High Level Trigger(s): Introduction

Paris Sphicas
CMS Initiators' Meeting
March 11, 1999

Introduction: Technical Stuff

- Main parameters/issues
- Processor Farm

Software Architecture for HLT

- Reconstruction & HLT

HLT: Current Thinking

- Architecture
- Work done so far
- Suggestions for priorities
- Program of Work

Summary

Main parameters/issues

HLT: Overview (I)
HLT: Overview (II)
HLT: Overview (III)
HLT: Ultimate Goals
Current Technologies: Gb/s links

HLT: Overview (I)

Rejection > or ≈ same as Level-1 Trigger

- **Level-1: 40 MHz $\rightarrow$ 75 kHz $\Rightarrow$ accept ≈ 1:500**
- **Level-2/3: 75 kHz $\rightarrow$ 100-75 Hz $\Rightarrow$ accept ≈ 1:750**
  extra complication: physics content higher

No special Level-2 Trigger

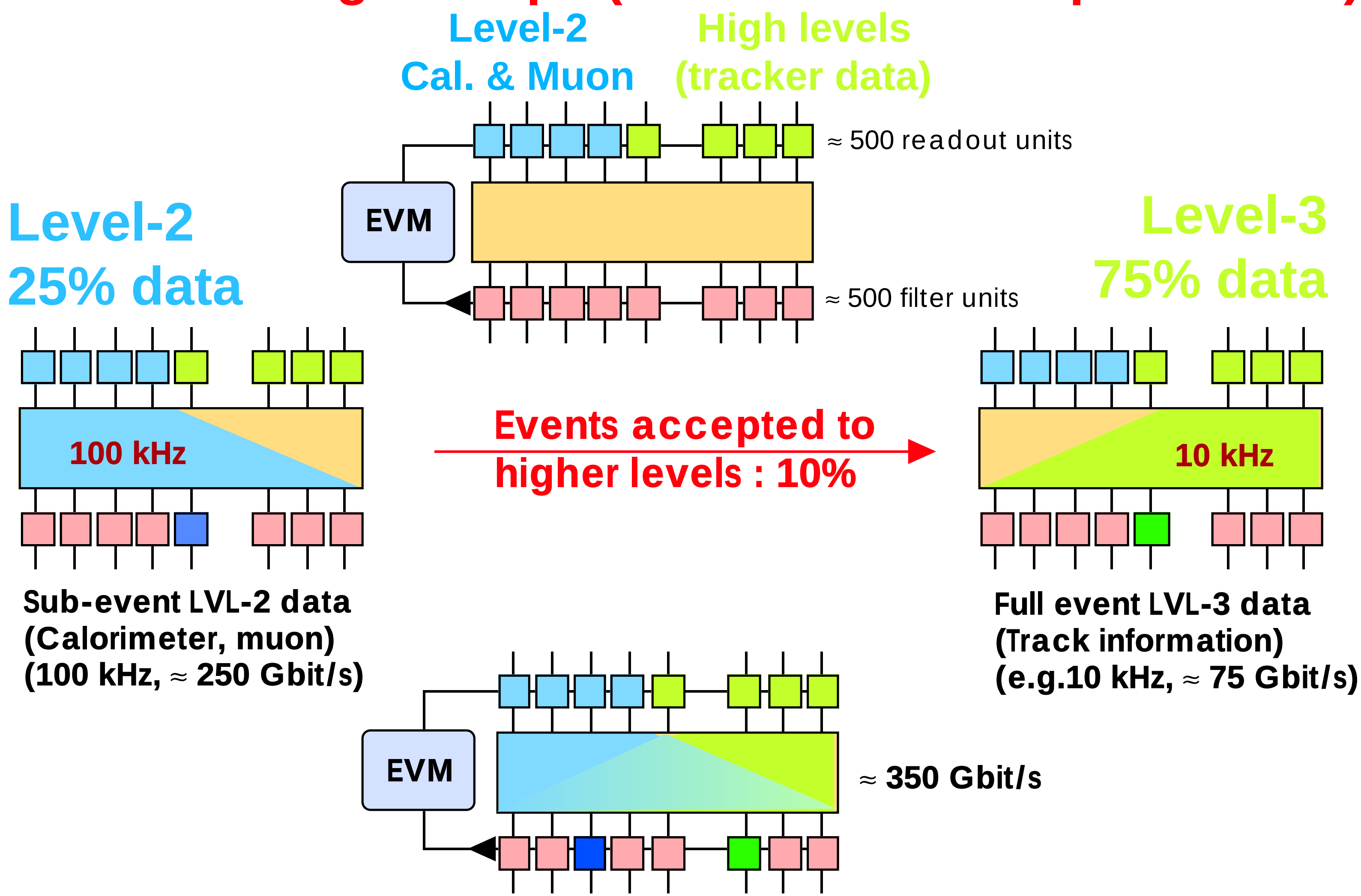
- **Level-2, Level-3, ..., Level-N in processor farm**
- **Technically: HLT depends on/requires things from:**
  Data Acquisition System
  Offline (reconstruction) software

Other external parameters:

- **Work on HLT must be ready by DAQ TDR (2001)**
- **Work complete once details of readout incorporated**
- **Technology extrapolation/code optimization**

HLT: Overview (II)

Both Level-2 & Level-3 Triggers in processor farm;
Event Building in steps (reduce switch requirements)

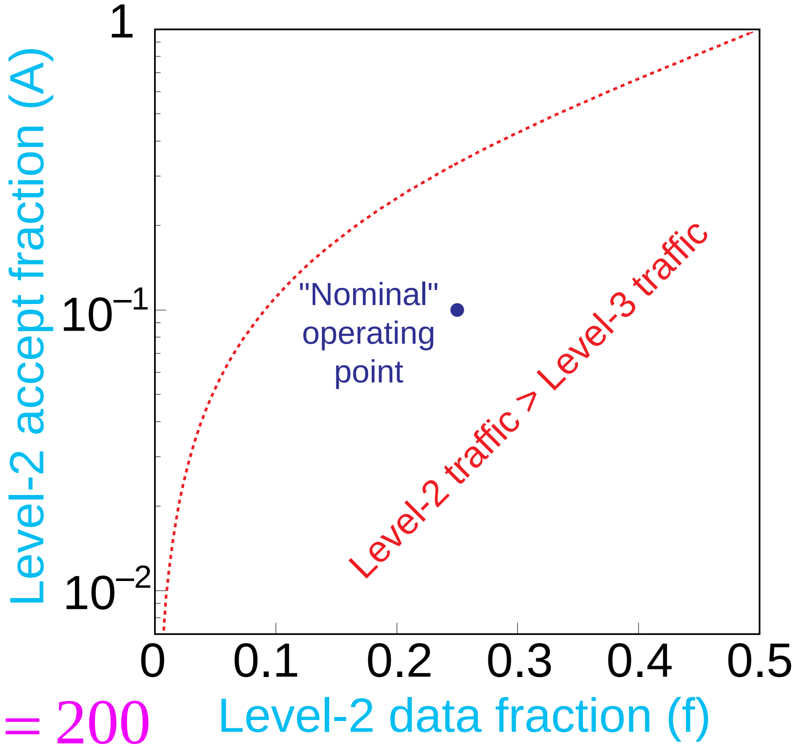


HLT: Overview (III)

Parameters determining the number of switch ports (N):

Event Size	(S)	1 MB
Rate	(R)	75 kHz
Link speed	(v)	1 Gb/s

$$N = \frac{SR}{v} = 75 \times 8 = 600$$



Above holds for single-step Event-Builder (all data into processor). In the presence of a Level-2 rejection

Data fraction	(f)	0.25
L2 accept	(A)	0.1

$$\left.\begin{aligned} N_2 &= f\frac{SR}{v} = 150 \\ N_3 &= (1-f)A\frac{SR}{v} = 45 \end{aligned}\right\} \Rightarrow N = N_2 + N_3 = 200$$

Level-2 traffic dominates

HLT: Ultimate Goals

Issues for HLT:

Readout

Physics

- Basic Unit of Information (parton model) of CMS readout
- Tradeoff(s) between small data access and efficiency of the data transfer: small blocksizes $\rightarrow$ low efficiency
- Depending on link utilization efficiency, may have a pre-Event Building step $\rightarrow$ need a hadron model of CMS readout
- Implementation of Level-2 algorithms; resulting rates
- How many trigger levels? (Could have continuum...)
- Amount of information needed by Levels 2 and 3
- Selection criteria for what ends up on tape

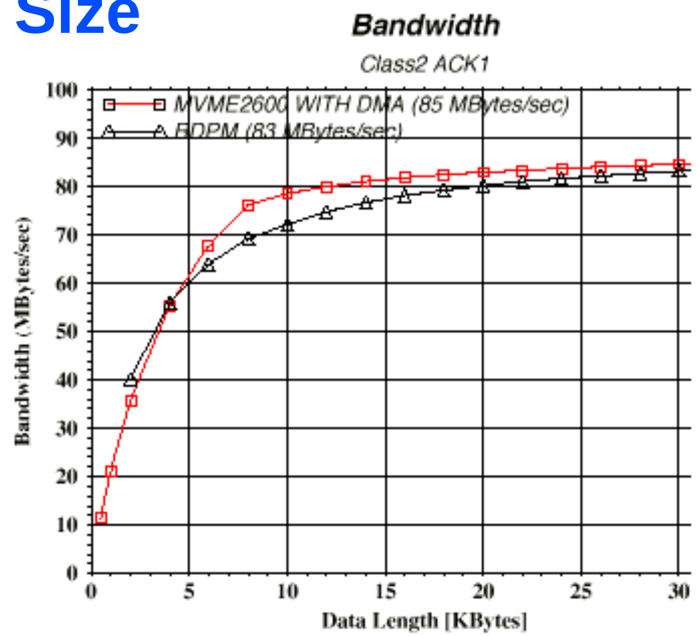
Current Technologies: Gb/s links

Link speeds valid only for data transfer

- **sustained speed depends on block size**
- **CMS: 400 ports; 1 MB event Size**
  - **⇒ blk_Size ≈ 2-3 kB**

$$\frac{\Delta s}{v_{eff}} = \Delta t = \Delta t_O + \frac{\Delta s}{v_{link}}$$

$$\therefore v_{eff} = \frac{v_{link}\Delta s}{\Delta s + v_{link}\Delta t_O}$$



Typical protocol/switch

latency ≈ 10-20 μs. At v_{link} = 1Gb/s, $1/v_{link} \approx 8\mu s/kB$

⇒ At blk_Size=2 kB, protocol overhead ≈ data transfer

Then: add software overheads, setup times, etc...

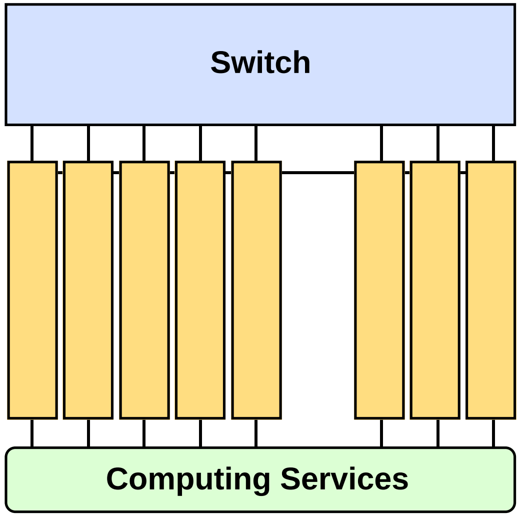
Effective speed @ 2kB ≈ factor 4 smaller than link speed

Processor Farm

Processor Farm Architectures
Level-2/3 CPUs: platforms
Processor Farm: plan

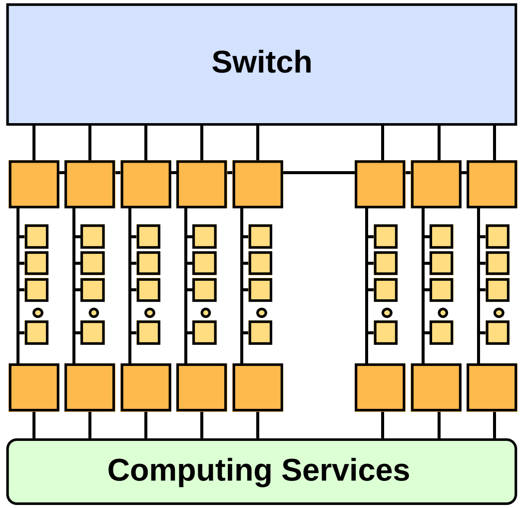
Processor Farm Architectures

Multi-CPU solutions (e.g. SGI Origin 2000, DEC 8200, etc...)



Lvl-3 Farm

PC/Workstation sub-farm on each switch output



Cost of
Origin 2000 : Origin 200: P6-based CPU:
≈ 5 : 2 : 1
(i.e. Decision may be made for us...)

Level-2/3 CPUs: platforms

CDF farm in Run I:

- 32 R4400/(200 MHz, 4MB L2) processors
- 0.57 CPU-sec/evt

On CDF code:

- dual-P6 (200 MHz, 256k L2) = 2.5 x R4400
- R10000 (180 MHz, 1MB L2) = 2.5 x R4400

Run II @ 300 Hz Level-2 output:

- Requires ~ 140 R10K or ~ 280 P6
- Expect that cutting-edge SGI/Intel CPUs are a factor 1.5–2 faster by Summer 1999

Platforms:

- SGI Origin 2000: ≤ 128 R10K/R12K processors
- SGI Origin 200: ≤ 4 R10K/R12K processors
- SGI Challenge: no plan to support new chips
- Intel Pentium 1-2 processor commodity PCs

Expandability:

- Either Origin 2000 or
- Many boxes per sub-farm

Processor Farm: plan

Processor Farm: in all 4 LHC experiments

- **Ideal example of a (possible) "common project"**
- **Had first meeting with CERN-IT**
  - presentations from CMS, ATLAS, IT
  - agreed to work on "PEP" to present to LCB
- **Issues for a common project:**
  - management of ~ 1000 processors
  - infrastructure (Operating System, etc...)
  - farm control and monitoring
  - networking...

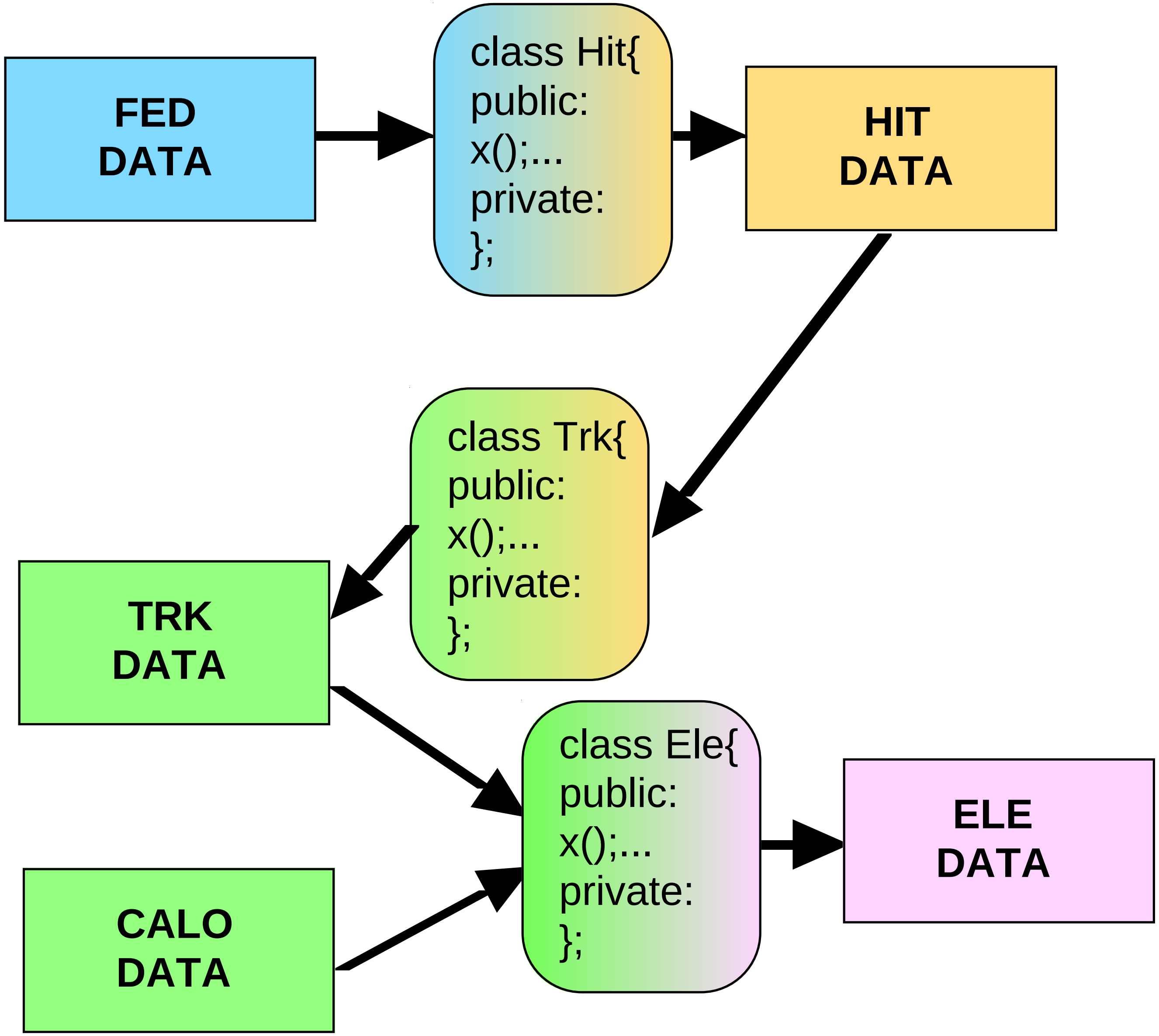
Action:

- **Working towards a final project definition for LCB**

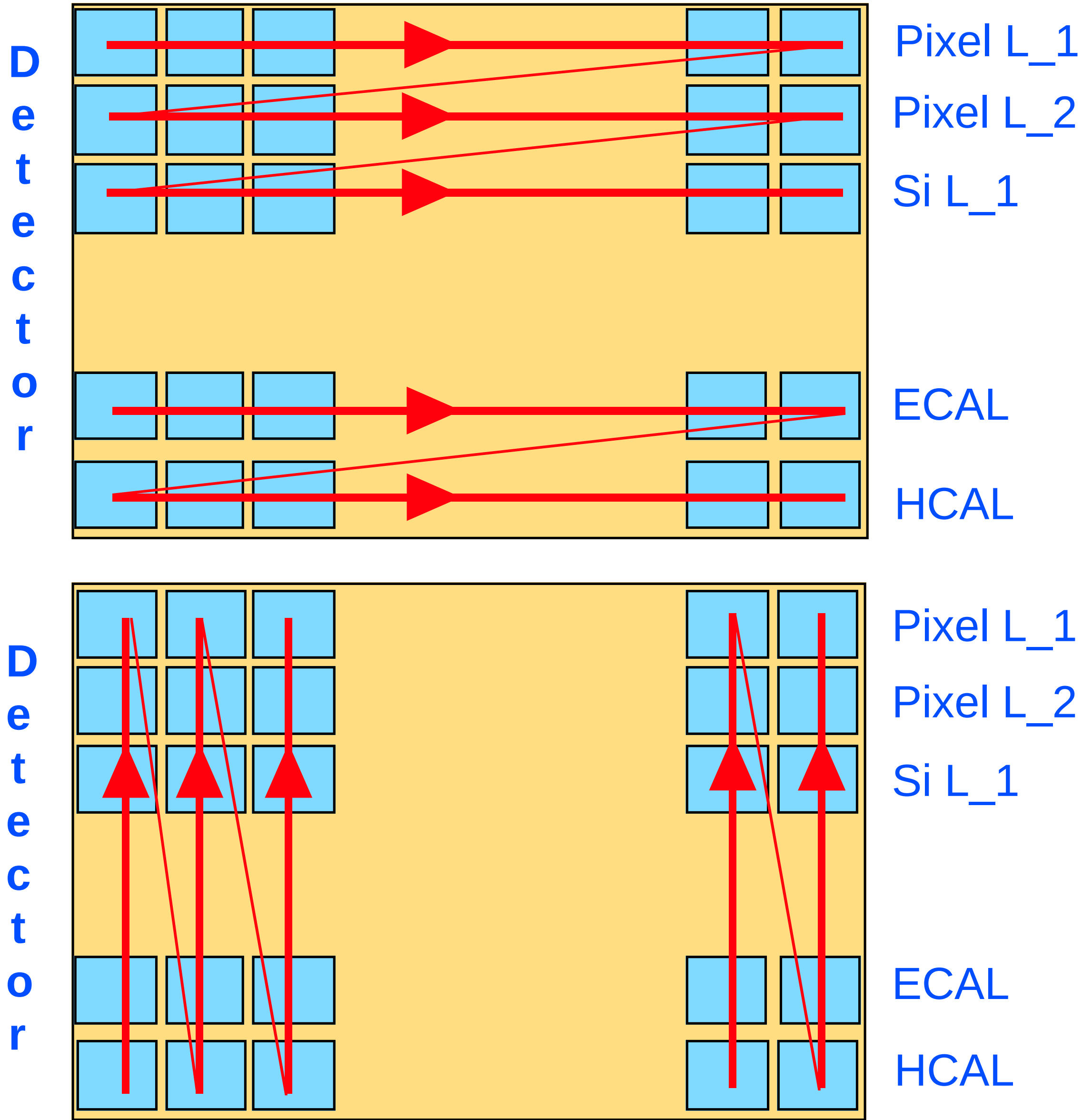
Reconstruction & HLT

(Typical) Electron Reconstruction
Global vs Regional reconstruction
Regional Reconstruction
Regional Reco: Implications

(Typical) Electron Reconstruction



Global vs Regional reconstruction



Global

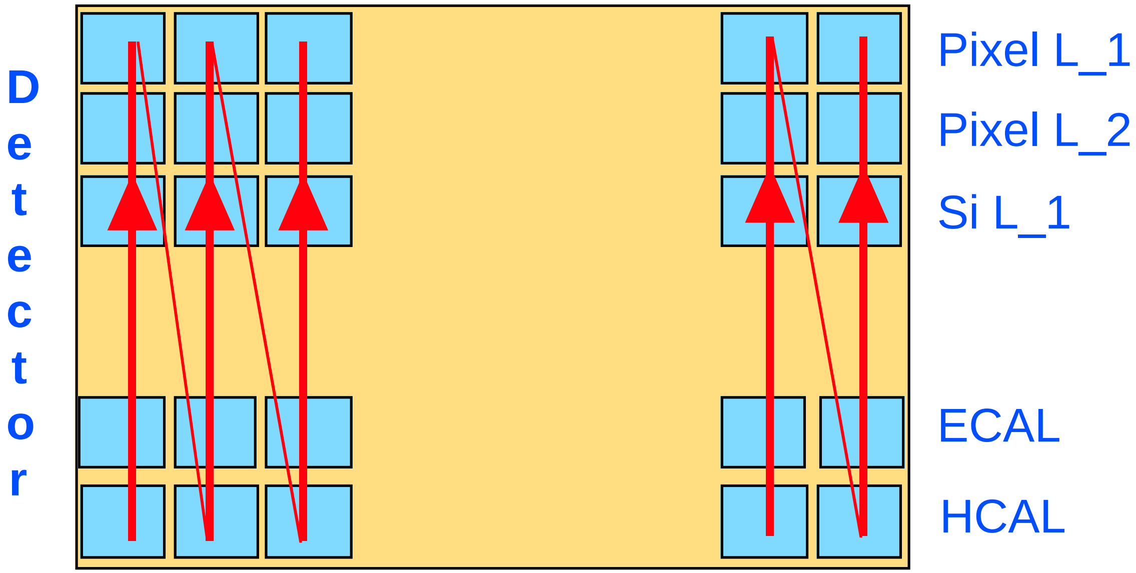
- process (e.g. DIGI to RHITs) each detector fully
- then link detectors
- then make physics objects

Regional

- process (e.g. DIGI to RHITs) each detector on a "need" basis
- link detectors as one goes along
- physics objects: same

Regional Reconstruction

For this to work:
need to know where to start the reconstruction (seed)



For this to be useful:
(a) horizontal slice(s) should be narrow
(b) there should be few slices

Seeds (from Lvl-1):
1. e/γ triggers: ECAL
2. μ triggers: μ sys
3. jet triggers: E/H-CAL

Seeds ≈ absent:
1. Other side of lepton
2. Global tracking
3. Global objects
   (Sum E_T, Missing E_T)

Side effects:
1. No volunteers
2. Need more online monitoring of what is happening

Regional Reco: Implications

Measuring Level-3 efficiency:

Must design system so that actual Level-3 code (that ran on any single event) is run-able off-line

This *should* lead to

better understanding/debugging

and it should also

add burden to calibration/constants databases

⇒ Requirement to off-line software:
Design database and reconstruction code so that Level-2/3/... (a "shell") is run-able off-line, at any point in time (much, much later...)

Architecture

Top-level flow
Rejection Factors
Flow Chart: from Lvl-1 to Lvl-2
Level-1 Rates
Level-2 Verification
Tracking in HLT
Deliverables

Top-level flow

Steering:

- We get Lvl-1 trigger information
- Ask for detector data from Lvl-1 OR
  ask for detector data in extended Lvl-1 area
- FETCH data
- Run Lvl-2.x algorithm
- IF (GOOD) calculate what data we should bring in next
- Loop until reject or final ok

Rejection Factors

Level-1 Verification

- Sharper threshold, better resolution
- Will also be needed for monitoring anyway
- Need it now (to develop algorithms need samples of events passing Lvl-1 trigger)

Lvl 2.1 step:

- Can one do more with the same data (or slightly enlarged area) that Lvl-1 uses without appealing to another data FETCH?

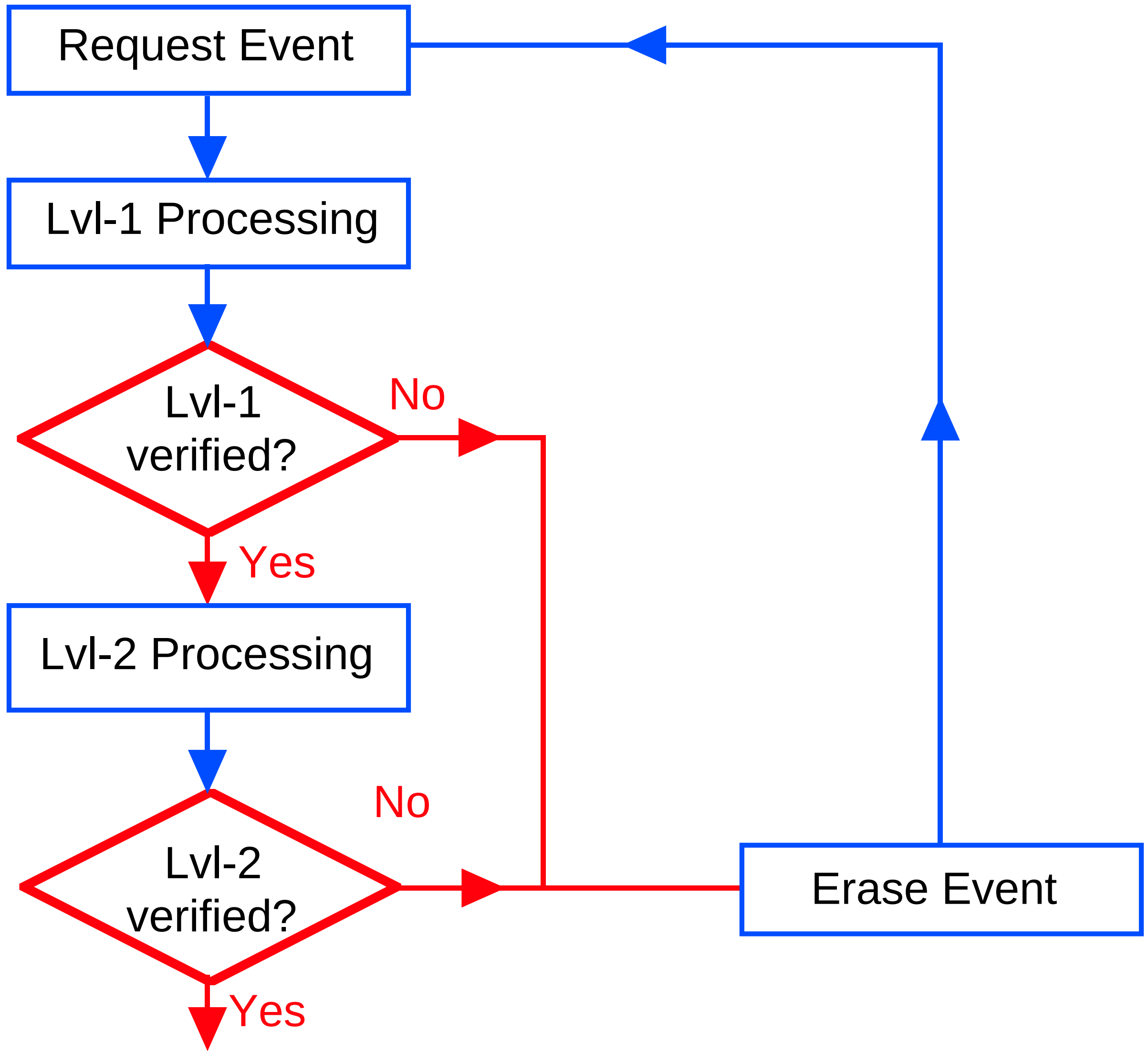
Lvl 2.2 — Lvl 2.9 steps:

- Various tracking jobs (e.g. tracks, primary vertex, inside-out or outside-in pattern recognition, etc etc)

Flow Chart: from Lvl-1 to Lvl-2

Step 1:
confirm Lvl-1 trigger decision, counting on higher segmentation, resolution

Step 2:
If data same as Lvl-1, request more...
If data more than in Lvl-1, fast algorithm...



Level-1 Rates

Calorimeter Trigger:

Heaviest Consumer: single and double e/γ trigger

Muon Trigger:

Heaviest Consumer: single and double μ trigger

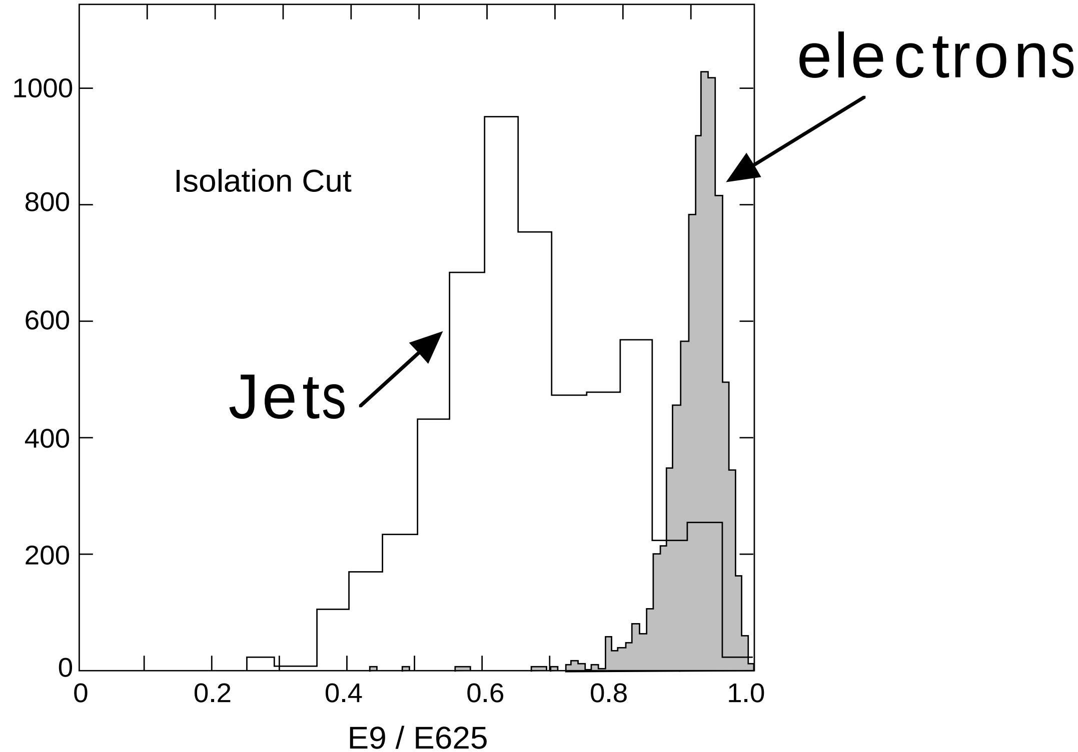
Seeds are easy; questions:

- Maximum rate reduction with calo & mu info only
- How much tracking info is needed
- How precise a tracking algorithm is needed?
- Can we survive without special HLT-only tracking reconstruction?
- If only calo/mu information, what are the implications on the physics? (e.g. mass cuts already @ Lvl-2?)

Level-2 Verification

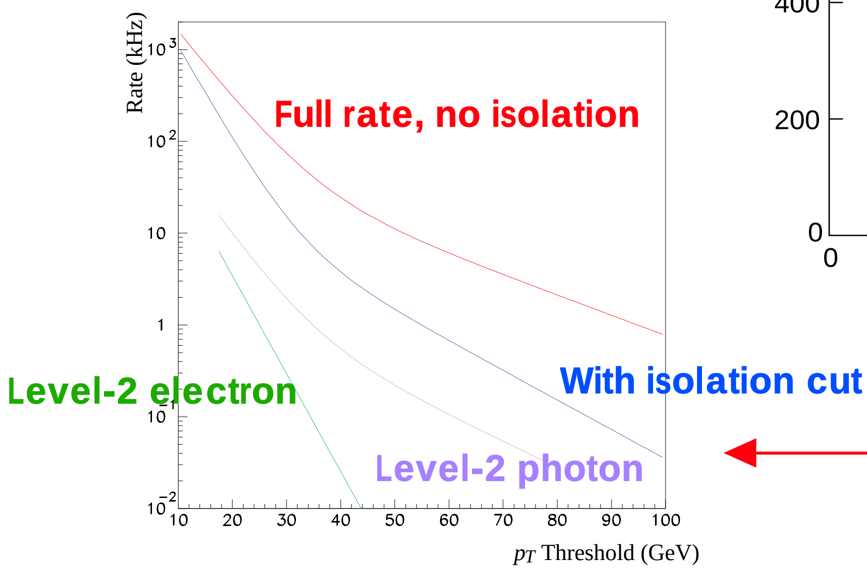
Example using only calorimeter information:

finer granularity, larger isolation area for electron ID at Lvl-2



Next (natural) step:

bring in tracker...



ATLAS Level-2 analysis

Tracking in HLT

Two types:

- **Seed-driven (e.g. ECAL)**

  Clearly, the best case; need geometrical extrapolation. May even have enough CPU for full track fitting, good E/p matching

- **"Blind"/global**

  Examples: $B^0 \rightarrow \pi\pi$, $B_s \rightarrow D_s\pi$ or D_sK
  The "nightmare" scenario? Needs a lot of work...

Deliverables

What the HLT work must deliver:

- A set of algorithms (software that works)
- For each algorithm, a specification of input trigger rate, output rate
- Efficiencies for channels affected by relevant object
- Measure of data needed by algorithm
- Breakdown in steps (can be only 2... can be 8-9)
- Perform so that required switch bandwidth reduced (because of HLT) by a factor $\approx$ 5

CMS TriDAS milestone:

- First results for "Lvl-2": October 99

Work done so far

WDSF
Electron/photon (I)
Electron/photon (II)
Electron/photon (III)
Muons (I)
Muons (II)
Tracking in HLT

WDSF

Currently working on

- **Inclusive electron and muon triggers**

  for both: major task is to generate the backgrounds

Requirements

- **We need to get full simulated background events, not just an estimate of the rates (so one can apply filtering algorithms beyond Lvl-1)**
- **For the time being: use CMSIM (115)**

  few exceptions (e.g. ECAL C++ reconstruction)
- **Clearly, tracker information will be used at some point. Current plan: get Lvl-2 rates using (a) detector-only quantities (e.g. calorimeter) and (b) using full offline track reconstruction. True Level-2 rates should be in between** (defines boundaries)

Electron/photon (I)

Get: probability per jet to pass Lvl-1 e trigger

- Bkg generation: double "jets", from PYTHIA two-parton generation, plus simple color connection; the standard PYTHIA parton shower + JETSET hadronization. Small trick (generate back to back) doubles statistics. No underlying event (can be added afterwards via the pileup mechanism; precision of this method adequate...)
- Push single jets through simulation (including Lvl-1)
- Measure efficiency for passing Lvl-1 vs E_t(part-jet)

Electron/photon (II)

- **Convolute $\varepsilon(E_t)$ with jet $d\sigma/dE_t$ (and multiplicity)**
  $\rightarrow$ get Lvl-1 accept rate

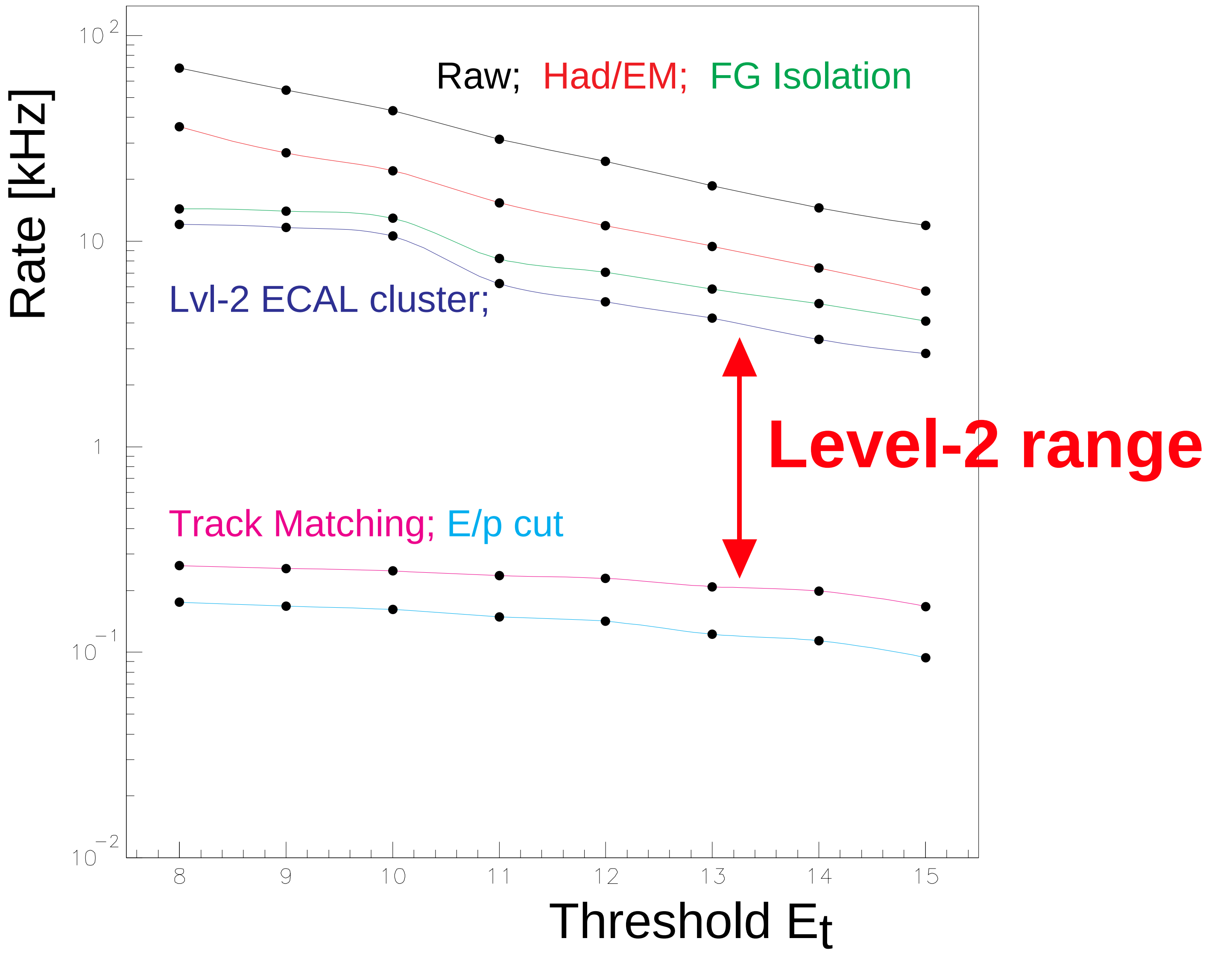
  Example: PYTHIA event with two jets with E_t^1 and E_t^2

  Define: $\varepsilon_i = \varepsilon(E_t^i)$; Probability to trigger = $\varepsilon_1+\varepsilon_2-\varepsilon_1\varepsilon_2$ etc...
- **Cross-check rates with previous Lvl-1 studies**

  (note: only BARREL so far)
- **Then:**
  - **cluster-finding using full granularity, resolution**
  - **full track reconstruction, match to ECAL cluster**

(work of E. Meschi)

Electron/photon (III)



Muons (I)

Problem: most muons are real

- **They may be non-prompt (e.g. $K \rightarrow \mu\nu$) but they are real**
- **Need to generate full events, that can be simulated afterwards, containing the correct mix of muon origins (e.g. heavy flavors, decays, $J/\psi \rightarrow \mu\mu$, etc...) and not just get rates**
- **Solution:**

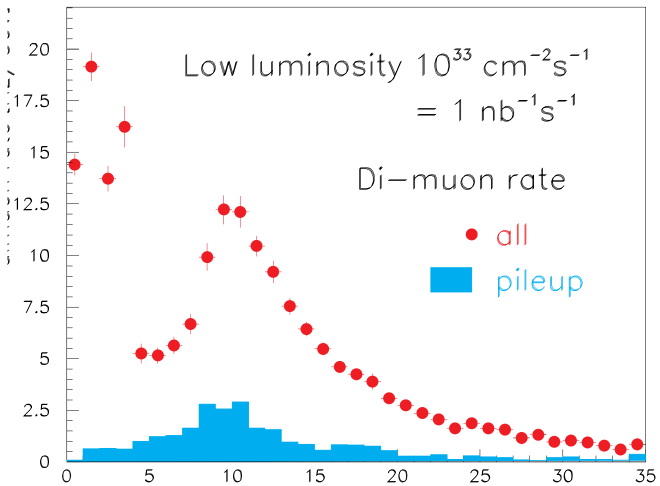
  (a) for each event generated by PYTHIA, look at set of final-state pseudo-scalar mesons (B, D, π, K, ρ, ...)

  (b) compute probability that a muon (passing acceptance requirements) will appear. "Force" this configuration, store event weight.

  (c) Then simulate event, Lvl-1 μ trigger, apply cuts...
- **Method extendable to any μ multiplicity (e.g. dimuons)** **(work of H. Rick)**

Muons (II)

Example: dimuon rate



Muon Sources

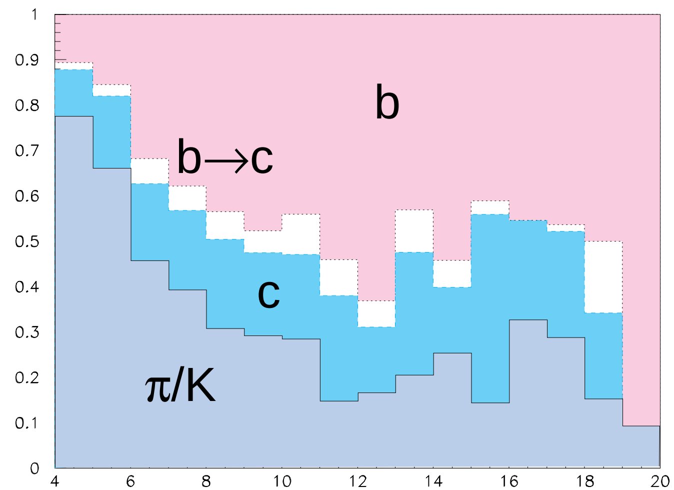
Muon sources

Decayed parents of muons at $p_T^{\mu} > 6\,\mathrm{GeV}$:

	$B^{\pm}$	B^0	B_s^0	Λ_b^0	$\Xi_b^{\pm 0}$	$\pi^{\pm}$	$K^{\pm}$	K_L^0
%	16.3	14.4	5.3	3.2	0.4	20.3	17.6	0.2
%			39.6				38.1	

	D^0	$D^{\pm}$	$D_s^{\pm}$	J/ψ	$\Lambda_c^{\pm}$	$\tau^{\pm}$	η	ρ^0
%	10.5	6.8	2.7	0.9	0.4	0.8	0.1	0.1
%			21.3				1.0	

Heaviest parton in decay history (rel. contributions):



Tracking in HLT

Issue: how much tracking info needed?

- **Regional algorithms: given seed (e.g. e, μ at Lvl-1) determine road in tracker that should contain hits from the (particle's) track. Ongoing work (MSGCs ok)**

  (T. Monteiro)

- **Once road is identified, call on track reconstruction to find tracks using only detector modules in road**

  (S. Khanov, N. Stepanov)

- **Preliminary results:**

  (a) For electrons one should start from inner layers (e.g. pixels); tracker material $\rightarrow$ lots of radiation, so MSGC stubs don't help much

  (b) For muons, starting from outer detector layers (MSGCs) should be ok

- NOTE: advent of OO software may render this obsolete

Suggestions for priorities

Electron/photon
Muons
Jets
Tracking

Electron/photon

Status: most advanced

- Lvl-1 simulation ok (but need final ok from Wesley)
- Clustering ok; need to install in ORCA
- First π^0 rejection algorithms born couple weeks ago

Work:

- Endcap
- Tune/decide on "baseline" clustering, correctors, calo-only criteria
- Tune/decide on π^0 rejection algorithms
- What type of tracking? in$\rightarrow$out or out$\rightarrow$in

Muons

Status: in infant stage

- Lvl-1 simulation being worked on

  Claudio Grandi + Norbert Neuimeister

Work:

- C++ reconstruction of DT, CSC & RPC (ok for RPC?)
- Rates, quality of muon-only measurements
- System overlaps (coincidences etc)
- What type of tracking? in$\rightarrow$out or out$\rightarrow$in

Jets

Status: in embryonic stage

- Not even a baseline jet algorithm

Work:

- Clearly, everything.
- Big issue: verify that fixed-window algorithm planned by Lvl-1 is ok for physics (ATLAS and FNAL experience says no)

Tracking

Status: in various stages

- FORTRAN works (I ran it)
- C++: don't know

Work:

- Solidify the in-out vs out-in recipe
- Seeded (i.e. regional) tracking
- Non-seeded (blind) tracking (needed for B's)
- Can we make the quality of the tracking a parameter?
- Displaced vertices:
  - — for jets
  - — for secondary vert (e.g. K_s)

Program of Work

Phase I
Phase IIa
Guidelines

(Transparencies from June 98 HLT meeting)

Phase I

Background Generation:

Generate enough events

Push them through detector + Level-1 simulation

- **Calo rates**
  - Electrons/photons
  - Jets
- **Muon rates**
  - single and di-muons

Signal Generation:

Generate a few clean signatures (W, Z, b)

- **Effiencies of Lvl-1**

Outcome: confirm current Lvl-1 studies

Phase IIa

Offline (brute) analysis on bkg+signal

Get best-case signal efficiency

Get best-case bkg rejection

- **Work with offline group on reconstruction**
  - Electrons/photons
  - Jets
- **Muon rates**
  - Muon identification

In parallel: Lvl-1 verification algorithms

Outcome: best-case scenario, no reference to CPU concerns; real rate into Lvl-2 algorithm

Guidelines

Use OO:

- As much as possible
- But only if it makes sense... If something can *only* be done with FORTRAN, so be it...

New code:

- Regional to the greatest (possible) extent

Coordination of MC generations:

- Through frequent (every 2 weeks?) HLT meetings
- Grand get-togethers suring CMS weeks

Summary

1. It's a big job

2. HLT *must* be regional in nature

3. Background generation: method ok

4. Need: Understand Rates from Level-1
   $\rightarrow$ full Lvl-1 simulation x-check with previous results

5. Need: detector-only reco in ORCA
   $\rightarrow$ baseline algorithms, understand performance

6. Need: tracking