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Recent ALICE results on charmonium production in Pb-Pb collisions

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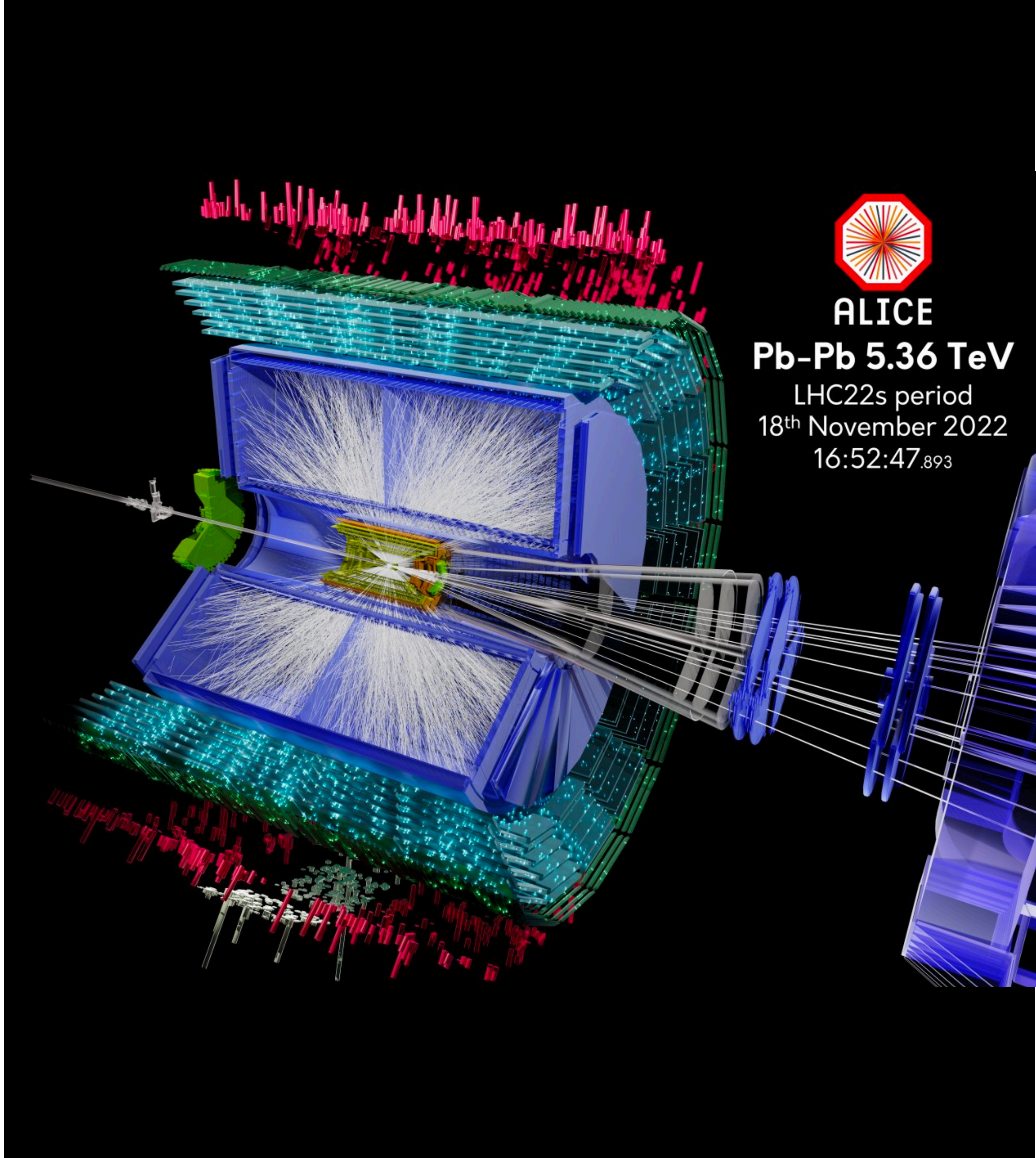


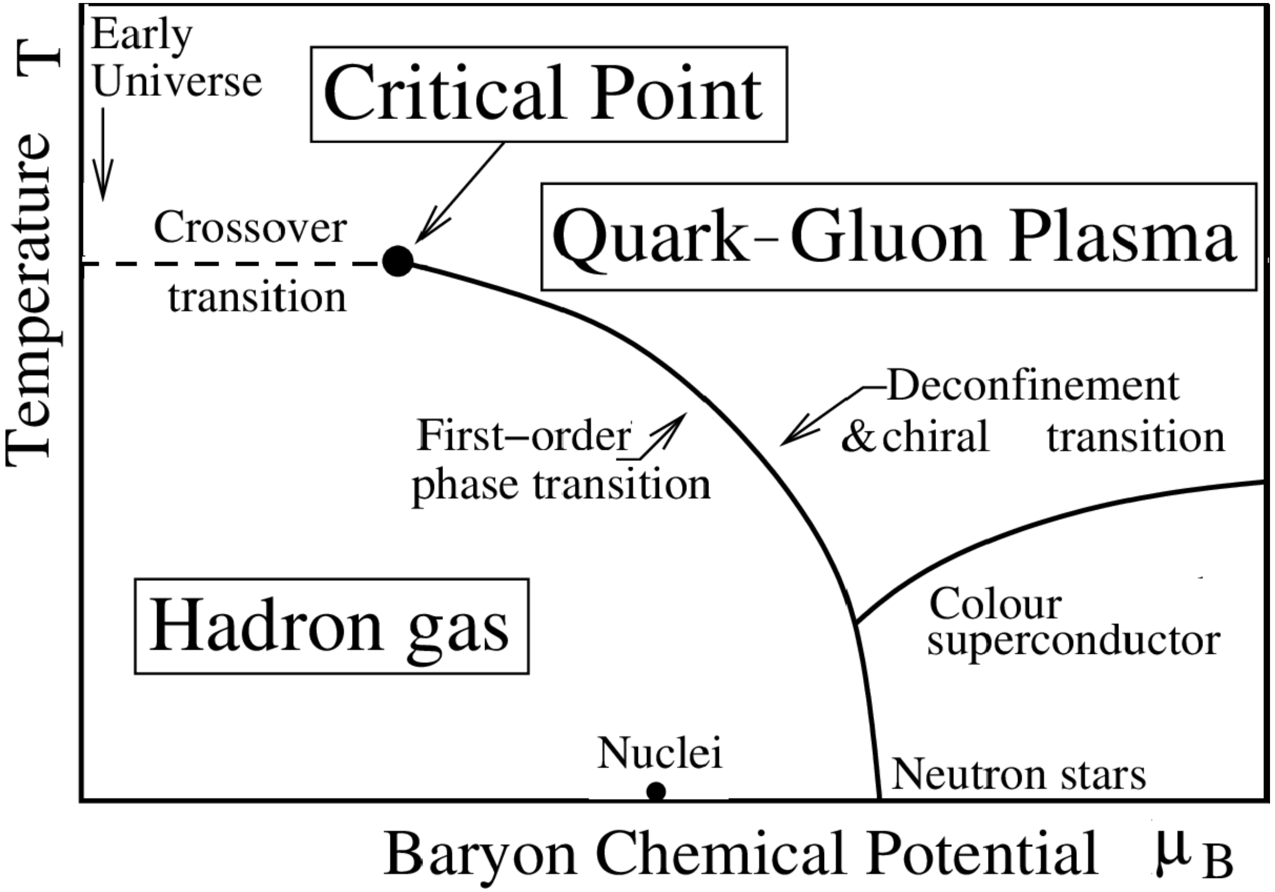
Content

Quarkonia: $c\bar{c}$ and $b\bar{b}$, example J/ψ

- Why measuring quarkonia?
- The ALICE detector
- Run 2 quarkonium measurements:
  - Nuclear modification factor for inclusive, prompt and non-prompt J/ψ
  - Nuclear modification factor of $\psi(2S)$
  - Anisotropic azimuthal distribution of J/ψ
- Outlook: Quarkonia measurements in Run 3

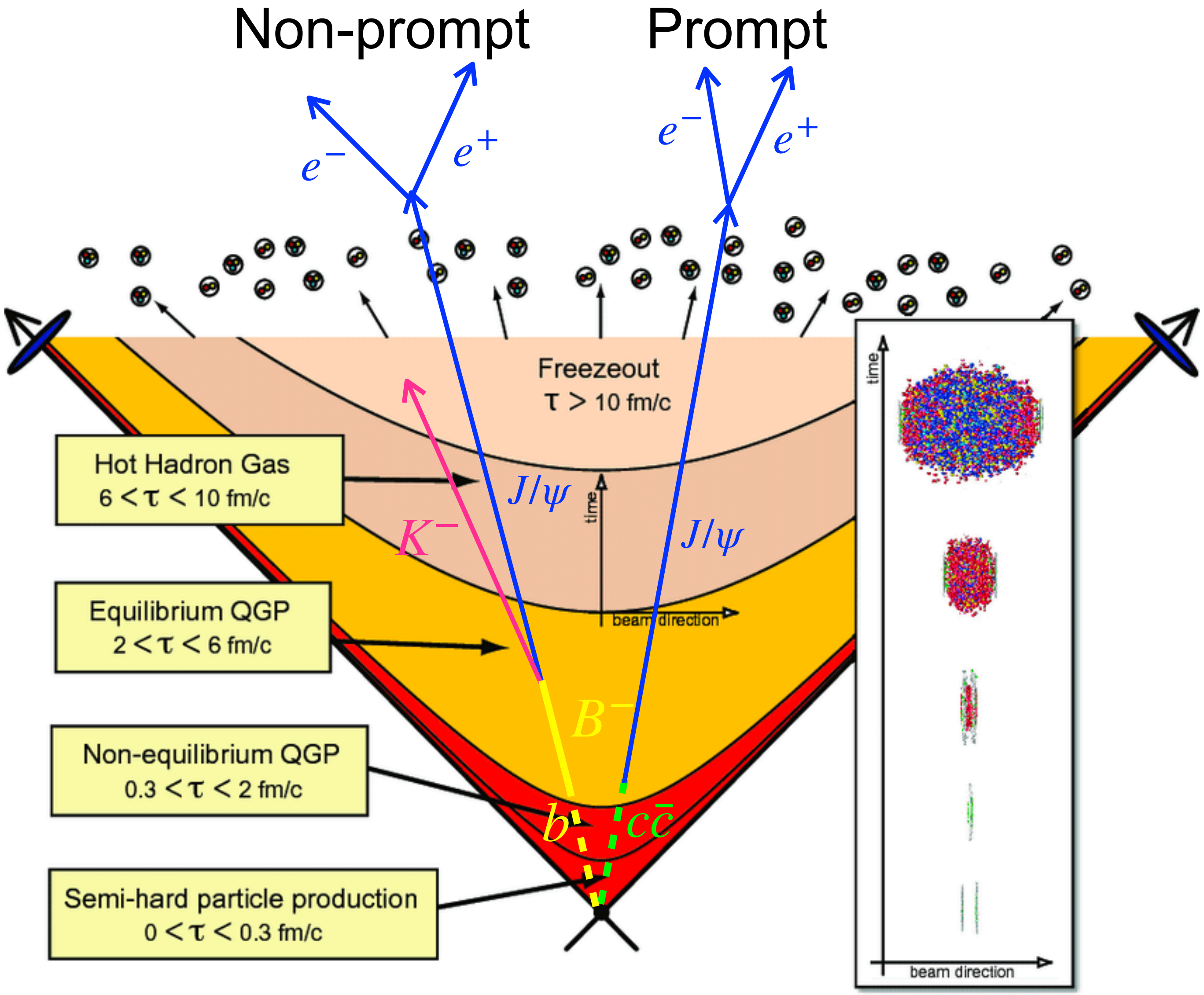
Nuclear matter phase diagram

- Studying the properties of deconfined matter is the main mission of ALICE
- Properties of QGP can be studied by using a variety of experimental probes
  - Temperature → quarkonia as a thermometer
  - Entropy density/viscosity → anisotropic flow



Quarkonium production

- Heavy quark-antiquark pairs: $c\bar{c}$ and $b\bar{b}$
- Heavy quark pairs created in the initial stages of the collision (as $m_{c,b} \gg T_{QGP}$) → experience the full medium evolution
  - Calculable with pQCD
- J/ψ production mechanisms:
  - Prompt J/ψ: bound state of $c\bar{c}$-pairs with vertex indistinguishable from primary vertex
  - Non-prompt J/ψ: Feed-down processes, from B hadron decays



[1] arXiv: 1410.5786

Quarkonium in heavy ion collisions

- Color screening and dissociation by the medium results in suppression of bound quarkonia

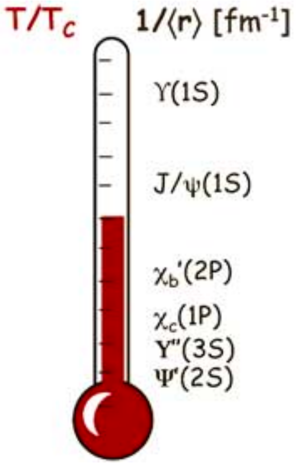
  T. Matsui and H. Satz, PLB 178 (1986) 416, A Rothkopf, Phys. Rept. 858 (2020) 1-117

  - Different binding energy of different quarkonium states, $\mathcal{O}$(MeV)-$\mathcal{O}$(GeV) results in «sequential» suppression
  - Large heavy quark cross section at LHC energies → recombination

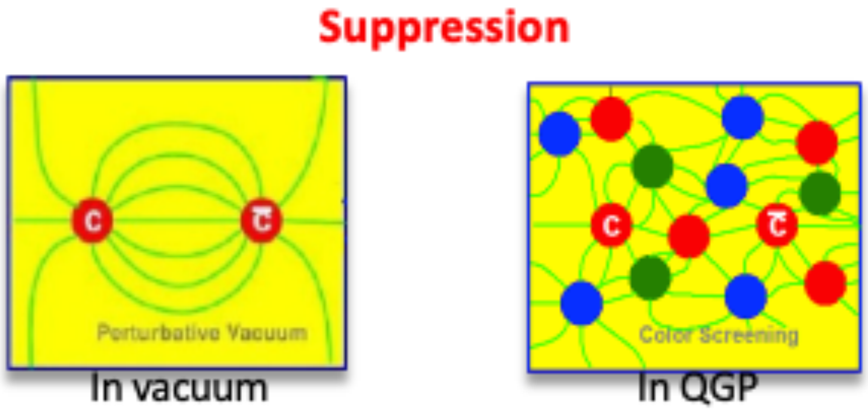
  P. Braun-Muzinger, J. Stachel, PLB 490 (2000) 196, R. Thews et al, Phys. Rev. C 63 (2001) 054905

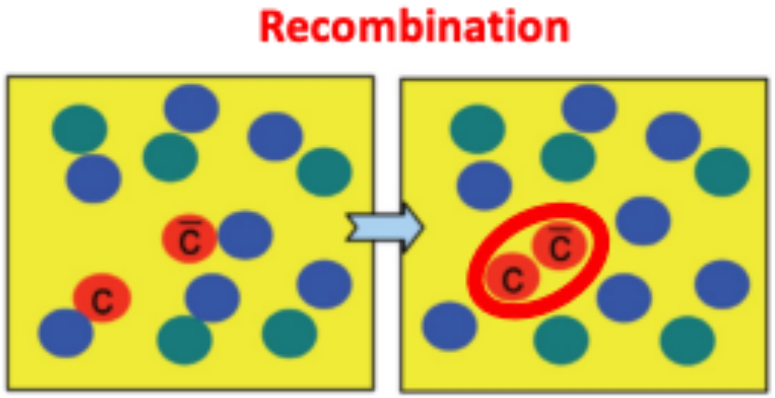
  - Quantified by the nuclear modification factor R_{AA}
- Quarkonium measurements in different systems
  - pp: reference, and QCD studies
  - pPb: cold nuclear matter effects
  - PbPb: cold + hot medium effects

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$



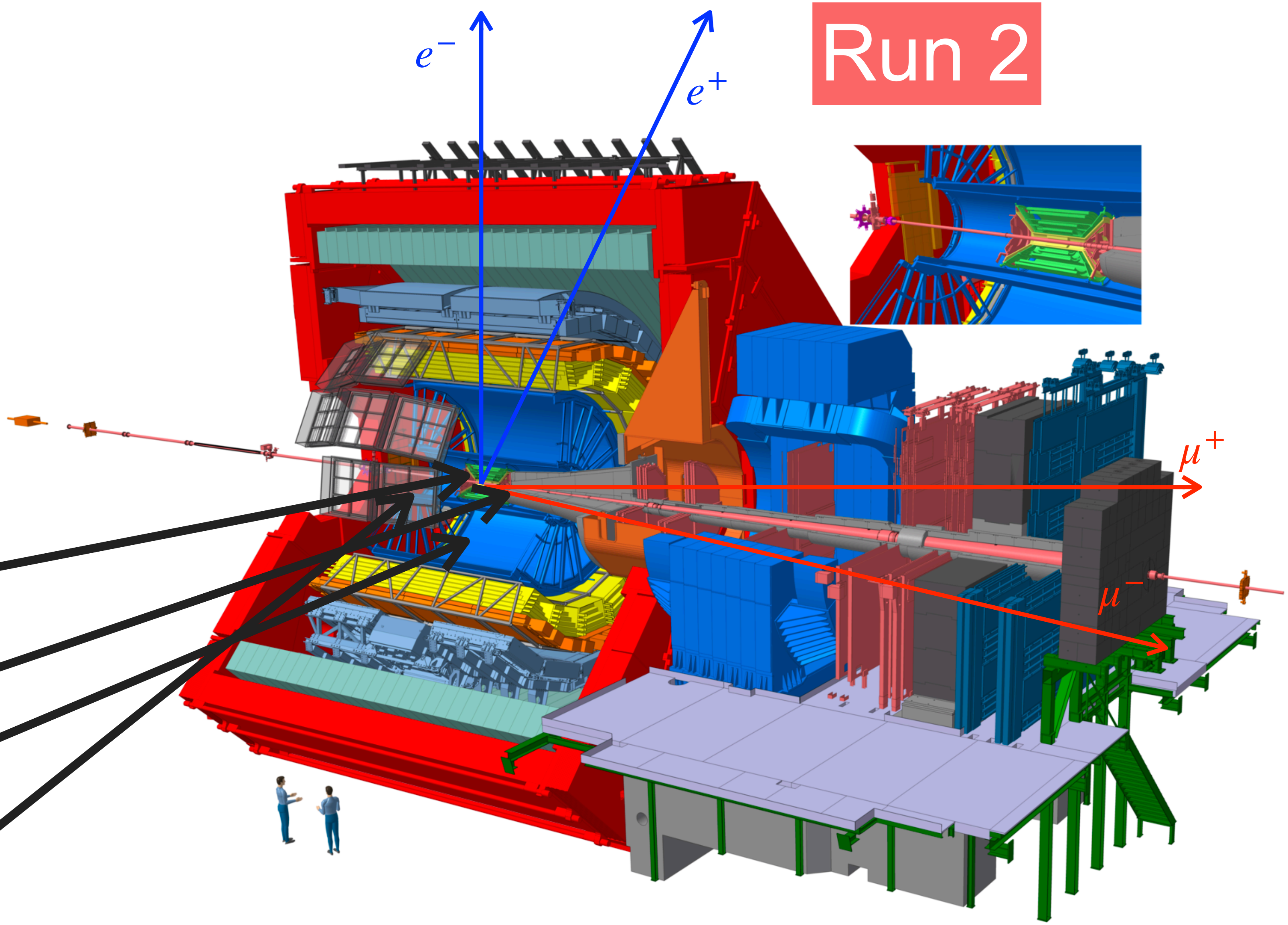
[2] arXiv: 0811.0337





The ALICE detector

- Midrapidity ($|y| < 0.9$): $J/\psi \to e^+e^-$
- Forward rapidity ($2.5 < y < 4$): $J/\psi \to \mu^+\mu^-, \psi(2S) \to \mu^+\mu^-$
- Inclusive quarkonia reconstructed down to zero p_T at both mid- and forward rapidity
- Separation of prompt and non-prompt J/ψ:
    - vertex reconstruction at midrapidity with **Inner Tracking System**
    - vertex reconstruction at forward with **Muon Forward Tracker**
- **Time Projection Chamber** Tracking and particle identification
- **V0 detector** for triggering, centrality determination, and background rejection

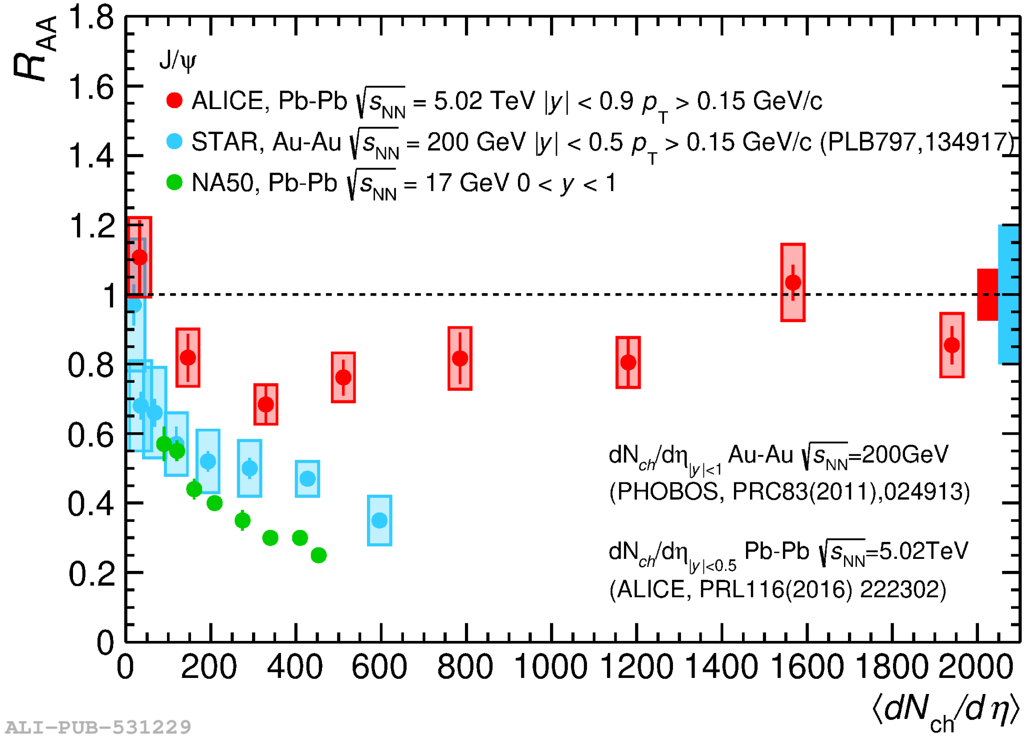


Inclusive J/ψ at mid- and forward rapidity

- Results from Run 2 indicate competition between J/ψ dissociation and recombination
  - Decrease in J/ψ suppression with increasing collision energy
  - LHC: Less or no suppression at low p_T, more pronounced at midrapidity, and suppression at high p_T

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- Both transport and statistical hadronisation models are in agreement with data at low p_T where there is evidence for recombination



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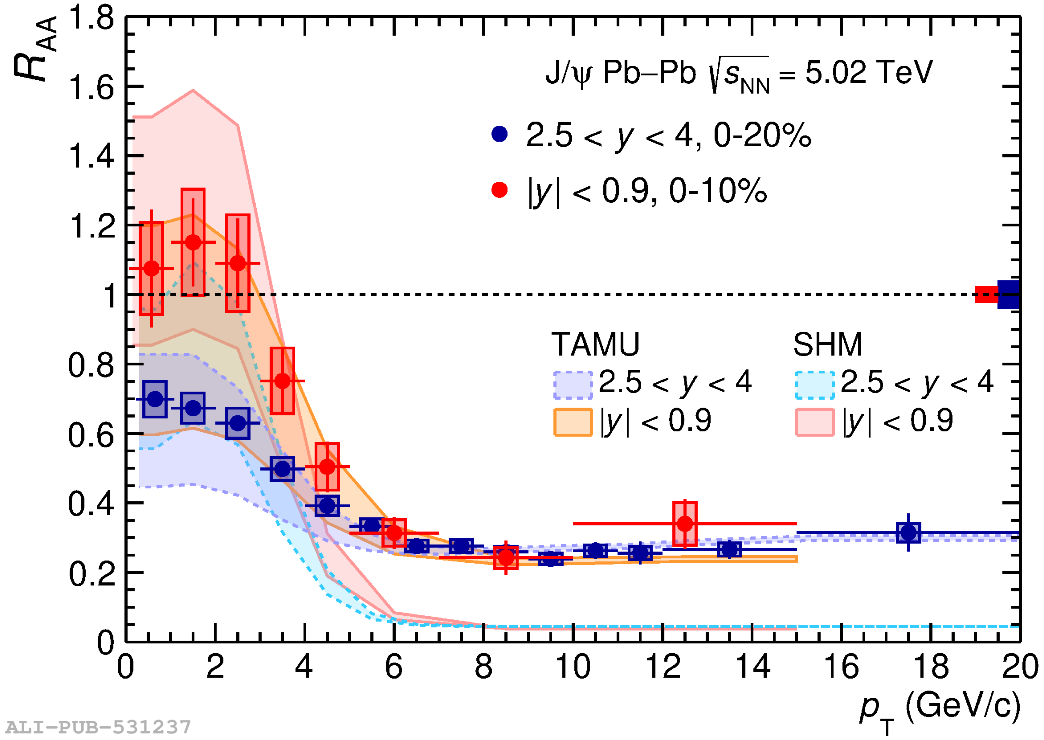

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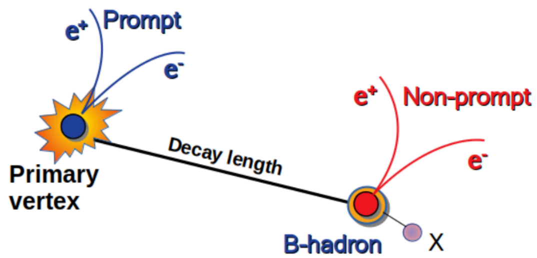
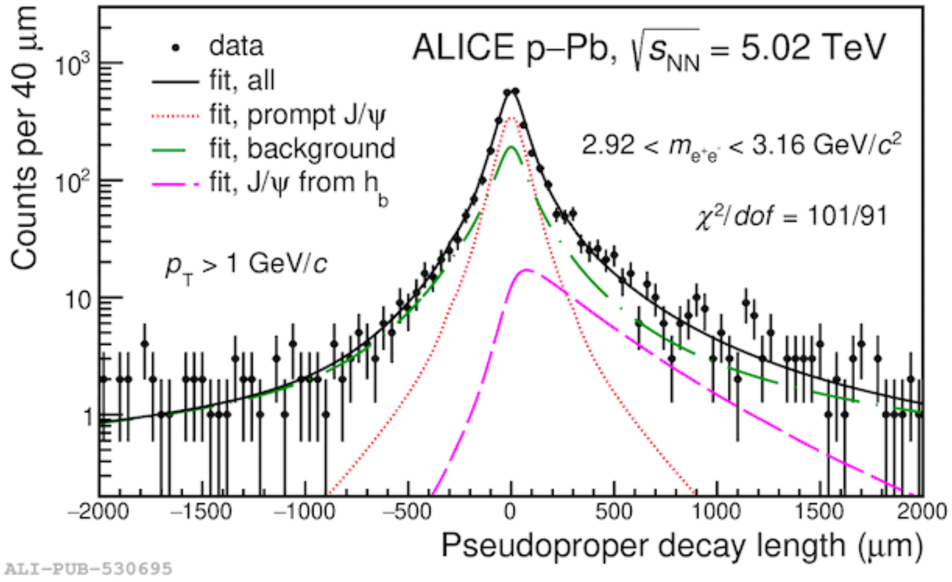
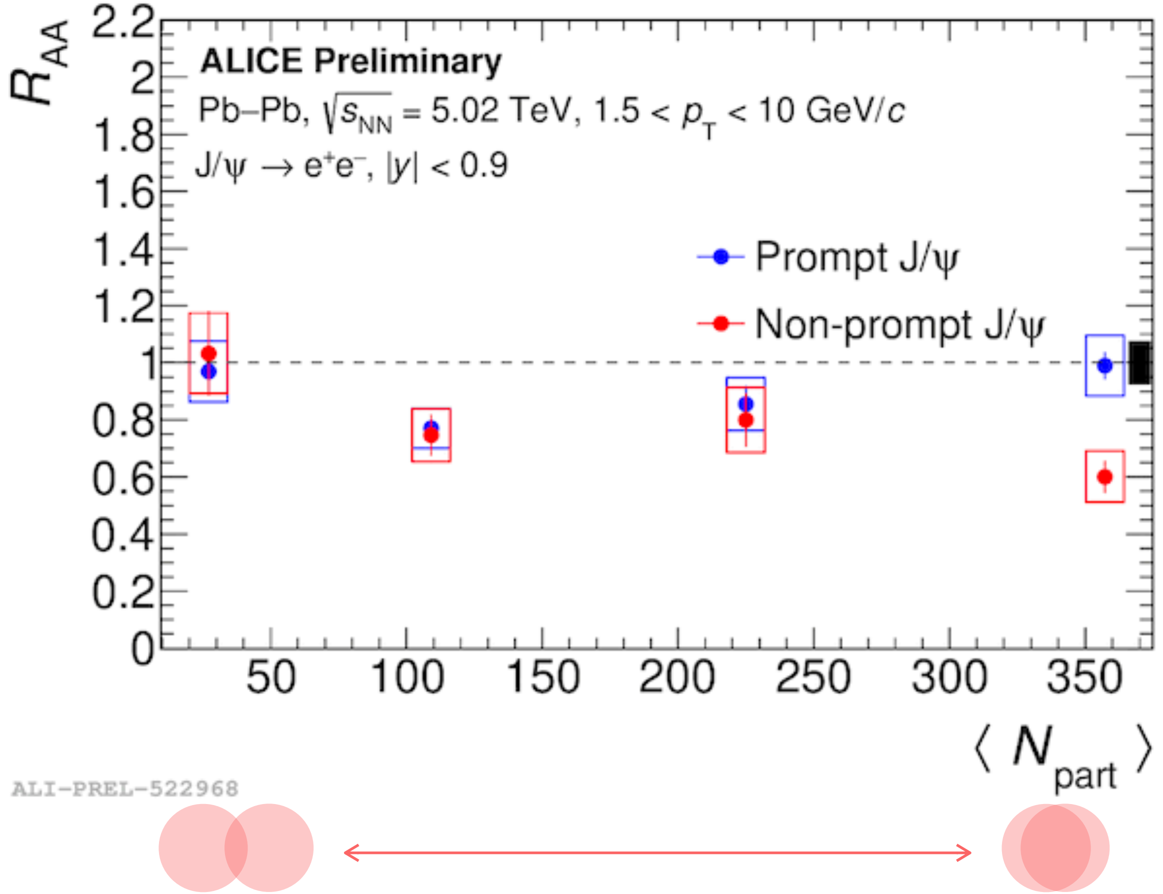
Prompt and non-prompt J/ψ at midrapidity

- Similar suppression in semi-central collisions
- Difference in central collisions → indication of recombination for prompt J/ψ

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$



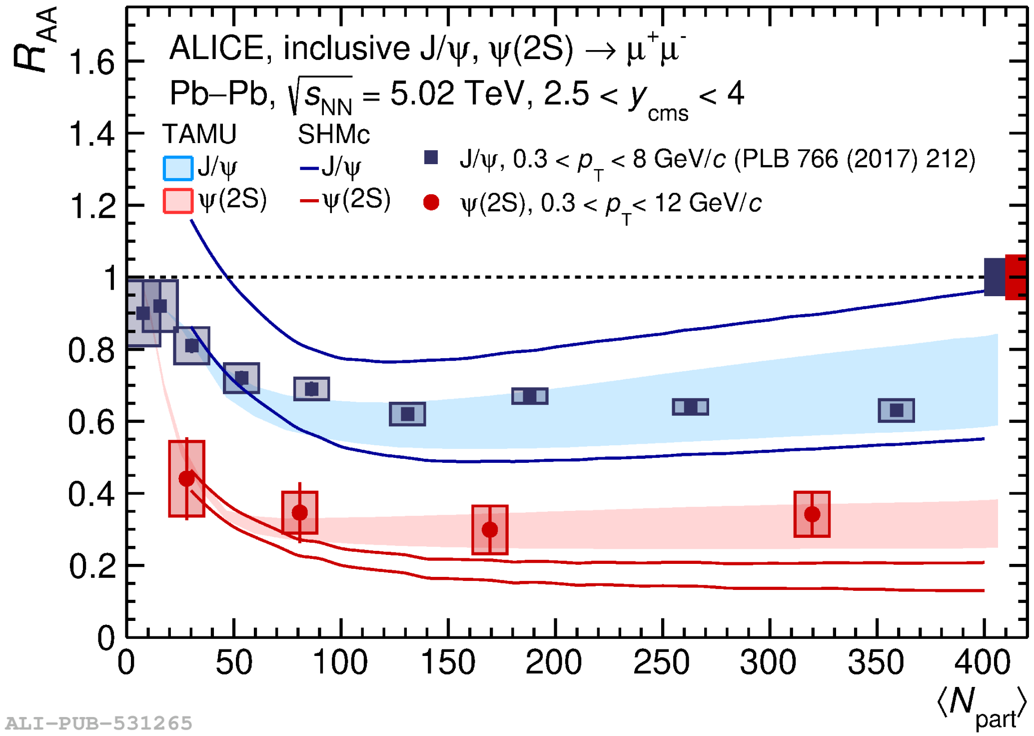




$\psi(2S)$ at forward rapidity

- Smaller binding energy leads to stronger suppression → sequential melting in the QGP
- Hint of recombination also for $\psi(2S)$?
- Transport model TAMU is in good agreement, while SHM overestimates suppression in central events.

$$R_{AA} = \frac{1}{\langle T_{AA}\rangle}\frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$



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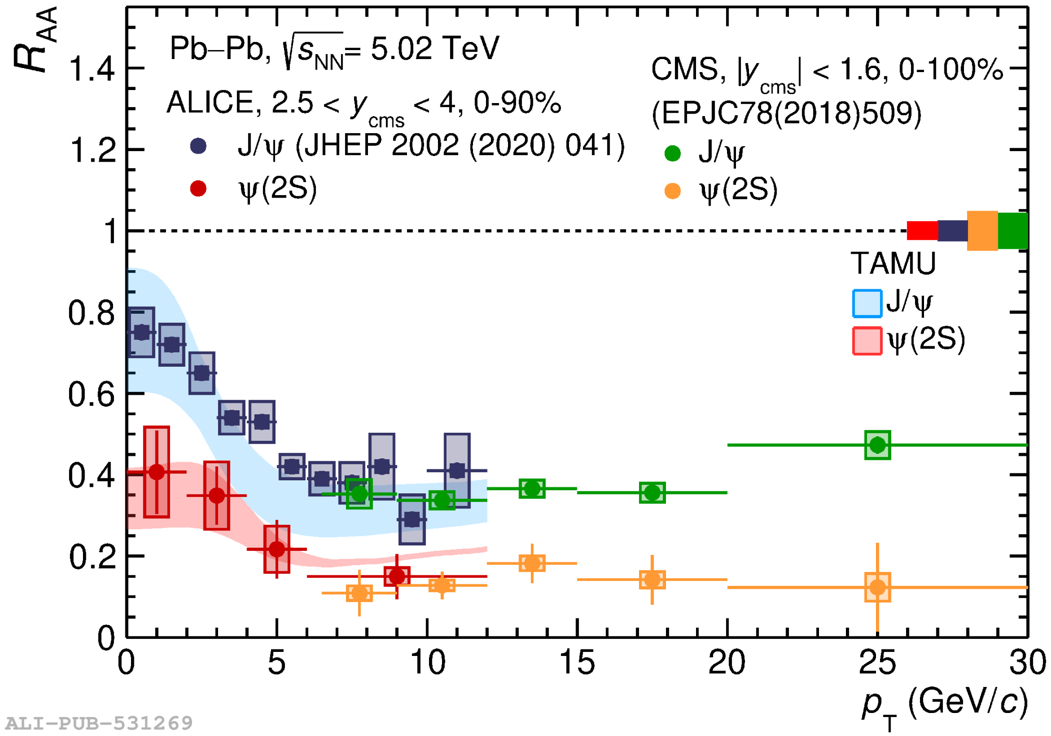
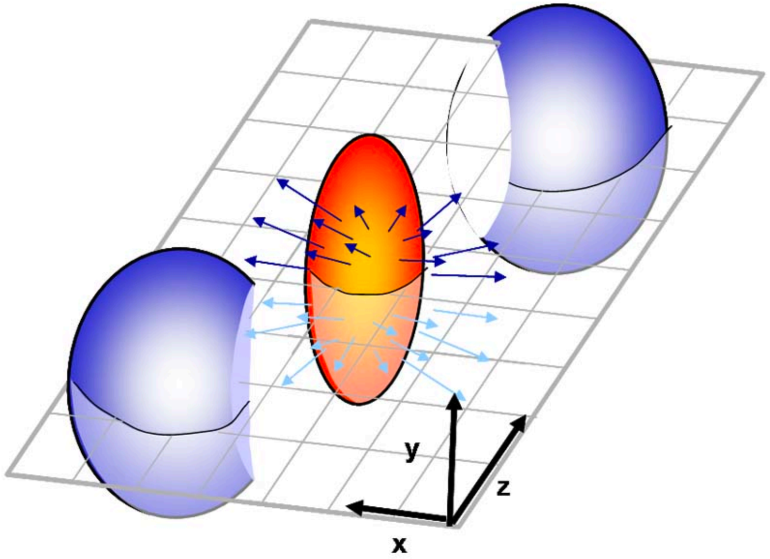


ALI-PUB-531269

J/ψ anisotropic azimuthal distribution

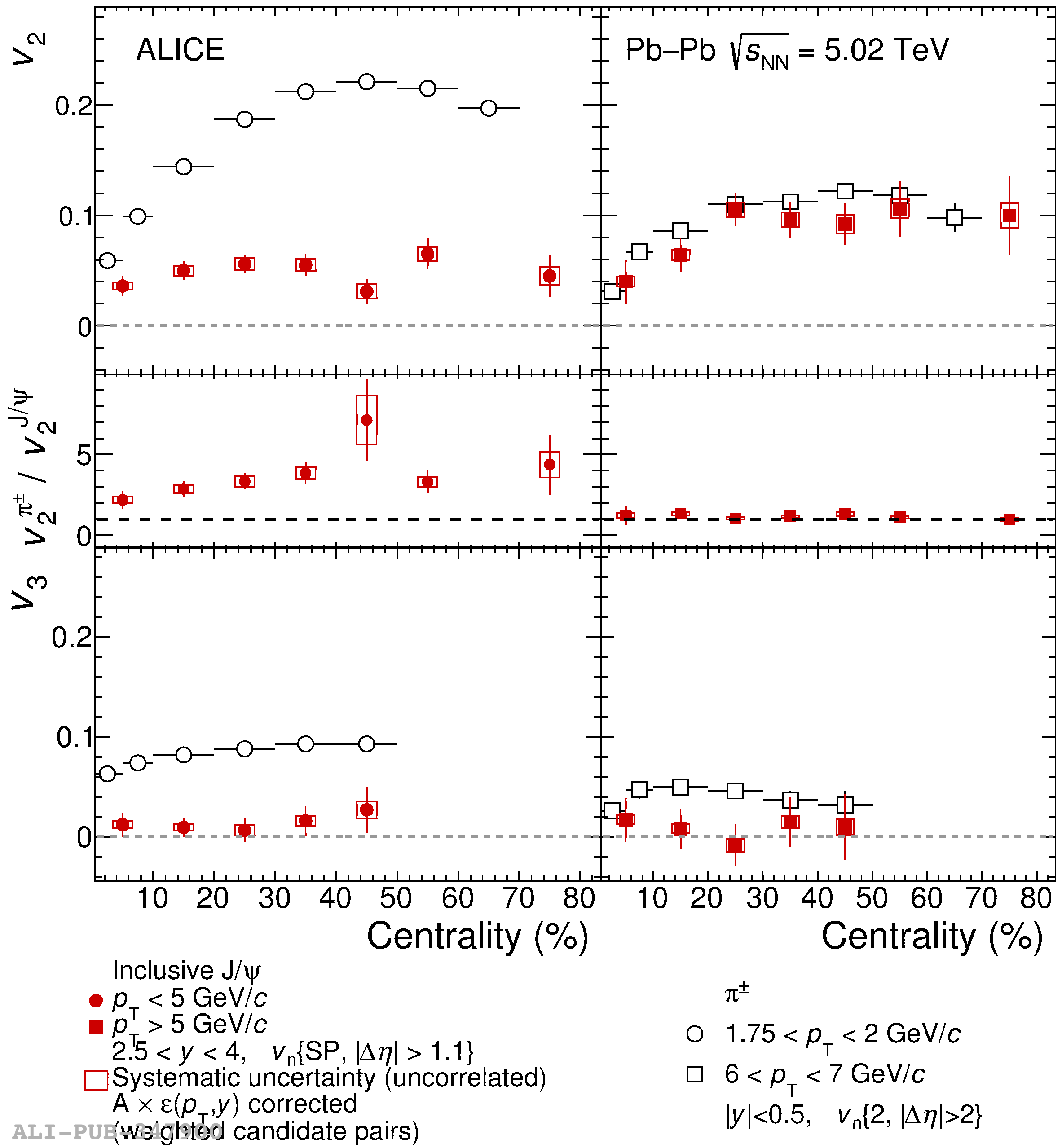
- Initial eccentric profile leads to final state momentum anisotropy
    - Density gradients
    - p_T dependent
- The final state particle azimuthal distribution can be modeled in terms of a Fourier expansion
    - 2nd order coefficient → Elliptic flow
    - 3rd order coefficient → Triangular flow



$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]$$

J/ψ anisotropic azimuthal distribution

- v_2 is higher for pions
  - More pronounced than J/ψ v_2 for semi-central events
  - Pion flow reflects the initial geometry
- v_2 for J/ψ
  - saturates at 20% centrality
  - Increases at higher p_T, while v_2 for pions decreases
- Pronounced v_3 for pions, but not for J/ψ, indicates J/ψ formation at later stage in the collision



Conclusion and outlook

- Sequential suppression for charmonium states
  - $R_{AA}(\psi(2S)) < R_{AA}(J/\psi)$
- Clear indication of charmonium recombination
  - Major production mechanism for J/ψ
  - Hint of similar effect for $\psi(2S)$
- J/ψ v_2 indicates a collective charm flow, with charm quarks thermalizing later than light quarks
- Prospects for Run 3:
  - Increased statistics: improved precision on $\psi(2S)$
  - Improved or new vertexing capabilities due to
    - Inner Tracking System upgrade (midrapidity)
    - Muon Forward Tracker upgrade (forward)
    - → Improved separation between prompt and non-prompt charmonia