Experimental Overview of Quarkonia

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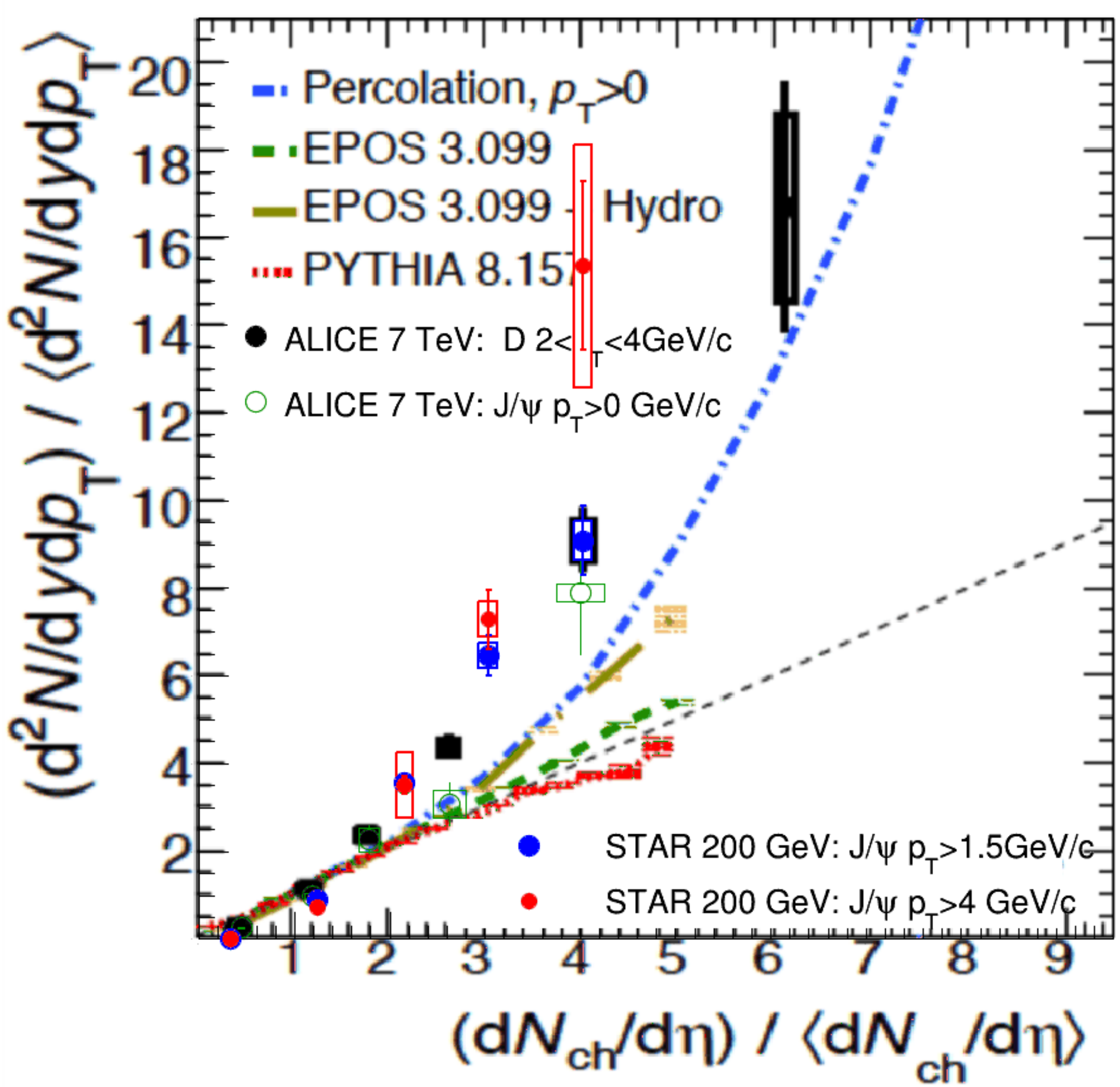
Excellence Cluster “Universe” - TUM

Strangeness in Quark Matter 2016
UC Berkeley
June 27th, 2016

Excellence Cluster Universe
Technische Universität München

Charmonia

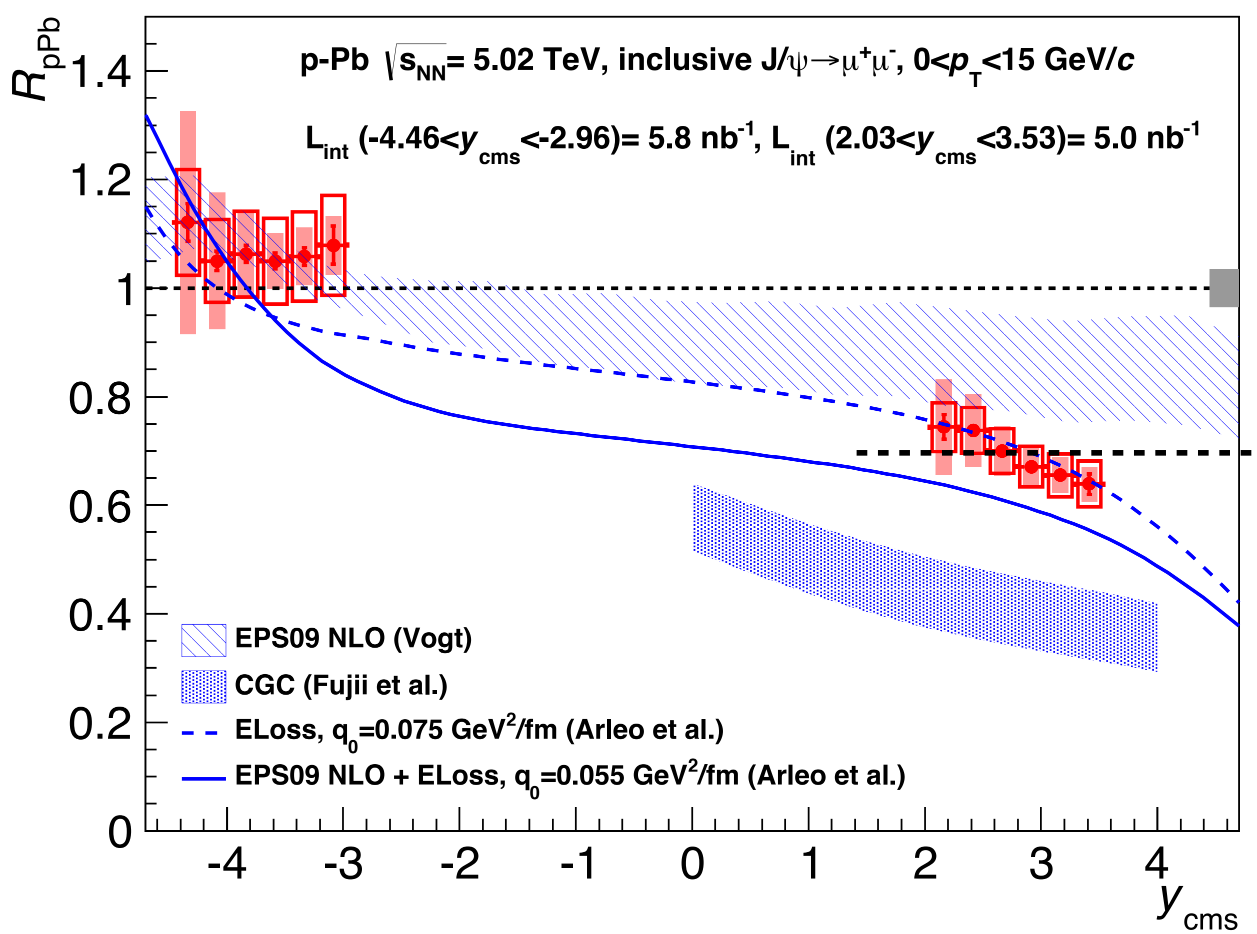
J/ψ in pp vs N_{ch}

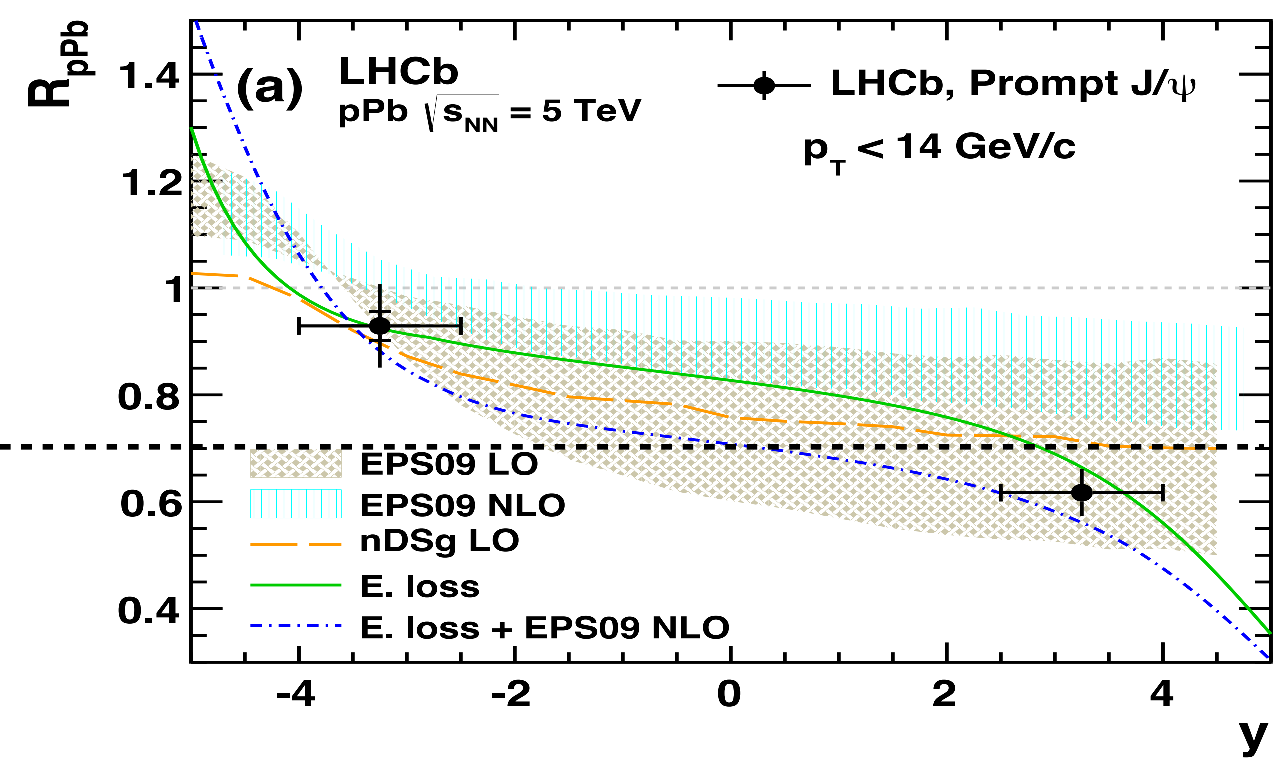


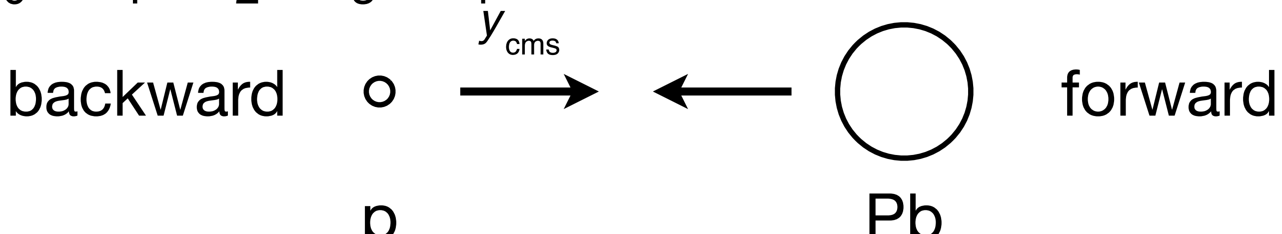
- Faster than linear rise of self-normalised J/ψ yield with multiplicity
  - was seen already at the LHC (open and closed HF)
  - now also at RHIC
- Sign of fundamental process, such as MPI

J/ψ in p-Pb $\sqrt{s_{NN}}$ = 5 TeV

- R_{pA} at forward and backward rapidity
  - no pp data at 5 TeV at the time, reference from interpolation (updates soon?)
  - ALICE and LHCb roughly agree
  - strong suppression at forward
    - agreement with shadowing only, but also with models that include parton energy loss
  - no strong suppression/enhancement in the backward region

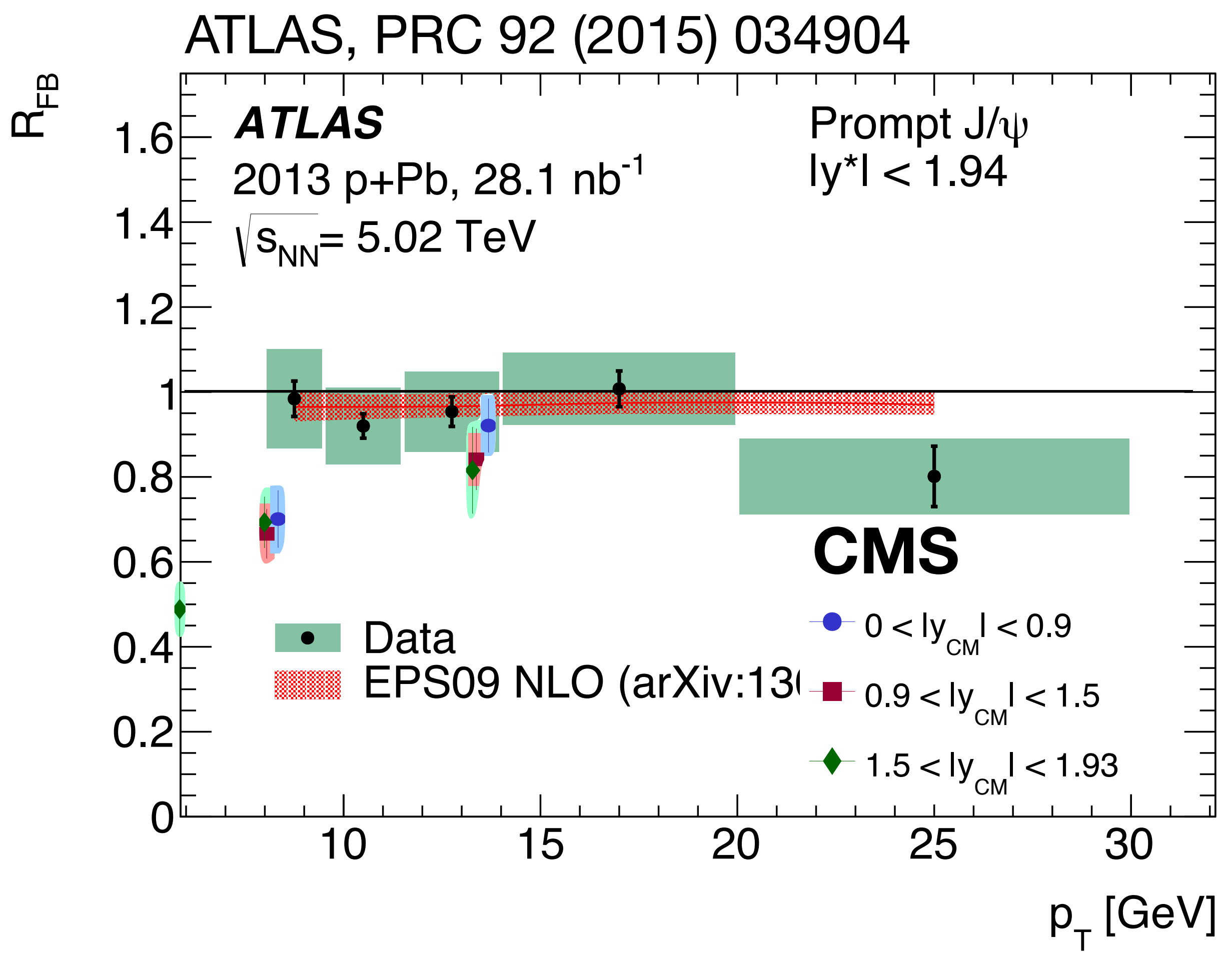


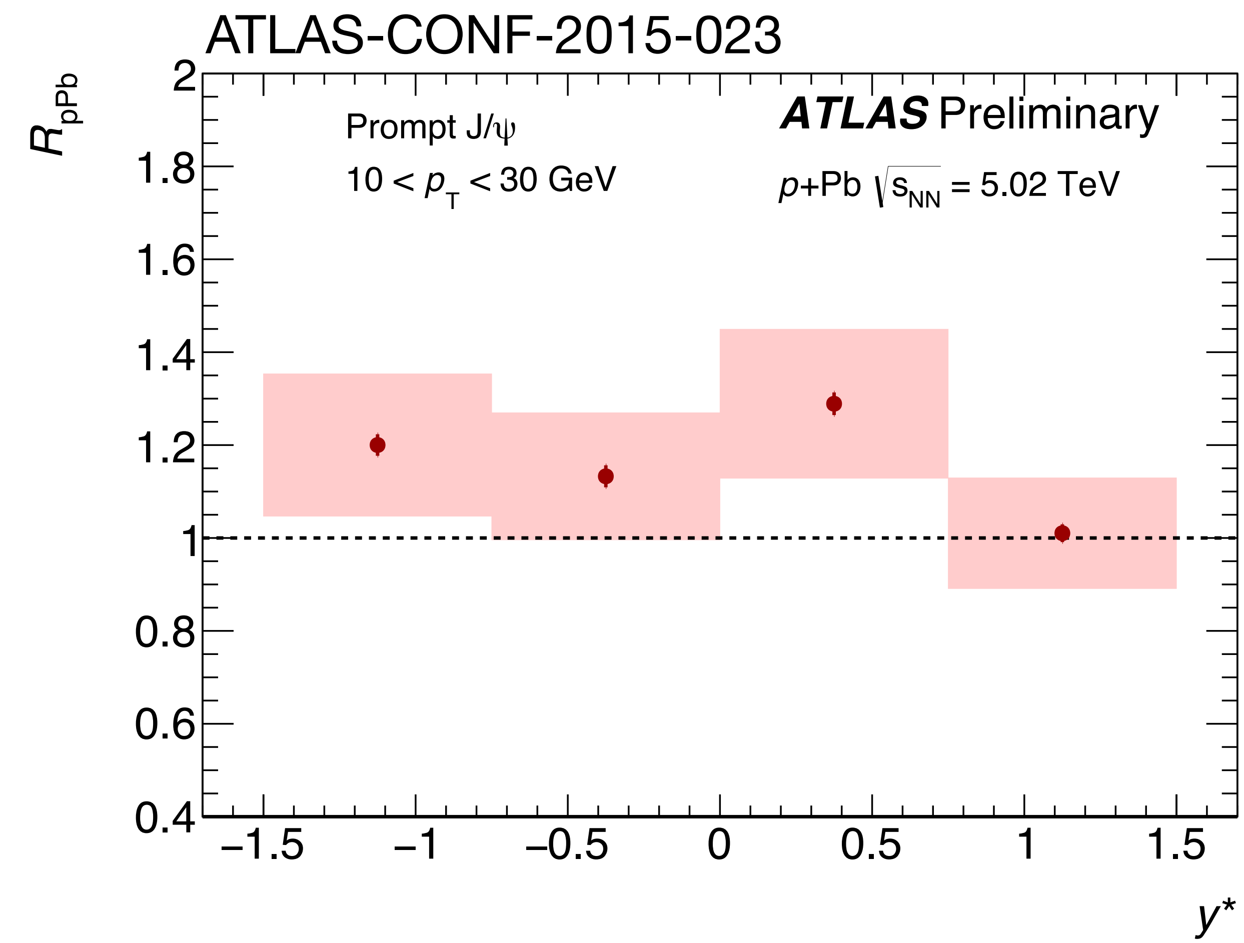




ALICE, JHEP 02 (2014) 073
LHCb, JHEP 02 (2014) 072

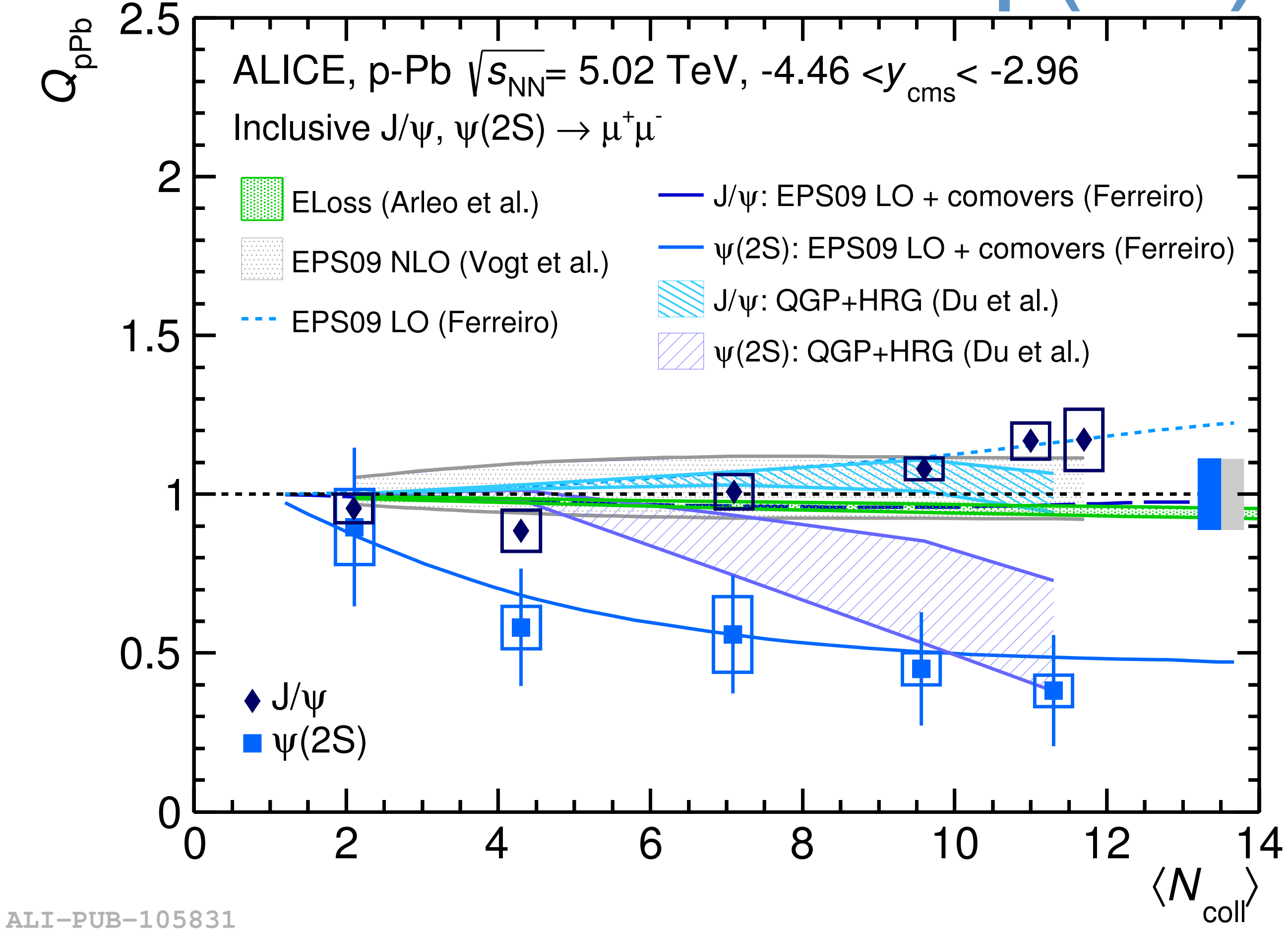
High-p_T J/ψ in p-Pb

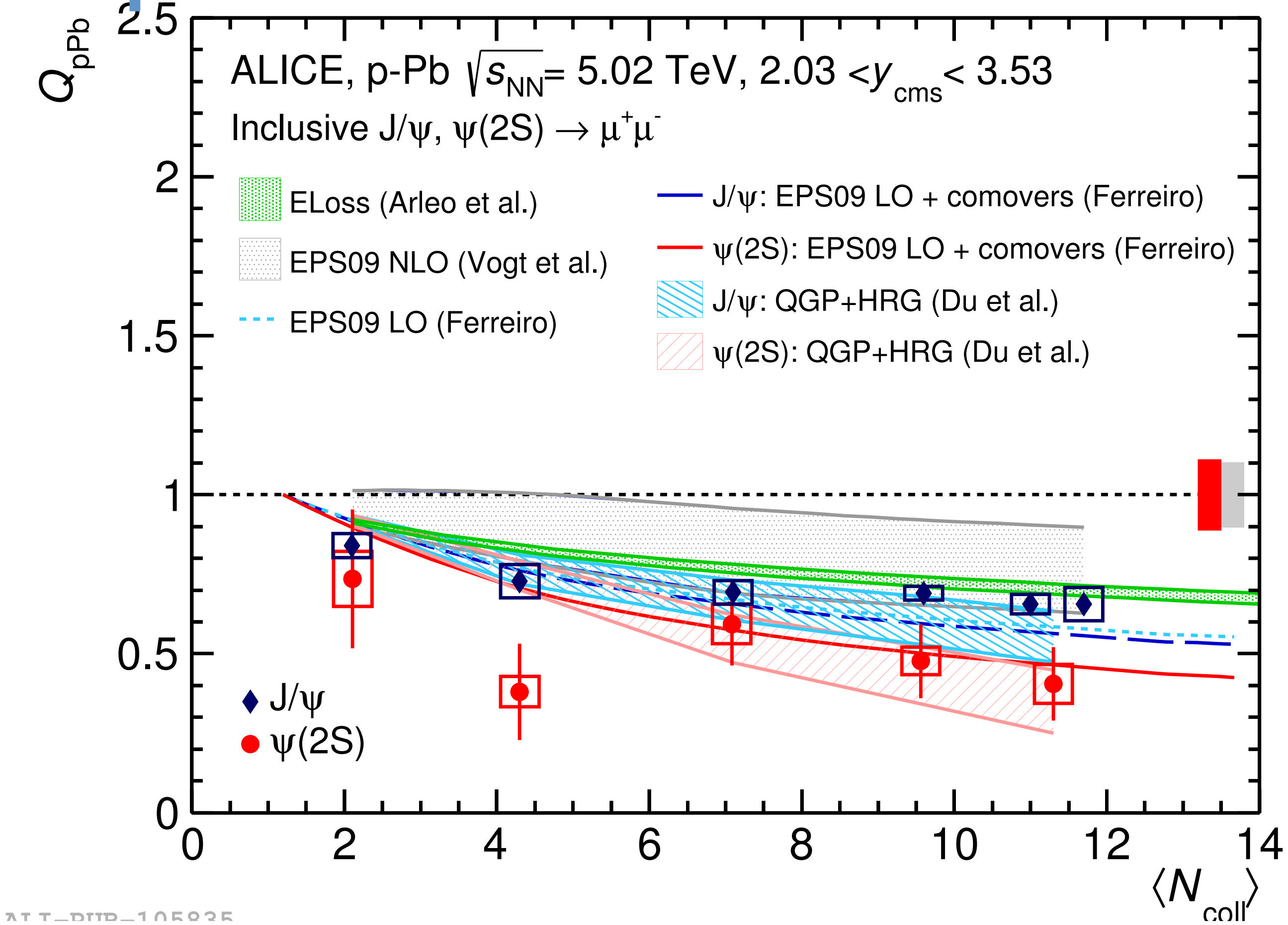




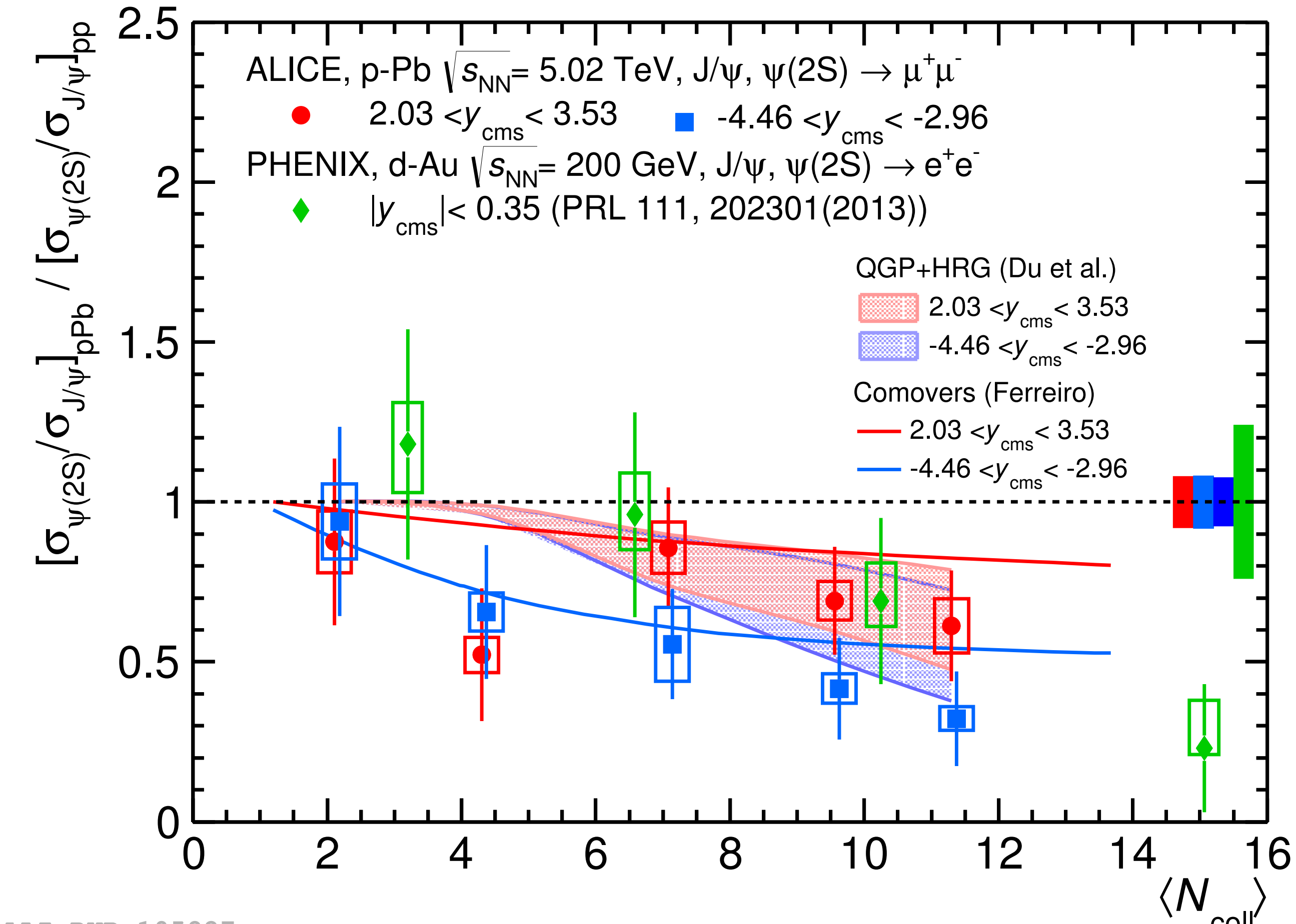
- No significant CNM effects at high p_T (none expected)
  - discrepancy between ATLAS and CMS at intermediate p_T (<10 GeV)?
- R_{pPb} based on interpolation with large uncertainties
  - wait for update based on pp measurement at proper energy

ψ(2S) in p-Pb





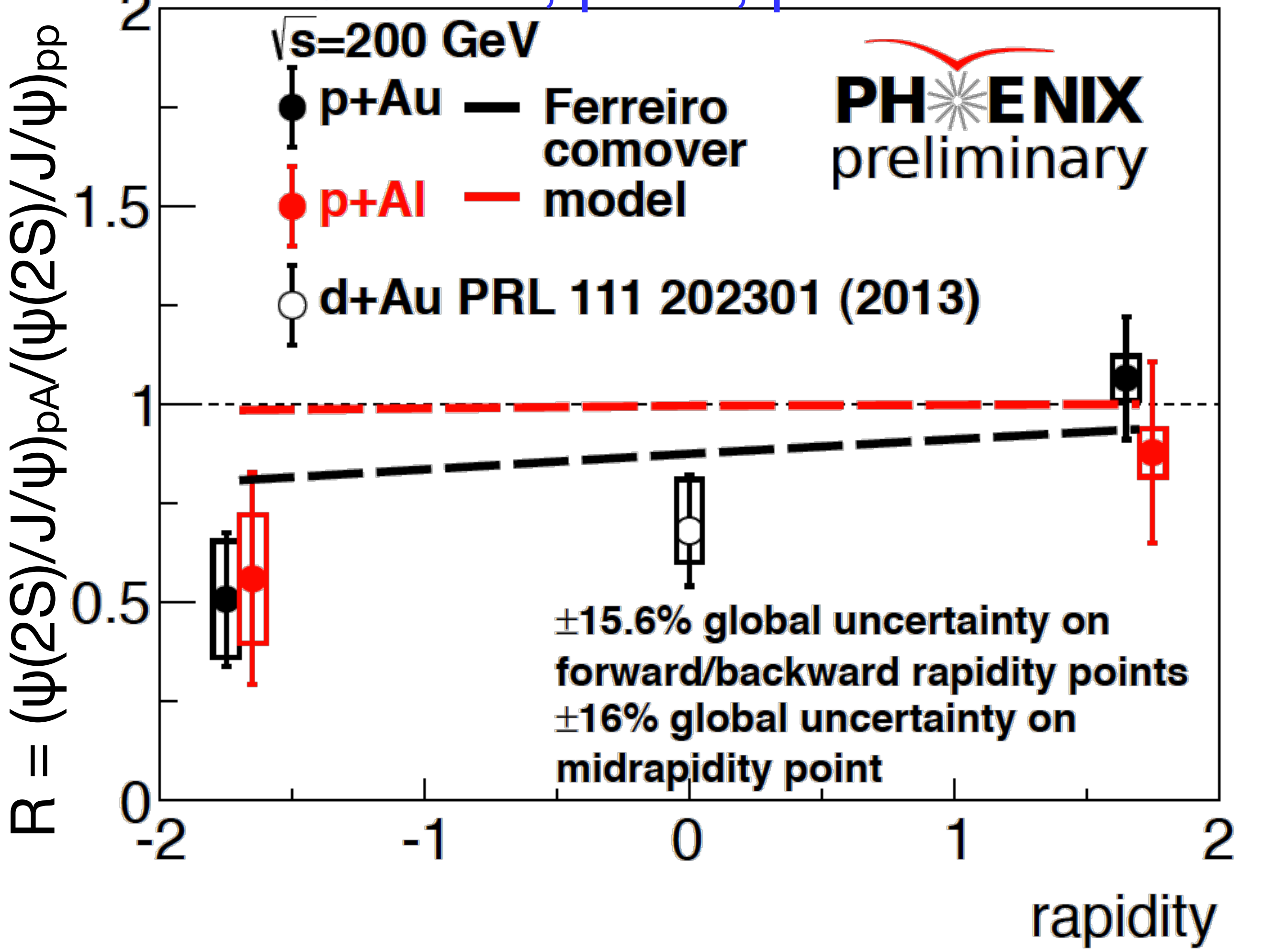
- **Backward:** suppression of ψ(2S), none for J/ψ
  - J/ψ maybe enhanced in central p-Pb
- **Forward:** suppression of ψ(2S) and J/ψ almost the same
- Comover interaction model qualitatively describes patterns



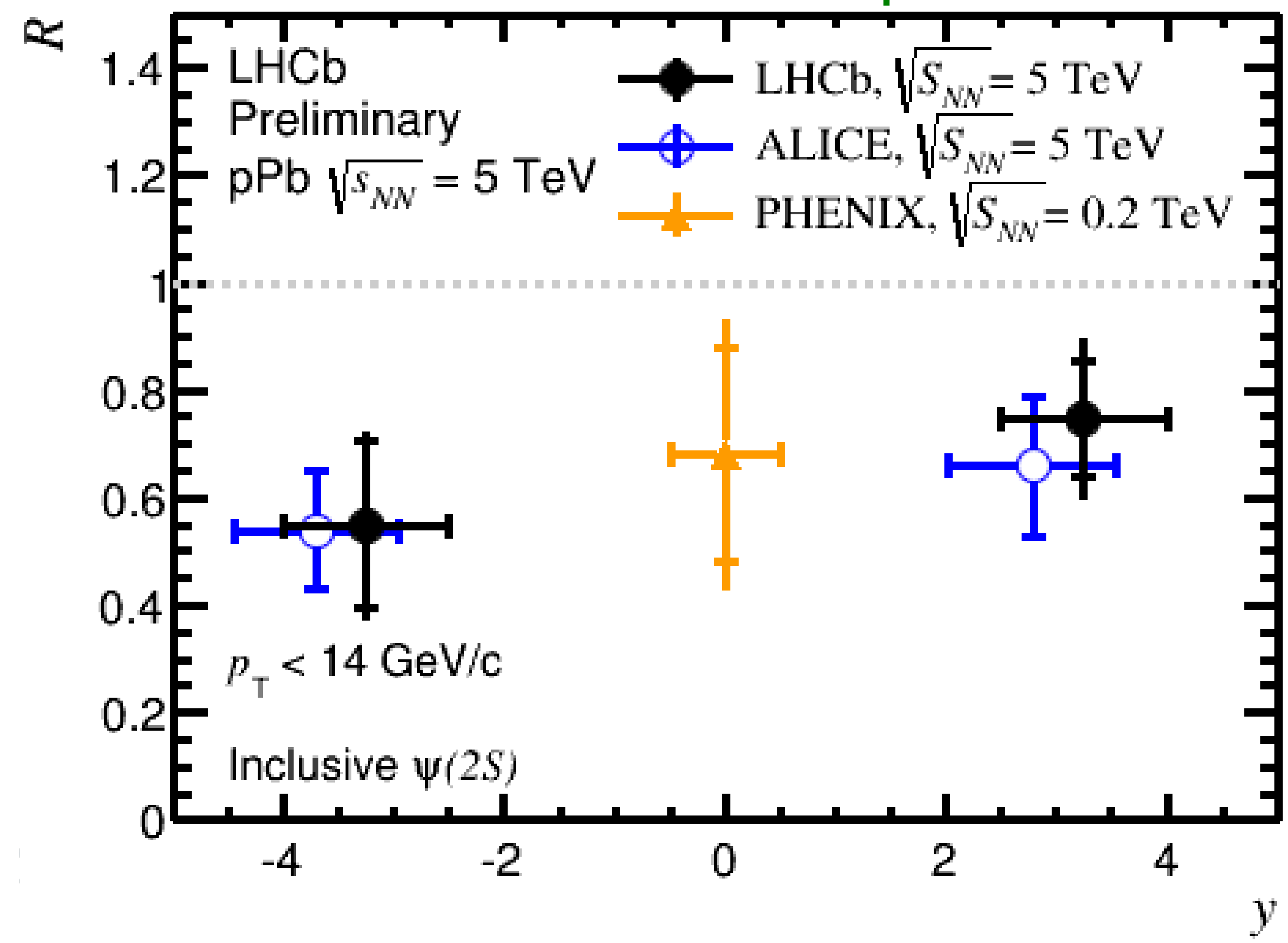
ALICE, arXiv:1603.02816
also see: LHCb, JHEP 03 (2016) 133

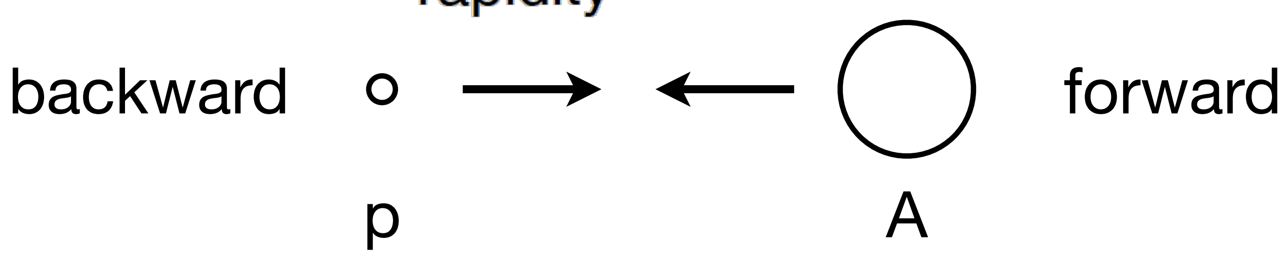
ψ(2S) in p-A from RHIC to the LHC

RHIC: d+Au, p+Au, p+Al



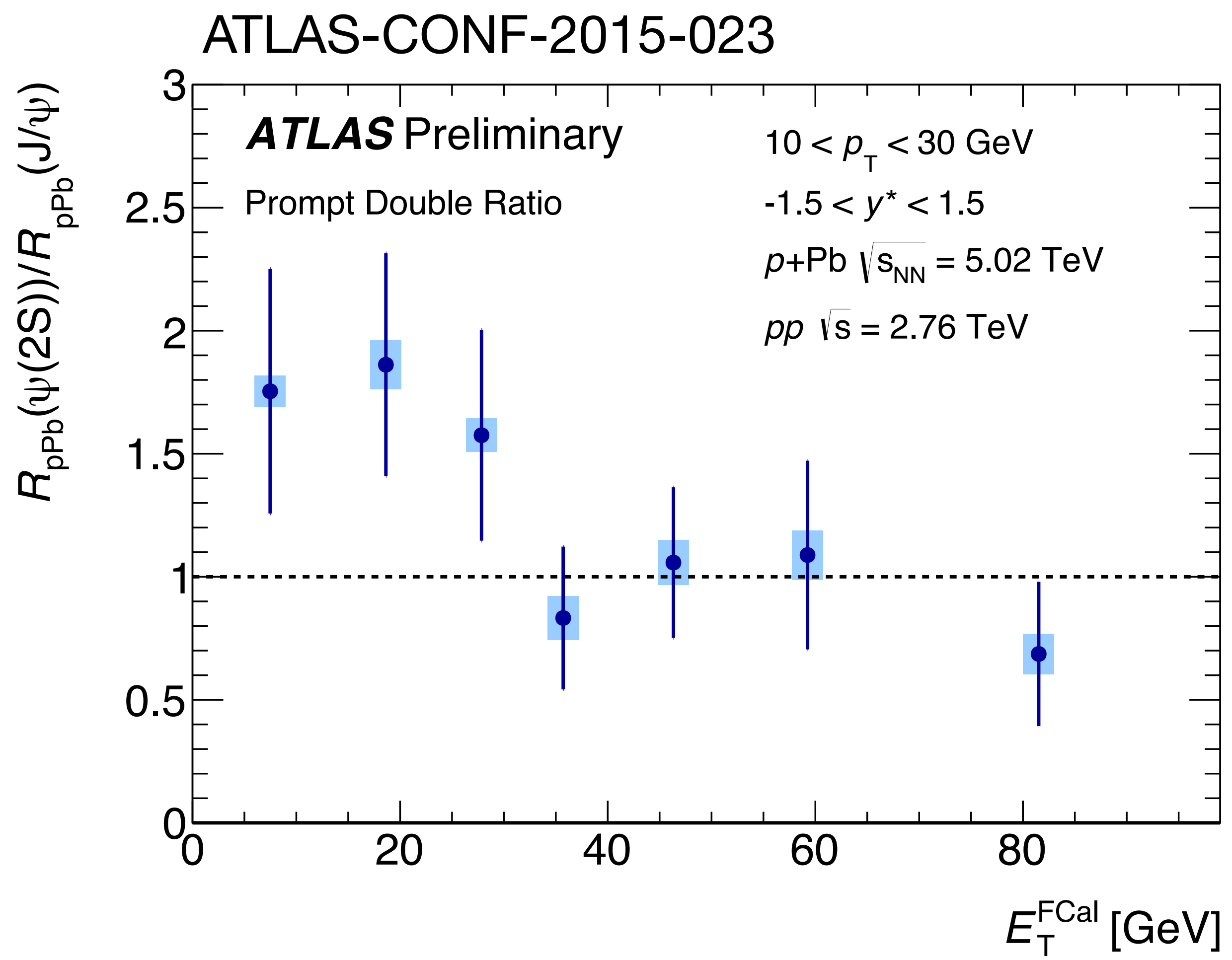
RHIC: d+Au and LHC: p+Pb





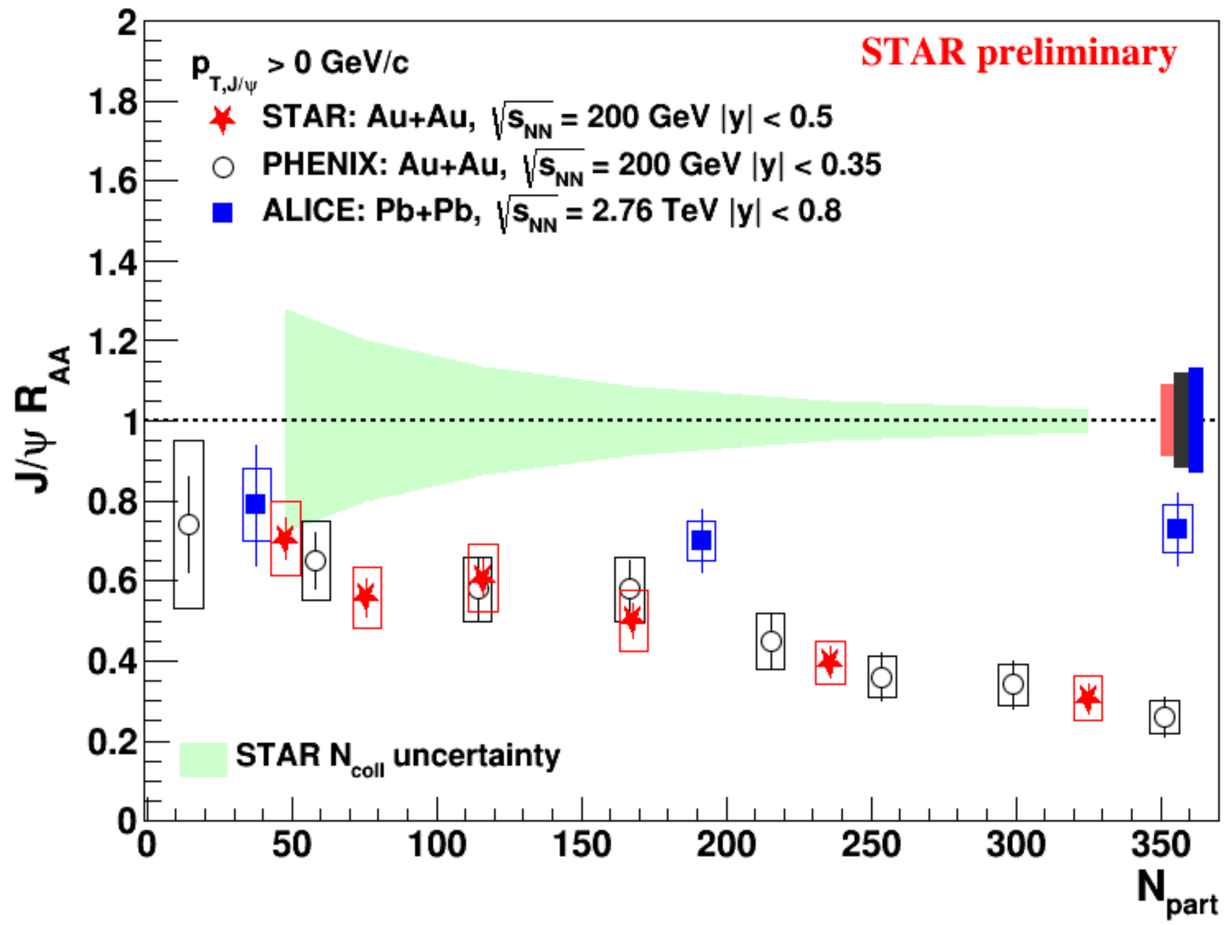
- Relative ψ(2S) suppression observed in p-A from 200 GeV to 5 TeV
  - A = Al, Au, Pb
  - hints for stronger suppression at backward rapidity, comover dissociation?

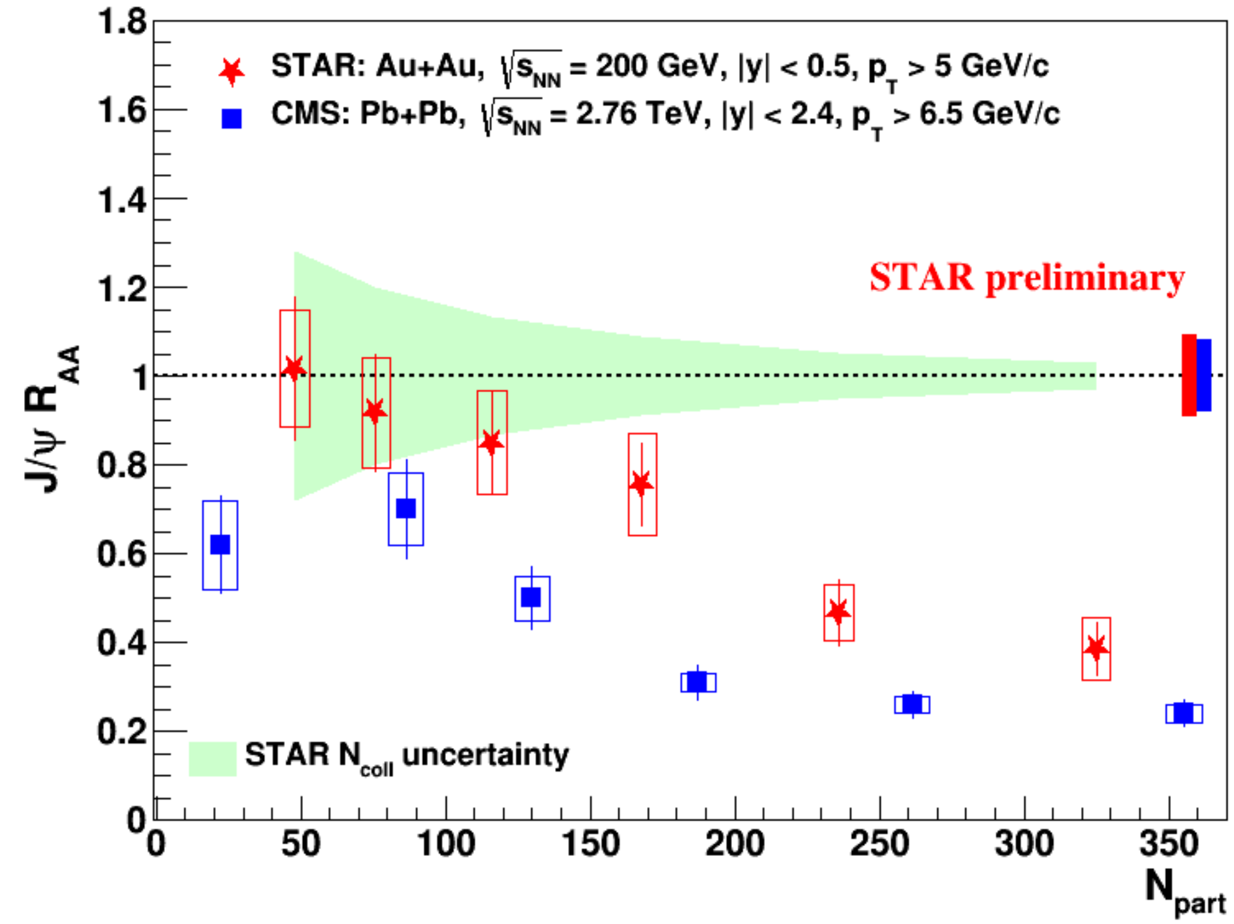
High-p_T ψ(2S) in p-Pb



- At high p_T and midrapidity: hint of opposite behavior of ψ(2S) to J/ψ double ratio in peripheral p-Pb collisions
  - disappears in central collisions

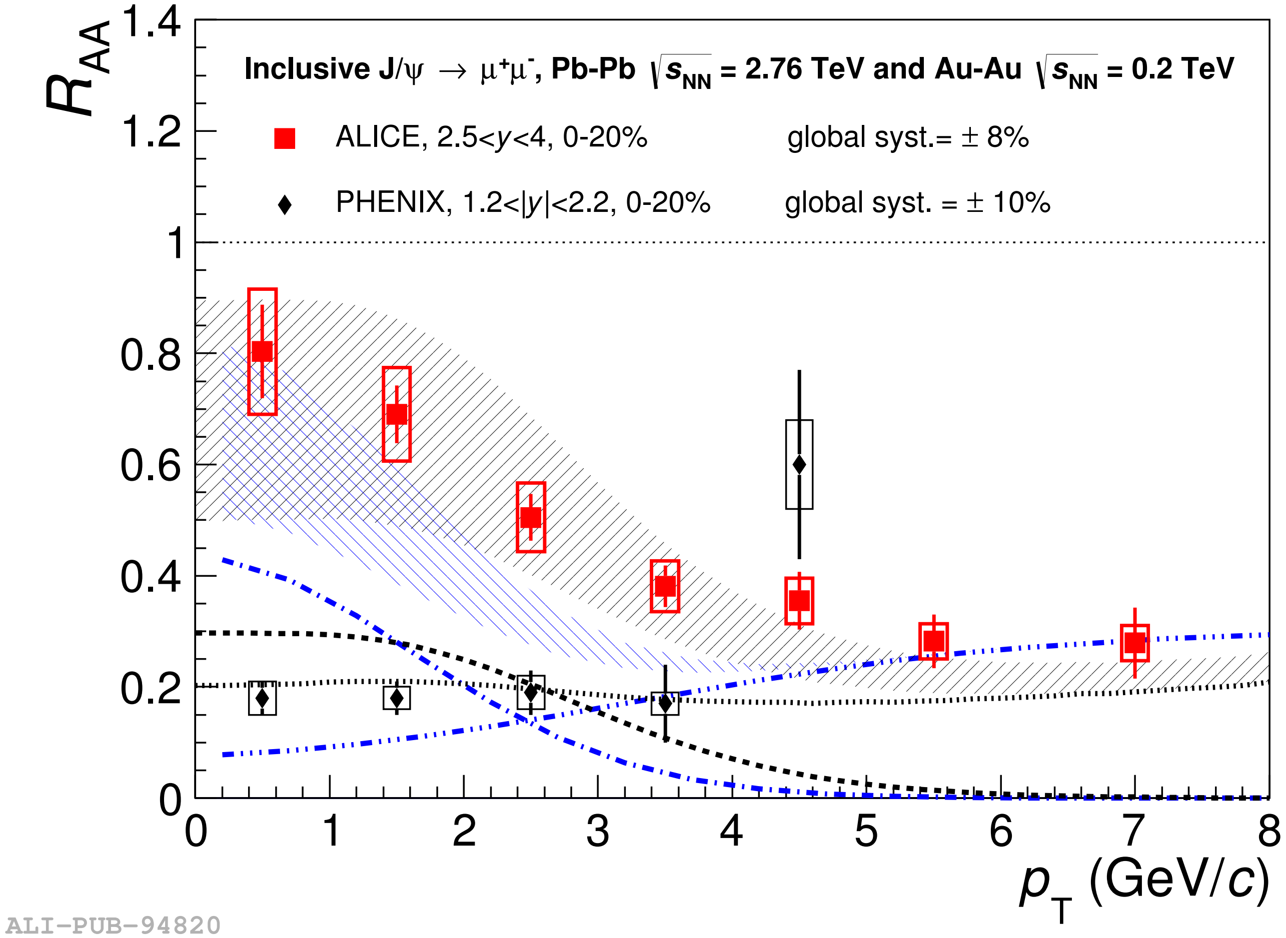
J/ψ in A-A from RHIC to the LHC

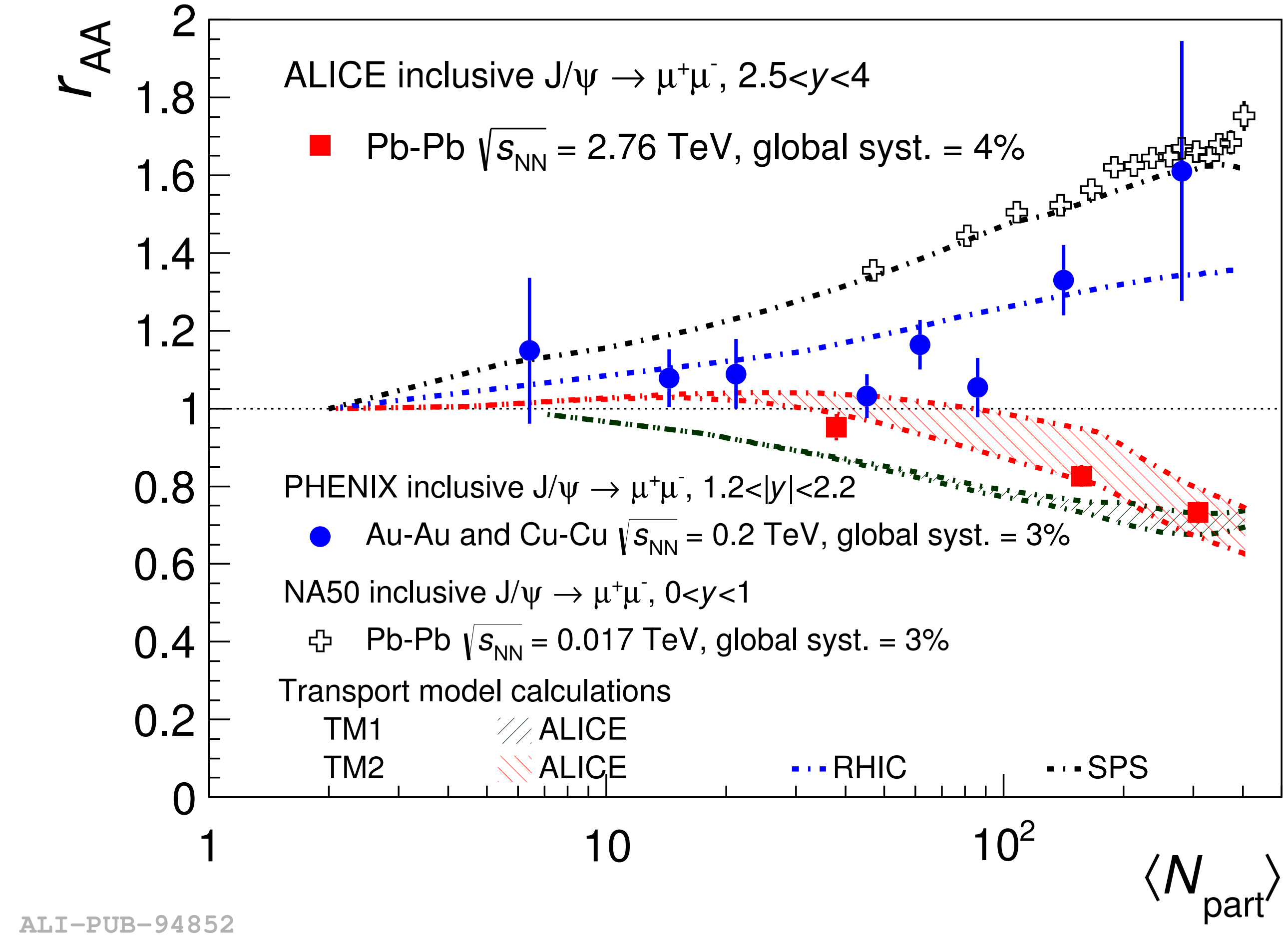




- STAR: new, independent measurement at |y|<0.5 via muon channel
- Confirms existing picture:
    - Low-p_T J/ψ at the LHC are less suppressed than at RHIC, extra source
    - High-p_T J/ψ at the LHC are more suppressed than at RHIC, more dissociation

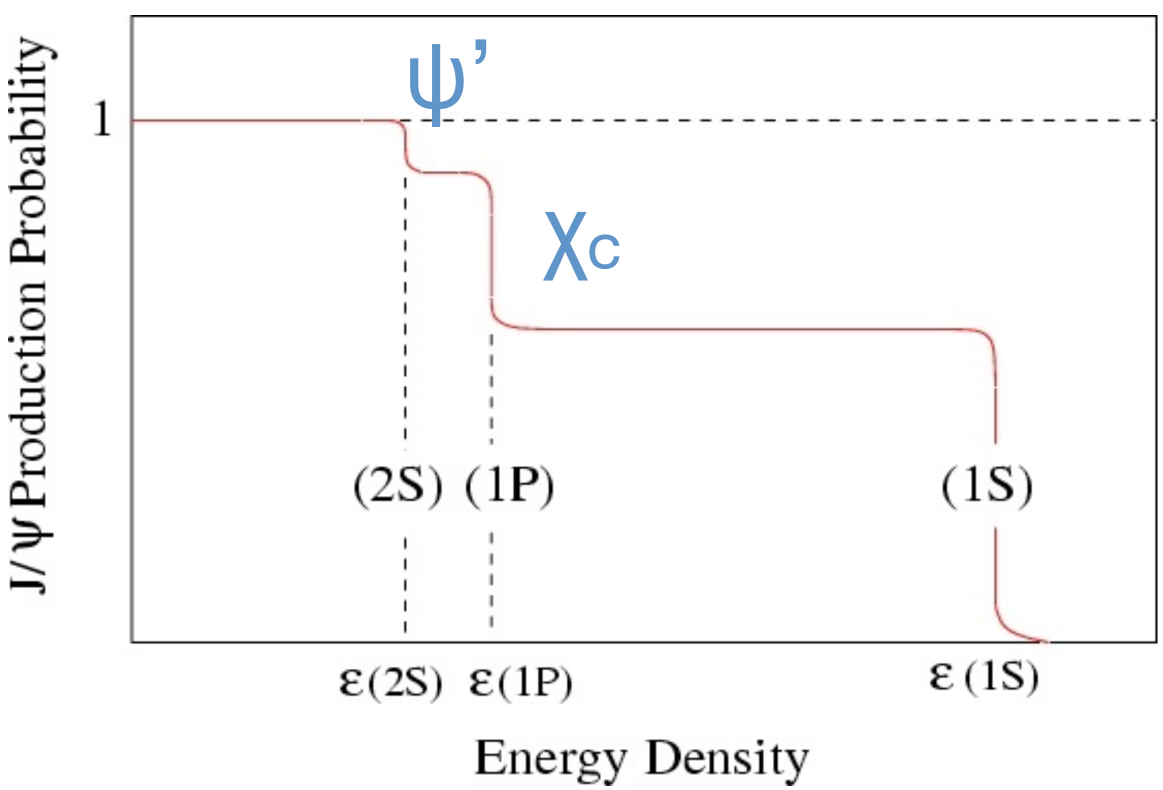
J/ψ in A-A from RHIC to the LHC



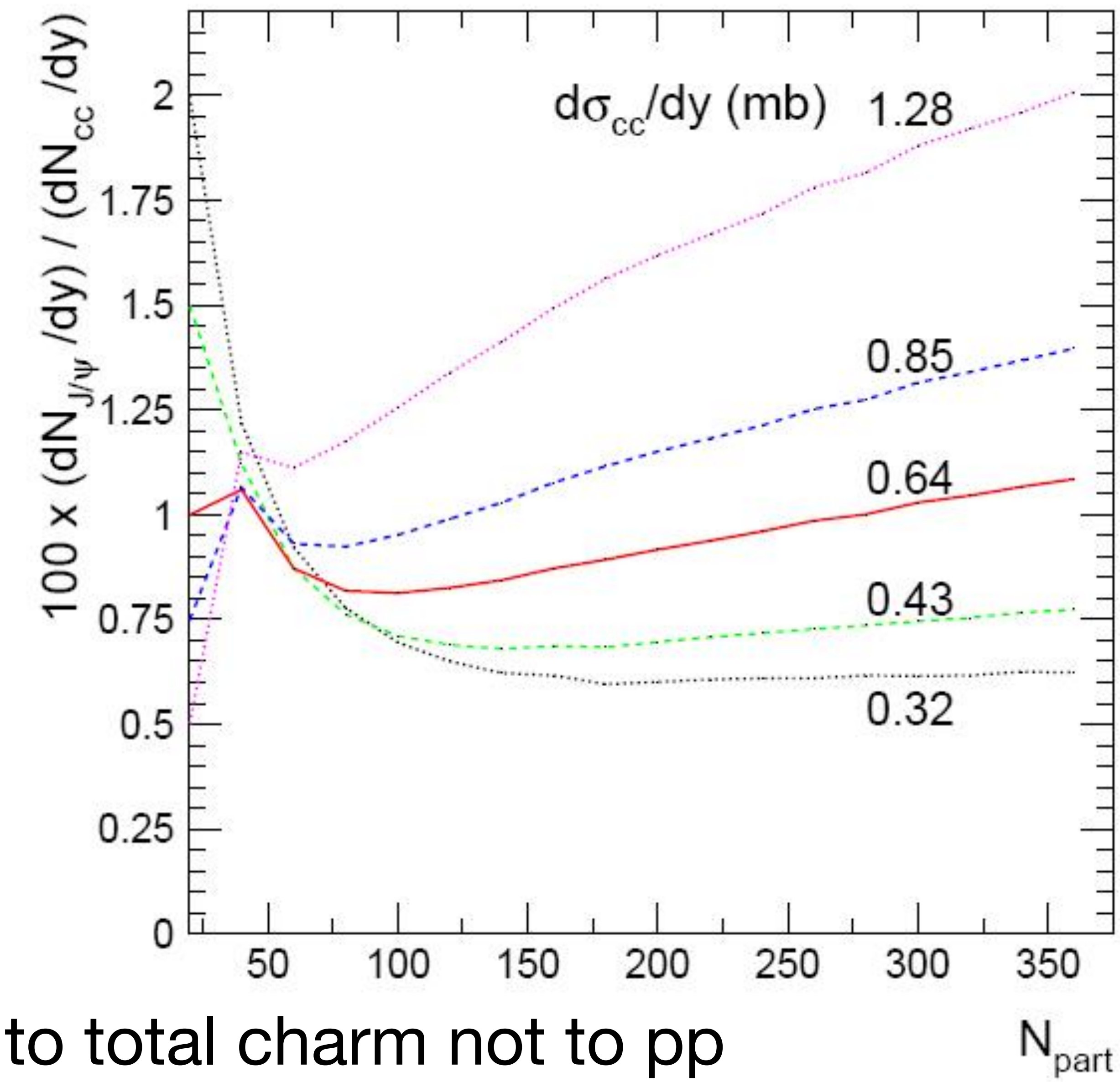


- First time that J/ψ are less suppressed at low p_T than high p_T
- Also visible in $r_{AA} = \langle p_T \rangle_{AA} / \langle p_T \rangle_{pp}$
- Models including regeneration component describe data well

Sequential Melting vs. Regeneration



A. Andronic et al., PLB 652 (2007) 259

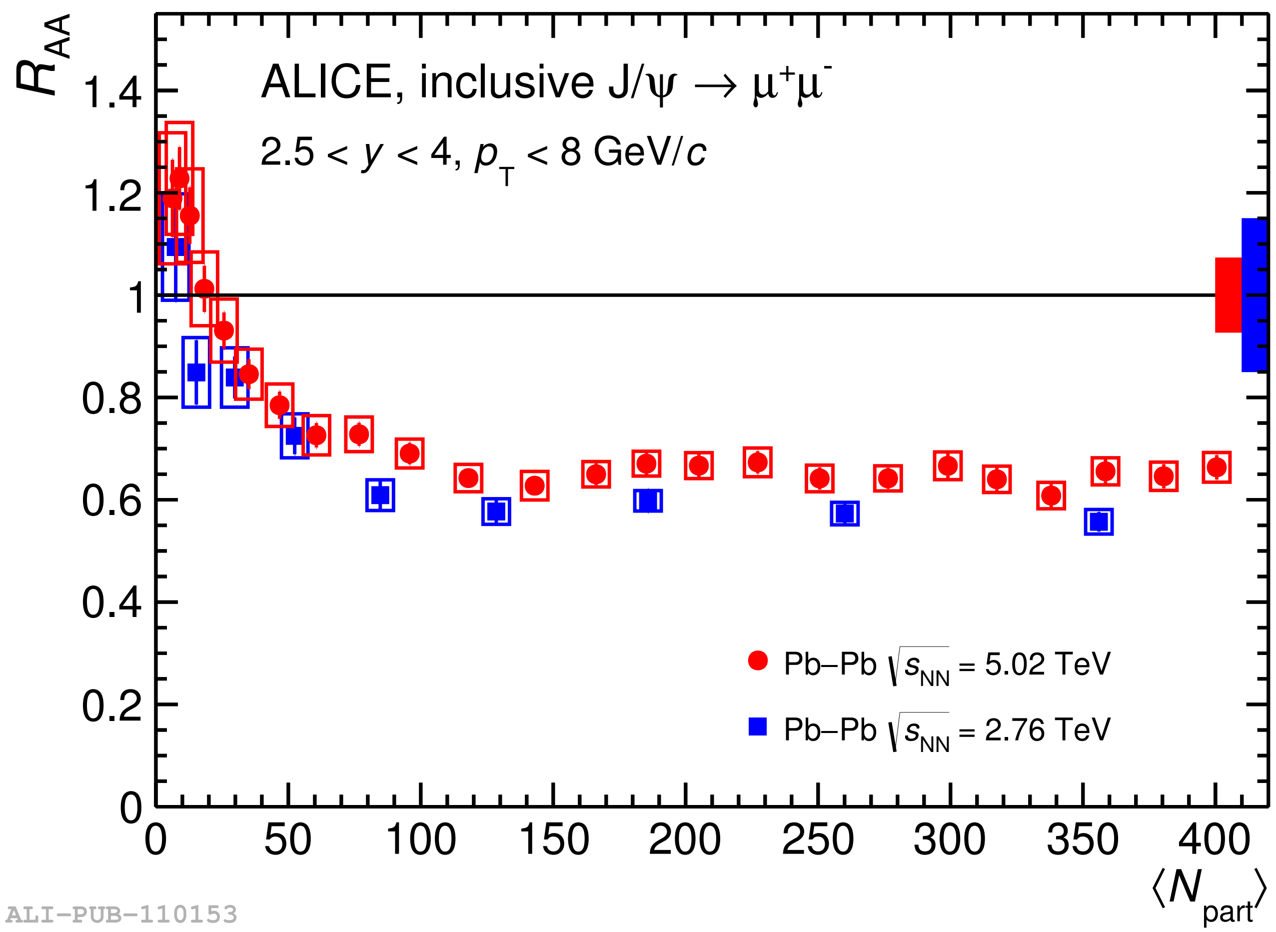


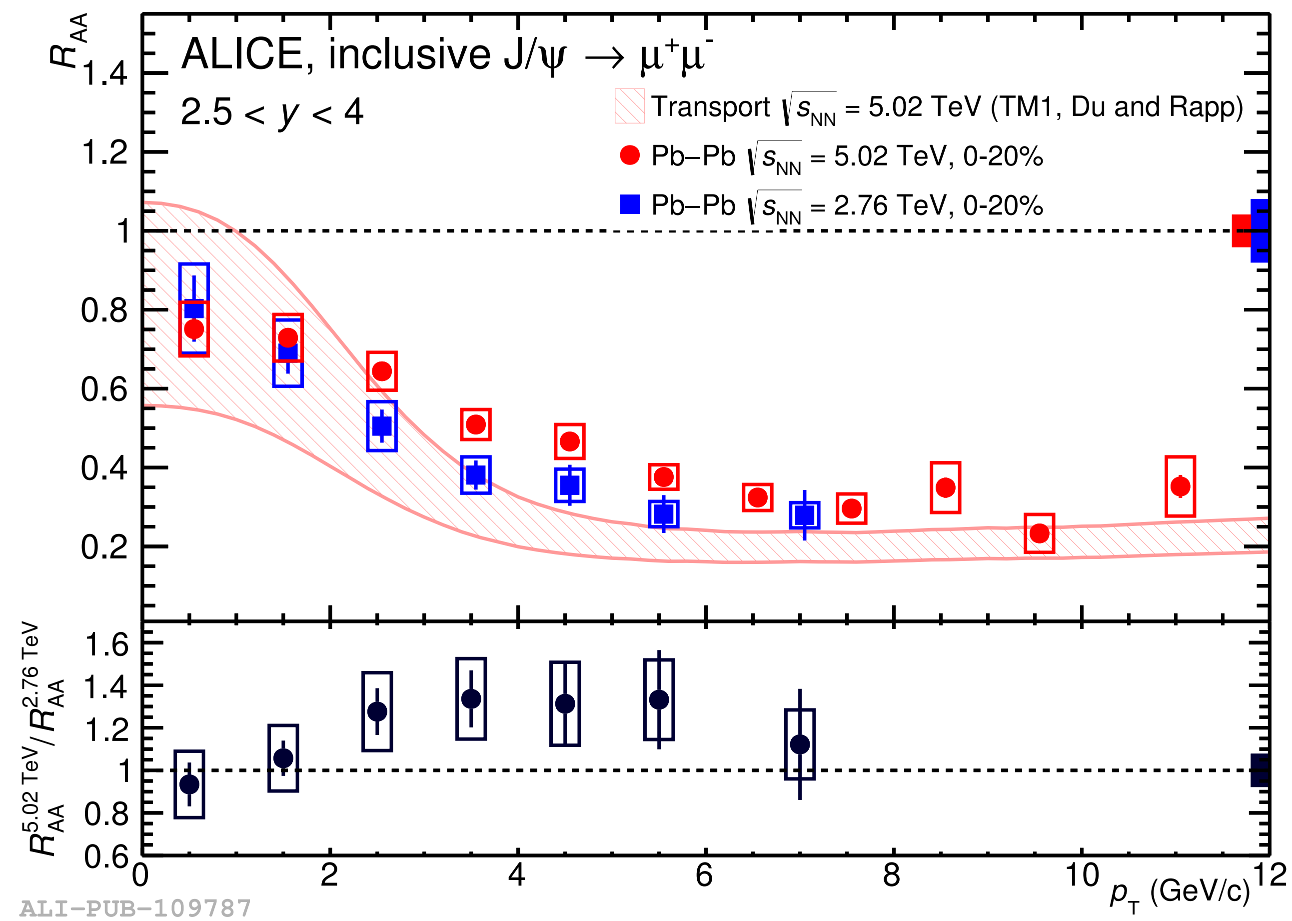
- Always change of J/ψ yield relative to total charm not to pp
- Sequential Melting: naively expect plateaus and steps as $\sqrt{s_{NN}}$ increases
- Regeneration: at high enough $\sqrt{s_{NN}}$, R_{AA} should increase with centrality
  - from 2.76 TeV to 5 TeV, charm cross section expected to increase by factor 1.5
  - really need a measurement of the charm cross section in AA

J/ψ in Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

R_{AA}: assumes binary scaling of charm cross section

ALICE, CERN-EP-2016-162
(submitted for publication)





- Centrality independent increase from 2.76 TeV to 5.02 TeV (<1σ)
  - present also in peripheral collision: LHCb?
- No change at low p_T (phase space? dN/dp_T peaks around 1–2 GeV)
- Increase for p_T>2 GeV, recombination + radial flow effects?
- Extends to p_T~6 GeV: ATLAS, CMS…?
- Do we need an FCC to see/rule out an increase of R_{AA} (or y=0 at LHC)?

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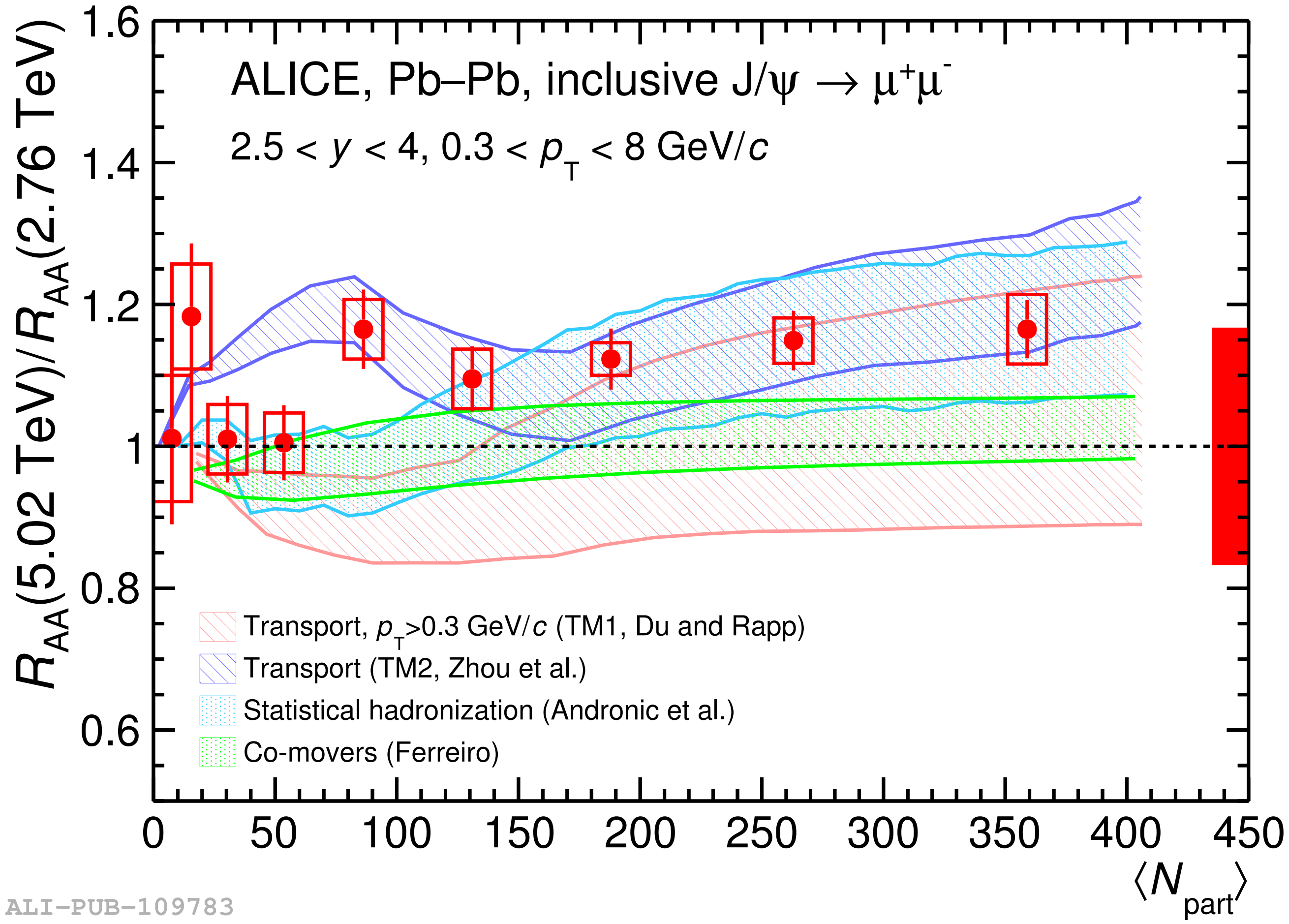

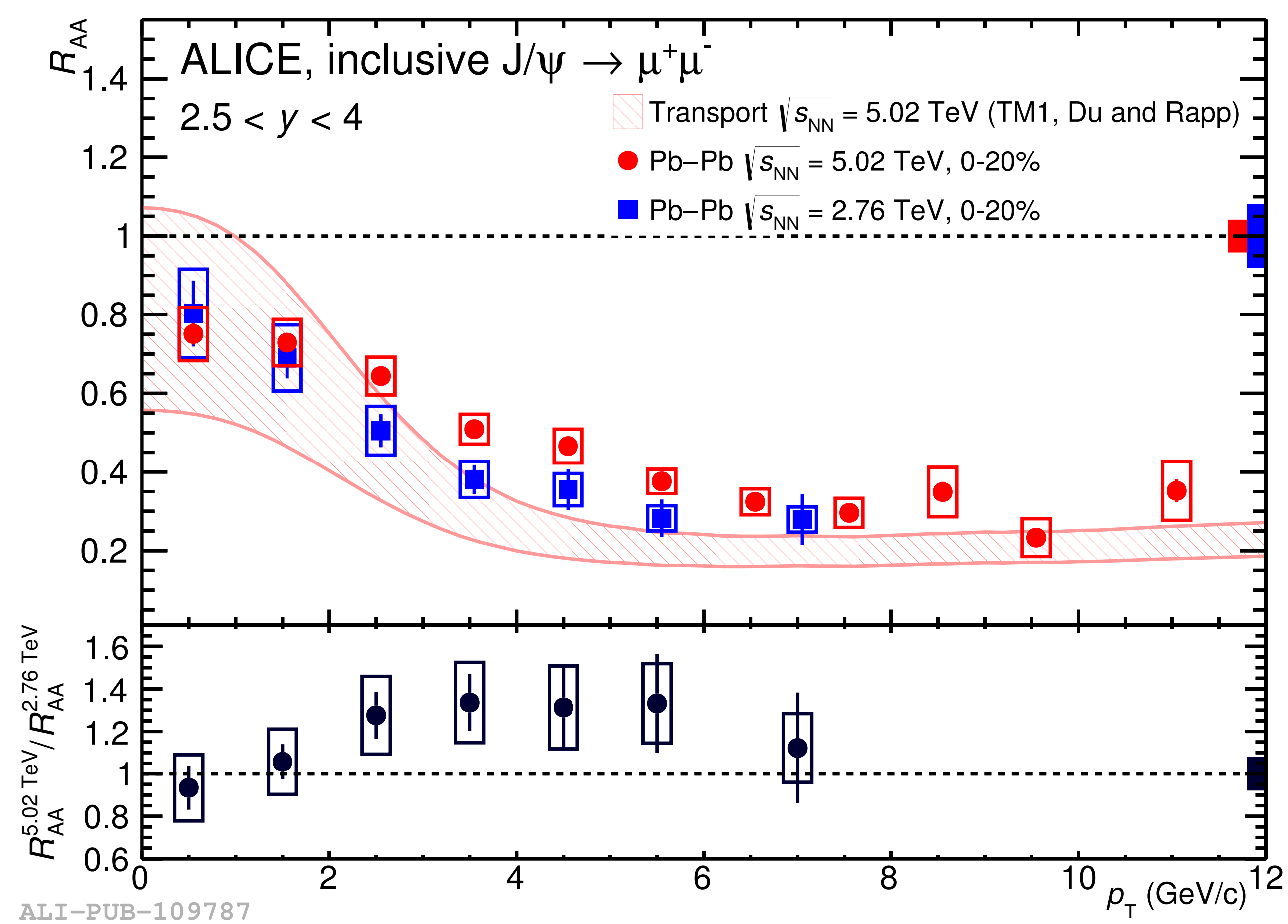

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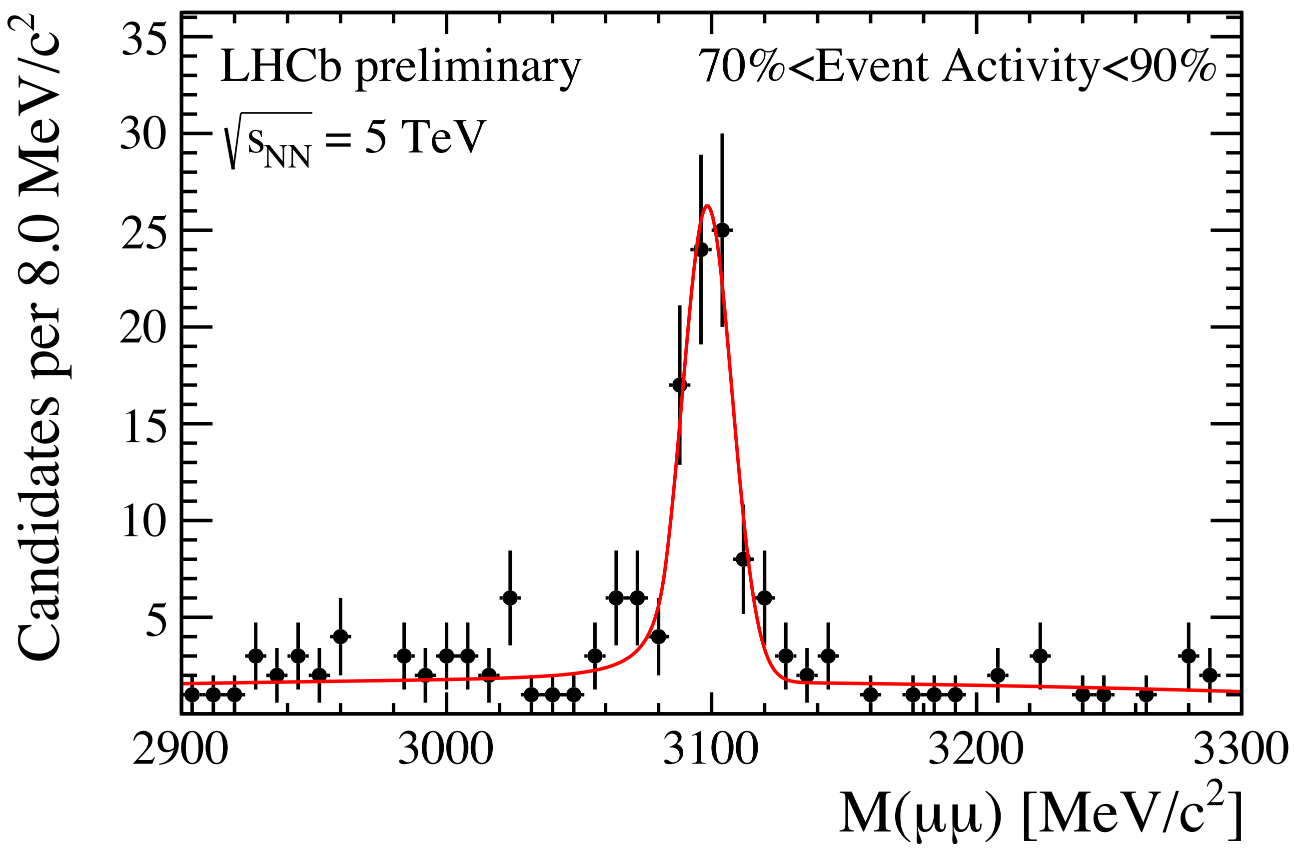
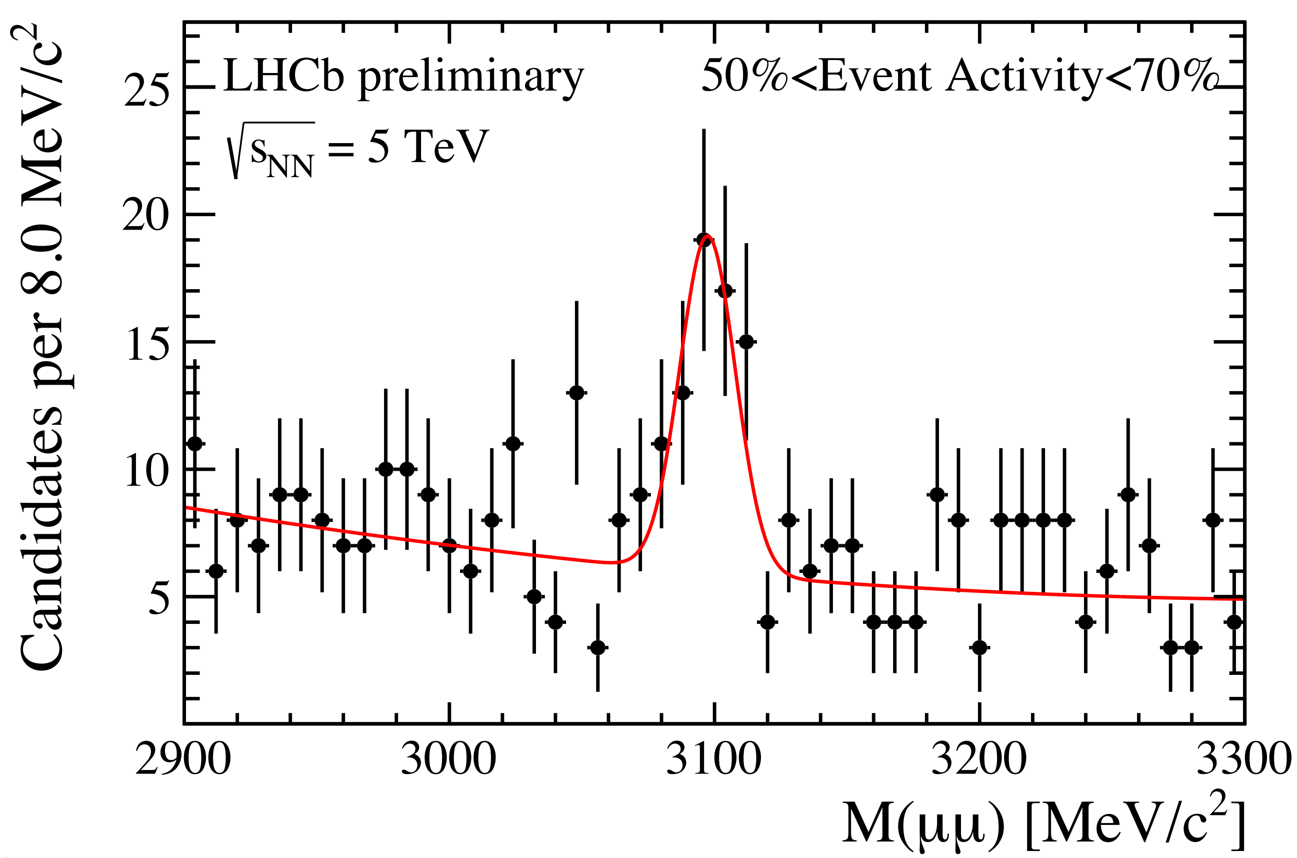
Low-p_T J/ψ in Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- LHCb measured inclusive J/ψ with p_T>0 in two centrality bins:
  - 70–90%
  - 50–70%

- R_{CP} = ?
  - uncharted territory for the VELO
  - need to understand (strong) centrality dependence of efficiency

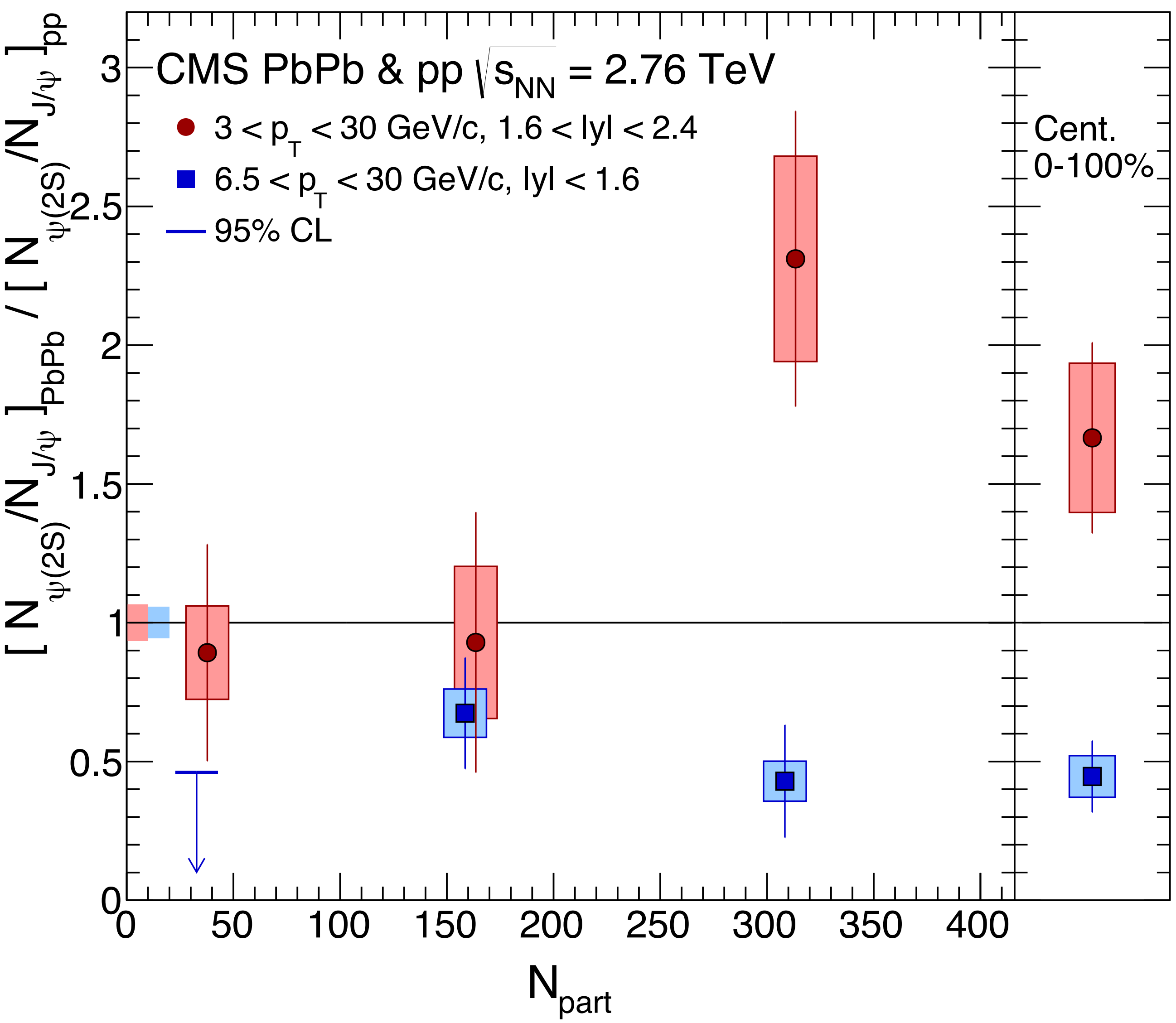




LHCb,
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

ψ(2S) in Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

- Puzzling results from CMS
  - high p_T and midrapidity: as expected
  - more forward rapidity and p_T>3 GeV: hint of relative enhancement
  - Data not precise enough to conclude yet
- ALICE data not precise enough either to confirm or rule out
- What will happen at 5 TeV?
- Regeneration in hadronic phase would favor ψ(2S):
  - PBM and K. Redlich, EPJ C16 (2000) 519
  - Xiaojian Du and R. Rapp, NPA 943 (2015) 147



CMS, PRL 113 (2014) 262301
ALICE, arXiv:1506.08804

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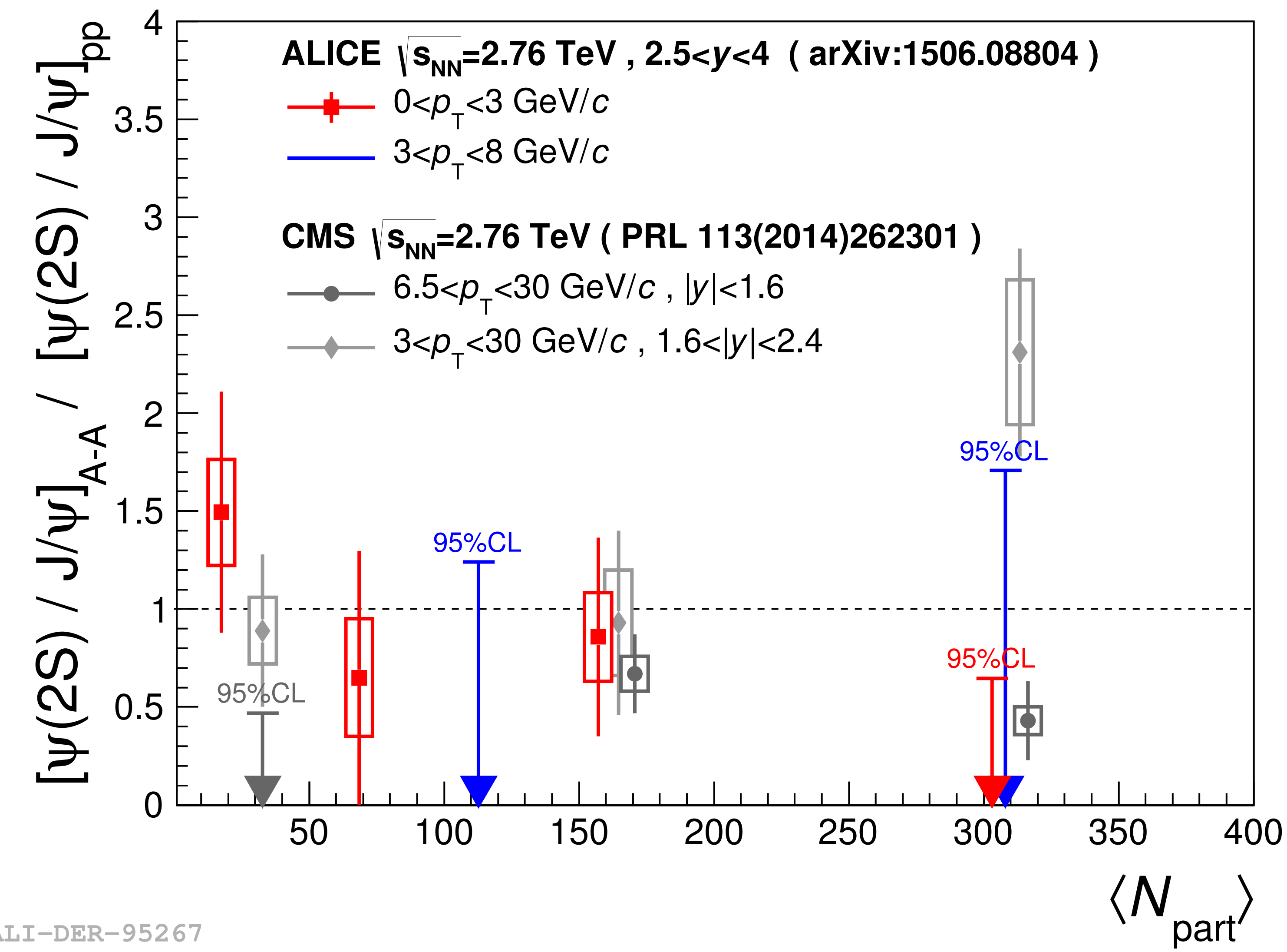

CMS, PRL 113 (2014) 262301
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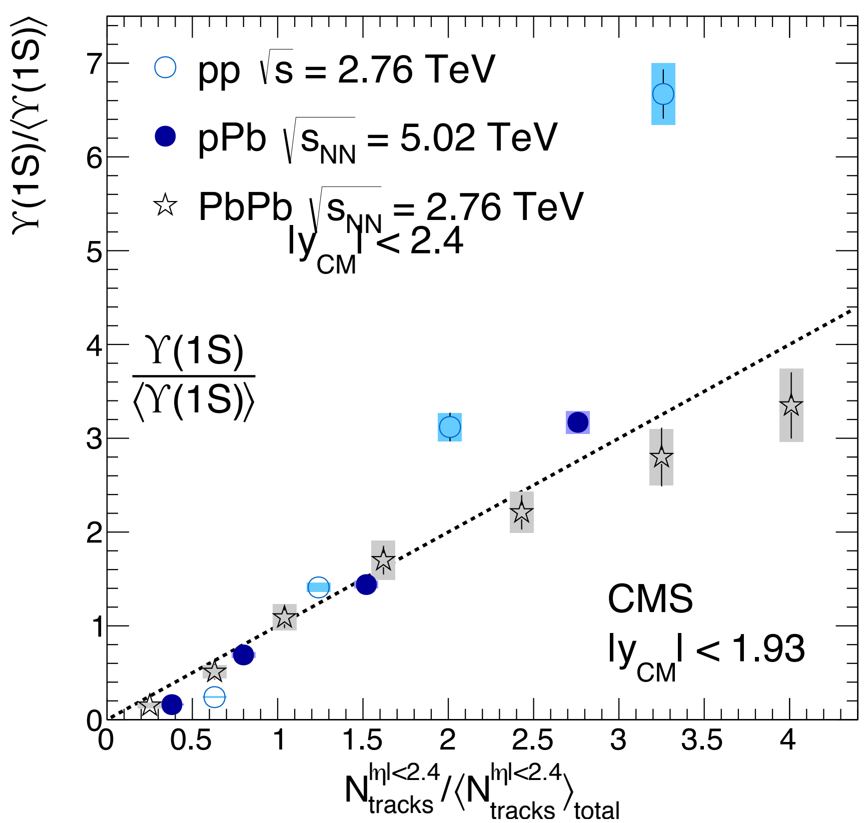
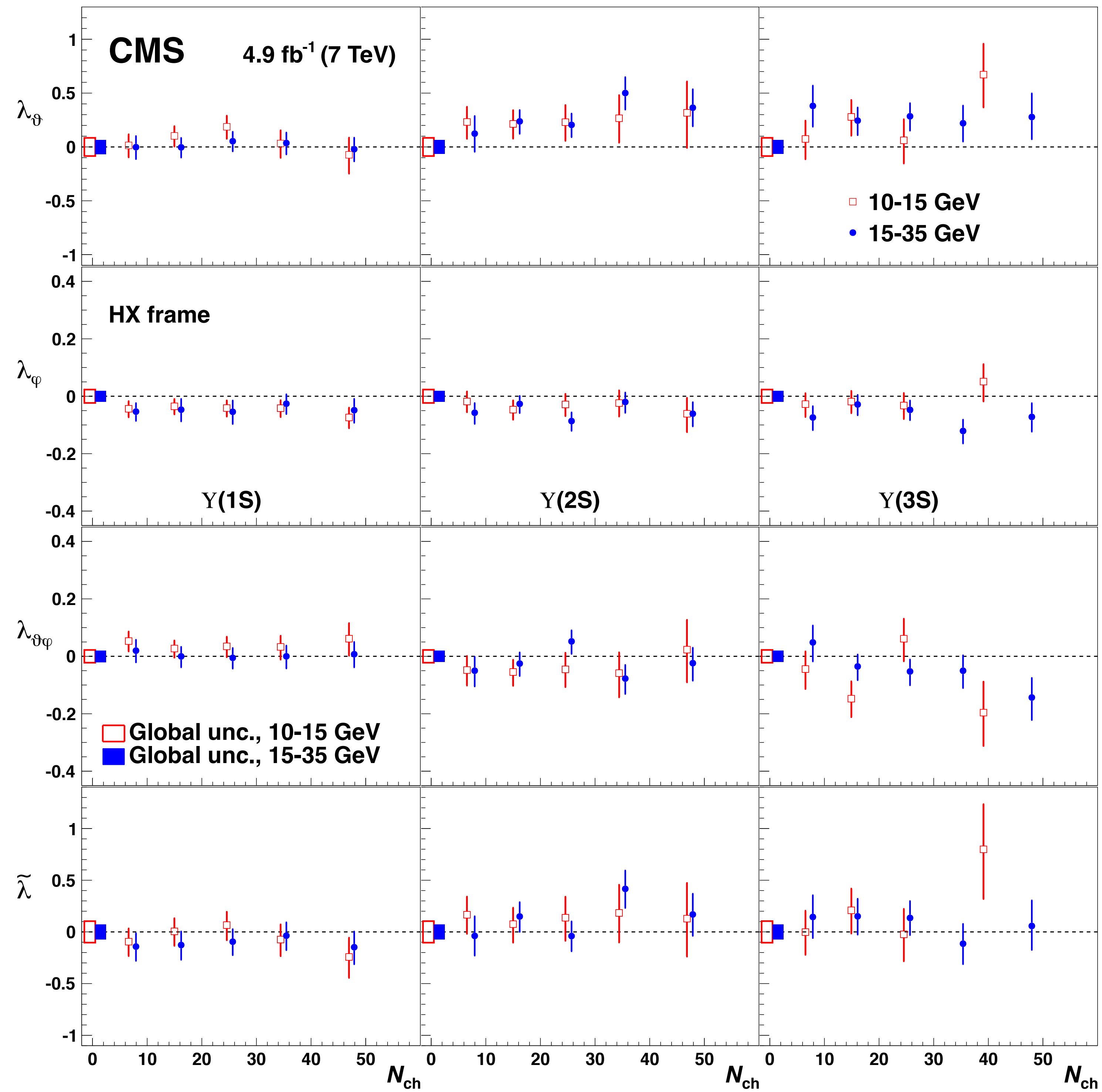
Bottomonia

Υ yield & polarization vs multiplicity

- No significant change of Υ polarization with multiplicity
  - no change of production mechanism at high p_T
  - but multiplicity dependence was measured at low p_T

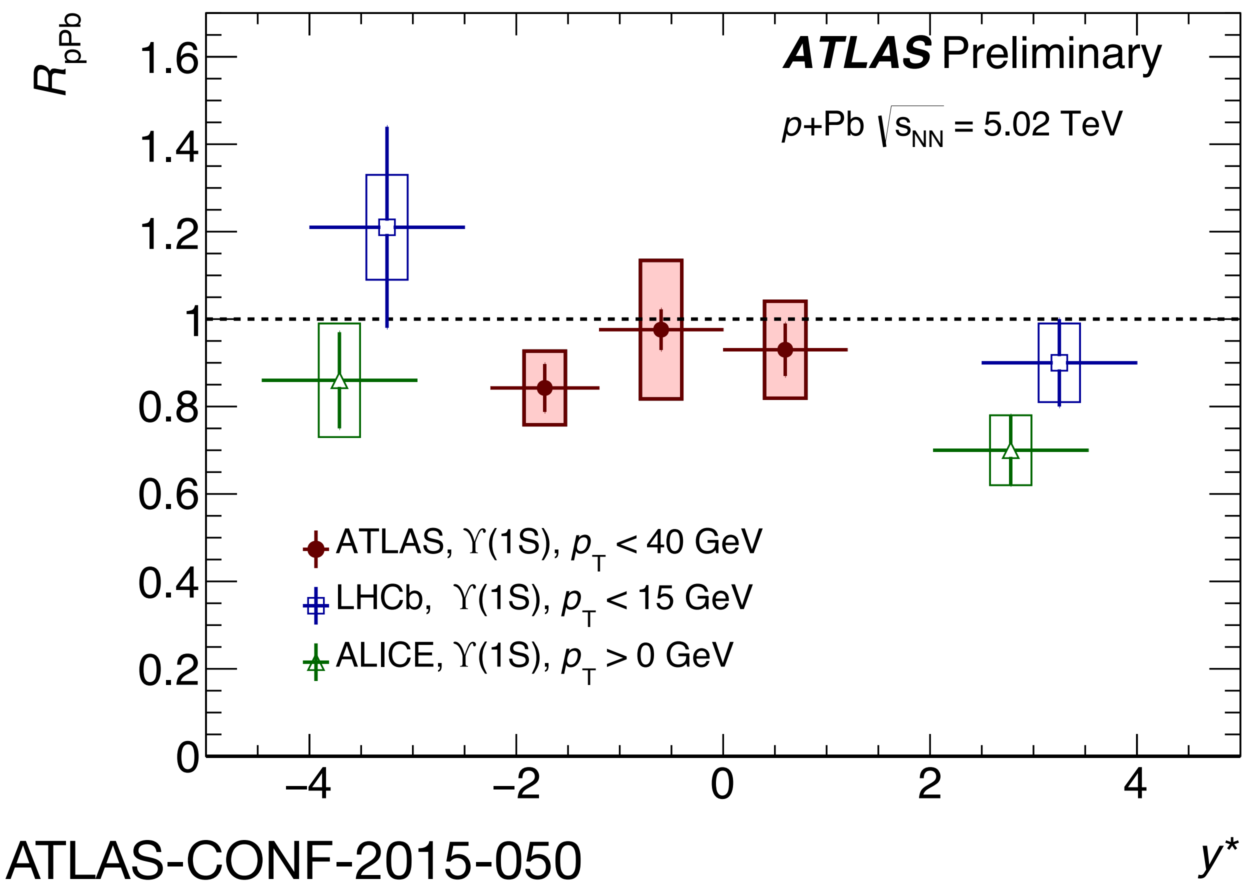


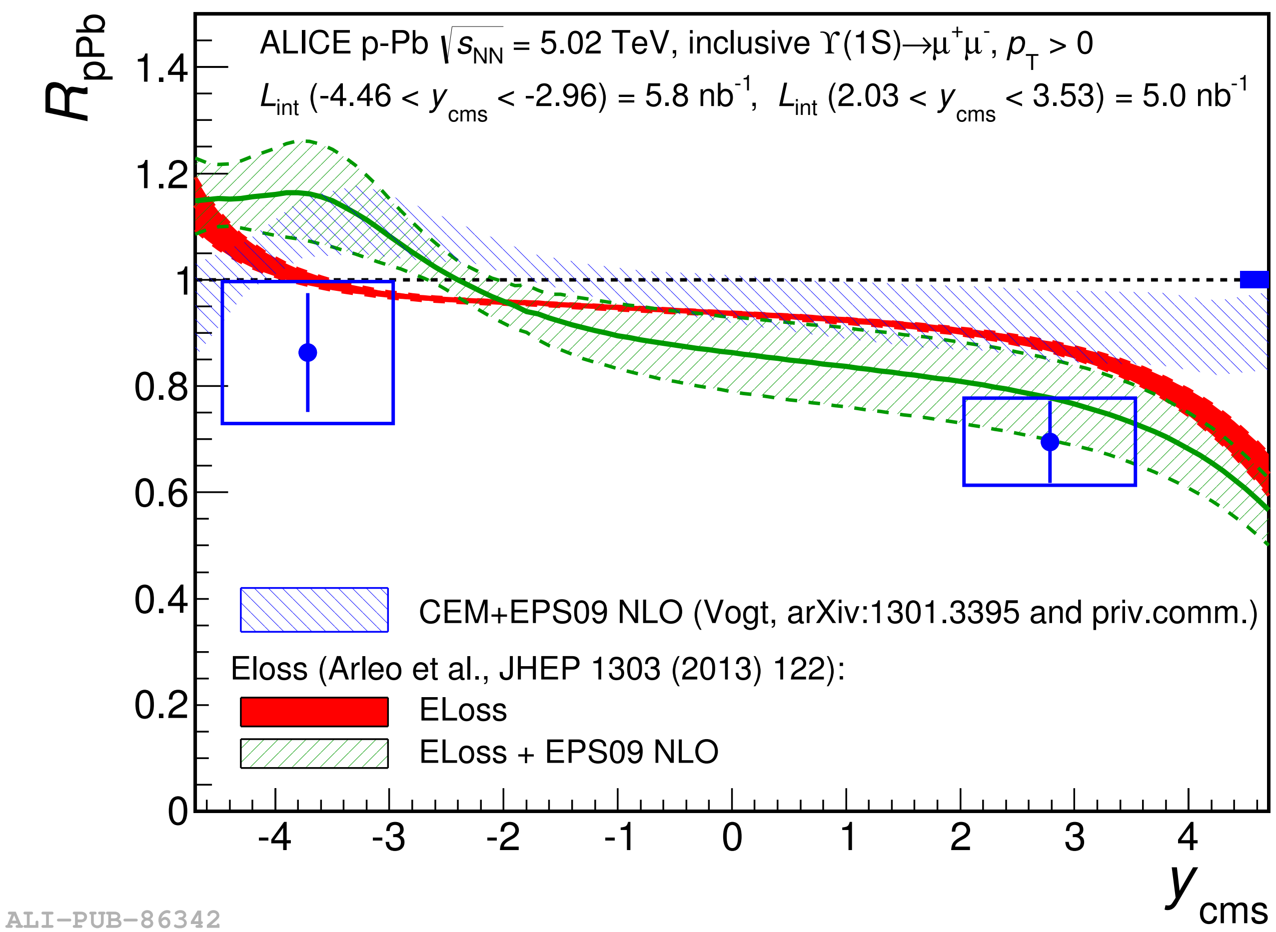
CMS HIN-15-003 (arXiv:1603.02913)



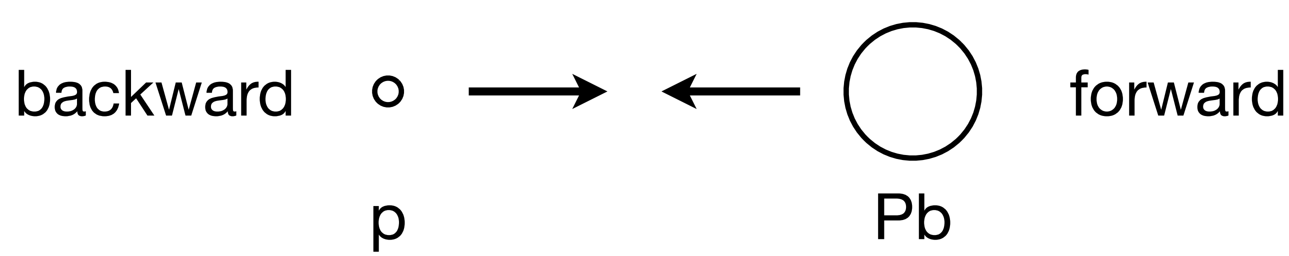
- Yield vs N_{ch} at high p_T?

ϒ in p-Pb





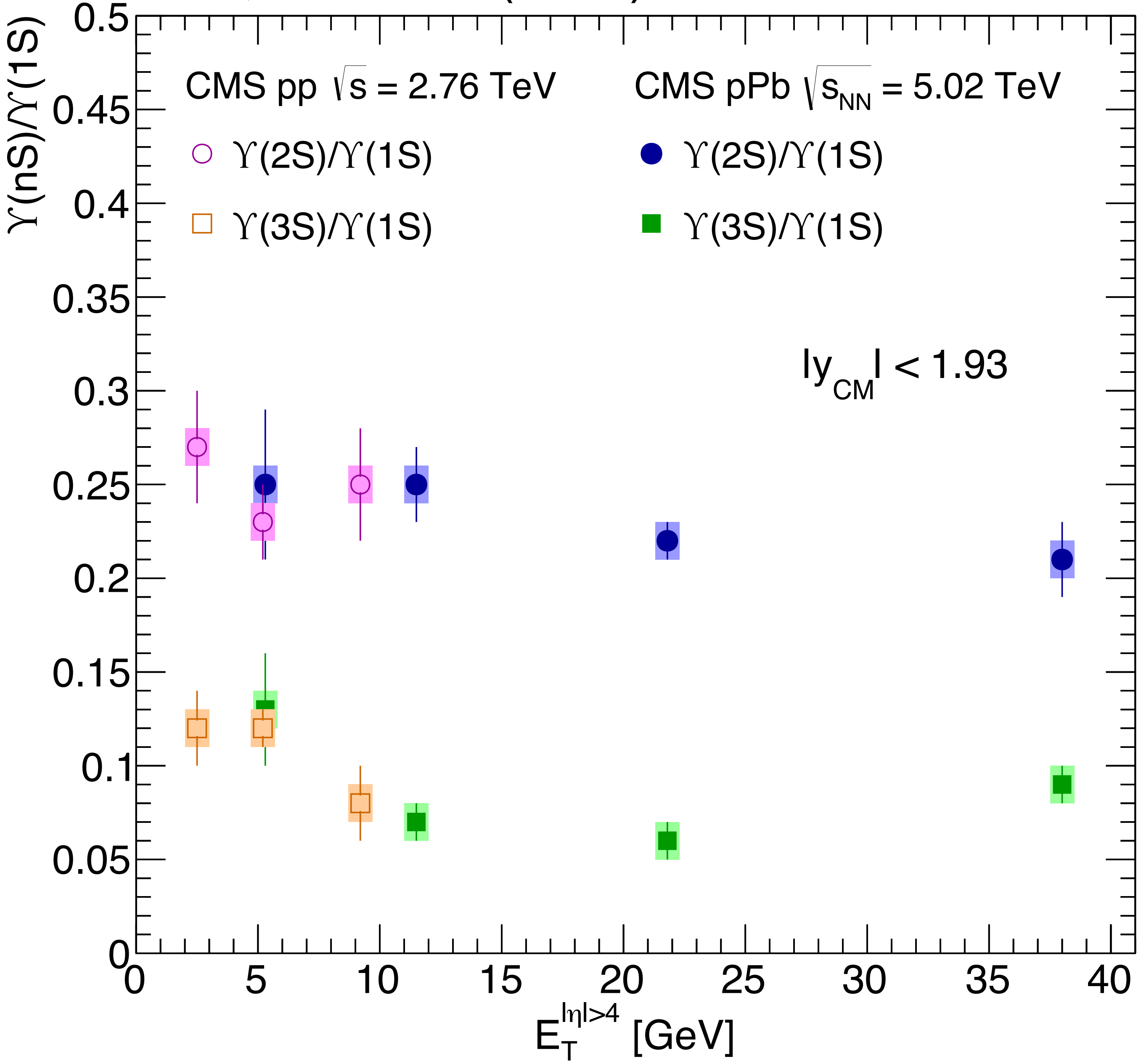
ATLAS-CONF-2015-050
ALICE, PLB 740 (2015) 105
LHCb, JHEP 07 (2014) 094



- Observed suppressions consistent with shadowing
- LHCb and ALICE results seem to give different message but agree within uncertainties

Υ(nS)/Υ(1S) vs. “event activity”

CMS, JHEP 04 (2014) 103



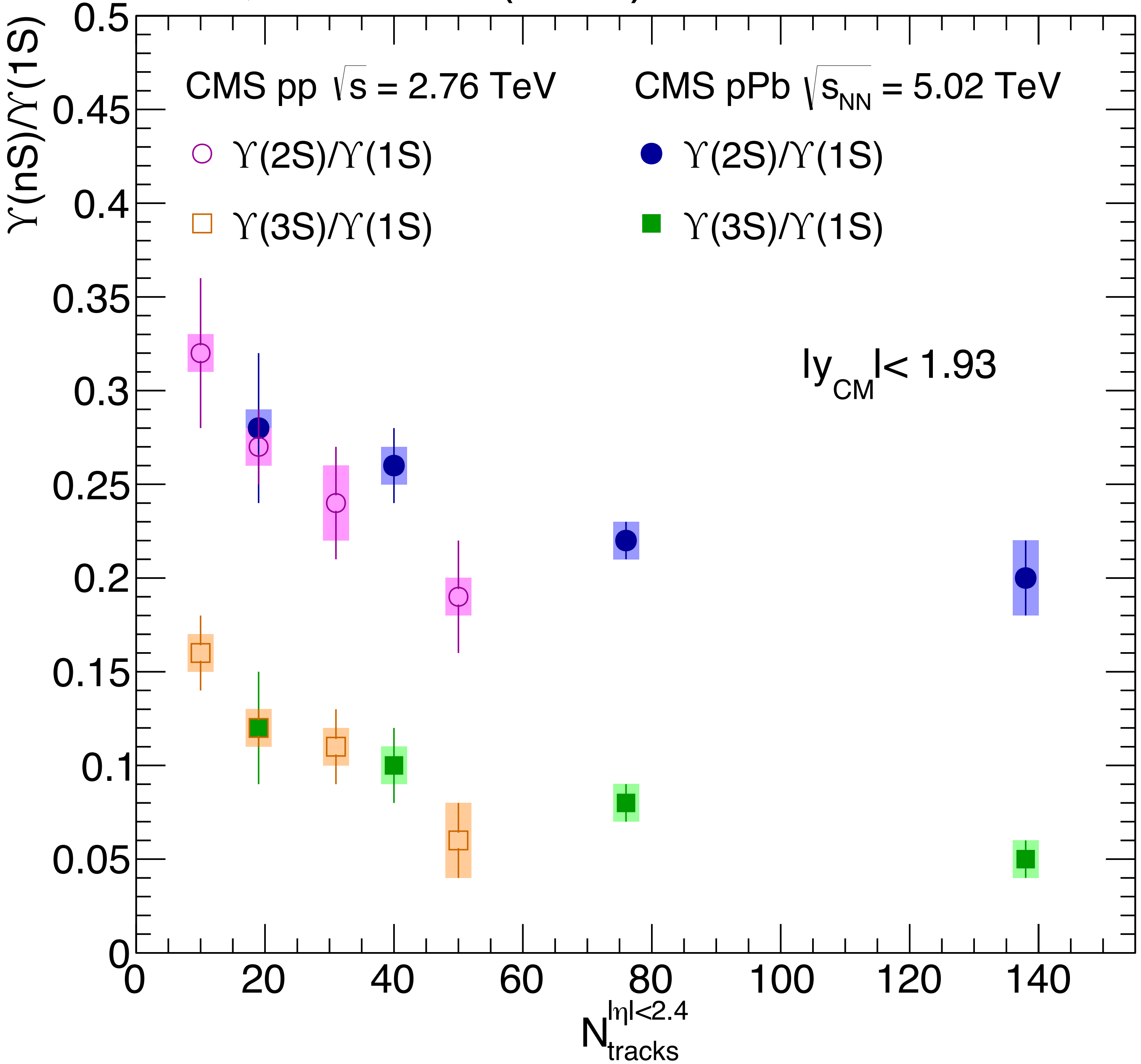
Single Ratios corrected for acceptance and efficiency

Measure event activity at

- Forward rapidity ($4<|\eta_{lab}|<5.2$)
  - $\sum E_T$ in Hadronic Forward Calorimeter
  - weak dependence
  - independent sets consistent with flat

ϒ(nS)/ϒ(1S) vs. "event activity"

CMS, JHEP 04 (2014) 103



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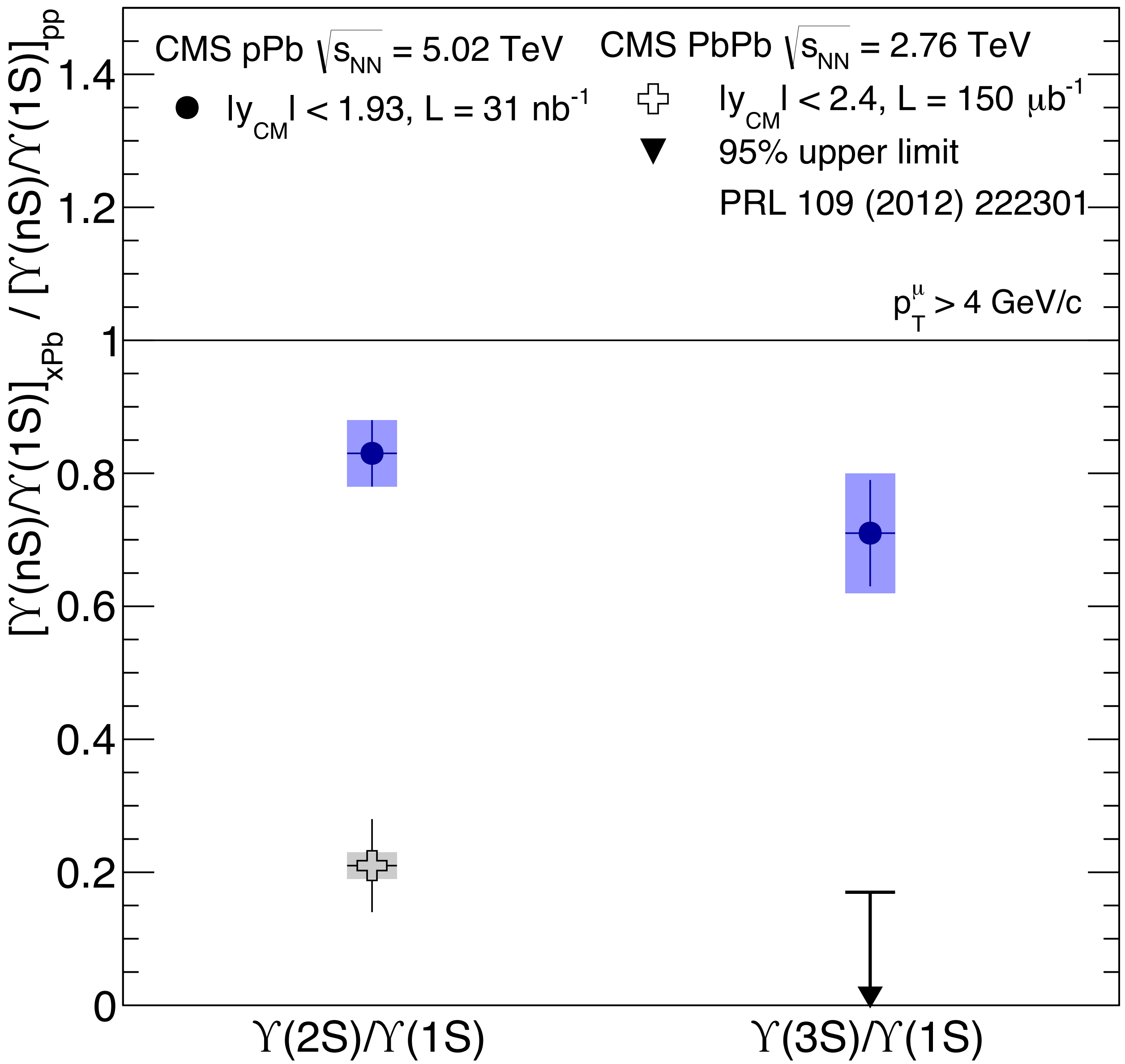
Measure event activity at

- Forward rapidity $(4<|\eta_{lab}|<5.2)$
  - $\sum E_T$ in Hadronic Forward Calorimeter
  - weak dependence
  - independent sets consistent with flat
- Midrapidity $(|\eta_{lab}|<2.4)$
  - N_{tracks}: multiplicity in silicon tracker
  - significant decrease with multiplicity
- Two options to explain results at midrapidity:
  - ϒ affects multiplicity
    - ground states comes with 2 tracks more than excited state
  - multiplicity affects ϒ
    - activity around the ϒ breaks the state (comovers?)
- Consequences for PbPb?!

Υ(nS)/Υ(1S) Double Ratio in p-Pb

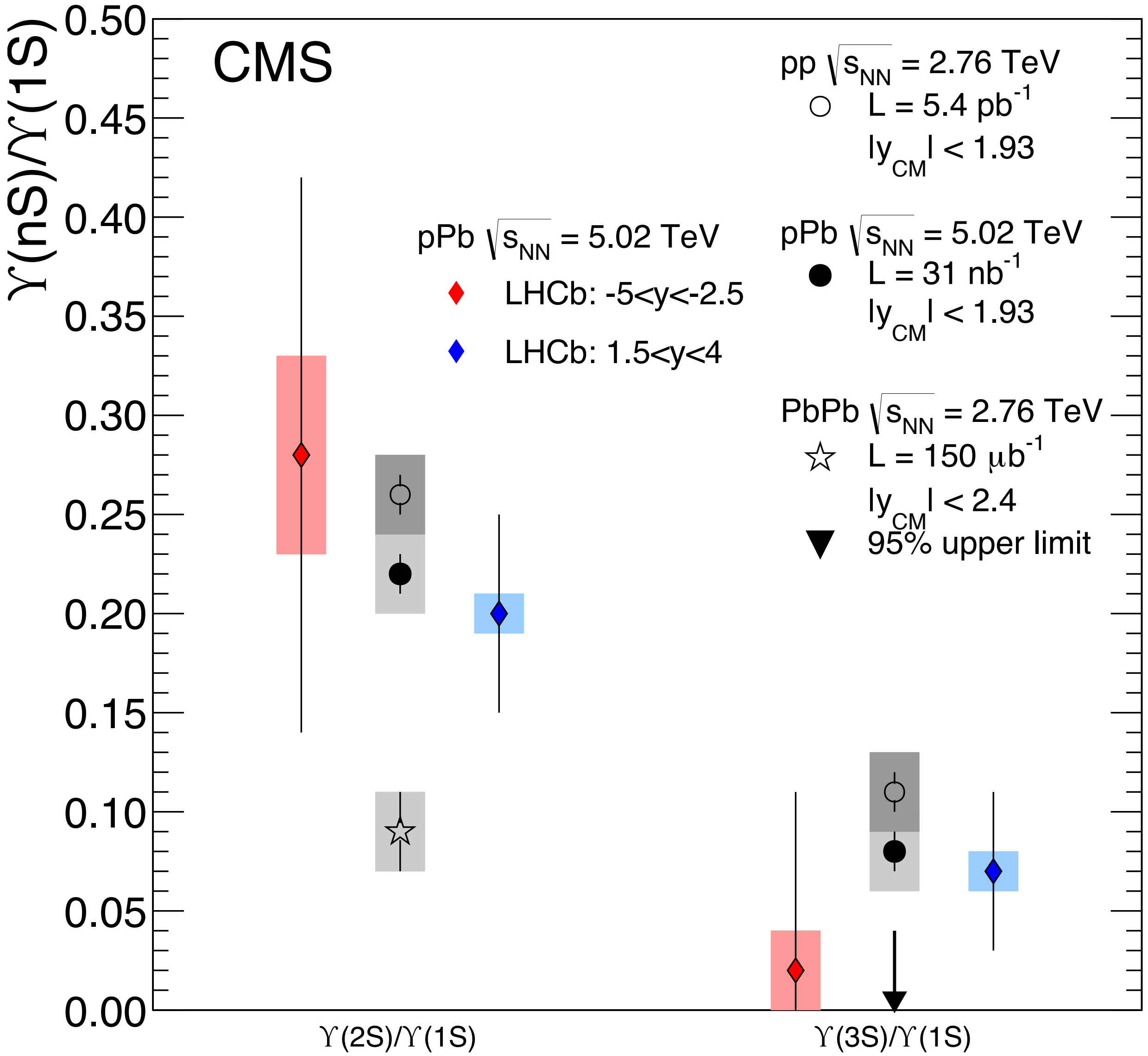
CMS, JHEP 04 (2014) 103



- Pb-Pb: PRL 109 (2012)
  - slightly different rapidity ($|y_{CM}|<2.4$)
  - 2011 pp dataset
- Double ratios in p-Pb larger than in Pb-Pb
  - suggests further final state effects in Pb-Pb
  - but: model dependent extrapolation from pPb to PbPb
- p-Pb vs pp:
  - double ratio less than unity (significance <3σ)
  - if multiplicity integrated double ratio indeed less unity: it’s not the Y that affects the multiplicity → comovers?

Υ(nS)/Υ(1S) Single Ratios

CMS, JHEP 04 (2014) 103
LHCb, JHEP 07 (2014) 094



SHM prediction: Υ(2S)/Υ(1S) = 0.032
Andronic, NPA 931 (2014) 135

- CMS:
  - midrapidity: slightly smaller values in pPb than pp (|y|<1.93)
- LHCb:
  - backward rapidity: Υ(2S) consistent with pp (-5<y<-2.5)
  - forward rapidity: Υ(2S) large uncertainties but slightly lower than pp (1.5<y<4)
  - Υ(3S): too large uncertainties to discriminate
- STAR
  - excited states accessible in muon channel
  - hint of less suppression of excited states, consistent with Υ(1S) R_{AA}

ϒ(nS)/ϒ(1S) Single Ratios

CMS, JHEP 04 (2014) 103
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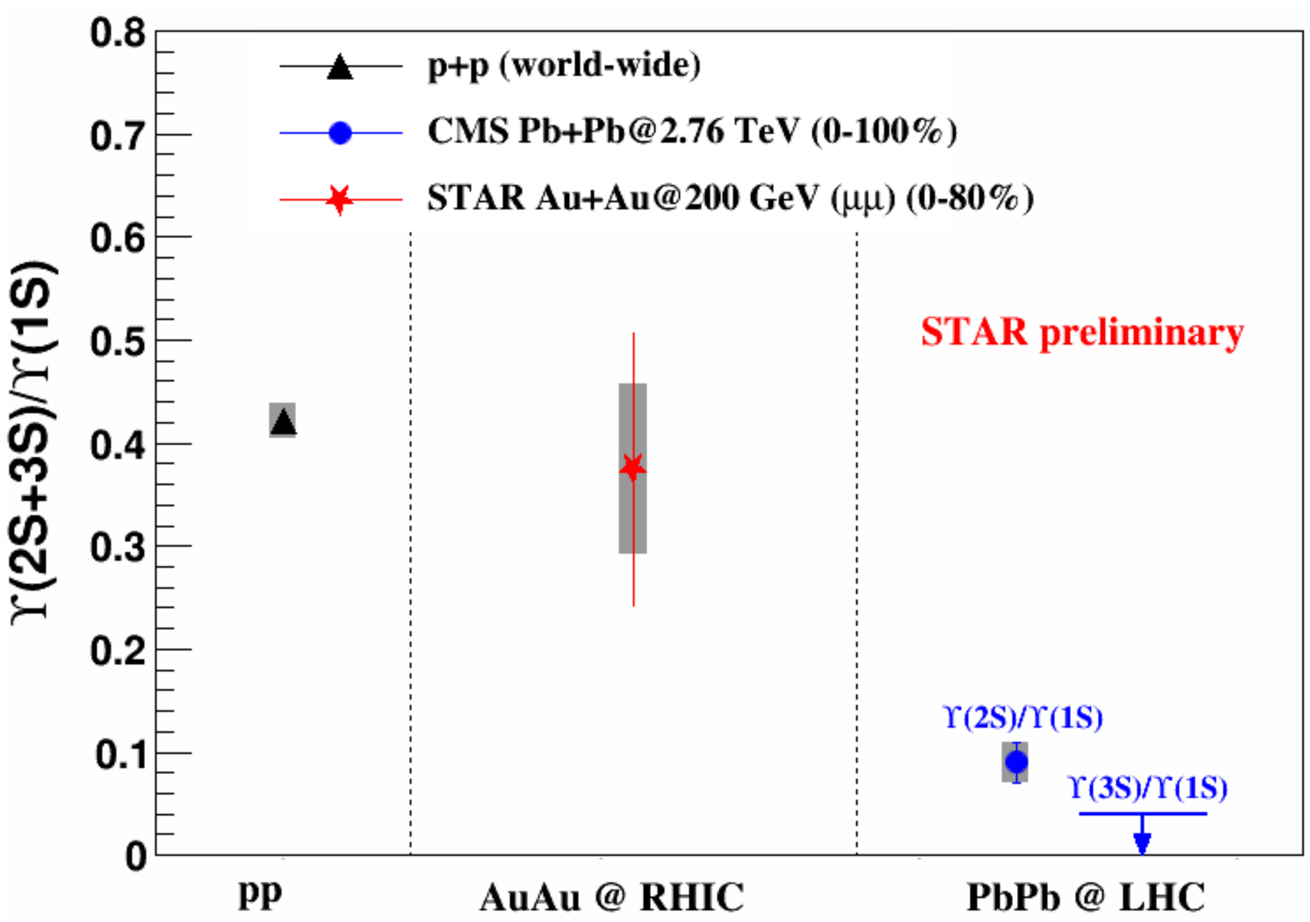

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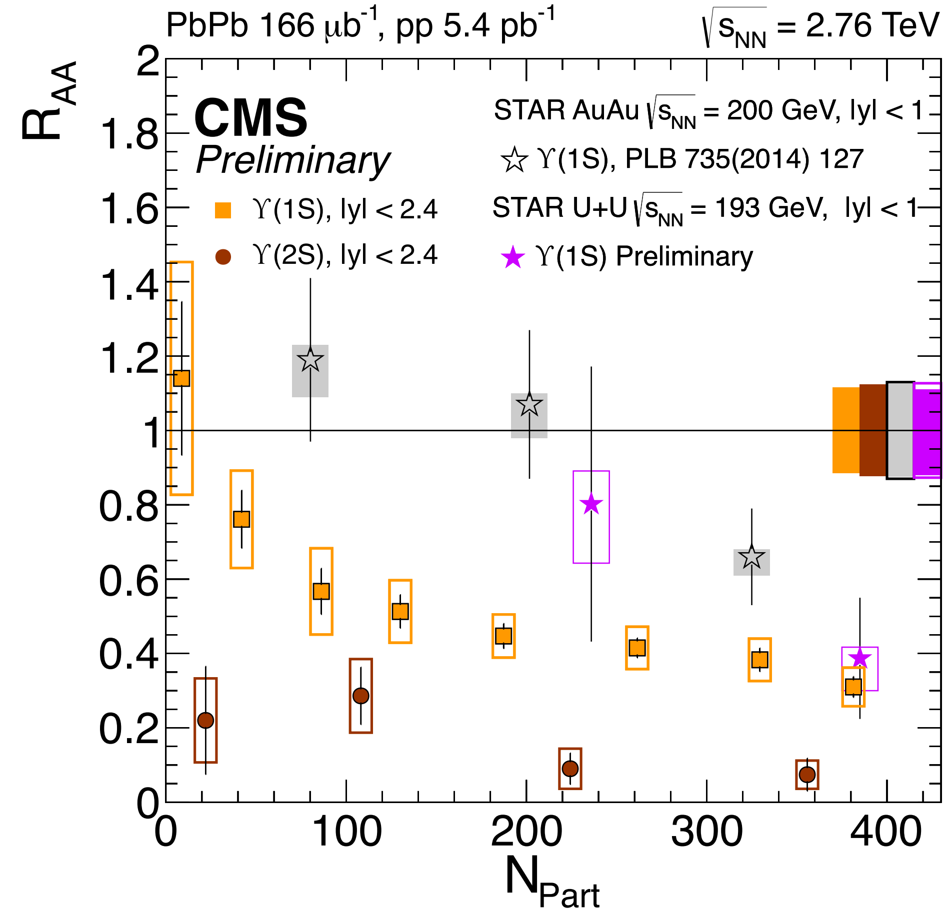
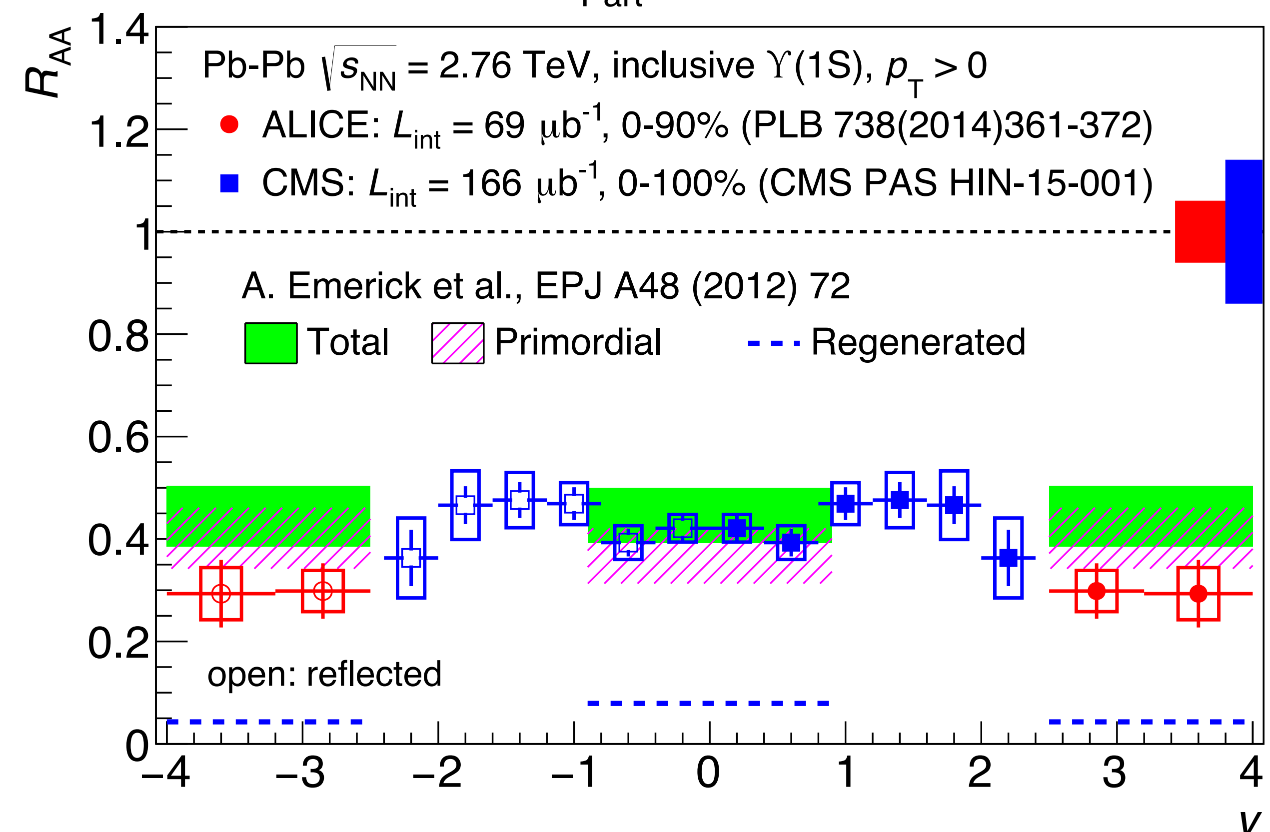
ϒ(1S) in Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

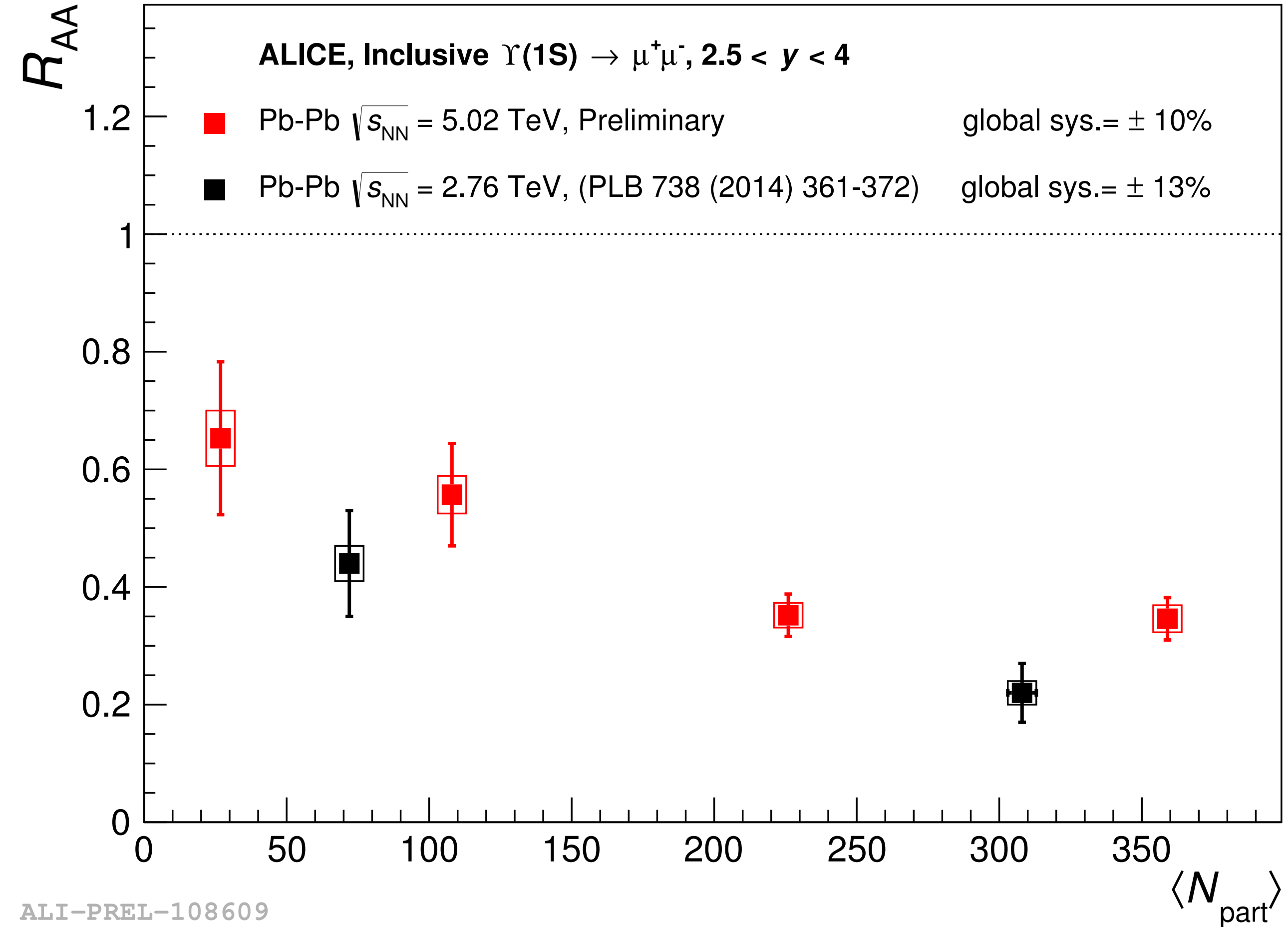
- At the LHC, ϒ(1S) already suppressed in semi-peripheral collisions
  - at RHIC only in central collisions
- ϒ(1S) suppression in most central collisions might be larger than just lack of feed-down
  - feed-down fraction 30–40% but large uncertainties
- More suppression at forward than at midrapidity
  - beware of uncertainties
  - same story as charmonia at RHIC?
  - recombination also for bottomonia
  - ~2 $b\bar{b}$ pairs per event but 10x smaller closed/open ratio than charm

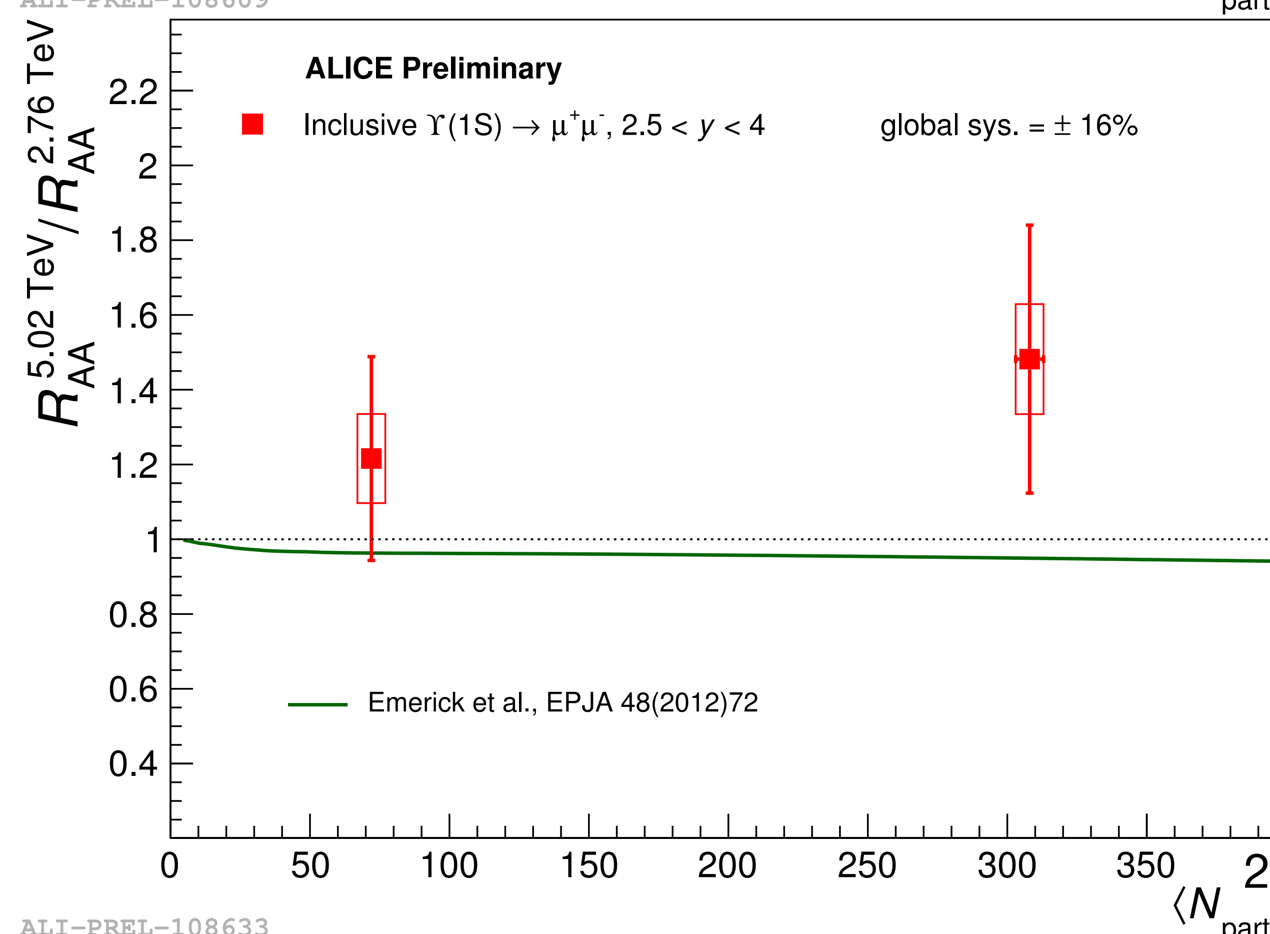




Υ(1S) in Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- ALICE finds similar suppression to the one at 2.76 TeV
- Increase less than 0.5σ
  - centrality integrated: 1.3±0.2±0.2
- Yet, so far quarkonia R_{AA} went only up with $\sqrt{s_{NN}}$
  - excited states? CMS…?
- Need feed-down measurements!
  - split “opinions” on signs of direct Υ(1S) suppression





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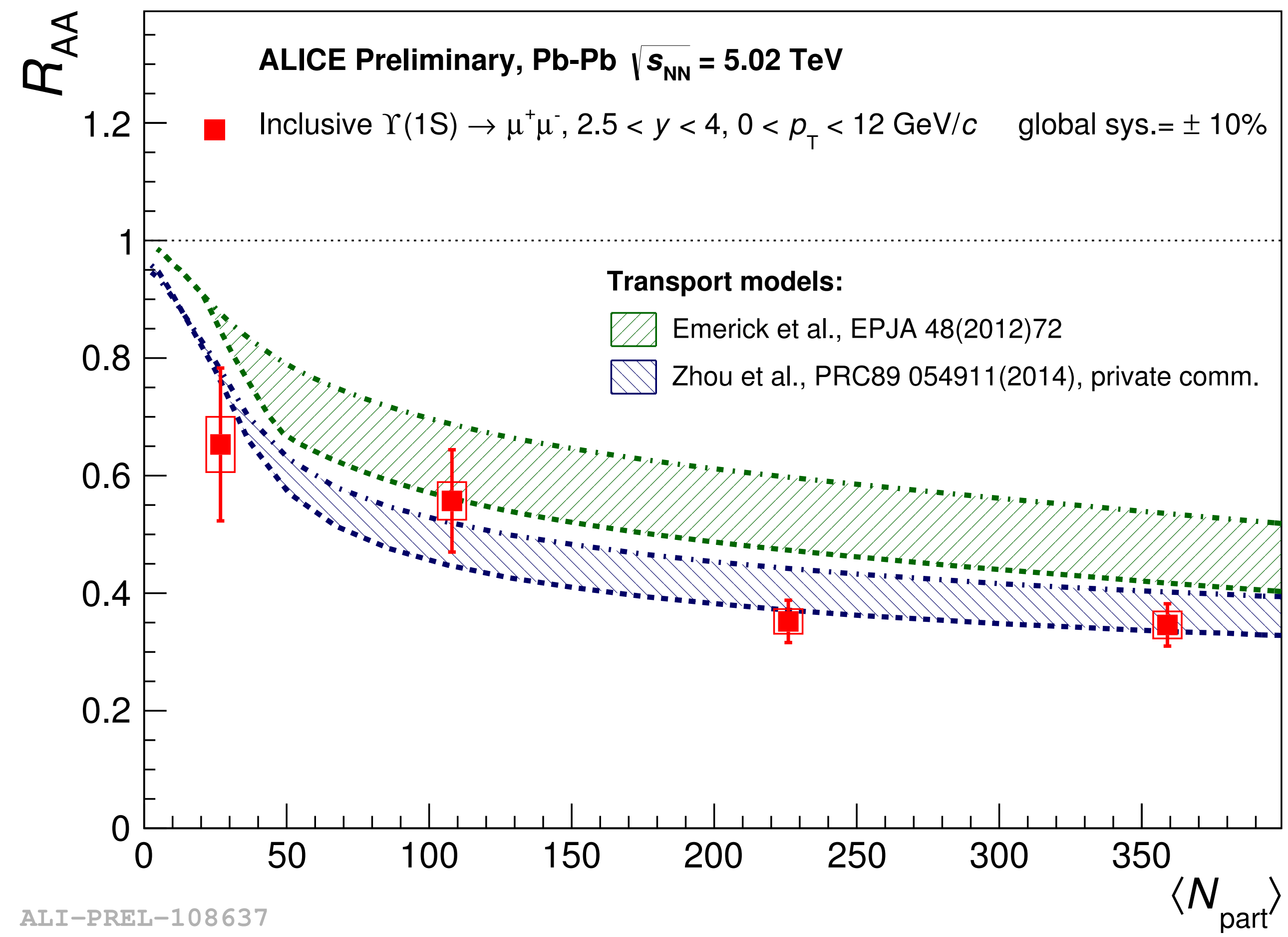
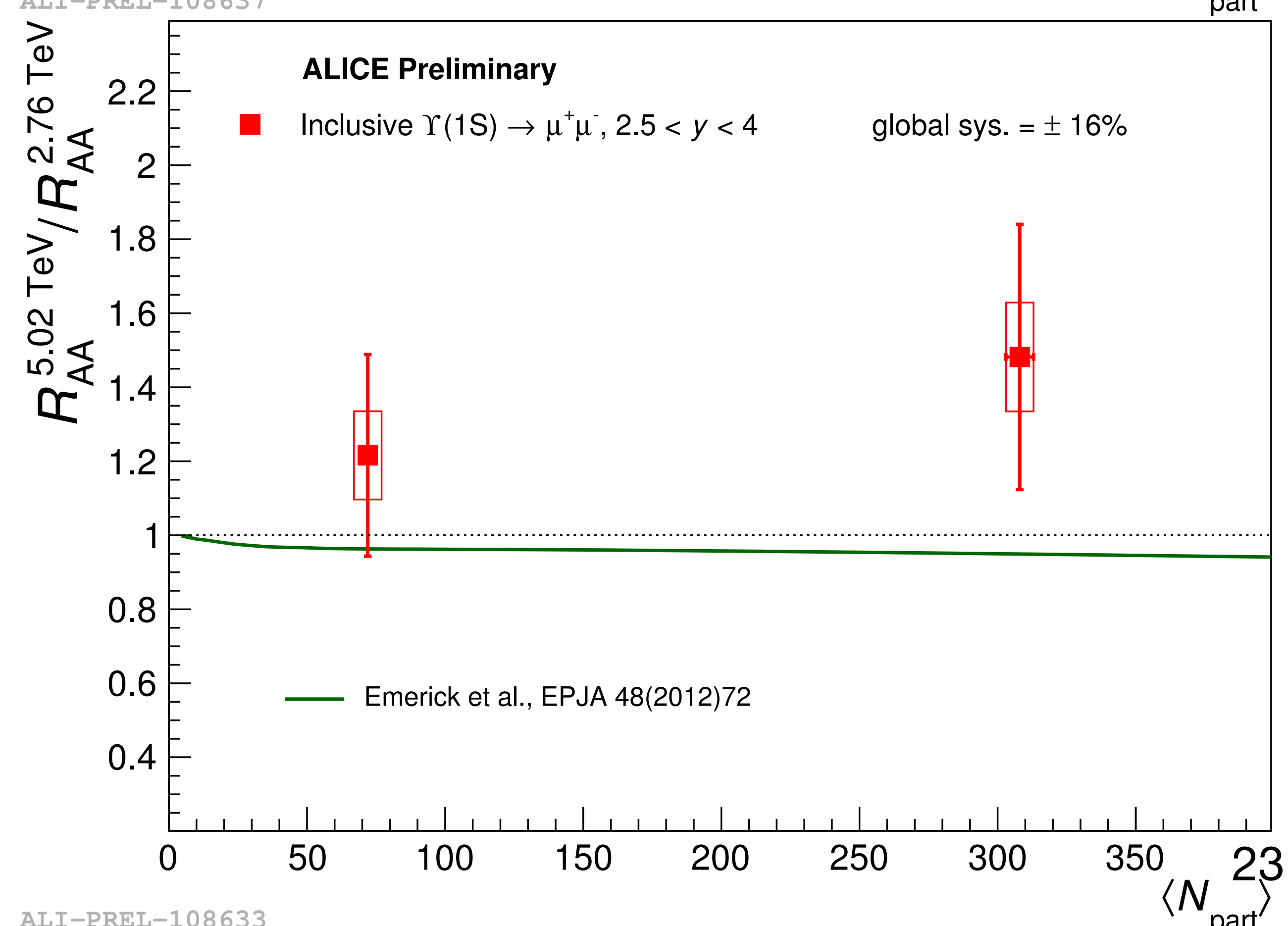
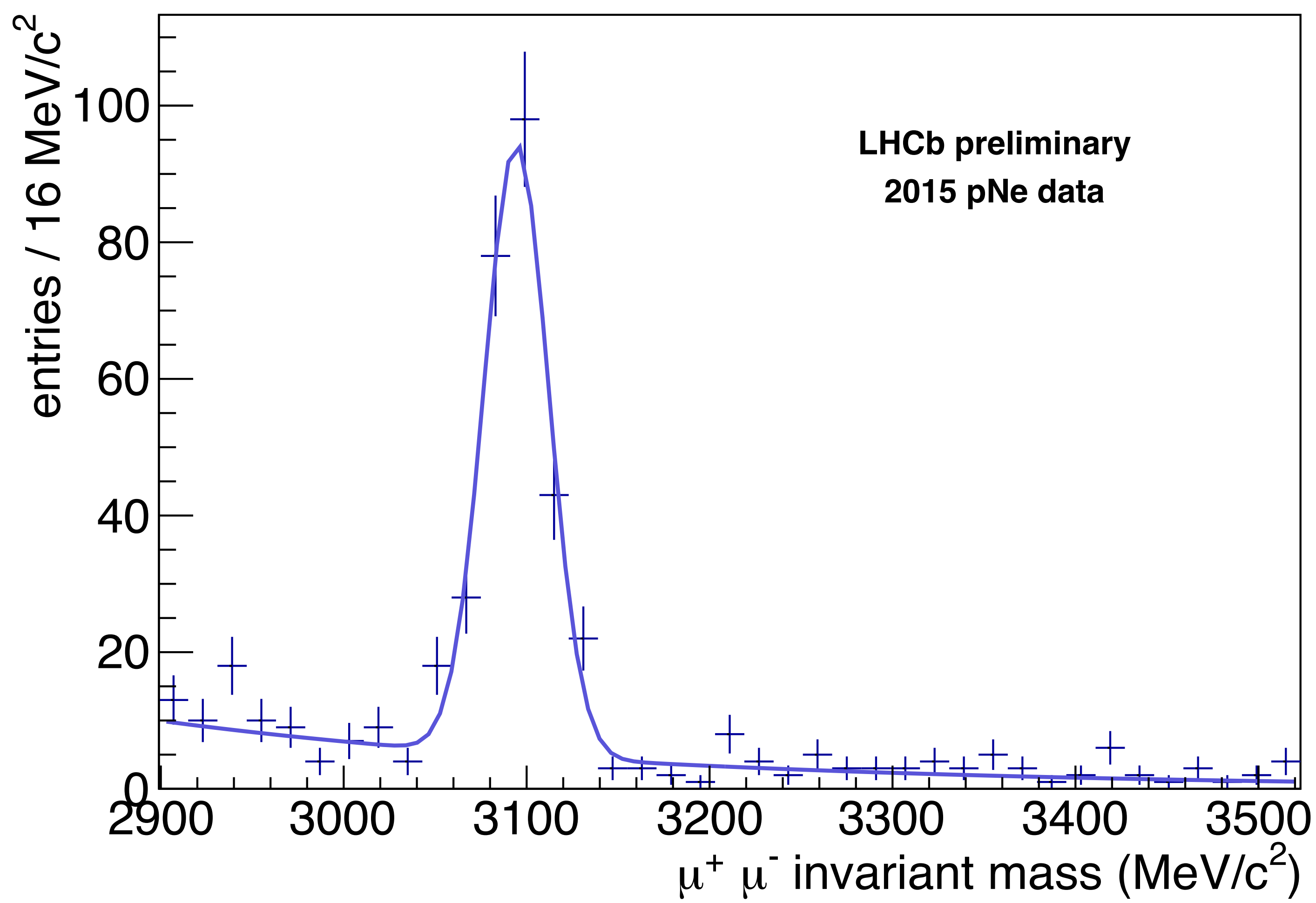




Fixed Target Experiments at the LHC



- Using SMOG to inject nobel gas
  - He, Ne, Ar
- Moves LHCb detector to “midrapidity” in center of mass
  - $\Delta y = 4.5$
- Moves LHC to RHIC energy domain: $\sqrt{s_{NN}} = 87$ GeV

Summary

p-A:

- quarkonium data point towards some kind of comover effects

A-A:

- some form of regeneration seems to be present for J/ψ (unless charm cross section scales faster then N_{coll})
- precise measurements of excited states crucial to kill models
- Υ(1S) looks more and more like the new J/ψ
  - with all its problems (competing hot and cold processes)

SMOG:

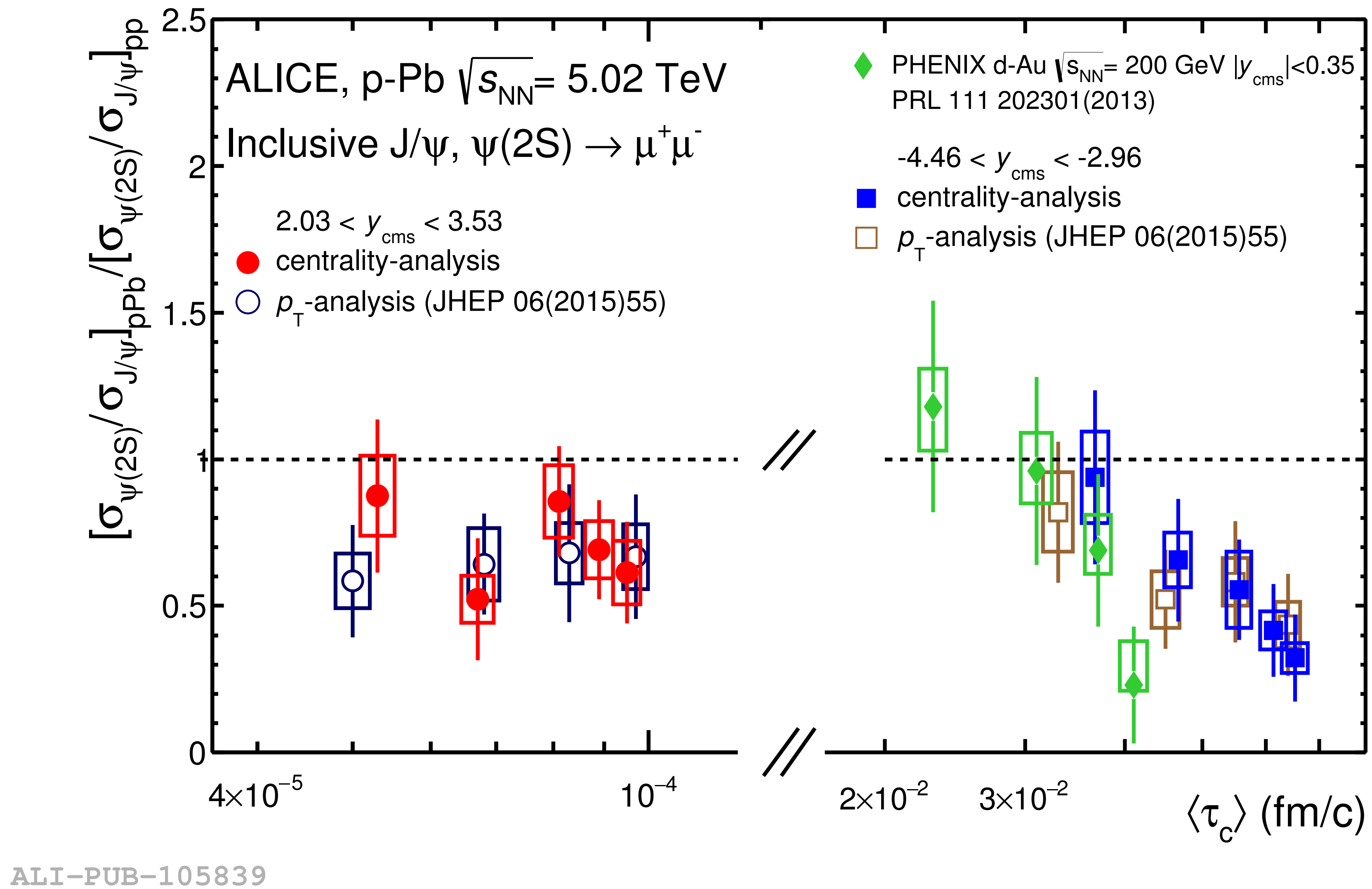
- turns LHCb into a fixed-target experiments at back-/midrapidity with p-gas and Pb-gas collisions in RHIC energy range

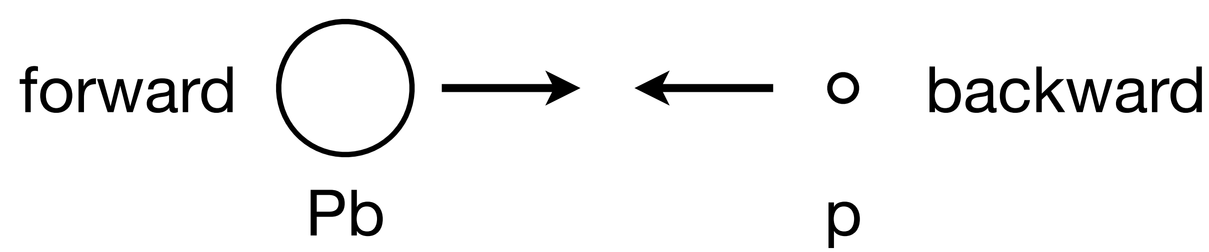
Quarkonium Talks at SQM

- ALICE
  - Javier Castillo, Mon at 9h
  - Hugo Pereira Da Costa, Tue at 16h
  - Biswarup Paul, Tue at 17h
  - Orlando Baillie, Thu at 11h
  - Antoine Lardeux, Thu at 11h20
- ATLAS
  - Qipeng Hu, Mon at 10h
  - William Brooks, Thu at 12h20
- CMS
  - Wei Xie, Mon at 9h30
  - Songkyo Lee, Tue at 16h40
  - Chad Steven Flores, Thu at 11h40
- LHCb
  - Michael Schmelling, Mon at 12h
- PHENIX
  - Rachid Nouicer, Mon at 11h30
- STAR
  - Zhenyu Ye, Mon at 11h
  - Wangmei Zha, Tue at 16h20
  - Takahito Todorok, Tue at 17h40
- The full HF summary:
  - Rongrong Ma, Fri at 14h

Backup

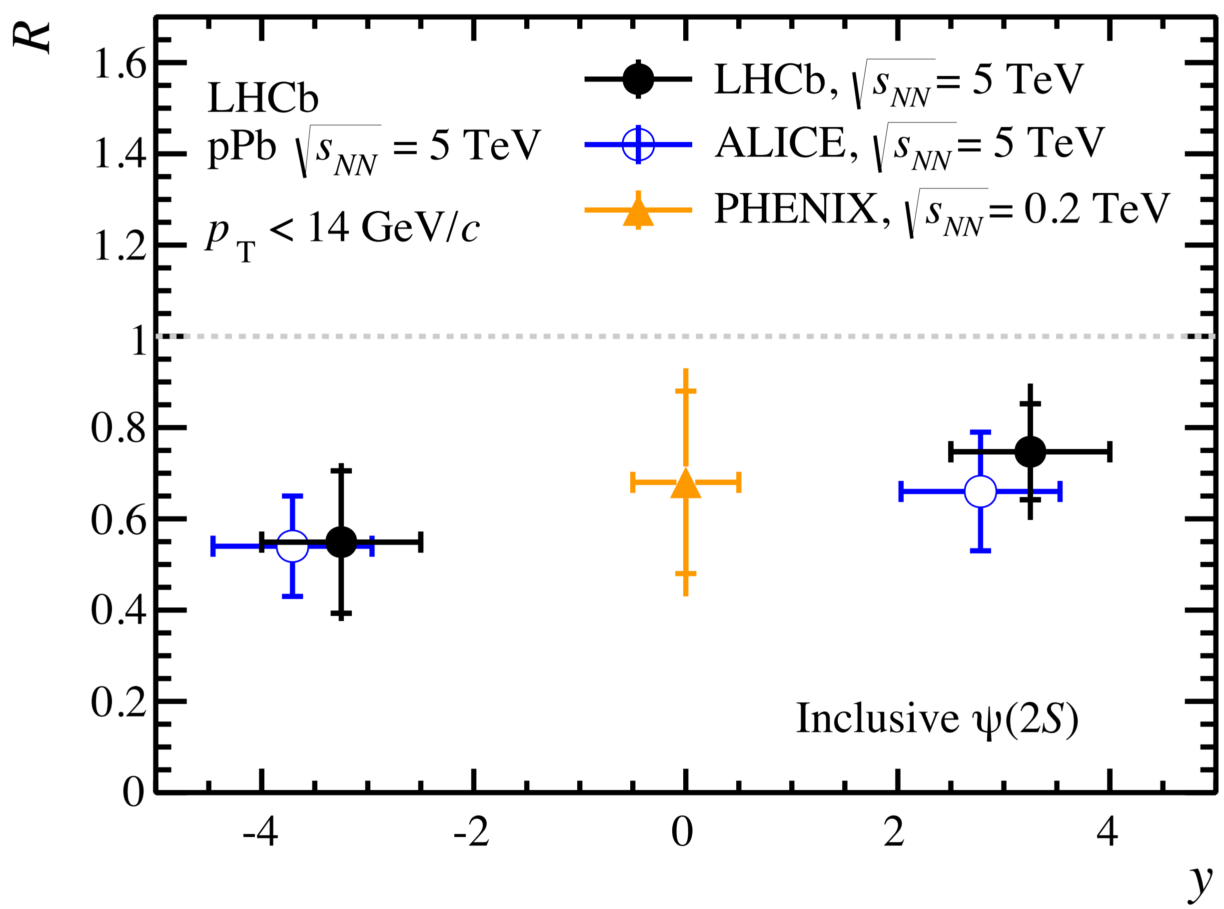
ALICE: ψ(2S) in p-Pb

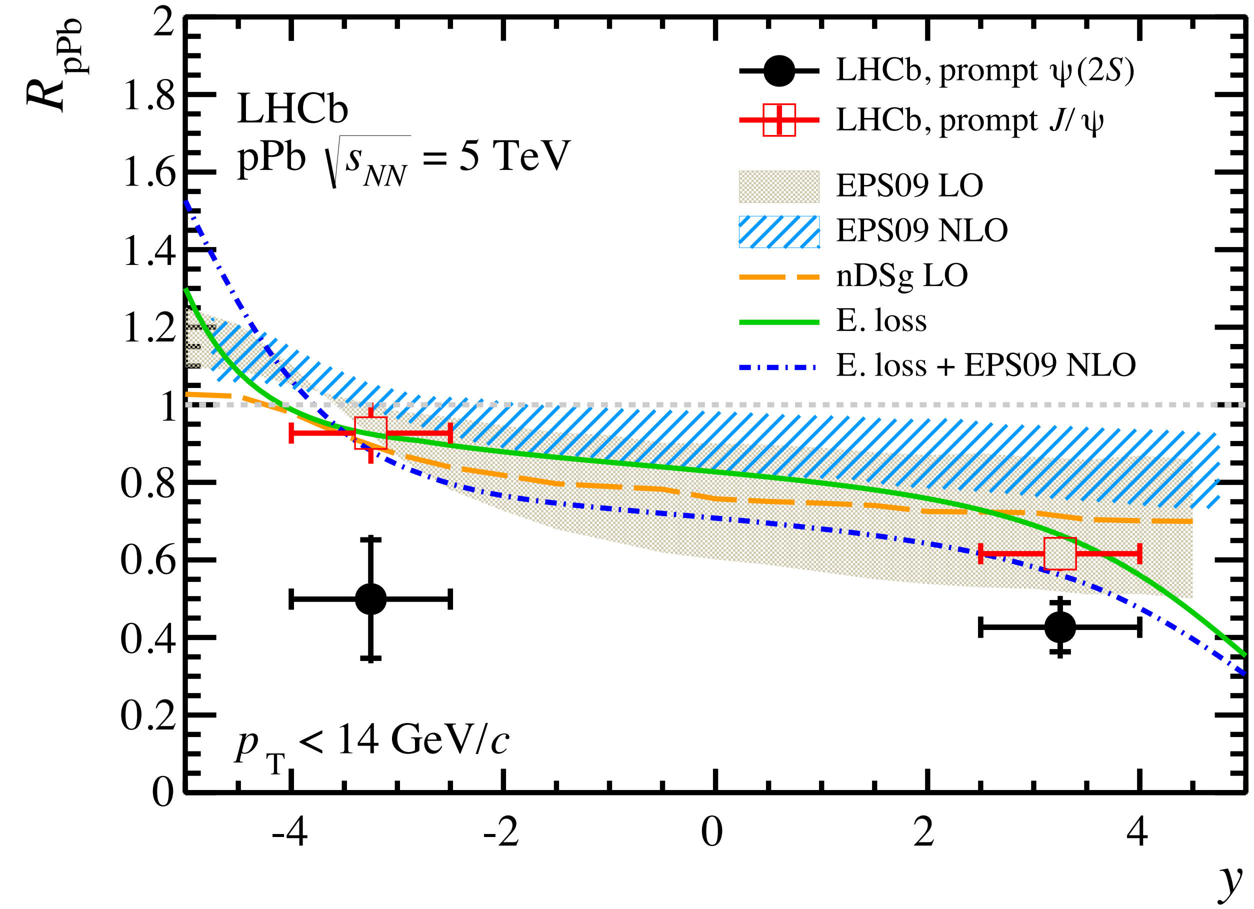


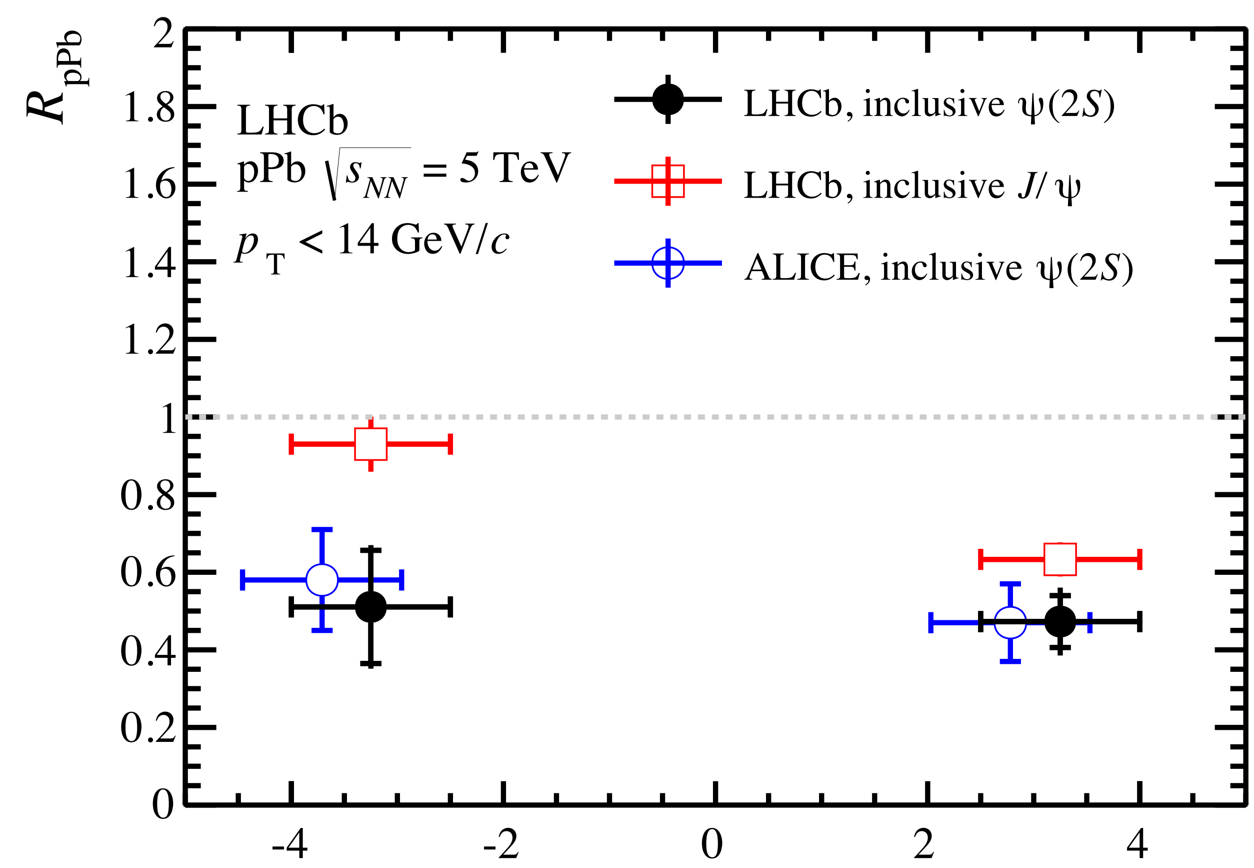


Prompt ψ(2S) in p-Pb

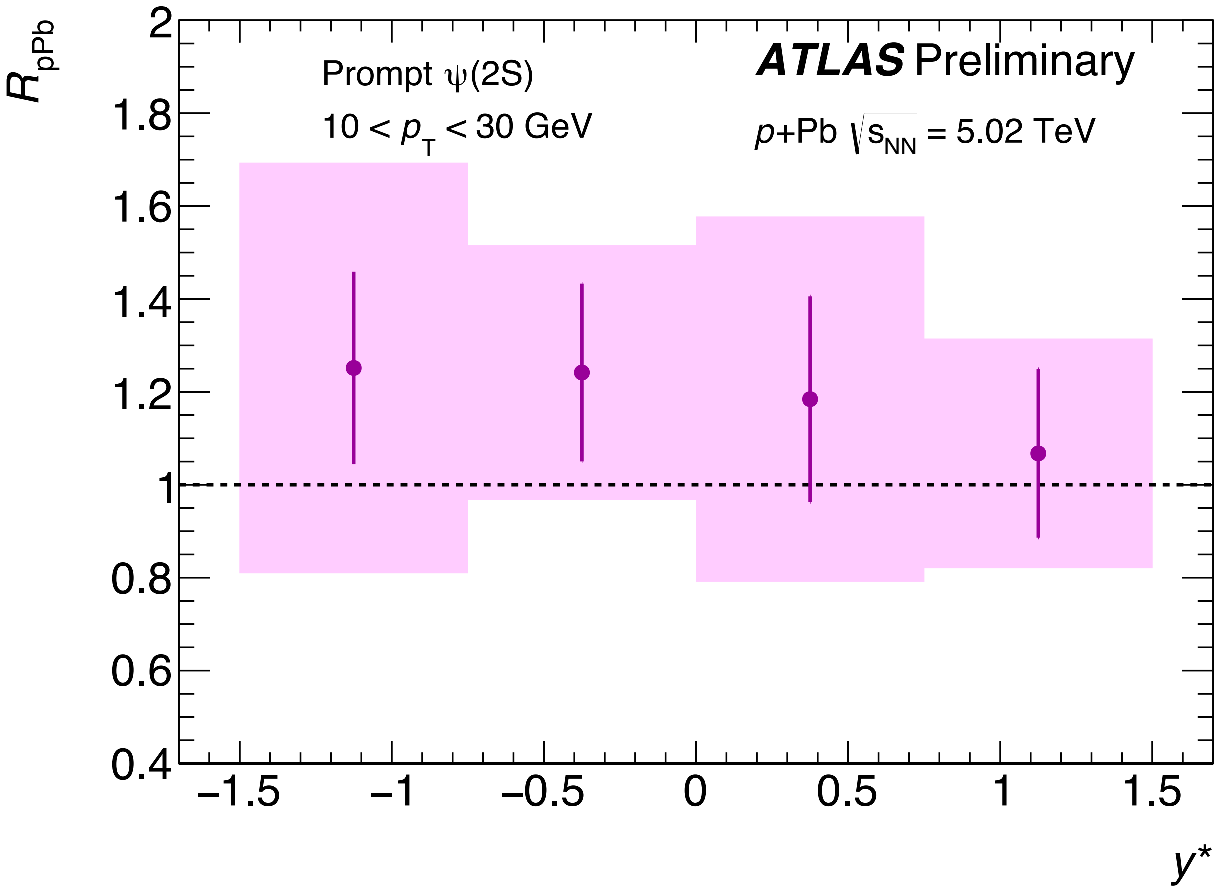
LHCb, JHEP 03 (2016) 133

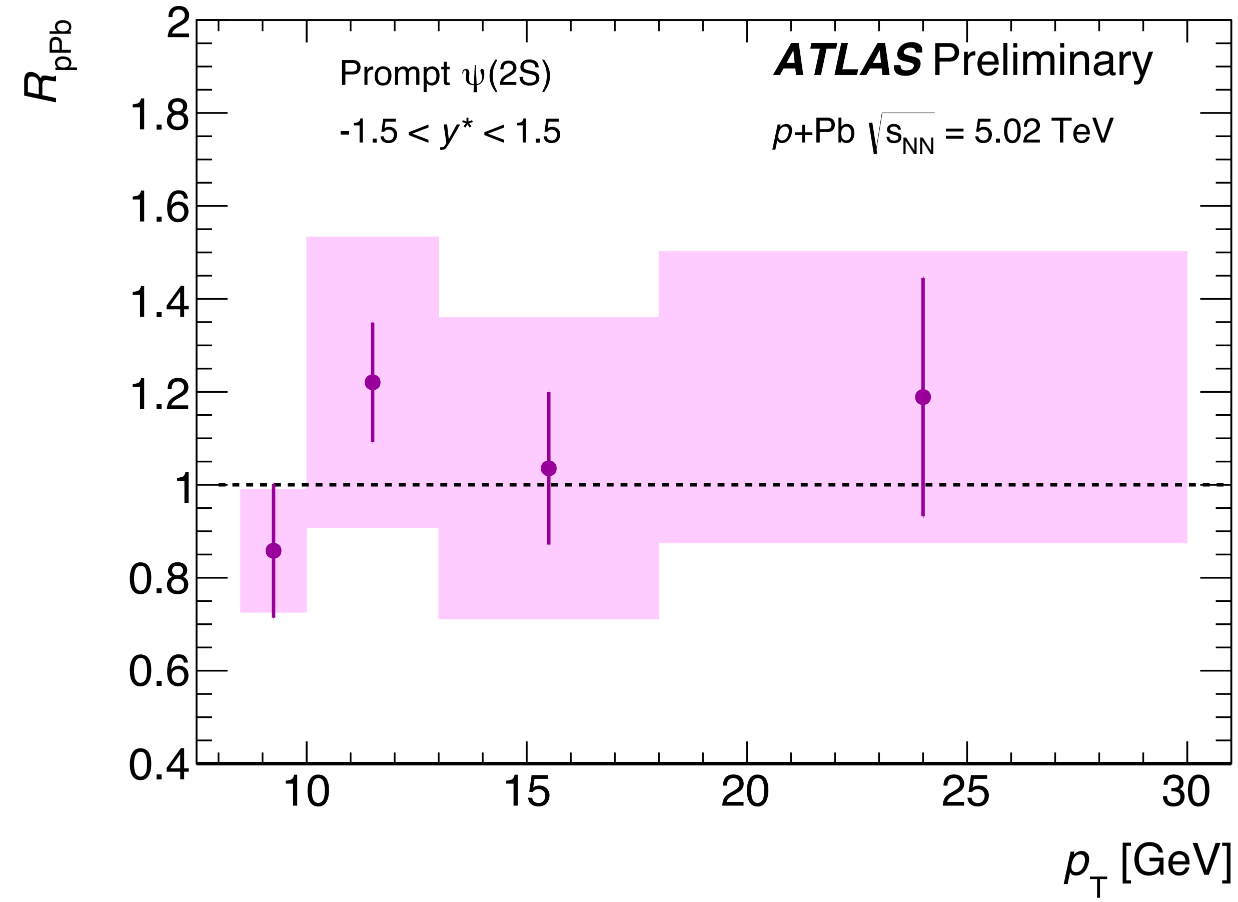


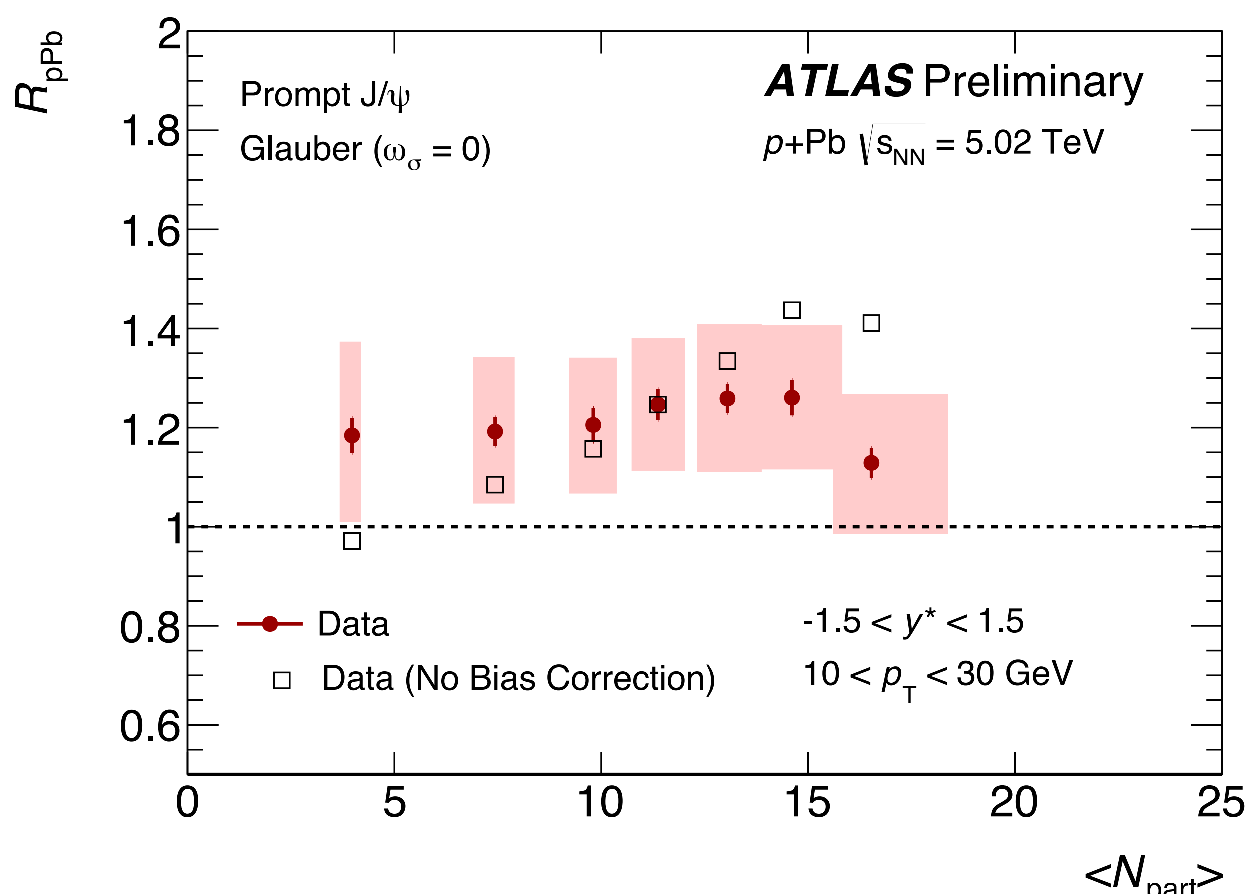




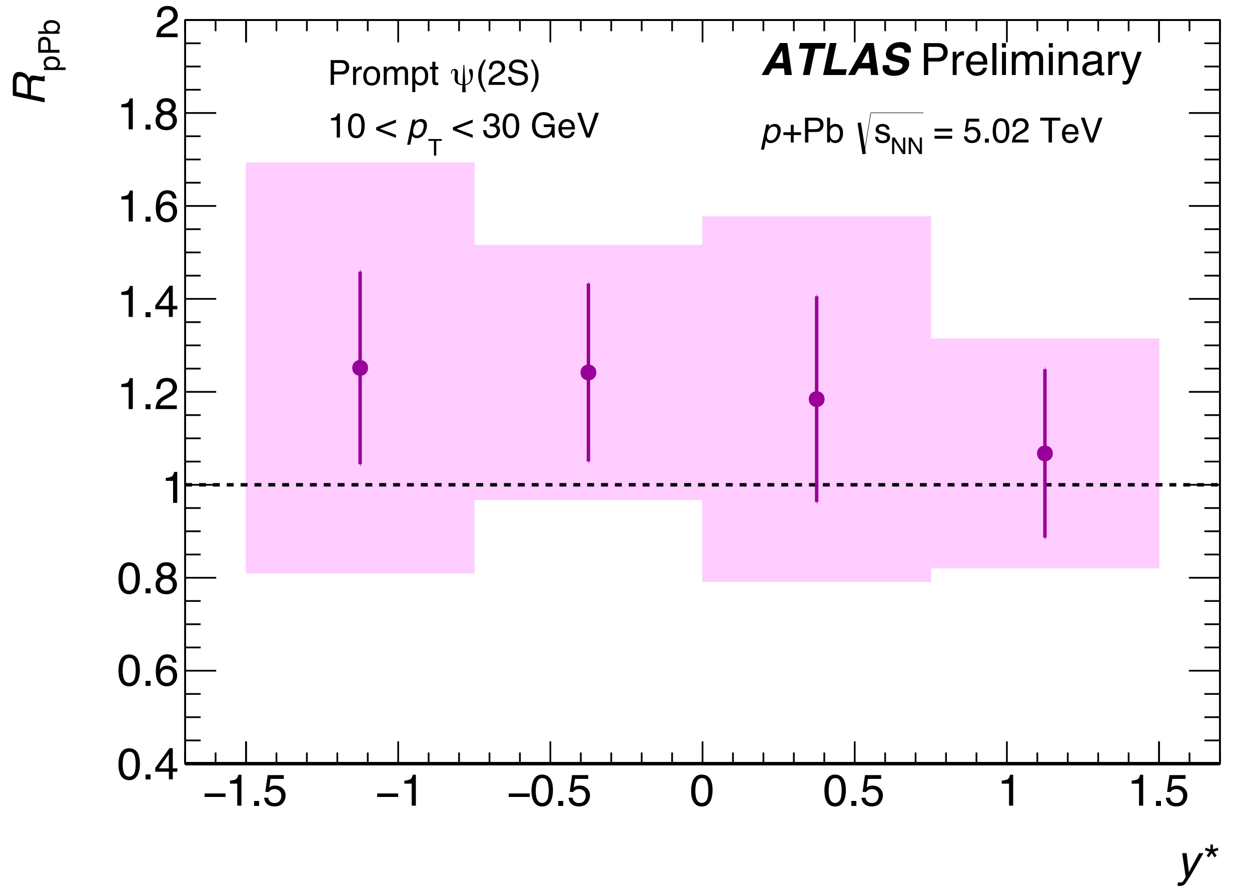
High-p_T ψ(2S) in p-Pb

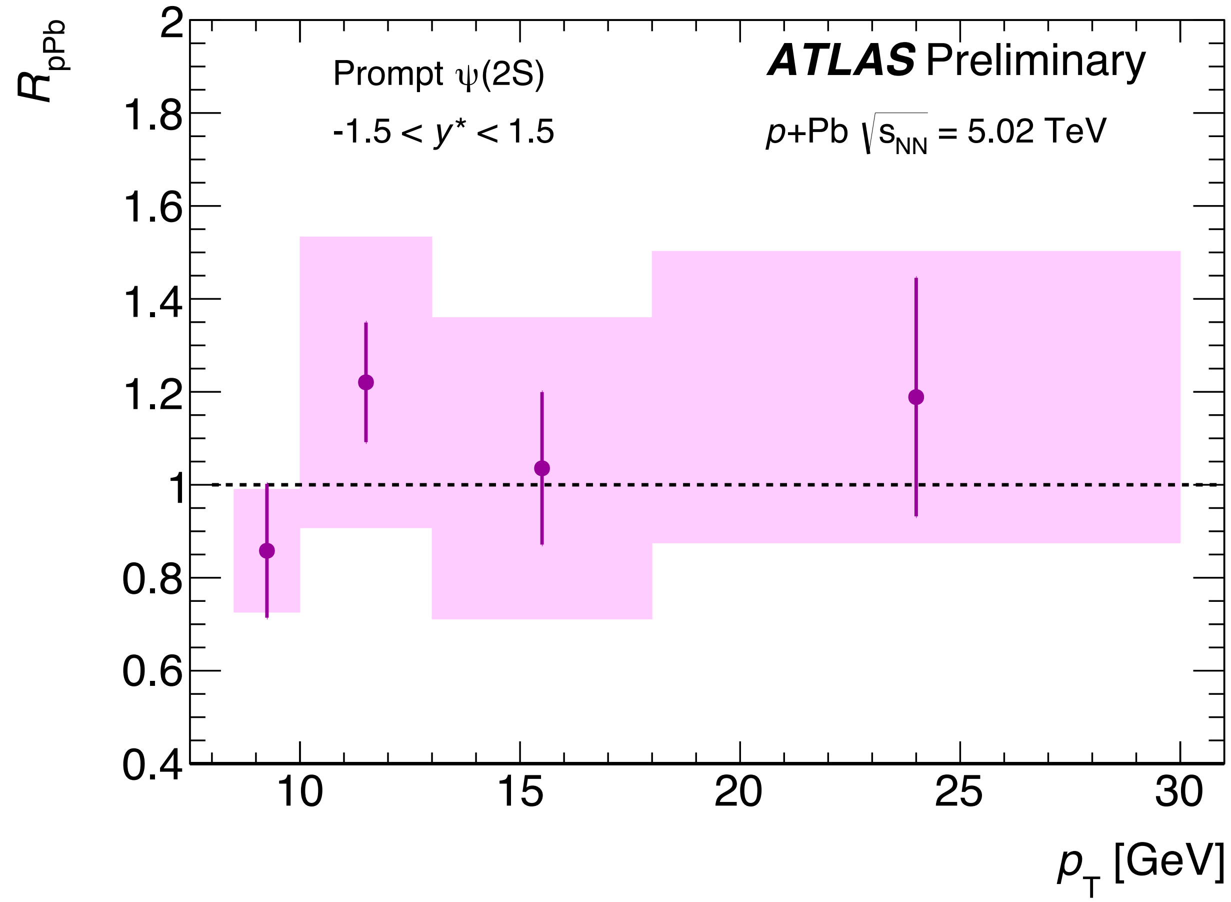


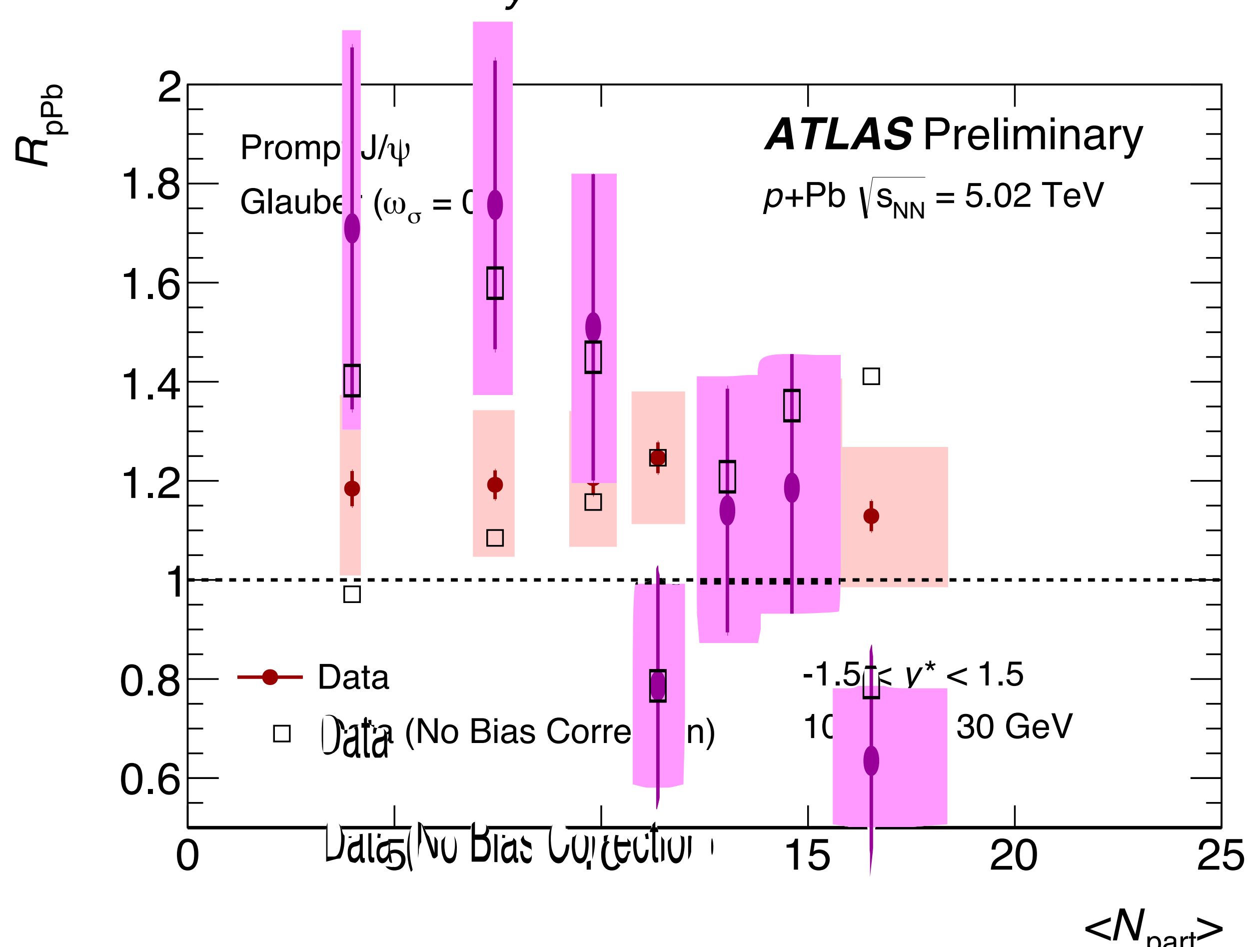




High-pT ψ(2S) in p-Pb

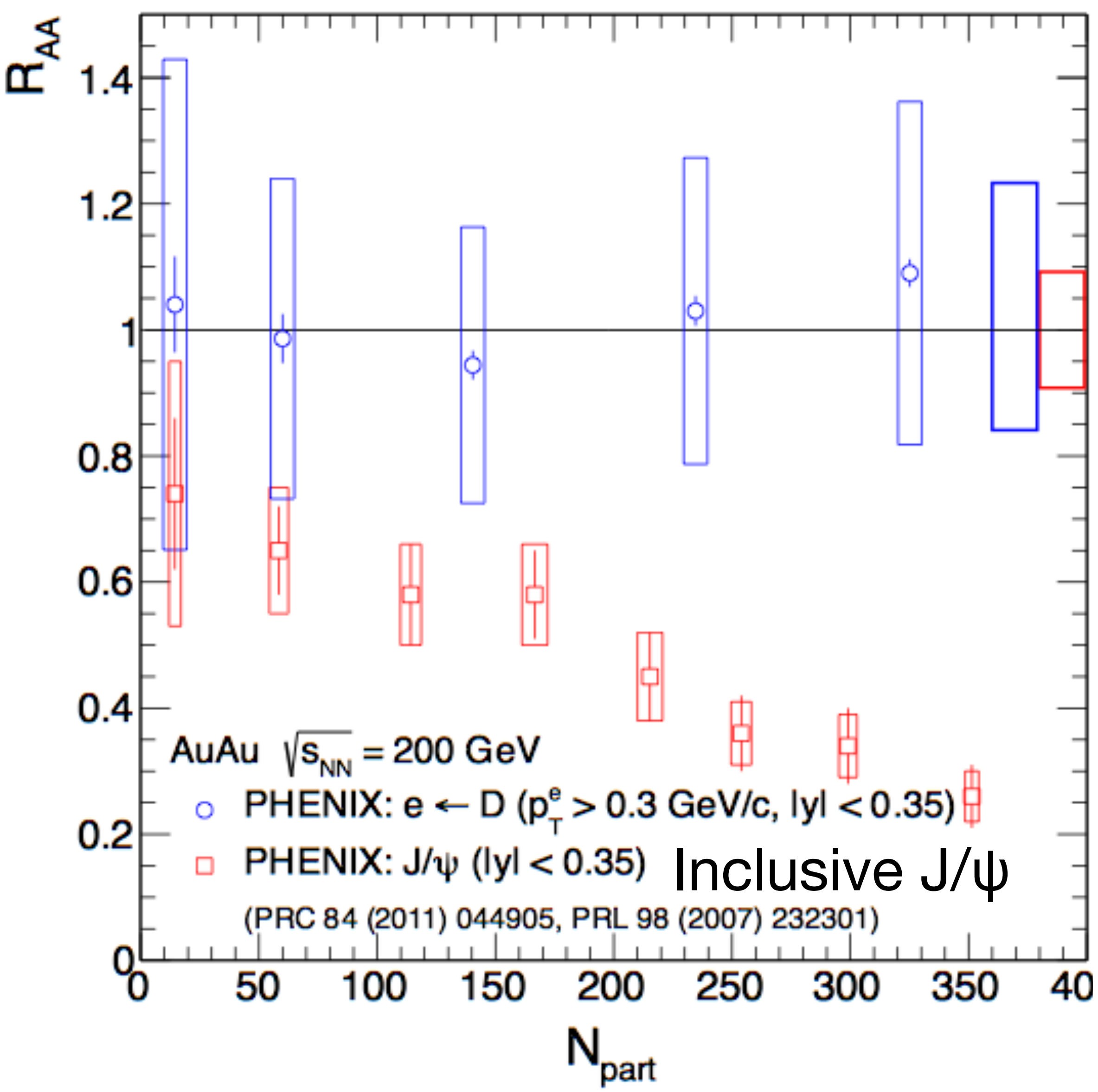


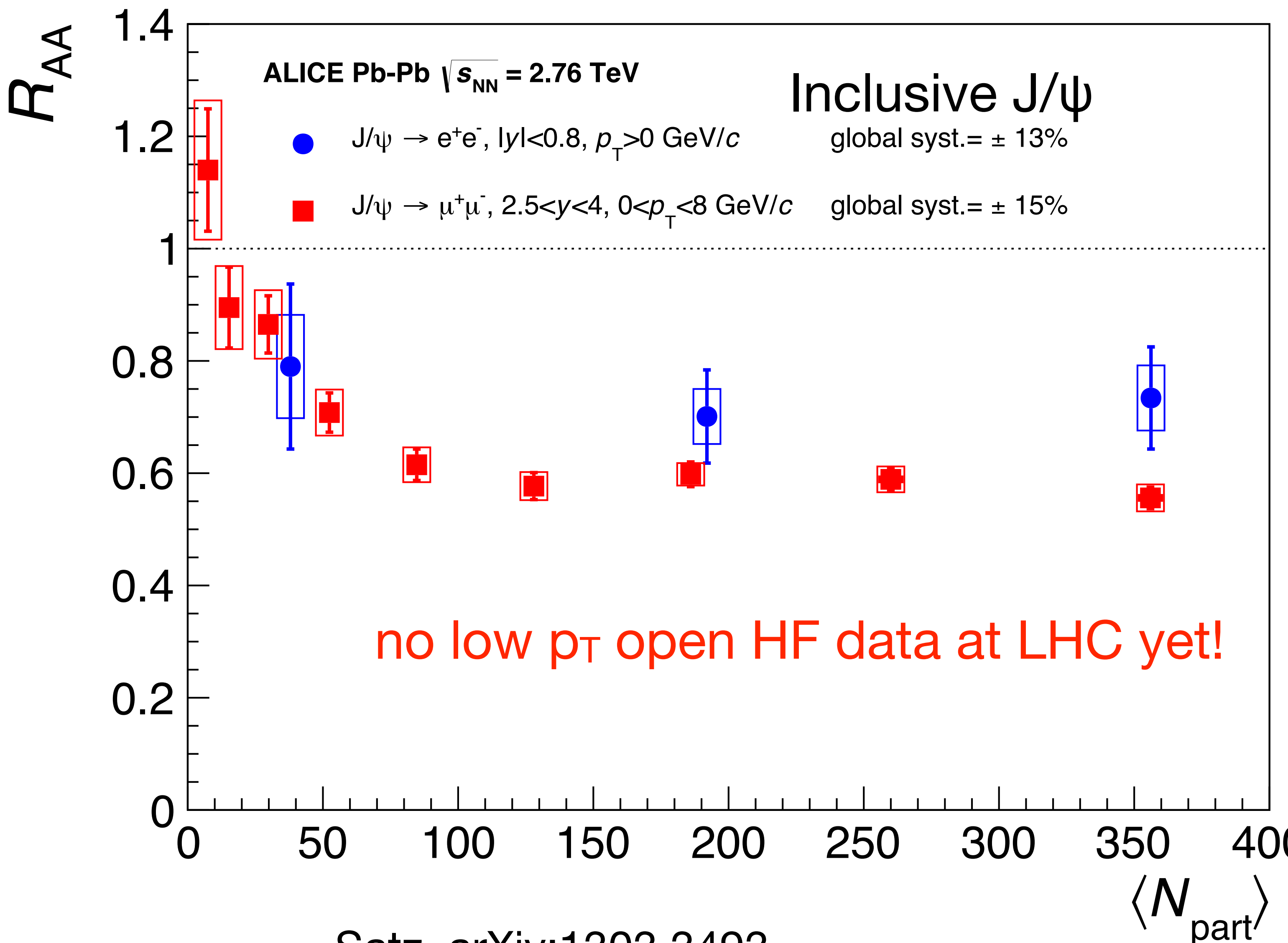




Open vs. Hidden HF in AA

- A brief reminder: Sequential melting a la Satz:
  - less closed than open HF
  - not: less closed HF in AA than in pp
- At RHIC: open charm scales with N_{coll} → $R_{AA}(J/\psi) = J/\psi$ / D in PbPb
  - ignoring the large uncertainties on open charm

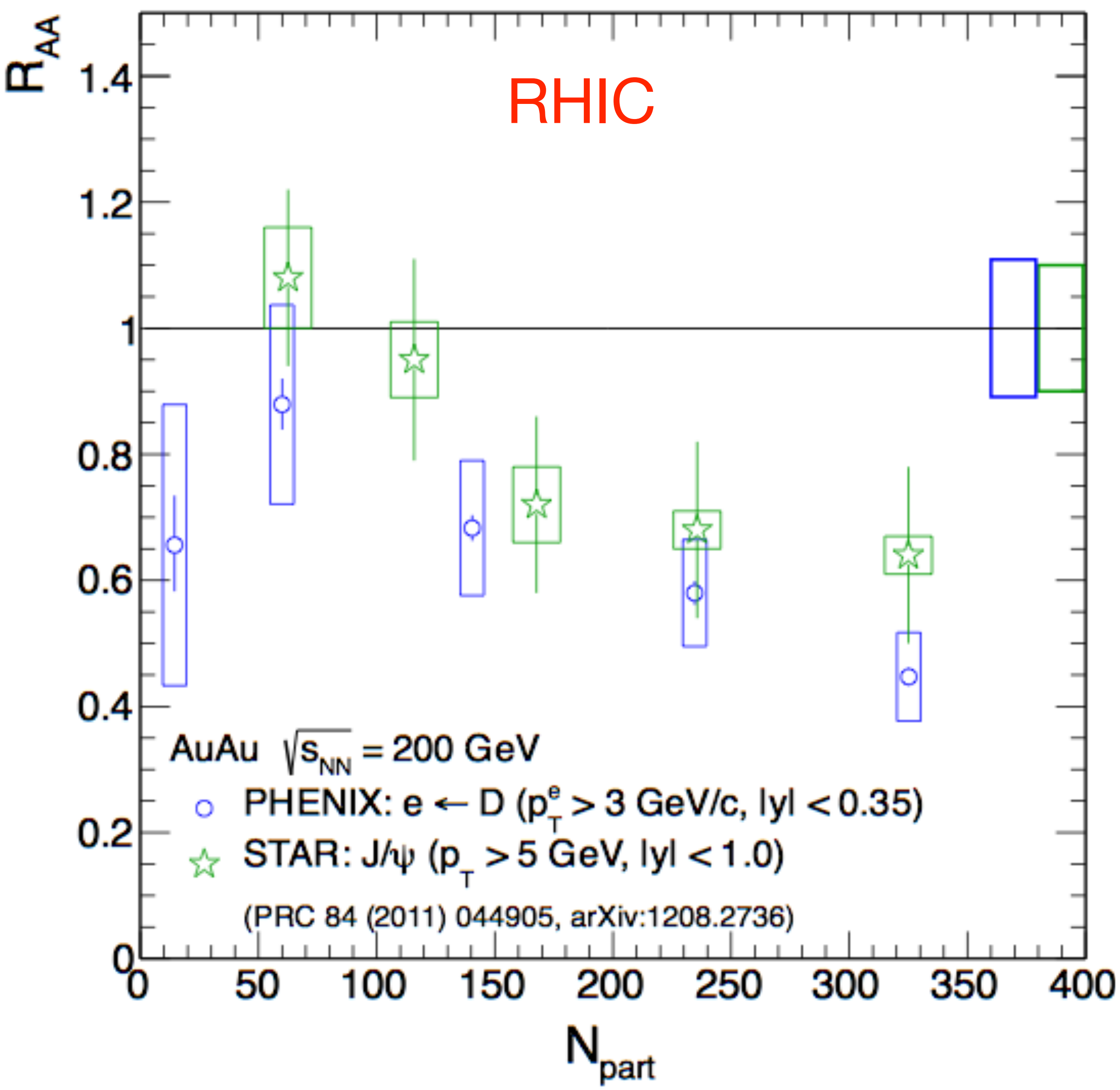


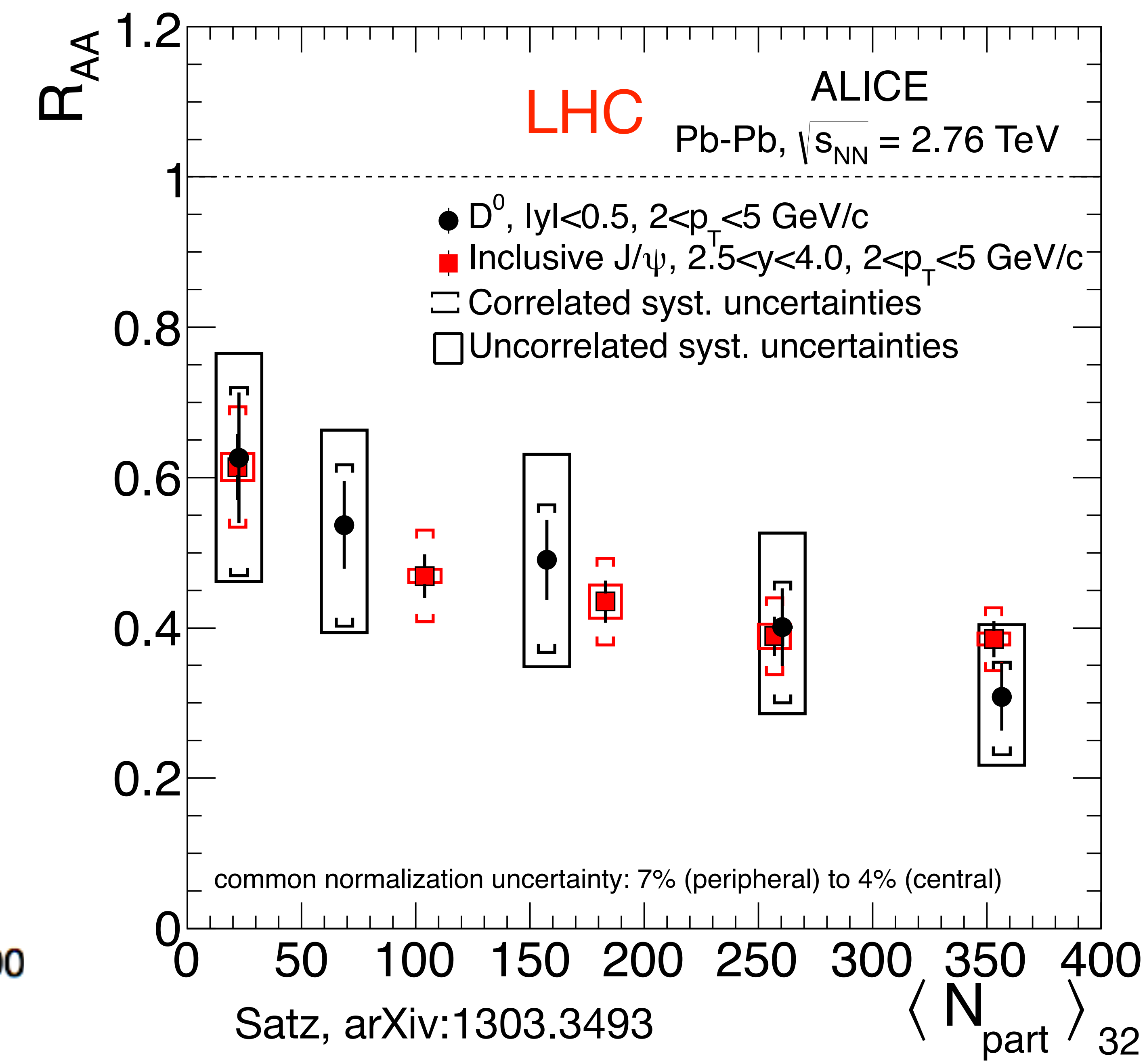


Satz, arXiv:1303.3493

Open vs. Hidden HF in AA: high p_T

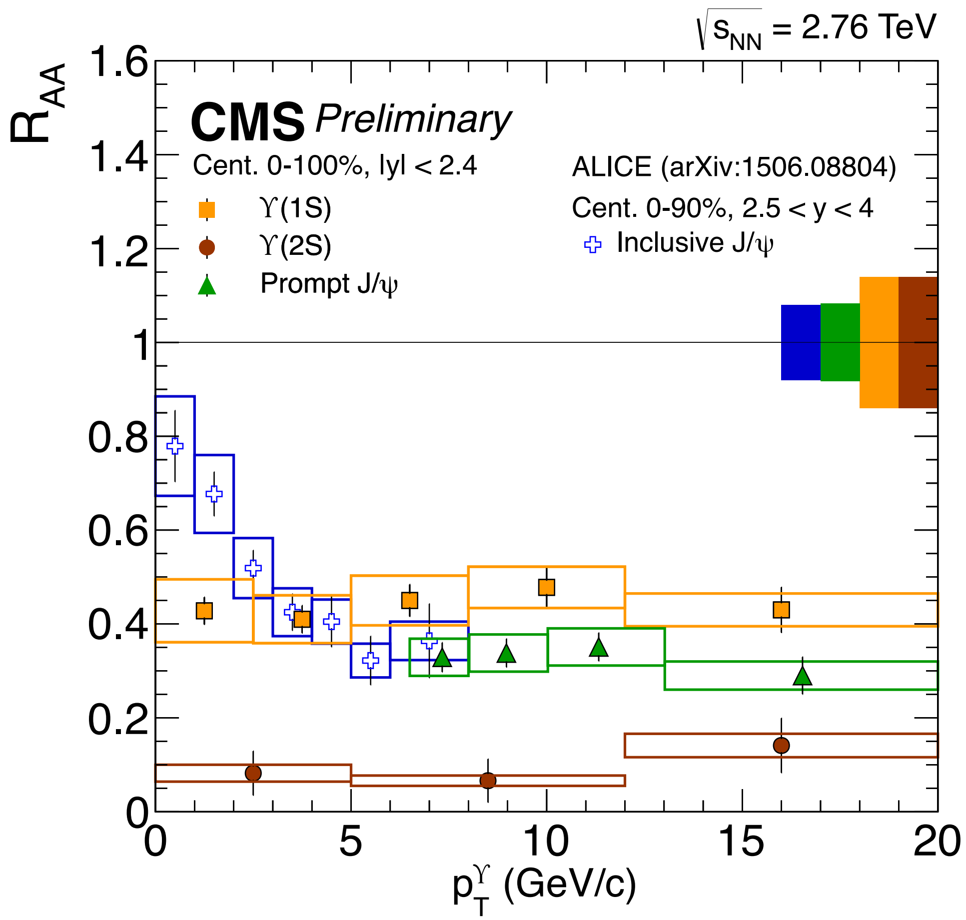
- But how to compare open and closed HF with p_T cuts?
  - not trivial to select kinematic region of interest: same quark p_T, same hadron p_T,...?
- Similar suppression for "high-p_T" D and J/ψ
  (energy loss rather than screening?)



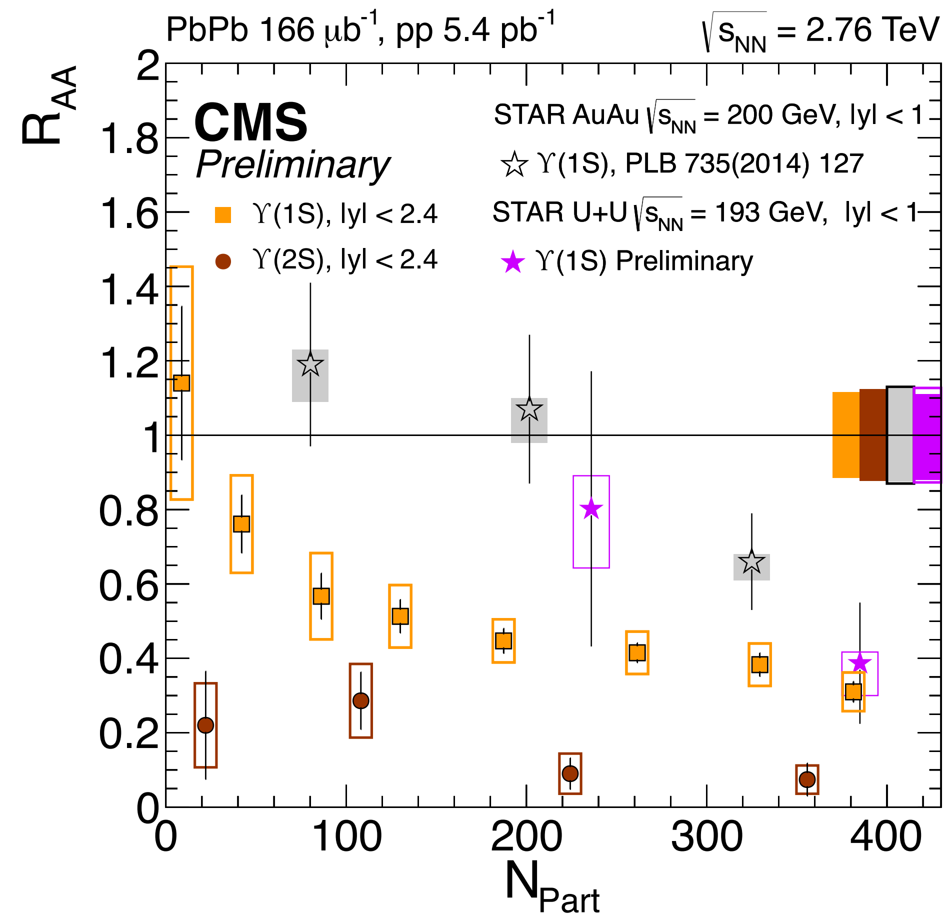


Satz, arXiv:1303.3493

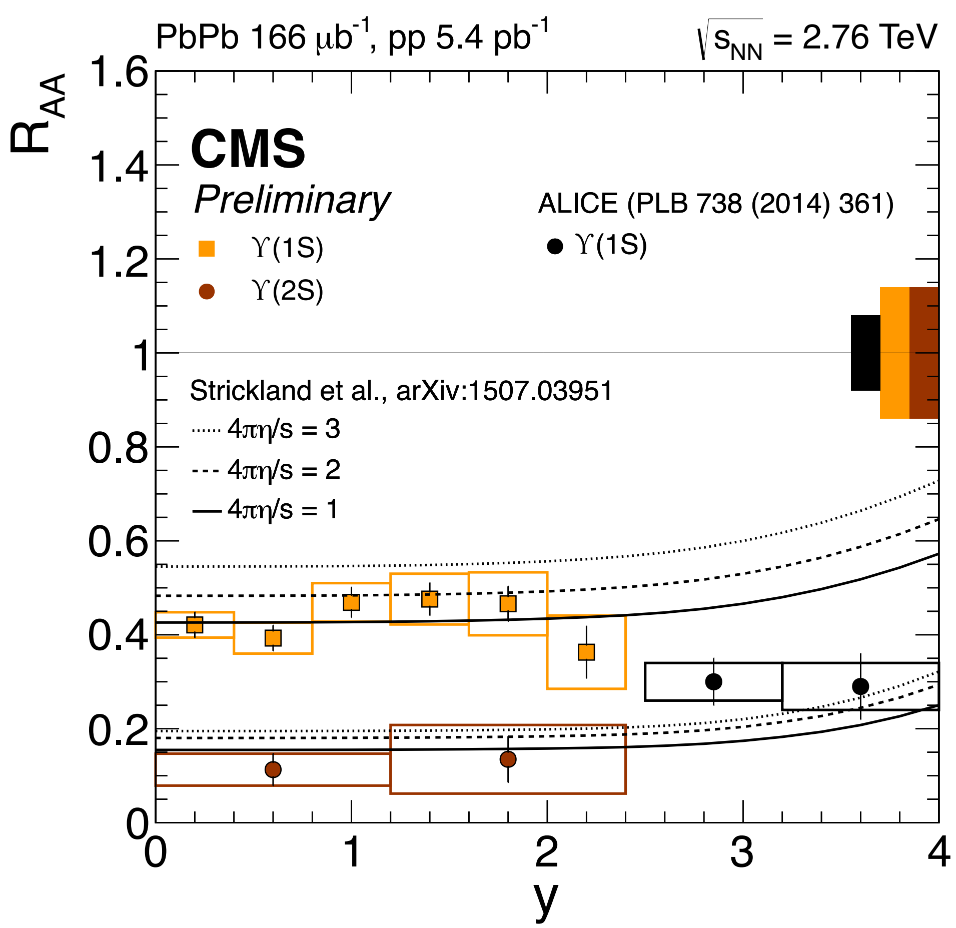
ϒ(nS) in Pb-Pb



$\sqrt{s_{NN}}$ = 2.76 TeV
CMS Preliminary
Cent. 0-100%, |y| < 2.4
ϒ(1S)
ϒ(2S)
Prompt J/ψ
ALICE (arXiv:1506.08804)
Cent. 0-90%, 2.5 < y < 4
Inclusive J/ψ
R_{AA}
p_T^{Υ} (GeV/c)

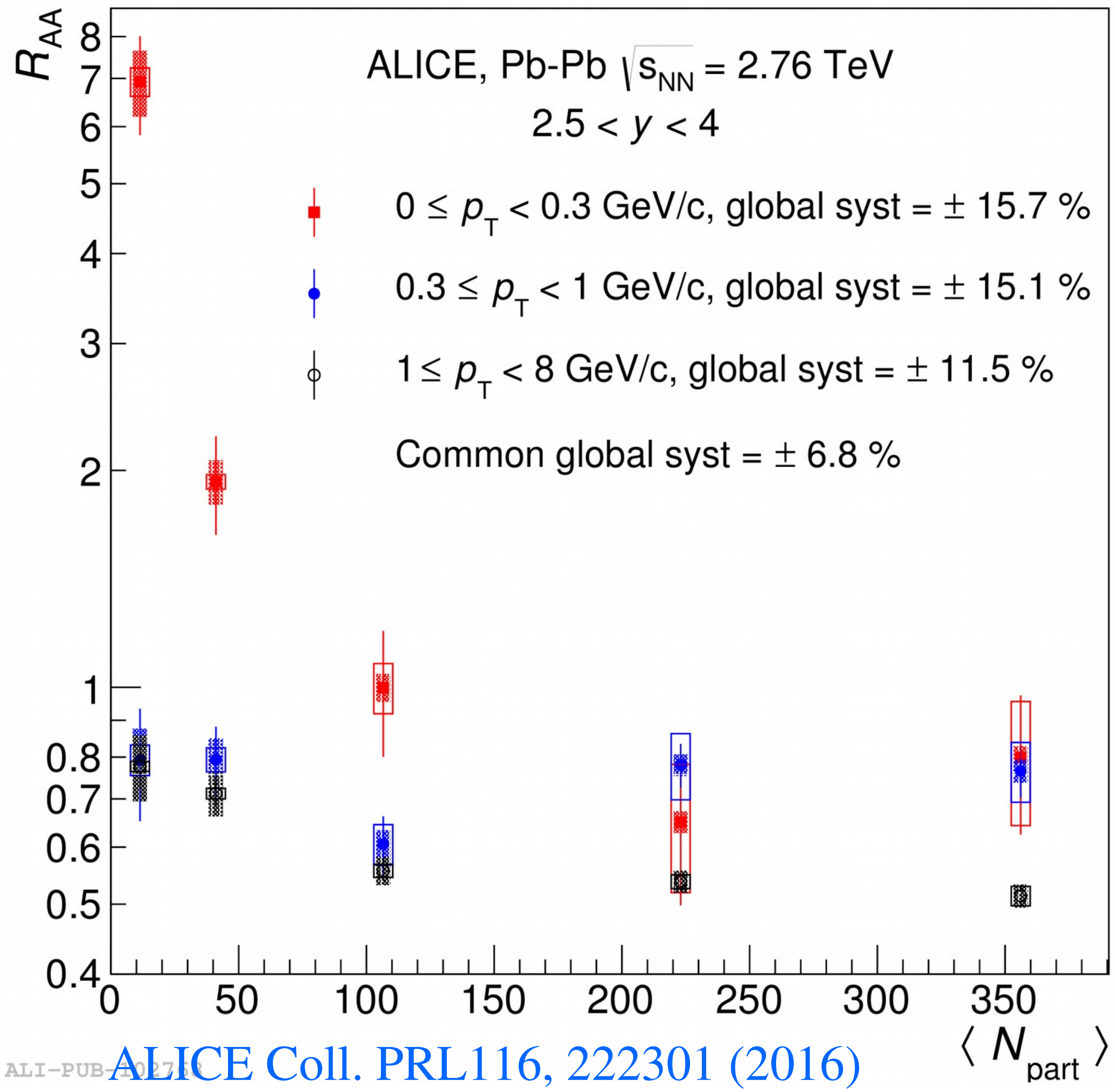


PbPb 166 μb⁻¹, pp 5.4 pb⁻¹
$\sqrt{s_{NN}}$ = 2.76 TeV
CMS Preliminary
ϒ(1S), |y| < 2.4
ϒ(2S), |y| < 2.4
STAR AuAu $\sqrt{s_{NN}}$ = 200 GeV, |y| < 1
ϒ(1S), PLB 735(2014) 127
STAR U+U $\sqrt{s_{NN}}$ = 193 GeV, |y| < 1
ϒ(1S) Preliminary
R_{AA}
N_{Part}



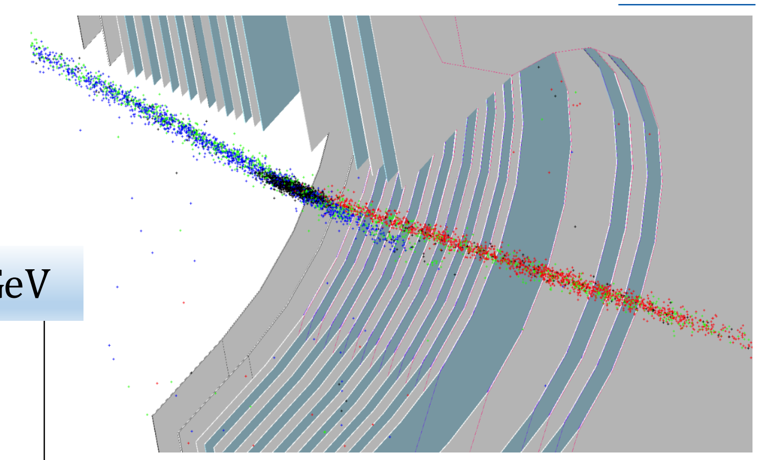
PbPb 166 μb⁻¹, pp 5.4 pb⁻¹
$\sqrt{s_{NN}}$ = 2.76 TeV
CMS Preliminary
ϒ(1S)
ϒ(2S)
ALICE (PLB 738 (2014) 361)
ϒ(1S)
Strickland et al., arXiv:1507.03951
4πη/s = 3
4πη/s = 2
4πη/s = 1
R_{AA}
y

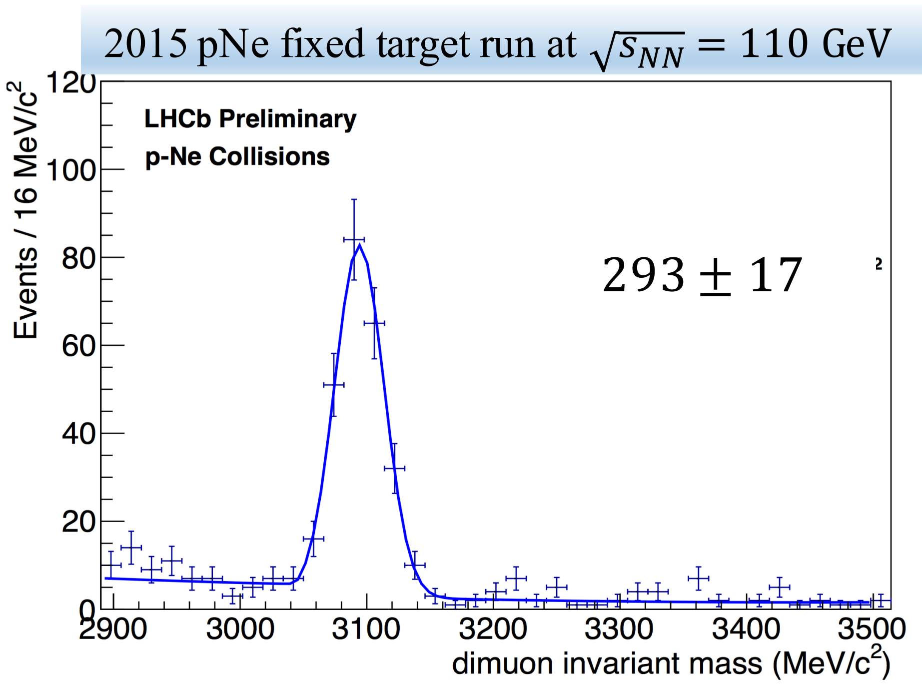
Low-p_T J/ψ in Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

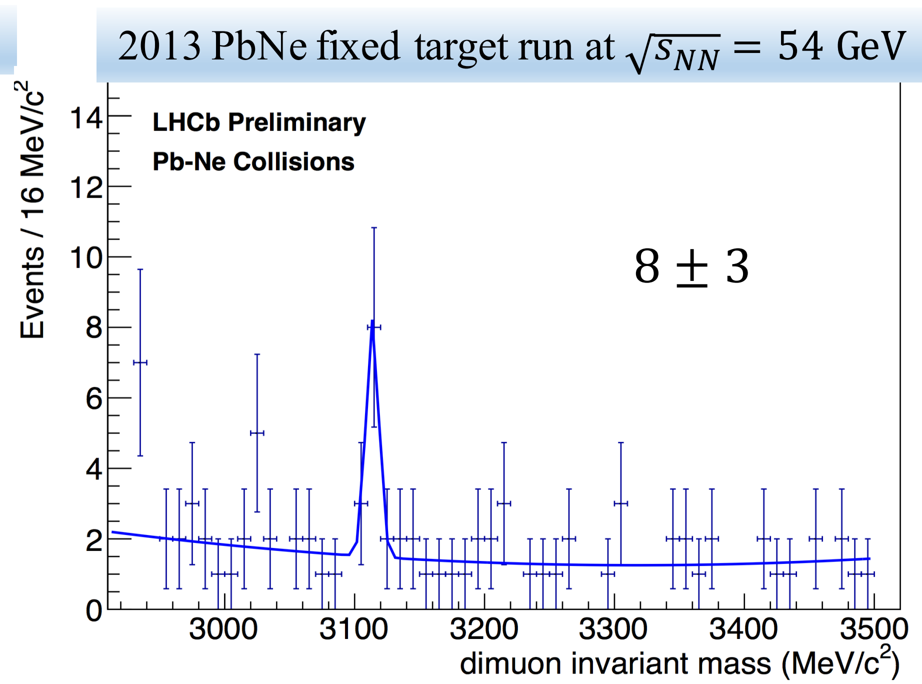


ALICE Coll. PRL116, 222301 (2016)

LHCb: Prospects with SMOG







Y. Zhang, Moriond (QCD) 2016

- **S**ystem for **M**onitoring the **O**verlap with **G**as
- Injection of noble gas in interaction region
- Provides Pb-gas and p-gas collisions with $\sqrt{s_{NN}}$ in RHIC energy regime