Recent progress in jet substructure calculations

Daniel Reichelt

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Introduction

"event built from jets" $\Rightarrow$ "jet built from constituents"

"cluster the event into jets"
$\rightarrow$ "cluster jet into subjets"

- tagging
- trimming
- soft-drop
  - + recursive
  - + dynamical
  - includes modified mass-drop
- collinear-drop
- ...

"observables from jets"
$\rightarrow$ "observables from constituents"

- jet mass
- angularities
- energy correlation functions
- jet pull
- ...

* disclaimer: this is a non-exhaustive and biased list of examples

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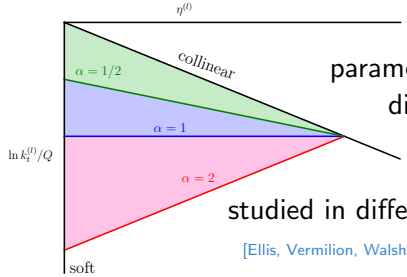
Angularities

study family of observables

$$\lambda_\alpha^\kappa = \sum_{i \in J} \left(\frac{p_{T,i}}{p_{T,J}} \right)^\kappa \left(\frac{\Delta R_i}{R} \right)^\alpha$$

here: calculations need IRC safety, so $\kappa = 1$



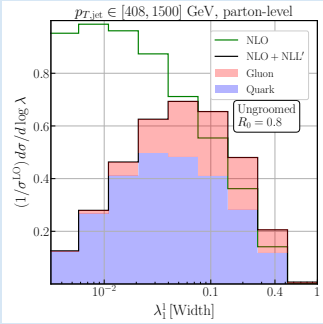
parameter $\alpha \Rightarrow$ probe different kinematic regimes

studied in different frameworks

[Ellis, Vermilion, Walsh, Hornig, Lee '10] [Hornig, Makris, Mehen '16] [Kang, Lee, Ringer '18]

reuse energy-correlations @ NLL [Larkoski, Salam, Thaler '13] [Larkoski, Neill, Thaler '14] [Banfi, Salam, Zanderighi '04]

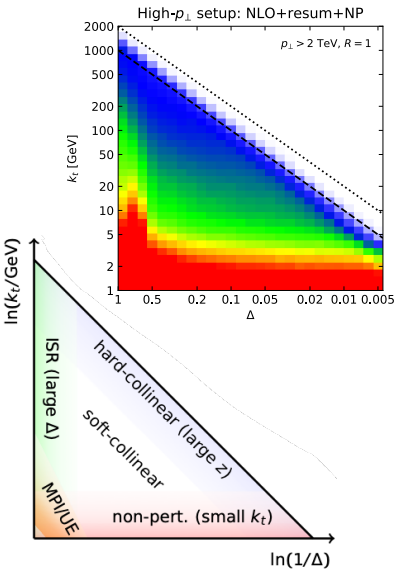
context: [Les Houches 15/17/19] [Larkoski, Thaler, Waalewijn '14]
quark-gluon tagging



Zj @ 13 TeV from [Caletti, Fedkevych, Marzani, DR, Schumann, Soyez, Theeuwes '20]

Interlude: Lund Plane

[Andersson, Gustafson, Lönnblad, Petterson '88]
[Dreyer, Salam, Soyez '18] [Lifson, Salam, Soyez '20]



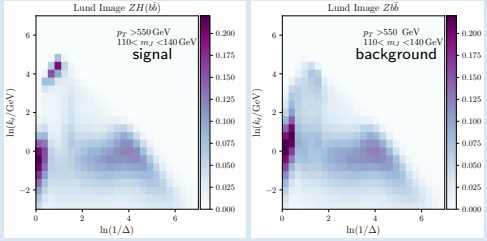
representation of single emission phase space

→ at LL uniform ⇒ predicted deviations

uses:

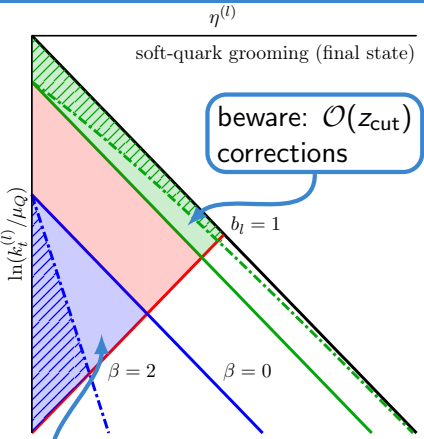
1. forward: resummed calculations / parton shower building
   e.g. [Gustafson '92] [Hamilton, Medves, Salam, Scyboz, Soyez '20]
2. backwards: map cluster steps of final jets to Lund plane
   ⇒ physics insights to build optimal observables

Example: Higgs tagging [Khosa, Marzani '21]



Soft-Drop: Intro

[Larkoski, Marzani, Soyez, Thaler '14]



beware: $\mathcal{O}(z_{\text{cut}})$ corrections

idea: remove soft wide-angle contamination

method: decluster w/ C/A, remove softer branch if

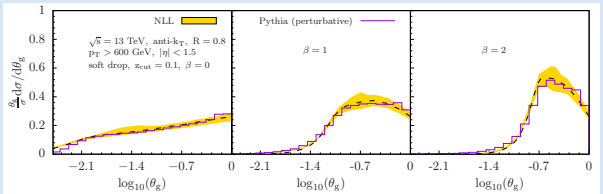
$$\frac{\min(p_{T,i}, p_{T,j})}{p_{T,i}+p_{T,j}} < z_{\text{cut}} \left(\frac{\Delta R}{R}\right)^{\beta}$$

analytical understanding: [Larkoski, Marzani, Thaler '15]

p_T fraction z_g, separation $\theta_g = R_g/R$ of splitting

$\Rightarrow$ using concept of Sudakov safety

calculations available at NLL, NLL′ [Kang, Lee, Liu, Neill, Ringer '19] [Cal *et. al.*, Jets @ LHC '21]



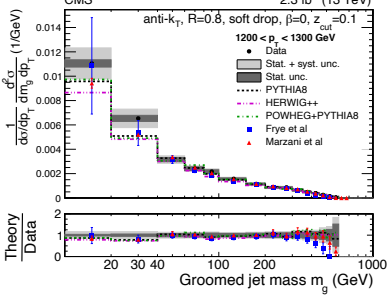
Soft-Drop: Application

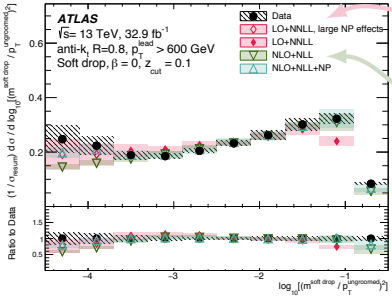
[CMS '18] [ATLAS '17]

procedure:

1. soft-drop groom jet constituents
2. calc standard observable "after grooming"

example: jet mass after grooming





[Frye, Larkoski, Schwartz, Yan '16]

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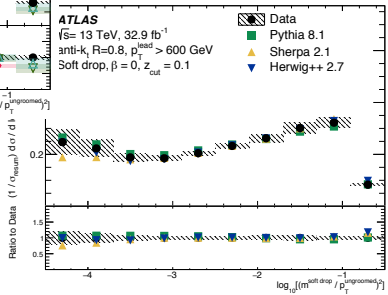


side note: also applicable to global event shapes

[Baron, Marzani, Theeuwes '18], [Marzani, DR, Schumann, Soyez, Theeuwes '19],

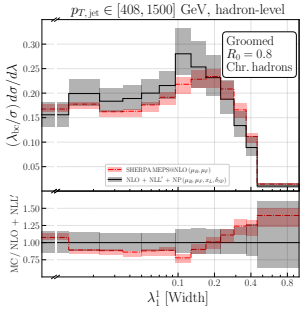
even in pp [Baron, DR, Schumann, Schwanemann, Theeuwes '20]

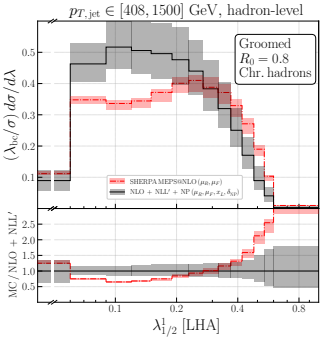
Soft-Drop: Application

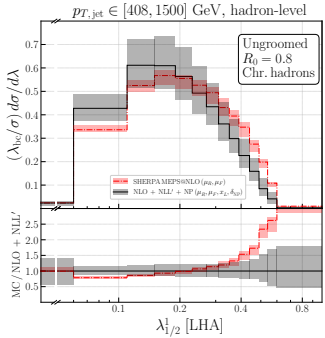
[Caletti, Fedkevych, Marzani, DR, Schumann, Soyez, Theeuwes '20]

back to angularities λ_α

- → Z + jet at $\sqrt{s} = 13$ TeV
- → p_T bins like [CMS '21]
- → NLO + NLL′, NP from Sherpa/Herwig/Pythia
- → Sherpa MEPS@NLO







towards automation: CAESAR formalism [Banfi, Salam, Zanderighi '04]

established implementation as Sherpa plugin [Gerwick, Höche, Marzani, Schumann '15]

general implementation for soft-drop [Baron, DR, Schumann, Schwanemann, Theeuwes '20]

here: ingredients for angularities (non-global logs/radius R) [Dasgupta, Khelifa-Kerfa, Marzani, Spannowski '12], [Dasgupta, Salam, '01]

Summary

- jet substructure as a rapidly growing field
  with close interplay between
  - experiment
  - theory
  - construction of methods
  - Monte Carlo / parton shower development
- examples:
  - jet angularities w/ different parameters as playground
  - soft-drop grooming to eliminate UE/NP corrections $\rightarrow$ increase resummation regime
- Outlook:
  - non-perturbative corrections?
  - transition point effects?
  - automation?

Backup