Jet Cleansing: Pileup Mitigation at High Luminosity

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arxiv:1308.soon

Outline

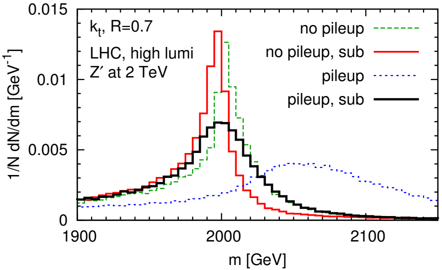
- Current Methods for Pileup
- Jet Cleansing Technique
- Demonstration of Jet Cleansing
- Conclusions

Current Pileup Techniques

- Subtraction [Cacciari, Salam; arxiv:0707.1378]

$$p_T^{(\text{sub})} = p_T - \rho A$$

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



- Grooming
  - Filtering (+ Mass Drop) [Butterworth, Davison, Rubin, Salam: arxiv:0802.2470]
  - Pruning [Ellis, Vermilion, Walsh; arxiv:0903.5081, arxiv:0912.0033]
  - Trimming [Krohn, Thaler, Wang; arxiv:0912.1342]

Current Pileup Techniques

Current techniques work very well!

- Subtraction used in 100+ ATLAS/CMS papers (including Higgs).
- Grooming successively removes pileup effects.

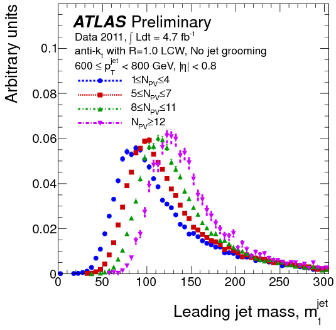


Figure: Pre-grooming

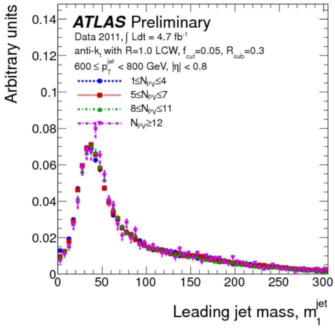
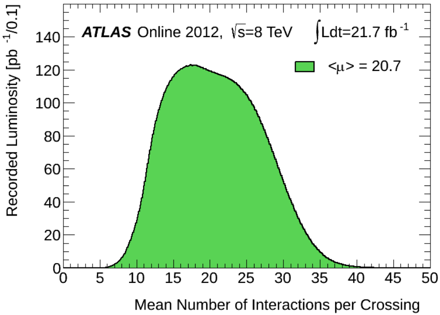
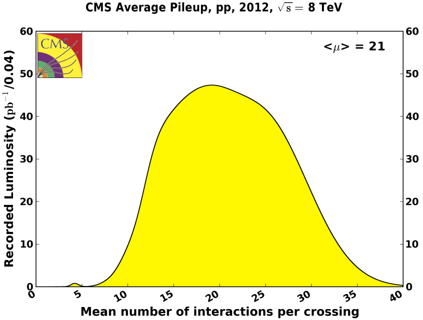


Figure: Post-grooming

Current Pileup Techniques

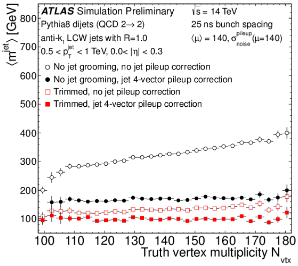
Current pileup levels have been $\langle\mu\rangle = 21$.





We may need to be able to do physics at $\langle\mu\rangle = 140$!

Future Pileup



- Current plots mostly show restored *mean* of distributions.
- We can go further and look event-by-event (at high pileup).

- Look at correlations between truth (FSR/ISR/MI) and corrected jets.

$$\rho_{12} = \frac{E[(m_1 - \mu_1)(m_2 - \mu_2)]}{\sigma_1 \sigma_2}$$

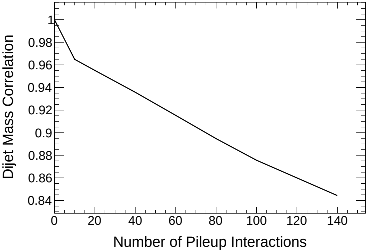
$$-1 \leq \rho_{12} \leq 1$$

Future Grooming

- Grooming is not invariant with respect to pileup.
- Example: Dijet mass resonance to light quarks (color singlet scalar with $m = 500$ GeV).
- Details: 13 TeV, Pythia 8: default tune, jets clustered with anti-k_T ($R = 1.0$), subjets clustered with k_T ($R = 0.3$).

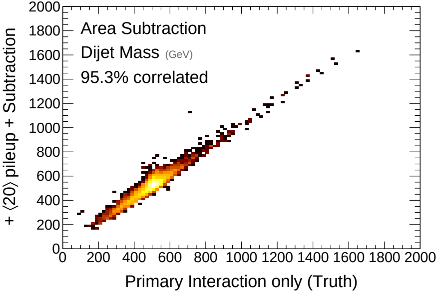
- Look at correlations between truth (FSR/ISR/MI) and corrected jets.

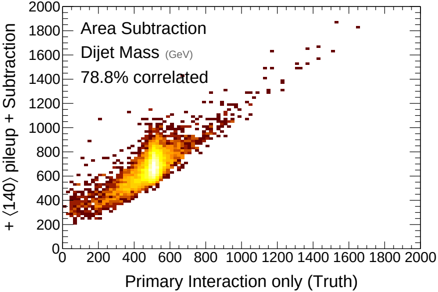
$$\rho_{12} = \frac{E[(m_1 - \mu_1)(m_2 - \mu_2)]}{\sigma_1 \sigma_2}$$



Future Subtraction

- Subtraction will be challenged at high pileup. Shown are 20 pileup events (left) and 140 pileup events (right).





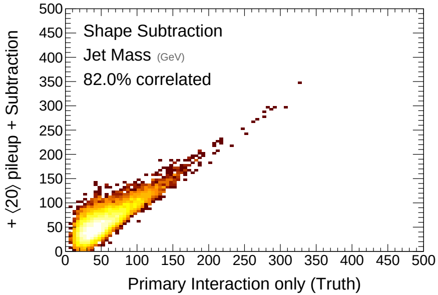
- Subtraction approximates pileup with uniform density.
- Depends on properties of event.
- Is a kinematic correction.

Future Shape Subtraction

- Jet shapes can also be subtracted [Soyez, Salam, Kim, Duta, Cacciari; arxiv:1211.280110]

$$V_{\text{jet,sub}} = V_{\text{jet}} - \rho V_{\text{jet}}^{[1]} + \frac{1}{2}\rho^2 V_{\text{jet}}^{[2]} + \ldots$$

- Computed separately for each observable. Shown are 20 pileup events (left) and 140 pileup events (right).



Future Pileup Conditions

Would be nice to have a pileup technique that

- is observable independent.
- does not degrade with amount of pileup.

There is additional information we can use.

- Subtraction cleverly uses the rest of the event.
- Information from tracker can be used to identify charged particles.
- Tracking can distinguish pileup from the leading primary vertex (PV).

Jet Cleansing – Algorithm

- Cluster cells into jets (only jets with $|\eta| < 2.5$).
- Recluster cells into subjets. Convert tracks (with $p_T > 0.5$ GeV) into ghosts and include in clustering.
- Rescale *constituents* in subjets $p^\mu \to \lambda p^\mu$, where $\lambda = \lambda(\text{calo cells}, \text{PV tracks}, \text{pileup tracks})$.
- Reassemble subjets into cleansed jet.

What should the scaling factor be?

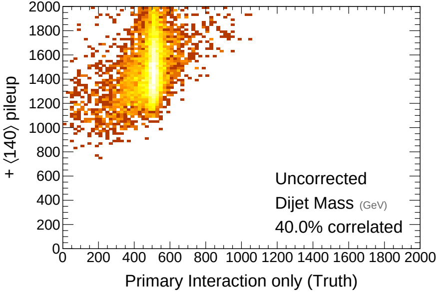
- Calorimeter measures $p_T(\text{PV}) + p_T(\text{pileup})$, but we want $p_T(\text{PV})$.
- Simplest scaling factor would be

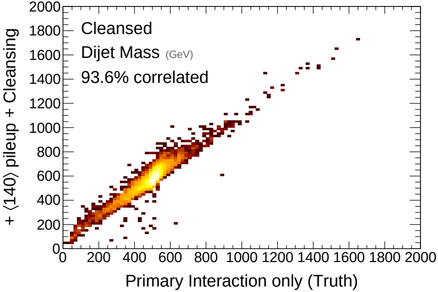
$$p^\mu \to p^\mu \times \left(\frac{p_T^C(\text{PV})}{p_T^C(\text{PV}) + p_T^C(\text{pileup})} \right)$$

- This approximates charge-to-all ratio as constant for primary vertex and pileup.

Jet Cleansing – Demonstration

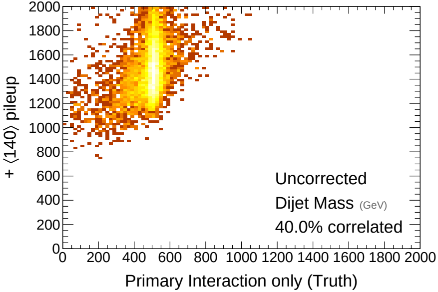
- Look at correlations between truth and corrected jets.
- Shown below with 140 pileup events.
- Cleansing returns jet very close to uncontaminated state.

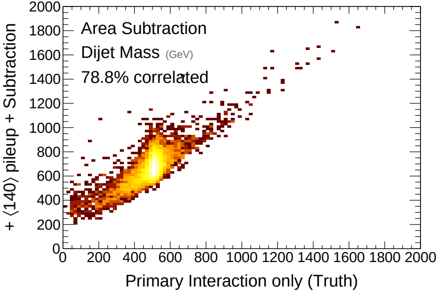




Jet Cleansing – Demonstration

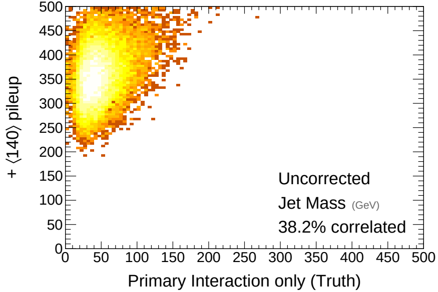
- Look at correlations between truth and corrected jets.
- Shown below with 140 pileup events.
- Subtraction *alone* does not perform as well.

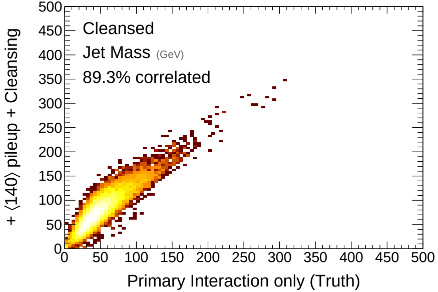




Jet Cleansing – Demonstration

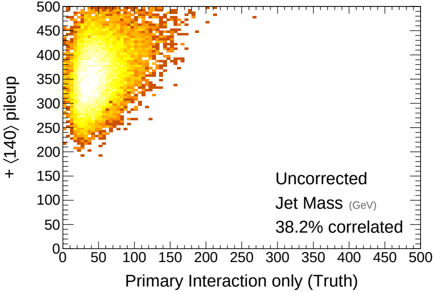
- Look at correlations between truth and corrected jets.
- Shown below with 140 pileup events.
- Cleansing can also do jet mass.

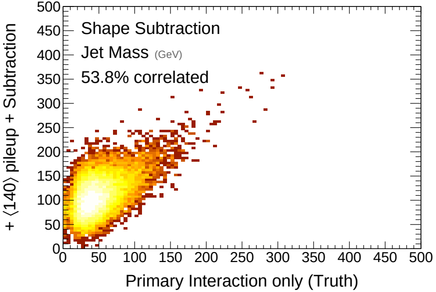




Jet Cleansing – Demonstration

- Look at correlations between truth and corrected jets.
- Shown below with 140 pileup events.
- Shape subtraction does not perform as well on QCD jet mass.





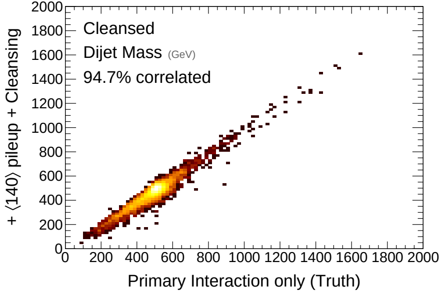
Jet Cleansing with Groomers

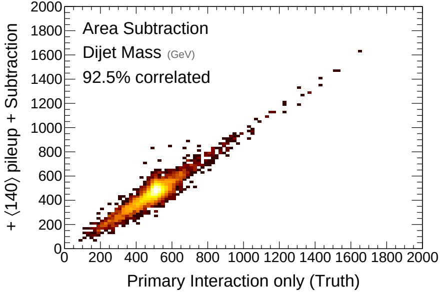
Cleansing (and subtraction) can be naturally applied with groomers (e.g. *trimming*).

- Cluster cells into jets.
- Recluster cells into subjets. Convert tracks into ghosts and include in clustering.
- Rescale *constituents* in subjets $p^\mu \to \lambda p^\mu$, where $\lambda = \lambda(\text{calo cells}, \text{PV tracks}, \text{pileup tracks})$.
- Only keep subjets with $p_{T,\text{sub}} > f_{\text{cut}} p_{T,\text{jet}}$.
- Reassemble subjets into cleansed jet.

Jet Cleansing + Trimming ($f_{cut} = 0.05$)

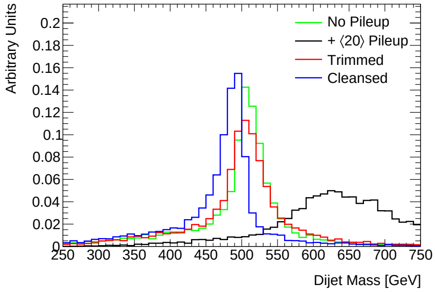
- Look at correlations between truth and corrected jets.
- Shown below with 140 pileup events.
- Pileup correction *and* grooming is very effective.

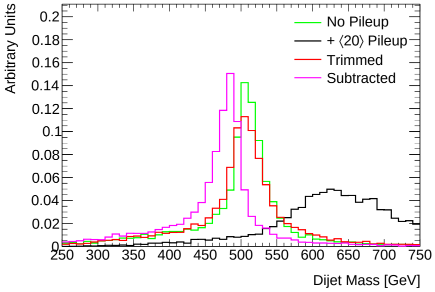




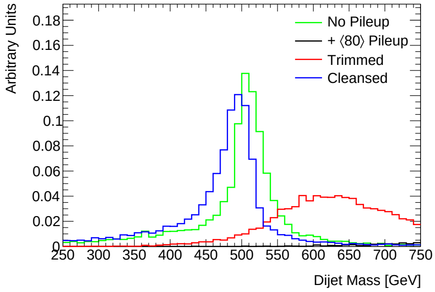
Jet Cleansing – Demonstration

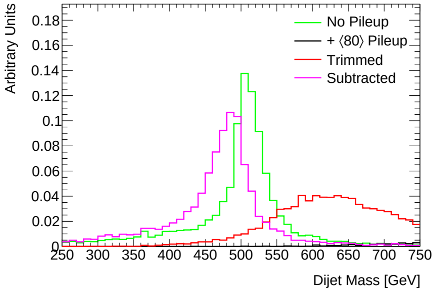
- Example: Dijet mass resonance to light quarks (color singlet scalar with $m = 500$ GeV).
- Shown below with 20 pileup events and $f_{\text{cut}} = 0.05$.





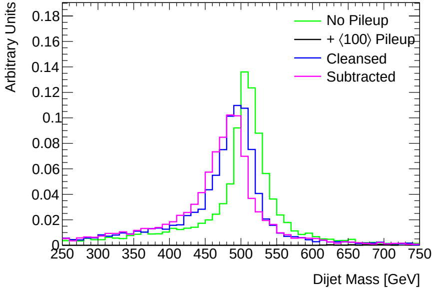
- Example: Dijet mass resonance to light quarks (color singlet scalar with $m = 500$ GeV).
- Shown below with 80 pileup events and $f_{\text{cut}} = 0.05$.

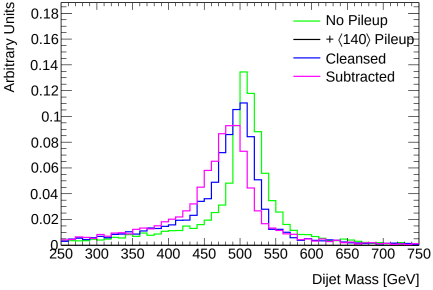




Jet Cleansing – Demonstration

- Example: Dijet mass resonance to light quarks (color singlet scalar with $m = 500$ GeV).
- Shown below with 100 (left) and 140 (right) pileup events and $f_{\text{cut}} = 0.05$.





Data-Driven Jet Cleansing

- Let the charge-to-all ratio be

$$\gamma = \frac{p_T^C}{p_T}$$

- We can let PV and pileup have independent charge-to-all ratios

$$p^\mu \to p^\mu \times \left(\frac{\gamma_{pv}^{-1} p_T^C(\text{PV})}{\gamma_{pv}^{-1} p_T^C(\text{PV}) + \gamma_{pu}^{-1} p_T^C(\text{pileup})} \right)$$

$$p^\mu \to p^\mu \times \left(1 - \frac{\gamma_{pu}^{-1} p_T^C(\text{pileup})}{\gamma_{pv}^{-1} p_T^C(\text{PV}) + \gamma_{pu}^{-1} p_T^C(\text{pileup})} \right)$$

Data-Driven Jet Cleansing

- $$p^\mu \to p^\mu \times \left(1 - \frac{\gamma_{pu}^{-1} p_T^C(\text{pileup})}{\gamma_{pv}^{-1} p_T^C(\text{PV}) + \gamma_{pu}^{-1} p_T^C(\text{pileup})}\right)$$

$$p^\mu \to p^\mu \times \left(1 - \frac{p_T^C(\text{pileup})}{\gamma_{pu} p_T(\text{calo})}\right) \Rightarrow \boxed{p_T \to p_T - \frac{p_T^C(\text{pileup})}{\gamma_{pu}}}$$

- We take γ_{pu} as a constant ($\gamma_{pu} = 0.55$), but it can in principle be taken from data.
- All results shown in this talk with cleansing use this (the difference is a few percent).

Conclusions

- Current pileup mitigation techniques will be challenged at high pileup.
- By incorporating charged track information we can maintain performance at high luminosities $\rightarrow$ jet cleansing.
- Cleansing can be used in conjunction with trimming.
- Can use input from data for improvements to charged-to-all ratio value.