Quarkonium production in Pb-Pb and Xe-Xe collisions with ALICE at the LHC

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on behalf of the ALICE Collaboration

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UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

ISOQUANT SFB1225

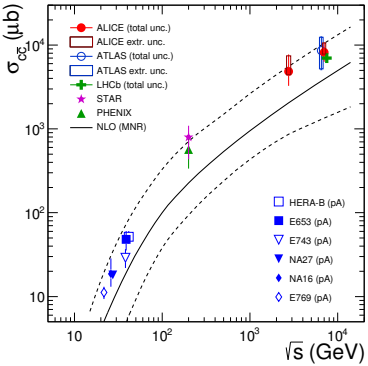
EMMI

ALICE

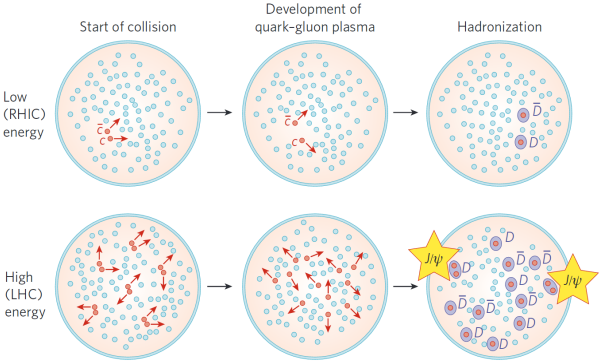
International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September 2018 to 5 October 2018 • Aix-Les-Bains • France

Quarkonium production as a probe in heavy-ion collisions

- Connects perturbative ($m_{Q\bar{Q}} \gg \Lambda_{\mathrm{QCD}}$) with non-perturbative ($Q\bar{Q} \to$ hadron) scales
- Quarkonia are hard probes which are sensitive to the hot and dense medium



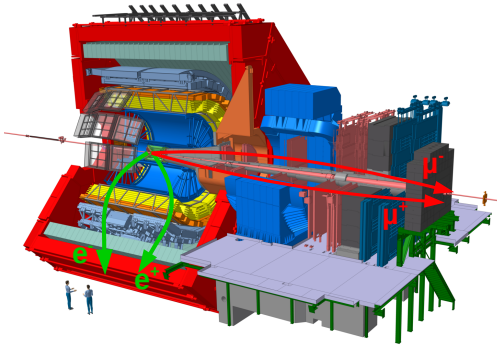
[ALICE Coll., PRC 94 (2016) 054908]



[Braun-Munzinger & Stachel, Nature 448 (2007) 302]

- $\left\{\begin{matrix}\text{Low}\\ \text{High}\end{matrix}\right\}$ energy: $\left\{\begin{matrix}\text{few}\\ \text{many}\end{matrix}\right\}$ $Q\bar{Q}$ pairs per collision $\Rightarrow$ $\left\{\begin{matrix}\text{suppression}\\ \text{enhancement}\end{matrix}\right\}$ of $\mathrm{J}/\psi, \Upsilon, \ldots$

Quarkonium measurements in ALICE



Dielectron channel

- Min. bias trigger
- $|y_{ee}| < 0.9$
- $\Delta m/m \sim 1$ %

Dimuon channel

- Dimuon trigger
- $2.5 < y_{\mu\mu} < 4$
- $\Delta m/m \sim 2$ %

Run2 luminosities used ($\mathscr{L}_{2\mu}|\mathscr{L}_{\mathrm{MB}}$)

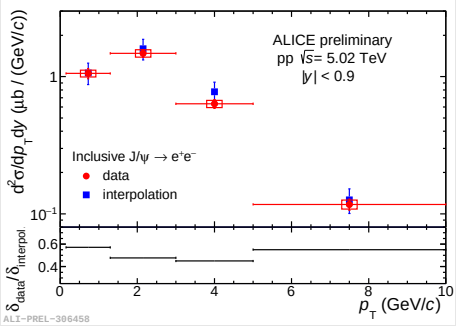
Coll. system	$\sqrt{s_{(\mathrm{NN})}}$ (TeV) 5.02	5.44
pp	106|19 nb^{-1}	-
Pb-Pb	225|14 μb^{-1}	-
Xe-Xe	-	0.34|0.26 μb^{-1}

- Possibility to measure all quarkonia down to zero p_{T}

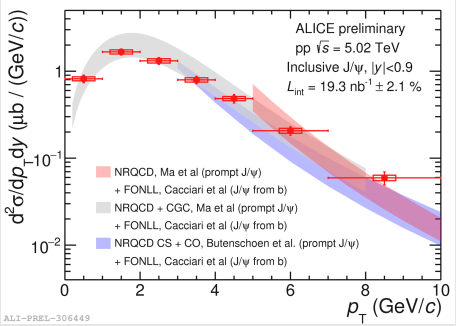
Cross section measurements in pp at mid-rapidity

New!

High-precision reference



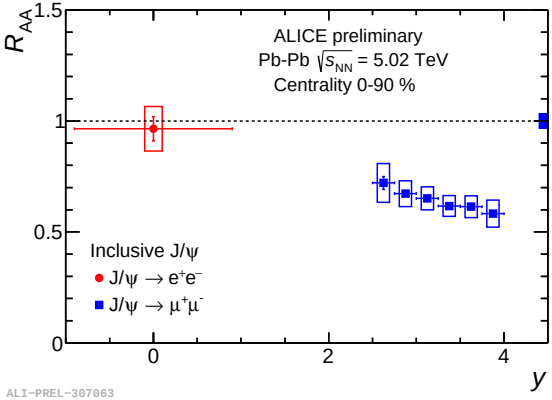
Model comparison



- Superseding the previous pp reference from an interpolation procedure with the pp data at 5 TeV taken in 2017 → decrease of uncertainty by a factor $\gtrsim 2$
- NRQCD(+CGC) together with FONLL (b→ J/ψ) describes the p_{T} spectrum

J/ψ nuclear modification factor vs rapidity

New!

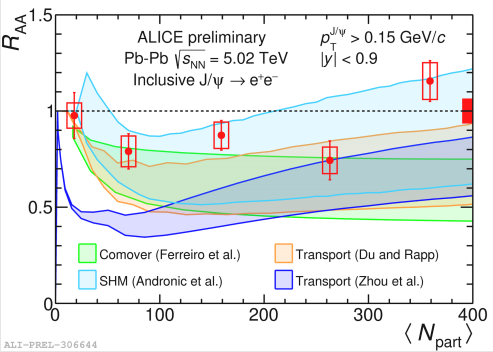


- Weaker suppression at mid- compared to forward rapidity
- Expected in (re)generation scenario from larger charm-quark density

J/ψ nuclear modification factor vs centrality

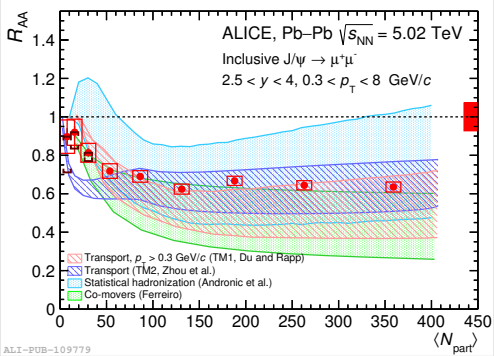
New!

Mid-rapidity



Forward rapidity

[ALICE Coll., PLB 766 (2017) 212]

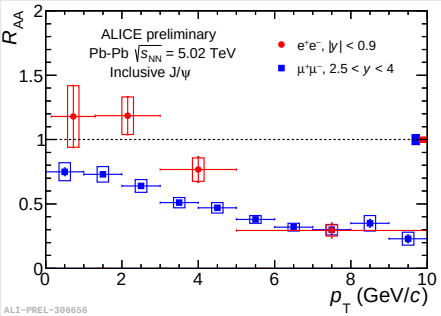


- Models including (re)generation describe centrality dependence of the data
- Need higher precision on $\sigma_{c\bar{c}}^{\mathrm{PbPb}}$ for a better discrimination between models

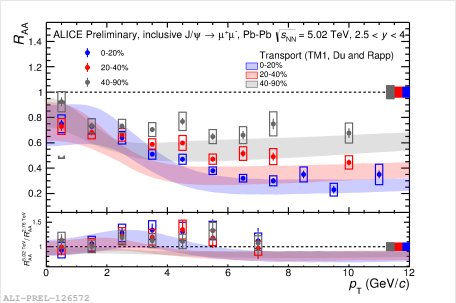
J/ψ nuclear modification factor vs p_T

New!

Mid- vs forward rapidity



Forward rapidity

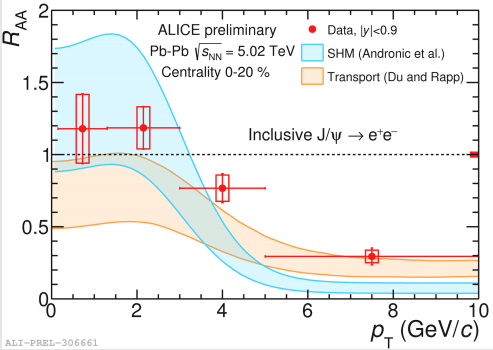


- Comparable suppression for mid- and forward rapidity at high p_T
- R_{AA} increases towards lower p_T, stronger for mid- than forward rapidity
  $\rightarrow$ (Re)generated J/ψ concentrated at low p_T
- Trend for different centralities described by transport model

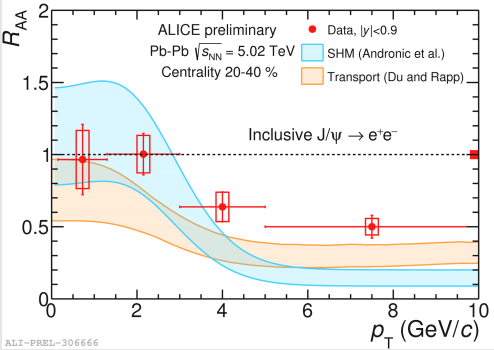
Model comparison of J/ψ R_{AA} vs p_T

New!

Centrality 0-20 %



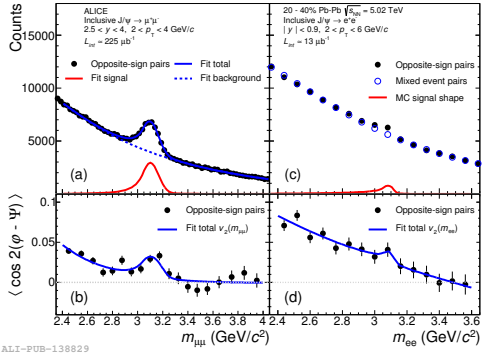
Centrality 20-40 %

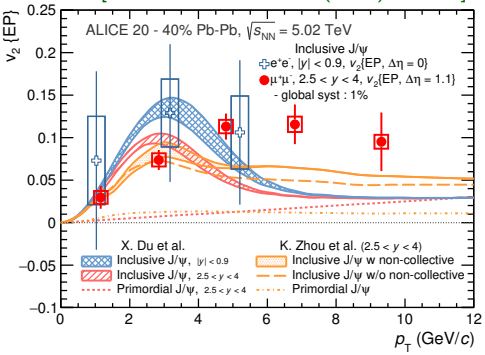


- Trend described by transport and statistical hadronisation model
- Transport model describes the shape, but slightly undershoots the data
- Hadronisation model describes low p_T, but undershoots for $p_T \gtrsim 4$ GeV/c

J/ψ elliptic flow

[ALICE Coll., PRL 119 (2017) 242301]

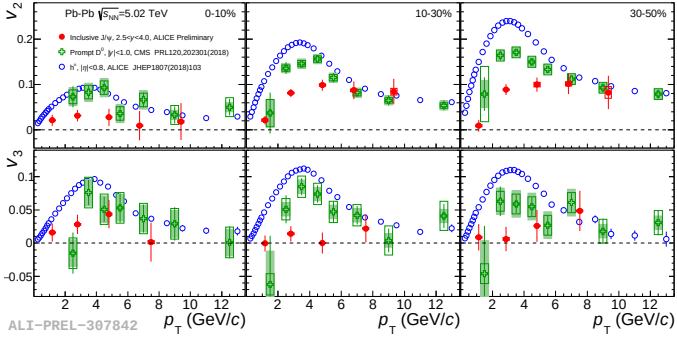


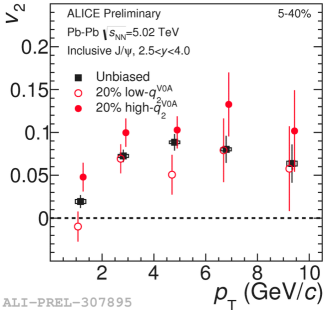


- (Re)generated J/ψ inherit elliptic flow from deconfined (thermalised) charm quarks
- Positive v_2 measured at mid- and forward rapidity
- Transport models describe data at low p_T, undershoot for $p_T \gtrsim 5$ GeV/c

J/ψ elliptic and triangular flow at forward rapidity

New!



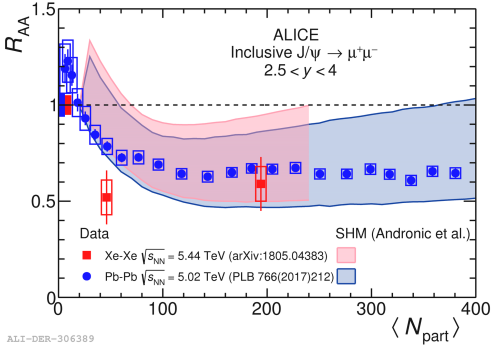


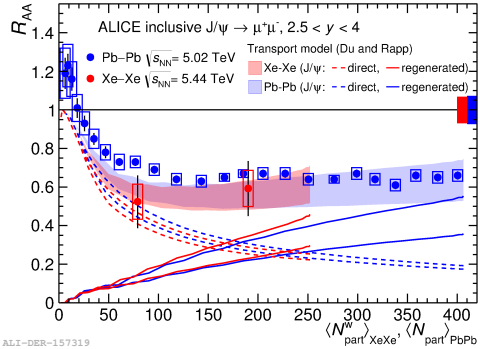
- v_3 sensitive to initial nucleon distributions in the overlap region
- First (!) observation of positive J/ψ v_3 in Pb–Pb collisions (3.7 σ)
- Ordering $v_n(J/\psi) < v_n(D^0) < v_n(h^{\pm})$ with $n = \{2, 3\}$ for low p_T
- $v_2(J/\psi) \approx v_2(D^0) \approx v_2(h^{\pm})$ for $p_T \gtrsim 6$ GeV/c
- Event shape engineering shows a correlation between bulk and J/ψ v_2

J/ψ nuclear modification factor in Xe-Xe collisions

New!

[ALICE Coll., arXiv:1805.04383]
[ALICE Coll., PLB 766 (2017) 212]



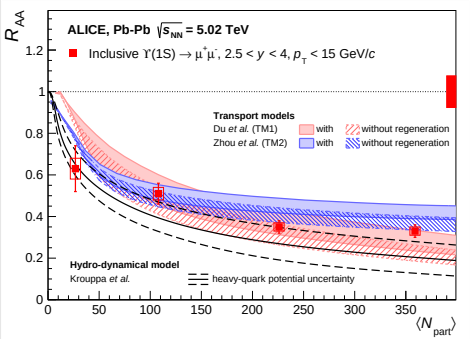


- Study nuclear modification in a smaller collision system
  $\rightarrow$ Same fireball volume with different shape at fixed N_{part}
- Data suffers from large statistical uncertainty
- Transport and statistical hadronisation model consistent with data

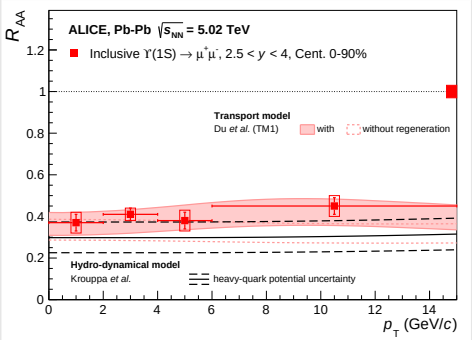
ϒ nuclear modification factor at forward rapidity

[ALICE Coll., arXiv:1805.04387 [nucl-ex]]

Centrality



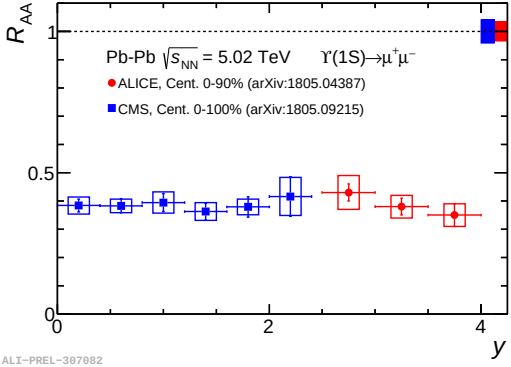
Transverse momentum



- Strong suppression seen towards central collisions
- At current collision energies no sensitivity to (re)generation component in beauty sector

Υ nuclear modification factor vs rapidity

[ALICE Coll., arXiv:1805.04387 [nucl-ex]]
[CMS Coll., arXiv:1805.09215 [hep-ex]]



- No rapidity dependence of Υ R_{AA} observed for $|y| < 4$
- $R_{AA}^{\Upsilon(2S)}/R_{AA}^{\Upsilon(1S)} = 0.28 \pm 0.12(\text{stat}) \pm 0.06(\text{syst})$ in $2.5 < y < 4$

Summary and conclusions

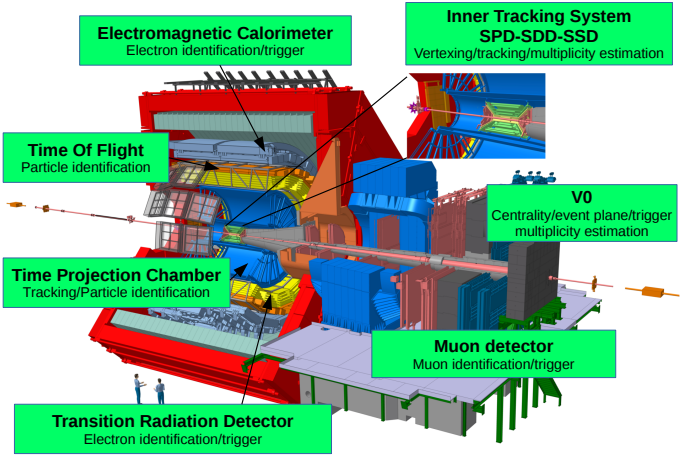
- Results on quarkonium production shown as function of centrality, rapidity and p_T
- (Re)generation dominant production mechanism for J/ψ
  $\rightarrow$ Need higher precision on data and models for a better discrimination $\rightarrow$ PbPb run 2018
- Non-zero v_2 of J/ψ suggests thermalisation of charm quarks within the medium
- Positive v_3 of J/ψ with a significance of 3.7 σ observed
  $\rightarrow$ Input from theory would be very much appreciated
- J/ψ R_{AA} in Xe-Xe collisions similar to Pb-Pb and described by models
- Strong suppression of Υ in Pb-Pb collisions, no rapidity dependence for $|y| < 4$
- Studies on J/ψ polarisation in Pb-Pb collisions at 5 TeV ongoing

$\rightarrow$ Coherent J/ψ photo-production in Pb-Pb collisions, Laure Massacrier, Tue. 9:40

$\rightarrow$ Quarkonium in p–Pb collisions, Antoine Lardeux, Tue. 15:40

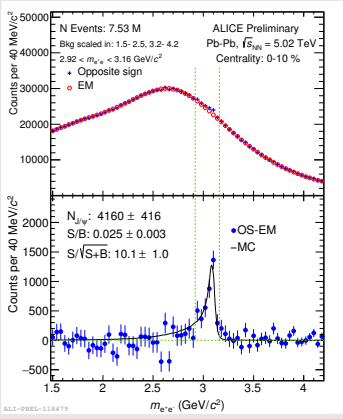
backup

A Large Ion Collider Experiment



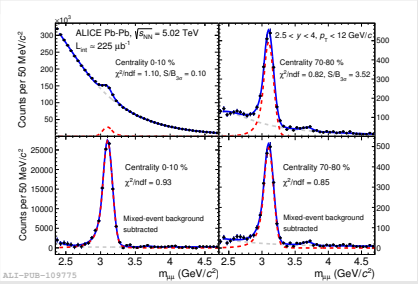
Signal extraction

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



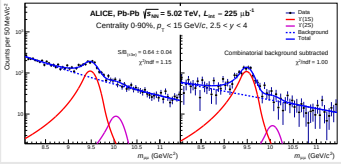
$J/\psi \to \mu^+\mu^-$

[ALICE Coll., PLB 766 (2017) 212]



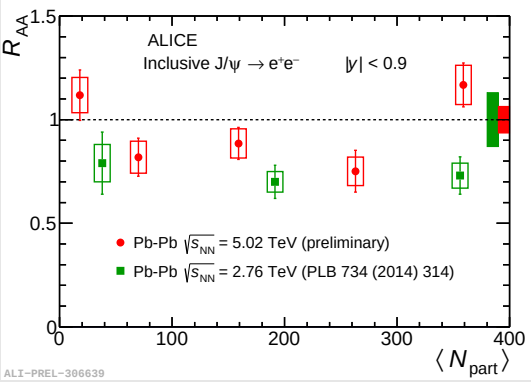
$\Upsilon \to \mu^+\mu^-$

[ALICE Coll., arXiv:1805.04387 [nucl-ex]]

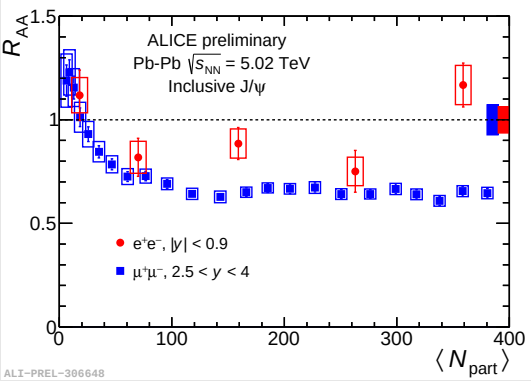


Comparison of the new results at mid-rapidity

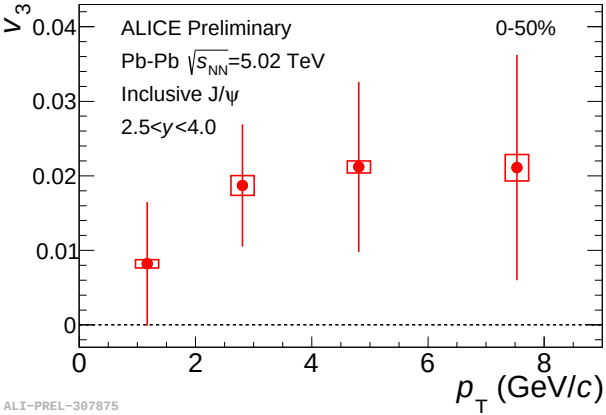
to results at 2.76 TeV



to results at forward rapidity

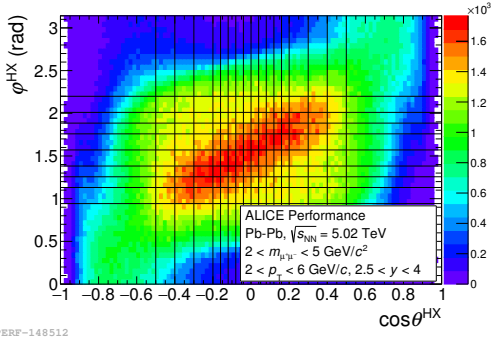


J/ψ v_3 vs pT for integrated centrality



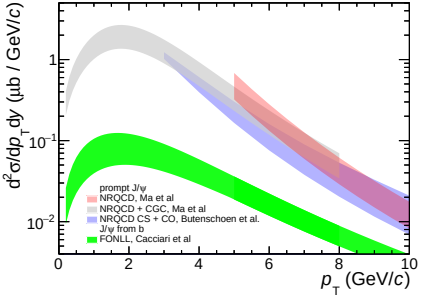
J/ψ polarisation in Pb-Pb collisions

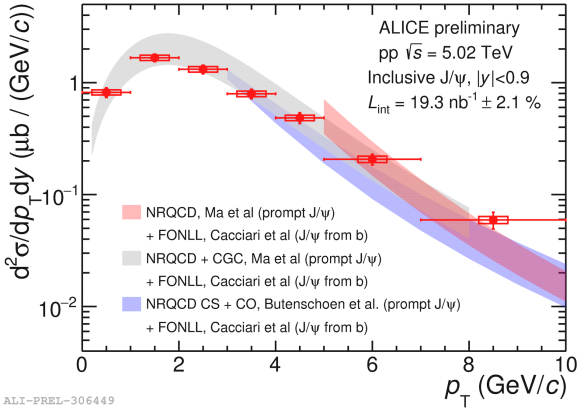
- Test/constrain models beside cross sections through polarisation of quarkonia ($J^{PC} = 1^{--}$)
- Angular distribution $W(\cos\theta, \varphi)$ $\rightarrow$ Polarisation parameters $\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}$
- Ongoing work for Pb-Pb collisions in forward direction



Inclusive J/ψ cross section at $\sqrt{s} = 5$ TeV vs p_T

[Butenschoen & Kniehl, PRL 106 (2011) 022003]
[Ma, Wang & Chao, PRL 106 (2011) 042002]
[Ma & Venugopalan, PRL 113 (2014) 192301]
[Cacciari et al., JHEP10 (2012) 137]

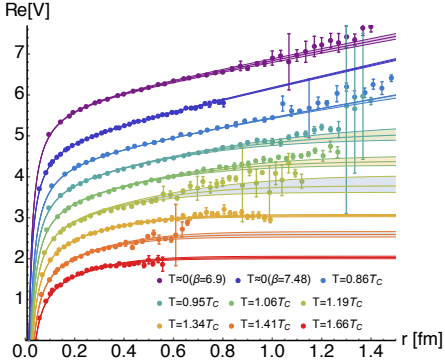


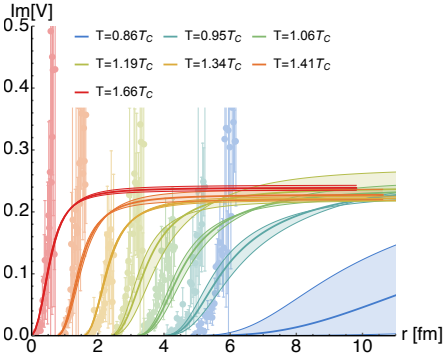


- Compare cross sections to NLO NRQCD calculations (only prompt-J/ψ)
- Add non-prompt component from FONLL ($B \to$ J/ψ)
- Good agreement over the measured p_T range

Heavy-quark potential in the medium

[Burnier, Kaczmarek & Rothkopf, JHEP 1512 (2015) 101, JHEP 1610 (2016) 032]





- Connects perturbative ($m_{Q\bar{Q}} \gg \Lambda_{\mathrm{QCD}}$) with non-perturbative ($Q\bar{Q} \to$ hadron) scales
- Quarkonia are hard probes which are sensitive to the hot and dense medium
- Active field of research in experiment, phenomenology and theory