Heavy flavour and Quarkonium measurements with ALICE at LHC

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for the
ALICE Collaboration
Outline

• Physics motivations
• ALICE experiment
• ALICE capabilities
  – Open heavy flavour
  – Quarkonia
• First results from 7 TeV p-p collisions
• Conclusions

• Disclaimer:
  – muon spectrometer biased
  – other heavy flavour results in
    • G. Bruno, session 05 - 22/7
    • A. Grelli, session 05 - 22/7
    • R. Bailhache, session 05 - poster
Heavy flavours

• In Pb-Pb collisions: probe the properties of the medium
  – created in the hard initial collisions
    • experience the whole collision history
  – possible comparison heavy quarks/light partons
    • energy loss:

\[ \Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b \]

\[ R^H_{AA}(p_t) = \frac{1}{N_{coll}} \frac{dN^H_{AA}}{dN^H_{pp}} \left( \frac{dp_t}{dp_t} \right) \]

medium density and size

\[ R^{\pi}_{AA} < R^D_{AA} < R^B_{AA} \]

dead cone effect (mass)
Casimir factor (colour charge)

• In p-p collisions:
  – baseline for Pb-Pb
  – measure charm and beauty cross section
  – compare to pQCD predictions
Quarkonia, heavy ions and the QGP?

- A long lasting story...
  - 1986, Matsui and Satz: J/ψ suppression as a QGP signature
  - NA38, NA50, NA60 at SPS
  - PHENIX, STAR at RHIC
- ... and many open questions
  - similar suppression at RHIC and at SPS
  - larger suppression at larger rapidities
  - cold nuclear matter effect (still) weakly constrained
  - statistical hadronization, recombination?

... and then??
The LHC might enlighten us ...
The LHC and its features

• Large energy step (RHIC x30)
  – A QGP that will be
    • hotter,
    • bigger,
    • longer lived,
    • earlier thermalized.
  – Large hard probe production cross-sections

<table>
<thead>
<tr>
<th></th>
<th>SPS 17 GeV</th>
<th>RHIC 200 GeV</th>
<th>LHC 5.5 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial T</td>
<td>~ 200 MeV</td>
<td>~ 300 MeV</td>
<td>&gt; 600 MeV</td>
</tr>
<tr>
<td>volume</td>
<td>$10^3$ fm$^3$</td>
<td>$10^4$ fm$^3$</td>
<td>$10^5$ fm$^3$</td>
</tr>
<tr>
<td>lifetime</td>
<td>&lt; 2 fm/$c$</td>
<td>2-4 fm/$c$</td>
<td>&gt; 10 fm/$c$</td>
</tr>
</tbody>
</table>

Event rate at $L=10^{27}$ cm$^{-2}$s$^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>SPS PbPb Cent</th>
<th>RHIC AuAu Cent</th>
<th>LHC pp</th>
<th>LHC pPb</th>
<th>LHC PbPb Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>cc</td>
<td>0.2</td>
<td>10</td>
<td>0.2</td>
<td>1</td>
<td>115</td>
</tr>
<tr>
<td>bb</td>
<td>-</td>
<td>0.05</td>
<td>0.007</td>
<td>0.03</td>
<td>5</td>
</tr>
</tbody>
</table>
• Central barrel (|\eta|<0.9)
  – Open heavy flavour
    • hadronic channel
    • semi-leptonic decays (e)
  – Quarkonia
    • e^+e^-

• Muon spectrometer (-4.0<\eta<-2.5)
  – Open heavy flavour
    • semi-leptonic decays (\mu)
  – Quarkonia
    • \mu^+\mu^-

Tracking:
  ITS+TPC+TRD
  PID: TPC+TRD+TOF
Secondary vertexing:
  ITS

Absorber
  Tracking chambers
  MUON Trigger

ZDC
\sim 116m from I.P.
Heavy flavour measurement potential

Comparison with pQCD

Energy loss studies

\[ R_{D/h}(p_t) = \frac{R^D_{AA}(p_t)}{R^h_{AA}(p_t)} \]

(from simulation) MC

\[ R_{B/D}(p_t) = \frac{R^e_{\text{from } B}(p_t)}{R^e_{\text{from } D}(p_t)} \]

Good discriminating power!
Muons from charm at forward rapidity

- Unfold single muon $p_t$ and dimuon invariant mass spectra
- No dca cuts $\rightarrow$ use large statistics to constrain the fits

**pp, single muon $p_t$**

**pp, di-muon invariant mass**

1 month at reduced luminosity ($10^{30}$ cm$^{-2}$s$^{-1}$, 7 x $10^{10}$ pp events)
Secondary J/ψ

- $X_c$: contribution $\sim 30\%$
  - $X_c \rightarrow \text{J/ψ+γ}$
    - J/ψ in dielectron channel
    - γ in γ-conversion
  - feasible in pp collisions
    - $\sim 7k$ $X_c$ but requires a trigger strategy which is under study

- $\psi'$: contribution $\sim 10\%$
  - challenging

- B mesons: contribution $\sim 20\%$
  - $B \rightarrow \text{J/ψ+X}$
    - Non photonic electrons
    - à la CDF: simultaneous fit
      - Invariant mass distribution
      - Pseudo proper decay time
  - In muon arm
    - method using 3 muon events is under study

ICHEP2010 – Paris, France – 22/10/2010
Quarkonia: what could be achieved

- Upsilon measurements
  - Separation of family states is possible (100 MeV resolution)
  - Good sensitivity to “suppression” scenarii
    - Suppression 1: $T_C = 270$ MeV; $T_D/T_C = 4.0$ (1.4) for $\Upsilon(\Upsilon')$;
    - Suppression 2: $T_C = 190$ MeV; $T_D/T_C = 2.9$ (1.1) for $\Upsilon(\Upsilon')$;

- Polarization
  - Angular distribution of $\mu^+$ in the quarkonium rest frame.
    - $\frac{d\sigma}{d\cos\theta_H} \propto 1 + \alpha \cos^2 \theta_H$
    - $\alpha = \frac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L} \Rightarrow \begin{cases} 1 & \text{transverse} \\ 0 & \text{no polarization} \\ -1 & \text{longitudinal} \end{cases}$
  - $\Upsilon$ polarization
    - 1 nominal year for integrated studies
    - Several years for differentials
First results from 7 TeV p-p collisions

- **CINT1B**: interaction trigger
  - at least one charged particle in 8 $\eta$ units
- **CMUS1B**: single-muon trigger:
  - forward muon in coincidence with interaction trigger

Further background-event rejection is performed offline by selecting events which:
1. have the correct event type (physics);
2. trigger on bunch crossings;
3. fulfill at least -one- of the three following conditions:
   a) 2 fired chips in the SPD*
   b) 1 fired chip in the SPD* and a beam-beam flag in either V0A or V0C**
   c) beam-beam flags on both sides V0A and V0C**;
4. are not flagged as beam-gas by either V0A or V0C**.

* calculated offline from reconstructed clusters
** calculated offline from the V0 signals
Open heavy flavour: D mesons

Expected to cover 0.5 < $p_T$ < 15 GeV/c with $10^9$ events

Observed differentially in $p_T$:
- up to $p_T$ = 12 GeV/c
- down to 1 GeV/c for D$^0$

See A. Grelli
Session 05 – 24/7
Open heavy flavour in the electron channel

- Compute the inclusive cross section using electrons
- For high $p_T$, the contribution from charm and beauty becomes dominant
- Essential ingredient for the analysis: electron Identification
  - For the moment: TPC + TOF
  - Hard work to add the TRD is going on!
  - EMCal will also contribute

See R. Bailhache
Session 05 – Poster
J/ψ in the di-electron channel

- 110M p-p events at 7 TeV
  - 1/3 of available statistics
- Track reconstruction
  - TPC + ITS
- Electron identification (and pion rejection)
  - TPC
  - TRD could be included later
- Fit with a Cristal Ball function
- $|\eta|<0.9$

\[ \text{Counts} \left[ \frac{\text{iMeV/c}^2}{\text{MeV/c}^2} \right] \]

\[ N_{\text{signal}} = 59 \pm 9 \]

\[ \text{Significance} = 6.72 \pm 1.14 \]

\[ S/B = 3.22 \pm 1.62 \]

\[ \text{Mass} = 3.076 \pm 0.009 \text{ GeV/c}^2 \]

\[ \text{width} = 51 \pm 10 \text{ MeV/c}^2 \]

See G. Bruno
Session 05 – 22/7
Measurements with the forward muon spectrometer
Open heavy flavour from single muons

- **Trigger matching**
  - Iron wall stop hadrons produced in the absorbers

- **Distance of Closest Approach**
  - Could be used to separate $c$ and $b$ signal from $\pi$ and $K$ background (using simulations)

- $\pi$ and $K$ contribution
  - subtracted using Pythia simulations normalized at low $p_T$

- $c$ and $b$ contribution
  - dominates for $p_T>2$ GeV/c

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**Graph:**
- $p+p @ \sqrt{s}=7$ TeV
- ALICE Performance
- $07/06/2010$

**Data:**
- $pp @ \sqrt{s}=7$ TeV
- MB data w/ $-4<\eta<-2.5$
- $17.6 \text{ cm}<r_{abs}<80 \text{ cm}$
- ALICE Performance
- $09/06/2010$
J/ψ in the di-muon channel

The alignment of the tracking chambers is a critical step for the J/ψ measurements

- First alignment: straight tracks from B=0 T data

\[ \sigma_{J/\psi} = 91 \pm 9 \text{ MeV} \]

\[ \sigma_{J/\psi} = 232 \pm 50 \text{ MeV} \]

Without alignment

First alignment

Target

\[ \sigma_{J/\psi} (\text{MeV}) \]

- Without alignment: 230
- First alignment: 90
- Target: 70
Transverse momentum dependence

The width of the J/ψ peak is well reproduced by our Monte Carlo including residual misalignment and other realistic conditions!
Monte Carlo comparison

The acceptance and efficiency corrected distributions are compared to generated MC distribution.

- “CDF pp 7 TeV” parameterization
  - $p_T$ extrapolated from CDF results
  - $y$ obtained from CEM calculations
  - No polarization ($\lambda = 0$)
To extract $<p_T^2>$ we use the fit function first proposed by Yoh et al., PRL 41 (1978) 684 and also used by previous experiments.

\[ \frac{dN}{dp_T} \propto p_T \times \left( 1 + \left( \frac{p_T}{p_0} \right)^2 \right)^x \]

\[ x = 3.2 \pm 0.7 \]

Quoted uncertainties include systematics from the fit function.

Full systematic uncertainties are being evaluated.
Conclusion

- The LHC provides a new and promising environment for the study of open heavy flavour and quarkonium production
- ALICE is well suited for the study of heavy flavours
  - Two rapidity domains

- Exciting results from first pp data at 7 TeV
  - J/ψ transverse momentum distribution

- Coming soon
  - J/ψ differential cross-section
  - Corrected open heavy flavour measurements

- Looking forward for Pb-Pb data at the end of the year
The LHC and its other “features”

• Only 1 month per year for the heavy ion program
  – Including pA or lighter ions

• Lead beam luminosity is limited by the magnets “quench limit” due to EM processes induced by PbPb collisions;

• Large contribution from B-hadron decays to charmonia yields
  – ~20% for J/ψ

• Cold nuclear matter effects are not well under control
  – Could try different normalizations
  – Will be measured with pA runs

• Heavy Ion running plan (1 month per year)
  – First 5 years: 1 PbPb low luminosity, 2 PbPb runs at nominal luminosity, 1 pPb and 1 lighter ion runs
  – Next 5 years (based on results): lower energies, pp at 5.5 TeV, other AA or pA, more stat …
Quarkonia in dielectron channel

<table>
<thead>
<tr>
<th></th>
<th>$J/\psi$</th>
<th>$\Upsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass resolution</td>
<td>$\sim 30$ MeV/c$^2$</td>
<td>$\sim 90$ MeV/c$^2$</td>
</tr>
<tr>
<td>Signal/Noise</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Counts (nominal PbPb year) 10%</td>
<td>120k</td>
<td>900</td>
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</tbody>
</table>
Quarkonia in dimuon channel

<table>
<thead>
<tr>
<th>&amp;</th>
<th>J/ψ</th>
<th>Υ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass resolution</td>
<td>~70 MeV/c²</td>
<td>~100 MeV/c²</td>
</tr>
<tr>
<td>Signal/Noise</td>
<td>0.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Counts (nominal PbPb year) MB</td>
<td>680k</td>
<td>6000</td>
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</table>
ALICE performances in $\mu^+\mu^-$

### 0<b<3 fm

<table>
<thead>
<tr>
<th>State</th>
<th>$S[10^3]$</th>
<th>$S/B$</th>
<th>$S/(S+B)^{1/2}$</th>
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<tbody>
<tr>
<td>$J/\Psi$</td>
<td>130</td>
<td>0.20</td>
<td>150</td>
</tr>
<tr>
<td>$\Psi'$</td>
<td>3.7</td>
<td>0.01</td>
<td>6.7</td>
</tr>
<tr>
<td>$\gamma(1S)$</td>
<td>1.3</td>
<td>1.7</td>
<td>29</td>
</tr>
<tr>
<td>$\gamma(2S)$</td>
<td>0.35</td>
<td>0.68</td>
<td>13</td>
</tr>
<tr>
<td>$\gamma(3S)$</td>
<td>0.20</td>
<td>0.48</td>
<td>8.1</td>
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### 6<b<9 fm

<table>
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<th>$S/(S+B)^{1/2}$</th>
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<tbody>
<tr>
<td>$J/\Psi$</td>
<td>200</td>
<td>0.49</td>
<td>250</td>
</tr>
<tr>
<td>$\Psi'$</td>
<td>5.5</td>
<td>0.03</td>
<td>13</td>
</tr>
<tr>
<td>$\gamma(1S)$</td>
<td>2.0</td>
<td>3.6</td>
<td>39</td>
</tr>
<tr>
<td>$\gamma(2S)$</td>
<td>0.52</td>
<td>1.4</td>
<td>18</td>
</tr>
<tr>
<td>$\gamma(3S)$</td>
<td>0.28</td>
<td>0.95</td>
<td>12</td>
</tr>
</tbody>
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### b>12 fm

<table>
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<th>$S[10^3]$</th>
<th>$S/B$</th>
<th>$S/(S+B)^{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\Psi$</td>
<td>22</td>
<td>3.14</td>
<td>130</td>
</tr>
<tr>
<td>$\Psi'$</td>
<td>0.6</td>
<td>0.18</td>
<td>9.7</td>
</tr>
<tr>
<td>$\gamma(1S)$</td>
<td>0.21</td>
<td>9.5</td>
<td>15</td>
</tr>
<tr>
<td>$\gamma(2S)$</td>
<td>0.06</td>
<td>3.6</td>
<td>6.5</td>
</tr>
<tr>
<td>$\gamma(3S)$</td>
<td>0.03</td>
<td>1.9</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Quarkonia: what will be done

• The bread and butter of J/ψ
  – Production yields, cross-sections
    • High statistics
    • From $p_T = 0$ GeV/c
  – Detailed “suppression” studies
    • With respect to
      – Beauty
      – pp ($R_{AA}$)
    • As a function of
      – Centrality
      – Transverse momentum (0-20 GeV/c)
      – Rapidity (two domains)
  – Precise pp measurement
    • $3.10^6$ J/ψ in nominal pp run
    • Sensitivity to low $x$-Bjorken
      – probing gluon distribution at $x_{Bj} = 2x10^{-4} – 4x10^{-6}$ ;
Particle Identification

Complementary momentum coverage

TPC

ITS

TOF

ALICE Performance
p+p at $\sqrt{s} = 900$ GeV (2009 data)

ALICE performance
work in progress

pp @ 7 TeV

Complementary momentum coverage
D⁰ Invariant Mass Spectra in p_T bins

pp \sqrt{s} = 7 TeV, 1.4 \times 10^8 events, 1 < p_T^{D^0} < 2 GeV/c

pp \sqrt{s} = 7 TeV, 1.4 \times 10^8 events, 2 < p_T^{D^0} < 3 GeV/c

pp \sqrt{s} = 7 TeV, 1.4 \times 10^8 events, 3 < p_T^{D^0} < 5 GeV/c

pp \sqrt{s} = 7 TeV, 1.4 \times 10^8 events, 5 < p_T^{D^0} < 8 GeV/c

pp \sqrt{s} = 7 TeV, 1.4 \times 10^8 events, 8 < p_T^{D^0} < 12 GeV/c
D\(^+\) Invariant Mass Spectra in p\(_T\) bins

**pp\(\sqrt{s}=7\) TeV, 1.41 \times 10^8 events, 2 < p\(_T\) < 3 GeV/c**

**D\(^+\) \rightarrow K^- \pi^+ \pi^+**

ALICE Performance
13/07/2010

Mean = 1.870 ± 0.002
Sigma = 0.010 ± 0.001

Significance(2\(\sigma\)) 7.2 ± 1.0
S(2\(\sigma\)) 66 ± 9
B(2\(\sigma\)) 19 ± 2

**pp\(\sqrt{s}=7\) TeV, 1.41 \times 10^8 events, 3 < p\(_T\) < 5 GeV/c**

**D\(^+\) \rightarrow K^- \pi^+ \pi^+**

ALICE Performance
13/07/2010

Mean = 1.868 ± 0.001
Sigma = 0.011 ± 0.001

Significance(2\(\sigma\)) 11.5 ± 1.1
S(2\(\sigma\)) 180 ± 15
B(2\(\sigma\)) 63 ± 3

**pp\(\sqrt{s}=7\) TeV, 1.41 \times 10^8 events, 5 < p\(_T\) < 8 GeV/c**

**D\(^+\) \rightarrow K^- \pi^+ \pi^+**

ALICE Performance
13/07/2010

Mean = 1.871 ± 0.002
Sigma = 0.014 ± 0.001

Significance(2\(\sigma\)) 10.4 ± 1.1
S(2\(\sigma\)) 160 ± 16
B(2\(\sigma\)) 74 ± 4

**pp\(\sqrt{s}=7\) TeV, 1.41 \times 10^8 events, 8 < p\(_T\) < 12 GeV/c**

**D\(^+\) \rightarrow K^- \pi^+ \pi^+**

ALICE Performance
13/07/2010

Mean = 1.870 ± 0.004
Sigma = 0.022 ± 0.003

Significance(2\(\sigma\)) 6.9 ± 1.2
S(2\(\sigma\)) 103 ± 16
B(2\(\sigma\)) 118 ± 7
D* Invariant Mass Spectra in p_T bins

**pp\sqrt{s} = 7 TeV, 1.40 \times 10^8 events, 2 < p_T < 3 GeV/c**

- **ALICE performance**
- **15/07/2010**
- **Significance = 4.7 ± 1.4**
- **S = 55 ± 7**
- **B = 85 ± 9**
- **Mean = (145.25 ± 0.15) MeV/c²**
- **Sigma = (436 ± 184) keV/c²**

**pp\sqrt{s} = 7 TeV, 1.40 \times 10^8 events, 3 < p_T < 5 GeV/c**

- **Significance = 11.4 ± 2.3**
- **S = 218 ± 15**
- **B = 198 ± 12**
- **Mean = (145.41 ± 0.07) MeV/c²**
- **Sigma = (688 ± 86) keV/c²**

**pp\sqrt{s} = 7 TeV, 1.40 \times 10^8 events, 5 < p_T < 8 GeV/c**

- **Significance = 16.8 ± 2.4**
- **S = 260 ± 16**
- **B = 76 ± 9**
- **Mean = (145.54 ± 0.05) MeV/c²**
- **Sigma = (548 ± 37) keV/c²**

**pp\sqrt{s} = 7 TeV, 1.40 \times 10^8 events, 8 < p_T < 12 GeV/c**

- **Significance = 8.5 ± 2.5**
- **S = 84 ± 9**
- **B = 12 ± 4**
- **Mean = (145.37 ± 0.08) MeV/c²**
- **Sigma = (659 ± 82) keV/c²**

**pp\sqrt{s} = 7 TeV, 1.40 \times 10^8 events, 12 < p_T < 18 GeV/c**

- **Significance = 4.2 ± 1.9**
- **S = 22 ± 5**
- **B = 5 ± 2**
- **Mean = (145.6 ± 0.1) MeV/c²**
- **Sigma = (499 ± 115) keV/c²**