Open Charm and Charmonium Production: First Results from LHCb

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Outline

- Physics ambition of LHCb
- LHCb detector and performance
- Physics interests on charm
- First results on charmonium and open charm
- Summary
➢ Successful running in 2009 @ 2.36 TeV
➢ First collisions @ 7 TeV on March 30, 2010
➢ Integrated Lumi ~ 20 pb⁻¹ (20 Oct, 2010)
Physics Aims of LHCb

“dedicated to heavy flavour physics at the LHC”

• **New Physics**
  CP violation: precise measurements of CKM angles
  rare decays of beauty and charm hadrons

• **Heavy Flavour Physics**
  B production
  $B_c$, b-baryon physics
  charm decays (e.g. D-mixing)
  tau lepton flavour violation
\( \bar{b}b \) production at LHC


- \( \bar{b}b \) pair production correlated
  - \( \sigma_{\bar{b}b} \sim 300-500 \text{ } \mu\text{b} (@7-14 \text{ TeV}) \)
  - \( 15<\theta<300 \text{ mrad}, \text{ unique acceptance} \)

- \( \text{Average design Luminosity} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
  - \( 2 \text{ fb}^{-1} \text{ per nominal year (10}^7 \text{ s}, \sim 10^{12} \bar{b}b \text{ pairs per year} \)
LHCb Detector

**Tracking System**
- good tracking efficiency
- & momentum resolution

**Muon System**
- good muon-ID

**VELO**
- high position resolutions

**RICH1 & RICH2**
- Excellent PID of K-pi

**Calorimeters**
- e, γ, π^0

beam 1

beam 2

VELO

RICH1 & RICH2
LHCb Data Taking

Stable data taking with high efficiency in all subsystems
Physics Interests on Charm

1) $J/\psi$ cross-section (and polarization)
   - Production mechanism still not well understood, theoretical interests on direct $J/\psi$
   - Three main sources of $J/\psi$
     1) Direct $J/\psi$
     2) Decay from heavier charmonium
     3) Decay from $b$-hadrons
   - Fractions of heavier charmonia are helpful

2) Essentially related to many investigations of CP violation and rare decays
   (see talk of Patrick Spradlin tomorrow afternoon)

3) Understanding of charm is fundamental for later analyses
Measurement of $J/\psi$ cross section

• Cross section (both prompt $J/\psi$ and $J/\psi$ from b)

$$\sigma = \frac{N(J/\psi \rightarrow \mu^+ \mu^-)}{L \cdot \varepsilon \cdot Br(J/\psi \rightarrow \mu^+ \mu^-)}$$

$N$: Signals from reconstruction of $J/\psi \rightarrow \mu^+ \mu^-$

$$\varepsilon = \varepsilon_{\text{acc}} \times \varepsilon_{\text{rec}} \times \varepsilon_{\text{trig}}$$

• Separate “prompt $J/\psi$” from “$J/\psi$ from b” by fitting pseudo-proper time $t_z$
Measurement of $J/\psi$ cross section

$\tau_z = \frac{d_z \times M_{J/\psi}}{p_{J/\psi}}$

(for $J/\psi$ from $b$)

- good approximation of average $b$ lifetime
- well described by exponential distribution

Prompt

generator level distribution of $t_z$
Mass fit

Signal: Crystal Ball function

\[ f(m, \mu, \sigma, \alpha, n) = \begin{cases} \left( \frac{n}{|\alpha|} \right)^n e^{-\frac{1}{2} \alpha^2} \\ \frac{n}{|\alpha|} - |\alpha| - \frac{m-\mu}{\sigma} \end{cases} \]

\begin{align*}
\frac{m-\mu}{\sigma} &< -|\alpha| \\
\frac{m-\mu}{\sigma} &> -|\alpha|,
\end{align*}

Background: 1\textsuperscript{st} order polynomial

\[ \mu = (3088 \pm 0.4) \text{ MeV/c}^2 \]

\[ \sigma = (15.0 \pm 0.4) \text{ MeV/c}^2 \]

Fit results (2.5<y<4, p_T<10 GeV/c): Signal = 2872 ± 73

S/B = 1.3

L=14.2 nb\textsuperscript{-1}

LHCB Preliminary \( \sqrt{s} = 7 \text{ TeV Data} \)
$t_z$ Fit Result

1) Background from invariant mass sidebands
2) Crosscheck with a binned fit gives consistent results

Fit results:

Number of prompt $J/\psi$, $n_p : 2527 \pm 74$
Number of $J/\psi$ from $b$, $n_b : 316 \pm 24$

$\sigma$ of two Gaussian: $(111\pm13)$ fs, $(40 \pm 3)$ fs
Core resolution fraction between: $0.74 \pm 0.06$

Average $b$ lifetime $\tau_b = (1.35 \pm 0.10)$ ps

$\chi^2/\text{ndof}=1.6$
Total Efficiency and Polarization Effect

- $\varepsilon$ depends strongly on polarization
- treated as systematic error for first measurement

\[ \frac{dN}{d \cos \theta} = \frac{1 + \alpha \cos^2 \theta}{2 + 2\alpha / 3}, \]  where $\alpha = \begin{cases} +1 & \text{fully transverse} \\ 0 & \text{no polarization} \\ -1 & \text{fully longitudinal} \end{cases}$

With more statistics, a direct measurement of polarization with full angular analysis, in different reference frames and bins of $y$ and $p_T$, is foreseen.
Preliminary Results: 14.2 nb$^{-1}$

Compare to Monte-Carlo (zero-polarization)

\[
\sigma(\text{incl. } J/\psi, \ p_T < 10\text{GeV/c}, \ 2.5 < y < 4) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27} \mu b
\]

\[
\sigma(\text{ } J/\psi \text{ from } b, \ p_T < 10\text{GeV/c}, \ 2.5 < y < 4) = 0.81 \pm 0.06 \pm 0.13 \mu b
\]

Systematic errors mainly come from data/MC discrepancy. Dominant contributions from trigger and tracking efficiencies.

( see CERN-LHCb-CONF-2010-010 )
Perspectives with More Data

- Will measure also polarization
- Region of measurement \((y, p_T)\) will be extended with more data, some overlap with CMS/ATLAS

- Much more data since ICHEP
  \(O(1M)\) \(J/\psi\) for 20 pb\(^{-1}\)
χ_c \quad (L=600 \text{ nb}^{-1})

1) Already seen χ_c peak
2) With more statistics, we will measure \( \sigma(\chi_{c1} + \chi_{c2})/\sigma(J/\psi) \) separately for prompt χ_c and χ_c from b
   This will help us to interpret J/ψ cross section.

\( \chi_c \rightarrow J/\psi(\mu\mu) \gamma \)
$\psi(2S)$ (L=600 nb\(^{-1}\))

1) Well reconstructed through two decay channels
2) With more statistics, we will measure separately cross sections of prompt $\psi(2S)$ and $\psi(2S)$ from $b$, and eventually polarization, like for $J/\psi$
3) No feed-down contribution from heavier charmonia, easier to interpret
$X(3872)$  \hspace{1cm} (L=5 \text{ pb}^{-1})$

- Mass fixed to PDG value $M_X=3871.56\pm0.22 \text{ MeV}/c^2$
- $\psi(2S)$ could be used as calibration channel
- Mass measurement when O(0.1) MeV/$c^2$ statistical uncertainty is reached
- Production measurement
- $J^{PC}$ as ultimate goal
Open Charm Production

- First measurements at $\sqrt{s}=7$ TeV.
- Measure cross section versus $y$, $p_T$ in 1.8 nb$^{-1}$, with open trigger.
- Use impact parameter distributions to separate prompt D and those from b-hadrons.
- Good agreement with expectations!
Mass Peaks of Open Charm (L=1.8 nb$^{-1}$)

\[ D^0 \rightarrow K^- \pi^+ \]

\[ D^+ \rightarrow K^- \pi^+ \pi^+ \]

\[ D^*+ \rightarrow (D^0 \rightarrow K^-\pi^+)\pi^+ \]

\[ D_s \rightarrow (\phi \rightarrow K^-K^+)\pi^+ \]
Mass Peaks of Open Charm

$$\Lambda_c^+ \rightarrow pK^-\pi^+$$

LHCb Preliminary
$$\sqrt{s} = 7 \text{ TeV Data}$$

N_{Signal} = 52.7 \pm 9.3
m_0 = 2286.1 \pm 0.73 \text{ MeV}
$$\sigma_{\text{Gauss}} = 3.8 \pm 0.82 \text{ MeV}$$

- Luminosity only 0.8 nb$^{-1}$ for this plot
$D^0$ cross section ($L=1.8$ nb$^{-1}$)

$D^0$+c.c. cross-section

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

Shadow: theoretical uncertainty from MC et al.
D$^+$ cross section (L=1.8 nb$^{-1}$)
$D^{*+}$ cross section ($L=1.8\ \text{nb}^{-1}$)

$D^{*+}$+c.c. cross-section

LHCb, $\sqrt{s}=7\ \text{TeV}$

2.0\leq y\leq 2.5

2.5\leq y\leq 3.0

3.0\leq y\leq 3.5

3.5\leq y\leq 4.0

4.0\leq y\leq 4.5
$D_s$ cross section (L=1.8 nb$^{-1}$)

$\sigma(D^+)/\sigma(D_s^+)=2.32 \pm 0.27 \pm 0.26$

Consistent with PDG:
$f(c \to D^+)/f(c \to D_s^+)=3.08 \pm 0.70$
Summary

• LHCb producing physics measurements with high quality @ $\sqrt{s} = 7$ TeV

• Cross sections of prompt $J/\psi$ and $J/\psi$ from $b$ measured separately

• Cross sections of $D^0, D^*, D^+, D_s^+$ are measured, good agreement with theor. expectations

• Heavier charmonia well reconstructed and waiting for more statistics
Thank you
back up
Event Selection of $J/\psi$

Data Sample
• $(14.15 \pm 1.42) \text{ nb}^{-1}$ (low pile-up conditions)

Event selection
• 2 muons
  – with fully reconstructed tracks (VELO + Tracker)
  – identified by muon system
  – good vertex reconstructed
  – $p_T > 700 \text{ MeV/c}$
  – Mass window for signal definition: $(M_{J/\psi} \pm 390) \text{ MeV/c}^2$

• Trigger L0
  – single muon, $p_T > 480 \text{ MeV/c}$

• HLT:
  – single muon, $p_T > 1.3 \text{ GeV/c}$ OR. muon pair with $M_{\mu\mu} > 2700 \text{ MeV/c}^2$
Efficiencies: \( \varepsilon = \varepsilon_{\text{acc}} \times \varepsilon_{\text{rec}} \times \varepsilon_{\text{trig}} \)

- \(0 < P_T < 10 \text{ GeV/c} \) divided into 10 bins
- Integrate over \(2.5 < y < 4\) due to low statistics
- Plenty of cross check with data
Using log(IP) to separate direct D-meson and D meson from b

Open (microbias trigger): 2.9 nb⁻¹
Data Set of $J/\psi \pi \pi$ (1)

**Data**
- 600 nb$^{-1}$ from stripping 7, di-muon strip
- Tracks refitted with alignment v4.1

**$J/\psi$ selection**
- Loose $J/\psi$ candidates from the DST, TOS
- Muon cuts $\chi^2$/dof $< 4$, $pt > 700$ MeV, $8 < p < 500$ GeV
- $pt > 2$ GeV
- $|dM(J/\psi)| < 50$ MeV

**Global event cuts**
- $< 10000$ OT hit, $< 3000$ IT hits
Data Set of J/ψπππ (2)

π pair selection

- Pion pair selection $\chi^2$/dof < 4, $pt > 300$ MeV, pidE < 0, $p < 500$ GeV
- $pt_1 + pt_2 > 800$ MeV

Candidate selection

- $Q < 300$ MeV
- Refit with J/ψ mass constraint (DecayTreeFitter), require $\chi^2$/dof < 8

Quite similar to selection of Stefano

- Mass constrained fit
- Use of electron veto
- Tighter cut on pt sum, no cut on product of pts
Selections of D₀ & D⁺

\[ \text{D}^0 \rightarrow \text{K}^- \pi^+ \text{ and } \text{D}^{*+} \rightarrow (\text{D}^0 \rightarrow \text{K}^-\pi^+) \pi^+ \]

- **K, π**: \( \chi^2(\text{track})/\text{DoF} < 9 \)
  \( \chi^2(\text{IP}) > 9 \)
  \( pT > 700 \text{ MeV/c} \)

- **K**: \( \Delta LL(\text{K-π}) > \pi \)
  \( \Delta LL(\text{K-π}) \)

- **D₀**: \( \chi^2(\text{vertex}) < 9 \)
  \( \chi^2(\text{flight}) > 16 \)
  \( \chi^2(\text{IP}) < 9 \)
  \( \theta < 12 \text{ mrad} \)

- **K, π**: \( \chi^2(\text{track})/\text{DoF} < 10 \)
  \( \chi^2(\text{IP}) > 9 \)

- **K, πD**: \( \Delta LL(\text{K-π}) > 0 \)

- **π**: \( \Delta LL(\text{π-K}) > 0 \)

- **D₀**: \( \chi^2(\text{vertex}) < 9 \)
  \( c\tau > 90 \mu\text{m} \)
  \( \chi^2(\text{IP}) < 9 \)

- **D⁺**: \( \chi^2(\text{vertex}) < 9 \)
Selections of D+ and Ds

$$D^+ \rightarrow K^- \pi^+ \pi^+ \text{ and } D_s \rightarrow (\phi \rightarrow K^-K^+)\pi^+$$

K,π : Prob($\chi^2$(track)) > 10^{-4}
   - pT > 200 MeV/c
   - p > 3.2 GeV/c
   - $\chi^2$(IP) > 3.0

2 daughters: pT > 400 MeV/c
   - $\chi^2$(IP) > 10

1 daughter: $\chi^2$(IP) > 50

K : $\Delta LL(K-\pi)$ > 3.3

π : $\Delta LL(\pi-K)$ > -10

D+ : $\chi^2$(vertex) < 8
   - $\theta$ < 14 mrad
   - $\chi^2$(flight) > 90
   - $\tau$ < 0.01 ns

K,π: $\chi^2$(track)/DoF<4

K : $\chi^2$(IP) > 2

π : $\chi^2$(IP) > 10

K : $\Delta LL(K-\pi)$ > 9

π : $\Delta LL(\pi-K)$ > -2

φ : $|\Delta M| < 20\text{MeV/c}^2$

Ds : $\chi^2$(vertex)/DoF<5

Ds : $\chi^2$(flight) > 67