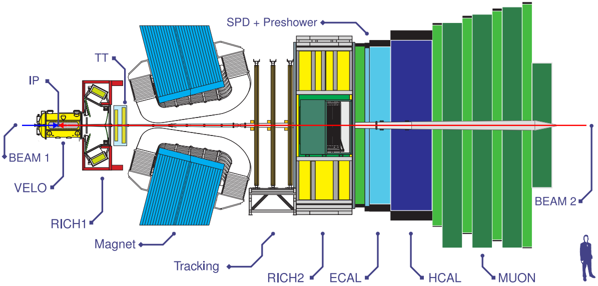
Charmonium and Heavy Flavour at LHCb

C. Fitzpatrick (University of Edinburgh)
on behalf of the LHCb collaboration

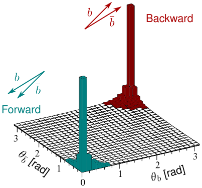
Heavy Quarks & Leptons X
INFN Frascati

Outline

The LHCb Experiment



- LHCb is a precision b,c-physics experiment
- We aim to measure CP violation in a number of modes requiring:
  - Precise vertexing (VELO)
  - Particle ID (RICH)
- LHCb is fully instrumented on $15 < \Theta < 300$ mrad
  - high sensitivity in a unique region of phase space

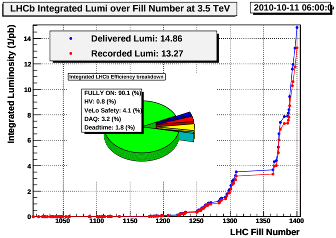


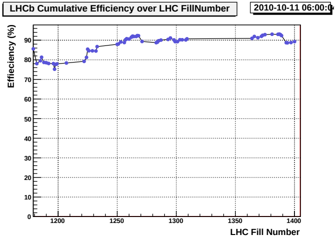
- Single-arm spectrometer to take advantage of correlated forward b,$\bar{\mathrm{b}}$-quark production at LHC

C. Fitzpatrick

October 11, 2010

LHCb Performance





- LHCb is operating with high efficiency: 90% of collisions supplied are recorded, with 13.3 pb^{-1} on disk
  - VELO moves from 58 mm to within 8 mm of the beam at start of collisions
  - procedure takes only $\simeq 3$ minutes, limited by mechanical operation

- All subdetectors performing within expectation ($\gg$ 98% channel efficiency)
- A real pleasure to operate! Only requires two shifters to run (Shift leader + Data Manager)

C. Fitzpatrick

October 11, 2010

$c\bar{c}$ and Heavy Flavor at LHCb

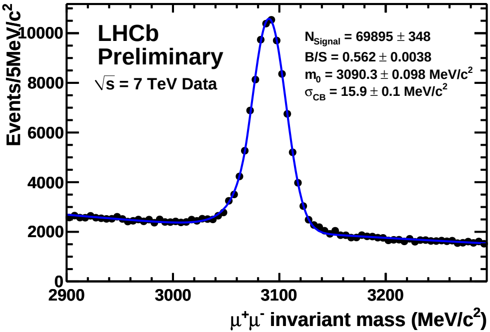
- b and c are the essence of the LHCb physics program (See talks by R. Lambert, N. Tuning, J. Blouw)
- with early data we can explore b and c production which are themselves interesting as:
  - Test of NRQCD predictions for prompt onia production
  - Confirmation and measurement of higher charmonia states
  - Measurement of fragmentation fractions for comparison to LEP and Tevatron results
  - Future LHCb analyses will rely on knowing $\sigma(pp \to b\bar{b}X)$
  - Tuning of generators at this energy regime
- LHCb is in a unique position to measure b and c hadron production at large rapidities
- This talk will present the measurements to date and future plans

C. Fitzpatrick

October 11, 2010

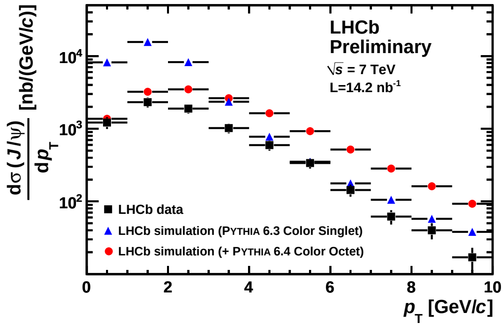
$J/\psi(1S)$

$J/\psi(1S) \rightarrow \mu^- \mu^+$ with 250 nb^{-1}



- $J/\psi(1S)$ cross-section measurements are of particular interest at LHC, with all 4 experiments presenting results
  - $J/\psi(1S)$ cross-sections measured at the Tevatron did not agree well with color singlet
  - LHC presents a new opportunity to compare to Tevatron results and the octet model
- Sources of $J/\psi(1S)$ at LHC:
  - Direct pp production
  - Feed-down from heavier charmonia ($\chi_c \rightarrow J/\psi(1S)\gamma$, $\psi(2S) \rightarrow J/\psi(1S)\pi\pi$)
  - From b hadrons ($B \rightarrow J/\psi(1S)X$)
- At ICHEP the inclusive cross-section was presented in bins of p_T with 14 nb^{-1}

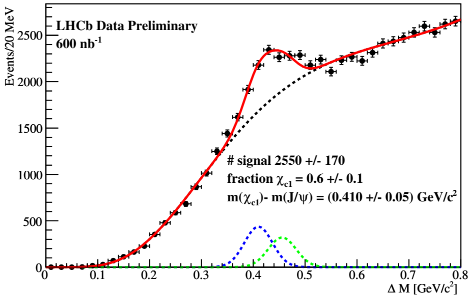
$J/\psi(1S)$



- The cross-section is presented on the range $0 \rightarrow 10$ GeV/c
  - There is an efficiency dependence on the polarisation, to which we presently assign a conservative systematic error
  - This will be measured with a larger dataset
- $\sigma(\mathrm{pp} \rightarrow J/\psi(1S)X) = \left(7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\right)$ μb ($p_T < 10$ GeV/c, $2.5 < y < 4$)
- $J/\psi(1S)$ measurement seems to favour neither color singlet or octet models

χ_c

$\chi_c \to J/\psi(1S)\gamma$, 600nb^{-1}



- Already seeing χ_c with sensitivity to $\chi_{c1}(1P)$ and $\chi_{c2}(1P)$ (30 MeV/c^2resolution, fixed)
- The ratio of $\sigma(\chi_c)/\sigma(J/\psi(1S))$ is interesting:
  - Our MC predicts $\approx$ 40% $J/\psi(1S)$ from χ_c
  - This needs to be measured to properly interpret the inclusive $J/\psi(1S)$ cross-section
- We intend to measure cross-sections in p_T as per $J/\psi(1S)$
- as well as measuring $\sigma(\chi_c)/\sigma(J/\psi(1S))$, $\sigma(\chi_{c1}(1P))/\sigma(\chi_c)$ and $\sigma(\chi_{c2}(1P))/\sigma(\chi_c)$ for both prompt χ_c and χ_c from b quarks

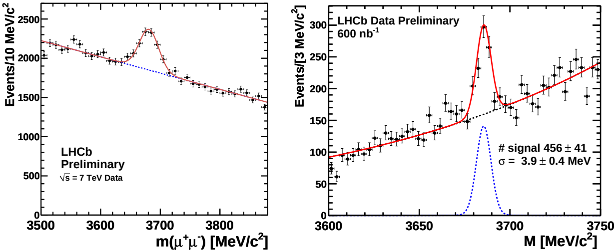
C. Fitzpatrick

October 11, 2010

$\psi(2S)$

600 nb^{-1}

$\psi(2S) \to \mu^-\mu^+$ $\qquad$ $\psi(2S) \to J/\psi(1S)\pi^+\pi^-$



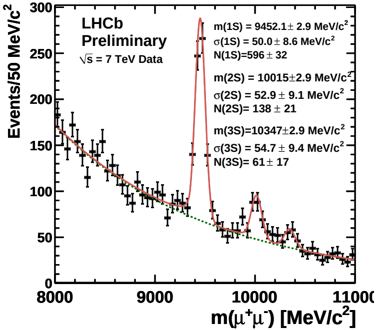
- Two modes under investigation at LHCb: $\psi(2S) \to \mu^-\mu^+$ and $\psi(2S) \to J/\psi(1S)\pi^+\pi^-$
- $\psi(2S)$ has essentially no feed-down from higher quarkonia states, so the production cross-section is easier to interpret than $J/\psi(1S)$
- When we have enough statistics production cross-sections in p_T will be presented for both prompt and $\psi(2S)$ from b quarks

Heavier charmonia

- $\mathrm{X}(3872)$:
  - Presently we are looking for $\mathrm{X}(3872) \to \mathrm{J}/\psi(1\mathrm{S})\pi^{+}\pi^{-}$ using $\psi(2\mathrm{S})$ as a cross-check
  - Extrapolating backgrounds from the $\psi(2\mathrm{S})$ plot shown earlier it is clear we will benefit from focusing on $\mathrm{X}(3872)$ from B
    - Separating the $\mathrm{X}(3872)$ from the primary vertex greatly reduces combinatoric background
  - This analysis is in the early stages: a mass measurement with 50pb^{-1}this year is looking promising
  - With a much larger dataset angular analysis of $\mathrm{B}^{+} \to \mathrm{X}(3872)\{\mathrm{J}/\psi(1\mathrm{S})\rho^{0}\}\mathrm{K}^{+}$ should be possible
- $Z(4430)^{\pm}$:
  - We intend also to look for $\mathrm{B}^{0} \to Z(4430)^{\pm}\mathrm{K}^{\mp}$
  - So far sensitivity studies at $\sqrt{s} = 14$ TeV predict 6200 events in 2 fb^{-1}with 2.7<B/S<5.3
- See CERN-THESIS-2009-129 and LHCb-PUB-2010-003 for more details

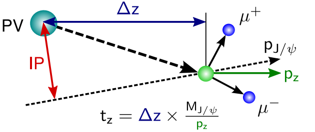
ϒ

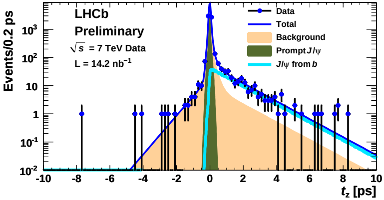
600 nb^{-1}



- ≈ 50 MeV/c^2 mass resolution!
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ well separated
- Expect a $\Upsilon(1S)$ cross-section in p_T and a few y bins by the winter conferences

B from $J/\psi(1S)$ X

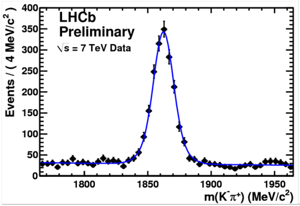




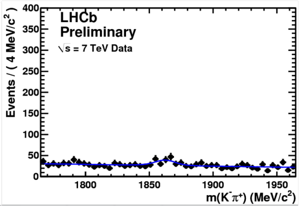
- The LHCb $J/\psi(1S)$ analysis uses the pseudo-propertime distribution (t_z) to separate prompt and "from b " components in a simultaneous fit to t_z and the $\mu^-\ \mu^+$ invariant mass
- The fraction of inclusive $J/\psi(1S)$ from b in the $J/\psi(1S)$ analysis acceptance is $f_b = 11.1 \pm 0.8\%$
- $\sigma(J/\psi(1S) \text{ from b}) = (0.81 \pm 0.06 \pm 0.13)$ µb ($p_T < 10$ GeV/c, $2 < y < 4.5$)
- This is extrapolated to a b hadron cross-section on $2 < \eta < 6$ and a total $b\bar{b}$ cross-section using the LEP hadronisation fractions and MC (Pythia 6.4) to determine the acceptance:
  - $\sigma(pp \to H_b X) = (84.5 \pm 6.3 \pm 15.6)$ µb ($2 < \eta < 6$)
  - $\sigma(pp \to b\bar{b}X) = (319 \pm 24 \pm 59)$ µb

B from $D^0 X \mu^- \nu_\mu$

Right Sign $D^0\ \mu^-$



Wrong sign $D^0\ \mu^+$



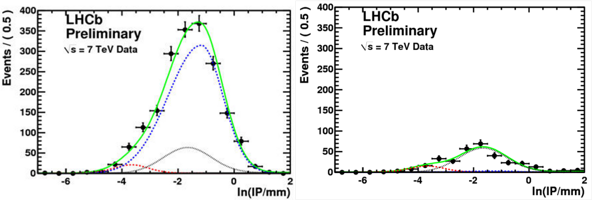
- The first b cross-section published at $\sqrt{s} = 7$ TeV (arXiv:1009.2731v1)
- $D^0\ \mu^-$ + h.c. reconstructed (right sign) and compared to $D^0\ \mu^+$ + h.c. (wrong sign) for background determination (Above: With 100 nb^{-1})
- For the publication, two datasets used:
  - "microbias" requiring at least one track in the VELO or tracking stations: 2.9 nb^{-1}
  - "muon triggered" requiring one identified muon per event: 12.2 nb^{-1}
  - These results are then averaged

C. Fitzpatrick

October 11, 2010

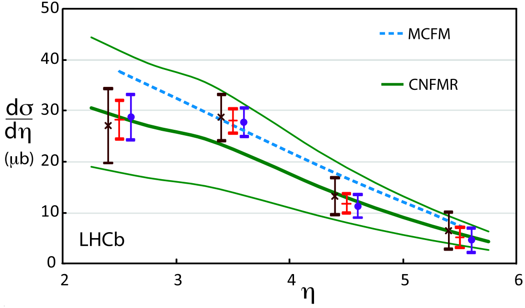
B from $D^0 X \mu^- \nu_\mu$

Right Sign $D^0\ \mu^-$ Wrong sign $D^0\ \mu^+$



- To separate prompt D^0 and D^0 from b, this analysis fits to the ln(IP) distribution
  - Prompt candidates (red) have a smaller IP than those from b (blue)
  - The prompt yield is consistent between right-sign and wrong-sign distributions
- The yield of D^0 from b is determined in bins of $2 < \eta < 6$ using a simultaneous 2D fit to the D^0 mass and ln(IP) distributions

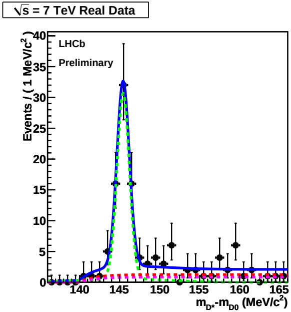
B from $D^0X\mu^-\nu_\mu$



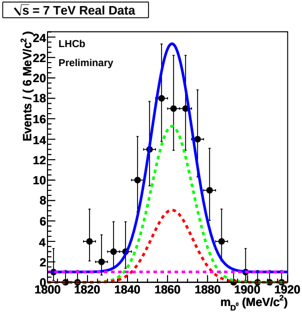
- $\sigma(pp \to b\bar{b}X)$ for microbias, muon triggered and averaged compared to two theory predictions:
  - MCFM: NLO using MSTW8NL
  - CNFMR: NNLO using CTEQ6.5 including b and $\bar{b}$ fragmentation into hadrons
- $\sigma(pp \to H_bX) = (75.3 \pm 5.4 \pm 13.0)$ μb $(2 < \eta < 6)$
- Again extrapolated using MC and the LEP hadronisation fractions:
- $\sigma(pp \to b\bar{b}X) = (284 \pm 20 \pm 49)$ μb
  - Excellent agreement between datasets and theory!
  - previously published sensitivity studies assumed 250 μb

B from $D^* \mu^- \nu_\mu$ X

$\Delta M(D^* - D^0)$



D^0



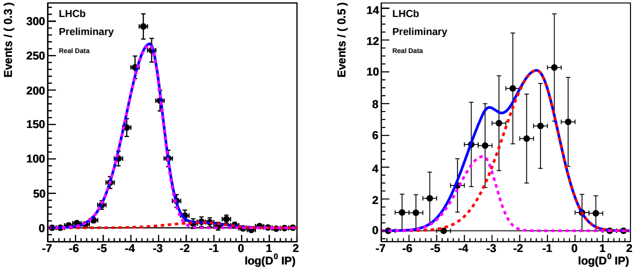
- Using 14.9nb^{-1} an independent analysis has been performed selecting $B^0 \rightarrow D^* \mu^- \nu_\mu X$
- $D^* \mu^-$ Yields determined from simultaneous fit to $M(K^+\pi^-)$ (right) and $\Delta M = M(K^+\pi^-\pi^-) - M(K^+\pi^-)$ (left)

C. Fitzpatrick

October 11, 2010

B from $D^* \mu^- \nu_\mu X$

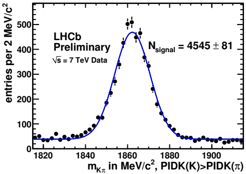
D^* incl. $\qquad$ $D^* \mu^- \nu_\mu X$



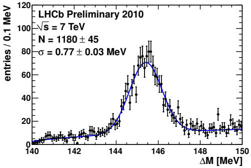
- The D^0 log(IP) distribution is again used to determine the yield of $D^* \mu^- \nu_\mu X$ from b (right)
- In this analysis the prompt component is fixed using an inclusive D^* selection to boost statistics (left)
- $\sigma(pp \to B^0 X) = (73 \pm 12 \pm 17)$ μb $(2 < \eta < 6)$
- $\sigma(pp \to b\bar{b} X) = (275 \pm 44 \pm 66)$ μb

Open Charm

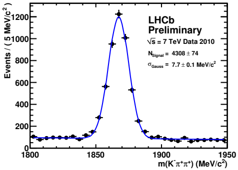
$D^0 \to K^-\pi^+$



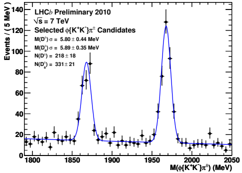
$D^{*+} \to D^0\pi^+$



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



$D^+_s \to \phi\{K^+K^-\}\pi^+$



- Open charm production cross-sections at $\sqrt{s} = 7$ TeV in bins of $0 < p_T < 8$ GeV$/c$, $2 < y < 5$.
- The analysis strategies for the 4 measurements are independent, and results are cross-checked:
  - D^0 cross section consistent with the D^0 yield from D^* analysis
  - D^+ cross section consistent with the D^+ yield from D^+_s analysis and vice-versa

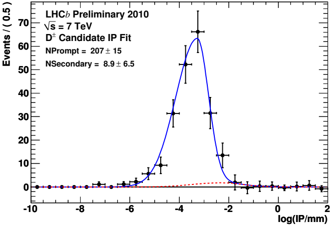
C. Fitzpatrick

October 11, 2010

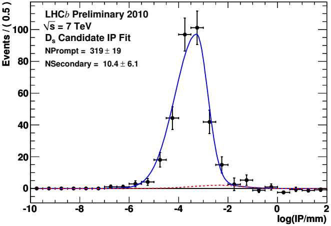
Open Charm

- As with previously presented results, we use the Impact Parameter wrt. the Primary Vertex to discriminate between prompt charm and those coming from b hadrons

D^{+}

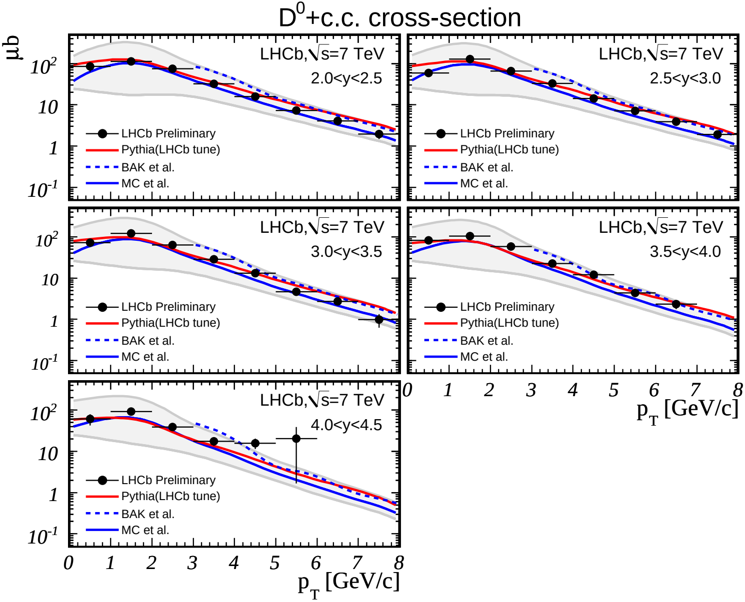


$\mathrm{D}_{\mathrm{s}}^{+}$

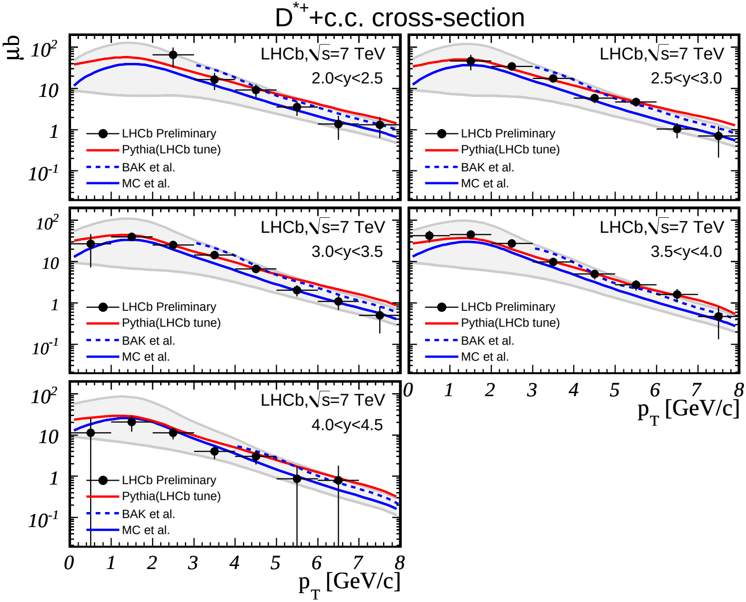


- For the $\mathrm{D}_{\mathrm{s}}^{+}$ measurement we use the sPlot technique to unfold signal/background and prompt/secondary components
  - For the other analyses these are determined from a fit in bins of p_{T},y.
- Results are compared to theory predictions from two groups
  - MC et. al: M. Cacciari, S. Frixione, M. Mangano, M. Nason, G. Ridolfi
  - BAK et. al: B. A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger

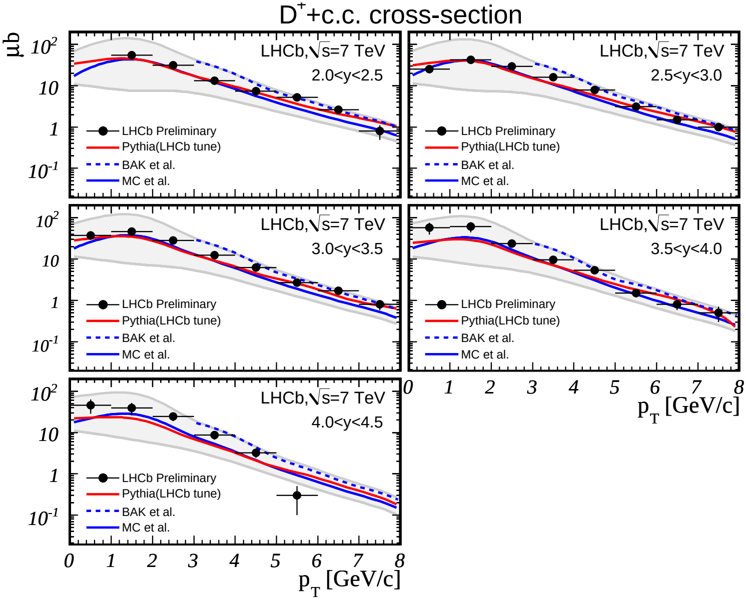
D^0 cross-section



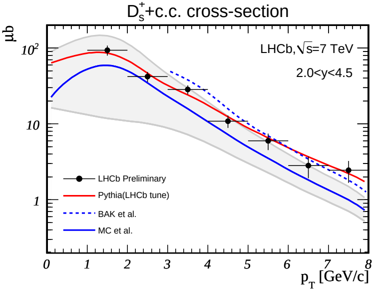
D* cross-section

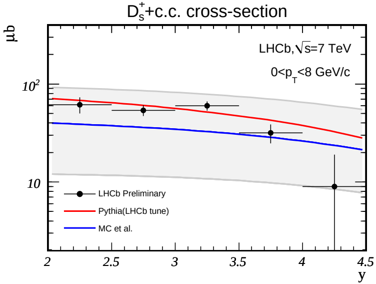


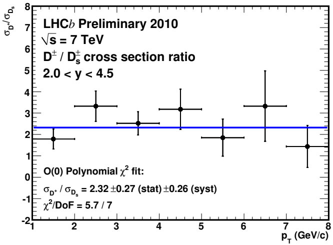
D^+ cross-section



D_s^+ cross-section







- The D_s^+ analysis also selects D^+
- This allows us to measure the ratio $\sigma_{D^+}/\sigma_{D_s^+}$
- luminosity, particle ID, tracking systematics cancel
- $\sigma_{D^+}/\sigma_{D_s^+} = 2.32 \pm 0.27 \pm 0.26$
- Result is consistent with $f(c \to D^+)/f(c \to D_s^+) = 3.08 \pm 0.70$ (PDG)

C. Fitzpatrick

October 11, 2010

Conclusions

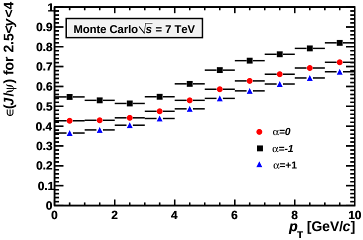
- LHCb probes a unique and unexplored domain with respect to previous experiments
- This talk has presented cross-section measurements from LHCb with the 2010 data in b and c
- $\mathrm{J}/\psi(1\mathrm{S})$ appears to favor neither the color singlet or color octet models
  - Further measurements will include polarisation and χ_{c}, $\psi(2\mathrm{S})$ cross-sections
- Three separate $\mathrm{b}\,\overline{\mathrm{b}}$ production cross sections have been measured with excellent agreement
- Open charm results show good agreement with theory predictions
- We expect to measure the $\mathrm{X}(3872)$ mass this year

C. Fitzpatrick

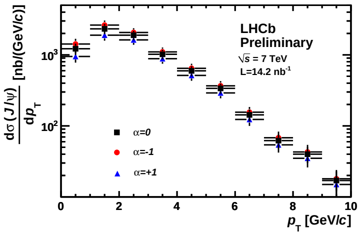
October 11, 2010

J/ψ(1S) polarisation

Total Efficiency (MC)



Cross-section measurement



- J/ψ(1S) cross-section assuming three polarisations: fully longitudinal ($\alpha = -1$), unpolarised ($\alpha = 0$), fully transverse ($\alpha = 1$)
- Ignoring the azimuthal dependence the angular distribution of the J/ψ(1S) is:

$$\frac{dN}{d\cos\theta} = \frac{1 + \alpha\cos^2\theta}{2 + 2 \times \alpha/3}$$

- θ is the angle made by the positive muon momentum in the J/ψ(1S) CM frame WRT the J/ψ(1S) momentum in the Lab frame