INSTITUTO DE FÍSICA CORPUSCULAR
Centro mixto U. de València (Estudi General) - CSIC

Exotic Physics using top quarks in ATLAS
Current analysis at IFIC

Santiago González de la Hoz, Elena Oliver, Eduardo Ros, José Salt,
Miguel Villaplana, Marcel Vos

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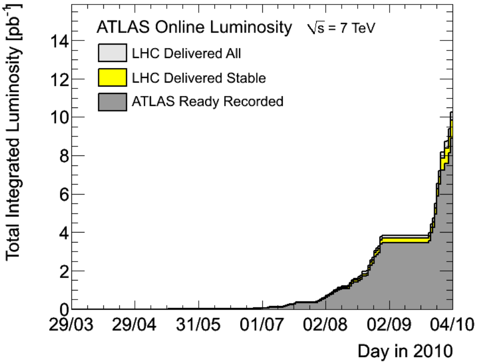
LHC Status

LHC luminosity ramping up steadily



ATLAS counters by Sunday, October 3rd 2010

- Highest luminosity = $5.14x10^{31} cm^{-2}s^{-1}$
- Recorded luminosity = $8.903pb^{-1}$

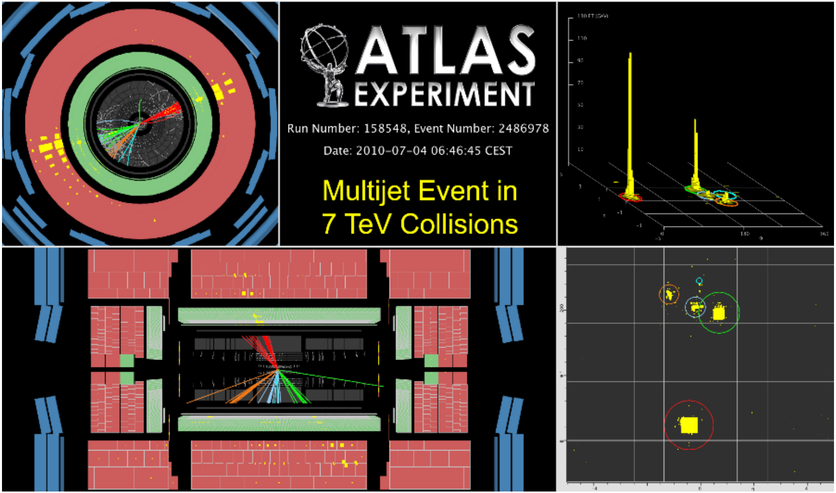
Early ATLAS studies

- Commissioning I with cosmics, 900 GeV, 2.36 TeV and earliest 7 TeV data.
  - Debug reconstruction software
  - Get to know the detector, learn about its imperfections
  - Get inner detector alignment and material
- Commissioning II rediscover the Standard Model
  - Underlying event/pile-up tunes
  - Estimate systematic errors
  - Rate measurements SM processes at 7 TeV

Process	**Rate in nominal LHC** $10^{34} cm^{-2} s^{-1}$ **@ 14 TeV**
Inelastic pp collissions	10^9 Hz
B-quark pair production	10^6 Hz
Jet production, $E_T > 250 GeV$	10^3 Hz
$W \to l\nu$	10^2 Hz
Top quark pair production	10 Hz
Higgs production ($m_H = 100 GeV$)	0.2 Hz

So far we have seen...

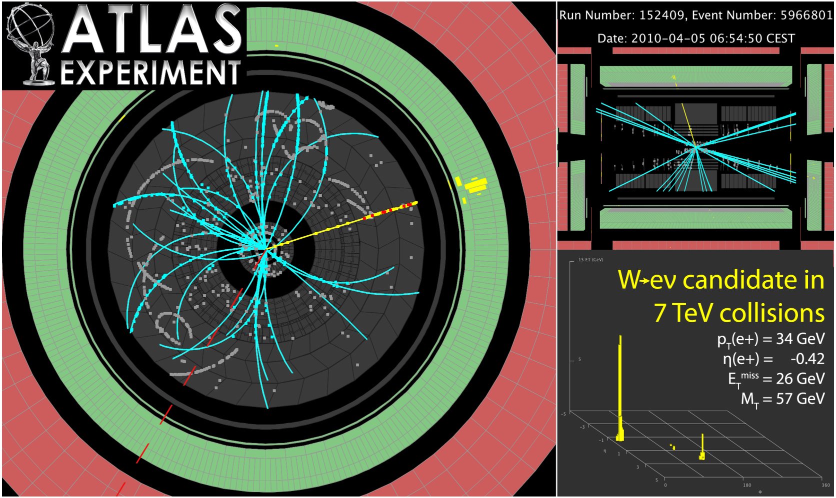
Jets



High p_T dijet angular distributions in pp interactions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector at the LHC, ATL-CONF-2010-074

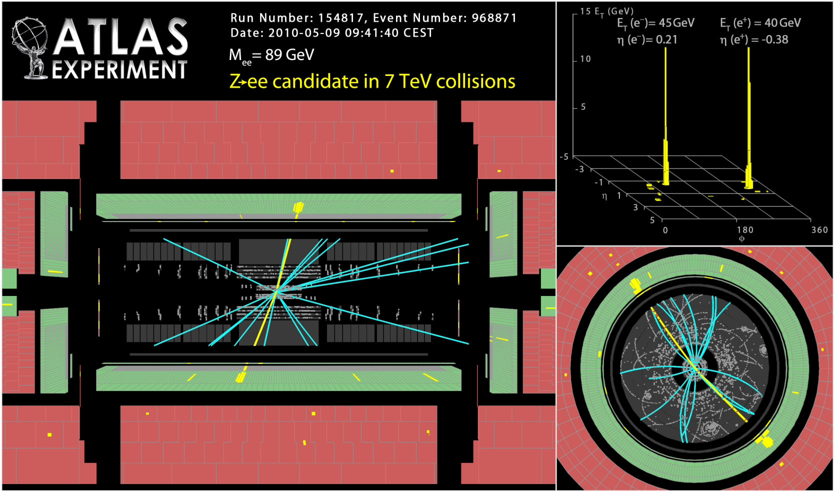
So far we have seen...

Candidates of W



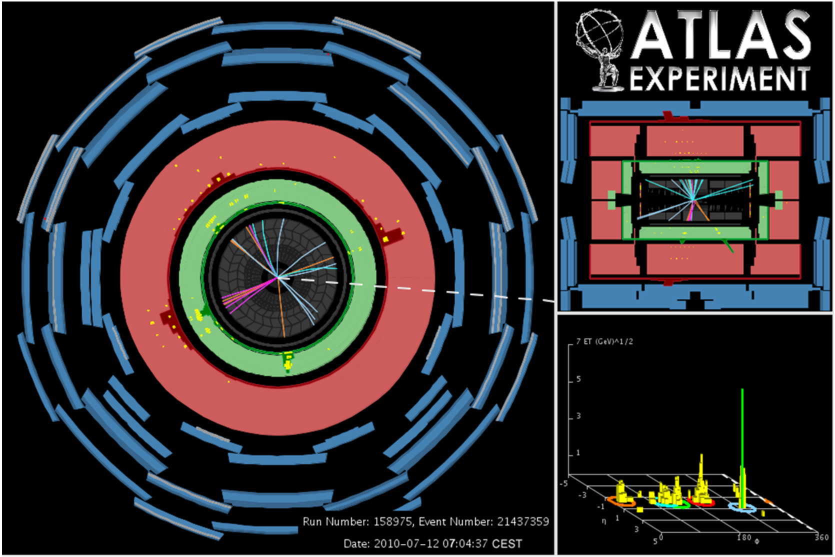
So far we have seen...

Candidates of Z



Measurement of the $Z \to ll$ production cross-section in proton-proton collissions at *sqrts*= 7 TeV with the ATLAS detector, ATL-CONF-2010-076

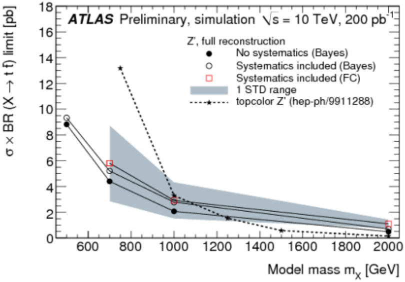
And (nearly) a top

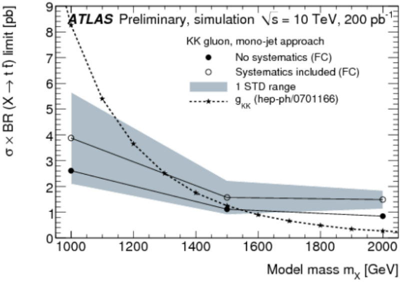


Search for top pair candidate events in ATLAS at $\sqrt{s} = 7$ TeV, ATL-CONF-2010-063

$t\bar{t}$ resonance searches

The improvements in the algorithms bring $t\bar{t}$ resonance searches in the realm of early physics (even though our mass reach does not quite compete with $Z' \rightarrow e^+e^-$ and $q* \rightarrow jj$)





- Exclusion possible with 200 pb^{-1} @ 10 TeV for a broad resonance (coloured object like the KK gluon) at $\approx$ 1 TeV mass.
- New cross section limits for Z'-like resonances could be set to 4 (2) pb for M =1 (2) TeV

Constraining new physics

How to get the most out of the data?

- Three different $t\bar{t}$ final states:
  - di-lepton (no public ATLAS results)
  - lepton +jets (ATL-PHYS-PUB-2010-008)
  - fully hadronic (no ATLAS study, but see CMS)
- At least three different reconstruction algorithms:
  - aimed at tops at rest/in high-mass tail
- Several possible observables:
  - $t\bar{t}$ mass (traditional resonance search)
  - charge asymmetry (See Smail Belaaouja's talk)

Top as a signature for new physics?

Why the top?

The top is too heavy, it's less constrained by (LEP) data

An experimentalist's view

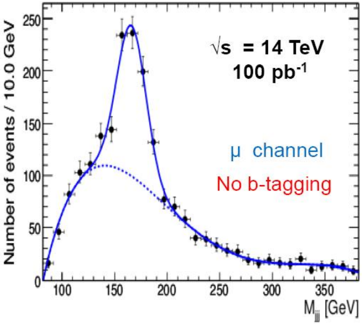
Bottom and top quarks can be identified efficiently. Top is the only quark that produces isolated leptons and where quarks can be easily distinguished from anti-quarks (charge asymmetries, same-sign top signature)

The program:

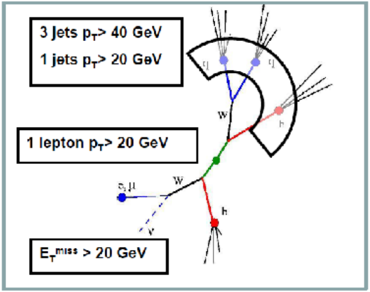
So far, concentrated early effort on $t\bar{t}$ resonance search in lepton+jets final state (ATL-PHYS-PUB-2010-008). Other final states and $W' \to tb$ to follow soon after. A very rich program in the long run.

Top reconstruction basics

- Top reconstruction algorithms are well-established at the Tevatron. The same “resolved“ approach forms the back-bone of the ATLAS preparation for top physics.
- Find isolated lepton.
- Find 4 jets.
- Reconstruct neutrino using lepton, E_T^{miss} and W-mass constraint.
- (Optional) Tag b-jets.
- Piece it all together again, selecting the right combination.



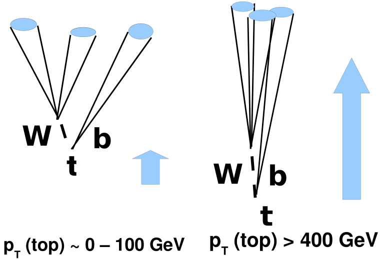
three jet mass

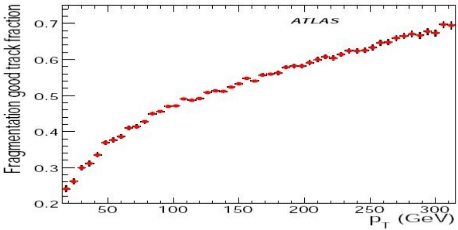


tt -> Wb Wb -> ℓνb qqb

Why are high p_T tops so hard?

Charged multiplicity in cone

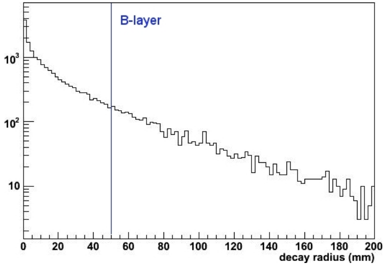


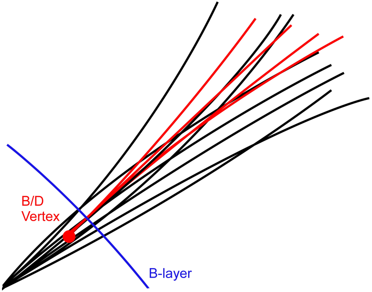


- Number of tracks in b-jet (core) increases with jet E_T
- As $\#$ tracks from B-decay is constant its relative weight decreases.

Why are high p_T tops so hard?

Displaced vertex



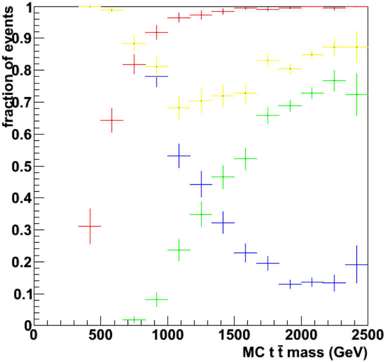


- Average decay radius of B hadrons: $L = c\tau\gamma$
- For $Z_H(2TeV)$ L no longer $<<$ B-layer radius.
- B/D decays "right in front" of the B-layer: tracks from secondary/tertiary vertex have no "time" to separate.

The Transition Region Problem

Moderate p_T tops from 1-2 TeV resonances are too hard to be resolved, but too soft to be treated as mono-jets. Both a pure resolved approach and a pure mono-jet approach will show an inefficiency due to signal events that fail to create the right topology.

Resolved	: 3 jets are well separated (good at low energies)
Mono-jet	: jets are so close you can see them as one big jet (good at high energies)
Resolver or Mono-jet	: Just choose between one or the other.



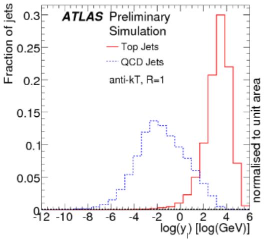
Leptonic Top:To reconstruct both tops and the resonance all we need to know is which jet to assign to the leptonic top. Taking the closest jet is correct in 90 % of events for a 1 TeV resonance. All jets "far" from the lepton are assigned to the hadronic top.

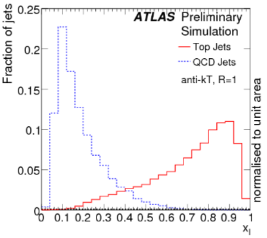
Embedded lepton

For moderate p_T (700 GeV < resonance mass < 2 TeV) the lepton from W-decay in $t\bar{t}$ events is typically "embedded":

- contained in the fat top jet (isolation likely to fail)
- usually found in the jet periphery (efficient reconstruction can be achieved)

If traditional isolation is discarded, leptons from bottom and charm decay become a dangerous background

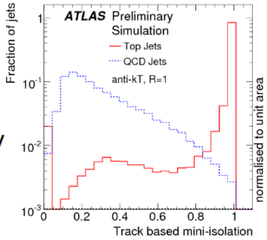




Energy sharing between jet and lepton

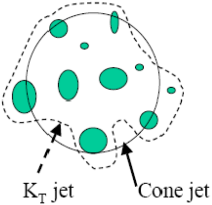
Mini-isolation: energy sum in dynamically shrinking cone around the lepton

(ATL-PHYS-PUB-2010-008)



Boosted jet techniques

- ATLAS jet finding default is anti-k_T (R=0.4 or 0.6)
- For a parent with m and p_T, merging starts showing at $R > \frac{2m}{p_T}$.
- Use jet mass and jet substructure to resolve merging.
- Rerun jet algorithms on jet components to reveal jet substructure (k_T or Cone)

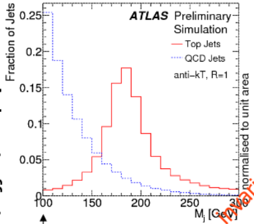


- Jets suffer from contamination due to underlying event and pile-up (can be partially corrected for by associating clusters to tracks to vertices)
- Several jet grooming techniques have been developed to remove the "softest" subjets: filtering, trimming, pruning...

Complete inventory of existing literature to appear in proceedings of BOOST2010

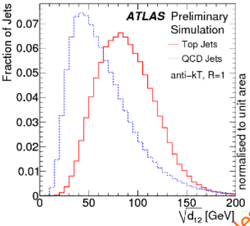
Jet mass and splitting scales

Axis cut off at m=100 GeV



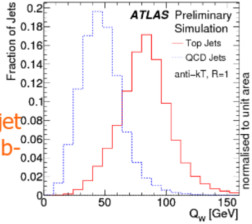
Jet mass: invariant mass of all components

Re-run jet algorithm (or unwind the clustering sequence)



(ATL-PHYS-PUB-2010-008)

Splitting scales or energy sharing variables



Mass of non-leading sub-jet pair, refined direction for b-tagging

Use the sub-jet information to calculate further observables

To sum up

- The LHC has (finally) started to explore the TeV regime.
- ATLAS has a commissioned detector, validated reconstruction algorithms and exercised key analyses on MC.
- Top reconstruction techniques that are adequate for the kinematic regime of the LHC have been implemented and tested exhaustively on MC and are being commissioned on (QCD di-jet) data as we speak.
- Early $t\bar{t}$ resonance search to pave the way for a rich program of searches with top quarks, from resonance searches to more exotic possibilities.

Current analysis at IFIC

Probing jet sub-structure

Towards the commissioning of the top-tagger observables

- We study the distributions of the top-tagging variables on a sample of high p_T jets found in (predominantly) QCD di-jet events collected in August.
- We compare the result to the standard Pythia J1-J5 Monte Carlo.
- We consider several systematic effects, due to uncertainties in the parton shower model, the underlying event description and detector effects.
- We present (conservative) systematic error estimates based on these studies.

Data Sample

- Using a jet sample with $200GeV < p_T^{jet} < 400GeV$ corresponding to $184nb^{-1}$ of 7 TeV ATLAS data
- Period D Runs:159157, 159224, 159113, 159086 & 159041
- GRL from top group (tends to be more strict, where different from jet/E_T^{miss})
- Peak luminosity up to $10^{30}cm^{-2}s^{-1}$

Good Run List

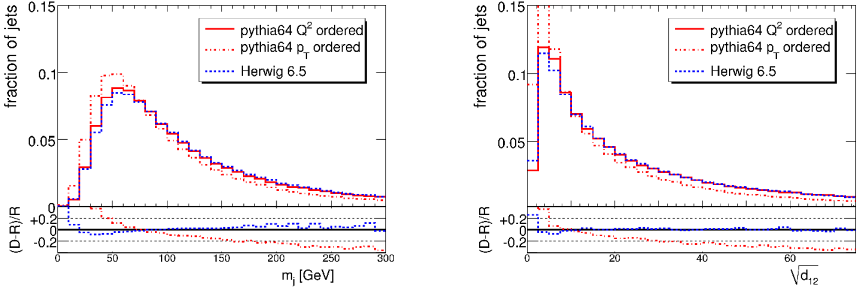
- https://atlasdqm.cern.ch/grl/
- **Configuration file:** StandardGRL.top_allchannels_7TeV
- **Project tag/data period:** Data10_7TeV periondD (Runs 158045 - 159224)
- **DQ folder:** LBSUMM
- **COOL tag:** DetStatus-v03-pass1-analysis-2010D-RPCloose

Selection

- Analysed L1Calo stream
- Skimmed by requiring p_T of leading jet > 100 GeV
- Create a jet sample containing all good AntiKt6LCTopo jets (n90, good jet) with 200 GeV < p_T < 400 GeV
- Accompanied by Pythia J1-J5
- normalized MC by applying an ad-hoc scale factor determined as the ratio of the number of events in the $100 < p_T < 200 GeV$ bin.
- And a series of custom generator-level samples to study systematics

Systematics

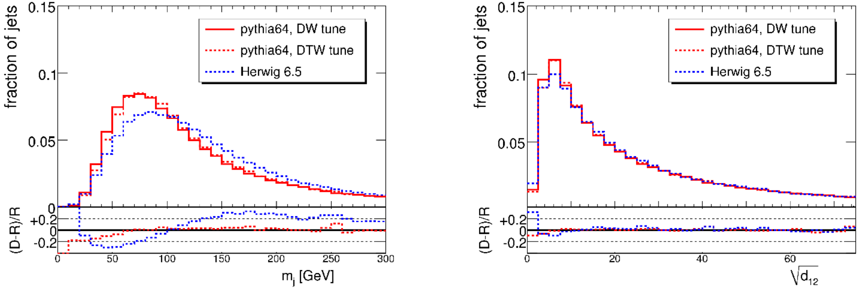
Parton Shower



Comparing the properties of particle-level jets on three samples with different parton shower models. All plots correspond to an approximately flat distribution over a wide range of jet p_T from 200-1600 GeV. To isolate the effect of the parton shower, the underlying event generation was switched off for these samples. Most studies rely on Pythia Q^2 ordered showers, or the Herwig shower. First bins are very sensitive due to steep rise of the jet mass distribution. Good agreement Herwig and Pythia-Q^2: max deviations less than 10%, much less for d_{12}. Deviation of the p_T-ordered shower wrt default pythia is up to 30%. Samples courtesy of Gavin Salam and the BOOST2010 hadronic WG.

Systematics

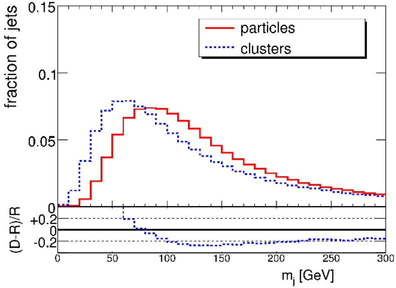
Underlying Event

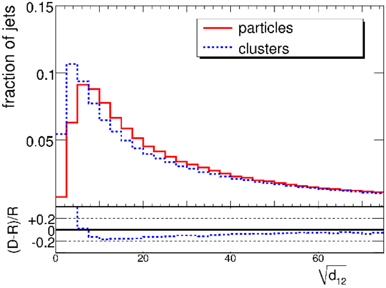


Comparing different Underlying Event tunes. PythiaDTW has more activitity than PythiaDW, Herwig (out-of-the-box) still more. Jet mass is found to be very sensitive to soft activity with an origin outside the jet (deviations Herwig-Pythia of up to 30%). The splitting scales are much more robust, with tiny deviations (further splitting scales d_{23} and d_{34} are again more sensitive). Samples courtesy of Gavin Salam and the BOOST2010 hadronic WG.

Systematics

Detector





Comparing particle-level to cluster-level jets. The clusters were formed using a 0.1x0.1 $\eta - \phi$ grid. For each cell a massless cluster is formed if the energy sum exceeds 1 GeV. Thus, we take into account the finite detector granularity and the noise threshold; no other detector effects are simulated. Detectors shape the jet mass distribution in an important way. Deviations in low m bins can exceed 100%. Splitting scales are less sensitive, maximum 20%. Expect the ATLAS detector simulation to represent the data reasonably well (i.e. systematic uncertainty should be smaller than the difference particle-cluster shown here). Samples courtesy of Brock Tweedie, Chris Vermillion, Steve Ellis, and the BOOST2010 hadronic WG.

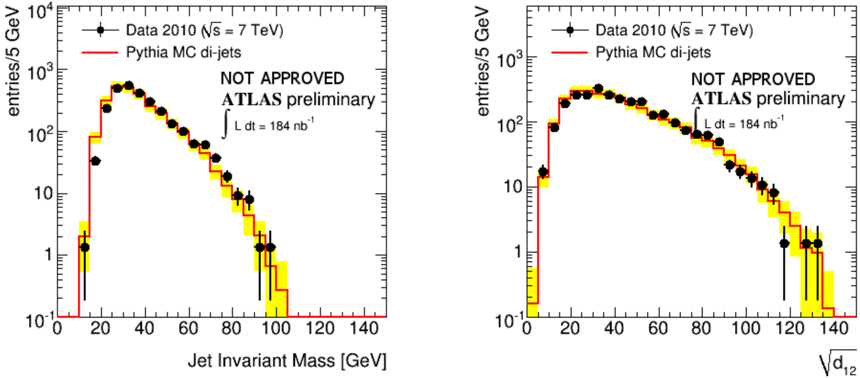
Systematics

Still working to add...

Pile-up, calibration, jet energy scale...

Results

Jet mass distribution and kT splitting scale for $200 < p_T < 300$ GeV



Jet mass cuts for top tagging on early data: 100 - 140 GeV

Conclusions & Outlook

Crucial jet substructure observables for top-tagging are reproduced well by MC (at the EM scale)

TO DO

- Go to higher p_T still: analyse period E/F
- Study more systemetics
- Extend analysis to energy sharing (z_{ij}).
- Extend analysis to groomed jets

Machinery to analyse top-tagging observables on high p_T jets sample mostly in place.