Collecting Events Based on Jet Substructure with the ATLAS Detector

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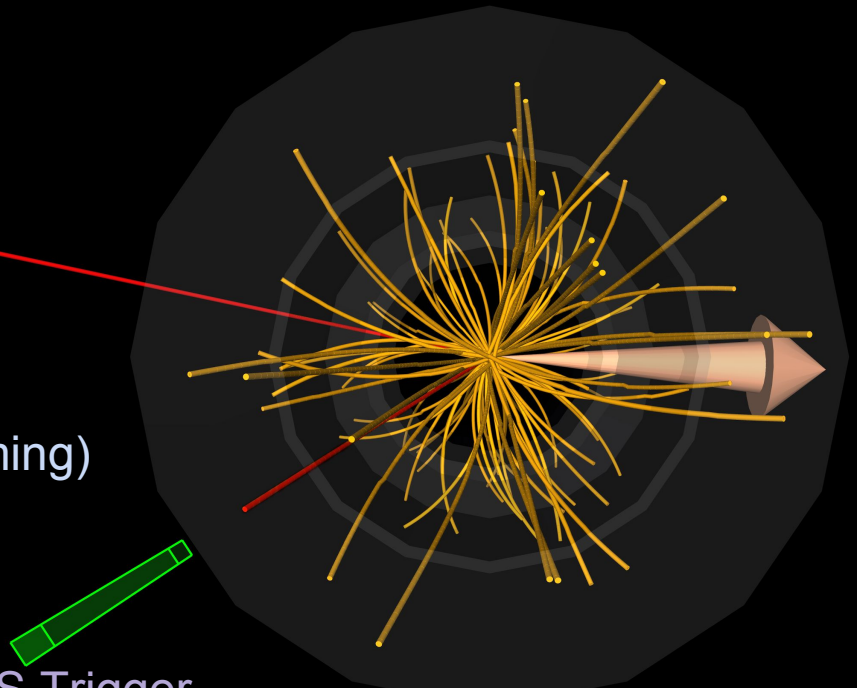
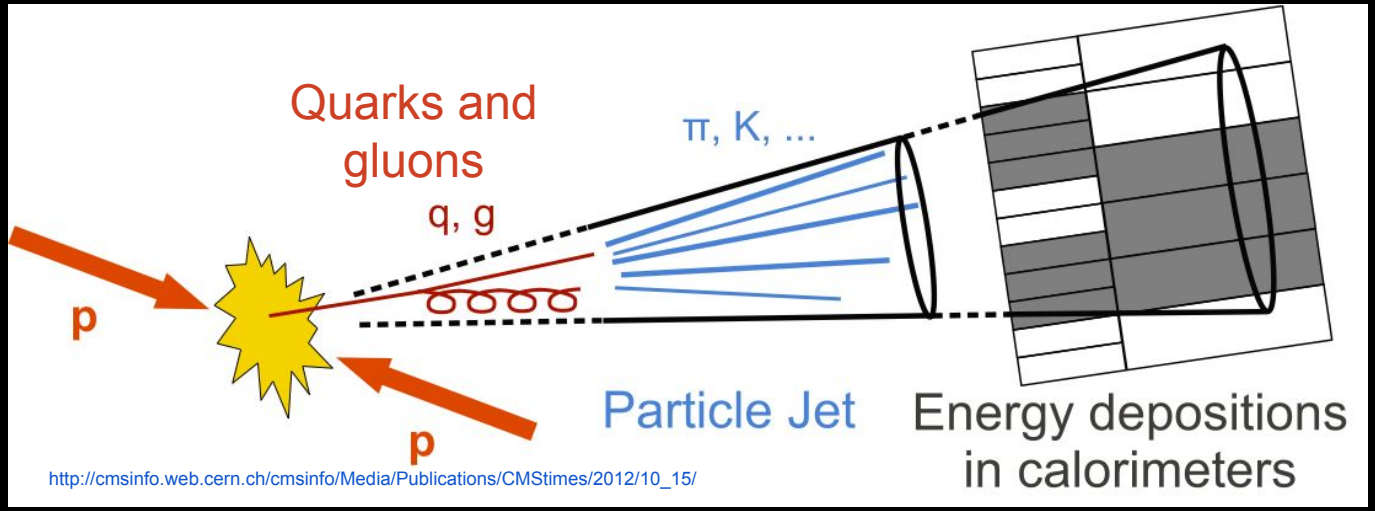
Outline

- Jets in proton-proton collisions
- Boosted jets
  - Example of ***W boson*** decay
  - Boosted jets in new physics scenario
- Challenges with boosted jets
- Jet substructure algorithms (grooming)
  - Trimming as an example
- The ATLAS trigger system
  - Jet trigger
- Applying jet grooming in the ATLAS Trigger
  - Comparison between three event triggers
  - Can grooming improve the event collection ?
- Conclusion



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayStandAlone

Jets in proton-proton collisions

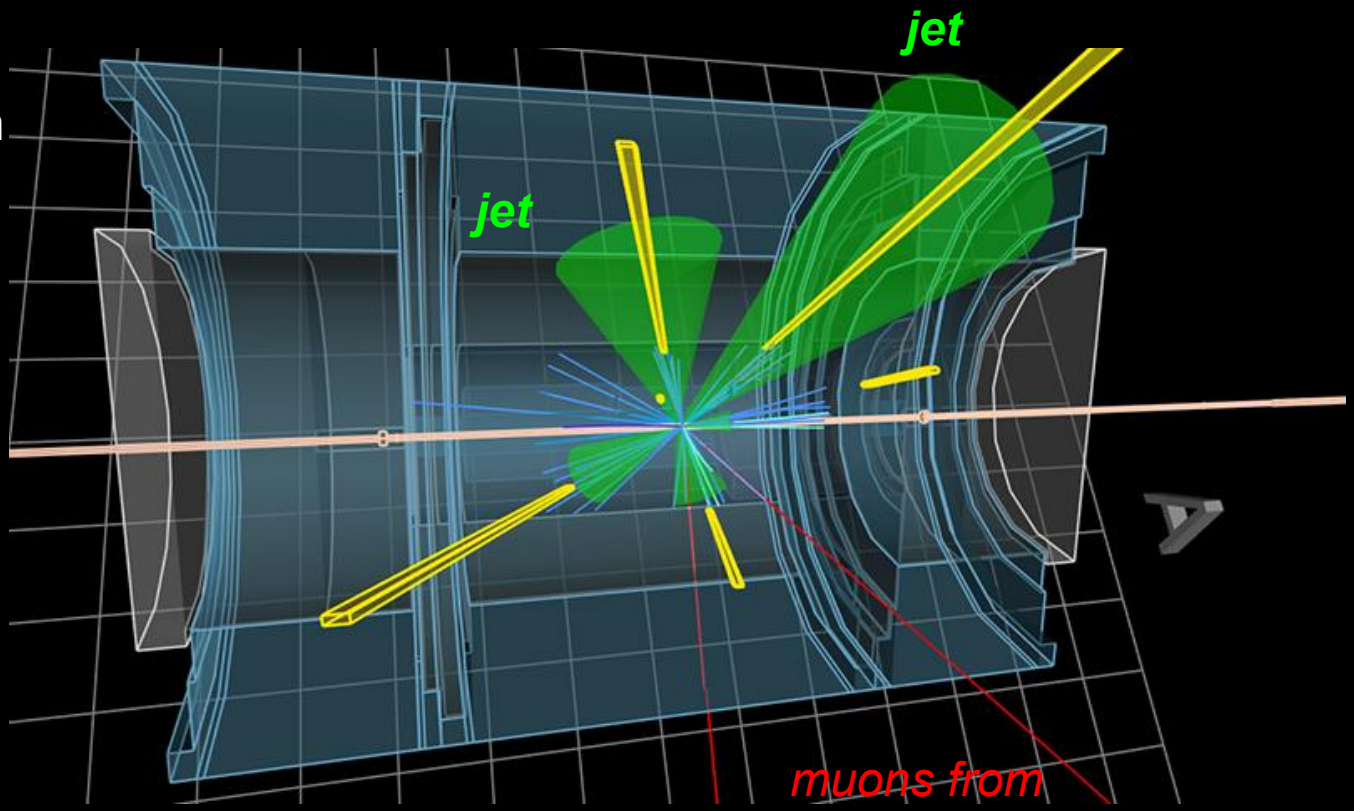


LHC is a hadronic collider → **Producing large number of colored particles (QCD)**

Due to color confinement → Colored particles hadronize to form collimated sprays of particles called ***jets***

Jets produced in a proton-proton collision

- A simulated collision event containing a ***Z boson*** and 5 ***hadronic jets*** in the ATLAS detector
- The lengths of the jets are proportional to their momenta

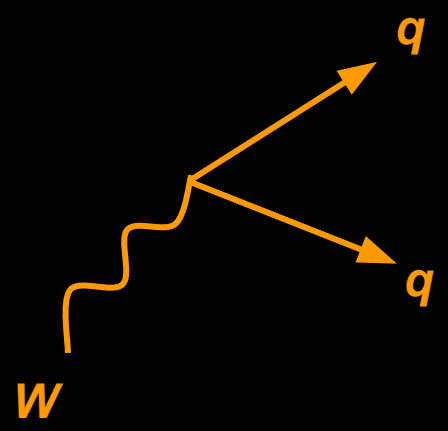


Source : phys.org 2015, by Jim Collins

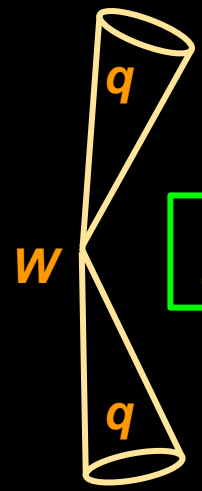
Jets from Heavy Particles

$W \rightarrow qq$

$m_W = 80$ GeV



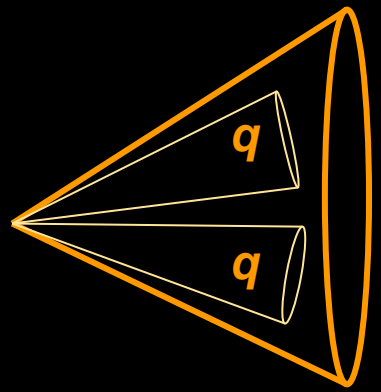
Two normal jets



$p_W \geq 3 \times m_W$

Boosted (high momentum)

One Large jet with substructure



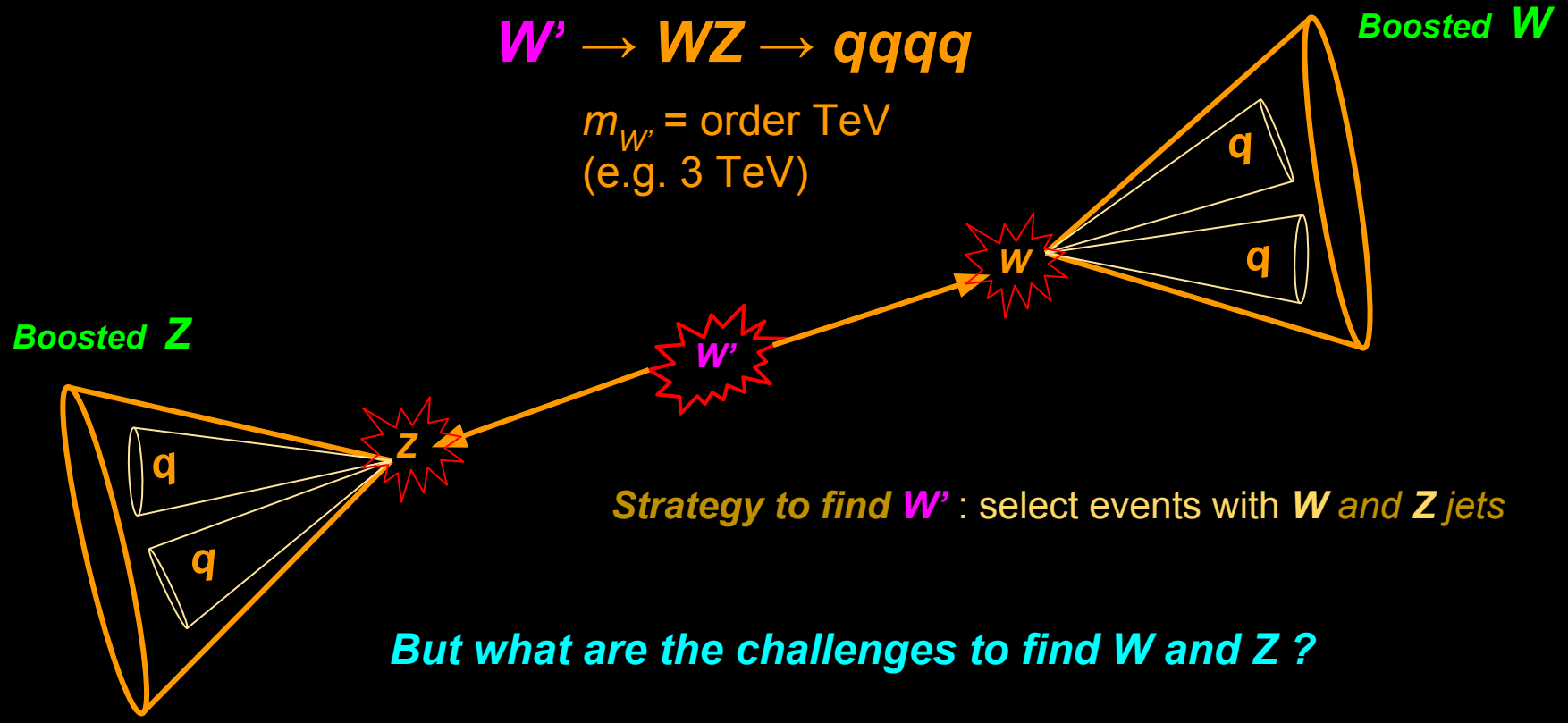
*If W has **low** momentum: it will produce 2 separate jets*

*If W has **high** momentum:*
→ collimated quarks
*→ single boosted jet with internal **substructure***

Boosted jets : new physics scenario (example)

W' → WZ → qqqq

$m_{W'}$ = order TeV
(e.g. 3 TeV)



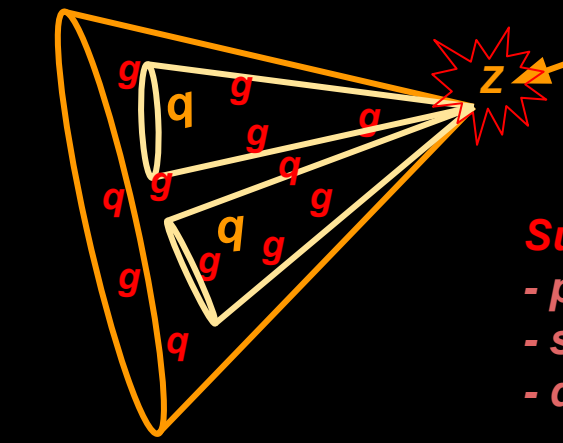
Strategy to find W' : select events with ***W*** *and* ***Z*** *jets*

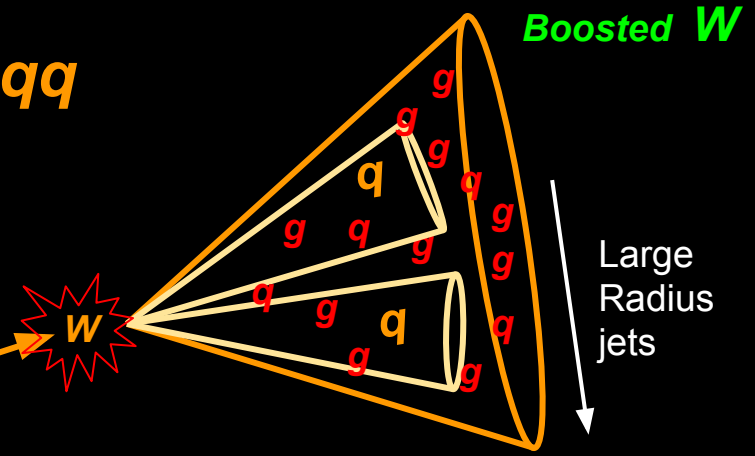
But what are the challenges to find W and Z ?

Boosted jets : *first challenge*

W' → WZ → qqqq

Large jets susceptible to Pileup and soft QCD



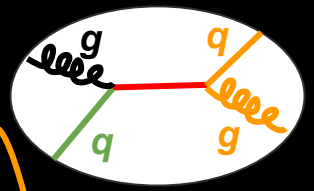


QCD background

Signal : W→qq jet (substructure of boosted jets)

Substructure in signal jets is deteriorated due to
- ***pileup particles from additional pp interactions***
- ***soft QCD effects*** *(MPI, soft ISR/FSR, hadronization)*
- ***detector resolution***

Boosted jets : ***second challenge***

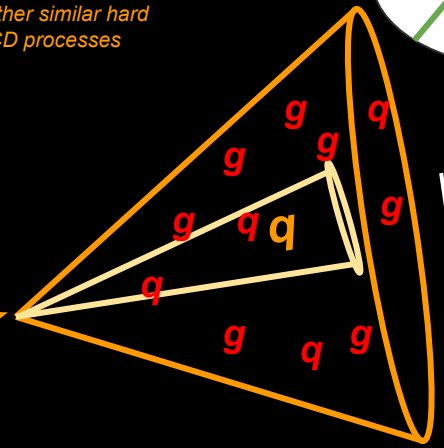


gq → gq

and other similar hard QCD processes

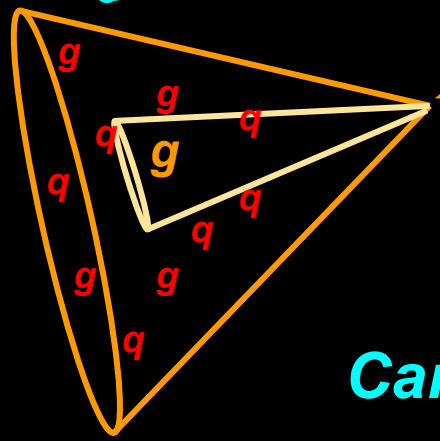
With a lot of energy

Hard QCD jets sometimes look just like the signal jets



Large Radius jets

Hard QCD



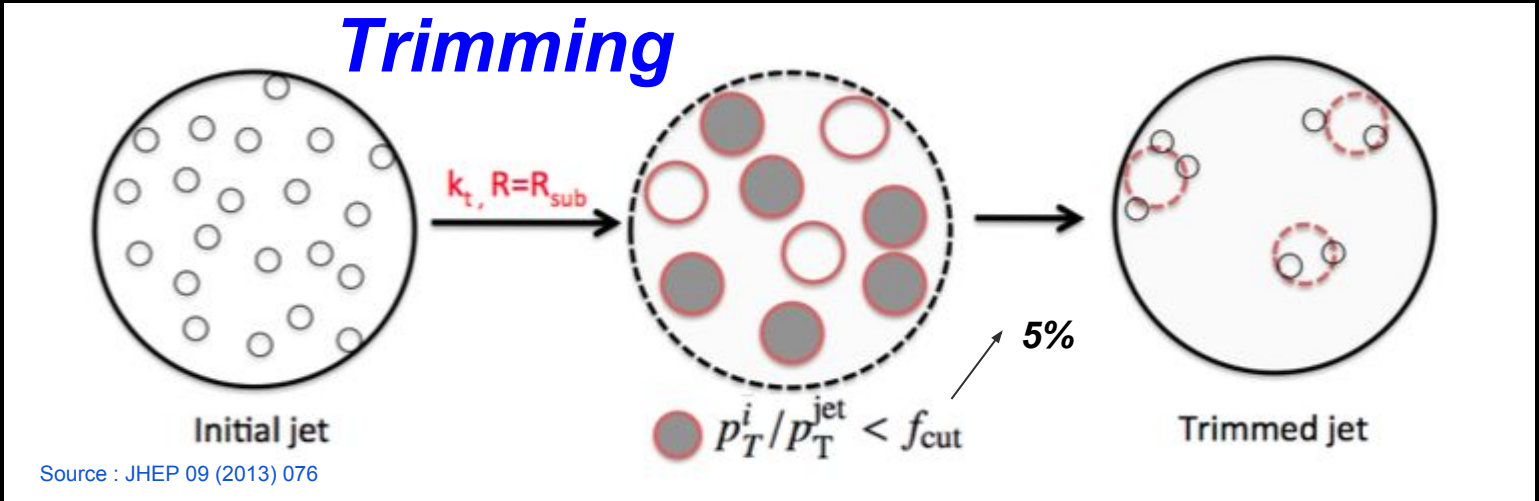
- ***Signal jets*** and ***hard QCD jets*** can have the same physical characteristics such as ***Mass, p_T*** and ***energy***
- ***Difficult*** to ***discriminate signal*** from **hard QCD jets**

Can we improve the discrimination ?

Jet Substructure Algorithms (Grooming)

Jet Grooming : Seeks to ***get rid of softer components*** in a jet and leave constituents from hard scatter behind.

- Grooming algorithms are often used to analyse ***recorded events***
  - Makes ***substructure visible*** (e.g. ***improve*** mass resolution)
  - Very ***useful*** for many physics analysis searching for ***heavy boosted particles***



Source : JHEP 09 (2013) 076

The trigger system: ***a filter for recording data***

The ATLAS trigger system decides, ***in real time***, whether to ***record an event or not***.

Need to:

- Reduce data rate from up to ***40 MHz*** to ***1 kHz***
  - Detector is read out every ***25 ns***
- Keep the ***interesting collisions*** with as ***high efficiency*** as possible
  - Such as events with ***hard jet substructure***

Jet Trigger : ***implementation***

- To achieve this goal ATLAS trigger is ***divided in two levels*** :
  - Level 1 : ***implemented in hardware***
    - Reduce data rate from ***40 MHz to 100 kHz***
  - High-Level Trigger (**HLT**) : ***implemented in software***
    - Reduce data rate from ***100 kHz to 1 kHz***
      - Jet reconstruction algorithm
      - Energy and momentum threshold are considered

Question : Can we apply ***grooming techniques at HLT*** to collect more events with hard ***jet substructure*** and less ***QCD background*** events ?

Applying Jet Grooming at HLT

- The goal is to make it possible to trigger events based on jet substructure
  - These triggers can be used for jet substructure analysis
    - W' and Z' searches (for example)

- ***Challenges :***
  - These triggers have to ***run very fast***
    - Decisions must be made in ***fraction of a second***

  - Need to carefully check if all is working
    - Trigger decision ***cannot be undone!***

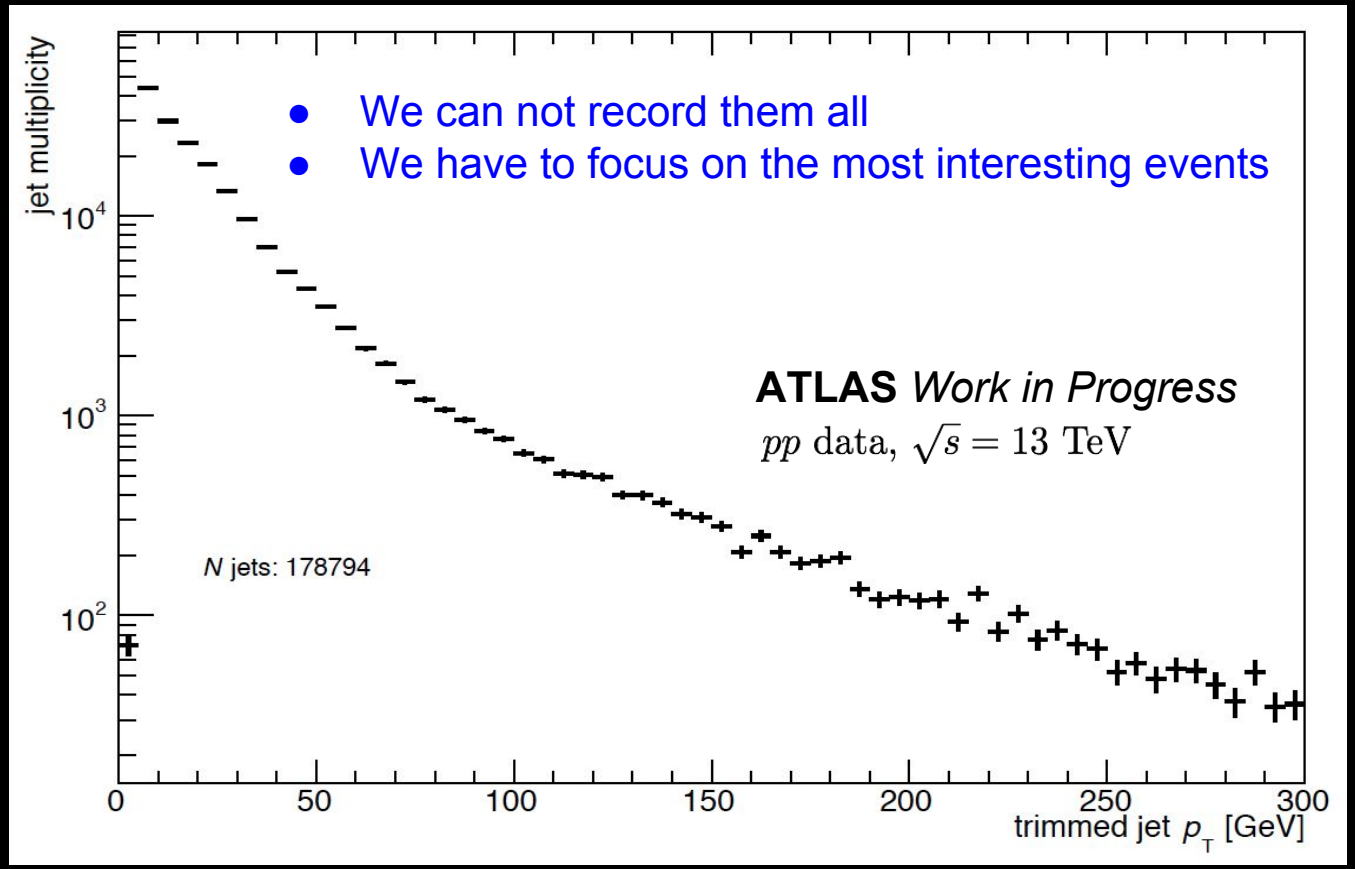
  - Collecting more ***interesting events*** (jets with ***hard substructure***)
    - ***Increasing signal efficiency***
    - ***Decreasing collecting event rate*** *of events without jet substructure*

Applying Jet Grooming at HLT : ***Trigger conditions***

Three trigger conditions have been considered for comparison :

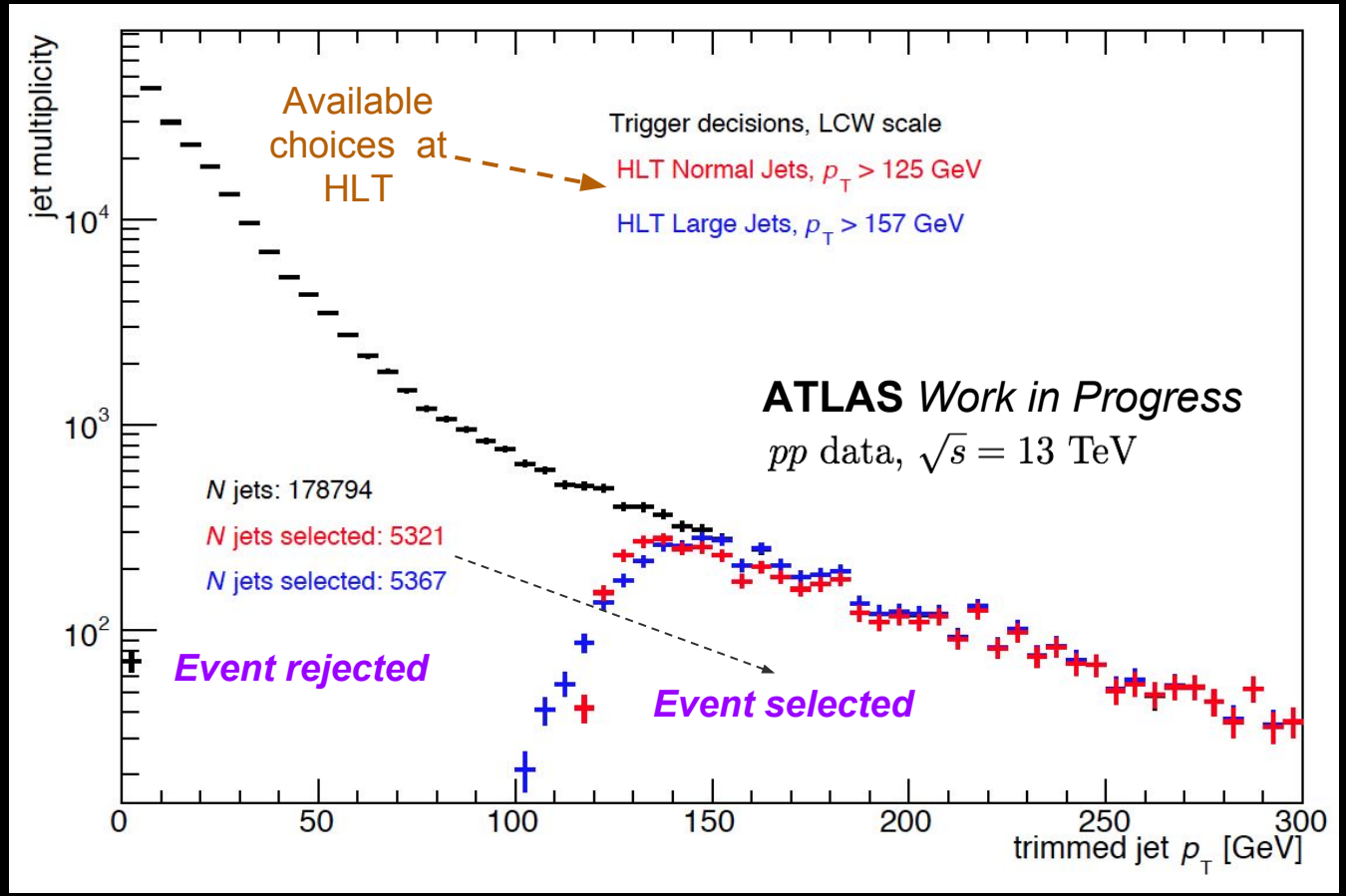
- **Current HLT *can use*** :
  - Normal jets
  - Large-radius jets
- **Current HLT *can not* use :**
  - Large-radius jets with grooming (trimming)

Collecting Events Rate : Total number of available jets



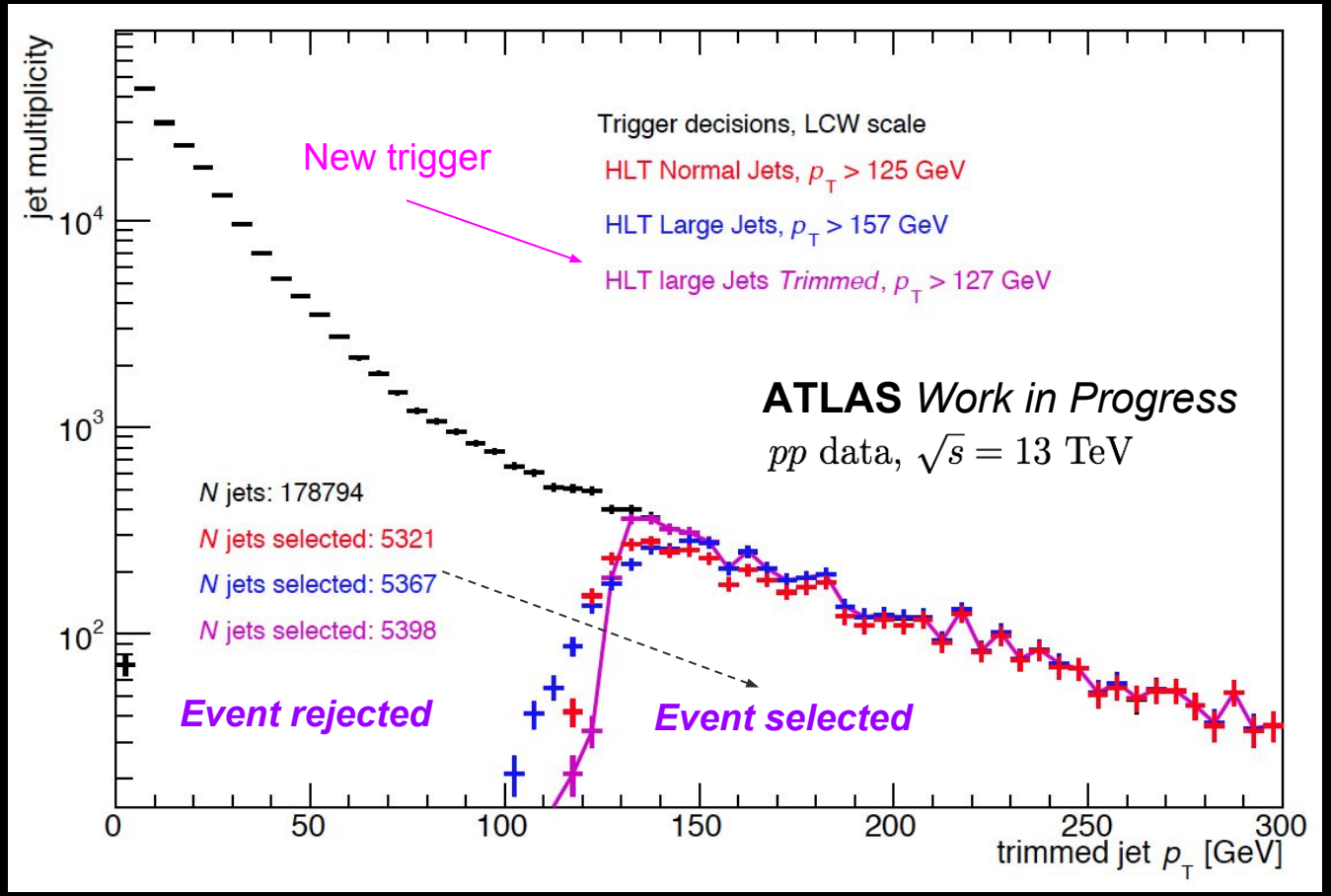
- All ***trimmed jets***
- ***N_{jets}*** : total number of jets (***area of full histogram***)

Collecting Events Rate : Comparison of Trigger Decisions



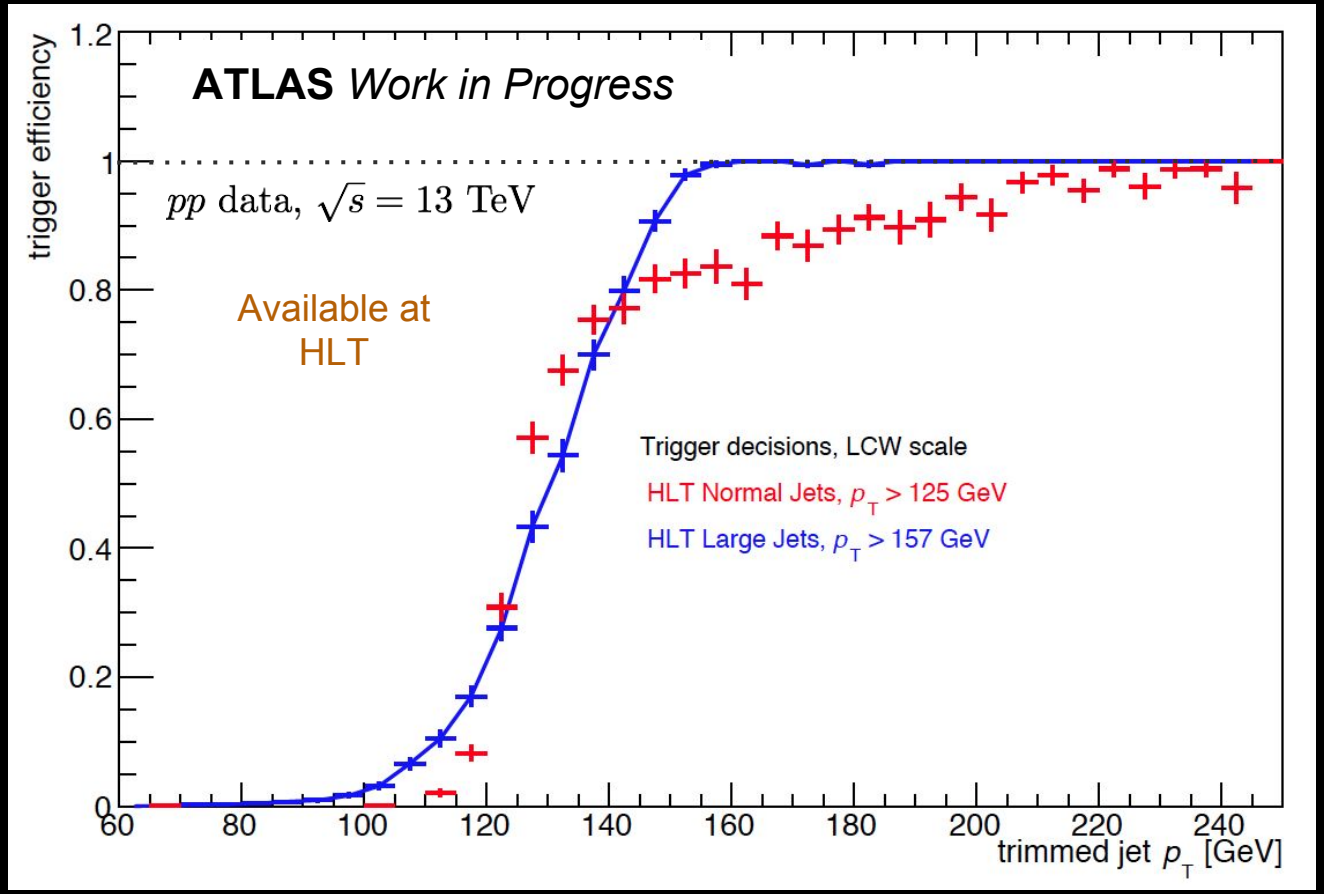
- both triggers collect ***same amount of events***
- Current HLT ***can use*** both trigger conditions
- ***N jets selected*** : number of jets that ***satisfied*** the trigger condition

Collecting Events Rate : Comparison of Trigger Decisions



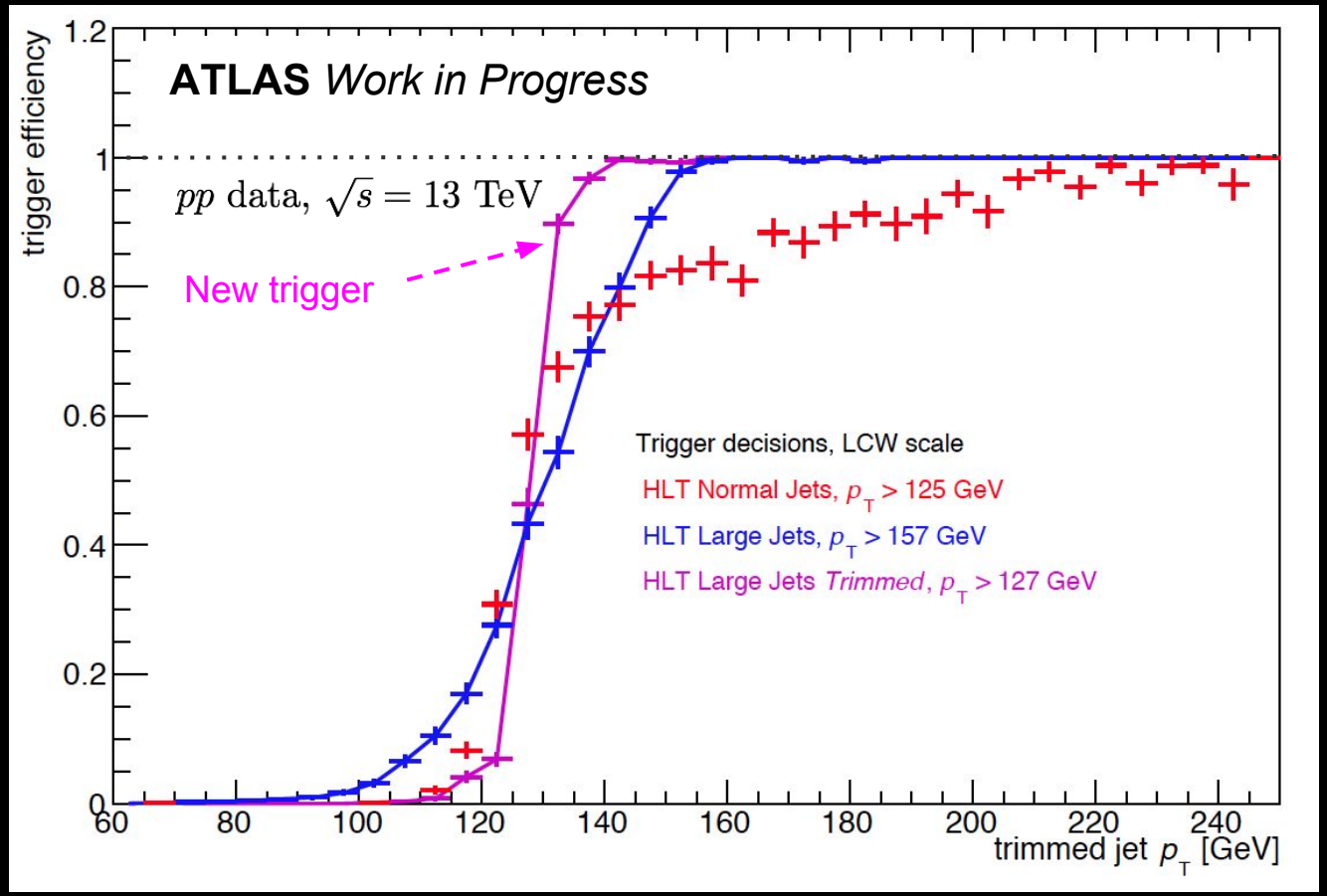
- All triggers collect ***same amount of events***
- Make it ***easier to compare*** their ***efficiencies*** directly

Collecting Events Efficiency : Comparison of Trigger Decisions



- Trigger efficiency as a function of groomed jet transverse momentum
- 2 triggers are compared - each collects data at the same rate
- These two options are available in the current ATLAS trigger menu

Collecting Events Efficiency : Comparison of Trigger Decisions



- Trigger efficiency as a function of groomed jet transverse momentum
- 3 Triggers are compared - each collects data at the same rate
- The first two options are available in the current ATLAS trigger menu
- My added trigger (***trimming***) is ***sharper***
  - ***Better collections***
  - ***Better performance***

Conclusion

- Several searches for ***new high energy physics*** rely on ***jet grooming techniques*** to identify hadronically decaying ***heavy boosted objects*** (e.g. Higgs, W, Z and top quak)
  - Grooming makes ***jet substructure visible*** which helps ***reject QCD background***
- My work is to ***implement jet grooming*** and ***event selection*** based on ***jet substructure*** in the ATLAS trigger system (HLT)
  - To ***improve efficiency*** of boosted heavy jets while keeping rate low
  - Useful for analysis relying on ***jet substructure***, e.g. W' and Z' searches
- A comparison between three Trigger conditions performed in this study :
  - For the ***same event collection rate*** :
    - Trigger decision with ***grooming (trimming)*** perform ***significantly better***
      - Efficiency plateau ***extended to lower*** jet transverse momentum (p_T)
- ***Will hopefully be implemented for ATLAS data taking by the end of this year***

Thank you for your attention

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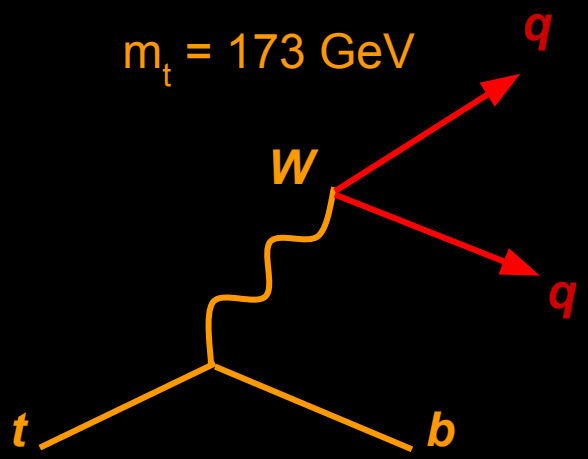
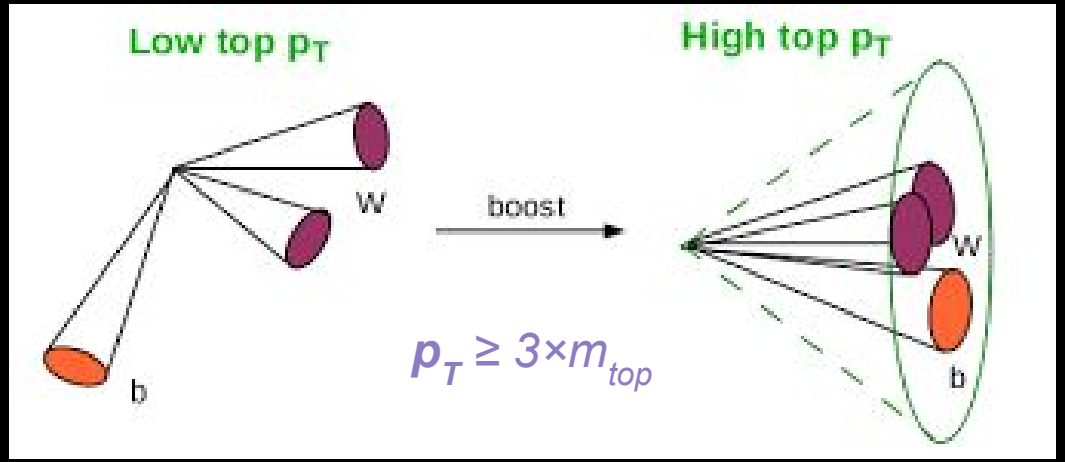
Back Up slides

Jets from Heavy Particles

t → Wb

m_t = 173 GeV





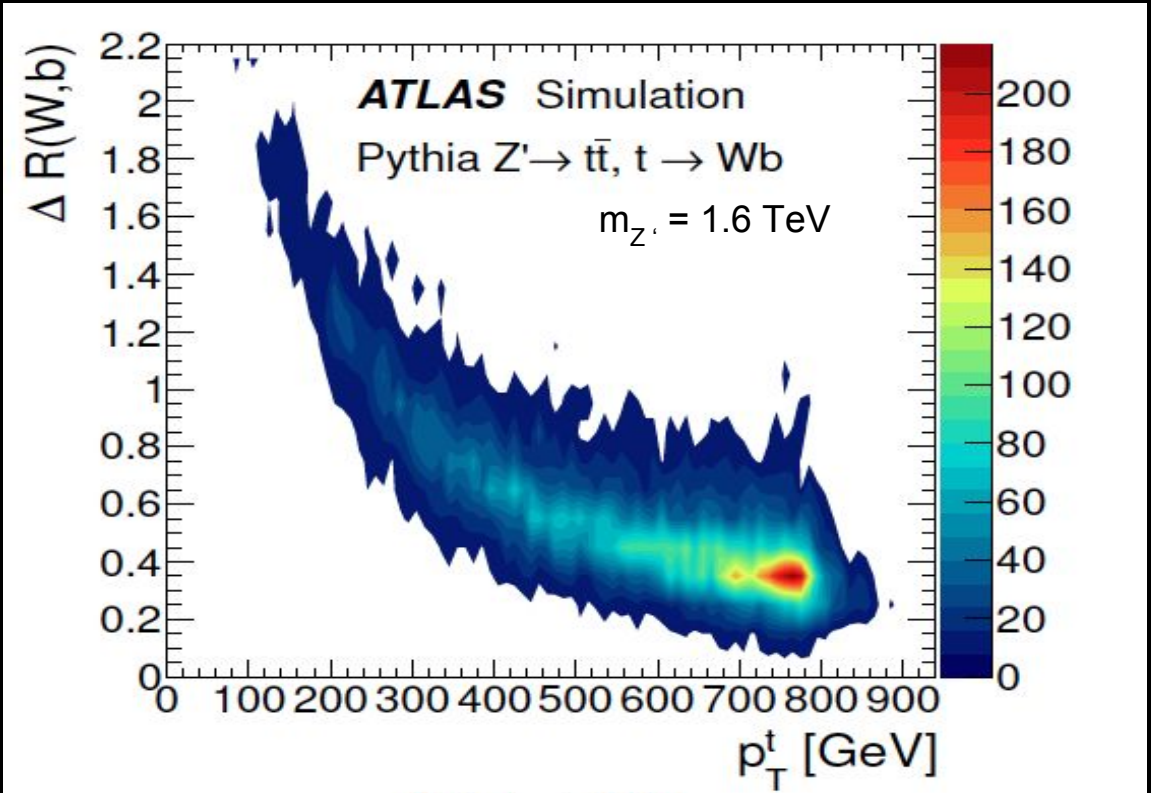
If a top quark that decays to 3 quarks has ...

- Heavy particles decay to lighter particles that can have high momentum

... low momentum: it will produce 3 separate jets

… high momentum:
→ collimated quarks
→ single jet with internal ***substructure***

Angular separation as a function of p_T



(a) $t \to Wb$

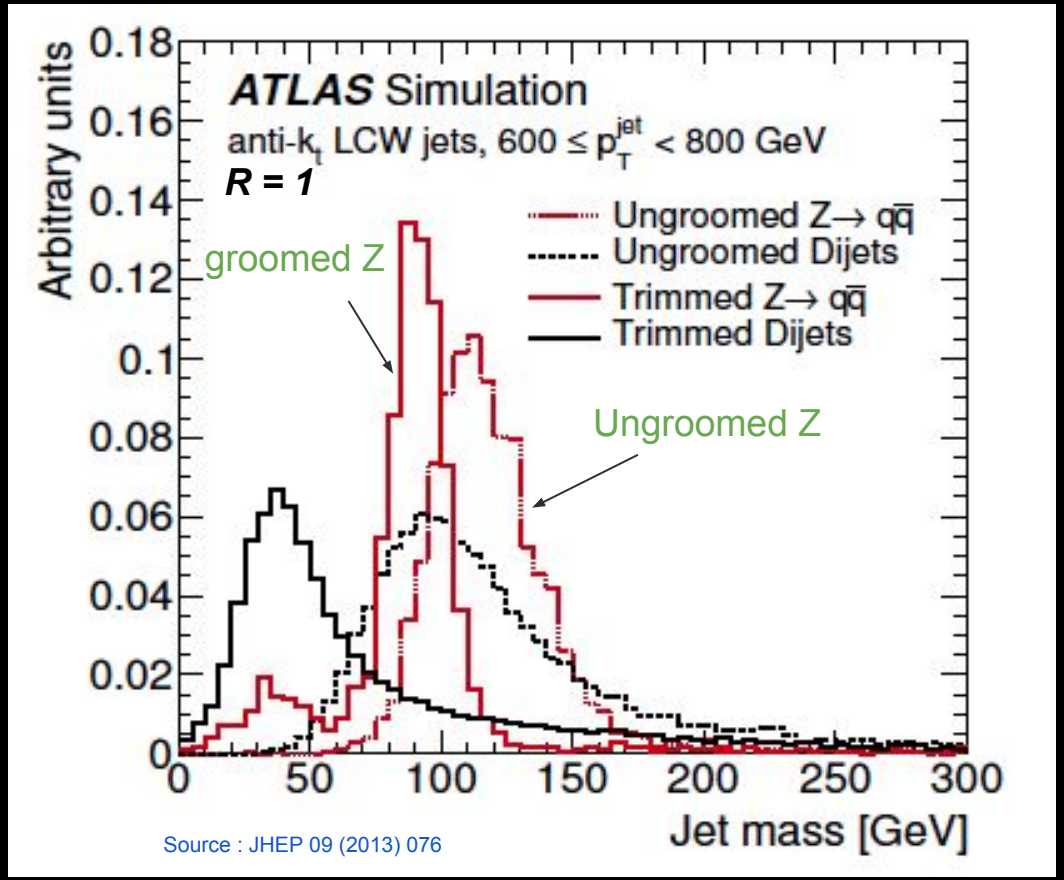
Source : JHEP 09 (2013) 076

Mass of decaying particle

$$\Delta R \approx \frac{2m}{p_T}$$

Transverse momentum of decaying particle

An Example of Jet Trimming



Source : JHEP 09 (2013) 076

- Dijets mass reduces significantly after trimming
- Constituents of signal Jets survive the trimming procedure due to higher p_T
- After trimming :
  - Discrimination between signal and background improved

Applying Jet Grooming at HLT : Trigger decisions

Four Trigger decisions has been considered for collecting events :

1. Jet reconstruction algorithm : ***Anti-k_t , R = 0.4 , p_T > 70 GeV***
2. Jet reconstruction algorithm : ***Anti-k_t , R = 1.0 , p_T > 120 GeV***
3. Jet reconstruction algorithm : ***Anti-k_t , R = 1.0 , p_T > 100 Gev***
   3.1. Jet grooming algorithm : ***Trimming , R_{sub} = 0.2 , f_{cut} = 5%***

- LCW-scale : Local calibration weighted