ALICE results on quarkonium production in p–Pb collisions

Antoine Lardeux
University of Oslo

On behalf of the ALICE collaboration

Hard Probes - Aix-les-bains
October 2, 2018

Quarkonia in p–A collisions

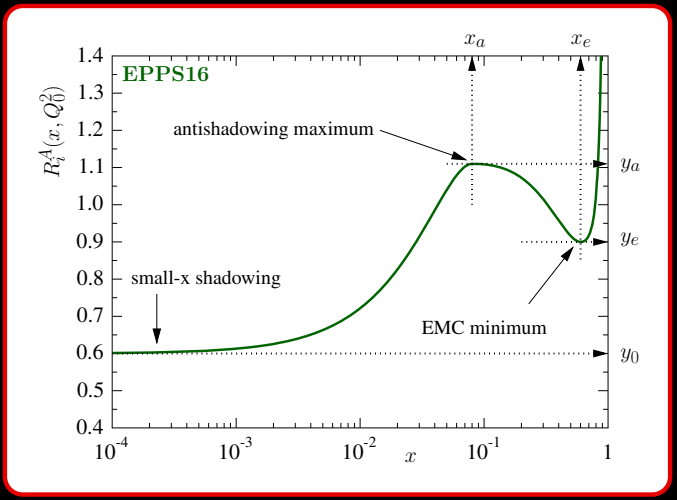
[EPJC (2017) 77:163]

What? **Cold nuclear matter effects** as shadowing/CGC (initial state), *E*loss, comover (final state), etc

Why? Study non-perturbative QCD and understand A–A collisions (cold + hot effects)

How? **p–A collisions:** no quark-gluon plasma expected

Who? **Quarkonia:** meson bound states formed by a pair of heavy quark + anti-quark

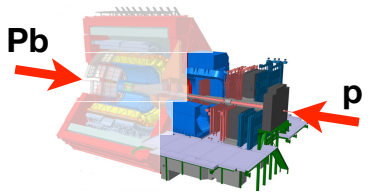


ALICE:

Quarkonia measured **down to zero p_T** via the reconstruction of their leptonic decay products: dielectron at mid-rapidity and dimuon at backward and forward rapidity

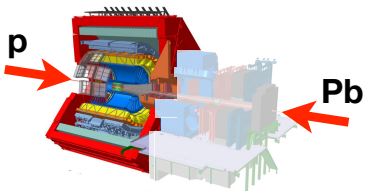
Data collected at $\sqrt{s_{NN}}$ = **5.02 and 8.16 TeV** with **two beam configurations**: p–Pb and Pb–p with $\Delta y = 0.465$ in the p-going direction

Backward



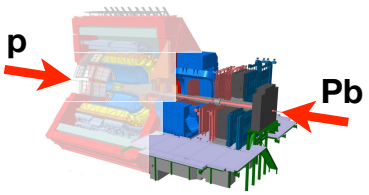
$-4.46 < y_{cms} < -2.96$

Mid



$-1.37 < y_{cms} < 0.43$

Forward



$2.03 < y_{cms} < 3.53$

Outline

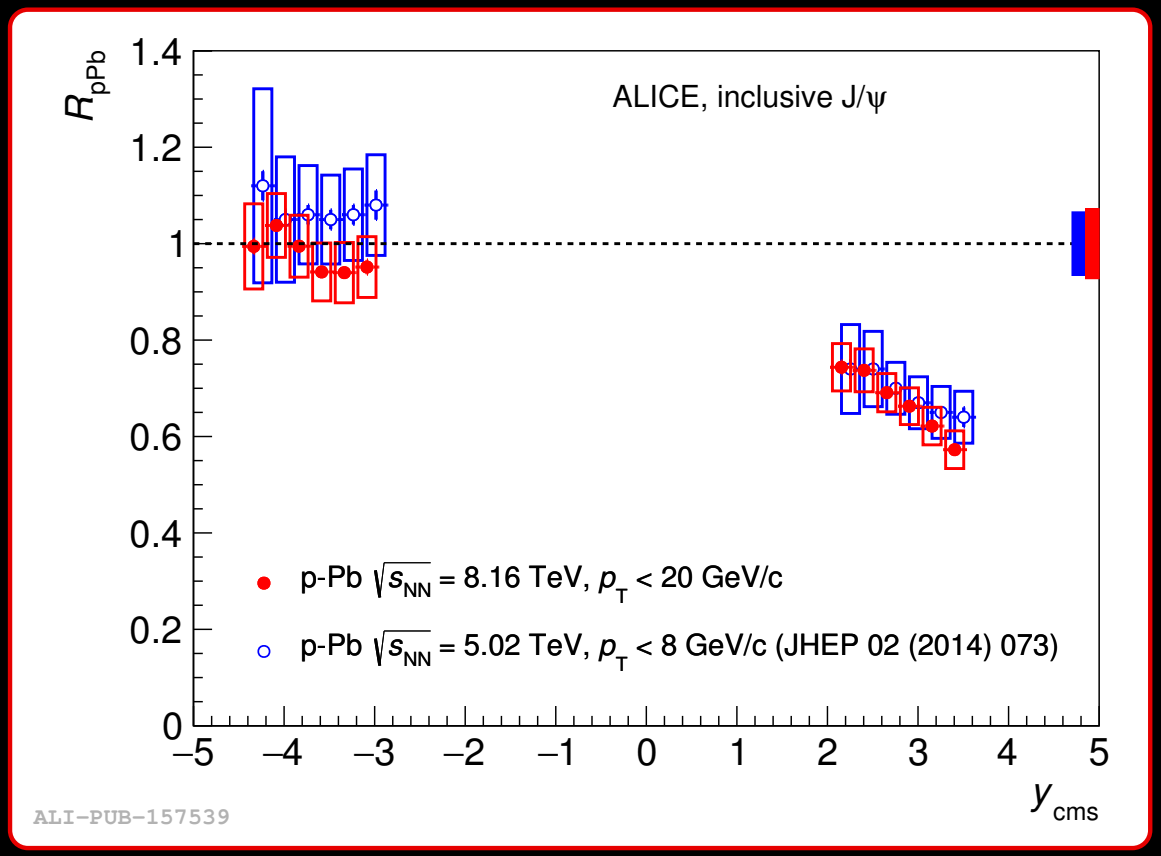
1. J/ψ and ψ(2S) nuclear modification factor
2. Prompt/non-prompt J/ψ
3. J/ψ elliptic flow
4. Υ(1S) and Υ(2S) nuclear modification factor

Outline

1. **J/ψ and ψ(2S) nuclear modification factor**
   - *vs* rapidity
   - *vs* transverse momentum
   - *vs* centrality
   - multi-differential
2. **Prompt/non-prompt J/ψ**
3. **J/ψ elliptic flow**
4. **ϒ(1S) and ϒ(2S) nuclear modification factor**

J/ψ R_{pPb} *vs* rapidity

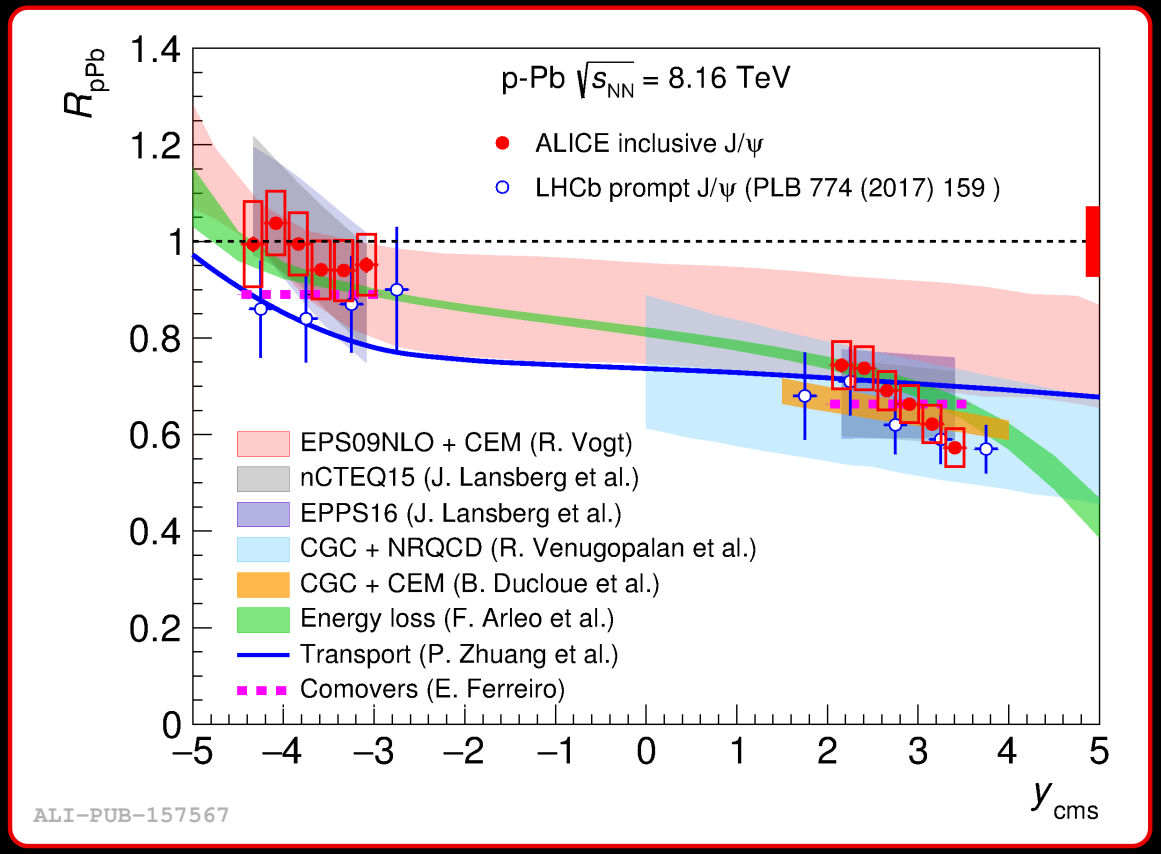
[JHEP 1807 (2018) 160]



- **J/ψ suppression at forward rapidity**
- Same magnitude within uncertainties at $\sqrt{s_{\mathrm{NN}}} = 5.02$ and 8.16 TeV

J/ψ R_{pPb} *vs* rapidity

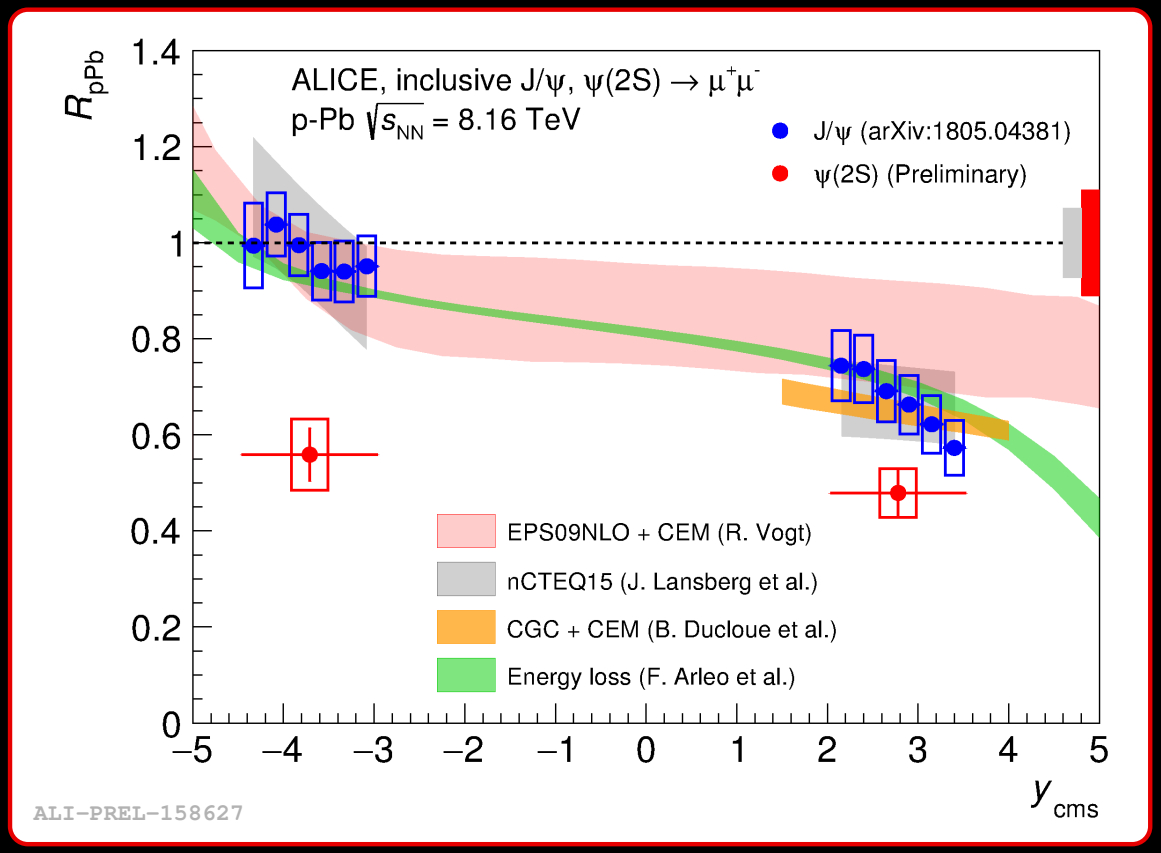
[JHEP 1807 (2018) 160]



- **J/ψ suppression at forward rapidity**
- Same magnitude within uncertainties at $\sqrt{s_{\mathrm{NN}}} = 5.02$ and 8.16 TeV
- Same magnitude within uncertainties with prompt J/ψ from LHCb
- All the models fairly describe the J/ψ data

J/ψ and ψ(2S) R_{pPb} *vs* rapidity

[JHEP 1807 (2018) 160]

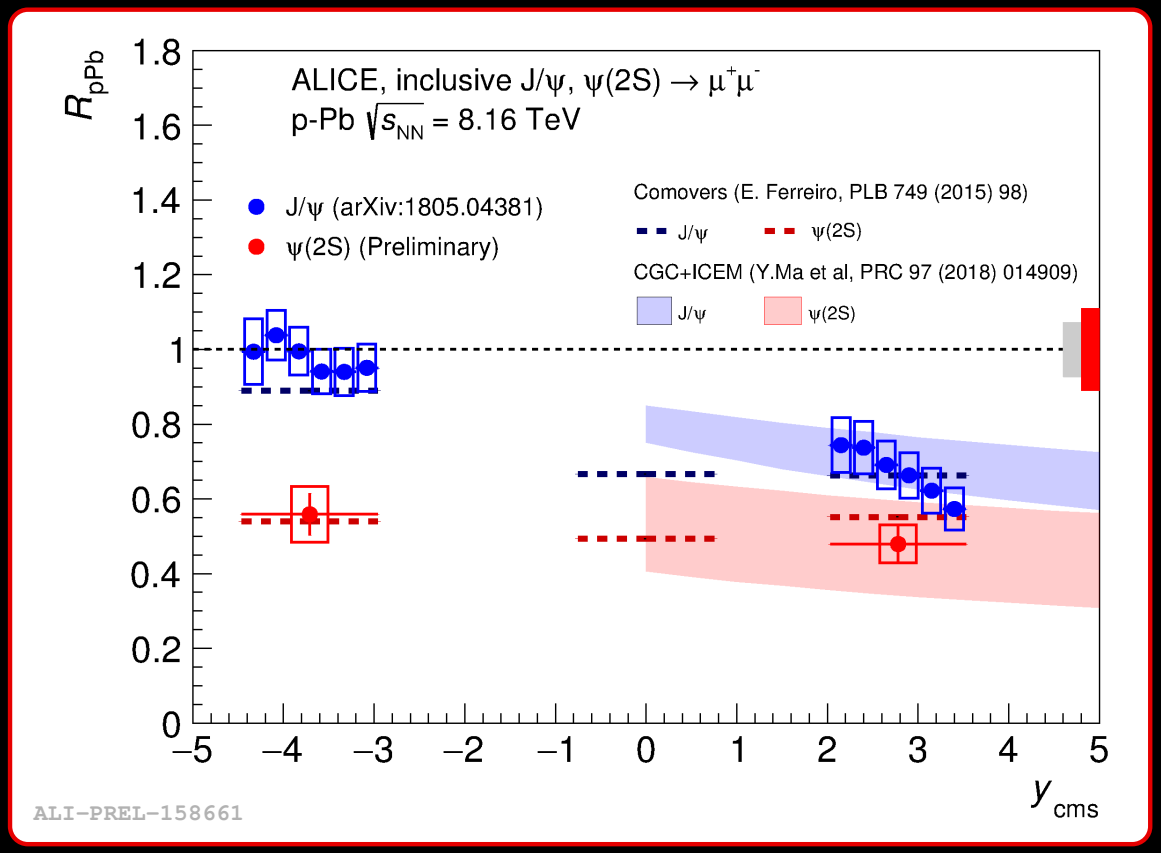


- **J/ψ suppression at forward rapidity**
- Same magnitude within uncertainties at $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV
- Same magnitude within uncertainties with prompt J/ψ from LHCb
- All the models fairly describe the J/ψ data
- **Stronger ψ(2S) suppression than the J/ψ one**, especially at backward rapidity (Pb-going)

- Models based on different shadowing/CGC implementations and energy loss cannot describe the ψ(2S) data

J/ψ and ψ(2S) R_{pPb} *vs* rapidity

[JHEP 1807 (2018) 160]



- **J/ψ suppression at forward rapidity**
- Same magnitude within uncertainties at $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV
- Same magnitude within uncertainties with prompt J/ψ from LHCb
- All the models fairly describe the J/ψ data
- **Stronger ψ(2S) suppression than the J/ψ one**, especially at backward rapidity (Pb-going)

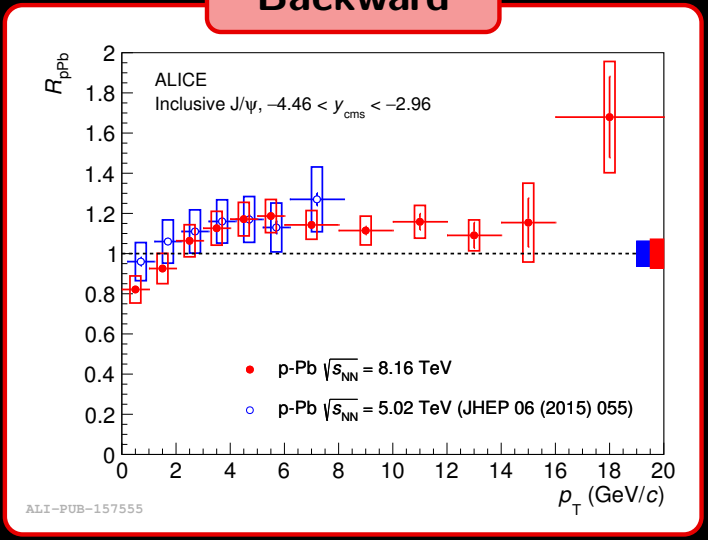
- Models based on different shadowing/CGC implementations and energy loss cannot describe the ψ(2S) data
- **Models including partonic or hadronic interactions with comovers (final-state effects) reproduce both J/ψ and ψ(2S) data**

Final-state effects needed to explain the ψ(2S) behaviour

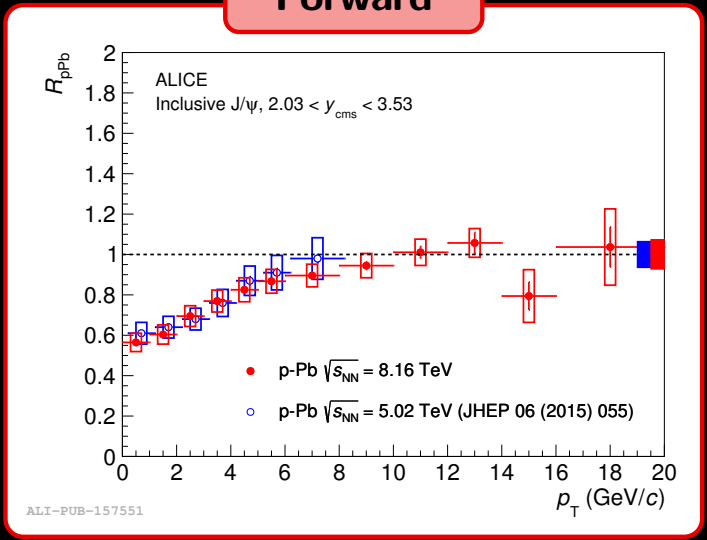
J/ψ R_{pPb} vs p_{T}

[JHEP 1807 (2018) 160], [ALICE-PUBLIC-2018-007]

Backward

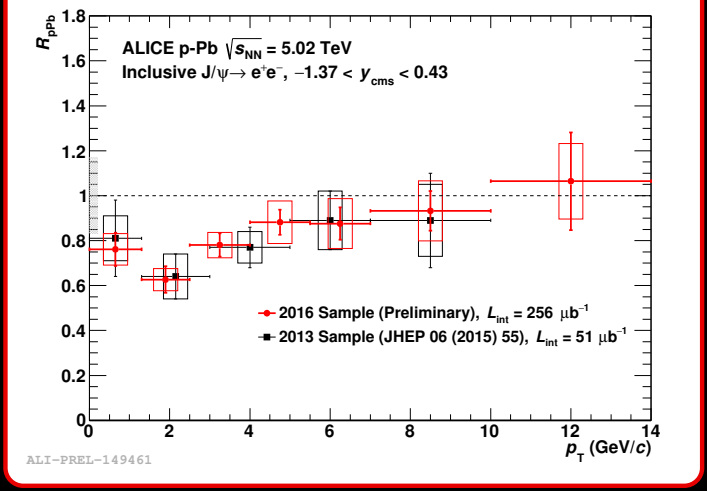


Forward



- higher p_{T} reached with Run-2 datasets
- **p_{T}-dependence** increasing from low to high p_{T}
- J/ψ suppression at mid and forward rapidity is **a low-p_{T} effect**

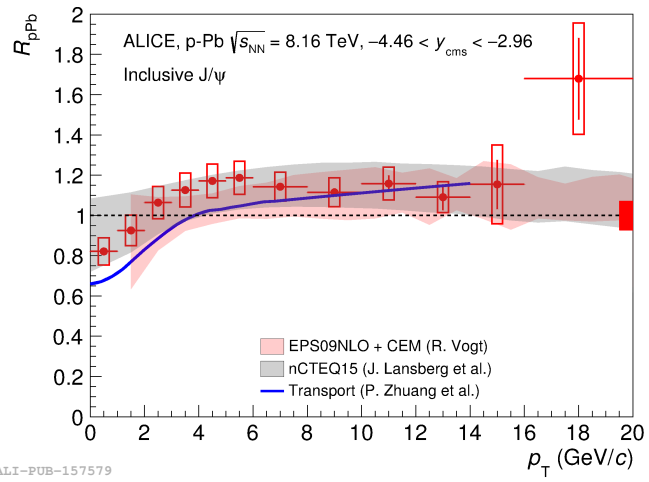
Mid



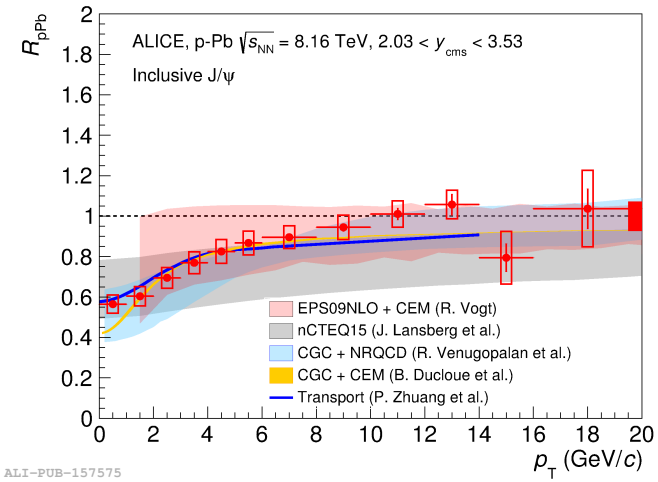
J/ψ R_{pPb} vs p_{T}

[JHEP 1807 (2018) 160], [ALICE-PUBLIC-2018-007]

Backward

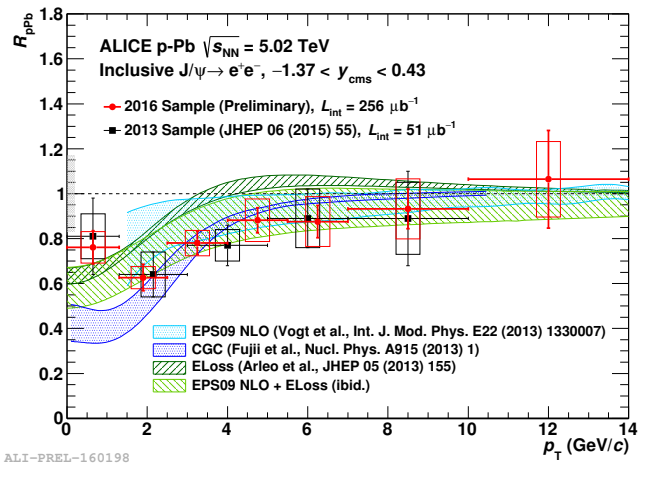


Forward



- higher p_{T} reached with Run-2 datasets
- **p_{T}-dependence** increasing from low to high p_{T}
- J/ψ suppression at mid and forward rapidity is **a low-p_{T} effect**
- Various models based on different theoretical approaches describe the data

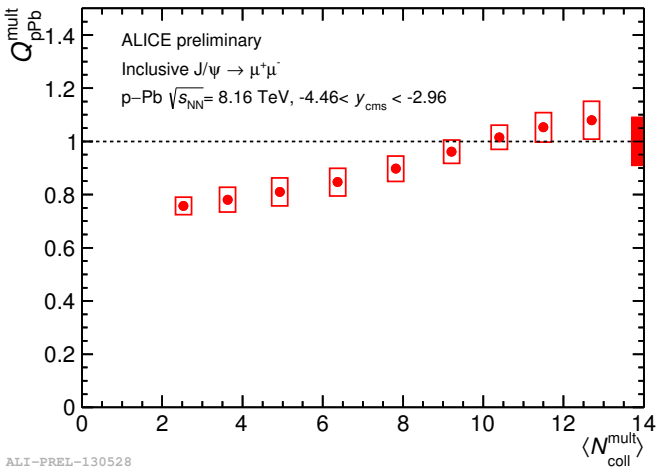
Mid



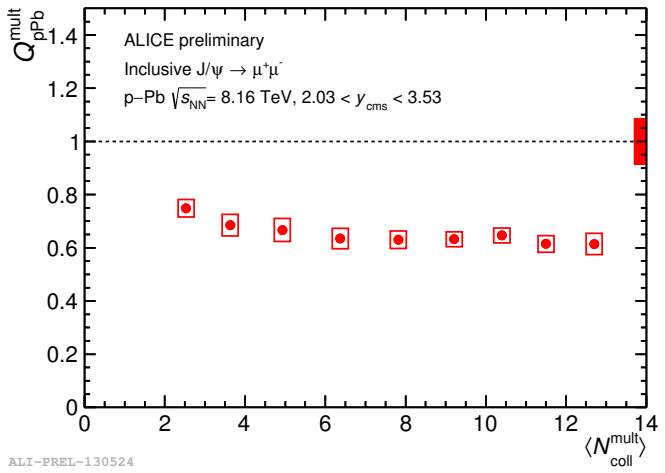
J/ψ Q_{pPb} *vs* N_{coll}

[ALICE-PUBLIC-2018-007]

Backward

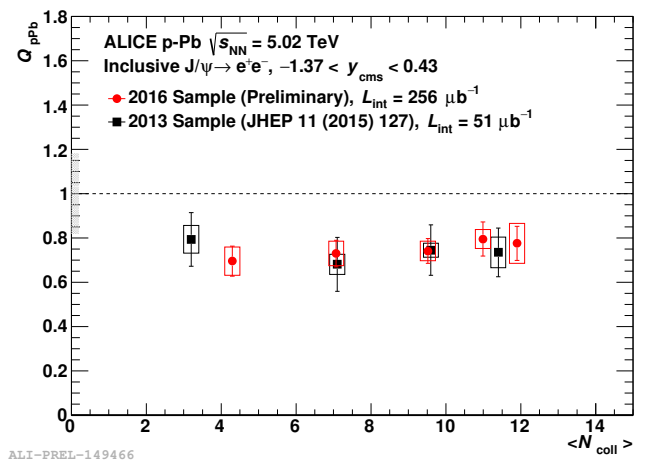


Forward



- Q_{pPb} increases at backward rapidity from peripheral to central collisions
- Q_{pPb} is constant at mid-rapidity and slightly decreases at forward rapidity from peripheral to central collisions

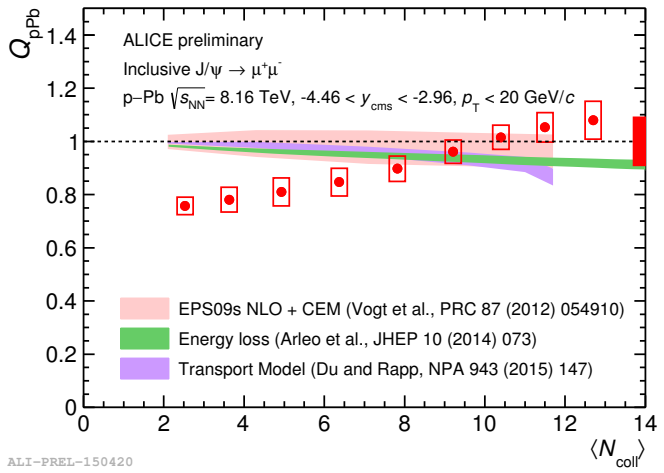
Mid



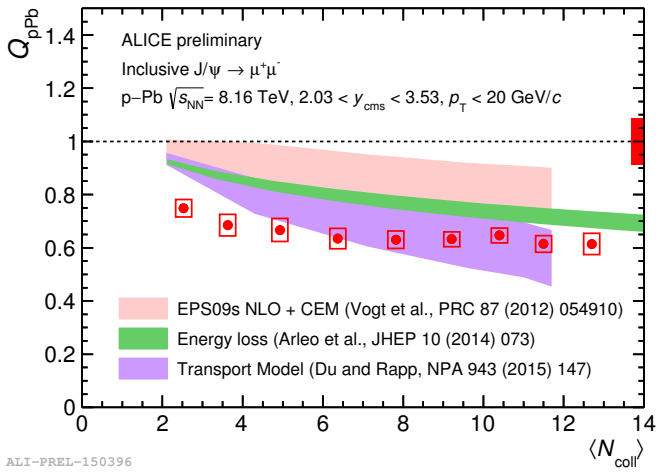
J/ψ Q_{pPb} *vs* N_{coll}

[ALICE-PUBLIC-2018-007]

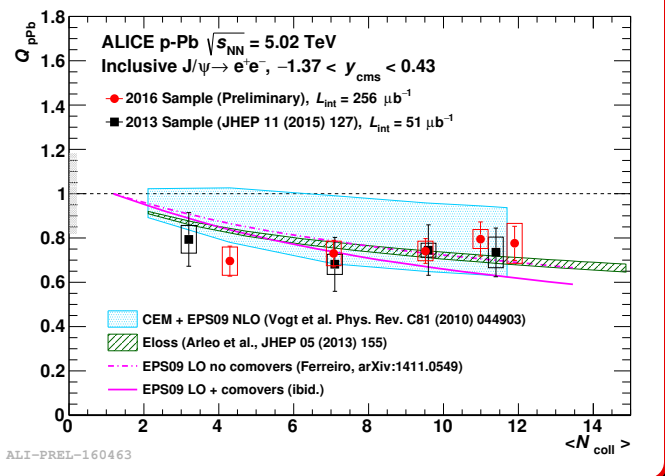
Backward



Forward



Mid

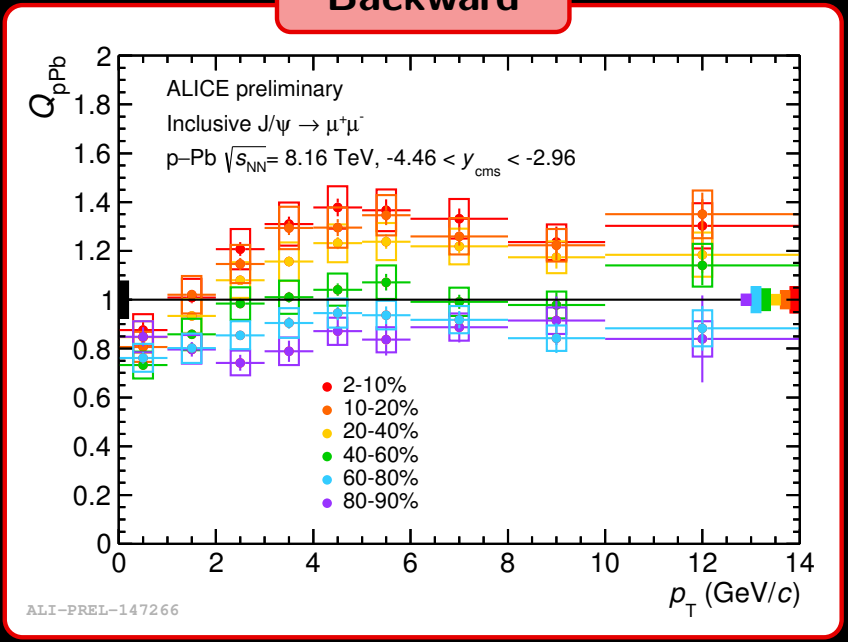


- Q_{pPb} increases at backward rapidity from peripheral to central collisions
- Q_{pPb} is constant at mid-rapidity and slightly decreases at forward rapidity from peripheral to central collisions
- Models do not reproduce the slope of the data at backward rapidity

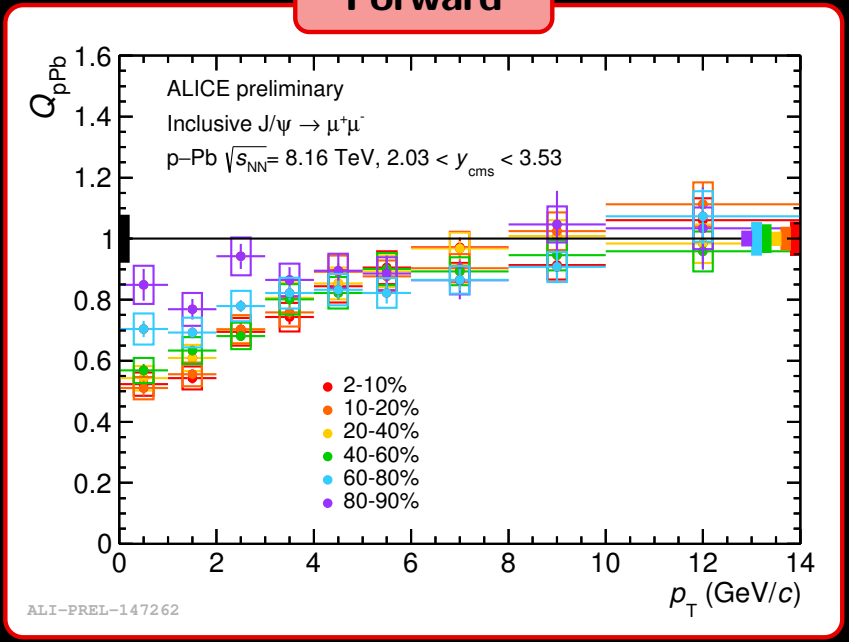
J/ψ Q_{pPb} *vs* p_{T} for different centrality

Preliminary

Backward



Forward



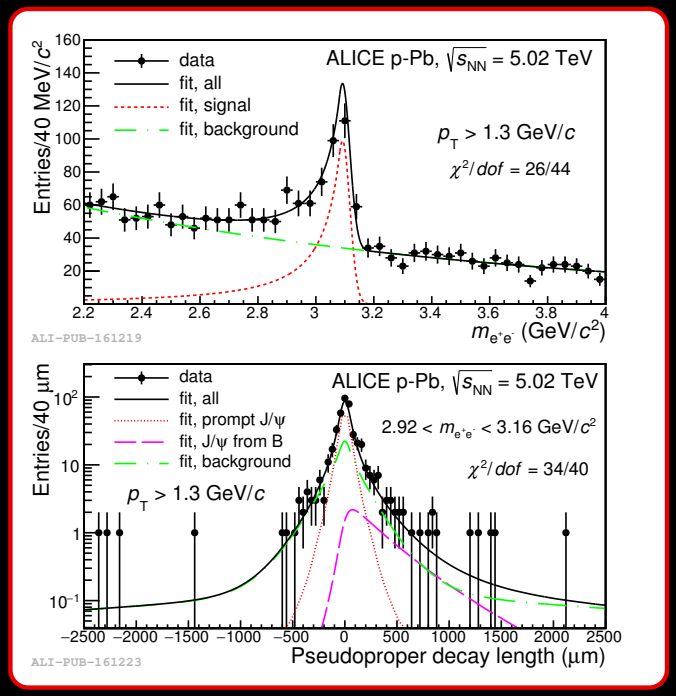
- Clear evolution of Q_{pPb} *vs* p_{T} in different centrality classes
- Backward: enhancement in most central collisions for $p_{\mathrm{T}} > 3$ GeV/c
- Forward: stronger suppression at low p_{T} in most central collisions

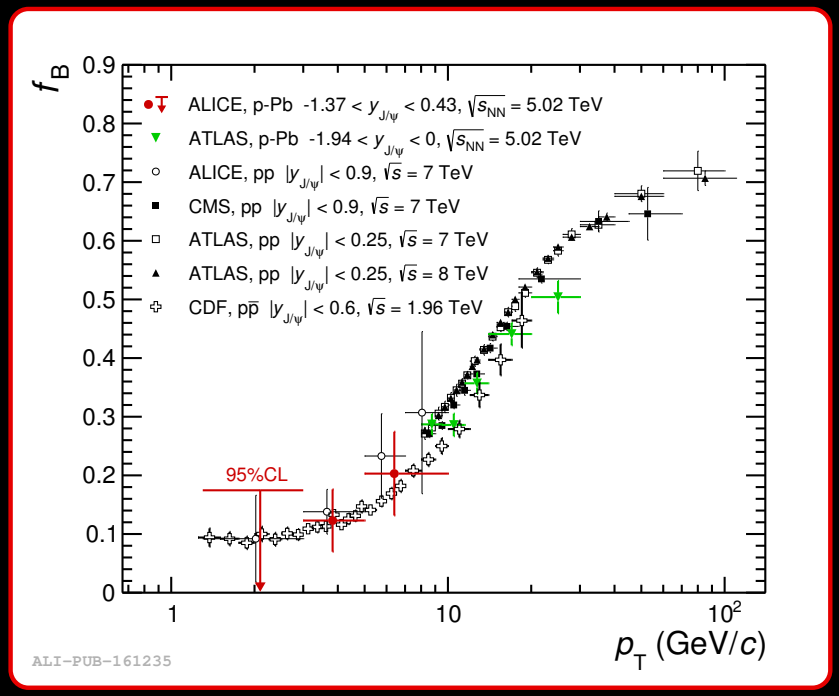
Outline

1. J/ψ and ψ(2S) nuclear modification factor
2. Prompt/non-prompt J/ψ
3. J/ψ elliptic flow
4. Υ(1S) and Υ(2S) nuclear modification factor

Prompt/non-prompt J/ψ at mid-rapidity

[EPJC 78 (2018) 466]



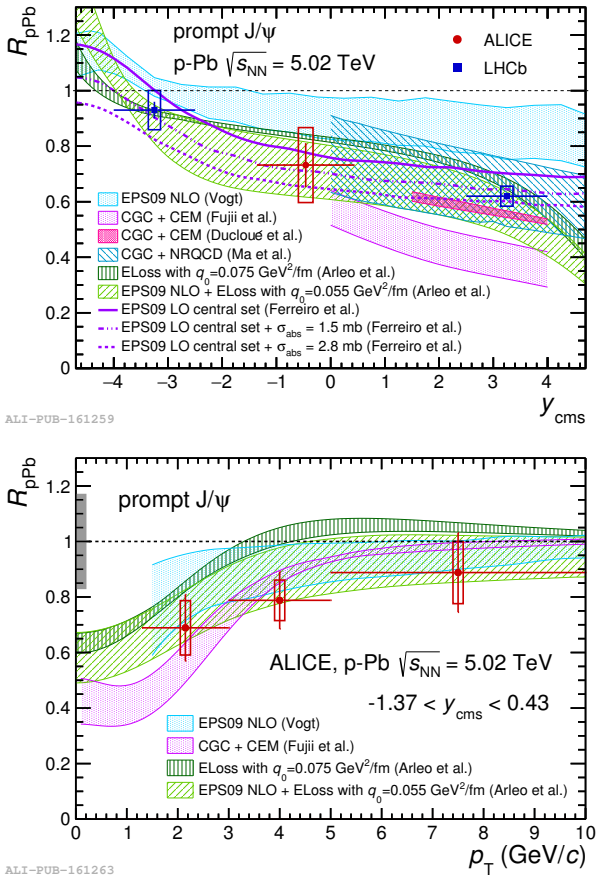


- Prompt/non-prompt separation via a combined fit to dielectron invariant mass and pseudoproper decay length
- Fraction of J/ψ originating from B-hadron decays is compatible with pp measurement: f_B ($p_T > 1.3$ GeV/c, $-1.37 < y < 0.43$) = **0.105** ± 0.038 (stat) ± 0.012 (syst)

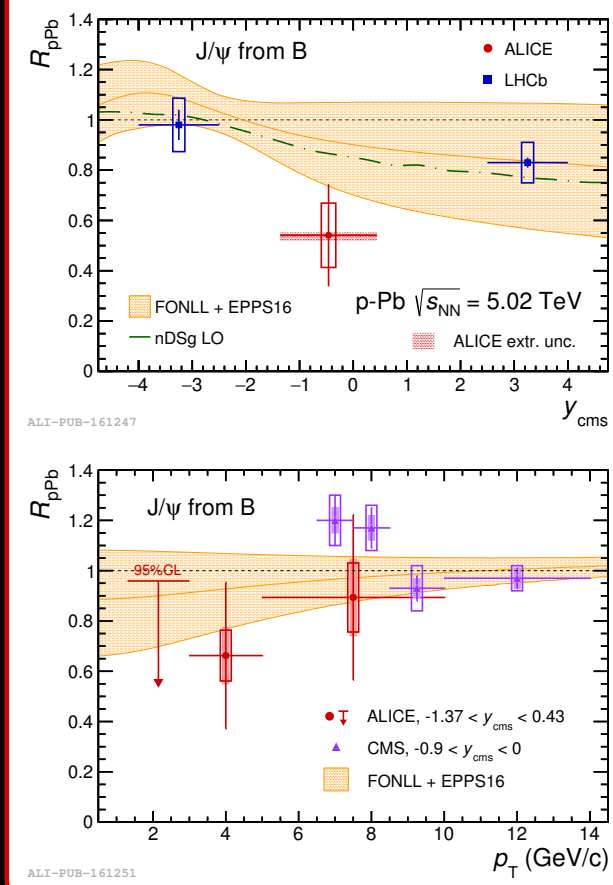
Prompt/non-prompt J/ψ at mid-rapidity

[EPJC 78 (2018) 466]

prompt



non-prompt



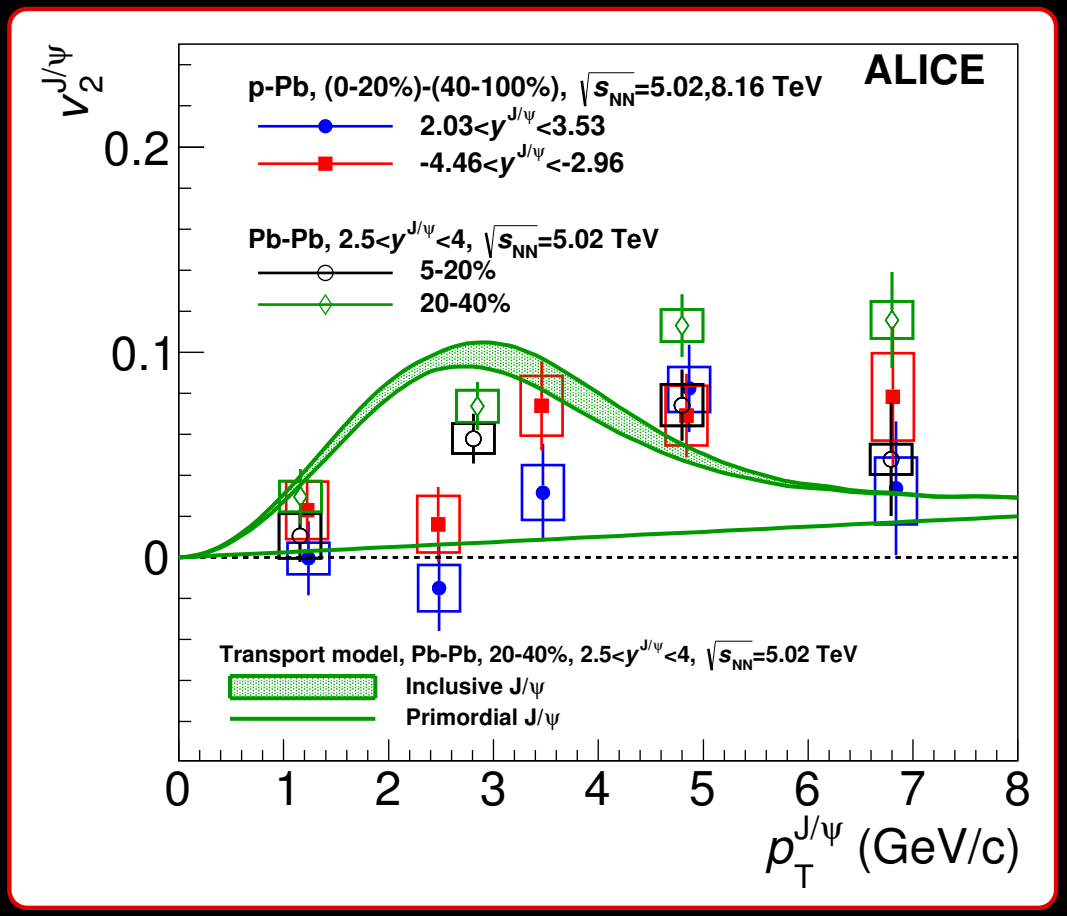
- Same R_{pPb} conclusions for prompt J/ψ as for the inclusive production: suppression at mid-rapidity with a hint for a low-p_{T} effect
- R_{pPb} of non-prompt J/ψ from B-hadron decays indicates a stronger suppression than the prompt J/ψ production

Outline

1. J/ψ and ψ(2S) nuclear modification factor
2. Prompt/non-prompt J/ψ
3. J/ψ elliptic flow
4. Υ(1S) and Υ(2S) nuclear modification factor

J/ψ elliptic flow v_2

[PLB 780 (2018) 2]



Anisotropy is quantified by the 2nd order coefficient v_2 of the Fourier expansion of the long-range particle azimuthal distribution

- Low p_T: **v_2 compatible with zero**

  → agree with no regeneration due to the low production of charm quarks

- High p_T: **positive v_2**

  → similar to the Pb–Pb data!!
  Not understood
  (Negligible path-length dependence regarding the small system size)

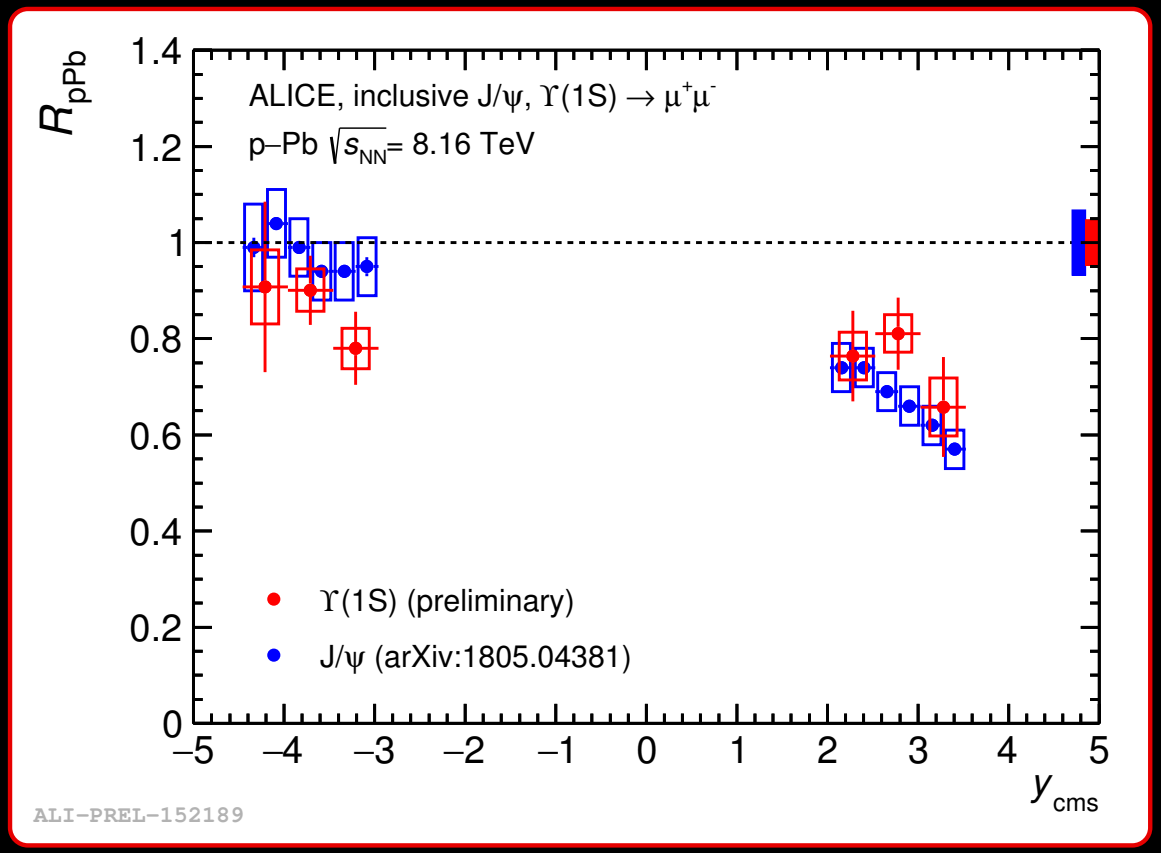
Similar magnitude of J/ψ v_2 in p–Pb and Pb–Pb collisions could indicate a common mechanism

Outline

1. **J/ψ and ψ(2S) nuclear modification factor**
2. **Prompt/non-prompt J/ψ**
3. **J/ψ elliptic flow**
4. **ϒ(1S) and ϒ(2S) nuclear modification factor**
   - *vs* rapidity
   - *vs* transverse momentum

$\Upsilon(1S)$ R_{pPb} *vs* rapidity

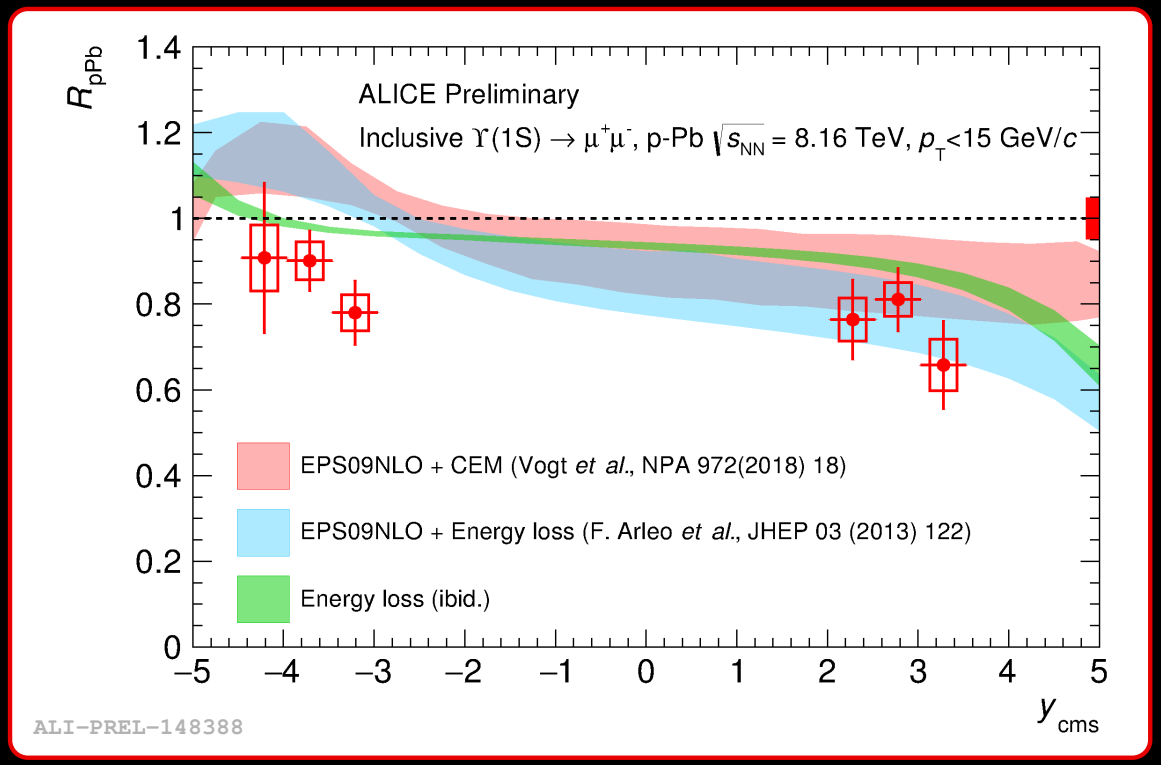
[ALICE-PUBLIC-2018-008]



- Similar **$\Upsilon(1S)$ suppression** within uncertainties **at forward and backward rapidity**
- Similar magnitude of $\Upsilon(1S)$ and J/ψ R_{pPb} within uncertainties

$\Upsilon(1S)$ R_{pPb} *vs* rapidity

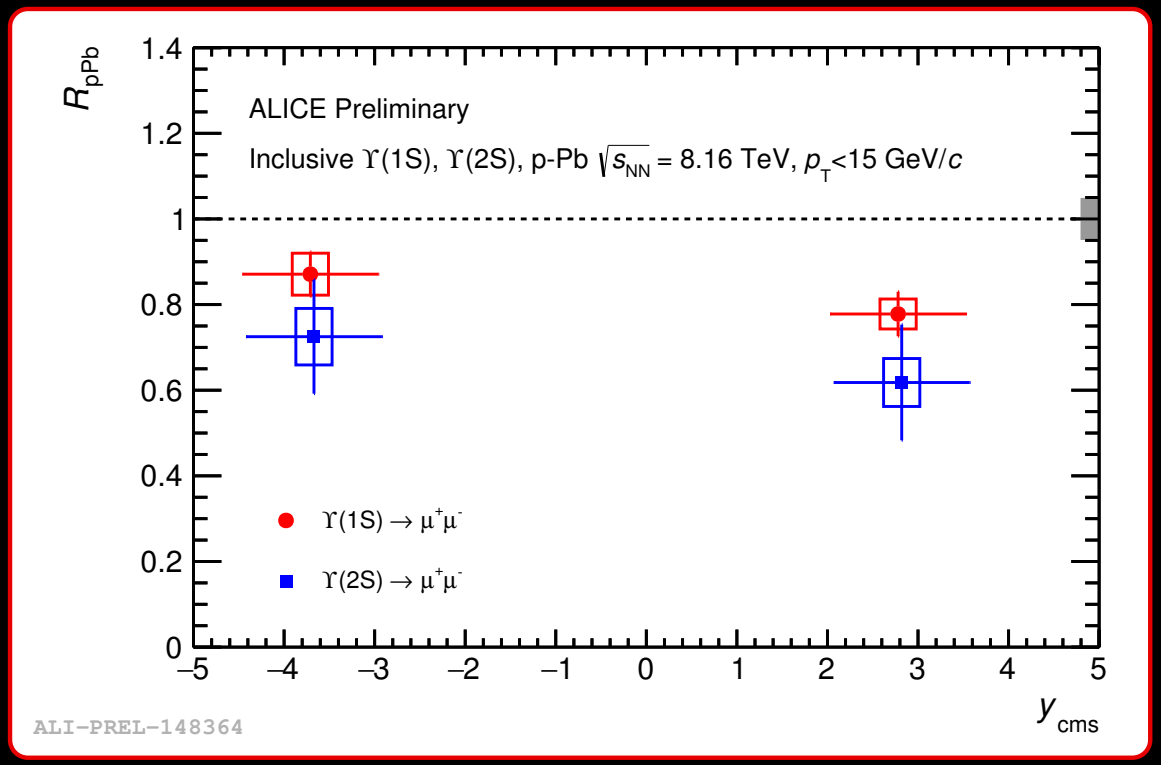
[ALICE-PUBLIC-2018-008]



- Similar **$\Upsilon(1S)$ suppression** within uncertainties **at forward and backward rapidity**
- Similar magnitude of $\Upsilon(1S)$ and J/ψ R_{pPb} within uncertainties
- Models based on shadowing and/or energy loss reproduce the forward rapidity data but slightly overestimate the backward rapidity data

$\Upsilon(2S)$ R_{pPb} *vs* rapidity

[ALICE-PUBLIC-2018-008]



- Similar **$\Upsilon(1S)$ suppression** within uncertainties **at forward and backward rapidity**
- Similar magnitude of $\Upsilon(1S)$ and J/ψ R_{pPb} within uncertainties
- Models based on shadowing and/or energy loss reproduce the forward rapidity data but slightly overestimate the backward rapidity data

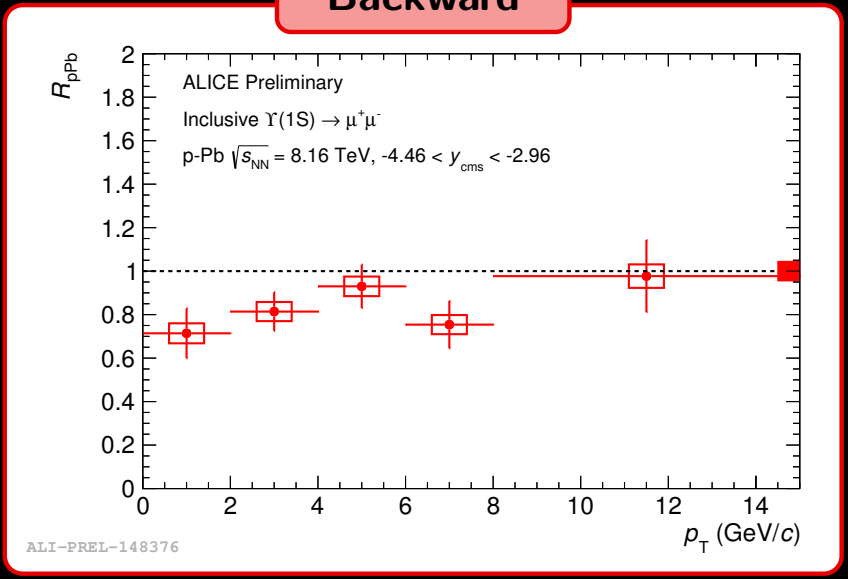
- **$\Upsilon(2S)$ R_{pPb} consistent with the $\Upsilon(1S)$ one** within uncertainties with a **hint for a stronger suppression of $\Upsilon(2S)$** (as observed by CMS and ATLAS at mid-y)

Similar CNM effects within uncertainties for Υ at backward and forward rapidity

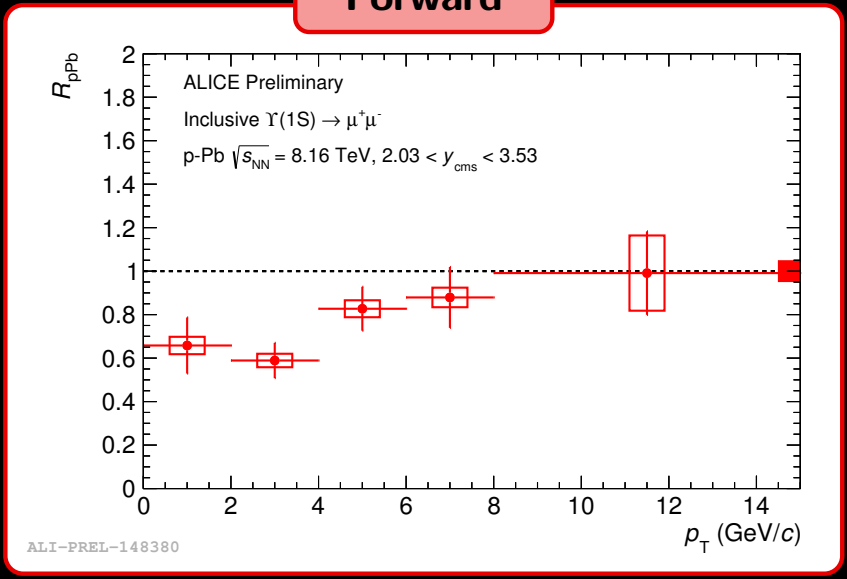
$\Upsilon(1S)$ R_{pPb} *vs* p_T

[ALICE-PUBLIC-2018-008]

Backward



Forward

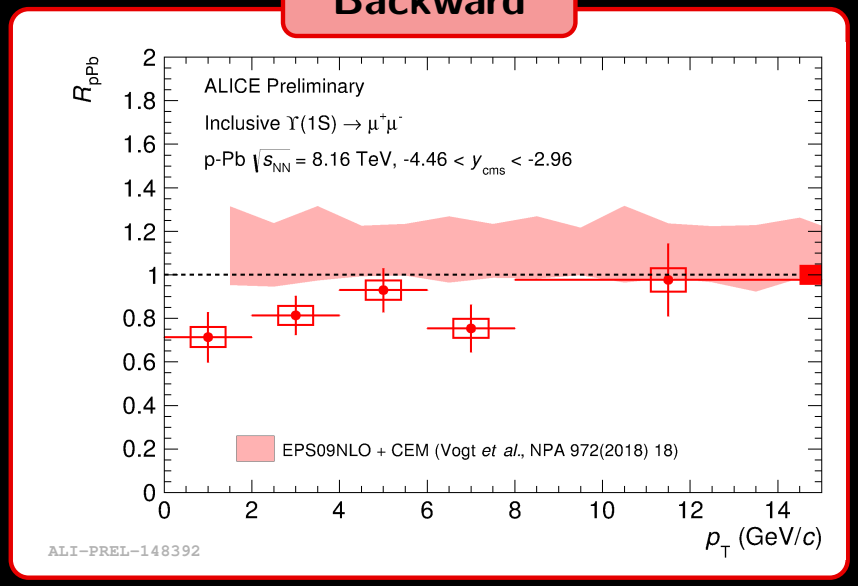


- Similar behavior at both backward and forward rapidity with a **hint for a stronger suppression at low p_T**

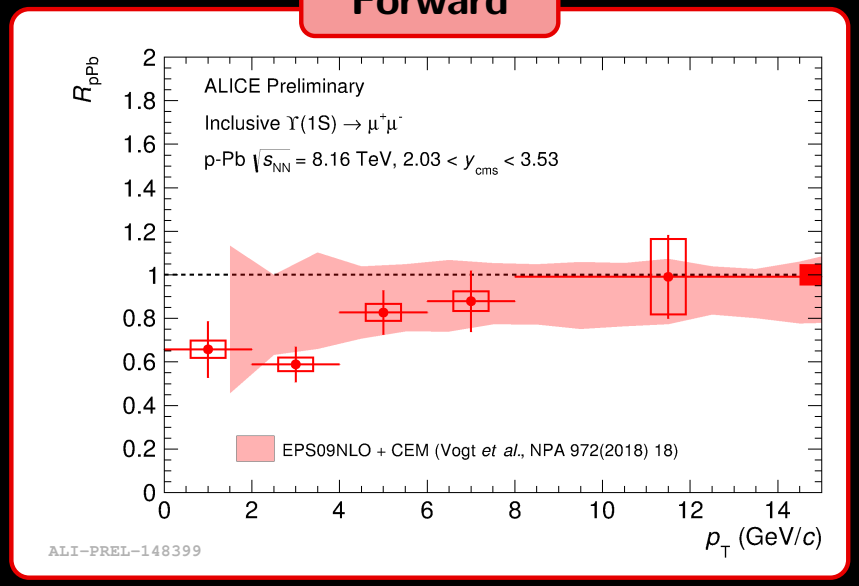
$\Upsilon(1S)$ R_{pPb} *vs* p_T

[ALICE-PUBLIC-2018-008]

Backward



Forward



- Similar behavior at both backward and forward rapidity with a **hint for a stronger suppression at low p_T**
- Model based on shadowing describes the forward rapidity results but slightly overestimate the backward rapidity ones

Summary

- ALICE has measured J/ψ, ψ(2S), ϒ(1S) and ϒ(2S) production in p–Pb collisions at both $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV LHC energies
- Run-2 results increased significantly the precision of the measurements
- Models face difficulties in describing consistently all results

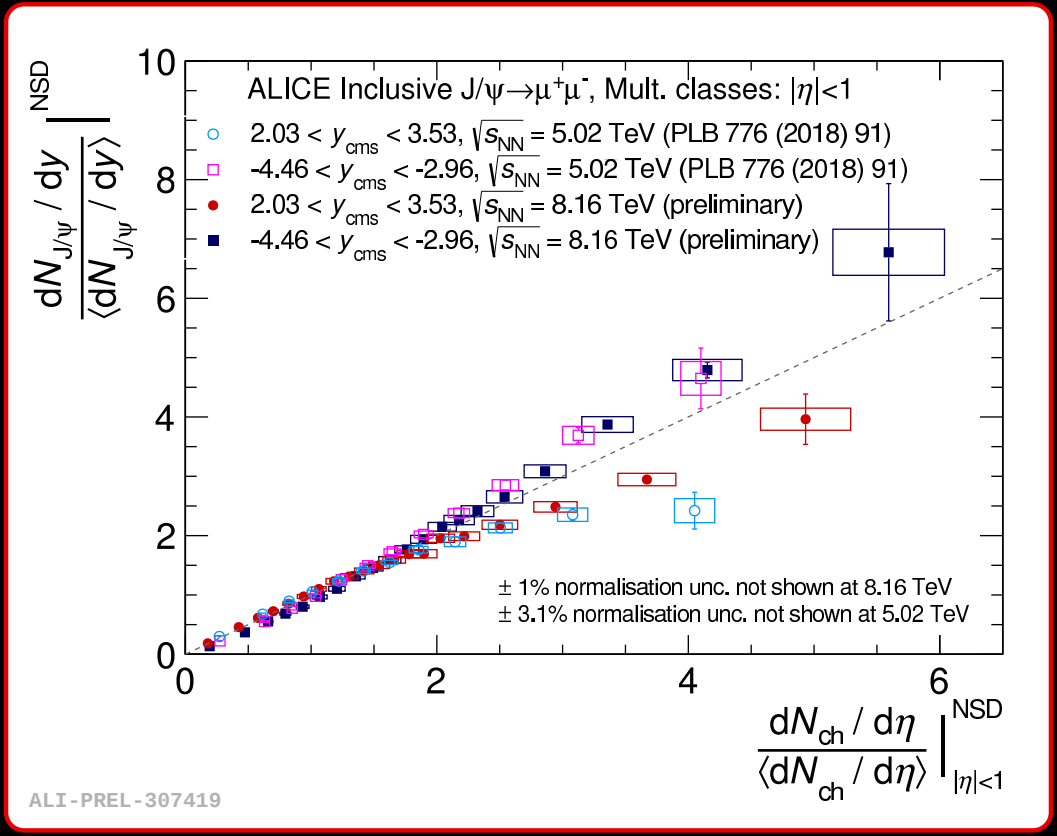
J/ψ
- R_{pPb} show a suppression at mid and forward rapidity mainly in the low-p_{T} region
- Various models based on different theoretical approaches qualitatively describe the results
- Positive v_2 similar to Pb–Pb for $p_{\mathrm{T}} > 4$ GeV/c → common mechanism?

ψ(2S)
- Final state effects needed to describe its stronger suppression than the J/ψ

ϒ
- Suppression of ϒ(1S) at backward and forward rapidity with a hint for a stronger ϒ(2S) suppression

Summary

Preliminary

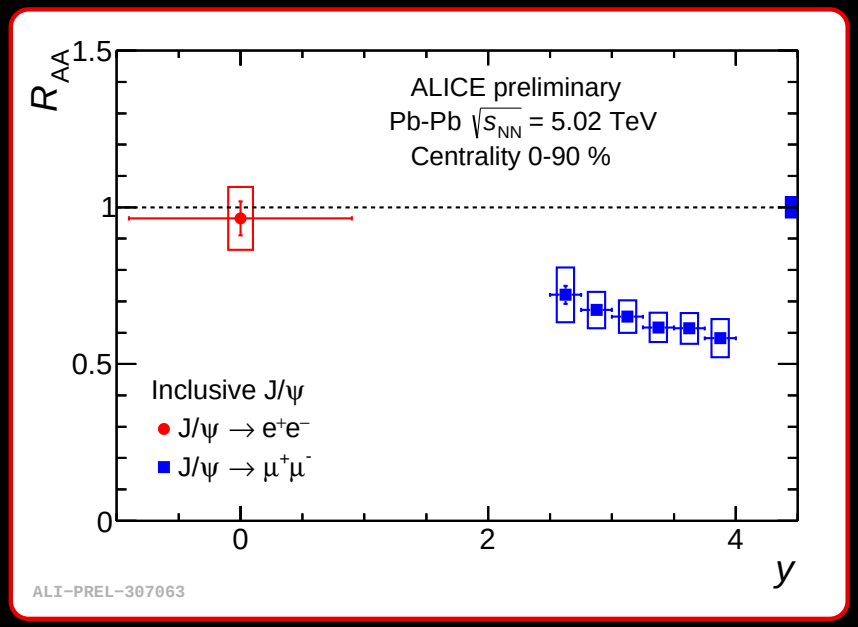


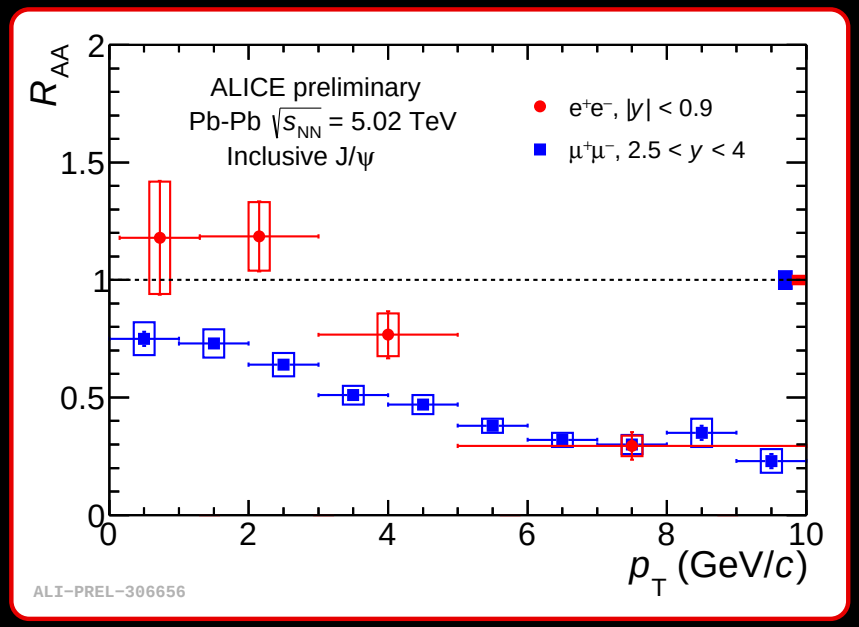
Perspectives:

- In 45 min → D. Thakur's talk (16:45, //4): J/ψ production *vs* multiplicity in p–Pb

Summary

Preliminary





Perspectives:

- In 45 min → D. Thakur's talk (16:45, //4): J/ψ production *vs* multiplicity in p–Pb
- At short terms → New Pb–Pb data taking period this autumn (hot effects)
  M. Kohler's talk (Wednesday 09:20, //3): Quarkonium production in A–A

Summary

- ALICE has measured J/ψ, ψ(2S), ϒ(1S) and ϒ(2S) production in p–Pb collisions at both $\sqrt{s_{\rm NN}} = 5.02$ TeV and $\sqrt{s_{\rm NN}} = 8.16$ TeV LHC energies
- Run-2 results increased significantly the precision of the measurements
- Models face difficulties in describing consistently all results

J/ψ
- $R_{\rm pPb}$ show a suppression at mid and forward rapidity mainly in the low-$p_{\rm T}$ region
- Various models based on different theoretical approaches qualitatively describe the results
- Positive v_2 similar to Pb–Pb for $p_{\rm T} > 4$ GeV/c → common mechanism?

ψ(2S)
- Final state effects needed to describe its stronger suppression than the J/ψ

ϒ
- Suppression of ϒ(1S) at backward and forward rapidity with a hint for a stronger ϒ(2S) suppression

Perspectives:

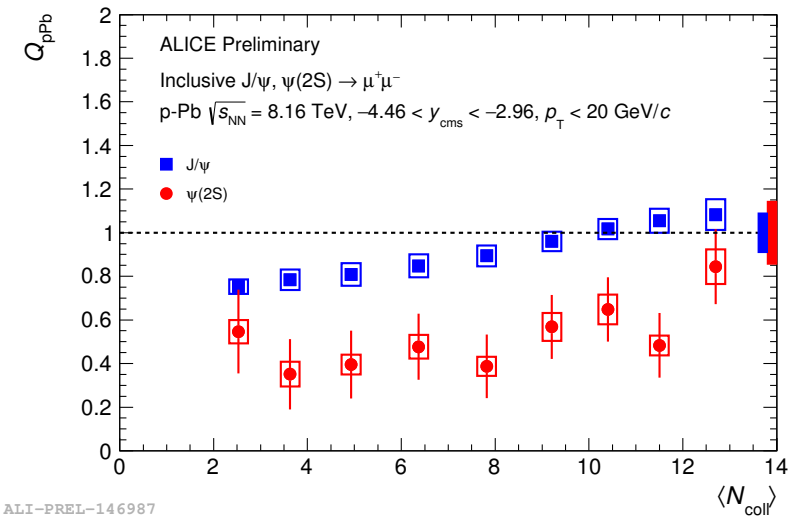
- In 45 min → D. Thakur's talk (16:45, //4): J/ψ production *vs* multiplicity in p–Pb
- At short terms → New Pb–Pb data taking period this autumn (hot effects)
  M. Kohler's talk (Wednesday 09:20, //3): Quarkonium production in A–A
- At long terms → ALICE upgrades for Run-3: continuous readout, new Muon Forward Tracker detector (separation of prompt/non-prompt J/ψ at forward rapidity)

Backup

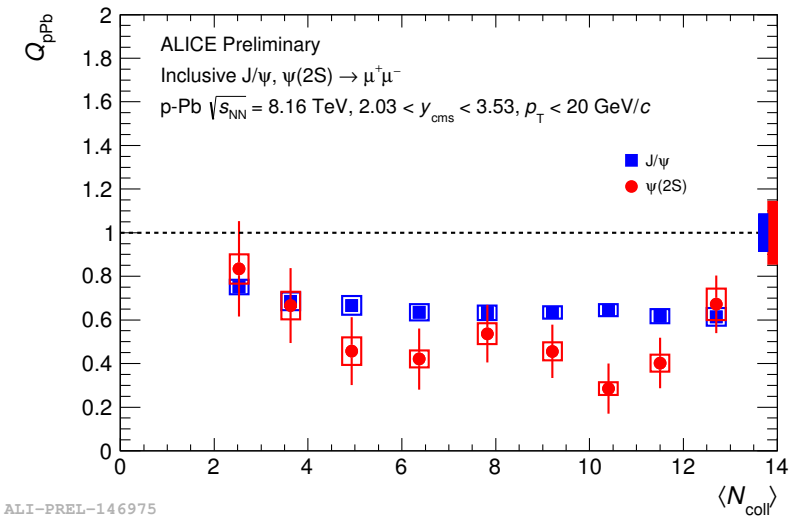
$\psi(2S)$ Q_{pPb} *vs* N_{coll}

Preliminary

Backward



Forward

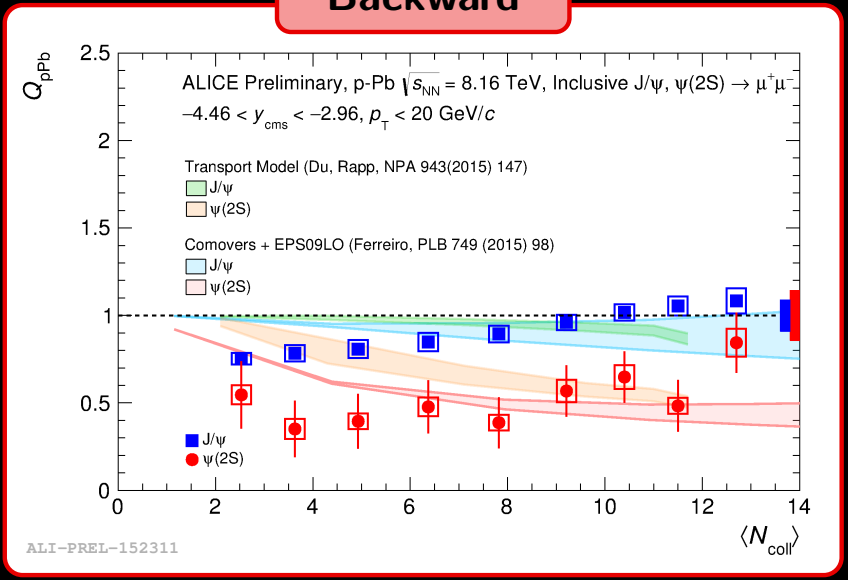


- **$\psi(2S)$ suppression** both at forward and backward rapidity
- Stronger suppression than the J/ψ one, especially at backward rapidity

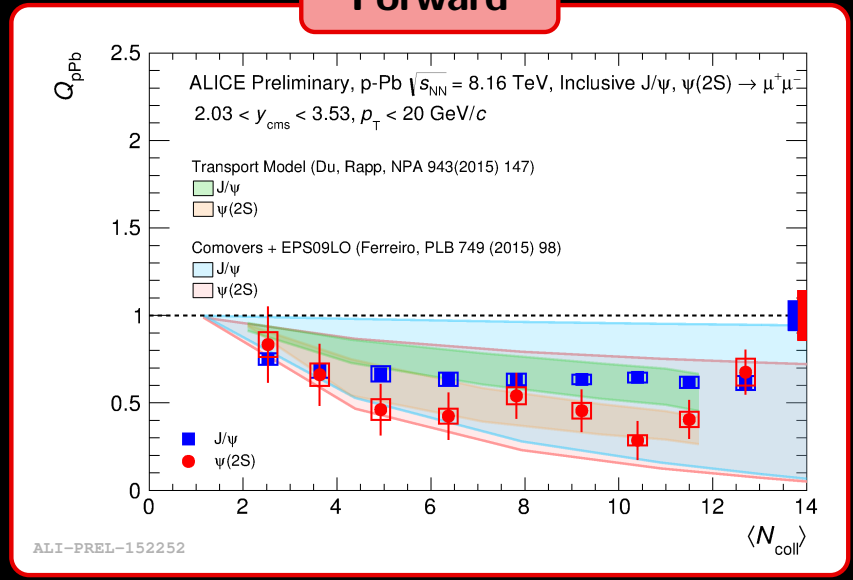
$\psi(2S)$ Q_{pPb} *vs* N_{coll}

Preliminary

Backward



Forward

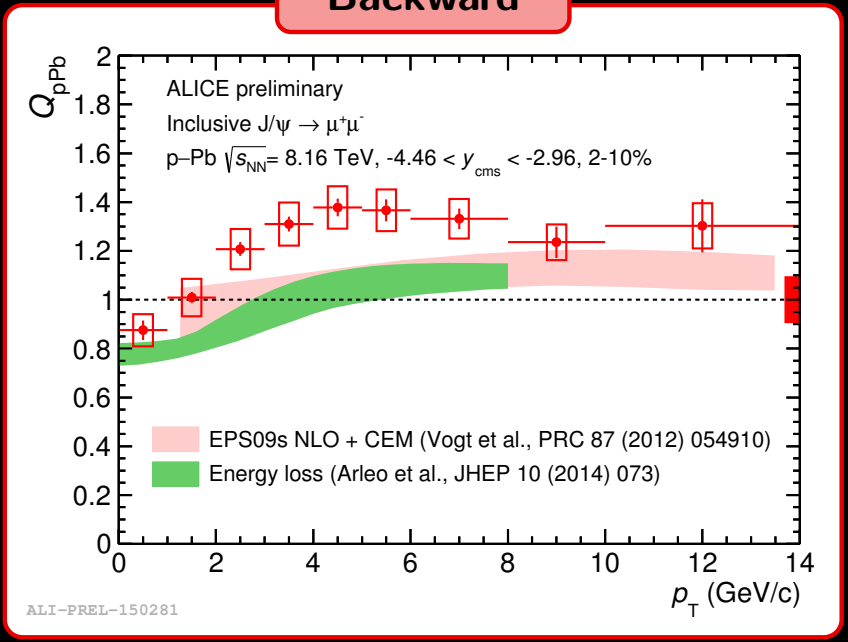


- **$\psi(2S)$ suppression** both at forward and backward rapidity
- Stronger suppression than the J/ψ one, especially at backward rapidity
- $\psi(2S)$ suppression fairly **reproduced by models including final-state effects**
- Tension between models and data at backward rapidity for peripheral collisions

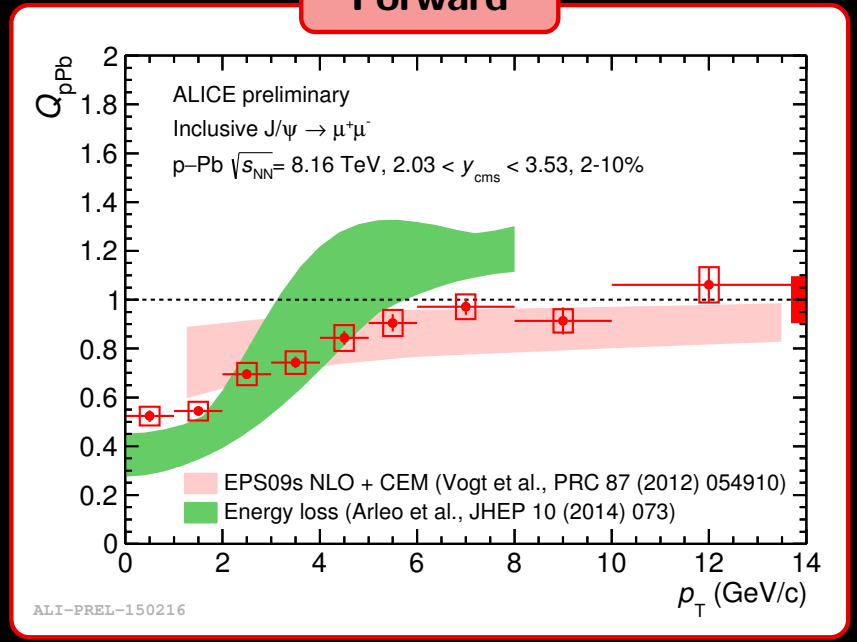
J/ψ Q_{pPb} *vs* p_{T} for 2–10% centrality

Preliminary

Backward



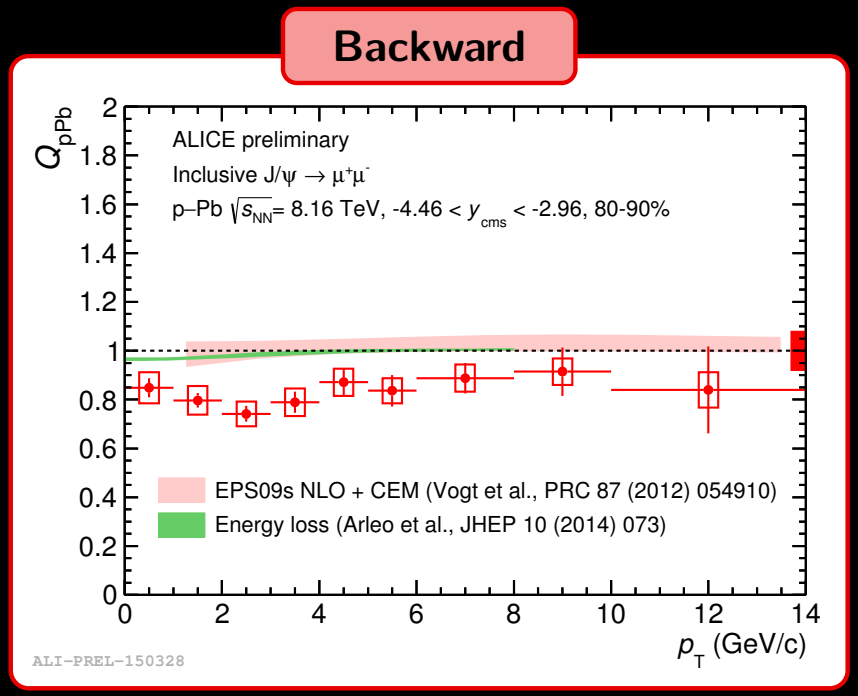
Forward

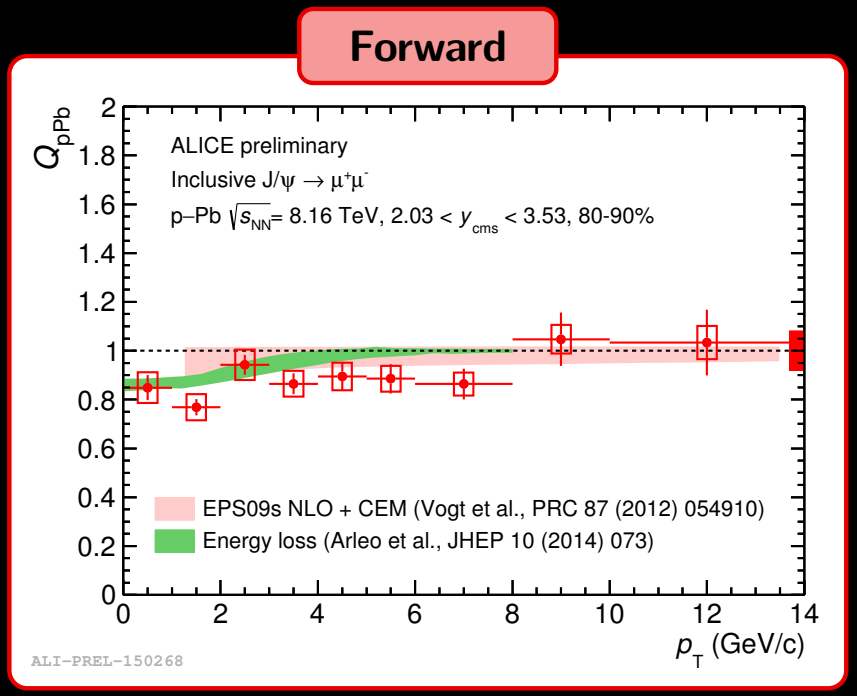


- Clear evolution of Q_{pPb} *vs* p_{T} in different centrality classes
- Backward: enhancement in most central collisions for $p_{\mathrm{T}} > 3$ GeV/c
- Forward: stronger suppression at low-p_{T} in most central collisions
- Tension between models and data for most central collisions

J/ψ Q_{pPb} *vs* p_{T} for 80–90% centrality

Preliminary



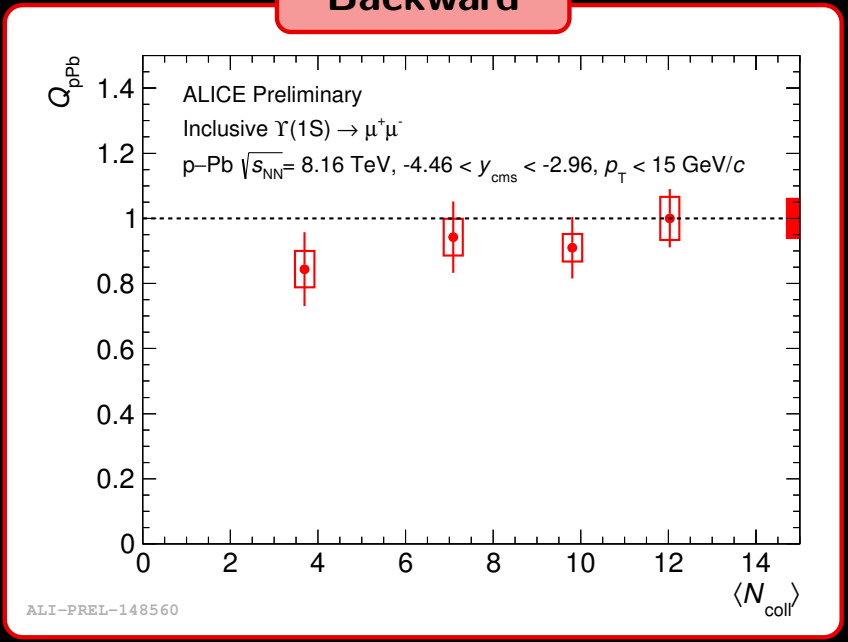


- Clear evolution of Q_{pPb} *vs* p_{T} in different centrality classes
- Backward: enhancement in most central collisions for $p_{\mathrm{T}} > 3$ GeV/c
- Forward: stronger suppression at low-p_{T} in most central collisions
- Tension between models and data for most central collisions

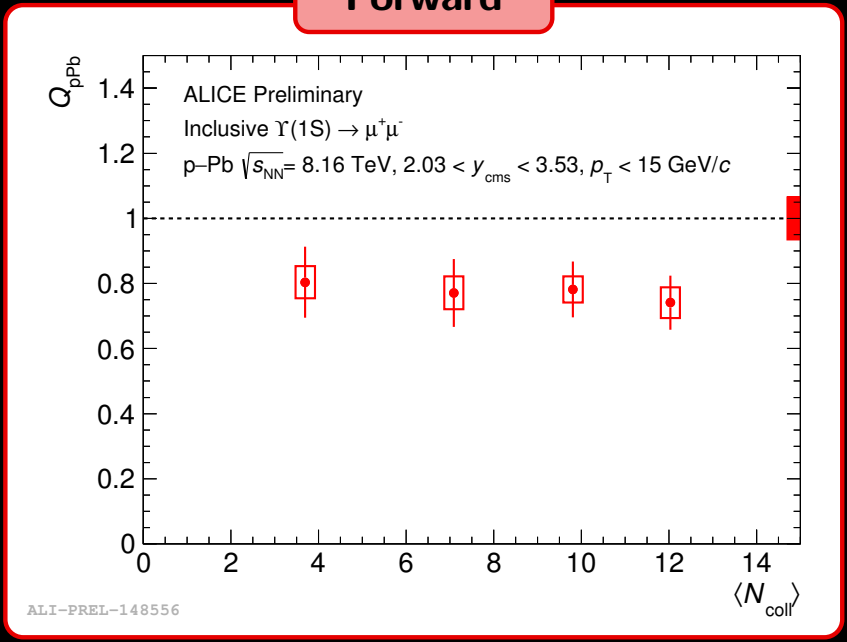
$\Upsilon(1S)$ Q_{pPb} *vs* N_{coll}

[ALICE-PUBLIC-2018-008]

Backward



Forward



- **Almost no centrality dependence** of Q_{pPb} both at forward and backward rapidity
- Hint for a stronger suppression at forward rapidity