Charmonium production in p-Pb collisions with ALICE at the LHC

Michael Winn
on behalf of the ALICE Collaboration
Universität Heidelberg

05.12.2014
Initial Stages 2014
J/ψ in nucleus-nucleus collisions

J/ψ suppression via colour screening suggested as a probe of deconfinement in heavy-ion collisions in 1986

LHC energies: production from deconfined charm quarks as consequence of deconfinement in AA collisions

- J/ψ production at phase boundary

- J/ψ production and destruction during lifetime of deconfined phase

Clear interpretation: pA as baseline for non-QGP nuclear effects
Predicted $J/\psi$ modifications in p-Pb at the LHC

leading twist gluon shadowing

saturation via Colour Glass Condensate (CGC)
also soon in NRQCD approach: R. Venogopalan et al., link: talk at Quarkonium '14

coherent energy loss of pre-resonant $c\bar{c}$

charm shadowing & dipole break-up

hot medium effects

- negligible/small nuclear absorption expected

Caveats:
- no consensus about pp production mechanism
- besides direct $J/\psi$: feed-down from B hadrons, $\psi(2S)$ and $\chi_c$
Charmonium with ALICE at the LHC

Acceptance in p-Pb:
Forward: $2.03 < y_{\text{cms}} < 3.53$
Backward: $-4.46 < y_{\text{cms}} < -2.96$
$p_T > 0$

Inclusive J/$\psi$ and $\psi(2S)$ down to $p_T = 0$ GeV/$c$ at forward rapidity
p-Pb: forward and backward rapidity via beam direction inversion

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Charmonium with ALICE at the LHC

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Forward: \(2.03 < y_{\text{cms}} < 3.53\)
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Inclusive \(J/\psi\) and \(\psi(2S)\) down to \(p_T = 0\) GeV/c at forward rapidity
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Charmonium with ALICE at the LHC

Acceptance in p-Pb:
-1.37 < \( y_{\text{cms}} \) < 0.43
\( p_T > 0 \)

Inclusive J/\( \psi \) down to \( p_T = 0 \) GeV/c at midrapidity
Prompt and non-prompt J/\( \psi \) down to low \( p_T \)
2013 p-Pb run

Dimuons: dedicated trigger

\[ L_{\text{int}} = 5.0 \text{ nb}^{-1} \text{ (forward)} \]

\[ L_{\text{int}} = 5.8 \text{ nb}^{-1} \text{ (backward)} \]

Dielectrons: Minimum Bias

\[ L_{\text{int}} = 52 \mu\text{b}^{-1} \]

-1.37 < \( y_{\text{cms}} \) < 0.43

\[ |y_{\text{lab}}| < 0.9 \]

\[ p_{T} > 0 \text{ GeV/c} \]

all plots \( p_{T} \)-and \( y \)-integrated here
$R_{pPb}^{J/\psi}$ as a function of rapidity

- significant suppression at forward rapidity
- mid-rapidity result compatible with forward rapidity result
- backward rapidity result consistent with no suppression

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$R_{pPb}^{J/\psi}$ as a function ofrapidity

Forward and backward rapidity results consistent with LHCb:
link: arXiv:1308.6729
JHEP 1402 (2014) 072

- EPS09 shadowing combined with CEM/CSM consistent with data
- energy loss models with/without shadowing consistent with data
- this CGC-based model disfavoured

μ⁺μ⁻: link: arXiv:1308.6726
JHEP 1402 (2014) 073
Prelim. HP' 13 e⁺e⁻:
link: arXiv:1404.1615

μ⁺μ⁻: link: arXiv:1308.6726
JHEP 1402 (2014) 073
Prelim. HP' 13 e⁺e⁻:
link: arXiv:1404.1615
Backward rapidity: $R_{pPb}^{J/\psi}(p_T)$

- EPS09 shadowing combined with CEM consistent with data
- roughly consistent with coherent energy loss models within uncertainties
Midrapidity: $R_{pPb}^{J/\psi}(p_T)$

- rise of $R_{pPb}$ with increasing $p_T$
- EPS09 shadowing with CEM production consistent with data
- coherent energy loss models consistent with data
- this CGC-based model consistent with data in this rapidity range

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: correlated
Forward rapidity: $R_{p\text{Pb}}^{J/\psi}(p_T)$

- similar pattern as at midrapidity
- consistent with EPS09 shadowing with CEM for $p_T > 4$ GeV/c
- underpredicted by energy loss models at low $p_T$ with/without shadowing
- underpredicted by this CGC-based model

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated
$R_{p\text{Pb}}^{J/\psi}(p_T)$ versus $R_{\text{PbPb}}^{J/\psi}(p_T)$

- different $p_T$-dependences of nuclear modification factor in Pb-Pb and p-Pb at forward and backward rapidity
Forward & backward rapidity

$R_{pPb}^{J/\psi}(p_T)$ versus $R_{PbPb}^{J/\psi}(p_T)$

2 → 1 kinematics probes ≈ the same Bjorken-x of Pb in p-Pb and Pb-Pb

- Assuming factorization of nuclear effects (e.g. only nPDF as nucl. effects in pA)

$R_{pPb}^{\text{forw}} \times R_{pPb}^{\text{backw}} (R_{pPb}^2)$: can be used as Pb-Pb expectation

→ enhancement at low-$p_T$ + suppression at high-$p_T$ in Pb-Pb

'extrapolation' also approximate for 2 → 2 kinematics within CEM at finite $p_T$

→ see talk by R. Vogt at Quarkonium 2014: link

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\[ R_{pPb} (p_T) \text{ versus } R_{PbPb}^{J/\psi} (p_T) \]

2 → 1 kinematics probes \( \approx \) the same Bjorken-x of Pb in p-Pb and Pb-Pb

- Assuming factorization of nuclear effects (e.g. only nPDF as nucl. effects in pA)

\[ R_{pPb}^{\text{forw}} x R_{pPb}^{\text{backw}} (R_{pPb}^2) : \text{ can be used as Pb-Pb expectation} \]

\[ \rightarrow \text{ enhancement at low } p_T + \text{ suppression at high } p_T \text{ in Pb-Pb} \]

'extrapolation' also approximate for 2 → 2 kinematics within CEM at finite \( p_T \)

\[ \rightarrow \text{ see talk by R. Vogt at Quarkonium 2014: link} \]
ψ(2S) in p-Pb: more suppressed than J/ψ

- Decrease of ψ(2S)/J/ψ-ratio from pp to p-Pb
- Hint of rapidity dependence, no dependence on $p_T$ within uncertainties
- Similar effect seen by PHENIX in d-Au collisions at midrapidity at $\sqrt{s_{NN}} = 200$ GeV

Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ → no explanation for this behaviour with these mechanisms


link: arXiv:1405.3796
Accepted by JHEP

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\( Q_{pA} \): event activity dependence of \( J/\psi \) & \( \psi(2S) \)

At forward rapidity (p-going):

- \( J/\psi \) and \( \psi(2S) \) exhibit stronger suppression with increasing event activity
- no dependence of additional \( \psi(2S) \) suppression w.r.t. \( J/\psi \) observed within uncertainties

\( Q_{pPb} \) instead of \( R_{pA} \) due to weaker correlation between estimator and geometry than in AA, and due to biases

ALICE: slicing events in signal from neutron energy measured by the Zero Degree Calor. to avoid biases:

\[
Q_{pPb}^{\text{mult.}} = \frac{N_{J/\psi \text{ in pPb in ZNA perc.}}}{<T_{pPb} \cdot \sigma_{J/\psi \text{ in pp}}} 
\]

\(<T_{pPb}>\) constructed such that multiplicity at midrapidity fulfills \( N_{\text{part}} \) scaling
$Q_{pA}$ : event activity dependence of $J/\psi$ & $\psi(2S)$

At backward rapidity (Pb-going):
- $Q_{pA}$ of $J/\psi$ consistent with unity
- $Q_{pA}$ of $\psi(2S)$ decreasing with increasing event activity

'event' activity dependence called $Q_{pPb}$ instead of $R_{pA}$ due to weaker correlation between estimator and geometry than in AA, and due to biases

ALICE: slicing events in signal from neutron energy measured by the Zero Degree Calor. to avoid biases:

\[
Q_{pPb}^{\text{mult.}} = \frac{N_{J/\psi \text{ in } pPb \text{ in } ZNA \text{ perc.}}}{<T_{pPb}^{J/\psi \text{ in } pp}> \cdot \sigma_{J/\psi \text{ in } pp}}
\]

$<T_{pPb}>$ constructed such that multiplicity at midrapidity fulfills $N_{\text{part}}$ scaling
Multiplicity dependence of J/ψ: pp vs p-Pb

- Clear increase of relative J/ψ yield in p-Pb at forw. & backw. rapidity
- Linear increase for backward rapidity (Pb-going) very similar to pp
- Onset of saturation at forward rapidity (p-going)
Multiplicity dependence of $\langle p_T^{J/\psi} \rangle$

Increase of relative $\langle p_T^{J/\psi} \rangle$ as function of multiplicity in $|\eta_{lab}|<0.5$

- saturation of increase at about $1.5 \cdot \langle dN_{ch}/d\eta \rangle$

- same behaviour at forward and backward rapidity within uncertainties
Conclusions

- $R_{pPb}^{J/\psi}$ as a function of rapidity consistent with
  - EPS09 gluon shadowing combined with CEM/CSM
  - coherent energy loss with/without shadowing
    some discrepancies for $R_{pPb}^{J/\psi}(p_T)$ at low $p_T$

- $R_{pPb}^{J/\psi}$ versus $R_{PbPb}^{J/\psi}$
  - low $p_T$: enhancement in Pb-Pb w.r.t. simple 'extrapolation' from p-Pb
  - high $p_T$: stronger suppression in Pb-Pb with respect to p-Pb

- $Q_{pPb}^{J/\psi}$ vs. event activity: suppression at forward rapidity & close to unity at backward rapidity

- Multiplicity dependence of relative $J/\psi$ yields similar to $pp$

- $<p_T^{J/\psi}>$ increasing with multiplicity and saturating at forward & backward rapidity

- $R_{pPb}^{\psi(2S)}$ at backward/forward rapidity: stronger suppression than $J/\psi$
p-Pb vs Pb-Pb:

- looser correlation between $N_{\text{part}}$ and impact parameter
- looser correlation between $N_{\text{part}}$ and multiplicity
  - fluctuations much more important
  - biases associated with experimental estimator choice important

- ALICE approach as consequence of observations in data:
  - slice events in zero degree neutron energy deposit on the Pb remnant side (ZNA), build $T_{pA}$ such that:
    a) midrapidity $dN/d\eta$ scales with $N_{\text{part target}}$
    b) Pb-side $dN/d\eta$ scales with $N_{\text{part target}}$
    c) high-pT yield at midrapidity scales with $dN/d\eta N_{\text{coll}}$

Underlying assumption: ZN insensitive to dynamical biases

Details in new p-Pb centrality publication
Comparison between the used multiplicity estimator and the variable used for the slicing in event activity bins for $Q_{pPb}$. 
Back-up: 2013 p-Pb Run

Dimuons: dedicated trigger

\[ L_{\text{int}} = 5.0 \text{ nb}^{-1} \text{ (forward)} \]

\[ L_{\text{int}} = 5.8 \text{ nb}^{-1} \text{ (backward)} \]

Dielectrons: Minimum Bias

\[ L_{\text{int}} = 52 \text{ \mu b}^{-1} \]

extensive usage of TPC-PID

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Back-up: Acceptance x efficiency for muon channel

Acceptance x Efficiency

$p$-$p_b$ $\sqrt{s_{NN}} = 5.02$ TeV, $J/\psi \rightarrow \mu^+\mu^-$, $p_T > 0$

- $2.03 < y_{cms} < 3.53$
- $-4.46 < y_{cms} < -2.96$

- ALICE PERFORMANCE 5/09/2013

Acceptance x Efficiency

$p$-$p_b$ $\sqrt{s_{NN}} = 5.02$ TeV, $J/\psi \rightarrow \mu^+\mu^-$

- $2.03 < y_{cms} < 3.53$
- $-4.46 < y_{cms} < -2.96$

- ALICE PERFORMANCE 5/09/2013
Dimuons:
- interpolation of ALICE results in pp at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7.0$ TeV in bins of $y, p_T$
- extrapolation in $y$, where necessary
  $y$-ranges only partially overlapping between pp and p-Pb
  cross-checked with approach chosen for the dielectrons

Dielectrons:
- $d\sigma/dy$ via interpolation of results (PHENIX, CDF, ALICE) at $y \approx 0$:
  $\text{BR}(J/\psi \rightarrow ee) \times d\sigma/dy_{pp, y \approx 0} (\sqrt{s} = 5.02 \text{ TeV}) = 368 \pm 91 \text{ nb}$
  effect of rapidity shift negligible w.r.t. total uncertainty
- $p_T$-dependence from
  phenomenological scaling
  inspired by arXiv:1103.2394

Back-up: pp-reference at $\sqrt{s} = 5.02$ TeV
Back-up: Uncertainties: $R_{pA}^{J/\psi}$ at midrapidity

<table>
<thead>
<tr>
<th>Source</th>
<th>$p_T$-integrated $R_{pA}$</th>
<th>$p_T$-differential $R_{pA}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistical uncertainty</strong></td>
<td>11.6 %</td>
<td>14 - 31 %</td>
</tr>
<tr>
<td><strong>Systematic uncertainties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal extraction &amp; PID</td>
<td>11.1 %</td>
<td>10 - 20 %</td>
</tr>
<tr>
<td>uncorr. between $p_T$-bins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>6.0 %</td>
<td>6.0 %</td>
</tr>
<tr>
<td>uncorr. between $p_T$-bins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC kinematics</td>
<td>3.0 %</td>
<td>negligible</td>
</tr>
<tr>
<td>Total syst. uncert. on yield</td>
<td>12.9 %</td>
<td>12 - 21 %</td>
</tr>
<tr>
<td>uncorr. between $p_T$-bins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{pA}$</td>
<td>3.4 %</td>
<td>not used</td>
</tr>
<tr>
<td>fully corr. w.r.t. forward and backward</td>
<td></td>
<td>consistent with use of MB</td>
</tr>
<tr>
<td>results</td>
<td></td>
<td>cross section</td>
</tr>
<tr>
<td>MB cross section</td>
<td>not used</td>
<td>3.4 %</td>
</tr>
<tr>
<td>corr. between $p_T$-bins and w.r.t. forward</td>
<td></td>
<td>consistent with use of $T$</td>
</tr>
<tr>
<td>result</td>
<td></td>
<td>$pA$</td>
</tr>
<tr>
<td>pp-reference</td>
<td>16.6 %</td>
<td>17.0 - 27.0 %</td>
</tr>
<tr>
<td>16.6 % correlated between $p_T$-bins</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Back-up: Bjoerken-x ranges for $J/\psi$ in p-Pb and Pb-Pb in $2 \rightarrow 1$ kinematics

For $2 \rightarrow 1$ kinematics: \[ x_{1/2} = \frac{m_T}{\sqrt{s_{NN}}} \exp(-/+y_{\text{cms}}) \]

Values for $p_T = 0 \text{ GeV}/c$ for the analysed data samples in 2010-2013:

**Dimuons:**
- p-Pb forward rapidity ($\sqrt{s_{NN}} = 5.02 \text{ TeV}$) \[ x_{\text{Pb}} = 1.8 - 8.1 \cdot 10^{-5} \]
- p-Pb backward rapidity ($\sqrt{s_{NN}} = 5.02 \text{ TeV}$) \[ x_{\text{Pb}} = 1.1 - 5.3 \cdot 10^{-2} \]
- Pb-Pb ($\sqrt{s_{NN}} = 2.76 \text{ TeV}$) \[ x_{\text{Pb}1} = 1.4 - 6.1 \cdot 10^{-2} \]
  \[ x_{\text{Pb}2} = 2.1 - 9.2 \cdot 10^{-5} \]

**Dielectrons:**
- p-Pb ($\sqrt{s_{NN}} = 5.02 \text{ TeV}$) \[ x_{\text{Pb}} = 0.4 - 2.4 \cdot 10^{-3} \]
- Pb-Pb ($\sqrt{s_{NN}} = 2.76 \text{ TeV}$) \[ x_{\text{Pb}} = 0.5 - 2.5 \cdot 10^{-3} \]
Back-up: $R_{pA}^\psi$: \( \psi(2S) \) and \( J/\psi \) model comparison

Model calculations for \( J/\psi \): very minor differences expected for \( \psi(2S) \)

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated
- grey box: fully correlated between \( \psi(2S) \) & \( J/\psi \)

link: arXiv:1308.6726  
JHEP 1402 (2014) 073

Shadowing & E-loss models: identical treatment of \( \psi(2S) \) & \( J/\psi \)

\[ \rightarrow \] no explanation for \( \psi(2S) \) behaviour
**Back-up:** $R_{pA}$ : $\psi(2S)$ and $J/\psi$ model comparison

Systematic uncertainties:
- Green box: uncorrelated
- Filled areas: (part.) correlated
- Grey box: fully correlated between $\psi(2S)$ & $J/\psi$

ALICE, p-Pb $|y_{NN}| = 5.02$ TeV, $2.03 < y_{cms} < 3.53$

- EPS09 NLO + ELoss with $q_s=0.055$ GeV$^2$/fm (Arleo et al.)
- ELoss with $q_s=0.075$ GeV$^2$/fm (Arleo et al.)
- EPS09 NLO (Vogt)

ShADOWING & E-loss models: identical treatment of $\psi(2S)$ & $J/\psi$

→ no explanation for $\psi(2S)$ behaviour

Same uncertainty display as on previous slide

**link:** arXiv:1308.6726
JHEP 1402 (2014) 073

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Back-up: $d\sigma/dy_{J/\psi}^{pA}$

$p$-Pb $\sqrt{s_{NN}} = 5.02$ TeV

$L_{\text{int}} = 52 \mu$b$^{-1}$ ($e^+e^-$)

$L_{\text{int}} = 5.0$ nb$^{-1}$ ($\mu^+\mu^-$, forward)

$L_{\text{int}} = 5.8$ nb$^{-1}$ ($\mu^+\mu^-$, backward)

ALICE Preliminary:
- inclusive $J/\psi \rightarrow e^+e^-$, $p_T > 0$ GeV/c

ALICE arXiv:1308.6726:
- Inclusive $J/\psi \rightarrow \mu^+\mu^-$, $0 < p_T < 15$ GeV/c
Back-up: $d^2\sigma/dydp_T^{J/\psi}$ 

$p$-Pb $s_{NN} = 5.02$ TeV

$L_{int} = 5.0$ nb$^{-1}$ ($\mu^+\mu^-$, forward)
$L_{int} = 5.8$ nb$^{-1}$ ($\mu^+\mu^-$, backward)
$L_{int} = 52$ μb$^{-1}$ ($e^+e^-$)

- inclusive $J/\psi \rightarrow \mu^+\mu^-$, $2.03 < y_{cms} < 3.53$
- inclusive $J/\psi \rightarrow \mu^+\mu^-$, $-4.46 < y_{cms} < -2.96$
- inclusive $J/\psi \rightarrow e^+e^-$, $-1.37 < y_{cms} < 0.43$
Back-up: $R^\text{J/\psi}_{\text{FB}}$

$p$-Pb $\sqrt{s_{\text{NN}}}= 5.02$ TeV, inclusive $J/\psi \rightarrow \mu^+\mu^-$
$2.96 < |y_{\text{cms}}| < 3.53, \ 0 < p_T < 15$ GeV/c

ALICE

- EPS09 NLO (Vogt)
- EPS09 LO (Ferreiro et al.)
- nDSG LO (Ferreiro et al.)
- EPS09 NLO and ELoss, $q_0 = 0.055$ GeV$^2$/fm (Arleo et al.)
- ELoss, $q_0 = 0.075$ GeV$^2$/fm (Arleo et al.)

link: arXiv:1308.6726
JHEP 1402 (2014) 073
### Back-up: Uncertainties: $R_{pA}^{J/\psi}$ at forward/backward rapidity

#### Statistical uncertainty

0.7 % (0.8 %)

#### Systematic uncertainties:

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma_{pPb}^{J/\psi}, R_{pPb}$</th>
<th>$\sigma_{Pbp}^{J/\psi}, R_{Pbp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Uncorrelated</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Signal extraction</td>
<td>1.3 (1.5 – 3.4)</td>
<td>1.2 (1.6 – 3.8)</td>
</tr>
<tr>
<td>MC input</td>
<td>1.5 (1.1 – 3)</td>
<td>1.5 (0.9 – 4.2)</td>
</tr>
<tr>
<td>Matching efficiency</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$F$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_{pp}^{J/\psi}$</td>
<td>4.3 (3.1 – 6.0)</td>
<td>4.6 (3.1 – 13.4)</td>
</tr>
<tr>
<td><em>Partially correlated</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{pPb}^{MB}$</td>
<td>3.2</td>
<td>3</td>
</tr>
<tr>
<td>$\sigma_{pp}^{J/\psi}$</td>
<td>3.7 (2.7 – 9.2)</td>
<td>3.1 (1.2 – 8.3)</td>
</tr>
<tr>
<td><em>Correlated</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.R.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$\langle T_{pPb} \rangle$</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{pp}^{J/\psi}$</td>
<td>5.5</td>
<td></td>
</tr>
</tbody>
</table>

#### y-differential $R_{pA}^{J/\psi}$

1.3 - 3.2 %

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Link: arXiv:1308.6726

JHEP 1402 (2014) 073
Back-up: Uncertainties: $R_{pA}^{J/\psi}$ at forward/backward rapidity

Preliminary

$p_T$-differential $R_{pA}^{J/\psi}$
forward (backward)

Statistical uncertainty
1.5 - 2.3 % (1.5 - 3.1 %)

Systematic uncertainties

Uncorrelated
4.8 - 8.0 % (6.8 - 10.1 %)
including uncertainty on tracking eff.,
matching between trigger system and
tracking chambers, signal extraction, trigger and MC kinematics

Partially correlated
8.4 - 9.7 % (8.1 - 9.9 %)
including uncertainty on pp-reference and MB cross section

$Q_{pA}$ has an additional uncertainty due to pile-up: 2 %
$Q_{pA}$ has an additional bin-by-bin uncorrelated $<T_{pPb}>$ between 1.5-9.5 % depending on the bin

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Back-up: Uncertainties: $R_{\text{pA}}^{\psi(2S)}$ at forward/backward rapidity

**Statistical uncertainty**

12 % (15 %)

**Systematic uncertainties:**

<table>
<thead>
<tr>
<th>Uncorrelated</th>
<th>$B.R. \cdot \sigma_{\text{pPb}}$</th>
<th>$B.R. \cdot \sigma_{\text{pPb}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking efficiency</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>2.8 (2 – 3.5)</td>
<td>3.2 (2 – 3.5)</td>
</tr>
<tr>
<td>Signal extraction</td>
<td>9.5 (8 – 11.9)</td>
<td>9.3 (8.6 – 12.7)</td>
</tr>
<tr>
<td>MC input</td>
<td>1.8 (1.5 – 1.5)</td>
<td>2.5 (1.5 – 1.7)</td>
</tr>
<tr>
<td>Matching efficiency $N_{\text{MB}}$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Partially correlated</td>
<td>$\sigma_{\text{pPb}}^{\text{MB}}$</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

link: arXiv:1308.6726  
JHEP 1402 (2014) 073
### Systematic uncertainties

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Forward Rapidity</th>
<th>Backward Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal method $N_{\text{bin}}^{J/\psi}$</td>
<td>1.5-3.3 %</td>
<td>1.5-4.6 %</td>
</tr>
<tr>
<td>Signal extraction $N_{\text{bin}}^{J/\psi}/N^{J/\psi}$</td>
<td>1.5-3.3 %</td>
<td>1.5-4.6 %</td>
</tr>
<tr>
<td>$&lt;p_T&gt;$ MC input</td>
<td>2 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Extraction $&lt;p_T&gt;/&lt;p_T&gt;^{\text{int}}$</td>
<td>0.1-0.4 %</td>
<td>0.1-1.2 %</td>
</tr>
<tr>
<td>$F$</td>
<td>1-7 %</td>
<td>1-4 %</td>
</tr>
<tr>
<td>$&lt;dN_{\text{ch}}/d\eta&gt;$</td>
<td>3.9 %</td>
<td>3.9 %</td>
</tr>
<tr>
<td>Pile-up</td>
<td>1-4 %</td>
<td>1.2 %</td>
</tr>
</tbody>
</table>
$d\sigma/dy_{\mu^+\mu^-}^{J/\psi_{pA}}$: comparison with LHCb

$p$-Pb $\sqrt{s_{NN}} = 5.02$ TeV, inclusive $J/\psi \rightarrow \mu^+\mu^-$

$R_{pA}^{J/\psi}$: comparison with LHCb

$p$-Pb $\sqrt{s_{NN}} = 5.02$ TeV, inclusive $J/\psi \rightarrow \mu^+\mu^-$


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\[ \frac{d^2 \sigma}{dy dp_T}^{J/\psi}_{pA} : \text{comparison with LHCb} \]

**p-Pb \( \sqrt{s_{NN}} = 5.02 \text{ TeV}, \text{inclusive } J/\psi \rightarrow \mu^+\mu^- \)**

- **ALICE:** \( 2.0 < y_{\text{cms}} < 3.5, \text{arXiv:1308.6726} \)
- **LHCb:** \( 2.0 < y_{\text{cms}} < 3.5, \text{arXiv:1308.6729} \)