Quarkonium production in pp, p-Pb and Pb-Pb collisions with the ALICE experiment

Lizardo Valencia Palomo

ALICE

cnrs dépasser les frontières

Content

Physics motivation

The ALICE experiment

Quarkonium production in
- pp $\sqrt{s}$ = 7 & 2.76 TeV
- p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

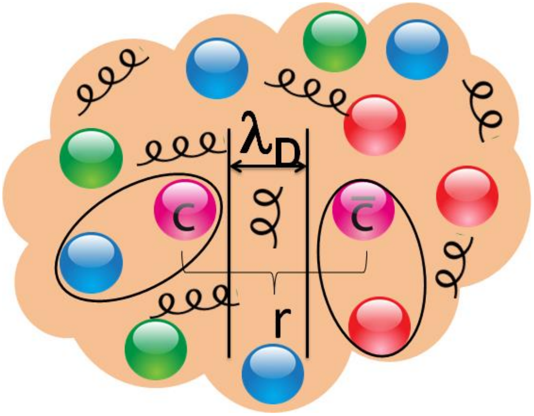
Conclusions

The ALICE collaboration

Physics motivation

Quarkonium in A-A collisions

- In 1980's J/ψ is proposed as a probe of the Quark Gluon Plasma (PLB 178 (1986) 416):
  - Produced in the early stages of the collisions.
  - Suppressed by the Debye screening.



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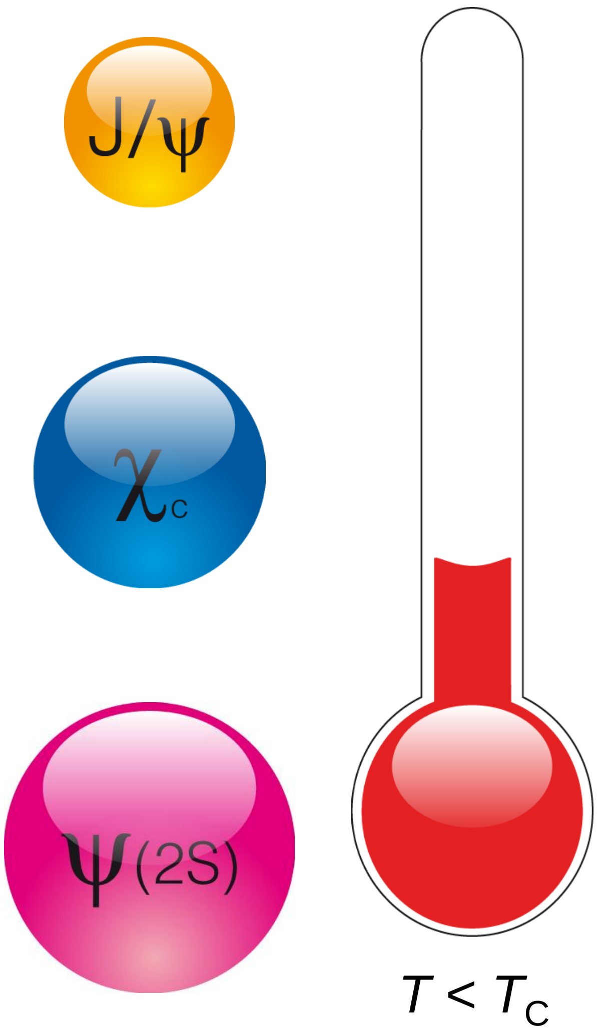
    - Excited states melt down at different temperatures ➔ sequential suppression.



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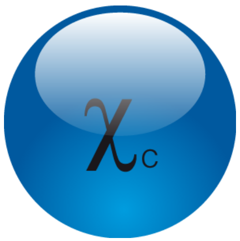

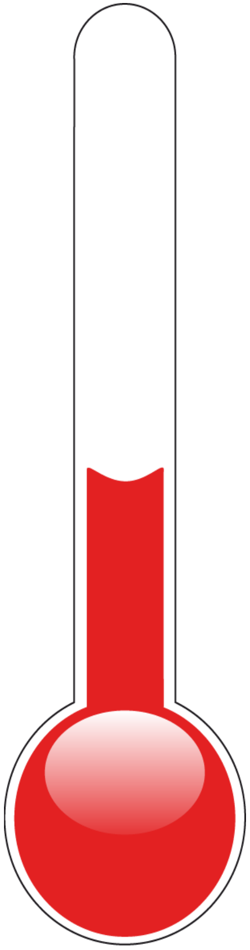

$T \approx T_C$

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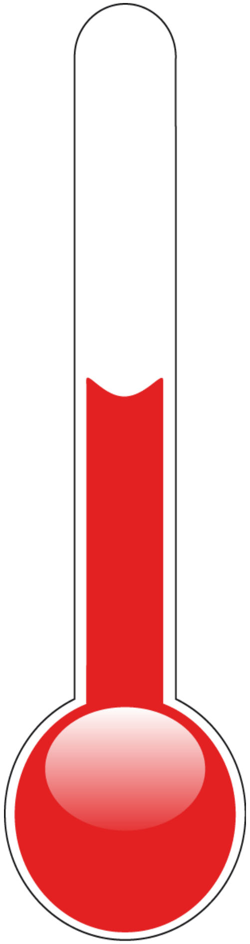

$T \approx 1.1\ T_C$

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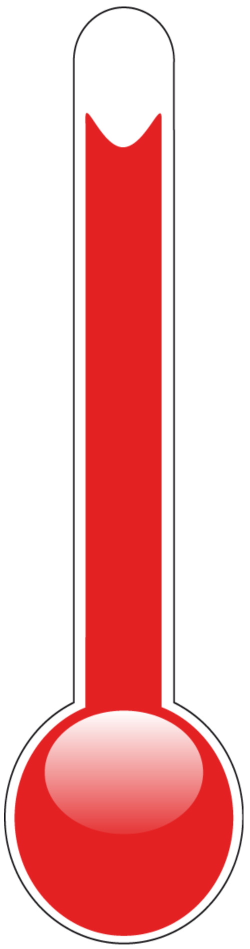
  - Quarkonium as a thermometer of the QGP!



$T \approx 2.1\ T_C$

Quarkonium in A-A collisions

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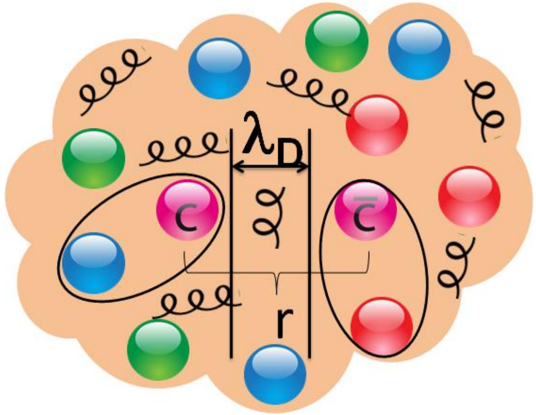

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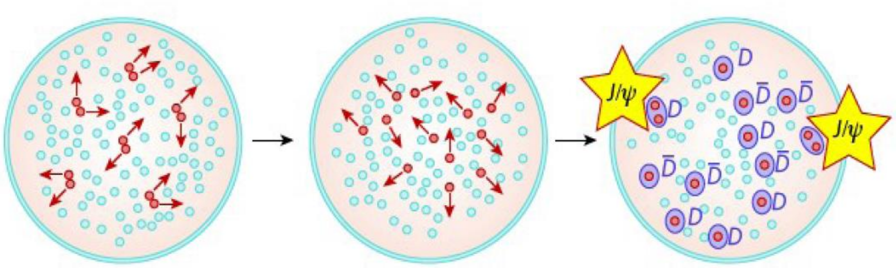
  - Excited states melt down at different temperatures ➔ sequential suppression.
  - Quarkonium as a thermometer of the QGP!

- At top LHC energy:
  - $N_{c\bar{c}}$/central collision ≈ 120 ➔ new source of charmonium production from recombination of $c\bar{c}$ pairs?

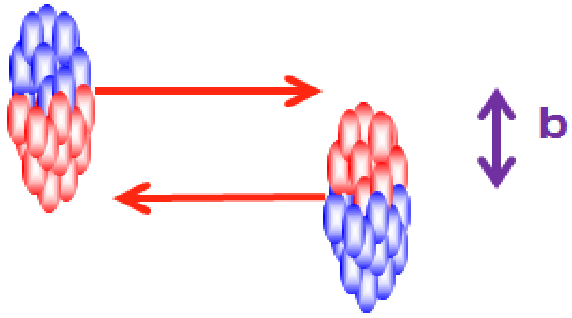


Nature 448 (2007) 302

Quarkonium in pp and pA collisions

- proton-proton (pp) collisions:
  - Test pQCD inspired models.
  - Reference for HI studies.
- proton-nucleus (pA) collisions:
  - Study Cold Nuclear Matter (CNM) effects.
  - Particle production can be affected by initial/final state effects:
    - Shadowing (JPG 32 (2006) R367): gluon PDF of nucleons embedded in nucleus ≠ gluon PDF of free nucleons.
    - Comovers (PRL 77 (1996) 1703): dissocation by other particles produced during the collision.
    - Energy loss (PRL 68 (1992) 1834): initial/final state partons may undergo scattering.

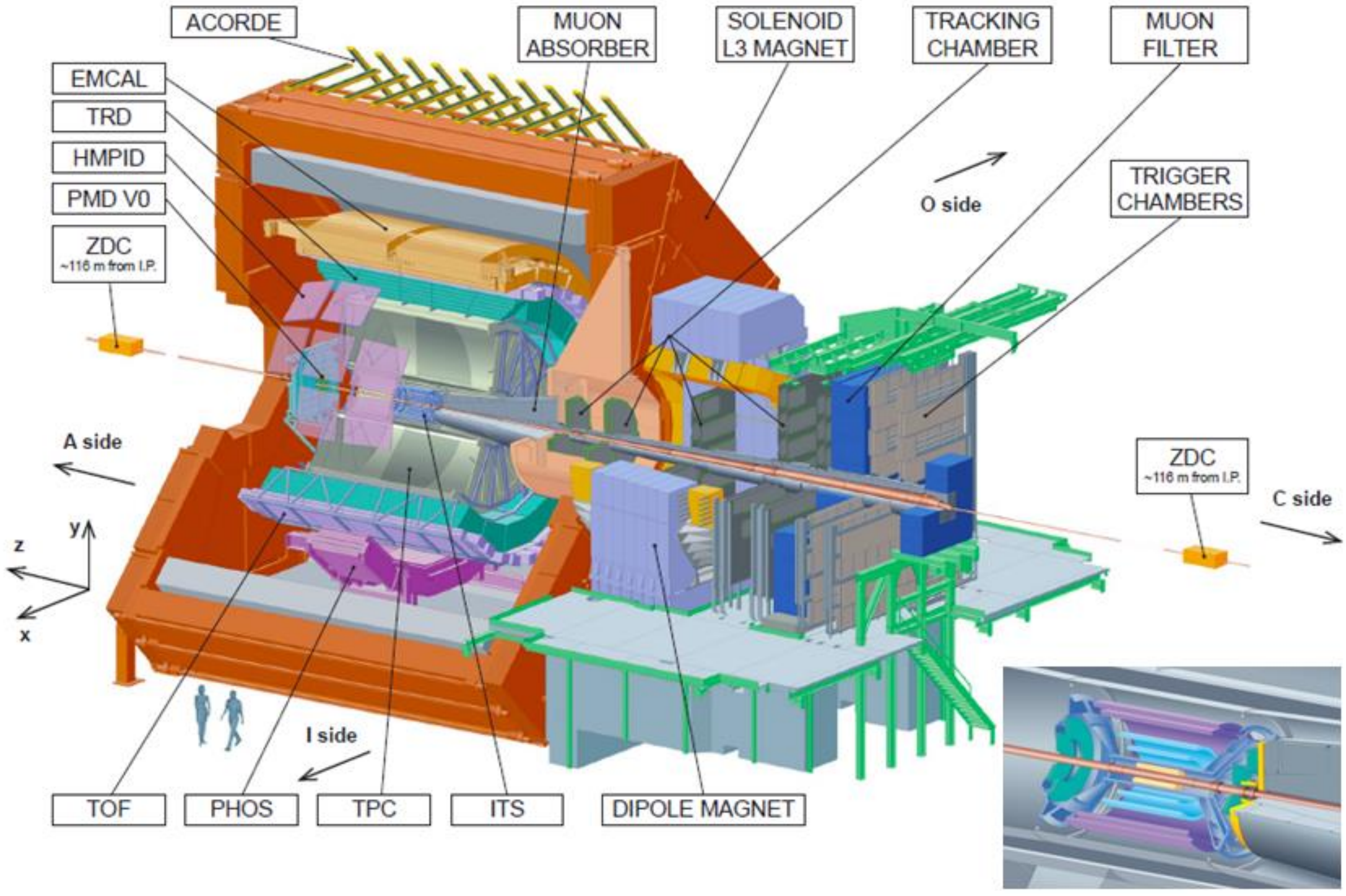
$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{\langle N_{coll}\rangle \; d^2N_{pp}/dp_T d\eta}$$



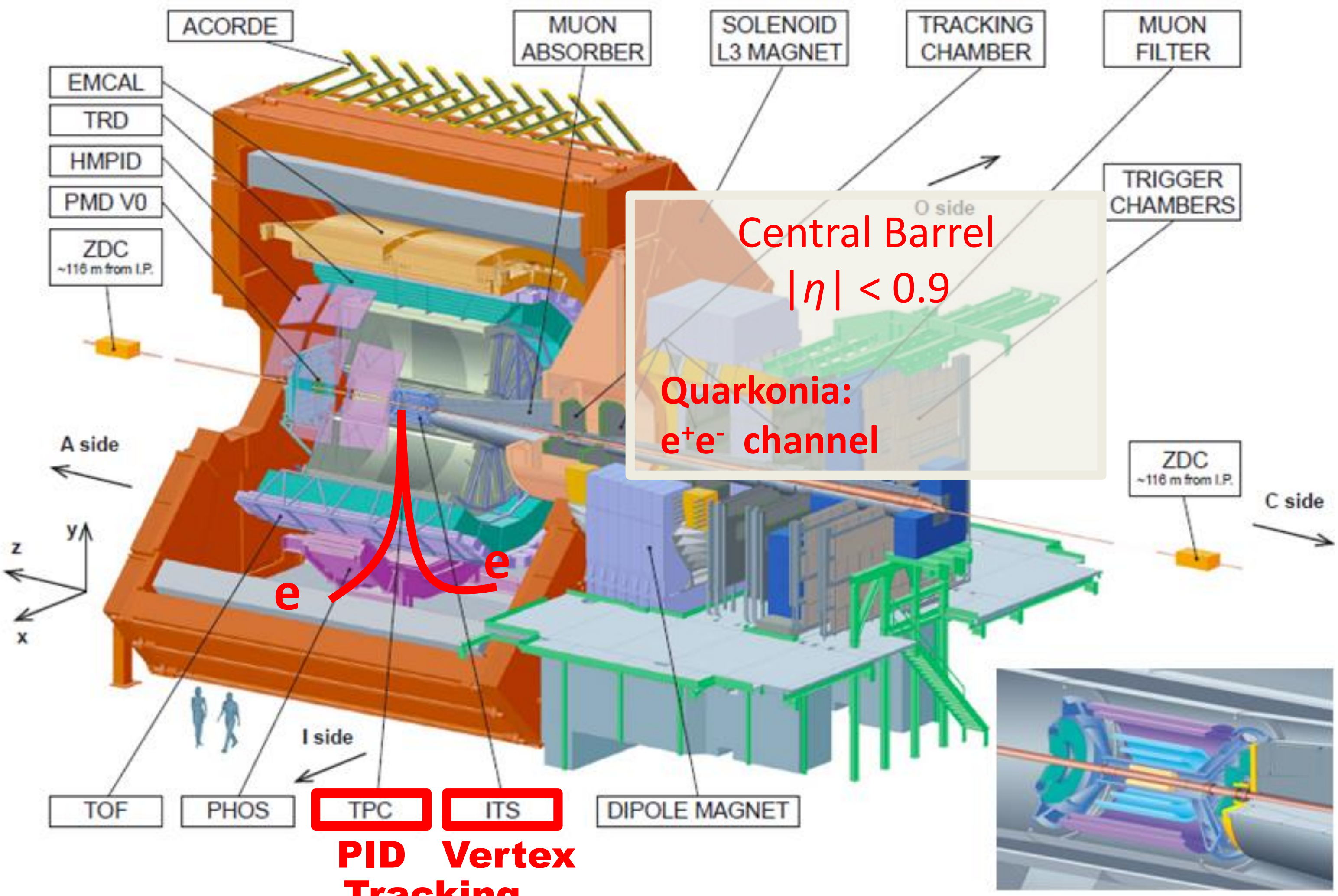
Spectators
Participants
impact parameter

The ALICE experiment

The ALICE experiment



The ALICE experiment

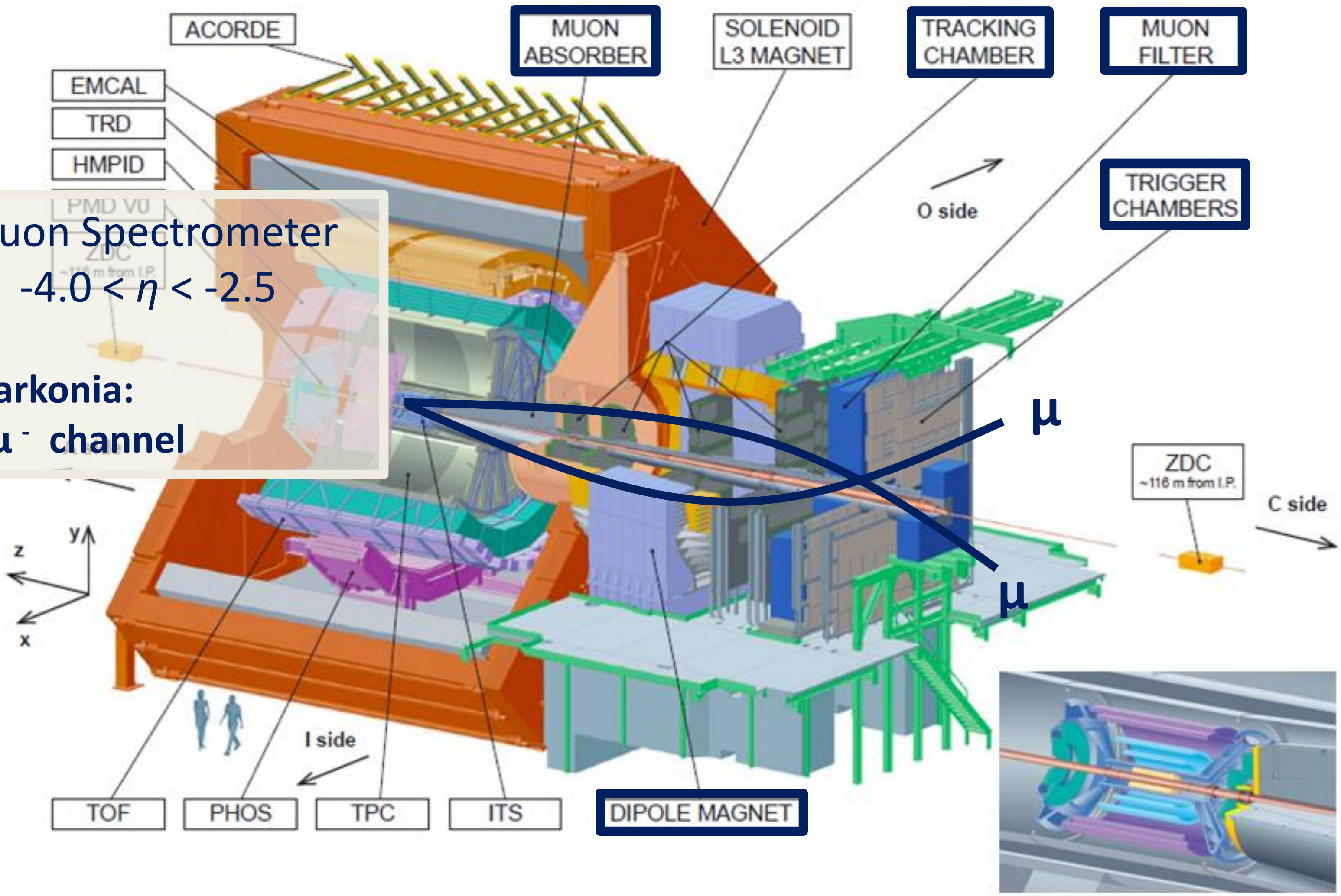


Central Barrel
$|\eta| < 0.9$

Quarkonia:
e^+e^- channel

PID Vertex
Tracking

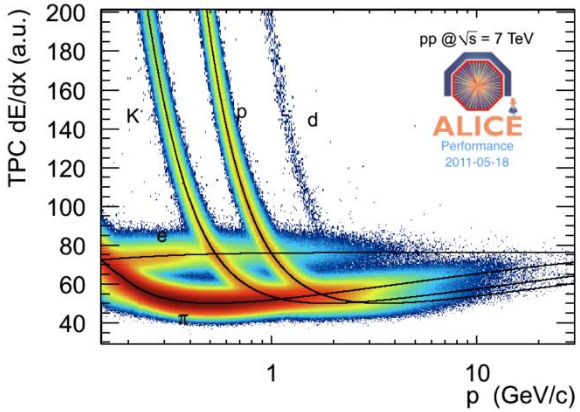
The ALICE experiment



Muon Spectrometer
$-4.0 < \eta < -2.5$

Quarkonia:
$\mu^+ \mu^-$ channel

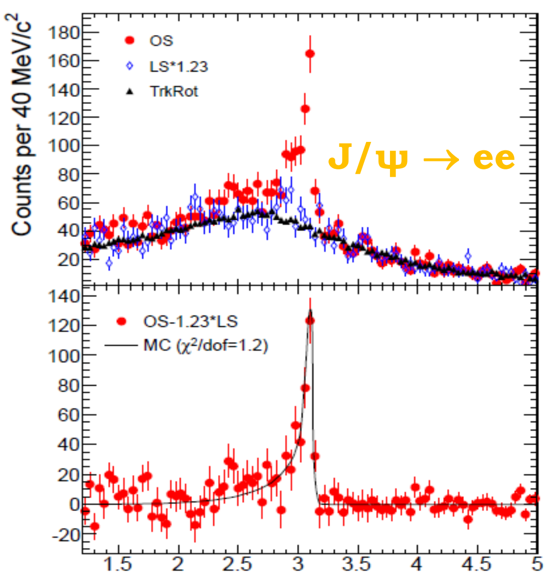
ALICE performance



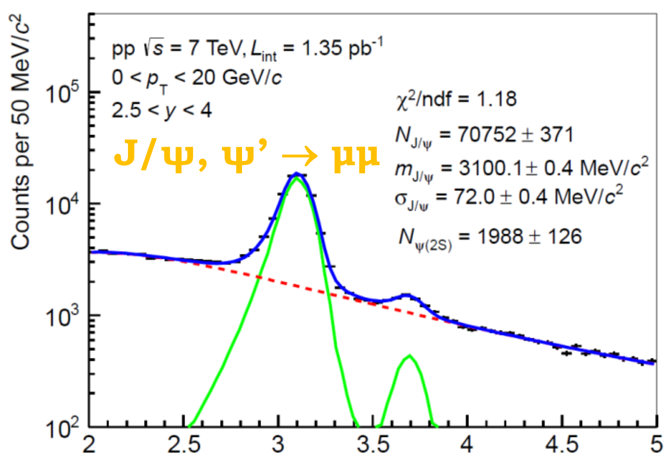
ALICE is unique at the LHC: quarkonium measurements, both at mid and forward rapidity, are performed down to $p_T = 0$.

Electron identification via the specific energy loss (dE/dx) in the TPC.

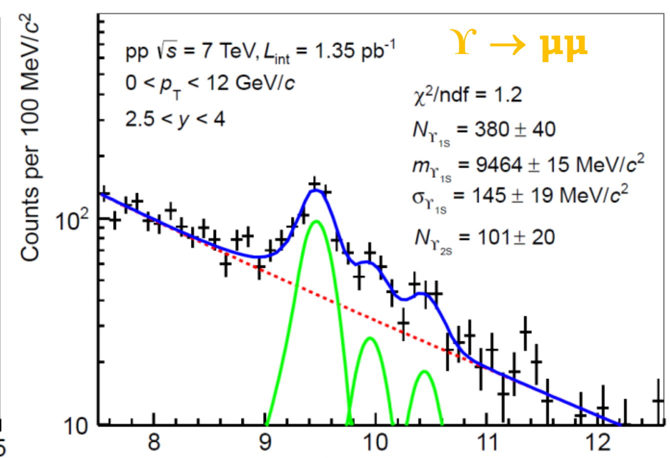
Muons selected with specific triggers and identified thanks to a set of absorbers.



PLB 718 (2012) 295



EPJC 74 (2014) 2974



EPJC 74 (2014) 2974

Quarkonium production in pp

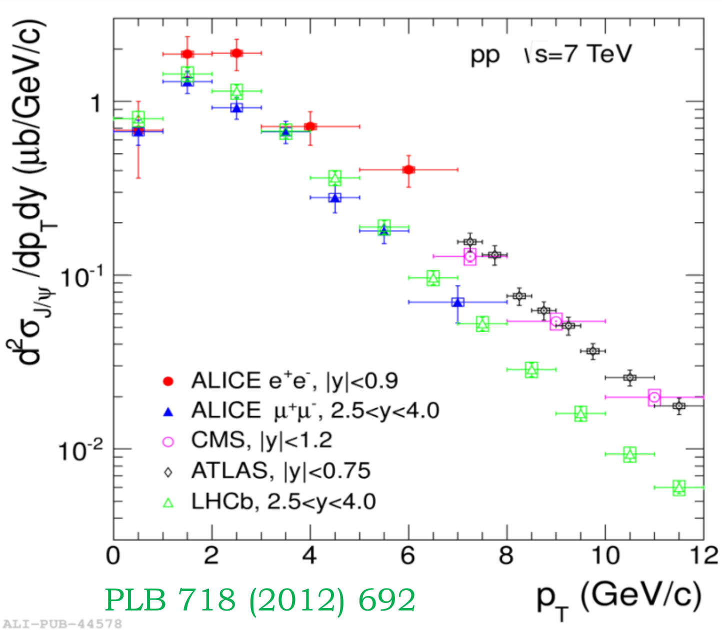
Inclusive J/ψ cross sections

At mid rapidity ALICE complements ATLAS and CMS measurements down to $p_T = 0$.

Forward rapidity: a good agreement between ALICE and LHCb results is found.

$2.5 < y < 4.0$: NRQCD calculations describe the measured $d^2\sigma/dydp_T$ at 7 and 2.76 TeV.

NRQCD: contribution from heavy quark pairs in CS+CO states @ NLO. Passage from CO to CS states is treated as a non-perturbative process.



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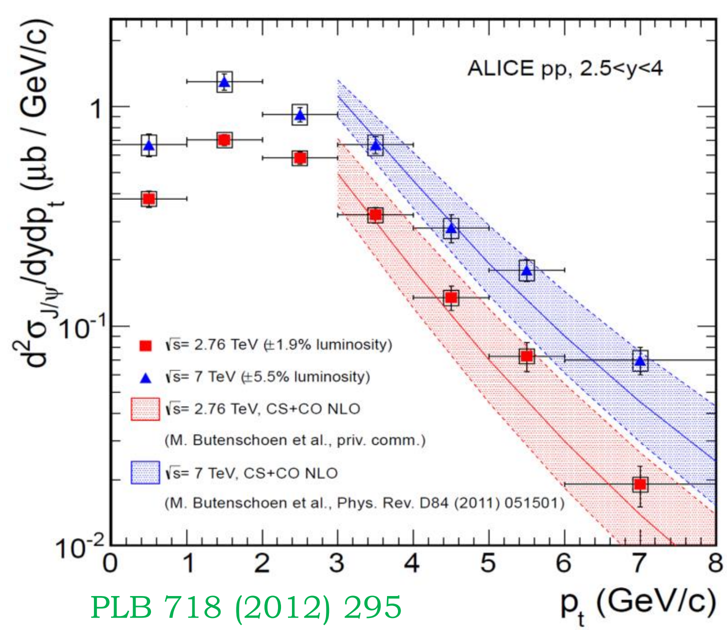


PLB 718 (2012) 295

Inclusive ψ(2S) and Υ(1S) cross sections

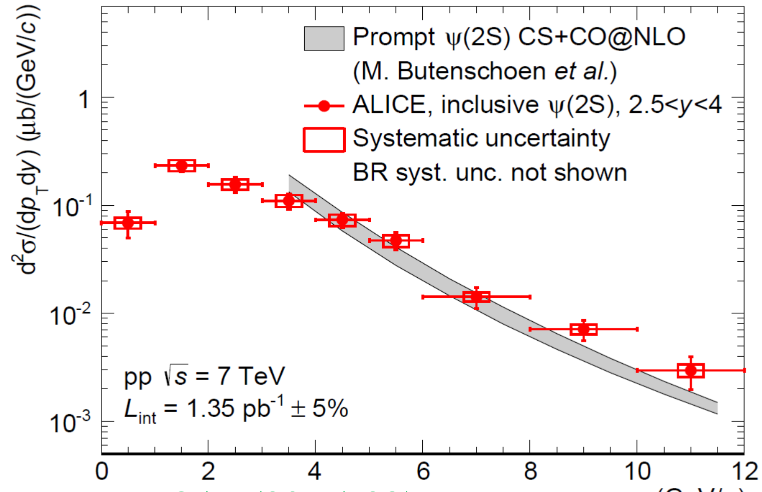
Good agreement between NRQCD and inclusive ψ(2S) measurements, although predictions are for prompt ψ(2S).

Υ(1S) vs CSM: only on-shell color-singlet quark pairs considered in the model.

Scaled predictions: originally suited for direct production.

LO and NLO: complete calculations. NNLO*: only the leading-p_T contributions at NNLO.

LO: underestimates data for p_T > 4 GeV/c. NLO: closer to data but not complete description. Good agreement achieved with NNLO*, but over a limited p_T range and large uncertainties.



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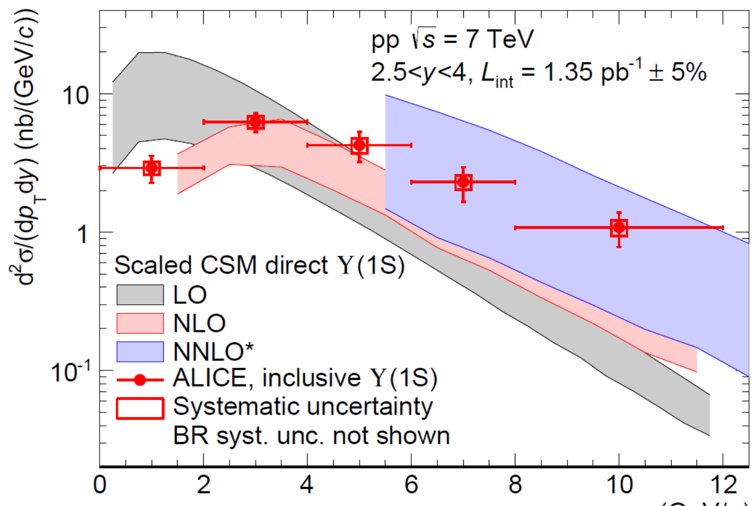
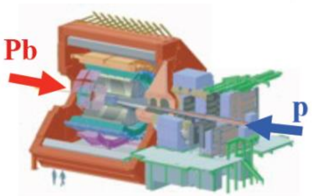


EPJC 74 (2014) 2974

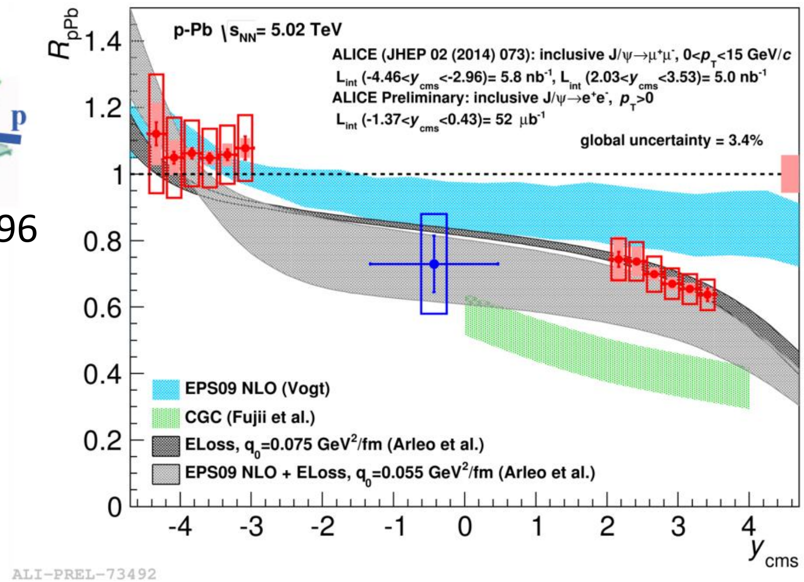
Quarkonium production in p-Pb

J/ψ nuclear modification factor

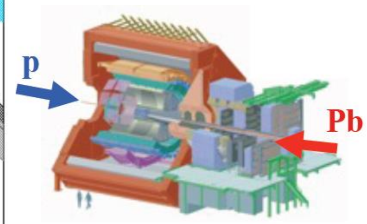


$-4.46 < y_{CMS} < -2.96$

Backward



Forward



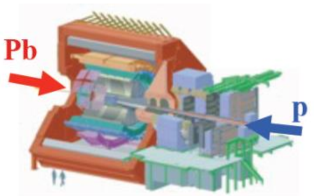
$2.03 < y_{CMS} < 3.53$

Mid and forward rapidity: clear suppression relative to binary scaled pp collisions.

EPS09 NLO: NLO CEM (CO neutralize color via evaporation) plus shadowing. CGC: nucleus as a saturated partonic system (dominated by gluons with small x_B) plus CEM. Energy loss: characterized by the transport coefficient in the target nucleons (q_0).

CGC/EPS09 NLO overestimates/underestimates suppression at forward rapidity, while Eloss and Eloss plus shadowing models can correctly describe all the data.

ϒ(1S) nuclear modification factor



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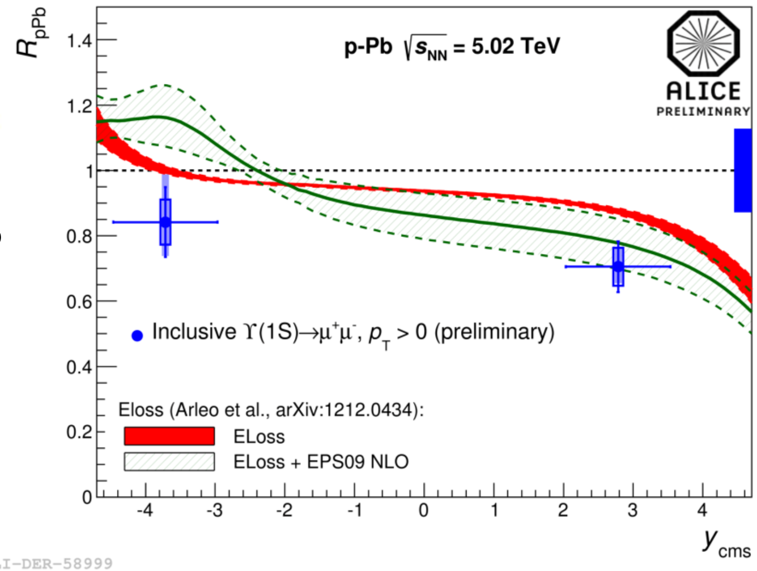
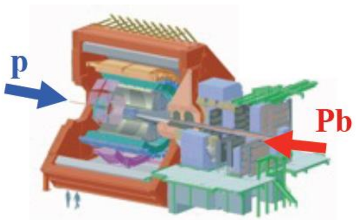


Forward



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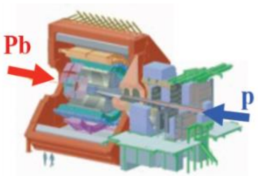
EPS09 NLO: NLO CEM (CO neutralize color via evaporation) plus shadowing.

Energy loss: characterized by the transport coefficient in the target nucleons (q_0).

The Eloss plus shadowing is in reasonable agreement with the ϒ(1S) R_{pPb} at forward rapidity but tends to overestimate it at backward rapidity. The opposite behaviour is found for Eloss only.

J/ψ and ψ(2S) nuclear modification factor



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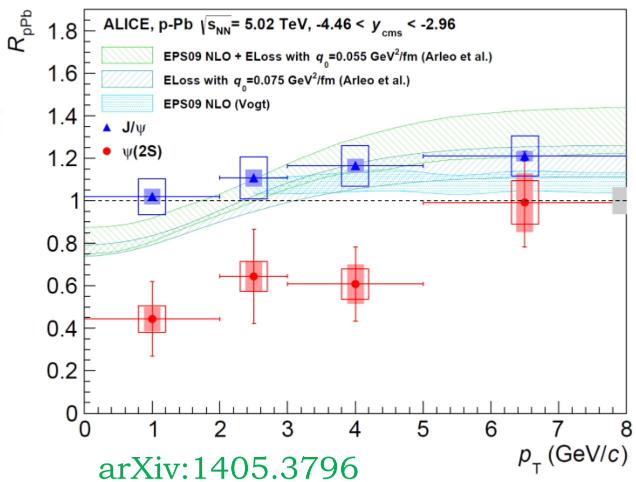
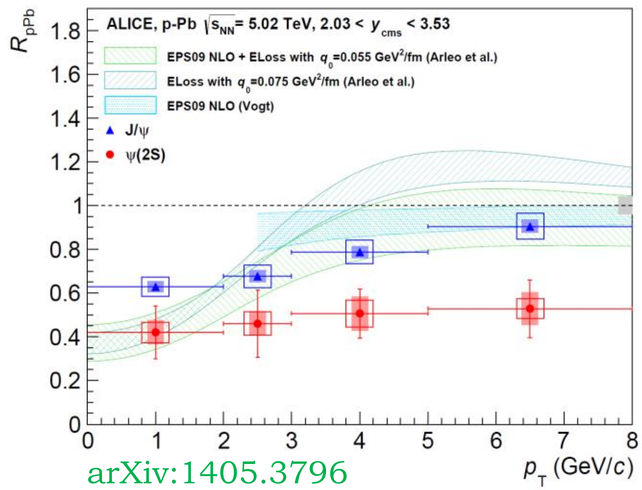


arXiv:1405.3796



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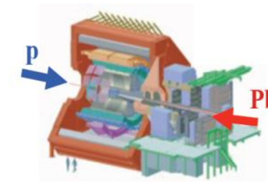
Forward



$2.03 < y_{CMS} < 3.53$

R_{pPb} for ψ(2S) presents a stronger suppression relative to R_{pPb} for J/ψ.

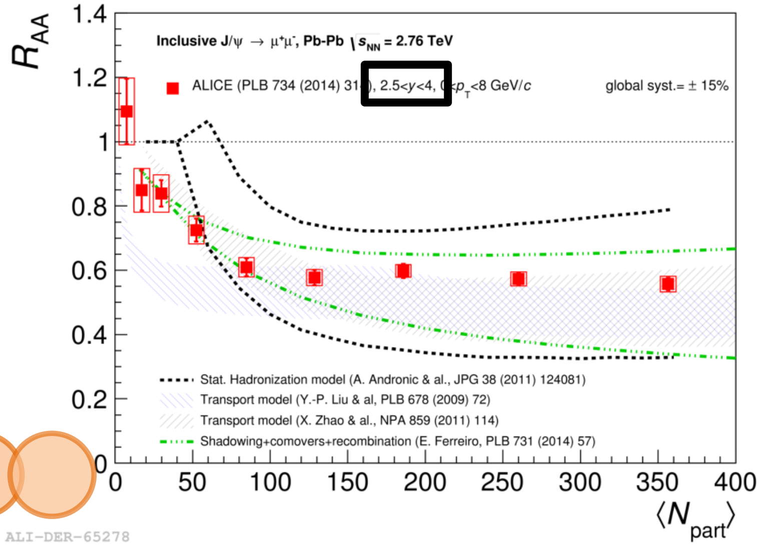
Models suited for J/ψ are also valid for ψ(2S) ➔ all three models would predict an almost identical suppression for both resonances.

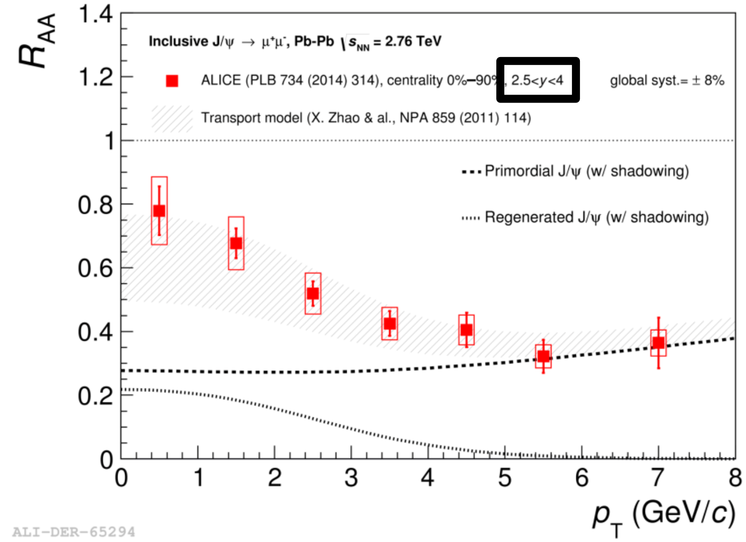
Predictions overestimate the ψ(2S) nuclear modification factor, indicating that shadowing and energy loss effects alone can not account for the ψ(2S) R_{pPb} values!

Final state effects should be then considered in order to describe the observed effect.

Quarkonium production in Pb-Pb

J/ψ nuclear modification factor



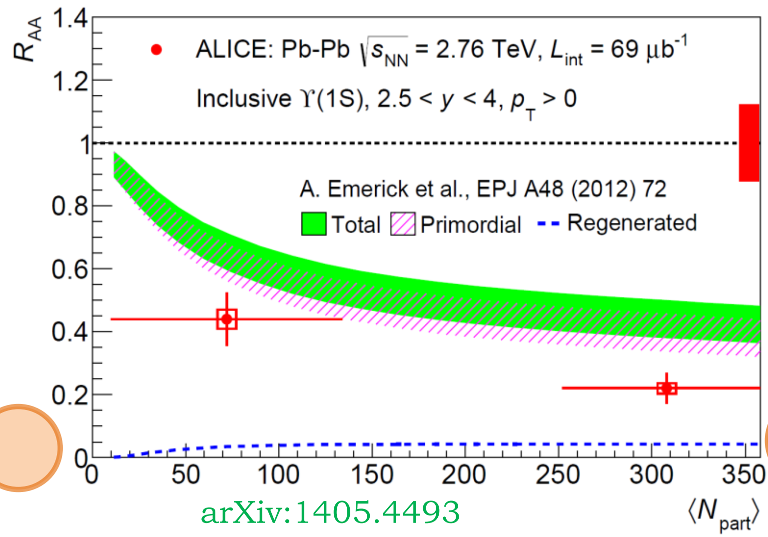


Forward rapidity results compared to theoretical models including J/ψ from (re)generation: full generation, dissociation and regeneration, comovers plus regeneration.

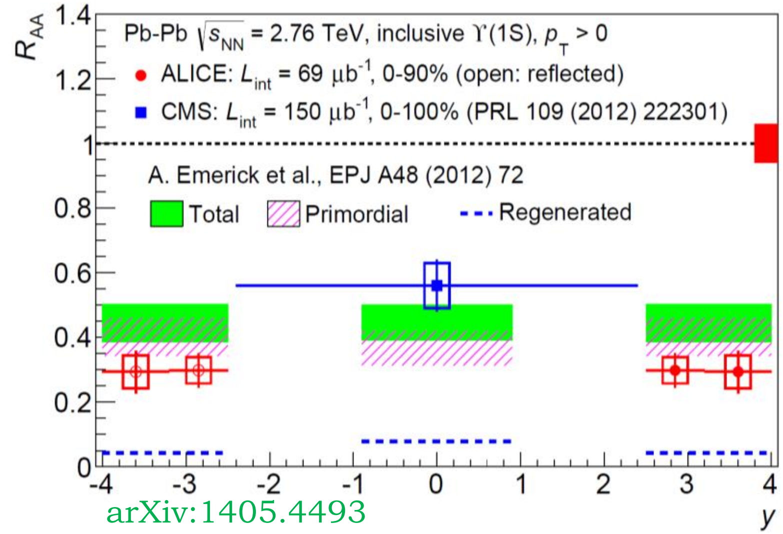
Dissociation and regeneration model: regeneration at work in the low-p_T regime, while primordial J/ψ dominate for $p_T > 5$ GeV/c.

Both R_{AA} vs N_{part} and R_{AA} vs p_T are well described by the models. Most important source of uncertainty in models: Cold Nuclear Matter effects and $c\bar{c}$ cross section.

Υ(1S) nuclear modification factor



arXiv:1405.4493



arXiv:1405.4493

Clear suppression of ϒ(1S) in semicentral and semiperipheral collisions. Larger suppression as compared to CMS measurements (mid rapidity).

Suppression + regeneration + CNM effects model. Low production cross section of $b\bar{b}$ states ➔ ϒ from regeneration much smaller than J/ψ.

The transport model underestimates the observed suppression in ALICE, both as a function of the centrality and rapidity.

Conclusions

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- Quarkonium is a useful probe for the QGP created in Pb-Pb collisions, it can also be used to constrain pQCD inspired models in pp collisions and shadowing and/or energy loss models in pPb collisions.
- ALICE is unique at the LHC: quarkonium measurements down to $p_T = 0$ at mid and forward rapidity.
- pp collisions: J/ψ, ψ(2S) and ϒ(1S) differential cross sections can be described by NRQCD @ NLO.
- pPb collisions: shadowing plus energy loss models reproduce the J/ψ and ϒ(1S) R_{pPb}, but fail to describe the important suppression from ψ(2S).
- Pb-Pb collisions: important evidence of J/ψ production from (re)generation at low-p_T. Models underestimate the observed ϒ(1S) suppression at forward rapidity.

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- pPb collisions: shadowing plus energy loss models reproduce the J/ψ and ϒ(1S) R_{pPb}, but fail to describe the important suppression from ψ(2S).

- Pb-Pb collisions: important evidence of J/ψ production from (re)generation at low-p_T. Models underestimate the observed ϒ(1S) suppression at forward rapidity.

Thanks for your attention

Backup

Polarization

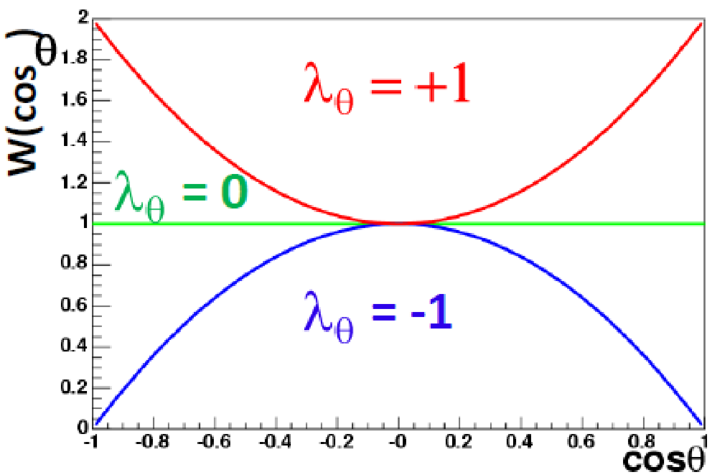
Inclusive J/ψ polarization measured using the angular distribution of daughter muons in the quarkonium rest frame

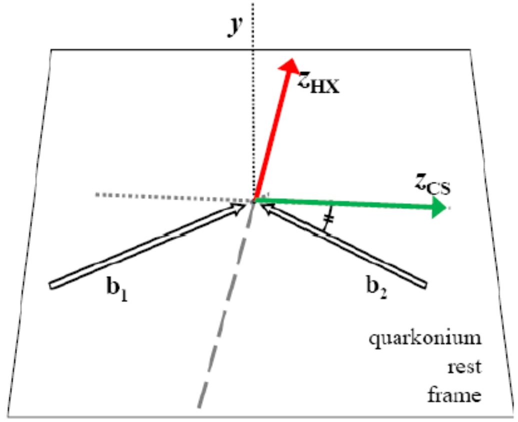
$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}(1+\lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

$\lambda_\theta = +1 \rightarrow$ transverse polarization

$\lambda_\theta = 0 \rightarrow$ no polarization

$\lambda_\theta = -1 \rightarrow$ longitudinal polarization

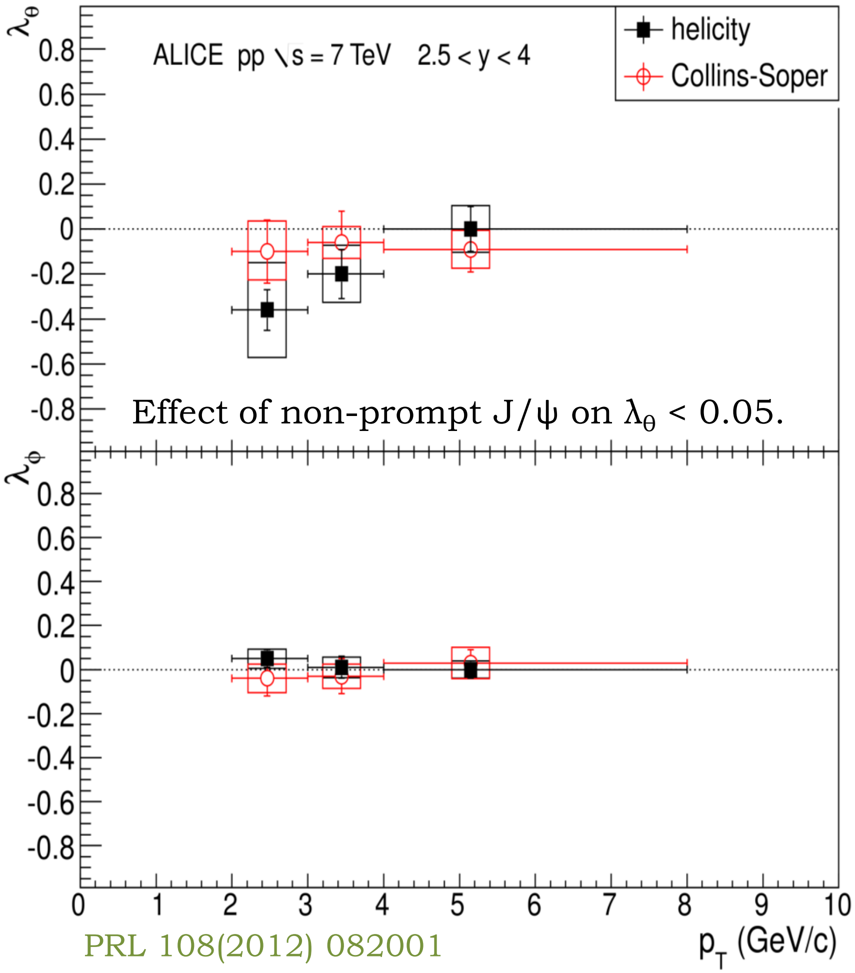




Two different definitions of *z*-axis considered

- Helicity: direction of the decaying particle in the CM frame of the collision.
- Collins-Soper: bisector of the angle between one beam and the opposite of the direction of the other one, in the rest frame of the decaying particle.

Polarization



PRL 108(2012) 082001

ALI-PUB-12784

No significant polarization observed for p_T < 8 GeV/c.

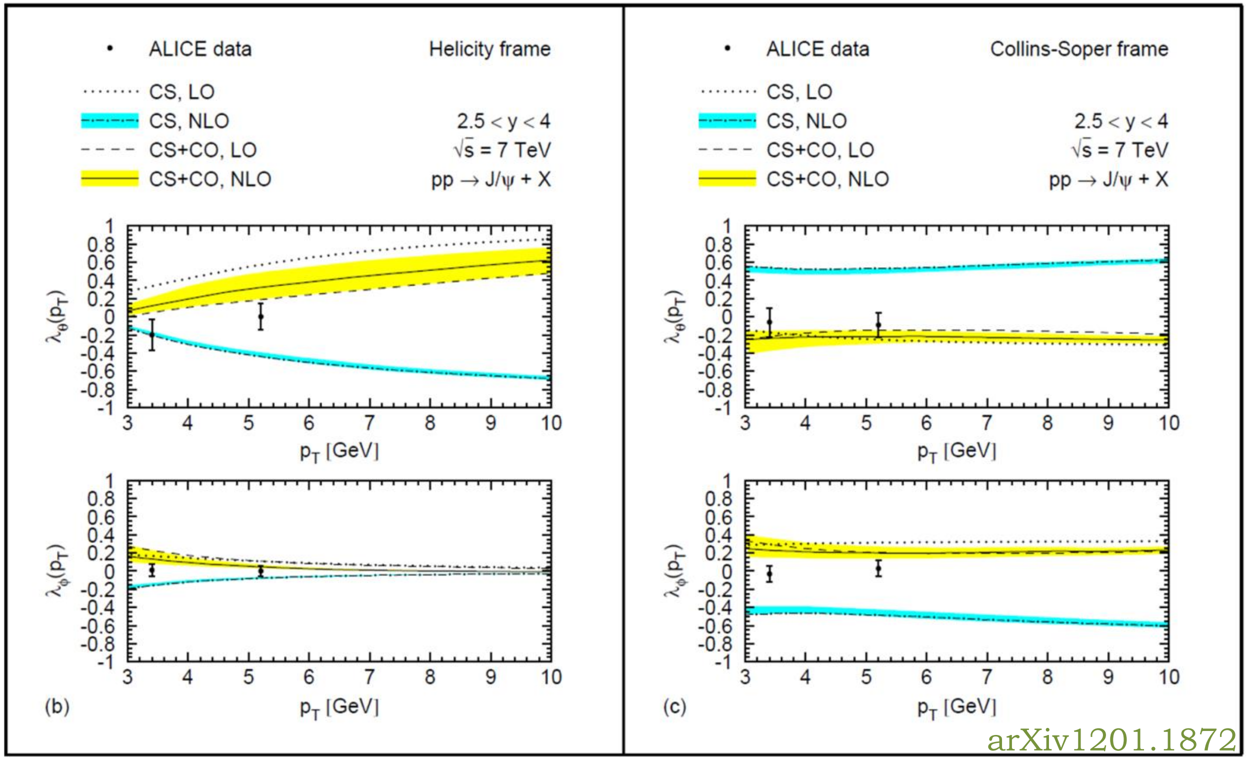
Hint of longitudinal polarization at low-p_T in the helicity frame.

In the Collins-Soper reference frame λ_θ always compatible with zero.

λ_φ always compatible with zero in both reference frames.

Polarization

ALICE results compared to LO and NLO predictions from **NRQCD** and **CSM**.



arXiv1201.1872

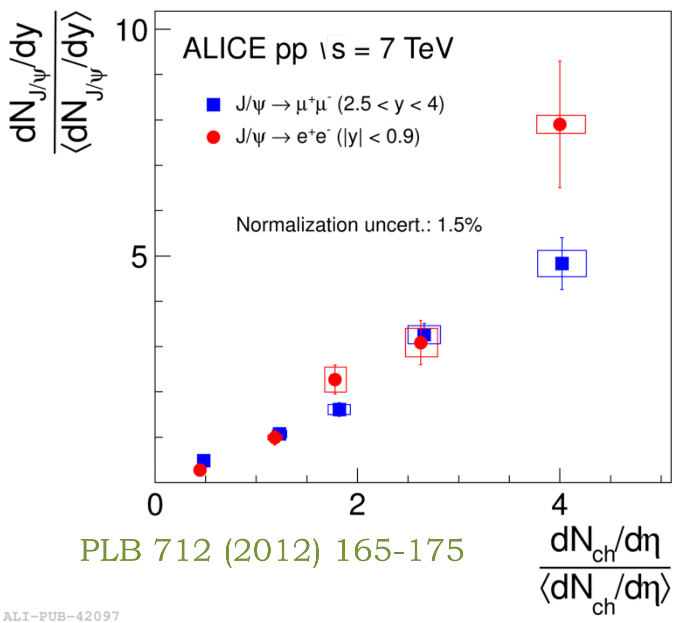
None of the models can perfectly describe the experimental results.

However, NRQCD is slightly favored.

Yield vs multiplicity

$dN_{ch}/d\eta$ in pp at $\sqrt{s}$ = 7 TeV ≈ $dN_{ch}/d\eta$ in 50-55% centrality Cu-Cu at $\sqrt{s_{NN}}$ = 200 GeV.

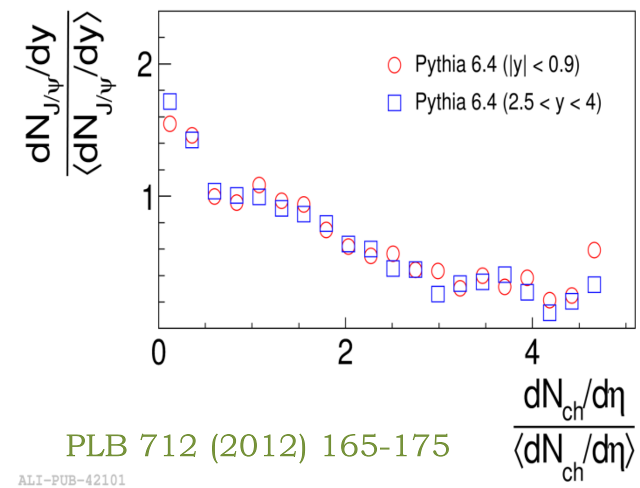
➡ MPI affecting hard processes as J/ψ production?



PLB 712 (2012) 165-175

Approximately linear increase observed in both rapidity ragions.

Results are in clear disagreement with PYTHIA 6.4 with Perugia-0 tunning.



PLB 712 (2012) 165-175

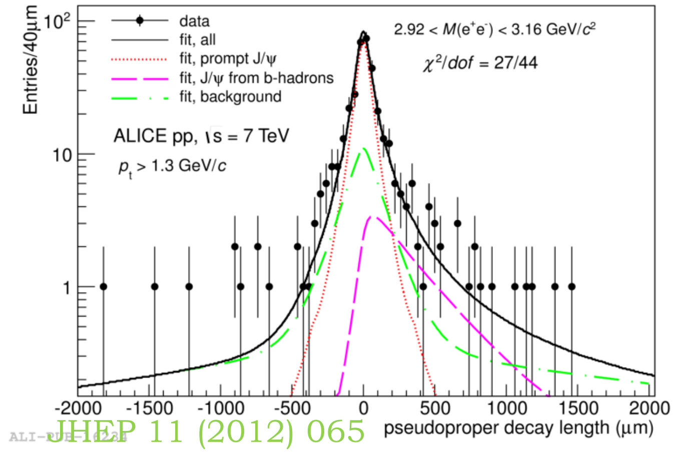
First relative J/ψ production yield as a function of the relative charged particle multiplicity density at mid rapidity.

Prompt/non-prompt J/ψ

prompt J/ψ + non-prompt J/ψ = inclusive J/ψ

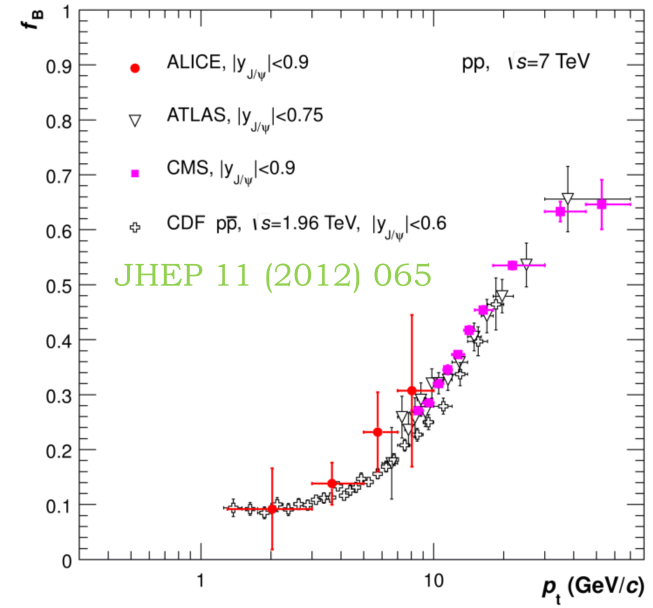
Can be separated at mid rapidity by measuring the J/ψ pseudoproper decay length.

→ Precise determination of the primary and secondary vertex is needed!



ALICE complements ATLAS and CMS measurments: p_T reach extended down to ≈ 1 GeV/c.

Contribution of non-prompt J/ψ in the kinematical range probed by ALICE ranges from 10% (at low- p_T) up to 30% (p_T ≈ 10 GeV/c).



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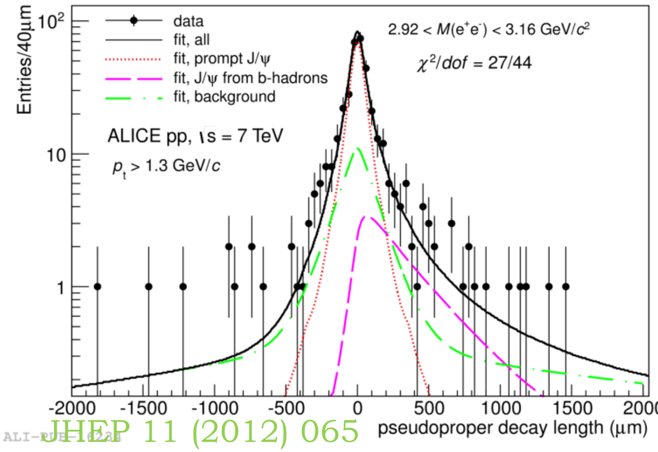

JHEP 11 (2012) 065

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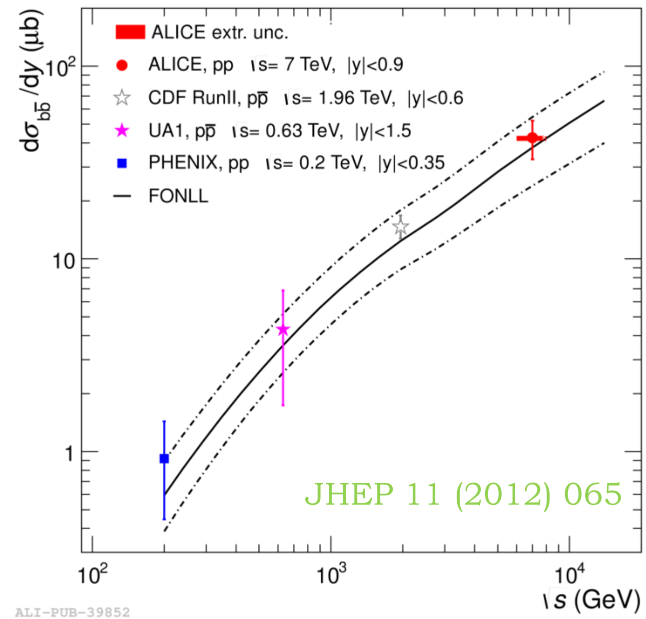
Contribution of non-prompt J/ψ in the kinematical range probed by ALICE ranges from 10% (at low- p_T) up to 30% (p_T ≈ 10 GeV/c).

B production cross-section at mid rapidity from ALICE and lower energy experiments is well described by FONLL calculations.



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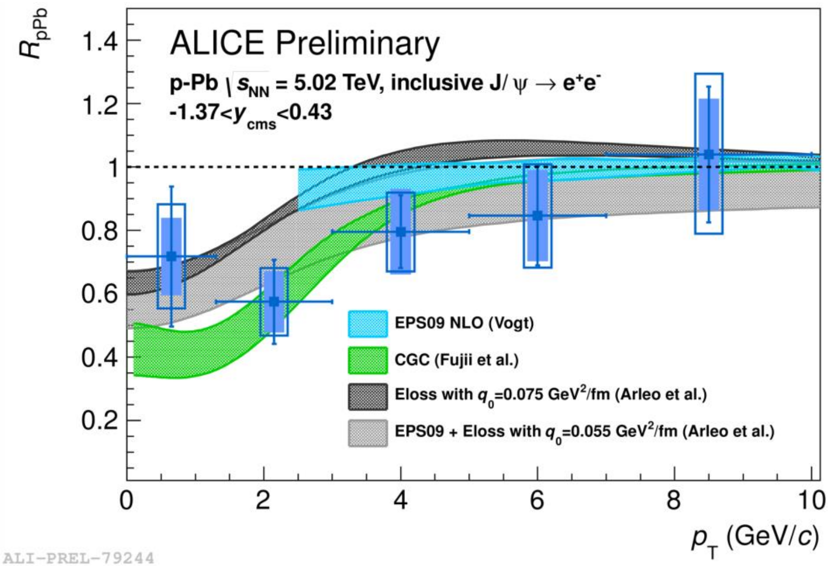
J/ψ nuclear modification factor vs p_T



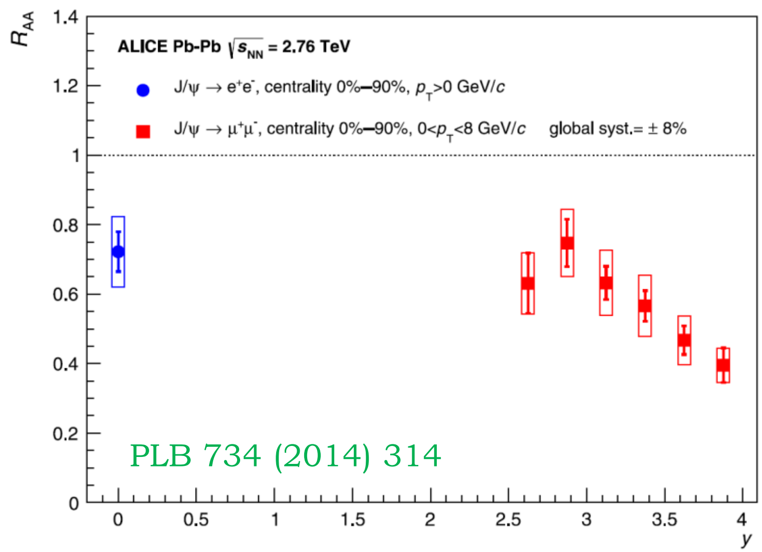
Small/null suppression for low/high-p_T relative to binary scaled pp collisions.

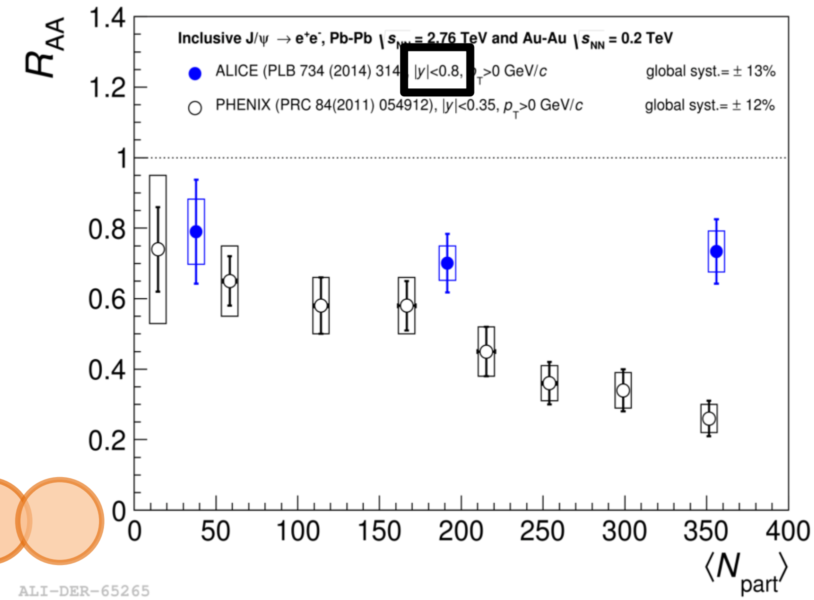
EPS09 NLO: NLO CEM (CO neutralize color via evaporation) plus shadowing. CGC: nucleus as a saturated partonic system (dominated by gluons with small x_B) plus CEM.

Energy loss: characterized by the transport coefficient in the target nucleons (q_0).

Energy loss and shadowing models can correctly describe the data.

J/ψ nuclear modification factor



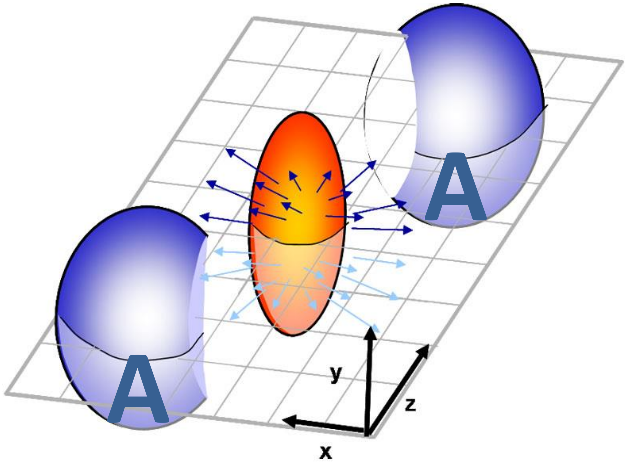


J/ψ nuclear modification factor in Pb-Pb collisions has been measured both at mid and forward rapidity.

R_{AA} vs y suggests a slight increase of the suppression towards forward rapidity.

ALICE R_{AA} vs N_{part} at mid rapidity is independent of the centrality of the collision, a complete different behaviour relative to PHENIX at RHIC (Au-Au at $\sqrt{s_{NN}}$= 200 GeV).

J/ψ elliptic flow



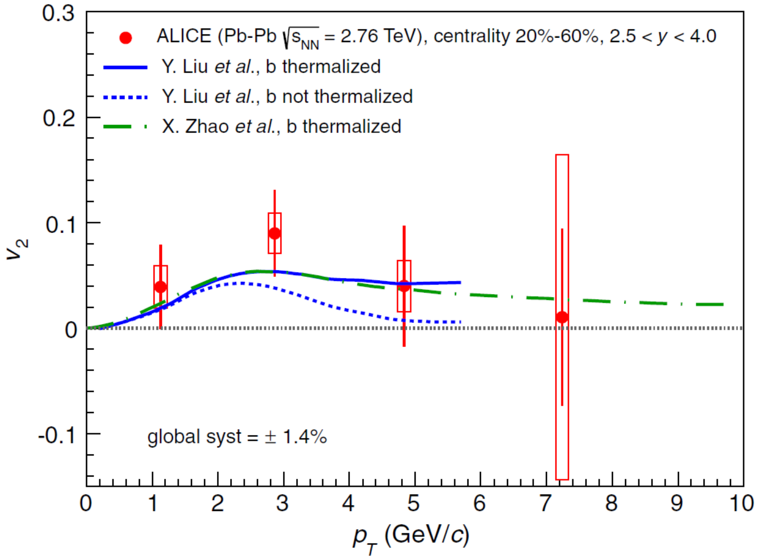
Non central A-A collisions: initial spatial anisotropy → preferential direction of particle emission in the space of momenta.

The azimuthal momentum distribution can be expanded into a Fourier series. The second harmonic is called elliptic flow (v_2).

J/ψ elliptic flow is different from zero by 2 sigmas for $2 < p_T < 4$ GeV/c.

The trend is qualitatively different from the STAR measurement (Au-Au at $\sqrt{s_{NN}}$= 200 GeV): J/ψ v_2 compatible with zero for $p_T > 2$ GeV/c.

Data well reproduced by models including a significant fraction of J/ψ produced from regeneration.



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