FORWARD PRODUCTION STUDIES AT LHCb

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on behalf of the LHCb collaboration

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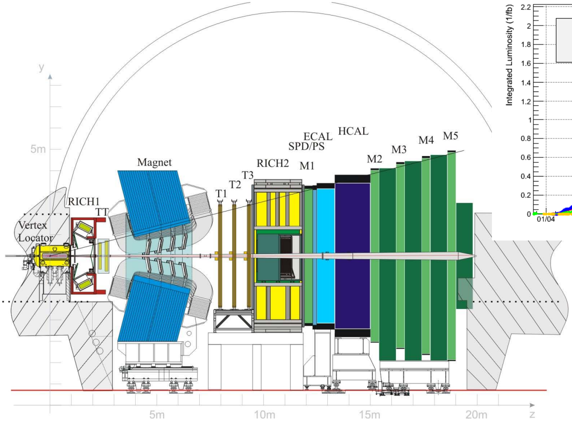
OUTLINE

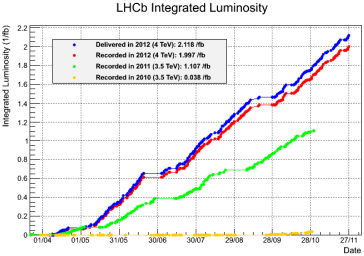
1. INTRODUCTION
2. DRELL-YAN PRODUCTION
3. $b\bar{b}$ FRAGMENTATION AND INCLUSIVE PRODUCTION
4. B HADRON PRODUCTION
5. D HADRON PRODUCTION
6. SUMMARY

LHCb

LHCb: a forward-arm spectrometer at the LHC

Optimized for heavy flavor physics in *pp* collisions.





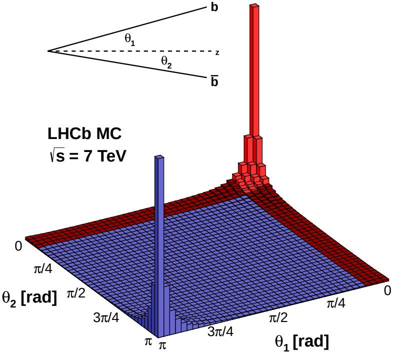
Data collection:

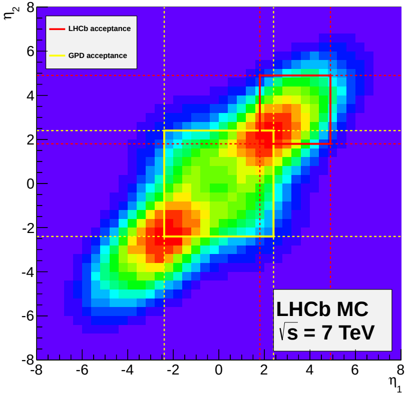
2010 38 pb^{-1} $\sqrt{s} = 7\,\text{TeV}$,
2011 1.1 fb^{-1} $\sqrt{s} = 7\,\text{TeV}$,
2012 2.0 fb^{-1} $\sqrt{s} = 8\,\text{TeV}$.

FORWARD ACCEPTANCE

Forward acceptance $2 < \eta < 5$.

Takes advantage of the predominant forward production of heavy flavored hadrons.





Pseudorapidity range unique among the LHC detectors.

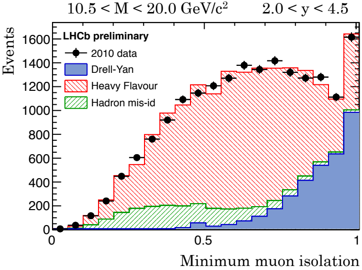
Complementary to the GPDs.

INCLUSIVE LOW MASS DRELL-YAN PRODUCTION
LHCb-CONF-2012-013

Cross-section of the Drell-Yan process $Z/\gamma^* \to \mu^+\mu^-$ for $2 < \eta < 4.5$ and $5 < M_{\mu\mu} < 120\,\mathrm{GeV}/c^2$

- Reach for low Björken x at low masses,
- Tests of QCD models at low masses.

Muon requirements: $|\vec{p^\mu}| > 10\,\mathrm{GeV}/c$, $p_{\mathrm{T}}{}^{\mu} > 3\,\mathrm{GeV}/c$, and $2 < \eta^\mu < 4.5$. For $M_{\mu\mu} > 40\,\mathrm{GeV}/c^2$ require $p_{\mathrm{T}}{}^{\mu} > 15\,\mathrm{GeV}/c$.



Efficiencies determined in data.

For each muon, define isolation as

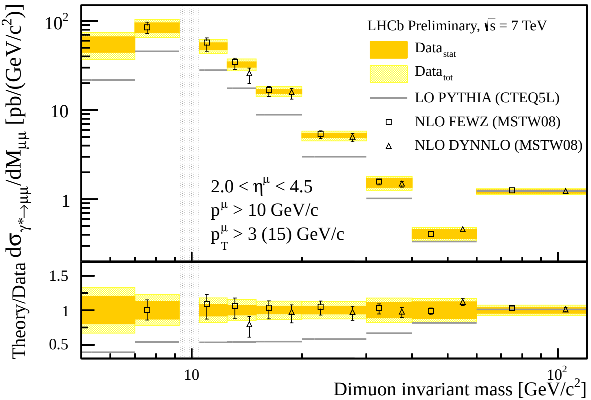
$$\mathrm{Iso} = p_{\mathrm{T}}{}^{\mu} / p_{\mathrm{T}}{}^{\mathrm{Jet}},$$

the fraction of the transverse momentum of the muon jet carried by the muon.

Signal yields determined with a fit to MinIso, the minimum of the two Iso values.

DIFFERENTIAL CROSS-SECTION: $d\sigma/dM_{\mu\mu}$

LHCb-CONF-2012-013



See LHCb-CONF-2012-013 for MC configuration details

FEWZ (Comput. Phys. Commun. 182 (2011) 2388)
MSTW08 (Eur. Phys. J. C63 (2009) 189)

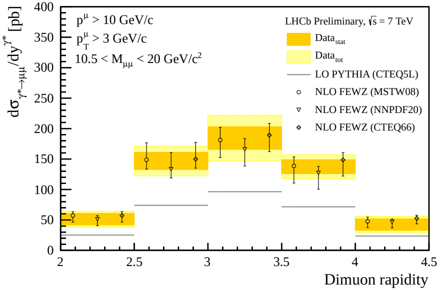
Mass region around Υ resonances excluded

Integrated luminosity of $37\,\mathrm{pb}^{-1}$ at pp $\sqrt{s} = 7\,\mathrm{TeV}$

DIFFERENTIAL CROSS-SECTION: $d\sigma/dy$

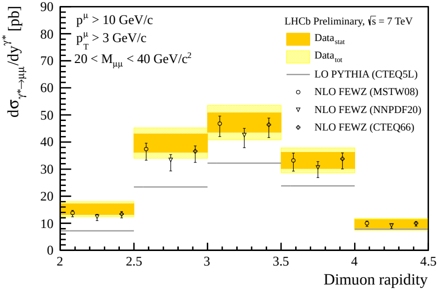
LHCb-CONF-2012-013

$d\sigma/dy$ determined for two mass ranges



$10.5 < M_{\mu\mu} < 20\,\mathrm{GeV}/c^2$

$20 < M_{\mu\mu} < 40\,\mathrm{GeV}/c^2$



FROM INCLUSIVE $b\bar{b}$ TO HADRON CROSS-SECTIONS

Two LHCb measurements of the inclusive $b\bar{b}$ production cross-section for pp $\sqrt{s} = 7\,\mathrm{TeV}$ (extrapolated to 4π)

- Using $b \to D\mu\nu X$ with $14.9\,\mathrm{nb}^{-1}$ (Phys. Lett. B694 (2010) 209-216)
  $\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\,\mu\mathrm{b}$
- Using detached J/ψ with $5.2\,\mathrm{pb}^{-1}$ (Eur. Phys. J. C 71 (2011) 1645)
  $\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\,\mu\mathrm{b}$

Related to production cross-sections of specific b-hadron species by fragmentation functions

- Here we use $f_q \equiv \mathcal{B}(b \to B_q)$, $f_{\Lambda_b^0} \equiv \mathcal{B}(b \to \Lambda_b^0)$,
- In principle, can depend on $\sqrt{s}$ and location in b phase space.

Necessary for normalization of B_s^0 and Λ_b^0 branching ratio measurements at LHC

- Also useful for sensitivity and background studies.

Two recent measurements of fragmentation function ratios at LHCb.

f_s/f_d WITH $B \to Dh$

PHYS. REV. LETT. 107 (2011) 211801

Three decay modes for two determinations of f_s/f_d:

$$B^0 \to D^- K^+, \qquad B^0 \to D^- \pi^+, \qquad B_s^0 \to D_s^- \pi^+.$$

Using theoretical expressions for the branching fractions, the ratio from $B_s^0 \to D_s^- \pi^+$ and $B^0 \to D^- K^+$ is

$$\frac{f_s}{f_d} = 0.971 \left| \frac{V_{us}}{V_{ud}} \right|^2 \left(\frac{f_K}{f_\pi} \right)^2 \frac{\tau_{B^0}}{\tau_{B_s^0}} \frac{1}{\mathcal{N}_a \mathcal{N}_F} \left(\frac{\epsilon(D^- K^+)}{\epsilon(D_s^- \pi^+)} \frac{N(D_s^- \pi^+)}{N(D^- K^+)} \right)$$

and that from $B_s^0 \to D_s^- \pi^+$ and $B^0 \to D^- \pi^+$ is

$$\frac{f_s}{f_d} = 0.982 \frac{\tau_{B^0}}{\tau_{B_s^0}} \frac{1}{\mathcal{N}_a \mathcal{N}_F \mathcal{N}_E} \left(\frac{\epsilon(D^- \pi^+)}{\epsilon(D_s^- \pi^+)} \frac{N(D_s^- \pi^+)}{N(D^- \pi^+)} \right)$$

$N(X)$ and $\epsilon(X)$ are the experimental yields and efficiencies, $\mathcal{N}_a$ parameterizes nonfactorizable SU(3)-breaking, $\mathcal{N}_F$ is the ratio of form factors, and $\mathcal{N}_E$ accounts for the W-exchange diagram in $B^0 \to D^- \pi^+$.

f_s/f_d WITH $B \to Dh$

PHYS. REV. LETT. 107 (2011) 211801

Result from $B_s^0 \to D_s^- \pi^+$ and $B^0 \to D^- K^+$

$$\frac{f_s}{f_d} = (0.310 \pm 0.030(\text{stat}) \pm 0.021(\text{syst}))\frac{1}{\mathcal{N}_a \mathcal{N}_F}$$

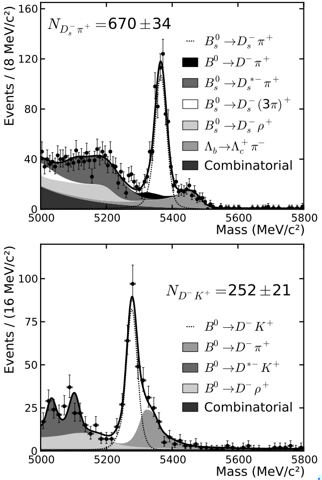
and that from $B_s^0 \to D_s^- \pi^+$ and $B^0 \to D^- \pi^+$ is

$$\frac{f_s}{f_d} = (0.307 \pm 0.017(\text{stat}) \pm 0.023(\text{syst}))\frac{1}{\mathcal{N}_a \mathcal{N}_F \mathcal{N}_E}$$

Combining the two with substituted theory parameters

$$\frac{f_s}{f_d} = 0.253 \pm 0.017(\text{stat}) \pm 0.017(\text{syst}) \pm 0.020(\text{theor})$$

$B_s^0 \to D_s^- \pi^+$



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

$f_{s(\Lambda_b^0)}/(f_u + f_d)$ WITH SEMILEPTONIC DECAYS

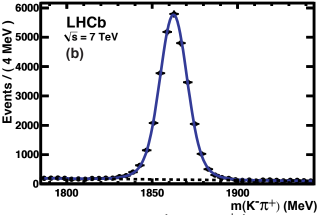
PHYS. REV. D 85 (2012) 032008

Attempt to reduce theoretical input by analyzing the abundances of the products of semileptonic b-hadron decays.

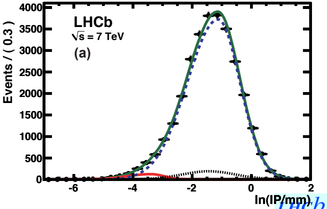
Six inclusive final states

- $\Lambda_c^+ \mu^+ \nu X$ and $D^0 p \mu^+ \nu X$ to determine abundance of Λ_b^0, $n_{\rm corr}(\Lambda_b^0 \to D\mu)$,
- $D_s^- \mu^+ \nu X$ and $\bar{D}^0 K^- \mu^+ \nu X$ to determine abundance of B_s^0, $n_{\rm corr}(B_s^0 \to D\mu)$,
- $\bar{D}^0 \mu^+ \nu X$ and $D^- \mu^+ \nu X$ with corrections from the other final states to determine the combined abundance of B^0 and B^+, $n_{\rm corr}(B^0 \to D\mu) + n_{\rm corr}(B^+ \to D\mu)$.

b-hadron semileptonic decays separated from prompt D production with characteristic distribution of D impact parameter.



Mass $m(K^-\pi^+)$



$\log(IP/\,\mathrm{mm})$

$f_{s(\Lambda_b^0)}/(f_u + f_d)$ WITH SEMILEPTONIC DECAYS

PHYS. REV. D 85 (2012) 032008

From these,

$$\frac{f_s}{f_u + f_d} = \frac{n_{\mathrm{corr}}(B_s^0 \to D\mu)}{n_{\mathrm{corr}}(B^0 \to D\mu) + n_{\mathrm{corr}}(B^+ \to D\mu)} \frac{\tau_{B^+} + \tau_{B^0}}{2\tau_{B_s^0}}$$

and

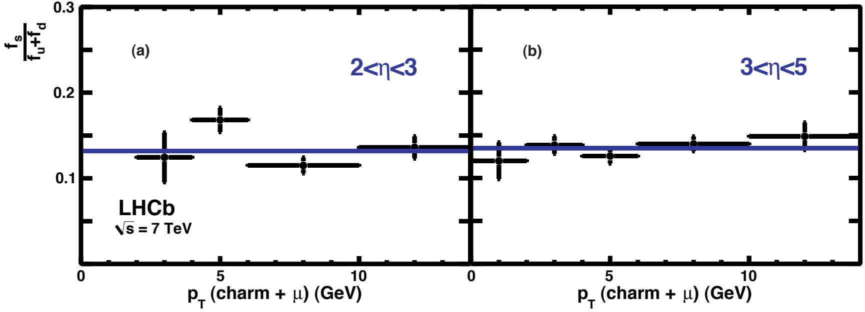
$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = \frac{n_{\mathrm{corr}}(\Lambda_b^0 \to D\mu)}{n_{\mathrm{corr}}(B^0 \to D\mu) + n_{\mathrm{corr}}(B^+ \to D\mu)} \frac{\tau_{B^+} + \tau_{B^0}}{2\tau_{\Lambda_b^0}}(1 - \xi)$$

where the factor ξ accounts for the chromomagnetic correction that affects b mesons but not b baryons.

Analyzed as a function of $D\mu$ p_{T} in two bins of $D\mu$ η to investigate variations in phase space.

$f_s/(f_u + f_d)$ WITH SEMILEPTONIC DECAYS

PHYS. REV. D 85 (2012) 032008



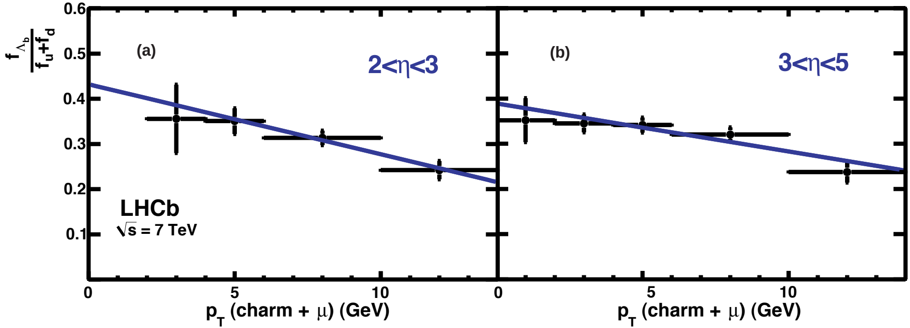
No sign of p_{T} dependence for $f_s/f_u + f_d$

Constant fit to all data gives

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

$f_{\Lambda_b^0}/(f_u + f_d)$ WITH SEMILEPTONIC DECAYS

PHYS. REV. D 85 (2012) 032008



Apparent p_{T} dependence for $f_{\Lambda_b^0}/f_u + f_d$.

Expressing the result as a best-fit linear function of p_{T}:

$$\left[f_{\Lambda_b^0}/(f_u + f_d)\right](p_{\mathrm{T}}) = a \times [1 - b \times p_{\mathrm{T}}],$$

$$a = 0.404 \pm 0.017(\mathrm{stat}) \pm 0.027(\mathrm{syst}) \pm 0.105(\mathrm{BF}) \qquad (1)$$

$$b = 0.031 \pm 0.004 \pm 0.003\,\mathrm{GeV}^{-1}$$

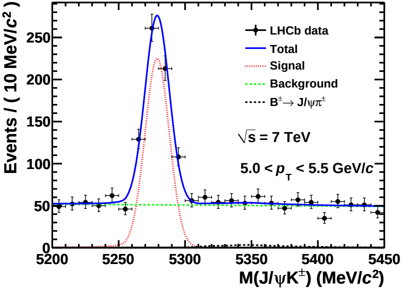
$B^{\pm}$ PRODUCTION CROSS-SECTION

JHEP 04 (2012) 039

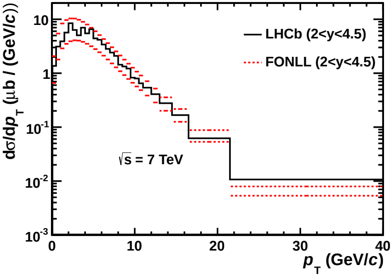
Measured in the mode $B^{\pm} \to J/\psi K^{\pm}$

- $\sim$9100 signal events in $35\,\mathrm{pb}^{-1}$ $\sqrt{s} = 7\,\mathrm{TeV}$ data,

Total cross-section and $\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}$



Mass distribution for bin $5 < p_{\mathrm{T}} < 5.5\,\mathrm{GeV}/c$



Differential $\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}$ compared to FONLL predictions (JHEP 03 (2001) 006),

- $f_{\bar{b}\to B^{+}} = (40.1 \pm 1.3)\%$.

$\sigma(pp \to B^{\pm}X) = 41.4 \pm 1.5(\mathrm{stat}) \pm 3.1(\mathrm{syst})\,\mu\mathrm{b}$ for $0 < p_{\mathrm{T}} < 40\,\mathrm{GeV}/c$, $2 < y < 4.5$.

$B_c^{\pm}$ PRODUCTION CROSS-SECTION

ARXIV:1209.5634, SUBMITTED TO PHYS. REV. LETT.

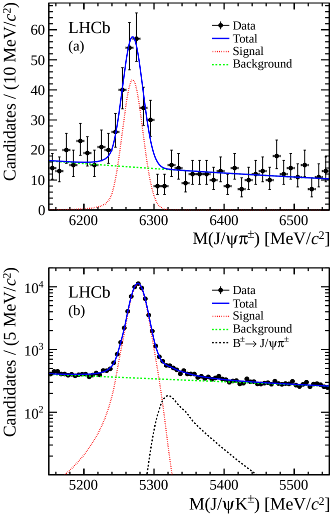
$B_c^{\pm} \to J/\psi\,\pi^{\pm}$ production at $\sqrt{s} = 7\,\mathrm{TeV}$,

- 162 ± 18 signal in $370\,\mathrm{pb}^{-1}$,
- Measurement range: $p_{\mathrm{T}} > 4\,\mathrm{GeV}/c$, $2.5 < \eta < 4.5$

$$R_{c/u} = \frac{\sigma(B_c^+)\mathcal{B}(B_c^+ \to J/\psi\,\pi^+)}{\sigma(B^+)\mathcal{B}(B^+ \to J/\psi\,K^+)}$$
$$= (0.68 \pm 0.10(\mathrm{stat}) \pm 0.03(\mathrm{syst}) \pm 0.05(\mathrm{lifetime}))\%$$

Measurement includes the most precise measurement of $M(B_c^+)$

$$M(B_c^+) = 6273.7 \pm 1.3(\mathrm{stat}) \pm 1.6(\mathrm{syst})\,\mathrm{MeV}/c^2$$
$$M(B_c^+) - M(B^+) = 994.6 \pm 1.3(\mathrm{stat}) \pm 0.06(\mathrm{syst})\,\mathrm{MeV}/c^2$$



Λ_b^0 PRODUCTION CROSS-SECTION
LHCb-CONF-2012-031

$\Lambda_b^0 \to J/\psi\,\Lambda$ production at $\sqrt{s} = 7\,\text{TeV}$,

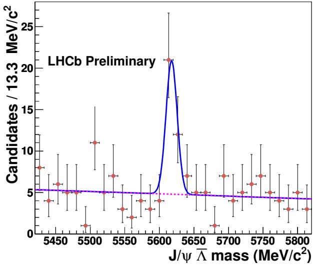
- Measurement range: $p_{\text{T}} > 13\,\text{GeV}/c$, $2.2 < \eta < 4.5$,
- 2010 data, $36\,\text{pb}^{-1}$

Analyzed in eight subsets divided by

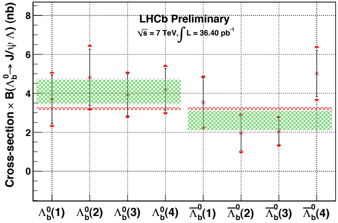
- Λ_b^0 and $\overline{\Lambda}_b^0$
- Magnet polarity,
- Whether the Λ decays in the VELO,

Cross-section of conjugates measured separately

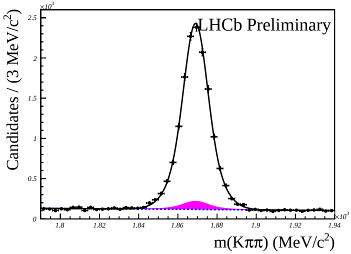
$$\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda) = 4.19 \pm 0.61(\text{stat}) \pm 0.37(\text{syst})\,\text{nb}$$
$$\sigma(\overline{\Lambda}_b^0)\mathcal{B}(\overline{\Lambda}_b^0 \to J/\psi\,\overline{\Lambda}) = 2.63 \pm 0.48(\text{stat}) \pm 0.27(\text{syst})\,\text{nb}$$

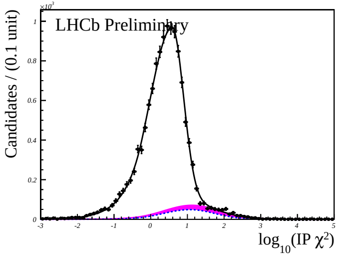


One of eight subsamples



OPEN CHARM PRODUCTION CROSS-SECTIONS
LHCb-PAPER-2012-041 NEW!





Supercedes LHCb-CONF-2010-013.

Suite of open charm cross-sections

- $D^0 \to K^-\pi^+$
- $D^{*+} \to D^0\pi^+$
- $D^+ \to K^-\pi^+\pi^+$
- $D_s^+ \to \phi(K^-K^+)\pi^+$
- $\Lambda_c^+ \to p^+K^-\pi^+$

Binned in p_{T} and y, differential $\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}$

- $p_{\mathrm{T}} < 8\,\mathrm{GeV}/c$, $2 < y < 4.5$,
- $15\,\mathrm{nb}^{-1}$ of 2010 data

Measure prompt production

- Production from *b*-hadron decays isolated with $IP\chi^2$ distribution.

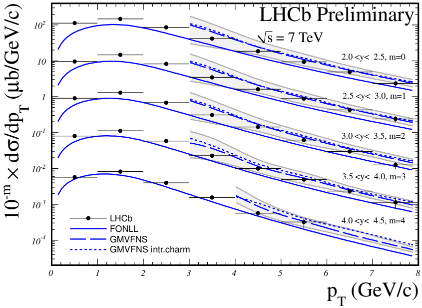
Includes measurements of

- Differential cross-sections,
- Charm species production ratios,
- Total $c\bar{c}$ cross-section.

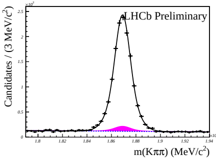
DIFFERENTIAL CROSS-SECTIONS: D^0 AND D^+

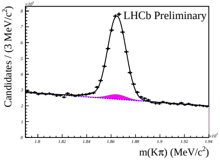
LHCb-PAPER-2012-041 NEW!

$d\sigma/dp_T$ compared to predictions from FONLL and GMVFNS

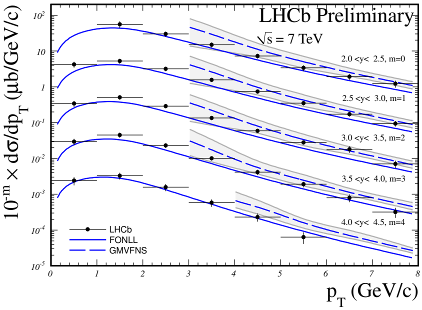


D^+ from
$D^+ \to K^-\pi^+\pi^+$





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

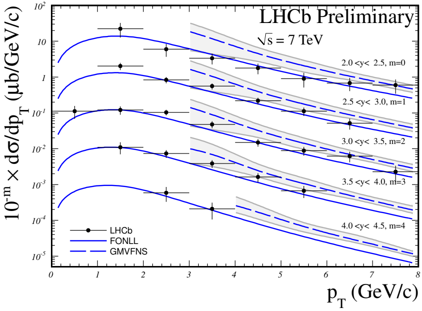


FONLL: Fixed-Order-Next-to-Leading-Logarithm, JHEP 1210 (2012) 137
GMVFNS: Generalized Mass Variable Flavour Number Scheme, Eur.Phys.J.C72 (2012) 2082

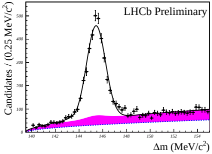
DIFFERENTIAL CROSS-SECTIONS: D_s^+ AND D^{*+}

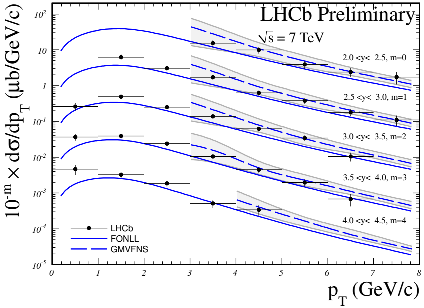
LHCb-PAPER-2012-041 NEW!

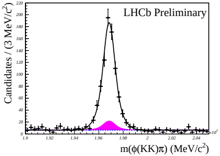
$\mathrm{d}\sigma/\mathrm{d}p_\mathrm{T}$ compared to predictions from FONLL and GMVFNS



D^{*+} from $D^{*+} \to D^0\pi^+$





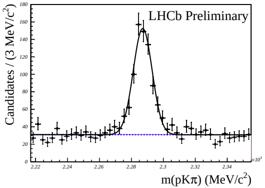


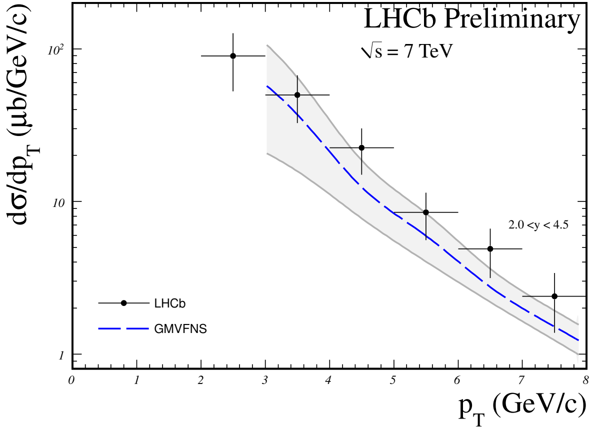
D_s^+ from $D_s^+ \to \phi(K^-K^+)\pi^+$

DIFFERENTIAL CROSS-SECTIONS: $\Lambda_c^+ \to p^+ K^- \pi^+$

LHCb-PAPER-2012-041 NEW!

$d\sigma/dp_T$ compared to predictions from GMVFNS





SUMMARY

LHCb making precise measurements of forward production at $\sqrt{s} = 7\,\mathrm{TeV}$, including

- Drell-Yan $Z/\gamma^* \to \mu^+\mu^-$ cross-section differential in mass and rapidity,
- Inclusive $b\overline{b}$ cross-section and form factor ratios,
- Production cross-sections of ground state b and c hadrons.

Related results appearing in talk by Vanya Belyaev tomorrow:

- $Z+$ jets production
- Double charm production

Related results not presented in this workshop

- $D_s^{\pm}$ production asymmetry (Phys. Lett. B 713 (2012), 186),
- $D^{\pm}$ production asymmetry (LHCB-PAPER-2012-026, accepted by Phys. Lett. B),

Most of these results will be repeated with the $\sqrt{s} = 8\,\mathrm{TeV}$ data collected in 2012.