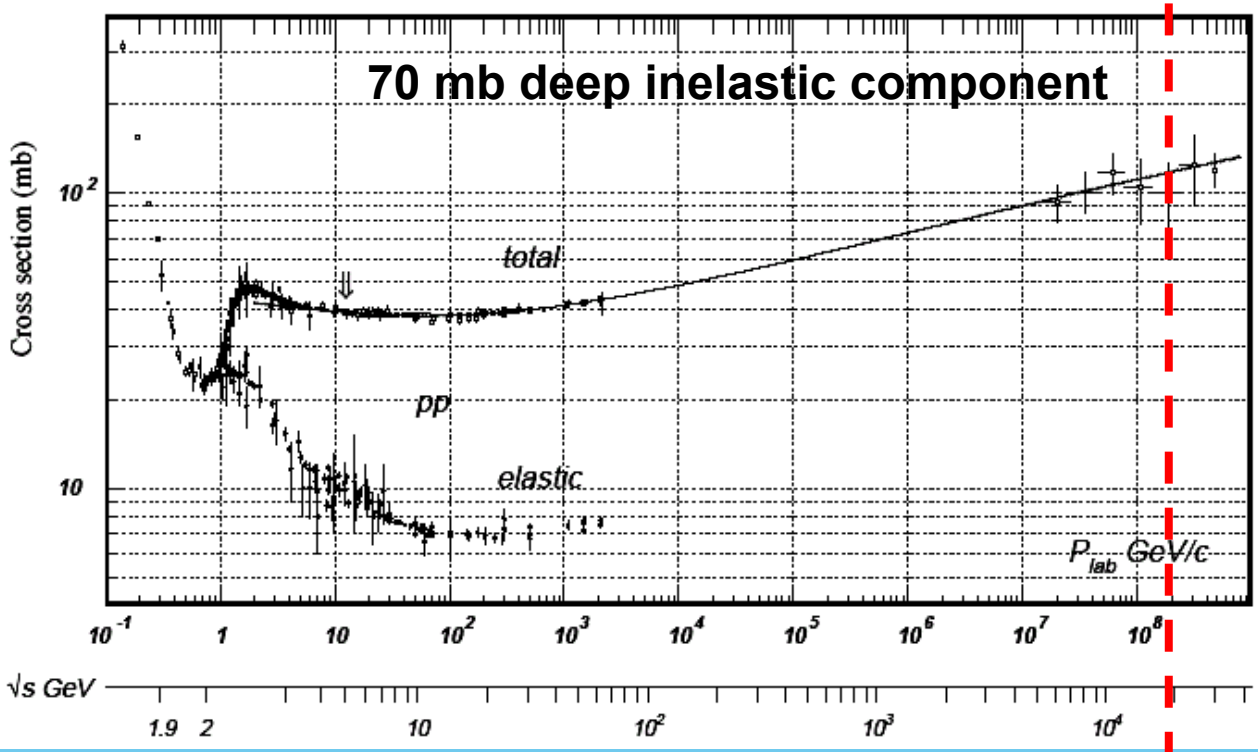
LHC Start-up:
Trigger Commissioning

Overview:

- Trigger Challenges at LHC
- Main Trigger Goals
- Triggering Systems at LHC
- Pilot run Triggers (2007)
- Physics Triggers (2008)

Minimum Bias Events

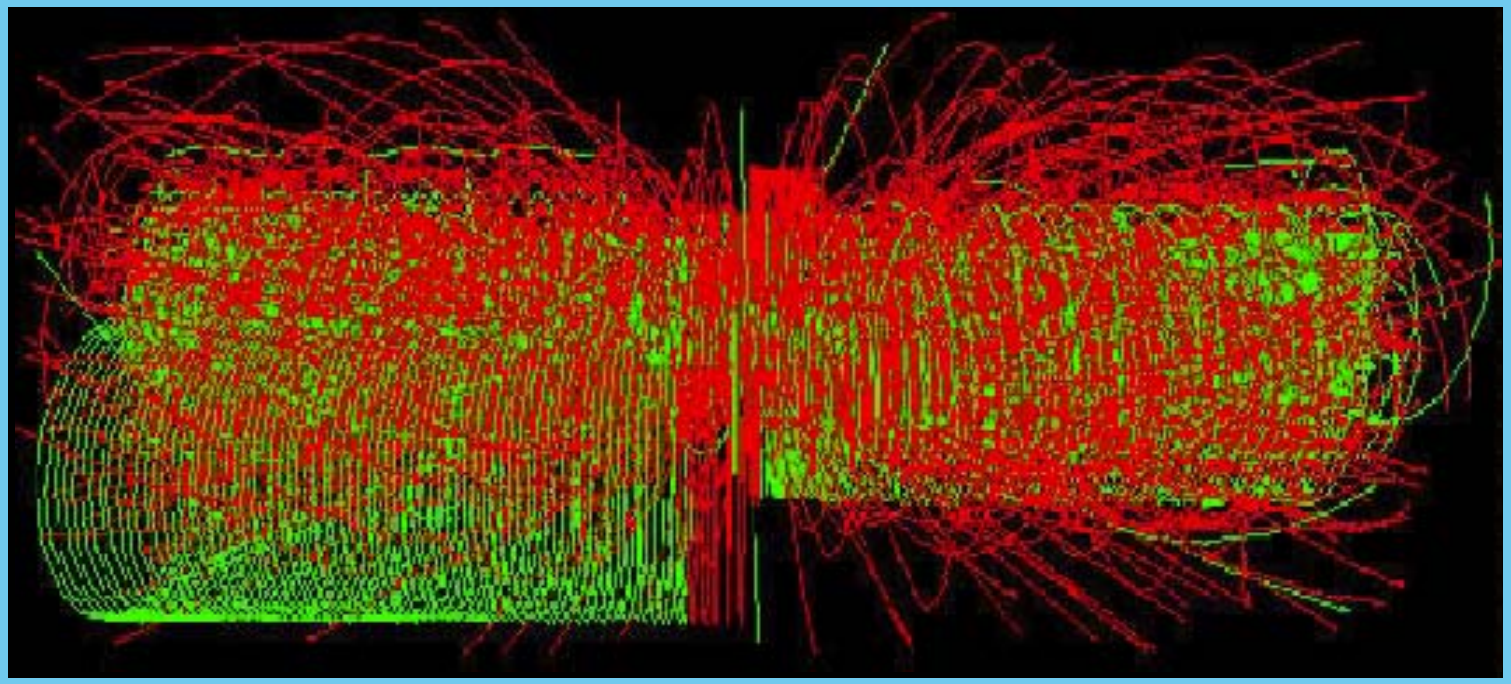


- $L = 10^{34}\ cm^{-2}\ s^{-1} = 10^{7}\ mb^{-1}\ Hz$
- σ_{inel} (pp) ≈ 70 mb
  → **Event Rate = 7 x 10^{8} Hz**
- $\Delta t = 25\ ns = 25 \times 10^{-9}\ Hz^{-1}$
  → **Events/25ns =7 x 2.5 = 17.5**
- Not all bunches full (2835/3564)
  → **Events/crossing = 22**

Challenge 1

- At full LHC Luminosity we have 22 events superimposed on any discovery signal.
- **First Level Event Selection requires considerable sophistication to limit the enormous data rate.**
- Typical event size: 1-2 Mbytes.

Trigger Challenge at LHC

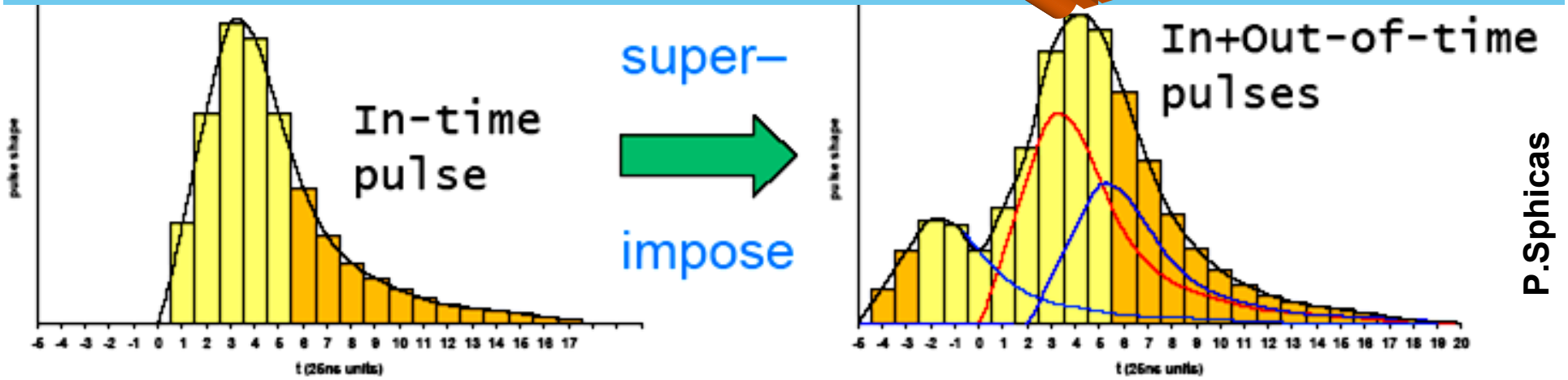


Higgs -> 4μ

+30 MinBias

- We want to select this type of event (for example Higgs to 4 muons) which are superimposed by this……

Challenge 2: Pileup



- In-time pile up: Same crossing different interactions
- New events come every 25 nsec → 7.5 m radial reparation.
- Out-of-time pile up: Due to events from different crossings.
- Need a to identify the bunch crossing that a given event comes from.

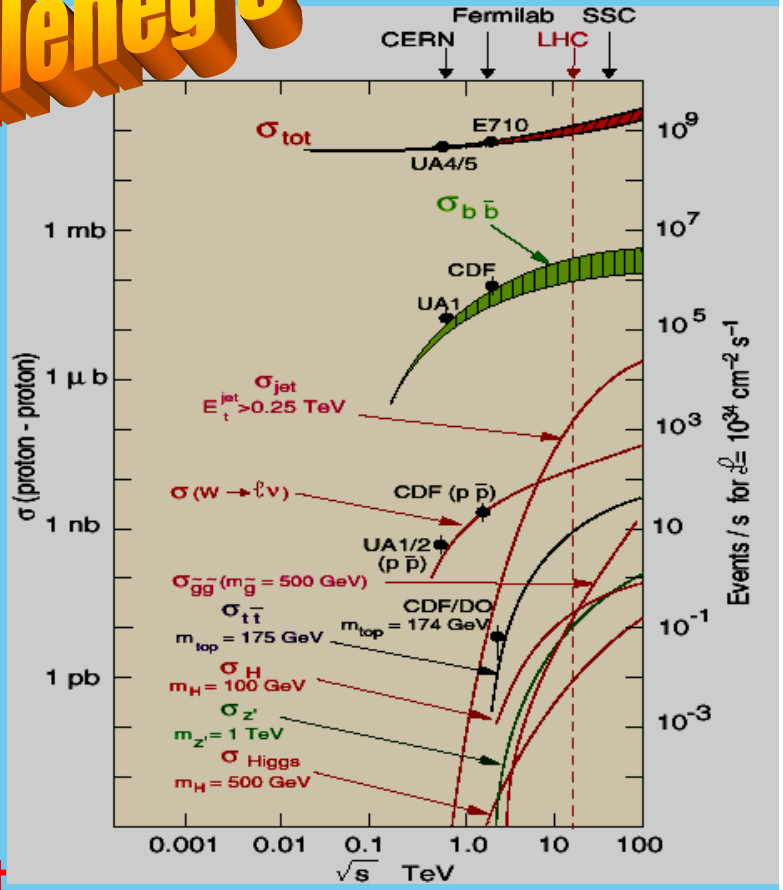
Trigger Goals at LHC

- At LHC we want to select events that have:
  - **(1) Isolated leptons and photons,**
  - **(2) τ-, central- and forward-jets**
  - **(3) Events with high E_T**
  - **(4) Events with missing E_T.**
- The QCD-σ are orders of magnitude larger than any exotic channel **σ.**

Indicative event rates
(1) Inelastic: 10^9 Hz; (2) W→lν : 100 Hz ;
(3) t-tbar:10Hz (4) H(100 Gev): 0.1 Hz;
(5) H(600 GeV): 0.01 Hz

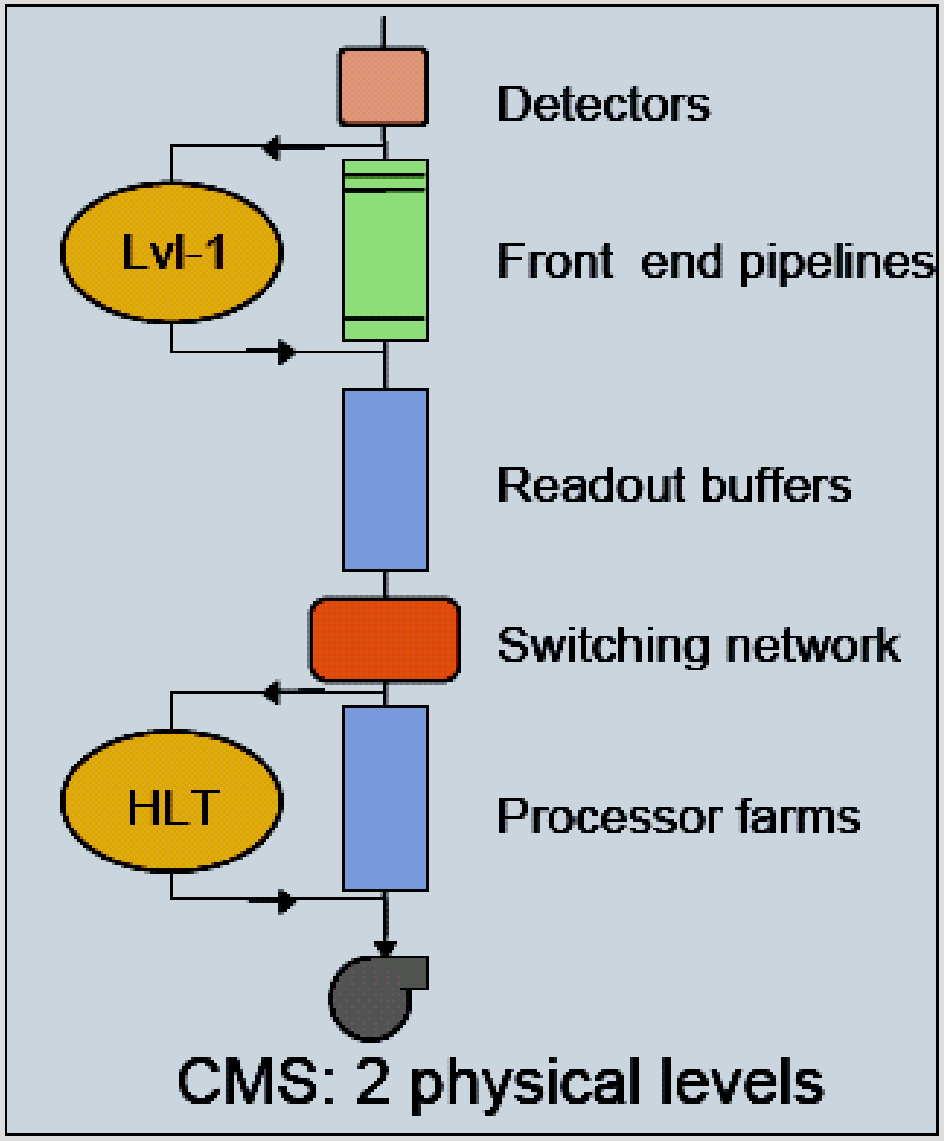
- QCD events must be rejected early in the DAQ chain and selecting them using high E_T cuts in the trigger will simply not work. ⇒ **Need to select events at the 1:10^{11} level with almost no dead-time**

Challeneg 3



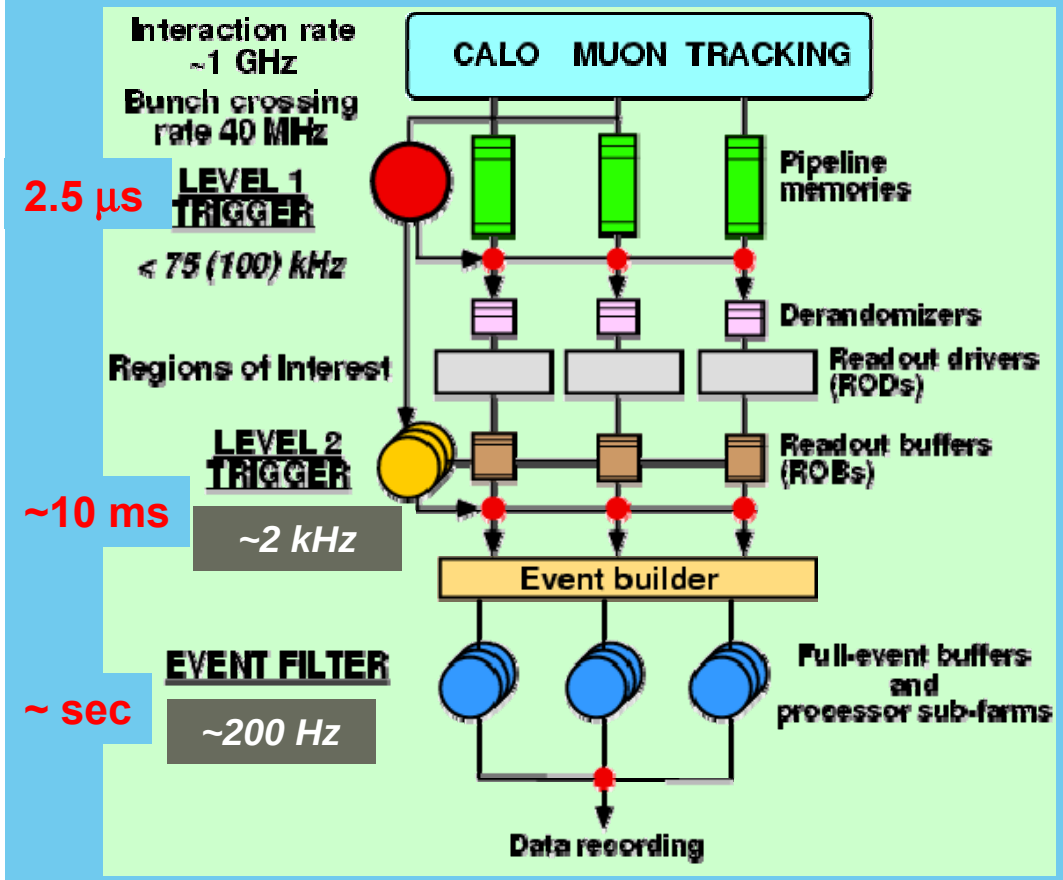
+ Power, Rad. Hard……

The CMS Trigger System



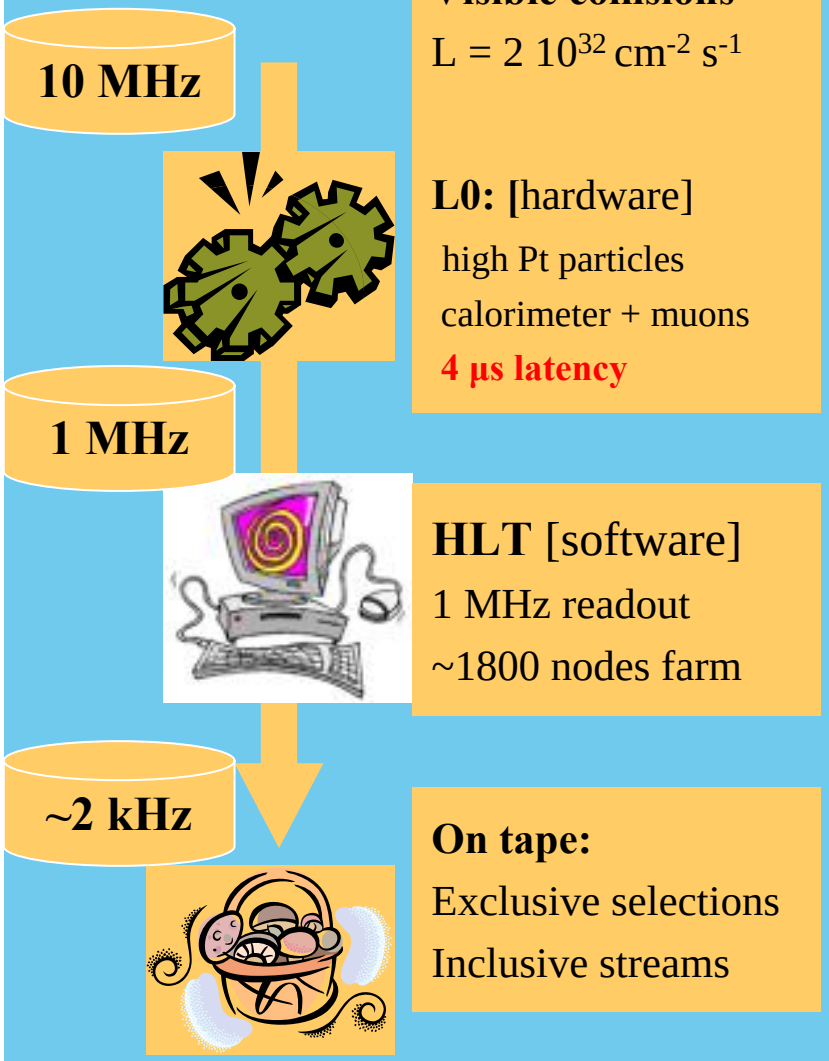
- **40 MHz input**
- **100 KHz FLT rate**
- **3.2 μsec Latency**
- **100 Hz written at the output**
- **Event Size 1-2 Mbytes**
- **The requirements on the Level-1 Trigger are demanding.**
- **Level-1 Trigger: Custom made hardware processor.**
- **High Level Trigger: PC Farm using reconstruction software and event filters similar to the offline analysis.**

The ATLAS Trigger System



- 40 MHz input
- 100 KHz Level 1 rate (similar with CMS)
- 1 KHz Level 2 rate
- 1-2 10^2 Hz HLT output
- Event Size ~1 Mbyte
- Traditional 3 level system.
- Regions of interest.

LHCb Trigger System I



Visible collisions
$L = 2\ 10^{32}\ cm^{-2}\ s^{-1}$

L0: [hardware]
high Pt particles
calorimeter + muons
4 μs latency

HLT [software]
1 MHz readout
~1800 nodes farm

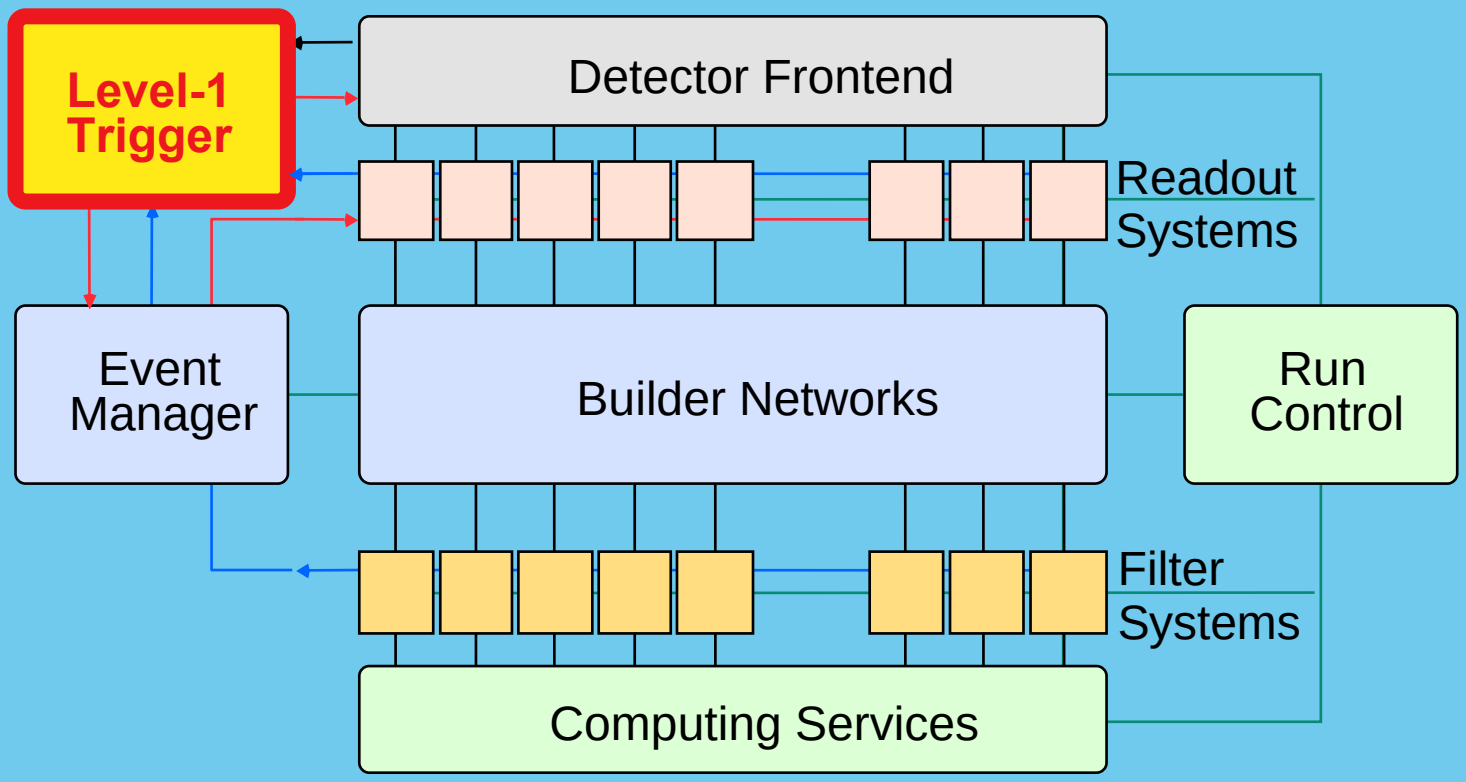
On tape:
Exclusive selections
Inclusive streams

LHCb trigger:

- Two trigger levels:
  - L0: hardware
  - HLT: software
- Trigger Strategy:
  - Enhance the b content in sample
    - High Pt particles (e,γ, μ,hadrons)
    - Displaced tracks
    - Increase b content: 1% → ~50-60%
  - Follow seed particles of the decays
    - Trigger divided in alleys
  - Favor inclusive channels

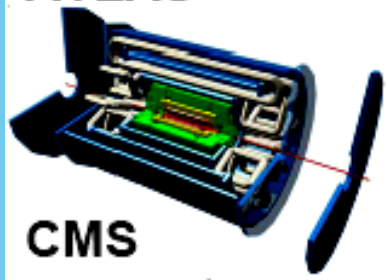
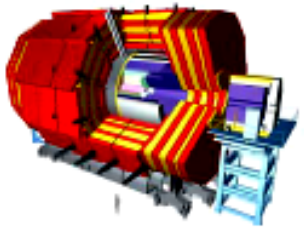
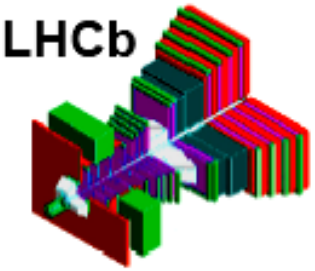
- Similar to CMS….

Trigger and DAQ (CMS Example)



- The First Level decision is distributed to the Front-end as well as the readout units.
- Front-end and readout buffers take care of Poisson fluctuations in the trigger rate.
- Hand-shaking using back-pressure guarantees synchronization

LHC Trigger and DAQ Rates

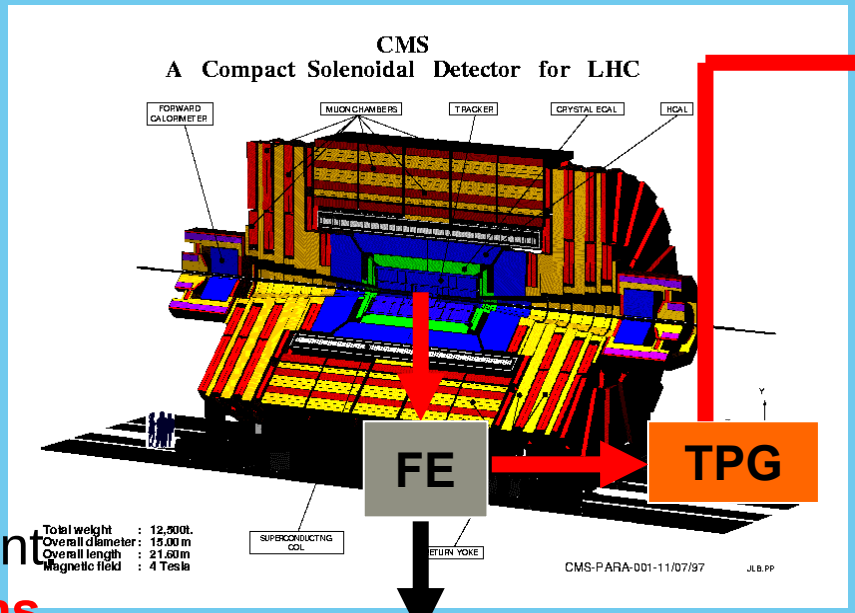
	No.Levels Trigger	Level-1 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	Filter Out MB/s (Event/s)
ATLAS 	3	10^5 LV-2 10^3	10^6	10	100 (10^2)
CMS 	2	10^5	10^6	100	100 (10^2)
LHCb 	2	LV-0 10^6 LV-1 $4\ 10^4$	$2x10^5$	4	40 ($2x10^2$)
ALICE 	4	Pp-Pp 500 p-p 10^3	$5x10^7$ $2x10^6$	5	1250 (10^2) 200 (10^2)

P. Sphicas

The CMS First Level Trigger

- Detector data stored in **Front End Pipelines.**
- Trigger decision derived from **Trigger Primitives** generated on the detector.
- Regional Triggers search for **Isolated e/γ and μ and compute the transverse, missing energy** of the event
- **Event Selection Algorithms run on the Global Triggers**

- **FE: Front End**
- **P: Pipeline**
- **RCT: Regional Calorimeter Trigger**
- **GCT: Global Calorimeter Trigger**
- **GT: Global Trigger**



Level-1 Strategy

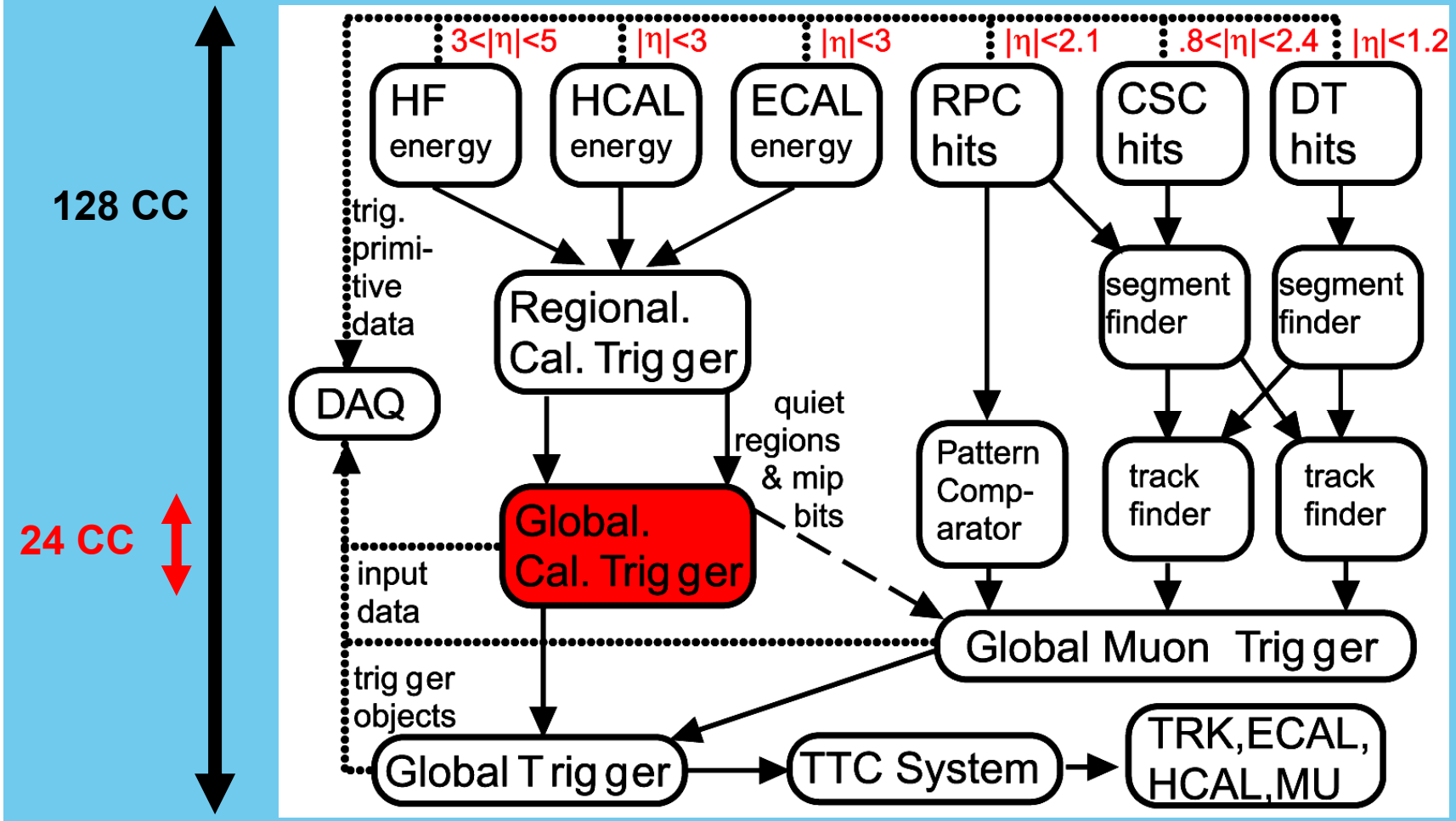
- Selecting events with high E_T at the High Level Trigger level (HLT CPU farms) is not good enough. The rate must be cut earlier before the HLT is overwhelmed by many KHz of background QCD jet events.

- It follows that the first level of selection, the First Level Trigger, should include algorithms of considerable sophistication which can find Isolated Electrons, Jets and detect specific event topologies.

- This is a challenging task because we only have 15x25 ns = 375 ns to accomplish it for all sub-triggers. Jets take longer: 24x25 nsec = 600 nsec; which is many orders of magnitude faster than offline.

- **An example of this is CMS Global Calorimeter Trigger (GCT)**

Level 1 Trigger Components (CMS)

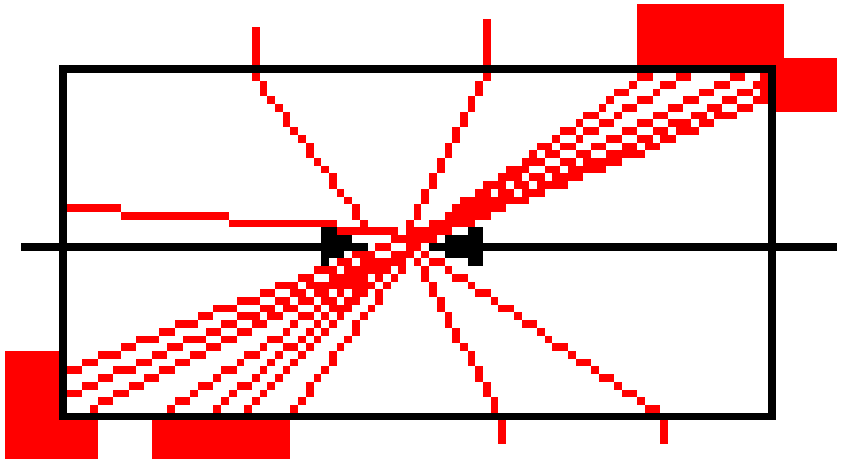


- Level-1 Decision is based on Calorimeter and Muon information (as in ATLAS also)

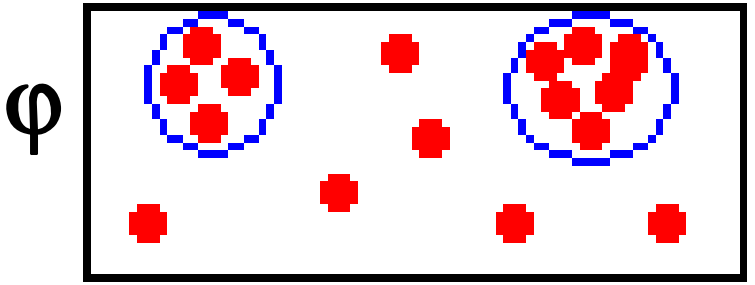
The CMS GCT Task

- **Jet Triggers:** Central, Tau and Forward jet finding and sorting.
- **Jet Counters:** Count Jets in 12 different regions of the detector or 12 different thresholds within the detector.
- **Electron/γ triggers:** Select and Sort the e/γ candidates from Regional Calorimeter Trigger
- **Total Transverse, Total Missing Transverse and Total Jet Transverse Energy** Calculation
- Receive the Muon data and send them to the Global Muon Trigger.
- Luminosity Monitoring and readout all the RCT and GCT data for every L1A.

Jet Finders: A summary



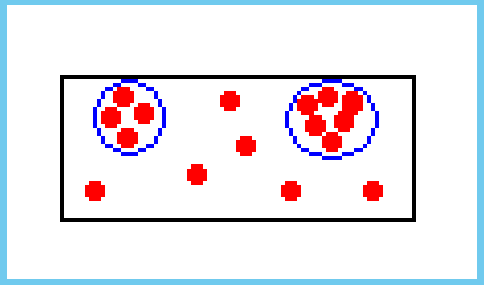
$\eta_{jet}=(-1)\ln(\tan(\theta_{jet}/2))$

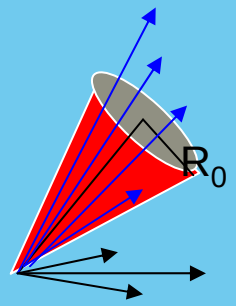


- Particles strike the detectors and deposit their energy in the calorimeters.
- Energy deposits in the calorimeters need to be recombined to reconstruct the transverse energy and direction of the original parton.
- This is done using tools that are called Jet finders.

Cone Jet Finders

- Searches for high transverse energy seeds and a cone in the η-φ space is drawn around each seed.





$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

- Energy depositions within a cone are combined and the Et weighted η is calculated:

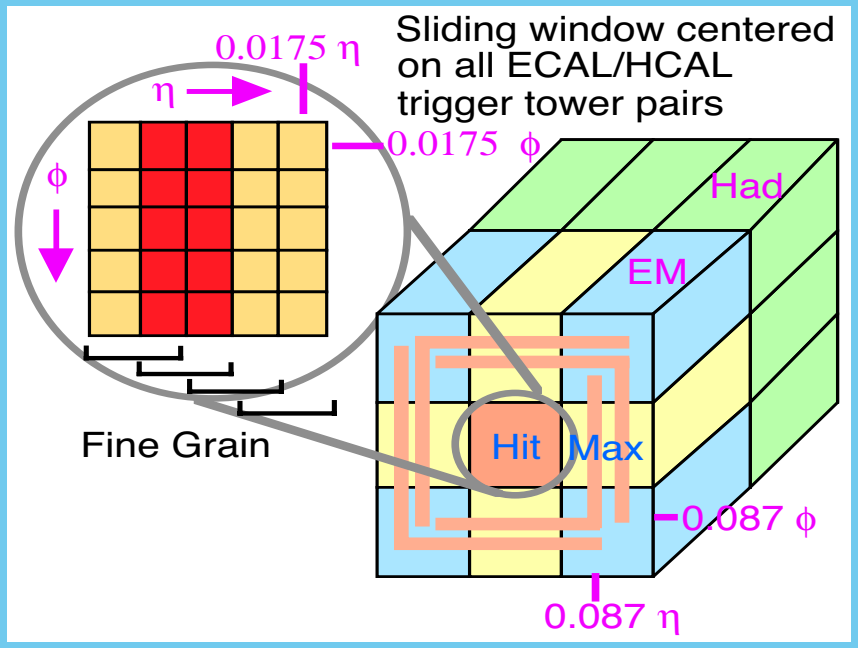
$$\eta = \frac{1}{E_T}\sum_i E_{T,i} \cdot \eta_i$$

- The new cone is drawn and the process is repeated until the cone transverse energy does not change

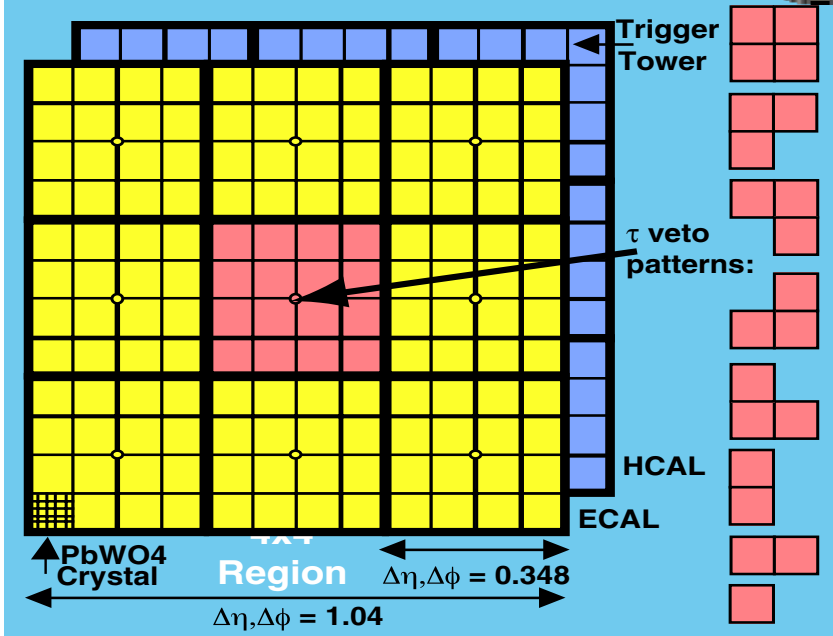
$$E_T = \sum_i E_{T,i} \qquad \Phi = \frac{1}{E_T}\sum_i E_{T,i} \cdot \Phi_i$$

Example Algorithms

Electrons/photon finder



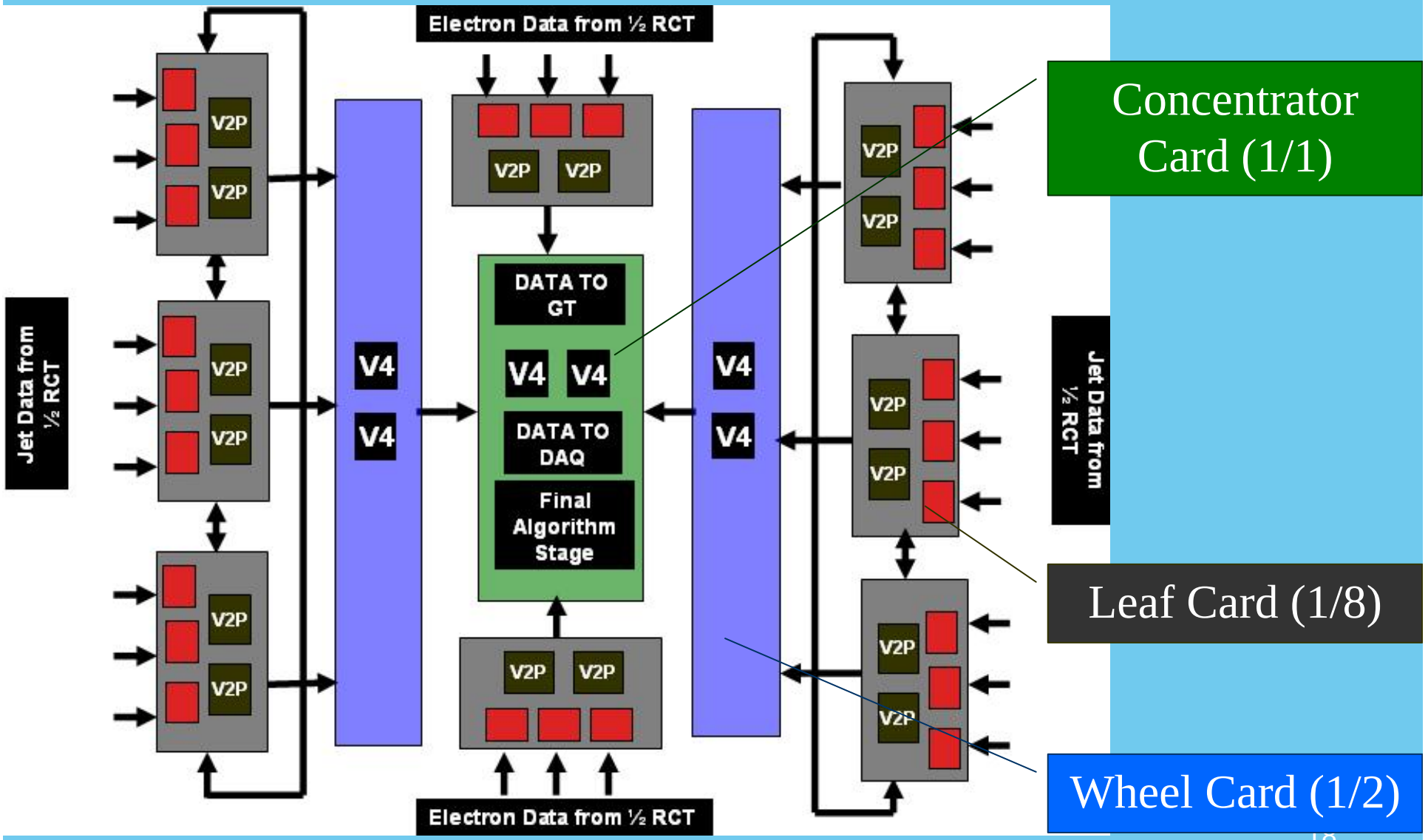
Jet Finder



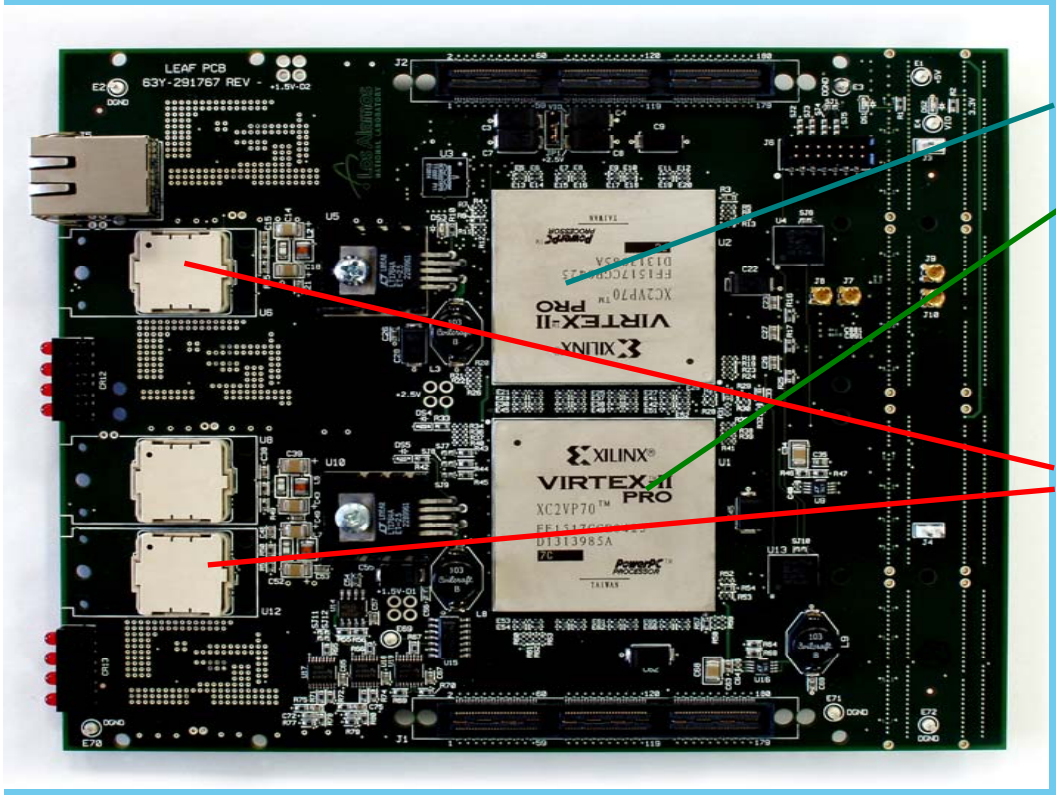
- **Electron (Hit Tower + Max)**
  - –2-tower ΣET + Hit tower H/E
  - –Hit tower 2x5-crystal strips >90% ET in 5x5 (Fine Grain)
- **Isolated Electron (3x3 Tower)**
  - –Quiet neighbors: all towers pass Fine Grain & H/E
  - –One group of 5 EM ET < Thr.

- **Jet or τ E_T**
  - –12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others
- **τ: isolated narrow energy deposits**
  - –Energy spread outside τ veto pattern sets veto
  - –Jet ≡ τ if all 9 4x4 region τ vetoes off

The GCT Design

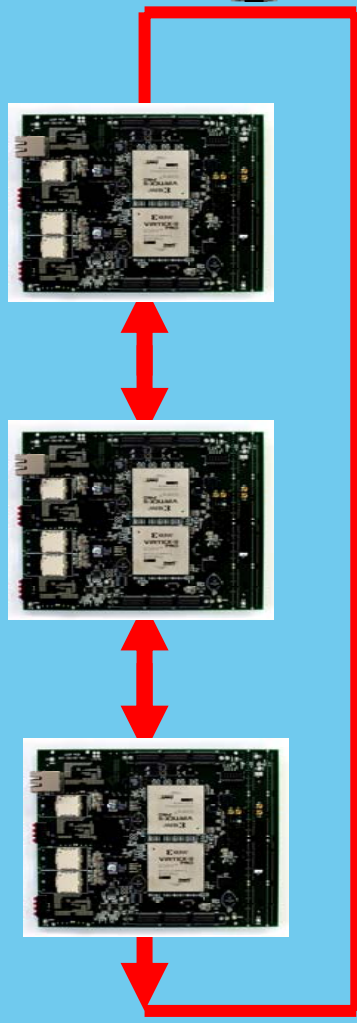


The Leaf Card ($e^{\pm}$, Jets, E_T)



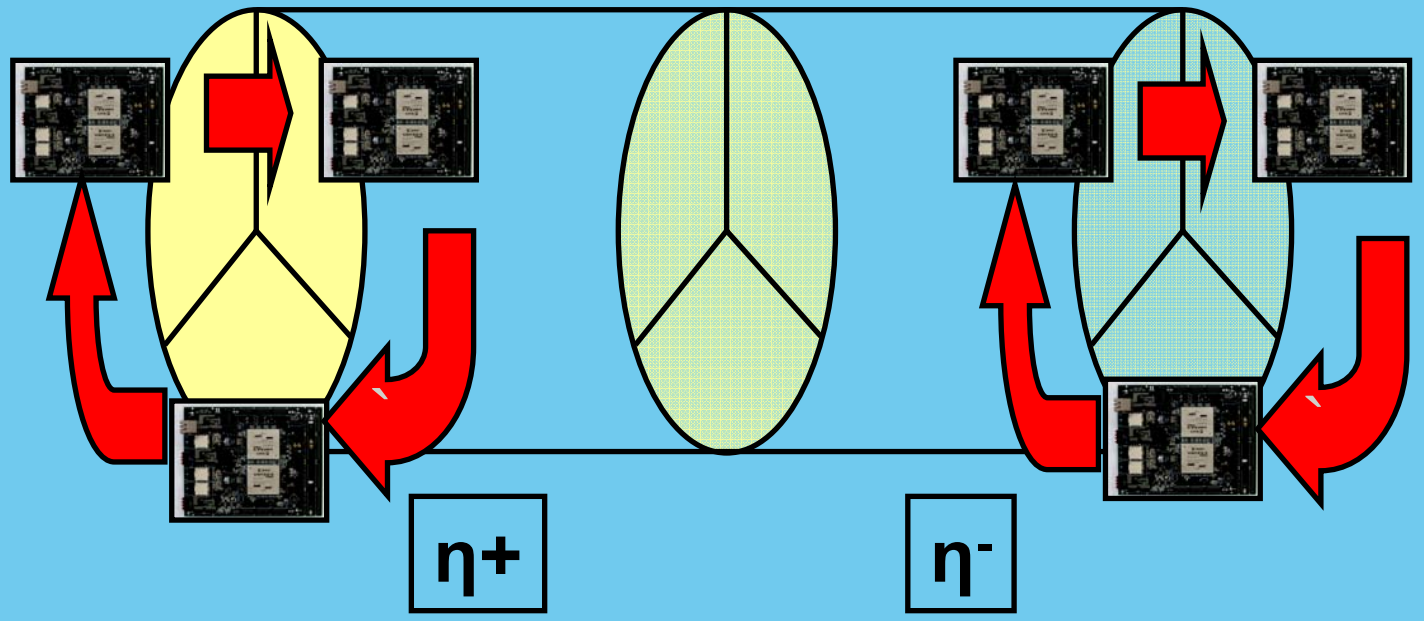
Virtex-II Pro-P70

3x12 Channel 10 Gbit/s Optical Links (eventually)



- Main processing devices: Xilinx Virtex II Pro P70
- 32 x 10 Gbit/sec Links with Serializers/Deserializers
- Each serves 1/6 of the detector in Jet finding mode.

Data Sharing Scheme



- Each Jet Leaf Card Serves 3 Regional calorimeter crates or 1/3 of half Barrel calorimeter (forward calorimeters have been included as edges of the barrel).
- Each Leaf Searches for Jets using a 3x3 region sliding window and then passes the data to the next one in the circle.

Commissioning and testing without Beam (CMS Example)

- Install, integrate trigger chain and connect TTC system.
- **Pattern testing:** Propagate known patters from the Trigger front end all the way to HLT and DAQ.
- **Take cosmic ray (CR) runs.** Trigger using the muon detectors (RPC,DT,CSC) However be aware that CR do not come synchronously with the clock and do not necessarily go through the interaction point where the muon systems are optimized to trigger.
- Raw rate should be ~ 2 KHz for muon momentum above 10 GeV. This should decrease a lot after trigger efficiency for CR is folded in.

- **Goals:** (a) Exercise and validate the data taking system.
  (b) Establish coarse synchronization.
  (c) Start aligning the detectors.

- Almost no Level-1 cuts; HLT runs Level-1 simulation to validate the Level-1 trigger; Muon reconstruction at HLT but no momentum cuts.

Pilot Run 2007 (I)

Expected settings:

Beams/Collisions with 1x1 → 43 x 43 → 156 x156 bunches at maximum,

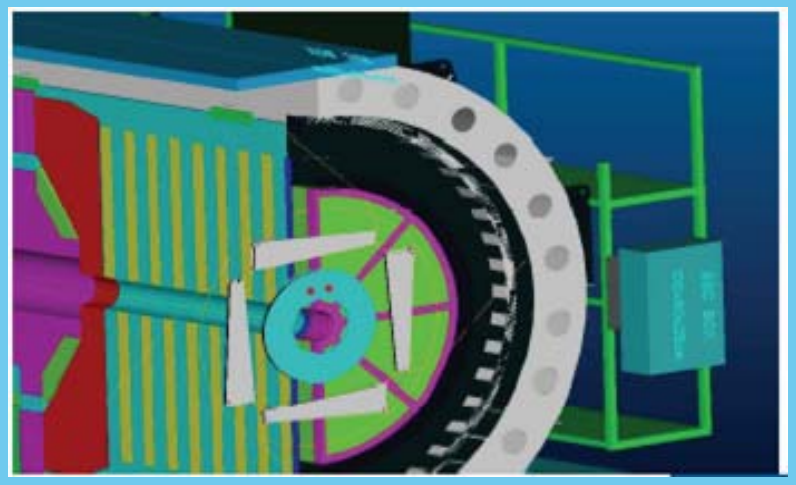
$E_{beam} = 450$ GeV , $\sqrt{s} = 900$ GeV collisions

$\mathscr{L} = 1 \cdot 10^{29}\ cm^{-2}s^{-1}$ $\times \sigma_{total} \approx 40mb$ $\Rightarrow$ 4 kHz

$\mathscr{L} = 1 \cdot 10^{30}\ cm^{-2}s^{-1}$ $\Rightarrow$ 40 kHz (at very max)

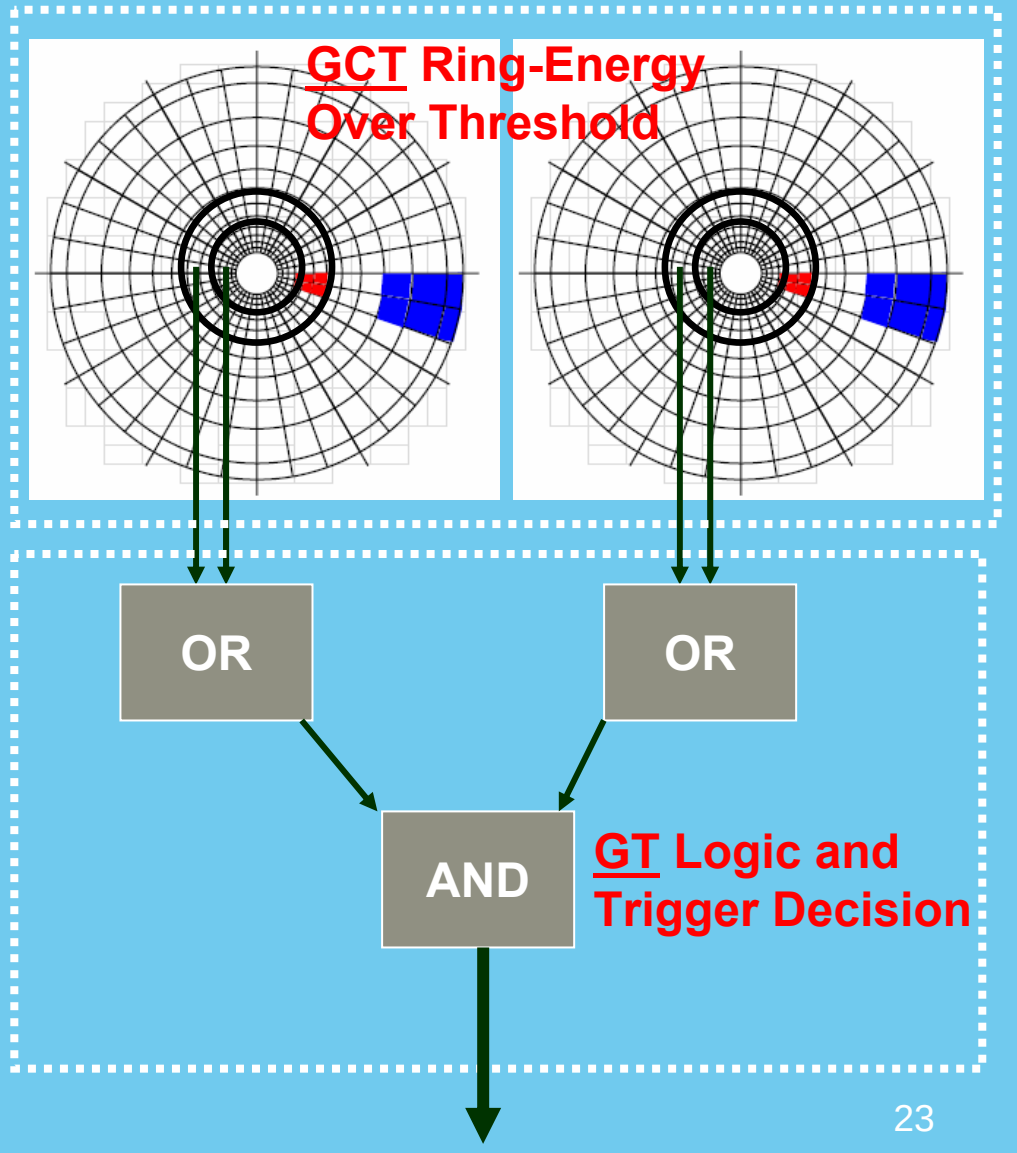
- **Need triggers to 'see' the beam (minimum bias triggers) and there is plenty of ideas:**
  - **(1) ATLAS will be triggering using scintillators located in front of the ATLAS end-caps (10 KHz)**
  - **(2) Random Level-1 triggers at 1% level.**
  - **(3) CMS will be using the OPAL scintillators mounted at the HF + energy/Et over threshold from the first 2 rings around the beams pipe from both sides in coincidence.**

Pilot Run 2007 (II)



OPAL Scintillators

- Simple Activity Triggers
- Useful for:
  - (a) Commissioning
  - (b) Calibration (may be)
  - (c) Alignment



Pilot Run HLT

- **CMS: Minimum selection at Level-1.**
- **CMS:Validate Level-1 Triggers using the Level-1 emulators running in HLT. Migrate algorithms to Level-1 as soon as they are understood.**
- **CMS:Main rate reduction at HLT.**
- **CMS (CSC) +ATLAS: Halo Muons for alignment.**
- **ATLAS: Activity HLT trigger based on tracking, calorimeter and scintillators.**
- **ATLAS: Muon (5 GeV) OR Calorimeter (10 Gev e/gamma) OR Jet (25 GeV)**

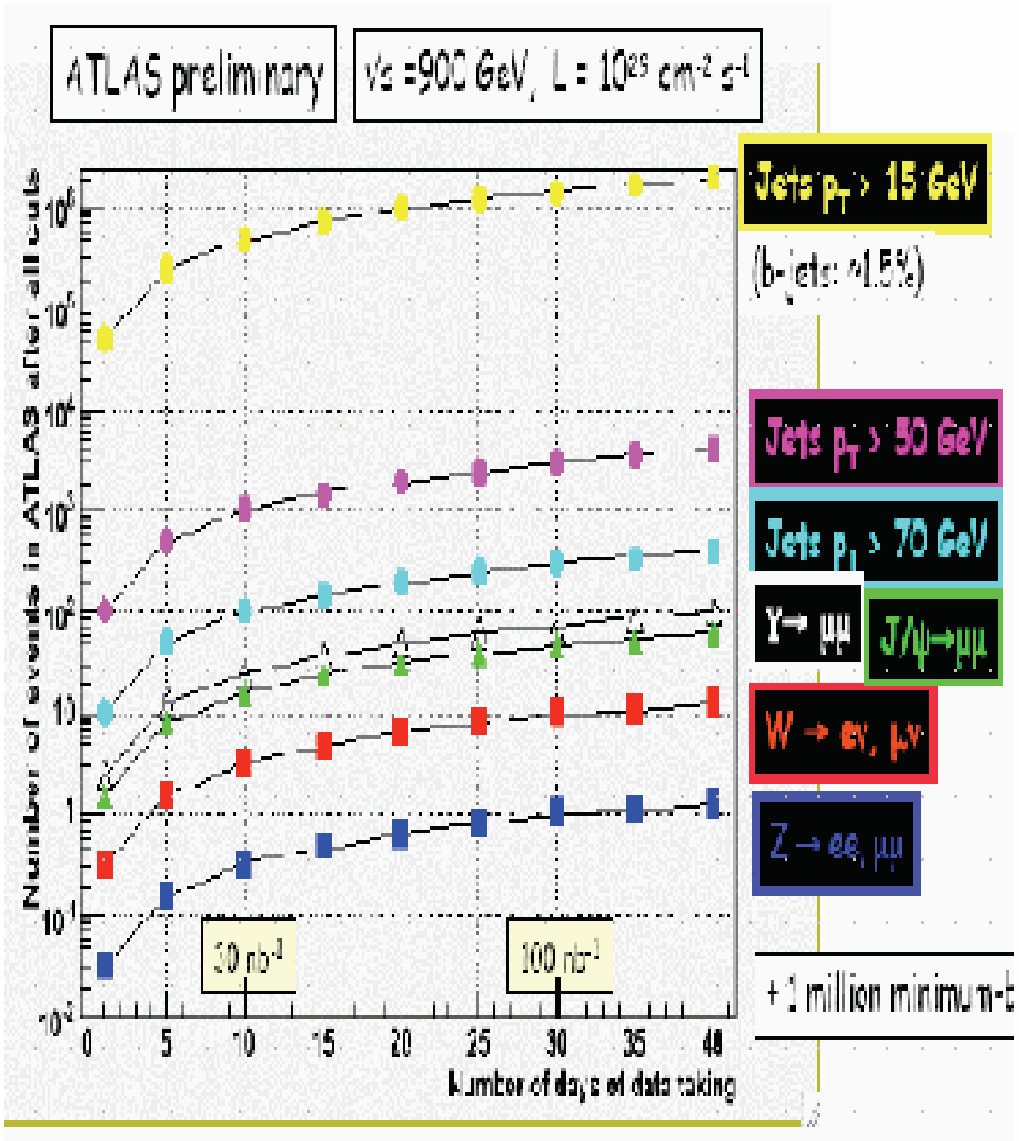
What do we expect to gain from the 2007 Pilot Run (I)

- **To gain the first experience with LHC beams validate as much as possible the detectors and prepare for the 2008 Physics run.**
- **Some calibration studies may be possible from phi-symmetry**
- **However, we should also see (CMS):**

"Standard Channels" in the Tracker Acceptance

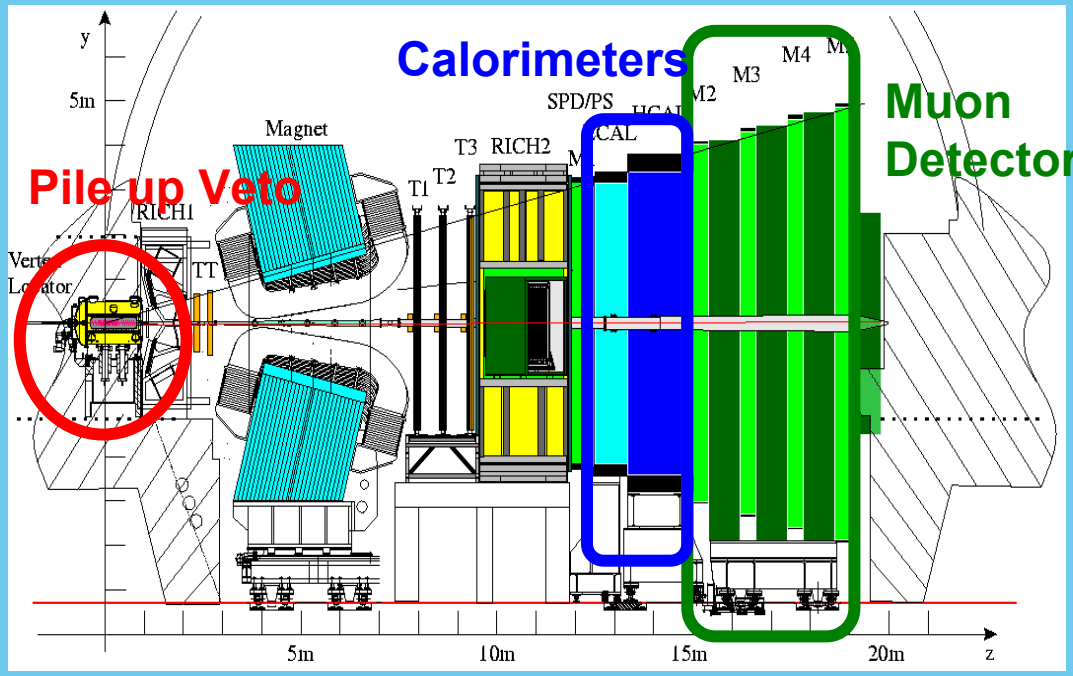
- $\sigma(W) \times BR(W \to \mu\upsilon) \approx 8\ \text{nb} \times 10\% = 800\ \text{pb}$
- $\sigma(Z) \times BR(Z \to \mu\mu) \approx 2\ \text{nb} \times 3\% = 60\ \text{pb}$
- after $100\ \text{nb}^{-1} \Rightarrow 80\ W \to \mu\upsilon$ & $6\ Z \to \mu\mu$, produced in Tracker acceptance
  - Should not be a problem for triggering, (efficiency?), but cannot be used for the alignment purposes
- $J/\psi \to \mu\mu$ ($p_T^{J/\psi} > 5$ GeV) $\approx 10\ \text{nb} \times 100\ \text{nb}^{-1} \approx 1\text{k}$

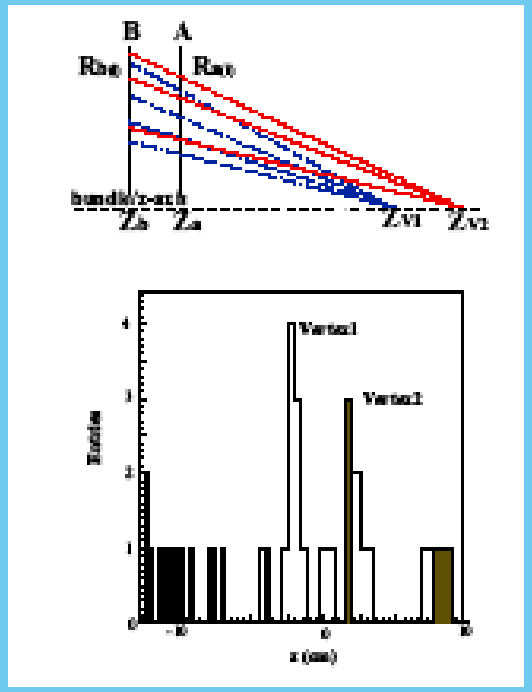
Event rates for the 2007 Run



- **We should be able to time the detectors.**
- **Validate detector and data taking concepts**
- **A course alignment will be possible.**

LHCb Level-0 Decision





- **Selects high Pt particles.**
- **Level-0 decision derived from calorimeter, muon and pileup veto information: 10 MHz➔ 1 MHz (@ 10^{32})**
- **Pile-up Veto removes crossings with multiple vertices.**

LHCb plans: Pilot run 2007

- Goal: Select single High-Pt particles.
- Start selection using the hadronic calorimeter to select clusters with High-Pt.
- Trigger rate = 50 – 100 Hz
- The data will be used for:
  - (a) Timing alignment
  - (b) Detector main alignment with B-field= off
  - (c) Turn on Magnetic Field and test E/p (RICH)
  - (d) Test Velo with Magnetic Field off and validate impact parameter algorithms

Plans for 2008 Physics Run I

- **LHCb**: At 10^{31} LHCb is almost an order of magnitude away from the target Luminosity ($2x10^{32}$).
- 15% of all Level-0 triggers are overlapping → excellent for computing trigger efficiencies and understanding the algorithms.
- With 35 Kbytes/event LHCb will be writing 2 KHz on disc.
- $\mathbf{B_S \rightarrow \mu^+\mu^-}$ need 0.5 fb^{-1}
- $\mathbf{J/\Psi \rightarrow \mu^+\mu^-}$ can write 300 Hz which are 50% pure and are excellent for momentum and impact parameter calibration
- Out of 1 MHz Level-0 rate there should be 600 Hz **D*** good for calibrating the RICH.
- Exclusive triggers (**$B \rightarrow hh$, $B \rightarrow D_S h$, $B \rightarrow \mu^+\mu^-$**) can be activated.

Plans for 2008 Physics Run

- **ATLAS+CMS**: At 10^{31} commissioning of the LHC algorithms can be tried.
- Algorithm cuts will be relaxed.
- Level-1 Rate will be up to 50 KHz.
- Redundancy between triggers will be used to compute the trigger efficiency using data.
- 200 Hz 'on tape'
- Emphasis: To understand the Trigger and the detector at LHC running conditions.

LHC Trigger Overview

- The LHC experiments are gearing up for the first data. Preparations of almost two decades come to a conclusion and I am sure it will be a very exciting time.
- However, the trigger and DAQ systems at LHC are orders of magnitude more complicated than before but also more sophisticated producing samples of purity not seen before.
- Understanding the first samples will not be easy, it will take time and requires a methodical and systematic approach.
- But you can be sure that he who understands his detector first will be closer to discovery using the data after 2008.