Charmonium production in Pb-Pb and p-Pb collisions with ALICE at the LHC

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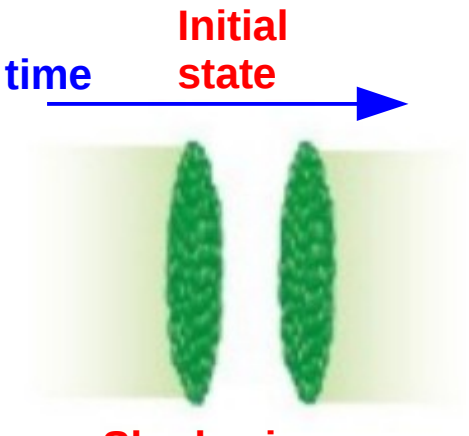
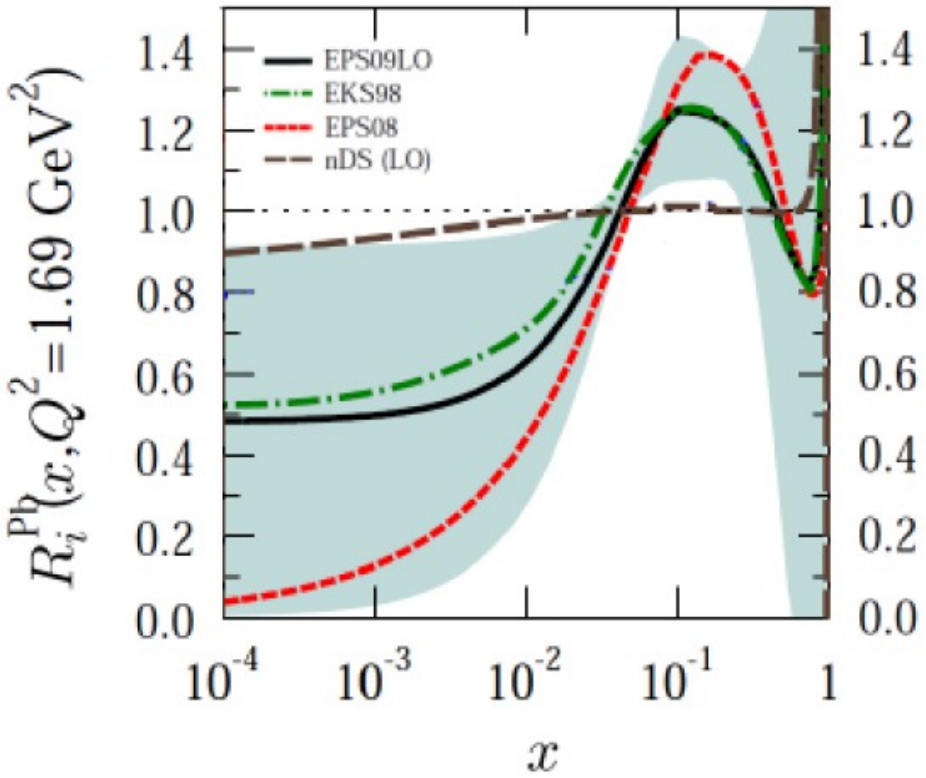
on behalf of the
ALICE Collaboration
University of Oslo

Discovery Physics at the LHC, Kruger Gate, South Africa, 1-6 december 2014

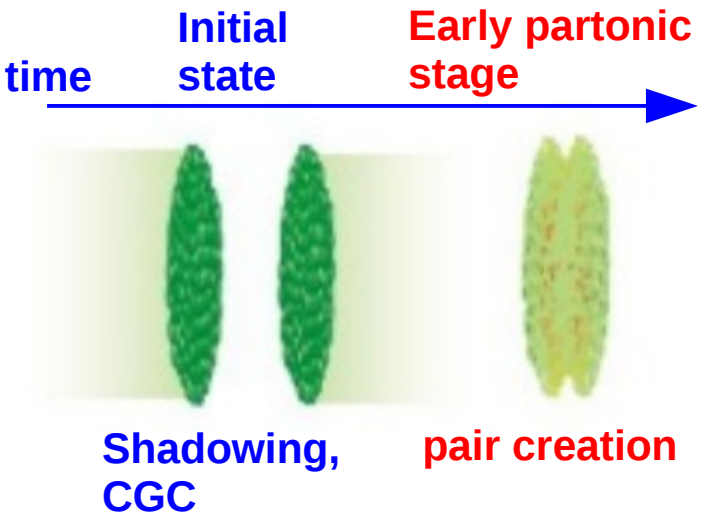
Charmonia in nucleus-nucleus collisions





- Cold nuclear matter (CNM) effects
  - Gluon shadowing or gluon saturation expected to play an important role in the small-*x* region at LHC
  - Initial state parton energy loss
- Cold nuclear matter effects currently studied in p-Pb collisions at $\sqrt{s_{NN}}$=5 TeV

Charmonia in nucleus-nucleus collisions



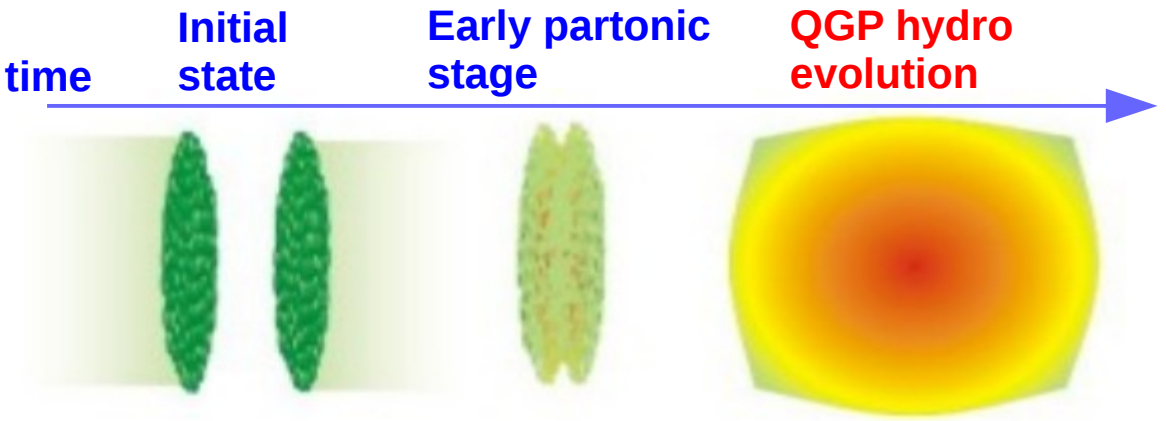
- Charm quarks produced via pair creation in gg processes
- Pair production in pp
  - $\sigma_{c\bar{c}}$(pp @ 7TeV) = 8.5mb, ALICE JHEP 1207 (2012) 191

- Central Pb-Pb collisions at LHC at $\sqrt{s_{NN}}$=2.76 TeV have ~1500 nucleon-nucleon collisions: ~100 $c\bar{c}$

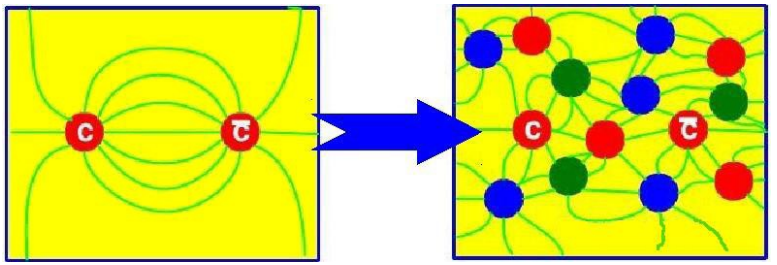
- Number of charm quarks conserved throughout the collision → well calibrated probe !

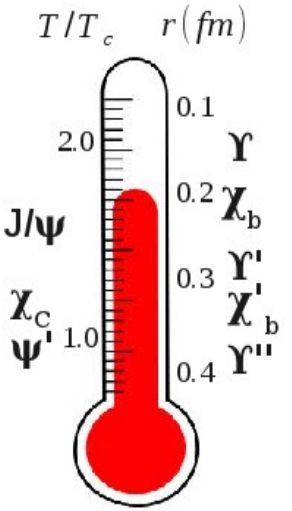
- CNM: Nuclear absorption negligible at the LHC: formation time >> collision time

Charmonia in nucleus-nucleus collisions



- Colour screening
  - Matsui and Satz, PLB 178 (1986) 416
- Sequential suppression depending on binding energy
  - Digal, Petreczky, Satz, PRD (2001) 0940150
- Melting ↔ formation of quarkonium states
  - Thews et al., PRC 63 (2001) 054905
  - Transport models





Charmonia in nucleus-nucleus collisions

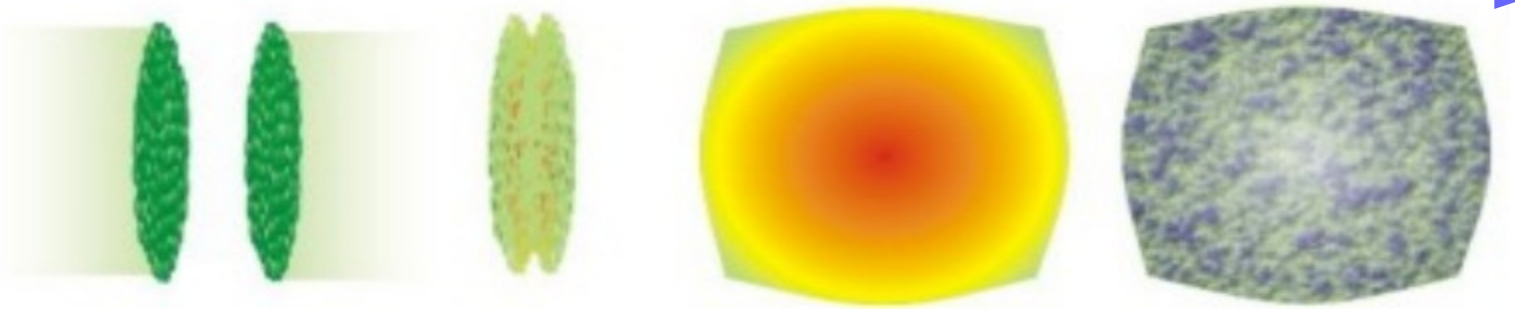
time

Initial state

Early partonic stage

QGP hydro evolution

Chemical freeze-out



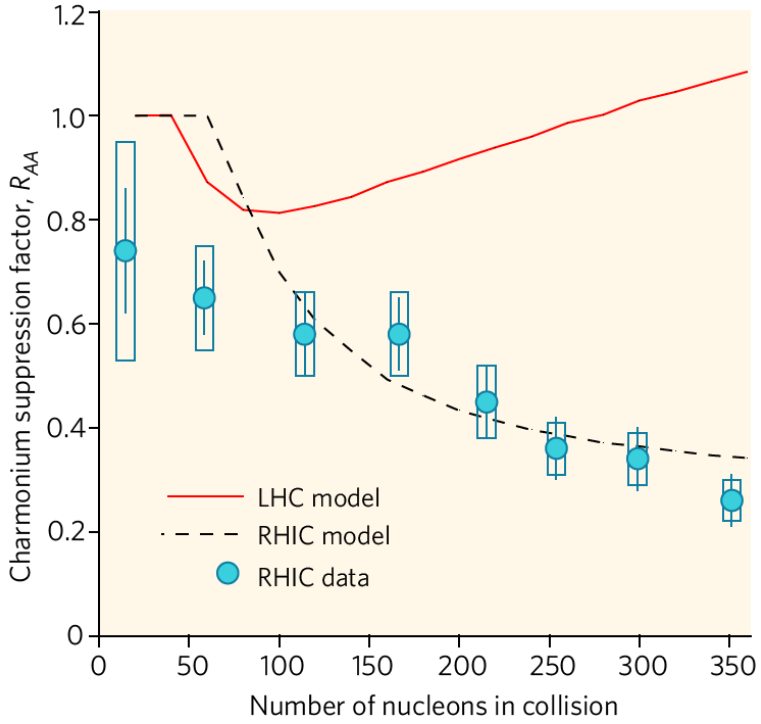
Shadowing, CGC

pair creation: ~100 $c\bar{c}$

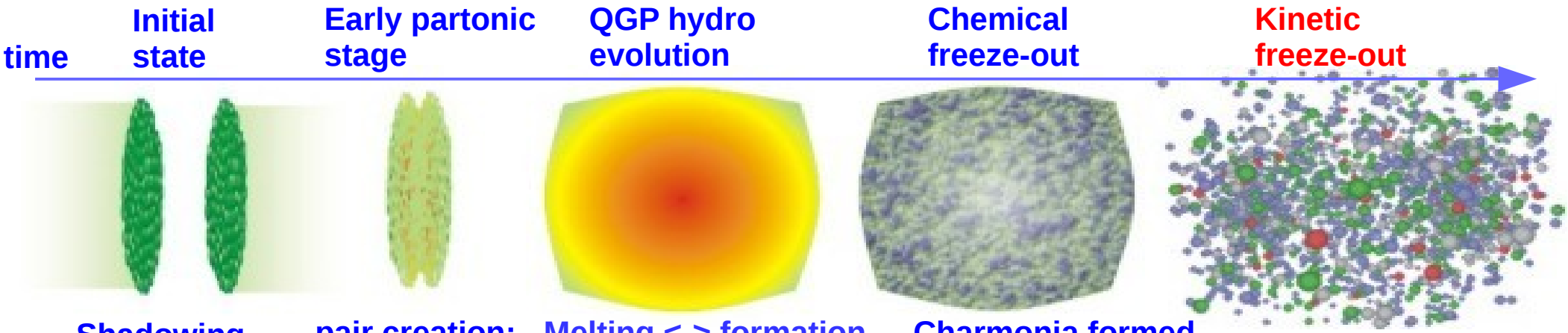
Melting <-> formation of charmonium states
Thermalization
Flow of heavy quarks

Charmonia formed via statistical hadronization at the phase boundary ?

- Enhancement of charmonia states from $c\bar{c}$ pairs at the chemical freeze-out
- Open charm and charmonium abundancies calculated assuming statistical hadronization.
  - Braun-Munzinger and Stachel, PLB 490 (2000) 196

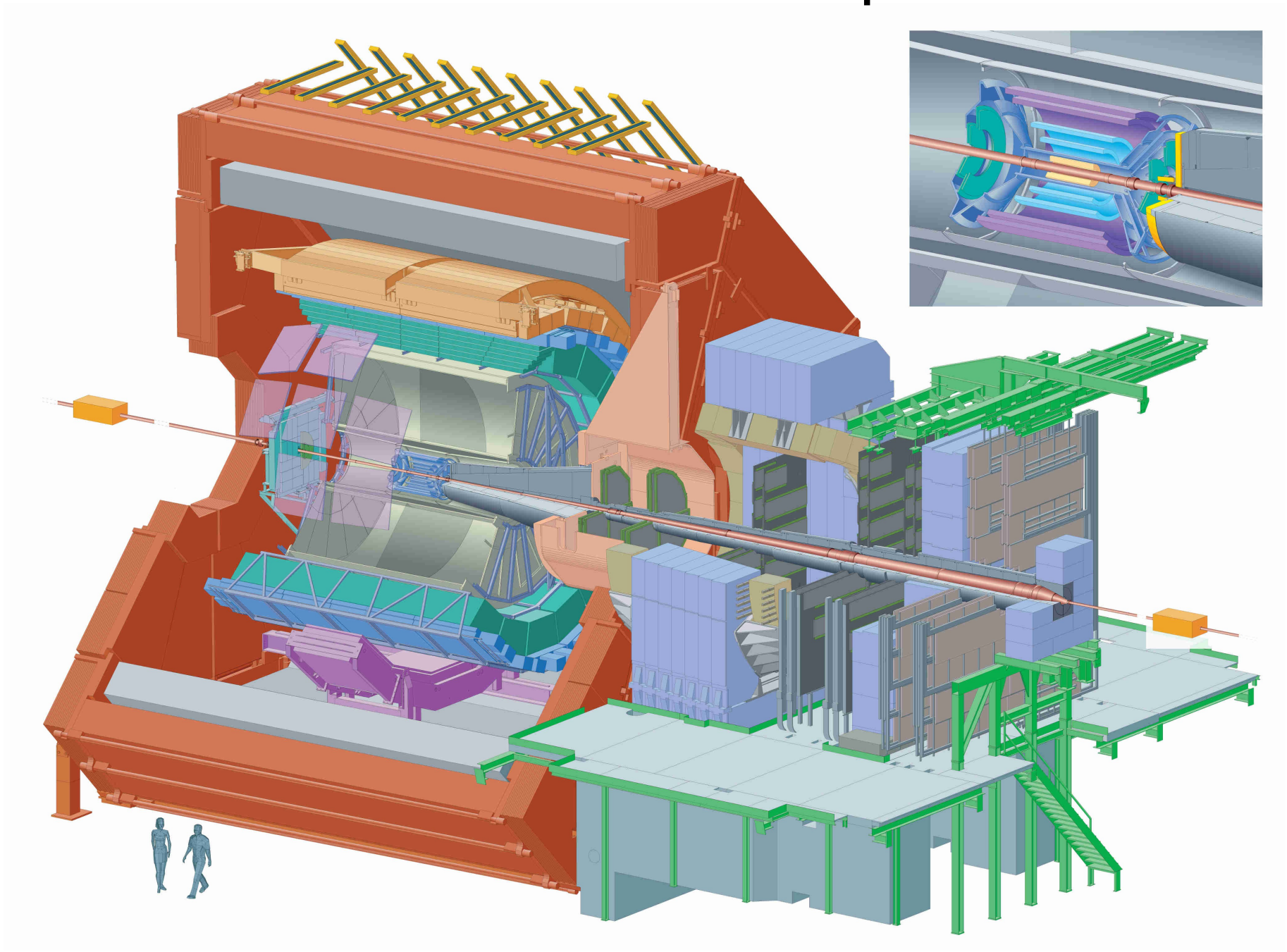


Charmonia in nucleus-nucleus collisions



- J/ψ prompt feed-down from χ_c and ψ' (~35%)
- J/ψ non-prompt feed-down from weak decays of beauty mesons (~10%)

The ALICE setup



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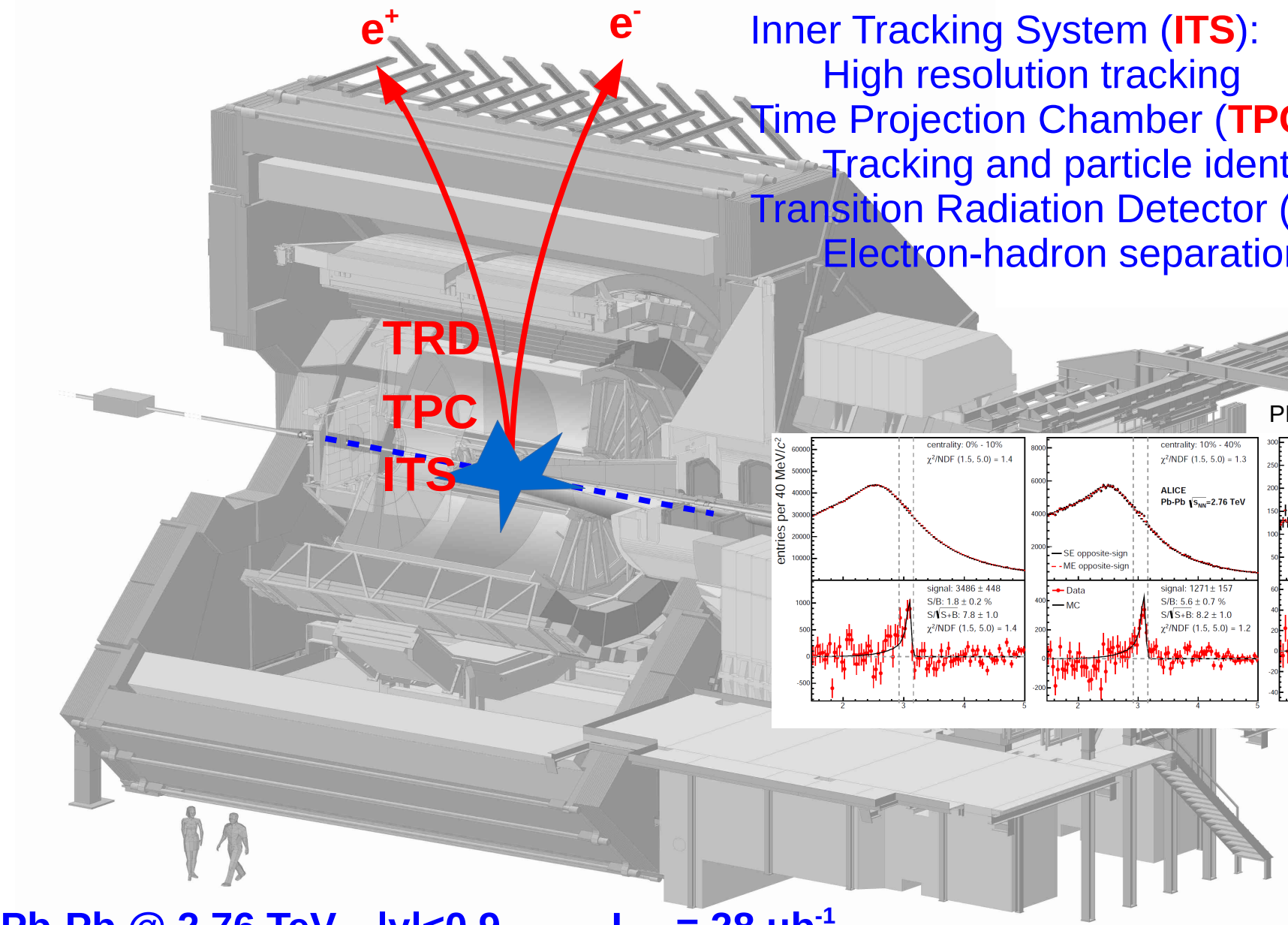


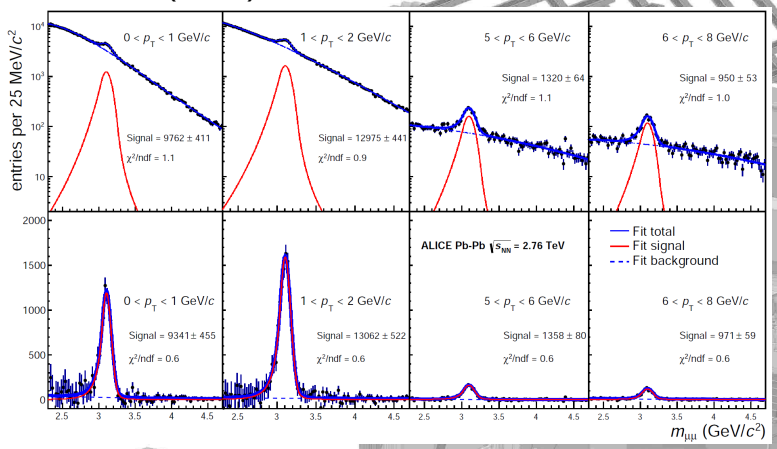
Inner Tracking System (**ITS**):
High resolution tracking
Time Projection Chamber (**TPC**):
Tracking and particle identification
Transition Radiation Detector (**TRD**):
Electron-hadron separation

PLB734 (2014) 314

Pb-Pb @ 2.76 TeV, |y|<0.9, L_{int} = 28 μb^{-1}

The ALICE setup

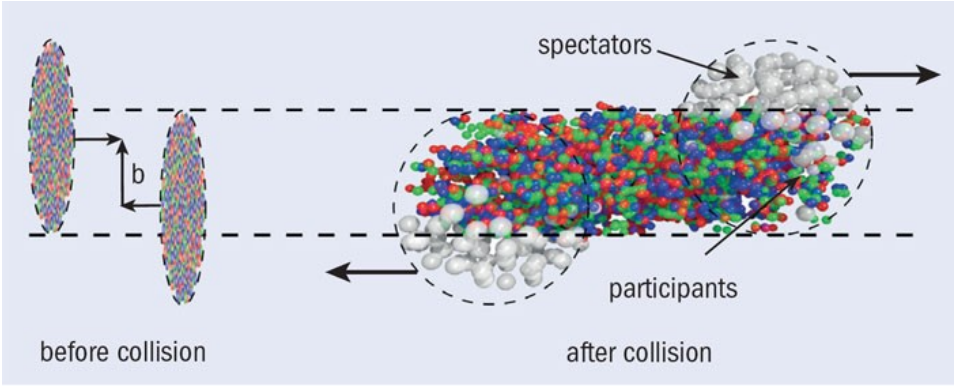
PLB734 (2014) 314



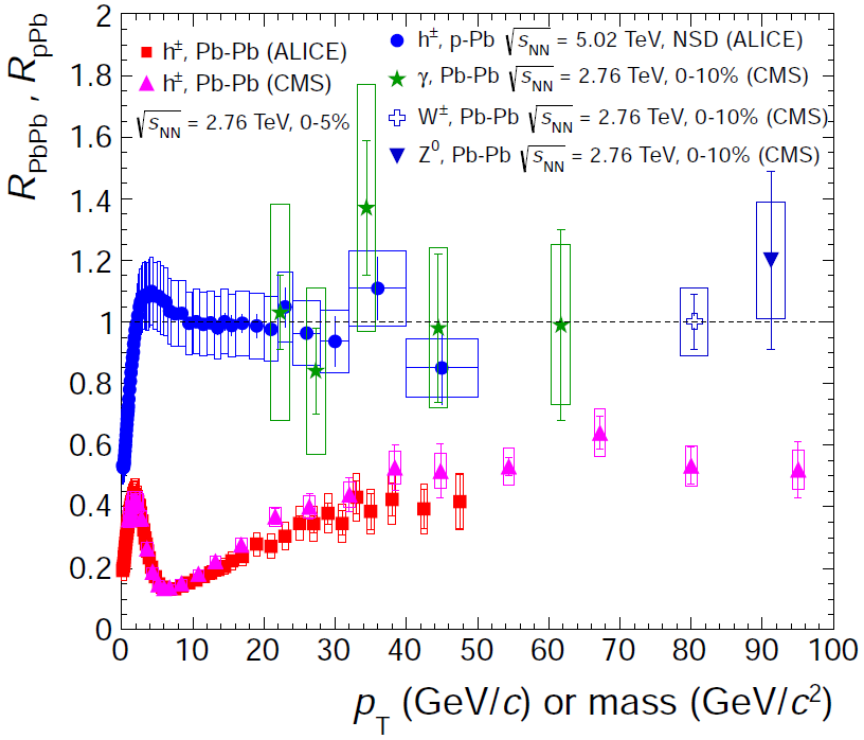
Forward Muon Spectrometer:
Dipole magnet,
Five muon tracking stations behind a front hadron absorber,
Two trigger stations behind an additional hadron absorber.

Pb-Pb @ 2.76 TeV, 2.5<y<4.0, L_{int} = 68.8 μb^{-1}

Quantifying medium effects -nuclear modification factor-



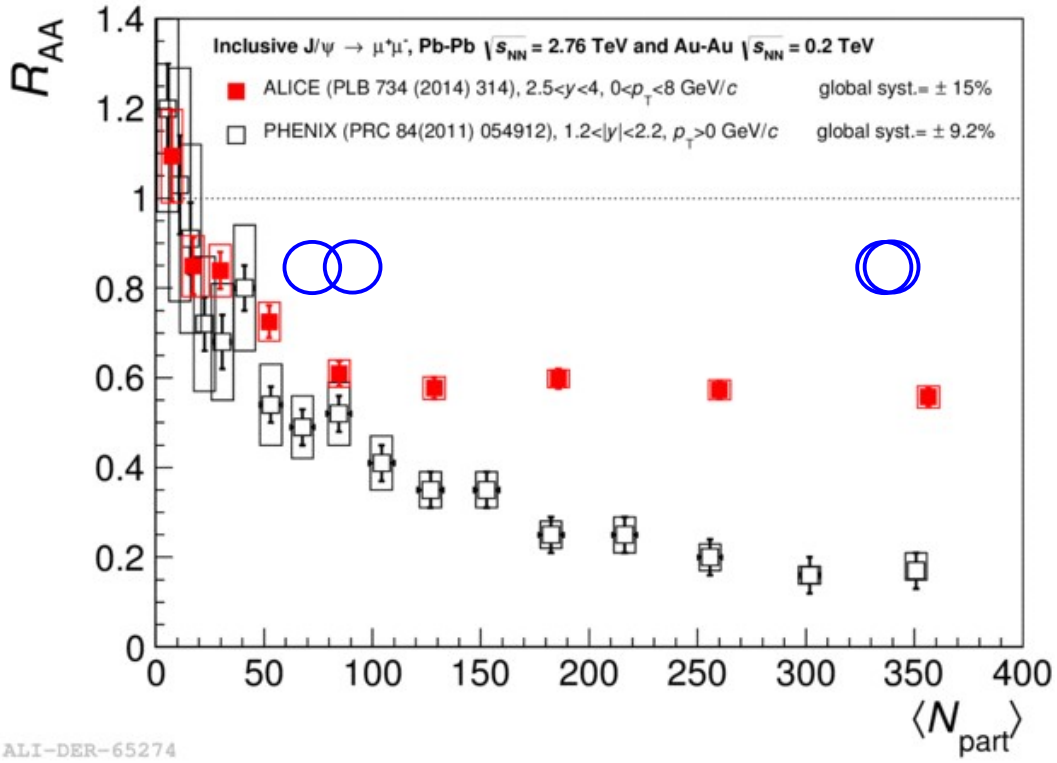
$$R_{AA} = \frac{d^2 N_{AA}/dp_T dy}{N_{coll} \times d^2 N_{pp}/dp_T dy}$$

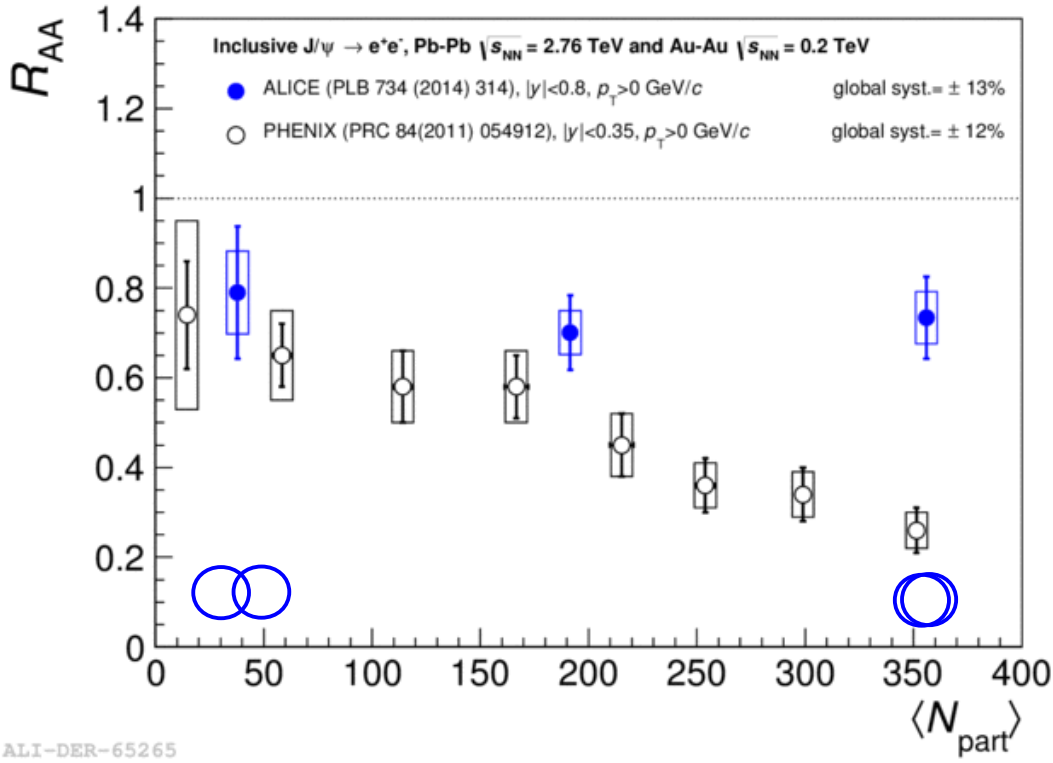


- Superposition of NN collisions → R_{AA}=1
- Strong suppression for light hadrons observed at LHC in Pb-Pb collisions
- Weakly interacting particles are not affected by the QGP
  - Photons, $W^{\pm}$ and Z^0 bosons R_{AA} is compatible with unity.

p-Pb, ALICE EPJ C74 (2014) 9, 3054
Pb-Pb, ALICE, Phys.Lett.B720 (2013)52
Pb-Pb, CMS, EPJC (2012) 72
γ, CMS, PLB 710 (2012) 256
$W^{\pm}$, CMS, PLB715 (2012) 66
Z^0, CMS, PRL106 (2011) 212301

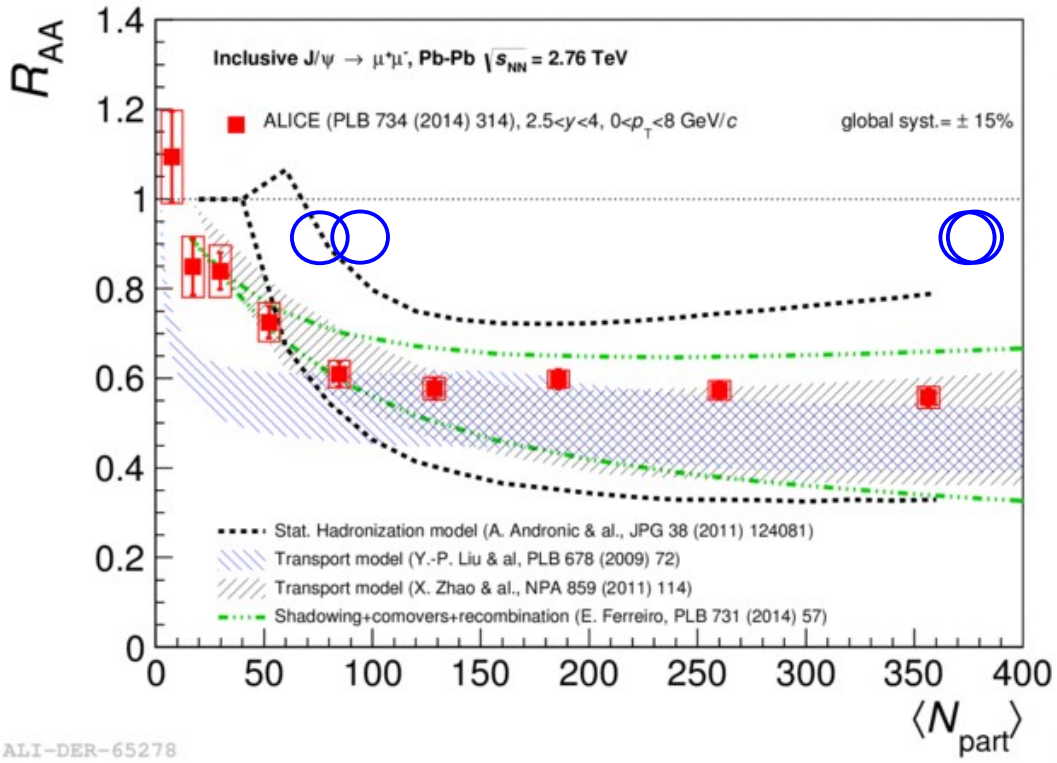
Inclusive J/ψ at the LHC

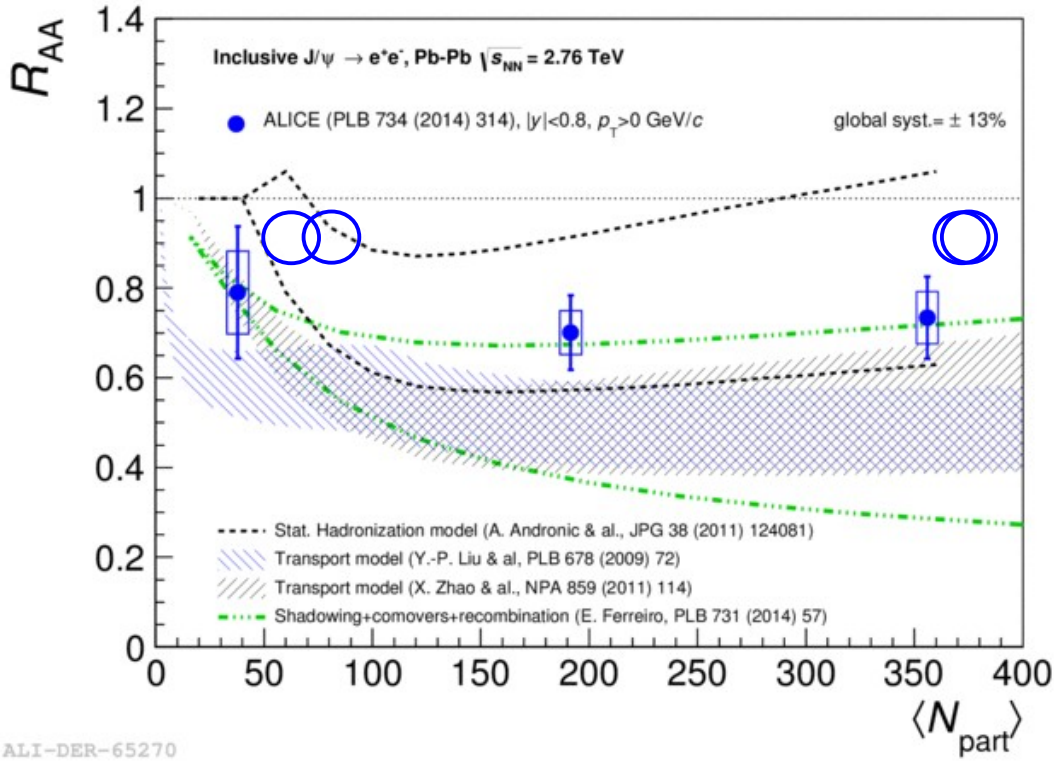




- Clear J/ψ suppression seen for all centralities
- Indication of less suppression at mid- than at forward rapidity
- ALICE results show smaller suppression compared to lower energy (PHENIX) in central collisions

Inclusive J/ψ at the LHC





- Models which include (re)combination agree with the data.
- Model uncertainties are dominated by the poor knowledge of the total $c\bar{c}$ cross-section and CNM effects

Inclusive J/ψ as a function of p_T

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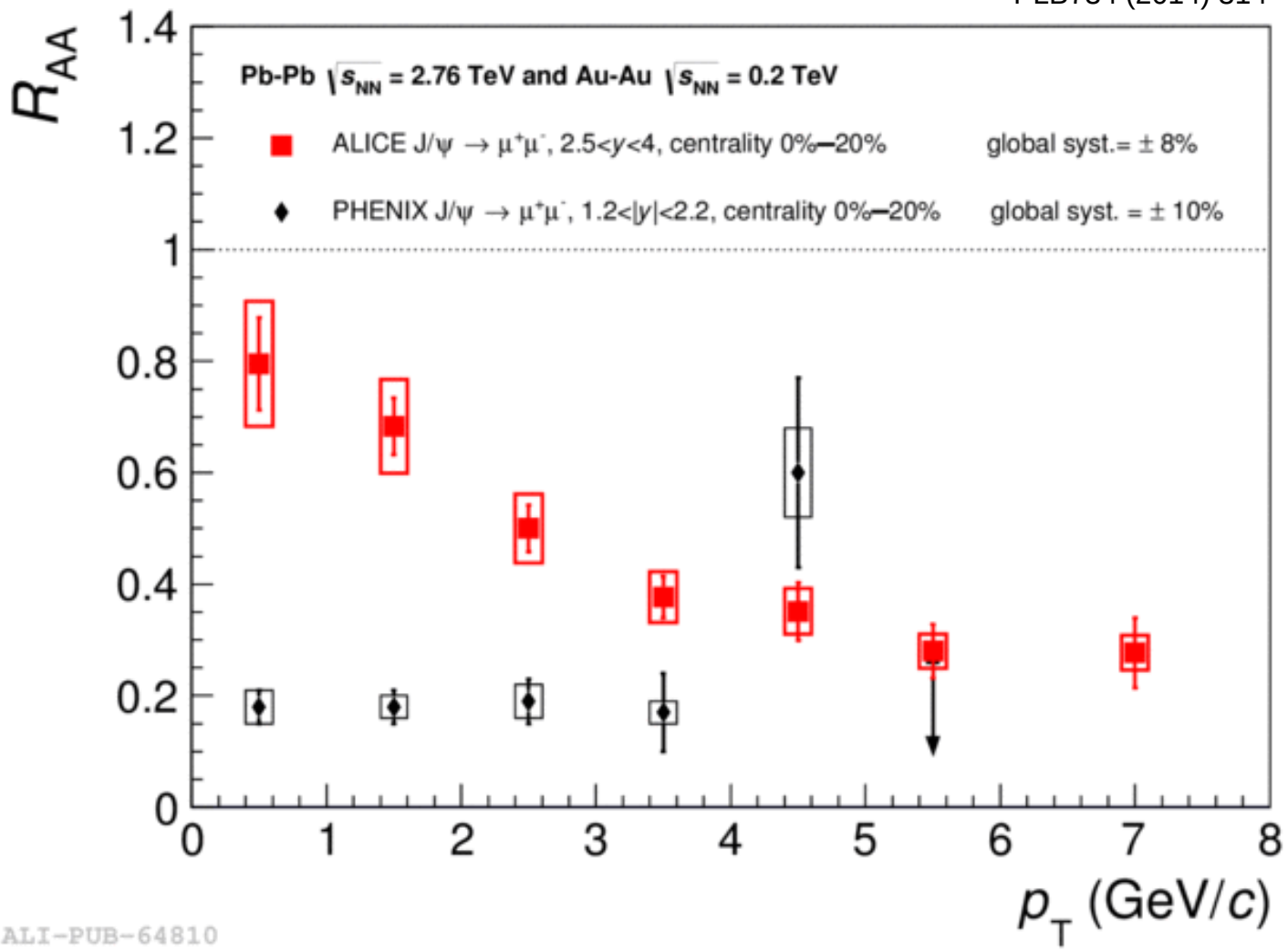
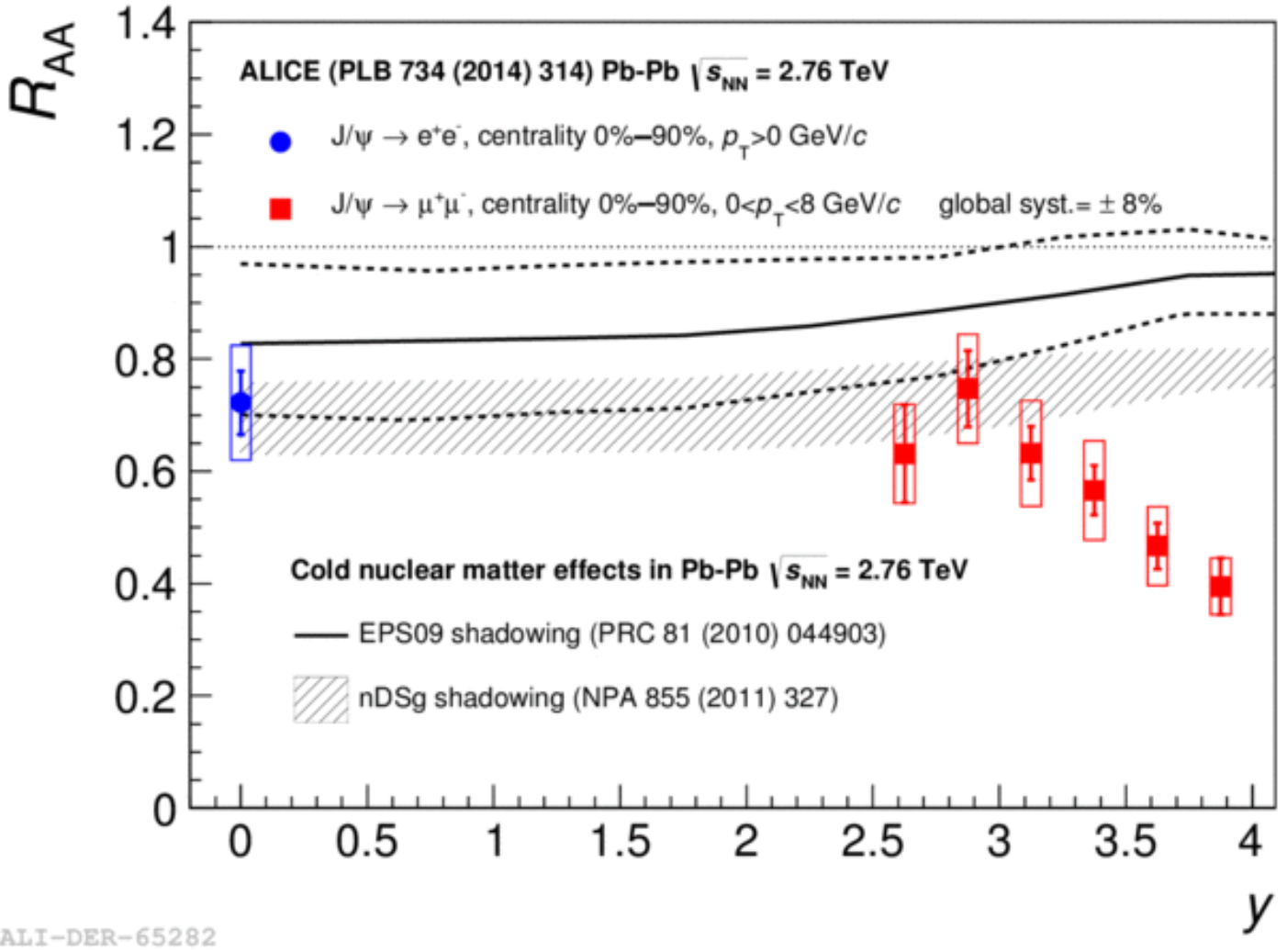


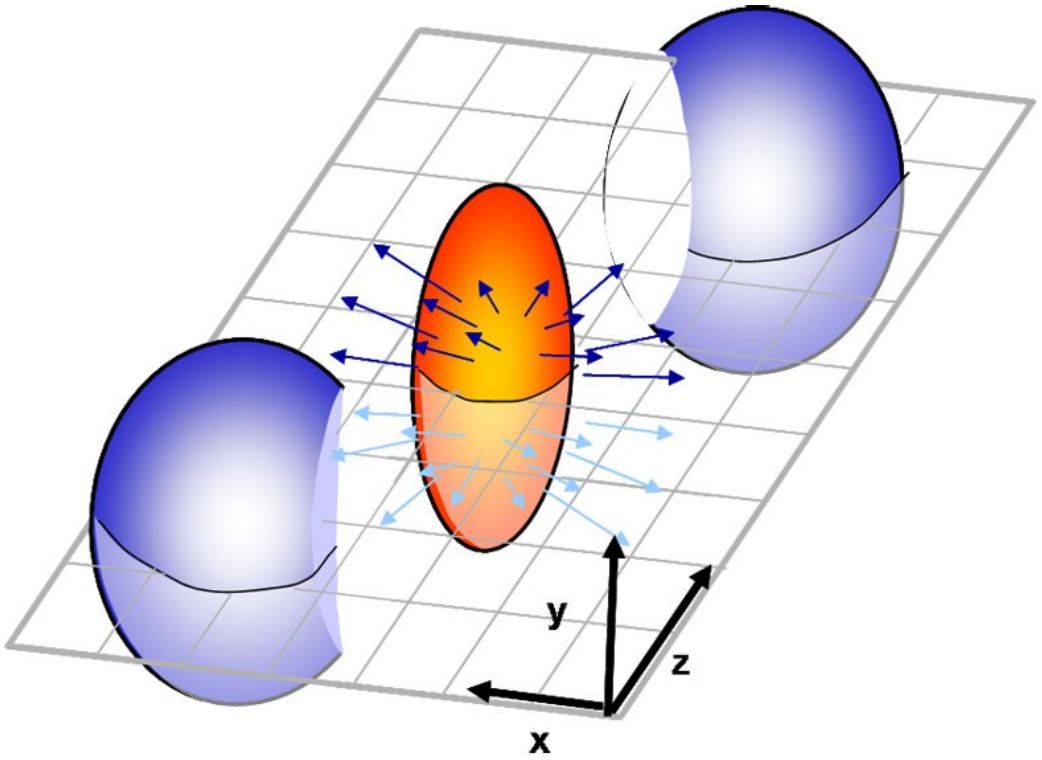
- Striking difference between LHC and RHIC at low-p_T
  - "Smoking gun" for (re)combination ?

Inclusive J/ψ as a function of rapidity

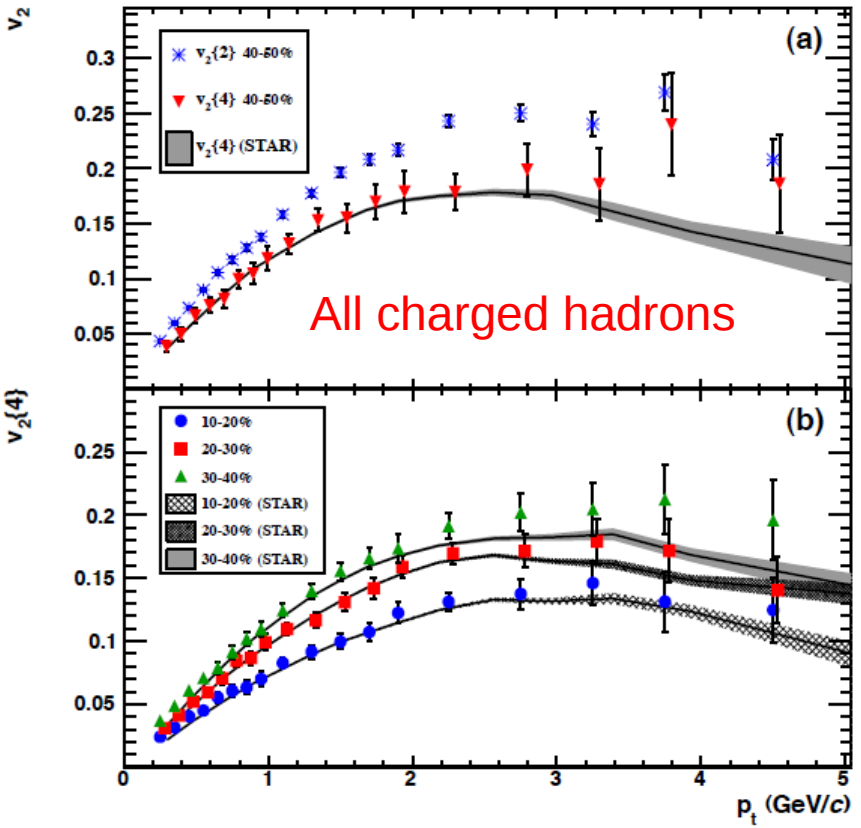


- Strong rapidity dependence for low-p_T at y>3 (ALICE)
  - CNM effects, (re)combination ?

Elliptic flow



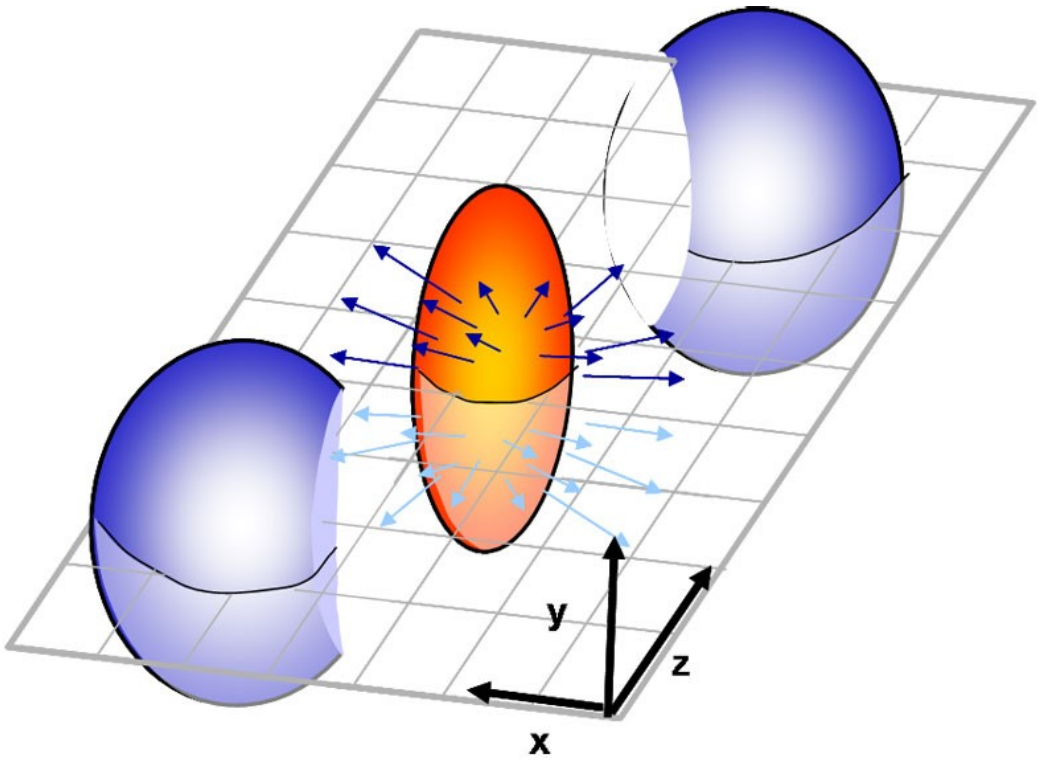
ALICE PRL105 (2010) 252302

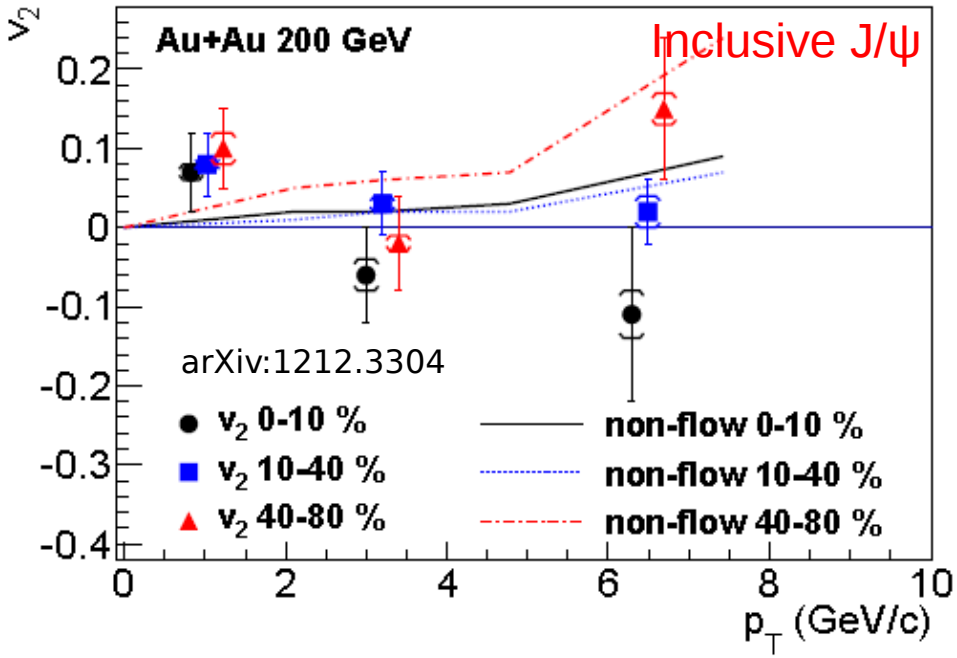


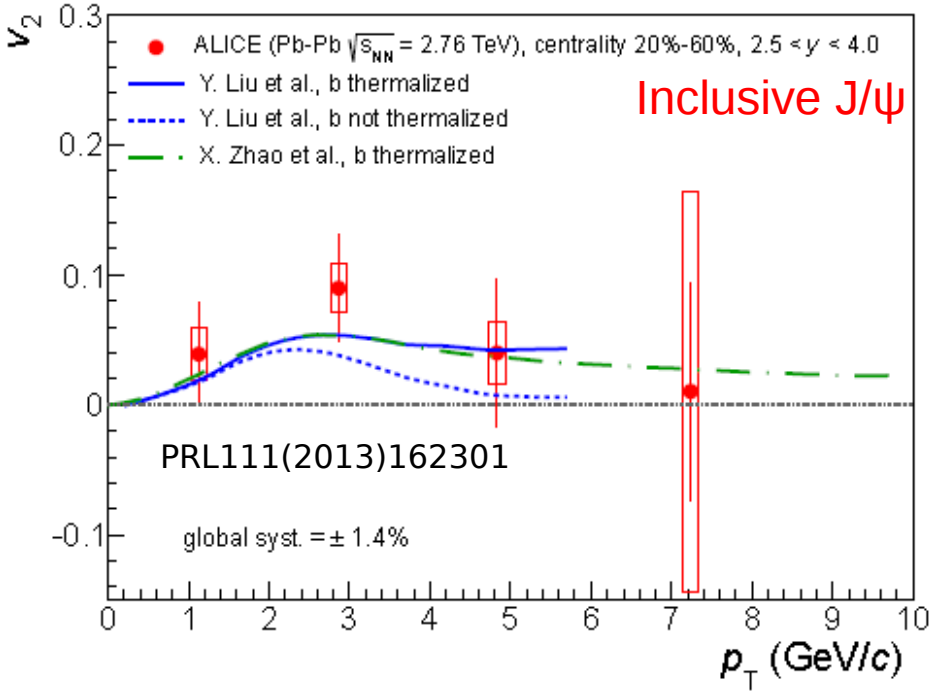
$$\frac{dN}{dy} \simeq 1+2v_1\cos(\phi-\Psi_r)+2v_2\cos(2(\phi-\Psi_r))\ldots$$

- Initial spatial anisotropy is converted into momentum-space anisotropy
- Strong elliptic flow observed for light particles
- Is J/ψ inheriting any of the fireball collective flow via (re)combination?

Elliptic flow

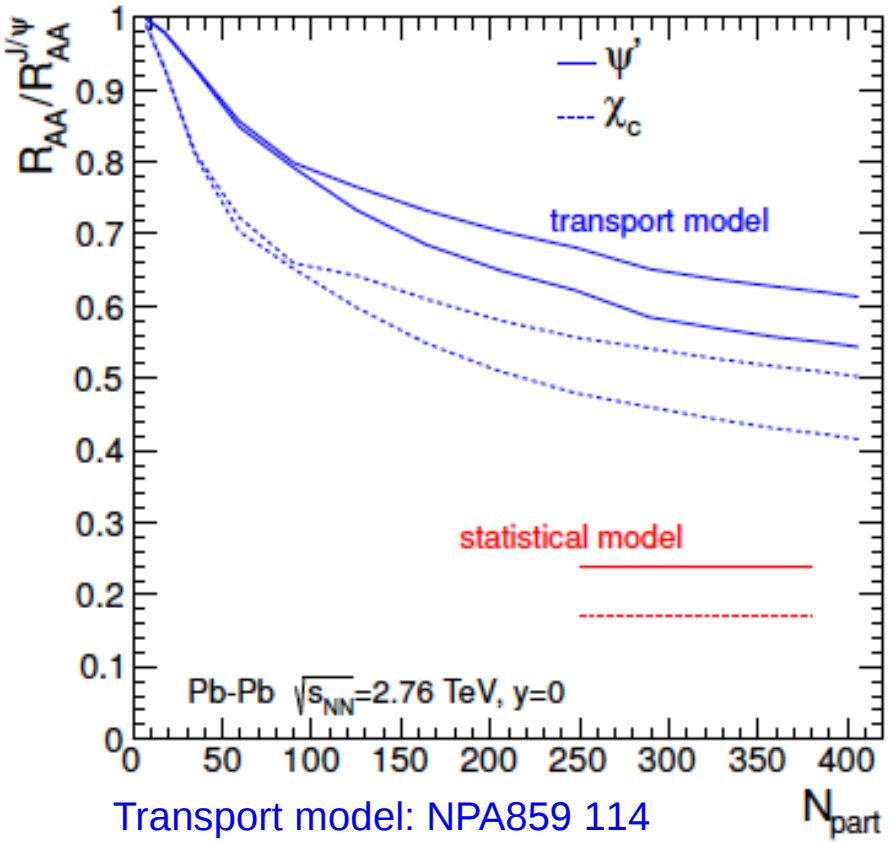






- Measurements at RHIC compatible with no flow
- LHC data hints towards a non-zero flow in semi-central collisions

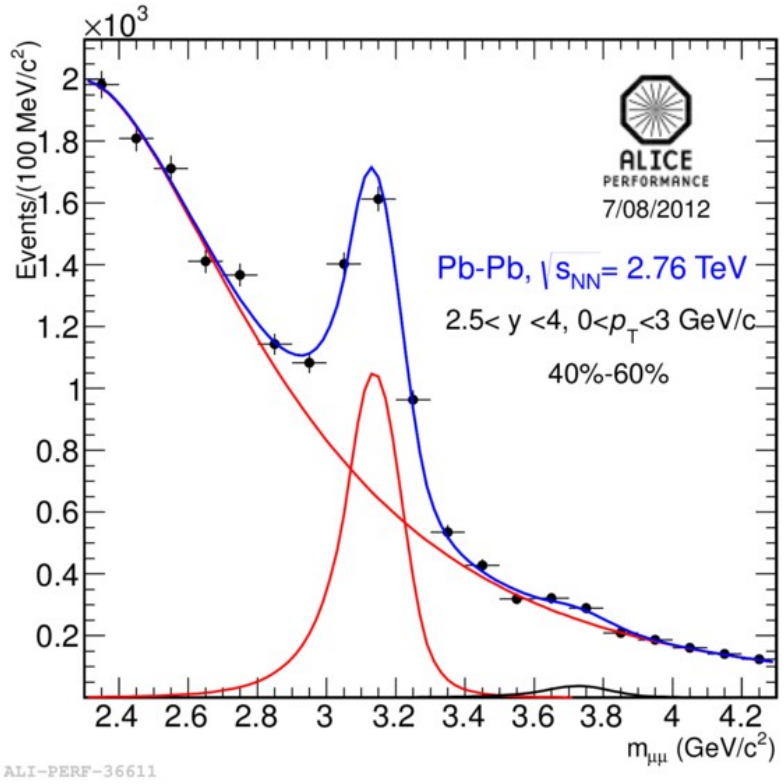
ψ' production

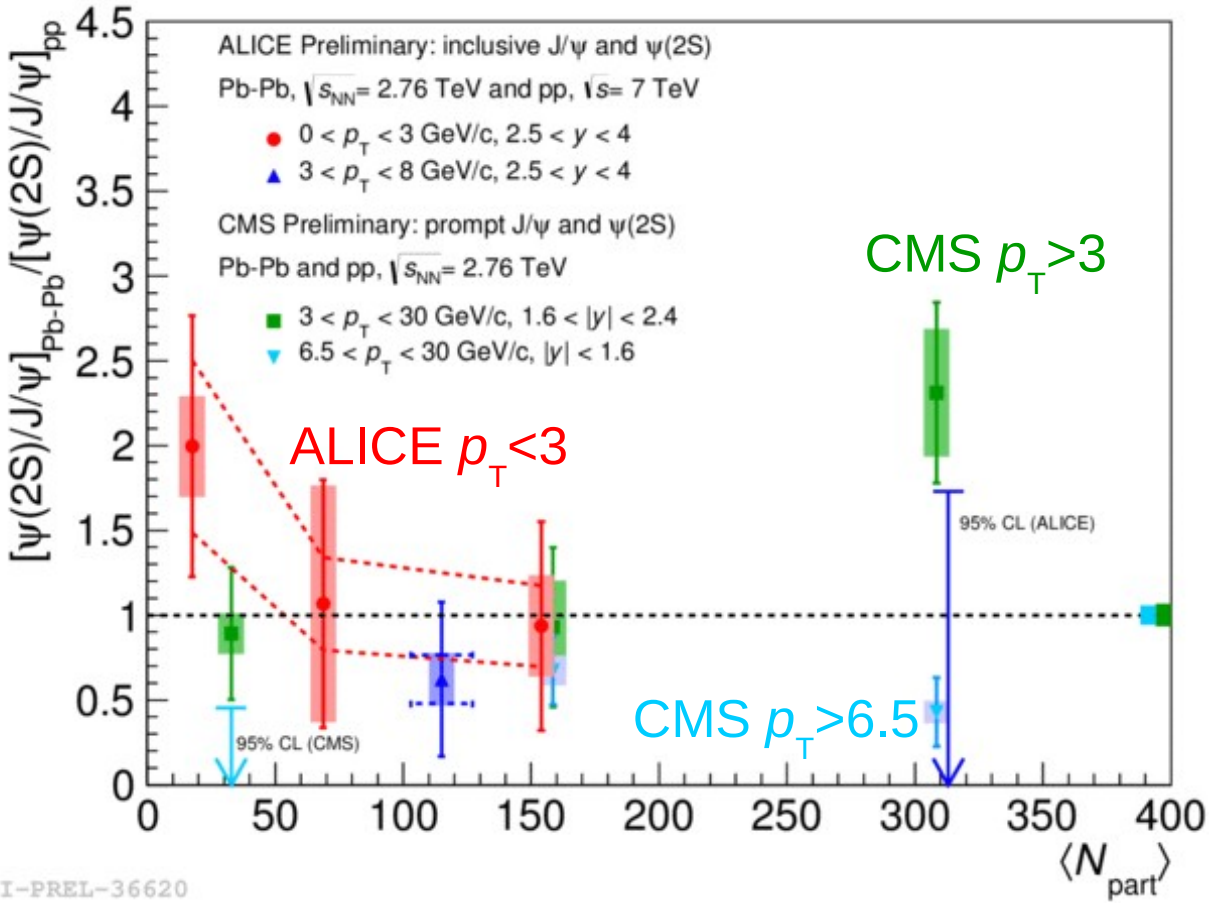


Transport model: NPA859 114
Statistical model: PLB490 196

- ψ' is much less bound than J/ψ
- Ratio of R_{AA} for different charmonia are less dependent on the charm x-section
- Transport and statistical hadronization models can be disentangled !

ψ' production





- Results available from both ALICE and CMS, but in different kinematical ranges
- The results still have large uncertainties
- ALICE data seems to exclude a large ψ' enhancement in central collisions

p - Pb @ 5.02 TeV

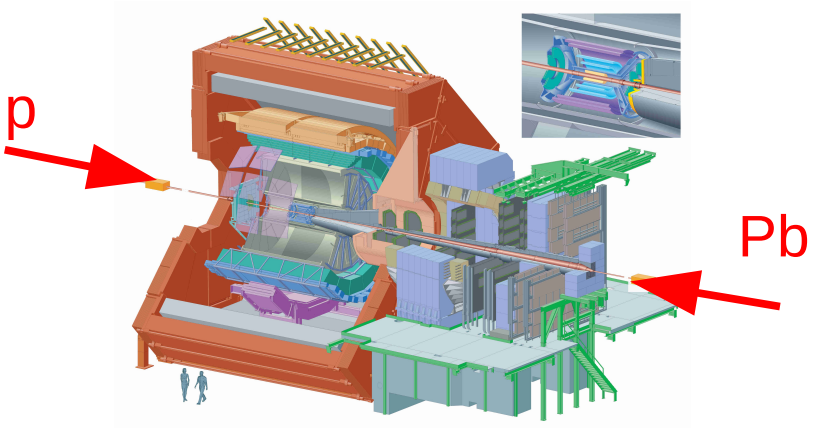
E_{Pb}=1.58 A TeV, E_p=4 TeV

The center-of-mass of the collision is shifted by Δy=0.465 towards the proton fragmention direction

p → ← Pb (p-going)

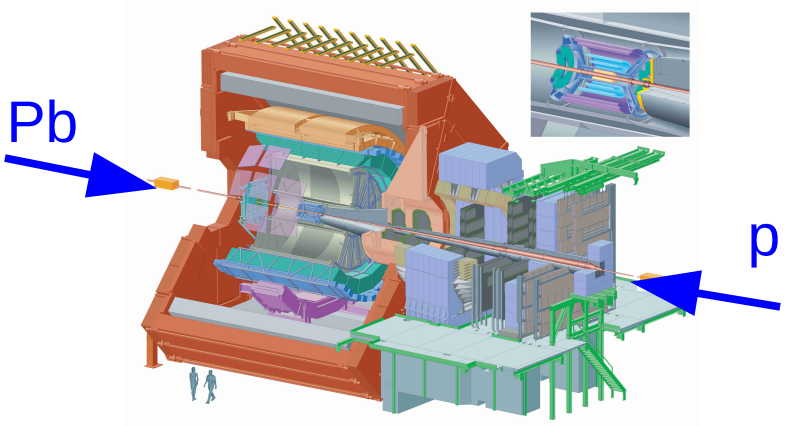
p-Pb, -1.37<y<0.43, L_{int} = 52 μb^{-1}

2.03<y< 3.53, L_{int} = 5.0 nb^{-1}

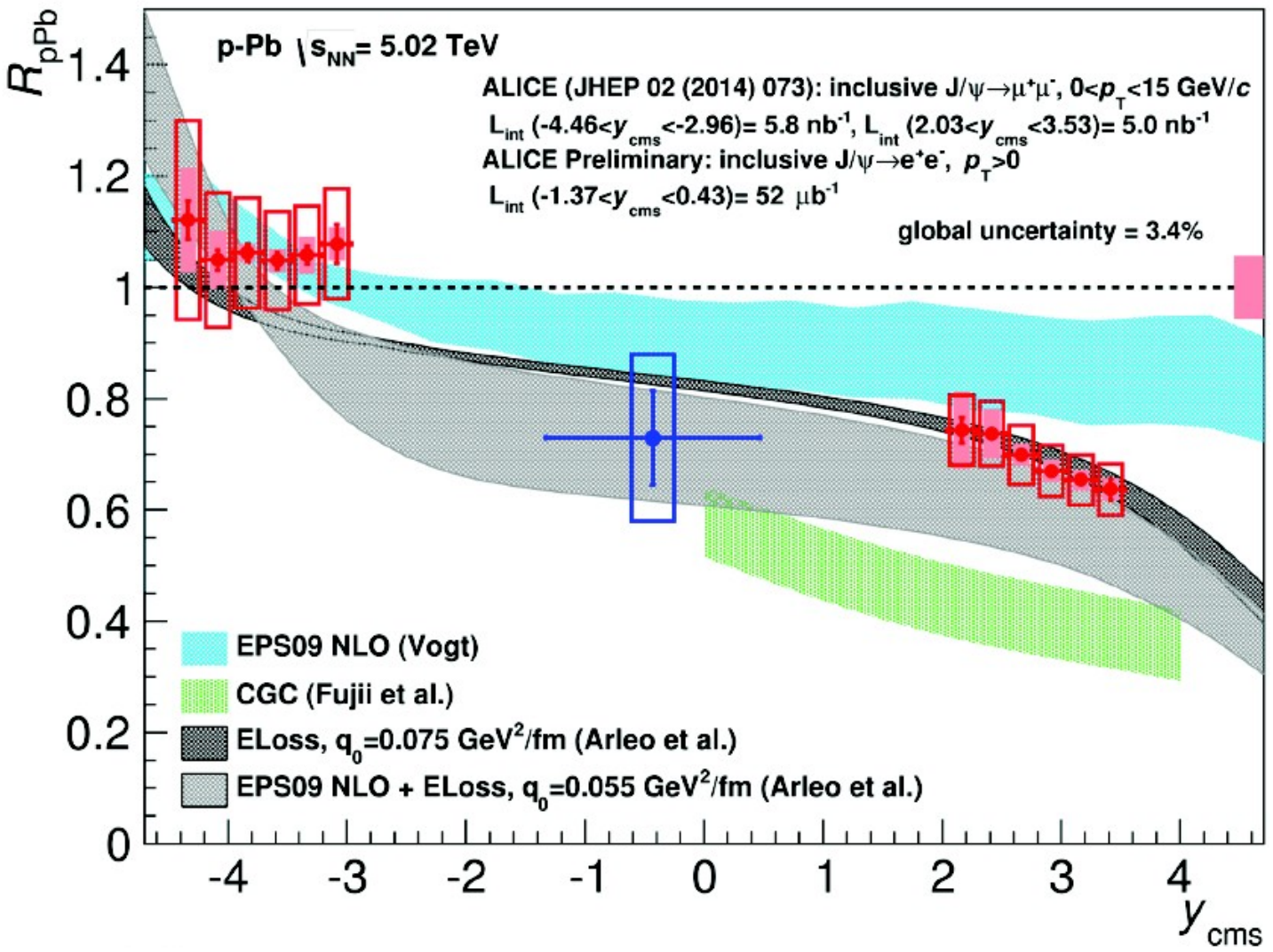


Pb → ← p (Pb-going)

Pb-p, -4.46<y<-2.96, L_{int} = 5.8 nb^{-1}

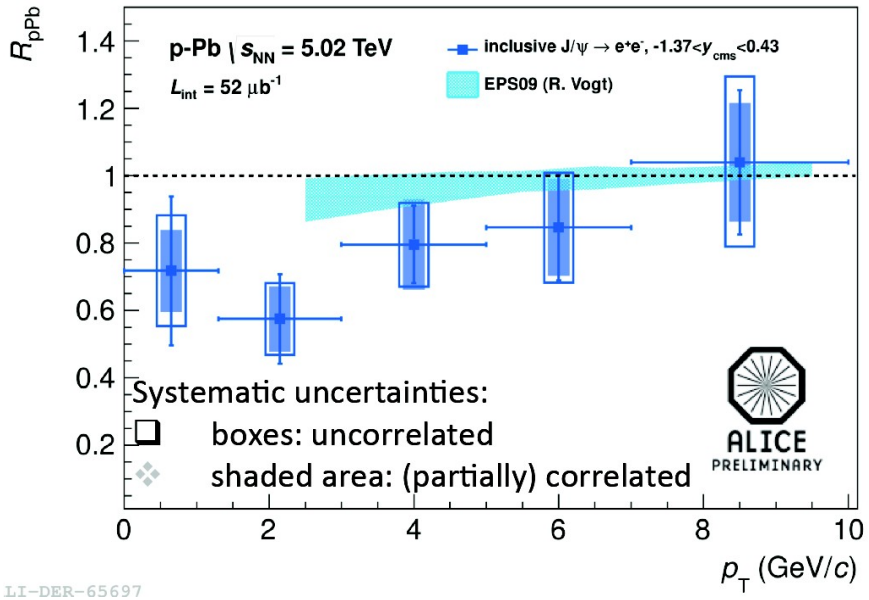


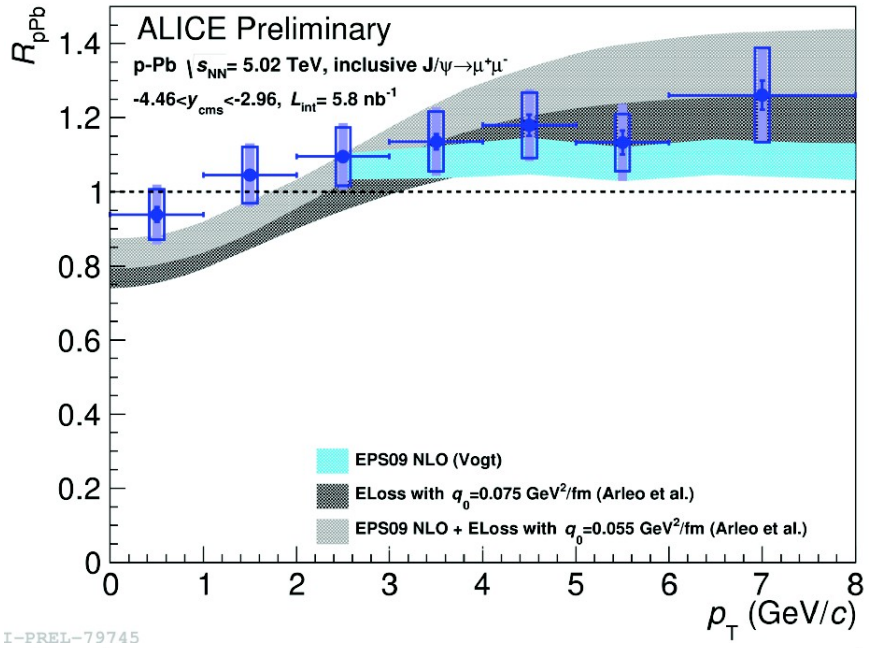
Inclusive J/ψ vs rapidity

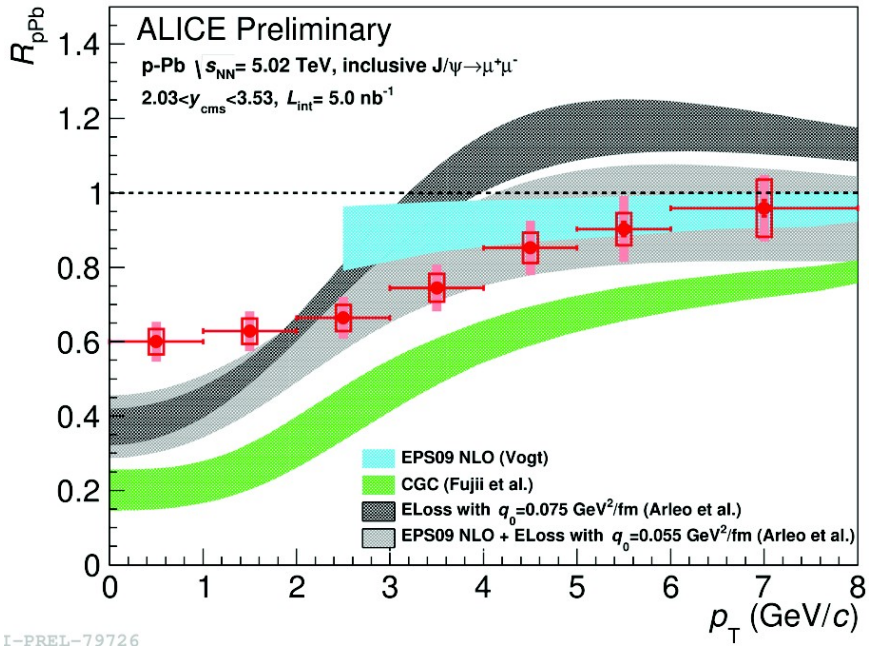


- J/ψ is suppressed at mid-rapidity and in the forward direction, compatible with energy loss (+shadowing) models
- No suppression observed in the backward direction

Inclusive J/ψ vs p_T

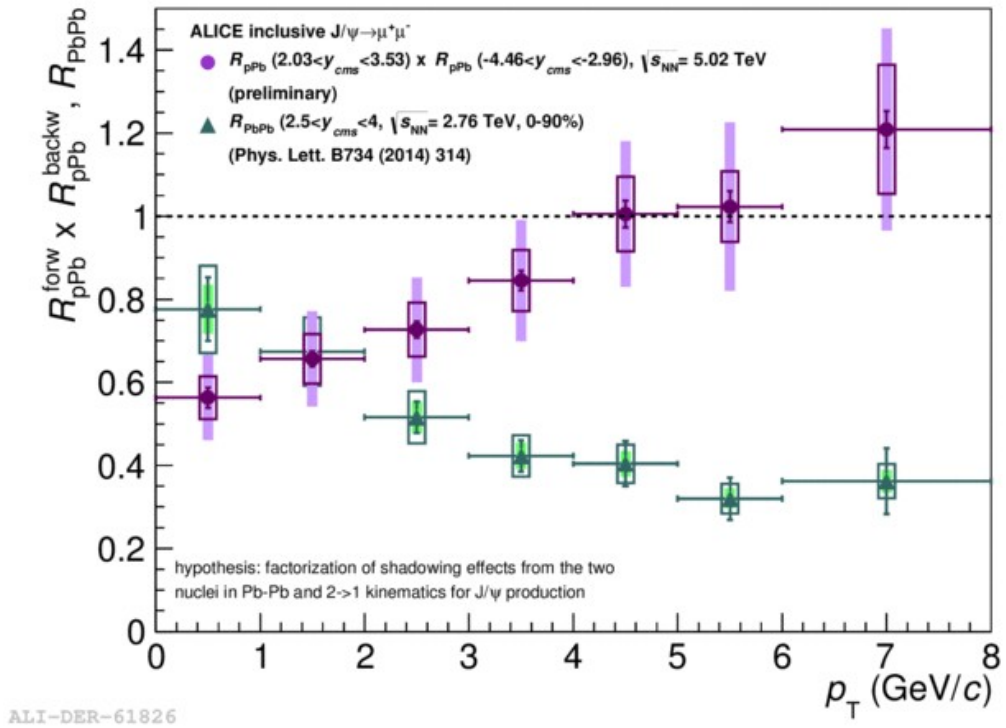


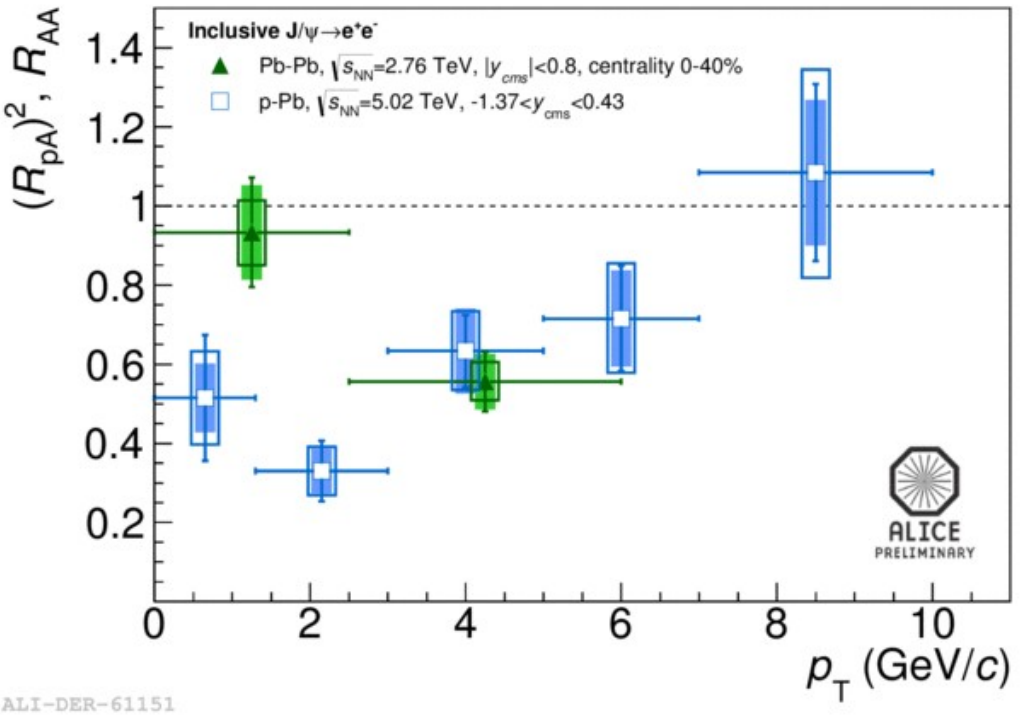




- J/ψ is suppressed at mid and forward rapidity, except for the highest p_T region
- R_{pPb} grows with p_T, consistent with expectations from shadowing and energy loss calculations
- Early CGC calculation overestimate the suppression at forward rapidity

Quantifying CNM effects

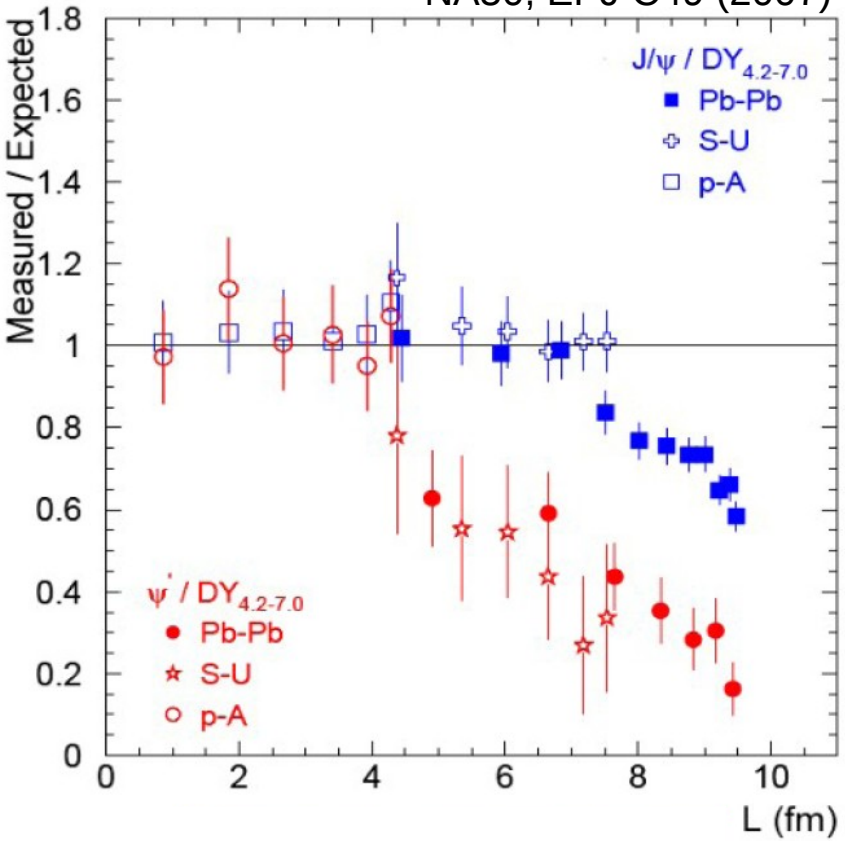




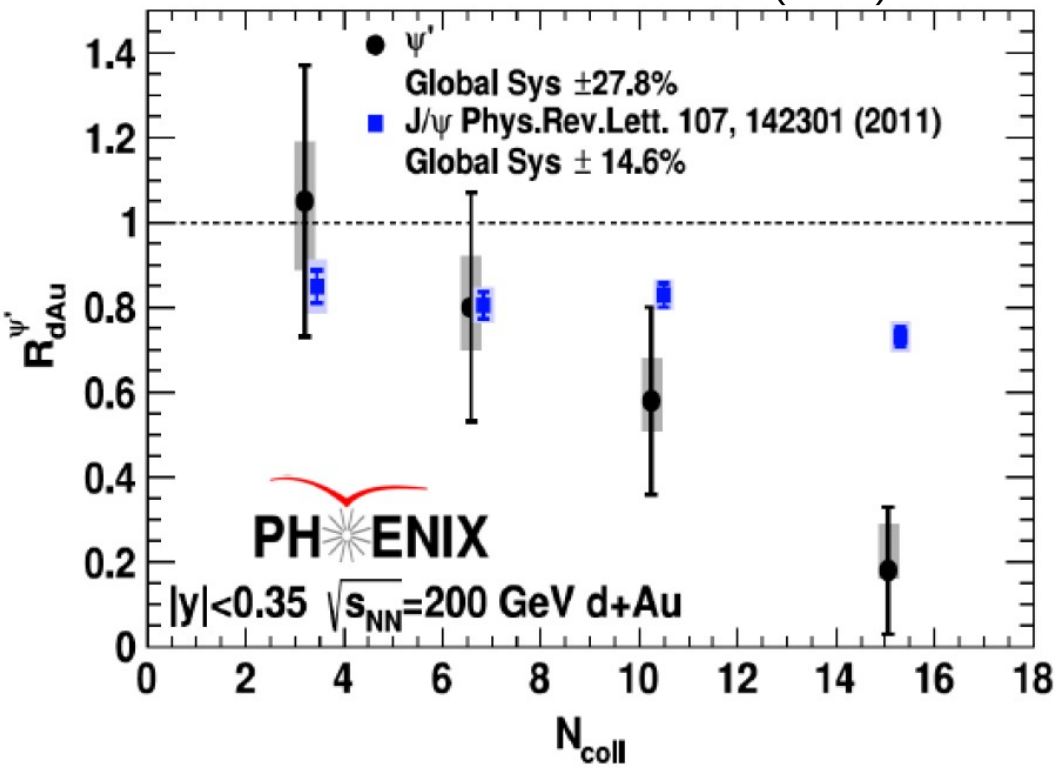
- Similar Bjorken-*x* ranges probed for Pb-Pb @ 2.76 TeV and p-Pb @ 5.02 TeV
- Assume 2->1 kinematics for the J/ψ production mechanism:
  - Factorization of shadowing effects: CNM(Pb-Pb) = $R_{pPb}(y>0)$ x $R_{pPb}(y<0)$
- At low p_T, (re)combination effects are equal or even larger than the suppression effects, when CNM effects are taken into account
- A large suppression is observed at forward rapidity and high p_T, where the CNM effects are negligible.

ψ' at SPS and RHIC

NA50, EPJ C49 (2007)



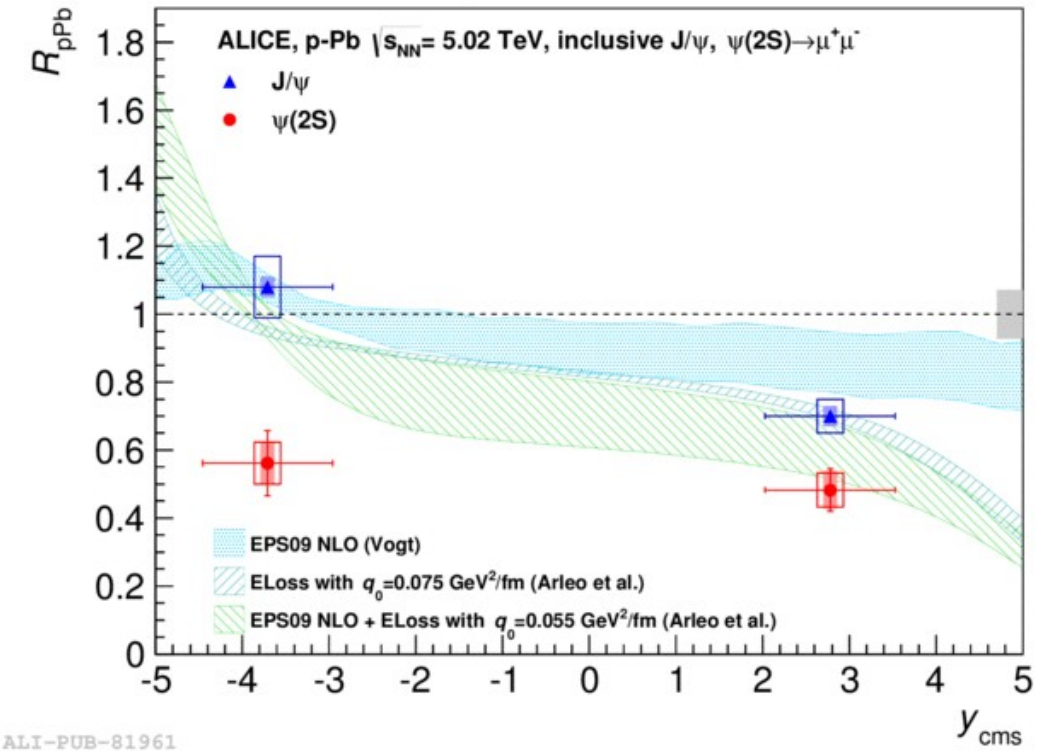
PRL 111 (2013) 202301



- ψ' suppressed at SPS in relatively small systems (like S-U), not in p-A
  - Final state interactions of the formed resonance in the cold nuclear medium
- Puzzle? ψ' suppressed in d-Au at RHIC
  - No significant differences between J/ψ and ψ' expected at RHIC and LHC from CNM effects or formation time

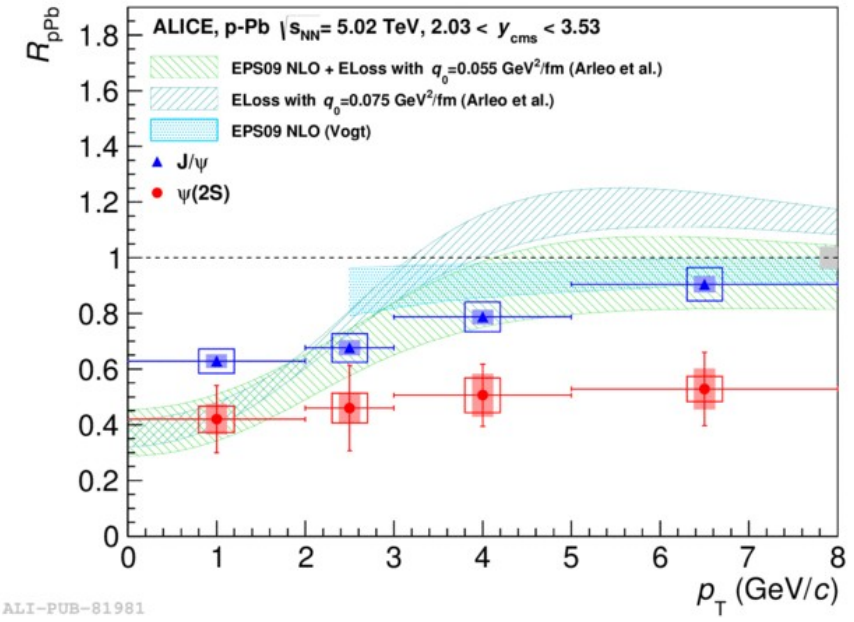
ψ' at the LHC

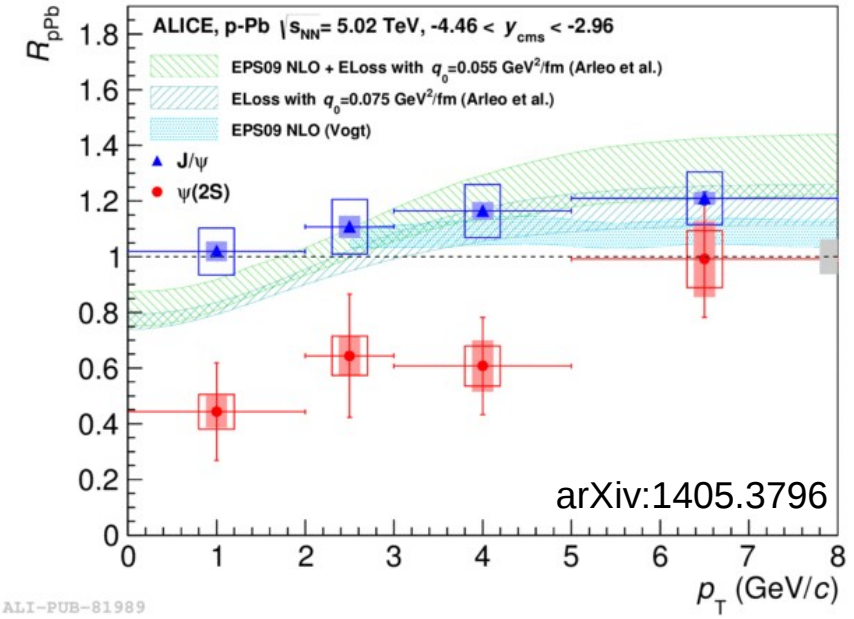
arXiv:1405.3796



- Strong ψ' suppression observed in p-Pb at both forward and backward rapidities
- Not expected from either shadowing or energy loss models

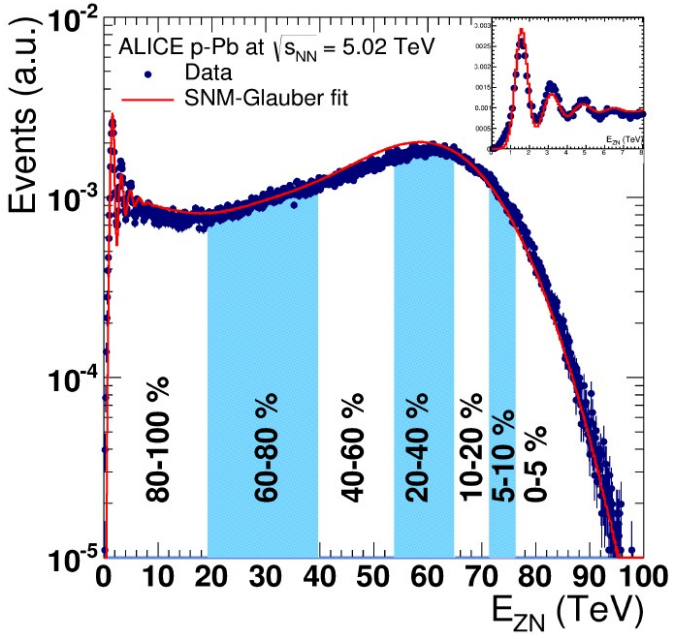
arXiv:1405.3796

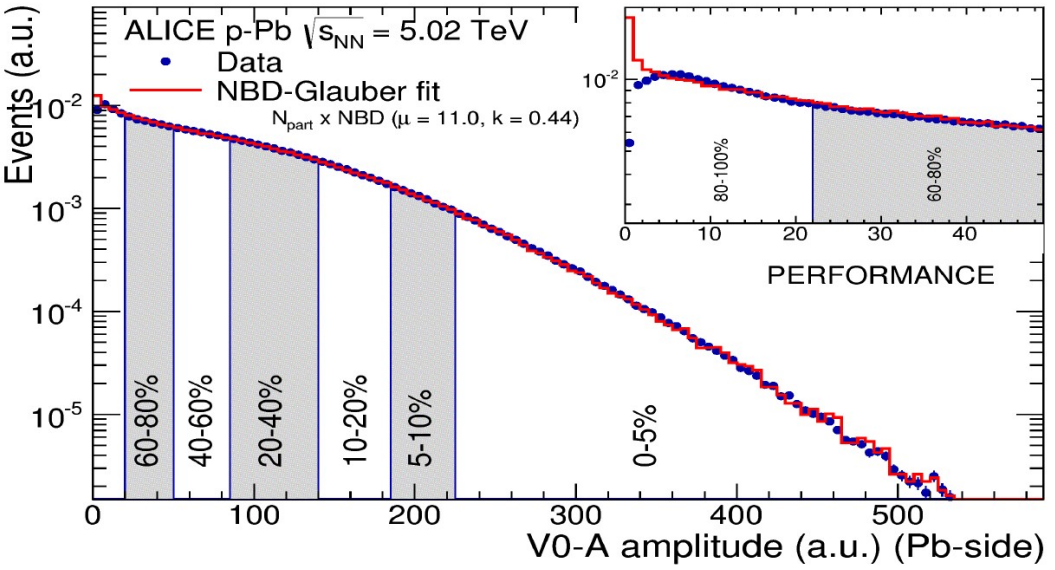


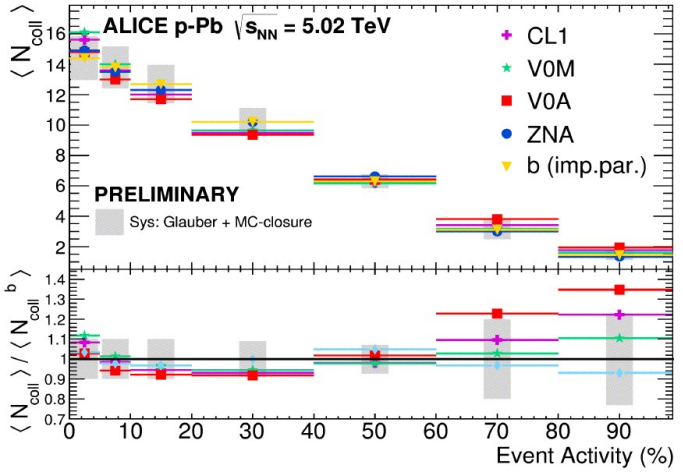


arXiv:1405.3796

p-Pb event activity



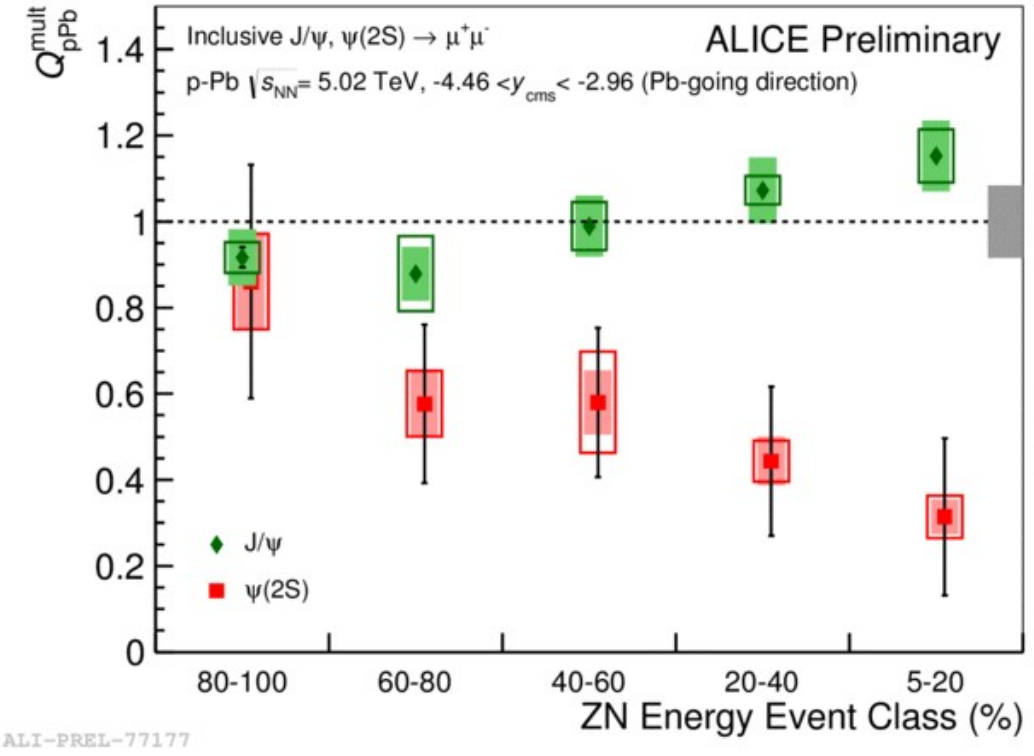


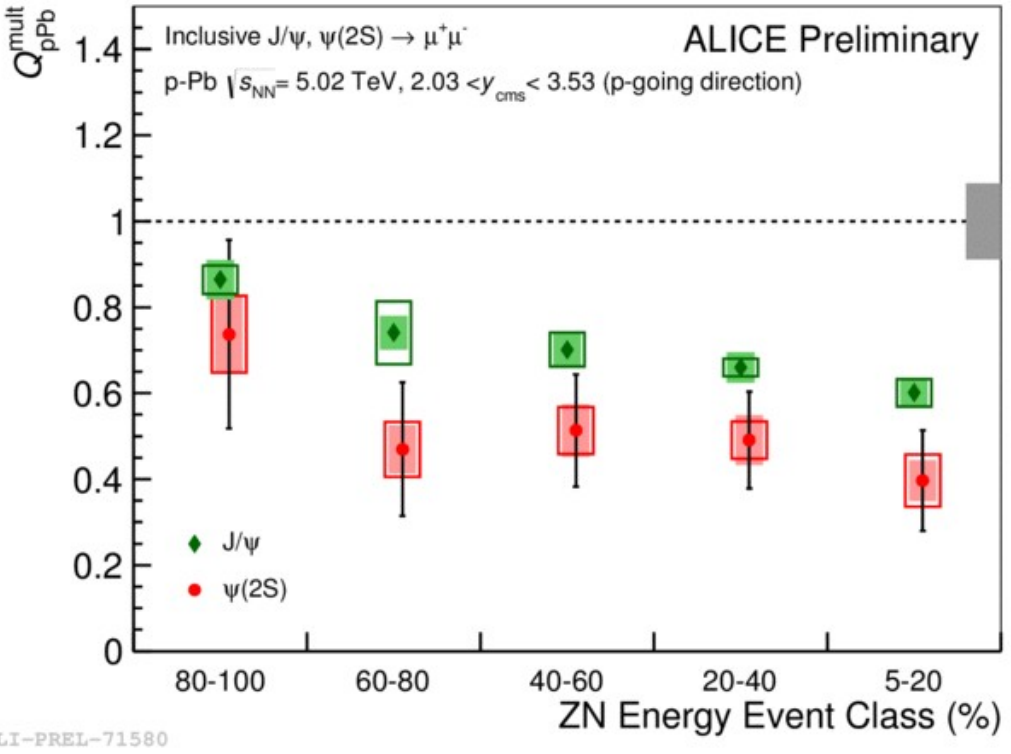


- Categorize events based on the multiplicity/energy measured with various detectors -> proxy to centrality
- Caveat: Correlation between multiplicity estimators and collision centrality much weaker compared to AA collisions -> posible biases!
- Assume p-Pb is a superposition of binary NN collisions and perform a Glauber fit, as for Pb-Pb
- Use the Glauber <N_{coll}> to define the nuclear modification factor in p-Pb event activity classes

$$R_{pPb} \rightarrow Q_{pPb} = \frac{Y^{i}_{pPb}}{\langle T^{i}_{pPb} \rangle \sigma^{J/\psi}_{pp}}$$

Charmonia vs event activity





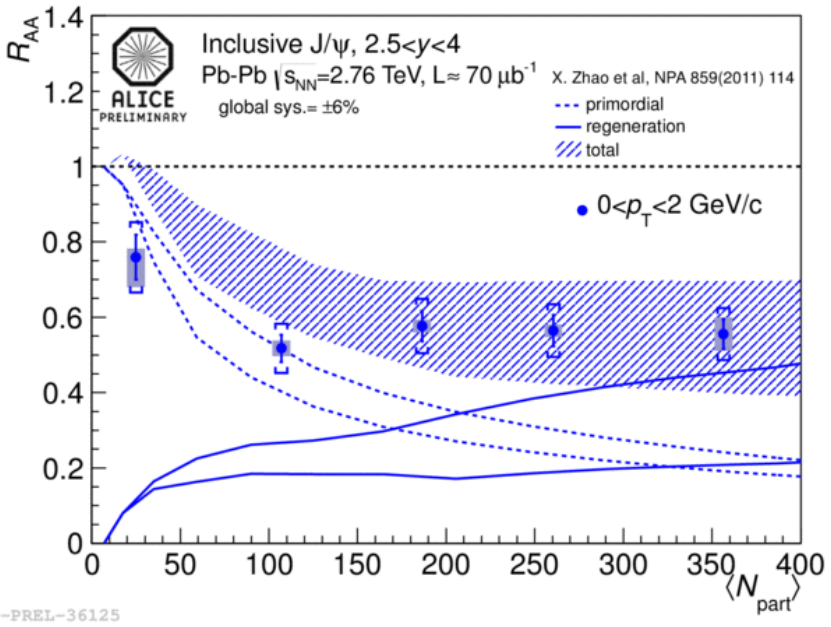
- Both J/ψ and ψ' suppression factors seem to be correlated with the event activity
- ψ' strongly suppressed in events with large ZDC activity
  - The trend suggests a final state effect
  - e.g. the pre-resonant state interaction with the comover cloud?
    Ferreiro et al. arXiv: 1411.0549
- What about the J/ψ dependence on event activity?

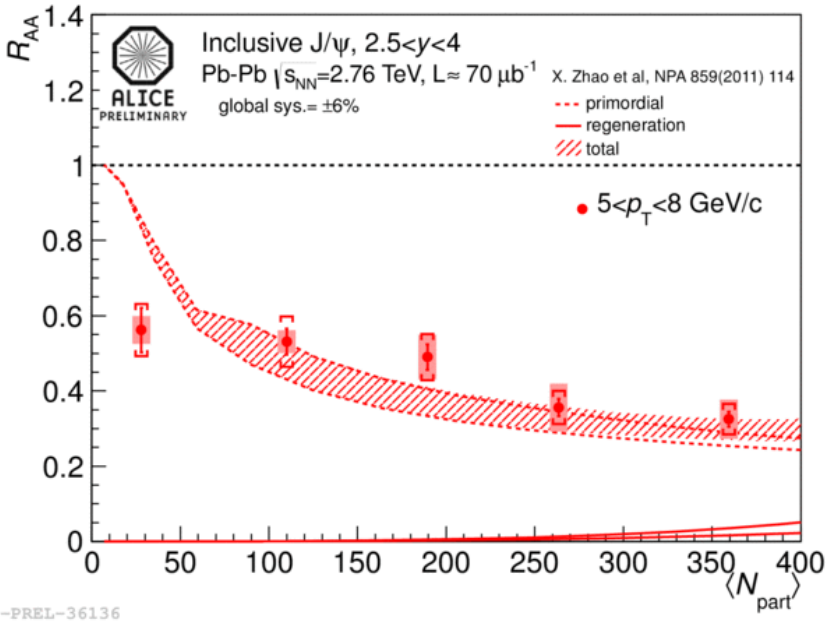
Summary

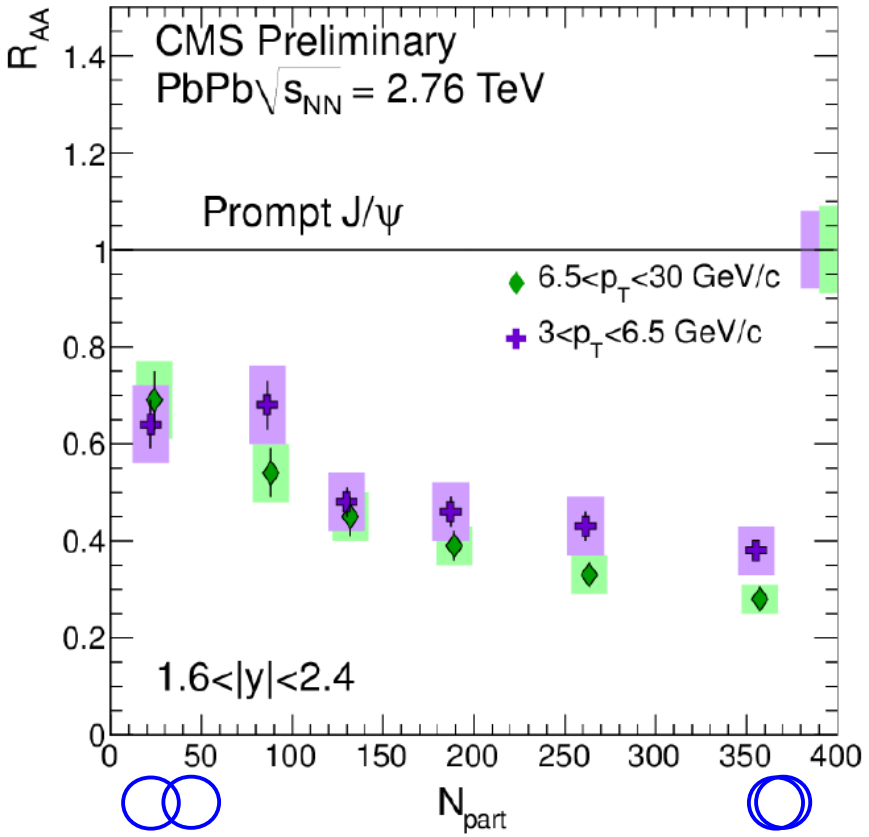
- We presented ALICE results on J/ψ and ψ' production in Pb-Pb and p-Pb collisions
- ALICE results support the (re)combination picture in Pb-Pb:
  - Integrated J/ψ R_{AA} in central collisions much higher w.r.t. RHIC results
  - The effect is concentrated at low p_T
  - The CNM effects estimated in p-Pb even indicate enhancement at low p_T
  - Indications of non-zero elliptic flow at forward rapidity
- High p_T J/ψ at LHC are more suppressed compared to RHIC, as expected due to larger energy density of the fireball
- The J/ψ measurements in p-Pb are compatible with shadowing and energy loss expectations
- J/ψ suppression in p-Pb also depends on event activity, but the trend is different from the one of ψ' at backward rapidity.
- ψ' suppression in p-Pb cannot be explained with shadowing and energy loss effects alone. Strong dependence of the suppression on event activity indicative of comover interactions?
- Various possible final state effects in p-Pb makes it difficult to rigourously estimate the CNM effects applicable to Pb-Pb collisions

Backup

J/ψ as a function of p_T

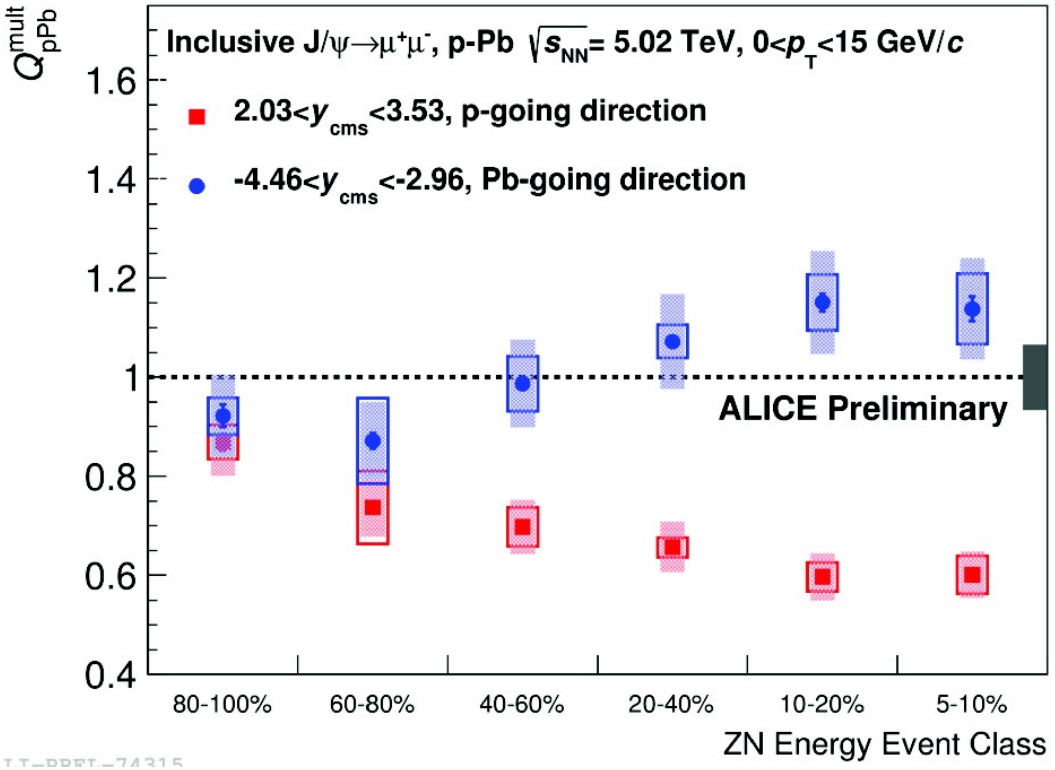




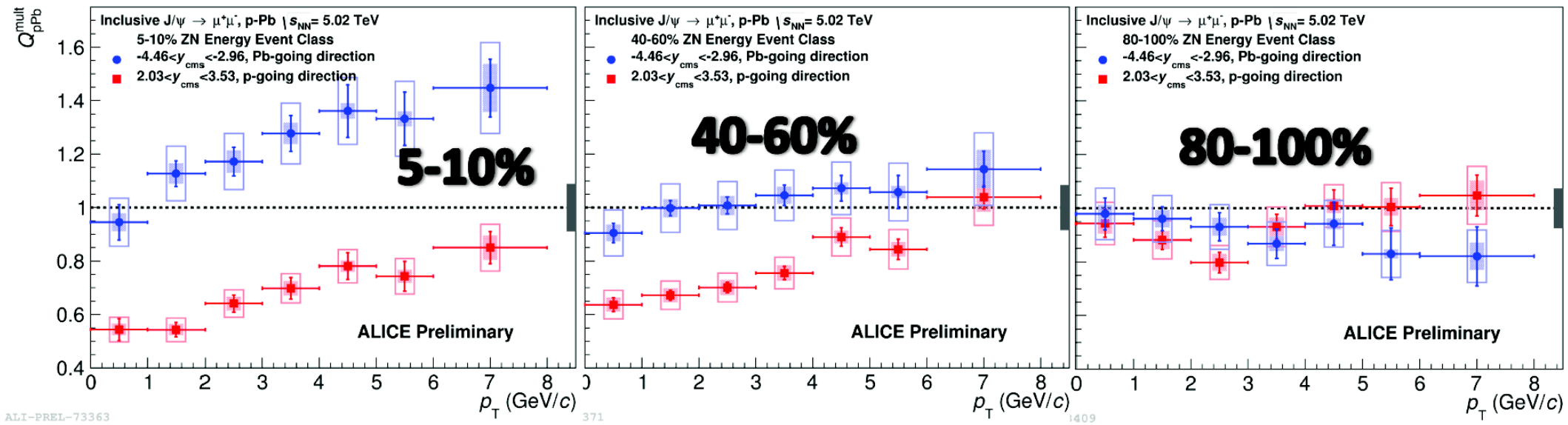


- Less suppression observed at low p_T (ALICE)
  - 50% of the J/ψ yield produced via (re)combination in transport models
- Stronger suppression and centrality dependence at high p_T (CMS, ALICE)

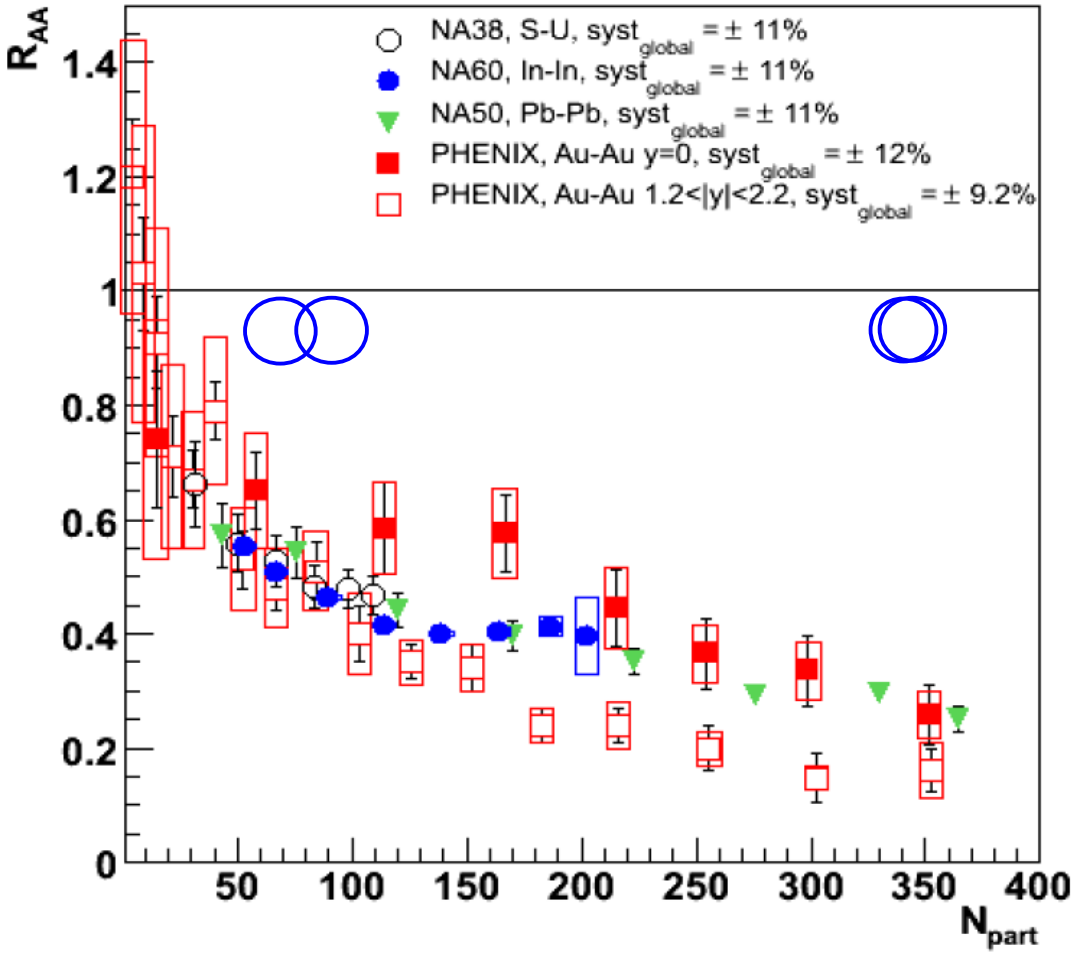
J/psi vs event activity



J/psi vs pt in event activity categories

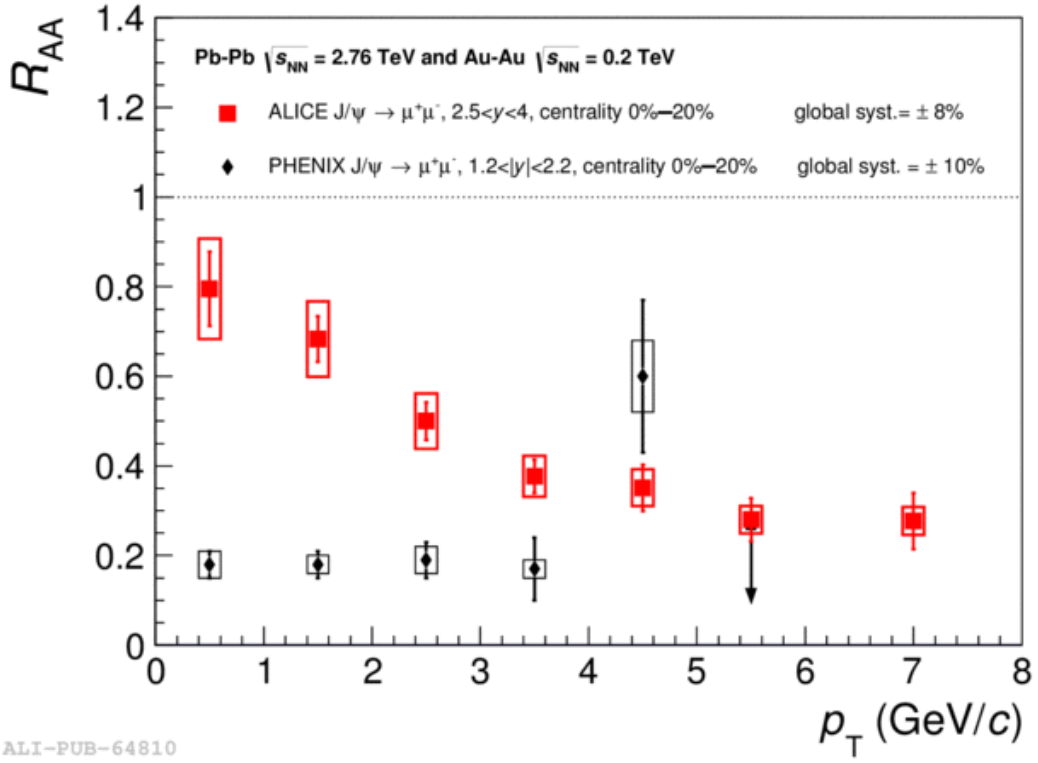


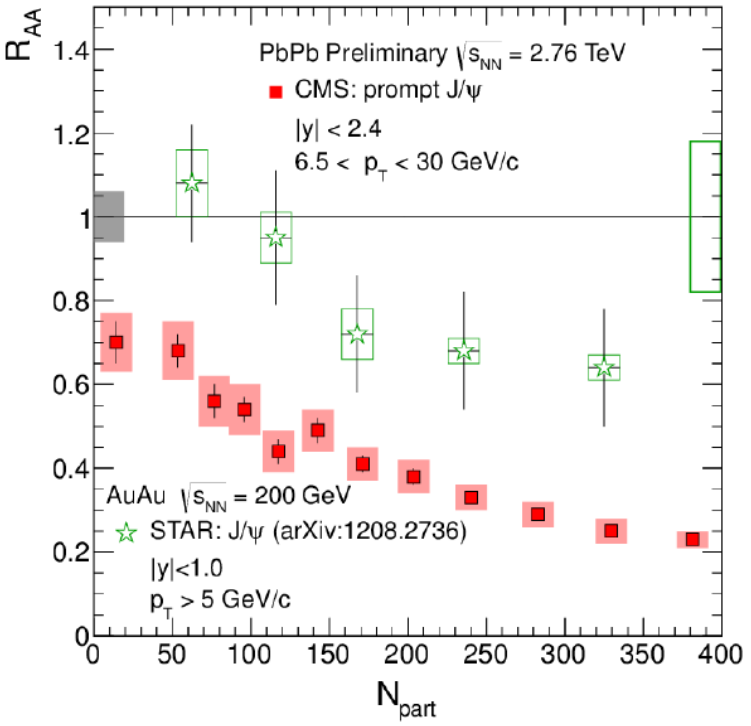
Charmonium at lower energy experiments



- Puzzles:
  - Observation: Similar suppression factor vs centrality observed at mid-rapidity at SPS and RHIC.
    Explanation: Charmonia created from uncorrelated $c\bar{c}$ pairs during fireball evolution or at freeze-out, aka (re)combination
  - Observation: At RHIC, more suppression at forward than at mid-rapidity
    Explanation: (Re)combination and shadowing/saturation effects could depend on rapidity

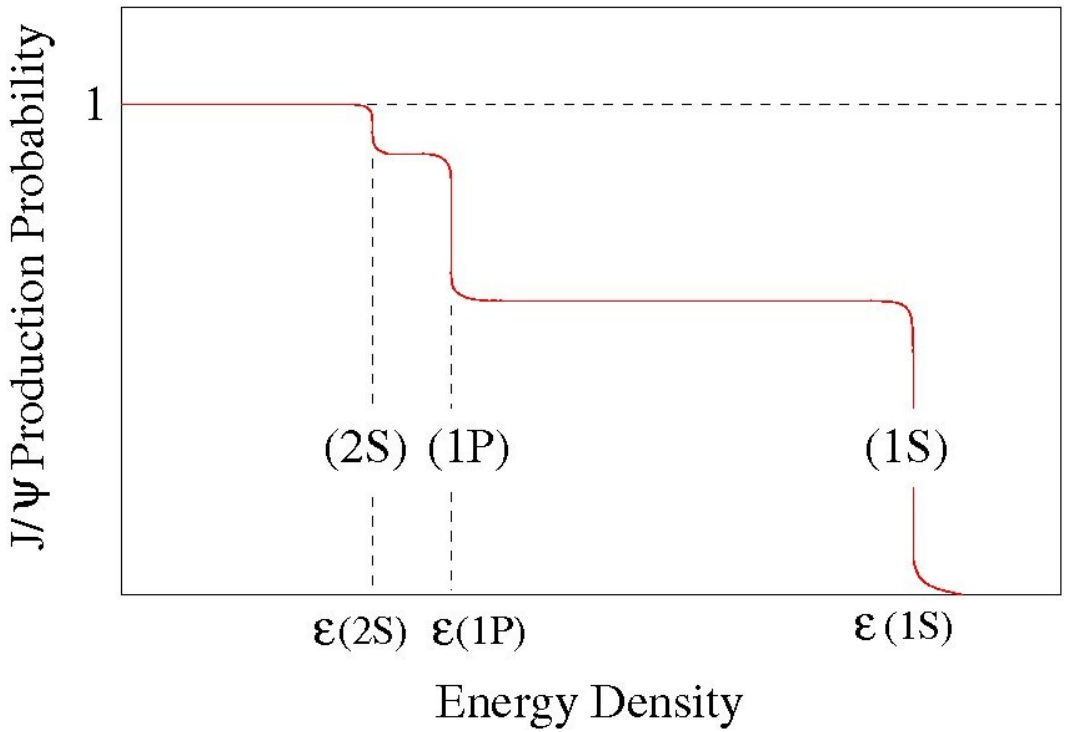
Inclusive J/ψ as a function of p_T

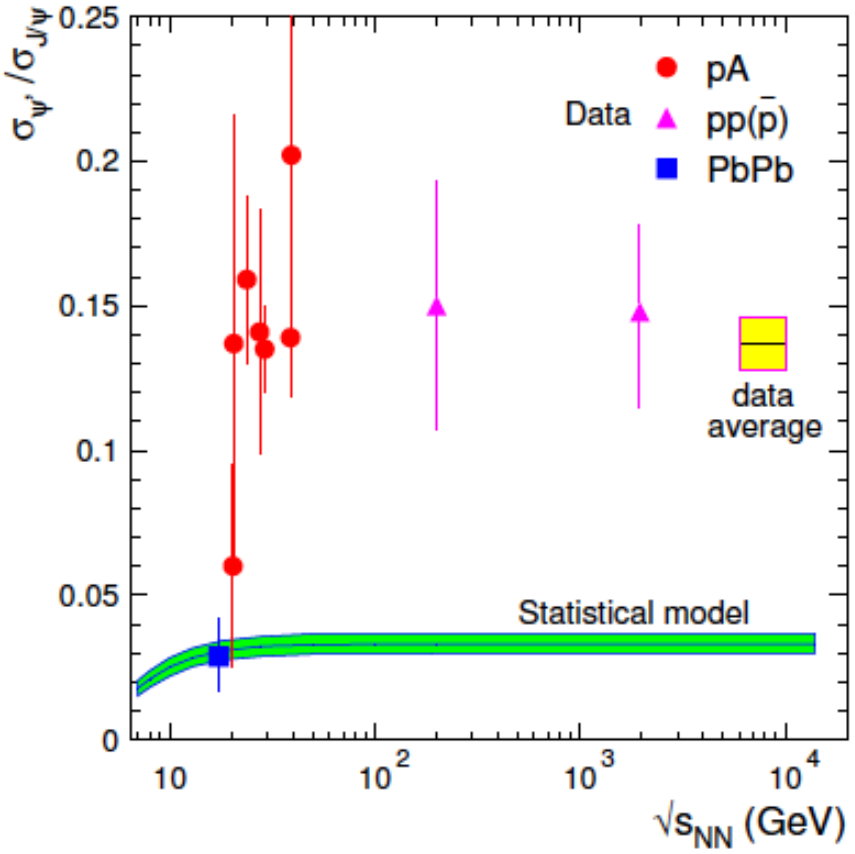




- Striking difference between LHC and RHIC at low-p_T
  - "Smoking gun" for (re)combination ?

- Stronger suppression at LHC for high-p_T J/ψ's
  - Negligible (re)combination expected in this kinematic range
  - Higher energy density at LHC at play ?


J/ψ Production Probability
1
(2S)
(1P)
(1S)
ε(2S)
ε(1P)
ε(1S)
Energy Density


$\sigma_{\psi'}/\sigma_{J/\psi}$
0.25
0.2
0.15
0.1
0.05
0
Data
pA
pp($\bar{p}$)
PbPb
data
average
Statistical model
10
10^2
10^3
10^4
$\sqrt{s_{NN}}$ (GeV)