Lepton Photon 2015

17-22 August 2015, Ljubljana

RESULTS FROM HEAVY ION COLLISIONS

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INFN Torino

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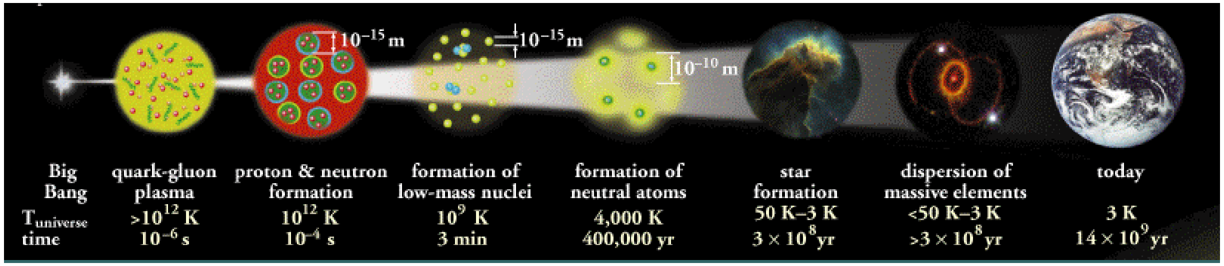
OUTLINE

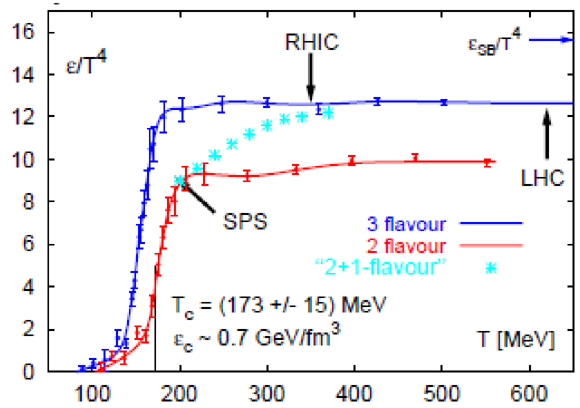
- A "biased selection" of recent results from the large wealth of heavy-ion p-A (d-A) and A-A data from RHIC and LHC experiments!

HEAVY-ION PHYSICS

- QCD predicts a phase transition from hadronic matter to a deconfined phase (at high temperatures)

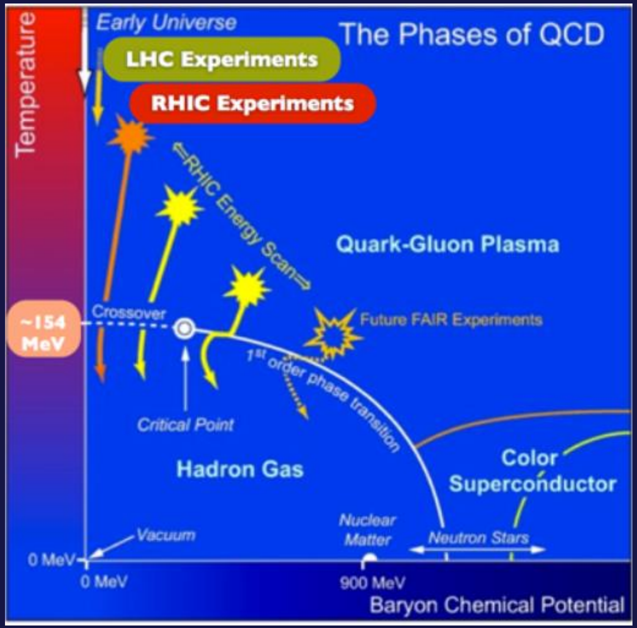
QGP at μ~0 similar to early Universe (~ few first μs)





F. Karsch, hep-lat/0106019

- **Heavy-ion collisions provide experimental access to the QCD matter**



- **SPS**: first signals of QGP formation
- **RHIC:** QGP is a strongly interacting perfect liquid
- **LHC:** detailed investigation of QGP properties

Heavy-ion collisions overview...

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38,NA44, NA45,NA49, NA50,NA57, WA98,NA60	S-U	19	1986-2004
		Pb-Pb	17	
		In-In	17	
		p-A	17-29	
	NA61	A-A,p-A	5-17	2009-2015
RHIC	(BRAHMS/ PHOBOS) PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	7.7-200	2000-2015
		d-Au	200	
		p-Au, p-Al	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2012
		p-Pb	5020	2013

HEAVY-ION COLLISIONS OVERVIEW...

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~30 years long story

HEAVY-ION COLLISIONS OVERVIEW...

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More than a factor ~100 increase in energy

HEAVY-ION COLLISIONS OVERVIEW...

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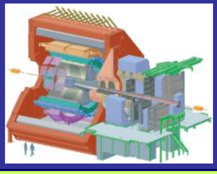
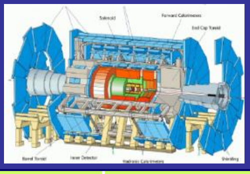
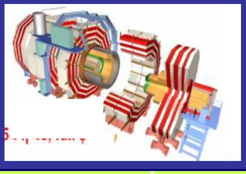
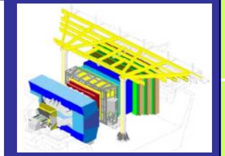
		p		
LHC	ALICE/ATLAS/ CMS/LHCb			

All LHC experiments participate to the HI program

HEAVY-ION COLLISIONS OVERVIEW. . .

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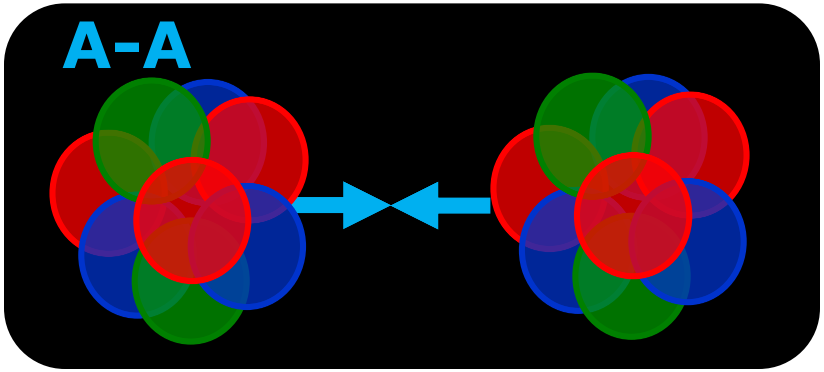
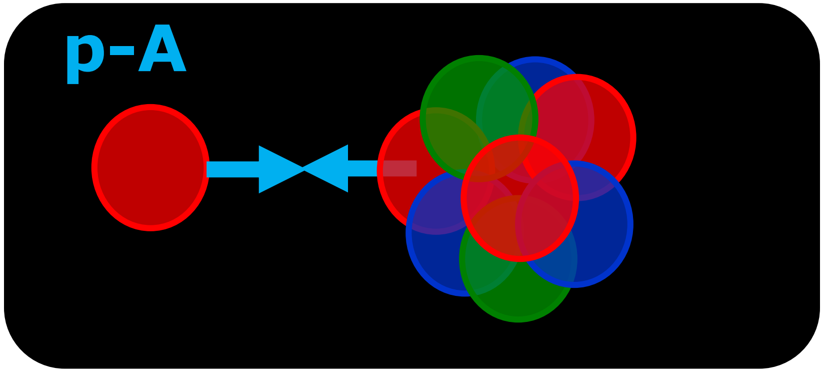
For all experiments, the A-A program is followed by a p-A one

HEAVY-ION COLLISIONS PROGRAM

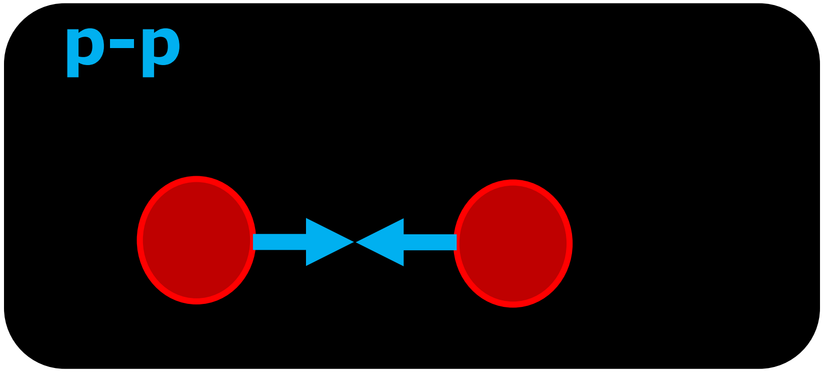
Different types of collisions.... ...to investigate....



→ "Hot and dense" QCD matter



→ "cold nuclear matter", but not only...



→ **"vacuum" reference**

- reference for Pb-Pb and p-Pb
- genuine pp physics program

(not covered in this talk)

HOW DO WE STUDY HEAVY-ION COLLISIONS?

Soft probes

Observables: multiplicity, energy density, collective flow

→ Access to the global properties of the system

Hard probes

Observables: jets, EW bosons, heavy-flavour, quarkonia

→ Sensitive to initial and final state effects

Nuclear modification factor

Medium effects are quantified comparing yields in AA with the pp ones, scaled by a geometrical factor (from Glauber model)

$$R_{AA} = \frac{Y_{AA}}{\langle T_{AA} \rangle \sigma_{pp}}$$

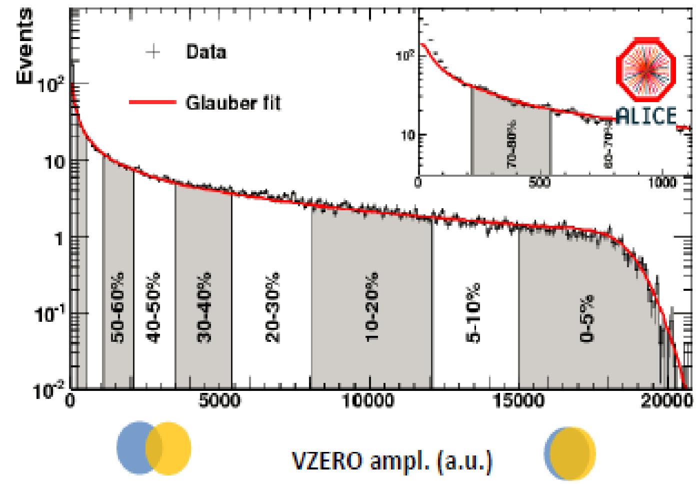
- $R_{AA} = 1$ → no medium effects
- $R_{AA} \neq 1$ → hot/cold matter effects

CENTRALITY OF THE COLLISIONS

Centrality in A-A collisions

Impact parameter cannot be directly measured

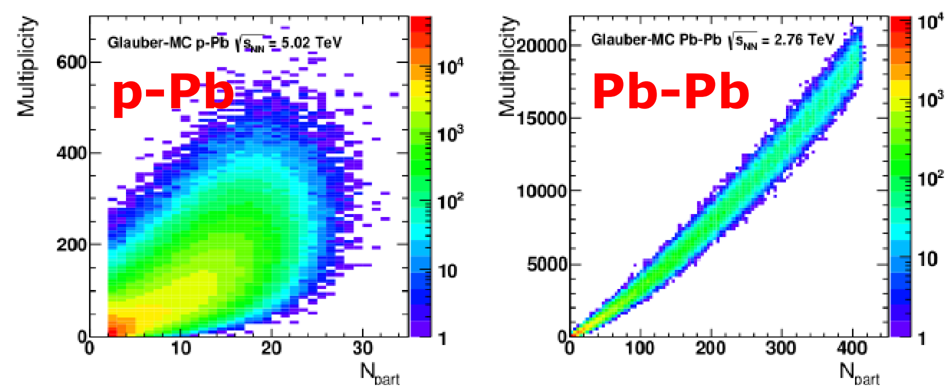
- Evaluated through measured quantities as N_{ch}, E_{ZDC}...
- Link with number of binary collisions (N_{coll}) or participants (N_{part}) done with the Glauber model



Centrality in p-A collisions

Centrality determination in p-Pb is challenging!

- looser correlation between N_{part} and multiplicity
- small number of nucleon-nucleon collisions



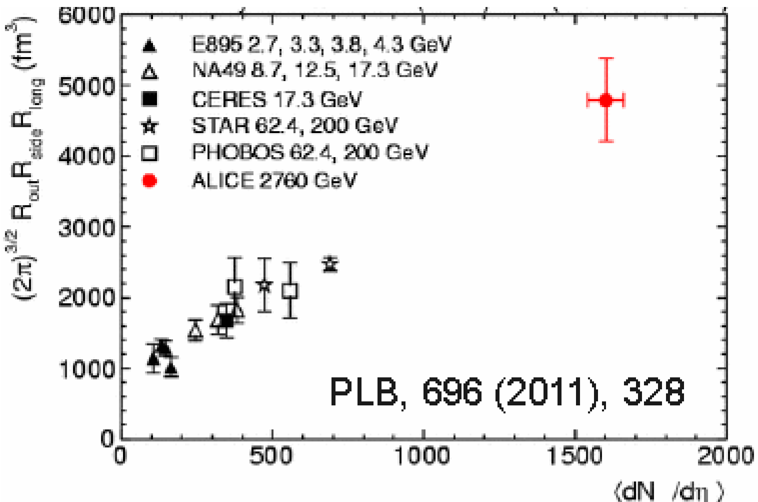
→ broad correlation between multiplicity and centrality

→ different strategies developed to extract centrality informations

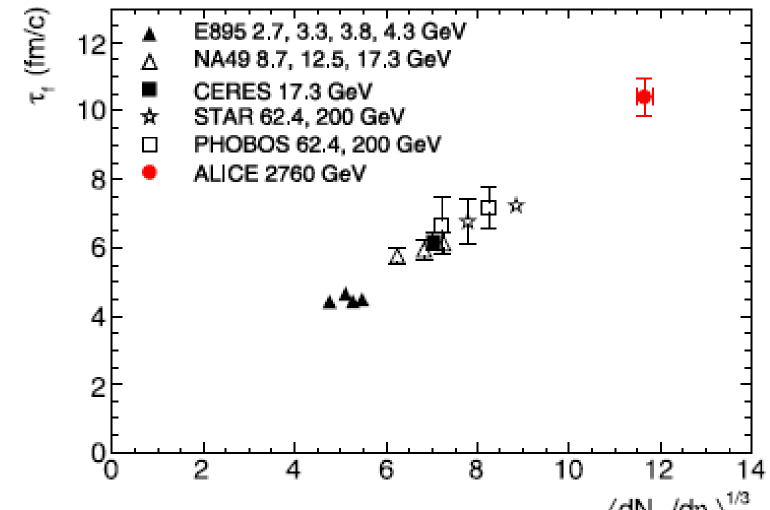
Global Properties

B. Heinemann, Mon 17th
L. Malgeri, Mon 17th
J.F. Grosse-Oetringhaus Tue 18th

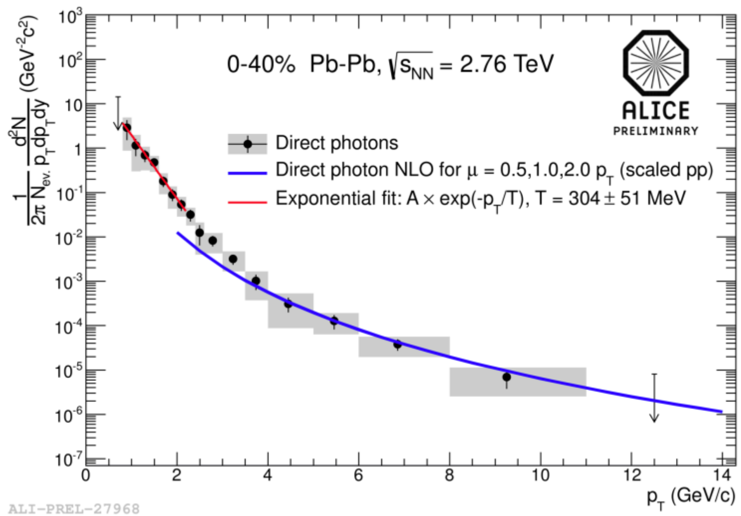
GLOBAL PROPERTIES: LHC VS RHIC



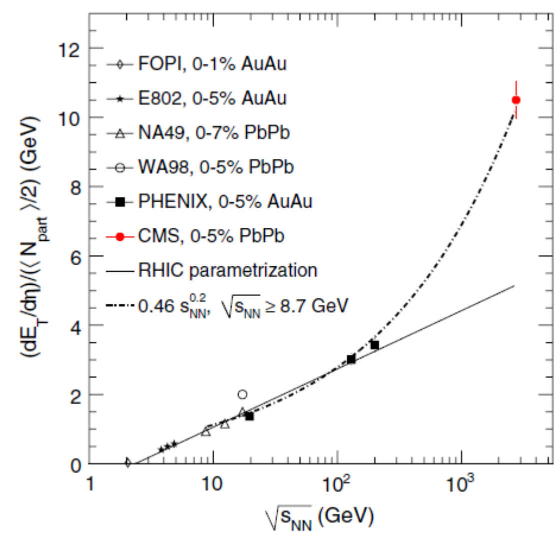
Freeze-out volume LHC~ 2 x V_{RHIC}



Lifetime LHC~ 40% larger than RHIC

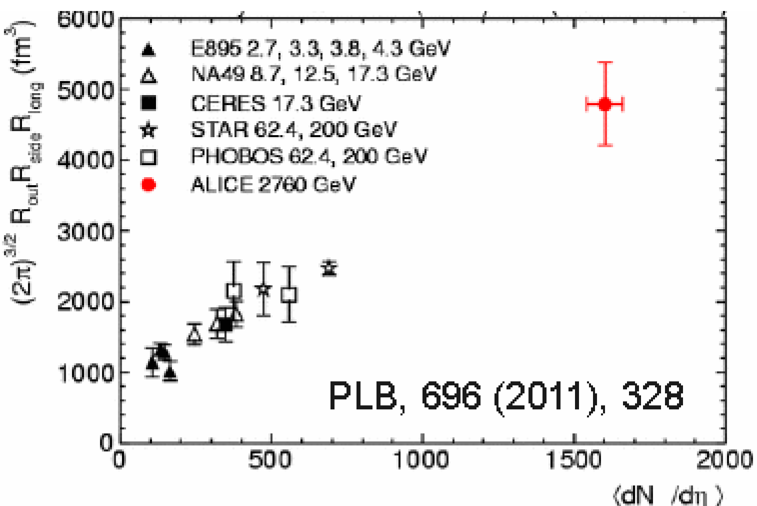


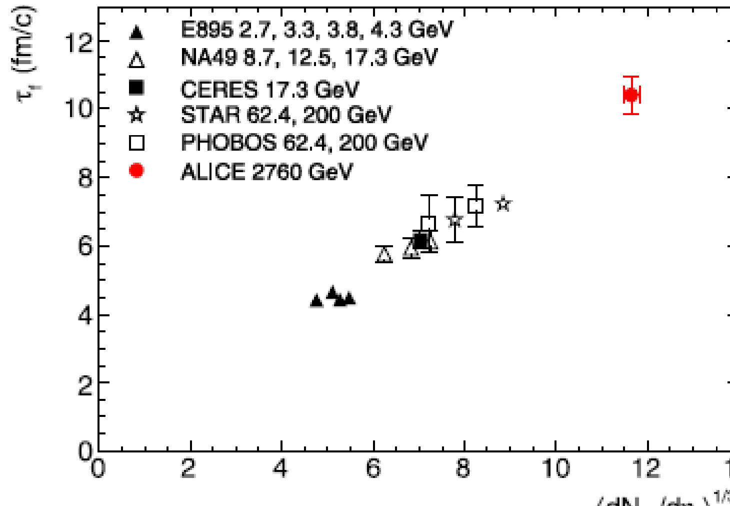
$T = 304 \pm 51$MeV ~ 1.4 x T_{RHIC}



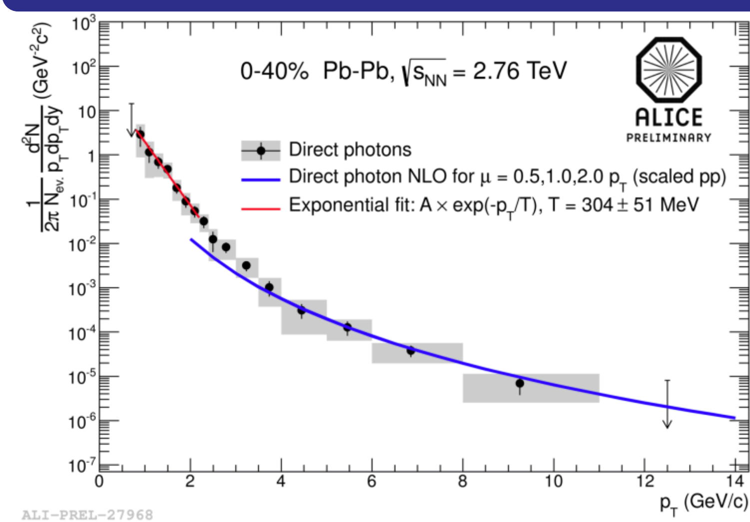
Energy density=15GeV/fm^3 ~ 3 x ε_{RHIC}

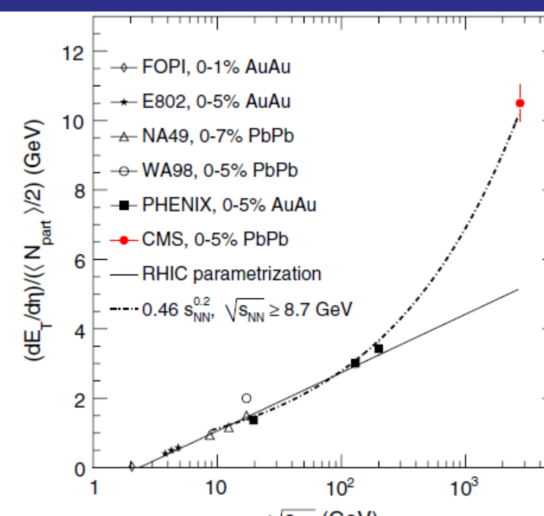
GLOBAL PROPERTIES: LHC VS RHIC





@LHC the fireball has larger volume and lives longer



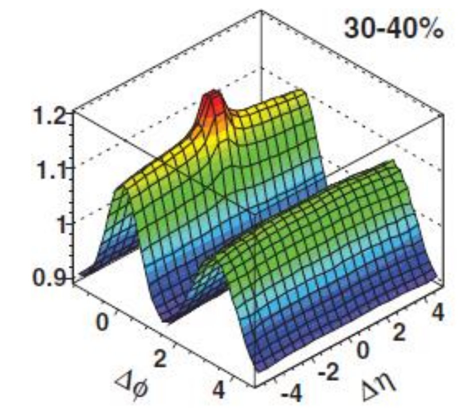


@LHC denser and hotter system!

THE RIDGE

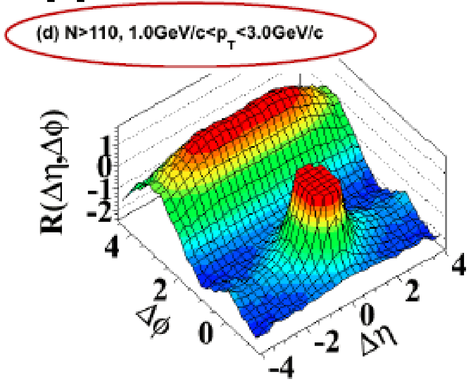
- two particles ($\Delta\eta$, $\Delta\phi$) correlations → tool to investigate particle production mechanisms
- hints of collective effects also in p-Pb and in high multiplicity pp collisions @LHC and d-Au@RHIC → the ridges
  - pp and p-Pb are not only a "baseline" for PbPb!

PbPb @$\sqrt{s_{NN}}$=2.76TeV



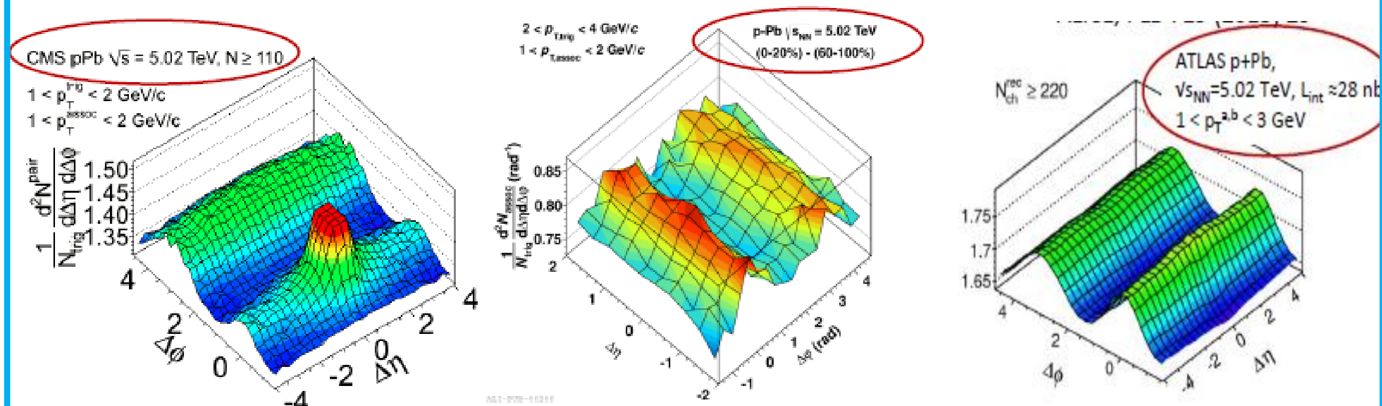
ATLAS, Phys.Rev.C86,014907

high-mult pp@$\sqrt{s}$=7TeV



CMS, JHEP09(2010)091

pPb@$\sqrt{s_{NN}}$=5.02TeV



CMS, PLB718(2012)795 ALICE, PLB719(2013)29 ATLAS, PRC90(2014)044906

- Structures reminiscent of those observed in Pb-Pb, attributed to collective behaviour
- Double ridge described by color glass condensate (initial state effect), final state parton-parton interactions or hydrodynamics models

COLLECTIVE FLOW

- $\Delta\phi$ correlations can be studied via a Fourier decomposition

$$\frac{dN}{Nd\phi} \sim 1 + 2v_2 \cos(2(\phi - \Psi_{RP})) + \textit{higher harmonics } (v_3, v_4, \ldots)$$

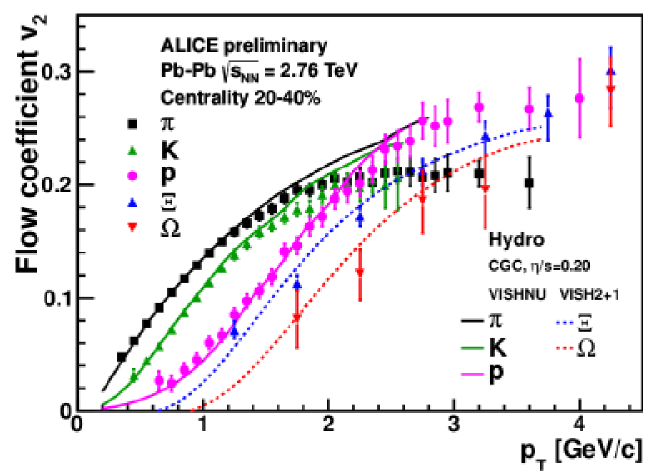
v_2 elliptic flow parameter

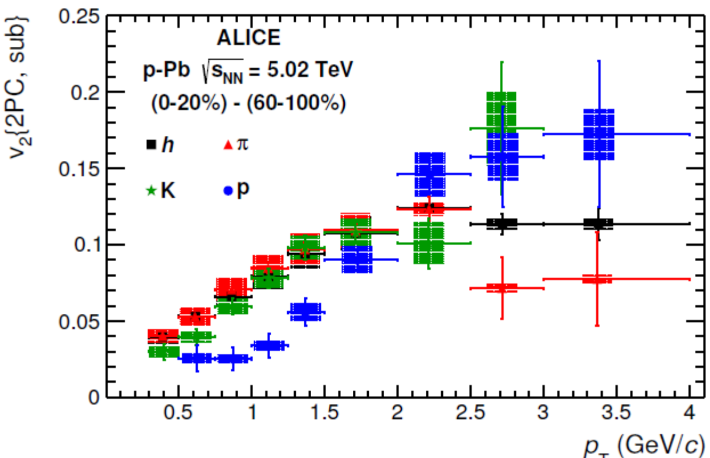
- v_n coefficients provides infos on

- Equation of state, shear viscosity…
  → comparing data with hydrodynamic models
- Initial conditions
  → geometrical distribution of energy density within nuclear overlap zone

- v_2 mass ordering at low p_T

- Similar features in p-Pb and Pb-Pb
  Same physics on-going?

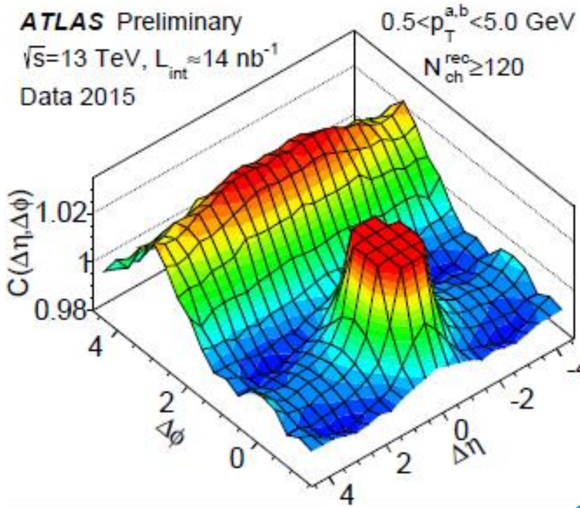




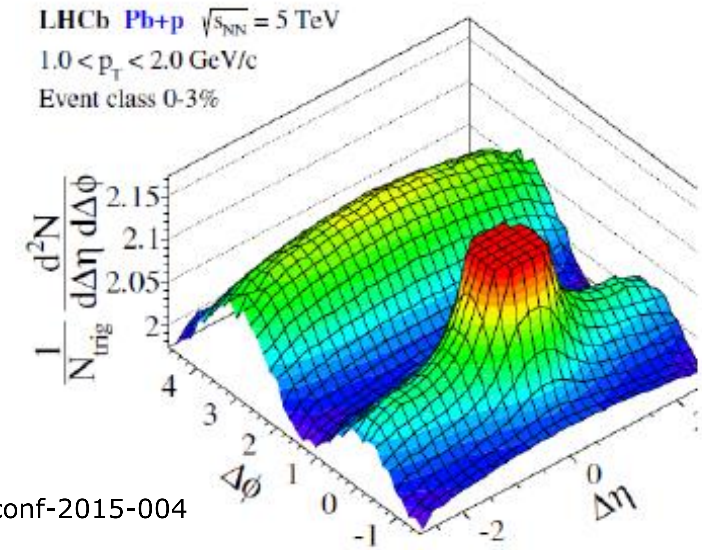
NEWS ON RIDGES

➡ Ridge observed also in pp@√s=13TeV

High multiplicity



➡ Ridge extended at forward-y

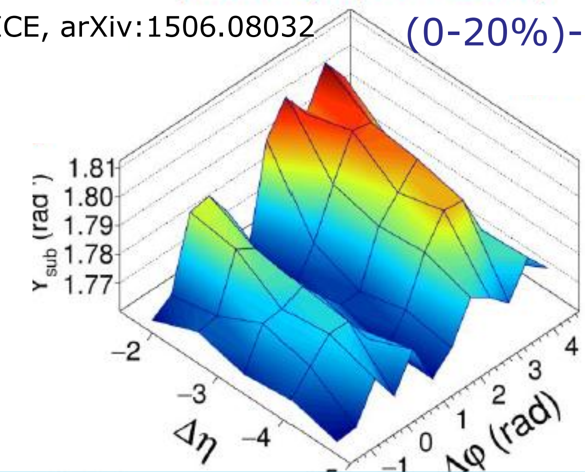


LHCb-conf-2015-004

➡ Ridge extended to large rapidities in p-Pb (via muon-tracklet correlations)

ALICE, arXiv:1506.08032

(0-20%)-(60-100%)



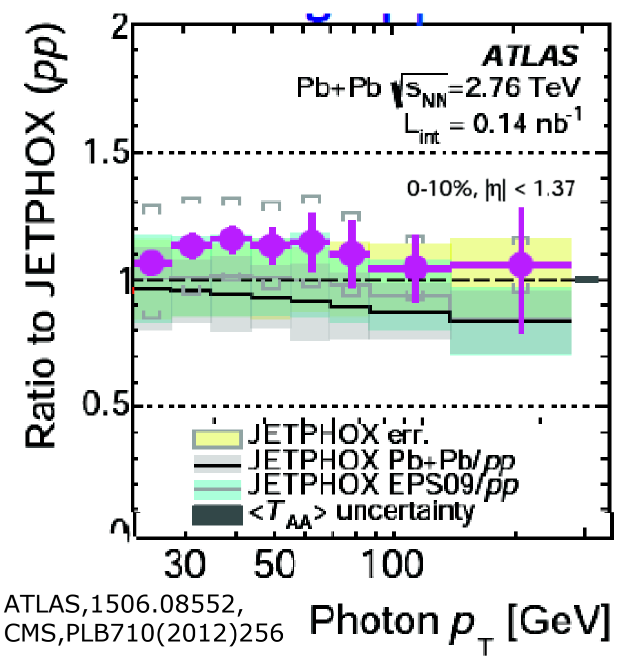
B. Heinemann, Mon 17th
J.F. Grosse-Oetringhaus, Tue 18th

HARD PROBES

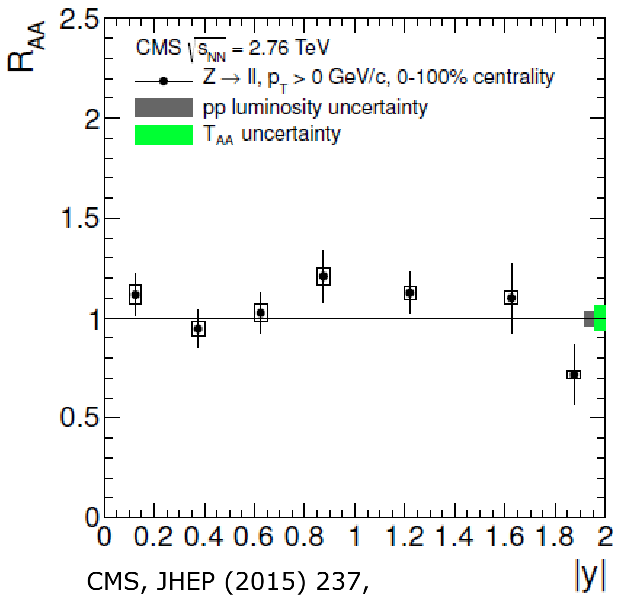
PHOTONS, W, Z IN PB-PB

- EW bosons not affected by the strongly interacting medium
  → clean probes of initial state effects

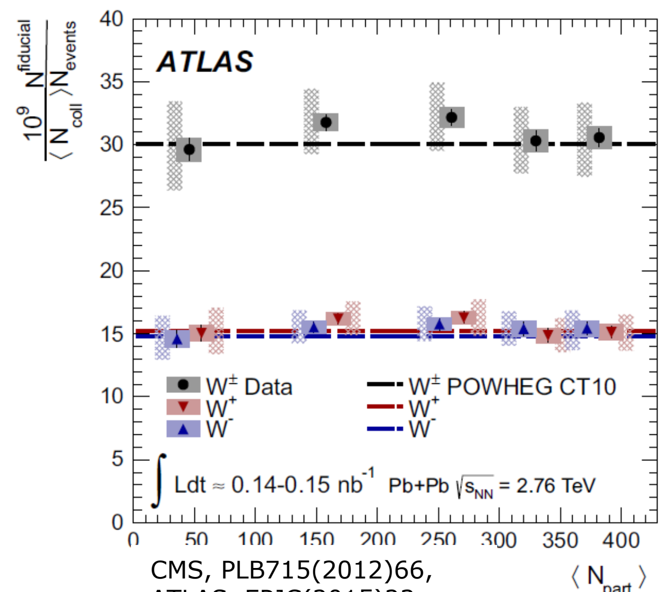
prompt photons | **Z** | **W**



ATLAS,1506.08552,
CMS,PLB710(2012)256



CMS, JHEP (2015) 237,
ATLAS, PRL(2013) 022301



CMS, PLB715(2012)66,
ATLAS, EPJC(2015)23

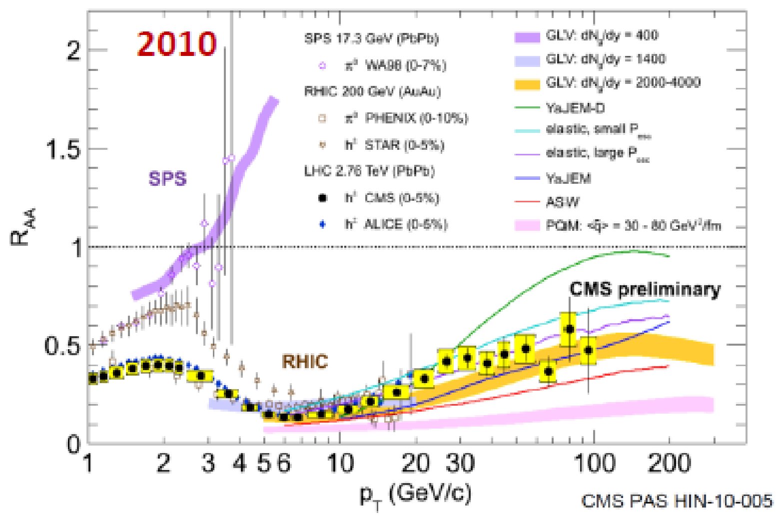
- EW bosons R_{AA}~1 → N_{coll} scaling works!
- Z, W, γ start to constrain nPDF (…but more precision needed!)

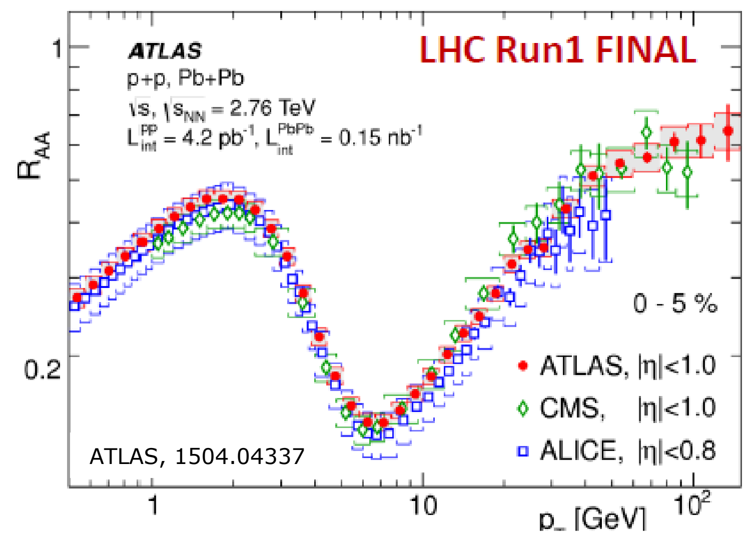
HIGH-PT CHARGED PARTICLES

- Hard scattering produce high p_T partons that propagate through the medium, losing energy, and eventually fragment into jets of hadrons

Jet quenching
- high-p_T hadron yields suppression
- jets suppression
- di-jet energy imbalance

→ tool to probe the dense medium in A-A collisions



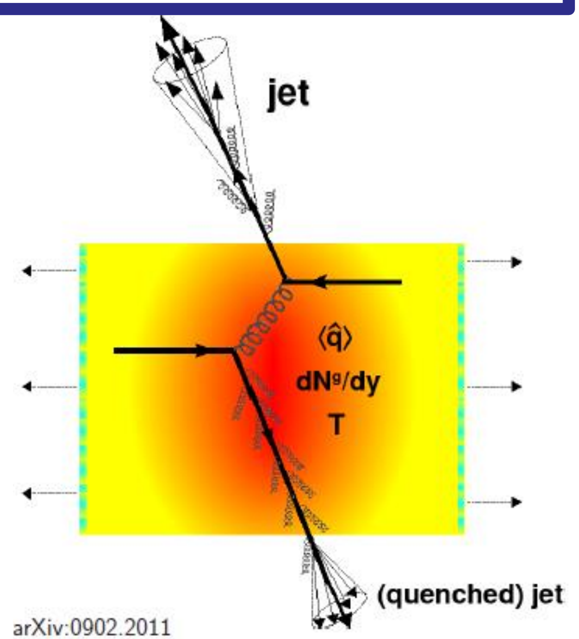


- R_{AA}(LHC)<R_{AA}(RHIC)
- LHC
  - R_{AA} up to p_T= 150GeV/c
  - clear p_T dependence: minimum at 7GeV/c, increase up to 60GeV/c, then hint for a plateau

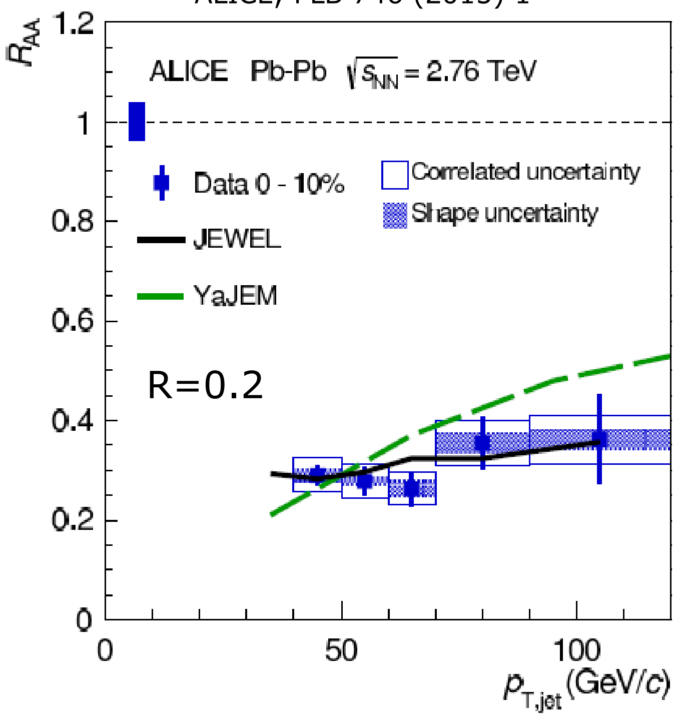
→ Constraints to energy loss models?

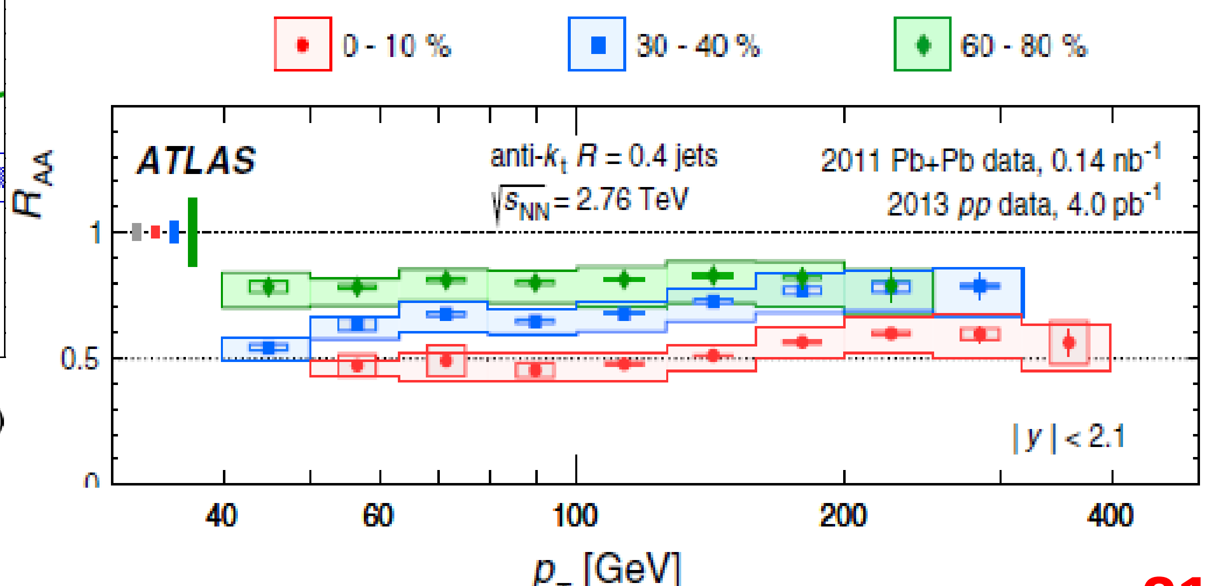
JET SUPPRESSION

- Significant suppression of inclusive jets, for $40<p_T<400$ GeV/c
- In central Pb-Pb collisions@LHC, up to a factor 2 compared to pp

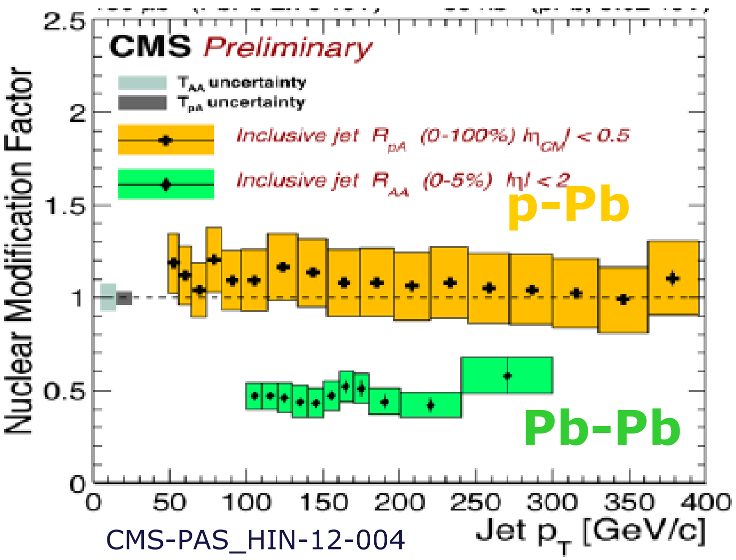


ALICE, PLB 746 (2015) 1



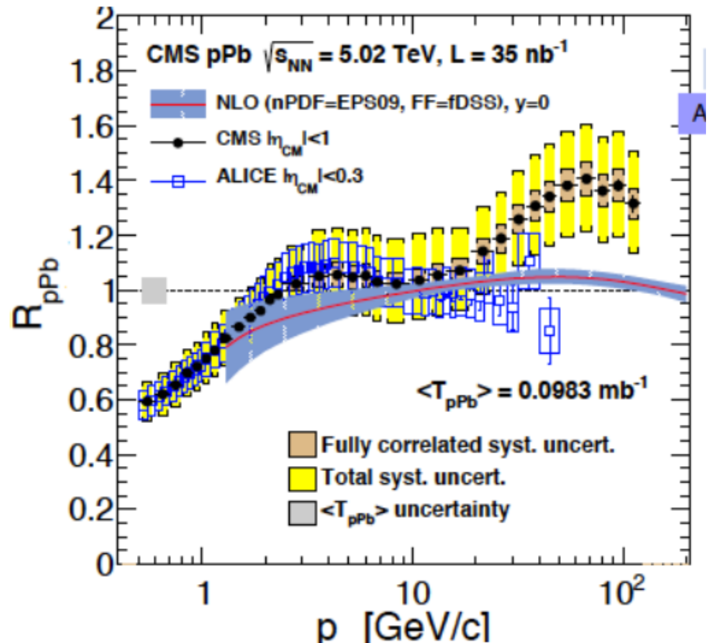


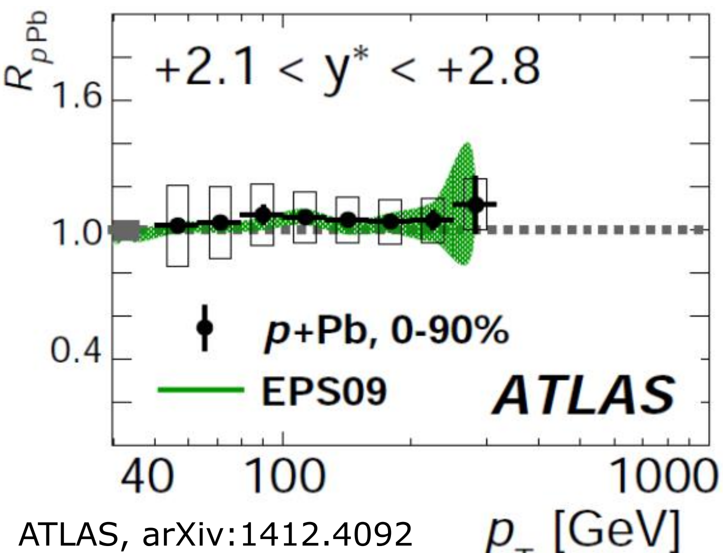
JETS AND HIGH P_T HADRONS IN P-A



CMS-PAS_HIN-12-004

- Jets R_{pA} compatible with unity, described by predictions including nPDF
- Jets suppression is a final state effect



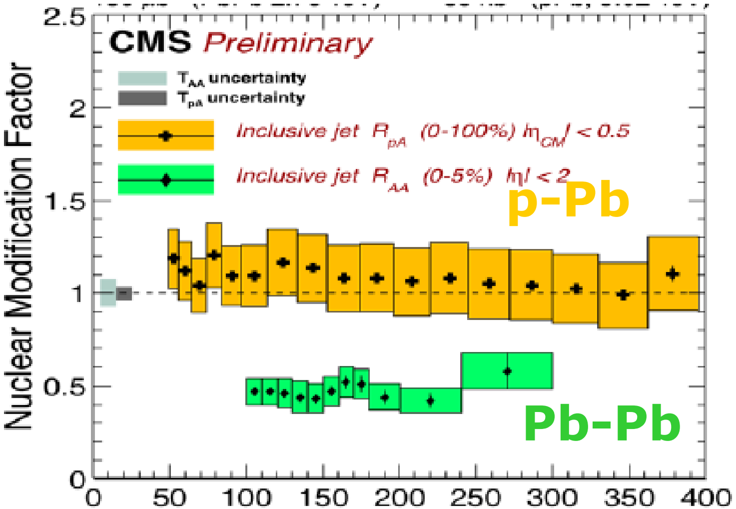


ATLAS, arXiv:1412.4092

- Tension between high p_T hadrons trend measured by ATLAS, CMS and ALICE

→ Difficult to reconcile with jet R_{pA}~1

JETS AND HIGH P_T HADRONS IN PA



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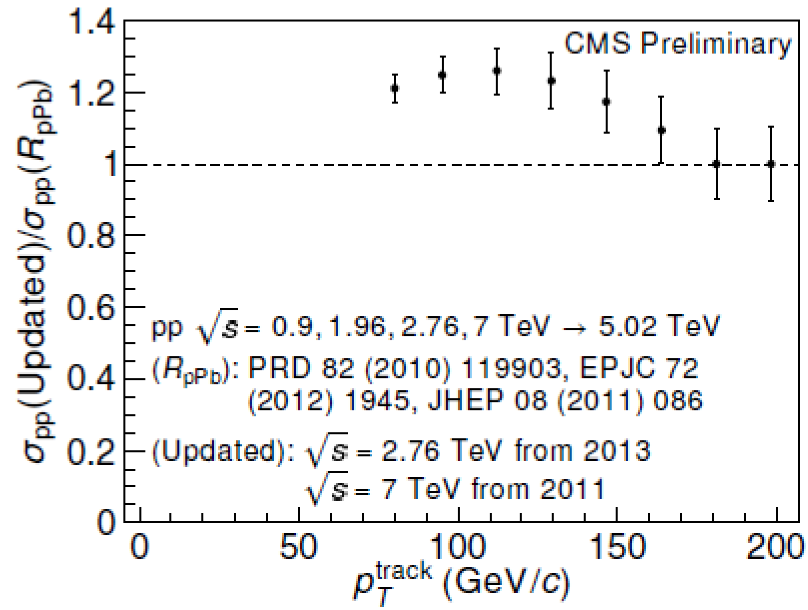
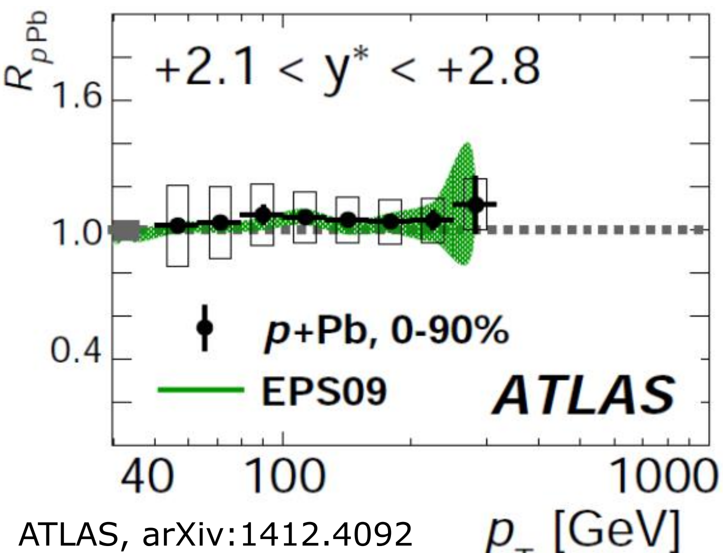




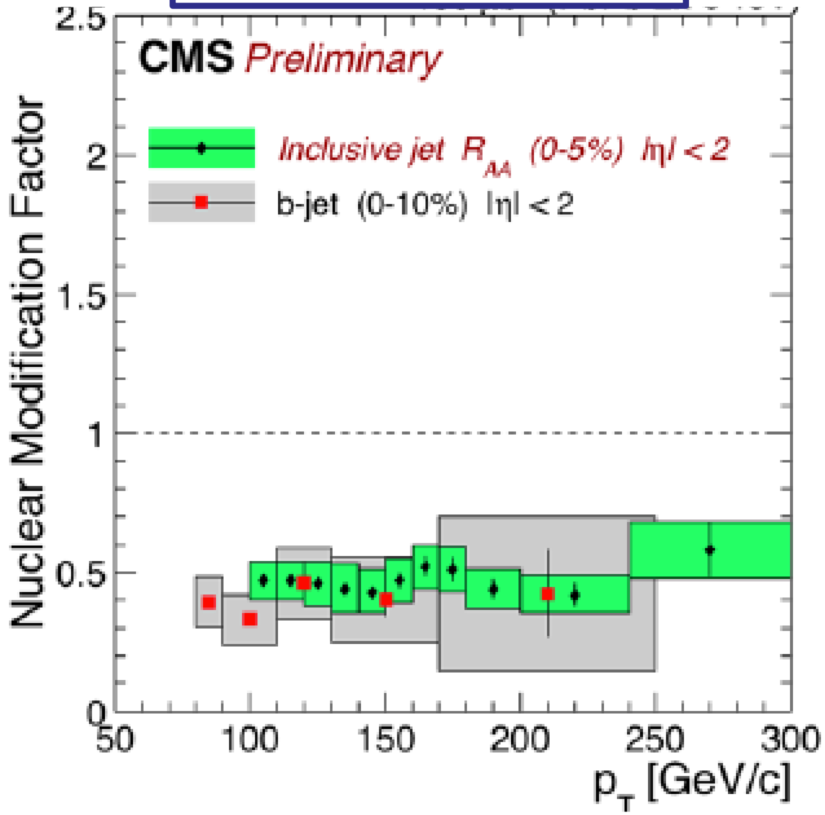
ATLAS, arXiv:1412.4092

- Tension between high p_T hadrons trend measured by ATLAS, CMS and ALICE
  - → Difficult to reconcile with jet R_{pA}~1
  - → Issue related to pp reference? Need pp run@√s= 5TeV!

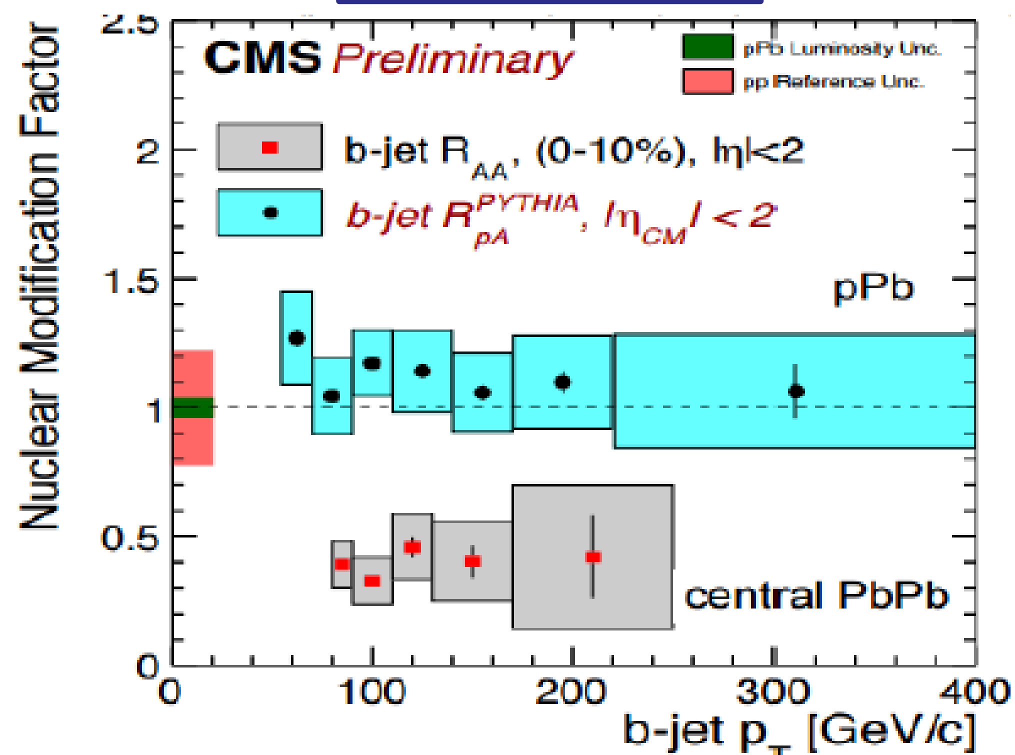
b-JETS

Jet quenching is expected to depend on the fragmenting parton flavor

Inclusive vs b-jet



p-Pb vs Pb-Pb



CMS, PRL113(2014) 132301, CMS PAS-HIN-14-007

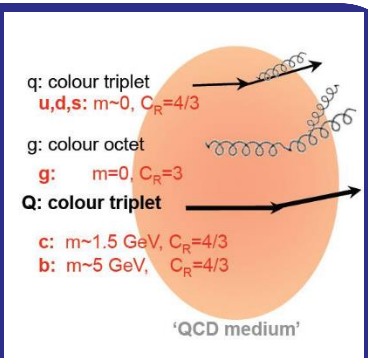
b-jets (identified through secondary vertex tagging) look like inclusive jets

- not suppressed in p-Pb
- similarly suppressed in Pb-Pb (R_{AA}~0.5) for p_T>80 GeV/c

HEAVY-FLAVOR ENERGY LOSS

- Heavy quarks are produced in initial hard scattering and experience the full system evolution

  Uniqueness of heavy quarks: cannot be destroyed/created in the medium



- Energy loss in the medium depends on:

$$\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$$

- Properties of the medium
- Path length
- Parton properties

Casimir factor (color-charge dependence)
→ 3 for g, 4/3 for q interactions
Dead cone effect (mass dependence)
→ Gluon radiation is suppressed for angles $\vartheta < M_Q/E_Q$

$\Delta E_g > \Delta E_{charm} > \Delta E_{beauty}$

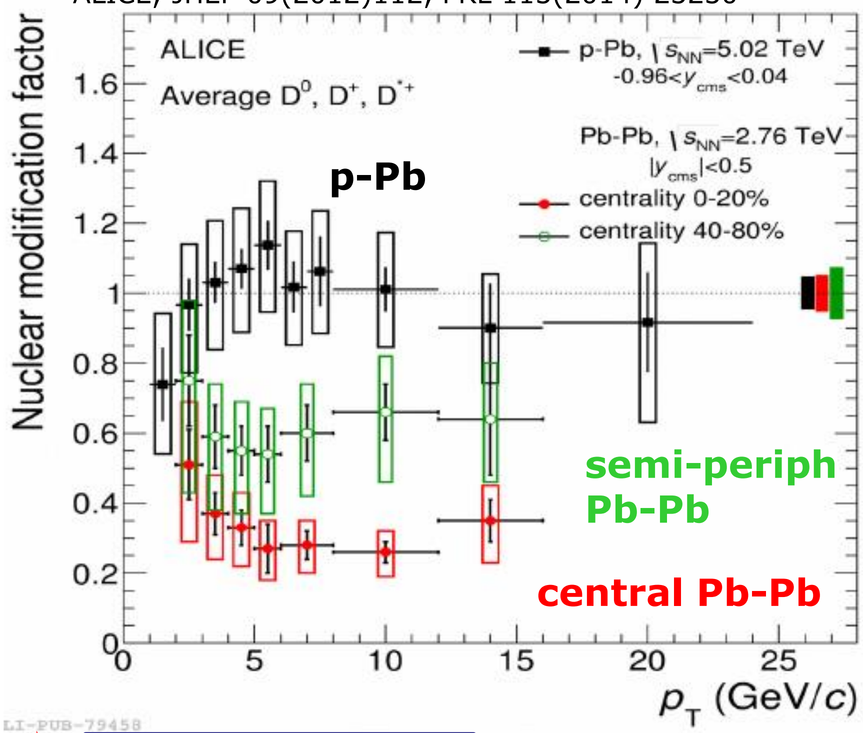
?

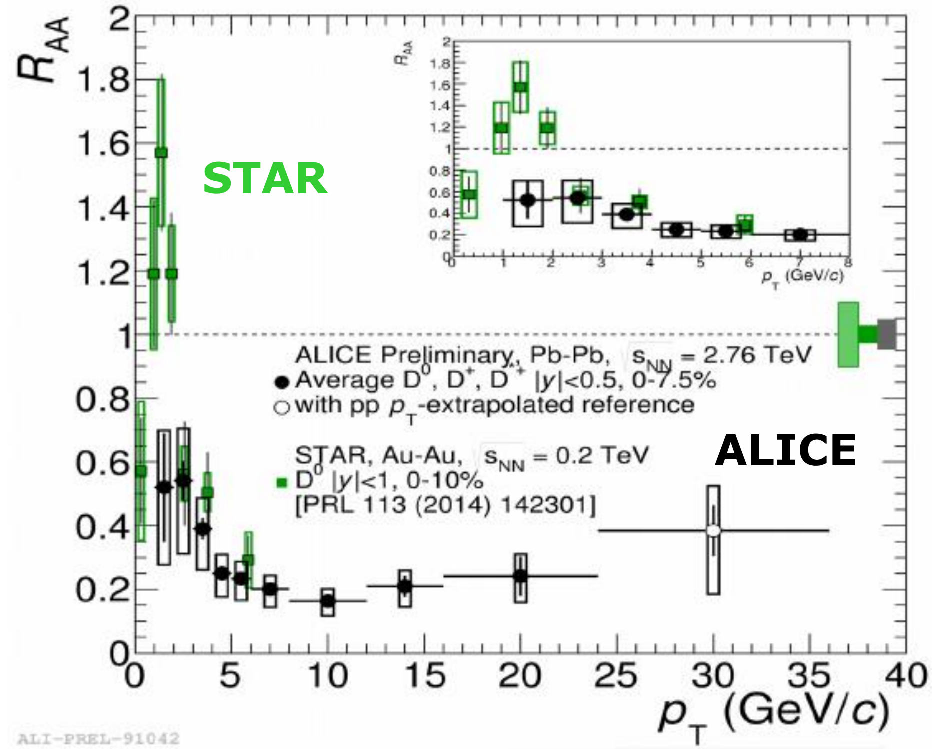
R_{AA} (light hadrons) < R_{AA} (D) < R_{AA} (B)

- Heavy flavor abundantly produced at LHC → allow precision measurements

CHARM SUPPRESSION

ALICE, JHEP 09(2012)112, PRL 113(2014) 23230





Pb-Pb @ LHC

Strong suppression of D mesons in central collisions

p-Pb vs Pb-Pb @ LHC

Suppression in Pb-Pb due to strong final state effects induced by hot partonic matter

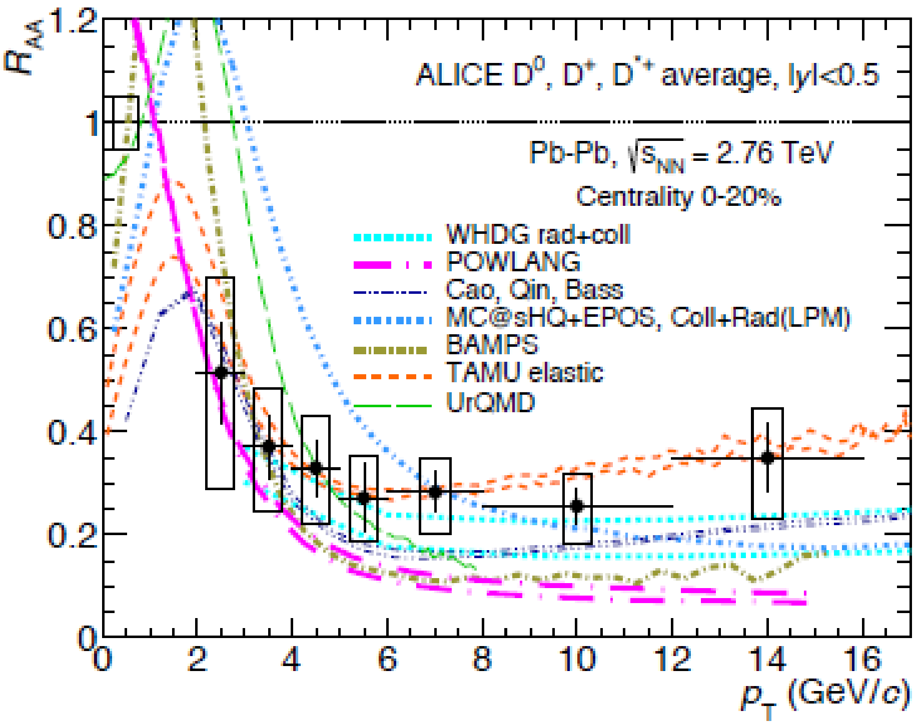
RHIC vs LHC

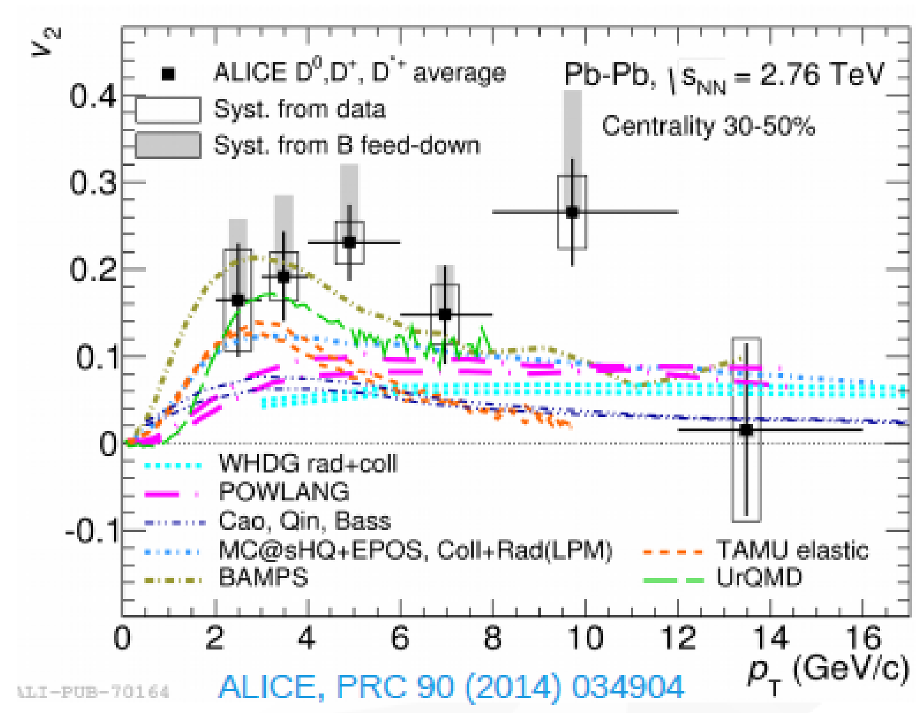
R_{AA}^{RHIC} compatible with R_{AA}^{LHC} (p_T>2GeV/c)

Differences for p_T<2GeV/c but:

- Stronger shadowing at RHIC
- Less steep p_T spectrum in pp@LHC

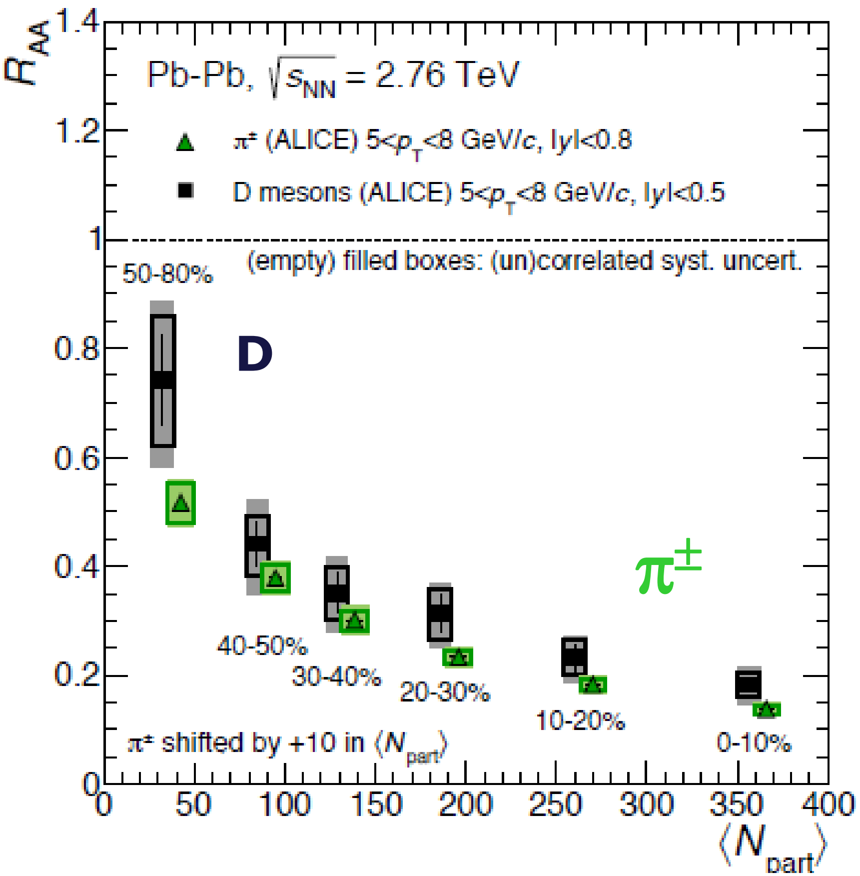
CHARM SUPPRESSION

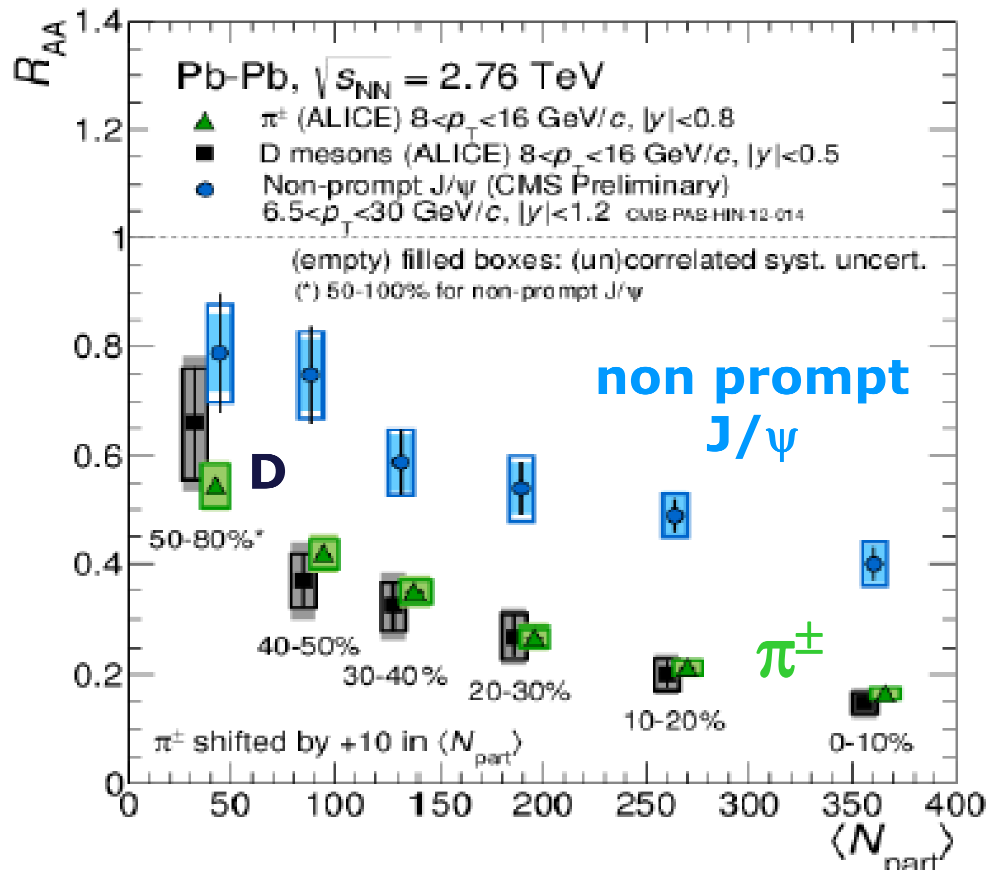




- Challenging simultaneous theoretical description of D R_{AA} and v_2
- With current precision, measurements can now start to constrain models
- Precise measurement of R_{AA} and v_2 down to p_T=0 at RHIC and LHC → goal of detector upgrades

R_{AA} OF D, B AND π





D vs light hadrons

$R_{AA}(D) \approx R_{AA}(\pi)$
(within uncertainties)

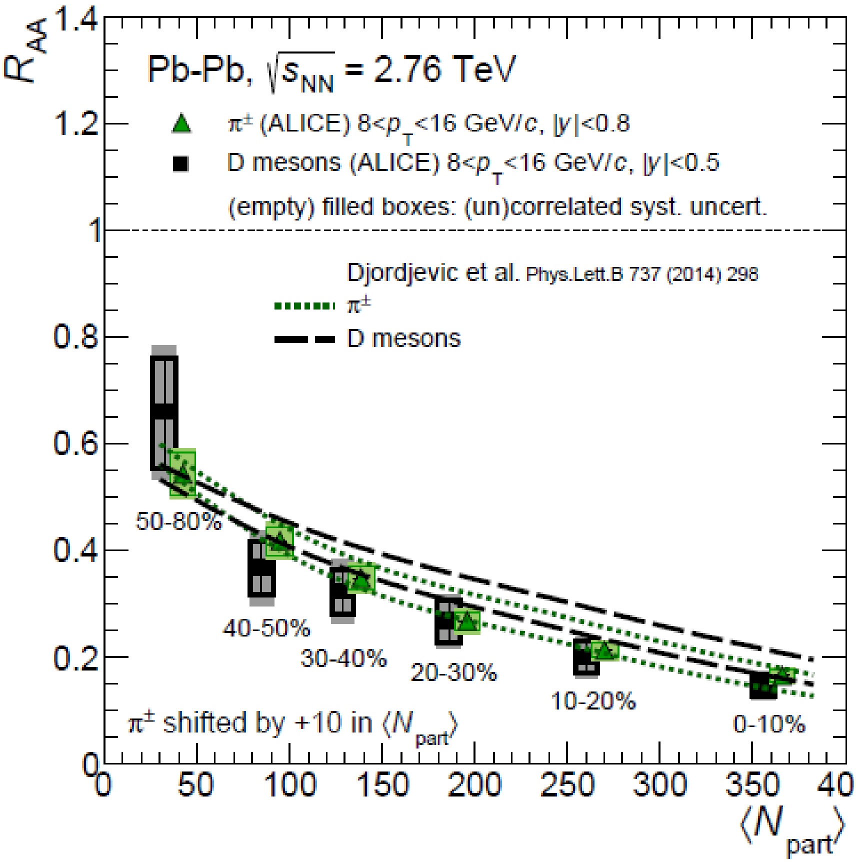
ALICE, arXiv:1506.06604

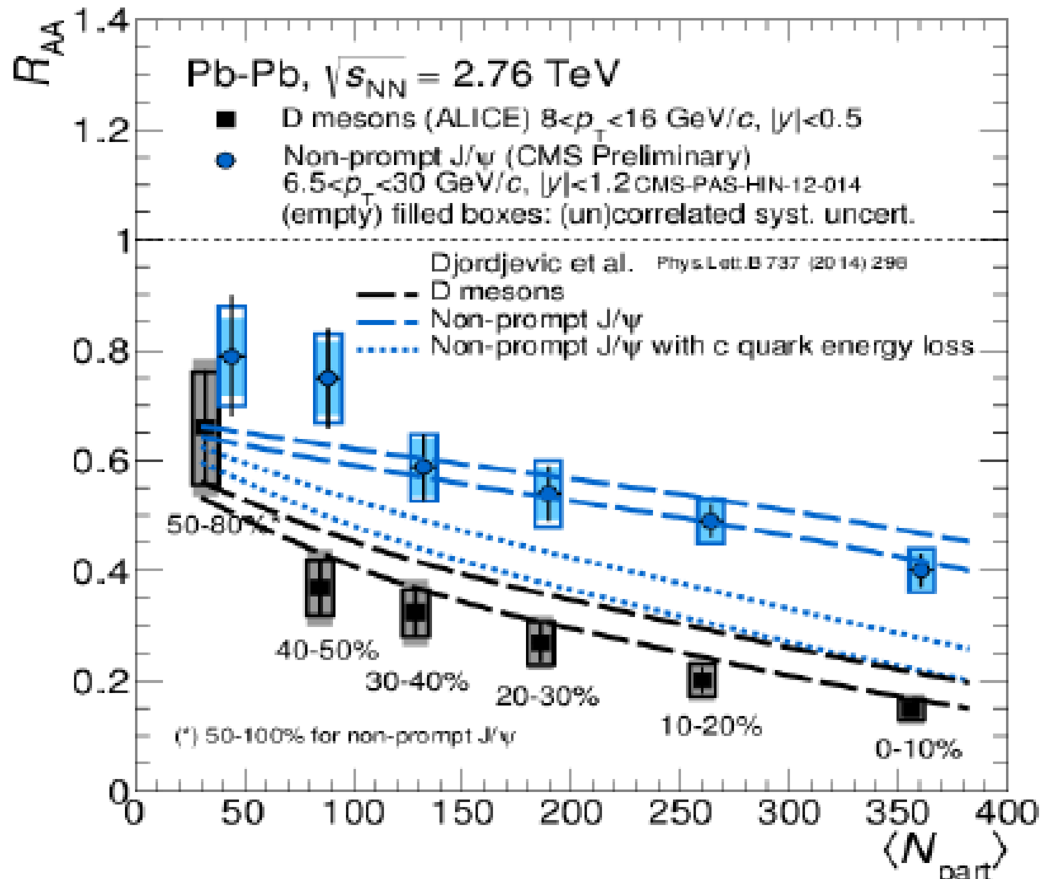
Charm vs beauty

$R_{AA}(D) < R_{AA}(J/\psi \leftarrow B)$

ALICE arXiv:1506.06604,
CMS HIN-12-014, JHEP 05(2012) 063

R_{AA} OF D, B AND π





D vs light hadrons

$R_{AA}(D) \approx R_{AA}(\pi)$

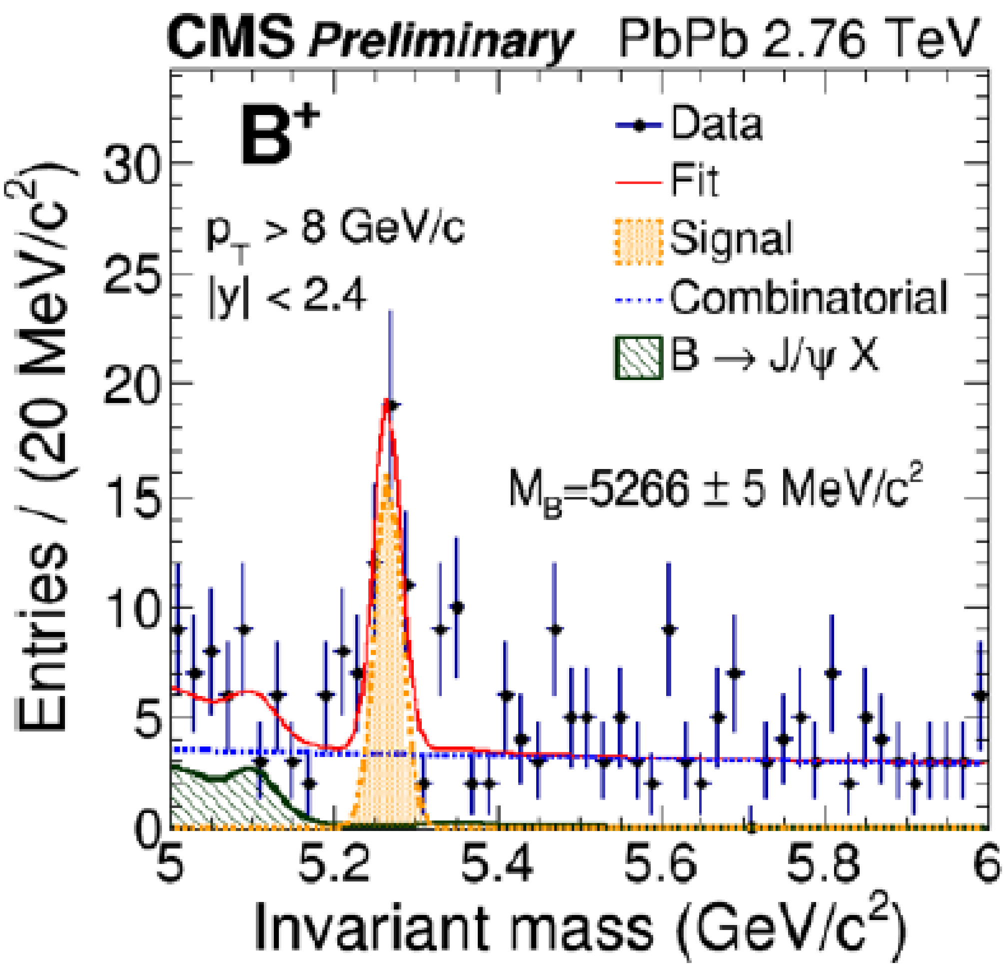
consistency described by theory including en. loss mass dependence, different q and g p_T shapes and fragmentation functions

Charm vs beauty

$R_{AA}(D) < R_{AA}(J/\psi \leftarrow B)$

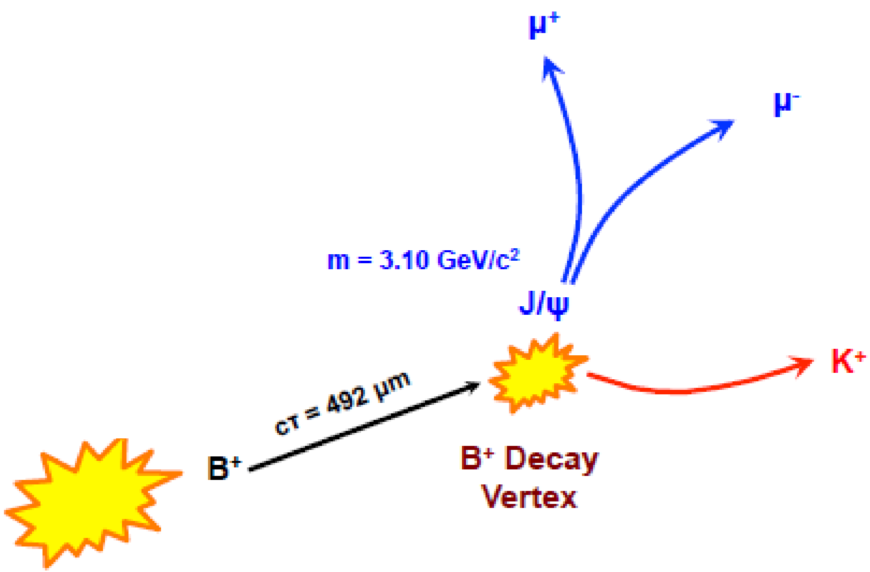
consistent with mass dependent energy loss

B meson in Pb-Pb @ LHC



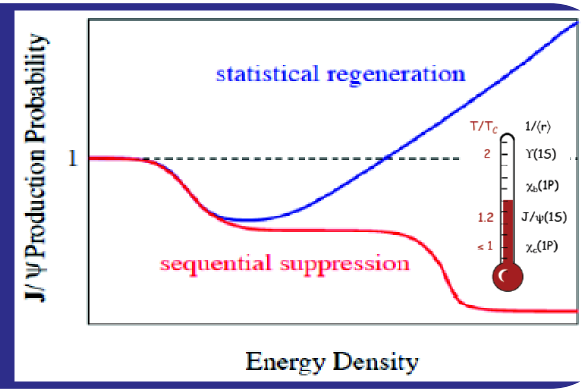
(Ta-Wei Wang, HP2015)

- First B meson reconstruction in PbPb collisions!
- Looking forward to Run-2 (x20 stat)

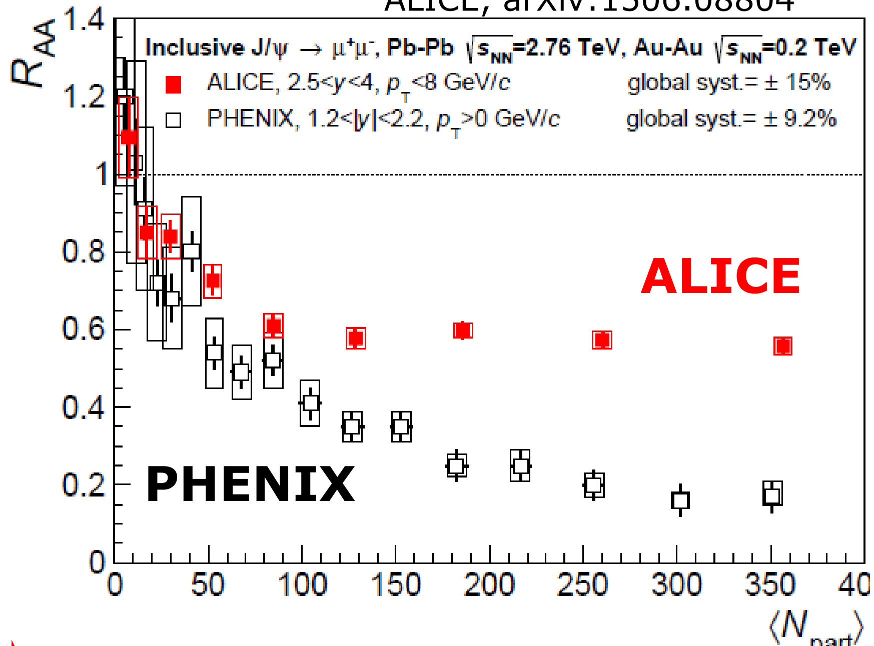


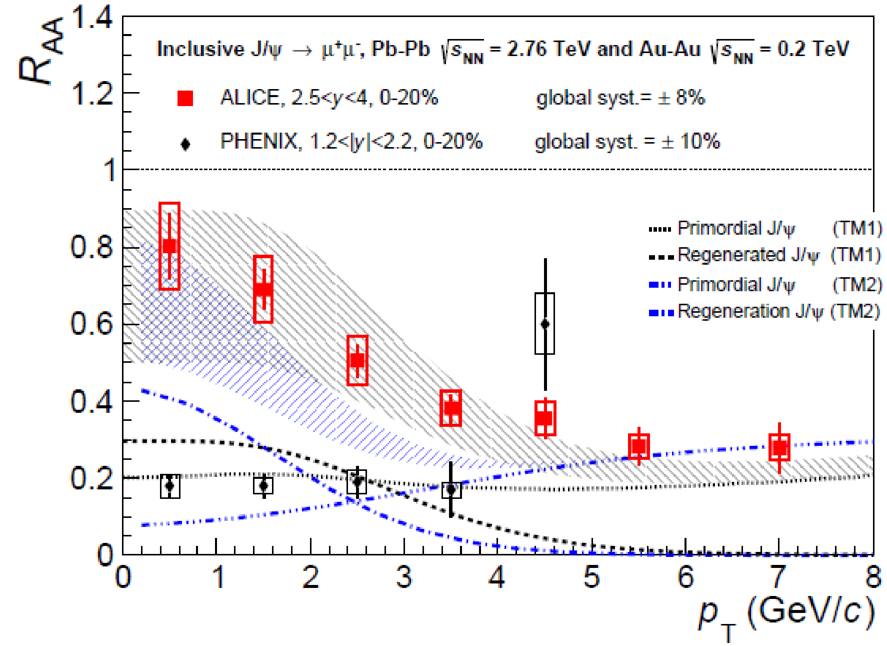
CHARMONIUM IN A-A

- Quarkonium strongly affected by the hot medium→ suppression vs. recombination
- Differences in the quarkonium states binding energies → sequential melting with increasing temperature



ALICE, arXiv:1506.08804

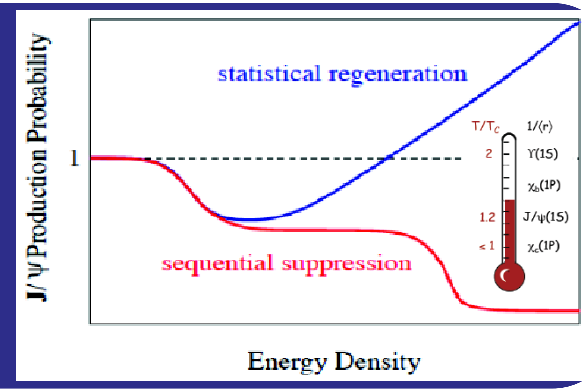




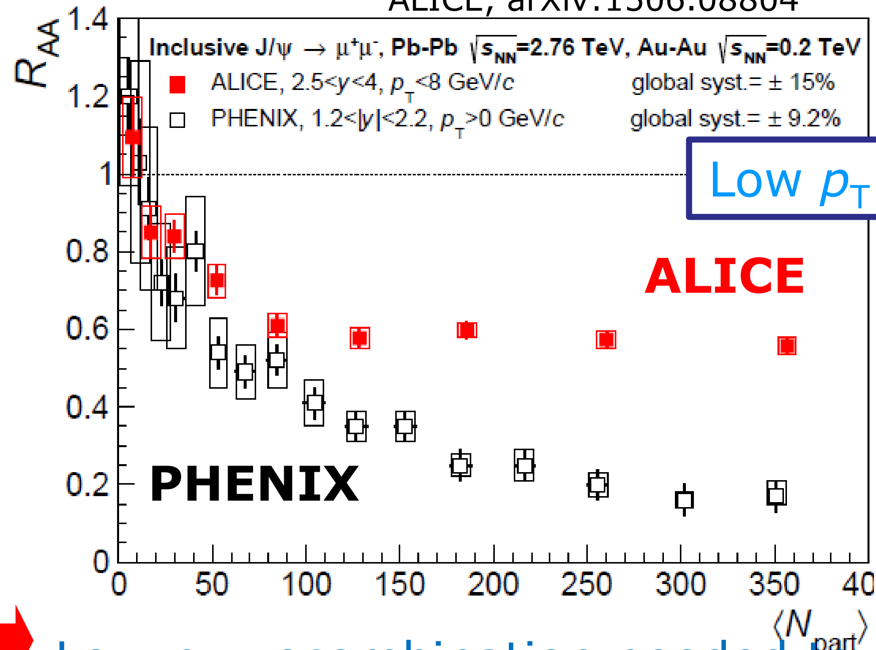
- stronger J/ψ suppression at RHIC than at LHC, in spite of larger energy densities at LHC
- recombination needed, at low p_T, to explain J/ψ R_{AA} @ LHC

CHARMONIUM IN PB-PB

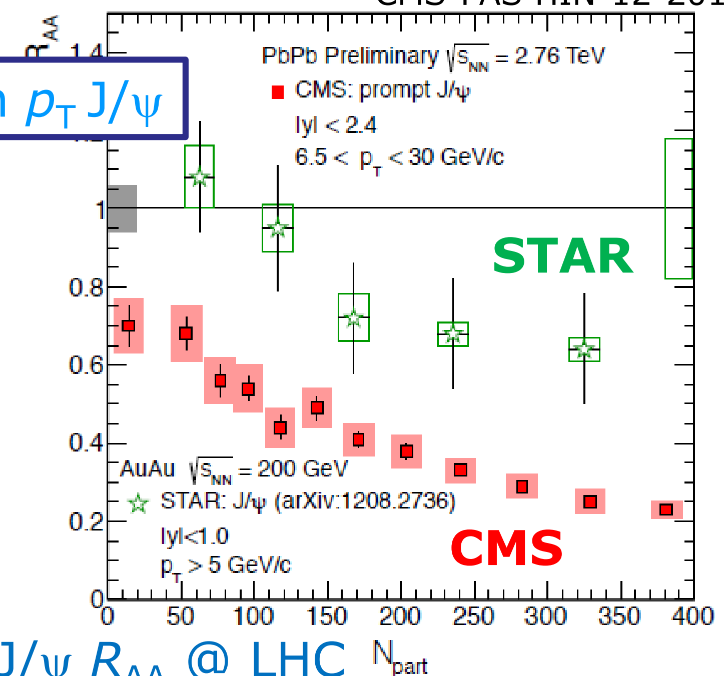
- Quarkonium strongly affected by the hot medium→ suppression vs. recombination
- Differences in the quarkonium states binding energies → sequential melting with increasing temperature



ALICE, arXiv:1506.08804



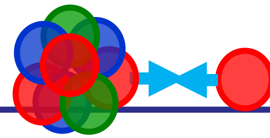
CMS-PAS HIN-12-2014



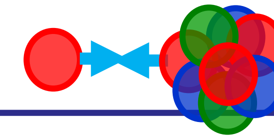
- Low p_T: recombination needed to explain J/ψ R_{AA} @ LHC
- High-p_T: no recombination, suppression increases with √s, as expected from Debye screening

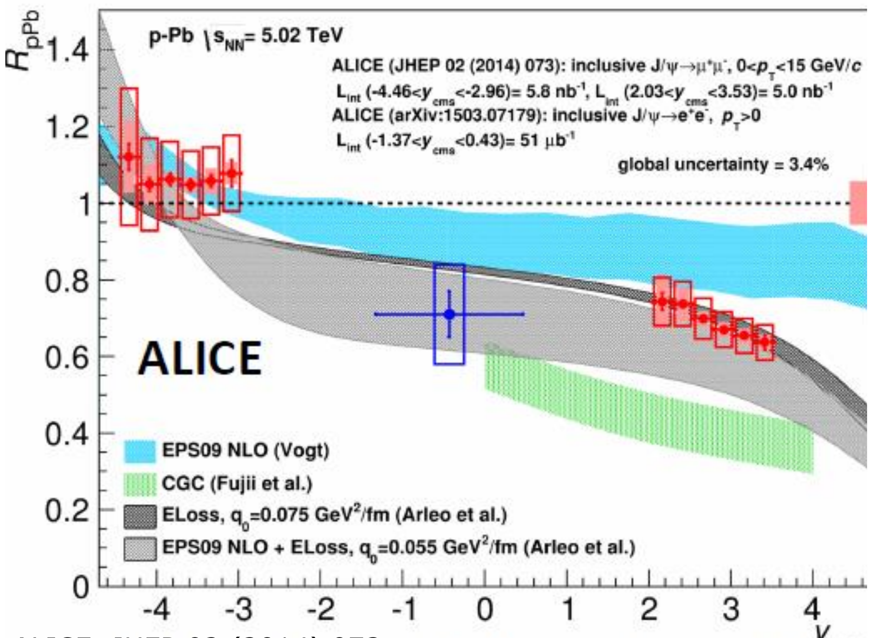
CHARMONIUM IN P-PB

Backward-y:
pP going direction

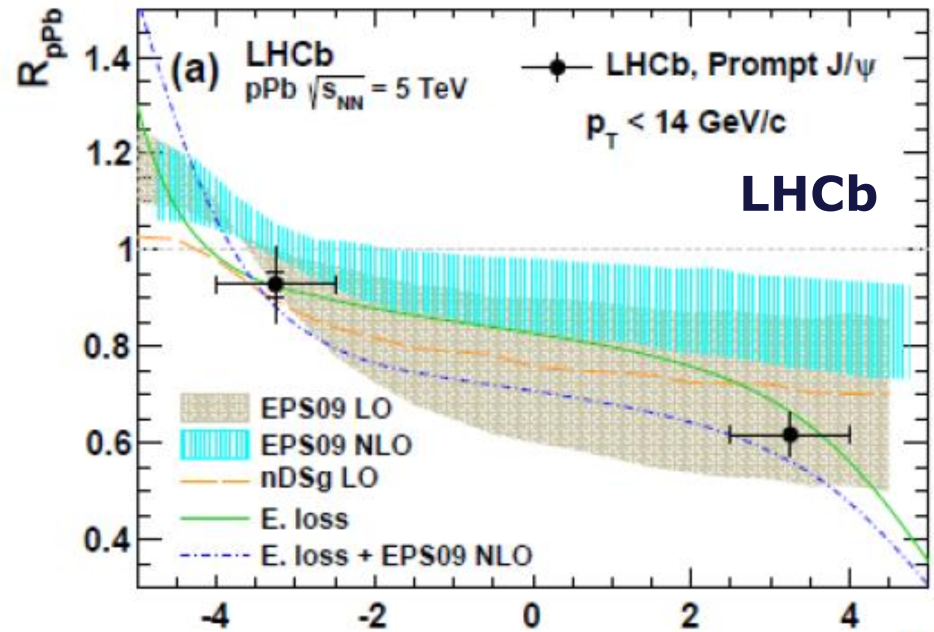


Forward-y:
p going direction





ALICE, JHEP 02 (2014) 073

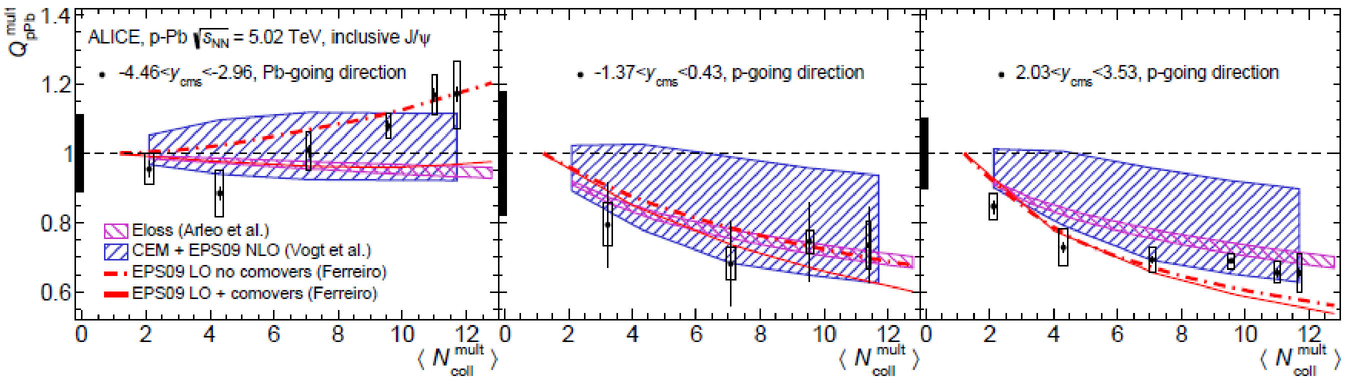


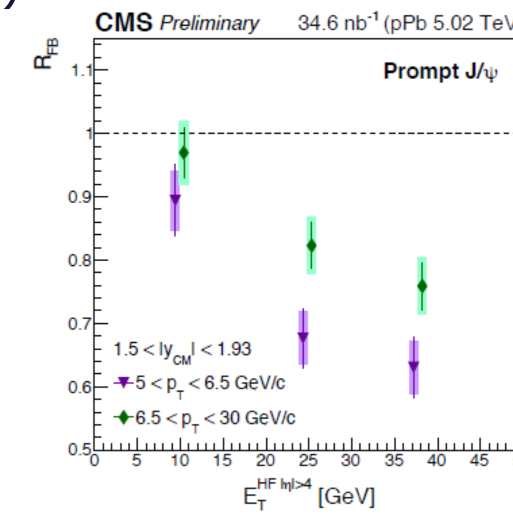
LHCb Coll., JHEP 02 (2014) 072

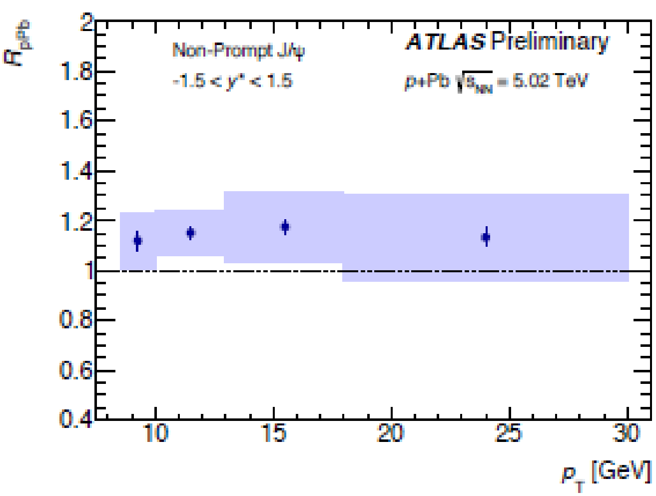
- J/ψ production modified in p-Pb because of cold nuclear matter effects:
  → R_{pA} decreases towards forward y
- Theoretical predictions: reasonable agreement with
  - shadowing calculations and models including coherent parton energy loss
  - CGC description seems not to be favoured

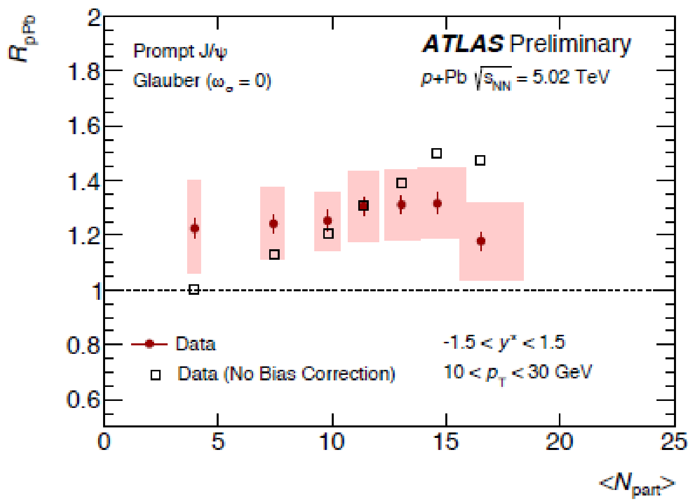
NEWS ON CHARMONIUM IN P-PB

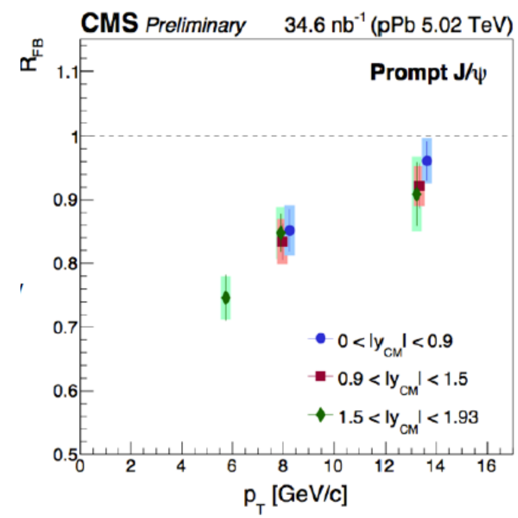
- Lots of new results now available on J/ψ production in p-Pb (…versus centrality and in many different kinematic ranges…)









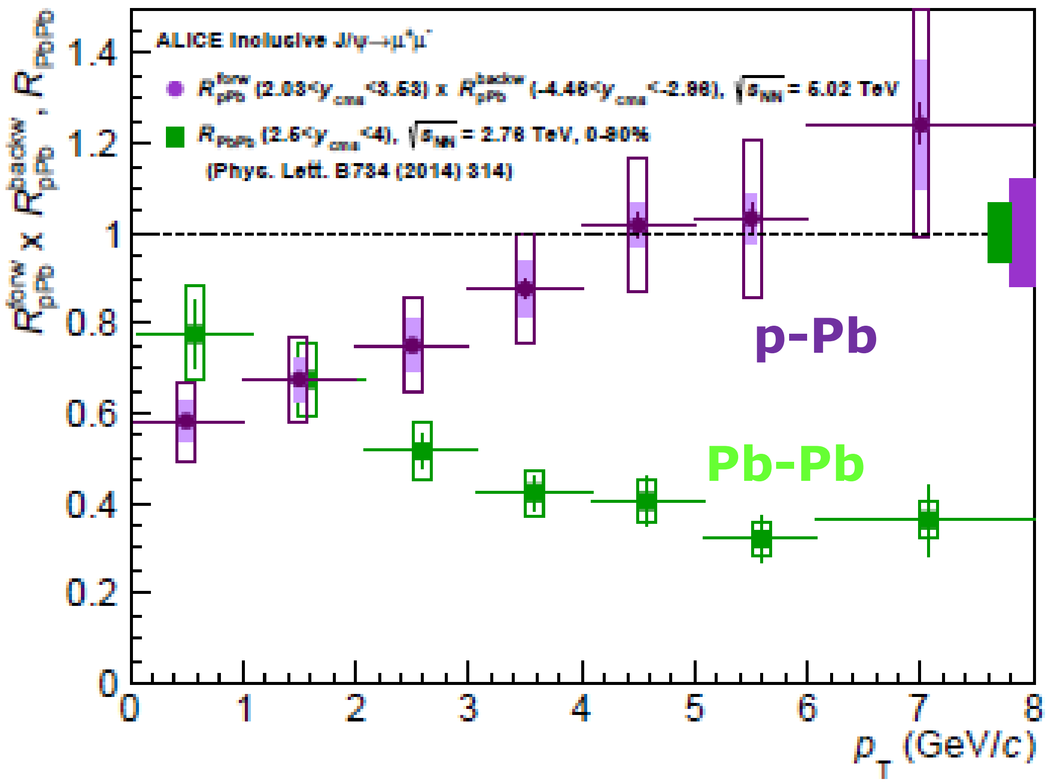


ATLAS-CONF-2015-023, CMS-PAS-HIN-14-009, ALICE arXiv:1506.08808

CHARMONIUM: FROM P-PB TO PB-PB

- Once CNM effects are measured in pA, what can we learn on J/ψ production in PbPb?

Hypothesis:
- 2→1 kinematics for J/ψ production
- CNM effects (dominated by shadowing) factorize in p-A
- CNM obtained as R_{pA} x R_{Ap} (R_{pA}^2), similar x-coverage as PbPb



Sizeable p_T dependent suppression still visible
→ CNM effects not enough to explain AA data at high p_T

we get rid of CNM effects, by doing the ratio

AA / pA

Charmonium: from p-Pb to Pb-Pb

- Once CNM effects are measured in pA, what can we learn on J/ψ production in PbPb?

Hypothesis:
- 2→1 kinematics for J/ψ production
- CNM effects (dominated by shadowing) factorize in p-A
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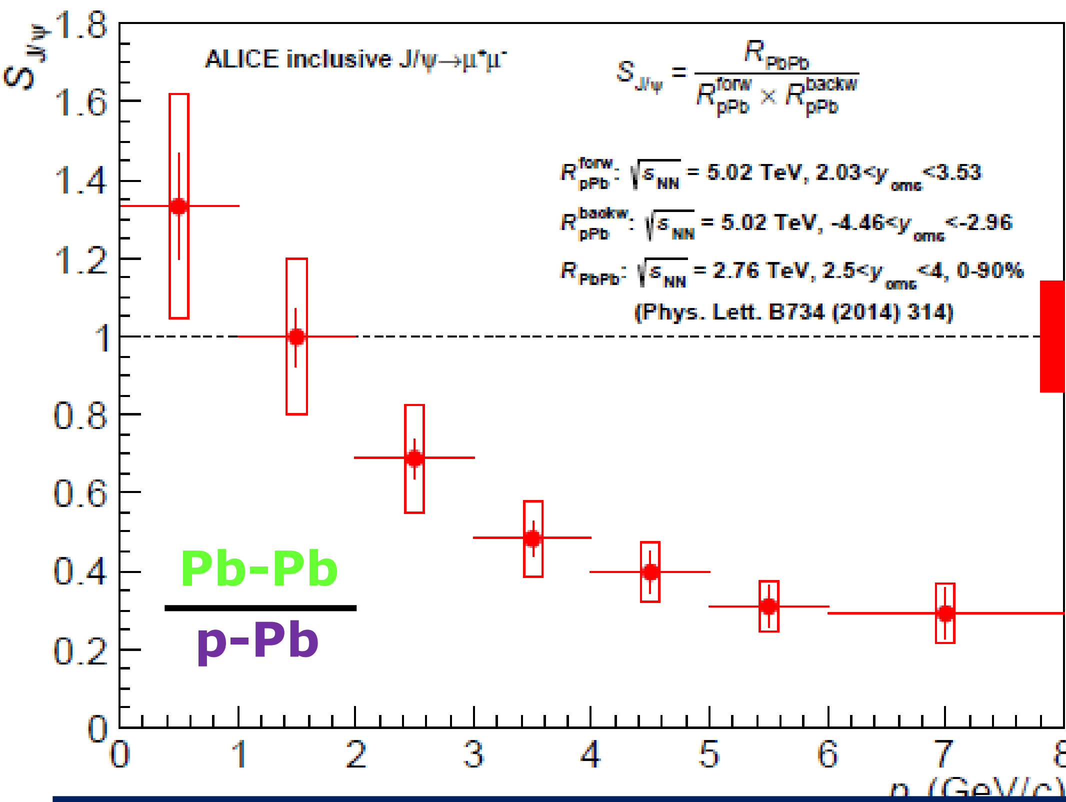


- Sizeable p_T dependent suppression still visible
  → CNM effects not enough to explain AA data at high p_T
- we get rid of CNM effects, by doing the ratio

AA / pA

- Evidence for hot matter effects in Pb-Pb!

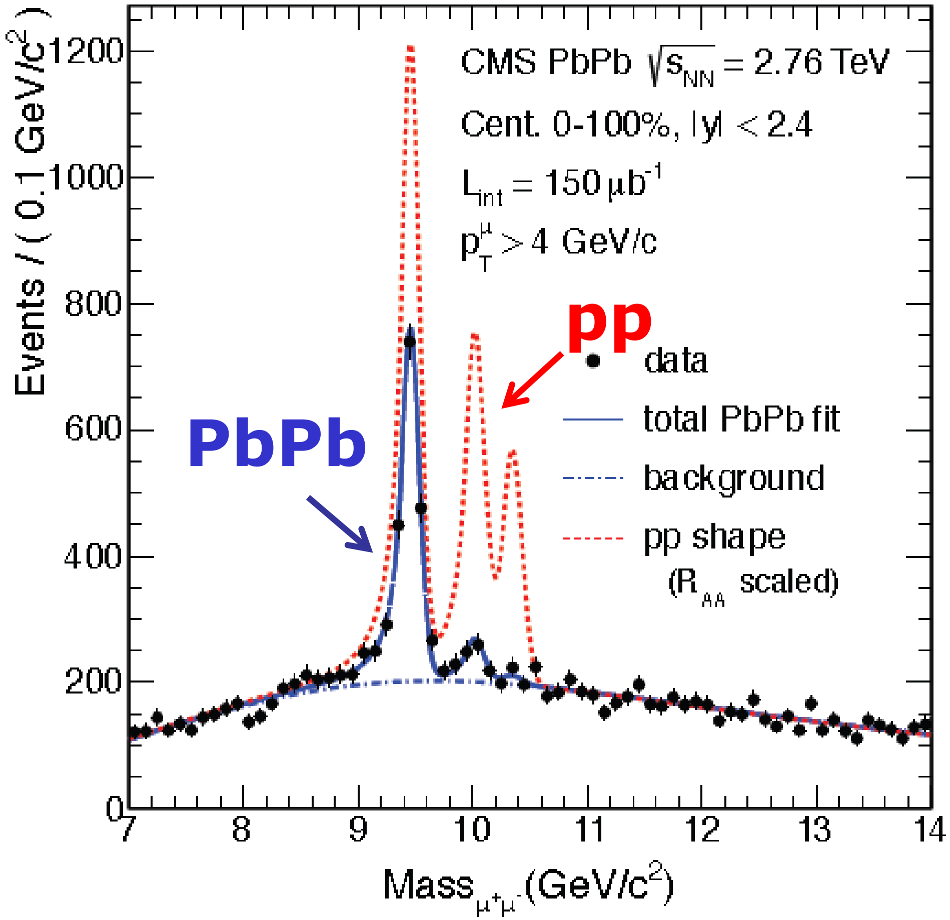
Bottomonium in Pb-Pb

Main features of bottomonium production wrt charmonia:

- no B hadron feed-down
- gluon shadowing effect are smaller
- (re)combination expected to be smaller
- theoretical predictions more robust due to the higher mass of b quark

with a drawback…smaller production cross-section

PRL 109, 222301 (2012)



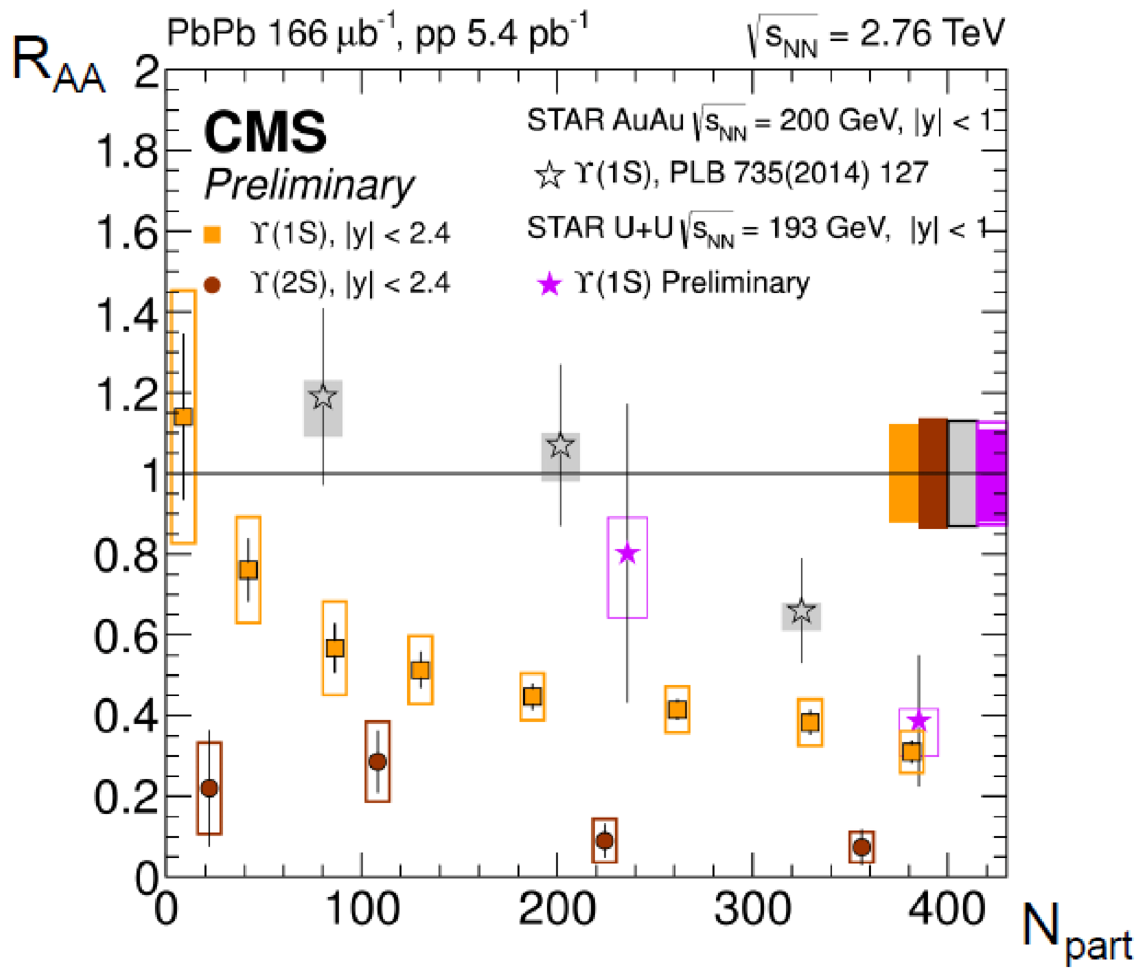
➡ Clear suppression of ϒ states in PbPb with respect to pp collisions

BOTTOMONIUM IN A-A

- Centrality dependent suppression for $\Upsilon(1S)$ and $\Upsilon(2S)$
- Sequential suppression observed at LHC:

$$R_{AA}^{\Upsilon(3S)} < R_{AA}^{\Upsilon(2S)} < R_{AA}^{\Upsilon(1S)}$$

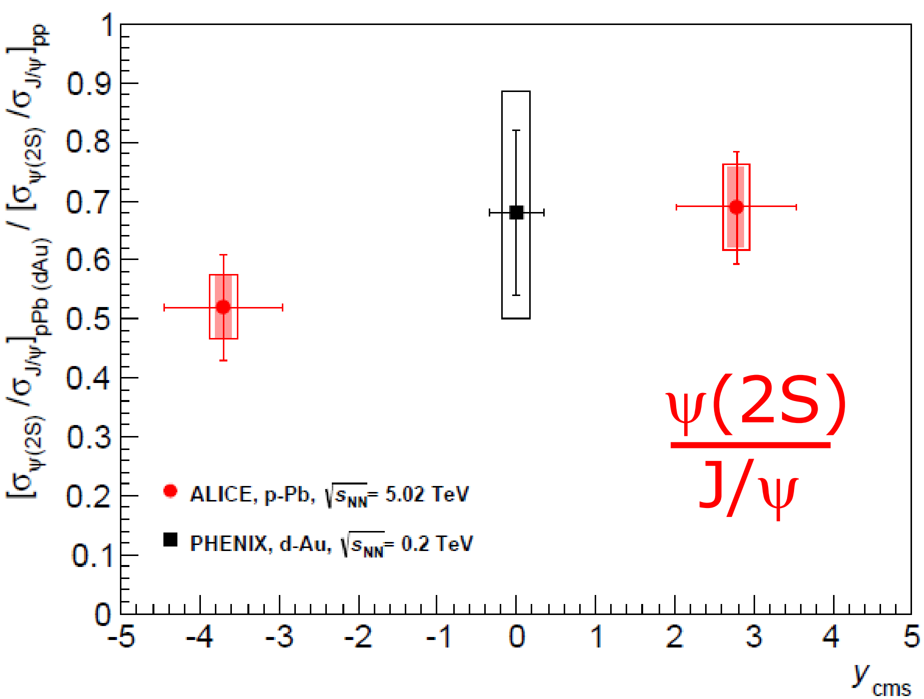
$$\begin{aligned} R_{AA}(\Upsilon(1S)) &= 0.425 \pm 0.029 \pm 0.070, \\ R_{AA}(\Upsilon(2S)) &= 0.116 \pm 0.028 \pm 0.022, \\ R_{AA}(\Upsilon(3S)) &< 0.14 \text{ at } 95\% \text{ CL}, \end{aligned}$$



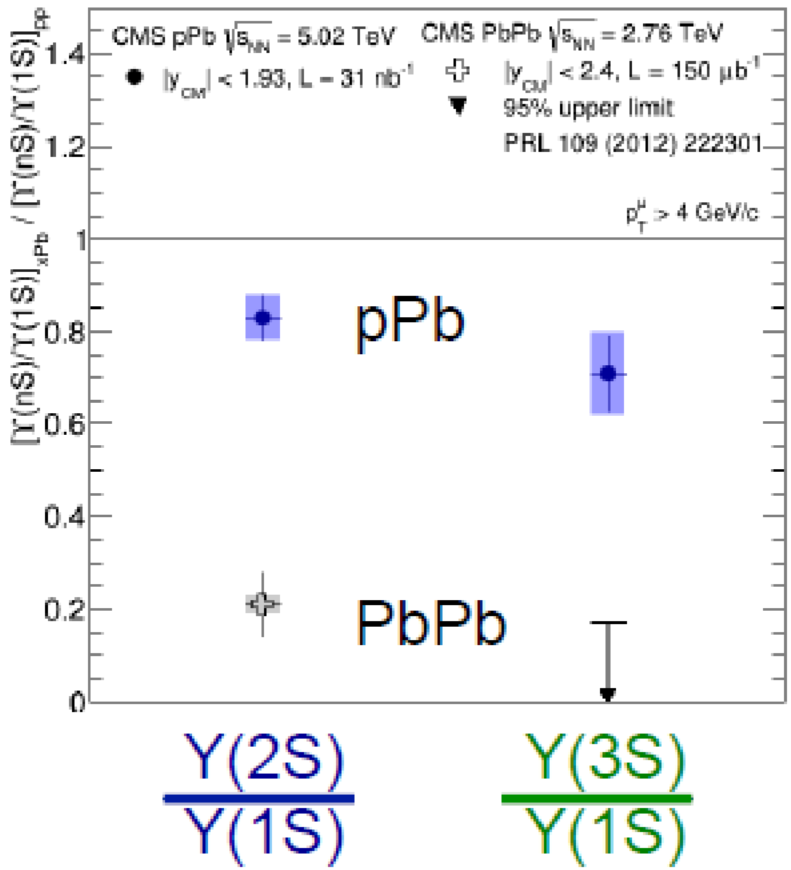
- $\Upsilon(1S)$ suppressed also in central Au-Au and U-U collisions at RHIC

EXCITED STATES IN P-PB

- In p-Pb (d-Au) collisions the excited states suffer more suppression. Unexpected if only initial state effects are at play!



ALICE, 1405.3795
PHENIX, PRL111(2013) 202301



CMS,JHEP04(2014)103

- Final state effects related to the (hadronic) medium created in the p-Pb collisions?

WHAT'S NEXT?

In spite of the large wealth of results…lots more will come!

RHIC

- STAR: upgraded with Muon Telescope Detector and Heavy Flavour Tracker
- Proposal for sPHENIX
- BES-II in 2019-2020 → to explore the phase diagram, focus on QCD critical point

Lower energies:

FAIR (Darmstadt), NICA (Dubna)
$\sqrt{s_{NN}}$ <10GeV

LHC

- On-going Run2:
  - Higher energies (PbPb@$\sqrt{s}$=5TeV)
  - Higher luminosity
- Upgrade in view of Run3 for all experiments
- A new player: LHCb!
  - Pb-Pb@5TeV (50-80μb^{-1} this year)
  - Fixed target mode (SMOG): p/Pb on gas like He, Ne, Ar, Kr, Xe exploring energy densities between those probed at SPS and RHIC

CONCLUSIONS

A-A:

- Significant progress in precision:
  - Jets quenched up to 400 GeV
  - Heavy-quarks: hints for energy loss mass dependence
  - Charmonia suppression is a final state effect. Recombination needed to explain low p_T production in PbPb@LHC
  - Bottomonia: indication of sequential suppression

p-A (d-A):

- Not only a "control" experiment to compare to A-A!
- Tool to investigate cold nuclear matter effects
- Existence of collective effects also in small systems?

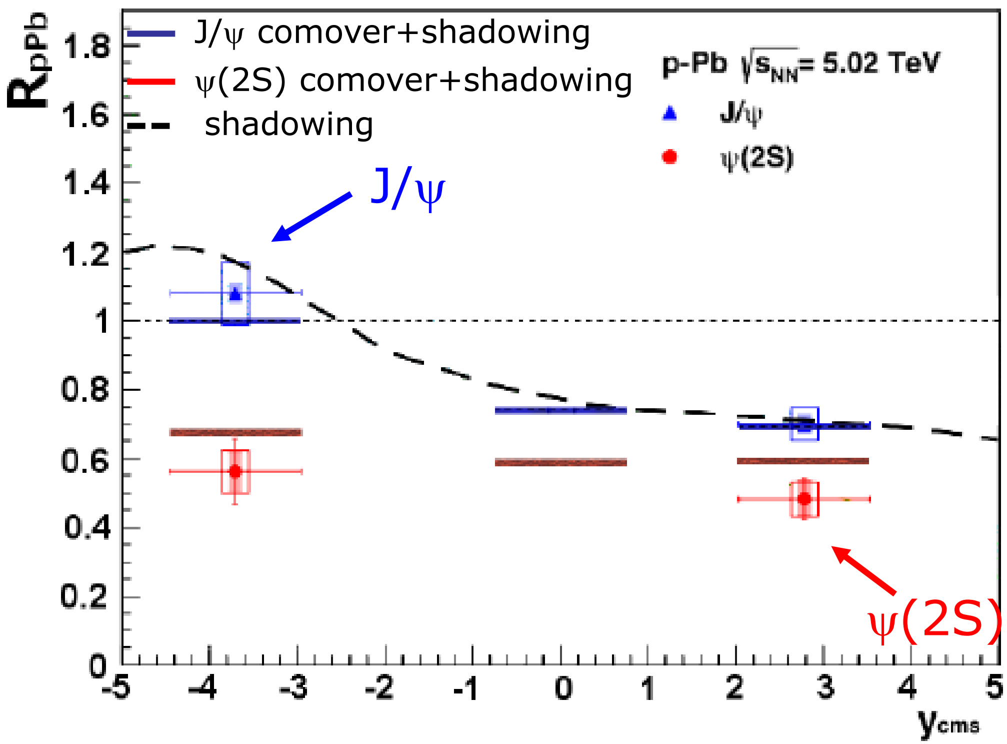
- Large wealth of data from RHIC and LHC, heading forward a quantitative characterization of deconfined matter

...and lots more to come!

BACKUP SLIDES

ψ(2S) vs J/ψ in p-A collisions

Final state effects related to the (hadronic) medium created in the p-Pb collisions?



Charmonium interaction with comoving particles:

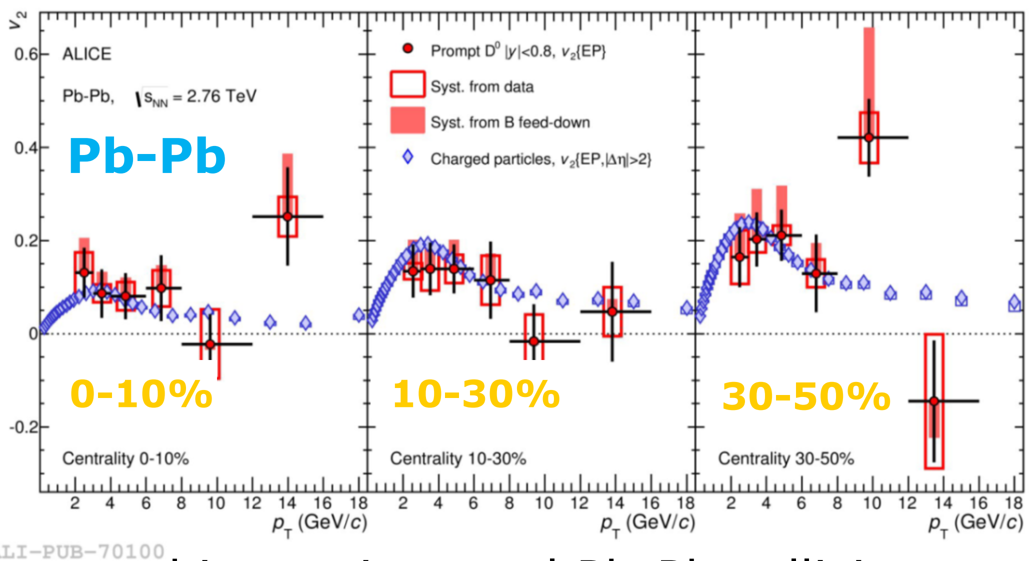
- Comovers dissociation affects more strongly the loosely bound ψ(2S) than the J/ψ
- Comovers density larger at backward rapidity

E. Ferreiro arXiv:1411.0549

HEAVY FLAVOR: ELLIPTIC FLOW

- Due to the large mass, b and c quarks should take longer time to be influenced by the collective expansion of the medium (→ $v_2^b < v_2^c$)

  Heavy-flavor v_2 measurements probe:
  - Low p_T: collective motion, thermalization of heavy-quarks
  - High p_T: path-length dependence of heavy-quark energy loss



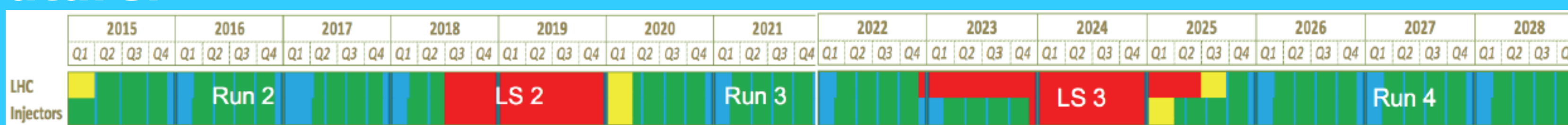
- Non-zero v_2 observed in semi-central Pb-Pb collisions (hint of increase from central to semi-central collisions)
- v_2 (D) ~ charged particle v_2
- Confirm significant interaction of charm quarks with the medium → suggest collective motion of low p_T charm quarks in the expanding fireball

ALICE PAST & FUTURE

Heavy-ion data from RUN1:

System	$\sqrt{s_{NN}}$ (TeV)	Year	Integrated luminosity
Pb-Pb	2.76	2010	~10 μb^{-1}
		2011	~100 μb^{-1}
p-Pb	5.02	2013	~30nb^{-1}

Future:



RUN2 (2015-2017): complete the heavy-ion program:

- improved detectors, readout and trigger
- higher LHC energy ($\sqrt{s}$ = 13TeV for pp, 5.1TeV for PbPb)
- pp, p-Pb, Pb-Pb runs with much larger statistics!

RUN3+4 (~2020): major detectors upgrade

- operate ALICE at high rate (increased by a factor 100!), preserving unique tracking and PID
- improvements in vertexing capability and low p_T tracking (new ITS and TPC readout)
- focus on rare probes (heavy flavor,quarkonia,low-mass dileptons,jets…)

LHCB IN HI COLLISIONS

E_{beam}(p)	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.1 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

Preferred targets for SMOG operation:

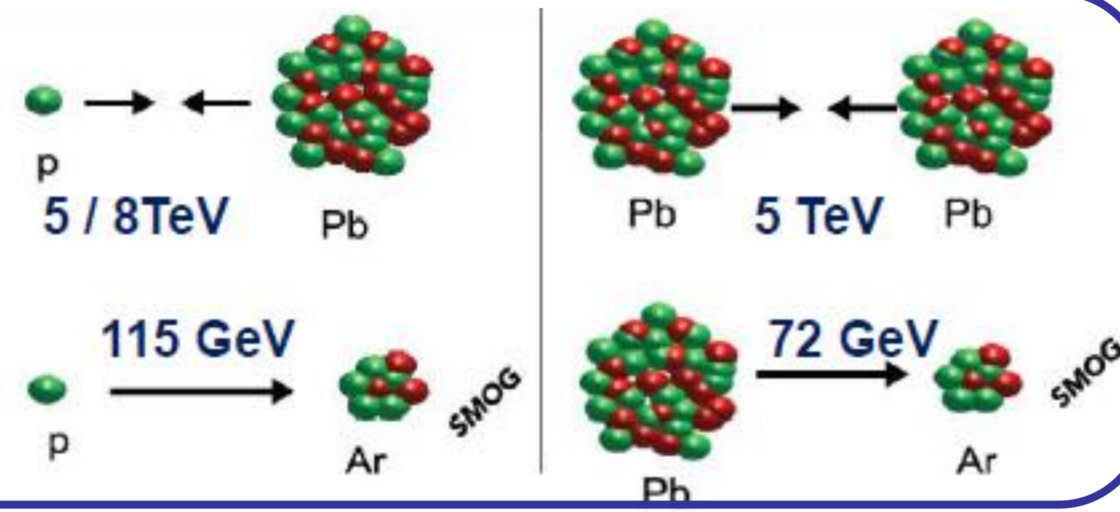
element	He	Ne	Ar	Kr	Xe
A	2	20	40	84	131

HI PHYSICS WITH LHCB

LHCb participated to the pPb run and now it will join also the Run2 AA run!

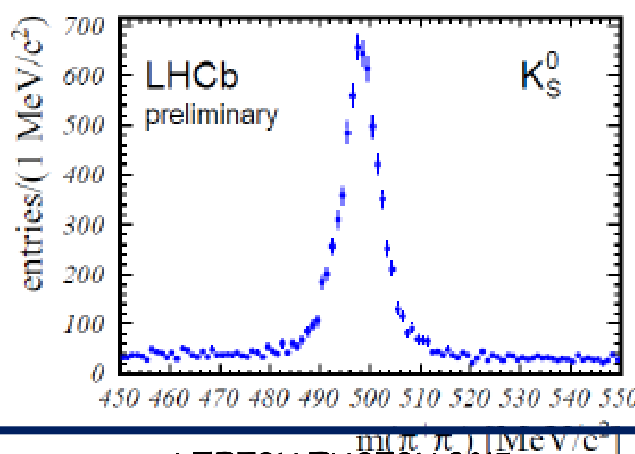
Colliding beam mode

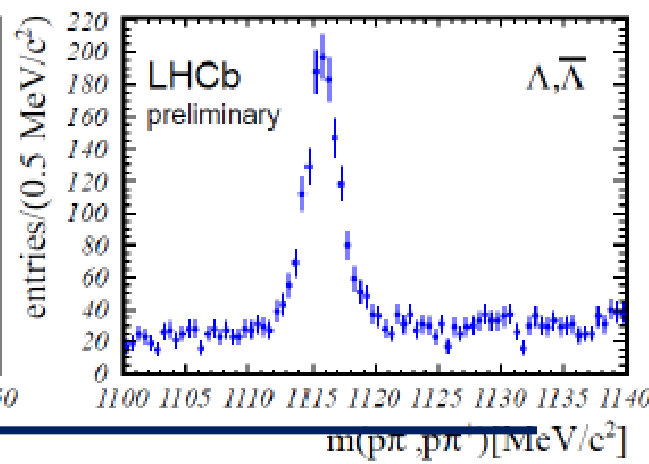
Fixed target mode (SMOG)



Fixed target mode (proton on gas like He, Ne, Ar, Kr, Xe): explored energy densities between those probed at SPS and RHIC

First look to Pb-Ne@$\sqrt{s_{NN}}$=54.4GeV

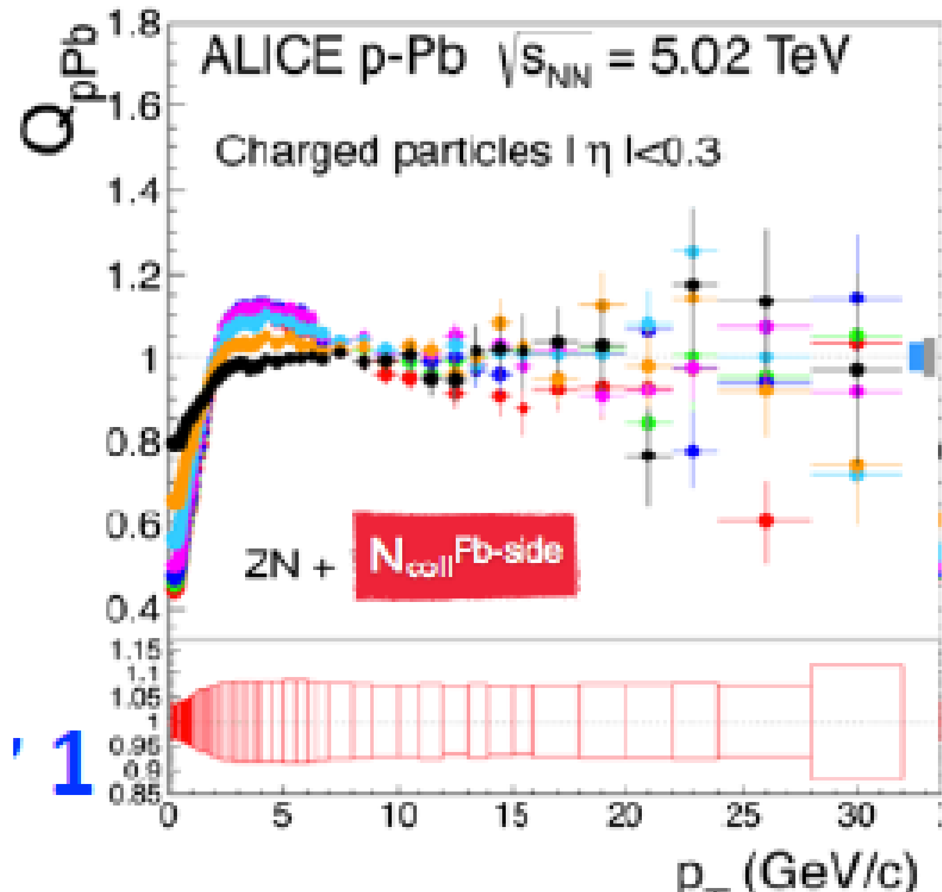




(B. Schmidt, HP2015)

CENTRALITY IN P-PB

- Event selection based on Pb-going neutron energy released in ZDC → minimizes the bias
- N_{part} and N_{coll} obtained assuming one out of:
  - forward $dN_{ch}/d\eta \sim N_{part}^{Pb} = N_{part} - 1$
  - mid-rapidity $dN_{ch}/d\eta \sim N_{part}$
  - high-p_T yields $\sim N_{Coll}$



- Q_{pA} instead of R_{pA} due to potential bias from the centrality estimator, not related to nuclear effects

$$Q^{i}_{pA} = \frac{dN_{pA}/dp_T}{\langle N_{coll}\rangle_i \, dN_{pp}/dp_T}$$

- Flat Q_{pPb} at high p_T for all event activity classes

CENTRALITY IN P-PB

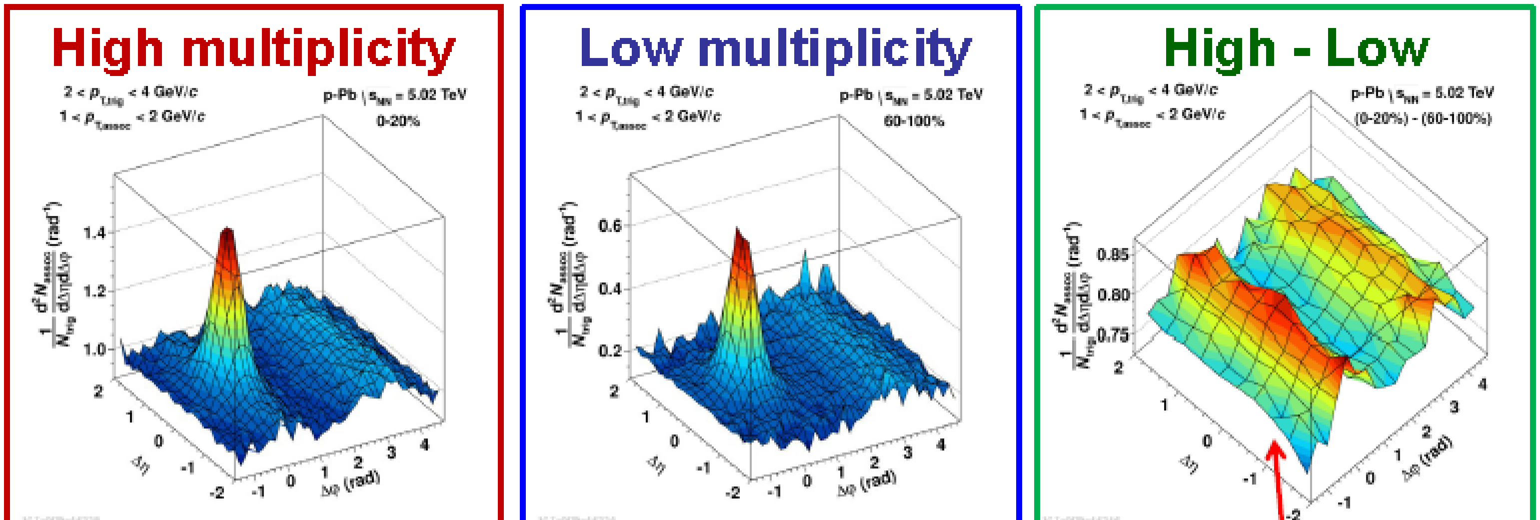
ATLAS Strategy

$$R_{p\mathrm{Pb}} \propto \frac{\mathrm{Yield}}{N_{\mathrm{coll}}} \mathrm{Bias}$$

ALICE Strategy

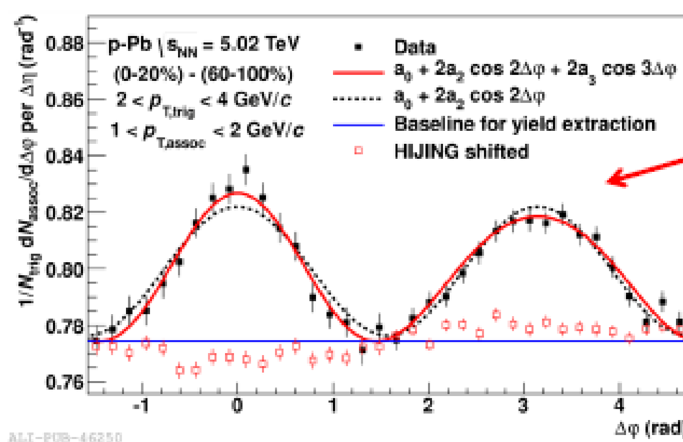
Two ostensibly different approaches…

Two particles (Δη, Δϕ) correlations are a tool to explore particle production mechanisms: unexpected observation of an underlying azimuthal anisotropy in high-multiplicity p-Pb collisions



Double ridge structure

- Double ridge described by both color glass condensate (initial state effect) or hydro (final state effect) (PLB719 (2013) 29)

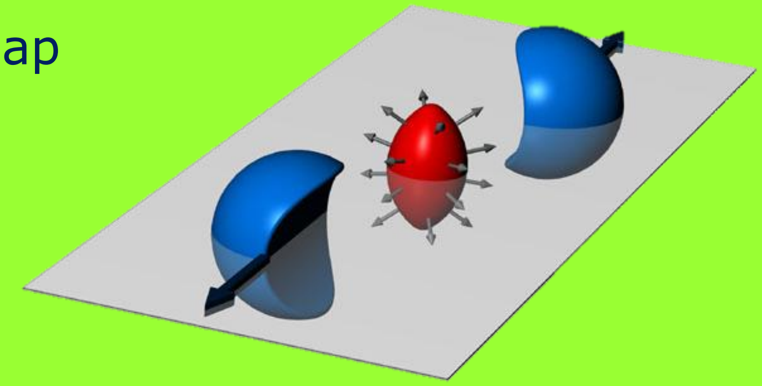


Remaining correlation: two twin long-range structures (double ridge)

COLLECTIVE FLOW

Initial spatial anisotropy of the overlap region of colliding nuclei

→ anisotropy in momentum space through interactions of produced particles



Measured by the elliptic flow parameter (v_2) extracted from the Fourier decomposition of particle azimuthal distributions relative to the reaction plane

$$\frac{dN}{Nd\phi} \sim 1 + 2v_2 \cos(2(\phi - \Psi_{RP})) + \textit{higher harmonics } (v_3, v_4, \ldots)$$

v_2 provides a measurement of collectivity
→ constraints the properties of deconfined medium

- Large mean free path → particles stream out isotropically, no memory of initial asymmetry (ideal gas)
- Small mean free path → large density and pressure gradients, larger momentum anisotropy (ideal liquid)

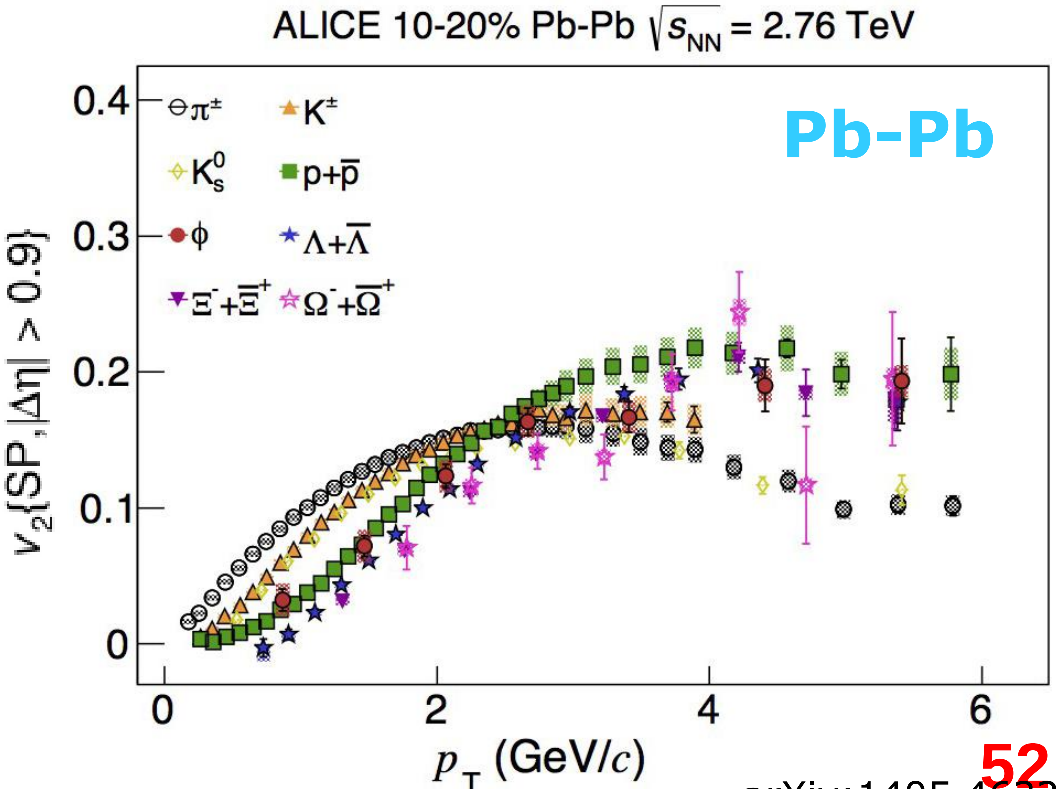
v_2 OF IDENTIFIED PARTICLES

- Identified particle $v_2\{SP\}$ (π^{+-}, K^{+-}, K^0, p, ϕ, Λ, Ξ, Ω)
  - → allows for precision measurements
    - add constraints to initial conditions, particle production mechanisms
    - probes the freeze-out conditions of the system
    - checks the number of constituents quarks scaling

Low p_T:
mass ordering
→ attributed to interplay between radial and elliptic flow

Qualitative description with hydrodynamical calculations + hadronic cascade model
→ small η/s favoured

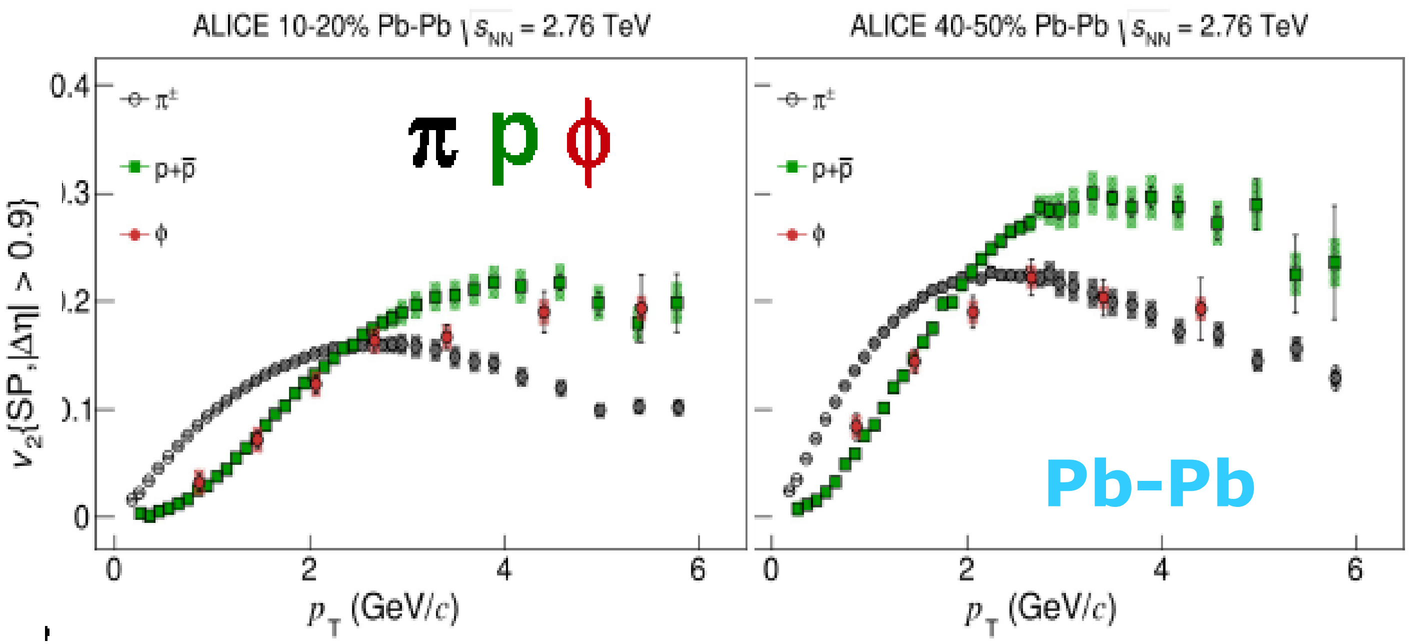
High p_T:
particles tend to group into mesons and baryons



arXiv:1405.4632

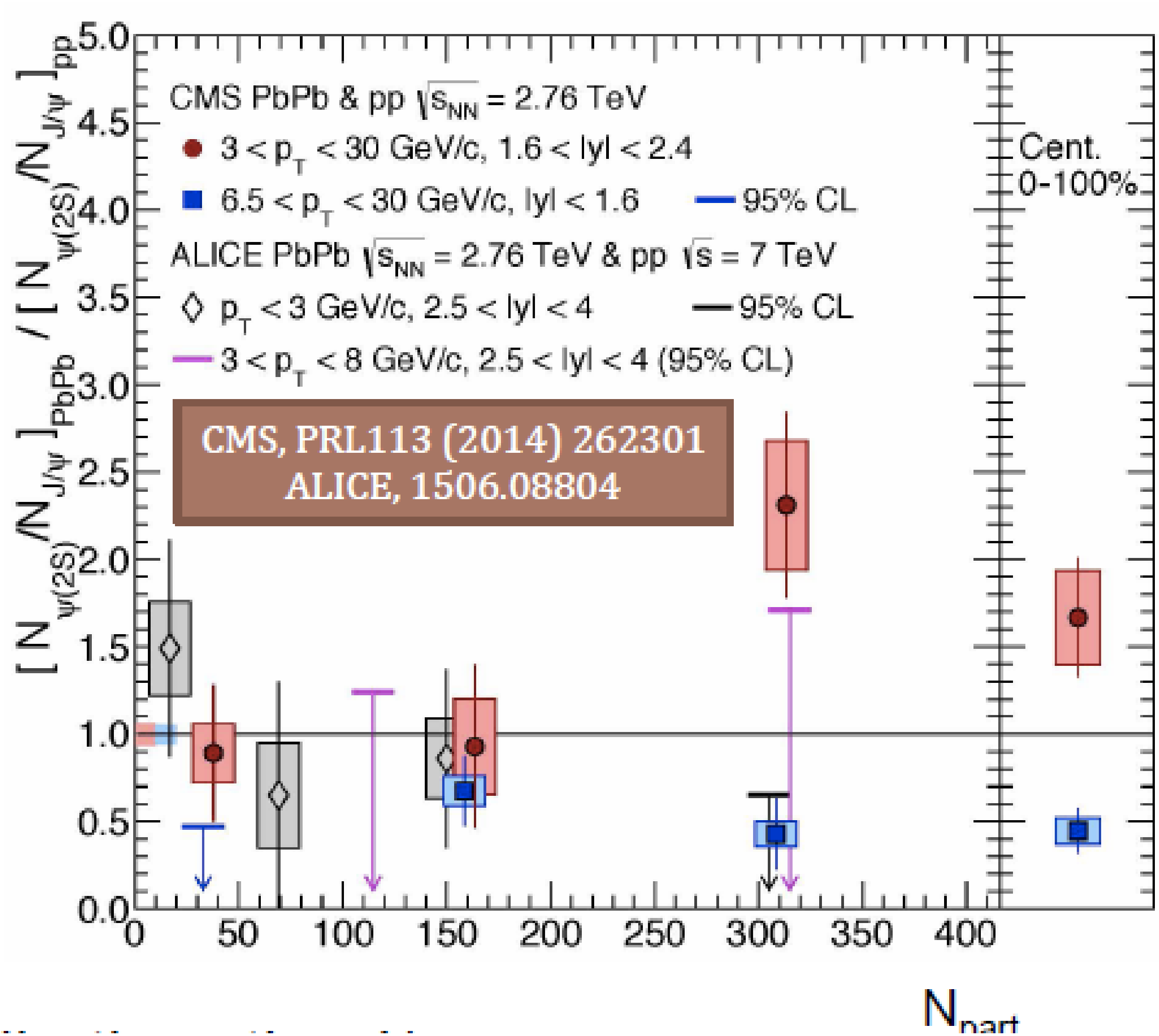
v_2 OF IDENTIFIED PARTICLES: ϕ

- ϕ (heavy meson) is of particular interest as testing ground for mass ordering and baryon-meson grouping



- Low p_T: v_2 follows mass ordering
- High p_T: v_2 close to p in central collisions and close to π in mid-central

- Mass (and not number of constituent quarks) is main driver for v_2 in central Pb-Pb → consistent with hydrodynamic picture
- Scaling with number of quark constituents violated by 20%, in particular in central collisions


CMS PbPb & pp √sNN = 2.76 TeV
3 < pT < 30 GeV/c, 1.6 < |y| < 2.4
6.5 < pT < 30 GeV/c, |y| < 1.6
95% CL
ALICE PbPb √sNN = 2.76 TeV & pp √s = 7 TeV
pT < 3 GeV/c, 2.5 < |y| < 4
95% CL
3 < pT < 8 GeV/c, 2.5 < |y| < 4 (95% CL)
CMS, PRL113 (2014) 262301
ALICE, 1506.08804
Cent.
0-100%
[Nψ(2S)/NJ/ψ]PbPb / [Nψ(2S)/NJ/ψ]pp
Npart