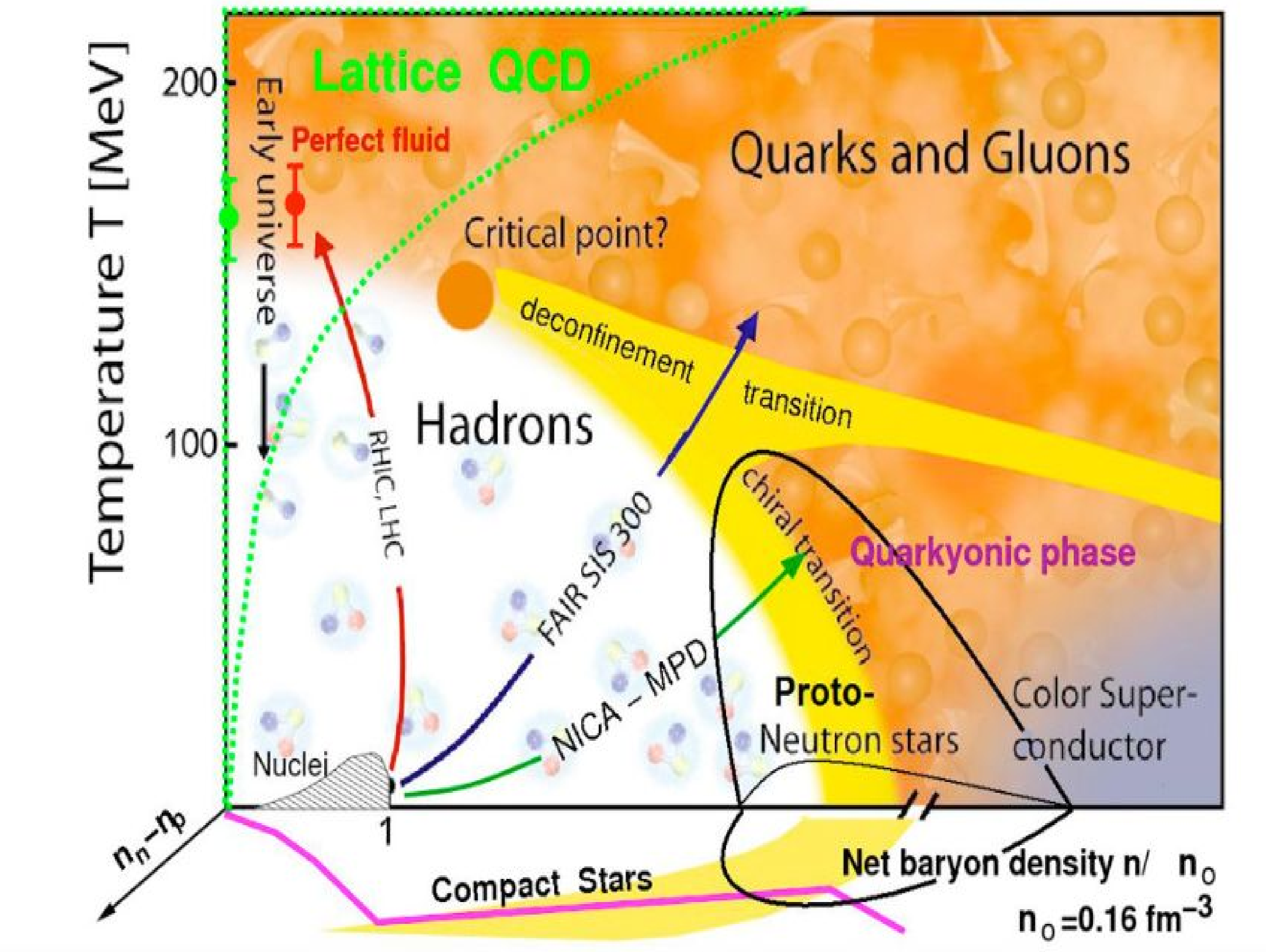
Heavy Ion Physics

Measurement of jet suppression in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.
ALICE 2015
arXiv:1502.01689v2

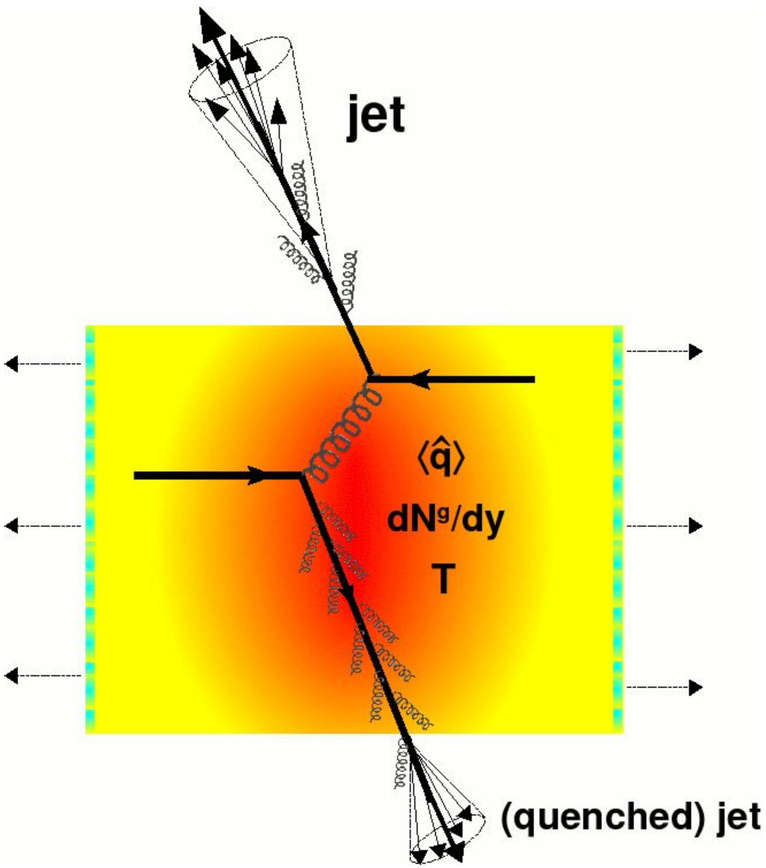
D Collaboration

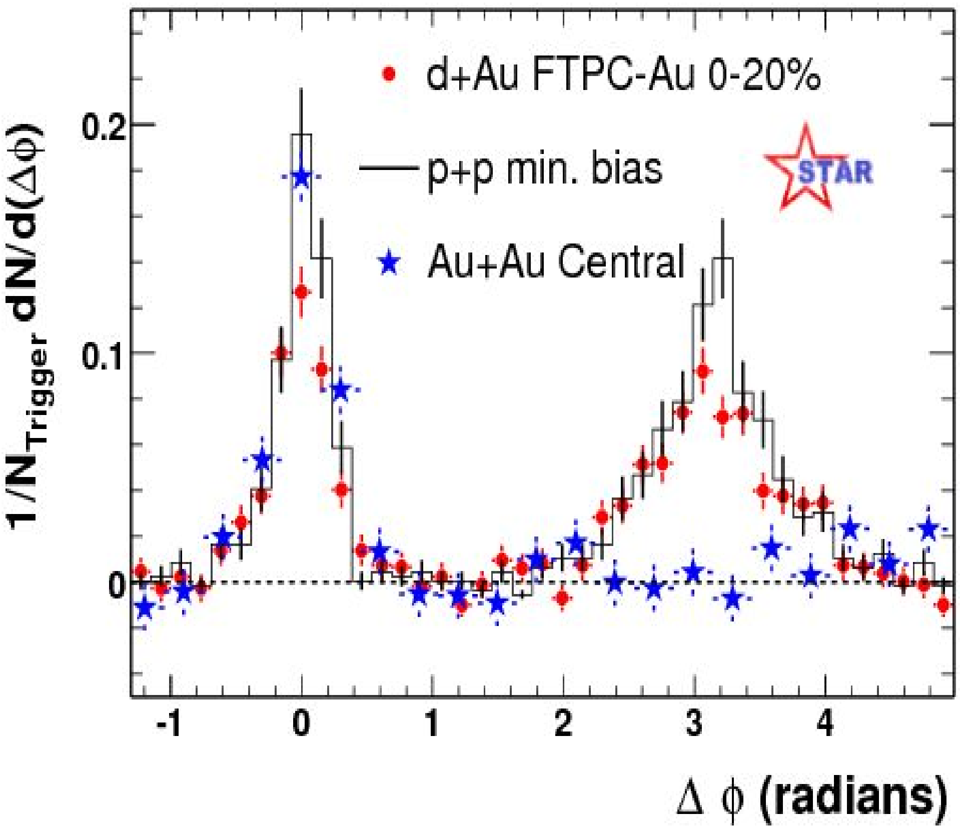
Motivation



A. Ayala CLASHEP (2017)

Jet quenching: Angular correlations





Rajeev S. Bhalerao, ArXiv:1404.3294v1 (2014)

Quenched Jets Properties

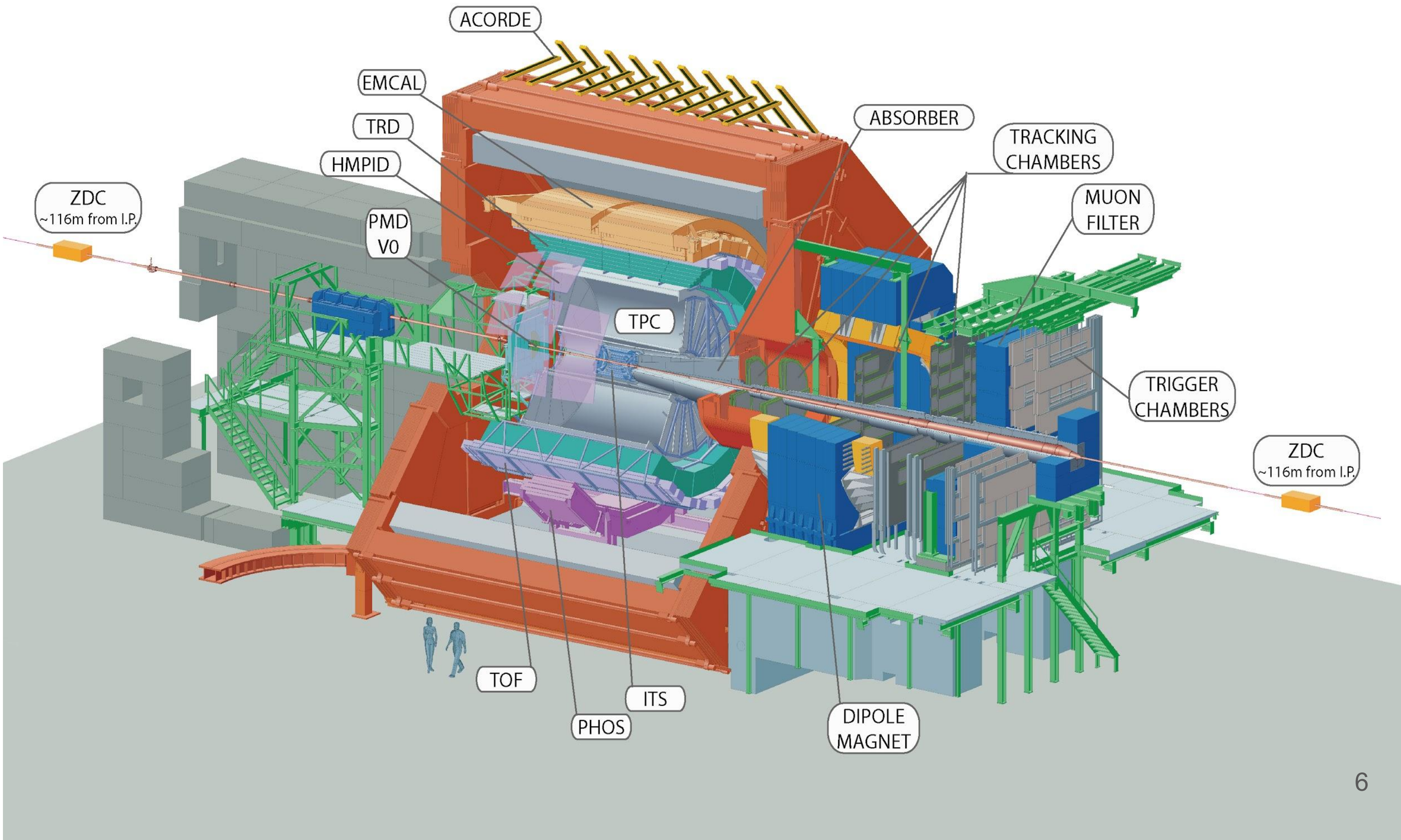
- Broadening of the jet shape.
- Softening of the jet fragmentation.
- Increasing out-of-cone gluon radiation.

Nuclear modification factor

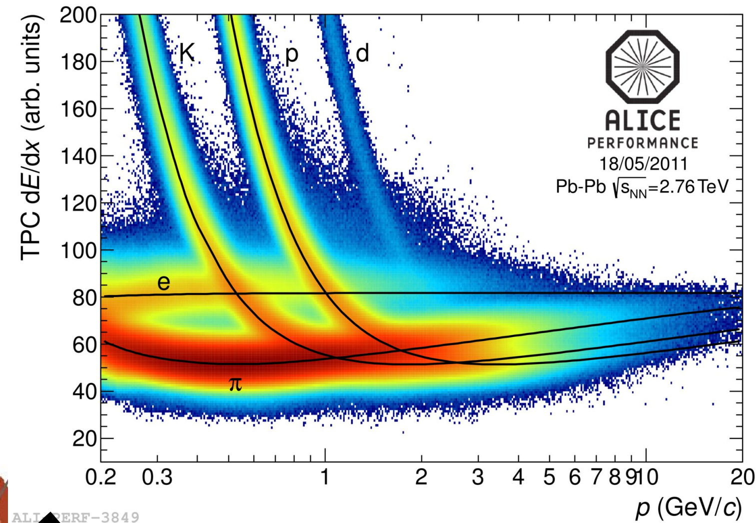
- Ratio of the jet spectrum in Pb-Pb divided by the spectrum in pp collisions scaled by $N_{col.}$

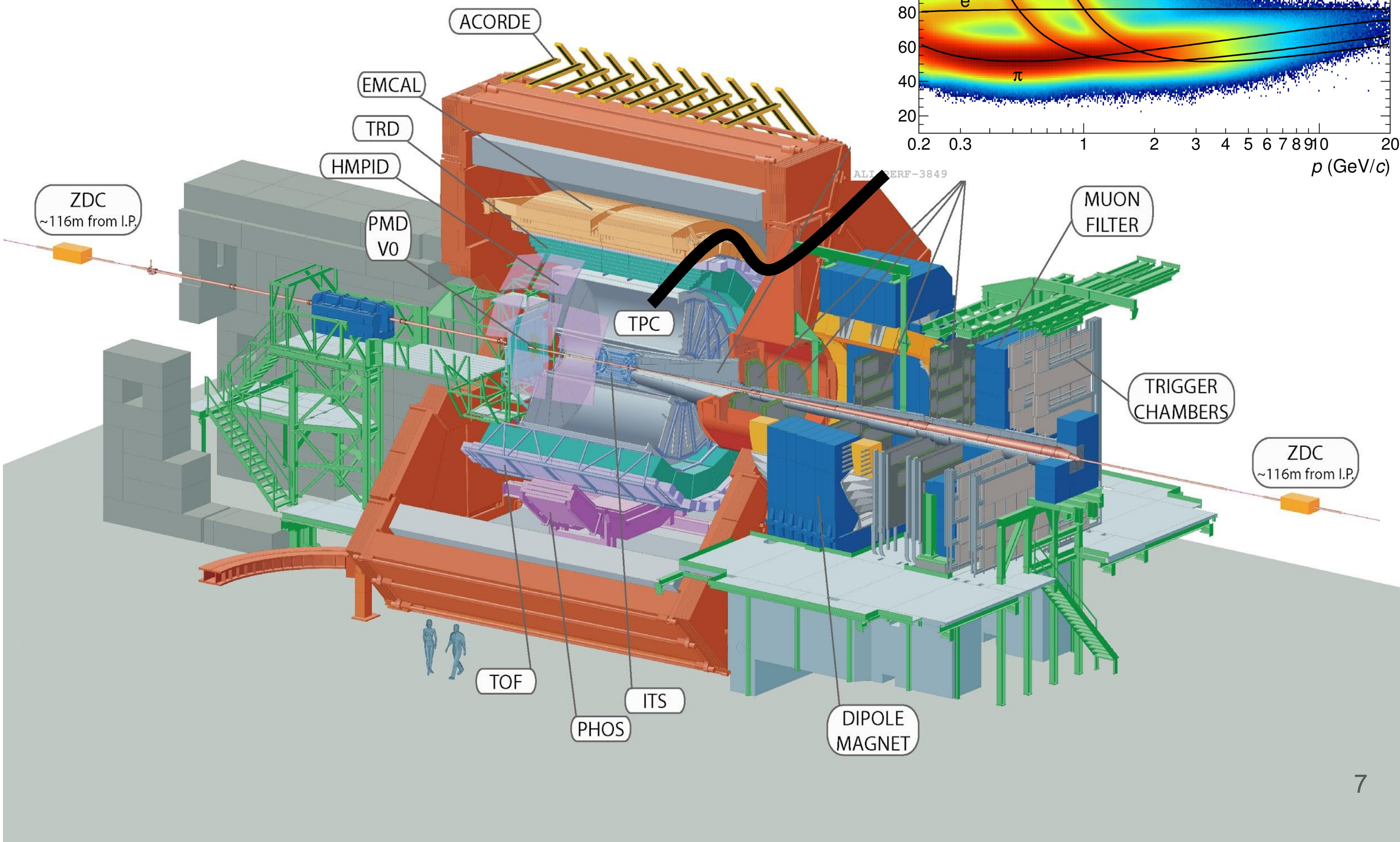
$$R_{AA}(p_T) = \frac{dN^{AA}(p_T)/dp_T}{\langle N_{\mathrm{col}}\rangle dN^{pp}(p_T)/dp_T}$$

Experimental setup



Acceptance covers 2π in azimuthal angle and a pseudo-rapidity interval |η|<0.9





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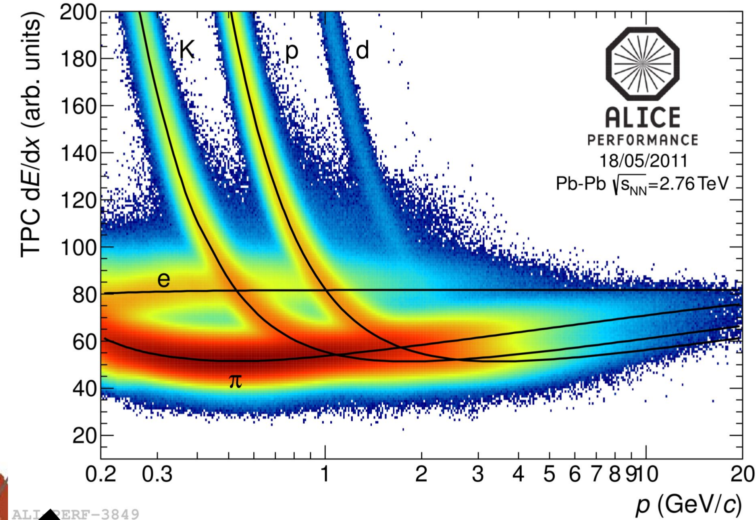
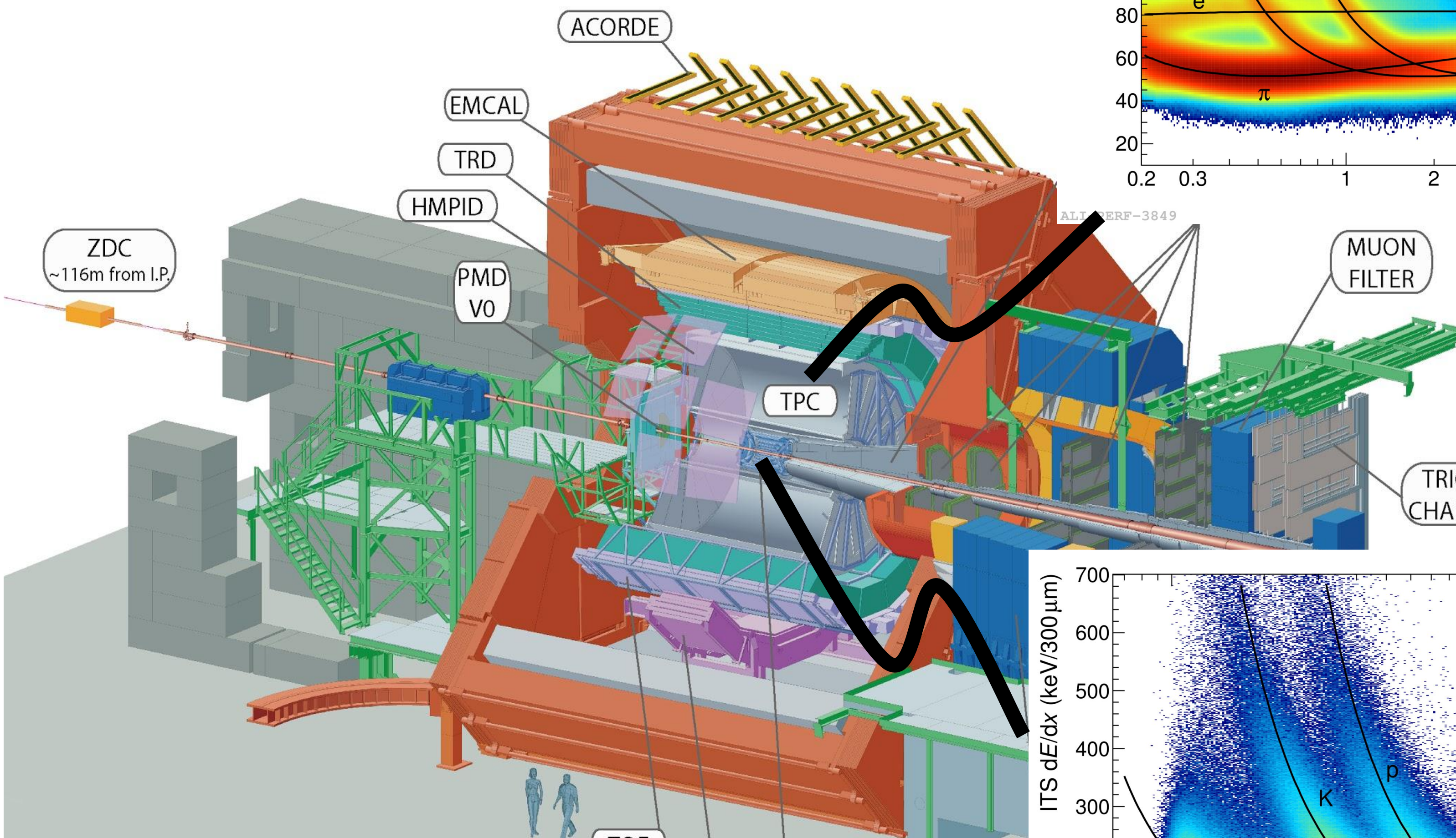
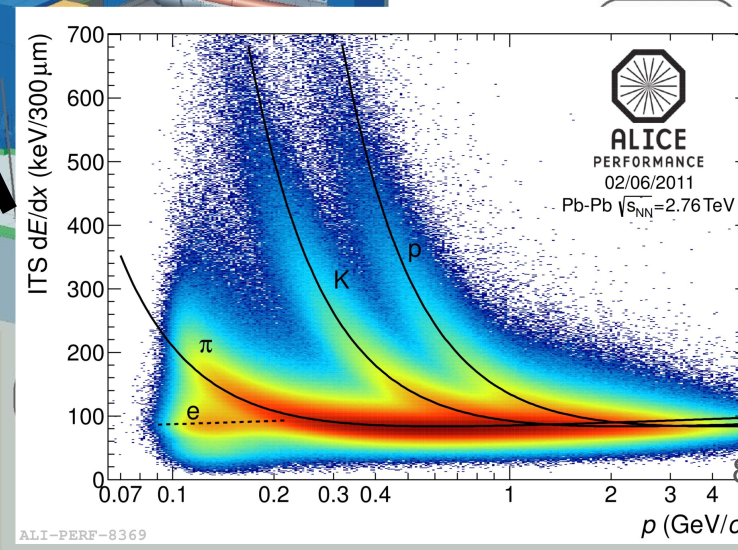
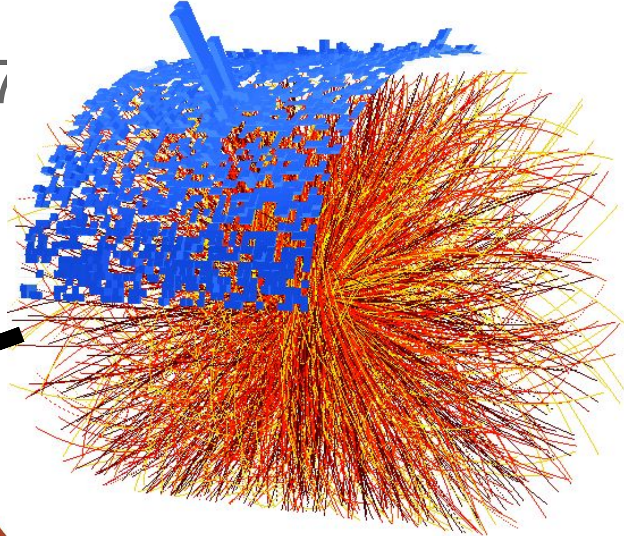


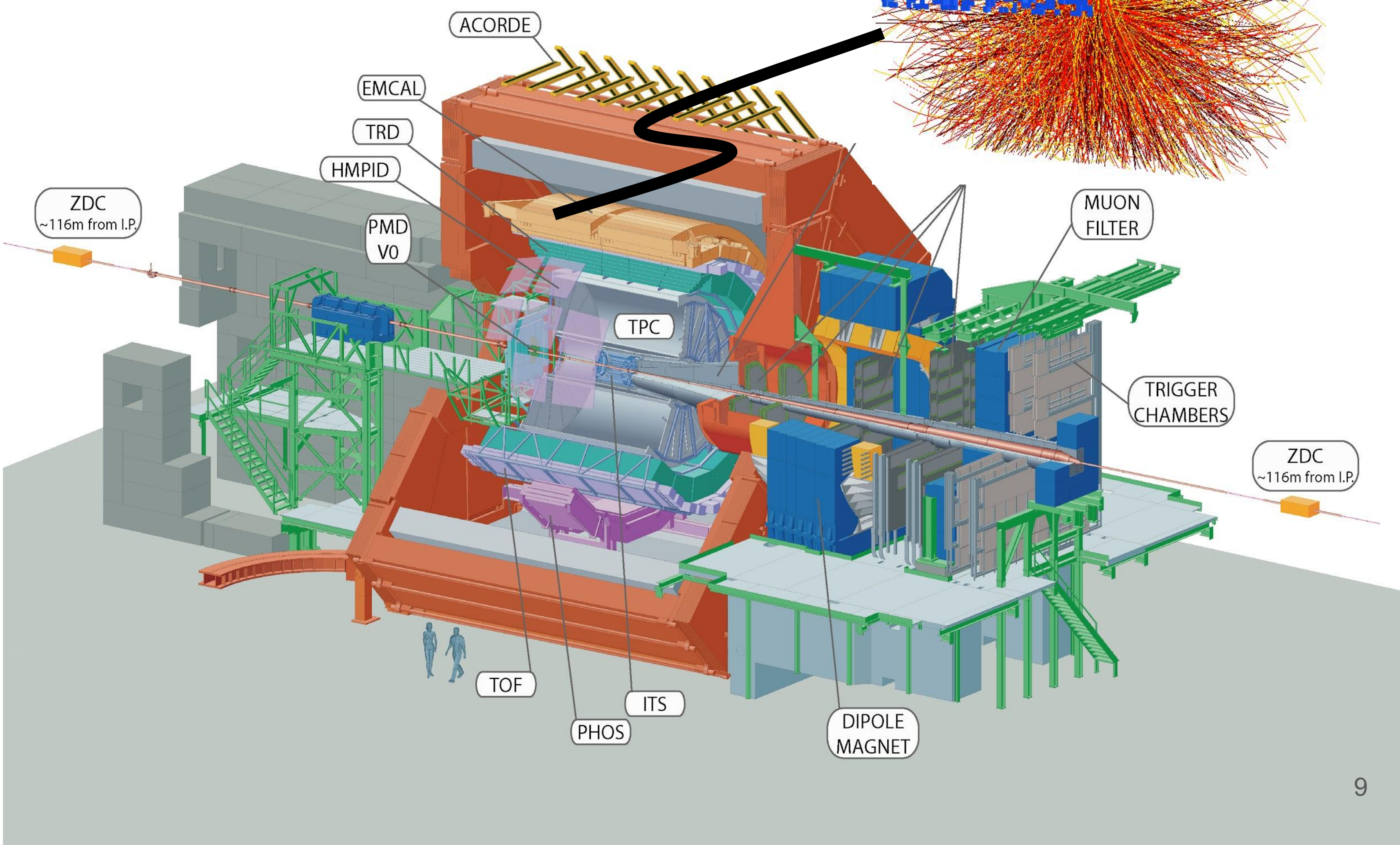




The two innermost layers (SPD) of the ITS detector covers the full azimuthal angle and a pseudo-rapidity interval |η|<2.0 and |η|<1.4

The EMcal is a Pb-scintillator that covers 107 degrees in azimuth angle and $|\eta|<0.9$





Event and Track Selection

- 11.5M and 5.7M events corresponding to 0-10% and 10-30% most central events were selected.

Track requirements

- At least 3 hits in the ITS.
- $0.15 < p_T < 100$ GeV/c in $|\eta|<0.9$
- At least 70 TPC space-points and no less than 80% of them in the TPC.

Avoid double counting

- Charged hadrons deposit energy via ionisation and nuclear interactions
- Remove the energy of the reconstructed tracks from the EMCal.

Jet reconstruction

Anti-k_T algorithm

$\Downarrow$

Signal jets

k_T algorithm

$\Downarrow$

Underlying event jets

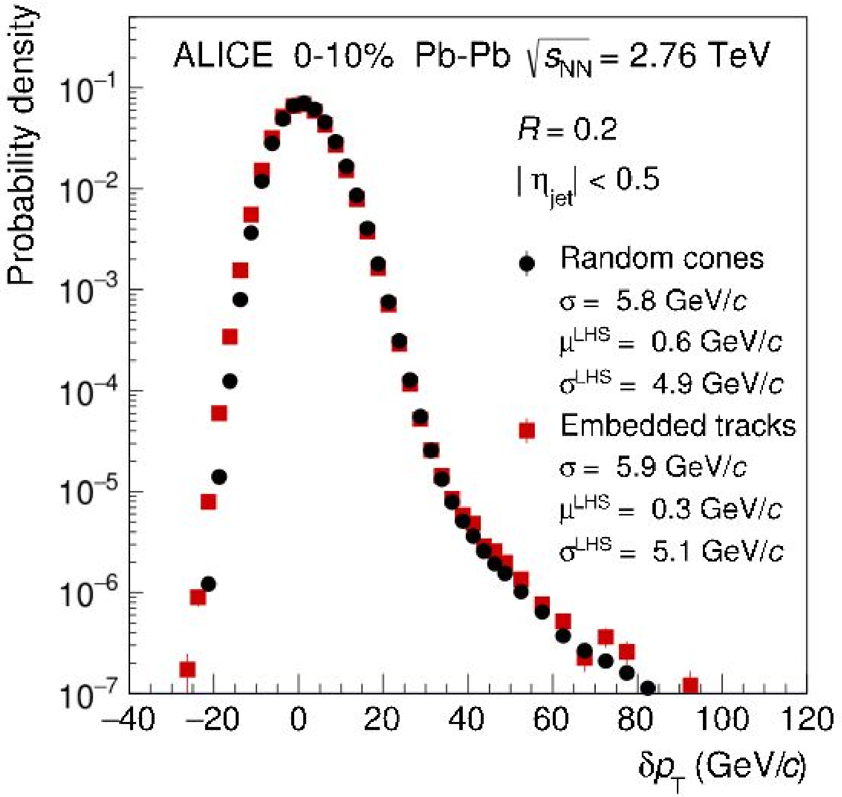
Signal jets are required to contain at least one charged particle with $p_T > 5$ GeV/c

Momentum corrections

- Background fluctuations lead to smearing of the reconstructed jet energy
- Random cone method

Background fluctuations were quantified as follows :

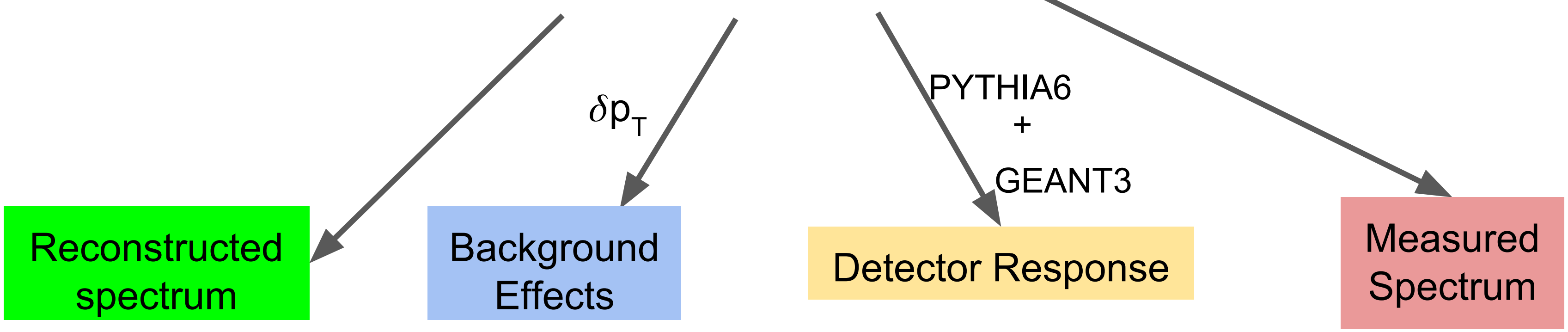
- $\delta p_T = p_T^{cone} - \rho_{momentum} \pi R^2$
- Neglect correlations of δp_T with azimuthal angle
- The magnitude of these effects was estimated to be <0.1GeV/c



Unfolding

- Correcting for detector efficiencies and biases introduced in removing the underlying event.

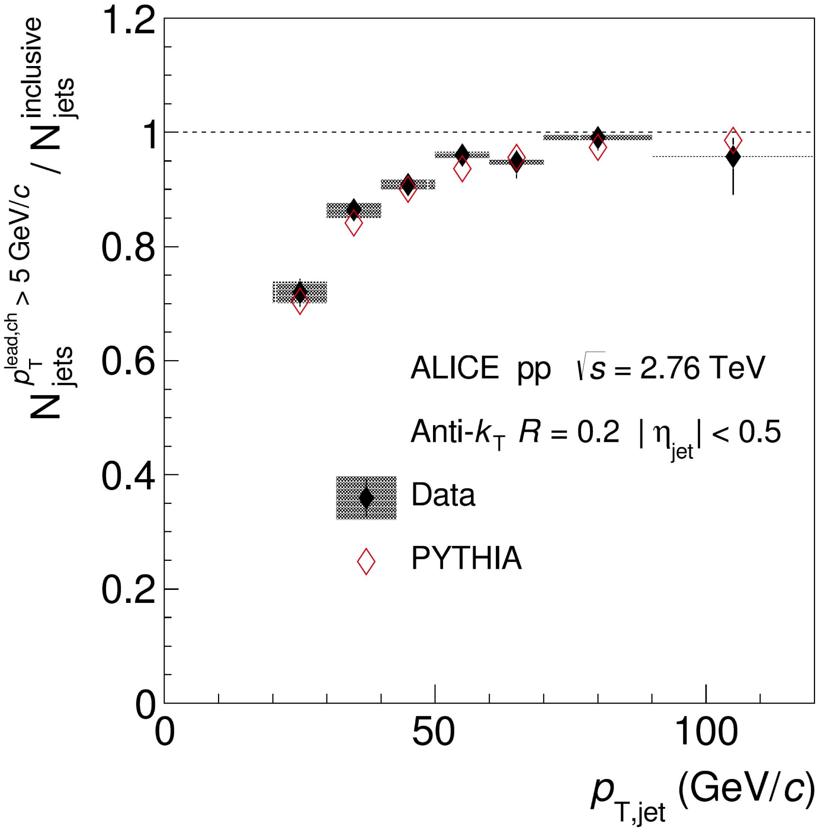
$$p_{T\ jet}^{reco} = M_{bkg} \times M_{det} \times p_T^{true}$$



- Unfolding introduces correlated errors that primarily affect a distortion of the jet energy spectrum. These uncertainties were estimated to be ~5.3%.

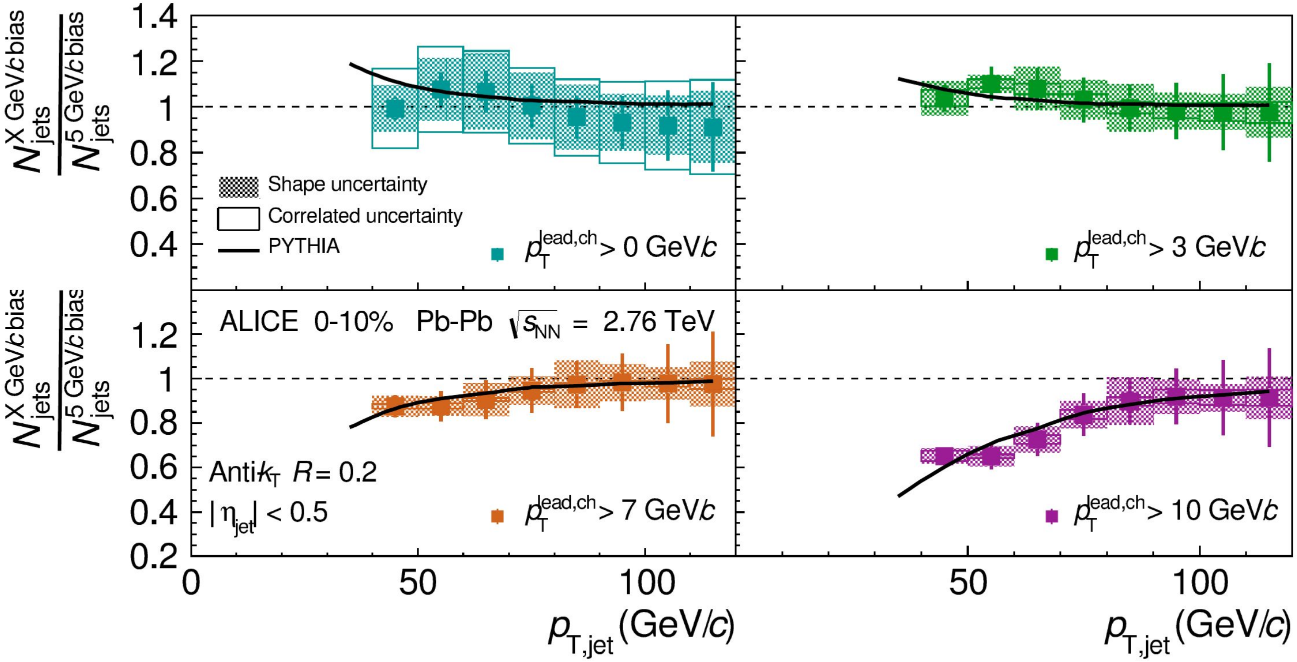
Results

Results: Leading track effects (I)



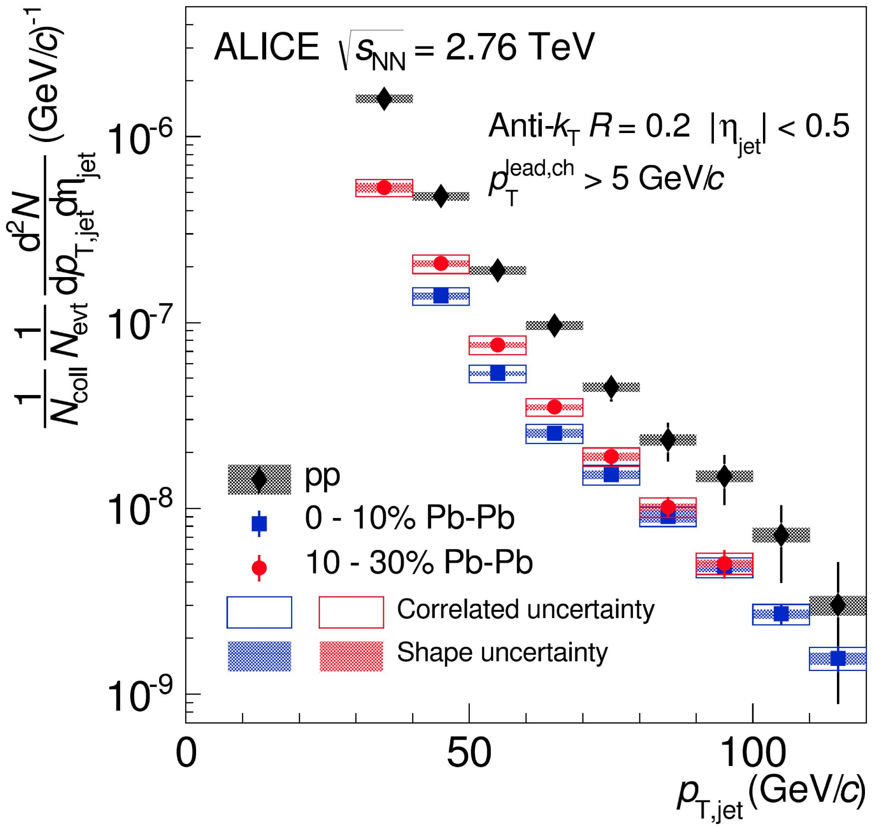
- A selection of jets with a leading track with $\mathbf{p_T}$ **> 5 GeV/c** was performed.
- At least 95 % of reconstructed jets with $\mathbf{p_{T,jet}}$ **> 50 GeV/c** have at least one track with $\mathbf{p_T}$ **> 5 GeV/c**.
- This shows that selecting jets with a leading track with $\mathbf{p_T}$ **> 5 GeV/c** is reasonable.

Results: Leading track effects (II)



- Ratios of jet spectra with different leading track requirements (*"0 over 5", "3 over 5", etc..*)
- Leading jets having p_T > 0 and 3 are consistent with the baseline of 5 GeV.
- The unfolding procedure is less stable when considering the p_T > 0 and 3 requirements.

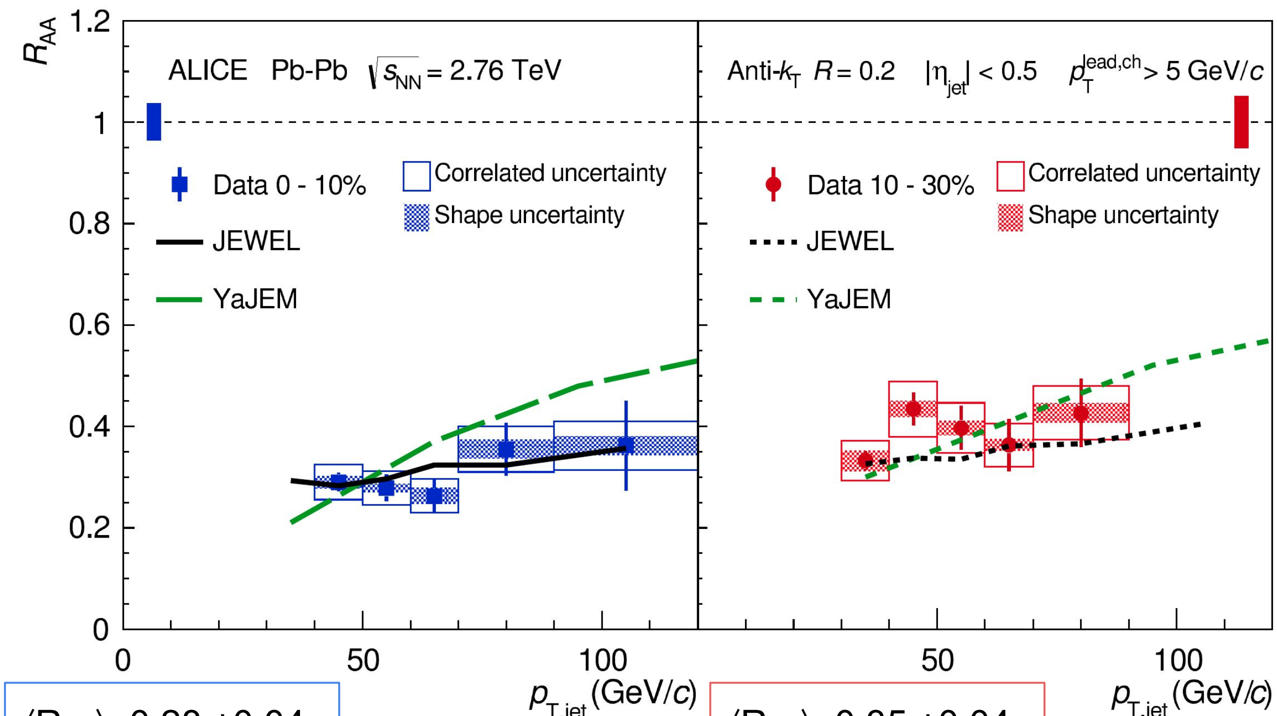
Results: Spectra Comparison



- Comparison of pp and Pb-Pb jets with leading track of p_T > 5 GeV/c
- In Pb-Pb collisions the jet spectra is shifted to lower p_T compared to the p-p collisions (*after proper normalization*)
- **This is a sign of jet quenching**

Results: Nuclear Modification Factor

- A strong suppression in the jet spectrum is found in terms of the R_{AA}.



$\langle R_{AA} \rangle$=0.28 ±0.04

$\langle R_{AA} \rangle$=0.35 ±0.04

- **JEWEL** uses a microscopical description of transport coefficients. (X^2 = 0.368)
- **YaJEM** uses a **hydrodynamical** approach, as well as a LO pQCD calculation and a Glauber MC. (X^2 = 1.690)

Summary

- Requiring a leading track of p_t>5 GeV/c is reasonable
- The scaled jet spectrum gets displaced to lower values of p_T in a Pb-Pb collision compared to the case with pp collisions
- A strong jet suppression is found for the case of Pb-Pb collisions, consistent with two models for R_{AA}.

Backup and removed slides

Event and Track Selection

Two classes of events were selected for analysis, using hit multiplicity in VZERO and the Glauber Model to estimate centrality:

0-10% centrality

10-30% centrality

Events were required to have $|z_{vertex}| < 10cm$

To provide sufficient accuracy and reduce azimuthal dependence of the selection, tracks were required to have:

$0.15 < pT < 100$ GeV/c and $|\eta| < 0.9$

>70 points and >80% of all track points in the TPC

> 3 hits in the ITS

Jets reconstruction

- Anti k_T and k_T algorithms with a resolution parameter of R = 0.2.

$$d_{ij} = d_{ji} = min(p_{ti}^2, p_{tj}^2)\frac{\Delta R_{ij}^2}{R^2} \qquad d_{iB} = p_{ti}^2$$

$$d_{ij} = min(\frac{1}{p_{ti}^2}, \frac{1}{p_{tj}^2})\frac{\Delta R_{ij}^2}{R^2} \qquad d_{iB} = \frac{1}{p_{ti}^2}$$

- Only jets that were at least R away from the EMCal boundaries of $|\eta|<0.7$ and $1.4 < \phi < \pi$, and thus fully contained within the EMCal acceptance, were kept in the analysis.
- Signal jets were required to contain at least 1 particle with $p_T > 5$ GeV.
- To correct for EM calorimeter double-counting, energy from charged tracks. associated with an EM_{cal} clusters was subtracted from the cluster energy.

Unfolding

Unfolding is used to correct for detector efficiencies and biases introduced in removing the underlying event. It also corrected for energy underestimation due to the track and EM_{cal} cuts.

$p_{T\ jet}^{reco} = M_{bkg} \times M_{det} \times p_T^{true}$

M_{det} is estimated by simulating p-p events and comparing truth reconstruction based on prompt particles with full reconstruction based on detector response

M_{bkg} is generated by placing the smearing spectrum δp_T shifted to each p_T

Unfolding introduces correlated errors that primarily affect a distortion of the jet energy spectrum. These uncertainties were estimated to be ~5.3%.

Data analysis

- Clusters selection
- Jets reconstruction
- Energy measurement corrections

Cluster selection

- The event with multiplicities corresponding to 0-10% and 10-30% most central collisions were selected using the Glauber model.
- The reconstructed primary vertex of accepted events was required to be within 10 cm of the center of the detector.
- Those reconstructed tracks were required to have at least 3 hits in the ITS in order to ensure an adequate track momentum resolution for the jet reconstruction.
- For the tracks without any hits in the SPD, the primary vertex location was used in addition to the TPC and ITS hits for the moment determination of the tracks.

Cluster selection

To reduce the azimuthal dependence of the track reconstruction efficiency, the accepted tracks were required to be measured with 0.15<p_T< 100 GeV/c and $|\eta|<0.9$, not less than 80 % of space-points in the TPC and the dependence between the efficiency and azimuthal angle was estimated using MC tools (GEANT3 and HIJING). The momentum resolution $\delta p_T/p_T$ is about 1% at 1 GeV/c and about 3% at 50 GeV/c. Interactions of slow neutrons or highly ionizing particles are removed from the analysis.

To avoid double counting, the energy deposited in the EMCal by charged particles that were already reconstructed as tracks, the clusters' energy were corrected as follows: all tracks with p_T>0.15 GeV/c were propagated to the average cluster depth within the EMCal, and then associated to clusters with E_T > 0.15 GeV within $|\eta|<0.015$ and $|\Delta\varphi|<0.025$. Tracks were always matched to their nearest cluster. Clusters were allowed to have multiple track matches. Clusters with matched tracks were corrected for charged particle contamination by removing 100% of the sum of momenta of all matched tracks. Clusters with E_T > 0.30 GeV after this correction were used in this analysis.

Momentum corrections

The region-to-region background fluctuations lead to to smearing of the reconstructed jet energy.The magnitude of this fluctuations were estimated in two differents way:

- by taking the scalar sum of the p_T of all particles found in a cone randomly placed in the event (random-cone method.
- Embedding a single particle in the event and inspecting the anti-k_T jet that contains that embedded particle (embedded track method).

The background fluctuations were quantified as follows :

- $\delta p_T = p_T^{cone} - \rho_{scaled}\, \pi R^2$ for the random-cone method
- $\delta p_T = p^{reco}{}_{T,jet} - \rho_{scaled}\, \pi R^2$ for embedded-track method

Momentum corrections

The two methods appear to provide the same quantitative response to the background fluctuation,with only marginal differences mainly due to small jet area fluctuations in the embedding track method.

The widths of the δp_T distributions are about 6 GeV/c , the left-hand-side of the distributions is Gaussian-like and the right-hand-side has additional contributions from hard scattering process, and this results in a non-Gaussian at high δp_T due to overlapping jets.

Both the average background and the background fluctuations are average over all possible orientations of the event plane, assuming that the jet sample being analyzed is isotropically distributed respect to the event plane.

Momentum corrections

However the jet sample may show some degree of correlation with the event plane, for physicals(path length dependence of the jet energy loss) and analysis (the requirements of the leading hadron p_T).Also the background is correlated with the event plane due to flow (v_2).

The upper limits on the magnitude of these effects have been estimated by using random cones biased towards the event plane , either by requiring the presence of a 5 GeV/c track or weighting the distribution using an upper limit on the jet v_2 of 0.1.

In both cases,the upper limits on the shift of the jet energy scale (JES) were found to be smaller than 0.1 GeV/c.

When selecting events a cut is applied requiring constituent energies of >150MeV for tracks and 300MeV (charged track corrected energy) for clusters.

No such cut was applied to MC truth, so this cut is 'corrected for' by the unfolding process. This mainly accounts for undetected neutral particles and tracking inefficiency.

The result was a net energy shift of the Jet Energy Scale of -23% to -29%.