Quarkonium and open heavy-flavor production in Pb-Pb and p-Pb collisions with ALICE at the LHC

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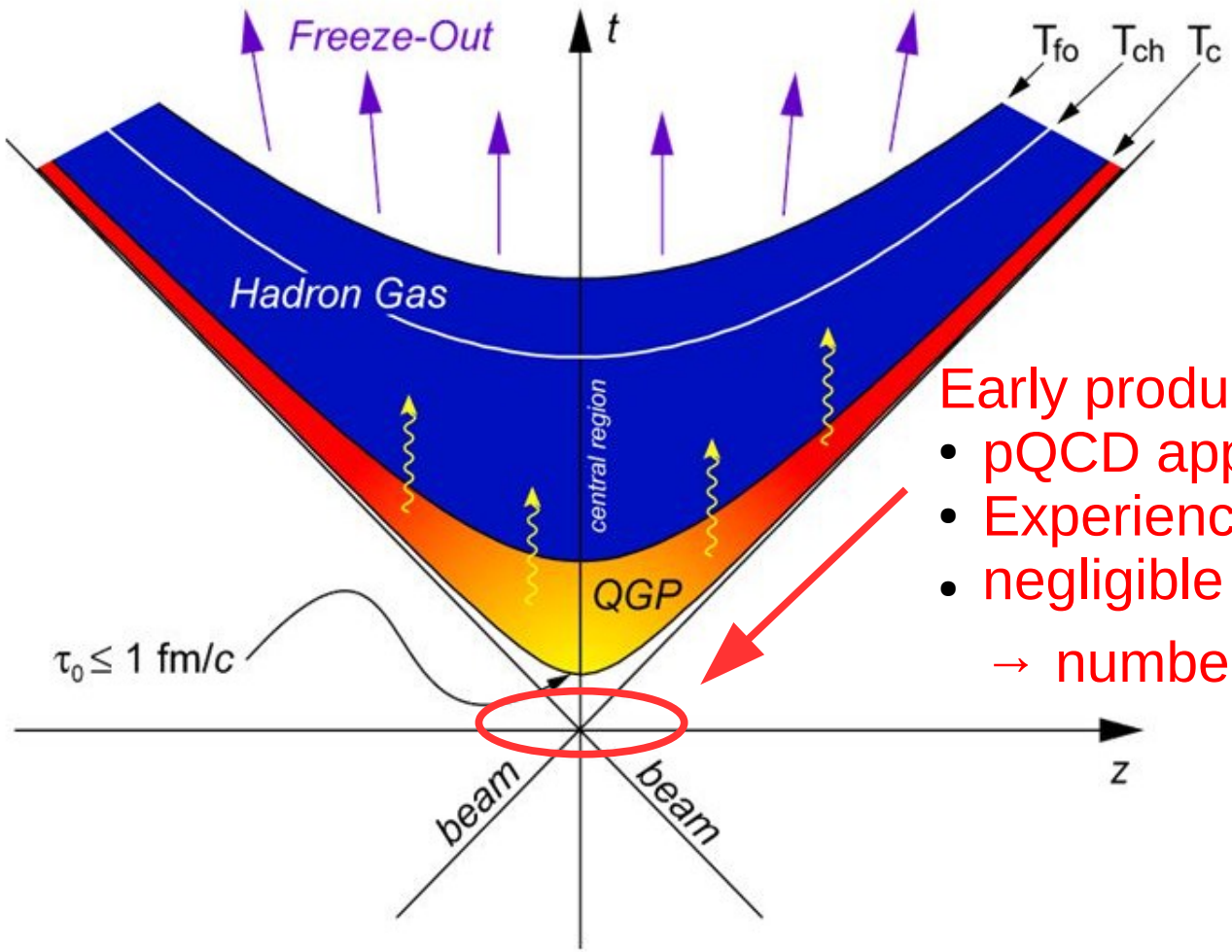
ICHEP2016CHICAGO

ALICE

Outline

- Introduction
- ALICE detector
- Nuclear modification and elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV
- New quarkonia results at 5.02 TeV
- Open and hidden heavy-flavor production in p-Pb collisions
- Conclusions

Heavy quarks and heavy-ion collisions

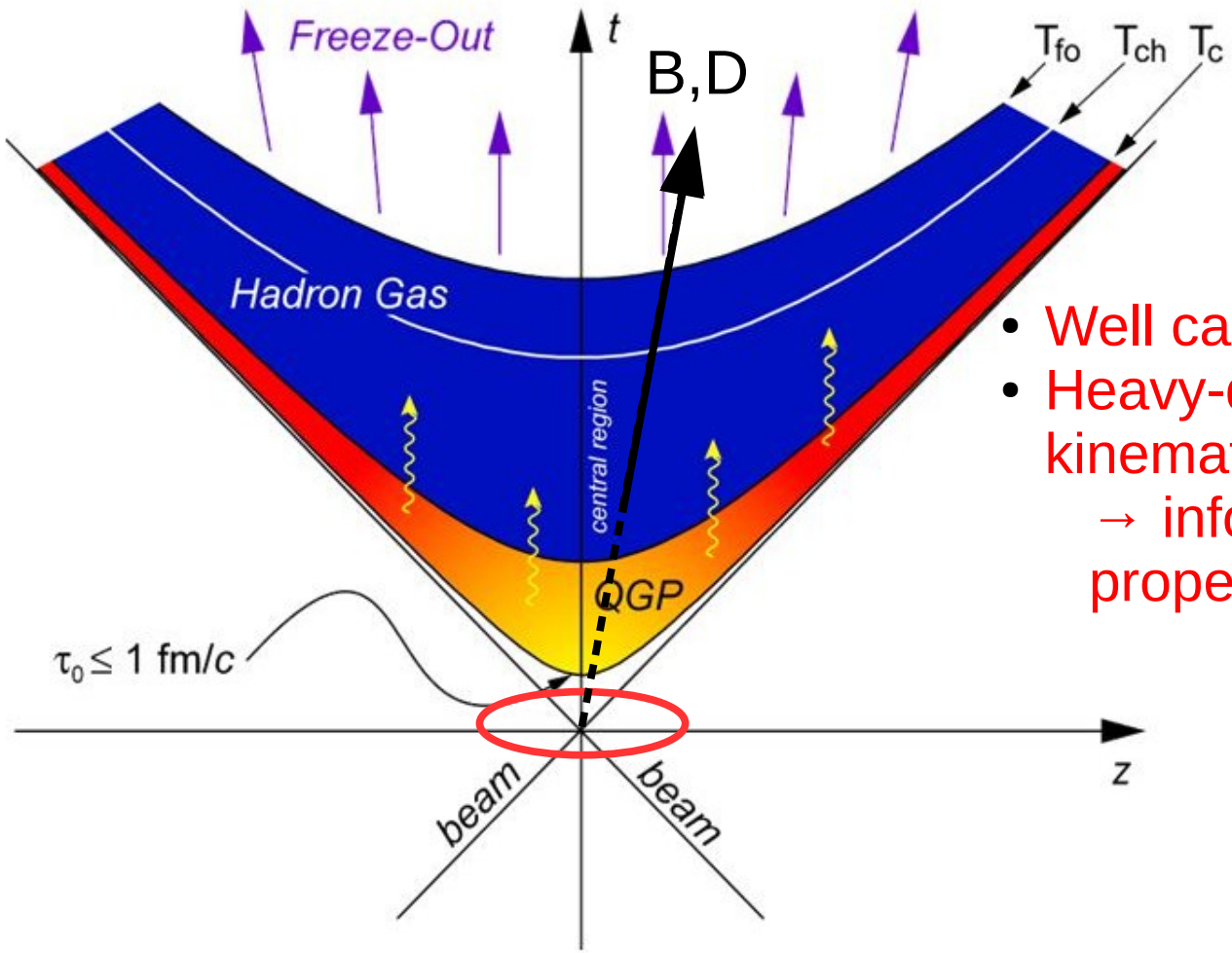


Early production in high-Q^2 processes

- pQCD applicable for cross-sections
- Experience the whole collision history
- negligible thermal production ($m_{c,b} >> T$)

→ number of c,b quarks is conserved

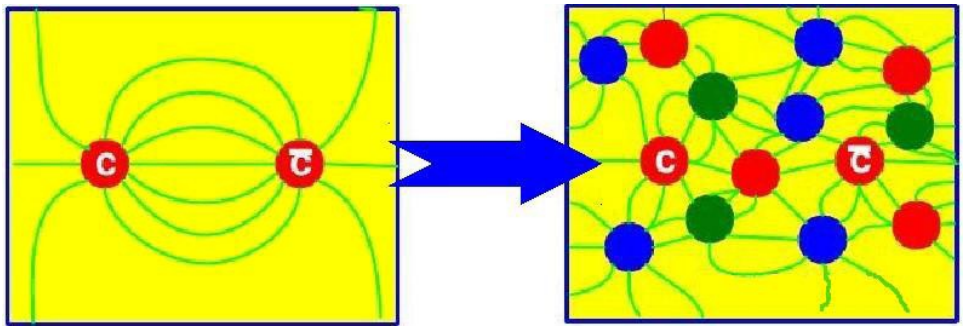
Heavy quarks and heavy-ion collisions



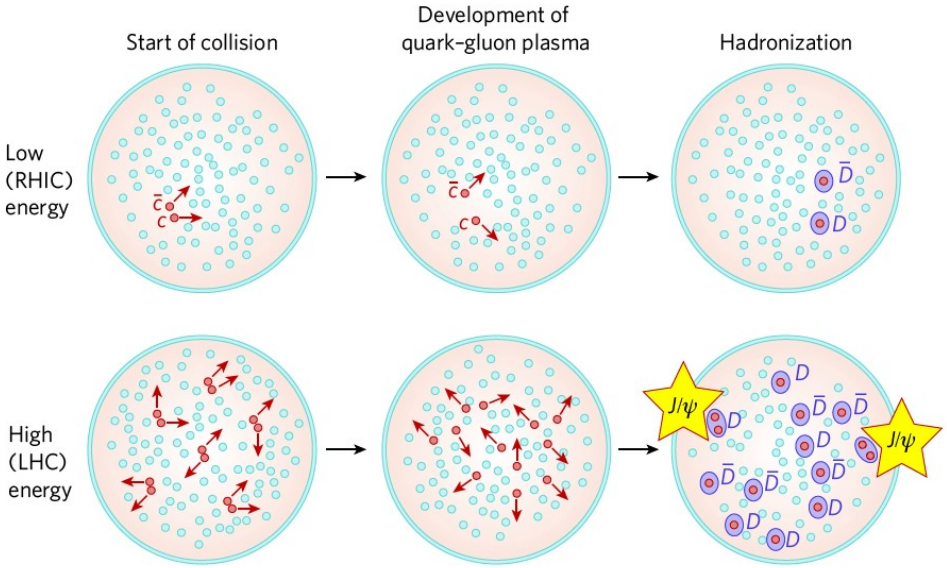
- Well calibrated probe
- Heavy-quark modification of the kinematics and hadronization
  → information on the QGP properties

Quarkonia

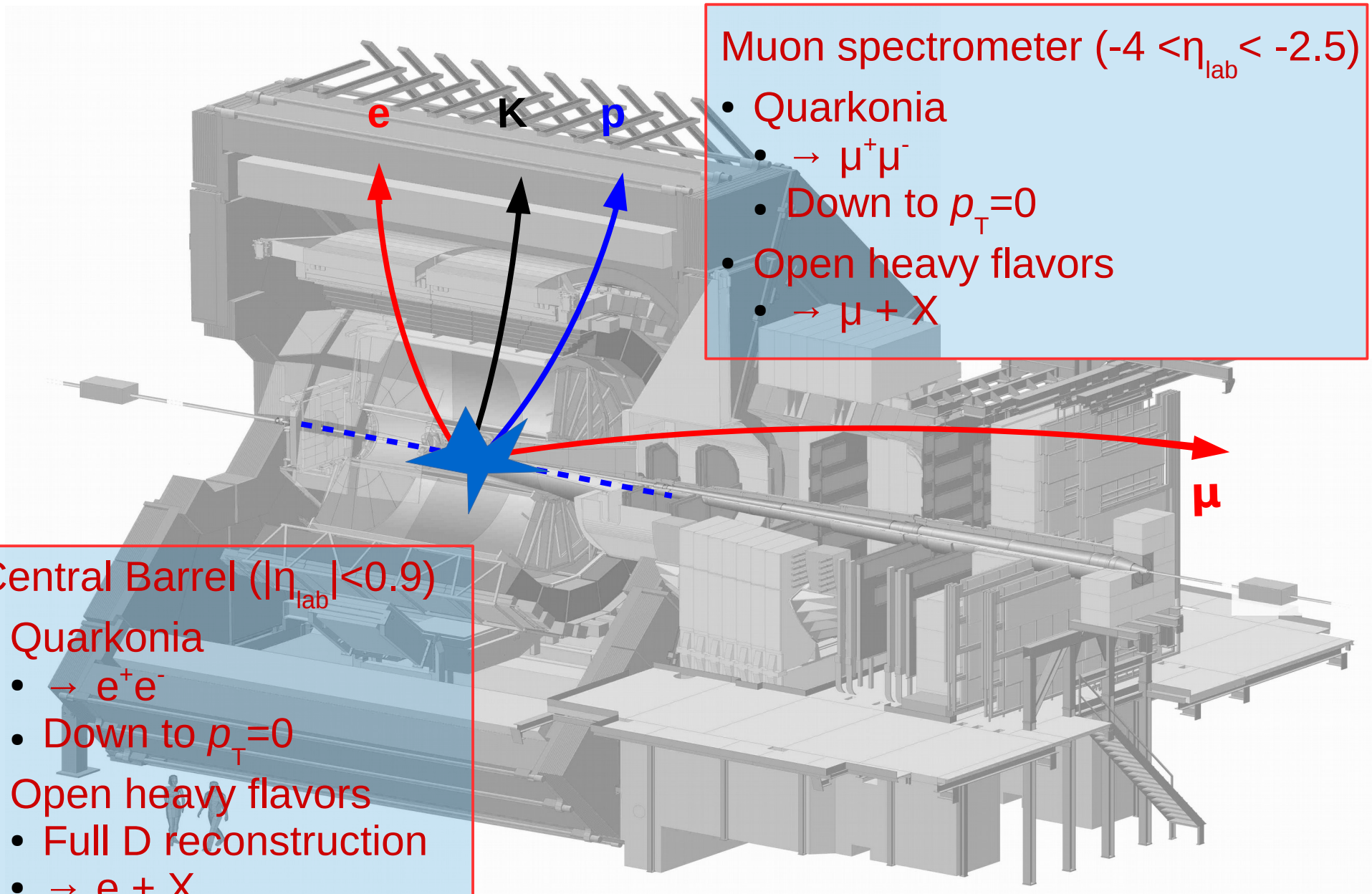
- Color screening (Matsui and Satz 1986)
  - Sequential suppression (Digal, Petreczcy, Satz 2001)



- Copious heavy-quark production at LHC
  - ~100 $c\bar{c}$ and 5-6 $b\bar{b}$ in central Pb-Pb collisions
- Charmonium creation at the phase boundary (Braun-Munzinger, Stachel 2000)
- Continuous melting and regeneration (Thews et al. 2001)



Open heavy flavours and quarkonia in ALICE



Muon spectrometer ($-4 < \eta_{lab} < -2.5$)

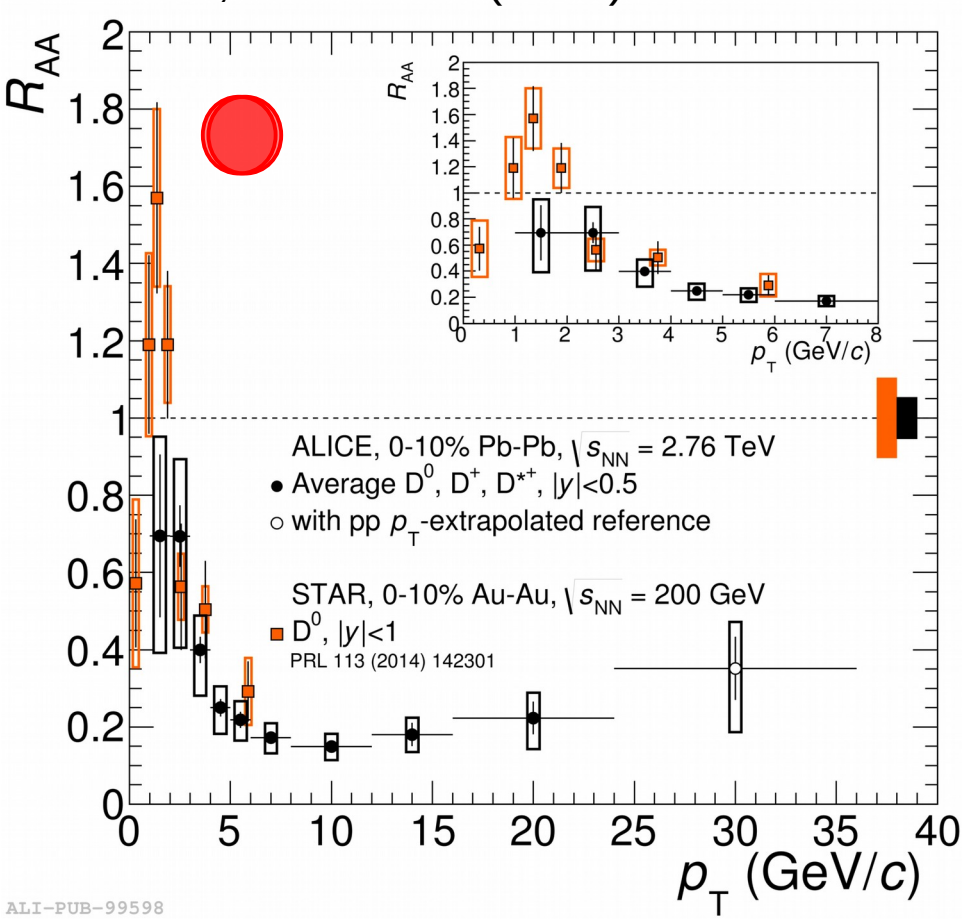
- Quarkonia
  - → $\mu^+\mu^-$
  - Down to p_T=0
- Open heavy flavors
  - → μ + X

Central Barrel ($|\eta_{lab}|<0.9$)

- Quarkonia
  - → e^+e^-
  - Down to p_T=0
- Open heavy flavors
  - Full D reconstruction
  - → e + X

D meson suppression in AA collisions

ALICE, JHEP1603 (2016) 081

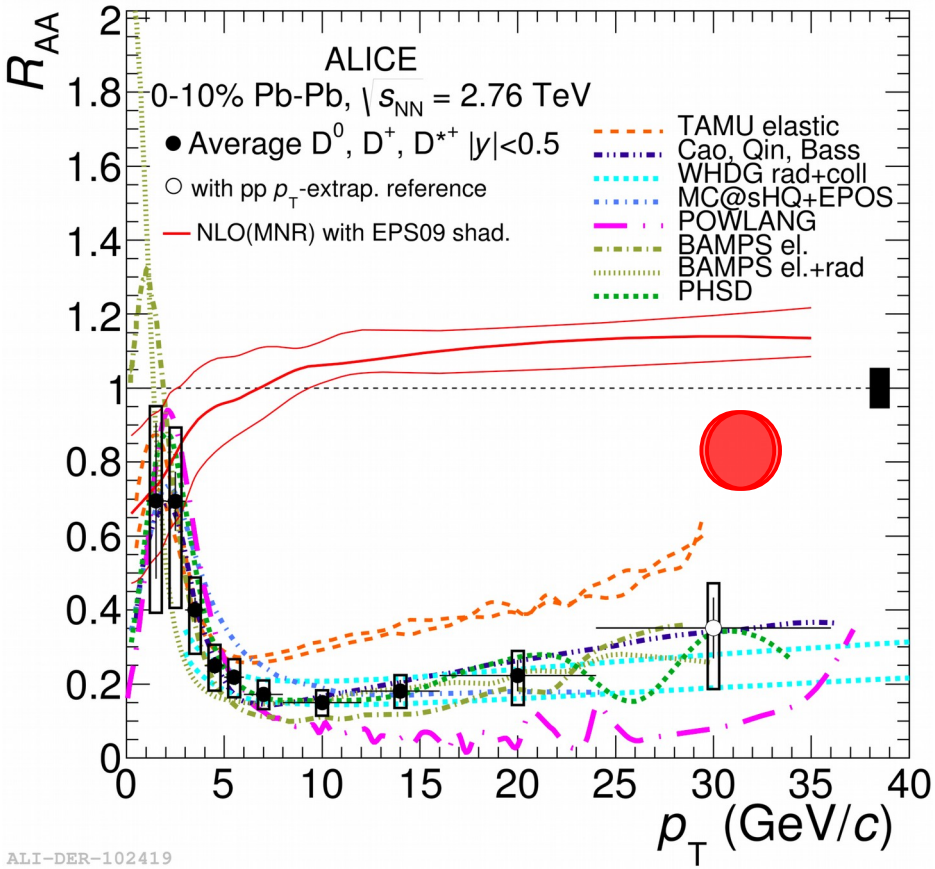


- Strong suppression of D-meson yields in the most central Pb-Pb collisions at mid-rapidity
- Results by STAR at $\sqrt{s_{NN}}$=200 GeV indicate that R_{AA}>1 at low p_T
  - Expected from charm conservation

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \times \frac{Y_{AA}}{Y_{pp}} = \frac{medium}{vacuum}$$

D-meson suppression in Pb-Pb collisions

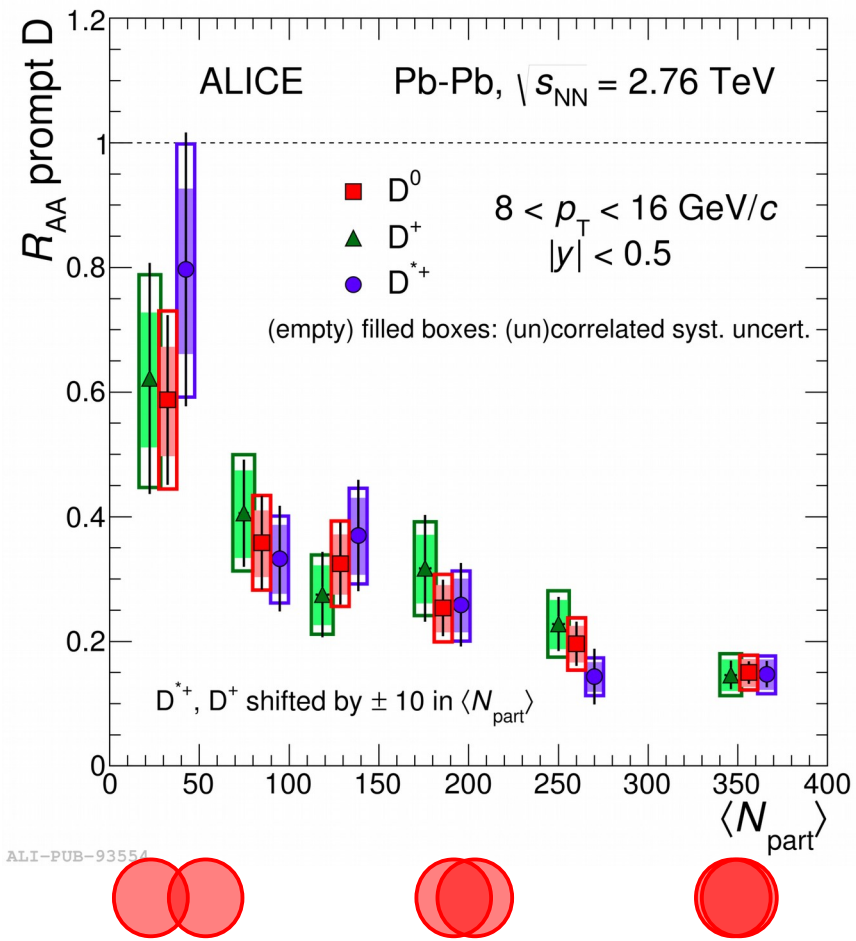
ALICE, JHEP1603 (2016) 081



- Strong final-state interactions of the charm quarks with the medium suggested by model calculations
- Main mechanism at play: energy loss via collisional and radiative processes
- A pQCD calculation implementing only shadowing indicates mild CNM effects

Heavy-quark energy loss

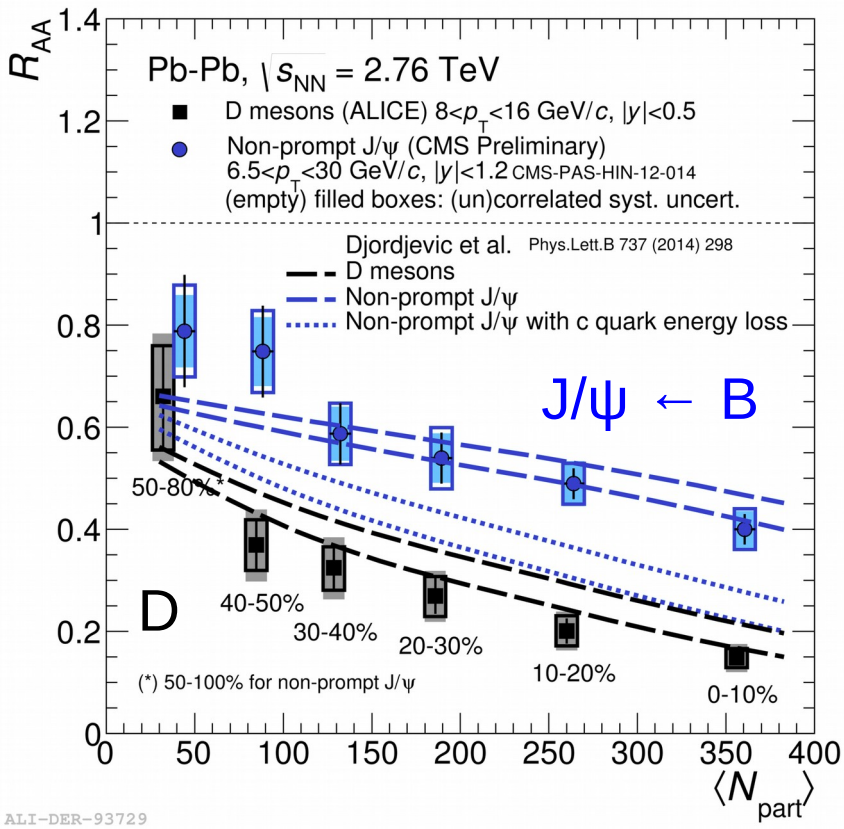
ALICE, JHEP11 (2015) 205



- Energy loss (ΔE) in the medium depends on
  - medium properties (e.g. density, temperature)
  - path length
- Suppression grows from peripheral to central Pb-Pb collisions

Heavy quark energy loss

ALICE, JHEP1603 (2016) 081

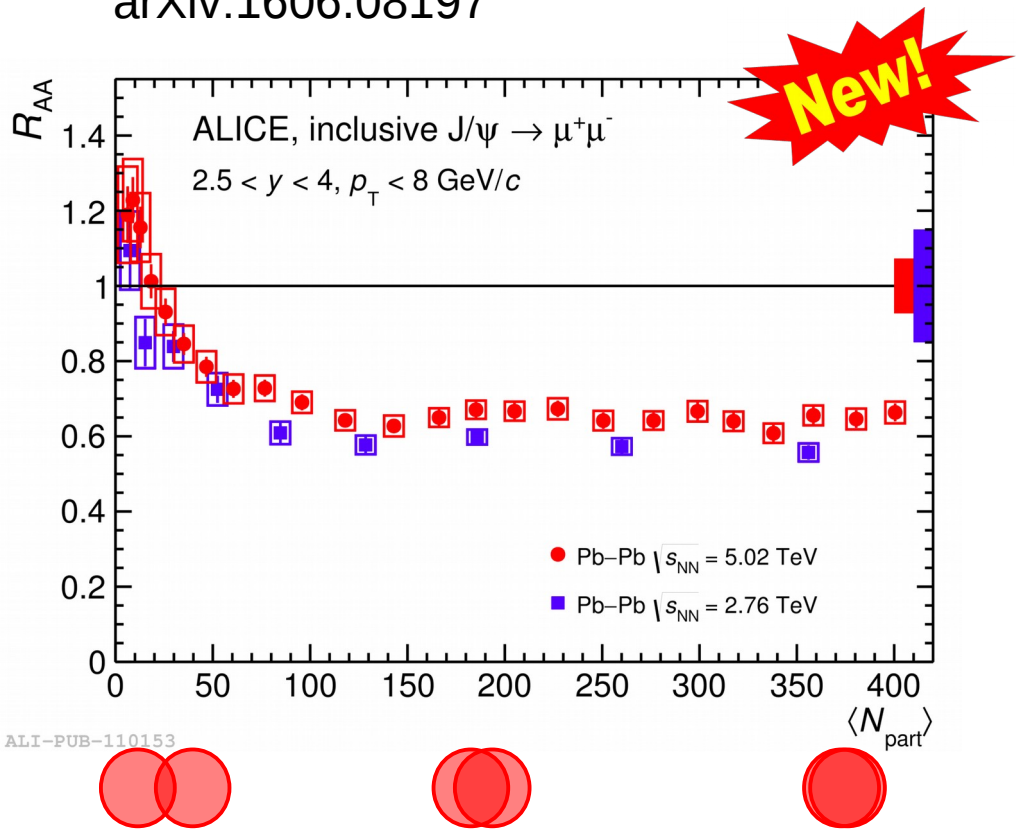


- Energy loss (ΔE) in the medium depends on
  - medium properties (e.g. density, temperature)
  - path length
  - parton type (via mass, Casimir factor)
- b-quarks clearly less suppressed than c-quarks

  → consistent with the expectation $\Delta E_c > \Delta E_b$

Inclusive J/ψ suppression in Pb-Pb collisions at 5.02 TeV

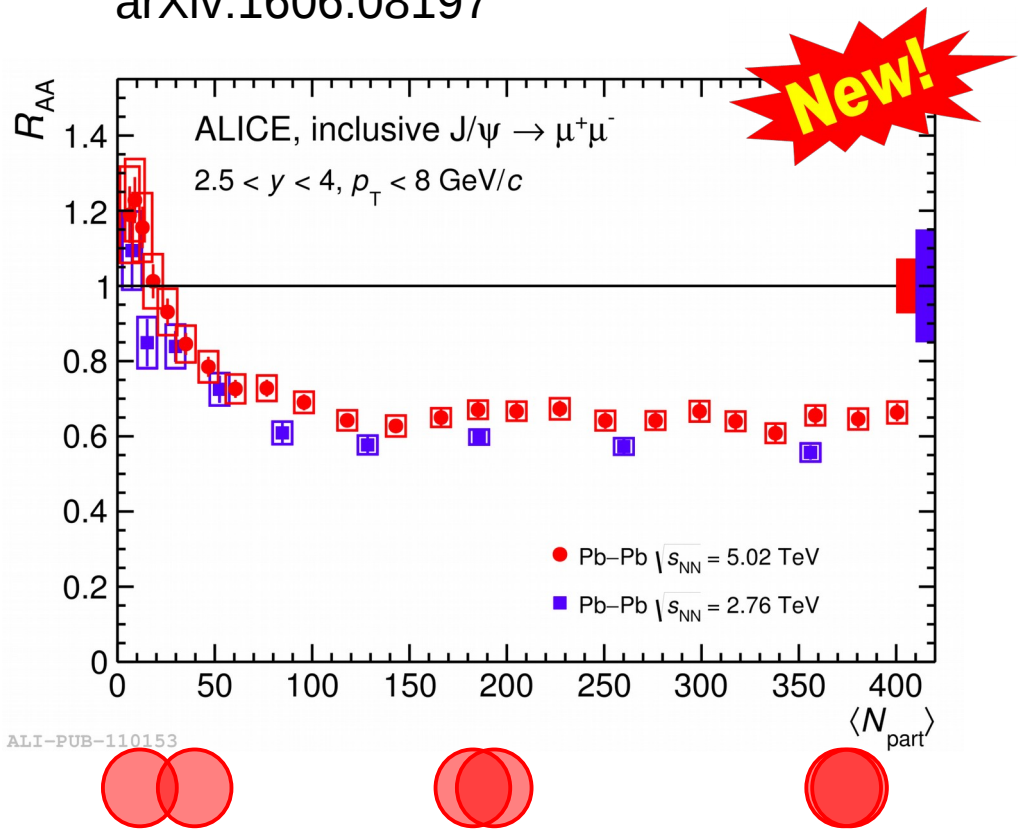
arXiv:1606.08197

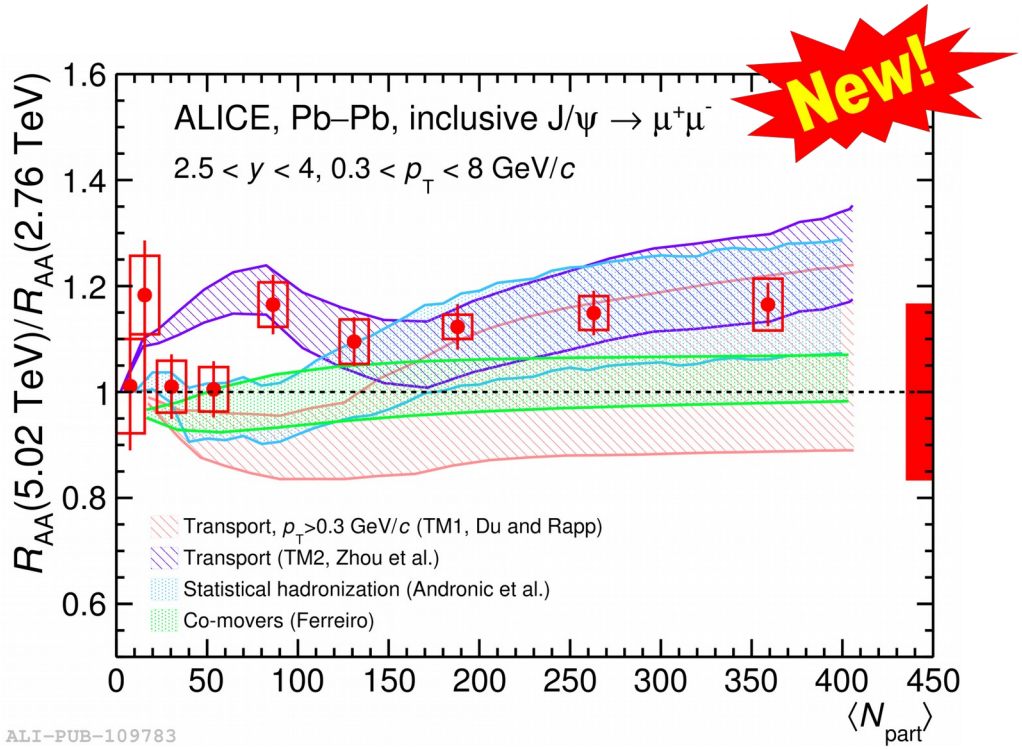


- Similar suppression levels at both 5.02 and 2.76 TeV with nearly no centrality dependence for N_{part}>100

Inclusive J/ψ suppression in Pb-Pb collisions at 5.02 TeV

arXiv:1606.08197

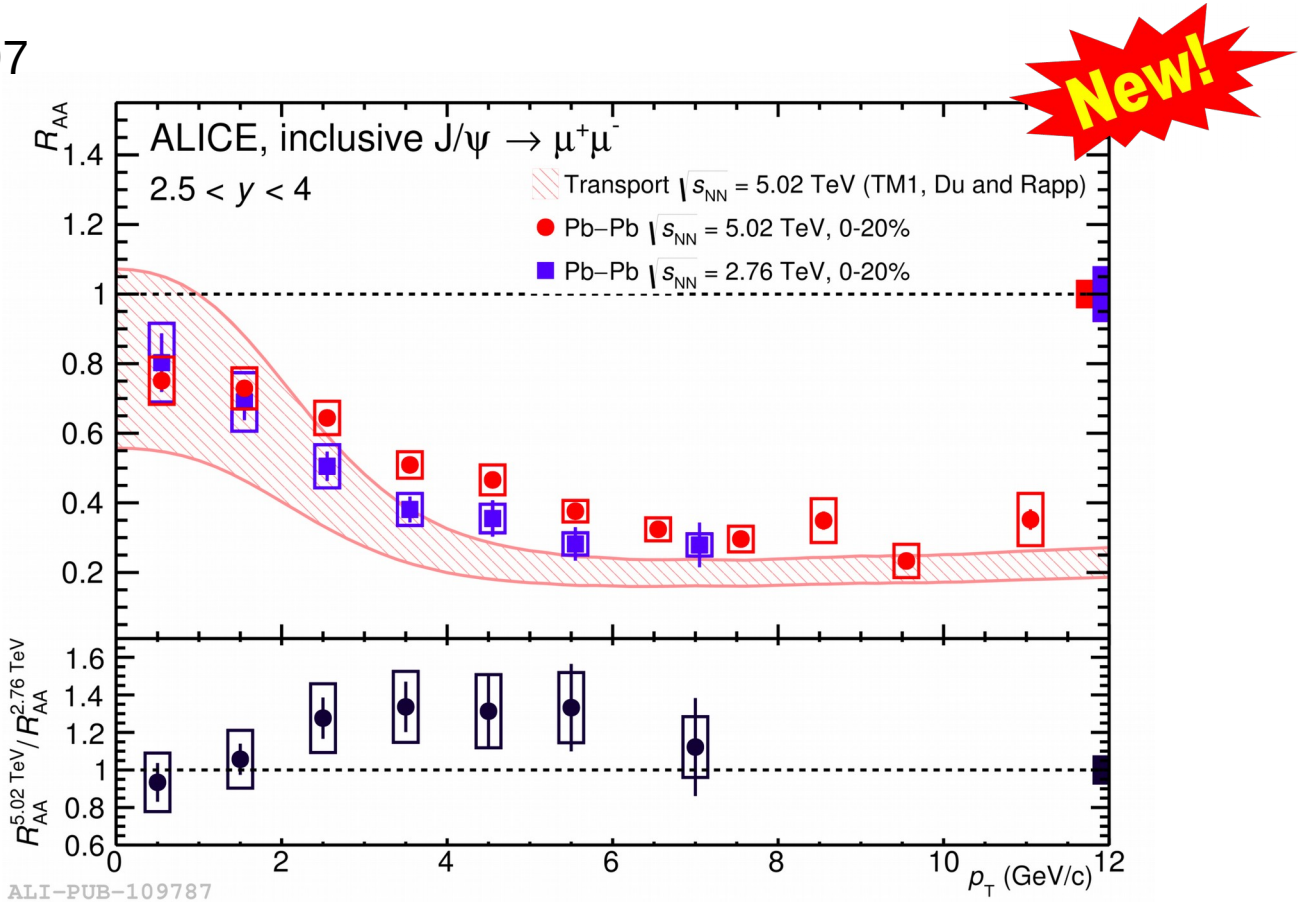




- Hint of an increase of R_{AA} with energy in central collisions
- Good agreement between data and models which include J/ψ regeneration

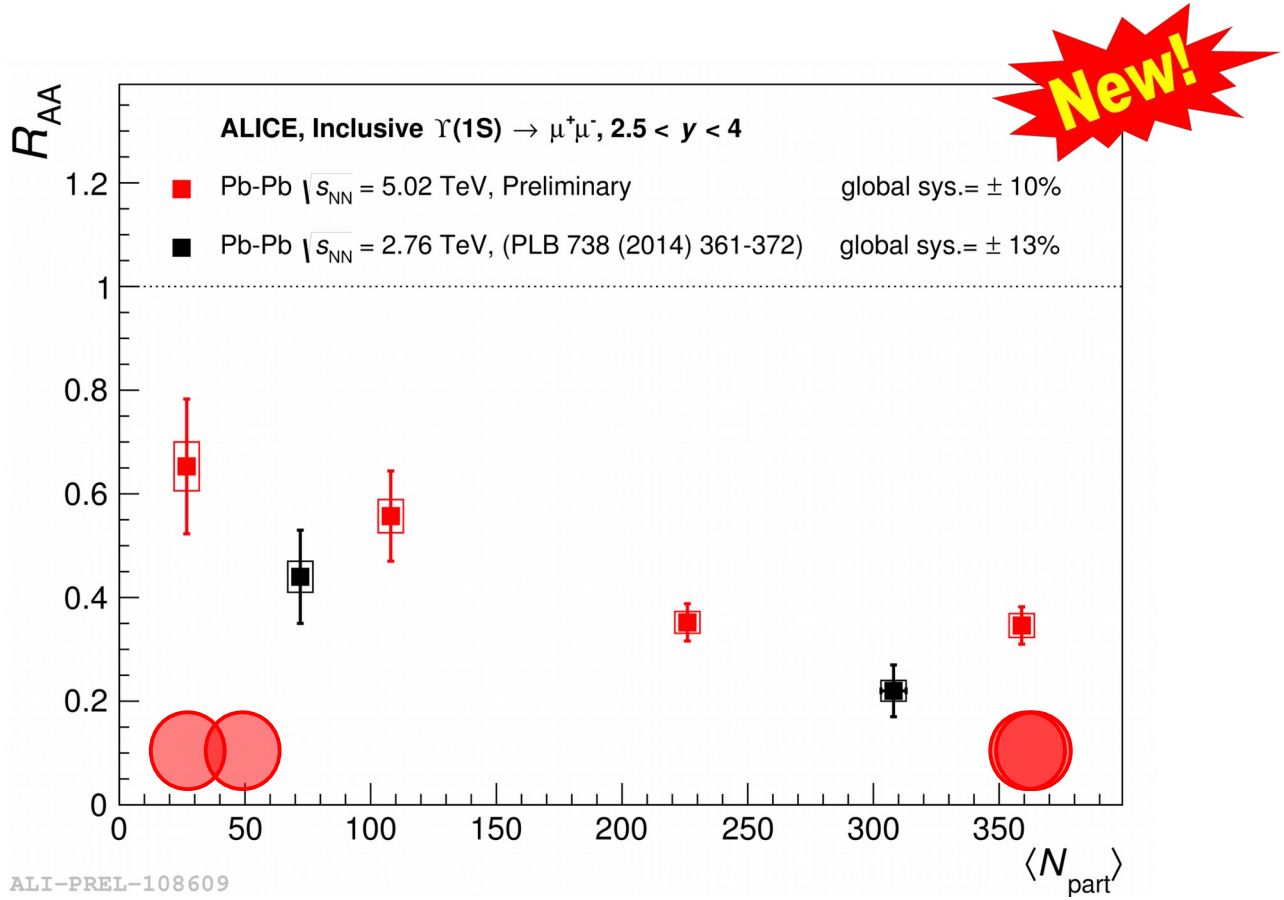
Inclusive J/ψ as a function of p_T

arXiv:1606.08197



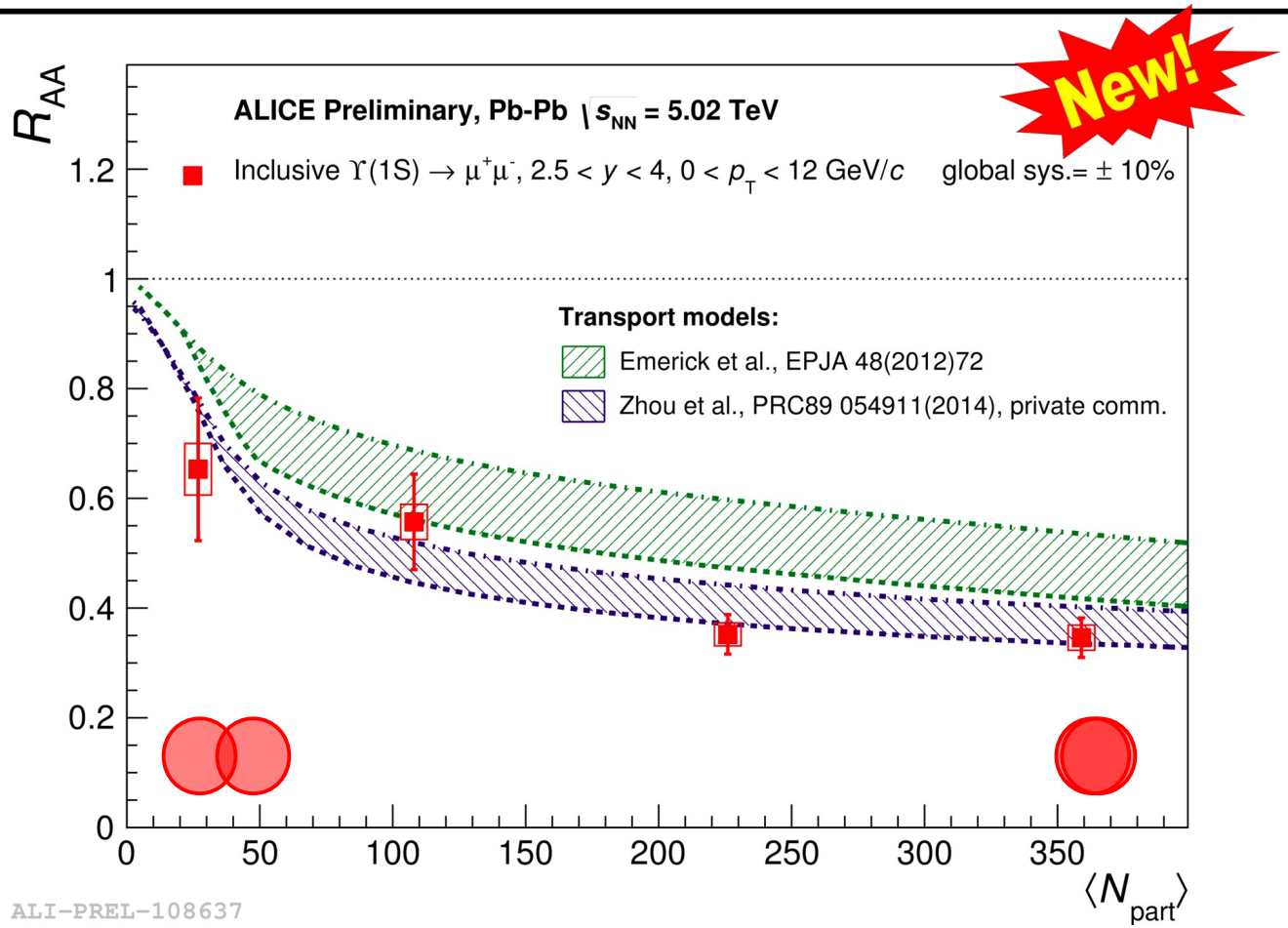
- Similar decreasing trend with increasing p_T at both 2.76 and 5.02 TeV
- Hint for an increase of R_{AA} with beam energy for p_T > 2 GeV/*c*

Υ(1S) suppression in Pb-Pb collisions at 5.02 TeV



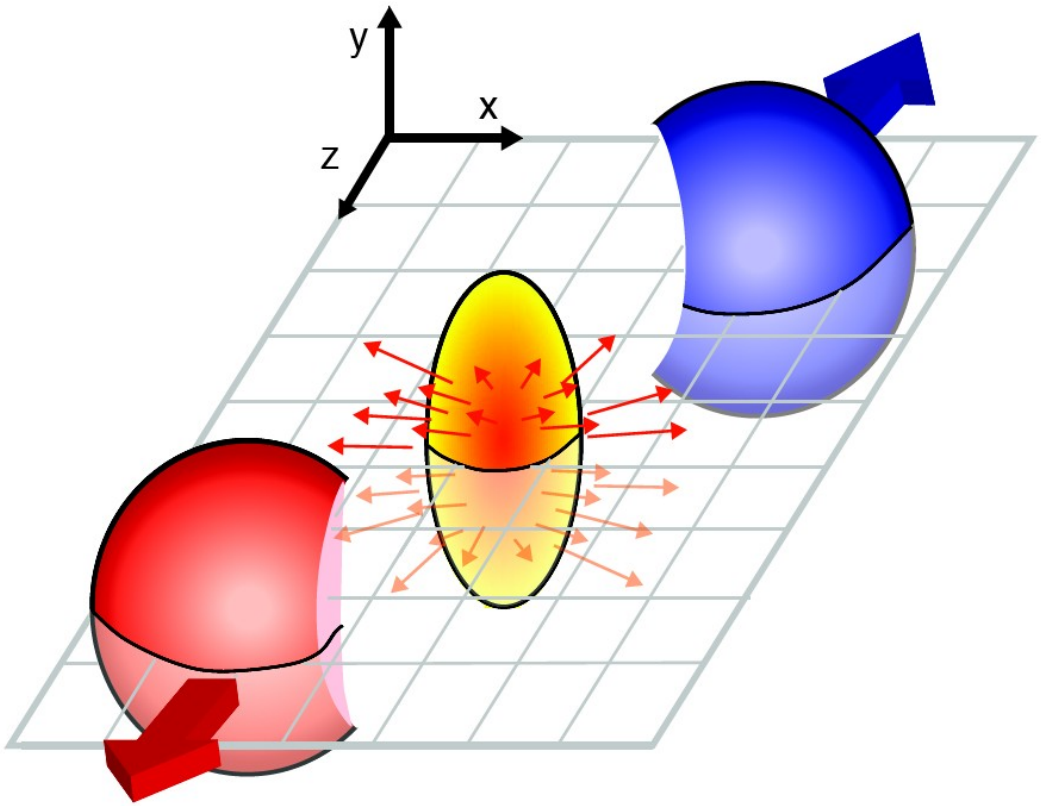
- Bottomonium is much less affected by regeneration effects → cleaner probe for the medium properties
- A strong Y(1S) suppression is observed in central collisions at both 2.76 and 5.02 TeV

Υ(1S) suppression in Pb-Pb collisions at 5.02 TeV



- Bottomonium is much less affected by regeneration effects → cleaner probe for the medium properties
- The suppression trend is well described by transport model calculations with (Emerick et al.) or without (Zhou et al.) regeneration

Elliptic flow (v_2)



- Determined by the initial spatial eccentricity, with energy density as weight
  ...the strongly coupled system transforms it into momentum anisotropy

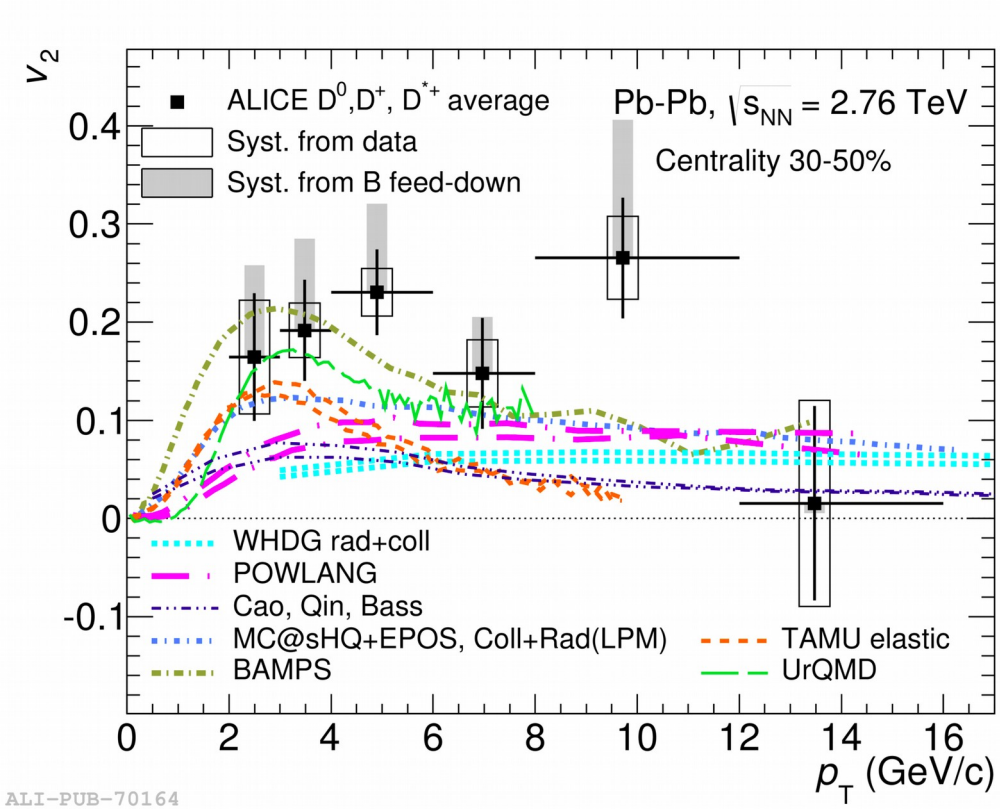
- Do heavy flavors thermalize and consequently flow like the light flavored particles ?

$$\frac{dN}{d\varphi} \sim [1 + 2v_1 \cos(\varphi) + 2v_2 \cos(2\varphi) + \ldots]$$

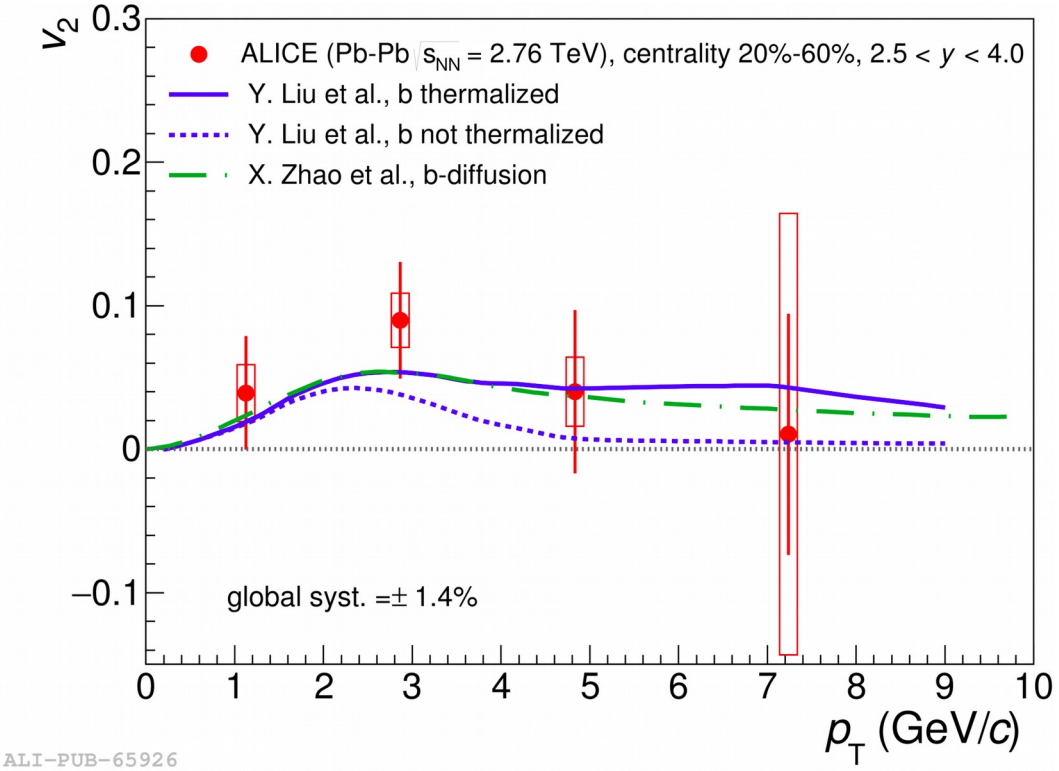
φ - azimuthal angle w.r.t. reaction plane

Elliptic flow of heavy-flavors

ALICE, arXiv: 1606.00321



ALICE, PRL111 (2013) 162301



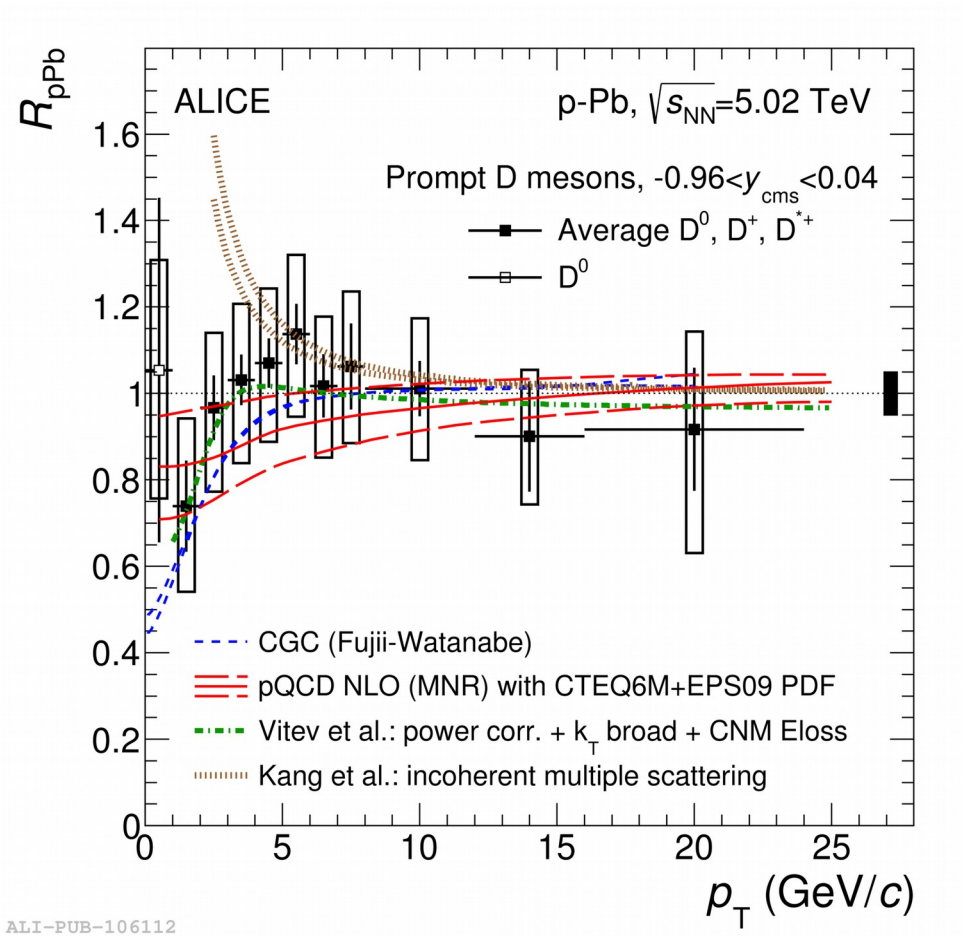
- Significant non-zero elliptic flow observed for D mesons
- The intermediate-p_T J/ψ hints non-zero v_2 in semi-central collisions
- Reproducing both v_2 and R_{AA} is a challenge for models

Heavy-flavor production in p-Pb collisions

- Reference for Pb-Pb results: understand the role of Cold Nuclear Matter (CNM) effects using a system where the formation of a QGP is not expected
  - Nuclear modifications of the PDFs, i.e. shadowing, Color Glass Condensate
  - Partonic coherent energy loss
  - Parton-k_T broadening
  - Nuclear absorption
- Check for the presence of non-CNM effects:
  - Collective behaviour ?
  - Formation of a QGP droplet ?

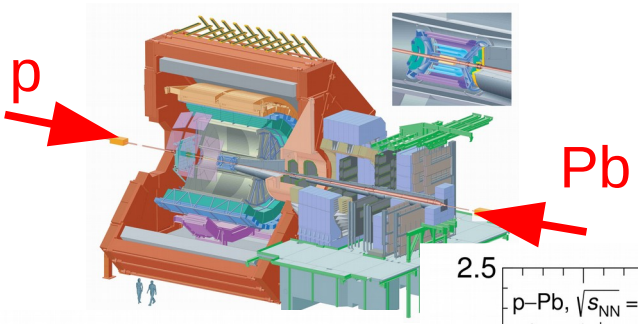
D-meson suppression in p-Pb collisions

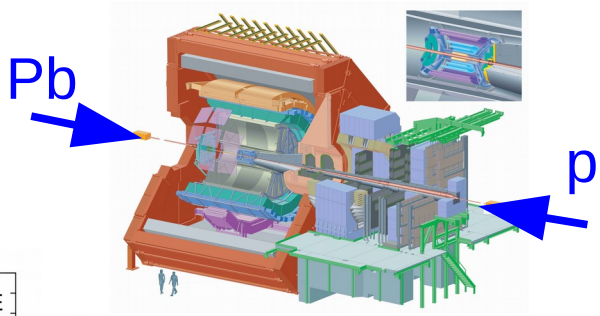
ALICE, arXiv: 1605.07569

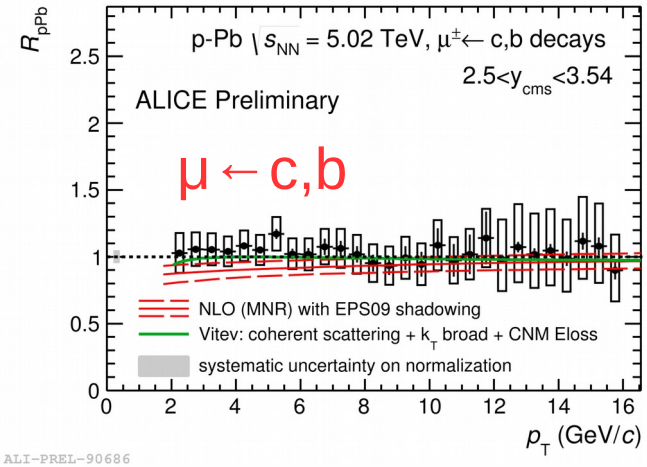


- $R_{pPb}(p_T>0, -0.96<y_{cms}<0.04) = 0.89 \pm 0.11(\text{stat.})^{+0.13}_{-0.18}(\text{syst.})$
- Measurement compatible with no CNM effects
- Experimental uncertainties are still too large to distinguish between existing models

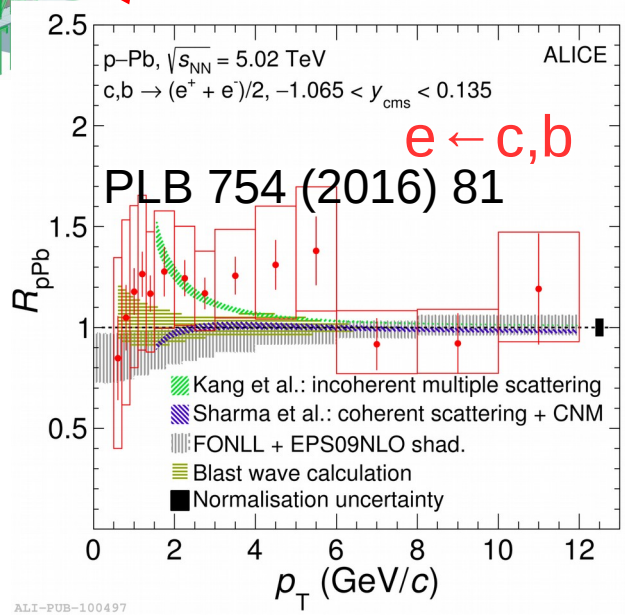
Heavy-flavor lepton suppression in p-Pb collisions



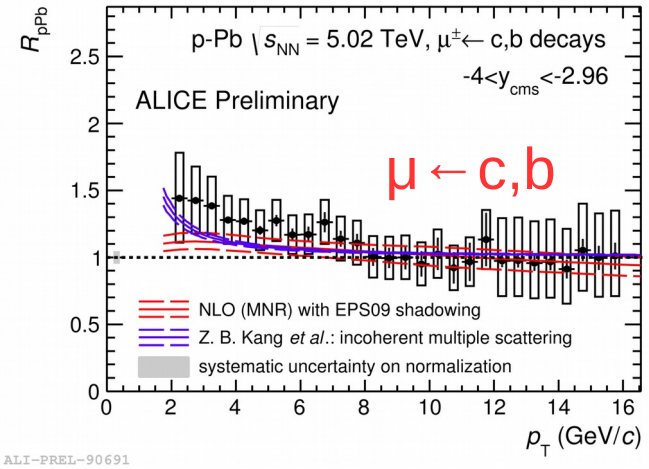




2.5<y_{cms}<3.54



-1.06<y_{cms}<0.14



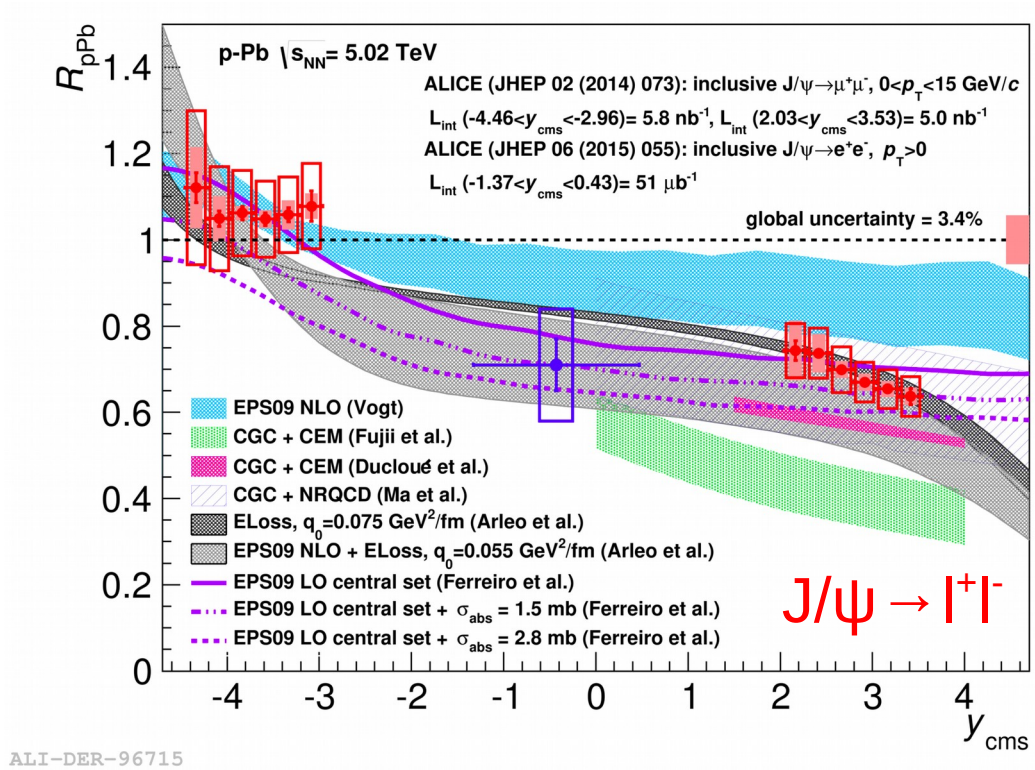
-4<y_{cms}<-2.96

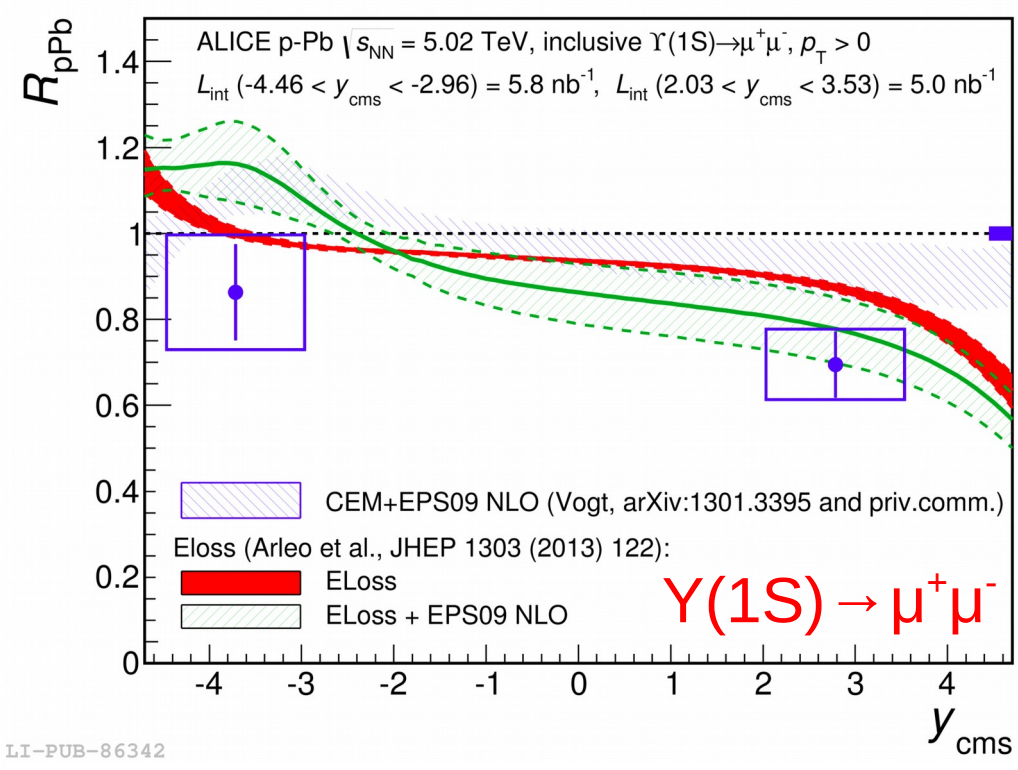
- Heavy-flavor leptons show no suppression at forward and mid-rapidity
- Indication of an enhancement at backward rapidity for 2<p_T<4 GeV/c
- Data consistent with models which include cold nuclear matter effects

Quarkonia in p-Pb collisions at 5.02 TeV

ALICE, JHEP02 (2014) 073
JHEP06 (2015) 055

PLB740 (2015) 105





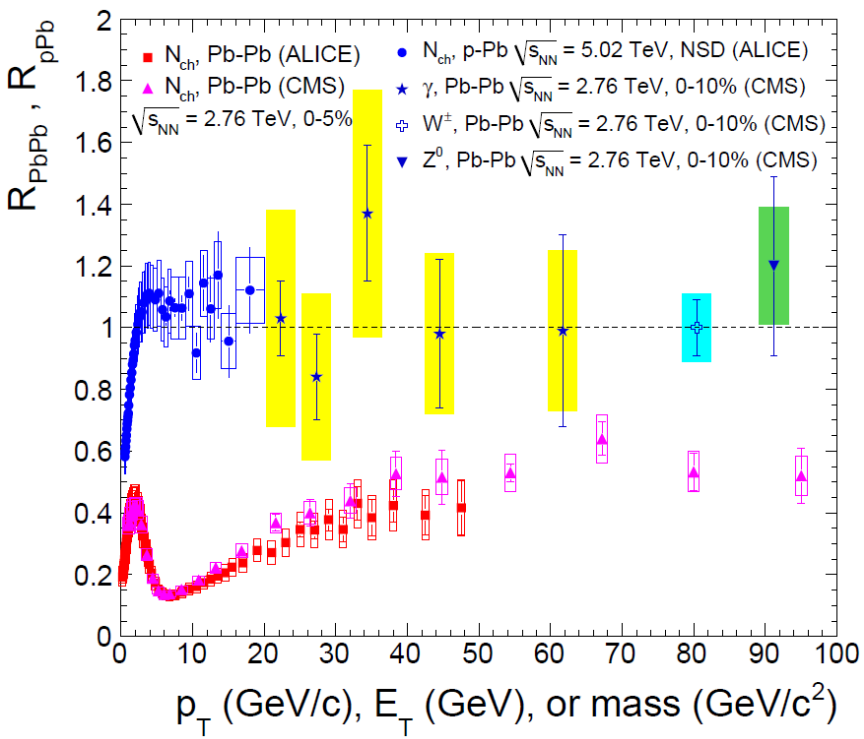
- J/ψ and Y(1S) are suppressed at forward rapidity
- At backward rapidity both states are compatible with no suppression
- Data are consistent with expectations from energy loss models (+shadowing)

Conclusions

- Open heavy flavors
  - Strong modification of the charm and beauty kinematics in Pb-Pb collisions w.r.t. pp collisions, with a significant centrality dependence
  - Indication of stronger charm suppression w.r.t. beauty → quark-mass dependent energy loss
  - Positive D-meson elliptic flow
  - No large CNM effects supported by the p-Pb data → the strong suppression in central Pb-Pb collisions is largely a hot medium effect
- Quarkonia
  - New results on J/ψ suppression in Pb-Pb collisions at 5.02 TeV indicate similar suppression level as the 2.76 TeV data
  - The p_T dependence of the J/ψ suppression suggests an important contribution from regeneration
  - The new Υ(1S) results at 5.02 TeV confirm the strong suppression observed in central Pb-Pb collisions at 2.76 TeV
- Next steps and questions:
  - Measure open heavy-flavor suppression down to p_T=0
  - Understand and disentangle CNM effects
  - Is the observed open heavy-flavor v_2 of hydro origin ?
  - Does J/ψ flow ?
  - Is the direct Υ(1S) suppressed ?
- More Run-2 results coming soon !

Backup

Medium effects (the nuclear modification factor)



p-Pb, ALICE PRL110(2013)082302
Pb-Pb, ALICE, Phys.Lett.B720 (2013)52
Pb-Pb, CMS, EPJC (2012) 72

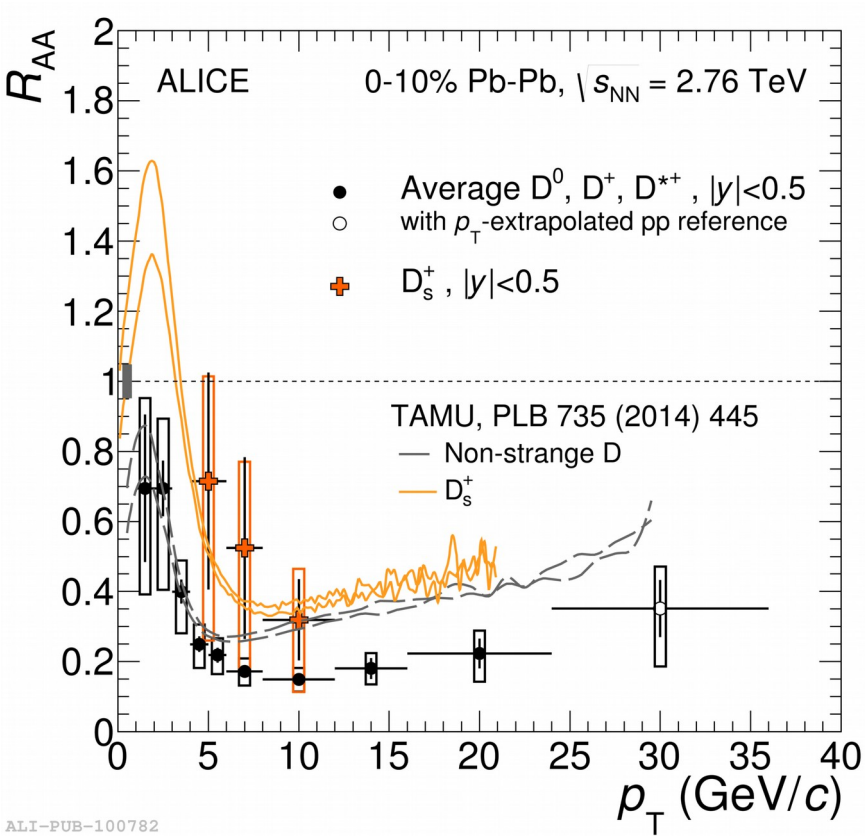
γ, CMS, PLB 710 (2012) 256
$W^{\pm}$, CMS, PLB715 (2012) 66
Z^0, CMS, PRL106 (2011) 212301

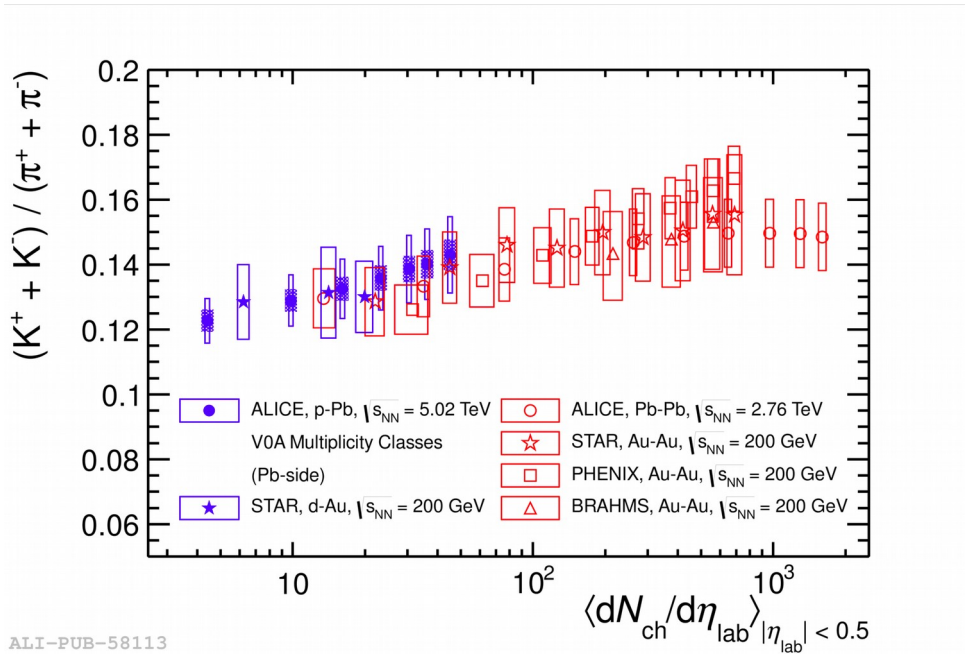
$$R_{AA} = \frac{1}{N_{coll}} \times \frac{Y_{AA}}{Y_{pp}}$$

- N_{coll}: the number of binary nucleon-nucleon collisions
- Superposition of NN collisions → $R_{AA}=1$
  Suppression → $R_{AA}<1$
  Enhancement → $R_{AA}>1$

- Weakly interacting particles are not affected by the QGP
  - Photons, $W^{\pm}$ and Z^0 bosons R_{AA} are compatible with 1

Strange D-meson production

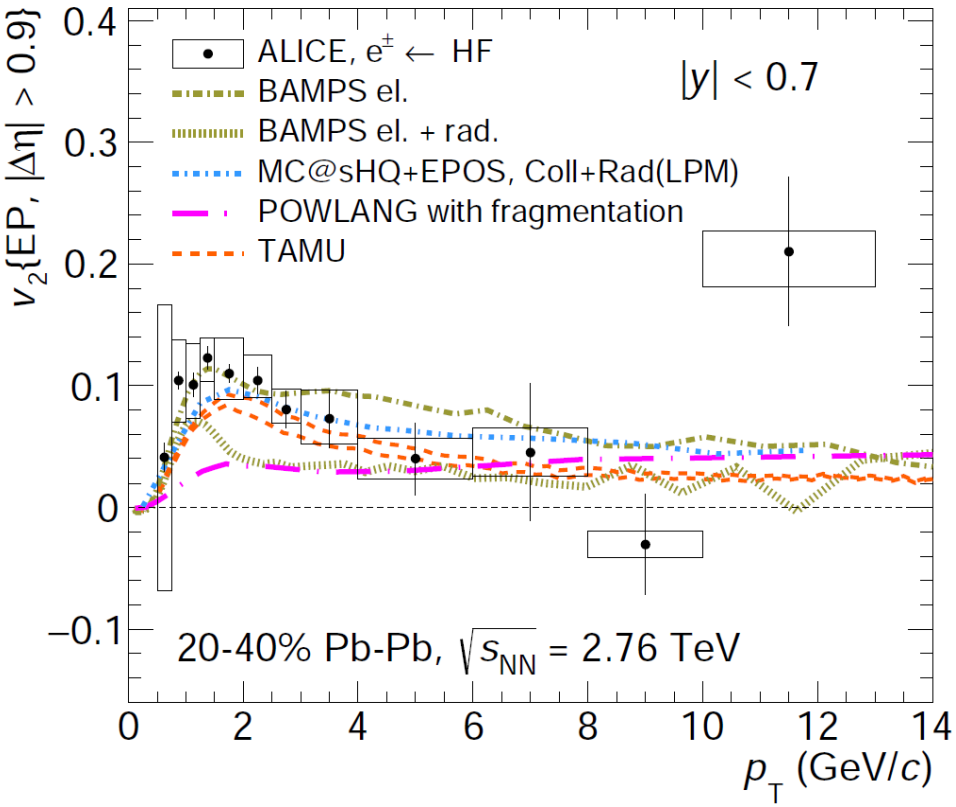


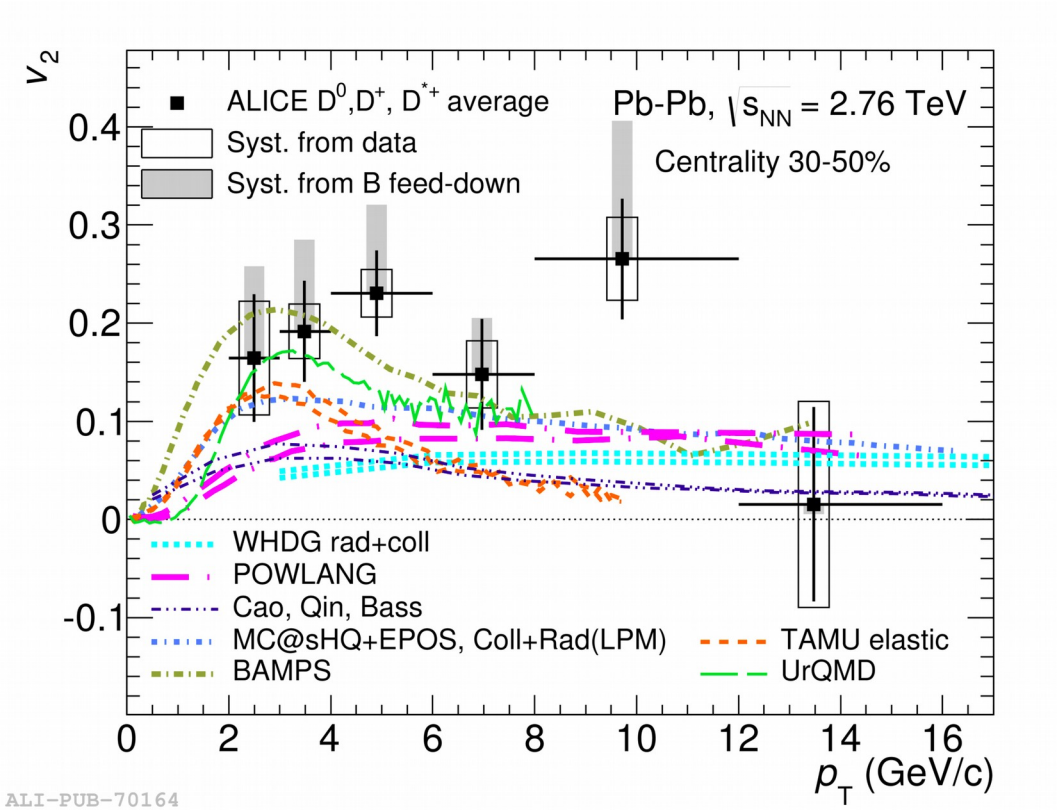


- Hint for a smaller suppression of Ds mesons wrt non-strange D's
  - Expected if the charm hadronizes by picking up light quarks from the surrounding strangeness enhanced medium

Elliptic flow of heavy-flavor

ALICE, arXiv: 1606.00321

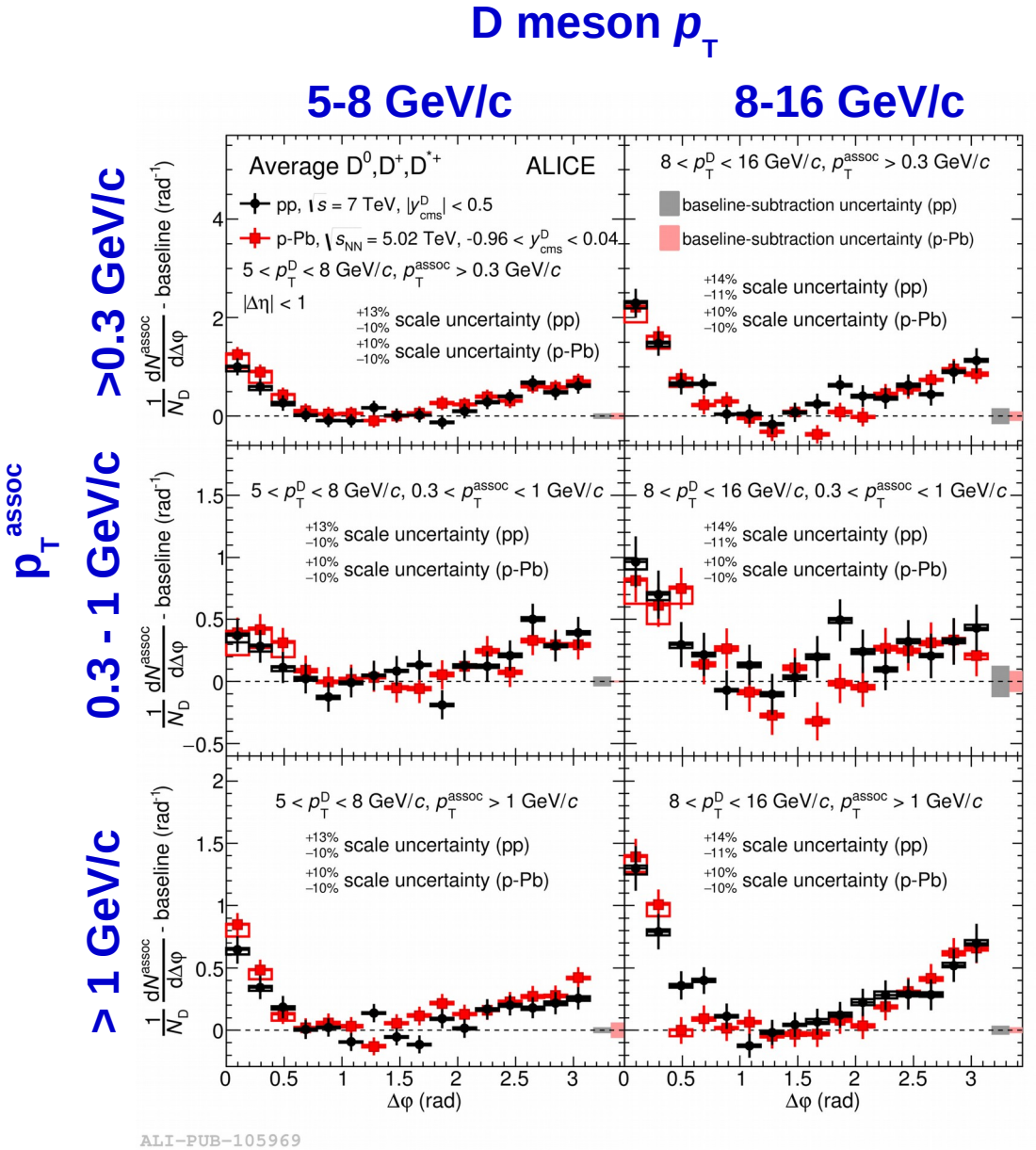


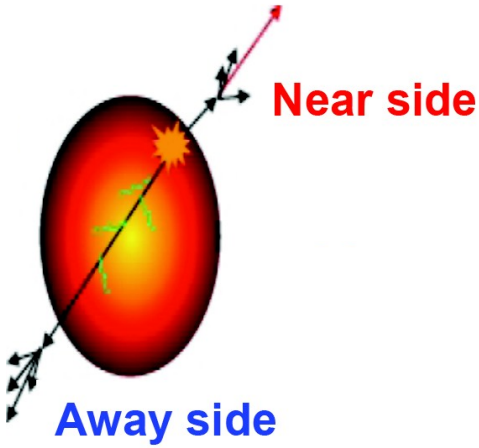


- Significant non-zero elliptic flow observed for heavy-flavor electrons and D mesons

D – hadron correlations in pp and p-Pb

ALICE, arXiv: 1605.06963

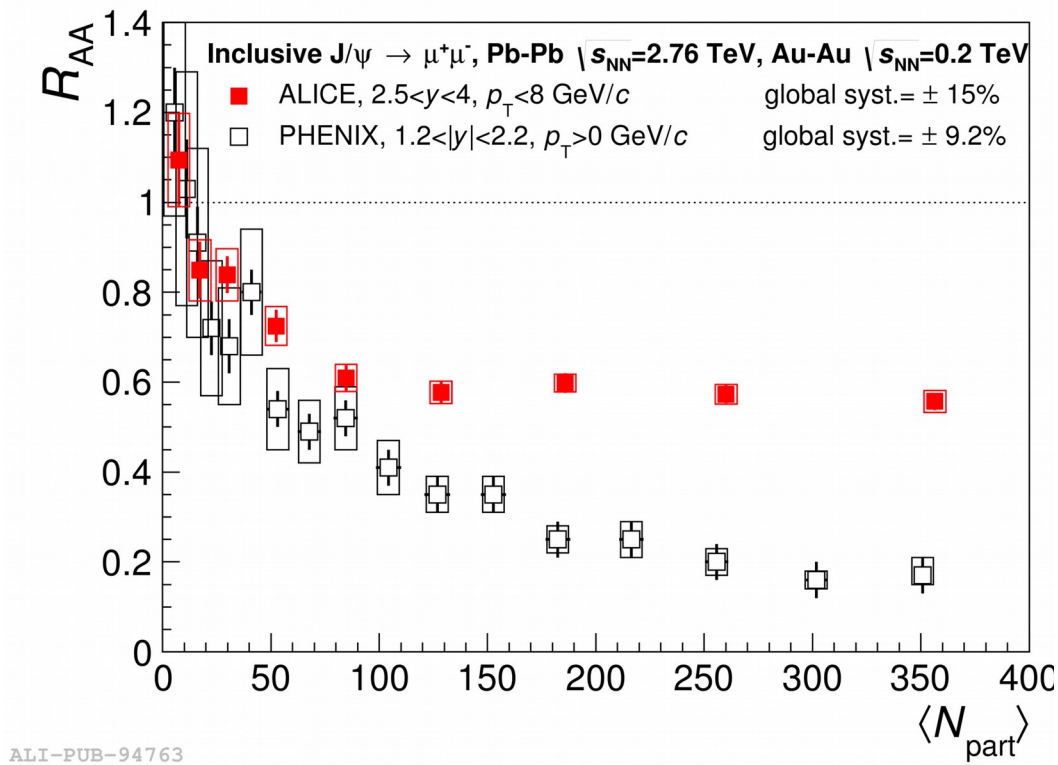


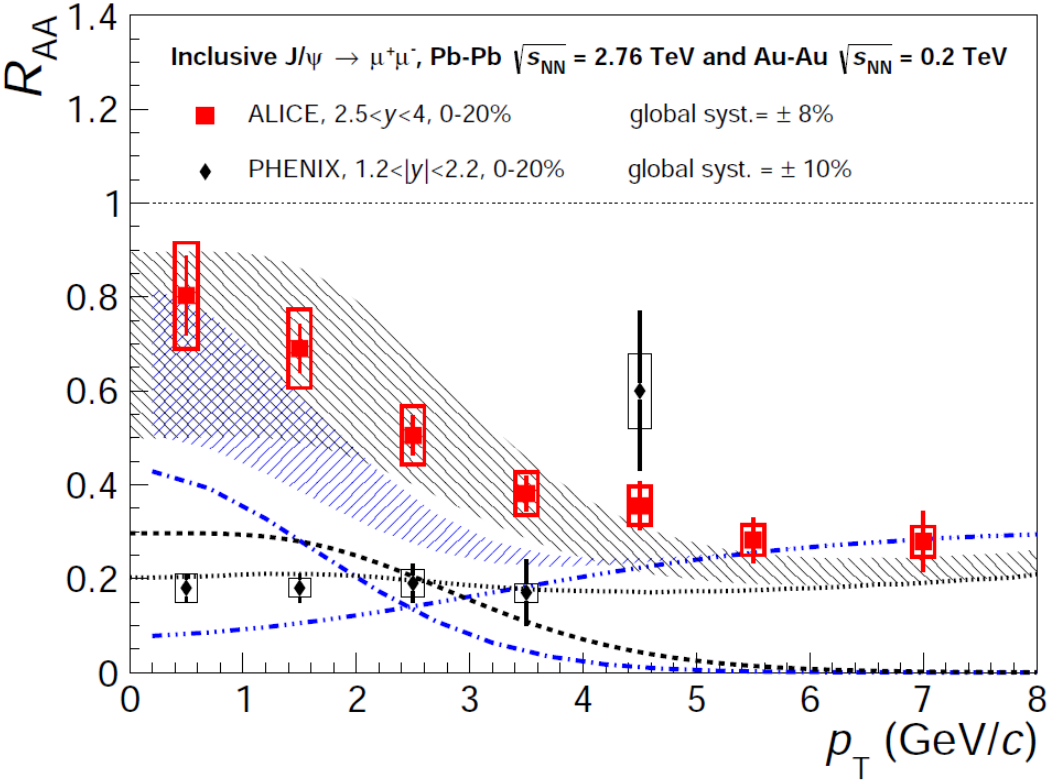


- Look for hadronic activity near and away from the direction of the D-meson momentum vector
- Very similar correlation functions obtained in both pp and p-Pb for all the scanned kinematic ranges
  - Charm-quark fragmentation unmodified by CNM effects ?

Inclusive J/ψ suppression from Run-1

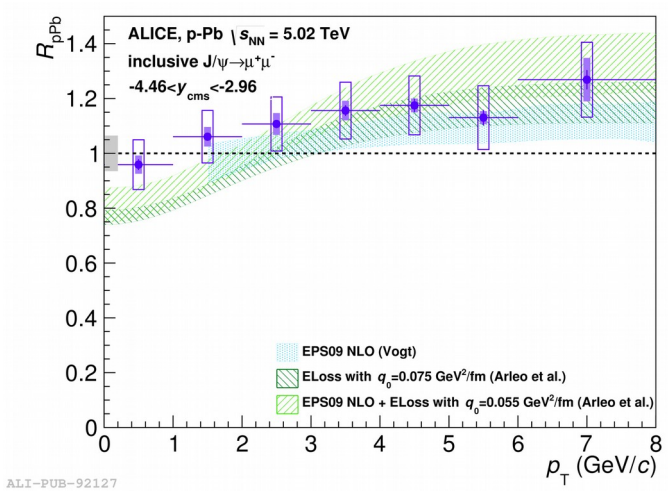
ALICE, JHEP1605 (2016) 179

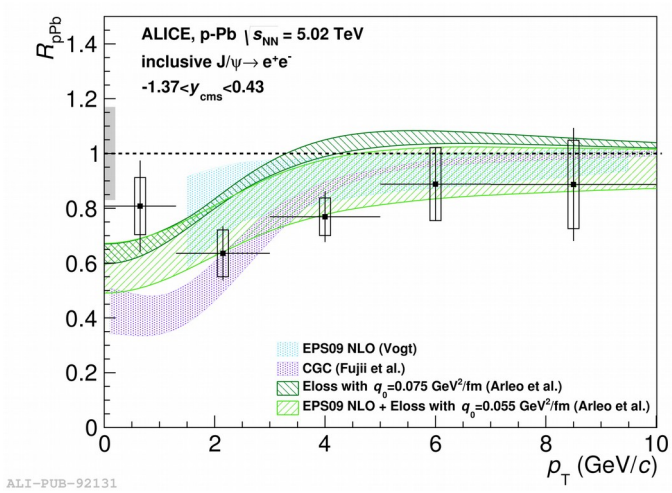


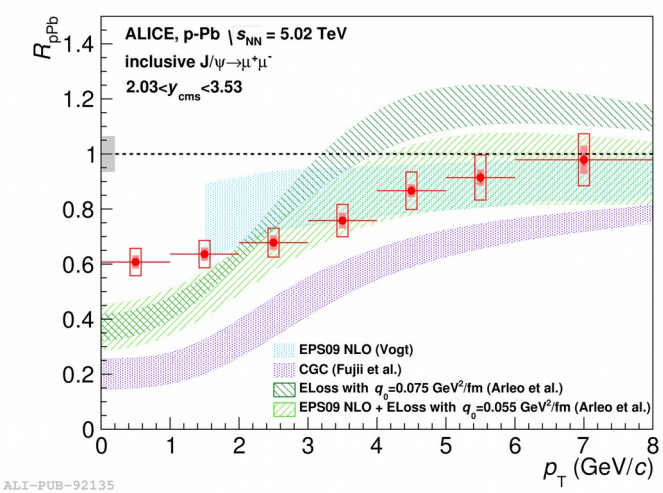


- Much less suppression in central collisions compared to the observation of PHENIX at $\sqrt{s_{NN}}$=200 GeV
- Striking discrepancy between LHC and RHIC data at low p_T
- Described by models in terms of J/ψ regeneration

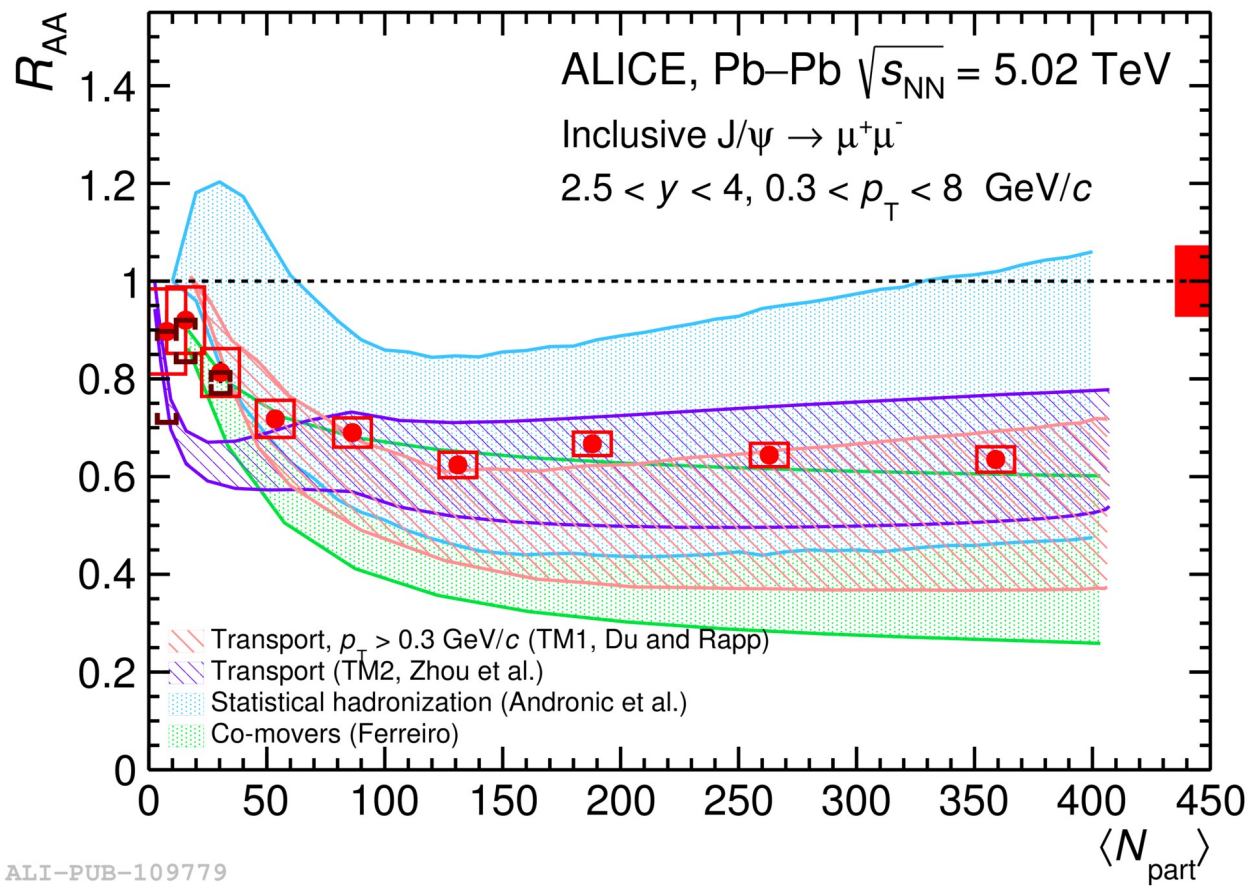
J/psi nuclear modification in p-Pb



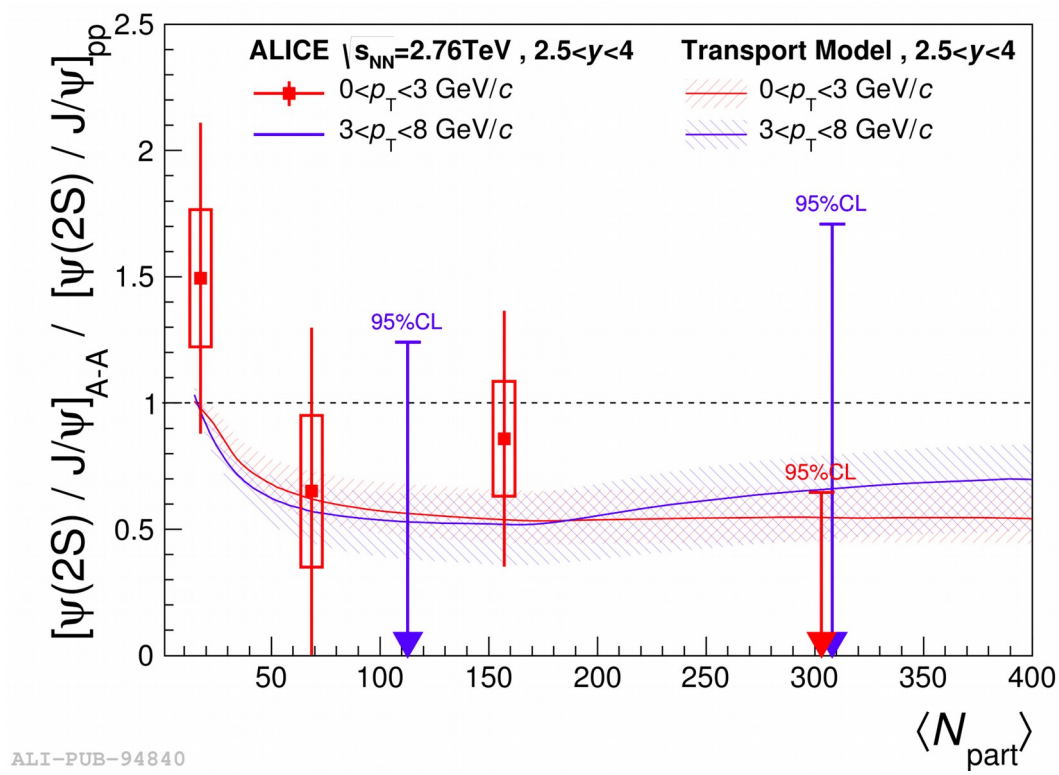


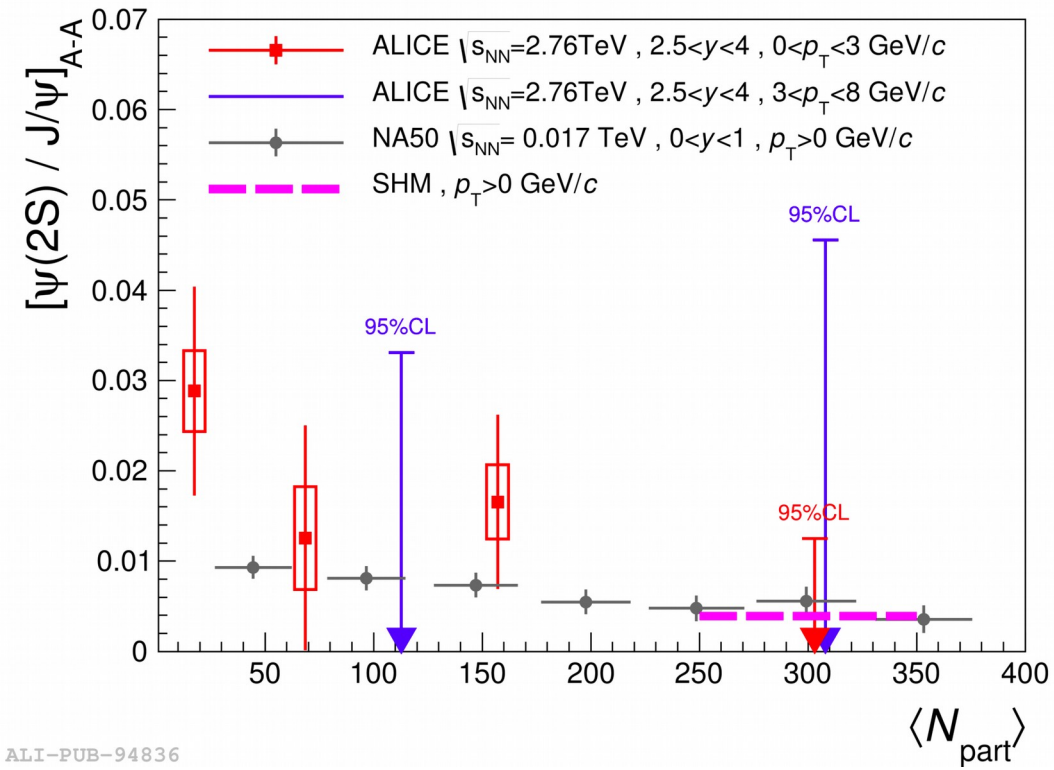


J/psi production in Pb-Pb collisions at 5.02 TeV

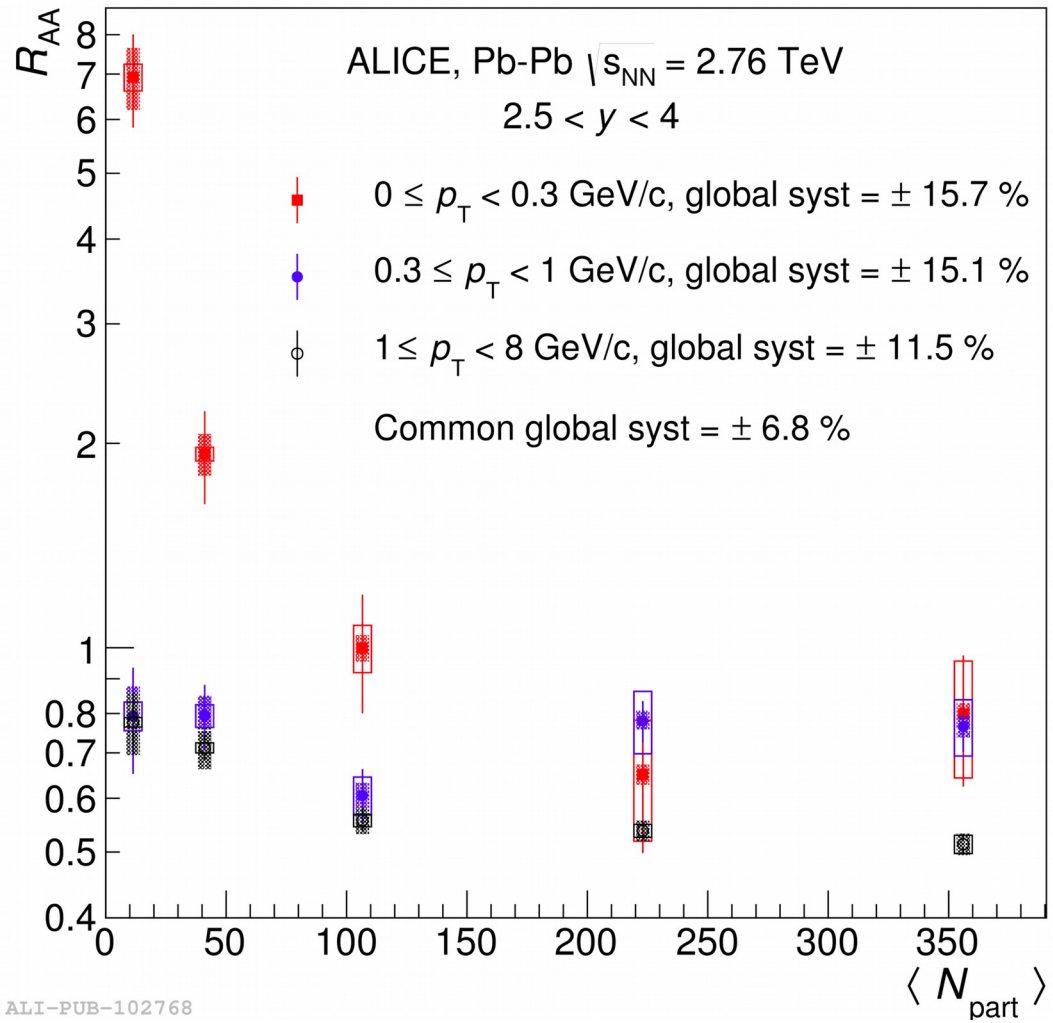


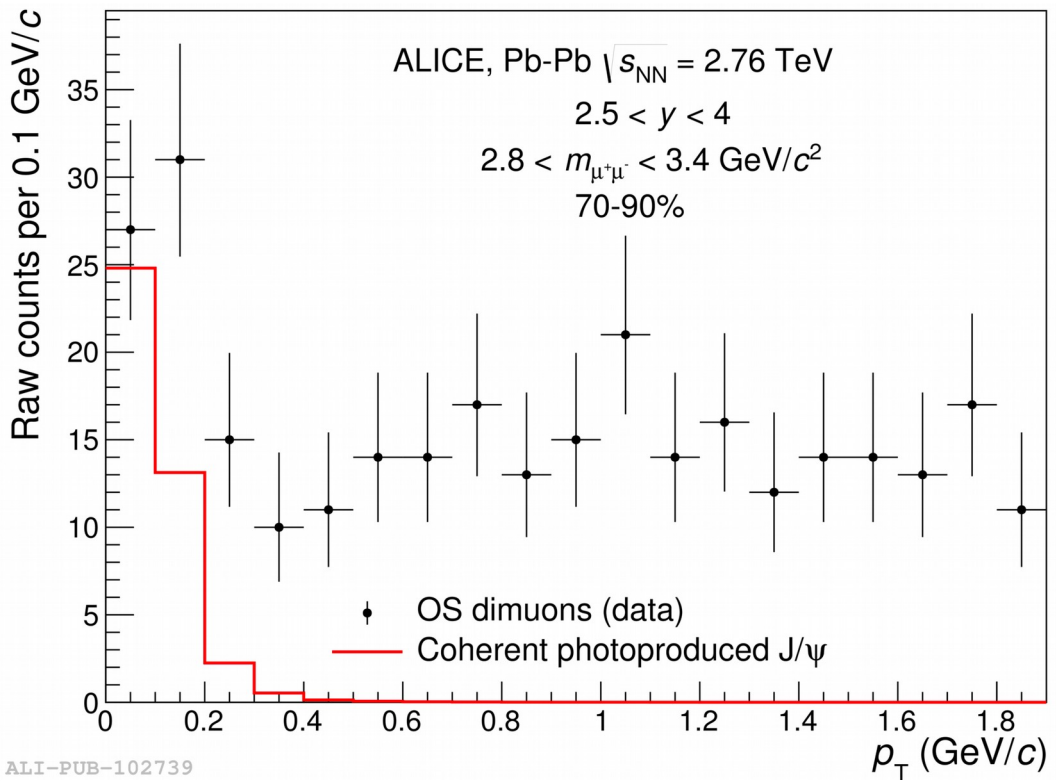
psi(2S)


ALICE √sNN=2.76TeV , 2.5<y<4
0<pT<3 GeV/c
3<pT<8 GeV/c
Transport Model , 2.5<y<4
0<pT<3 GeV/c
3<pT<8 GeV/c
95%CL
95%CL
95%CL
[ψ(2S) / J/ψ]A-A / [ψ(2S) / J/ψ]pp
⟨Npart⟩
ALI-PUB-94840

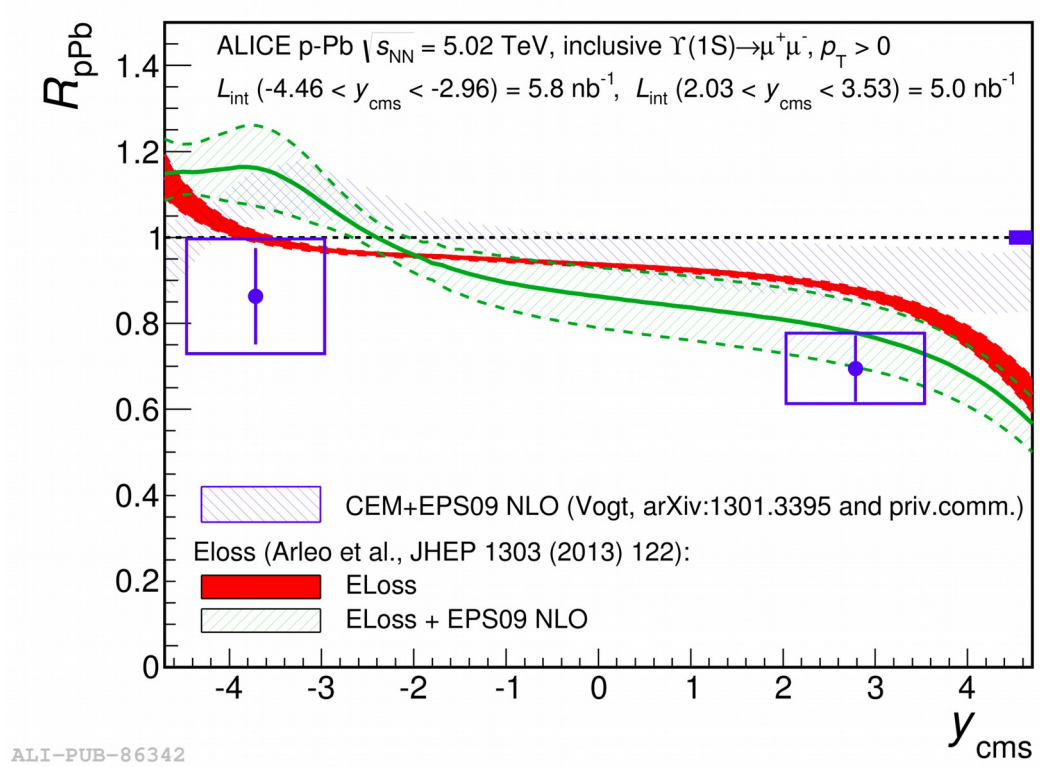

ALICE √sNN=2.76TeV , 2.5<y<4 , 0<pT<3 GeV/c
ALICE √sNN=2.76TeV , 2.5<y<4 , 3<pT<8 GeV/c
NA50 √sNN= 0.017 TeV , 0<y<1 , pT>0 GeV/c
SHM , pT>0 GeV/c
95%CL
95%CL
95%CL
[ψ(2S) / J/ψ]A-A
⟨Npart⟩
ALI-PUB-94836

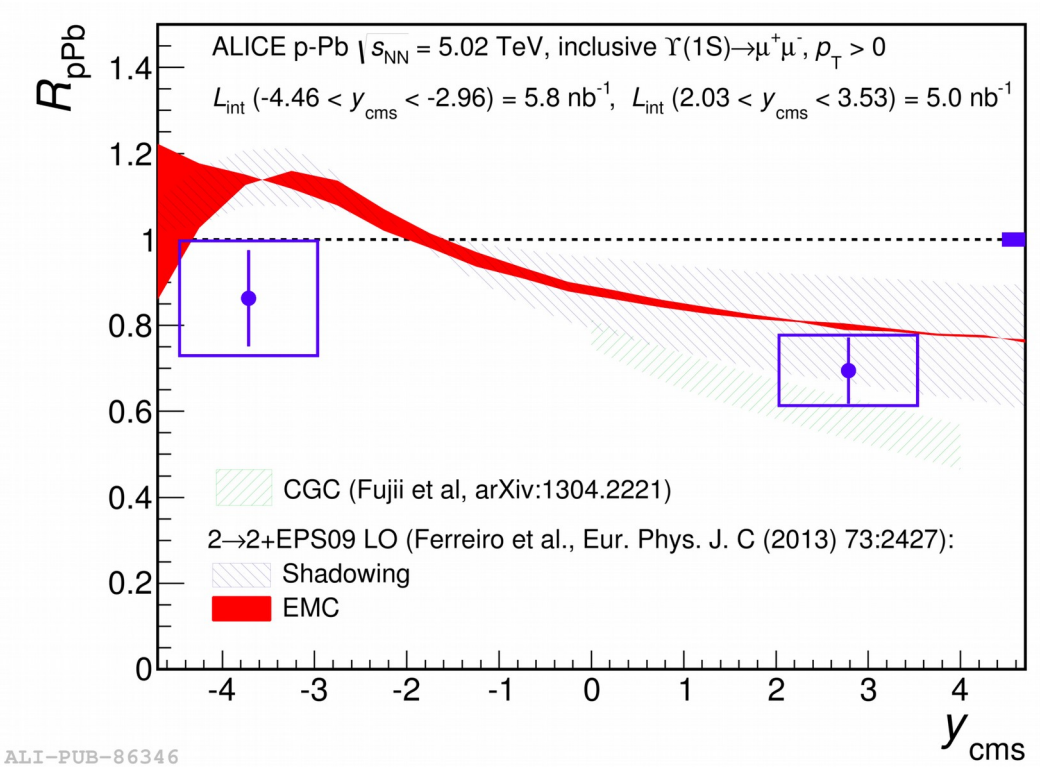
Low-p_T J/psi


ALICE, Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
2.5 < y < 4
0 ≤ p_T < 0.3 GeV/c, global syst = ± 15.7 %
0.3 ≤ p_T < 1 GeV/c, global syst = ± 15.1 %
1 ≤ p_T < 8 GeV/c, global syst = ± 11.5 %
Common global syst = ± 6.8 %
R_{AA}
⟨ N_{part} ⟩
ALI-PUB-102768

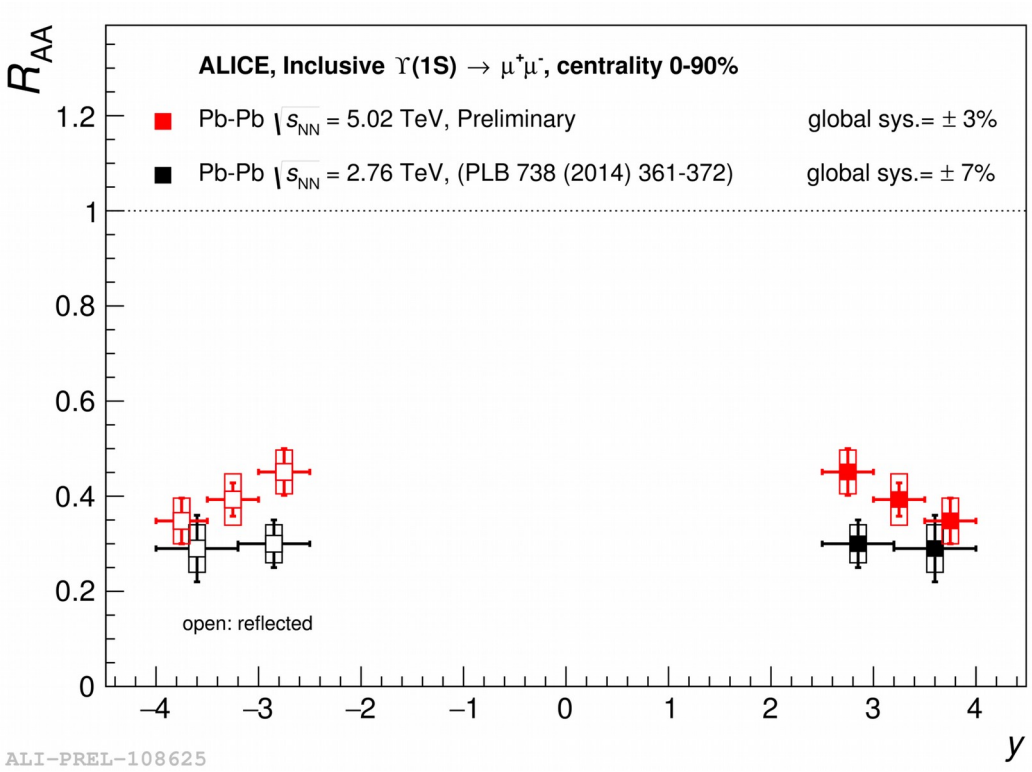

ALICE, Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
2.5 < y < 4
2.8 < $m_{\mu^+\mu^-}$ < 3.4 GeV/c^2
70-90%
OS dimuons (data)
Coherent photoproduced J/ψ
Raw counts per 0.1 GeV/c
p_T (GeV/c)
ALI-PUB-102739

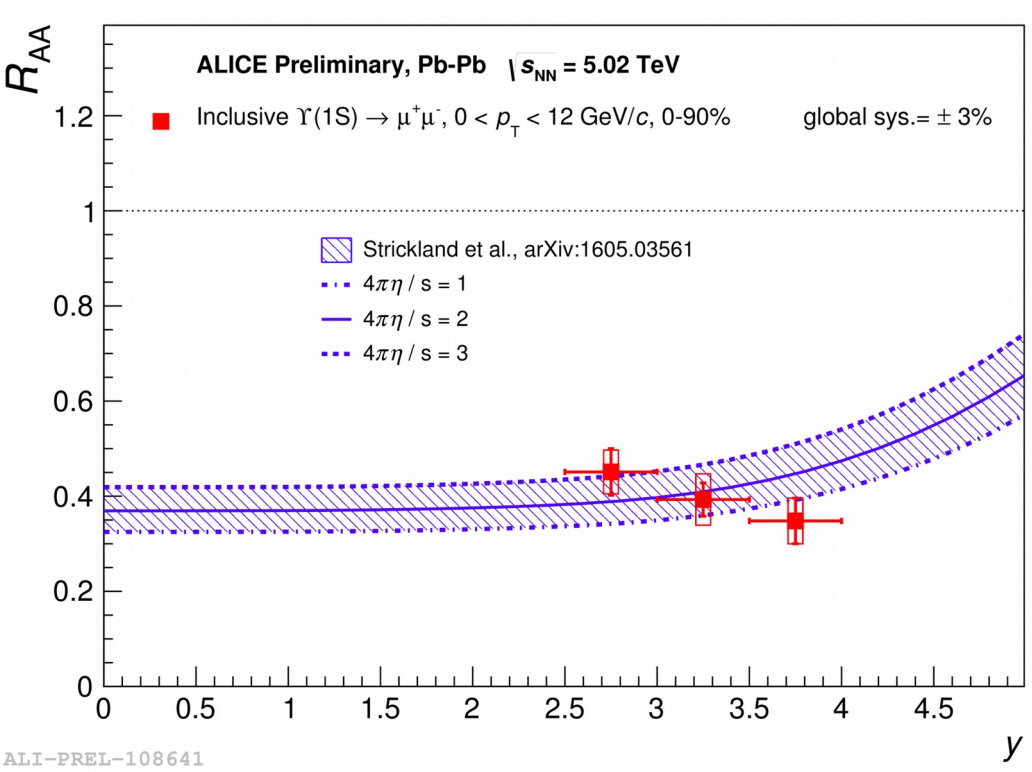
Upsilon nuclear modification in p-Pb



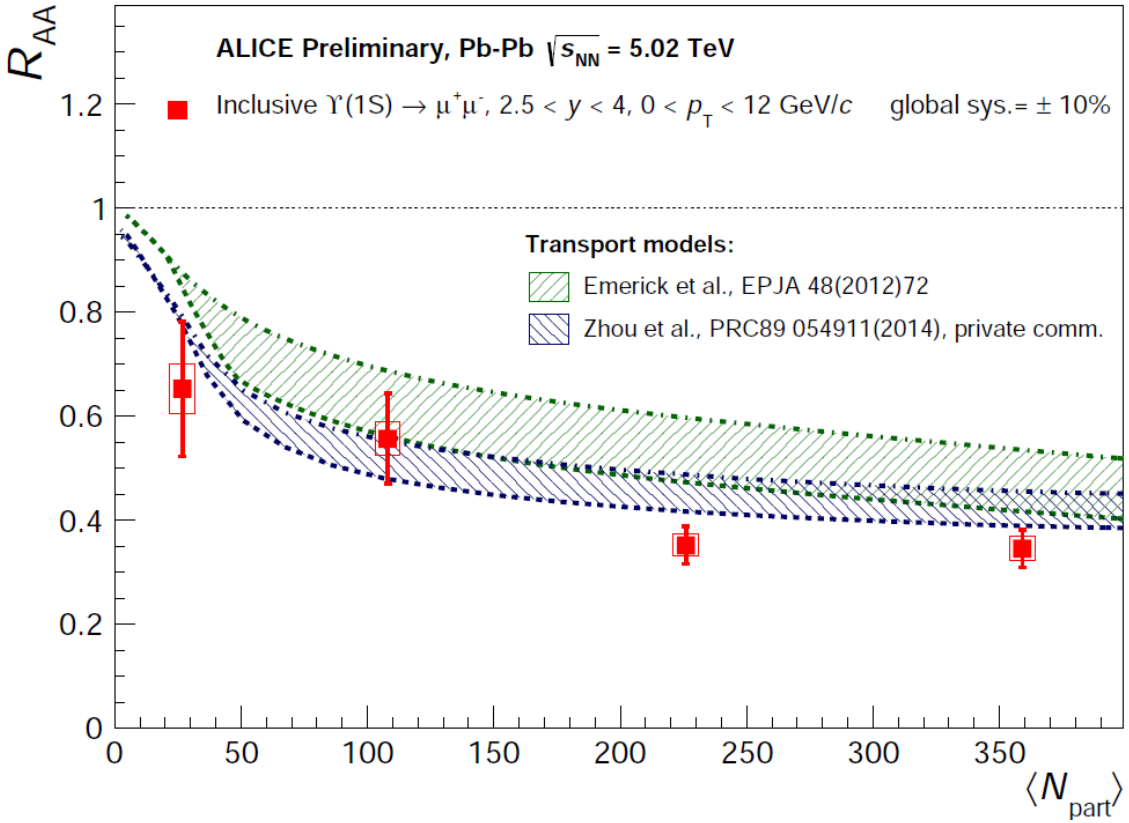


Υ(1S) suppression in Pb-Pb collisions at 5.02 TeV



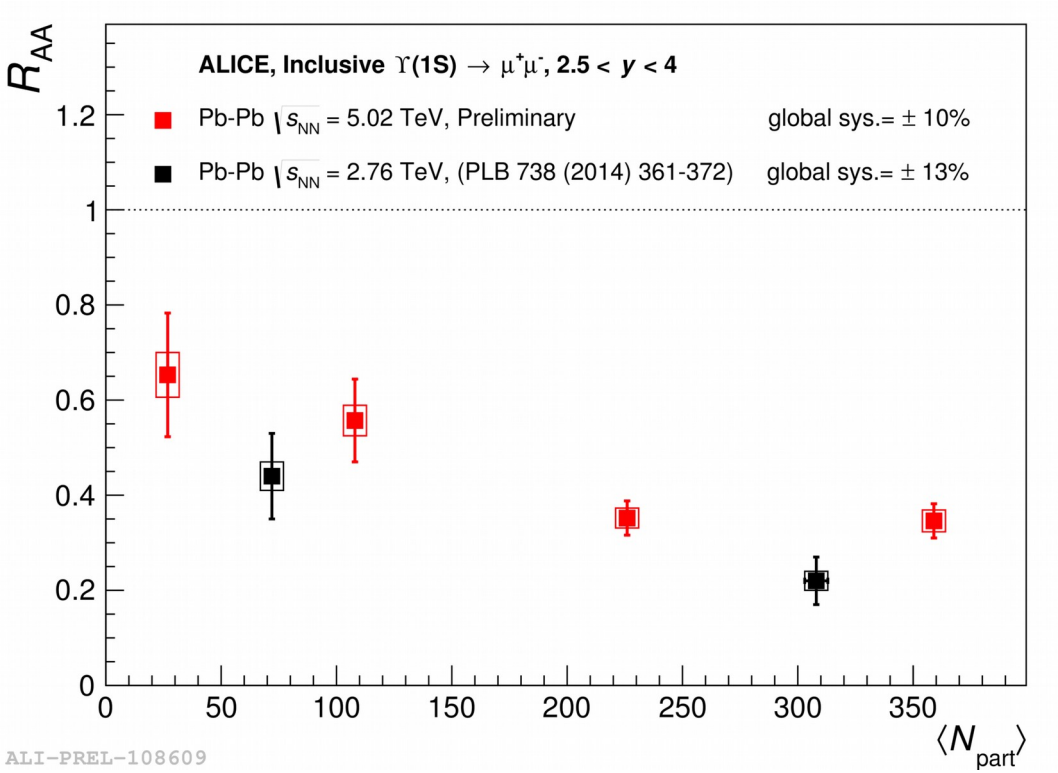


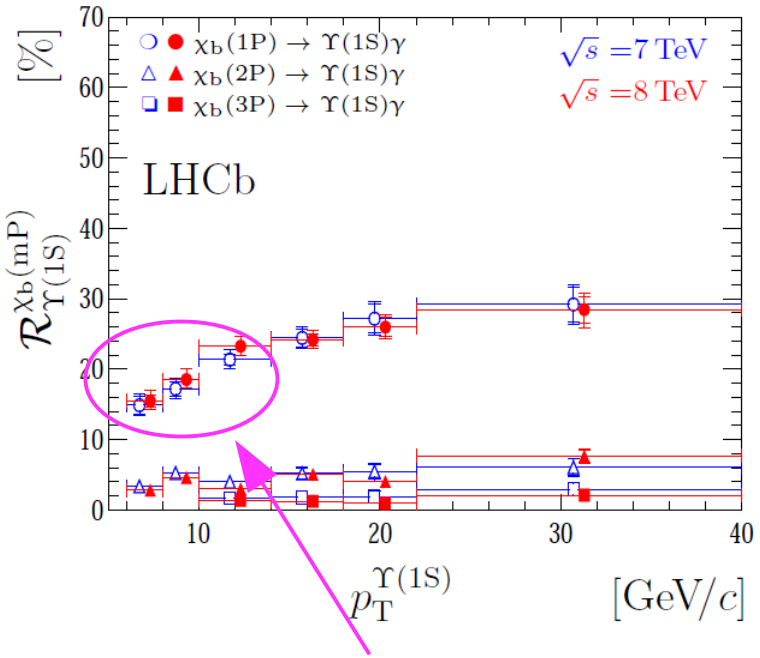
Υ(1S) suppression in Pb-Pb collisions at 5.02 TeV



Data compared with calculations of Emerick et al and Zhou et al, both implementing regeneration

Υ(1S) production at 2.76 and 5.02 TeV





Feed-down from χ_b

- Bottomonium is much less affected by regeneration effects → cleaner probe for the medium properties
- A strong Υ(1S) suppression is observed in central collisions at both 2.76 and 5.02 TeV