# LHC Experiments - Trigger, Data-taking and Computing

- data rates
- physics signals
- ATLAS trigger concept
- LHC computing model

# Data rates at the LHC

- 20 (40) MHz bunch crossing rate; about 35 collisions / xing
- –> ~ $10^9$ interactions per second (at L = $10^{34}$ $cm^{-2}s^{-1}$)
- ATLAS: ca. $1.5 \cdot 10^8$ electronic channels
- 1-2 MByte detector data per event (bunch crossing) (including active zero suppression)
- –> ~$10^{14}$ - $10^{15}$Bytes/s raw data (~ 10 billion phone calls )
- data taking time per year: $10^7$ seconds (~100 efficient days)
- impossible to store $10^{21}$ B per year (1 million Petabytes)!

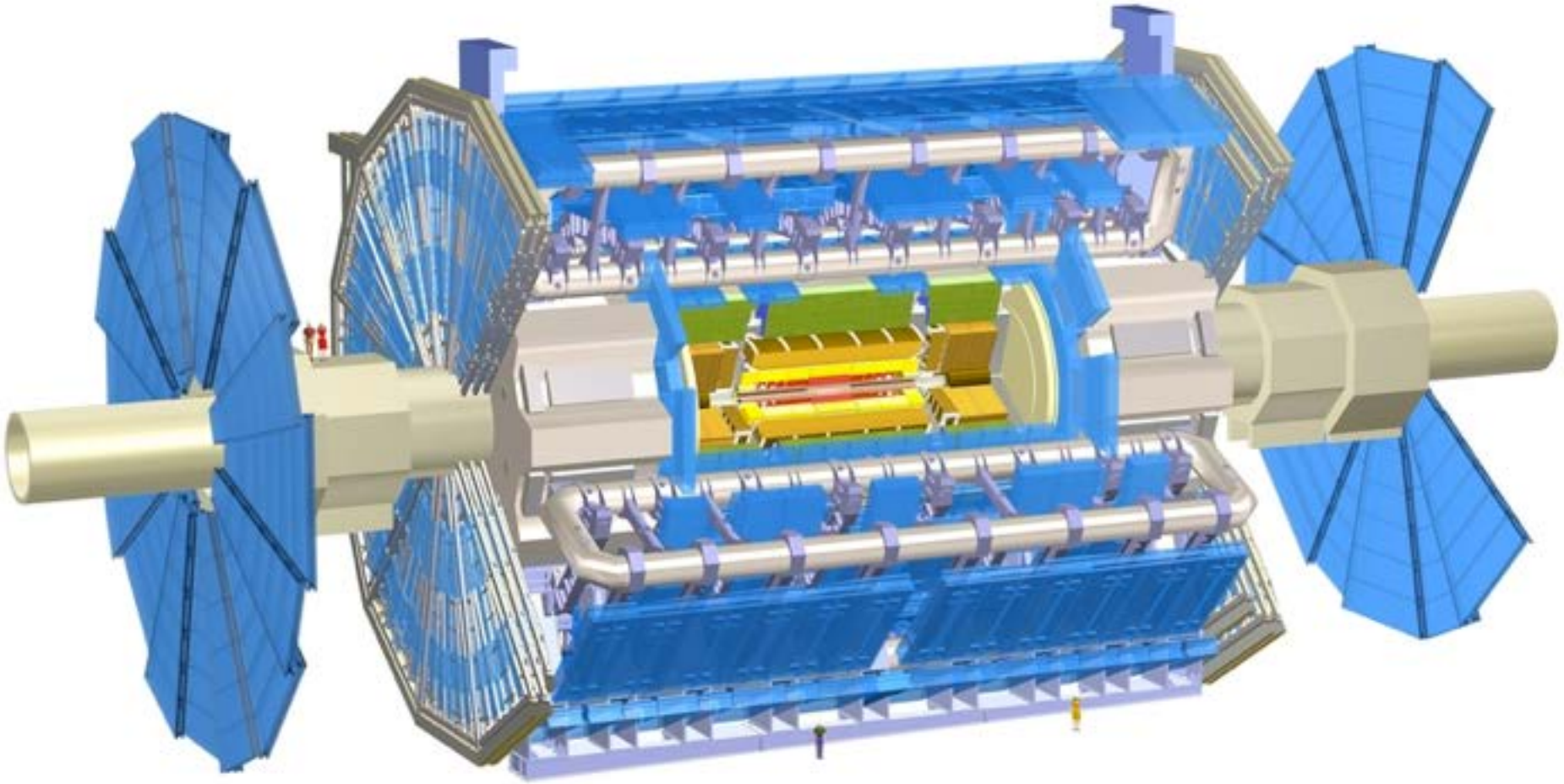
–> need to reduce data flow by about a factor of $10^6$ !!

# The ATLAS Detector at the LHC

| | |
|---|---|
| Length: | 44 m |
| Height: | 22 m |
| Weight: | 7000 t |

3000 Physicists & Engineers
(incl. 1000 Students)
178 Institutes
38 Nations

| | |
|---|---|
| $150 \cdot 10^6$ | electronic readout channels |
| 40 MHz | collision rate |
| $10^{14}$ B/s | raw data flux |

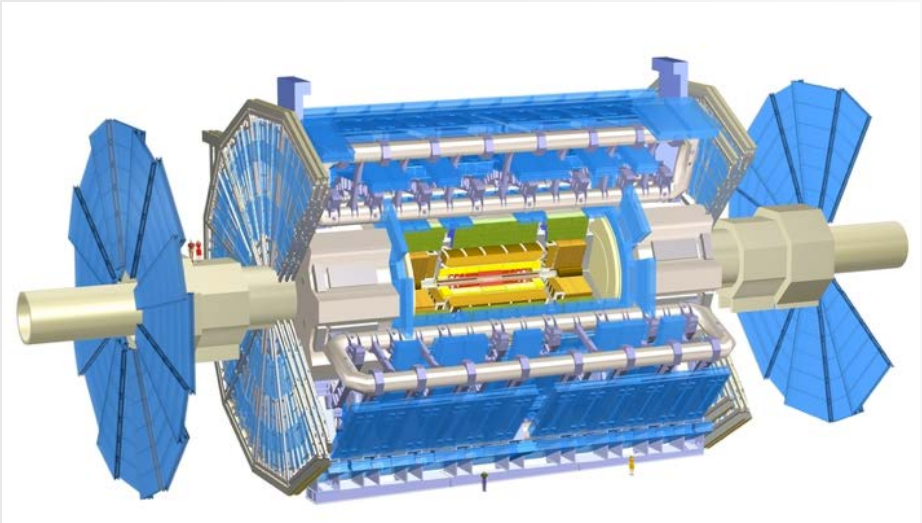


# number of active detector channels at ATLAS

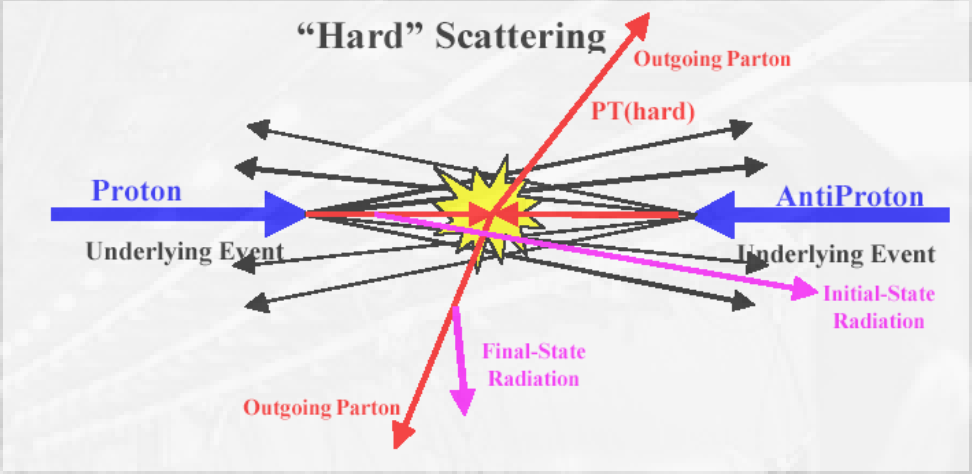
**Table 2-1** Number of active detector elements, number of modules or chambers, and number of GEANT volumes defined for the detailed simulation of each of the various ATLAS detector systems.

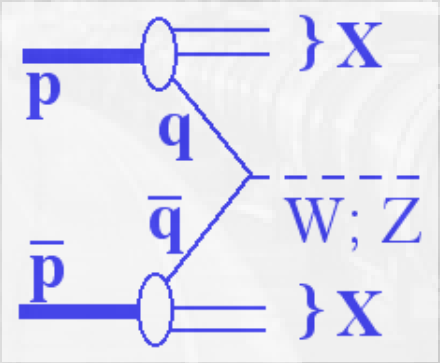
| Detector system | Number of active detector elements | Number of modules or chambers | Number of GEANT volumes defined |
|---|---|---|---|
| Pixels | 140 000 000 | ~2 200 | 26 000 |
| Silicon microstrips | 6 280 000 | ~4100 | 50 000 |
| Transition radiation tracker | 420 000 | ~240 | 2 260 000 |
| LAr accordion calorimeters | 170 000 | 48 | 9 960 000 |
| LAr hadronic end-cap and forward calorimeters | 9 000 | 134 | 890 000 |
| Tile Calorimeters | 10 000 | 192 | 900 000 |
| Muon System | 1 230 000 | ~2 000 | 1 850 000 |

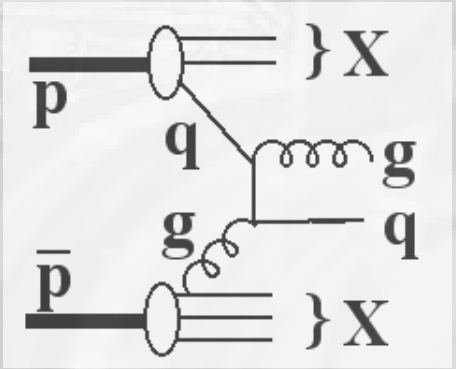
relevant for MC simulation

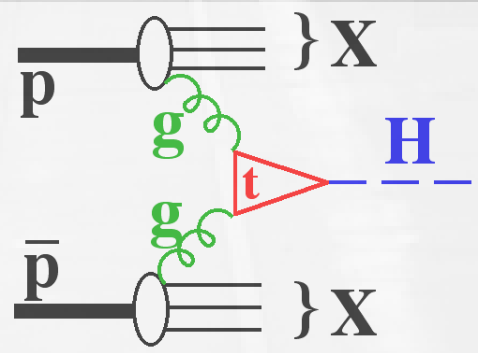


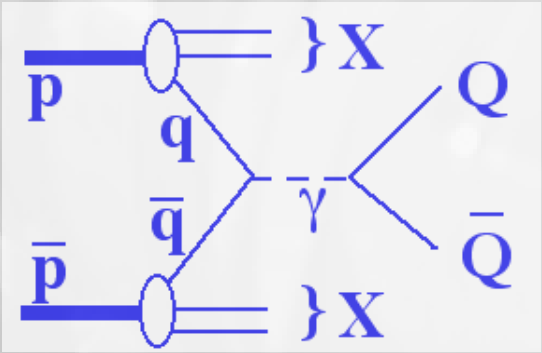
# physics signatures at Tevatron ($p\bar{p}$) / LHC ($pp$)



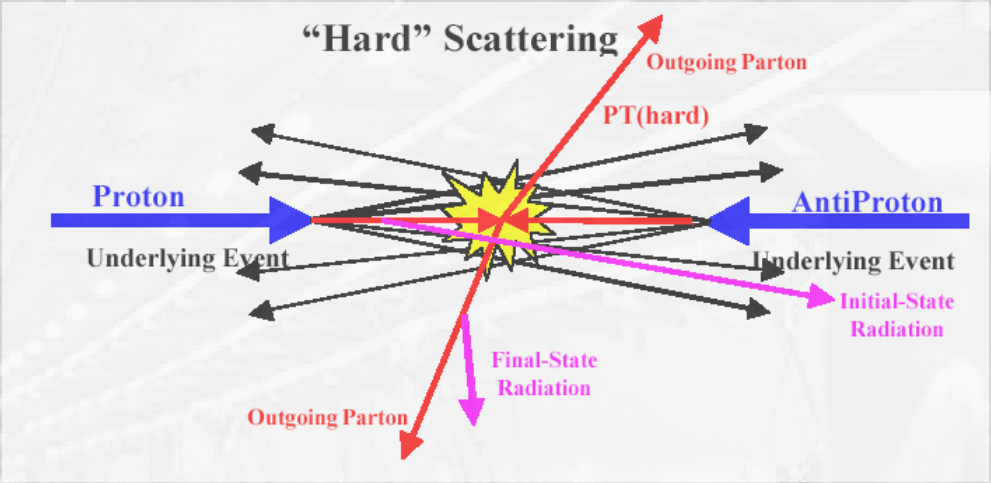



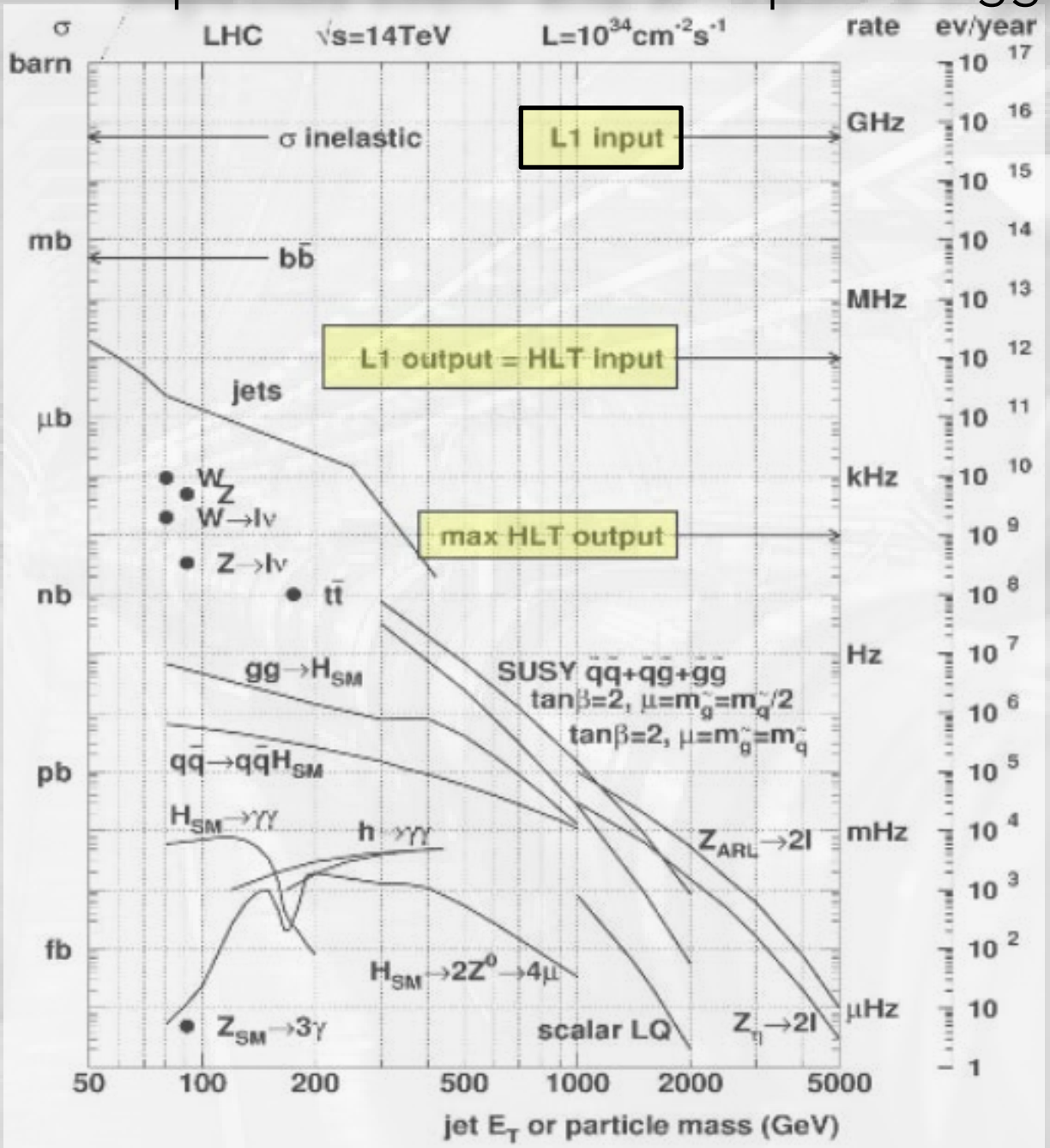
# physics signatures




- as energies of colliding quarks/gluons are unknown:
  in general, restrict to "transverse" observables
  (i.e. ⊥ wrt. beam axis, where E-p-conservation holds: $\sum \vec{p}_T = 0$

- particular signatures of almost all "interesting" processes:
  - high energetic hadron-jets
  - high energetic leptons (e, μ, τ) or photons (γ);
  - missing (transverse) energy (Neutrinos, Neutralinos….);
  - secondary vertices (b-Quark-decays)

# expected event- and anticipated trigger-rates



# trigger-language:

**pile-up:**

- more than one p-p collision in one event (in time pile-up)
- effects through neighbouring bunch-crossings
- at L = $10^{34}$ $cm^{-2}$ $s^{-1}$ about 35 collisions per bunch-crossing

**Threshold:**

- cut on measured quantity, e.g.: Jet $p_T$ > 200 GeV; $E_T^{miss}$ > 50 GeV

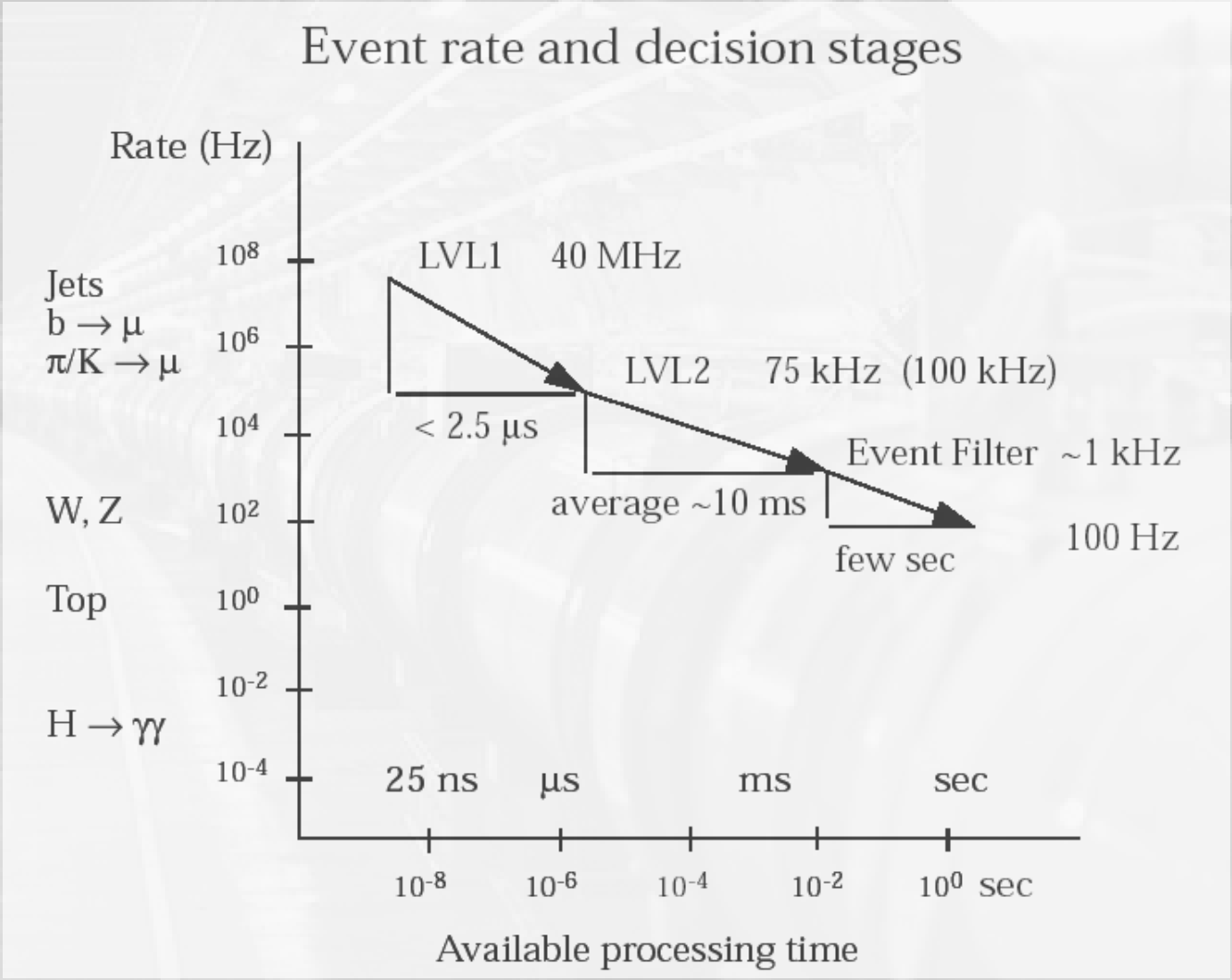
**Trigger Rate:**

- rate of selected events (mostly dominated by QCD or „junk“)

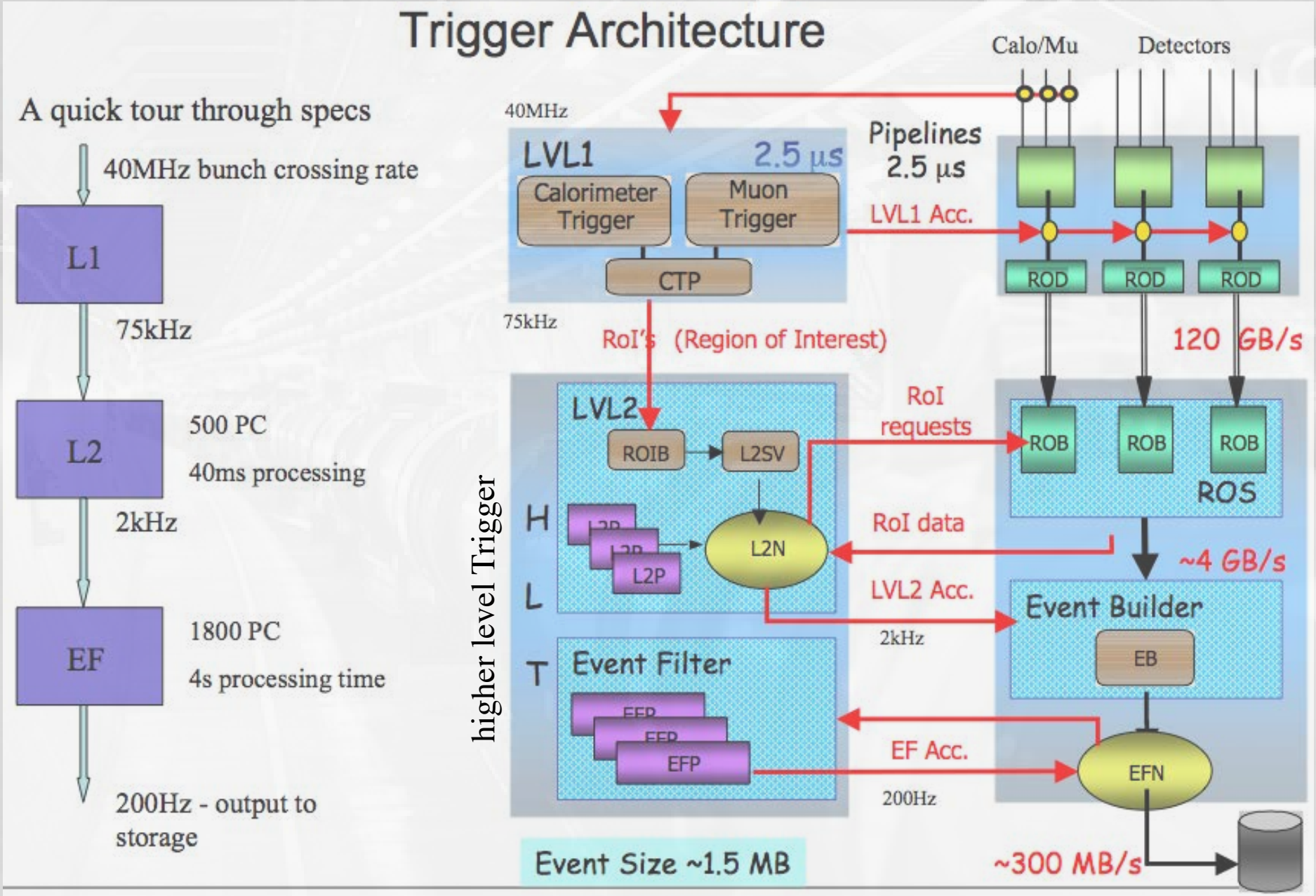
**pre-scaling:**

- only keep a fraction of selected events
- method to keep low thresholds without too large data volume
- method to study performance of high thresholds
- **no** good for discovery of New Physics…

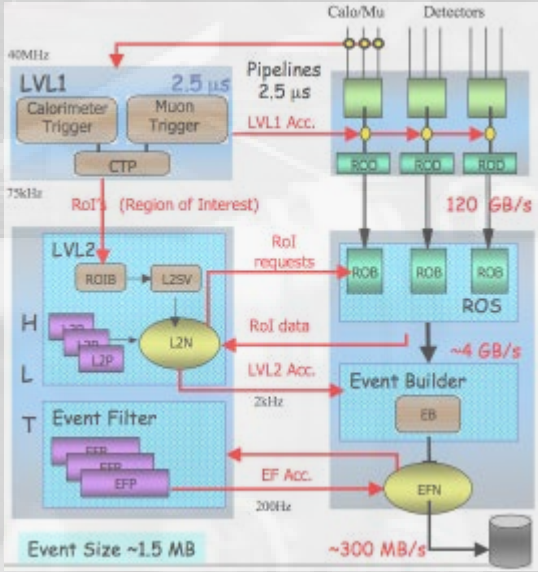
# ATLAS: data rates and trigger decisions



# ATLAS Trigger/DAQ System



# ATLAS Level 1 Trigger




- fast identification of
  basic signatures of 'interesting' physics

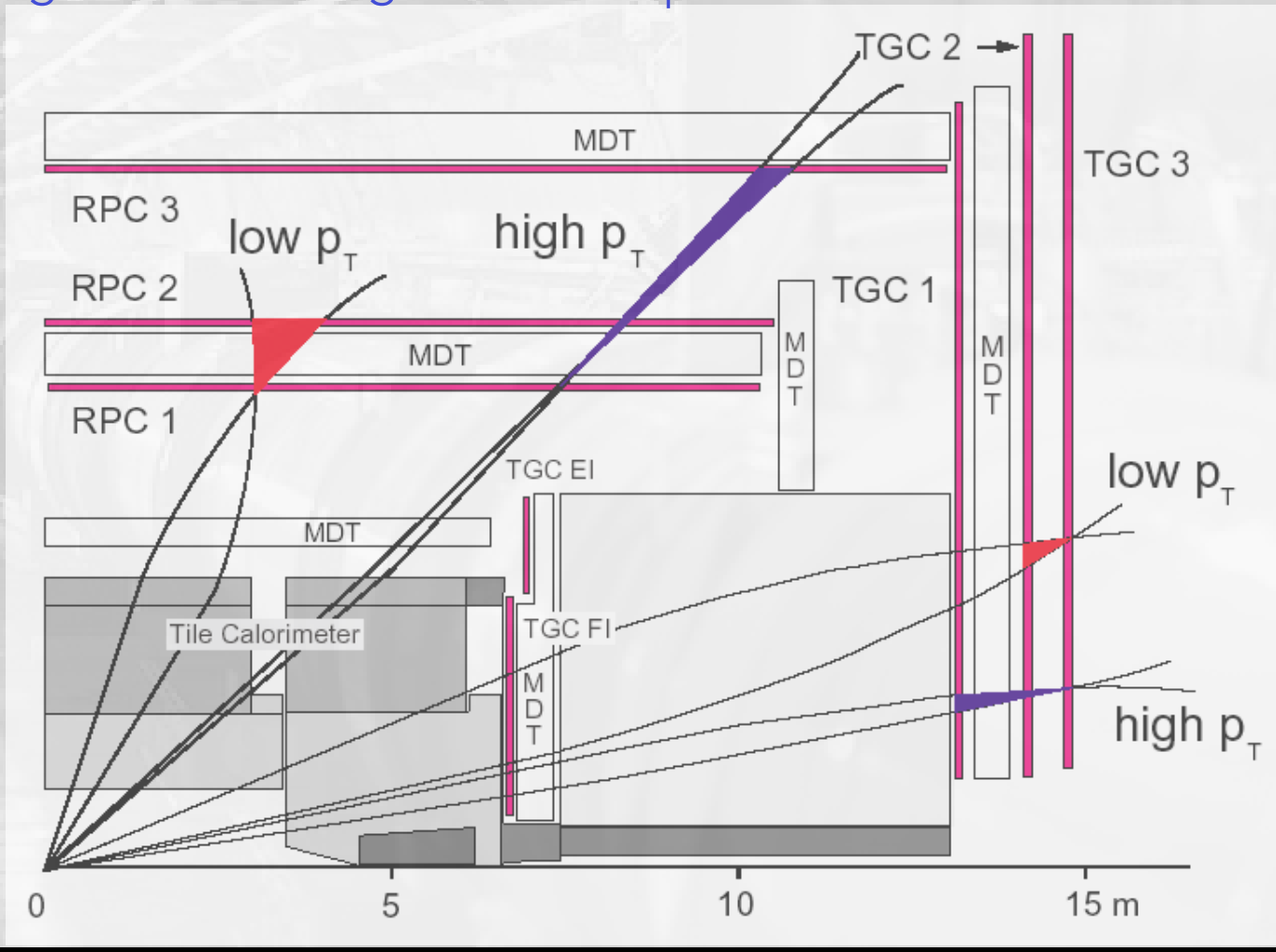
- decisions based on existence of
  local trigger-objects for different $p_T$ thresholds:
  - muons
  - electromagnetic cluster (perhaps with isolation criteria)
  - narrow particle jets (hadr. τ decays, isolated hadrons)
  - hadronic jets
  - missing transverse energy
  - total scalar transverse energy

- simple algorithms for fast decisions (~ 2 µs), based on
  coarse information from:
  - µ-trigger chambers und 'tower summing' calorimeter information

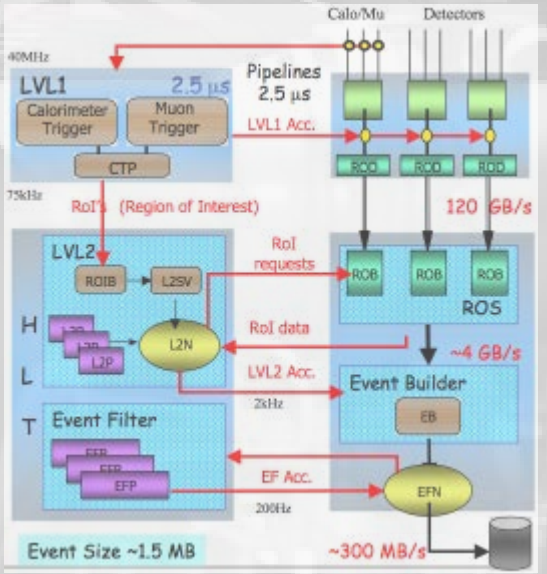
- algorithms are executed by fast 'custom made electronics', e.g. FPGA's

# ATLAS Level 1 μ–Trigger

- measurement of bending of tracks in magnetic field through three fast μ trigger-stations
- deviation of track signals from straight-line extrapolation



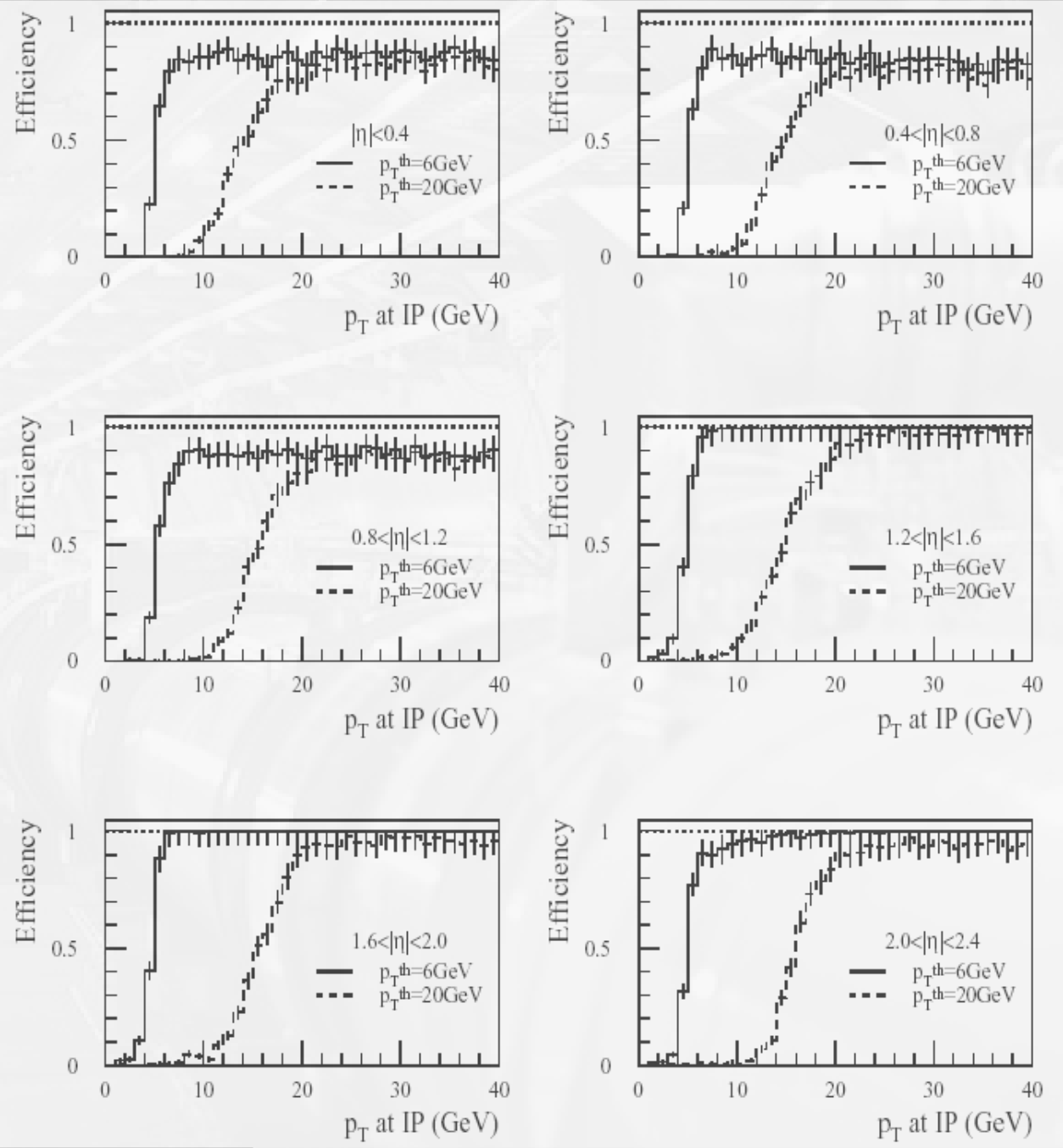
# ATLAS Level 1 Trigger (cont.)




- during LVL1 processing, all data of all detector systems are kept in pipeline memories (close to detector; radiation hard electronics, $> 10^7$ electron. channels!)
- LVL1 defines "Regions of Interest" (RoIs) as input for LVL2 (marks position $\{\eta = -\ln(\tan(\theta/2)), \varphi\}$ und $p_T$)
- LVL1 also identifies and defines individual bunch crossing (difficult as distance is only 25 ns, similar to time-of-flight through detector and much shorter than typical puls lengths measured in calorimeters)
- adjustment of acceptance criteria, such that reduction from 40 MHz to max. 75 kHz is achieved
- if LVL1 accepts the event, data will be read out and formatted; derandomizer sorts data to events; RODs (read-out drivers): on detector.

efficiency of

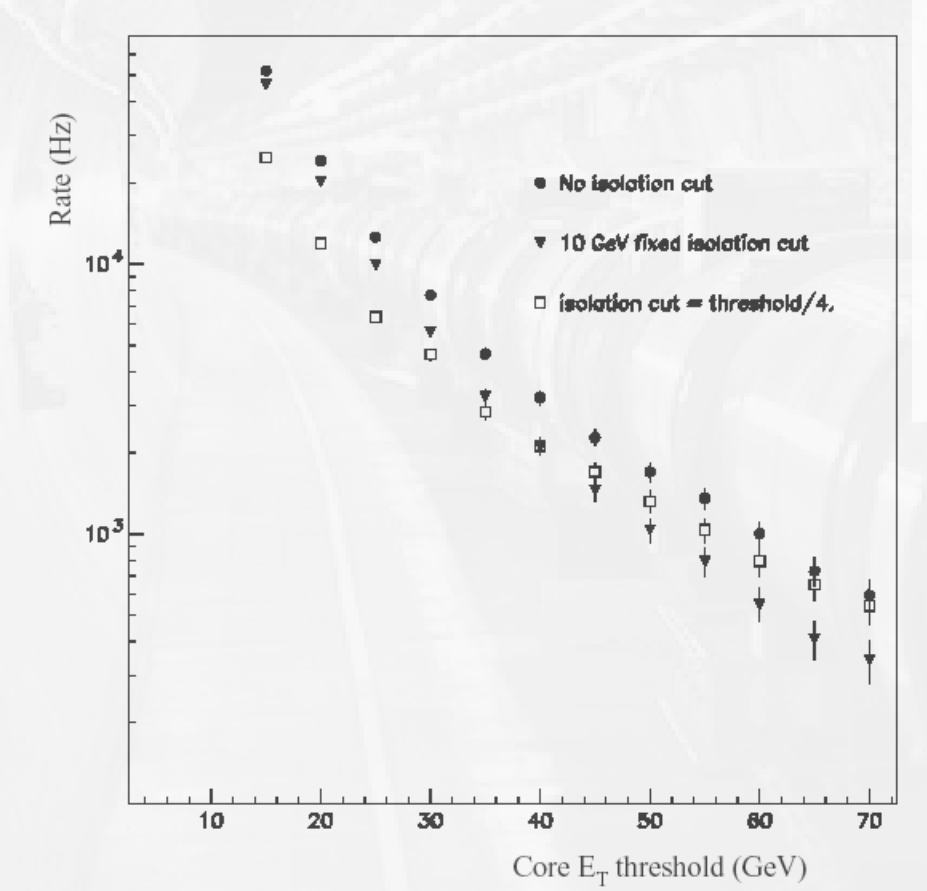
ATLAS LVL1 μ trigger

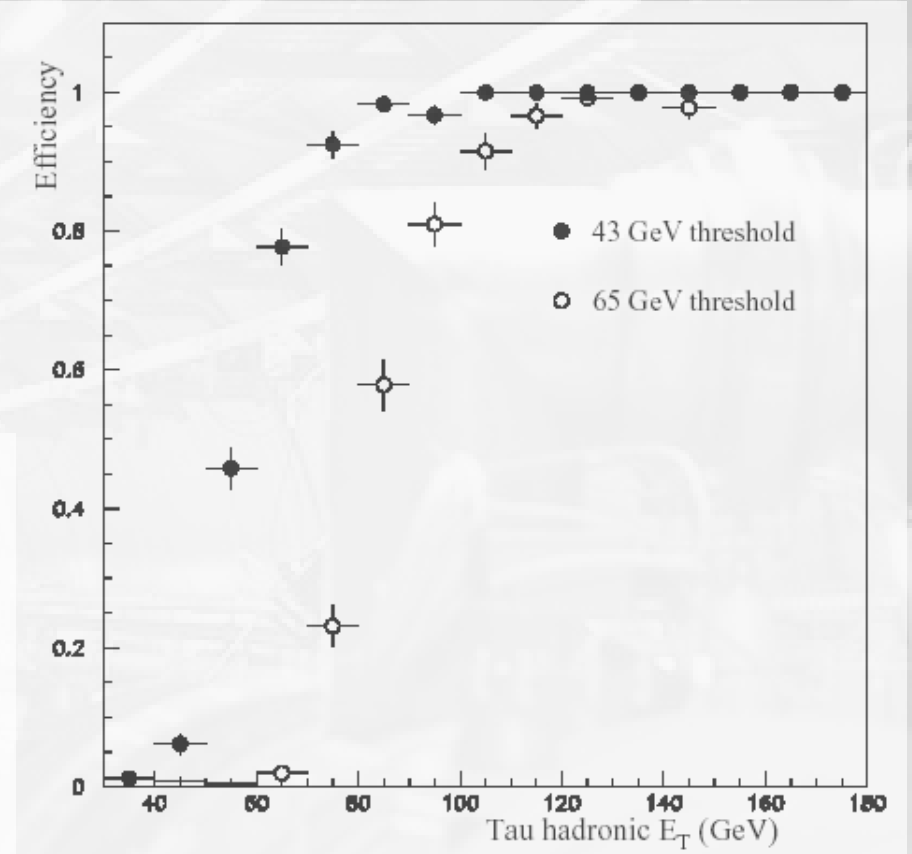


efficiency and rate of

ATLAS LVL1 τ trigger

($L = 10^{33}\ cm^{-2}s^{-1}$)



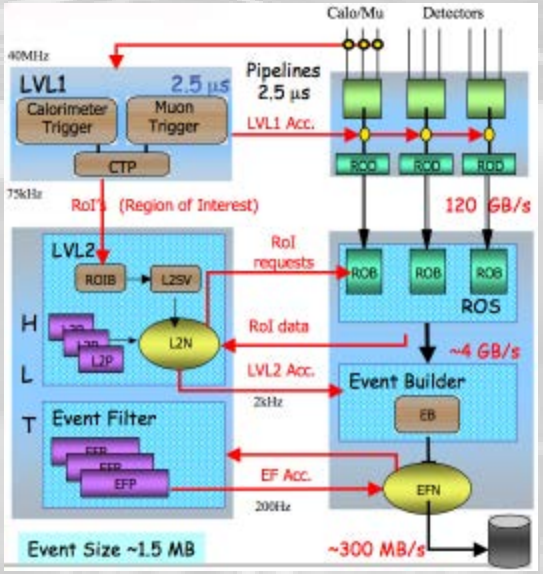



# ATLAS trigger processor

# ATLAS trigger-daq racks

# ATLAS Level 2 Trigger

- verification of objects identified by LVL1, and further evaluation of their properties
- input information:
  - RoIs
  - access to **all** data in ROBs, however selectively due to RoI informations (ca. 1% of all data)
  - also includes data from other detectors, as e.g. central tracker (SCT, Pixel, TRTs)




- combination of informations from all detector systems to more specialised trigger-objects –> candidates for e, μ, τ, *jets*, as well as $E_{T\ miss}$, $E_{T\ tot}$ and objects specific for b-physics (secondary vertex, invariant mass).
- average processing time per event: 10 ms
- runs on processor farm (1000s of PC's)
- acceptance rate at LVL2 output: ca. 1 kHz

# Level 1 objects

**Table 11-1** LVL1 objects and their attributes in addition to $E_T$. Tables 11-1 and 11-2 introduce the mnemonics for trigger objects used in the trigger menus, see Section 11.7. A total of 16 thresholds is available for EM and T objects combined.

| Object | Number of thresholds | Isolation | $\|\eta\|$ range | description |
|---|---|---|---|---|
| MU | 6 | no | 2.4 | muon |
| EM | 8 – 16 | yes | 2.5 | EM cluster |
| T | 0 – 8 | yes | 2.5 | $\tau \rightarrow$ hadrons or single hadron |
| J | 8 | no | 3.2 | jet |
| XE | 8 | – | 4.9 | missing-$E_T$ |
| SE | 4 | – | 4.9 | total scalar $E_T$ |

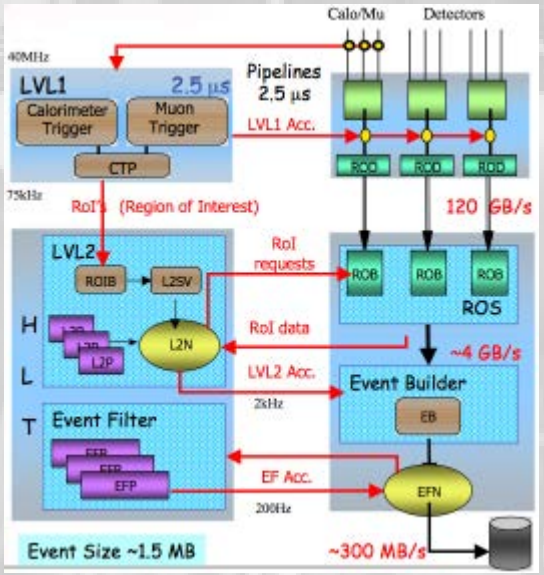
# Level 2 objects

**Table 11-2** LVL2 objects and attributes in addition to $E_T$. Additional attributes are discussed in Section 11.4.

| Object | Attribute | $\|\eta\|$ range | Candidate for |
|---|---|---|---|
| $\mu$ | isolation | 2.4 | muon |
| e | isolation | 2.5 | electron |
| $\gamma$ | isolation | 2.5 | photon |
| $\tau$ | isolation | 2.5 | $\tau \rightarrow$ hadrons |
| h | isolation | 2.5 | single hadron |
| j | b-tag ($\|\eta\| < 2.5$) | 3.2 | jet |
| xE | – | 4.9 | missing-$E_T$ |

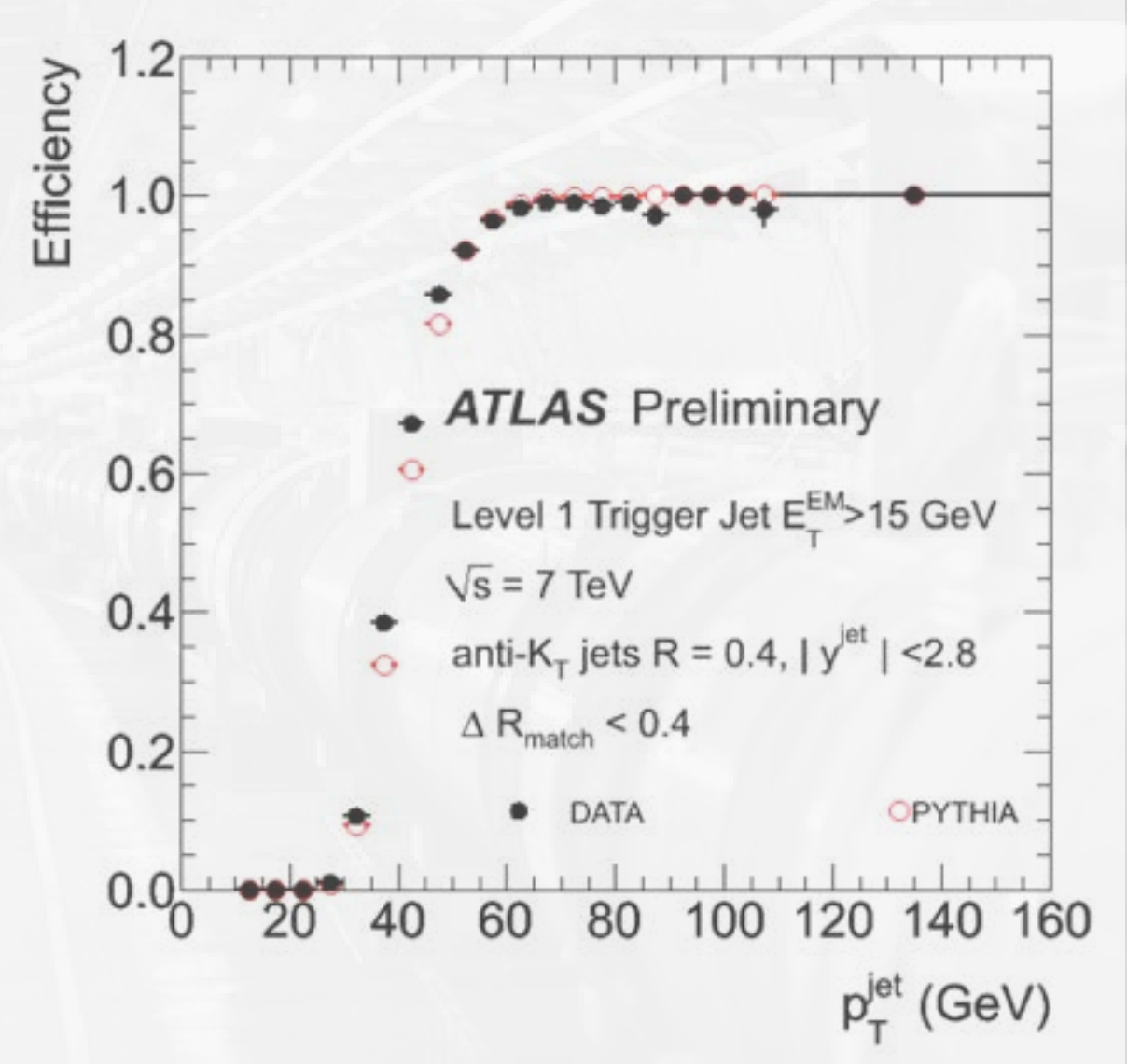
# ATLAS Event Filter (EF)

- further specification and assessment of trigger objects
- usage of offline algorithms and methods;
  usage of most actual calibration data;
  usage of field maps of magnetic fields
- sharpening of selection criteria,
  e.g. $p_T$, isolation, second. vertices
- processor farm, similar (or identical) to LVL2
- acceptance rate up to 200 Hz, –> writing Daten to disk/tape with 100 - 200 MB/s



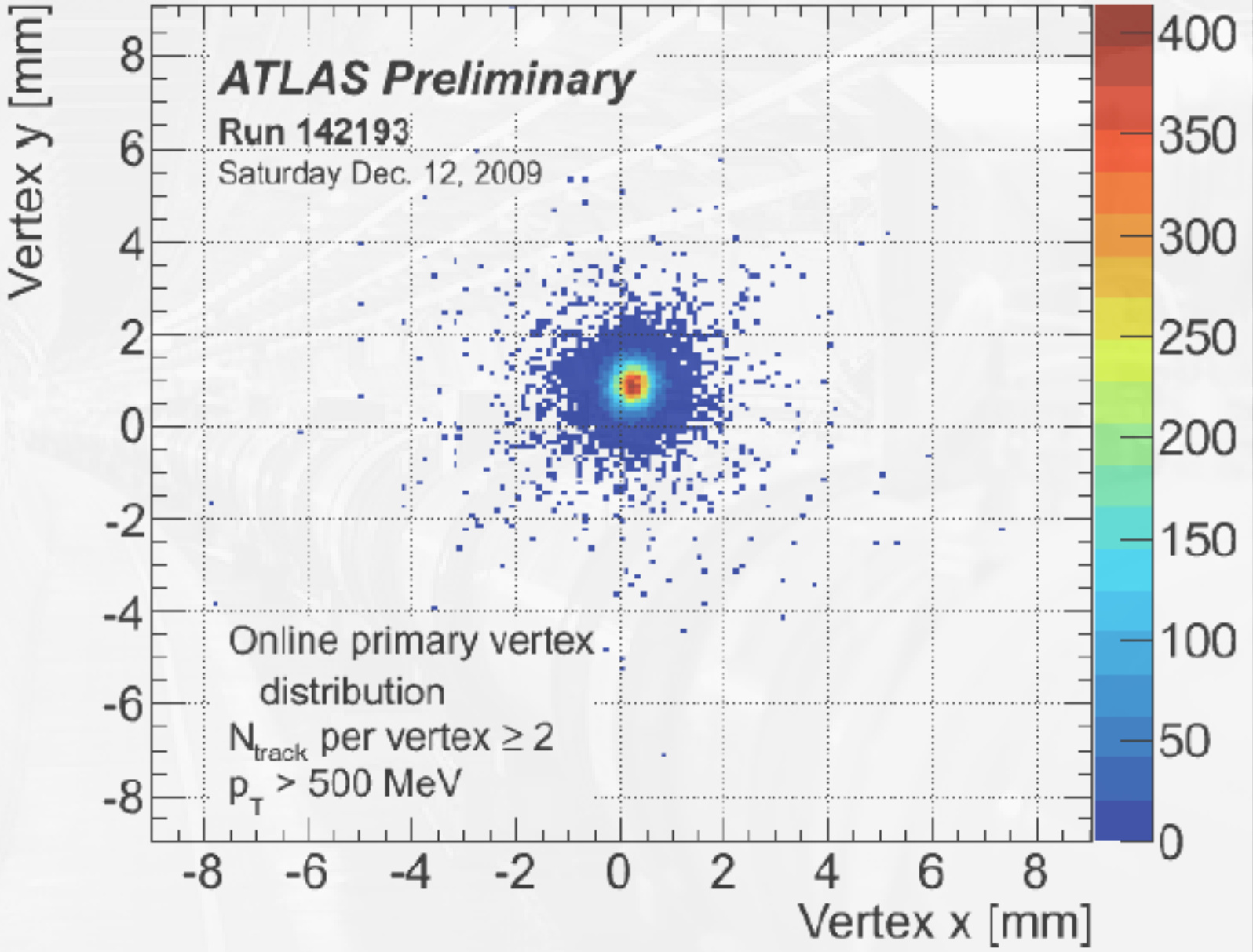
# ATLAS LVL1 Jet Trigger Efficiency (Oct. 2010)

(from offline reconstructed jets)




arXiv:1010.0017

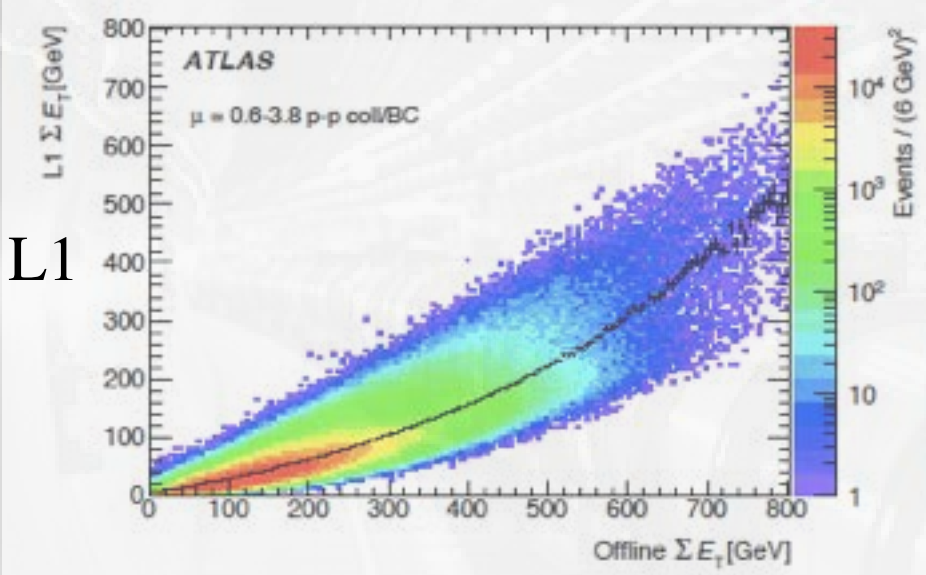
# Beam spot determined by L2 tracking (Oct. 2010)



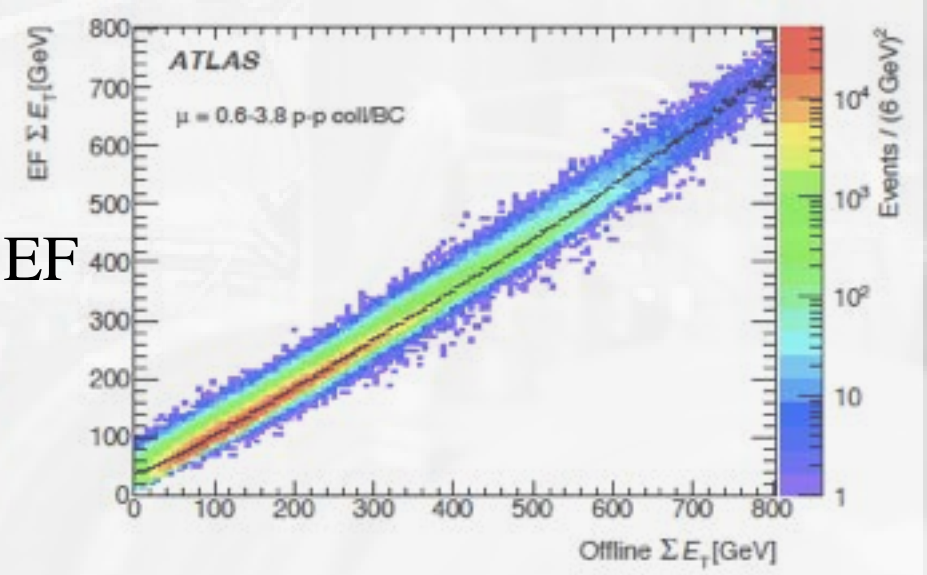

arXiv:1010.0017

# correlation between trigger- and offline event reconstruction Σ $E_T$

L1

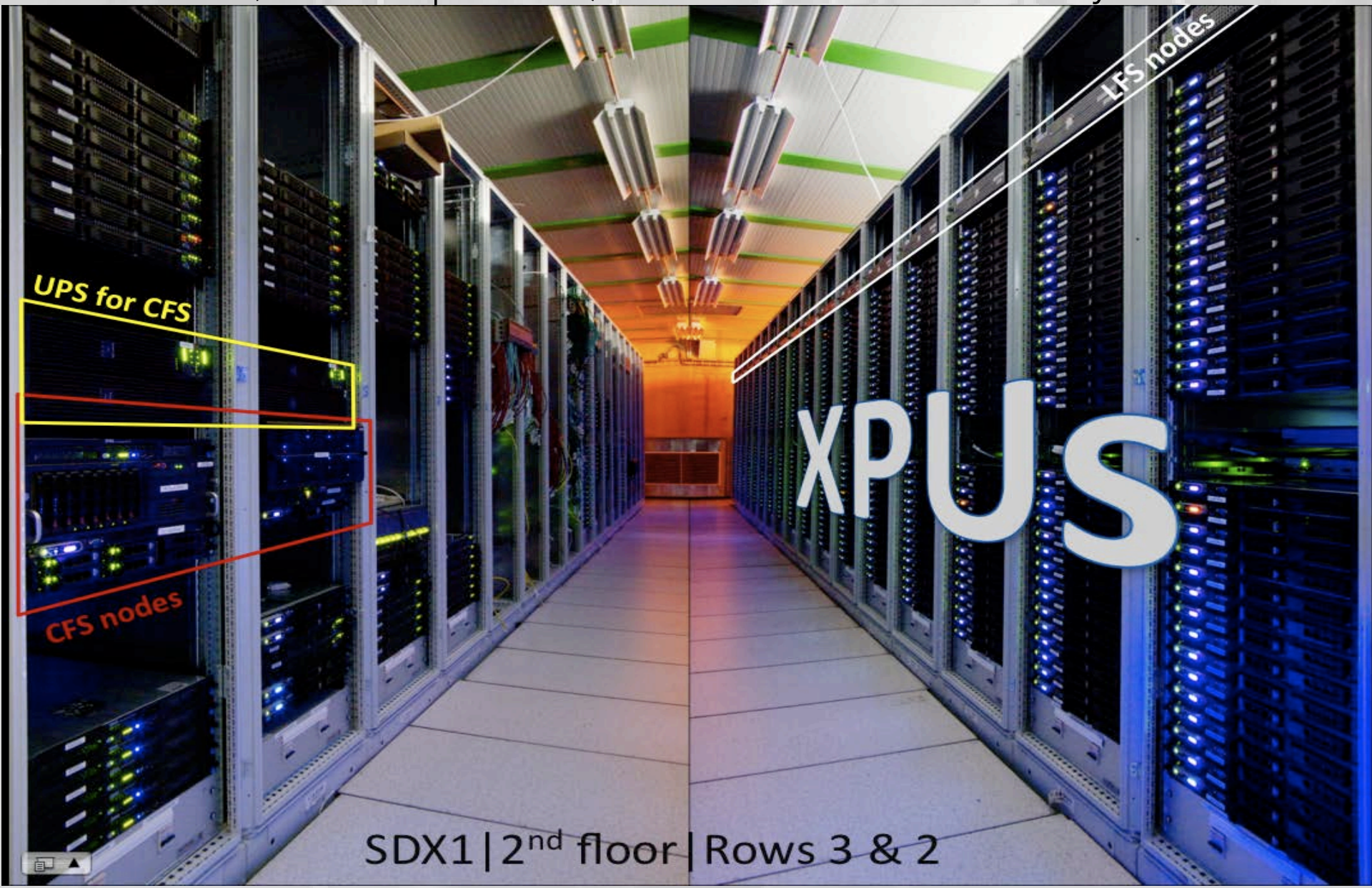



EF



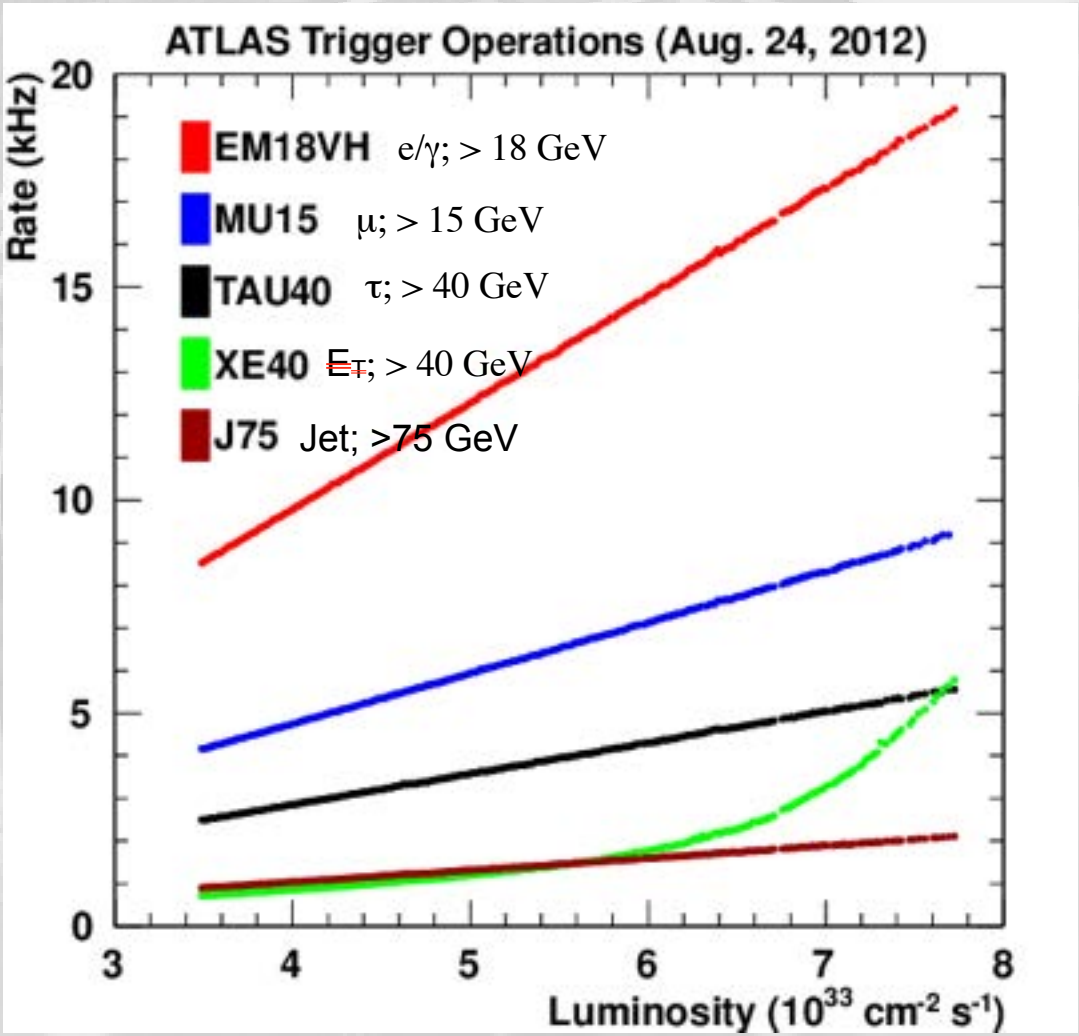
# ATLAS High-Level-Trigger (HLT) farm

850 PC (CPU: 2 x quad-core) installed = 35% of the final system



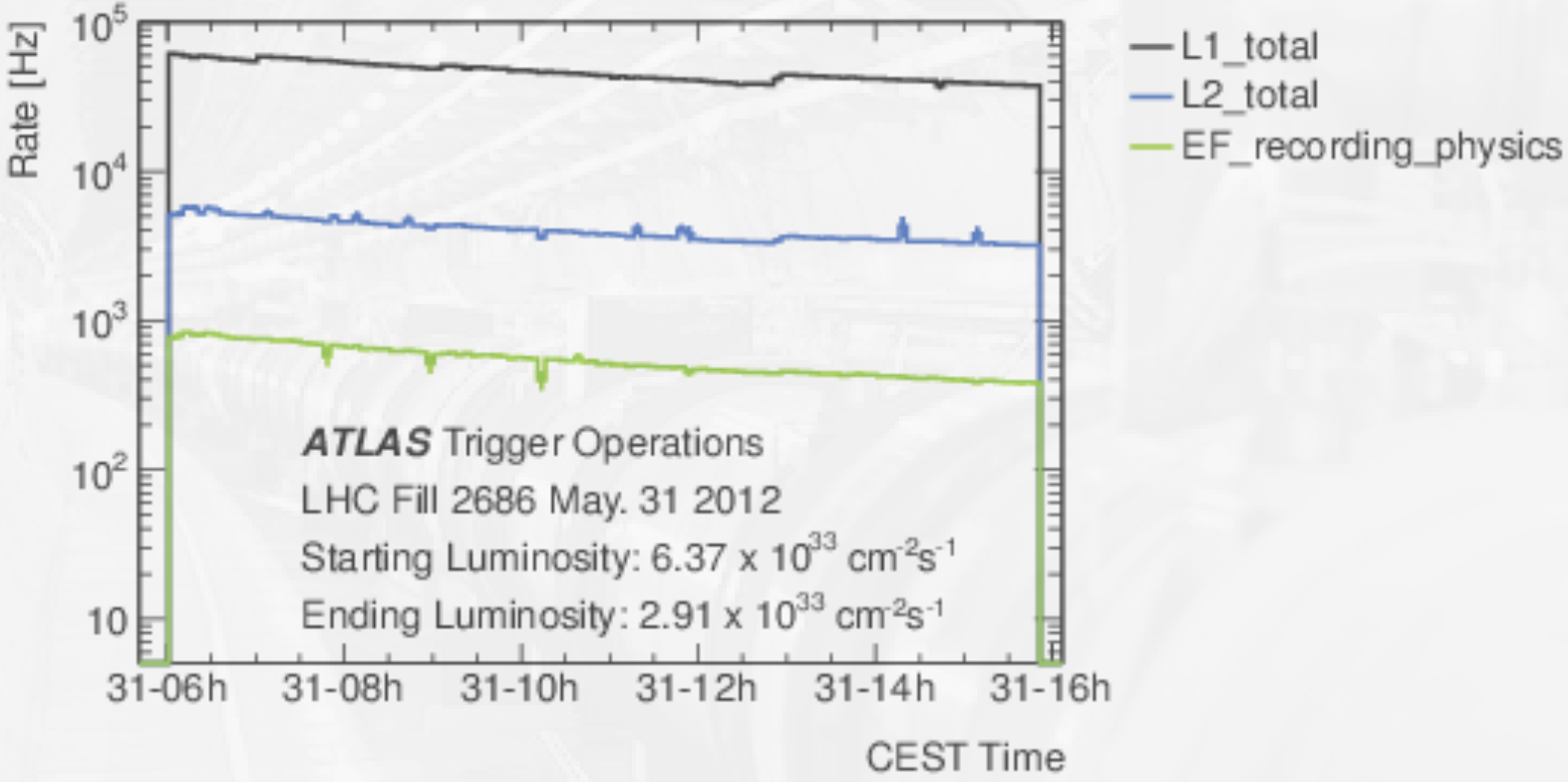
# ATLAS Level-1 single-object Trigger rates

at 7.8 x $10^{33}$ $cm^{-2}$ $s^{-1}$

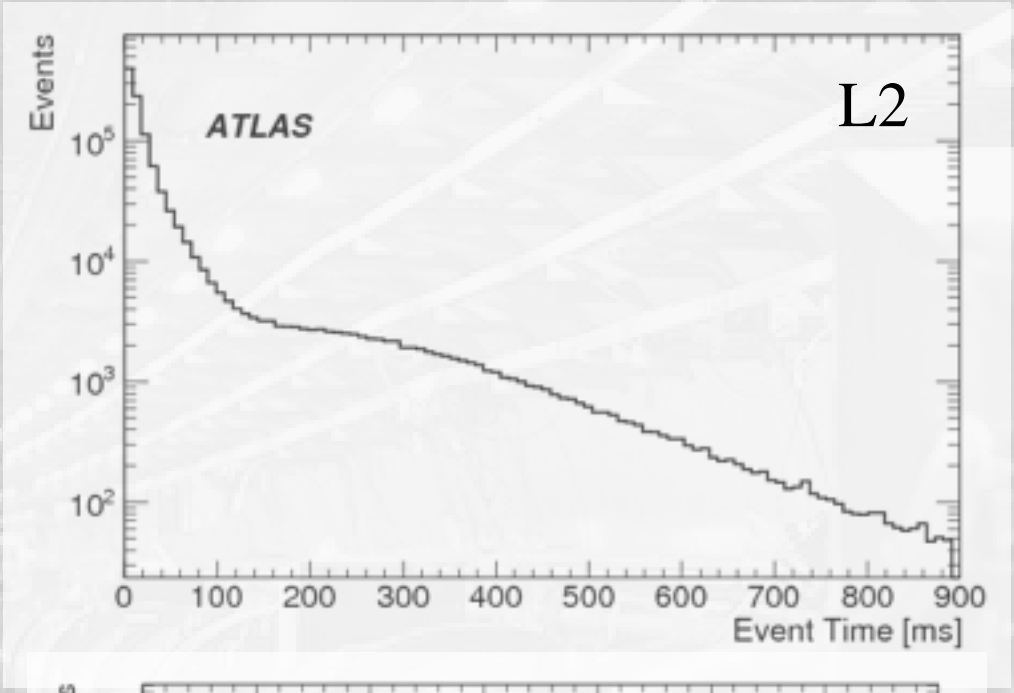


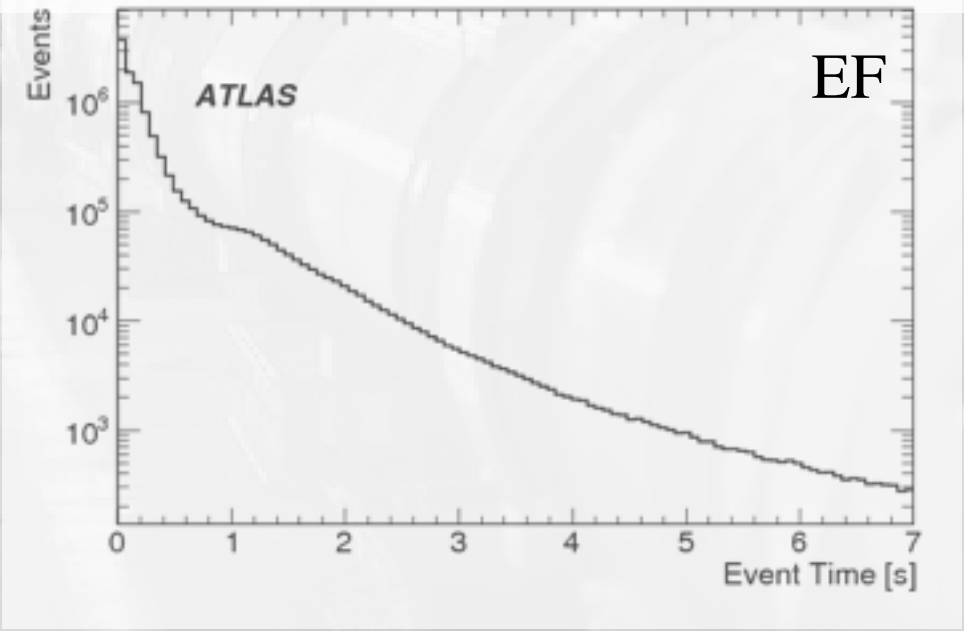
# ATLAS Trigger output rates

at 6.4 x $10^{33}$ $cm^{-2}$ $s^{-1}$



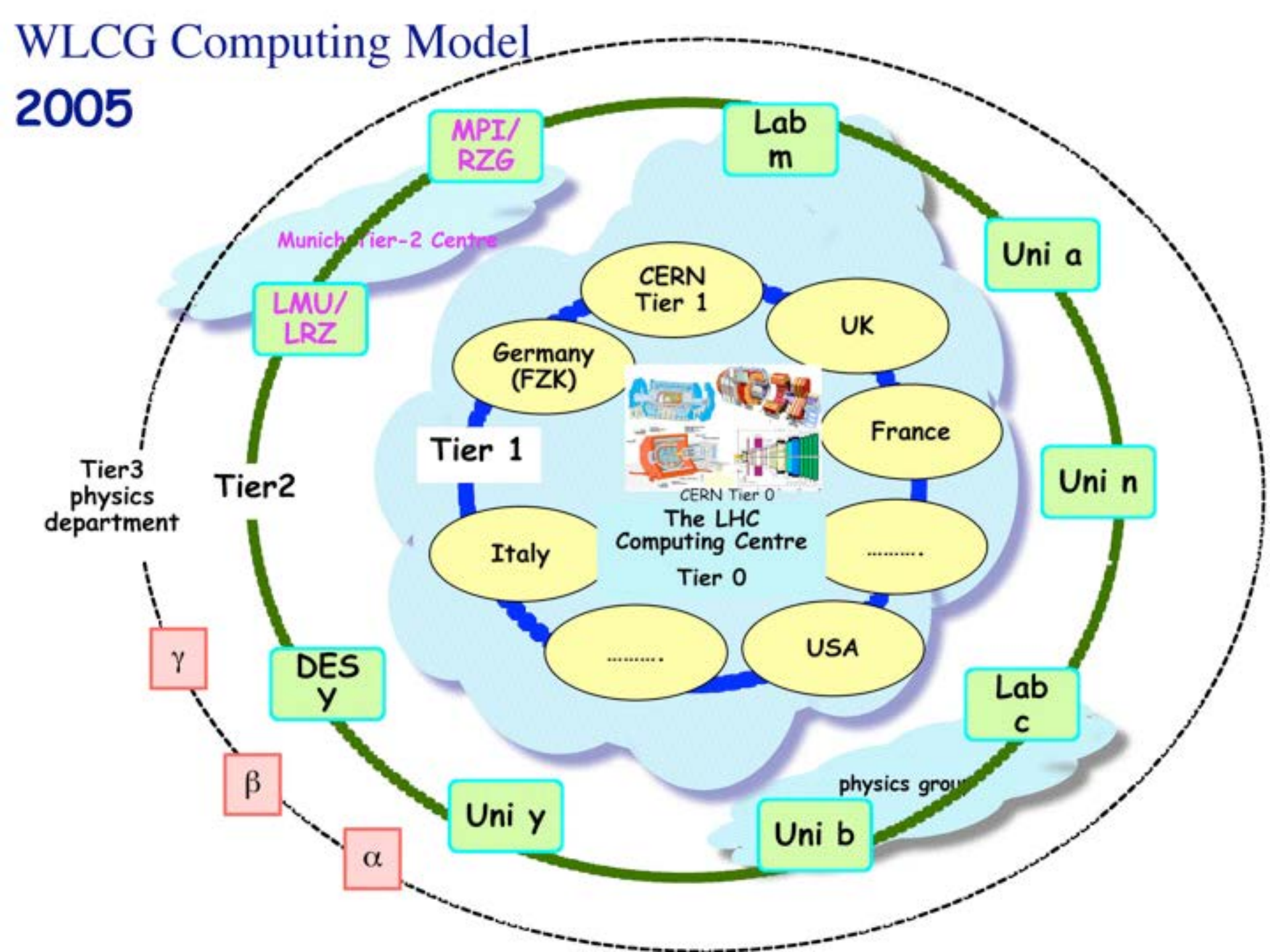
# ATLAS Trigger: event processing times



# WLCG Computing Model

## 2005

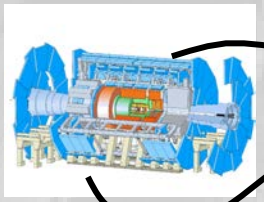


# LHC-GRID (WLCG): worldwide networking and distribution of tasks:

- redundant data storage (Tier-0 , -1)
- generation (Tier-2) and storage (-1, -2) of simulation data (MC)
- data reduction; calibration (Tier-0) and data bases (-0, -1)
- processing of analysis jobs (Tier-1, -2, ...)

WLCG
Worldwide LHC Computing Grid

# Task distribution



1st pass raw data reconstruction at Tier0 and export

reconstruction

raw data

Event Summary Data

processed data

Reprocessing at Tier1

Physics analysis at Tier2

analysis

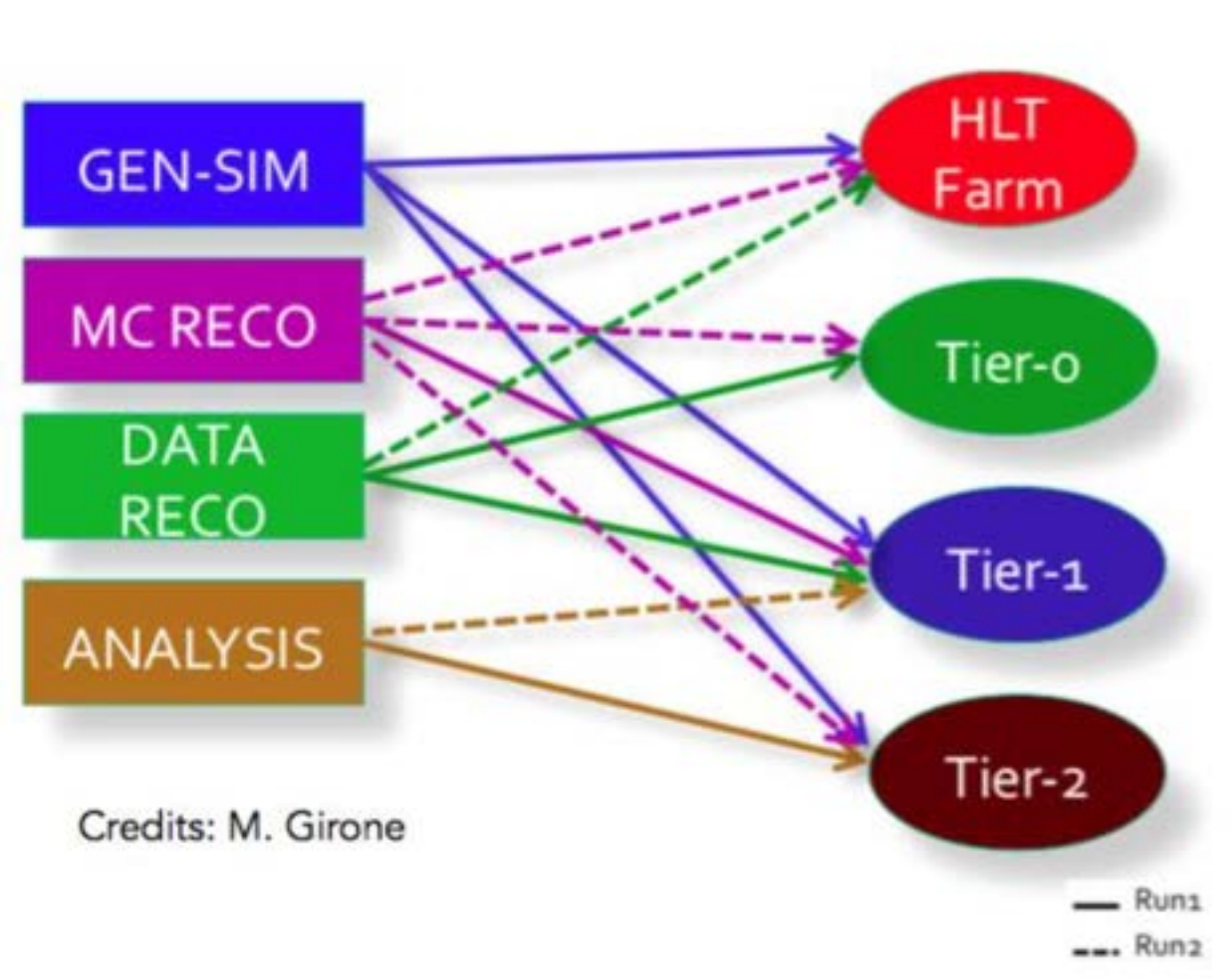
simulation

Simulation at Tier1/2

analysis objects (extracted by physics topic)

interactive physics analysis

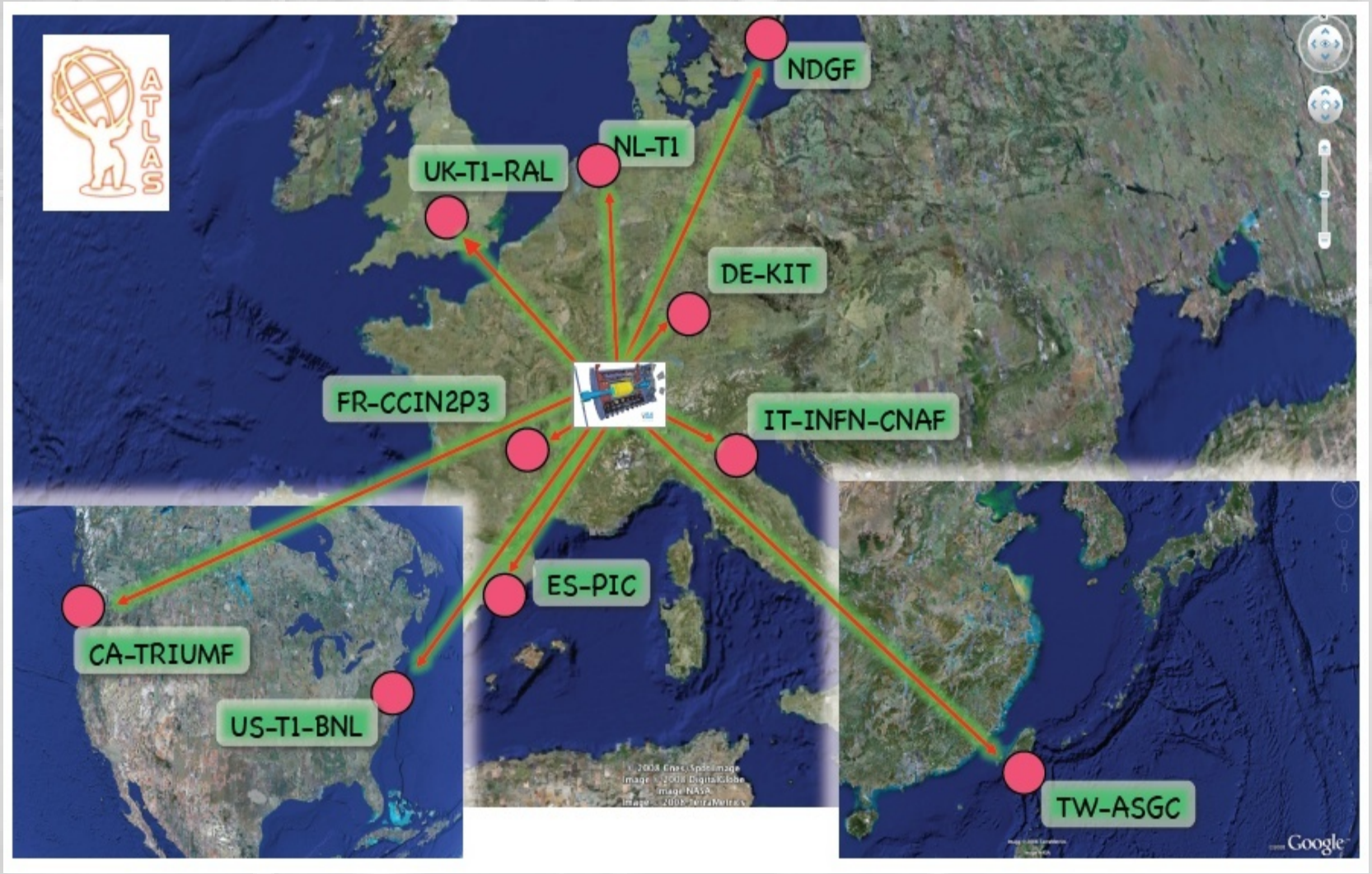
# WLCG Computing Model becomes more flexible…




… and thus uses existing resources more efficiently!

# Computing infrastructure and operation

ATLAS wLCG world-wide computing: ~ 70 sites
(including CERN Tier0, 10 Tier-1s, ~ 40 Tier-2 federations)



WLCG
Worldwide LHC Computing Grid

# Components

# WLCG: installed capacities

**Normalisation:**
**Intel Xeon E5430**
**mit 8-core** 2666 MHZ, 16 GB Ram:
**HEPSPEC 73.24**

VO: ALL Year: 2014 Month: 10

Note: Sorting by multiple columns at the same time can be activated by 'shift' clicking on the column headers which they want to add to the sort. Hovering mouse over the column headers to get descriptions of table columns.

All Tiers | Tier 0 | Tier 1 | Tier 2

Search:

| Country | Federation | Physical CPU | Logical CPU | HEPSPEC06 | Total Online Storage (GB) | Total Nearline Storage (GB) |
|---|---|---|---|---|---|---|
| Canada | CA-TRIUMF | 852 | 4,832 | 73,235 | 6,480,931 | 5,485,696 |
| France | FR-CCIN2P3 | 1,147 | 15,882 | 161,986 | 9,411,255 | 4,001,311 |
| Germany | DE-KIT | 1,230 | 16,144 | 183,880 | 10,361,981 | 46,536,041 |
| Italy | IT-INFN-CNAF | 2,744 | 19,208 | 211,864 | 14,693,398 | 7,573,494 |
| Netherlands | NL-T1 | 1,492 | 7,846 | 111,005 | 7,201,334 | 0 |
| Nordic | NDGF | 56,103 | 56,103 | 730,005 | 5,943,898 | 5,471,376 |
| Republic of Korea | KR-KISTI-GSDC | 168 | 2,688 | 28,055 | 52 | 0 |
| Russian Federation | NRC-KI-T1 | 120 | 1,440 | 22,320 | 757,321 | 0 |
| Russian Federation | RU-JINR-T1 | 600 | 1,200 | 18,024 | 653,701 | 0 |
| Spain | ES-PIC | 664 | 4,267 | 53,704 | 0 | 0 |
| Taiwan | TW-ASGC | 466 | 1,864 | 22,299 | 8,080,359 | 8,010,796 |
| UK | UK-T1-RAL | 802 | 5,760 | 59,522 | 10,582,929 | 13,248,185 |
| USA | US-FNAL-CMS | 1,683 | 6,730 | 58,000 | 10,000,000 | 22,000,000 |
| USA | US-T1-BNL | 1,622 | 14,233 | 82,000 | 11,000,000 | 12,000,000 |
| **Total** | | **69,693** | **158,197** | **1,815,899** | **95,167,159** | **124,326,899** |

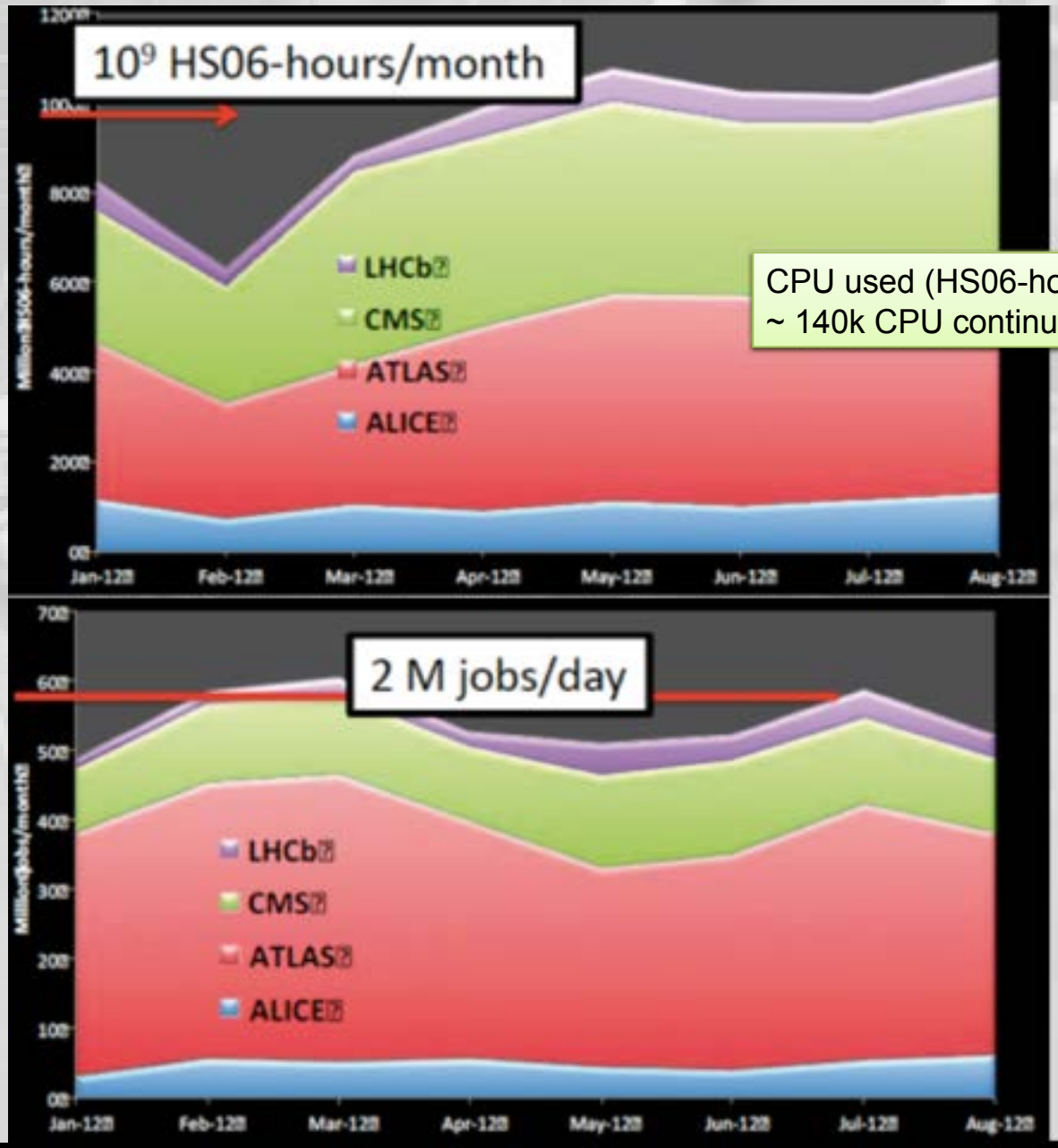
Tier 0:

| | | | | | |
|---|---|---|---|---|---|
| **Total** | **39,066** | **42,585** | **317,383** | **36,416,885** | **97,537,985** |

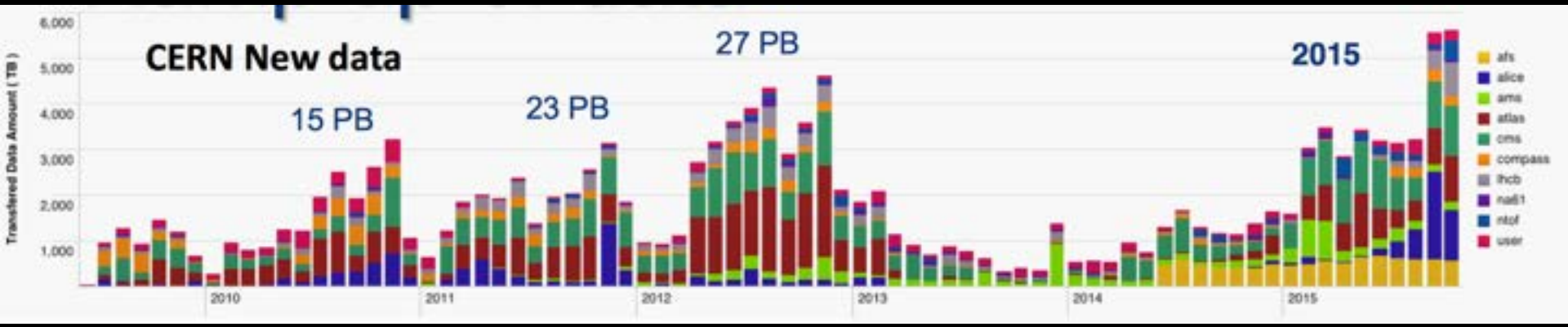
Tier 2:

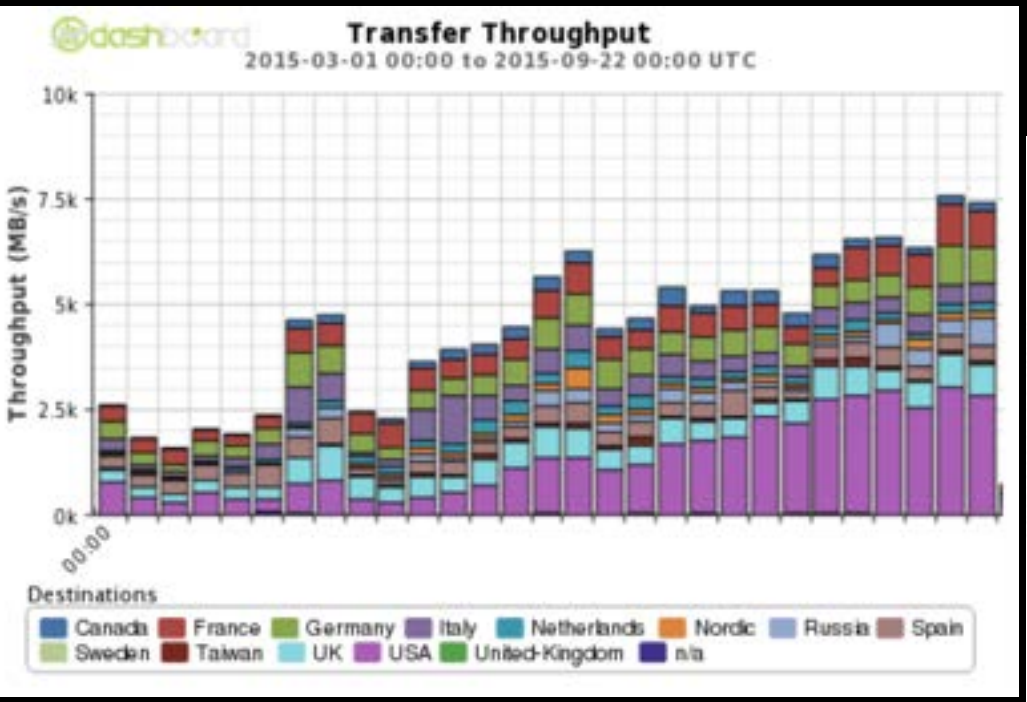
| | | | | | |
|---|---|---|---|---|---|
| **Total** | **52,856** | **287,958** | **3,130,845** | **148,145,287** | **5,711,073** |

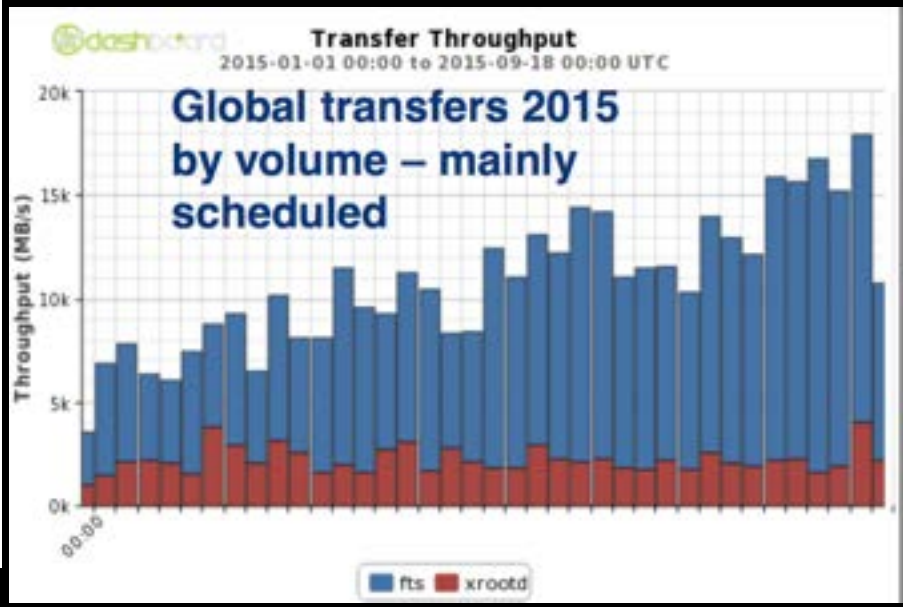
# WLCG: usage




CPU used (HS06-hours/month)
~ 140k CPU continuous use


CERN New data
15 PB
23 PB
27 PB
2015
Transfered Data Amount ( TB )
6,000
5,000
4,000
3,000
2,000
1,000
2010
2011
2012
2013
2014
2015
afs
alice
ams
atlas
cms
compass
lhcb
na61
ntof
user


Transfer Throughput
2015-03-01 00:00 to 2015-09-22 00:00 UTC
Throughput (MB/s)
10k
7.5k
5k
2.5k
0k
00:00
Destinations
Canada
France
Germany
Italy
Netherlands
Nordic
Russia
Spain
Sweden
Taiwan
UK
USA
United-Kingdom
n/a


Transfer Throughput
2015-01-01 00:00 to 2015-09-18 00:00 UTC
Global transfers 2015
by volume – mainly
scheduled
Throughput (MB/s)
20k
15k
10k
5k
0k
00:00
fts
xrootd

# interior of a tape-robot

# Literature:

- ATLAS Detector and Physics Performance Technical Design Report Vol. 1, CERN/LHCC 99-14
- The ATLAS Trigger System Commissioning and Performance, arXiv:1010.0017
- Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics. arXiv:0901.0512 [hep-ex]
- Performance of the ATLAS Trigger System in 2010, Eur.Phys.J. C72 (2012) 1849, arXiv:1110.1530 [hep-ex]
- The LHC Computing Grid, http://wlcg.web.cern.ch