Jet fragmentation with the ATLAS detector

Martin Spousta
on behalf of the ATLAS Collaboration

Charles University

Introduction

- The goal is to study the modified fragmentation of jets originating from partons passing through the hot and dense medium in Pb+Pb collisions.
- Tools: full jets measured in the calorimeter + charged particles measured in the inner detector.
- UE corrected anti- k_T jets with $R=0.4$, $R=0.3$, and $R=0.2$ with $p_T > 100, 92$, and 85 GeV, respectively, within $|\eta| < 2.1$.
- Data: 2011 Pb+Pb run of $140 \mu\text{b}^{-1}$, events triggered using high-level trigger. In total, 60M events analyzed.
- MC: PYTHIA jets embedded to minimum-bias Pb+Pb Data.

Jet performance

Jet energy
resolution

Jet energy
scale

- Jet performance in terms of jet energy scale, jet energy resolution, and jet reconstruction efficiency.
- Different jet radii exhibit different level of influence by the sizable UE => measurement using different jet radii serves as a baseline cross-check of results.

Track selection in Pb+Pb

MC to data comparison
of tracking performance

- Tracks match to jets using $\Delta R = 0.4$ for all three radii.
- Track selection based on number of hits in Silicon tracker and Pixel detector and significance of pointing to the vertex.
- Tracks with $p_T > 2 \text{ GeV}$ and $|\eta| < 2.5$ used

Jet fragmentation observables

- Measured quantity #1: Distribution of momentum of fragments inside jets, $D(p_T)$.

$$\begin{aligned} D(p_T)(p_T^{jet}) &= \frac{1}{N_{jet}} \frac{1}{\epsilon} \frac{dN}{dp_T} (p_T^{jet}) = \\ &= \frac{1}{N_{jet}(p_T^{jet})} \frac{1}{\epsilon(p_T, \eta)} \left(\frac{\Delta N_{ch}(p_T, p_T^{jet})}{\Delta p_T} - \frac{\Delta N_{ch}^{UE}(p_T, p_T^{jet})}{\Delta p_T} \right) \end{aligned}$$

Tracking efficiency
correction

Underlying event
subtraction

- Further, the central-to-peripheral ratio of the $D(p_T)$ distribution, $R_{D(p_T)}$, is evaluated.

Jet fragmentation observables

- Measured quantity #2: Distribution of longitudinal momentum fraction of fragments with respect to jet, $D(z)$.

$$\begin{aligned} D(z)(p_T^{jet}) &= \frac{1}{N_{jet}} \frac{1}{\epsilon} \frac{dN}{dz} (p_T^{jet}) = \\ &= \frac{1}{N_{jet}(p_T^{jet})} \frac{1}{\epsilon(p_T, \eta)} \left(\frac{\Delta N_{ch}(z, p_T^{jet})}{\Delta z} - \frac{\Delta N_{ch}^{UE}(z, p_T^{jet})}{\Delta z} \right) \end{aligned}$$

$$z = p_T / p_T^{jet} \cos R$$

- Further, the central-to-peripheral ratio of the $D(z)$ distribution, $R_{D(z)}$, is evaluated.

Important experimental corrections

- Contribution from UE to the measured distributions:
 - subtracted jet-by-jet
 - evaluated in each event using a grid of cones
 - each particle in the cone corrected for elliptic flow and difference in eta position
- Tracking efficiency correction:
 - as a function of: centrality, track p_T , and pseudorapidity
- Correction of the jet p_T to reduce the effect of the jet up-feeding due to jet energy resolution.

Example of tracking efficiency for barrel and end-cap region

Unfolding

- Correction from the reconstructed level to the truth level.
- Corrects mainly for jet energy and track momentum resolution.
- Singular value decomposition technique implemented in RooUnfold package used.

Example of the performance of unfolding for $D(z)$ distributions

D(z) and D(pt) distributions for R=0.4 jets

- Fully corrected D(z) distribution for R=0.4 jets.
- Yellow boxes: uncorrelated or partially correlated systematic uncertainties due to:
 - Jet energy scale
 - Jet energy resolution
 - Track reconstruction
 - Unfolding
 - Residual MC non-closure
- Statistical error by error bars (typically invisible).
- Gray band to guide the eye.

D(z) and D(p_T) distributions for R=0.4 jets

D(z) and D(p_T) distributions for R=0.4 jets

$$R_{D(z)} = \frac{D(z)|_{\text{cent}}}{D(z)|_{60-80\%}}$$

$$R_{D(p_T)} = \frac{D(p_T)|_{\text{cent}}}{D(p_T)|_{60-80\%}}$$

$R_{D(z)}$ and $R_{D(p_T)}$

$$R_{D(z)} = \frac{D(z)|_{\text{cent}}}{D(z)|_{60-80\%}}$$

$$R_{D(p_T)} = \frac{D(p_T)|_{\text{cent}}}{D(p_T)|_{60-80\%}}$$

$R_{D(z)}$ and $R_{D(p_T)}$

$$R_{D(z)} = \frac{D(z)|_{\text{cent}}}{D(z)|_{60-80\%}}$$

$$R_{D(p_T)} = \frac{D(p_T)|_{\text{cent}}}{D(p_T)|_{60-80\%}}$$

Full set of $R_{D(z)}$ for $R=0.4$ jets

Full set of $R_{D(p_T)}$ for $R=0.4$ jets

Fragmentation for different jet radii

Results from $R=0.4$ jets are consistent with results from $R=0.2$ and $R=0.3$ jets

Quantifying the difference using

$$\Delta D(z) = D(z)|_{\text{cent}} - D(z)|_{60-80}$$

Quantifying the difference using

$$\Delta D(z) = D(z)|_{\text{cent}} - D(z)|_{60-80}$$

centrality	$z = 0.02 - 0.04$		$z = 0.04 - 0.2$		$z = 0.4 - 1.0$	
	$\int \Delta D(z) dz$	$\int z \Delta D(z) dz$	$\int \Delta D(z) dz$	$\int z \Delta D(z) dz$	$\int \Delta D(z) dz$	$\int z \Delta D(z) dz$
0-10%	$0.65^{+0.21}_{-0.20}$	$0.017^{+0.006}_{-0.005}$	$-1.7^{+0.5}_{-0.6}$	$-0.14^{+0.04}_{-0.05}$	$0.07^{+0.05}_{-0.04}$	$0.037^{+0.030}_{-0.022}$
10-20%	$0.60^{+0.16}_{-0.16}$	$0.016^{+0.005}_{-0.004}$	$-1.6^{+0.7}_{-0.7}$	$-0.12^{+0.05}_{-0.05}$	$0.08^{+0.05}_{-0.04}$	$0.046^{+0.029}_{-0.025}$
20-30%	$0.48^{+0.11}_{-0.14}$	$0.013^{+0.003}_{-0.004}$	$-1.6^{+0.6}_{-0.5}$	$-0.13^{+0.04}_{-0.04}$	$0.04^{+0.05}_{-0.04}$	$0.026^{+0.029}_{-0.024}$
30-40%	$0.44^{+0.11}_{-0.15}$	$0.011^{+0.003}_{-0.004}$	$-1.4^{+0.6}_{-0.7}$	$-0.11^{+0.05}_{-0.05}$	$0.07^{+0.04}_{-0.05}$	$0.044^{+0.021}_{-0.028}$
40-50%	$0.33^{+0.09}_{-0.14}$	$0.009^{+0.003}_{-0.004}$	$-1.0^{+0.6}_{-0.8}$	$-0.09^{+0.04}_{-0.06}$	$-0.03^{+0.05}_{-0.04}$	$-0.011^{+0.030}_{-0.020}$
50-60%	$0.27^{+0.12}_{-0.18}$	$0.007^{+0.003}_{-0.005}$	$-1.0^{+0.8}_{-0.7}$	$-0.07^{+0.06}_{-0.06}$	$0.04^{+0.04}_{-0.05}$	$0.027^{+0.024}_{-0.029}$

Extending $D(z)$ distributions

“Extended” $D(z)$ distributions below $z=0.02$, that is a cut-off corresponding to track p_T of 2 GeV if reconstructed in a jet with $p_T=100$ GeV.

ratio

Corresponding ratio continues growing rapidly below $z=0.02$.

$D(z)$ recalculated to $D(\xi)$

$D(z)$ recalculated to $D(\xi)$ that was previously measured by CMS.

Direct quantitative comparison with CMS not possible due to different kinematic cuts and acceptance

Summary and conclusion

- Jet fragmentation has been evaluated in terms of $D(z)$ and $D(p_T)$ distributions and their central-to-peripheral ratio for three different jet radii, six different centrality bins.
- A modest but significant modification of fragmentation seen: an enhancement in fragment yield in central collisions for $z < 0.04$, a reduction in fragment yield for $0.04 < z < 0.25$ and an enhancement in the fragment yield for $z > 0.25$.
- Similar set of modifications seen also in $D(p_T)$ distributions.
- The modification decreases monotonically with decreasing centrality.
- Modifications observed for all three jet radii.
- Presented measurements put direct constraints on modeling of the jet response to the QCD medium. They should further stimulate the development of MC generators needed to reduce the systematic uncertainties and to improve Run II measurements of jets in HI collisions.

Backup slides

Unfolding performance for $D(z)$

Unfolding

- Correction from the reconstructed level to the truth level.
- Corrects mainly for jet energy and track momentum resolution.
- Singular value decomposition technique implemented in RooUnfold package used.

Example of the performance of unfolding for $R_{D(z)}$ distributions

Unfolding performance for D(pt)

Ratios of $D(\xi)$

D(z) and D(p_T) for R=0.2

$R_{D(z)}$ for $R=0.3$

$R_{D(z)}$ for $R=0.2$

$R_{D(pt)}$ for $R=0.3$

$R_{D(pt)}$ for $R=0.2$