Charmonia and Bottom production measurements with J/ψ at LHCb

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Outline

• Introduction
• $J/\psi + B$ cross-section measurement
• Other Charmonium studies
• Summary
LHCb

Dedicated b physics experiment at the LHC:
• Angular coverage 15 - 300 mrad \( [2 < \eta < 5] \)
• Trigger \( \mu \) pt \( \sim 1 \) GeV, hadron/electron pt \( \sim 3 \) GeV
• Nominal LHCb luminosity of \( \sim 2 \times 10^{32} \) cm\(^{-2}\)s\(^{-1}\)

Experiment installed + ready for first physics in 2009/10

Late 2009/early 2010

Spring 2010

Detector calibration/alignment +first physics with \( 10^8 \) minimum bias. [See talk M. Britsch]

Collect 5 pb\(^{-1}\) events with muon trigger
B and prompt \( J/\psi \) production studies

End 2010

\( 300 \) pb\(^{-1}\) data first CP and rare B physics
e.g. \( \beta_s \) with \( B_s \rightarrow J/\psi \phi \) and \( B_s \rightarrow \mu \mu \).
[See talk of J. Albrecht]
The Detector

- Muon System
- RICH Detectors
- Vertex Locator (VELO)
- Calorimeters
- Tracking System

pp collision Point

~1 cm
J/ψ Production

Prompt J/ψ production not fully understood

- NRQCD (Colour Octet Model) successful in reproducing pt spectrum at Tevatron
  - But predicts increasing transverse polarization at high pt (not observed)

Cross-section + polarization important probes of Charmonium production

- LHCb has unique acceptance coverage in pt and η

- Synergy with b production measurement

![Detector Acceptance](chart.png)
J/ψ Production

LHCb moving to using Pythia 6.4, with Colour Octet Model

Model parameters tuned to reproduce CDF data [LHCb-2007-042]

Both muons in 400 mrad (LHCb acceptance)

- $\sigma(\text{prompt}) = 3100 \text{ nb}$
- $\sigma(b \to J/\psi) = 240 \text{ nb}$
- $\sim 8 \% J/\psi$ from b decays
J/ψ Selection

- Pair of good quality tracks coming from a common vertex
  - vertex $\chi^2$/dof < 6 and track $\chi^2$/dof < 5
- Both tracks identified as muons, one good muon
  - $\Delta \ln L(\mu,\pi) > -1$ [efficiency 90%, mis-id rate 1.4%]
- One track with $p_t > 1.5$ GeV

J/ψ signal in 19 million min bias events
[1.1 s of running @ nominal luminosity]
- L0 trigger applied
- Mass resolution ~ 11 MeV
- S/B ~ 4
- Expect $3.2 \times 10^6$ events in 5 pb$^{-1}$ at 8 TeV

Background dominated by decays in flight
Identifying Prompt J/ψ

Monte Carlo expect ~ 8 % J/ψ come from b decays

To separate J/ψ from prompt and b decays:

\[ t = \frac{dz}{p_{z}^{J/ψ}} \times m^{J/ψ} \]

Simple approximation of b quark proper time
t distribution

Four components to the t distribution

- Prompt component Gaussian
- Prompt background [extract from mass sidebands]
- J/ψ from b Exponential
- Long tail due to association of to wrong primary vertex
  Measure using the J/ψ vertex and the PV in different event
J/ψ Cross-section Measurement

- Measurement in bins of $\eta$ and $p_t$
- $t$ distribution used to extract number of prompt J/ψ
- Efficiency correction estimated using Monte Carlo

Colour Octet Model
- $5 \text{ pb}^{-1}$, $2 < \eta < 3$
- $40k$ $p_t > 10$ GeV
- $380k$ $2 < p_t < 3$ GeV
**J/ψ Cross-section Measurement**

Tests of fitting procedure on sample corresponding to 0.145 pb⁻¹, 14 TeV

Signal: inclusive J/ψ sample with full simulation

Background: toy Monte-Carlo reproducing behaviour on Minimum Bias sample

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**Number of prompt J/ψ**

**Fraction of J/ψ from b**
Systematics

Measurement will not be statistically limited. Systematics from:

• Knowledge of the integrated luminosity. [see talk of F. De Lorenzi]

• Acceptance correction
  • Knowledge and modelling of detector geometry in Monte Carlo
  • Polarization [see next slide]

• Uncertainty in $b \rightarrow J/\psi$ X branching ratio: 9 %

• Uncertainties from the fit procedure + t resolution model
Polarization Effects

Prompt J/ψ polarized

\[
\frac{dN}{d \cos \theta^*} \propto 1 + \alpha \cos^2 \theta^*
\]

Helicity frame

Reconstructed events in MC with no polarization

LHCb acceptance generates an artificial polarization

Systematic of up to 25%

Cross-section measurement needs to account for polarization

- Bin in \( \cos \theta \) as well as \( \eta \) and \( p_T \) [Polarization measurement for free]
\( \chi_c \) Production

\(~ 30\% \) of \( J/\psi \) come from \( \chi_{c1,2} \rightarrow J/\psi \gamma \) [Tevatron measurements]

Important observables: fraction of \( J/\psi \) from \( \chi_{c1,2} \)

\[ R_{\chi_c} = \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} \]

\( J/\psi + \text{photon, } pt > 500 \text{ MeV} \)

Plot \( \Delta M = m(\psi \gamma) - m(\psi) \)

Signal modelled as two Gaussians

Background:

\[ P(m) = (m - m_r)^c_0 \cdot \exp(-c_1 \cdot m - c_2 \cdot m^2) \]

\( \sigma_m \sim 27 \text{ MeV} \) [cf \( M(\chi_{c2}) - M(\chi_{c1}) = 55 \text{ MeV} \)]

Some sensitivity to ratio \( \sigma(\chi_{c2}) / \sigma(\chi_{c1}) \)
Other Measurements

ψ(2S) production and polarization

- Measurement of $\sigma(\psi(2S))/\sigma(J/\psi)$ very clean [most systematics cancel]

Production and polarization of $Y$

Studies of XYZ states

- $B^+ \rightarrow X(3872) K^-$ angular analysis to disentangle $J^{PC} = 1^{++}$ from $2^{-+}$
- $B \rightarrow Z^+(4430) K^-$
- $B^+ \rightarrow Y(4140) K^-$
Summary

• Integrated luminosity of 5 pb$^{-1}$ will contain ~ 3.2 million J/$\psi$

• This will allow study of prompt J/$\psi$ cross-section

• Naturally leads to measurement/studies of:
  
  • b production
  
  • J/$\psi$ Polarization
  
  • $\chi_{c1,2}$, $\psi(2S)$ Production

• Also under study:
  
  • $\gamma$ production cross-section and polarization
  
  • Possible measurements of exotic XYZ states
Back-up
Key Ingredients

- Perform time dependent measurements
- Harsh environment of the LHC
- ~ 50 tracks per event from primary vertex
- B events 1% of the visible cross-section
- Selective trigger needed

Mass + pointing constraints to reduce background

Example: \( B_s \rightarrow D_s K \)

Good primary + secondary vertexing to measure proper time

Flavour Tagging

Good K/\( \pi \) separation

LHCb Geant4 simulation

\( p_B \approx 80 \text{ GeV} \)
The Detector

Detector ready for physics
First Physics

Sample will contain ~500,000 reconstructed $K_s$ and 2000 $J/\psi$

- Alignment, calibration of tracking/PID
- Studies of single particle production, generator tuning
- $K_s$, $\Lambda$ production + polarization + hyperon production $\Xi^{-}\rightarrow\Lambda\pi^{-}$, $\Omega^{-}\rightarrow\Lambda K^{-}$
- Vector meson production ($K^*$, $\phi$)

Minimum bias running
- 4 filled bunches $L = 1.1 \times 10^{29} \text{cm}^{-2}\text{s}^{-1}$
- 2 kHz minimum bias to disk
- Collect $2 \times 10^8$ events in 100 hours
Events with only one reconstructed primary vertex
$\Upsilon(1S)$

Resolution

$\sim 37$ MeV

$a = 1.57 \pm 0.03$

$\text{mean} = 9457.3 \pm 0.3$

$n = 2.16 \pm 0.08$

$\sigma = 37.3 \pm 0.3$

pt distribution

$\eta$ distribution