Perspectives for the measurement of beauty production via semileptonic decays in ALICE

Rosario Turrisi
INFN Padova (Italy)
for the ALICE collaboration
Contents

- Motivation: energy loss
- ALICE detector highlights
- Performances: electron separation and vertexing
- $B \rightarrow e^+ X$: attainable statistics and errors
- $B \rightarrow e^+ X$: sensitivity of energy loss measurement
- $B \rightarrow \mu^+ X$: strategy and performance
- Conclusions
Physics motivation

Heavy quarks:
- abundant yield
- produced early
- travel ~4 fm in the medium

probe the collision dynamics!

ALICE: very low $p_t$ explored, complementary to other LHC exps.

<table>
<thead>
<tr>
<th>$\sigma_{Q\bar{Q}}(NN)$ [mb]</th>
<th>PbPb (0-5% centr.)</th>
<th>pp 14 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.21</td>
<td>5.5 TeV</td>
<td>0.51</td>
</tr>
</tbody>
</table>

N_{Q\bar{Q}} per collision
4.56

0.0072

b production cross section
transverse momentum spectrum

In AA:
- quarkonia dissociation
- energy loss

(+pA) disentangle medium effects

In pp:
- (p)QCD test bench
- AA, pA baseline

1 year pp 14 TeV @ nominal lumin

HERA-LHC workshop
CERN-2005-14

Krakow, July 7, 2006
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High $p_t$ suppression at RHIC

- Method: compare mesons’ $p_t$ distribution in pp and AA:

$$R_{AA}^{D,B} (p_t) = \frac{1}{N_{\text{coll}}} \times \frac{dN_{AA}^{D,B} / dp_t}{dN_{pp}^{D,B} / dp_t}$$

= 1 if no medium effect

- Observed at RHIC for light flavors and charm
- Reproduced by $\hat{q} = 4$-14 GeV$^2$/fm (see next slide)

Calculations: Armesto, Dainese, Salgado, Wiedemann, PRD71 (2005) 054027

Electrons from c/b decay
Possible explanation: *gluonsstrahlung*

- interactions may occur by gluon in-medium radiation (quenching)
- the amount of quenching depends on:
  - color charge: $C_R=4/3$, 3 if quark or gluon, resp. (Casimir factor)
    - heavy/light probes (b,c vs. direct pions)
  - quark mass (beauty/charm comparison)
    - *dead cone* effect

\[
\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2
\]

**medium dependence**

\[
\frac{1}{\left( \theta^2 + \left( \frac{m_Q}{E_Q} \right)^2 \right)^2}
\]

**mass dependence**

Dokshitzer, Kharzeev, PLB519 (2001) 199
Armesto, Salgado, Wiedemann, PRD69 (2004) 114003

Baier, Dokshitzer, Mueller, Peigné, Schiff, (BDMPS), NPB483 (1997) 291
Energy loss at LHC

- A promising strategy: study the $p_t$-dependent ratio…
  - …$R_{AA}$ of D or B mesons produced in AA and pp: quark energy loss
    
    
    
    
    $R_{AA}^{D,B} (p_t) = \frac{1}{N_{coll}} \times \frac{dN_{AA}^{D,B}}{dp_t} / \frac{dN_{pp}^{D,B}}{dp_t}$
  
  - …between $R_{AA}^B$ and $R_{AA}^D$ (beauty/charm ratio): mass dependence
    
    
    
    
    $R_{D(B)/h} (p_t) = R_{AA}^B (p_t) / R_{AA}^D (p_t)$
  
  - …between $R_{AA}^{B/D}$ and $R_{AA}^h$ (heavy/light probes): color charge dependence
    
    
    
    
    $R_{D(B)/h} (p_t) = R_{AA}^{D(B)} (p_t) / R_{AA}^h (p_t)$

- NB: study of charm detection performance done!
The ALICE Detector

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>4 ≤</td>
<td>0.9</td>
<td>TPC + silicon tracker (ITS=SSD+SDD+SPD)</td>
</tr>
<tr>
<td>4 ≤</td>
<td>2.5</td>
<td>TPC + silicon tracker (ITS=SSD+SDD+SPD)</td>
</tr>
<tr>
<td>e/π, K, p,… separation in TRD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-4 ≤ η ≤ -2.5
muons
Detection strategy: $B \rightarrow e + X$

- Background sources:
  - pions misidentified as electrons
  - charm decay electrons
  - Dalitz decays
  - photon conversions
  - strangeness decays

- Signal: <1 electron/ev out of $\sim 10^3$ (all $p_t$'s)!

- Detection strategy
  - electron ID in TPC + TRD
  - $p_t$ cut-off
  - impact parameter cut-off
  - specific for pp: primary vertex optimization

- $c\tau \sim 500 \mu m \rightarrow$ compare with 100-300 $\mu m$ from charm
- $m_b \sim 5$ GeV $\rightarrow$ hard $p_t$ spectrum

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Impact parameter resolution

- $d_0$ resolution Silicon Pixel Detector
  - 2 layers, $R=4$ and 7 cm, $\sim 10^7$ channels

\[ p_t > 1 \text{ GeV/c} \Rightarrow \sigma < 60 \text{ } \mu\text{m} \quad (r_\phi) \]

$\approx 12 \text{ } \mu\text{m}$ asymptotic

pixel size

50x425 $\mu$m
Electron separation

- Combined strategy TRD+TPC
  - TRD rejects 99% of pions and 100% of heavier hadrons (90% electron efficiency)
  - TPC (via dE/dx analysis) rejects again 99% of pions at 90% electrons efficiency (at low p_T's)
Electron spectra from b

- Results for electrons detection in:
  - pp, 14 TeV, $10^9$ events (“one year run”)
  - PbPb, “one month run” $10^7$ events
    - ALICE standard ‘underlying’ event $\rightarrow dN^{CH}/dy=6000$
  - systematic and statistical errors studied in detail

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B-meson level cross section

Using electrons in $2 < p_t < 20$ GeV/c

MC-based procedure à la UA1*

obtain B meson $2 < p^\text{min}_t < 30$ GeV/c

E Loss Calculation: Armesto, Dainese, Salgado, Wiedemann, PRD71 (2005) 054027


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Beauty quenching

- Reconstruction of meson-level cross section (details on request…)
- $R_{AA}$ (RHIC-like analysis) sensitivity to quenching/mass
- $R_{BD}$ (pure quark, no quark/gluon effect) prefers mass effect

\[
R_{BD}^e(p_t) = \frac{R_{AA}^e\text{ from } B(\frac{dN}{dp_t})}{R_{AA}^e\text{ from } D(\frac{dN}{dp_t})}
\]

NB: study of charm detection performance done!
Beauty in the muon channel

- Muon spectrometer:
  - pseudorapidity coverage: -4 < η < -2.5
  - absorber + tracking chambers layers + trigger chambers (22 layers)
  - 15 interaction lengths, but p_t as low as 1-1.5 GeV/c
  - p_t resolution ~ 2%

5 bBar pairs / central Pb-Pb collision (5 %)

\[ B^+ \rightarrow D^0 \ell^+_1 \nu_\ell \]
\[ \rightarrow \ell^-_2 X' \]
\[ \overline{B^0} \rightarrow D^+ \ell^-_3 \overline{\nu}_\ell \]
\[ \rightarrow \ell^+_4 X'' \]

<table>
<thead>
<tr>
<th>%</th>
<th>( \mu^+ )</th>
<th>( \mu^- )</th>
<th>( \mu^+\mu^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{geom}</td>
<td>12</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>A_{track}</td>
<td>75</td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td>( \varepsilon_{track} )</td>
<td>62</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>( \varepsilon_{trigger} )</td>
<td>53</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>( \varepsilon_{trigger} )</td>
<td>29</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>
**B-meson level cross section**

- **Method:**
  - combined fit of 3 muon data samples (singles, low mass OS, high mass OS) with fixed shape and b amplitude as the only free parameter
  - MC to derive $\sigma^B$ vs $p_t^{\text{min}}$ with $p_t$ as low as 1 GeV/c!
  - evaluate stat. and syst. errors

![Graph showing B-meson level cross section](image)

<table>
<thead>
<tr>
<th>$p_t$ (GeV/c)</th>
<th>1.5-2</th>
<th>1.2-5</th>
<th>2.5-3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-6</th>
<th>6-9</th>
<th>9-12</th>
<th>12-15</th>
<th>15-20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal (fit)</strong></td>
<td>4%</td>
<td>4%</td>
<td>3%</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
<td>4%</td>
<td>8%</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td><strong>Total pT-dep.</strong></td>
<td>11%</td>
<td>11%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>11%</td>
<td>13%</td>
<td>16%</td>
</tr>
<tr>
<td><strong>Decay of π,K</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4%</td>
</tr>
<tr>
<td><strong>Normalisation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9%</td>
</tr>
<tr>
<td><strong>Total pT-indep</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
</tr>
</tbody>
</table>
Conclusions

- Heavy flavors can play an outstanding role as QCD test bench in AA reactions at LHC:
  - at low $p_t$, explore small-$x$ region
  - at high $p_t$, probe the QCD extended medium via energy loss
- The studies outlined in this talk suggest that ALICE has a good potential in this field:
  - semielectronic decays in central barrel (-0.9 < $\eta$ < 0.9)
  - semimuonic decays in muon arm (-4 < $\eta$ < -2.5)

Same observable ($E_{\text{loss}}$) from two different analyses in the same experiment!

- ... and a lot has been left out:
  - charm hadronic and semileptonic decays
  - $e^{-}\mu$ coincidences
  - indirect $J/\psi$
  - $b$ tagging via topological selections

- (Lot of) work in progress in the ALICE Physics Working Group 3 “heavy flavors”...
Errors evaluation on e’s spectra

- Estimation of errors:
  - MC corrections (efficiency, acceptance, etc.) fixed at 10%, $p_T$-independent.
  - Indetermination on charm subtraction evaluated using as reference our study on hadronic charm detection.
  - Normalization error not shown.

![Diagram showing relative error on beauty as a function of $p_T$ for Pb-Pb and p-p collisions at different energies.](chart.png)
Energy loss at LHC

- A promising strategy: study the $p_T$-dependent ratio...

...$R_{AA}^B$ of D or B mesons produced in AA and pp: quark energy loss

...between $R_{AA}^B$ and $R_{AA}^D$ (beauty/charm ratio): pure quark analysis

Calculation of energy loss at LHC energies:
Charm/light ratio

- $R_{(D)Bh}$ mass+color charge effect

\[ R_{D/h}(p_t) = \frac{R_{AA}^D(p_t)}{R_{AA}^h(p_t)} \]
Extraction of a minimum-$p_T$-differential cross section for B mesons

* Using UA1 MC method (*), also adopted by ALICE µ 

(thanks to R. Guernane for useful discussions)

The B meson cross section per unit of rapidity at midrapidity with $p_T^B > p_T^{\text{min}}$ is obtained from a scaling of the electron-level cross section measured within a given electron phase space $\Phi^e$

$$
\frac{d\sigma^B}{dy}(p_T^B > p_T^{\text{min}}) = \sigma^{e,\text{beauty}}(\Phi^e) \bigg|_{\text{meas}} \times \frac{d\sigma^B}{dy}(p_T^B > p_T^{\text{min}}) \frac{1}{\sigma^B(\Phi^e)} 
$$

$$
= \sigma^{e,\text{beauty}}(\Phi^e) \bigg|_{\text{meas}} \times F_{e \rightarrow B}
$$

The phase space used is $\Phi^e \equiv \{\Delta p_T, \Delta \eta, \Delta d_0\}$ where $\Delta p_T$ are the previously used bins, $\Delta \eta = [-0.9, 0.9]$ and $\Delta d_0 = [200, 600] \mu$m

C. Albajar et al., UA1 Coll., Phys Lett B256 (1991) 121

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Systematic error for $F_{e \to B}$

- semi-electronic decay B.R.: $\sim 3\%$

- dependence on the shape of the B meson $p_T$ distribution used as input in the MC: can be minimized using a proper choice of $p_T^{\text{min}}$ for a given phase space $\Phi^e \rightarrow$ see following slides

- Monte Carlo correction for the efficiency of the selection cuts: this is, in principle, depending on the B meson $p_T$ distribution, and should be then evaluated at this stage of the analysis. For the present feasibility study we account for it with a 10% systematic.
1) we used the $B \rightarrow e + X$ decays from PYTHIA.

$F_{e \rightarrow B}$ is the ratio of the red area to the blue one.

Here $\Delta p_T^e = [3,4] \text{ GeV/c}$
Extraction of a minimum-$p_T$-differential cross section for B mesons

Evaluation of $F_{e\rightarrow B}$ and determination of the optimal $p_T^{\text{min}}$

2) in the HVQNMPr program we changed:

the theory parameters:

a) quark mass and scales

b) nuclear modification of the PDFs

c) $b \rightarrow B$ fragmentation (Peterson)

d) add the quenching

($\hat{q} = 100 \text{ GeV}^2/\text{fm}$ (*)


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Extraction of a minimum-p_T-differential cross section for B mesons

Evaluation of $F_{e\rightarrow B}$ and determination of the optimal $p_T^{\text{min}}$

$\Delta F \sim 1\%$