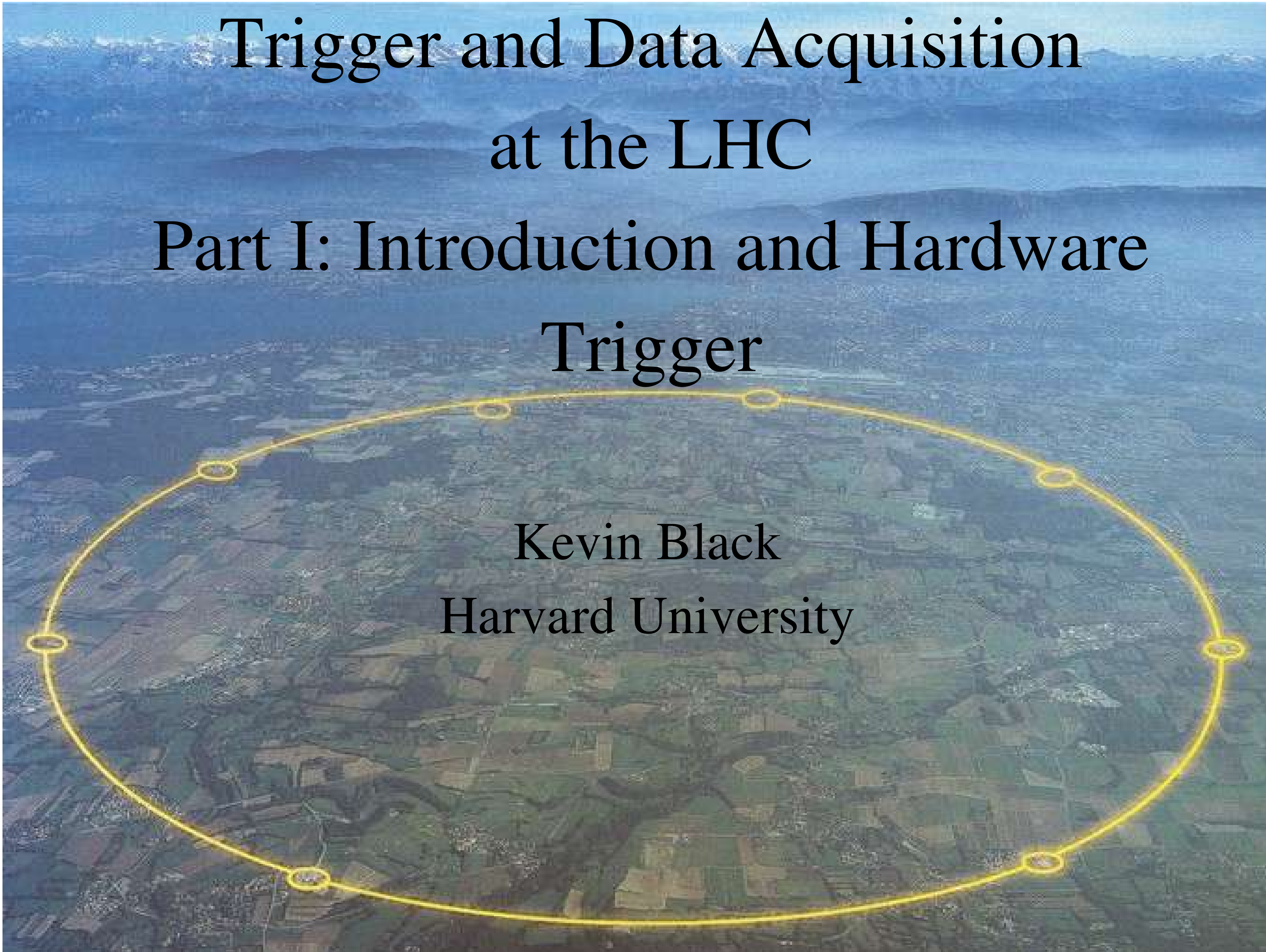
Trigger and Data Acquisition at the LHC

Part I: Introduction and Hardware Trigger



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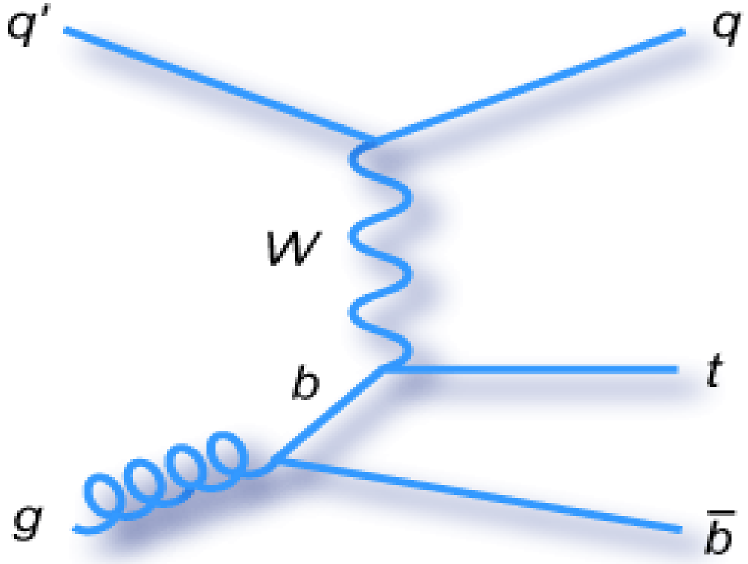
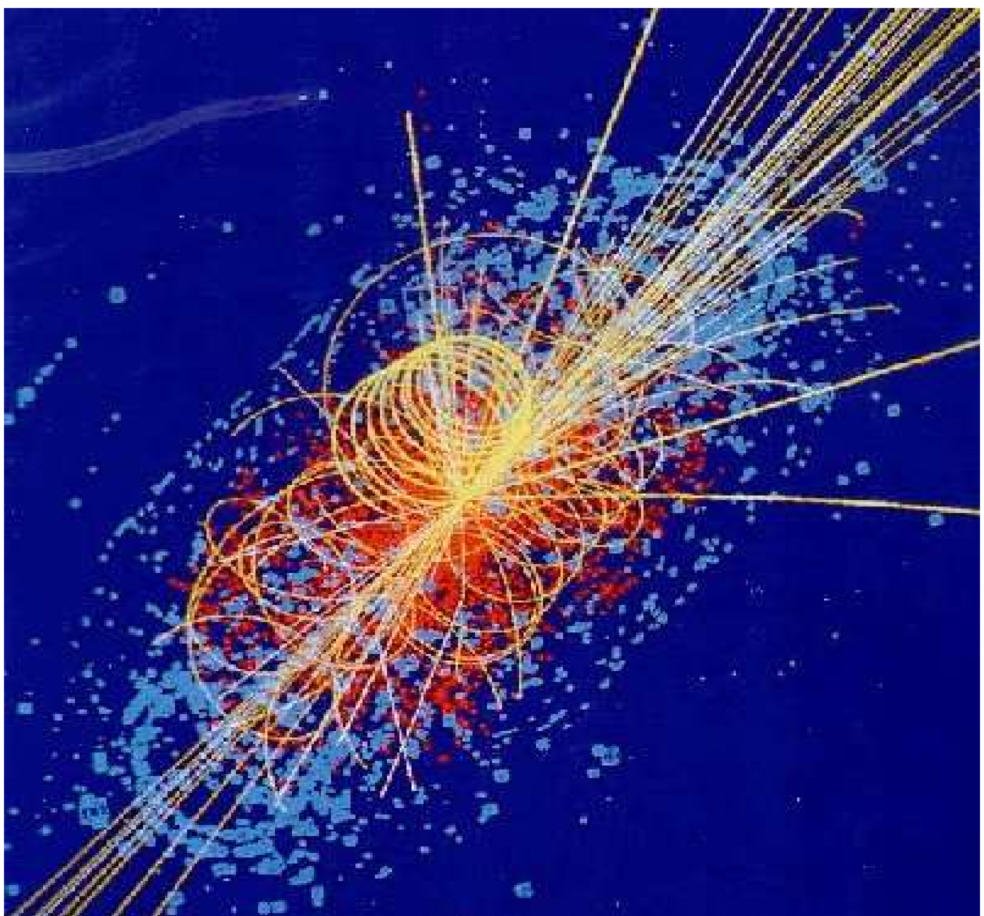
Outline

- Introduction
  - General Concepts
  - LHC Requirements
  - General Trigger Architecture
- Implementations of 'Level 1' Triggers at the LHC
  - ATLAS + CMS Architecture
  - Examples

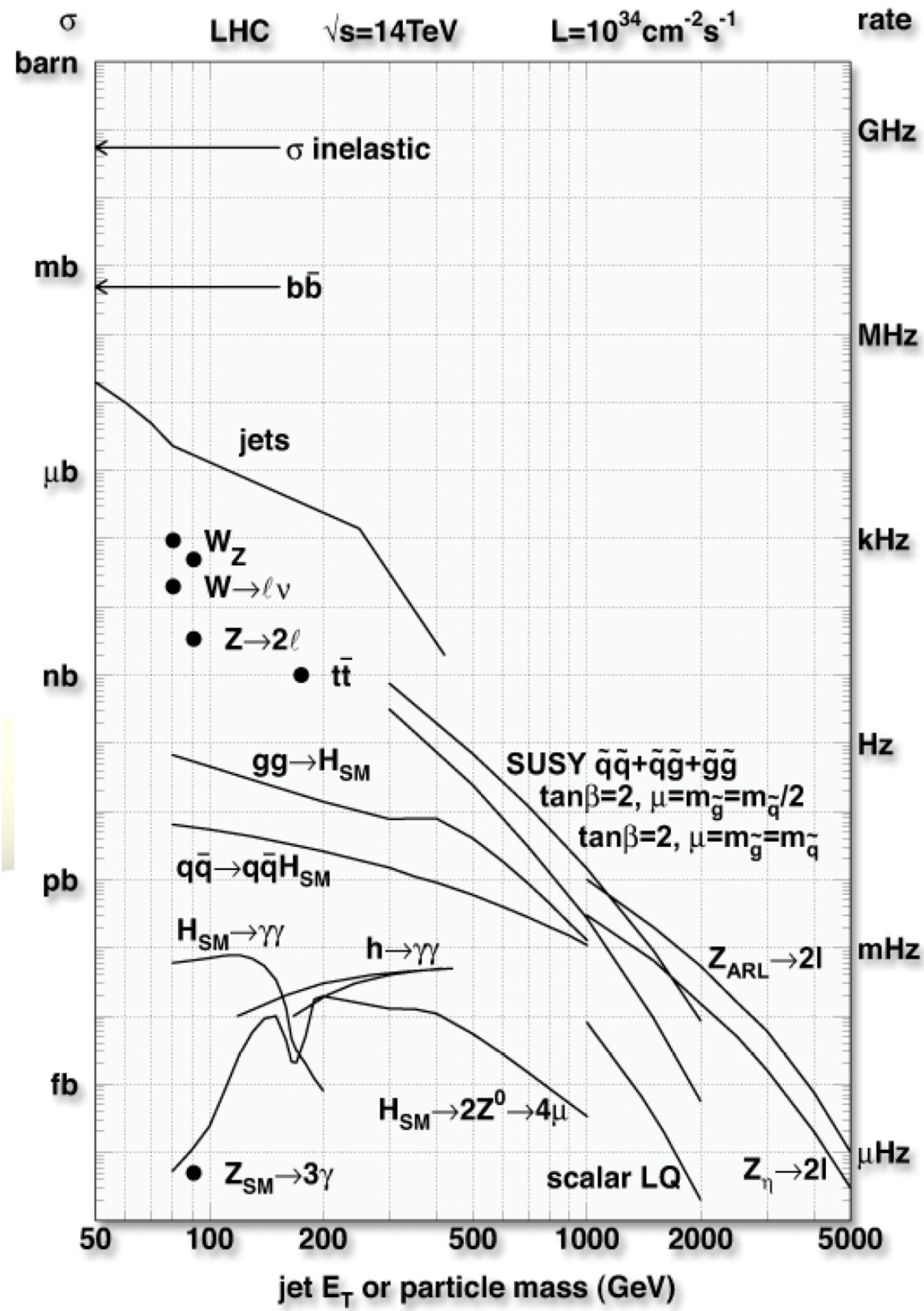


Basics



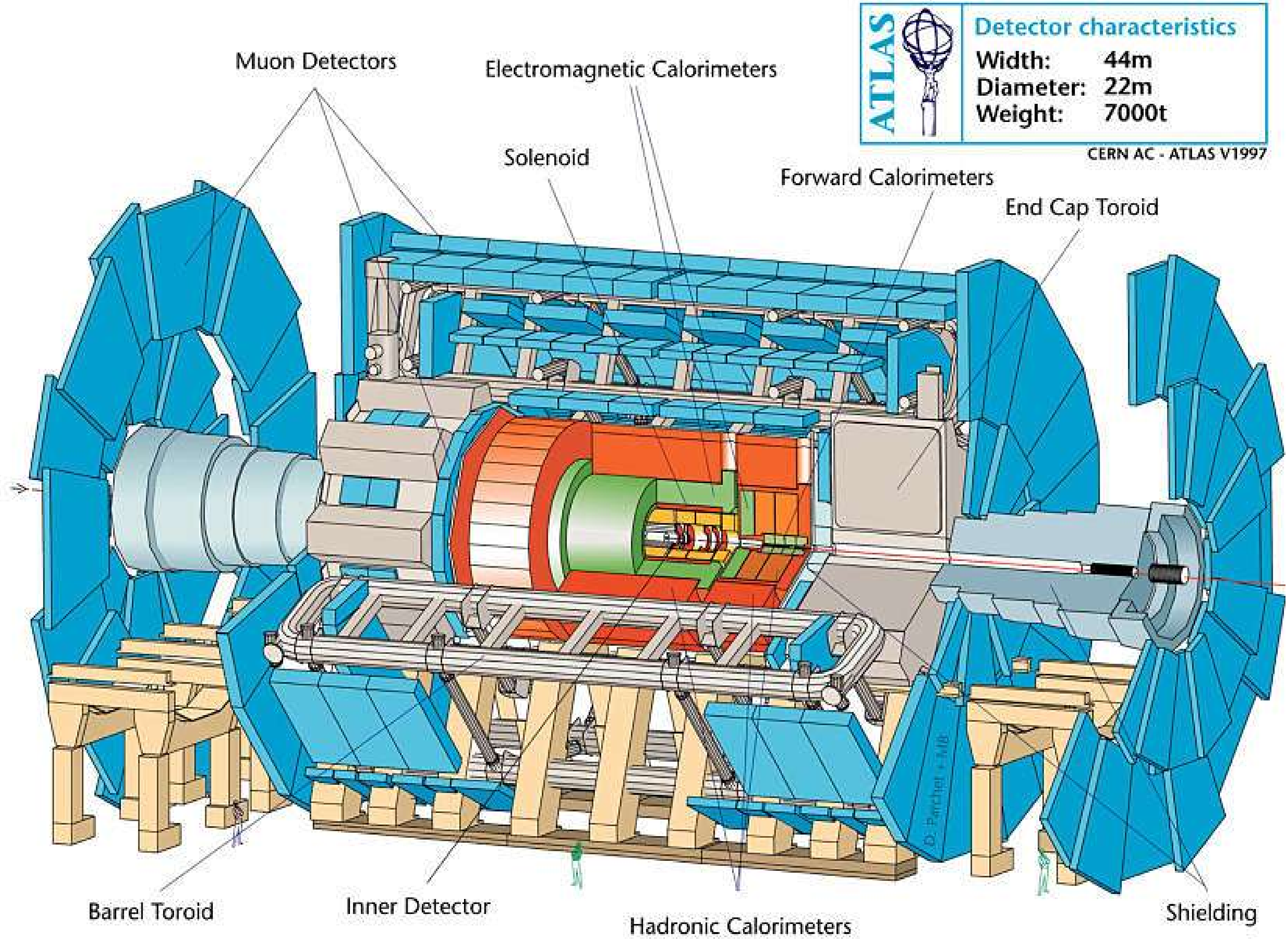
- LHC will collide protons at a center of mass energy of 14 TeV
- Collision Rate of 40 MHZ
- Most 'Interesting' physics doesn't happen at such a high rate
- Even if we wanted to , technological + $$ limitations to ~200 Hz

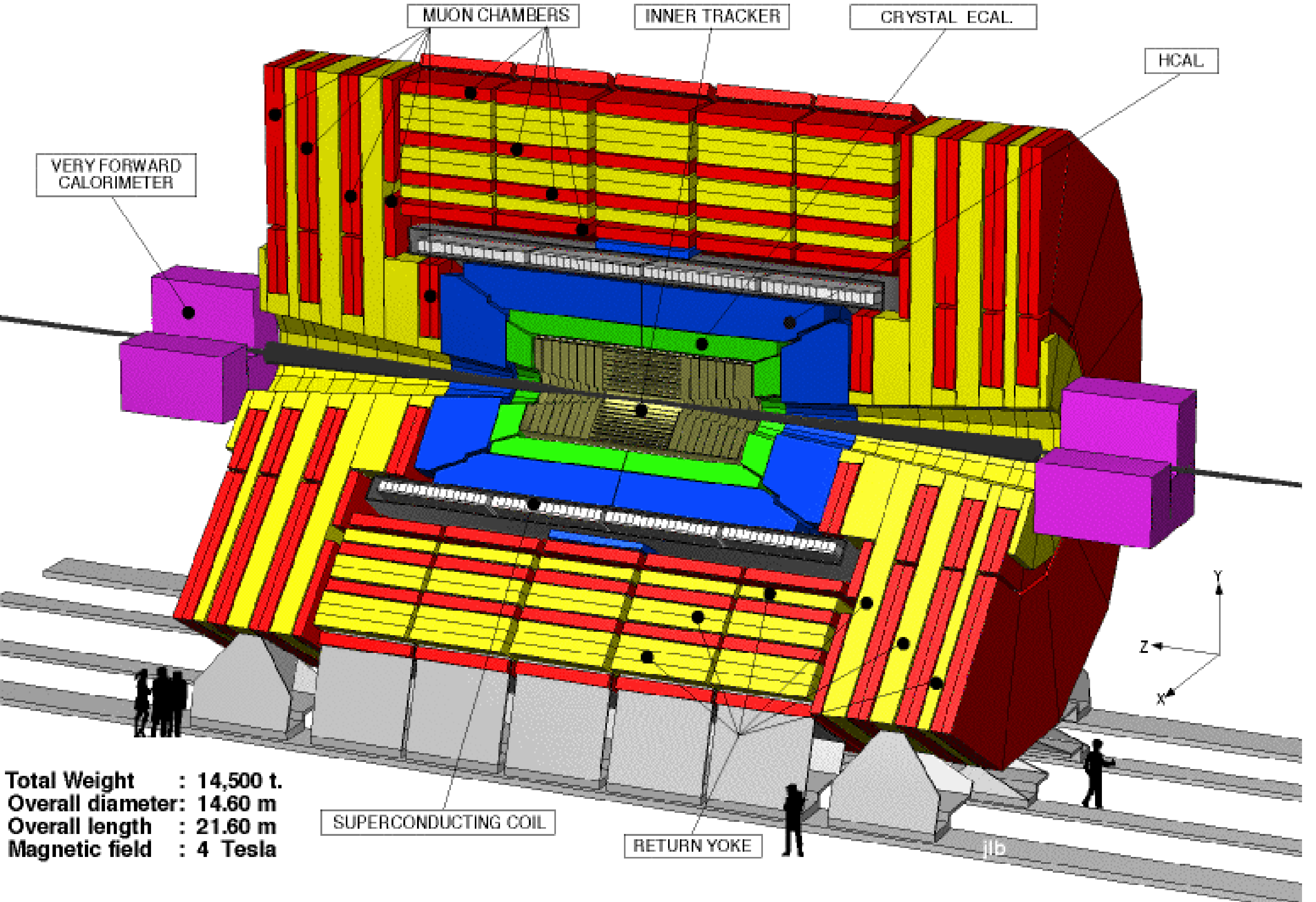
- Inelastic Cross-Section is ~70mb
- 'Interesting' Physics on the order of a few nb
- 'Discovery' Physics on the order of pb or even fb
- Cannot (and probably do not) want to record every beam crossing
- Need to make choices defining 'interesting'
- 99.99%+ of these choices are made very quickly (within microseconds) and



Generic Trigger Requirements and Challenges

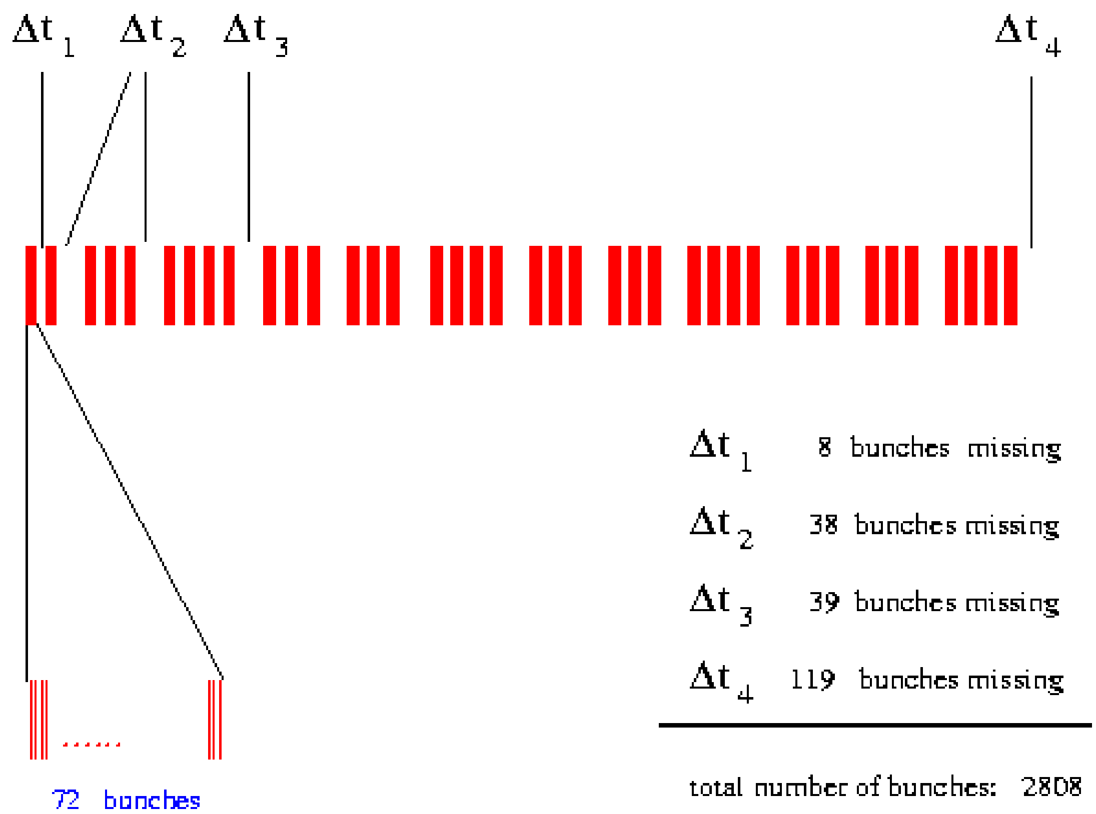
- Highly Efficient on the very rare processes that we wish to record
- Large Reduction of rate
  - Higher rate 'less interesting' processes
  - Instrumental Backgrounds
- High Processing Rate
- Large number of channels ~ 0.1 – few billion
- Push out 100 Mb/s to disk
- Not all detectors have data available in 25 ns (some take more than 10 times this)
- Do all of the above in simultaneously with a finite amount of $$ and time...


ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding


MUON CHAMBERS
INNER TRACKER
CRYSTAL ECAL.
HCAL
VERY FORWARD
CALORIMETER
Y
Z
X
SUPERCONDUCTING COIL
RETURN YOKE
jlb
Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

LHC Basics

- Beam is not continuous but comes in 'bunches' with very specific (and complicated) structure
- 25 ns between each 'bucket' (where there could be beam)
- 2808 bunches organized in superbunches
- Accelerator clock used to synchronize detectors

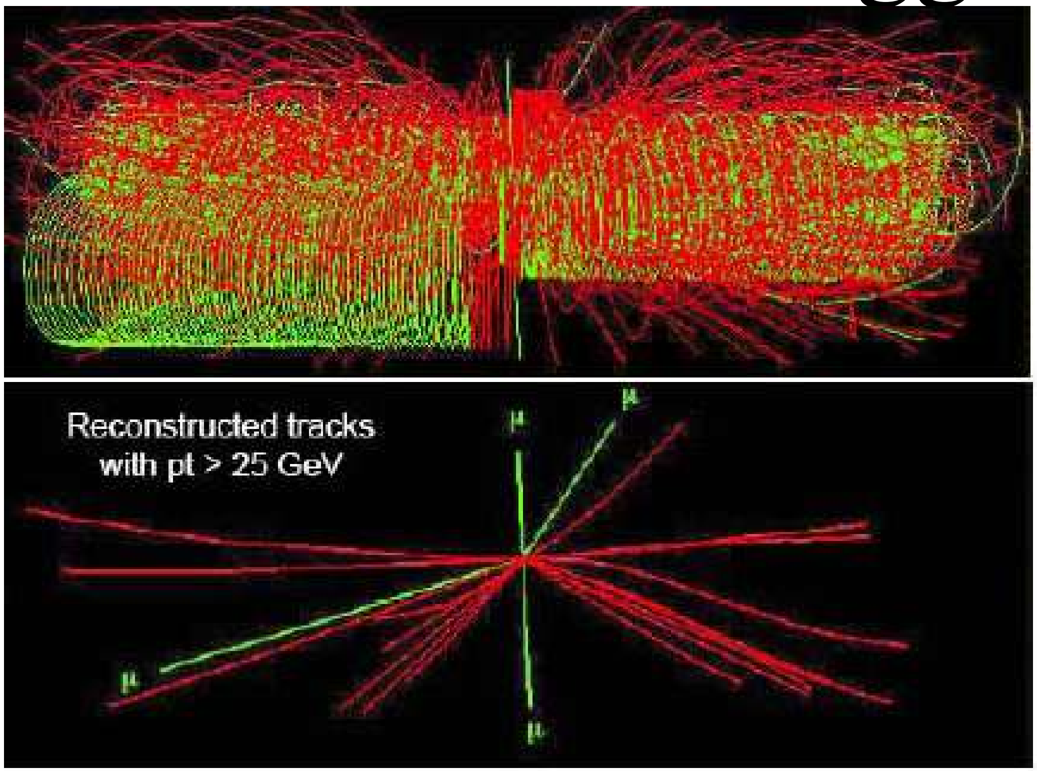


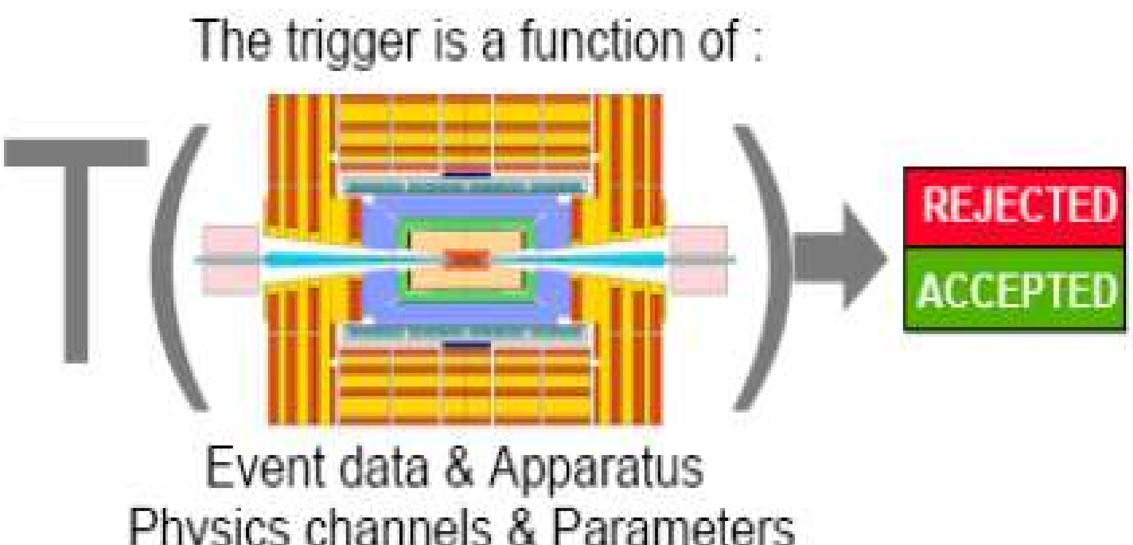
b = bucket with protons = 2808
e = empty bucket

$$3564 = \{[(72b + \overset{\text{SPS injection}}{\boxed{8e}}) \times 3 + \overset{\text{LHC injection}}{\boxed{30e}}] \times 2 + [(72b + \boxed{8e}) \times 4 + \boxed{31e}]\} \times 3 + \{[(72b + \boxed{8e}) \times 3 + \boxed{30e}] \times 3 + \underset{\text{LHC beam dump}}{\boxed{81e}}\}$$

$(8+30+81)\ (25\text{ ns}) = 3\ \mu s$

Trigger 101

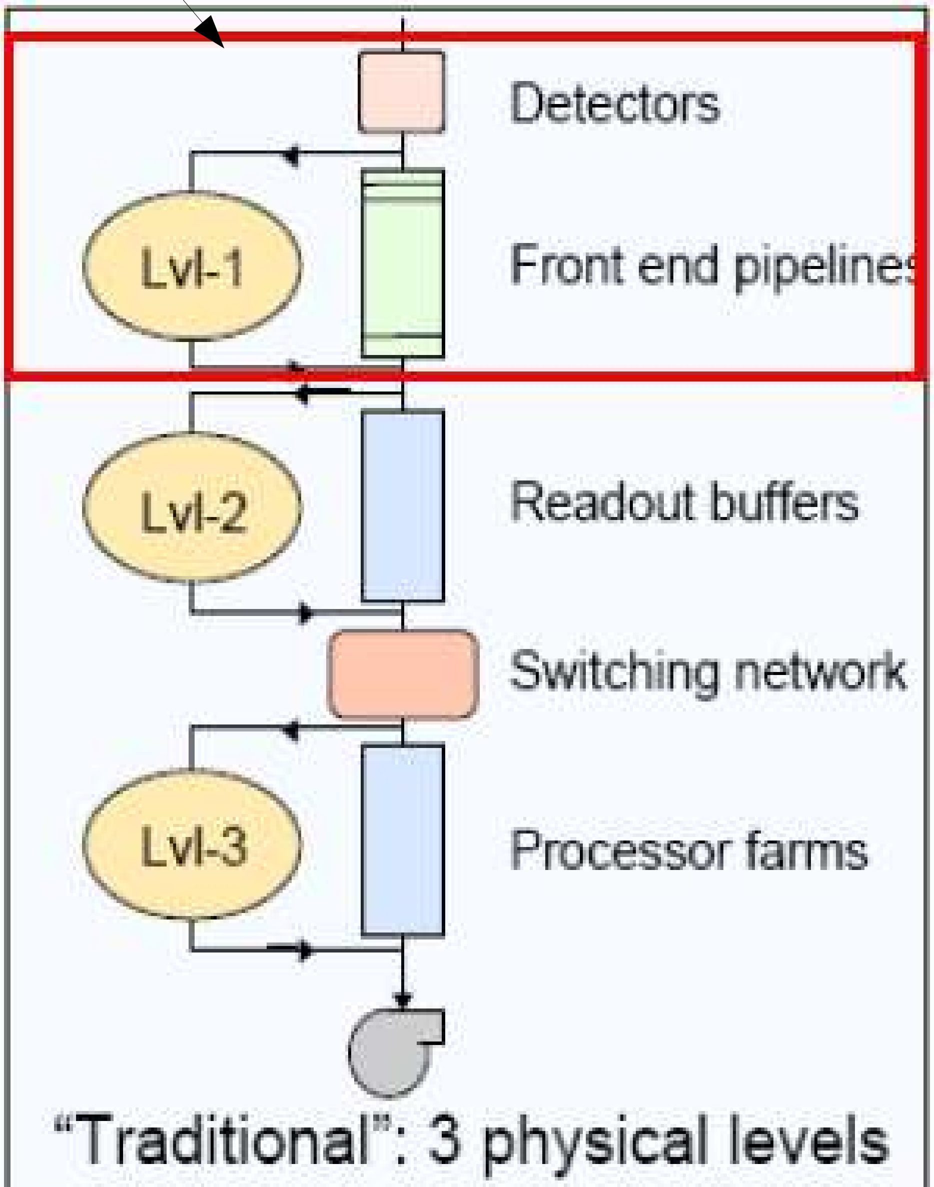




- Need to examine (nearly) every bunch crossing
  - select most interesting ones
  - collect all detector output, transfer from detector front-end to tape
- But, not all data will be available in 25 ns, T() gets evaluated piece wise

I will talk about this one

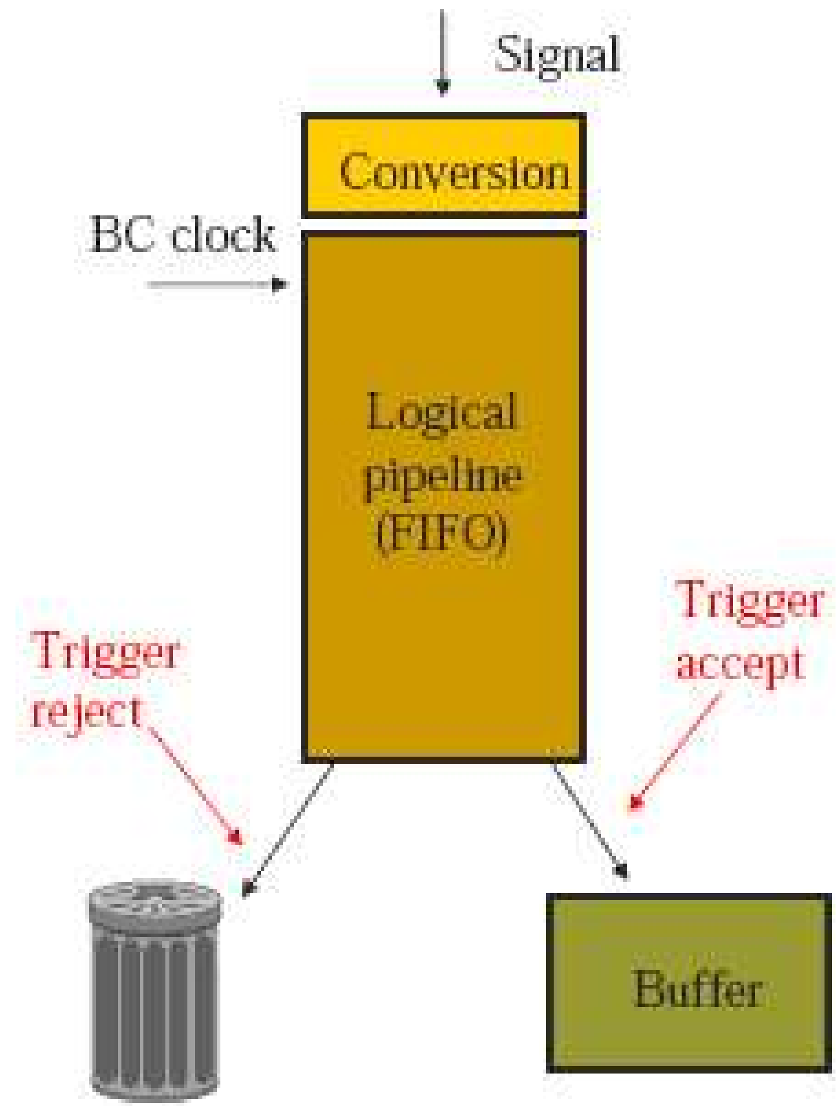
The Multilevel Trigger



- Level 1
  - Rapid rejection of most events in custom based hardware
  - short deadtime and fixed latency
  - examine every beam crossing
- High Level Trigger
  - more complex algorithms run on cpus which make final decisions
- Key – buffer events during the process rather than fully processing one at a time

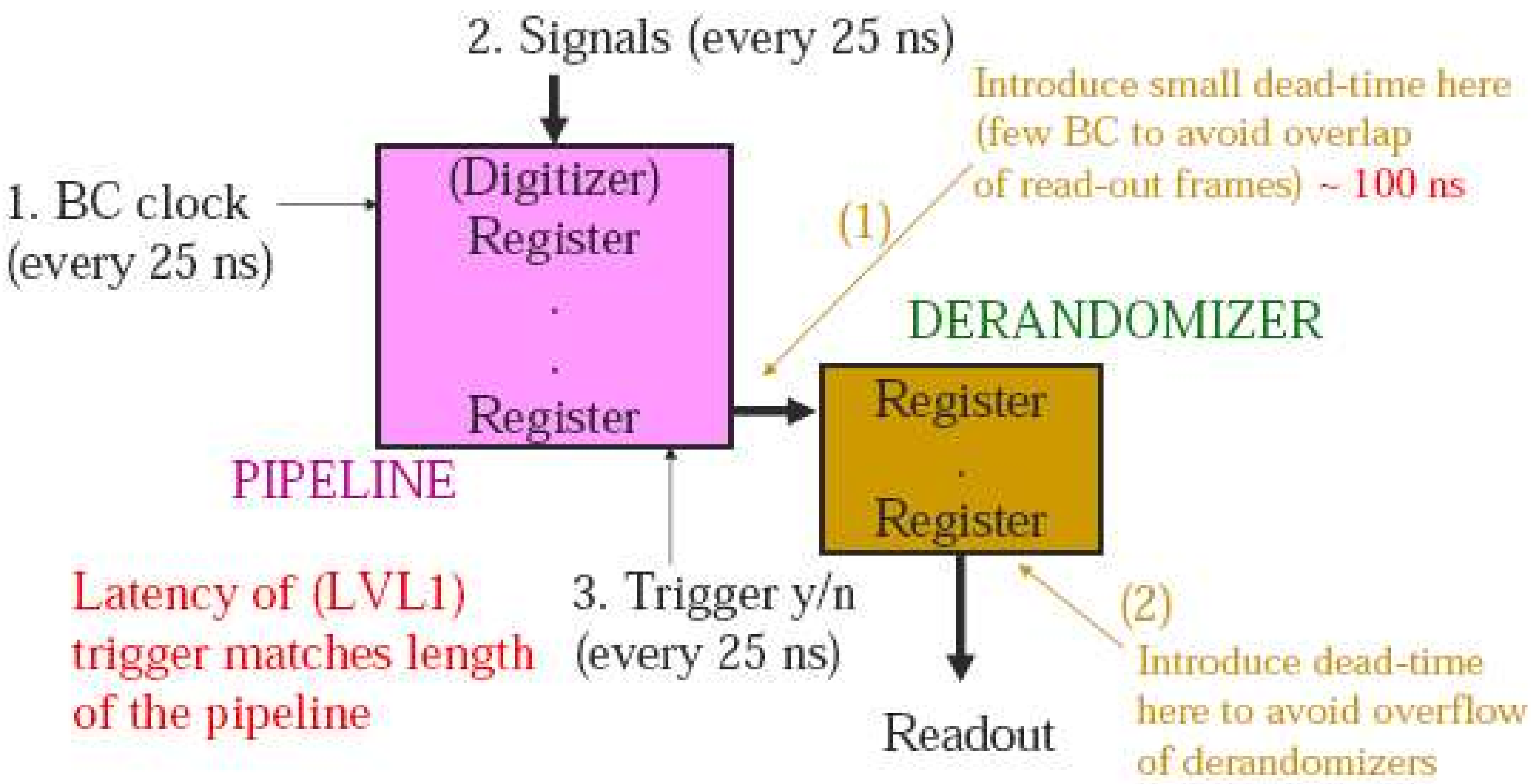
Pipelines

- Events come every 25ns
- However, it takes >> 25ns to decide if event is worth recording or not
- Introduce pipelined system
  - Trigger decision must be made every 25ns, but the decision time can be longer (if you processing many events in parallel)
- trigger latency -amount of time you have to make trigger decision + amount of time to move data around
- trigger latency FIXED at LVL1 ~3 microseconds at CMS/ATLAS

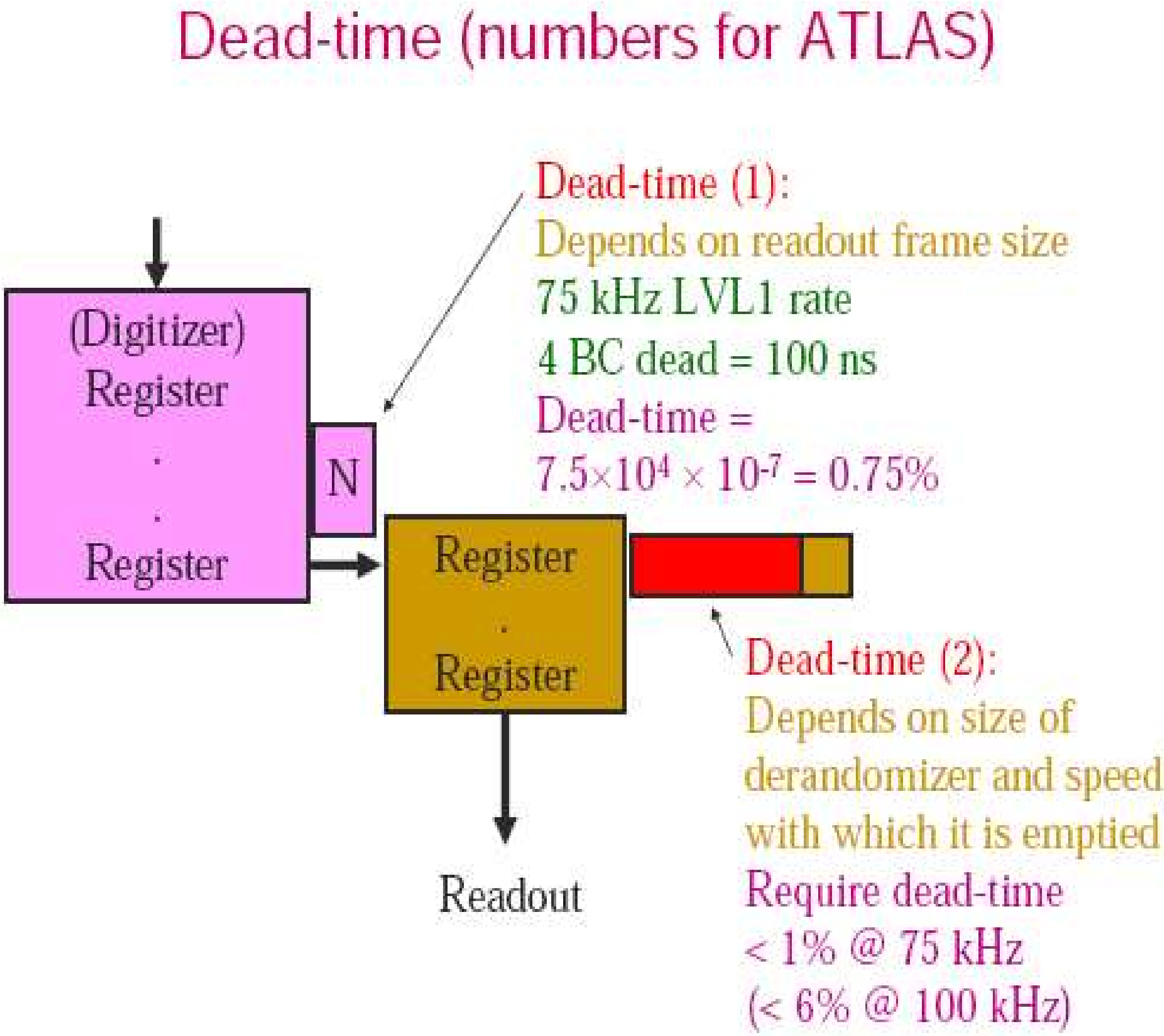


How to process ?

Pipe-lined readout at LHC

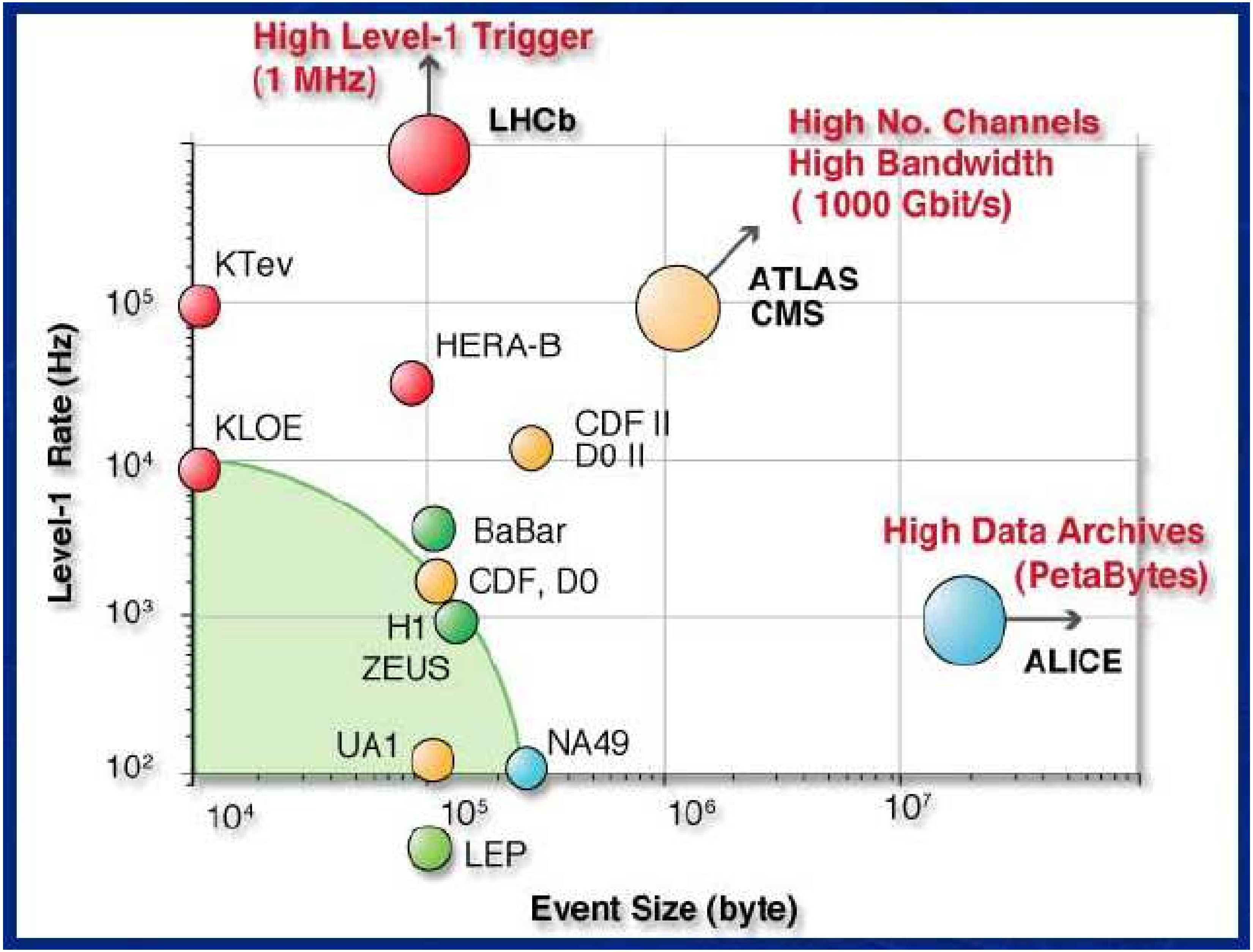


Deadtime



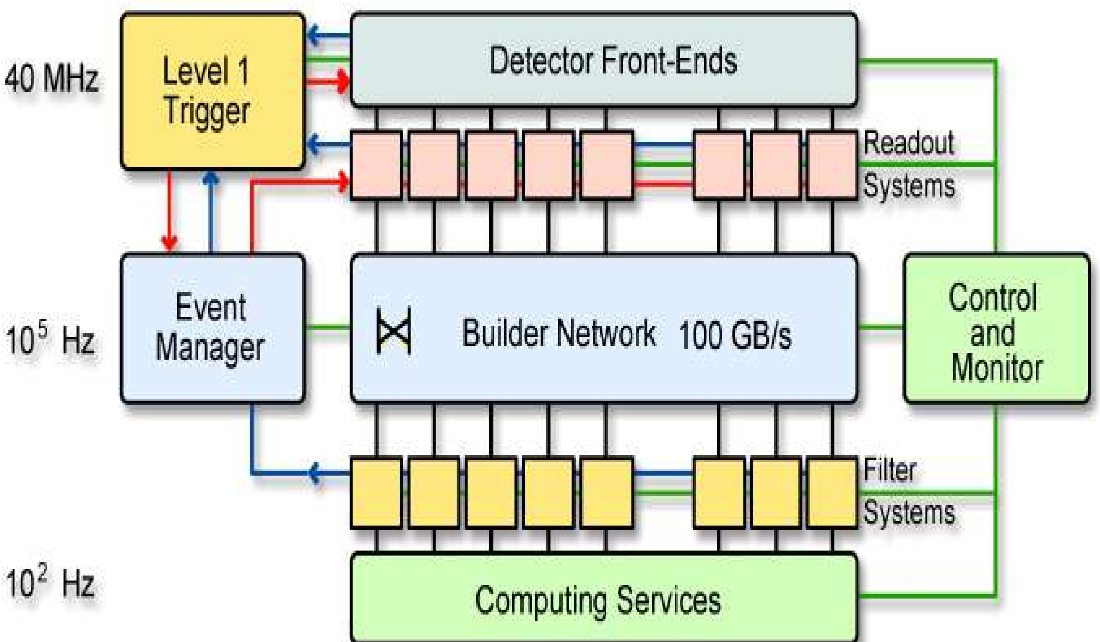
- Deadtime – Fraction of total time that the detector is not live due to various reasons
  - some time period after trigger accept where detector is readout (unavoidable)
  - start/stop runs, failures

How does this compare to previous experiments?

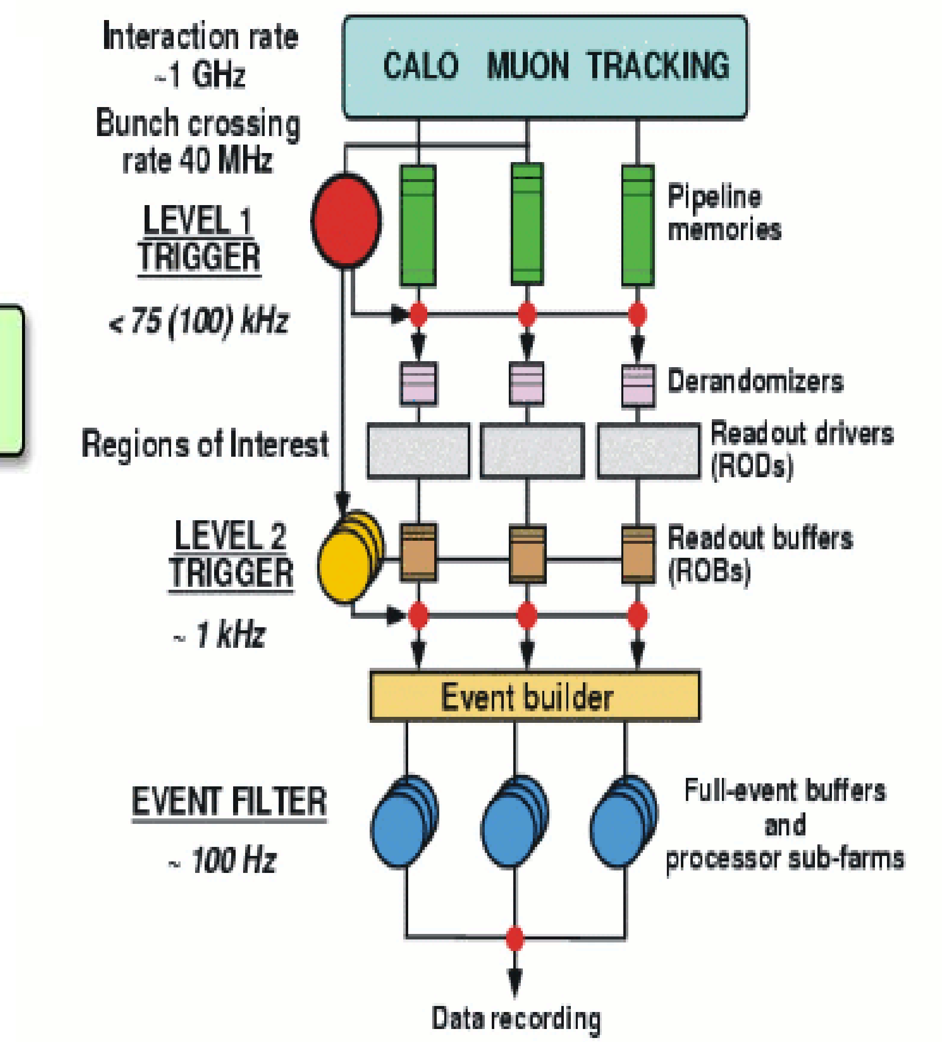


Overall Trigger Architecture

CMS

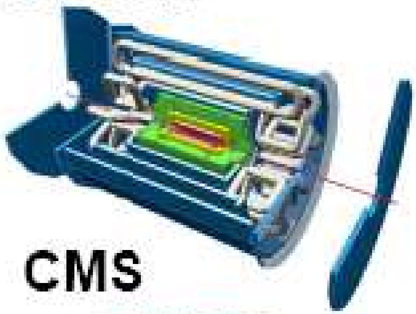


ATLAS



Similar, CMS has 2 levels
while ATLAS has 3

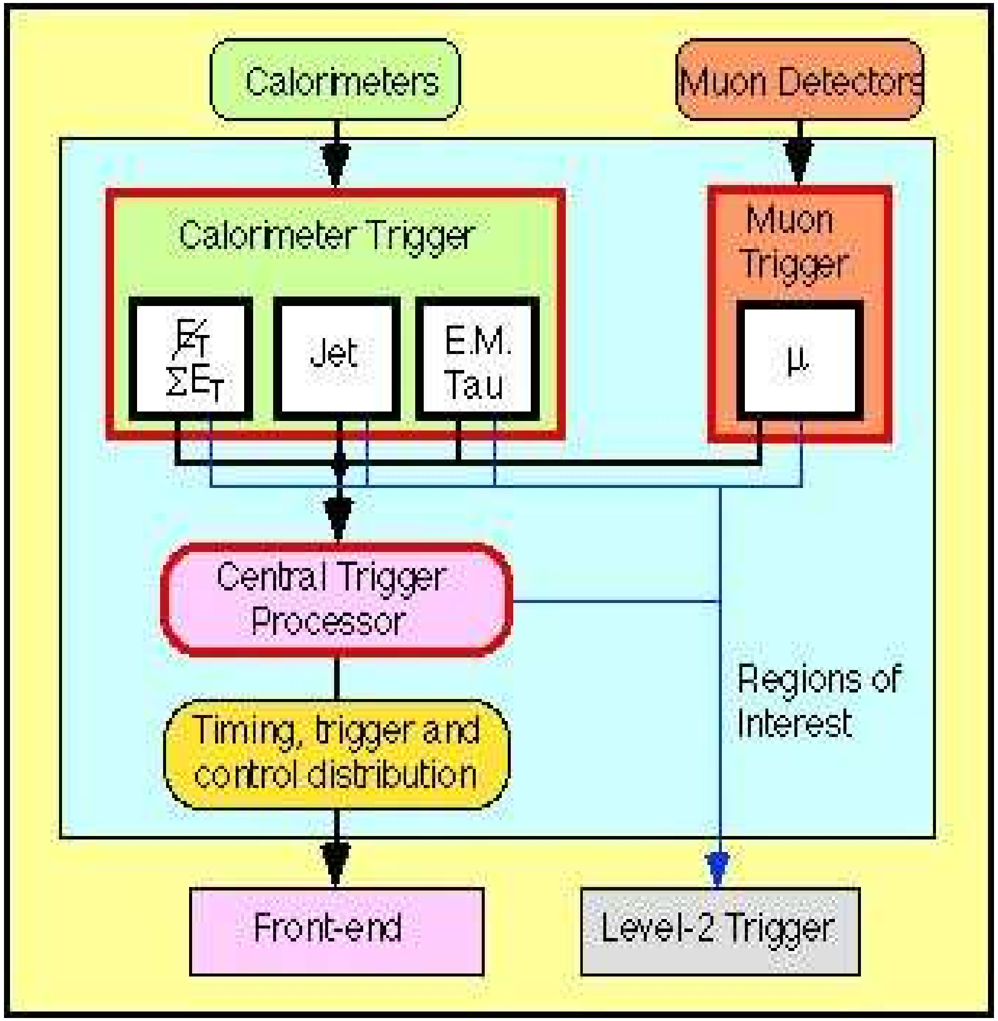
No Unique Solution ...



	No.Levels Trigger	Level-1 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	Filter Out MB/s (Event/s)
ATLAS	3	10^5 LV-2 10^3	10^6	10	100 (10^2)
CMS	2	10^5	10^6	100	100 (10^2)

With 3 level system – ATLAS reduces the load on readout but less flexible since only ROI are available at LVL2

Divide and Conquer

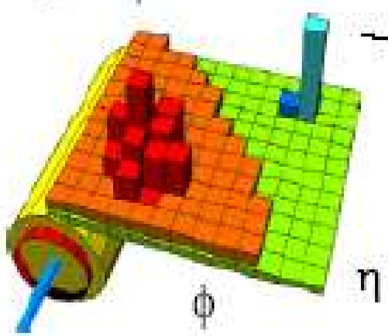


ATLAS LVL1 Example...

- Global LVL1 Trigger Processor fed by
  - Calorimeter LVL1 Trigger Processor
  - Muon LVL1 Trigger Processor
- In turn, Muon and Calorimeter Triggers are the sum of:
  - many calorimeter towers
  - local muon ASICS

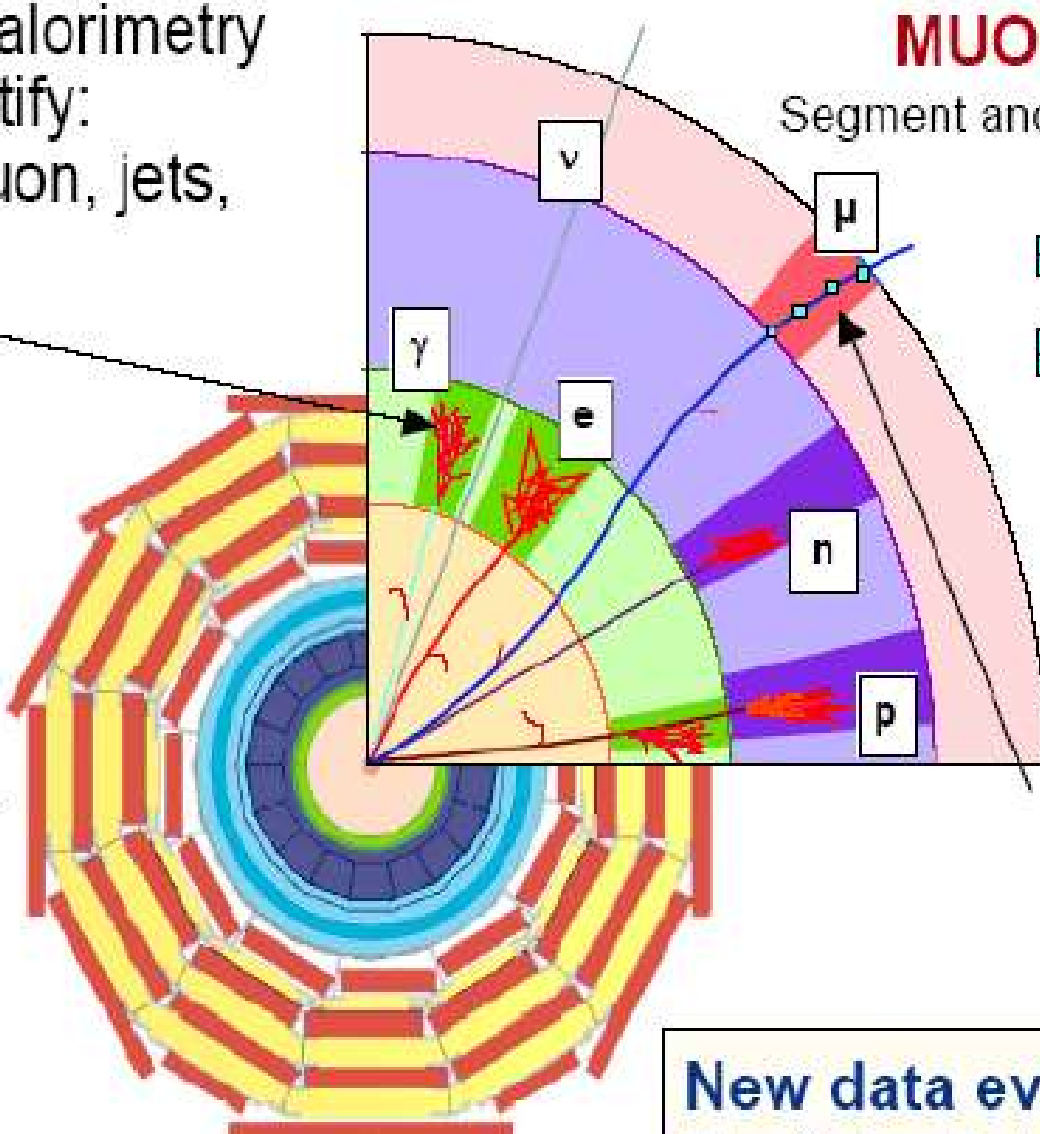
Which Detectors to use at L1?

Use prompt data (calorimetry and muons) to identify: High p_t electron, muon, jets, missing E_T



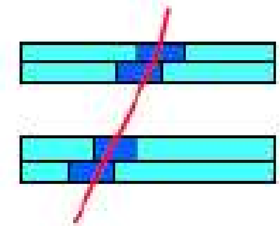
CALORIMETERs

Cluster finding and energy deposition evaluation



MUON System

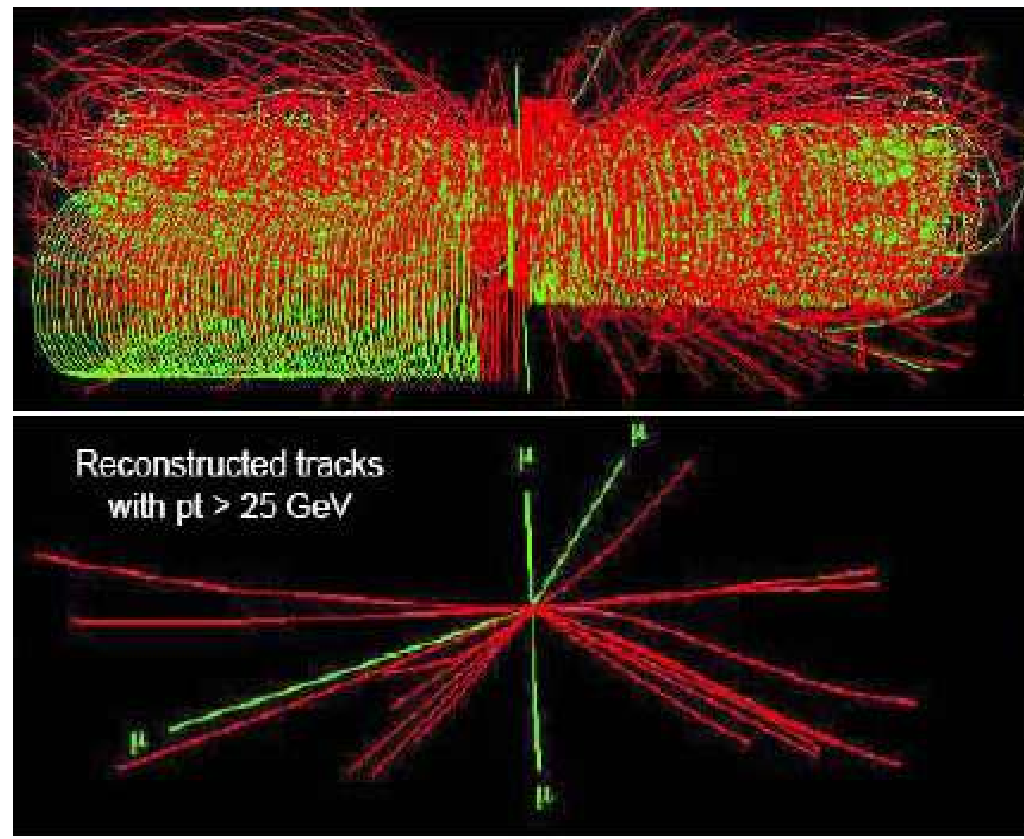
Segment and track finding



New data every 25 ns
Decision latency ~ μs

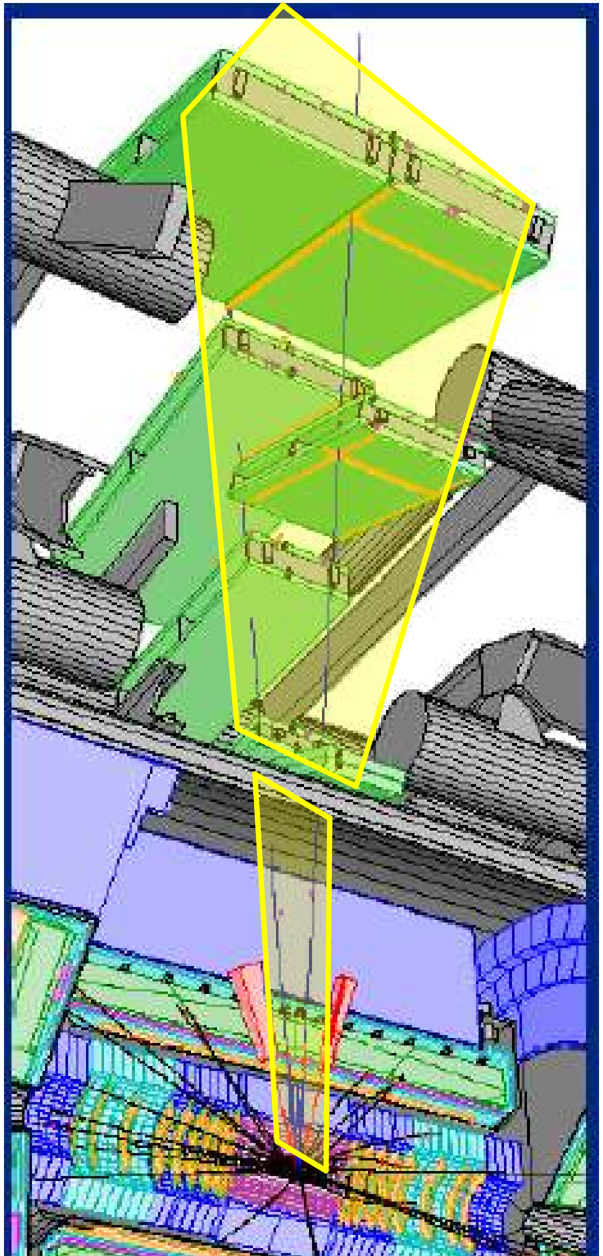
Why not Inner Detector Tracking at L1 at the LHC?

- High multiplicity, time consuming
- Huge number of channels
- Need to link up to other detector elements
- Technology at time of design and development just not fast enough
- Some sort of hardware trigger will be for an upgrade (though not at L1, but LHC is a 20 year program..)



Regions of Interest (ROI) - ATLAS

- Identify Regions based on local areas of activity at LVL1 and pass on to HLT
- Based on course, fast information
- Reduces stress on HLT
- Only ROI data readout to first part of HLT

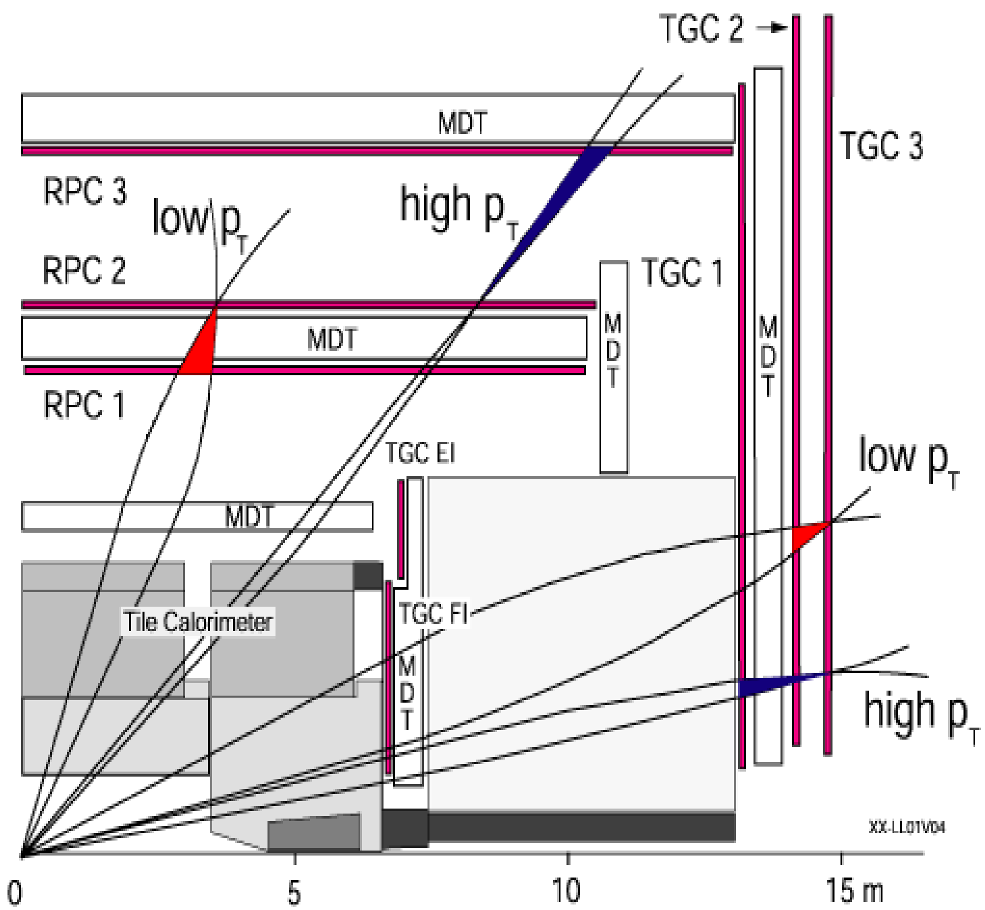


to ROI or not to ROI?

- Reduces output to first part of HLT to 1% of total
- Smaller Readout networks
- More complicated scheme
- At LVL1 logical OR of all trigger sectors (they are all independent!)

- High throughput
- Large readout networks
- Simpler scheme
- More flexible, but more demanding requirements

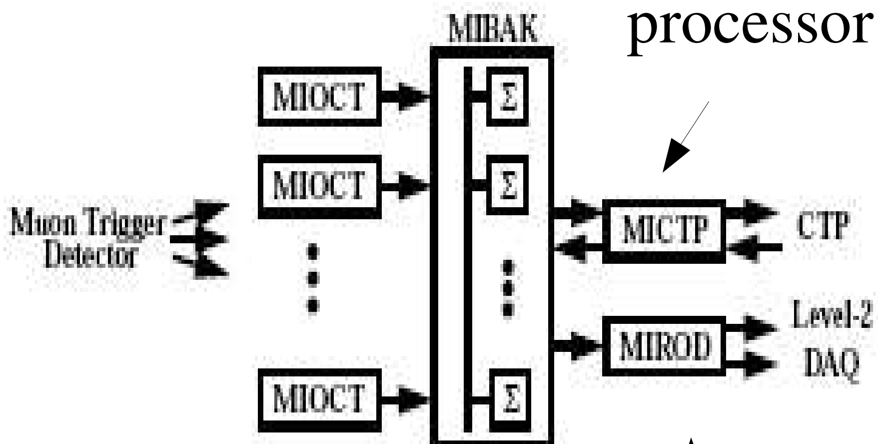
Example #1
ATLAS Muon Trigger

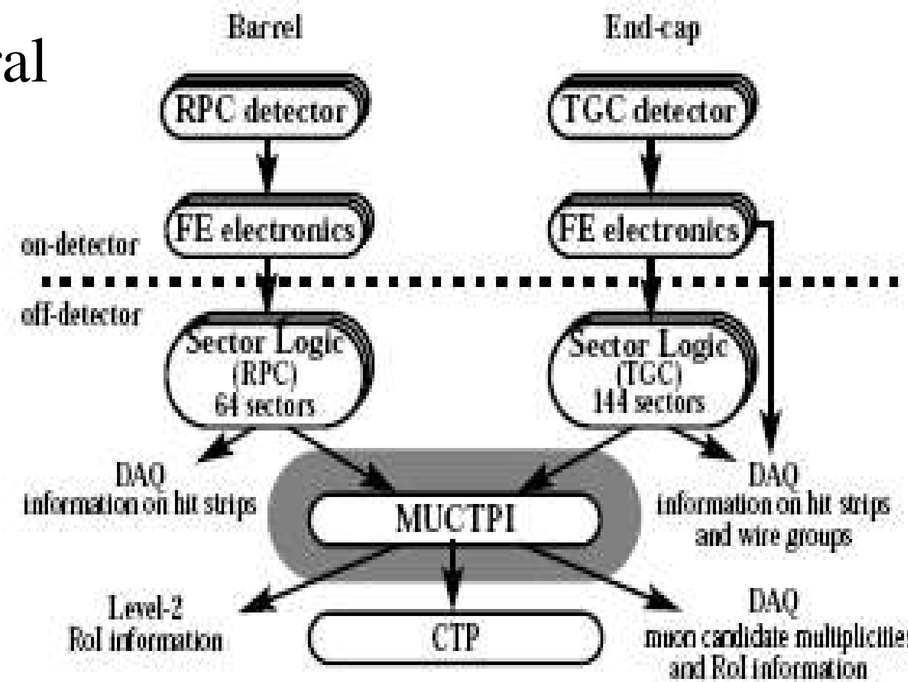


- 3 super layers in a toroid field, identify and measure momenta
- Precision drift tubes for precise track reconstruction
- Fast 'Resistive Plate Chambers', and 'Thin Gap Chambers' for trigger

Remove overlap, tabulate information for central trigger processor

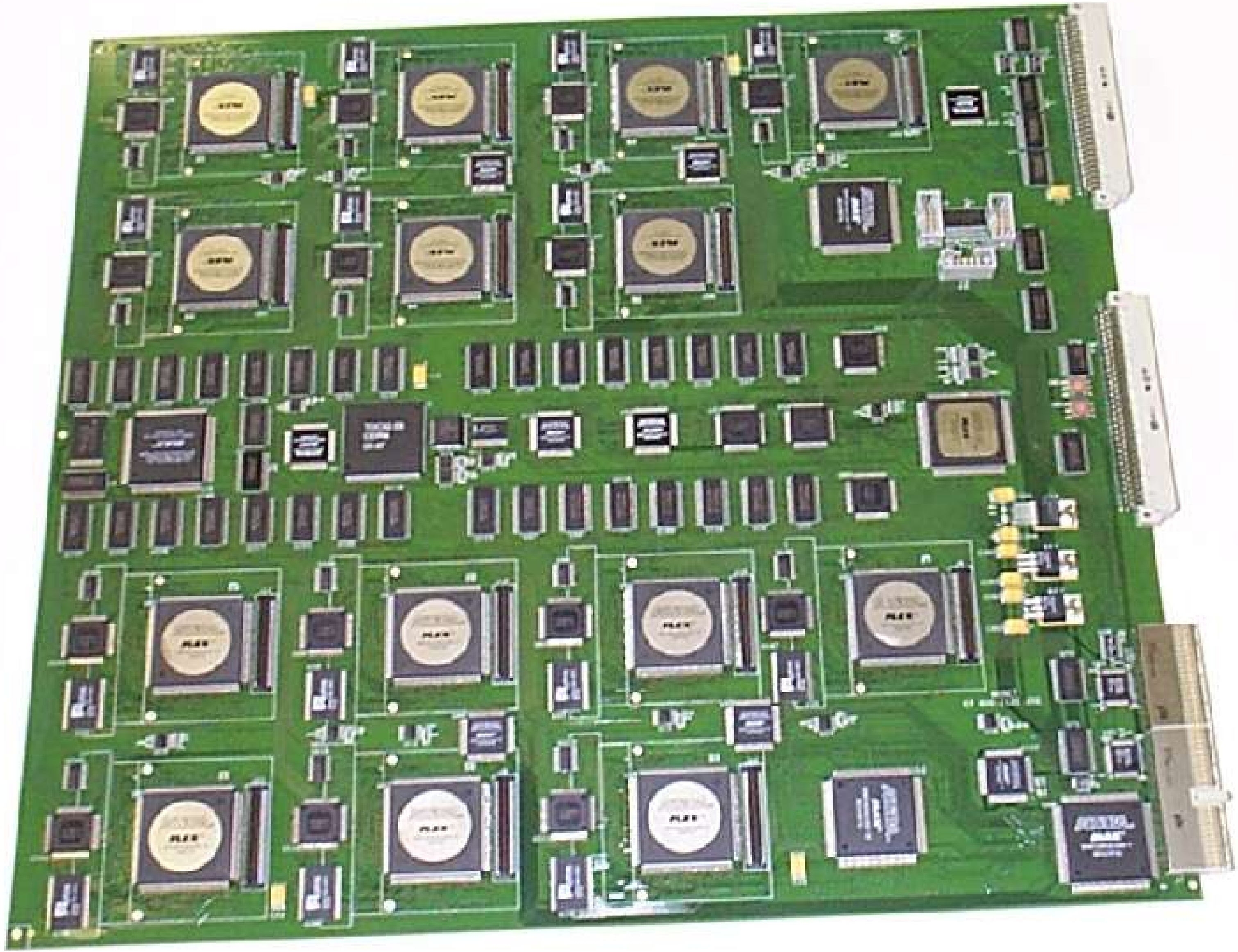
muon central processor





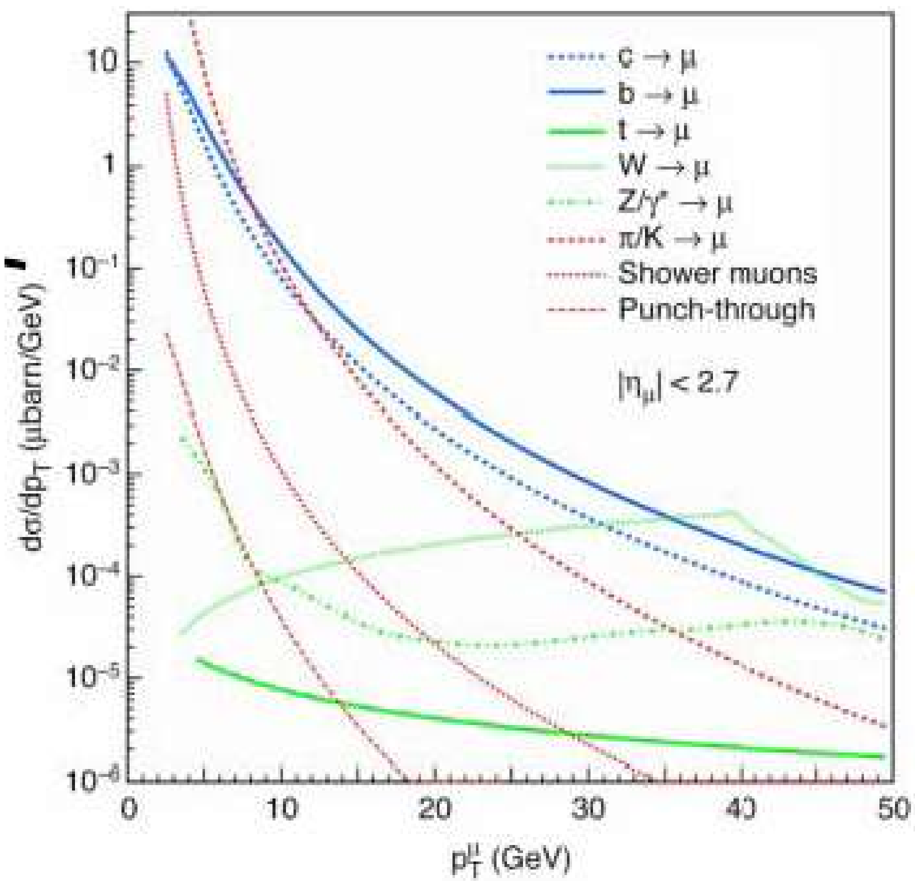
readout, control, LVL2

regional processors

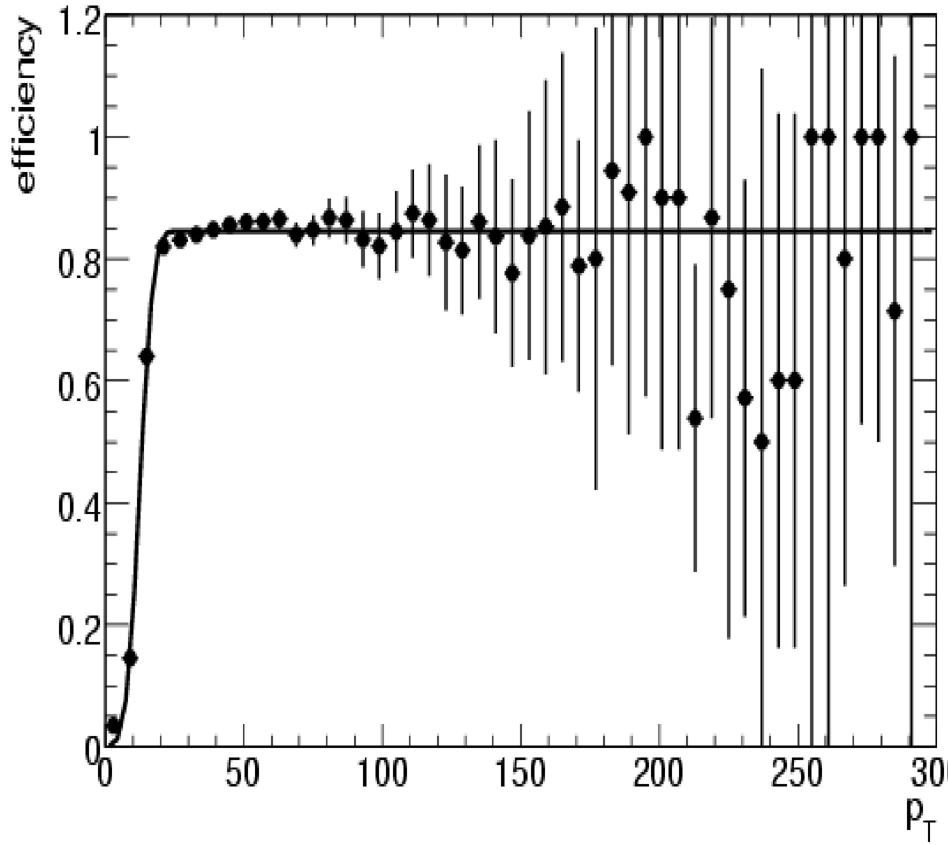


ATLAS MIOCT Board

Muon Trigger Efficiency and Rates

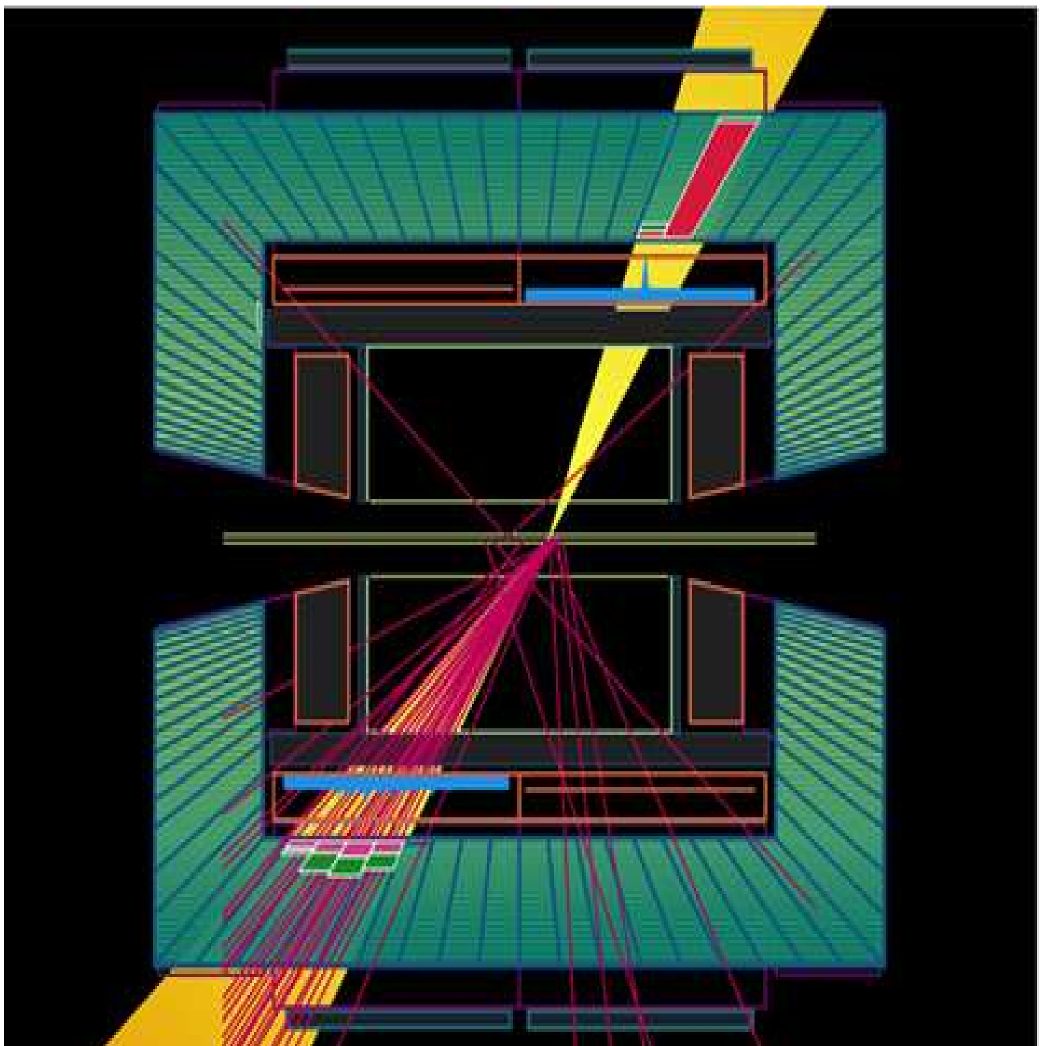


ATLAS



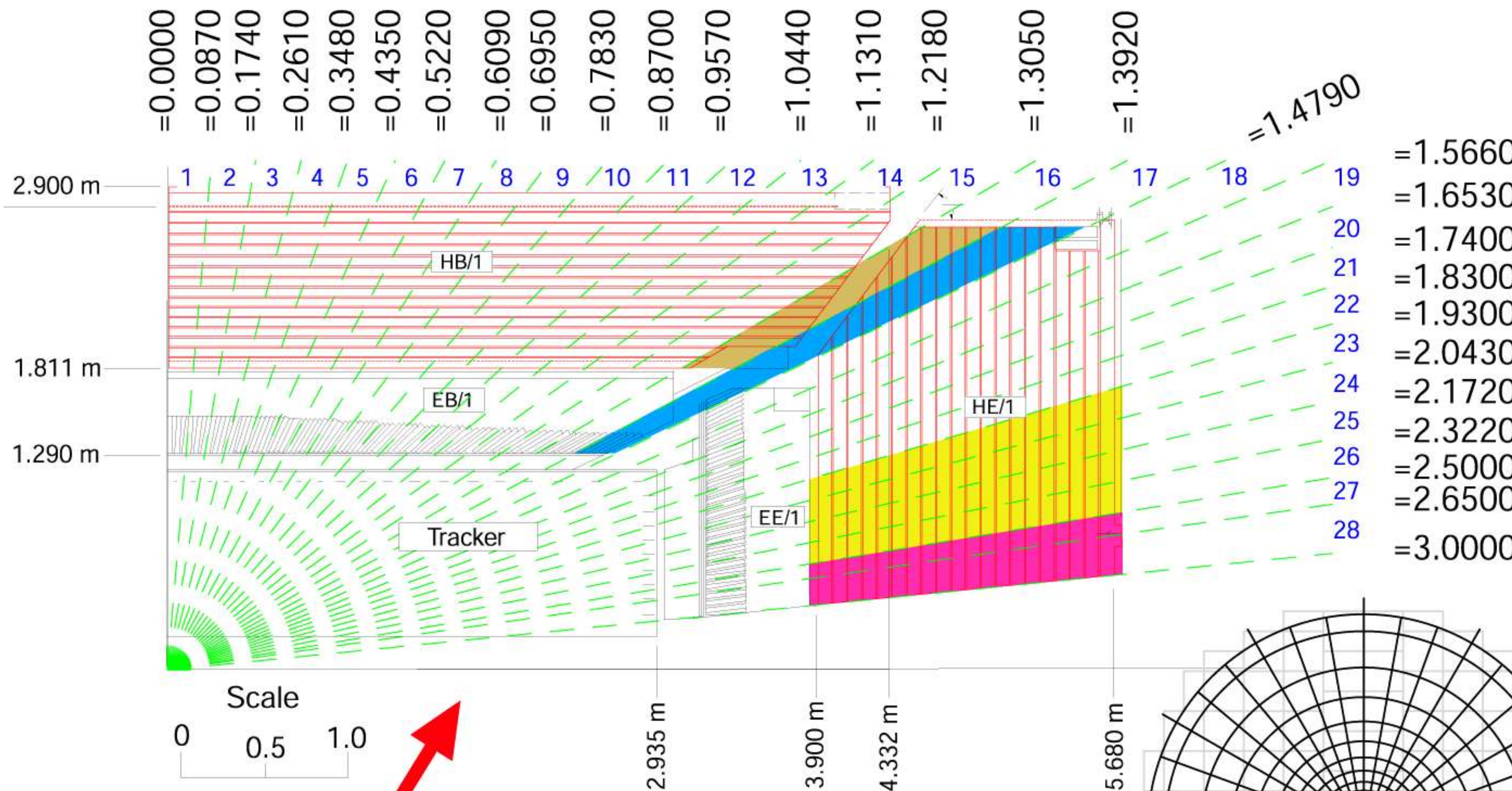
ATLAS

Example #2
CMS Jet Trigger



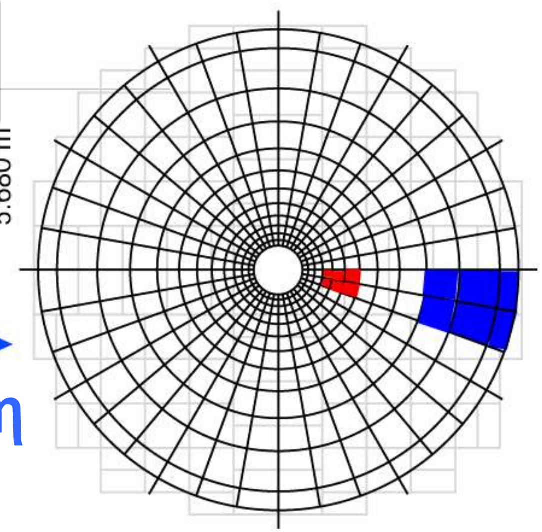
- Ubiquitous at the LHC
- Complicated objects , composed of many (different types) of particles
- Calibration, energy scale, need to control rate
- Need not to split jets (and overcount)

CMS Calorimeter Towers

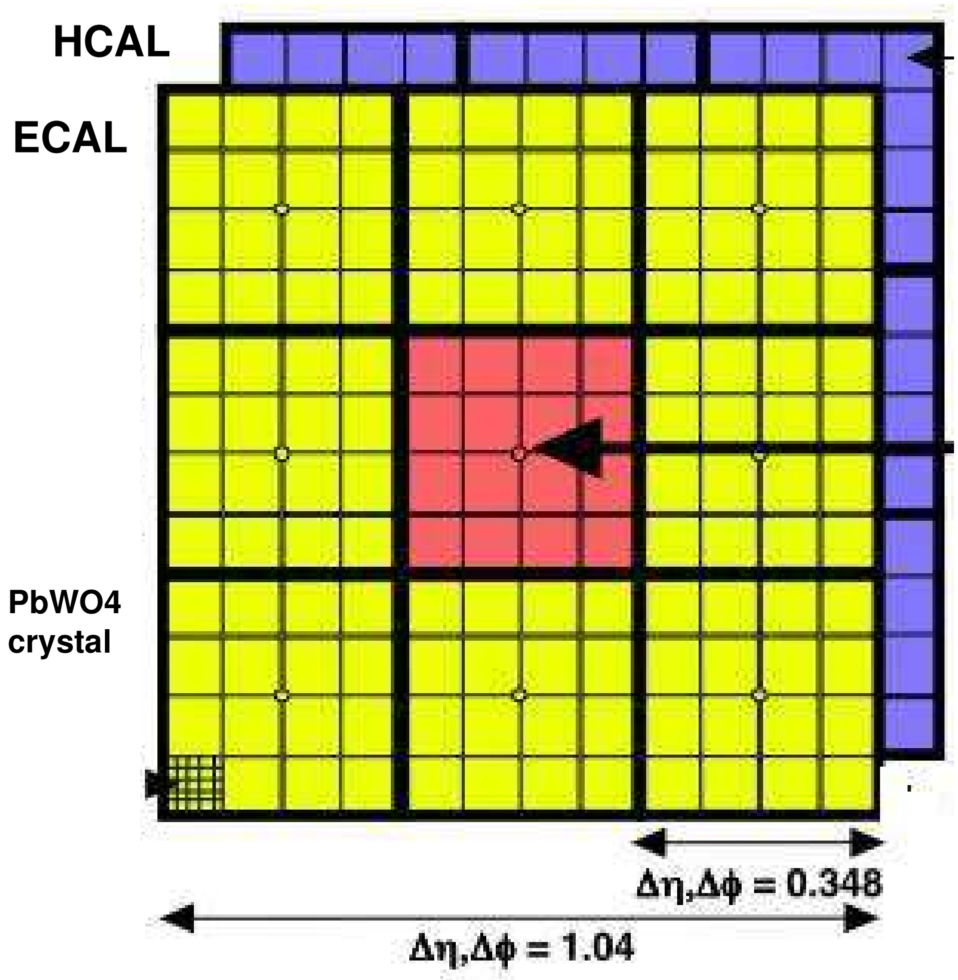


Barrel & Endcap:
E & H: 72 φ x 56 η
(|η| < 3.0)

Forward:
H only: 18 φ x 4 η
(3.0 < |η| < 5.0)



Sliding Window Algorithm

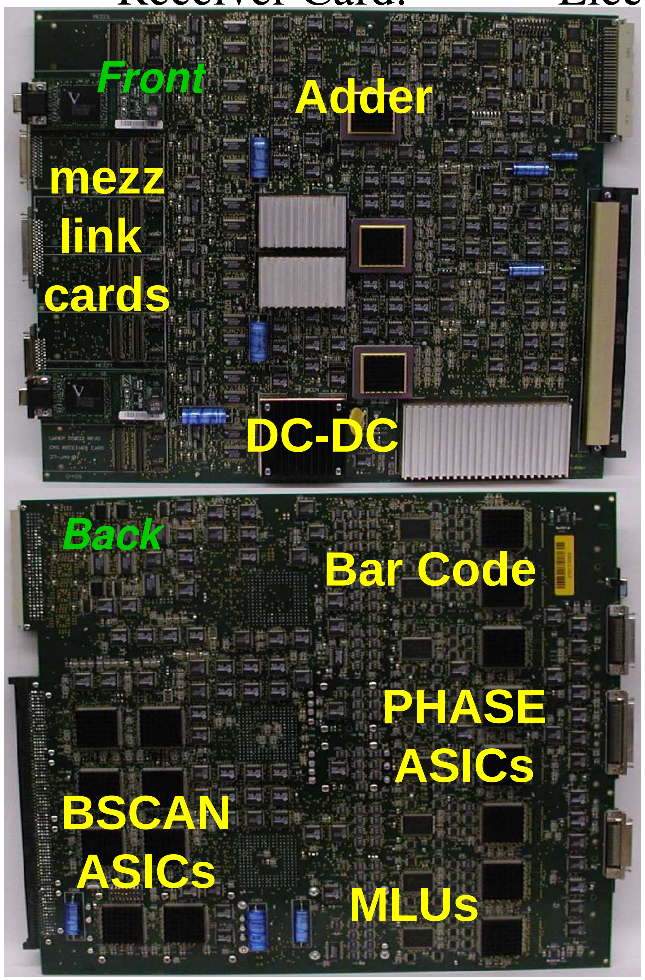


- 4x4 trigger towers = **region**
- Search for jets with a **sliding 3x3 regions window**
- **Jet** = 3x3 region where the E_T in the central region is above some threshold and is bigger than the E_T in any of the 8 outer regions
-

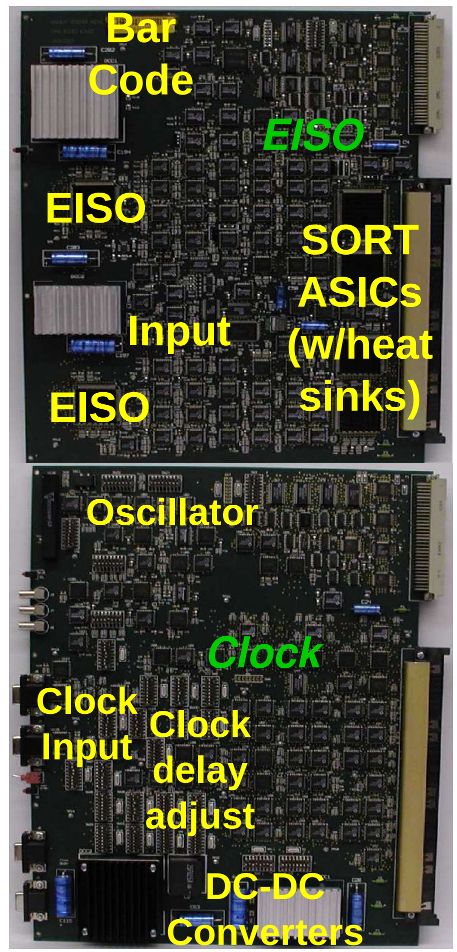
A jet = 144 trigger towers, with typical tower dimensions $\Delta\eta \times \Delta\phi = 0.09 \times 0.09$
Hence typical jet dimensions: $\Delta\eta \times \Delta\phi = 1 \times 1$

Regional Calorimeter Trigger

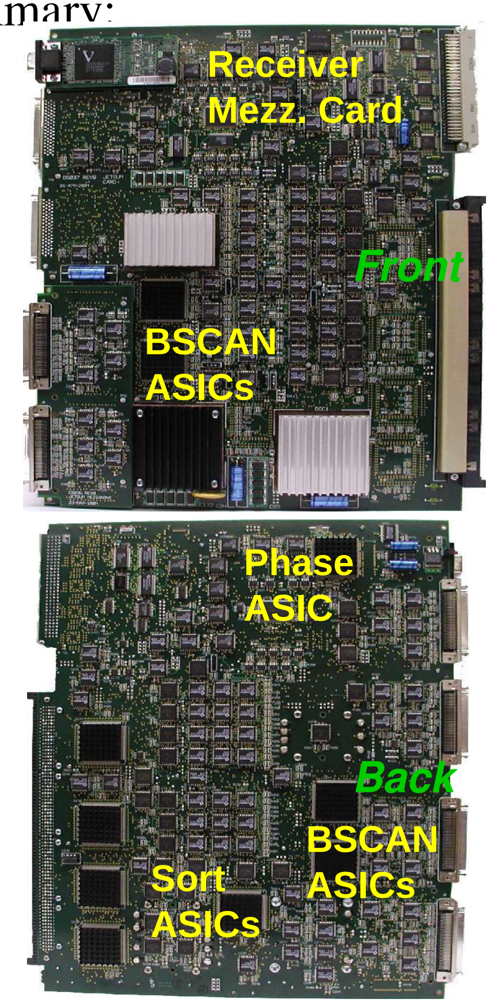
Receiver Card:



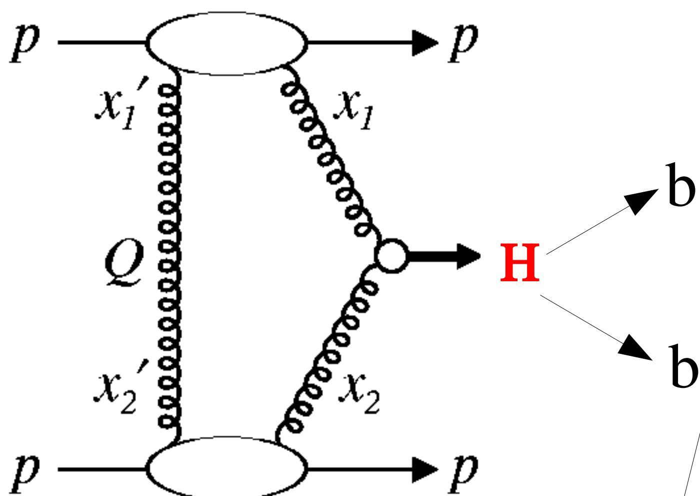
Electron Isolation & Clock:

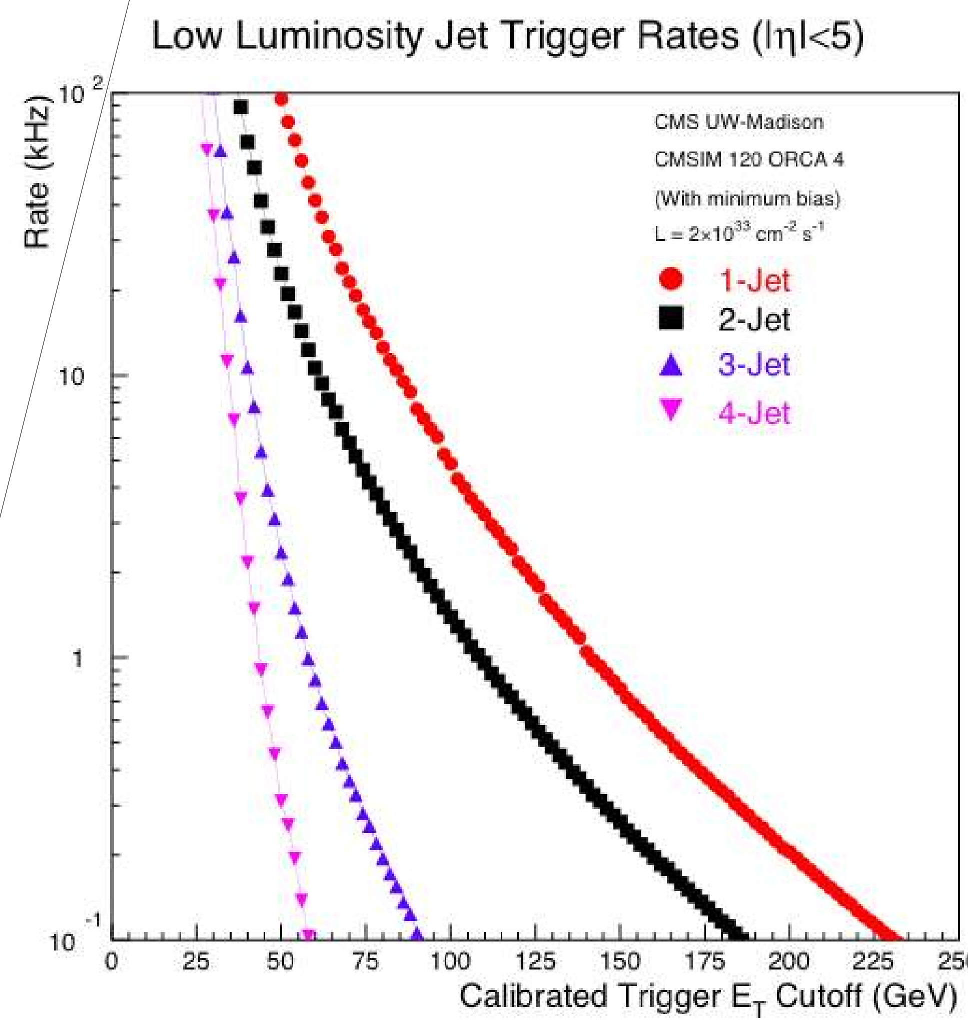


Jet/Summary:



Expected Rates





Would like to trigger on events like this.. but rate explodes at at low pT

Of Strawman and Real Menus

- Tevatron Experience
  - Initial Trigger Tables relatively simple -> over 600 triggers (including calibration triggers, different luminosity settings, ...)
  - Detailed Rate Studies done on monte carlo are often drastically (by factor of 10-1000!) wrong.
  - Real bandwidth is often < than on paper bandwidth
- Real work is preparing for different scenarios, not evaluating MC trigger efficiency to 0.001% (you can't trust monte carlo simulations to that level!)

Conclusions

- Triggering at the LHC is complicated
- No unique solution, though generically split into
  - Fast electronics in custom hardware for fast rejection
  - Offline or close to offline reconstruction for HLT
- Extremely important and contentious topic
  - most event selection takes place at LVL1
  - physics priorities decide which events you will see for your analysis and which you won't
- DAQ and HLT to follow...