Jet substructure and jet flavour

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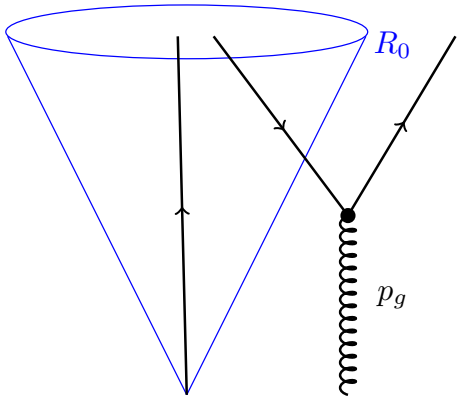
[Caletti, Larkoski, Marzani, DR in EPJ C 82 (2022) 7, 632]

Motivation

- experiments measure heavy flavour jet, e.g. Z+b production [CMS '17]
  - jet with anti-kt algorithm, tag as heavy by presence of b hadron
- potentially compared to high accuracy calculations
  - e.g. NNLO Z+jets calculation, cluster with anti-kt algorithm, tag as presence of b parton, e.g. [Gauld, Gehrmann-De Ridder, Glover, Huss, Majer '20]
  - problem: not irc safe starting from NNLO

Motivation: problems in naive flavour definition

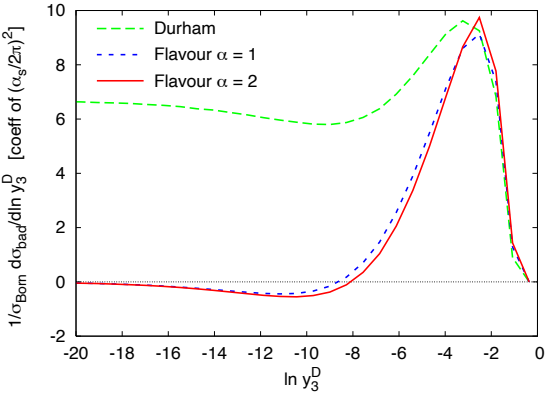
- starting at NNLO, consider configuration where a soft gluon splits into two quarks
- singularities in the limit where $p_q, p_{\bar{q}} \to 0$
- might belong to "gluon-jet" or "quark-jet" phases-space, depending on clustering
- virtual correction clearly in "quark-jet" phase-space
- $\Rightarrow$ IRC unsafe



Motivation: BSZ algorithm

[Banfi, Salam, Zanderighi '06]

- traditional solution:
  - use algorithm to with well defined flavour
  - achieved by modifying distance measure
    $\Rightarrow$ will tend to cluster soft quarks together first
- "unfold" to experimental procedure using MC



from [Banfi, Salam, Zanderighi '06]

Several proposed algorithms, defining . . .

. . . new jets with well defined flavour

- original BSZ [Banfi, Salam, Zanderighi '06]
- anti-kt variant [Czakon, Mitov, Poncelet '22]

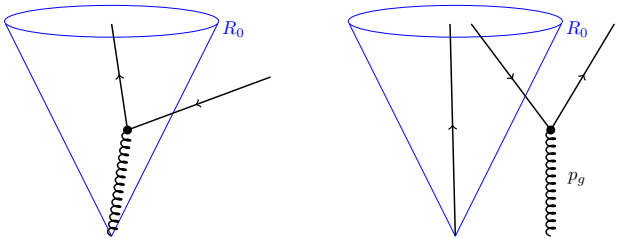
. . . flavour of jet(s) within event

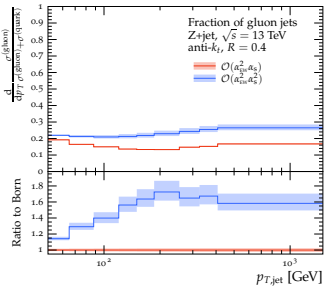
- iteration of BSZ [Caletti, Fedkevych, Marzani, DR, Schumann '21]
- dressing of jets [Gauld, Huss, Stagnitto '22]

. . . flavour of an isolated jet

- soft drop groomed jets [Caletti, Larkoski, Marzani, DR '22]

- background: matching in NLO + NLL′ matched calculation
- need to match jet flavour in NLL and FO precisely





Working solution: Iterative application of BSZ:

0. Start w/ list $\mathcal{O}$ of coloured final-state objects
1. Run the standard IR-safe algorithm with radius parameter R_0 on $\mathcal{O}$, and obtain the objects in the leading jet $J \subset \mathcal{O}$.
2. If $J = \{j \in \mathcal{O}\}$, terminate. The flavour is that of j.
3. Determine the pair $\{i, k\} \subset \mathcal{O}$ that minimises the BSZ measures, and combine them.

Go to step 1 and repeat.

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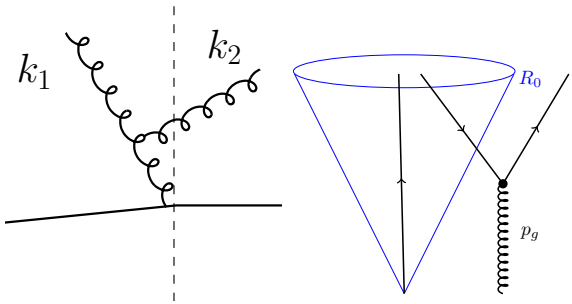
- soft drop groomed jets
  (? $\Rightarrow$ this talk)
  [Caletti, Larkoski, Marzani, DR '22]

idea of method

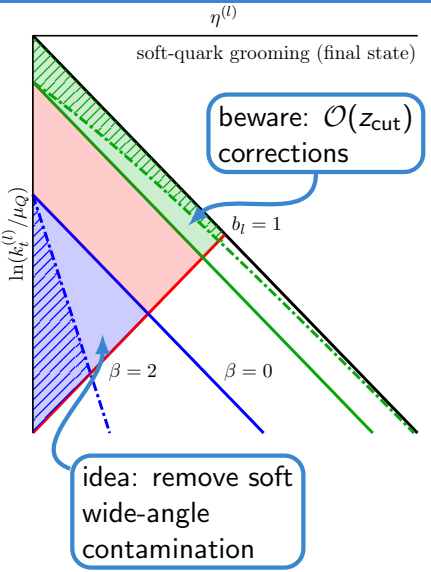
- soft drop [Larkoski, Marzani, Soyez, Thaler '14] well known method to eliminate soft-wide angle contributions
- in particular, shown to eliminate non-global logs
  $\Rightarrow$ should also eliminate configurations critical here!
- remainder of this talk:
  - explore this idea
  - establish (conditions for) irc safety at least through NNLO



adapted from [Dasgupta, Salam '01]

soft-drop algorithm

[Larkoski, Marzani, Soyez, Thaler '14]



method:

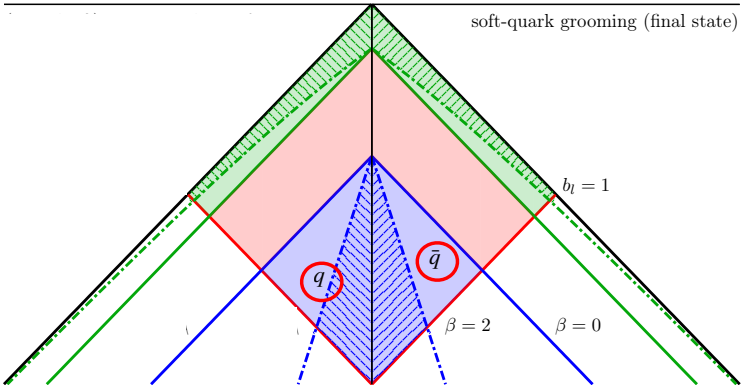
- re-cluster given jet to establish splitting sequence
  $\Rightarrow$ usually Cambridge/Aachen, e.g. angular ordered
- go through sequence, remove softer branch if
  $$\frac{\min(p_{T,i}, p_{T,j})}{p_{T,i}+p_{T,j}} < z_{\text{cut}} \left(\frac{\Delta R}{R}\right)^{\beta}$$
- stop if both branches are "hard enough" (or only one remaining)

here:

- count flavours of remaining particles $\equiv$ flavour of jet

idea of method

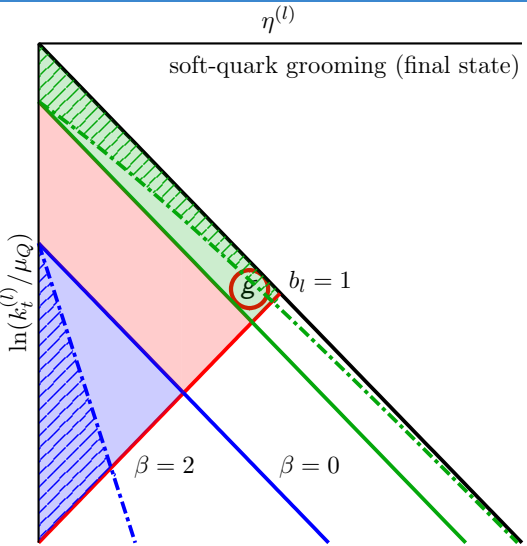
Critical configuration in Lund plane



$\Rightarrow$ can check this indeed works shields singularities e.g. of triple-collinear / double soft splitting functions

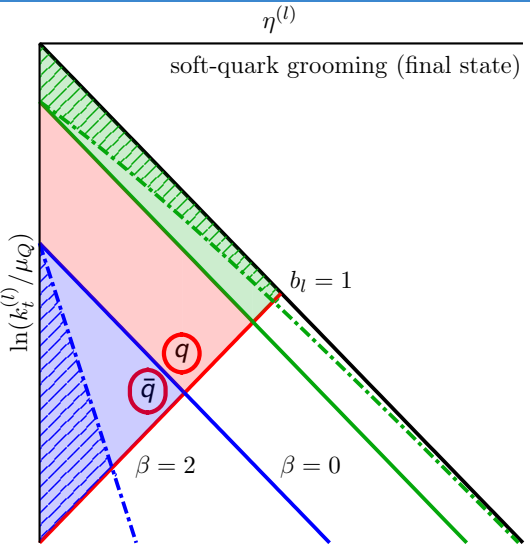
subtlety I: sd with $\beta = 0$?

- close to collinear region: may groom away "hard" quark instead of gluon
- logarithmic region for $\beta = 0 \Rightarrow$ spoils flavour already at LO!
- but power suppressed for $\beta > 0$

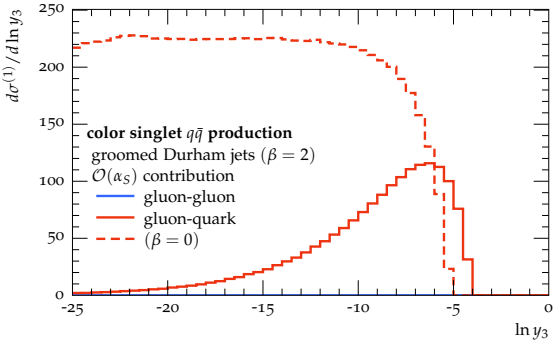


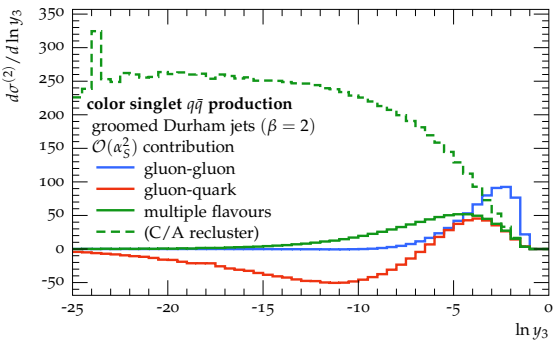
subtlety II: which cluster algorithm?

- soft drop involves re-clustering step to establish "splitting sequence"
- traditional: Cambridge/Aachen (i.e. angular ordered)
- but: consider jet with 3 particles (g q $\bar{q}$) $\rightarrow$ potentially assigned as quark jet, even if both quarks are soft
- need to make sure $q\bar{q}$ pair clustered together in this case
- can be achieved by using JADE algorithm (i.e. virtuality ordering)



final numerical checks





outlook & things to do

- works only through NNLO (higher orders $\rightarrow$ clustering can "protect" soft quarks)
  $\Rightarrow$ maybe acceptable for purpose of FO calculations? $\Rightarrow$ iterative procedures?
  - several extension of SD possible,

    e.g. [Frye, Larkoski, Thaler, Zhou '17], [Dreyer, Necib, Soyez, Thaler '18] [Mehtar-Tani, Soto-Ontoso, Tywoniuk '19]
- is it bad to use JADE?
- check hadronisation corrections / realistic setups

overview

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Backup