Pileup Subtraction for Jet Shapes

Ji-Hun Kim

IPhT, CEA-Saclay, France

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Based on :
arXiv:1211.2811, G. Soyez, G. Salam, JHK, S. Dutta, M. Cacciari.

Outline

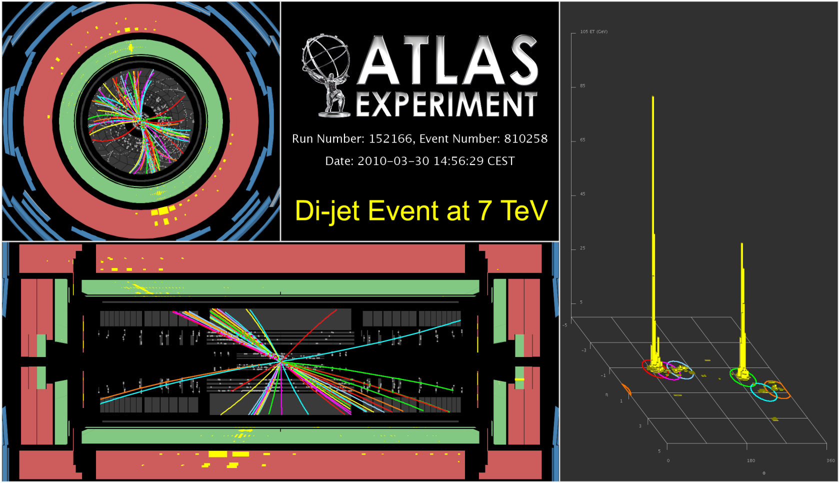
Hadron jet

Many QCD studies and BSM studies involve hadron jets :

- Quark jets vs gluon jets
- Multi-jet cross-sections.
- Jet mass, transverse momentum, . . .
- Perturbative QCD studies with jet substructure
- Top quark tagging.
- Fat jets from highly boosted heavy particle.
- New physics searches.

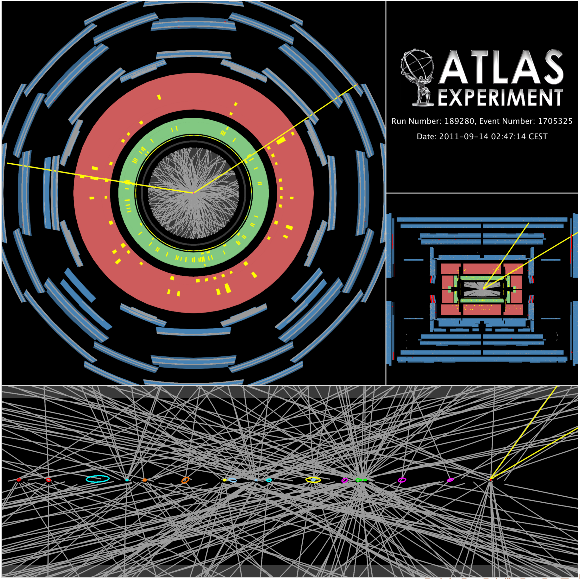
We need to precisely measure jet shapes(m, p_T, angularity, . . .).

Hardron jets

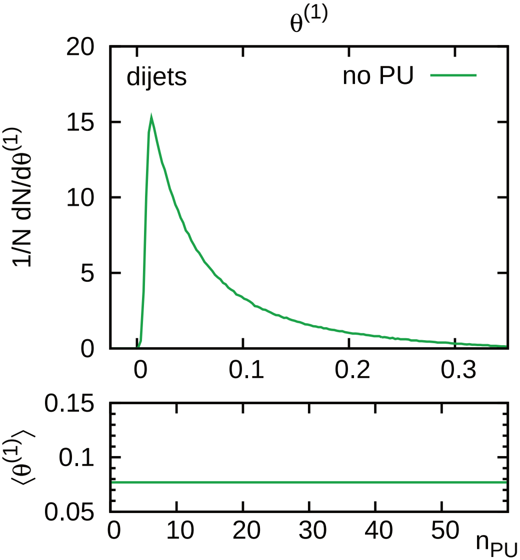


Pileup Events

Each proton bunch-crossing produce multiple collision events.

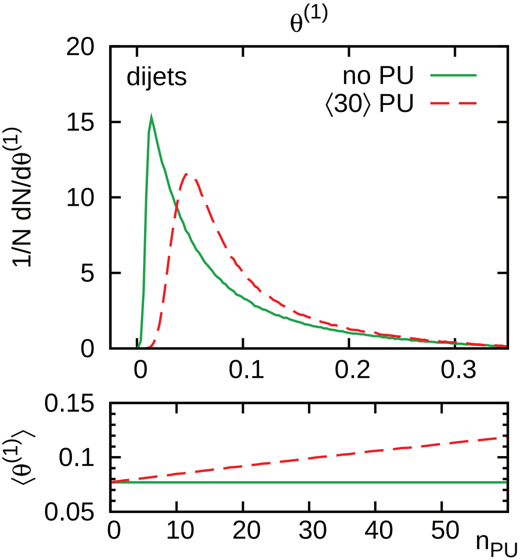


Objective : pileup subtraction for jet shapes



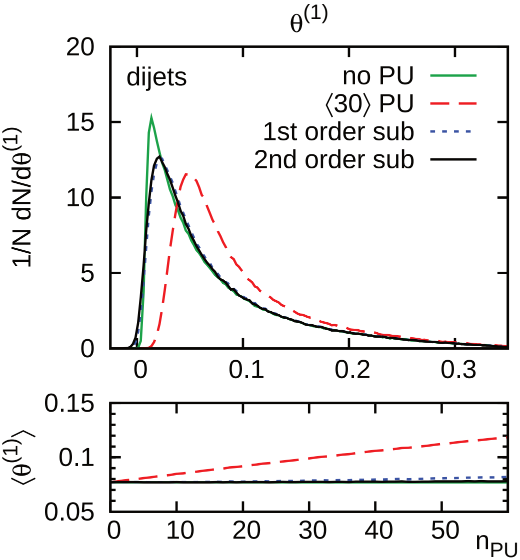
When there are no pileup.

Objective : pileup subtraction for jet shapes



But pileup does exists, usually.

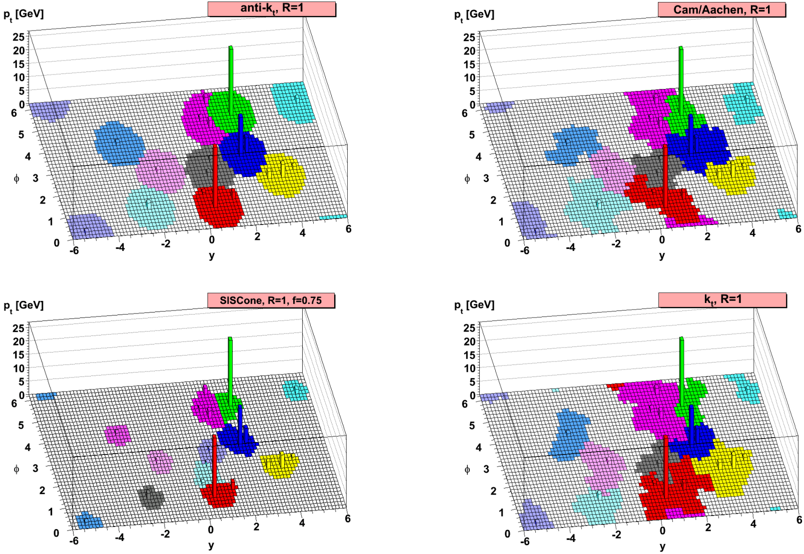
Objective : pileup subtraction for jet shapes



We want to reduce smearing effects of pileup.

Jet Area of a Parton Level Event

Objects inside jet area will be merged into the jet



Jet area : Definitions

It is useful for pileup subtraction techniques

- All of (Anti-)k_T jets, C/A jets, ... have a finite reach $\sim \mathcal{O}(R_{jet})$.
- If a soft particle is near to a jet axis, it will be merged into the jet.

Passive Area

$$a(J) \equiv \int dy\, d\phi\, \Theta_J(y,\phi) \qquad \Theta_J(y,\phi) = \begin{cases} 1 & \text{if } (y,\phi) \in J \\ 0 & \text{if } (y,\phi) \notin J \end{cases},$$

Active Area

- Randomly distribute massless 'ghost' particles, $\{g_i\}$, with negligible energy, and number density ν_g.
- Cluster jets with the particles and ghosts.

$$A(J \,|\, \{g_i\}) = \frac{\mathcal{N}_g(J)}{\nu_g} \text{ as } \nu_g \to \infty.$$

Active area is faster to calculate. In this talk, 'jet area' refers 'active area'.

Simplified Pileup Event Model

What we can subtract is what we already know

Each pileup event is non-uniform, but pileup events as a whole are roughly uniform since they are union of independent collisions.
Thus, pileup particles are

- evenly distributed over azimuth angle, ϕ.
- also nearly uniformly distributed over rapidity, y.

With above assumptions, pileup can be modeled with

- a number density, ν, and
- a probability function for their p_T spectrum.

p_T-sum of pileup particles are propotional to jet area.

$$\langle P_{\text{pileup}}(p_T|A)\rangle = A\langle\nu\rangle\langle p_T^{\text{pileup}}\rangle \equiv \rho A$$

$$\langle P_{\text{pileup}}(p_T)\rangle = \int dA\ P(A)\ \rho A = \rho\langle A\rangle$$

Simplified Pileup Event Model

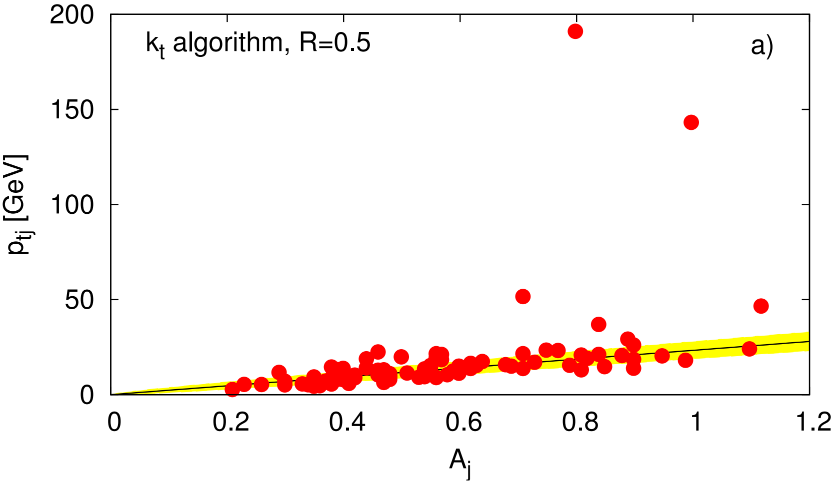


Figure: Dijet event with 22 pileup events generated by Pythia. arXiv:0707.1378, M. Cacciari, G. Salam

Pileup Subtraction for Jet p_T

One can measure ρ for each event :

$$\rho = \text{median}\left[\left\{\frac{p_{T\,j}}{A_j}\right\}\right].$$

Old one that is shifted and diluted by $P_{\text{Pileup}}(x)$

$$P_{\text{Full}}(p_T) = \int dx P_{\text{Hard}}(p_T - x) P_{\text{Pileup}}(x)$$

where $P_{\text{Hard}}(p_T - x) \equiv \int dA\ P(A)\ P_{\text{Hard}}(p_T - x|A)$ becomes

$$P_{\text{Sub}}(p_T) = \int dx \int dA\ P(A)\ P_{\text{Hard}}(p_T - x|A)\big(P_{\text{Pileup}}(x|A) - \rho A\big)$$

that is diluted only; P_{Sub} is less smeared than P_{Full}.

Pileup Subtraction for Jet Shapes

Jet Shapes

$$f : \{p_i^\mu\}_{i \in \text{jet}} \rightarrow \mathcal{R}$$

e.g. Jet Mass, Angularity, Planar Flow, N-Subjettiness, ...

IR and collinear safe jet shapes is insensitive to

- split each particle into particles of tiny p_T.
- move (or, 'remove and insert') particles of tiny p_T.

For a given hard jet, we define

$$f(\text{pileup constituents}, x)|_{\text{hardjet}}$$
$$\equiv f(\text{hard particle constituents} \oplus x * \text{pileup particle constituents})$$

Imagine we split and move pileup particles until it becomes uniform.

$$f(\text{pileup constituents}, x)|_{\text{hardjet}} \approx f(x)|_{\text{hardjet}}$$
$$\equiv f(\text{hard particle constituents} \oplus x * \text{uniform bkg. particles})$$

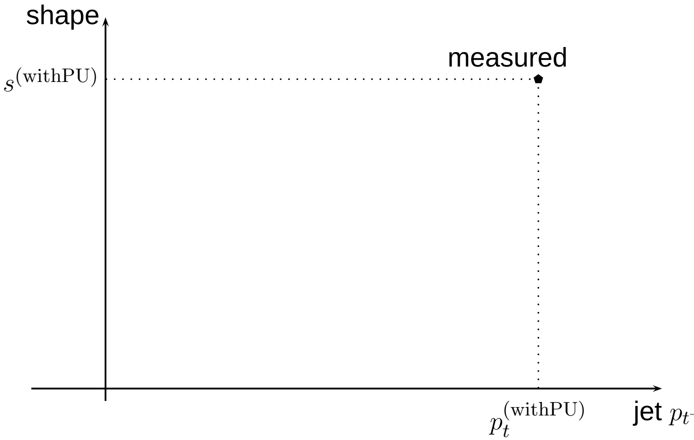
Pileup Subtraction for Jet Shapes

We can represent effects of pileup particles with a function of single variable, f(x), since the uniform background particles has no structure. Let's extrapolate $f(\text{pileup constituents}, x)|_{\text{hardjet}}$ for $x > 1$:

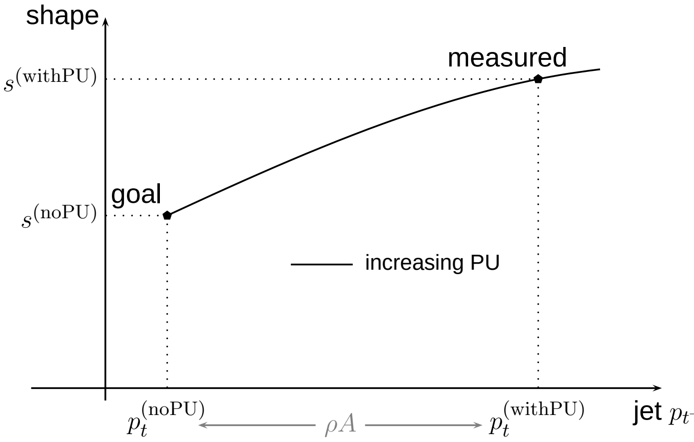
$$f(\text{pileup constituents}, x)|_{\text{hardjet}} \equiv f\big(\text{hard particle constituents} \\ \oplus \text{pileup particle constituents} \oplus (x-1) * \text{uniform bkg. particles}\big)$$

Since we know f(x) in a range $x \in [1, \infty)$, we can derive $f'(x)|_{x=1}, f''(x)|_{x=1}, \cdots$. Thus, we get f(0), approximately.

Pileup Subtraction for Jet Shapes



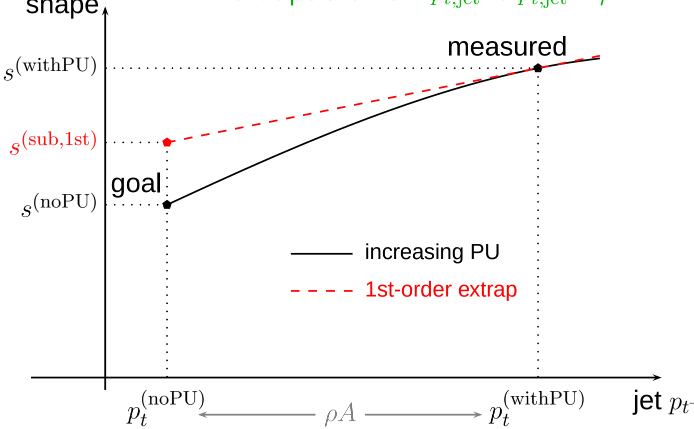
Pileup Subtraction for Jet Shapes



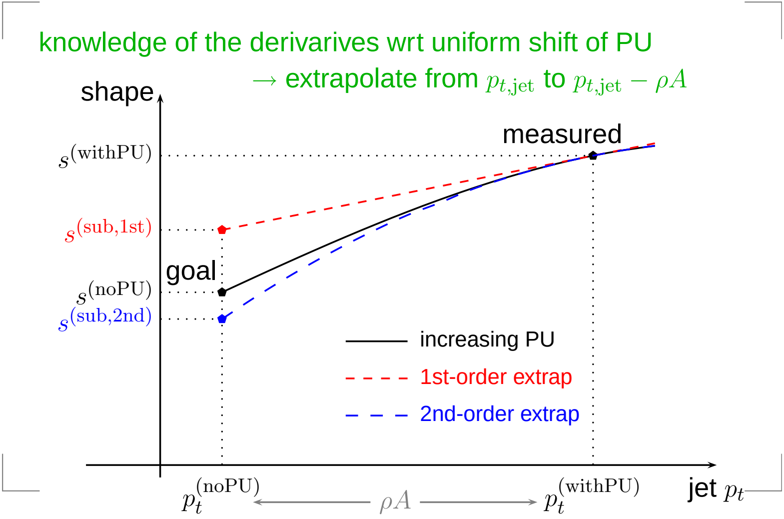
Pileup Subtraction for Jet Shapes

knowledge of the derivarives wrt uniform shift of PU

$\rightarrow$ extrapolate from $p_{t,\text{jet}}$ to $p_{t,\text{jet}} - \rho A$

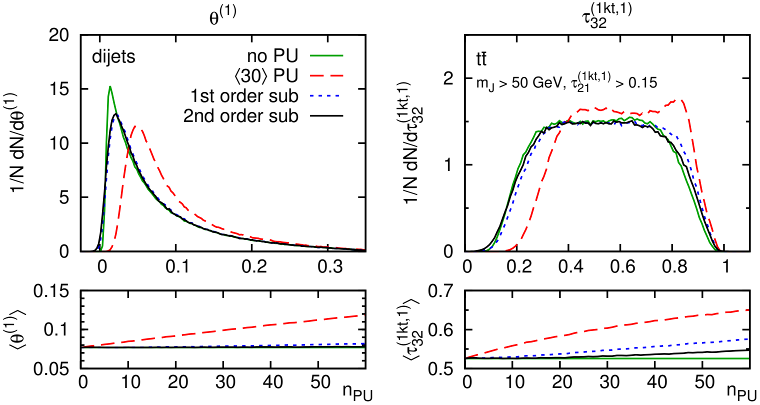


Pileup Subtraction for Jet Shapes



Pileup Subtraction for Jet Shapes in Action

Angularity and N-subjettiness ratio



Summary

- Employ simple, uniform models for pileup events.
  Rapidity dependence is also included.
- Pileup events affects jet clustering(back-reaction);
  but it is small effects.
- Pileup density and jet area is used to pileup subtraction for jet shapes.
- Pileup subtraction technique works well for many jet shapes.

For future works,

- Systematic uncertainty of the pileup subtraction of jet shapes?
- An improved pileup event modeling?