Inclusive J/Ψ production in the dimuon channel in pp collisions at $\sqrt{s} = 5.02$ TeV at the ALICE

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analysis performed in collaboration with
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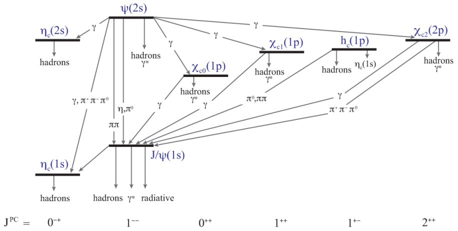
Outline

Charmonia as a probe of the QGP

- heavy quarks produced in the initial hard scattering
- their initial spectra not affected by the medium
- presence of QGP will modify spectra of $c\bar{c}$ bound states



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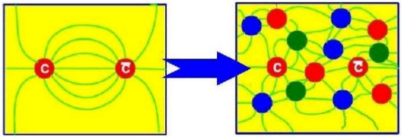
Debye-like colour screening

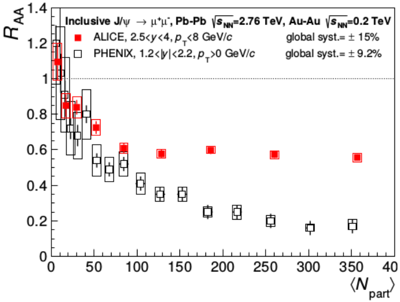
- high density of free colour charges in the medium causes colour screening in presence of QGP $\longrightarrow$ bound states cease to exist
- less tightly bound states "melt" first - sequential suppression



J/Ψ as a probe of the QGP

Other effects taking place...

- feed-down contribution from higher $c\bar{c}$ states, B-hadrons
- cold nuclear matter effects
- at LHC energies, recombination of $c\bar{c}$ pairs in the medium - $N_{c\bar{c}}^{LHC} \sim 10 N_{c\bar{c}}^{RHIC}$
- very low-p_T J/Ψ production (most likely) from photo-production



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Why measure J/Ψ in pp collisions

- understand the production mechanism - *see Astrid Morreale's talk, Nov 11 09.00*
- reference for A-A measurement

Nuclear modification factor R_{AA}

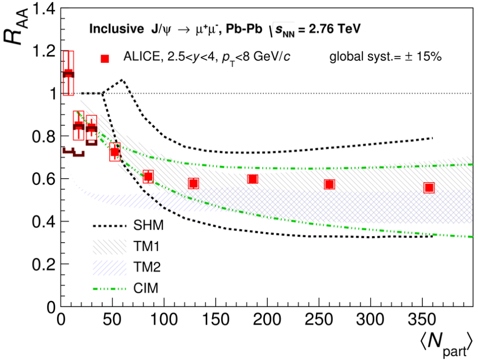
- production/suppression rates studied via Nuclear Modification factor R_{AA}

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{\mathrm{d}^2 N_{AA}/\mathrm{d}p_T \mathrm{d}y}{\mathrm{d}^2 \sigma_{pp}/\mathrm{d}p_T \mathrm{d}y}$$

$\Rightarrow$ directly compares behaviour in pp and in A-A

- $R_{AA} < 1$ suppression due to medium
- $R_{AA} > 1$ enhancement
- $R_{AA} = 1$ A-A is just a superposition of $N_{coll} \cdot$ pp OR both previous effects compensate

- compare with theoretical models
  - all models include dissociation by the hot medium + recombination to reproduce data
  - good agreement with ALICE data within uncertainty



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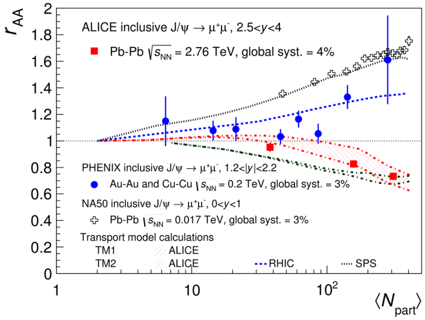
r_{AA}

- recombination can be studied by means of r_{AA}

$$r_{AA} = \frac{\langle p_T^2 \rangle_{AA}}{\langle p_T^2 \rangle_{pp}}$$

- thermalised c quarks decrease $\langle p_T \rangle$

- compared SPS, RHIC and LHC energies
- SPS increase due to Cronin effects
- RHIC r_{AA} consistent with 1
- Pb-Pb at 2.76 TeV significant decrease of r_{AA} with increasing centrality



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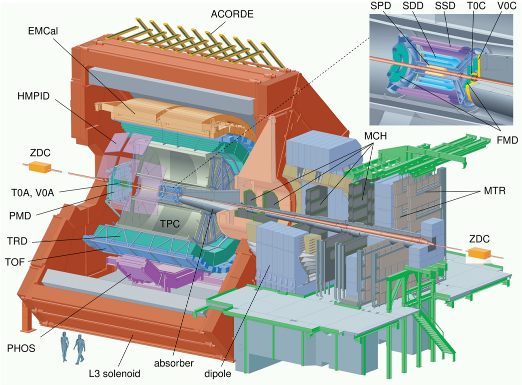
ALICE detector

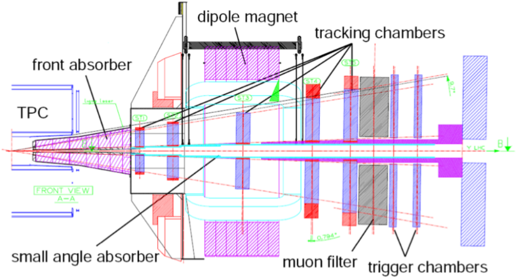


ALICE = A Large Ion Collider Experiment

Dimuon sample from Muon Spectrometer

- **V0** provides MB trigger, rejects beam-gas iteraction, centrality (A-A)
- **T0** MB trigger
- **ITS** collision vertex
- **ZDC** rejects UPC (A-A)

Muon spectrometer



Muon Spectrometer

- covers rapidity $2.5 < y < 4$
- $0 < \varphi < 2\pi$
- front absorber - background reduction
  - stops muons from π, K decays
  - stops hadrons produced in absorber itself
- dipole magnet + MCH detection of dimuon pair
- MTR shielded by an absorber on each side
  - excludes noise from beam-gas interactions

Analysis of $J/\Psi \longrightarrow \mu^+ + \mu^-$ in pp at 5.02 TeV

number of reconstructed J/Psi

$$\frac{d^2\sigma^{pp}_{J/\Psi}}{dp_T dy} = \frac{d^2 N^{pp}_{J/\Psi}/dp_T dy}{BR_{J/\Psi\rightarrow\mu\mu}\, A\times\varepsilon} \times \frac{\sigma^{pp}_{MB}}{N^{MB}_{evt}}$$

detector response

luminosity^{-1}

- σ^{pp}_{MB} from independent measurement and/or data
- $A \times \varepsilon$ computed from simulations
- $BR_{J/\Psi\rightarrow\mu^+ + \mu^-} = 5.96 \pm 0.03\%$ (PDG)

We analysed a sample of $\sim$1.2M events with dimuon trigger fired.

J/Ψ Signal Extraction

Kinematical cuts

single muon criteria:

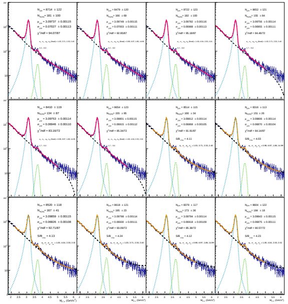
- ⋆ $-4 < \eta < -2.5$
- ⋆ $2^\circ < \Theta_{Abs} < 10^\circ$
- ⋆ *Lpt* trigger matching

pair criteria:

- ⋆ $2.5 < y < 4$ required for the dimuon pair

Fitting functions

- signal as CB2E and NA60
- background: VWG and Pol1/Pol2
- $1.7 < M_{inv} < 4.8$ GeV$/c^2$ and
  $2.0 < M_{inv} < 4.4$ GeV$/c^2$

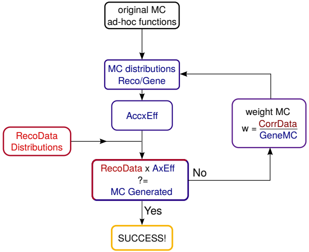


Integrated over $0 < p_T < 12$ GeV$/c$

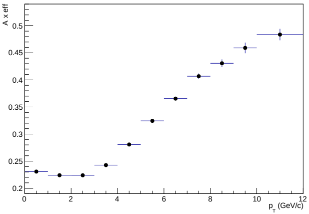
$$N_{J/\Psi} = \mathbf{8649} \pm \mathbf{123} \pm \mathbf{297}$$

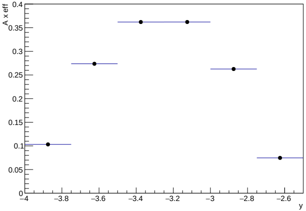
Acceptance-efficiency $A \times \varepsilon$

- correction for detector effects
- not all produced μ fire a trigger in the spectrometer
- MC simulations tuned to data through an iterative procedure



$$0 < p_T < 12 \text{ GeV}/c: \; A \times \varepsilon = \mathbf{0.2435} \pm \mathbf{0.0003} \pm \mathbf{0.0049}$$

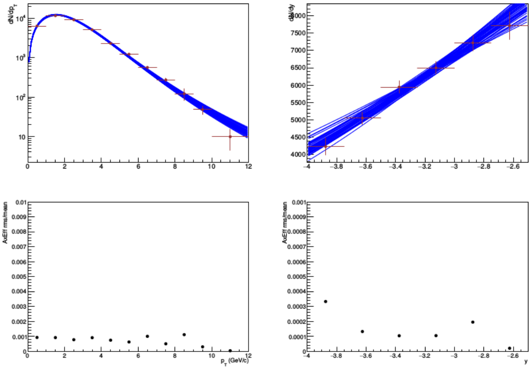




Systematics on $A \times \varepsilon$

Finite statistics

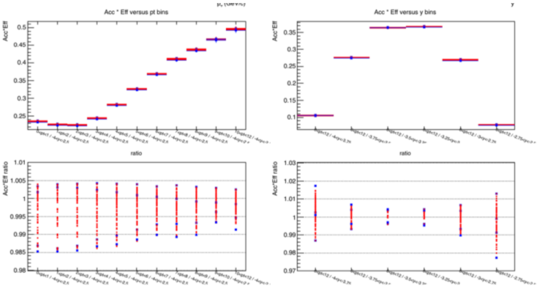
- related to statistical uncertainty on the data points
- gaussian smearing of the distribution within stat. uncertainty
- new set of shapes used to recompute $A \times \varepsilon$
- resulting systematics $< 0.1\%$



Systematics on $A \times \varepsilon$

$p_T - y$ correlations

- not enough statistics to carry 2D signal extraction
- p_T/y distributions at 13 TeV and 7 TeV (LHCb)
- re-weight our distributions and recompute $A \times \varepsilon$
- integrated over p_T and y amounts to 2%



Normalisation Factor F_{norm}

Determine the equivalent N_{MB}^{eq} corresponding to N_{CMUL7} analysed $N_{MB}^{eq} = \sum F_{norm}^{i} \times N_{MUL}^{i}$

- correction for pile-up $F_{Pile-Up}$ and purity $F_{purity} = \frac{N_{CINT7}(PhysicsSelected)}{N_{CINT7}(ALL)}$

$$\mu = -\ln\left(1 - \frac{F_{purity}^{MB} \times L0brate_{MB}}{N_{coll} \times f_{LHC}}\right)$$

$$F_{Pile-Up} = \frac{\mu}{1 - e^{-\mu}}$$

3 different methods:

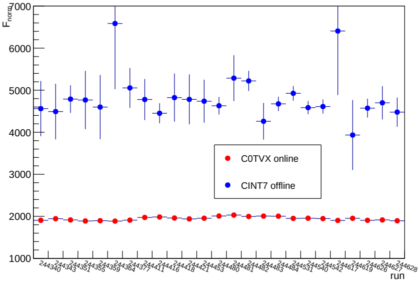
- **direct offline method:** $F_{norm} = \frac{\text{CINT7}}{\text{CINT7\&0MUL}} \times F_{Pile-Up}$ not enough statistics!
- **2-step offline method:** $F_{norm} = \frac{\text{CINT7}}{\text{CINT7\&0MSL}} \times \frac{\text{CMSL7}}{\text{CMSL7\&0MUL}} \times F_{Pile-Up}$
- **online scalers method** (CINT7/C0TVX): $F_{norm} = \frac{\text{L0b(MB)}}{\text{L0b(CMUL7)}} \times \frac{\text{PS}_{\text{MB}}}{\text{PS}_{\text{CMUL7}}} \times F_{Pile-Up}$

F_{norm}

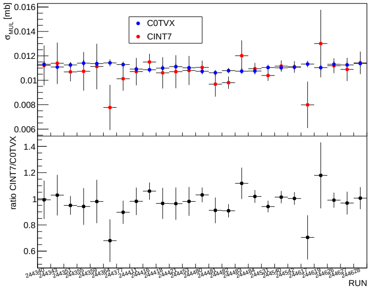
Assuming fully uncorrelated errors:

$$\text{V0 (CINT7)} \sim F_{norm} = 4736.87 \pm 60.29$$

$$\text{T0 (C0TVX)} \sim F_{norm} = 1960.18 \pm 1.67.$$



Integrated luminosity L_{int}



In the presented result we used the F_{norm} computed from the T0 scalers.

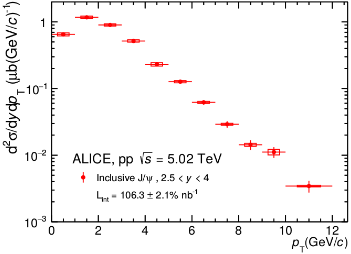
$$L_{int} = \frac{N_{MB}}{\sigma_{vdM}} = \frac{N_{MUL}^{tot} \times F_{norm}}{\sigma_{vdM}}$$

$$L_{int} = 106.28 \pm 0.09(stat) \pm 2.23(syst)\ \mathrm{nb}^{-1}$$

pp cross-section @ 5.02 TeV

$$\sigma^{pp}_{J/\Psi} = \frac{1}{\Delta p_T \Delta y} \frac{N_{J/\Psi}(\Delta p_T, \Delta y)}{BR_{J/\Psi \to \mu^+ + \mu^-} A \times \varepsilon(\Delta p_T, \Delta y)} \frac{1}{L_{int}}$$

$$\sigma^{pp}_{J/\Psi} = \mathbf{5.61} \pm \mathbf{0.08} \pm \mathbf{0.28}\ \mu\text{b}$$



arXiv:1606.08197

Comparison to interpolation

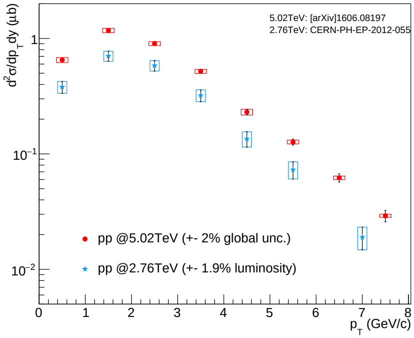
- interpolation done by ALICE+LHCb (ALICE-PUBLIC-2013-002) to be used as a reference for Run 1 p-Pb measurement at 5.02 TeV

$$\sigma^{pp,int}_{J/\Psi} = 5.28 \pm 0.42\ \mu\text{b}$$

- good agreement between data and interpolation

pp cross-section 5.02 TeV VS 2.76 TeV

- improved tracking + better statistics ⇒ lower uncertainties
- $\sim$ 9000 J/Ψ in 5.02 TeV X $\sim$ 1400 J/Ψ in 2.76 TeV
- improvement of R_{AA} uncertainty - *see Benjamin Audurier's talk, Nov 11 11.45*



Mean p_T

$\langle p_T \rangle$ extraction method

- corrected p_T spectra fitted with

$$f(p_T) = \frac{[0]p_T}{\left(1+(p_T/[1])^2\right)^{[2]}}$$

- compute $\langle p_T \rangle$ as the mean of $f(p_T)$

- 2 ways to compute error
  1. from a 1σ contour compute $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ from the points on the contour
  2. through error propagation from covariance matrix of the fit
- both methods give similar results

$$\langle p_T \rangle = 2.3204 \pm 0.0231 \pm 0.0170$$
$$\langle p_T^2 \rangle = 7.4144 \pm 0.1276 \pm 0.0733$$

Mean p_T and r_{AA}

- $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ for Pb-Pb computed by Mohamad T.
- r_{AA} @5.02TeV consistent within uncertainty r_{AA} @2.76TeV
- the former systematically above the latter - harder spectra with increasing $\sqrt{s}$

Conclusions

- first ALICE measurement on the inclusive $J/\Psi \rightarrow \mu^+ + \mu^-$ in pp at $\sqrt{s} = 5.02$ TeV
- first result on $\sigma^{pp}_{J/\Psi} = 5.61 \pm 0.08 \pm 0.28\ \mu$b
- interpolated $\sigma^{pp,interpolated}_{J/\Psi}$ in good agreement with the data
- we have taken a look at $\langle p_T \rangle$ and r_{AA}
- centrality dependence of r_{AA} consistent with Pb-Pb at 2.76 TeV in favour of recombination

Thank you for your attention!