Pileup Subtraction for Jet Shapes

Ji-Hun Kim
IPhT, CEA-Saclay, France

Many QCD studies and BSM studies involve hadron jets. For those studies, we need to precisely measure jet shapes such as jet mass, jet transverse momentum and angularity. Pileup events, however, significantly degrade jet shape measurements at the hadron collider experiments. In this talk, we introduce a general method to correct for pileup effects in jet shapes, which acts event-by-event and jet-by-jet, and accounts also for hadron masses.

1 Introduction

Colored partons radiate to produce soft and collinear quarks and gluons which evolve to a numerous hadrons collimated along some directions, so called hadron jets. Jet algorithms are for grouping them. Among them, inclusive kT, Cambridge/Aachen, Anti-kT, and SISCone jet algorithm are infrared and collinear safe and popular. Many QCD studies and BSM studies involve hadron jets, we need to precisely measure jets. At the LHC, however, signal events of our interest come together with lots of pileup events.

The effect of pileup events is a challenging issue for measuring hadron jets. When two protons are crossed at the LHC, nothing happened for most of times. Proton-proton collision events are extremely rare events. Furthermore, Hard events are even orders of smaller than that, *i.e.* $1 \gg p_{\text{soft}} \gg p_{\text{hard}}$. When two protons collide head-on, nothing would happen most of time. It's why LHC accelerate and collide not individual protons, but proton bunches. And each bunch contains more than 10^{11} protons. Whenever we see hard collision event, the law of rare events implies that it is likely to accompany additional events, which are likely to be soft, so called pileup events. At the 2012 run of LHC, the expected number of pileup events is about 30. They produce numerous low energy particles and affect jet clustering procedure. Due to the limitation of detector resolutions, we cannot identify and remove pileup particles; in effect, amount of pileup particle is a kernel, and measured jet shapes are convoluted by the kernel. The effects of pileup is mainly divided into two categories : it introduces biases to the jet shape measurements and also increases variance of uncertainties of the jet shape measurements.

One of method to reduce the pileup effects is defining an area of hadron jet [1] and using a simplified pileup model to correct pileup contribution to a jet transverse momentum [2]. Experiments including ATLAS and CMS have used this method and it is known to be almost remove the biases and also reduce the variances. However, this method is, by definition, only applicable to a jet transverse momentum.

Main contribution of this talk is extending the pileup subtraction method to be applicable to general jet shapes[3].

2 A Simplified Model of Pileup Events.

Although each pileup event is non-uniform, pileup events as a whole are roughly uniform since they are union of independent collisions. Pileup particles are evenly distributed over azimuth angle, ϕ, and nearly uniformly distributed over rapidity, y. With these assumptions, pileup particles can be modeled with a number density of pileup particle, ν, and a probability function for their p_T spectrum. Then, p_T-sum of pileup particles are propotional to jet area[1]:

$$\langle P_{\text{pileup}}(p_T|A)\rangle = A\langle\nu\rangle\langle p_T^{\text{pileup}}\rangle \equiv \rho A \tag{1}$$

$$\langle P_{\text{pileup}}(p_T)\rangle = \int dA \; P(A) \; \rho A = \rho\langle A\rangle. \tag{2}$$

A p_T density, $\rho = \langle\nu\rangle\langle p_T^{\text{pileup}}\rangle$, of pileup events can be measured for each event,

$$\rho = \underset{\text{patches}}{\text{median}}\left[\left\{\frac{p_{T\,\text{patch}}}{A_{\text{patch}}}\right\}\right]. \tag{3}$$

where patches are either jets with small radius or grids over the $\eta - \phi$ plane.

Four momentum can be written in terms of rapidity, azimuth angle, transverse momentum, mass. For a given jet area, rapidity and azimuth angle of four momenta sum of pileup particles in this model is fixed. And ρ gives transverse momentum. We introduce a parameter, ρ_m for accounting mass:

$$\rho_m = \underset{\text{patches}}{\text{median}}\left\{\frac{m_{\delta,\text{patch}}}{\text{patch}}\right\}, \tag{4}$$

where $m_{\delta,\text{patch}} = \sum_{i\in\text{patch}}\left(\sqrt{[b]m_i^2 + p_{t,i}^2} - p_{ti}\right)$ and the sum runs over particles i in the patch.

Pileup events may affect jet clustering procedure; thus constituents of jets can be changed significantly. However, it is hard to take it account and we ignore this effect. In fact, it is found to be a good approximation for most cases. Since we ignore the back-reaction effect of pileup, a measured jet of constituents, $\{p^\mu\}_{\text{full}}$, is a union of a hard part of the jet, $\{p^\mu\}_{\text{hard}}$, and particles from pileup events, $\{p^\mu\}_{\text{pileup}}$.

3 Pileup subtraction for jet shapes.

A jet shape, f, is a function of the jet's constituents, $\{p^\mu\}_{\text{jet}}$, to a real number. What we can measure from experiments is a value of a jet shape, $f(\{p^\mu\}_{\text{full}}) = f(\{p^\mu\}_{\text{hard}} \cup \{p^\mu\}_{\text{pileup}})$, while what we want to measure is $f(\{p^\mu\}_{\text{hard}})$.

What can we do for them to reduce pileup effects? The infra-red and collinear safety of jet shapes has a critical role in here. Jet shapes are insensitive to how low energy jet constituents are distributed inside the jet. Given the four momenta sum of pileup particles, we can split each pileup particles into a bunch of small p_T particles by using collinear safety, and re-distribute them uniformly and continuously inside the jets by using infra-red safety. In case of the jet shape is infra-red and collinear safe, $f(\{p^\mu\}_{\text{full}})$ does not much depends on the exact form of $\{p^\mu\}_{\text{pileup}}$, and $f(\{p^\mu\}_{\text{full}}) \approx f(\{p^\mu\}_{\text{hard}} \cup \{p^\mu\}_{\text{uniform}})$, where $\{p^\mu\}_{\text{uniform}}$ represent background particles uniformly distributed inside the jet. For given $f(\{p^\mu\}_{\text{hard}}$ and a jet area, we define a function of a single variable $f_H(x) \equiv f(\{p^\mu\}_{\text{hard}} + x \times \{p^\mu\}_{\text{pileup}})$; *i.e.* $f_H(0)$ corresponds to the $f(\{p^\mu\}_{\text{hard}})$ and $f_H(1)$ is $f(\{p^\mu\}_{\text{full}})$. Although it is unknown that which subgroup of the jet constituents are comes from pileup, it is possible to add another uniform background to the jet to increase $\{p^\mu\}_{\text{uniform}}$. In this way, we can estimate $f_H(x)$ in a range of $x \in [1, \infty)$; thus we derive $f'(x)|_{x=1}, f''(x)|_{x=1}, \cdots$ and finally, we get $f_H(0)$. It is a brief summary for how the pileup subtraction for jet shapes works.

In Fig. 1(from [3]), we apply this pileup subtraction scheme with angularity, $\theta^{(1)}$, and N-subjettiness, τ_{21}. As expected, the pileup subtraction scheme reduce the effects of pileup events. In Fig. 2 (from[3]), we also apply this scheme for top quark tagging or quark/gluon discrimination.

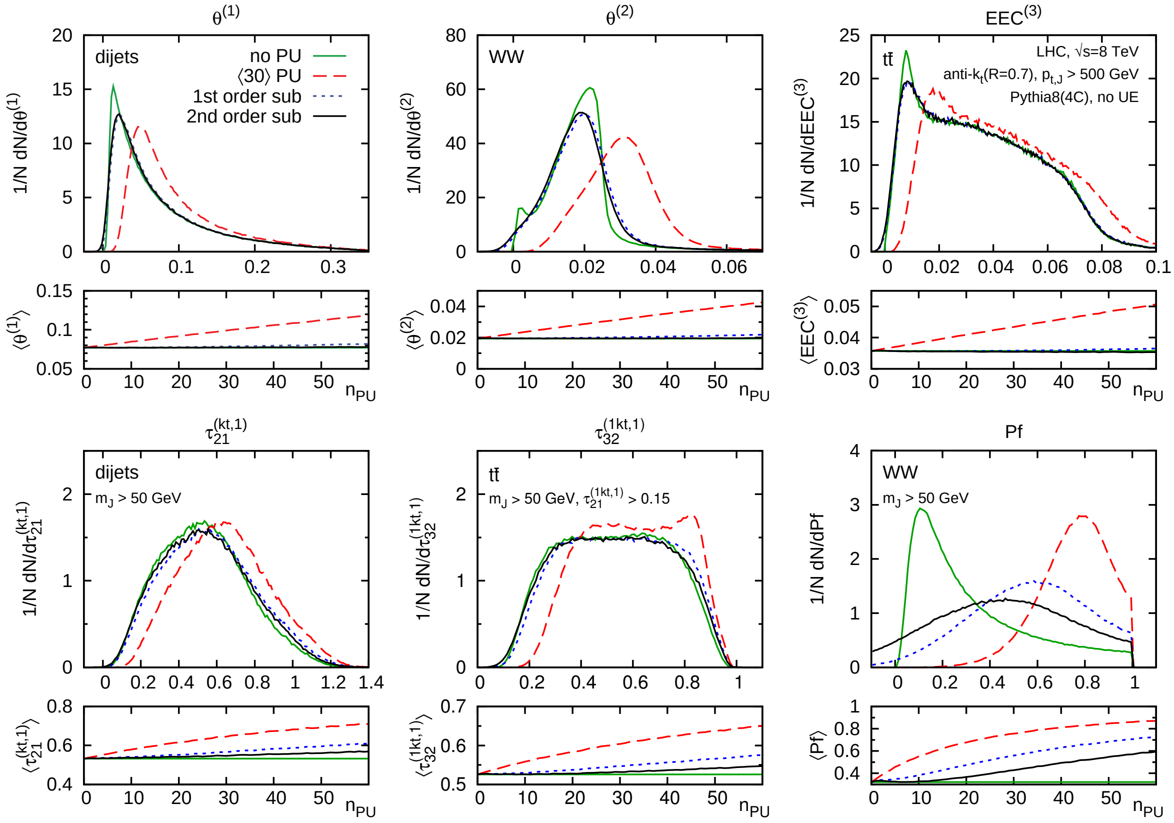

Figure 1: Impact of pileup and subtraction on various jet-shape distributions and their averages, in dijet, W W and tt production processes. The distributions are shown for Poisson distributed pileup (with an average of 30 pileup events) and the averages are shown as a function of the number of pileup events, nPU. The shapes are calculated for jets with $p_T > 500GeV$ (the cut is applied before adding pileup, as are the cuts on the jet mass mJ and subjettiness ratio τ_{21} where relevant).

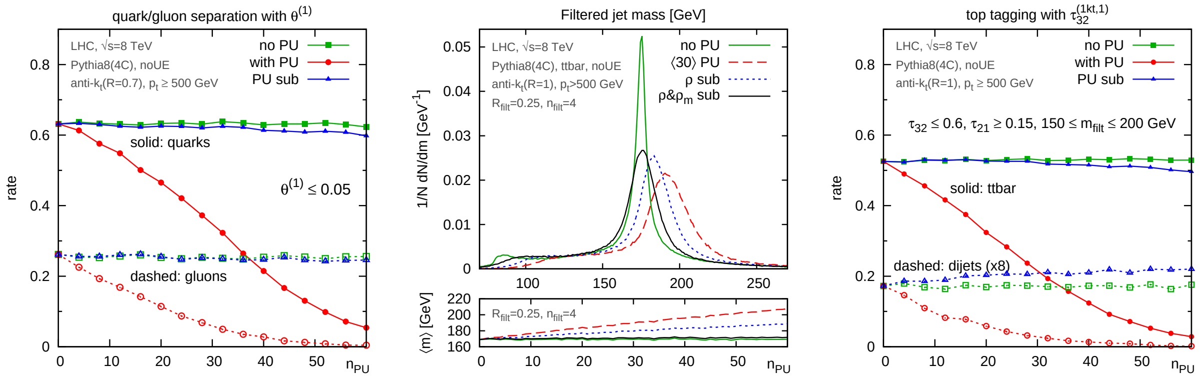

Figure 2: Left: rate for tagging quark and gluon jets using a fixed cut on the jet width, shown as a function of the number of pileup vertices. Middle: filtered jet-mass distribution for fat jets in $t\bar{t}$ events, showing the impact of the ρ and ρ_m components of the subtraction. Right: tagging rate of an N-subjettiness top tagger for $t\bar{t}$ signal and dijet background as a function of the number of pileup vertices. All cuts are applied after addition (and possible subtraction) of pileup. Subtraction acts on τ_1, τ_2 and τ_3 individually.

4 Conclusion

Using Pythia and Herwig simulation, we show that the pileup subtraction scheme works well for jet shape such as jet mass, transverse momentum, angularity, and N-subjettiness even in presence of up to 60 pileup events. On the other hands, some widely used jet shape including planar flow are not infra-red safe, and our subtraction scheme shows relatively poor performance. We hope this progress will help ensure the viability of a broad range of jet substructure tools in high-luminosity LHC running. The software for the general shape subtraction approach presented here will be made available as part of the FastJet Contrib project [4].

References

1. M. Cacciari, G. P. Salam and G. Soyez, "The Catchment Area of Jets," JHEP **0804** (2008) 005 [arXiv:0802.1188 [hep-ph]].
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3. G. Soyez, G. P. Salam, J. Kim, S. Dutta and M. Cacciari, "Pileup subtraction for jet shapes," arXiv:1211.2811 [hep-ph].
4. `http://fastjet.hepforge.org/contrib`