

# Lund Plane Reweighting for Jet Substructure Correction at CMS

---

**Anna Benecke<sup>a,\*</sup> for the CMS Collaboration**

<sup>a</sup>UCLouvain,  
Louvain-La-Neuve, Belgium

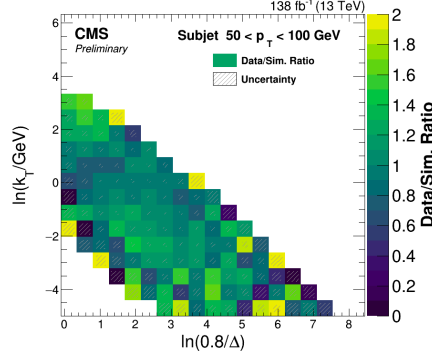
E-mail: [anna.benecke@cern.ch](mailto:anna.benecke@cern.ch)

Current calibration techniques are based on standard model candles like  $W$  bosons, top quarks or gluon splitting. However, this does not cover jets that originate from decays with more than three energy prongs, such as  $H \rightarrow WW \rightarrow 4q$  or exotic jets. A new calibration technique called Lund Plane Reweighting based on the Lund Jet Plane is presented. A correction map is derived from jets originating from  $W$  bosons and validated on jets originating from top quarks.

*42nd International Conference on High Energy Physics (ICHEP2024)  
18-24 July 2024  
Prague, Czech Republic*

---

\*Speaker



**Figure 1:** The Lund Jet Plane reweighting map derived from a  $W$  boson enriched region, showing correction factors for subjets in the  $p_T$  range of 50-100 GeV. Taken from Ref. [1].

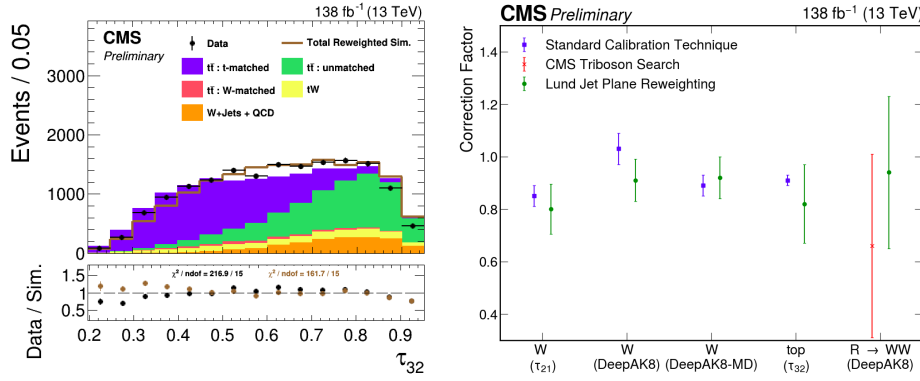
## 1. Creating the Lund jet plane reweighting map

When calibrating jet substructure related quantities, usually standard model candles like jets originating from  $W$  bosons, top quarks or gluon splitting are considered. However, searching for beyond the standard model physics process may generate exotic jets with more than three prongs. For such jets there are no standard model candles that can be used in their calibration. This is also true when considering jets originating in multi-prong decays of standard model particles, like the  $H \rightarrow WW \rightarrow 4q$ . In order to overcome this limitation the Lund Jet Plane reweighting (LPR) [1] was developed by the CMS Collaborations [2]. The Lund Jet Plane [3] is a 2D representation of the density splitting inside the showering process of a jet. In a data sample composed of top-antitop pair production events, which is enriched in  $W$  bosons, the Lund Jet Plane can be derived for each of the subjets of the large-cone jet in each event. Dividing the data plane by the simulation one, a map of correction factors for each jet density splitting is derived. This map can be used to reweight the substructure of any jet simply based on its density splitting. The extrapolation to jets with a higher number of prongs is validated by applying the method to jets originating from hadronically decaying top quarks.

In order to create the reweighting map, the constituents of the large-cone jet originating from hadronically decaying  $W$  bosons in top-antitop pair production events are reclustered using the exclusive jet clustering algorithm in order to obtain subjets. The exact number of subjets is defined by the number of true quarks matched to the large-cone jet. The clustering history of the subjets is used to construct the Lund Jet Plane, separately for data and simulation, in bins of the subjet transverse momentum ( $p_T$ ). An example reweighting map can be seen in Fig. 1.

## 2. Validation in events with jets originating from top quarks and systematic uncertainties

The map can be used to calculate the correction factor for any kind of jet by reclustering into the corresponding number of subjets, constructing the Lund plane for each subjet, and multiplying the correction factor for each splitting of a subjets. To validate the procedure works for jets with a higher number of prongs, the weights derived from jets originating from  $W$  bosons (two prongs)



**Figure 2:** (left) Jet substructure variable  $\tau_{32}$  before (colored areas) and after (brown solid line) the reweighting for jets originating from top quarks. (right) Correction factors derived by the standard calibration techniques using standard model handles and by the new Lund Plane Reweighting. Taken from Ref. [1].

are applied to jets originating from top quarks (three prongs). Fig. 2 (left) shows the substructure variable  $\tau_{32}$  for jets originating from top quarks. The brown solid line represents the simulation reweighted with the LPR. It shows a significantly better data-to-simulation agreement than the original simulation represented by the colored areas.

The extrapolation from  $W$ -originated jets to top-originated jets does not only need to take into account a higher number of prongs, but also the presence of a  $b$  quark in the decay. An uncertainty is determined from simulation based on the differences in the Lund Jet Plane between light quarks and  $b$  quarks. Other uncertainties considered are the statistical uncertainty from the ratio maps, a  $p_T$  extrapolation for subjets outside the range probed by events in the  $W$  boson enriched region, and a matching uncertainty. The matching uncertainty contains three components: how well the quarks are represented by the reclustered subjets, how often more than one quark is matched to a subjet, and how often a quark is only partially represented in a subjet and therefore in the large-cone jet.

Fig. 2 (right) shows the comparison of correction factors derived by the standard calibration techniques using standard model candles (square) and the new LPR (circle). The correction factors agree within the uncertainty, however, the LPR has larger error bars. On the other hand, for certain (exotic) jets this is currently the only available calibration technique. This new calibration technique expands the toolkit for understanding jet substructure, particularly for exotic and high-prong decay processes, which are crucial for searches beyond the standard model.

## References

- [1] CMS Collaboration, *Lund Plane Reweighting for Jet Substructure Correction*, [CMS-DP-2023-046](#), Jul. 2023
- [2] CMS Collaboration, *The CMS experiment at the CERN LHC*, [DOI:10.1088/1748-0221/3/08/S08004](#), JINST 3, Aug. 2008
- [3] Frederic A. Dreyer, Gavin P. Salam, Gregory Soyez, *The Lund Jet Plane*, [arXiv:1807.04758](#), JHEP 12, Dec. 2018