Nuclear Modification of Light-Flavour Hadron Production with the ALICE Experiment

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ALICE

Motivation

Relativistic heavy-ion collisions produce a hot and dense state of strongly interacting matter, the Quark-Gluon Plasma (QGP). The presence of QGP has been observed to affect the yields of final state particles. High-p_T partons may lose energy while traversing the medium, resulting in the suppression of hadrons at high p_T (p_T > 8 GeV/c) with respect to the reference values obtained from binary-collision (N_{coll}) scaled pp measurements. This modification is quantified as the nuclear modification factor R_{AA}. Possible initial state effects due to the nuclear nature of the collision system are quantified in the absence of a QGP with measurements from p-Pb collisions.

The analysis of light flavoured hadrons with different quark content may reveal peculiarities regarding the partonic energy loss ΔE(u,d) vs. ΔE(s) at high p_T and the particle production mechanisms as well as the influence of initial state effects at low p_T.

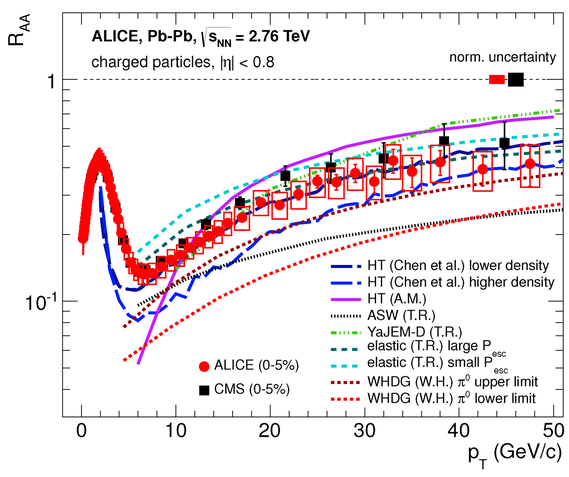

Fig. 1: R_{AA} of charged particles in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV measured by ALICE (*Phys. Lett.* B 720 (2013) 52)

ALICE detector

Main detectors used for these analyses:

- **Time Projection Chamber (TPC):**
  - Main tracking device.
  - Particle identification (PID) via specific energy loss (dE/dx) from low to high momenta.
- **Inner Tracking System (ITS):**
  - Primary and secondary vertex reconstruction.
  - Improved momentum measurement.
  - PID via dE/dx at low momenta.
- **Time Of Flight (TOF):**
  - Improved momentum measurement and
  - PID at intermediate momenta.

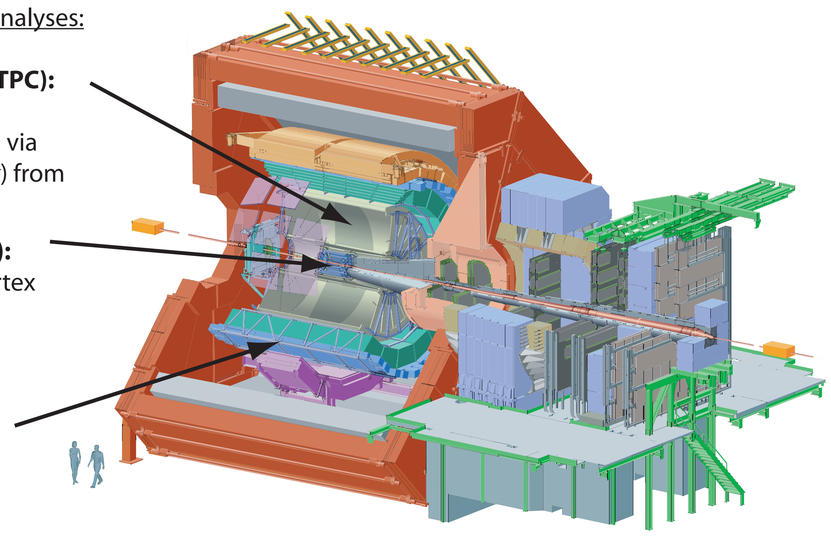

Fig. 2: Sketch of the ALICE experiment at the LHC

Results

Nuclear modification factor R_{AA} :

$T_{AA} = N_{coll} / \sigma^{pp}_{INEL}$: nuclear thickness function (Glauber model)

$$R_{AA} = \frac{1}{\sigma^{pp}_{INEL}\,\langle T_{AA}\rangle}\cdot\frac{(dN/dp_T)_{AA}}{(dN/dp_T)_{pp}}$$

- **High p_T:**
  - Strong suppression observed in Pb-Pb with respect to pp ⇨ large modification of p_T spectra and particle production in Pb-Pb.
  - $R_{AA}(h^{+,-}) = R_{AA}(h[u,d]) = R_{AA}(h[s]) = R_{AA}(h[c])$.
  - Mass-independent suppression.
- **Low p_T:**
  - Separation of baryon and meson modification.
  - Mass ordering.

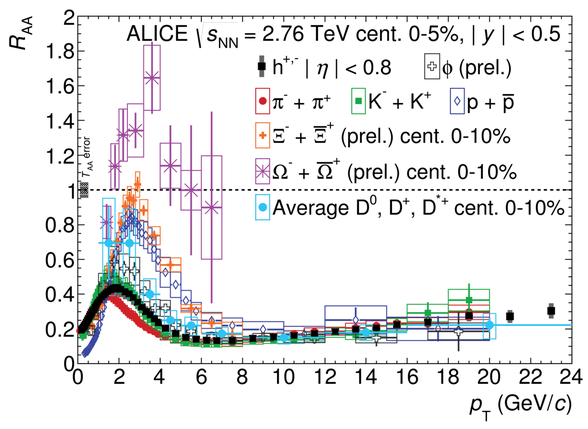

Fig. 3: R_{AA} of different hadrons in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV measured by ALICE (*arXiv:* 1506.07287 [nucl-ex], 1509.06888 [nucl-ex])

Nuclear modification factor R_{pPb} :

$T_{pPb} = N_{coll} / \sigma^{pp}_{INEL}$, where N_{coll} is the number of binary collisions in p-Pb

$$R_{pPb} = \frac{1}{\sigma^{pp}_{INEL}\,\langle T_{pPb}\rangle}\cdot\frac{(dN/dp_T)_{pPb}}{(dN/dp_T)_{pp}}$$

- **High p_T:**
  - No suppression observed in p-Pb with repect to pp.
  - All hadrons show similar, negligible modification.
- **Low p_T:**
  - Baryons show a strong modification in contrast to mesons for 2 < p_T < 8 GeV/c.
  - No significant mass ordering.
  - No Cronin enhancement visible for mesons within the uncertainties.

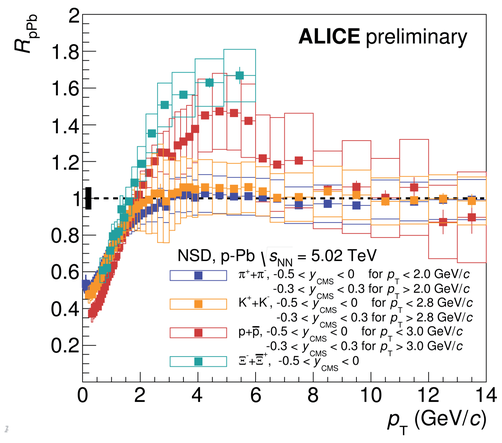

Fig. 4: ALICE preliminary R_{pPb} of different hadrons in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Discussion

Nuclear modification factor R_{AA} :

- **High p_T** (fig. 5 and 7):
  - Strong suppression in Pb-Pb of all species described by BAMPS (Boltzmann Approach to Multiparton Scattering) employing parton spectra from PYTHIA and AKK fragmentation functions.
  - 1. No splitting of baryons and mesons in BAMPS despite the different fragmentation functions, i.e. different quark and gluon fragmentation contribution, and the smaller energy loss of quarks by a factor of 9/4. (Splitting may occur at much higher p_T than measured here.)
    2. Similar modification for all considered hadrons in data and BAMPS with ΔE(u,d) = ΔE(s):
    ⇨ total in-medium energy loss in Pb-Pb collisions appears to be comparable for u,d and s quarks.
  - Particle production very likely via fragmentation in Pb-Pb since inside the jet the particle ratio agrees with pp, see fig. 7.

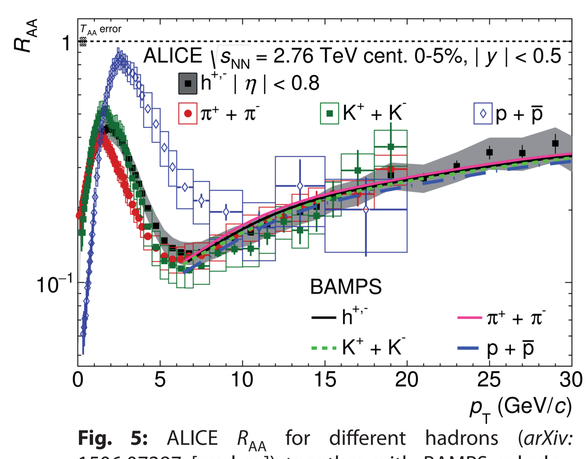

Fig. 5: ALICE R_{AA} for different hadrons (*arXiv:* 1506.07287 [nucl-ex]) together with BAMPS calculations (*Nucl. Phys.* A 931 (2014) 937)

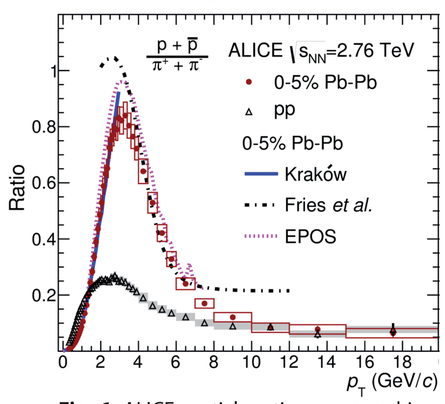

Fig. 6: ALICE particle ratios measured in central Pb-Pb and pp collisions (*Phys. Lett.* B 736 (2014) 196)

- **Low p_T** (fig. 6 and 7):
  - Mass ordering due to radial flow and particle production via recombination.
  - Baryon-to-meson separation: bulk phenomenon.

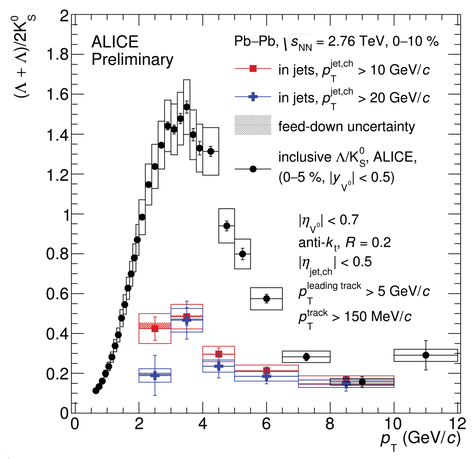

Fig. 7: ALICE preliminary ($\Lambda + \bar{\Lambda}$) / 2 K^0_s in charged jets in central (0-10%) Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV for trigger $p_T^{jet,ch}$ > 10 and 20 GeV/c (inclusive spectra: *Phys. Rev. Lett.* 111 (2013) 222301)

Nuclear modification factor R_{pPb} :

- **High p_T** (fig. 8):
  - R_{pPb} = 1: N_{coll} scaling seems to work, although the nuclear parton distribution functions (PDF) are different from the proton PDFs.
  - EPS09 with shadowing describes the measurements: initial state effects do not contribute to the suppression observed in R_{AA}.
  - HIJING 2.1 also agrees with the data within the large uncertainties of data and model.
  - In contrast to NLO, LO pQCD underpredicts the data above p_T = 4 GeV/c.

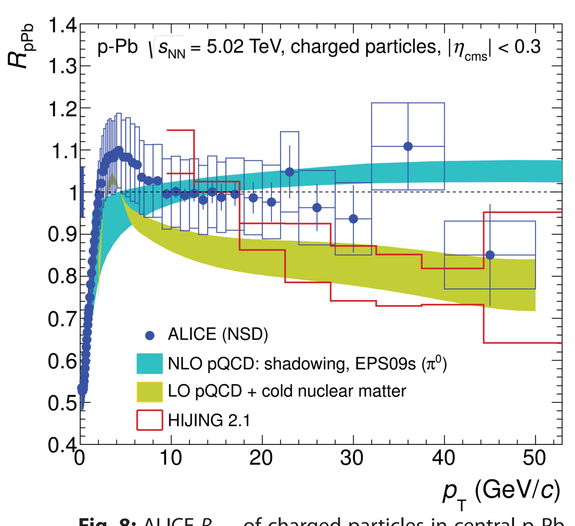

Fig. 8: ALICE R_{pPb} of charged particles in central p-Pb collisions at $\sqrt{s_{NN}}$ = 5.2 TeV (*Eur. Phys. J.* C 74 (2014) 3054)

- **Low p_T** (fig. 8 and 9):
  - Calculations in fig. 8 for π^0: differences to measured charged particle spectra were expected.
  - Cold nuclear matter effect in LO pQCD calculation describes data at very low p_T (< 4 GeV/c).
  - Enhancement of bulk part compared to the jet part is smaller by a factor of two in p-Pb than in Pb-Pb collisions (fig. 9).
  - Mass ordering or baryon-to-meson separation in fig. 4? :
    ⇨ Baryon enhancement (fig. 9) seems to be a bulk effect.
    ⇨ Is radial flow present in p-Pb collisions?

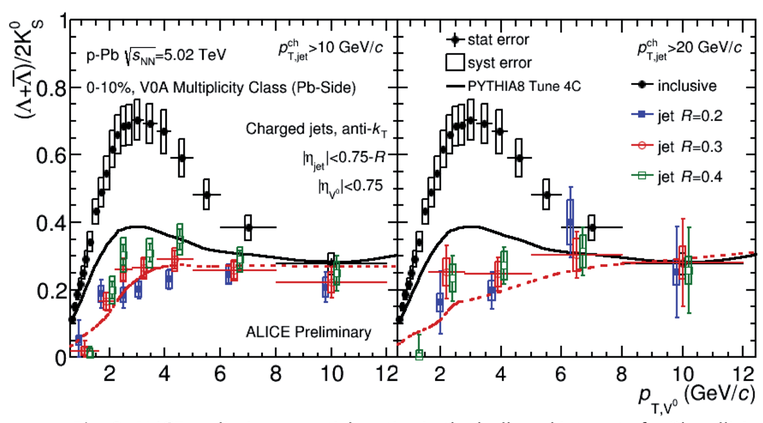

Fig. 9: ALICE preliminary particle ratios in the bulk and jet part of p-Pb collisions (0-10%) together with PYTHIA calculations (inclusive spectra: *Phys. Lett.* B 728 (2014) 25)

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