ATLAS TRIGGER AND DAQ: CAPABILITIES AND COMMISSIONING

- Introduction
- DataFlow
- Trigger and Menu
- Conclusions

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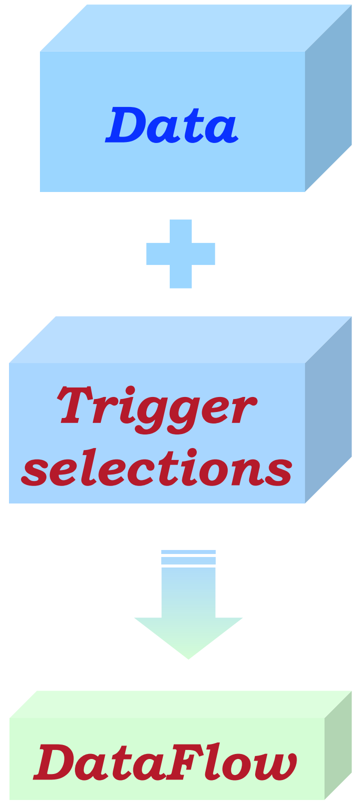
on behalf of the
ATLAS TDAQ Collaboration

General

- LHC (**L**arge **H**adron **C**ollider)
  - ★ proton-proton collisions at 14 TeV (design)
  - ★ 25 ns bunch-crossing interval, 40 MHz bunch-crossing rate
  - ★ Design luminosity 10^{34} cm^{-2} s^{-1} (~23 interactions per crossing)
  - ★ Start-up luminosity 10^{31} cm^{-2} s^{-1}

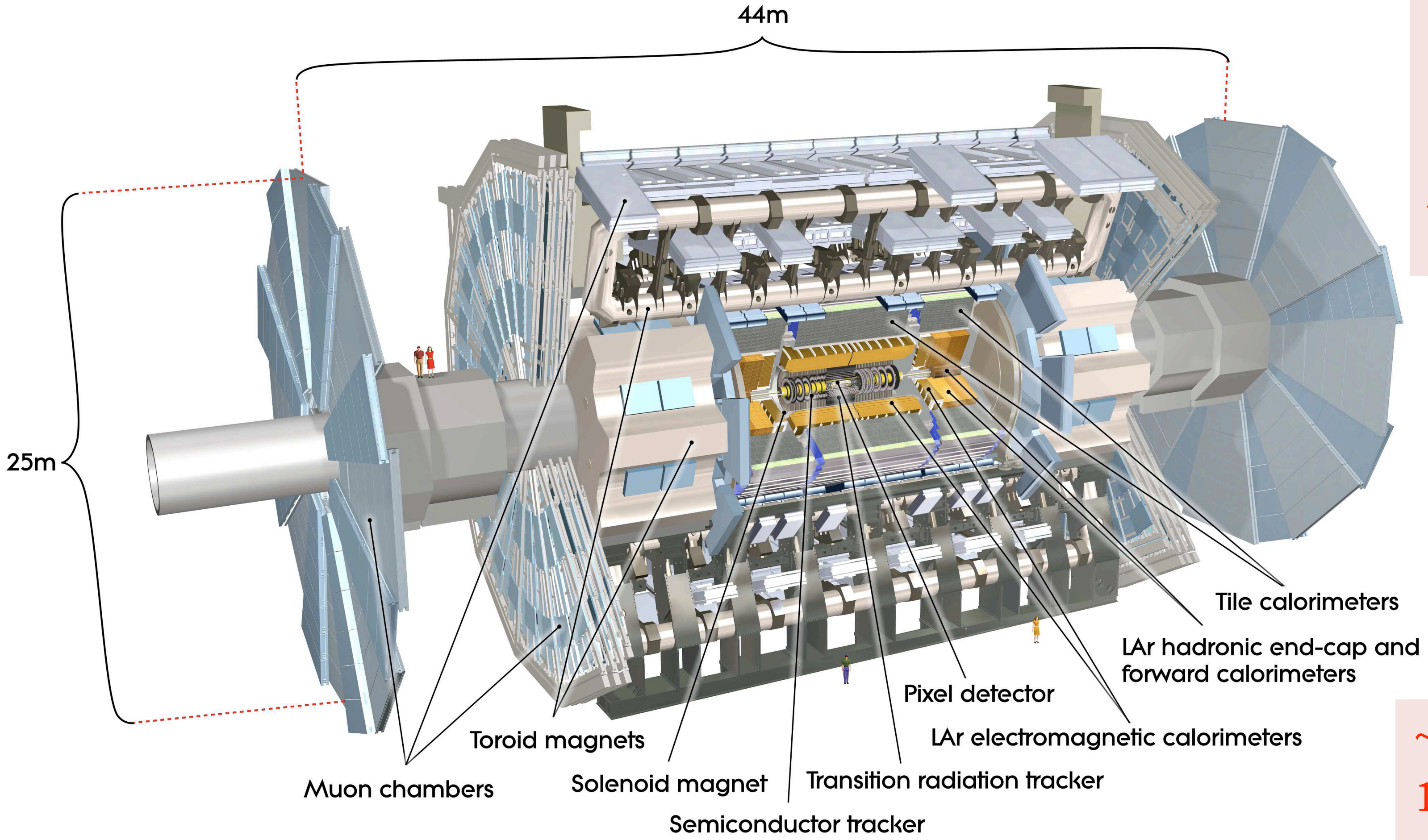
- ATLAS (**A** **T**oroidal **L**HC **A**pparatu**S**)
  - ★ A general purpose experiment
  - ★ If all data would be recorded:
    - ➢ data rate equivalent to 50 billion phone calls at the same time
  - ★ Storage:
    - ➢ event rate ~200 Hz, event size ~1.5 MB, bandwidth ~300 MB/s



- Trigger (event selection) performance is connected to the Dataflow (data conveyance) performance
  - ★ No data to analyze if trigger and/or dataflow fails!

ATLAS

- ATLAS is one of the 4 major experiments installed at LHC (CERN)
  - ★ Largest volume particle detector ever constructed



SIZE

Length 44 m

Diameter 25 m

Weight 7000 t

~2500 scientists

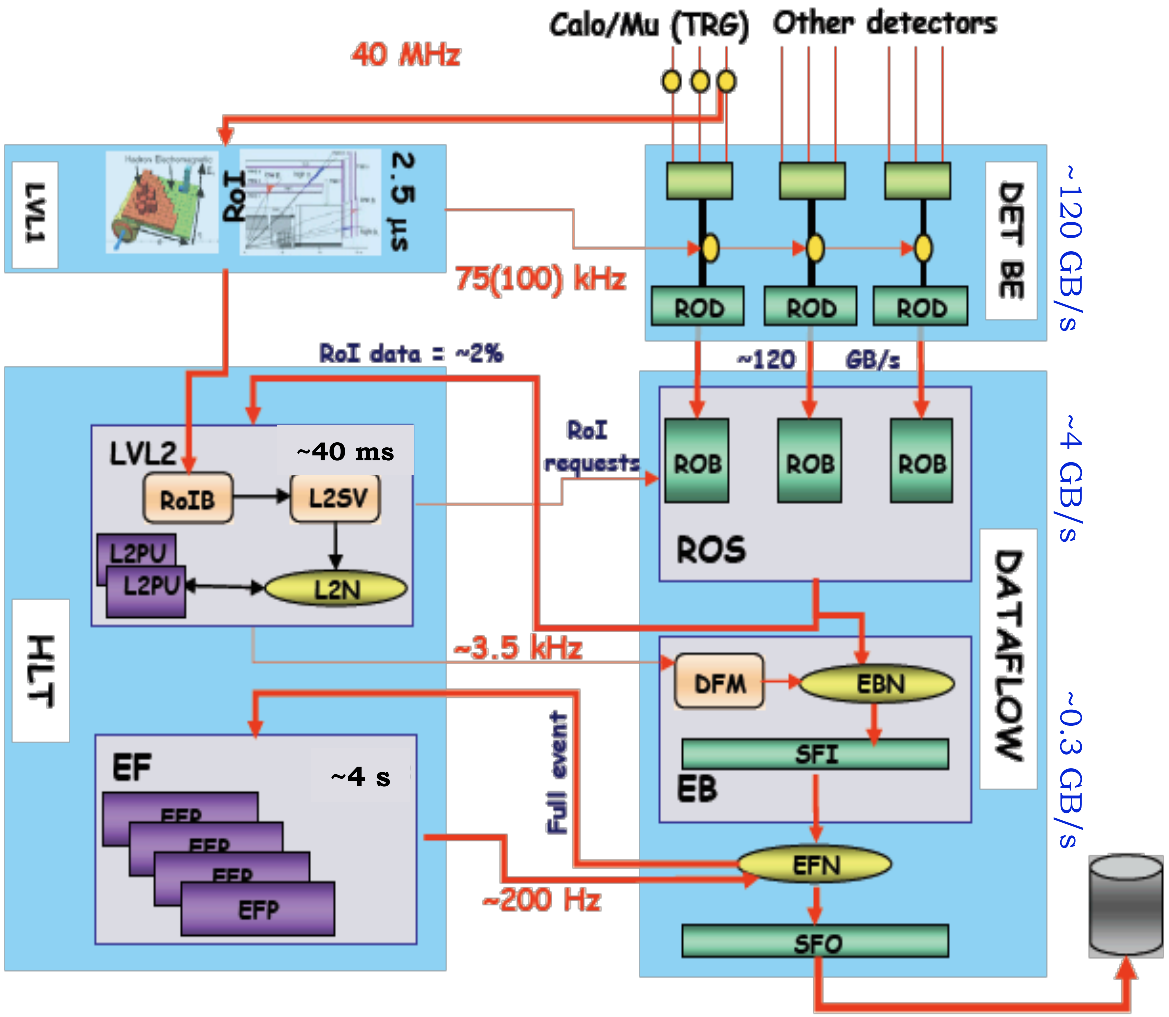
169 institutes

37 countries

ATLAS DataFlow

Trigger and DAQ overview

3-levels selection schema



① **Level 1 (LVL1)**

- ★ Custom electronics
- ★ Reduced granularity (calorimeter, muon)
- ★ Latency 2.5 µs
- ★ Select rate 75 kHz

② **Level 2 (LVL2)**

- ★ Software based, specialized algorithms
- ★ Full granularity
- ★ **R**egion **O**f **I**nterest (2% of data transferred)
- ★ Event processing time: ~40 ms

③ **Event Filter (EF)**

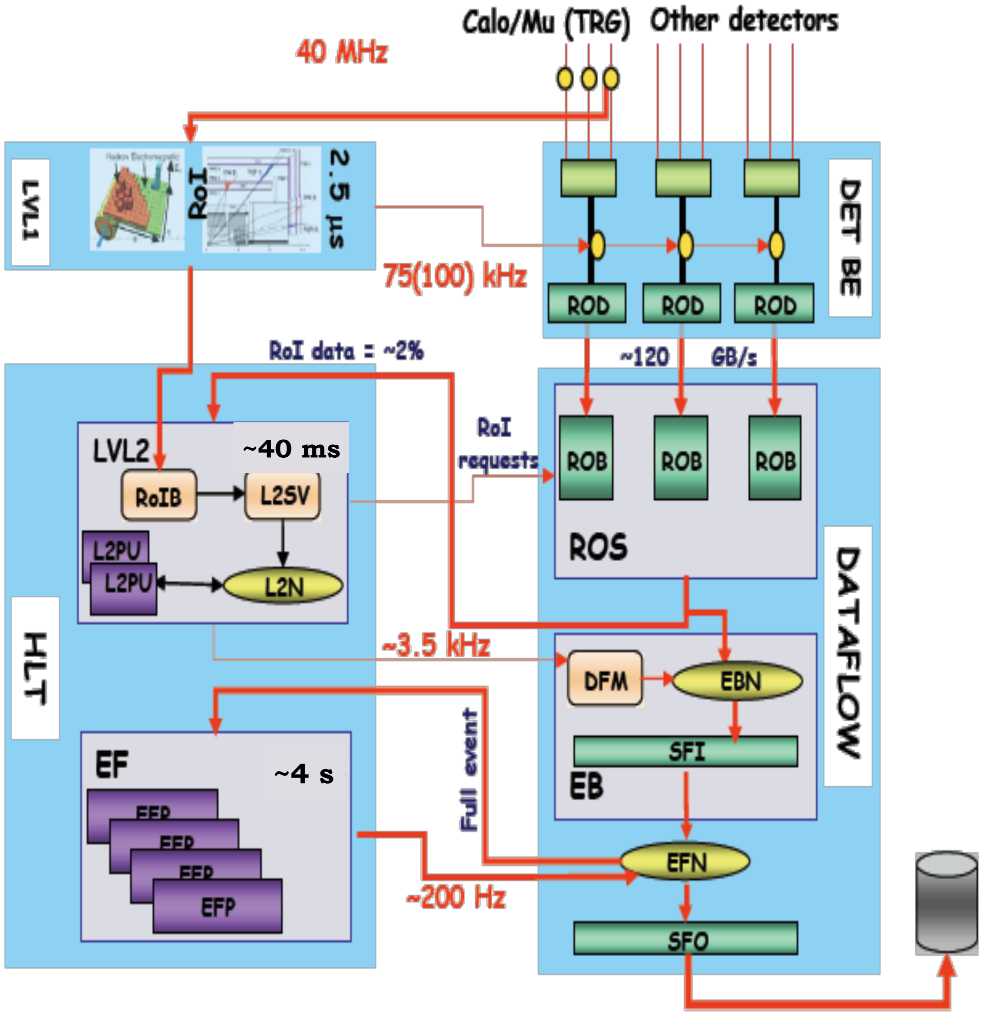
- ★ Software based, offline algorithms
- ★ Full event available
- ★ Seeded by LVL2
- ★ Event processing time: ~4s

DataFlow components

responsible for the collection and the conveyance of event data from the detector front-end electronics to the mass storage, and provision of data to LVL2 and EF

push-pull architecture

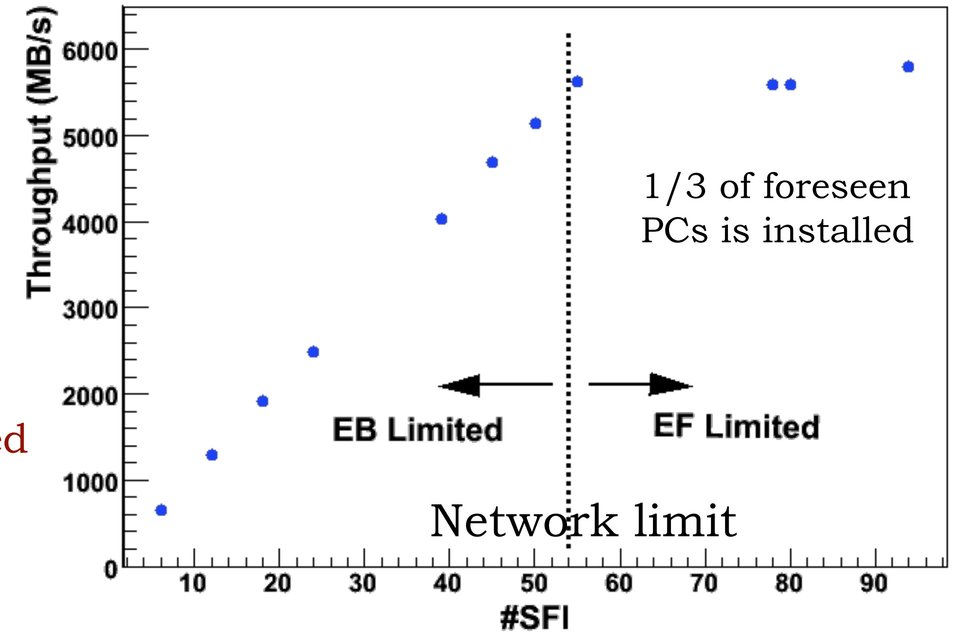
RoIB	▪ RoI info assembled into a unique data structure and sent to LVL2
LVL2	▪ Guided by RoI info, data fragments are requested from the **R**ead**O**ut **S**ystem for analysis ▪ Decision sent to **D**ata**F**low **M**anager
DFM	▪ receives LVL2 decision ▪ assigns accepted events to **E**vent **B**uilding ▪ for rejected and built events notifies ROS to expunge event data
EB	▪ collects data from ROSs, i.e. builds the full event ▪ notifies DFM when events are built ▪ built events are sent to **E**vent **F**ilter
EF	▪ selects and classifies the events ▪ selected events are sent to SFO
SFO	▪ Received events are stored locally



DataFlow Performance

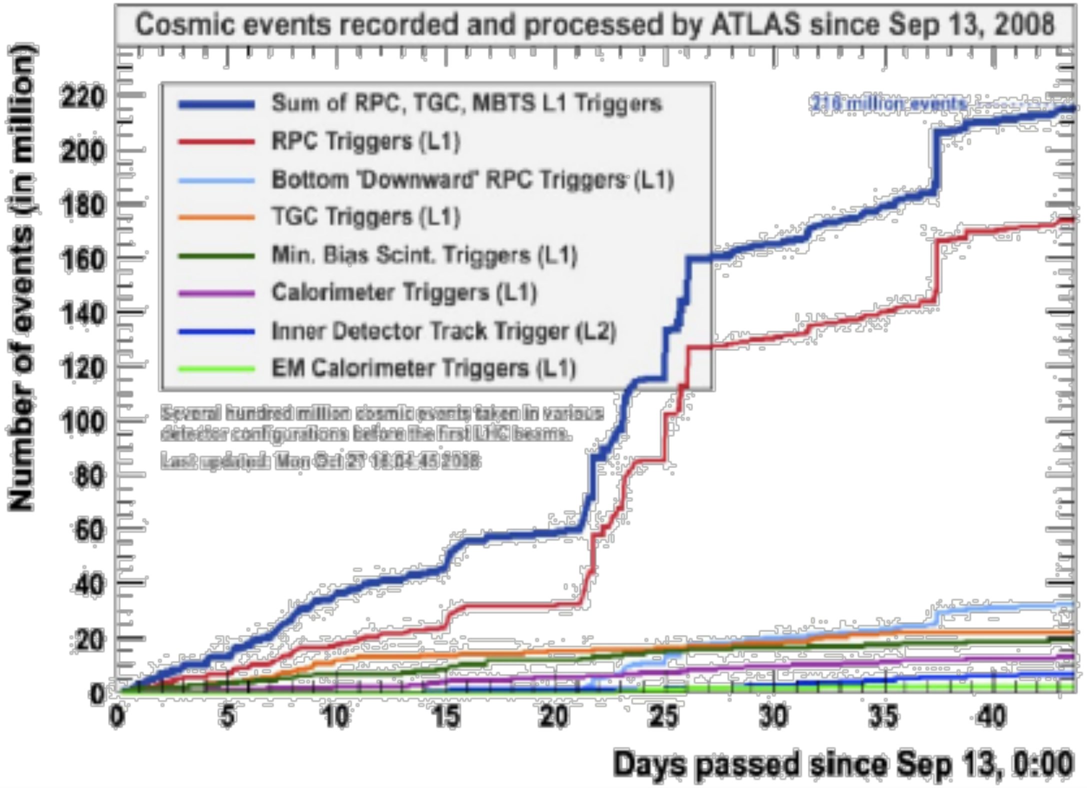
- Regular TDAQ tests are performed to assess the system performance
- Current system size allows for the evaluation of scalability & performance
- Connection between the EB and EF is organized in sub-farms
  - ★ Each sub-farms contains a subset of the EB and EF nodes
  - ★ Such a configuration allows for flexibility and redundancy in the usage of the available resources

- Standalone EB performance
  - ★ scales linearly with the number of SFIs
  - ★ an SFI contributes ~90 MB/s to the aggregate bandwidth
- The full system runs successfully at a
  - ★ LVL1 trigger rate of 70 kHz,
    - ➢ depending on test conditions, can be limited by the ROS processing power
  - ★ LVL2 trigger rate of 3.5 kHz



DataFlow Performance: Sub-Farm Output

- During detector commissioning and combined running the SFO farm has been regularly used at the design working point and even beyond
  - ★ The farm is able to sustain an aggregated I/O rate of 550 MB/s (design value is 300 MB/s)
- Roughly 1 PB of data, distributed over 650 thousand files, has been handled by the farm during the ATLAS cosmic data-taking



mid July 2008

end October 2008

=

1 PB

500 M events

HLT (LVL2+EF) Farms: status

1 rack	31 PC 1 Local File Server	2 quad-core (2.5 GHz)	RAM: 16 GB (2GB/core)

Current System

- 27 racks (XPU)
  - X= LVL2 or EF
  - 850 PC (850x8 core)
- 35% of the final system
  - sufficient for $10^{31}cm^{-2}\ s^{-1}$

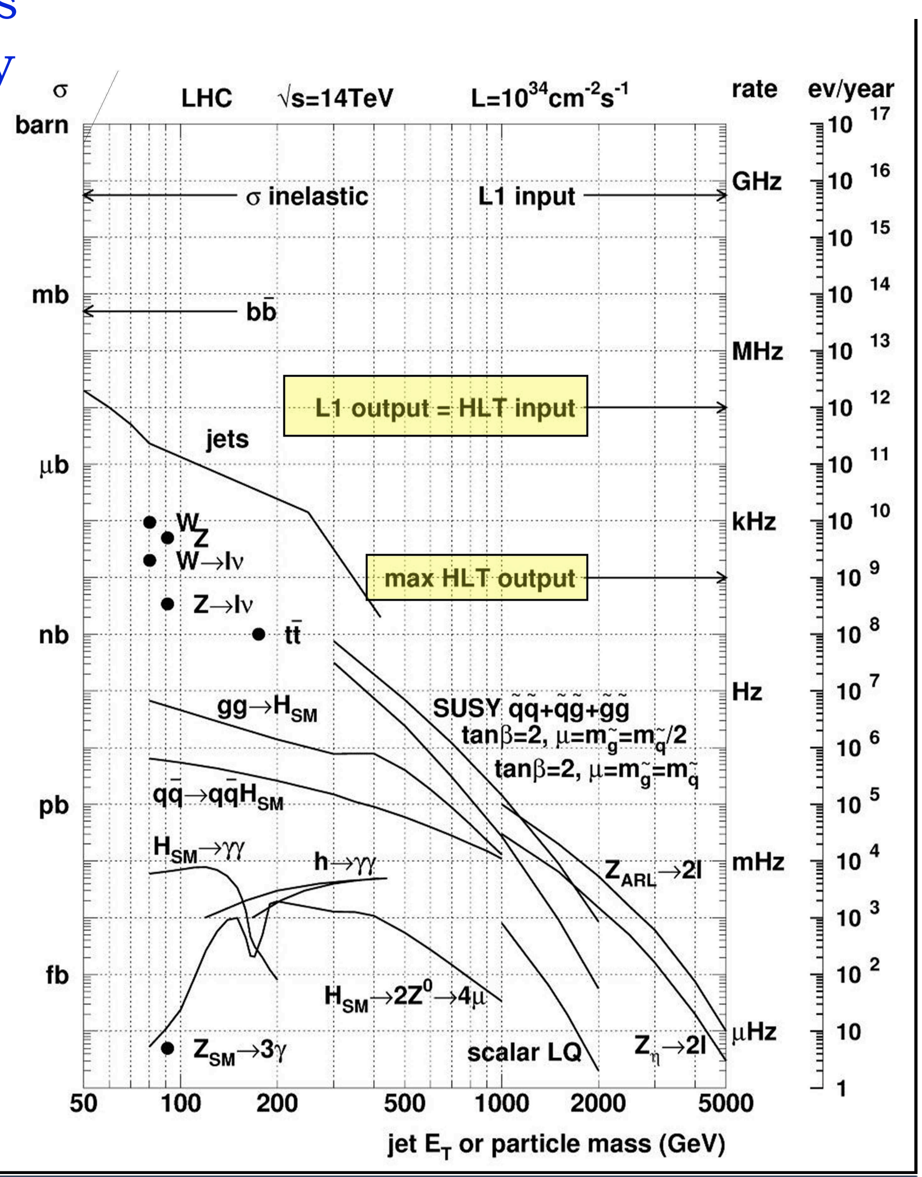
Final system

- 17 LVL2 racks (~500 PC)
- 62 EF racks (~1800 PC)
  - 28 configurable as LVL2 or EF (XPU)

ATLAS Trigger

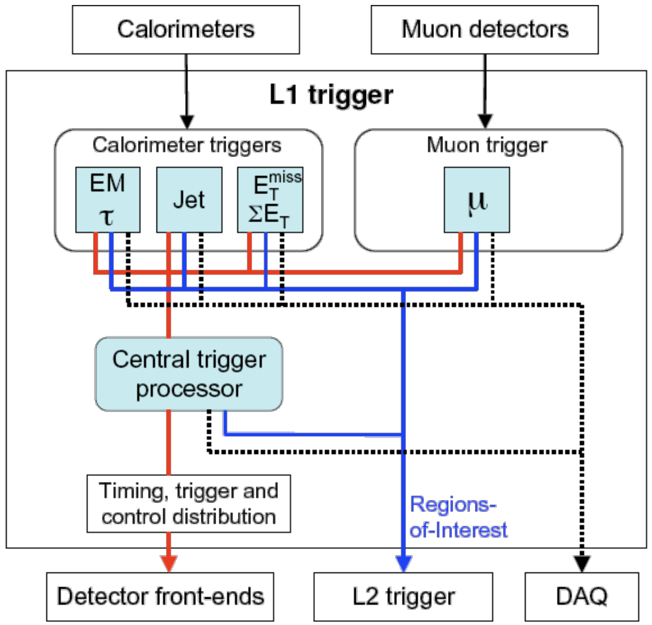
Trigger: Introduction

- Large rejection against QCD processes is needed while maintaining high efficiency for low cross-section physics processes (e.g. new physics)
- Start-up luminosity (up to 10^{31} cm^{-2} s^{-1})
  - ★ Standard Model processes
  - ★ Trigger and detector commissioning
  - ★ Selection strategy focused on
    - ➢ Low thresholds
    - ➢ Loose selection criteria
    - ➢ HLT algorithms in pass-through mode (only at the very beginning)
- Design luminosity (10^{34} cm^{-2} s^{-1})
  - ★ reduce background rates while achieving selection of interesting physics with high efficiency
    - ➢ Higher thresholds
    - ➢ Isolation criteria
    - ➢ Tighter selections



Level 1

- Rate to be reduced from 40 MHz to ~40 kHz
  - ★ 75 kHz at nominal luminosity
- Latency 2.5 μs
- Data from calorimeter and muon detectors
  - ★ reduced granularity of precision measurements
- Identifies physics objects: EM, τ, jet, μ, ΣE_T, E_T^{miss}
- Identifies the regions of the detector that contains the object, i.e. RoIs



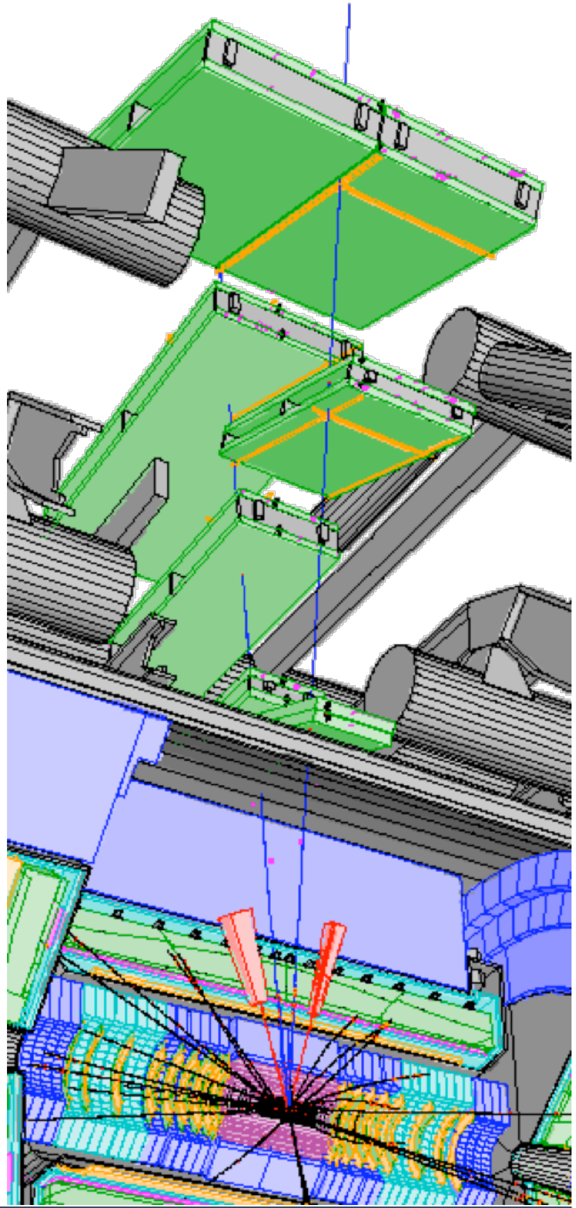
Object	Thresholds #
EM	8-16
τ	0-8
Jets	8
For. jets	4+4
E_T^{miss}	8
$\Sigma\ E_T$	4
$\Sigma\ E_T$(jets)	4
$\mu \leq 10$ GeV	3
μ >10 GeV	3

- Total number of LVL1 trigger items up to 256
  - ★ Each item is a combination of one or more of the configured thresholds
  - ★ For each item a pre-scale value can be specified

LVL1 pre-scale value can be adjusted to keep the output bandwidth filled without stopping and restarting a run

Level 2

- Rate to be reduced from 40 kHz to 3.5 kHz
- Average event processing time is 40 ms
- The selection is performed by specialized algorithms running on a farm of PCs
- The LVL2 processing is seeded by the RoI
  - ★ selectively accesses and analyzes data from limited regions of the detector (i.e. the RoIs)
  - ★ reduces processing time and required network bandwidth
- Refined analysis of the LVL1 object based on
  - ★ full granularity detector data
  - ★ up-to-date calibration constants
  - ★ ability to access all detector data such as tracking
    - ➢ primarily within the RoI
  - ★ topological selection criteria that can be applied



Event Filter

- EF performs the final online selection
  - the complete built event is available
  - algorithms are seeded by LVL2
- Rate to be reduced from 3.5 kHz to ~200 Hz (corresponding to ~300 MB/s) at both start-up and nominal luminosity
  - the output rate is limited by the offline computing budget and storage capacity
- The average event processing time is 4 s
- Seeded by the result of the LVL2 processing
  - although it has direct access to the complete data for a given event
- EF mostly uses offline algorithms running on a farm of PCs
  - more sophisticated and time consuming selection algorithms
  - Up-to-date calibrations constants are used to improve the selection
- Event classification is performed
- Based on classification, events are written by SFO to different data streams for storage

Data Streams

- Inclusive streaming model has been adopted
- Events will be streamed to one or more files based on the EF classification
  - ★ 4 data streams: electrons or photons, jetTauEtmiss, muons and minbias
    - ➢ foreseen for physics running
  - ★ express stream: it contains a subset of triggers and can be used to provide a feedback on the quality of data
    - ➢ intended for monitoring (not for physics analysis)
  - ★ calibration stream: it includes triggers that provide data needed for detector alignment and energy scale operations
    - ➢ partial event building is available
- Each stream contains events that pass one or more signatures

example

Stream	Total rate (Hz)	Unique rate (Hz)
egamma	55	48
jetTauEtmiss	104	89
muon	35	29
minbias	10	10
express	18	0
calibration	15	13

- Unique rate reflects the number of events written only to the specified stream
  - ★ difference between the total rate and the unique rate is the rate of replicated events in each stream

ATLAS
Trigger Menu

Trigger Menu

- Table of trigger signatures, each specifying the thresholds and selection criteria to be used at each trigger level
  - ★ A criteria is based on one or more objects
- It provides a recipe for triggering on various physics processes

- Each signature is considered carefully:
  - ★ its physics goals
    - ➢ or commissioning or calibration goals
  - ★ efficiency and background rejection it provides to meet these goals
  - ★ bandwidth consumed
- Start-up phase will be an extend period of time (more than 6 months)
- Different menus are being prepared with increasing complexity to match different running conditions

Objects	Examples of signatures
Electrons	$e3$, $e7$
Photons	γ60i, 2γ20i
Muons	μ4, μ6
Jets	$j5$, $j10$, $j70$, $3j10$
Jet + E_T^{miss}	$j70$ + xE70
Tau + E_T^{miss}	τ35 + xE45

Physics strategy

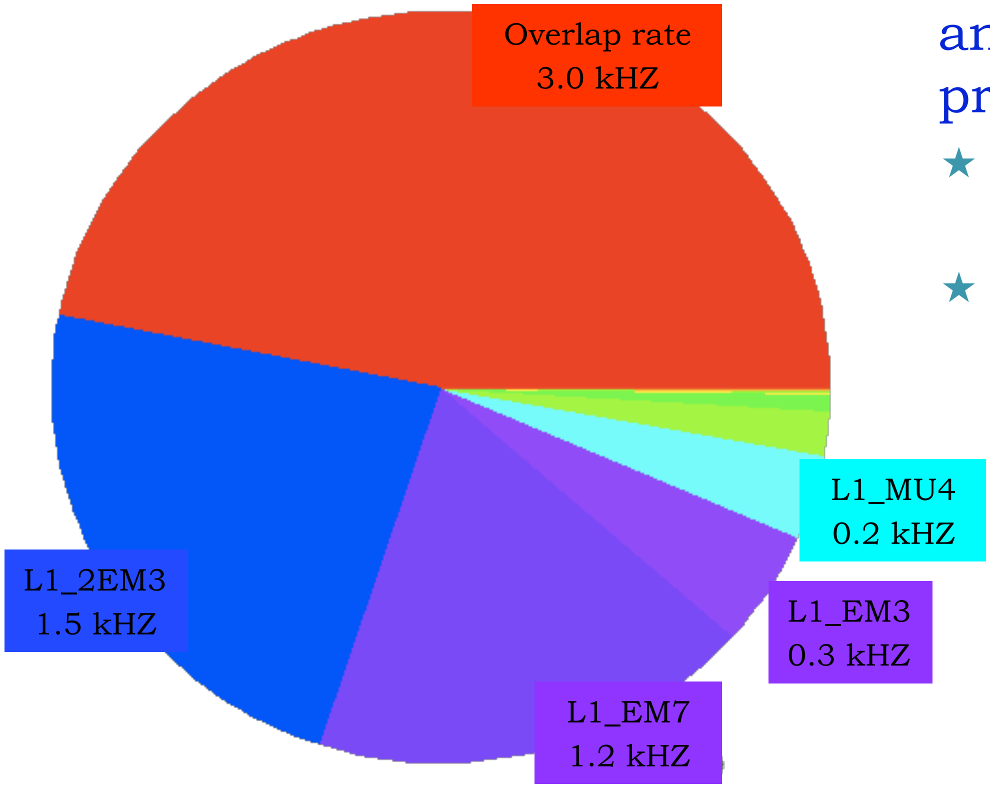
- Initial physics is almost all about
  - understanding the detector
  - object triggering
  - identification performance (background, efficiency)
- High priorities in the first data:
  - Understanding simpler object triggering, reconstruction, identification, background, efficiency
    - e, γ, μ, jets
  - At the same time, start commissioning more complex signatures
    - τ, E_T^{miss}, flavour tagging
- A trigger menu for the start-up phase has been developed
  - ~150 items at LVL1
  - ~200 items at HLT
- Trigger menus also include additional signatures for trigger validation, monitoring, calibration and measuring the performance of the physics trigger signatures

Physics motivations: examples

Signature	Motivation
e (10 GeV)	$e+$, $e-$ from b, c decays, E/p studies, $Z\to\tau\ \tau\to eX$
$2e$ (5 GeV)	$J/\psi\to ee$, $\Upsilon\to ee$, Drell-Yan
e (20 GeV)	Z→ee, W→eν, top, main physics, efficiency estimation for tau trigger, high-p_T physics
γ (20 GeV)	direct photon, jet calibration using γ-jet events, high p_T physics
μ (10 GeV)	Bphysics, W, Z, top to muons, $Z\to\tau\ \tau$
2μ (4 GeV)	Bphysics, Drell-Yan, J/ψ, Υ
μ (4 GeV), $J/\psi\to\mu\ \mu$ (full scan)	$J/\psi\to\mu\ \mu$ cross section and polarization, B-cross section measurement
μ (4 GeV), $J/\psi\to e$ (5 GeV) e (3 GeV) (full scan)	$J/\psi\to ee$ channels
τ (16 GeV) & EF E_T^{miss} (30 GeV)	$W\to\tau\ \nu$, $W\to e\nu$, X→$\tau\ \tau$ (X=Z, SM h, Heavy Higgs, Z, SUSY di τ
…	…

LVL1 Trigger Menu at $10^{31}cm^{-2}\ s^{-1}$

LVL1 Unique Rates



- Unique rate is the number of events that fulfill one trigger signature
- Overlap rate includes events that fulfill more than one trigger signature

- Combining objects provides at LVL1 another mechanism to control the rates preserving many physics requirements
  - ★ single-object triggers may suffice for low luminosity running
  - ★ multi-objects triggers need to be deployed at low luminosity to
    - ➢ validate them
    - ➢ ensure their reliability at high luminosity

Trigger chain	Rate (Hz)	Unique Rate (Hz)
L1_2EM3	3300	1490
L1_EM7	2600	1200
L1_2EM3_TAU6	1770	0
L1_MU4	1060	236
L1_2EM3_EM7	1030	0
L1_MU6	755	0
L1_MU10	610	0
…	…	…

HLT Trigger Menu at $10^{31} cm^{-2} s^{-1}$

Most of the LVL2 and EF triggers are used

in pass-through mode

or

with loose selections and low un-prescaled thresholds

LVL2

Trigger chain	Rate (Hz)	Unique Rate (Hz)
Egamma_L2	186.0	165.0
Express_L2	79.6	6.71
jetTauETmiss_L2	160.0	138.0
Minbias_L2	0.17	0.17
Muon_L2	104.0	100.0

EF

Trigger chain	Rate (Hz)	Unique rate (Hz)
Egamma_EF	41.80	30.30
Express_EF	14.50	3.65
jetTauETmiss_EF	29.40	27.90
Minbias_EF	0.17	0.17
Muon_EF	16.90	16.20

- This allows validation of many trigger algorithms during the start-up phase
- Higher threshold trigger signatures required during high luminosity running are also deployed to validated them early on

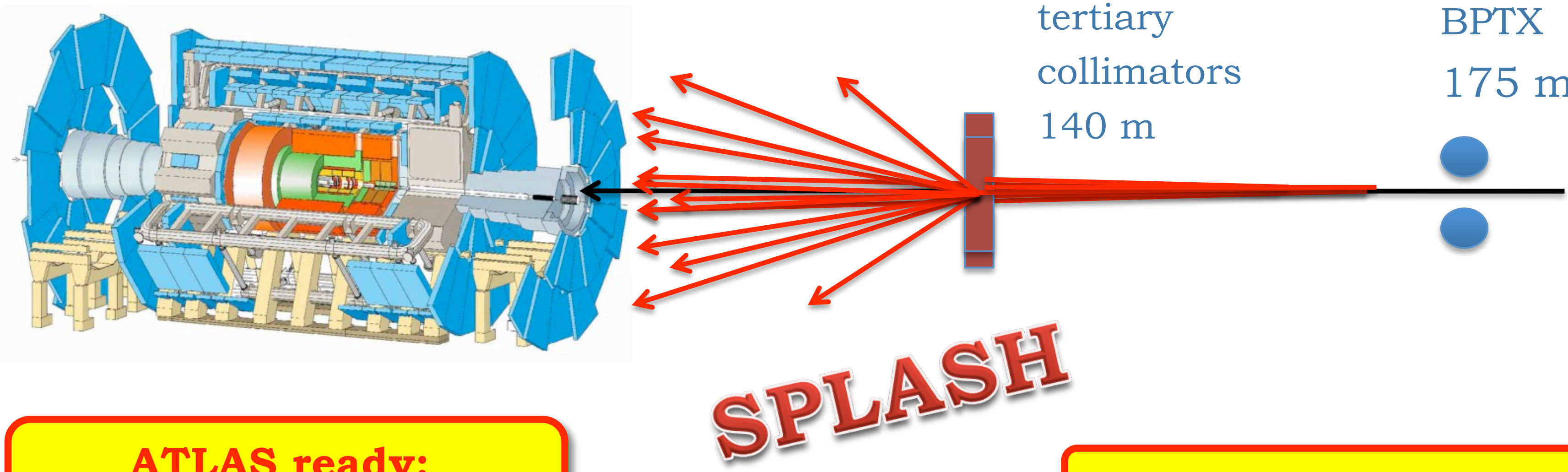
Well within the design bandwidth

Rates estimated using a sample of simulated minimum-bias events: large uncertainties in simulation

Level	Rate at L = 10^{31} cm^{-2} s^{-1}
LVL1	6470.0 Hz
LVL2	427.0 Hz
EF	94.2 Hz

10 September 2008
ATLAS was ready

10 September 2008: firsts beams



ATLAS ready: beam operation mode

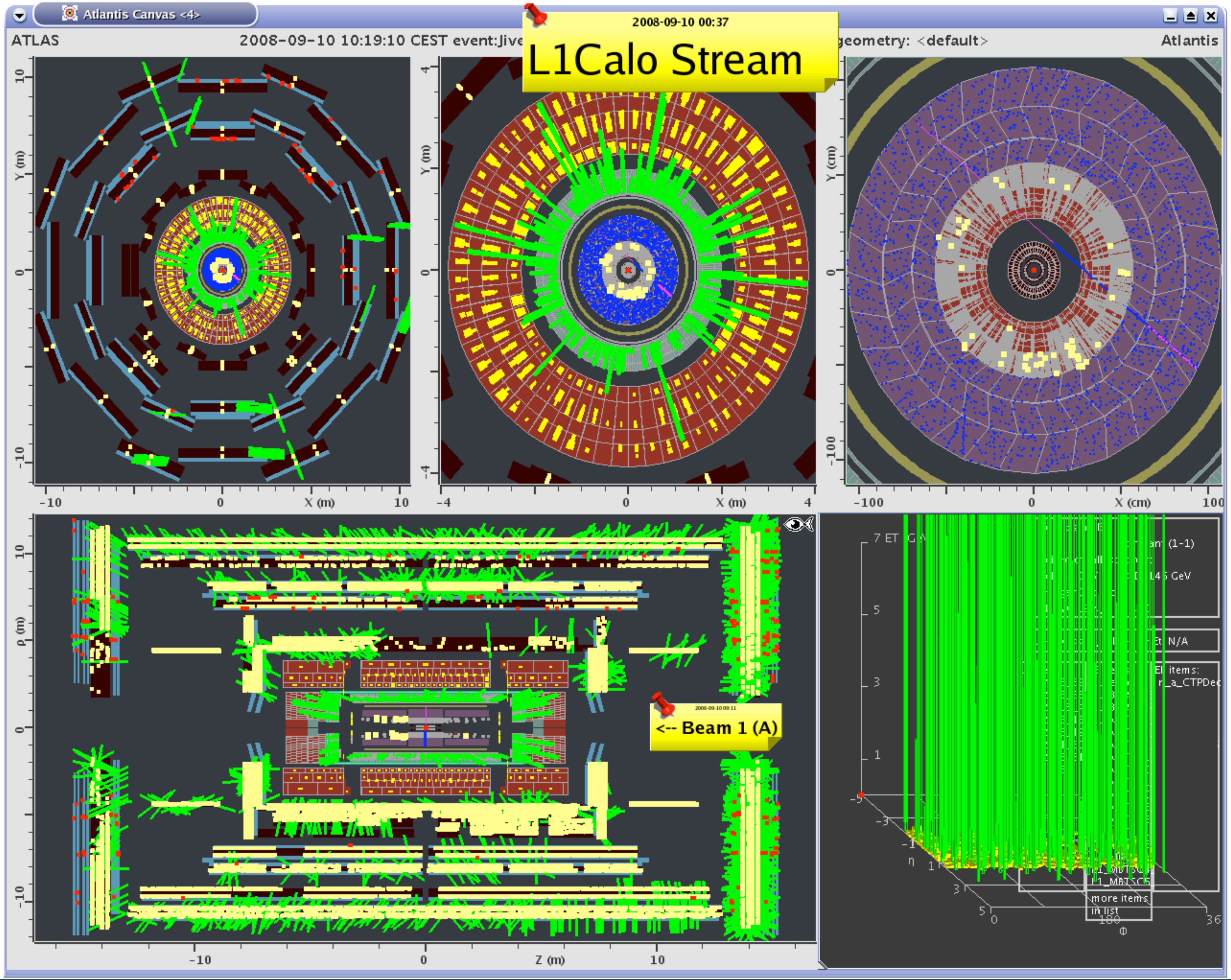
- Muon system with reduced HV
- TRT on, SCT reduced HV, Pixel off
- BCM, LUCID, MinBias Scint. (MBTS), Beam Pickups (BPTX)
- L1 trigger processor, DAQ up and running, HLT available (but used only for streaming)
- Trigger Menu: single beam

LHC startup scenario

- Machine strategy:
  - ★ Stopping beam on collimators
  - ★ Re-aligning with centre
  - ★ Opening collimator
  - ★ Circulating beam (up to 30 minutes)
- **Splash** from collimators for each *beam shot*
- Radio Frequency turned on

At Trigger desk...

… and on the projector …

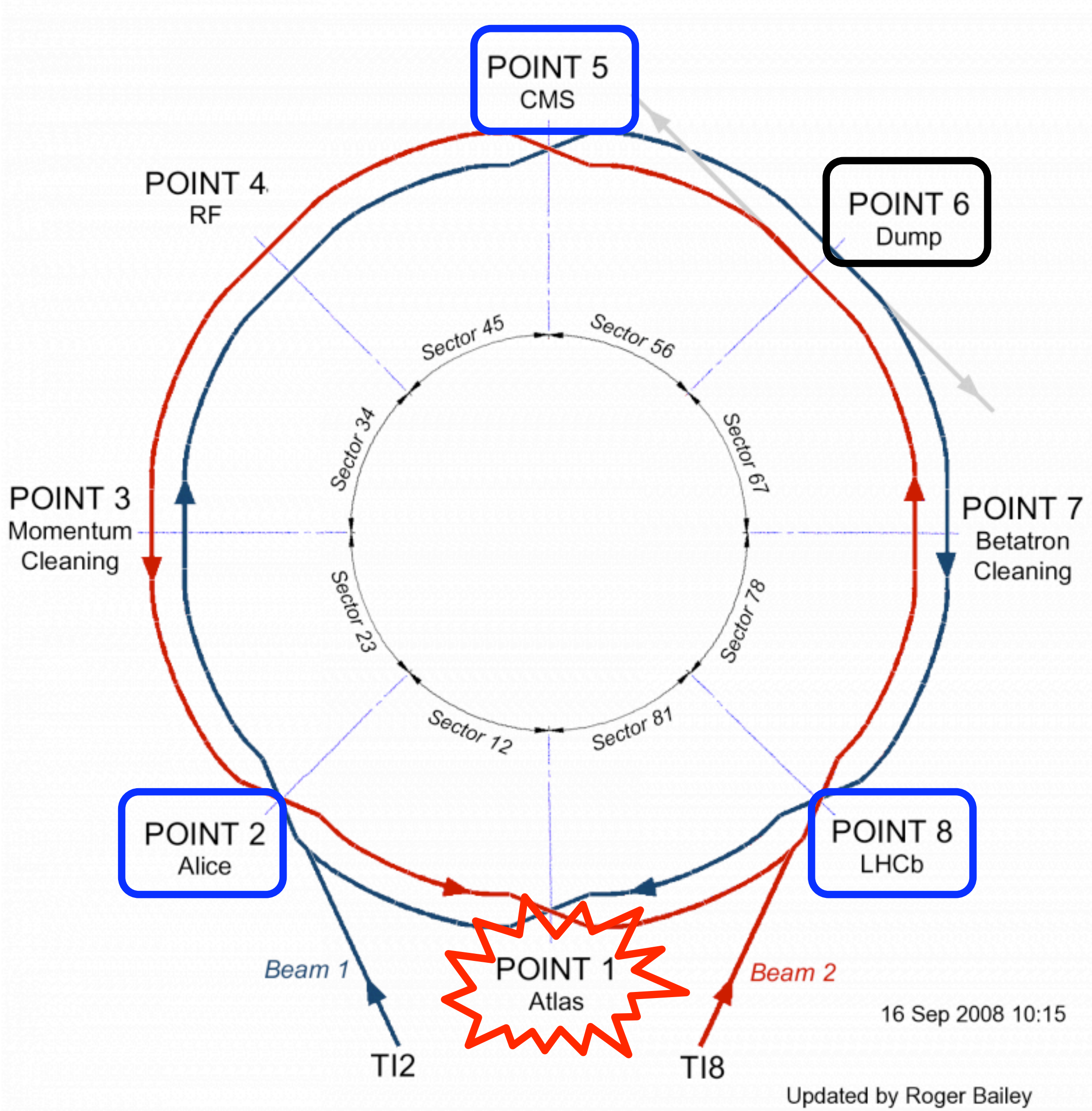


Conclusions

- ATLAS is (was on September 10th, 2008) ready to take data
  - ★ Successfully operated with first beams
- Large fraction of the Trigger and Data Acquisition system has been installed and commissioned
  - ★ Functionality are all there, 65% of the HLT farm to be added (CPUs)
    - ➢ imply a lot more processes to configure and control the system
  - ★ Tests performed show that both the architecture and the hardware deployed meet ATLAS requirements
- A trigger menu has been developed for the LHC start-up phase
  - ★ Low thresholds and loose selections allow for rapid commissioning and preparation for high luminosity
  - ★ Trigger items and their performance have been studied in detail with MC at both low and high luminosity
  - ★ Detector commissioning needs feedback on its performance
- Trigger rate estimates are within the TDAQ design specifications
- Trigger and Data Acquisition system was (and is being) used successfully in data taking for commissioning runs (cosmic rays)

Backup slides

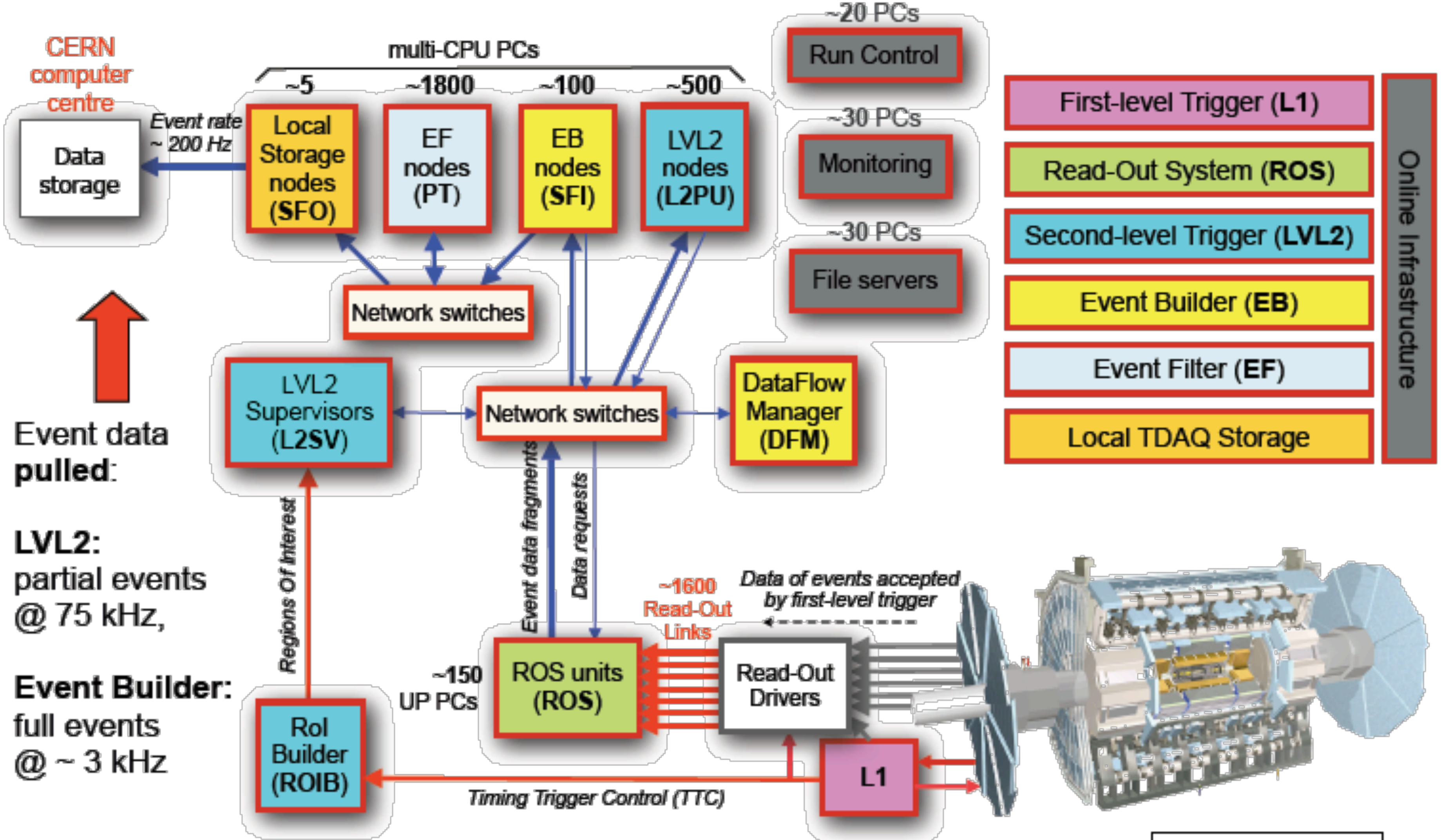
LHC: schema of the 2 beams and sites



10 September 2008

- 7025 applications
  - Maximum tried 9000
- 1535 computer
  - TDAQ
    - 25 online nodes
    - 31 monitoring nodes
    - 154 ROS
    - 63 SFI
    - 5 SFO
    - 11 DFM
    - 2 L2SV
    - 789 XPU
  - Detector nodes
- Log file (Run 87764)
  - 115 k messages archived into database (Oracle)
- DAQ Configuration
  - Described in a database (OKS) di 47 MB
  - 49 schema files, 483 classes
  - 771 data file, 114 k "objects"
- Data Quality
  - 100 k histograms saved
  - 10 k histograms checked per minute

Trigger and DAQ overview



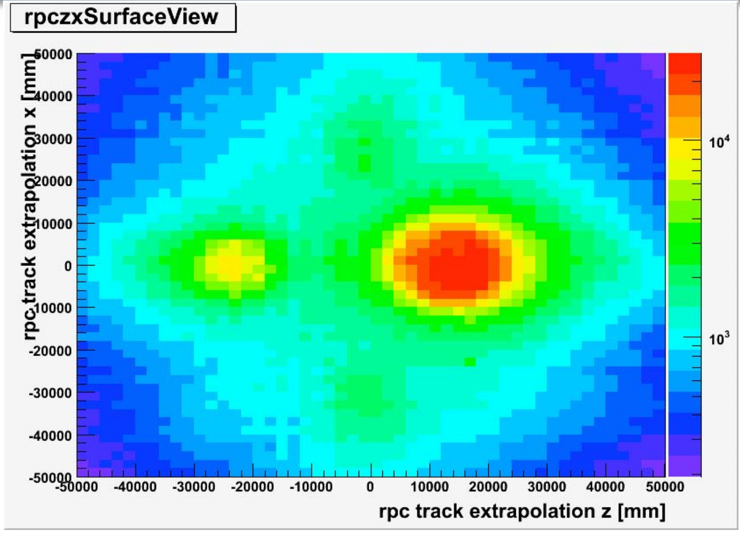
Event data **pulled**:

LVL2:
partial events
@ 75 kHz,

Event Builder:
full events
@ ~ 3 kHz

Event data **pushed** @ ≤ 100 kHz,
1600 fragments of ~ 1 kByte each

Cosmic rays


rpczxSurfaceView
rpc track extrapolation x [mm]
rpc track extrapolation z [mm]
50000
40000
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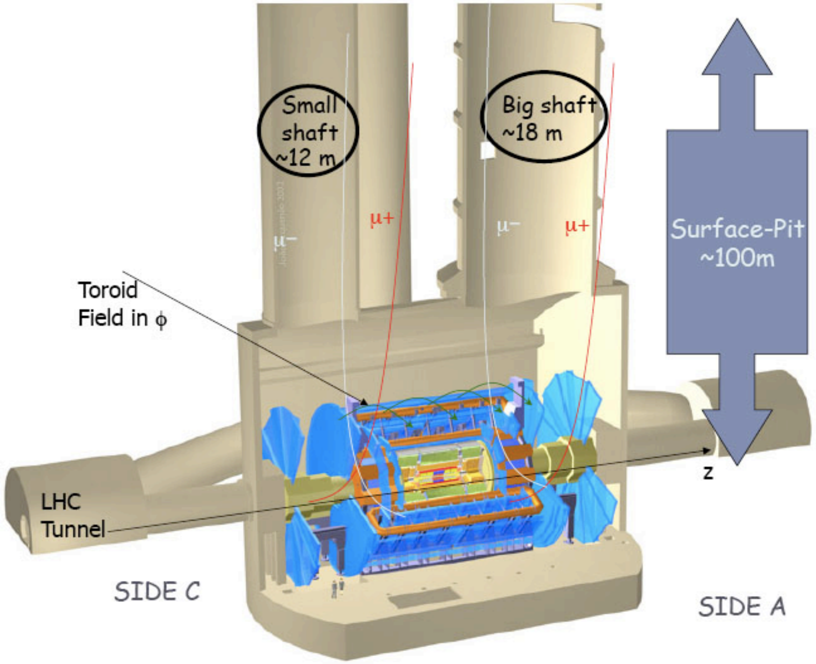
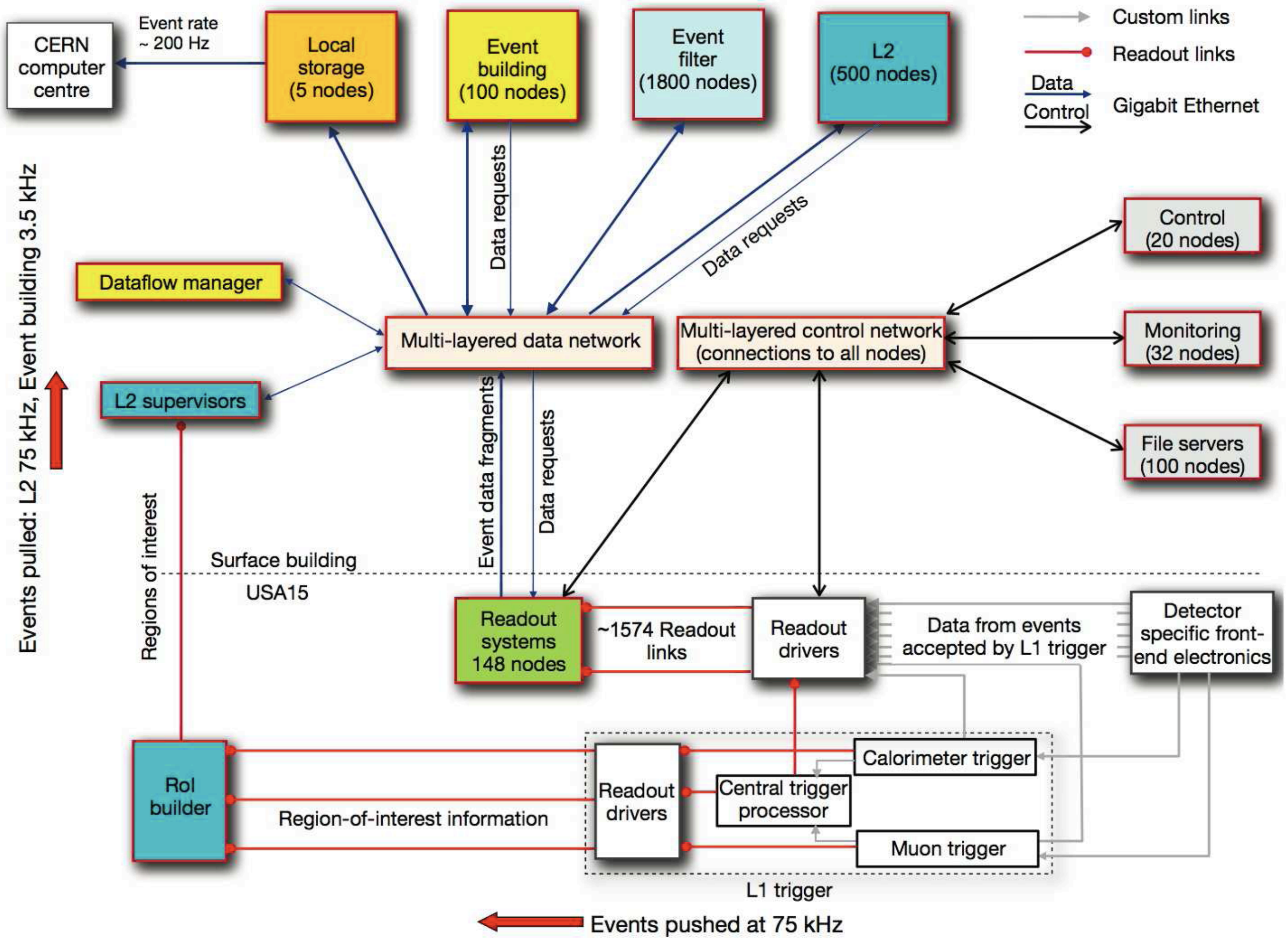
10^4
10^3


Small shaft ~12 m
Big shaft ~18 m
μ−
μ+
μ−
μ+
Surface-Pit ~100m
Toroid Field in φ
LHC Tunnel
z
SIDE C
SIDE A

TDAQ block diagram



Rates: view of 10 TeV at 10^{31}cm^{-2} s^{-1}

Rates estimated using a sample of simulated minimum-bias events

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Well within the foreseen bandwidth