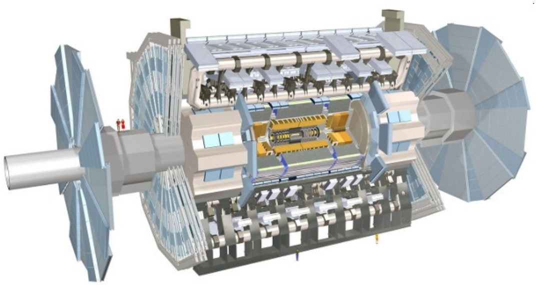
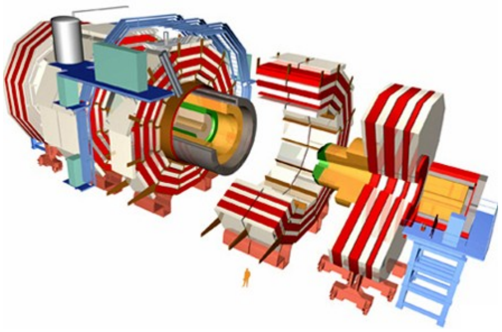
Jets and jet substructure after LHC Run 1



Emily Thompson
Columbia University

on behalf of ATLAS and CMS



BOOST'14 @ LONDON – AUGUST 18, 2014

- Outline:
  - A brief Run1 history, and what have we learned
  - Putting jet substructure techniques to use
  - Run2 and beyond!

Introduction

- BOOST workshop, a history.

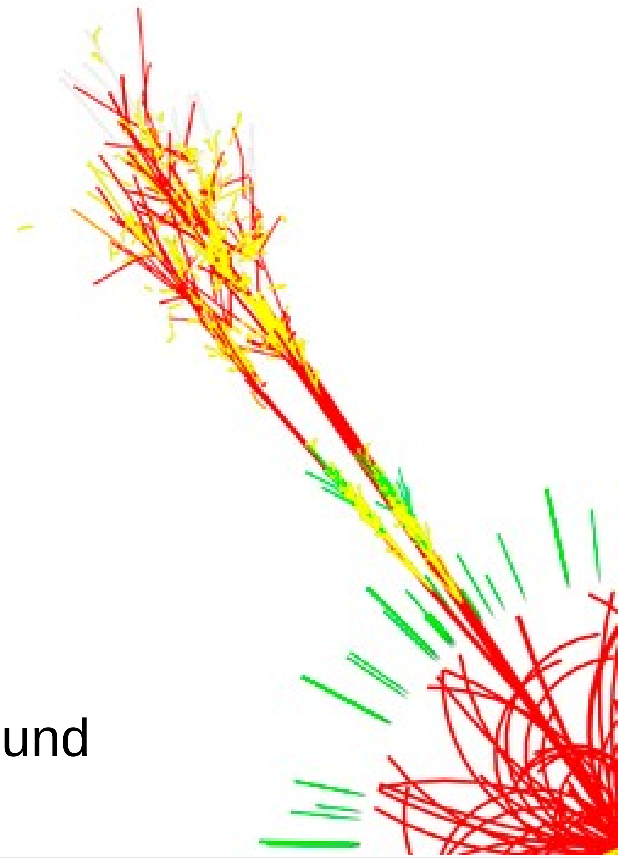
  A Look Back at the Experimental Progression of Substructure at BOOST (from David Miller's summary talk last year)
  - BOOST 2010: These aren't your daddy's jets
  - BOOST 2011: "First" data
  - BOOST 2012: Kids in a candy store
  - BOOST 2013: Bringing substructure into the mainstream

- Theme of Run1:
  - Validating, calibrating and exploiting jet substructure

- BOOST 2014: Getting ready for Run2!

  ...wait, are we ready??

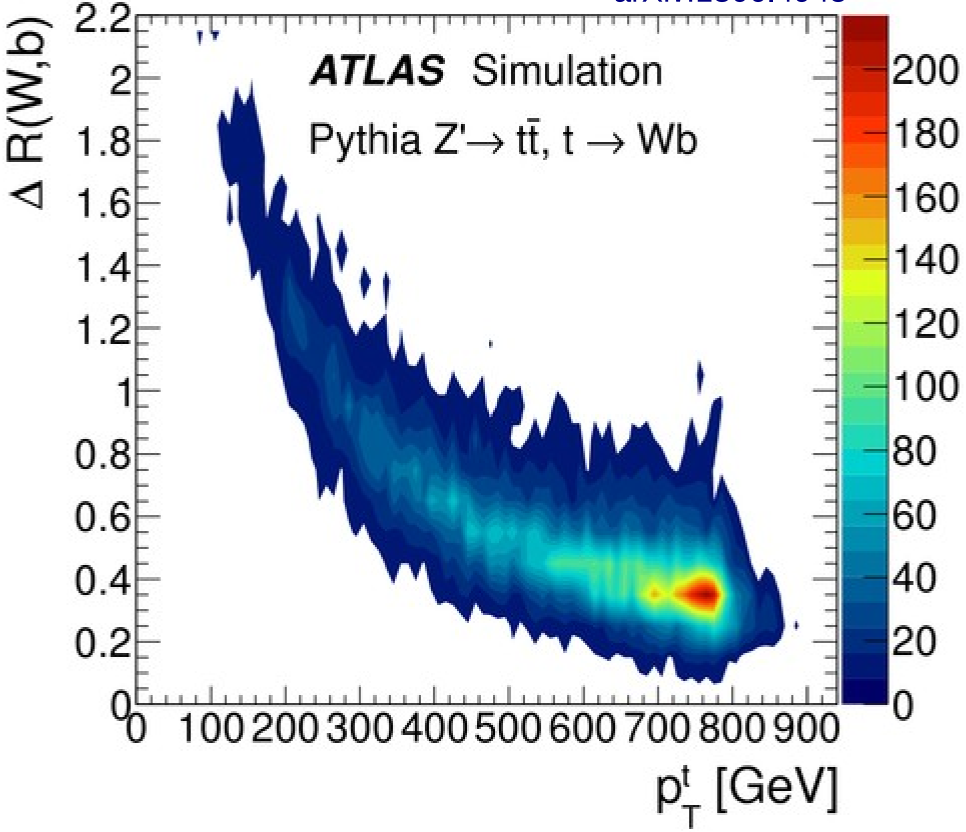
- Go back and ask...what does "boost" mean?
  - High pT
  - Dense environments
  - Tagging boosted objects over a light quark/gluon background

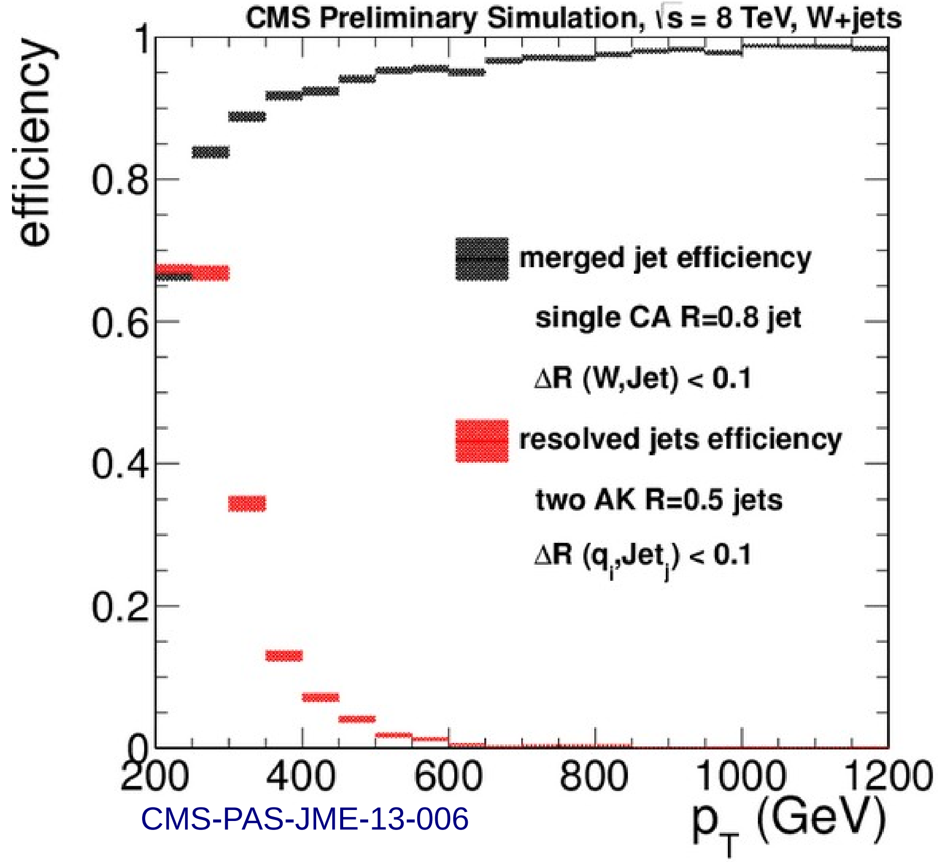


Where we started...

- We knew that new techniques would have to be developed to understand hadronic final states at the LHC
- Needed to convince ourselves it would work, especially in the presence of extreme pileup

arXiv:1306.4945

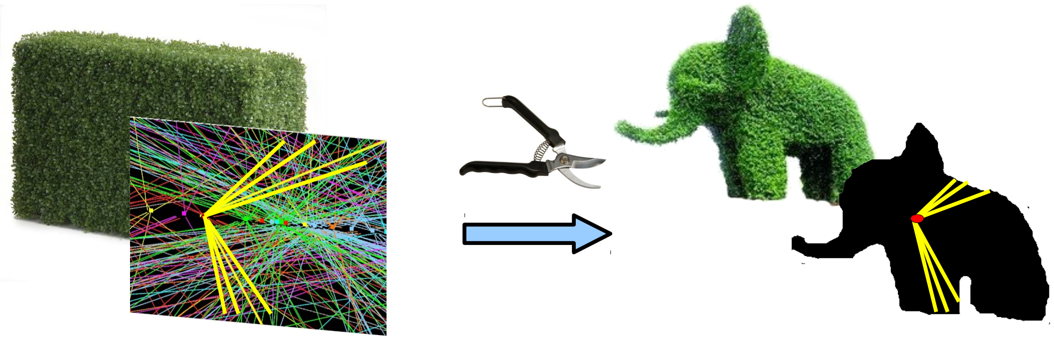


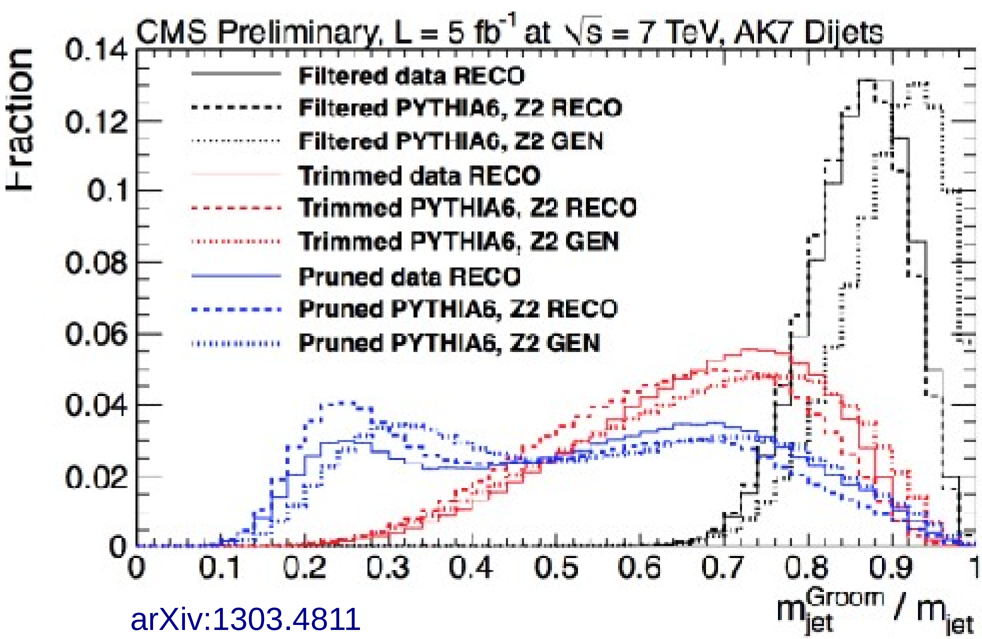


CMS-PAS-JME-13-006

Where we started...

- Pileup mitigation...the three amigos! Trimming, Filtering, Pruning
  - They do it all...use mass to tag a boosted object, maybe with some jet shapes, after performing grooming to remove pileup + UE





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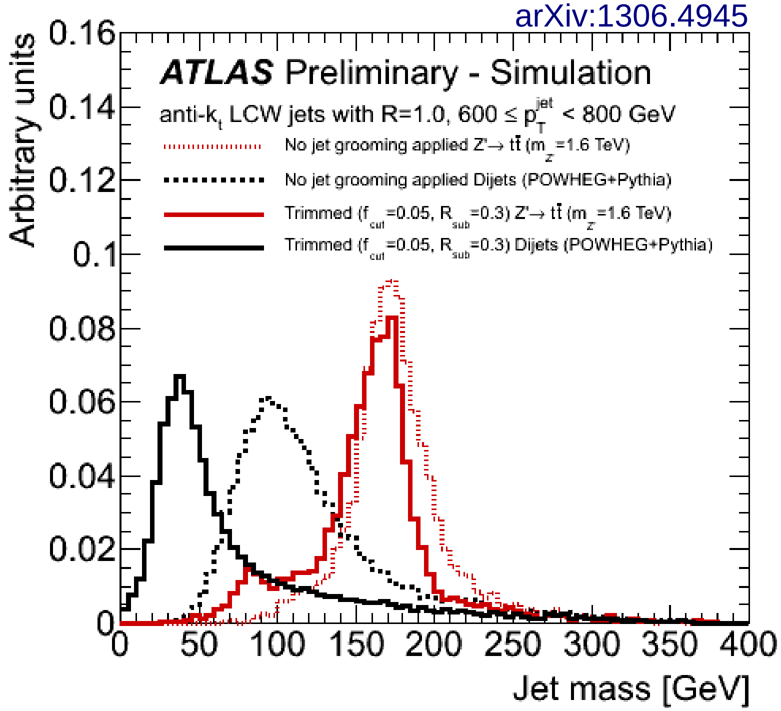
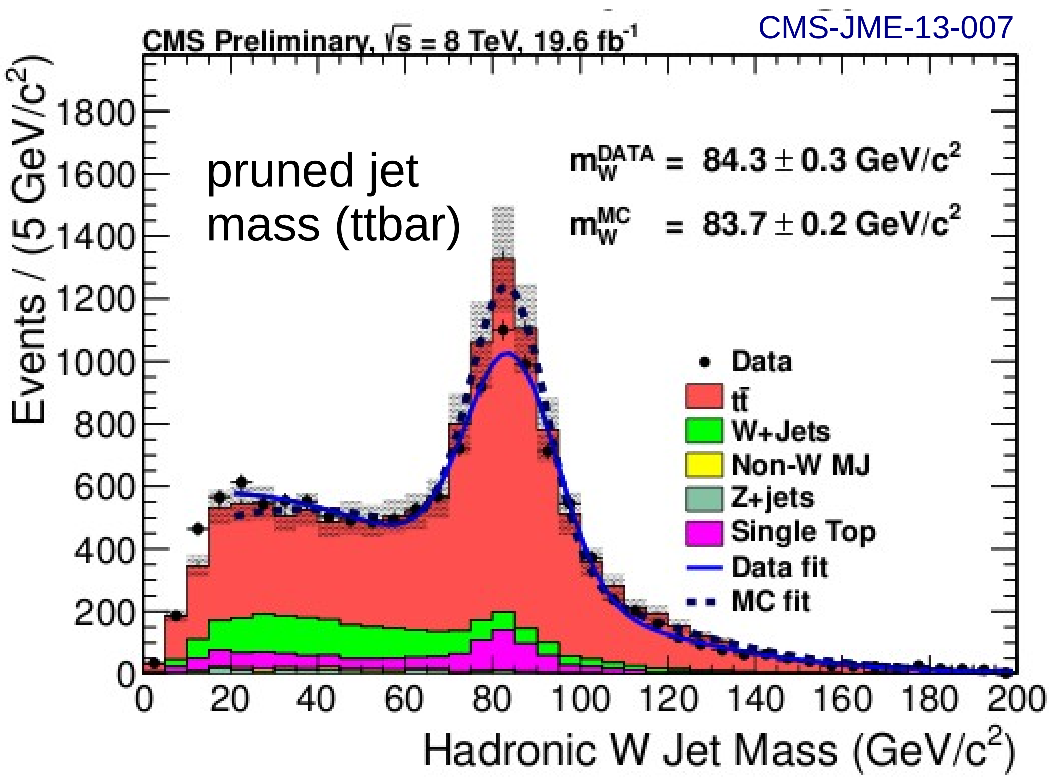
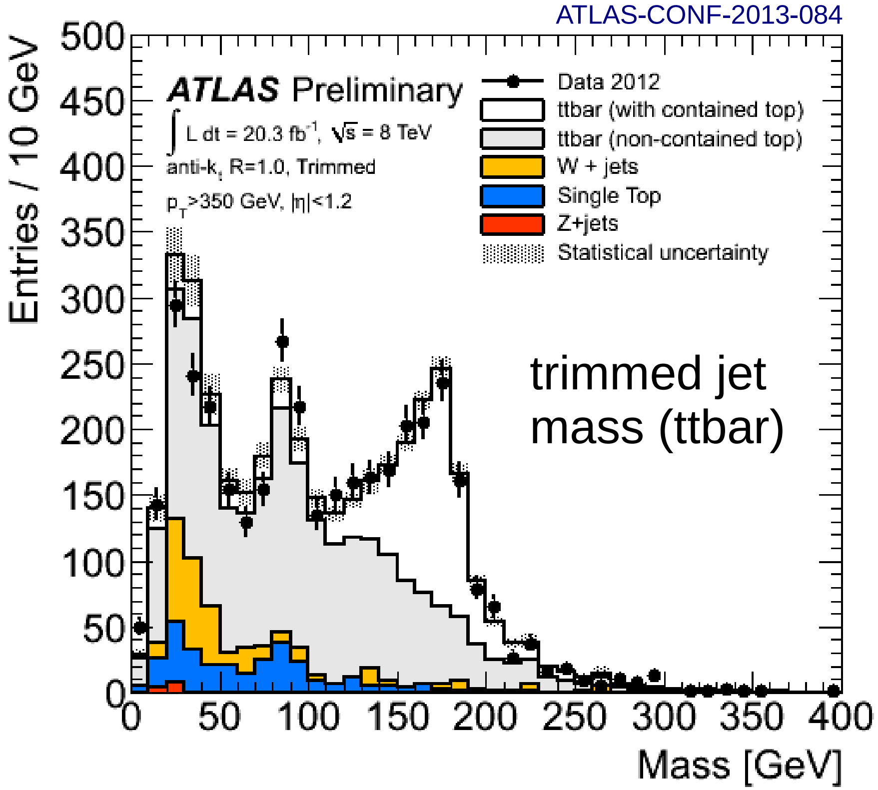


Where we started...

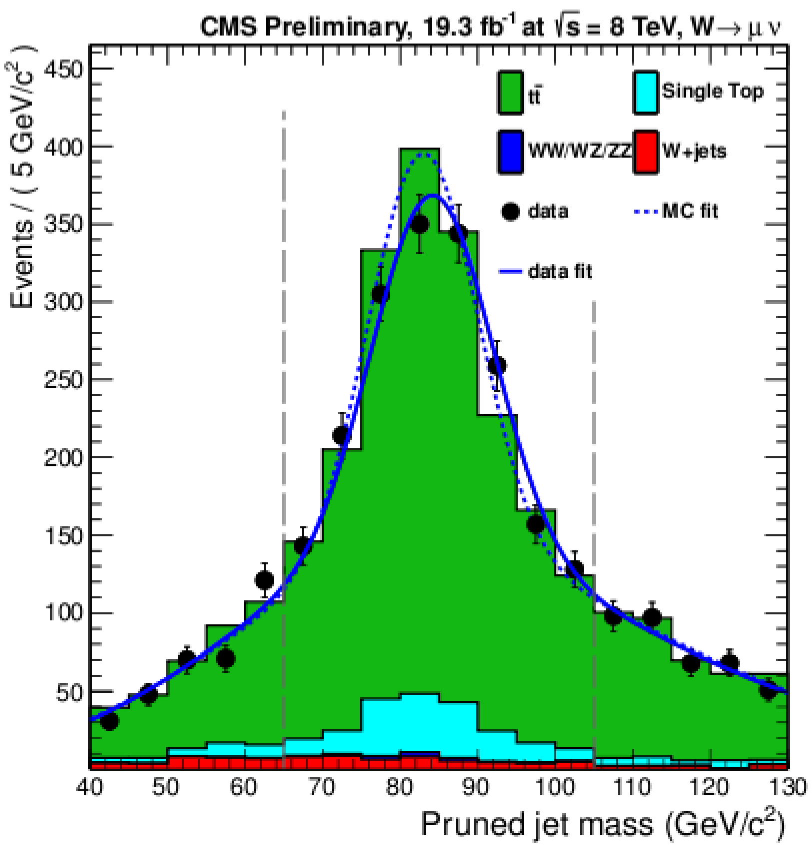
- Pileup mitigation...the three amigos! Trimming, Filtering, Pruning
  - They do it all...use mass to tag a boosted object, maybe with some jet shapes, after performing grooming to remove pileup + UE
- And we compared them in data! Things looked pretty good in 20 fb^{-1}



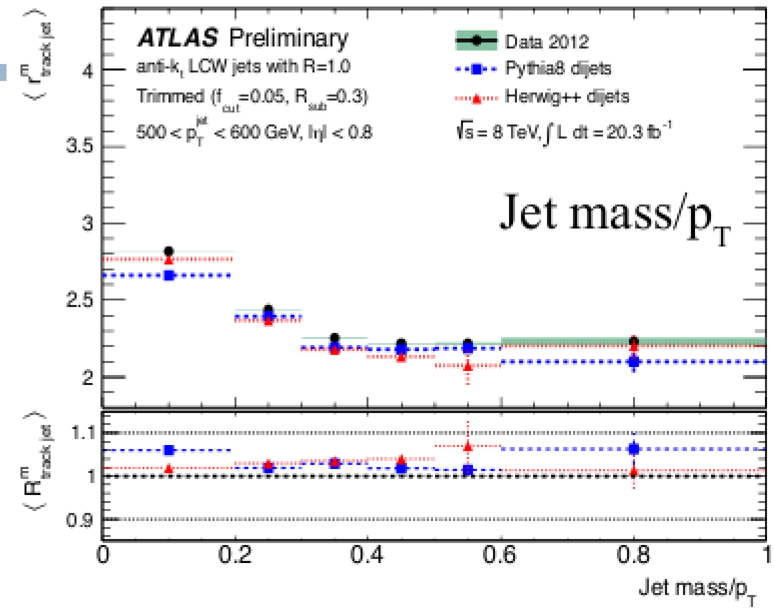


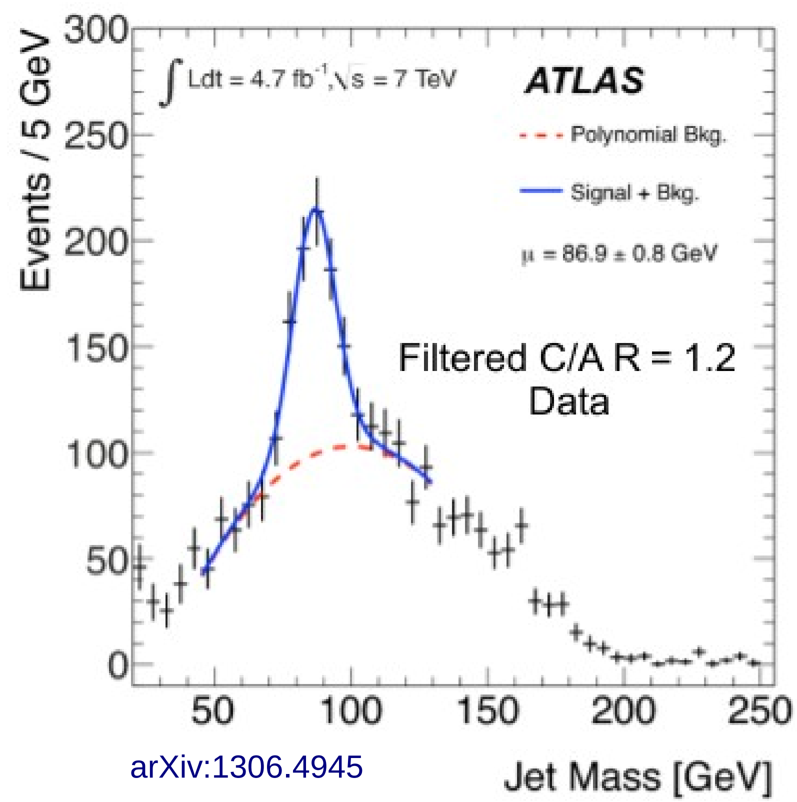
Where we started...

- Grooming works on on uncalibrated substructure components (ie: subjet pT), but we needed to show that we could successfully calibrate on “global” jet scale (ie: jet mass, pT)...



CMS-PAS-JME-13-006





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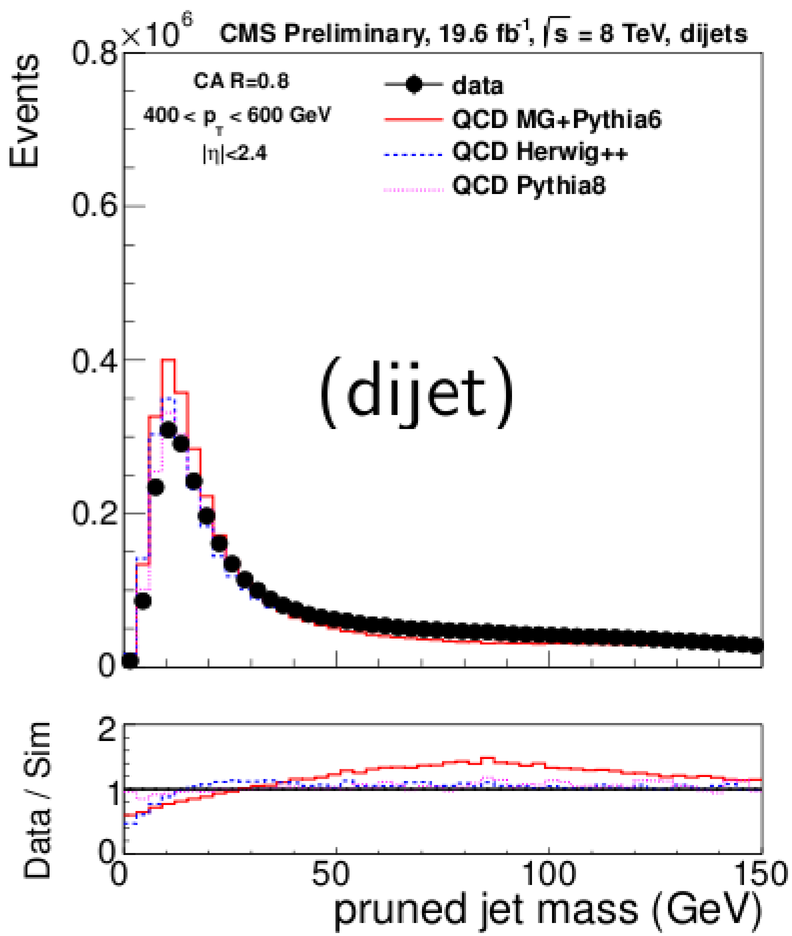
Where we started...

- ...but don't forget the generators! Large differences seen depending on what kind of parton showering was chosen



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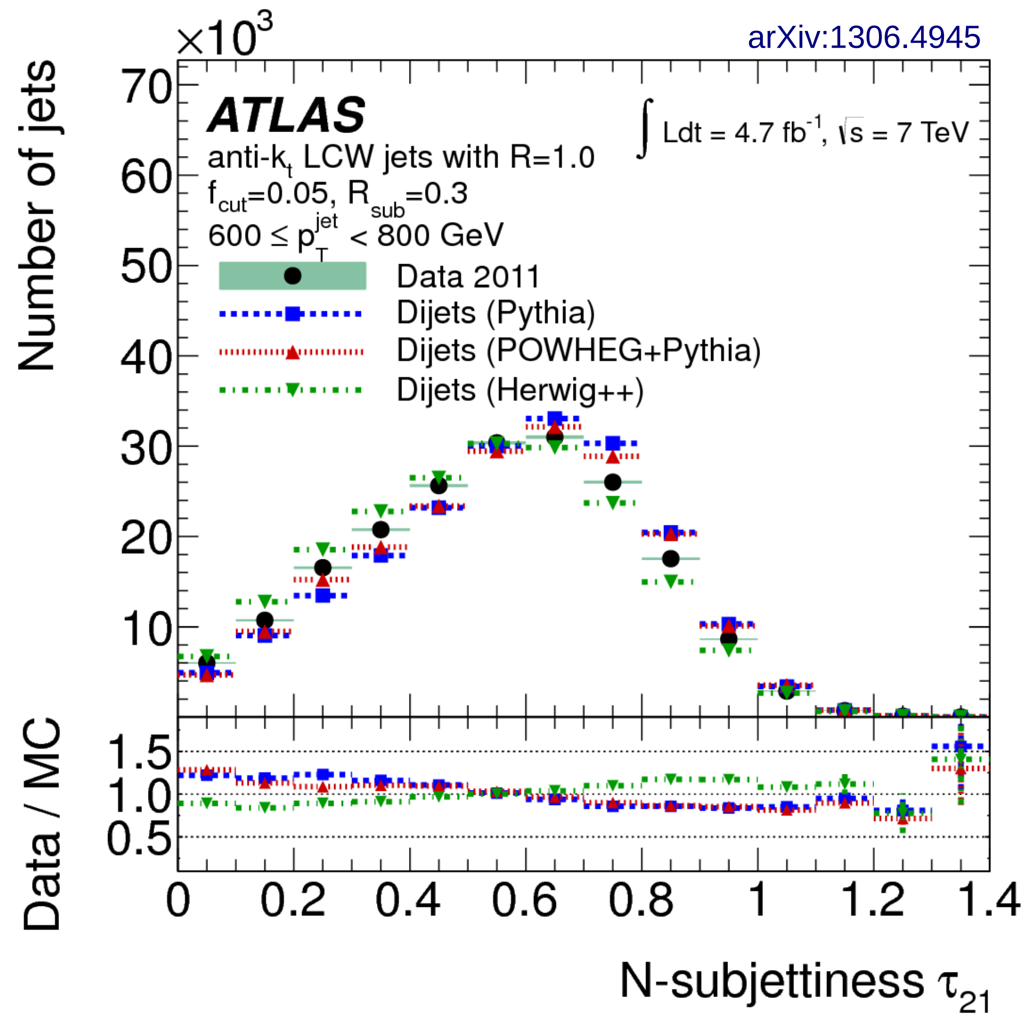
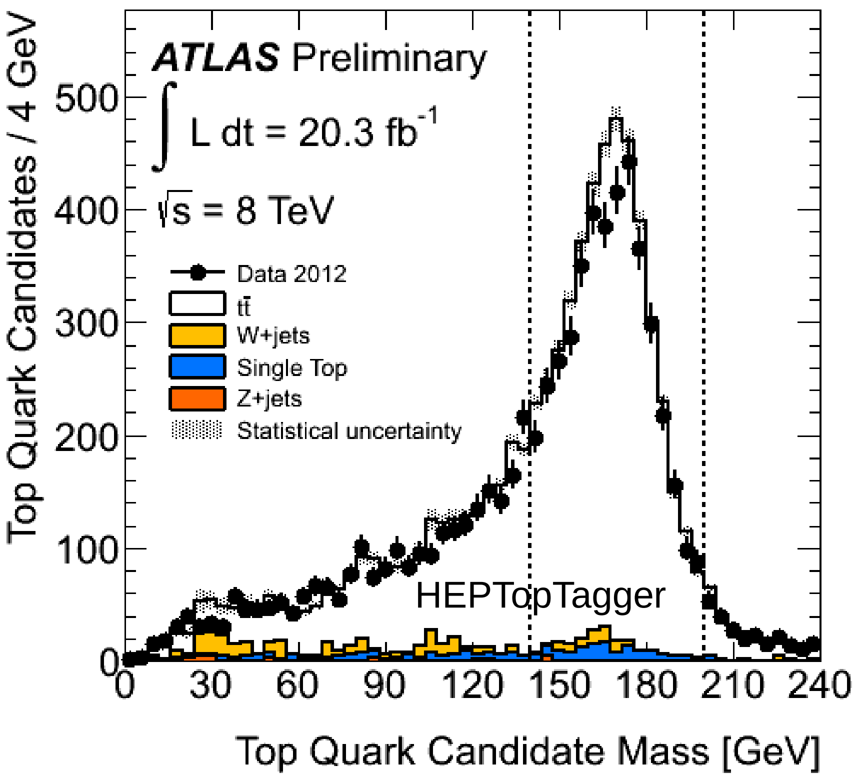
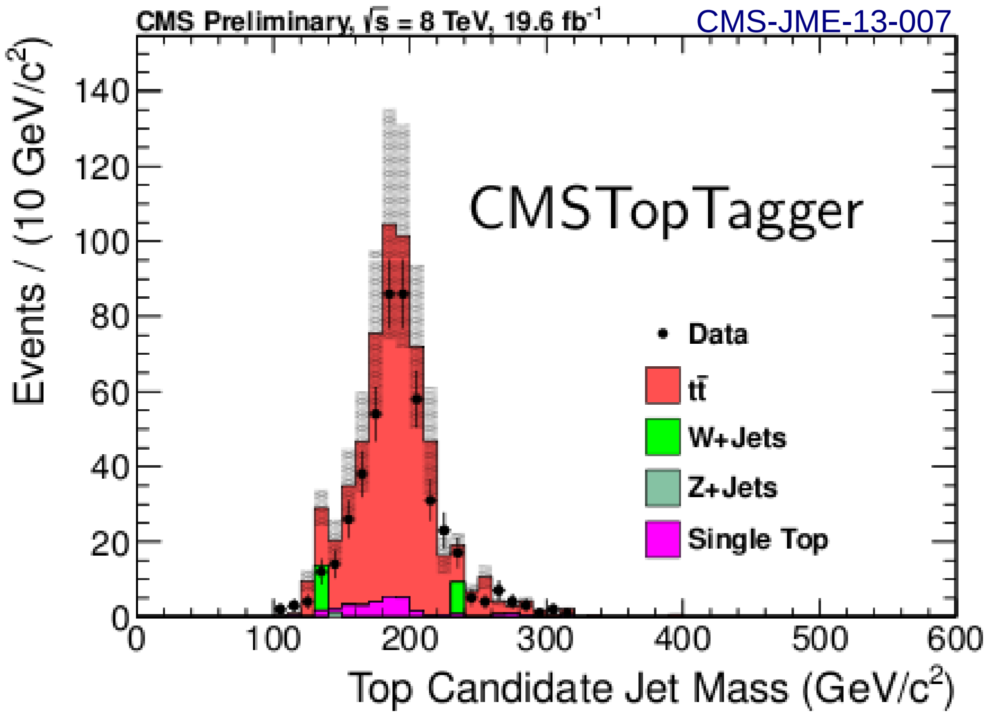


...where we are now...

- Along came advanced tagging: “grooming++”
  - Tagging+grooming all in one!
  - eg: HEPTopTagger, shower deconstruction, CMS top tagger, MVA-based tagging...

ATLAS-CONF-2013-084





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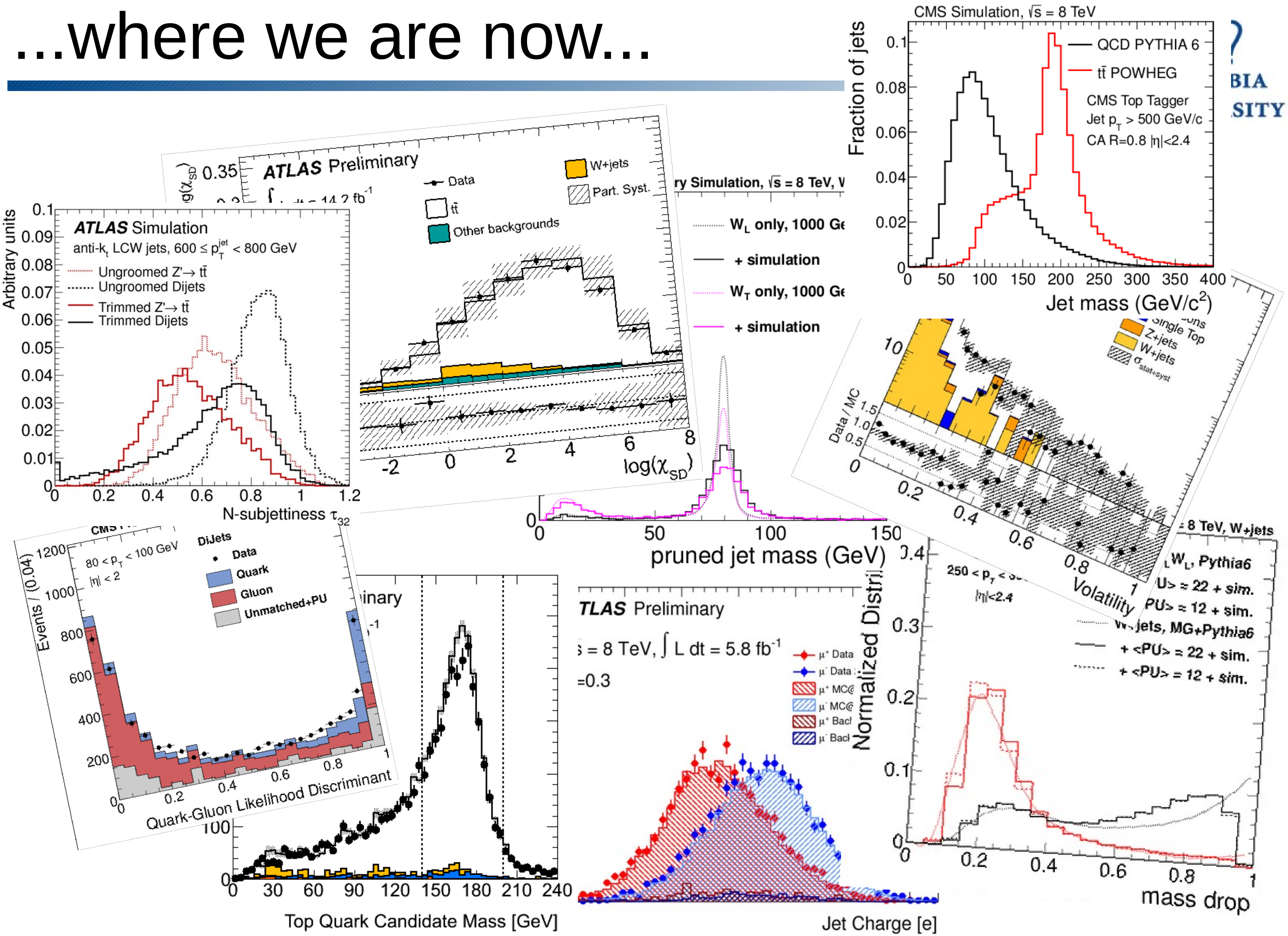
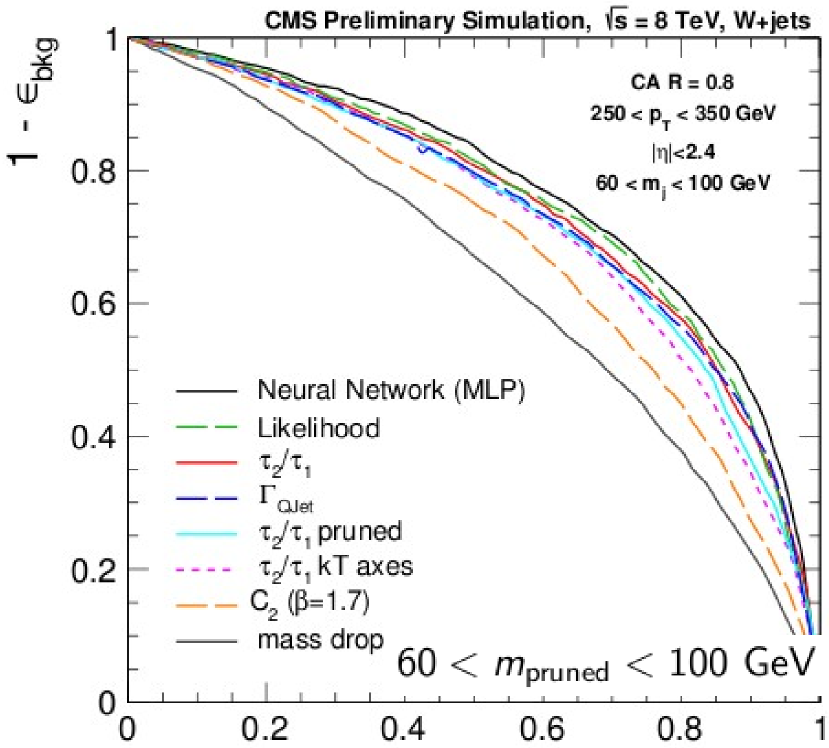


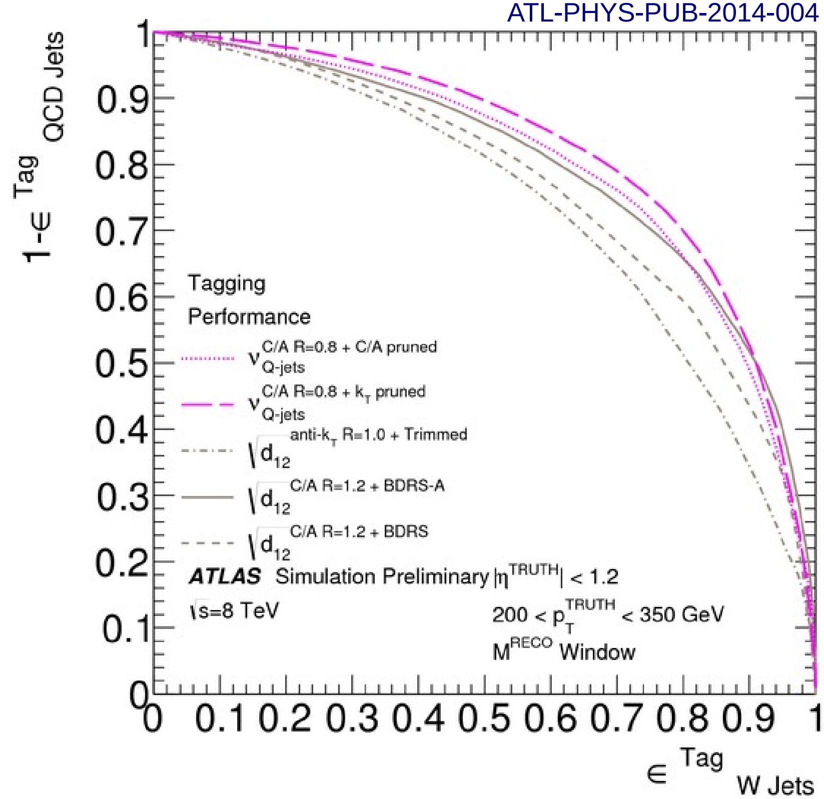
...where we are now...

- More rigorous comparisons to focus on just a few taggers, before we move on to Run2
- Caveat: need to add systematics to these curves!
  - This is non trivial! Correlations also need to be properly taken into account



CMS-PAS-JME-13-006

ATL-PHYS-PUB-2014-004



2-pronged "W" tagging

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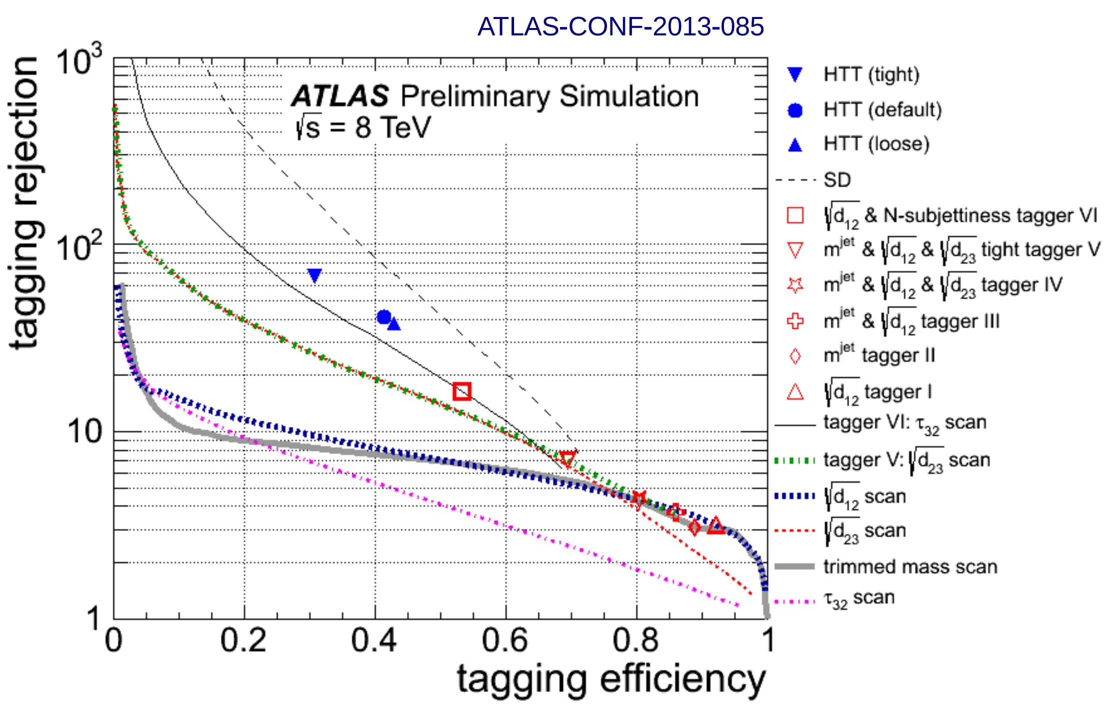
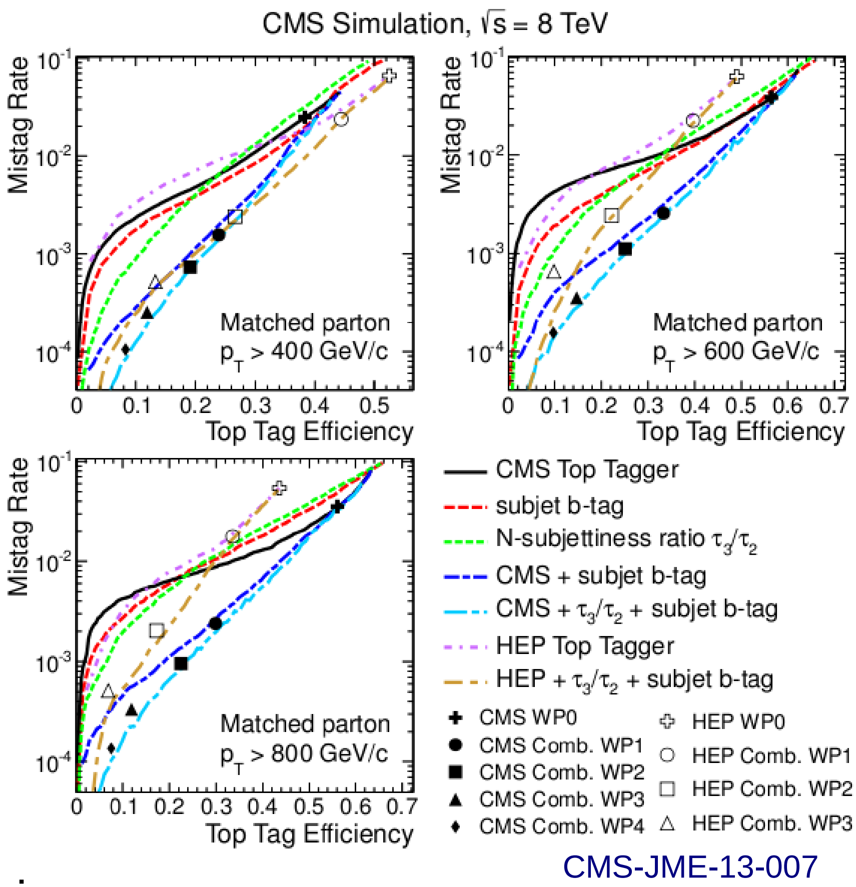
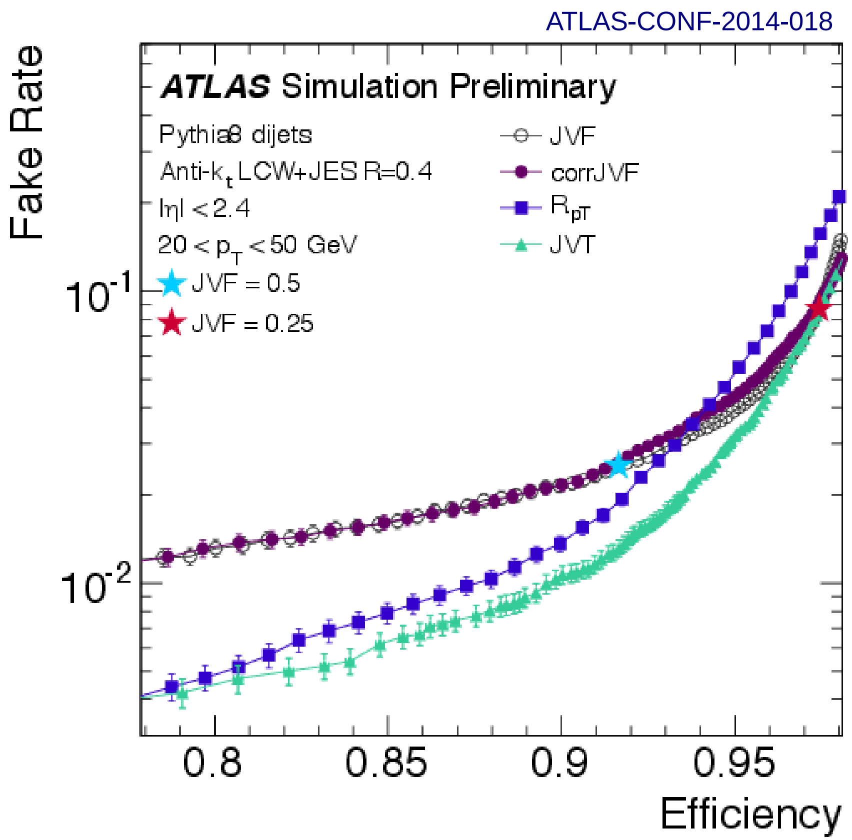


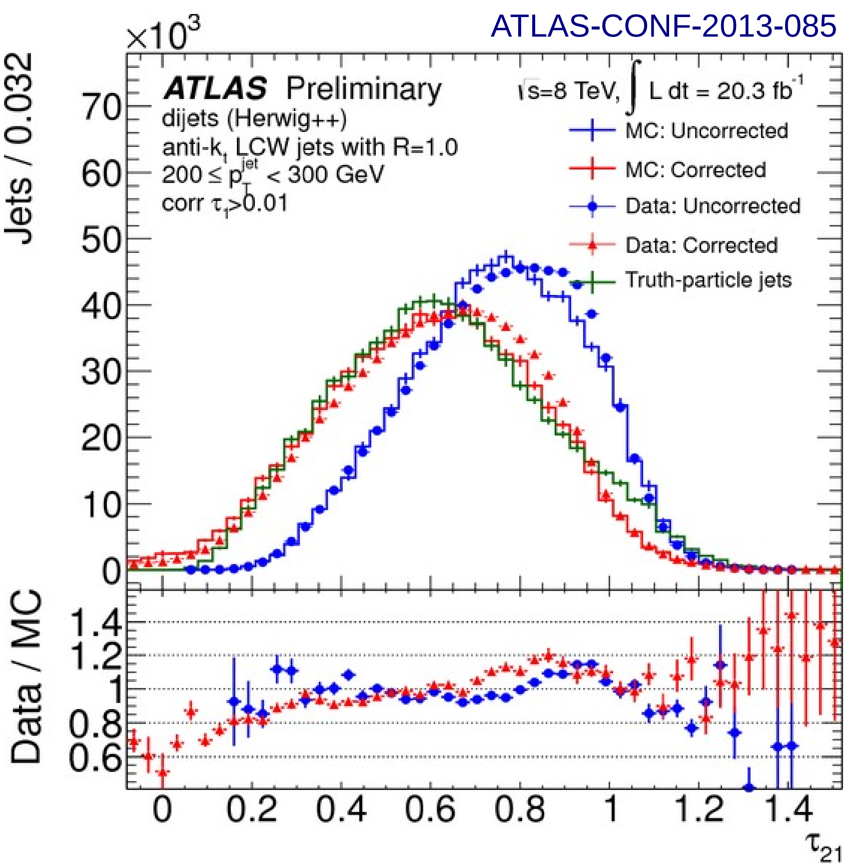


3-pronged “top” tagging

...where we are now...

- Pileup suppression: different approaches from the two experiments:
  - ATLAS: jet vertex fraction, jet areas correction and jet shapes subtraction work well...the latter can help “ease” the task of unfolding to particle level
  - CMS: PFlow reconstruction coupled with charged hadron subtraction...large effort to commission track-based pileup jet ID (already used in analyses)





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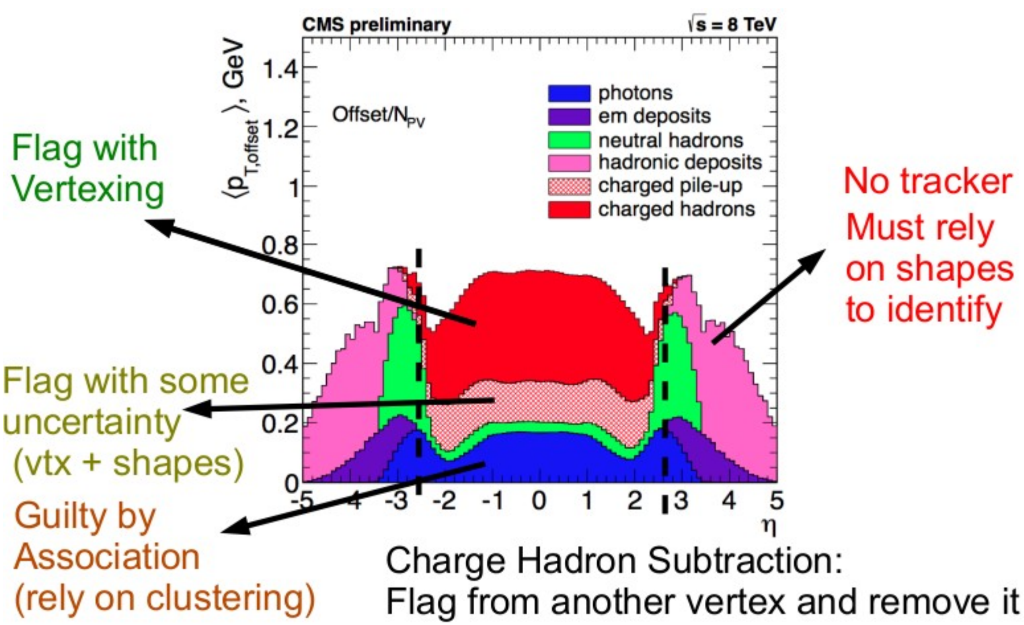
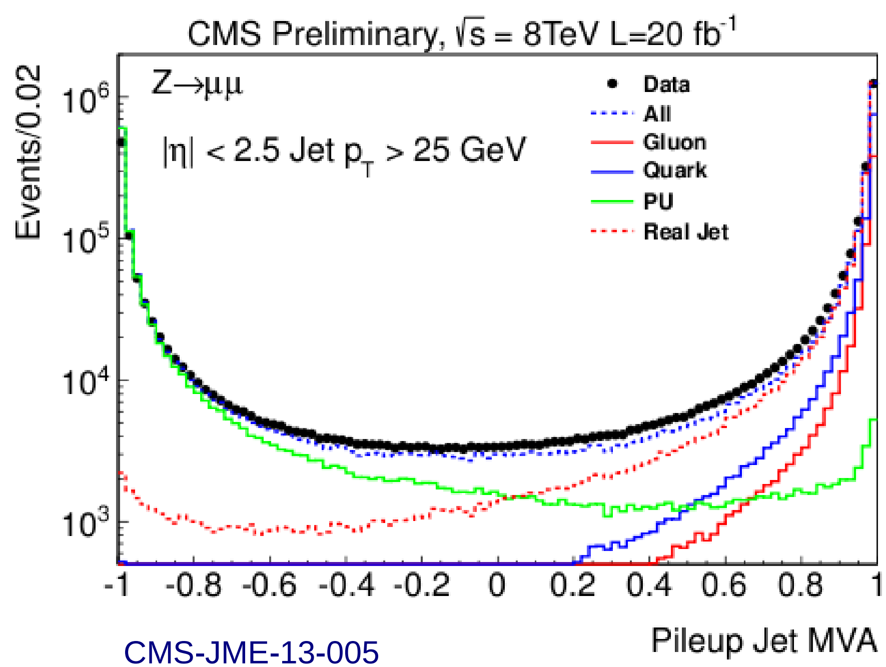
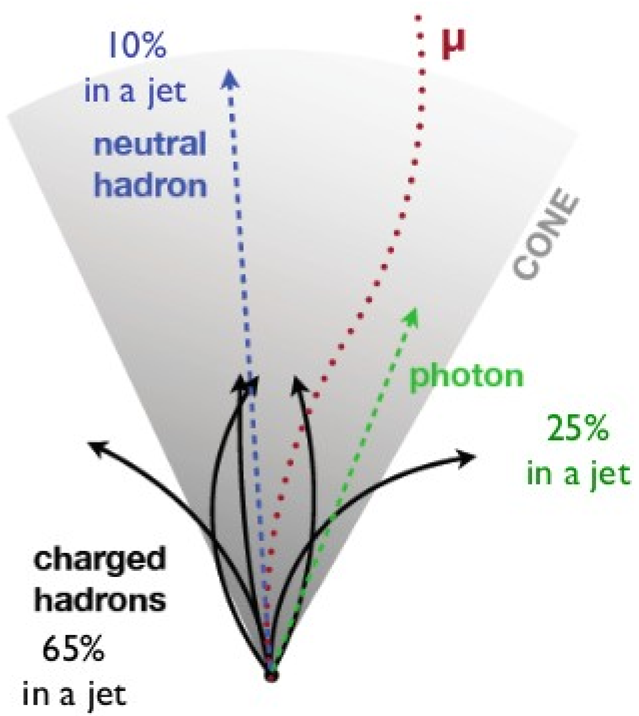


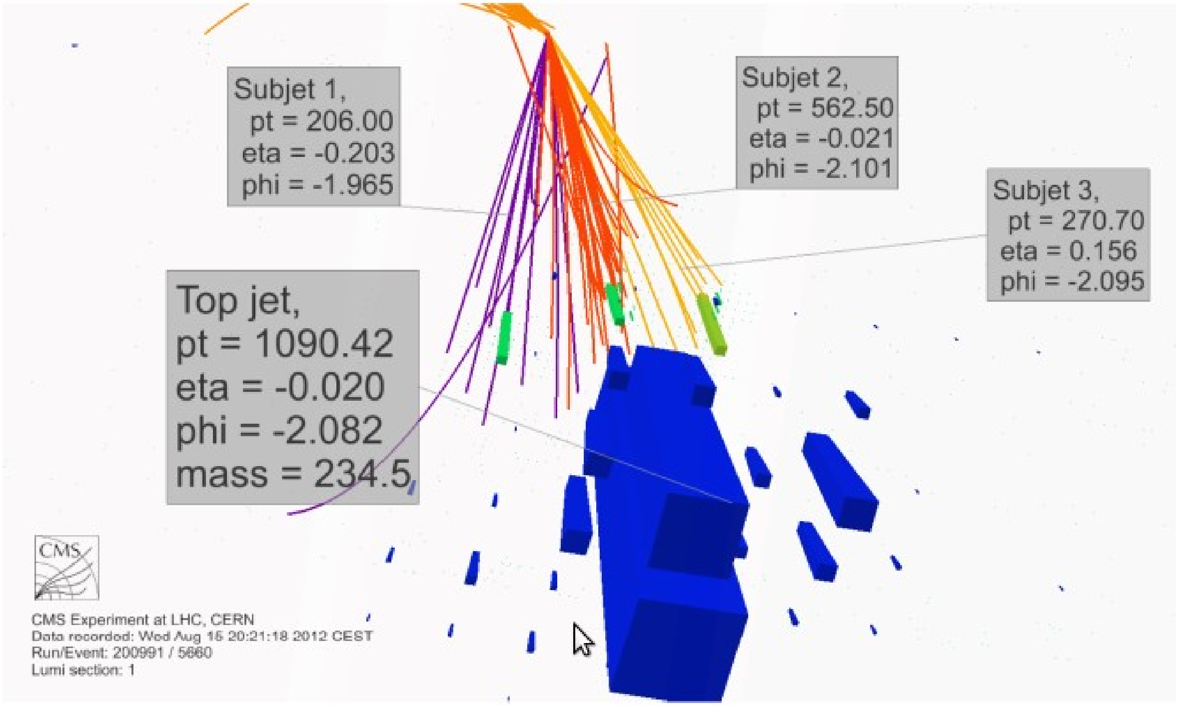


CMS-JME-13-005

Tracking in jet substructure

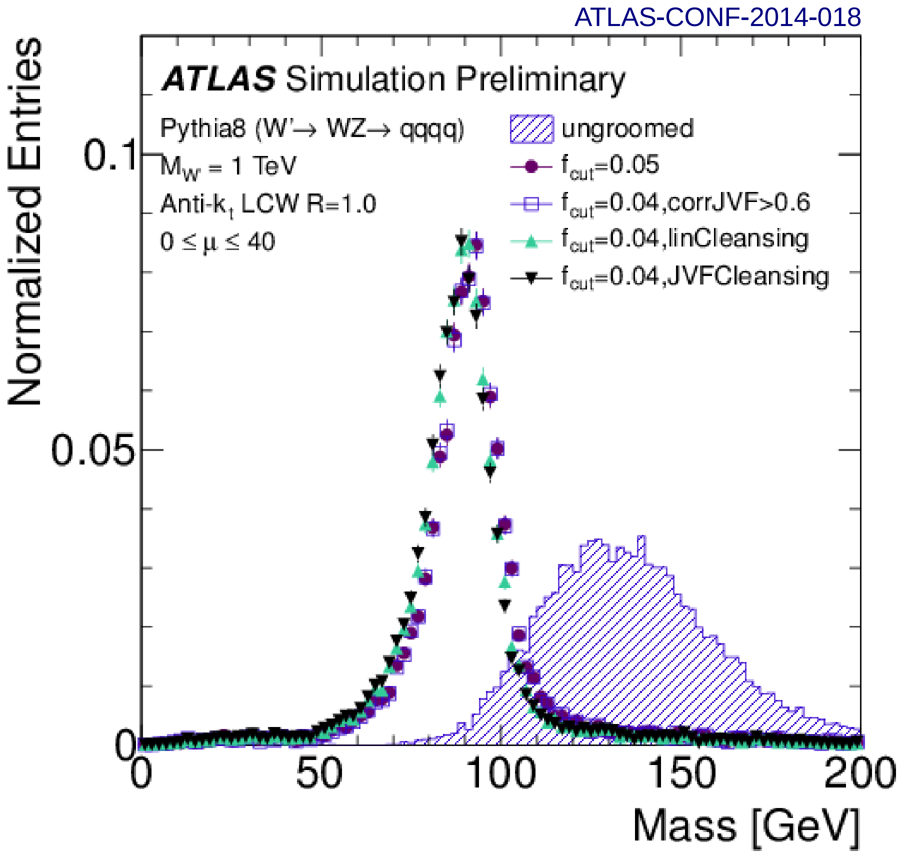
- Use of tracking in substructure: eg: CMS particle flow
  - Combines tracking and calorimeter information, where individual pflow objects are used as inputs to jet finding: ideal for jet substructure!
  - Directly removes up to 60% of charged pileup tracks
  - Relies on high granularity and resolution of ECAL and high magnetic field to separate individual showers...only limitation is being able to understand the overlap between showers

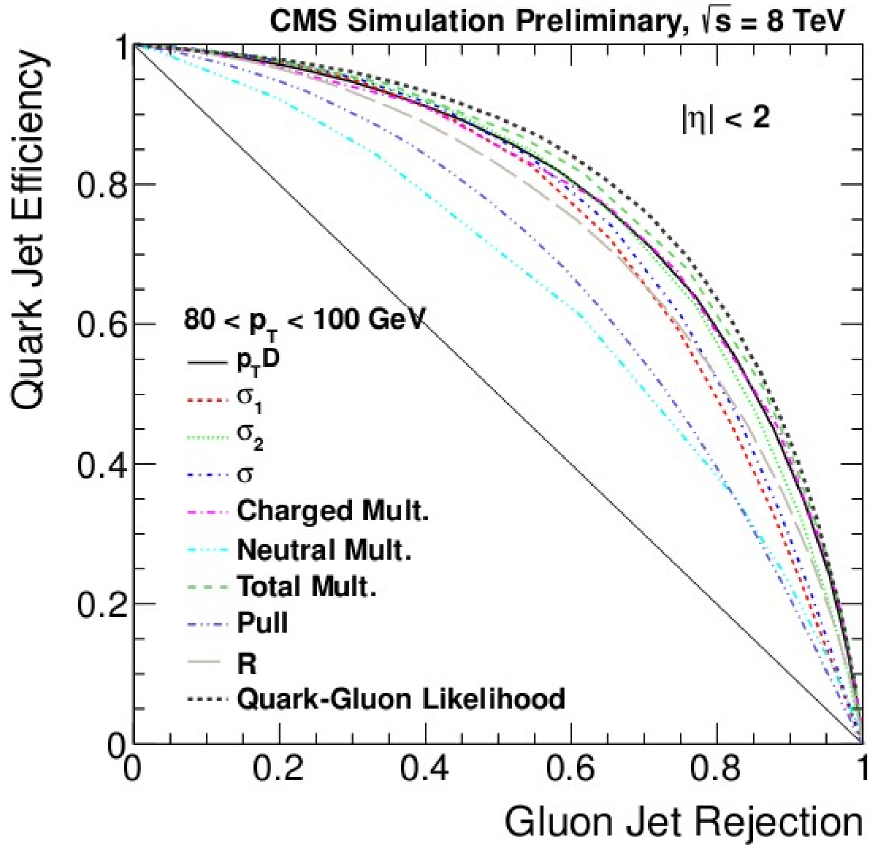




Tracking in jet substructure

- other examples: Jet charge, q/g, track-based trimming...

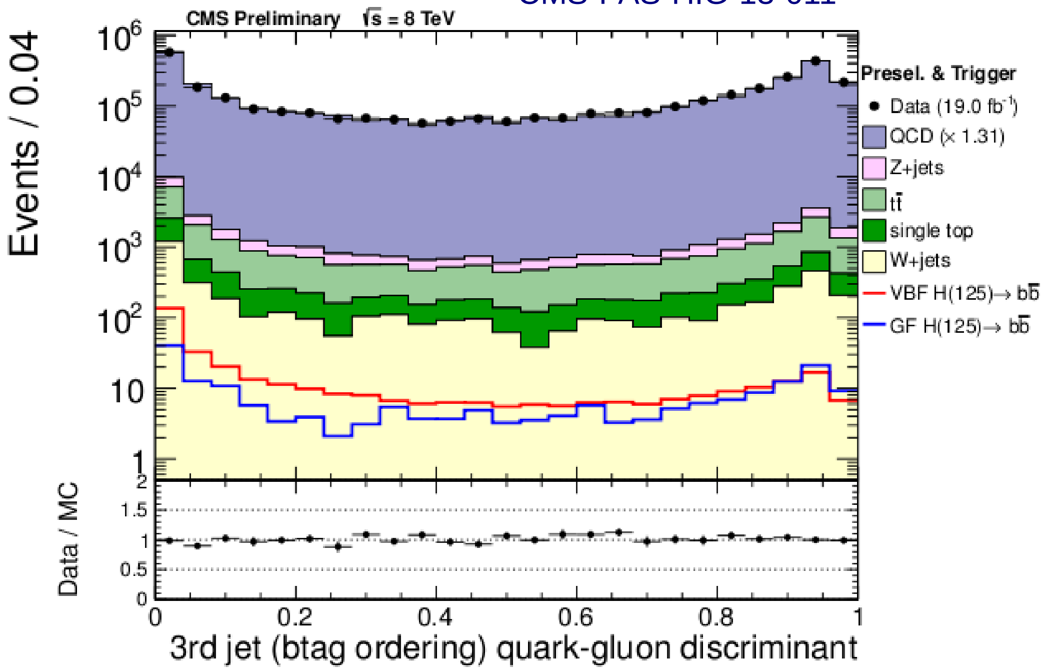




Putting the techniques to use

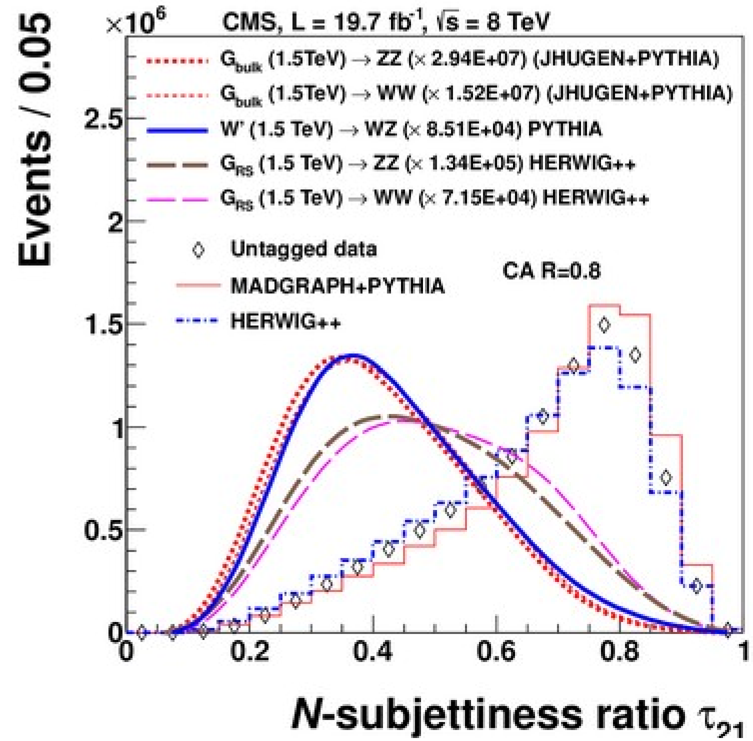
- In the end, only one thing matters...are the new techniques improving the sensitivity to new physics/providing a better measurement than could have been done with traditional jet algorithms?

CMS-PAS-HIG-13-011



VBF → Vh(bb)

CMS-EXO-12-024



X → VV → qq qq

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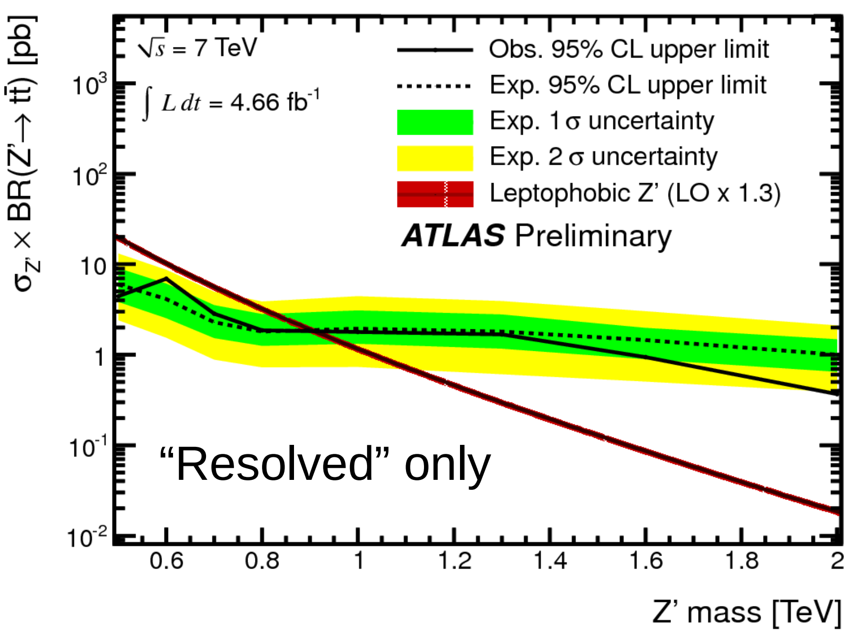
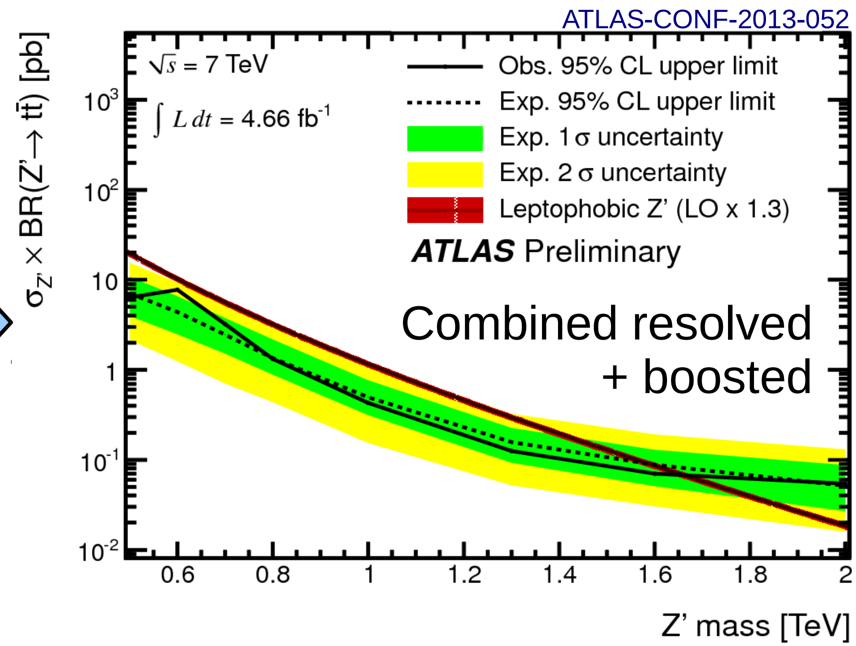
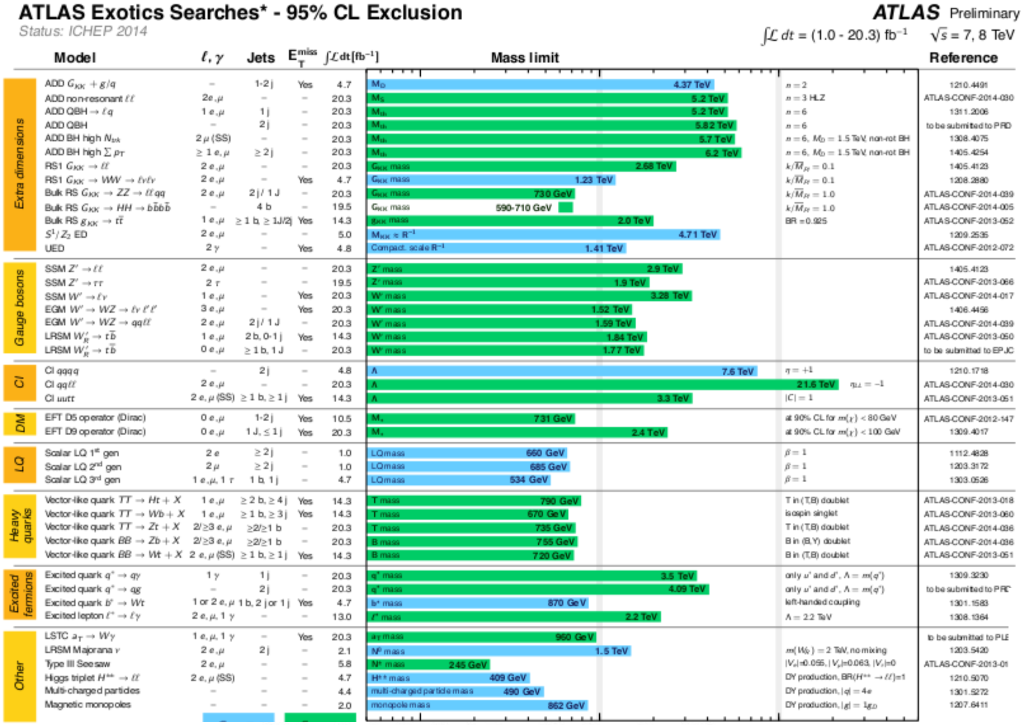
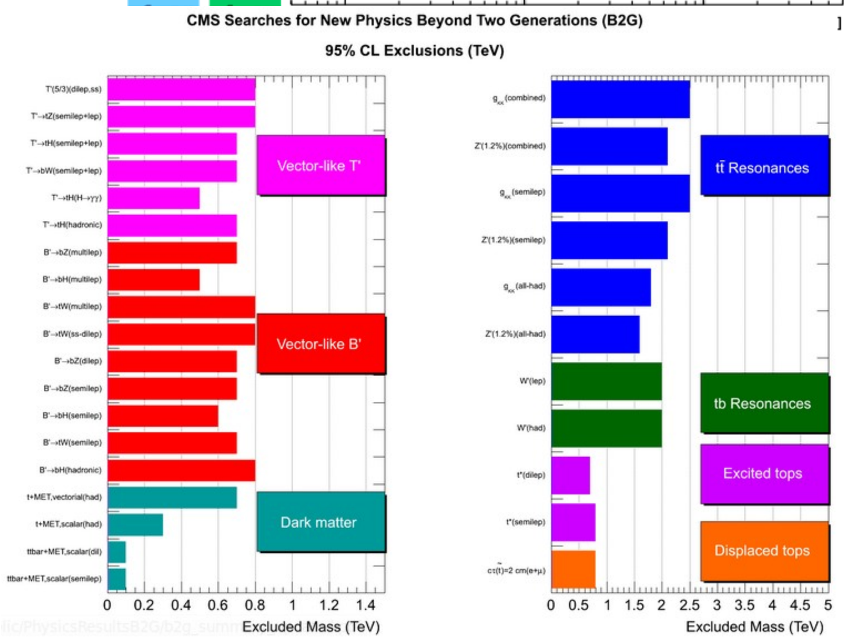




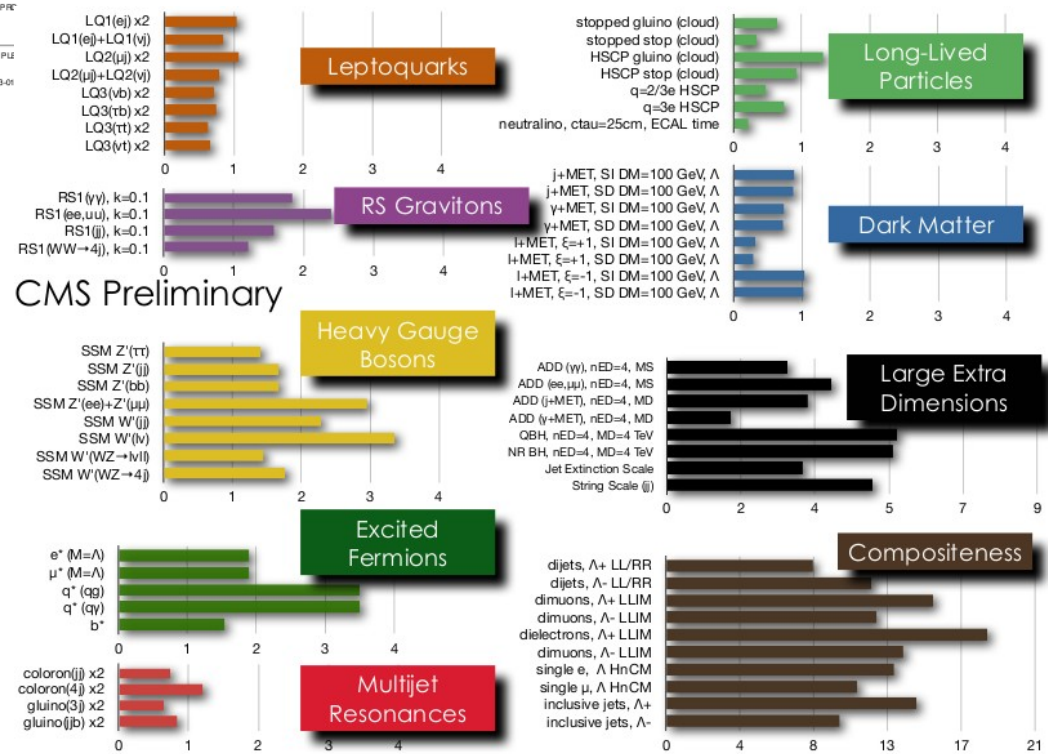
Z' → tt (semi-lep), 7 TeV
"boosted" employed simple trimmed R=1.0 jet with sqrt(d12) cut

Putting the techniques to use





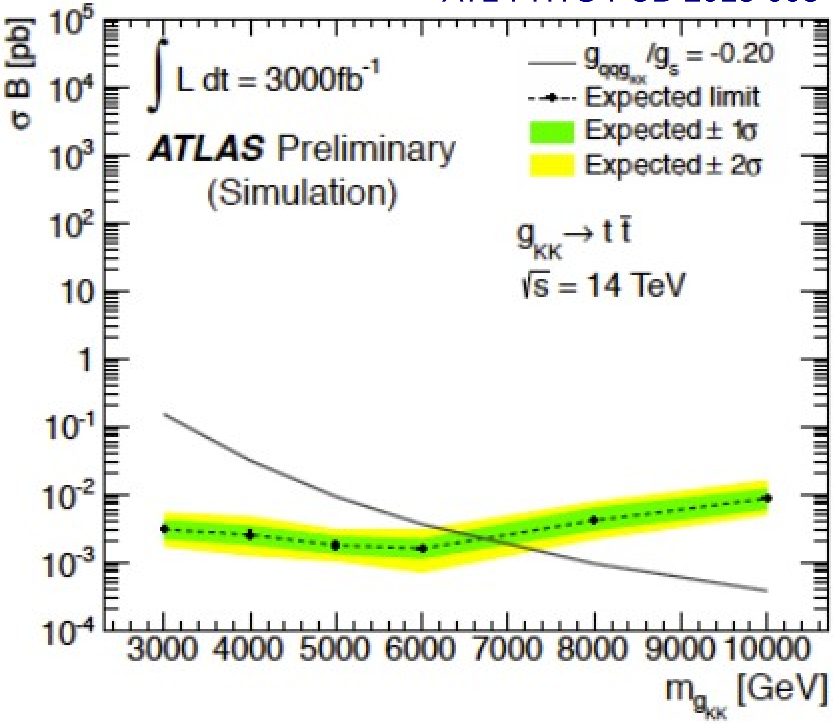
* only a selection shown!



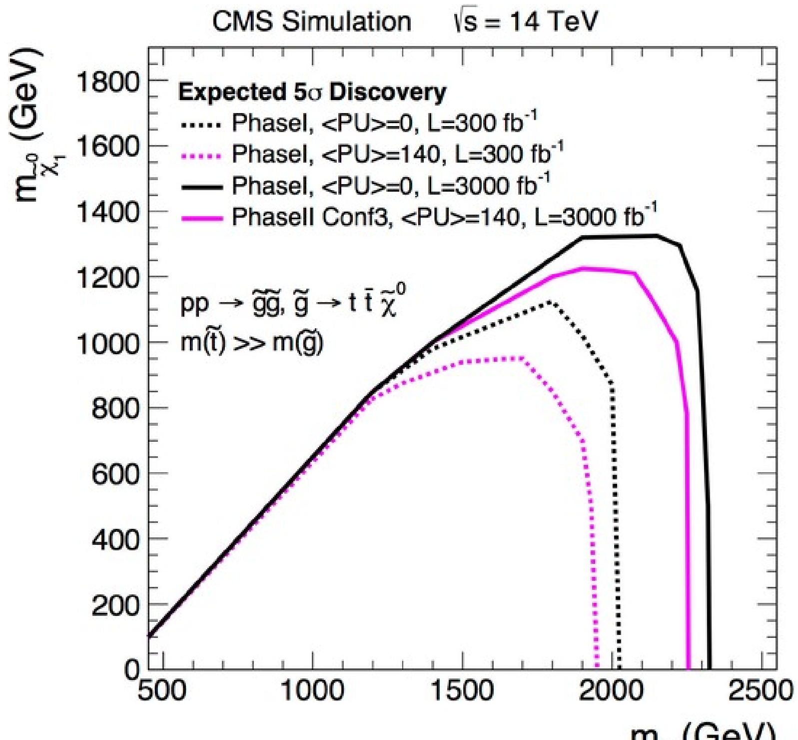
On to Run2...and beyond!

- You can't do physics in Run2 without BOOST
  - Any objects with pT > ~500 GeV are going to need jet substructure techniques in order to extend discovery reach for new particles into the multi-TeV region

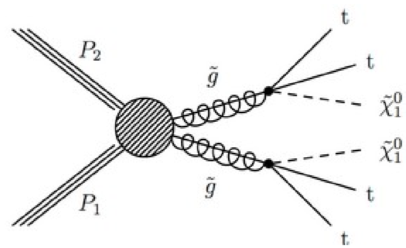
ATL-PHYS-PUB-2013-003



X → ttbar resonance

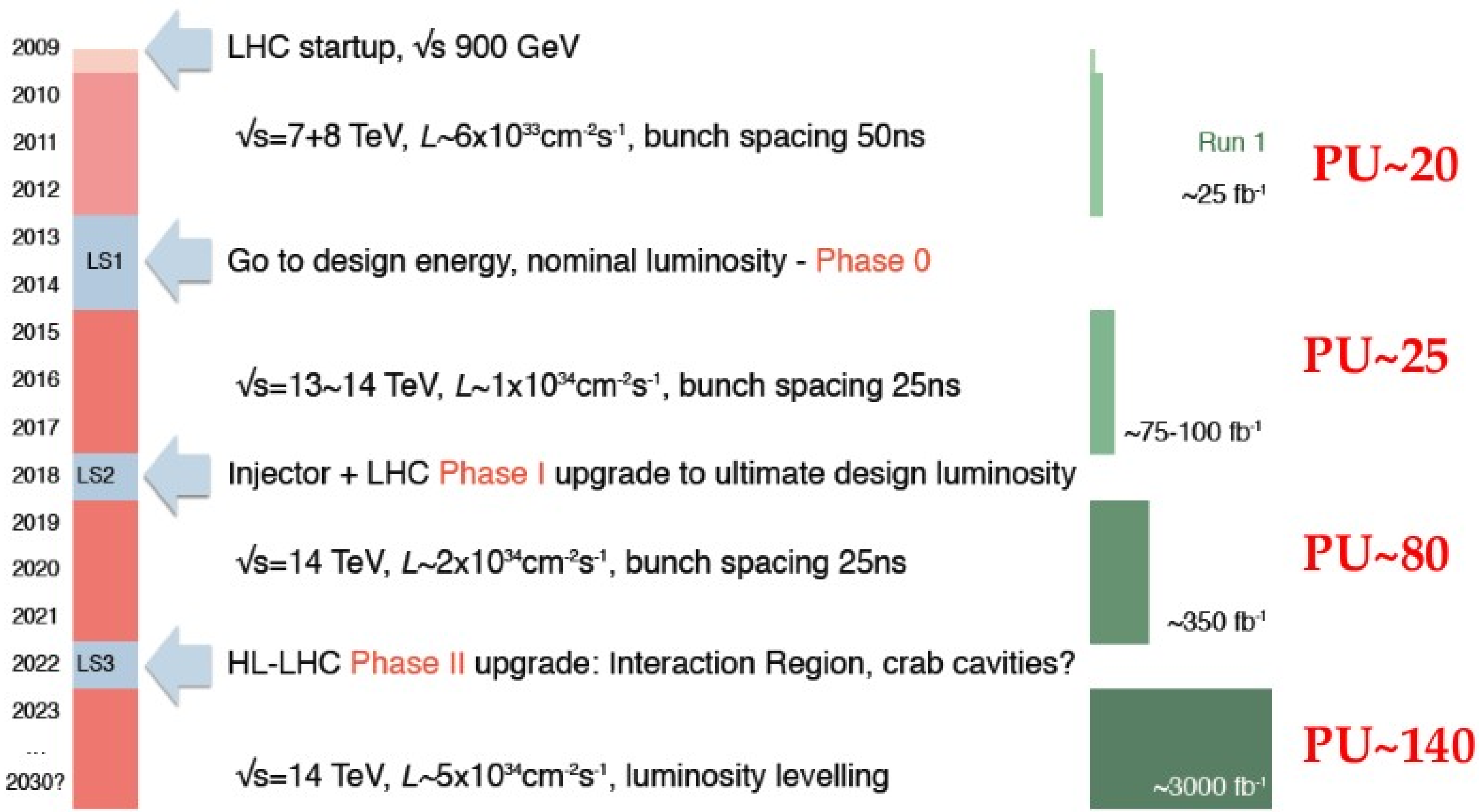


CMS-PAS-FTR-13-014



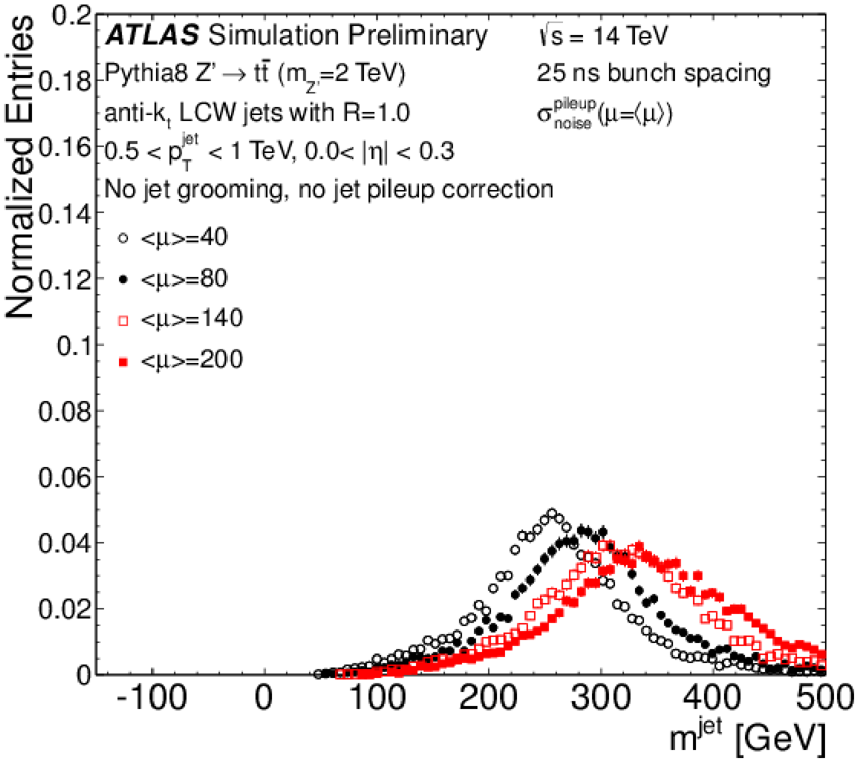
On to Run2...and beyond!

- You can't do physics in Run2 without BOOST
  - Any objects with pT > ~500 GeV are going to need jet substructure techniques in order to extend discovery reach for new particles into the multi-TeV region
- Can we handle it?

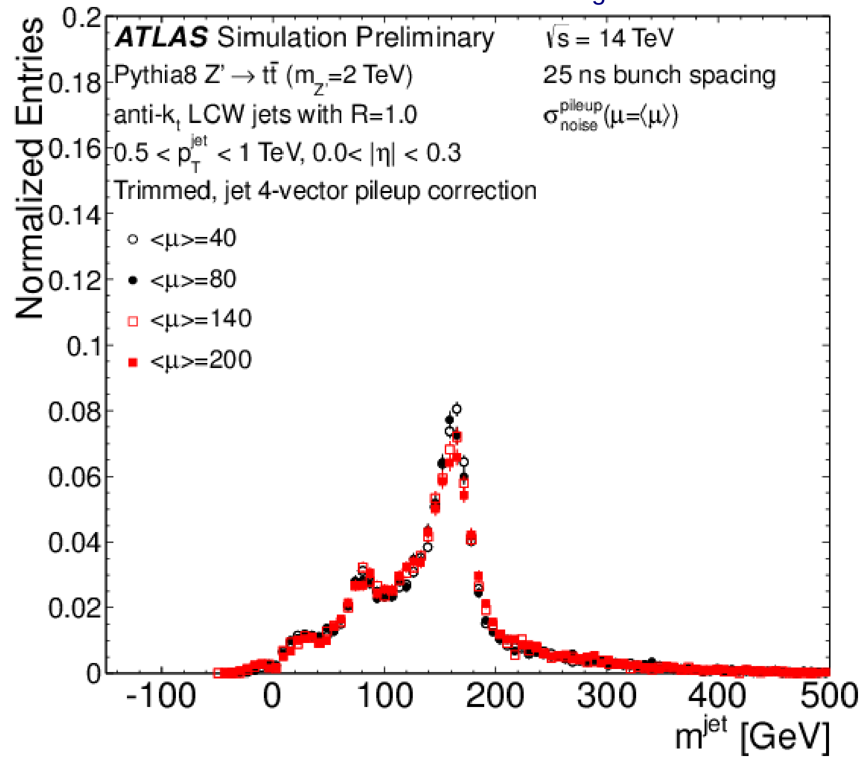


Pileup mitigation

- Our current strategies actually do surprisingly well (at least in simulation!)
- You can't have enough pileup mitigation...we'll never be “done” on this front

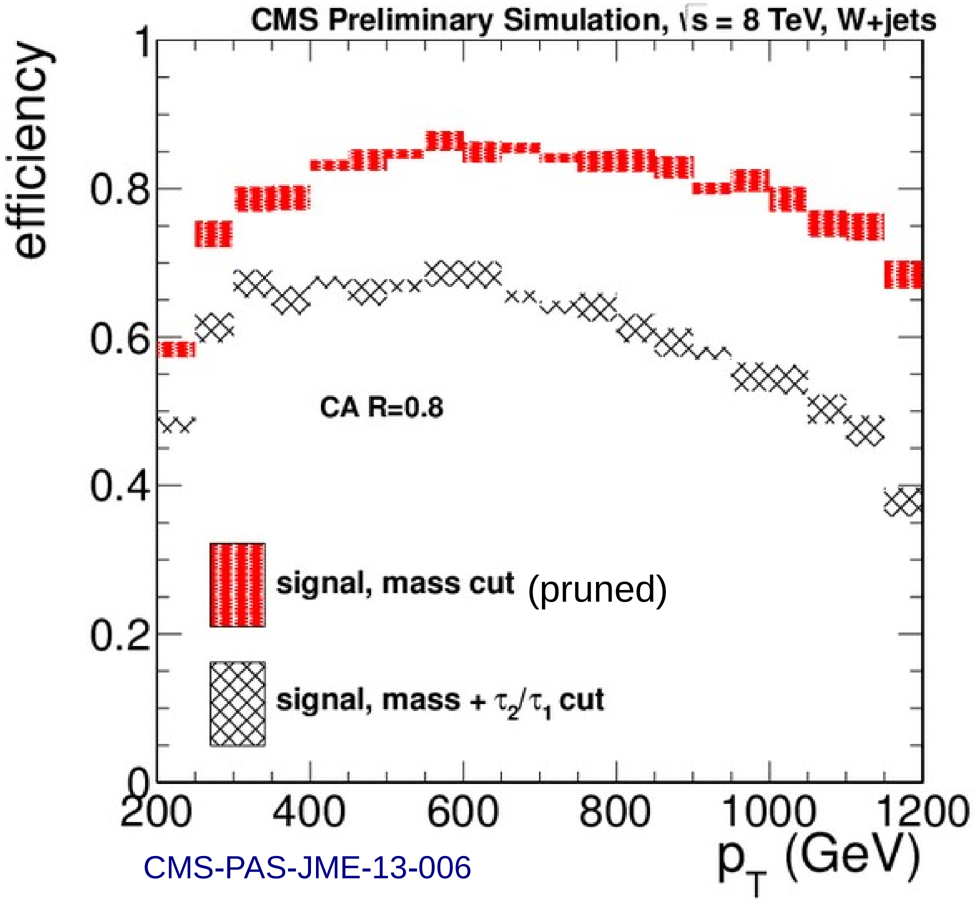


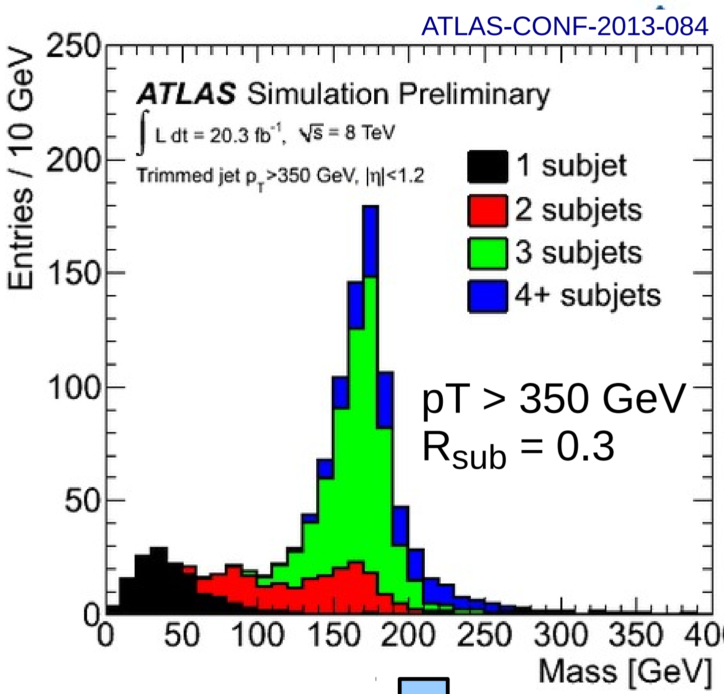
ATLAS PUB High mu substructure

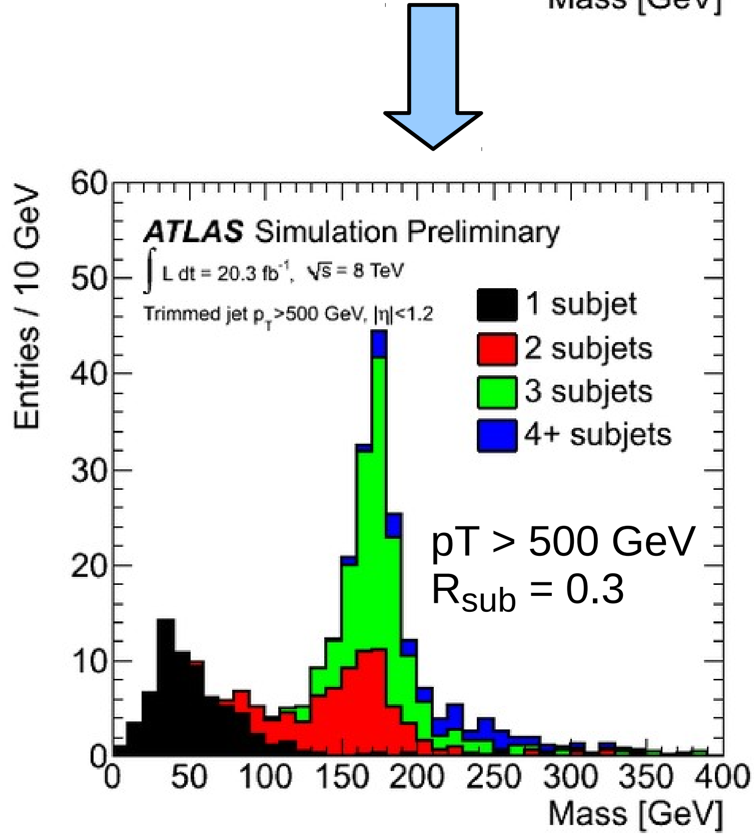


Re-optimization

- Entering the extreme substructure regime
- Retuning grooming parameters for Run2:
  - At really high boost, subjets with current parameters start to merge







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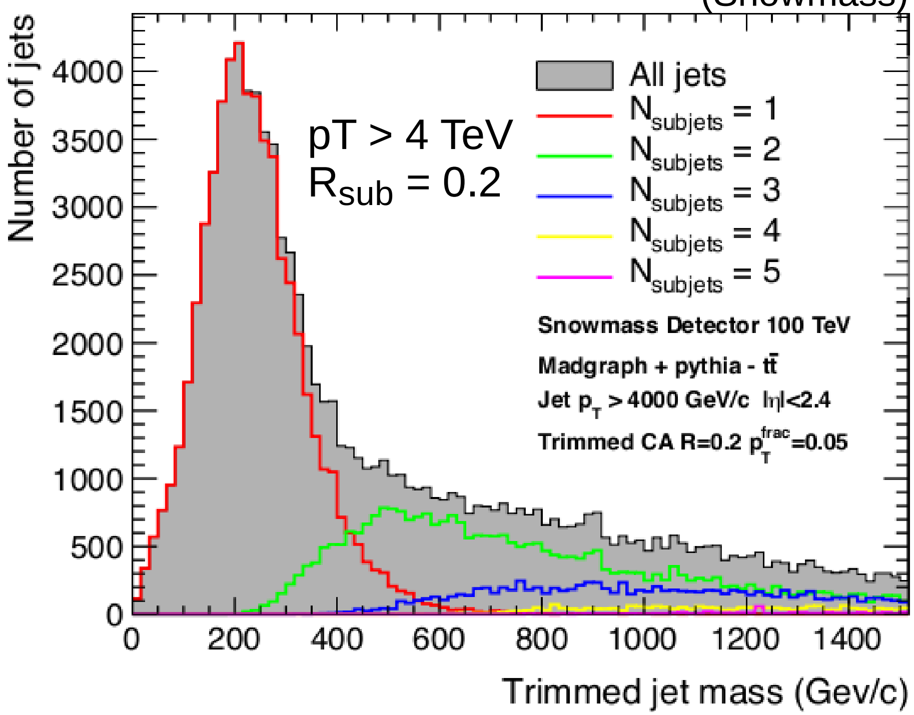
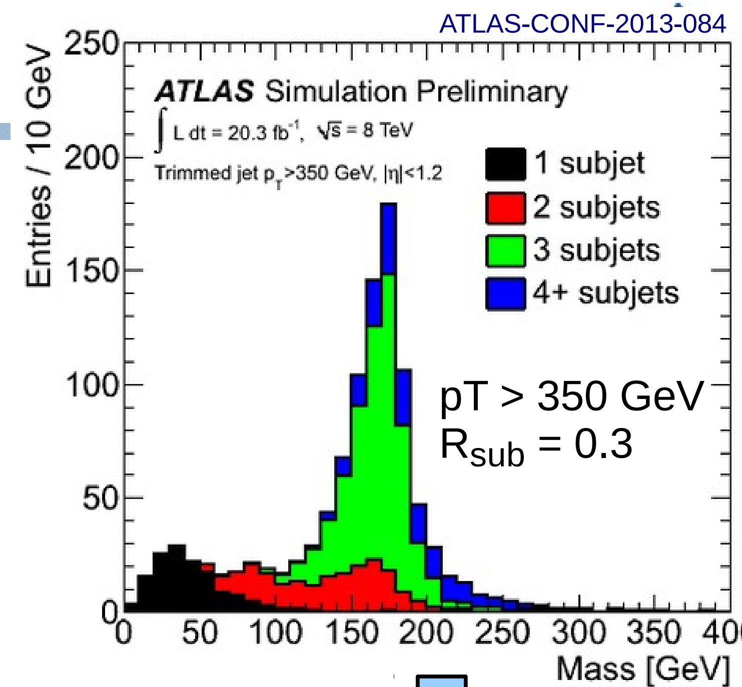
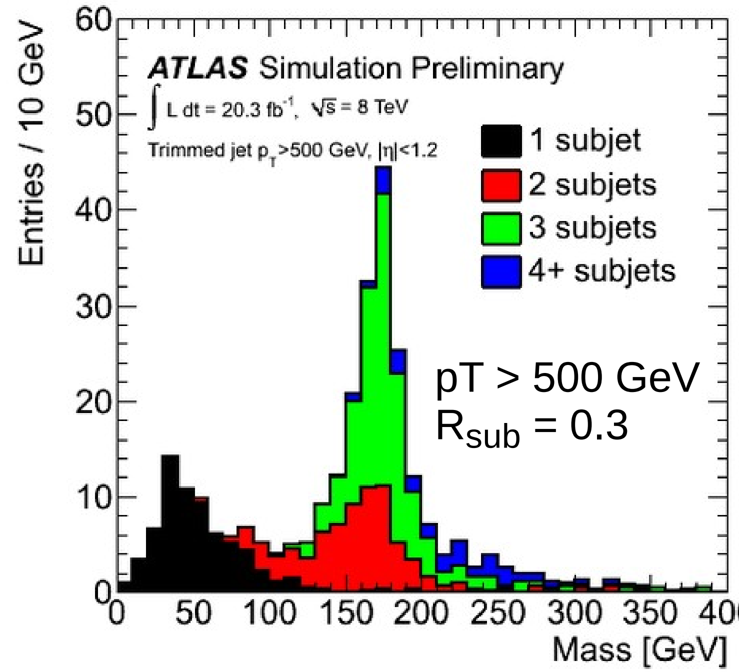
(Snowmass)



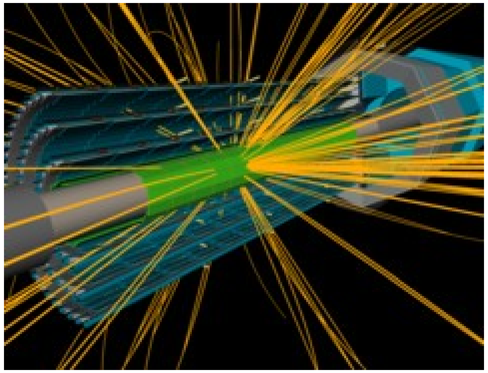
(ok..maybe a *bit* extreme to worry about right now...)



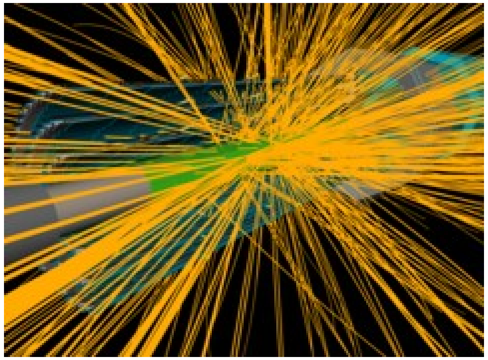


Re-optimization

- Substructure scale: how low can you go?
  - At some point, you're limited by calo granularity...and substructure scale is on the order of cells/clusters
  - Might try jet reconstruction with ecal-only to improve angular resolution.
  - Also take a look at more track based measurements
- Detector upgrades will include tracker and calorimeter improvements
  - ATLAS phase 0: new IBL layer (extra pixel layer)
  - CMS phase 1: new pixel tracker, HCAL with finer longitudinal segmentation

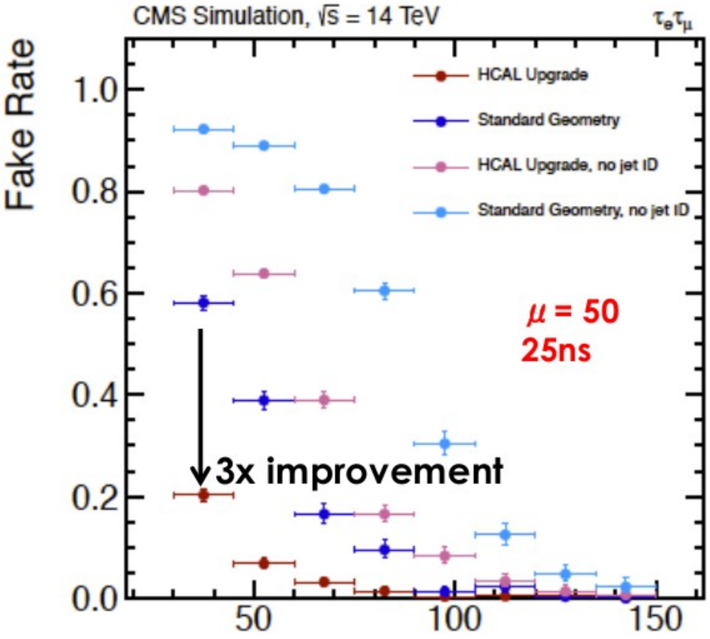


Two jets with pT > 500 GeV



adding $2{\times}10^{34}$ $cm^{-2}s^{-1}$ pileup

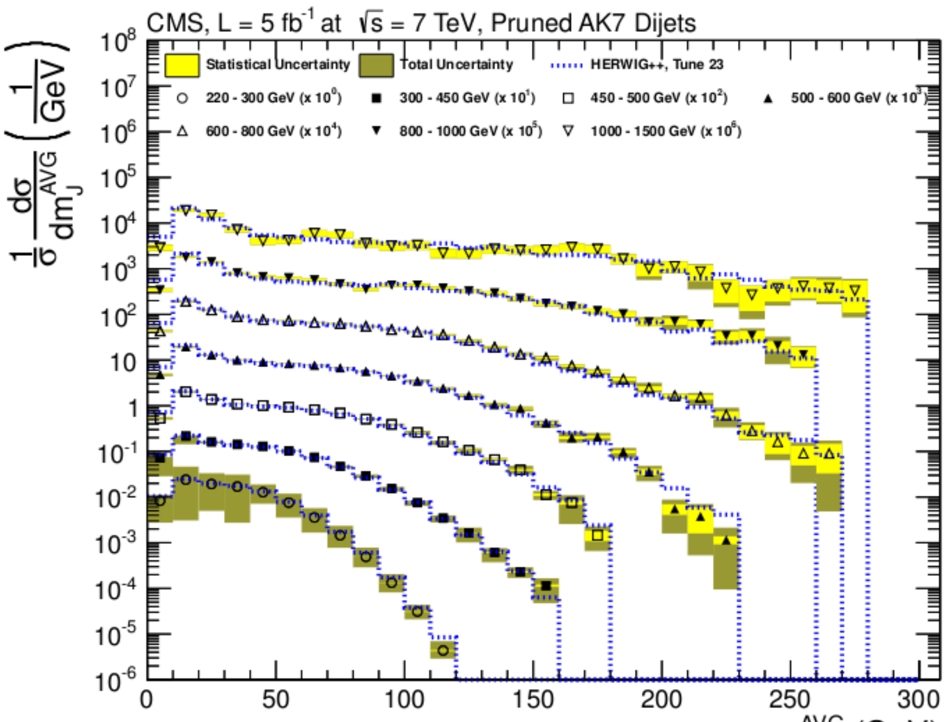
all tracks in dijet event with pT > 0.5 GeV and more than 1 Pixel+IBL cluster



CERN-LHCC-2012-015

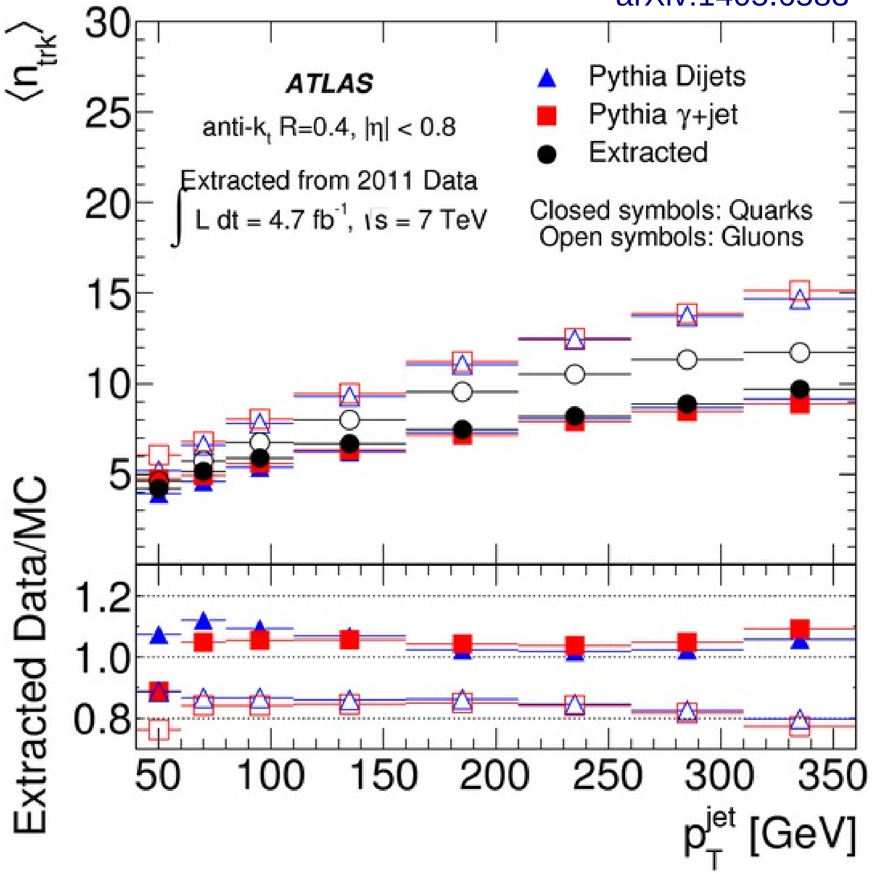
Don't forget those generators!

- One piece missing from us: measurements from jet mass and other shapes have not yet been fed back into generators for tuning
  - Generator modeling is already a limiting systematic for many searches
  - Also high pT differential cross sections of boosted objects (ttbar, Z → bb, etc)
  - Correcting back to the particle level is very challenging!



arXiv:1303.4811

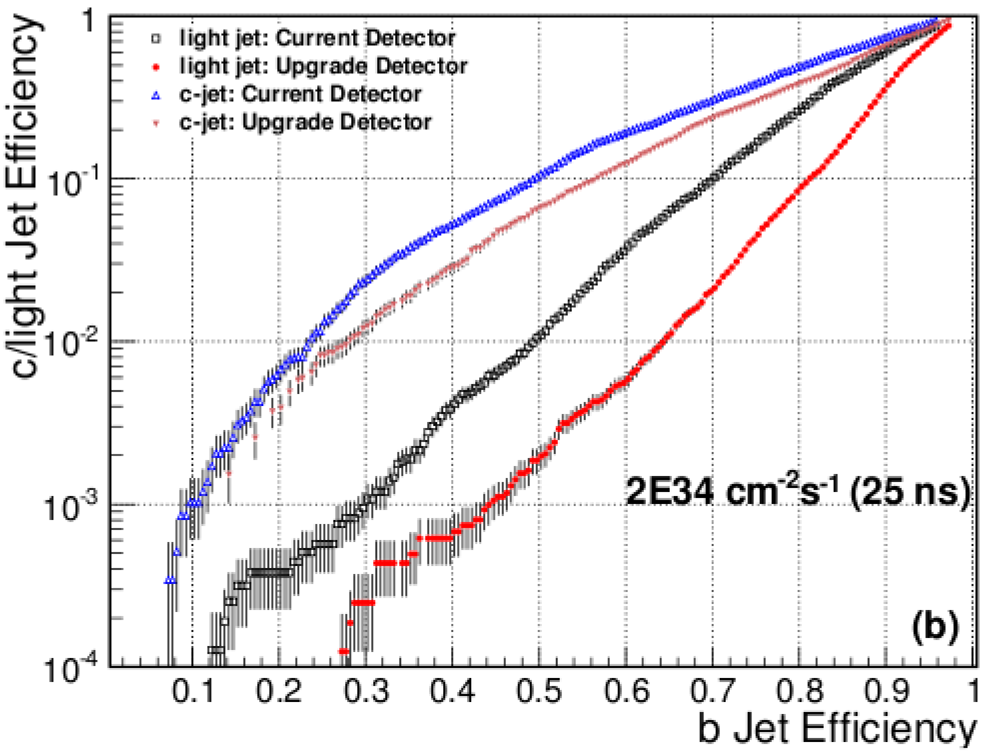
arXiv:1405.6583

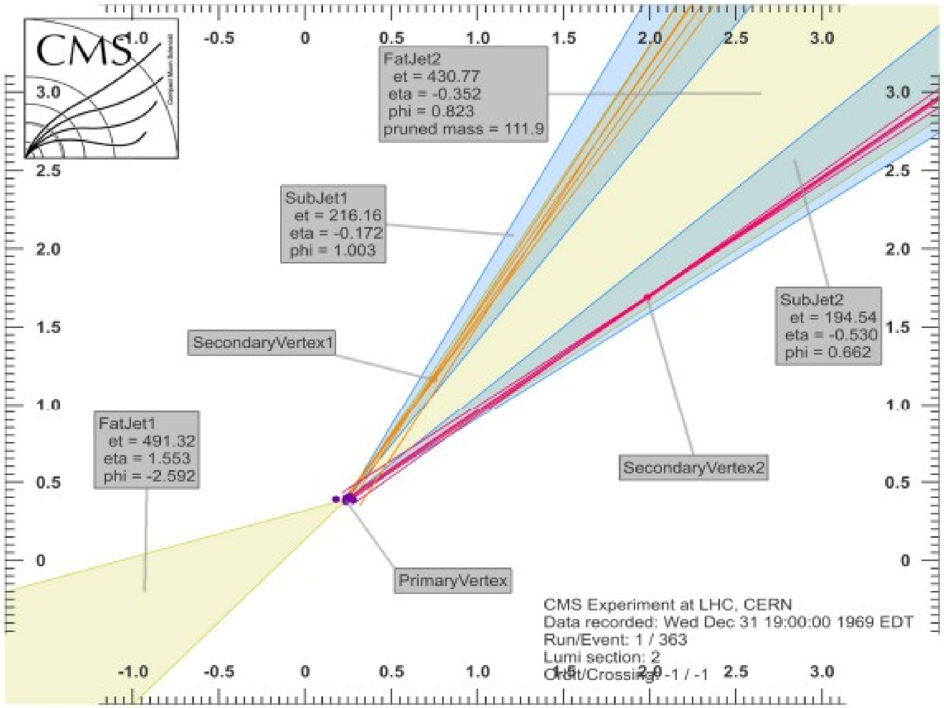


B-tagging in jet substructure

- Last comment: B-tagging was really only seriously brought up last year for the first time (see Ivan Marchesini's talk from BOOST'13)

arXiv:1307.7135

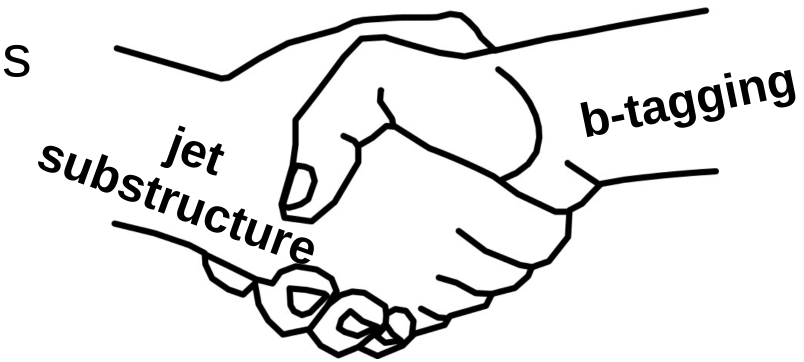




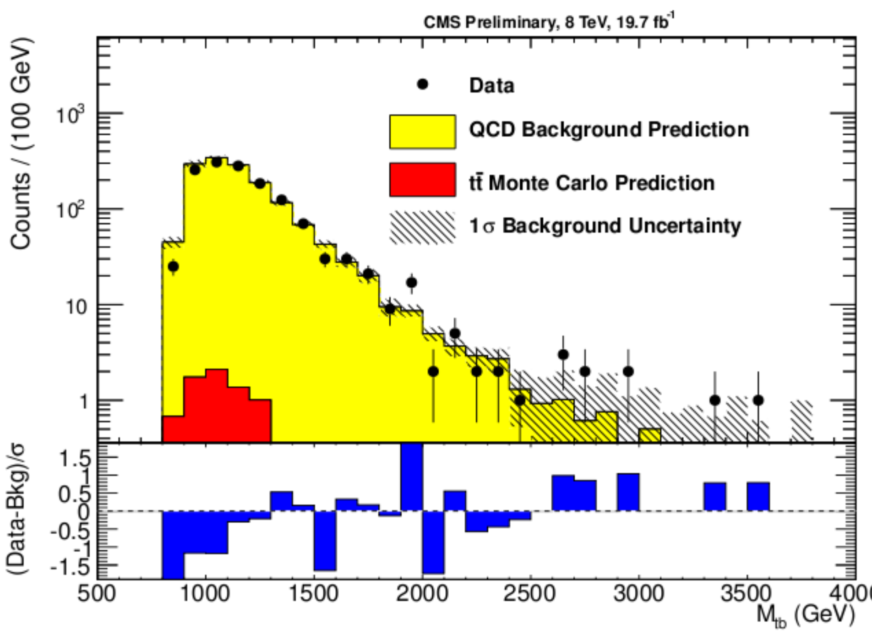
boosted higgs → bb (MC)

B-tagging in jet substructure

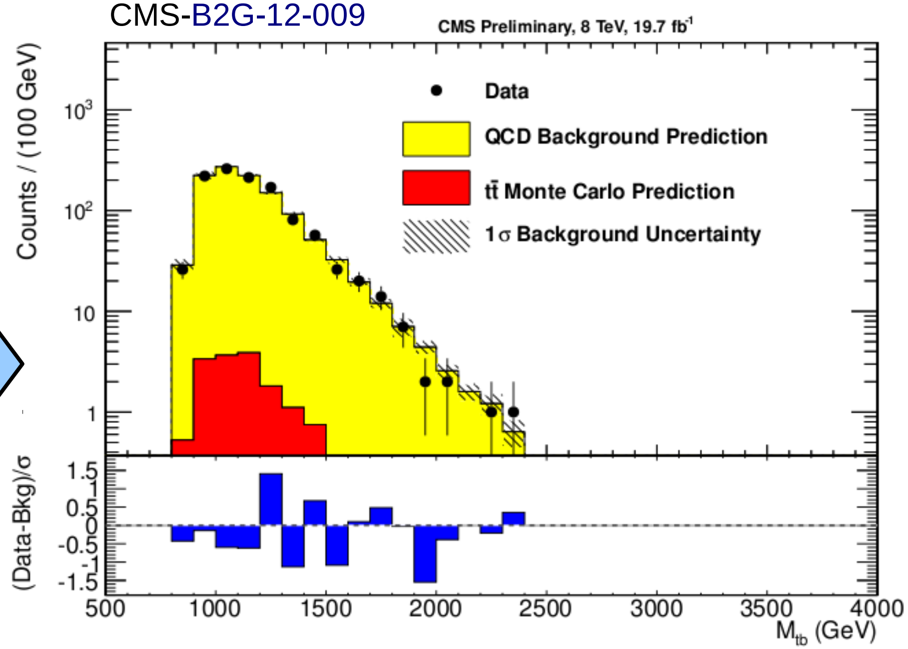
- B-tagging subjets: integrating b-tagging and substructure techniques in boosted topologies
- eg: CMS W' → tb resonance



CMS-B2G-12-009



after top candidate selection



after top candidate selection
+ subjet btagging requirement

B-tagging in jet substructure

- Further improvements can be gained...

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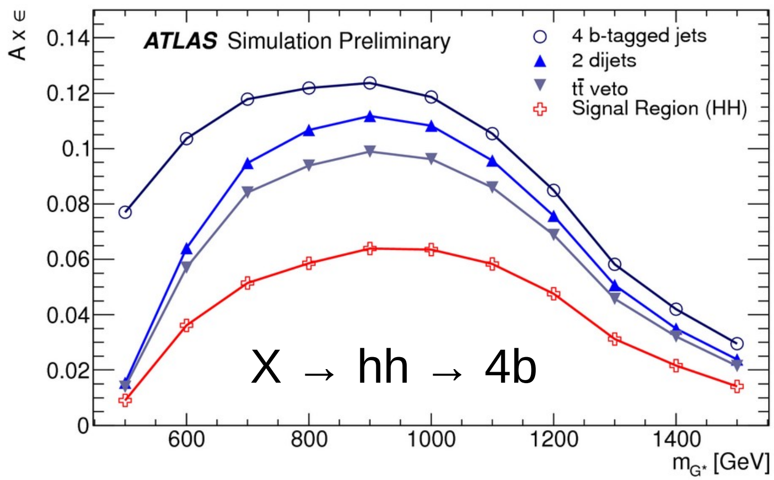
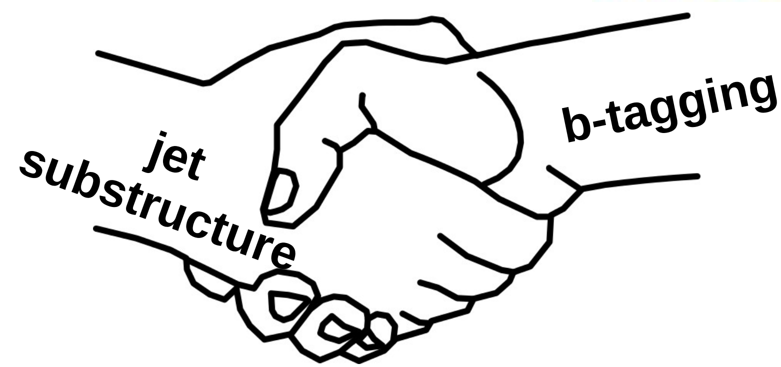
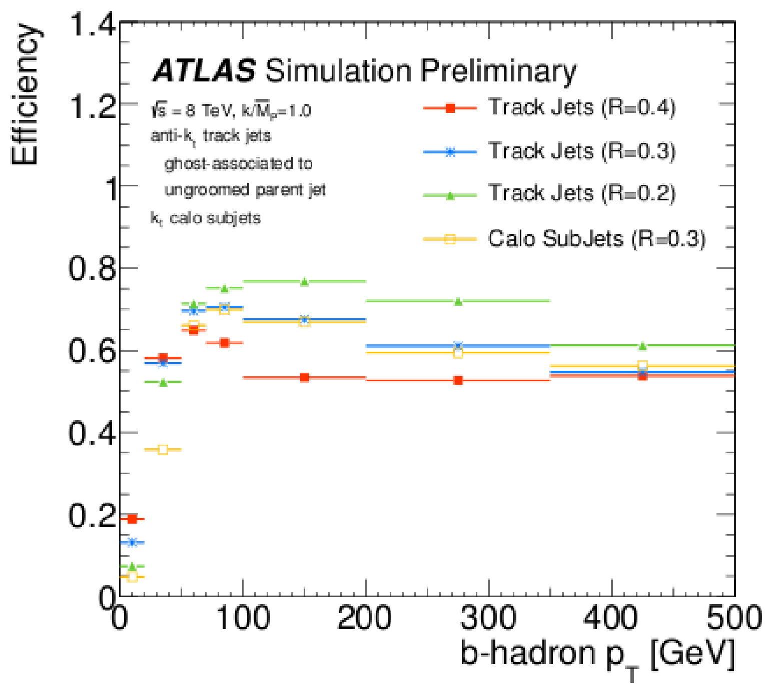




Resolved analysis loses efficiency where b-tagged R=0.4 jets begin to merge



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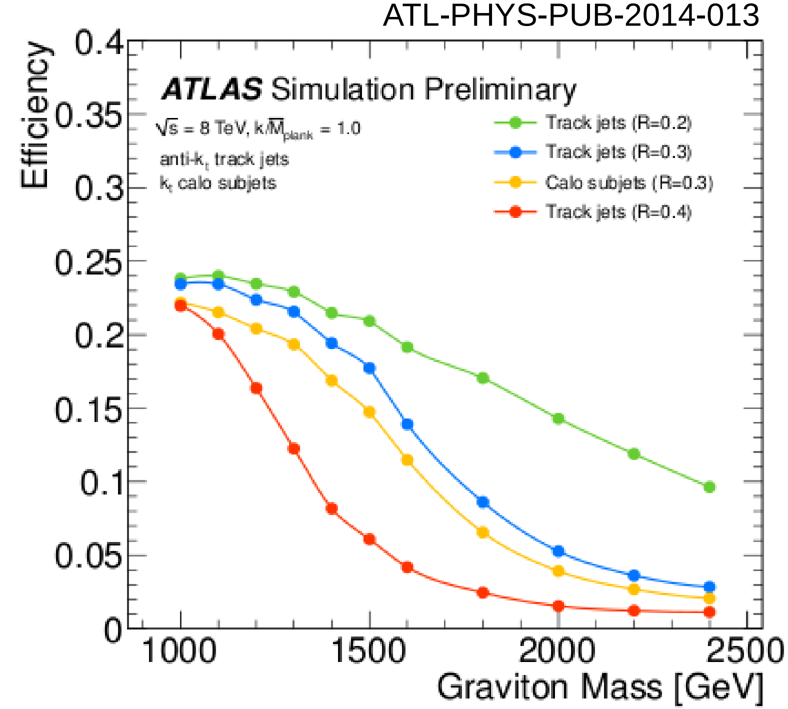

In conclusion...

- Can't do Run2 without boosted techniques! Questions to ask going in:
  - What are the optimal taggers? Need to do proper comparisons with systematics
  - How will we define the uncertainties on W and Top tagging efficiency? Using in-situ techniques on the global jet or by propagating individual substructure uncertainties? How can these be improved?
  - Can we improve pileup mitigation? ie: for the jet 4-vector and internal shapes
  - What else can we do with tracking? Where does this break down?
  - How well do things improve when we feed measurements back to generators?
- Ultimate question: If we see evidence of new physics, how do we convince the world (and ourselves) that we're right, and that its not a feature of a tagger? how do you understand the tails?
- Looking forward to a great workshop!