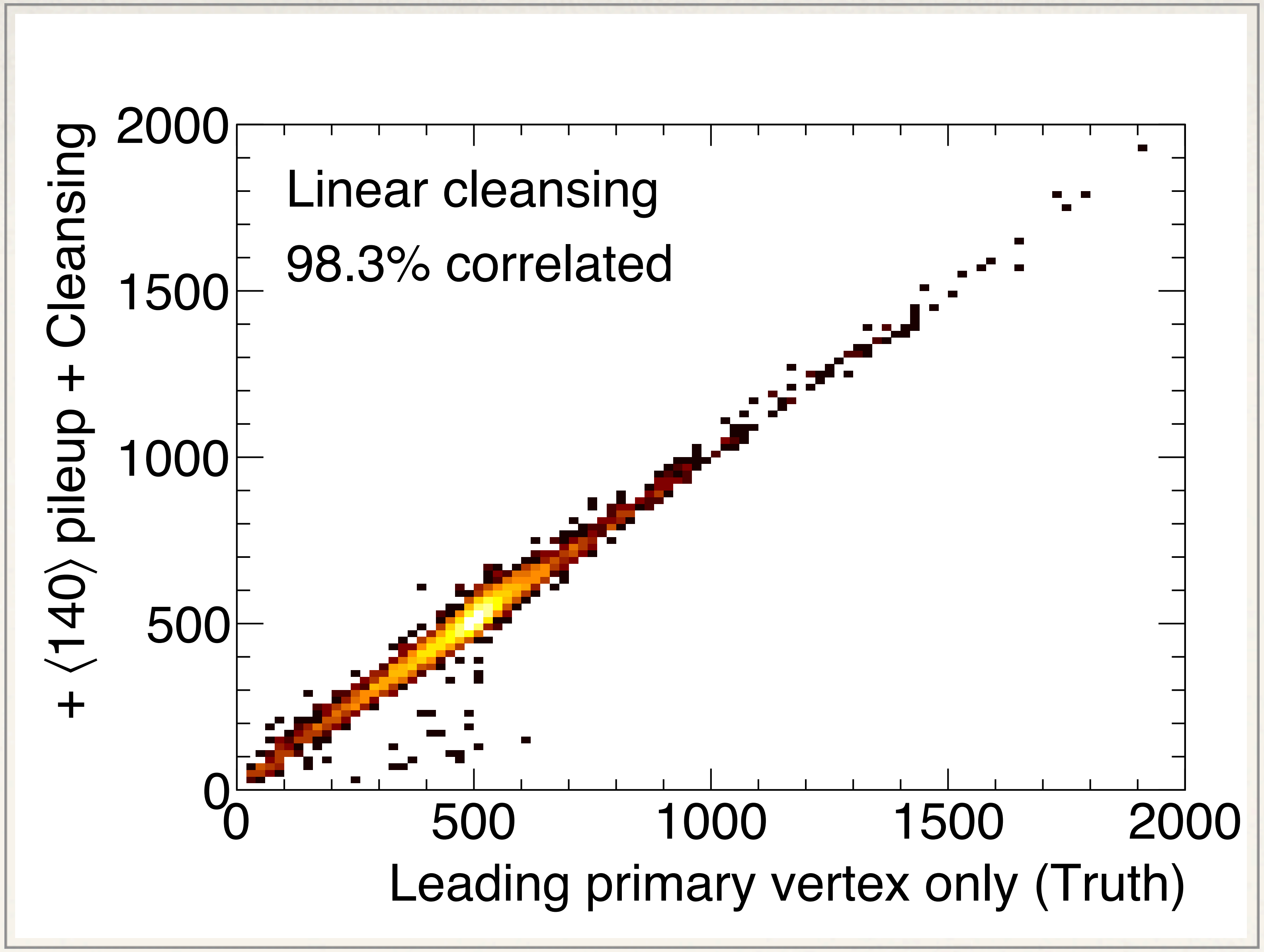


Jets and New Physics Searches

(at high luminosity)

David Krohn (Harvard)

ISMD 2013 - 9/19/13

Outline

- Observables sensitive to new-physics
- Pileup: a major challenge to their use at high luminosity
- Tools:
  - Subtraction
  - Grooming
  - **New**: *Jet Cleansing*

Takeaway

- No signs of BSM physics thus far
- Will have to go to higher luminosity / energy
- However, many jetty observables see significant performance degradation from pileup contamination
- Subtraction and grooming have proven very helpful, but may not be enough
- New techniques like jet cleansing can help!

Tools for jetty collider searches (I)

- Taggers: Top tagging, Higgs tagging, W-tagging, ISR Tagging
- Jet radiation patterns: template tagging, energy correlation fcns, N-subjettiness, planar flow

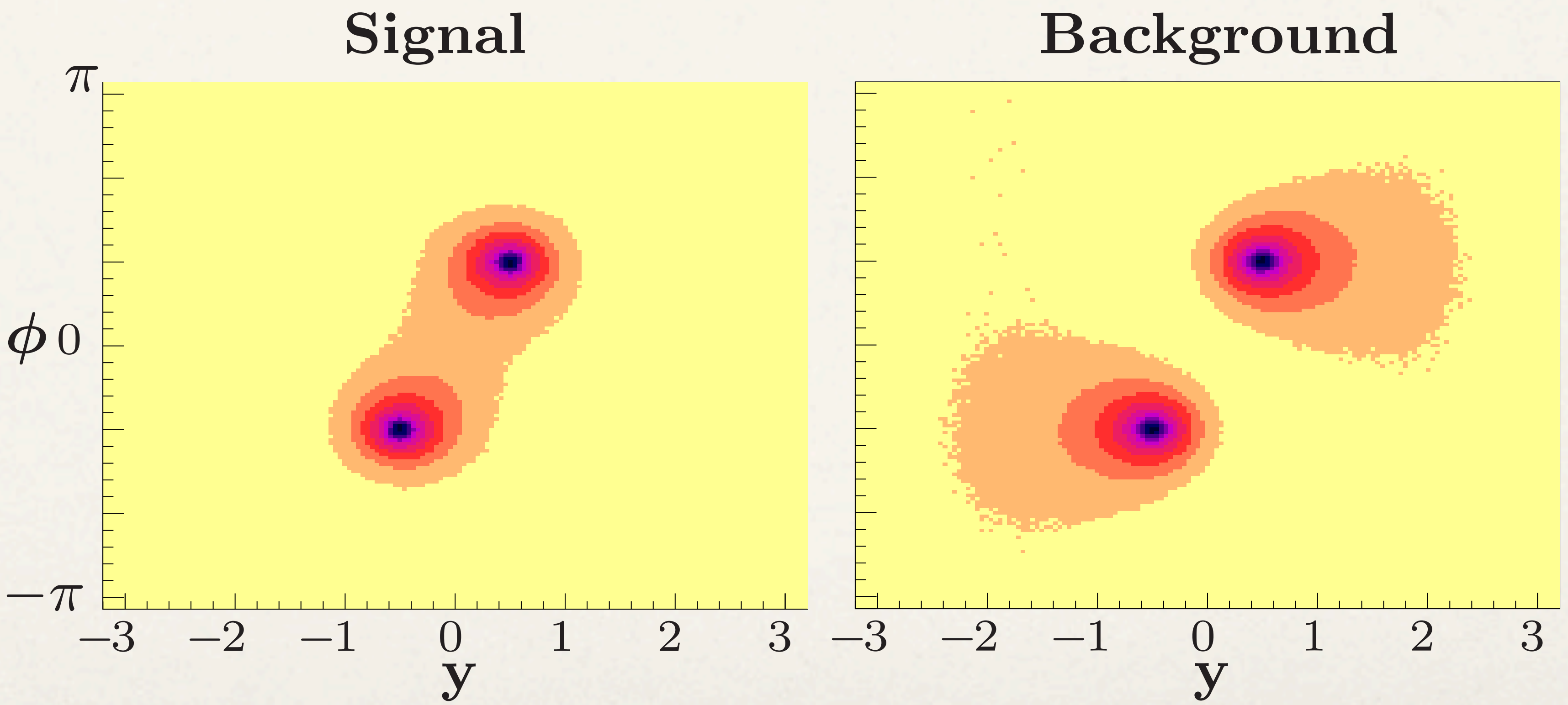
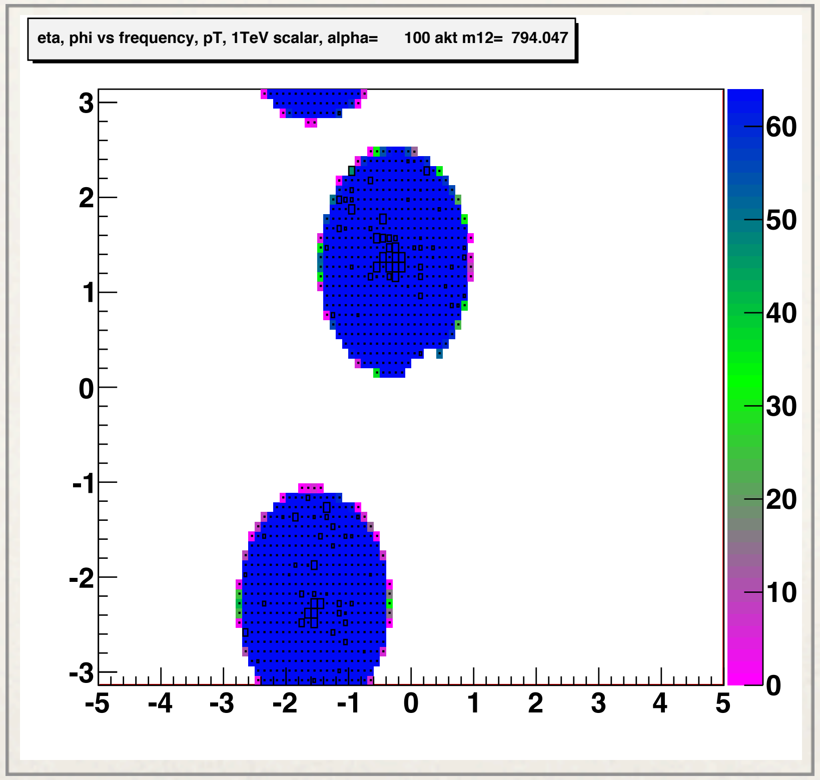


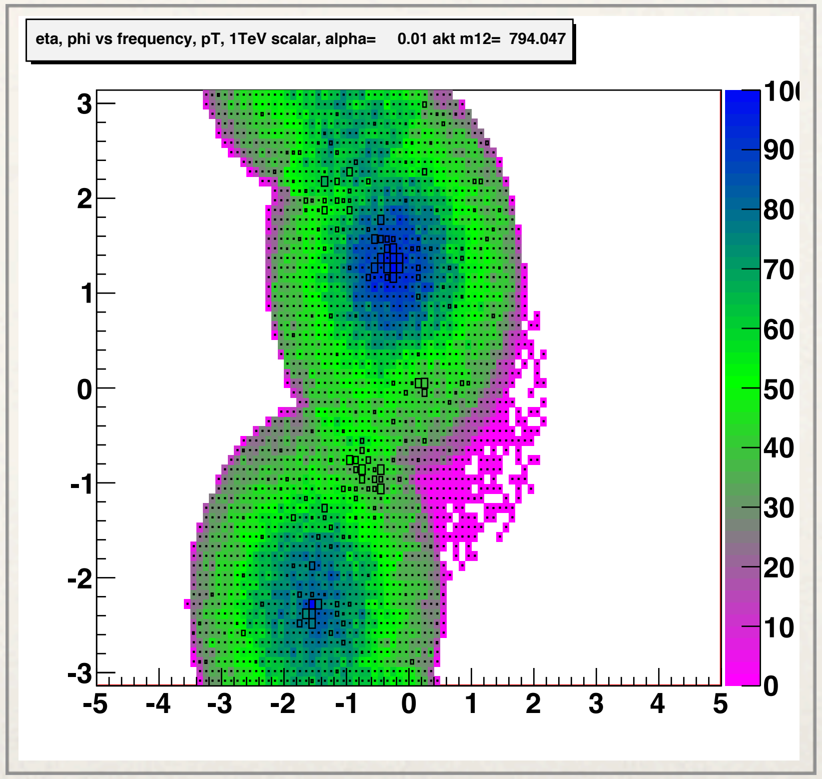
Figure: 1001.5027

Reviews: 0906.1833, 1112.4441, 1201.0008, 1302.0260

Tools for jetty collider searches (II)

- Detailed jet properties: color connections, quarks vs. gluons, jet charge, particle
- Powerful general-purpose techniques: Q-jets, Telescoping jets, high-multiplicity searches via fat jets





Pileup

$$\rho \sim \left(1 + \frac{N_{\mathrm{PU}}}{4}\right) \times (2 \leftrightarrow 3\ \mathrm{GeV})$$

- What is pileup?
  - Multiple collisions in the same bunch-bunch crossing.
- Why is it a problem?
  - For N_{PU}~100, pileup can completely wash things out many signals
  - We expect to encounter this level when the LHC turns back on

N-Subjettiness before and after pileup

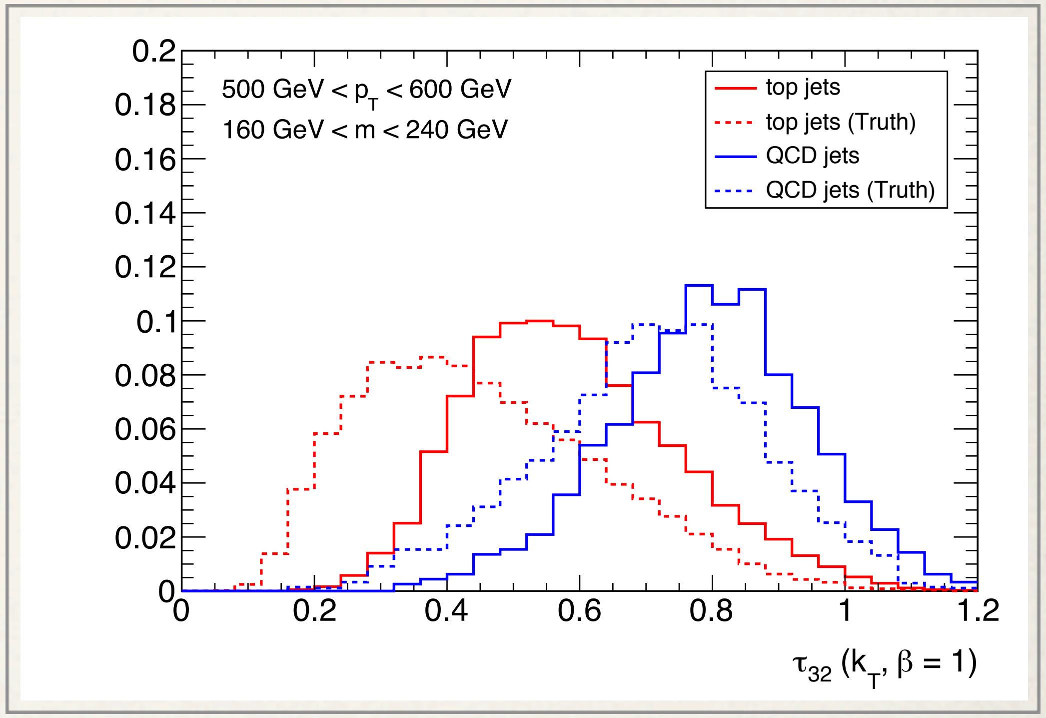
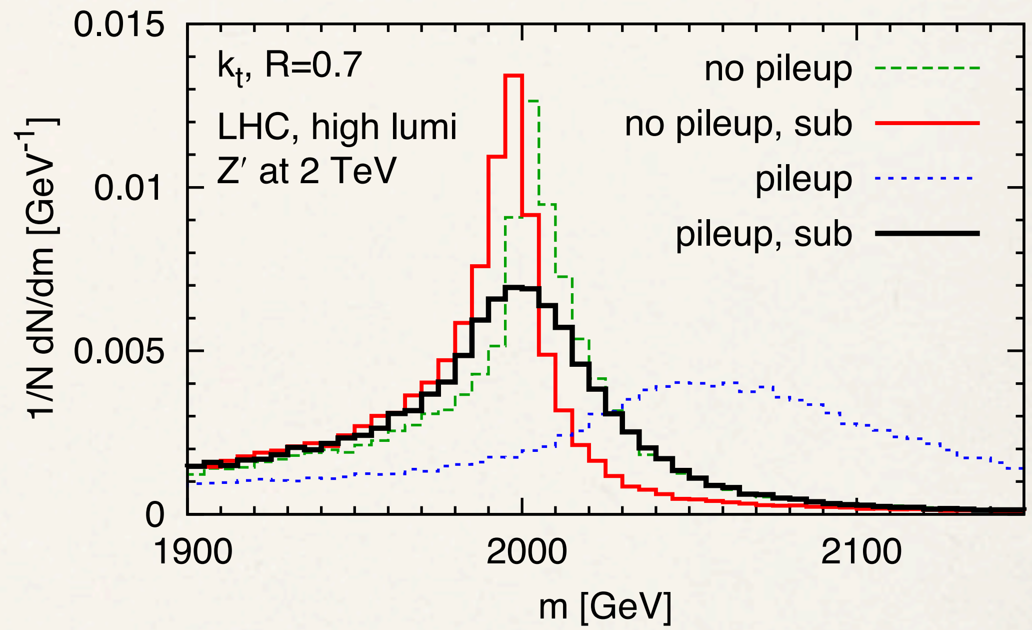
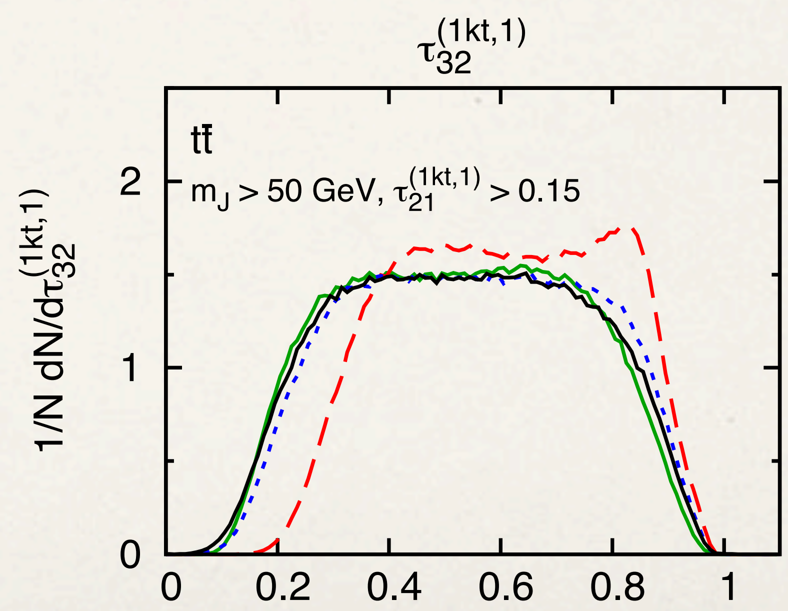


Figure: M. Low (UChicago)

Subtraction

- Assume uniform contamination per unit area of the detector
  - Measure this event by event
- Subtract off Area * pileup-density
- Can also work on jet shapes
  - Taylor series expansion of shape sensitivity to pileup





Figures: 0707.1378, 1211.2811

Grooming

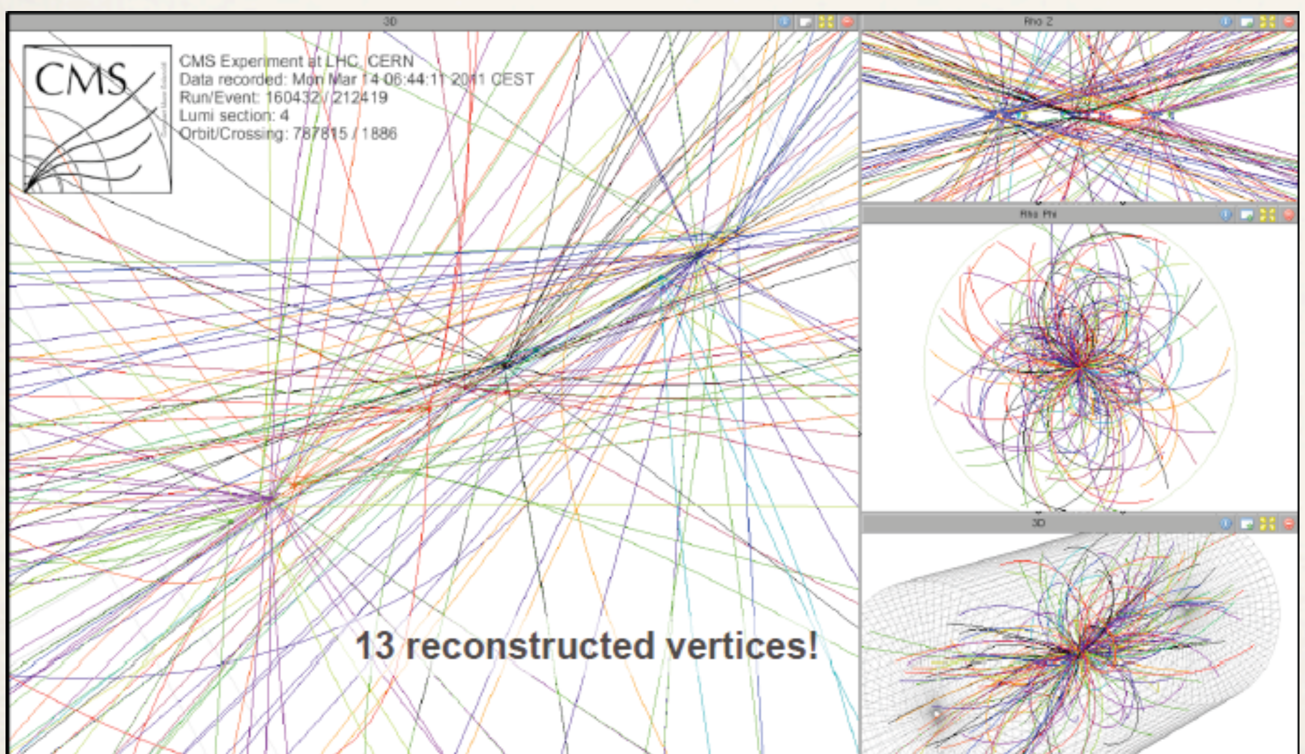
- Try to more actively distinguish contaminating radiation from signal
- Three main algorithms:
  - **Filtering**: Designed for boosted object decays where the number of hard partons is known
  - **Pruning**: Remove soft & wide angle mergings in parton shower to reduce the effects of contamination and lower QCD backgrounds.
  - **Trimming**: Designed for QCD jets from light partons. Keep all subjets above a threshold

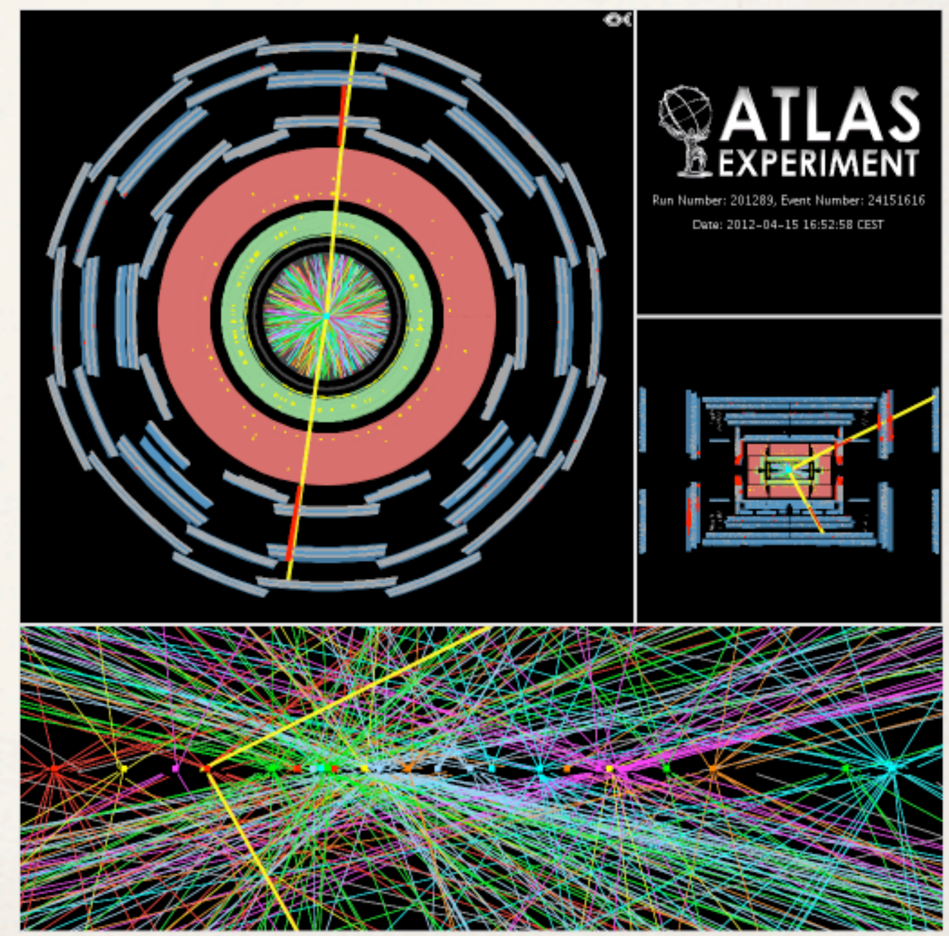
Pros and Cons

- **Subtraction**
  - Easily understood, can be used with any jet shape.
  - Assumption of uniform contamination misses local information.
  - Observables can take unphysical values if expansion parameter (PU density) too large.
- **Grooming**
  - Functions at a local level - no assumption of uniform pileup.
  - Can change the perturbative calculation.
  - Groomers can distort jet shape measurements if one is not careful.

Jet Cleansing

- It turns out that neither subtraction nor grooming take full advantage of the data from the detectors.
  - **What about charged tracks?**





Jet Cleansing, DK, M. Low, M. Schwartz, L.-T. Wang, on the arXiv tonight

Jet Cleansing

- **Basic idea: Subtract off charged particles from pileup, but also use these to rescale the neutral momentum.**

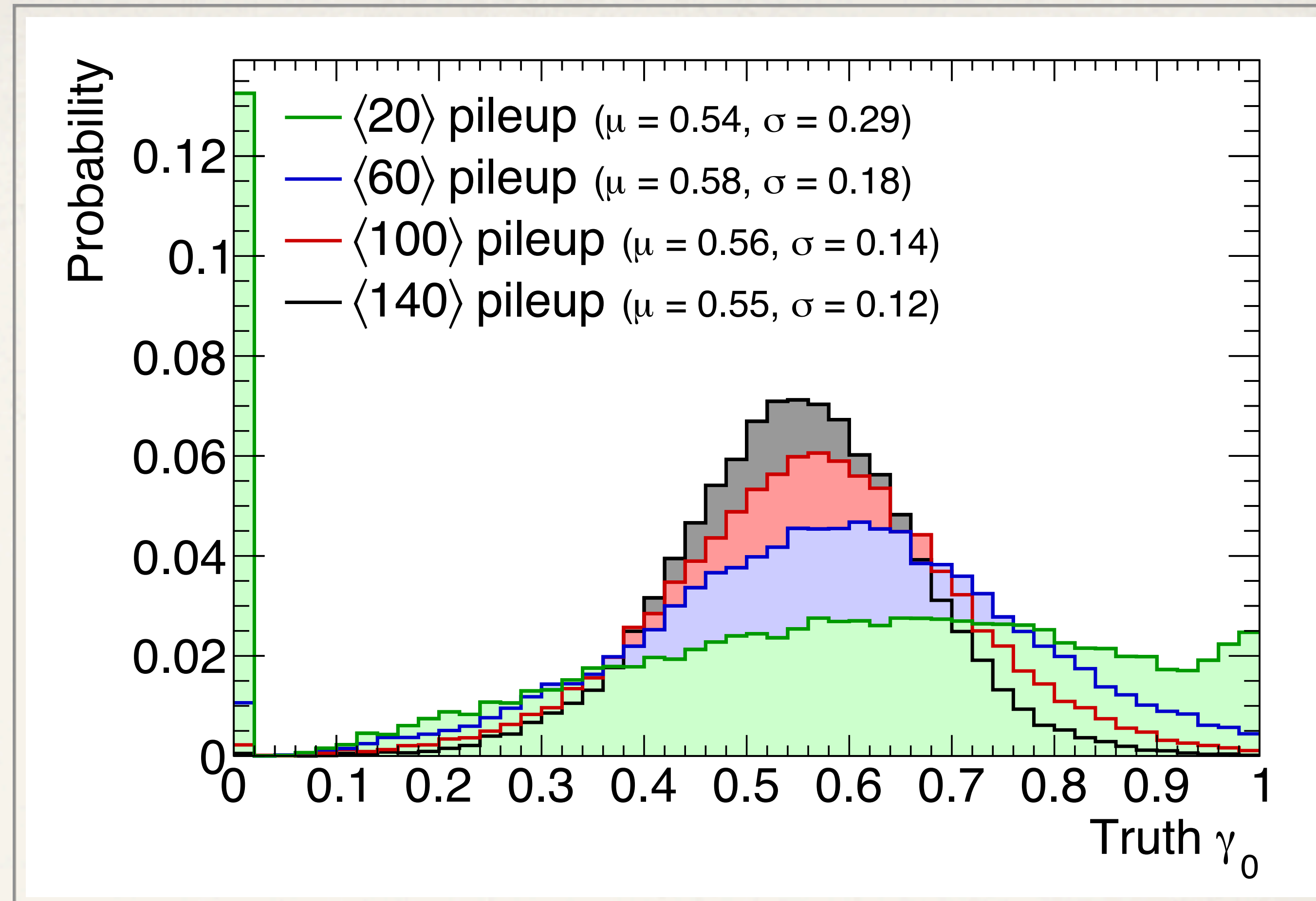
- Let γ be the charged to total p_T ratio in a subjet (γ_0 is for pileup, γ_1 is for the primary vertex)

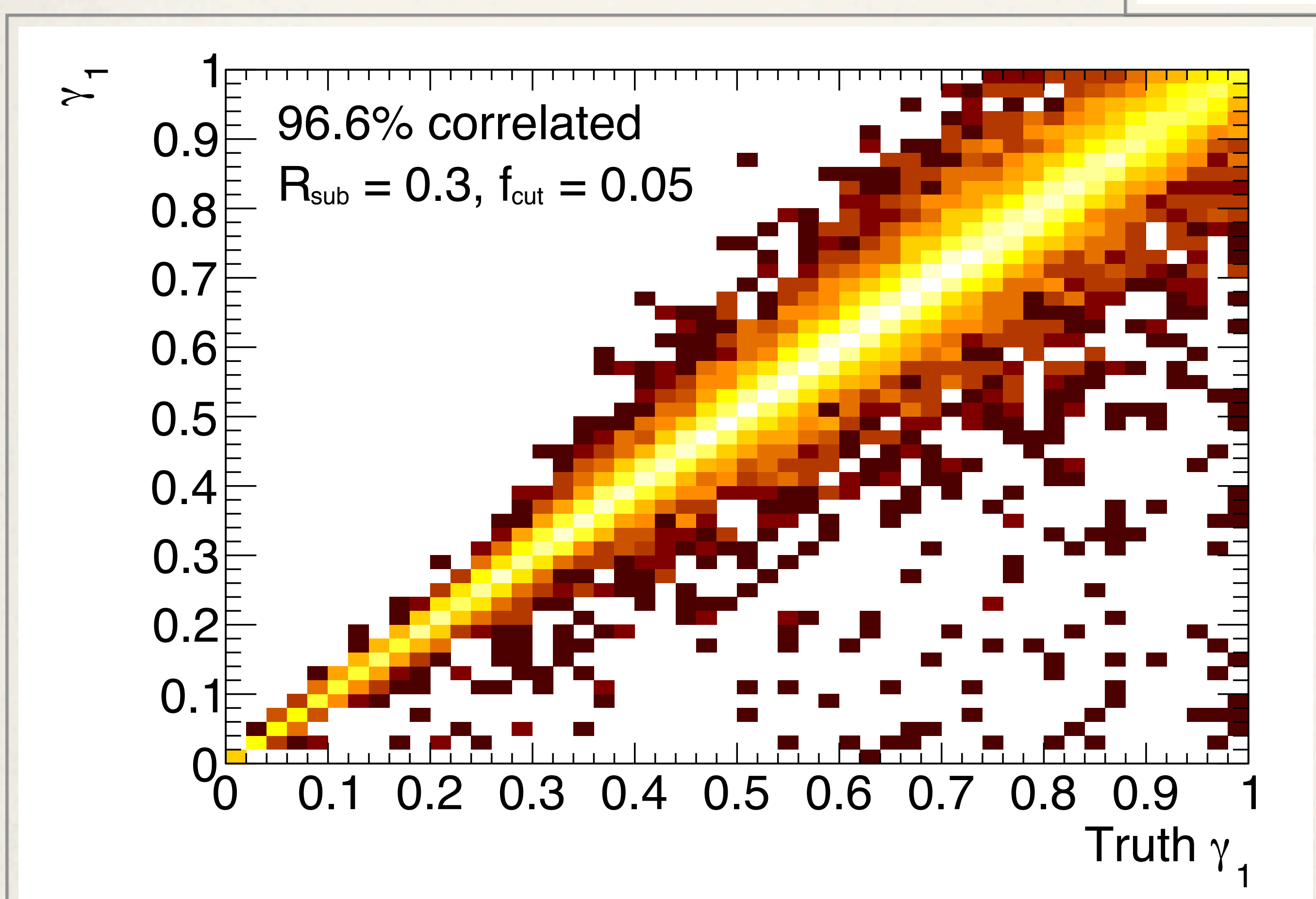
$$p_T^{\text{tot}} = \frac{p_T^{\text{C,PU}}}{\gamma_0} + \frac{p_T^{\text{C,LV}}}{\gamma_1}$$

- Once we have these two ratios the neutral rescaling is simple. In cleansing we present three ways of measuring this ratio:

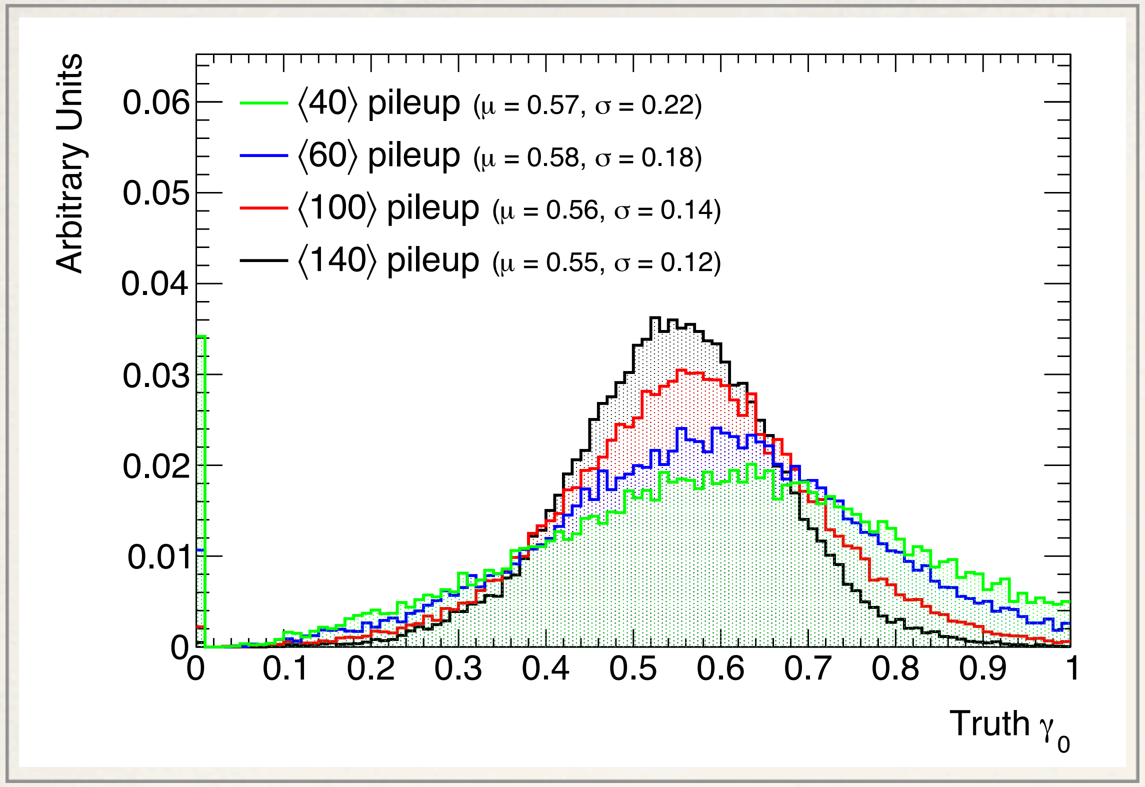
1. Assume it's the same for the primary vertex and for pileup
2. Assume that the pileup charged to neutral ratio is constant
3. Use some more sophisticated likelihood

As the pileup level increases the assumption of a constant charged to neutral ratio becomes more valid



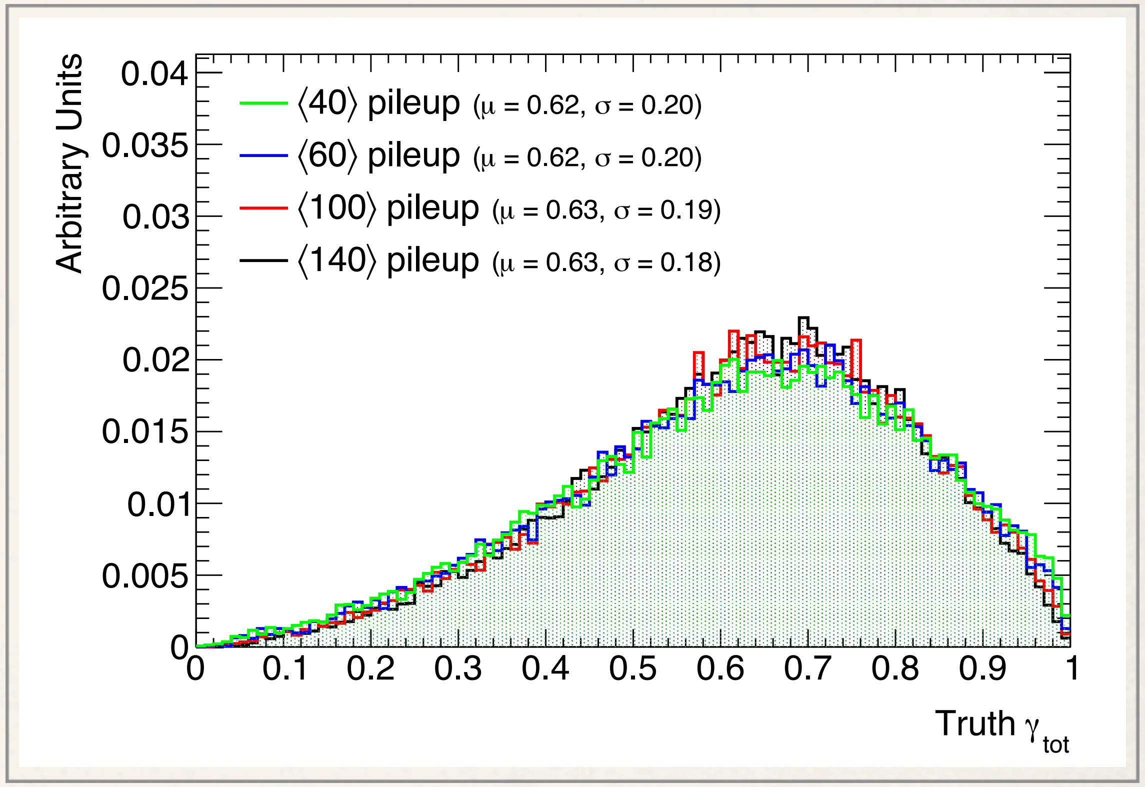


The inferred charged to neutral ratio using this naive guess is pretty accurate



Charged / total ratio for pileup

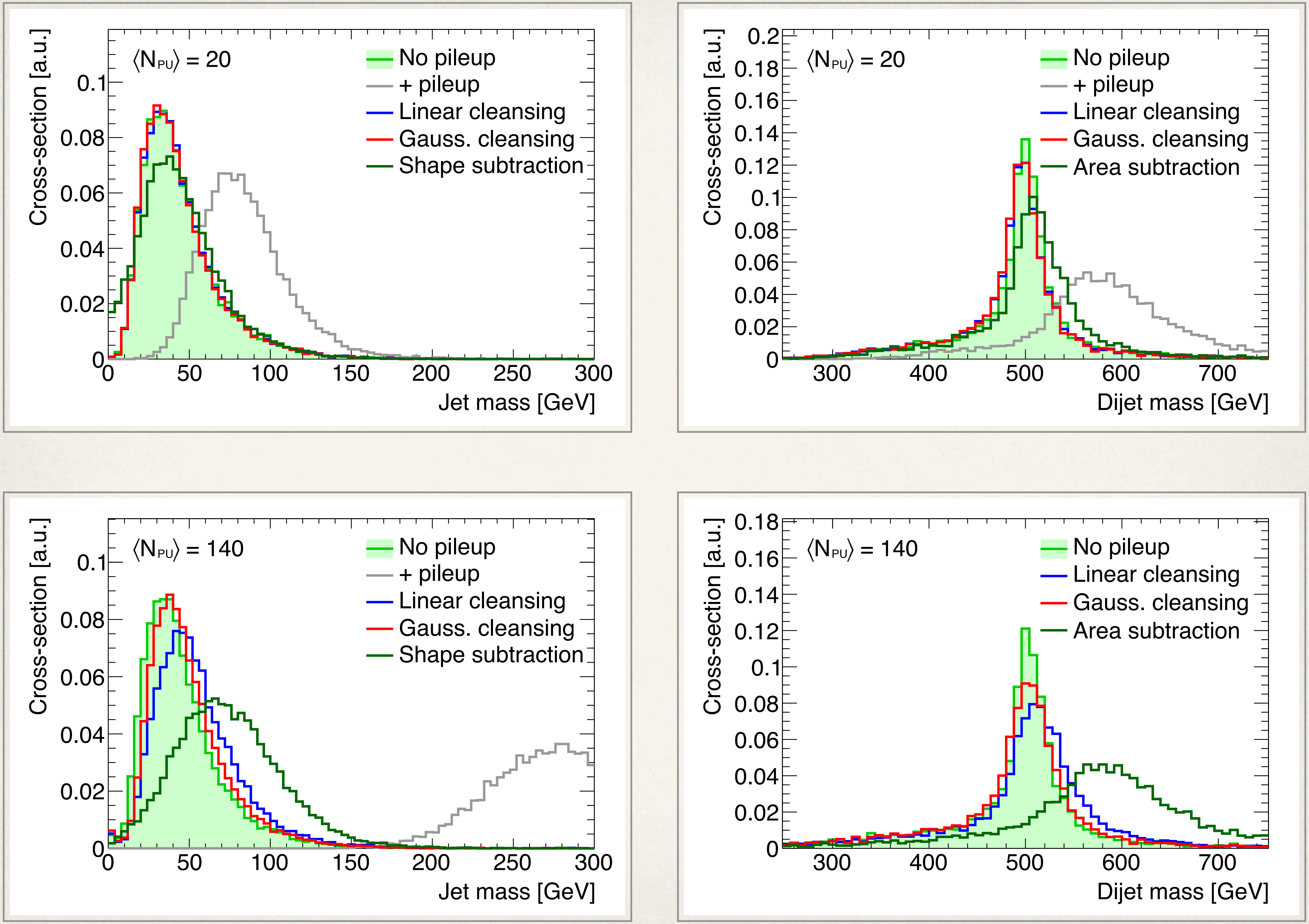
Charged / total for the leading vertex

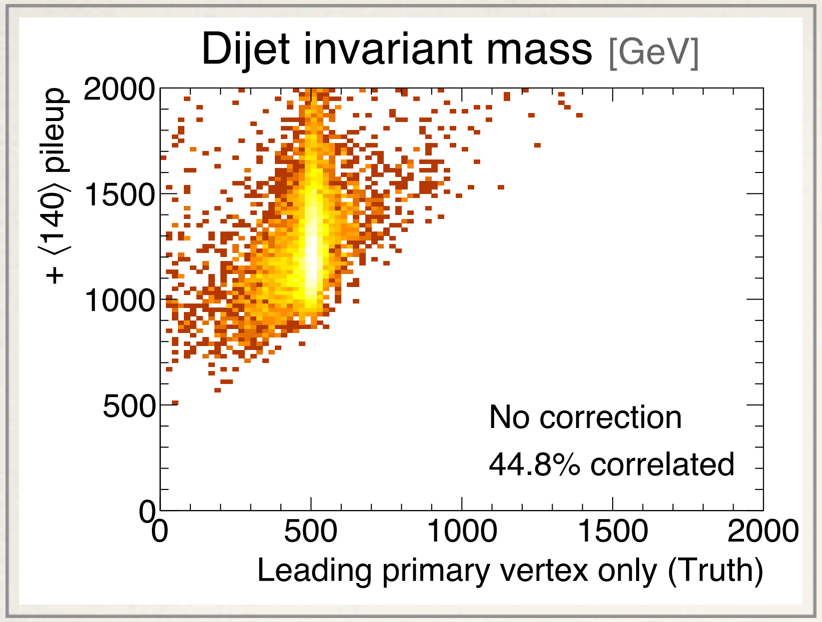


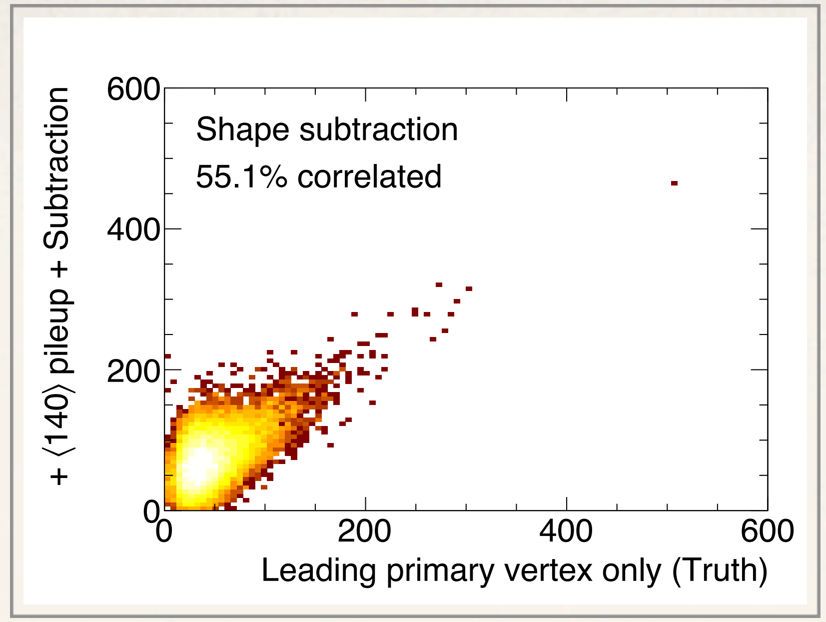
"Gaussian Cleansing"

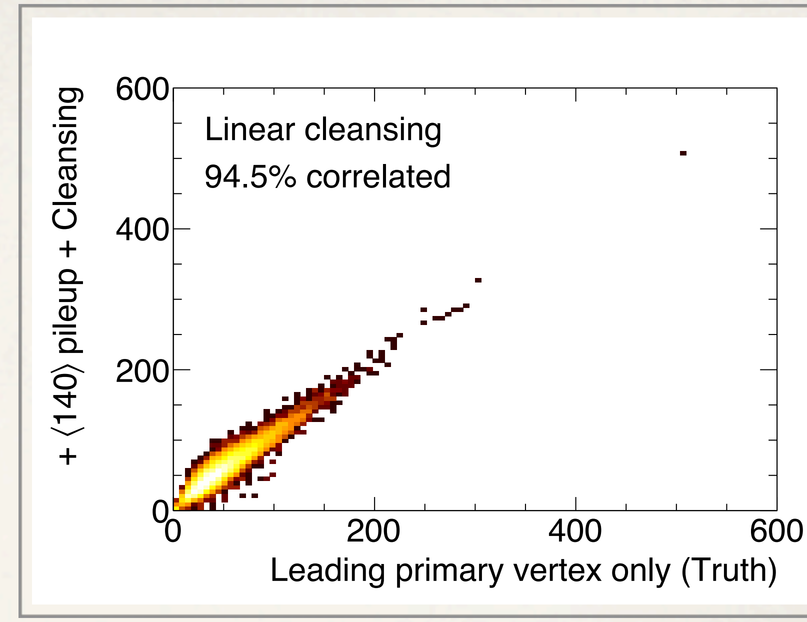
Approximate the combined distribution with two Gaussians:

$$P(\gamma_0, \gamma_1) \propto \exp\left[-\frac{1}{2}\sum_{i=0,1}\left(\frac{\gamma_i - \overline{\gamma_i}}{\sigma_i}\right)^2\right]$$


⟨N_PU⟩ = 20
No pileup
+ pileup
Linear cleansing
Gauss. cleansing
Shape subtraction
Cross-section [a.u.]
Jet mass [GeV]
⟨N_PU⟩ = 20
No pileup
+ pileup
Linear cleansing
Gauss. cleansing
Area subtraction
Cross-section [a.u.]
Dijet mass [GeV]
⟨N_PU⟩ = 140
No pileup
+ pileup
Linear cleansing
Gauss. cleansing
Shape subtraction
Cross-section [a.u.]
Jet mass [GeV]
⟨N_PU⟩ = 140
No pileup
Linear cleansing
Gauss. cleansing
Area subtraction
Cross-section [a.u.]
Dijet mass [GeV]



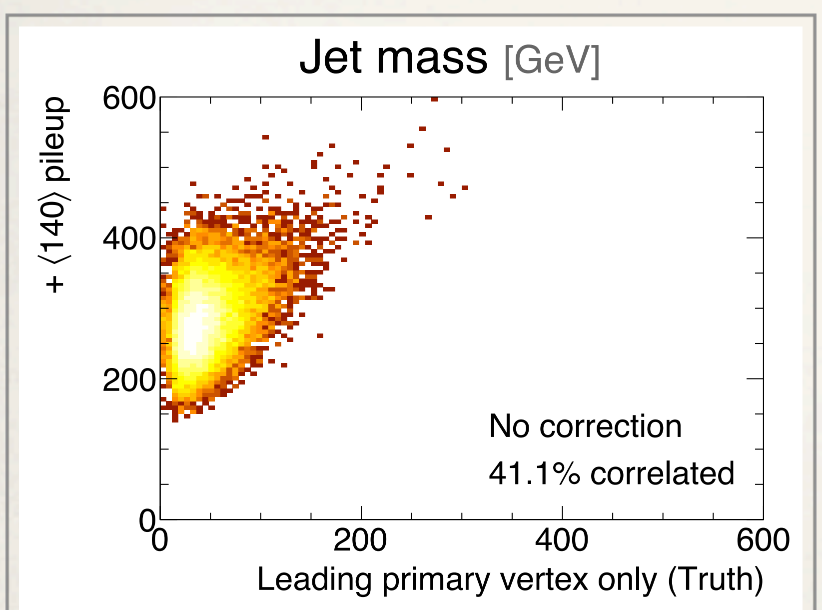


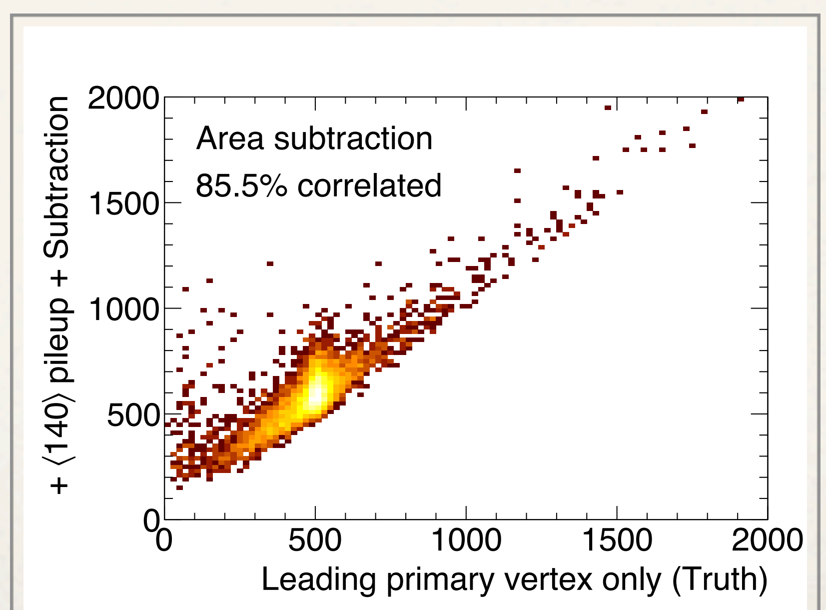


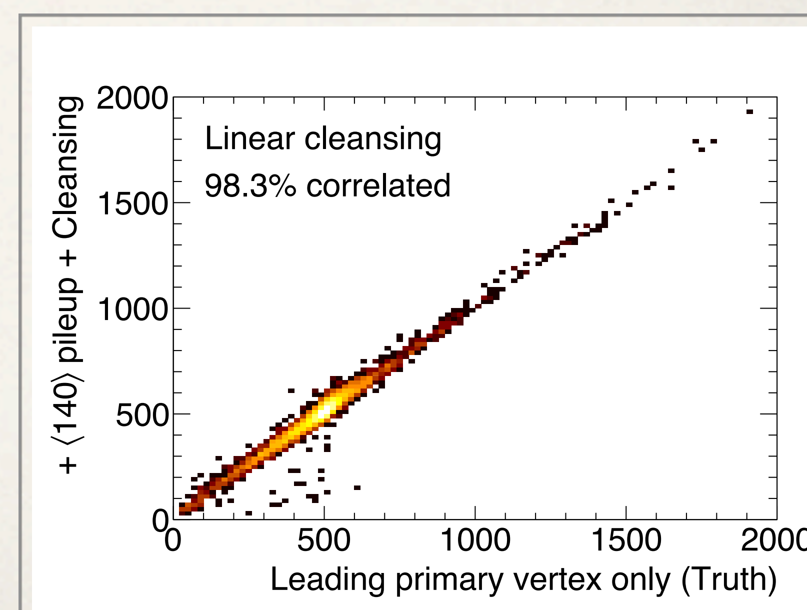
Before grooming / cleansing

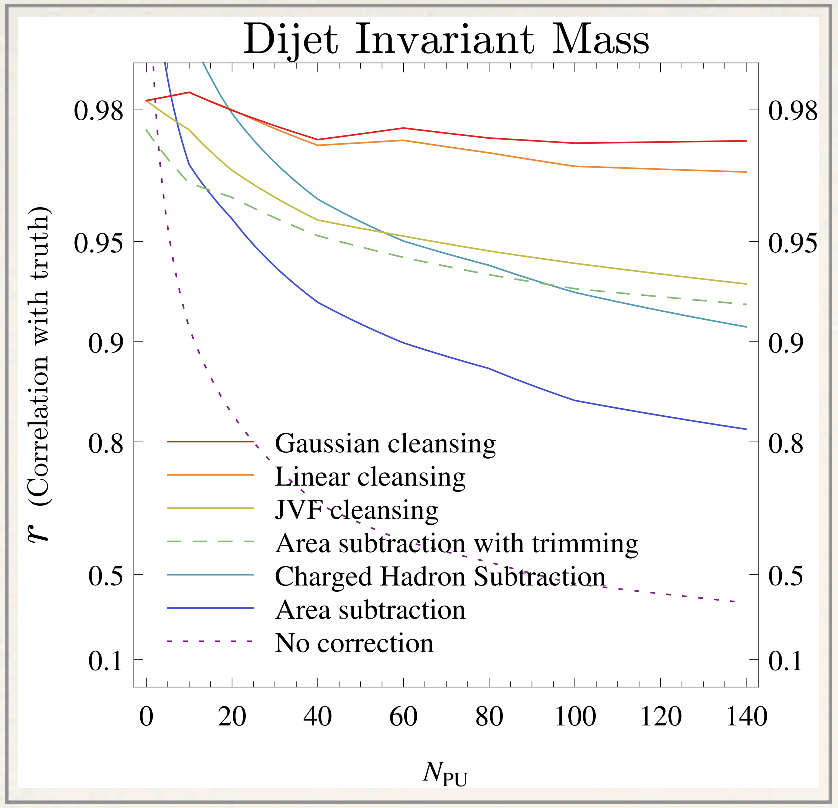
After shape / area subtraction

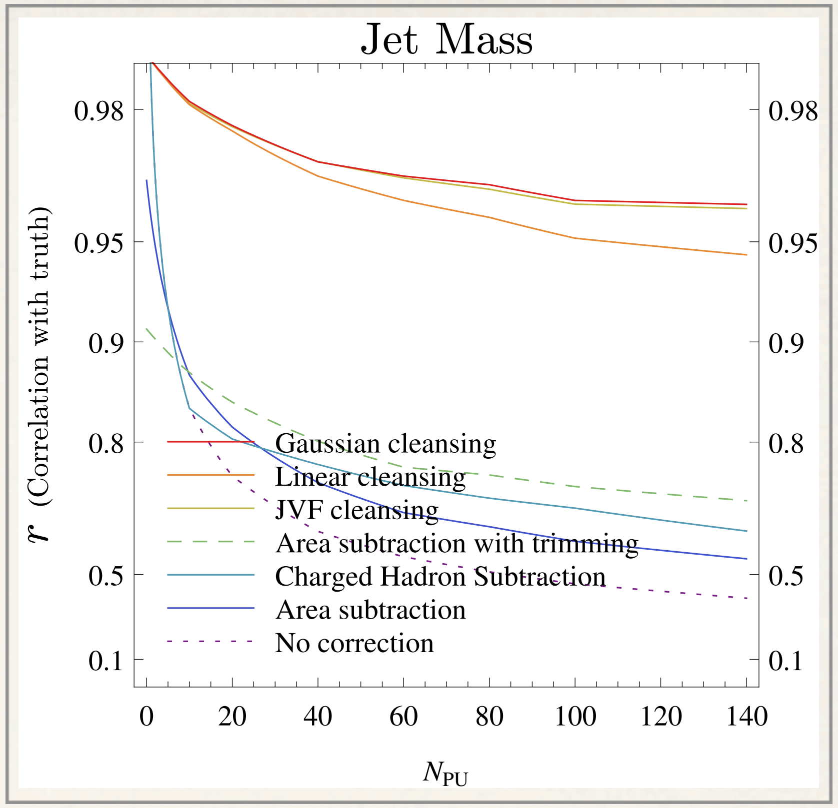
After cleansing











Significance improvement				
Algorithm	$N_{PU} = 20$		$N_{PU} = 140$	
	plain	trimmed	plain	trimmed
CHS	0.86	1.07	0.48	0.63
Area Subtraction	0.87	1.00	0.45	0.85
JVF Cleansing	0.93	1.06	0.82	0.81
Linear Cleansing	0.94	1.08	0.78	1.00
Gaussian Cleansing	0.95	1.07	0.91	0.98

Distance correlation				
Algorithm	Jet mass		Dijet mass	
	$N_{PU} = 20$	140	$N_{PU} = 20$	140
CHS	20	37	0.9	13
Shape/Area Sub.	18	45	2.9	15
JVF Cleansing	2.3	4.0	1.6	3.6
Linear Cleansing	2.3	5.5	1.1	1.7
Gaussian Cleansing	2.2	3.9	1.1	1.3

Download at `http://jets.physics.harvard.edu/Cleansing/`
or at `http://fastjet.hepforge.org/contrib`

Advantages

- Cleansing doesn't change one's perturbative calculations
- Requires subjet calibration, which experimental collaborations already have much experience with.
- Cleansing fixes general jet shapes - you cleanse once and then measure anything you'd like (N-Subjettiness, etc).
- Numerically, jet cleansing seems to outperform grooming, subtraction, and combinations of the two for measures of correlation and measures like S/r(B)

Challenges

- May ultimately be limited by systematic uncertainties.
  - However, one would still expect cleansing to help with jet shapes since it uses local information.
  - Try it with N-subjettiness!
- Distinguishing pileup vertices may be hard at very high PU levels.
  - How much does this degrade the method?

Conclusions

- Many great new tools now exist to help dig-out and characterize BSM physics (if it's there).
- These have all been tested in 7/8 TeV data and the agreement with theory is remarkable.
- However, as we go to higher luminosity to search for BSM physics we're going to encounter new challenges with increased pileup.
- Subtraction and jet grooming are effective, but they can't fully alleviate pileup issues.
- Perhaps **jet cleansing** can help