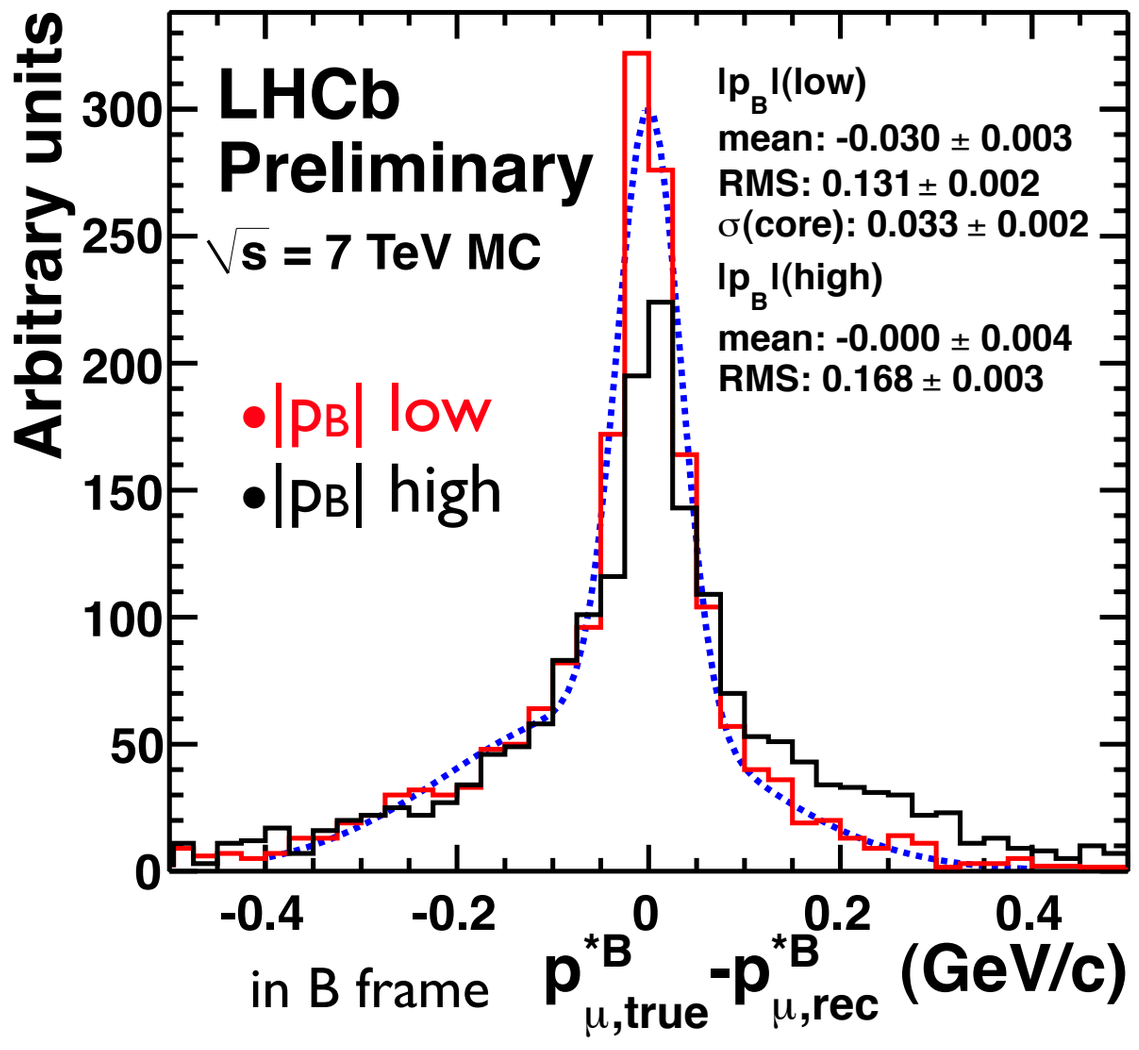
B direction determined from vertex displacement.

|pB| in semileptonic decays can be determined with two-fold ambiguity.

Lower |pB| provides better resolution → unfold for bias

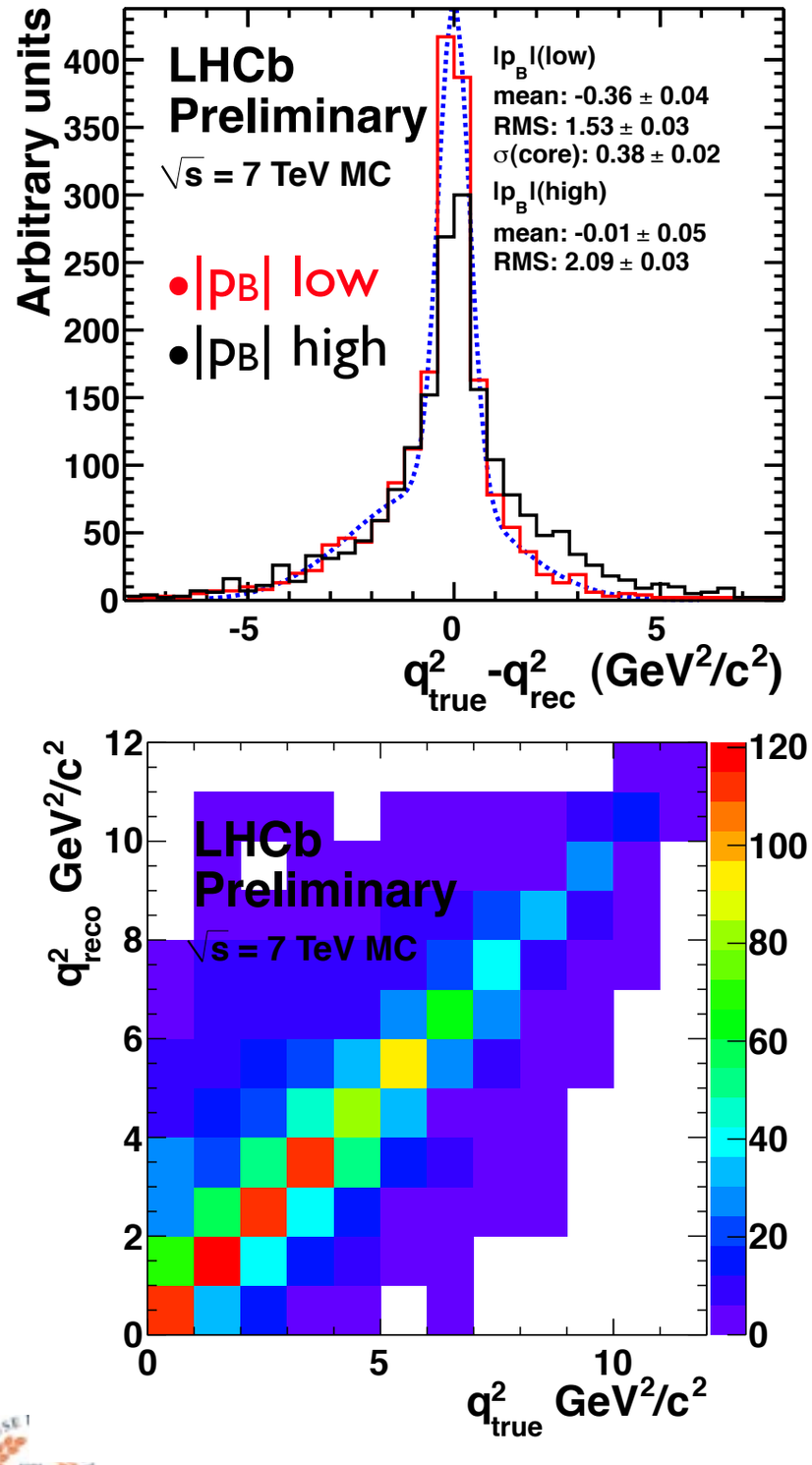


Boosted frame

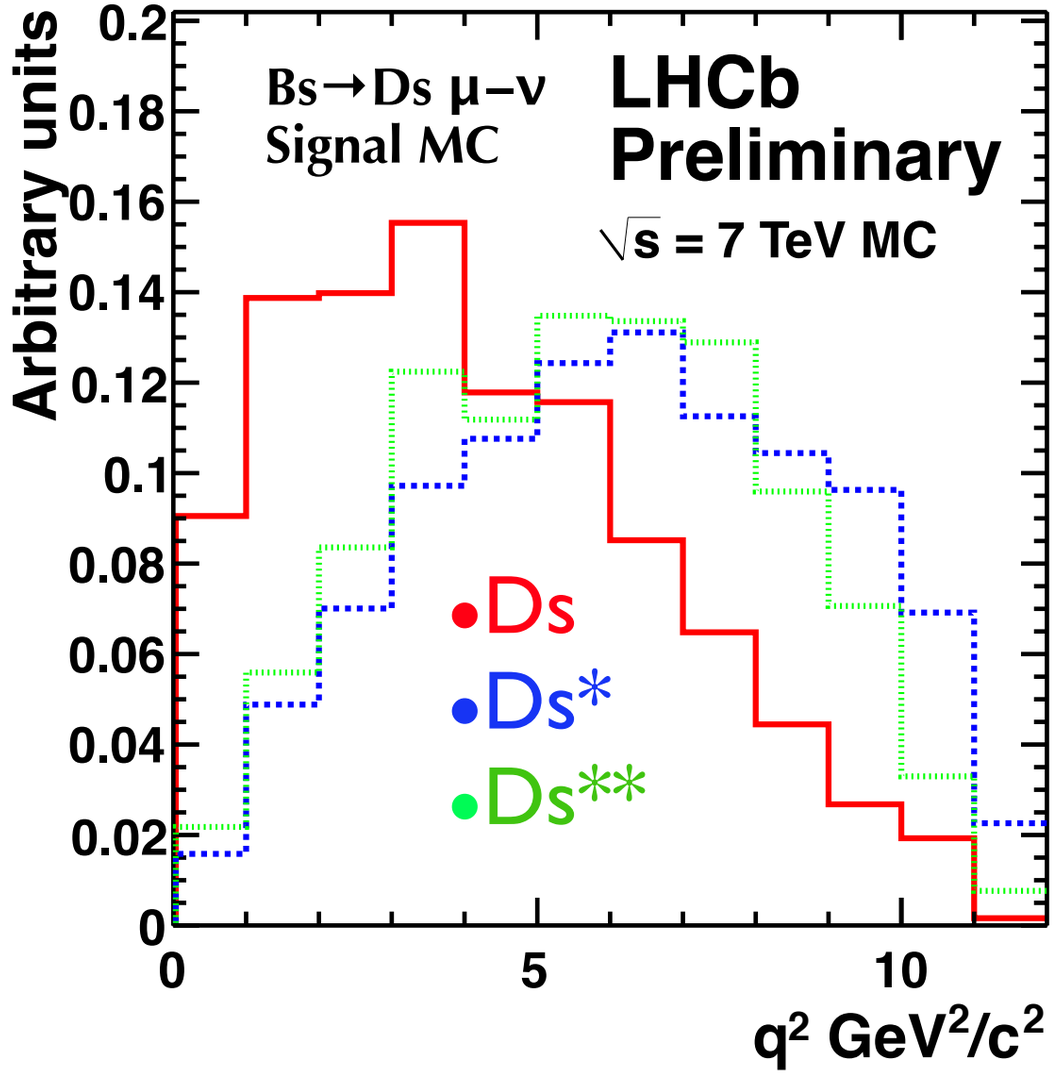


Neutrino Reco. Resolution

Resolution is adequate for sensitivity in q2 for Bs $\rightarrow D_s$ $\mu-\nu$.

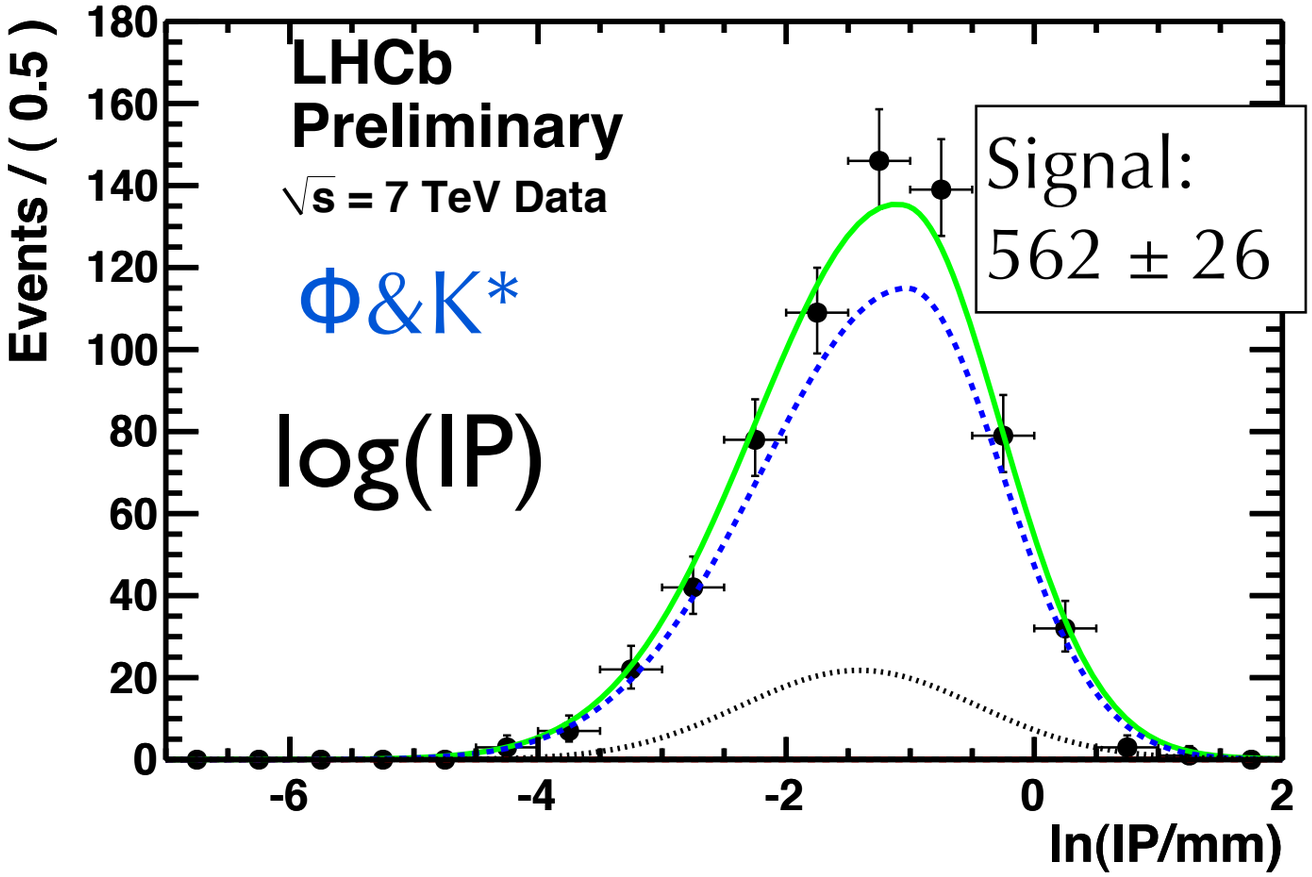


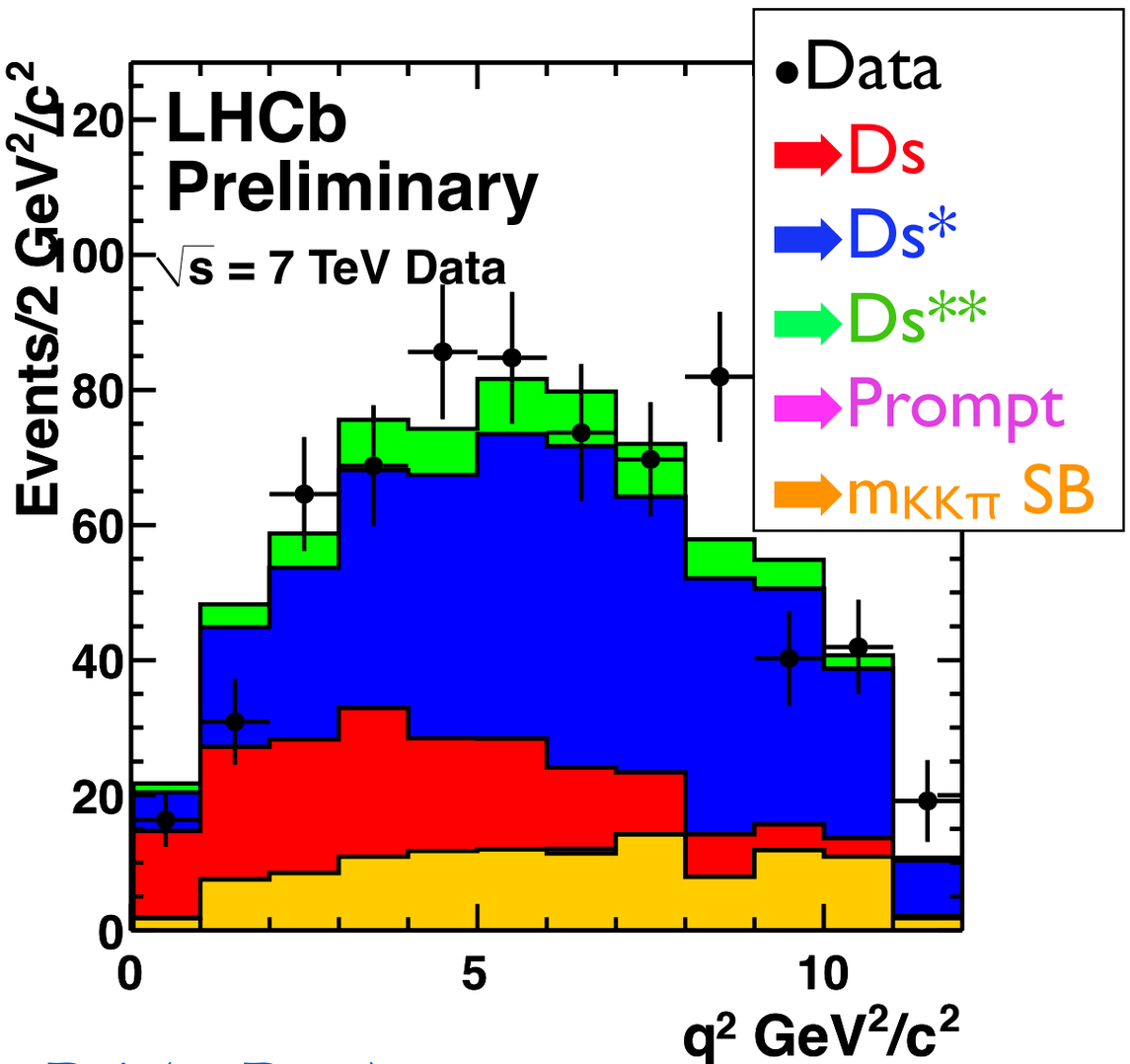
Signal predictions for Ds and D_s^* ($\rightarrow$Ds γ/π^0) channels, based on D^+ and D^{*+} form factors



$B_s \rightarrow D_s X \mu^- \nu$ q^2

- $B_s \rightarrow D_s \mu^- \nu$ fit to IP&m(KKπ) in q2 bins ~800 nb^{-1} (in $D_s \rightarrow \Phi$&K* modes)
  - Relative fractions based on D/D*/D**, not all D** decaying to Ds **~2.5:~6:~1.5**





Very clean signature for CKM studies!

Constraints from $B \rightarrow D^0 K \mu \nu$ for Ds** & $B \rightarrow D_s^* (\rightarrow D_s \gamma) \mu \nu$

Cross check with $B \rightarrow D^+ (\rightarrow K\pi\pi) X \mu \nu$

Summary

- First b-physics paper on LHCb using semileptonic B decays for the b-cross section.
- We have observed the main components of the b semileptonic decay width.
  - Provides essential information for b fragmentation fraction determination.
- These measurements will be important for a deep understanding of the Cabibbo favoured *sl* width in B_s & other *b*-hadrons.
  - Upon which precision CKM (in B_s and Λ_b), and A_{SL} measurements will be based.
- LHCb resolution and phase space coverage good for CKM studies.

WGII Lattice Request

- Exclusive semileptonic B_s exclusive decays are not yet described on the lattice.
  - Calculations exist for Λ_b .
  - We need form factor normalisation input from lattice for high precision interpretations.
  - For both, Cabibbo favoured (Ds/Ds*) and suppressed modes(K/K*).

Systematics

- Cross section systematics highly dependent on absolute normalisation (i.e. luminosity, tracking efficiency, branching fractions, and fragmentation fraction).

Source	Error (%)	Source	Error (%)
Luminosity	10.0	Prompt & Dfb shapes	1.4
Tracking efficiency	10.0	$\mathcal{B}(D^0 \to K^-\pi^+)$	1.3
$\mathcal{B}(b \to D^0 X \mu^- \overline{\nu})$	5.1	$D^0\mu^-$ vertex χ^2 cut	1.2
Assumed branching fractions	4.4	Kaon identification	1.2
LEP fragmentation fractions	4.2	Muon fakes	1.0
Generated b p_{T} distribution	3.0	D^0 mass cut	1.0
Muon identification	2.5	D^0 vertex χ^2 cut	0.6
χ^2_{IP} cut	2.5	D^0 flight distance cut	0.4
MC statistics	1.5	Pion identification	0.3
Total		17.3%	