J/ψ production measurements in pp and PbPb collisions with ALICE at LHC

Francesco Bossù
for the ALICE collaboration

University and INFN of Turin

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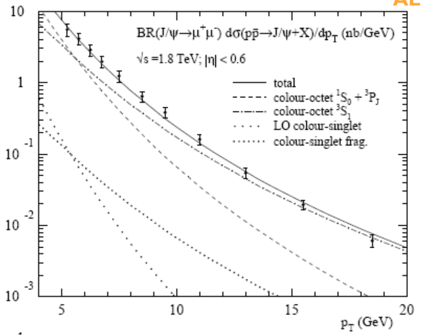
Outline

Outline

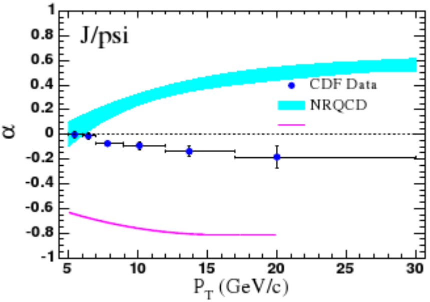
Physics motivations - proton-proton

Heavy quarkonium production is usually considered a two-stage process:

- Perturbative $q\bar{q}$ production
- Non-perturbative evolution when the bound state is formed

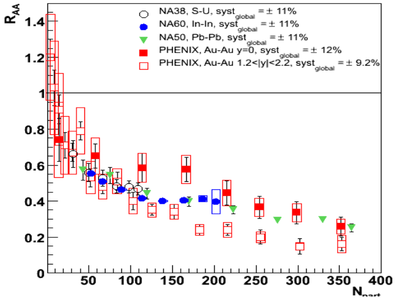


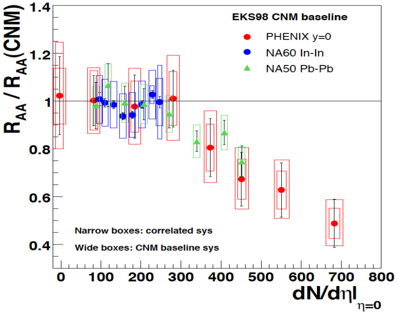
- J/ψ represents a good laboratory to test non-perturbative QCD
- Different models are available for the description of the production mechanism, but many issues are still open (x-section in wide range of $p_{\rm t}$, polarization...)
- New energy domain at LHC: measurement of the production cross section and kinematical properties will give new clues



Physics motivations - Pb-Pb

- Quarkonium suppression: one of the most promising probes of the QGP formation
- Not so easy: other effects such as Cold Nuclear Matter effects and $c\bar{c}$ regeneration play a role
- Suppression observed at SPS and RHIC but still many open issues
  - Suppression observed on top of CNM effects
  - Suppression at PHENIX not larger than at SPS
  - PHENIX measured larger suppression at forward rapidity

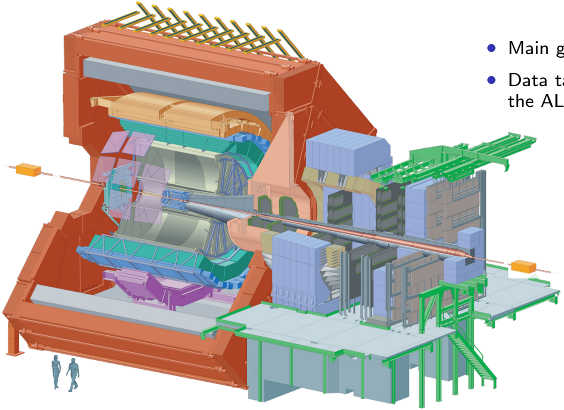




At LHC

- the cross section for $c\bar{c}$ production is 10 times larger with respect to RHIC
- higher energy density and lifetime of the fireball
- possible measurements in a wide range of p_t and y

The ALICE experiment



- Main goal: heavy-ion collisions
- Data taking in *p*-*p* collisions also included in the ALICE physics programme

ALICE in numbers

- $\sim$ 1300 members
- 116 institutes
- 33 countries
- 18 sub-detectors
- 10000 tons
- $16 \times 16 \times 26 m^3$

Central Barrel

- $|\eta| \leq 0.9$
- Hadrons, electrons and photons
- $p_t \rightarrow 0$

Muon Spectrometer

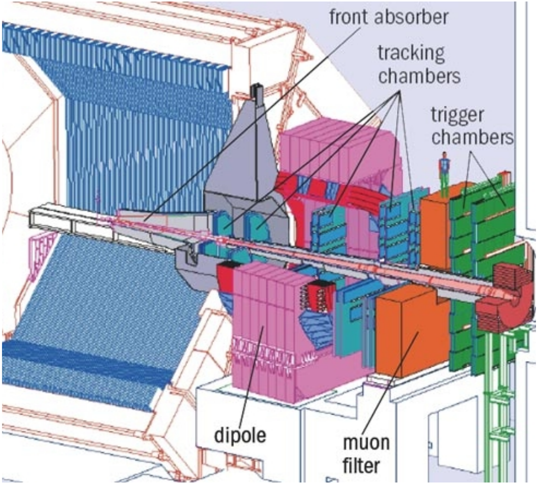
- $-4 \leq \eta \leq -2.5$
- Muons
- $p_{muons} > 4 GeV/c$

Forward Detectors

- Large η
- Interaction trigger
- Event centrality

Muon Spectrometer

- Quarkonia (J/ψ, ψ' and $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$) down to $p_t = 0$
- Open heavy flavours via single muons and dimuons
- Electroweak bosons (Z^0 and $W^\pm$)



Expected mass resolutions

	Single muon p_t cut
$\sim 70 MeV/c^2 \rightarrow J/\psi$	$1 GeV/c$
$\sim 100 MeV/c^2 \rightarrow \Upsilon$	$2 GeV/c$

Dipole

- B = 3 T m

Tracking System

- 5 stations of 2 planes of Cathode Pad Chambers (CPC) each
- 1.1M read-out channels
- spatial resolution $< 100 \mu m$ (bending plane)

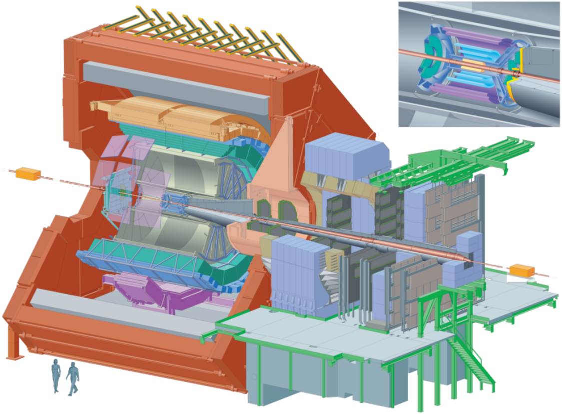
Trigger System

- 2 stations of 2 planes of Resistive Plate Chambers (RPC) each
- 21k read-out channels
- 2 programmable p_t cuts
- 5 different trigger signals sent in $\sim 800 ns$

Central Barrel

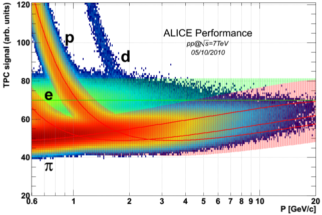
Inner Tracking System

- two layers each of silicon pixel, drift and strip detectors
- between 4 and 44 cm from the interaction point
- vertexing detector (primary and secondary)
- used in minimum bias trigger



Time Projection Chamber

- 90 m^3 of active volume
- 72 multiwire proportional readout chambers in 18 sectors
- main tracking detector
- PID via specific energy loss (dE/dx)

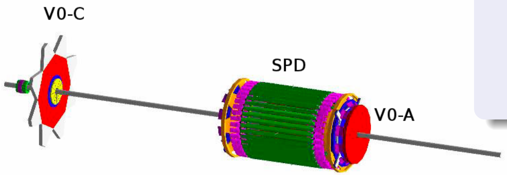


Outline

J/ψ in p-p collisions

- ALICE took data in p-p runs at two energies: $\sqrt{s} =$ 2.76 and 7 TeV
- Analysis results at 7 TeV published (PLB704 (2011) 442)
- At 2.76 TeV preliminary results
- Integrated luminosity used for cross section determination

	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
$\sqrt{s} = 7 TeV$	15.6 nb^{-1}	5.6 nb^{-1}
$\sqrt{s} = 2.76 TeV$	20.2 nb^{-1}	1.1 nb^{-1}



Event selection

- Minimum bias trigger (MB): OR between SPD (pixels) and V0s (scintillators)
- At least one particle in 8 η units

- Additional requirement for muon analysis: Single Muon trigger
- In coincidence with a MB
- Hardware p_{t} threshold: ≈ 0.5 GeV/c

J/ψ in p-p collisions

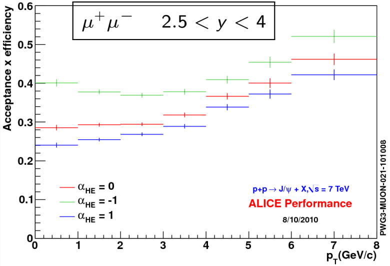
Kinematical and track quality cuts

$J/\psi \rightarrow e^+e^-$

- $|\eta_e| < 0.9$
- $p_{T\,e} > 1$ GeV/c
- $|y_{J/\psi}| < 0.9$
- Tracks ITS+TPC
- PID based on dE/dx
- Rejection of e^+e^- from γ

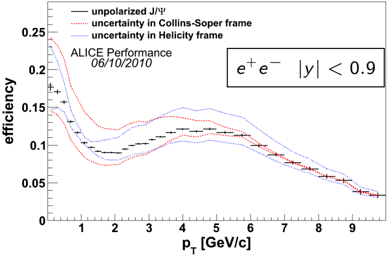
$J/\psi \rightarrow \mu^+\mu^-$

- $2.5 < \eta_\mu < 4$
- $2.5 < y_{J/\psi} < 4$
- At least one muon matching the trigger
- Cut at the end of the absorber



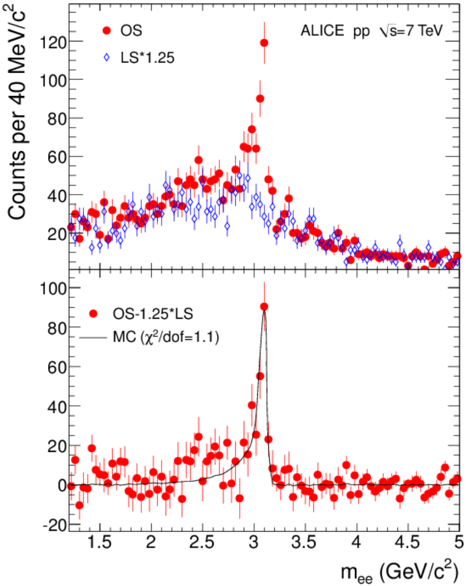
acceptance X efficiency

- In the the forward spectrometer it is slowly dependent on p_t and goes down to $p_t = 0$
- At mid-rapidity, ALICE is unique at LHC for low p_t reached

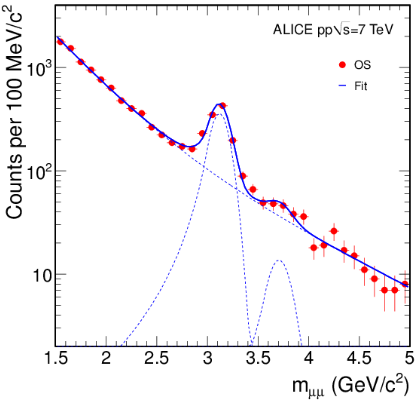


J/ψ in p-p collisions - Signal Extraction

$J/\psi \rightarrow e^+e^-$



$J/\psi \rightarrow \mu^+\mu^-$



- e^+e^-: signal extraction using bin counting after background subtraction. MC shape reproduces the data.
- $\mu^+\mu^-$: fit with Cristal-Ball functions ψ and ψ'; background described with a sum of two exponentials

J/ψ in p-p collisions - Cross Sections

$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{Acc \times \epsilon} \times \sigma_{MB}$$

σ_{MB}

Determination from van Der Meer scans

	σ_{MB}
7 TeV	62.3 ± 4.3 mb
2.76 TeV	54.2 ± 3.8 mb

(arXiv:1107.0692)

Inclusive J/ψ production cross section

- $\sqrt{s} = 7$ TeV (PLB704 (2011) 442)

$$\sigma_{J/\psi}(2.5 < y < 4) = 6.31 \pm 0.22(stat) \pm 0.76(syst)^{+0.95}_{-1.96}(syst.pol.)\ \mu\mathrm{b}$$

$$\sigma_{J/\psi}(|y| < 0.9) = 10.7 \pm 1.0(stat) \pm 1.6(syst)^{+1.6}_{-2.3}(syst.pol.)\ \mu\mathrm{b}$$

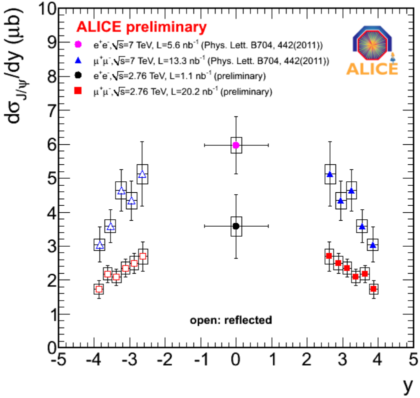
- $\sqrt{s} = 2.76$ TeV (preliminary; arXiv:1107.0137)

$$\sigma_{J/\psi}(2.5 < y < 4) = 3.46 \pm 0.13(stat) \pm 0.32(syst) \pm 0.28(lumi)^{+0.55}_{-1.11}(syst.pol.)\ \mu\mathrm{b}$$

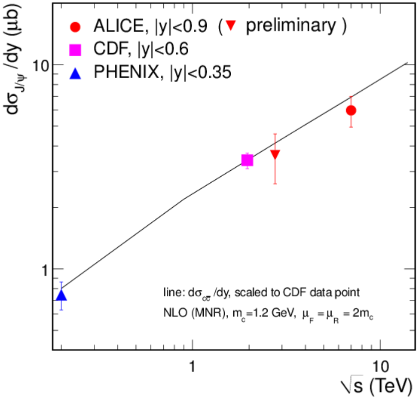
$$\sigma_{J/\psi}(|y| < 0.9) = 6.44 \pm 1.42(stat) \pm 0.88(syst) \pm 0.52(lumi)^{+0.64}_{-1.42}(syst.pol.)\ \mu\mathrm{b}$$

J/ψ in p-p collisions - Cross Sections - y distribution

- ALICE can measure J/ψ in a wide range of rapidity



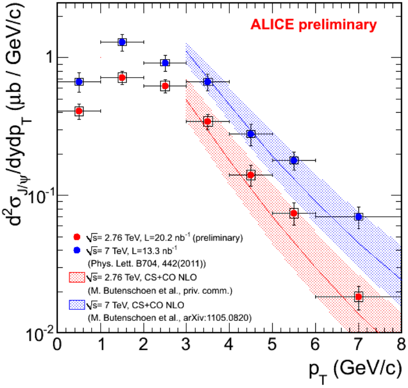
- NLO calculations lie on top of the data at different energies

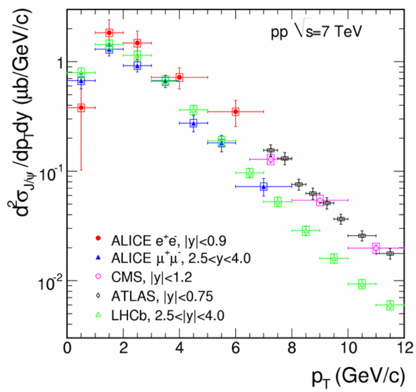


J/ψ in p-p collisions - Cross Sections - p_t distribution

- $d^2\sigma/dydp_t$ extracted at forward rapidities for both the energies
- NRQCD calculations well reproduce the data (for $p_t > 3$GeV/c)

- Fair agreement at 7 TeV with other LHC experiments
- At forward rapidities with LHCb
- At mid-rapidity ALICE is complementary to ATLAS and CMS



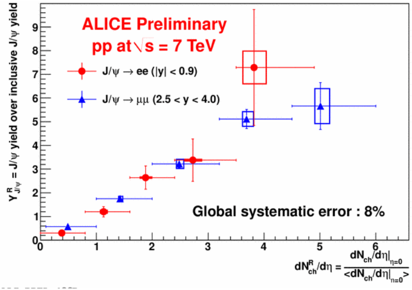


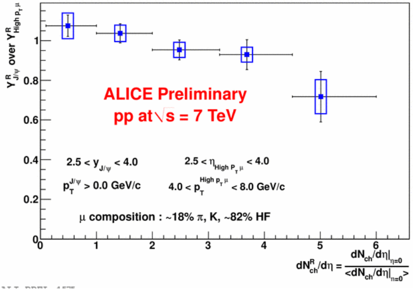
J/ψ in p-p collisions - Multiplicity dependence

J/ψ yield as a function of the charged particle multiplicity

- $dN_{ch}/d\eta^{max} \sim 30$ at $\sqrt{s} = 7$ TeV; comparable with semi-central CuCu collisions at 200GeV
- A linear increase is observed
- A smaller increase of the J/ψ yield with respect to high-p_{t} muons

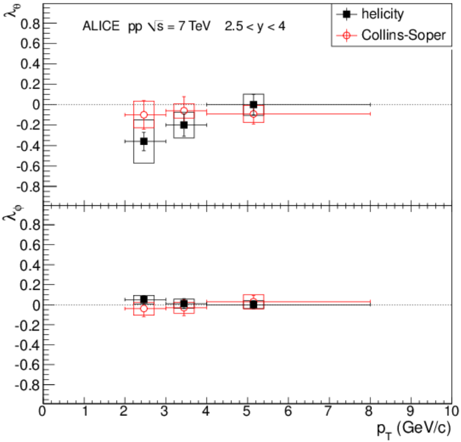
Solid explanations not yet available. Input from theorists needed





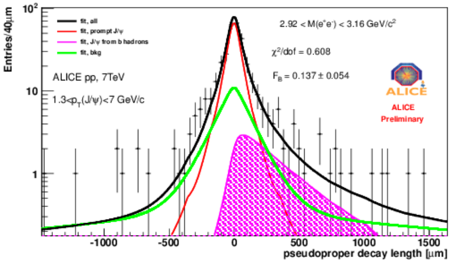
J/ψ in p-p collisions - Polarization

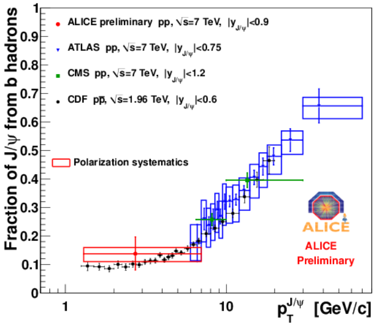
- J/ψ polarization studied in two different reference frames: Collins-Soper (CS) and Helicity (HE)
- Fresh results submitted for publication: arXiv:1111.1630
- The polarization parameters λ_θ and λ_ϕ were extracted in 3 p_t bins (from 2 to 8 GeV/c)
- Results show a slight increase of λ_θ with p_t in the helicity reference frame



J/ψ in p-p collisions - Non-prompt J/ψ

- At mid-rapidity ($|y| < 0.9$) excellent vertexing capabilities of the ITS
- It is possible to extract the non-prompt fraction of the total inclusive J/ψ cross section
- Simultaneous likelihood fit of the invariant mass and the pseudo-proper decay length





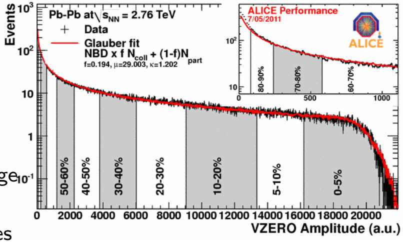
- The measurement extend the $p_{\rm t}$ reach of the LHC experiments at central rapidity down to 1.3 GeV/c
- It is also in agreement with CDF results

$$F_B = 0.137 \pm 0.054(stat) + 0.025 - 0 - 018(syst)^{+0.040}_{-0.021}(pol)$$

Outline

1. Motivations
2. J/ψ in p-p collisions
3. J/ψ in Pb-Pb collisions
4. Conclusions

J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV

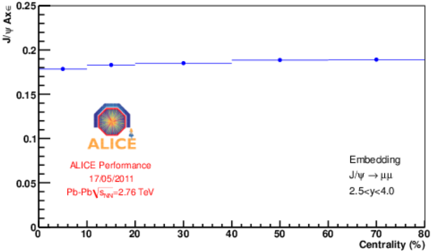


Trigger

- Minimum Bias: AND between V0s and SPD
- $\sim 17 \cdot 10^6$ MB events, Int. Lumi. $\sim 2.7 \mu b^{-1}$

Centrality

- Glauber model fit to VZERO amplitude
- EM contribution negligible in the centrality range 0-80%
- Limited statistics for J/ψ : less centrality classes
- $\mu^+\mu^-$: $[0, 10]$ $[10, 20]$ $[20, 40]$ $[40, 80]$%
- e^+e^-: $[0, 40]$ $[40, 80]$%



Track selection

- $\mu^+\mu^-$
- Both muons matching the trigger
- As in p-p : $2.5 < y_{J/\psi} < 4$, $2.5 < \eta_\mu < 4$, cut on position at the end of the absorber
- e^+e^-
- ITS+TPC tracks, PID by TPC
- $|\eta_e| < 0.8$

Acceptance

- Standard MC and real event embedding
- $\mu^+\mu^-$ small decrease ($\sim$5%) for central events

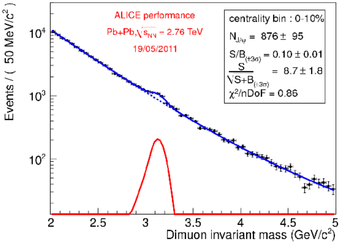
J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV - Signal Extraction

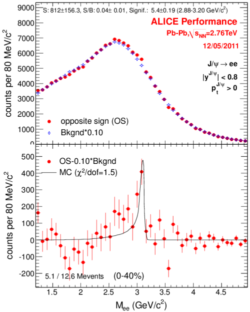
$\mu^+\mu^-$

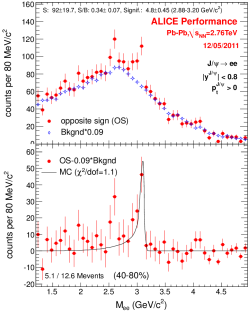
- Crystal-Ball shape (signal) and 2 exponentials for the background
- Mixed event technique, background subtraction and fit with the Crystal-Ball
- Results from different techniques combined to extract $< N_{J/\psi} >$

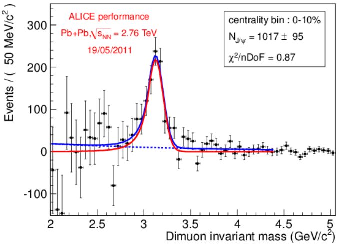
e^+e^-

- Small statistics, but signal is visible in spite of the low S/B
- Signal extraction: bin counting after background subtraction









J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV - R_{AA}

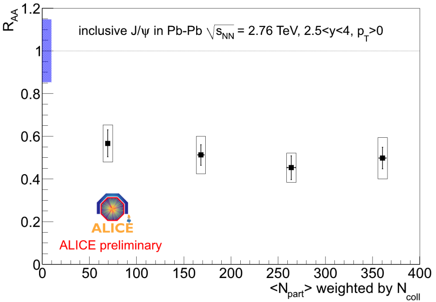
Nuclear Modification Factor

$$R^i_{AA} = \frac{Y^i_{J/\psi}}{\langle T^i_{AA}\rangle \times \sigma^{incl}_{J/\psi}(pp@2.76\,TeV)}$$

Inclusive J/$\psi \to \mu^+\mu^-$ - $2.5 < y < 4$, down to $p_t = 0$

$$R^{0-80}_{AA} = 0.49 \pm 0.03(stat) \pm 0.11(syst)$$

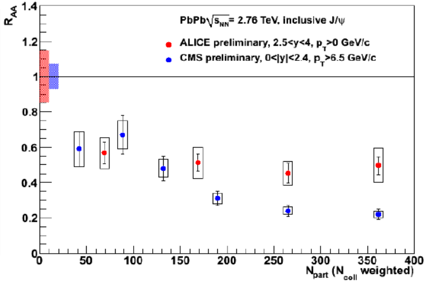
- Raw yield: $Y^i_{J/\psi} = \frac{N^i_{J/\psi}}{BR \cdot Acc \times eff \cdot N^i_{MB}}$
- Acceptance x efficiency corrections applied
- pp@2.76 TeV reference: see slide 13
- Error bars: statistical uncertainties
- Open boxes: centrality-dependent systematic uncertainties
- Blue box: common systematics
- Systematics dominated by signal extraction (up to 19% in the most central bin) and by the pp inclusive cross-section measurement (13%)

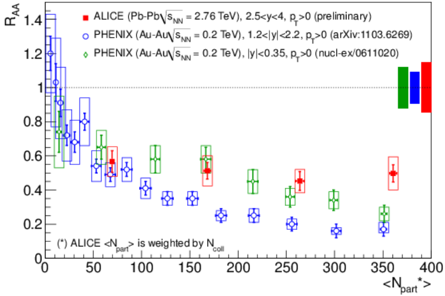


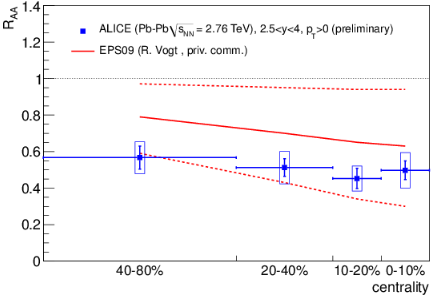
Suppression with no strong centrality dependence

J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV - R_{AA}

- Comparison with PHENIX
  - In the froward region J/ψ R_{AA} shows less suppression at LHC wrt RHIC, but...
  - PHENIX: $\sqrt{s_{NN}} = 0.2$ TeV, $1.2 < |y| < 2.2$
  - Need to understand the role of the CNM: theoretical predictions still have large uncertainties. Runs p-Pb and Pb-p needed
- Comparison with CMS
  - ALICE R_{AA} is slightly higher
  - but different kinematical region







J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV - R_{AA}

Comparison with models

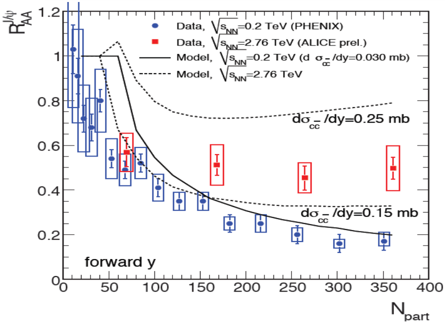
Statistical hadronization

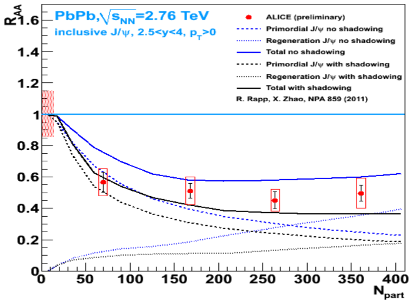
- Screening of all direct J/ψ
- CNM effects
- Charmonium production by statistical recombination of uncorrelated charm quarks

Parton transport model

- Prompt J/ψ dissociation
- Shadowing
- Charmonium production by statistical recombination of uncorrelated charm quarks
- B feed-down

Model needs recombination of $c\bar{c}$ quarks for reproducing the measured RAA, but more measurement are needed: total charm cross-section and J/ψ in pA collisions.



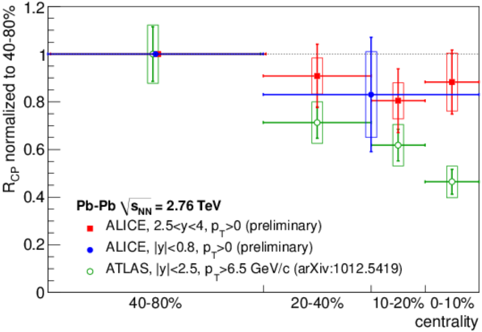


J/ψ in Pb-Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV - R_{CP}

R_{CP}

$$R^i_{CP} = \frac{Y^i_{J/\psi}/\langle T^i_{AA}\rangle}{Y^{40-80\%}_{J/\psi}/\langle T^{40-80\%}_{AA}\rangle}$$

- Independent from the p-p reference



ALICE

- $2.5 < y < 4$
- $|y| < 0.8$
- $p_t > 0$

ATLAS

- $|y| < 2.5$
- $p_t > 6.5$ GeV/c

- Error in the 40-80% bin not propagated
- R_{CP} larger for ALICE wrt ATLAS, but very different kinematical regions
- ALICE measurement of inclusive J/ψ R_{CP} at mid-rapidity is very challenging
- More statistics needed

Outline

Conclusions

- ALICE measured the inclusive J/ψ production cross section in p-p collisions at $\sqrt{s} = 7$ and 2.76 TeV both at mid rapidity and at forward rapidity down to $p_{\rm t} = 0$
- The measured cross section, as well as the $p_{\rm t}$ and y differential cross section, are in agreement with results from the other LHC experiments.
- J/ψ production shows a linear increase with the charged particle multiplicity: interpretations needed.
- First measurement of J/ψ polarization at LHC: J/ψ seems to be unpolarized except for low $p_{\rm t}$ bin in the helicity frame where a longitudinal polarization is measured.
- ALICE is able to measure J/ψ from B at mid-rapidity down to $p_{\rm t} = 0$, and first results were shown.

- Inclusive J/ψ production in Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV measured both at forward and mid-rapidity .
- R_{AA} at forward rapidity shows a clear suppression with N_{part} but less than PHENIX.
- R_{AA} and R_{CP} values larger than CMS and ATLAS, but kinematical coverage is different.
- It is mandatory a deep understanding of the CNM effects. p-Pb collisions expected at the end of 2012.

BACKUP

J/ψ in p-p - Polarization

ALICE

The polarization of the J/ψ can be measured through the angular analysis of its daughter particles. Taking as a reference the μ^+, its angular distribution can be expressed as:

$$W(\cos\theta, \varphi) \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$

The reference frame can be chosen in different ways and is defined on a event-by-event basis

All the three parameters can be extracted in a 1D approach

$$W(\cos\vartheta) \propto \frac{1}{3+\lambda_\vartheta}\left(1+\lambda_\vartheta \cos^2\vartheta\right)$$

Integrating over ϕ

$$W(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3+\lambda_\vartheta}\cos 2\varphi$$

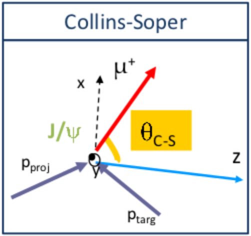
Integrating over $\cos\theta$

Defining $\tilde{\varphi} = \begin{cases} \varphi - \frac{3}{4}\pi & \text{for} \quad \cos\vartheta < 0 \\ \varphi - \frac{\pi}{4} & \text{for} \quad \cos\vartheta > 0 \end{cases}$

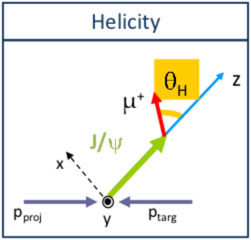
$$W(\tilde{\varphi}) \propto 1 + \frac{\sqrt{2}\,\lambda_{\vartheta\varphi}}{3+\lambda_\vartheta}\cos\tilde{\varphi}\,.$$

and integrating over $\cos\theta$

P.Faccioli *et al.*, arXiv:1006.2738



bisector of the angle between proj. and (-) target in the quarkonium C.M. frame.



Direction of the quarkonium in the C.M. frame of the collision.

J/ψ in Pb-Pb - Systematics

sources	centrality				
	0-10%	10-20%	20-40%	40-80%	correlated
$N_{J/\psi}$	19 %	14 %	17%	14%	-
$N_{J/\psi}/N_{J/\psi}^{40-80\%}$	12%	8%	7%	-	-
Acc. inputs	-	-	-	-	3%
Trigger eff.	-	-	-	-	4%
Tracking eff.	4%	2%	1%	0%	5%
Reco eff.	-	-	-	-	2%
Branching ratio	-	-	-	-	1%
Cross Section	-	-	-	-	13%
$\langle T_{AA}\rangle$	4%	4%	4%	6%	-
$\langle T_{AA}\rangle^i/\langle T_{AA}\rangle^{40-80\%}$	6%	5%	4%	-	-
Total for R_{AA}	**20%**	**15%**	**17%**	**15%**	**15%**
Total for R_{CP}	**14%**	**10%**	**8%**	**-**	**-**