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

Due to color confinement

Producing large number of colored particles (QCD)

Colored particles hadronize to form collimated sprays of particles called jets

Quarks and gluons

π, K, ...

Particle Jet

Energy depositions in calorimeters

http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2012/10_15/
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
Jet from Heavy Particles

\[ W \rightarrow qq \]
\[ m_W = 80 \text{ GeV} \]

If \( W \) has low momentum:
- it will produce 2 separate jets

If \( W \) has high momentum:
- \( p_W \geq 3 \times m_W \)
- \( W \) will be boosted
- \( W \) will produce one large jet with substructure

- \( W \) will produce collimated quarks
- \( W \) will produce a single boosted jet with internal substructure
Boosted jets: new physics scenario (example)

$W' \rightarrow WZ \rightarrow qqqq$

$m_{W'} = \text{order TeV}$
(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

$W' \rightarrow WZ \rightarrow qqqq$

Signal: $W \rightarrow qq$ 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

$gq \rightarrow gq$

With a lot of energy

Hard QCD jets sometimes look just like the signal jets

- 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

- We can not record them all
- We have to focus on the most interesting events

ATLAS Work in Progress

$pp$ data, $\sqrt{s} = 13$ TeV

$N_{\text{jets}}$: total number of jets (area of full histogram)

All trimmed jets
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

**ATLAS Work in Progress**

*pp data, $\sqrt{s} = 13$ TeV*
Collecting Events Rate: Comparison of Trigger Decisions

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

**ATLAS Work in Progress**

*PP data, $\sqrt{s} = 13$ TeV*
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

*ATLAS Work in Progress*

*pp data, $\sqrt{s} = 13$ TeV*

Available at HLT

**Graphical Content:**
- *Triggers decisions, LCW scale*
- HLT Normal Jets, $p_T > 125$ GeV
- HLT Large Jets, $p_T > 157$ GeV
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

ATLAS Work in Progress

$pp$ data, $\sqrt{s} = 13$ TeV

New trigger

Trigger decisions, LCW scale
- HLT Normal Jets, $p_T > 125$ GeV
- HLT Large Jets, $p_T > 157$ GeV
- HLT Large Jets Trimmed, $p_T > 127$ GeV
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 quark)
  - 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

Emails:
Dr. Dag Gillberg: dag.gillberg@cern.ch
Nima Sherafati: nima.sherafati@carleton.ca
Back Up slides
Jets from Heavy Particles

$t \rightarrow Wb$

$m_t = 173$ GeV

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

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

- ...low momentum: it will produce 3 separate jets
- ...high momentum: → collimated quarks → single jet with internal substructure

$p_T \geq 3 \times m_{\text{top}}$
Angular separation as a function of $p_T$

Source: JHEP 09 (2013) 076

ATLAS Simulation
Pythia $Z' \to t\bar{t}, t \to Wb$

$m_{Z'} = 1.6$ TeV

Mass of decaying particle

Transverse momentum of decaying particle

$(a) \ t \to Wb$

Source: JHEP 09 (2013) 076

Nima Sherafati
An Example of Jet Trimming

- 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

Source: JHEP 09 (2013) 076
Applying Jet Grooming at HLT: Trigger decisions

Four Trigger decisions have been considered for collecting events:

1. Jet reconstruction algorithm: $\text{Anti-}k_t$, $R = 0.4$, $p_T > 70$ GeV

2. Jet reconstruction algorithm: $\text{Anti-}k_t$, $R = 1.0$, $p_T > 120$ GeV

3. Jet reconstruction algorithm: $\text{Anti-}k_t$, $R = 1.0$, $p_T > 100$ GeV
   3.1. Jet grooming algorithm: $\text{Trimming}$, $R_{sub} = 0.2$, $f_{cut} = 5\%$

   ○ LCW-scale: Local calibration weighted