# Charmonium production in *pp* and *p*-Pb collisions with ALICE at the LHC

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#### ALICE at the LHC

#### *pp* analysis:

Inclusive J/ $\psi$  cross section and polarization Prompt and non-Prompt J/ $\psi$  cross sections J/ $\psi$  as a function of charged particle multiplicity

*p*-Pb and Pb-*p* perspectives

#### Conclusions





# ALICE at the LHC



#### ALICE: A Large Ion Collider Experiment

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ALICE studies  $J/\psi$ production down to  $p_t=0$ at mid-rapidity (**|y|<0.9**) in the di-electron channel



Inner Tracking System (ITS), 6 layers: •2 Si pixel layers (SPD) •2 Si drift layers (SDD) •2 Si strip layers (SSD) Time Projection Chamber (TPC): main tracking detector, used for PID via specific energy loss

V0: scintillator arrays at forward and backward rapidities – used for MB trigger (with SPD) and for centrality determination



#### ALICE: A Large Ion Collider Experiment

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ALICE studies J/ψ production down to p<sub>t</sub>=0 at mid-rapidity (**|y|<0.9**) in the di-electron channel and at forward rapidity (**2.5<y<4**) in the di-muon channel



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V0: scintillator arrays at forward and backward rapidities – used for MB trigger (with SPD) and for centrality determination Muon Spectrometer:

- Front absorber
- 5 tracking stations
- Dipole magnet
- Iron wall
- 2 trigger stations



### $J/\psi \rightarrow (e^+e^-)\mu^+\mu^-$ in *pp*: ALICE performance

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Good performance in quarkonia detection



 $J/\psi$  studies in *pp* : inclusive cross section



Inclusive J/ $\psi$  cross section extracted for |y|<0.9 and 2.5<y<4 at vs = 7 and 2.76 TeV. Data collected during 2010 used, corresponding to an integrated luminosity:



#### Good agreement among the four LHC experiments!!



#### Inclusive J/ $\psi$ cross section

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 $d^2\sigma/dydpt$  at 7 TeV and at forward rapidity used for the NRQCD global fit (Butenschoen et al., Phys. Rev. D84 (2011) 051501) together with other data from LHC, Tevatron, B-factories, LEP and HERA

#### Cross sections well reproduced by NRQCD calculations at NLO

 $J/\psi$  polarization at the LHC very interesting to test the general understanding of quarkonium hadroproduction



### $J/\psi$ studies in *pp* : inclusive polarization



 $J/\psi$  polarization measured through extraction of anisotropies in angular distribution of decay muons. Taking as a reference the  $\mu^+$ (conventionally) :

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_{\theta}} \cdot (1+\lambda_{\theta}\cos^2\theta + \lambda_{\phi}\sin^2\theta\cos 2\phi + \lambda_{\theta\phi}\sin 2\theta\cos\phi)$$

 $\theta$  and  $\phi$  are the polar and azimuth angles of the  $\mu^{\scriptscriptstyle +}$  momentum in a given reference frame.

 $\lambda_{\theta}$  is the fundamental parameter:



P. Faccioli et al., EPJ C69 (2010) 657673



Two definitions of the *z*-axis considered:

- **helicity**: quarkonium momentum direction in the collision's reference frame;
- **Collins-Soper**: bisector of angle between one beam and the opposite of the other beam in the quarkonium rest frame;



Statistics not enough to perform a 2D study, parameters  $\lambda_{\theta}$  and  $\lambda_{\phi}$  extracted integrating over  $\phi$  and  $\cos\theta$  respectively.

Possible bias on the acceptance correction due to the integration avoided making use of an iterative procedure.

After each step of the iterative procedure the corrected spectra were fitted simultaneously in the two reference frames. The invariance condition:

$$\mathcal{F} = \frac{\lambda_{\theta}^{HE} + 3\lambda_{\phi}^{HE}}{1 - \lambda_{\phi}^{HE}} = \frac{\lambda_{\theta}^{CS} + 3\lambda_{\phi}^{CS}}{1 - \lambda_{\phi}^{CS}}$$

is required in the fit.

Releasing the F constraint the result is everywhere compatible with the one obtained with the default approach



![](_page_12_Picture_0.jpeg)

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ALICE Coll., Phys. Rev. Lett. 108 (2012) 082001  $\overset{\theta}{\prec}$ 0.8 helicity ALICE pp  $\sqrt{s} = 7$  TeV 2.5 < y < 4Collins-Soper 0.6 0.4 0.2⊨ 0 -0.2 -0.4 -0.6 Effect of non-prompt  $J/\psi$ -0.8E on  $\lambda_{\theta}$  is < 0.05 ≺°<sub>0.8</sub>⊧ 0.6 0.4 ⊟ 0.2⊨ 0 -0.2 -0.4E -0.6 -0.8 0 2 3 5 6 8 9 10 4  $p_{_{T}}$  (GeV/c)

No significant polarization observed in all the  $p_{t}$  range

Hint for longitudinal polarization at low  $p_t$  in the helicity frame which vanishes at higher  $p_t$ 

In the Collins-Soper reference frame  $\lambda_\theta$  always compatible with (but sistematically lower than) zero

 $\lambda_{\phi}$  always compatible with zero in both the reference frames

![](_page_13_Picture_0.jpeg)

### $J/\psi$ polarization: comparison with theory

M. Butenschön B.A. Kniehl, PRL 108(2011) 172002

![](_page_13_Figure_4.jpeg)

ALICE results compared with LO and NLO NRQCD and CSM predictions

None of the curves can perfectly describe data. NRQCD slightly favored, in particular in Collins-Soper

# In order to make the comparison data-theory more conclusive need to reach higher p<sub>t</sub> (new ALICE 2011 and 2012 data, other LHC experiments)

B. Gong at al., arXiv:1205.6682

![](_page_14_Picture_0.jpeg)

### $J/\psi$ studies in *pp* : (non-)prompt cross sections

![](_page_15_Picture_0.jpeg)

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For |y| < 0.9 ALICE is able to extract the non-prompt fraction of the inclusive J/ $\psi$  cross-section. Done with the same data sample used for the inclusive production study (L<sub>int</sub>= 5.6 nb<sup>-1</sup>)

# Simultaneous log-likelihood fit to the invariant mass and the pseudo-proper decay length distributions:

$$x = \frac{c \cdot L_{xy} \cdot m_{\mathrm{J}/\psi}}{p_{\mathrm{t}}^{\mathrm{J}/\psi}}, \qquad L_{xy} = \vec{L} \cdot \vec{p}_{\mathrm{t}}^{\mathrm{J}/\psi} / p_{\mathrm{t}}^{\mathrm{J}/\psi}$$

![](_page_15_Figure_6.jpeg)

![](_page_16_Picture_0.jpeg)

### Prompt J/ $\psi$ : results

ALICE Coll., JHEP11(2012)065

![](_page_16_Figure_4.jpeg)

Prompt cross section vs  $p_t$  and y complements the measurement of other LHC experiments

Several theoretical curves compared to the  $d^2\sigma/dydpt$ . Again, NRQCD factorization approach provides a good description of the data

Y-Q. Ma et al., PRL 106(2011) 042002 V.A. Saleev et al., Phys Rev D 85(2012) 074013 M. Butenschön B.A. Kniehl, Phys Rev D 84 (2011) 051501

![](_page_17_Picture_0.jpeg)

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Non-prompt cross section vs y compared with the other LHC experiments (when reaching  $p_t = 0$  or extrapolating to  $p_t = 0$ ) and with FONLL. **The agreement is very good (despite the large statistical uncertainty)** 

ALICE's result follows the FONLL predicted trend for the total  $b\overline{b}$  cross section as a function of Vs

![](_page_17_Figure_5.jpeg)

![](_page_18_Picture_0.jpeg)

 $J/\psi$  studies in *pp* : yields vs charged particle multiplicity

![](_page_19_Picture_0.jpeg)

![](_page_19_Figure_3.jpeg)

CHARGED PARTICLE MULTIPLICITY DENSITY: estimated at mid-rapidity ( $|\eta| < 1$ ) using tracks reconstructed by the SPD ( $N_{trk} \propto dN_{ch}/d\eta$  from MC simulation). Only events with a  $|z_{vtx}| < 10$  cm were retained and an event-by-event acceptance and efficiency correction is performed. Signal extracted starting from the di-muons and di-electrons invariant mass spectra with two different techniques:

at forward rapidity: fit (C.Ball+ sum of 2 expo)
at mid-rapidity: event counting after
subtraction of the background in the region
2.92-3.16 GeV/c<sup>2</sup>

![](_page_20_Picture_0.jpeg)

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 $1^{st}$  measurement at the LHC of relative J/ $\psi$  production yields as a function of the relative charged particle multiplicity density

![](_page_20_Figure_5.jpeg)

# Approximately linear increase observed in both *y* regions

#### Same behavior observed in open charm:

![](_page_20_Figure_8.jpeg)

![](_page_21_Picture_0.jpeg)

Perspectives for quarkonium studies in p-Pb and Pb-p

![](_page_22_Picture_0.jpeg)

### Perspectives for *p*-Pb studies

![](_page_22_Figure_3.jpeg)

ALICE took data in *p*-Pb and Pb-*p* collisions at  $\sqrt{s} = 5.02$  ATeV  $\rightarrow$  useful for studying cold nuclear matter effects (for QGP related studies)

# Very good performances of detectors involved in quarkonia detection

First results on  $R_{p-Pb}$  and  $R_{Pb-p}$  will be released very soon!

![](_page_22_Figure_7.jpeg)

![](_page_23_Picture_0.jpeg)

Conclusions

ALICE studied inclusive J/ $\psi$  production and polarization in *pp* collisions at  $\sqrt{s}$  = 7 and 2.76 TeV

The inclusive cross section is in agreement with what measured by the other LHC experiments and is well reproduced by NLO NRQCD

No significant polarization observed in the 2<pt<8 GeV/c region at forward rapidity in the helicity and Collins-Soper frames. NLO NRQCD and NLO CSM were compared with our result, showing a slightly better behavior of the first one with respect to the second.

Prompt and non-prompt J/ $\psi$  cross sections were extracted at mid-rapidity, thus providing a complementary measurement at low pt with respect to the other LHC experiments. The agreement with NLO NRQCD is again verified.

The J/psi yield measured at forward and mid-rapidity was found to increase linearly with the charged particle multiplicity density measured at mid-rapidity. The same trend is observed for open charm

Proton-nucleus data were collected during 2013 and they will be used to study cold nuclear matter effects. Results will be released very soon

![](_page_23_Picture_8.jpeg)