Heavy Quark production at ALICE/LHC

Raphaelle Bailhache
on behalf of the ALICE collaboration

R.Bailhache IKF, Goethe Universität Frankfurt, 27.01.2011
Outline

- Introduction
  - Motivations and predictions at the LHC
  - The ALICE experiment

- Heavy-flavour results in proton-proton at $\sqrt{s}=7$ TeV
  - D meson $p_T$ distributions and $D^0/D^+$ ratio
  - Heavy-flavour electrons at mid-rapidity
  - Heavy-flavour muons at forward-rapidity
  - $J/\psi$ production cross section at mid- and forward rapidity

- First look at Pb-Pb collisions at $\sqrt{s_{_{NN}}}=2.76$ TeV
Motivation
to measure Charm and Beauty production cross-sections

In heavy-ion collisions:

- Produced at the beginning of the collision (large $Q^2$)
- Experience the evolution of the fireball (large $c\tau$)
- Interact strongly with the medium (parton energy-loss)

In proton-proton collisions:

- Test of pQCD
- Baseline for studies in heavy-ion collisions
Why heavy Quarks in pp at the LHC?

Test pQCD in a new energy domain ($3.5-7\sqrt{s}$ Tevatron) - 4 -

Charm production
Measurements on the upper edge of prediction at Tevatron in ppbar at $\sqrt{s}=1.96$TeV

CDF data PRL 91:241804,2003

at RHIC in pp at $\sqrt{s}=200$GeV

Beauty production
Fairly well reproduced by NLO calculations

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Heavy Quarks production: predictions in pp

Mangano, Nason, Ridolfi, NPB373 (1992) 295

LHC production much higher than at RHIC

Still a factor 2 uncertainty

Probe unexplored small-x region

$\sigma_{\text{LHC}}^{c\bar{c}} \approx 10 \cdot \sigma_{\text{RHIC}}^{c\bar{c}}$

$\sigma_{\text{LHC}}^{b\bar{b}} \approx 50 \cdot \sigma_{\text{RHIC}}^{b\bar{b}}$

$\rightarrow$ Need a measurement at these energies

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Trigger detectors:

Central barrel:
- VZERO scintillator counters
- 2 pixel layers (ITS)

μ spectrometer:
- + μ trigger chambers

Central Barrel $|\eta| < 0.9$

μ Spectrometer
$-4 < \eta < -2.5$
D meson decays

\[ D^0 \rightarrow K\pi \]
\[ D^\pm \rightarrow K\pi\pi \]
\[ D_S^\pm \rightarrow KK\pi \]
\[ D^* \rightarrow D^0\pi \]
\[ D^0 \rightarrow K\pi\pi\pi \]
\[ \Lambda_c \rightarrow \pi Kp \]

**b/c -> hadrons (D mesons)**

**b/c -> e + X**

**J/ψ -> e^+e^-**

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ALICE Experiment

μ Spectrometer

\(-4 < \eta < -2.5\)

Trigger system with programmable \(p_T\) cuts: lowest in 2010 \(p_T^{\mu} > 0.5\) GeV/c

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Heavy-flavour results in pp at $\sqrt{s}=7$ TeV

$b/c \rightarrow$ hadrons (D mesons)
D meson reconstruction

- Main selection: displaced-vertex topology (ITS)
- Example: $D^0 \rightarrow K\pi$
  - Good pointing of reconstructed $D^0$ momentum to primary vertex
  - Pair of opposite charged tracks with large impact parameters
- Kaon PID with TPC + TOF to reduce background at low $p_T$

$D^0: c\tau = 122.9\ \mu m$
$D^\pm: c\tau = 311.8\ \mu m$
$D^\pm_S: c\tau = 149.9\ \mu m$
D meson reconstruction
Detector performances

- Tracking and vertexing precision crucial
- Inner Tracking System (ITS) with 6 layers: two pixel layers at 3.8 cm and 7 cm
- ITS aligned using cosmics and collisions: pixel resolution 14 \( \mu \text{m} \) (nominal \( \sim 11 \mu \text{m} \))

![Graph 1](image1.png)

![Graph 2](image2.png)
Signal extraction

**D^0 -> K^- π^+**

10^8 events; 1-12 GeV in 7 bins

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$D^0$ and $D^+$ $d\sigma/dp_T$

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

\[ pp, \sqrt{s} = 7 \text{ TeV}, 1.4 \text{ nb}^{-1} \]

ALICE Preliminary

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

\[ pp, \sqrt{s} = 7 \text{ TeV}, 1.4 \text{ nb}^{-1} \]

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$D^*+ dN/dp_T$

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Integrated $D^0/D^+$ and $D^0/D^{+*}$ ratio

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Heavy-flavour results in pp at $\sqrt{s}=7$ TeV

Heavy-flavour electrons at mid-rapidity

$\text{b/c} \rightarrow e + X$
Heavy-flavour electrons at mid-rapidity

Measure the Charm and Beauty production cross sections through semi-electronic decays of open charm and open beauty hadrons

- Select electrons with large displacement to primary vertex
  -> reconstruct beauty cross-section ($c\tau_{(B \text{ hadrons})} \approx 400-500 \mu m$)
- Measure inclusive electron spectrum
  -> subtract a cocktail describing the background electron sources
  -> reconstruct charm + beauty cross-section

Branching Ratios:
- $c \rightarrow e + X \quad \mathcal{O}(9.6\%)$
- $b \rightarrow e + X \quad \mathcal{O}(11\%)$
- $b \rightarrow c \rightarrow e + X \quad \mathcal{O}(10\%)$
Electron identification with TOF and TPC

TOF PID in pp at 7 TeV

- ±3 σ TOF inclusion cut for $e^\pm$
  - Rejection of kaons ($p < 1.5$ GeV/c) and protons ($p < 3$ GeV/c)
- TPC momentum dependent cut
  - Rejection of pions

$\beta = \frac{v}{c}$

$p \times \text{charge (GeV/c)}$

$\text{dE/dx in TPC (a.u.)}$

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Hadron contamination

Gaussian fits of dEdx of TPC after TOF cut in momentum slices

-> Determine the hadron contamination as function of p
Comparison cocktail and inclusive electron spectrum

- Inclusive electron spectrum corrected for
  - Hadron contamination
  - Detector efficiency and acceptance
  - $p_T$ resolution (due to Bremsstrahlung)

- Compared to cocktail based on $\pi^0$ cross section measured from double conversion reconstruction

- Large D and B decay electrons in ratio to cocktail

110 million minimum bias events

$p+p @ \sqrt{s} = 7$ TeV
$1.1 \times 10^8$ Min. Bias Events

cocktail: $(e^+e^-)/2$

$\gamma$ conversion
$\pi^0 \rightarrow \gamma e^+e^-$
$\eta \rightarrow \gamma e^+e^-$ and $\eta \rightarrow \pi^0 e^+e^-$
$\omega \rightarrow ee$ and $\omega \rightarrow \pi^0 e^+e^-$
$\phi \rightarrow e^+e^-$
$\eta' \rightarrow \gamma e^+e^-$ and $\eta' \rightarrow \pi^0 e^+e^-$
$\rho \rightarrow e^+e^-$

Using $\pi^0$ from ALICE Data

ALICE Performance
8/10/2010

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Ratio inclusive electron spectrum to cocktail

110 million minimum bias events

The significant excess of electrons comes from charm and beauty, semileptonic decays, J/ψ, direction radiation

now much smaller systematic error on input π^0

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Heavy-flavour results in pp at $\sqrt{s}=7$ TeV

Heavy-flavour muons at forward-rapidity

$b/c \rightarrow \mu + X$
Heavy-flavour muons at forward-rapidity

μ sources (MC)

- Remove hadrons and low-$p_T$ secondary $\mu$ by requiring a $\mu$ trigger signal
- Remove decay $\mu$ by subtracting MC $dN/dp_T$ normalized to data at low $p_T$
  - Alternative method: use $\mu$ distance of closest approach to primary vertex
- What is left are muons from charm and beauty

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Systematic errors

Background substraction
- Above $p_T > 2$ GeV/c, secondary $\mu$ contribution low (< 10%)
- Taken from MC and varied by 100%
- Main source of background: decay $\mu$
- Subtract the contribution using two different MC Pythia tunes

$\rightarrow$ 20% systematic model bias errors

Efficiency
- About 87% above 2.5 GeV/c
- 5% systematic errors
$d\sigma/dp_T$ of D and B muons

Next step: use the $\mu$ distance of closest approach to primary vertex to reduce systematic errors from secondary $\mu$ background subtraction.
Heavy-flavour results in pp at $\sqrt{s}=7$ TeV

$J/\psi$ production cross section at mid- and forward rapidity

$J/\psi \rightarrow e^+e^-$ and $J/\psi \rightarrow \mu^+\mu^-$
Quarkonia at the LHC

- Quarkonia dissociation due to colour screening
- Dissociation pattern depends on binding energy $T_D$ and medium temp. $T$
  - $\Upsilon$ would dissociate only at LHC
  - $\Upsilon'$ $T_D \sim J/\psi$ $T_D$

- Expected regeneration for charmonia due to amount of charm quarks in the medium
$J/\psi \rightarrow e^+e^-$

at mid-rapidity

- Identify electrons with TPC
  - $\pm 3\sigma$ inclusion cut for electrons
  - $\pm 3\sigma$ exclusion for pions and protons

- Invariant mass distributions for like-sign (LS) and opposite sign (OS) electron pairs
  - Match the LS to OS in mass interval 3.2-5.0 GeV/c$^2$
The unknown polarization dominates the systematic errors

<table>
<thead>
<tr>
<th>Channel</th>
<th>e^+e^-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal extraction</td>
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</tr>
<tr>
<td>Acceptance input</td>
<td>1</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>0</td>
</tr>
<tr>
<td>Reconstruction efficiency</td>
<td>10</td>
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<tr>
<td>Luminosity</td>
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<tr>
<td>B.R.</td>
<td>1</td>
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<tr>
<td>Polarization</td>
<td>( \lambda = -1 )</td>
</tr>
<tr>
<td>CS</td>
<td>+25</td>
</tr>
<tr>
<td>HE</td>
<td>+20</td>
</tr>
</tbody>
</table>

\( \text{N}_{J/\psi} = 218 \pm 26 \) (stat.) \( \pm 17 \) (syst.) for \( L = 3.0 \text{ nb}^{-1} \)

CS = Collins-Soper
HE = helicity reference frames
\( \lambda = -1 \) longitudinal polarization
\( \lambda = 1 \) transverse polarization
$J/\psi \rightarrow \mu^+\mu^-$ at forward-rapidity

- Single $\mu$ trigger ($p_T^{\mu} > 0.5$ GeV/c)

- Invariant mass distributions for opposite sign muon pairs

- Extract the signal with a fit in 1.5-5 GeV/c$^2$ region
  - Crystal Ball functions for $J/\psi$ and $\psi$
  - Sum of two exponentials for background

Sub-period with $N_{J/\psi} = 957 \pm 56$
$J/\psi \rightarrow \mu^+\mu^-$ at forward-rapidity

Systematic errors

<table>
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<tr>
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<th>$e^+e^-$</th>
<th>$\mu^+\mu^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal extraction</td>
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<td>Trigger efficiency</td>
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<tr>
<td>Reconstruction efficiency</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Luminosity</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>B.R.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Polarization $\lambda = -1$</td>
<td>$+25$</td>
<td>$-12$</td>
</tr>
<tr>
<td>$\lambda = 1$</td>
<td>$+31$</td>
<td>$-15$</td>
</tr>
<tr>
<td>$\lambda = -1$</td>
<td>$+22$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>

$N_{J/\psi} = 1924 \pm 77\text{(stat.)} \pm 144\text{(syst.)}$ for $L = 13.6 \text{ nb}^{-1}$
$J/\psi \rightarrow \mu^+\mu^-$ at forward-rapidity $d\sigma/dp_T$ spectrum

$\sigma_{HE} = 0$
$\sigma_{HE} = -1$
$\sigma_{HE} = 1$

$p+p \rightarrow J/\psi + X, \sqrt{s} = 7\text{ TeV}$
$2.5 < y < 4, L = 11.6\text{ nb}^{-1}$
ALICE Preliminary

$p+p \rightarrow J/\psi + X, \sqrt{s} = 7\text{ TeV}$
$2.5 < y < 4, L = 11.6\text{ nb}^{-1}$
ALICE Preliminary

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This measurement = direct $J/\psi + \psi$ radiative decay of higher-mass charmonium

Next: separate the different contributions

-> Central barrel:
   - $J/\psi$ from $b$ via pseudo-proper time distribution
   - $\chi_c \rightarrow J/\psi + \gamma$ decay measurement

-> forward-rapidity:
   - Contribution from $b$-decays estimated from the measured beauty cross section via single $\mu$
First look at Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV
$D^0 \rightarrow K^-\pi^+$

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\( \text{J/\psi} \rightarrow \mu^+ \mu^- \)
Next: centrality selection

$R_{AA}$ or $R_{CP}$

● Zero Degree Calorimeter

● Sum of amplitudes in the VZERO scintillator tiles

-> fit of Glauber calculation to the data

(low amplitude dominated by electromagnetic the processes not taken in the fit)
ATLAS results

- J/$\psi$ -> $\mu\mu$
- $|\eta_{\mu}| < 2.4$
- $p_{T\mu} > 3$ GeV/c
- Corrected for efficiency per centrality bins

Centrality from the total transverse energy measured in the forward calorimeter

$$R_{CP} = \frac{N_c^{corr}}{(N_{40-80}\%^{corr} \times N_{coll})}$$

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Summary and outlook

• ALICE Heavy-flavour results in proton-proton at $\sqrt{s}=7$ TeV
  • D meson $p_T$ distributions and $D^0/D^+$ ratio
  • Heavy-flavour electrons at mid-rapidity
  • Heavy-flavour $\mu$s at forward-rapidity
  • $J/\psi$ production cross section at mid- and forward rapidity

  Most of them on the upper edge of prediction
  but in agreement within errors

• Working on PbPb collisions!

THANK YOU
Electron identification

$\pi^\pm$ rejection with TPC

TPC PID after TOF PID in pp at 7 TeV

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Heavy Quarks production: prediction in pp and features

Mangano, Nason, Ridolfi, NPB373 (1992) 295

LHC production much higher than at RHIC

- $\sigma_{LHC}^{cc} \approx 10 \cdot \sigma_{RHIC}^{cc}$
- $\sigma_{LHC}^{b\bar{b}} \approx 50 \cdot \sigma_{RHIC}^{b\bar{b}}$

Still a factor 2 uncertainty

Probe unexplored small-x region

$\rightarrow$ Need a measurement at these energies

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Data Taking in ALICE

INT1B: minimum-bias trigger
- Signals from two beam πck-up counters
- AND a hit in:
  - One of the VZERO scintillator hodoscopes
  - OR one of the two πxels layers

MUS1B: µ trigger
- Single µ trigger

Additional event selection
- offline minimum bias trigger
- beam-gas events excluded by VZERO
- primary vertex reconstruction
Reduced luminosity since 01/07 for ALICE (displaced beams)

pp collisions

- $\sqrt{s}=900$ GeV (2009 & 2010)
- $\sqrt{s}=2.36$ TeV (not all detectors in ALICE ON 2009)
- $\sqrt{s}=7$ TeV (2010)

PbPb collisions

- $\sqrt{s_{NN}}=2.76$ TeV
  (startet on 8th nov 2010 until 5th dec)
Back-up slices
Inclusive $p_T$ electron spectrum
and an electron cocktail

All sources of electrons:

- Dalitz decays of light neutral mesons ($\pi^0, \eta, \omega, \eta', \varphi \rightarrow \gamma e^+e^-$)
- Photon conversions in material
- Direct radiation (direct photon conversions, virtual photons $\gamma \rightarrow e^+e^-$)
- Weak kaon decays (e.g. $K^\pm \rightarrow \pi^0 e^\pm \nu_e$)
- Dielectron decays of vector mesons ($\rho, \omega, \varphi \rightarrow e^+e^-$)
- HEAVY FLAVOR DECAYS (open charm and beauty, $J/\psi, \Upsilon$)

Current cocktail ingredients used to interpret the data:

- Neutral $\pi$s (based on the measured $\pi^0$ spectrum!)
- Heavier mesons: $\eta, \rho, \omega, \varphi, \eta'$
- Photon conversions
- $J/\psi$ not official yet (based on data)
Back-up slices
Cocktail ingredients:
The input $\Pi^0$ spectrum data

- $\Pi^0$ (and $\eta$) reconstructed via photon conversion in the detector material $\gamma \rightarrow e^+e^-$

$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2})}$$

- With $9.5 \times 10^7$ Minimum Bias collisions:
  - $\pi^0$ measured from $p_T = 0.4$ GeV/c to $p_T = 7$ GeV/c
  - $\eta$ measured from $p_T = 0.6$ GeV/c to $p_T = 6$ GeV/c
- Important to know the detector budget and the probability for a photon to convert (about 8.6%)
Back-up slices
Cocktail ingredients:
The input $\Pi^0$ spectrum data

NLO calculations from Werner Vogelsang


- Results in agreement with two other methods using:
  - the PHOS calorimeter to measure photons
  - A combination: one photon via conversion, the other via PHOS

- Smaller uncertainties today

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Back-up slices
Cocktail ingredients:
\( \Pi^0 \) Dalitz decays and heavier mesons decays

- Electrons from Dalitz \( \pi^0 \) decays:

  \( \Pi^0 \) Spectrum fitted with the Hagedorn function, decay kinematics used to produce \( e^\pm \)

\[
E \frac{d^3\sigma}{dp^3} = \frac{c}{\left( p_0 + p_T/p_L \right)^n}
\]

- Heavier mesons decays contributions (\( \eta, \eta', \rho, \omega, \phi \)):
  - Use \( m_T \) scaling for the shape (verified with \( \eta \))

\[
E \frac{d^3\sigma}{dp^3} = \frac{c \times \text{meson/pion}}{\left( p_0 + \sqrt{m_T^2 - m_x^2}/p_L \right)^n}
\]

  - Use ratio at high \( p_T \) for the normalisation
Back-up slices
Cocktail ingredients:
electrons from photon conversion

Conversions provide a γ-ray tomography of ALICE
Very useful tool to check the material budget
Well known down to ±6% accuracy
Back-up slices
Cocktail ingredients: electrons from photon conversion

- To know the material budget is not enough!
  - Need to know the fraction of electrons from conversion not rejected by the track quality cuts (One hit in the first pixel layer)

- Material budget to be considered:
  - beam π pe + a fraction x of the first pixel layer
  - x determined via three different methods
    - from the material budget map (material and sensor position)
    - from the simulations: check for conversions in the first layer if a hit was produced
    - from simulations (and/or data): use the ratio of conversion electron spectra with hit in first layer vs second layer

  \[ x = 0.45 \pm 0.05 \]
Identify in pp collisions pure samples of electrons and πs independently from the TRD detector via V0 technics:

- $K_0 \rightarrow π^+π^-$
- Photon conversion in material: $γ \rightarrow e^+e^-$

Compare the deposited energy of this particles with the distributions obtained with test-beam data in 2002.
Back-up slices
Electron identification with EMCAL

Electro Magnetic Calorimeter

- Sampling calorimeter:
  - Layers of Pb to produce showers
  - Layers of scintillators to detect

- High momenta electron identification until 200 GeV/c

-0.7<\eta<0.7
120° in \Phi

36% installed in 2010

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Electrons candidates (TPC dE/dx), EMCAL clusters assigned:

After matching with TPC
Select electrons with $E/p\approx 1$

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Back-up slices
Back-up slices

Efficiency to reject πle up of about 0.7% -> maximum 4%
Back-up slices

110 million minimum bias events

- Systematic error on input $\pi^0$ spectrum from conversions: +20% - 40%
- Variation of the NLO prediction between the 2 extreme scales: $p_T/2$ and $2p_T$
- The significant excess electrons come from charm and beauty semileptonic decays and from direct radiation

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