Exploring the jet substructure in pp and Pb-Pb collisions at LHC energies with ALICE

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ITS+TPC: charged particle tracking down to $p_T = 150$ MeV/$c$
$|\eta| < 0.9$, $0 < \varphi < 2\pi$

EMCal and DCal/PHOS allow for full jets measurements
Introduction: jet quenching in Pb-Pb

- Jets are quenched in quark-gluon plasma.
- What happens with the internal structure of a quenched jet?
- How does the internal structure affect quenching?
Jet Substructure in QGP

- Idea: study the parton shower in QGP
- Analyze the final-state jet and its clustering history
- Select the observables of interest
- Today’s focus: declustering with Soft Drop
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medium-induced emissions
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medium-induced emissions
in-medium splittings
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medium-induced emissions
in-medium splittings
coherent/incoherent energy loss
Soft Drop

1. Find jets with (anti-$k_T$-algorithm), recluster them with C/A algorithm.
2. Undo the last C/A clustering step (jet $\rightarrow$ two subjets).
3. Remove the softer subjet, if the SD condition is not fulfilled.
4. Repeat (2-3) until the SD condition is fulfilled (or no subjets left).

\[
\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left( \frac{\Delta R_{12}}{R_0} \right)^\beta
\]
Soft Drop (SD) searches for a hard splitting within a jet by recursively removing soft subjets.

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$\beta = 0$

$z_{\text{cut}} = 0.1$
Reference measurement in pp collisions

In vacuum:

\[ p(z_g) = \frac{P(z_g)}{\int_{z_{cut}}^{1/2} dz \bar{P}(z)} \Theta(z_g - z_{cut}) + O(\alpha_s^2) \]

- unfolded \( z_g \) in pp at 7 TeV
- validation of PYTHIA as a reliable reference for the Pb-Pb measurement

\[ z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} \]
More $z_g$ measurements in small systems

Full jets in pp at 13 TeV

Charged jets in p-Pb at 5 TeV

- number of systems and energies explored
- overall good agreement with PYTHIA
Reference measurement in pp collisions

- unfolded $R_g$ in pp at 7 TeV
- track-based jets -> low $\Delta R$ region accessible
Reference measurement in pp collisions

\[ \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \]

- total number of hard splittings identified in a jet
- well described by PYTHIA

recursive SD: always proceed into the harder branch
Pb-Pb results: $z_g$

- For Pb-Pb results are not unfolded
- Comparison with the smeared PYTHIA reference
- normalized to the number of jets before grooming
- suppression of the symmetric configurations in Pb-Pb
Pb-Pb results: $z_g$ in $\Delta R$ bins

- Suppression pronounced at large opening angles between subjets, $\Delta R > 0.1$
- Hint for enhancement at low angular separation ($\Delta R < 0.1$)
- Relevance for the antenna energy loss in QGP
Pb-Pb results: total number of hard splittings

- the number of hard splittings is not increased in Pb-Pb
- a hint for the $n_{SD} = 0$ enhancement
On-going work: the Lund map

- measure the Lund plane of jet splittings
- detailed snapshot of jet substructure in natural coordinates

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Summary

- ALICE jet program is extended with the substructures studies
- Hard jet substructure in Pb-Pb explored with Soft Drop declustering
  - $z_g$ is suppressed for large $\Delta R$ configurations
  - No increase in the number of hard splittings ($n_{SD}$) found
- Other substructure measurements available
  - (nsubjettiness, girth, ...)

Further directions

- Improve and advance existing measurements with the new 2018 sample Pb-Pb at 5 TeV
- On-going work on new substructure ideas: the Lund map measurement, substructure with heavy-flavor (sub)jets, ...