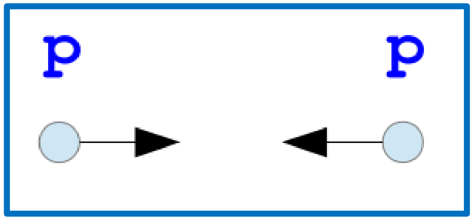
Quarkonia in hadronic collisions with ALICE at the LHC

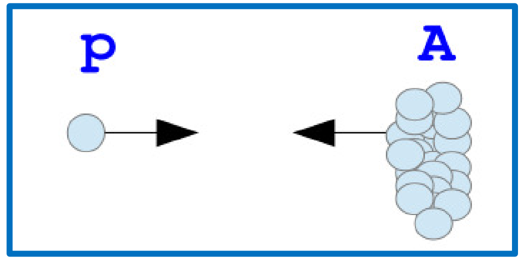
- Motivations
- p-p collisions at $\sqrt{s}$ = 2.76 and 7 TeV
- Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Loïc Manceau
for the ALICE Collaboration
INFN Torino
lmanceau@to.infn.it

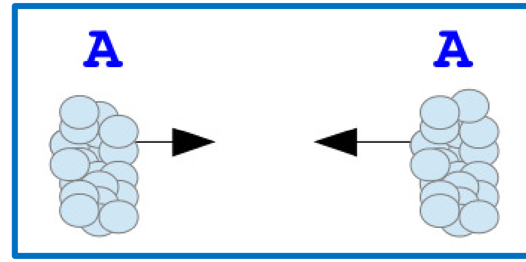
Hadronic collisions and nuclear effects



- No nuclear effects
- Test for hadroproduction models
- Baseline for pA and AA studies

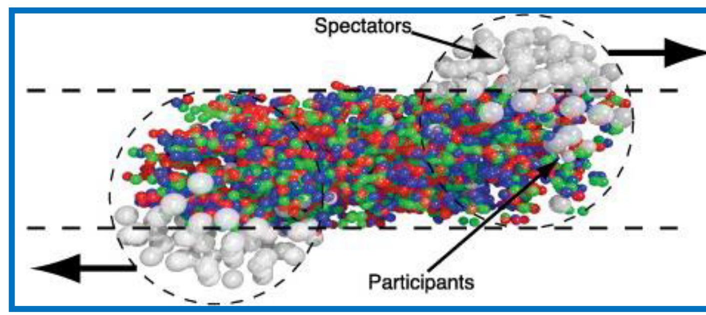


- Cold Nuclear Matter (CNM) effects
- No medium created
- Estimate of Cold Nuclear Matter effects in AA collisions



- CNM effects
- Deconfinement of quarks and gluons → creation of the Quark-Gluon Plasma (QGP) → hot nuclear matter effects

- The centrality of AA collisions can be expressed as a number of participant nucleons



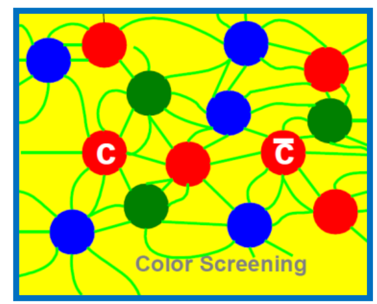
- Nuclear modification factor:
  - Key observable for nuclear matter effects
  - Relative particle production in AA or pA with respect to pp collisions
  - $R_{pA(AA)} \neq 1$ → Nuclear effects

$$R_{pA(AA)} = \frac{\sigma_{pA(AA)}}{N_{coll} \cdot \sigma_{pp}}$$

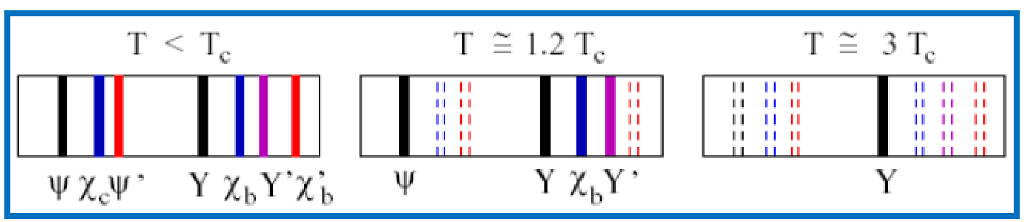
Nuclear matter effects and quarkonia

- Cold Nuclear Matter effects:
  - Shadowing → modification of gluon distribution functions in the nucleus
  - Color Glass Condensate (CGC) → Low x $_{bjorken}$ color saturation
  - Coherent energy loss → the incoming partons and the pre-resonance states radiate gluons when passing through the CNM
  - Final state effects → absorption or break up of the quarkonia in the CNM

- Hot Nuclear Matter effects:



- Signature of the deconfinement *(Matsui and Satz, PLB 178 (1986) 416)*
  → Quarkonium suppression by color screening
- Temperature probe → Sequential suppression of quarkonia



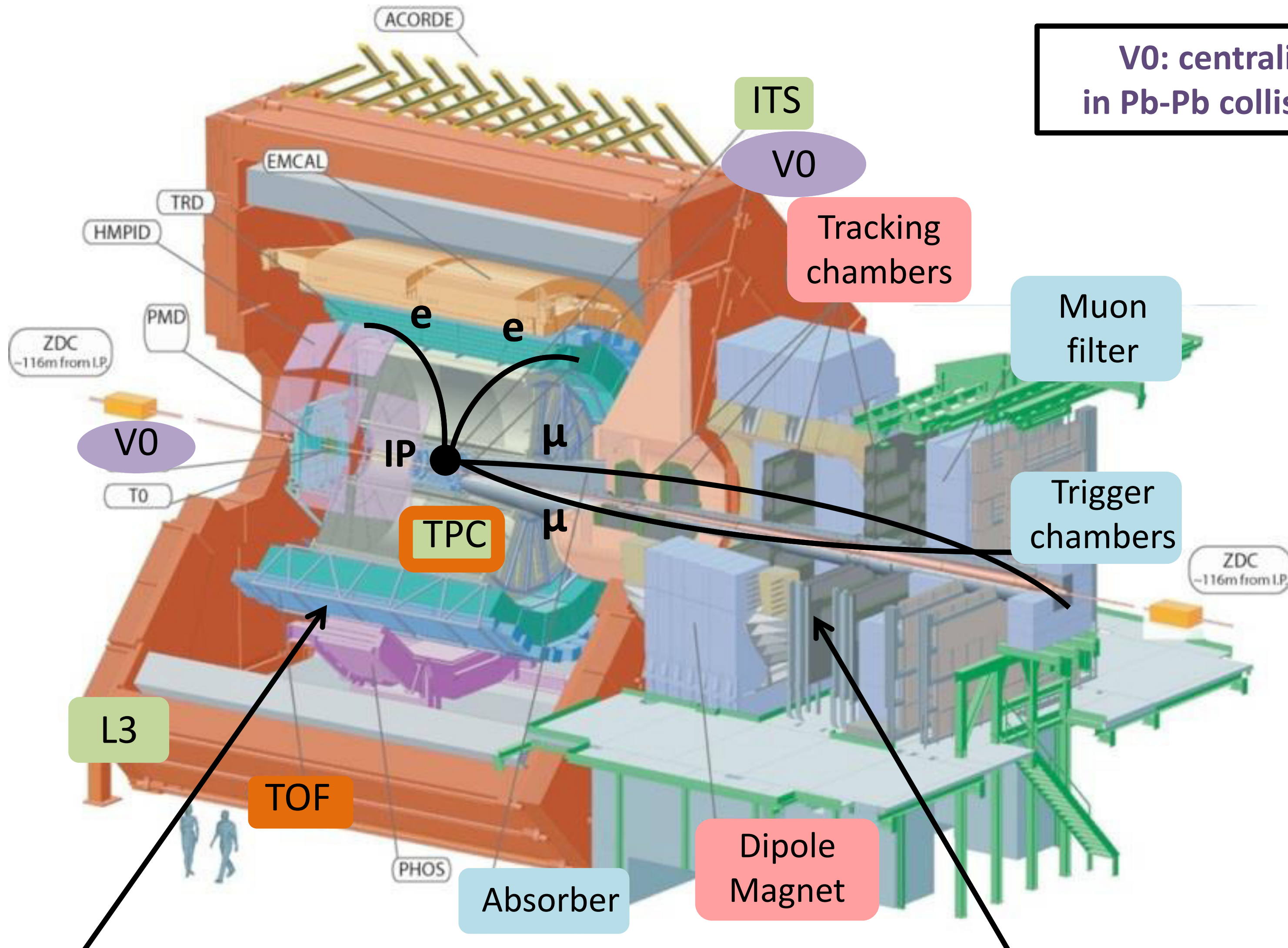
(Digal et al. PRD 64 (2001) 0940150)

- Possible (re-)generation if heavy quark multiplicity is important in the medium

(Andronic et al., PLB 571(2003) 36, Rafelski et al. PRC 63 (2001) 0549057)

Quarkonium measurements in ALICE

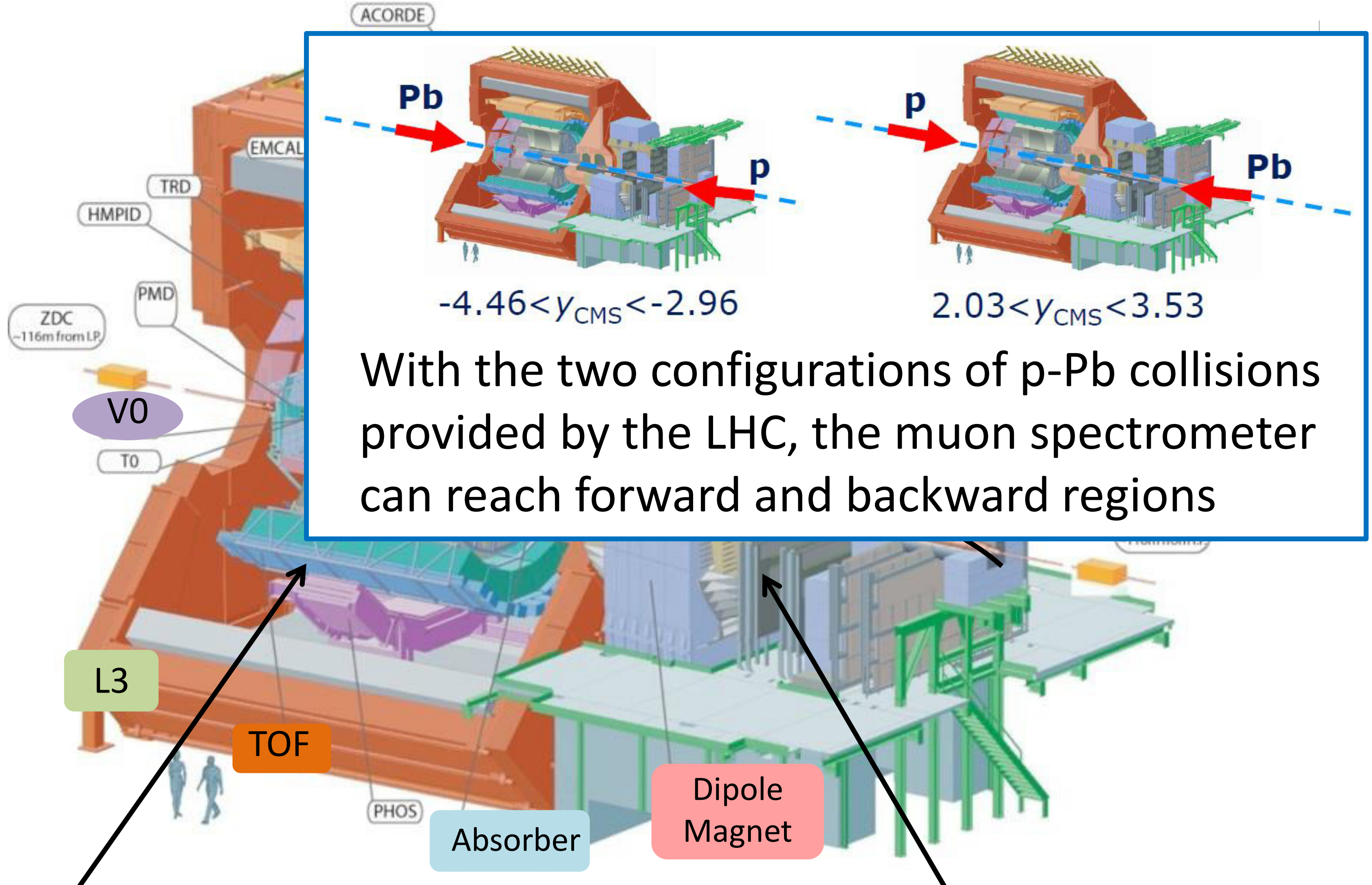
V0: centrality
in Pb-Pb collisions



- Central barrel (|y_{lab}|<0.9,p_t>0): **J/ψ→e^+e^-**
  - **Tracking: ITS, TPC**
  - **Identification: TPC**

- Muon spectrometer (2.5<y_{lab}<4, p_t>0): **J/ψ→$\mu^+\mu^-$**, **Ψ(2S)→$\mu^+\mu^-$**, **ϒ(1S)→$\mu^+\mu^-$**, **ϒ(2S)→$\mu^+\mu^-$**
  - **Tracking**
  - **Identification**

Quarkonium measurements in ALICE



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

$2.03<y_{CMS}<3.53$

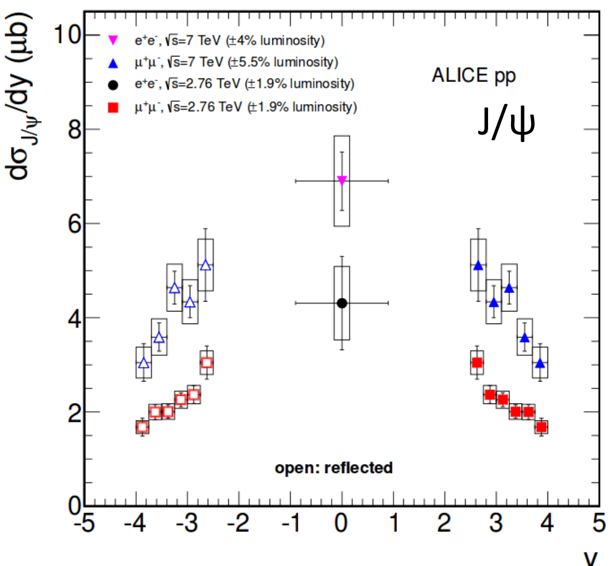
With the two configurations of p-Pb collisions provided by the LHC, the muon spectrometer can reach forward and backward regions

- Central barrel ($|y_{lab}|<0.9, p_t>0$): **$J/\psi \rightarrow e^+e^-$**
  - **Tracking: ITS, TPC**
  - **Identification: TPC**

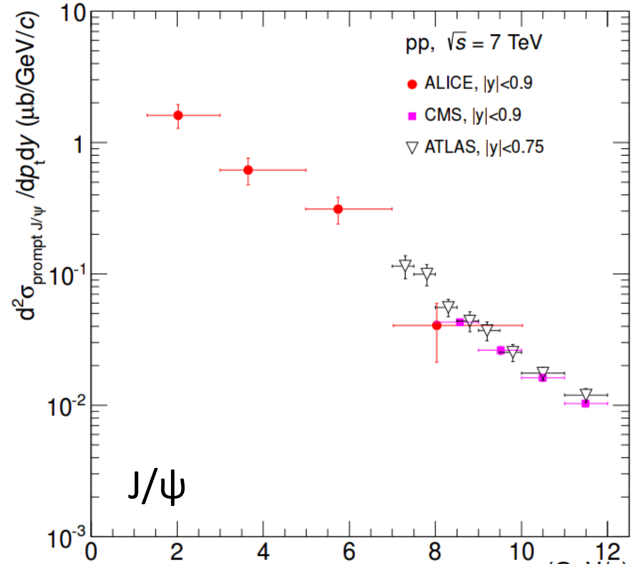
- Muon spectrometer ($2.5<y_{lab}<4$, $p_t>0$):
  - **Tracking**
  - **Identification**

$J/\psi \rightarrow \mu^+\mu^-$
$\Psi(2S) \rightarrow \mu^+\mu^-$
$\Upsilon(1S) \rightarrow \mu^+\mu^-$
$\Upsilon(2S) \rightarrow \mu^+\mu^-$

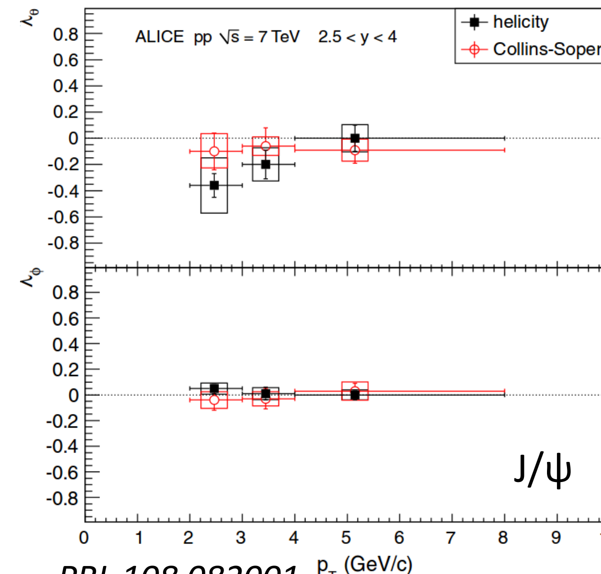
Quarkonia in pp collisions at √s = 2.76 and 7 TeV



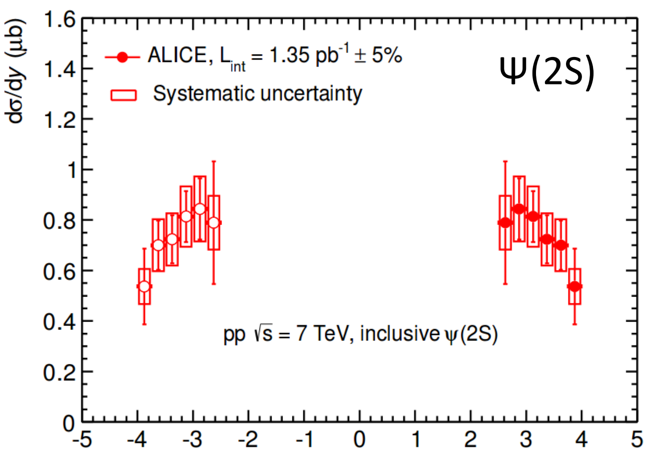
PLB718 (2012) 295-306



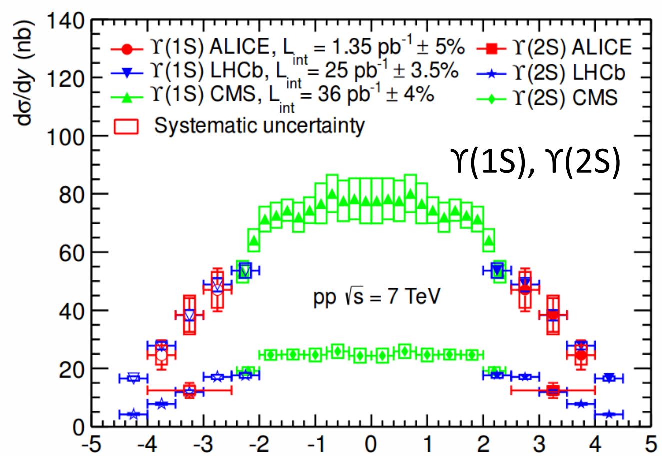
JHEP 1211 (2012) 065



PRL 108 082001



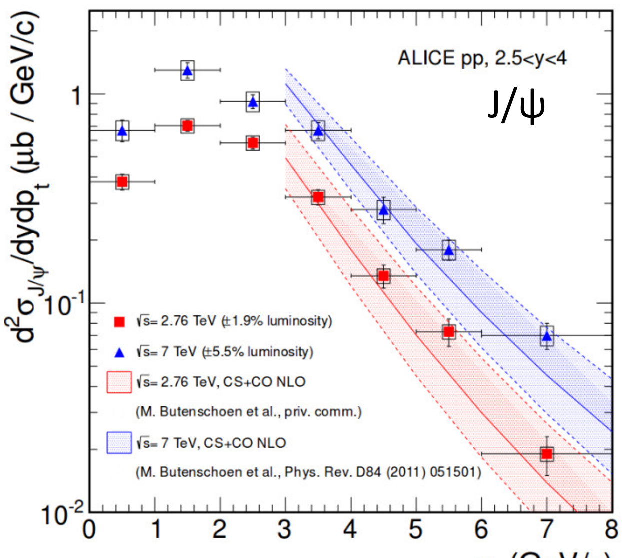
arXiv:1403.3648



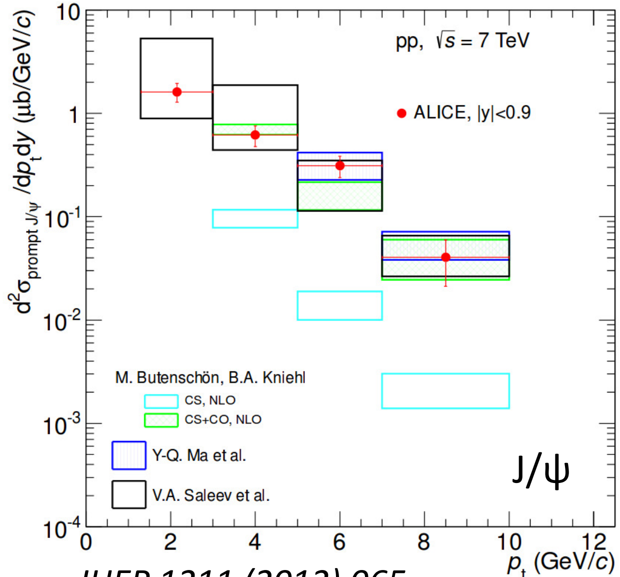
arXiv:1403.3648

- Unique ALICE coverage
- 6 papers published or close to be published

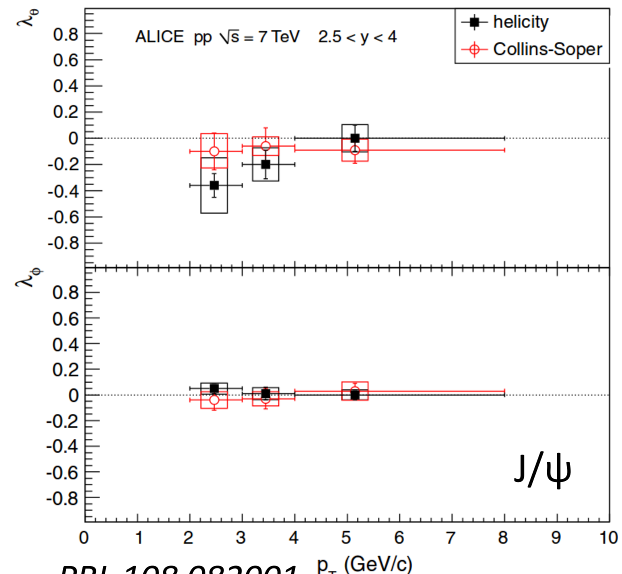
Quarkonia in pp collisions at √s = 2.76 and 7 TeV



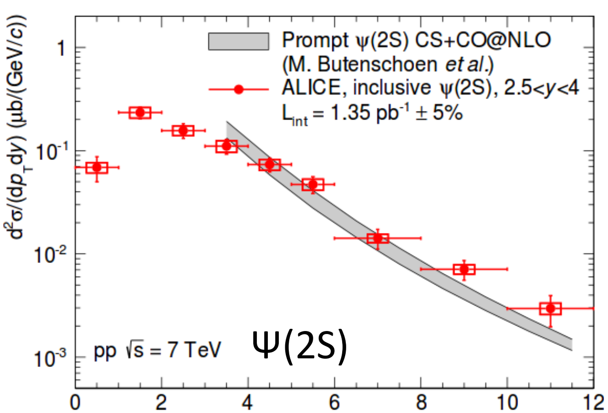
PLB718 (2012) 295-306



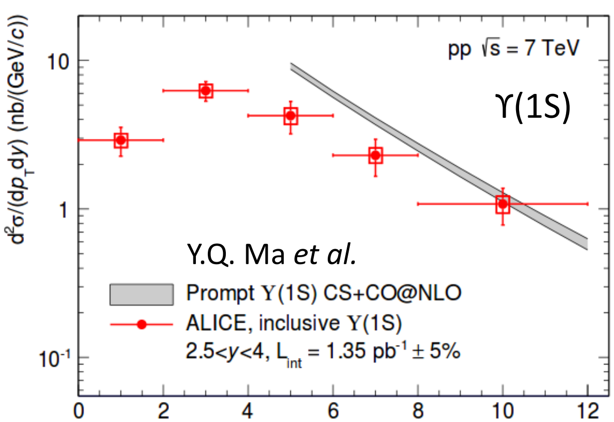
JHEP 1211 (2012) 065



PRL 108 082001



arXiv:1403.3648



arXiv:1403.3648

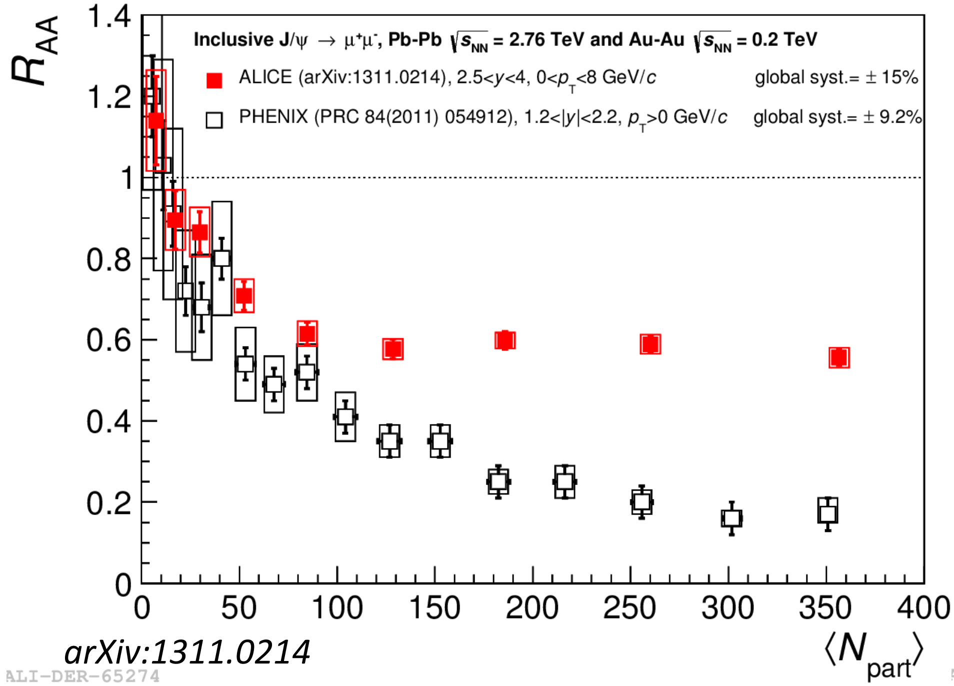
- Stringent tests for quarkonium hadroproduction models
- Rather good agreement of pt-differential cross section with NLO NRQCD tuned according to Tevatron and LHC data
- CAVEATS: challenging topic
  → No consensus about pp production mechanism (CEM, CSM, NRQCD)

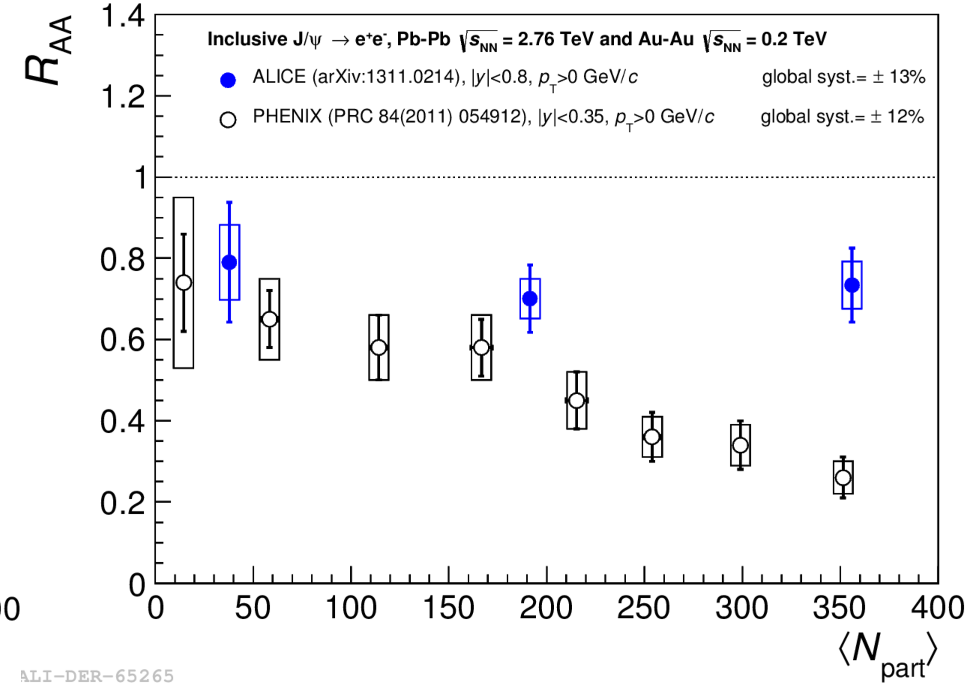
Quarkonia in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

- Shown here:
  - J/ψ at forward and mid-rapidity
- Also available, preliminary results on:
  - ψ(2S) at forward rapidity
  - ϒ(1S) at forward rapidity

  (paper in preparation, see you at Quark Matter 2014)

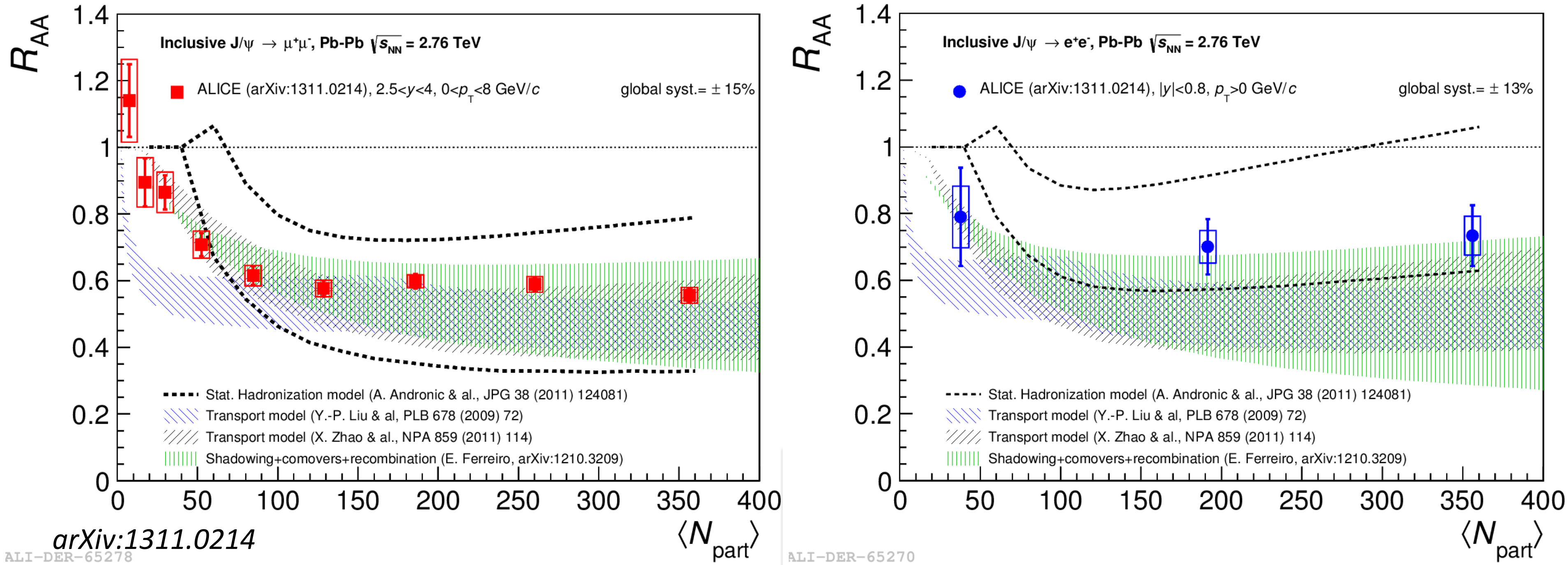
Important J/ψ regeneration at LHC?





- Factor 10 increase in energy from RHIC to LHC
  - → Larger charm quark multiplicity at LHC
  - → More regeneration expected at LHC
- Confirmed by the following indications:
  - In central collisions, inclusive J/ψ much less suppressed at LHC than at RHIC
  - Nuclear modification factor much less dependent on centrality at LHC

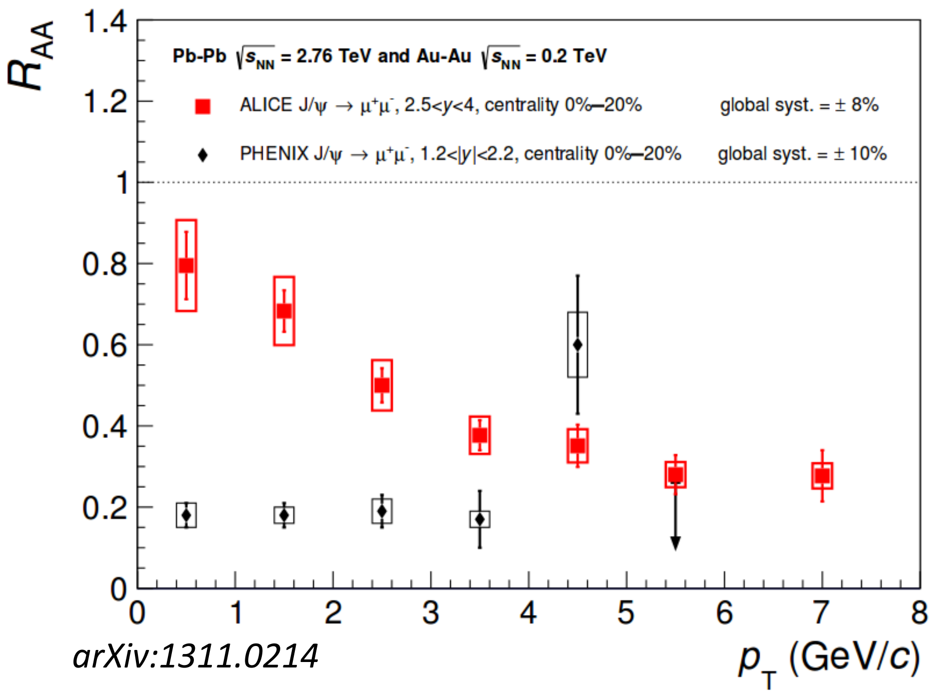
Important J/ψ regeneration at LHC?



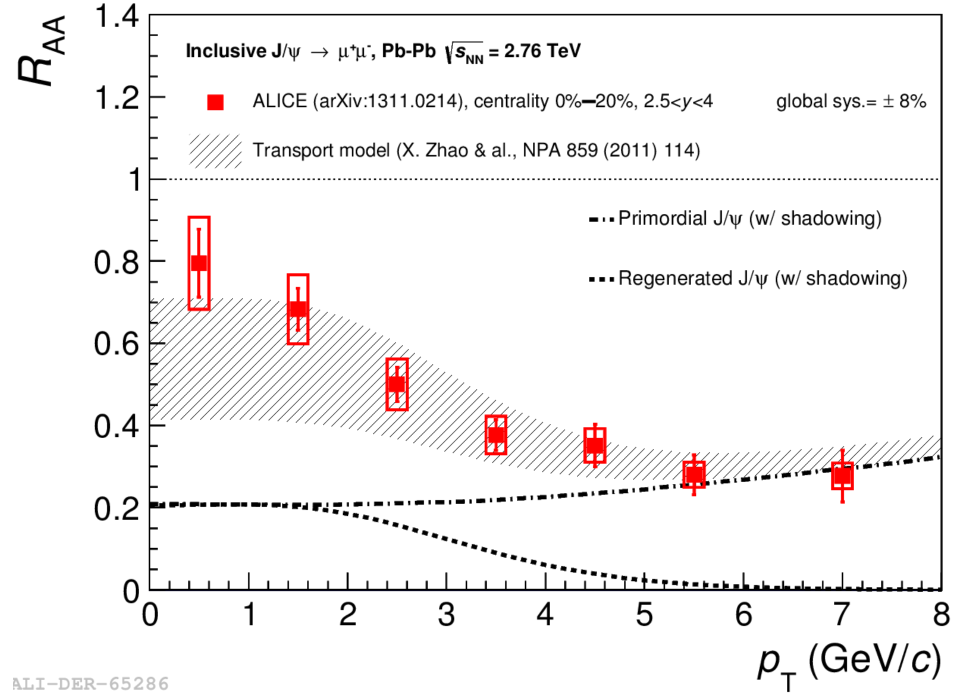
arXiv:1311.0214

➢ Models including (re-)generation reproduce rather well the data:
- Transport models: color screening + in-medium recombination of charm quarks
- Statistical hadronisation model: all J/ψ are created when the QGP cools down and becomes an hadron gas (phase boundary)

Important J/ψ regeneration at LHC?

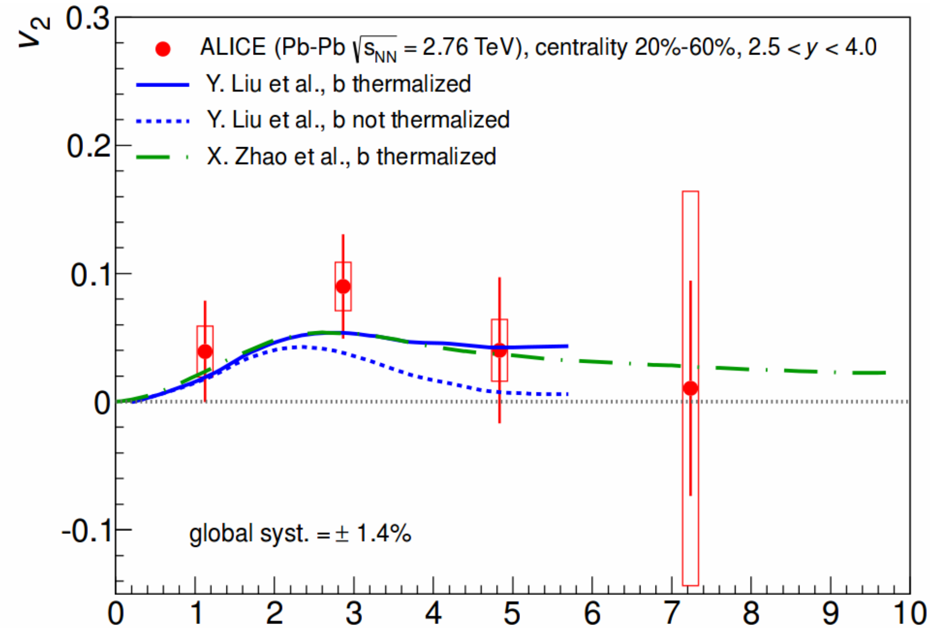


arXiv:1311.0214

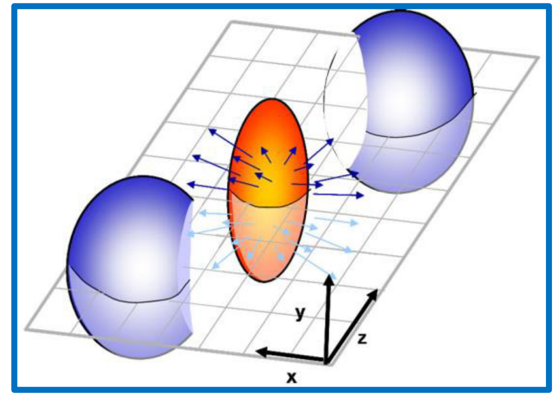


- J/ψ less suppressed at low p_t than at high p_t:
  - Contrary to what is observed at RHIC
  - As predicted by transport models

Important J/ψ regeneration at LHC?



PRL 111 (2013) 162301



- In peripheral collisions collective motions are expected to occur in the QGP
- Collective motions can be quantified with the elliptic flow (v_2) which corresponds to the second harmonic of the particle azimuthal angle distribution with respect to the reaction plane

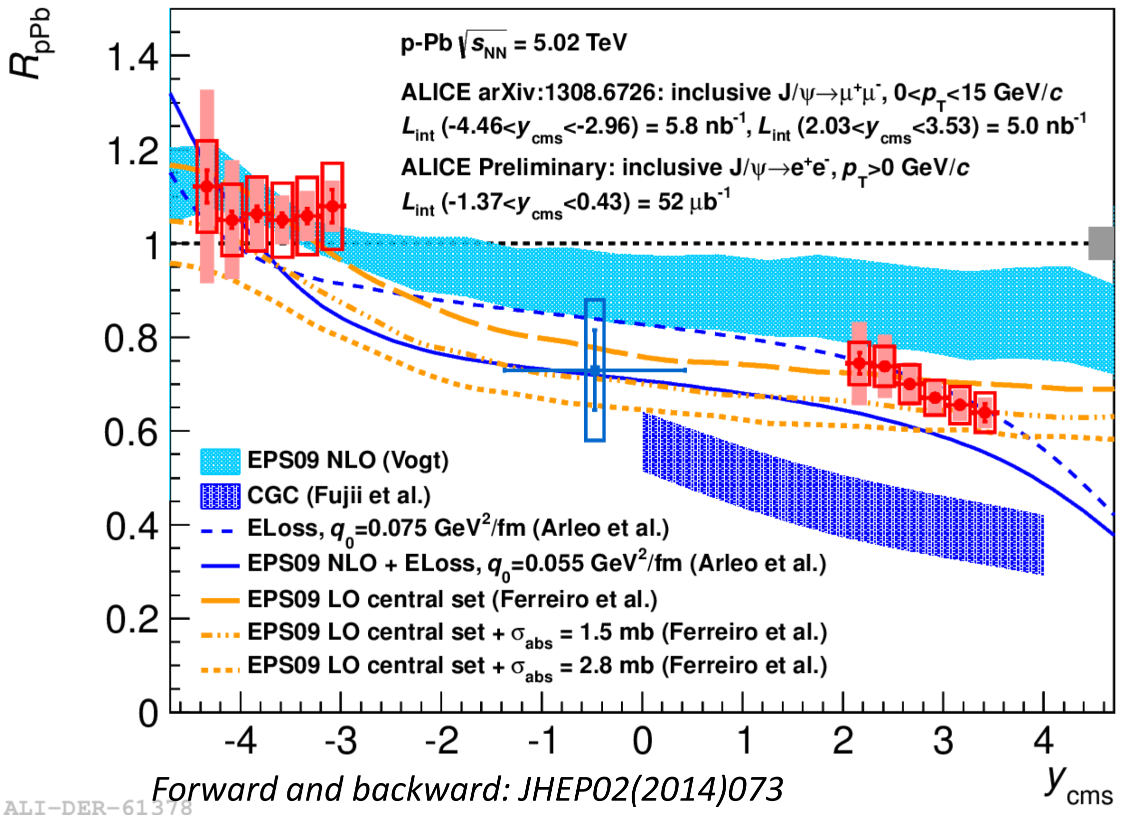
➢ Non zero J/ψ eliptic flow at low p_t :

- Charm quarks may take part to collective motions in the QGP before recombining and forming J/ψ
- Data rather well reproduced by transport models

Quarkonia in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- Shown here:
  - J/ψ at forward and mid-rapidity
  - ψ(2S) at forward rapidity
  - ϒ(1S) at forward rapidity
- Not shown here:
  - ϒ(2S) at forward rapidity
    (common ϒ(1S) paper in preparation, see you at QM2014)

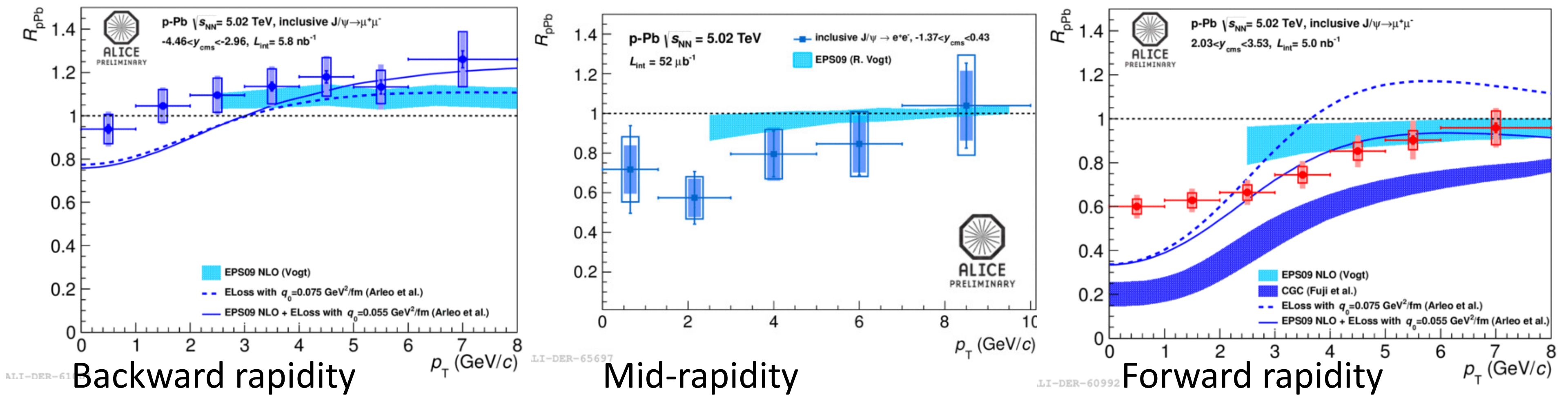
J/ψ and CNM effects in p-Pb collisions



Forward and backward: JHEP02(2014)073

- Backward rapidity: almost no suppression
- Forward rapidity: significant suppression
- Data in fair agreement with:
  - Shadowing calculations using the EPS09 parametrization
  - Models including a contribution from coherent partonic energy loss
- CGC model disfavored

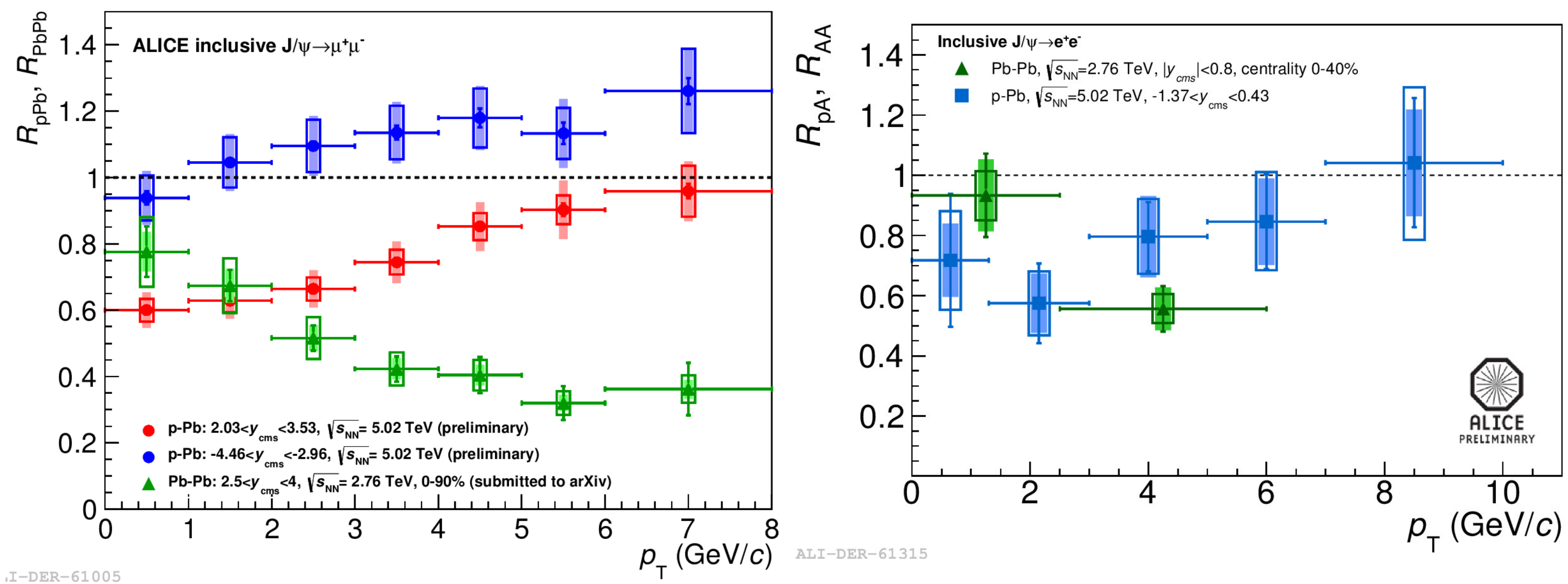
J/ψ and CNM effects in p-Pb collisions



Backward rapidity　　Mid-rapidity　　Forward rapidity

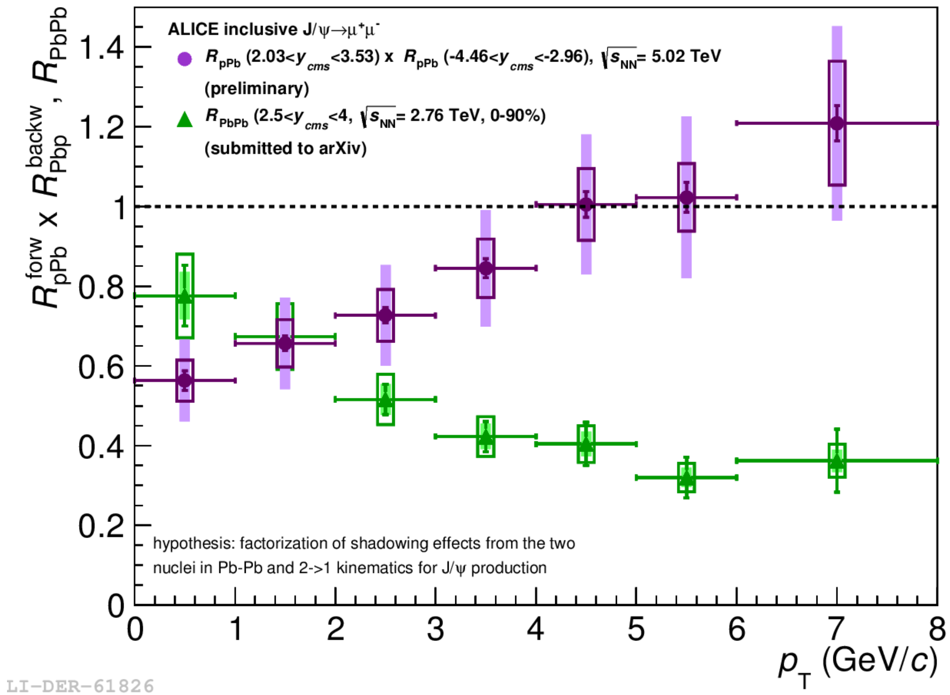
- At high p_t, data are in fair agreement with:
  - Shadowing calculations using the EPS09 parametrization
  - Models including a contribution from coherent partonic energy loss
- Models including a contribution from coherent partonic energy loss underestimate the data at low p_t
- CGC model disfavored

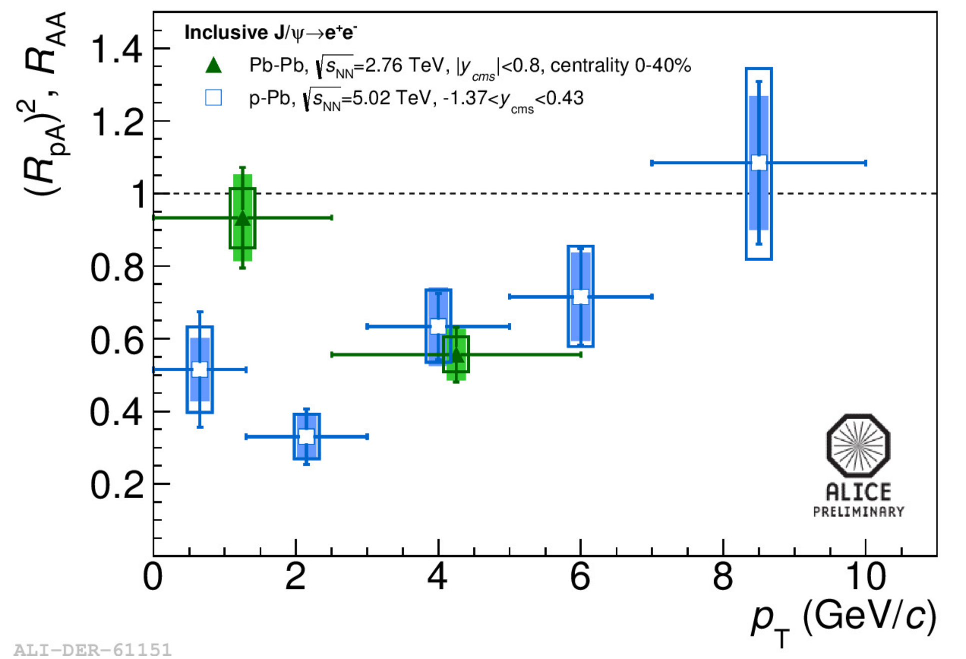
J/ψ and CNM effects in Pb-Pb collisions



- Different transverse momentum dependencies of nuclear modification factors in Pb-Pb and p-Pb

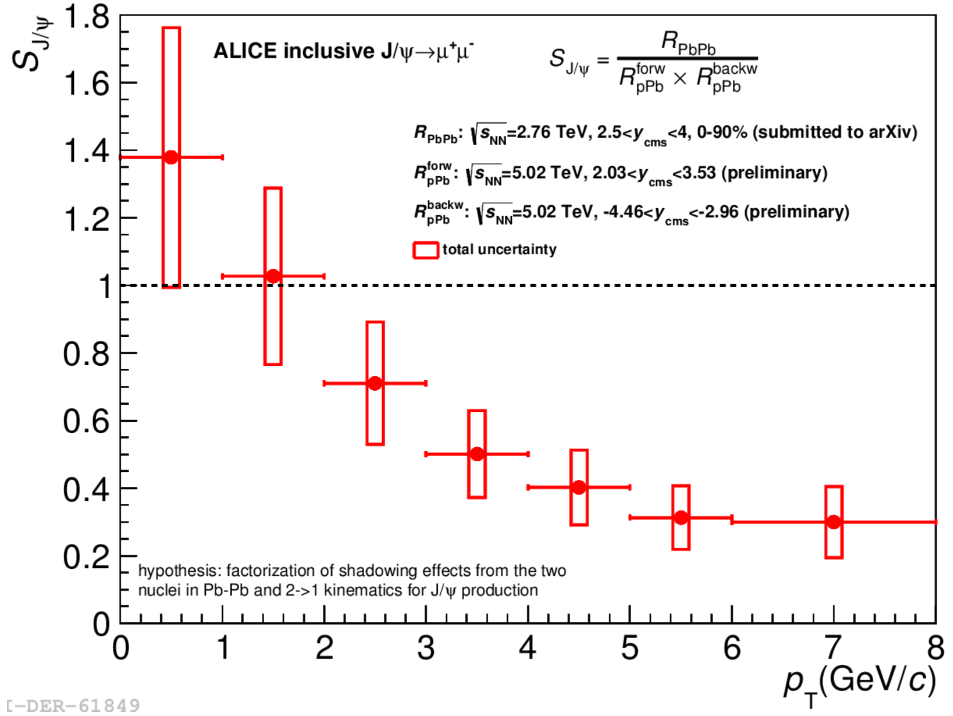
J/ψ and CNM effects in Pb-Pb collisions

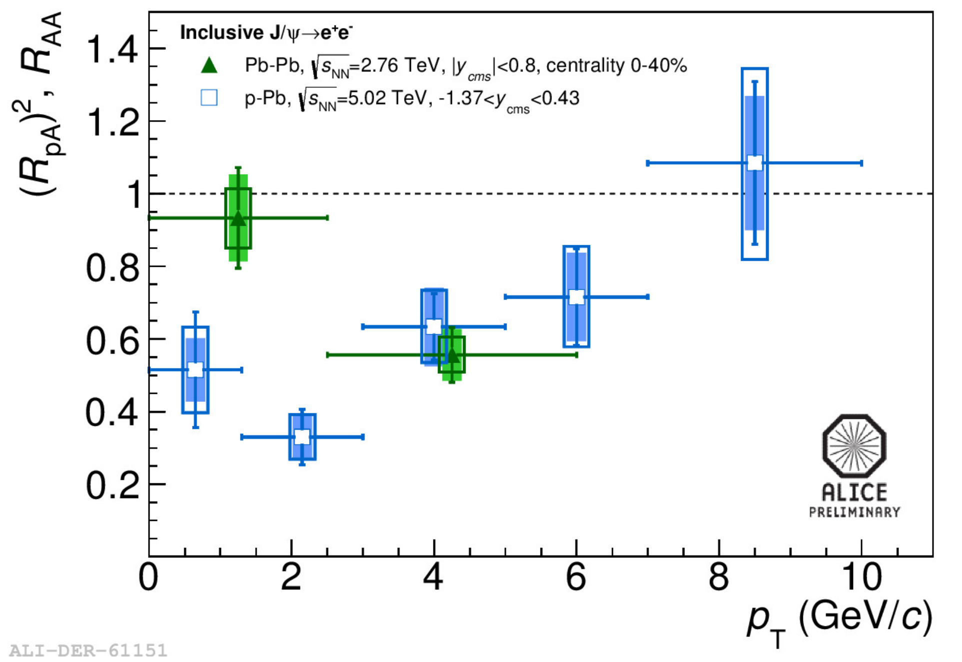




- CNM effects measured in p-Pb collisions are extrapolated to Pb-Pb collisions given the two following assumptions:
  - 2→1 kinematics (e.g. LO CEM)
  - factorization of nuclear effects (e.g. only shadowing as CNM)
- Results of the extrapolation are compared to Pb-Pb results
- Hints for hot nuclear matter effects in addition to CNM effects in Pb-Pb collisions

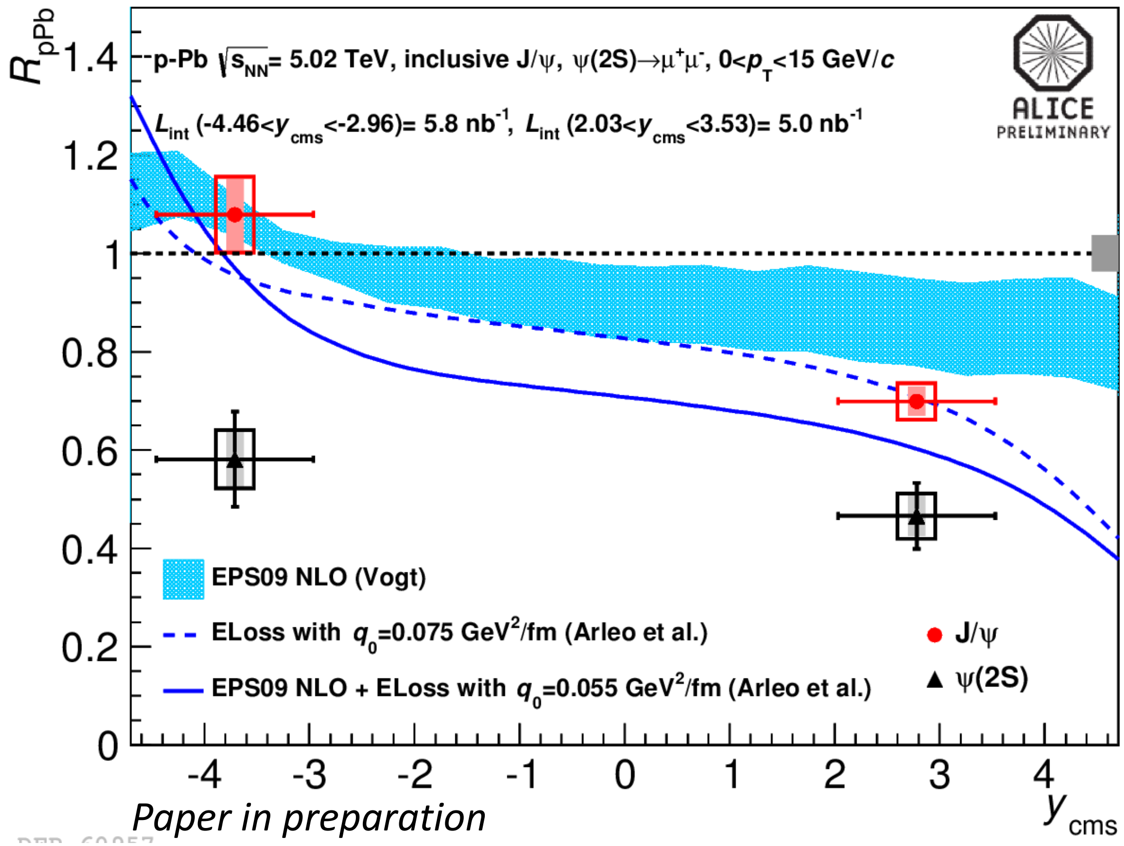
J/ψ and CNM effects in Pb-Pb collisions





- CNM effects measured in p-Pb collisions are extrapolated to Pb-Pb collisions given the two following assumptions:
  - 2→1 kinematics (e.g. LO CEM)
  - factorization of nuclear effects (e.g. only shadowing as CNM)
- Results of the extrapolation are compared to Pb-Pb results
- Hint of J/ψ enhancement at low p_t and suppression at high p_t due to hot nuclear matter effects in Pb-Pb collisions (forward rapidity)

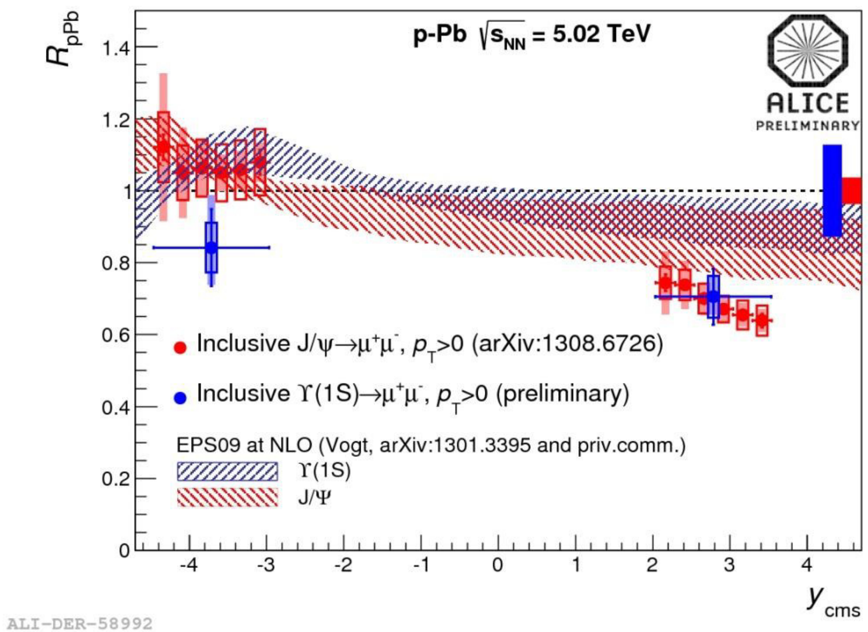
Ψ(2S) and CNM effects in p-Pb collisions

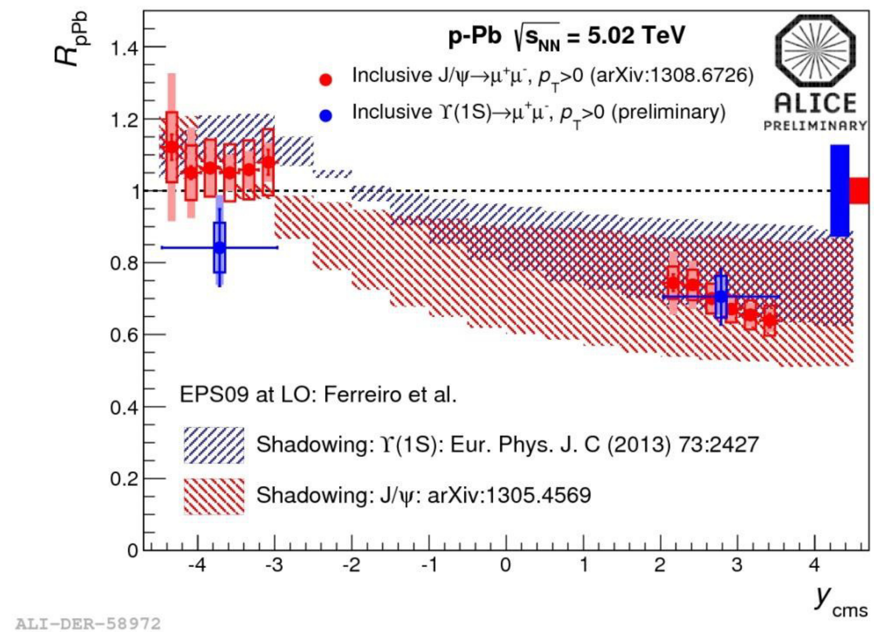


Paper in preparation

- ψ(2S) more suppressed than J/ψ → different CNM effects for the two quarkonia
- Shadowing and coherent energy loss models treat identically ψ(2S) and J/ψ and don't reproduce ψ(2S) results
  → ψ(2S) have a lower binding energy than J/ψ and are more affected by final state effects (e.g. pair break up) in the CNM

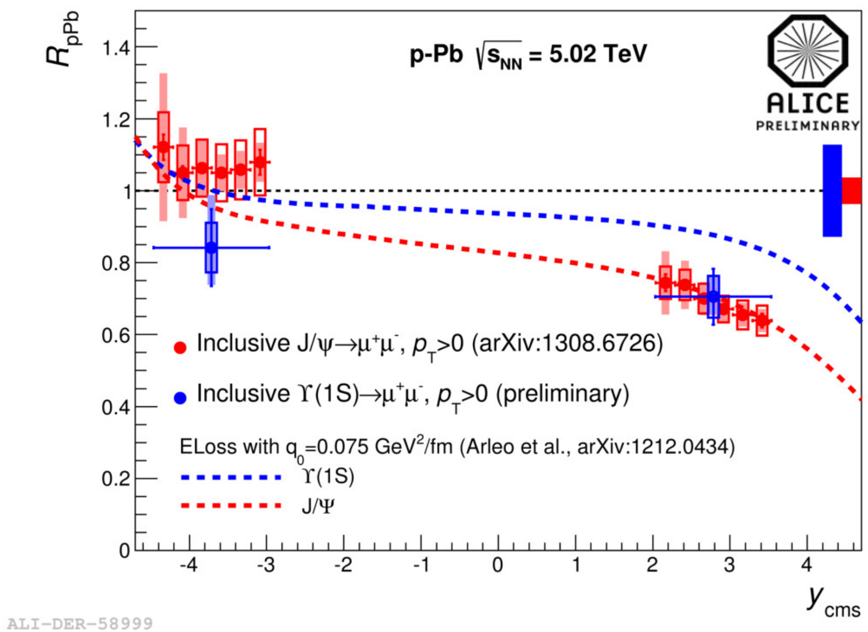
ϒ(1S) and CNM effects in p-Pb collisions

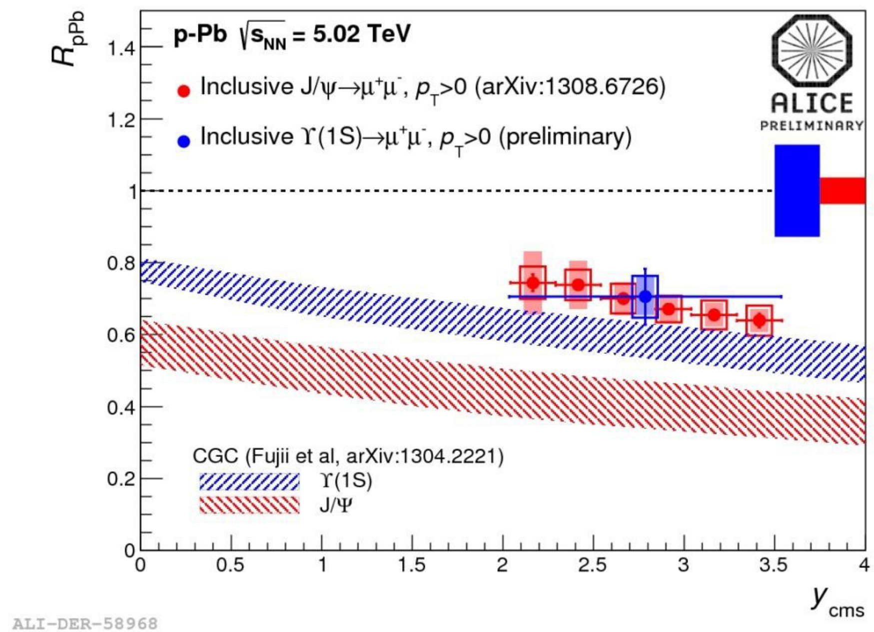




- Backward rapidity: compatible with no suppression
- Forward rapidity: hints for a stronger suppression
- ϒ(1S) and J/ψ suppressions are compatible
- Shadowing calculations based on EPS09 parametrization reproduce the ϒ(1S) data within large uncertainties.

ϒ(1S) and CNM effects in p-Pb collisions





- Model including a contribution from coherent partonic energy loss reproduces ϒ(1S) data within large uncertainties.
- The CGC model reproduces ϒ(1S) data, but is disvafoured by J/ψ data

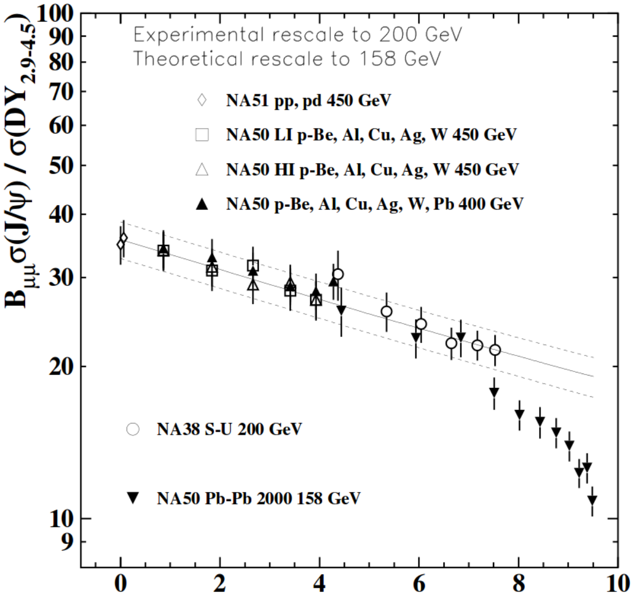
Conclusion

- pp collisions at $\sqrt{s}$ = 2.76 and 7 TeV
  - Many results that can be used as stringent tests for quarkonium hadroproduction models
- Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
  - Hints of strong regeneration of J/ψ at LHC energies
- p-Pb collsions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Shadowing calculations based on EPS09 parametrization and models including a contribution of coherent parton energy loss reproduce J/ψ data
  - The same models are not ruled out by ϒ(1S) data, given large uncertainties
  - ψ(2S) and J/ψ are not affected in the same way by CNM effects → Sizeable final state effects for ψ(2S)

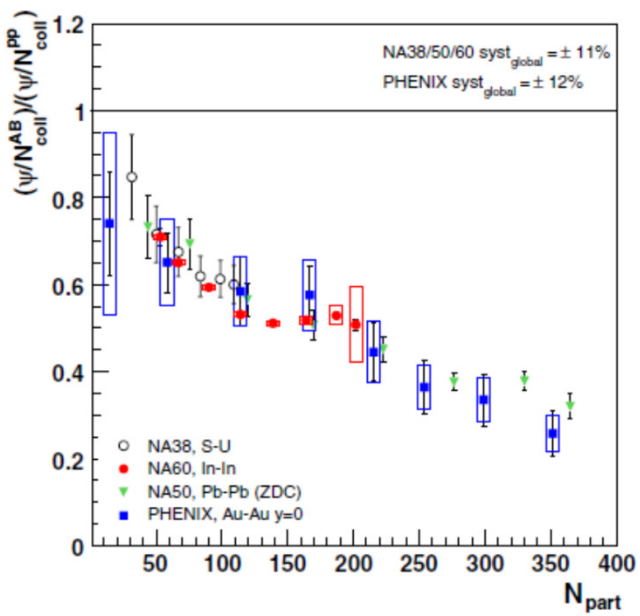
Back up

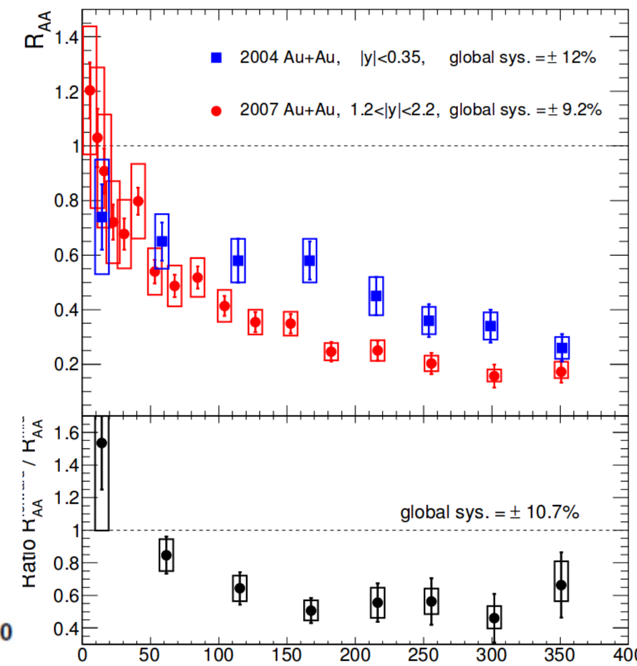
Toward ALICE physics

- Extensive results on J/ψ from SPS (fixed target) to RHIC (collider):



SPS: arXiv:hep-ex/0412036





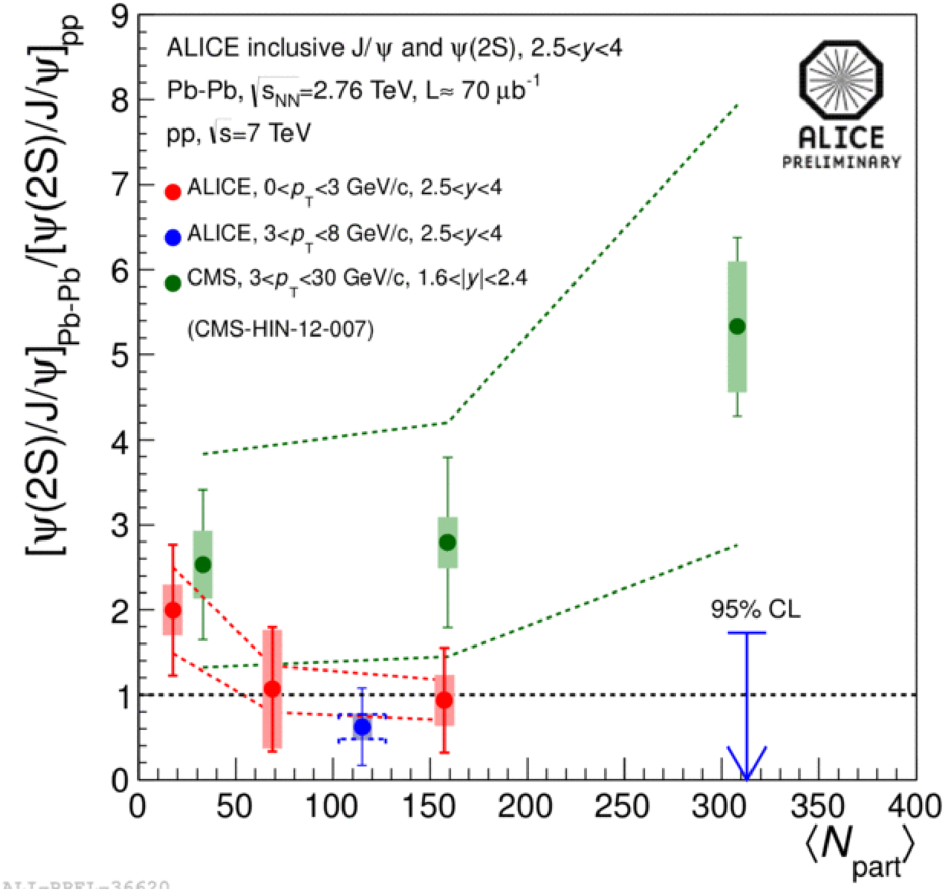
PHENIX: arXiv:1103.6269

- Observation of a suppression of inclusive J/ψ beyond CNM effects
- Suppression compatible with the dissociation of higher mass charmonia

- Suppression similar at RHIC and SPS despite an increase in energy by a factor about 10
- Are J/ψ not dissociated or an other mecanism sets in?

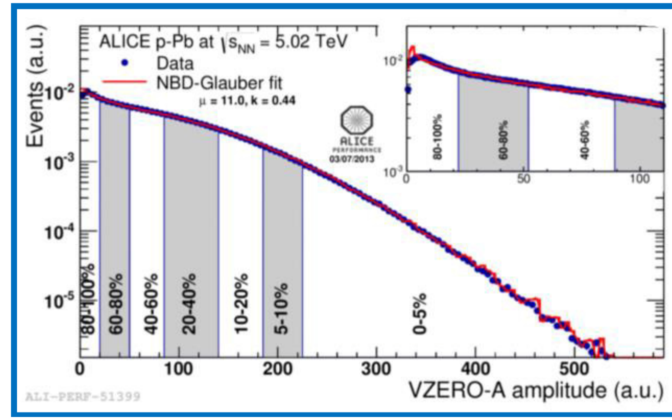
- At RHIC, PHENIX measured a larger suppression at forward than at mid-rapidity despite the larger energy density expected at mid-rapidity
- Development of (re-)generation models

Ψ(2S) in Pb-Pb collisions

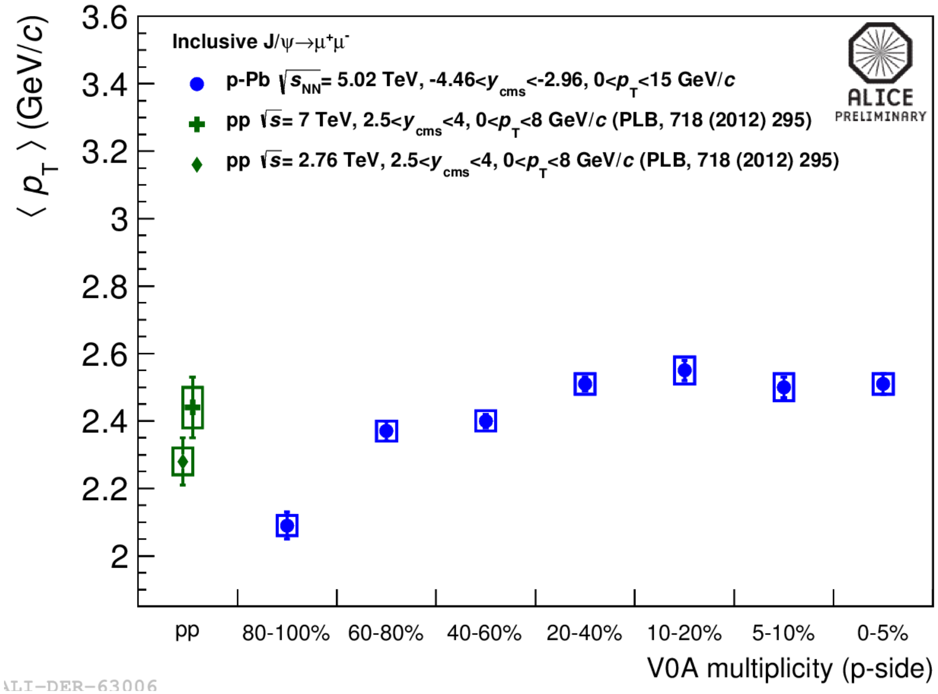


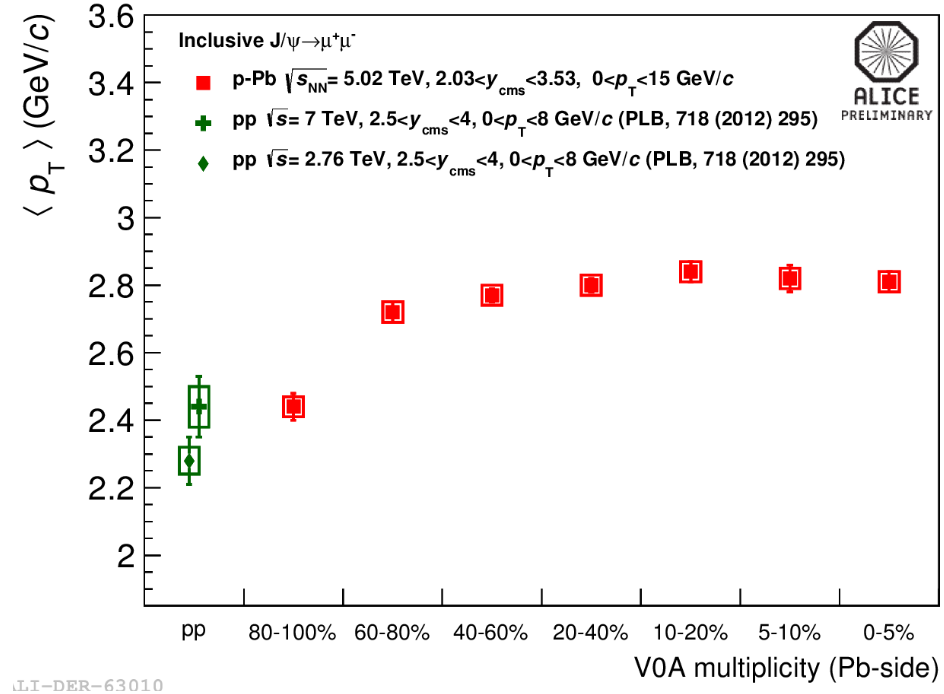
- Challenging but promising measurement
- Let's wait for more data

J/ψ p_t broadening with event multiplicity



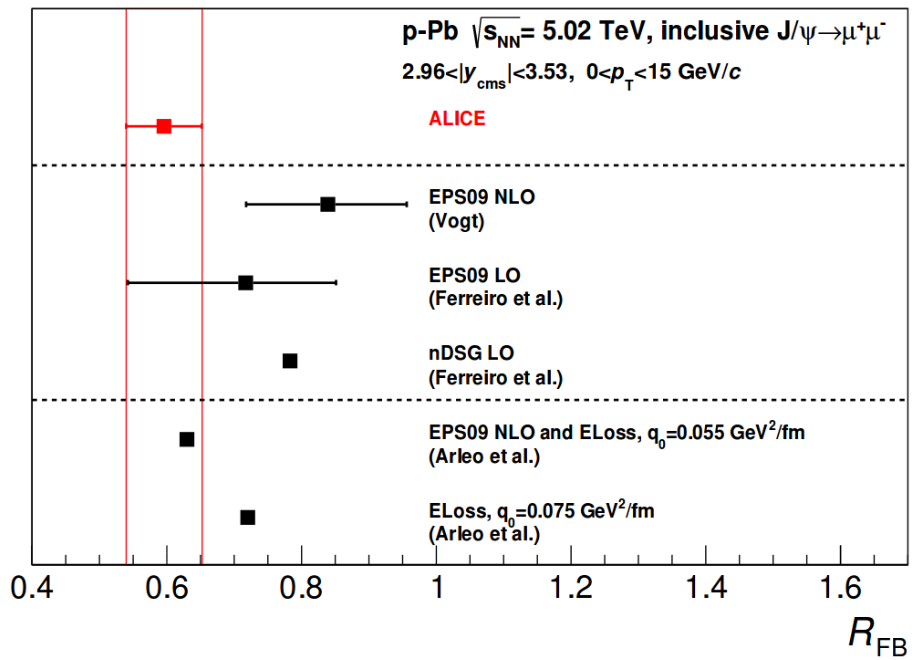
- Event multiplicity measured with the V0

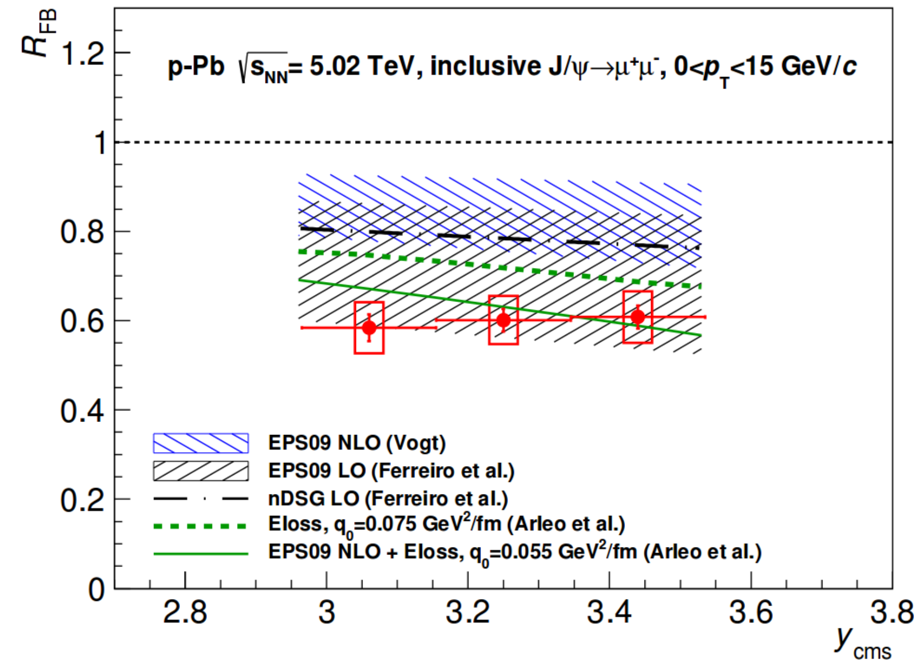


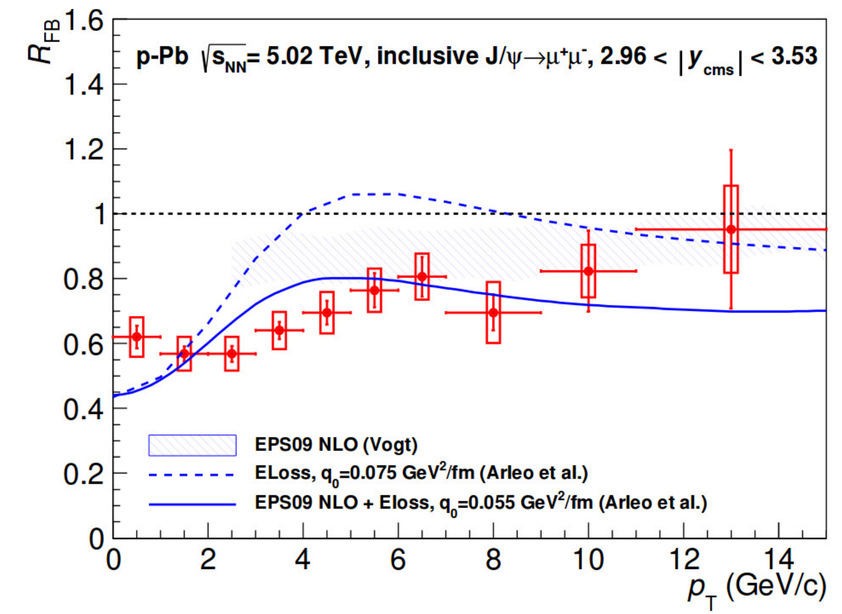


- Studying quarkonia properties as a function of the event multiplicity (or activity) can bring information on Multiple Partonic Interactions or interaction of the quarkonia with the surrounding environment
- At forward rapidity the J/ψ mean p_t increases with the event multiplicity

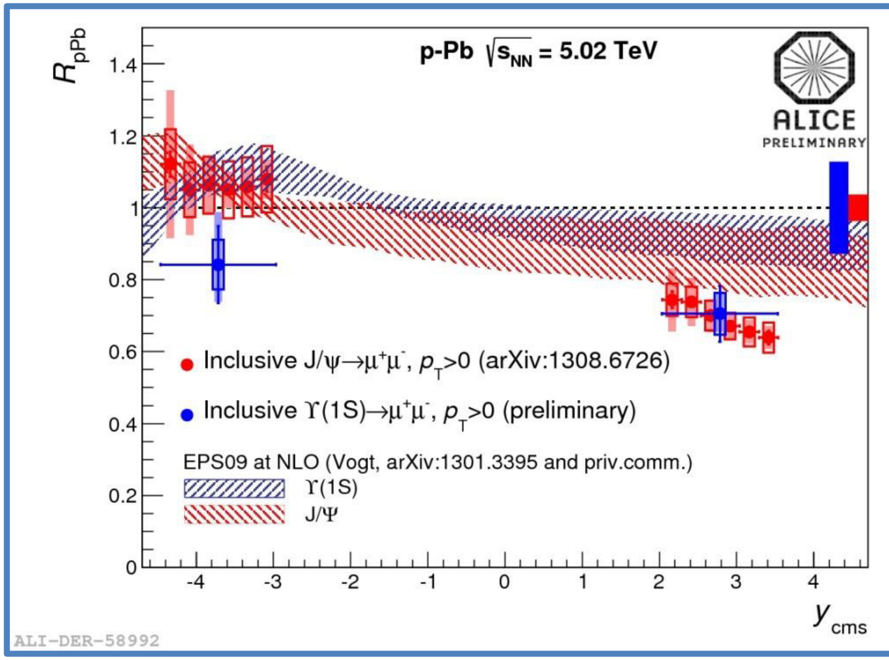
R_{FB} of the J/ψ

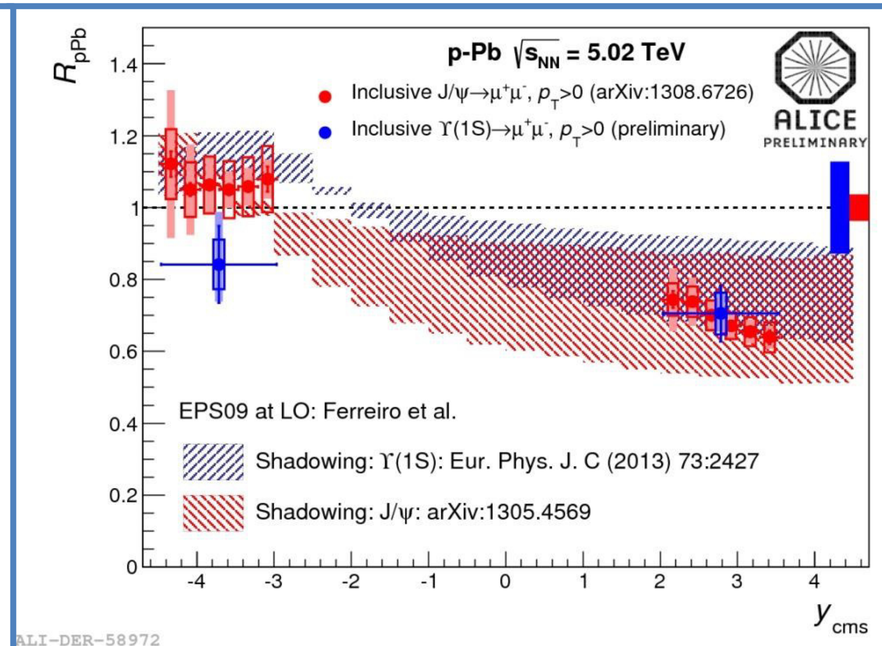

p-Pb √sNN = 5.02 TeV, inclusive J/ψ→μ+μ-
2.96<|ycms|<3.53, 0<pT<15 GeV/c
ALICE
EPS09 NLO (Vogt)
EPS09 LO (Ferreiro et al.)
nDSG LO (Ferreiro et al.)
EPS09 NLO and ELoss, q0=0.055 GeV2/fm (Arleo et al.)
ELoss, q0=0.075 GeV2/fm (Arleo et al.)
RFB


p-Pb √sNN = 5.02 TeV, inclusive J/ψ→μ+μ-, 0<pT<15 GeV/c
EPS09 NLO (Vogt)
EPS09 LO (Ferreiro et al.)
nDSG LO (Ferreiro et al.)
Eloss, q0=0.075 GeV2/fm (Arleo et al.)
EPS09 NLO + Eloss, q0=0.055 GeV2/fm (Arleo et al.)
RFB
ycms


p-Pb √sNN = 5.02 TeV, inclusive J/ψ→μ+μ-, 2.96 < |ycms| < 3.53
EPS09 NLO (Vogt)
ELoss, q0=0.075 GeV2/fm (Arleo et al.)
EPS09 NLO + Eloss, q0=0.055 GeV2/fm (Arleo et al.)
RFB
pT (GeV/c)

ϒ(1S) R_{pA} in p-Pb and Pb-p collisions at $\sqrt{s_{NN}}$ =5.02 TeV EPS09 LO and EPS09 NLO



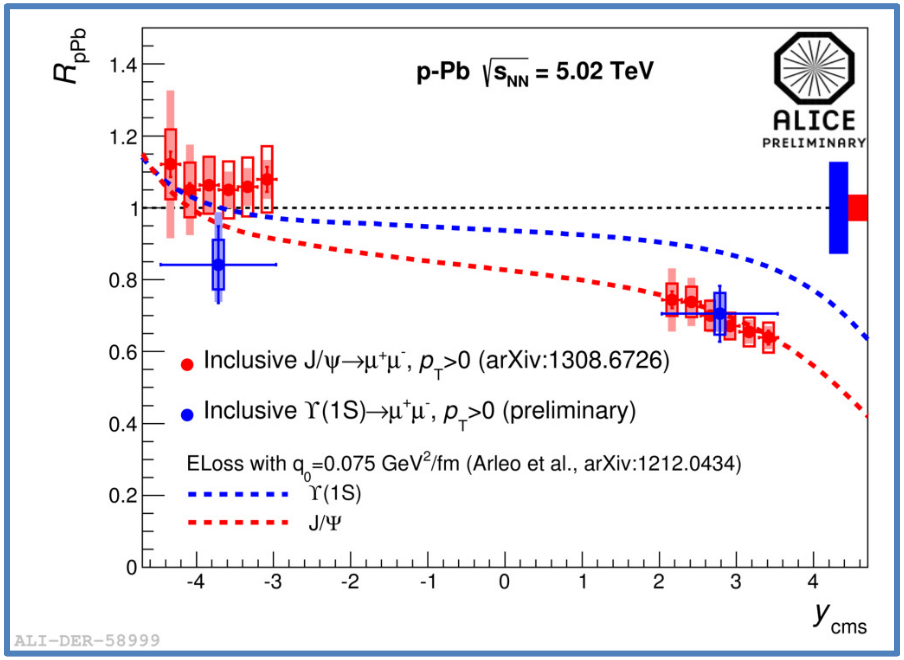


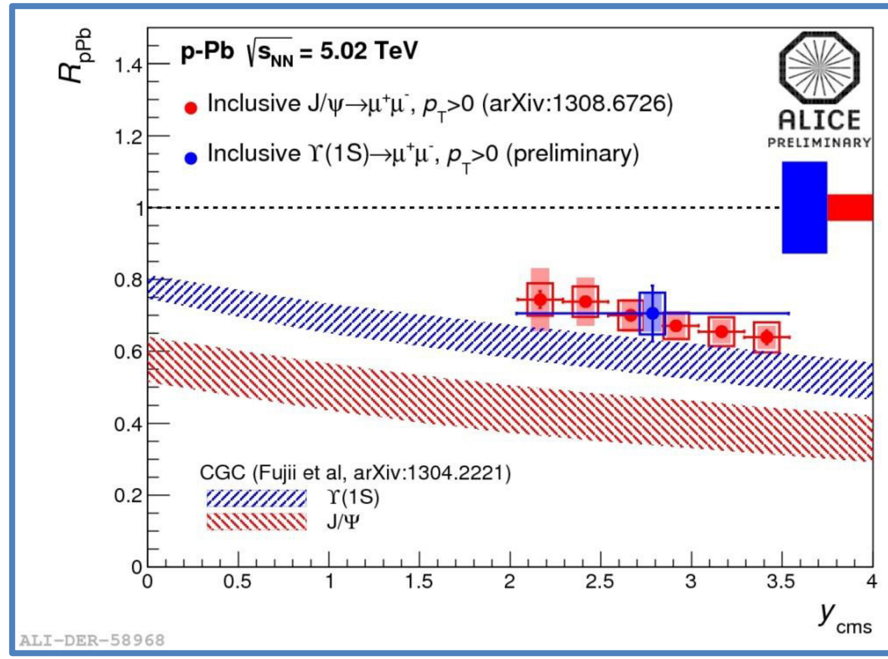
- NLO calculations
- Production model: CEM
- Error band: 30 EPS09 sets considered

- LO calculations
- Production model: CSM
- Error bands: Two identified EPS09 sets with maximum and minimum shadowing

- ϒ(1S) and J/ψ suppressions are compatible
- EPS09 NLO and LO predictions reproduce the data
- EPS09 NLO tends to underestimate the ϒ(1S) suppression at forward rapidity
- Better agreement with J/ψ data

Υ(1S) R_{pA} in p-Pb and Pb-p collisions at $\sqrt{s_{NN}}$ =5.02 TeV
Energy Loss and CGC models



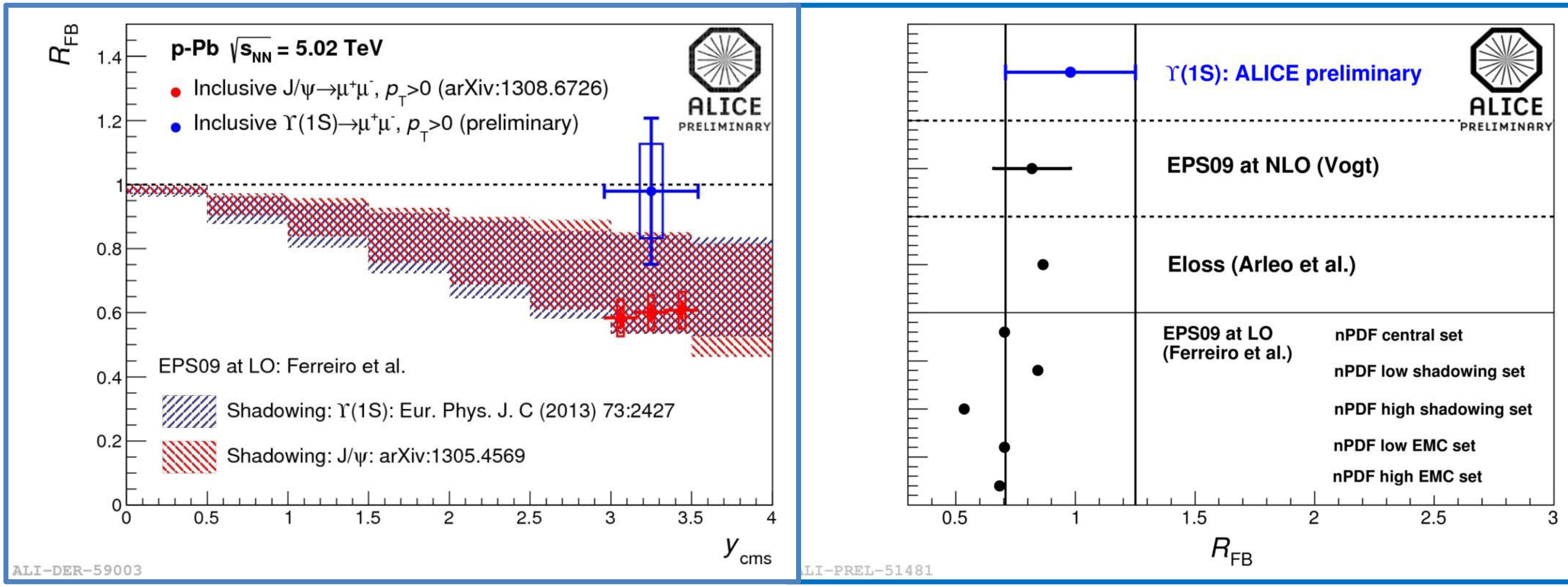


- Coherent parton energy loss:
  - Medium induced energy loss
  - Longed-lived, color octet heavy quark pairs
  - Single free parameter q_0

- Heavy quark pairs produced by a dense medium made of gluons of small $x_{bjorken}$ (saturation)
- Quarkonia production: CEM

- The energy loss model reproduces the data but tends to underestimate the ϒ(1S) suppression at forward rapidity
- The CGC model is disfavored by J/ ψ data, results are better with ϒ(1S) data

Forward-Backward ratio of inclusive Υ(1S): R_{FB}



- In the R_{pPb}/R_{Pbp} ratio the reference pp cross section and associated uncertainties are washed out but less statistics is available in the common y_{cms} range
- The Υ(1S) R_{FB} is compatible with the unity
- The J/ψ R_{FB} is significantly smaller than for Υ(1S)
- Models describe Υ(1S) R_{FB}