Quantifying the Performance of Jet Definitions

On the paper:
Quantifying the Performance of Jet Definitions for Kinematic Reconstruction at the LHC
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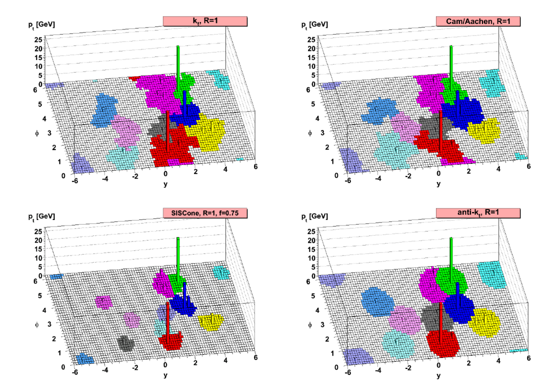
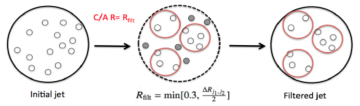
Motivation for Jet Definition Analysis

- in general many different jet definitions available
- experiments only calibrated to limited subset
- not clear which is best for a given analysis
- important to have previous knowledge about likely optimal definitions
- need for objective, robust “quality” measure



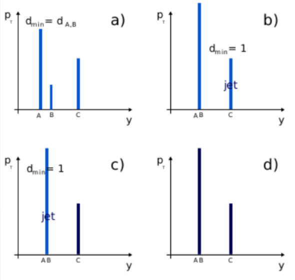
Jet Definitions

- **k_T**
  sequential-recombination algorithm
  distance: relative p_T ($p = 2$)
- **Cambridge/Aachen (C/A)**
  sequential-recombination algorithm
  distance: ΔR ($p = 0$)
- **anti-k_T**
  sequential-recombination algorithm
  distance: relative inverse p_T ($p = -2$)
- **SISCone**
  seedless-cone type algorithm
- **C/A with filtering**
  find n_{filt} hardest subjets at angular scale $x_{filt} R$
  $n_{filt} = 2$, $x_{filt} = 0.5$



sequential-recombination:

1. distances:
   $$d_{i,j} := \min\left(p_{T\,i}^p, p_{T\,j}^p\right) \cdot \left(\frac{\Delta R_{i,j}}{D}\right)^2$$
   $$d_{i,B} := p_{T\,i}^p$$
2. - if one $d_{i,j}$ is smallest: merge i and j
   - if one $d_{i,B}$ is smallest: define i as jet



Samples

- pp collisions at $\sqrt{s}$ =14 TeV
- for mono-energetic source of jets:
  - $H \to gg$
  - $Z' \to q\bar{q}$
  - vary masses m_H and $m_{Z'}$
  - widths of less than 1 GeV
- also use a more complex event: fully hadronic $t\bar{t}$ events

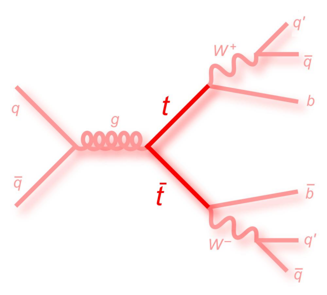


Figure: $t\bar{t}$ event fully hadronic, expect six jets.

Event Selection

gg and qq processes

1. carry out jet finding with chosen algorithm
2. keep two hardest jets with:
   - $p_t \geq 10\,\text{GeV}$
   - $|y| \leq 5$
   - $|\Delta y| \leq 1$
3. reconstruct invariant mass of the two jets

fully hadronic $t\bar{t}$ process

1. carry out jet finding with chosen algorithm
2. keep six hardest jets with:
   - $p_t \geq 10\,\text{GeV}$
   - $|y| \leq 5$
3. keep events with:
   - exactly six jets in total
   - exactly two b-jets
4. group non b-tagged jets to two W bosons by minimising $(m_{i_1 i_2} - m_W)^2 + (m_{i_3 i_4} - m_W)^2$
5. group W and b jets to two top jets
6. reconstruct invariant mass of the two top quarks

Figures of Merit

Aim: measure peak quality in each distribution

- *narrower peaks:* $Q^{w}_{f=z}$
  smallest window in reconstructed mass that contains a fraction $f = z$ of the generated massive objects
- *higher peaks:* $Q^{1/f}_{w=x\sqrt{M}}$
  inverse fraction of the (max.) number of reco. particles in a mass window against the total number of generated massive objects, where the window has a width of $w = x\sqrt{M}$
- lower values are better in both cases
- z chosen for each process separately (typ. window contains 25 % of post-cut objects)

- $w = 1.25\sqrt{\text{GeV}}$ according to calorimeter resolutions in ATLAS and CMS

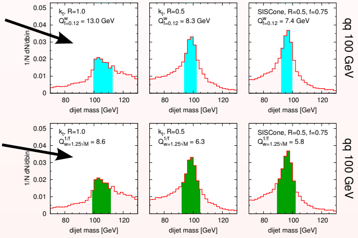
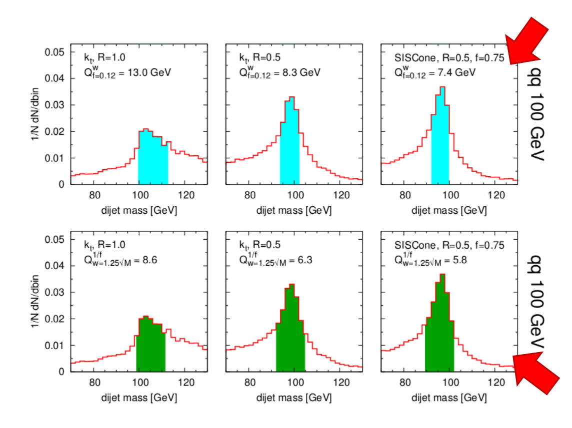


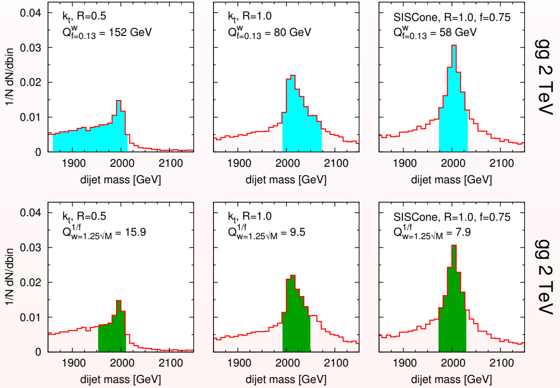
Figure: example for the two figures of merit: cyan: $Q^{w}_{f=z}$, green: $Q^{1/f}_{w=x\sqrt{M}}$

$Z' \to qq$ 100 GeV



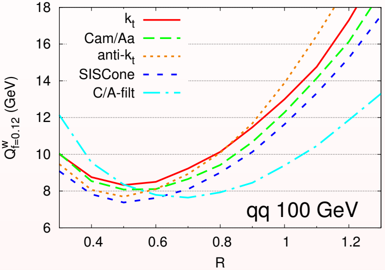
- The "best looking" histograms are those with smaller quality measure.
- Smaller R give better results.

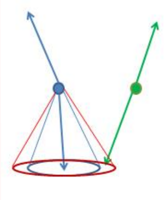
$H \rightarrow gg$ 2 TeV



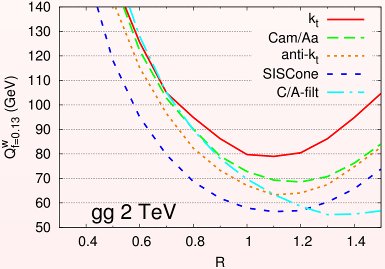
- Again a smaller value of Q corresponds with a better defined mass peak.
- Larger R give better results.

Dependence with the parameter R of the jet definition



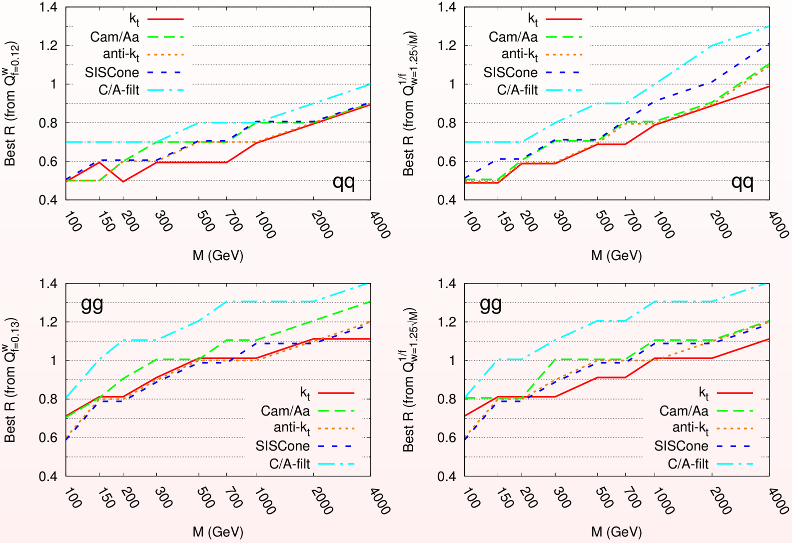


- A smaller value of the parameter R will avoid contamination from the underlying event (low p_t jets).

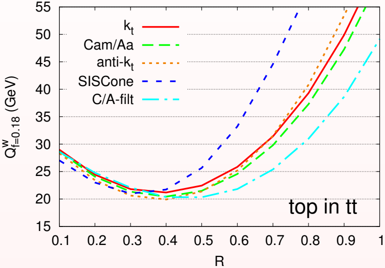


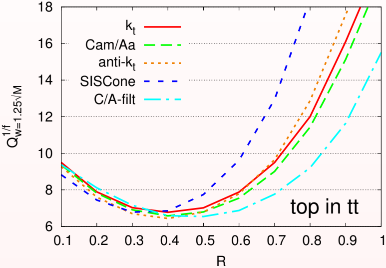
- A larger value of the parameter R will help to capture perturbative radiation (gluon jets have higher probability to radiate $\frac{C_A}{C_F} = \frac{9}{4}$).

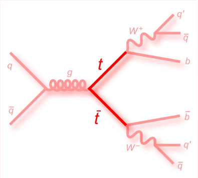
Dependence with the mass of the particle resonance



- Jet algorithms probed in a more complex multi-jet environment







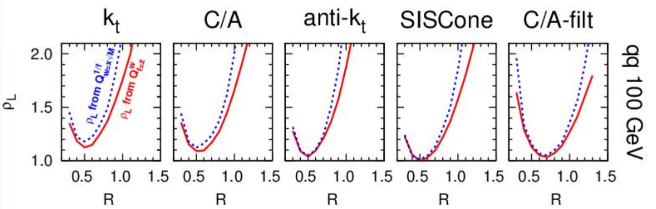
- Optimal R is significantly smaller than in the $q\bar{q}$ case.
- TENSION: Resolve the 6 jets **vs.** include the bulk of perturbative gluon emission in the jet.

Luminosity ratio $\rho_{\mathcal{L}}$ required in order to obtain the same significance as with the best JD.

JD≡ Jet Definition

Significance: $\Sigma(\mathrm{JD}) \equiv \frac{N_{signal}^{\mathrm{JD}}}{\sqrt{N_{bkgd}^{\mathrm{JD}}}}$

$\rho_{\mathcal{L}}(\mathrm{JD}2/\mathrm{JD}1) \equiv \left[\frac{\Sigma(\mathrm{JD}_1)}{\Sigma(\mathrm{JD}_2)}\right]^2$



- Choosing a non-optimal R:
  - SISCone with $R = 0.4(0.5)$ lead to a $\rho_{\mathcal{L}}$ of about 1.75(1.35) and 3(2) for the $q\bar{q}$ and gg case respectively at 2 TeV.
- Using the worst jet algorithm leads to an extra luminosity of $10 - 20\%$ at small energy scales and of $30 - 40\%$ at high scales.

Best jet definition for various processes

Process	$Q^{\omega}_{f=z}$			$Q^{1/f}_{\omega=1.25\sqrt{M}}$		
	$\mathrm{JD}_{\mathrm{best}}$		Q (GeV)	$\mathrm{JD}_{\mathrm{best}}$		Q
$q\bar{q}$, 100 GeV	SISCone	R=0.5	7.38	SISCone	R=0.5	5.83
$q\bar{q}$, 2 TeV	C/A–filt	R=0.9	20.8	SISCone	R=1.0	5.18
gg, 100 GeV	SISCone	R=0.6	14.7	SISCone	R=0.6	8.78
gg, 2 TeV	C/A–filt	R=1.3	55.2	C/A–filt	R=1.3	7.64
W in $t\bar{t}$	anti-k_t	R=0.4	10.7	anti-k_t	R=0.4	5.37
t in $t\bar{t}$	anti-k_t	R=0.4	19.9	anti-k_t	R=0.4	6.44

- Longitudinal invariant k_t and C/A algorithms are not usually the best choice.
- In most of the studied cases both quality measurements selects the same jet definition and the same parameter R.
- CAVEAT These results may change since the detector influence has not been taken into account.

ANALYSIS	ATLAS ANTI-KT	CMS ANTI-KT
Searches for new particles in dijet final states	R=0.6	R=0.5, 0.7 Wide jet
Dijet angular distributions	R=0.6	R=0.5
Top quark pair production	R=0.4	R=0.5
Jet, dijet cross sections	R=0.4, 0.6	R=0.5, 0.7
Searches for supersymmetry	R=0.4	R=0.5

Conclusions

- The best jet definition (algorithm + parameters) depends on the kinematics of the process and the mass scales involved.
- Larger mass implies larger R with the best performance since perturbative radiation will increase.
- In multi-jet events the value of the best choice of R is significantly smaller than in processes with the same scales and smaller jet multiplicities.
- In the presented results pile-up effects have not been taken into account.

THANK YOU FOR YOUR ATTENTION