SUMMARY OF CMS RESULTS IN HEAVY ION COLLISIONS

Javier Martin Blanco

Laboratoire Leprince-Ringuet, École Polytechnique, Palaiseau

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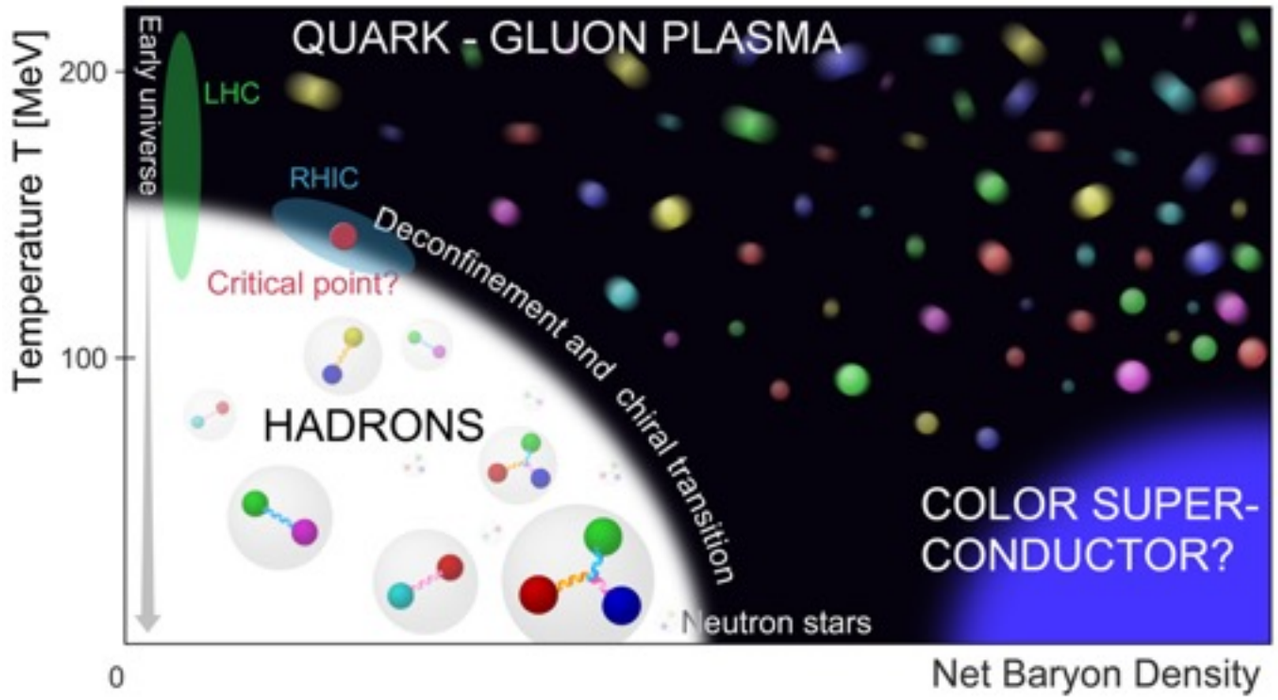
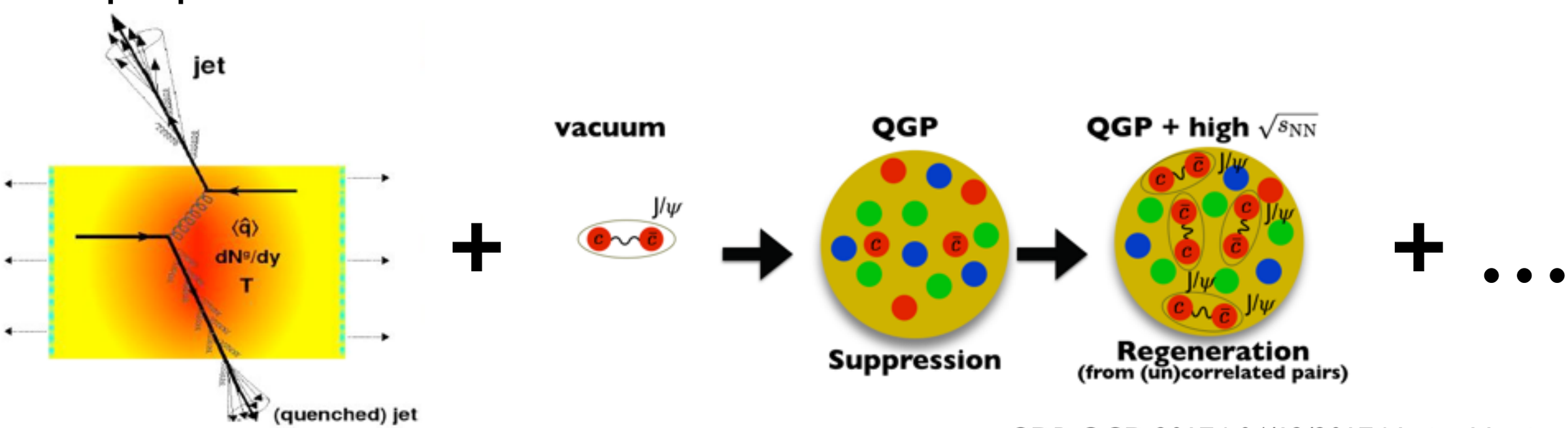
QUARK GLUON PLASMA



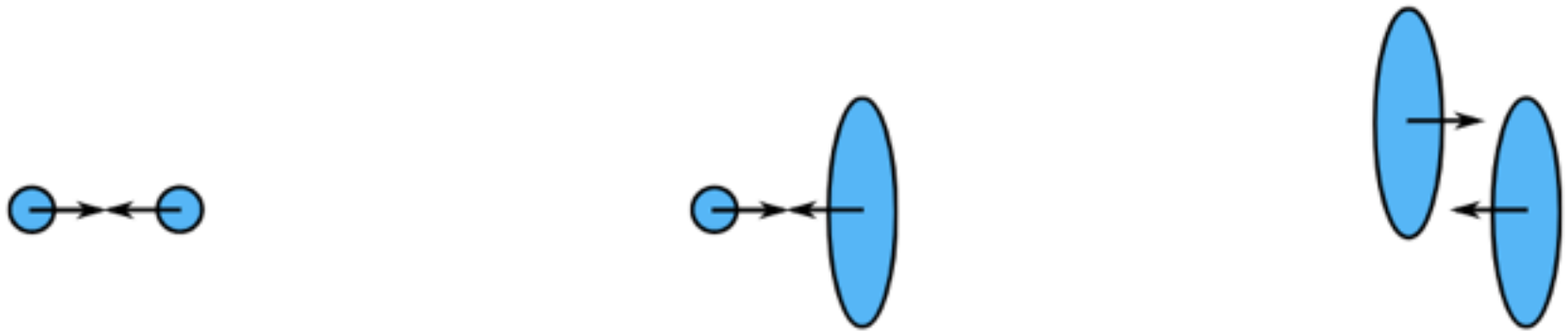
Conditions for QGP formation can be reached in ultra-relativistic heavy ion collisions

The properties are studied with:



OUTLINE

3 collision systems at LHC: pp, pPb and PbPb



Initial stage

- Constrain quark and gluon (nuclear) PDFs

  Scanning (x,Q^2) phase space

  - W and Z bosons
  - Dijets, b and c -jets
  - Top quarks
  - Hidden and open heavy flavor
- Initial state geometry and fluctuations
  - Correlation of Fourier harmonics (v_2 and v_3)

Final stage

- Study QGP properties

  Debye screening, energy loss…

  - Jet quenching
  - Nuclear modification factors

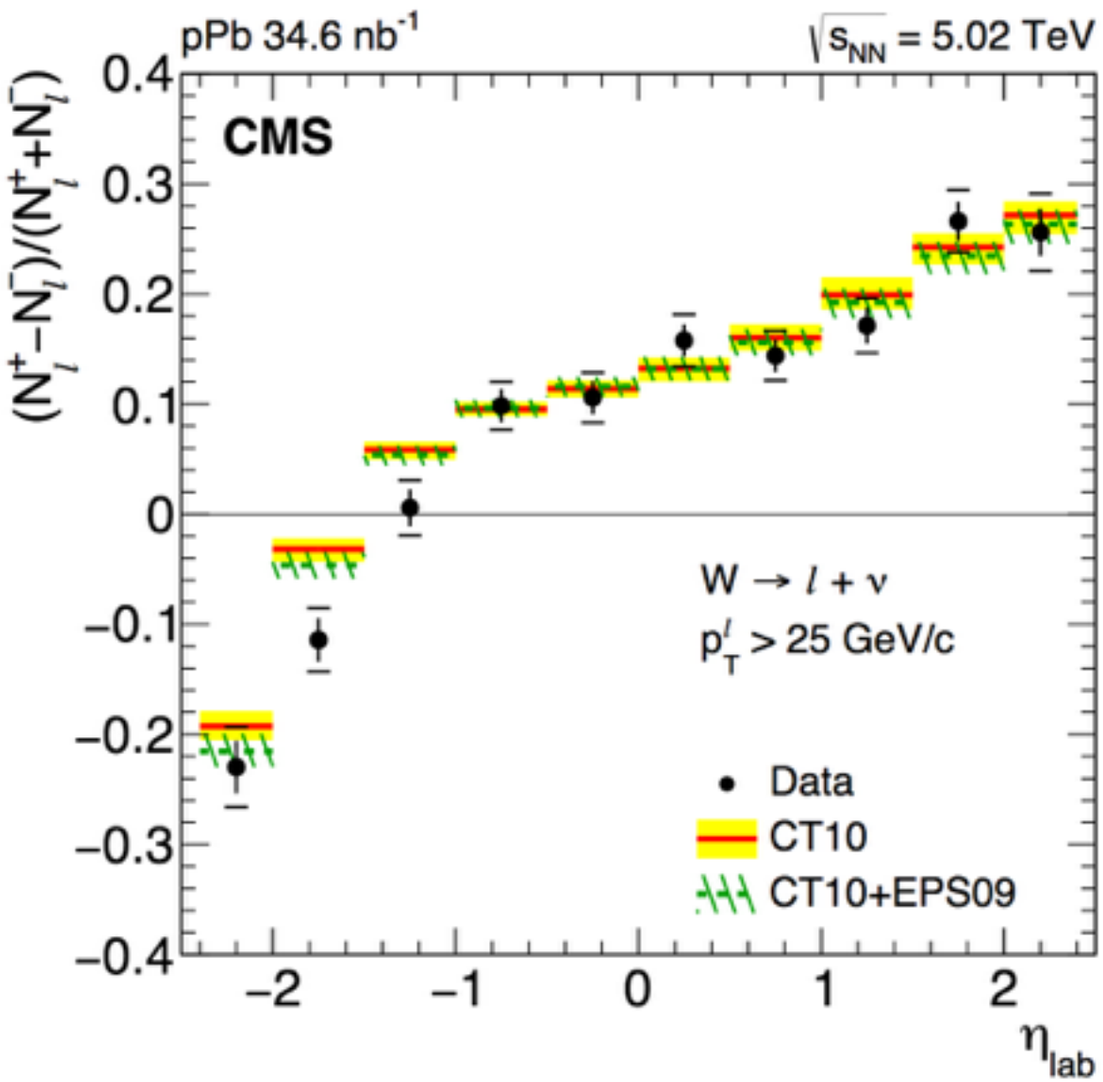
  Transport coefficients

  - Fourier harmonics and their correlation (v_2 and v_4)

W AND Z BOSONS IN pPb

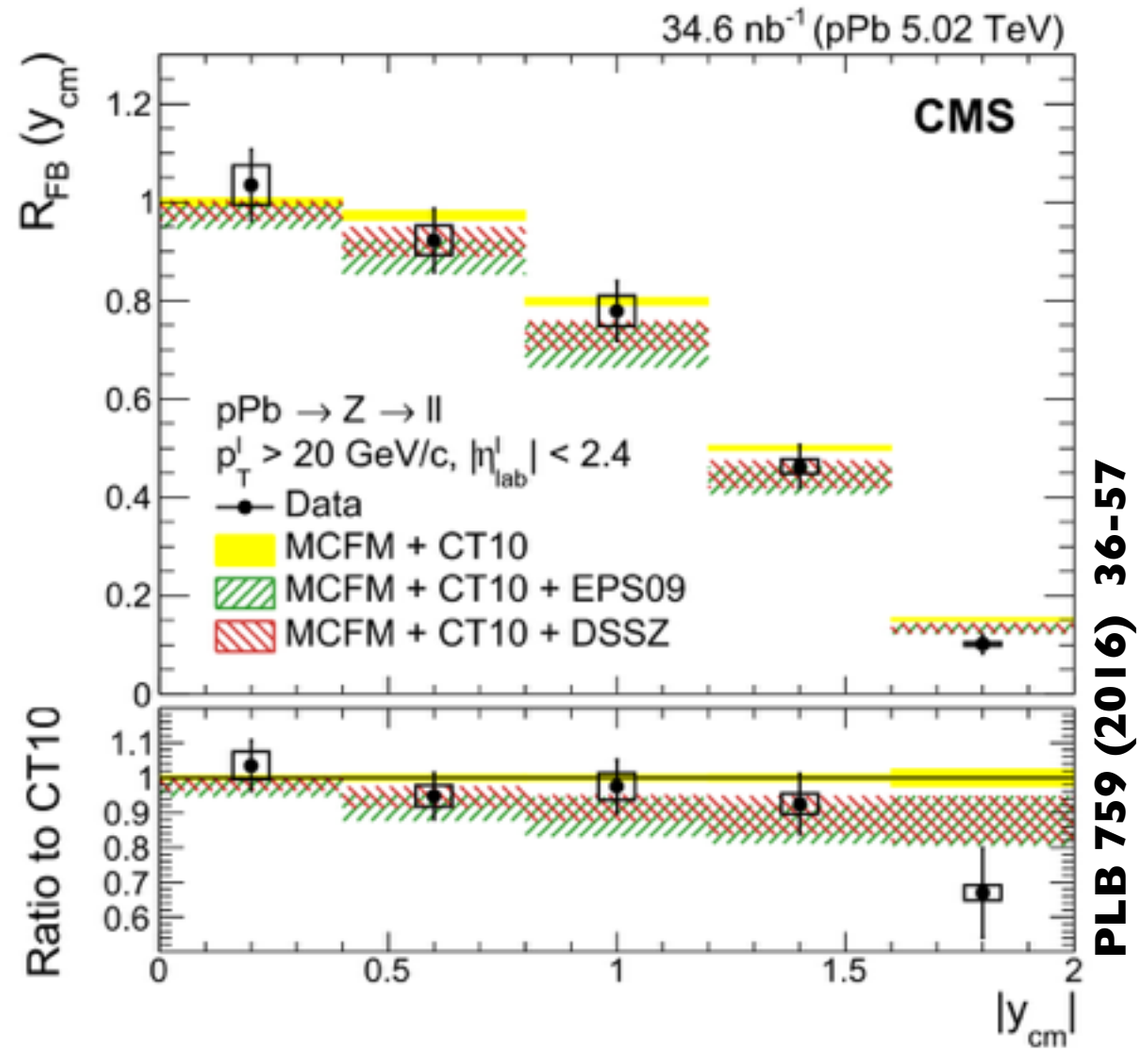
W and Z **sensitive to quark PDF**

W → ℓ ν



PLB 750 (2015) 565-586

Z → ℓ ℓ



PLB 759 (2016) 36-57

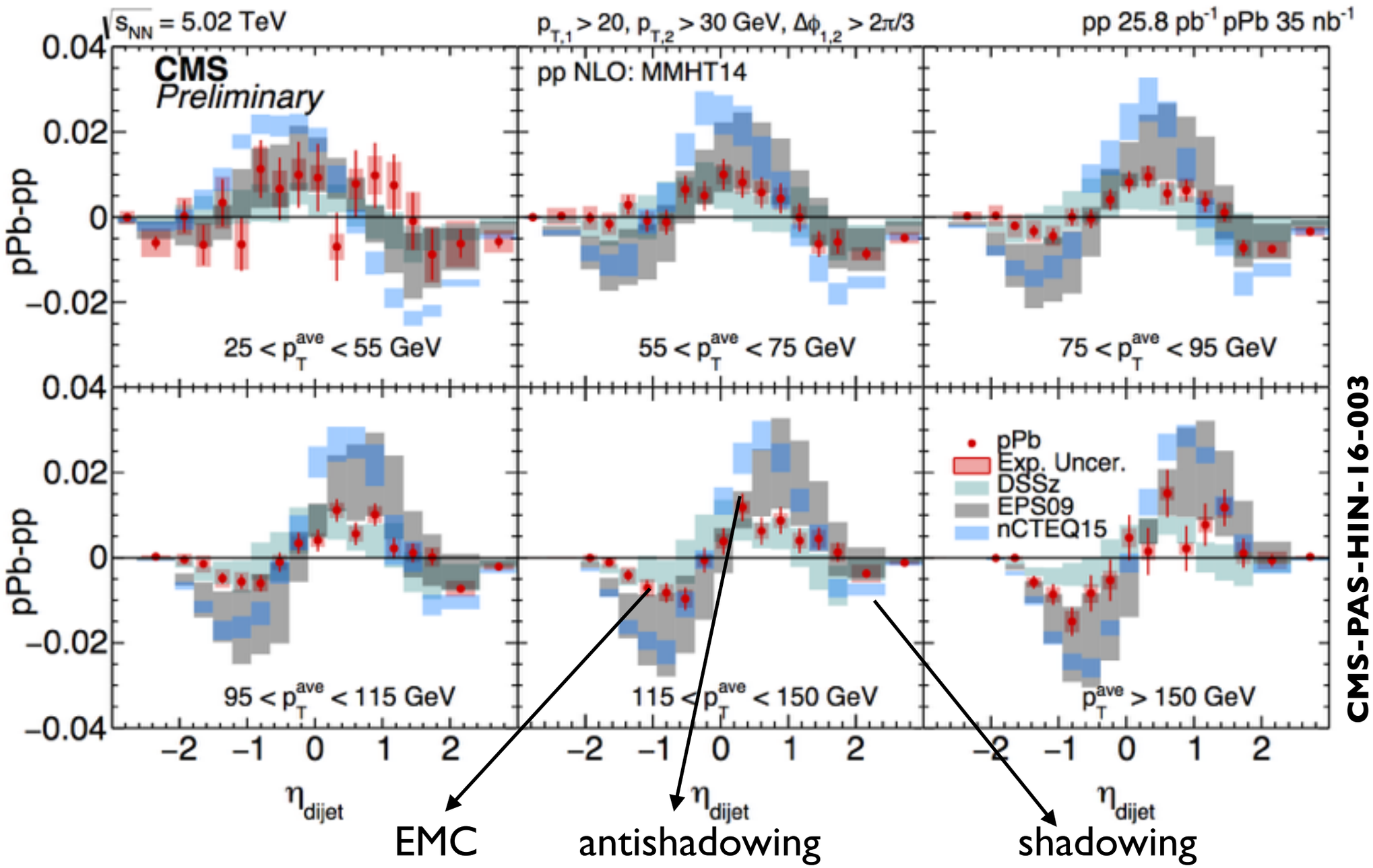
- Different modification of u and d PDFs ?
- Nuclear effects modify asymmetrically the rapidity distribution

New measurement of W production in pPb at 8 TeV ongoing
Stay tuned!

DIJET PSEUDORAPIDITY IN pp and pPb

Provide **important constrains to nPDFs** in a wide range of x and Q^2 (η_{dijet} and p^{avg}_T)

$\eta_{dijet} = (\eta_1 + \eta_2) / 2 \sim \log (x_1/x_2)$ $\qquad$ $p^{avg}_T = (p_{T,1} + p_{T,2}) / 2$

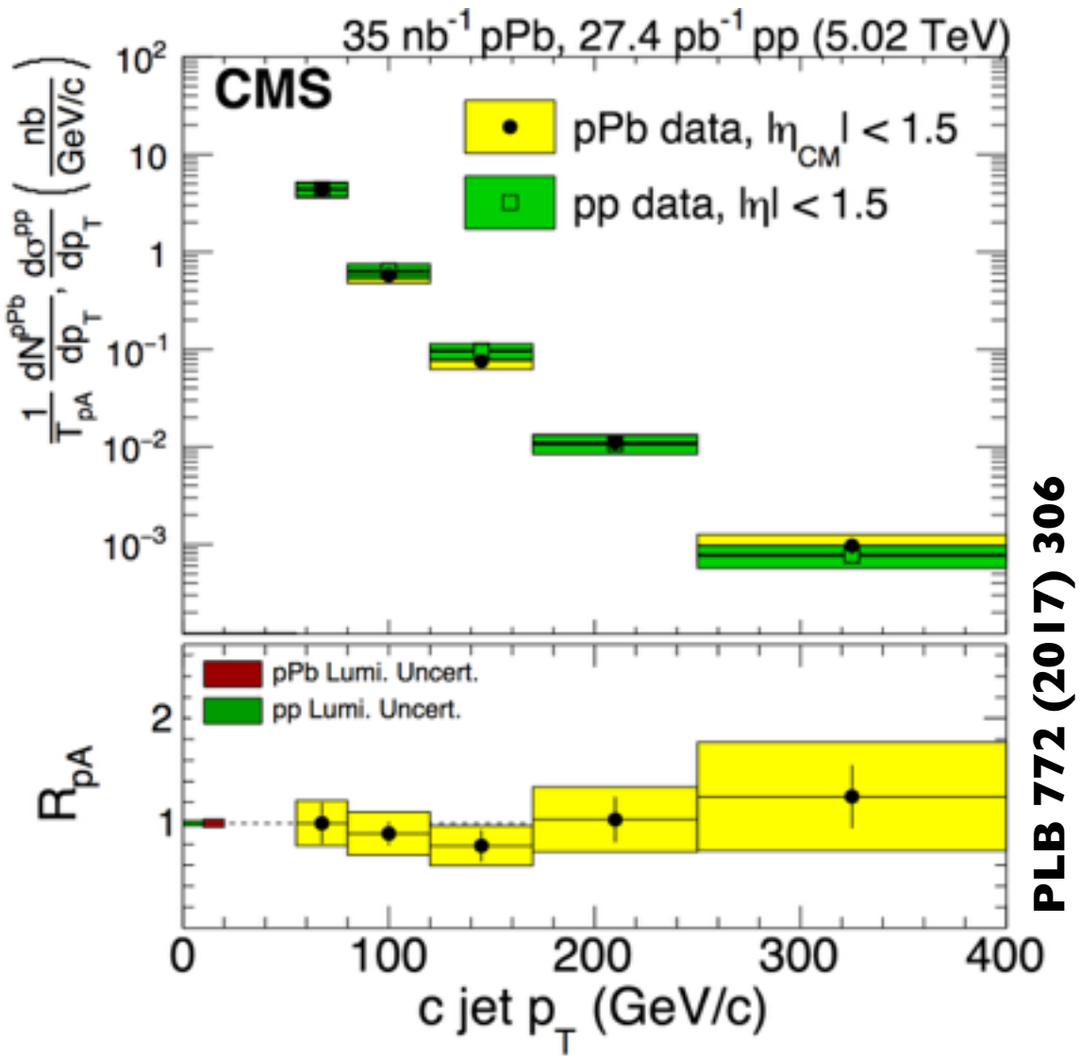


Significant modification of pPb pseudorapidity distribution wrt pp

c & b -JETS IN pPb

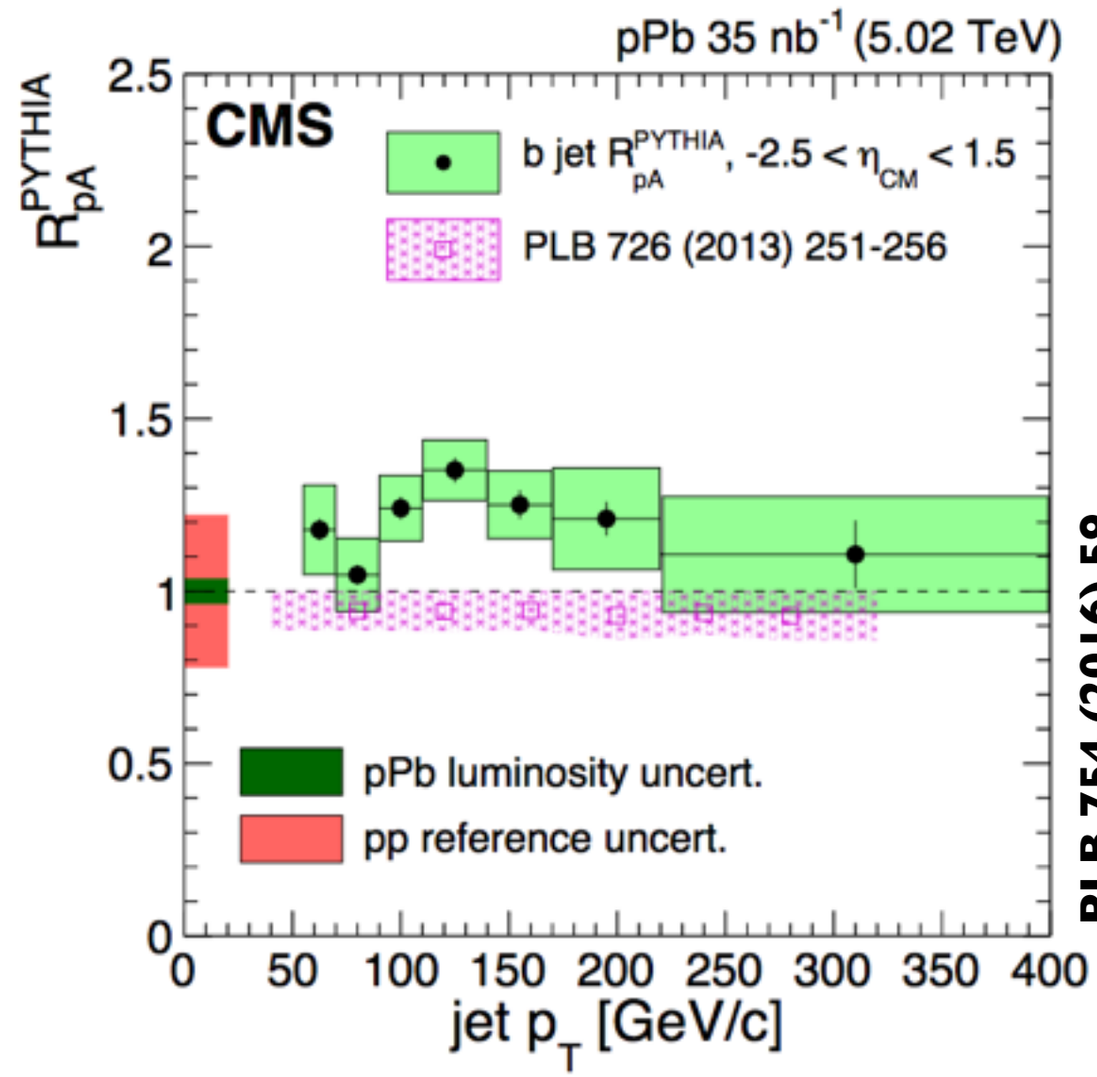
HF jets **sensitive to gluon PDF**

c-jets



PLB 772 (2017) 306

b-jets



PLB 754 (2016) 59

- First measurement of c-jets in pp and pPb

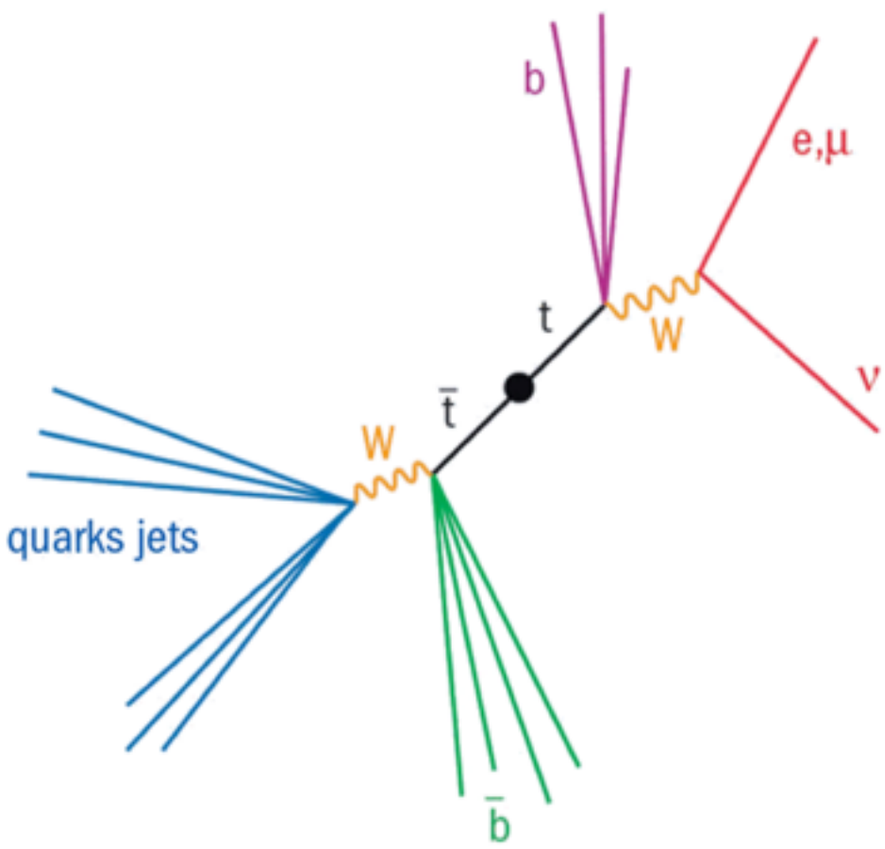
Compatible spectra in pp and pPb

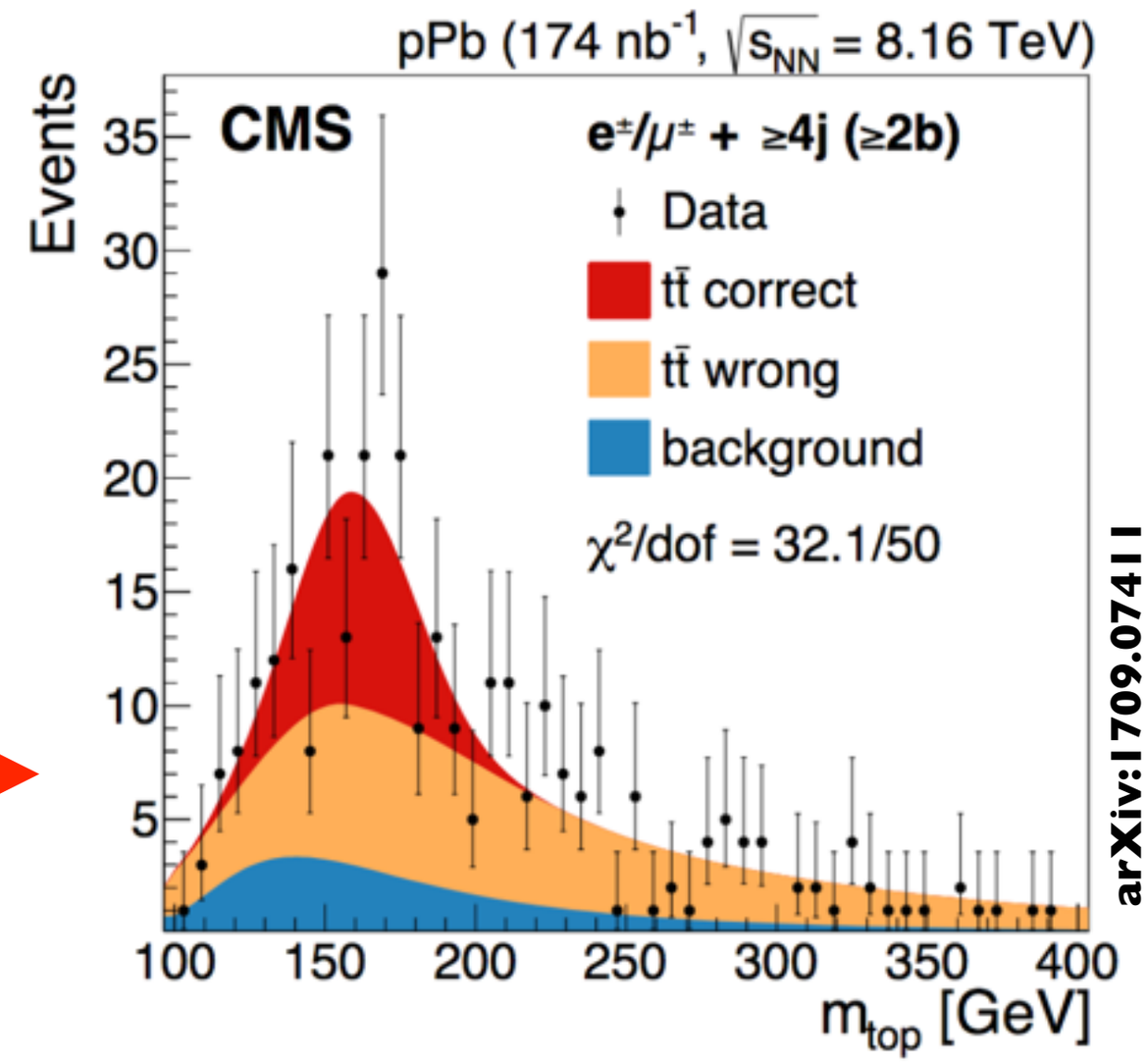
TOP QUARK CROSS SECTION IN pPb

Gluon PDF poorly constrained in the high x and Q^2 region

Measurement of **top cross section in pPb** allows to scan this region

Decay topology

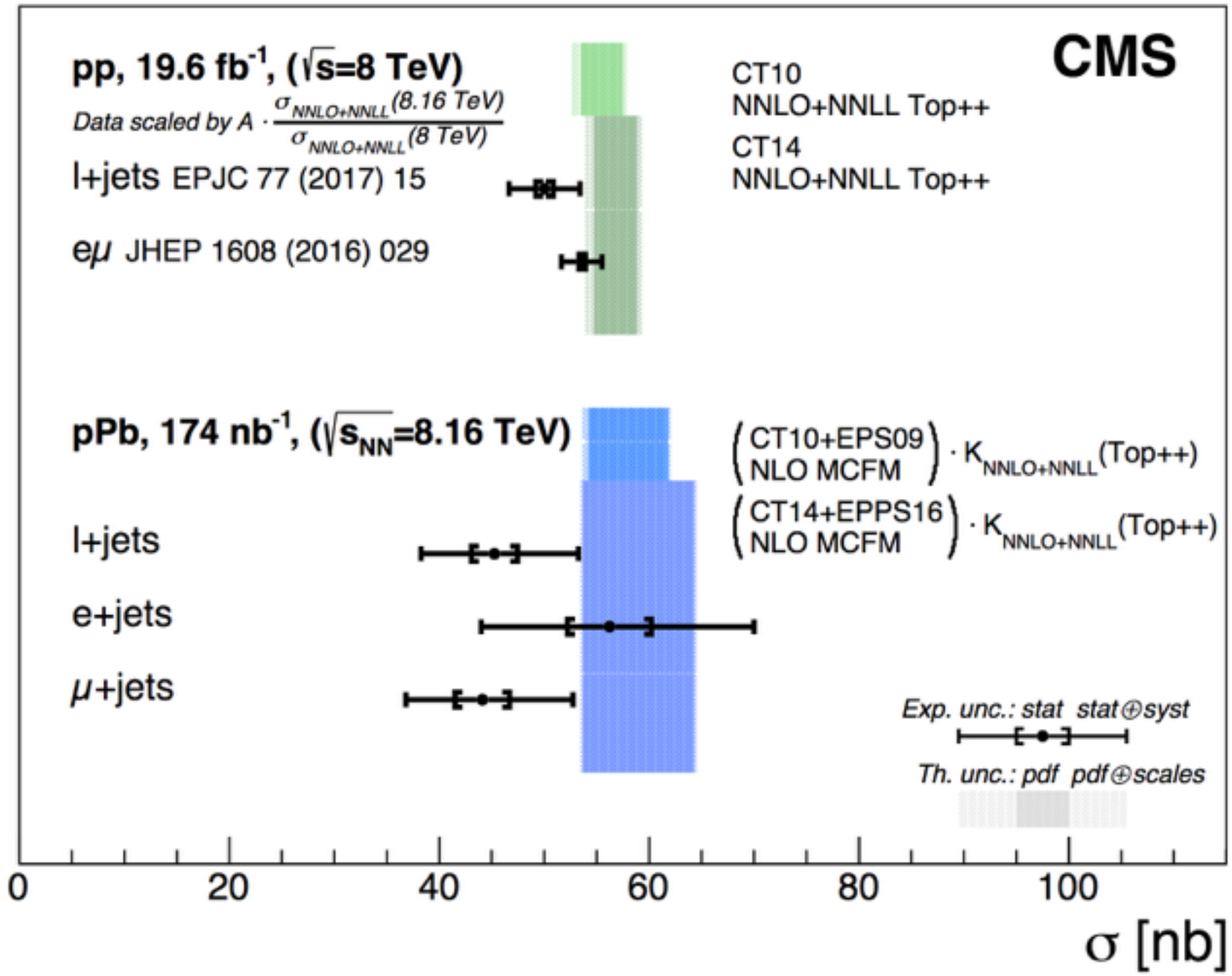




- 4 jets + 1 isolated lepton
- 2 b-jet requirement reduce background

First observation of top quarks in nuclear collisions

TOP QUARK CROSS SECTION IN pPb

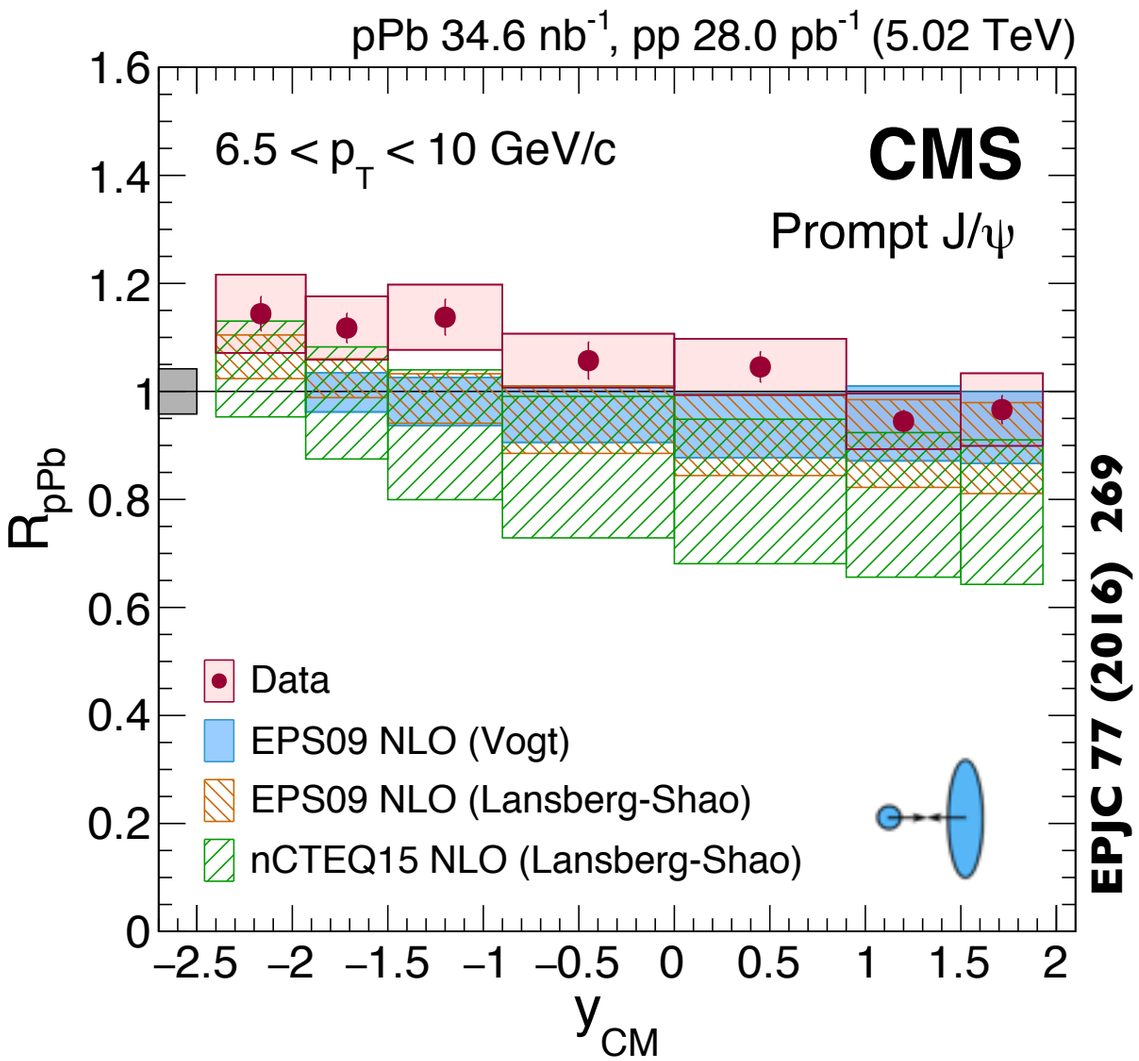


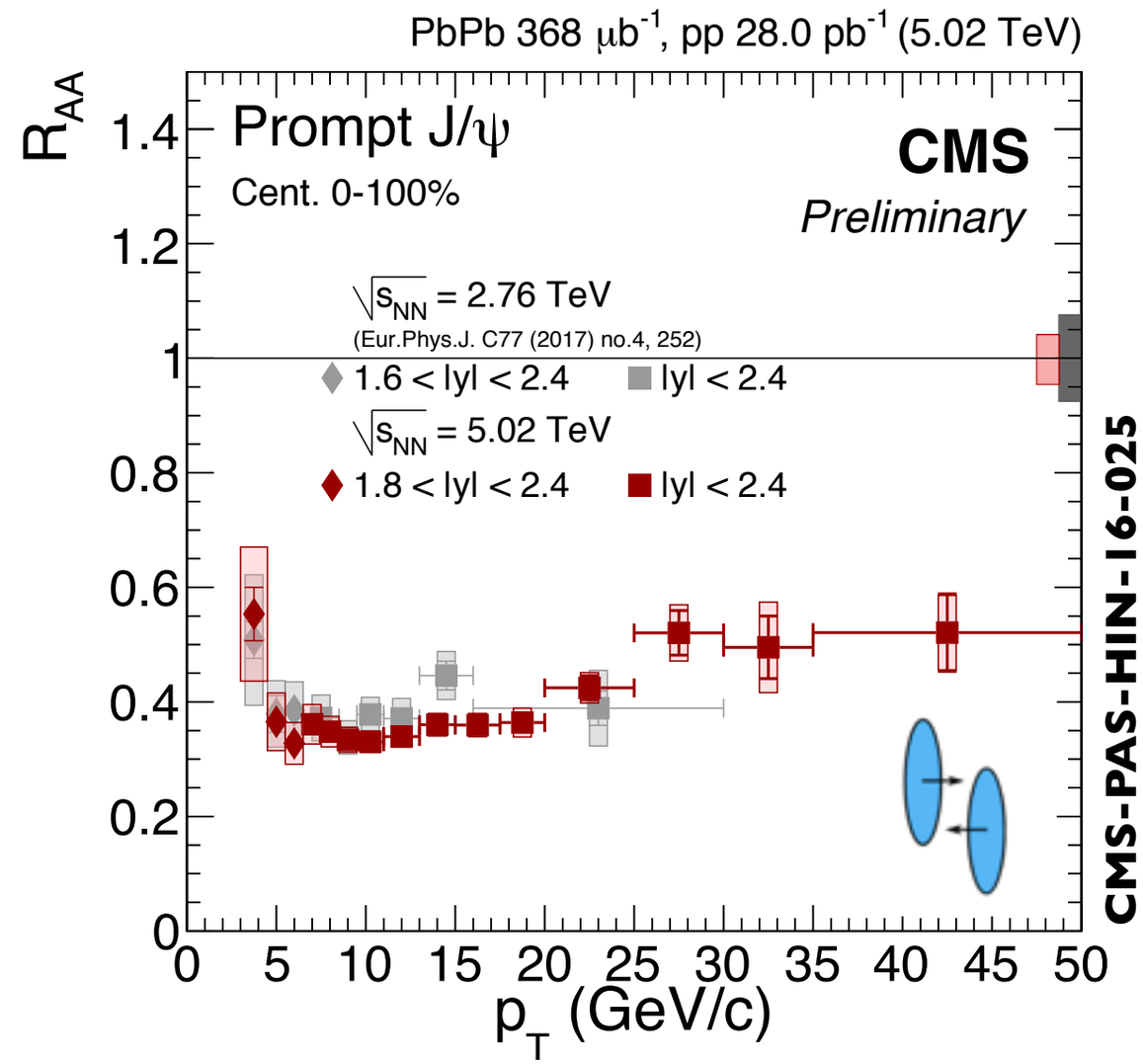
arXiv:1709.07411

Measured cross section σ_{tt} = 45 ± 8 nb

Consistent with theoretical calculations and pp scaled reference

PROMPT J/ψ IN pPb and PbPb





- **pPb**: small modification

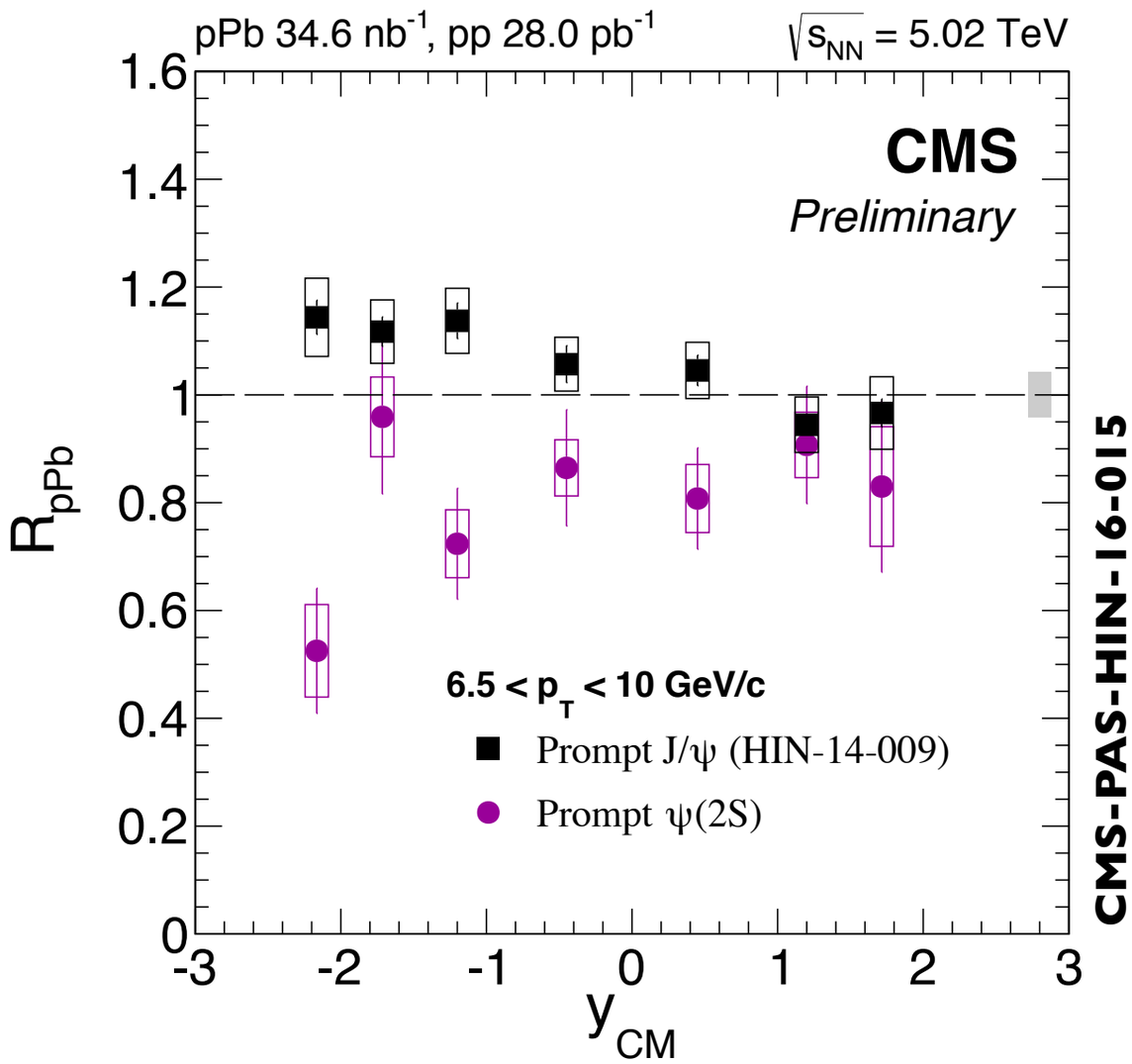
Constraint to nPDFs

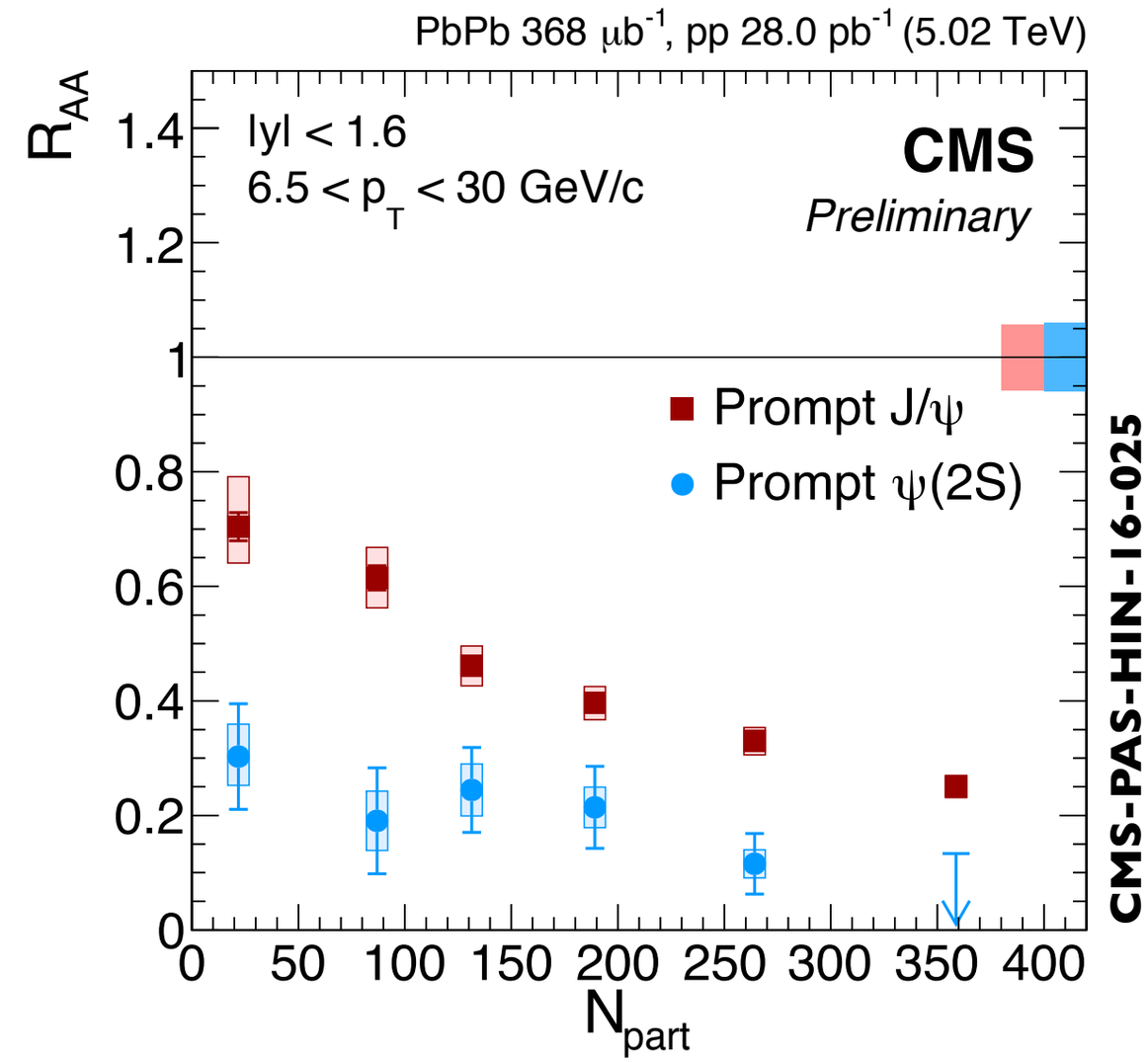
- **PbPb**: consistent with previous measurement

Low pt: regeneration?

High pt: energy loss?

PROMPT ψ(2S) vs J/ψ IN pPb and PbPb





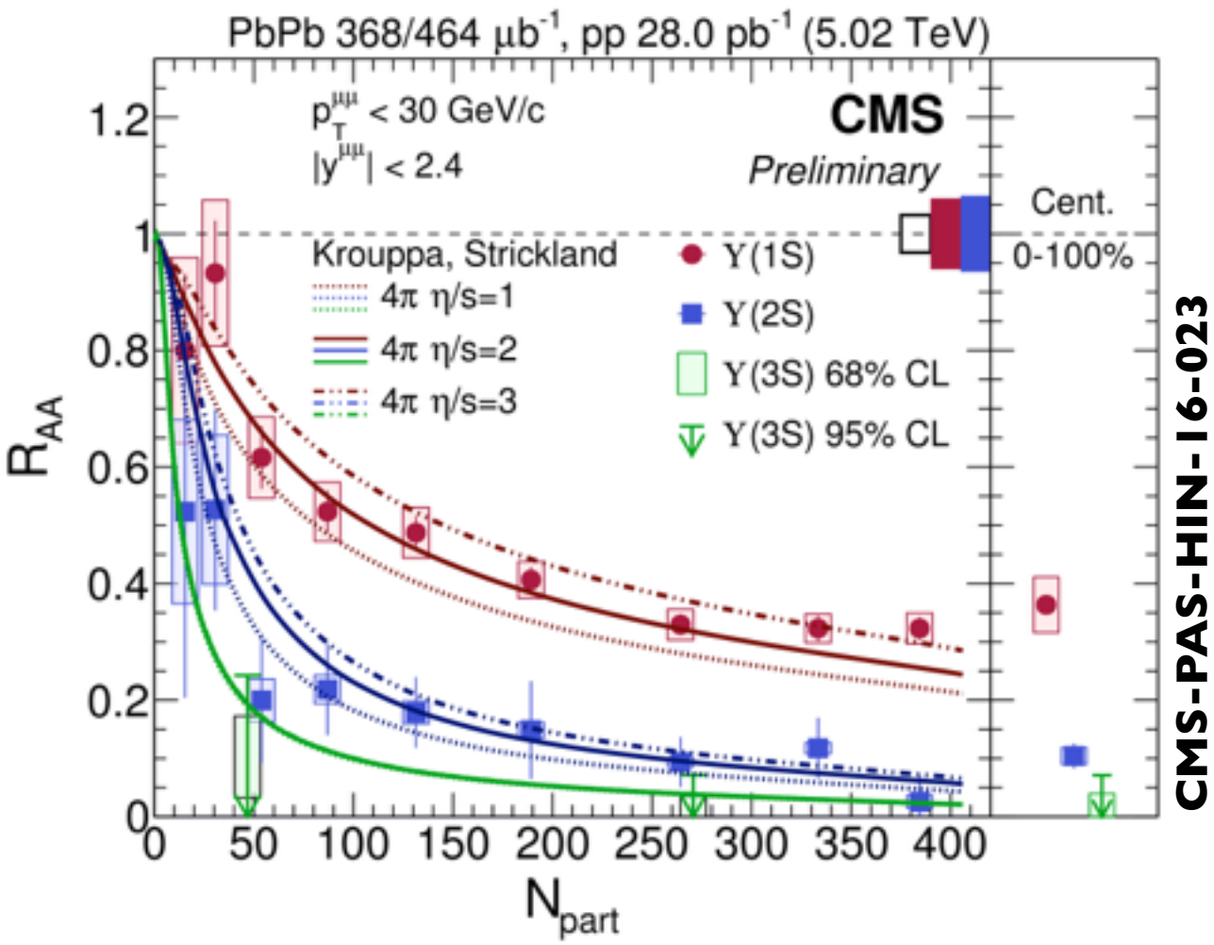
ψ(2S) **more suppressed** than J/ψ both in pPb and PbPb

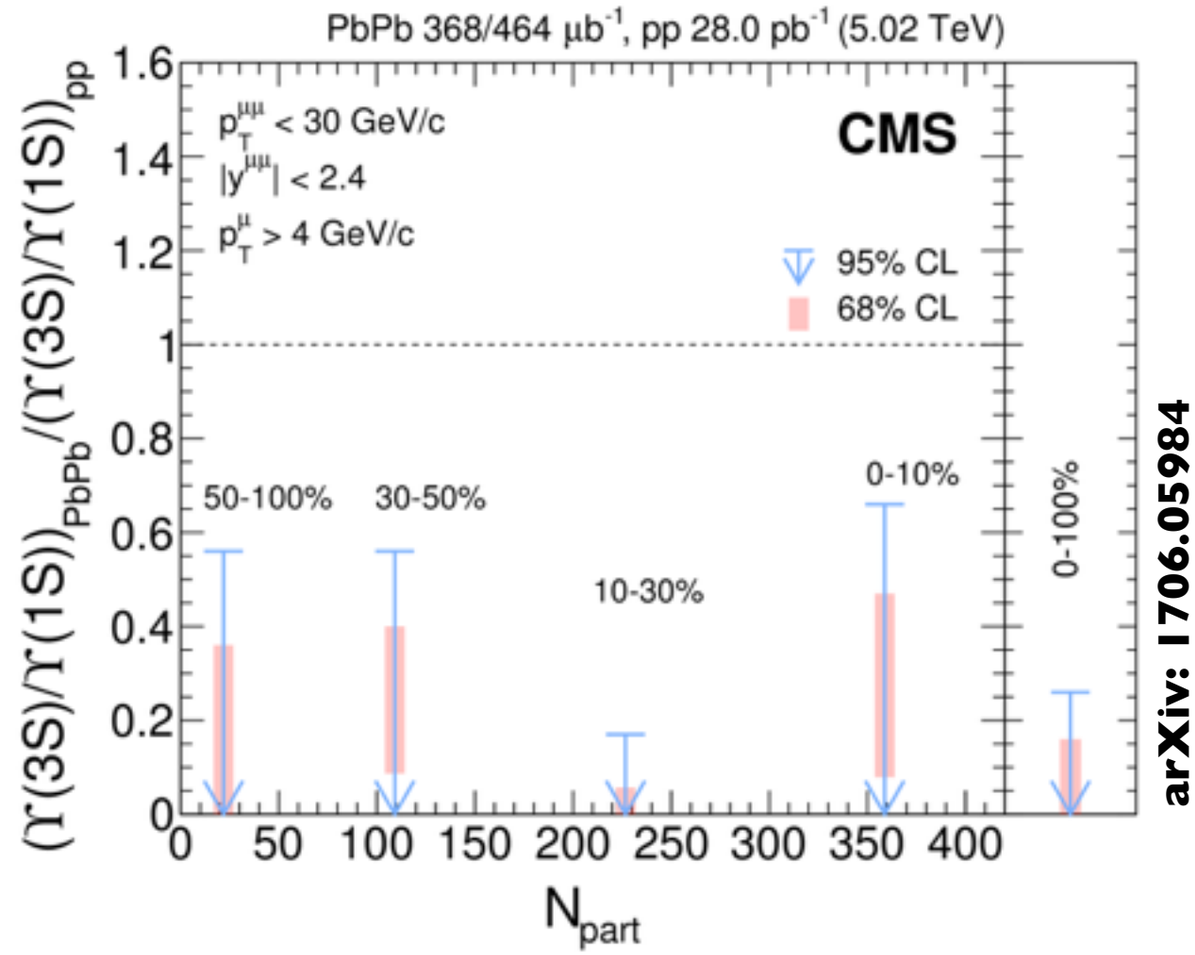
- **pPb**: importance of final state effects for excited states
- **PbPb**: medium effects stronger for excited states

Theoretical challenge, especially in pPb

Υ(1S,2S,3S) IN PbPb

Measurements of Υ family provide insight to **thermal properties of the medium**

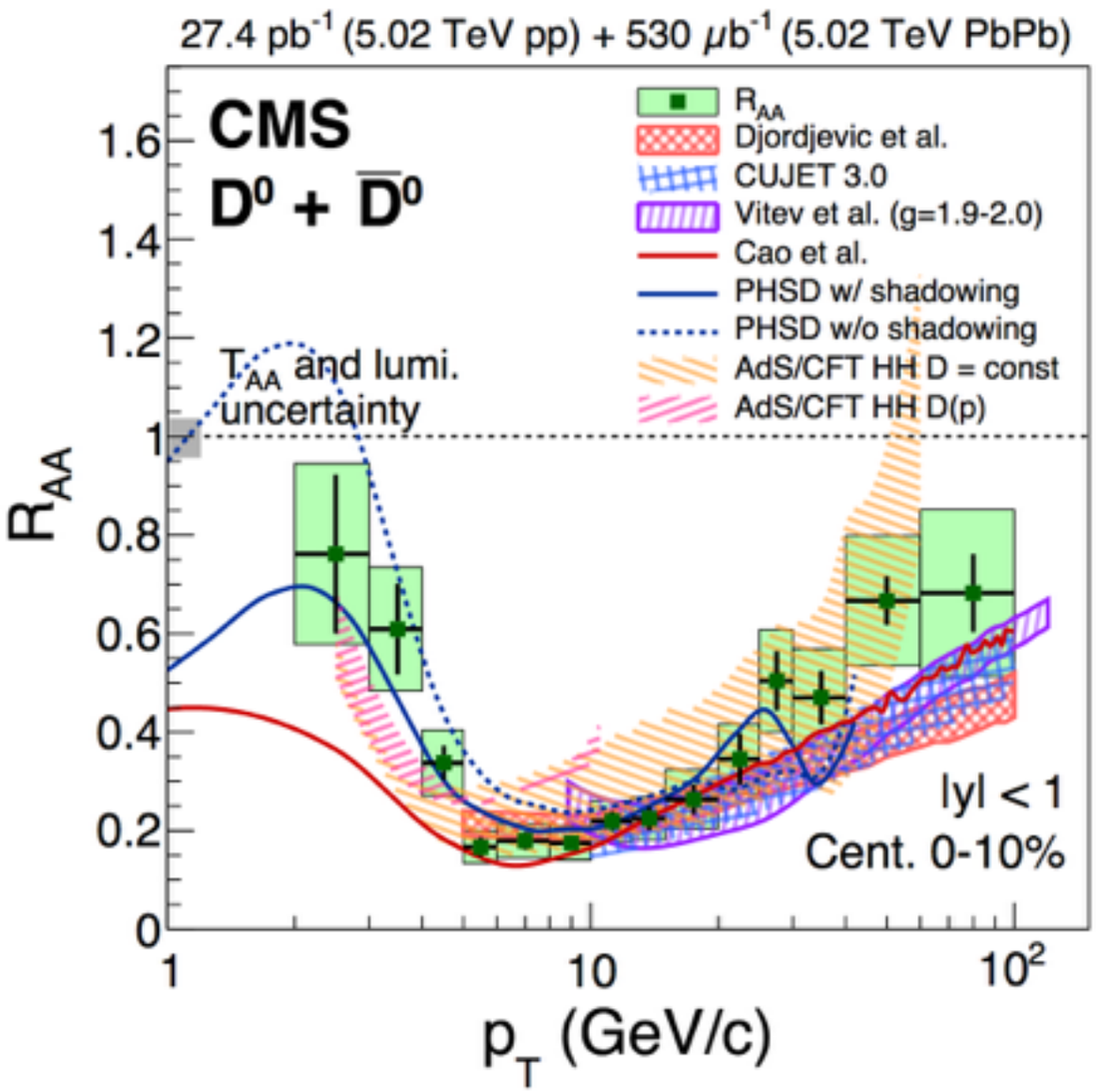




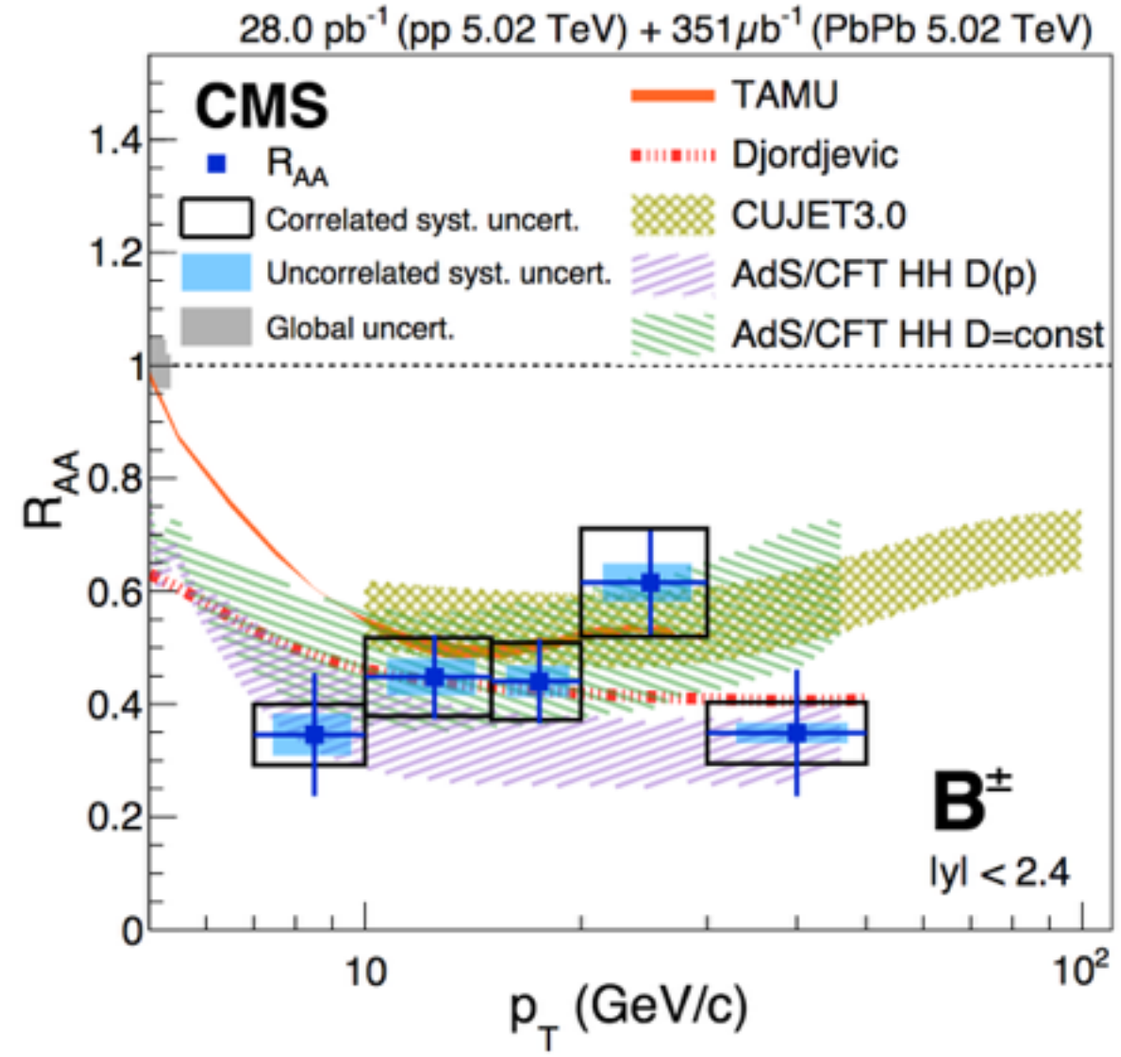
- Excited states **more suppressed** than ground state
- Increasing suppression with centrality
- Hydrodynamical model consistent with measurements: Initial medium temperature raises from T ~ 550 MeV @ 2.76 TeV to T ~ 630 MeV @ 5.02 TeV

D AND B MESONS IN PbPb

Measurements of open heavy flavor allow to study **properties of in-medium energy loss**



arXiv: 1708.04962



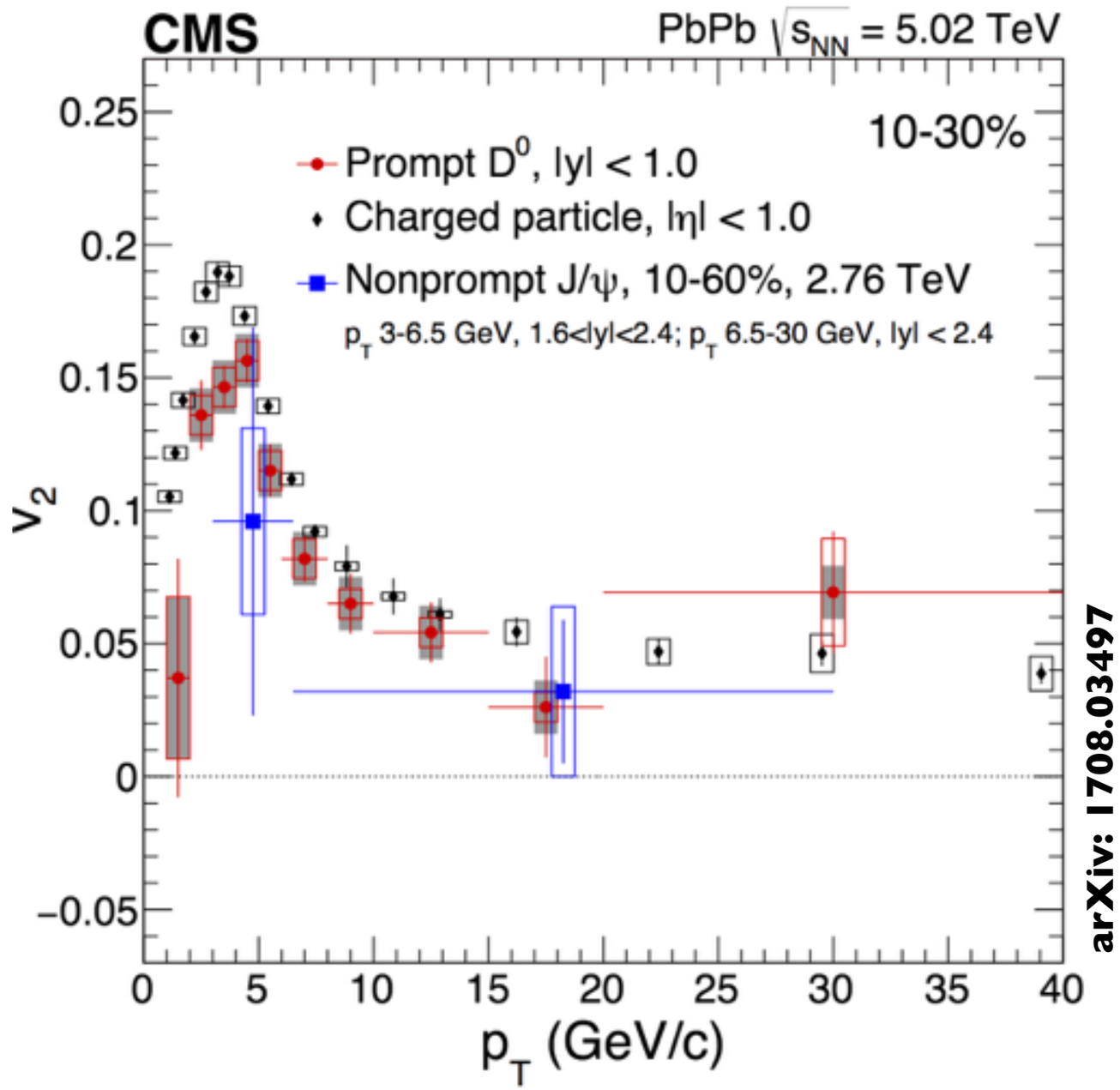
arXiv: 1705.04727

Similar suppression of D and B mesons

Theoretical models differ on modelling of the medium, energy loss sources and shadowing

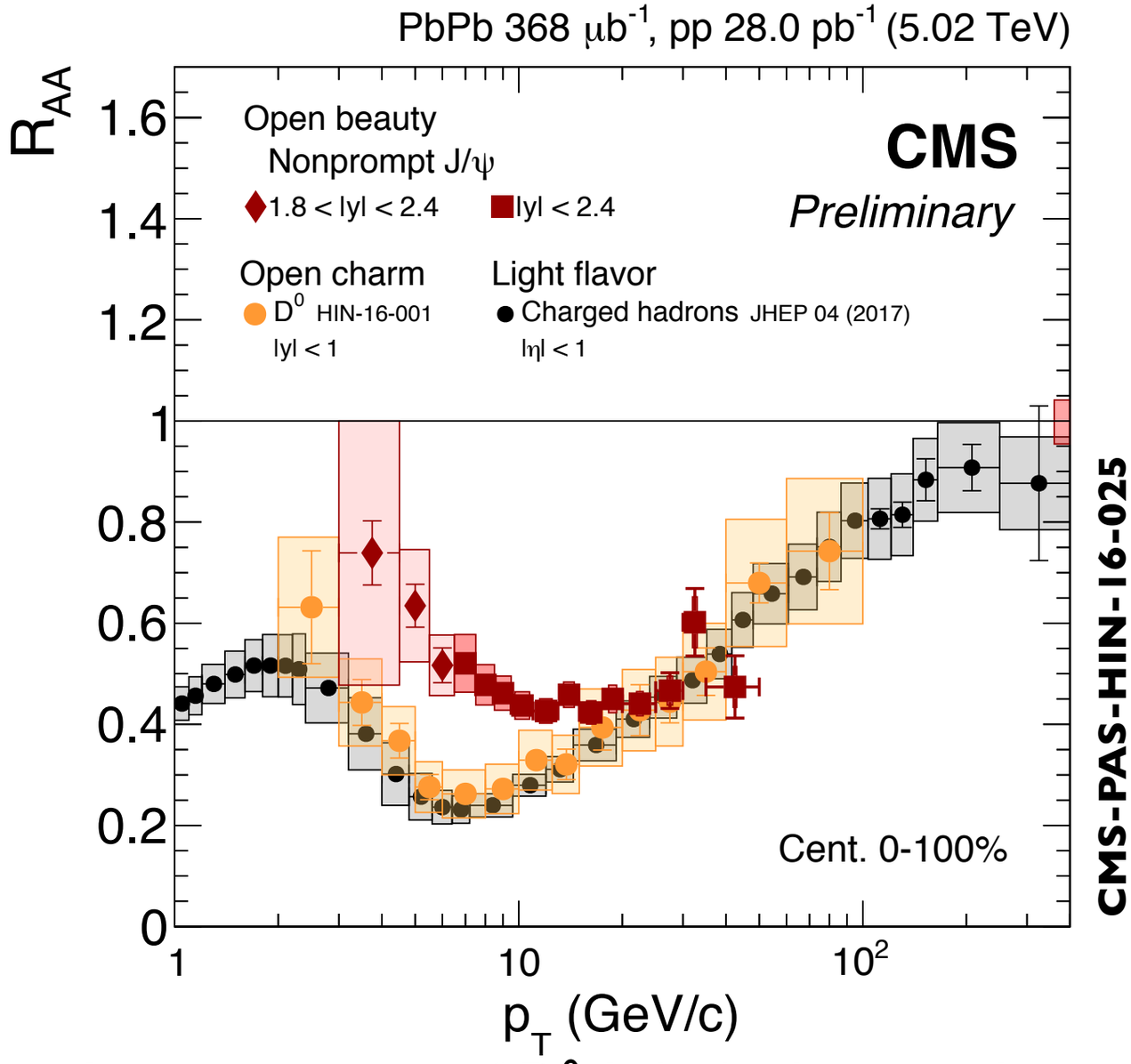
- D meson suppression at high p_T is qualitatively reproduced but not at low p_T
- More precise measurements needed for B mesons

D MESON AND NONPROMPT J/ψ IN PbPb



- Light quarks and charm flow with the medium
- If $v_2(B) > 0$ b quarks also flow
- Large uncertainties do not allow to draw conclusions on flavor dependence

FLAVOR DEPENDENCE OF E_{loss}



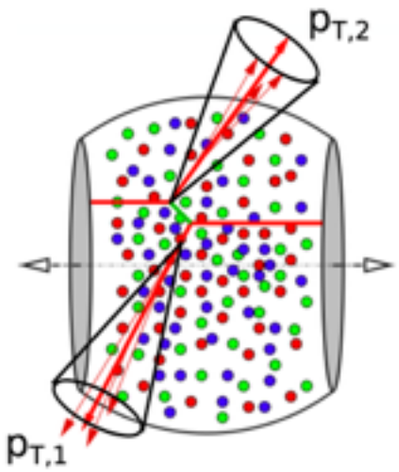
- High p_T: similar suppression of D^0, light hadrons and nonprompt J/ψ: **universal behaviour of Eloss at high p_T ?**

- Low p_T: hints of R_{AA} (B→J/ψ) > $R_{AA}(D^0)$ ~ R_{AA}(light hadrons): **smaller E_{loss} of b quarks at low p_T ?**

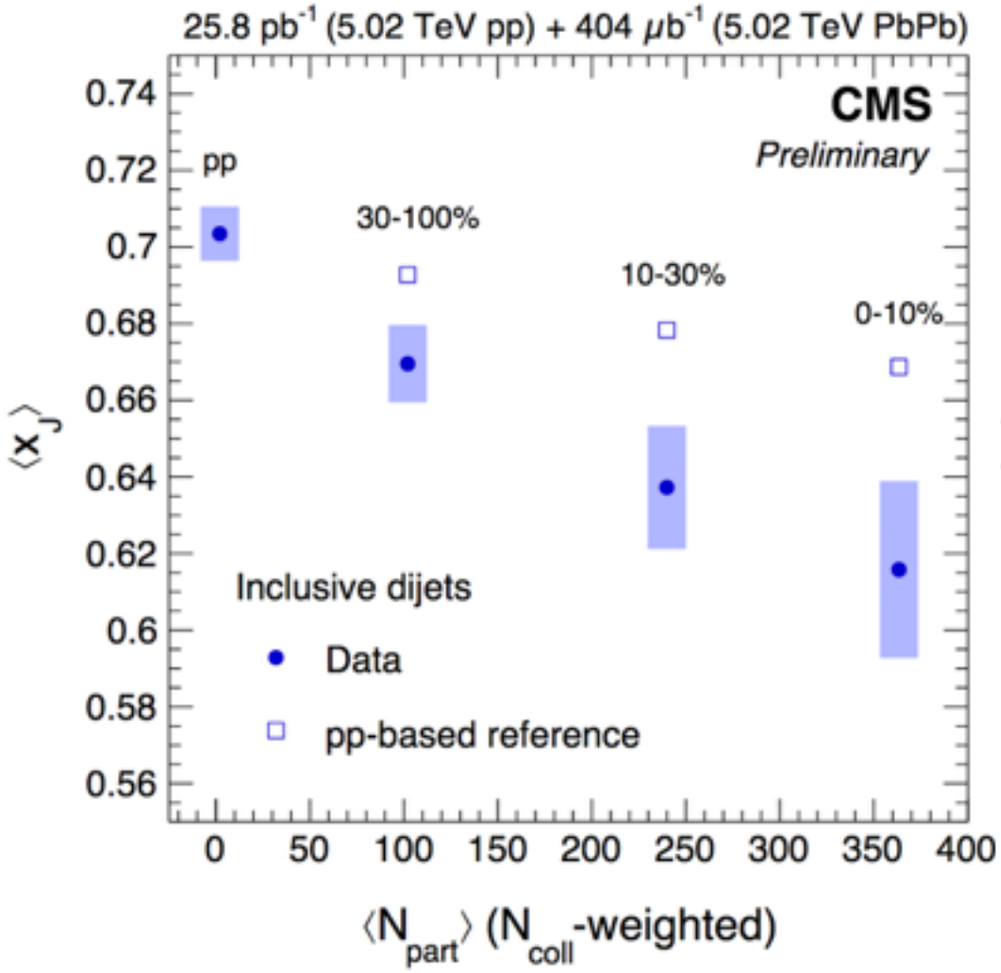
Constrains on flavor dependence of E_{loss}

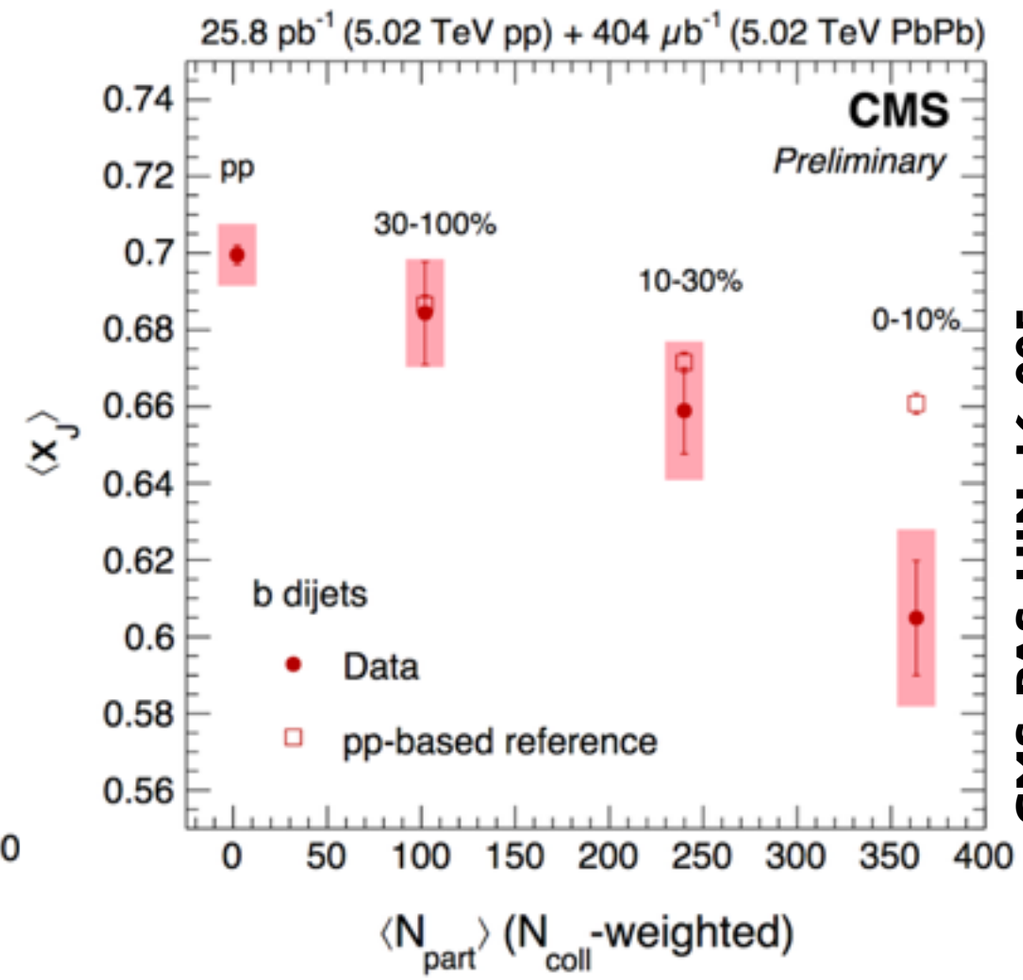
HF DIJETS: MOMENTUM IMBALANCE

Momentum imbalance is ascribed to jet quenching



$$\langle x_J \rangle = \frac{p_{T,2}}{p_{T,1}}$$



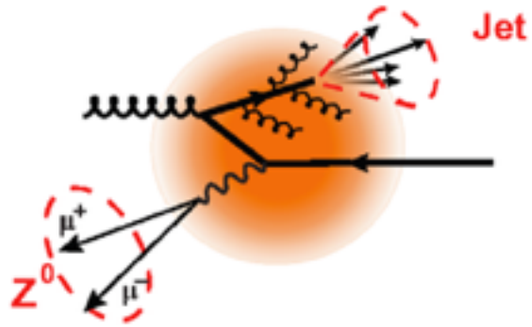


CMS-PAS-HIN-16-005

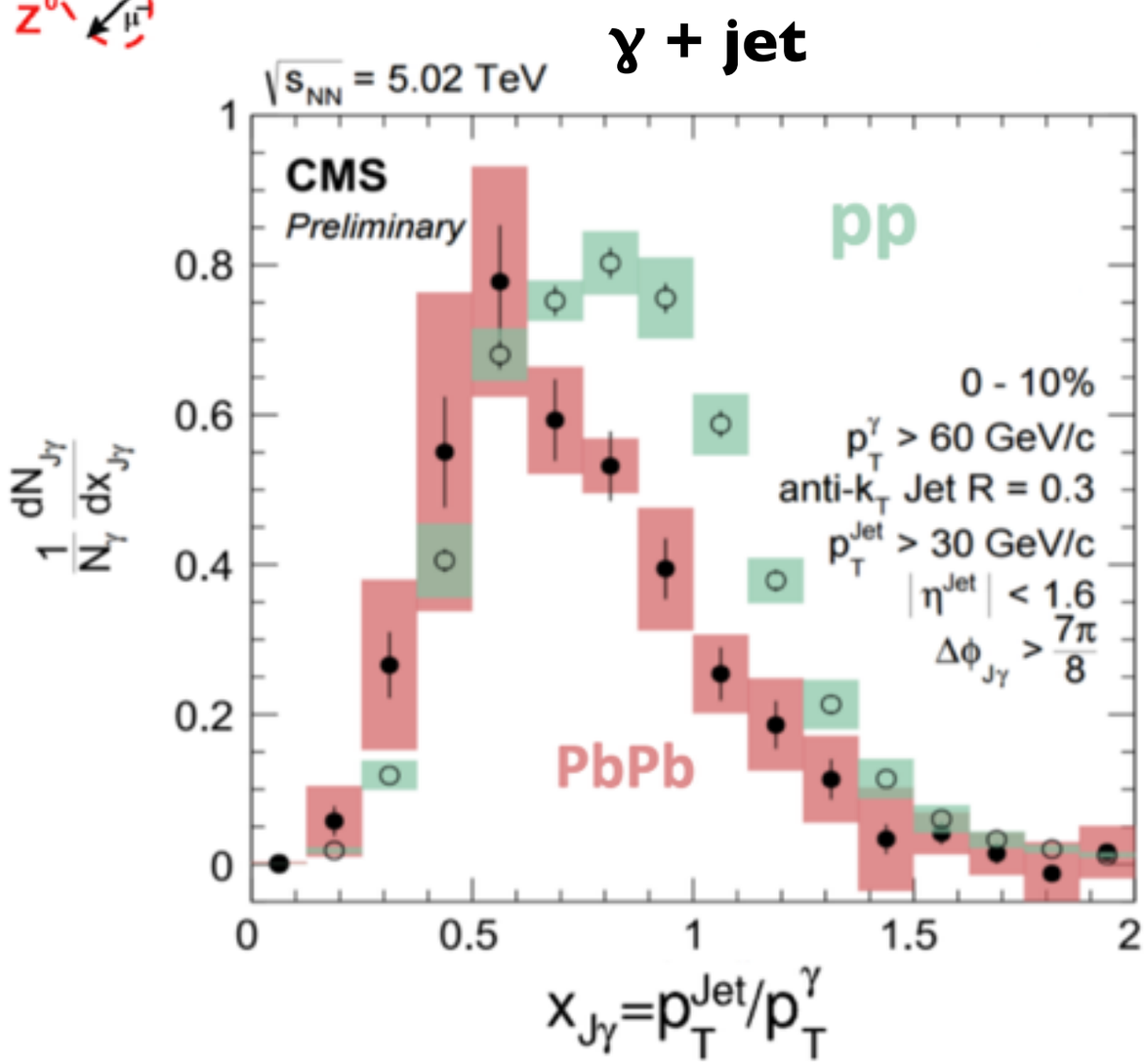
- b dijet removes ambiguity regarding production mechanism
- Consistent modification in inclusive and b dijets

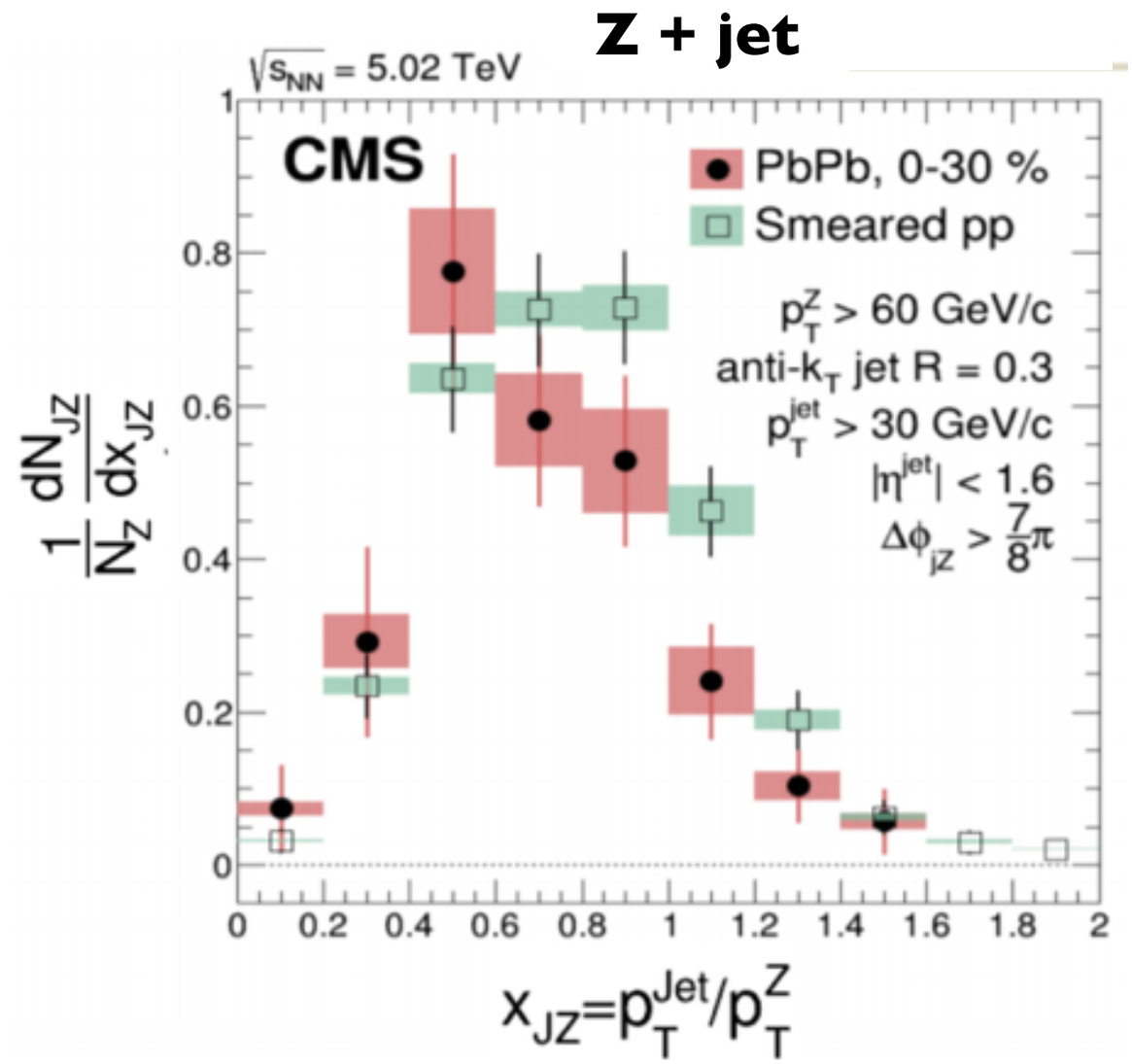
Constrains on mass and flavor dependence of energy loss

BOSON-JET MOMENTUM RATIO



γ and Z are not affected by the medium

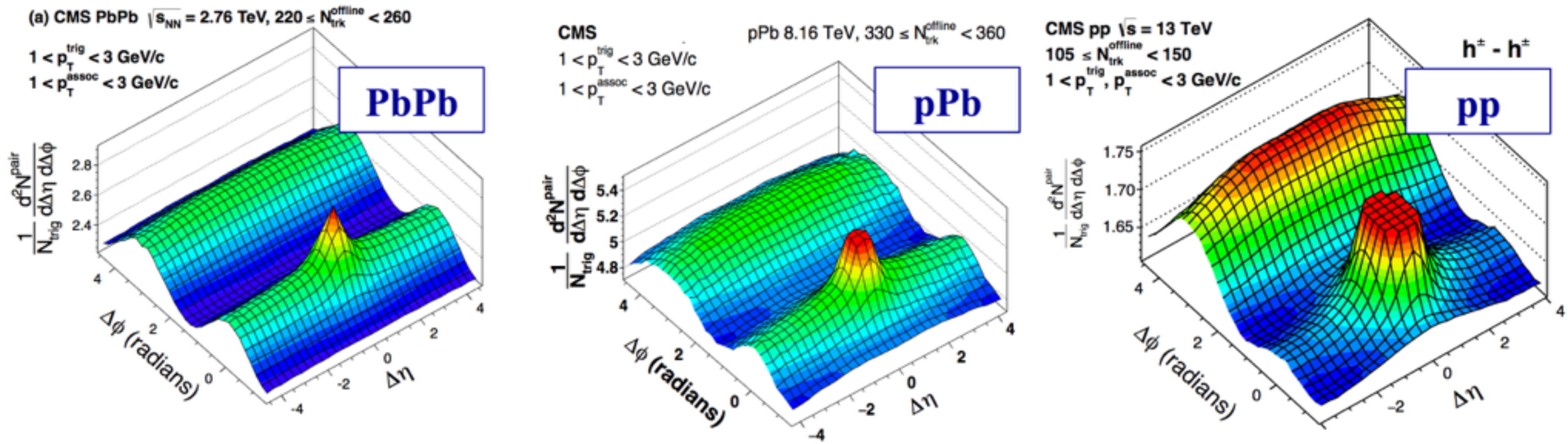




- Measures energy loss of jets wrt EW probe
- Average value of transverse momentum ratio smaller in PbPb than pp

Constrains to quenching with well-defined parton flavor and kinematics

COLLECTIVITY IN SMALL SYSTEMS



Similar ridge effect observed in all hadronic systems at LHC

Sensitive to:

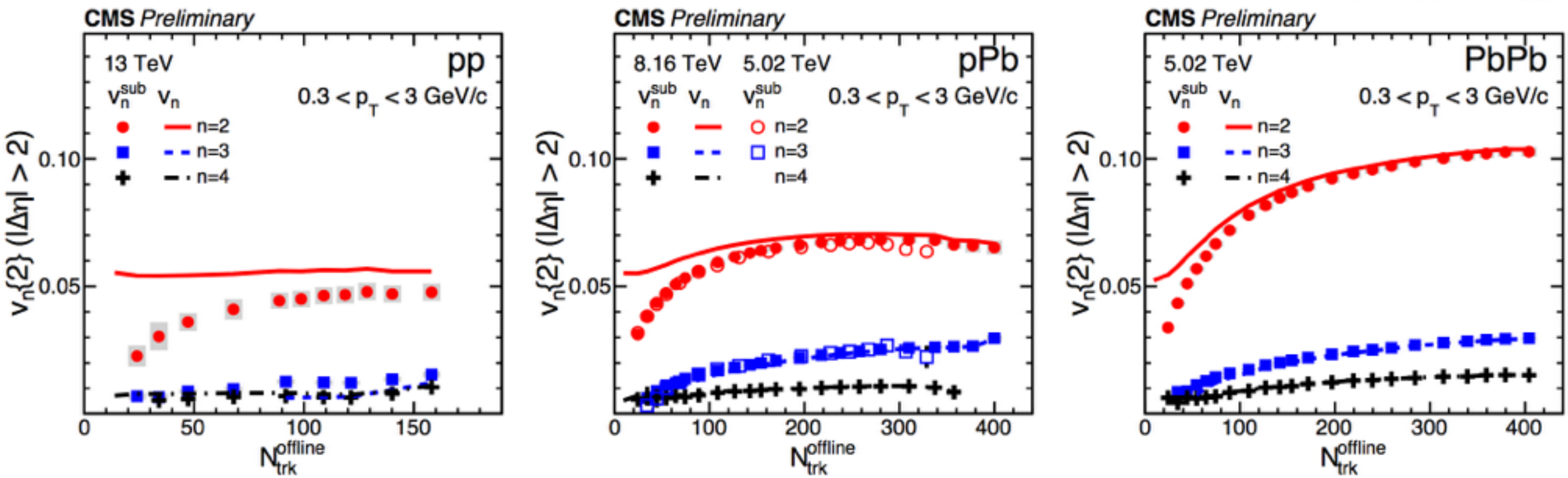
- ✦ Initial state geometry and fluctuations
- ✦ Transport coefficients of the medium

What is the origin of the ridge? Common paradigm in all systems?

COLLECTIVITY IN SMALL SYSTEMS

v_2, v_3 and v_4 harmonics studied with multi-particle correlations

CMS-PAS-HIN-16-022

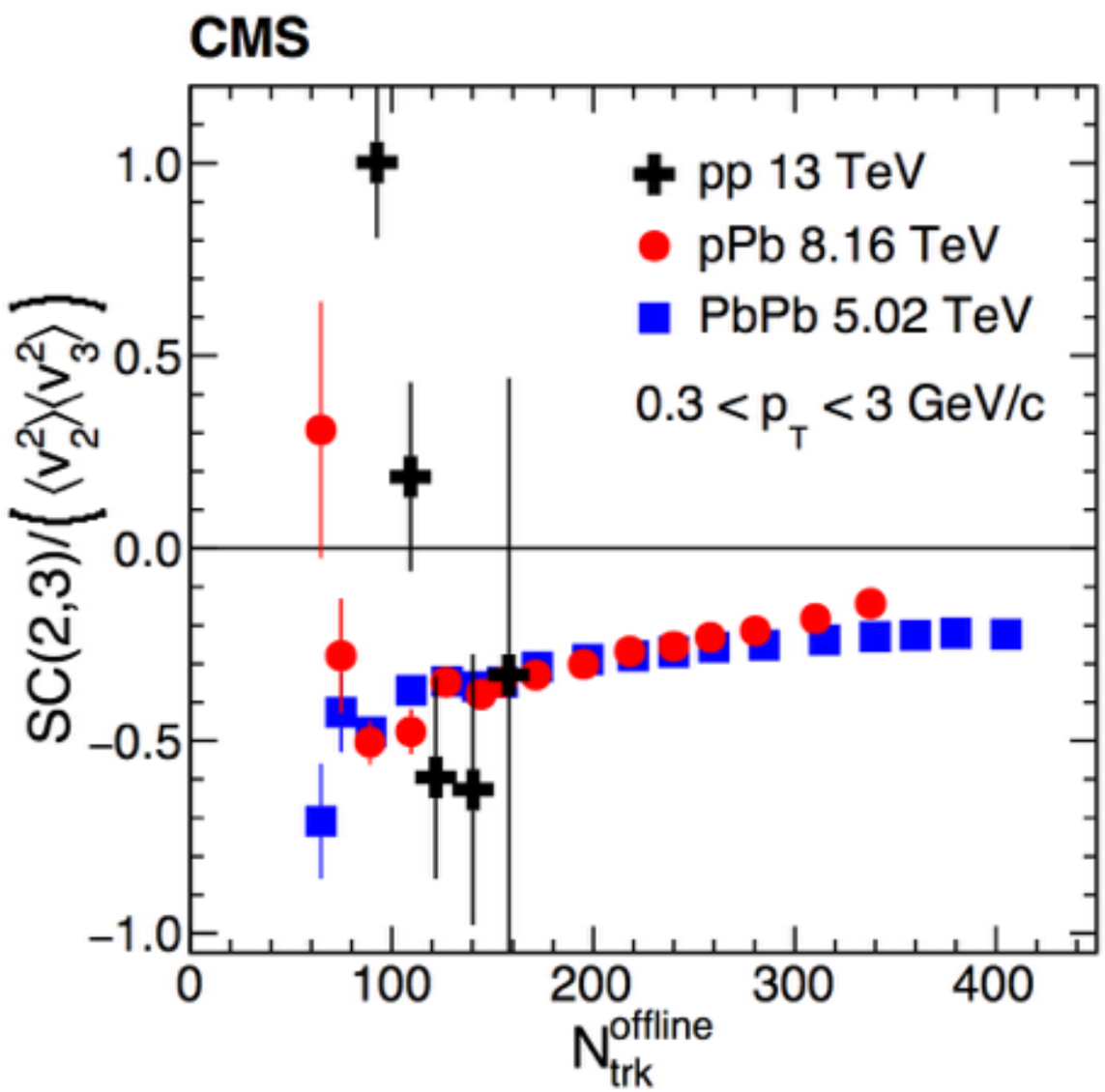


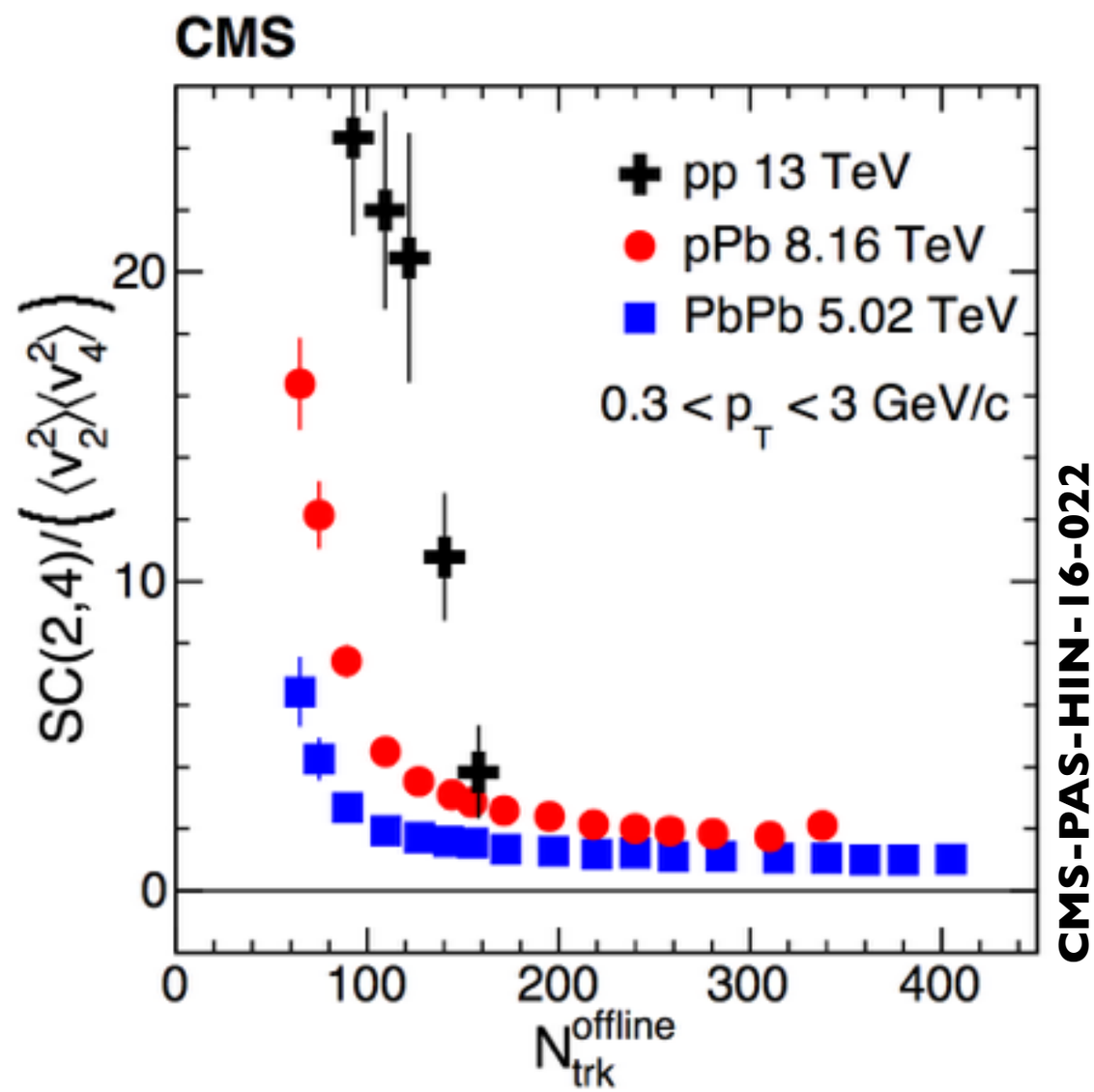
- Similar pattern of v_n observed for all systems
- Very small energy dependence in pPb collisions

Evidence of collectivity in all hadronic systems at the LHC

COLLECTIVITY IN SMALL SYSTEMS

Correlation between harmonics studied with normalised symmetric cumulants (SC)





- Similar in pPb and PbPb at high multiplicity

  → **Points to the same nature of initial state fluctuations**

- The same in high multiplicity pp ?

- Ordering observed: pp > pPb > PbPb

  → **May point to different medium transport coefficients**

SUMMARY

- Many **new CMS measurements** to**:**
  - ✦ Constrain PDFs and understand shadowing effects
  - ✦ Understand initial state geometry/fluctuations in all hadronic systems
  - ✦ Better understand QGP properties and interaction of partons with the medium

We still have to make full use of all the data collected so stay tuned !

THANK YOU FOR YOUR ATTENTION

BACKUP