

LHC Experiments - Trigger, Data-taking and Computing

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

Data rates at the LHC

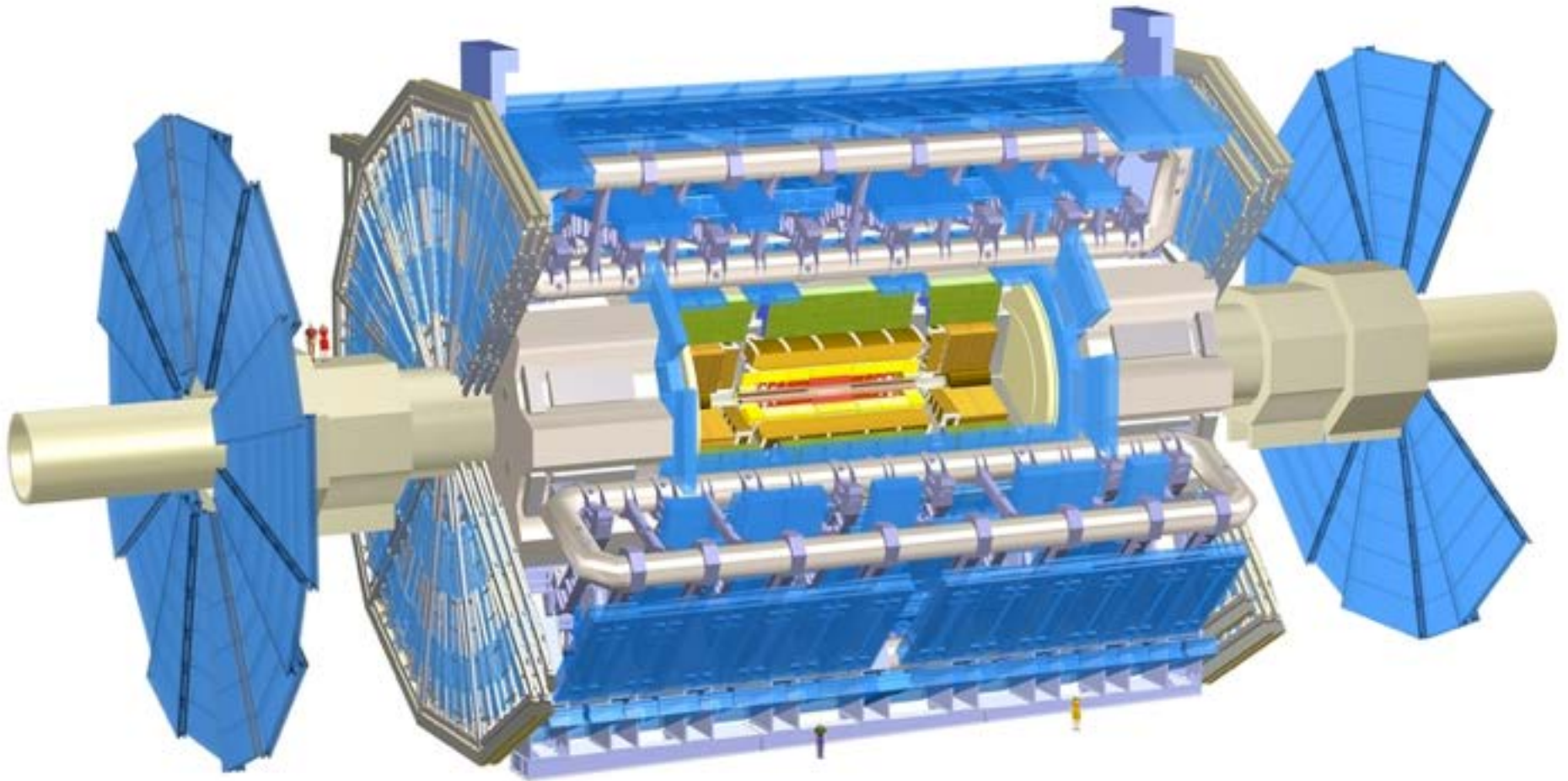
- 20 (40) MHz bunch crossing rate; about 35 collisions / xing
 - $\rightarrow \sim 10^9$ interactions per second (at $L = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)
 - ATLAS: ca. $1.5 \cdot 10^8$ electronic channels
 - 1-2 MByte detector data per event (bunch crossing)
(including active zero suppression)
 - $\rightarrow \sim 10^{14} - 10^{15}$ 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)!
- $\rightarrow$ 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

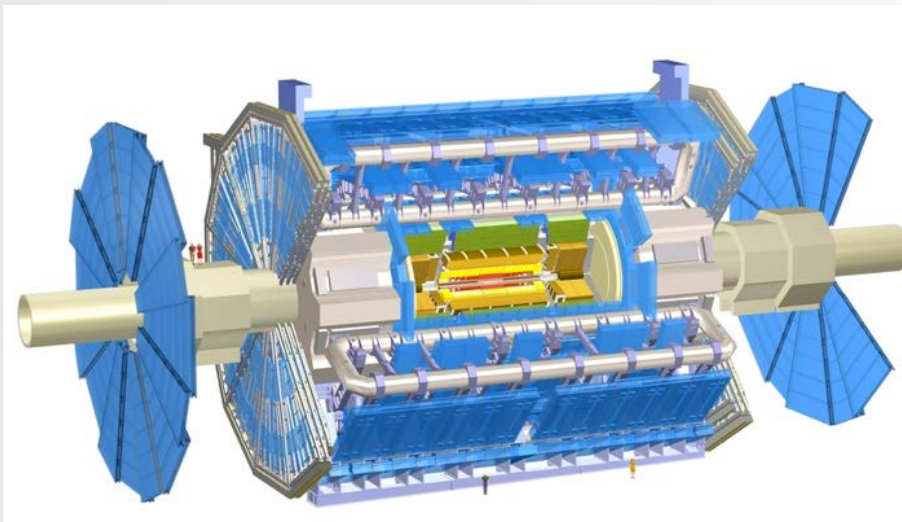


number of active detector channels at ATLAS

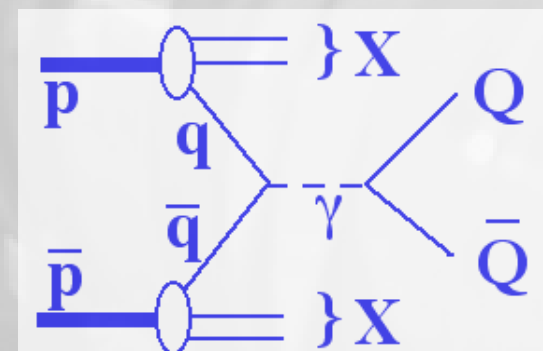
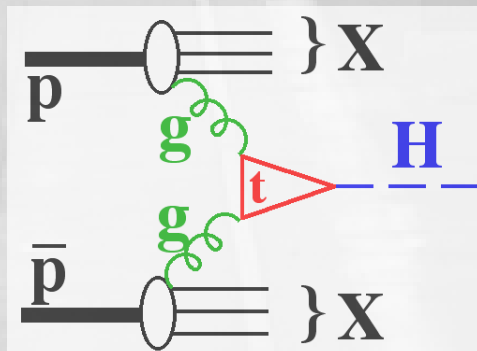
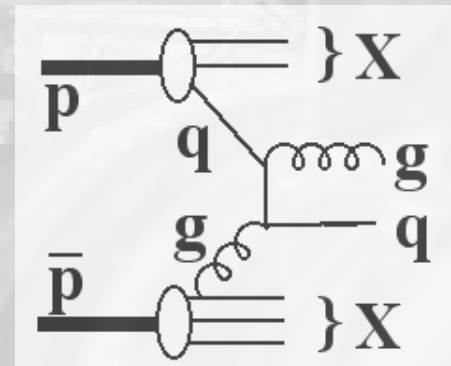
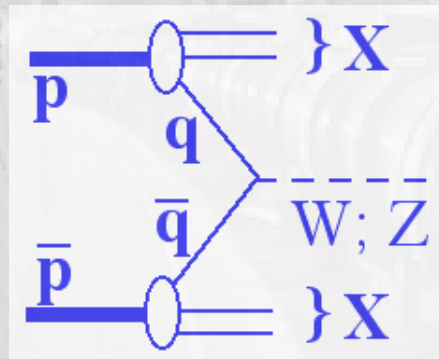
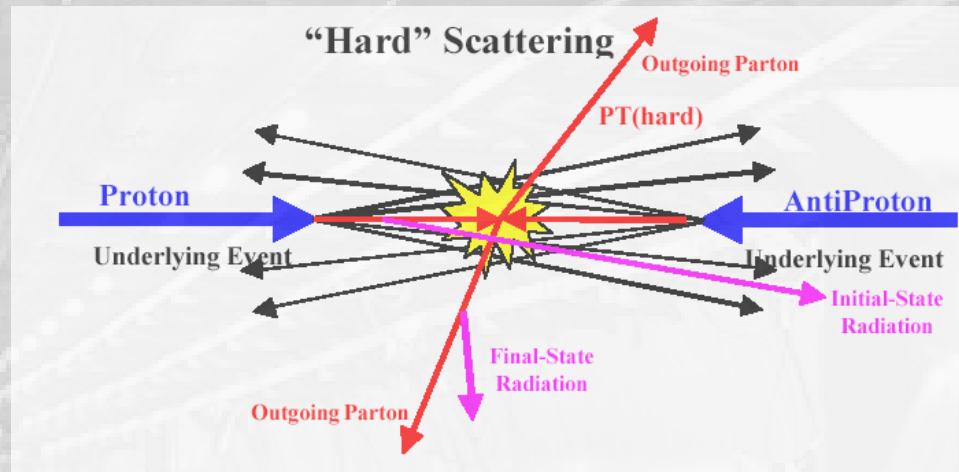
Table 2-1 Number of active detector elements, number of modules or chambers, and number of GEANT volumes defined for the detailed simulation of each of the various ATLAS detector systems.

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

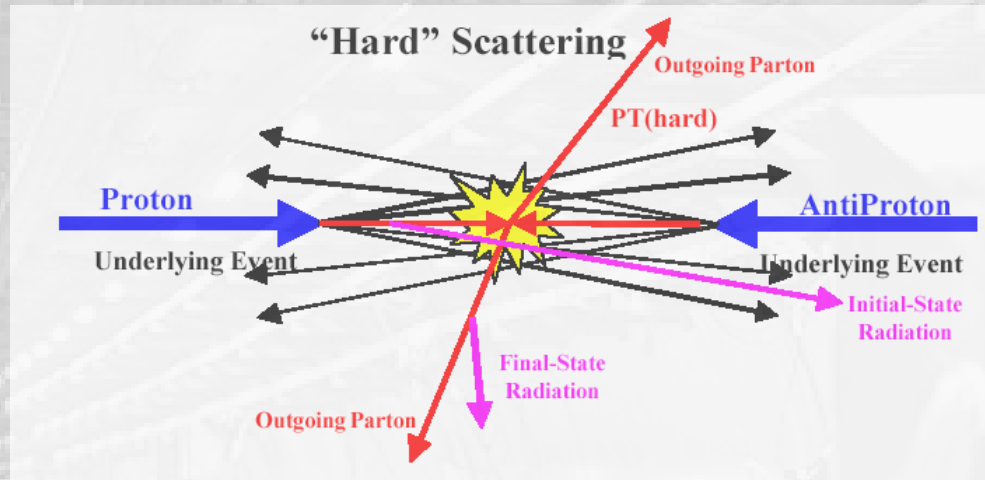
relevant for
MC simulation



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

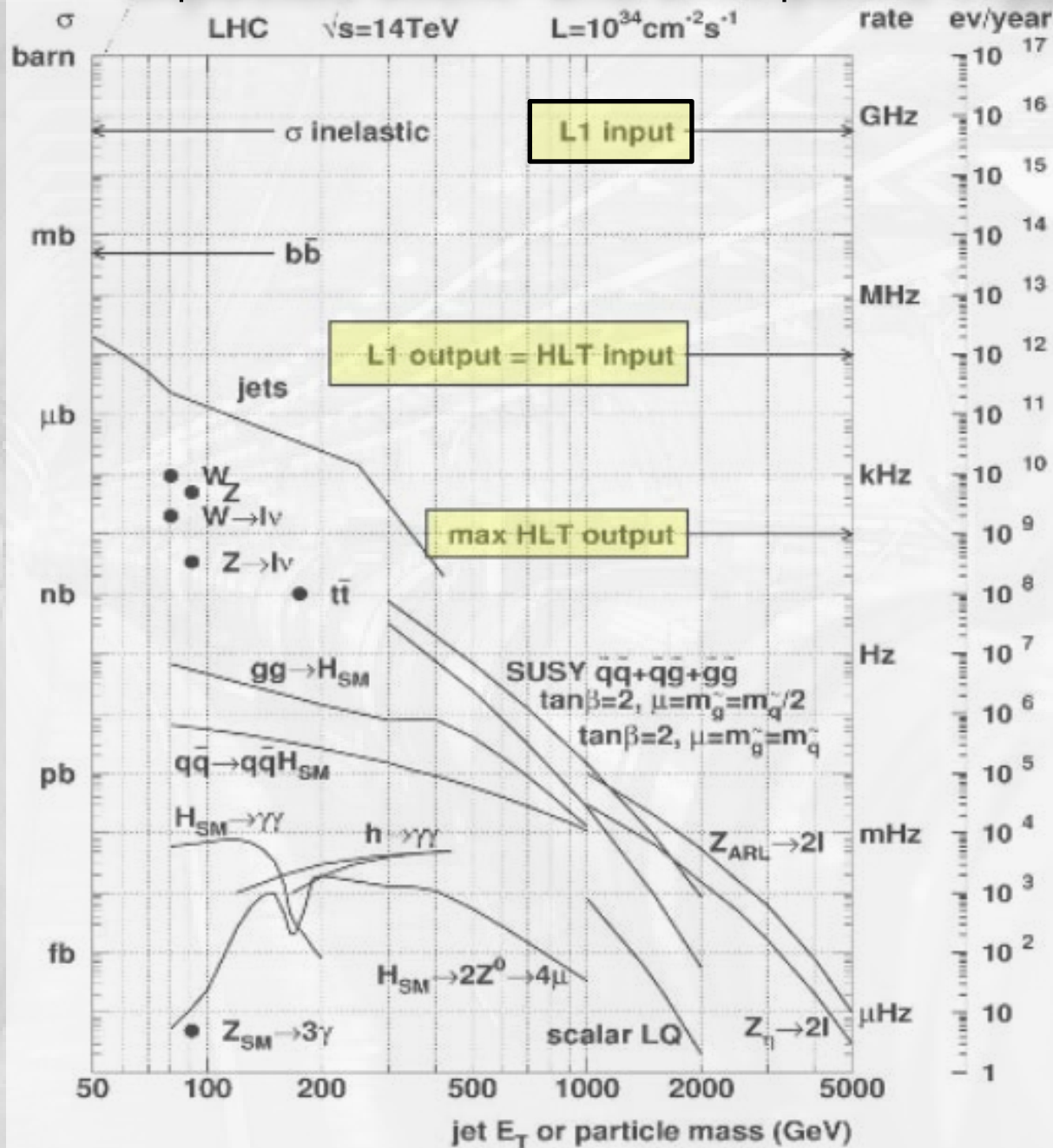


physics signatures



- as energies of colliding quarks/gluons are unknown:
in general, restrict to “transverse” observables
(i.e. $\perp$ 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) 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 $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ about 35 collisions per bunch-crossing

Threshold:

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

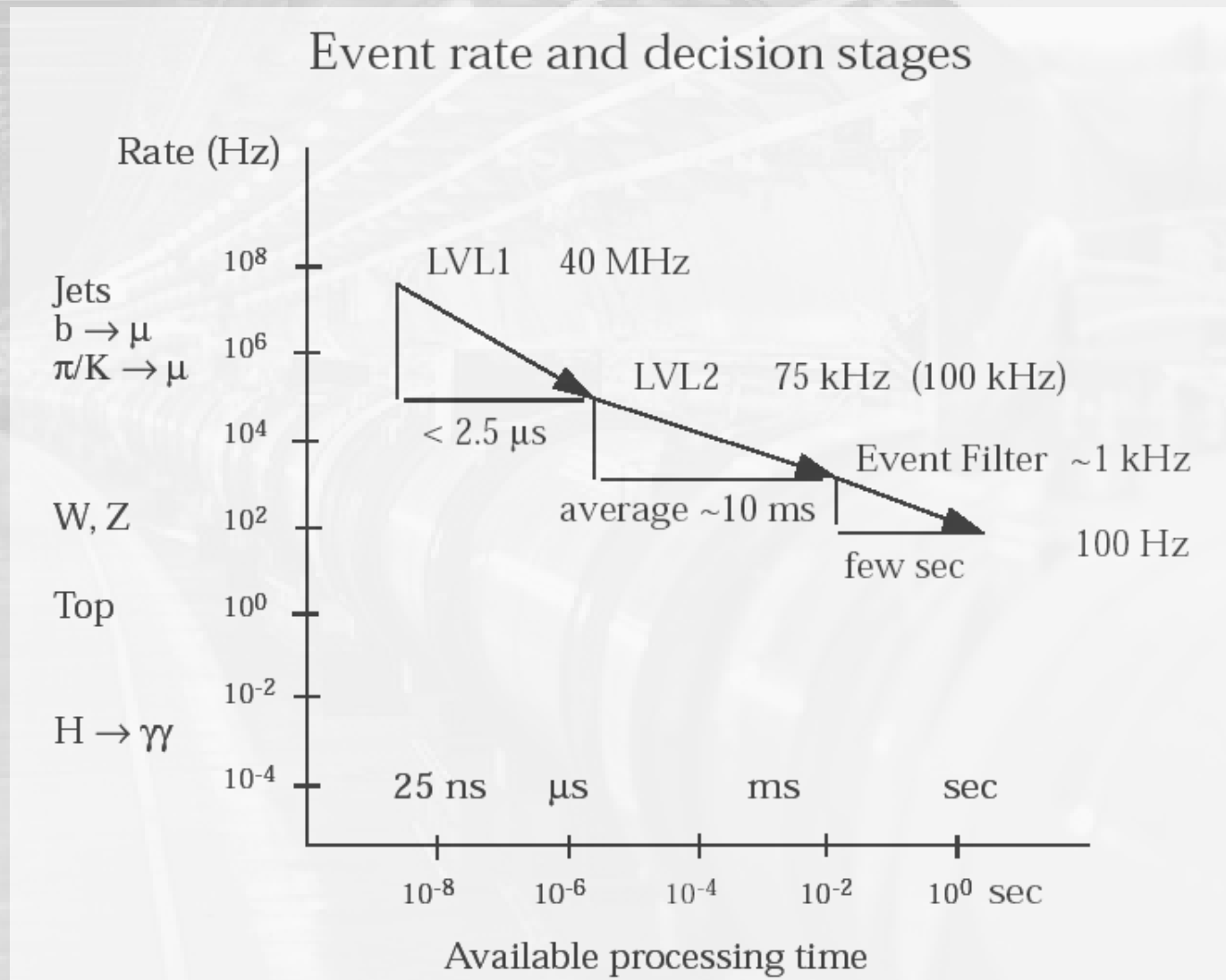
Trigger Rate:

- 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...

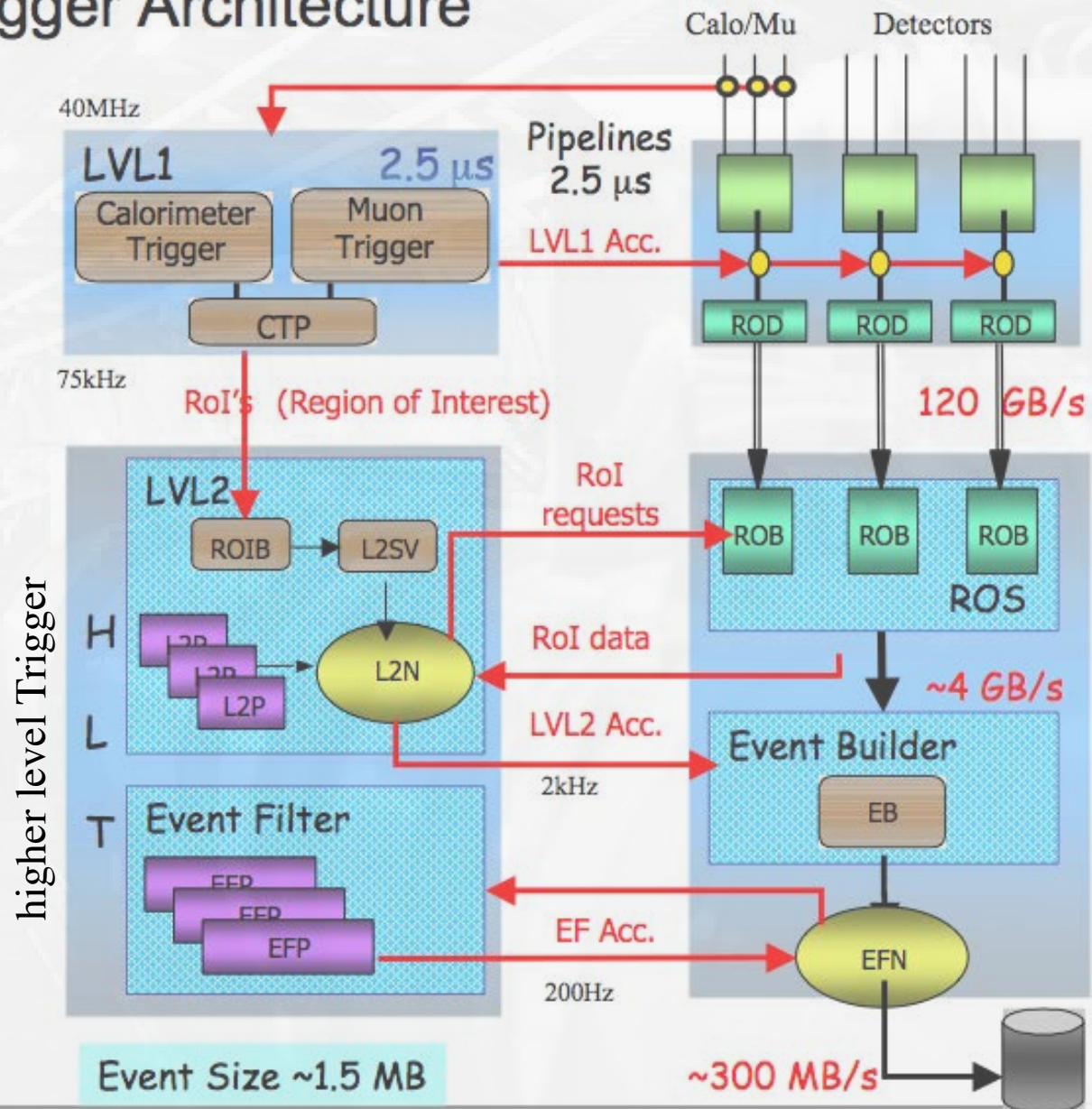
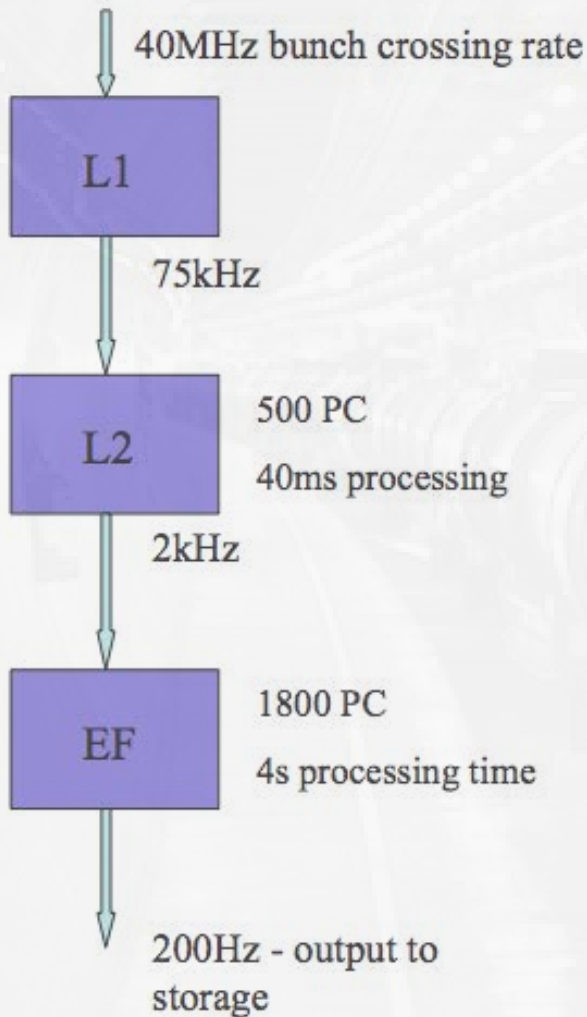
ATLAS: data rates and trigger decisions



ATLAS Trigger/DAQ System

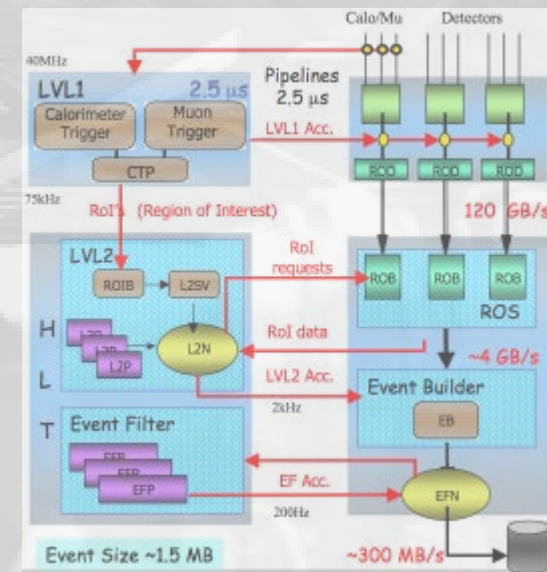
Trigger Architecture

A quick tour through specs



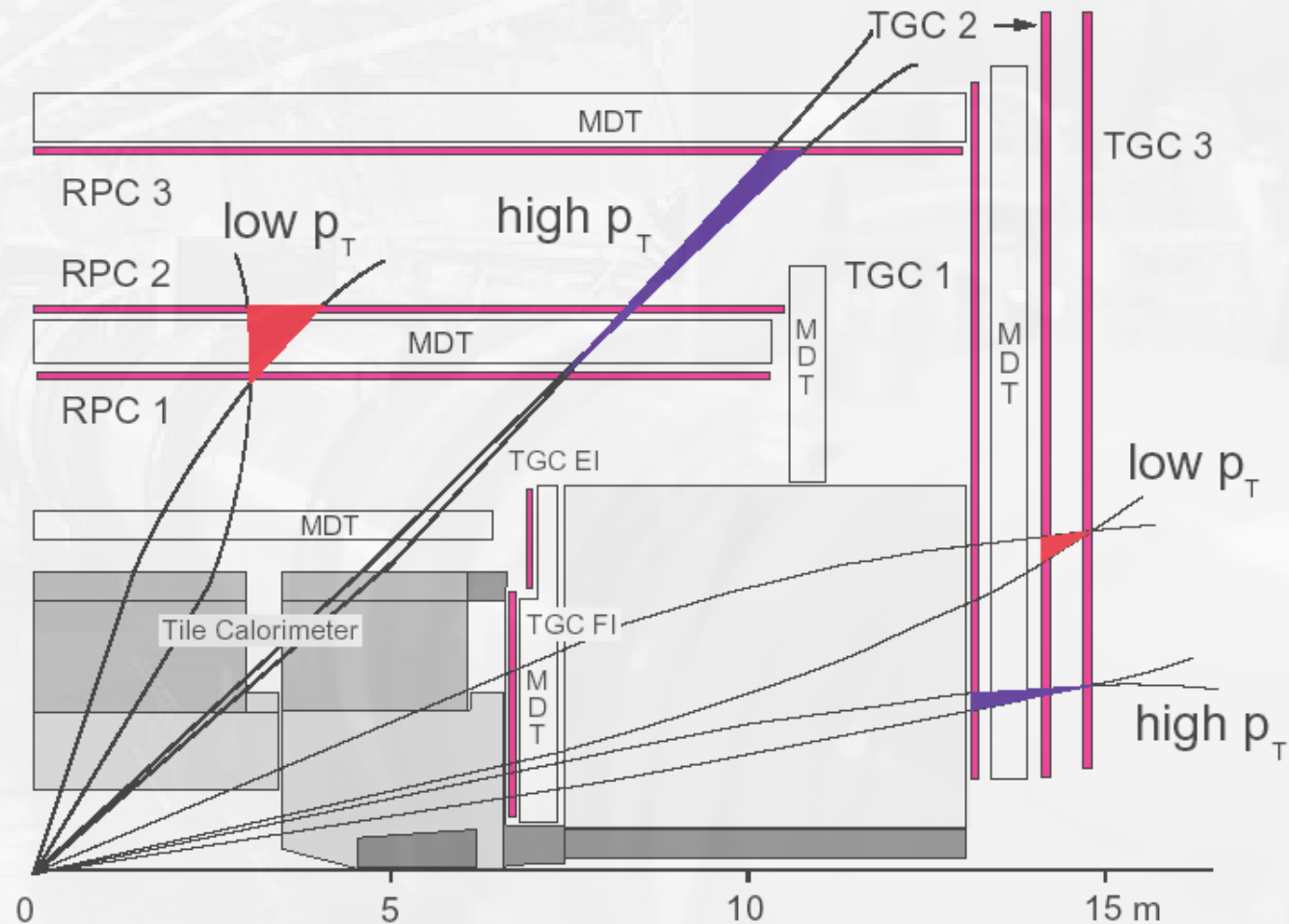
ATLAS Level 1 Trigger

- 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 ($\sim 2 \mu\text{s}$), 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



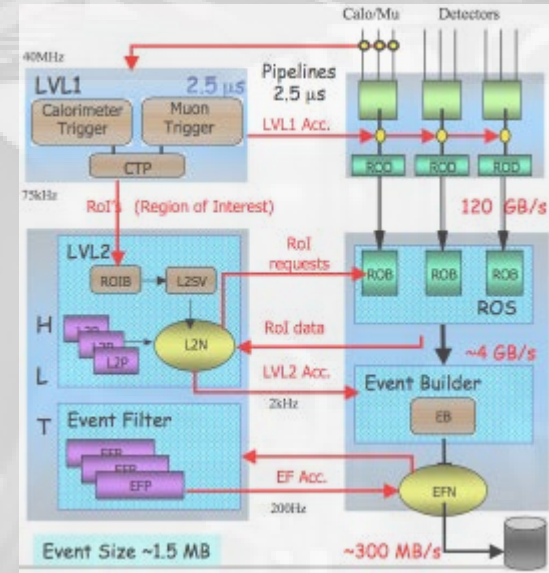
ATLAS Level 1 μ -Trigger

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

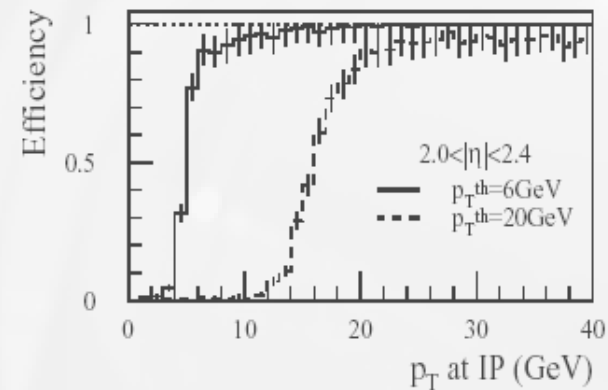
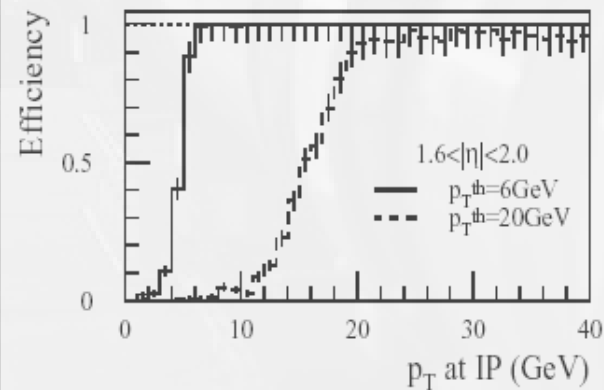
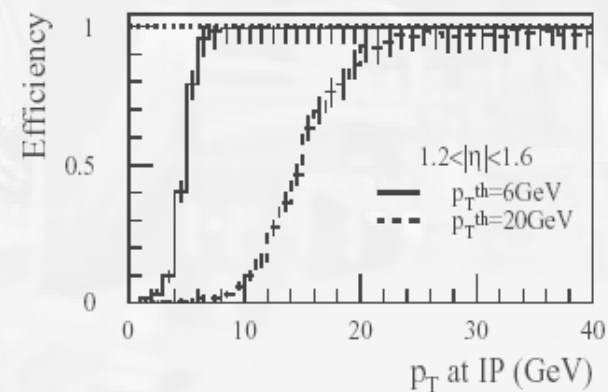
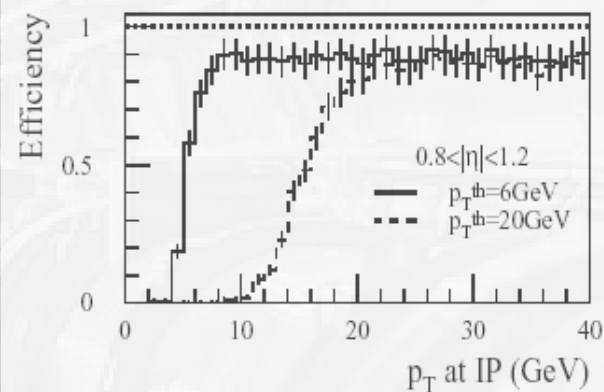
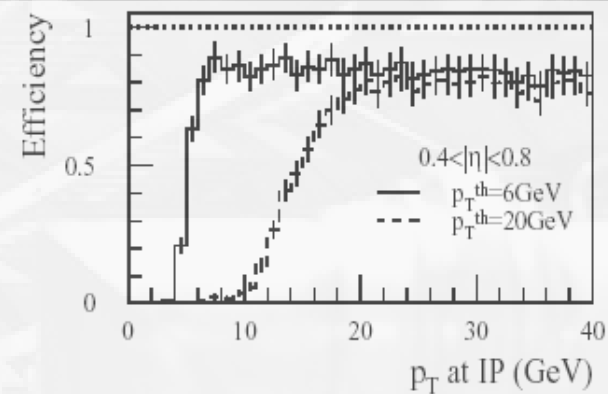
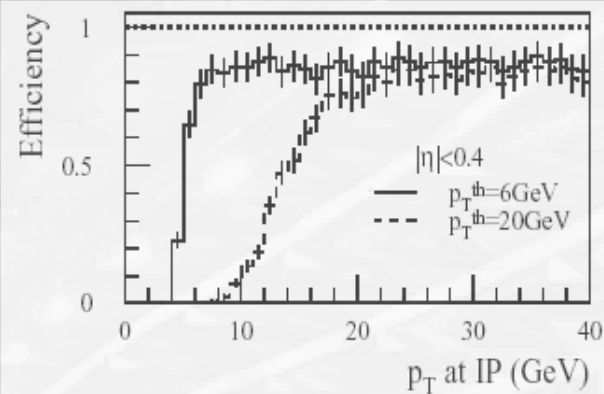


ATLAS Level 1 Trigger (cont.)

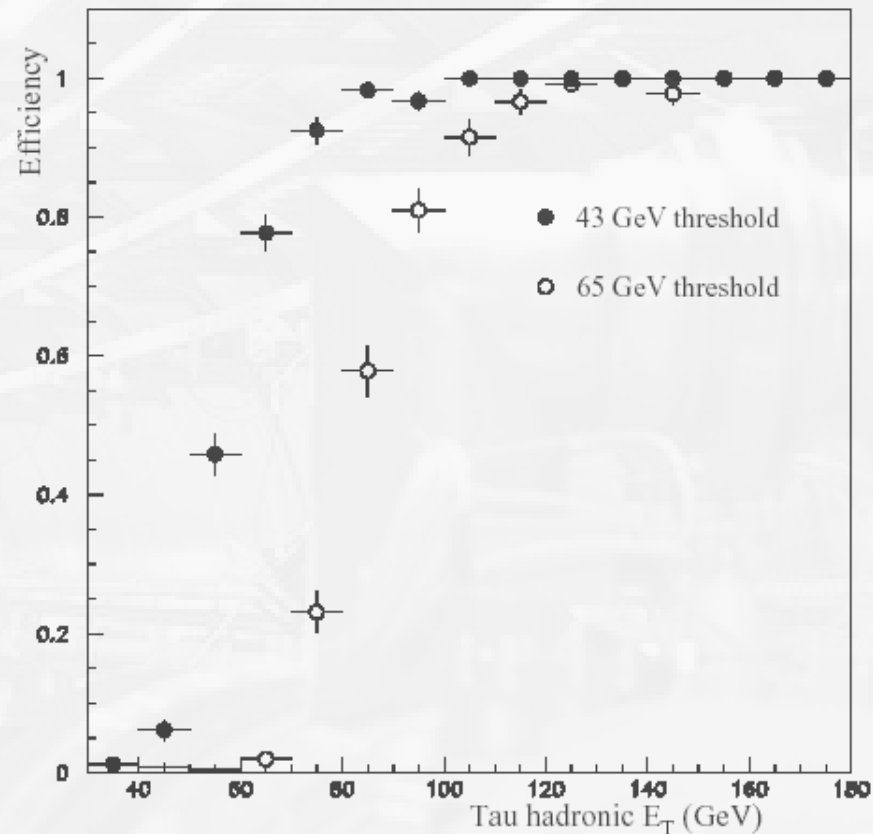
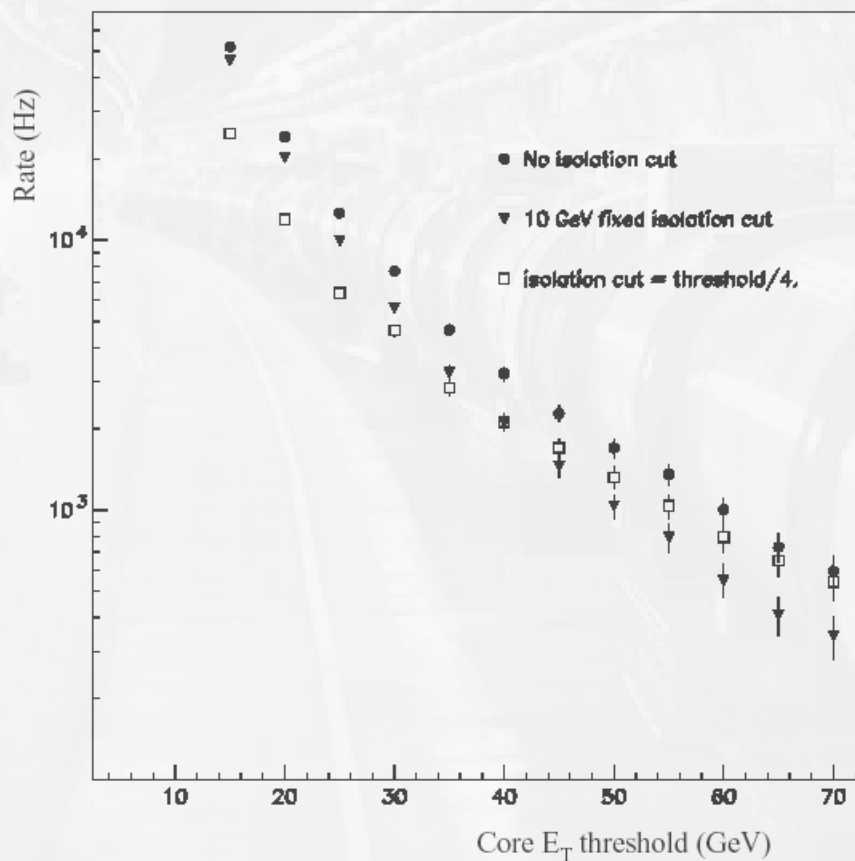
- during LVL1 processing, all data of all detector systems are kept in pipeline memories (close to detector; radiation hard electronics, $> 10^7$ electron. channels!)
- LVL1 defines "Regions of Interest" (Rols) as input for LVL2 (marks position $\{\eta = -\ln(\tan(\theta/2)), \varphi\}$ und p_T)
- LVL1 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
($L = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$)



ATLAS trigger processor

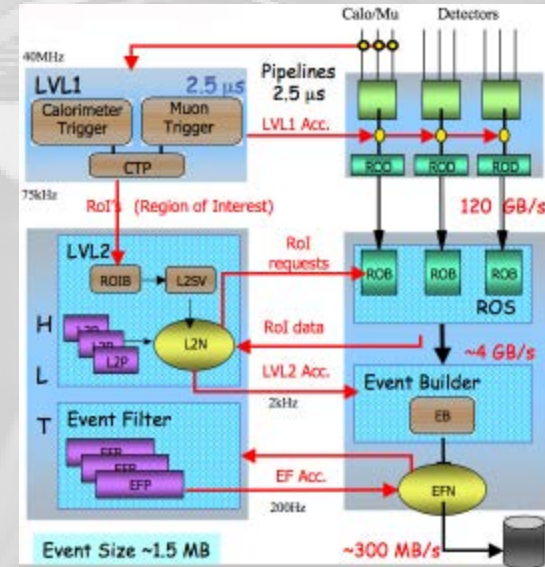


ATLAS trigger-daq racks



ATLAS Level 2 Trigger

- verification of objects identified by LVL1, and further evaluation of their properties
- input information:
 - Rols
 - access to **all** data in ROBs, however selectively due to Rol 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 $E_{T\text{ miss}}, E_{T\text{ tot}}$ 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.

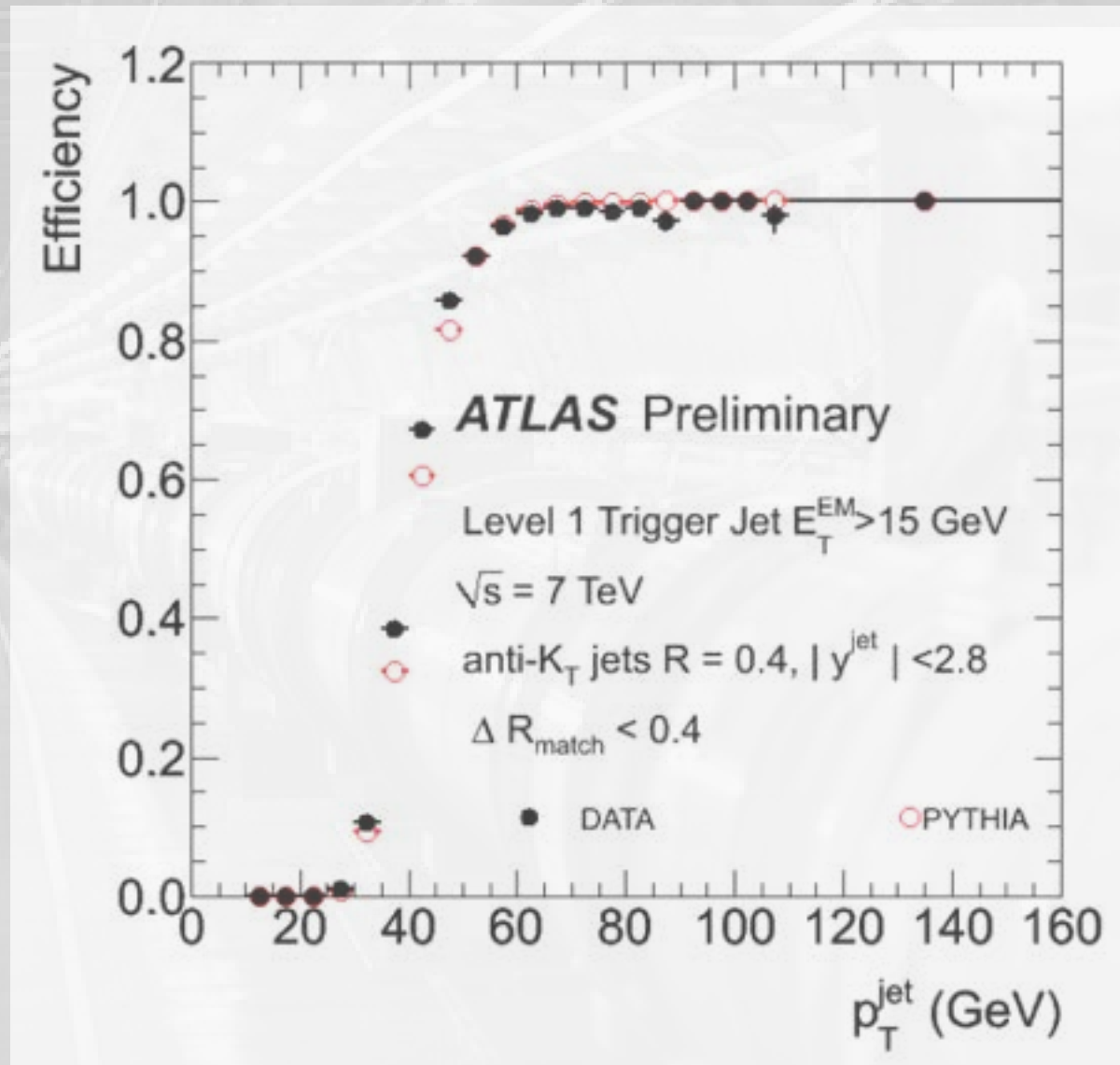
Object	Number of thresholds	Isolation	$ \eta $ range	description
MU	6	no	2.4	muon
EM	8 – 16	yes	2.5	EM cluster
T	0 – 8	yes	2.5	$\tau \rightarrow$ hadrons or single hadron
J	8	no	3.2	jet
XE	8	–	4.9	missing- E_T
SE	4	–	4.9	total scalar E_T

Level 2 objects

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

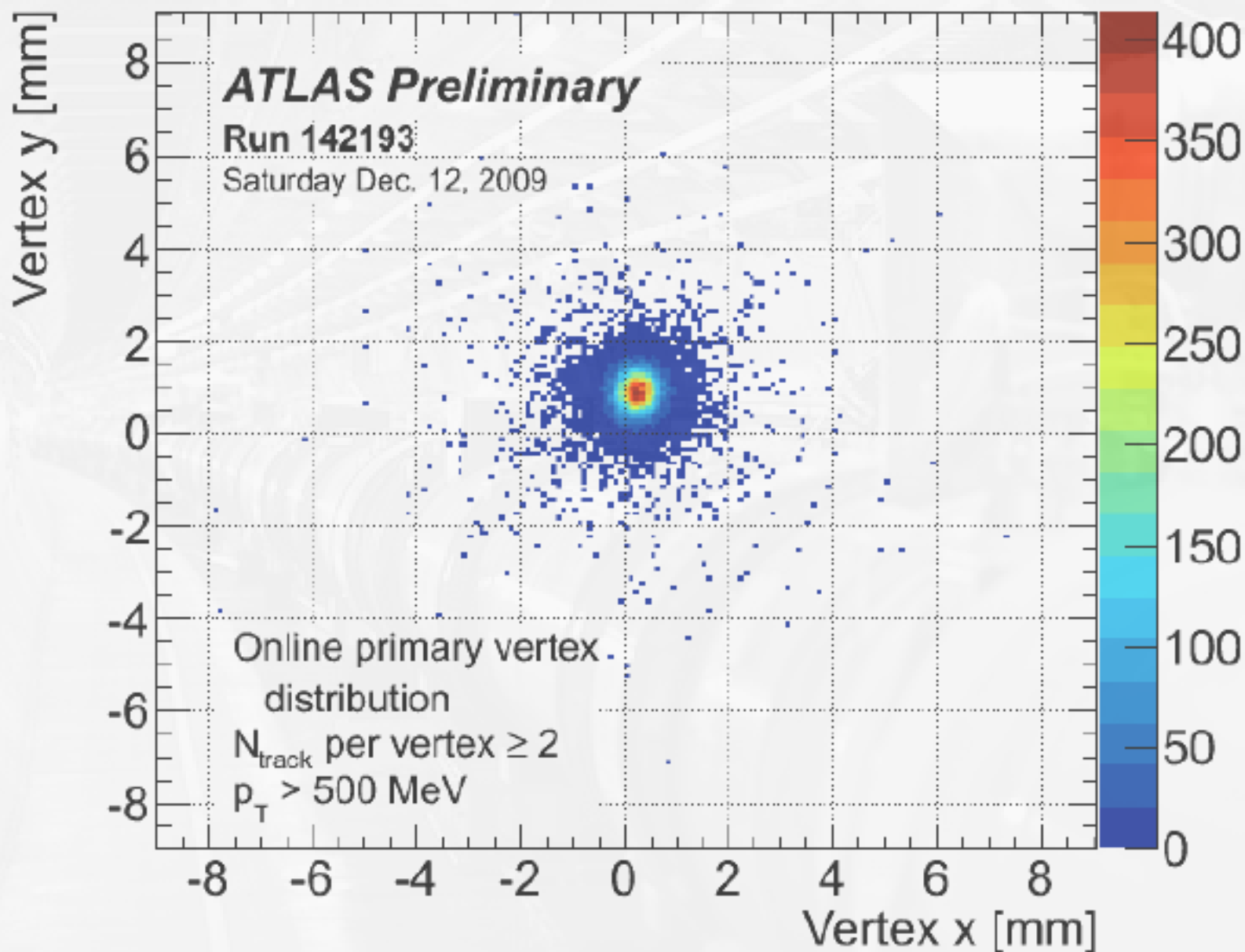
Object	Attribute	$ \eta $ range	Candidate for
μ	isolation	2.4	muon
e	isolation	2.5	electron
γ	isolation	2.5	photon
τ	isolation	2.5	$\tau \rightarrow$ hadrons
h	isolation	2.5	single hadron
j	b-tag ($ \eta < 2.5$)	3.2	jet
xE	–	4.9	missing- E_T

ATLAS LVL1 Jet Trigger Efficiency (Oct. 2010)



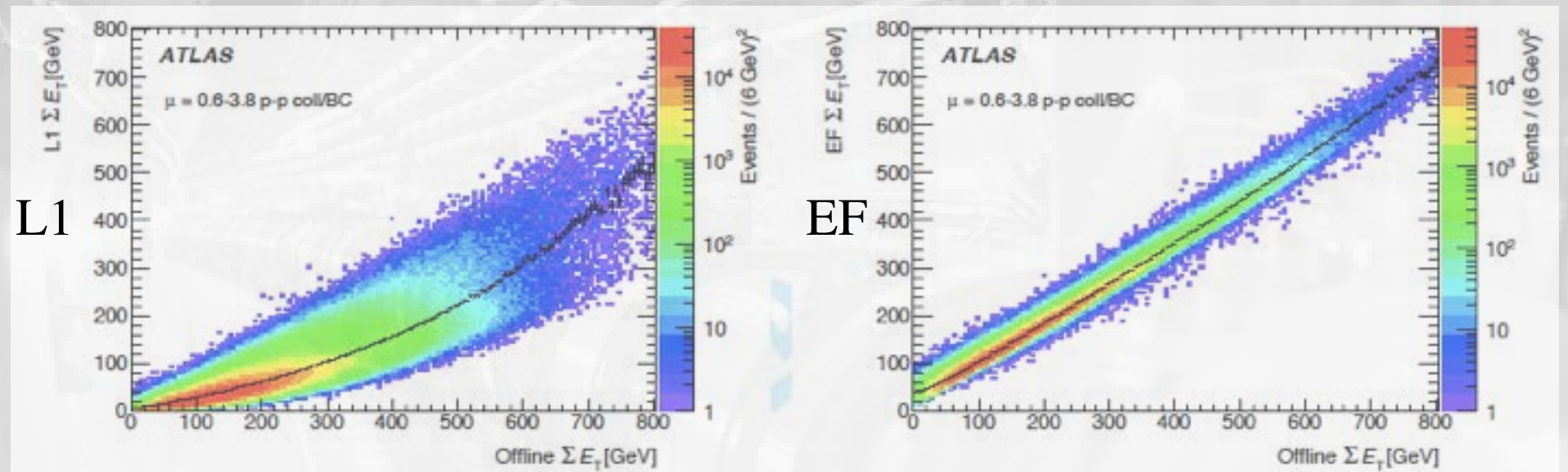
arXiv:1010.0017

Beam spot determined by L2 tracking (Oct. 2010)



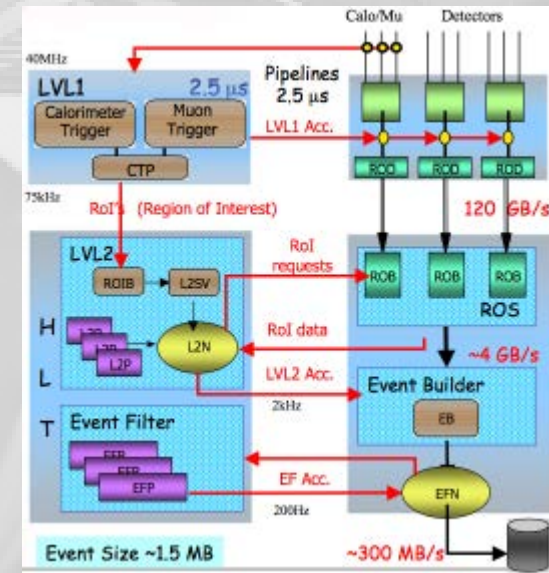
arXiv:1010.0017

correlation between trigger- and offline event reconstruction ΣE_T



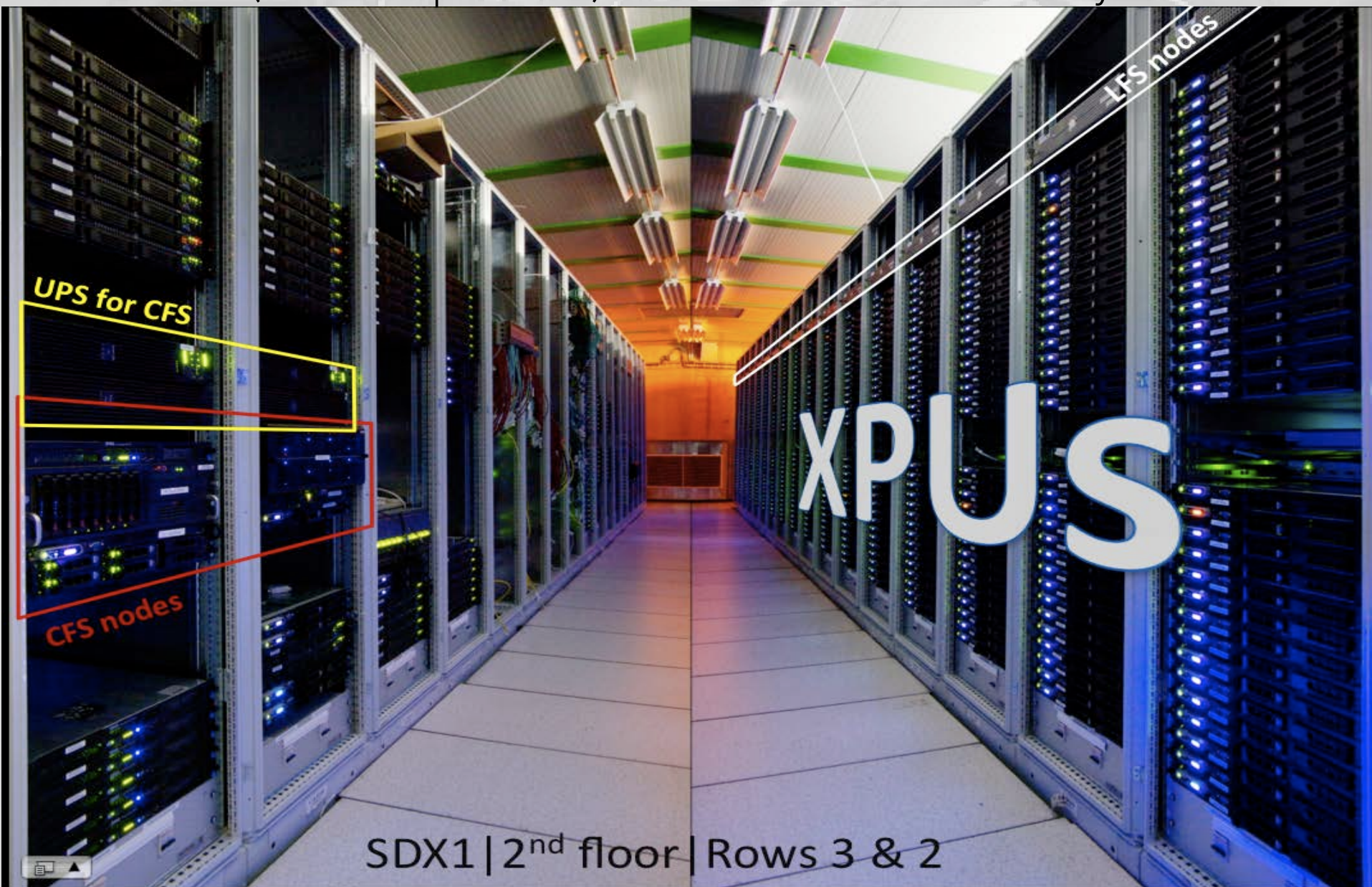
ATLAS Event Filter (EF)

- 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

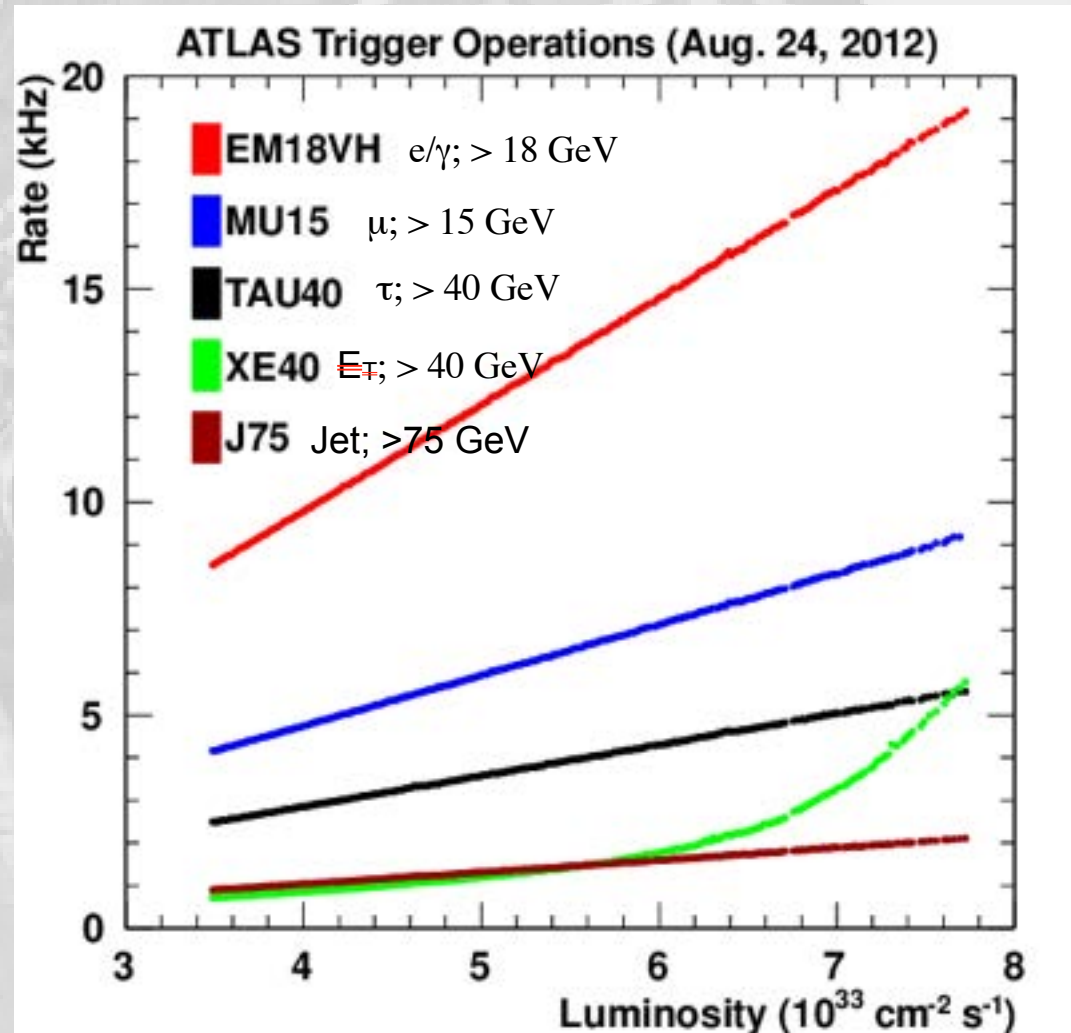


ATLAS High-Level-Trigger (HLT) farm

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

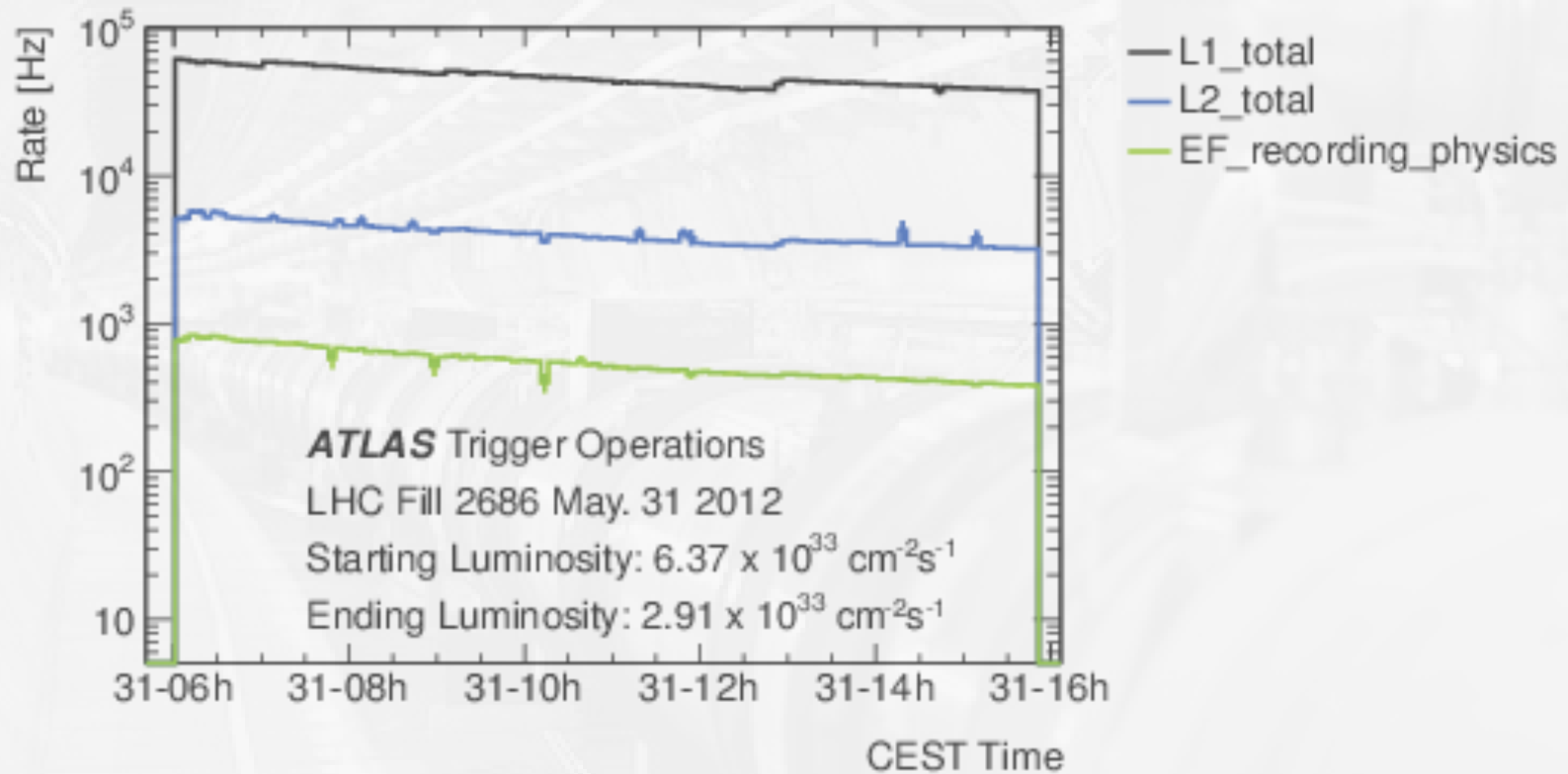


ATLAS Level-1 single-object Trigger rates at $7.8 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

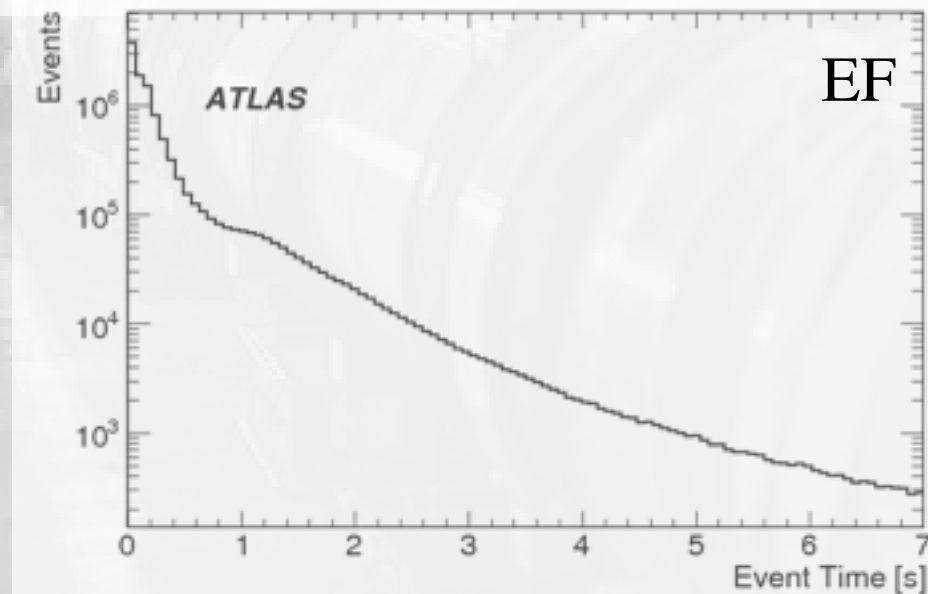
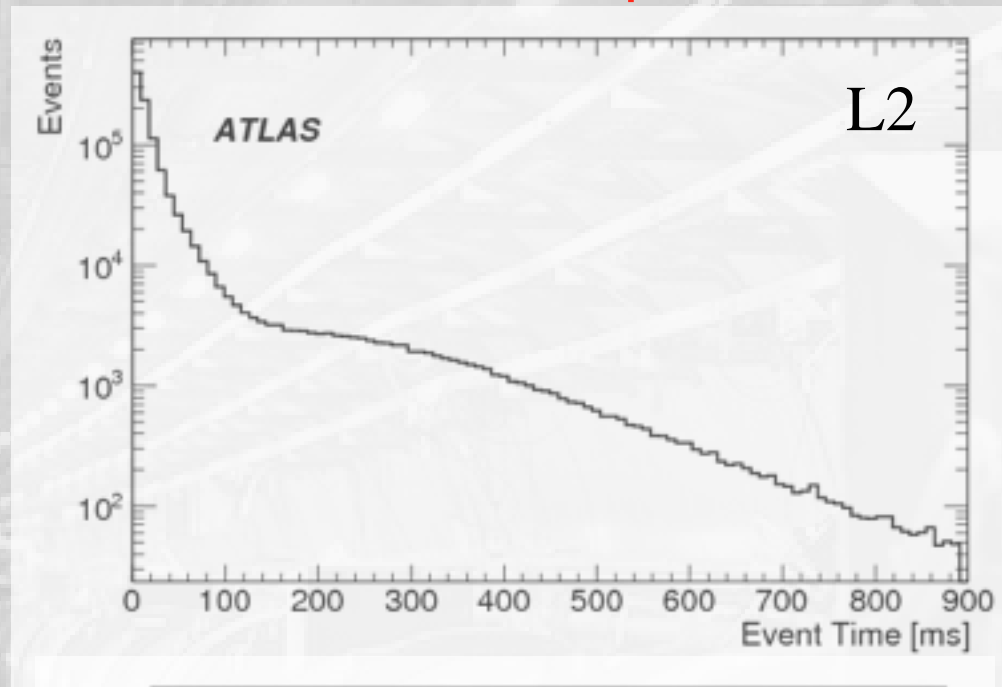


ATLAS Trigger output rates

at $6.4 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$



ATLAS Trigger: event processing times



LHC Data and Computing (Plan 2001)

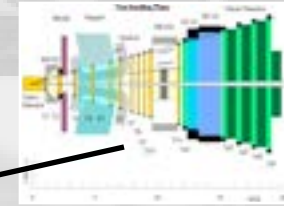
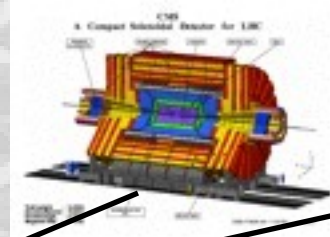
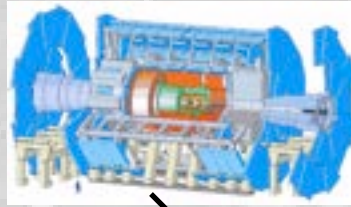
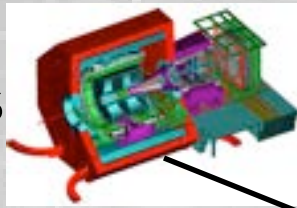
the challenge:

- 40 MHz collision rate → unfiltered data flow $\sim 10^{14}$ 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



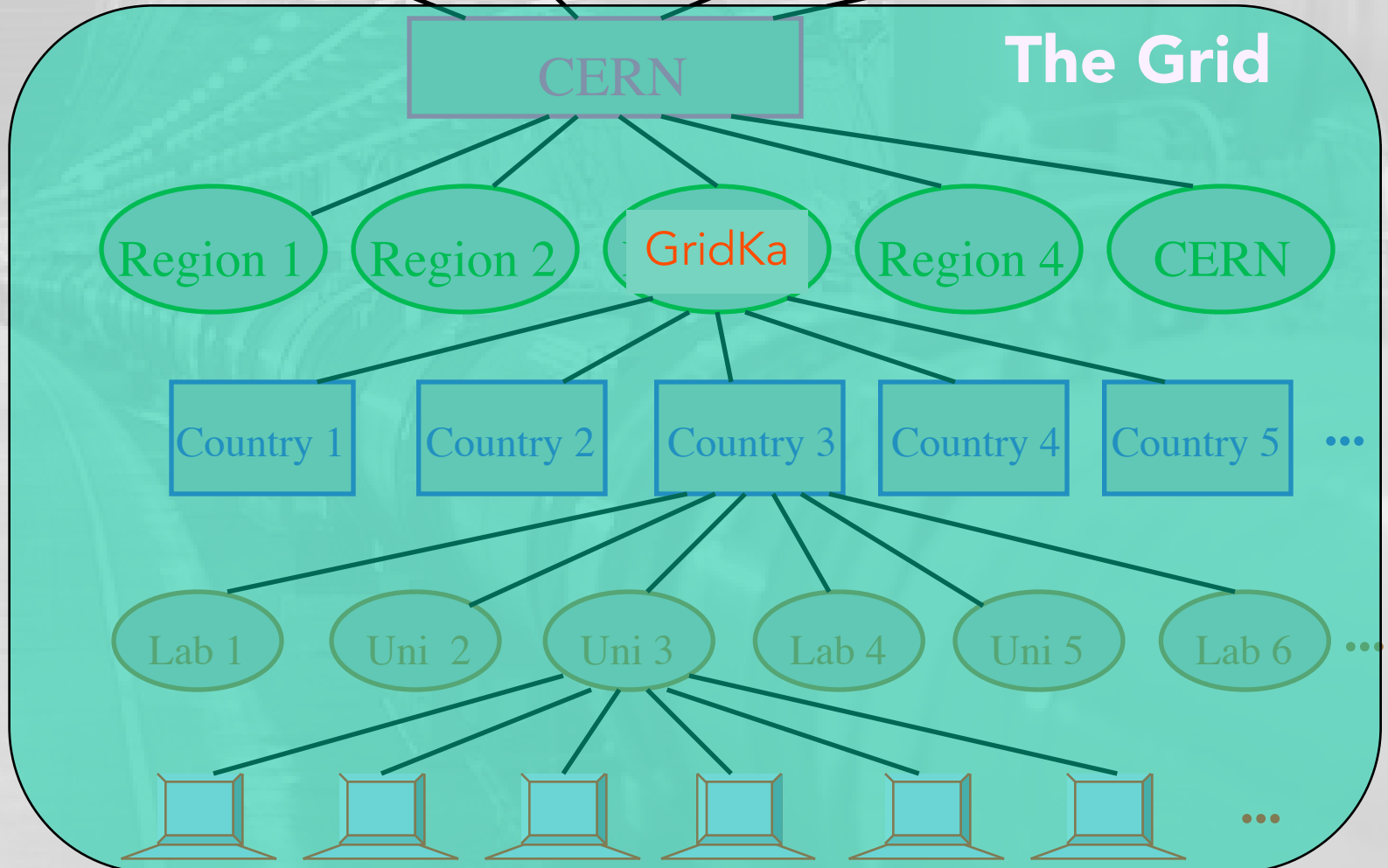
Tier-0

Tier-1

Tier-2

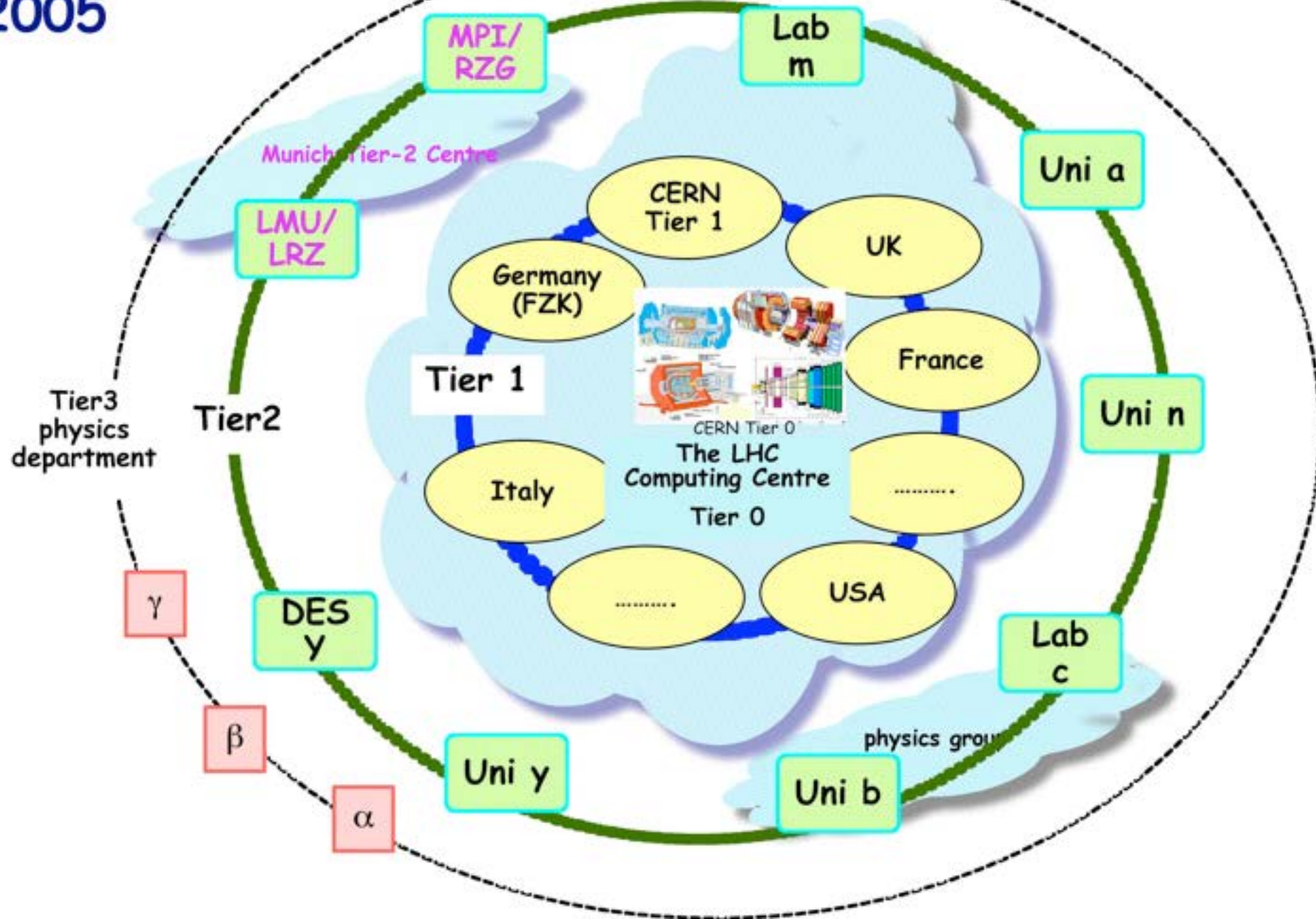
Tier-3

Tier-4



WLCG Computing Model

2005





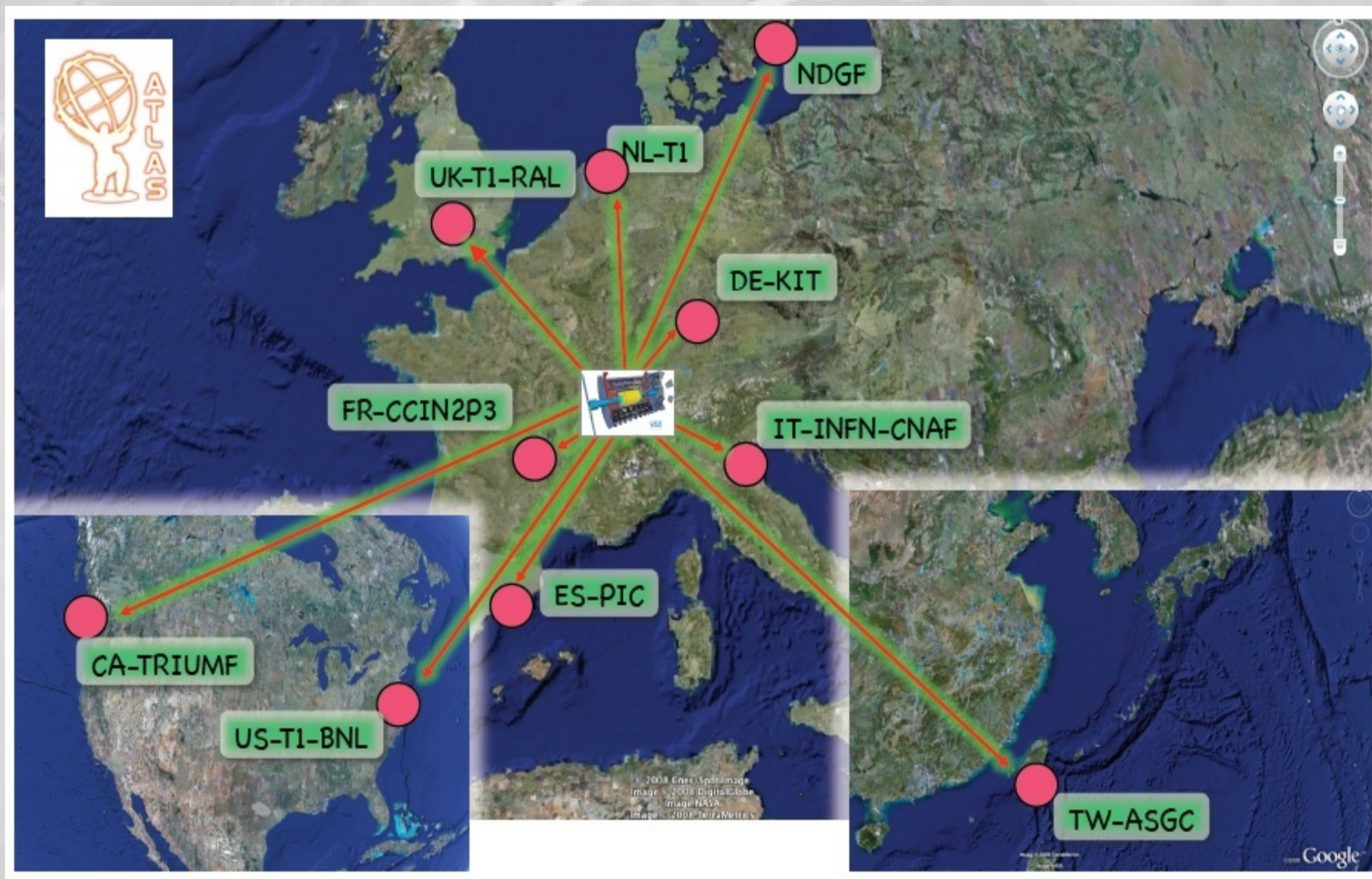
LHC-GRID (WLCG): worldwide networking and distribution of tasks:

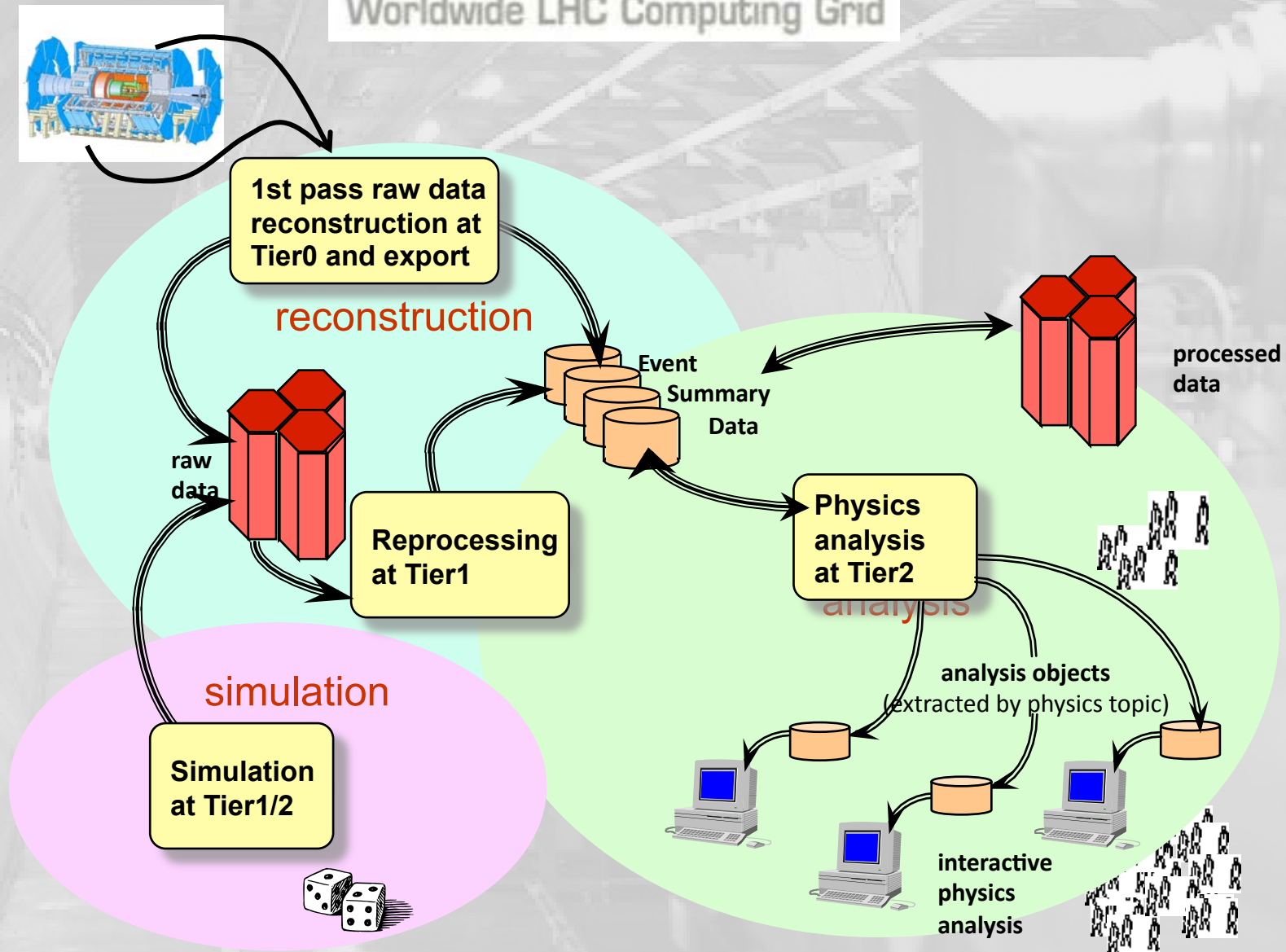
- redundant data storage (Tier-0 , -1)
- generation (Tier-2) and storage (-1, -2) of simulation data (MC)
- data reduction; calibration (Tier-0) and data bases (-0, -1)
- processing of analysis jobs (Tier-1, -2, ...)



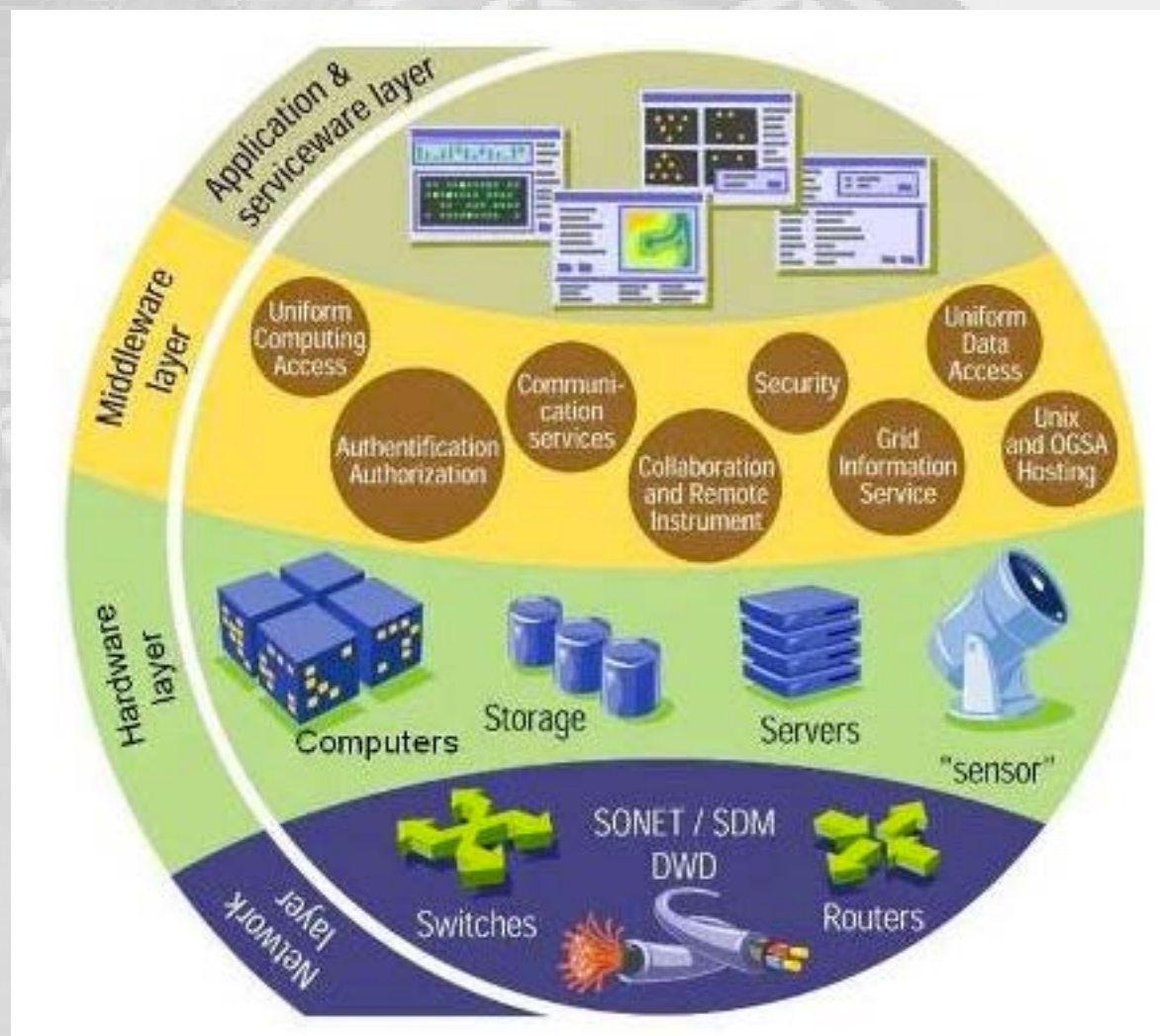
Computing infrastructure and operation

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





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

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

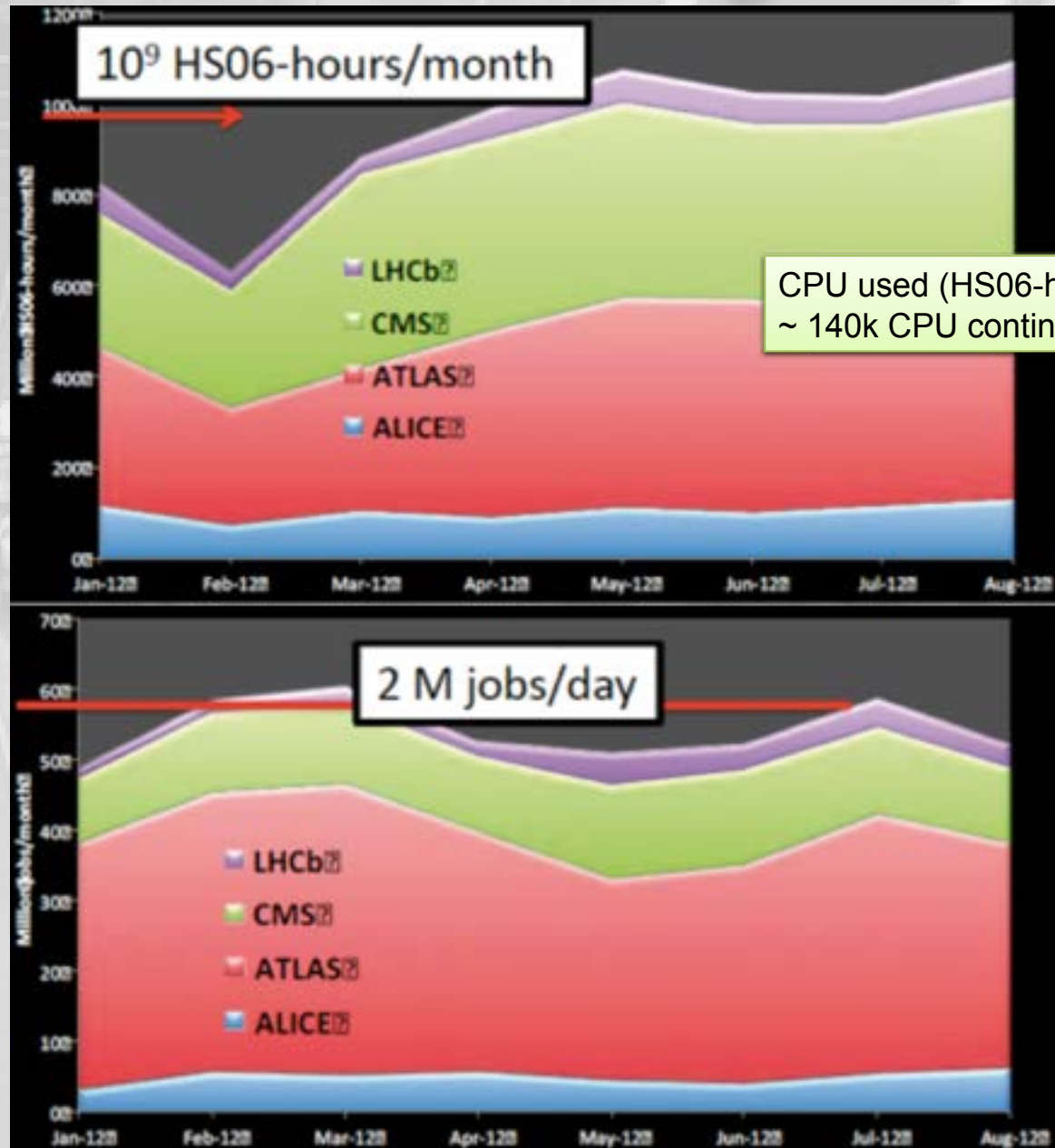
Tier 0:

Total	39,066	42,585	317,383	36,416,885	97,537,985
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Tier 2:

Total	52,856	287,958	3,130,845	148,145,287	5,711,073
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WLCG: usage

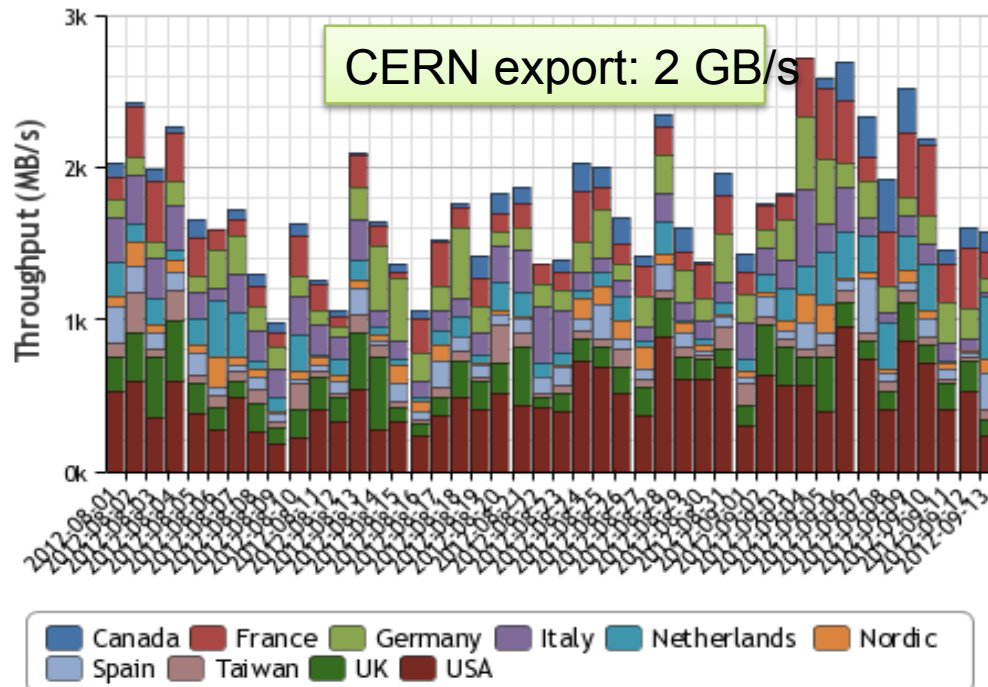


WLCG: usage

dashboard

Throughput

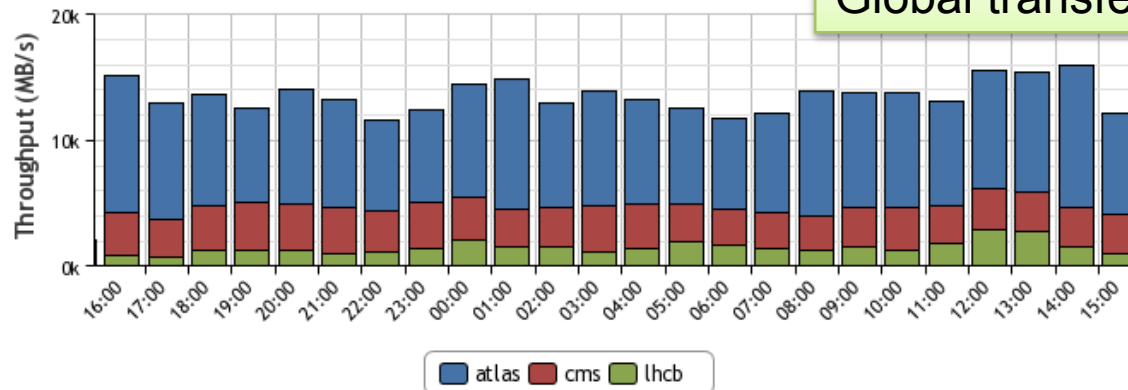
2012-08-01 00:00 to 2012-09-14 00:00 UTC



dashboard

Throughput

2012-10-17 15:50 to 2012-10-18 15:50 UTC

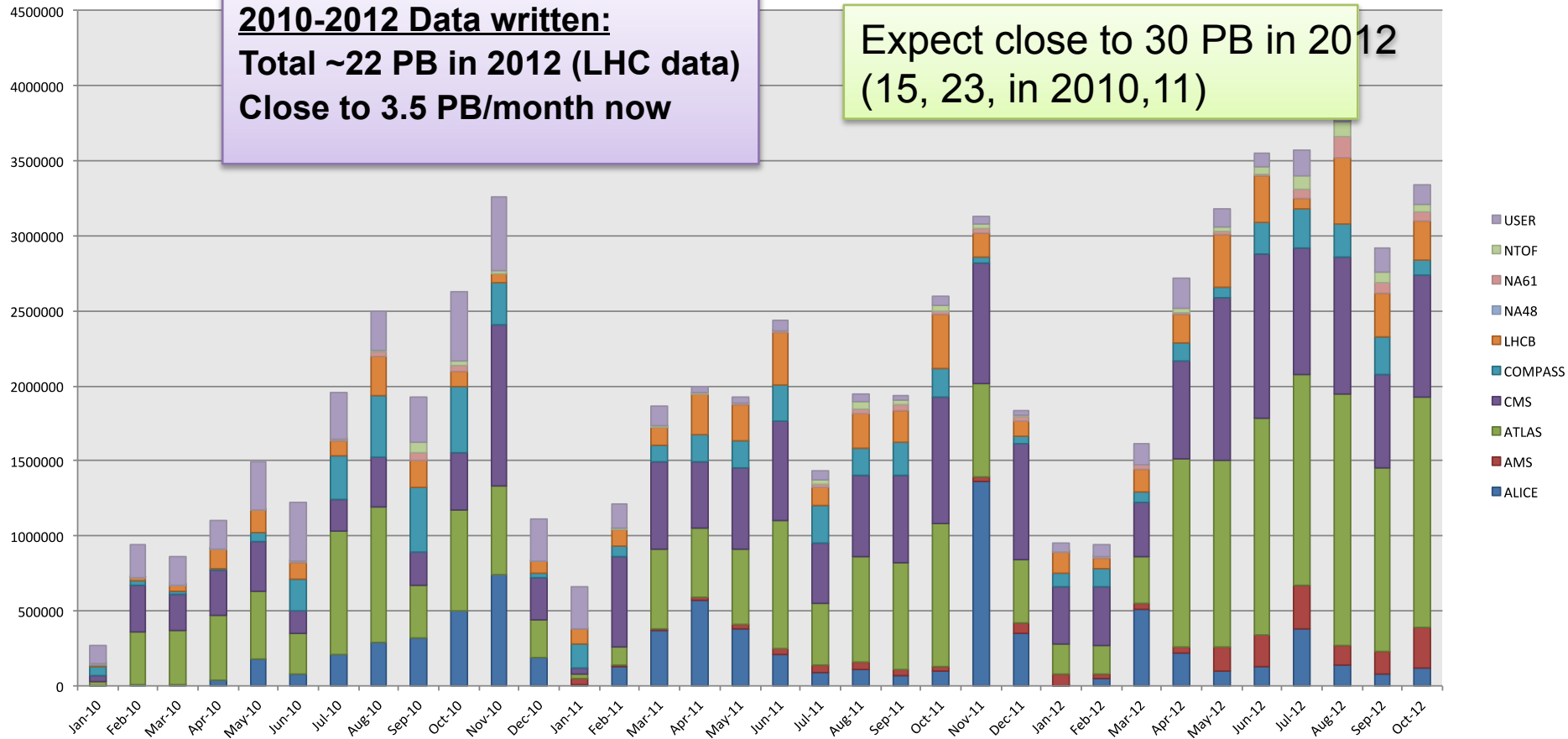


Castor data written 2010-12

CASTOR data written, 01/01/2010 to 29/10/2012 (in GB)

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]
- Performance of the ATLAS Trigger System in 2010, Eur.Phys.J. C72 (2012) 1849, arXiv:1110.1530 [hep-ex]
- The LHC Computing Grid, <http://lcg.web.cern.ch/LCG>