Fixed target charmonium production with proton and lead beams at LHC

A.B.Kurepin, N.S.Topilskaya, M.B.Golubeva
INR RAS, Moscow

1. Physics motivation.
2. Geometrical acceptances for $J/\psi$ measurement at ALICE for PbPb interactions at $\sqrt{s}=5.5$ TeV and pp interaction at $\sqrt{s}=14$ TeV.
3. Evaluation of geometrical acceptances for PbPb and p-A fixed target $J/\psi$ measurement by dimuon spectrometer of ALICE.
5. Luminosity and counting rate estimation.
6. Conclusions.
Charmonium

35 years ago: discovery of J/ψ, 23 years ago: Matsui & Satz

colour screening in deconfined matter
→ J/ψ suppression
→ possible signature of QGP formation

Experimental and theoretical investigations
→ situation is much more complicated

cold nuclear matter / initial state effects (CNM)

- “normal” nuclear absorption
- (anti)shadowing
- saturation, color glass condensate

suppression via comovers
feed down from χc, ψ’
sequential screening (first: χc, ψ’, J/ψ only well above Tc)
regeneration via statistical hadronization or charm coalescence

important for “large” charm yield, i.e. RHIC and LHC?
### Colliders (RHIC, LHC)

<table>
<thead>
<tr>
<th></th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AA collisions</strong></td>
<td>CuCu, AuAu</td>
<td>PbPb</td>
</tr>
<tr>
<td>√s(GeV)</td>
<td>=200</td>
<td>=5.5 TeV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pA collisions</strong></td>
<td>pp, dAu</td>
<td>pp, pA</td>
</tr>
<tr>
<td>√s(GeV)</td>
<td>=200</td>
<td>=14  TeV</td>
</tr>
</tbody>
</table>

### Fixed-target data (SPS, FNAL, HERA)

<table>
<thead>
<tr>
<th></th>
<th>SPS: NA38, NA50, NA60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AA collisions</strong></td>
<td>SU, PbPb, InIn</td>
</tr>
<tr>
<td>√s(GeV)</td>
<td>19.4, 17.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>HERA-B, E866, NA50/51, NA38/3, NA60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pA collisions</strong></td>
<td>HERA-B, E866, NA50/51, NA38/3, NA60</td>
</tr>
<tr>
<td>√s(GeV)</td>
<td>41.6, 38.8, 29.1/27.4, 19.4, 27.4/17.3</td>
</tr>
</tbody>
</table>

Comparison of $J/\psi$/DY (NA38, NA50, NA60)

$\langle (J/\psi)/DY \rangle = 29.2 \pm 2.3$

$\langle L \rangle = 3.4$ fm

$\sigma_{abs}(J/\psi) = 4.2 \pm 0.5$ mb

NA50 results- an “anomalous suppression” in PbPb.
Preliminary NA60- “anomalous suppression” presented already in In-In.
p-A at 158 GeV showed that rescaling from 400 and 450 GeV to 158 GeV is correct. $\sigma_{abs}$ does not have strong energy dependence.
**QM09 new reference**

\[ \sigma_{\text{abs}} \text{ is energy and kinematic domain dependent} \]

\[ \sigma_{\text{abs}}^{J/\psi} (158 \text{ GeV}) = 7.6 \pm 0.7 \pm 0.6 \text{ mb} \]

\[ \sigma_{\text{abs}}^{J/\psi} (400 \text{ GeV}) = 4.3 \pm 0.8 \pm 0.6 \text{ mb} \]

Anomalous suppression in In-In \( \leq 10\% \)

Anomalous suppression in Pb-Pb up to 30\%

If anti-shadowing is taken in account (but very model dependent!)

Central Pb-Pb: still anomalously suppressed

In-In: almost no anomalous suppression?
Comparison SPS and RHIC data

No energy dependence, but rapidity dependence
Suppression $R_{AA}$ vs $N_{part}$ at RHIC.

PHENIX Au-Au data

Models for mid-rapidity Au-Au data

Without regeneration

With regeneration
Gluon saturation model for J/ψ production

Physical mechanism of suppression: diffusion in momentum space makes J/ψ formation less probable.

Prediction- strong overall suppression at LHC energy

Kharzeev, Levin, Nardi, Tuchin, arXiv:0809.2933

Statistical hadronization model

With regeneration


Predictions for LHC

No theoretical model that could reproduce all data.

Fixed target experiment at LHC for charmonium production at the energy range between SPS and RHIC in p-A and A-A collisions with planning proton beam at T=7 TeV ($\sqrt{s} = 114.6$ GeV) and Pb beam at 2.75 TeV ($\sqrt{s} = 71.8$ GeV) is possibility to clarify the mechanism of charmonium production, to separate two possibilities: i): hard production and suppression in QGP and/or hadronic dissociation or ii): hard production and secondary statistical production with recombination, since the probability of recombination decrease with decreasing energy of collision in thermal model.
Geometrical acceptances for $J/\psi$ at ALICE

**Pb-Pb, $\sqrt{s}=5.5$ TeV**

$J/\psi$ are generated using CEM $y$-spectra and CDF scaled $p_T$-spectra and including shadowing for Pb-Pb.

$I_{acc} = \frac{N_{accepted}}{N_{total\ generated}}$

- \( I_{acc} = 5.76\% \) - w/o $p_T$ cut
- \( 4.26\% \) - with cut $p_T > 1$ GeV/c

**pp, $\sqrt{s}=14$ TeV**

$J/\psi$ are generated according R.Vogt 2002 approximation for $p_T$-spectra and $y$ - distribution.

- \( I_{acc} = 4.71\% \) - w/o $p_T$ cut
- \( 4.01\% \) - with cut $p_T > 1$ GeV/c

\( N_{gen}(J/\psi) = 30000 \)
Fixed target experiment
Pb-Pb, T=2750 GeV, $\sqrt{s}=71.8$ GeV.

$J/\psi$ are generated at $z=0$ and outside of ITS at $z=+50$ cm.

$J/\psi$ are generated using $p_T$-spectra with HERA and PHENIX form, consistent with COM model, but parameters are energy scaled: $dN/dp_T \sim p_T [1 + (35\pi \cdot p_T / 256 \cdot <p_T>)^2]^{-6}$ with $<p_T> = 1.4$, and using $y$-spectra as Gaussian with mean value $y_{cm} = 0$ and $\sigma = 1.1$

$J/\psi$ are accepted in the rapidity range $-2.5<\eta<-4.0$ ($-2.98<\eta<-4.14$), and each of 2 muons in the degree range $171^0<\theta<178^0$ ($174.2^0<\theta<178.2^0$) for generation $J/\psi$ at $z=0$ ($z=+50$ cm).

$z=0$
$I_{acc} = 12.0%$

$z=+50$ cm
$I_{acc} = 8.79%$
Fixed target experiment
pA, T=7000 GeV, √s=114.6 GeV.
J/ψ are generated at z=0 and outside ITS at z=+50 cm.

J/ψ are generated using p_T-spectra with the same parametrization with energy scaled parameter: \( \frac{dN}{dp_T} \sim p_T [1 + (35\pi \cdot \frac{p_T}{256} \cdot <p_T>)^2]^{-6} \) where \( <p_T> = 1.6 \), and using y-spectra as Gaussian with mean value \( y_{cm} = 0 \) and \( \sigma = 1.25 \).

\[ z=0 \]
\[ I_{acc} = 8.54\% \]

\[ z=+50 \text{ cm} \]
\[ I_{acc} = 5.98\% \]
## Geometrical acceptances

**System pPb \text{fixed}**

<table>
<thead>
<tr>
<th>pt cut</th>
<th>$\sqrt{s}$ (TeV)</th>
<th>$z = 0$ cm</th>
<th>$z = +50$ cm</th>
<th>$z = -50$ cm</th>
<th>$z = +350$ cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>no cut</td>
<td>0.1146</td>
<td>8.54</td>
<td>5.98</td>
<td>5.07</td>
<td>0.21</td>
</tr>
<tr>
<td>pt &gt; 1 GeV/c</td>
<td>0.1146</td>
<td>6.77</td>
<td>4.89</td>
<td>4.11</td>
<td>0.19</td>
</tr>
<tr>
<td>no cut</td>
<td>0.0718</td>
<td>12.0</td>
<td>7.97</td>
<td>7.44</td>
<td>0.33</td>
</tr>
<tr>
<td>pt &gt; 1 GeV/c</td>
<td>0.0718</td>
<td>9.79</td>
<td>6.62</td>
<td>6.20</td>
<td>0.26</td>
</tr>
<tr>
<td>$\eta$ range</td>
<td>-4.0 $\leftrightarrow$ -2.5</td>
<td>-4.09 $\leftrightarrow$ -2.97</td>
<td>-3.76 $\leftrightarrow$ -2.5</td>
<td>-4.3 $\leftrightarrow$ -4.10</td>
<td></td>
</tr>
</tbody>
</table>
As it was already used for the experiment on collider with a fixed target at HERA-B K.Ehret, Nucl. Instr. Meth. A 446 (2000) 190, the target in the form of thin ribbon could be placed around the main orbit of LHC. The life time of the beam is determined by the beam-beam and beam-gas interactions. Therefore after some time the particles will leave the main orbit and interact with the target ribbon. So for fixed target measurements only halo of the beam will be used. Therefore no deterioration of the main beam will be introduced. The experiments at different interaction points will not feel any presence of the fixed target at the IP of ALICE.
## Luminosity, cross sections ($x_F>0$), counting rates

<table>
<thead>
<tr>
<th>System</th>
<th>√s (TeV)</th>
<th>$\sigma_{nn}$ (µb)</th>
<th>$\sigma_{pA}=\sigma_{nn} \cdot A^{0.92}$ (µb)</th>
<th>$\varepsilon$ (%)</th>
<th>$\varepsilon \cdot B \cdot \sigma_{pA}$ (µb)</th>
<th>L (cm$^{-2}$s$^{-1}$)</th>
<th>Rate (hour$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>14</td>
<td>32.9</td>
<td>32.9</td>
<td>4.7</td>
<td>0.091</td>
<td>3·10$^{30}$</td>
<td>982</td>
</tr>
<tr>
<td>pp$_{\text{RHIC}}$</td>
<td>0.200</td>
<td>2.7</td>
<td>2.7</td>
<td>3.59</td>
<td>0.0057</td>
<td>2·10$^{31}$</td>
<td>410</td>
</tr>
<tr>
<td>pPb$_{\text{fixed}}$</td>
<td>0.1146</td>
<td>0.65</td>
<td>88.2</td>
<td>5.98</td>
<td>0.310</td>
<td>1.5·10$^{29}$(*)</td>
<td>168</td>
</tr>
<tr>
<td>pPb$_{\text{fixed}}$</td>
<td>0.0718</td>
<td>0.55</td>
<td>74.6</td>
<td>7.97</td>
<td>0.349</td>
<td>1.5·10$^{29}$**</td>
<td>189</td>
</tr>
<tr>
<td>pPb$_{\text{NA50}}$</td>
<td>0.0274</td>
<td>0.19</td>
<td>25.8</td>
<td>14.0</td>
<td>0.212</td>
<td>7.10$^{29}$**</td>
<td>535</td>
</tr>
<tr>
<td>PbPb$_{\text{fixed}}$</td>
<td>0.0718</td>
<td>0.55</td>
<td>10130</td>
<td>7.97</td>
<td>47.5</td>
<td>3.2·10$^{27}$***</td>
<td>547</td>
</tr>
</tbody>
</table>

(*) pPb$_{\text{fixed}}$, 500 µ wire, 10$^{12}$ protons/60 min, z=+50 cm  
(***) PbPb cross section, 6.8·10$^{8}$ ions/60 min
Conclusions

1. The integrated geometrical acceptances for charmonium measurement by dimuon spectrometer of ALICE are 5.76% for $\sqrt{s}=5.5$ TeV Pb-Pb and 4.71% for $\sqrt{s}=14$ TeV pp collisions.

2. For fixed target charmonium measurement by ALICE spectrometer the geometrical acceptances are of the same order, and even larger: 7.97% for $\sqrt{s}=71.8$ GeV Pb-Pb and 5.98% for $\sqrt{s}=114.6$ GeV pA at $z=+50$ cm. The acceptances are compatible with the acceptances from other experiments, except HERA.

3. The energy range for fixed target experiment between SPS and RHIC gives important additional information.
BACKUP
Theoretical models could not reproduce simultaneously NA50 and NA60

Suppression by produced hadrons (“comovers”)

Capella-Ferreiro EPJ C42(2005) 419

QGP + hadrons + regeneration + in-medium effects

Grandchamp, Rapp, Brown EPJ C43 (2005) 91

Suppression due to a percolation phase transition

New results from NA60
R.Arnaldi, E.Scomparin, QM09

\[ \sigma_{\text{abs}} \] is energy and kinematic domain dependent

\[ \sigma (J/\psi) \sim \exp(-\rho \sigma_{\text{abs}} L) \]

\[ \alpha \] (158 GeV) = 0.882 ± 0.009 ± 0.008
\[ \alpha \] (400 GeV) = 0.927 ± 0.013 ± 0.009
The luminosity estimate is shown in the Table. This number we obtain from the LHC proton parameters for the Commissioning Version 3(*)

http://bruening.home.cern.ch/bruening/lcc/WWW-pages/commissioning_parameter.htm

It gives $1.15 \cdot 10^{11}$ protons per bunch, 44 bunches and life time 15.4 hours. From these parameters we get particle loss of $3.2 \cdot 10^{11}$ during one hour and luminosity about $1.5 \cdot 10^{29}$ for 500 micron lead ribbon.