Implementation and Performance of the ATLAS Jet Trigger

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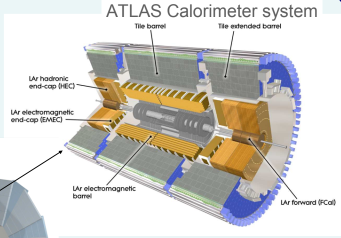
FCT Fundação para a Ciência e a Tecnologia – MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR – Portugal – Ciência.Inovação 2010

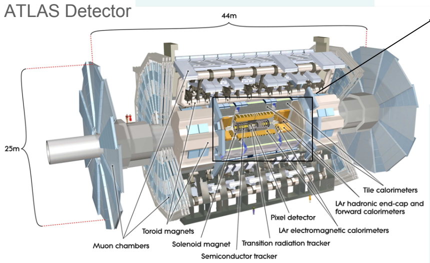
1. The ATLAS Experiment

- ATLAS is a multipurpose experiment designed for the LHC
- LHC design parameters
  - *Centre of mass energy*: 14 TeV
  - *Design luminosity*: 10^{34} $cm^{-2}s^{-1}$
  - *Bunch crossing rate*: 40 MHz

ATLAS Calorimeter system



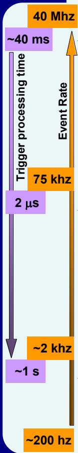
ATLAS Detector



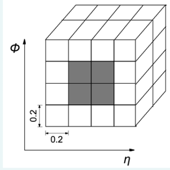
Weight ~ 7000 tonnes   Channels ~ 100 million

- Trigger system used to limit rate
  - 3-level system implemented in hardware and software
- Jets are the most common detector object
  - Main background for jets are jets
  - Jet energy must be accurately measured

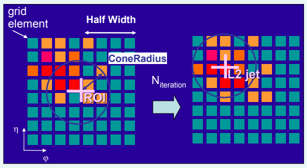
2. ATLAS Jet Trigger



LVL1: fast decision with limited resolution
- Implemented with custom designed hardware
- Coarse granularity
- Sliding window (0.8×0.8 in η,ϕ) with 0.4×0.4 central cluster
- Searches for a local transverse energy maximum
- Provides starting point (seed) for LVL2 trigger



LVL2: full detector resolution around seed
- Only access data in a Region of Interest (RoI) around LVL1 seed
- Full granularity
- Iterative cone algorithm (max. 3 iterat.)
- Calculate energy-weighted η,ϕ positions
- Dedicated calibration scheme



Event Filter: sophisticated offline-like algorithms
- Algorithms reconstruct only RoIs around LVL2 seed
- Potentially full event access
- Offline calibration available

3. Jet Trigger Menu

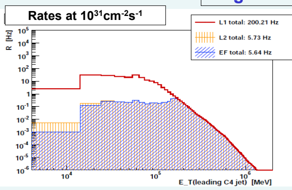
- Provide a set of jet trigger objects to select interesting physics events

Single Jet Triggers

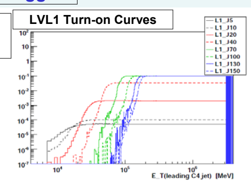
Initial Luminosity: $10^{31}cm^{-2}s^{-1}$

LVL1 threshold (GeV)	Prescale
5	200 K
10	100 K
20	5 K
40	300
70	50
100	10
130	1
150	1

LVL2, EF in pass-though mode



- Total single jet rate ~ 6Hz



- Flat rate from 10 to 130 GeV

Luminosity: $10^{32}cm^{-2}s^{-1}$, EF in pass-throug mode

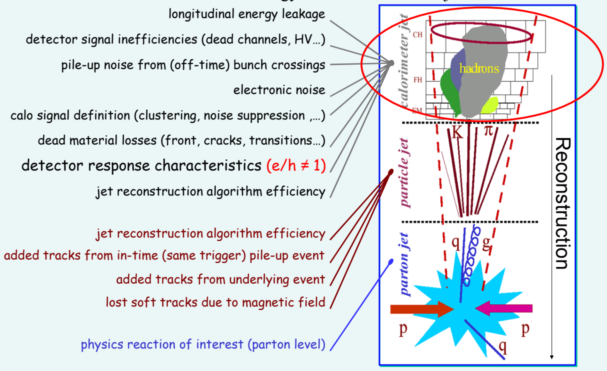
LVL1		LVL2	
Thr. (GeV)	Presc.	Thr. (GeV)	Presc.
5	30 K	10	10
10	12 K	20	10
20	1 K	50	10
40	50	80	20
70	1	120	160
100	1	160	40
130	1	200	1
150	1	250	1

Examples of other Jet Triggers

- forward jets
  - fj70 (QCD physics)
  - 2 fj25, Δη>3 (VBF Higgs, QCD)
- jets + missing E_T
  - j70+$E_T$miss 30 (SUSY, Higgs)
- jets + sum of all jets E_T
  - 6j40 + JE240 (top physics)

4. Hadronic Calibration

- Jets are reconstructed from energy depositions in calorimeter cells
- Multiple reconstruction effects need to be corrected
- Hadronic calibration corrects the energy scale of calorimeter jets



5. LVL2 Calibration

Very important to discriminate transverse energy thresholds ⇒ the jet energy scale has to be well measured for a large range of energies, from 20 to 400 GeV

LVL2 calibration: simple, robust and fast correction of jet energy scale

- Two sets of weights, applied to electromagnetic and hadronic energy depositions:

$E_{jet}=\sum_i(\omega_{EM}\times E_{EM}+\omega_{HAD}\times E_{HAD})_i$

- Weights computed by minimizing the energy difference w.r.t. Monte Carlo (MC) samples:

$$\chi^2 = \sum_{m=1}^{N_{jets}} \left[\frac{(E_m^{truth} - E_m^{rec})}{\sigma_m}\right]$$

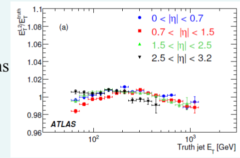
- Weights depend on E_{jet} logarithmically: $\omega_i = a_i + b_i\times\log(E_{jet})$
- Index i runs over 44 bins of 0.1 units in η ⇒ $\omega = \omega(E_{jet},\eta)$

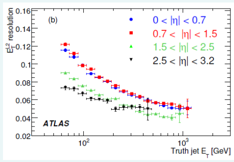
Performance of the LVL2 calibration

- Energy scale is correct within 2% for all energies and all η regions
- Improvement in the resolution when using the calibration

η region	Before calibration A	Before calibration B	After calibration A	After calibration B
(0.0,0.7)	1.03 ± 0.03	0.059 ± 0.001	0.96 ± 0.02	0.039 ± 0.001
(0.7,1.5)	1.28 ± 0.03	0.064 ± 0.001	1.18 ± 0.03	0.041 ± 0.001
(1.5,2.5)	1.53 ± 0.04	0.046 ± 0.001	1.37 ± 0.03	0.025 ± 0.002
(2.5,3.2)	1.86 ± 0.13	0.063 ± 0.003	1.46 ± 0.08	0.040 ± 0.003

Resolutions fitted to: $\frac{\sigma(E)}{E} = \frac{A(GeV^{1/2})}{\sqrt{E}} \oplus B$





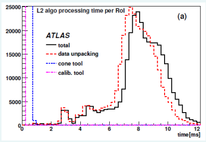
- Possible improvement in resolution when introduce a dependency of the weights with the fraction of electromagnetic energy:

$\omega = \omega(E_{jet},\eta, f_{EM})$

6. Performance

LVL2

- Processing time dominated by data unpacking



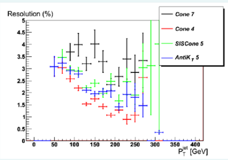
Consider two possible granularities for LVL2 jets
- Cell: standard one
- FEB: receive energy sums from the ROD energy sums corresponding to each Front-End Board (FEB)
  - reduces data unpacking and iteration time
  - algorithm time improved by factor of 3

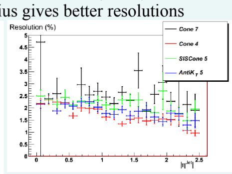
Both have similar performances
- Position resolution: 0.003 in η, 0.001 in ϕ
- Linearity within 2%

Event Filter

- Jet resolution measured w.r.t. offline jets: RoI size is 1.6x1.6 in η and ϕ
- Tested various algorithm and cone radii: small radius gives better resolutions due to window size

Algorithm	Mean time at EF /event
Cone 7 :	406 ms
Cone 4 :	246 ms
SISCone 5 :	1496 ms
AntiKt 5 :	258 ms





7. Data driven performance studies

Developing methods to study efficiencies directly from real data

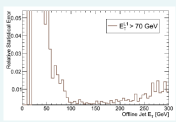
- Bootstrap method:

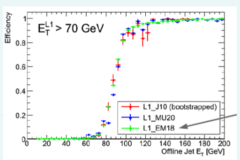
$$eff(L1\_J70) = eff(L1\_J10)\times\frac{eff(L1\_J70)}{eff(L1\_J10)}$$

Absolute efficiency from single μ triggers

Relative efficiency from single jet triggers with large prescales

- Single muon events
  - The statistical error as function of jet E_T for 10pb-1 is expected to be below 1% for E_T between 100 and 300 GeV





- Turn on curves with different methods for $10pb^{-1}$
  - Same results but worse resolution for the bootstrap method due to large prescales of low E_T triggers

8. Summary & conclusions

- The ATLAS Jet Trigger has been designed to cover a large variety of physics topics, from QCD to searches of physics beyond the standard model (charged Higgs, SUSY, extra dimentions, …)
- To cope with the high LHC rate, the trigger is designed in three levels
  - The first level is hardware based, running with coarse granularity
  - The second level runs a dedicated, simplified cone algorithm around LVL1 seed
    - Processing time well inside tight LVL2 budget
    - Good linearity in the jet energy scale after dedicated calibration (2%)
  - The third level (Event Filter) runs off-line like algorithms and calibration
    - Many algorithms available, best performance for anti-k_T ans SISCone
- Data driven performance studies are being developed and tested using MC simulation
  - For ex.: efficiencies can be measured with stat. error < 1% for 10 pb^{-1}