Jet tools for Higgs analysis

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MIT — July 26th 2013

Why jets when speaking about Higgs

- Measurements of Higgs with (or without) jets

- $H \to b\bar{b}$, boosted regime

- Soft hadronic activite (UE and pileup) affecting most of the analysis

Why jets when speaking about Higgs

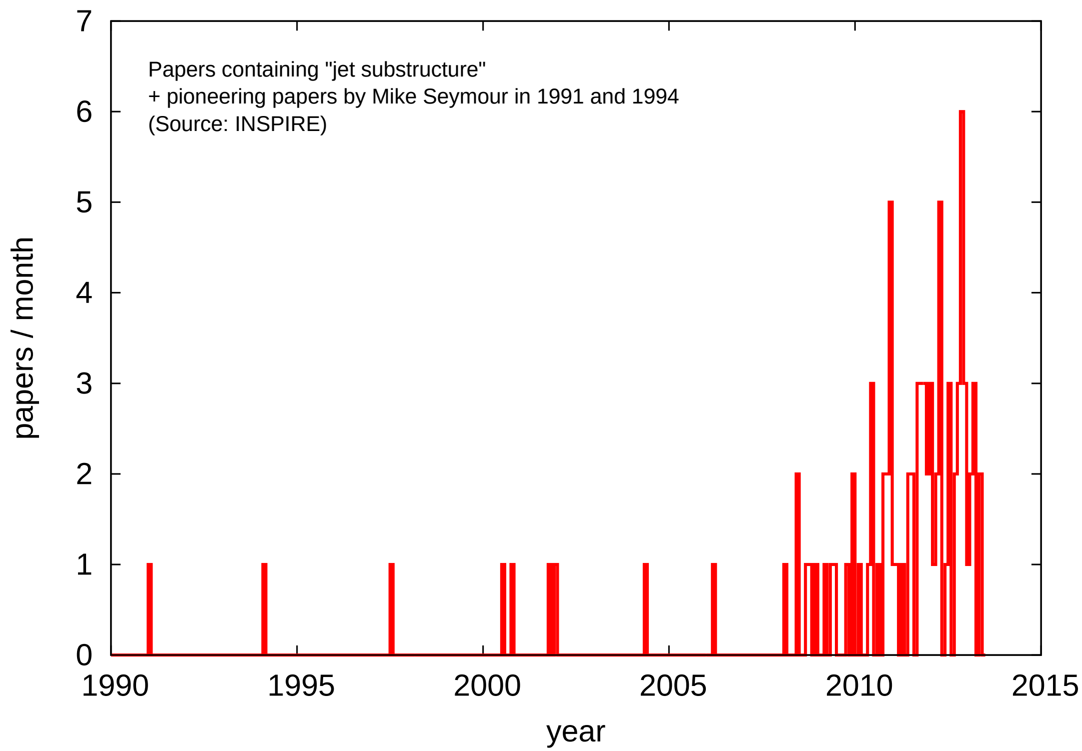
- Measurements of Higgs with (or without) jets
  Mostly covered yesterday in Kirill's and Rikkert's talks

- $H \to b\bar{b}$, boosted regime
  Jet substructure, grooming,
  experimental validation, analytic progress

- Soft hadronic activite (UE and pileup) affecting most of the analysis
  Pileup effect and subtraction, effect on jet substructure?

Jet substructure

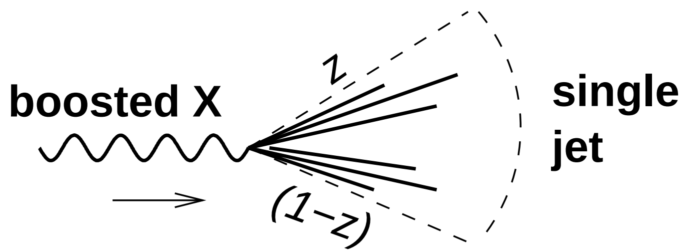
a lot of activity since 2008



Geneic idea and challenges (1/2)

Problem:

boosted heavy object $\Rightarrow$ decays in a single jet



$$R \gtrsim \frac{m}{p_t}\frac{1}{\sqrt{z(1-z)}}$$

How to disentangle that from a QCD jet?

Many applications: (examples)

- 2-pronged decay: $W \to q\bar{q}$, $H \to b\bar{b}$
- 3-pronged decay: $t \to qqb$, $\tilde{\chi} \to qqq$
- busier combinations: $t\bar{t}H$
- new physics: *e.g.* heavy SUSY $\to$ boosted top

Geneic idea and challenges (2/2)

Main ideas/methods:

- finding prongs
  Idea: QCD tends to have softer branchings
- constrain radiation patterns
  Idea: *e.g.* gluons radiate more and at large angles

Extra complications: fat jets typically use $R \sim 0.7 - 1/2$
$\rightarrow$ enhanced sensitivity to soft activity (UE,PU)

Geneic idea and challenges (2/2)

Main ideas/methods:

- finding prongs
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  Idea: *e.g.* gluons radiate more and at large angles

Taggers: discrimminate boosted X from QCD

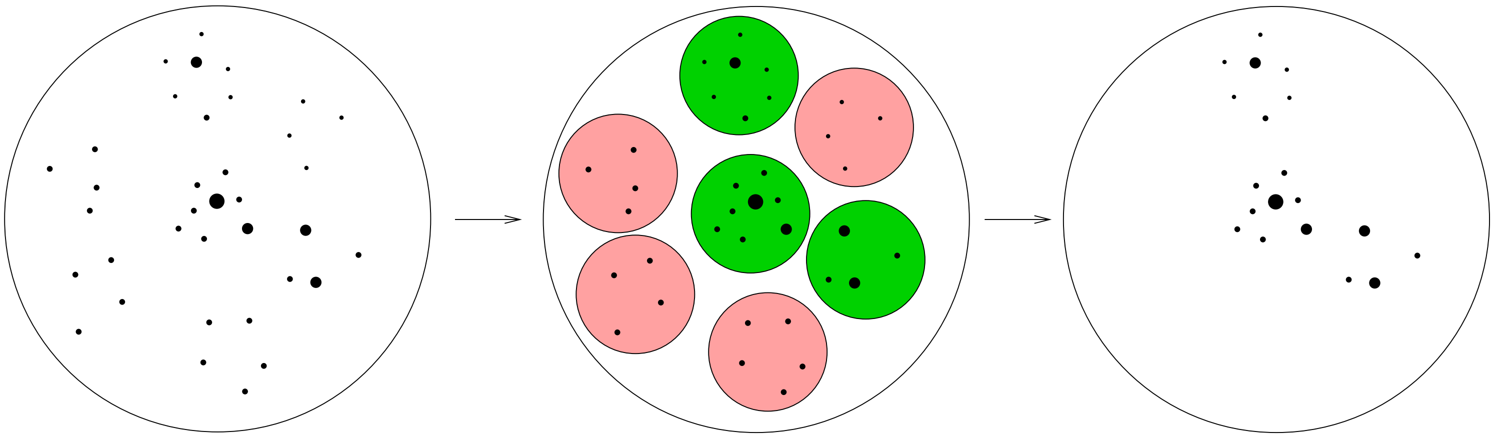
Extra complications: fat jets typically use $R \sim 0.7 - 1/2$
$\rightarrow$ enhanced sensitivity to soft activity (UE,PU)

Groomers: clean the UE/PU, improve resolution

(with overlap because of soft-gluon QCD radiation)

Groomers: filtering/trimming/pruning

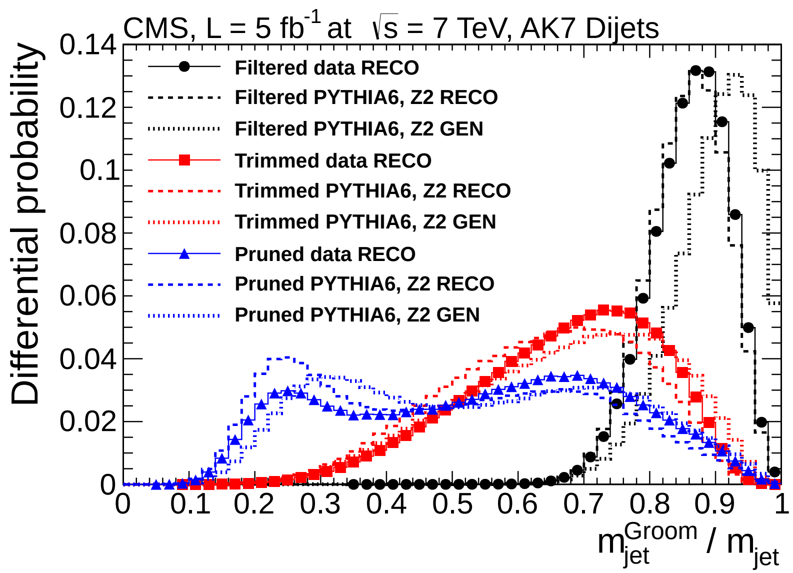
Idea: clean the jet from soft components
while keeping hard QCD radiation

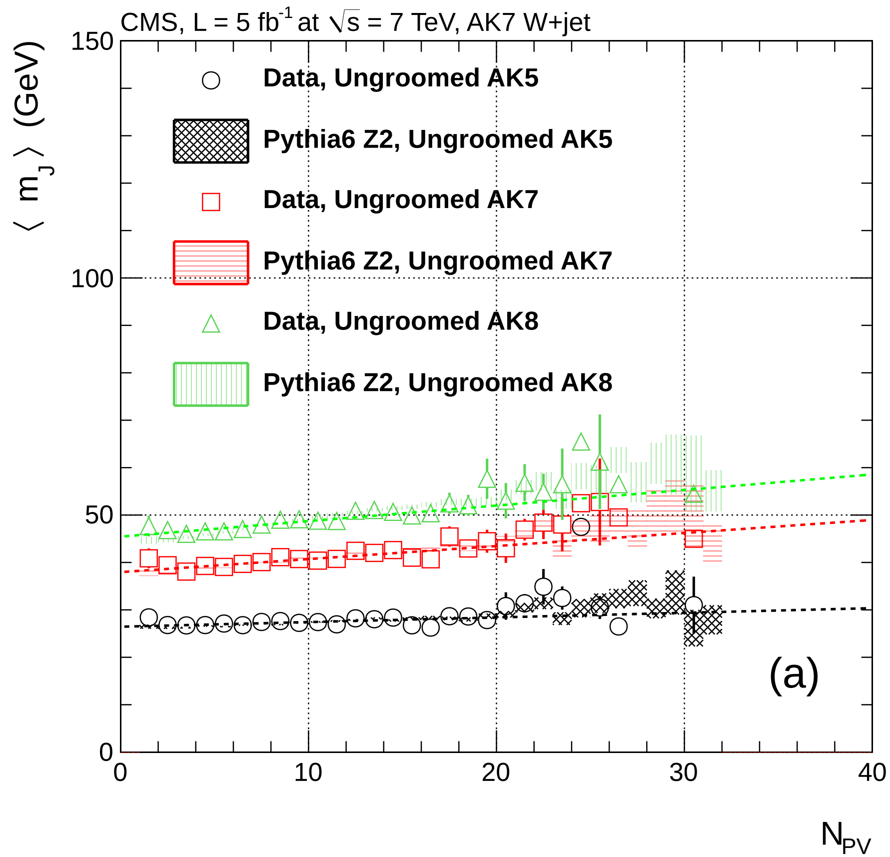


- Filtering: keep a fixed number of hard subjets
  - Reculter into subjets with $R = R_{\text{sub}}$; keep the n_{filt} hardest subjets
- Trimming: keep subjets over a p_t cut
  - Reculter into subjets with $R = R_{\text{sub}}$; keep subjets with $p_t > f_{\text{cut}} p_{t,\text{jets}}$
- Pruning: recluster + veto soft&large-angle recomb.
  - Recluster the jet constituents. When recombining p_i with p_j ($p_{ti} > p_{tj}$), if $\Delta R_{ij} > R_{\text{cut}}$ and $p_{t,j} < z_{\text{cut}} p_{t,i+j}$ keep only p_i (veto p_j)

Groomers: filtering/trimming/pruning

[CMS - arXiv:1303.4811]





Groomers: filtering/trimming/pruning

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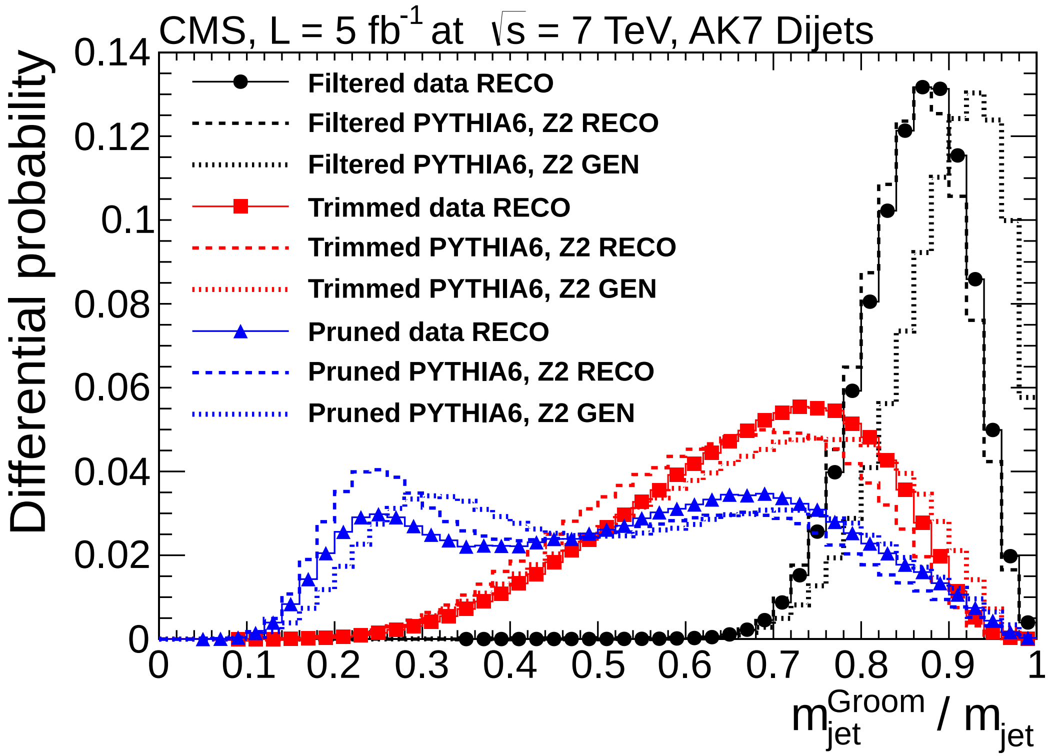
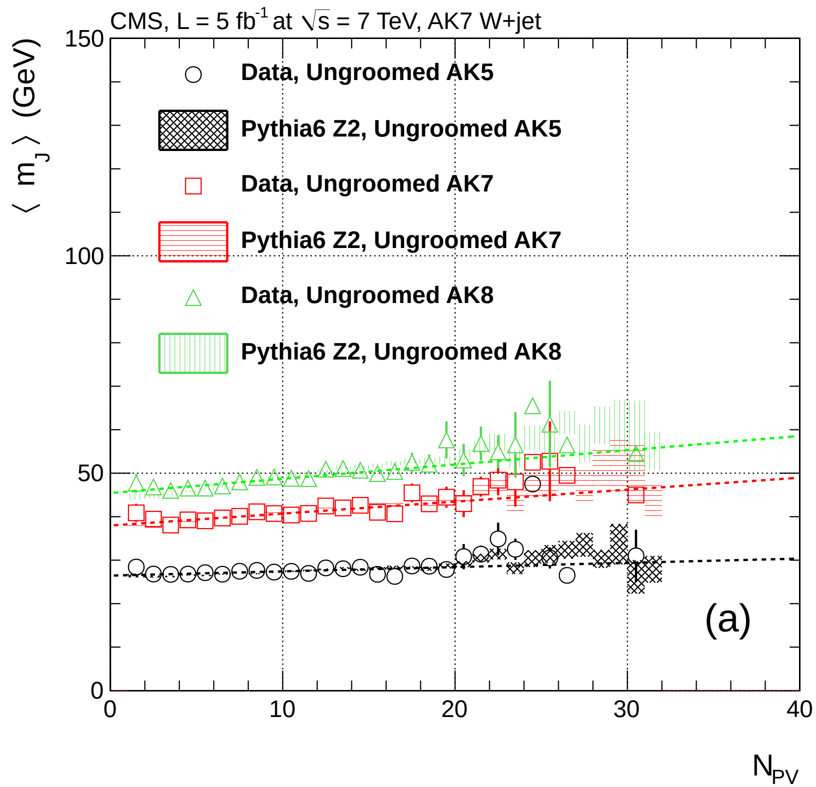
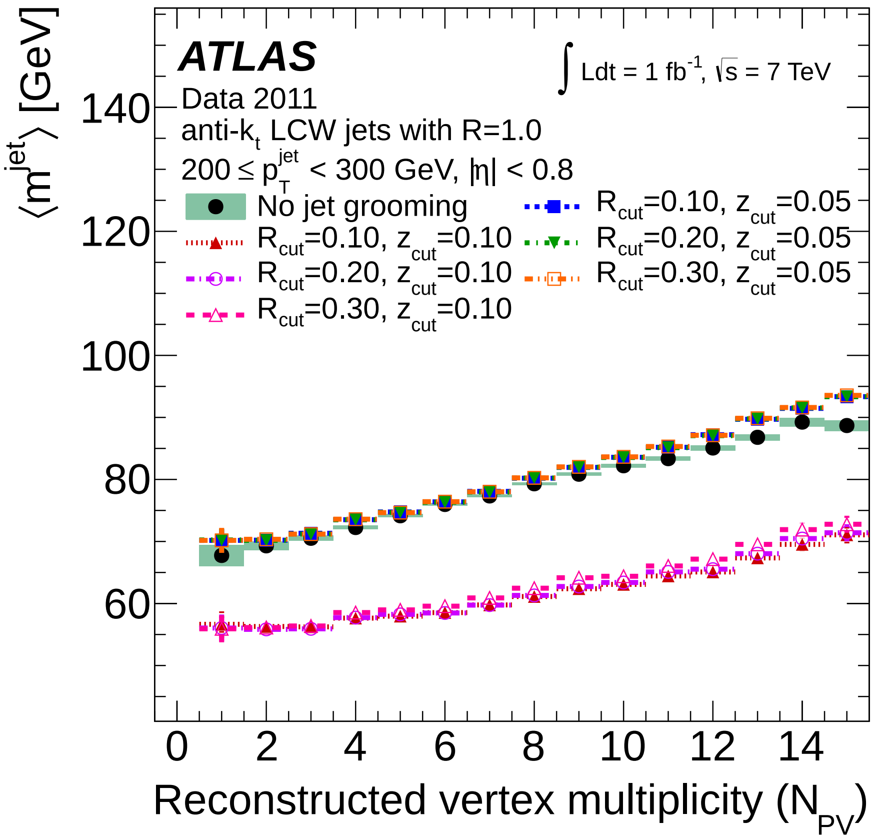


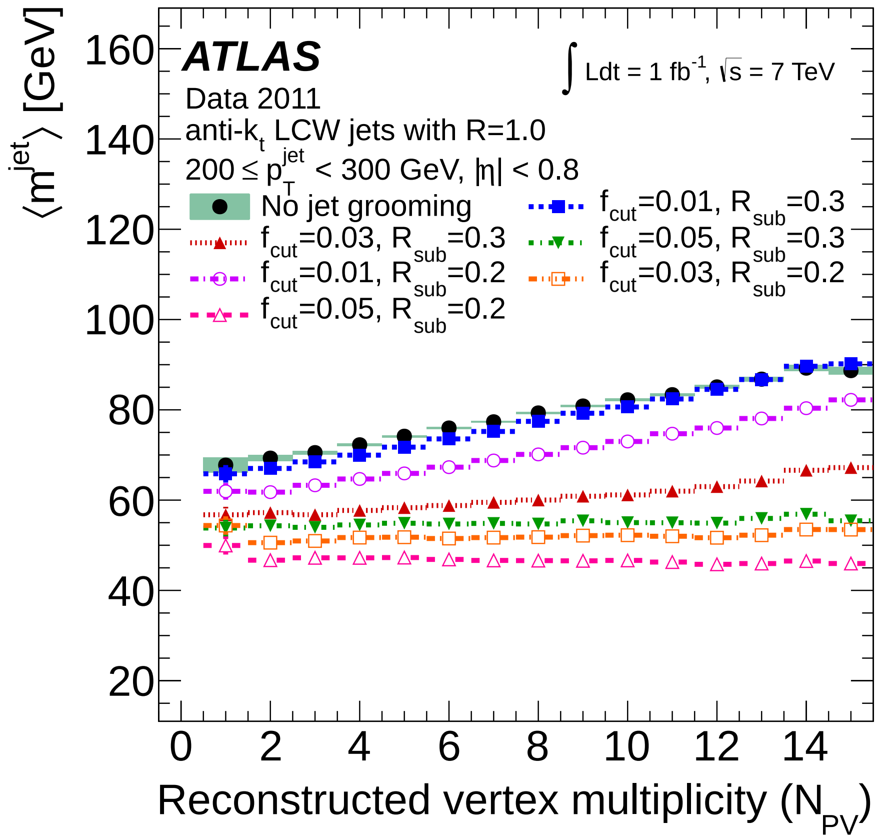


- reduction of the jet mass
- reduction of the sensitivity to PU

Groomers: filtering/trimming/pruning

[ATLAS - arXiv:1306.4945]



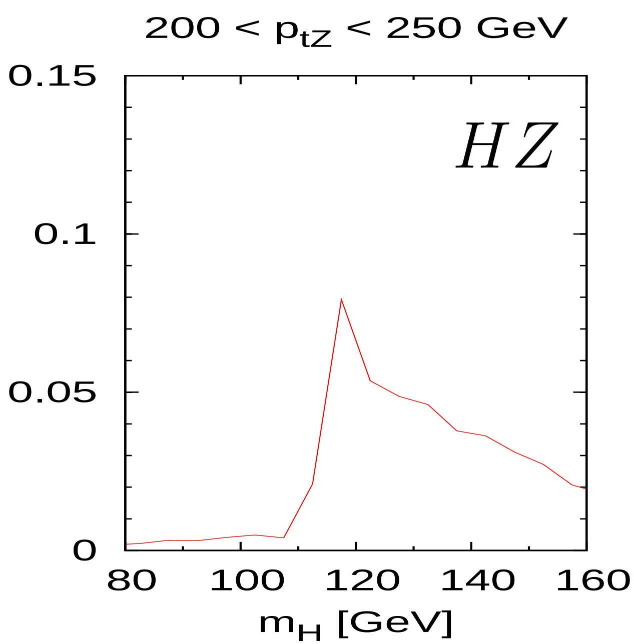


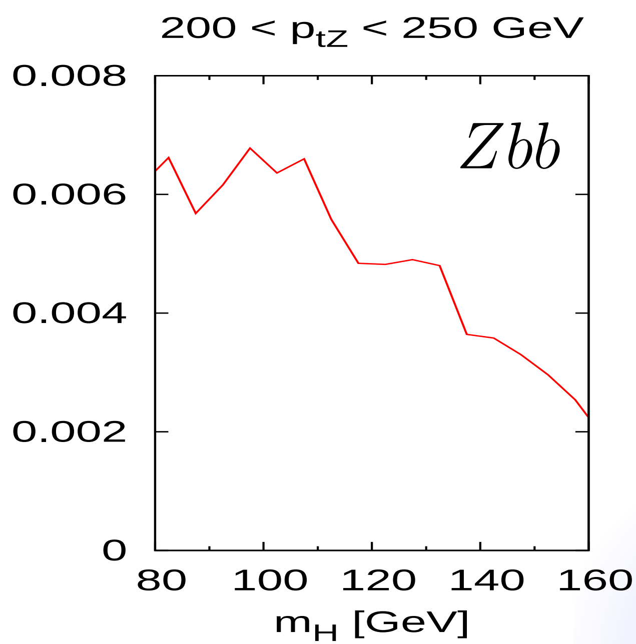
- trimming/filtering less PU-sensitive than pruning
- dependence on the parameters

Tagging: example 1: mass-drop

[J. Buterworth, A.Davison, M. Rubin, G.P. Salam; 2008]

- Start with a fat jet (C/A($R = 1.2$))





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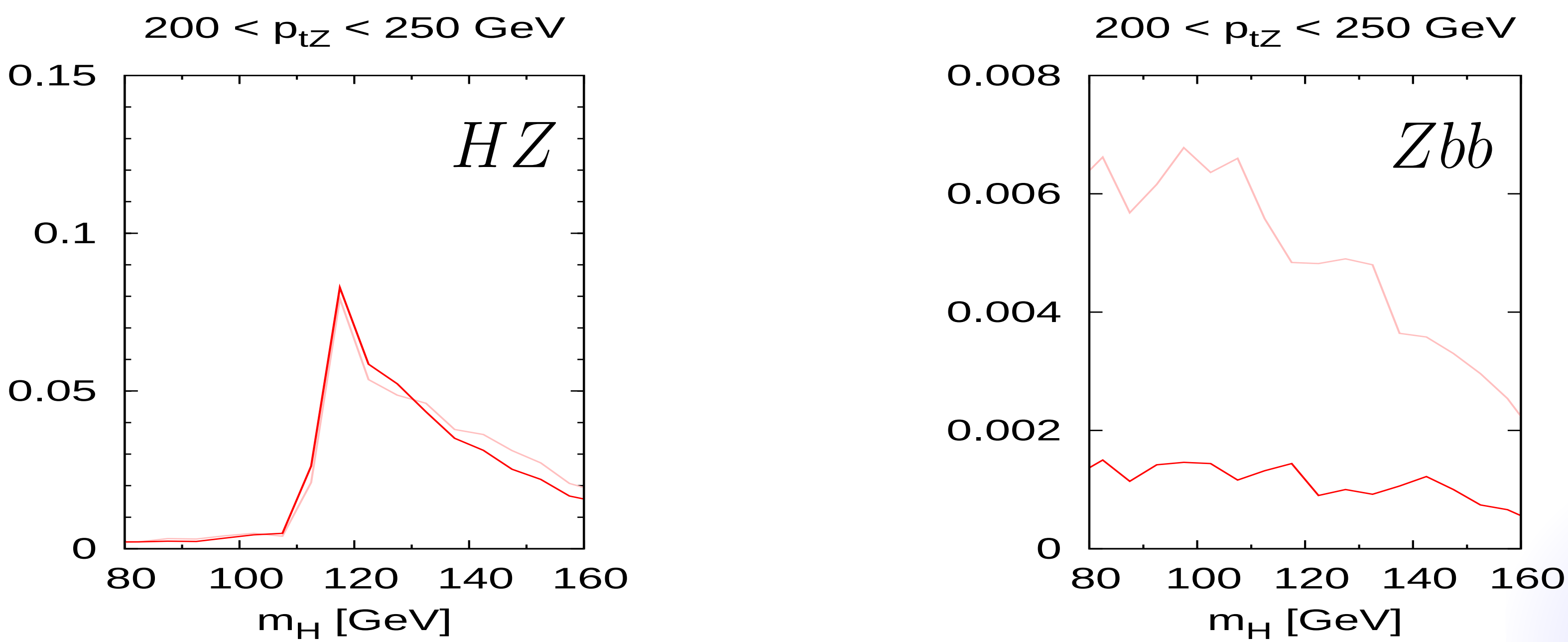
[J. Buterworth, A.Davison, M. Rubin, G.P. Salam; 2008]

- Start with a fat jet (C/A($R = 1.2$))
- find 2 prongs: undo last clustering $j_1 + j_2 \to j$ until
  - $\max(m_1, m_2) < \mu m$ (mass drop) and
  - $\min(p_{t1}^2, p_{t2}^2)\Delta R_{12}^2 > y_{\rm cut} m_j^2$ (symmetric)
- (require 2 b tagging)



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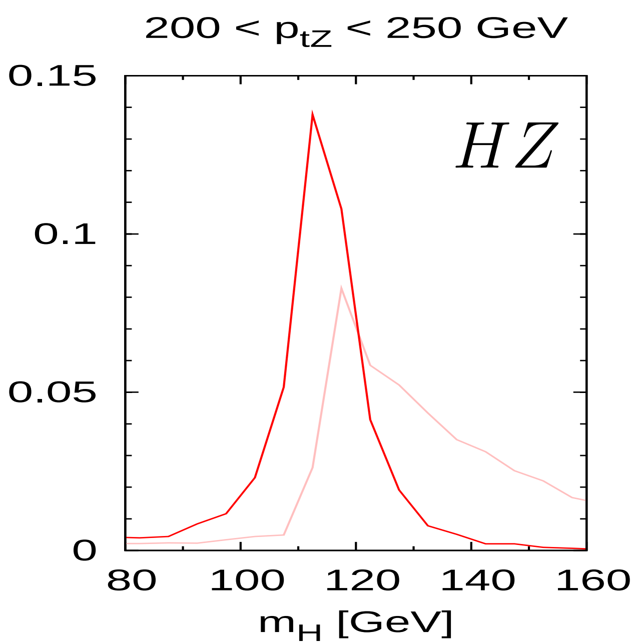
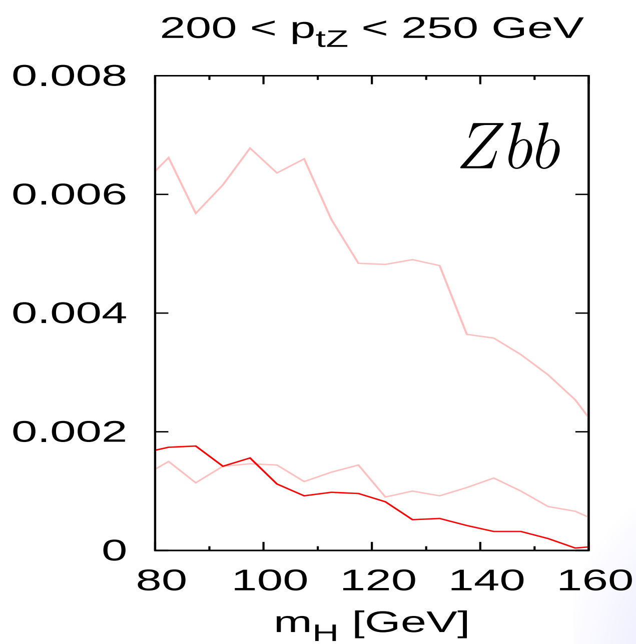
- (require 2 b tagging)
- apply filtering ($R_{\rm sub} = \min(0.3, R_{bb}/2)$, $n_{\rm filt} = 3$)

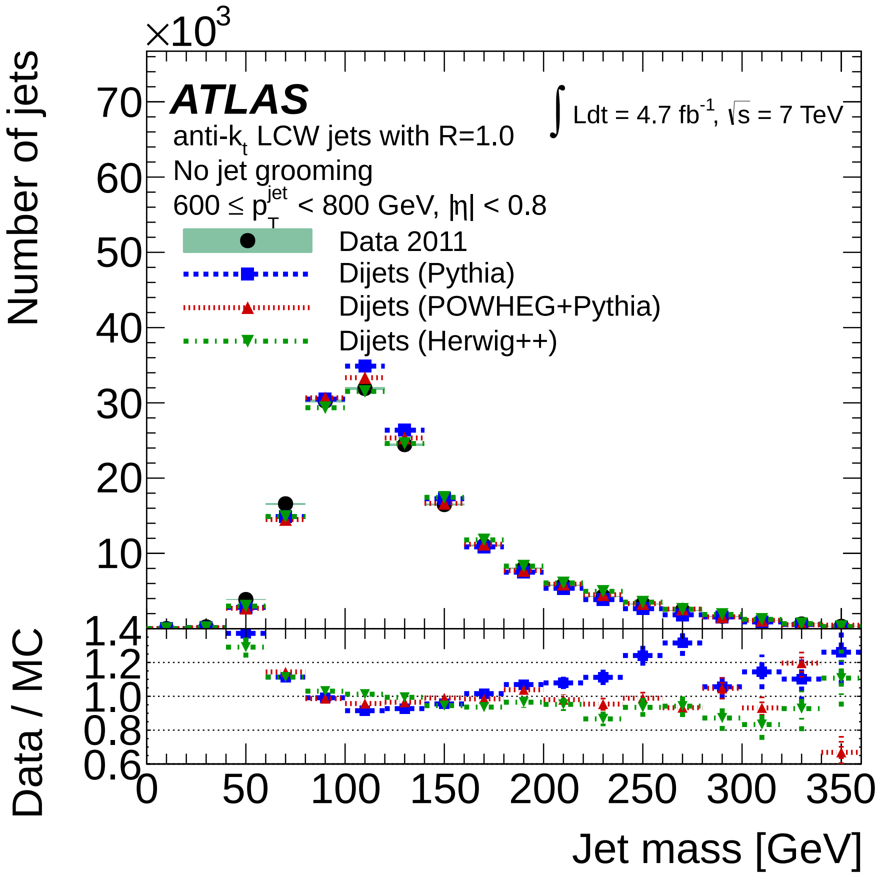


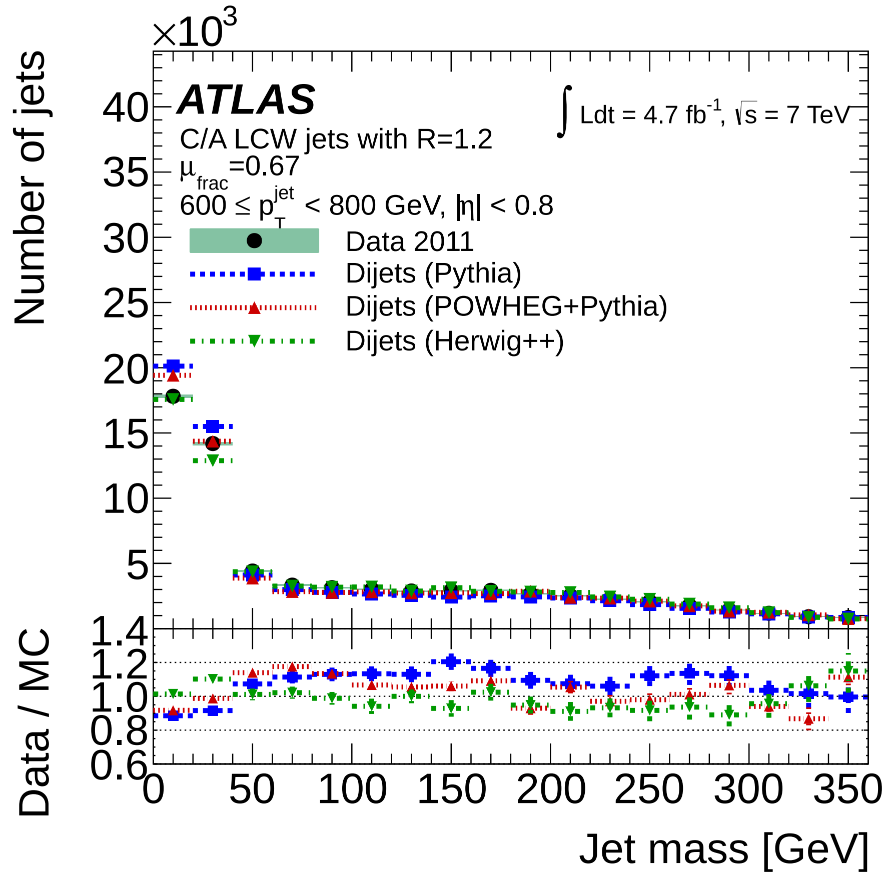


Tagging: example 1: mass-drop

[ATLAS - arXiv:1306.4945]

plain jet	Mass drop + filter





Tagging: example 2: jet shapes

- Shapes are functions of the jet constituents
Idea: constrain the flow of radiation)

- Many options: angularity, energy-energy correlators, N-subjettiness, planar flow, pull, ...

- Example: N-subjettiness ratios τ_2/τ_1 or τ_3/τ_2

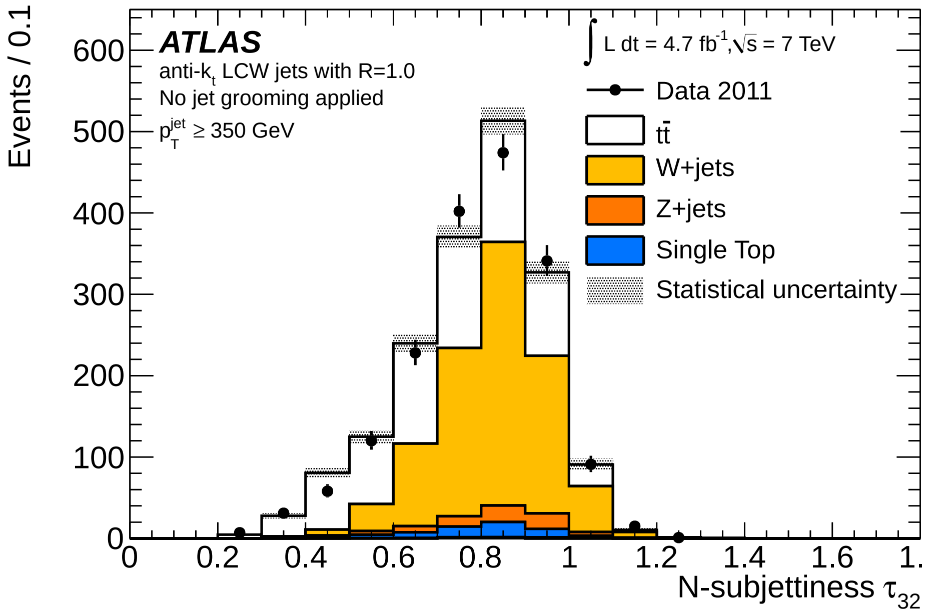
$$\tau_N = \frac{1}{p_t^N} \sum_{i \in \text{jet}} p_{t,i} \min_{\text{axes } a_1 \dots a_N} \Delta R_{i,a}$$

with the N axes taken *e.g.* as exclusive k_t subjets

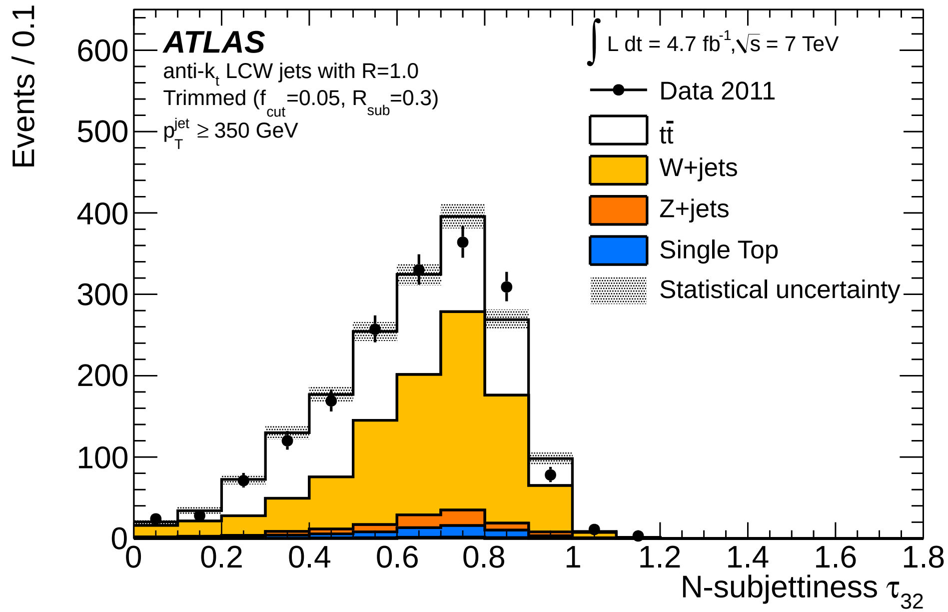
Tagging: example 2: jet shapes

[ATLAS - arXiv:1306.4945]

full jet



trimmed jet



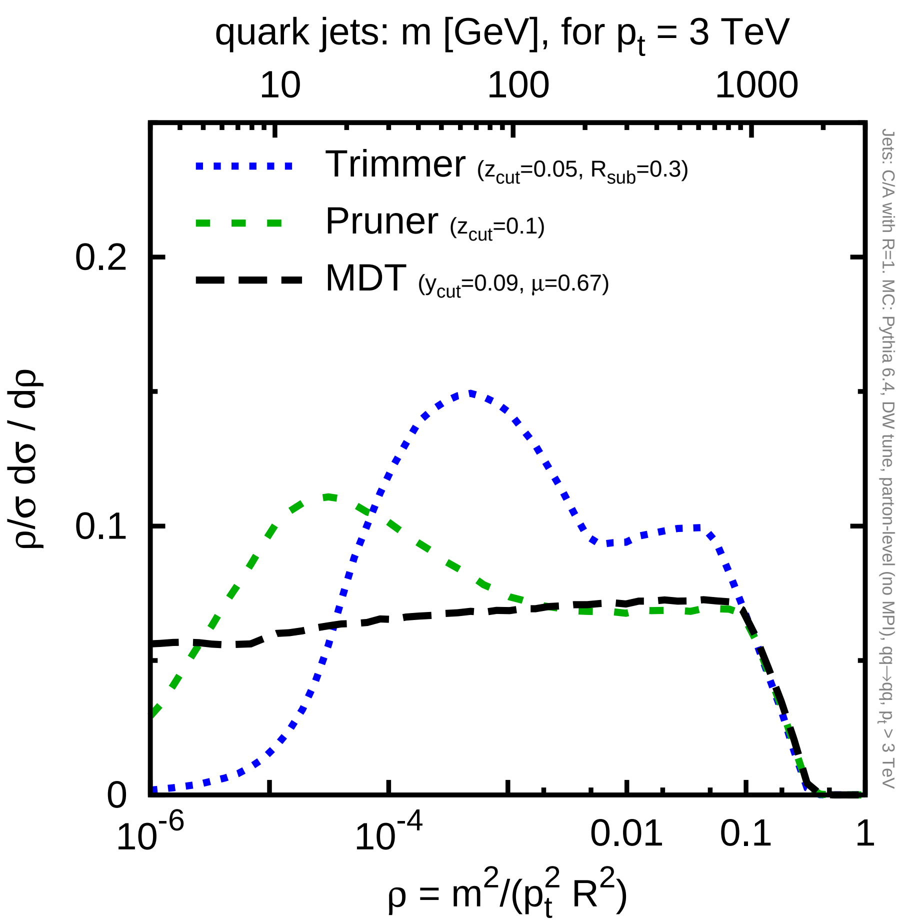
Analytic understanding

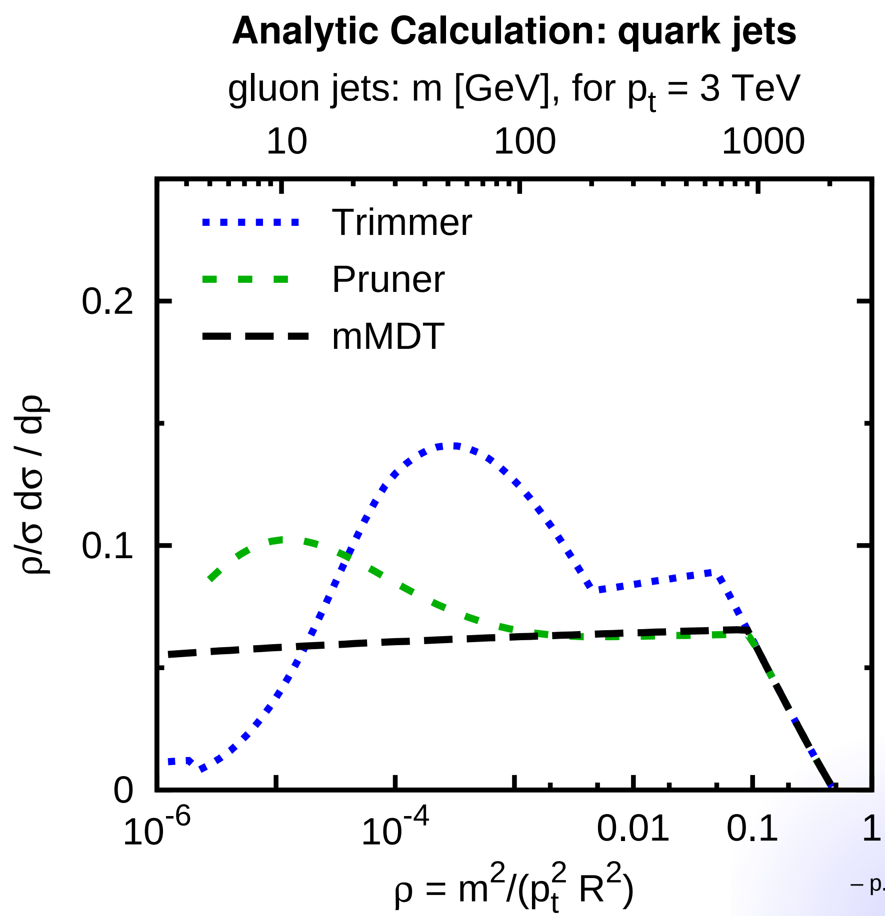
[M. Dasgupta, A. Fregoso, S. Marzani, G.P. Salam, 2013]

Mostly Monte Carlo studies although:

- there are some differences between different MCs
- MCs have limitations (p_t,m ranges; param scans)

$\Rightarrow$ analytic understanding beneficial



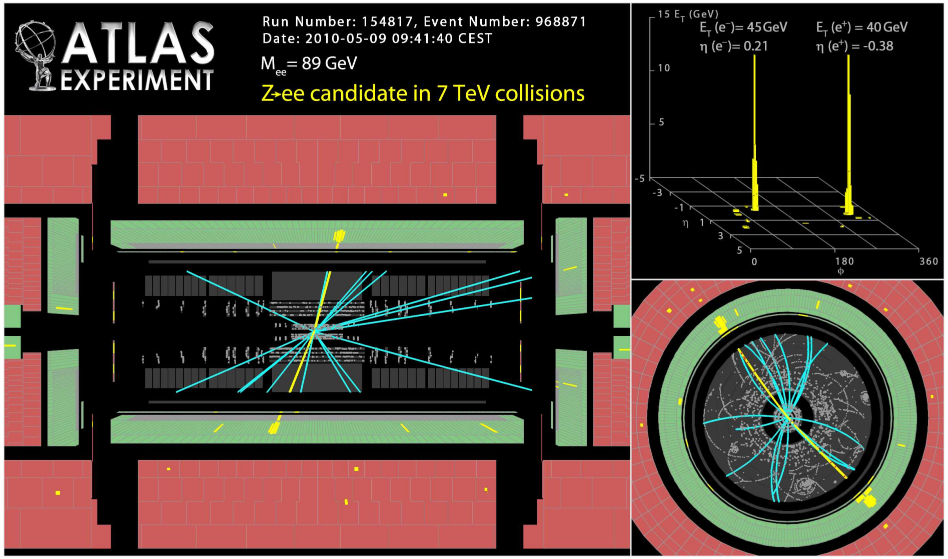


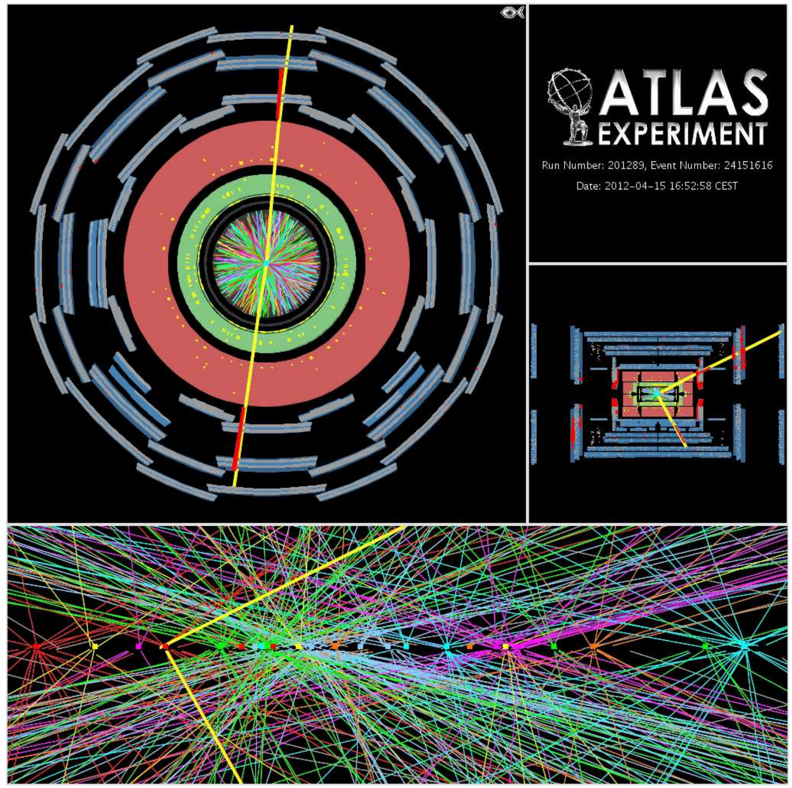
Jets in soft background (pileup)

Pileup

$Z \to \ell^+\ell^-$ candidate at ATLAS

Low luminosity (bunch population)	High luminosity (bunch population)



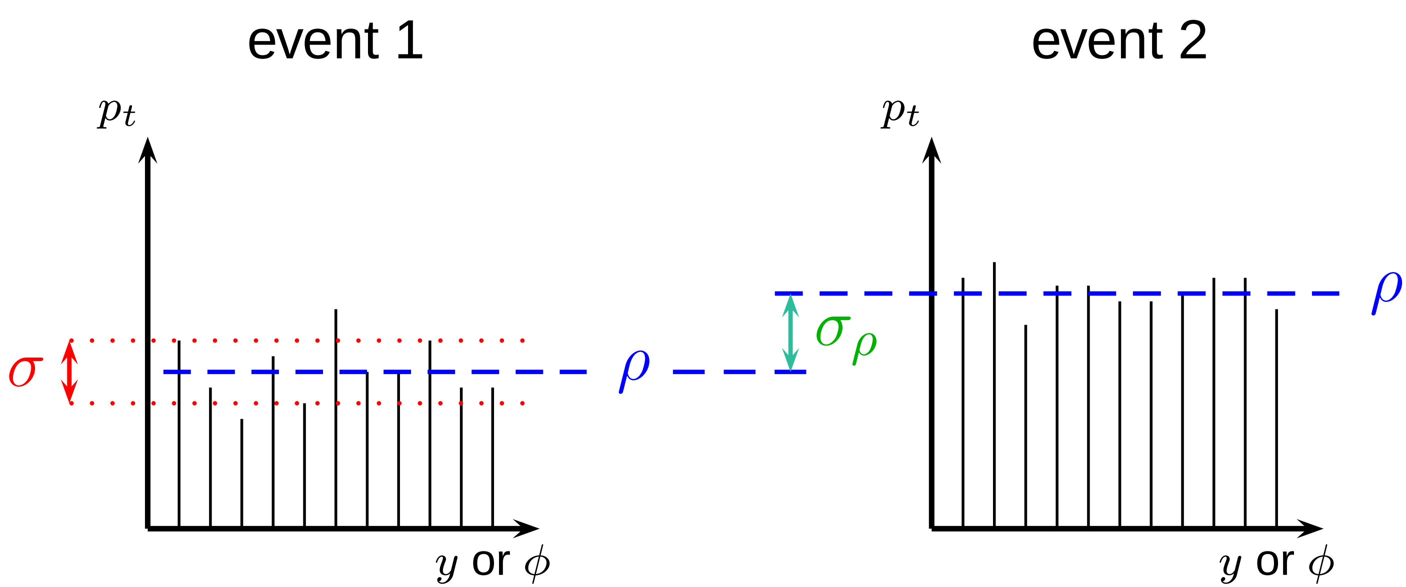


- many (soft) pp interactions with the hard one (here 25)
- soft background in the whole detector

Basic characterisation

Pileup mostly characterised by 3 numbers $^{(*)}$:

- ρ: the average activity in an event (per unit area)
- σ: the intra-event fluctuations (per unit area)
- σ_ρ: the event-to-event fluctuations of ρ



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Jet of momentum p_t and area A:

one event: $p_t \to p_t + \rho A \pm \sigma\sqrt{A}$

event average: $p_t \to p_t + \langle\rho\rangle A \pm \sigma_\rho A \pm \sigma\sqrt{A}$

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p_t shift

p_t smearing
resolution degradation

Event-by-event determinations of the shift (are expected to) reduce the smearing effects of PU

Median-area-based subtraction

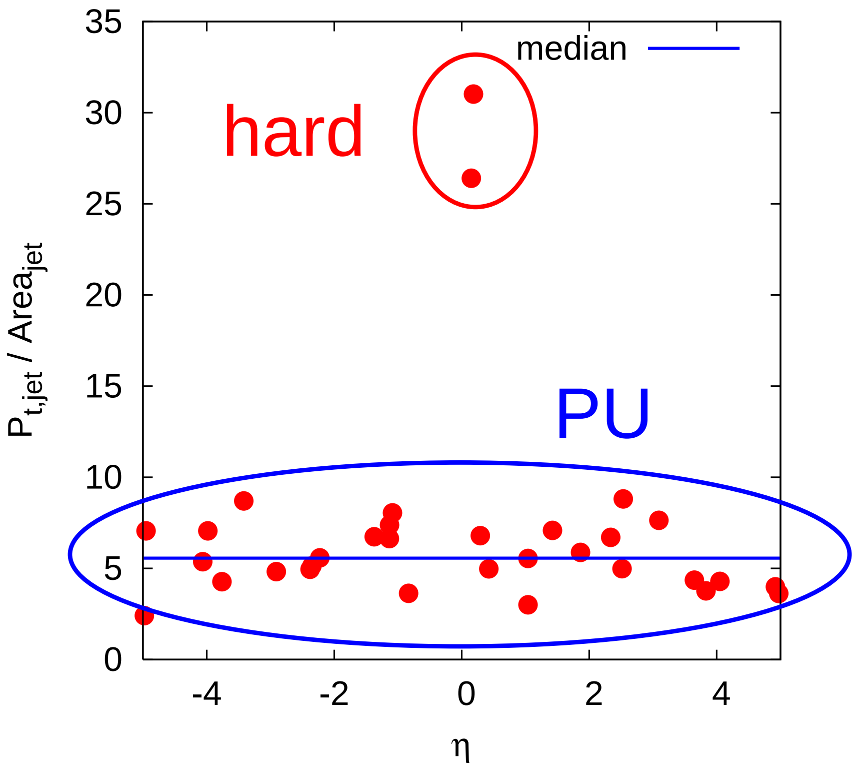
[M.Cacciari, G.P. Salam, 07; M.Cacciari, G.P. Salam, GS, 2008]

$$p_{t,\text{jet}}^{(\text{sub})} = p_{t,\text{jet}} - \rho_{\text{est}} A_{\text{jet}}$$

$$\rho_{\text{est}} = \underset{j \in \text{patches}}{\text{median}} \left\{ \frac{p_{t,j}}{A_j} \right\}$$

per event (typically)

per jet

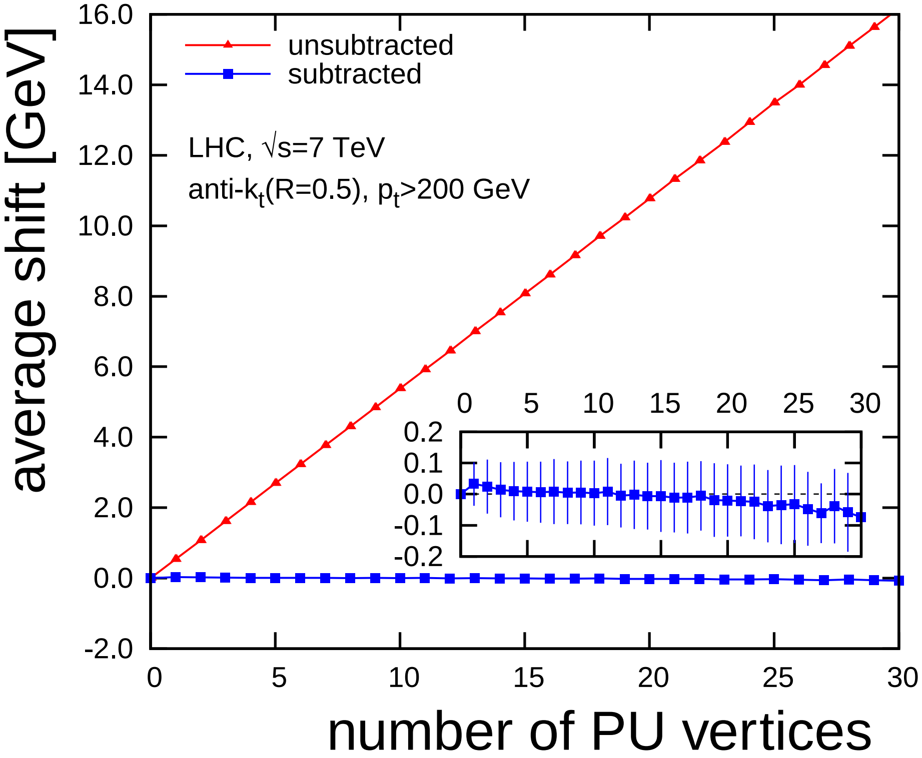


break the event in patches of similar size

e.g. cluster with k_t

Subtraction benchmarks

average p_t shift



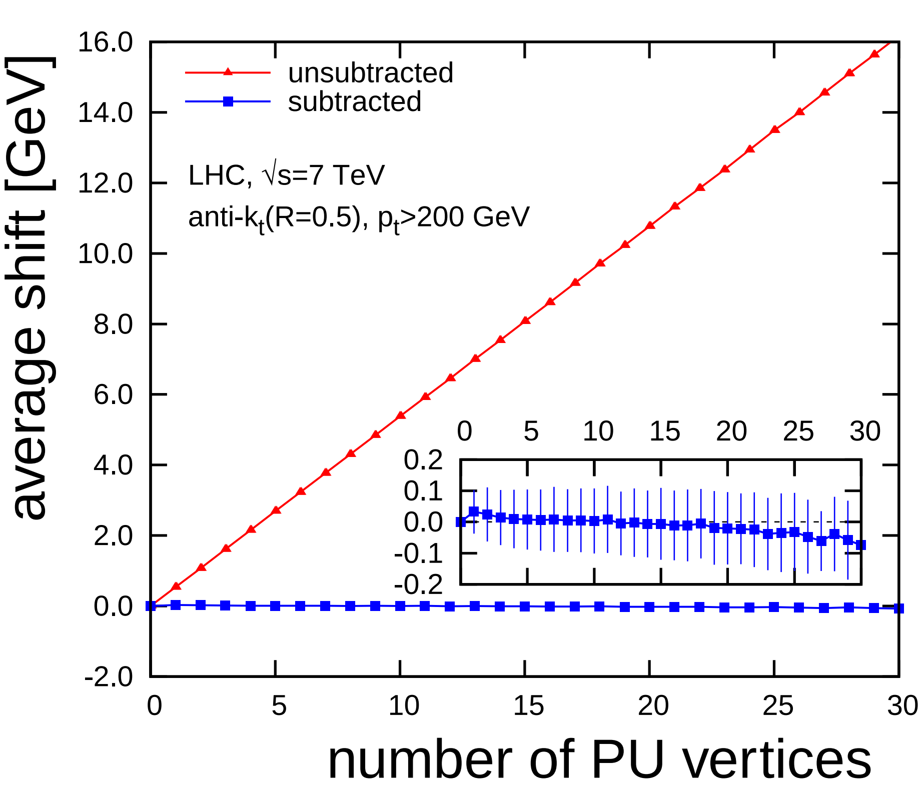
No subtraction

area-median subtraction

corrected for shift

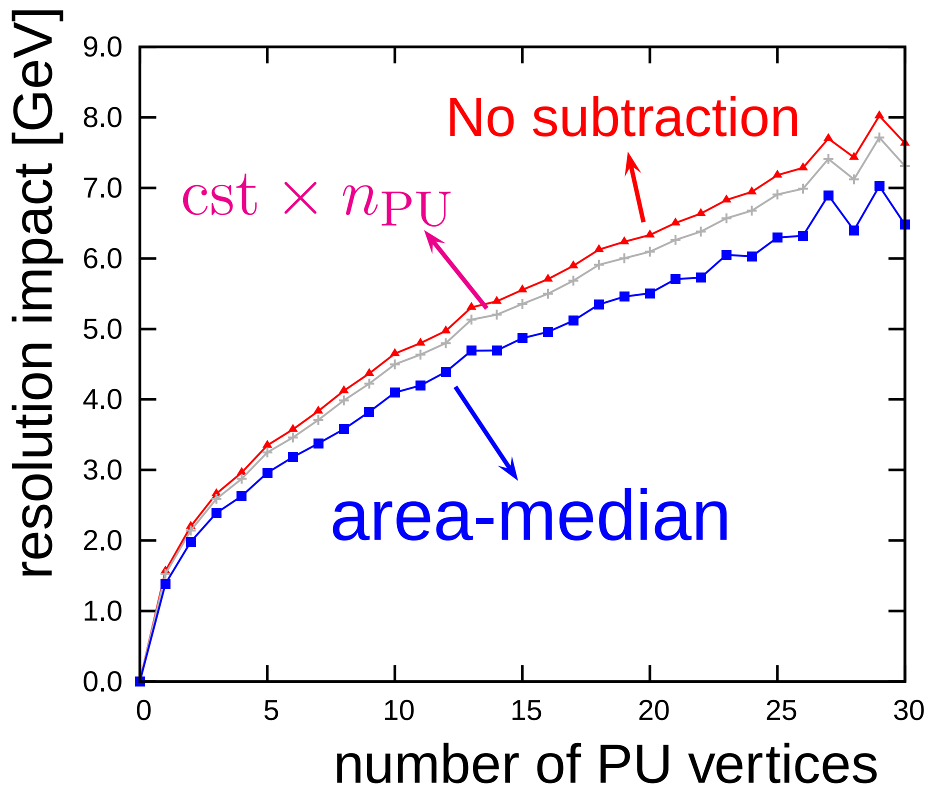
Subtraction benchmarks

average p_t shift



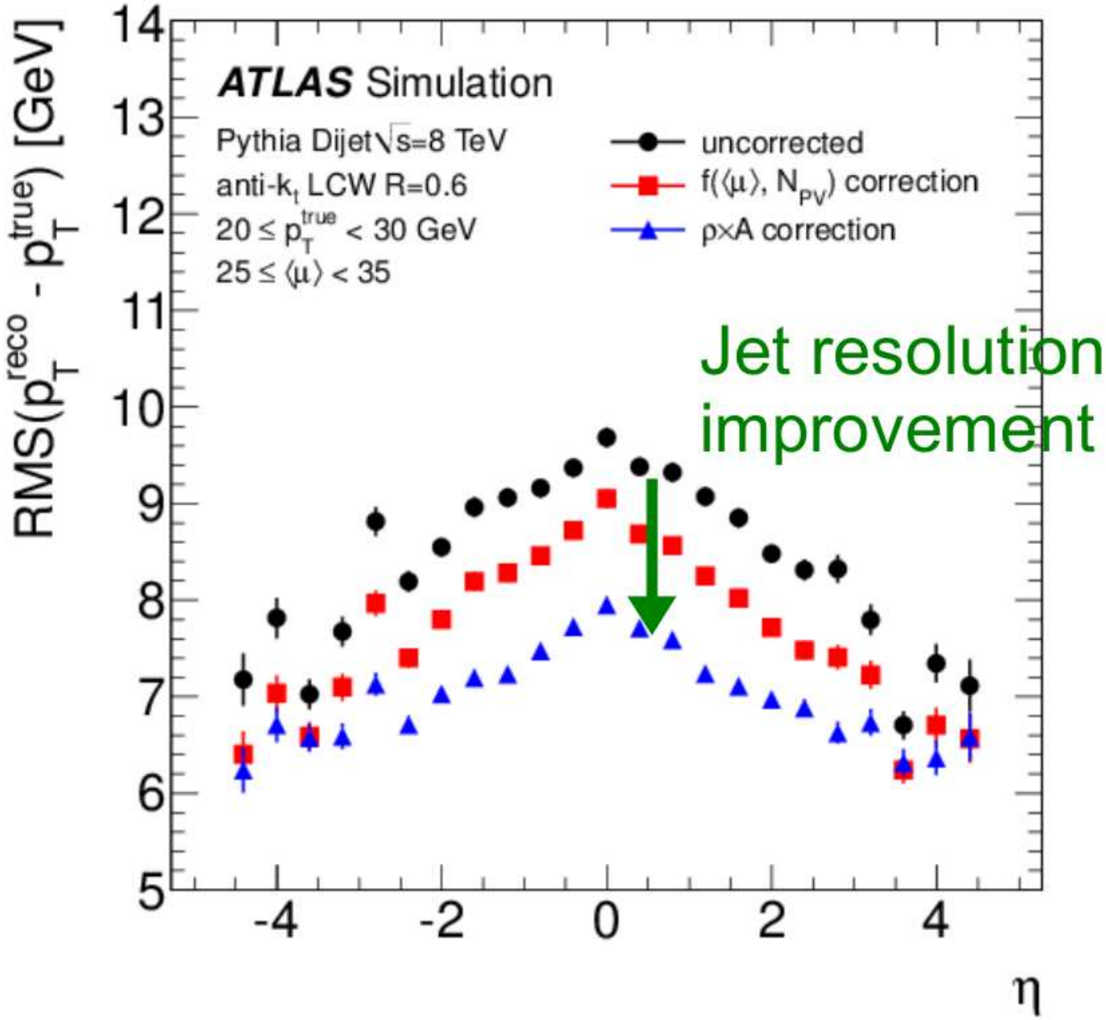
corrected for shift

impact on resolution



resolution improved

PU subtraction as seen in ATLAS



[B. Petersen, ATLAS Status report for the LHCC, 2013]

Pileup and substructure

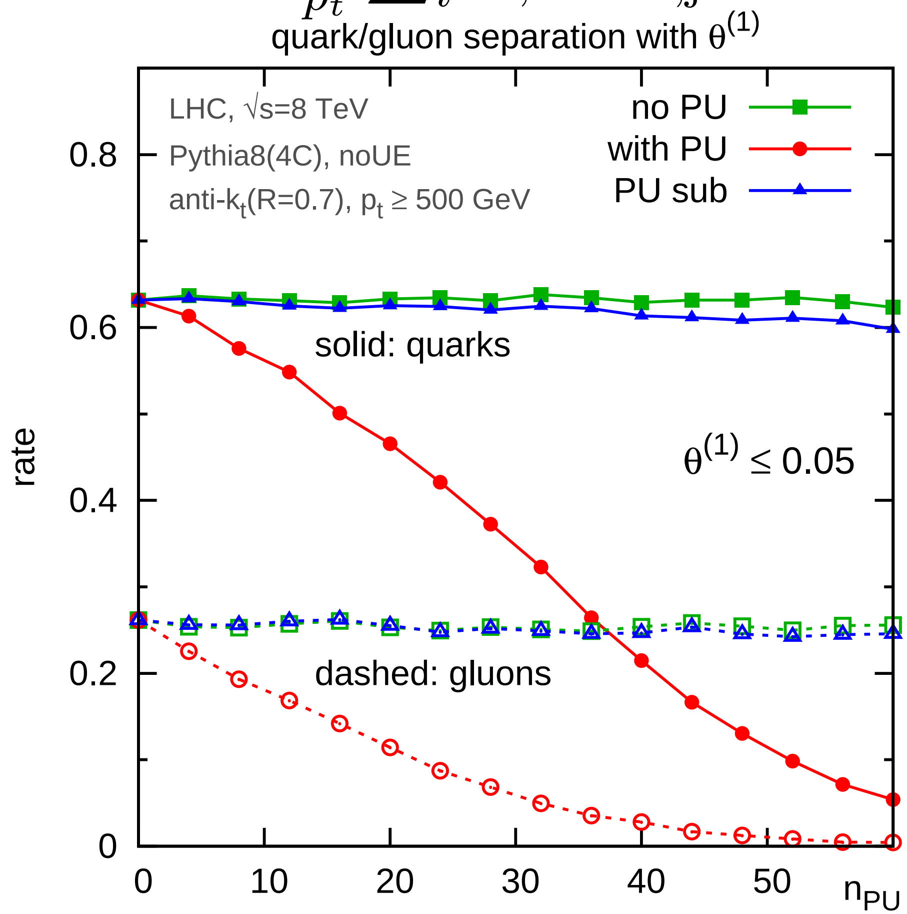
Application 1: shapes

[GS,G.Salam,J.Kim,S.Dutta,M.Cacciari,2013]

Subtraction for jet mass and jet shapes

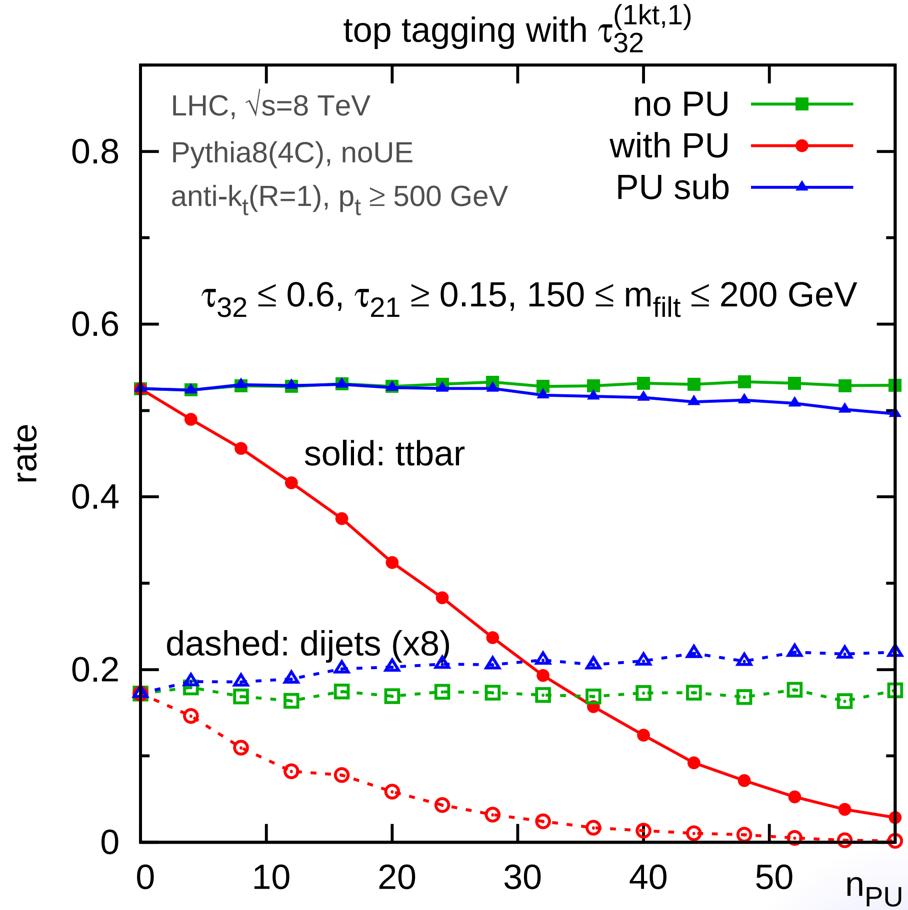
quark/gluon discrimination

$$\theta = \frac{1}{p_t} \sum_i p_{t,i} \Delta R_{i,\mathrm{jet}}$$

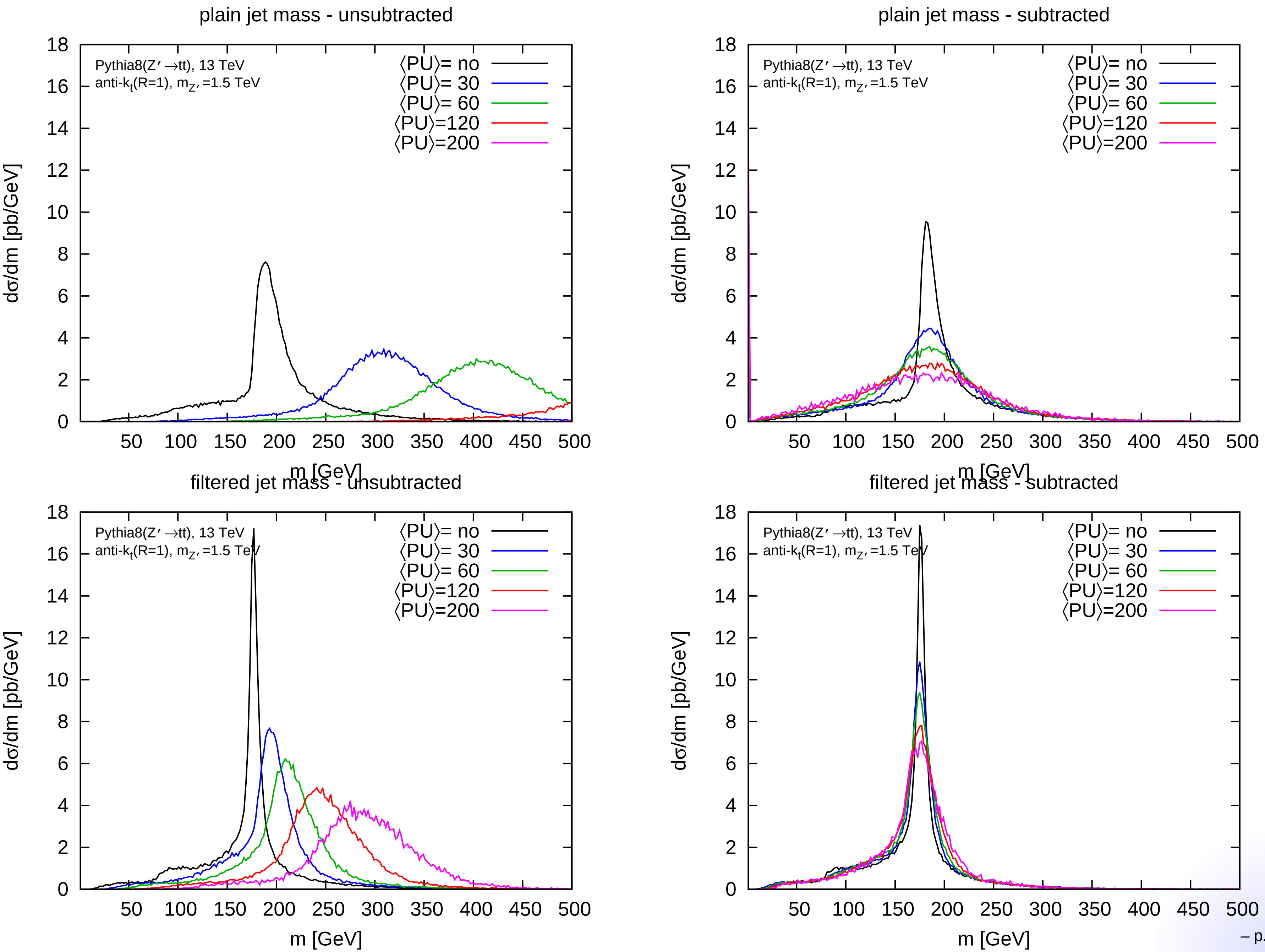


top tagging

τ_{32} + filtering



Example of grooming performance [Boost 2012]



Example of grooming performance [Boost 2012]

Quick explanation: pileup effect

$$p_t \to p_t + \rho A \pm \sigma\sqrt{A}$$

- Subtraction gets rid of the ρA term
- Grooming effectively reduces the area
  - reducing PU sensitivity (the ρA term)
  - improving resolution (the $\sigma\sqrt{A}$ term)
- combining both gets both advantages

Jet tools implementation: FastJet

FastJet

[M.Cacciari, G.Salam, GS, 2005-2013]

- Fast recombination algorithms (k_t, C/A, anti-k_t)
- Grown into a full-fledged jet interface:
  - plugins for used jet definitions
  - jet areas and background subtraction
  - tools for manipulating jets
- FastJet 3.0.4 released in June 2013
  see `www.fastjet.fr`
- Standard interface for jet physics
  for both theorists and experimentalists

FastJet contrib (New: Feb 2013)

- fastjet.fr
- fastjet-contrib
- contrib svn

FastJet Contrib

The fastjet-contrib space is intended to provide a common location for access to 3rd party extensions of FastJet.

Download the current version: fjcontrib-1.003 (released 1 May 2013), which contains these contributions. Changes relative to earlier versions are briefly described in the NEWS file.

Package	Version	Information
GenericSubtractor	1.1.0	README NEWS
JetFFMoments	1.0.0	README NEWS
VariableR	1.0.1	README NEWS
Nsubjettiness	1.0.2	README NEWS
EnergyCorrelator	1.0.1	README NEWS

- a quick and uniform access to 3rd-party code
- contributors are welcome (please contact us)

Conclusion and perspectives

- Jet substructure is a very active field
  - many taggers and groomers around
  - validation by the experiments
  - beginning of a deeper analytic understsanding
- Techniques to subtract pileup
  - area-median subtraction method
  - extension to jet shapes
  - combination with grooming
- FastJet keeps improving (3.1 to be released)