HERA-LHC
DESY, 12 March 2007

Jet Areas, and What They Are Good For

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in collaboration with
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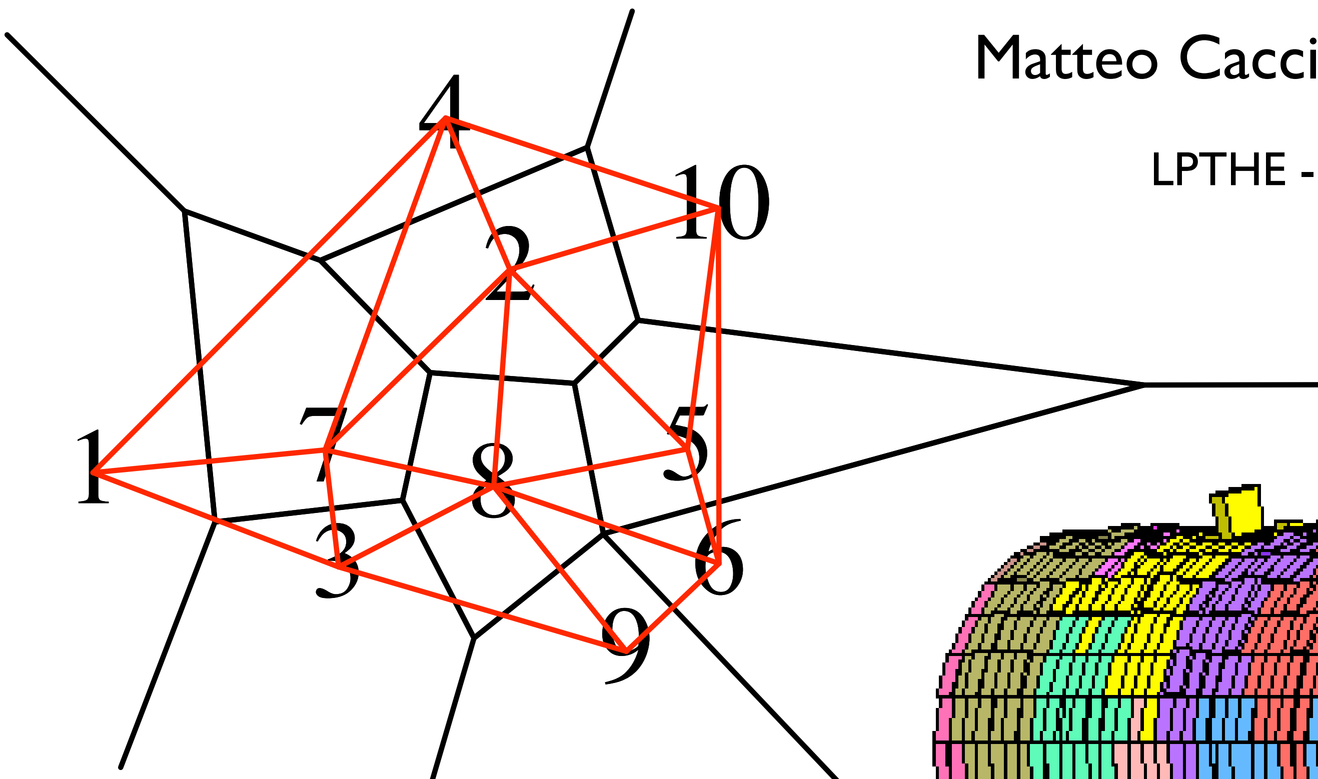
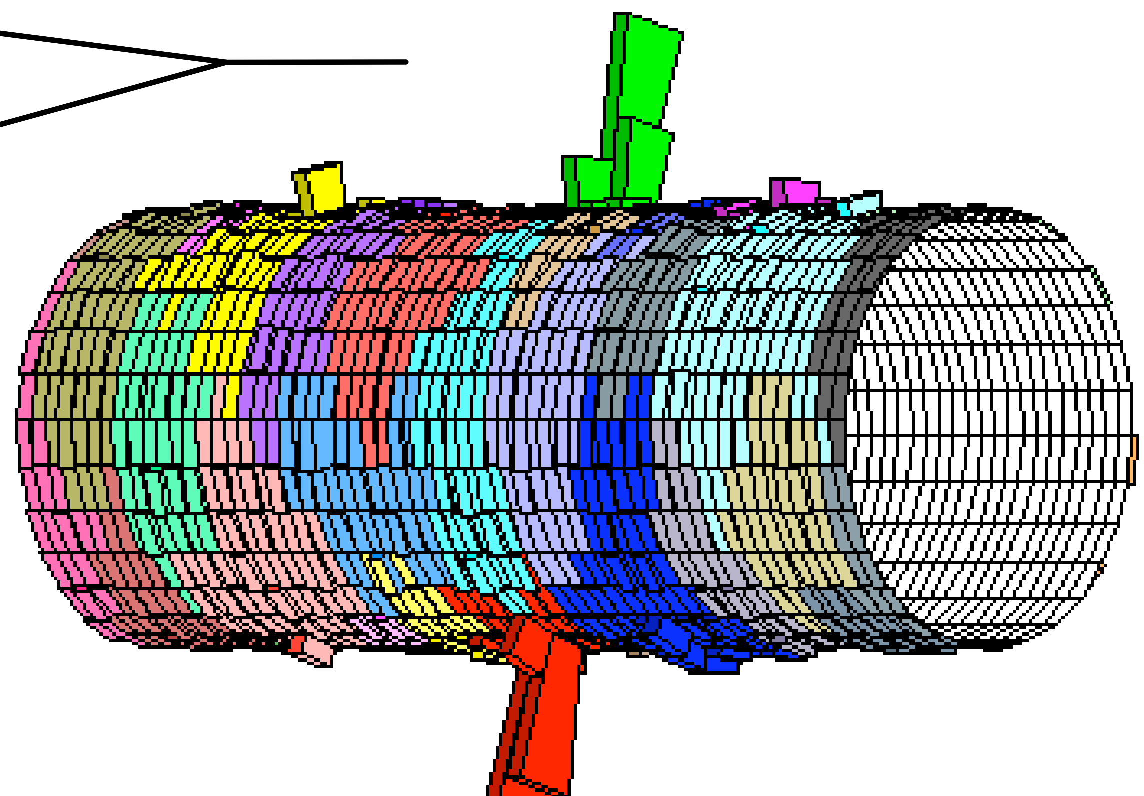
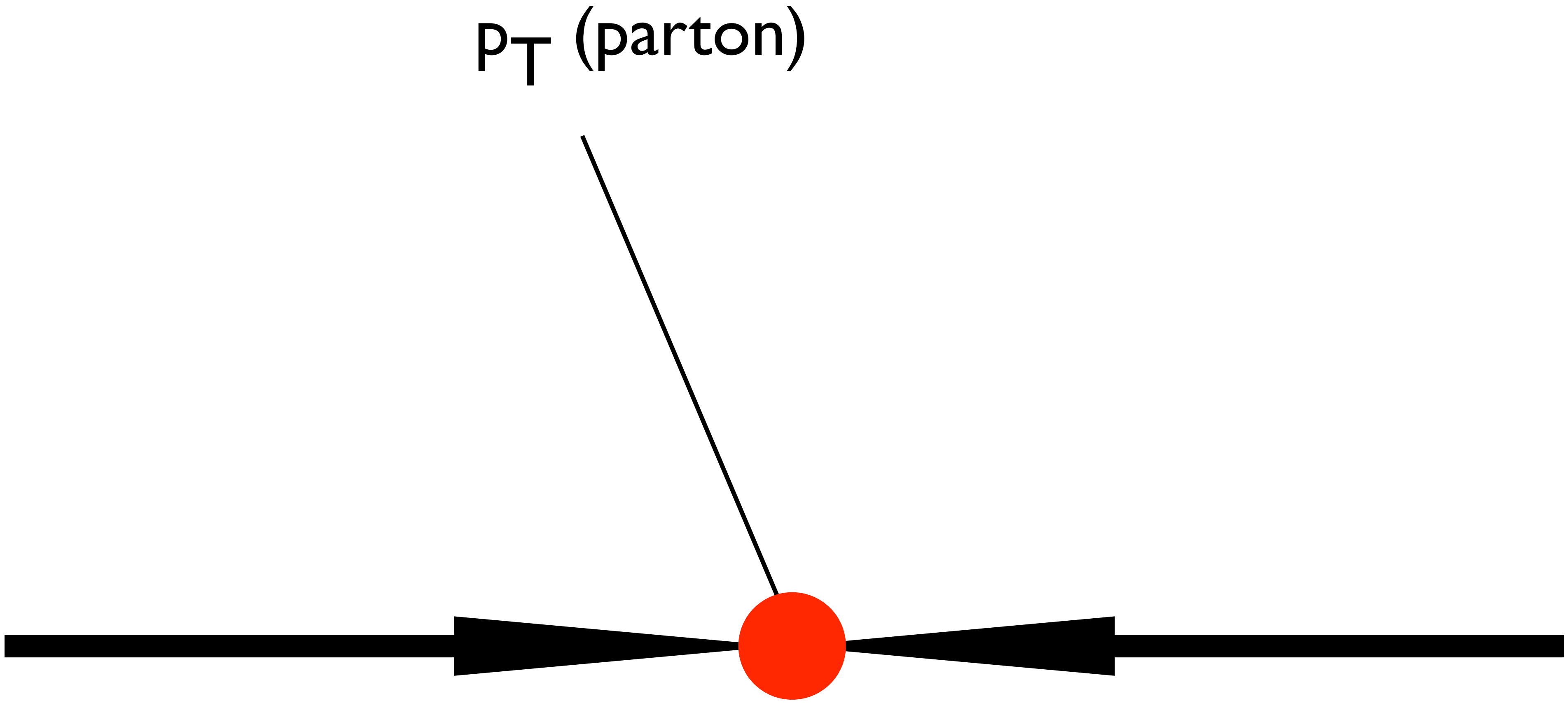
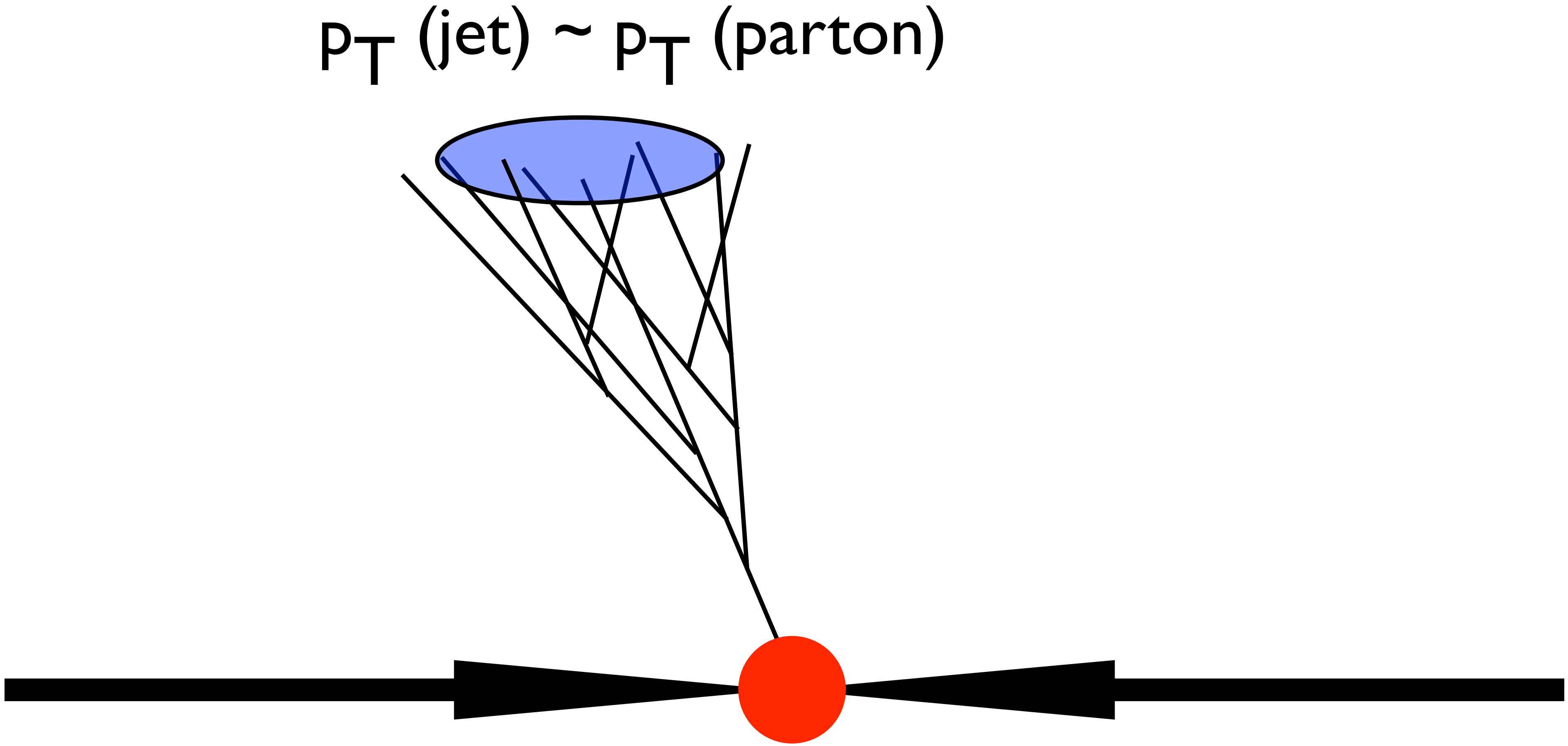




A simple event



A simple event

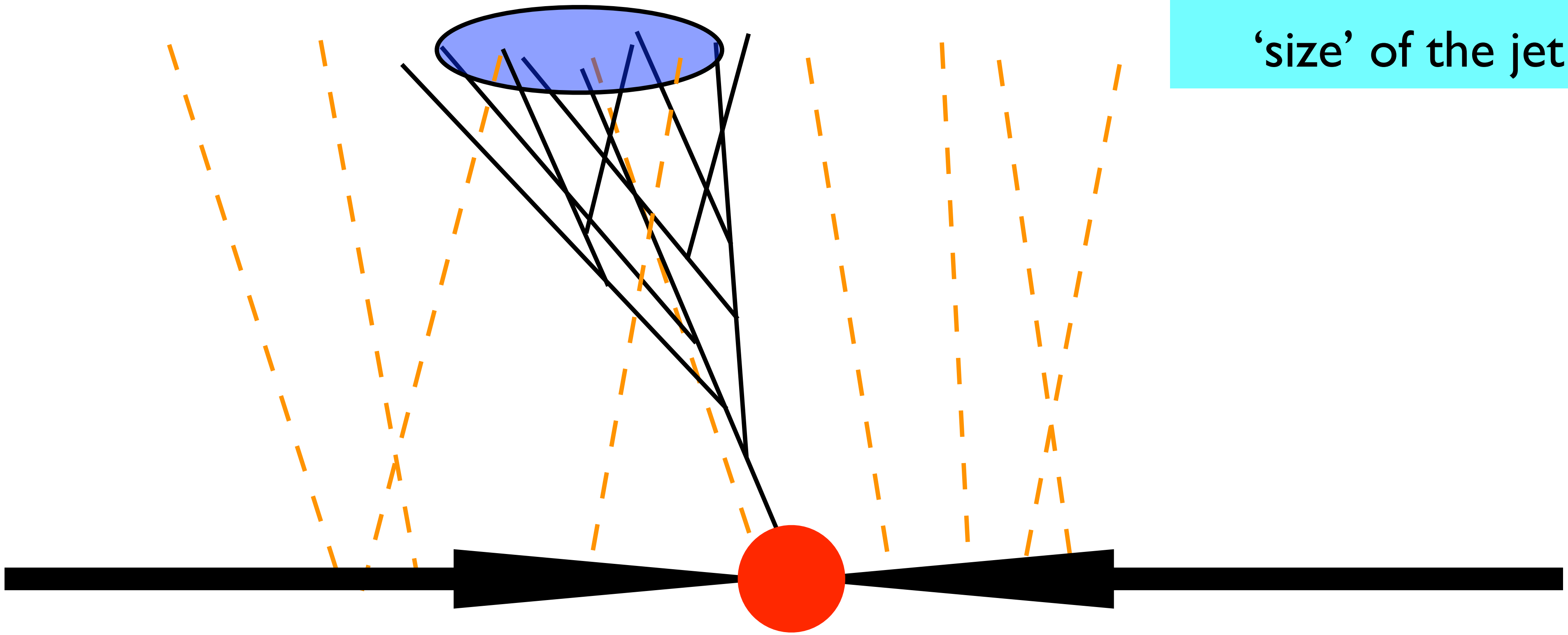


The parton radiates, but we can usually collect most of its momentum into a jet

A messier event

p_T (jet) ~ p_T (parton) +

Average underlying momentum density × 'size' of the jet

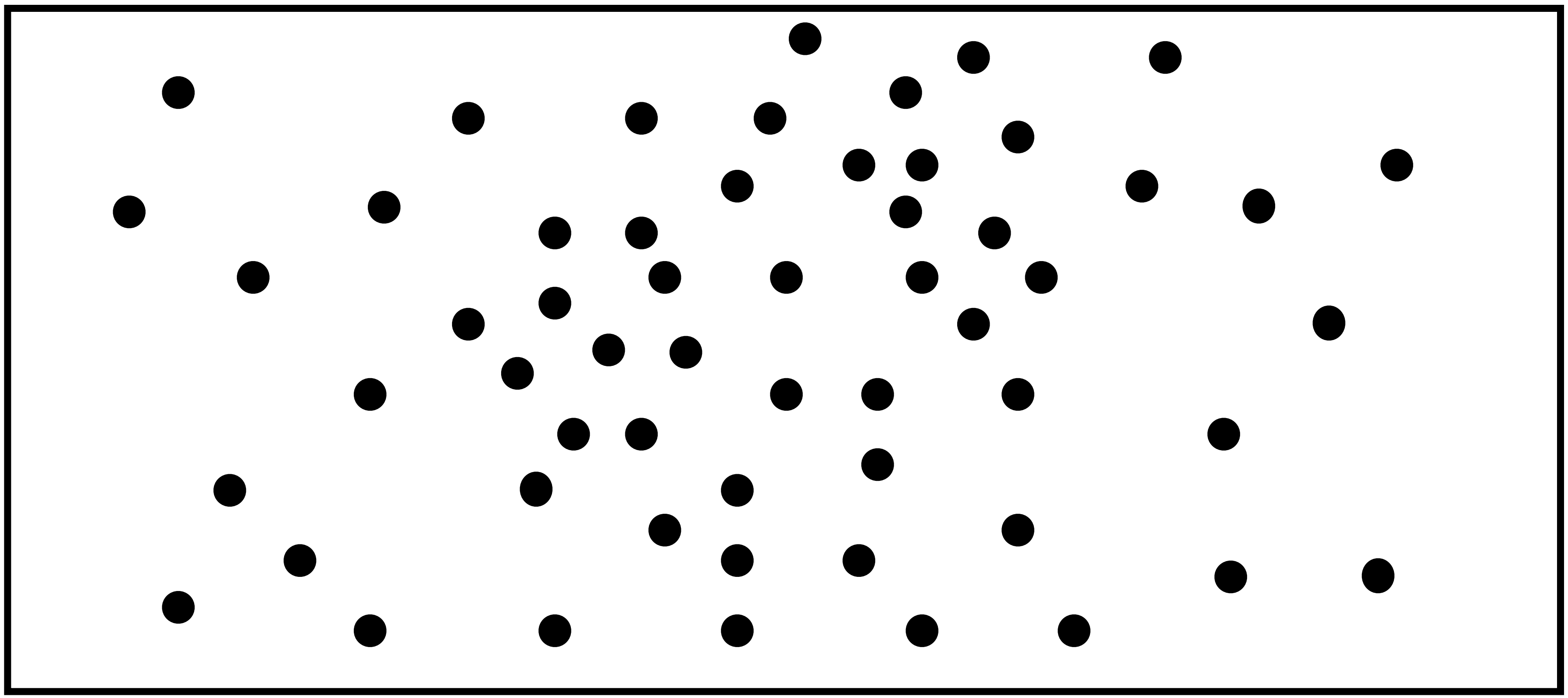


Can we get to know the momentum density of the radiation?

Can we subtract it from the jet to find the parton momentum?

What is the 'size' of a jet?

Consider an event made up of a number of particles



$\{p_i\}$ → $\{j_k\}$

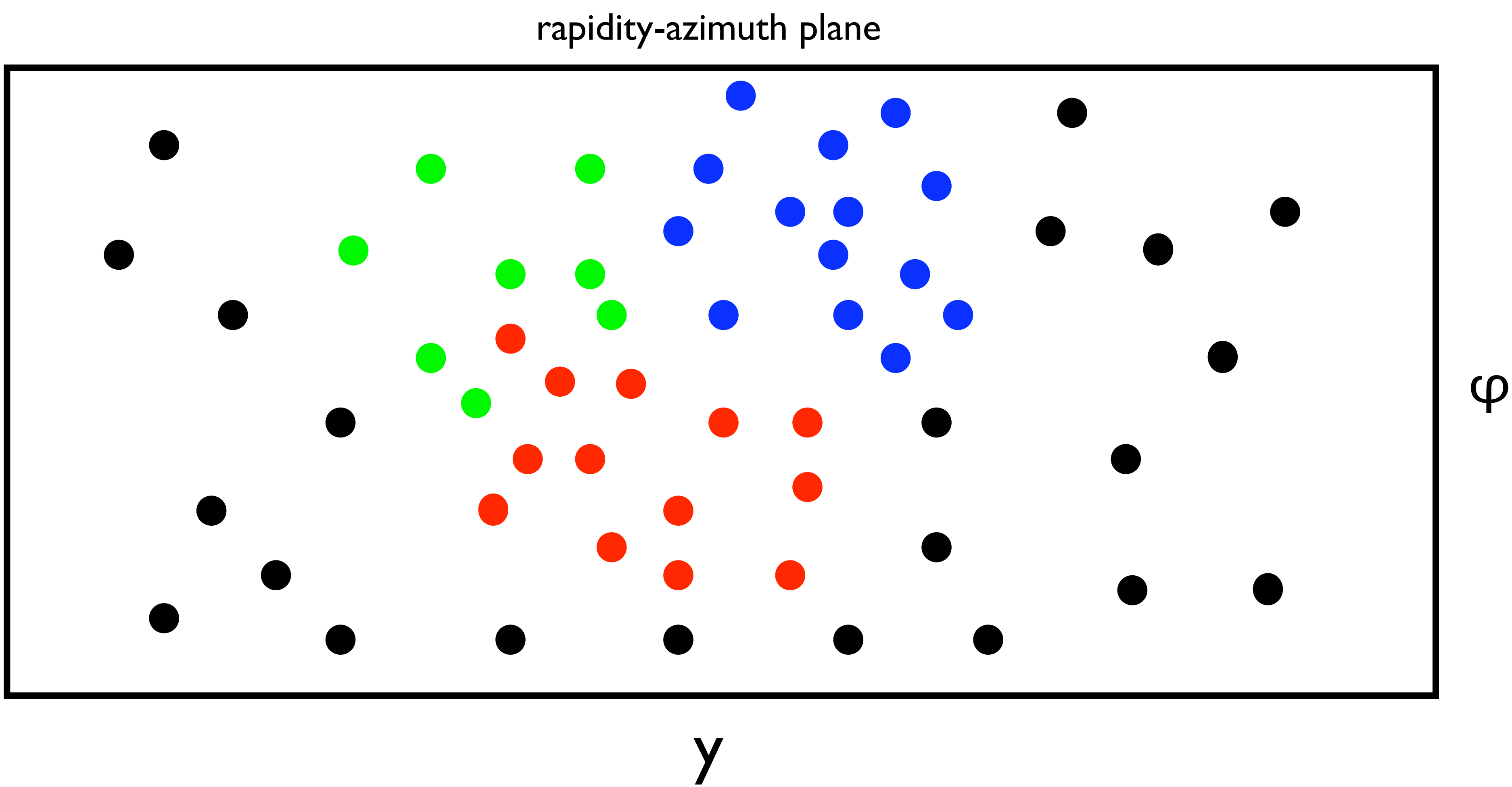
particles, 4-momenta, calorimeter towers, ...

jet-finder algorithm

jets

What is the 'size' of a jet?

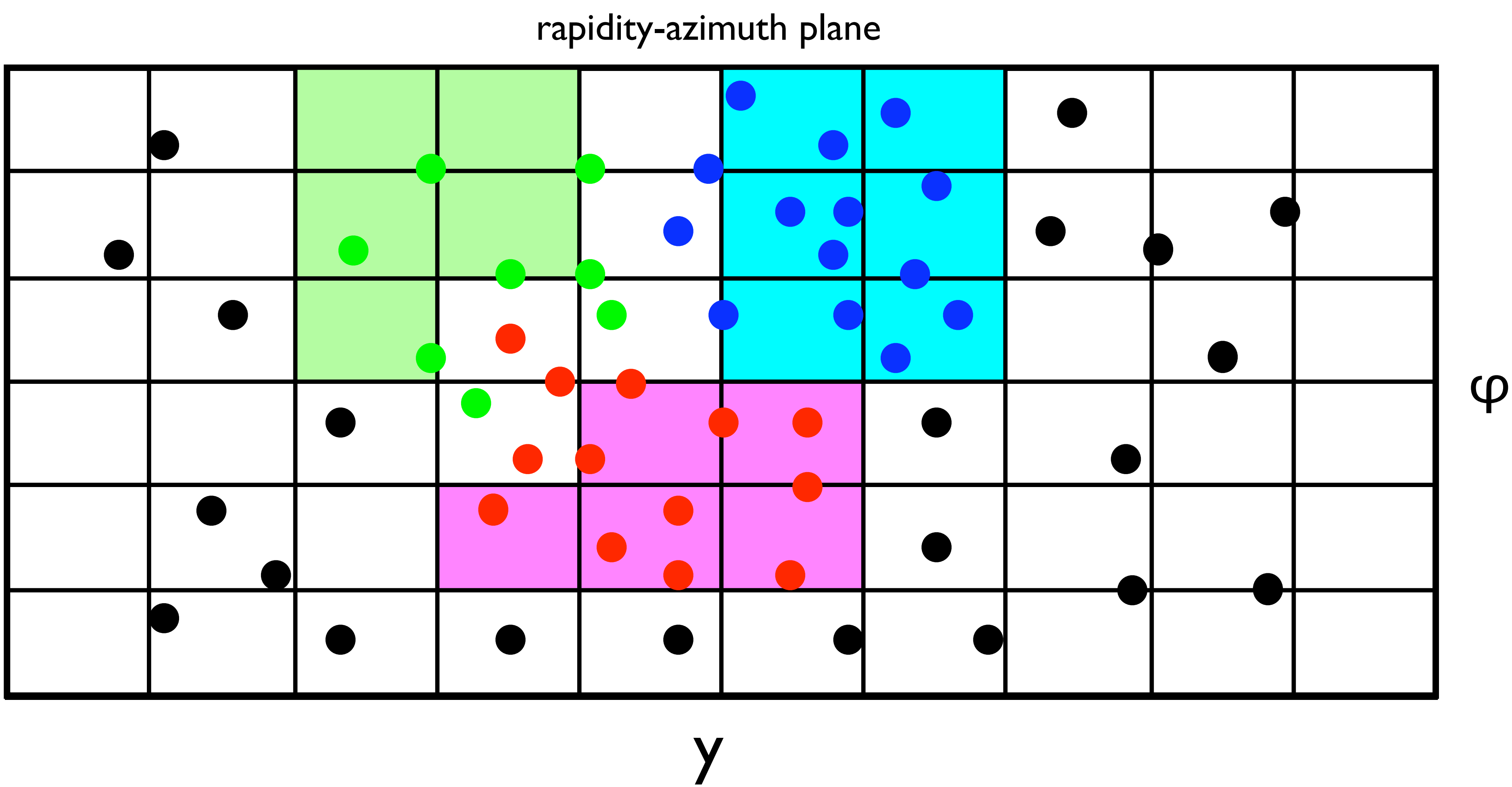
The clustering procedure assigns each particle to a jet:



But... where exactly does a jet end, and another begins?

Jet Area

One idea: tile the plane, count the cells of a jet, sum the areas

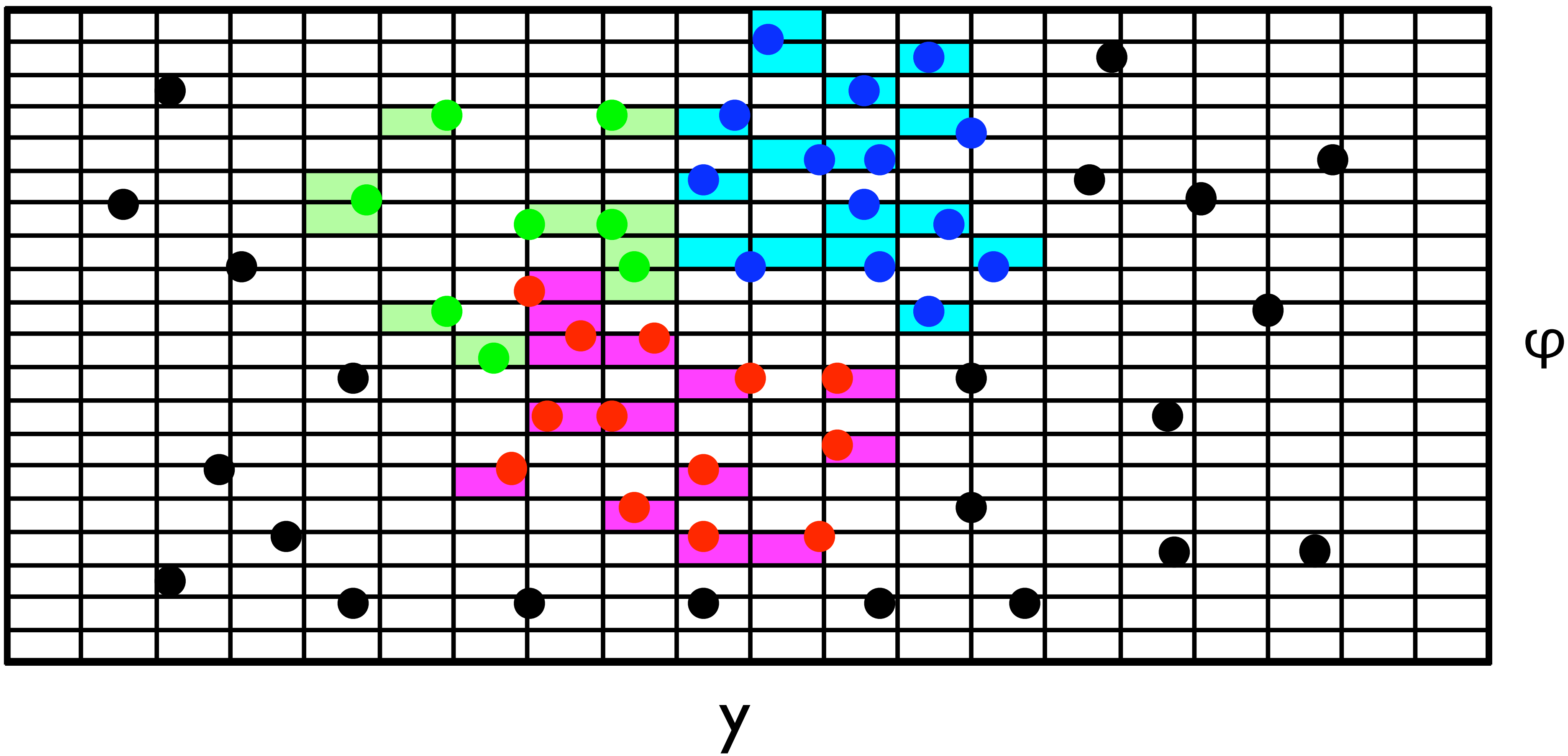


But what do I do when different jets share a cell?

Jet Area

Obviously, make the cells smaller to improve accuracy

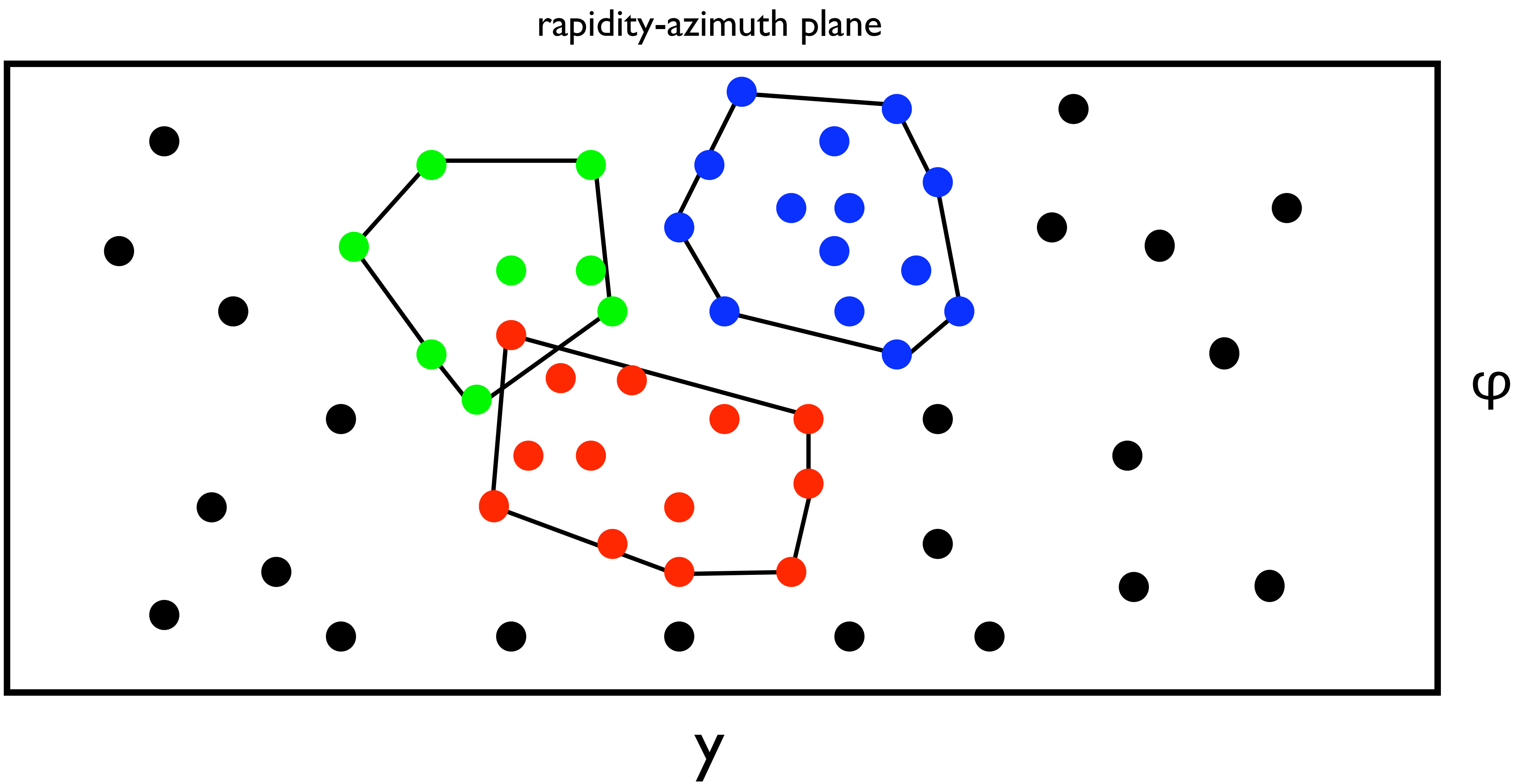
rapidity-azimuth plane



Unfortunately, particles being pointlike, the area tends to zero!

Jet Area

Next try, use the **convex hull**



But what do I do if they overlap?

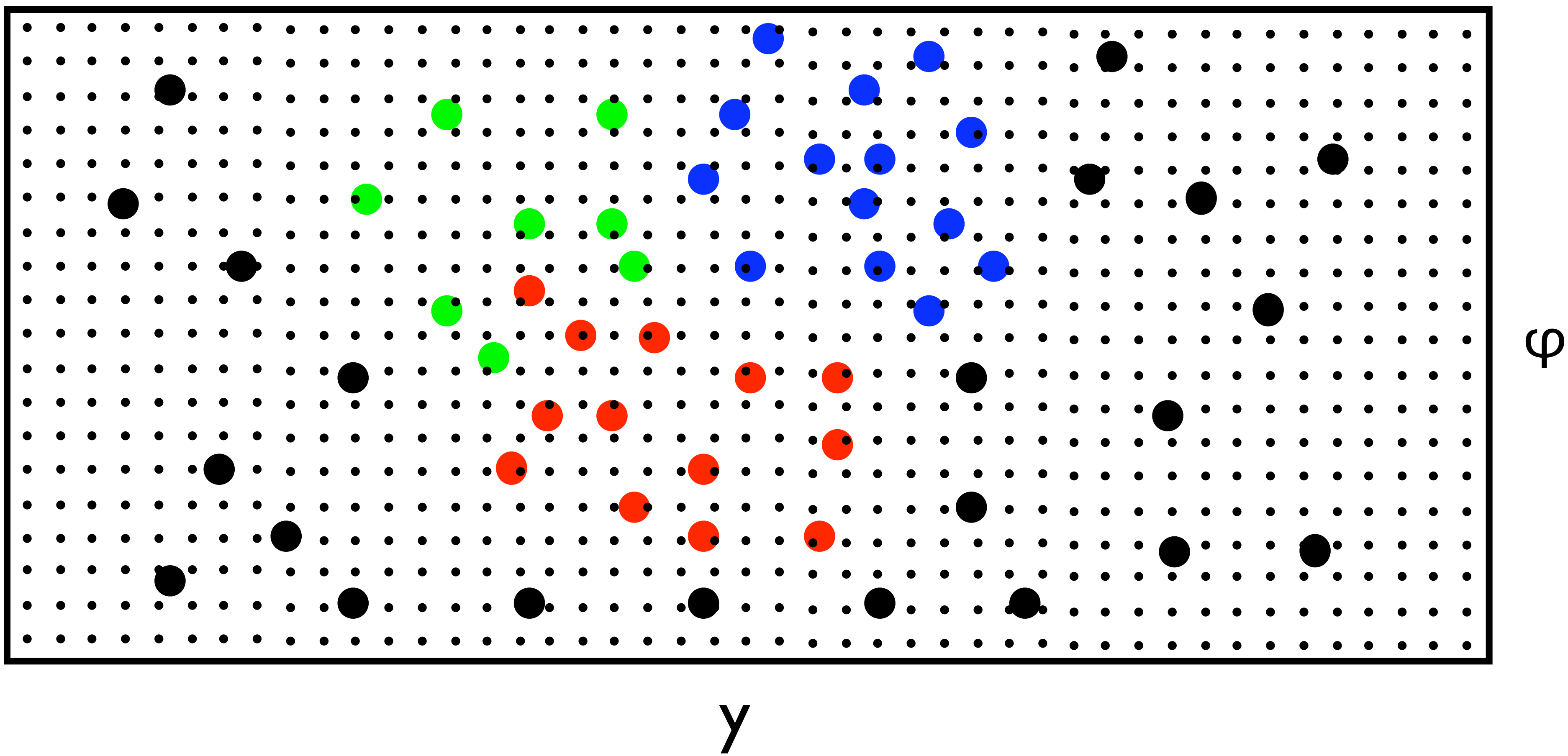
Moreover, what about the 'no man's land' ?

The Active Jet Area

We propose the following definition:

The 'active area' of a jet is (proportional to) the number of uniformly distributed infinitely soft particles that get clustered in it

rapidity-azimuth plane

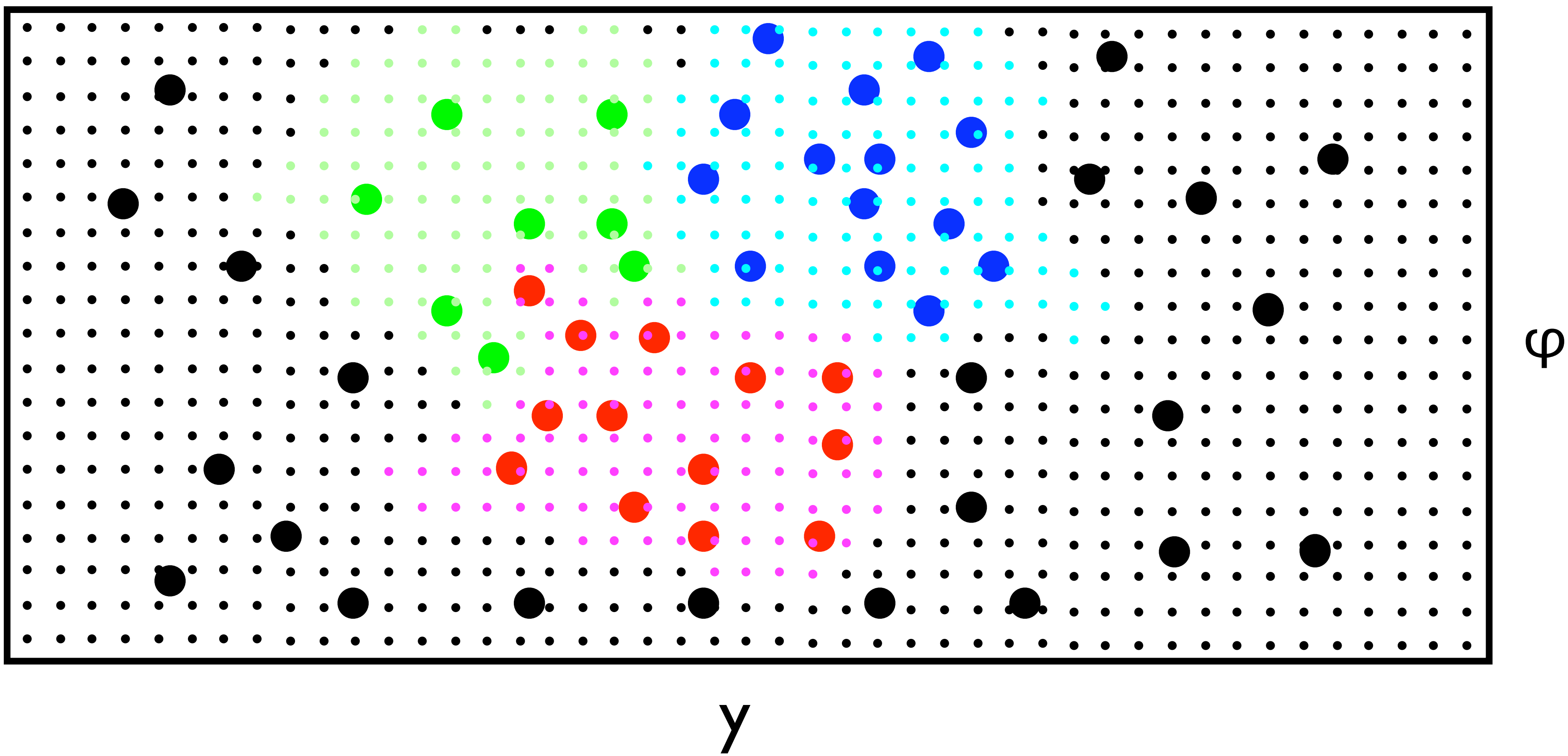


The Active Jet Area

After the clustering, a given set of ghosts belong to each jet

Their number (times the average area of a single ghost) defines the **catchment area** of the jet

rapidity-azimuth plane



The Active Jet Area

The definition of **active area** mimics the behaviour of the jet-clustering algorithms in the presence of a large number of randomly distributed soft particles

Tools needed to implement it:

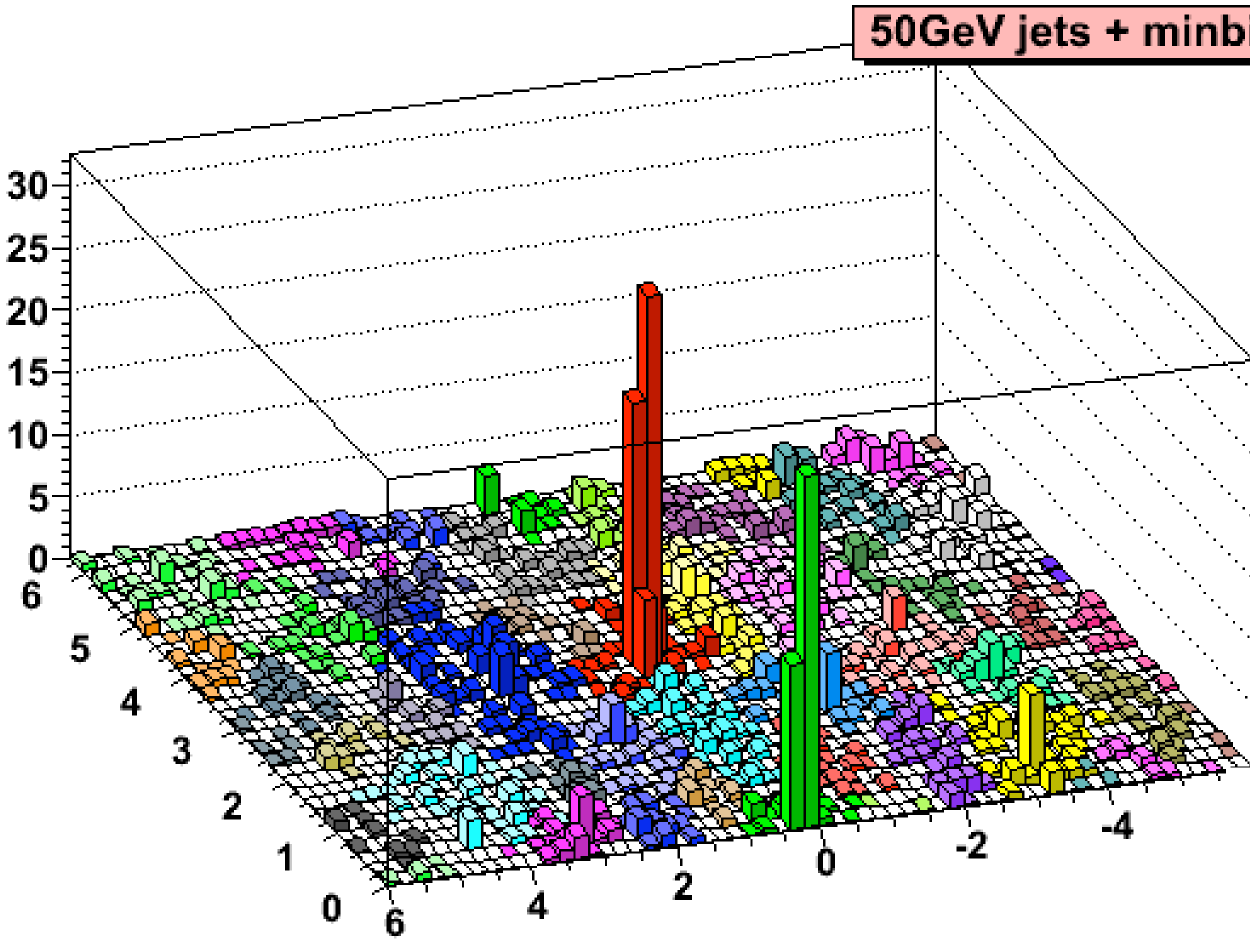
1. An **infrared safe jet-finder** (the ghosts should not change the jets)
2. A reasonably **fast implementation** (we are adding thousands of ghosts) [$O(10^4)$]

Both these characteristics are found in kt and Cambridge/Aachen jet-finders (as implemented in FastJet) and in SISCone

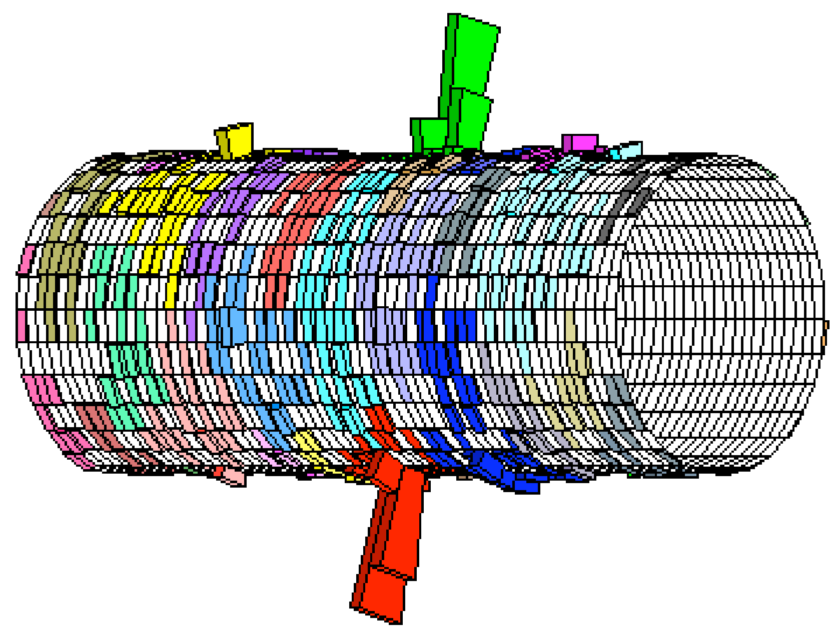
[~ 0.1 s] [~ 100 s]

www.lpthe.jussieu.fr/~salam/fastjet
projects.hepforge.org/siscone

A concrete example: LHC event with pile-up



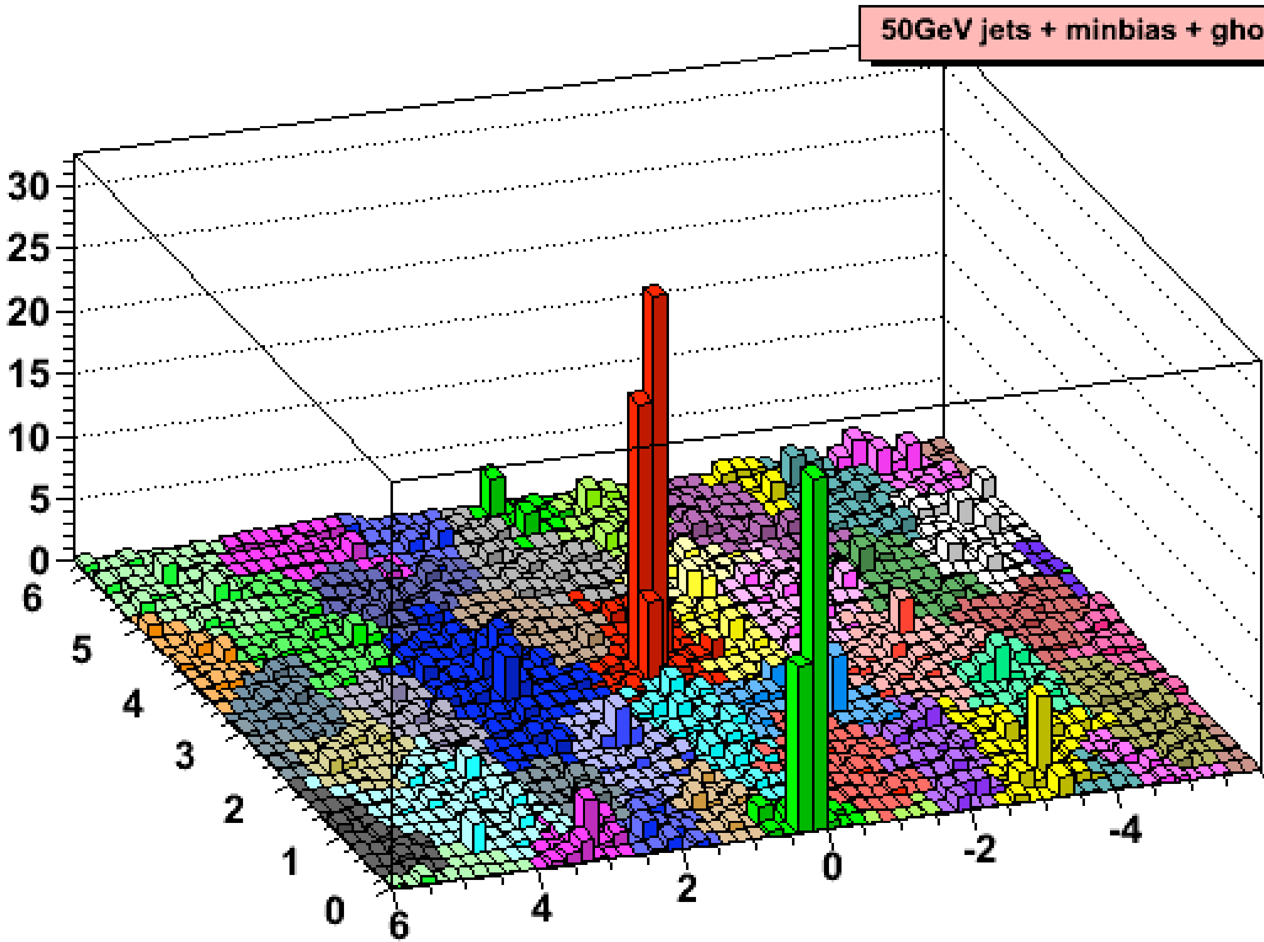
k_t-clustering



~ 2000 particles

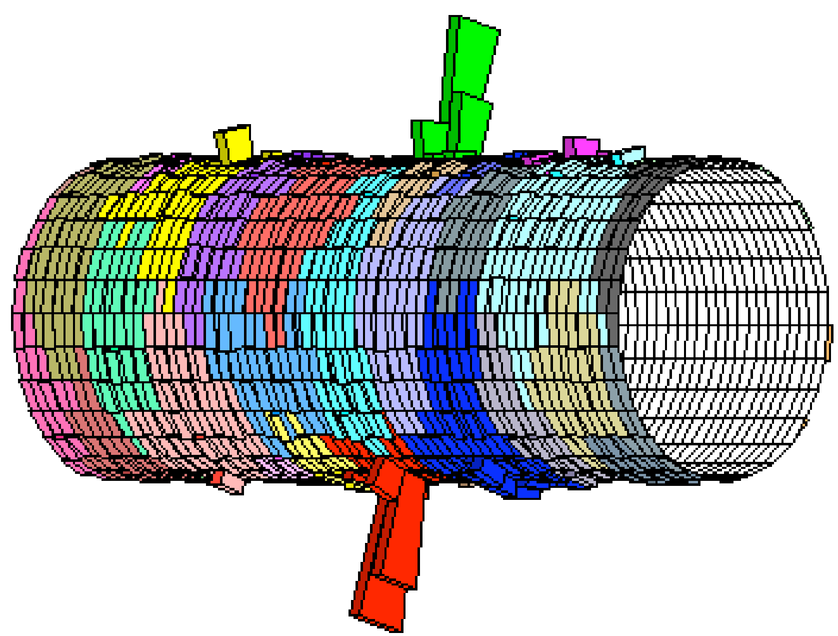
Clustering takes O(20 s) with standard algorithms, but only O(20 ms) with `FastJet`

The Active Jet Area



Try to estimate **area** of each jet

Fill event with many very soft particles, count how many are clustered into given jet



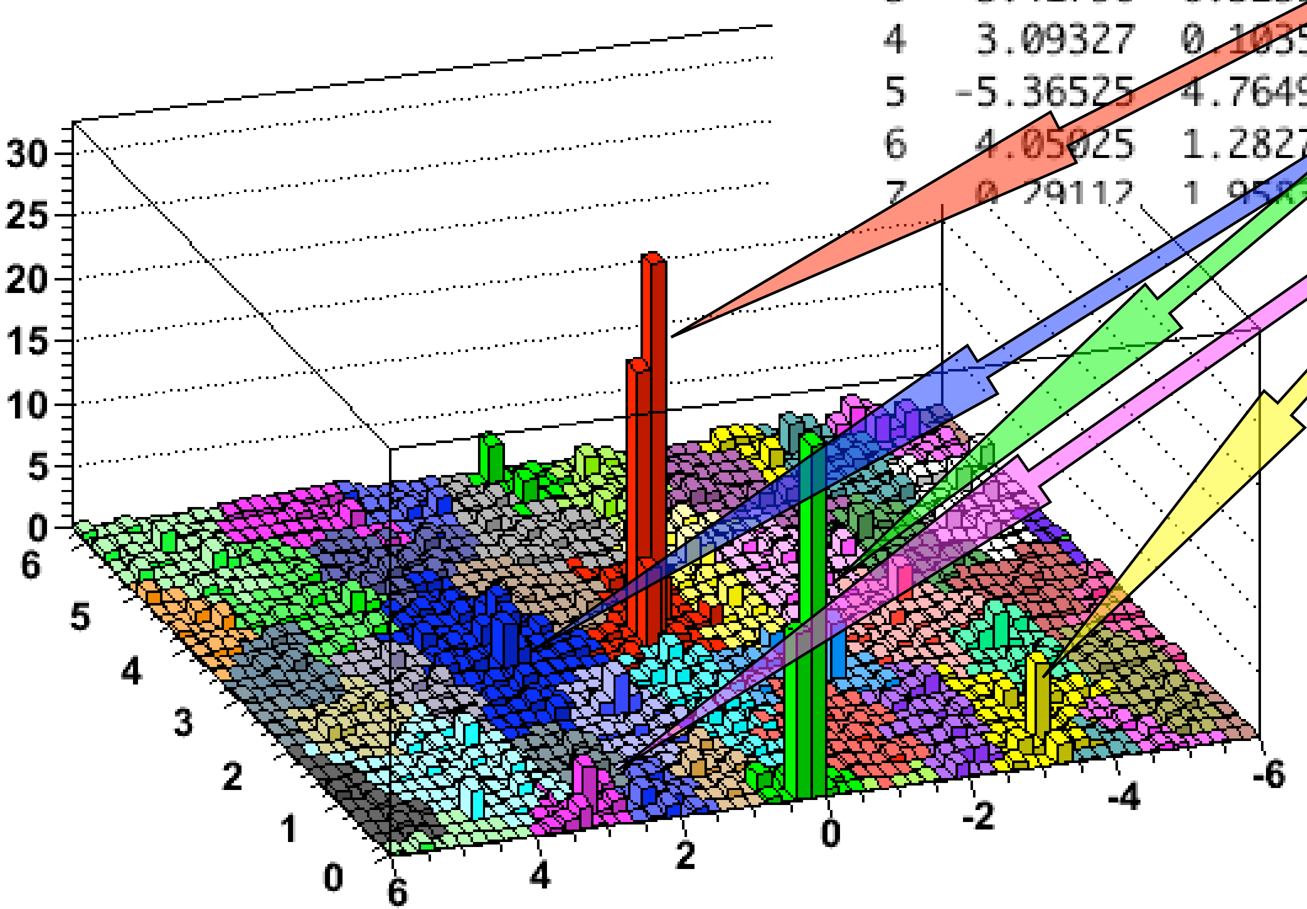
~ 10000 particles

Don't even think about it with standard algorithms, O(1 s) with `FastJet`

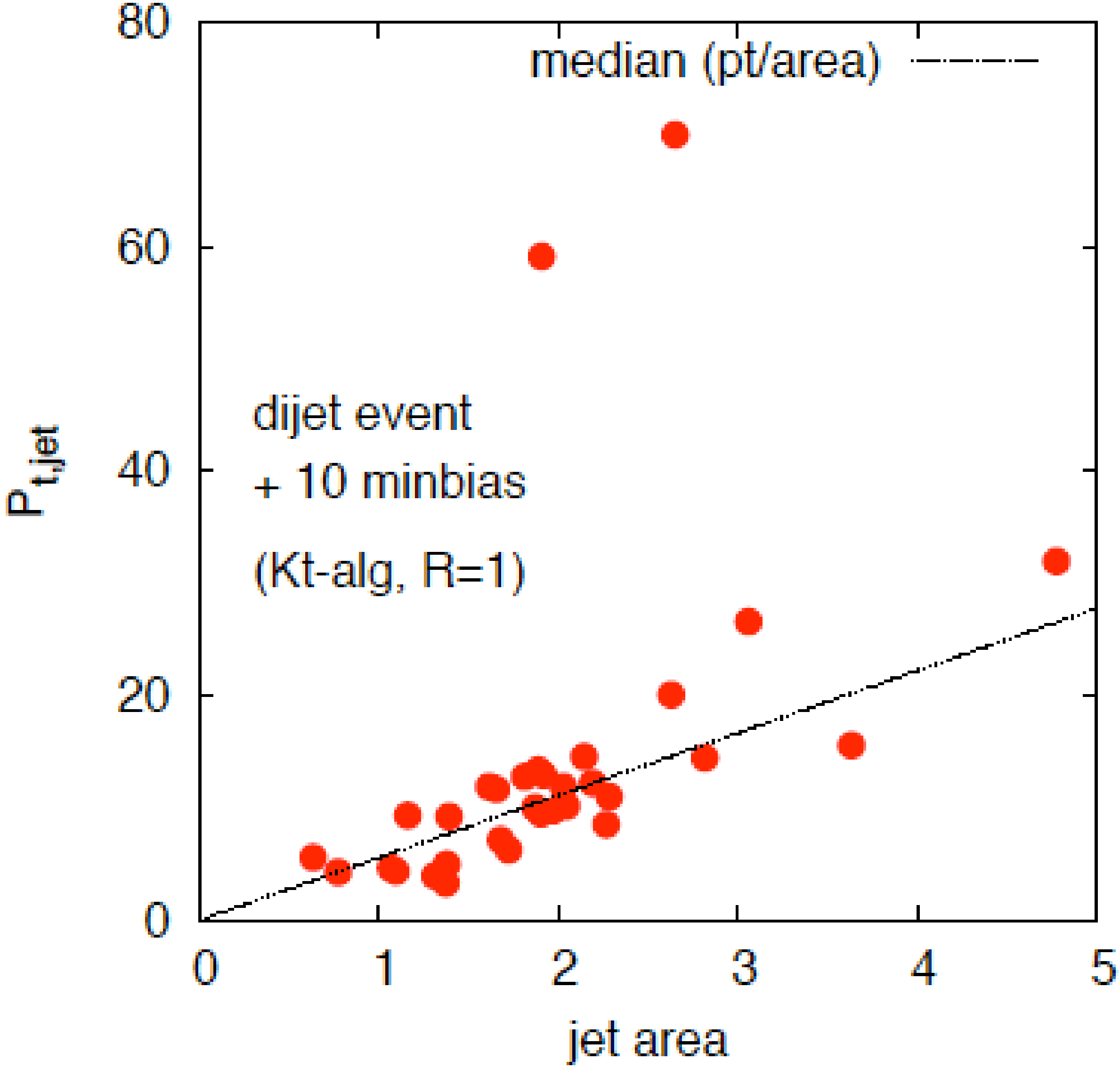
The Active Jet Area

```
iev 0 (irepeat 24): number of particles = 1428
strategy used =  NlnN
number of particles = 9051
Total area: 76.0265
Expected area: 76.0265
```

ijet	eta	phi	Pt	area	+-	err
0	0.15050	3.24498	69.970	2.625	+-	0.020
1	0.18579	0.13150	59.133	1.896	+-	0.020
2	2.33840	3.23960	31.976	4.749	+-	0.028
3	-3.41796	0.52394	26.595	3.084	+-	0.021
4	3.09327	0.10350	20.072	2.688	+-	0.023
5	-5.36525	4.76491	19.598	2.780	+-	0.012
6	4.05025	1.28279	15.561	3.592	+-	0.028
7	0.79112	1.95835	14.566	2.114	+-	0.018



Area vs. p_T



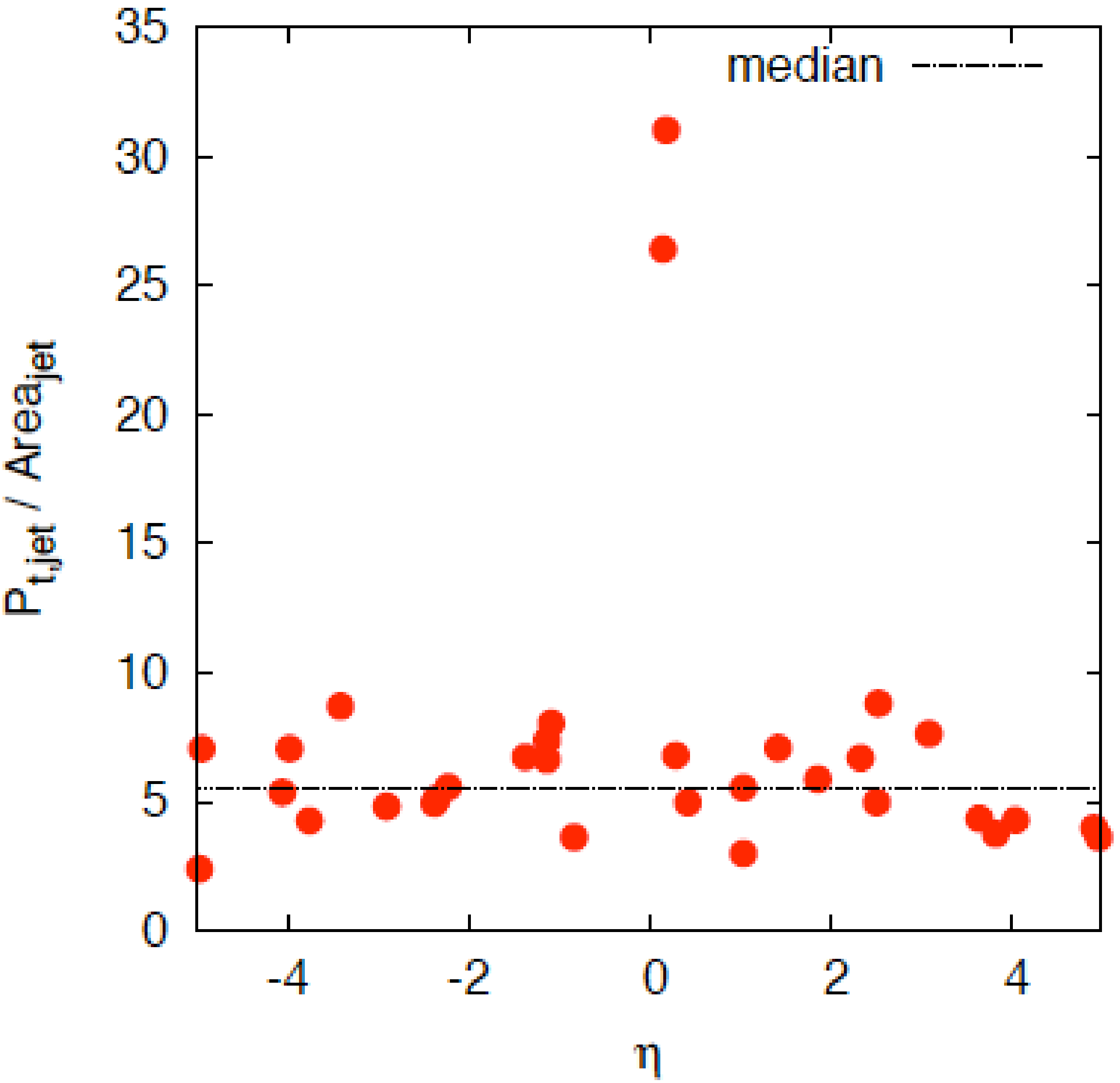
The jets adapt to the surrounding environment

They can have very different areas

Area vs. p_T

Key observation:

p_T/Area is fairly constant, except for the hard jets



The distribution of background jets establishes its own average momentum density

(NB. this is true on an event-by-event basis)

What we have seen so far

- A proper operative definition of **jet area** can be given
- When a hard event is superimposed on a **roughly uniformly distributed background**, study of **transverse momentum/area** of each jet allows one to determine the noise density **ρ** (and its fluctuation) on an event-by-event basis
- Once measured, the background density can be used to correct the transverse momentum of the hard jets:

$$p_T^{\text{hard jet, corrected}} = p_T^{\text{hard jet, raw}} - \rho \times \text{Area}_{\text{hard jet}}$$

A few examples follow...

Roughly uniformly distributed background

In decreasing order of number of particles/uniformity, we have, at the LHC,

- **Background** in heavy ion collisions
  (~ 30000 particles / event)

- **Pile-up** in high luminosity pp collisions
  (up to ~ 20 overlapping collisions, ⇒ ~ 4000 particles/event)

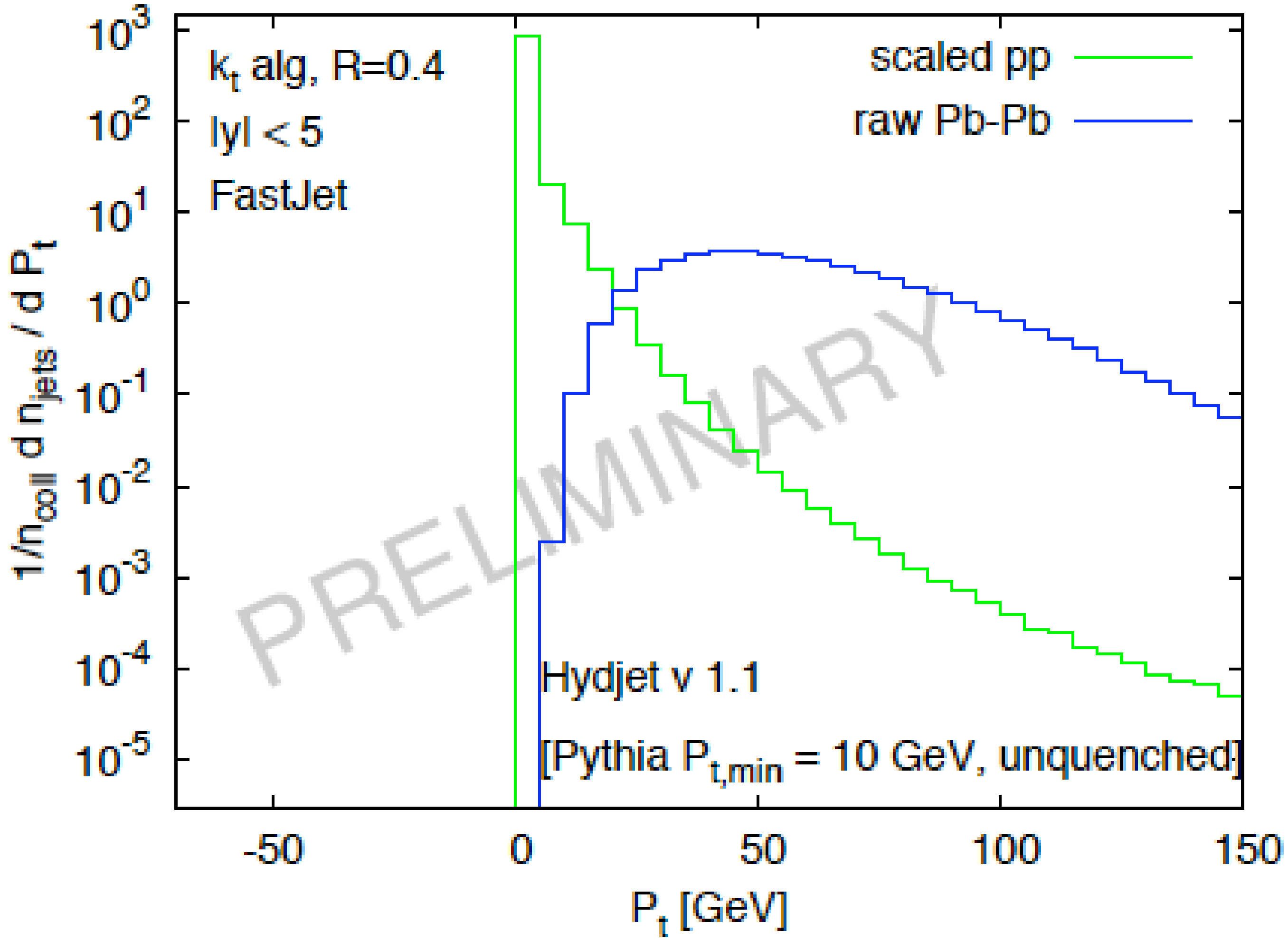
- **Underlying event** in a single pp collision
  (about 200 particles)

Since the measurement of the background level relies on a uniform distribution of the 'background particles' themselves, and assumes the background to be uncorrelated with the hard jets, we must expect the underlying event case to be the most challenging one

Inclusive jet distribution in HIC

The momentum density of simulated events is measured to be ~ 250 GeV per unit area

Hence, with R = 0.4 a jet on average gets ~ 125 GeV of additional transverse momentum



The jet distribution is completely distorted by the huge background……

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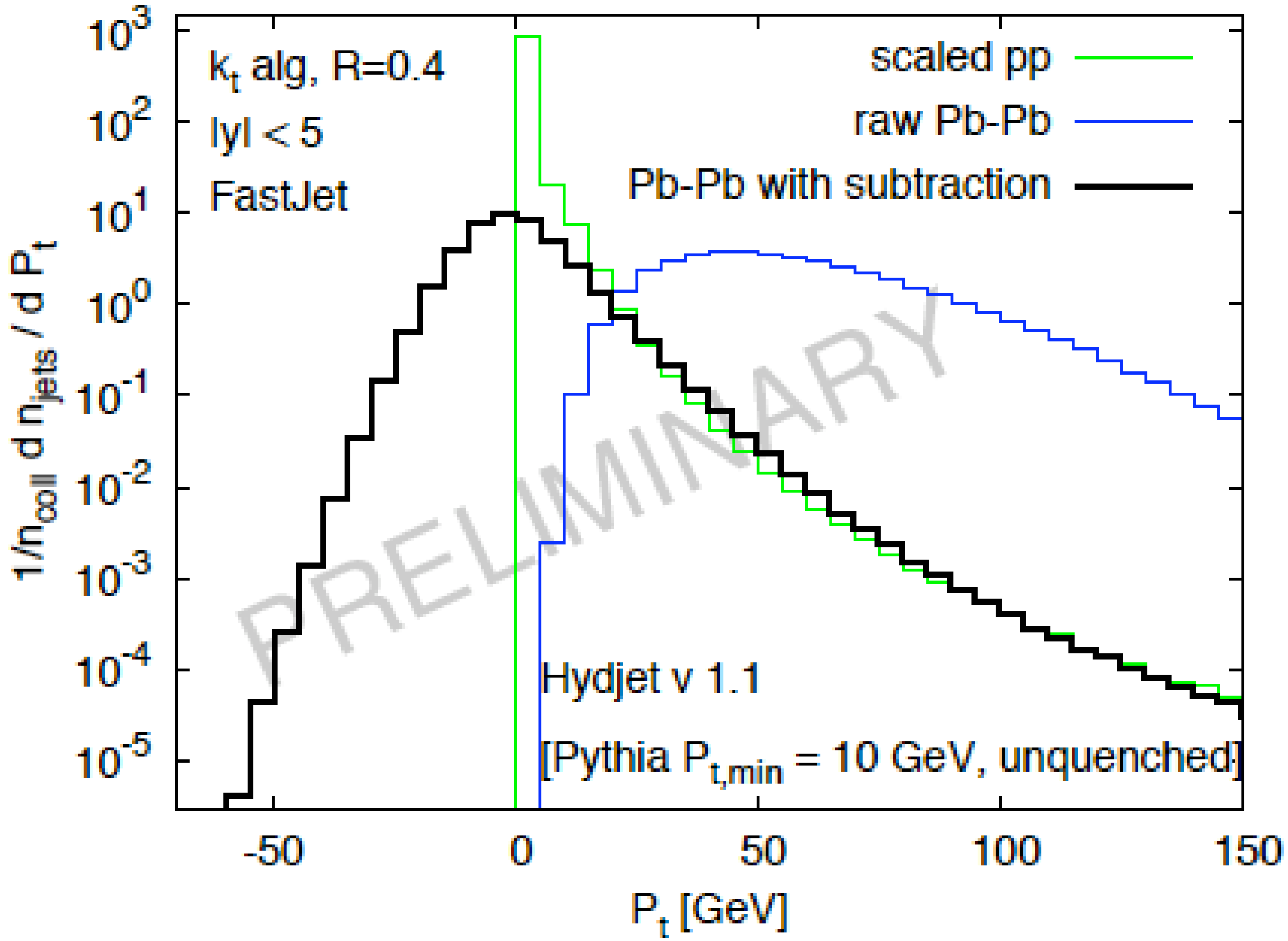
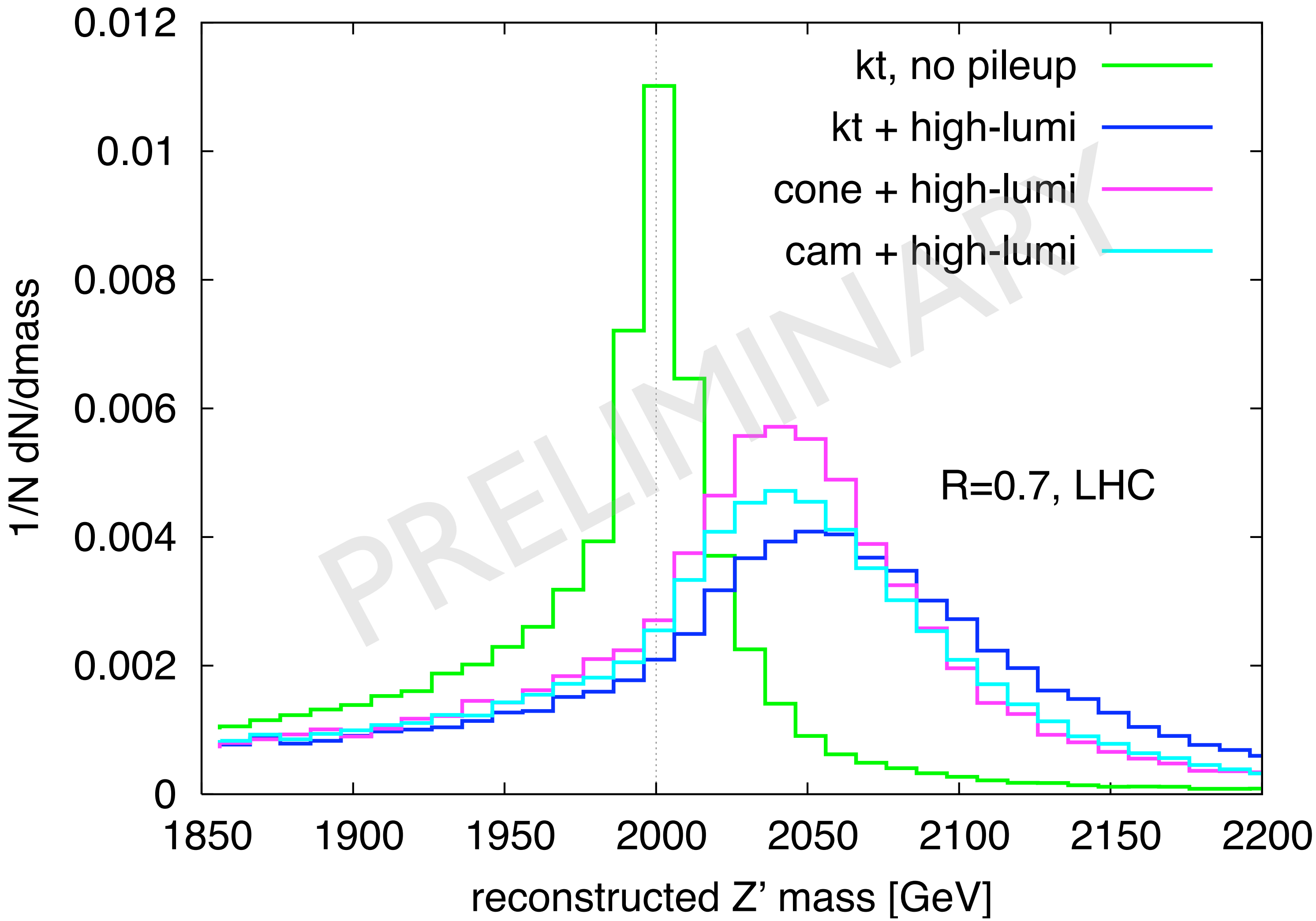


The jet distribution is completely distorted by the huge background......

...but it can be recovered down to fairly low p_T

Pile-up at the LHC

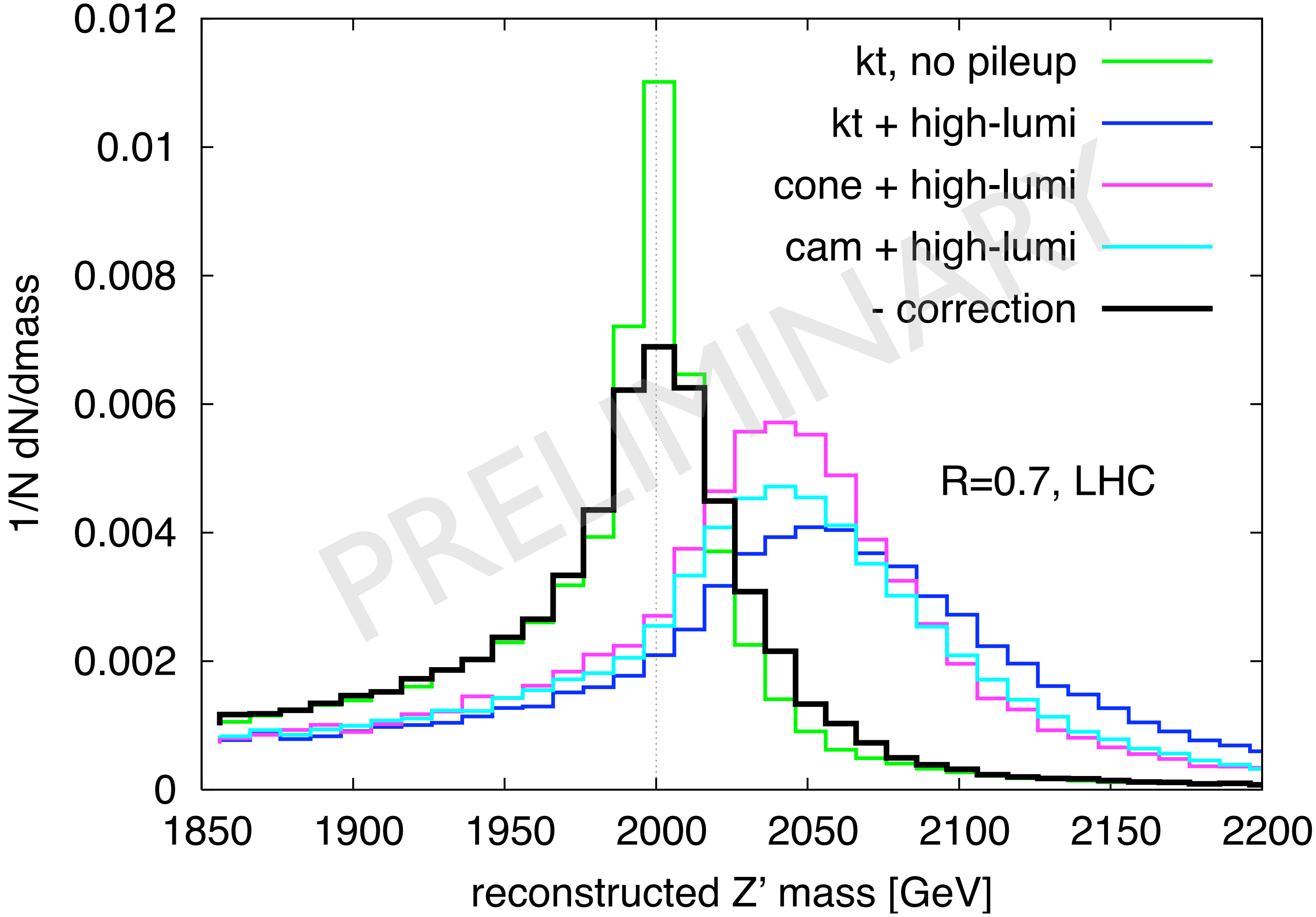
An hypothetical Z' invariant mass distribution



The peak is shifted and smeared when clustering together with the pile-up

Pile-up at the LHC

An hypothetical Z' invariant mass distribution

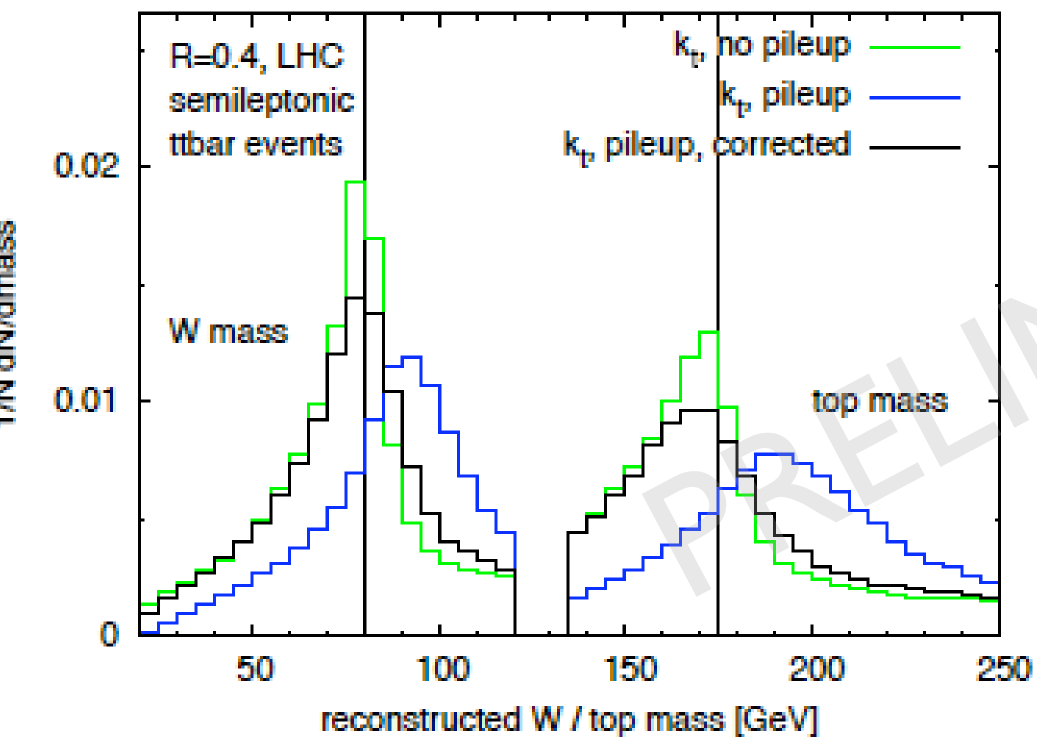


The correct mass is recovered, with good resolution, after subtraction

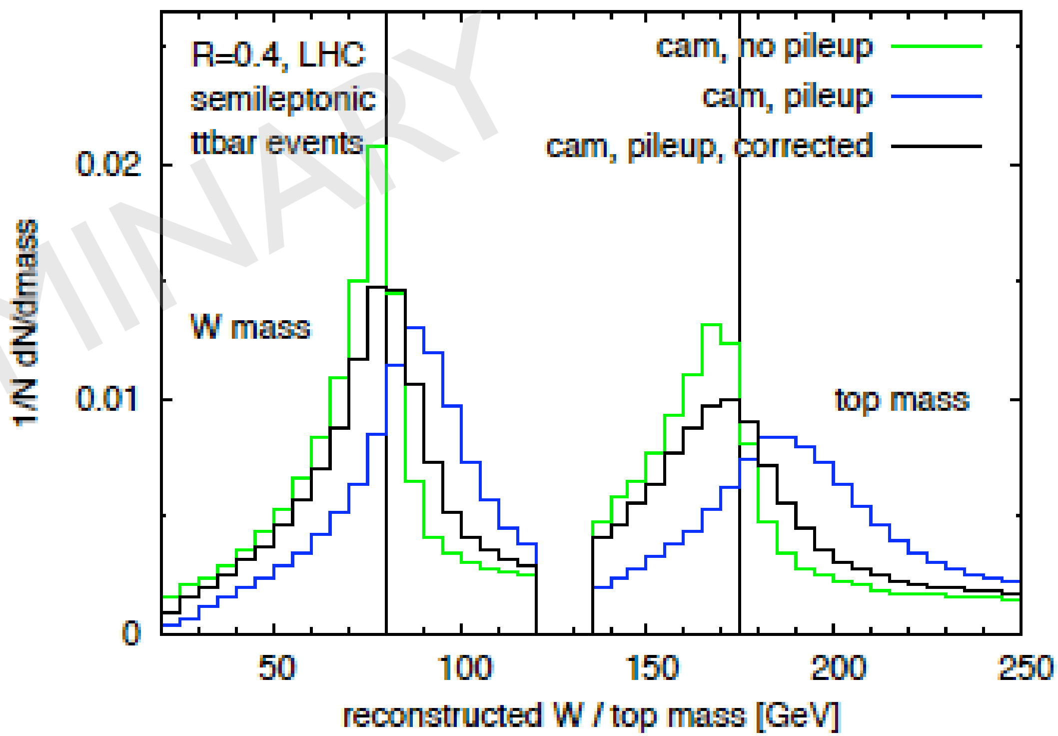
Pile-up at the LHC

Top production

k_t



Cambridge



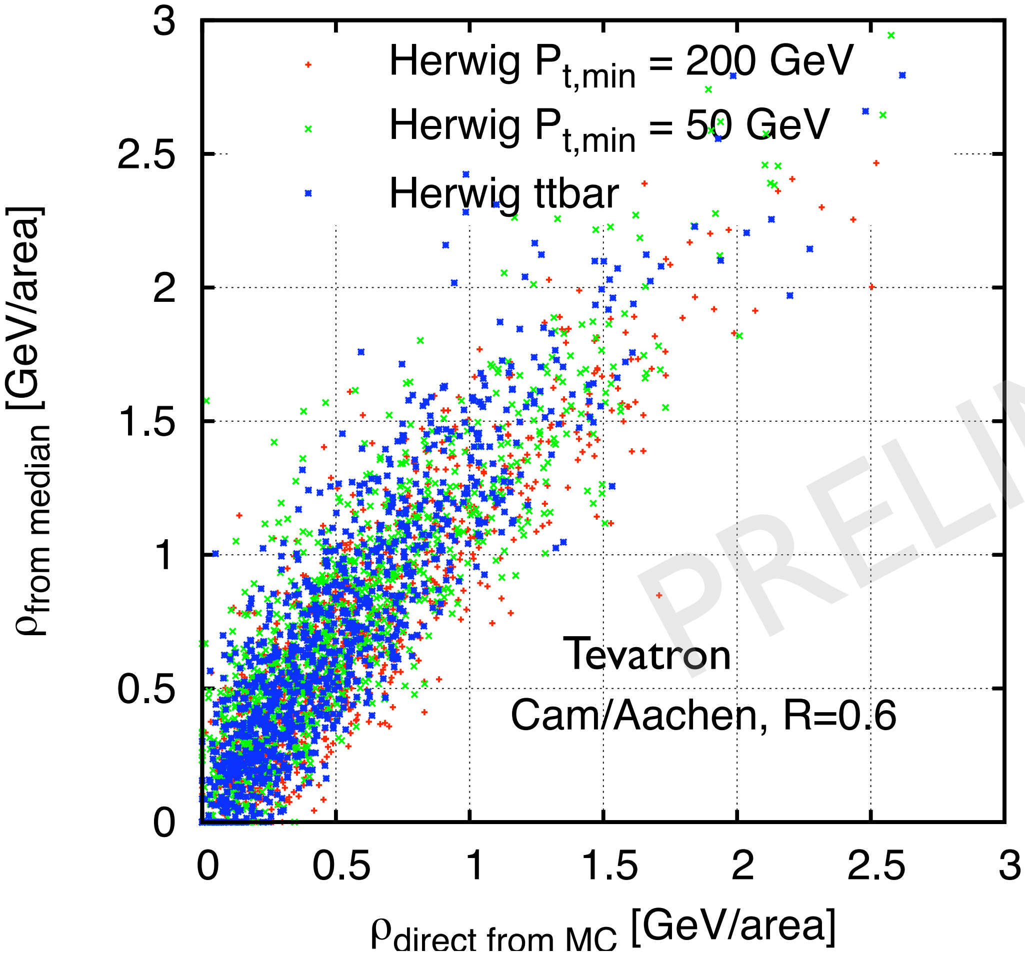
The top and W mass distributions get shifted, but they can be recovered after correction with good resolution

Underlying Event estimation

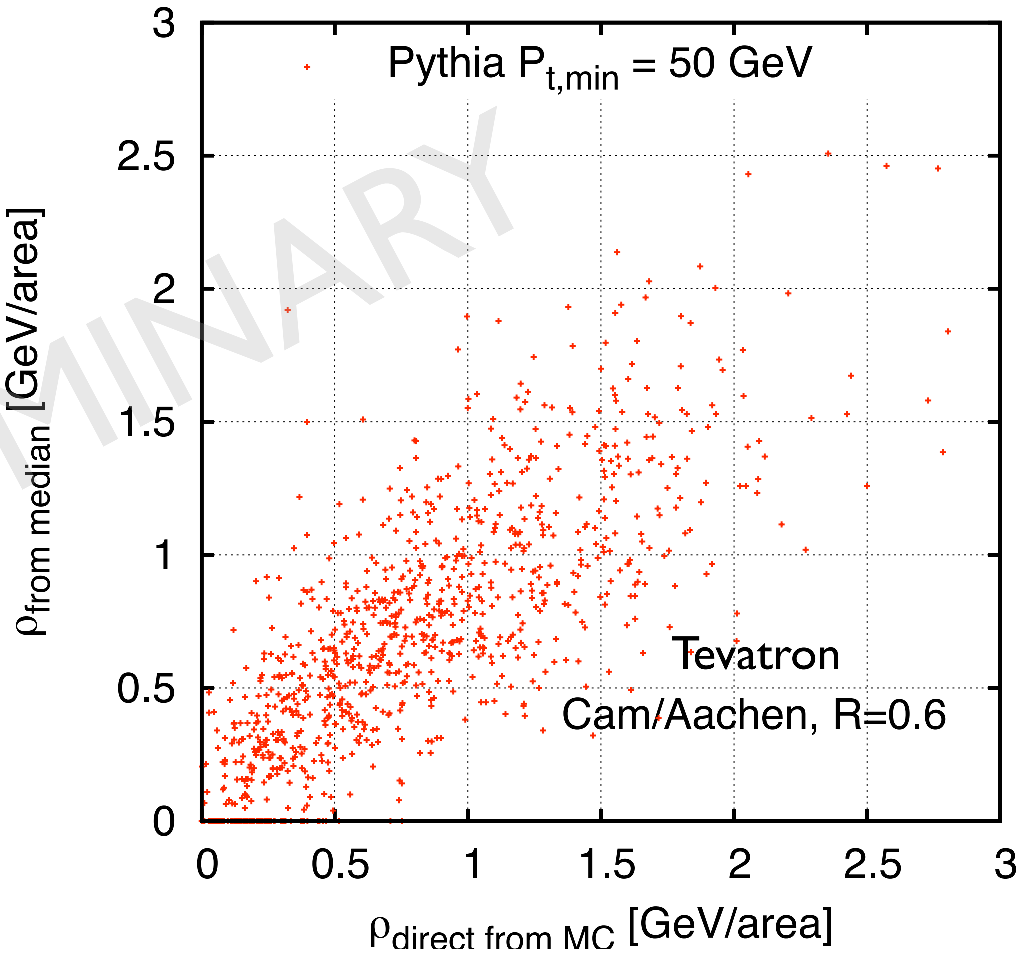
To test the procedure for the Underlying Event, compare the measurement of the background level made with areas with the known amount a Monte Carlo put in

Measurement

HERWIG

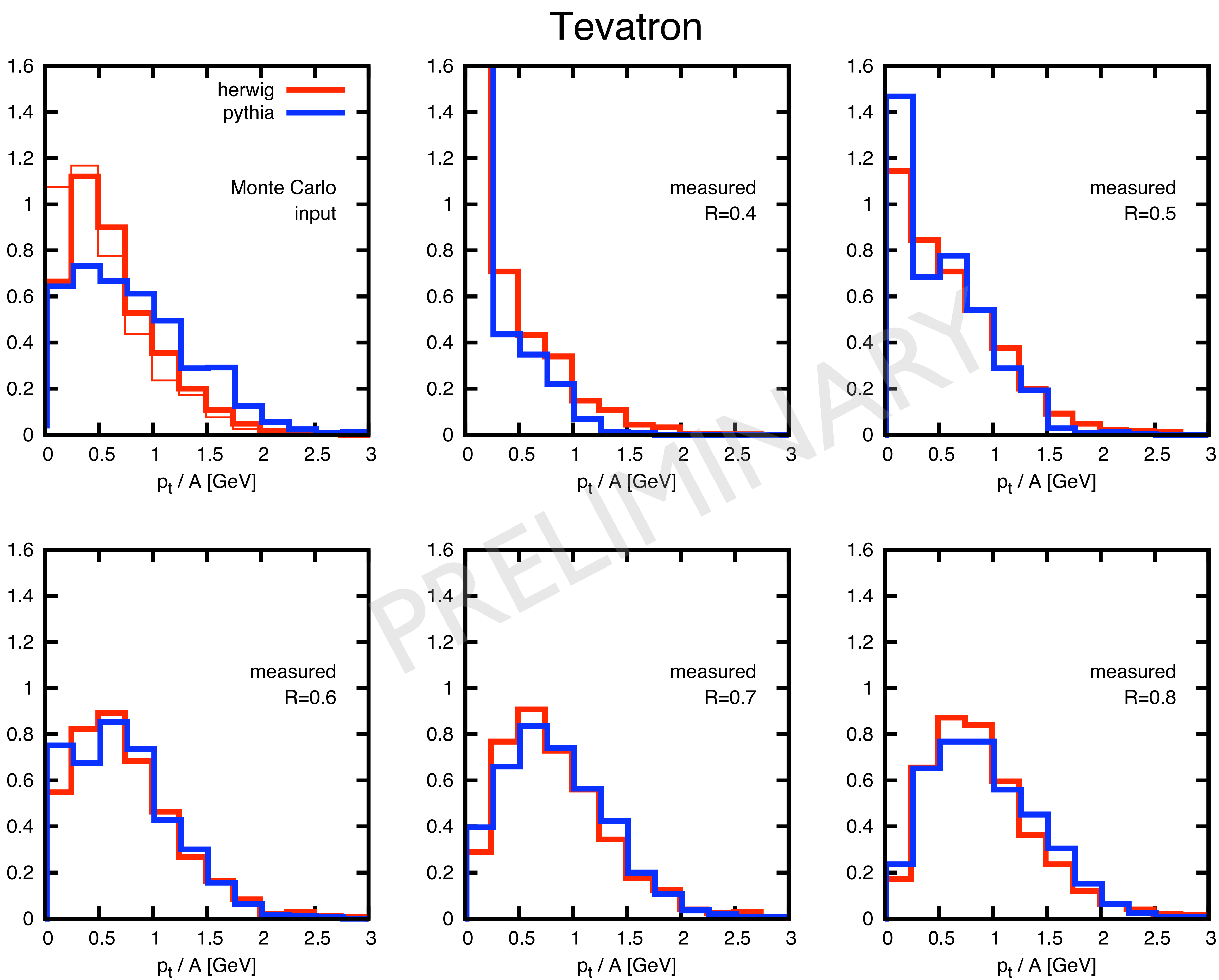


PYTHIA

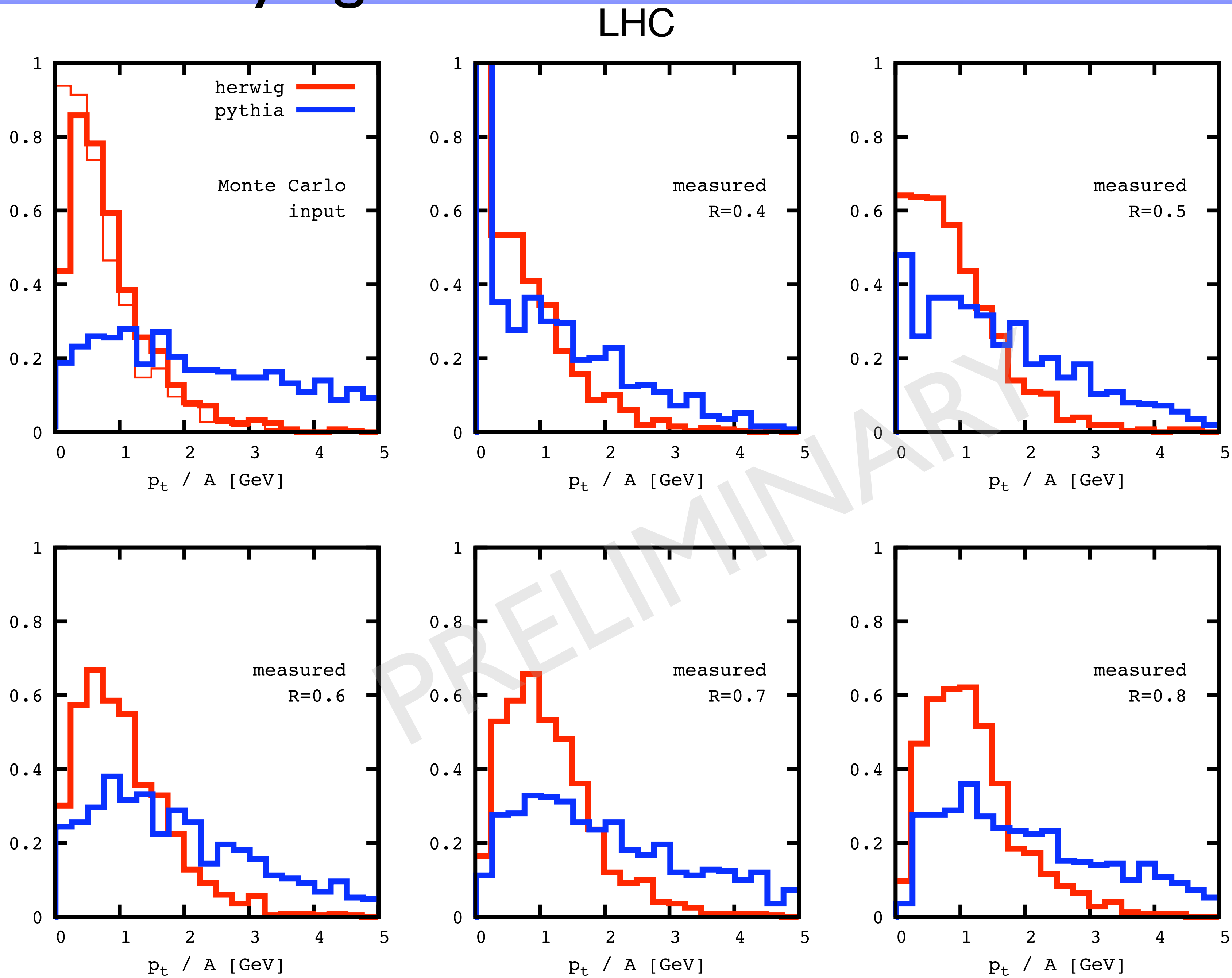


Input from Monte Carlo

Underlying Event estimation



Underlying Event estimation at the LHC



Herwig and Pythia differ. A similar analysis on the data would immediately tell which one (if either) is right

Conclusions

- ☑ Given a proper jet-finder, jet areas can be defined
- ☑ They can be used to estimate the level of a uniformly distributed noise
- ☑ They can be used to subtract the background contribution from the hard jets

Work in progress
To be published soon