Theory Lessons from LHC Run I

Grégory Soyez

IPhT, CEA Saclay

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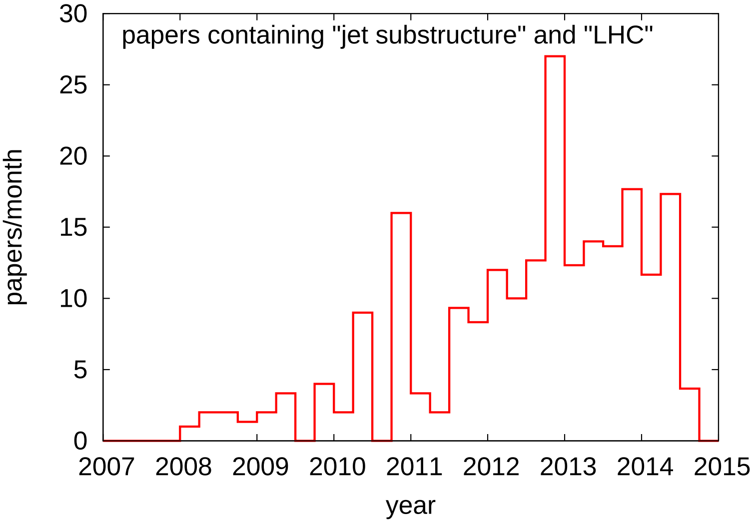
A lot of activity since 2008



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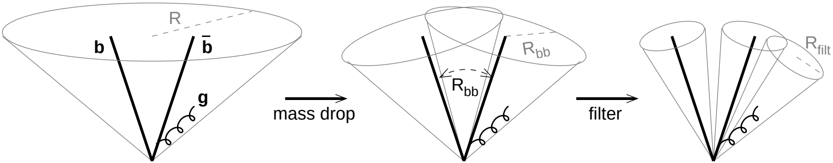
Concentrate on a few critical aspects

- Fundamental ideas, major achievements and lessons from Run I
- Ongoing important transitions
  - from a proof of concept to a first-principle control
  - combining various tools
  - towards high-pileup scenarii and particle-level subtraction

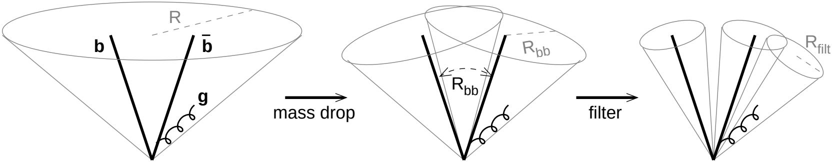
Lessons from Run I

Many tools



- Two major ideas:
  1. Find $N = 2, 3$ hard cores in a jet
     QCD jets typically have a single core + soft radiation
  2. constrain the radiation pattern in jets
     q/g jets radiate soft gluons differently from, *e.g.* $W \to q\bar{q}$

Many tools



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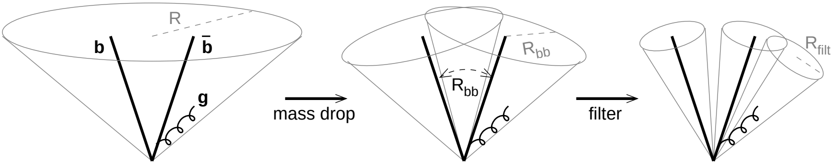
  2. use jet shapes (functions of jet constituents),...



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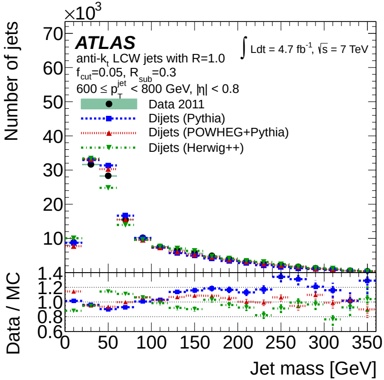
- Many approaches:
  1. uncluster the jet into subjets/investigate the clustering history
  2. use jet shapes (functions of jet constituents),...
- Many tools: mass drop; filtering, trimming, pruning; soft drop; N-subjettiness, planar flow, energy correlations, pull; template methods; Johns Hopkins top tagger, HEPTopTagger; ...

Main lesson from Run I: it works!

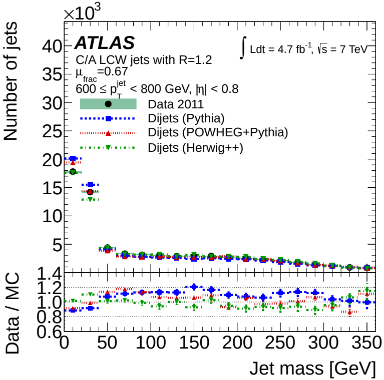
As you (probably) already heard from Emily (and Ben)

- these ideas do work in practice (*i.e.* on real data)
- sometimes surprise/differences wrt Monte-Carlo simulations

Trimming



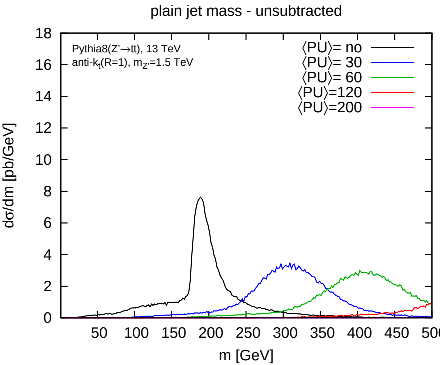
Mass-drop+filtering

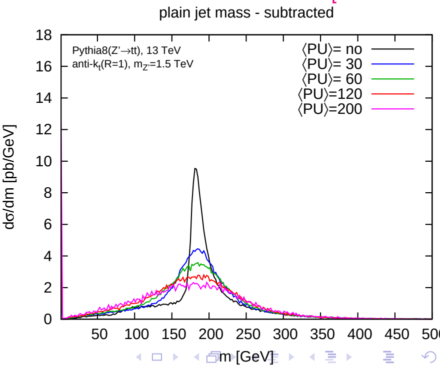


Pileup effects are mostly under control:

- not obvious for fat jets (p_t offset$\sim R^2$, smearing $\sim R$)
- Area-median subtraction corrects for the shift

[Boost 2012]





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  offset$\sim A_{\text{groomed}} < A_{\text{jet}}$, smearing $\sim \sqrt{A_{\text{groomed}}} < \sqrt{A_{\text{jet}}}$
  Note however that it affects the perturbative structure of the jet!

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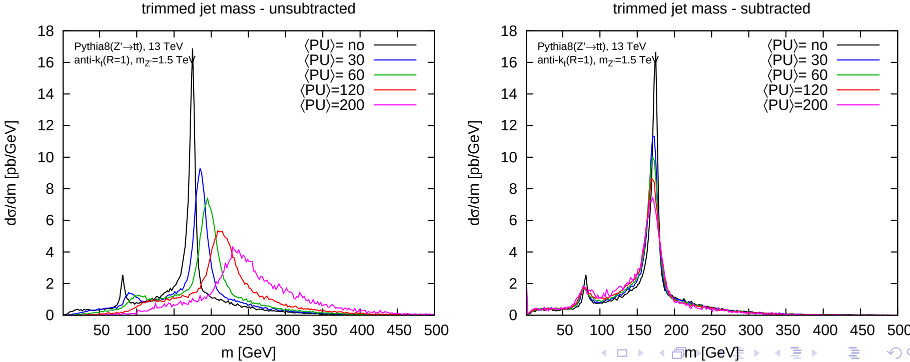

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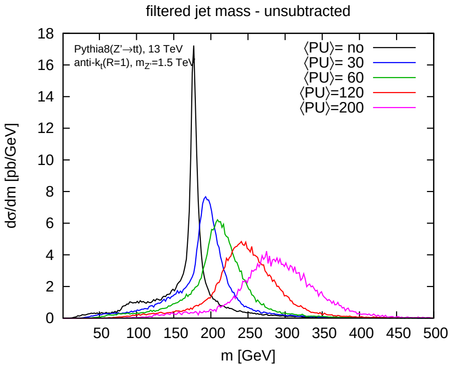
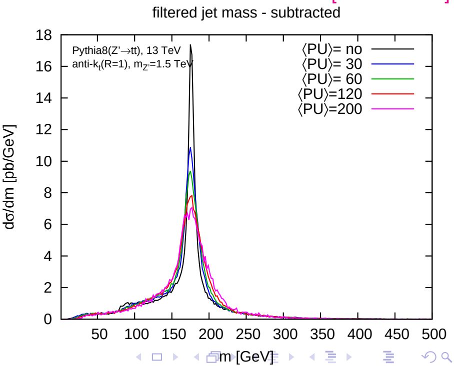




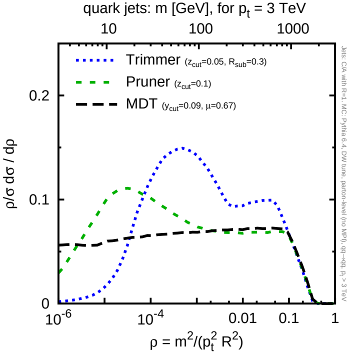
Looking towards Run II

First-principle understanding

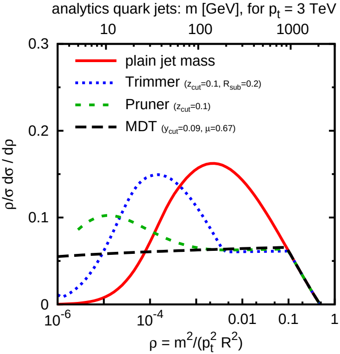
[M.Dasgupta,A.Fregoso,S.Marzani,G.Salam,13]

First analytic understanding of jet substructure:

Monte Carlo



Analytics



- Similar behaviour at large mass/small boost (region tested so far)
- Significant differences at larger boost

Remarks

Analytic control teaches many lessons:

- Mass-Drop:
  - Single-log behaviour
  - Original mass-drop tagger had an extra "mass-drop" condition: no contribution at this order
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- Trimming:
  - Same as mass-drop for $\rho \geq f_{\rm filt}(R_{\rm filt}/R)^2$
  - double log behaviour ($\log^2(1/\rho)$) of plain jet mass for $\rho < f_{\rm filt}(R_{\rm filt}/R)^2$

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- Pruning: more complicated structure

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- Pruning: more complicated structure
- Generically: transition points understood

Many other analytic studies

- Ratio of angularity, Sudakov-safe observables (A.Larkoski, J.Thaler)
- SoftDrop (see below+Simone's talk)
- many SCET calculations (N^3LL for N-subjettiness, ...)

Looking towards Run II

Combining methods

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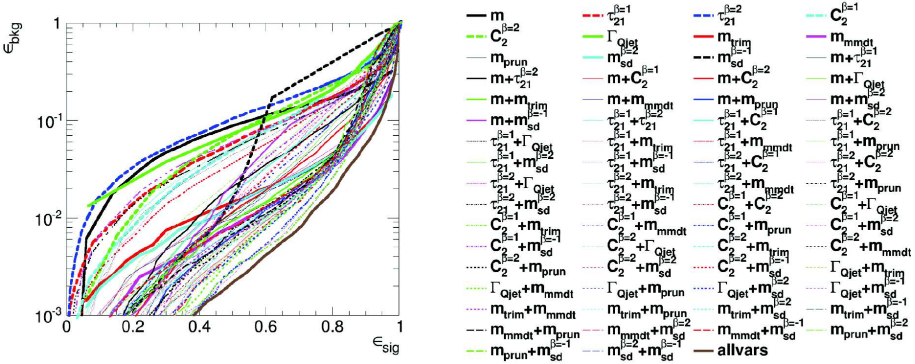
[Boost 2013]



- Combination largely helps
- details not so obvious

Combining methods:

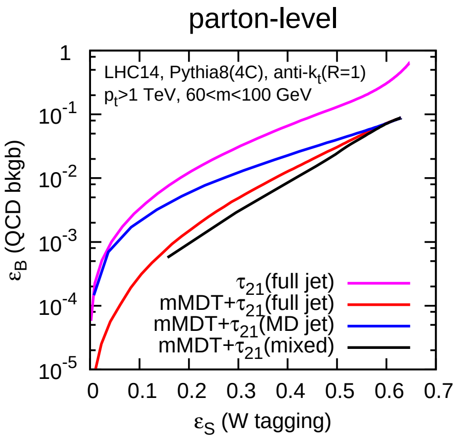
(theory) points for future discussions

Understanding these correlations would be great:

- "prong finders" are expected to be correlated: if they're not, why?
- "radiation constrainers" are expected to be correlated: if they're not, why?
- "prong finders" expected to be decorrelated from "radiation constrainers": if they're not, why?

(see also Jesse's talk for combinations in q/g discrimination)

Example: mMDT + N-subjettiness



- Combining helps!
- Various options for τ_{21}
  - τ_2 and τ_1 from the full jet
  - τ_2 and τ_1 from MD'd jet
  - τ_2 from MD, τ_1 from full
- mixed case most efficient
  - τ_1 from MD: 2-prongs resolved
  - τ_2 from full: reach large angles

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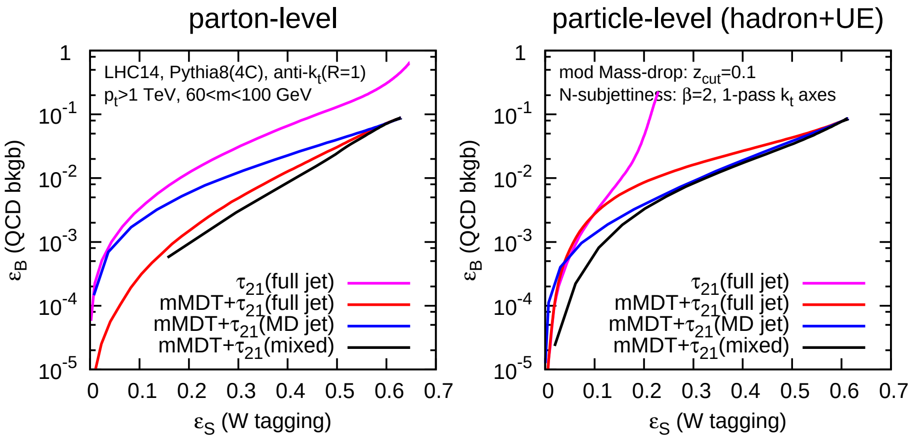


- Non-perturbative effects can change the picture quite drastically
- using mass-drop everywhere (*i.e.* grooming) limits NP effects

SoftDrop

[A.Larkoski,S.Marzani,GS,J.Thaler,14]

In a nutshell

- angular-dependent cut

$$z > z_{\rm cut}(\theta/R)^{\beta}$$

- $\beta > 0$: grooming
  $\beta = 0$: mass-drop tagger
  $\beta < 0$: more aggressive tagging
- Under analytic control
  (albeit double log for $\beta \neq 0$)

In the context of tools combinations

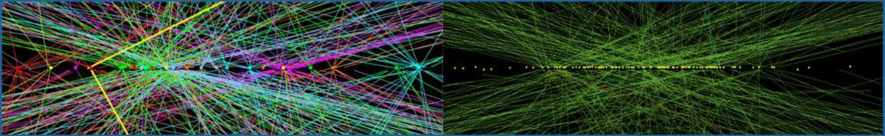
Tune β and $z_{\rm cut}$ to groom away non-perturbative contamination (more robust than trimming)

(see Simone's talk)

Looking towards Run II

Better pileup subtraction

Recent "pileup mitigation" workshop



Mitigation of pileup effects at the LHC

Salam, Gavin
Moortgat, Filip
Schwartzman, Ariel Gustavo

Starts 16 May 2014 08:00
Ends 18 May 2014 18:30

- $\sim$40 participants
- open sessions for discussions, comparisons and work

Recent "pileup mitigation" workshop

Pileup subtraction from jets

- ConstituentSubtractor [P.Berta,M.Spousta,D.Miller,R.Leitner,arXiv:1403.3108]
  particle-ghost balance for shape subtraction (see Peter's talk)
- NpC [M.Cacciari,G.P.Salam,GS,arXiv:1404.7353]
  uses neutral-to-charged proportionality (see maybe Matteo's talk)
- cleansing [D.Krohn,M.Low,M.D.Schwartz,LT.Wang,arXiv:1309.4777]
  Uses subjets and neutral-to-charged proportionality
- PUPPI [D.Bertolini,P.Harris,M.Low,N.Tran,arXiv:1407.6013]
  Pileup Per Particle Identification (see Philip's talk)
- SoftKiller [M.Cacciari,G.P.Salam,GS,arXiv:1407.0408]
  Pileup mitigation through soft-particle removal (see Matteo's talk)

Recent "pileup mitigation" workshop

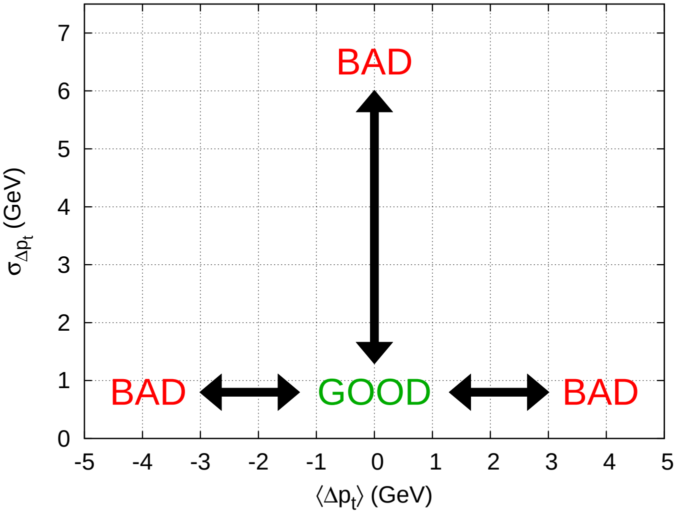
"pileup jets"

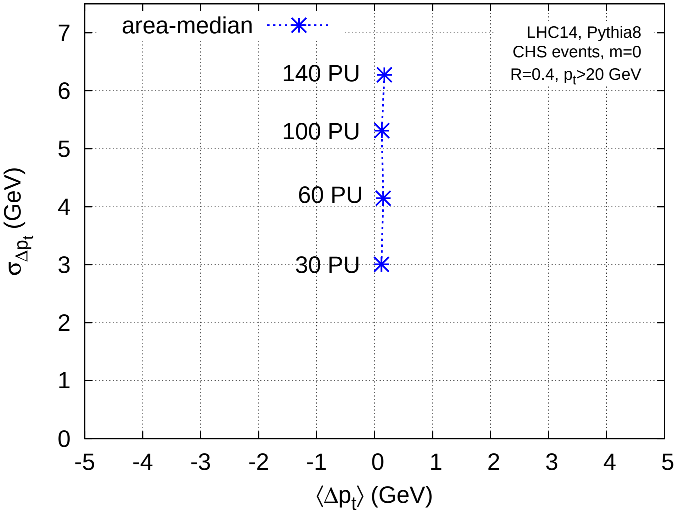
- JetVertex (JVF and corrJVF) P.Nef,A.Schwartzman
  Identifies if a jet is a pileup or a real jet

Other aspects covered

- Missing E_T determination
- Experimental aspects

Example of the work done in the PU workshop





The standard approach today

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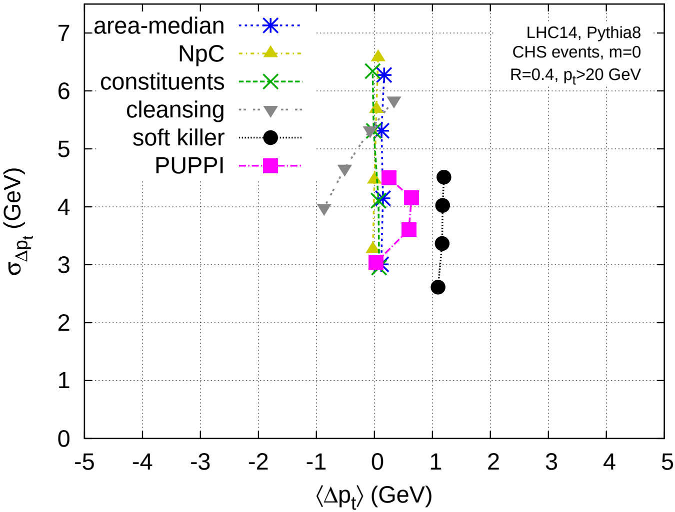

very promising methods for the future

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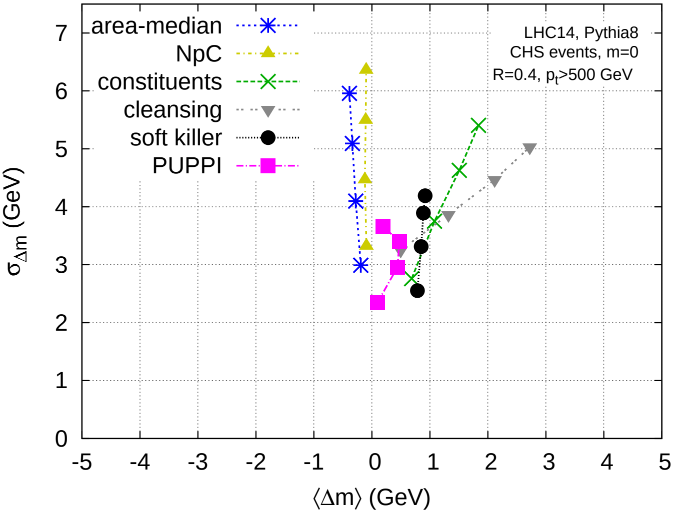

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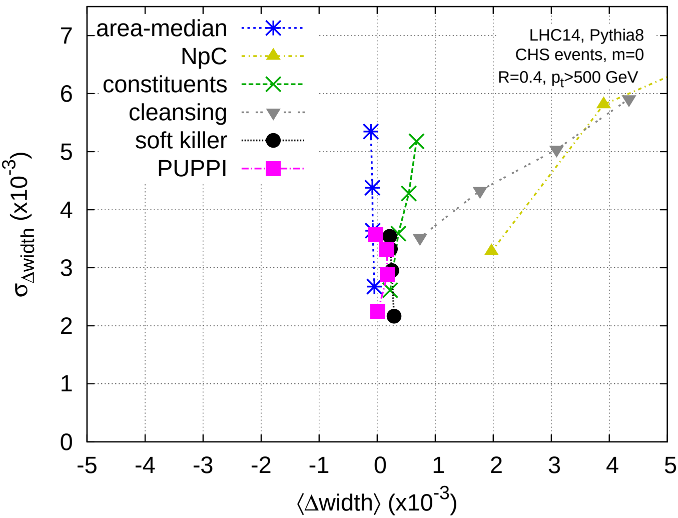

very promising methods for the future

Looking towards Run II

Computer interfaces

FastJet

FastJet 3.1.0-beta1 out last week

(Excerpt of the) major features

- Speed improvements (1.5-10 for $N \sim 2000 - 10^5$)
- Native particle-mass support in PU estimation and subtraction
- FASTJET_VERSION_NUMBER preprocessor symbol (in-code testing)
- New Recluster class, serving as base for Filter
- Fixed long-standing issue with coincident points in NlnN strategies

see the FastJet tutorial and www.fastjet.fr)

FastJet contrib

Version 1.014 of FastJet Contrib with the following packages

Package	Version	Information
ConstituentSubtractor	1.0.0	README NEWS
EnergyCorrelator	1.0.1	README NEWS
GenericSubtractor	1.2.0	README NEWS
JetCleanser	1.0.1	README NEWS
JetFFMoments	1.0.0	README NEWS
JetsWithoutJets	1.0.0	README NEWS
Nsubjettiness	2.1.0	README NEWS
RecursiveTools	1.0.0	README NEWS
ScJet	1.1.0	README NEWS
SoftKiller	1.0.0	README NEWS
SubjetCounting	1.0.1	README NEWS
VariableR	1.1.1	README NEWS

- 3$^{\mathrm{rd}}$-party contributions in a single location
- see `www.fastjet.fr`
- contributors welcome

See also in this workshop

Other relevant talks this week

- Rivet tutorial (see Andy's talk)
- Wavelet decomposition (see James's talk)
- Fuzzy jets (see Ben's talk)
- Qjets (see Andrew's talk)
- Matrix element + parton shower (see Keith's and Marek's talks)
- data-driven templates (see Martin's talk)

Instead of a conclusion

Past (LHC Run I)

- Myriad of available jet substructure tools
- Run I has shown that it is a (very) promising field

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Future: (my) (theory) wishlist

Pursue the analytic effort engaged over the past year

- understand combination more deeply
- can we avoid non-perturbative effects?
- see measurements to confirm(inform) these understandings
- "Collinear Monte-Carlo simualtions" not necessarily suited for all fat jet studies
- Higher energy/luminosity in Run2 $\Rightarrow$ new challenges/opportunities