Bottomonia in AA at the LHC

(a heavy questioning talk on an unquestionably heavy subject)

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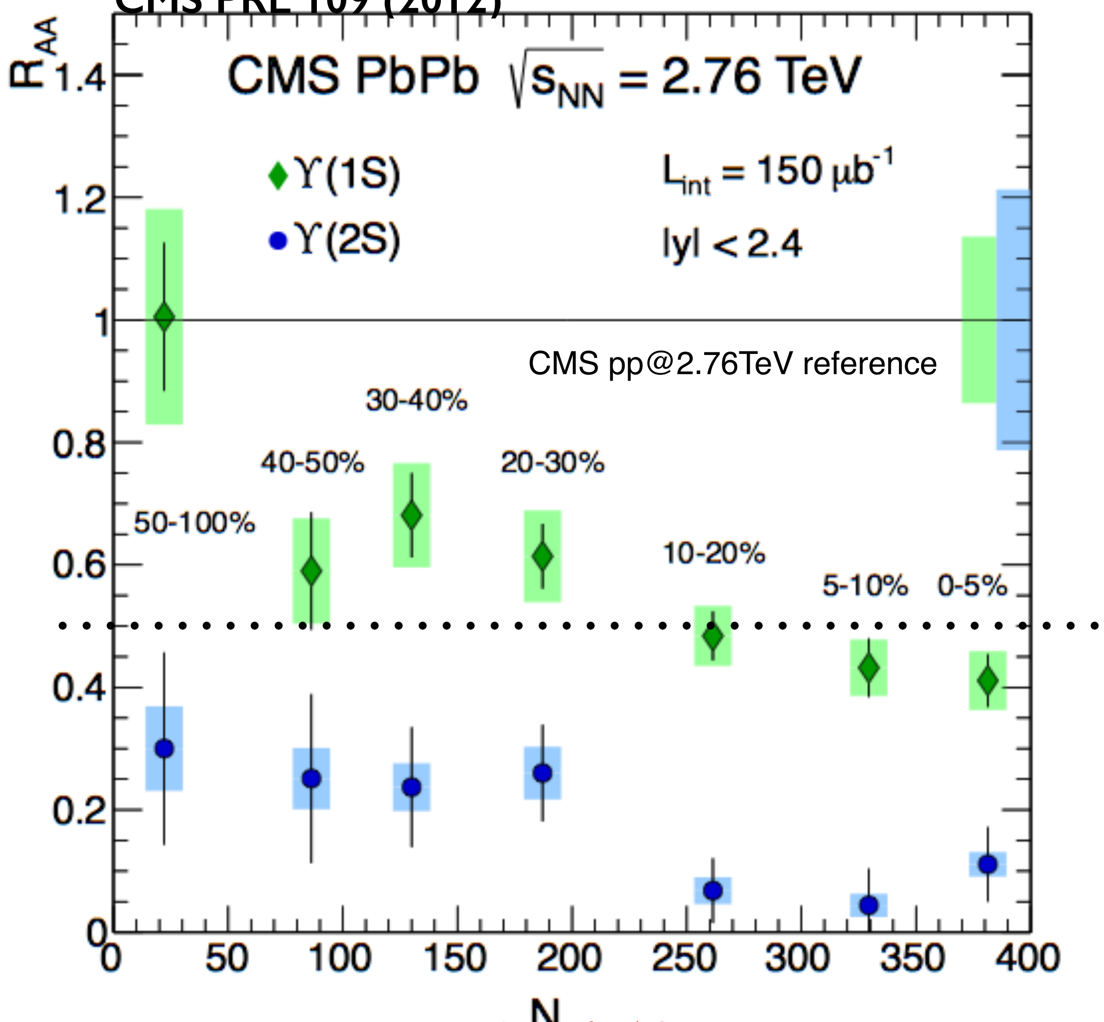
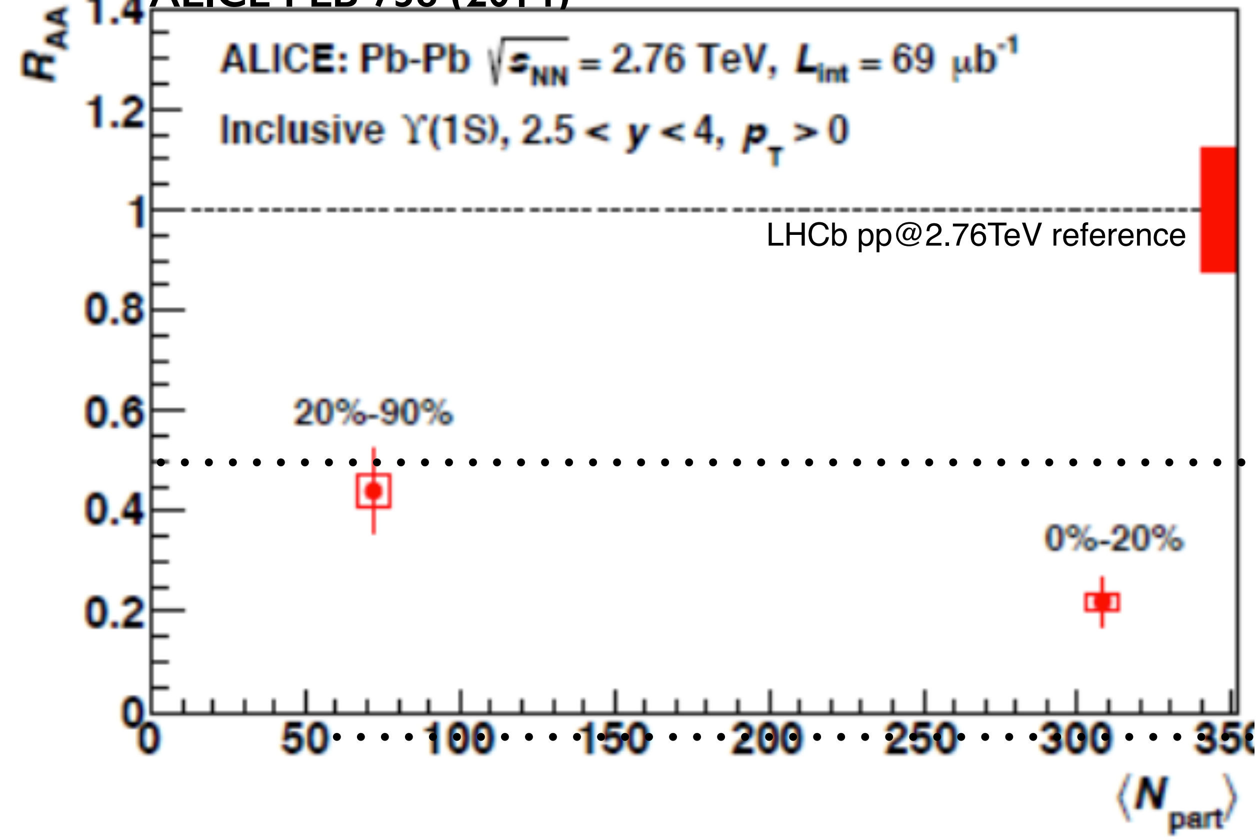
Υ(1S, 2S, 3S) in AA at the LHC

CMS PRL 109 (2012)

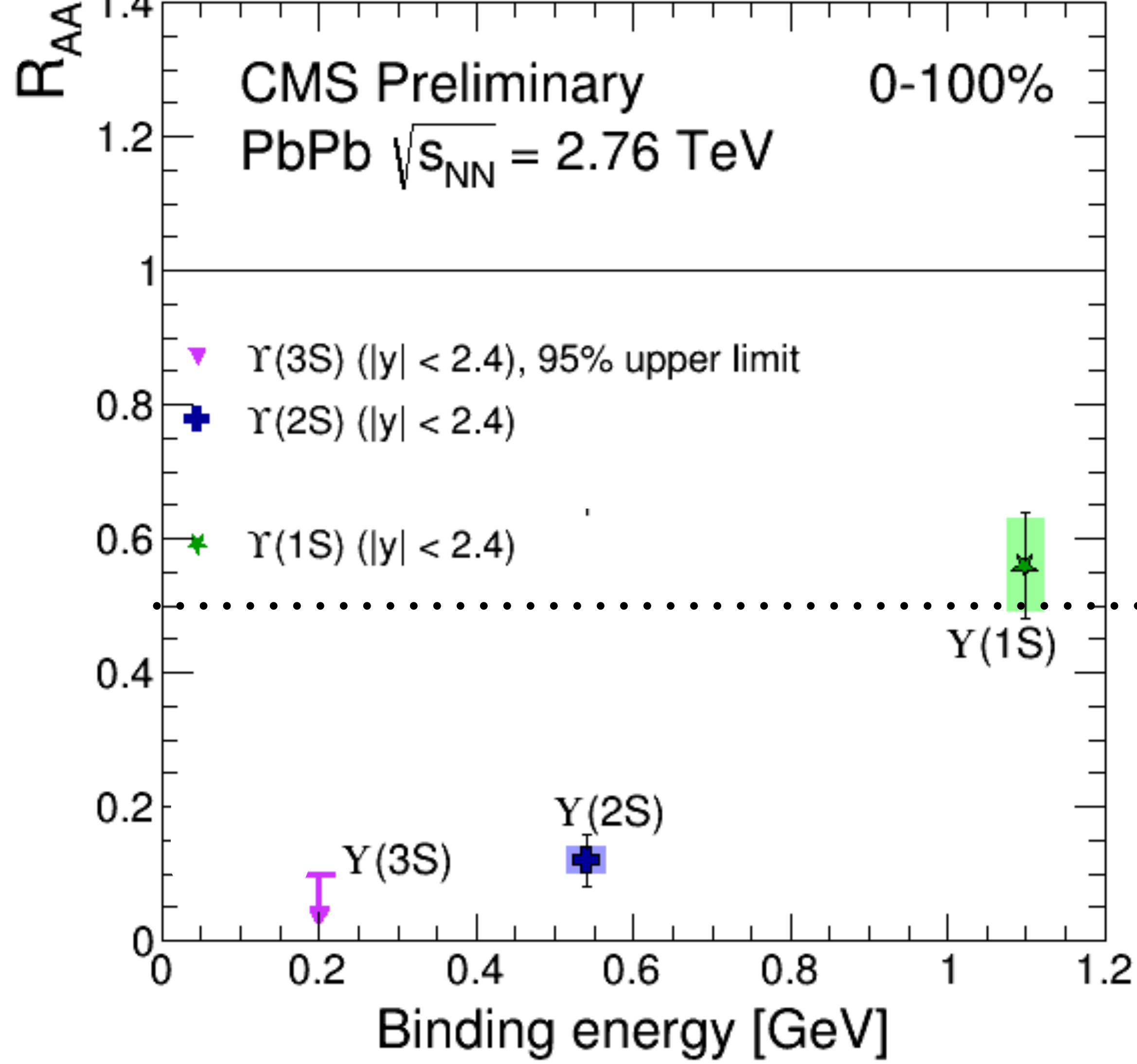


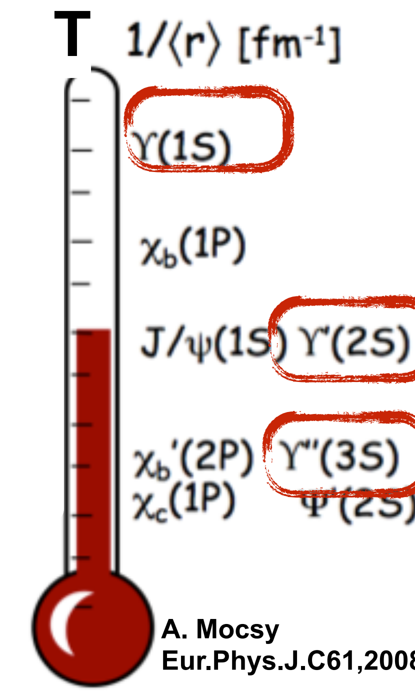
ALICE PLB 738 (2014)



- **CMS: |y|<2.4, p_T>0, 0-100%**
  - Υ(1S): 0.56 ± 0.11 (stat+systm)
  - Υ(2S): 0.12 ± 0.04 ± 0.02
  - Υ(3S): < 0.1 at 95% CL
- **ALICE: -2.5<y<-4, p_T>0, 0-100%**
  - Υ(1S): 0.30 ± 0.06 (stat+systm)

Summary



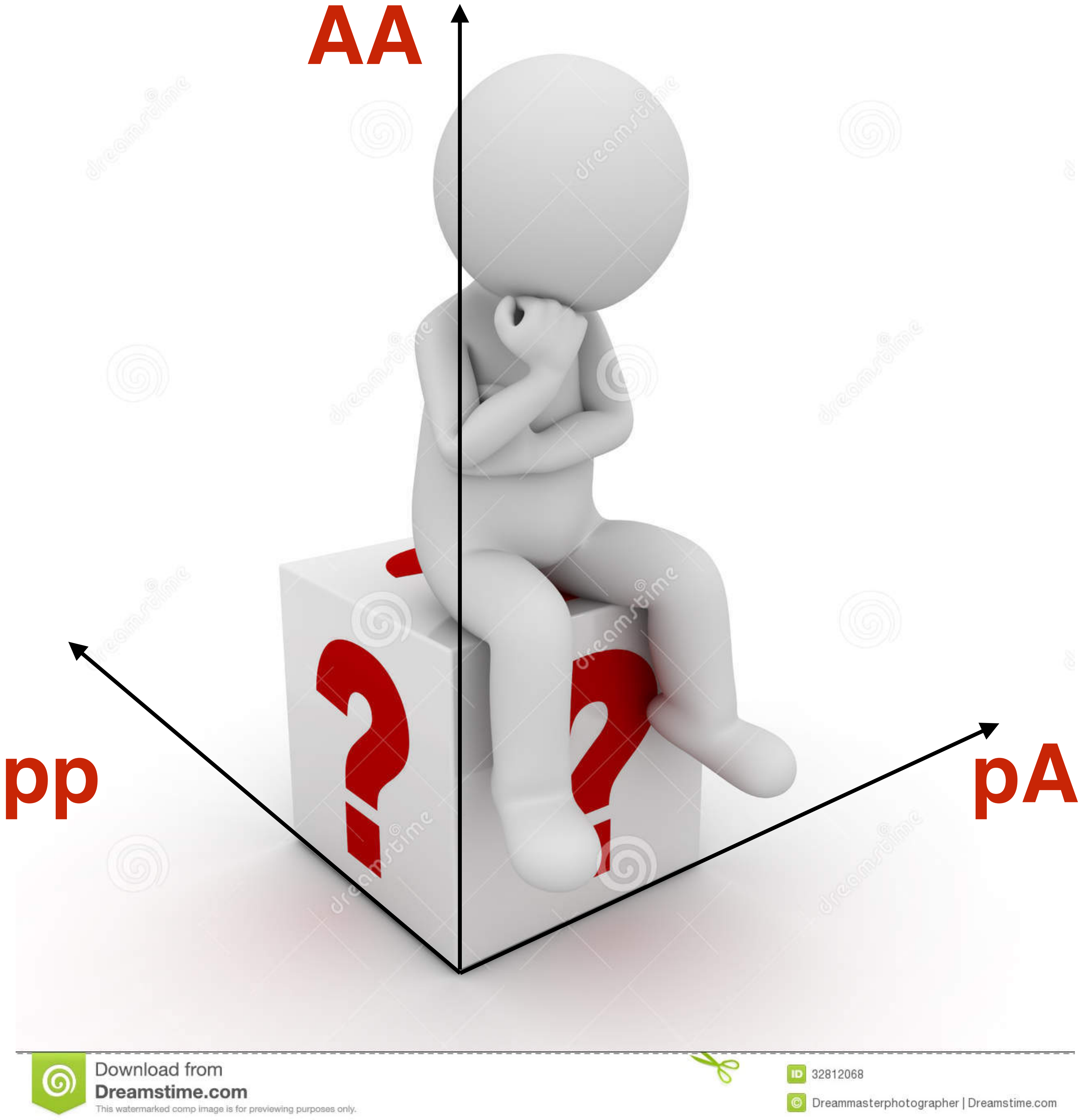


- **CMS: $R_{AA}^{\Upsilon(3S)} < R_{AA}^{\Upsilon(2S)} < R_{AA}^{\Upsilon(1S)}$**
  - ➡ order → thermometer-ish
    - still missing theory input on scale: 300-700MeV for 1S is rather large, not very useful, range …
  - ➡ assuming feed-down to 1S of ~40-50% (CDF and LHCb) → 1S is ~ not modified

- **ALICE: strong y-dependence**
  - ➡ theory '<u>predicted</u>' CNM (e.g. nPDF) & the HOT recombination for Υ(1S)~ negligible
    - re-predict soon…(until then, this qualifies as an experimental discrepancy)
  - ➡ !!!! caveat: pp reference is measured/provided by LHCb
    - I shall not panic until the result is updated with ALICE measured reference (2016 ? …)

Back-up

Think 3D



AA
pp
pA
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3D for 3Υ

- **1) Different in size, binding energy**
  - ➡ Debye screening to affect states … sequentially
- **2) Relatively close cross-section x branching ratios, close in mass**
  - ➡ initial effects should be <u>similar</u>
  - ➡ can test this in pA
- **3) Different (and largely unknown) feed-down contributions**
  - ➡ have to be settled in pp
- **4) Basic, unmodified production mechanism not fully understood**
  - ➡ have to be settled in pp
- **Missing something …?**

3D for 3Υ

- 1) **Different in size, binding energy (and formation time)**
  ➡ final effects (after hard-scattering) on each state expected to be different

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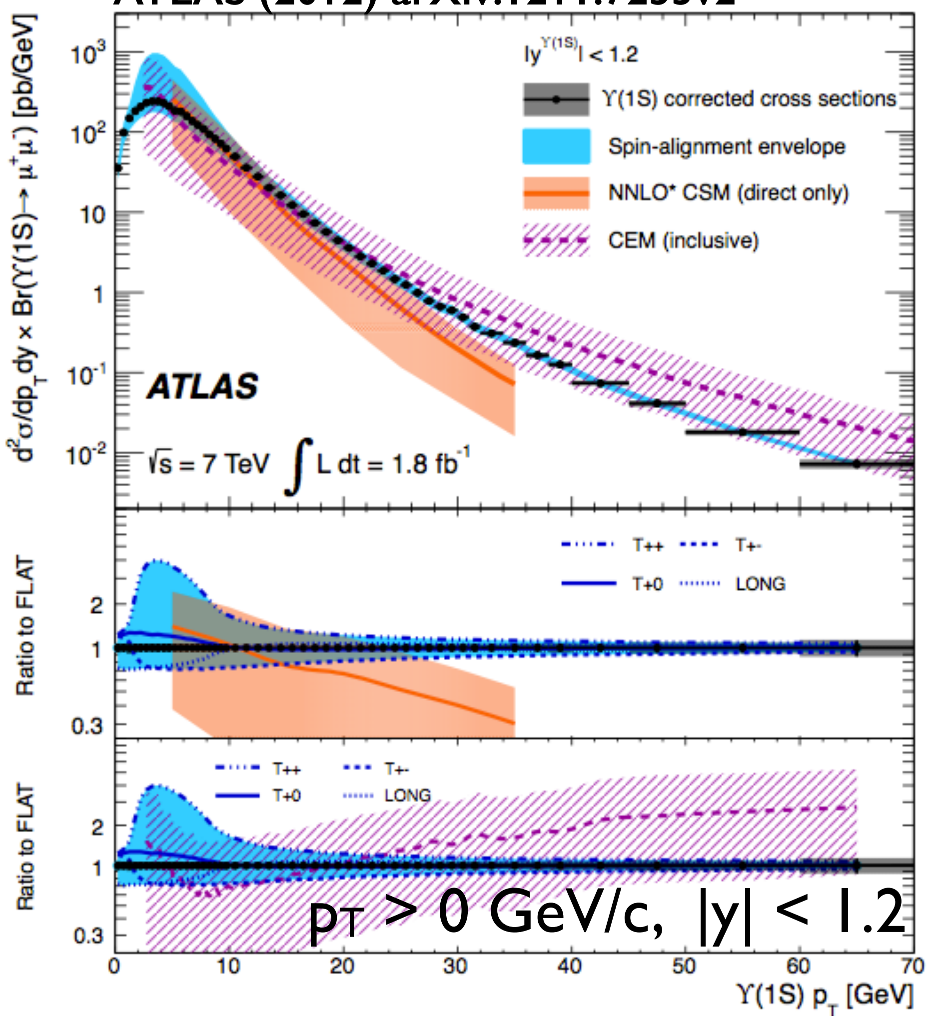
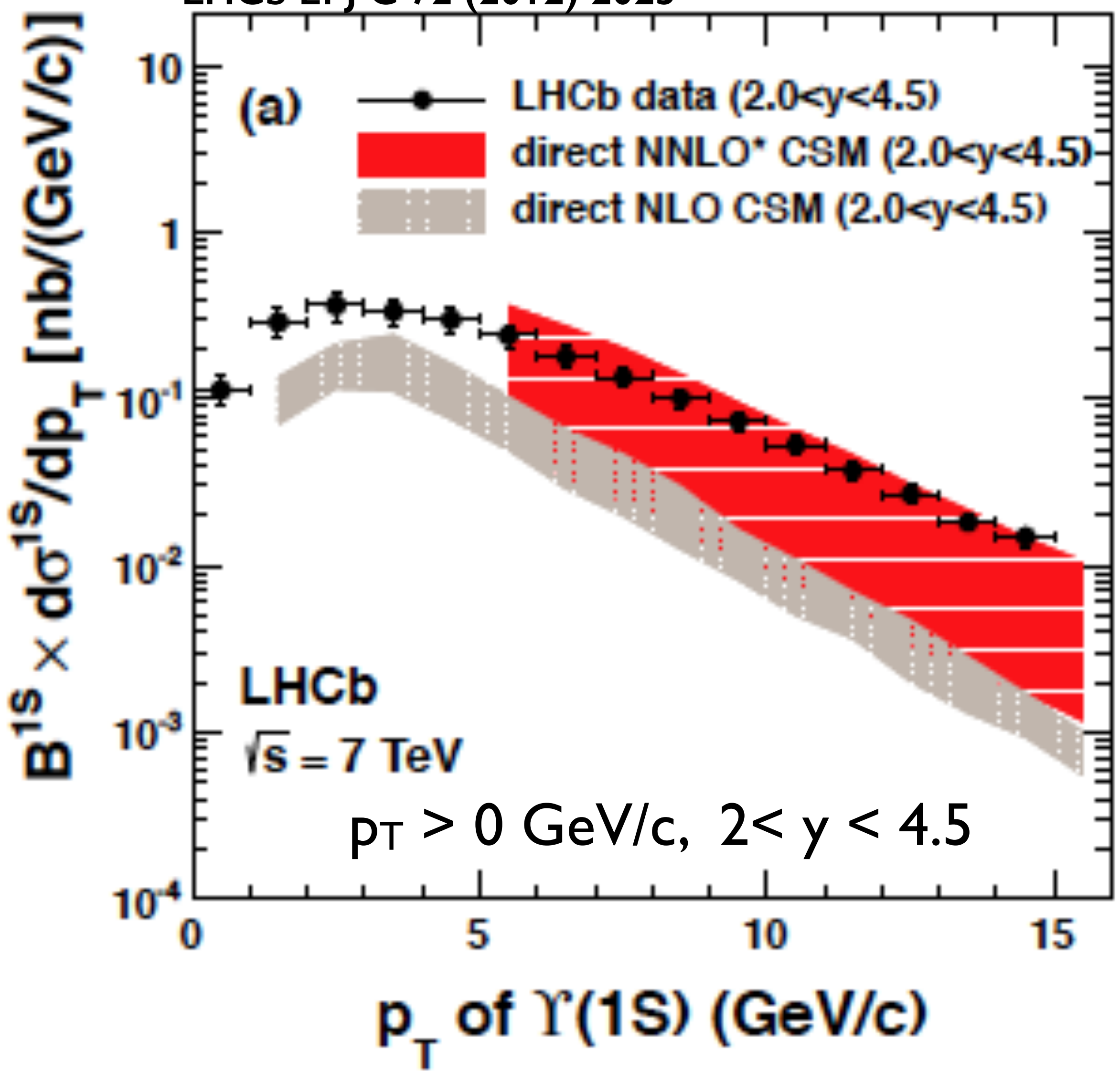
4) p+p: Theory vs Data   ϒ(1S)

ATLAS (2012) arXiv:1211.7255v2



LHCb EPJ C 72 (2012) 2025

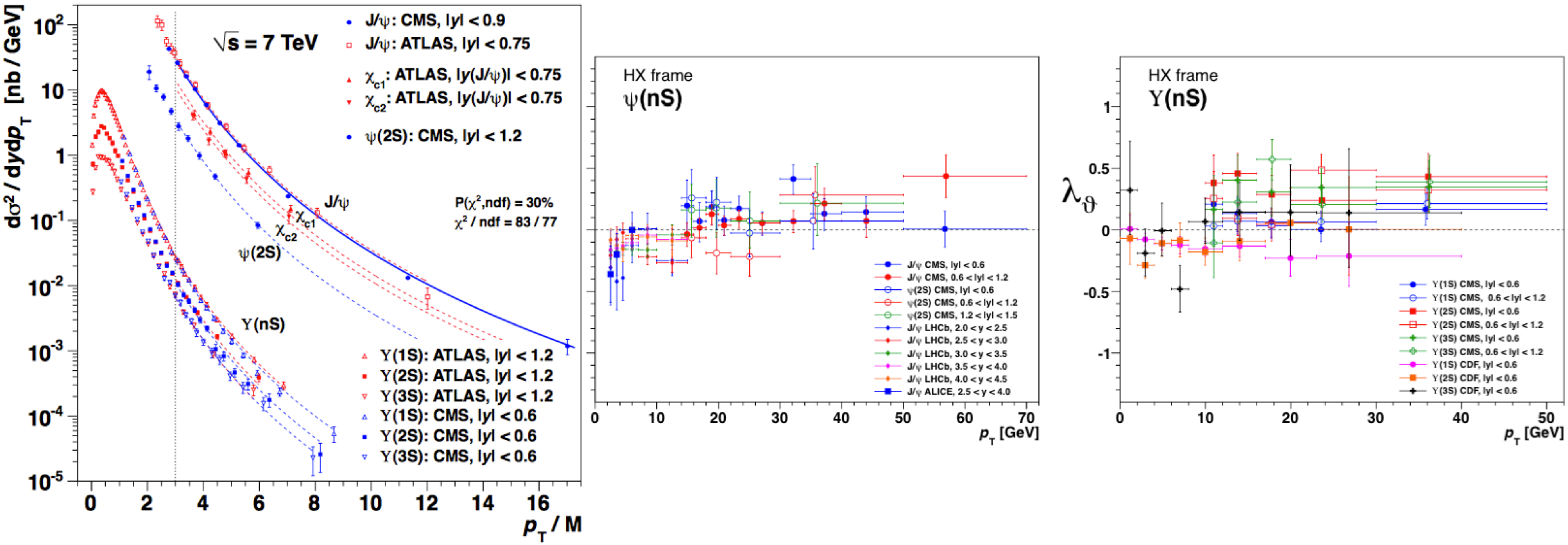


- **We thought it is easy to calculate ϒ(1S) (higher mass, higher scales, etc)…**
  ➡ it might be easyER, but doesn't look we have mastered the craft yet

- **Implication for pA & AA: life painfully difficult when no reference at same energy!!**

4) p+p: Data vs Data

Faccioli et al, arXiv.1403.3970



- **All onia states seem to be dominantly produced via one process**
  - ➡ for p_T/M>3: same scaling for all 7 onia (~10GeV/c for J/ψ and ~30GeV/c for ϒ)
  - ➡ S-wave onia polarization ~ between charmonia and bottomonia, independent of p_T, y,

- **Implication for AA, where (pair of) quarks & gluons couple different w/ medium**
  - ➡ a constrain for the theoretical models that include energy loss, azimuthal asymmetries, etc

3D for 3Υ

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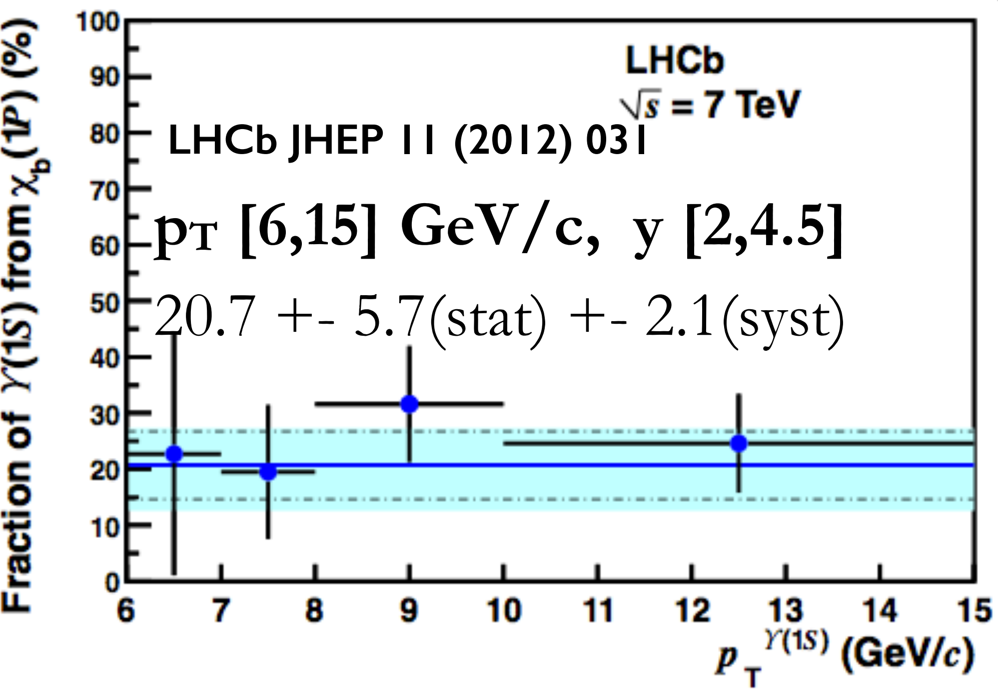
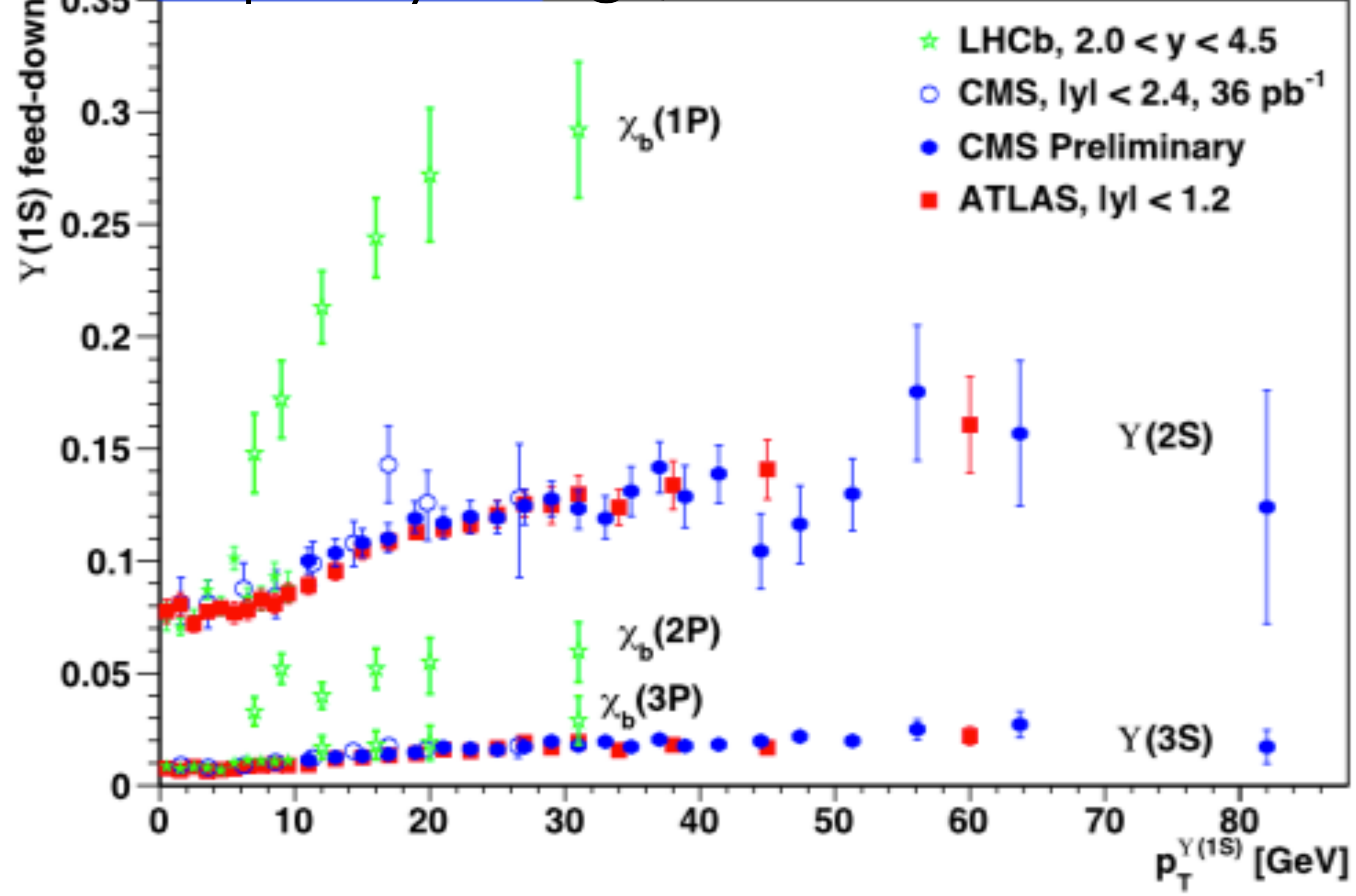
3) p+p: Data vs Data

CDF PRL 84 (2000) 2094
arXiv:1302.2180 Mocsy,Petreczky, Strickland

$\Upsilon(1s)$ feed down fractions	
Mechanism	**% ± Stat ± Sys** [135]
Direct Production	$50.9 \pm 8.2 \pm 9.0$
$\Upsilon(2s)$ decay	$10.7 \pm 7.7 \pm 4.8$
$\Upsilon(3s)$ decay	$0.8 \pm 0.6 \pm 0.4$
χ_{b1} decay	$27.1 \pm 6.9 \pm 4.4$
χ_{b2} decay	$10.5 \pm 4.4 \pm 1.4$

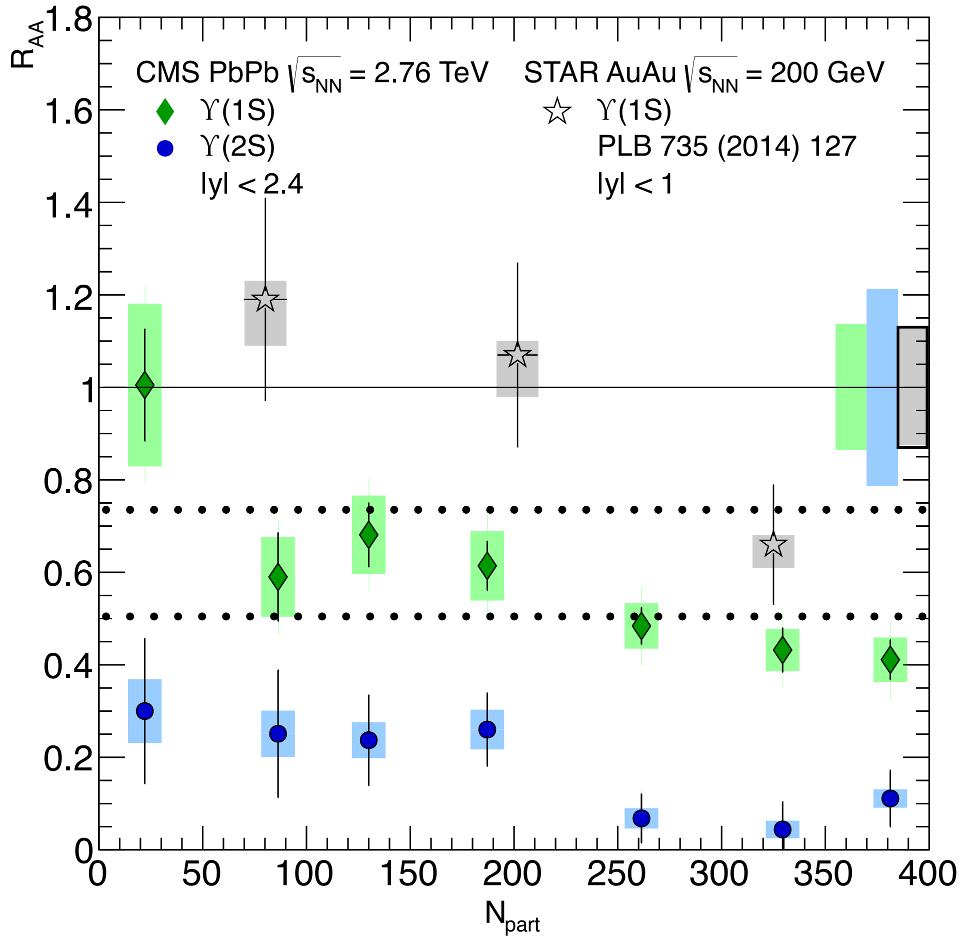


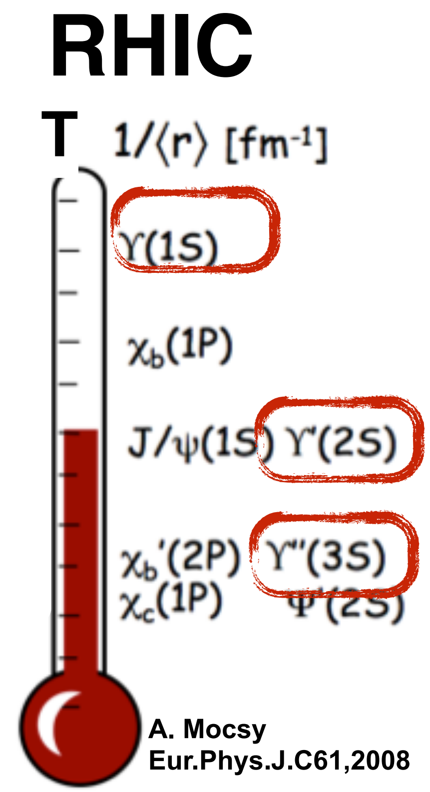
Compilation by Woehri @ QWG2014

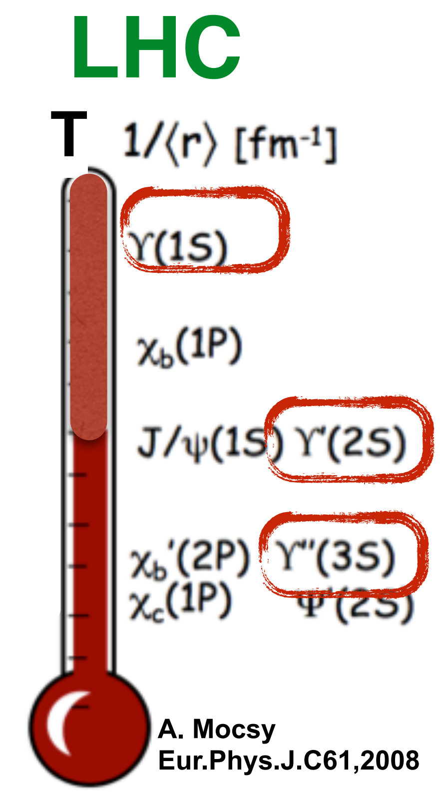


- For ~14 years: feed-down for Υ(1S) is ~50% at high-p_T
- 2014 news: more like 25-30% from feed-down at p_T~7GeV/c

3) A+A: Data vs Data







- **Implication for AA (&pA) (assuming the Debye screening picture is valid)**
  - ➡ Υ(1S) might've 'melt' after all … at LHC (~0.4 in 0-10%) but much less (if at all) at RHIC
  - ➡ $T_{RHIC(\sim 220MeV)} < T_{LHC\ (\sim 300MeV)}$ from thermal photons; medium much hotter though!
  - ➡ $T0_{RHIC} < T_{screening}(\Upsilon(1S)) < T0_{LHC}$

- **Bottomonia not a precise thermometer**
  - ➡ but a rather unique judge the 'realistic-ness' of models: range 300-700 MeV …

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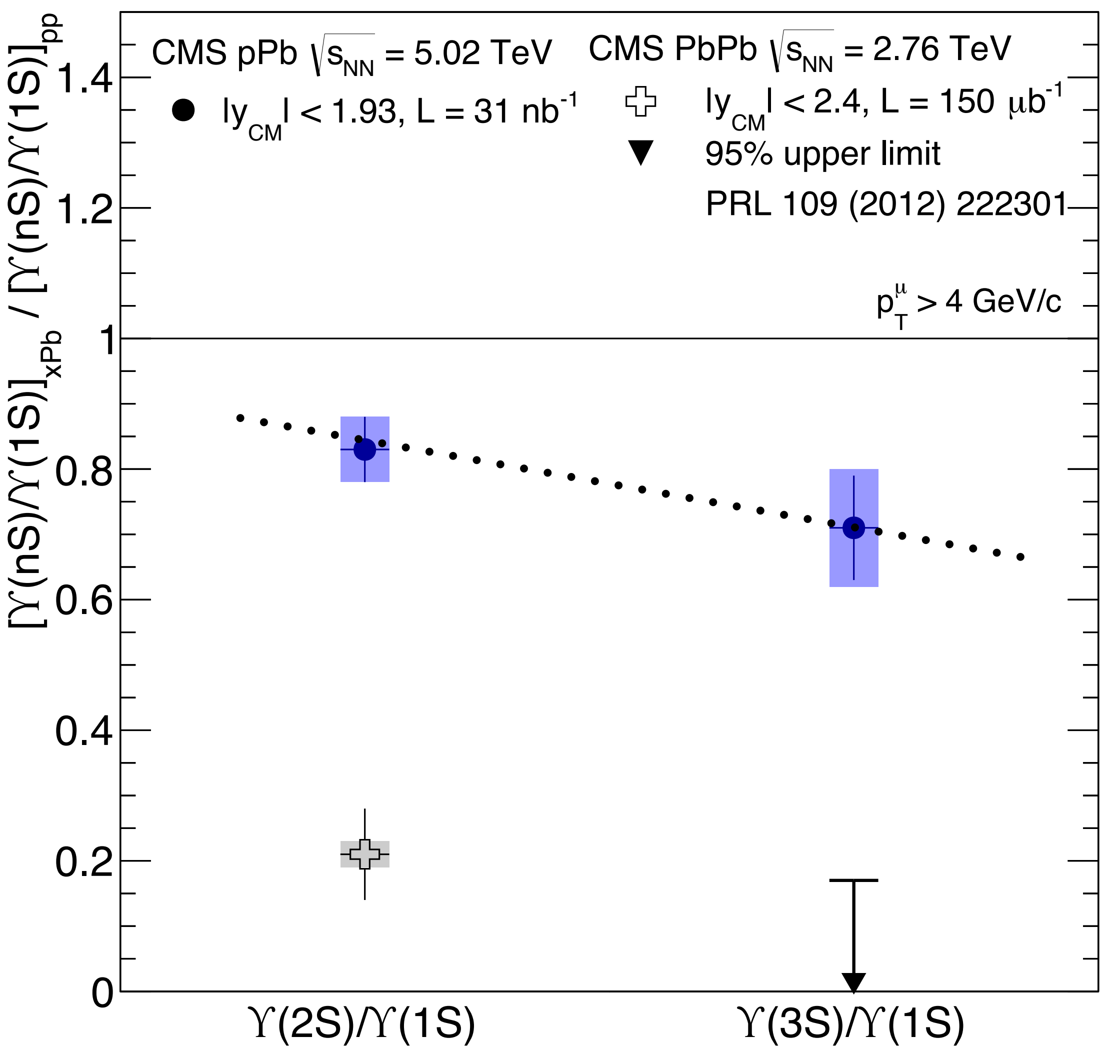
2) Final effects in pA



$$\frac{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pPb}}{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pp}} = \frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

Initial state effects (nPDFs, cold en. loss, etc) similar for the excited and ground states

➡ **Double ratio probes FINAL STATE EFFECTS**

- **pPb vs PbPb**: larger double ratios in pPb (though need extrapolation from 1->2 Pb)
  ➡ additional (and/or stronger) <u>final effects</u> in PbPb affecting more the excited states

- **pPb vs pp**:
  ➡ pPb <u>final effects</u> on the excited states suppress them w.r.t. the ground state (<3σ)
  ➡ 3S is more affected than 2S (a.k.a. there is size-ordering also in pPb) ?

3D for 3Υ

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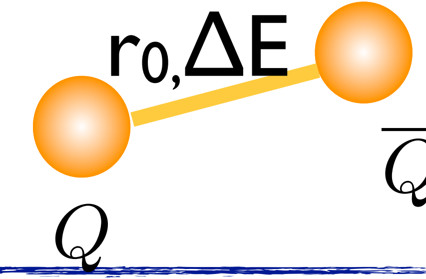
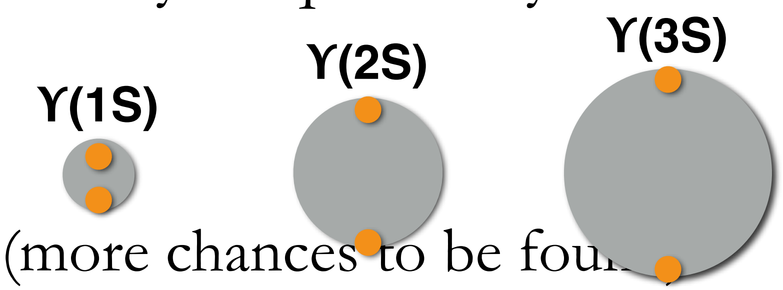
1) Size and binding energy

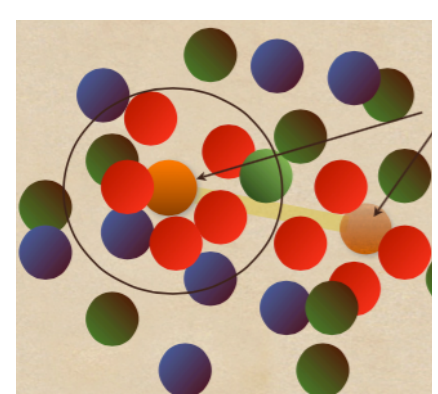


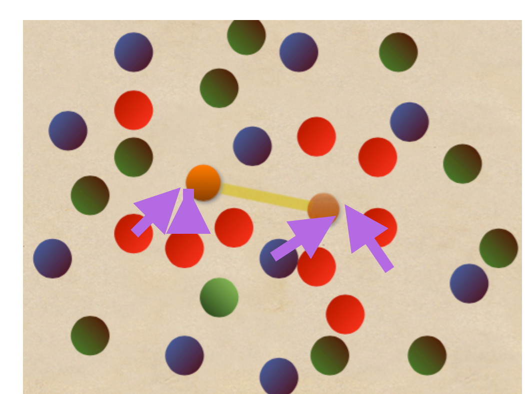
- If it's just binding en & size that matter, other processes can destroy 'sequentially'
  - ➡ excited states:



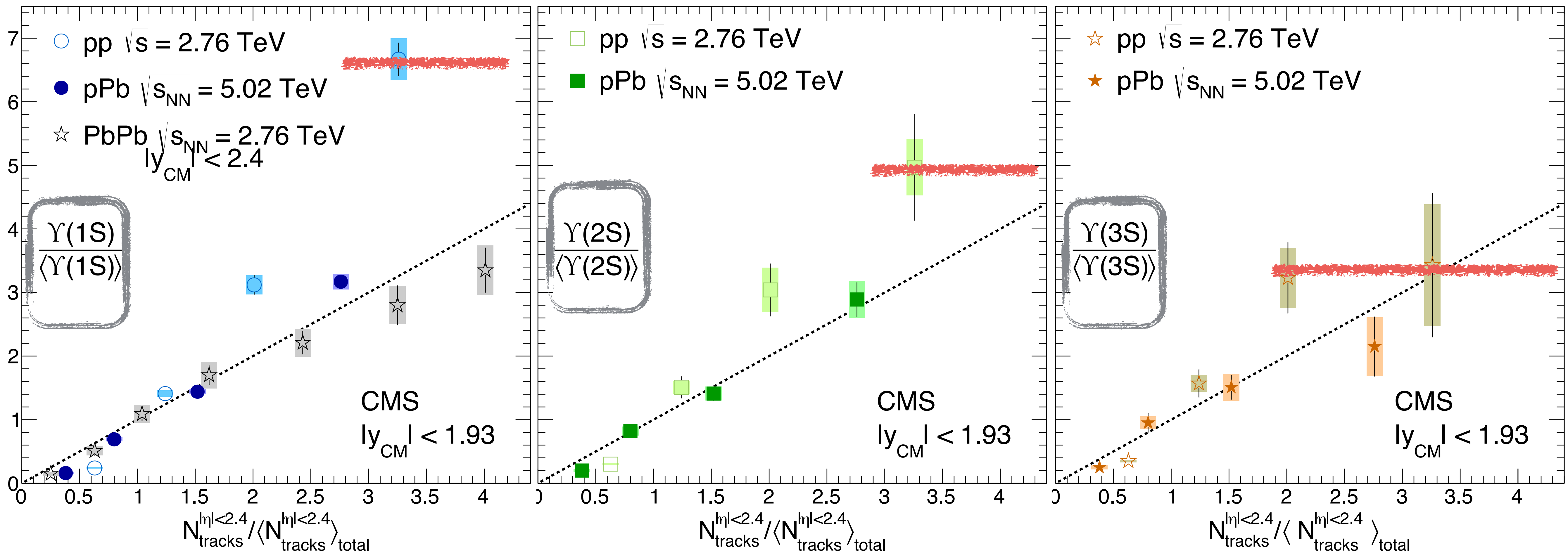
    - 'larger': easier to be 'found' even in more diluted environments;
    - $t^{formation} \sim 1/\Delta E$: longer time to form → longer in 'proto-state' (more chances to be fou
    - weaker bound:
      - easier to break once 'found' (by co-moving partons or hadrons)
      - but also easier to re-combine
  - ➡ need to consider also time/scales of the surrounding environment…
    - time to form, its lifetime and size are as important as its density

- **Several phenomena affecting bottomonia x-section**
  - ➡ 2 able to destroy/melt the states: Debye screening and inelastic collisions
    - *can we actually distinguish them? (more radically: does Debye screening actually exist?)*
  - ➡ 1 that can put back some yield: recombination





1) Size and binding energy …. in pp



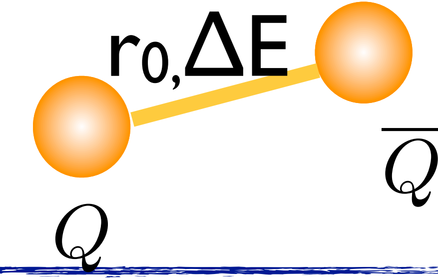
Evolution (w.r.t. minbias) of the individual x-sections with the increase of track multiplicity around the state

- **Don't freak out: in p-p, indications of 'ordered' behaviour !!!**

➡ at ~3x<N_{tracks}>:

$$\frac{\Upsilon(3S)}{\langle\Upsilon(3S)\rangle} < \frac{\Upsilon(2S)}{\langle\Upsilon(2S)\rangle} < \frac{\Upsilon(1S)}{\langle\Upsilon(1S)\rangle}$$

1) Size and binding energy

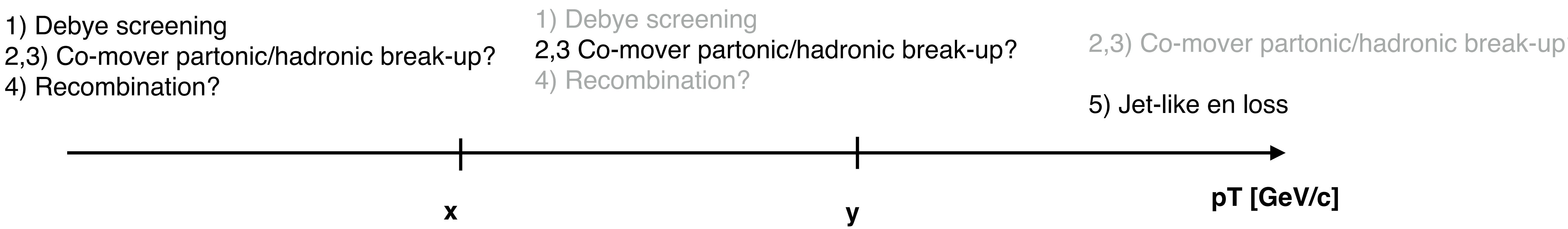


◉ **Can use "sequentiality" as proof of Debye screening/deconfined medium ?**

➡ Nope! (for sure not by itself)

➡ Just proof that size matters, hence it has to be considered by AA, pA and pp models!!!

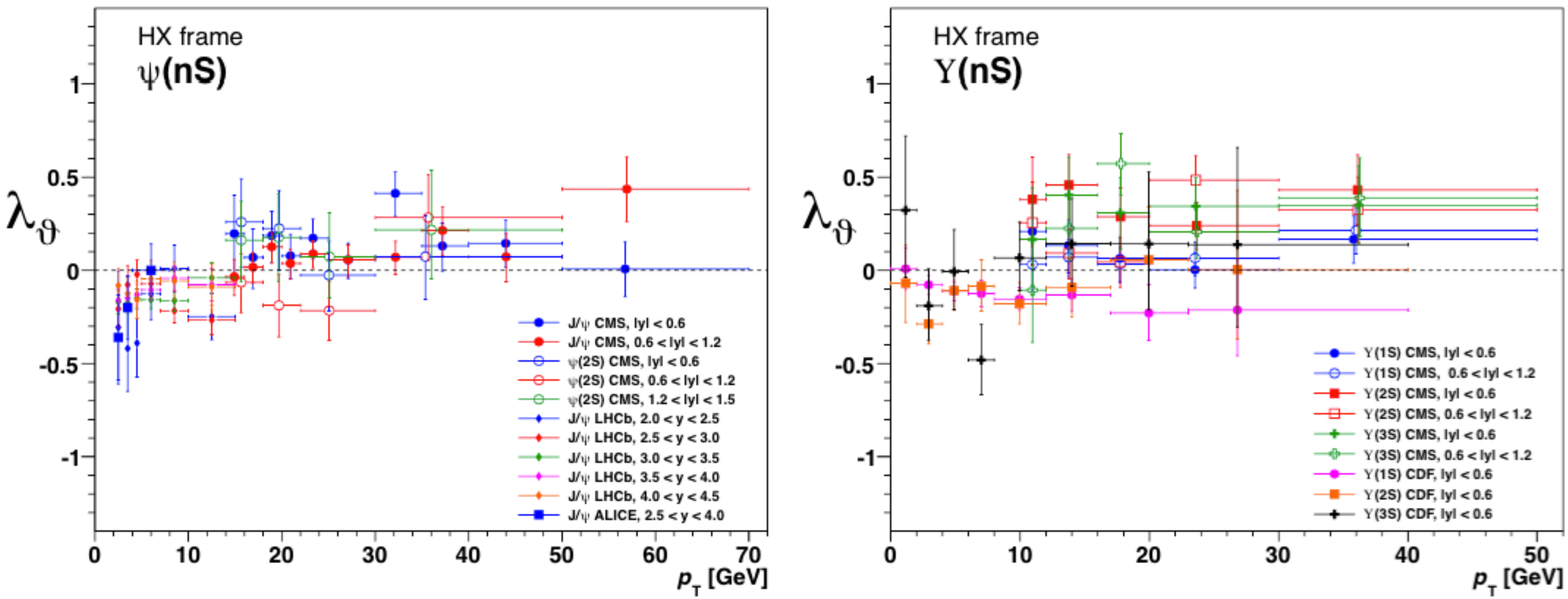
Instead of conclusion …



- **Interplay of final-state effects, each dominant in different kinematic regions.**
  - ➡ some can be at work (with different strength) also in pp and pA (use to gauge size of effect)
  - ➡ data for p_T dependence (at least) to define the regions of 'dominance'
    - CMS will do this before Run 2, but for some things might need p_T>20GeV

- **What I think data tell us so far (in the kinematic regions probed by CMS) …**
  - ➡ it's about final state effects!
  - ➡ 1S
    - (pp &) pPb: unmodified in any significant way
    - PbPb (0-10%): modified not only by Debye screening, but also by collisional dissociation
  - ➡ 2S and 3S
    - (pp high-multiplicity &) pPb : modified by *final state effects* (partonic/hadronic collisions)
    - PbPb (0->~60%): modified not only by Debye screening, but also by collisional dissociation

End

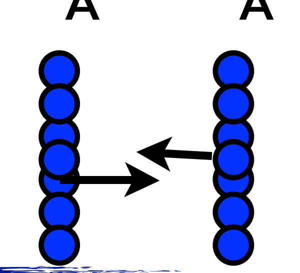


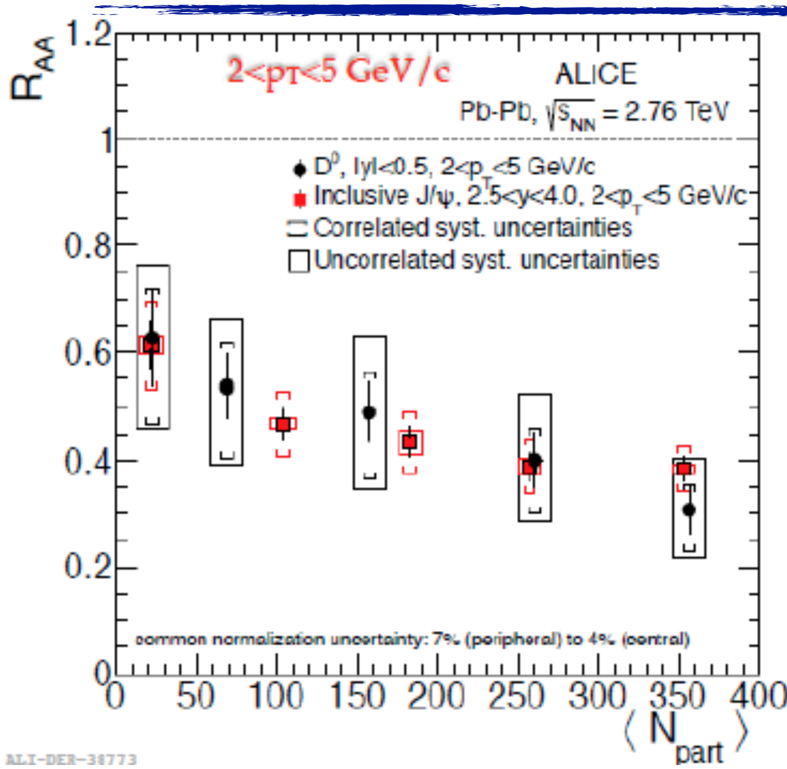
- **Quarkonium polarization measurements:**
  - ➡ polarizations of the S-wave quarkonia cluster around the unpolarized limit, with
    - no significant dependencies on p_T or rapidity
    - no strong changes from directly-produced states to those affected by P-wave feed-down decays
    - and no evident differences between charmonium and bottomonium

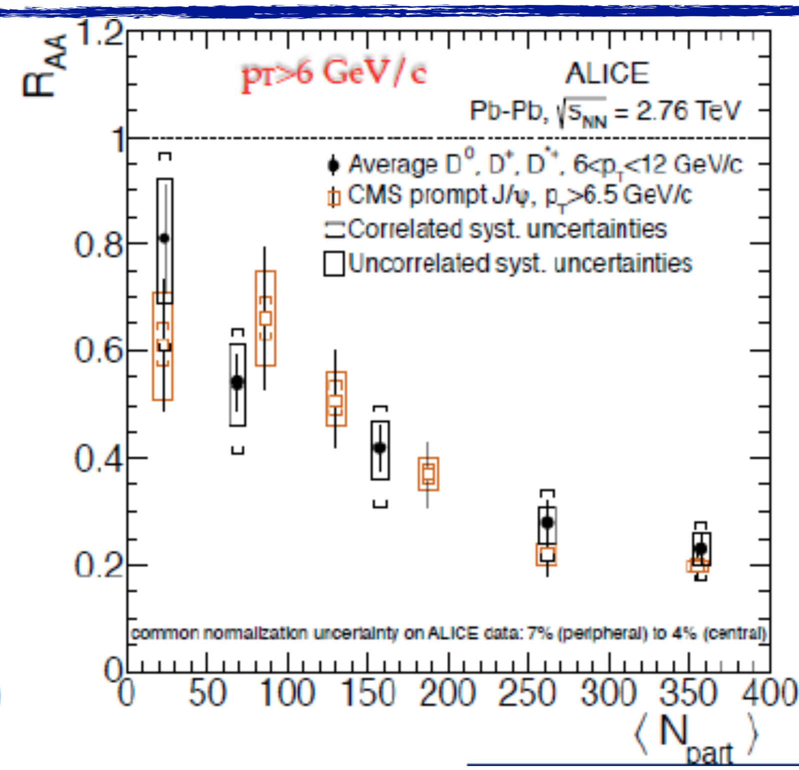
- **At "zero-order": all quarkonia are dominantly produced by a single mechanism!**

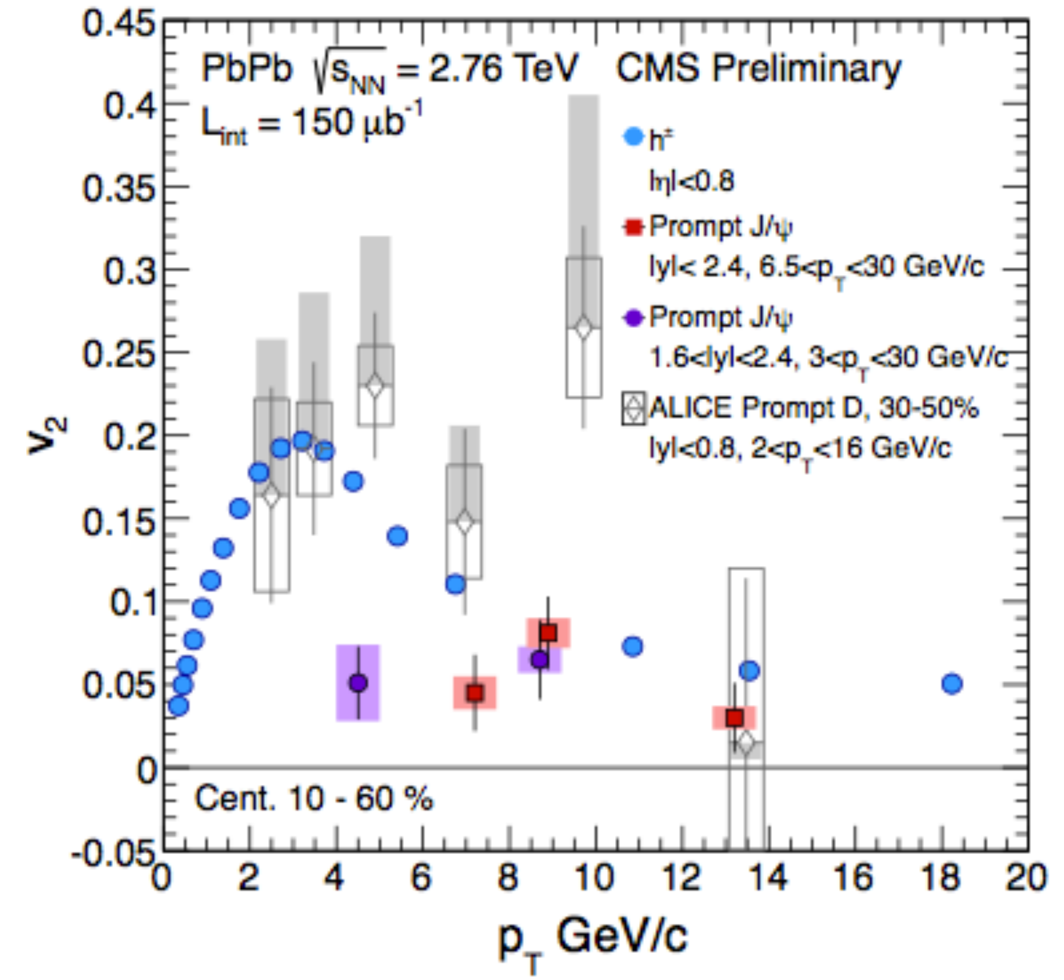
Onia in A+A: open vs closed

ALICE (2013) arXiv:1303.5880v2
CMS-PAS-HIN-12-001

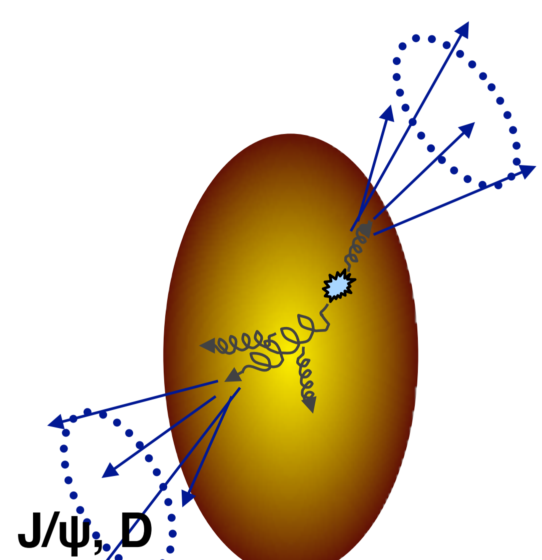






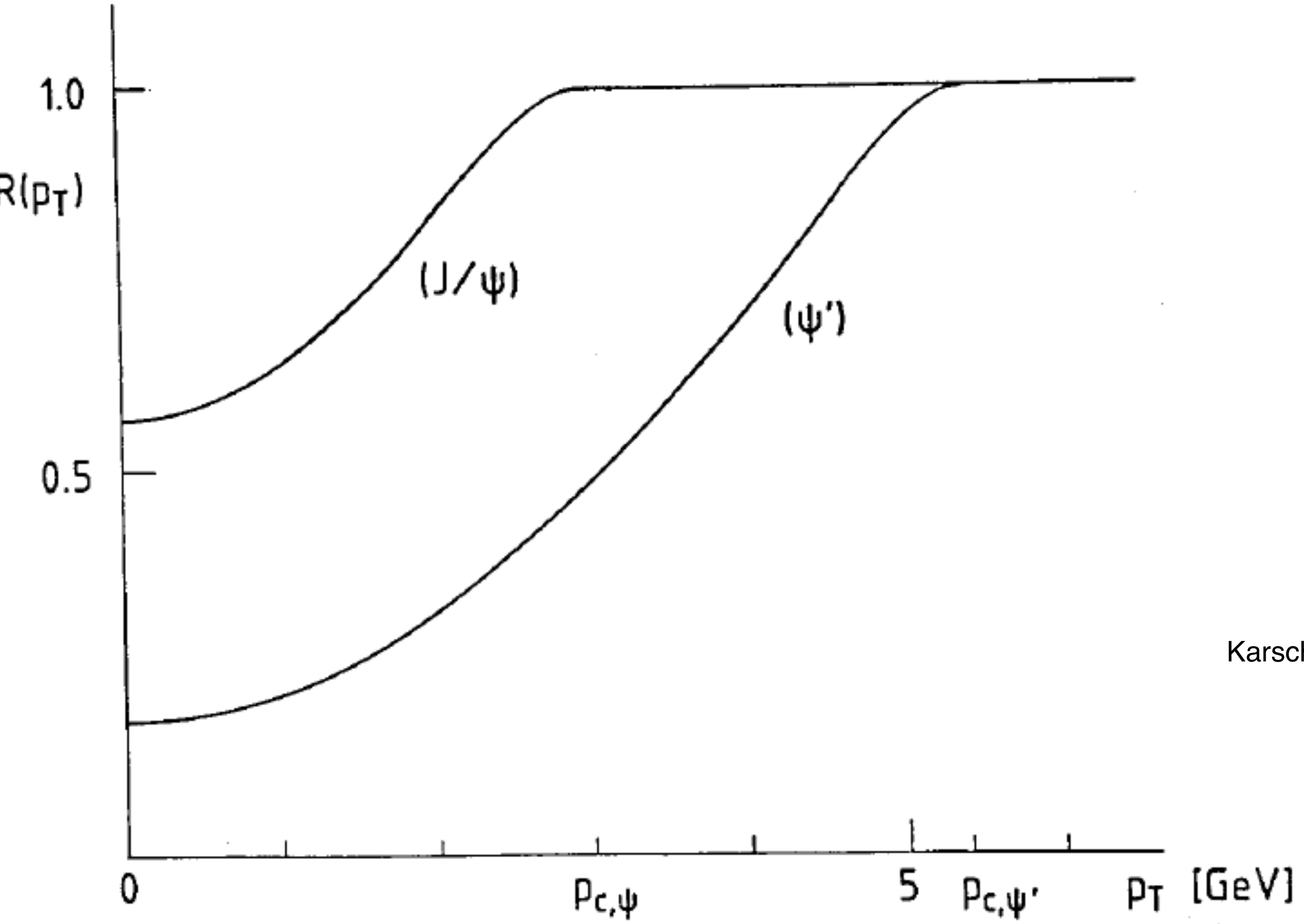


- R_{AA} for D and J/ψ similar
  - ➡ coincidence?
  - ➡ it's actually a parent gluon that looses an 'universal' energy before the mesons are formed?



- D has asymmetry from thermalized charm, OR from the light quark it combines with?
- Jpsi (not much recombination at pt>3GeV/c), so where from the asymmetry?
  - dominated by the path length dependence of en loss …. <u>whose en loss?</u>

Screening vs pT …



Karsch & Petronzio, 1987