Measurement of jet spectra with charged particles in Pb-Pb collisions at $\sqrt{s_{_{NN}}}=2.76$ TeV with the ALICE detector

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Jets in Heavy-Ion Collisions

- Probes to study properties of medium
- Due to interaction of the jet with the medium, the jet is modified: Jet Quenching

Experimental challenge in HI collisions:
Separate jet signal from large soft background originating from bulk

- In this analysis $R=0.2$ and $R=0.3$ anti-$k_T$ jets with $p_{T,\text{track}}>150$ MeV/c
Jets in HI events: background

Event-by-event subtraction of average background momentum density $\rho$.

Background fluctuations quantified by embedding high $p_T$ probes in Pb-Pb events

Width of fluctuations for jets with constituent $p_T>150$ MeV/c:

$\sigma(\delta p_T, R=0.2) = 4.5$ GeV

$\sigma(\delta p_T, R=0.3) = 7.1$ GeV

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Jets in HI events: background

Combinatorial jets: clusters which do not originate from a hard process. Reduced by triggering jets with a leading track of $p_T > 5$ and 10 GeV/$c$.

Combinatorial / fake jets

Jets reconstructed from charged particles with $p_T > 150$ MeV/$c$. 
Unfolding

Raw jet spectra need to be corrected for background fluctuations.

Background fluctuations shift low $p_T$ jets to high $p_T$.
Background and detector corrections

Raw jet spectra need to be corrected for background fluctuations and detector effects.

Background fluctuations shift low $p_T$ jets to high $p_T$.

Detector effects shift jets to lower $p_T$.
Jet Suppression

Corrected jet spectra:
Leading track requirement $\rightarrow$ fragmentation bias at low $p_T$
Jet Suppression

Corrected jet spectra:
Leading track requirement → fragmentation bias at low $p_T$

Strong jet suppression observed.
Fragmentation bias the same for central and peripheral events.
\( \sigma(R=0.2)/\sigma(R=0.3) \) consistent with vacuum jets for peripheral and central collisions → no sign of jet broadening

Good agreement with energy loss MC JEWEL.

\[ JEWEL: \text{Zapp, Krauss Wiedemann arXiv:1111.6838} \]
Summary

- ALICE measures charged particle jets with constituents $p_T > 150$ MeV/c
  - Average HI background is subtracted event-by-event
  - Background fluctuations and detector effects are corrected by unfolded
- Strong jet suppression in central events
  - Fragmentation bias due to leading track requirement the same for central and peripheral events
- No signs of modified jet structure observed in ratio of jet cross sections $\sigma(R=0.2)/\sigma(R=0.3)$
backup
Model Comparison
Jet $R_{AA}$: ALICE vs JEWEL

JEWEL reproduces
→ Hadron $R_{AA}$ (Zapp, Krauss Wiedemann arXiv:1111.6838)
→ Charged jet $R_{AA}$ for R=0.2 and R=0.3
Jet $R_{CP}$

Strong suppression for jets
No strong $p_t$ dependence

Central events jet $R_{CP} \sim 0.5$
Peripheral closer to 1
Unfolding the background

- Need to **unfold** measured jet spectrum to obtain 'real' jet spectrum (**Truth**)
- Low $p_t$ jets are dominated by random collections of particles → background jets. These appear up to very high $p_t$. 

![Graph showing the distribution of jet spectra with $p_{t,emb} = 15$ GeV/c and comparing measured, toy, and ALICE data with different cross sections.](image)
Jet Reconstruction

- ALICE uses sequential recombination algorithms from FastJet package:
  - anti-$k_t$ for signal (stable area)
  - $k_t$ to estimate background density
  - Boost invariant $p_t$ recombination scheme (sets jet mass to zero)
  - Charged tracks with $p_t > 150$ MeV/c

- Jet reconstruction with charged tracks reconstructed in tracking detectors (ITS + TPC):
  - High precision on particle level
  - Uniform $\eta$-$\phi$ acceptance: $|\eta|<0.9$ $0<\phi<2\pi$
  - Neutral energy missing, eg. $\pi^0$, n, $\gamma$
    measurement not corrected for neutral energy
  - No correction for hadronization effects

15M events from 2010 Pb-Pb run
Jet spectra have been measured for 2 cone radii and 4 centrality bins.
Jet Constituents

Spectra corrected for detector level effects for particles with $p_t > p_{t,\text{min,track}}$.

R=0.2: PbPb very similar to Pythia → shift of spectrum in $p_t$ for PbPb and Pythia. Not many soft particles in small cone of R=0.2.
Uncorrected Jet Spectra

$R=0.4$

Pb-Pb $\sqrt{s_{NN}}=2.76$ TeV

Charged Jets
Anti-$k_T$, $R = 0.4$
$p_T^{\text{track}} > 0.15$ GeV/c
Area > 0.4

$\sigma(\delta p_T) \sim 11$ GeV

$\sigma(\delta p_T)$ values for central events

$R=0.3$

Pb-Pb $\sqrt{s_{NN}}=2.76$ TeV

Charged Jets
Anti-$k_T$, $R = 0.3$
$p_T^{\text{track}} > 0.15$ GeV/c
Area > 0.25

$\sigma(\delta p_T) \sim 7$ GeV

$\sigma(\delta p_T)$ values for central events

$R=0.2$

Pb-Pb $\sqrt{s_{NN}}=2.76$ TeV

Charged Jets
Anti-$k_T$, $R = 0.2$
$p_T^{\text{track}} > 0.15$ GeV/c
Area > 0.07

$\sigma(\delta p_T) \sim 4.5$ GeV

Less Background Fluctuations

Smaller Jets $\rightarrow$ Less Background Fluctuations
Area dependence

- Multiplicity bin typical for 10% most central events
- Reduced background fluctuations for smaller jet areas
- Measured $\sigma(\delta p_T)$ larger than naive expectation from only statistical fluctuations
  $\rightarrow$ flow and hard jets
Background Fluctuations

- Background fluctuations estimated by studying the response of embedded high $p_T$ probe in heavy ion event.

- Data driven approach to estimate influence of background fluctuations on jet reconstruction.

- We embed different kind of probes:
  - Random cones
  - Single tracks
  - Jets from full detector simulation pp @ 2.76 TeV

- Response is quantified by comparing the reconstructed jet to the embedded probe:

\[
\delta p_T = p_{T, jet}^{rec} - \rho A - p_{T, probe}
\]
Event Background

- Event-by-event background subtraction

\[ \rho = \text{median} \left( \frac{p_T^{\text{jet},i}}{A_i^{\text{jet}}} \right) \]

- Background density scales with event multiplicity:
  \[ \rho \sim N \langle p_T \rangle \]

- 0-10% centrality:
  \[ \langle \rho \rangle \sim 140 \text{ GeV/area} \]
  \[ \rightarrow 70 \text{ GeV/c for } R=0.4 \text{ cone} \]

- Event-by-event fluctuations of \( \rho \) for fixed multiplicity.