Introduction

Trigger Hands-On Advance Tutorial Session

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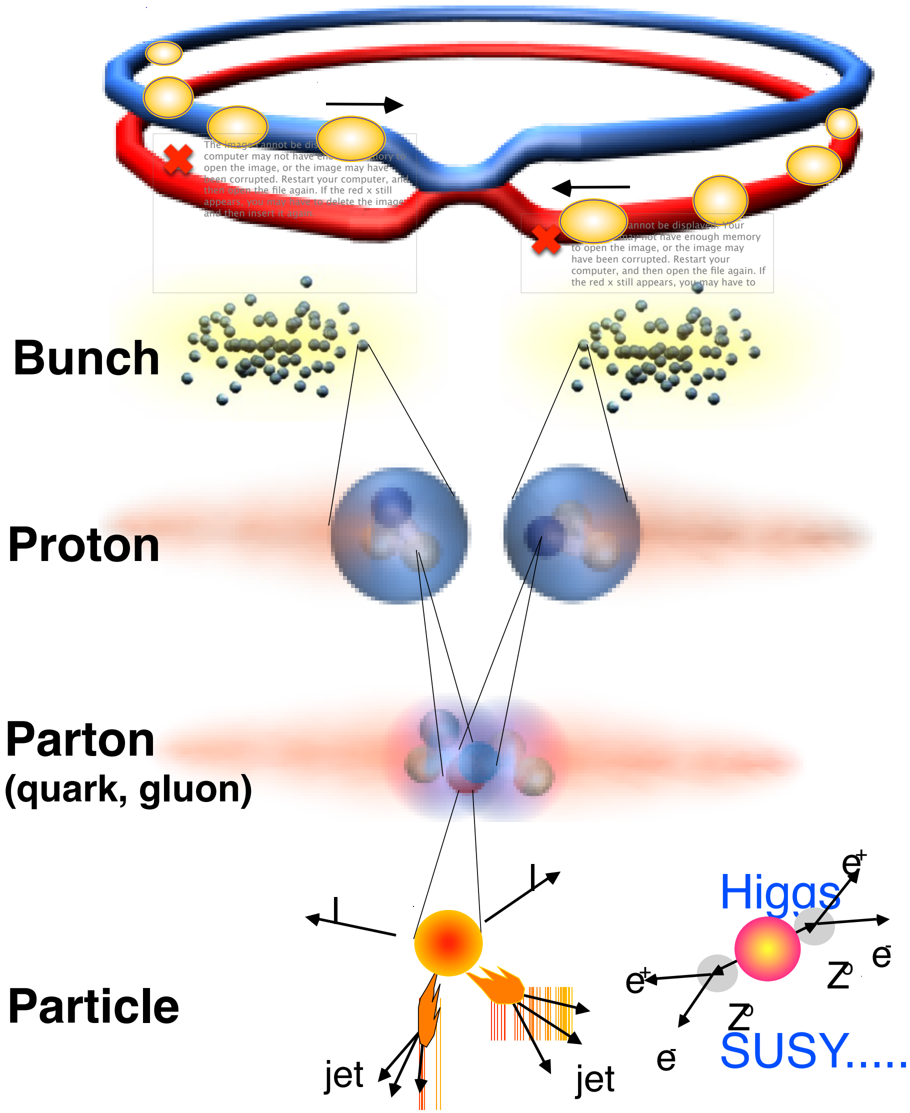
August 13th, 2014

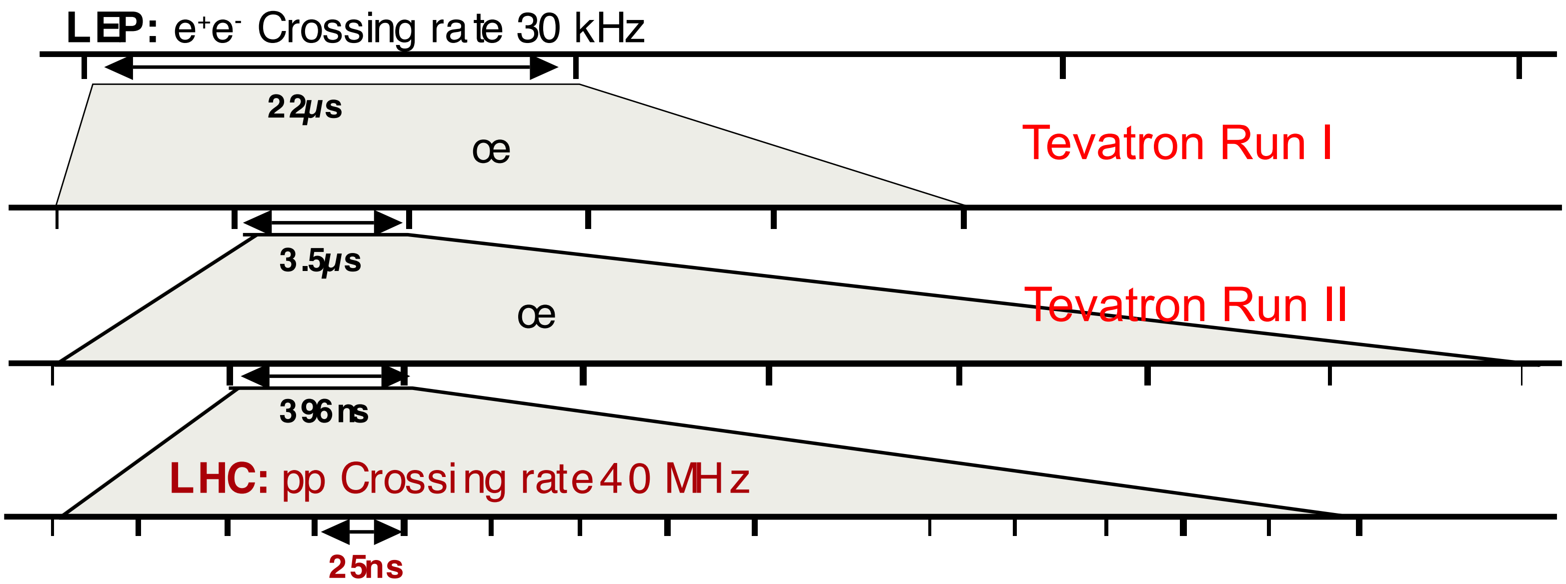
LHC



Proton - Proton	~3600 bunch/beam
Protons/bunch	$\sim 10^{11}$
Beam energy	~6.5 TeV (6.5×10^{12} eV)
Luminosity	$>10^{34}\,cm^{-2}s^{-1}$

Beam crossings: LEP, Tevatron & LHC

- LHC: ~3600 bunches (or ~2800 filled bunches)
  - And same length as LEP (27 km)
  - Distance between bunches: 27km/3600=7.5m
  - Distance between bunches in time: 7.5m/c=25ns

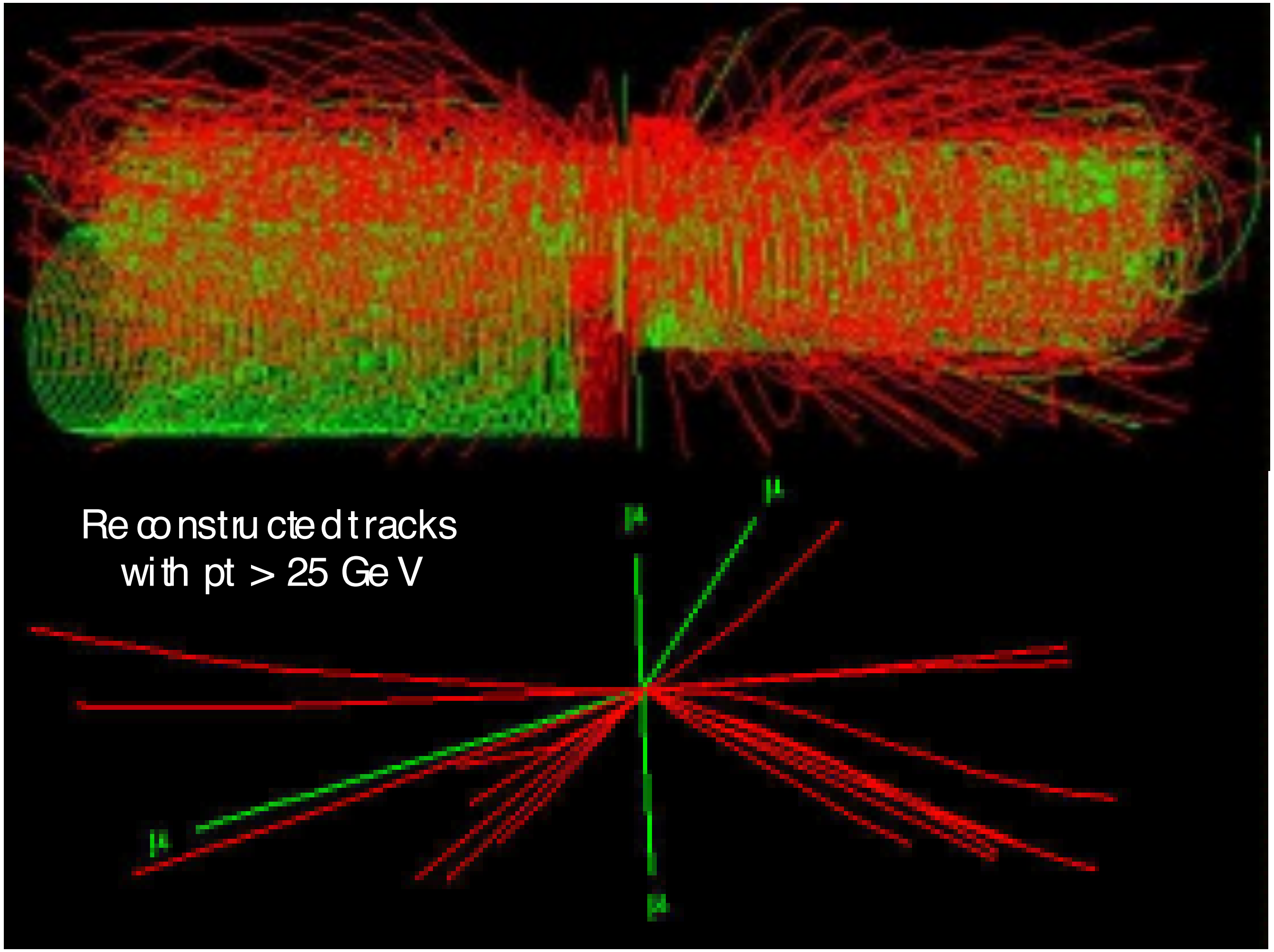


Summary of operating conditions: A "good" event (say containing a Higgs decay) + ~25 extra "bad" minimum bias interactions

pp collisions at 14 TeV at 10^{34} $cm^{-2}s^{-1}$

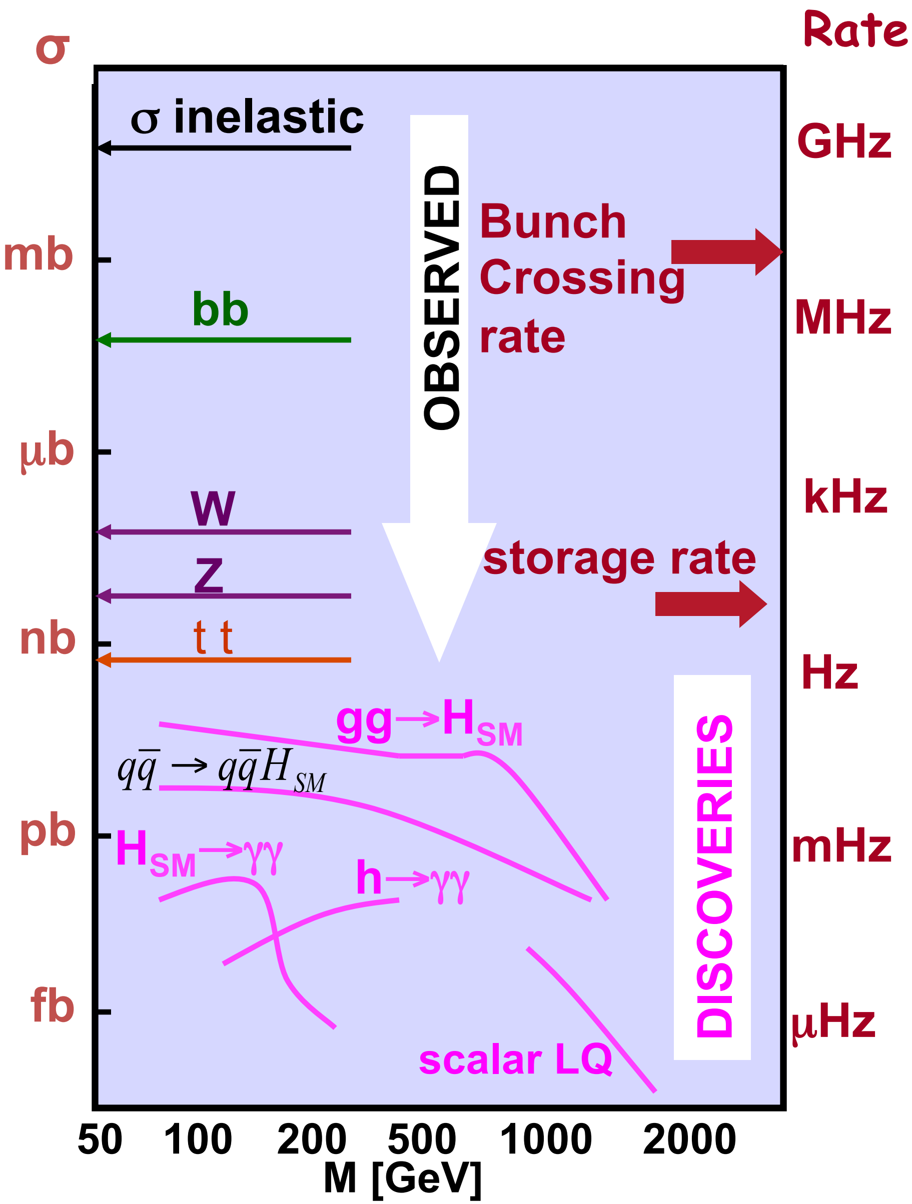
25 min bias events overlap

- H→ZZ (Z →μμ)
- H→ 4 muons: the cleanest ("golden") signature



And this (not the H though…) repeats every 25 ns…

Physics Selection @ LHC



Cross sections for various processes vary over many orders of magnitude

Bunch crossing frequency: 40MHz
Storage rate ~ 400-1000 Hz

→ online rejection: > 99.99%
→ crucial impact on physics reach

Keep in mind that what is discarded is lost forever

The Challenge @ LHC

The Challenge

Process	σ (nb)	Production rates (Hz)
Inelastic	~10^8	~10^9
$b\bar{b}$	5×10^5	5×10^6
$W \to \ell\nu$	15	100
$Z \to \ell\ell$	2	20
$t\bar{t}$	1	10
$H(100\,\mathrm{GeV})$	0.05	0.1
$Z'\,(1\,\mathrm{TeV})$	0.05	0.1
$\tilde{g}\tilde{g}\,(1\,\mathrm{TeV})$	0.05	0.1
$H(500\,\mathrm{GeV})$	10^{-3}	10^{-2}

The Solution

The Trigger

The Challenge

Process	σ (nb)	Production rates (Hz)
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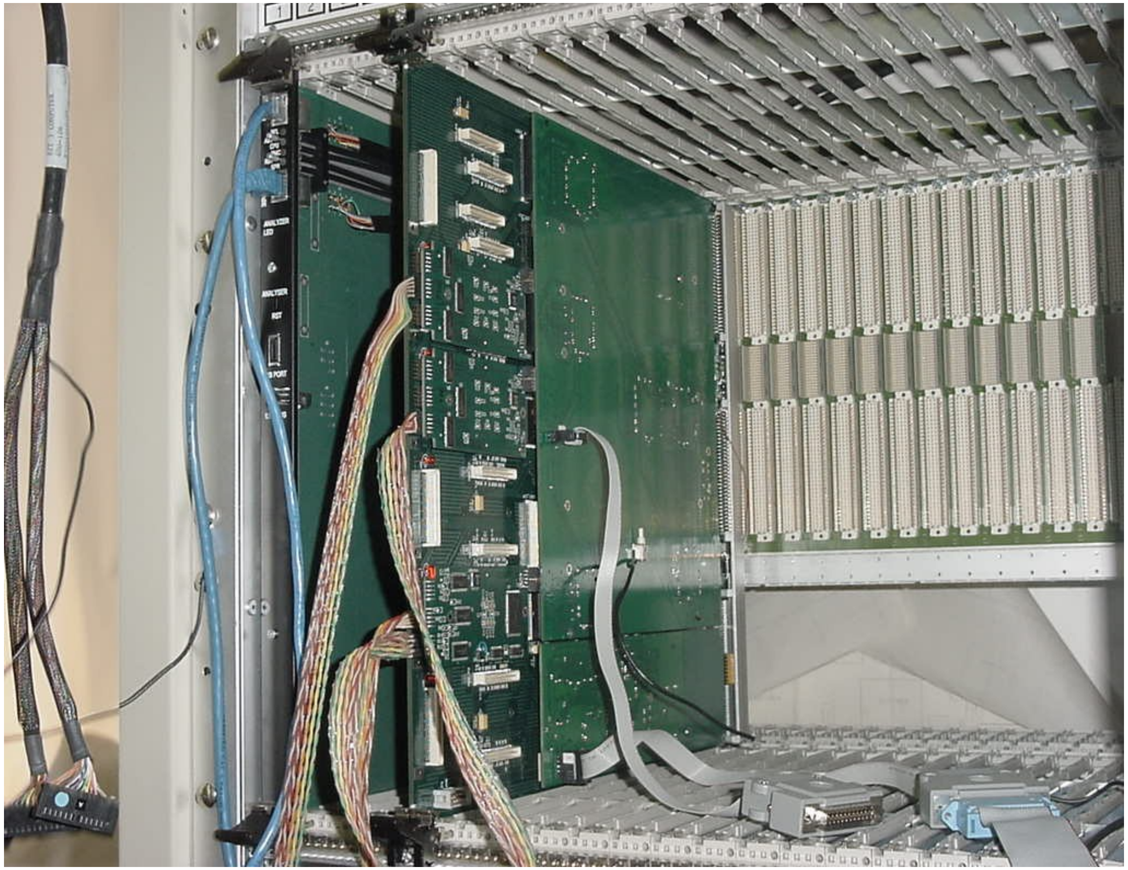
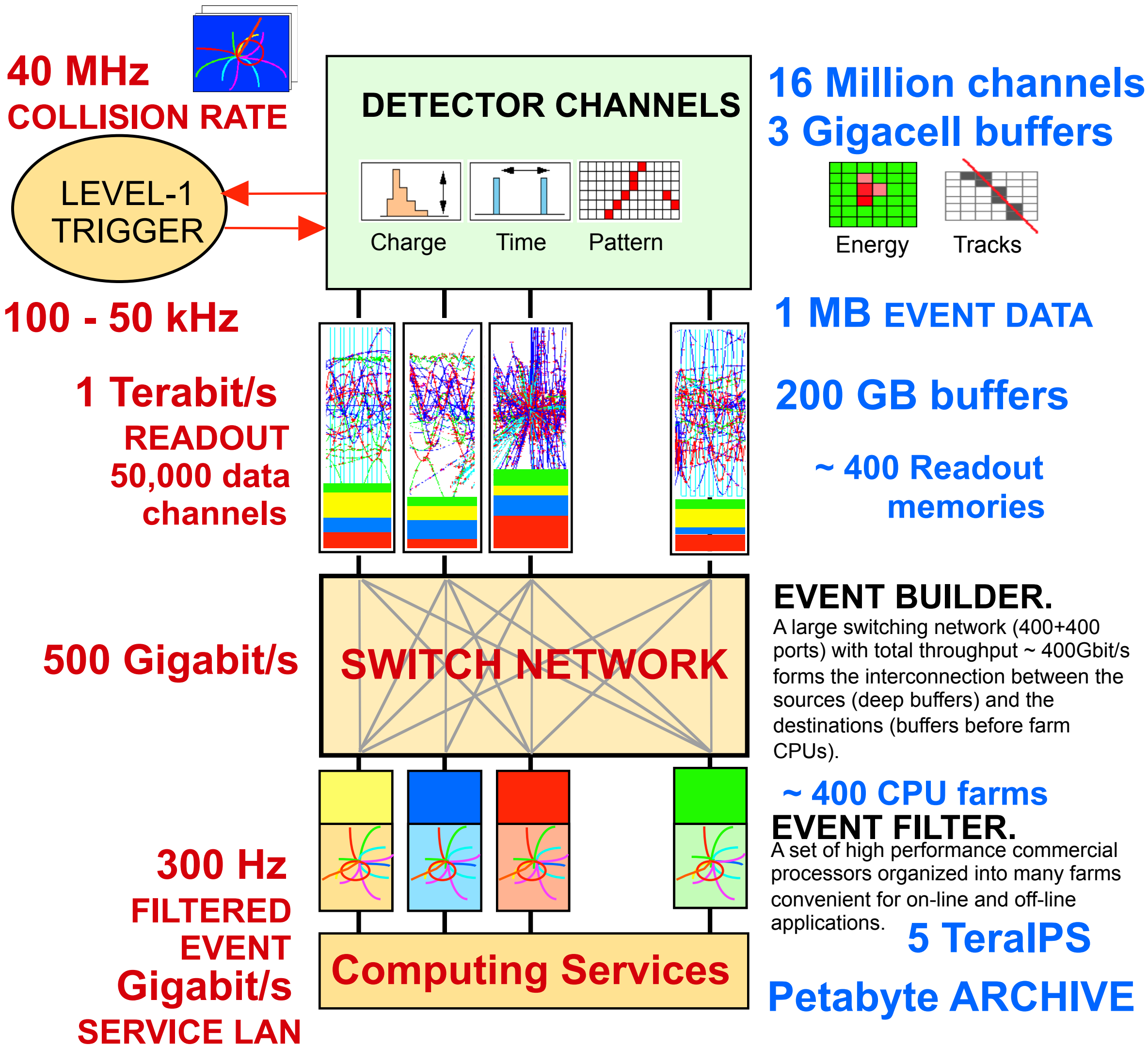
The Solution



Trigger/DAQ challenges @ LHC

- # of channel ~ O(10^7). ~25-50 interactions every 25ns
  - Need large number of connections
  - Need information super-highway
- Calorimeter information should correspond to tracker information
  - Need to synchronize detectors to better than 25ns
- Sometimes detector signal/time of flight > 25ns
  - Integrate information from more than one bunch crossing
  - Need to correctly identify bunch crossing
- Can store data at O(100 Hz)
  - Need to reject most events
- Selection is done Online in real-time
  - Cannot go back and recover events
  - Need to monitor selection

Trigger/DAQ Challenges



Challenges:

1 GHz of Input Interactions

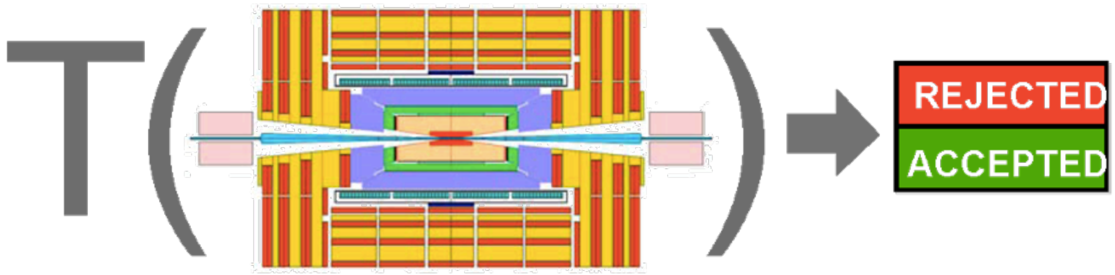
Beam-crossing every 25 ns with ~ 25 interactions produces over 1 MB of data

Archival Storage at about 300 Hz of 1 MB events

Triggering

- **Task: inspect detector information and provide a first decision on whether to keep the event or throw it out**

The trigger is a function of :



Event data & Apparatus
Physics channels & Parameters

- **Detector data not (all) promptly available**
- **Selection function highly complex**

⇒T(...) is evaluated by successive approximations, the

TRIGGER LEVELS

(possibly with zero dead time)

General trigger strategy

Needed: An efficient selection mechanism capable of selecting interesting events - this is the **TRIGGER**

"Needle in a haystack"

General strategy:

- System should be as inclusive as possible
- Robust
- Redundant
- Need high efficiency for selecting interesting processes for physics:
    - selection should not have biases that affect physics results
    - (understand biases in order to isolate and correct them)
- Need large reduction of rate from unwanted high-rate processes
    - instrumental background
    - high-rate physics processes that are not relevant (min. bias)

This complicated process involves a multi-level trigger system…

Multi-level trigger systems

- L1 trigger:
  - Selects 1 out of 10000 (max. output rate ~100kHz)

- This is NOT enough
  - Typical ATLAS and CMS event size is 1MB
  - 1MB x 100 kHz = 100 GB/s!

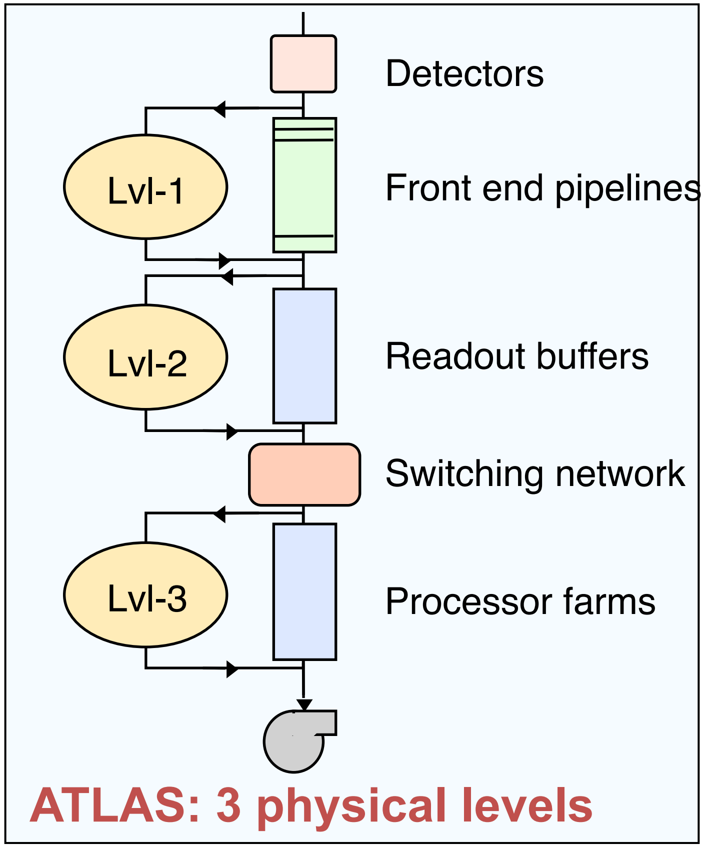
- What is the amount of data we can reasonably store these days ?
  - O(100) MB/s

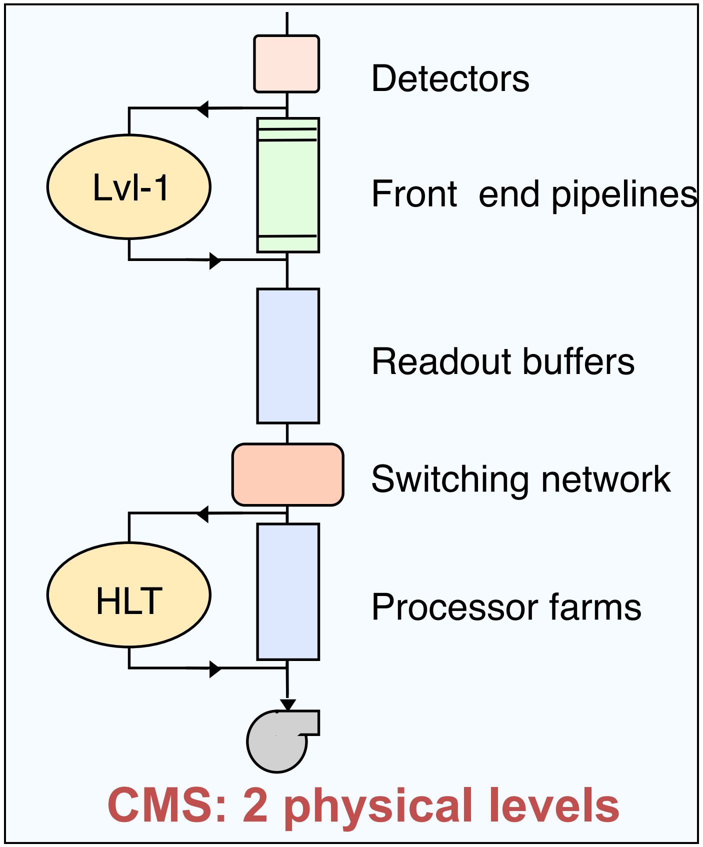
⇒ Additional trigger levels are needed to reduce the fraction of "less interesting" events before writing to permanent storage

Multi-tiered trigger systems

Level-1 trigger: Integral part of all trigger systems – always exists
reduces rate to ~50-100kHz.

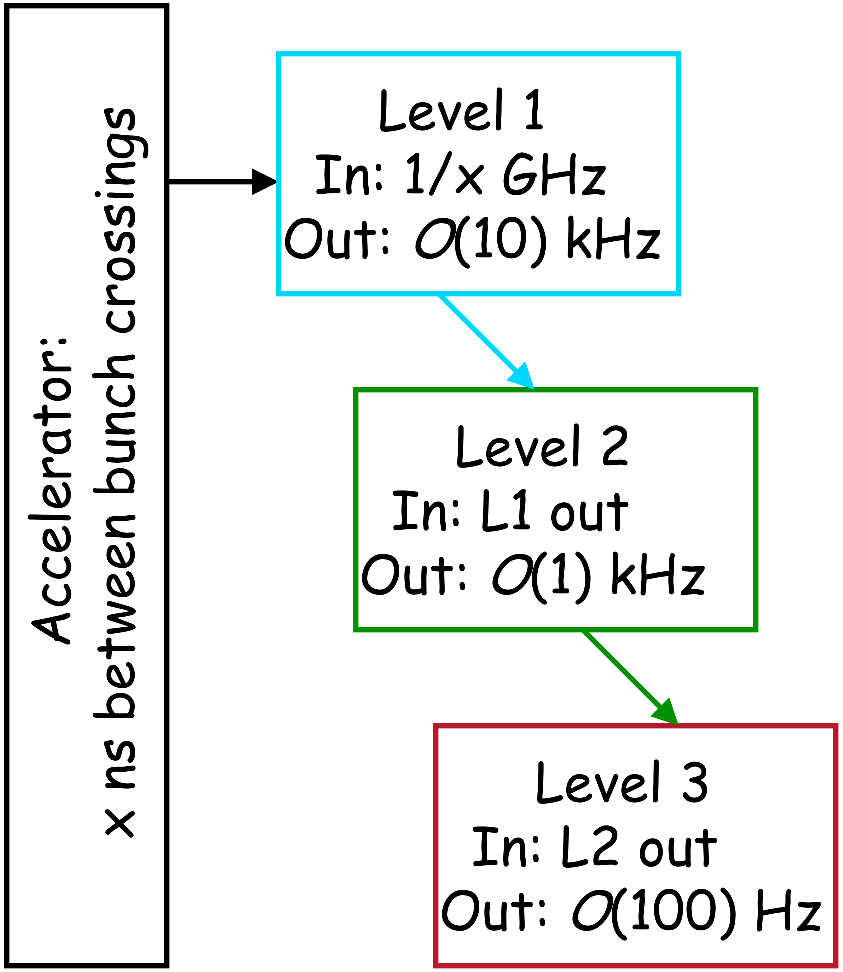
Upstream: further reduction needed – typically done in 1 or 2 steps





A multi-tiered Trigger System

Traditional 3-tiered system



Pipelined,
Hardware only, coarse readout,
~few μs latency

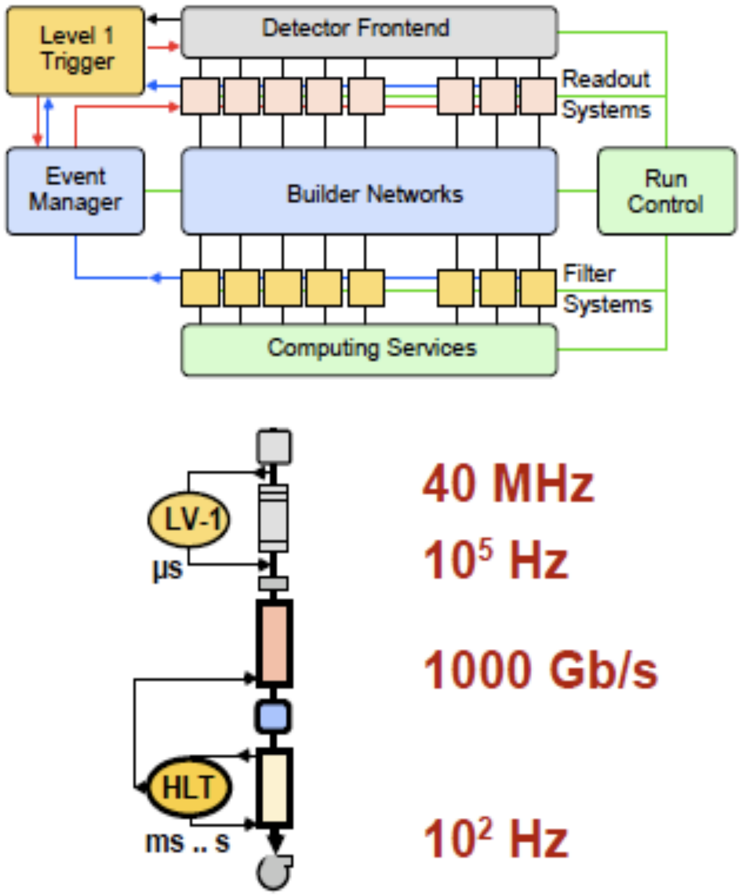
Hardware/Software mix,
L1 inputs, ~100 μs latency

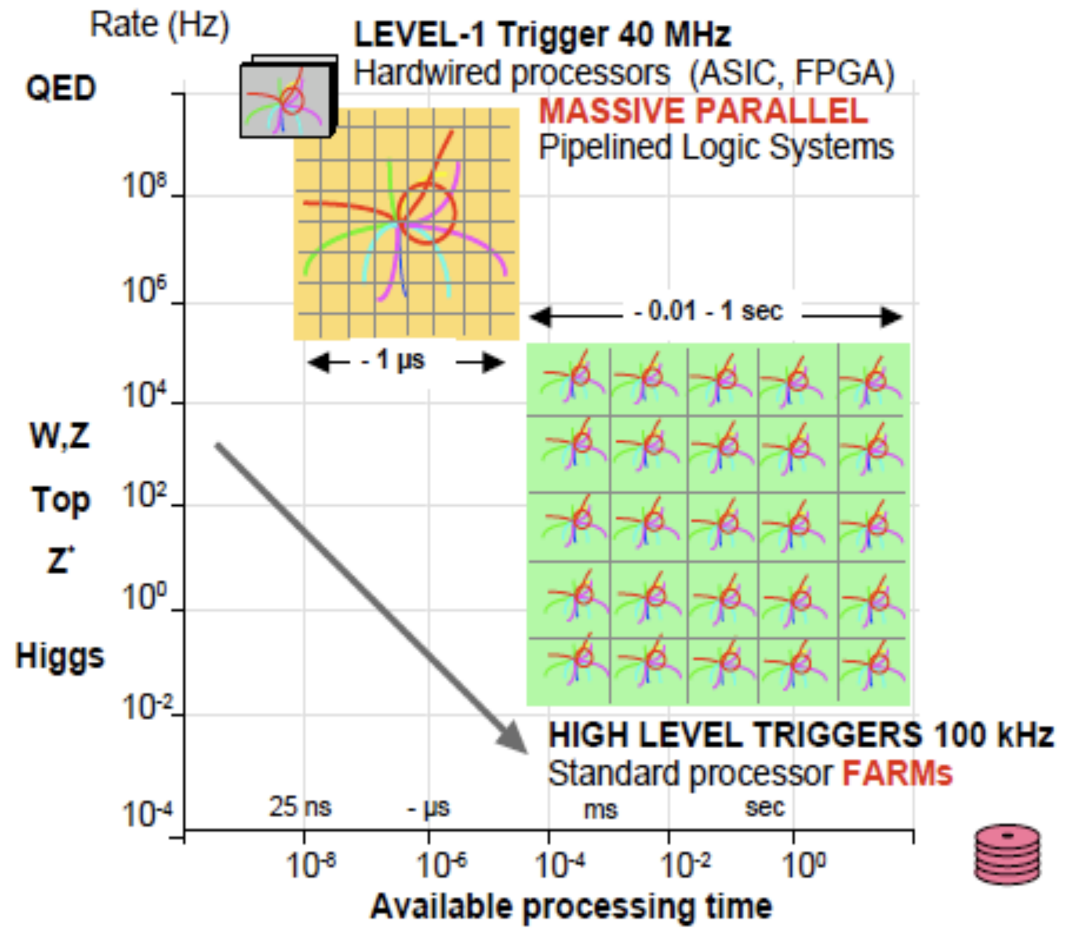
CPU farm, access to full event information, *O*(1)s/event

Two-tiered system

Two-level processing:

- Reduce number of building blocks
- Rely on commercial components for processing and communication

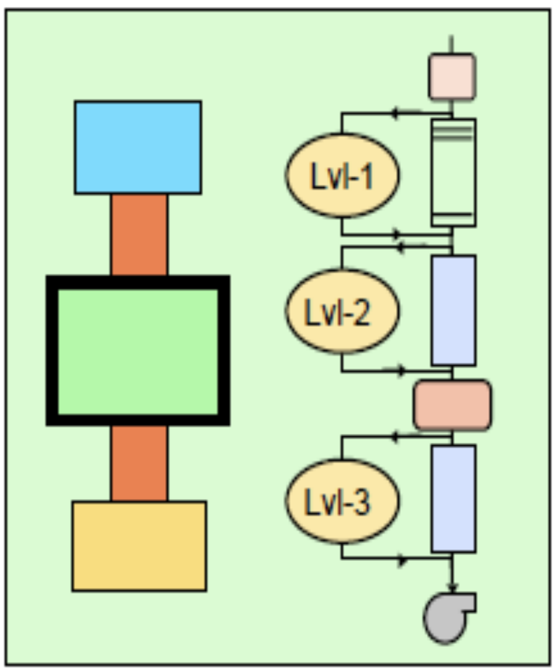


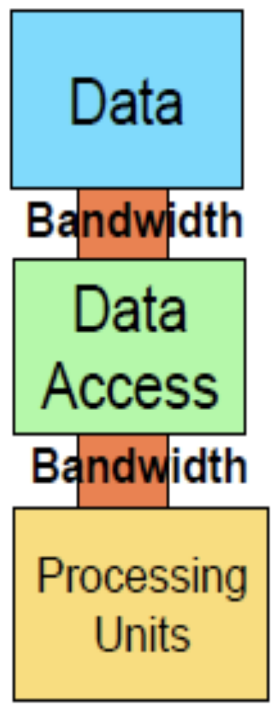


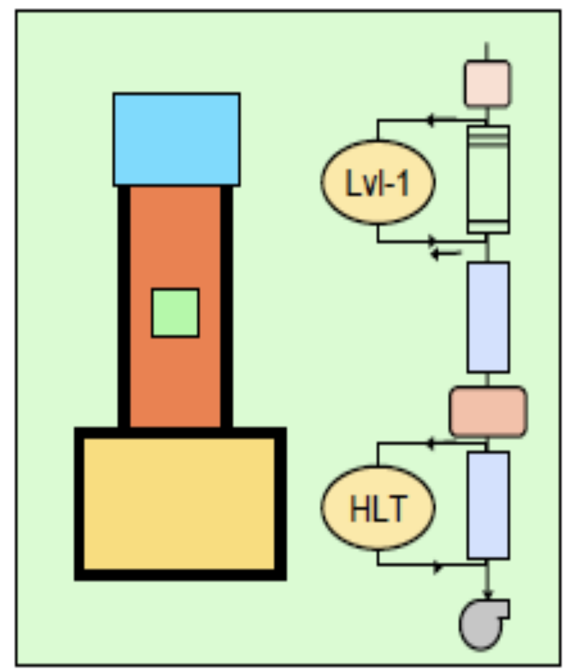
Comparison

- Three physical entities
  - Invest in
    - Control logic
    - Specialized processors

- Two physical entities
  - Invest in
    - Bandwidth
    - Commercial processors







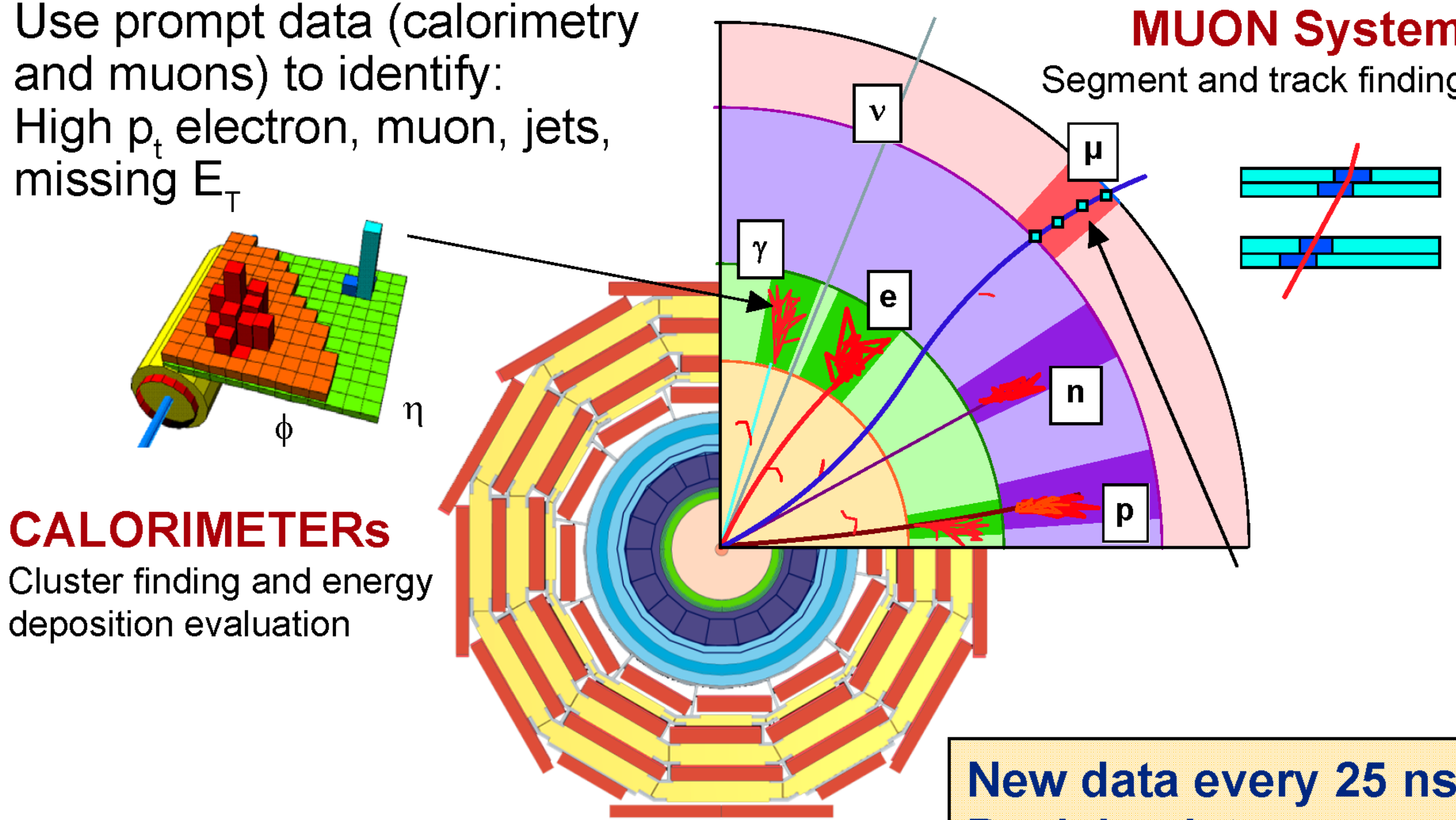
Level-1 algorithms

- Physics concerns:
  - pp collisions produce mainly low pT hadrons with pT ~ 1 GeV
  - Interesting physics has particles with large transverse momentum
    - W->eν : M(W) = 80 GeV; pT (e) ~ 30-40 GeV
    - H(120 GeV) → γγ ; pT(γγ) ~ 50-60 GeV
- Requirements
  - Impose high thresholds
    - Implies distinguishing particles
      - possible for electrons, muons and jets; beyond that need complex algorithms
  - Some typical thresholds from 2012:
    - Single muon with pt > 16 GeV
    - Double e/γ trigger with pT > 17, 8 GeV
    - Single jet with pT > 128 GeV
- Total of 128 physics algorithms possible at L1
  - Candidates' energy, kinematics, quality, correlations…

See Len's talk

Particle signatures

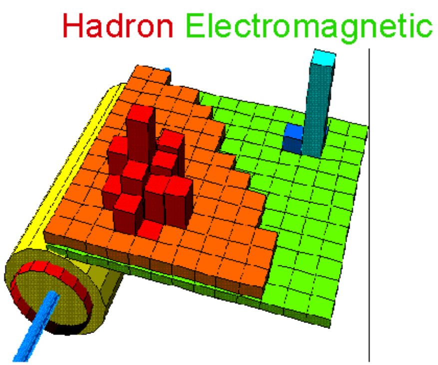
Use prompt data (calorimetry and muons) to identify:
High p_t electron, muon, jets, missing E_T

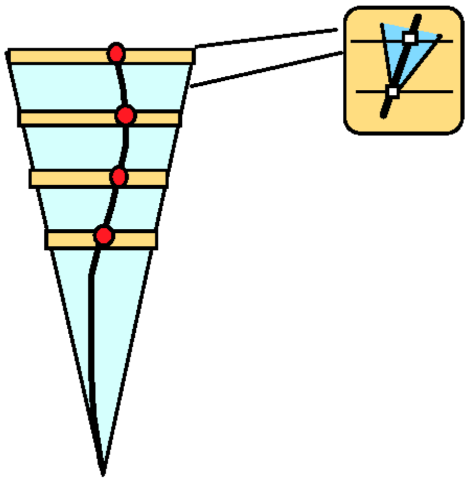


New data every 25 ns
Decision latency ~ μs

ATLAS & CMS Level 1:
Only Calorimeter & Muon

- **Pattern recognition much faster/easier**

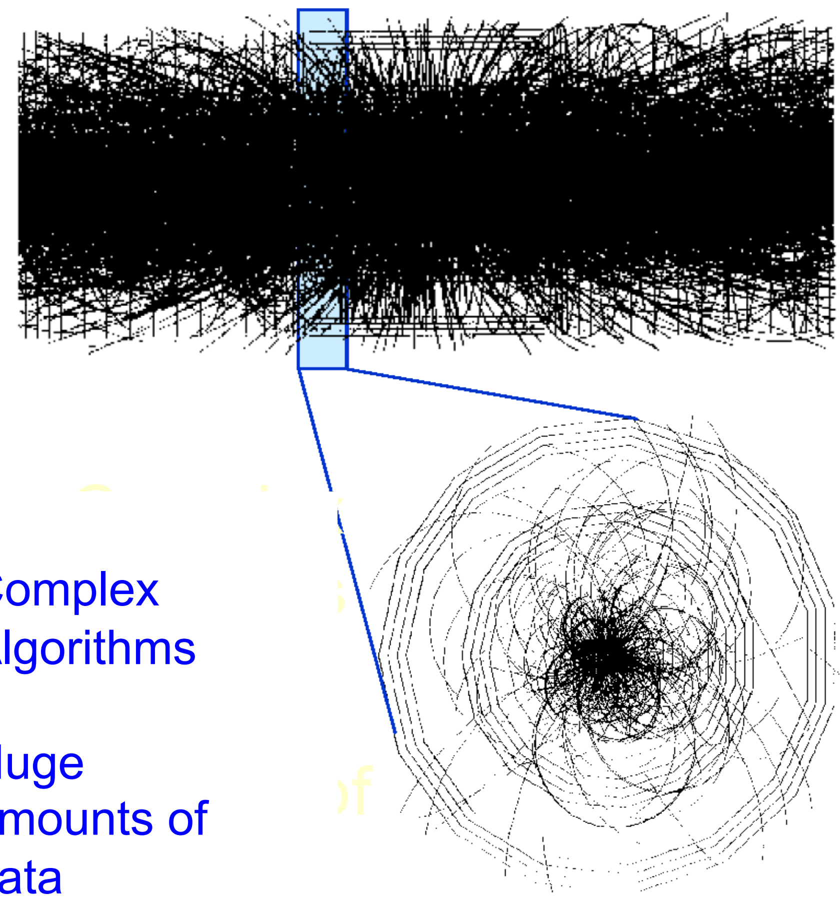




Simple Algorithms

Small amounts of data

- **Compare to tracker info**



Complex Algorithms

Huge amounts of data

High Occupancy in high granularity tracking detectors

High Level Trigger

HLT Processing

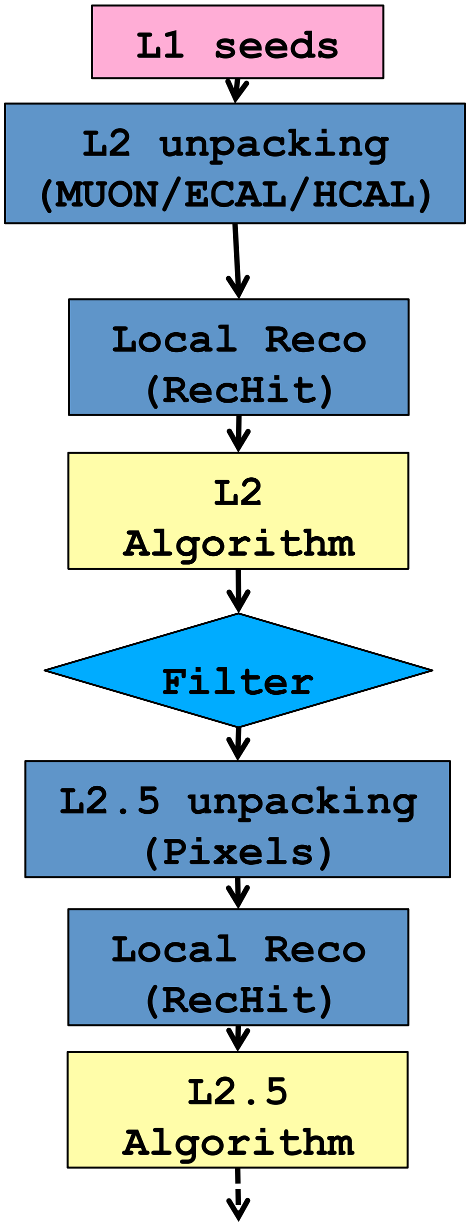
High Level Triggers (> Level 1) are implemented more or less as advanced software algorithms using CMSSW

- Run on standard processor farms with Linux as OS
  - cost effective since Linux is free
  - Different Intel Xeon generations (2008-2012)

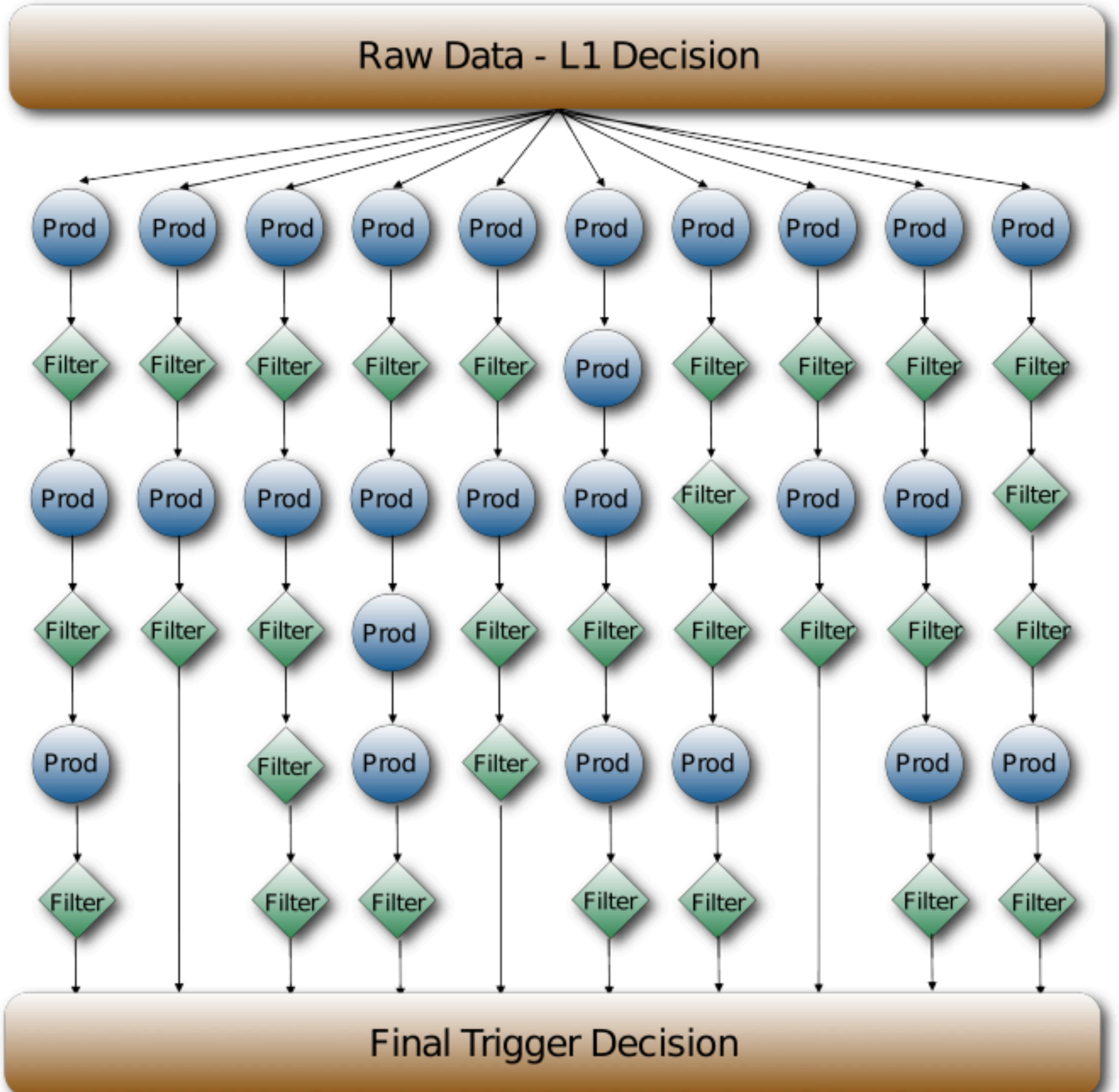
HLT filter algorithms are setup in various steps:

- Each HLT trigger path is a sequence of modules
  - Producer: creates/produces a new object
    - eg. unpacking, reconstruction
  - Filter: makes a true/false [pass/fail] decision
    - eg. muon p_T > X GeV ?
- Processing of the trigger path stops once a module returns false

See talks by Juliette and Dylan



HLT Menu



Many algorithms running in parallel

- Logically independent
- Determine
  - trigger decision
  - how to split the events, online and offline (Streams and Primary Datasets – more on this later)

HLT Guidelines

- Strategy/design:
  - Use offline software as much as possible
    - Easy to maintain (software can be easily updated)
    - Uses our best (bug-free) understanding of the detector
  - Optimize for running online (~100 times faster than offline)
    - Run the fastest algorithms first, reject events as early as possible, regional unpacking/reconstruction, reduce combinatorics/pileup

- Boundary conditions:
  - Have access to full event data (full granularity and resolution)
    - Take advantage of regions of interest to speed up reconstruction
  - Limitations:
    - CPU time — See Clint's talk
    - Output selection rate: ~400-1000 Hz — See Inga's talk
    - Precision of calibration constants
    - (While keeping physics acceptance as high as possible)

See talks by Dylan and Darren

HLT Requirements

- Flexible:
  - Working conditions at 14 TeV are difficult to evaluate (prepare for different scenarios)
- Robust:
  - HLT algorithms should not depend in a critical way on alignment and calibration constants
- Inclusive selection:
  - Rely on inclusive selection to guarantee maximum efficiency to new physics
- Fast event rejection:
  - Event not selected should be rejected as fast as possible (i.e. early on in the processing)
- Quasi-offline software:
  - Offline software used online should be optimized for performance
  - (we need to select events that are "interesting enough")

Trigger Menus

Need to address the following questions:

- What to save permanently on mass storage ?
  - Which trigger streams should be created ?
  - What is the bandwidth allocated to each stream ?
  - (Usually the bandwidth depends on the status of the experiment and its physics priorities)

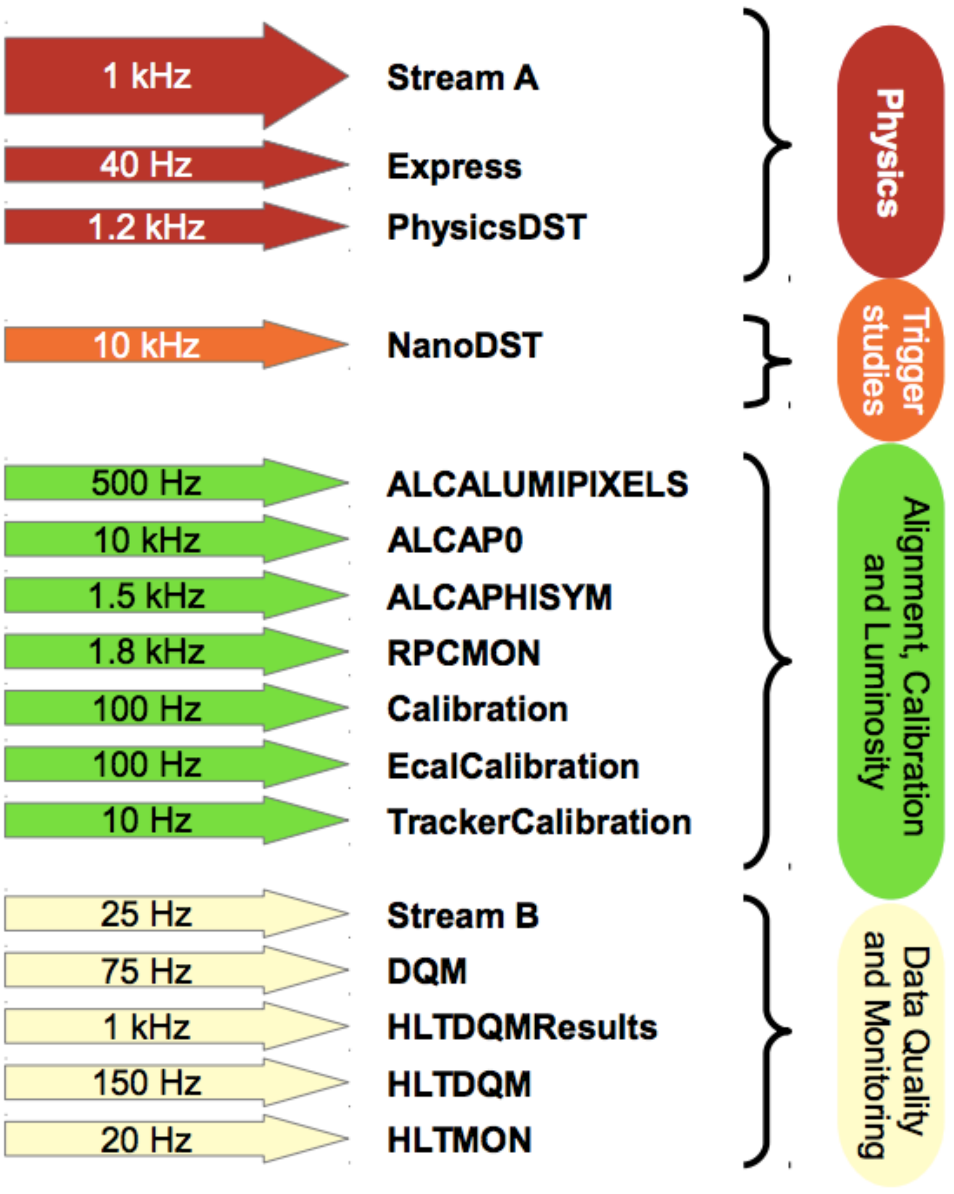
- What selection criteria to apply ?
  - Inclusive triggers (to cover major known or unknown physics channels)
  - Exclusive triggers (to extend the physics potential of certain analyses – say b-physics)
  - Prescaled triggers, triggers for calibration & monitoring

General rule :

Trigger tables should be flexible, extensible (to different luminosities for eg.), and allow the discovery of unexpected physics.

Streams

- The HLT is responsible for splitting the data into different streams
  - Different purposes
  - Different event content
  - Different rates
- Stream A collects all the data for physics analysis
  - Is further sub-divided into Primary Datasets (PDs)



High Level Trigger @ 13 TeV in 2015

- The higher collision energy leads to a higher cross-section
  - comparing 8 TeV and 13 TeV MC simulation we observe:
    - a factor 1.5 - 2 for leptons
    - a factor > 4 for jets !
  - assume an average increase by a factor ~ 2
- higher luminosity: ~ 1.4e34 cm-2s-1
  - a factor ~2 higher than the peak luminosity in 2012
- => a factor ~4 increase in the expected HLT rate
- Pileup will be higher too
  - Max. av. Pileup ~40 (compared to ~30 for 2012)
  - HLT rate ~robust against pileup but HLT timing increases linearly with pileup

Bottomline: need to make better use of the available bandwidth, improve online reconstruction, calibration, design smarter and better triggers…

Trigger Coordination

Trigger Coordinators
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Deputies
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Strategy Trigger Evaluation And Monitoring

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Muriel Vander Donckt

Rates & Prescales:
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Data & MC Release Validation:
D. Puigh, **TBD**

Offline DQM:
D. Puigh, **TBD**

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Andrea Perrotta

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Framework & Tools:
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ConfDB:
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Field Operations Group

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Online Deployment:
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Online DQM:
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Calibration/Alignment:
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POG/PAG Trigger Conveners

POG Trigger conveners

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Isobel Ojalvo

EGamma
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Matteo Sani

Jets/MET
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Kostas Kousouris

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Silvio Donato

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Luca Martini

SUSY
Pablo Martinez
Frank Golf

HIN
Krisztian Krajczar

L1 Trigger conveners

L1T
M. Pellicciono
L. Apanasevich

TSG Open Positions

- FOG:
  - Online Deployment:
    - development of software and tools for DAQ2
    - On-call expert training, documentation
  - Online DQM
  - On-call experts for Run 2

- STEAM:
  - Rates & Prescales
    - Rate and timing studies for the overall HLT menu
  - Validation/DQM
    - Coordinate the validation of new HLT menus, new software releases, and AlCa conditions
    - Maintenance of group software tools