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)!

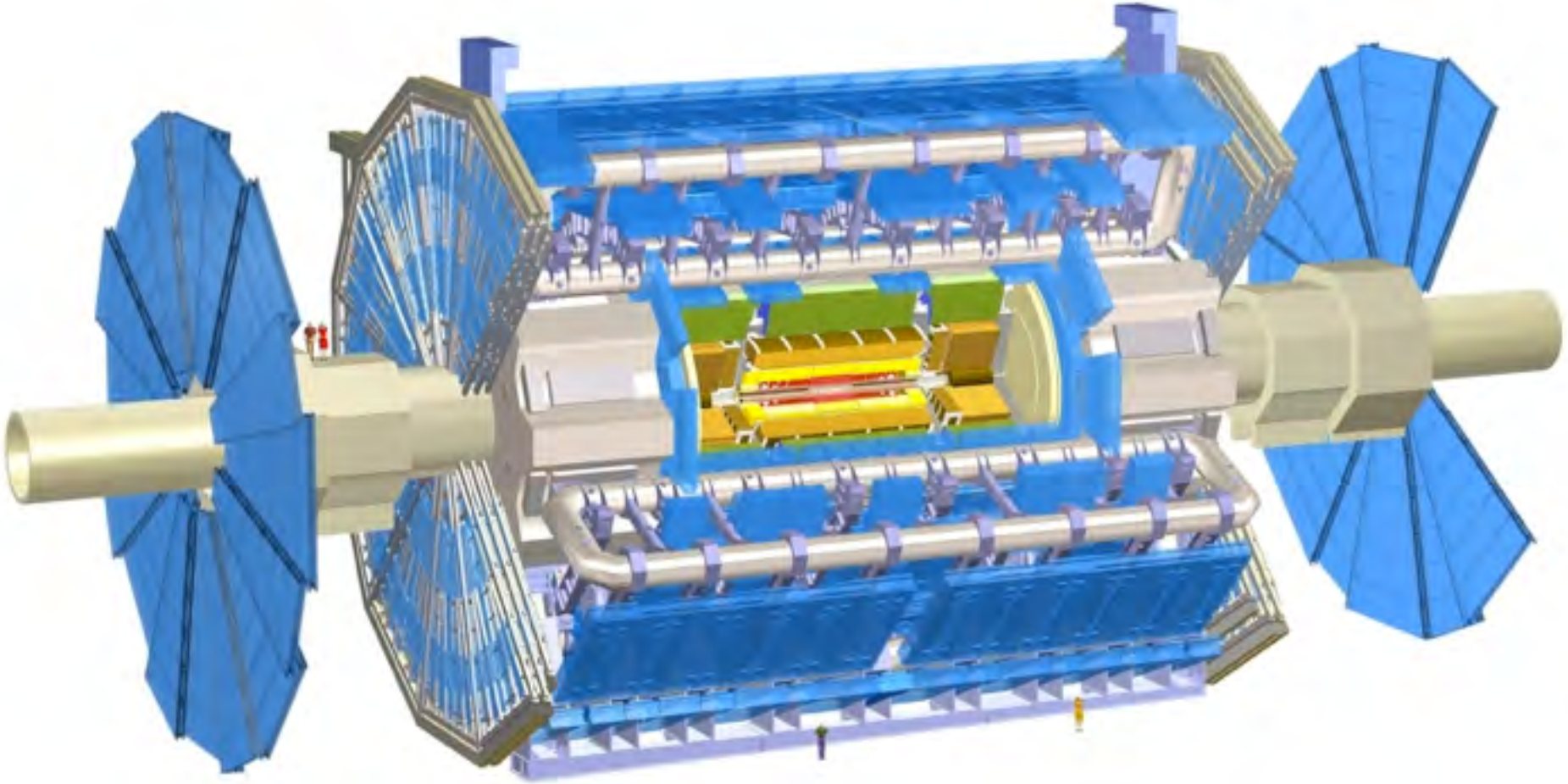
–> need to reduce data flow by about a factor of 10^6 !!

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

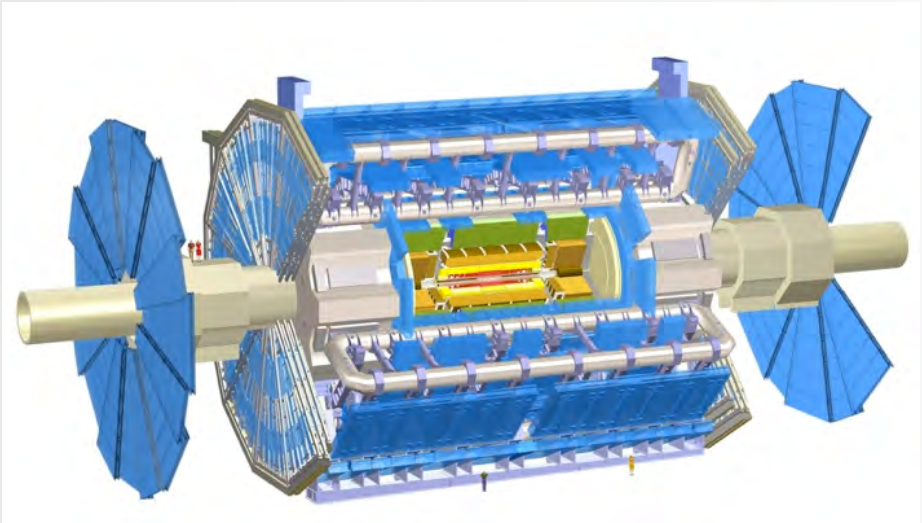


number of active detector channels at ATLAS

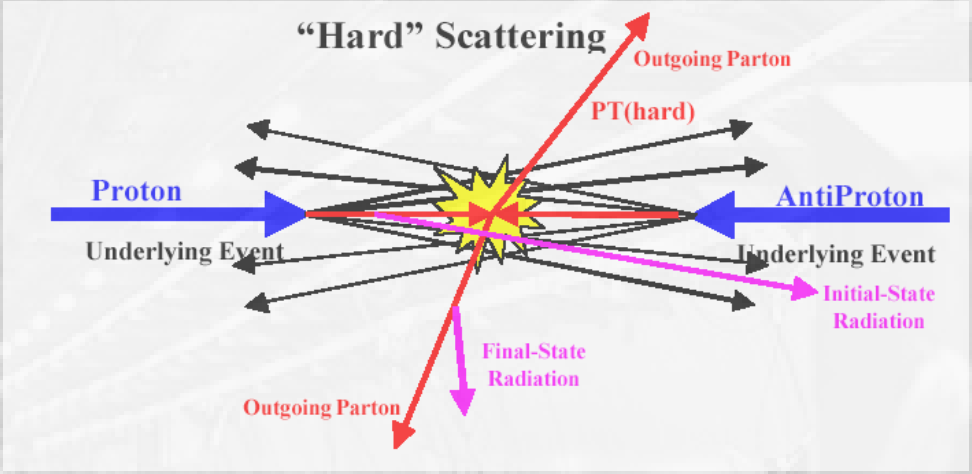
Table 2-1 Number of active detector elements, number of modules or chambers, and number of GEANT volumes defined for the detailed simulation of each of the various ATLAS detector systems.

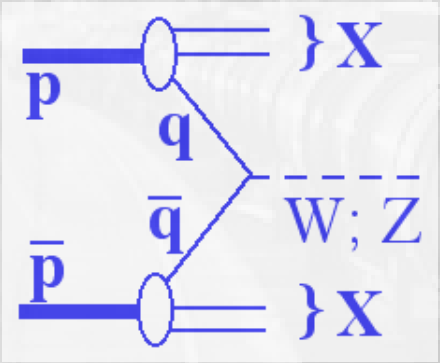
Detector system	Number of active detector elements	Number of modules or chambers	Number of GEANT volumes defined
Pixels	140 000 000	~2 200	26 000
Silicon microstrips	6 280 000	~4100	50 000
Transition radiation tracker	420 000	~240	2 260 000
LAr accordion calorimeters	170 000	48	9 960 000
LAr hadronic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

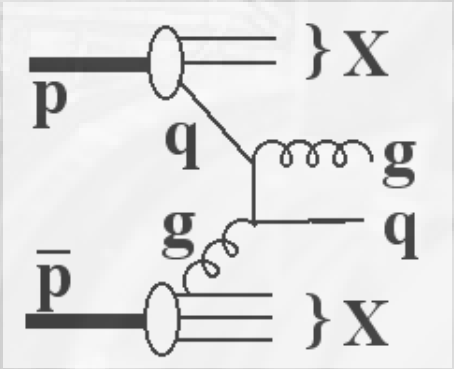
relevant for MC simulation

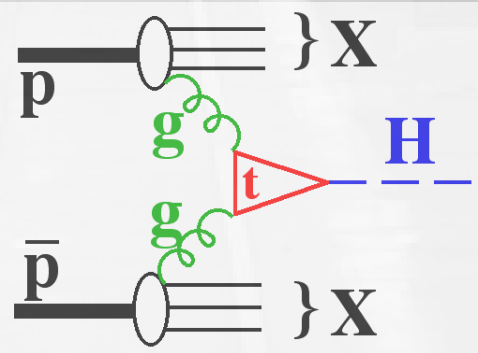


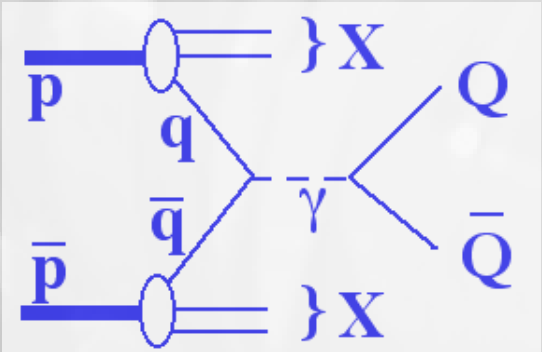
physics signatures at Tevatron ($p\bar{p}$) & LHC (pp)



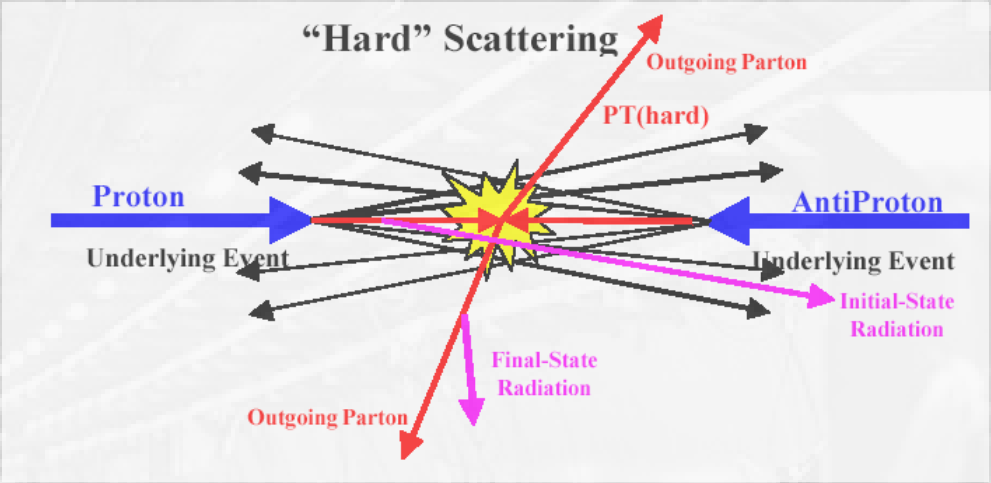








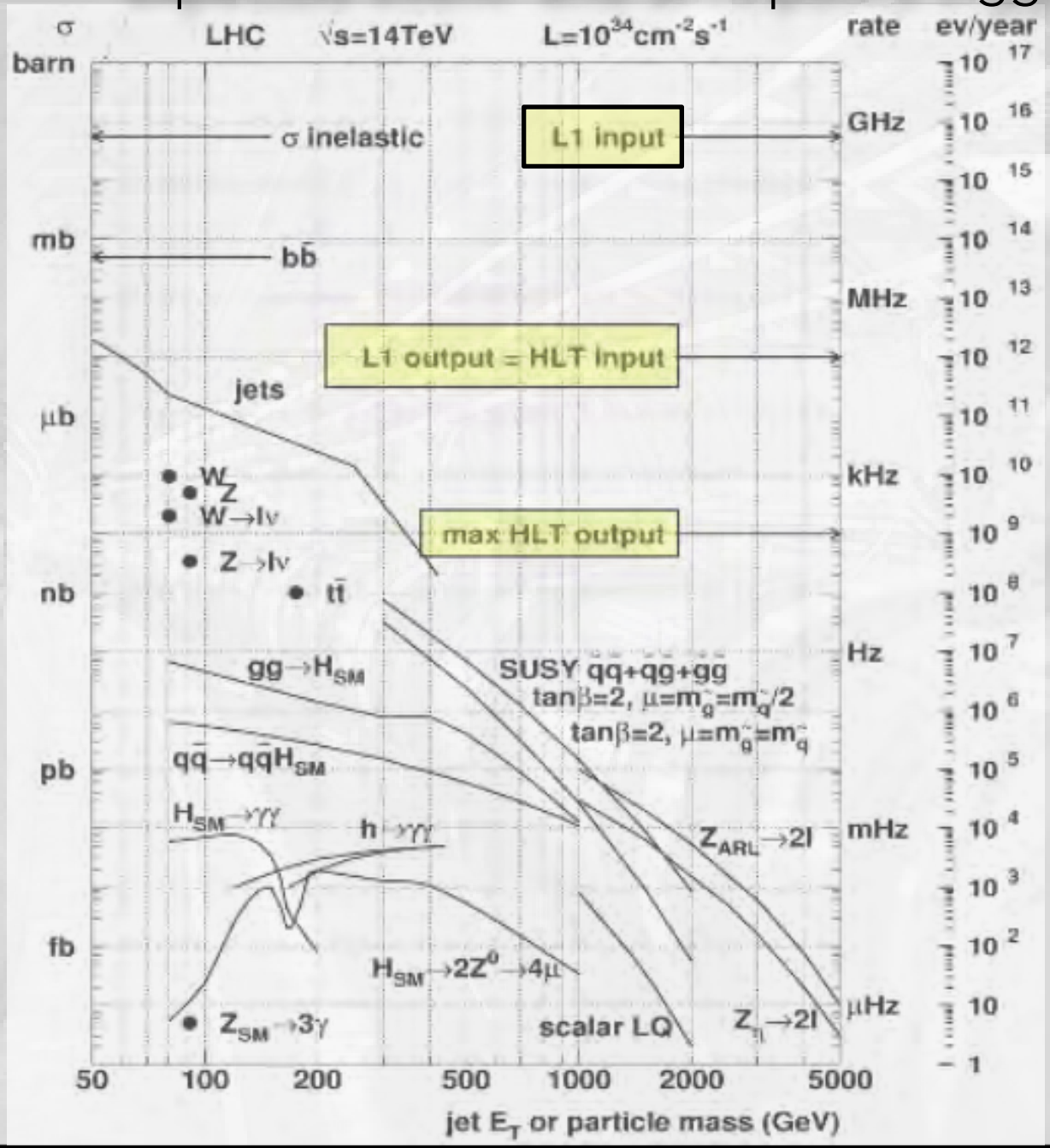
physics signatures



- as energies of colliding quarks/gluons are unknown:
  in general, restrict to "transverse" observables
  (i.e. ⊥ wrt. beam axis, where 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 neighboring 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

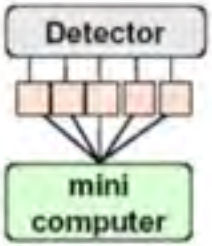
Trigger Rate:

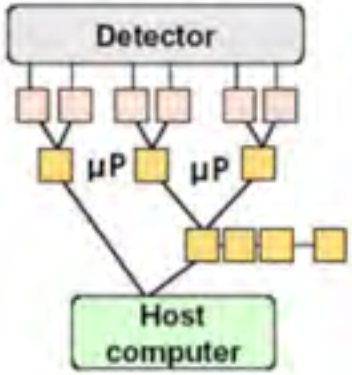
- rate of selected events (mostly dominated by QCD)

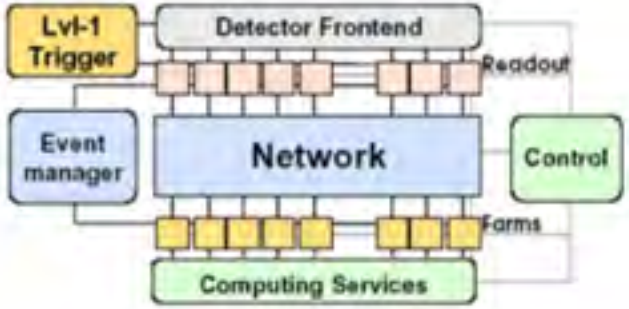
pre-scaling:

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

Evolution of Trigger and Data Acquisition Systems





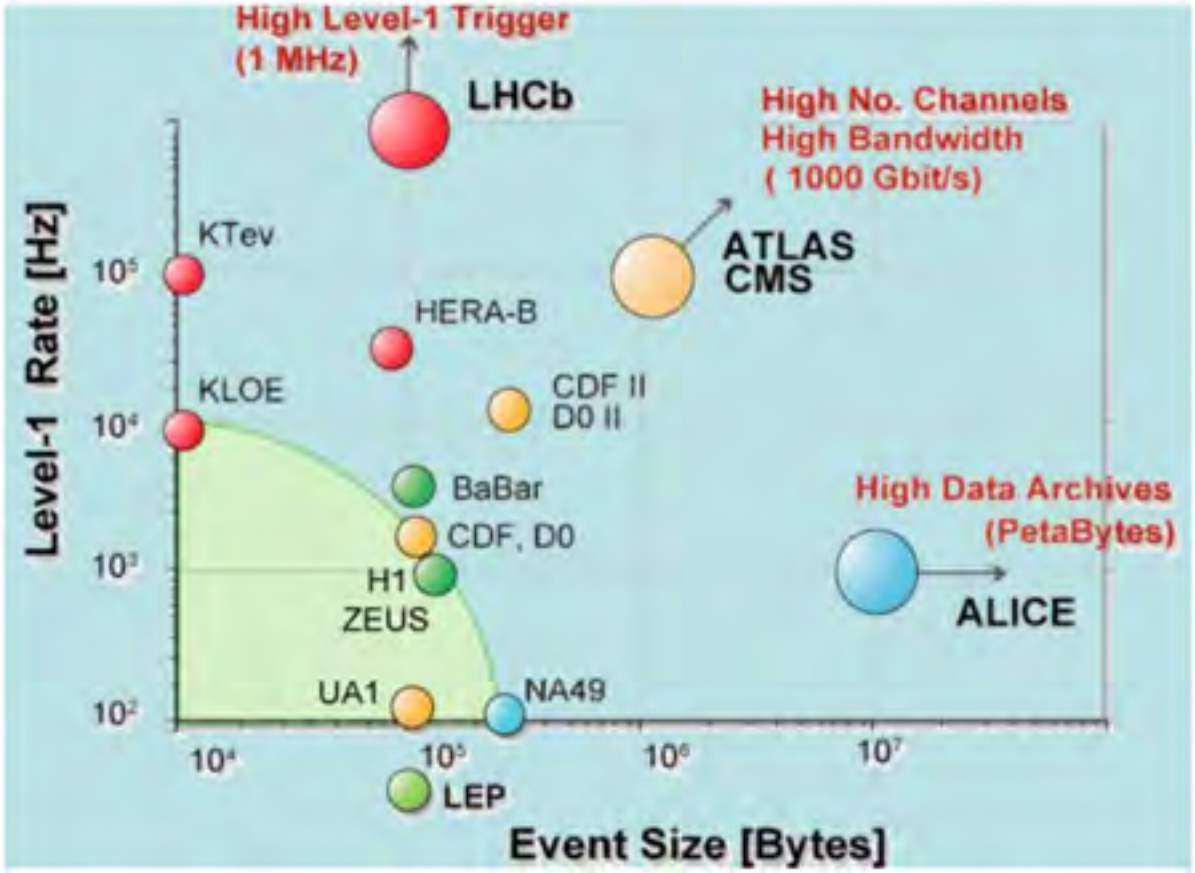


1970-80
MiniComputers
First standard:
CAMAC
•kByte/s

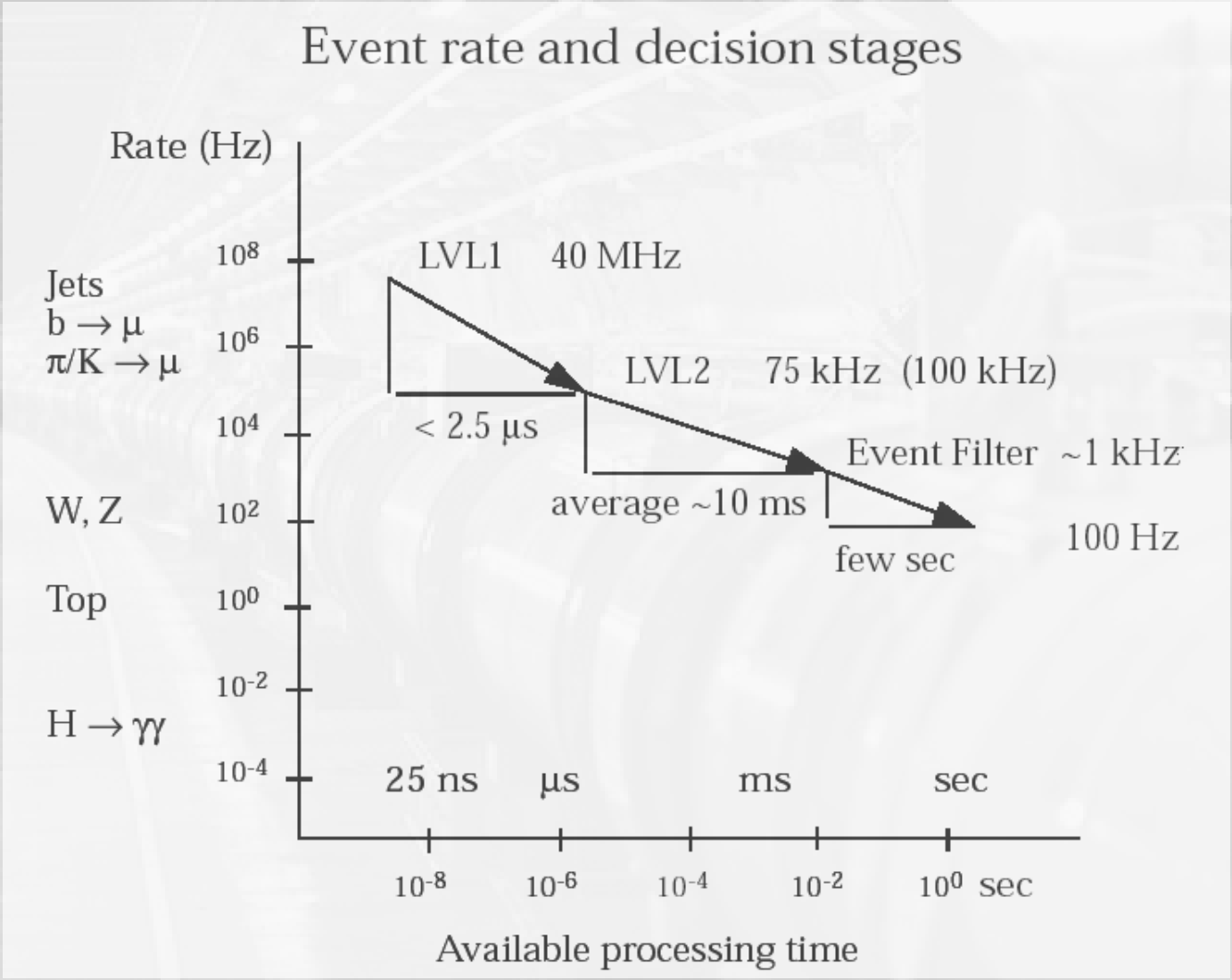
1980-90
Microprocessors
Distributed systems
•MByte/s

1990-2000+
Communications networks
Control & Data networks
Embedded processors
•GByte/s

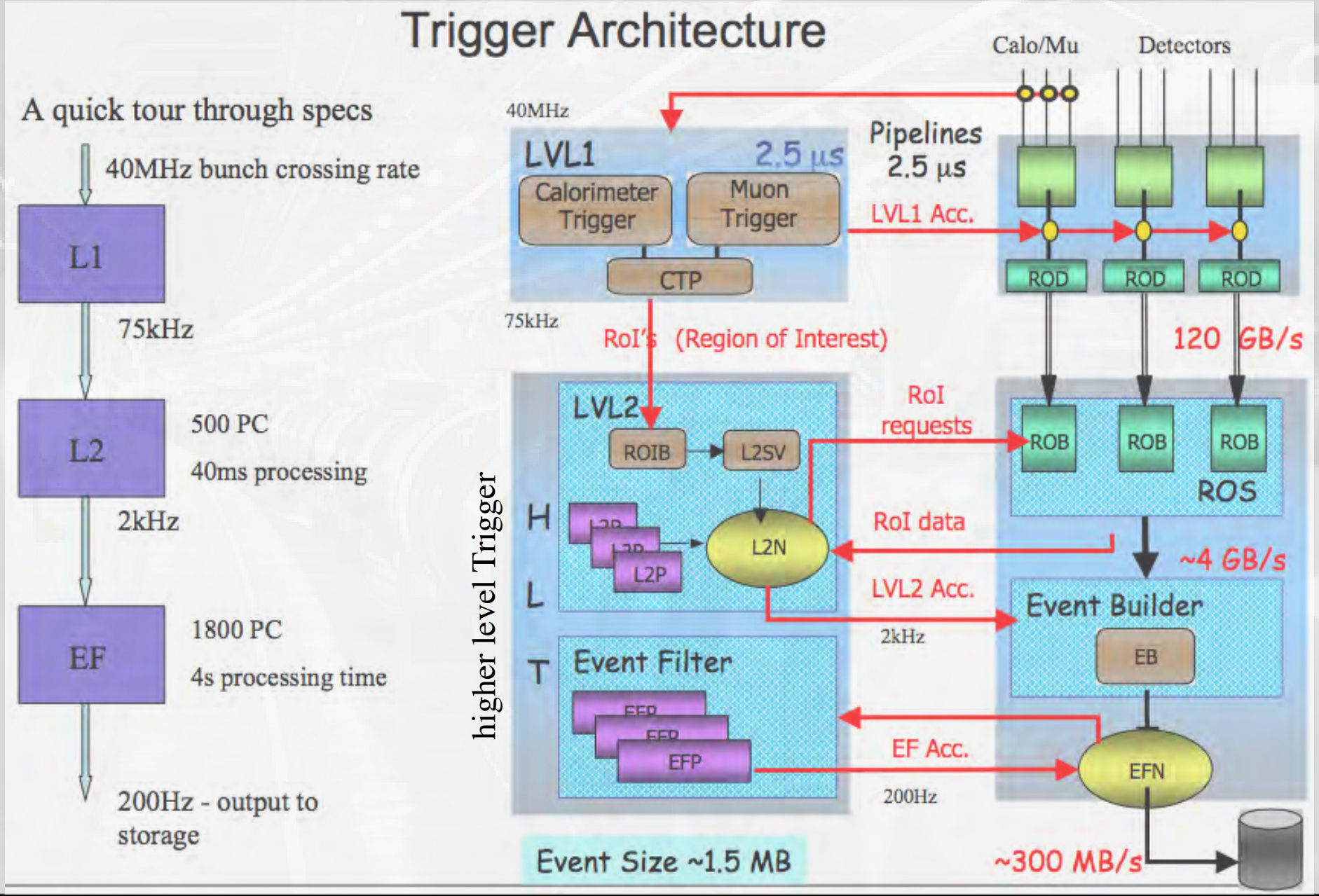
Trigger-DAQ system performances



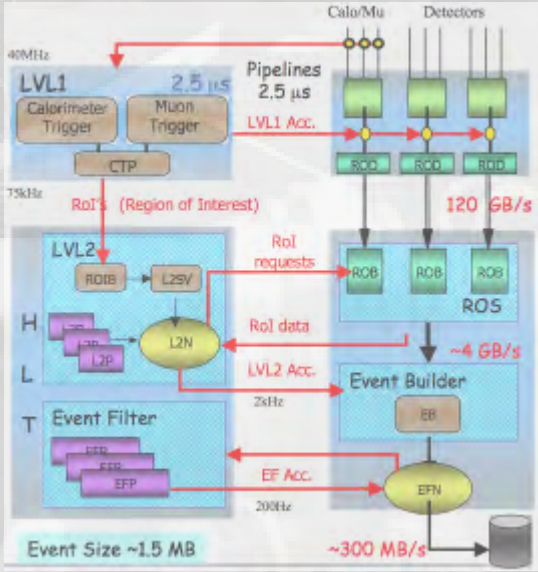
ATLAS: data rates and trigger decisions



ATLAS Trigger/DAQ System



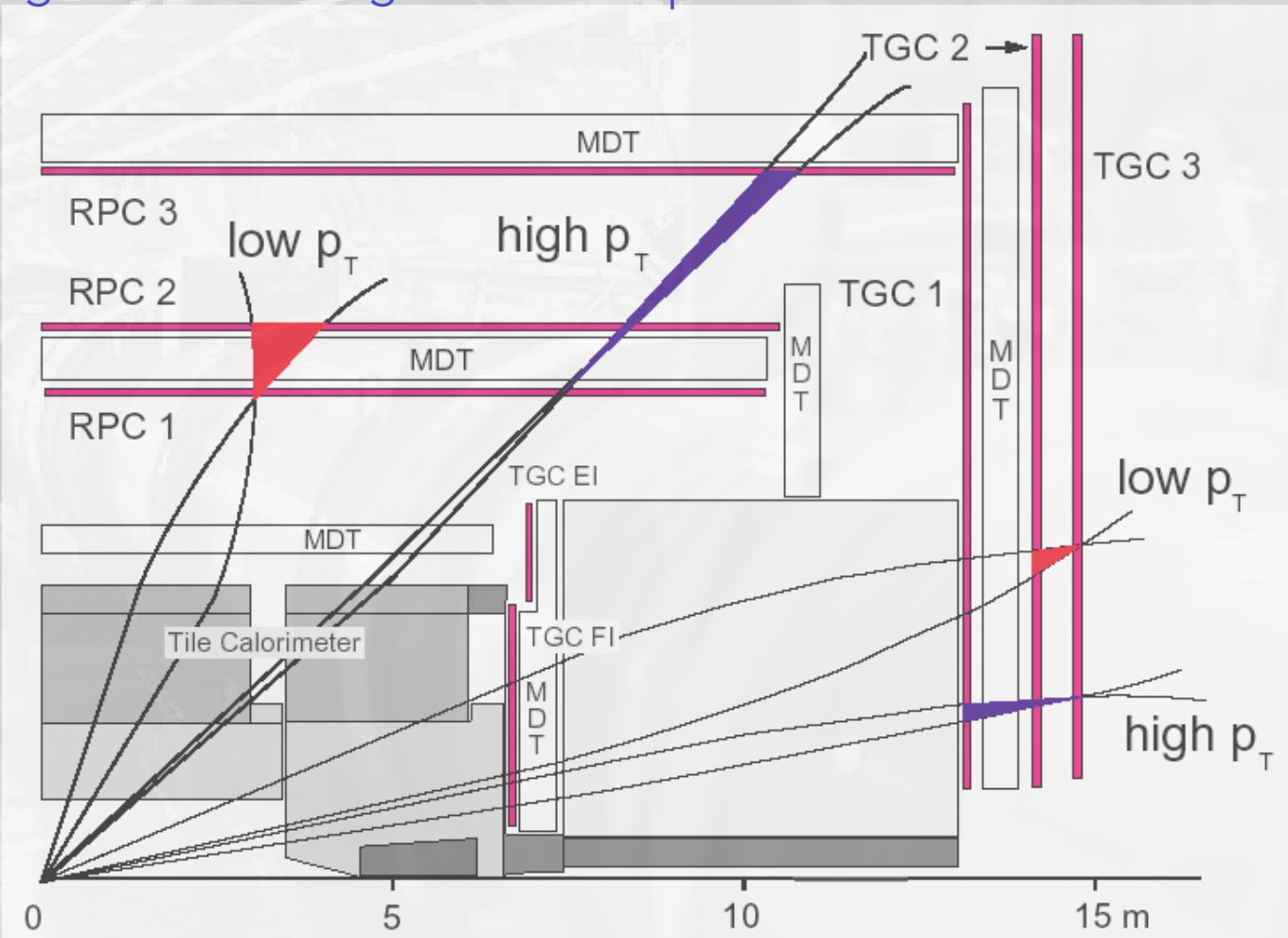
ATLAS Level 1 Trigger



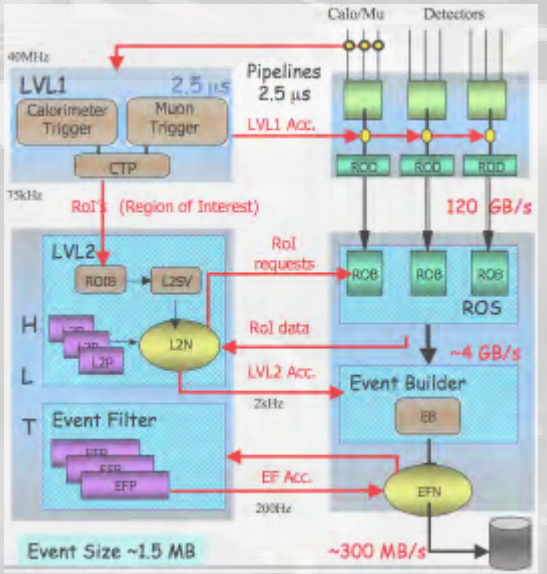
- fast identification of basic signatures of 'interesting' physics
- decisions based on existence of local trigger-objects for different p_T thresholds:
  - muons
  - electromagnetic cluster (perhaps with isolation criteria)
  - narrow particle jets (hadr. τ decays, isolated hadrons)
  - hadronic jets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



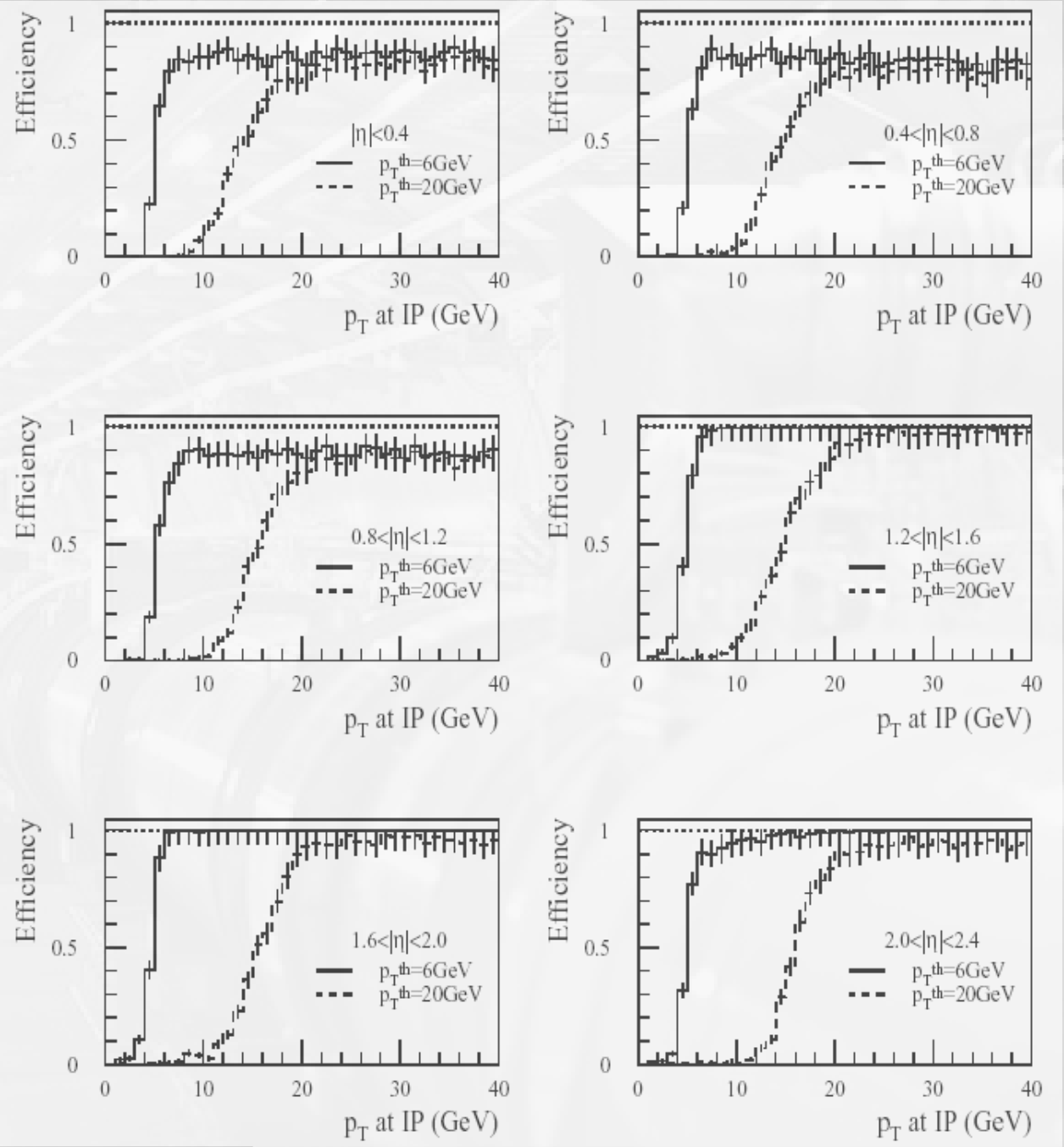
ATLAS Level 1 Trigger (cont.)



- 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

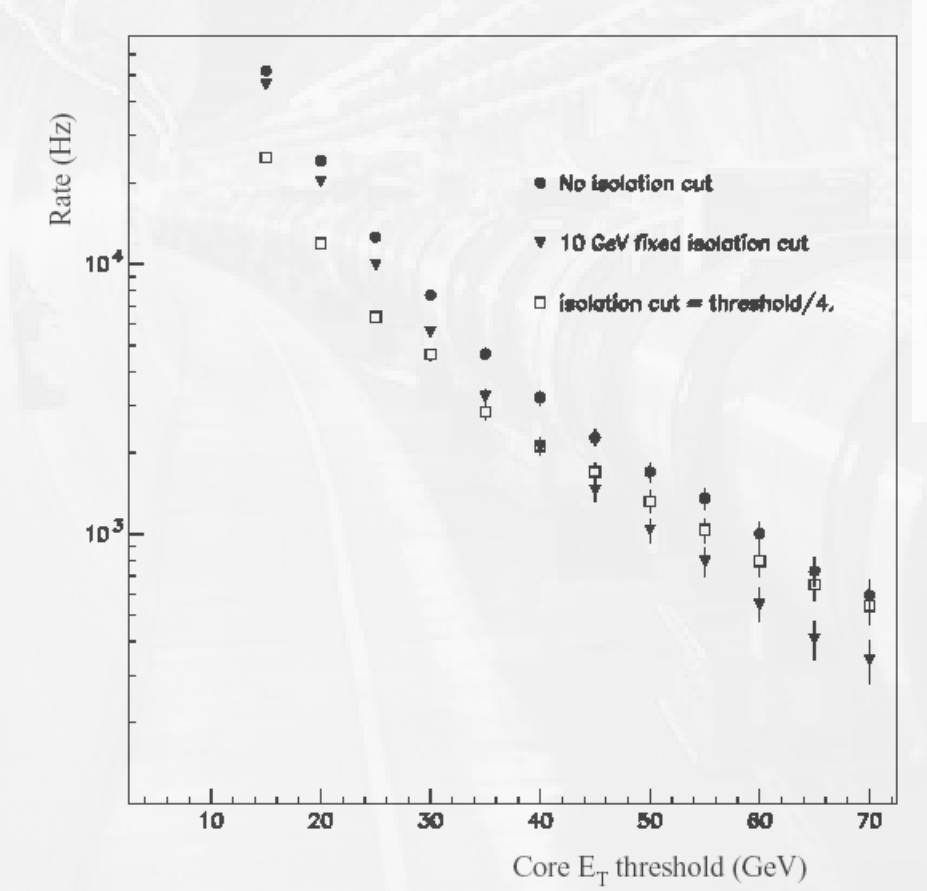
ATLAS LVL1 μ trigger

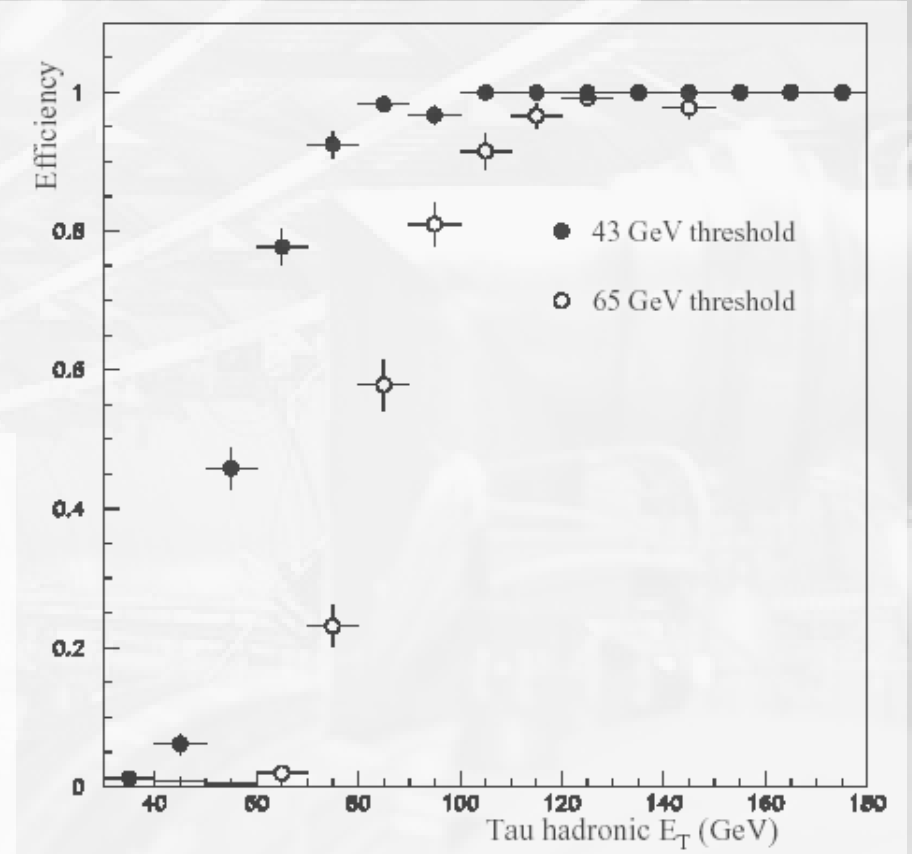


efficiency and rate of

ATLAS LVL1 τ trigger

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

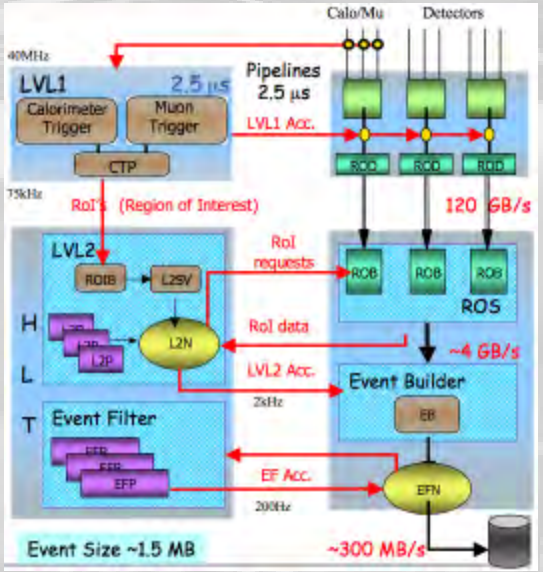




ATLAS trigger processor

ATLAS 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

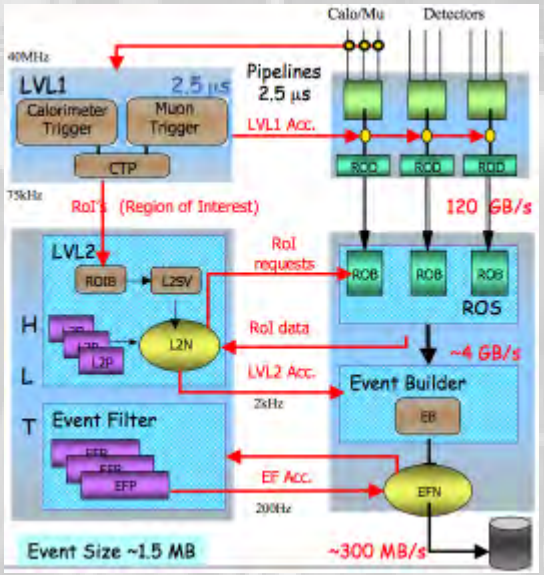
Level 2 objects

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
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

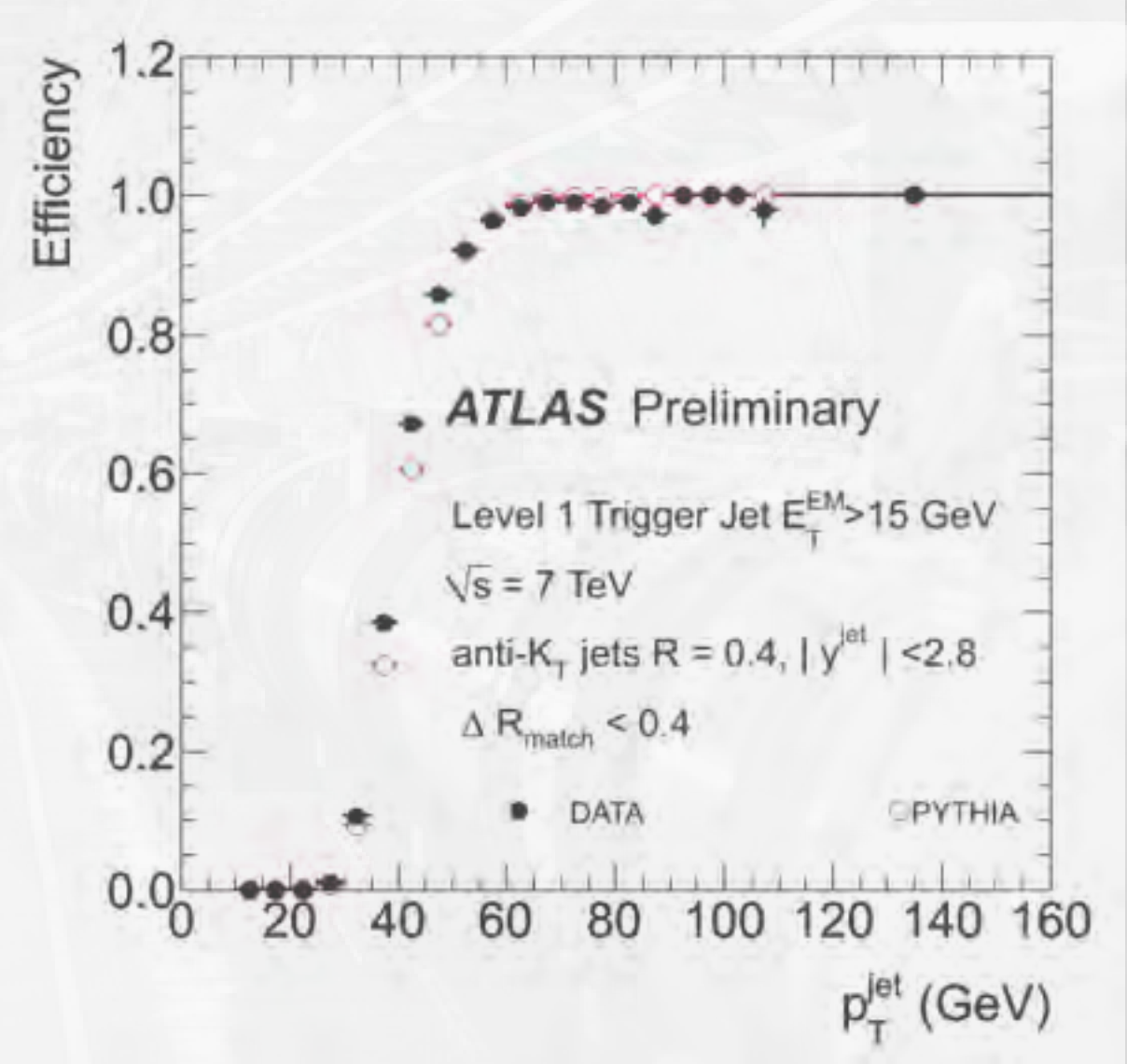
ATLAS Event Filter (EF)

- 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 few 100 Hz, –> writing data to disk/tape with 100 - 1000 MB/s



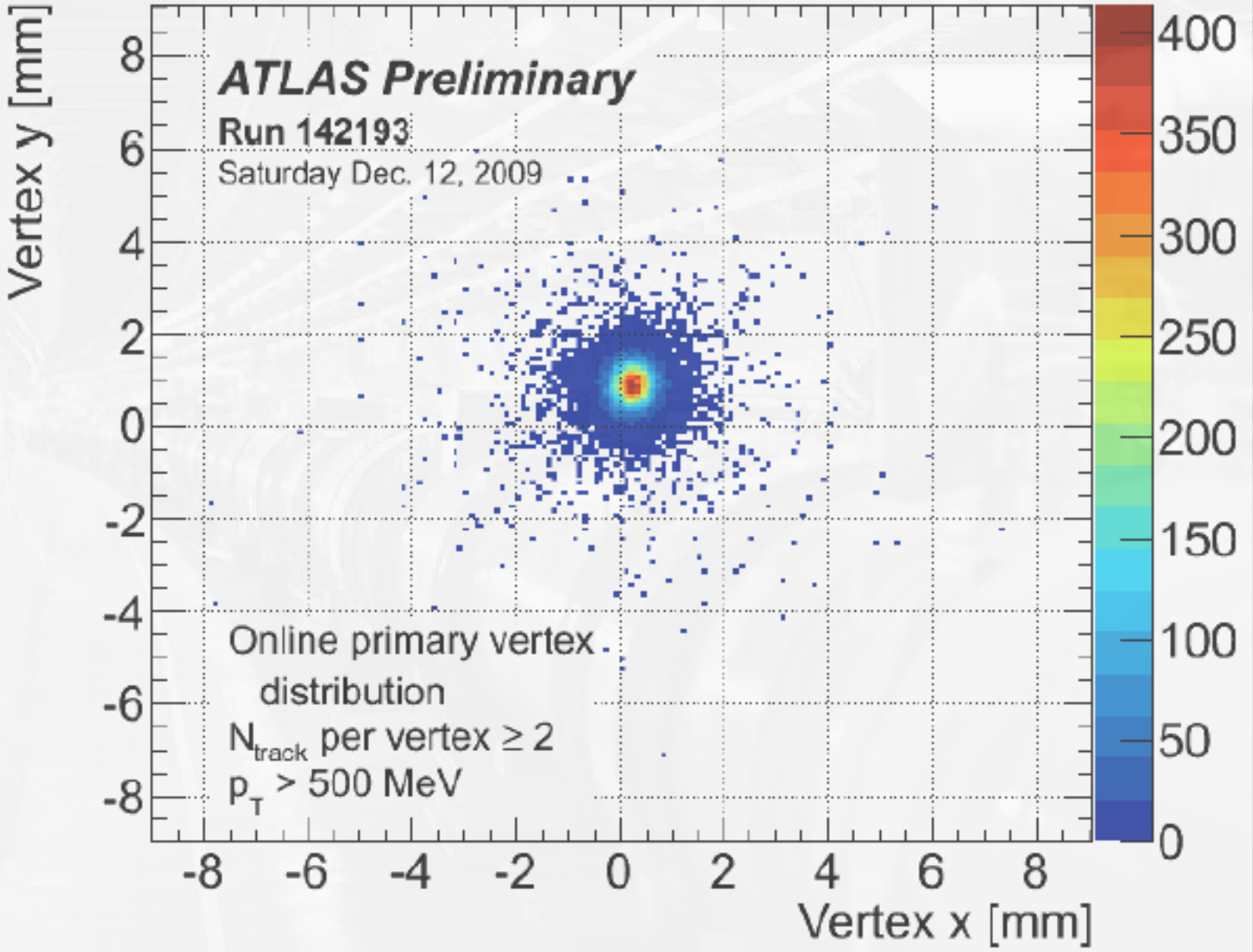
ATLAS LVL1 Jet Trigger Efficiency (Oct. 2010)

(from offline reconstructed jets)



arXiv:1010.0017

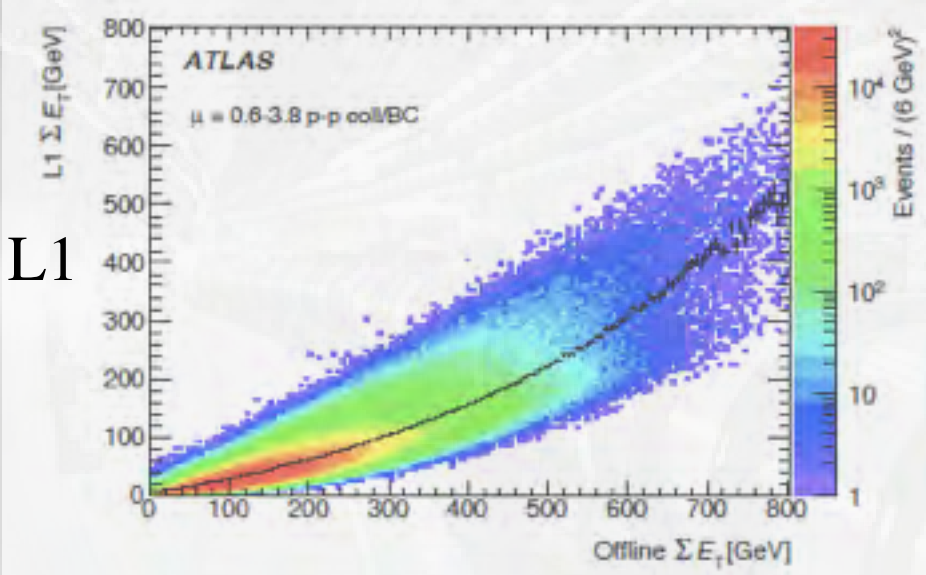
Beam spot determined by L2 tracking (Oct. 2010)



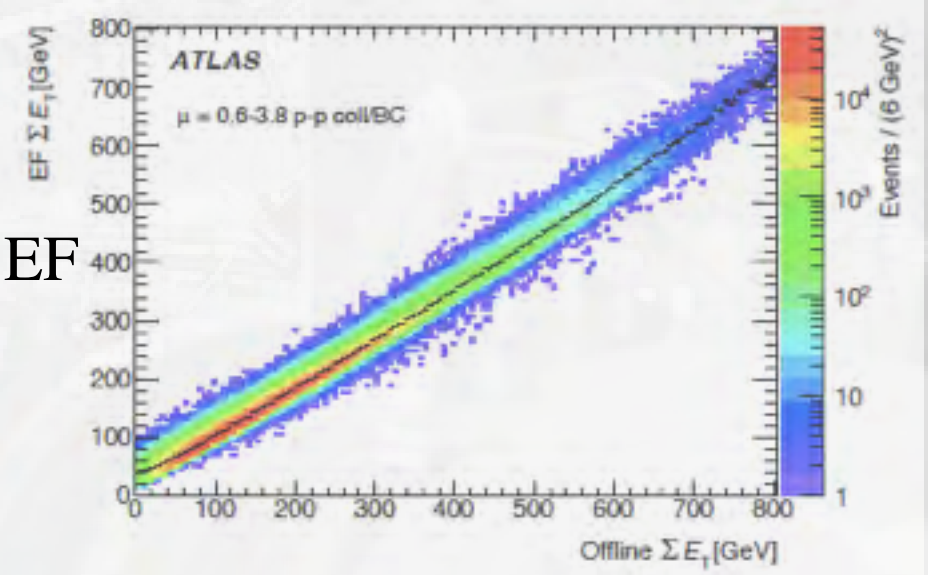
arXiv:1010.0017

correlation between trigger- and offline event reconstruction ΣE_T

L1

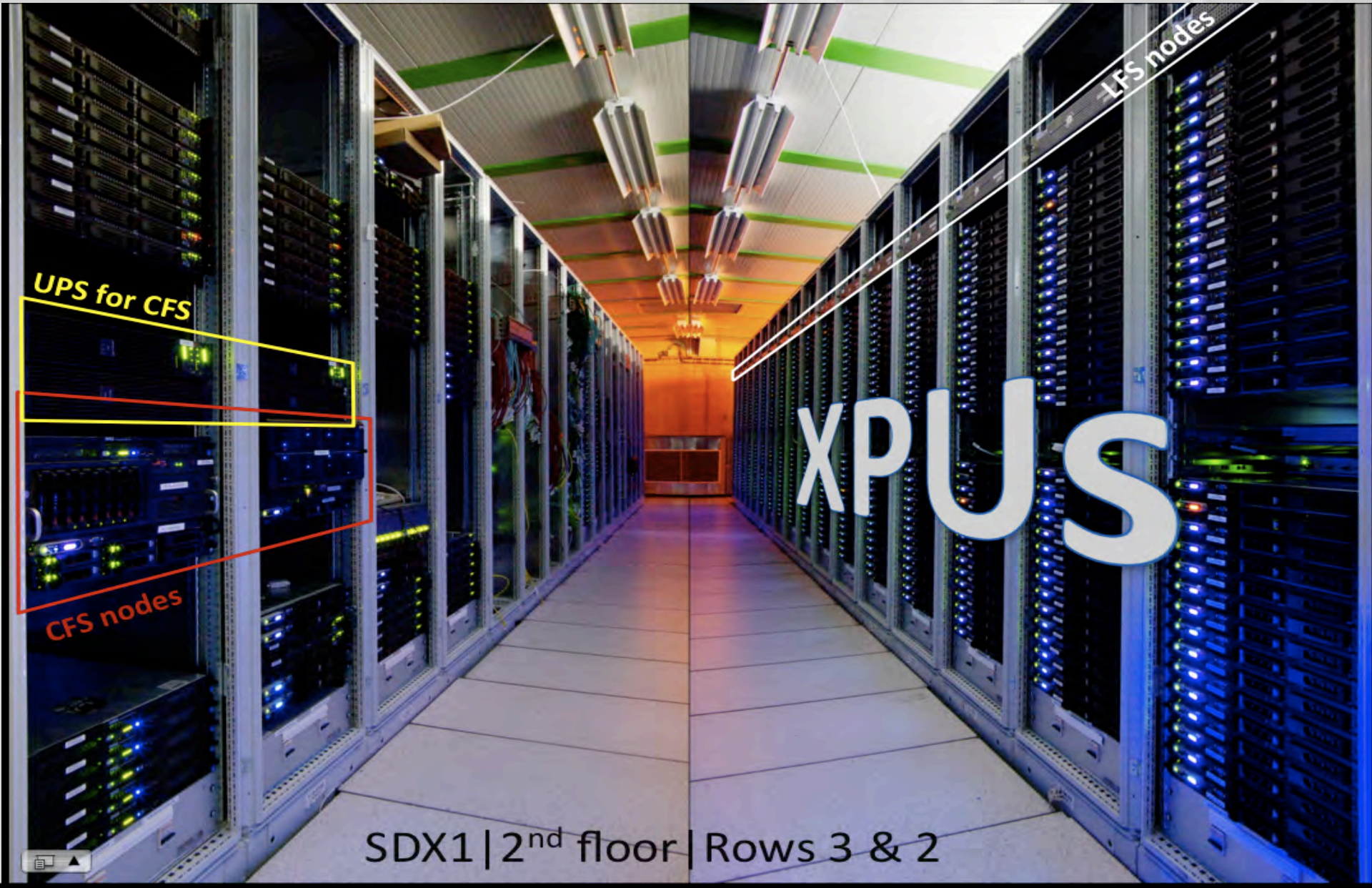


EF



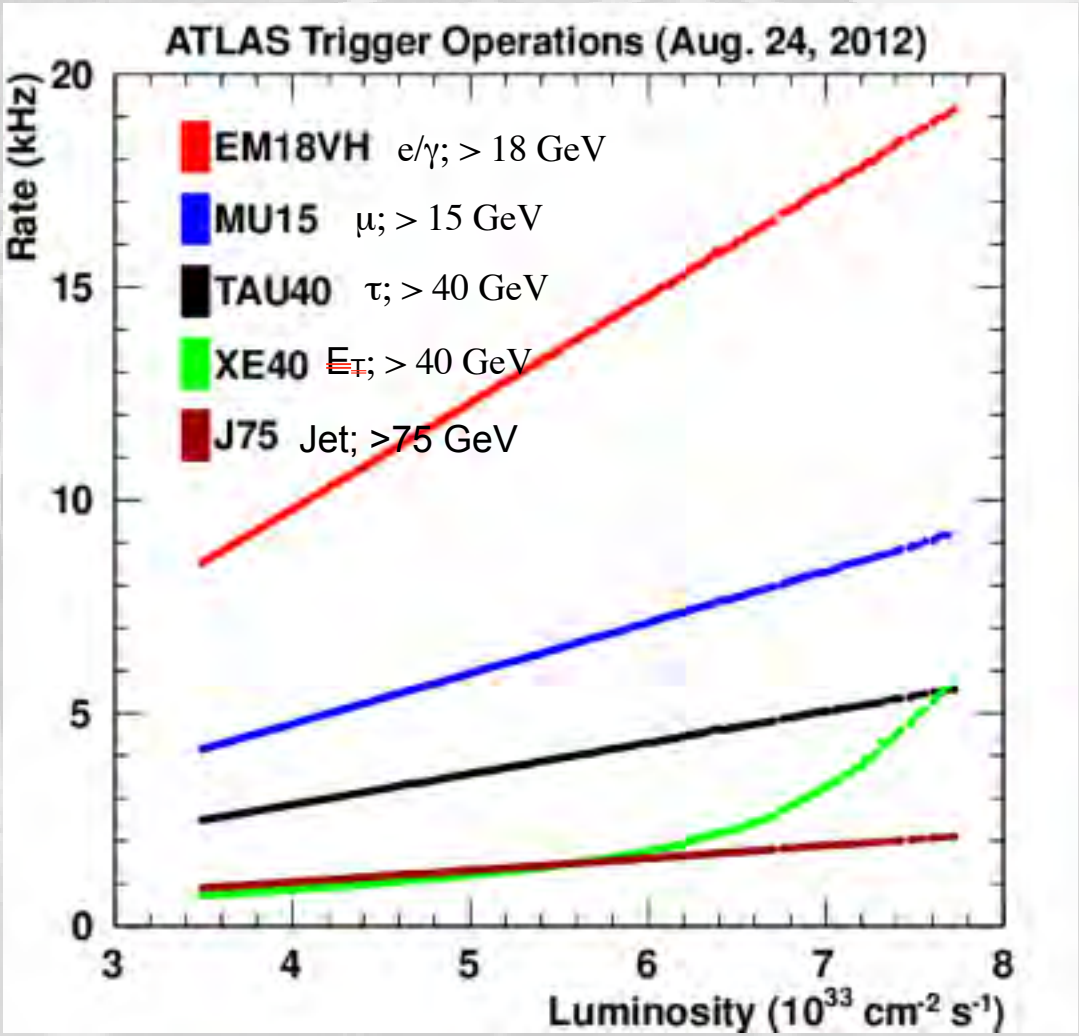
ATLAS High-Level-Trigger (HLT) farm

~15.000 cores in ~1500 “boxes” (CFS: central file system; UPS: uninterupt. power supplies)



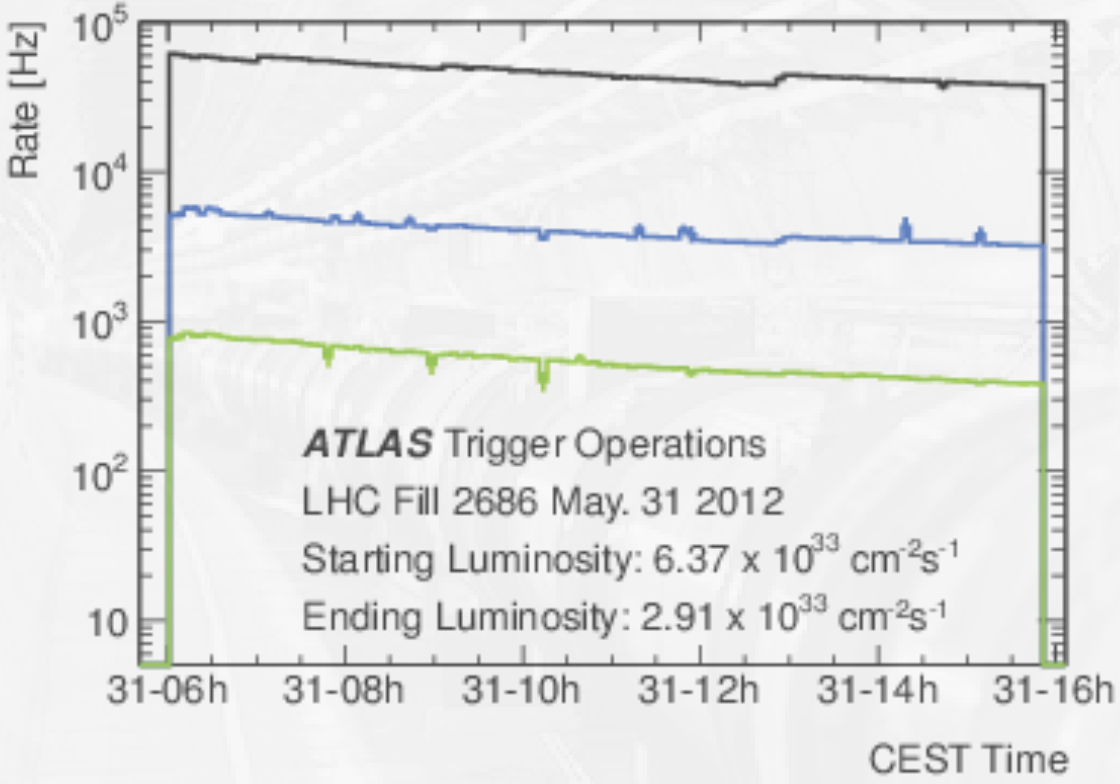
ATLAS Level-1 single-object Trigger rates

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

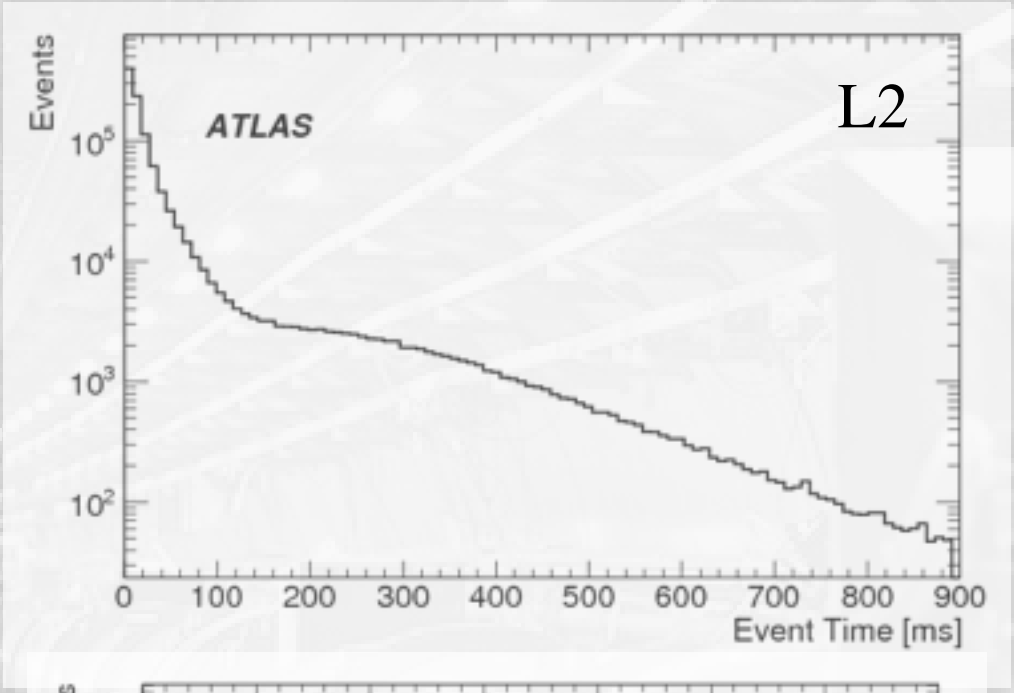


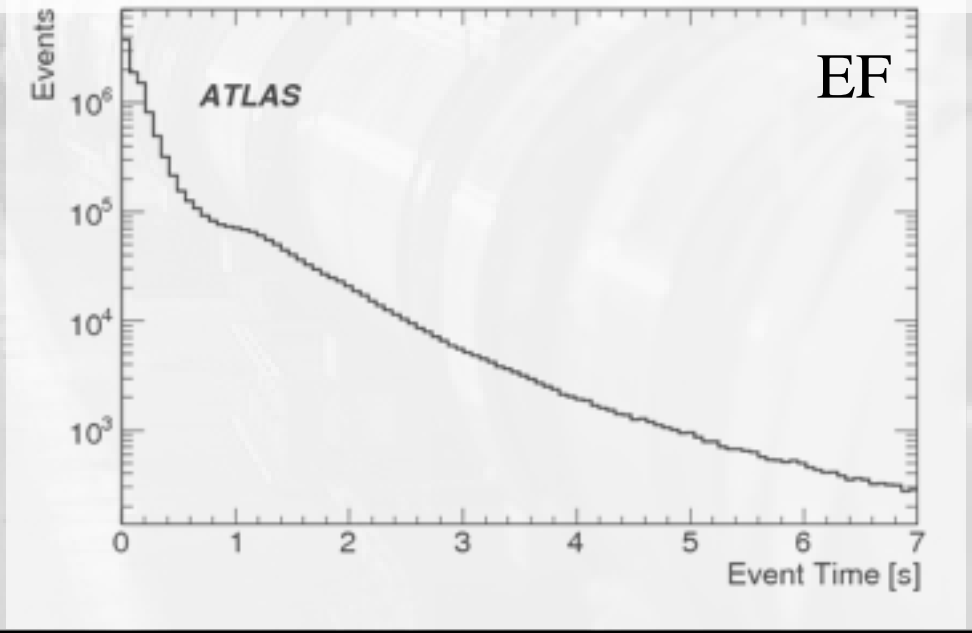
ATLAS Trigger output rates

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



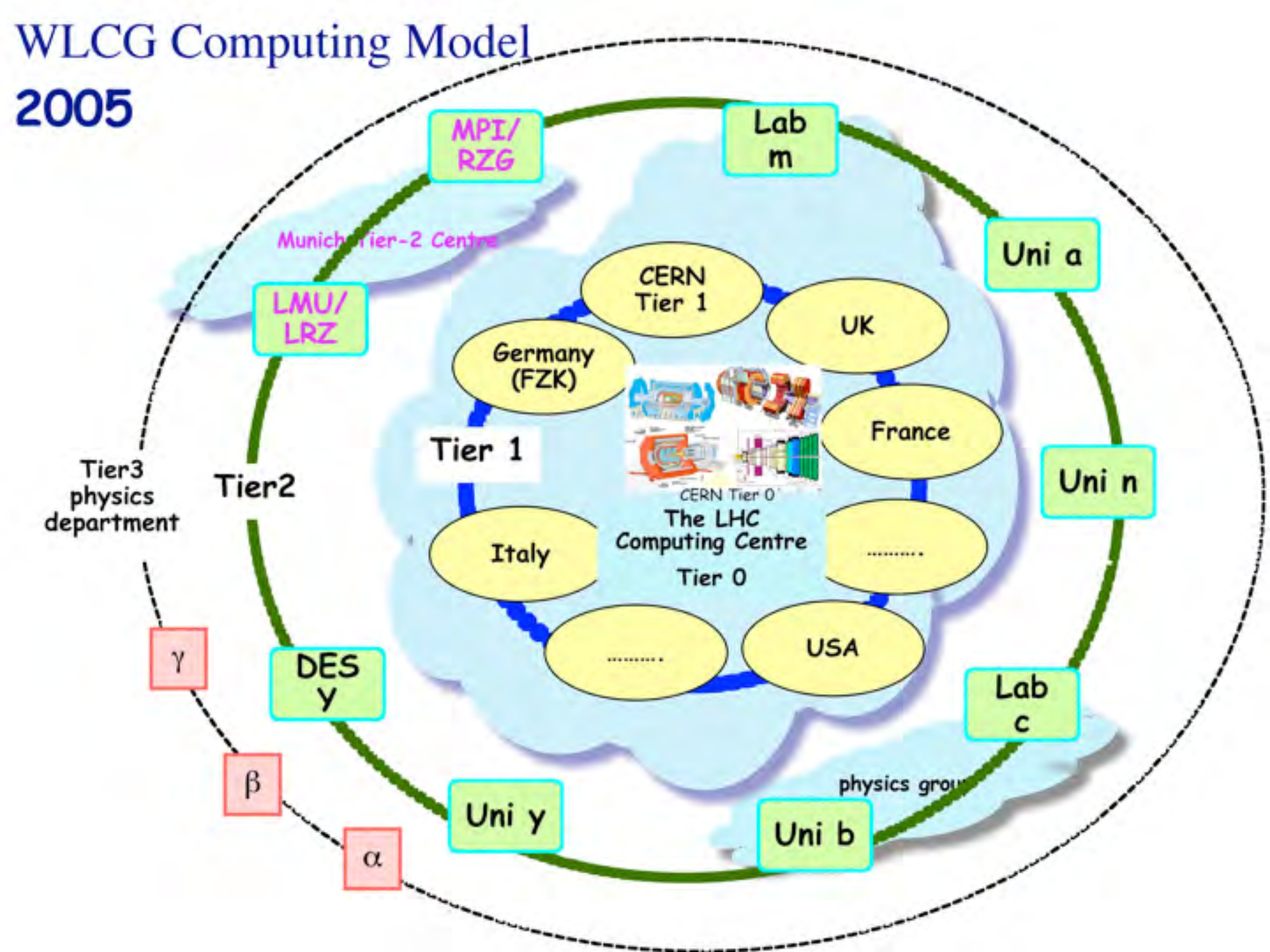
ATLAS Trigger: event processing times

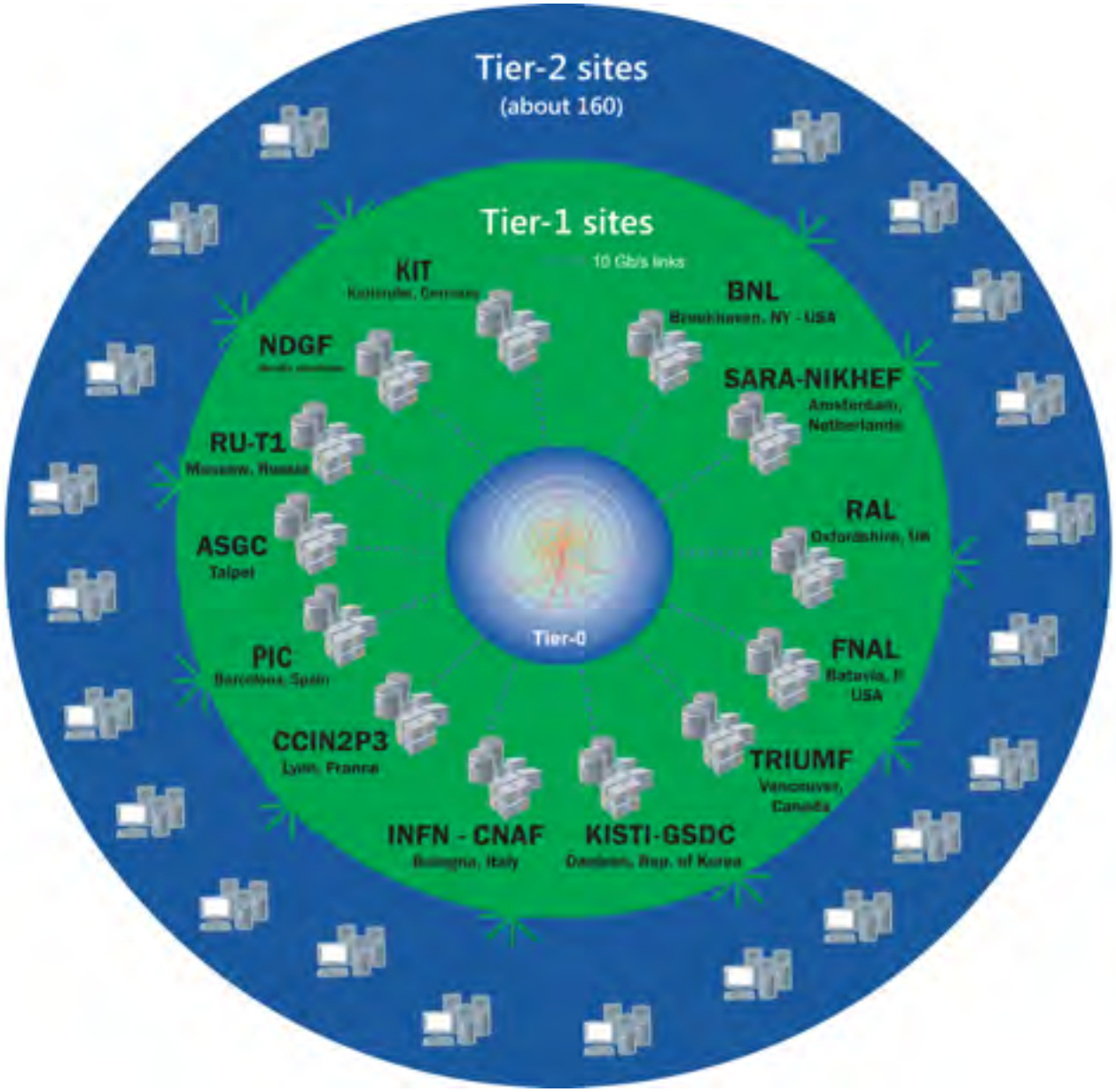




WLCG Computing Model

2005



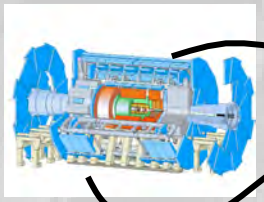

Tier-2 sites
(about 160)
Tier-1 sites
10 Gb/s links
KIT
BNL
NDGF
SARA-NIKHEF
Amsterdam,
RU-T1
RAL
ASGC
Taipei
Tier-0
PIC
FNAL
Batavia, I
USA
CCIN2P3
TRIUMF
Vancouver,
Canada
INFN - CNAF
Bologna, Italy
KISTI-GSDC

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

Event Summary Data

processed data

raw data

Reprocessing at Tier1

Physics analysis at Tier2

analysis

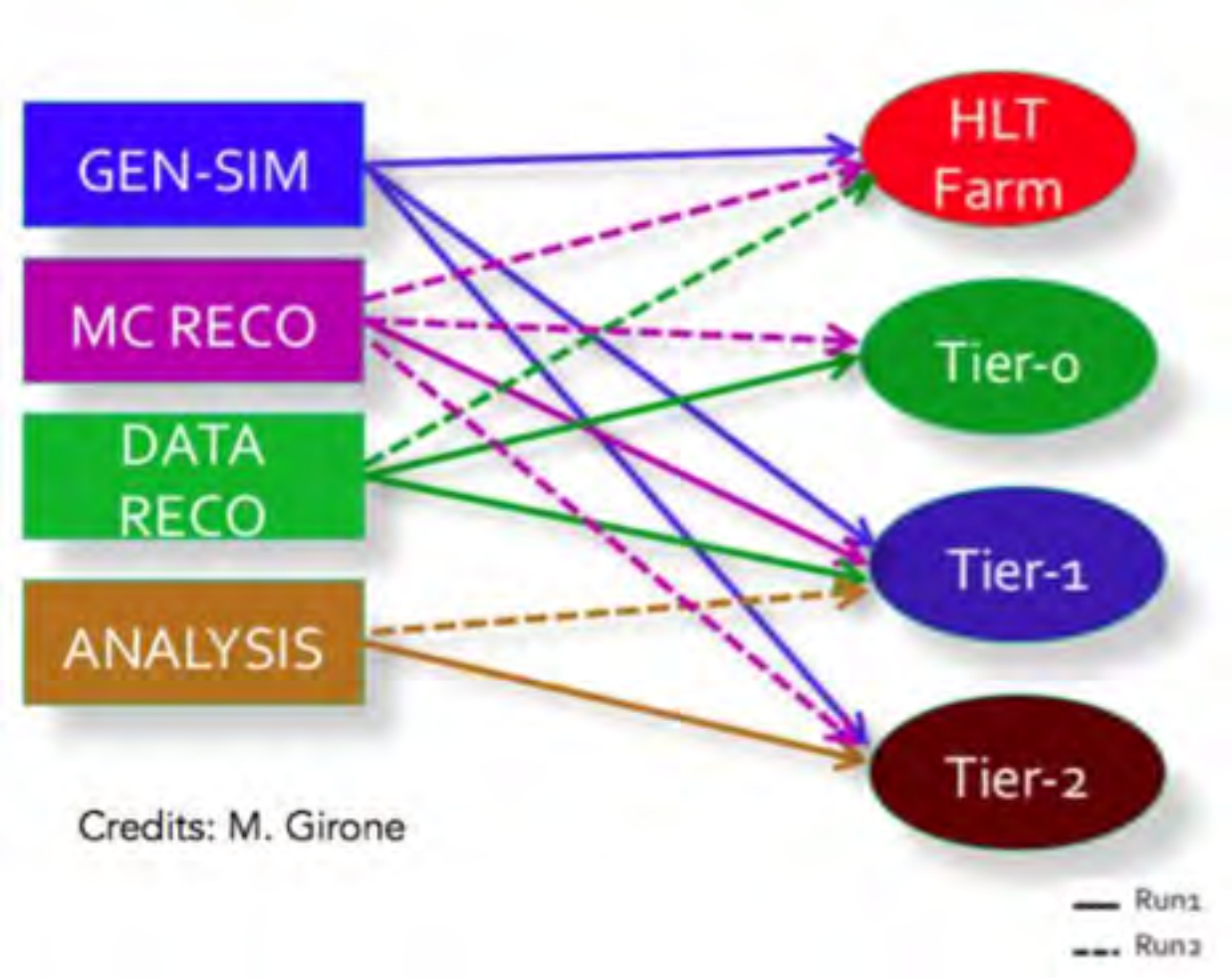
analysis objects (extracted by physics topic)

simulation

Simulation at Tier1/2

interactive physics analysis

WLCG Computing Model becomes more flexible…



… and thus uses existing resources more efficiently!

WLCG
Worldwide LHC Computing Grid

Components

Computing infrastructure and operation

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

Computing infrastructure and operation

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

WLCG: installed capacities

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

Capacities > Federation Capacities

VO: ALL Year: 2017 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)
Nordic	NDGF	3,394	64,832	925,215	12,412,319	5,464,000
France	FR-CCIN2P3	1,732	33,336	342,583	15,290,402	42,991,049
Germany	DE-KIT	1,643	29,835	340,984	16,846,710	46,113,310
Netherlands	NL-T1	1,418	12,320	192,824	12,023,384	0
UK	UK-T1-RAL	1,463	17,561	175,610	13,727,624	31,318,674
Russian Federation	NRC-KI-T1	552	8,928	138,384	4,622,466	0
USA	US-T1-BNL	0	0	130,000	16,800,000	27,000,000
Canada	CA-TRIUMF	856	4,872	74,266	8,870,714	18,032,500
Russian Federation	RU-JINR-T1	2,080	4,160	63,731	6,866,924	9,465,474
USA	US-FNAL-CMS	0	0	58,000	10,000,000	22,000,000
Spain	ES-PIC	380	3,167	38,412	7,914,141	23,404,779
Taiwan	TW-ASGC	403	3,224	32,691	8,939,004	4,000,000
Republic of Korea	KR-KISTI-GSDC	912	1,824	19,037	0	0
Italy	IT-INFN-CNAF	0	0	0	0	0
Total		**14,833**	**184,059**	**2,531,737**	**134,313,688**	**229,789,786**

Tier 0:

Total	**2,276**	**2,276**	**38,559**	**0**	**139,031,992**

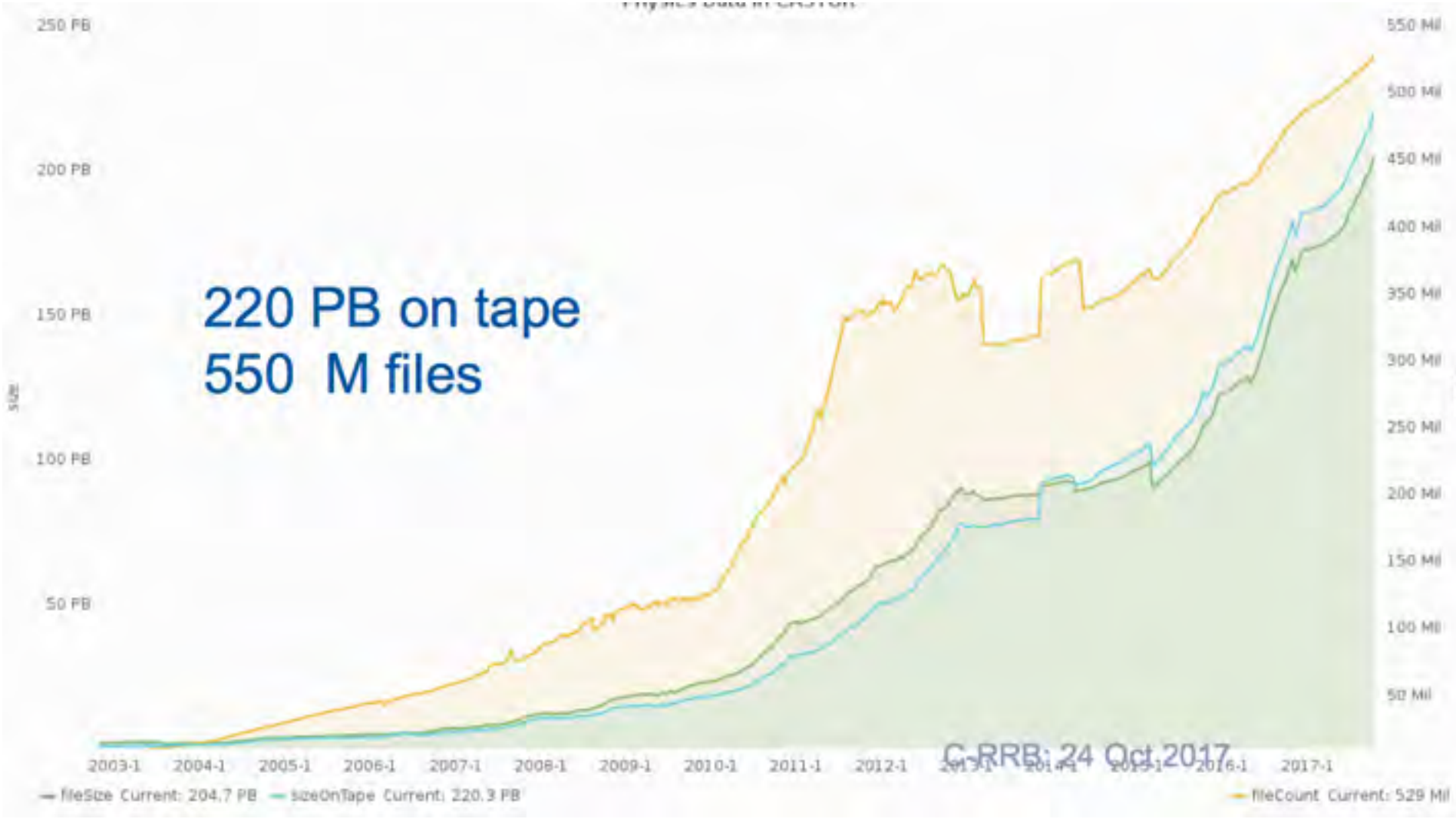
Tier 2:
total

54,379	**424,014**	**6,446,139**	**252,028,433**	**8,838,882**

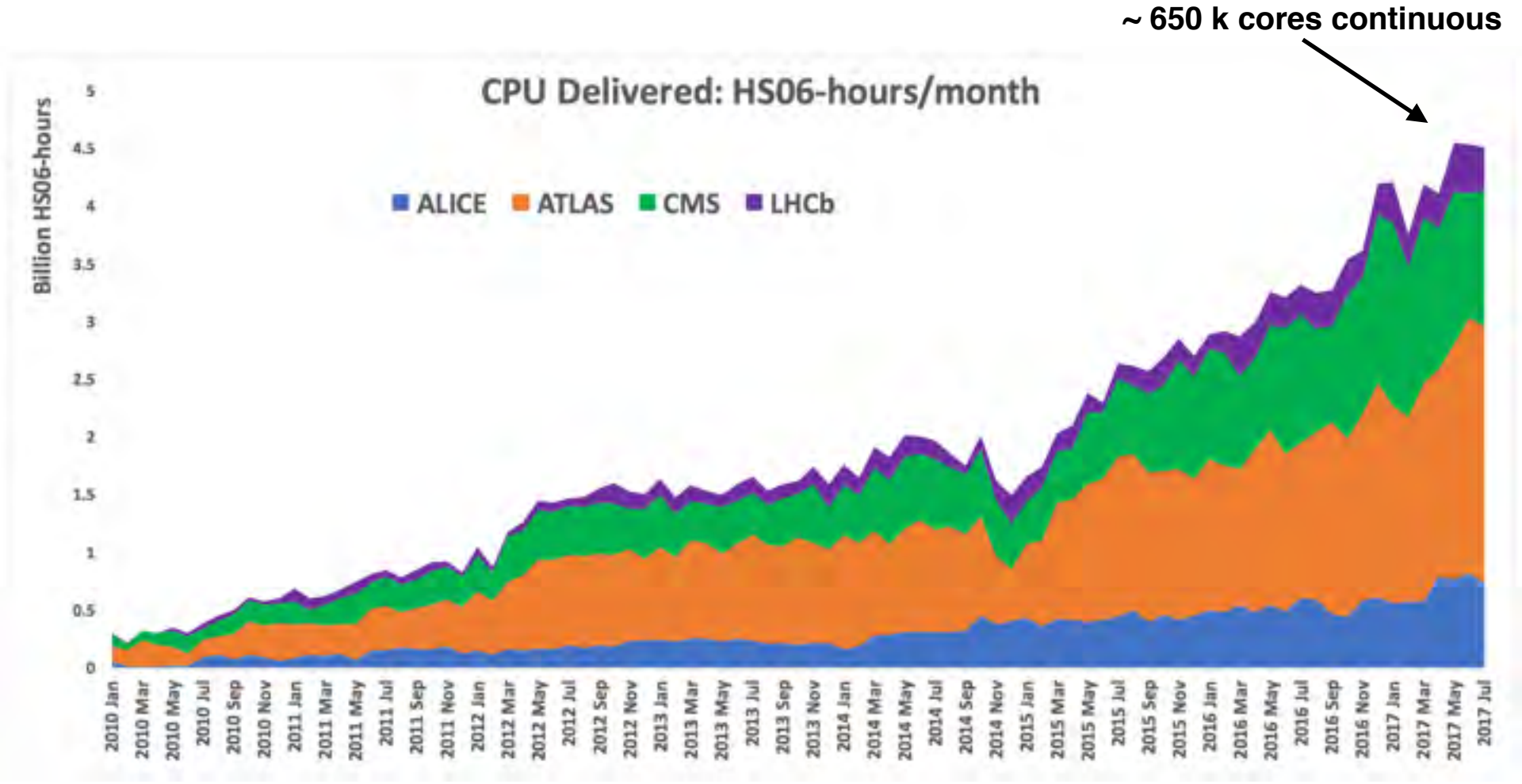
Munich Tier-2 annual upgrades

Germany, ATLAS Federation, Munich *	2017	2018	2019	Split 2018	ALICE	ATLAS	CMS	LHCb	SUM 2018
CPU (HEP-SPEC06)	37500	37500	0	Offered	0	37500	0	0	37500
				% of Total		3%			3%
Disk (Tbytes)	2766	2766	0	Offered	0	2766	0	0	2766
				% of Total		3%			3%

WLCG total data storage



WLCG: CPU usage



CERN computing centre

CERN Tier-0 data centre

interior of a tape-robot

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- ATLAS Detector and Physics Performance Technical Design Report Vol. 1, CERN/LHCC 99-14
- The ATLAS Trigger System Commissioning and Performance, arXiv:1010.0017
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