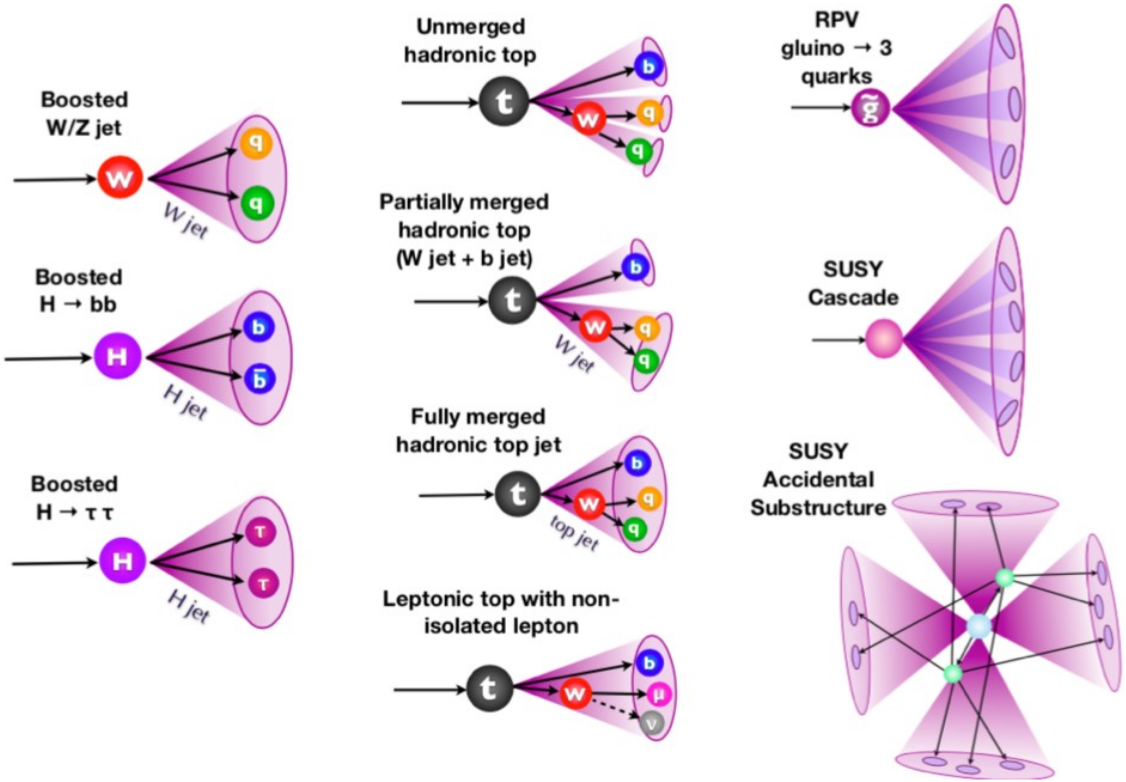
Jet substructure report



M.Campanelli, D.Sunar Cerci
On behalf of the editors

Why, and why now

- The idea of writing a jet substructure report has been present in our WG since several years
- The field is constantly evolving, and even if several reviews were published in the past, they do not contain the latest developments (especially in the use of ML)
- We are near the end of Run3, and it make sense to write a reference work on substructure under current pileup conditions
- Different techniques and tools used by the different experiments
  - Are differences justified and optimised for detector characteristics
  - ...or just historical?
  - Can we find common grounds for future measurements/techniques?

Aims and timeline

- We see this report not just as a compilation of results and techniques
  - Even if no “real work” expected, the report should be a platform for comparison and discussion, aiming at setting example and standards
  - Identify new trends of the field and anticipate future directions
- For this reason, the WG will continue to follow the development of the field, and help harmonising the efforts in this direction
- Have a first solid draft by the end of the year
- Expect a boost of the activity after the BOOST conference (July 29-August 2)

Paper outline

- 4 main sections
  - Theory (10pp)
  - Reconstruction (15pp)
  - Machine Learning (20 pp)
  - Measurements (20pp)
- Summary should contain ideas for the future

LHC EWWG 2 : Review of the status and prospects of jet substructure at the LHC

You

July 9, 2024

Abstract

Your abstract.

Contents

Theory and reconstruction

2 Status of theory (10 pp)

(Kyle Lee, Alba Soto Ontoso, Simone Marzani) Our definition of theory: anything for which you c provide a resummation prediction. 2020 as reference date for this review. Aim at max 10 pages.

- Papers by Thaler, Komiske and Metodiev: here or machine learning? Probably the latter.
- Energy-energy correlators
- Lund jet plane
- Discuss heavy-ion developments in jet substructure
- Recent developments on heavy-flavour: highlight that this is not as mature as the massless c plus some recent works on it
- Accuracy of calculations? Important: don't use N^kLL nomenclature since it can be misleadi
- Resummation of non-global logarithms at single log both from Monni et al and Becher et al
- Papers by Dasgupta et al on collinear limit ($B_2(z)$).
- Power corrections to jet observables. SCET work?

3 Jet reconstruction, calibration and substructure (15pp)

(Matt Leblanc, Jennifer Roloff, Ezra Lesser, Nima Zardoshti)

- trigger : substructure (GFex?) – ATLAS young people? (emily.ann.smith@cern.ch)
- input reconstruction + ParticleFlow (and why you use those inputs, e.g. charged vs full jet) – Jennifer, Matt, Ezra
- UE subtraction / pileup mitigation (CSSk, PUPPI, ...) – Jennifer, Nima (esp HI) - Connection to Heavy-ions (algorithms borrowed from the pp community) - Comparisons between different collaborations & looking towards future ideas
- jet reconstruction : algorithms (1-2 sentences why we use AKT)
- calibration : JER, JES, efficiencies, correction techniques – Jennifer, Ezra - How does it limit performance, what has been tried so far / used to fix issues
- grooming (trimming/pruning –¿ SD and dynamical(?)) : experimental reasons for choosing the algorithms that we currently use
  – Ezra, Nima, Matt - Some will be in introduction (historical part) – here can add more detail if wanted, but grooming is not the main topic of the paper - Intercept with pileup, different types of jet tagging, different defs of jet pT, etc

Names listed have agreed to edit or write part of these sections, but there is plenty of space for additional contributions

Machine Learning and measurements

4 Machine Learning techniques for jets (20pp)

(Gregor Kasieczka, Tilman Phen, Hulin Qu, Jad Sardain, Robert Les, Rikab Gambhir)
Some vague categories (RG):

1. **Taggers (Tilman, Huilin)**: (big plot of all taggers, top vs qcd, quark vs gluon, flavor tagging, etc, auc vs year, top tagging challenge), calibration of taggers
2. **Robustness, Uncertainty, and Calibration (Tilman, Rikab)**: AUC is not all you need, getting uncertainties / resolutions on ML predictions, calibrating robust taggers for experiments (e.g. gaussianansatz and similar, testing taggers on different parton showers for robustness, Omnifold, ...) [IRC Safety]
3. **Symmetries** Lorentz-based architectures (e.g. Pelican), equivariance and invariance, IRC-safety ... [POTENTIALLY FOLD INTO TAGGERS AND GENERATIVE MODELING]
4. **Generative Modeling (Gregor, Tilman))**: hadronization, epic-GANS, point cloud generation, calochallenge
5. **Optimal Transport for Jets (Rikab)**: Isotropy, SHAPER, EMD as a tagger (e.g. linearized EMD, Nathaniel Craig), persistant homology (e.g. Tianji Cai), recent work by Javier, recent work by Yoni, ...
6. **Anomaly Detection (Gregor, Rikab)**: CWOLA (and variants, e.g. ANODE, CATHODE, ...), non-resonant methods, ... Is this related to jets? Not sure there are many resonant methods applied to jets, but for non-resonant methods jets are the obvious and most attractive objects... LHC Olympics
7. **Foundation Models & Transformer (Gregor & Huilin)**: e.g. contrastive learning models for jets

5 Review of substructure measurements with Run 2 data (20pp)

Editors: Matt LeBlanc, Adam Rennie, Others? ***n.b. References, particularly to ALICE results, are incomplete so-far!***

While it was not a consideration during the initial design of LHC experiments, jet substructure techniques developed rapidly during Run 1 to become a trademark of searches for new particles by ATLAS and CMS[1]. The calculation of the soft-drop groomed jet mass at the LHC beyond leading-logarithmic accuracy in 2016 was a pivotal moment early in Run 2 that indicated a new level of understanding of JSS had been reached. These predictions initiated a series of extremely fruitful interactions between theory and experiment that resulted in numerous measurements made with the Run 2 dataset that probe the dynamical evolution of QCD within jets, which are summarised in the following sections and organised roughly by their motivating factors. These categorisations are not exclusive or unique: measurements that are compared with cutting-edge analytical predictions can also serve as valuable testbeds to improve MC models, and JSS techniques are applied fluidly betwee proton–proton and lead-ion collisions. They are; however, meant to explore three of the stories that are both representative of the Run 2 JSS programme at the LHC and of the future directions that these techniques will likely pursue.

5.1 Comparisons to high-precision analytical predictions and observations of fundamental SM phenomena

Measurements that would go here are *e.g.* soft-drop observables [17, 18, 19], Lund jet plane [20, 21, 22] and Lund multiplicities [23], angularities [24] and energy-energy correlators [25].
Dead cone? [26]
I would put [27] here ... ?

5.2 Measurements to test MC modelling

The spirit of the measurement and reconstruction session is more to foster comparisons and look for possible convergence than just having a shopping list

Conclusions

- The effort to (finally) write a report on substructure studies aligns with the group mission to increase cross-talk between experiments, and investigate in detail differences and possible confluence
- It also gives the opportunity to take a snapshot of the status of the field towards the end of Run3
- While we already have a number of (very good!) collaborators, there is still the opportunity to join the effort.