The ATLAS Trigger System

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on behalf of
the ATLAS collaboration

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    - Level 2 Trigger
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Physics Motivation

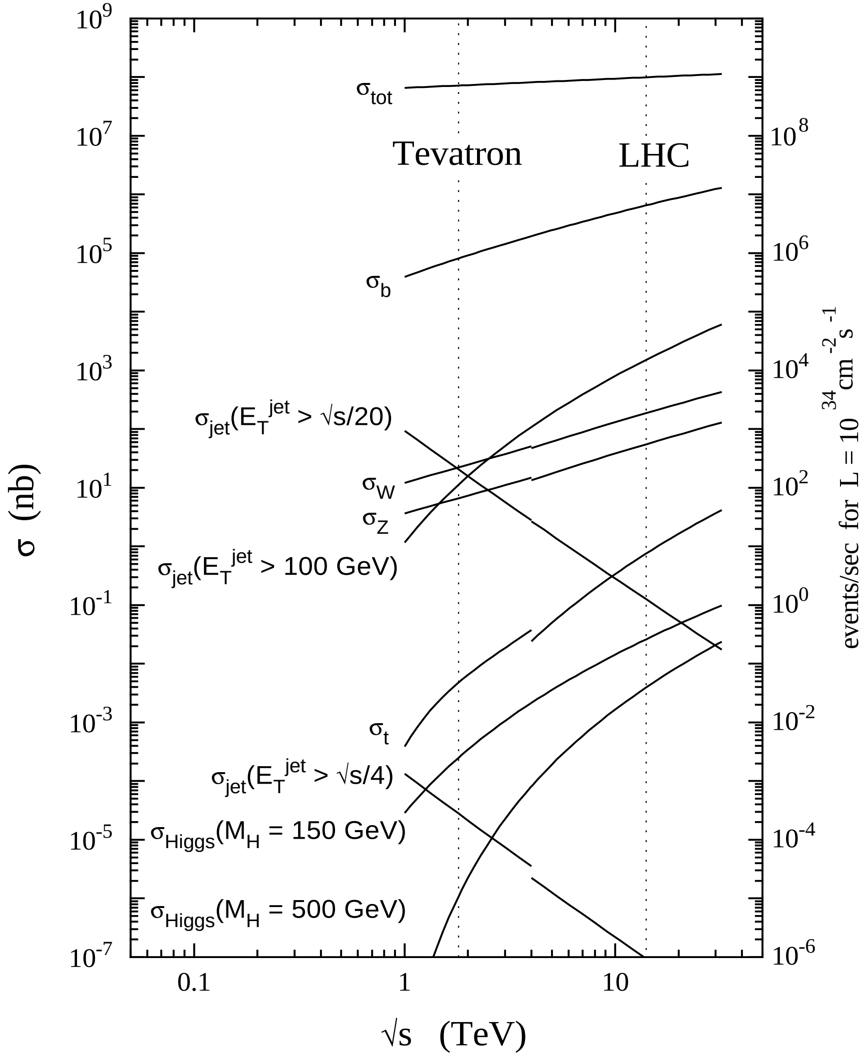
- **Electroweak symmetry breaking**
  - **Standard Model and supersymmetric Higgs etc.**
- **Precision measurements**
  - $\mathbf{m_t, m_W, \sin^2\theta^{eff}_{lepton}}$
  - **Triple gauge boson couplings**
  - **Constraints on new physics etc.**
- **New physics beyond the SM**
  - **SUSY, ED, compositeness, new heavy gauge bosons,...???**
- **b-physics**
  - **complement/extend B-factories**

Physics Motivation (2) : Trigger

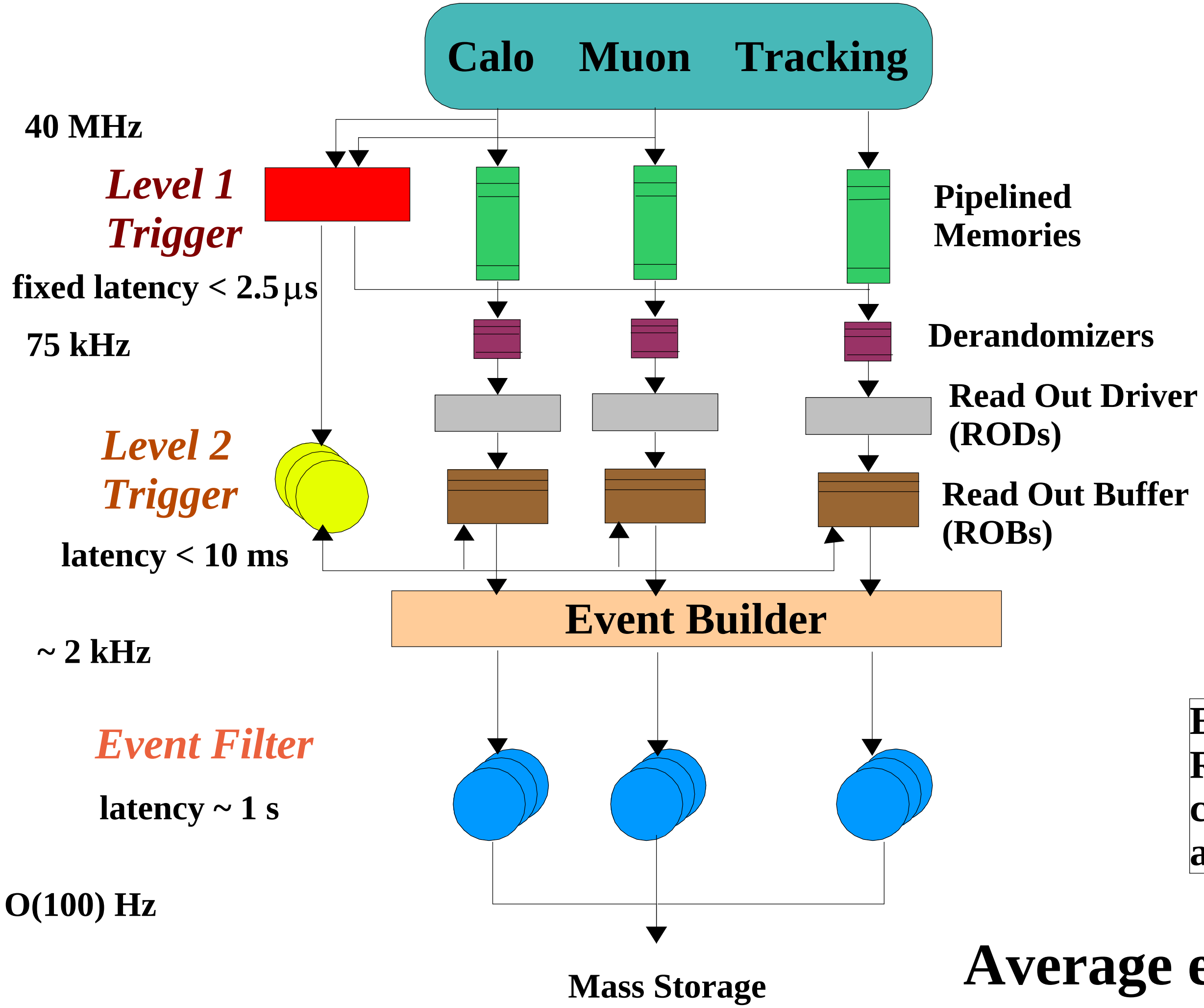
- **Mostly inclusive high p_T trigger selections with relatively low-p_T thresholds for fundamental objects (e.g leptons)**
  - **Cover all topologies expected from new physics.**
  - **Be sensitive to presently unknown new physics**
  - **Avoid biases from exclusive selections and/or topological criteria.**
  - **Ensure safe discovery overlap with Tevatron Run 2**
  - **Keep margin to refine/optimize selections offline with more powerful analyses and relax cuts for checks of systematics**
  - **Keep safety margin against uncertainties (e.g. QCD cross-sections)**

The Challenge

- **Bunch crossing rate of 40 MHz**
- **Design luminosity of $10^{34}cm^{-2}s^{-2}$**
  - **~ 23 interactions per crossing.**
  - **~10^9 interactions per second.**
- **Store to tape about O(100) Hz.**
  - **contains mostly physics signals,**
  - **vs. offline resources (storage media, reconstruction, reprocessing)**
  - **challenge: small signals**
    - **e.g. H -> γγ (m$_H$ ~ 120 GeV) rate is ~10^{-13} of LHC interaction rate.**
- **Trigger must be efficient, flexible and robust.**



Trigger System Overview



Level 1: coarse granularity calorimeter and muon trigger stations only

Level 2: full granularity data from all detectors; Regions of Interest (ROI) from Level 1 to reduce data access to ROBs (~2 % of full event)

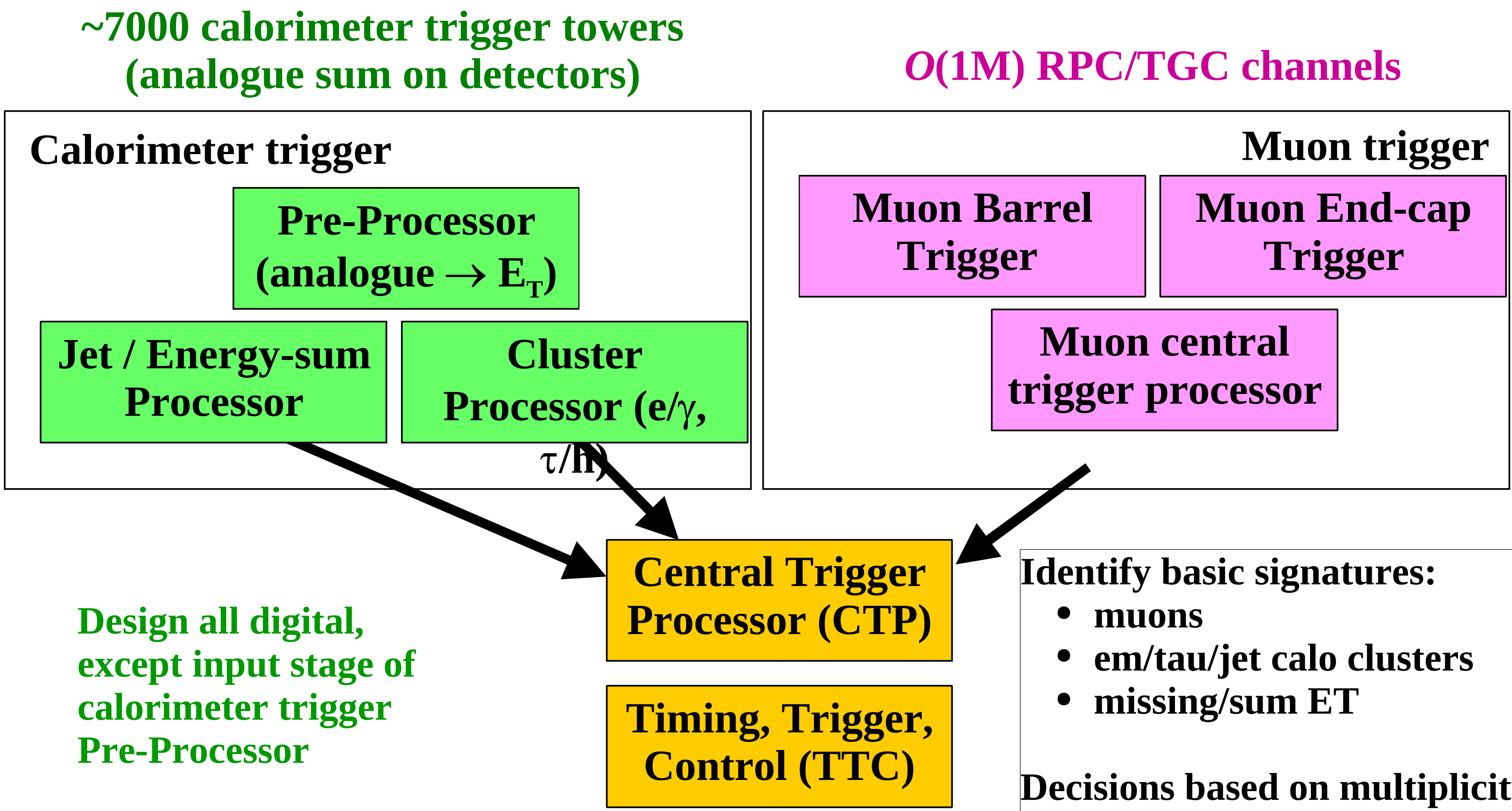
Eventfilter: access to full event data. Refine LVL2 selection; event classification; monitoring, best available alignment and calibration data;

Average event size: ~1.5 MByte

Examples of Physics Signatures

Objects	Examples of Physics Coverage	Nomenclature
Electron	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top	e25i, 2e15i
Photon	Higgs (SM, MSSM), extra dimensions, SUSY	γ60i, 2γ20i
Muon	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top	μ20i, 2μ10
Jet	SUSY, compositeness, resonances	j360, 3j150,4j100
Jet + missing ET	SUSY, leptoquarks	j60 + xE60
Tau + missing ET	Extended Higgs models (e.g. MSSM), SUSY	τ30 + xE40

Level 1 Trigger



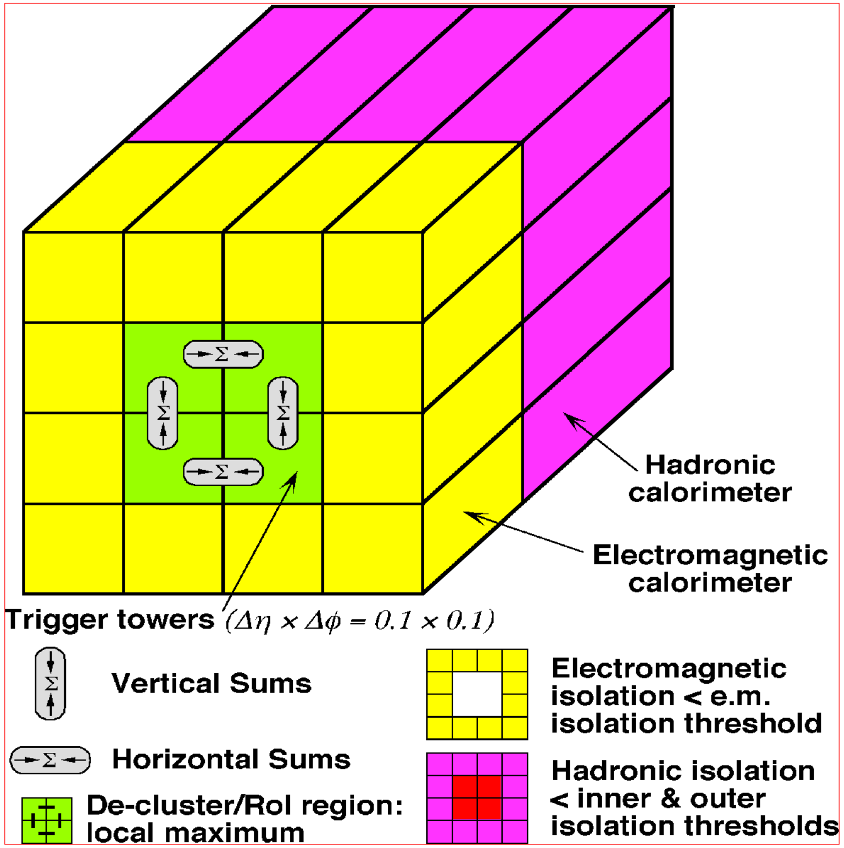
Identify basic signatures:
- **muons**
- **em/tau/jet calo clusters**
- **missing/sum ET**

Decisions based on multiplicity of trigger objects

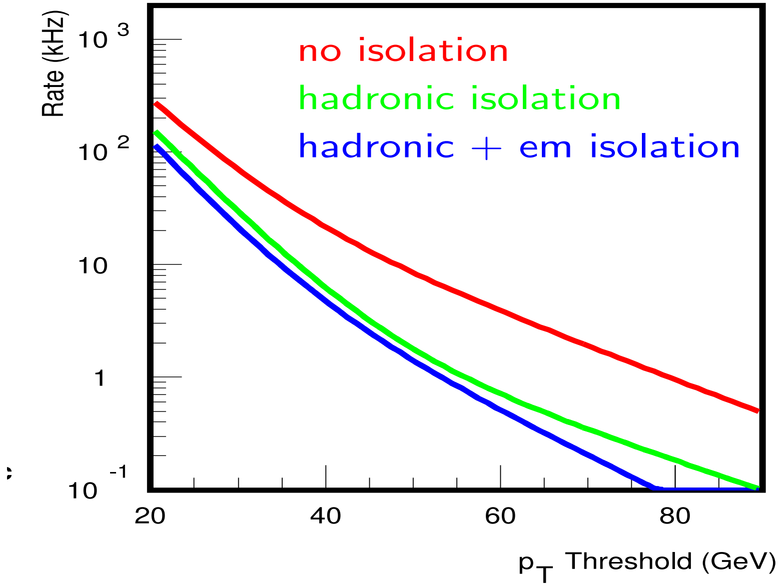
Programmable thresholds

Level 1 EM Trigger

Electron/photon Algorithm



Tau/hadron algorithm adds 1x2/2x1 e.m. clusters to 2x2 inner hadronic region. Isolation uses e.m. and outer hadronic 'rings'.

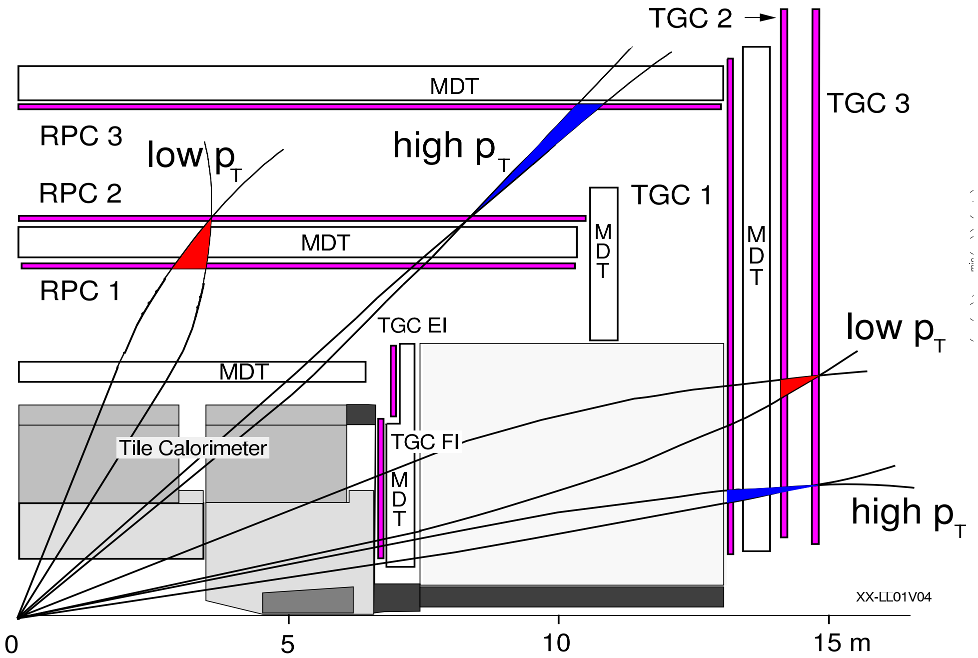


Inclusive EM trigger rate vs. p_T at 10^{34} cm^{-2}s^{-1}

To throttle rate: increase E_T thresholds.

Isolation criteria reduce rate by up to one order of magnitude.

Level 1 Muon Trigger



- RPC in barrel regions
- TGC in endcap regions

- Low p_T :
  - Require hits in 3 out of 4 layers in inner two stations.
- High p_T :
  - Require hits in 3 out of 4 layers in inner two stations.
  - Require hits in 1 out of 2 layers of the outer station (2 out of 3 in the endcaps)

The trigger logic is almost fully programmable; this flexibility will allow to optimize carefully the signal trigger efficiency vs the background rejection.

L1 Menu and Rates

Selection	High-p_T Thresholds	2 x 10^{33} $cm^{-2}s^{-1}$	10^{34} $cm^{-2}s^{-1}$
MU20	(20)	0.8	4.0
2MU6		0.2	1.0
EM25I	(30)	12.0	22.0
2EM15I	(20)	4.0	5.0
J200	(290)	0.2	0.2
3J90	(130)	0.2	0.2
4J65	(90)	0.2	0.2
J60 + xE60	(100+100)	0.4	0.5
TAU25 + xE30	(60+60)	2.0	1.0
MU10 + EM15I		0.1	0.4
Others (pre-scales, calibration, ?)		5.0	5.0
Total		~ 25	~ 40

Minimal trigger menu for 2 x 10^{33}, can be extended if resources available

Thresholds in GeV, rates in kHz, no safety factor included

High Level Trigger Overview

- Use simple inclusive high-p_T signatures.
  - Can do exclusive signatures in HLT if necessary.
- Level 2
  - Use seeding (ROIs) to reduce data access and processing time.
  - Reconstruct physics objects in stages by a sequence of algorithms requesting data as needed.
  - Reject early without executing the rest of the algorithms if not necessary.
  - Specialized Level 2 algorithms
- Event Filter based on offline reconstruction code.
  - Full event in memory
  - Refine Level 2
  - Event classification
  - Monitoring
- Common framework compatible with offline
  - Develop/Debug in offline environment
  - Flexible boundary between Level 2 and Event Filter.

HLT Menus

Selection	$2 \times 10^{33}\ cm^{-2}s^{-1}$	$10^{34}\ cm^{-2}s^{-1}$
Electron	e25i, 2e15i	e30i, 2e20i
Photon	γ60i, 2γ20i	γ60i, 2γ20i
Muon	μ20i, 2μ10	μ20i, 2μ10
Jets	j400, 3j165, 4j110	j590, 3j260, 4j150
Jet & E_T^{miss}	j70 + xE70	j100 + xE100
tau & E_T^{miss}	τ35 + xE45	τ60 + xE60
Muon & electron	μ10 + e15i	μ10 + e15i
b-physics	2μ6 with $m_B/m_{J/\psi}$	2μ6 with m_B

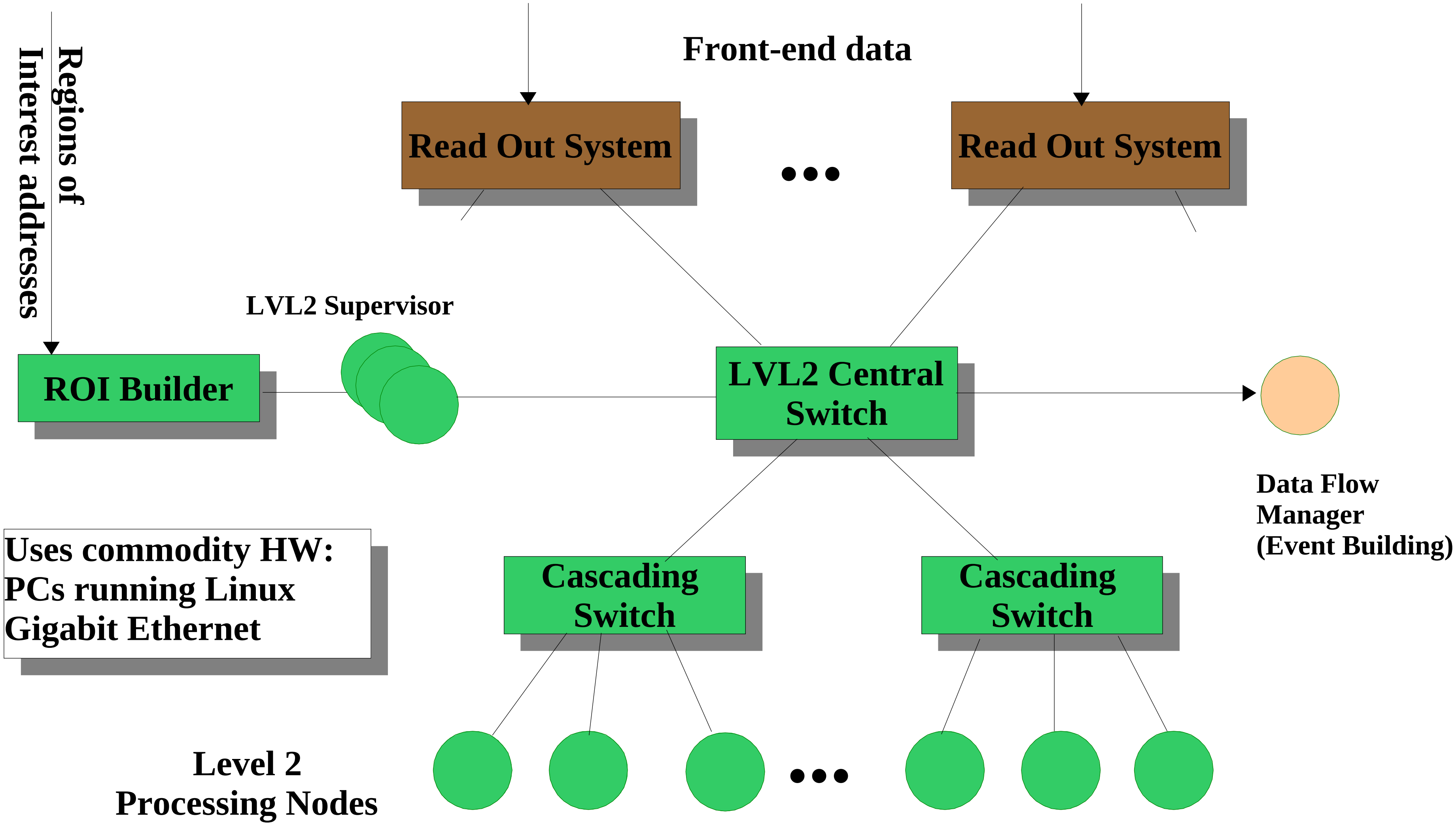
➠ **Concurrent optimization of**

- Physics performance (signal efficiency, background rejection)
- System performance (CPU execution time, data volume)
  - Rate x data size => bandwidth and/or storage size

Remark on Trigger Menu

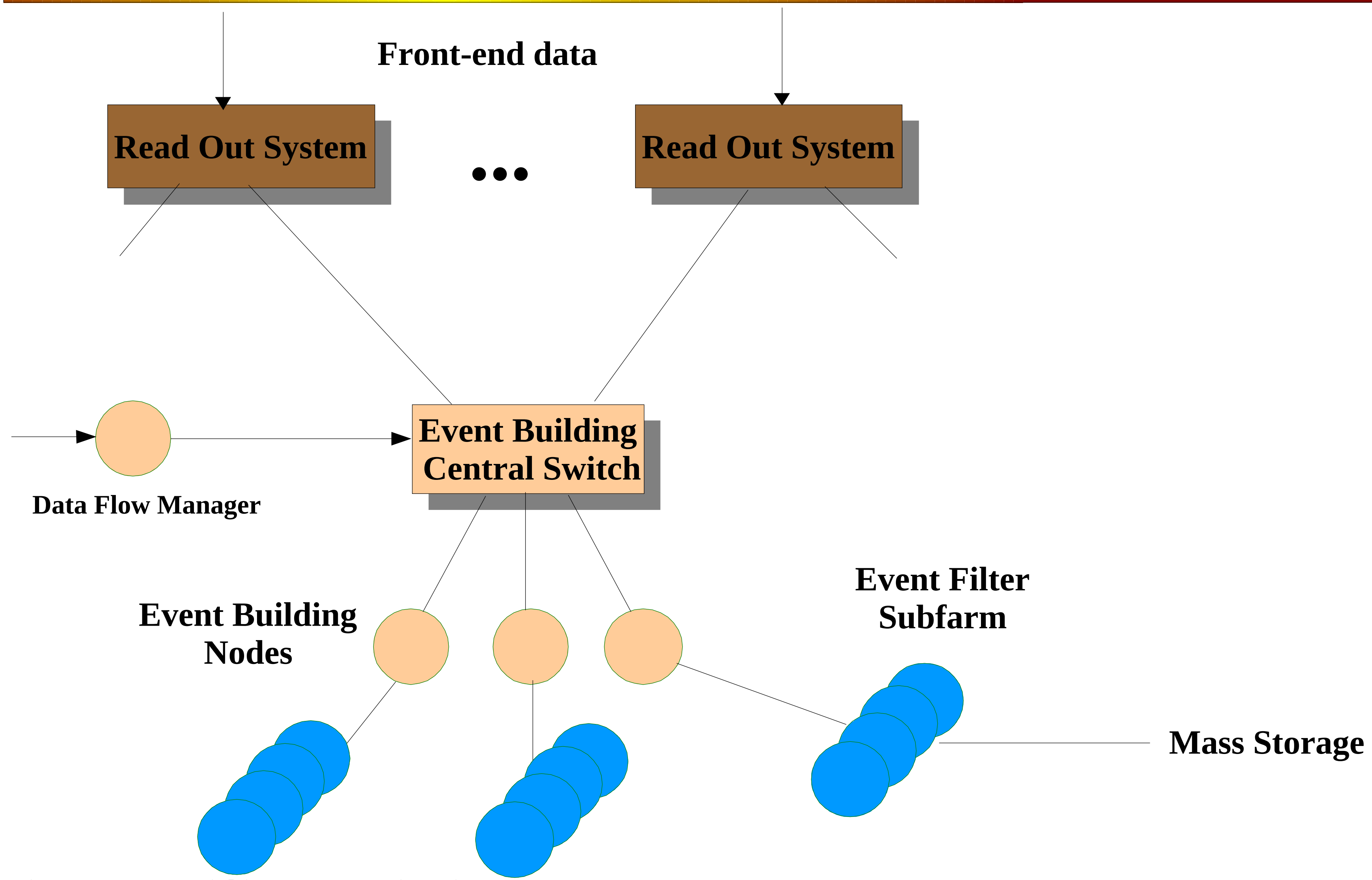
- **HLT menus and rates reflect deferrals in ATLAS Trigger/DAQ**
  - **Keeps most of high pT physics and discovery potential intact.**
  - **B physics restricted mostly to final states including di-muons**
    - **Investigations on applying ROI concepts to other B physics channels (e.g. hadronic decays).**
    - **Challenge: much lower p_T than for inclusive trigger**
  - **Staged installation and commissioning of large parts of Level 2 and Event Filter farms/networks.**
    - **Design allows this in a straightforward way.**

The Level 2 Trigger System

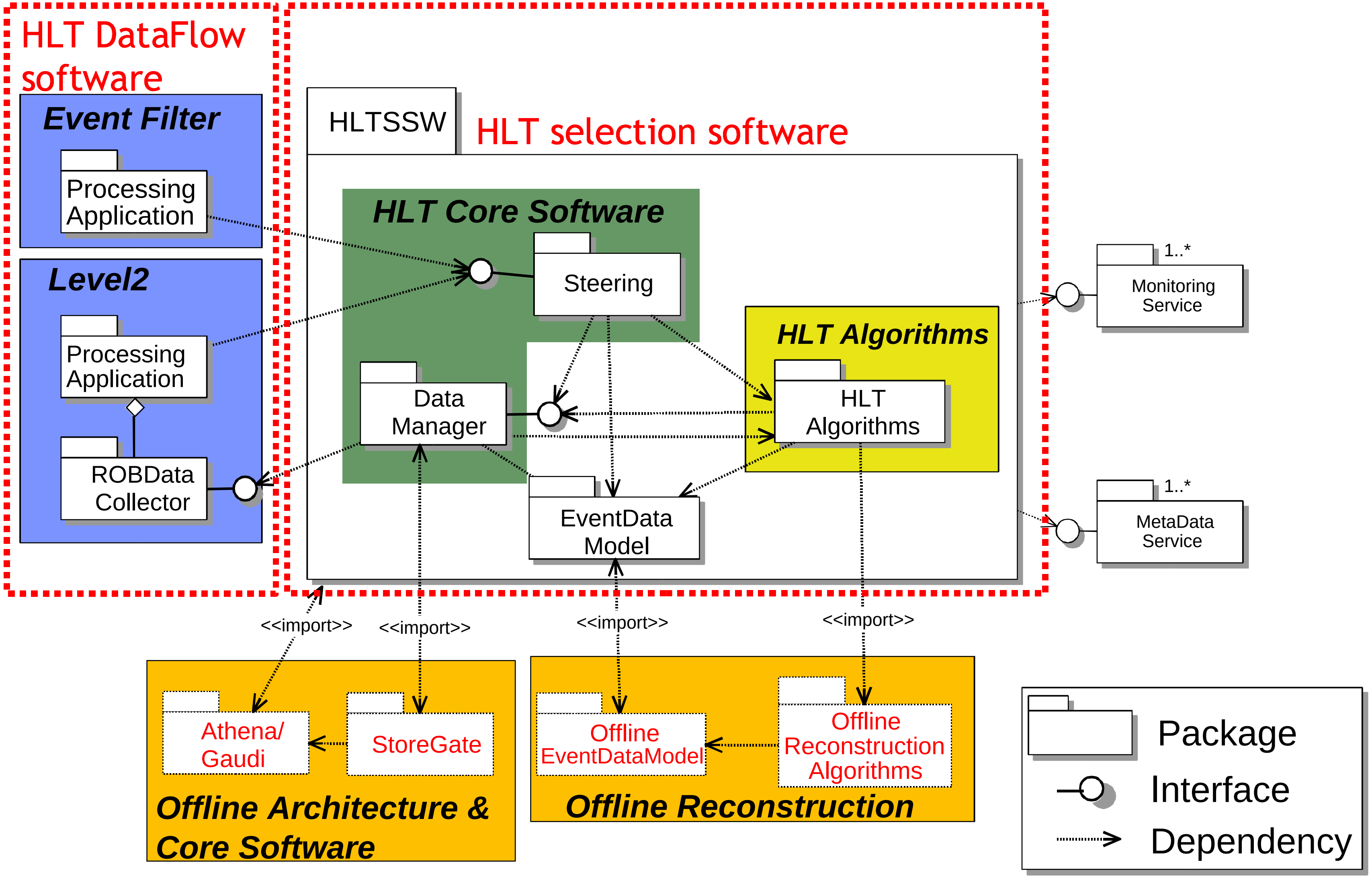


Uses commodity HW:
PCs running Linux
Gigabit Ethernet

Event Building and Event Filter

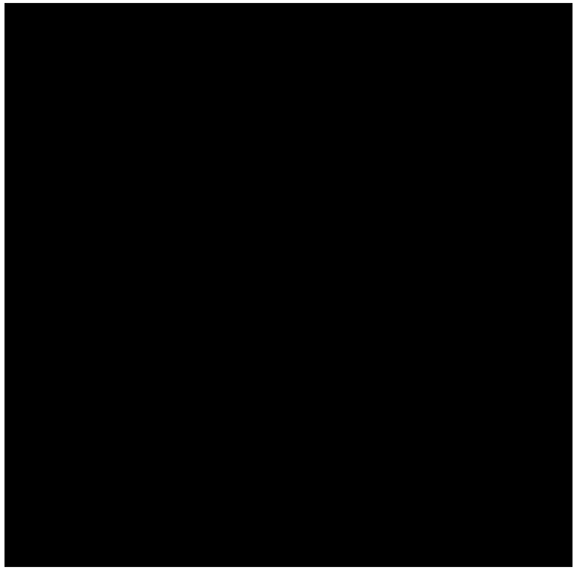


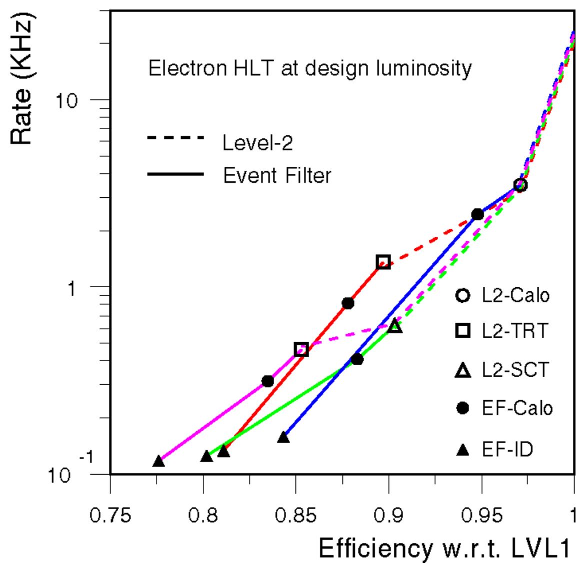
HLT and External Dependencies



Example: HLT Electron Trigger

- Example selection path:
  - Level 2
    - LVL1 EM ROIs
    - identify e/γ clusters by calorimeter E_T and shower shape
    - electron: search for inner detector track in region, match cluster
    - improve electron identification with transition radiation
  - Event Filter
    - shower shape analysis from calorimeter
    - electron: track search and match
    - photon: possible conversion recovery
    - bremsstrahlung recovery for electrons

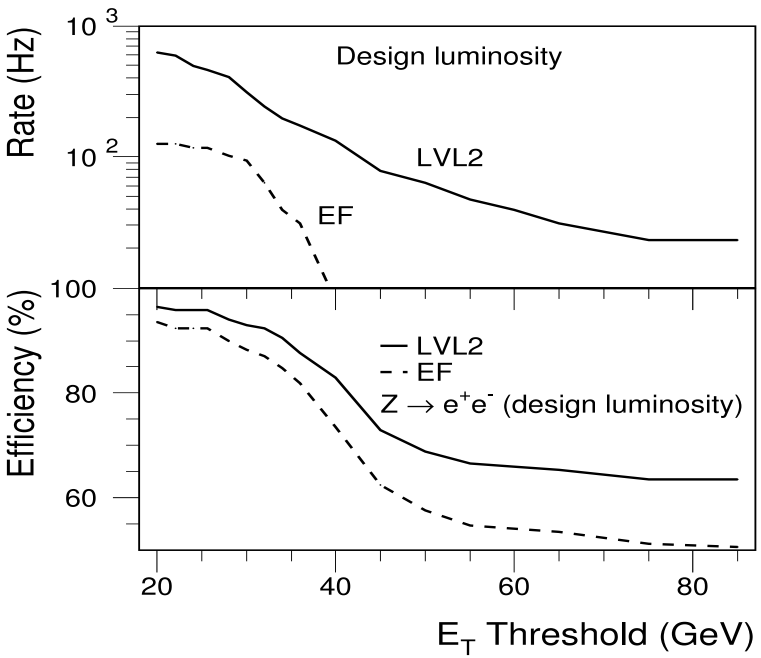




Different rate reduction paths:

- optimize order for fast rejection
- flexible boundary between LVL2/EF
- optimize both physics performance and system performance together

HLT Electron Trigger (2)



At high luminosity, rate reduced from 21.7 kHz (LVL1) to 114 Hz (HLT).

Composition of accepted events:

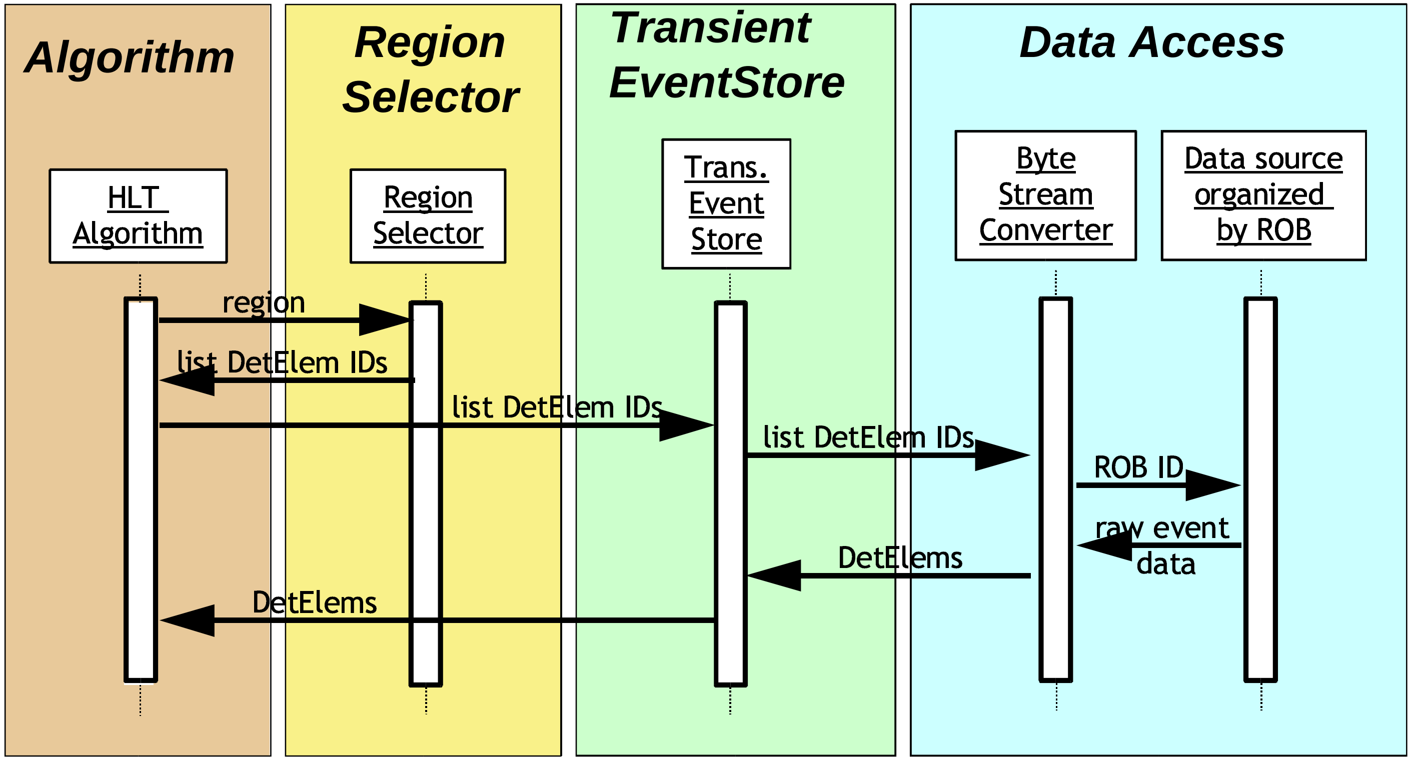
40% W -> eν

13% b, c -> eν

47% fakes and conversions

- **Example algorithm performance**
  - **Extrapolated to 2006**
    - **LVL2 Calorimeter: ~ 0.03 ms**
    - **LVL2 Tracking: ~ 1 ms**
    - **EF calorimeter: ~ 50 ms**
    - **EF tracking: ~ 1 s**
      - **Room for further improvement**
  - **These numbers do not include:**
    - **Data Access Time**
      - **Network access in case of Level 2**
    - **Data Preparation Time**
      - **Conversion of front-end data into format suitable for algorithm**
  - **Studies are ongoing to quantify these numbers**
    - **Can be as large or larger than algorithm times.**

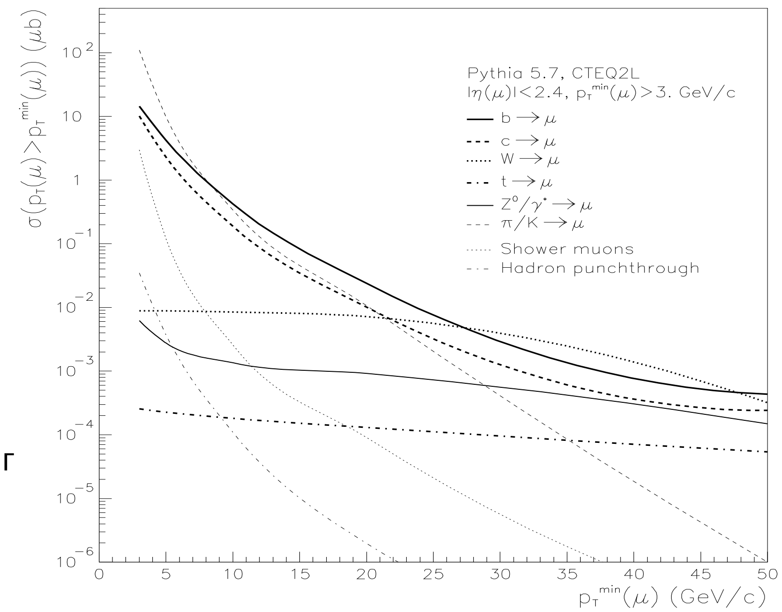
From Region of Interest to Data

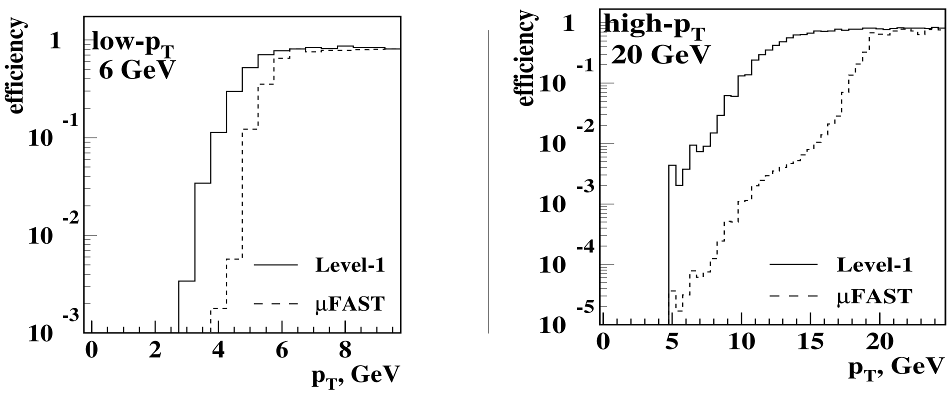


In the case of Event Filter, the full event is available in memory.
In the case of Level 2, the data is read from the Read Out Buffers via the network.

Example HLT Muon Trigger

- High rate of low-p_T muons accepted by Level 1: π, K decaying in flight
- Confirm L1 muon and reject fakes
- Uses MDT in addition to RPC
- p_T resolution
  - 5.5 % at low p_T, 4 % at high p_T
- ε ~ 90 % above trigger threshold
- Reduces L1 rate by a factor of
  - ~ 2 at low p_T, ~ 10 at high p_T





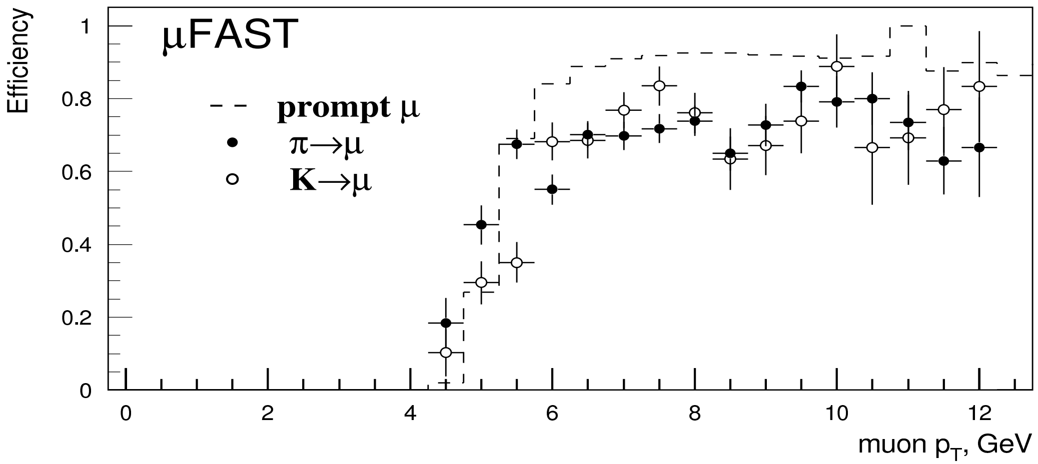
HLT Muon Trigger (2)

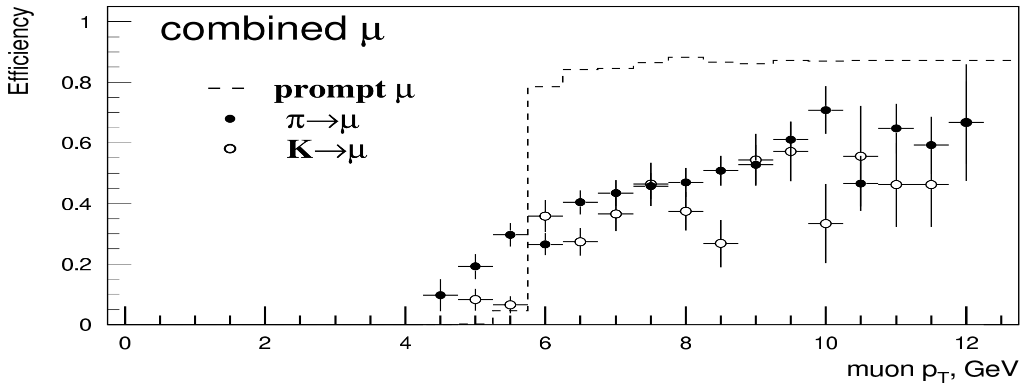
- Combine LVL2 muon with Precision Tracker info.
- Rejection of non-prompt muons from π and K decays
  - Makes use of different p_T for K in Inner Detector and Muon Det.
- Factor 3 vs. muon algorithm alone

Trigger rate in kHz at low-p_T

Contribution	Muon	combined
K/π decays	3.13	0.98
b decays	0.97	0.73
c decays	0.51	0.37
total	4.62	2.08

for barrel region $|\eta| < 1$





Further improvements:
Isolation in calorimeter to reject b and c's.

HLT Rates

Selection	$2 \times 10^{33}\ cm^{-2}s^{-1}$	Rates (Hz)
Electron	e25i, 2e15i	~40
Photon	γ60i, 2γ20i	~40
Muon	μ20i, 2μ10	~40
Jets	j400, 3j165, 4j110	~25
Jet & E_T^{miss}	j70 + xE70	~20
tau & E_T^{miss}	τ35 + xE45	~5
b-physics	2μ6 with m_B /$m_{J/\psi}$	~10
Others	pre-scales, calibration,	~20
Total		~200

Mostly physics signal, some thresholds already rather large (j70 + xE70)

Uncertainties

- Physics cross-sections (factor 2-3)
  - Monte Carlo
- Detector simulation
  - Shower simulation packages
  - Fragmentation functions
- Detector noise, misalignment
- Software performance
  - Algorithm execution time
  - Data conversion and preparations

Summary

- **ATLAS online selection chain and strategy**
  - **Support the physics program for the full LHC operation**
  - **Initial HLT/DAQ deployment for peak luminosities ~$2*10^{33}\ cm^{-2}s^{-1}$**
- **Inclusive high p_T selection covering the physics program**
  - **Discovery and precision measurements**
  - **Flexibility to handle the unexpected**
- **Exploit the features of the HLT/DAQ design**
  - **LVL2: fast and early rejection, EF: refine selection**
  - **Flexible boundary between the two**
  - **Concurrent optimization of physics and system performance**