The BOOST2012 report

Marcel Vos (IFIC, CSIC/UV, Valencia, Spain)

BOOST 2013 – Arizona - 11/08/2013

Boosting new physics since 2009...

The BOOST series

SLAC 2009

Oxford 2010 *Eur. Phys. J. C71 (2011) 1661 (122 citations)*

Princeton 2011 *J.Phys.G G39 (2012) 063001 (cited 67 times)*

Valencia 2012 *this talk*

Arizona 2013 *discuss this week...*

Europe 2014?

America 2015?

Report?

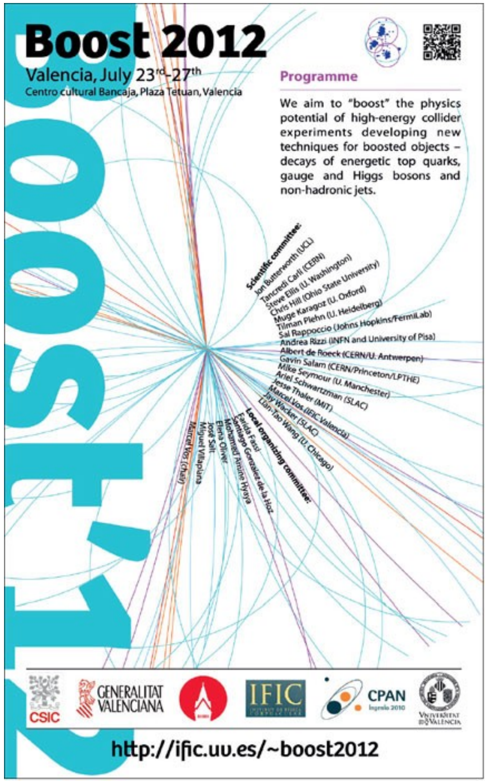
Report, not proceedings, nor review...
[well, 2010 is used as a review, 2011 has sections that have a proceedings feel]

They may come out a year later [but preferrably before BOOSTn+1]

They must contain new work [working groups have been formed and editors assigned in an ad hoc fashion shortly before or during the workshops]

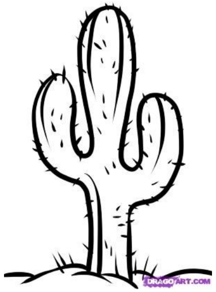
EPJC welcomes a 2012 report

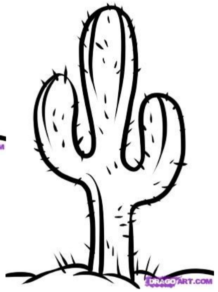
BOOST2012-3

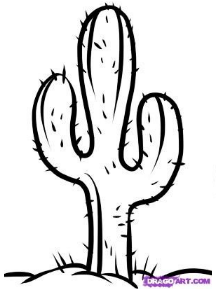


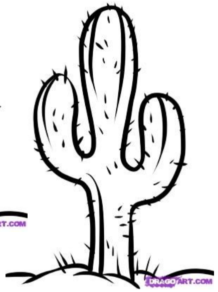
Boost 2012
Valencia, July 23rd-27th
Centro cultural Bancaja, Plaza Tetuan, Valencia
Programme
We aim to "boost" the physics potential of high-energy collider experiments developing new techniques for boosted objects – decays of energetic top quarks, gauge and Higgs bosons and non-hadronic jets.
Scientific committee:
Local organizing committee:
GENERALITAT VALENCIANA
IFIC
CPAN
http://ific.uv.es/~boost2012

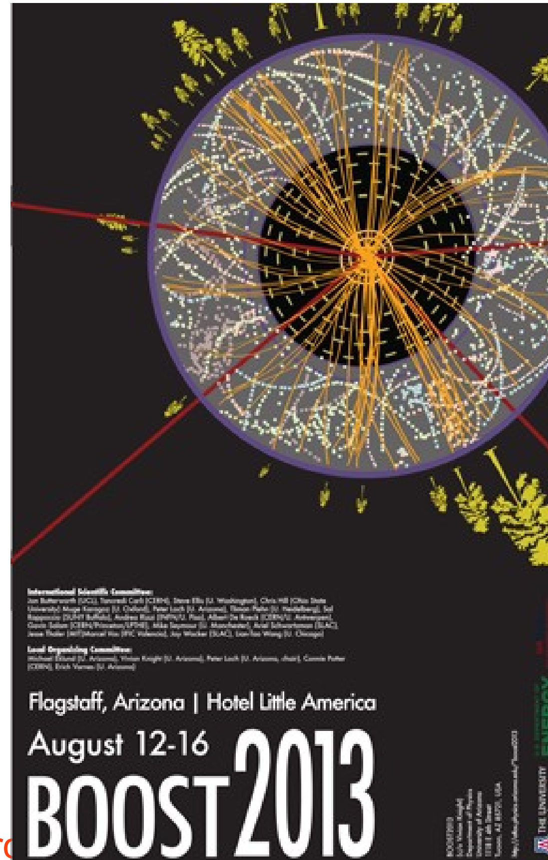
MADNESS
DESPAIR
NO THRU ROAD





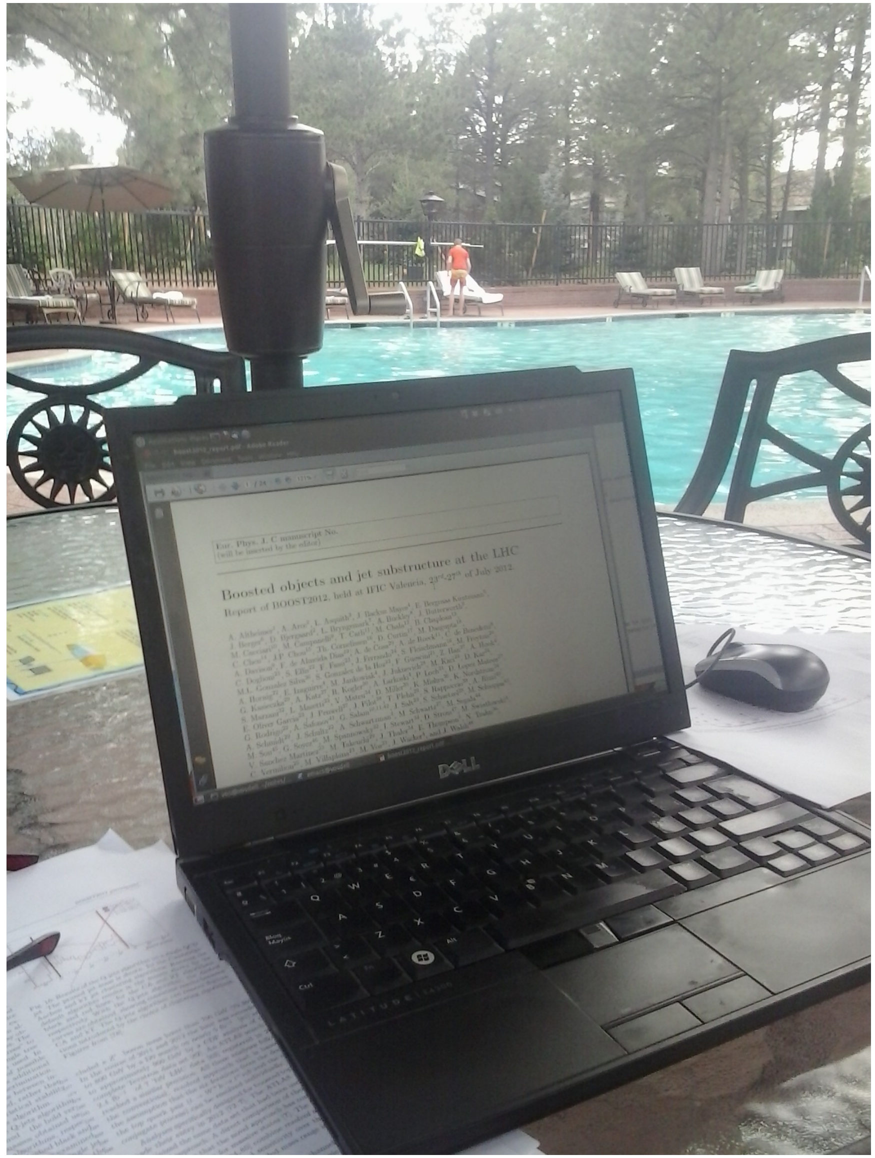






Flagstaff, Arizona | Hotel Little America
August 12-16
BOOST 2013

Report?


Eur. Phys. J. C manuscript No.
Boosted objects and jet substructure at the LHC
DELL

Working groups BOOST2012:

- **First principle calculations:** Andrew Hornig, Simone Marzani

- **MC modeling:** Ayana Arce, Deepak Kar

- **Detector response:** Ariel Schwartzman
    - fake jets due to pile-up
    - grooming, pile-up and jet mass

- **Boosted top:** Justin Pilot, Marcel Vos

- **Boosted Higgs:** XXX

First-principle calculations

Question: can we calculate jet substructure precisely ?

- Jet substructure observables computed to NLO accuracy typically contain large logarithms of ratios of involved scales (p_T/m) that must be resummed.
- Two approaches:
  - pQCD exploits factorization and exponentiation properties of QCD matrix elements and of the phase-space in the soft or collinear limits.
  - SCET factorizes hard, soft, and collinear modes at the Lagrangian level.

First principle vs. MC

- Calculations correct to NNLL can be obtained (cf. Monte Carlo is typically LL)
- Understanding: even if our MC description will get better (better model, tuning), it will always remain a black box. Analytical calculations lead to an enhanced understanding of jet substructure tools. Knowing 'how' and 'why' things work may guide our choices (see Simone Marzani's talk).

First-principle calculations

Two-page contribution to BOOST report:

"what we now know and what we may reasonably hope to understand and calculate in the short- and mid-term future."

A program towards a meaningful comparison of measurements and theory predictions

Available calculations: pQCD and SCET jet mass + several other observables

V+jets has easier colour structure than multi-jet production
SCET likes quantities to be exclusive in the number of jets
Discussion of differences in approach between the two "schools"

Available measurements:

jet mass, filtered jet mass, splitting scales, n-subjettiness, jet shapes on multi-jet events (ATLAS 2011)
Jet mass, groomed jet mass on multi-jet events and W+jets (CMS 2012)

Suggested measurements:

Jet mass on Z+jets (or W+jets), inclusive and exclusive in the number of jets

MC modeling

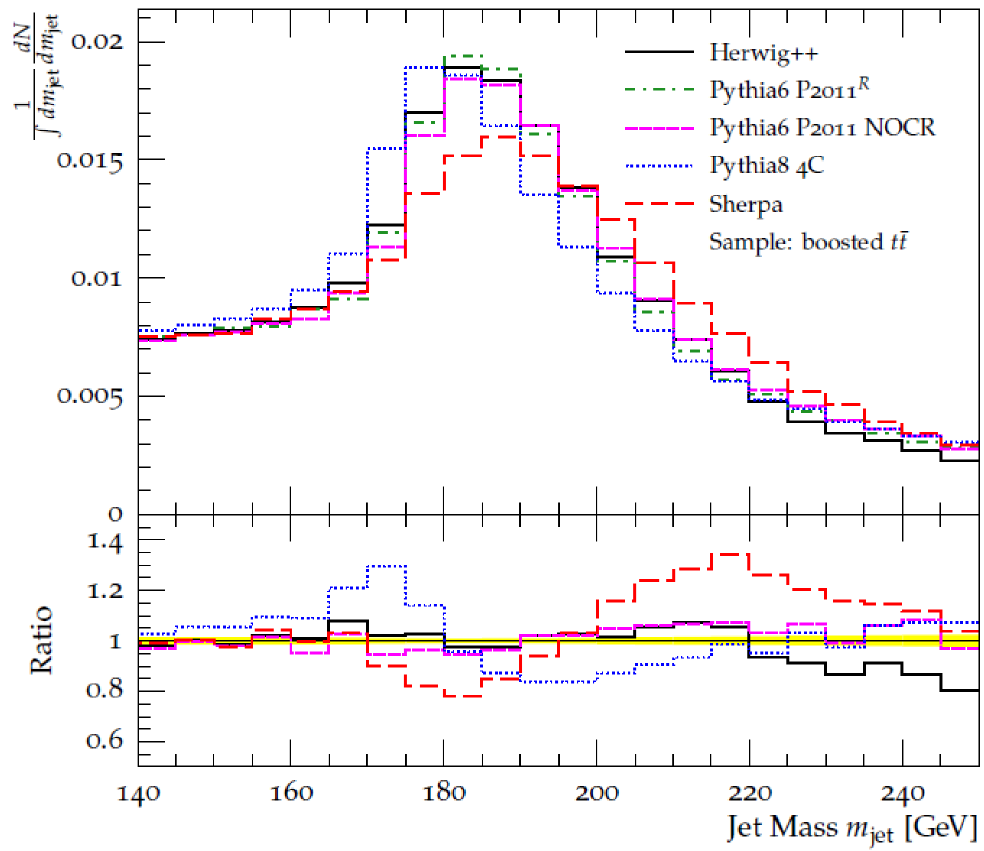
For the ongoing and immediate future LHC program, rely on MC

Understand how reliably it work, identify limitations, remedy if possible
RIVET code for large number of observables
several samples (boosted top, W+jet, multi-iets)

Some generators have serious "issues" with jet mass.
Maximum excursions in ratio wrt an "average" MC ~ 20-30%

Pythia8 is softer than Pythia6
Sherpa is harder than Pythia6
Herwig++ agrees with Pythia6

Data will tell who's right (next round)

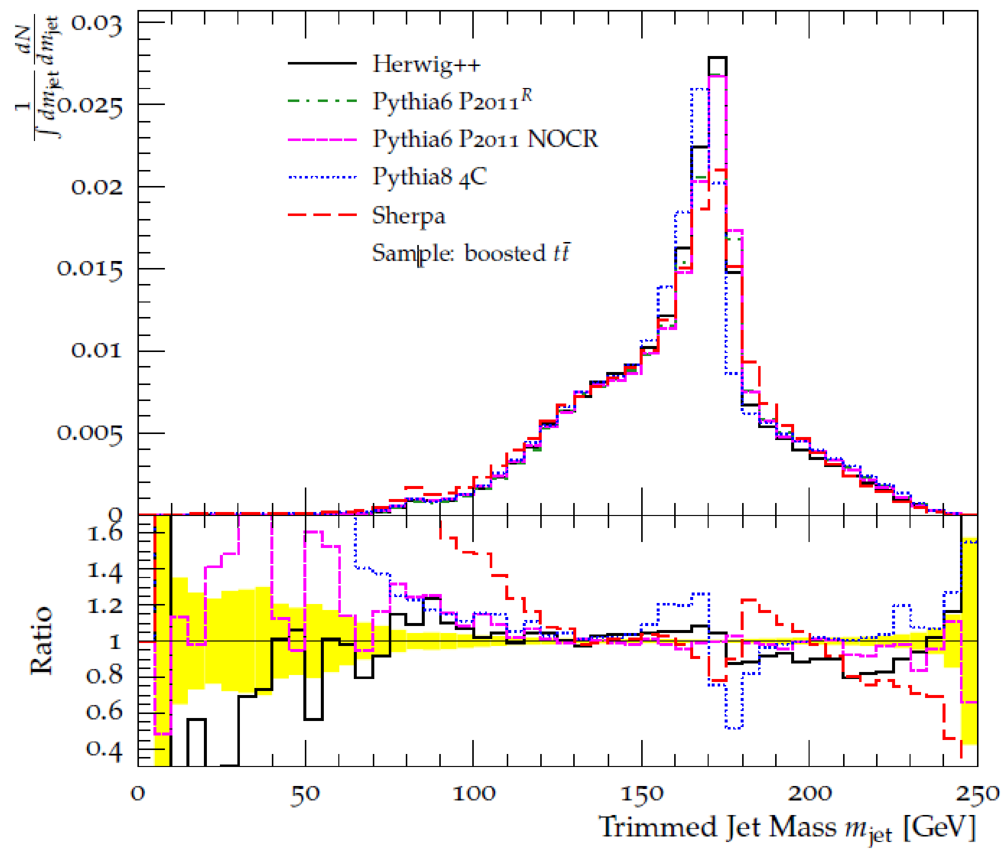


MC modeling

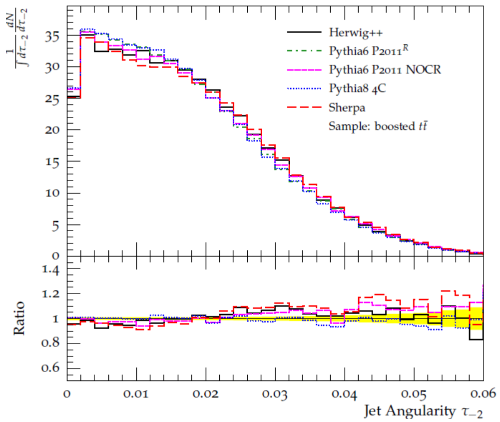
Common wisdom
Jet grooming allows to avoid “soft stuff” and thereby reduces the variance among generators

Sure, excursions in ratio in relevant part of the spectrum are now ~10%

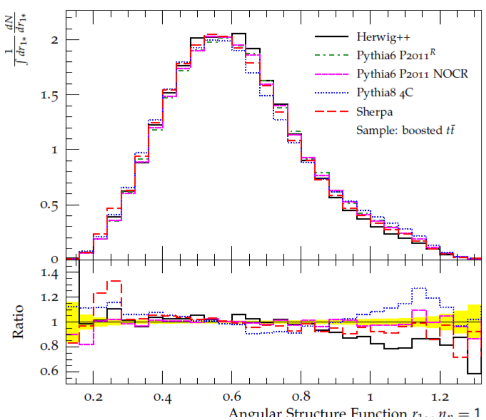
Filtering and pruning
→ qualitatively the same conclusion.



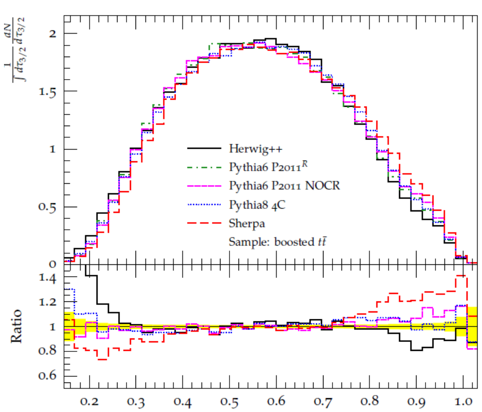
Other substructure observables



Angularity



Angular structure function



n-subjettiness τ_{32}

Whatever you do, it's better described than jet mass

Could one write, say, a top-tagger based only on well-described observables? Would it be any good from other aspects?

Define a figure of merit 'predictability' for observables: an appropriately defined measure of the spread over a standard set of generators

Also looked at color flow and jet charge

marcel.vos@ific.uv.es

Detector response

A. Schwartzman, P. Loch, D. Miller, K. Mishra, P. Nef, G. Soyez

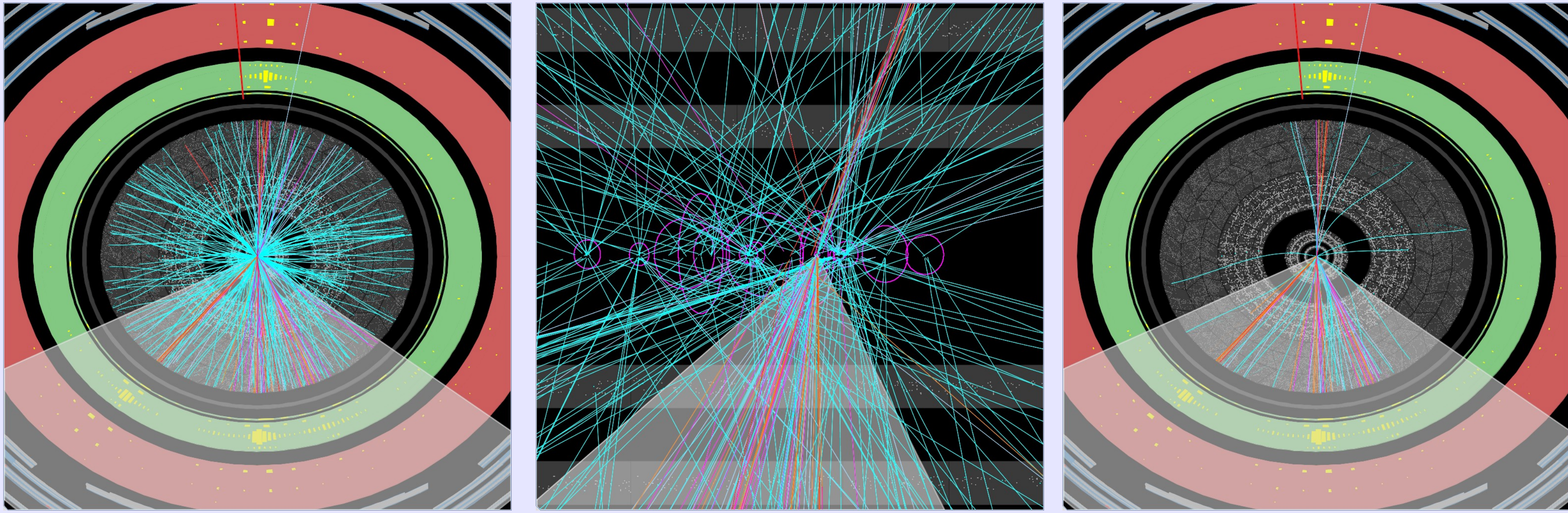
We shouldn't take for granted that we can measure jet substructure precisely and reliably.

Two main limitations:

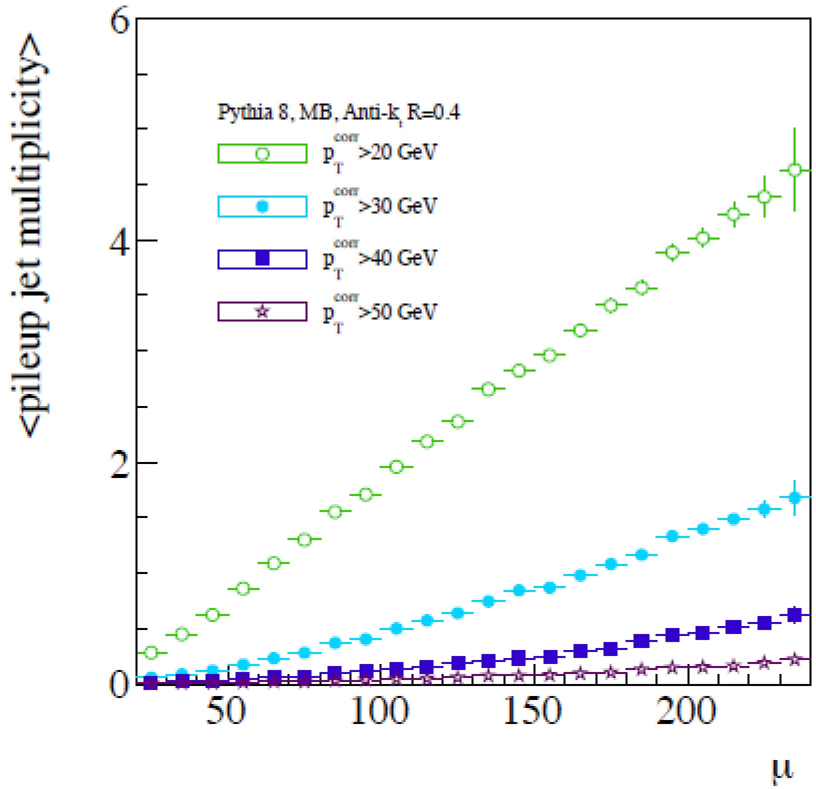
Detector granularity (or PFA association)

Pile-up

How does this scale to high-lumi LHC operation?



Detector response



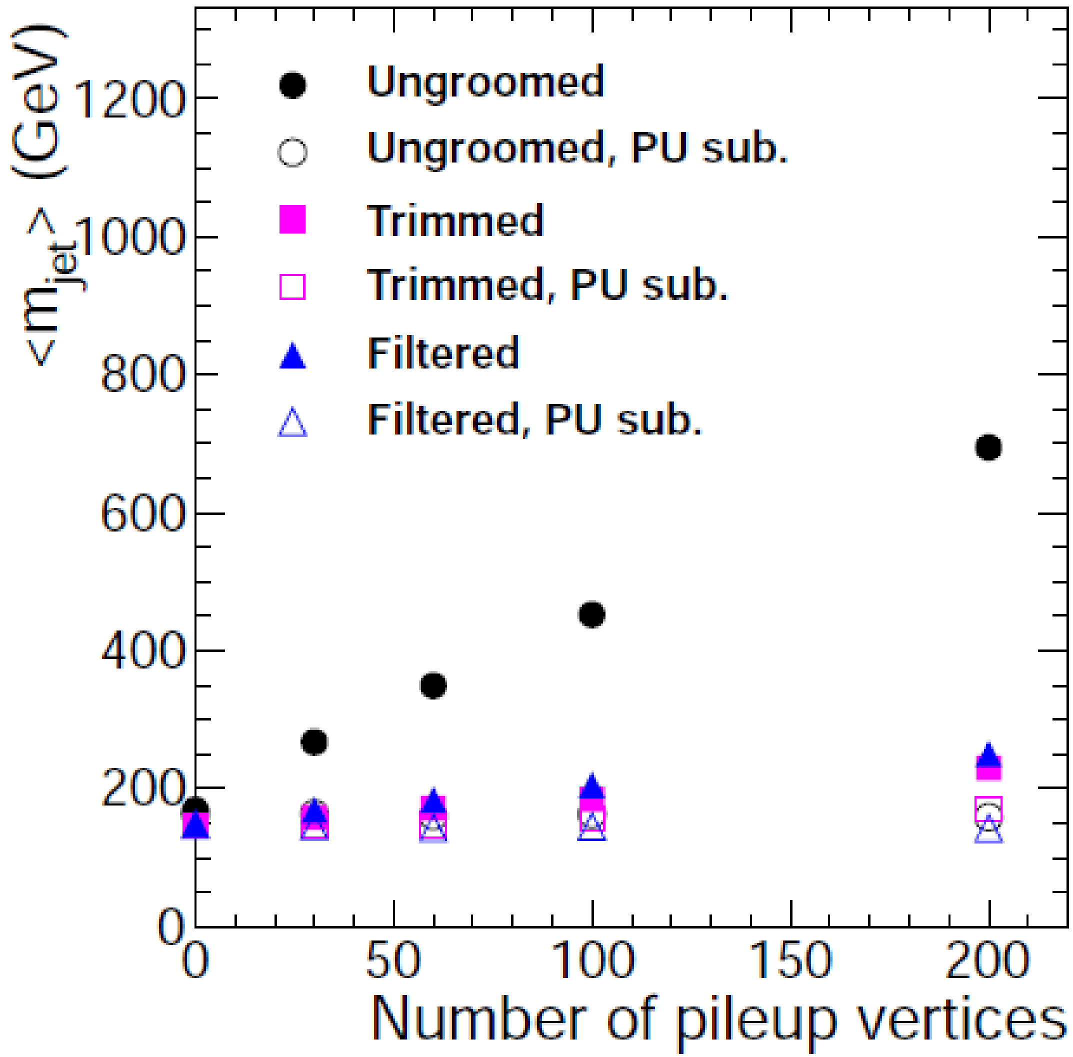
Reconstruct R=0.4 jets on events that contain nothing but pile-up

Count the number of jets above a certain p_T cut and study their properties

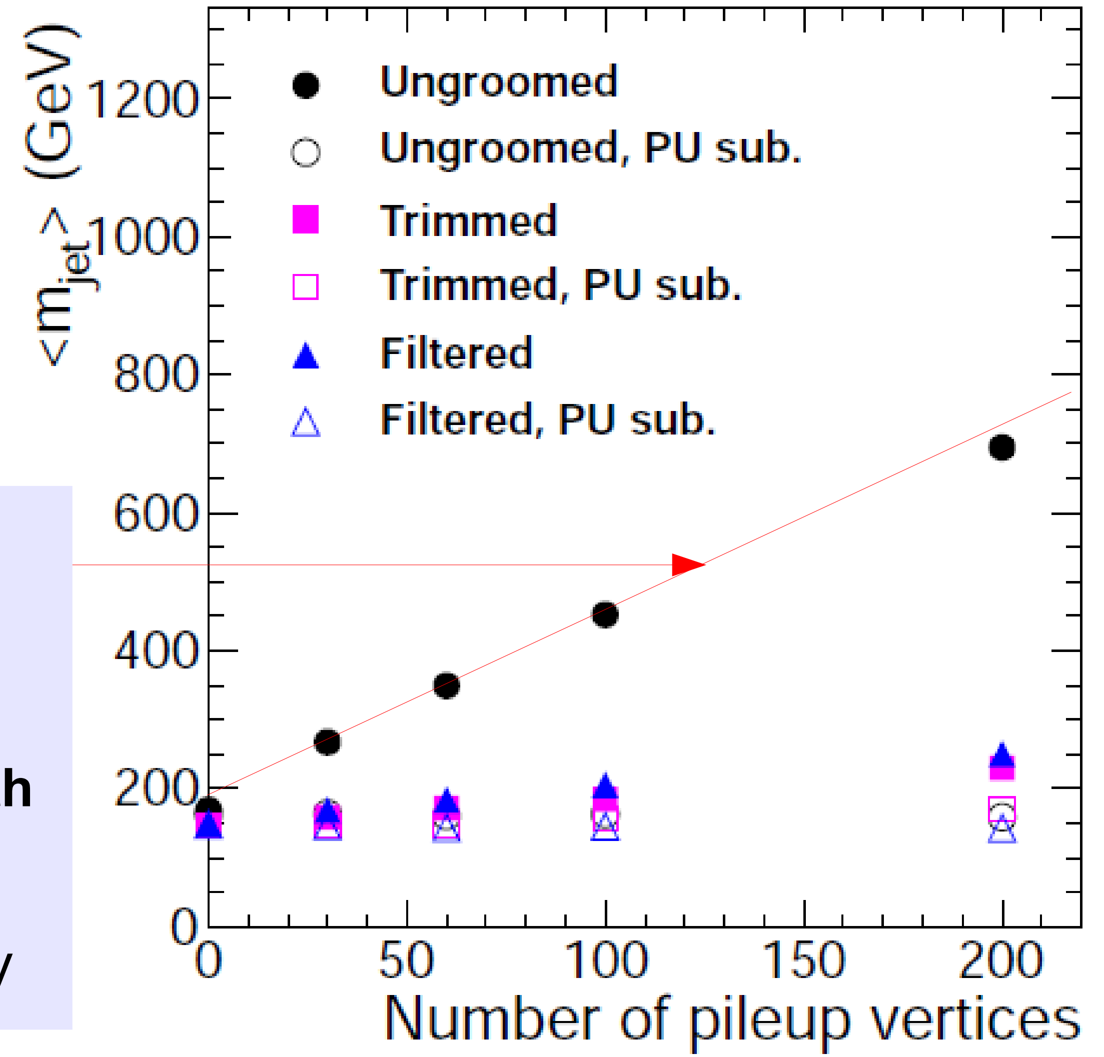
With O(100) interactions most jets are “stochastic”

Even after area-based pile-up subtraction on average two jets with p_T = 20 GeV remain when 100 interactions are overlaid

Detector response



Detector response

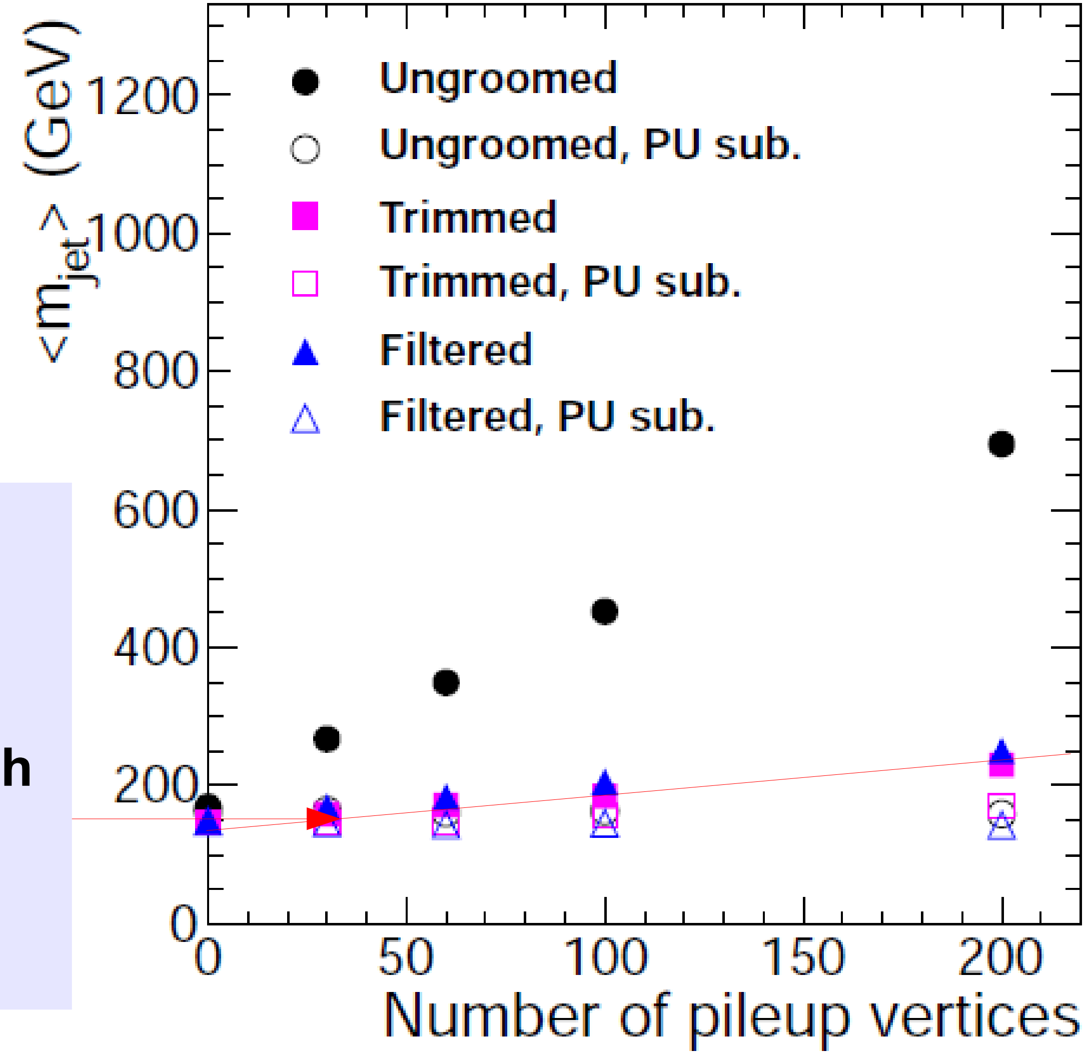


Jet mass (anti k_t, R=1) grows with pile-up:
~3 GeV/interaction

Future LHC operation with >100 interactions/bunch crossing:
$m_j = m_t$ + over 300 GeV

Ooops!

Detector response



Grooming mitigates the impact of pile-up:

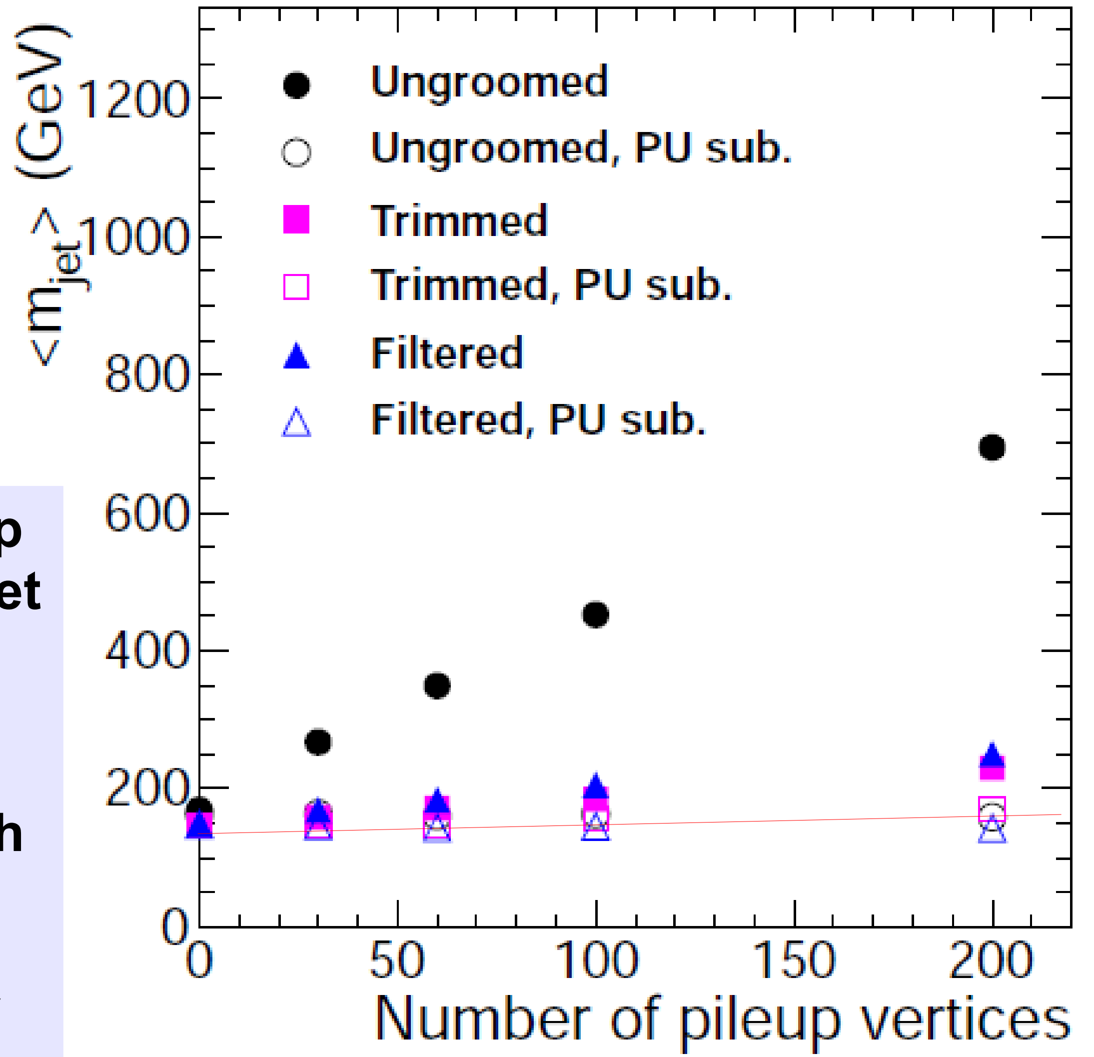
~0.4 GeV/interaction

Future LHC operation with >100 interactions/bunch crossing: :

$m_j = m_t$ + over 30 GeV

No surprise... Maybe this: grooming alone is not sufficient

Detector response



Adding area-based pile-up subtraction restores the jet mass scale:

~0 GeV/interaction

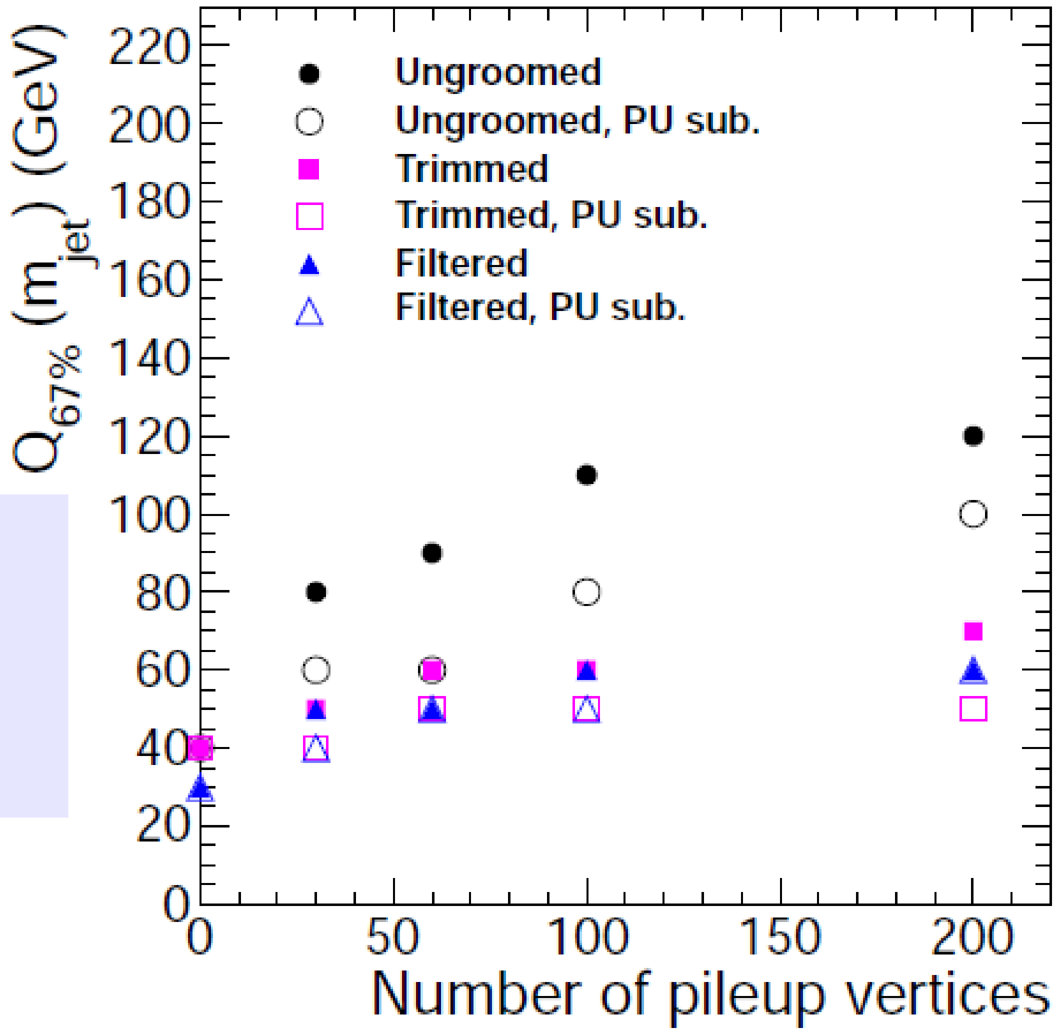
Future LHC operation with >100 interactions/bunch crossing: :

$m_j = m_t$ + maybe 3 GeV

OK! This works up to any number of interactions

Detector response

Resolution: this is what really matters!



Subtraction alone is not good enough!

Grooming is essential to keep the peak narrow

Take away message: grooming and pile-up subtraction keep jet substructure and fat jets alive up to 200 int./BX

The "boosted production" threshold

$\sqrt{s} >> E_{EW}$

Even the heaviest SM particles often acquire p_T > m

→ abundant production of "boosted objects"

A top factory, our first sample of boosted top quarks

Expected number of tt events in three different kinematical remies	*Tevatron run II* 10 fb^{-1} @ 1.96 TeV	*LHC 2012* 20 fb^{-1} @ 8 TeV	*LHC design* 300 fb^{-1} @ 13 TeV	*Very LHC* 300 fb^{-1} @ 33 TeV
Inclusive tt production	57.000	2.600.000	155.000.000	1.000.000.000
Boosted production: M_{tt} > 1 TeV	25	30.000	3.000.000	46.000.000
Highly boosted: M_{tt} > 2 TeV	0	300	47.000	2.300.000

Enough to discover the top quark, no boosted production

Millions of boosted top quarks, 50.000 extremely boosted events

M.V., Boosting sensitivity to new physics, CERN Courier, Oct 2012

Results obtained with MCFM, J. M. Campbell and R. K. Ellis, arXiv:1204.1513 [hep-ph] MSTW2008NLO PDFs

Boosted top quarks

Our favorite boosted object

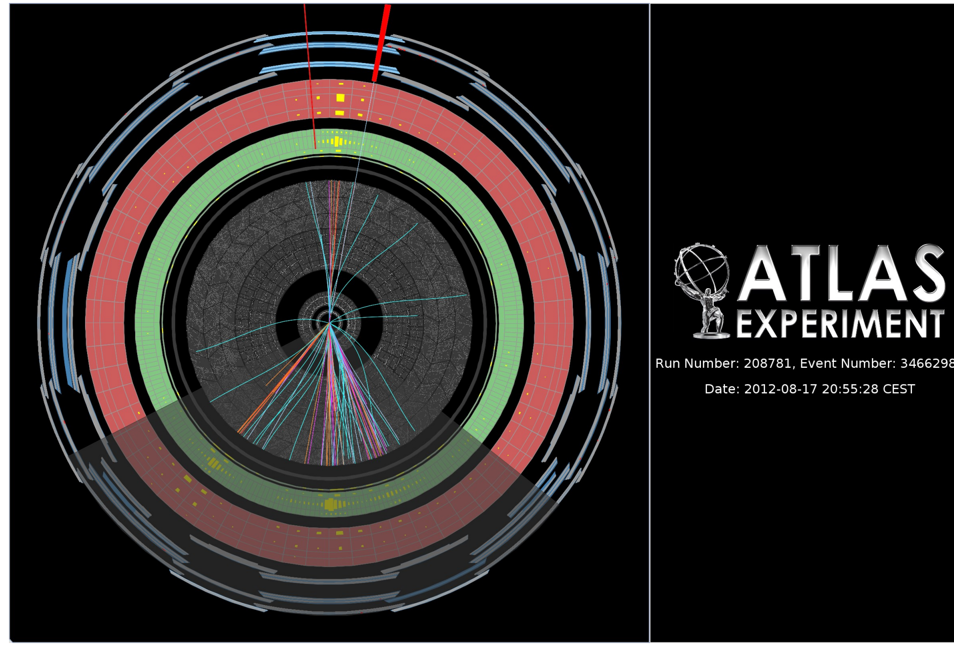
Bread-and-butter selection

Useful in performance studies
(+ source of boosted W)

Taggers deployed in experiments since some time

Searches for $t\bar{t}$ resonances in l+jets and fully hadronic channels

Evaluate sensitivity of different approaches, including "classical" approach

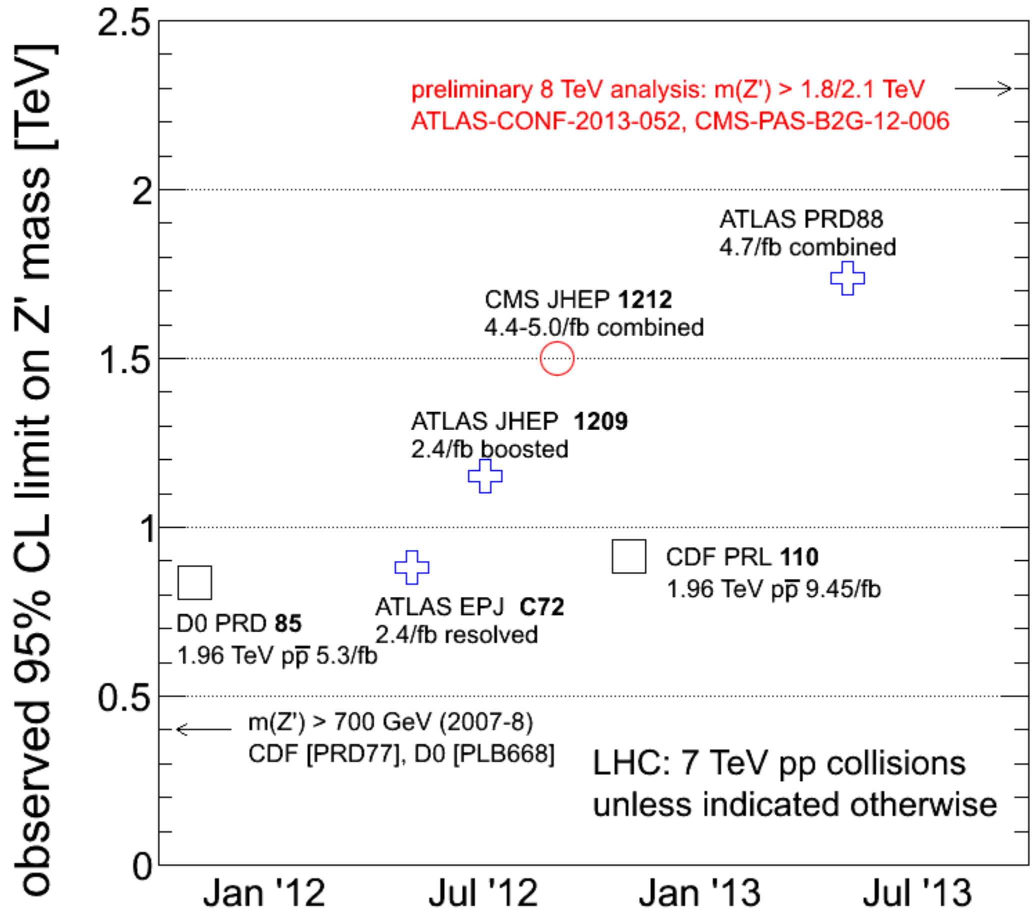


$m_{tt} \sim 2.5$ TeV
ATLAS-CONF-2013-052

Resonance searches

Narrow Z' is a sufficiently stable benchmark that it can be used to monitor progress

l+jets analyses only. Searches in fully hadronic events are close behind!



Fat jet systematics are dominant contribution to the limit. σ x BR limits are ~10% better if fat jets had no uncertainties or if the scale and resolution uncertainties were twice as small

- Keep improving understanding of jet substructure
- Explore further searches
- Take advantage of excellent truth-to-reco mapping → differential x-sec

marcel.vos@ific.uv.es

Conclusions

A 24-page report has been produced based on the contributions of four working groups. If you were at BOOST2012 you'll soon receive a draft.

Readers of the report will hopefully:

- be convinced that the analytical predictions of jet substructure are a noble cause and have a clearer view of where we stand
- not trust MC blindly for jet substructure and have some ideas to work around their limitations
- be confident that jet substructure can survive 100 pile-up events: state-of-the-art pile-up correction and grooming can restore the jet mass scale and mitigate the impact on mass resolution
- be able to point to a success story involving boosted objects: the sensitivity for heavy objects decaying to $t\bar{t}$ more than doubled
- be motivated to continue to improve jet substructure uncertainties and encouraged to explore other applications

marcel.vos@ific.uv.es