Open charm and beauty production at LHCb

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On behalf of the LHCb collaboration

LPCC December 2010
Charm and bottom quark production at the LHC

Charm & Beauty Production

Measurement of the b anti-b cross section in the forward region with semileptonic b-decays. (published, 15 nb^{-1})

b-hadron fragmentation fraction with semileptonic b-decays (preliminary, 3 pb^{-1})

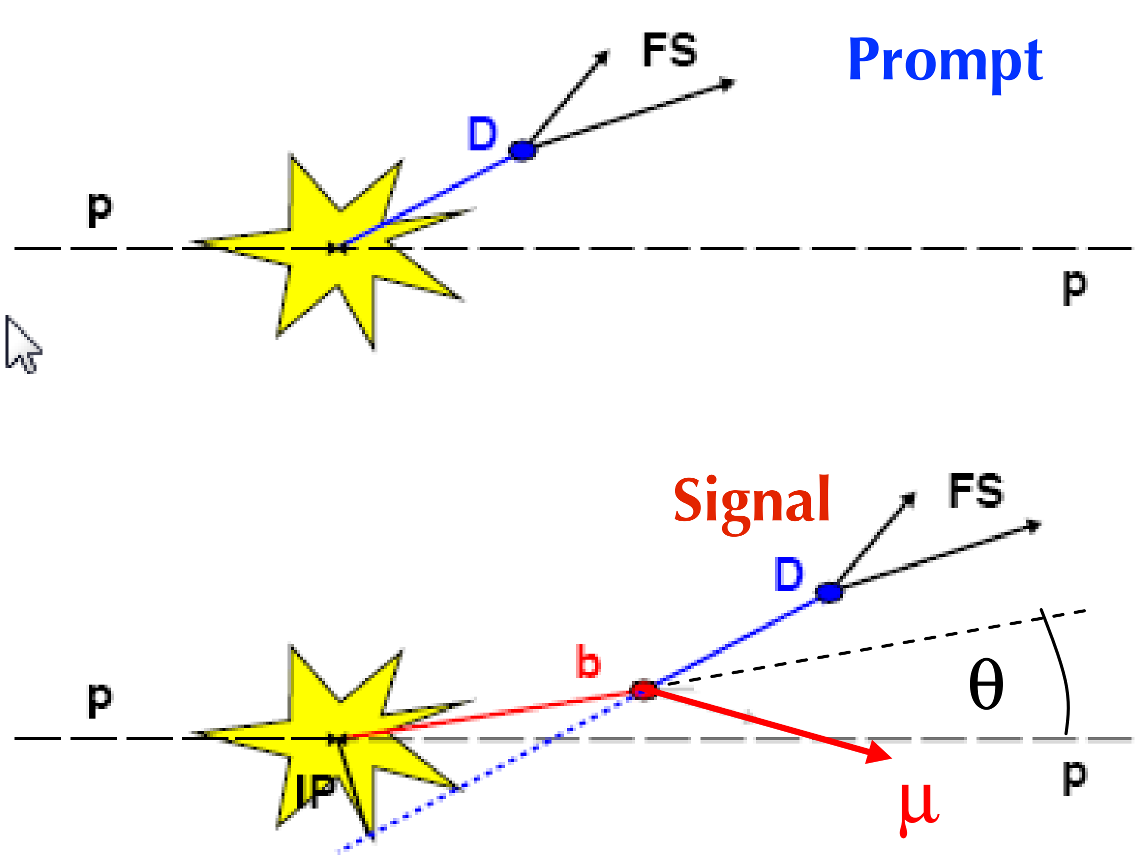
Open charm cross sections, D^+, D^0, D_s, D^{*+} (preliminary, 1.8 nb^{-1})

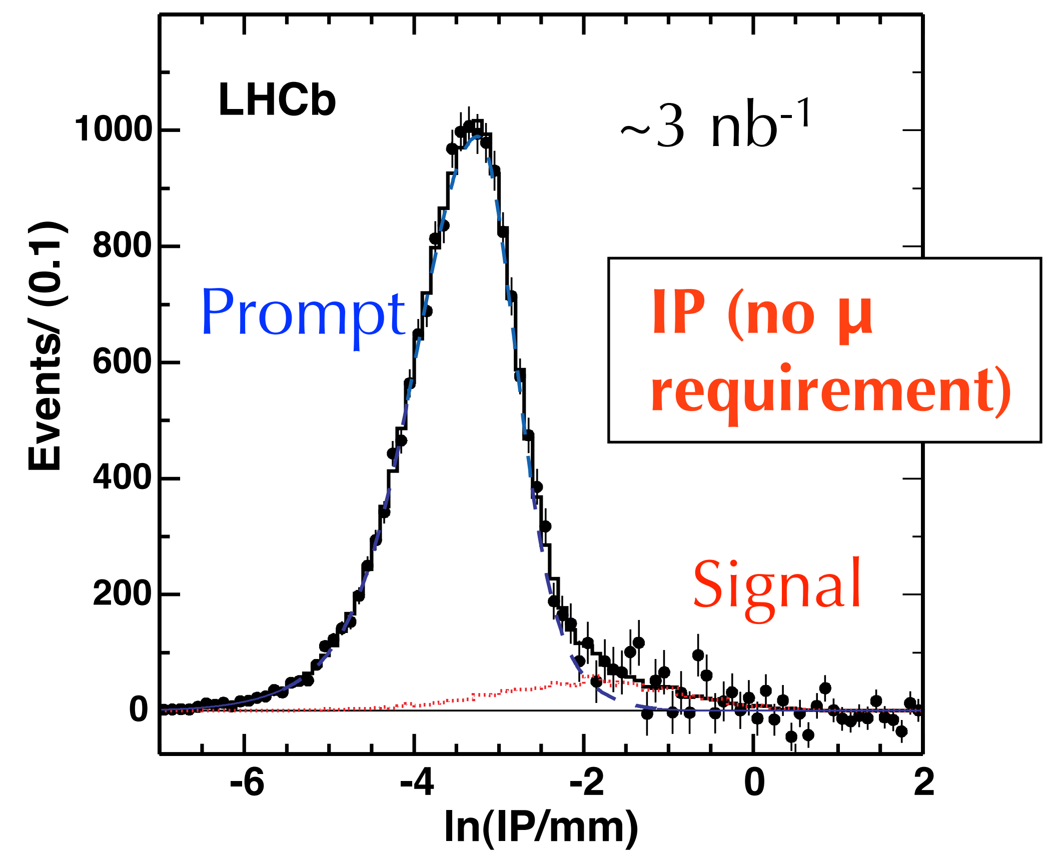
b-Cross section

Physics Letters B 694 (2010) 209–216

b Cross section

- Measure right-sign, vertexed, Dμ^- combinations with tracks not pointing at primary vertex
- Background from "**Prompt**" D separated from Signal using impact parameter
- Require minimum p_T on D so that IP is well defined

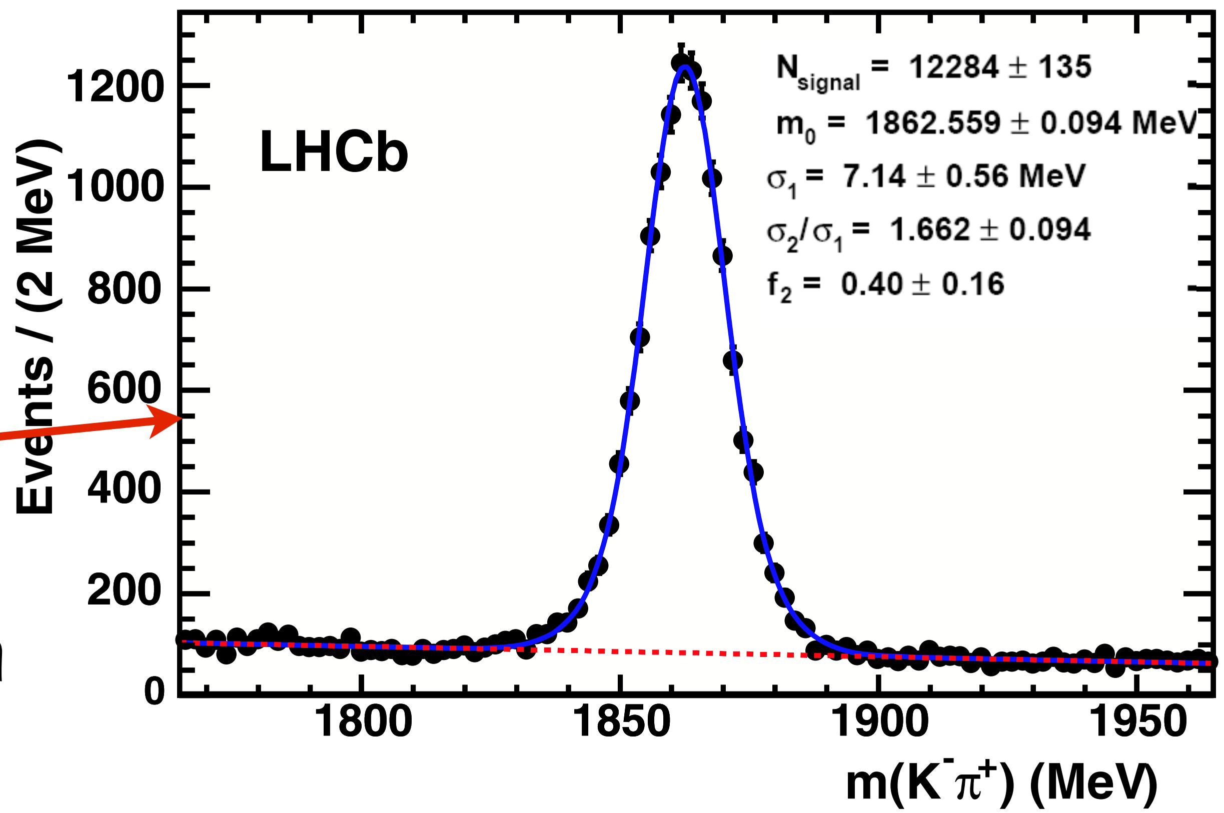




$\eta = -\ln[\tan(\theta/2)]$

Fit procedure

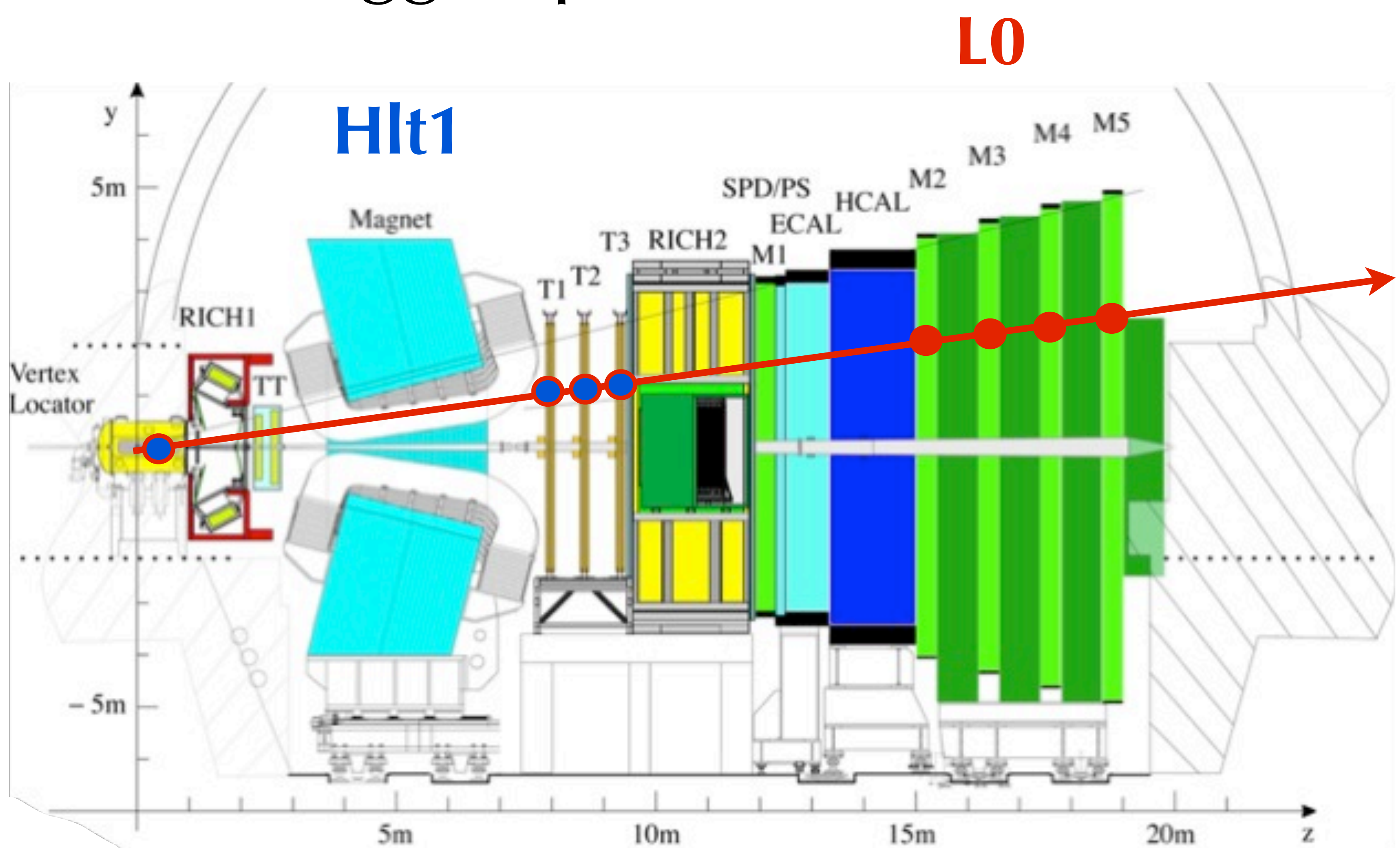
- 2D Unbinned log-likelihood fit to $m(K^{-}\pi^{+})$ & ln(IP). Separate fits for RS and WS samples.
- $m(K^{-}\pi^{+})$ shape from prompt D decays(no muon selection).
- ln(IP) shape for prompt taken from data, and DfB decays from MC.



- $m(K^{-}\pi^{+})$ sidebands give background under D^0 peak.
- Only free parameters are the yields.

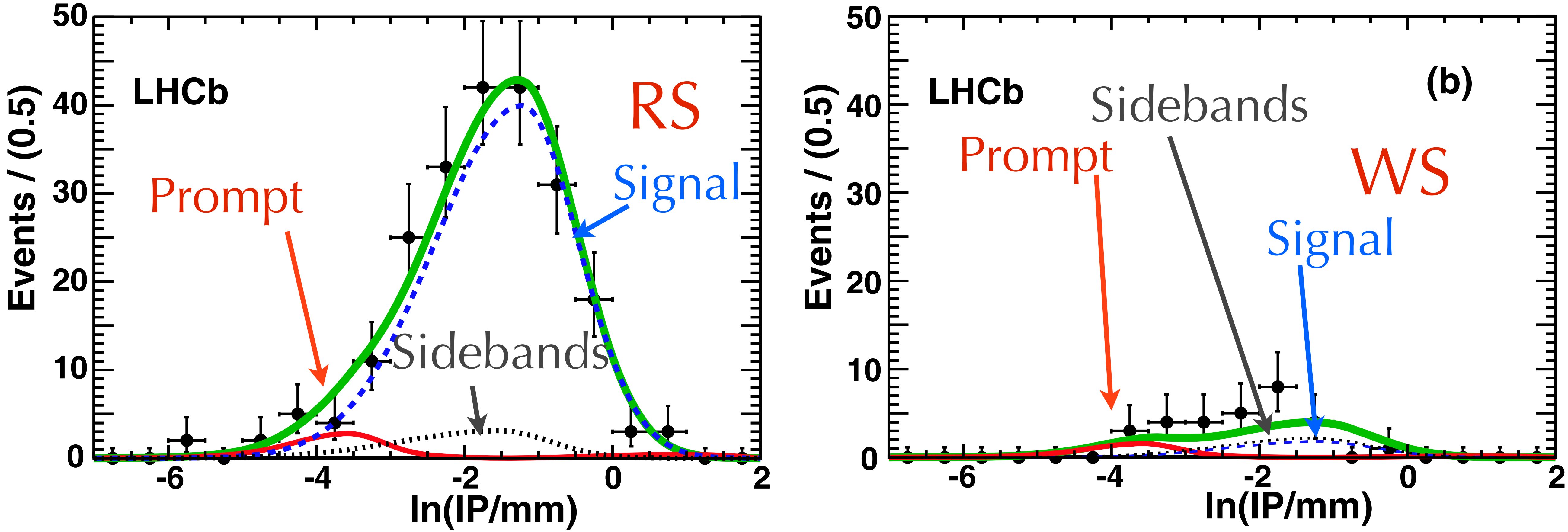
Data samples

- Two data samples:
  - 2.9 nb^{-1} of minimum bias triggers (>= 1Track).
    - $p(\mu^-)$> 3 GeV, $p_T(\mu^-)$>0.5 GeV
  - 12.2 nb^{-1} single muon trigger, p_T>1.3 GeV.
- For semileptonic decays, trigger much lower than Tevatron.



Fit projection in IP 12.2 nb^{-1}

- HLT1 Triggered Sample
- Fit results integrated over pseudo-rapidity [2,6].

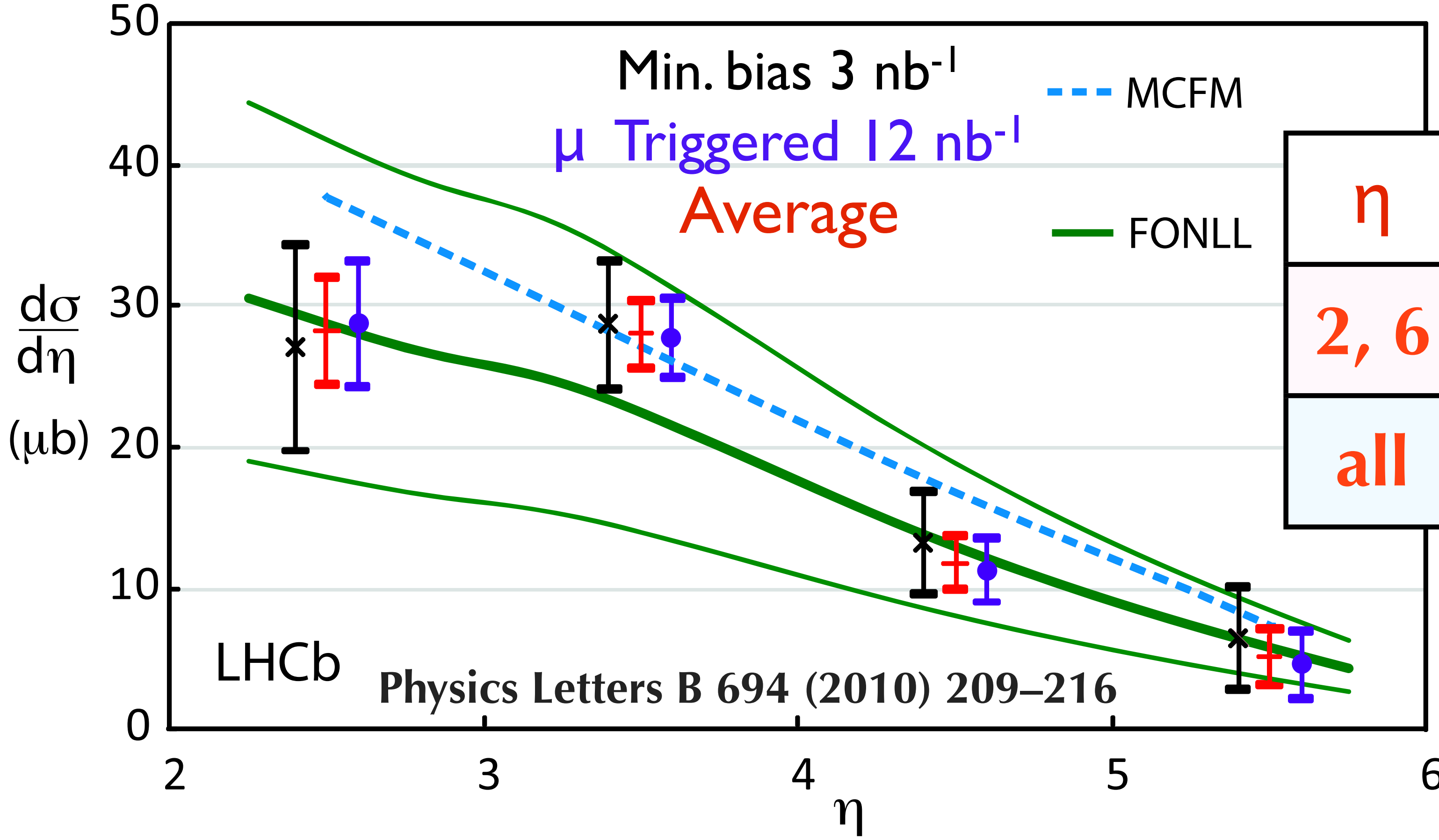


Signal:195±15

Signal:9±5

b Cross Section

$$\sigma(pp \to H_b X) = \frac{\#\text{ of detected } D^0\mu^- \text{ and } \overline{D}^0\mu^+ \text{ events}}{2\mathcal{L} \times \text{efficiency} \times \mathcal{B}(b \to D^0 X \mu^- \overline{\nu})\mathcal{B}(D^0 \to K^-\pi^+)}$$



σ(μb)

η	MCFM	FONLL	Average
2, 6	89.0	70.2^{+39}_{-44}	75.3±5.4±13.0
all	332	253^{+114}_{-96}	284±20±49

Main systematics:
luminosity 10%,
tracking 10%

Tevatron numbers rather than LEP, raise cross-section by 19%!

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**

b-hadron fractions

Preliminary

b-hadron fractions

- Measure using inclusive B semileptonic decays:
- $f_s/(f_u+f_d)$ & $f_{\Lambda b}/(f_u+f_d)$ where $f_q \equiv \text{Fraction}(b \rightarrow B_q X)$
- With $D^o X\ \mu^- \nu$, $D^+ X\ \mu^- \nu$, $D_s X\ \mu^- \nu$, $\Lambda_c X\ \mu^- \nu$
  - Cross feed between channels must be taken into account.

Channel	B (%)	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**

Limiting factors

Hadron Fractions

- Using semileptonic B decays, the fractions are determined as:

$$\frac{f_s}{f_u + f_d} = \frac{N(\overline{B}^0_s)}{N(\overline{B}^0 + B^-)} = \frac{n\left(\overline{B}^0_s \to DX\mu^-\overline{\nu}\right)}{n\left((\overline{B}^0 + B^-) \to DX\mu^-\overline{\nu}\right)} \frac{\tau_{B^-} + \tau_{\overline{B}^0}}{2\tau_{\overline{B}^0_s}}$$

$$= \frac{n_{\rm corr}(\overline{B}^0_s \to DX\mu^-\overline{\nu})}{n_{\rm corr}(B \to D^0X\mu^-\overline{\nu}) + n_{\rm corr}(B \to D^+X\mu^-\overline{\nu})} \frac{\tau_{B^-} + \tau_{\overline{B}^0}}{2\tau_{\overline{B}^0_s}}$$

cross feed correction e.g.

↑ $B_s \to (D_s^{**} \to DK)X\mu^-\nu$

↓ $B \to D_sKX\mu^-\nu$

- n_{corr}: efficiency, branching fraction and cross-feed corrected yield.
    - Cross feed significant for $n_{corr}(B_s)$.
- $\Gamma_{SL}(B_s) = \Gamma_{SL}(B_d) = \Gamma_{SL}(B_u)$, known from theory to <0.1%.

$b \rightarrow D^0 X \mu \nu$

RS

Signal=28474±190

Prompt=773±44

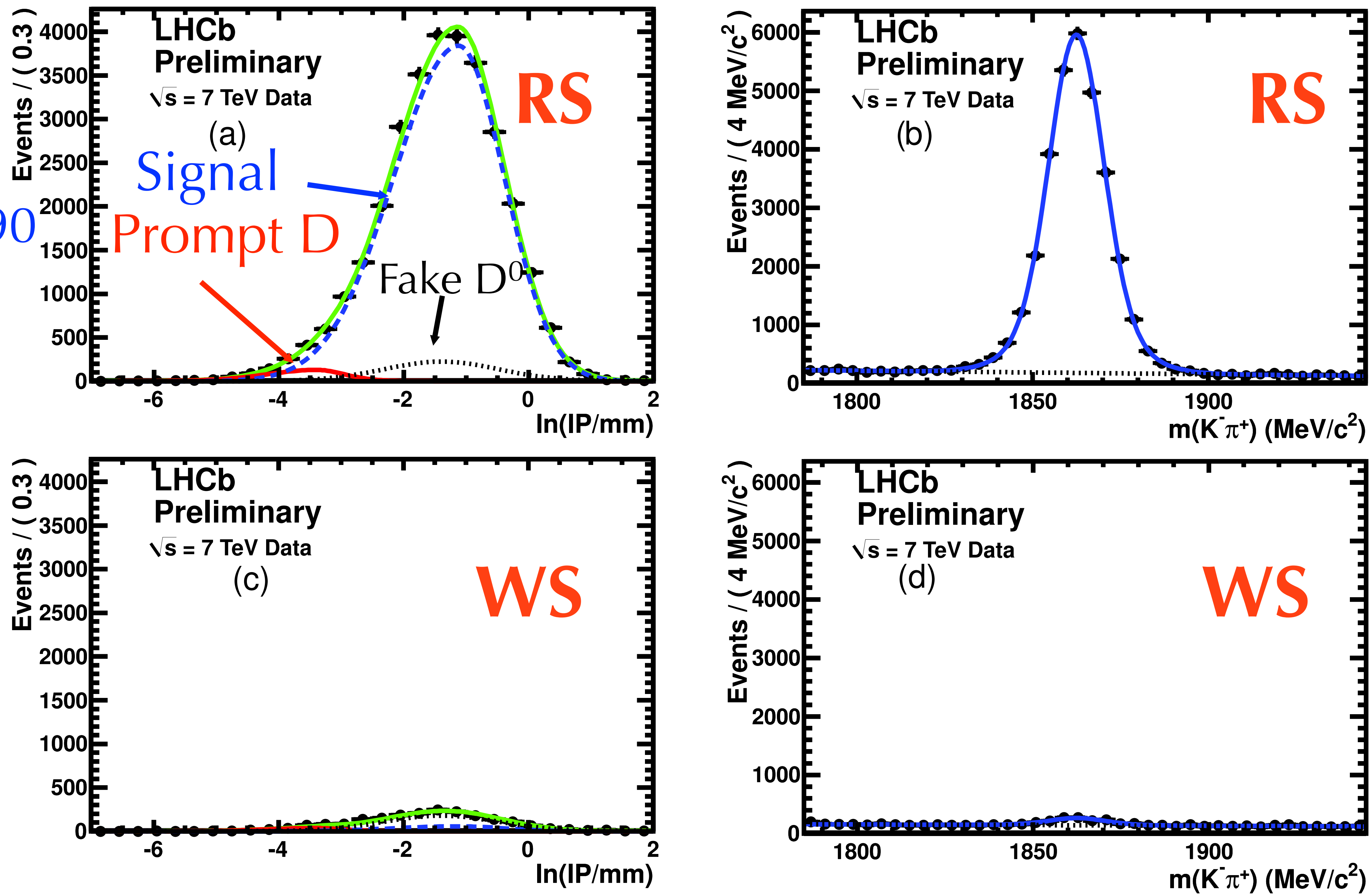
Sideb.=1776±33

WS

Signal=422±43

Prompt=204±19

Sideb.=1410±21



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

Reconstruct $D^+ \to K\pi\pi$ inclusive

RS

Signal=9406±105

Prompt=369±35

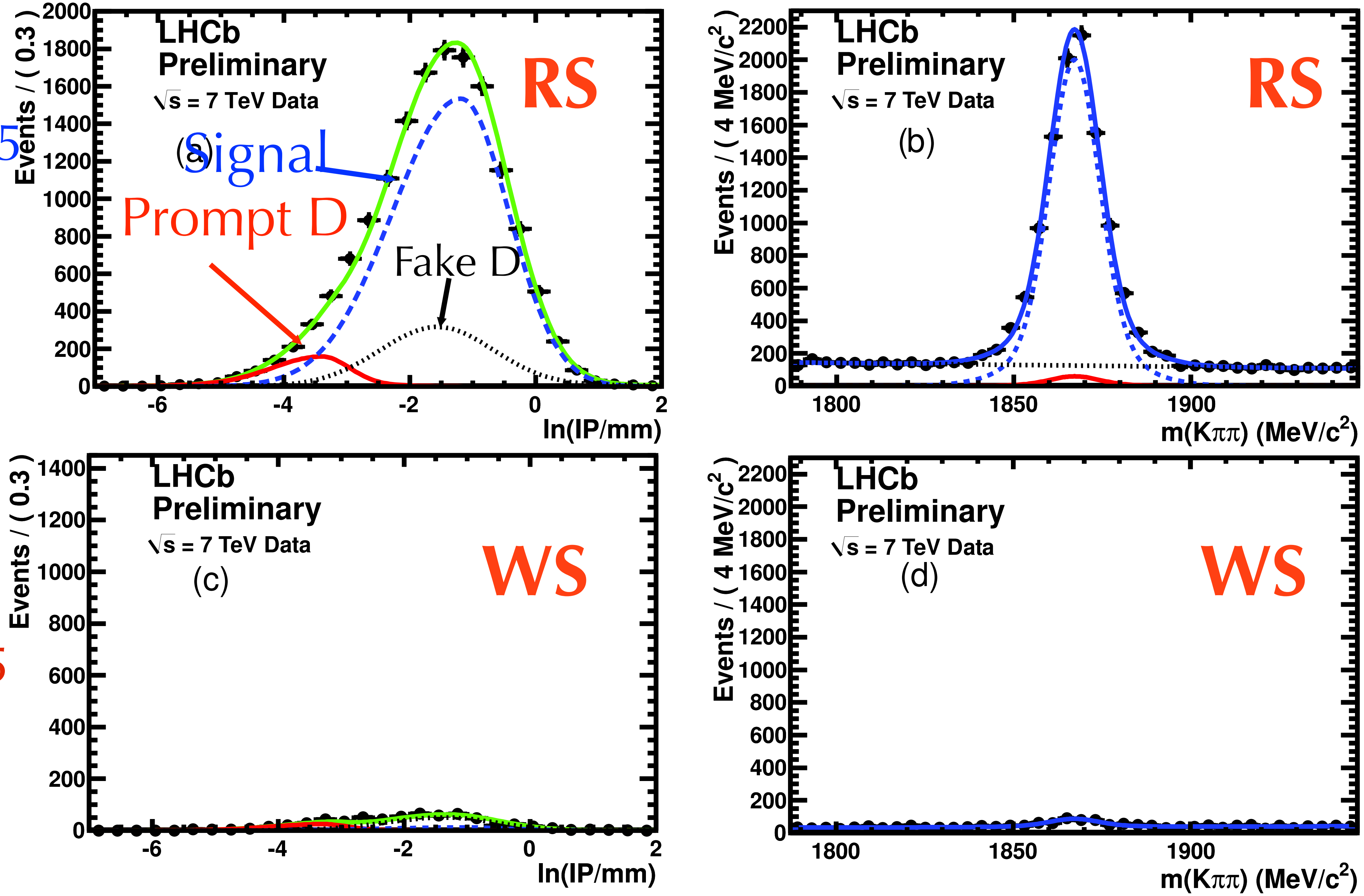
Sideb.=1266±21

WS

Signal=84±22

Prompt=140±15

Sideb.=374±11

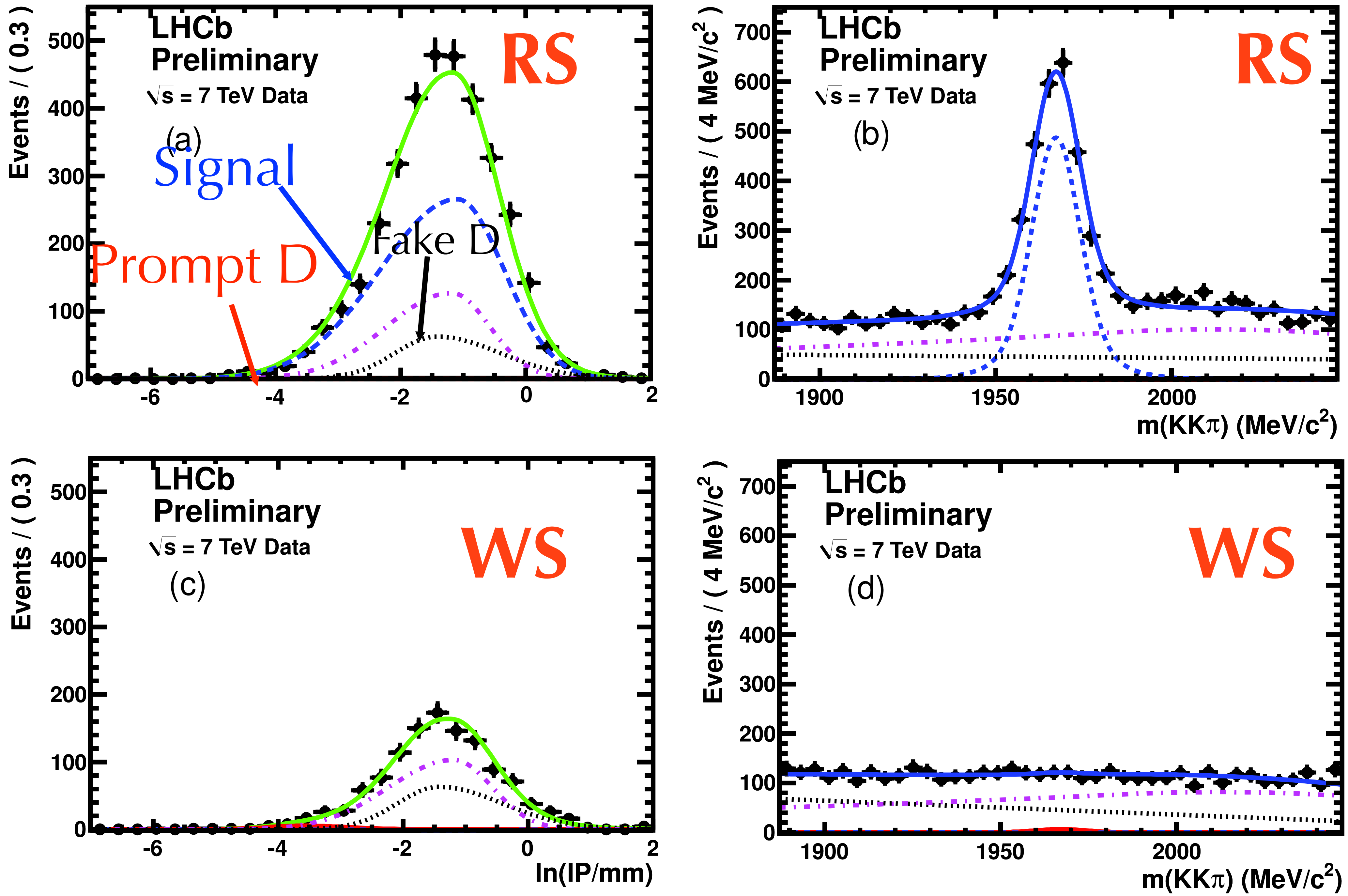


$b \to D_s^+ X \mu^- \nu$

$D_s^+ \to KK\pi$, Inclusive

RS
Signal=2208±61
Prompt=3±13
Sideb.=800±62
Λ_c=504±64

WS
Signal=20±32
Prompt=25±10
Sideb.=621±45
Λ_c=520±45

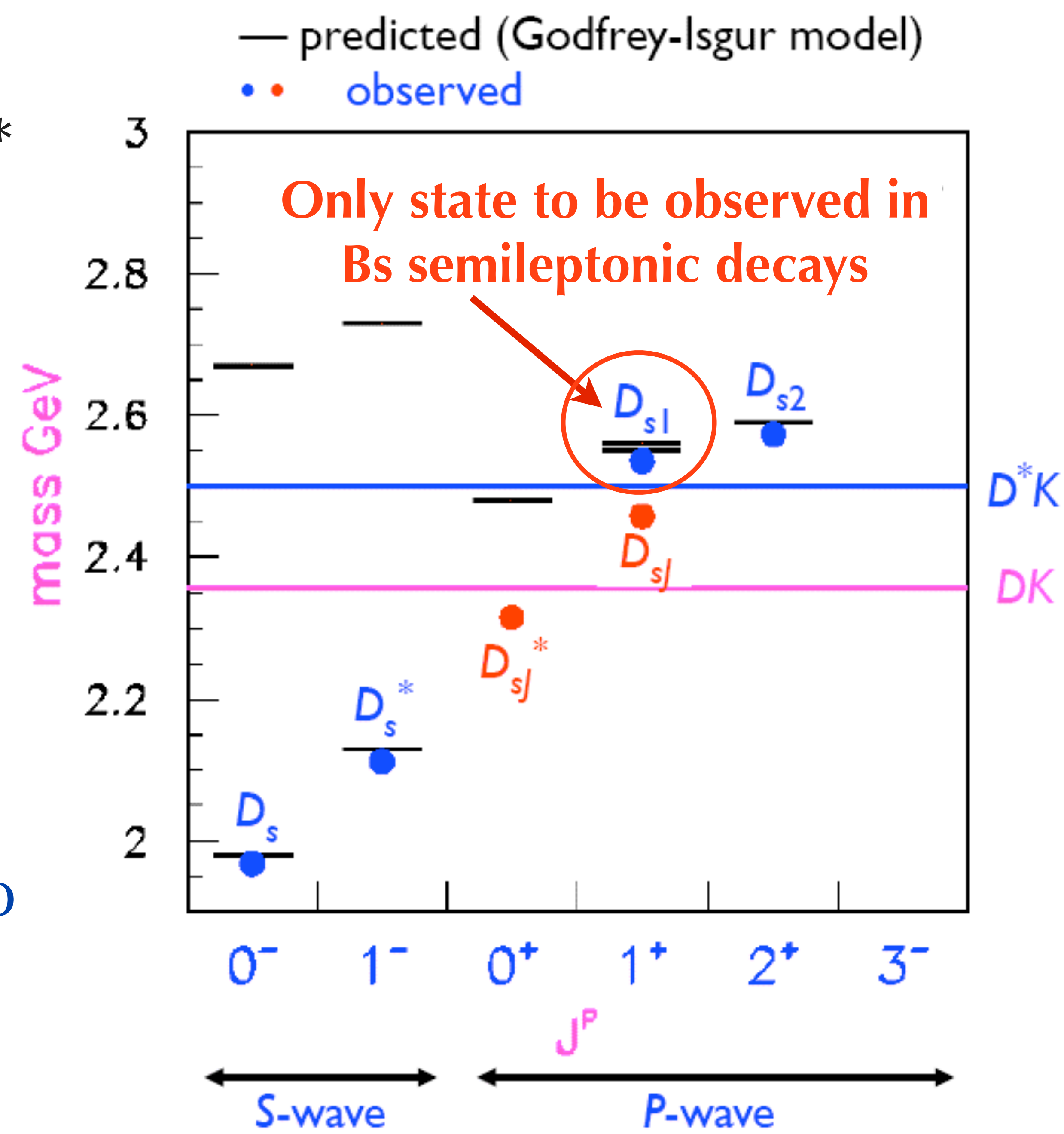


$b \to D_s X \mu^- \nu$ Composition

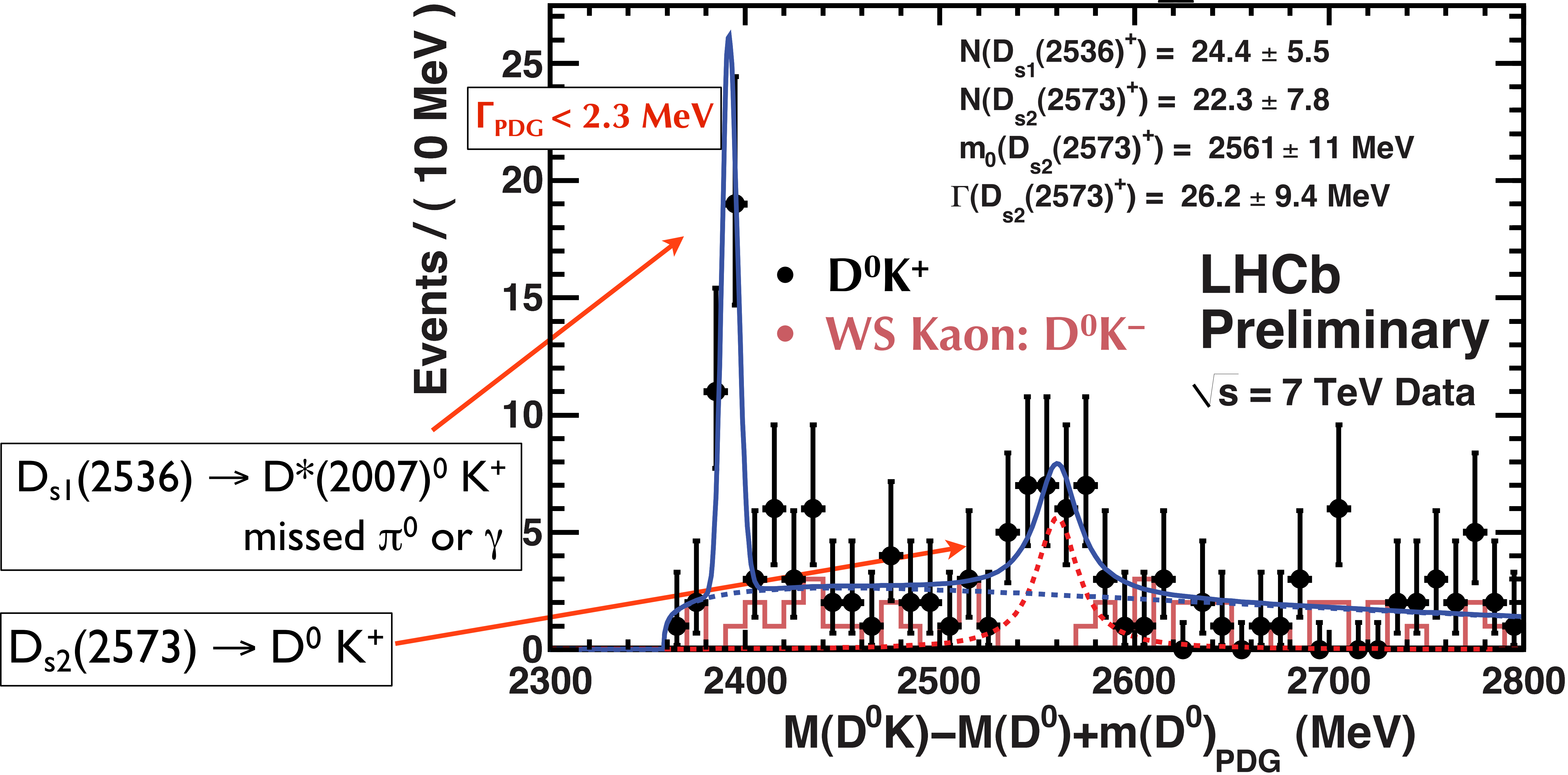
A recent theoretical prediction:
Γs(sl)~90% Ds+Ds* (Ds*/Ds=2.4) + Ds**
(arXiv: 1003.5576)

Only $B_s \to D_{s1} X \mu^- \nu$ has been measured (D∅, PRL**102** 051801).

D_{s1} & D_{s2} decays to a mixture of $\mathbf{D^{(*)}K}$ and $\mathbf{D_s X}$.
=>The fraction needs to be measured to determine cross feed.



$B_s \to D^0 K^+ X \mu^- \nu$ 3 pb^{-1}



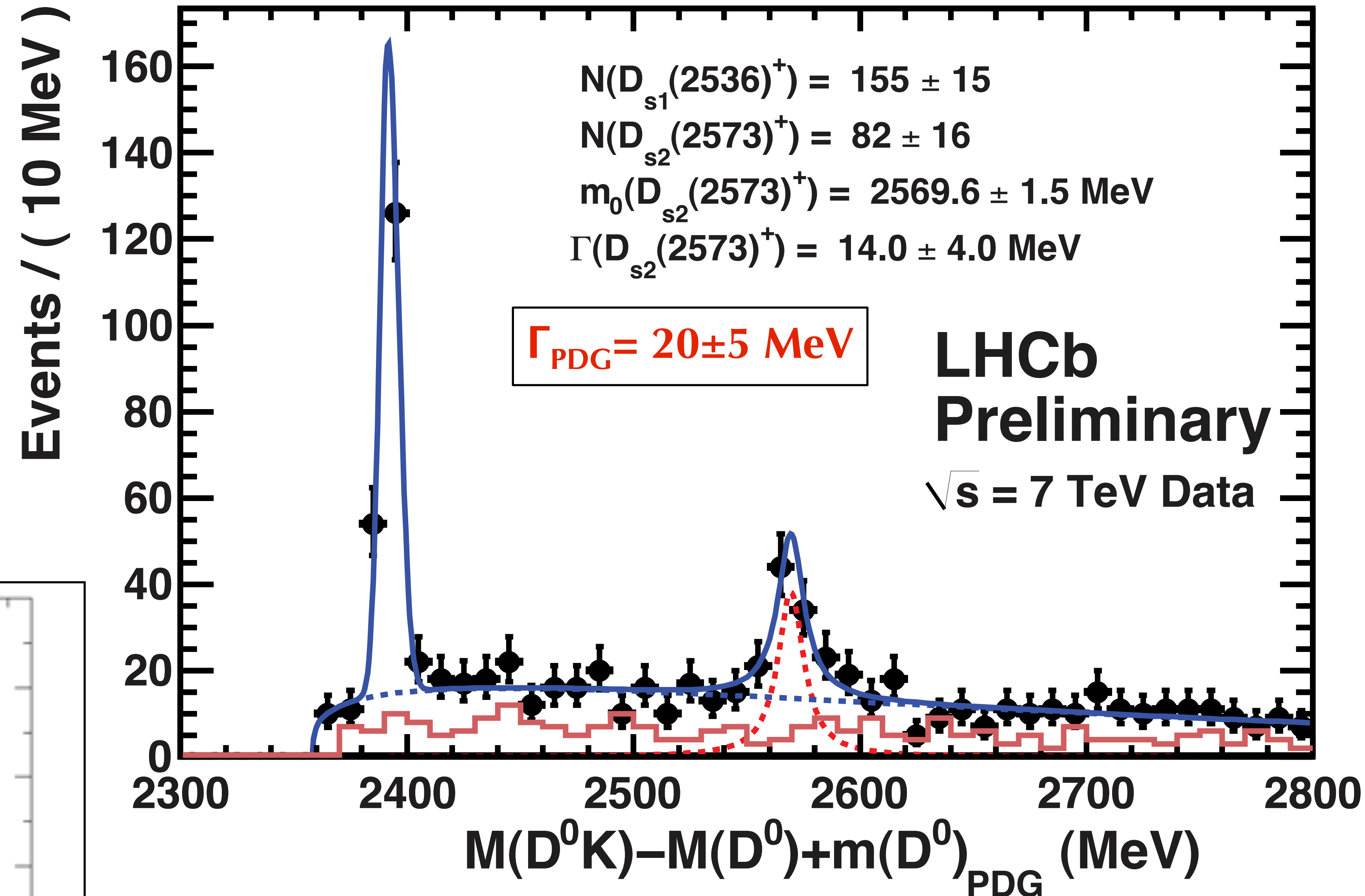
D0 observed $B_s \to D_{s1}(2536)^+ \mu\nu$, $D_{s1}(2536)^+ \to D^{*+} K^0$ [PRL 102 051801]

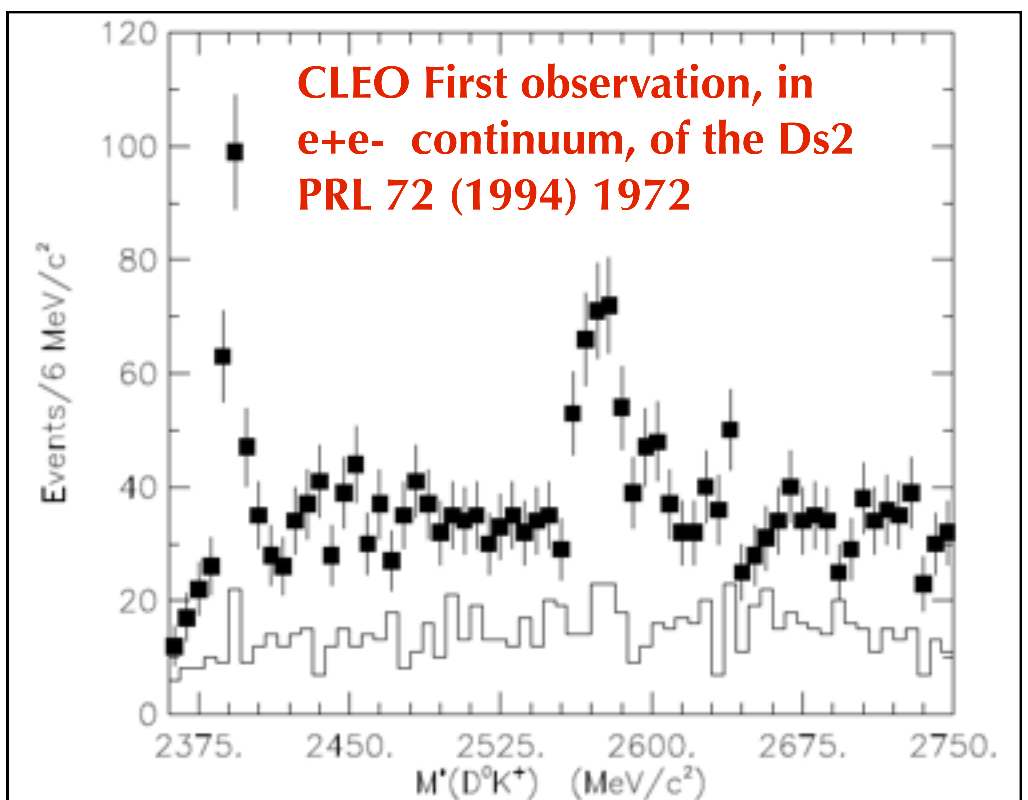
Nobody has seen $B_s \to D_{s2}(2536)^+ \mu\nu$ before. We used more data to confirm it.

$B_s \to D^0 K^+ X \mu^- \nu$ 20 pb^{-1}

8.3 σ significance for $B_s \to D_{s2} \mu^- \nu$ mode.

Discovery!





$B_s \to D^0 K^+ X \mu^- \nu$

- Determine branching fraction ratios:
  - Ratio of D_{s2}/D_{s1} from the 20pb^{-1} sample,

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

  - And with the semi-inclusive $B_s \to D_s X \mu^- \nu$ yield from 3pb^{-1} we get:

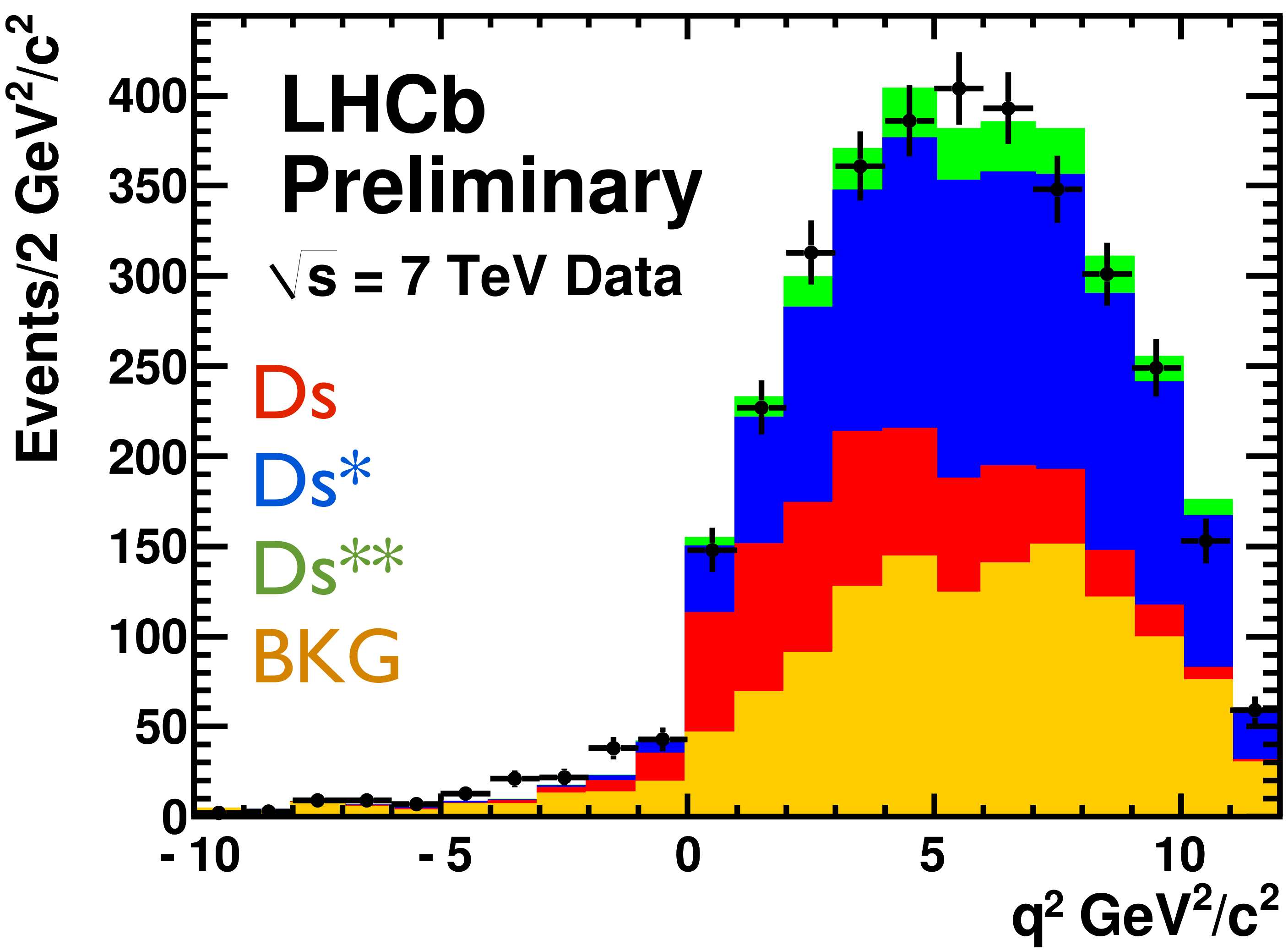
$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{+}_{s1} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = 5.3 \pm 1.2 \pm 0.4\%$$

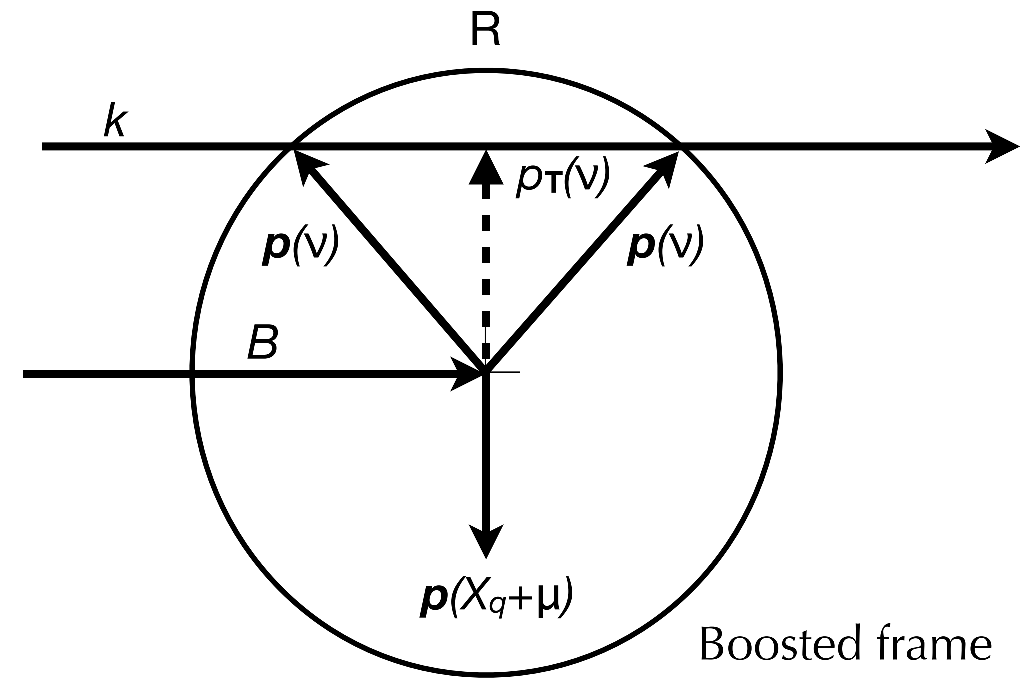
$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = 3.2 \pm 1.0 \pm 0.4\%$$

DØ, PRL102 051801
=(9.8±3.0)%

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

- Must know relative BR of $D_s/D_s^*/D_s^{**}$ to constrain D_s mode efficiency.
- Use neutrino reconstruction with B-flight information to access decay kinematics.
- D_s^*/D_s ratio well predicted, but D** fraction highly uncertain.





$$\frac{\mathcal{B}(\overline{B}_s^0 \rightarrow D_s^{**} X \mu\nu)}{\mathcal{B}(\overline{B}_s^0 \rightarrow D_s^{(*),**} X \mu\nu)} = (11^{+22}_{-11})\%$$

ΔEfficiency($B_s \rightarrow D_s X \mu^- \nu$) =3%.

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

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

RS

Signal=3250±71

Prompt=50±13

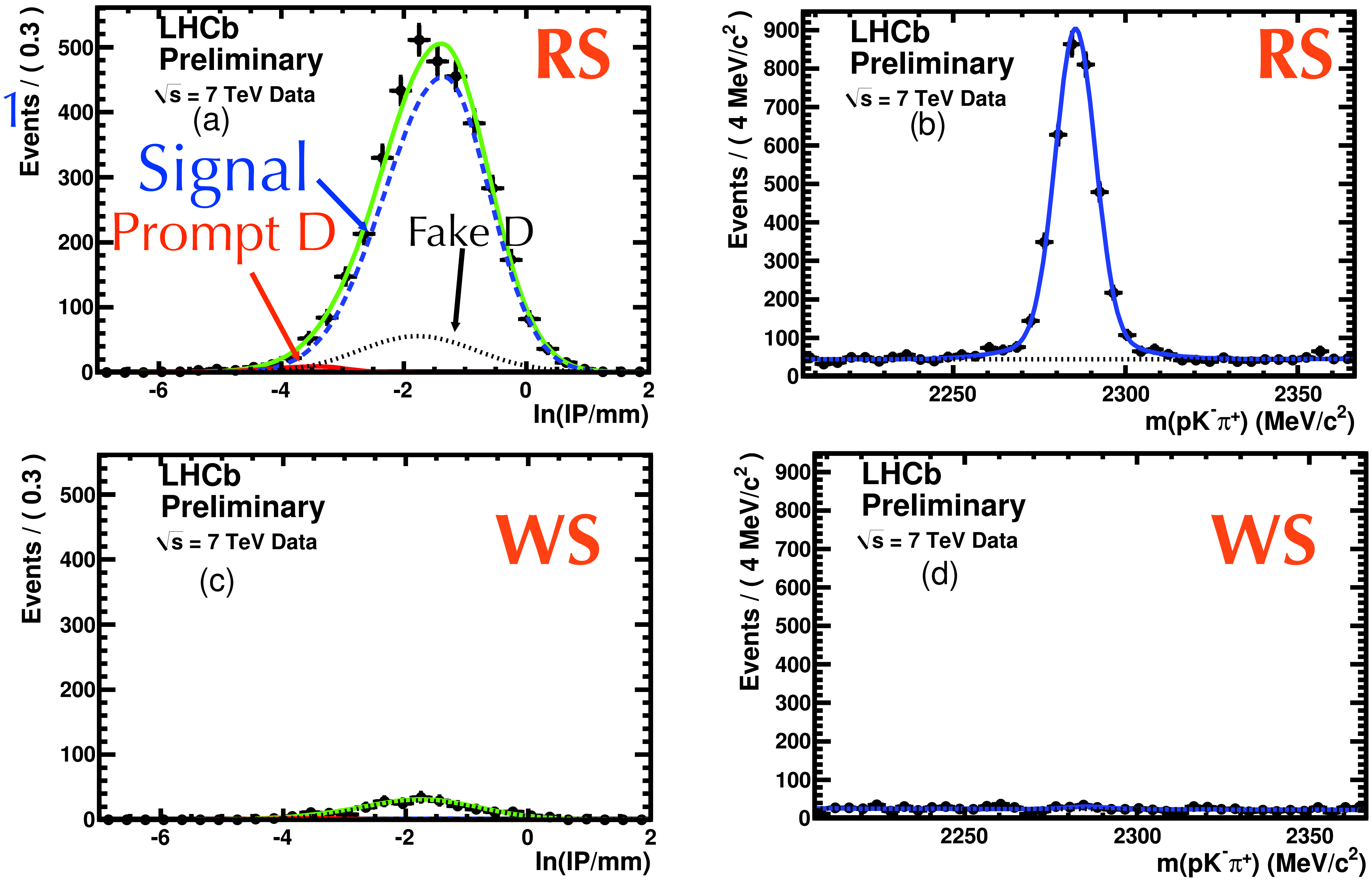
Sideb.=446±15

WS

Signal=12±13

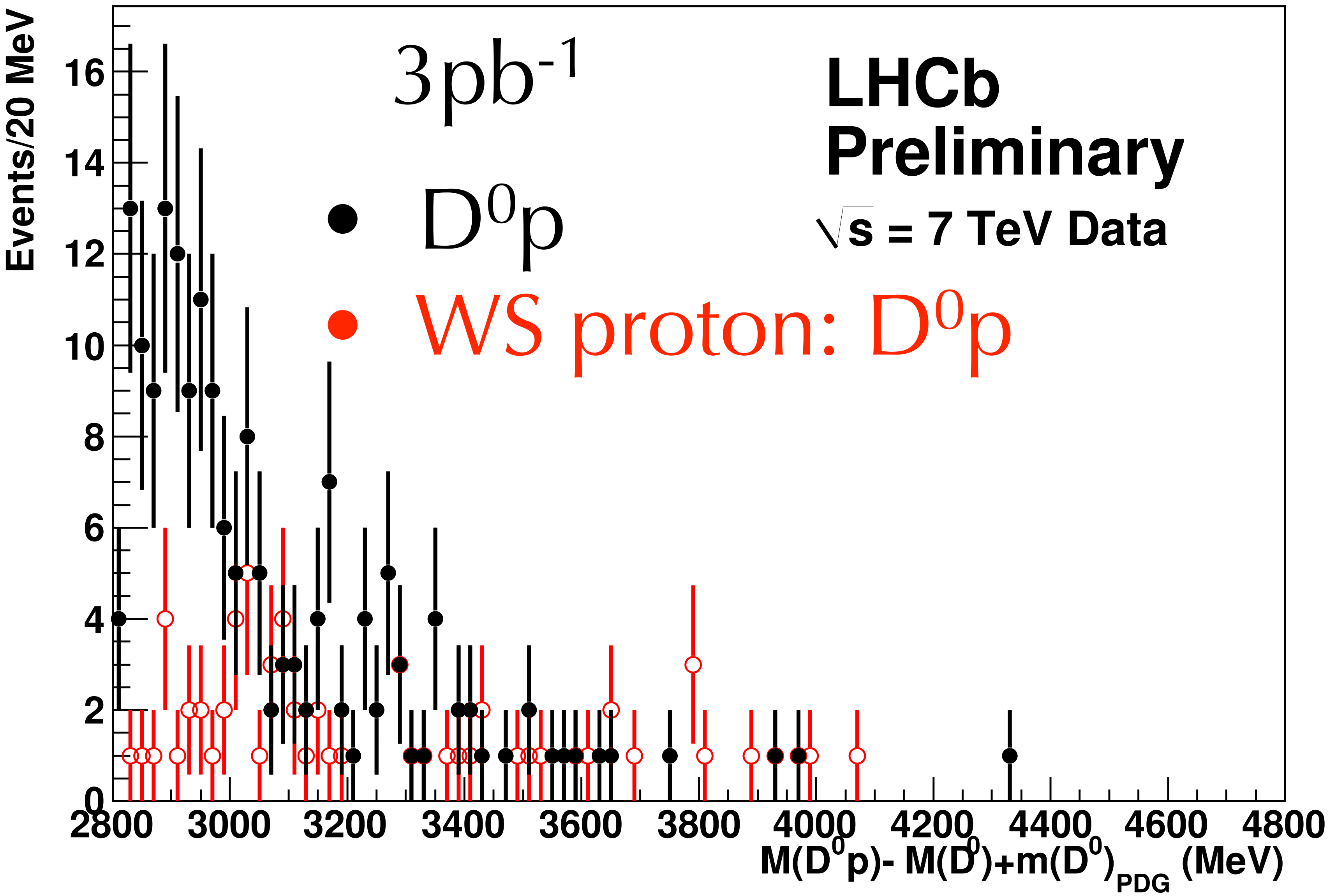
Prompt=13±6

Sideb.=238±8



$\Lambda_b \rightarrow D^0\, p\, X \mu^- \nu$

Similar criteria for D^0p mode, to determine Λ_b cross feed.



$n(D^0pX\mu^-\nu)$
$= 106 \pm 25 \pm 27$

c.f. Masses of observed states, though cannot confirm their presence.

$\Lambda_c(2880)^+ \rightarrow p\, D^0$, $m_{PDG} = 2881.5$ MeV, $\Gamma_{PDG} = 5.8 \pm 1.1$ MeV

$\Lambda_c(2940)^+ \rightarrow p\, D^0$, $m_{PDG} = 2939.3$ MeV, $\Gamma_{PDG} = 17 \pm 8$ MeV

$f_s/(f_u+f_d)$

$f_s/(f_u+f_d) = 0.130 \pm 0.004(\text{stat.}) \pm 0.013(\text{sys.})$ [preliminary]

LEP: 0.129 ± 0.012

Tevatron: 0.18 ± 0.03

→ Higher p_T threshold different cross feed treatment.

$B_s \to D^0 K X \mu\nu$ most important correction.

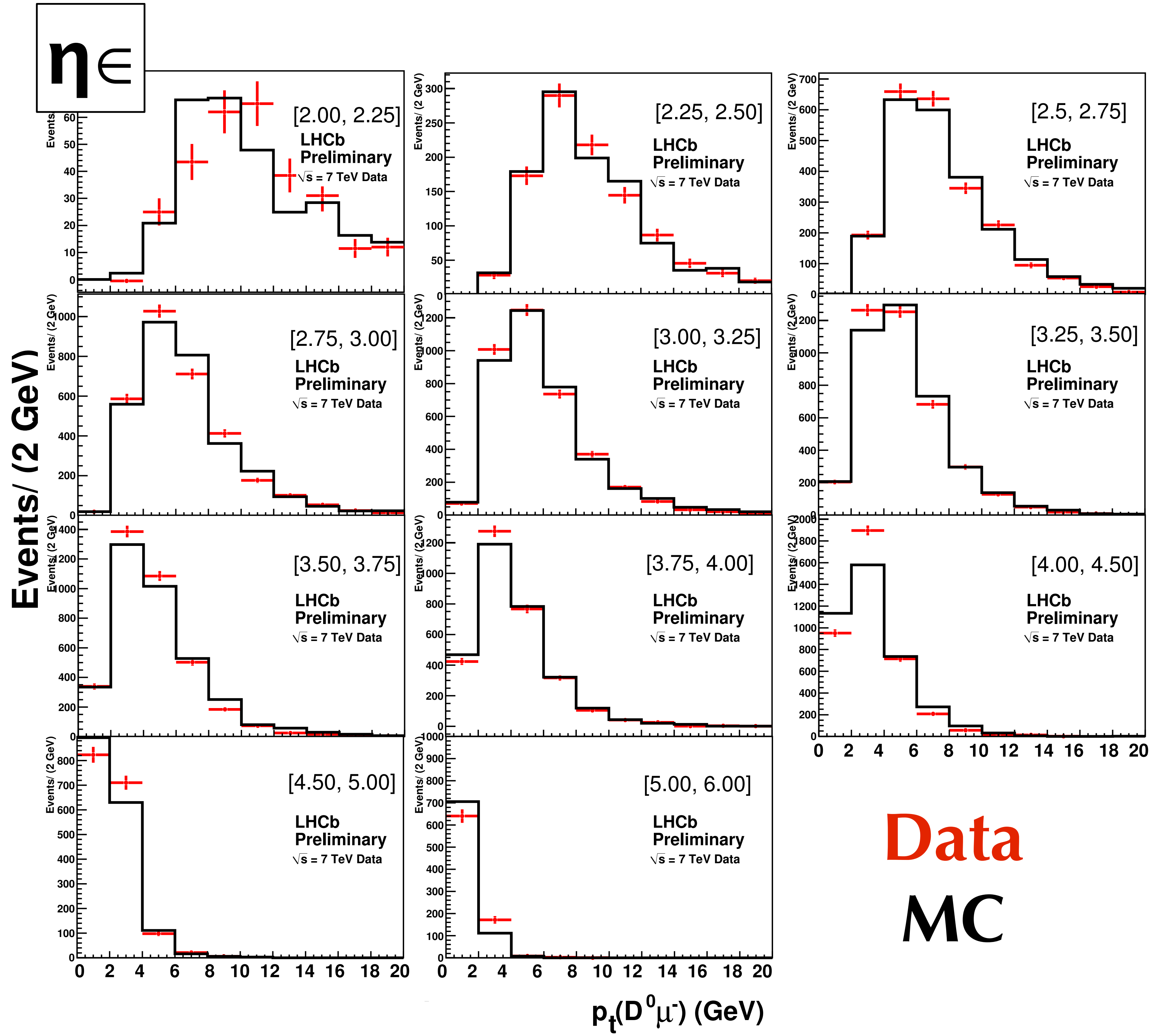
B backgrounds small.

Most systematics cancel in the ratio.

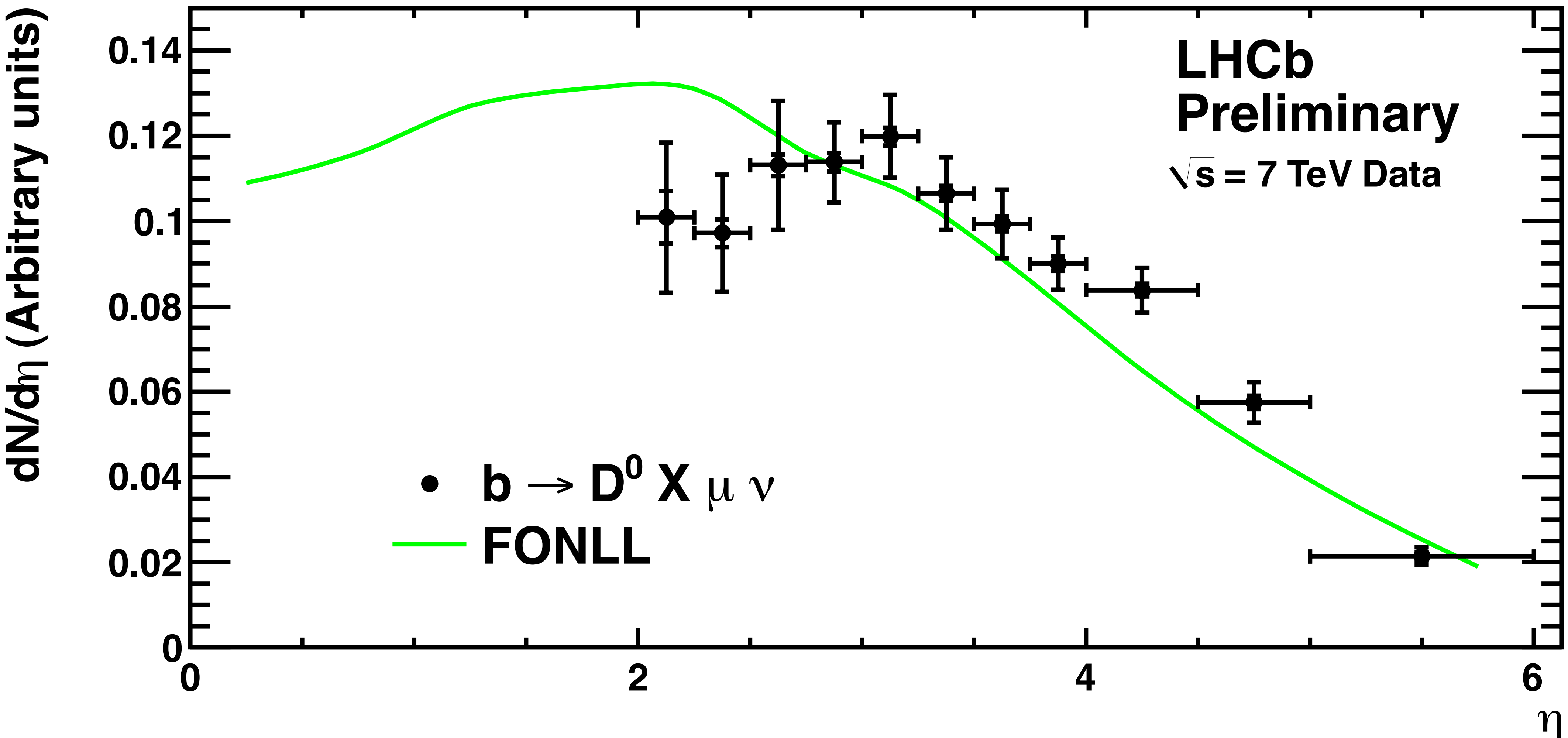
Systematic Sources	Relative Error [%]
Charm hadron BR	5.5
$B_s \to D^0 K X \mu\nu$ Yield	6.3
$B^{0/+}, \Lambda_b \to D_s K X \mu\nu$ Correction	2.0
Efficiencies, mainly Bs	3.0
Λ_c reflection	1.0
MC statistics	3.0
Background	2.0
Tracking	2.0
Lifetime ratio	1.8
PID	1.4
Trigger	1.4
Total	10

$b \to D^0 X \mu \nu$ in η&p_T

- Measure η dependence in D^0 mode to compare shape with theory.
- Few events @ low p_T, low η.
  - Due to μ trigger p_T threshold.
- Extrapolation error in efficiency correction for η bins with 0 efficiency @ low p_T is included.



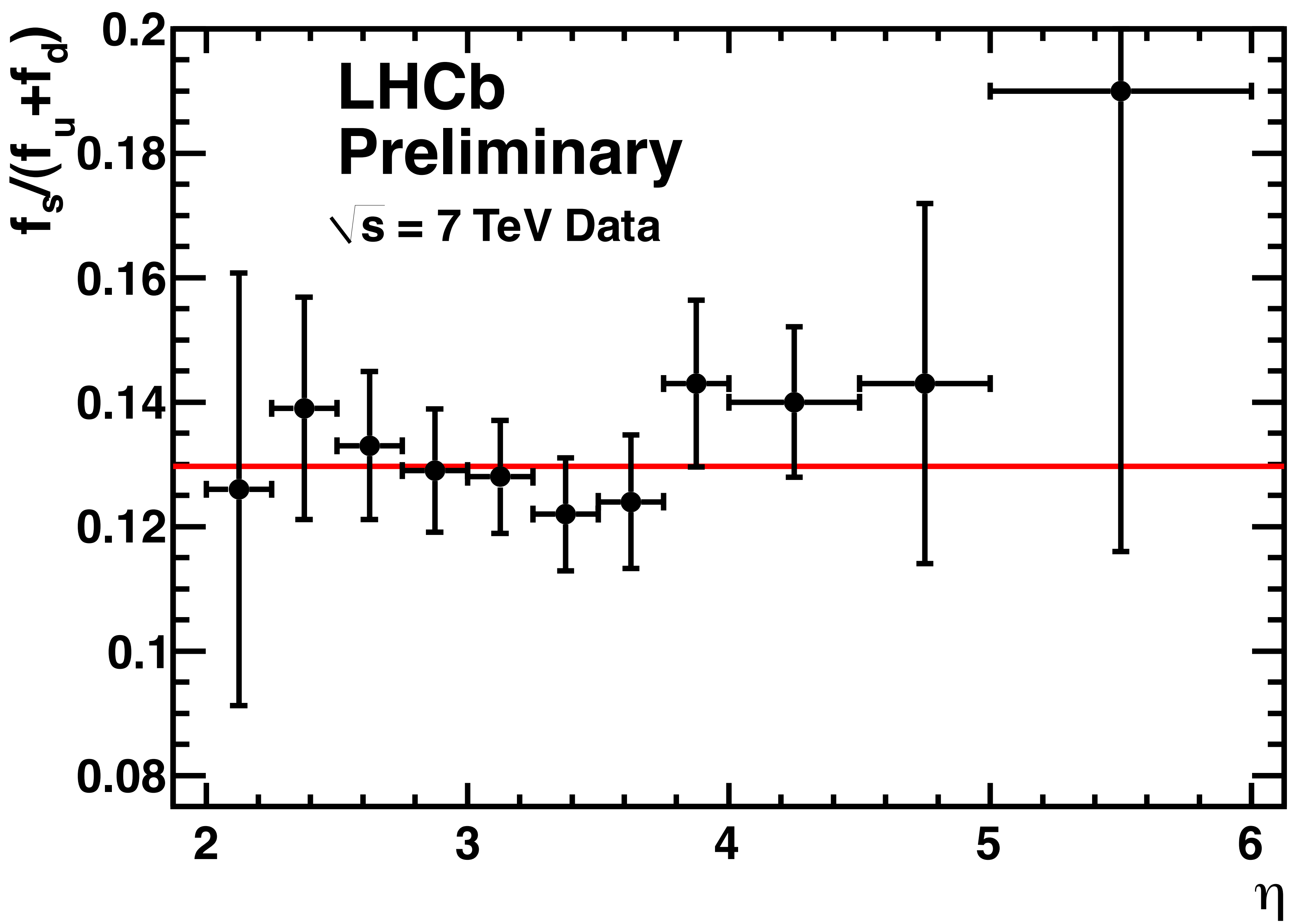
$b \to D^o X \mu \nu$ $dN/d\eta$



- Background subtracted.
- Uncorrelated errors shown: stat, and systematics (including efficiency extrapolation errors).
- Correlated errors are not negligible.

Cross check

- Within error, fragmentation fraction constant in η.
    - Only stat errors shown.



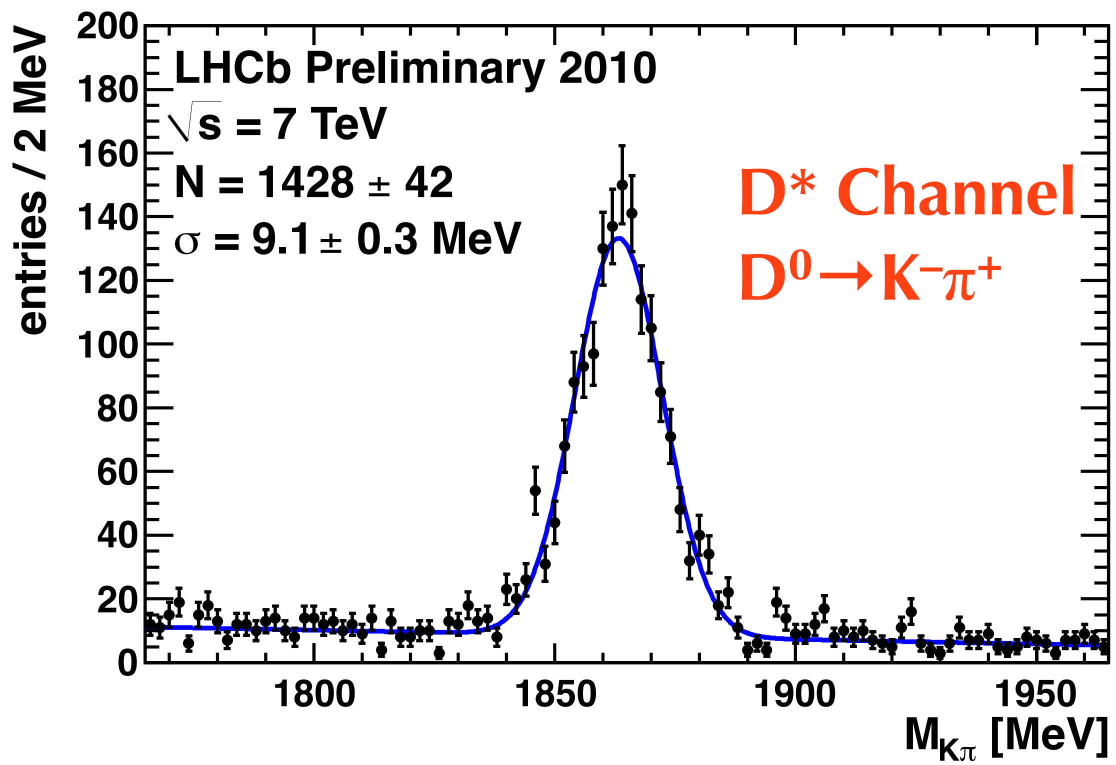
Open charm cross sections

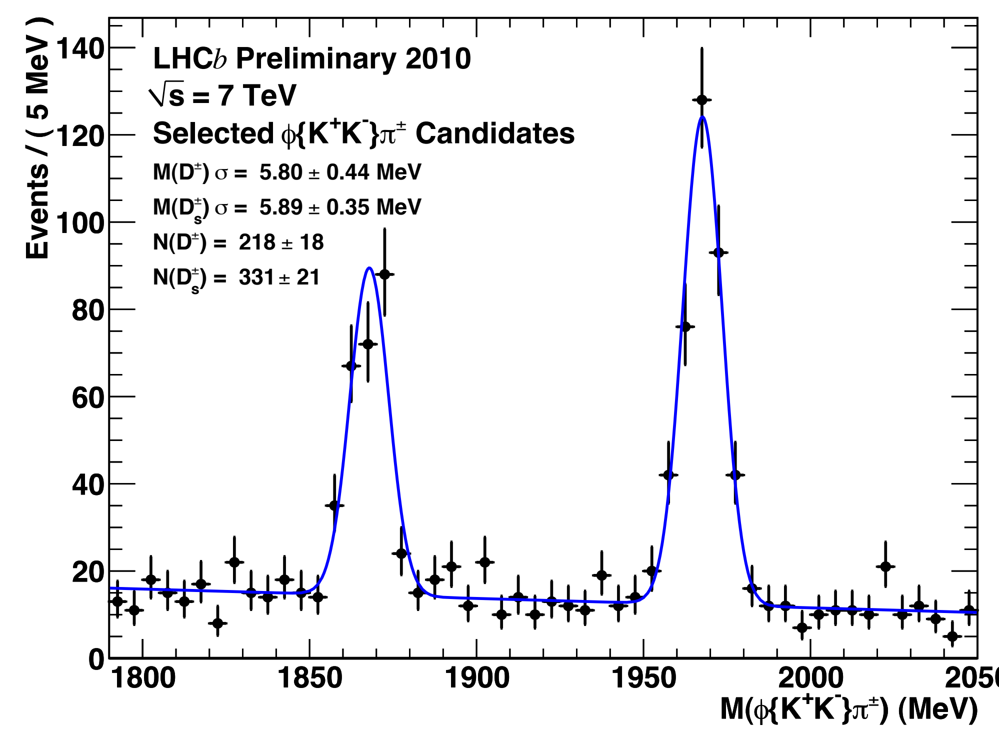
Preliminary

LHCb-CONF-2010-013

Open Charm Production

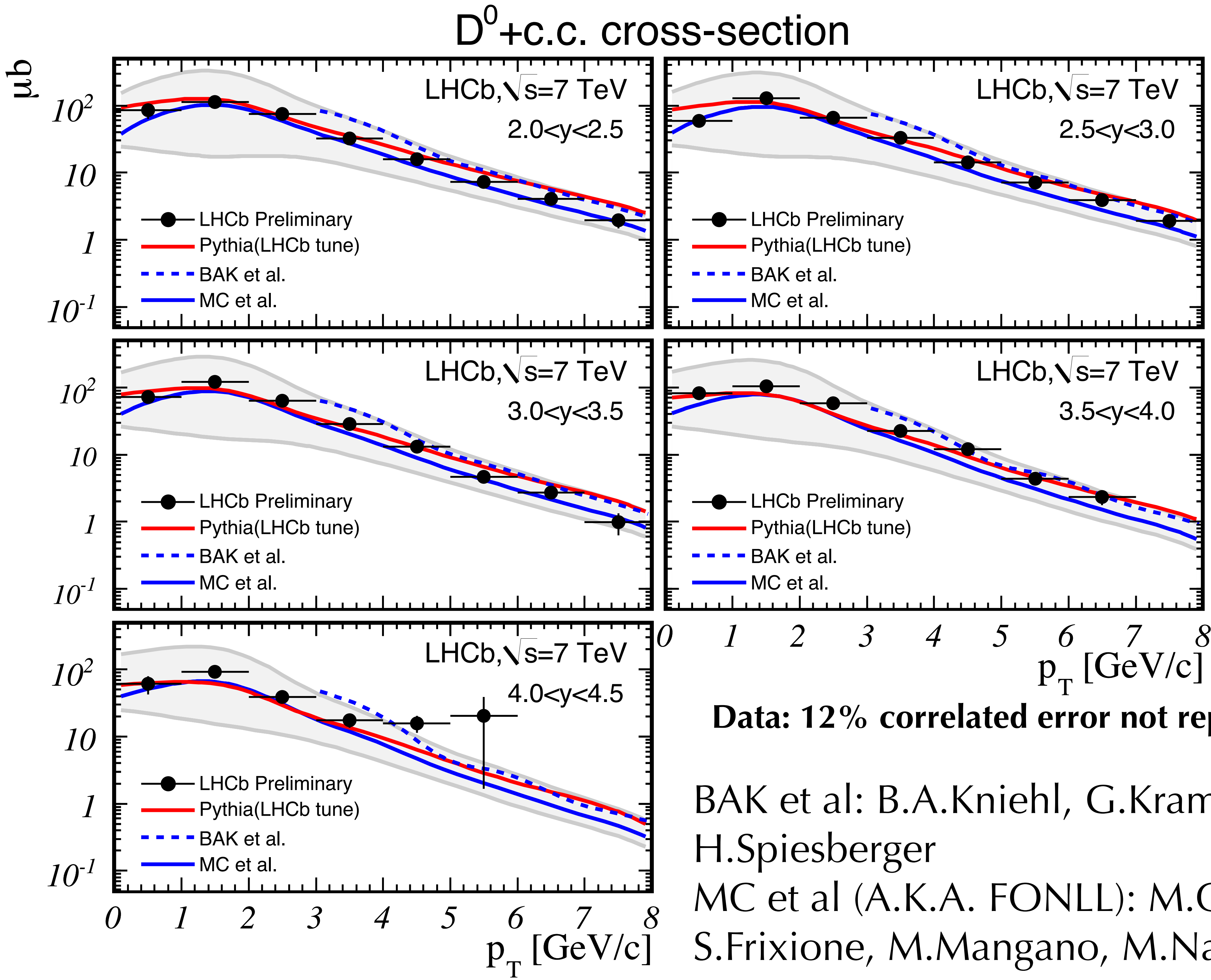
- Cross sections of D^0, $D^*(2010)^+$, D^+, D_s^+ in bins of y and p_T from $0<p_T<8$ GeV and $2<Y<4.5$
    - Preliminary results on 1.8 nb^{-1}.
- Same approach as *b*-cross section analysis.
    - Mass distributions determine D background fraction and Ln (IP) for background due to D's from B decays.





$D^+ \to K^- K^+ \pi^+$ $D_s^+ \to K^- K^+ \pi^+$

D^0 Cross section 1.8 nb^{-1}



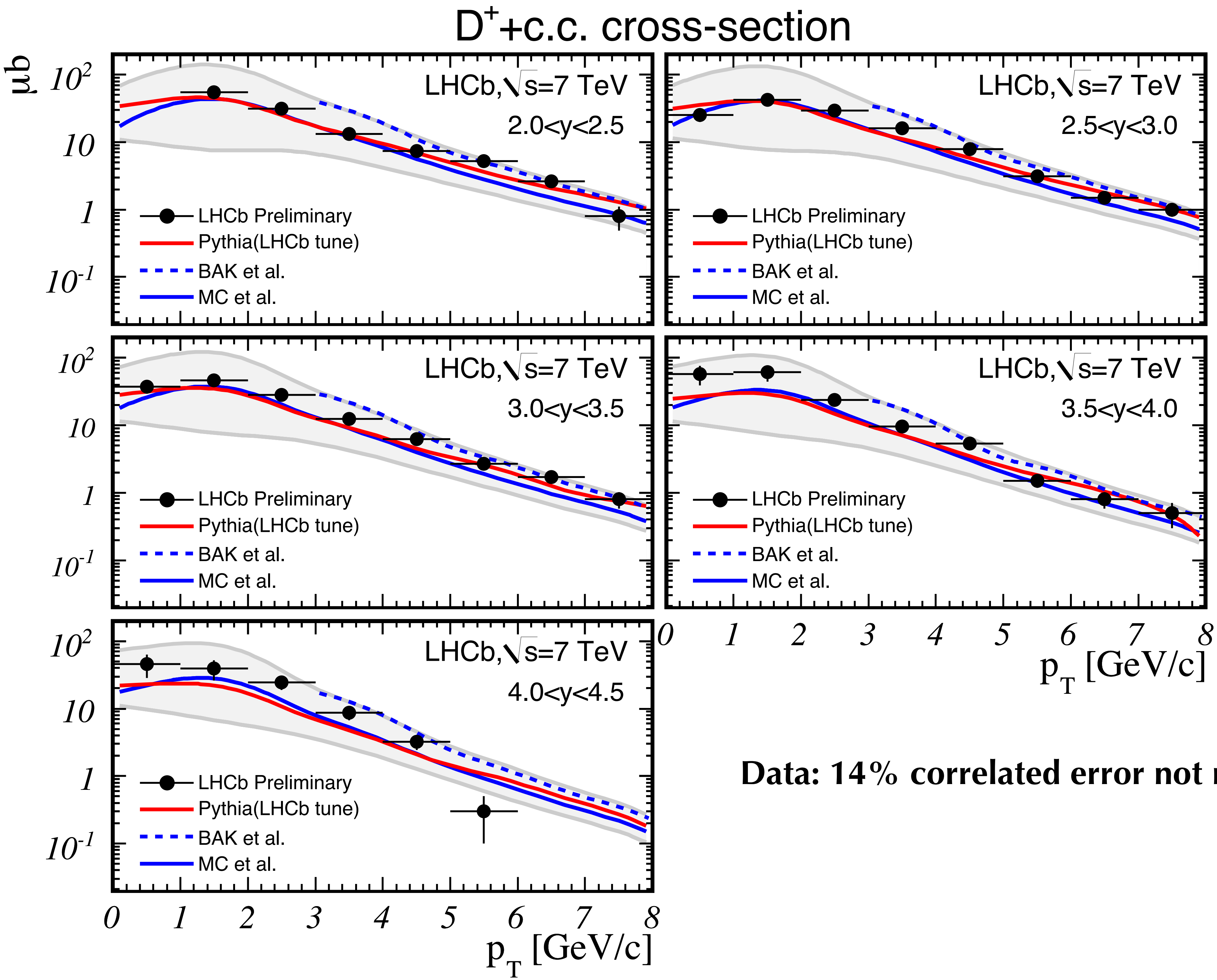
$D^0 \to K^- \pi^+$

Data: 12% correlated error not represented

BAK et al: B.A.Kniehl, G.Kramer, I.Schiembein, H.Spiesberger

MC et al (A.K.A. FONLL): M.Cacciari, S.Frixione, M.Mangano, M.Nason, G.Ridolf

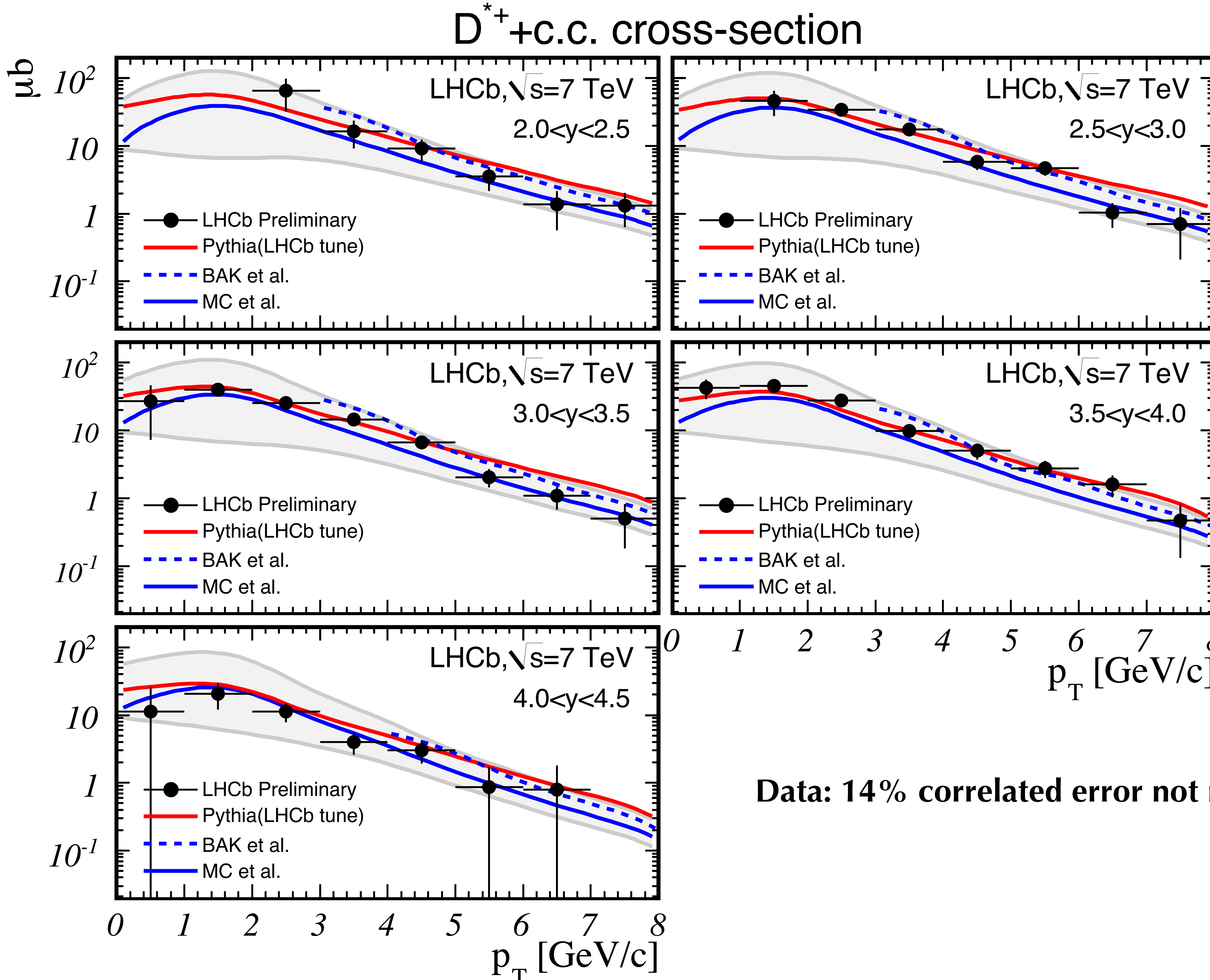
D^+ Cross section 1.8 nb^{-1}



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

Data: 14% correlated error not represented

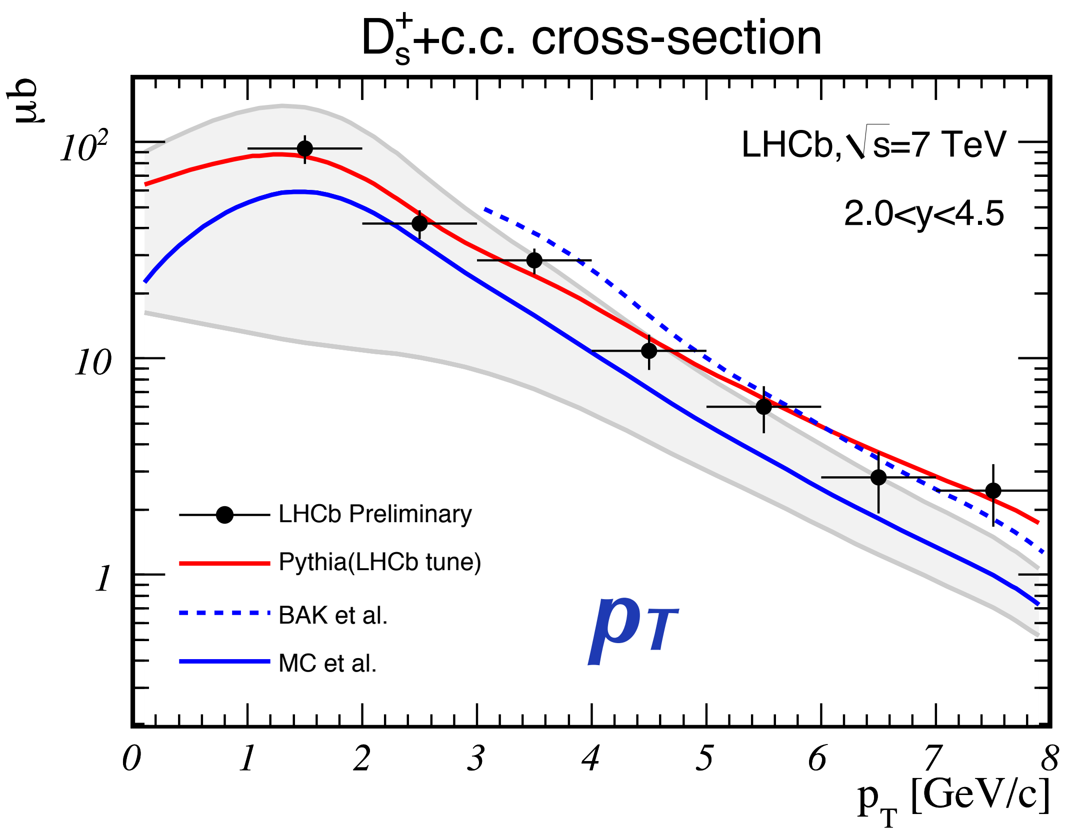
D^{*+} Cross section 1.8 nb^{-1}

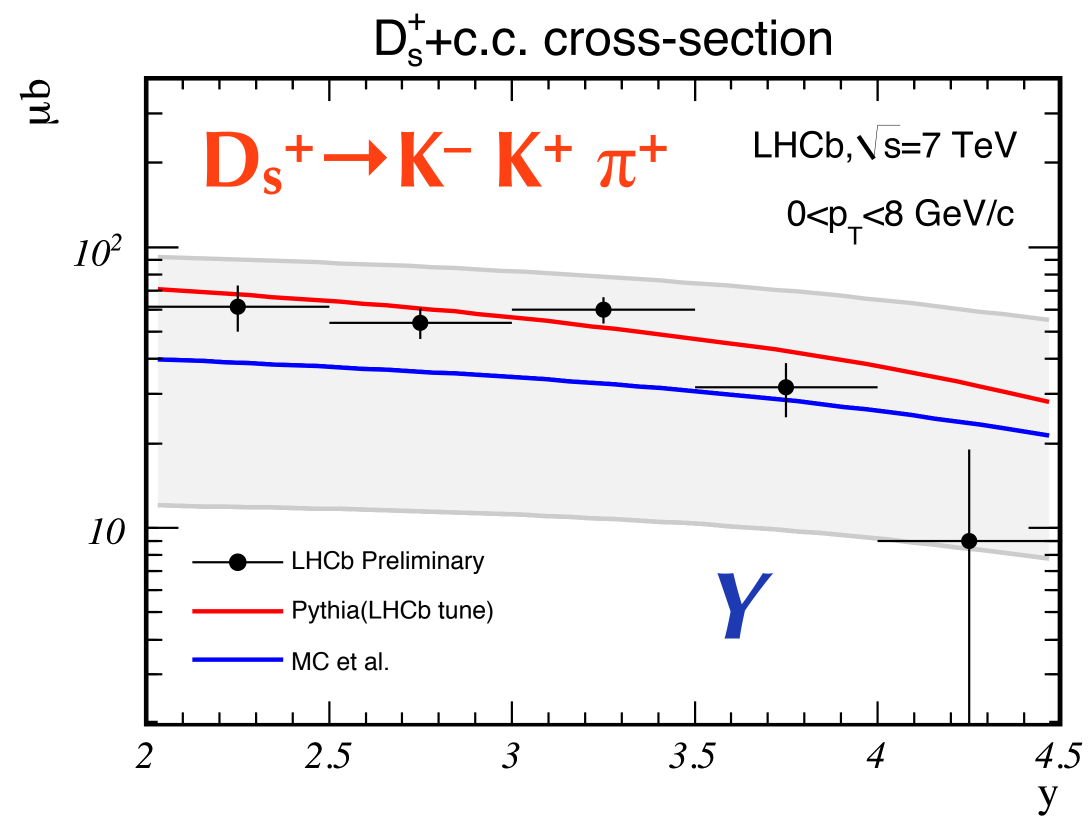


$D^* \to (D^0 \to K^- \pi^+)\pi^+$

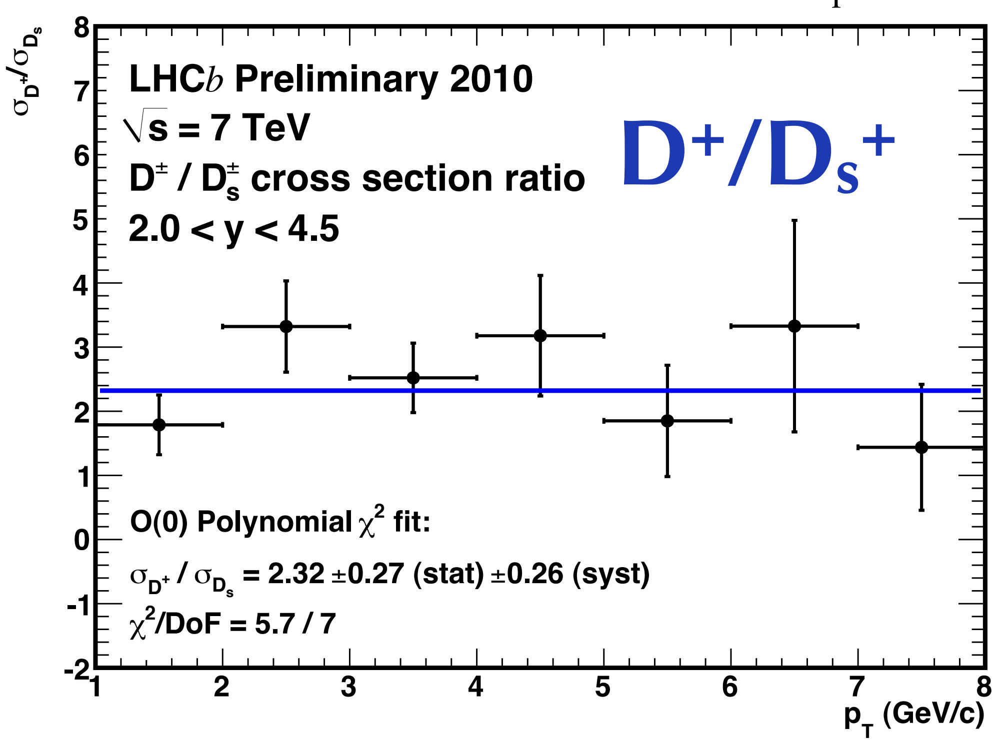
Data: 14% correlated error not represented

D_s Cross section (1.8 nb^{-1})





Data: 16% correlated error not represented



- $\sigma(D^+)/\sigma(D_s^+) = 2.32 \pm 0.27 \pm 0.26$
- $f(c \rightarrow D^+)/f(c \rightarrow D_s^+) = 3.08 \pm 0.70$ (PDG)

Charm Cross Section (Preliminary)

- X-sections in p_T and Y agree well with predictions.
- Combining $D^0/D^+/D^{*+}/D_s^+$(LHCb-CONF-2010-013)
  - $\sigma(pp\rightarrow ccX) = 1234 \pm 189\ \mu b$ (pT< 8 GeV/c, 2<y<4.5)
  - $\sigma(pp\rightarrow ccX) = 6100 \pm 934\ \mu b$ (full pT, Y, Pythia extrap.)
- Final result to come with more data ~ 14 nb^{-1}.
- Systematic uncertainties mostly constant in p_T and Y
  - 10% Luminosity, 3% per track for Tracking efficiency
  - Channel dependent: Fit systematics, Particle ID, Trigger, Selection efficiencies.

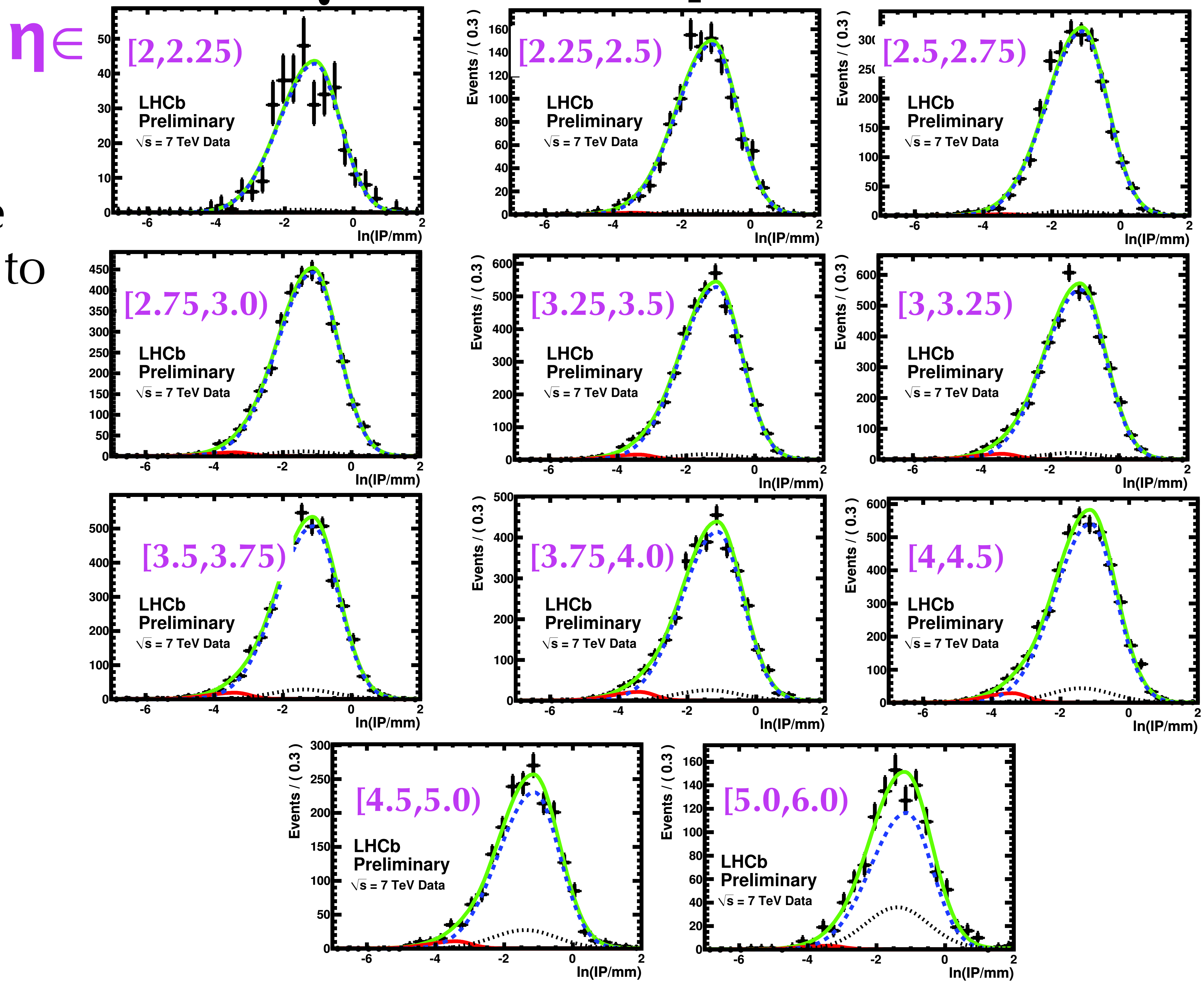
Conclusions

- Cross sections determined, error limited by luminosity measurement.
  - $\sigma(pp \rightarrow bbX) = 284 \pm 20 \pm 49\ \mu b$ PLB 694 (2010) 209–216
  - $\sigma(pp \rightarrow ccX) = 6100 \pm 934\ \mu b$ Preliminary
- Model independent b-hadron fragmentation fractions determined:
  - $f_s/(f_u+f_d) = 0.130 \pm 0.004(\text{stat.}) \pm 0.013(\text{sys.})$ Preliminary
- Discovered, and measured the BR of a new semileptonic b mode, D_{s2}, and improved understanding of B_s semileptonic width.
- Refined *b*-production measurements in η show unexpected shape at towards central region.
  - But must understand pT extrapolation.
- *J/ψ* results also tell us about *b*-production: *More details in Wenbin's talk.*

backup

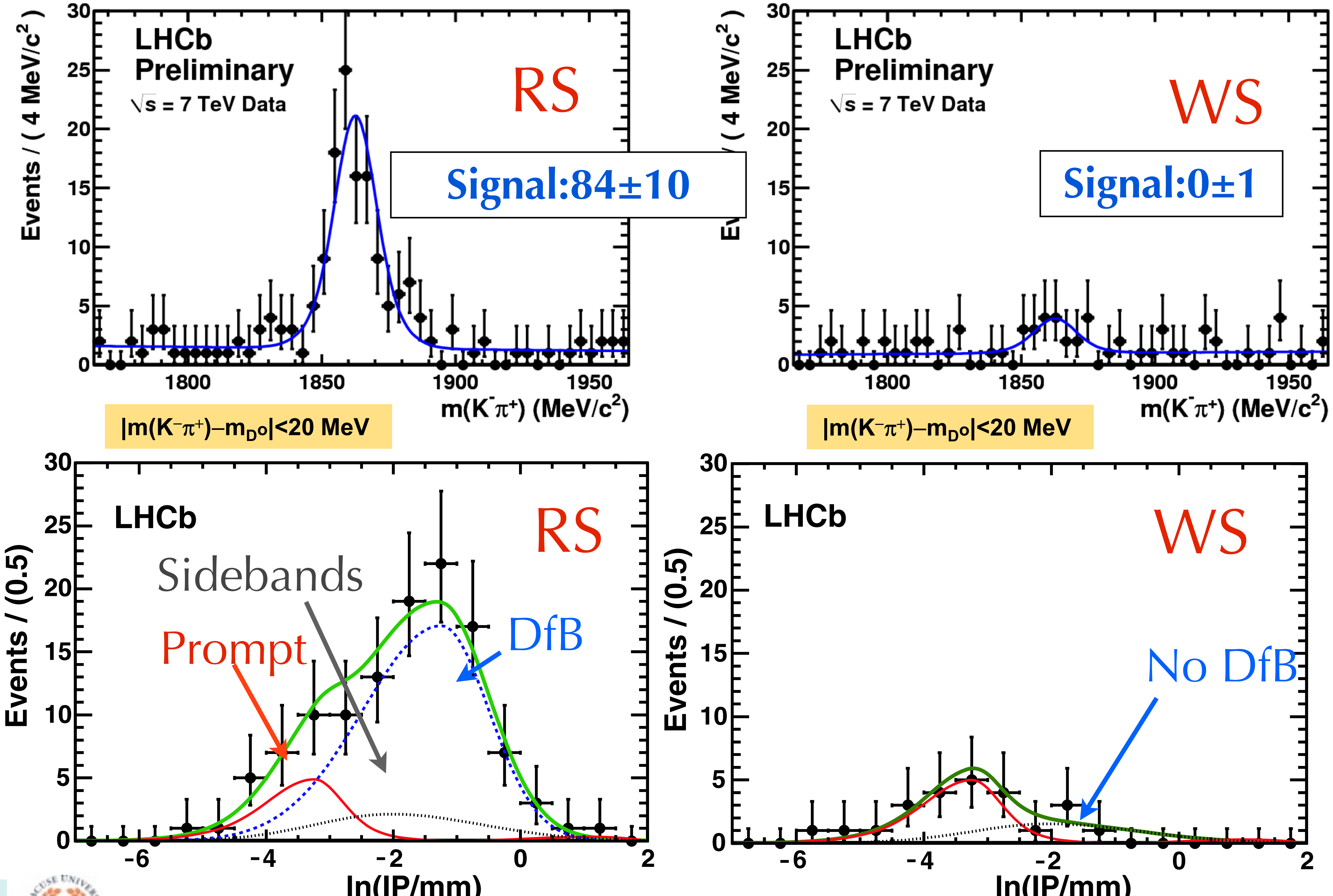
b→D⁰Xμν in η bins

- Measure η dependence in D^0 mode to compare shape with theory.



Fits to D°μ⁻ 2.9 nb^{-1}

Untriggered SampleFit results integrated $2<\eta<6$.



Hadron Fractions

- Yields must be corrected for cross feed between Bs, and Bu+Bd.

$$n_{\rm corr}(\overline{B}^0_s \to DX\mu^-\overline{\nu}) = \frac{n(D_s^+\mu^-)}{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)\epsilon(\overline{B}^0_s \to D_s^+)} + 2\frac{n(D^0K^+\mu^-\overline{\nu})}{\mathcal{B}(D^0 \to K^-\pi^+)\epsilon(\overline{B}^0_s \to D^0K^+)}$$

$$n_{\rm corr}(B \to D^0X\mu^-\overline{\nu}) = \frac{n(D^0X\mu^-\overline{\nu}) - n(D^0K^+X\mu^-\overline{\nu})\frac{\epsilon(\overline{B}^0_s \to D^0)}{\epsilon(\overline{B}^0_s \to D^0K^+)} - n(D^0p\mu^-\overline{\nu})\frac{\epsilon(\Lambda_b \to D^0)}{\epsilon(\Lambda_b \to D^0p)}}{\mathcal{B}(D^0 \to K^-\pi^+)\epsilon(B \to D^0)}$$

$$n_{\rm corr}(B \to D^+X\mu^-\overline{\nu}) = \frac{1}{\epsilon(B \to D^+)}\left[\frac{n(D^+\mu^-)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)} - \frac{n(D^0K^+\mu^-)}{\mathcal{B}(D^0 \to K^-\pi^+)}\frac{\epsilon(\overline{B}^0_s \to D^+)}{\epsilon(\overline{B}^0_s \to D^0K^+)}\right.$$

$$\left. - \frac{n(D^0p\mu^-)}{\mathcal{B}(D^0 \to K^-\pi^+)}\frac{\epsilon(\Lambda_b \to D^+)}{\epsilon(\Lambda_b \to D^0p)}\right]$$