Quarkonia

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Mont Sainte Odile III: the Woodstock festival of hard probes

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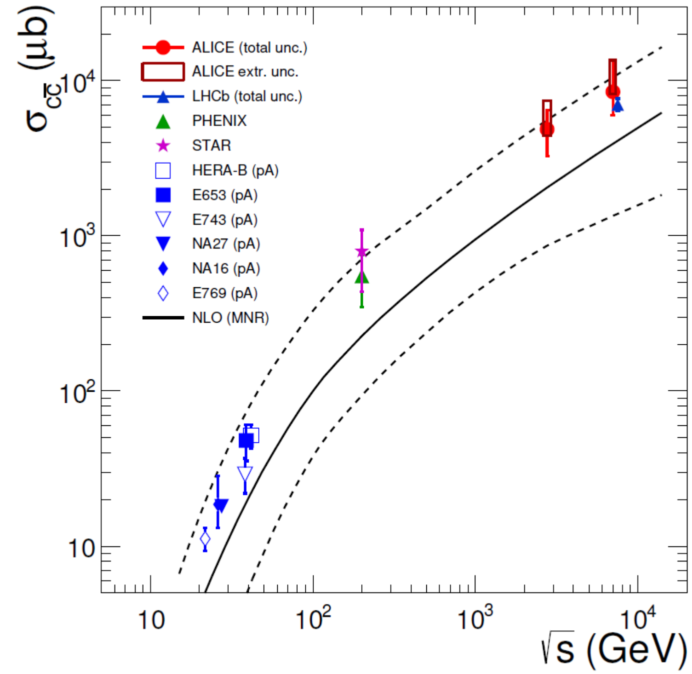
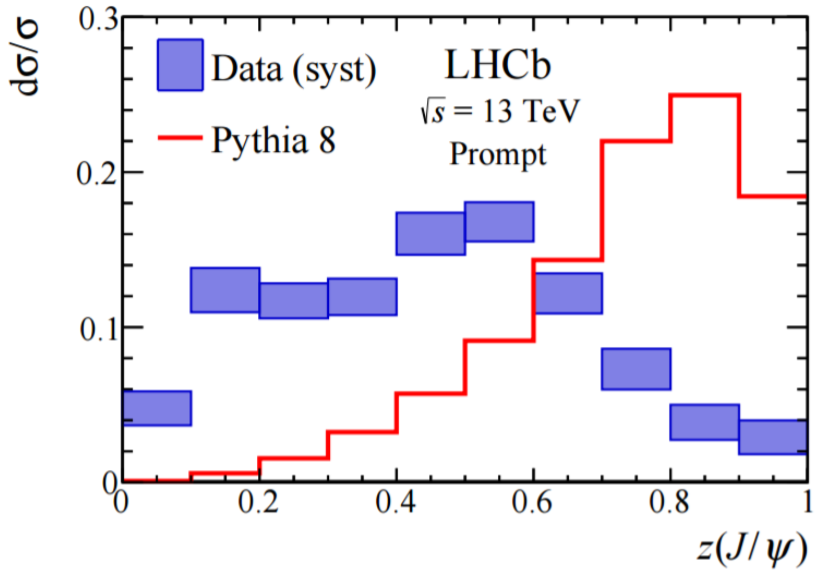
Charge

What are the perspectives for going on the experimental and on the theoretical side beyond the current state of the art?

Production

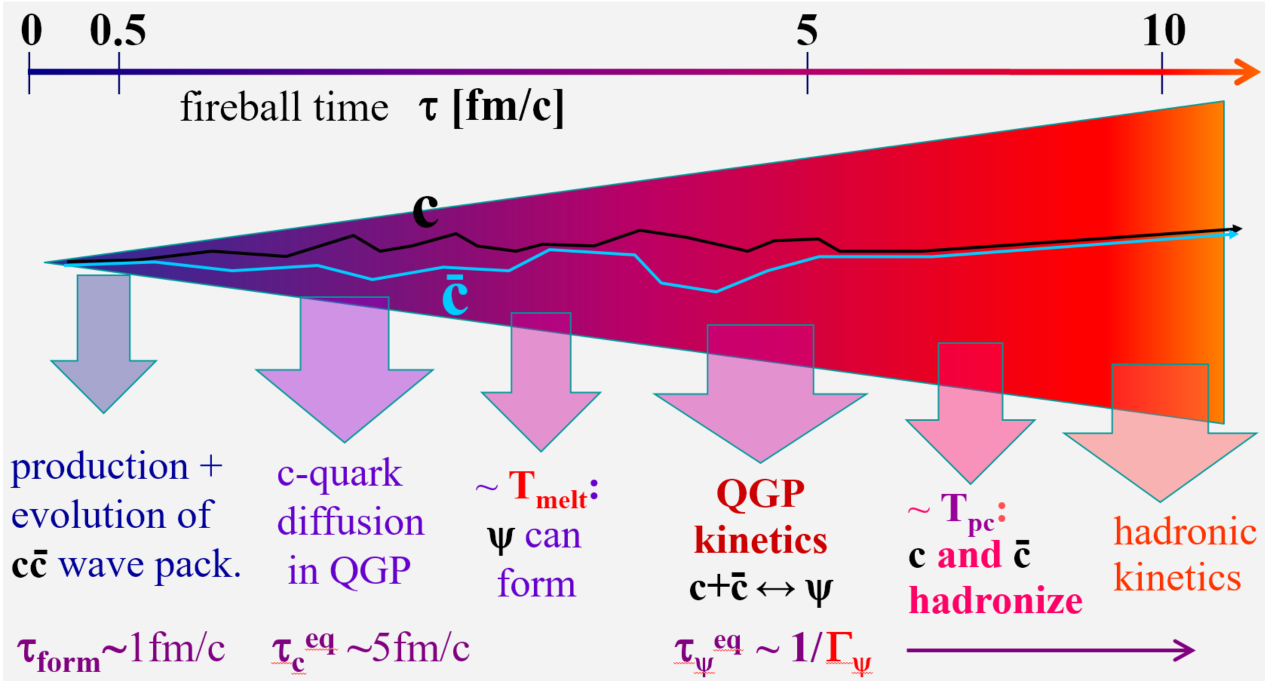
- We don't understand the production mechanism of Quarkonia in pp:
    - Very large theoretical uncertainty of ccbar and bbar cross-section
    - State-of-art NRQCD predicts a large transverse polarization which is inconsistent with data
    - Commonly believed paradigm is that Quarkonia is produced isolated which is largely untested.
    - LHCb showed that prompt J/psi fragmentation functions in jet are inconsistent with PYTHIA+NRQCD, similar to non-prompt J/ψ produced in parton shower modeled by PYTHIA. What's the fraction of J/ψ at low p_T from parton cascade?
- Is this important?





arXiv 1701.05116

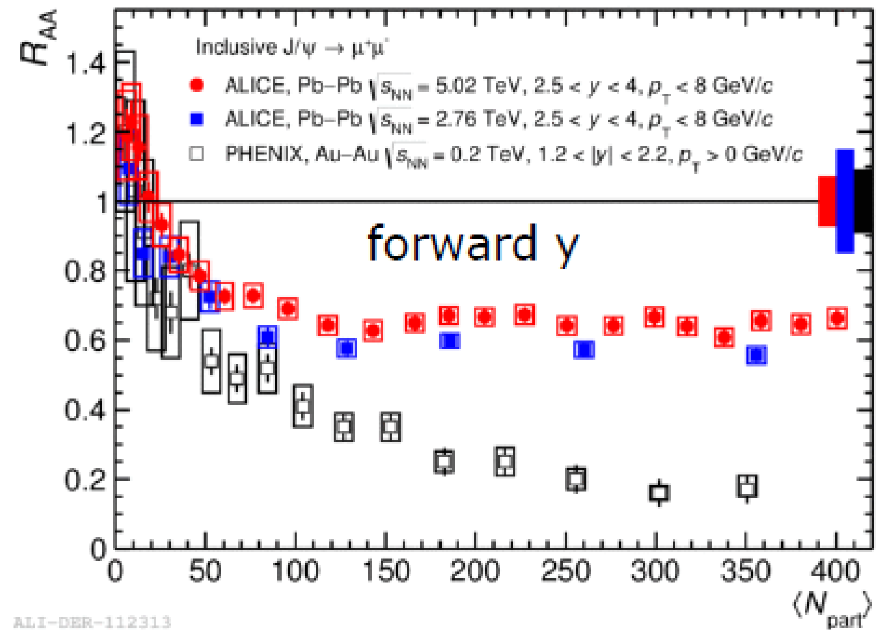
Time scale

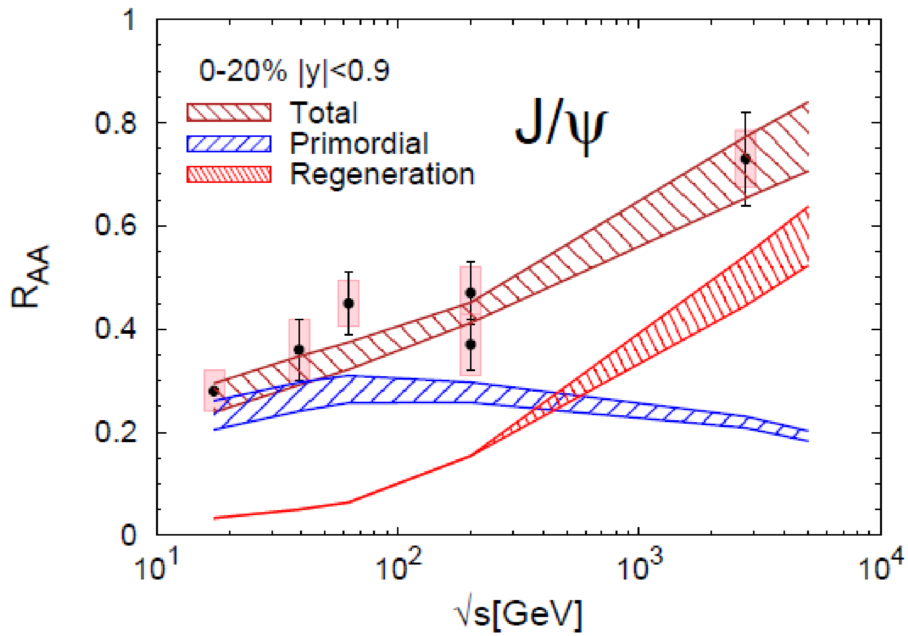


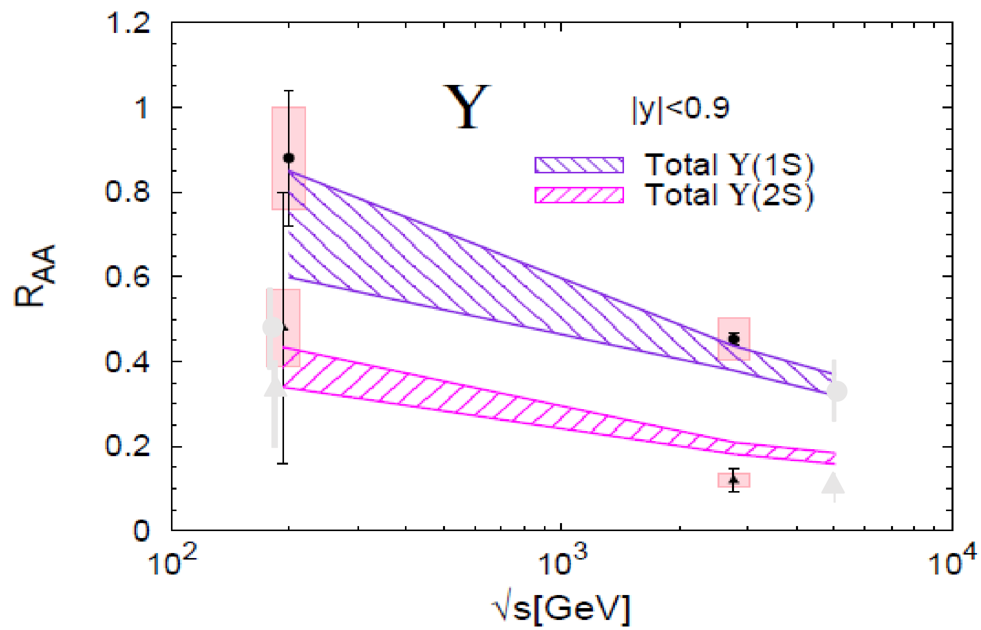
• Time scale: ccbar production, formation and hadronization time scales: do we have experimental evidence that the current theoretical understand is correct?

Recombination

- The role of recombination
  - Do we see the deconfinement of the charm at large distance?
    - For instance, can we rule out the contribution from D Dbar rescattering?
  - The extracted fraction of recombination J/psi is model dependent
  - We don’t know if there is recombination for Y







Recombination

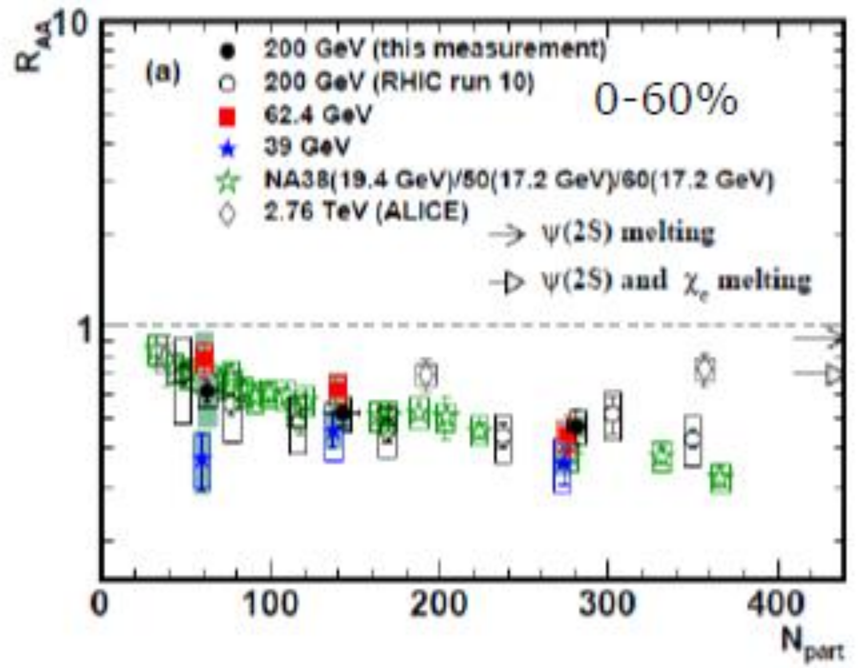
- Possible measurements:
  - The cross-section of the charm: needs to be measured to low pT
  - To vary the c cross-section, we need measurements vs rapidity (with high statistics data), and by varying the collision energy.
  - Measurement of the ratio of J/psi and open charm vs rapidity and p_T on R_{AA} and v_2
  - The role of psi' and check if the production rate of psi' is consistent with the recombination picture
  - Double J/psi production should be greatly enhanced
    - Also the J/psi should be more uncorrelated
  - Upsilon recombination and v_2 of upsilon
  - Measurement of X(3872): very enhancement in RAA and large v_2
  - Collinear Jpsi D production should be enhanced (J/psi – HF lepton)
  - B_C measurement

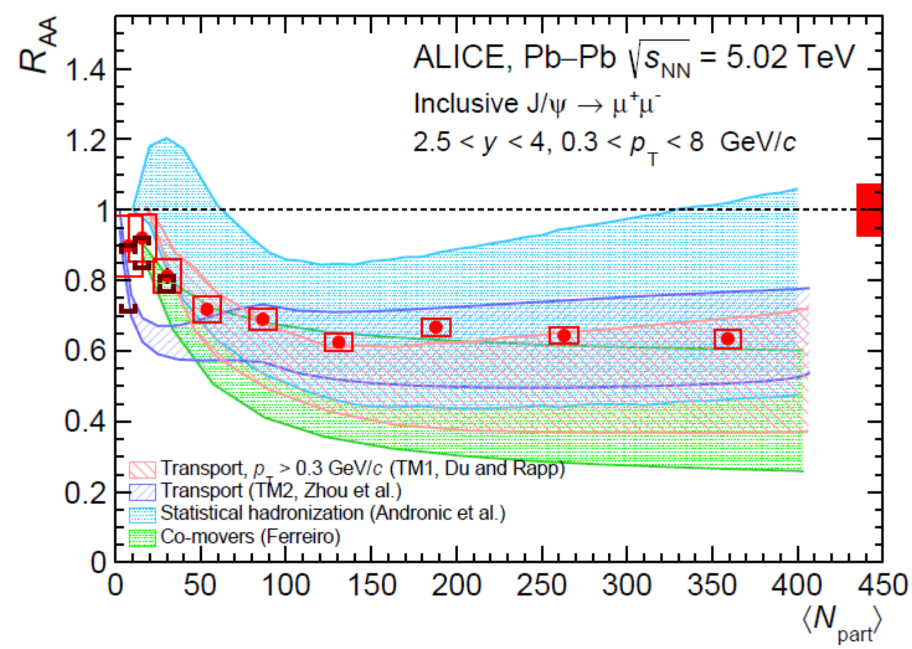
Sequential suppression

- We need to understand the mechanism of dissociation of Quarkonia in QGP. Do we know the fraction of the observed dissociation is happening in QGP?

- Precision of RHIC data and low energy run of LHC
  - Do we know if the RHIC data is dominated by effect from sequential suppression?
  - Crucial to have high quality data from RHIC especially for Upsilon (sPHENIX / STAR)
  - RHIC Beam energy scan? Too low in terms of luminosity
  - LHC Beam energy scan?
  - SPS energy? (NA60+)

- What is the role of CNM as shadowing (initial state)
  - Uncertainty ~ 20% (due to PDF)
  - Could we constrained by direct Quarkonia measurement in PA and complimentary measurements with high pt jets and UPCs

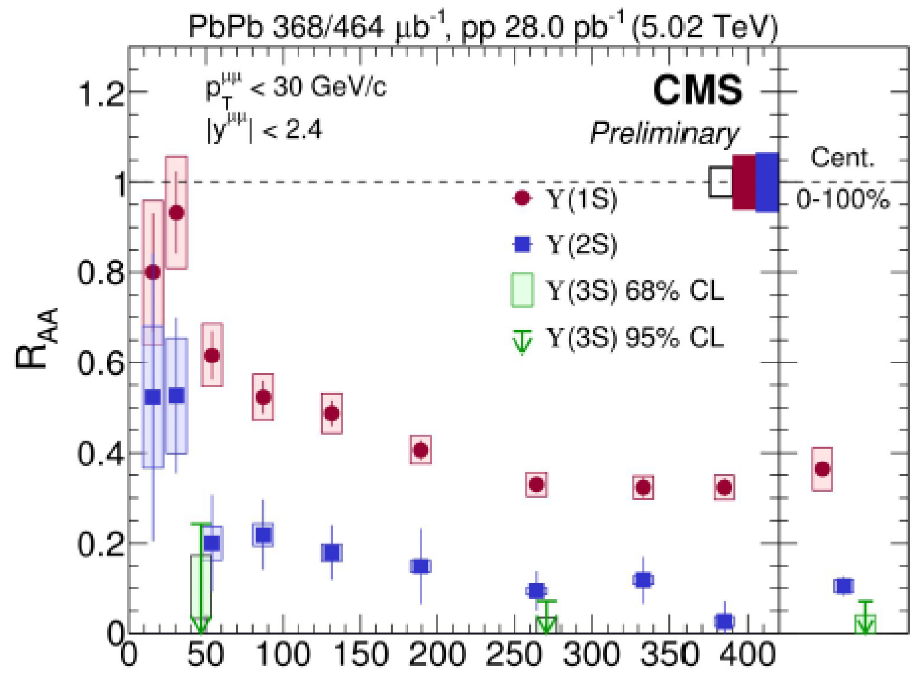


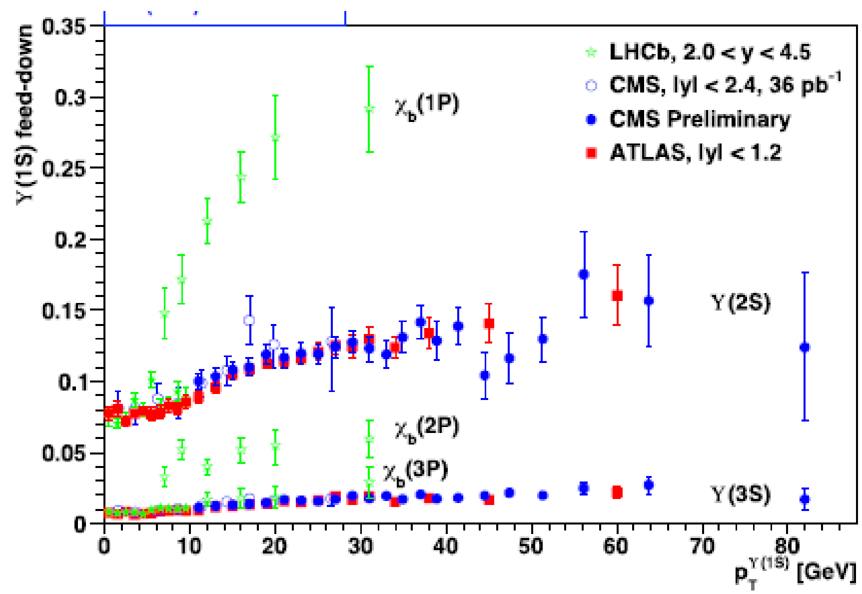


Sequential suppression

- Is Upsilon(1S) suppressed?
    - Improve the precision of RHIC data (sPHENIX)
        - Interesting trend of Upsilon (1S) RAA vs sqrt(s) observed in QM2017
    - We don't know precisely the feed down from the higher states for Upsilon.
        - Existing measurement from Tevatron and LHCb, data stop at high pT > 6 GeV/c

- Upsilon (3S) R_{AA} and Psi' need high statistics data

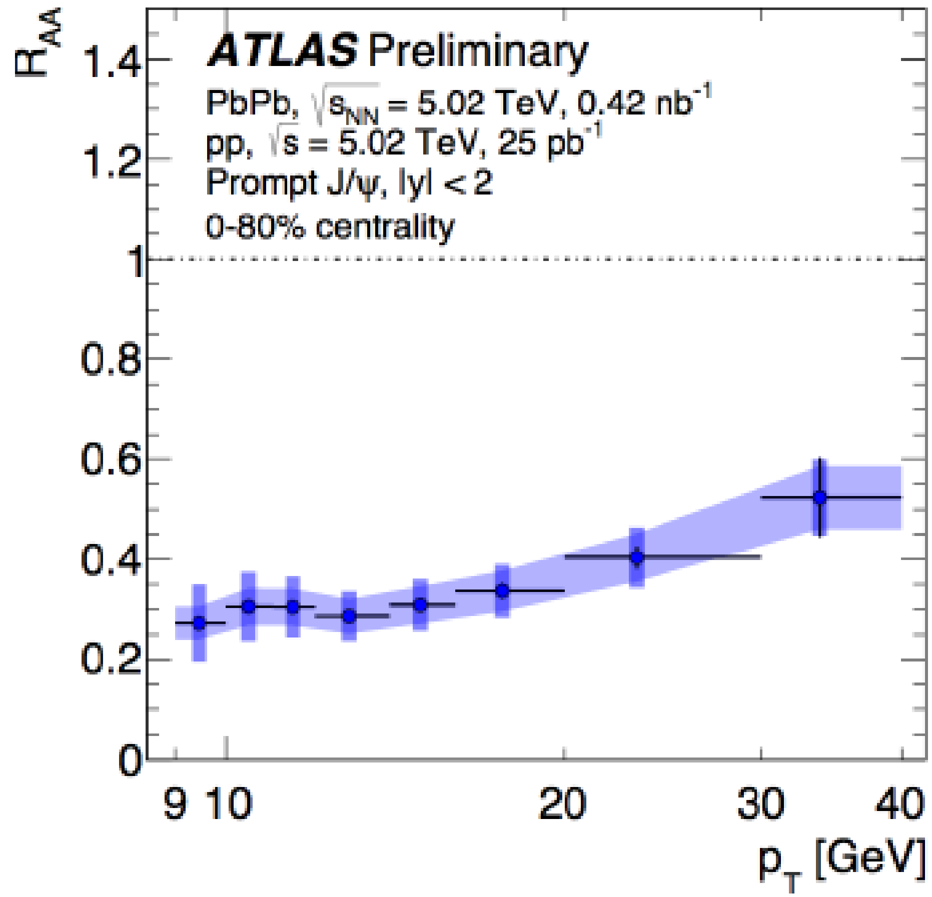




High pT Quarkonia

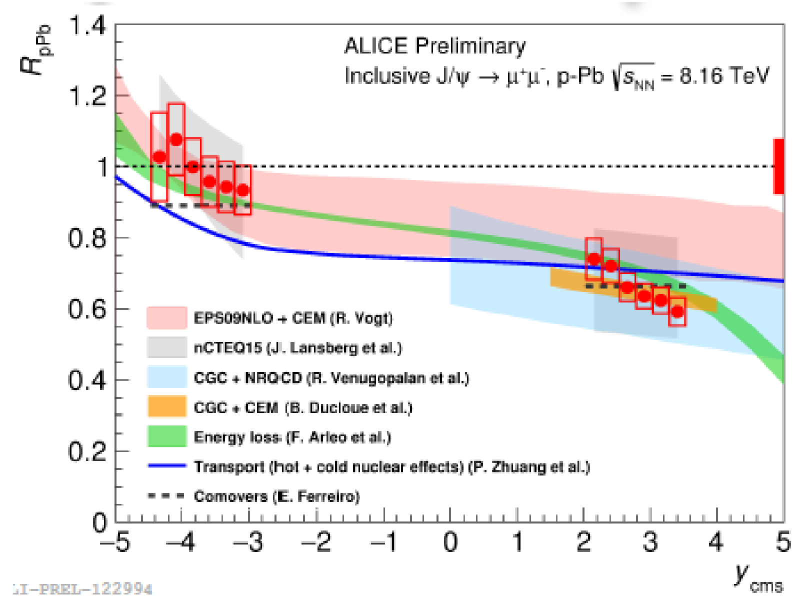
- Do we understand the mechanism of high pT Quarkonia suppression?
  - ccbar energy loss?
  - Or the mother parton energy loss?

- We need to measure Jpsi and Psi' R_{AA} vs p_T and sqrt(s)
  - Help the interpretation of the recombination



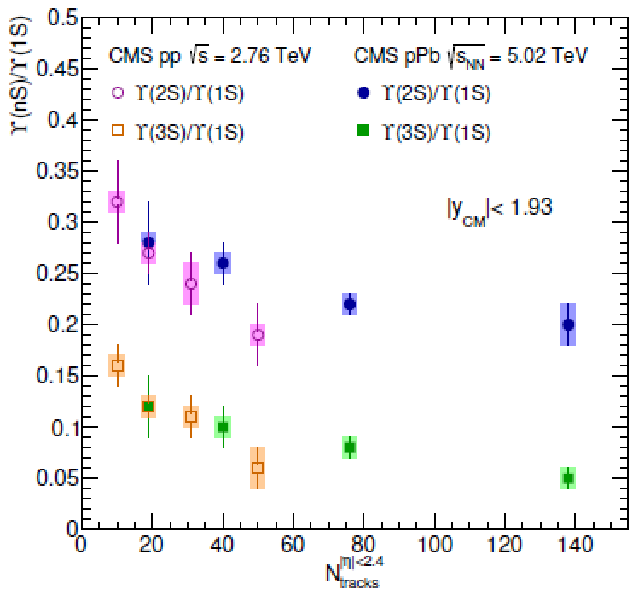
PA data

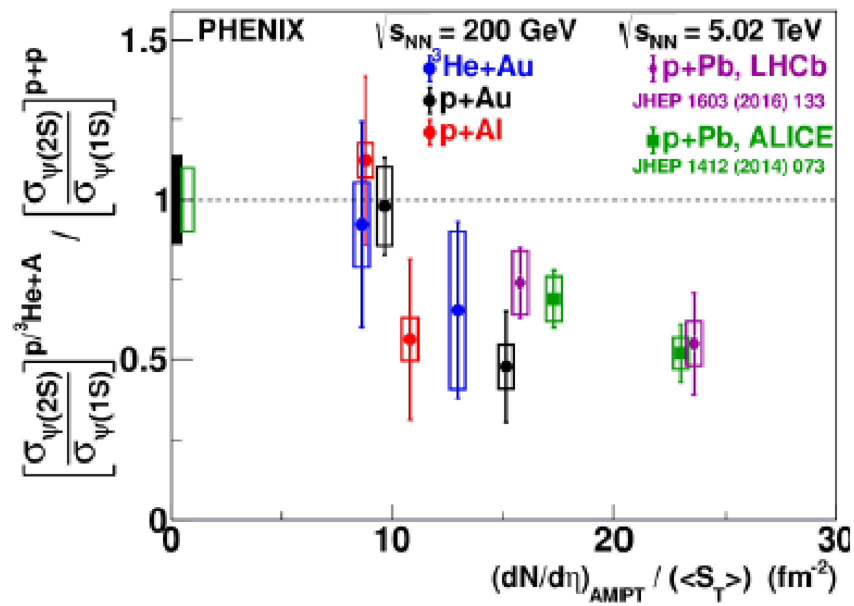
- Disentangling the cold nuclear effects
- The understanding of the Psi', Y(2S) and Y(3S) suppression in inclusive pA.
  - Y(2S) and Y(3S) are relatively more suppressed than Y(1S) in inclusive pA.
    - We don't understand why relative Y suppression increases with multiplicity
  - The relative suppression of Psi' / J/psi vs rapidity (PHENIX / CMS / ALICE)
- Quarkonia v2 in pA



- How do we go from pA to AA (can the cold nuclear effects be factorized out from data?)

- Need Xb and Xc data in pA

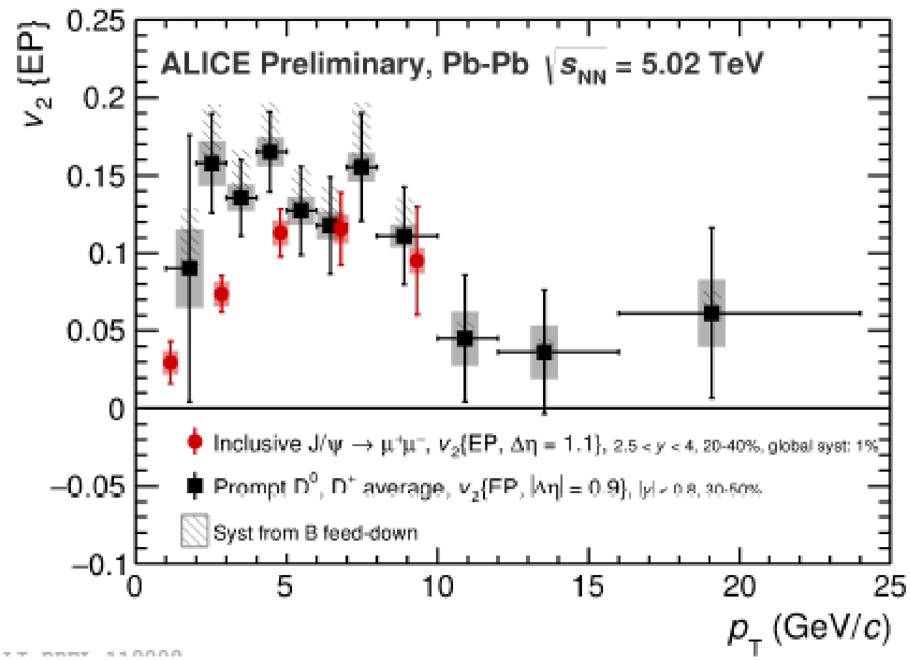


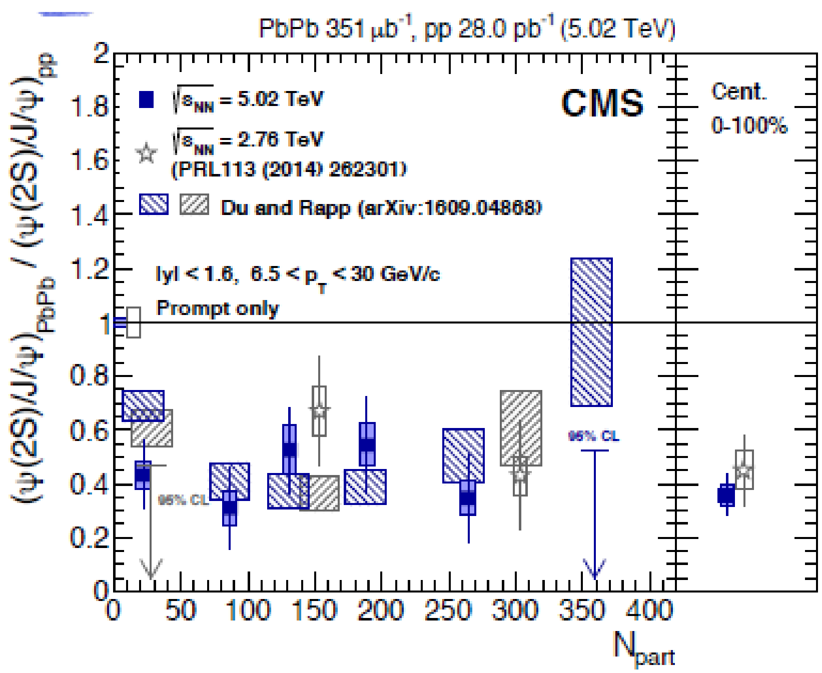


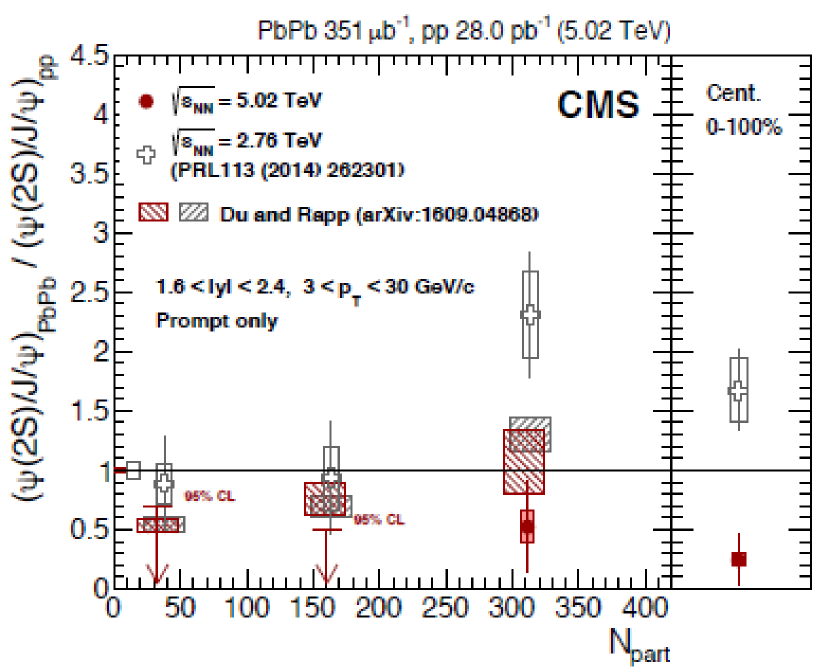
Open Issues from Data (1)

- Large inclusive J/psi v2 signal observed by ALICE
  - Does that really mean charm participate in flow?
  - Comparison to open charm v2

- Observations from data:
  - Psi(2S)/ J/psi ratio in 2.76 and 5.02 TeV in CMS data

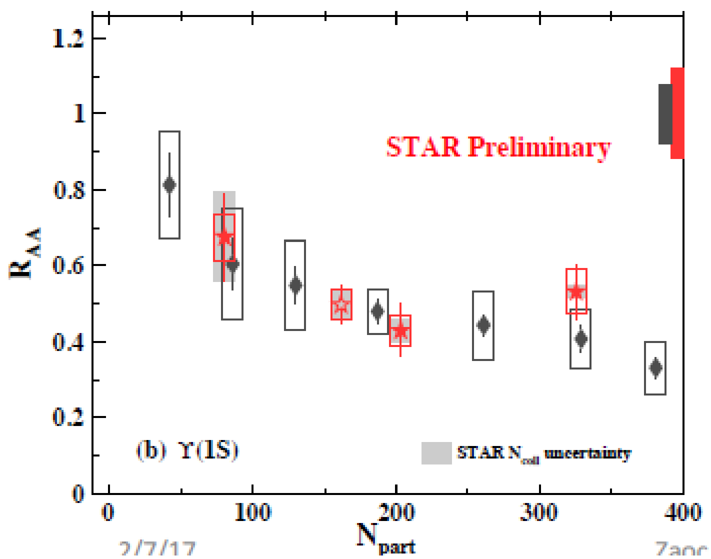


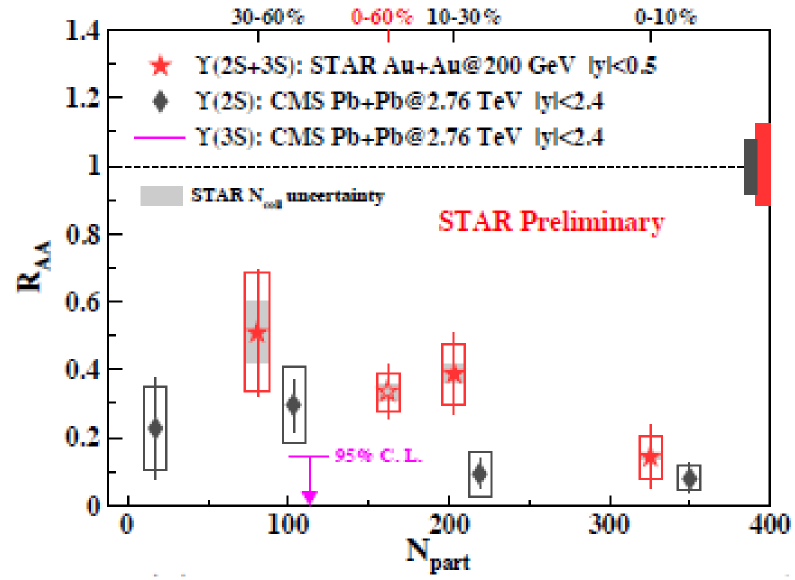




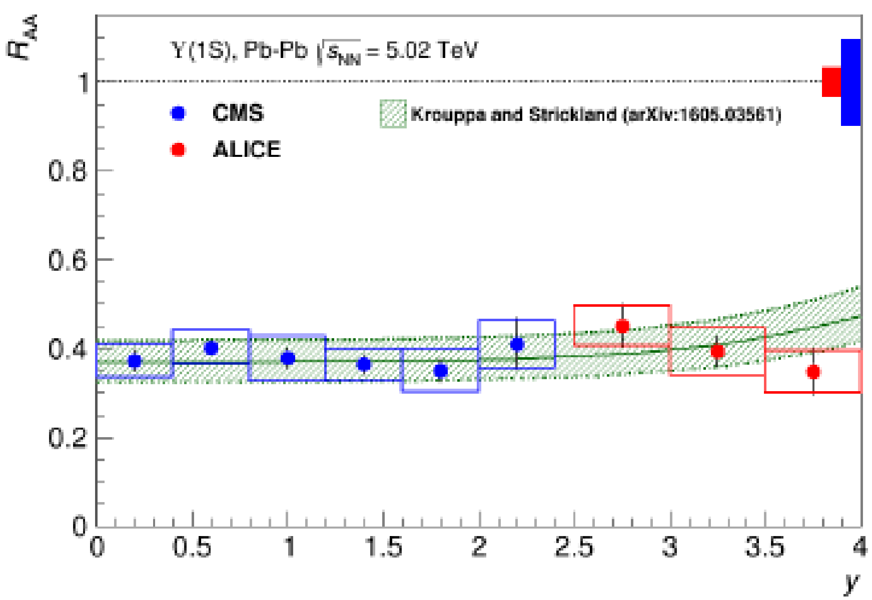
Open Issues from Data (2)

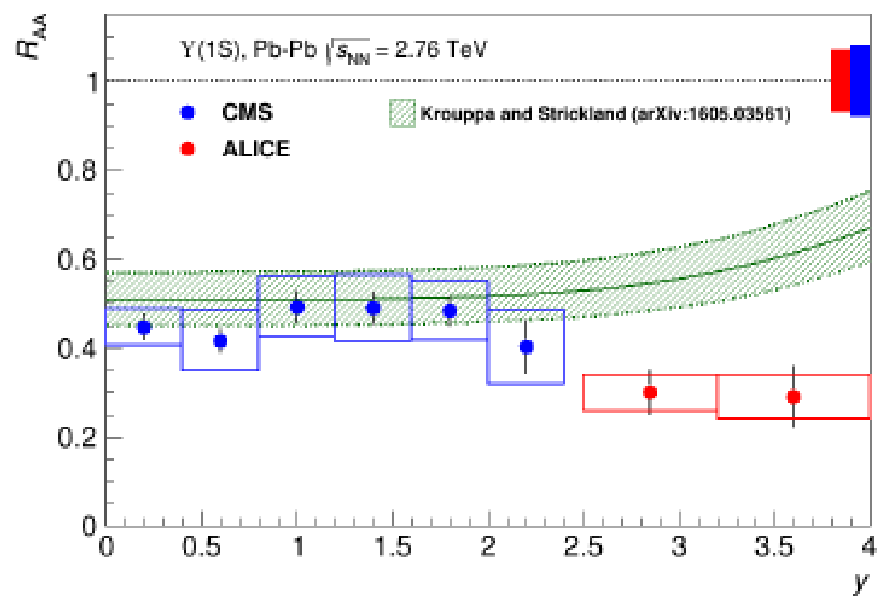
- Y(1S): Interesting trend of RAA from STAR 0.2 TeV, CMS 2.76 and 5 TeV





- Suppression pattern of the Υ(1S) state in 2.76 TeV and 5.02 TeV vs rapidity





Backup slides

New measurements

- Need precise ccbar and bbar cross-section and size of shadowing effect

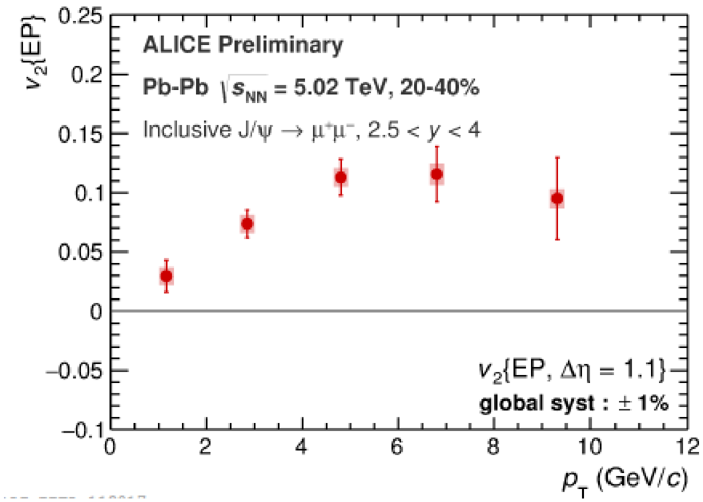
- Can we see the dissociation?
  - ccbar correlation via DDbar?

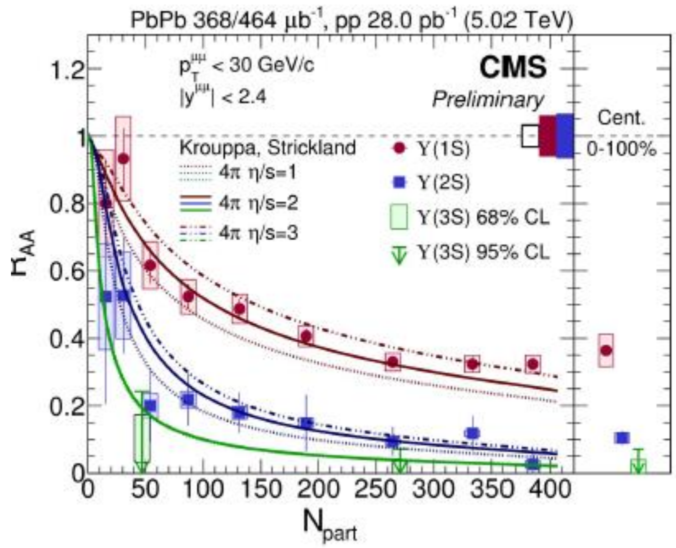
- Does bottom flow? (Upsilon v_2)

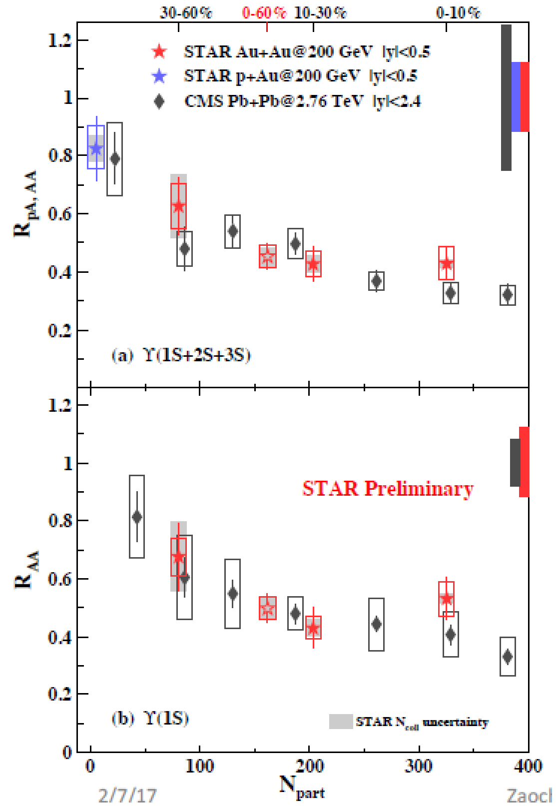
Quarkonium: experimental data

Large wealth of new data from RHIC and LHC presented at QM

→new results show an increased precision in quarkonium measurements
→ ground and excited states accessible
→multi-differential analyses, in narrower bins, now available



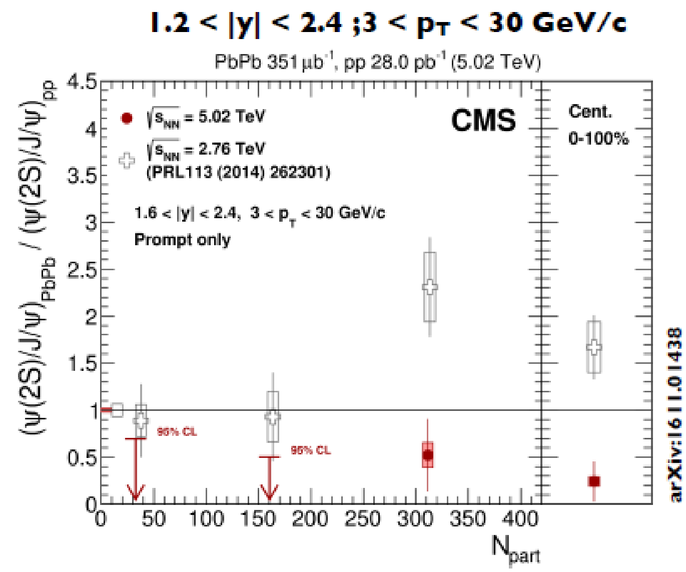




How to increase the precision of the measurements (experiment)?

Statistics is needed!
→ In PbPb: for statistics-hungry signatures as excited states

→In pp: to precisely access the pp reference (usually one of the largest sources of uncertainties), often still an issue, in particular for excited states

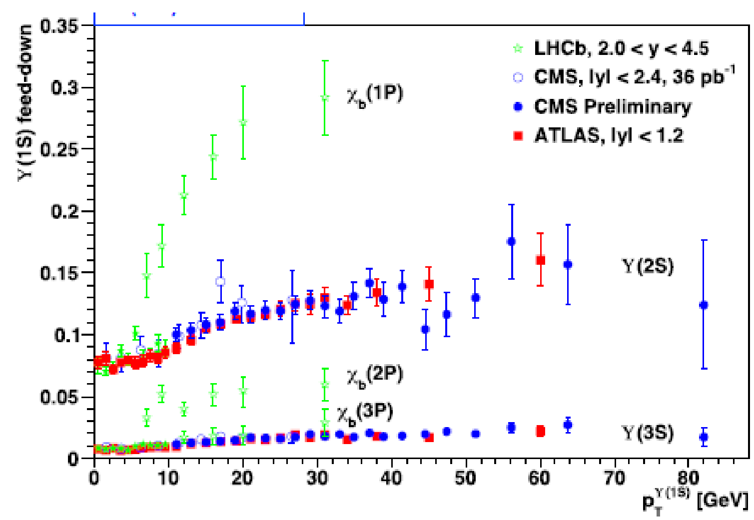


Which other measurements are needed?

→ Precise measurement of Upsilon feed down in the kinematic range of AA results [to quantify direct Y(1S) suppression]

→ Precise assessment of cold nuclear matter effects

→ Precise measurement of charm cross section

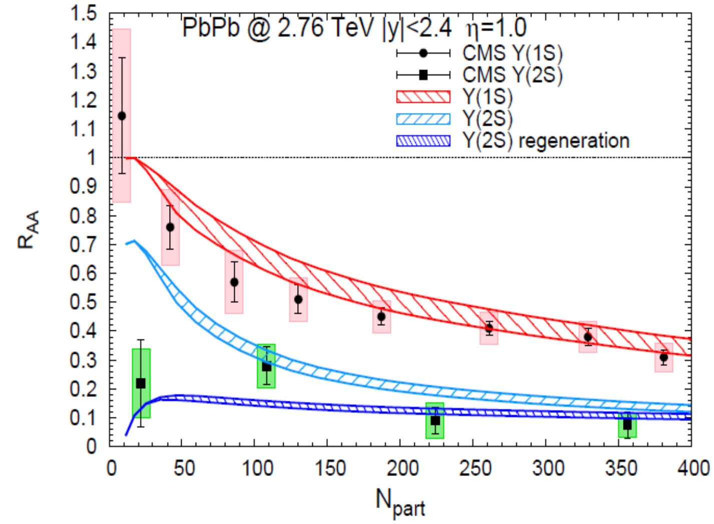


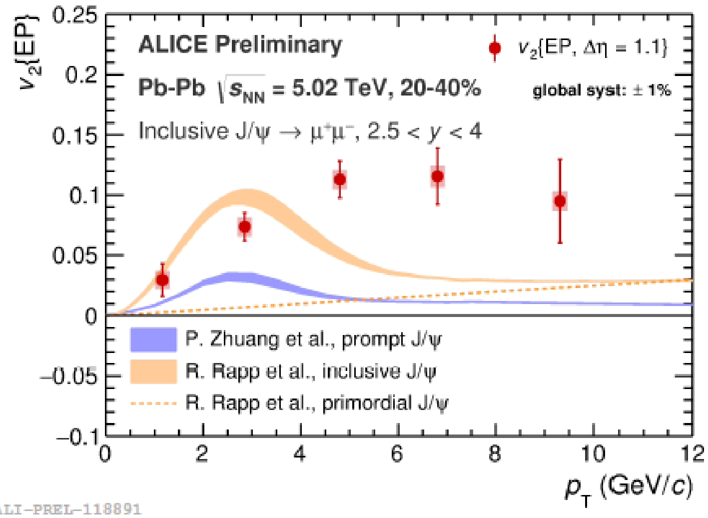
Data vs theory comparison:

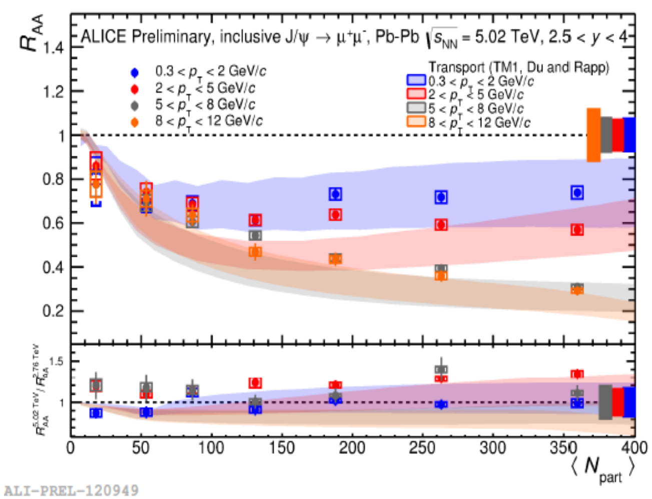
→RAA and v2 should be simultaneously described

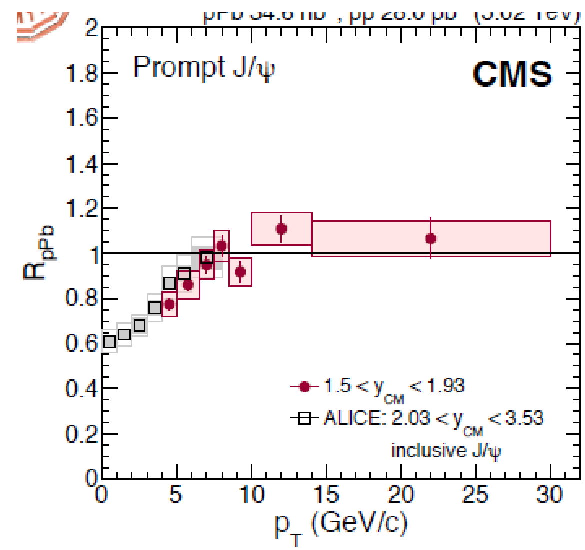
→Multi-differential distributions should impose constraints to theoretical models

→Simultaneous description of results from different experiments (covering different kinematic ranges and energies)







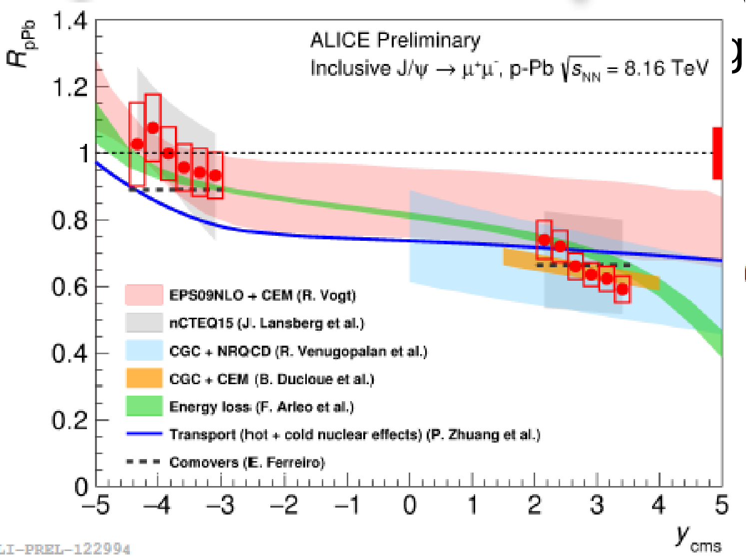


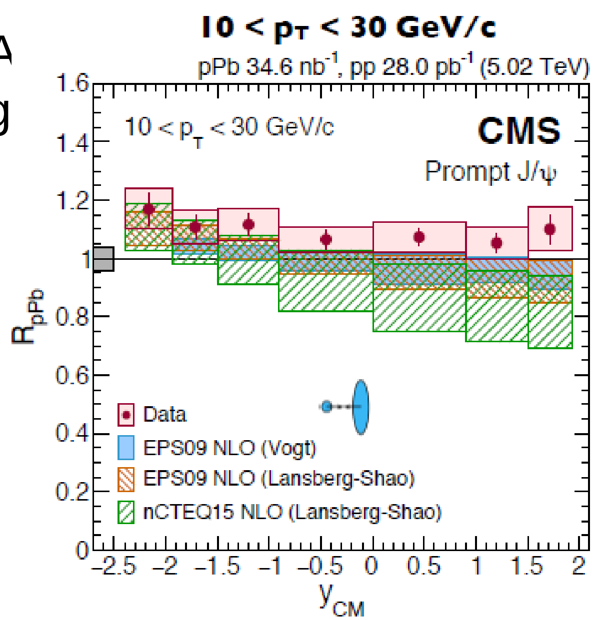
Data vs theory comparison:

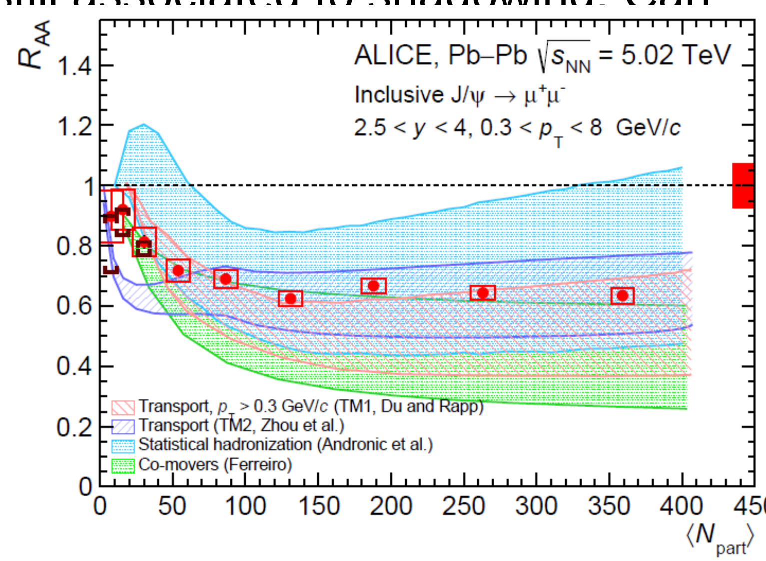
→Sigma_cc should be precisely measured in pp and in pA, AA, in order to directly account for production + CNM effects contributions (up to 40% difference in the values used in the models so far)

→Compare data vs model under the same assumptions (not all models include uncertainties on the same quantities, e.g. shadowing)

→Assess CNM effects from pA ... still associated to shadowing. Can







Alternative observables:

RAA is a convolutions of hot matter effects and pp production issues

→yields? Allow to get rid of pp reference related issues, but comparisons are less direct

→Closed vs open charm?

Need charm measurement down to pT = 0

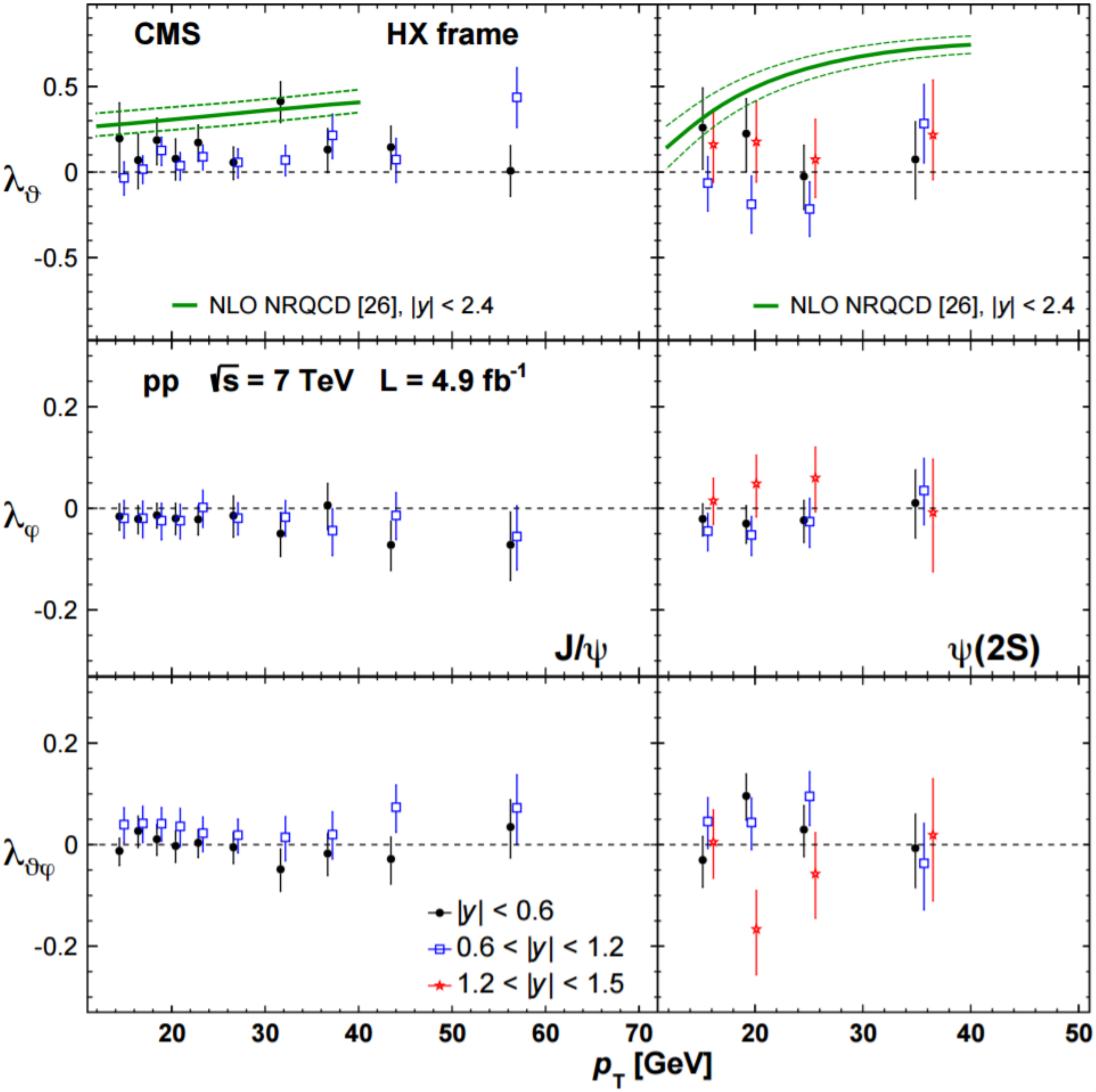
More tricky kinematical comparison?

From pA to AA:

Npart/NColl is a geometrical quantity. Now that results at various energies are available, should we investigate other variables as dN/deta, more related to the energy density?

Having precision pA data, can we extrapolate CNM effects from pA to AA? Shadowing, energy loss?

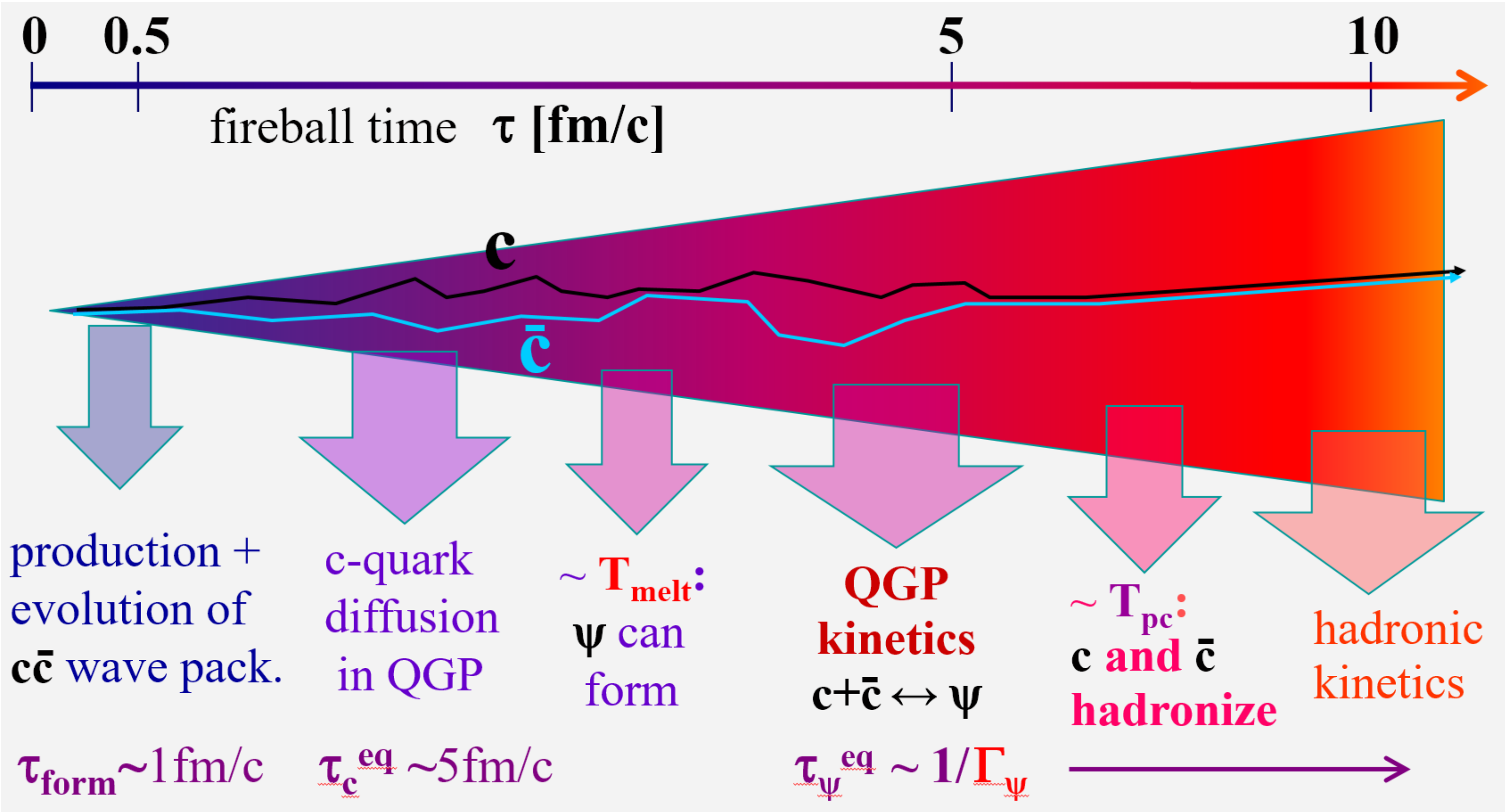
- Backup slides


CMS
HX frame
pp √s = 7 TeV L = 4.9 fb⁻¹
NLO NRQCD [26], |y| < 2.4
NLO NRQCD [26], |y| < 2.4
J/ψ
ψ(2S)
|y| < 0.6
0.6 < |y| < 1.2
1.2 < |y| < 1.5
λϑ
λφ
λϑφ
pT [GeV]

Charge

What are the perspectives for going on the experimental and on the theoretical side beyond the current state of the art?

In the coming decade, it is foreseen that CERN LHC provides p-Pb and Pb-Pb collisions at high luminosity, providing unprecedented access to hard probes at the TeV scale. Within the same time window, sPHENIX will come online at RHIC, which opens novel opportunities for experimenting with hard probes at the RHIC energy range. What do we know about hard probes at present? How can the field profit best from the planned beams and detector upgrades? Which fundamental questions in the sector of hard probes are accessible with this effort? How well is the theory developed to make use of the expected data and which further theoretical developments are possible and needed? The aim of the meeting is to have a free out-of-the-box discussion about the mid-term future of heavy-ion physics with focus on hard and electromagnetic probes, including all hard processes that are or may become experimentally accessible and our understanding of the medium properties that they probe.


0
0.5
5
10
fireball time τ [fm/c]
c
c̄
production + evolution of cc̄ wave pack.
c-quark diffusion in QGP
~ T_melt: ψ can form
QGP kinetics
c+c̄ ↔ ψ
~ T_pc: c and c̄ hadronize
hadronic kinetics
τ_form ~1fm/c
τ_c^eq ~5fm/c
τ_ψ^eq ~ 1/Γ_ψ