QJets

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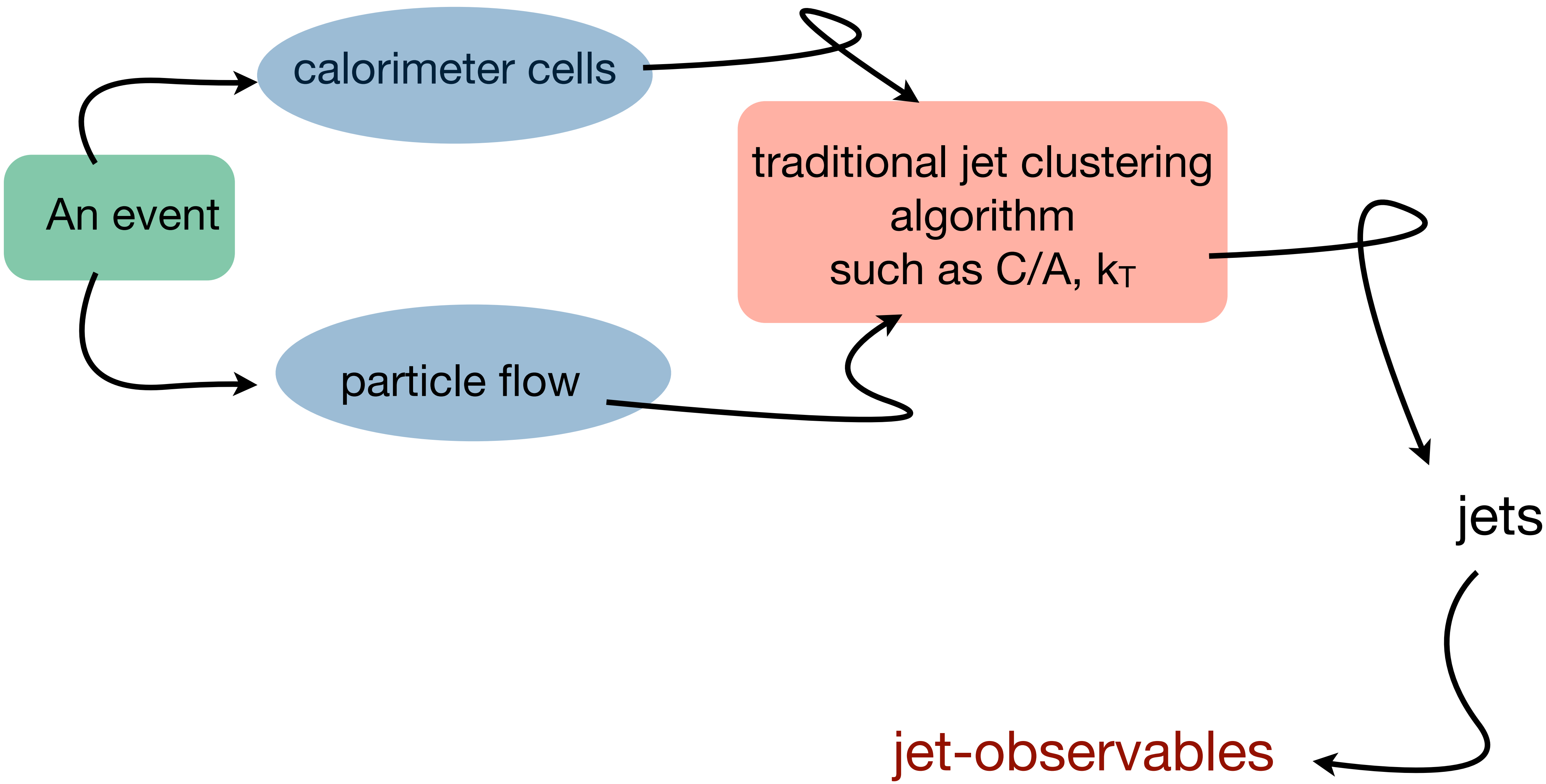
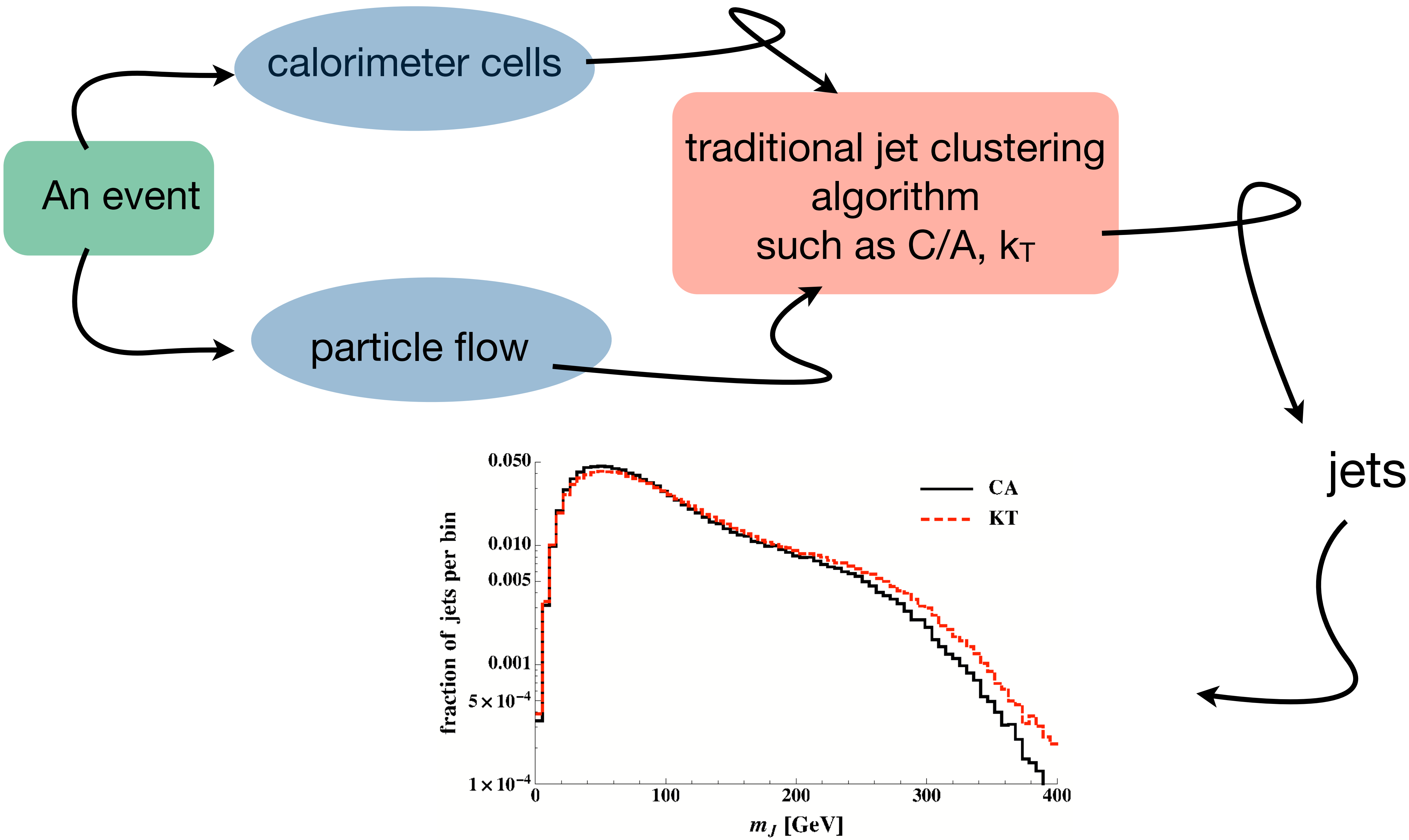
and Matt Schwartz

arXiv:1201.1914
Phys.Rev.Lett. 108 (2012)
work-in-progress

QJets

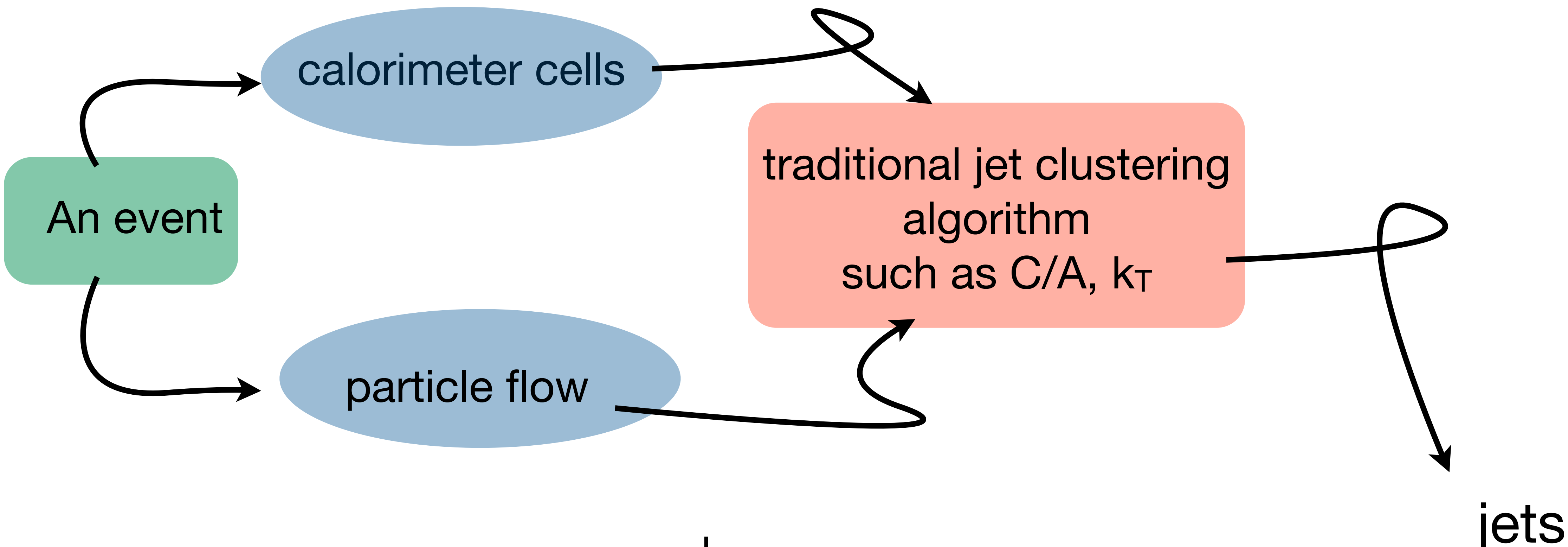

calorimeter cells
An event
traditional jet clustering algorithm such as C/A, k_T
particle flow
jets
jet-observables

QJets



calorimeter cells
An event
traditional jet clustering algorithm such as C/A, k_T
particle flow
jets
fraction of jets per bin
0.050
0.010
0.005
0.001
5×10^{-4}
1×10^{-4}
0
100
200
300
400
m_J [GeV]
CA
KT

QJets



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An event
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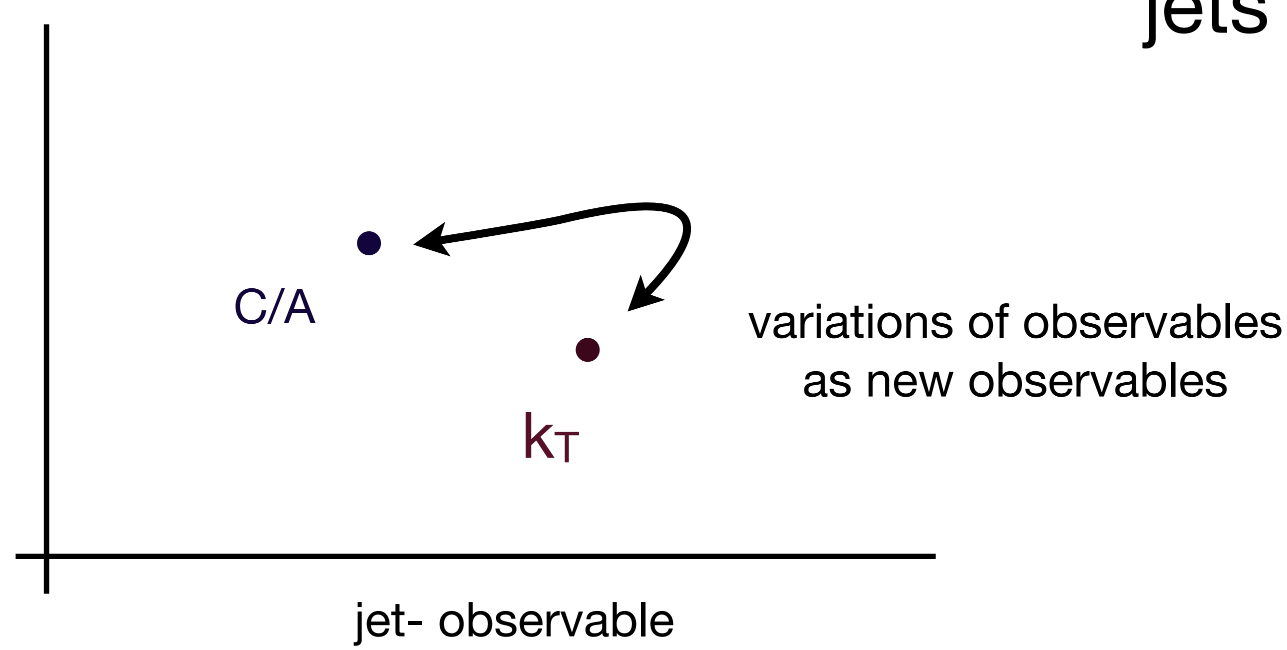
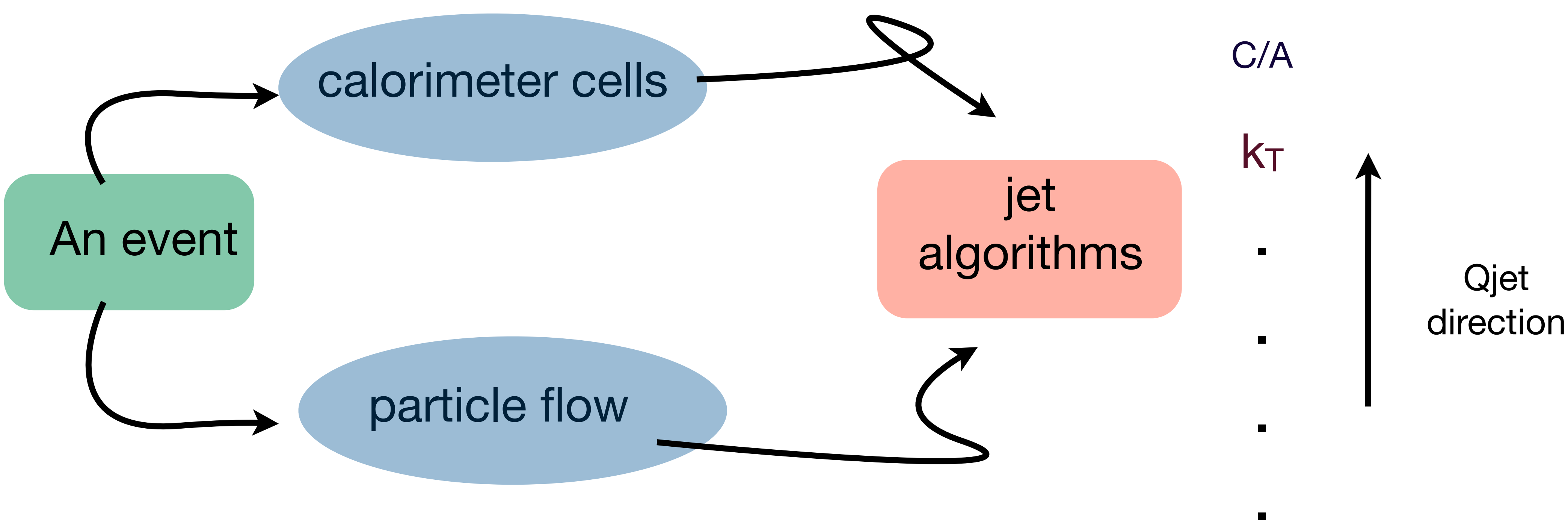


C/A
k_T
variations of observables as new observables
jet- observable

QJets

Qjets is an idea that explores the dimension of clustering history



QJets

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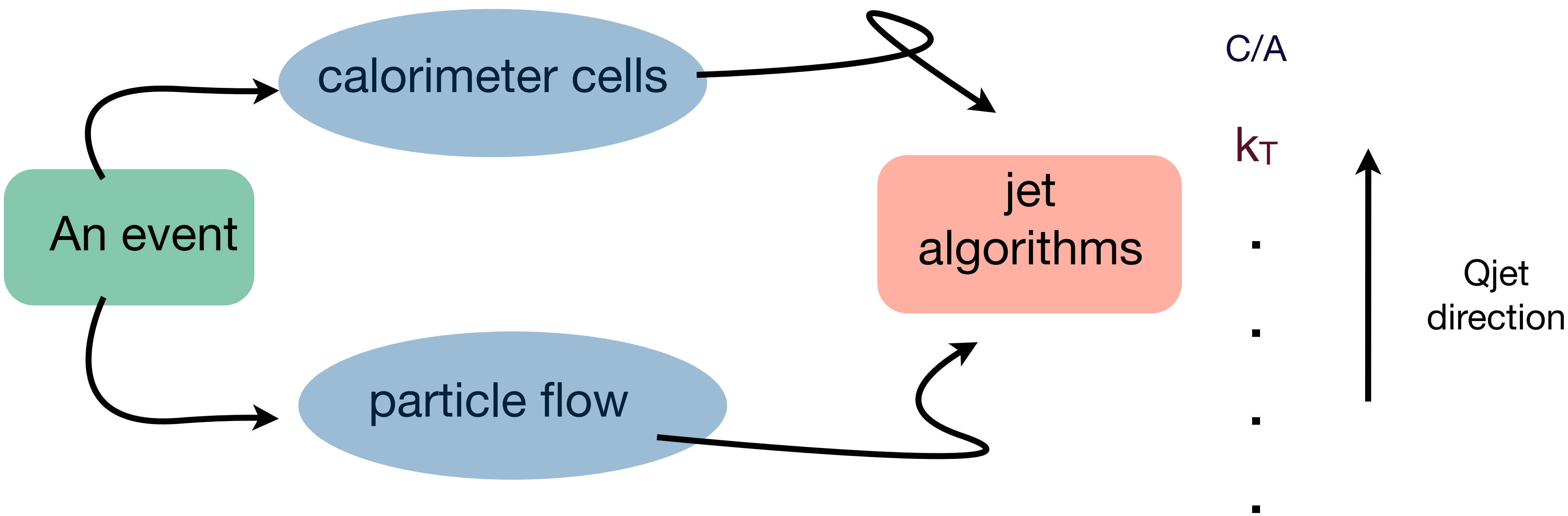
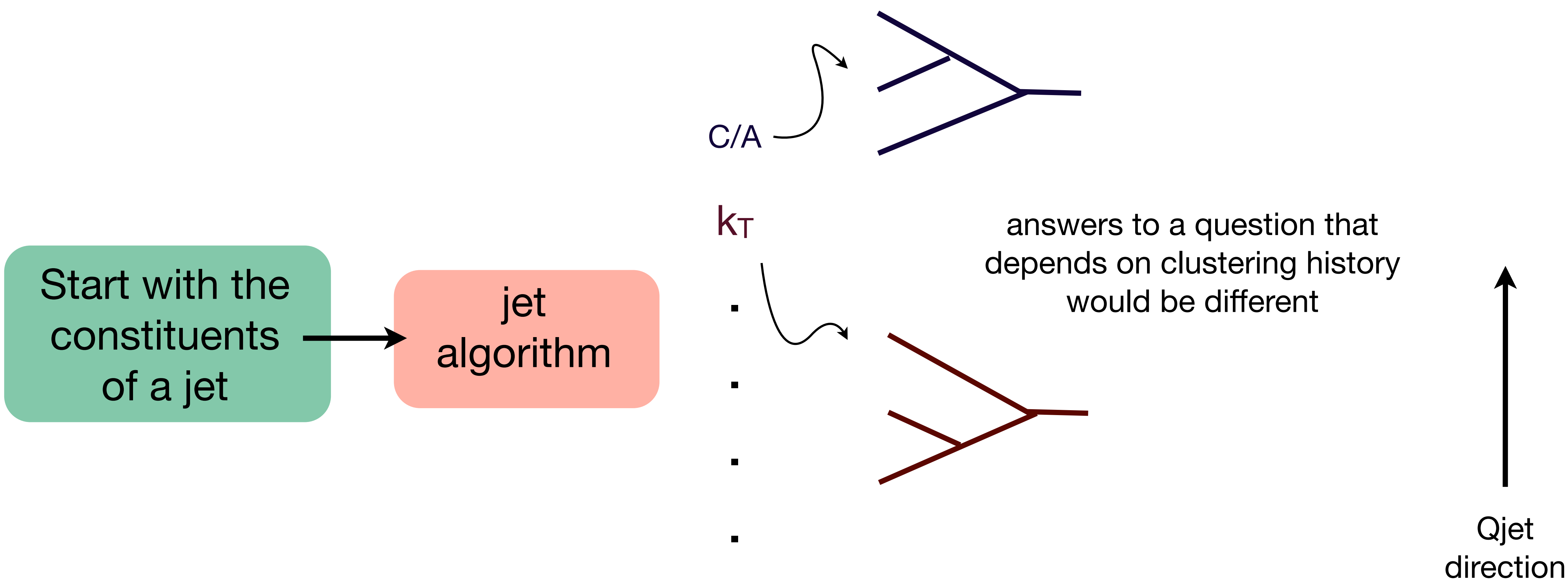


it is a challenging task -- let us start with something simpler

QJets

Qjets is an idea that explores the dimension of clustering history



it is a challenging task -- let us start with something simpler

Outline

Boosted Jets and Substructure Analysis

- Applications in Higgs Search
- Pruning

Clustering vs QClustering

- QPruning
    - Applications

Boosted jets and substructure analysis

Butterworth, Davison, Rubin, Salam
0802.2470

Recipe for boosted resonance search:

(if you know what you are looking for)

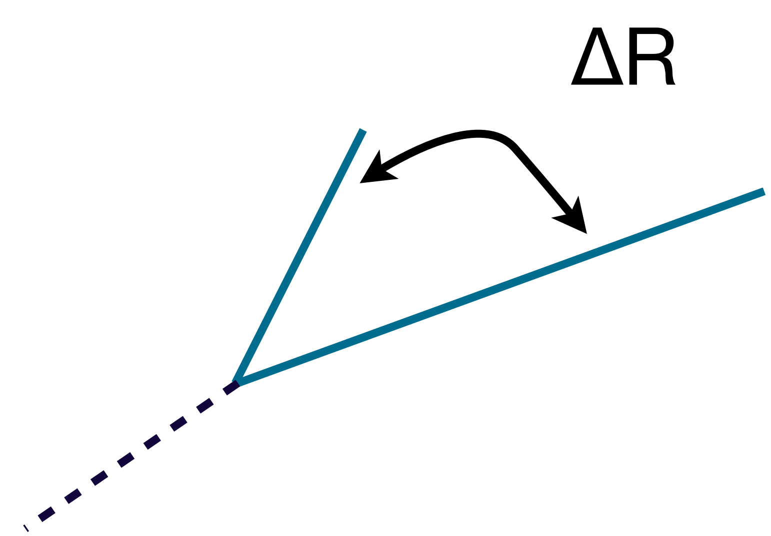
- Look for “boosted” jets
- Identify “interesting” jets
- Clean jets

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for)   ex. h -> bb

- Look for "boosted" jets



the angular separation of the decay products $\Delta R \sim 2\, m_h/p_{Th}$

"boosted jets" refer to jets containing four-vectors separated by $\Delta R \sim 1.0$ and with $p_T > 2\, m_h$

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for) ex. h -> bb

- Identify “interesting” jets

Higgs jets should have “mass-drop”

Higgs jets should be double b-tagged

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for)   ex. h -> bb

- Clean jets

  - signal jets contain ISR + UE + pile-up other than the decay products
  - cleaning a jet involves guessing which components are not due to decay + FSR and getting rid of these
    - ex: filtering, pruning, trimming etc.

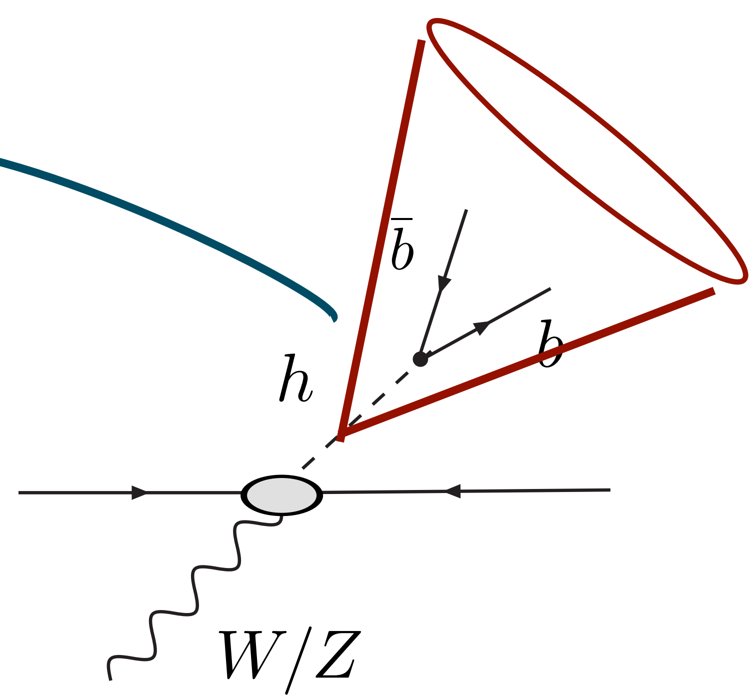
LHC Higgs reach

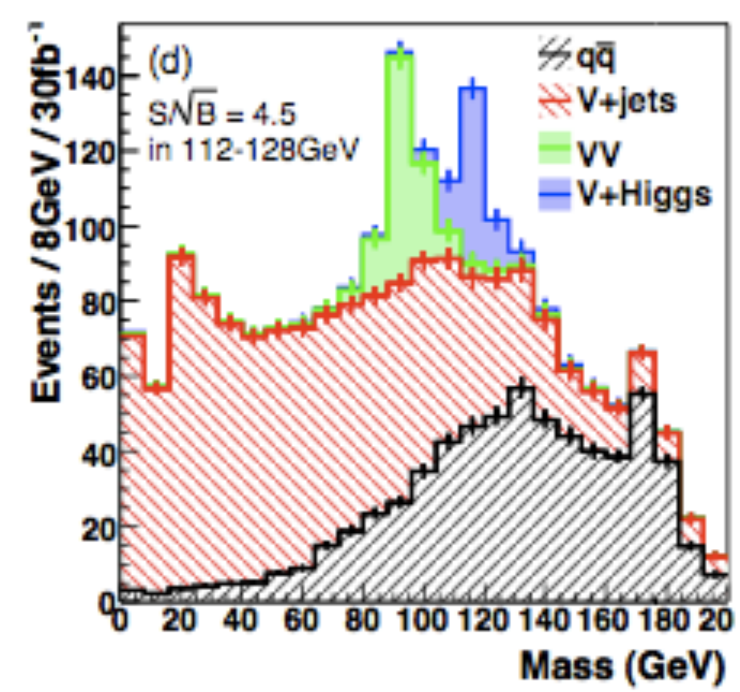
Butterworth, Davison, Rubin, Salam
0802.2470

Ex. $$pp \longrightarrow V\ h$$

significance of 4.2 σ at $\mathcal{L} = 30\ \mathrm{fb}^{-1}$
using jet-substructure for jets with $p_{T,h} > 200\ \mathrm{GeV}$

Jet with substructure





- subjets are significantly lighter than the jet
- splitting is not too asymmetric
- jet is double b-tagged

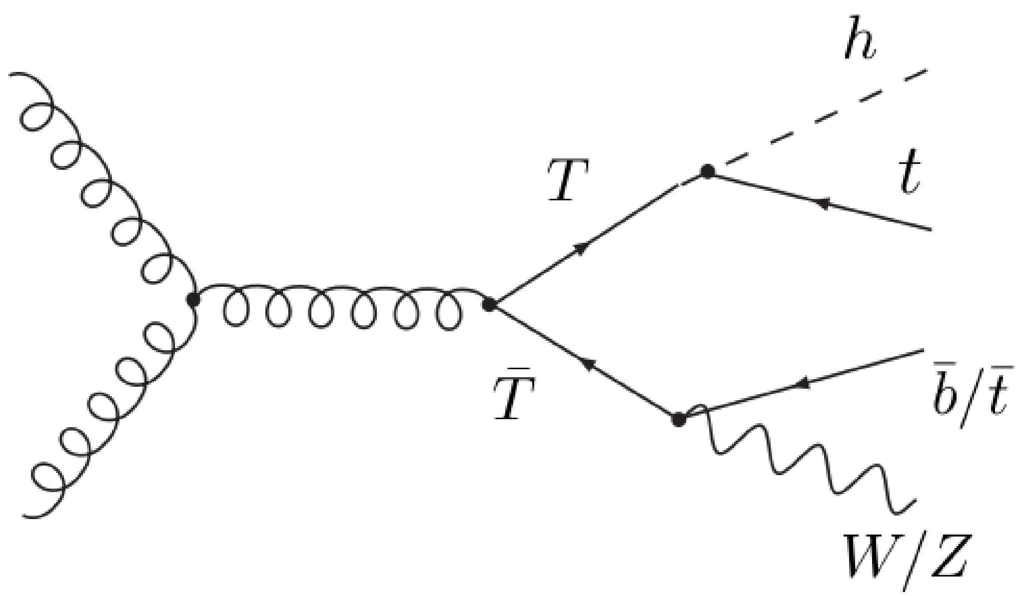
filtered

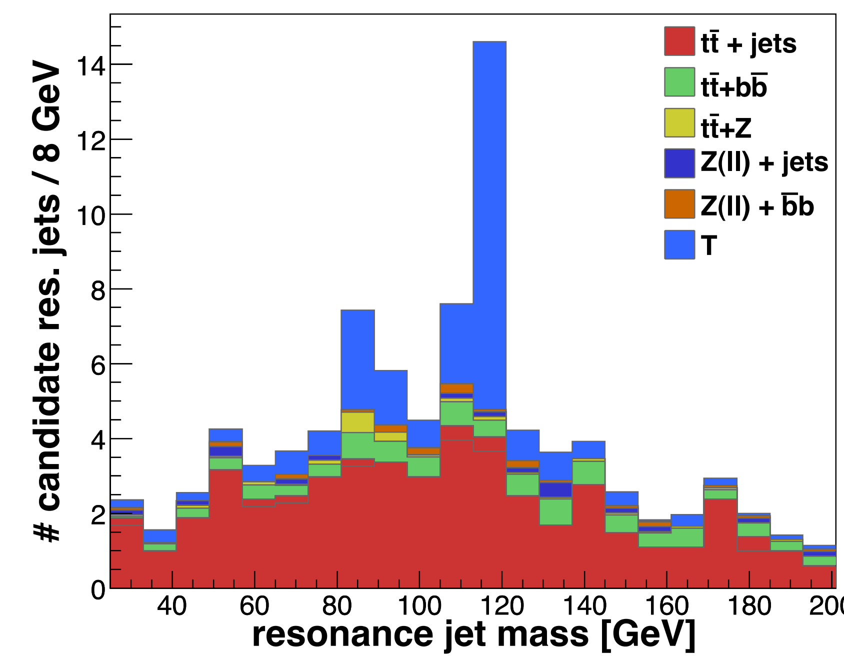
LHC Higgs reach

Kribs, Martin, TSR
1012.2866

Ex. Higgs from top partners

$\sqrt{s} = 14\ \mathrm{TeV}, \mathcal{L} = 10\ \mathrm{fb}^{-1}$





$M_T = 800\ \mathrm{GeV}$

LHC Higgs reach

Kribs, Martin, TSR
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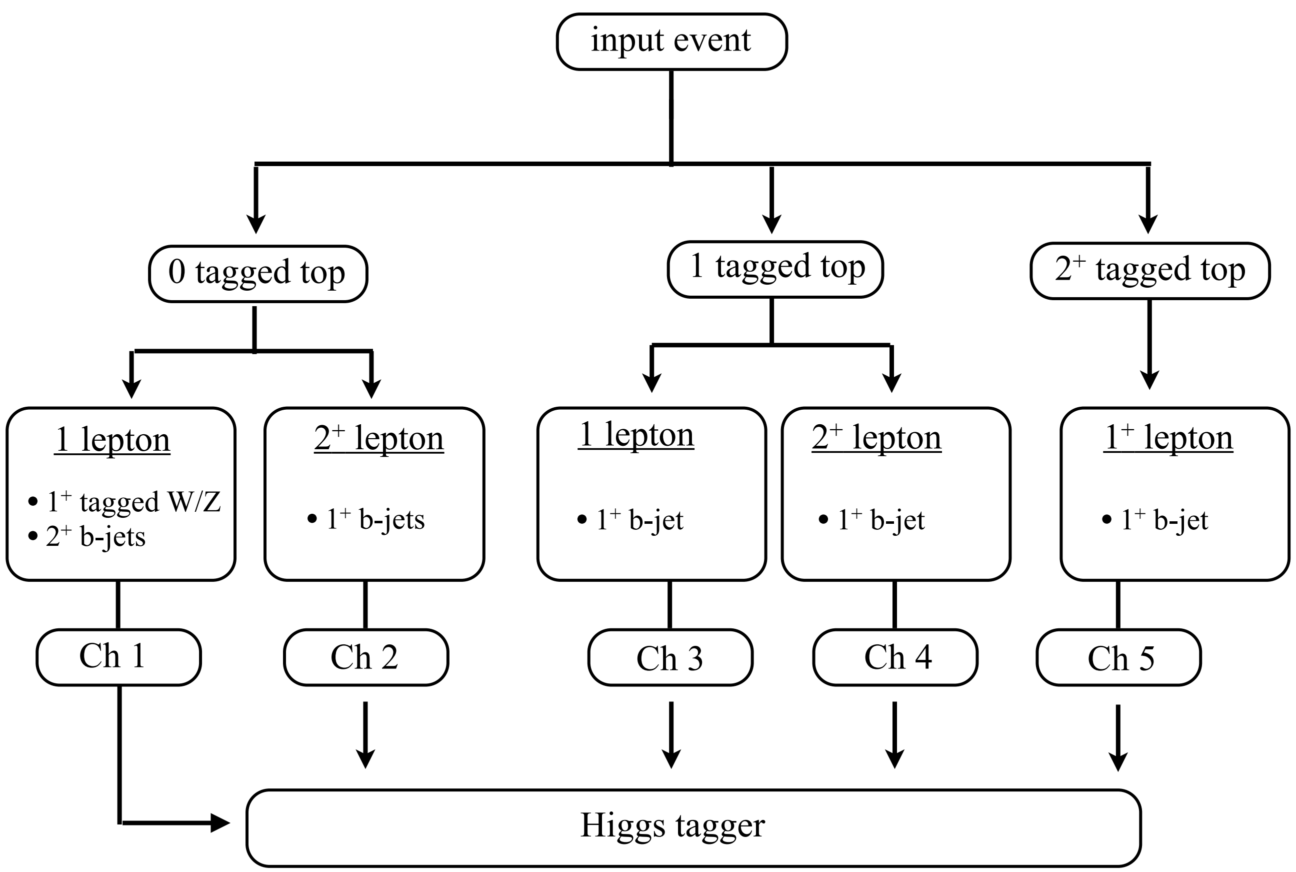
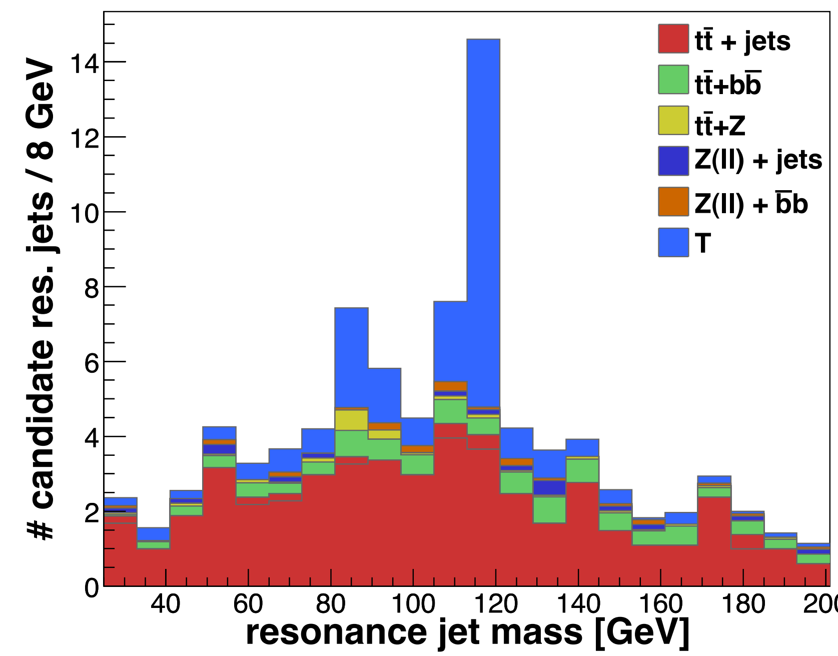
Ex. Higgs from top partners

$$\sqrt{s} = 14 \text{ TeV}, \mathcal{L} = 10 \text{ fb}^{-1}$$





$$M_T = 800 \text{ GeV}$$

$$S/\sqrt{B} = 5.2$$

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you don't know what you are looking for)

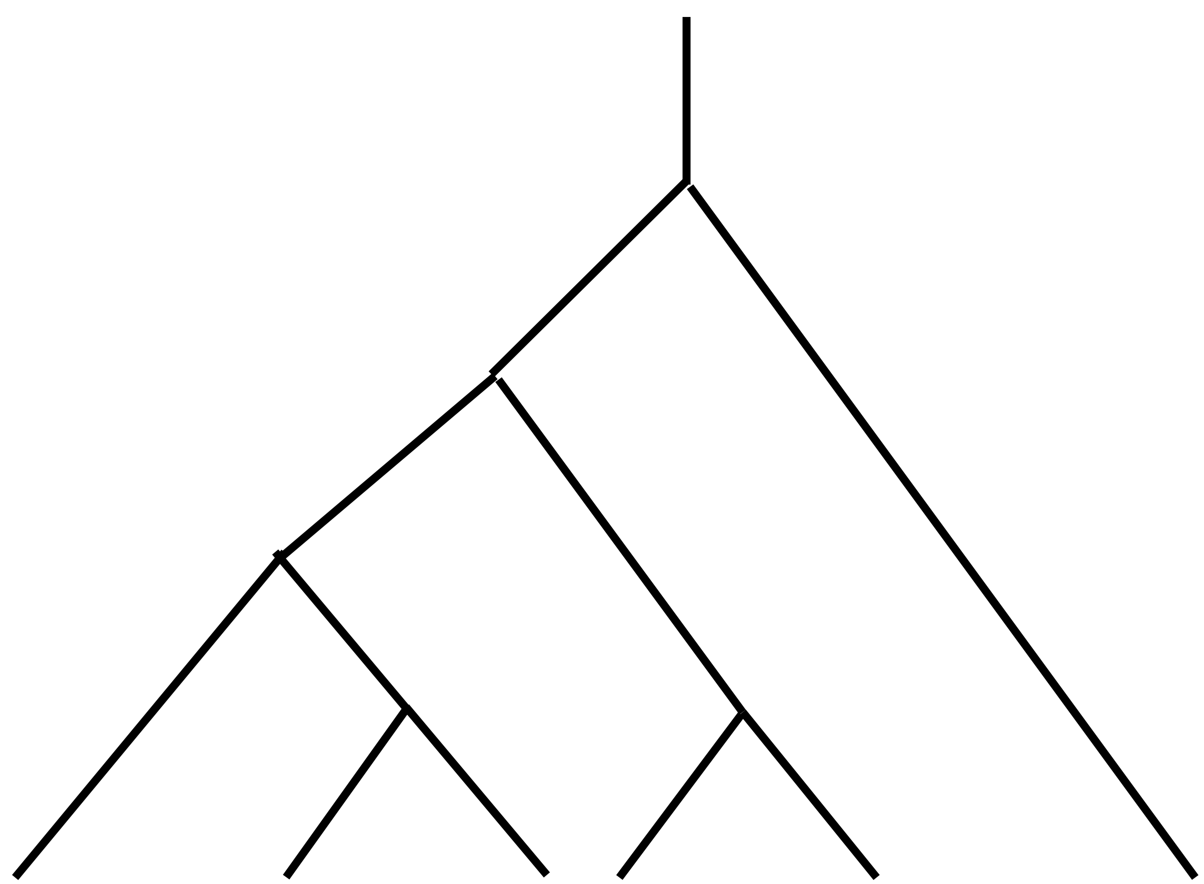
- Look for "boosted" jets
- ~~Identify "interesting" jets~~
- Clean jets

more important than ever

rest of the talk will be on how pruning can be made a more effective groomer.

Pruning

Start with the constituents of a given jet and rebuild the jet along C/A or k_T



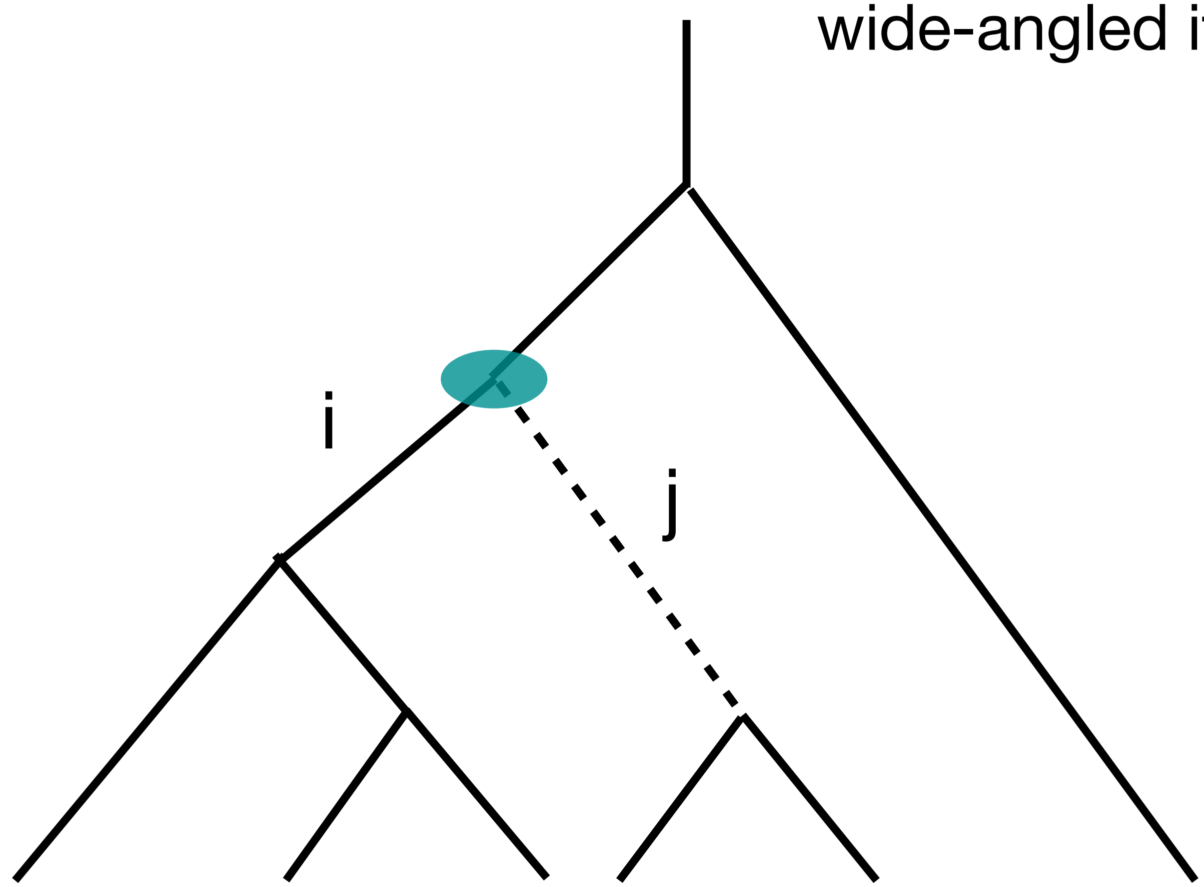
Pruning

At every step of clustering check whether the branch to be added is soft **and** wide angled.

- if yes discard the softer four-vector.

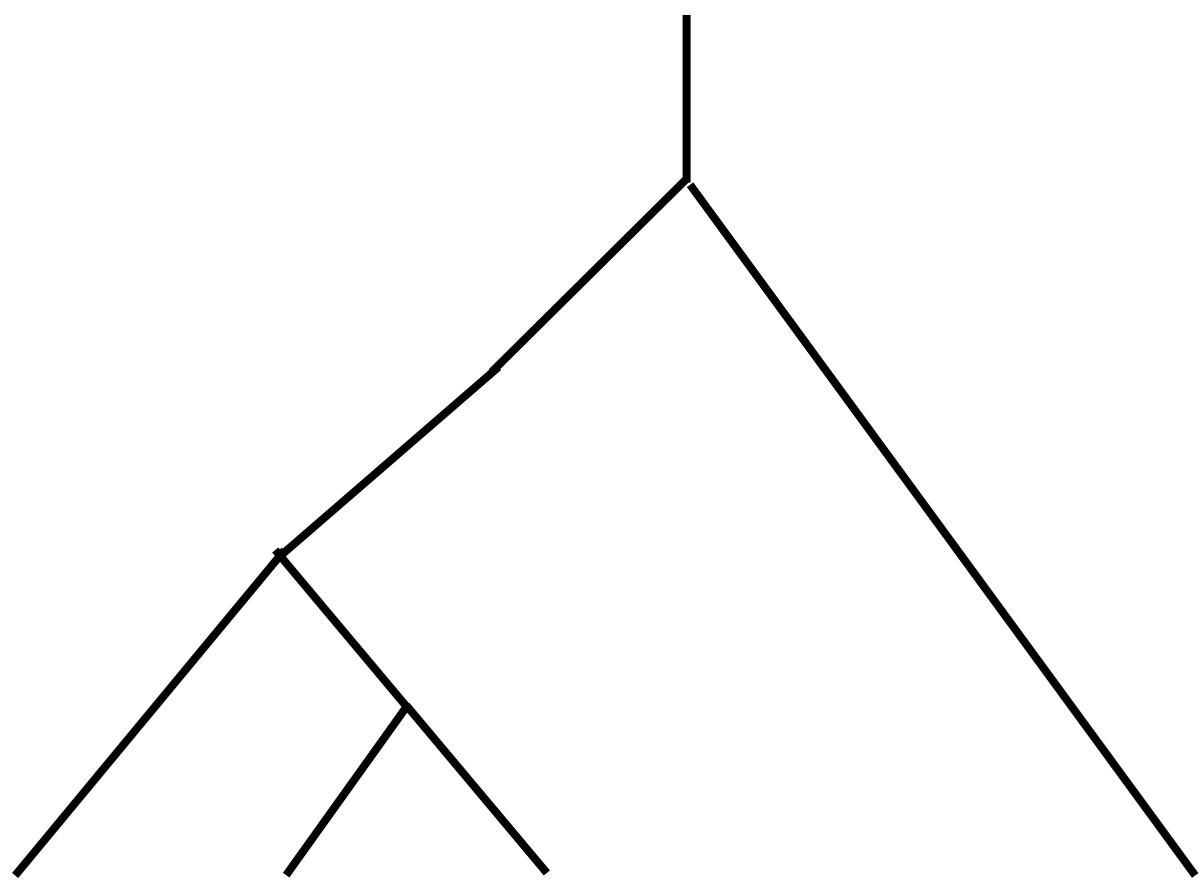
soft if: $\dfrac{\min\left(p_{T_i}, p_{T_j}\right)}{|\vec{p_{T_i}} + \vec{p_{T_j}}|} < z_{\mathrm{cut}}$

wide-angled if: $\Delta R_{ij} > D_{\mathrm{cut}}$

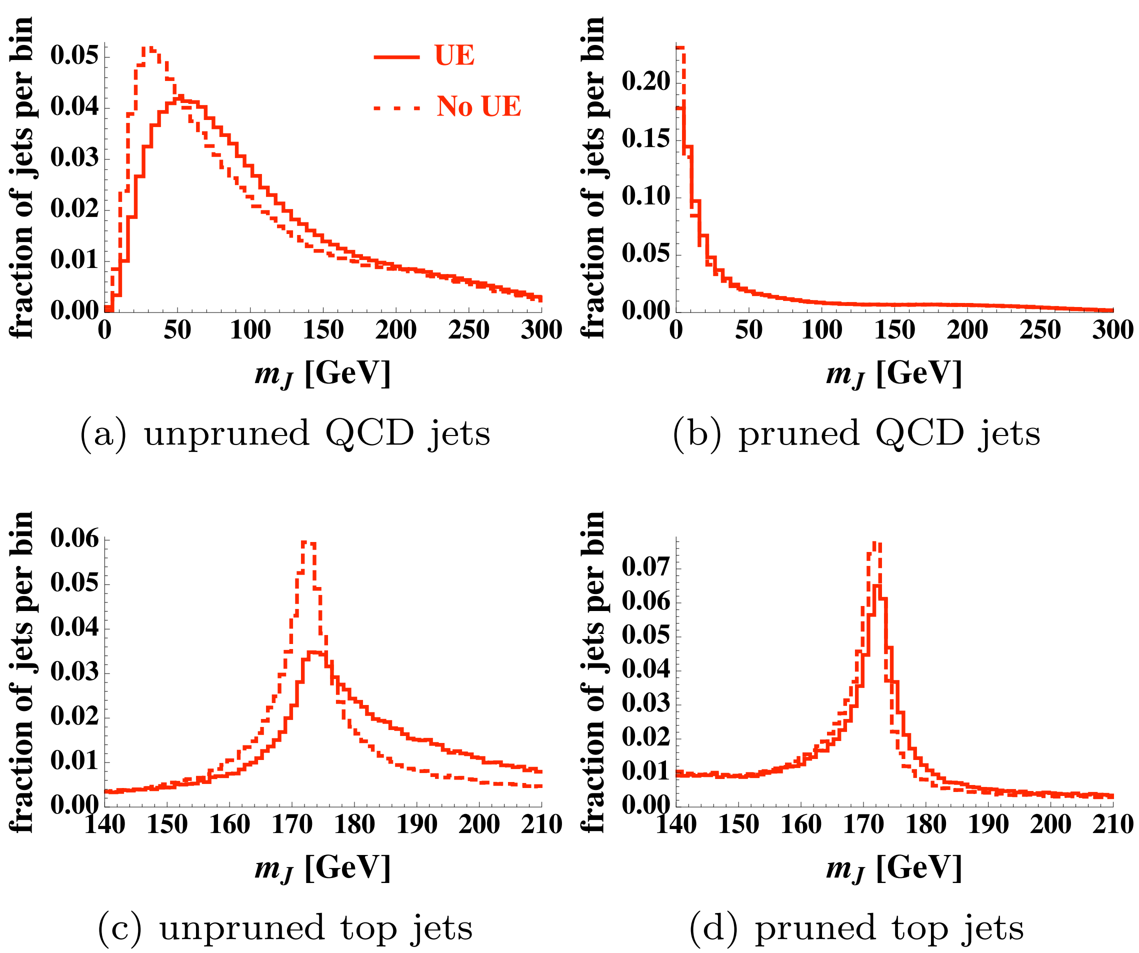


Pruning

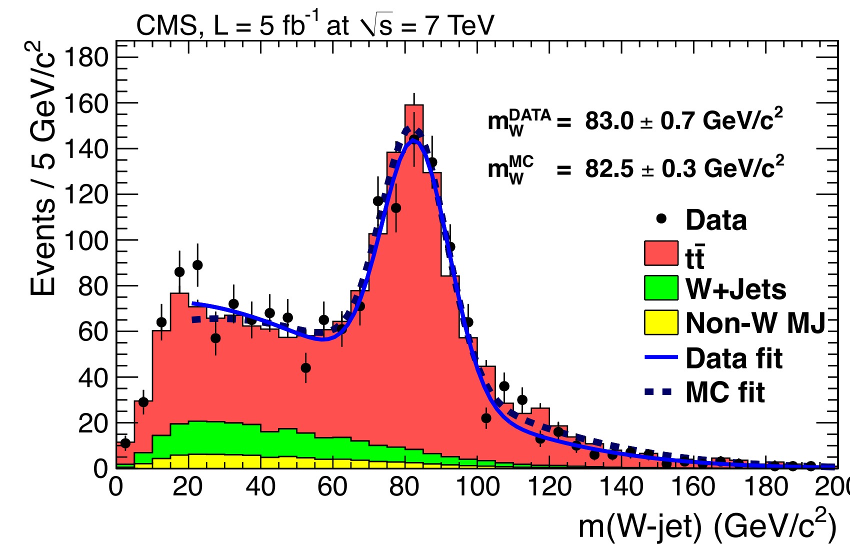
Pruned Jet

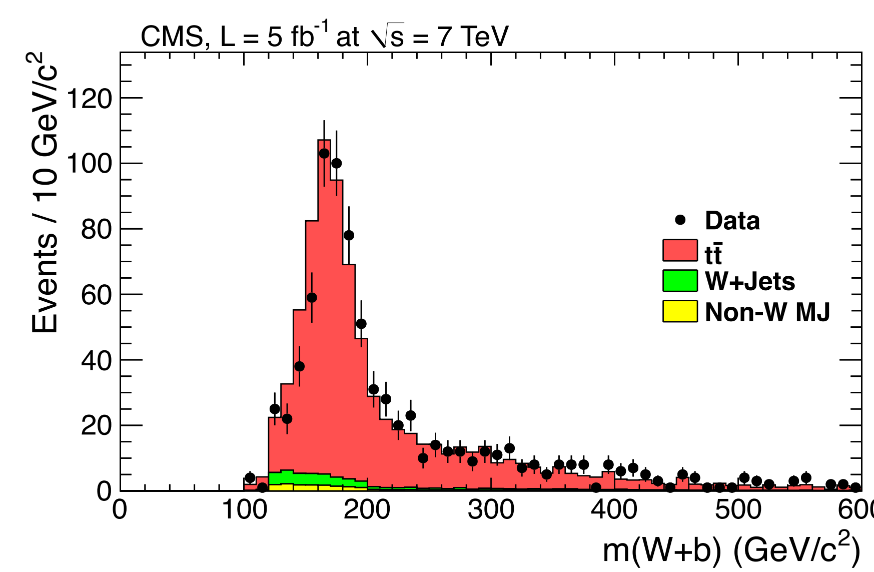


Pruning



arXiv:0912.0033v1





arXiv:1204.2488v1

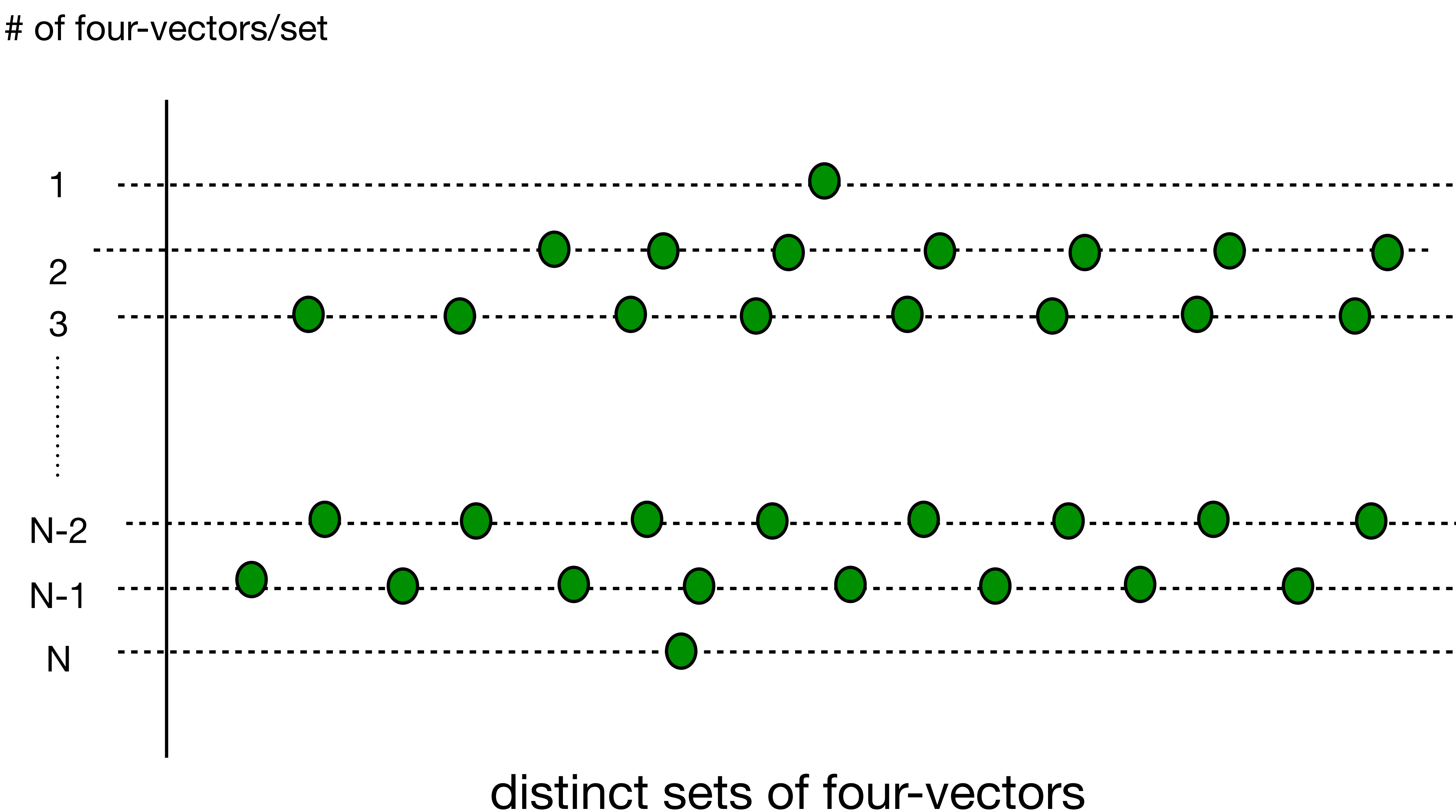
Pruning

- Four-vectors that are pruned are actually branches of the tree.

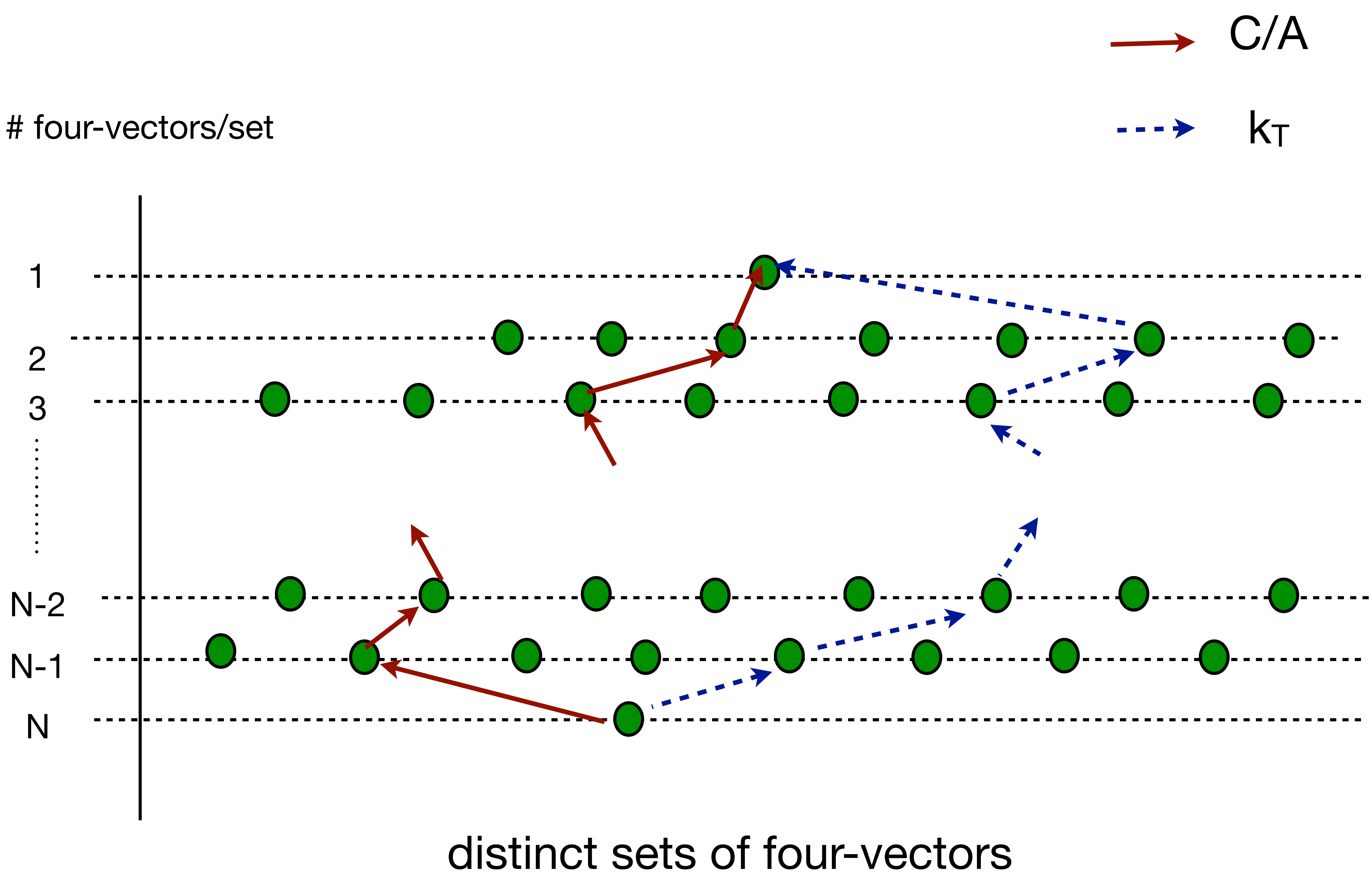
- Pruned jets depend crucially on the tree-structure or the clustering algorithm used to construct the jet.

but who ordered the clustering algorithm?

Clustering

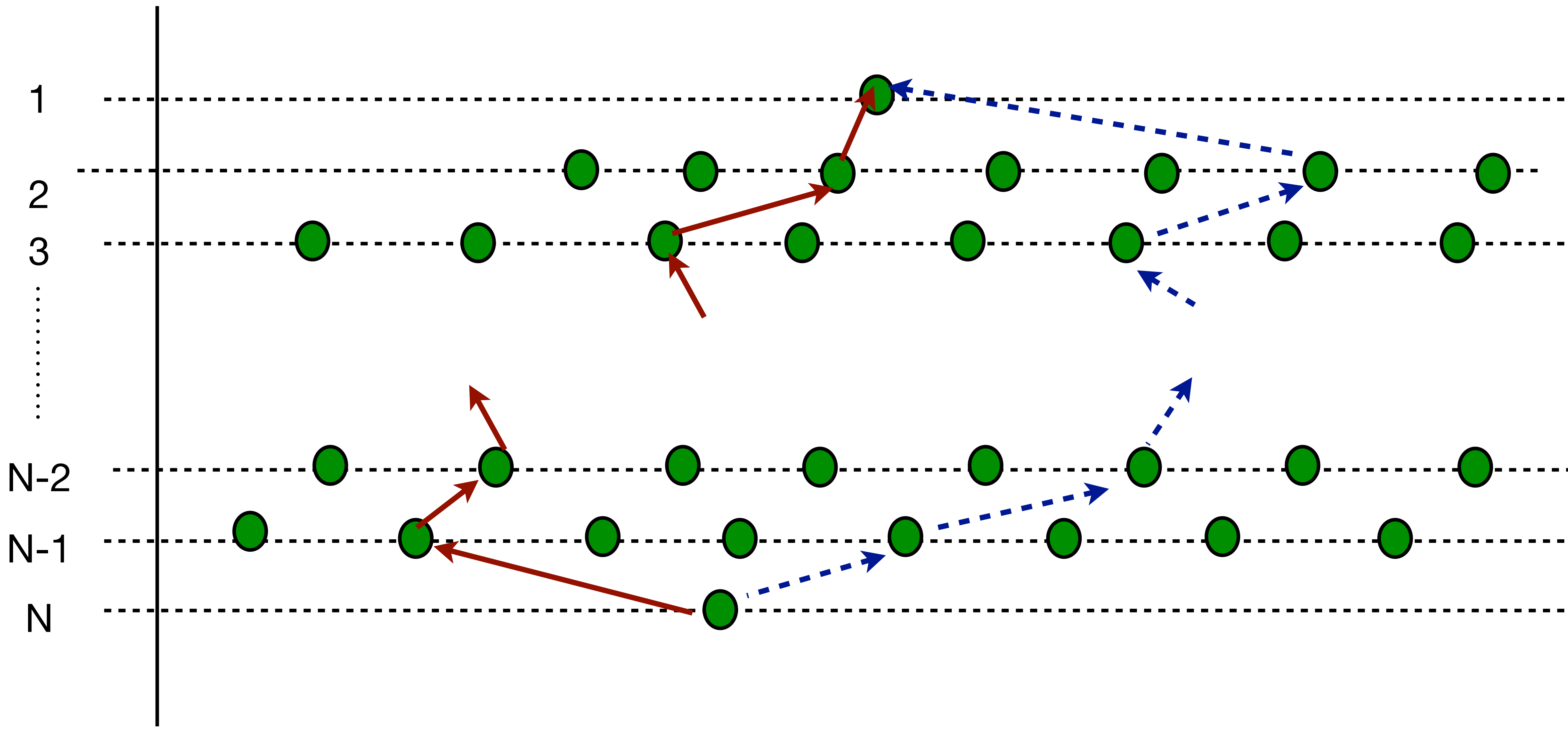


Clustering


C/A
k_T
four-vectors/set
1
2
3
N-2
N-1
N
distinct sets of four-vectors

Clustering

Many paths remain unexplored



distinct sets of four-vectors

Clustering

Many paths remain unexplored

A better formalism should explore all such paths

one needs to be clever since the total number of distinct trees is enormous

$$\frac{(2N)!}{2^N N!}$$

our prescription is QClustering

QClustering

As in a sequential recombination algorithm, assign every pair of four-vectors a distance measure d_{ij}.

However, unlike a normal sequential algorithm (where the pair with the smallest measure is clustered), here a given pair is randomly selected for merging with probability

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}}\right)$$

rigidity parameter

Repeat many (~100-1000) times, till the distribution stabilizes

QClustering

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}}\right)$$

d_{ij} : we take C/A or kT measure

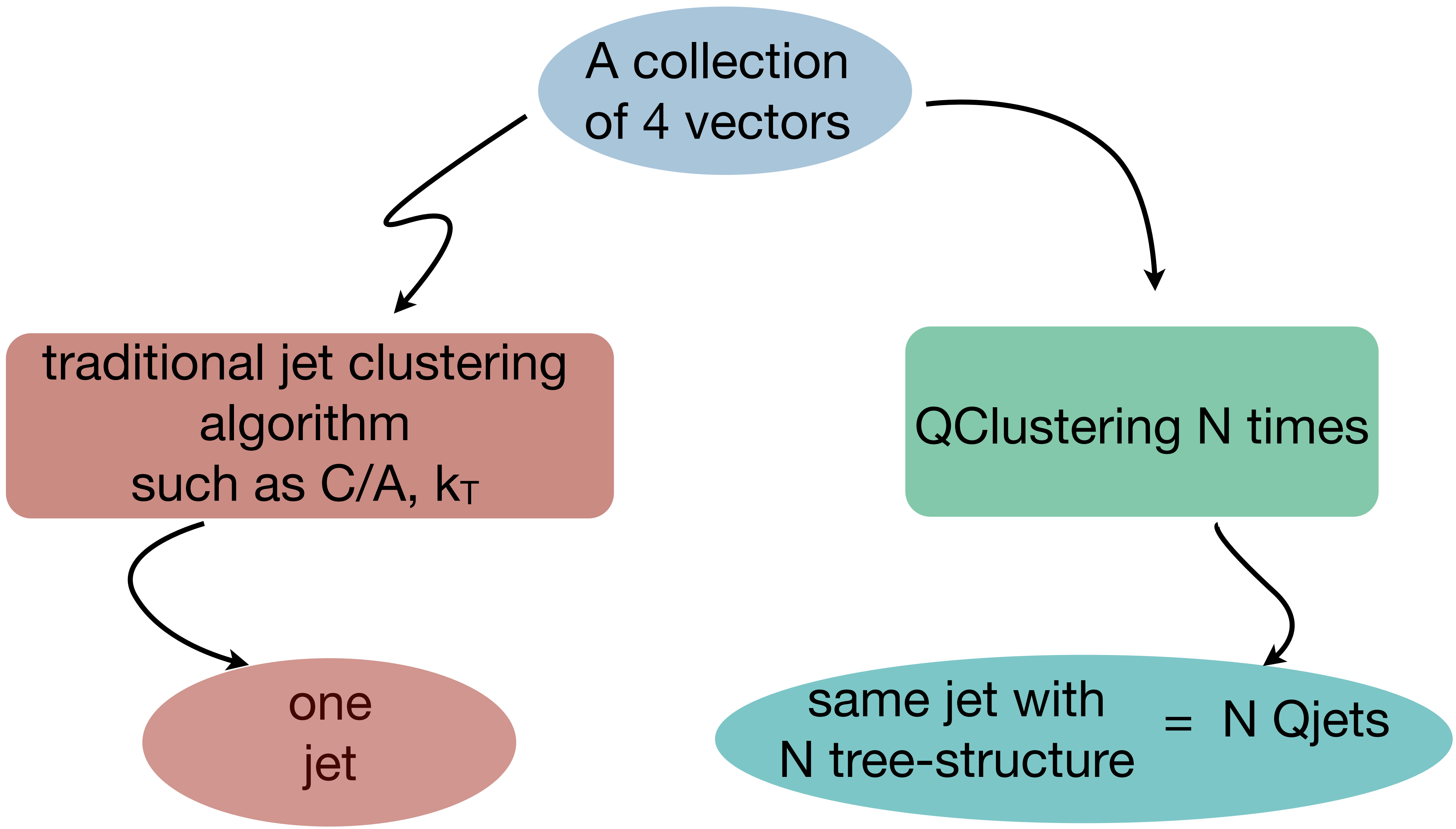
$\alpha \to \infty$ Classical regime: only path corresponding to d_{min} is selected

$\alpha > 0$ physical regime: physical paths are preferred

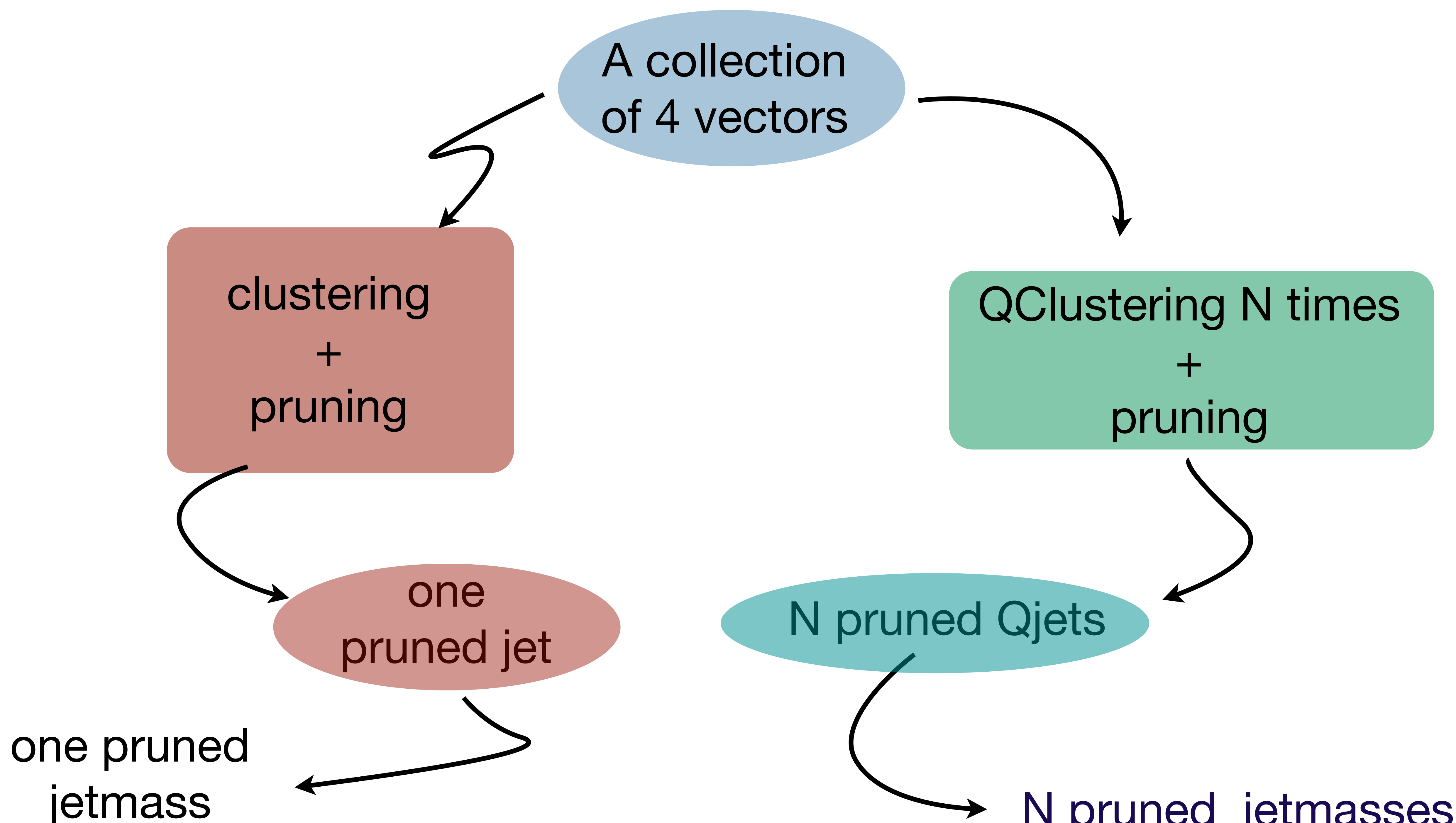
$\alpha \to 0$ democratic regime: all paths have same weight

$\alpha < 0$ unphysical regime: physical paths are de-weighted

QClustering vs. Clustering



QClustering vs. Clustering



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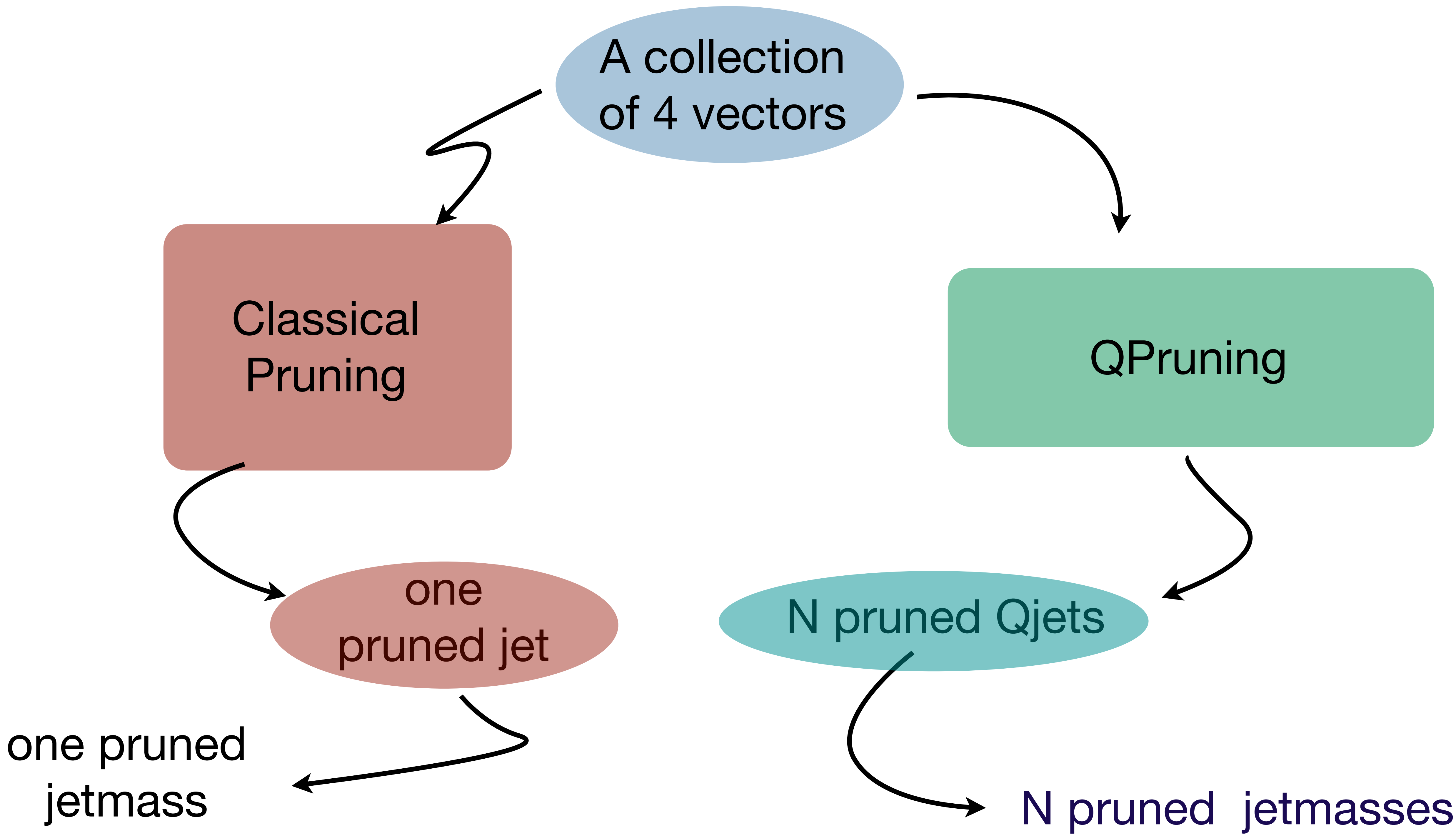
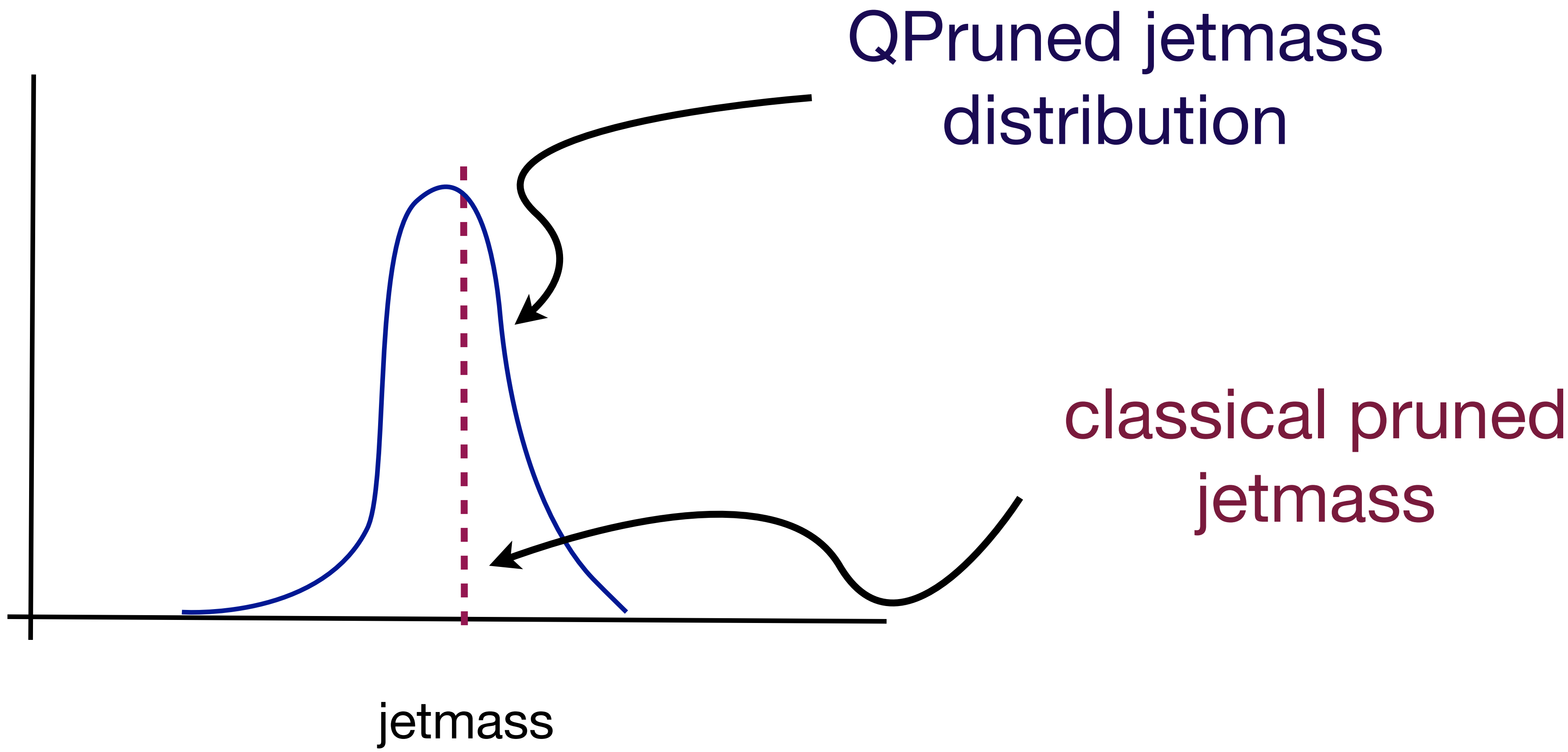


QClustering + Pruning

Ex. a hadronic W jet from WW events

The original jet is made from C/A algorithm with R = 1.0 and pT > 200GeV



QClustering + Pruning = QPruning

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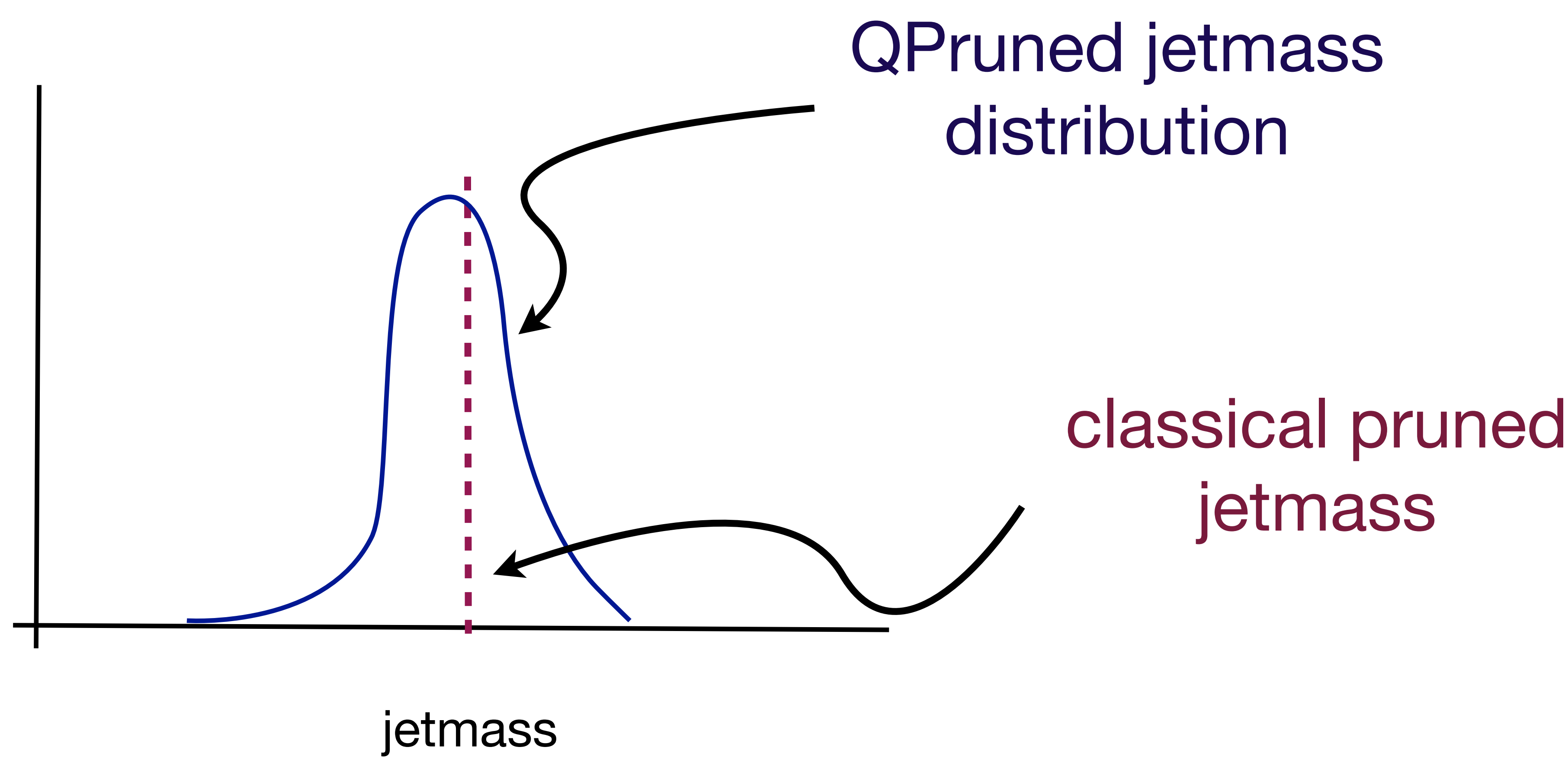

How can this distribution be used?

QClustering + Pruning = QPruning

Before we proceed, one comment about the choice of weight

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \, \frac{d_{ij}}{d_{\min}}\right)$$

Who ordered the choice of d_{ij} and α ?

QPruning

Before we proceed, one comment about the choice of weight

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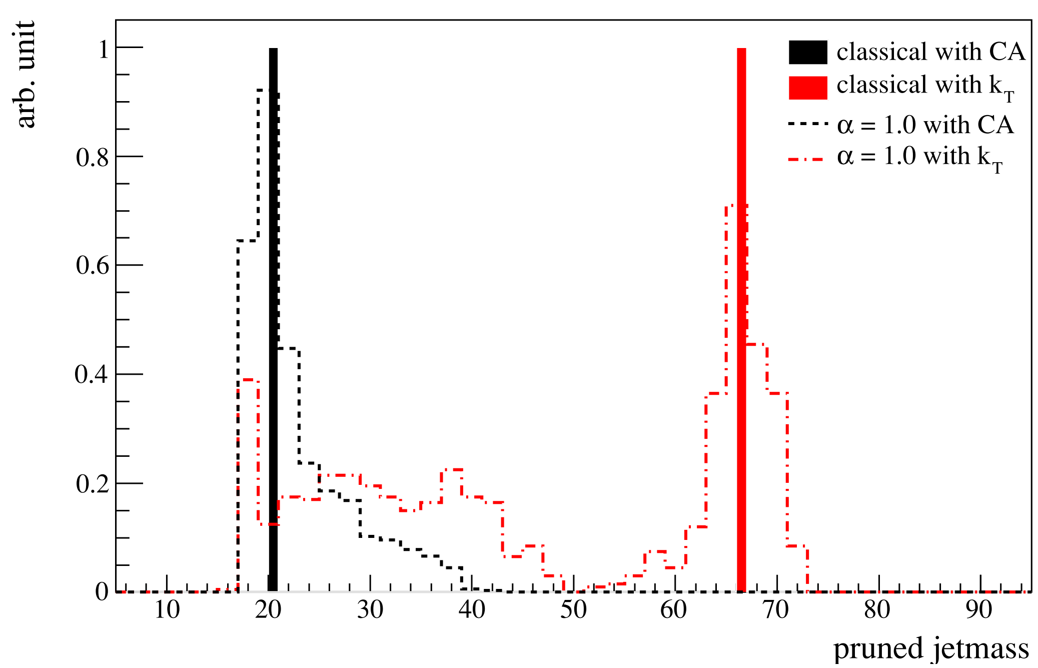
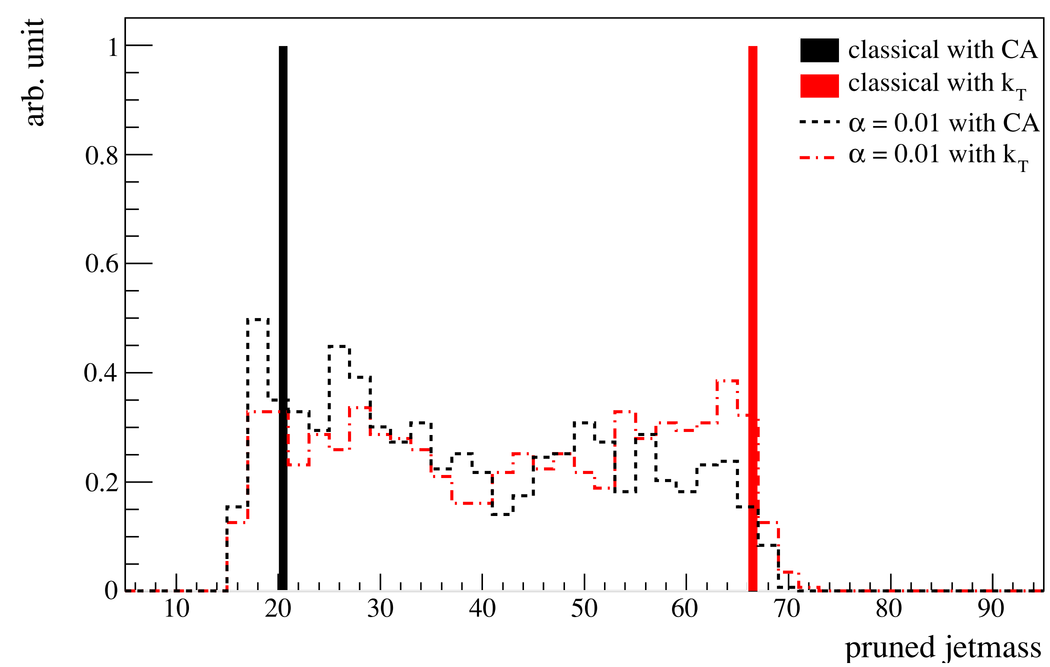




$\mathcal{QP}runing$

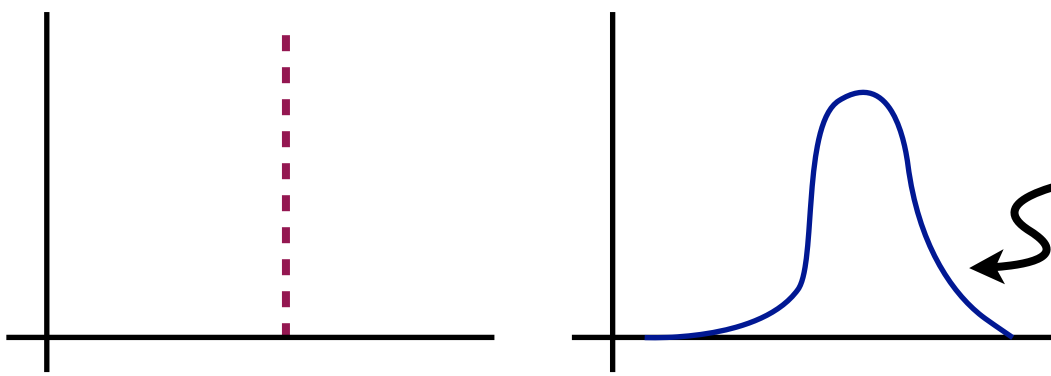
Before we proceed, one comment about the choice of weight

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}} \right)$$

For 0.1 > α > 0 our results are insensitive to the choice of α and the form of d_{ij}

QPruning vs. Pruning

Let us take a sample jet



classical pruned jetmass

QPruned jetmass distribution

How can this distribution be used?

Simply use the shape of the distribution to discriminate signal from background

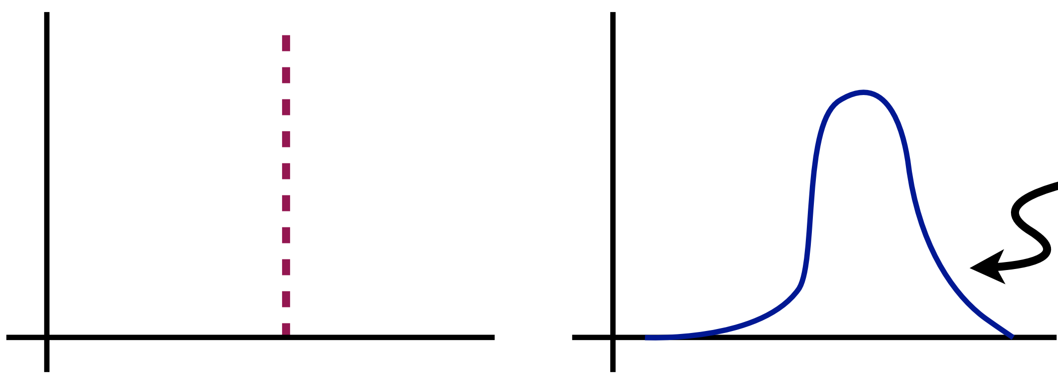
Application in signal discovery

Use the distribution to reduce statistical fluctuations in measurements

Application in determination of cross-section, mass etc.

QPruning vs. Pruning

Let us take a sample jet



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Application 1: discovery of W

- When there is an intrinsic mass scale for a jet, the pruned jetmass is more or less robust under variation of paths.

- Signal jets with decay products of massive resonances have intrinsic mass scales.

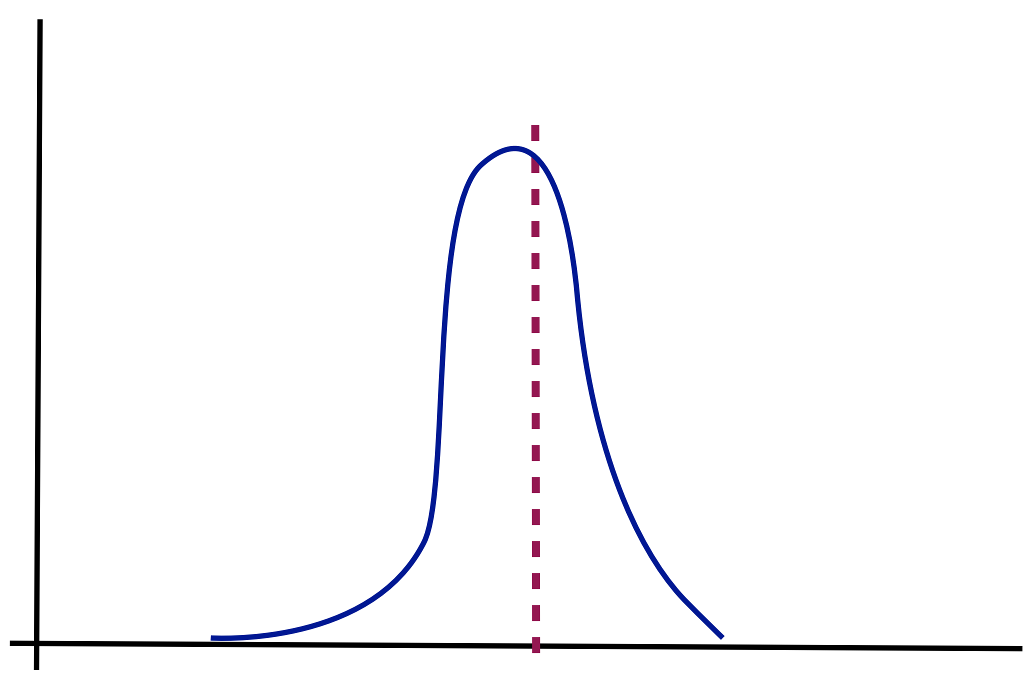
- Even QCD jets with $m/p_T \sim 1$ have hard splittings and hence intrinsic mass scales.

- But background is dominantly due to QCD jets with $m/pt < 1/2$ - whose masses are highly volatile.

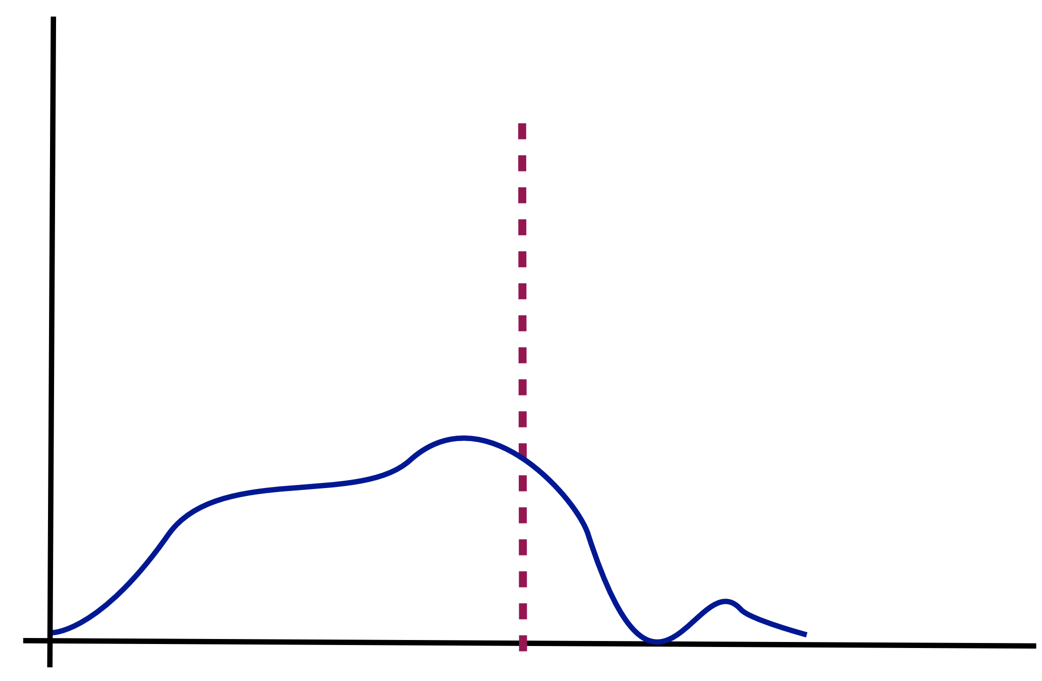
Application 1: discovery of W

When there is an intrinsic mass scale for a jet, the pruned jetmass is more of less robust under variation of paths.

W jet



QCD jet with $m/p_T < 1/2$

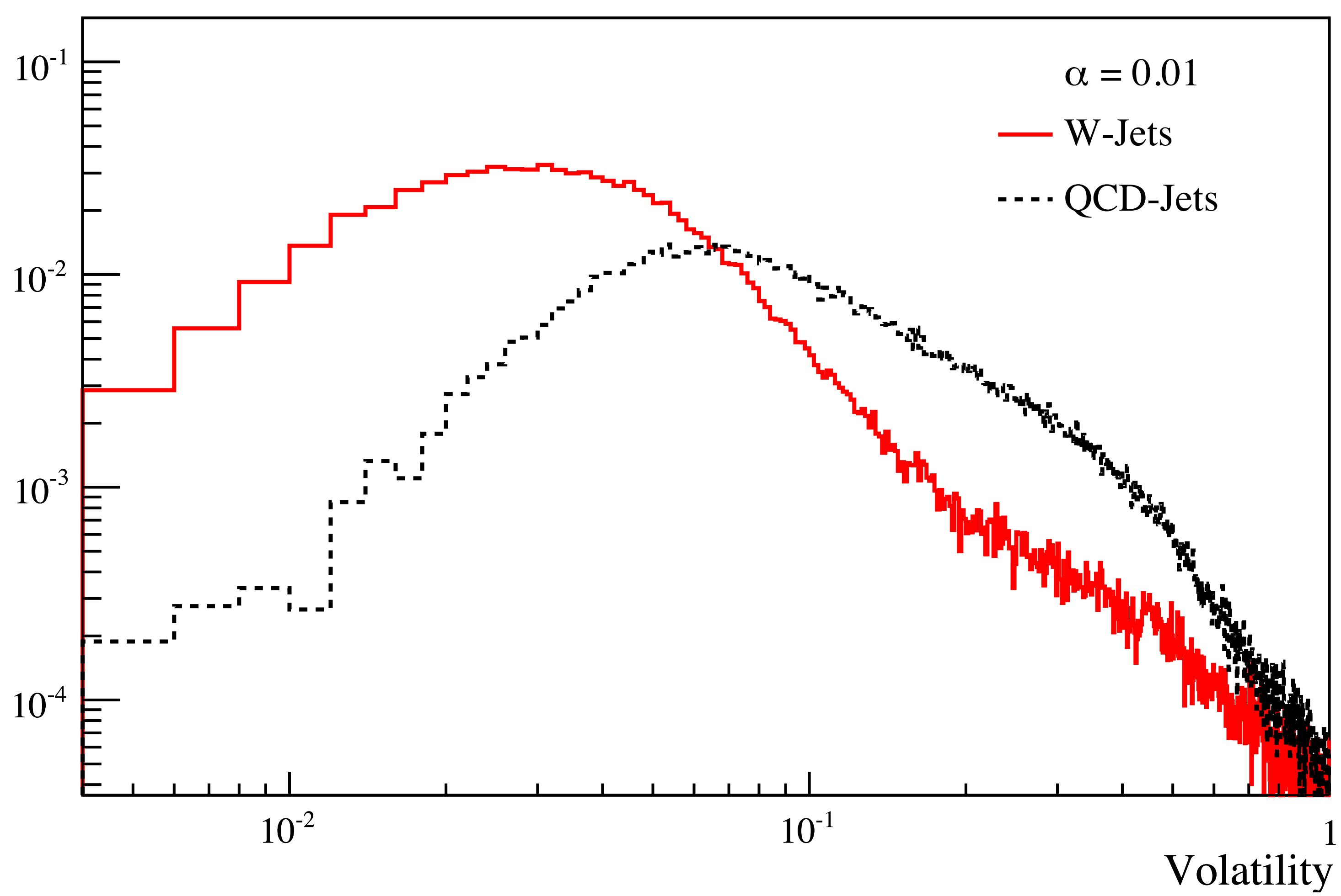


Application 1: discovery of W

volatility of a jet $\mathcal{V} = \frac{\omega_p}{m_p}$

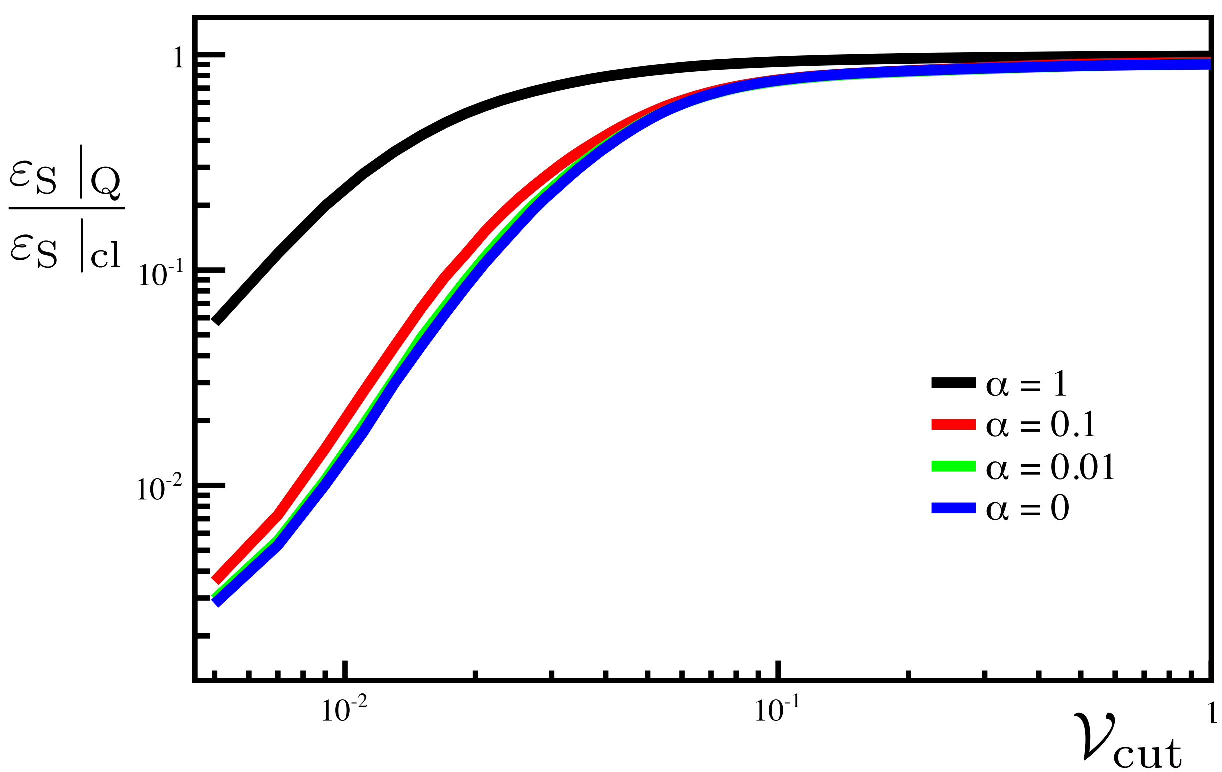
ω_p = width of jetmass distribution

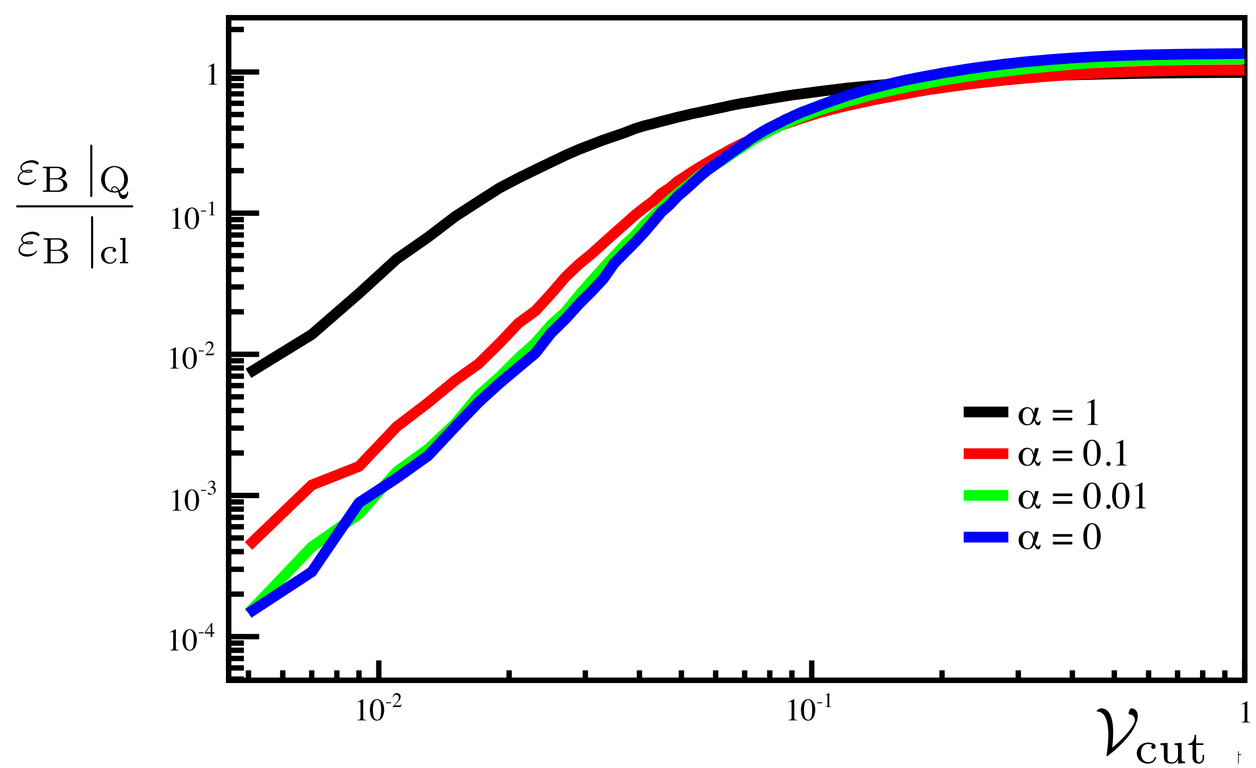
m_p = averaged pruned jetmass



Application 1: discovery of W

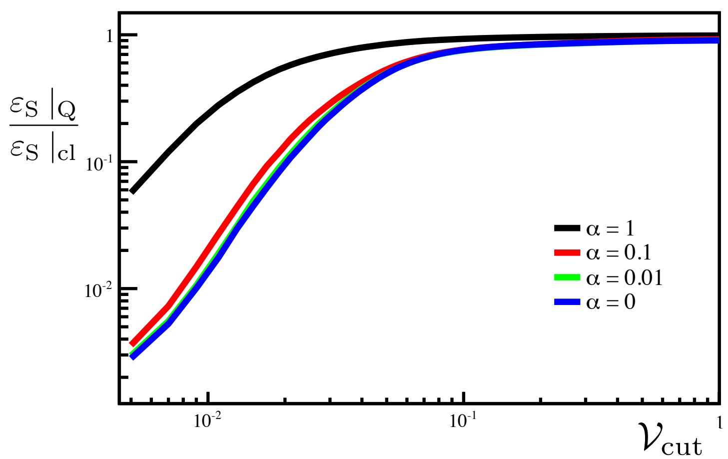
a cut on $\mathcal{V}$ decreases background significantly

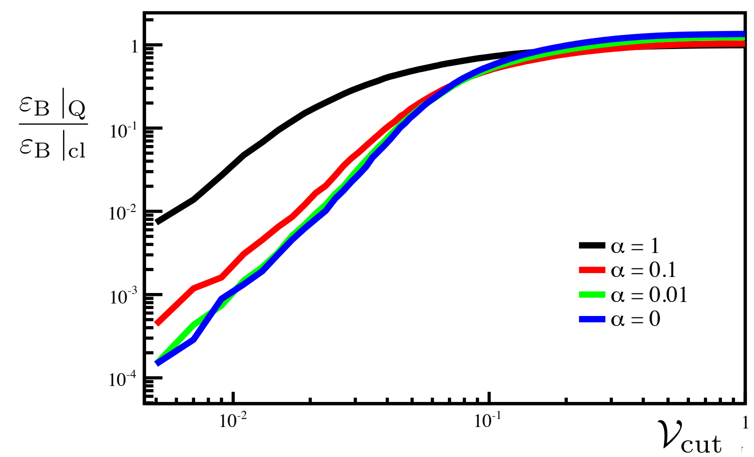


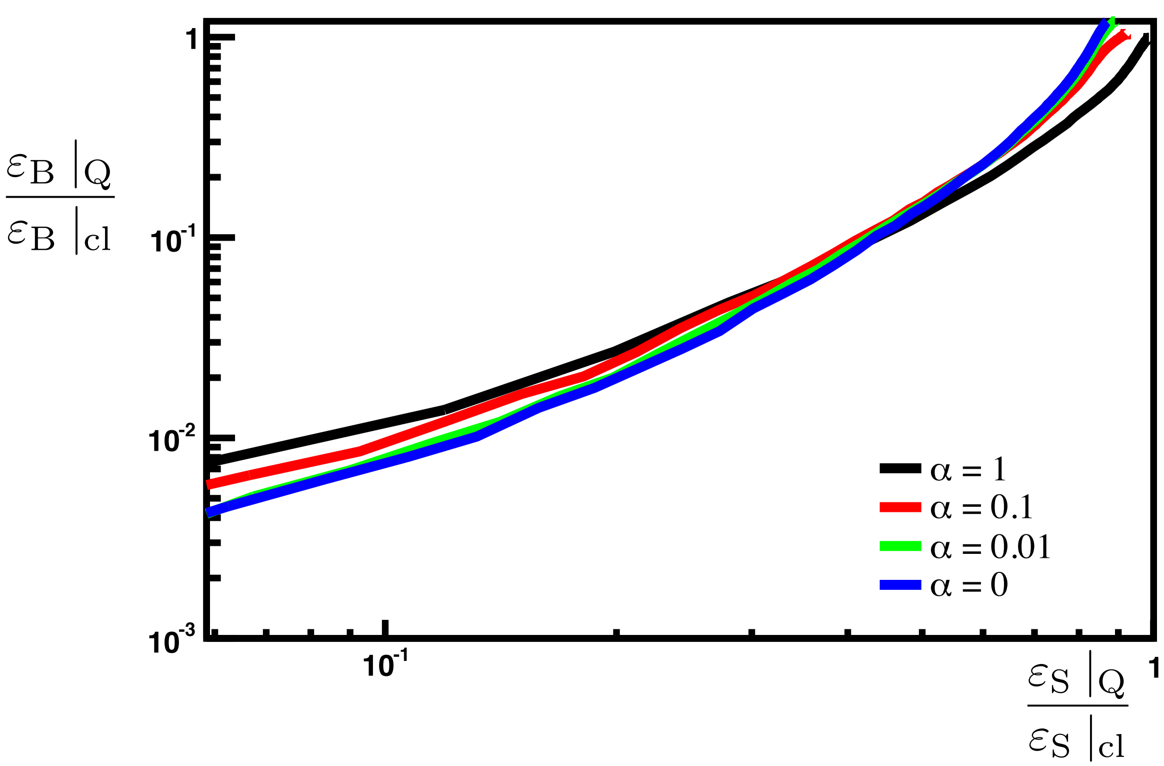


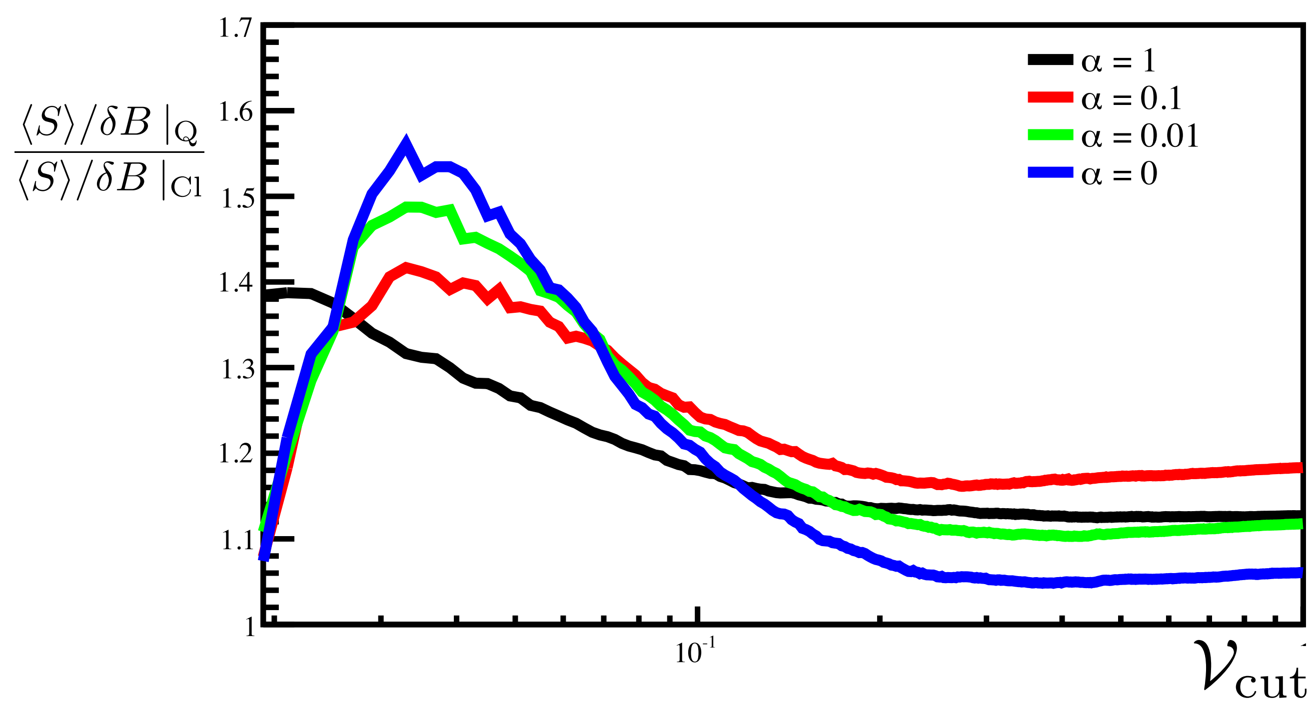
Application 1: discovery of $\mathcal{W}$

a cut on $\mathcal{V}$ decreases background significantly







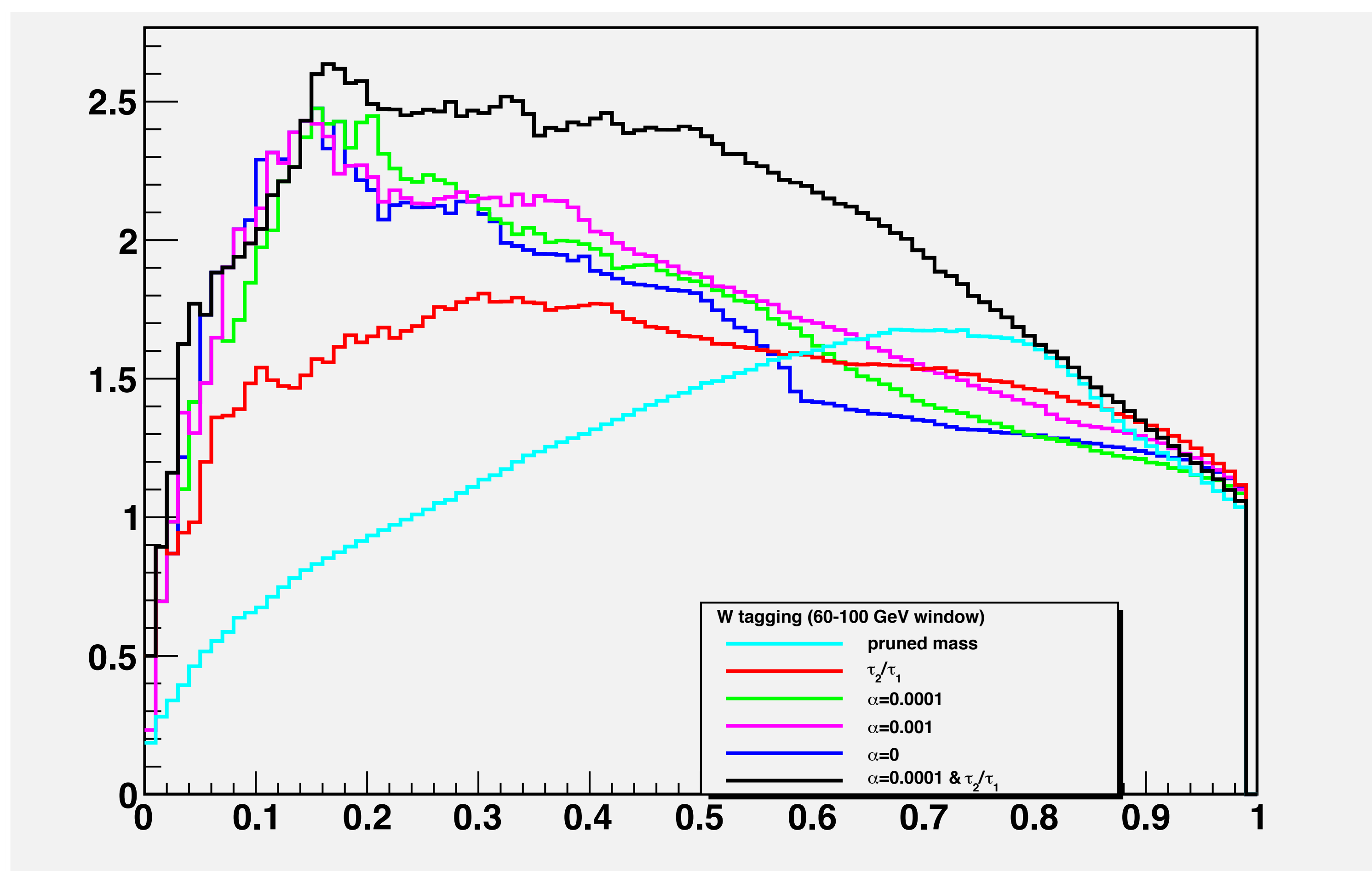


Monday, October 29, 12

Application 1: discovery of W

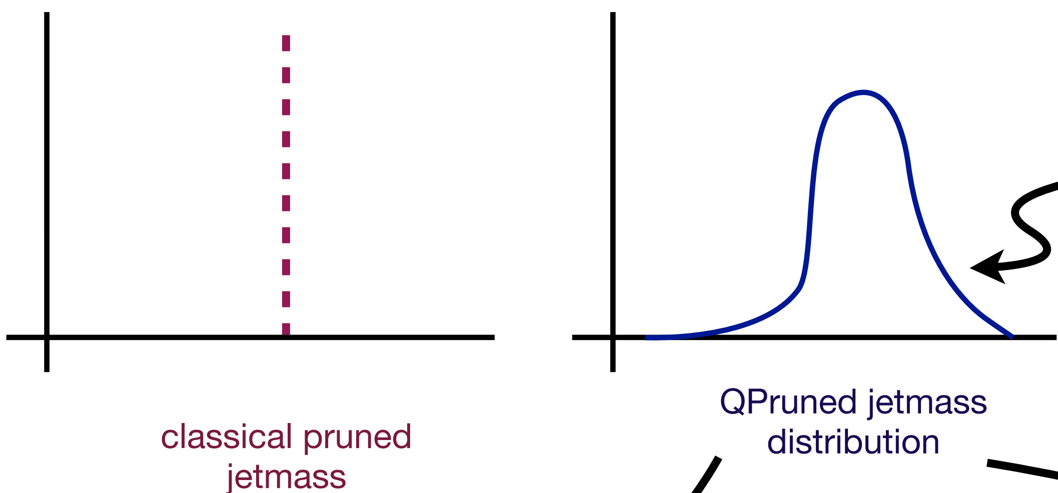
a cut on $\mathcal{V}$ decreases background significantly

Unofficial comparisons



QPruning vs. Pruning

Let us take a sample jet



How can this distribution be used?

Simply use the shape of the distribution to discriminate signal from background

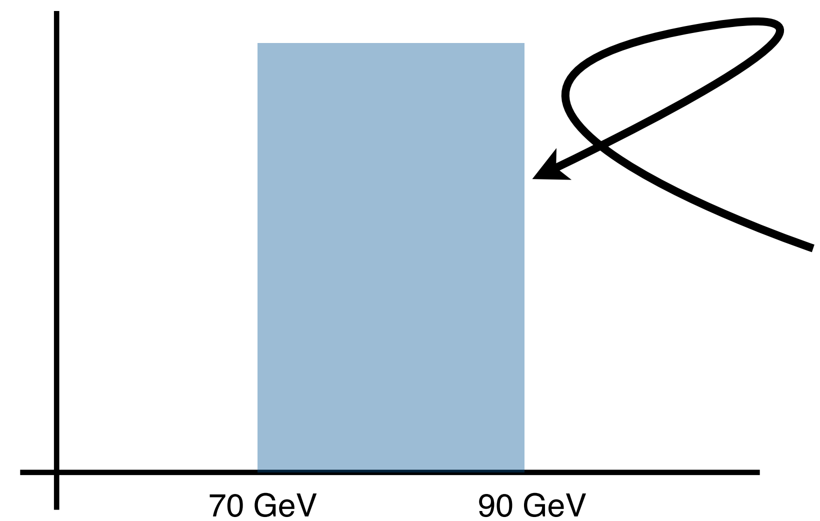
Application in signal discovery

Use the distribution to reduce statistical fluctuations in measurements

Application in determination of cross-section, mass etc.

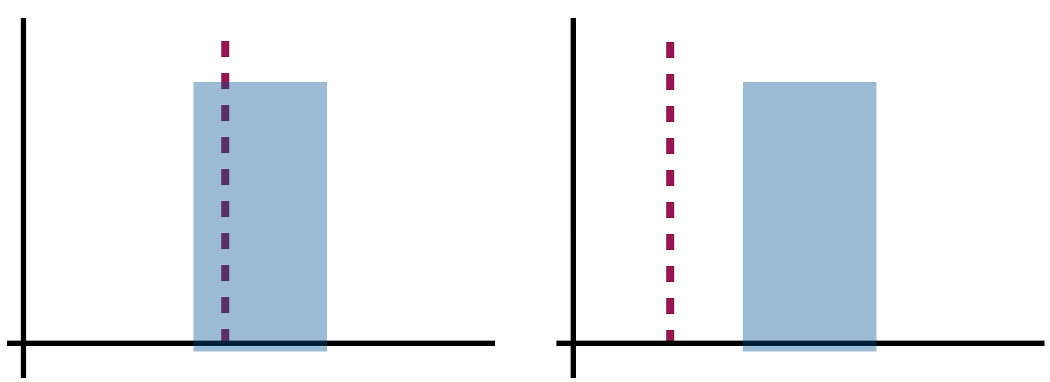
QPruning vs. Pruning

Consider candidates for a W jet



Mass window
for W

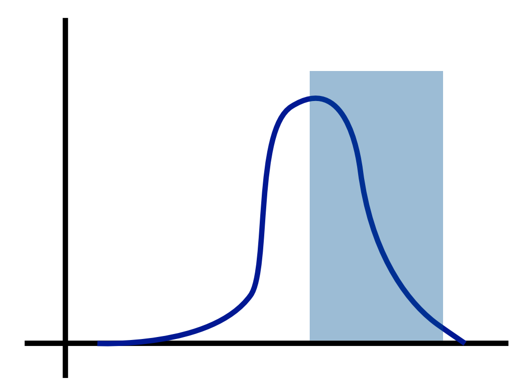
classical pruned
jetmass



pruned mass is
either in or out of the bin

tagging efficiency is either 0 or 1

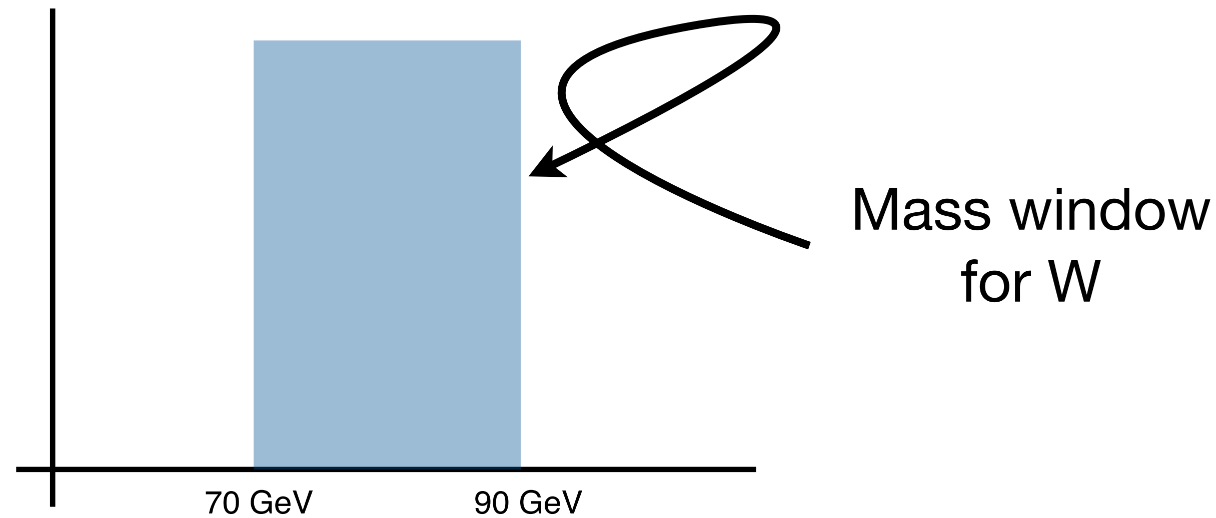
QPruned jetmass
distribution

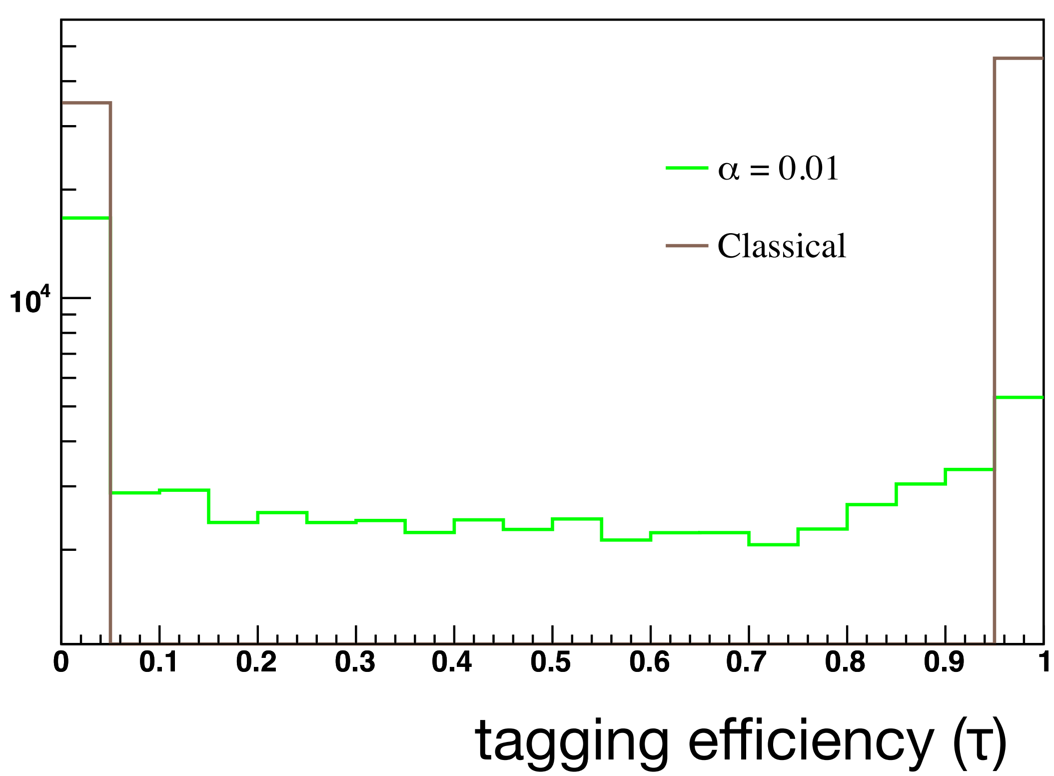


tagging efficiency is a number
between 0 to 1

QPruning vs. Pruning

Consider candidates for a W jet





Pruning -> QPruning

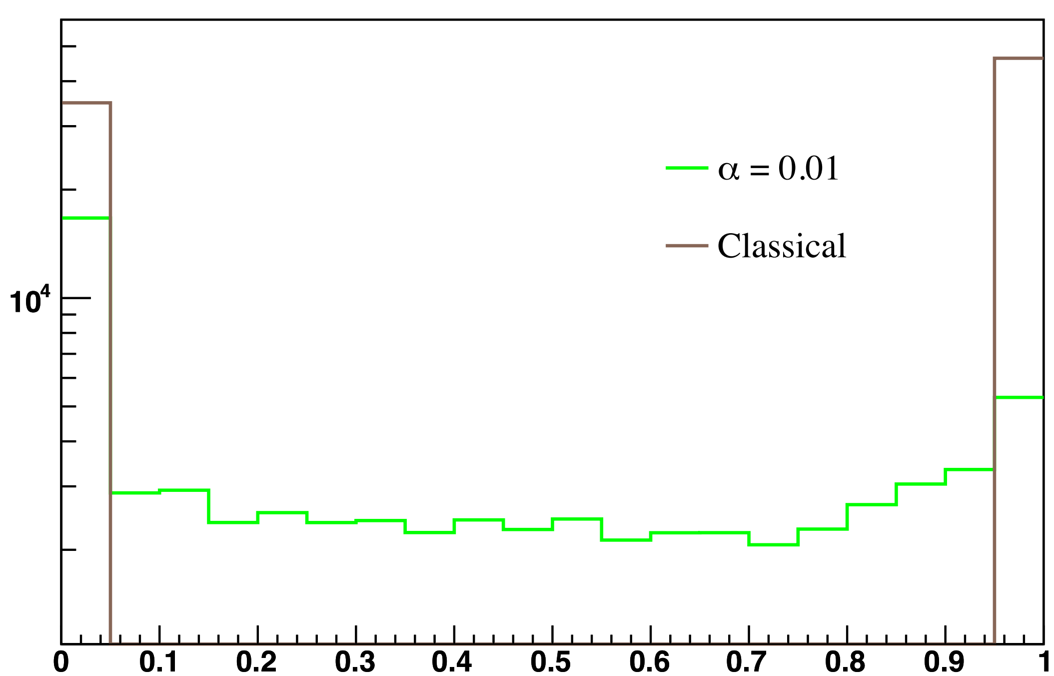
A transition from a discrete (binomial distribution) to a continuous distribution

QPruning vs. Pruning

Pruning --> QPruning

A binomial distribution --> a continuous distribution

Use the distribution to reduce statistical fluctuations in measurements



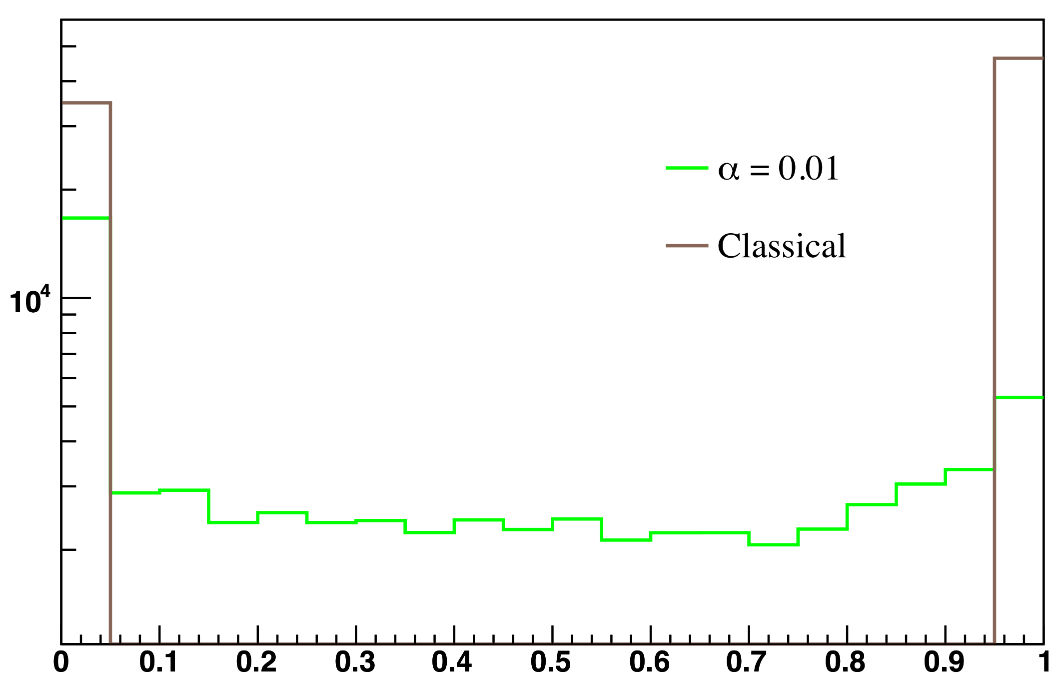
tagging efficiency (τ)

QPruning vs. Pruning

Pruning --> QPruning

A binomial distribution --> a continuous distribution

Use the distribution to reduce statistical fluctuations in measurements



tagging efficiency (τ)

How to measure statistical fluctuations ?

Statistical Fluctuation

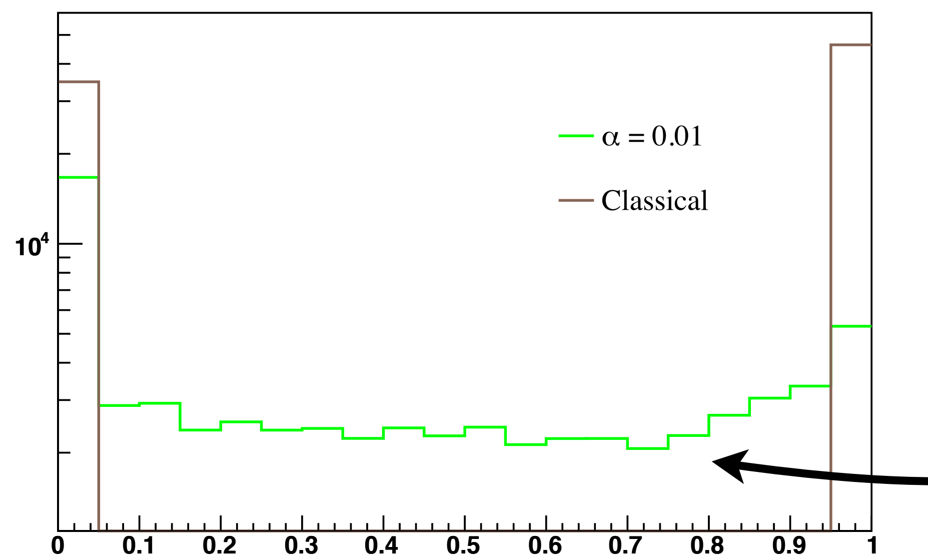
Consider a large number of pseudo-experiments

# of jets in these pseudo-experiments vary according to Poisson distribution

Experiments	Measurements (e.g. # tagged jet)
Expt #1	N_1
Expt #2	N_2
Expt #3	N_3
Expt #4	N_4
.	.
.	.
.	.
.	.
.	.

measure δN

Application 2: CS measurement

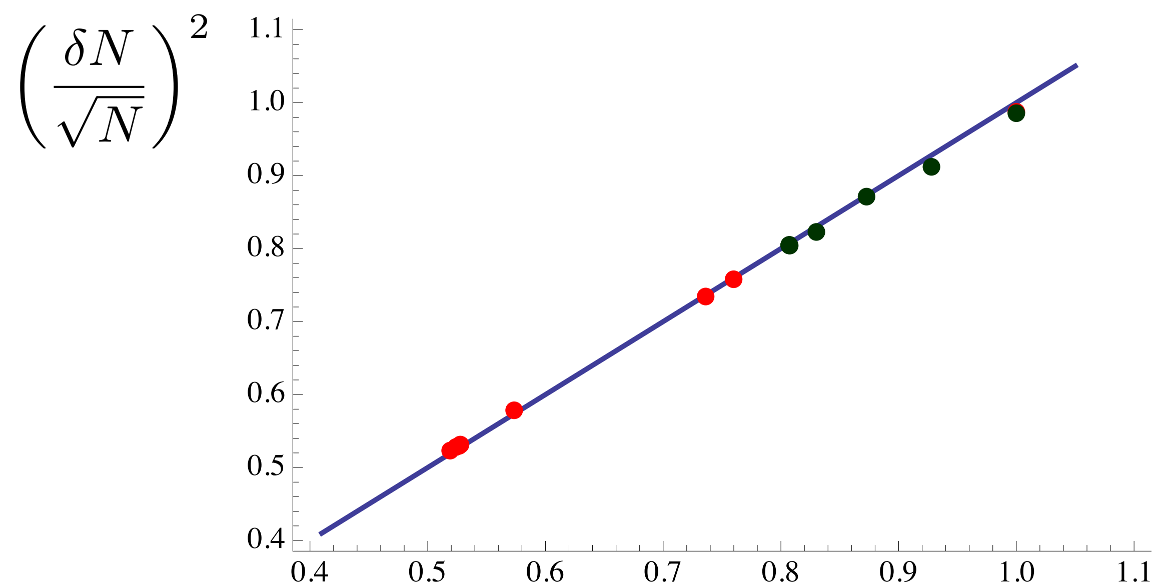


tagging efficiency (τ)

<τ> = average of the distribution

var(τ) = variance of the distribution

$$\frac{\delta N}{\sqrt{N}} = \sqrt{\langle\tau\rangle + \frac{\mathrm{var}(\tau)}{\langle\tau\rangle}}$$



$$\langle\tau\rangle + \frac{\mathrm{var}(\tau)}{\langle\tau\rangle}$$

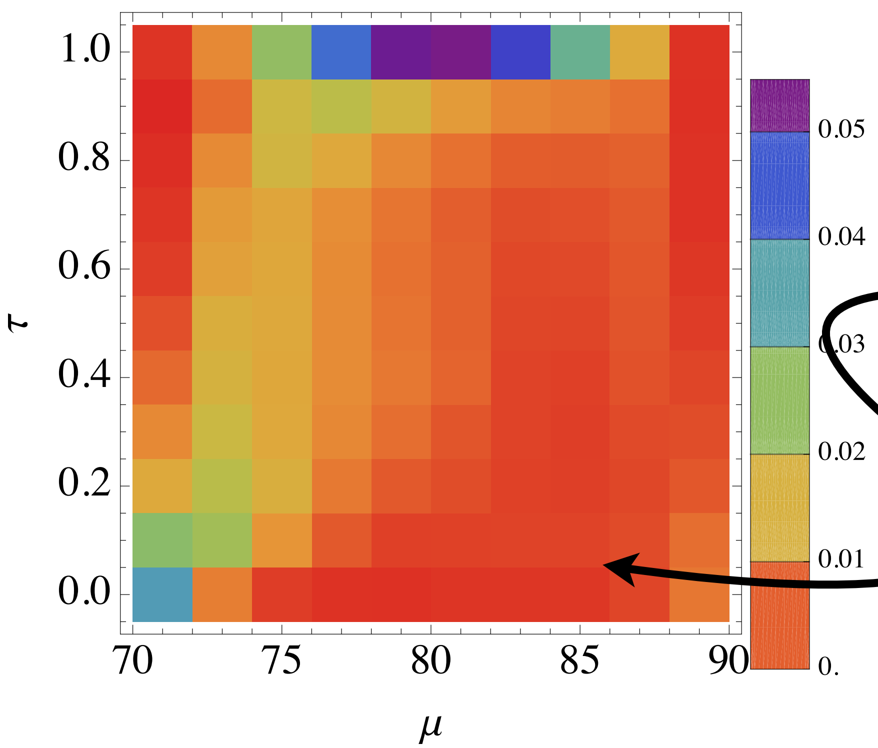
Application 2: CS measurement

$$\alpha = 10^{-2}$$

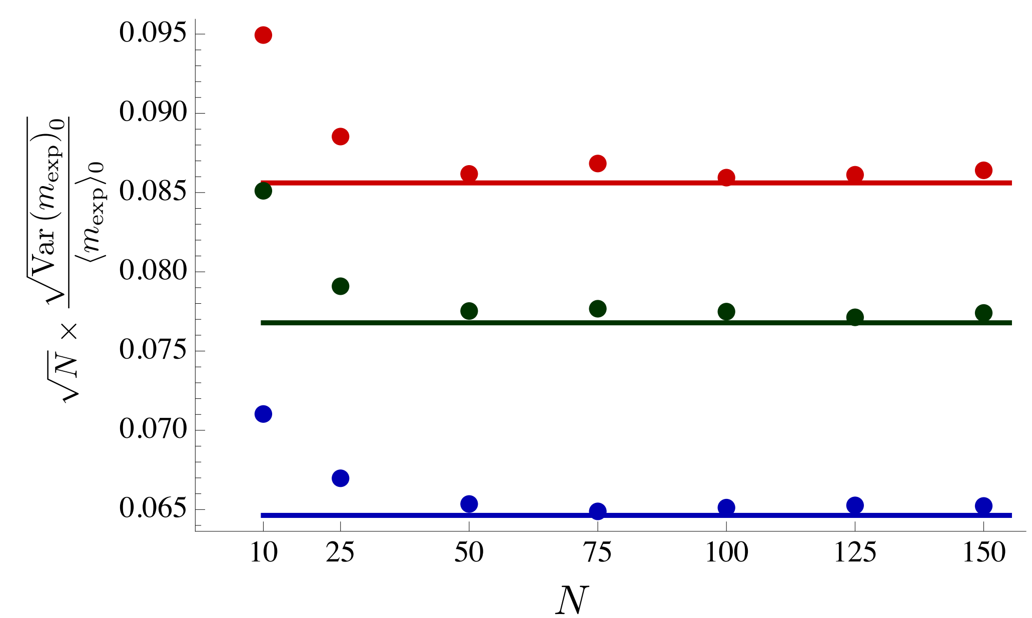
- As an example, take a sample of ~10 boosted QCD jets and ask for number of jets in a mass bin.
- The uncertainty associated with cross-section measurement decreases from classical pruning to QPruning
- Need half the luminosity to make a measurement of the same precision.

Algorithm	$\frac{\delta N}{\sqrt{N}}$	Relative luminosity required
prune with C/A	~1.0	1.0
QPrune	0.72	0.52

Application 3: mass measurement



probability distribution of W jets as a function of τ and μ



$$\frac{\delta m_{\mathrm{exp}}}{m_{\mathrm{exp}}} = \frac{1}{\sqrt{N}} \sqrt{\frac{\mathrm{var}(\tau)}{\langle \tau \rangle^2} + \frac{\mathrm{var}(\mu\tau)}{\langle \mu\tau \rangle^2} + \frac{\mathrm{cov}(\tau, \mu\tau)}{\langle \tau \rangle \langle \mu\tau \rangle}} + \mathcal{O}\left(\frac{1}{N}\right)$$

Application 3: mass measurement

$$\alpha = 10^{-2}$$

- As an example, take a sample of ~10 boosted W jets and ask for average jet mass.
- The uncertainty associated with mass measurement decreases from classical pruning to QPruning
- Need less than half the luminosity to make a measurement of the same precision.

Algorithm	Mass uncertainty [GeV]	Relative luminosity required
prune with C/A	3.2	1.0
QPrune	2.4	0.58

Future Directions

- In substructure physics, it still remains to be seen whether QClustering can be applied to other quantities such as mass-drop, Y_{23} etc.

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

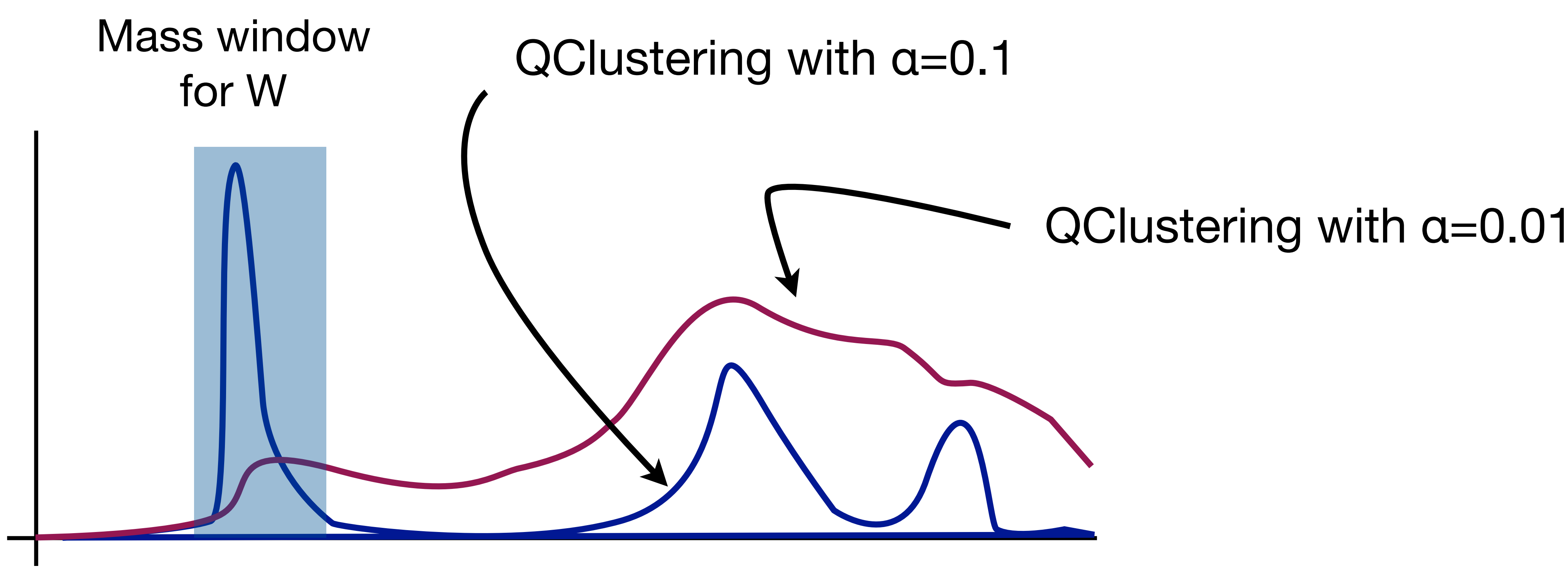
- We need to find a formalism towards analytical calculations.

Works in progress

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

work in progress with Ellis
also Kahawala, Krohn, Schwartz

Q-Anti-k_T Clustering



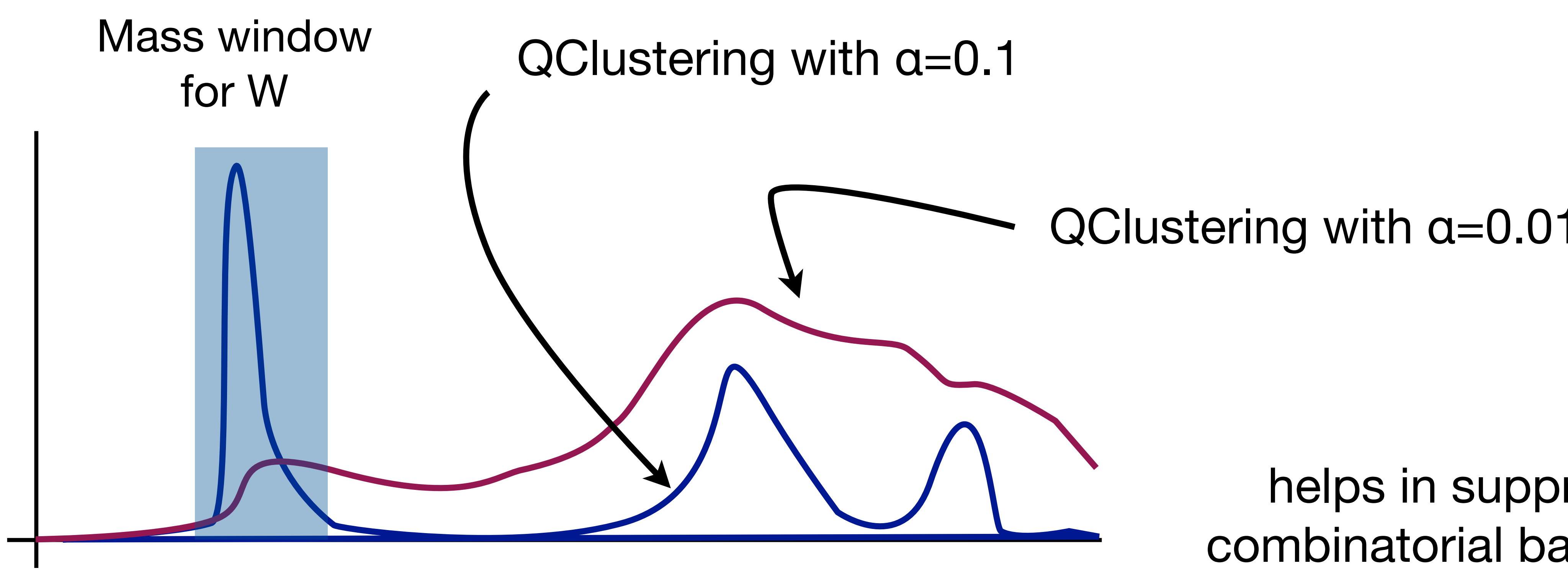
all di-jet masses in a W+jet event

Works in progress

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

work in progress with Ellis
also Kahawala, Krohn, Schwartz

Q-Anti-k_T Clustering

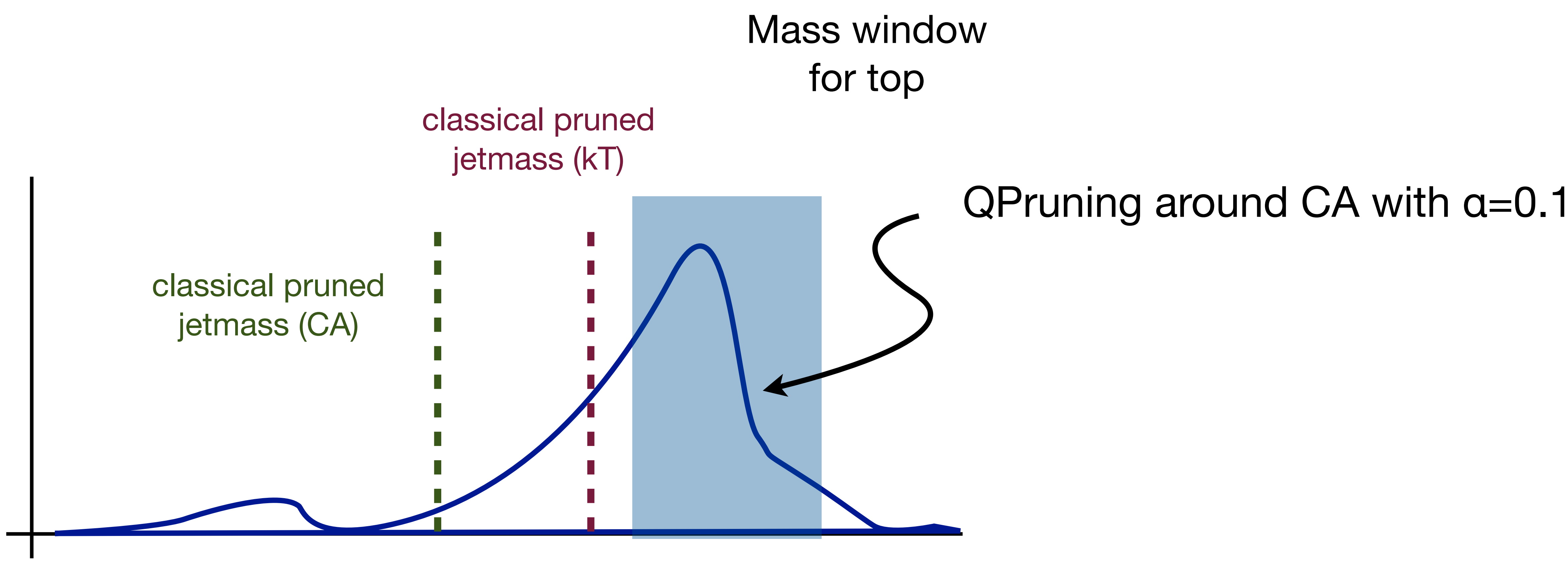


all di-jet masses in a W+ 2jet events

helps in suppressing combinatorial background

Works in progress

- QPruning extended to an event (tt event)



Pruned jetmass for a top candidate (3-jet resonance)

Works in progress

- Towards analytically calculation for Qclustering

(Hornig & Schwartz)