Revealing the jet substructure in a compressed spectrum

Chengcheng Han

Based on arXiv:1507.07729
Collaborate with M. Park

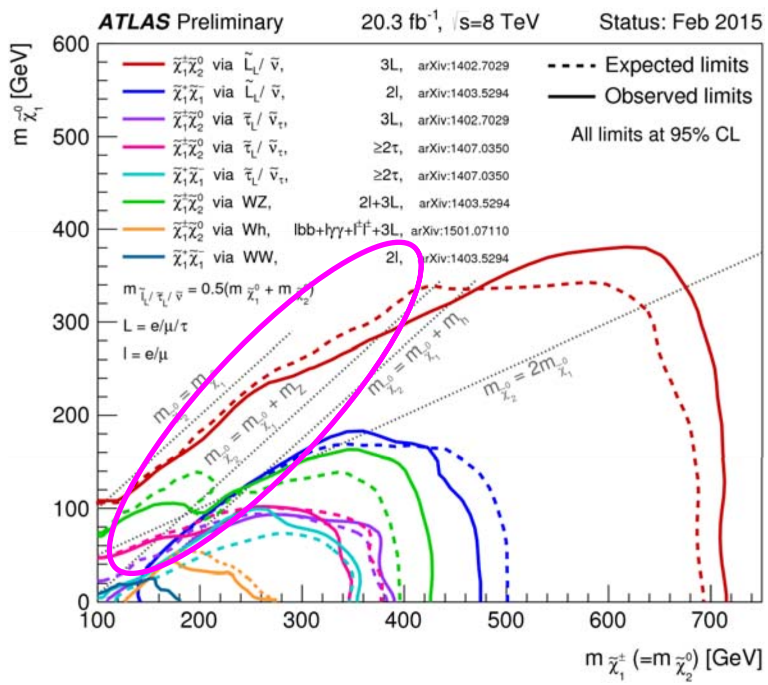
Kavli-IPMU-Durham-KIAS workshop

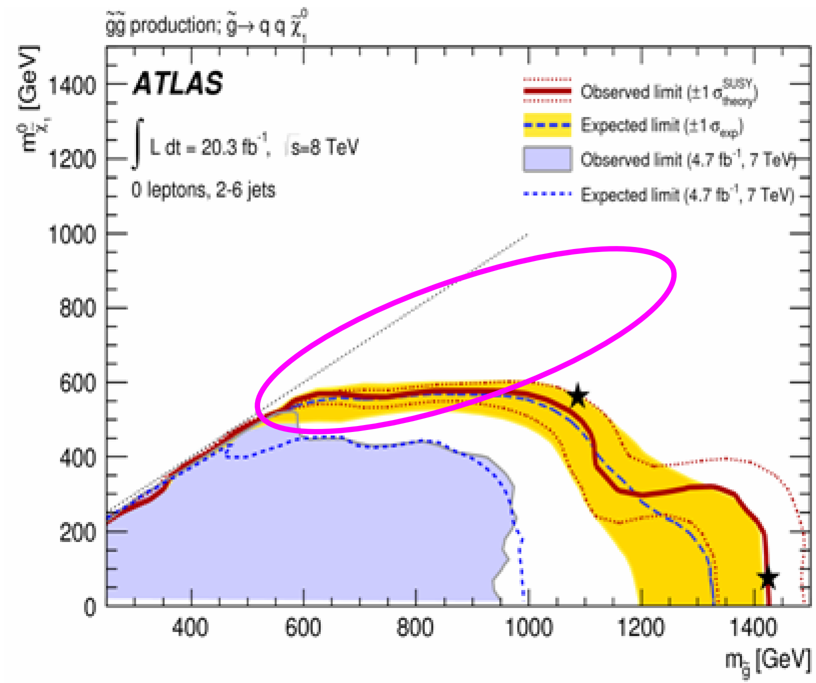
Outline

- Motivations
- Method description
- Application

Current Situation

LHC has excluded out a lot of parameter space of the new physics models. Taking SUSY search as an example:





- The LHC is approaching the limit of its energy in the search for the new physics.
- When the spectrum becomes compressed, the current analyses become less sensitive.

Compressed spectrum

Compressed spectrum is naturally predicted by some SUSY breaking models.

- through boundary condition in compact extra dimensions

  H. Murayama, Y. Nomura, S. Shirai and K. Tobioka, Phys. Rev. D **86** (2012) 115014

- pure gravity mediation model with the presence of axion

  K. Nakayama and T. T. Yanagida, Phys. Lett. B **722** (2013) 107

The compressed spectrum are also favored by dark matter: SUSY models like the bino wino co-annihilation region or bino gluino co-annihilation region.

S. Profumo and C. E. Yaguna, Phys. Rev. D **69** (2004) 115009

K. Harigaya, K. Kaneta and S. Matsumoto, Phys. Rev. D **89** (2014) 11, 115021
and etc.

How to probe the compressed spectrum?

Current search method: tagging "Initial State Radiation (ISR) Jet-s" + Missing Enegy.

- Signals from SUSY decay becay become soft
- p_T of ISR gets harder with the mass scale of SUSY
- Major BKG will be $Z(\nu\bar{\nu})$+jets

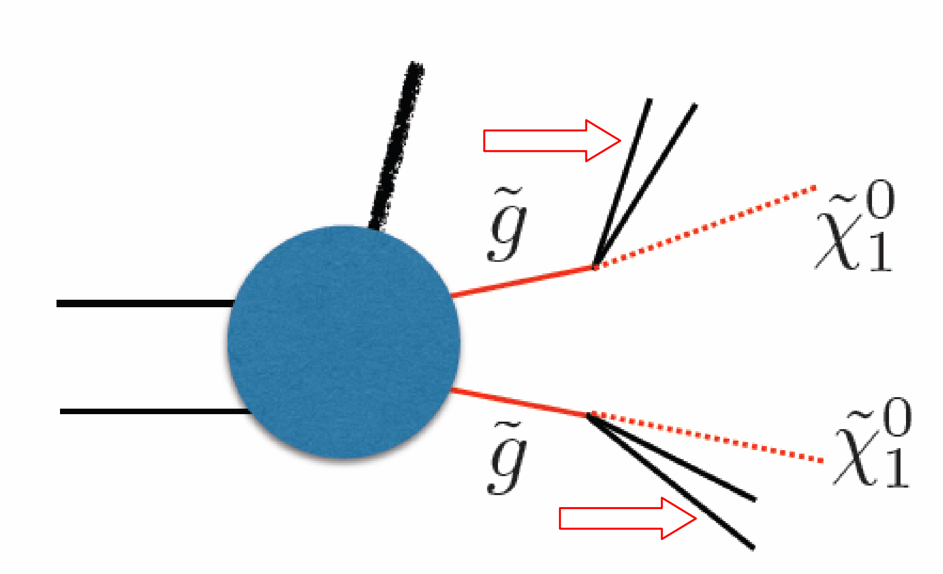
Possibility to discriminate

ISR jet(initially gluon) vs quark jets (Z+jets)

J. Gallicchio and M. D. Schwartz, Phys. Rev. Lett. **107** (2011) 172001
S. Mukhopadhyay, M. M. Nojiri and T. T. Yanagida, JHEP **1410** (2014) 12
B. Bhattacherjee, S. Mukhopadhyay, M. M. Nojiri, Y. Sakaki and B. R. Webber, JHEP **1504** (2015) 131
and etc..

But not enough

We need tag "Signals" from SUSY decay



To understand properties of SUSY particles(masses,spin and coupling structure)

Jet substructure in Compressed spectrum

Considering process $A \to q + q' + B$, A or B is a massive particle and generally have mass small splitting(compress), and q, q' denote the light quarks.

$$\Delta m = m_A - m_B \ll m_A$$

The two partons tend to be close with each other!

$$\frac{d\sigma}{dM_{qq'}^2} \propto \frac{\lambda^{\frac{1}{2}}(m_A^2, M_{qq'}^2, m_B^2)}{m_B^2} \Longrightarrow \qquad M_{qq'}^{peak} \sim \frac{\Delta m}{\sqrt{2}}$$

$$\Delta R \approx \frac{2M_{qq'}}{p_T} \quad \text{if we require } p_T > \Delta m,\ \Delta R \lesssim \sqrt{2} \sim 1.5$$

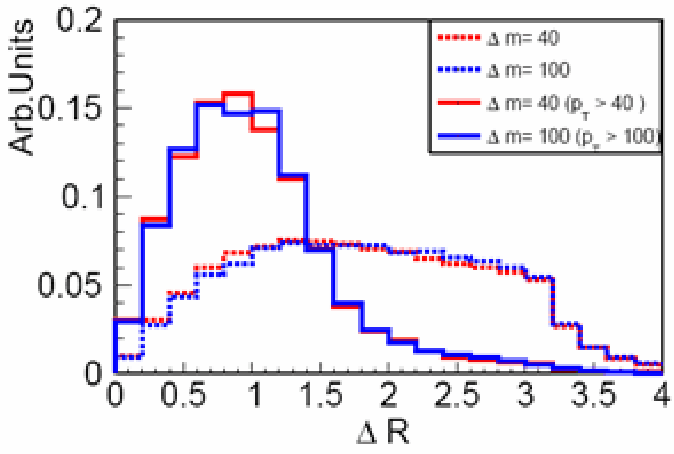
We can use the concept of fat jet with jet substructure!

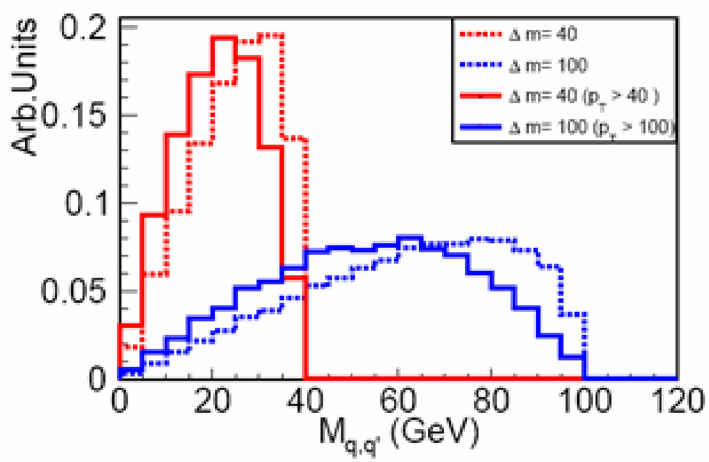
Different from the original fat jet: low p_T and wide mass range

Jet substructure in Compressed spectrum

Take gluino production as an example

$\tilde{g} \to q + \bar{q} + \chi_1^0$ LSP mass 600 GeV

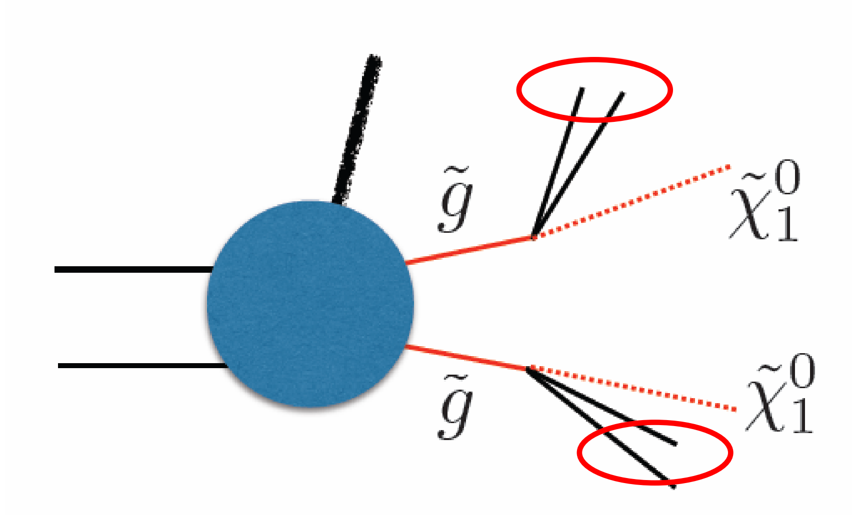




Jet substructure in Compressed spectrum

Cluster these two partons as a whole jet, and then distinguished it from the normal jet

An illustration for this process



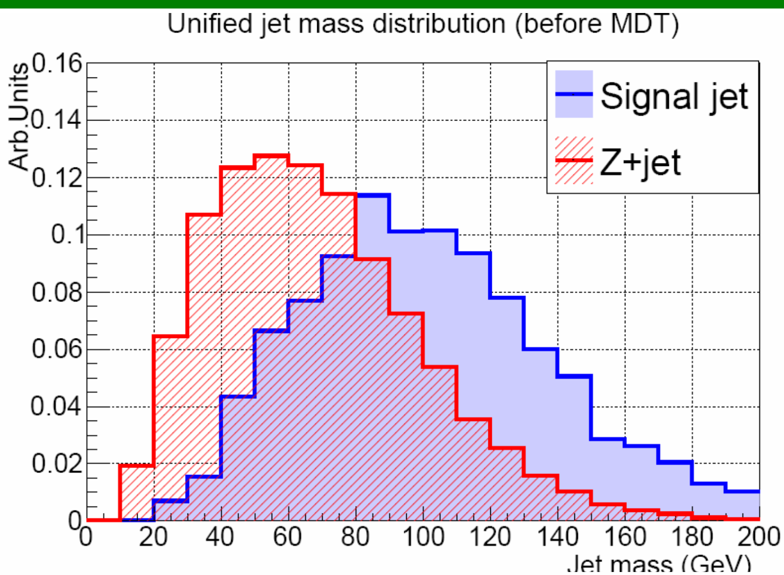
Jet substructure in Compressed spectrum

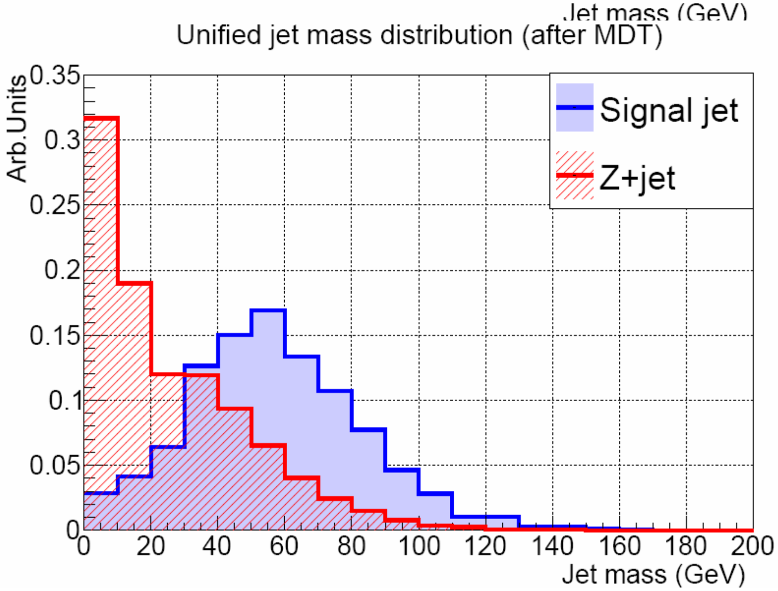
A fat-jet with a large radius R can have various QCD contaminations resulting in gaining extra mass. To remove this contamination, we implement the Mass Drop Filtering

PYTHIA with AUET2B tuning
Delphes3 for detector simulation

$\Delta m = 100$ GeV,
LSP mass 600 GeV

Consistent with the parton level analysis



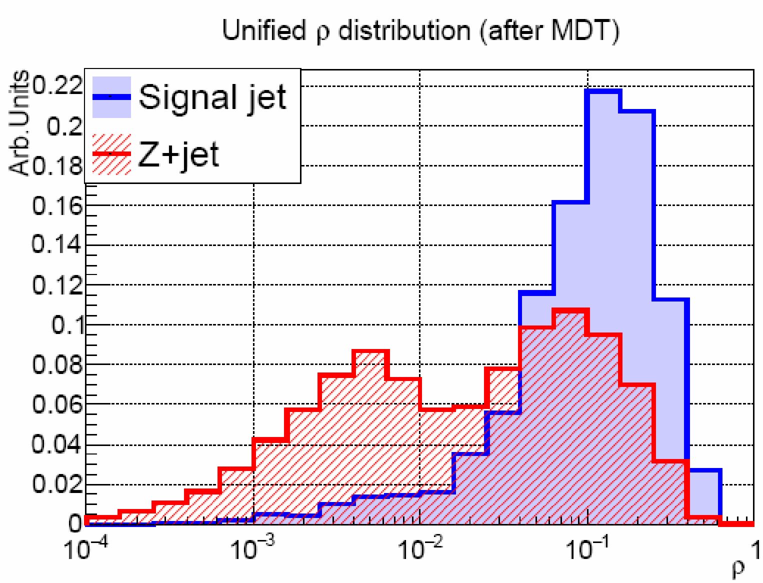


Jet substructure in Compressed spectrum

Define a dimensionless parameter $\rho = \frac{m_j^2}{p_{Tj}^2 R^2}$. Normal quark jet

$$\frac{\rho}{\sigma}\frac{d\sigma}{d\rho} = \frac{\alpha_s C_F}{\pi}[\Theta(\rho - y_{cut}) \ln\frac{1}{\rho} + \Theta(y_{cut} - \rho) \ln\frac{1}{y_{cut}} - \frac{3}{4}]$$

For signal jets, $\rho \sim 0.2$ $(m \sim \Delta m/\sqrt{2}, p_T \sim \Delta m$ and $R = 1.5)$



Jet substructure in Compressed spectrum

Tagger/fake efficiency

BP $m_{\tilde{\chi}_1^0} = 600$	cuts	Signal (ϵ_{tag})	$Z + j$ (ϵ_{fake})
BP1	$10 < m_{\text{FJ}} < 40$	0.75	0.55
$\Delta m = 40$	Additional $\rho > 0.1$ cut	0.40	0.18
BP2	$40 < m_{\text{FJ}} < 100$	0.62	0.22
$\Delta m = 100$	Additional $\rho > 0.1$ cut	0.42	0.12

Gluino search

Most sensitive region for the compressed gluino search ($20\ fb^{-1}$ 8 TeV LHC)

Signal region "2jm"	cuts
E_T^{miss} [GeV]	> 160
$p_T(j_1)$ [GeV]	> 130
$p_T(j_2)$ [GeV]	> 60
$\Delta\phi(jet_{1,2,(3)}, E_T^{miss})_{min}$	> 0.4
$E_T^{miss}/\sqrt{H_T}$[GeV$^{1/2}$]	> 15
$m_{eff}(incl.)$ [GeV]	> 1200

Upper limit is 90 events after all the cuts

Gluino search

Jets have been clustered by two algorithms, one is anti-k_T algorithm with R=0.4 as required in ATLAS paper and the other is C/A algorithm with R=1.5

To apply the cuts on the signal jet, we need choose out our signal jet from ISR jets. Here we use following criteria:

(1) Apply a cut $p_{T(\mathrm{FJ})} > \Delta m$ on fat-jets. Each fat-jet is groomed with MDT procedures.

(2) Choose the fat-jet with the largest ρ and mark this fat-jet as a candidate for a signal fat-jet (a fat-jet from a gluino decay).

Gluino search

To show the effectiveness of the above selection criteria, we define following two efficiencies:

$$\epsilon_1 = \frac{N_{\text{signal}}}{N_{\text{total}}}, \quad \epsilon_2 = \frac{N_{\text{candidate}}}{N_{\text{signal}}},$$

	$\Delta M = 40\,\text{GeV}$	$\Delta M = 100\,\text{GeV}$
ϵ_1	0.64	0.56
ϵ_2	0.58	0.74

where N_{total} is the number of generated signal events and N_{signal} denotes a number of events that contains a fat-jet from a gluino decay. The $N_{\text{candidate}}$ is the number of events where a fat-jet from a gluino decay is taken as the candidate through above criteria. Thus ϵ_1 gives the fraction of events containing the signal fat-jets and ϵ_2 show the efficiency of finding signal fat-jet.

Gluino search

For the backgrounds

$$N = \frac{N_{MC}^{after}}{N_{MC}^{before}} \times N_{fitted}$$

Where N_{MC}^{before} and N_{MC}^{after} is the number of events before or after the cuts on the faked signal jets. N_{fitted} is the number of background events from fit of control region events.

$$significance = \frac{S}{\sqrt{B + (\epsilon B)^2}}$$

ϵ is the sys. uncertainty. Taken as 10% and 7% with and without tagging the signal jet

Gluino search

Improvement on the gluino search

Methods			Z+js	W+js	$t\bar{t}$+js	Total	BP1	σ	BP2	σ
ATLAS			430	216	47	693	74	1.34	57	1.03
With FJ	Δm	40	48	31	7	86	27	2.12	—	
		100	21	18	11	50	—		17	1.96

Conclusion

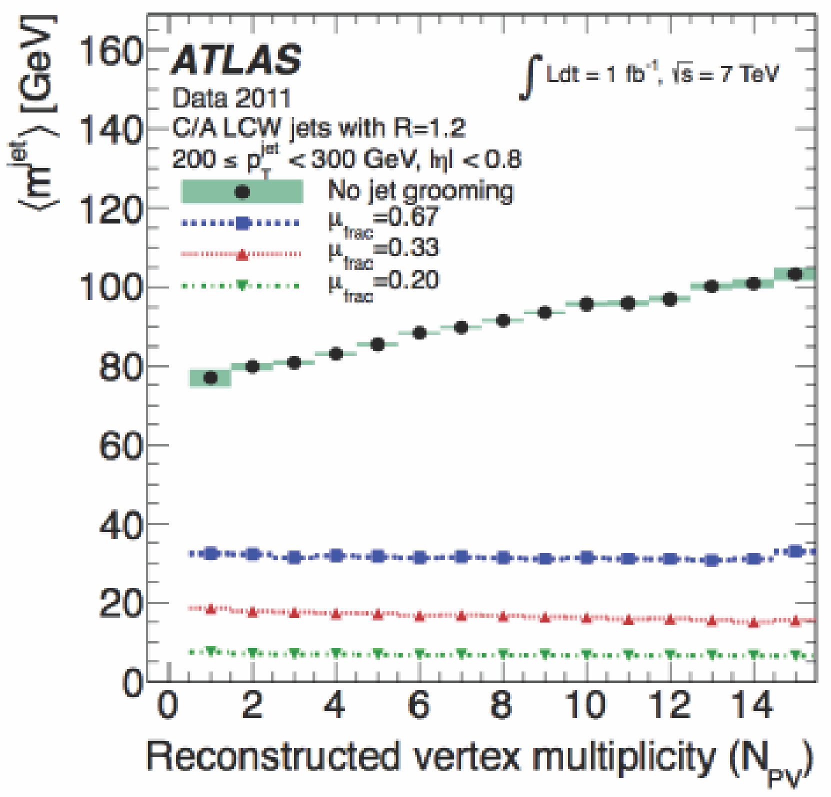
- From the jet substructure we can distinguish the decay products of compressed spectrum from normal jets.
- We can use fat jet to probe the compressed spectrum.


STEPHEN COVEY:
Begin with
the end in mind.

Back up

Gluino search

Pile up effect?



Pile up effects after MDT

Mass-drop Filtering

(1) Undo the last clustering step of j to get j_1 andj_2. These are ordered by their mass: $m_{j_1} > m_{j_2}$. If j cannot be unclustered, discard this jet.

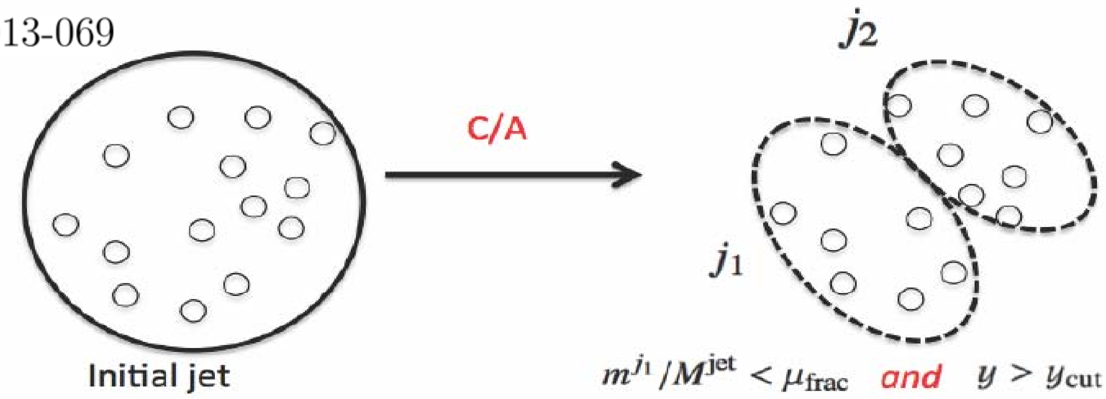
(2) If the splitting has $m_{j_1}/m_j < \mu$ (large change in jet mass) and $y > y_{cut}$ (fairly symmetric, here $y = \frac{min(p_{Tj_1}^2, p_{Tj_2}^2)}{m_j^2} \Delta R_{j_1,j_2}^2$), then continue, otherwise redefine j_1 as j and go back to step 1.

(3) Reculster the constituents of the jet with the C/A algorithm with an R-parameter of $R_{filt} = min(0.3, \Delta R_{j_1,j_2}/2)$ finding n new subjets $s_1, s_2 \ldots s_n$ ordered in descending p_T.

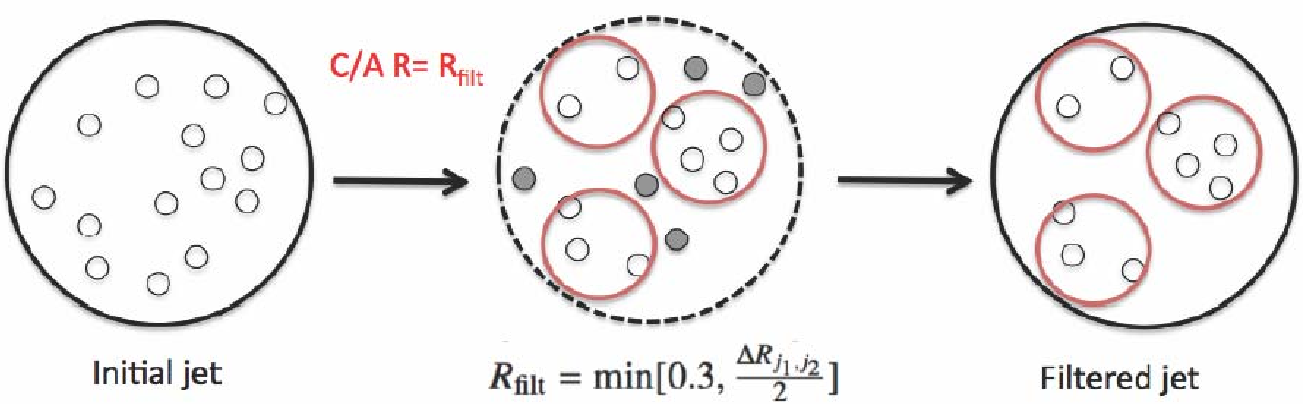
(4) Redefine the jet as the sum of subjet four-momenta $\sum_{i=1}^{min(n,3)} s_i$.

Mass-drop Filtering

CERN-PH-EP-2013-069



(a) The mass-drop and symmetric splitting criteria.



(b) Filtering.