LHC Experiments - Trigger, Data-taking and Computing

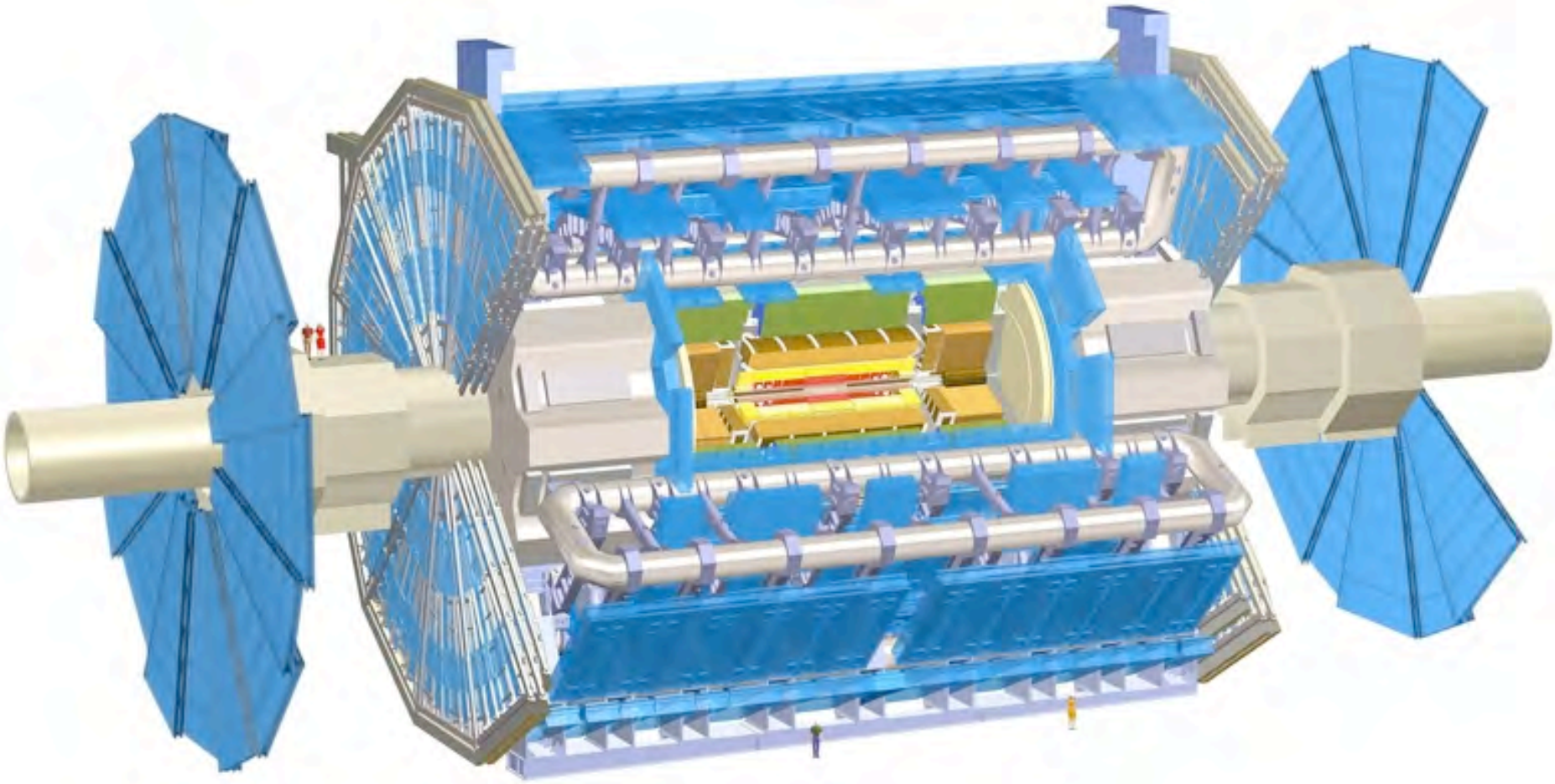
- data rates
- physics signals
- ATLAS trigger concept
- LHC computing model

Data rates at the LHC

- 20 (40) MHz bunch crossing rate; each with about 35 collisions
- –> ~ 10^9 interactions per second (at L = 10^{34} $cm^{-2}s^{-1}$)
- ATLAS: ca. $1.5 \cdot 10^8$ electronic chanels
- 1-2 MByte detector data per event (bunch crossing) (including active zero suppression)
- –> 10^{14} 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 10^7 !!

ATLAS at the Large Hadron Collider / CERN



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

1800 Physicists & Engineers
150 Institutes
35 Nations

$150 \cdot 10^6$ elektron. Read out channels
40 MHz collision rate
10^{14} B/s raw data flux

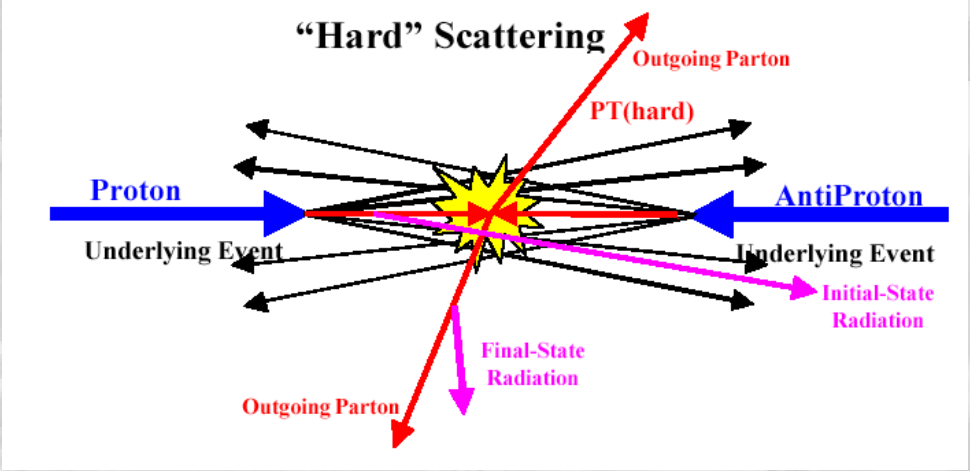
number of active detector channels at ATLAS

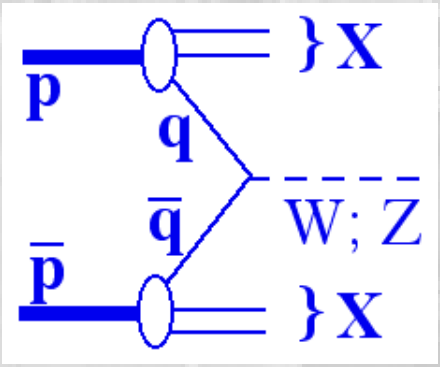
Table 2-1 Number of active detector elements, number of modules or chambers, and number of GEANT volumes defined for the detailed simulation of each of the various ATLAS detector systems.

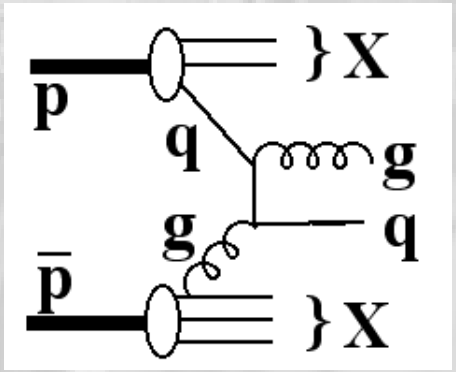
Detector system	Number of active detector elements	Number of modules or chambers	Number of GEANT volumes defined
Pixels	140 000 000	~2 200	26 000
Silicon microstrips	6 280 000	~4100	50 000
Transition radiation tracker	420 000	~240	2 260 000
LAr accordion calorimeters	170 000	48	9 960 000
LAr hadronic 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

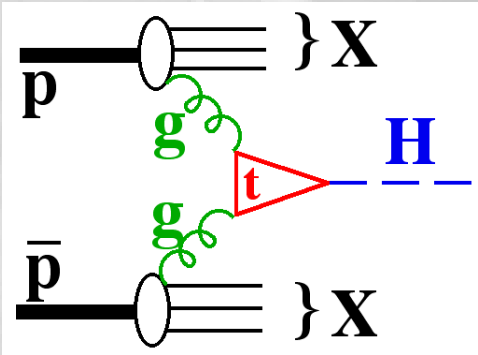
relevant for MC simulation

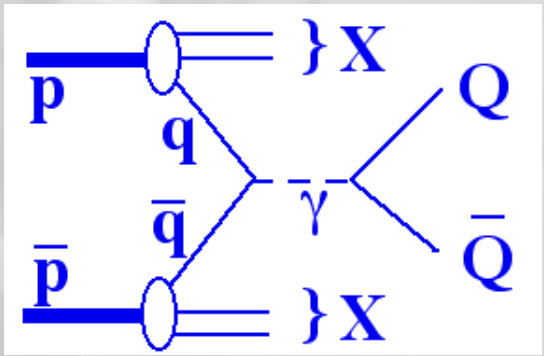
physics signatures at Tevatron ($p\bar{p}$) / LHC (pp)

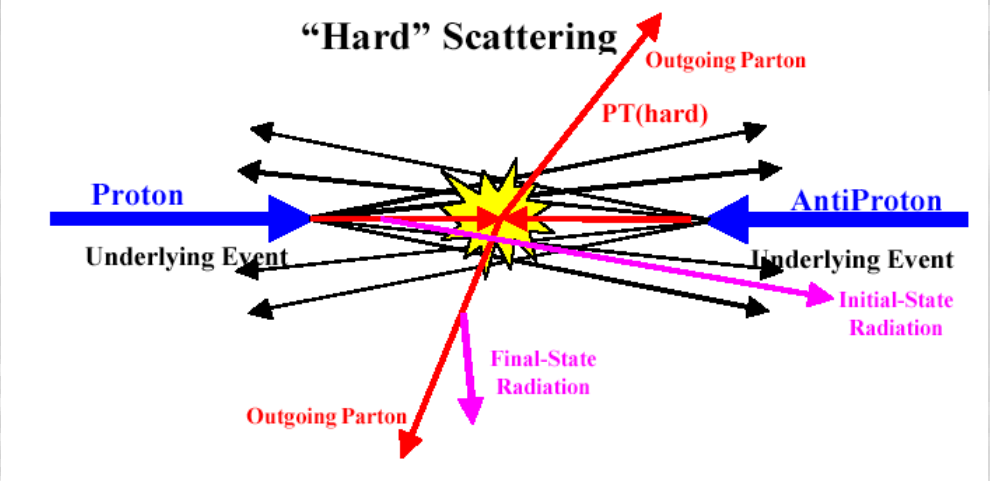








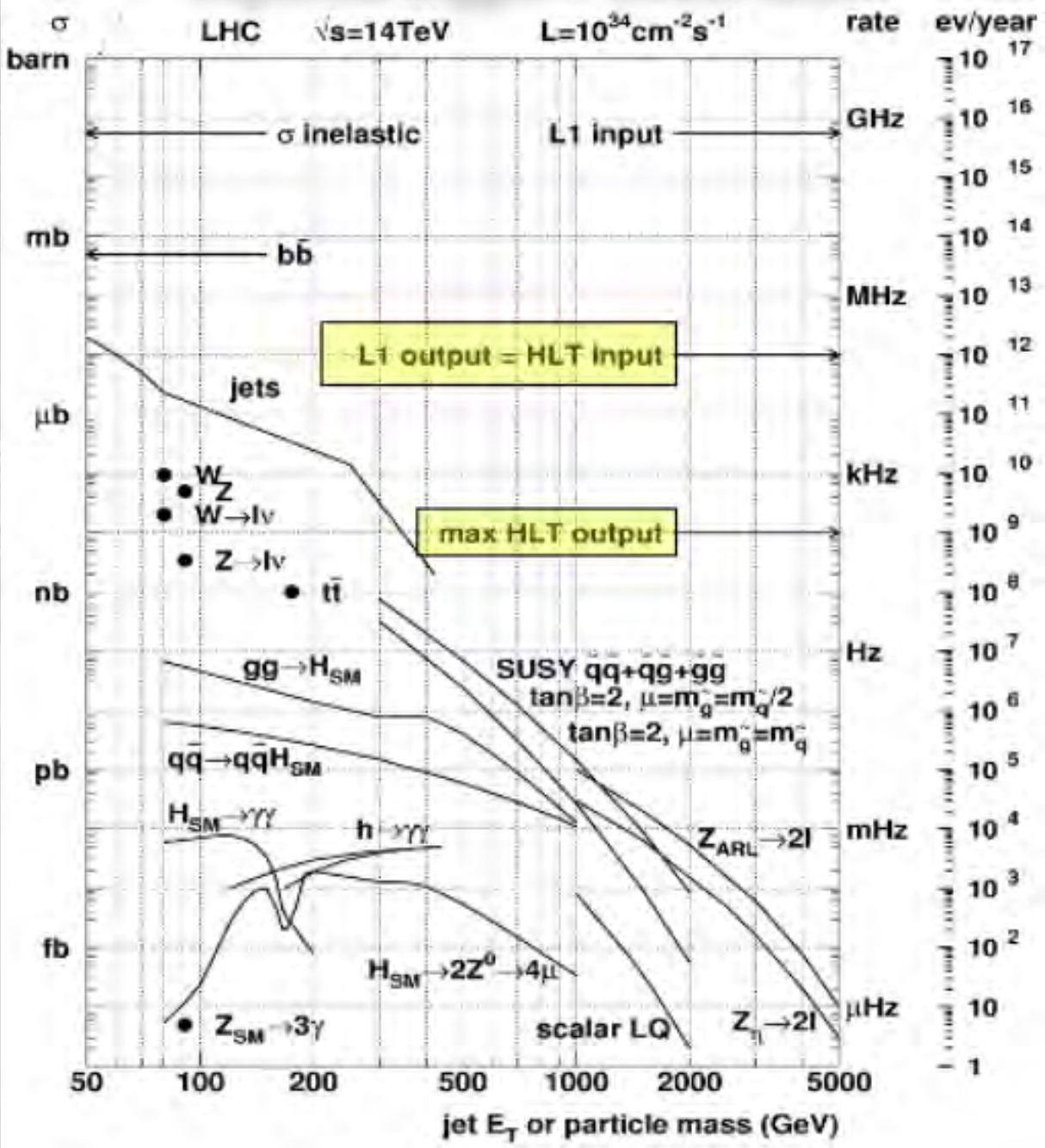




- as energies of colliding quarks/gluons are unknown:
  in general, restrict to "transverse" observables
  (i.e. $\perp$ wrt. beam axis, where E-p-conservation holds: $\sum \vec{p}_T = 0$

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

expected trigger- / Event-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

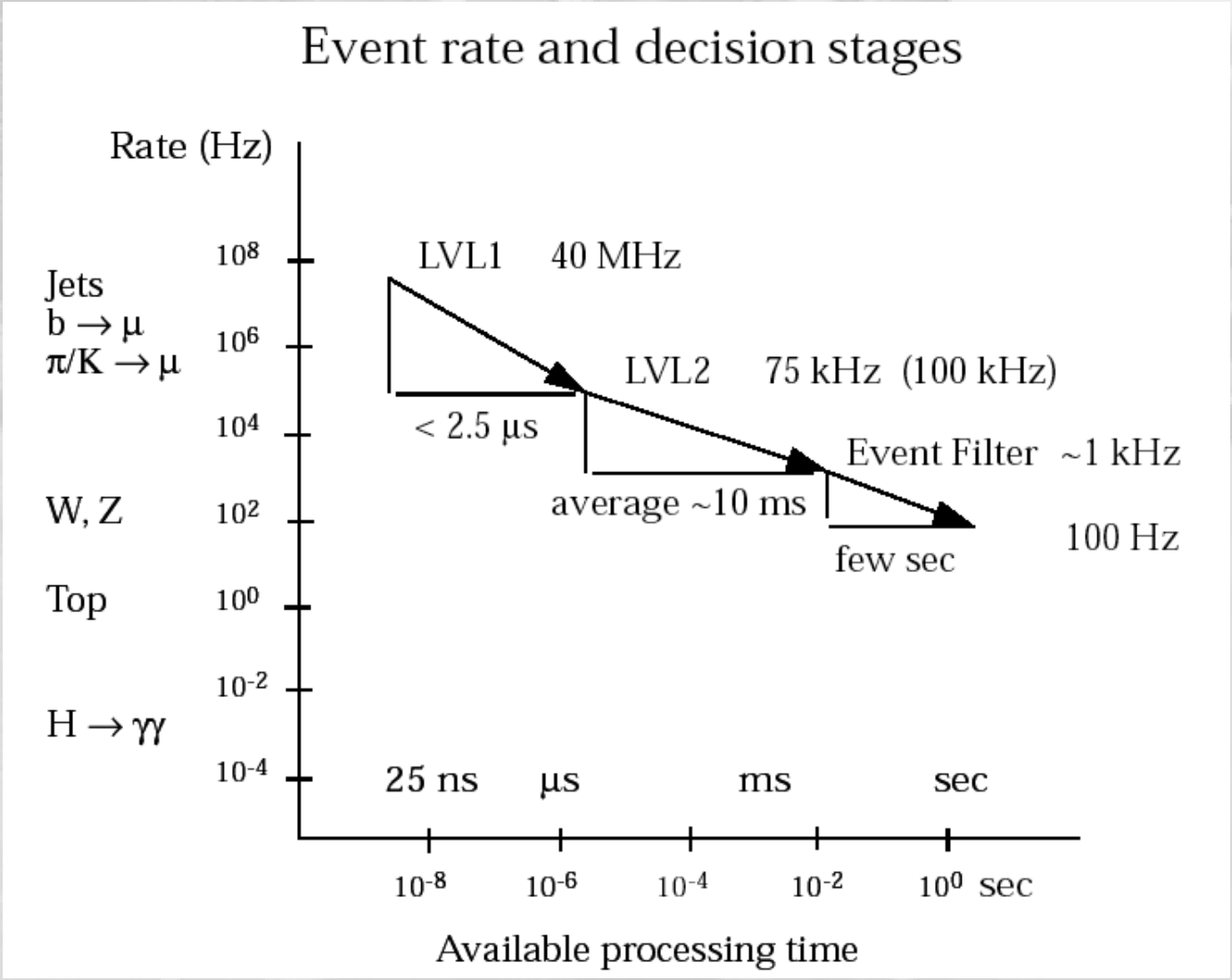
Trigger Rate:

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

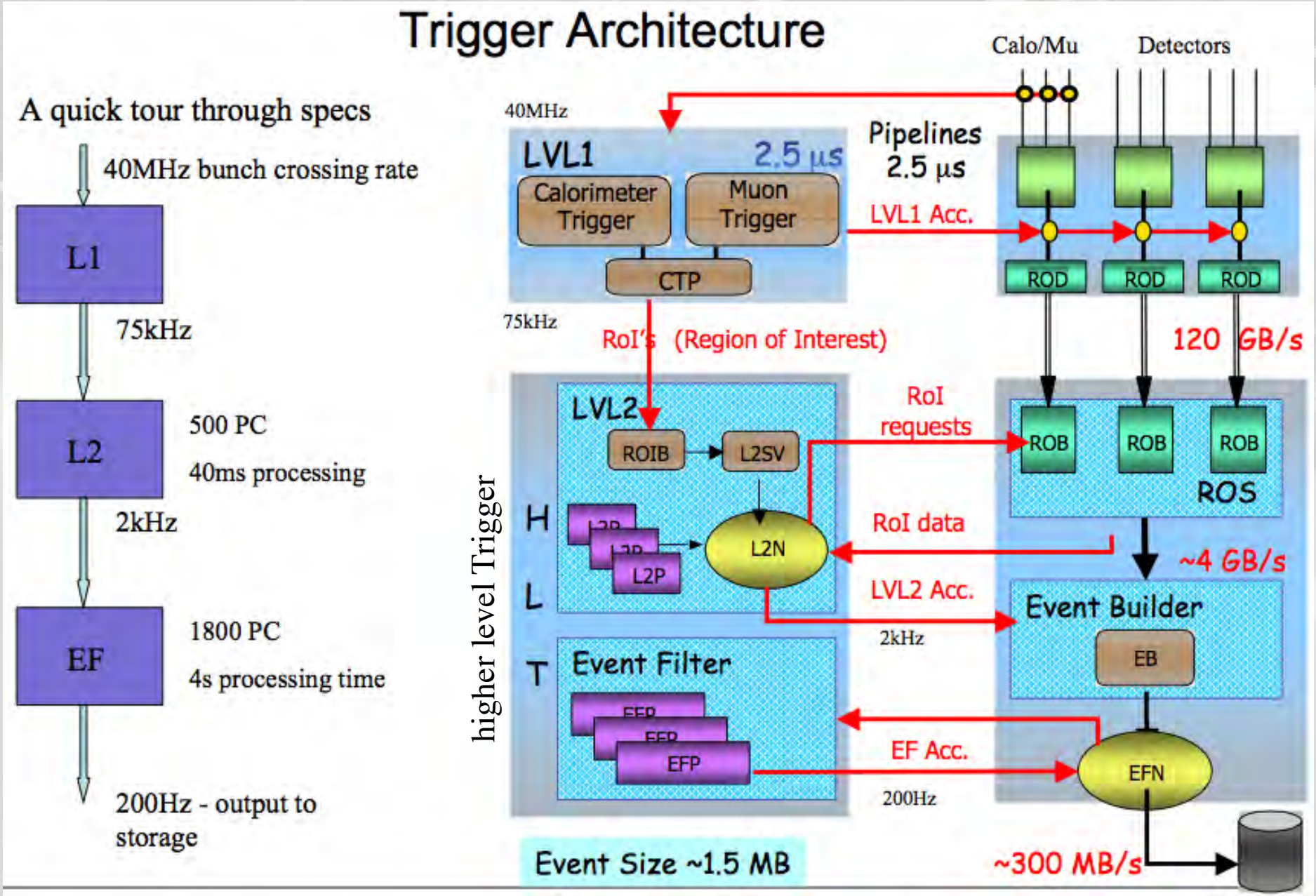
pre-scaling:

- 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…

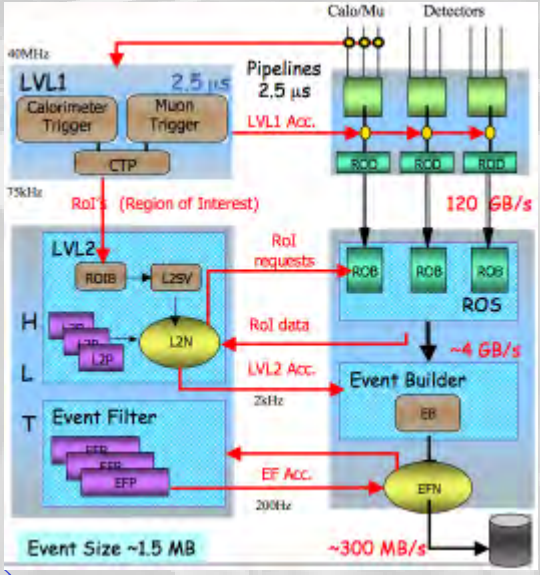
ATLAS: data rates and trigger decisions



ATLAS Trigger/DAQ System



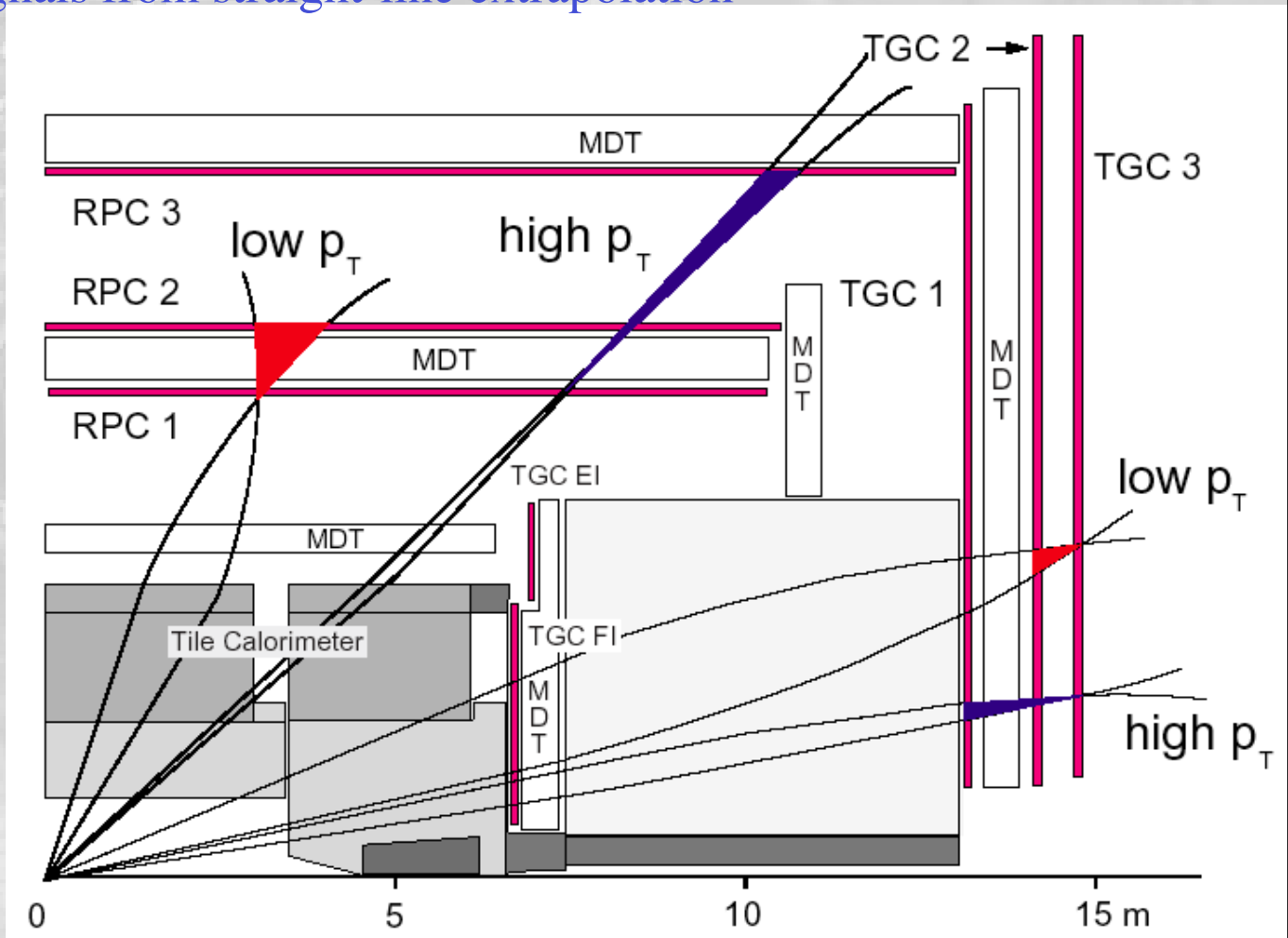
ATLAS Level 1 Trigger



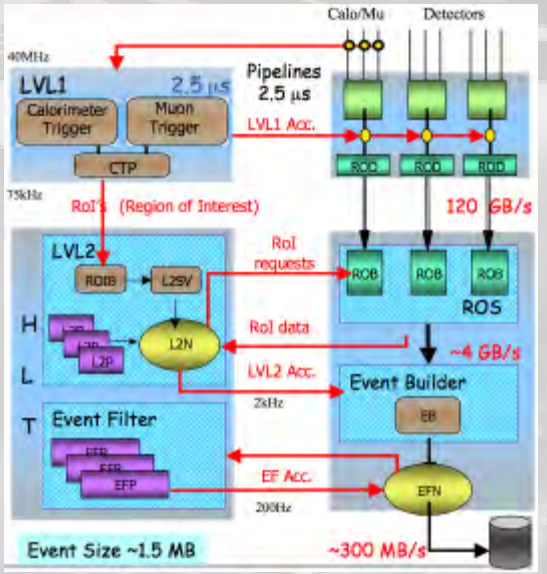
- fast identification of
  basic signatures of 'interesting' physics
- decisions based on existence of
  lokal trigger-objects for different p_T thresholds:
  - muons
  - electromagn. cluster (perhaps with isolation criteria)
  - narrow particle jets (hadr. τ decays, isolated hadrons)
  - hadronic jets
  - 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



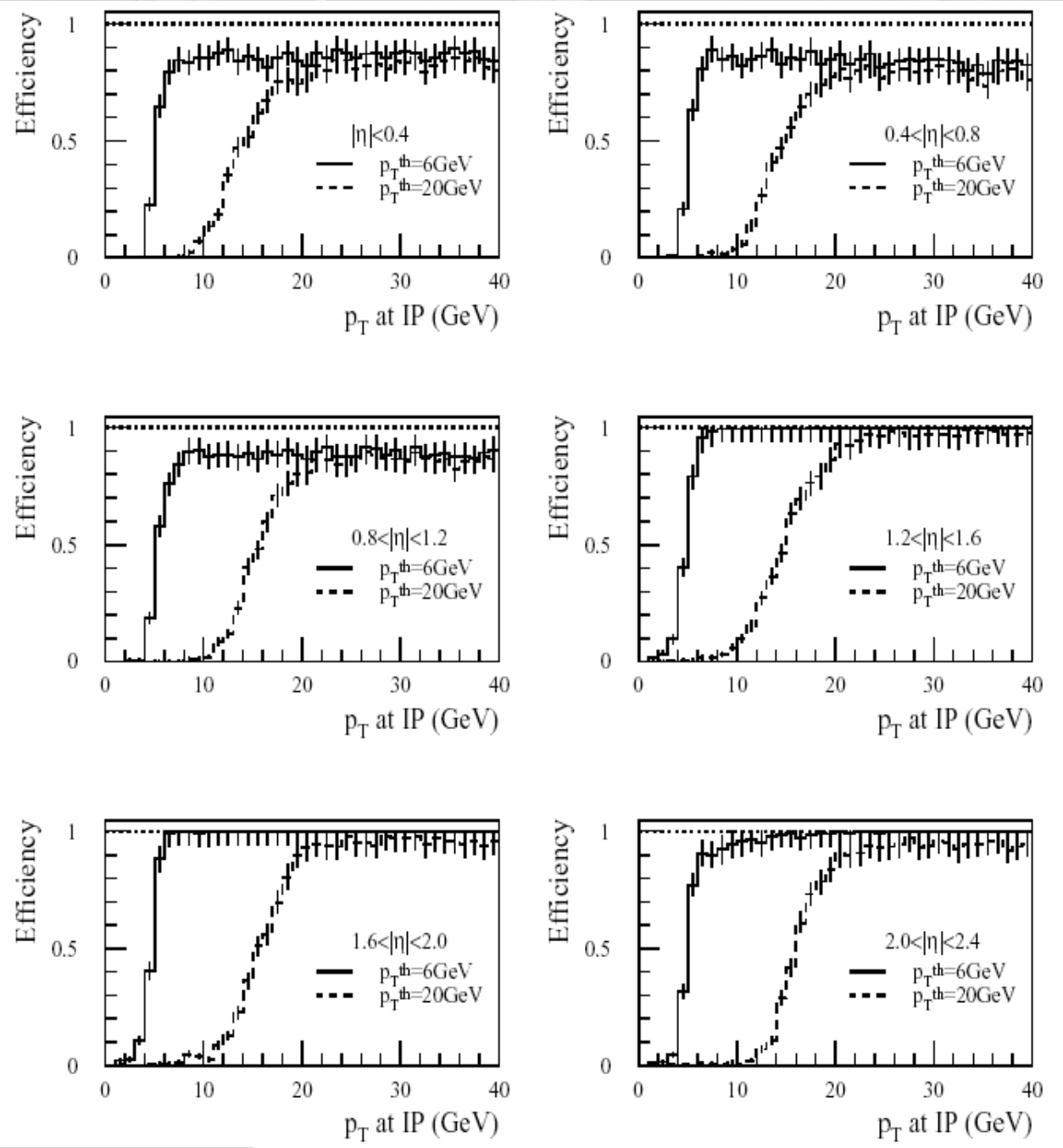
ATLAS Level 1 Trigger (cont.)



- 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 $\{\eta=-\ln(\tan(\theta/2), \phi\}$ 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): am Detektor.

efficiency of

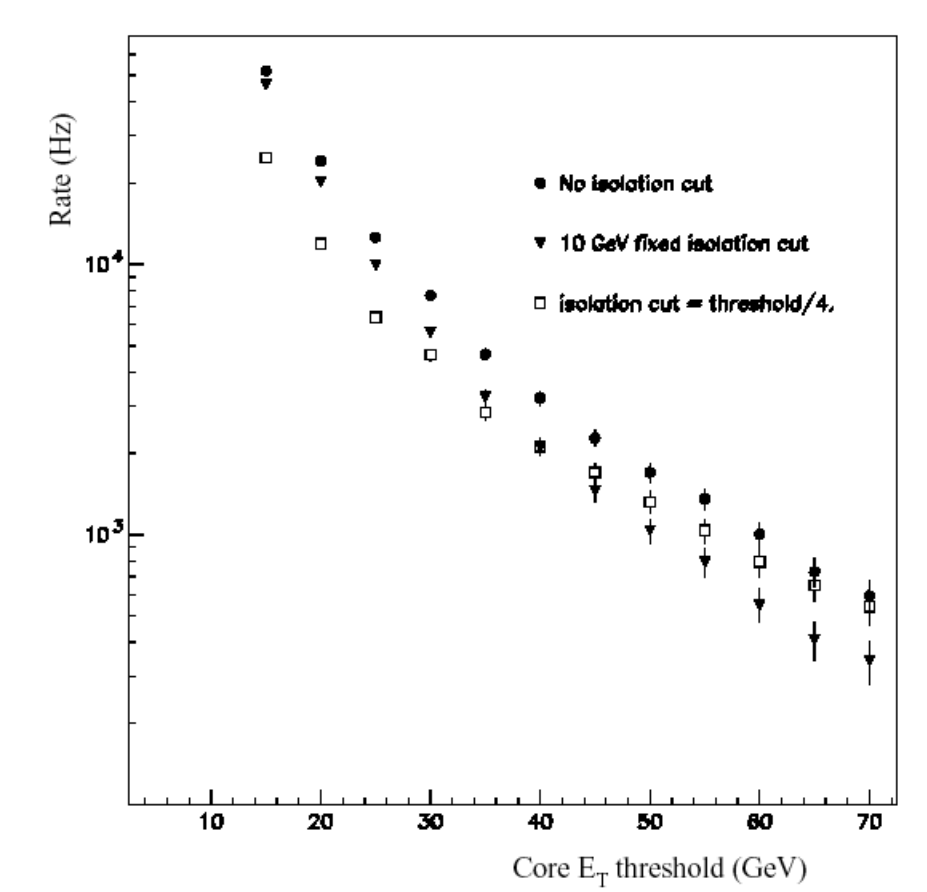
ATLAS LVL1 μ trigger

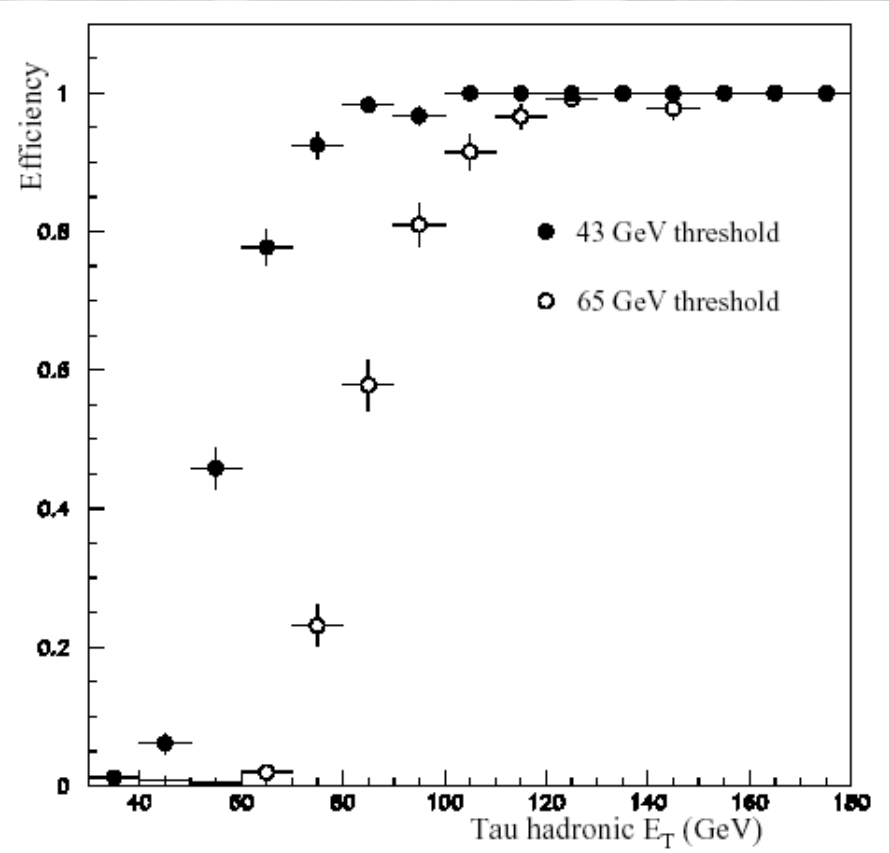


efficiency and rate of

ATLAS LVL1 τ trigger

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

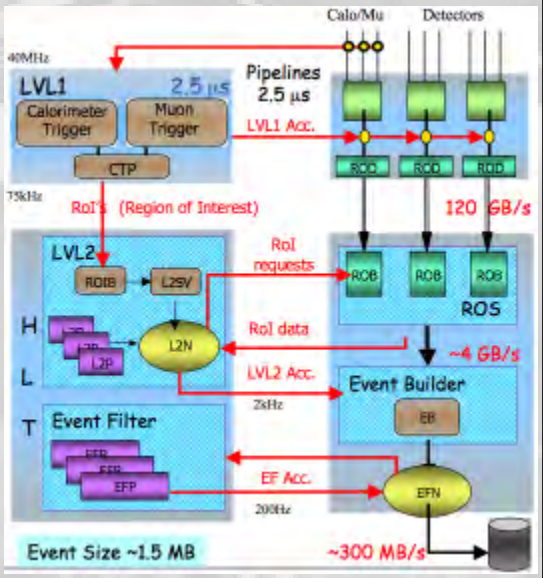




ATLAS trigger processor

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

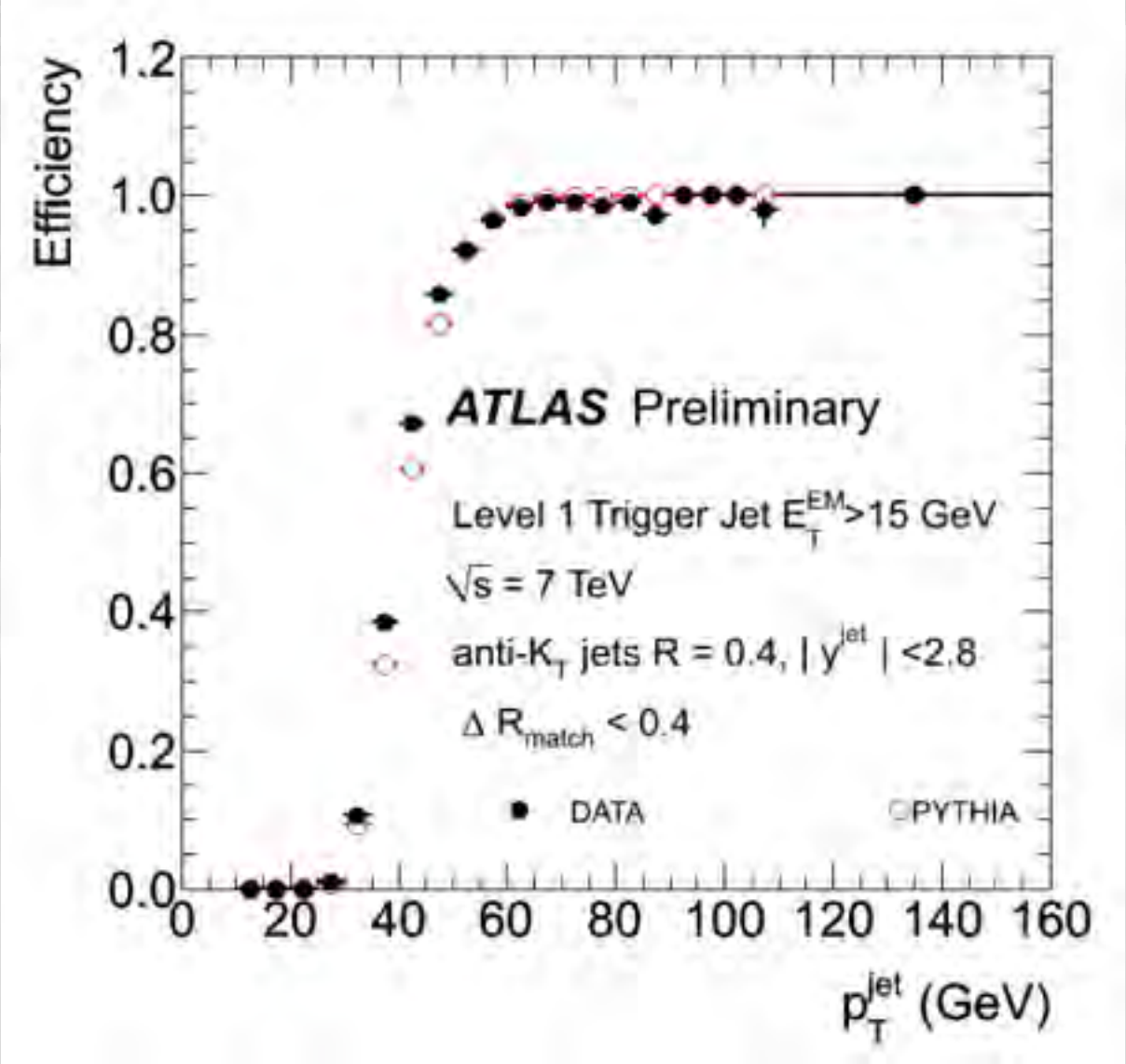
Table 11-1 LVL1 objects and their attributes in addition to E_T. Tables 11-1 and 11-2 introduce the mnemonics for trigger objects used in the trigger menus, see Section 11.7. A total of 16 thresholds is available for EM and T objects combined.

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

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

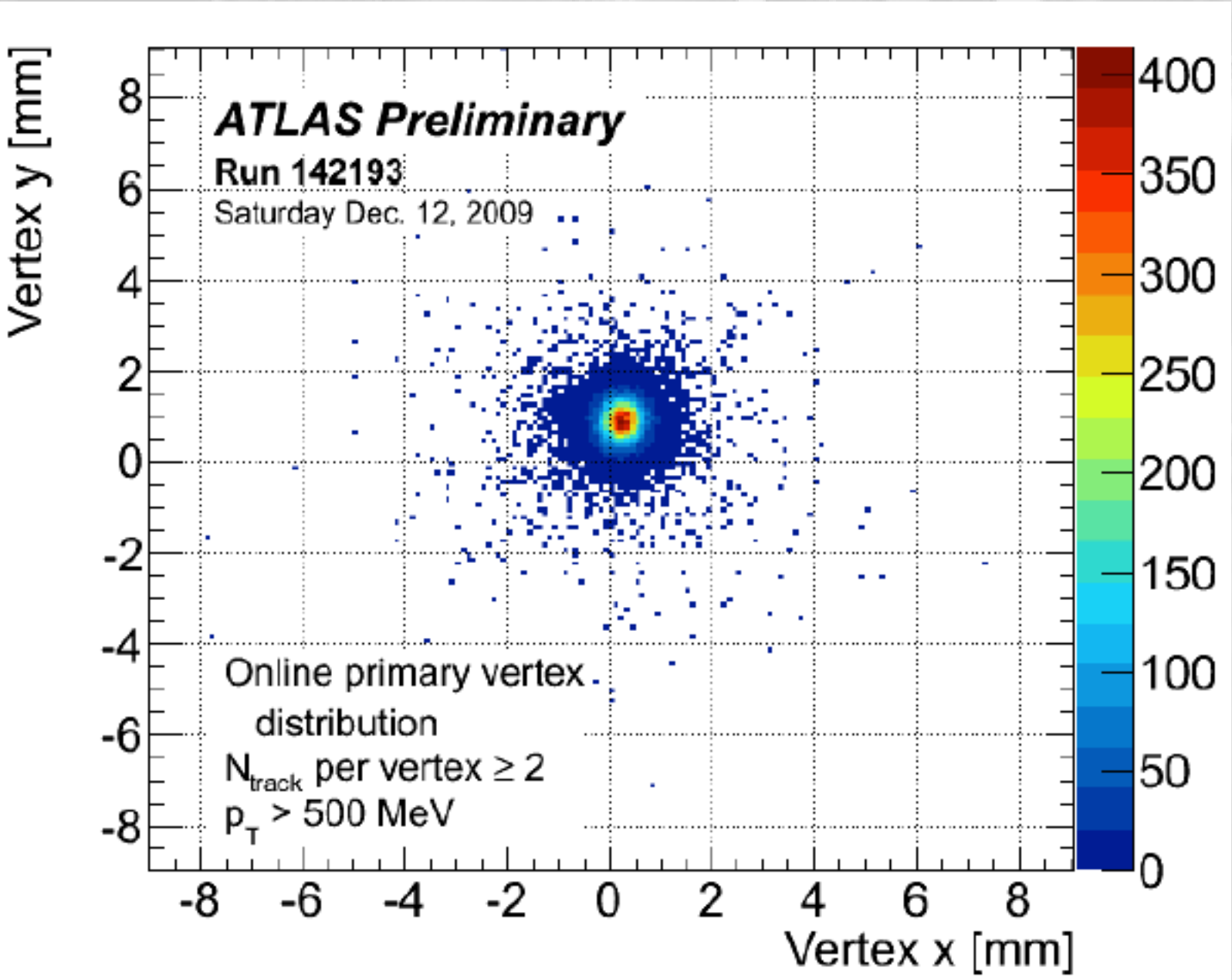
Object	Attribute	$\|\eta\|$ range	Candidate for
μ	isolation	2.4	muon
e	isolation	2.5	electron
γ	isolation	2.5	photon
τ	isolation	2.5	$\tau \rightarrow$ hadrons
h	isolation	2.5	single hadron
j	b-tag ($\|\eta\| < 2.5$)	3.2	jet
xE	–	4.9	missing-E_T

ATLAS LVL1 Jet Trigger Efficiency (Oct. 2010)



arXiv:1010.0017

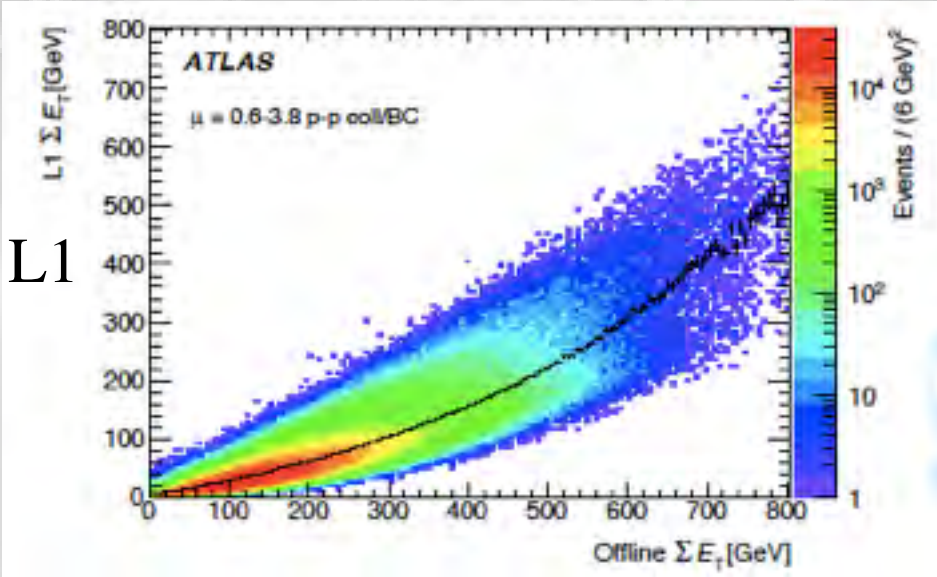
Beam spot determined by L2 tracking (Oct. 2010)



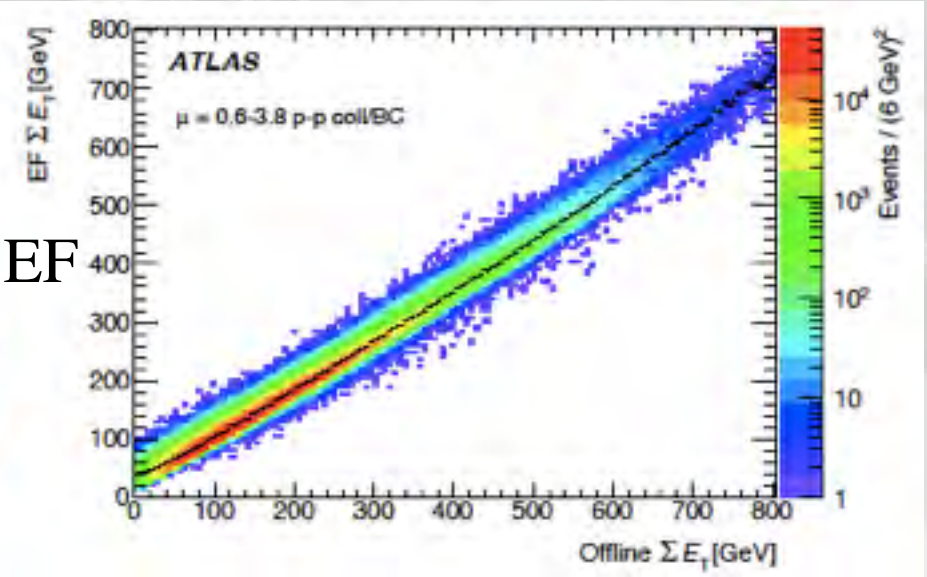
arXiv:1010.0017

Korrelation zwischen trigger- und offline event reconstruction ΣE_T

L1

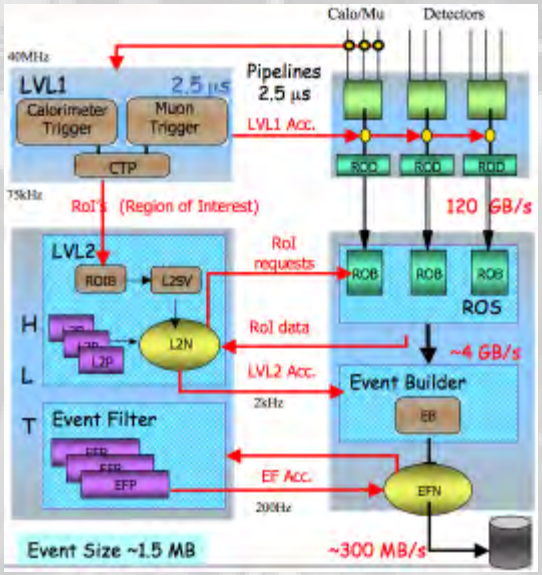


EF



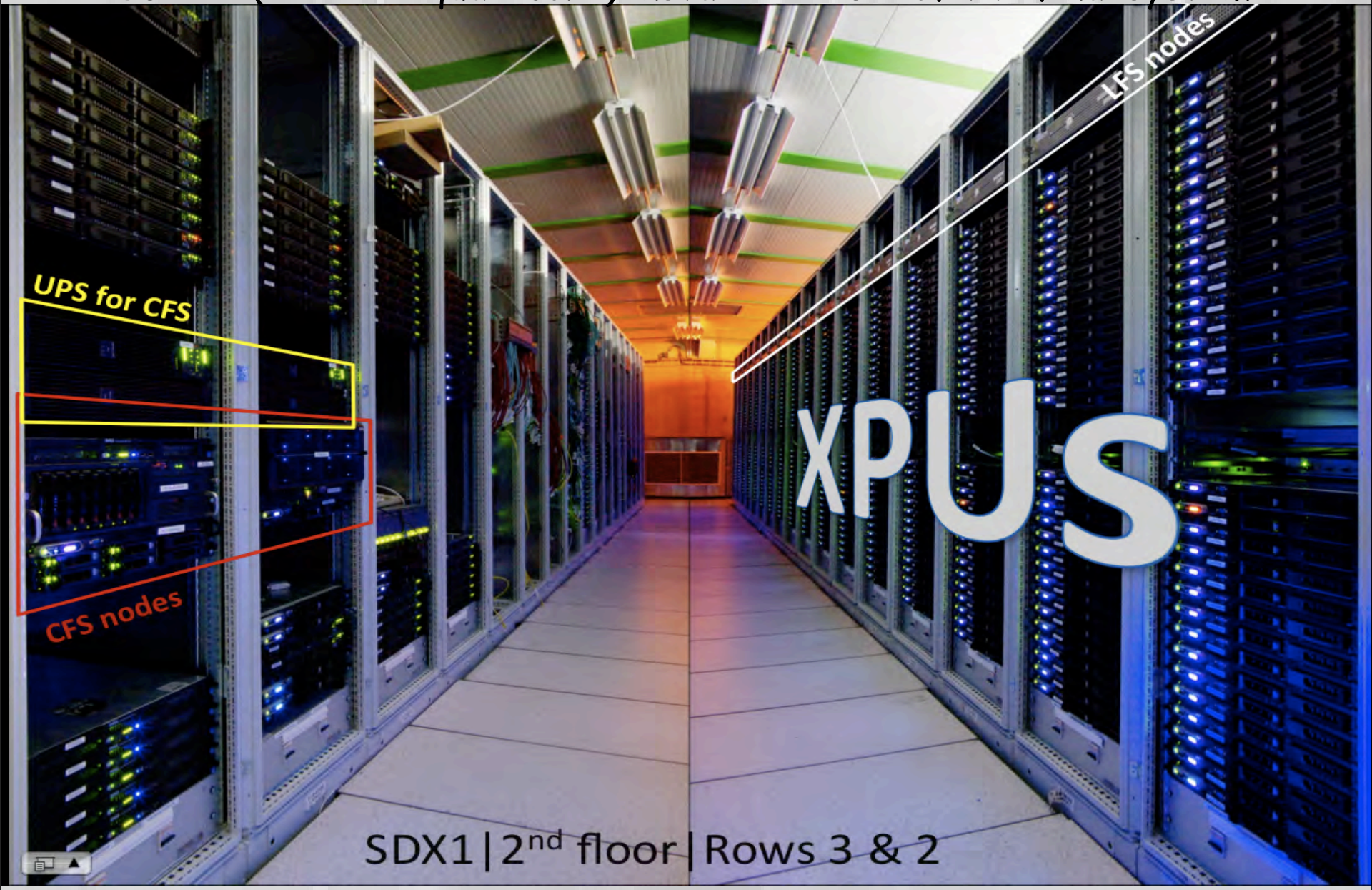
ATLAS Event Filter (EF)

- 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



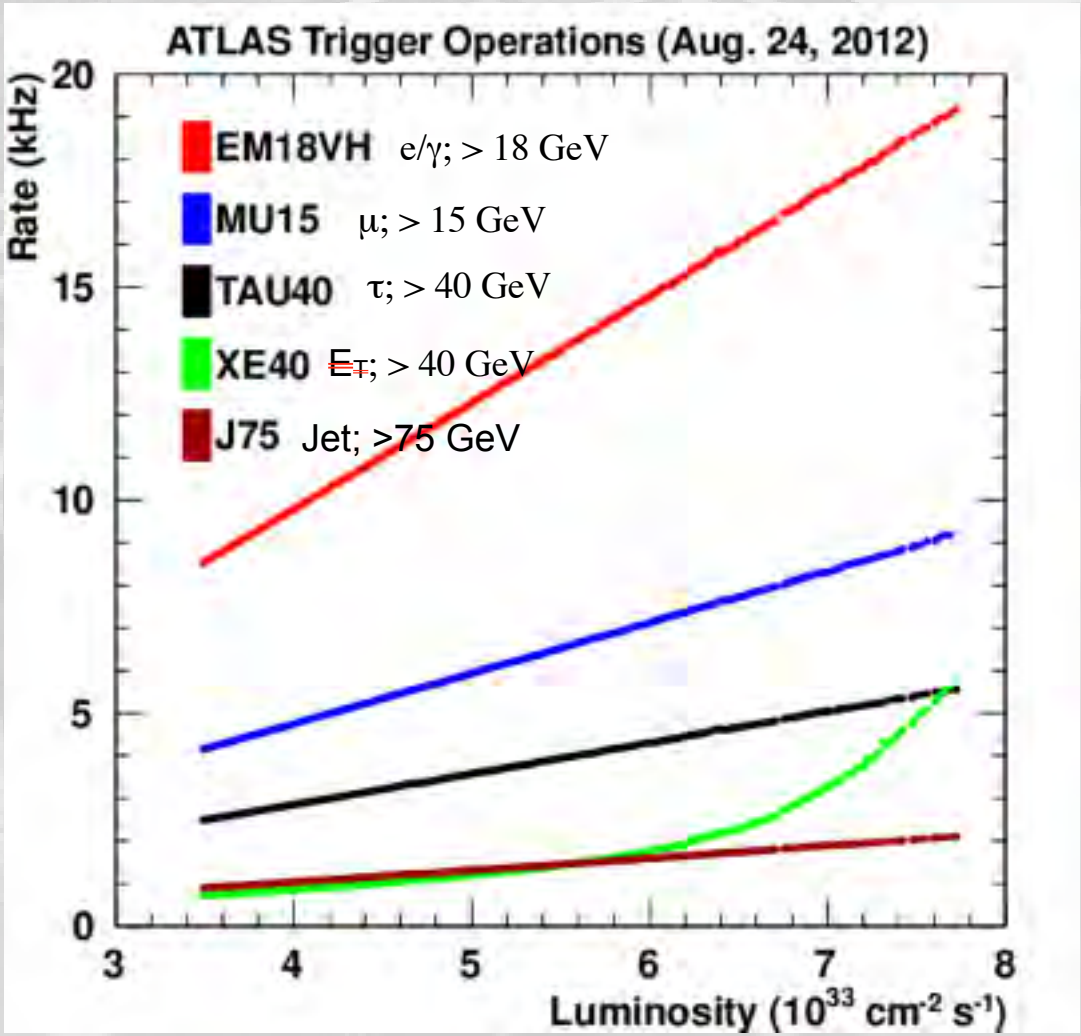
ATLAS High-Level-Trigger (HLT) farm

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



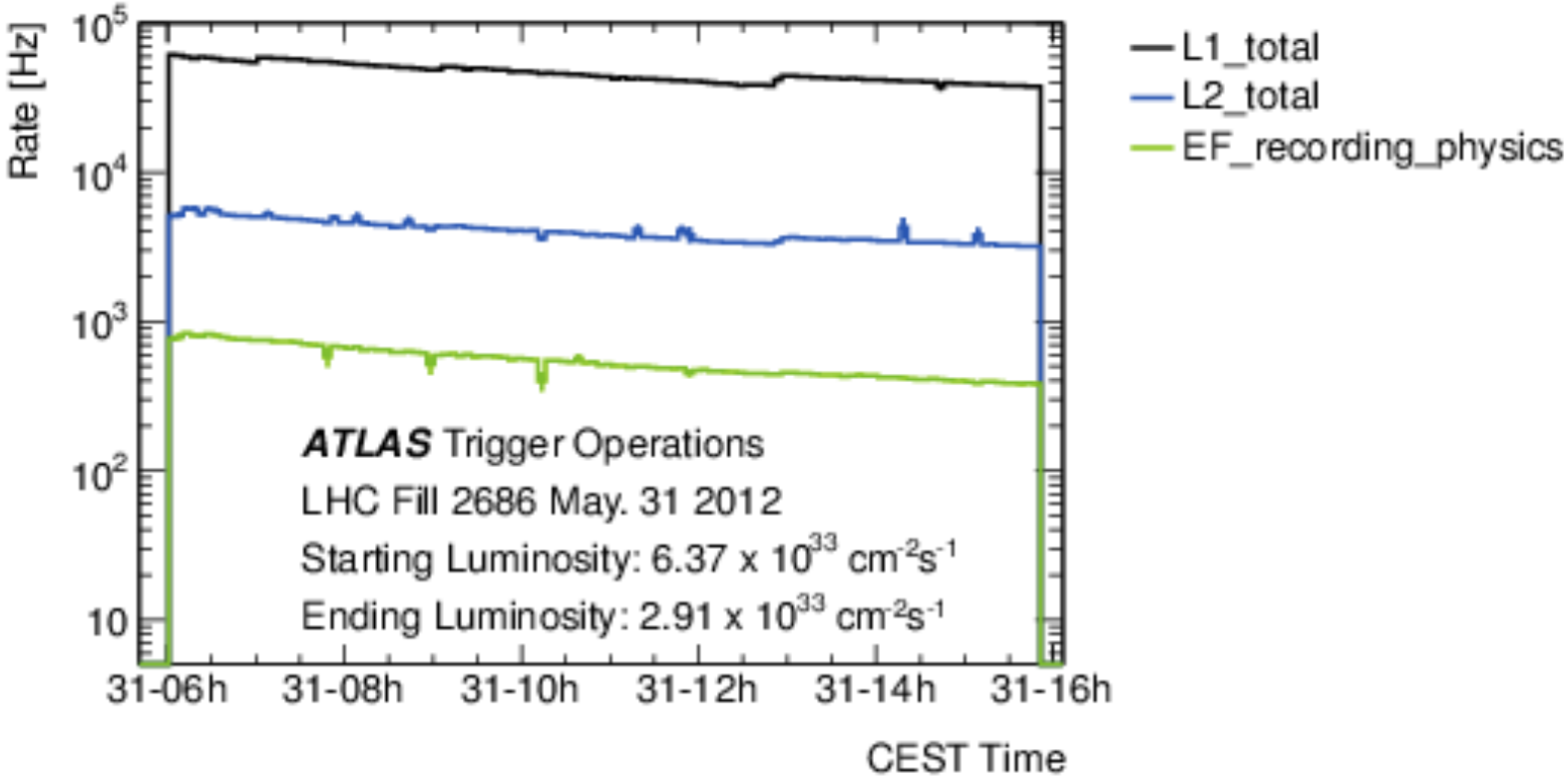
ATLAS Level-1 single-object Trigger rates

at 7.8×10^{33} cm^{-2} s^{-1}



ATLAS Trigger output rates

at 6.4×10^{33} cm^{-2} s^{-1}



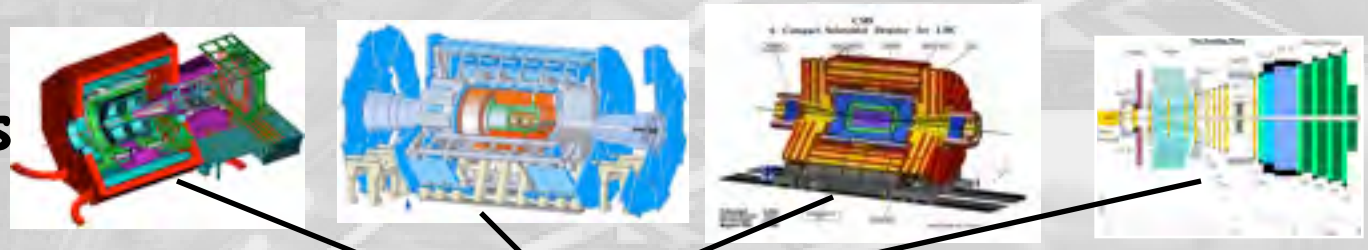
LHC Data and Computing (Plan 2001)

the challenge:

- 40 MHz collision rate -> unfiltered data flow ~ 10^{14} B/s (~10 Billion phone calls)
- 4 experiments; 50-200 Hz data taking rate
- raw event size: 0.12 / 1 / 1-25 MB (LHCb / ATLAS-CMS / ALICE)
- total raw data storage: 7 PB/a ($7 \cdot 10^{15}$ Bytes/year; 100 000 km thick pile of A4-paper)
- total simulated Data storage: 3.2 PB/a
- world-wide* tape storage: 28.5 PB/a (40 million CD-Rom's)
- world-wide* disk storage: 10.4 PB/a (140k disks à 75 GB)
- world-wide* CPU capacity: 7350 k SI-95 (360k today's PCs)
- WAN bandwidth (Tier-0/-1): 1500 Mbps (1 experiment)
  (5000 Mbps when serving all 4 exp.'s)

* all Tier-0, Tier-1 and Tier-2 computing centres, excl. Tier-3 and -4

The LHC Computing Model (2001)



Experiments

Tier-0

Tier-1

Tier-2

Tier-3

Tier-4

The Grid

CERN

Region 1 | Region 2 | GridKa | Region 4 | CERN

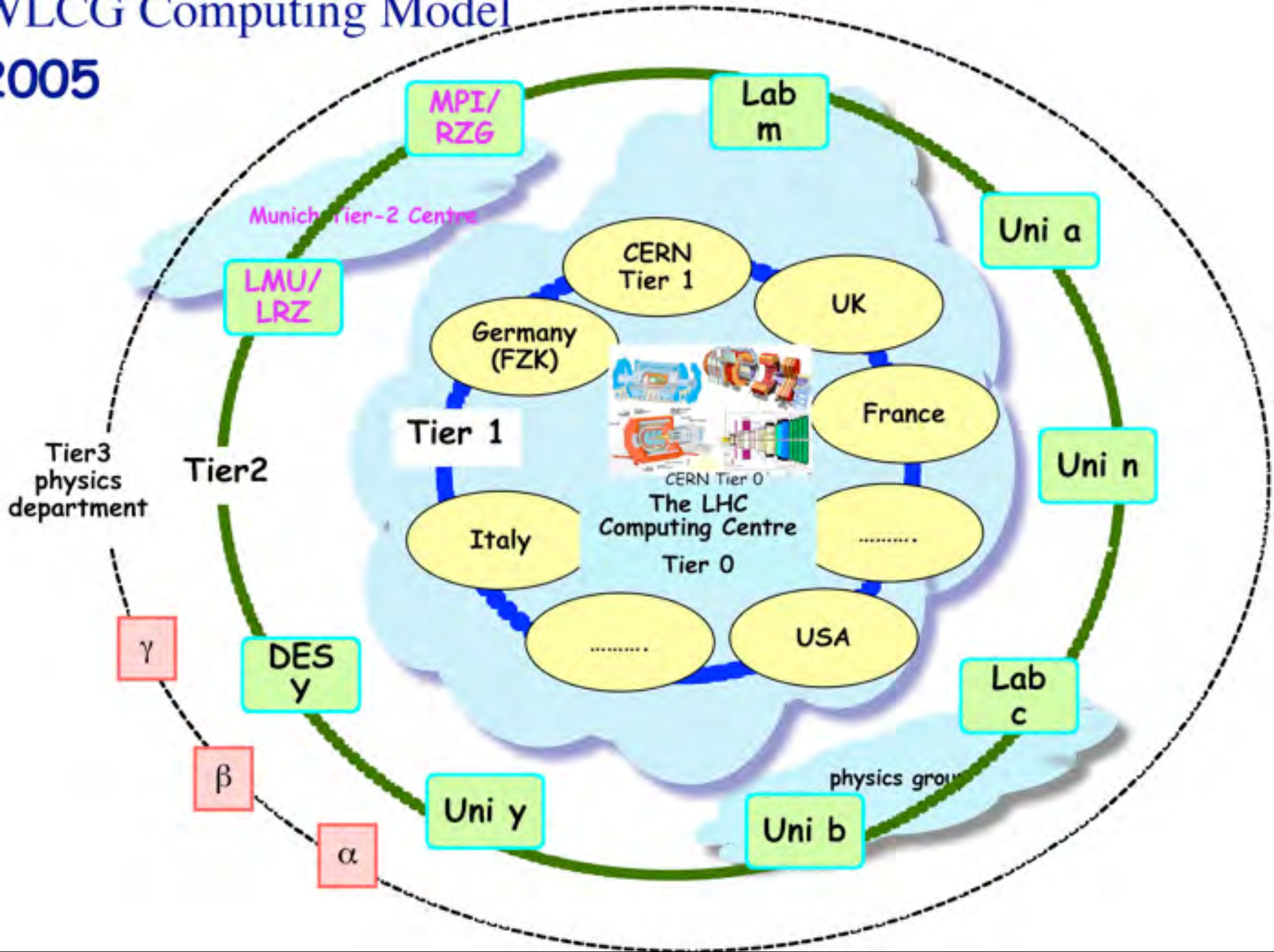
Country 1 | Country 2 | Country 3 | Country 4 | Country 5 | ...

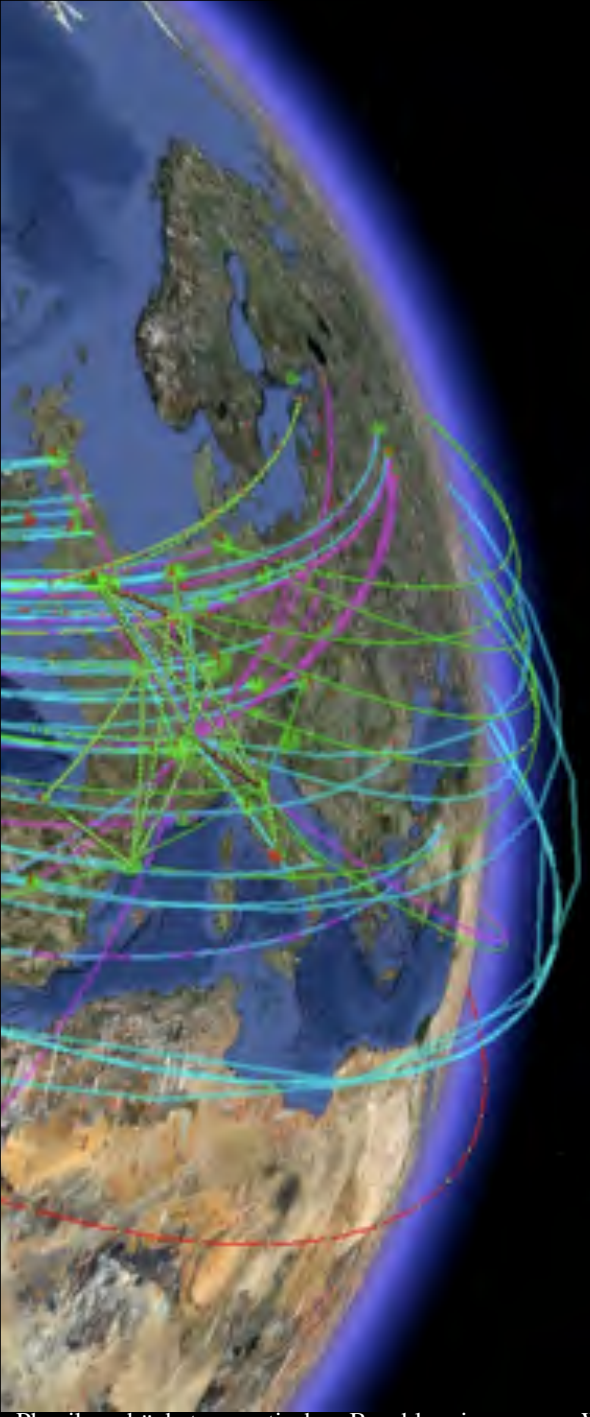
Lab 1 | Uni 2 | Uni 3 | Lab 4 | Uni 5 | Lab 6 | ...

...

WLCG Computing Model

2005





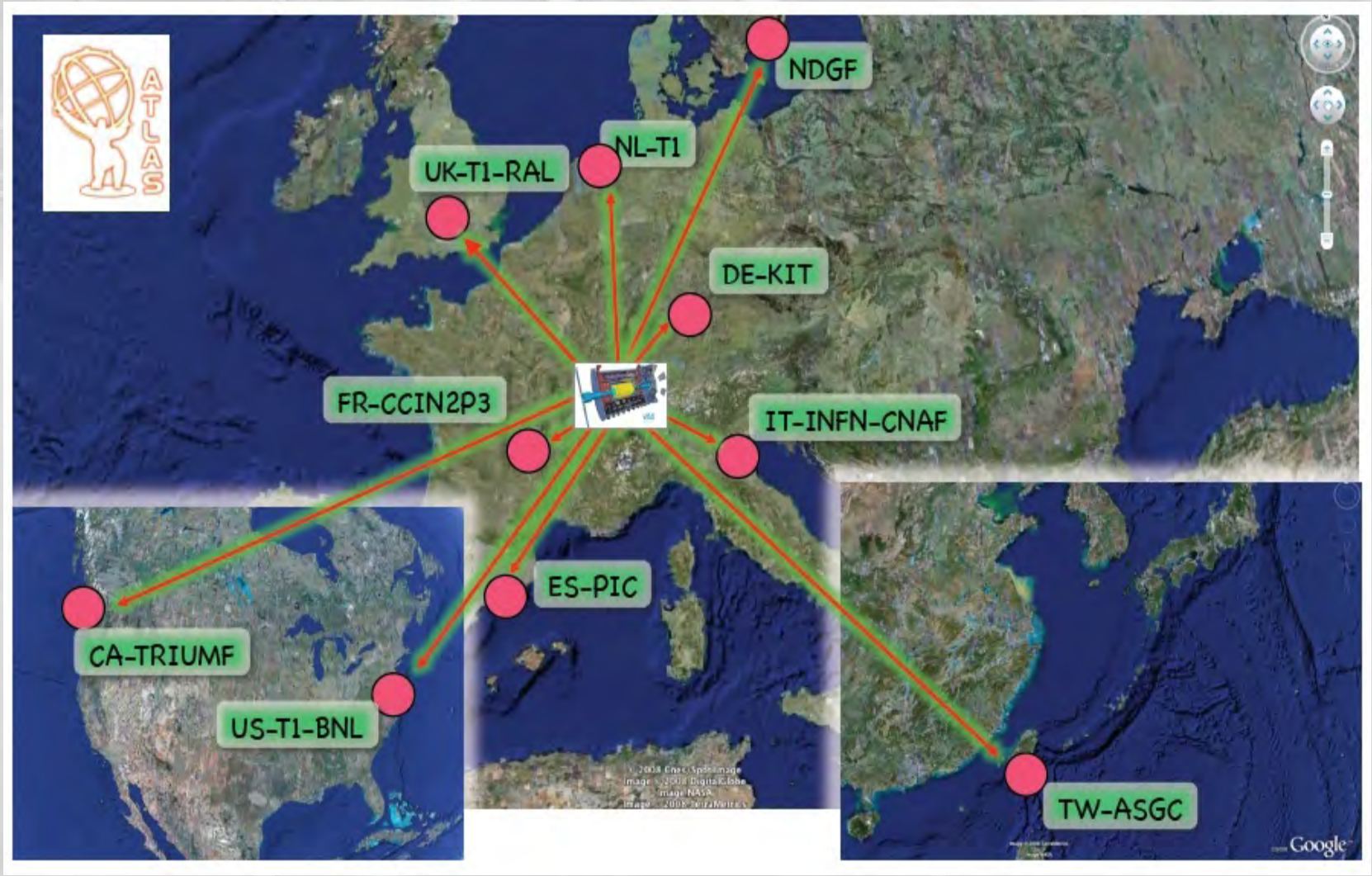
LHC-GRID (WLCG): worldwide networking and distribution of tasks:

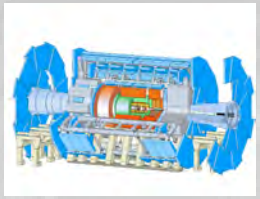
- redundant data storage (Tier-0 , -1)
- generation (Tier-2) and storage (-1, -2) of simulation data (MC)
- data reduction; calibration (Tier-0) and data bases (-0, -1)
- processing of analysis jobs (Tier-1, -2, ...)

WLCG
Worldwide LHC Computing Grid

Computing infrastructure and operation

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





1st pass raw data reconstruction at Tier0 and export

reconstruction

raw data

Reprocessing at Tier1

Event Summary Data

processed data

Physics analysis at Tier2

analysis

analysis objects
(extracted by physics topic)

interactive physics analysis

simulation

Simulation at Tier1/2

WLCG
Worldwide LHC Computing Grid

Components

WLCG: installed capacities

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

Capacities > Federation Capacities

VO: ALL Year: 2013 Month: 11

All Tiers | Tier 0 | Tier 1 | Tier 2

Search:

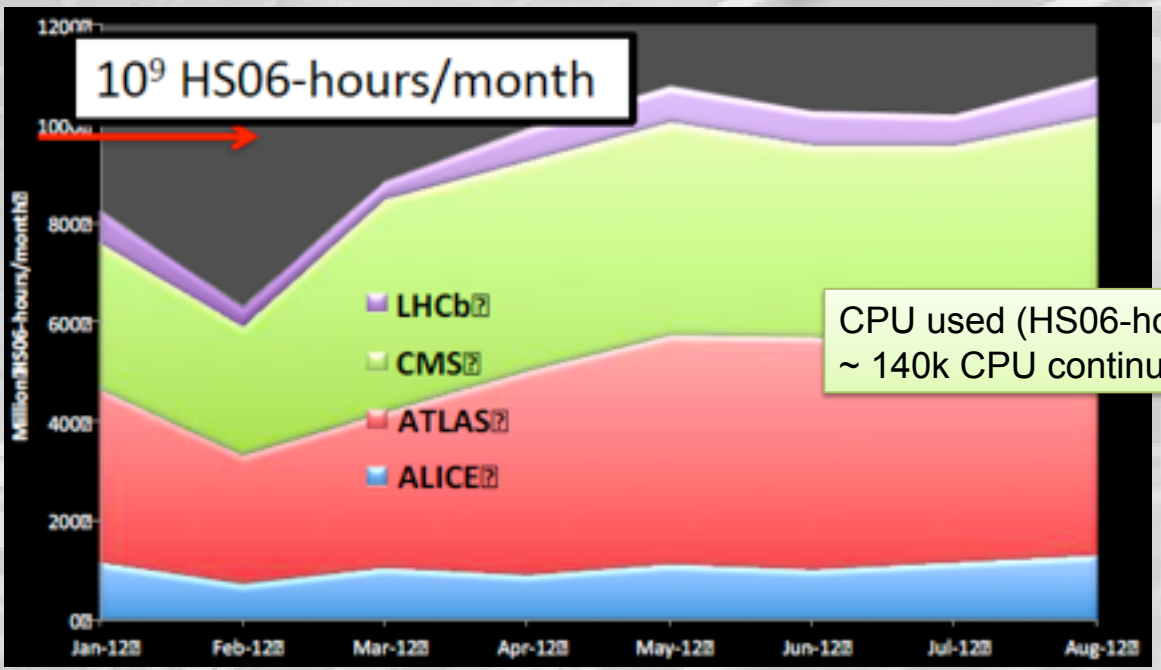
Country	Federation	Physical CPU	Logical CPU	HEPSPEC06	Total Online Storage (GB)	Total Nearline Storage (GB)
Canada	CA-TRIUMF	866	4,860	73,870	6,417,811	5,316,300
France	FR-CCIN2P3	989	13,787	142,786	8,980,896	14,926,505
Germany	DE-KIT	1,230	16,144	183,880	9,255,863	46,473,310
Italy	IT-INFN-CNAF	4,316	18,008	187,986	25,124,927	8,095,454
Netherlands	NL-T1	2,176	10,656	128,814	6,723,875	10,703,469
Nordic	NDGF	22,040	22,040	207,755	6,009,311	5,464,000
Republic of Korea	KR-KISTI-GSDC	150	1,800	20,502	1	0
Spain	ES-PIC	630	3,569	46,994	0	0
Taiwan	TW-ASGC	1,128	4,512	45,752	5,699,533	4,000,000
UK	UK-T1-RAL	1,556	10,288	104,904	10,465,176	10,820,030
USA	US-FNAL-CMS	1,692	6,768	58,000	10,000,000	22,000,000
USA	US-T1-BNL	1,590	14,072	74,000	11,000,000	8,600,000
Total		**38,363**	**126,504**	**1,275,243**	**99,677,393**	**136,399,068**

Tier 2:

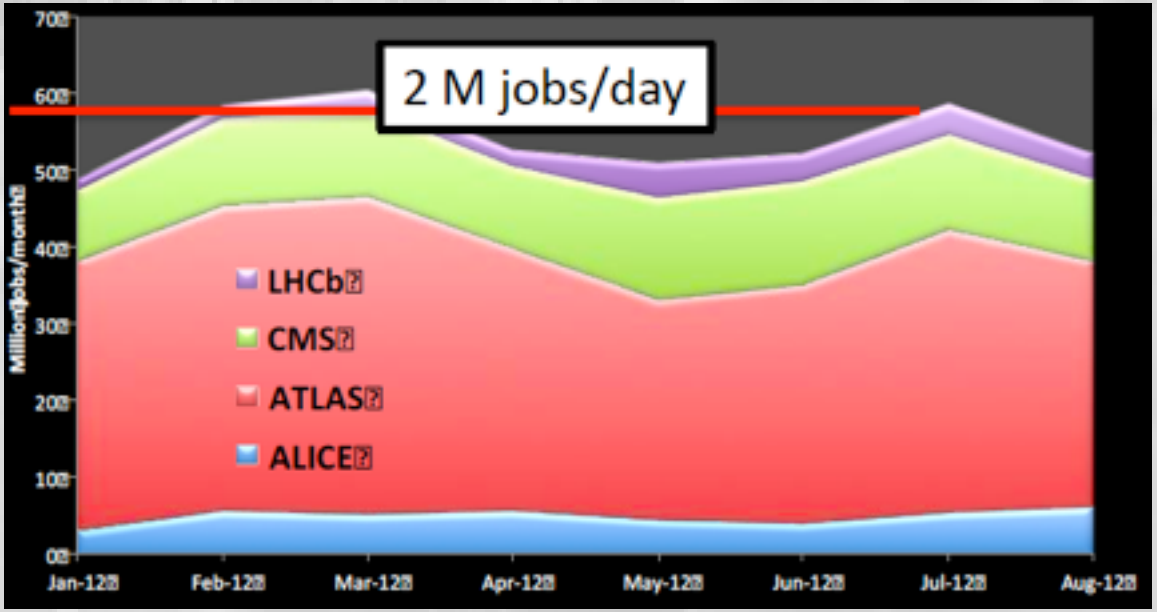
Total	**64,026**	**298,953**	**2,799,964**	**134,192,663**	**4,274,256**

Showing 1 to 66 of 66 entries

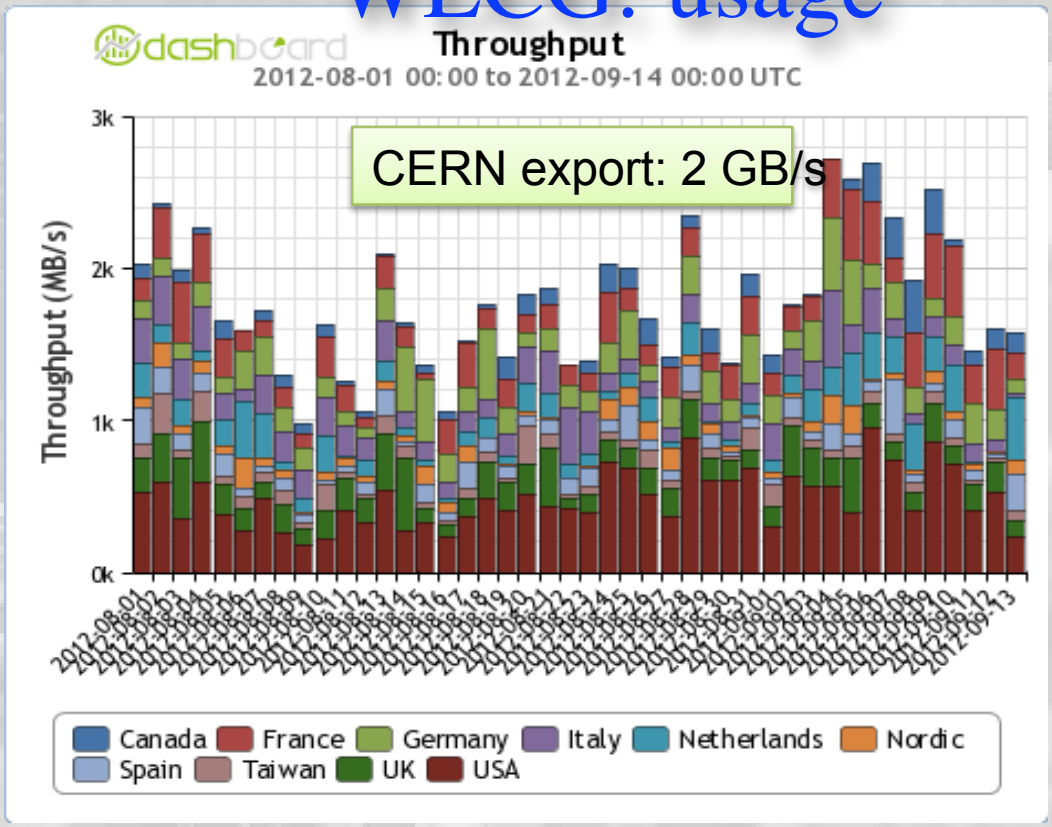
WLCG: usage

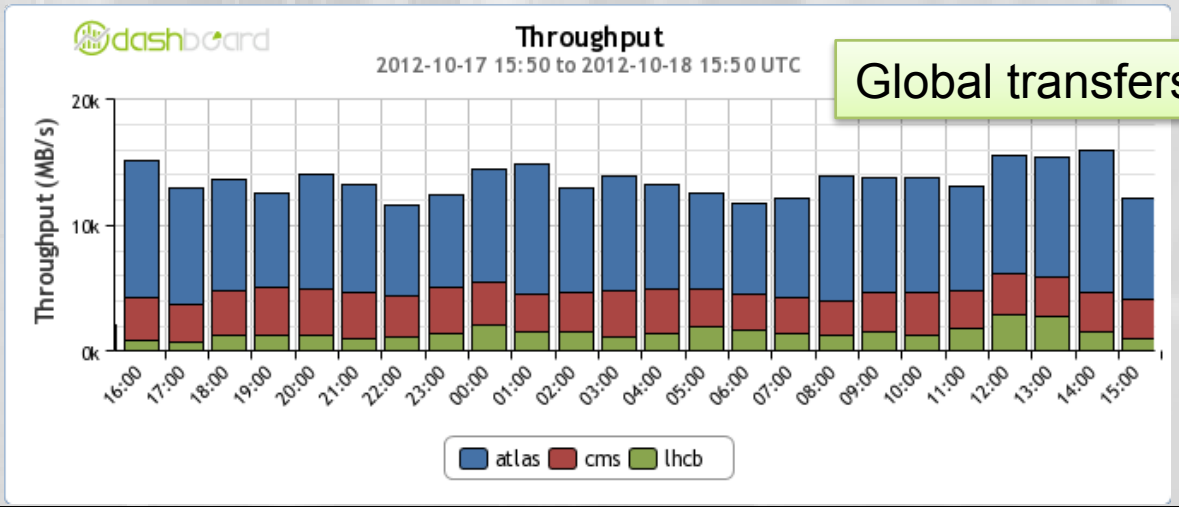


CPU used (HS06-hours/month)
~ 140k CPU continuous use

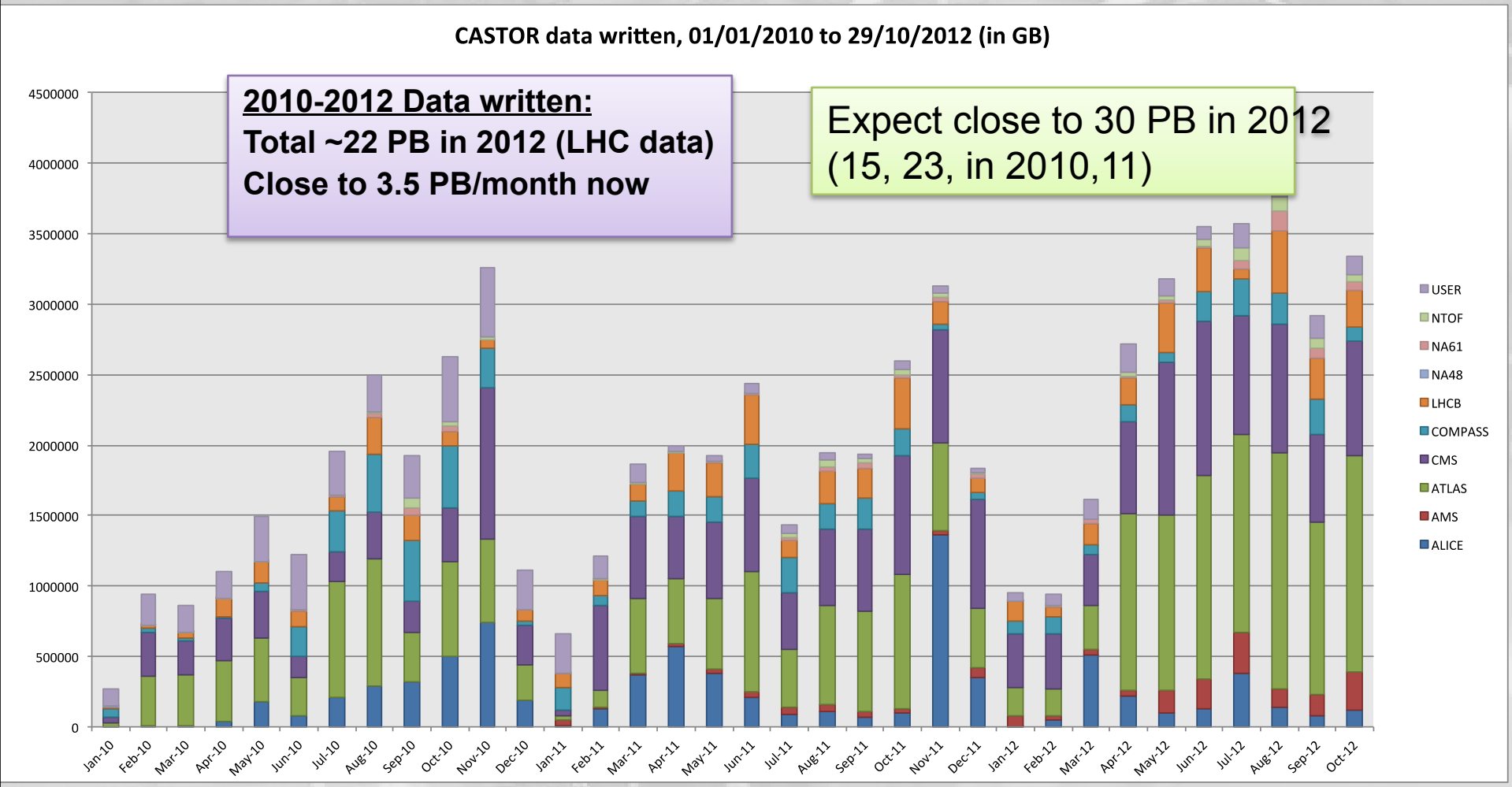


WLCG: usage


dashboard
Throughput
2012-08-01 00:00 to 2012-09-14 00:00 UTC
CERN export: 2 GB/s
Throughput (MB/s)
3k
2k
1k
0k
Canada
France
Germany
Italy
Netherlands
Nordic
Spain
Taiwan
UK
USA


dashboard
Throughput
2012-10-17 15:50 to 2012-10-18 15:50 UTC
Global transfers > 15 GB/s
Throughput (MB/s)
20k
10k
0k
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
atlas
cms
lhcb

Castor data written 2010-12



2010-2012 Data written:
Total ~22 PB in 2012 (LHC data)
Close to 3.5 PB/month now

Expect close to 30 PB in 2012
(15, 23, in 2010,11)

Data rates in Castor increased
3-4 GB/s input
~15 GB/s output

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]
- The LHC Computing Grid, http://lcg.web.cern.ch/LCG