A Large Ion Collider Experiment

European Organization for Nuclear Research

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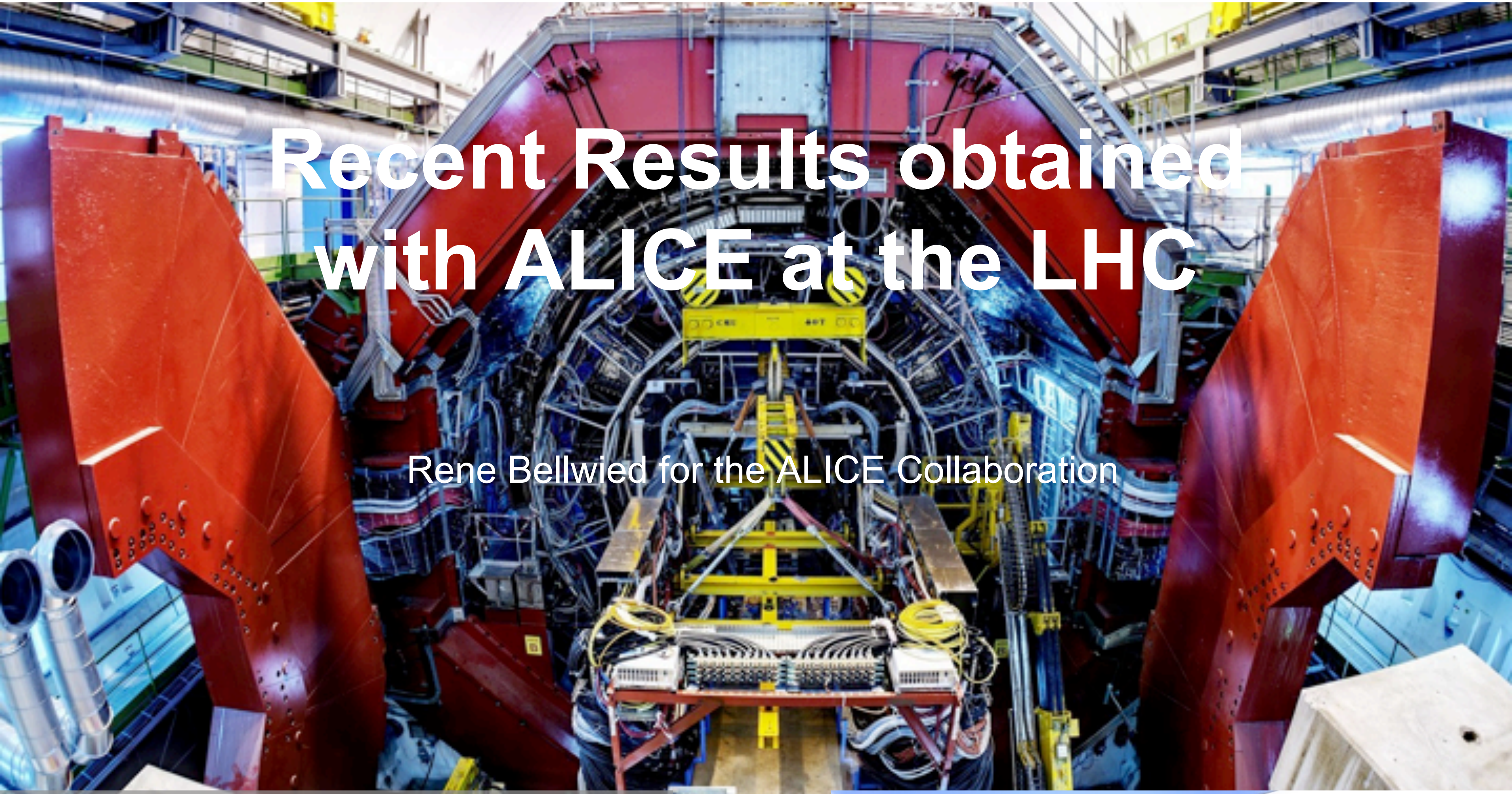

Recent Results obtained with ALICE at the LHC

Rene Bellwied for the ALICE Collaboration

Valparaiso, Chile
16-20 December 2013
Universidad Técnica Federico Santa María

High Energy Physics in the LHC Era
5th International Workshop

Overview

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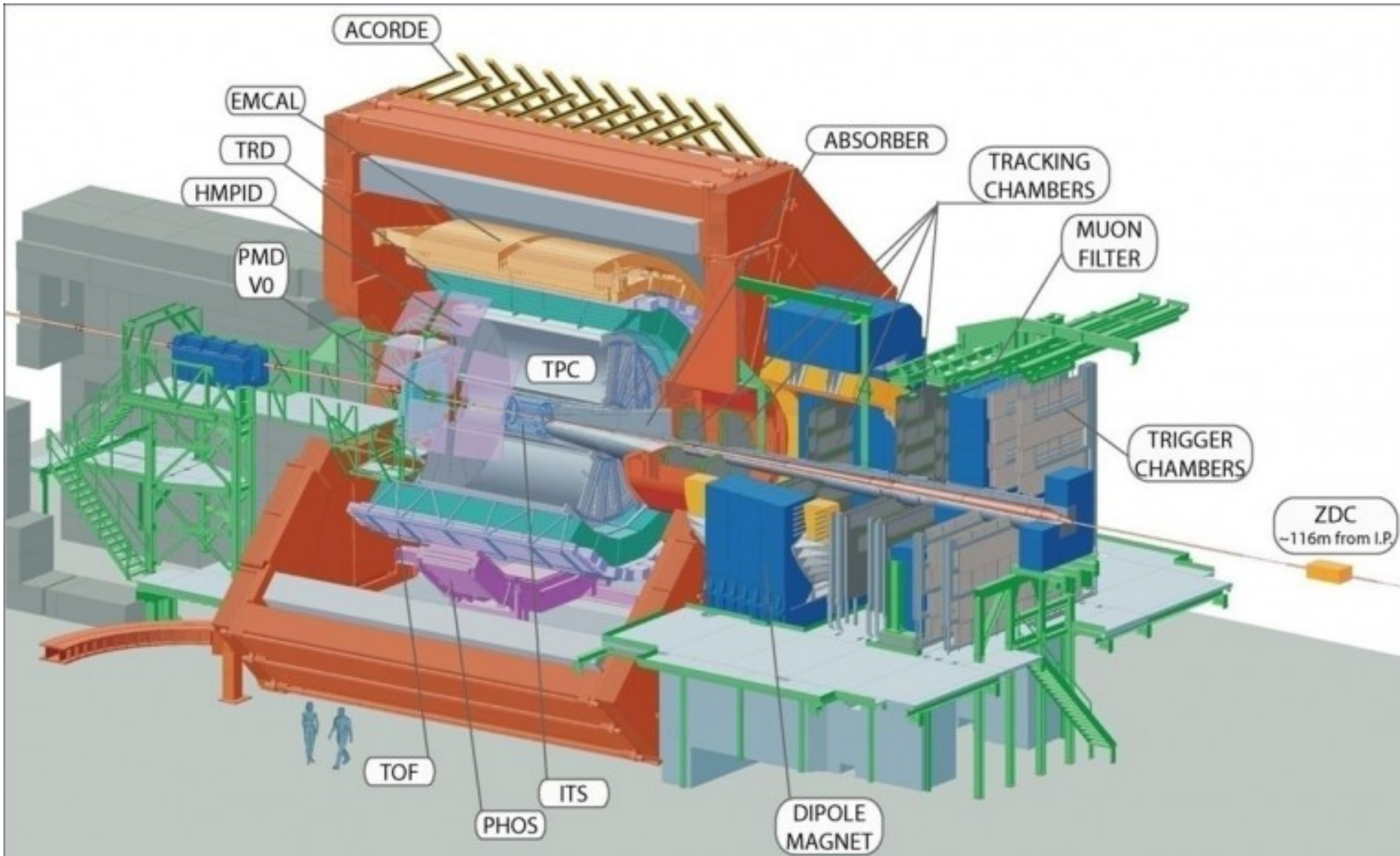
1. ALICE detector and data taking
2. Lessons from bulk production in PbPb collisions
3. Intriguing results for pPb collisions
4. Puzzles from correlations and quenching measurements
5. Puzzles from flavor behavior
6. Summary & Conclusions

ALICE

The Obligatory: the detector

a high resolution tracking device in a small magnetic field
with superior particle identification capabilities



What this detector can do better than any other

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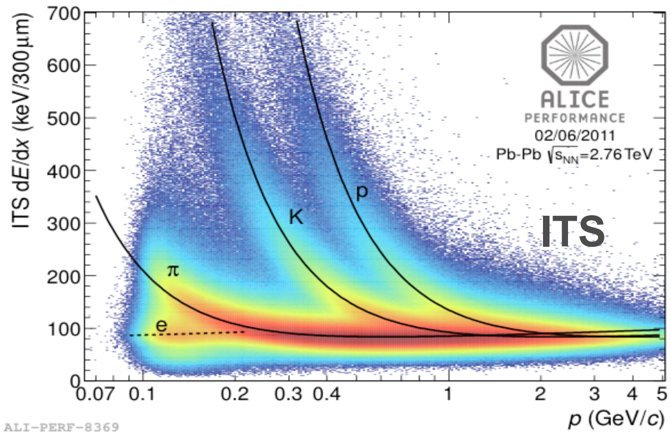

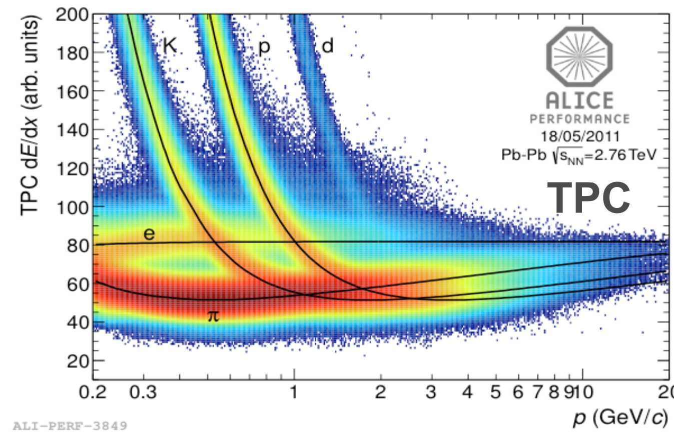

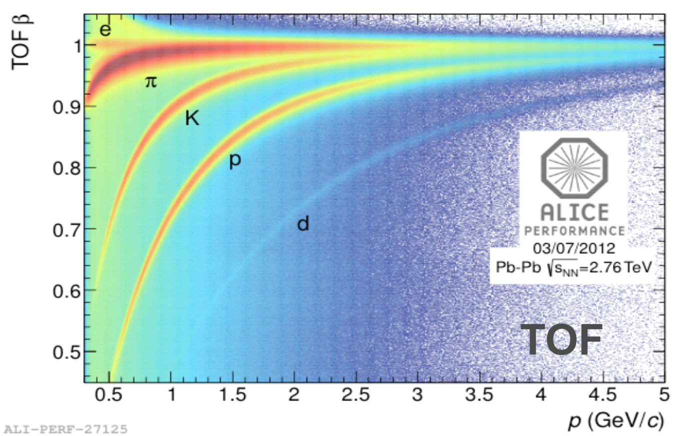

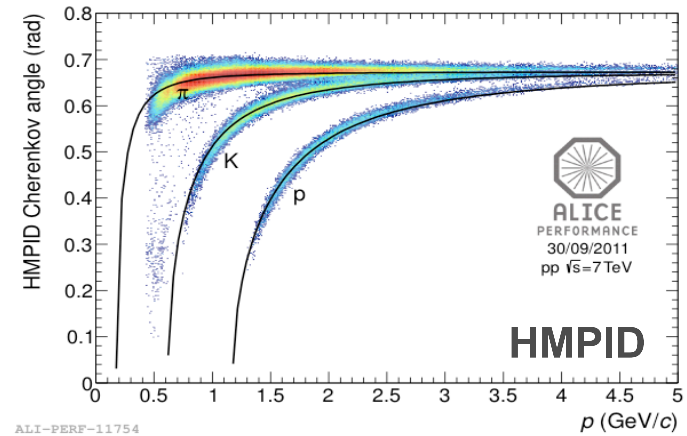

- Particle Identification ! Why ?
- *For the bulk (low momentum): Flavor behavior in the QCD crossover region*
- *For the hard probes (high momentum): Hadro-chemistry in medium and in vacuum*

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ALICE Data Samples

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Year	System	Energy $\sqrt{s_{NN}}$ (TeV)	Delivered Integrated luminosity
2010	Pb-Pb	2.76	10 μb^{-1}
2011	Pb-Pb	2.76	0.1 nb^{-1}
2013	p-Pb Pb-p	5.02	15 nb^{-1} 15 nb^{-1}

- ❑ Two Pb-Pb runs
  - ✓ In 2010 - commissioning and first data taking
  - ✓ In 2011 – Second run, factor 10 increase in luminosity
- ❑ p-Pb occurred this year
  - ✓ LHC delivered target luminosity
- ❑ In addition p-p runs at √sNN = 0.9, 2.76, 7 and 8 TeV
- ❑ Long shutdown now (LS1)
  - ✓ Various upgrades and maintenance in progress

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p-Pb and Pb-p samples

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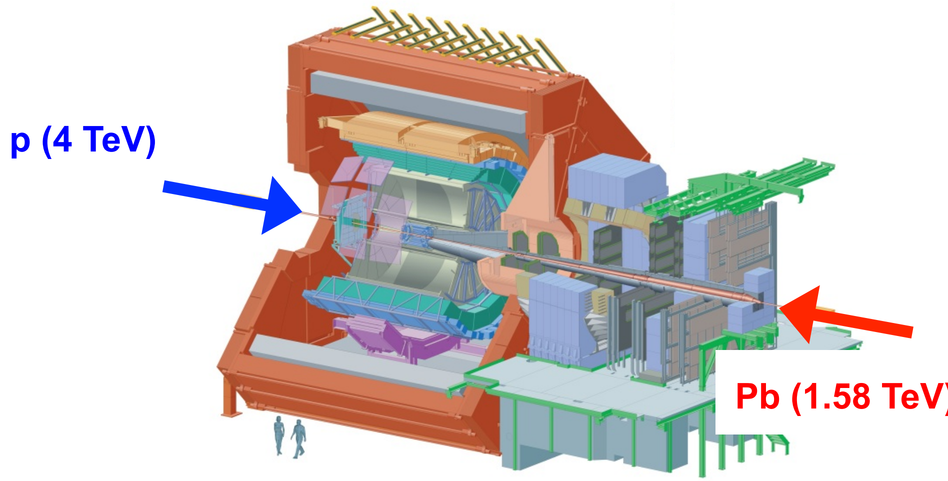
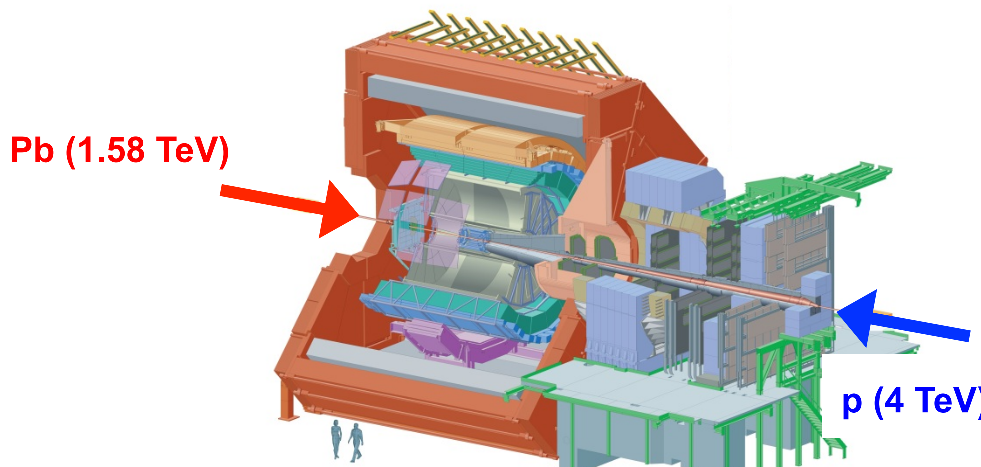
- p-Pb
  - proton going towards muon arm



y_{CM} = 0.465 in the p-beam direction



- Pb-p
  - Pb nucleus going towards muon arm

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6

Lessons from the bulk in PbPb (I)

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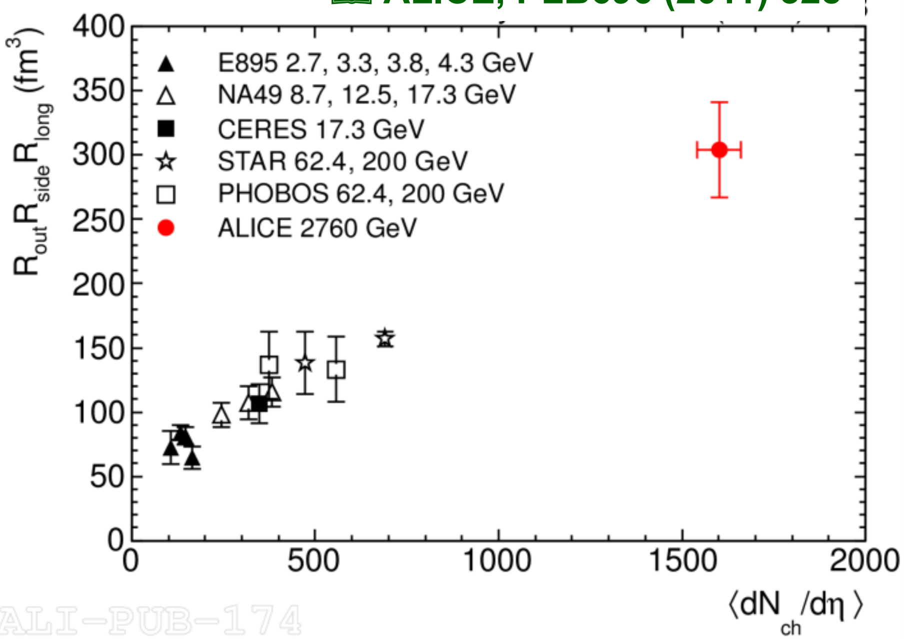
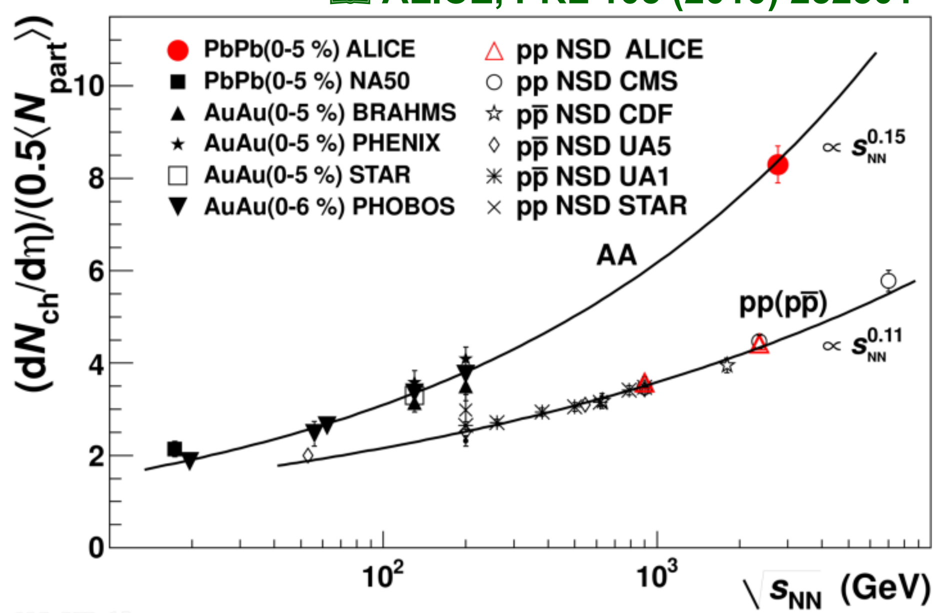
ALICE, PLB696 (2011) 328



ALICE, PRL 105 (2010) 252301



- Volume twice as large as at RHIC
- Lifetime 20% longer than at RHIC
- Multiplicity twice as large as at RHIC
- Energy density three times that of RHIC

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Lessons from the bulk in PbPb (II)

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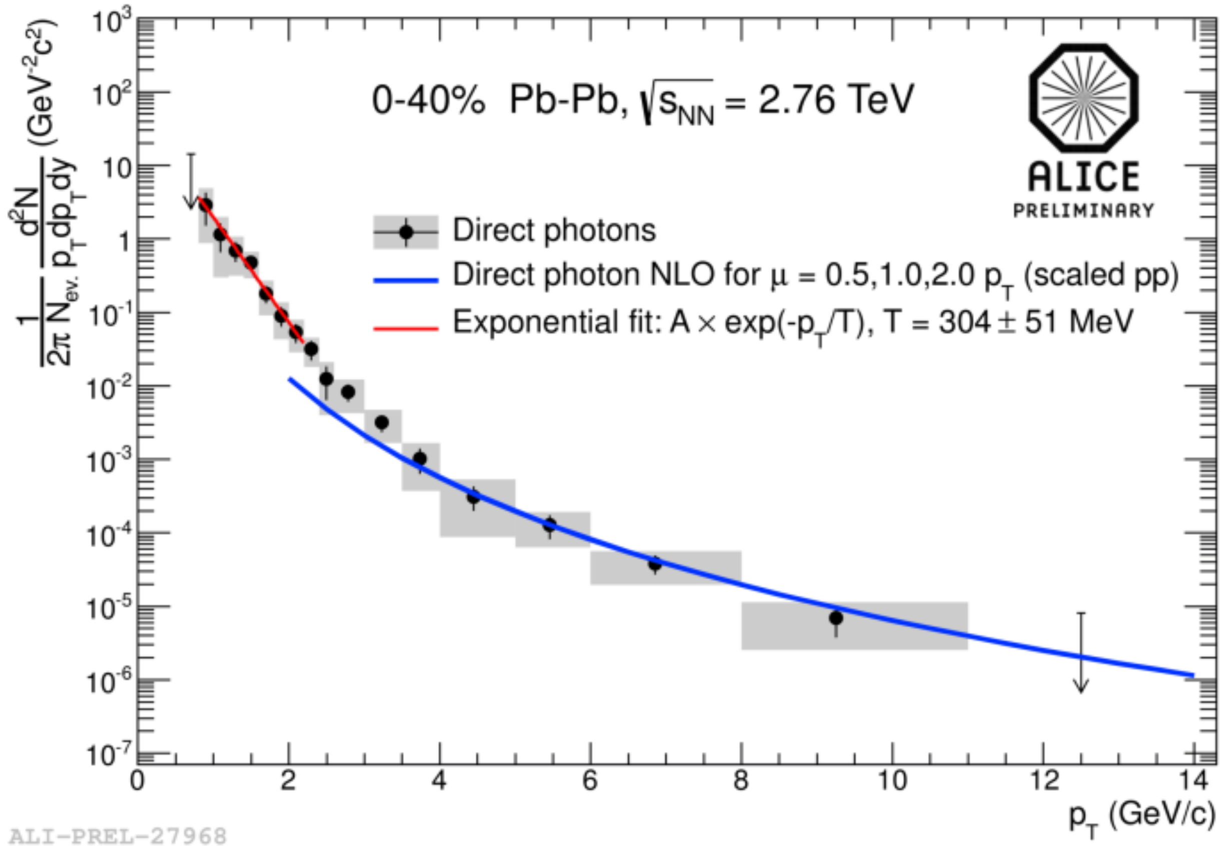

- The famous Guiness Book of Records entry: T_{LHC} = 1.4 T_{RHIC}
- T_{av} for thermal photons = 304+-51 MeV ⇨ T_{init} = 500-600 MeV

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Lessons from the bulk in PbPb (III)

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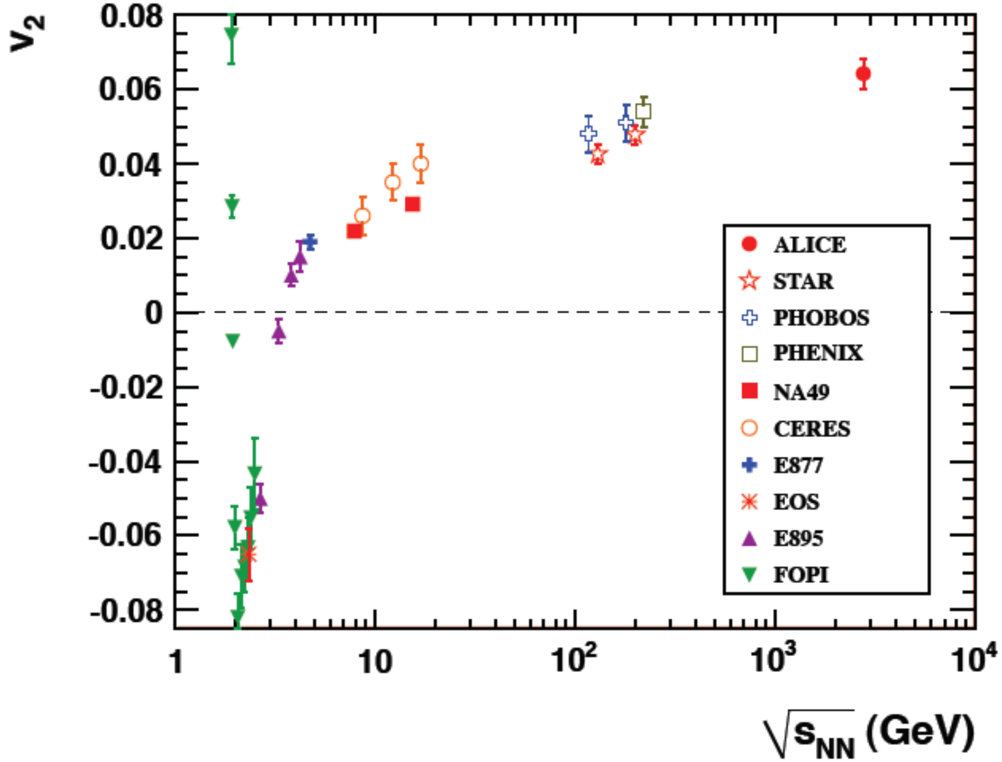
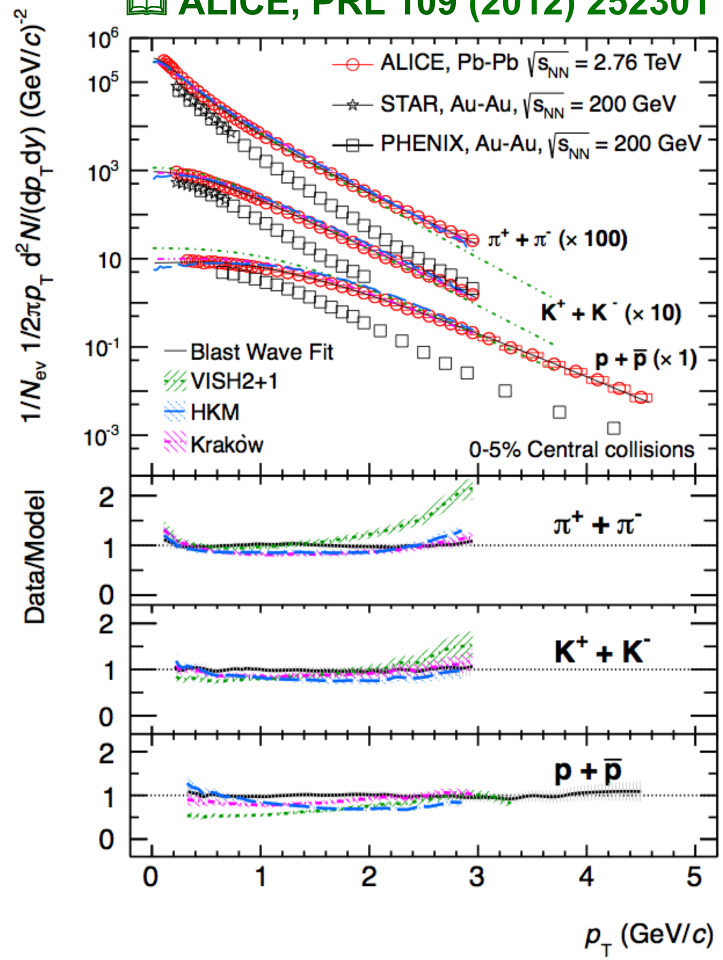
📖 ALICE, PRL 105 (2010) 252302



📖 ALICE, PRL 109 (2012) 252301



- Larger flow than at RHIC
- For anisotropic flow: larger pT integrated v2
- For radial flow: 10% larger expansion velocity ($\langle\beta_T\rangle$ = 0.65c, T_{kin} = 80-95 MeV)

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Lessons from the bulk in PbPb (IV)

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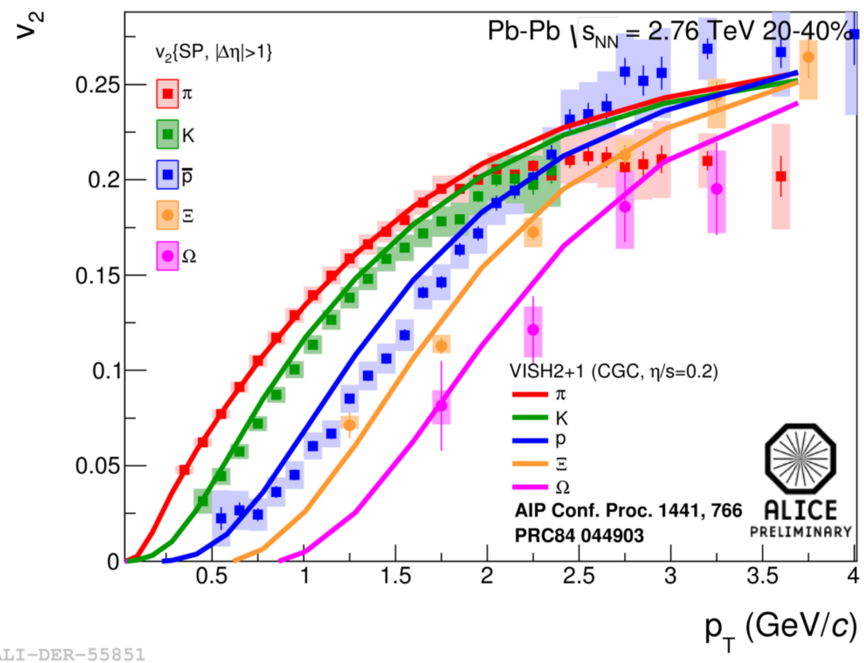
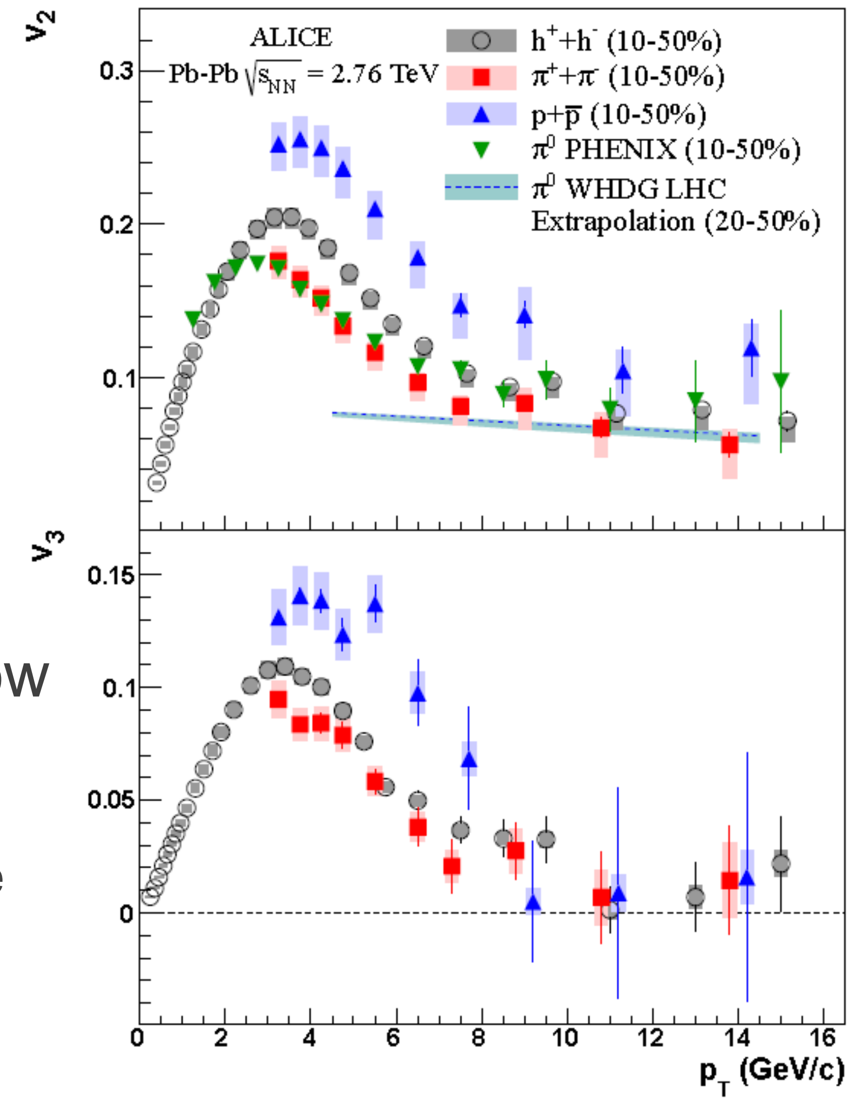


ALICE, PLB 719 (2013) 18



- Identified particle elliptic flow
  - Mass ordering at low p_T described by hydrodynamics
  - Particle species dependence persists up to $p_T \approx 8$ GeV/c
  - Validity of NCQ scaling is limited

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Lessons from the bulk in PbPb (V)

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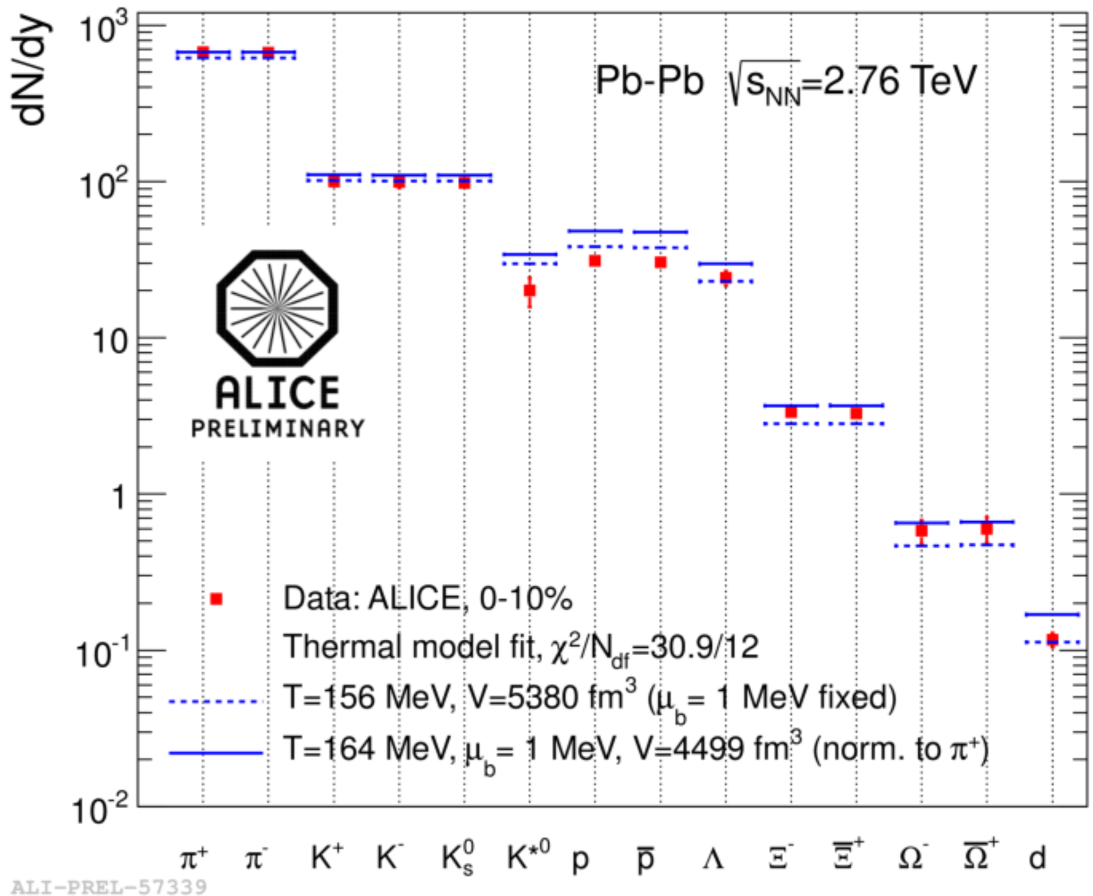
- So dynamics are 'as expected'. Is there anything exciting in the bulk ?



- Proton yield does not follow the results from statistical hadronization model when assuming a common chemical freeze-out temperature

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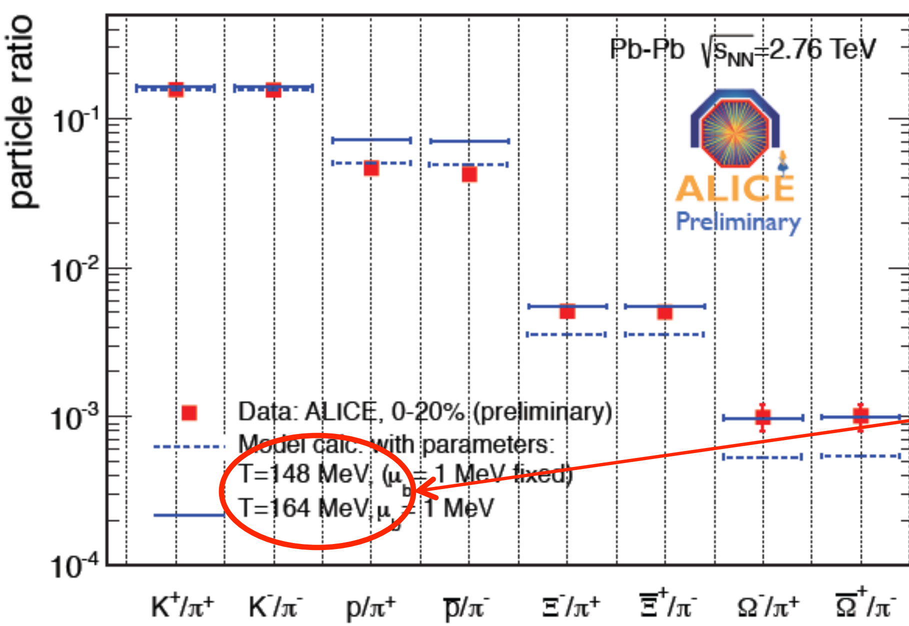
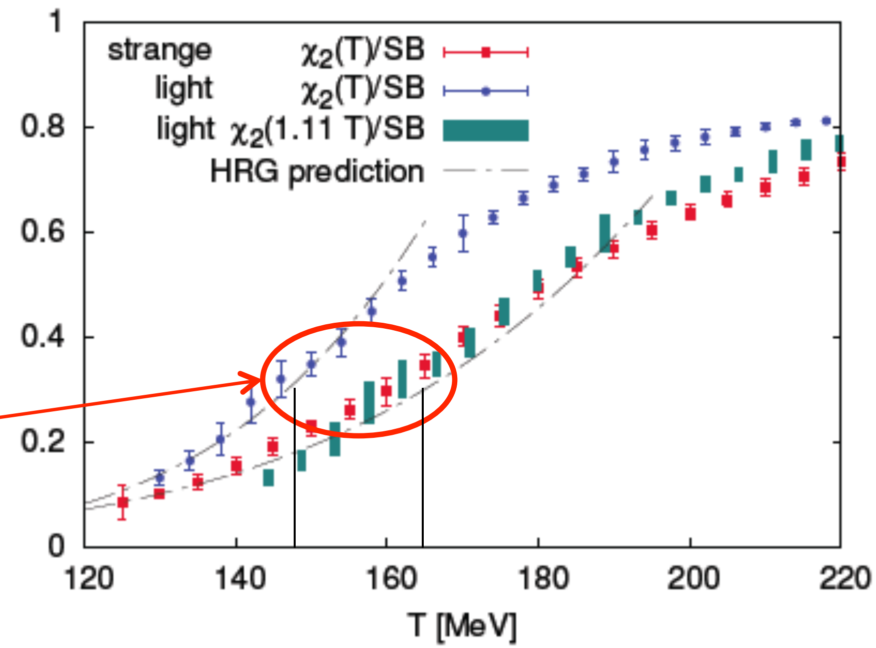
Lessons from the bulk in PbPb (VI)

- Possible explanations include an increased proton annihilation cross section in the hadronic phase (but model generates some tension with strange baryon annihilation, centrality dependence and lattice results for transition temperature)
- Potentially more intriguing: separate chemical freeze-out temperature for separate flavors ⇨ a flavor hierarchy in the freeze-out, which might be evident in high resolution, continuum extrapolated lattice QCD calculations for flavor susceptibilities (*see talk by C. Ratti, Tuesday, 17:25*)





Bellwied, Borsanyi, Fodor, Katz, Ratti, PRL 111 (2013) 202302

Hadron-hadron correlations in p-Pb

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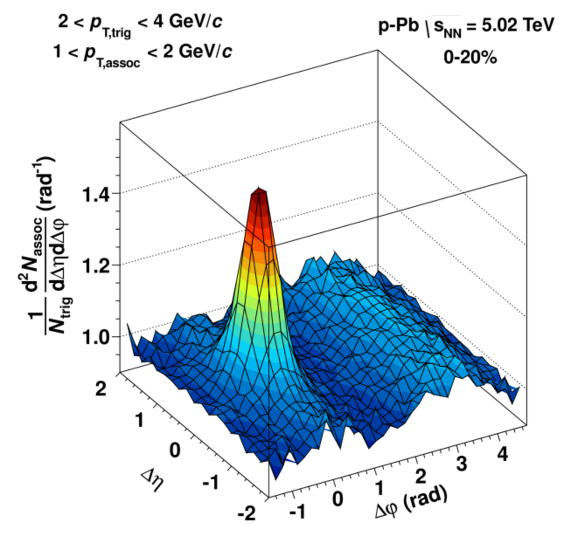
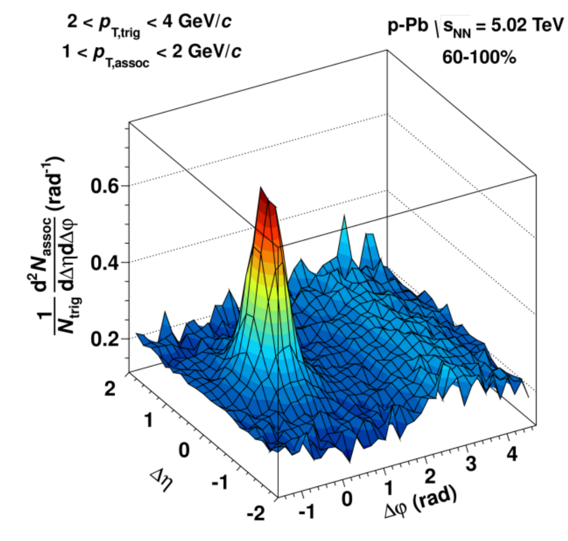
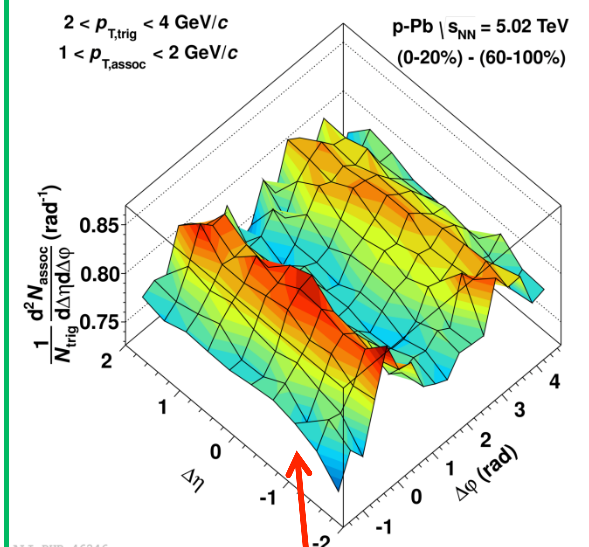
High multiplicity



Low multiplicity



High - Low

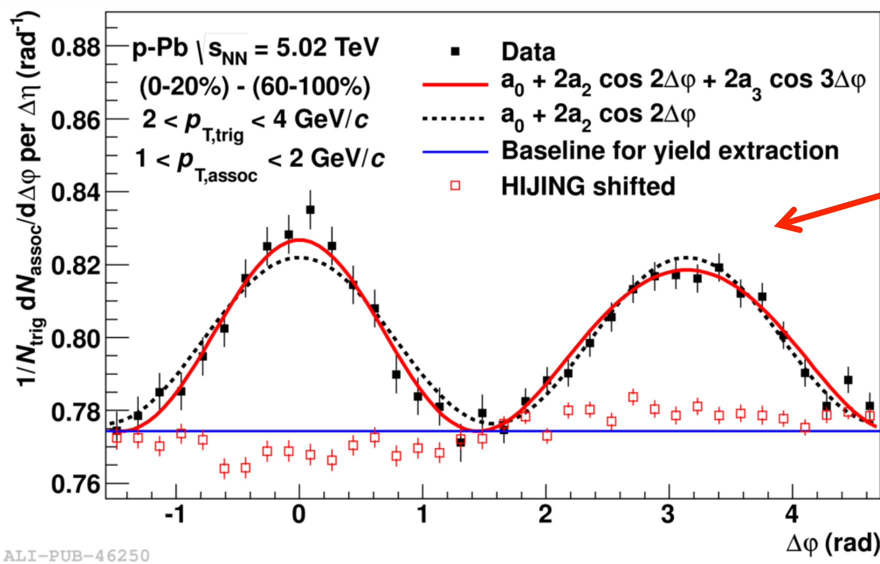


📖 **ALICE, PLB719 (2013) 29**

Double ridge structure described by both: hydro and CGC

📖 **Bozek et al., PLB (2013) 1557**

📖 **Dusling et al., PRD87 (2013) 094034**



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

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Hints of collectivity in cold nuclear matter ?

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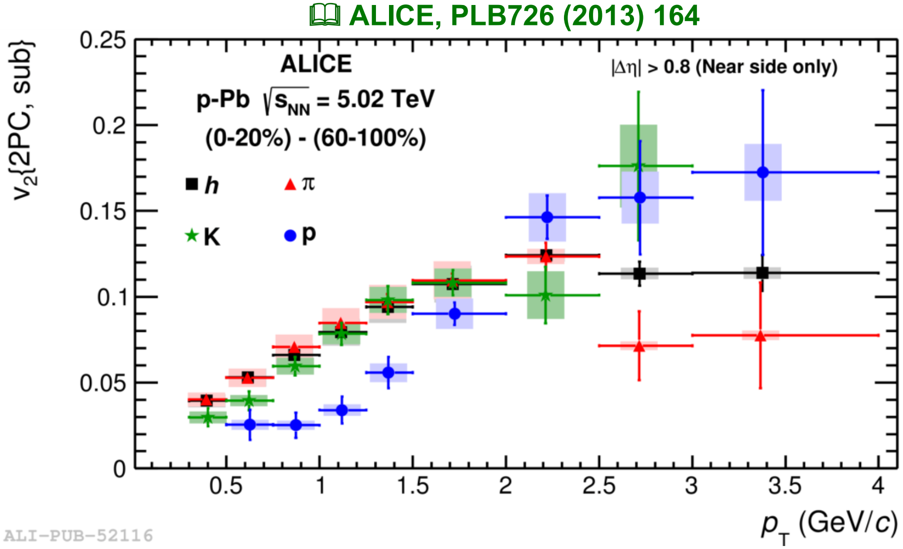
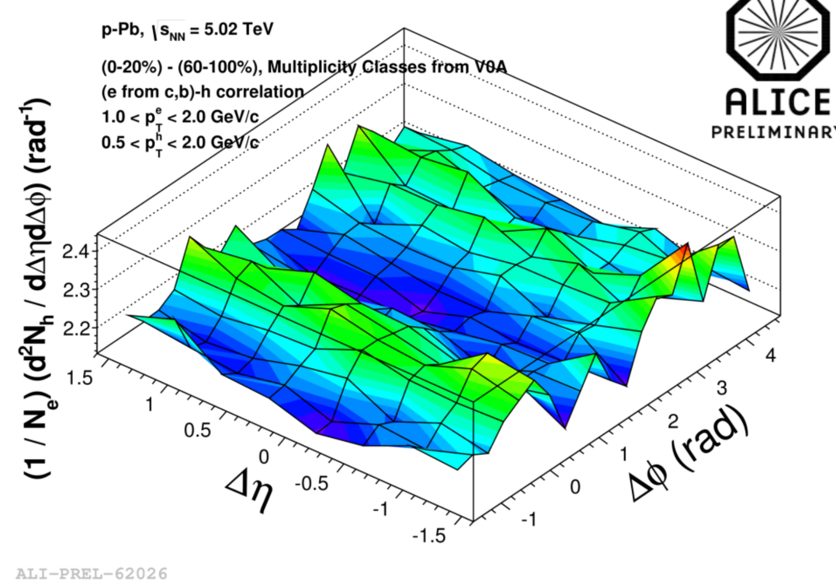
h - π,K,p correlations



HF decay e± - h correlations



- v_2 extracted from two-particle correlations
  - Mass ordering at low p_T
  - Crossing at p_T≈2 GeV/c
  - Qualitatively similar to Pb-Pb
- Double ridge seen also in the correlation of heavy-flavour decay electrons with hadrons
  - Suggests that the mechanism generating the double ridge is at work also for heavy flavours

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More hints: hydro describes spectra

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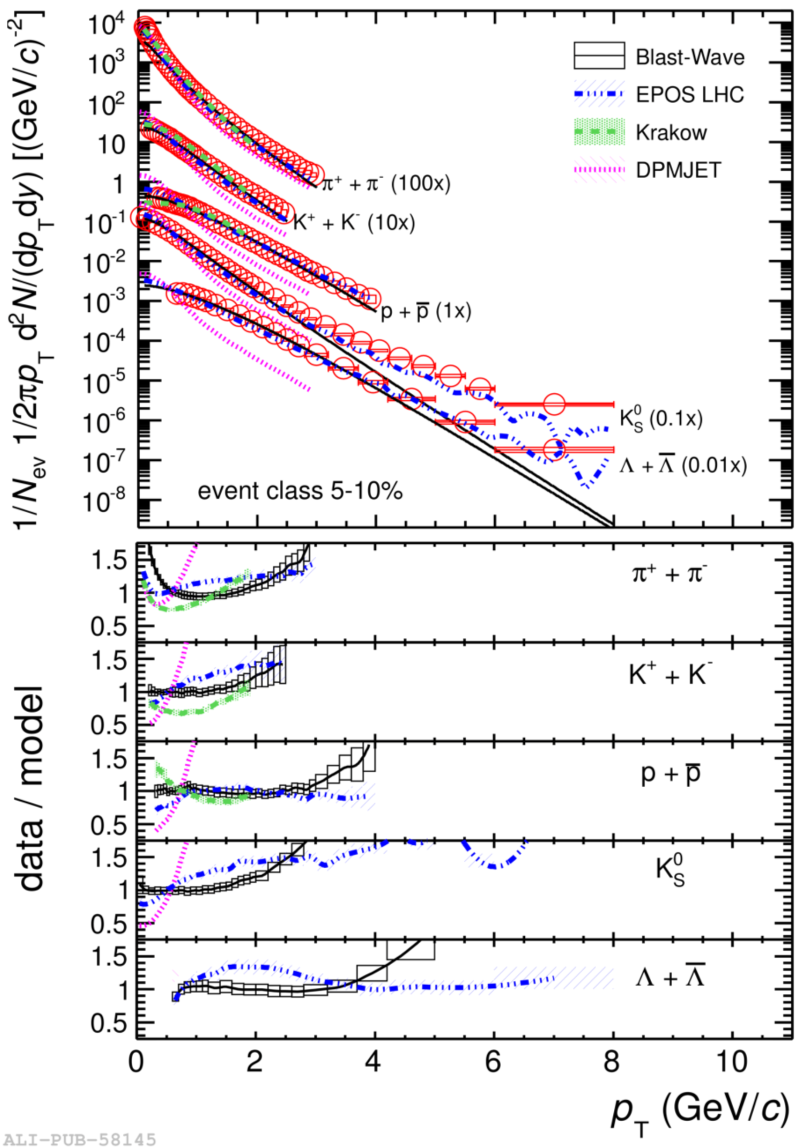
📖 ALICE, arXiv:1307.6796



- Models:
  - Blast-wave fit = locally thermalized medium expanding with collective flow velocity
  - EPOS LHC = full event generator including hydrodynamical evolution
  - Krakow = 3+1 viscous hydrodynamics (expected to work at low p_T)
  - DPMJET = PHOJET pp +nuclei via Glauber-Grybov approach
- Models including hydrodynamics give a better description of the spectra

More hints: Radial flow in p-Pb collisions

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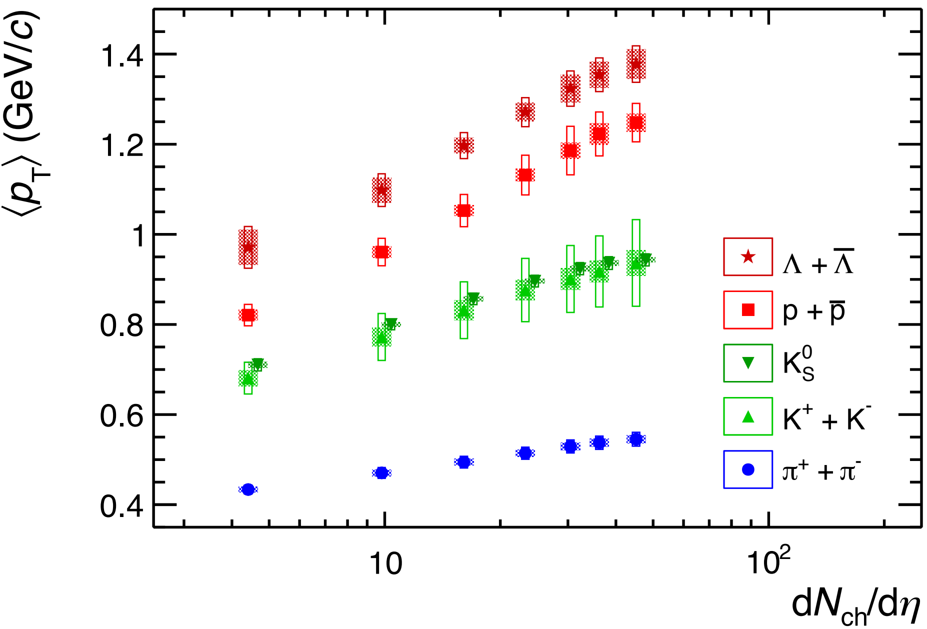
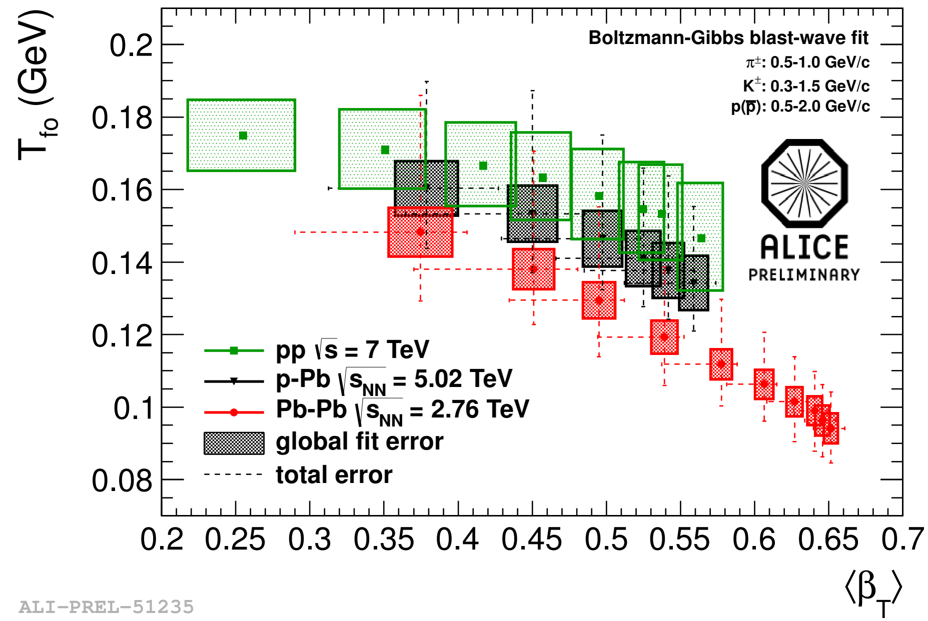
ALICE, arXiv:1307.6796





- Resembles Pb-Pb: <p_T> increases with centrality and mass
  - ✓ Blast wave fits <β_T> ~ 0.5c central p-Pb
  - ✓ Similar values observed in pp

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<p_T> in pp, pPb and PbPb

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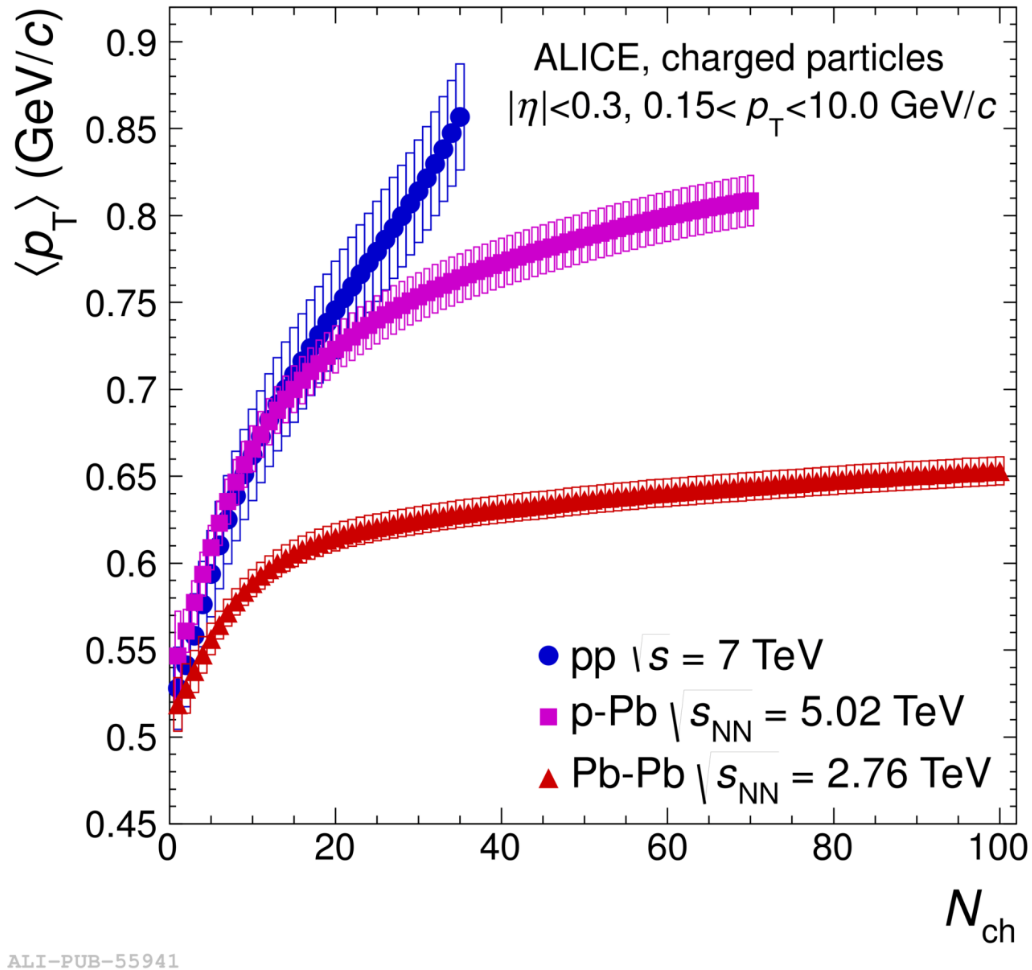

- Three different √s for pp, p-Pb and Pb-Pb
  - but √s dependence expected to be weak
- Much stronger increase of <p_T> in p-Pb than in Pb-Pb
- p-Pb follows pp up to N_{ch}~14-15
- N_{ch}>14 corresponds to
  - ~10% of pp x-section:
    - pp already highly biased
  - 50% of p-Pb x-section
    - only centrality bias

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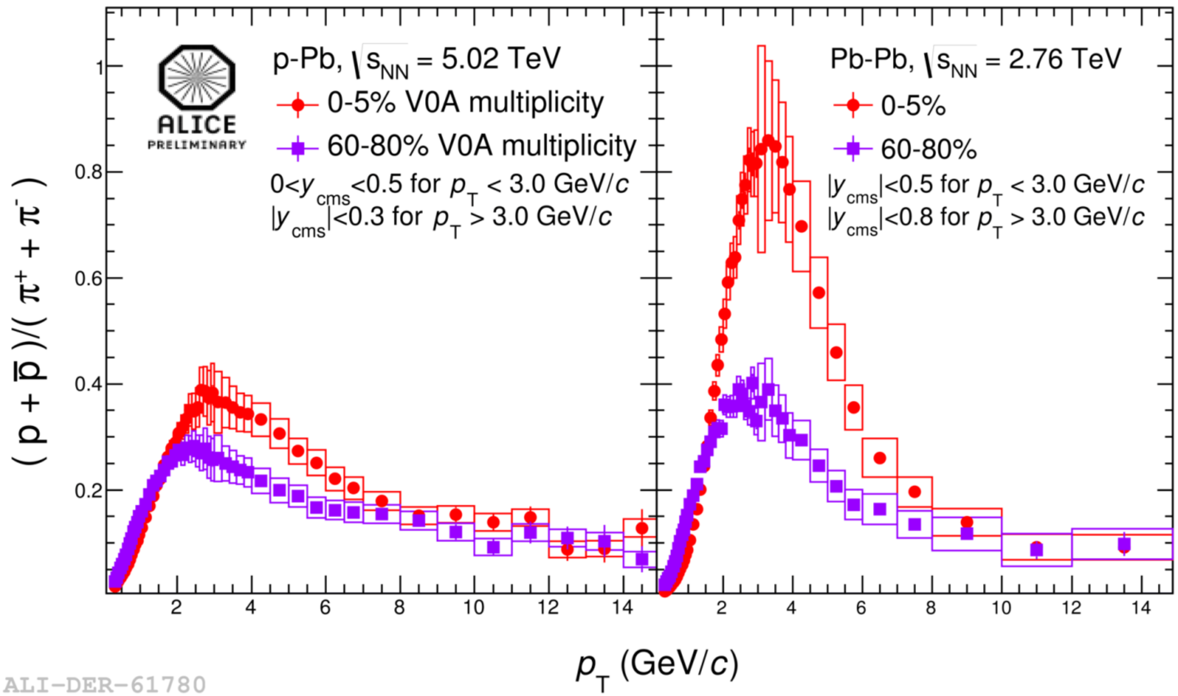
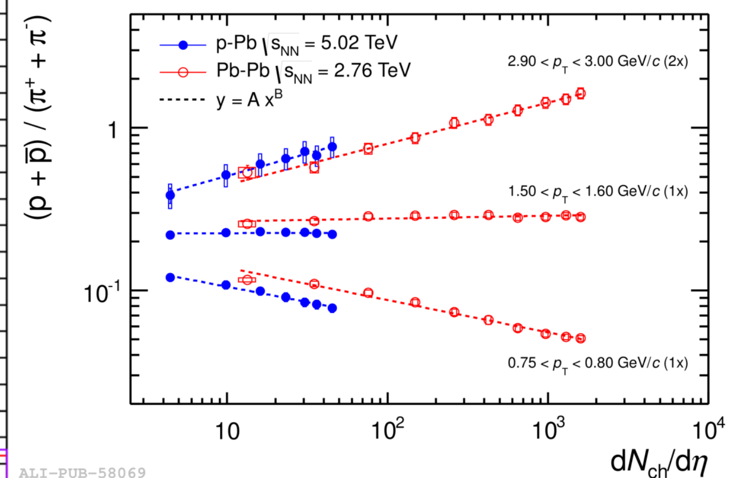
Baryon/meson ratio in pPb and PbPb



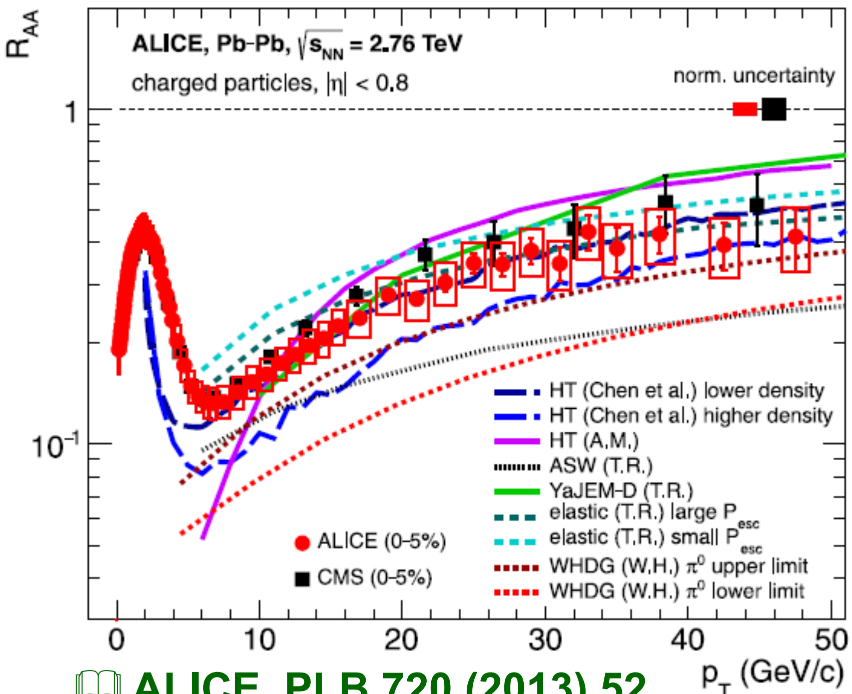
ALICE, arXiv:1307.6796



- Similar evolution of baryon/meson ratios vs. p_T with multiplicity
  - Enhancement at intermediate p_T
  - Pb-Pb results commonly understood in terms of collective radial expansion and hadronization via quark recombination
  - Magnitude of the effect significantly different in p-Pb and Pb-Pb
  - In a given p_T bin, the ratio as a function of dN_{ch}/dh follows a power-law behavior with same exponent in pPb and PbPb

Nuclear modification factor

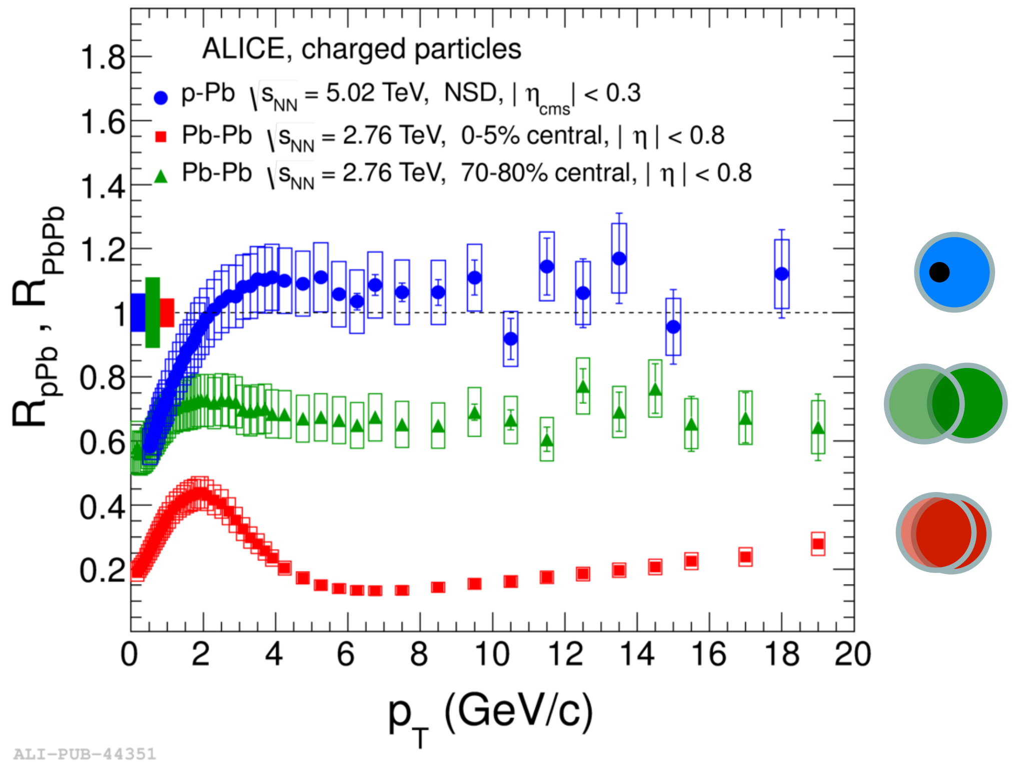
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$



ALICE, PLB 720 (2013) 52

CMS, EPJ C 72 (2012) 1945

ALICE, PRL 110 (2013) 082302



- ❑ Charged particle spectra strongly modified in PbPb compared to pp
- ❑ p-Pb results confirm that jet quenching is a final state effect

Identified particle R_{AA}

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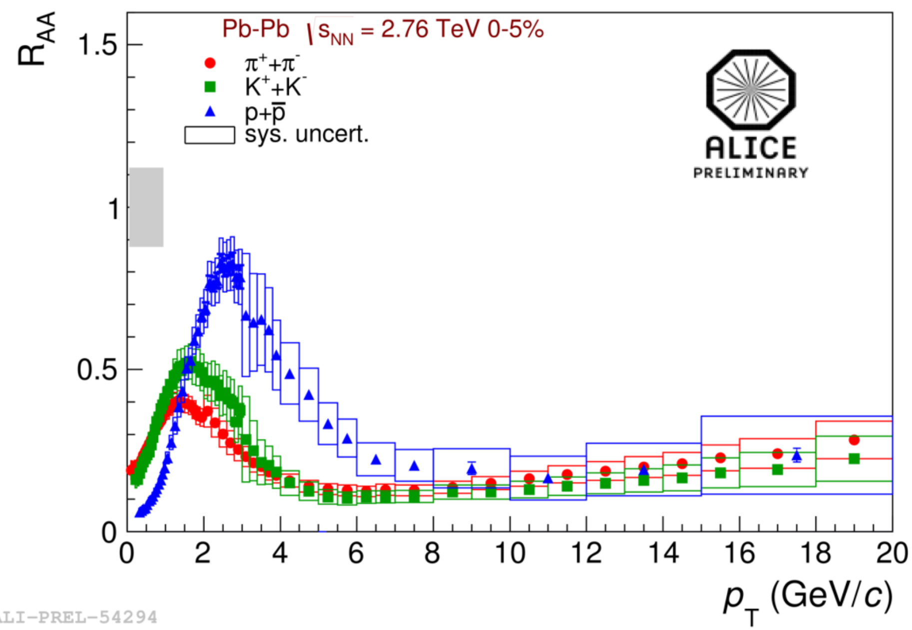
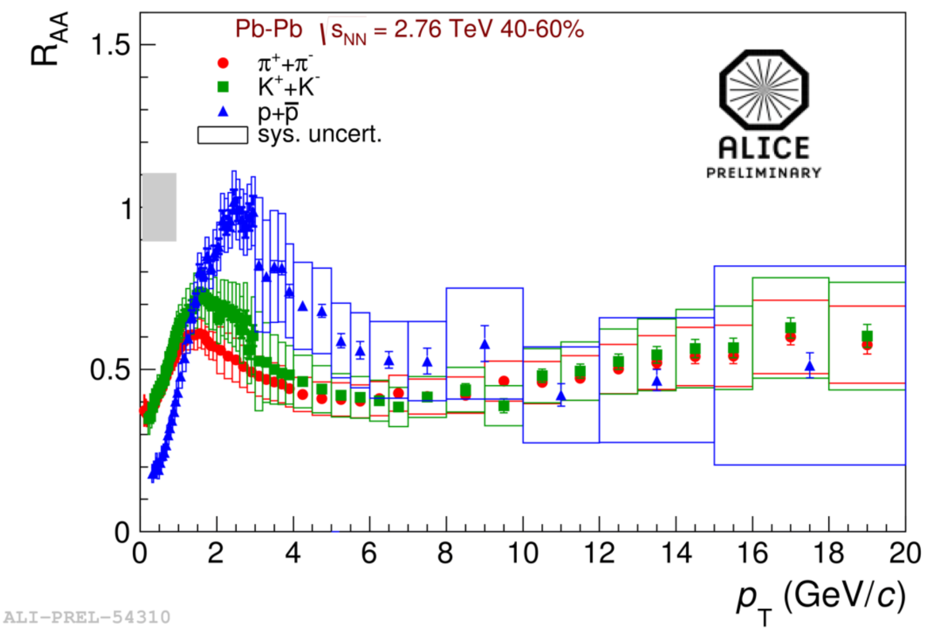
Centrality: 0-5% **Centrality: 40-60%**





- For p_T>8 GeV/c π, k and p are equally suppressed within uncertainties
  - Particle composition at high-p_T not affected by the medium
  - Hadro-chemistry not modified (excludes certain theoretical hadronization models based on enhanced gluon splitting, early formation time, and Schwinger di-quark mechanism

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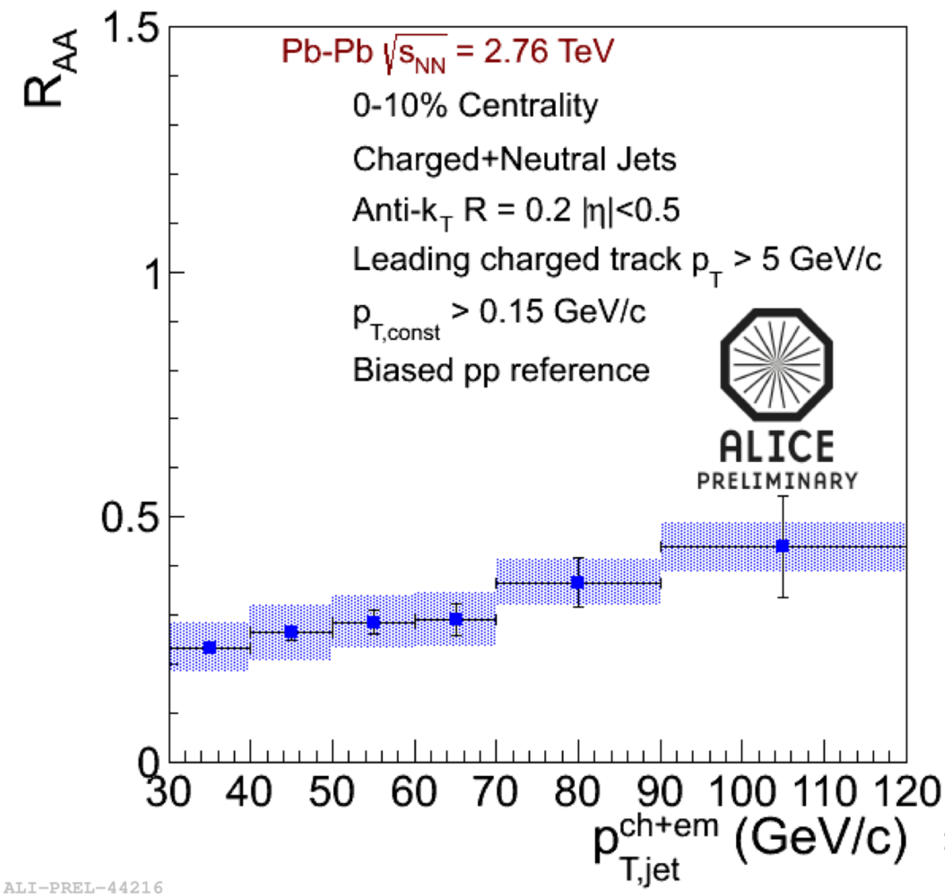
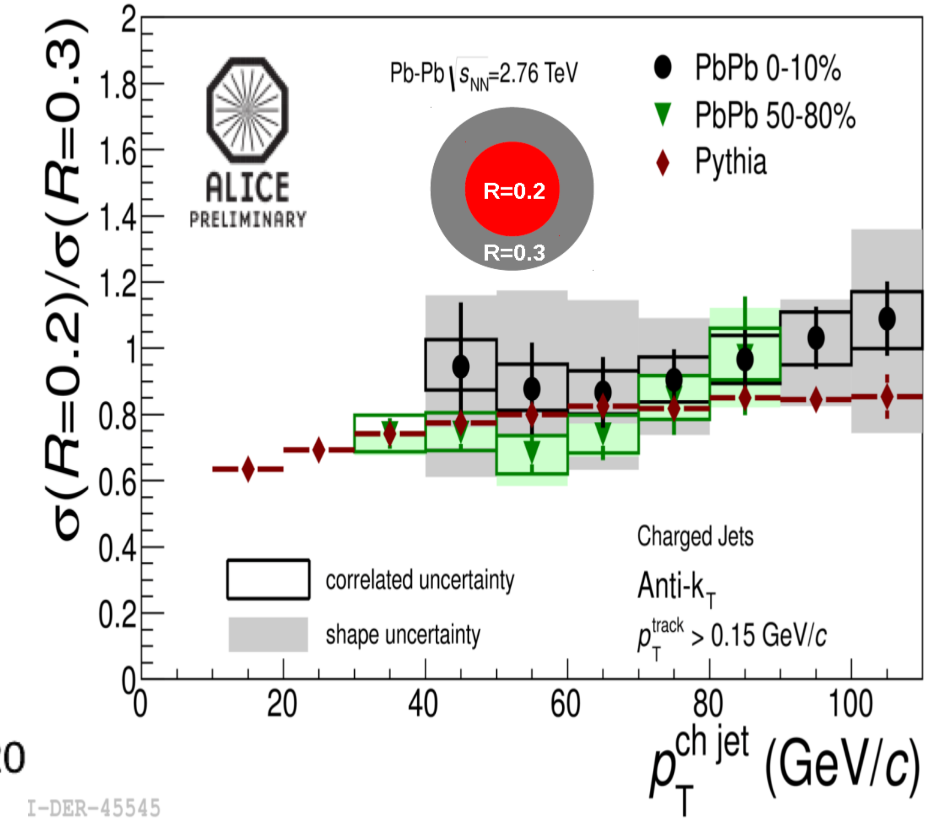
see R. Bustamante's talk, today at 15:00

Jet suppression and structure in PbPb





- Strong suppression of jet yield in most central Pb-Pb collisions
- Ratio σ(R=0.2)/σ(R=0.3) of jet cross sections in Pb-Pb compatible with fragmentation in vacuum (PYTHIA)
  - Sensitive to the profile of the jet energy density
  - No evidence of jet shape modification in jet core

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Jet suppression and structure in pPb

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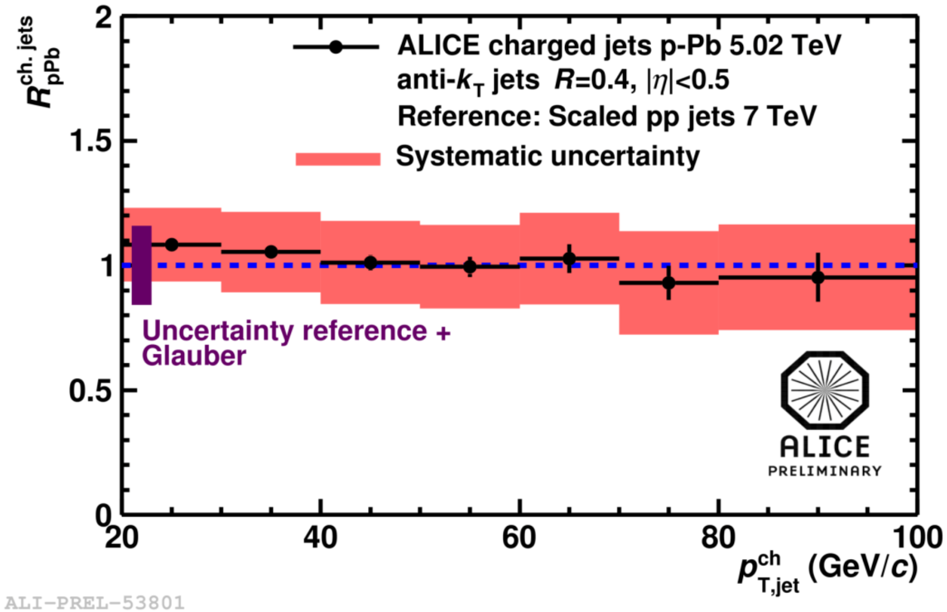

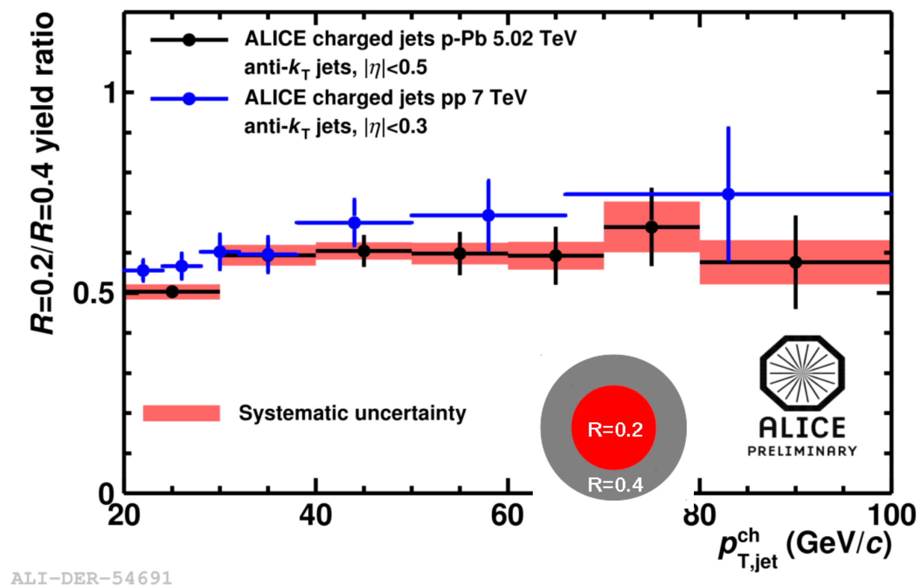

- No modification of jet cross section in pPb relative to pp
- Ratio σ(R=0.2)/σ(R=0.4)
  - compatible in pPb and pp (and PYTHIA)
    - NOTE: comparison between different √s
  - No indication of jet structure modification due to CNM effects

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D-meson R_{AA} in PbPb and pPb: a final state effect

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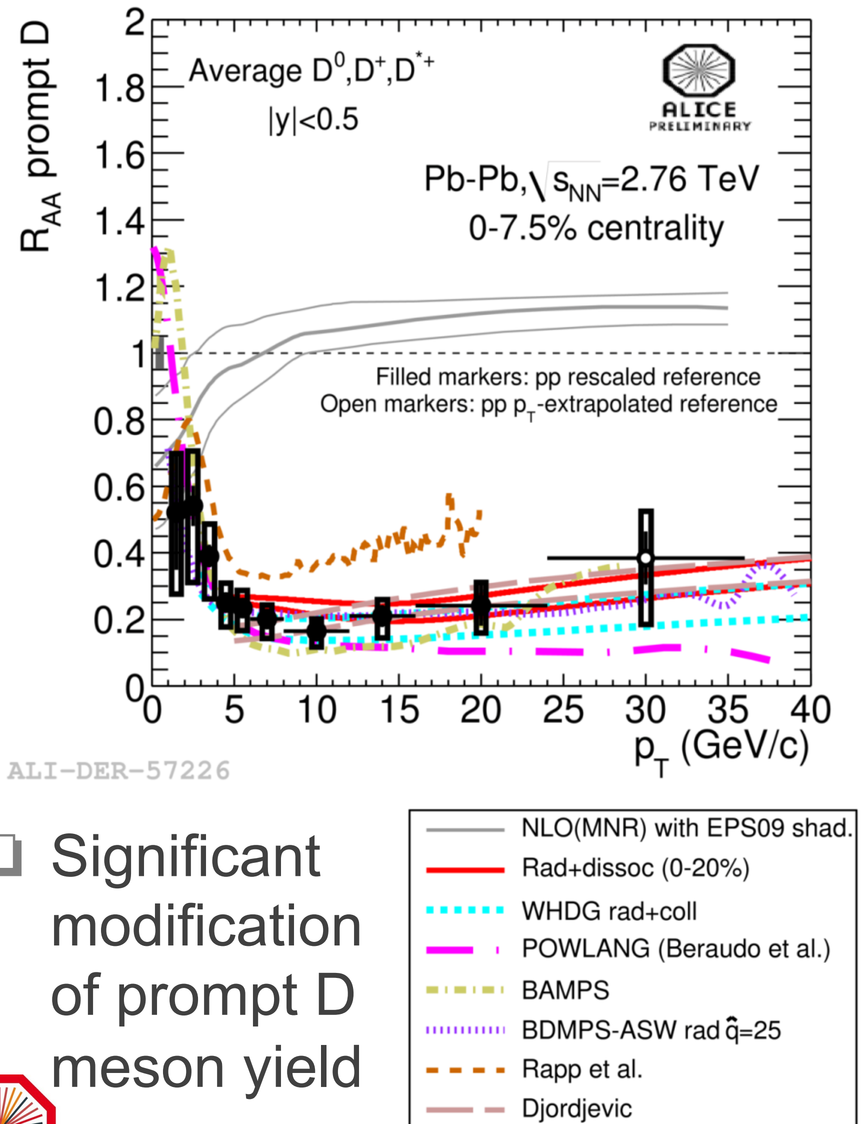

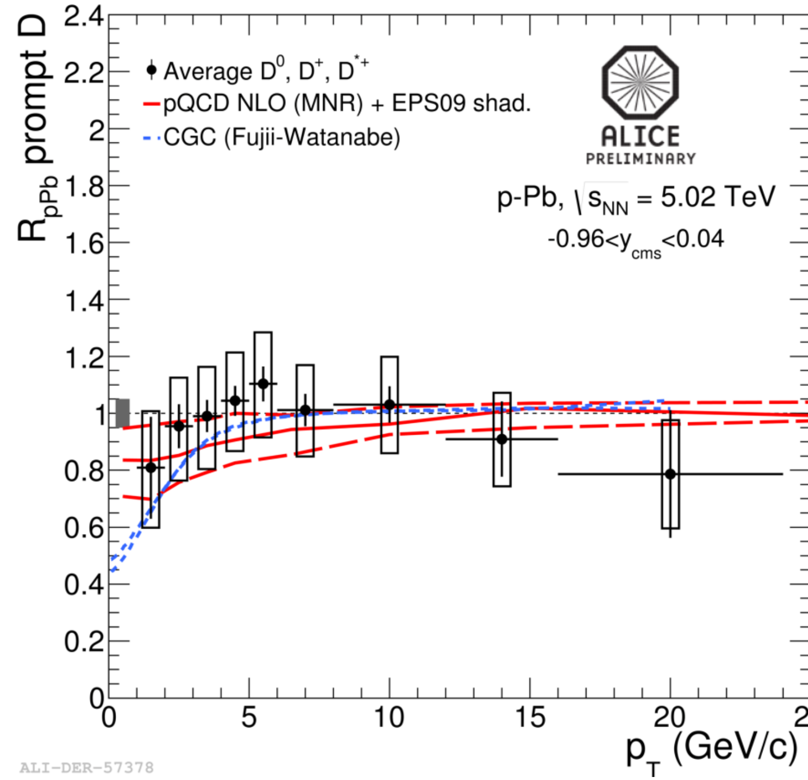

- Significant modification of prompt D meson yield

- R_{pPb} compatible with unity
- Data described both by EPS09 parameterization of nuclear PDFs and by CGC approach

EPS09: Eskola et al., JHEP 0904 (2009) 065
CGC: Fujii, Watanabe, arXiv: 1308.1258

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Open charm R_{AA} and v_2 in PbPb

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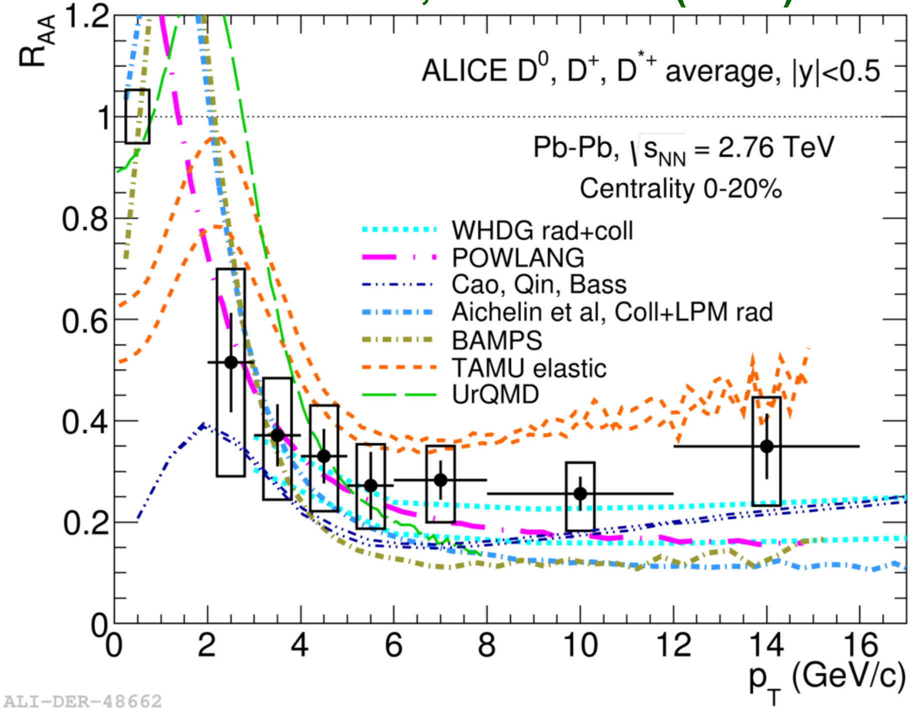
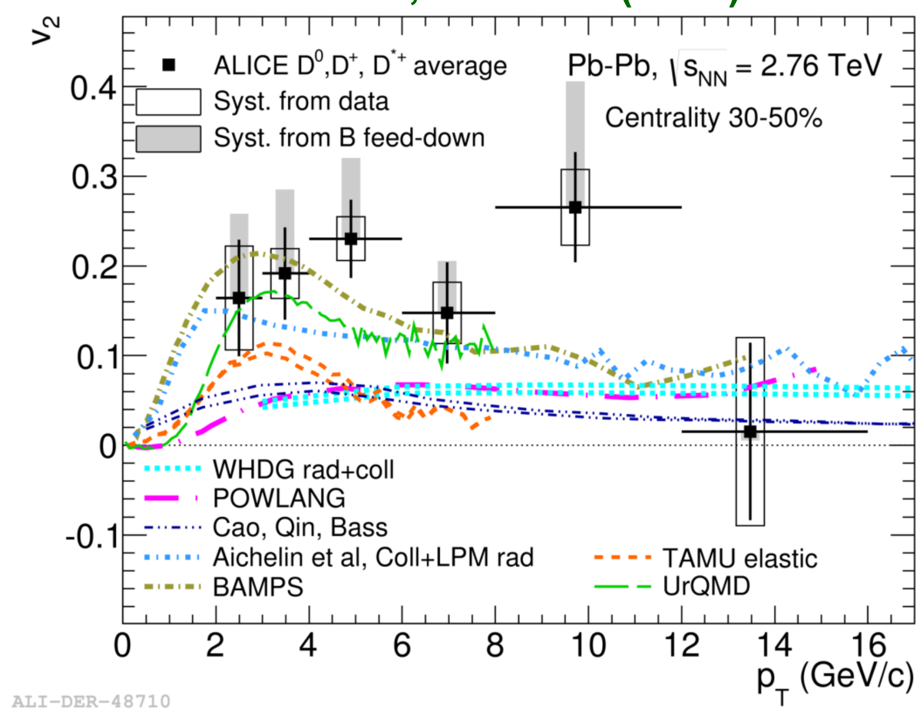
- Simultaneous description of open charm R_{AA} and v_2 is a challenge for theoretical models

ALICE, JHEP 1209 (2012) 112



ALICE, PRL 111 (2013) 102301



- WHDG: Horowitz et al., J Phys. G38 (2011) 124114
- POWLANG: Alberico et al., EPJ C71 (2011) 1666
- Cao, Qin, Bass, arXiv:1308.0617
- Aichelin et al.:PRC79 (2009) 044906, J. Phys. G37 (2010) 094019
- BAMPS: Fochler et al., J. Phys. G38 (2011) 124152
- TAMU: Rapp, He et al., PRC 86 (2012) 014903
- UrQMD: Lang et al, arXiv:1211.6912, arXiv:1212.0696

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Flavor hierarchy in energy loss?

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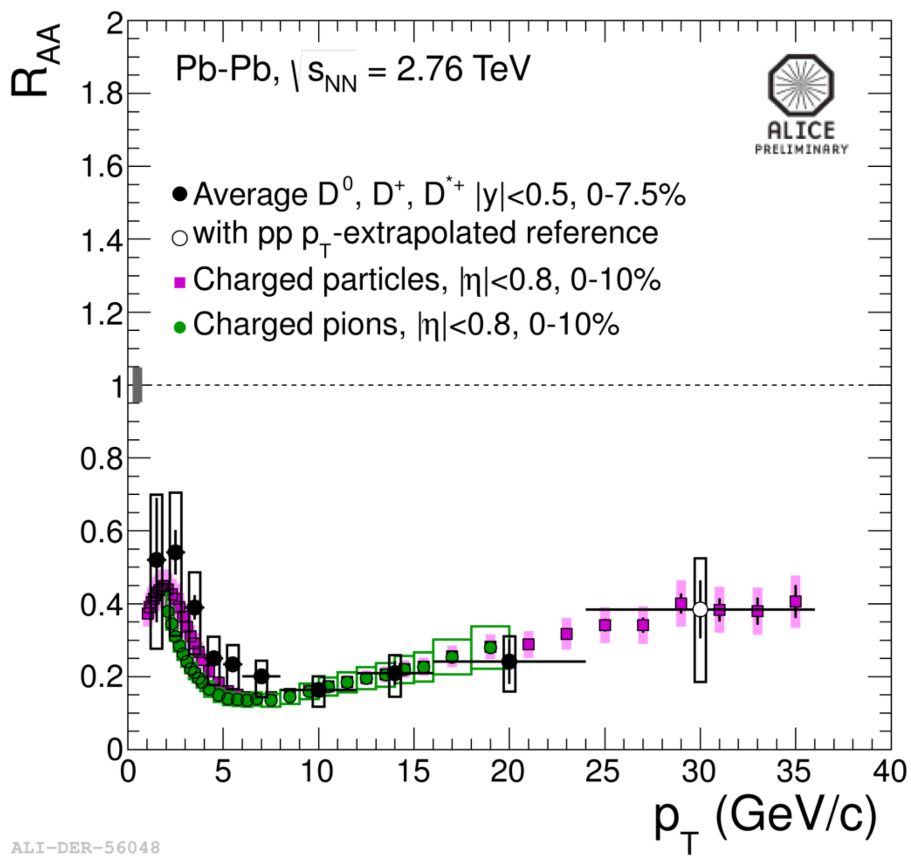
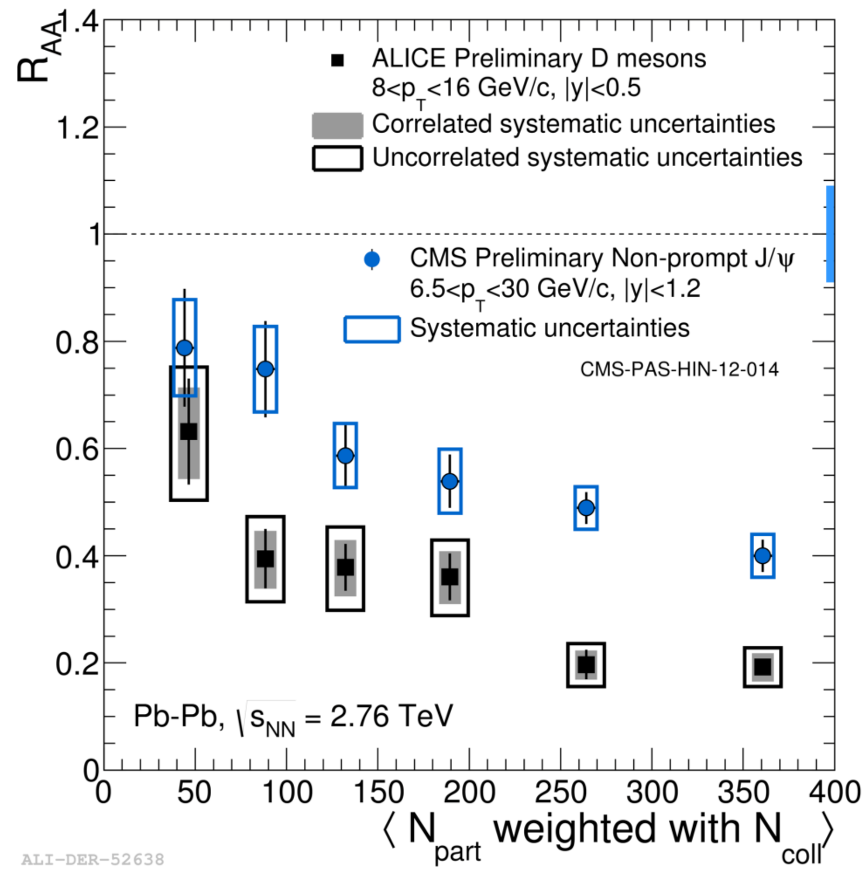
- Expectation from radiative energy loss: $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$
- Could be reflected in an hierarchy of R_{AA}: $R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$





- $R_{AA}(D) \sim R_{AA}(\pi)$
  (but different fragmentation and p_T spectra)
- $R_{AA}(B) > R_{AA}(D)$
  (but different fragmentation and p_T spectra)

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J/ψ in Pb-Pb

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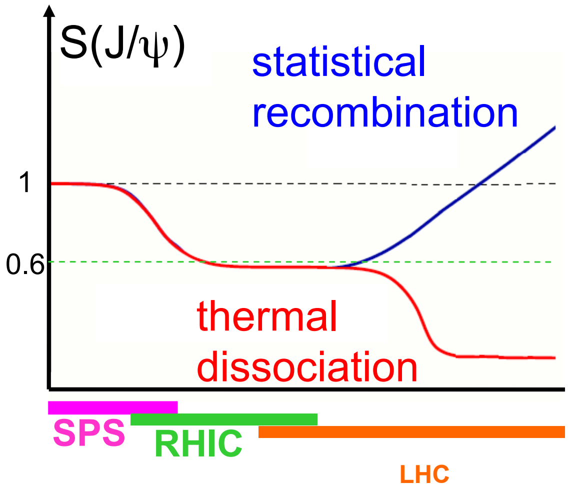
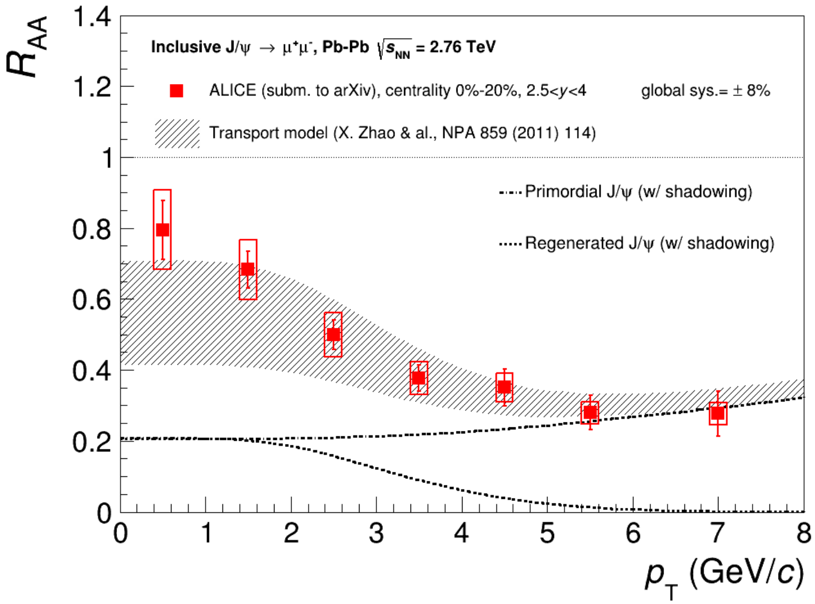
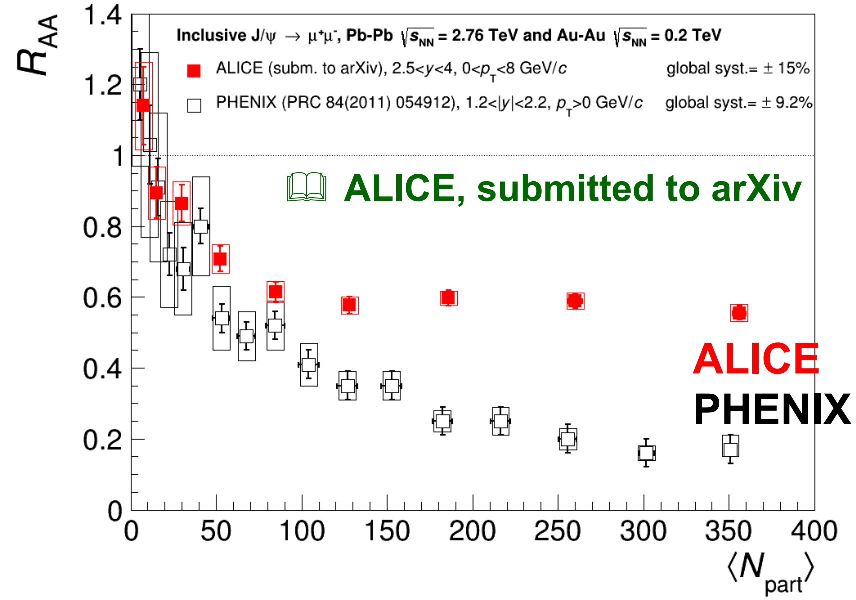


J/ψ→μ+μ- 2.5<y<4



📖 **ALICE, submitted to arXiv**



- J/ψ less suppressed at low p_T than at high p_T
- Different dependencies of J/ψ R_{AA} at RHIC and LHC
- As expected in a scenario with recombination
- Regeneration contribution important at low p_T

📖 **Liu, Qiu, Xu,Zhuang, PLB678(2009) 72**
📖 **Zhao, Rapp, NPA859(2011) 114**
📖 **Andronic et al., arXiv:1210.7724**

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Summary & Conclusions

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1 PbPb collisions

- ✓ Bulk production shows the expected strongly collective medium similar to RHIC
- ✓ Intriguing hints of a flavor hierarchy in the QCD transition
- ✓ Jet quenching has little effect on hadro-chemistry and jet structure
- ✓ Heavy and light quark energy loss very similar, hints of a b/c difference
- ✓ J/ψ p_T and centrality dependencies can be explained with dissociation/ recombination model.

2 pPb collisions

- ✓ Significant double ridge structure in angular hadron correlations, which can be explained with hydrodynamics (v_2) or CGC approach
- ✓ More hints of collective behavior in pPb from spectra (radial expansion, <pT>) and mass dependence of v_2 term
- ✓ Jets in pPb are not quenched and similar in pp jets in their structure

3 Characterising the deconfined phase and the crossover

- ✓ The system shows less flavor dependence in the deconfined phase than the crossover region

ALICE