SISCone

A Seedless Infrared-Safe Cone jet algorithm

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code available at `http://projects.hepforge.org/siscone`

or as a FastJet plugin (`http://www.lpthe.jussieu.fr/~salam/fastjet`)

Outline

- Cone jet algorithms
- Infrared-Safety issues:
  - Why is this mandatory ?
  - IR unsafety of the midpoint algorithm
- SISCone: a practical solution
- Physical consequences:
  - Algorithm speed
  - Inclusive jet spectrum
  - Jet mass spectrum in multi-jet events
- Conclusions

Cone jet algorithms

- Given: set of N particles with their 4-momentum
- Quest: clustering those particles into jets
- Idea: jets $\equiv$ cones around dominant energy flows

  for a cone of radius R in the (y, ϕ) plane, stable cones are such that:
  centre of the cone $\equiv$ direction of the total momentum of its particles
- Algorithm: Tevatron Run II
  - Step 1: find ALL stable cones of radius R
  - Step 2: run a split-merge procedure with overlap f

    to deal with overlapping stable cones
- This talk: Why finding all stable cones and how.

  $\longrightarrow$ C++ implementation: Seedless Infrared Safe Cone algorithm (SISCone)

Midpoint cone algorithm

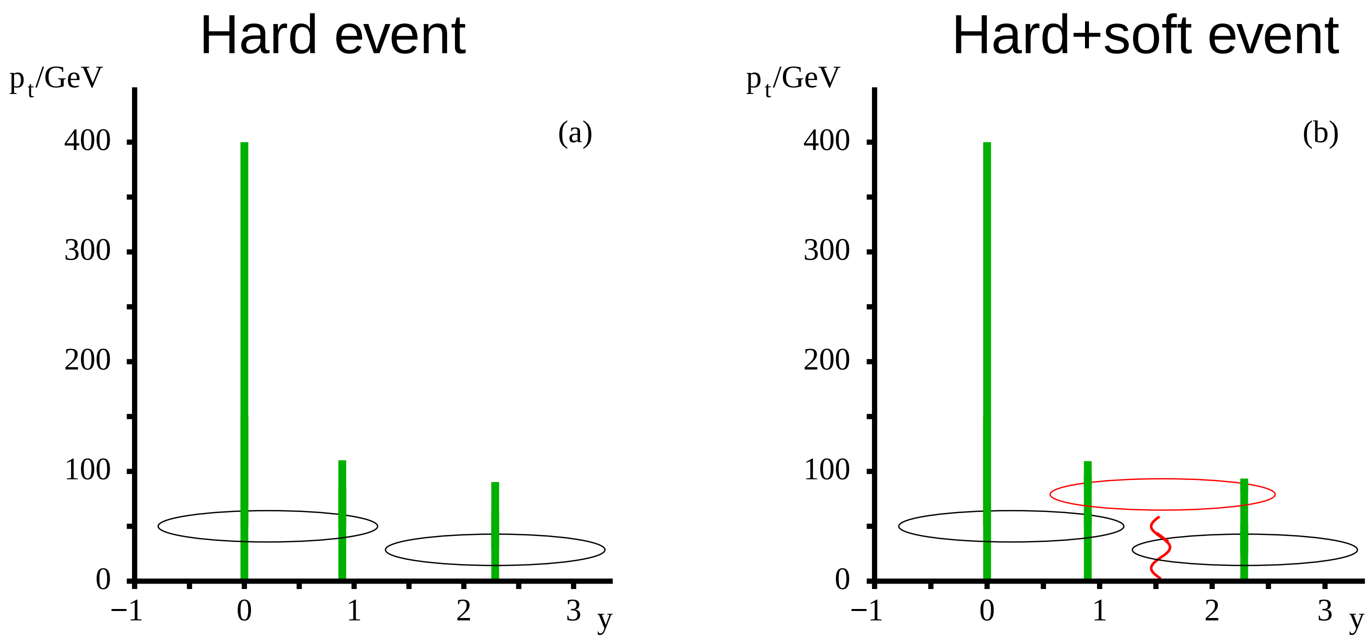
Usual seeded method to search stable cones: midpoint cone algorithm

- For an initial seed
  1. sum the momenta of all particles within the cone centred on the seed
  2. use the direction of that momentum as new seed
  3. repeat 1 & 2 until stable state cone reached
- Sets of seeds:
  1. All particles (above a p_t threshold s)
  2. Midpoints between stable cones found in 1.

Problems:

- the p_t threshold s is collinear unsafe
- seeded approach $\Rightarrow$ stable cones missed $\Rightarrow$ infrared unsafety

Midpoint IR Unsafety



Stable cones:

	Hard event	Hard+soft event
Midpoint:	{1,2} & {3}	{1,2} & {3} & {2,3}
Seedless:	{1,2} & {3} & {2,3}	{1,2} & {3} & {2,3}

Jets: ($f = 0.5$)

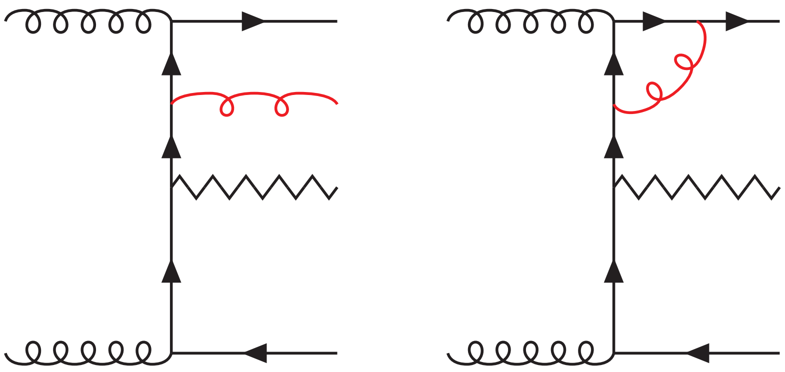
	Hard event	Hard+soft event
Midpoint:	{1,2} & {3}	{1,2,3}
Seedless:	{1,2,3}	{1,2,3}

$\longrightarrow$ **IR unsafety of the midpoint algorithm**

Infrared Safety: Why ?

Ellipsis: IR safety, i.e. stability upon emission of soft particles,
is required for perturbative computations to make sense!

Cancellation of IR divergences between real and virtual emissions of SOFT gluons

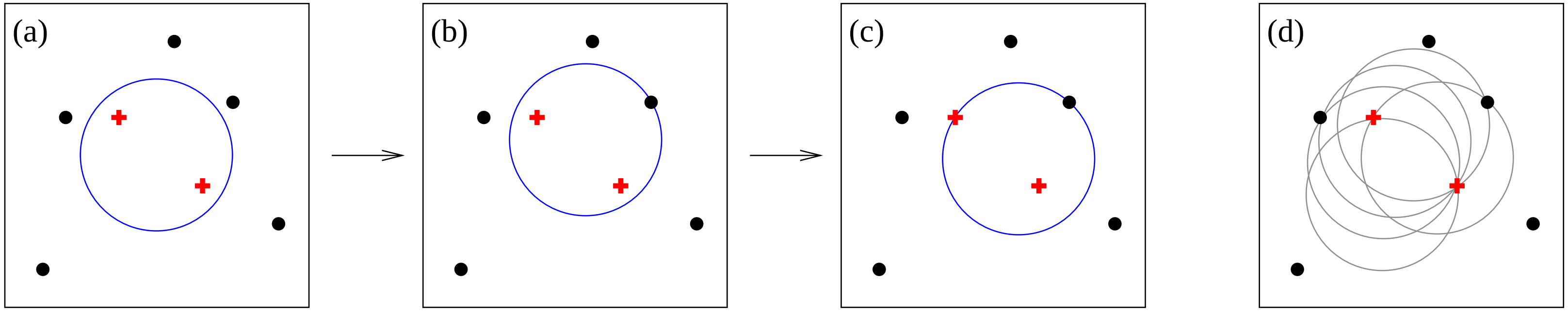


NLO, real NLO, virtual

- IF Jet clustering is different in both cases, THEN the cancellation is not done and the result is not consistent with pQCD
- Stable cones must not change upon addition of soft particles
- Divergence at NLO is parametrically of the same order as LO contribution

SISCone: seedless solution

- Naive approach: check stability of each subset of particle
  Complexity is $\mathcal{O}\left(N2^N\right)$ *i.e.* definitely unrealistic (10^{17} years for $N = 100$)
- Idea: all enclosures are defined by a pair of points



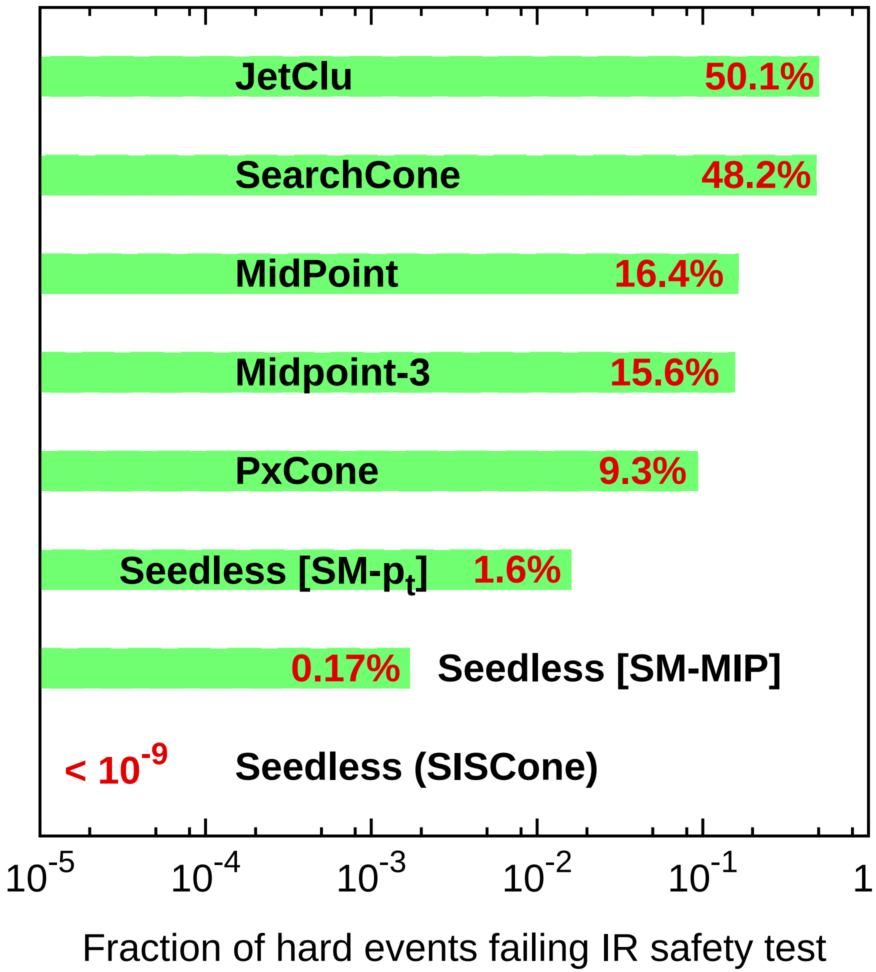
- Tricks: *e.g.* traversal order to avoid recomputation of the cone content
- Complexity:
  - SISCone is $\mathcal{O}\left(N n \ln n\right)$ (with $n \sim N$ the number of points in a circle of radius R)
  - midpoint standard implementation is $\mathcal{O}\left(N^2 n\right)$

IR Unsafety failure rates

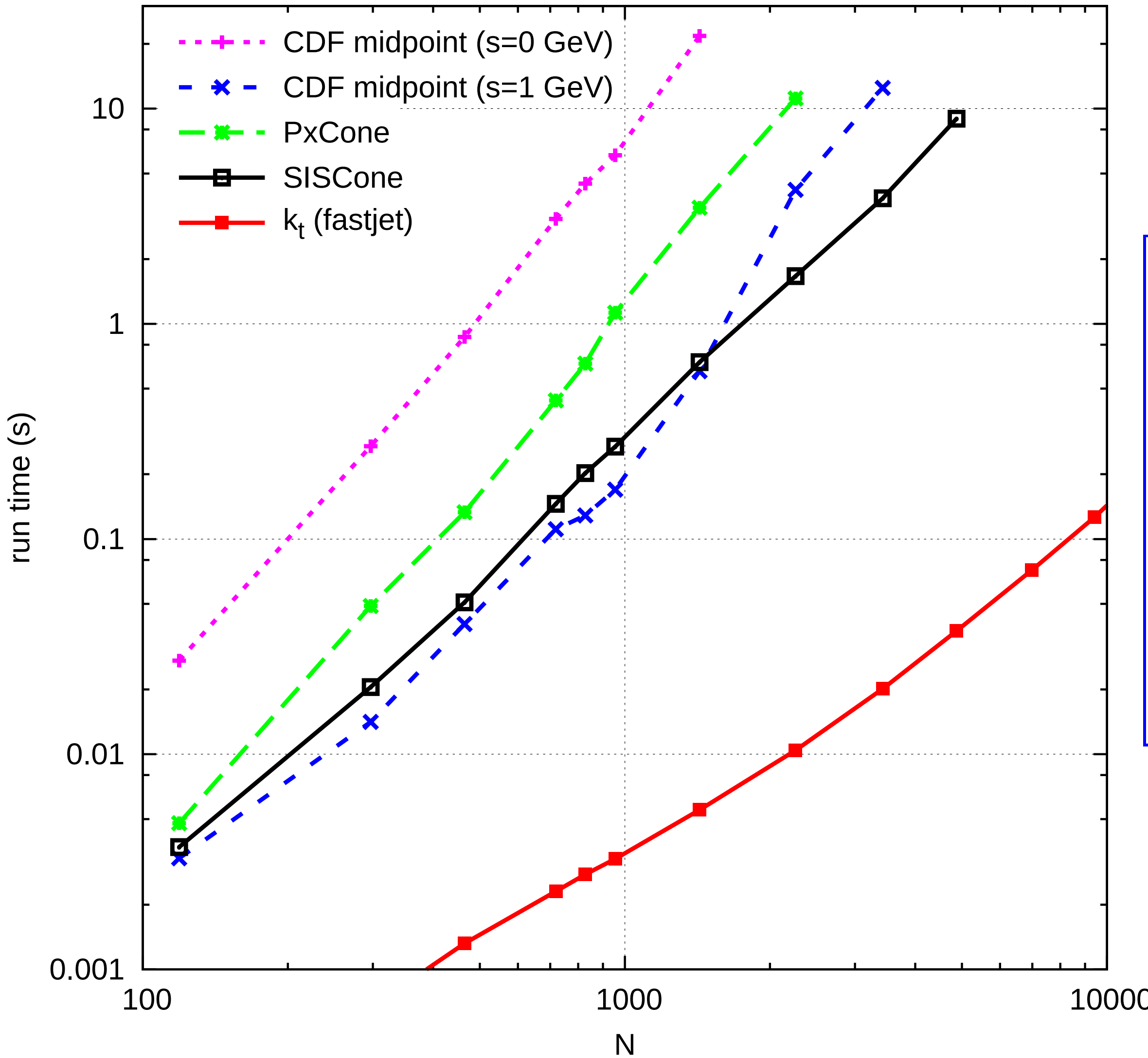
- Hard event: 2-10 particles
- Soft add-on: 1-5 particles
- Run:
  - “hard” only
  - many “hard+soft” trials
  - Search differences

Unsafety level	failure rate
2 hard + 1 soft	$\sim 50\%$
3 hard + 1 soft	$\sim 15\%$
SISCone	IR safe !

NB: small issues in the split-merge



Speed



- at least as fast as other cones
- IR safe
  others are not
- collinear safe
  midpoint($s > 0$) is not

Impact on inclusive jet spectrum

Physical impact: SISCone vs. midpoint(s) ?

- IR unsafety of midpoint: 3 particles in the same vicinity + 1 to balance p_t
  $\Rightarrow$ starts at the $2 \to 4$ level ($\mathcal{O}\left(\alpha_s^4\right)$)

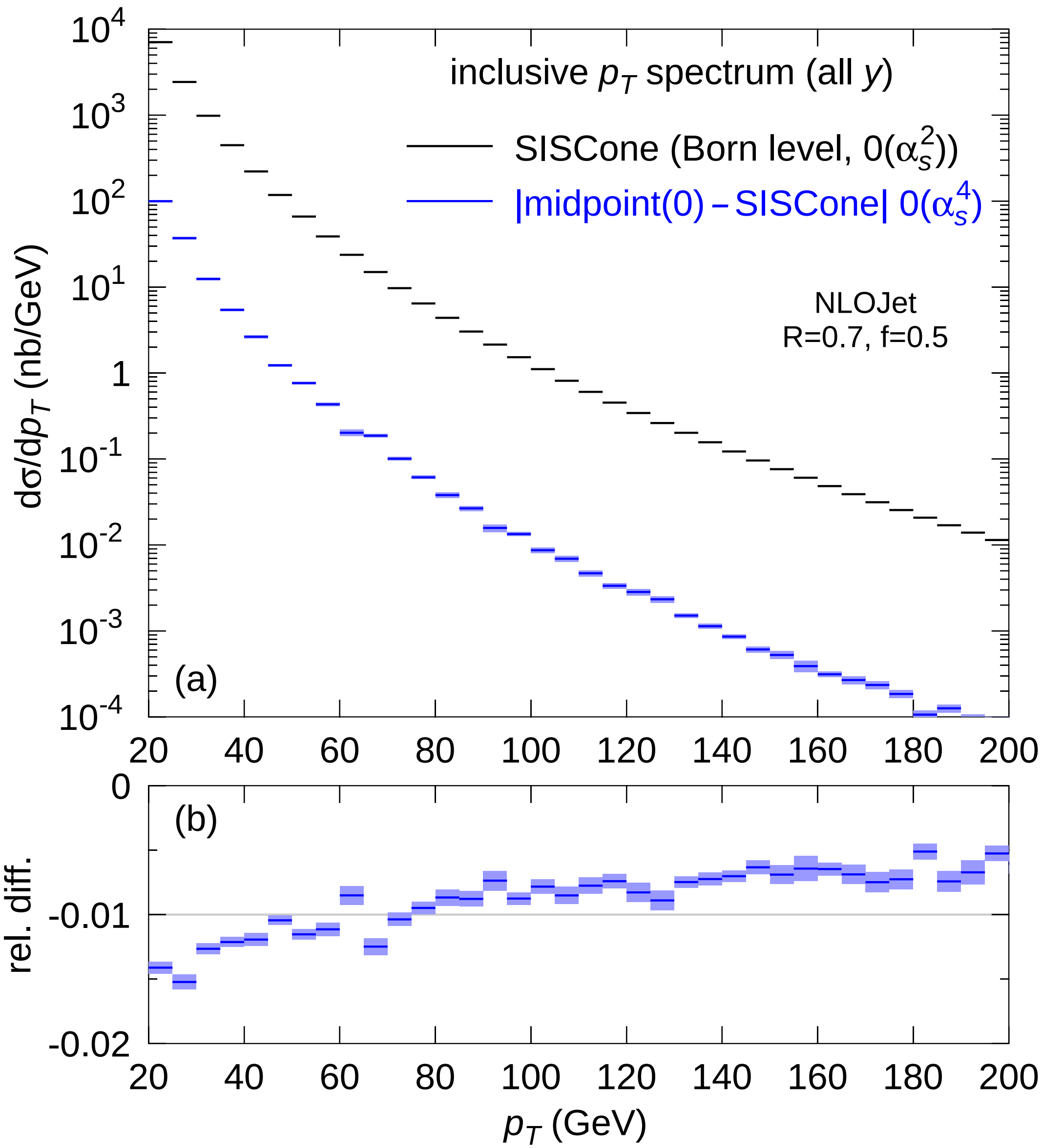
- 3 contributions at this order:
  $2 \to 4$ at LO (tree), $2 \to 3$ at NLO (1 loop) and $2 \to 2$ at NNLO (2 loops)

$\Rightarrow$ $2 \to 4$ at LO is IR divergent
BUT the difference between SISCone and midpoint(s) in finite since it is 0 at the $2 \to 2$ and $2 \to 3$ levels

$\Rightarrow$ compute $|$SISCone-midpoint$(s)|$ for $2 \to 4$ diagrams

- Compare with the $2 \to 2$ (LO) spectrum to estimate effect

Impact on inclusive jet spectrum

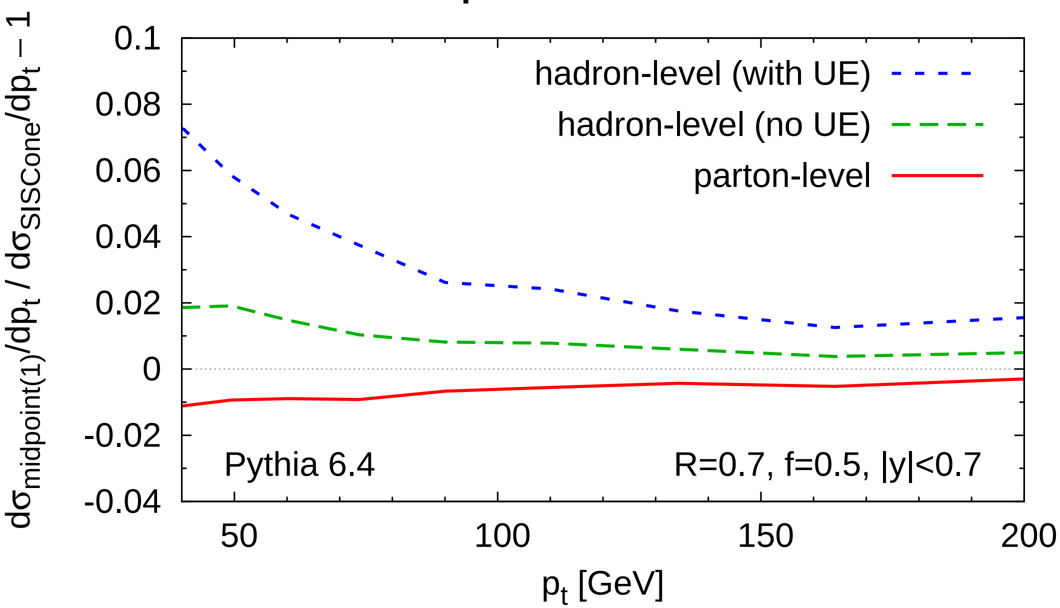


Differences of order 1-2 %

Impact on inclusive jet spectrum

Including parton shower, hadronic corrections and/or underlying event:

Ratio midpoint/SISCone:

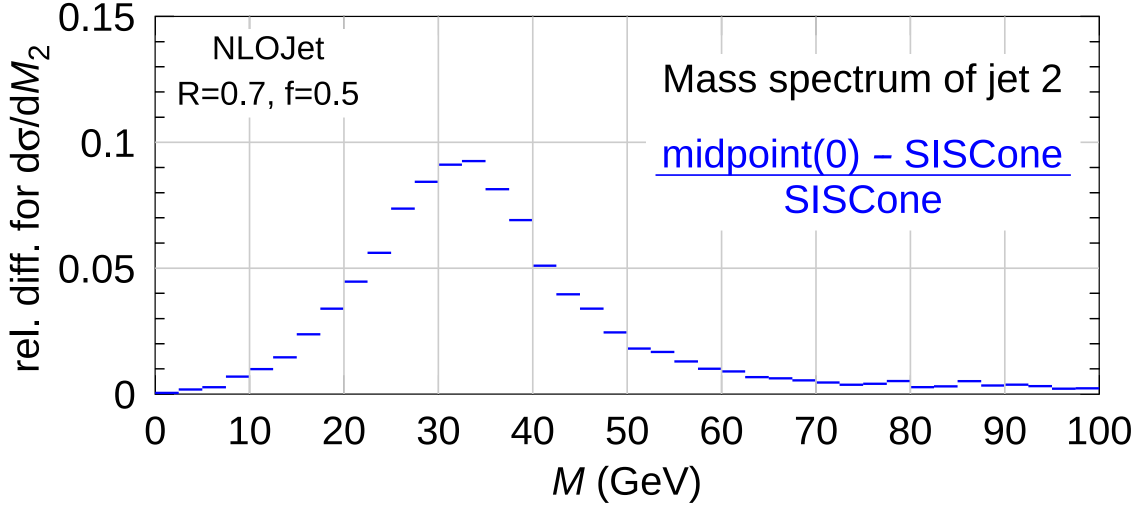


- Differences up to 6 %
- Less effect from underlying event in SISCone

Impact on jet mass spectrum

Study of more exclusive quantity *e.g.* mass spectrum in 3-jet events

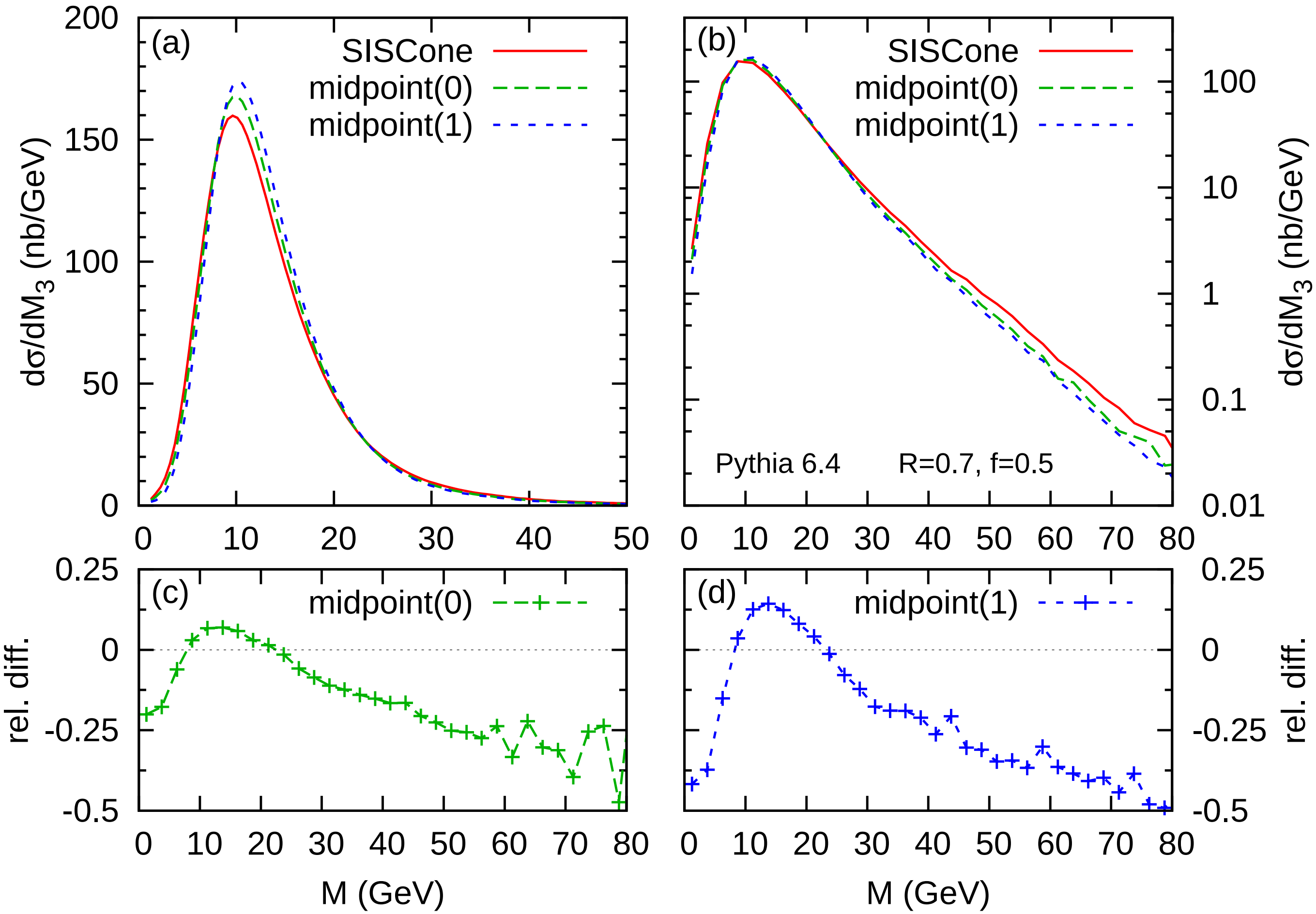
1. At fixed order (NLOJet, LO, $2 \to 4$)



Differences up to 10 %

Impact on jet mass spectrum

2. At fixed order (PYTHIA)



- ▷ Differences of order 10 %
- ▷ Larger effects in the tail
- ▷ seed threshold even worse

Conclusions

- Cone jet algorithms are widely used
- seeded implementations are IR unsafe (sometimes collinear unsafe)
  IR safety is a prerequisite for perturbative QCD to make sense

We propose a new cone algorithm (SISCone):

- IR safe (and collinear safe)
- as fast as available cone implementations
- has 10% impact on jet mass spectra
- is less affected by underlying events