Jets triggers for the ATLAS experiment

Measurement of Global Trigger Efficiency for Multi-Jets analysis

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Outline

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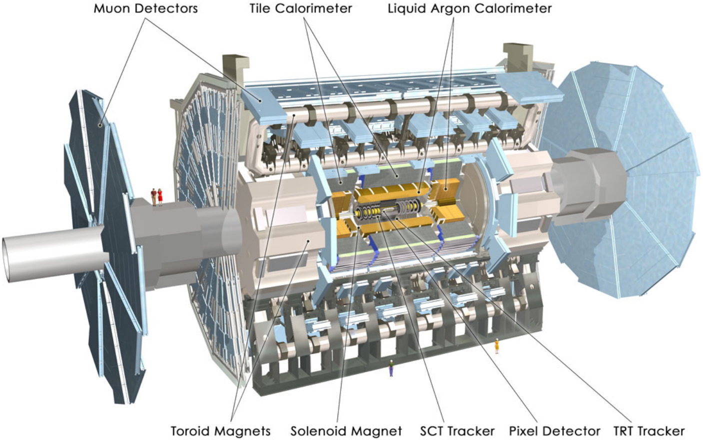
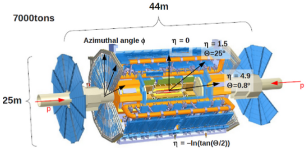
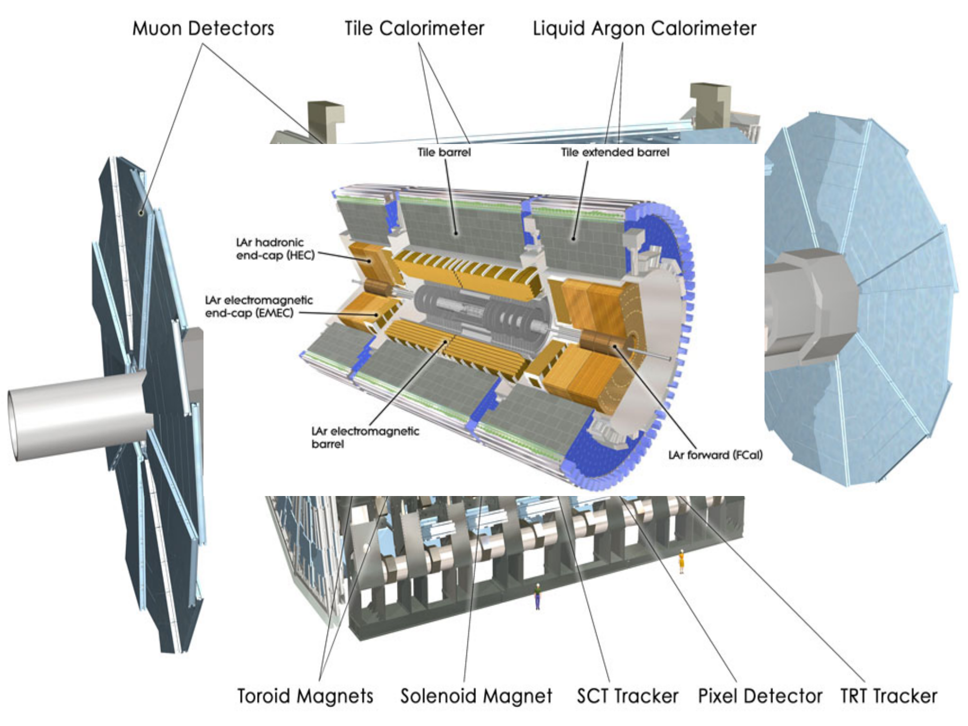
1. General Introduction: ATLAS Experiment
2. Jet Events in ATLAS
3. Jet Triggers in ATLAS
   - Global Triggers
     - JetEtSum trigger
     - sumET trigger
     - Tigger Efficiency Turn-on curves
     - Tigger Rates
     - Tigger Bootstrapping
     - Some Comparisons and Additions
4. Remarks and Conclusions

The ATLAS Detector

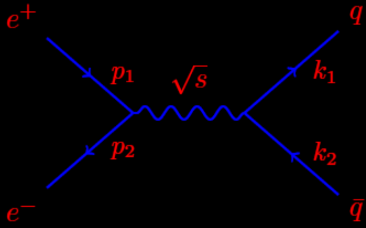





Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Tile barrel
Tile extended barrel
LAr hadronic end-cap (HEC)
LAr electromagnetic end-cap (EMEC)
LAr electromagnetic barrel
LAr forward (FCal)
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

Divergences: Physical origin in QCD dynamics

e^+e^- collisions give QCD final state without initial-state/beam contamination and are useful for many QCD studies



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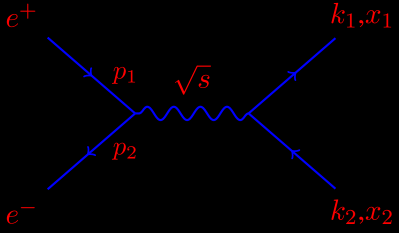
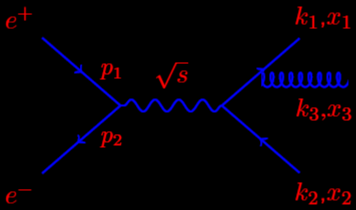
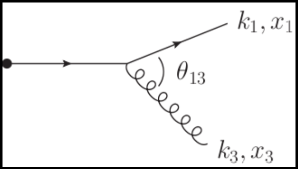






q propagator: $\sim \frac{1}{(k_1+k_3)^2} \to \infty$

$k_1 \cdot k_3 \to 0 \Rightarrow (k_1 + k_3)^2 \to 0$

- $k_3 \to 0$ Infrared divergences
- $\theta_{13} \to 0$ Collinear divergences

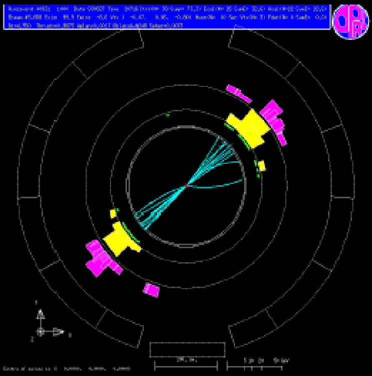
We have divergences when:

- a parton emits a soft gluon
- an outgoing parton splits into two collinear partons

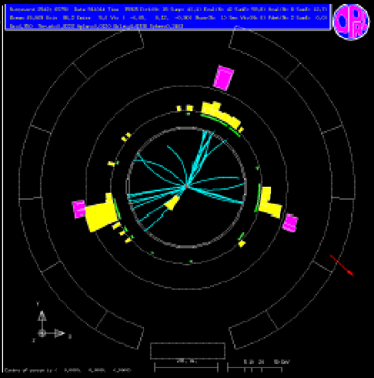
Jet: bunch of collimated particles → arbitrary concept

- As a consequence of the collinear divergence, in final states traces of original partons are visible as collimated bunches of energetic hadrons: QCD branchings are most likely collinear
- A particularly challenging class of jet production refers to the study of events with more than two jets in the final state, so-called multi-jet events

2-Jets event



How many jets do you see?



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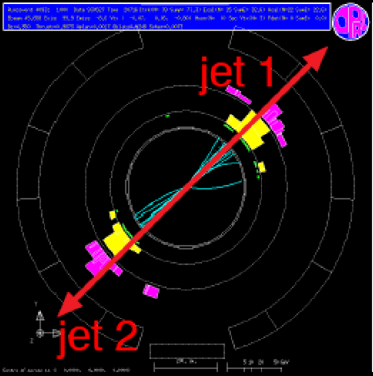

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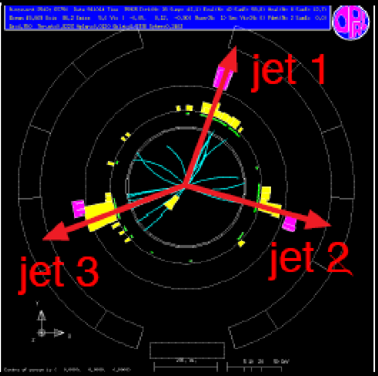

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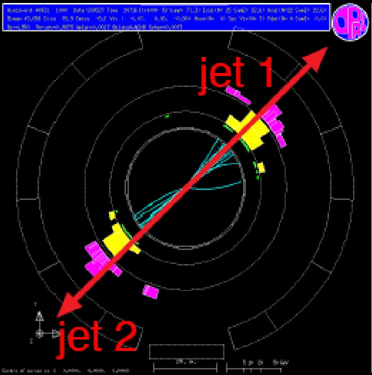
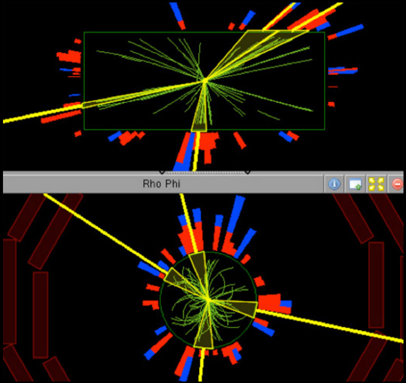
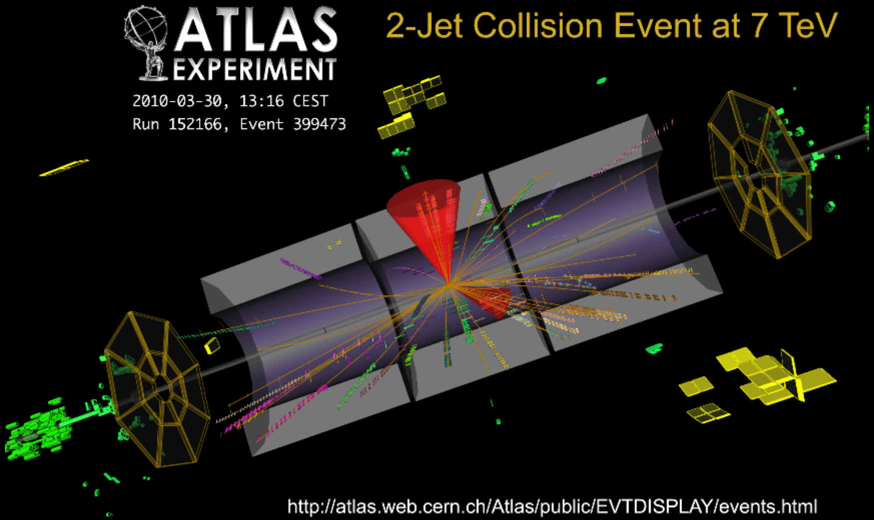


what we would expect from n events?





How to characterize a Jet? We need to define it: jet-finding: jet-algorithm

Jet Definitions: successive recombinations

- Clustering algorithms make the reconstruction grouping by pair nearby objects. Infrared and collinear safe!
  - kt: groups closest objects first
  - anti-kt groups highest pT objects first

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d_{ij}: particle's distance d_{iB}:beam distance

k_{ti}: transverse momentum η_i, ϕ_i: pseudorapidity and azimuth

$R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$

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5. Repeat from step 1 until no particles are left

Jet Definitions: successive recombinations

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Clustering algorithms definitions beyond kt

d_{ij}: particle's distance d_{iB}:beam distance
k_{ti}: transverse momentum η_i, ϕ_i: pseudorapidity and azimuth
$R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$ if in general, $d_{iB} = k_{ti}^{2p}$

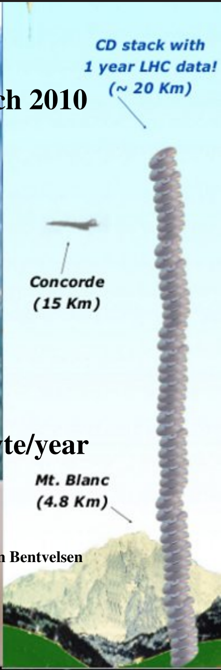
$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) R_{ij}^2$$

$$p = \begin{cases} 1, & \text{kt algorithm} \\ 0, & \text{Cambridge/Aachen algorithm} \\ -1, & \text{anti-kt algorithm} \end{cases}$$

LHC data Acquisition

- 3.5TeV/beam $\rightarrow$ collisions at $\sqrt{s}$ = 7TeV since March 2010
- 14TeV proton-proton collisions 2012
- Instantanious luminosity 10^{34} cm^{-2}s^{-1}
- 368 bunches/beam
- 40MHz bunch crossings
- 25ns between bunches

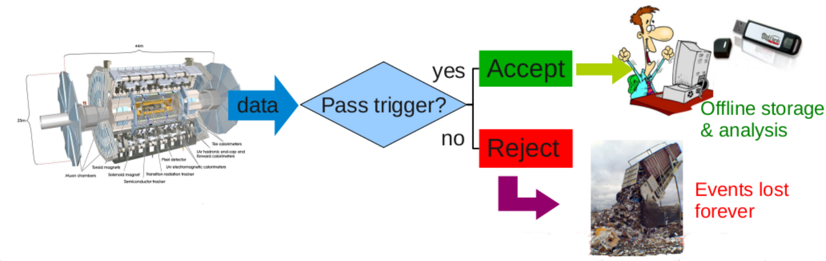
Records data at 200 Hz, event size = 1 MB 200 MB/sec
1 operational year = 107 seconds 2 PByte/year
Simulated data + derived data + calibration data 4 PByte/year
There are 4 experiments 16 PByte/year
For at least 10 years



by Stan Bentvelsen

Event Selection

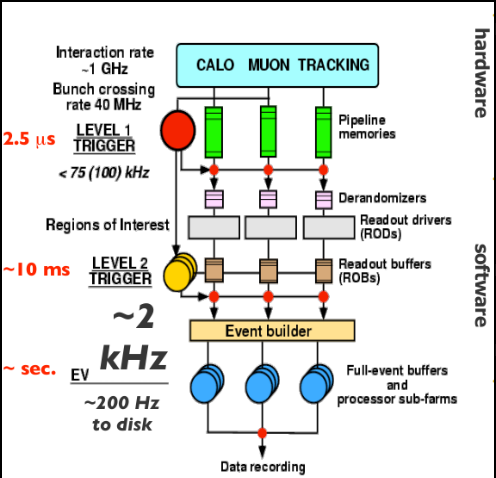
- We are not able to store and analyze all the data produced by the LHC
- Most of millions of events per second are totally uninteresting
- We need to select events online Trigger system
- The trigger selects interesting events for our analysis



by I. Aracena

- Trigger decision $\approx$ 2-3 μs $\rightarrow$ larger than interaction rate of 25 ns
- Therefore the trigger is split in several levels: level-1, level-2 and EventFilter in ATLAS

Three Level Trigger Architecture

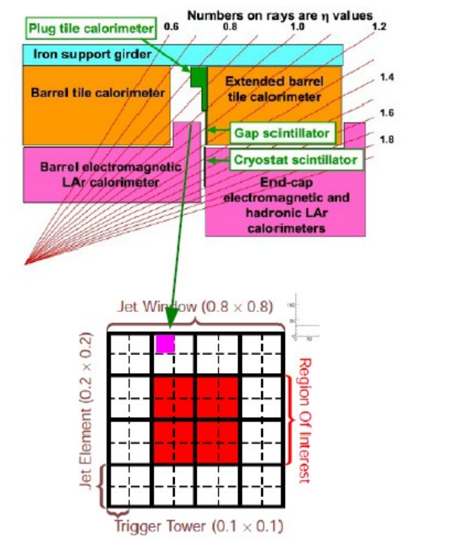


- level-1 uses data from calorimeters (e/γ, jets, τ, MeT) and muon detectors, finds η, ϕ and E_T of interesting physics objects: RoI

HLT

- level-2 Mainly partial event reconstruction in RoI
- level-2 with full granularity combines information from all detectors and performs fast rejection
- EventFilter refines the selection. Assemble the full event in the Event builder

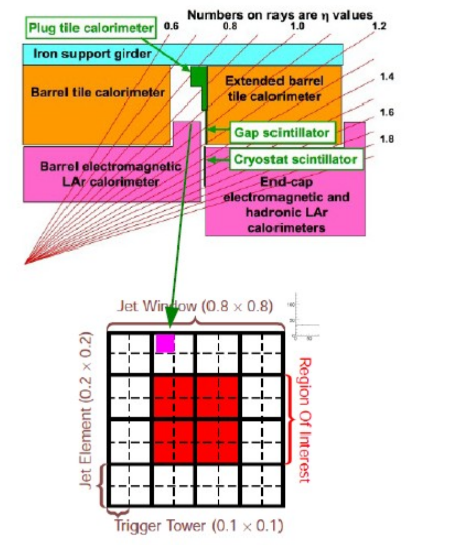
ATLAS Jet Level-1 Trigger



Window of 8x8 jet towers for L1 jet trigger

- Level-1 jet RoI is identified using coarse detector elements
- Calorimeter is segmented into fixed grid of trigger towers
- Trigger Tower is analog sum of cell energies in $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$
- Jet finder uses a sliding window algorithm and
- selected according to jet E_T threshold

ATLAS Jet Level-1 Trigger

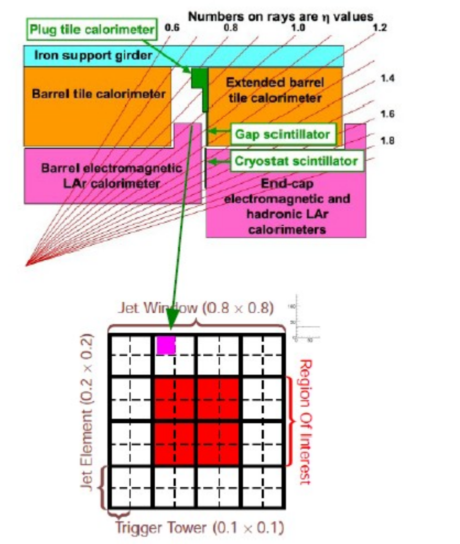


Window of 8x8 jet towers for L1 jet trigger

- Jet finder uses a sliding window algorithm and
- selected according to jet E_T threshold:
  - if $\eta < 3.2$:
    8 thresholds for central jets:
    Inclusive jet triggers

L1_J5
L1_J10
L1_J15
L1_J30
L1_J55
L1_J75
L1_J95
L1_J115

ATLAS Jet Level-1 Trigger



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How does it work?. Example: suppose a 3-jets event passing only L1_J5. These jets have energies between 5GeV and 10GeV because the L1 requirement is $E_T >$ threshold, in this case 5GeV. If one of these jets has energy >10 GeV, the event passes also the L1_J10 trigger

ATLAS Global Jet Triggers: JetEtSum (H_T or L1_JE)

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For example a 3-jets event, one passing threshold 0, one passing thresholds 0-2 and one passing thresholds 0-3, then we have:

Multiplicity [0] = 3

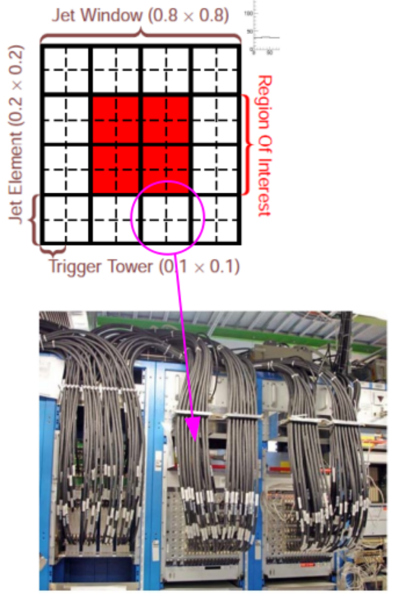
Multiplicity [1] = 2

Multiplicity [2] = 2

Multiplicity [3] = 1 and

jetSumEt=$3 \times$Weight[0]+$2 \times$Weight[1]+$2 \times$Weight[2]+$1 \times$Weight[3]

The ATLAS global sumET Trigger (L1_TE)



- Level-1 computes missingET and total transverse energy
  - computes missingET components (Ex, Ey) and scalar sum of all Trigger Towers (sumET) above a noise cut
- HLT simply forwards Level-1 result
  - Full calorimeter data ≈1MB
  - Level-2 network (3GB/s) cannot access to full calorimeter data
    - sustainable event rate is 3kHz << 75kHz, Level-1 output rate
  - Possible improvements being investigated

Trigger Efficiency turn-on

Definitions

- Data-Streams: The data can be streamed to different output files based on the event trigger decision. The stream names indicate the type of trigger signatures they will contain. For example, events passing single (inclusive) or jetEtSum triggers signatures are written to the Calorimeter stream: “L1Calo” or “jetTauEtmiss”

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- Trigger Efficiency ε: Probability that one event in the data sample from the stream S passes the L1_XXXX as a function of the $\mathrm{H_T}$
  $\varepsilon(\mathrm{H_T}, \mathrm{S}) = P(\mathrm{L1\_XXXX}|\mathrm{S}, \mathrm{H_T})$

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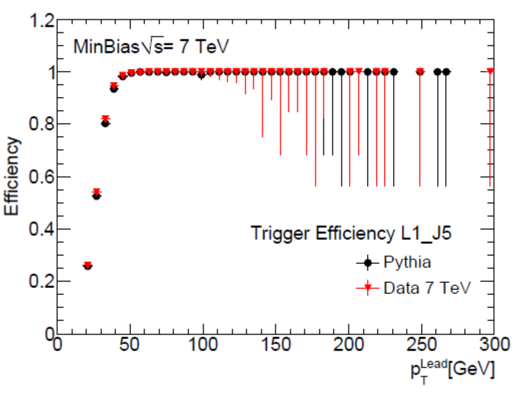
- Plateau: Localized region where ε is 100% or P=1

Single Jet turn on ⇒ Threshold 5GeV

S: MinBias: track based trigger



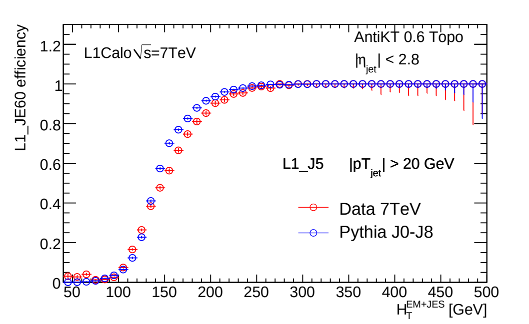
Turn-on curve for the L1_J5 trigger as a function of pT of the leading jet in the event. Data (red triangles) and Monte Carlo (black circles) comparison

Trigger Efficiency

- The efficiency for jets in the pseudorapidity region $|\eta|$ <2.8 that satisfy the Level-1 single jet trigger with a 5GeV threshold
- 100% close to 60GeV

$$\varepsilon(\mathrm{P_T^{Lead}}, \mathrm{MinBias}) = P(\mathrm{L1\_J5}|\mathrm{MinBias}, \mathrm{P_T^{Lead}})$$

jetSumEt (JE) turn on ⇒ Threshold 60GeV



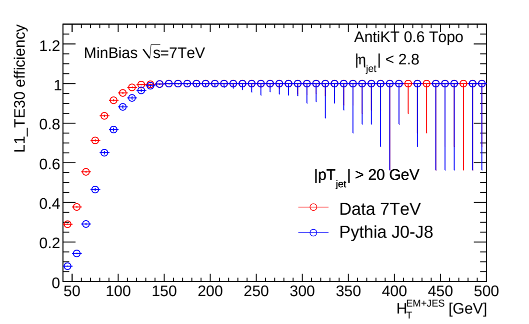
Turn-on curve for the L1_JE60 trigger as a function of H_T. Data (red circles) and Monte Carlo (blue circles) comparison

- Anti-kt jets with R=0.6

$$\varepsilon(H_T, L1Calo) = P(L1\_JE60 | L1Calo, H_T)$$

- The efficiency for multi-jet events in the pseudorapidity region $|\eta| < 2.8$ that satisfy the Level-1 jetSumEt trigger with a 60GeV threshold
- 100% close to 250GeV
- Satisfy data quality criteria
- Jet cleaning cuts: noisy cells, dead detector regions, acceptance effects

sumEt (TE) turn on ⇒ Threshold 30GeV



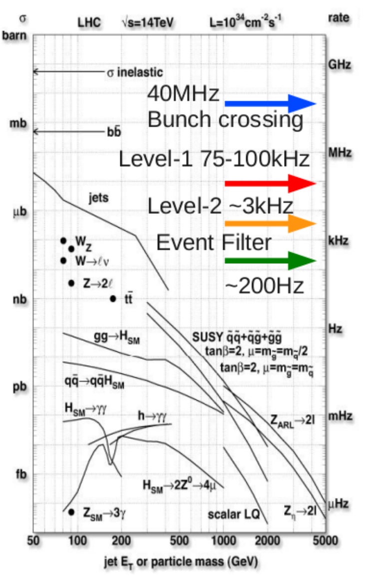
Turn-on curve for the L1_TE30 trigger as a function of $\mathrm{H_T}$. Data (red circles) and Monte Carlo (blue circles) comparison

- Anti-kt jets with R=0.6

$$\varepsilon(\mathrm{H_T}, \mathrm{MinBias}) = P(\mathrm{L1\_TE30}|\mathrm{MinBias}, \mathrm{H_T})$$

- The efficiency for multi-jet events in the pseudorapidity region $|\eta| < 2.8$ that satisfy the Level-1 sumEt trigger with a 30GeV threshold
- 100% close to 130GeV
- Satisfy data quality criteria
- Jet cleaning cuts

Remember the trigger outputs:

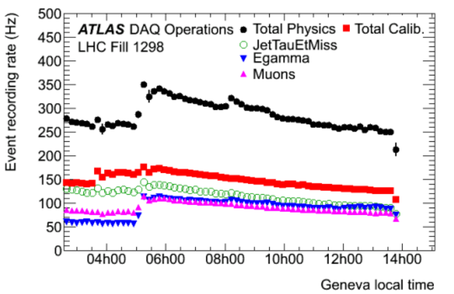


- level-1 Output rate 75-100kHz, latency 2.5μs
- level-2 output $\sim$3kHz, an average processing time of < 40ms $>$ per event is available to achieve this rejection
- EventFilter output $\sim$200Hz, < 4s $>$ per event

- How can we record all our information in 200Hz for the analysis? (think about the LHC luminosity)

Addapted by I. Aracena

- The event rates exceeded the event Filter output in ~150Hz:



- We should distribute them (200Hz) between different trigger objects or physical interest $\Longrightarrow$

Signature	Output rate (Hz)
Jets	25
MissingET	8
MissingET + jets	8
e/γ	55
μ	50
τ	10
MissingET + τ	8
b-jets	10
MinBias	11
Clibration	11
TOTAL	~200

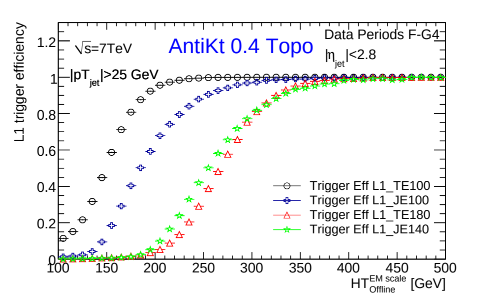
- How can we record all our jet information in 25Hz for the analysis?

Trigger Prescale PS

Prescales ≡ Keep event only every nth event

Examples

- PS=10⇒Keep 1 event every 10 events
- PS=1⇒no-prescale
- Keep highest threshold unprescaled

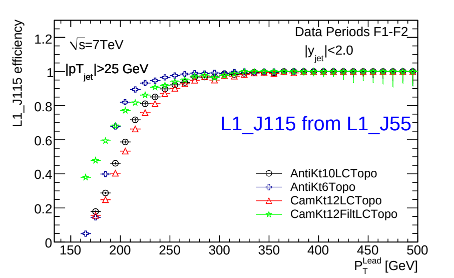


Trigger efficiency for the highest unprescaled global triggers using the latest data taken 2010

$$\varepsilon(\mathrm{H_T}, \mathrm{jetTauEtmiss}) = P(\mathrm{L1\_XEXX}|\mathrm{jetTauEtmiss}, \mathrm{H_T})$$

Bootstrapping a single jet trigger from a lower threshold

Bootstrapping: Consider a lower threshold trigger. Determine where the plateau is and for all jets in the plateau region, see if they also pass higher threshold



Turn-on curve for the L1_J115 trigger bootstrapped from L1_J55 as a function of P_T^{Lead}

Rapidity $y = 0.5 \times \ln[(E + p_z)/(E - p_z)]$

- The efficiency for single jet events in the rapidity region $|y| < 2.0$ that satisfy the Level-1 single trigger with a 115GeV threshold bootstrapped from L1_J55 trigger
- Different jet definitions
- Satisfy data quality criteria
- Jet cleaning cuts

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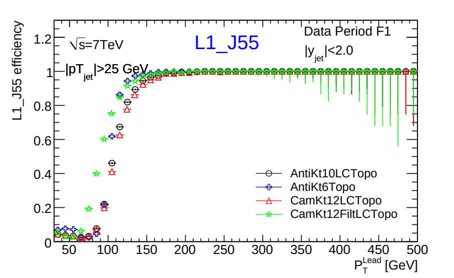

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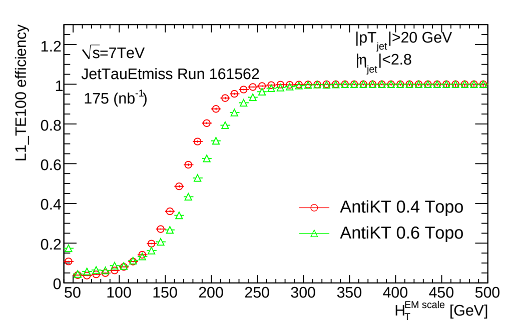
Global Trigger from different jet algorithm



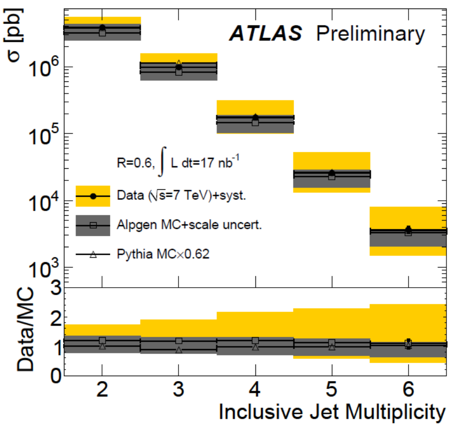
Turn-on curve for the L1_TE100 trigger as a function of H_T. R=0.4 (red circles) and R=0.6 (green triangles) comparison

- Anti-kt jets with R=0.6
- Anti-kt jets with R=0.4

$$\varepsilon(H_T, \text{jetTauEtmiss}) = P(\text{L1\_TE100}|\text{jetTauEtmiss}, H_T)$$

- The efficiency for multi-jet events in the pseudorapidity region $|\eta| < 2.8$ that satisfy the Level-1 sumEt trigger with a 100GeV threshold
- shift $\rightarrow$ size difference R
- H_T is algorithm-dependent

Trigger in multijet Analysis



$$\sigma = \frac{N_{\text{sig}}}{\mathcal{L} \times \varepsilon} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\mathcal{L} \times \varepsilon}$$

Inclusive jet multiplicity spectrum corrected to particle level asmeasured in data (solid circles) and as predicted by AlpGen (empty squares) and Pythia (empty circles)

Remarks and Conclusions

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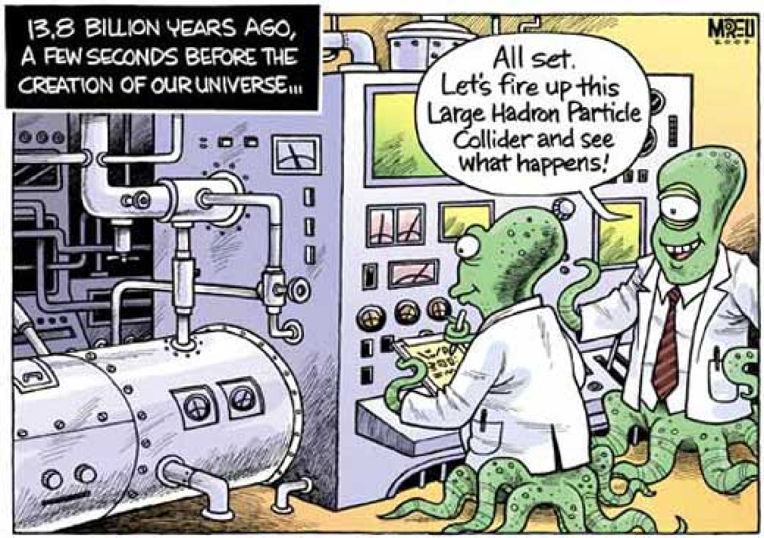
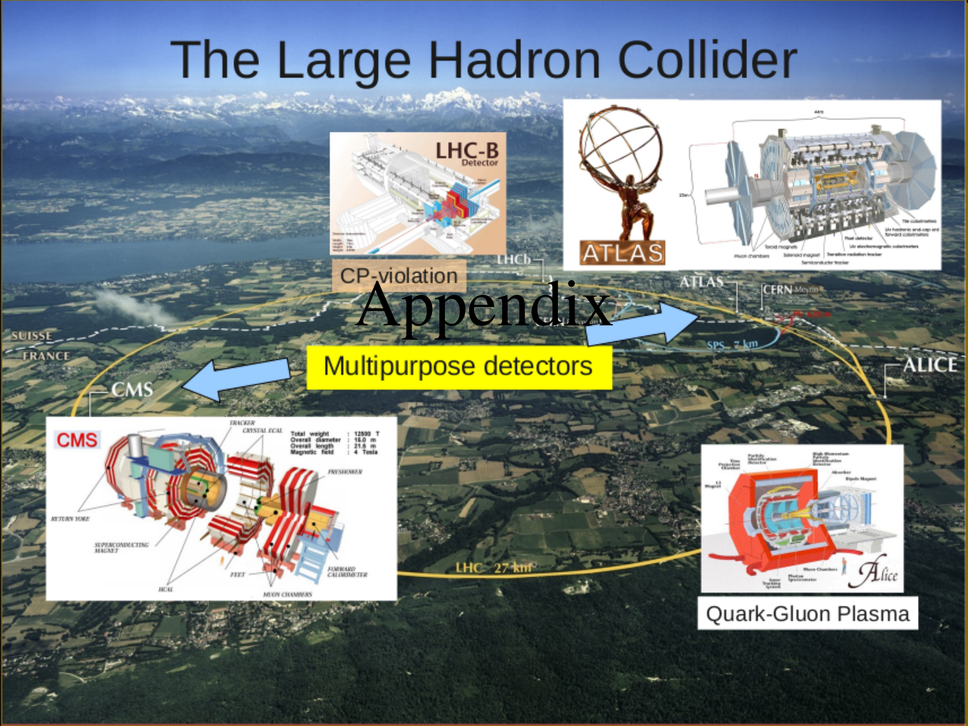
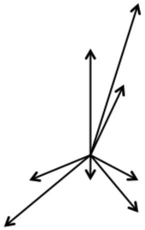
- We have seen how the global triggers behave in the ATLAS detector, specifically in the calorimeter region
- We have shown very good agreement between data and simulation for trigger efficiency calculations
- H_T depends on the jet algorithm
- Experimentaly, jets are expected in the final state of most physics channels such as:
  - Early QCD: di-jet σ
  - Early SM: $W/Z + jets$
  - Top analysis
  - BSM
  - Study dijet events with rapidity gap

Thank you for your attention!



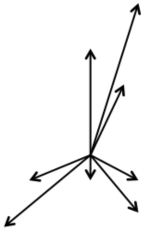

The Large Hadron Collider
Appendix
LHC-B
Detector
CP-violation
LHCb
ATLAS
ATLAS
CERN
SPS 7 km
SUISSE
FRANCE
Multipurpose detectors
CMS
ALICE
CMS
TRACKER
CRYSTAL ECAL
Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
PRESHOWER
RETURN YOKE
SUPERCONDUCTING MAGNET
FORWARD CALORIMETER
FEET
HCAL
MUON CHAMBERS
LHC 27 km
Alice
Quark-Gluon Plasma



- Clouster the jet constituents in a simple cone
- As a starting seed, consider each energy deposits in the calorimeter $> 2\text{GeV}$

- The 4-vector energy-momentum depositions within a cone of radius $\Delta R = \sqrt{(\eta_i - \eta_{seed})^2 - (\phi_i - \phi_{seed})^2}$=0.7 are summed, forming a proto-jet
- Stable cone $\rightarrow$ direction of energy flow
  - cone: fixed radius R in the (y, ϕ) plane
  - stable: their axis coincides with sum of momentum of particles in it

Jet Definitions: Cone algorithm



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- Start with proto-jets above some seed highest energy

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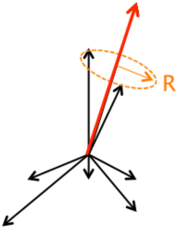

- Start with proto-jets above some seed highest energy
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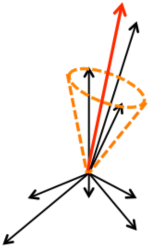

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- draw a cone of radius R around it
- Sum of particles in the cone, calculates the E_T weighted, gives new direction and draw another cone of radius R around this new point. Repeats until centroid is stable

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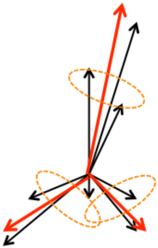
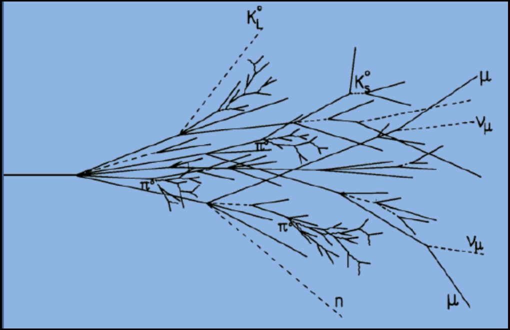


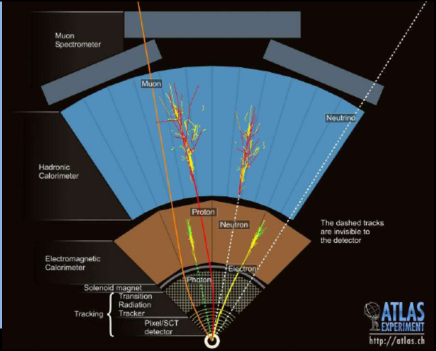
Figures and idea taken from Kerstin Perez

- Clouster the jet constituents in a simple cone
- Consider only energy deposits in the calorimeter > 2GeV
- Infrared and collinear unsafe!

- Start with proto-jets above some seed highest energy
- draw a cone of radius R around it
- Sum of particles in the cone, calculates the E_T weighted, gives new direction and draw another cone of radius R around this new point. Repeats until centroid is stable
- repeat until all proto-jets are in a jet

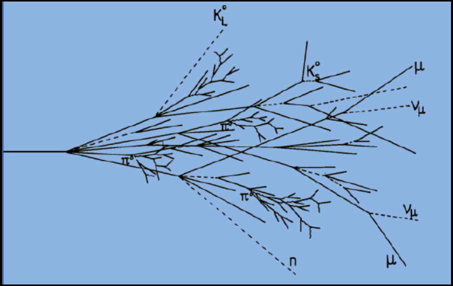
Jet Calibration





- Charged hadrons loose energy continuously due to ionization/excitation of atoms, nuclear exitation, nuclear brak up, spallation (invisible energy)
- ν, μ (Escaped energy)
- The the reconstructed jet energy deposits in the hadronic calorimeter is lower than the true energy of interacting particles within the jet. Calibration: Compensate the invisible and escaped energies

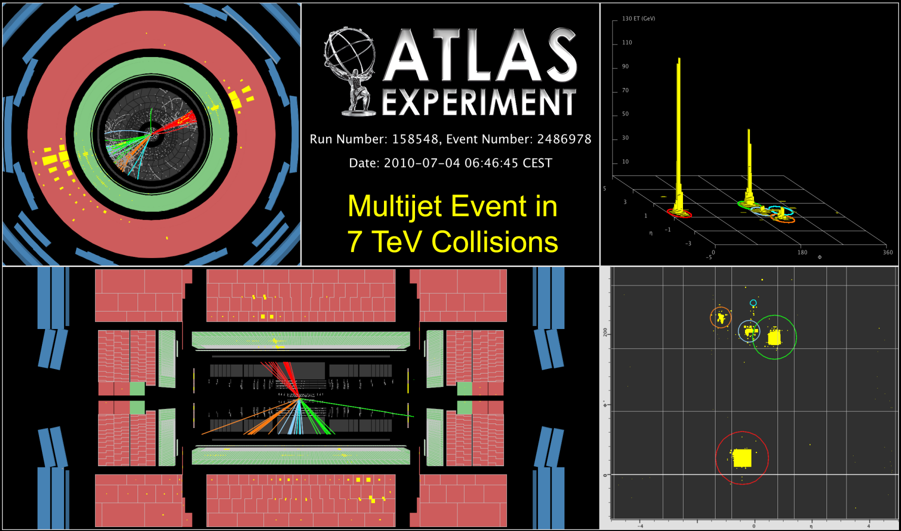
Jet Calibration



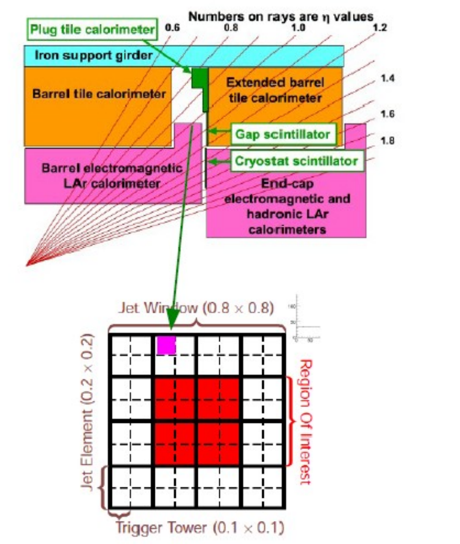
$$\chi^2 = \sum_{m=1}^{N_{jets}} \left[\frac{(E_m^{truth} - E_m^{rec})}{\sigma_m} \right]^2$$

Where the sum runs over all jets in the events

- The calibrated jet energy can then be written as $E_{jet}^{rec} = \Sigma_i w_i E_i$ where E_i is the uncalibrated energy in the sampling i and the sum runs over all samplings considered
- w_i weights are calculated using MC samples
- Output : calibrated jets : JES do not depend (in principle) on the calorimeter characteristics
- ATLAS Jet calibration: EM+JES pT and η dependent scale


ATLAS
EXPERIMENT
Run Number: 158548, Event Number: 2486978
Date: 2010-07-04 06:46:45 CEST
Multijet Event in
7 TeV Collisions
130 ET (GeV)
110
90
70
50
30
10
η
Φ
180
360
200
0
-4
4

ATLAS Jet Level-1 Trigger

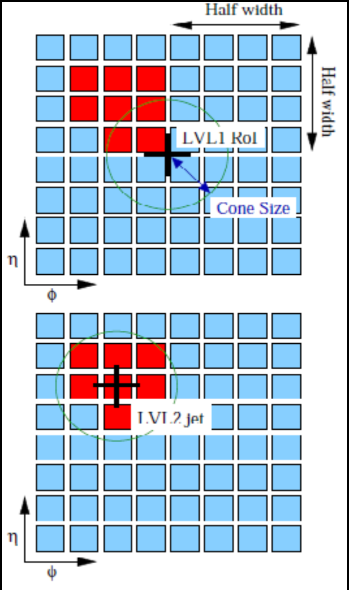


Window of 8x8 jet towers for L1 jet trigger

- Jet finder uses a sliding window algorithm and
- selected according to jet E_T threshold:
  - if 3.2< $|\eta|$ <4.9:
    4 thresholds for forward jets:
    Forward jets triggers

L1_FJ10
L1_FJ30
L1_FJ55
L1_FJ95

ATLAS Jet HLT Trigger



- calorimeter granularity $\approx \Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- Level-2
  cone algorithm with R=0.4
  - selects data in $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ window around L1 jet Region of interest RoI
  - draws a barycenter inside window and updates position and energy of the jet
  - L2 je at Level-2 : sum of all L2 jet in an event with jet ET $>$15GeV
- EventFilter uses anti-k$_T$ finder
  - Not activated in 2010 for selection

ATLAS Global Jet Triggers: JetEtSum (H_T or L1_JE)

- if η <3.2 8 thresholds for central jets: *Inclusive jets triggers*

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  - To get an “estimate” of the total energy of the jets in the event

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Example

1 Again, one 3-jet event passing only L1_J5 $\Rightarrow$ jets have energies between 5GeV and 10GeV

weight$\rightarrow$7.5GeV$\Rightarrow$threshold between L1_J5 and L1_J10

$\Rightarrow$jetEtsum=3$\times$7.5=22.5

as the weight should be an integer value, weight=8 and jetEtsum=24GeV

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Example

one 2-jet event both passing L1_J5 and one jet passing also L1_J10
$2\times J5, 1\times J10 \Rightarrow (1\times 8)+1\times(8+w)=12.5GeV$
w=5 and jetEtsum=22GeV

The unbiased muon stream

Why using an unbiased trigger?

- If we take events with JEXX/TEXX trigger(s) and compare them only against data taken using calorimeter triggers, we do not have an absolute representation of the efficiency
- To obtain the absolute efficiency we would have to compare JEXX/TEXX events against all events produced by the LHC
- As far as we know we can not record all events, instead we select events based on triggers like Jet and MeT triggers
- In order to get an idea of the absolute efficiency of JEXX/TEXX triggers we do compare events taken from JEXX/TEXX to events that have a minimum correlation (bias) in JEXX/TEXX, for instance those from **Muon Stream**.

Muon-JetTauEtMiss Comparison H_T Triggers JE-TE