The ALICE Grid upgrade, methods and tools for LHC Run 3 and beyond

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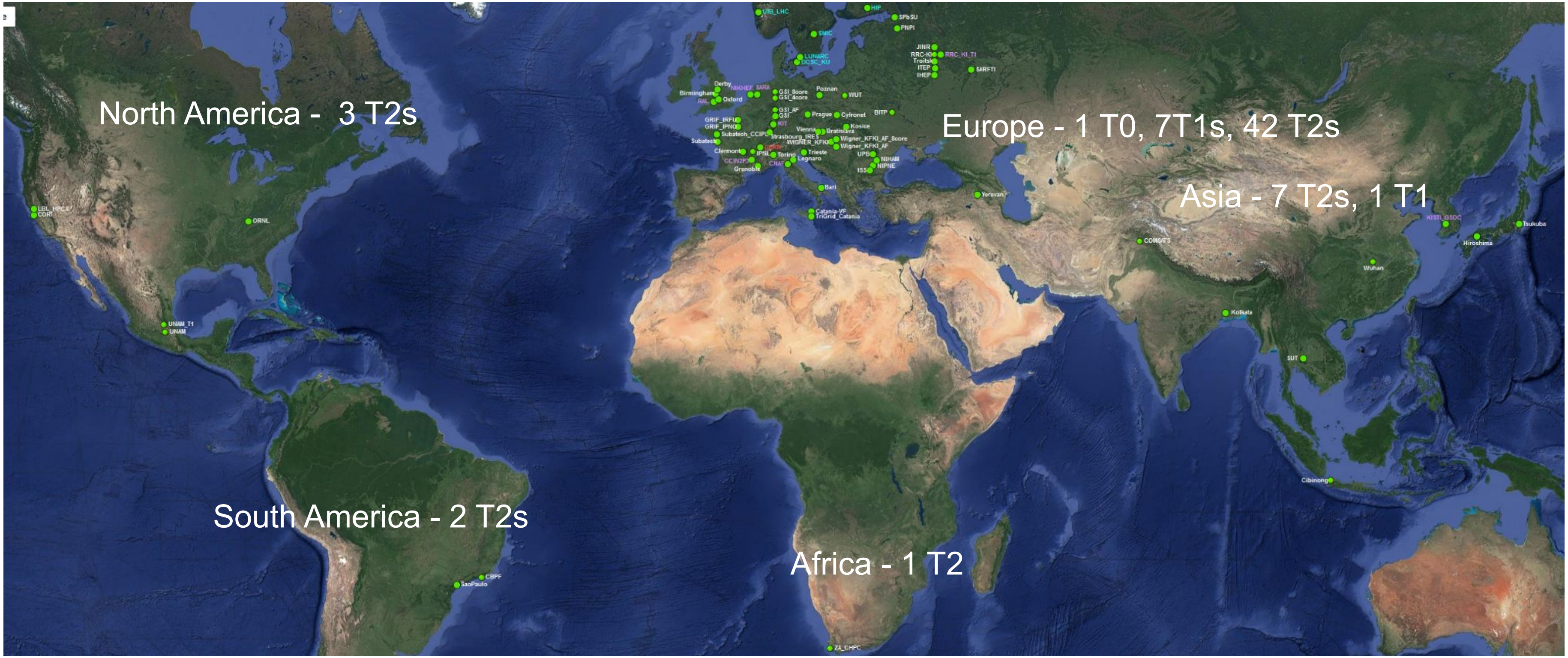
Journées LCG-France, LPNHE, 6-8 June 2023

The ALICE Grid - individual computing centres



North America - 3 T2s

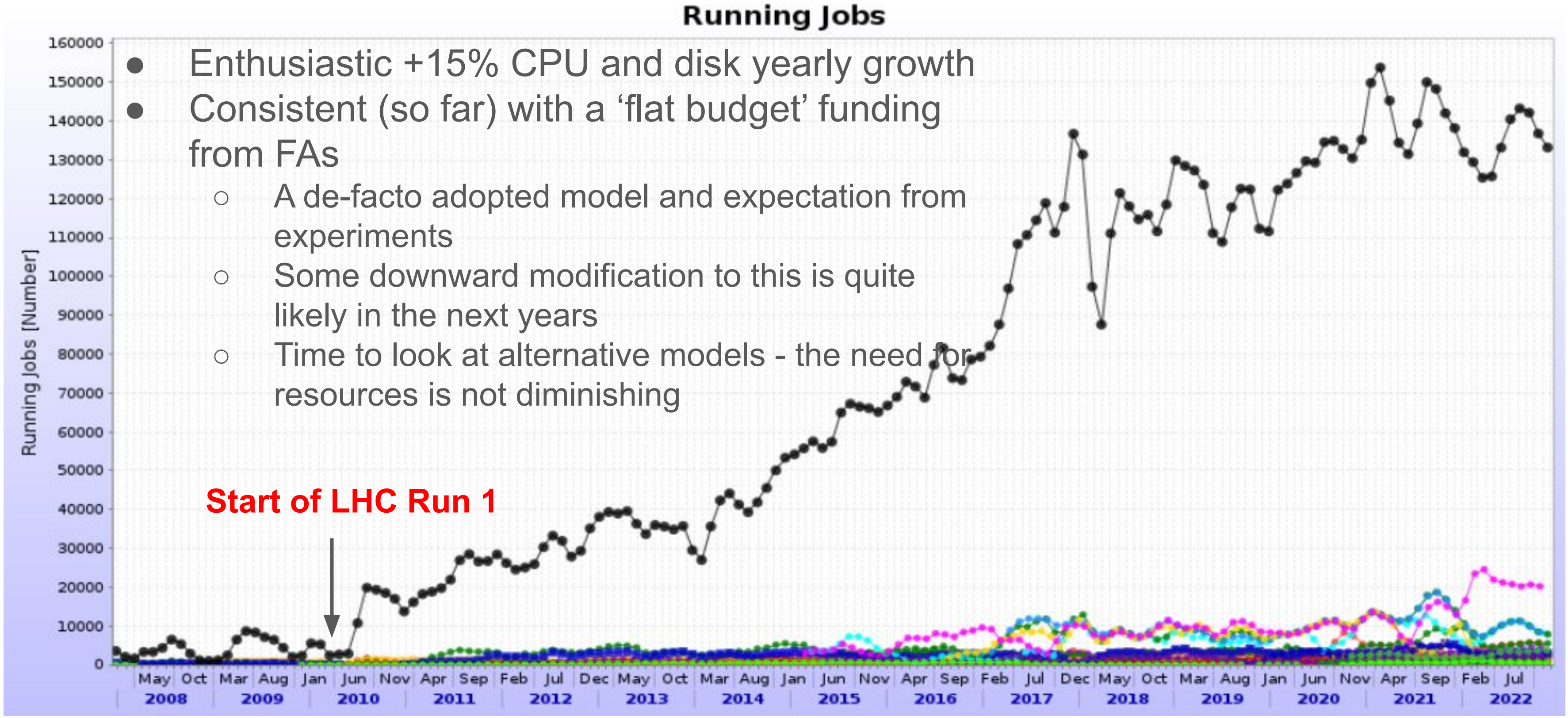
Europe - 1 T0, 7T1s, 42 T2s

Asia - 7 T2s, 1 T1

South America - 2 T2s

Africa - 1 T2

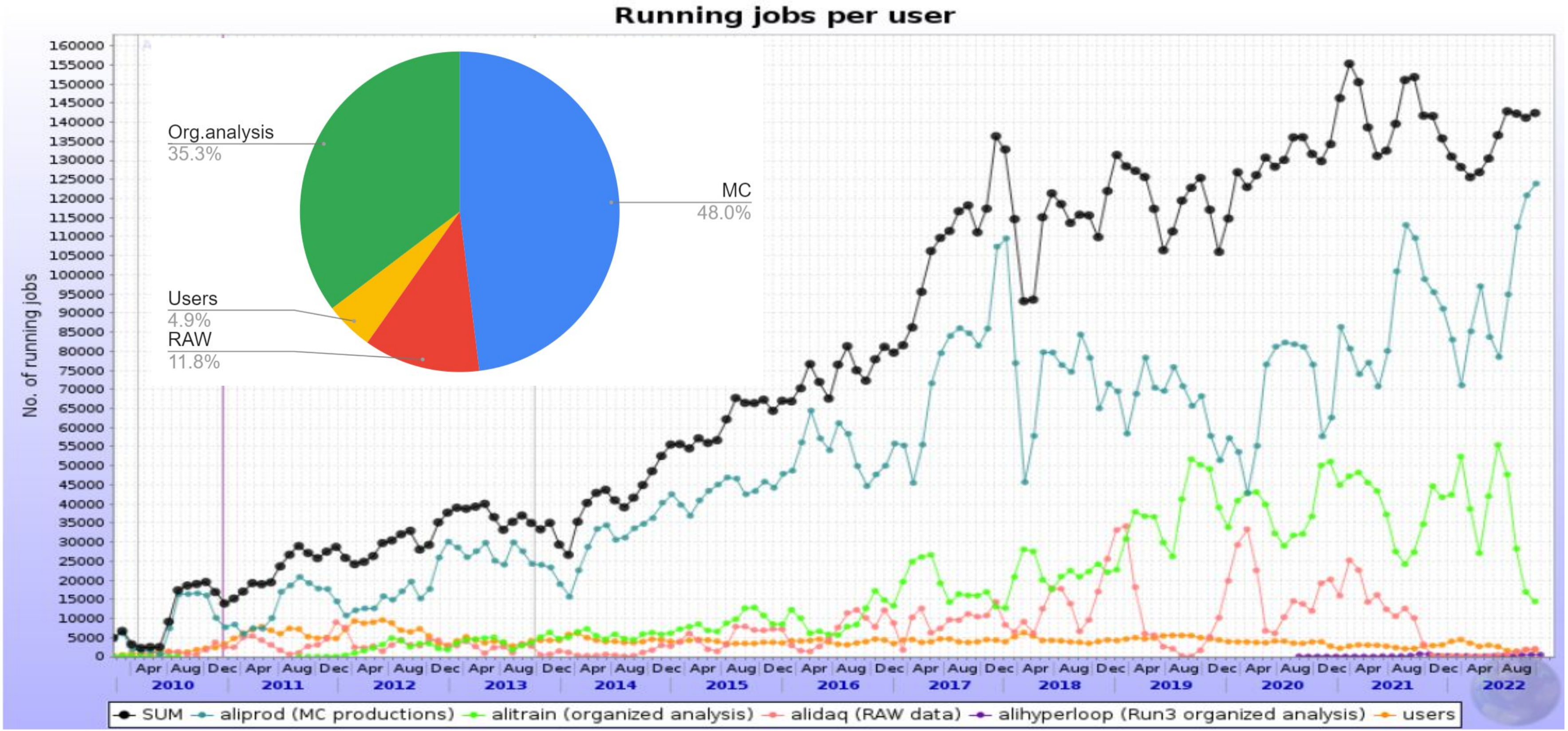
ALICE resources evolution



- Enthusiastic +15% CPU and disk yearly growth
- Consistent (so far) with a ‘flat budget’ funding from FAs
  - ○ A de-facto adopted model and expectation from experiments
  - ○ Some downward modification to this is quite likely in the next years
  - ○ Time to look at alternative models - the need for resources is not diminishing

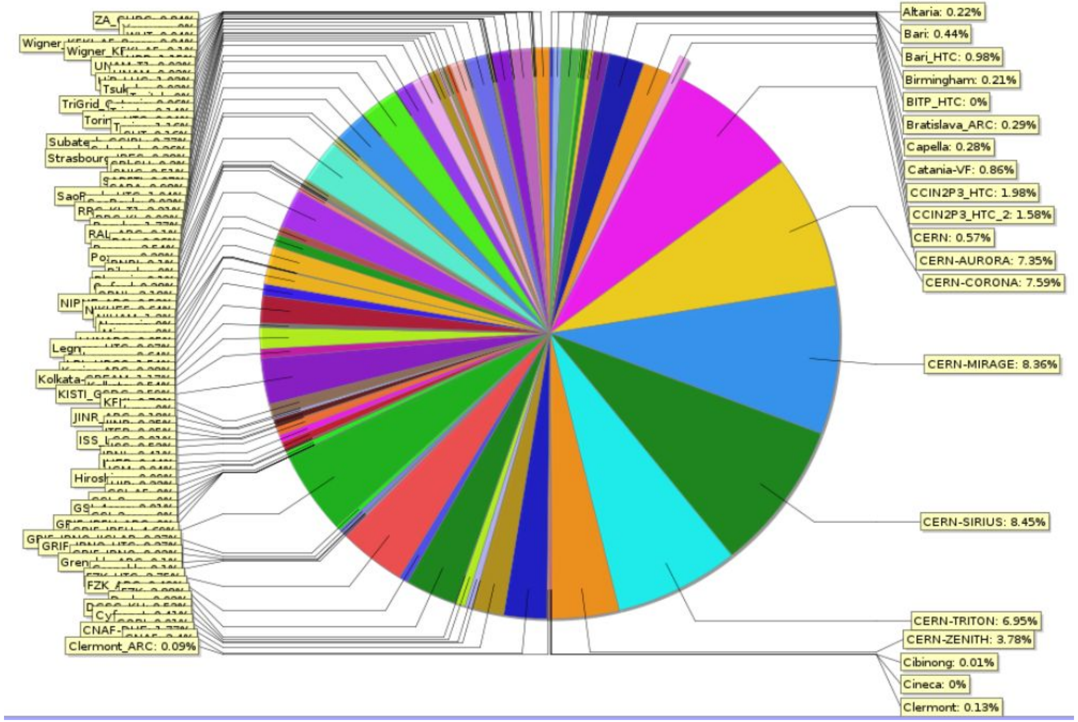
Start of LHC Run 1

ALICE resources use per activity



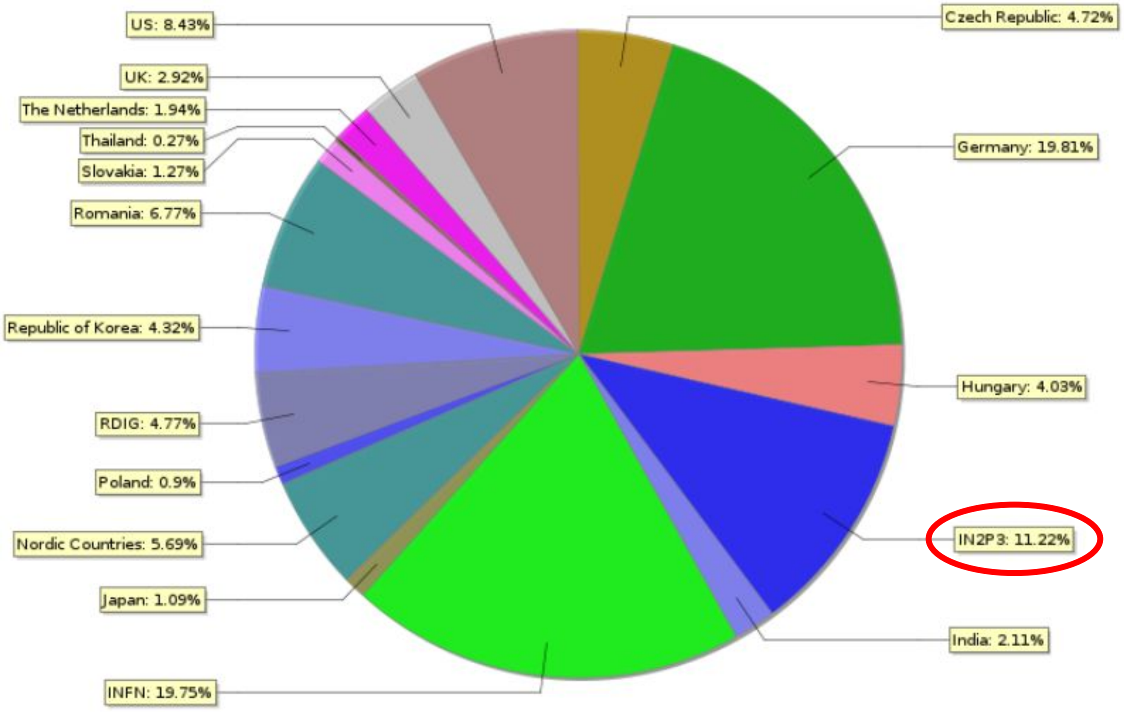
Role of Tiers

- T0 - RAW reco + MC + analysis
- T1s - RAW reco + MC + analysis
- T2s - MC + Analysis
- Differences between tiers - custodial storage + nominal services response time
- In practice - all tiers run effectively all types of workload (except RAW reco) and availability is ~same
- ALICE model can absorb any site size



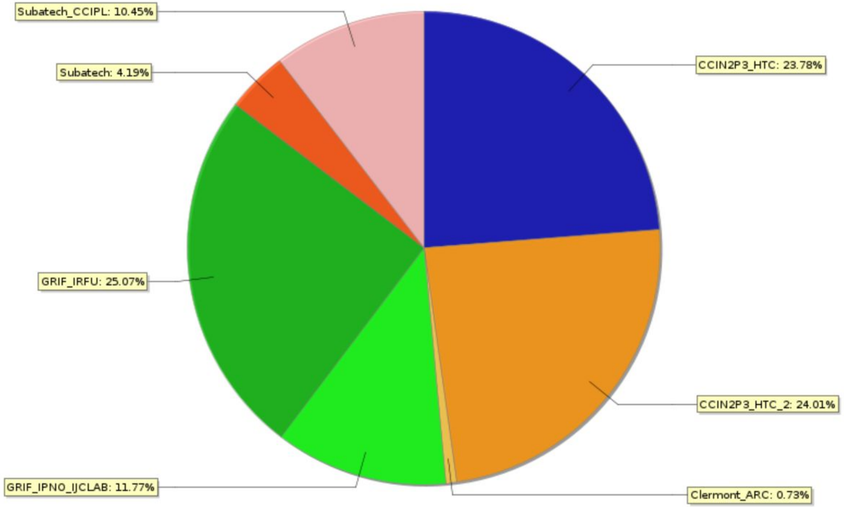
Regional contribution to ALICE computing

- ~12% FR contribution
- T1@CCIN2P3
- 4 (soon to be 3) T2s
  - Clermont
  - GRIF_IRFU
  - GRIF_IJCLAB
  - Subatech (+CCIPL)
- Diminishing role of T2 centres - this is an unfortunate global trend

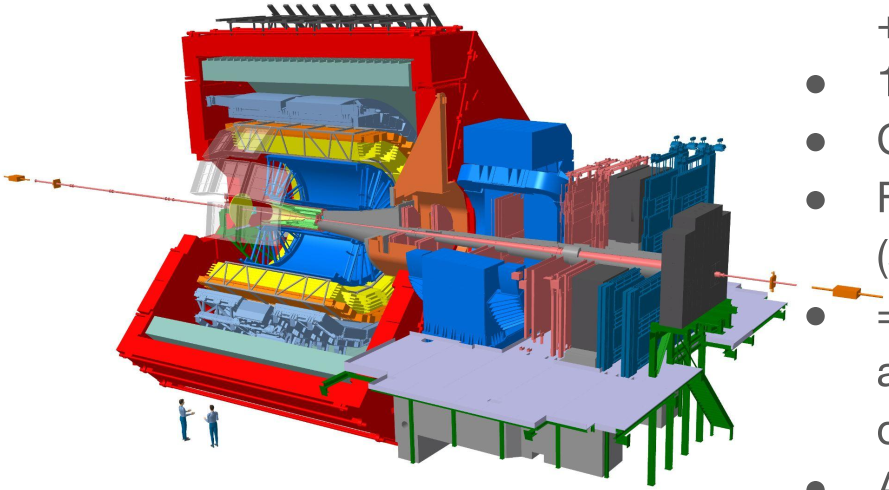


Repartition of resources in FR sites

- ~50% at CCIN2P3
- ~15% Subatech
- ~35% GRIF (IRFU+IJCLAB)
- ~1% Clermont
- The imminent loss of Subatech is a substantial hit to ALICE computing in France
  - In addition it is the loss of one of the oldest Grid centres in the country(!)

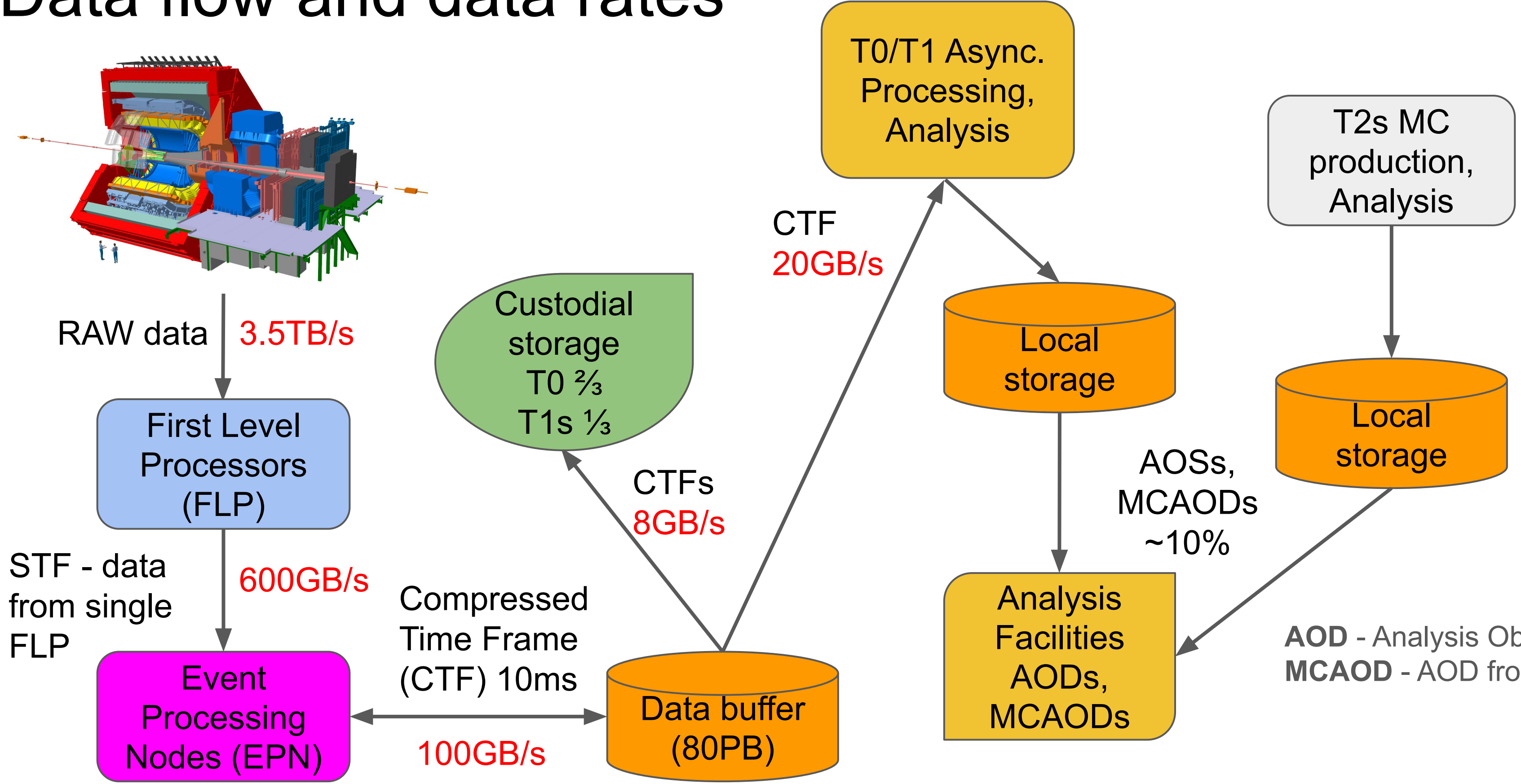


ALICE upgrade general



- p-p and HI physics
- 10x integrated luminosity L~10nb^{-1} (B=0.5T) + 3nb^{-1} (B=0.2T)
- 100x event rate of Run 1/2, 10x more data
- Continuous readout
- Focus on data compression and real time (synchronous) data reconstruction
- => Reasonable rates and data volumes after compression to storage and secondary data formats
- Adherence to ‘flat budget’ resources funding for data processing and analysis

Data flow and data rates



RAW data 3.5TB/s

First Level Processors (FLP)

STF - data from single FLP

600GB/s

Event Processing Nodes (EPN)

Compressed Time Frame (CTF) 10ms

100GB/s

Data buffer (80PB)

CTFs 8GB/s

Custodial storage T0 ⅔ T1s ⅓

CTF 20GB/s

T0/T1 Async. Processing, Analysis

Local storage

T2s MC production, Analysis

Local storage

AOSs, MCAODs ~10%

Analysis Facilities AODs, MCAODs

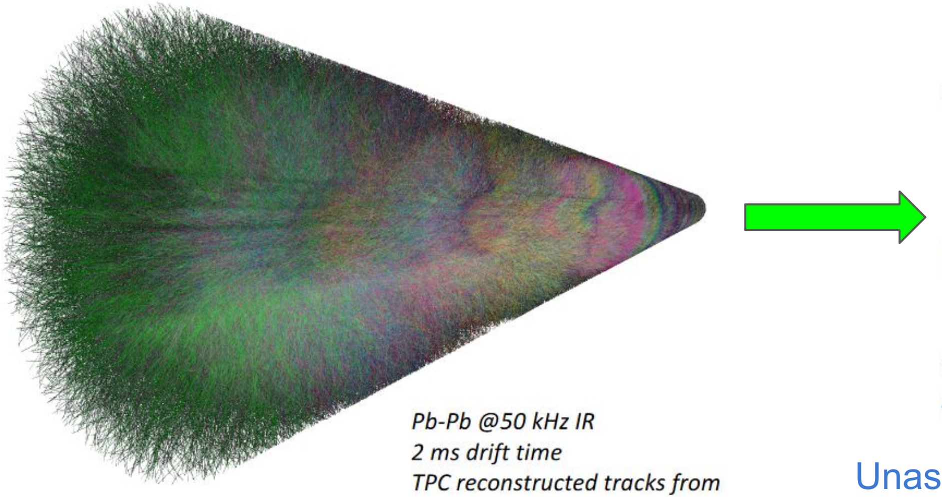
AOD - Analysis Object Data
MCAOD - AOD from MC

The O2 facility (EPNs)

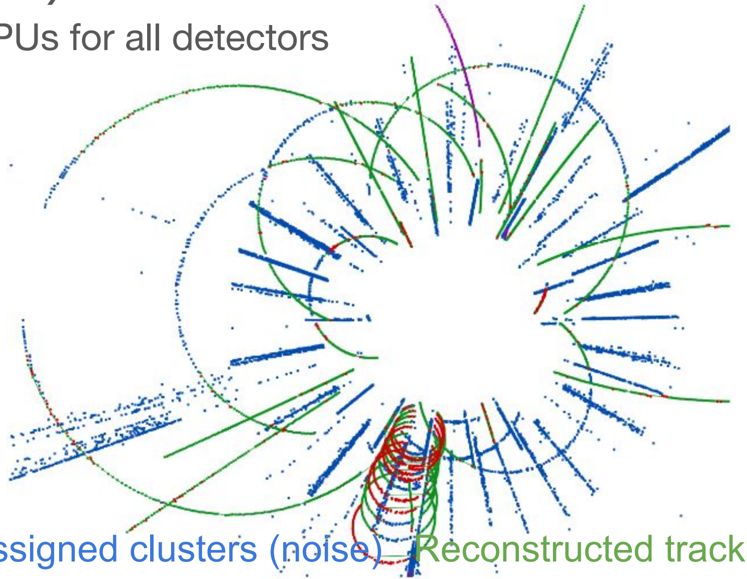
- Container-hosted computing facility located at the ALICE site, PUE<1.07
- High-throughput system, heterogeneous computing platform (CPU+GPU)
- 250 dual CPU nodes (ROME, 64 cores, 512GB RAM) with 8 AMD (MI50, 32GB) GPUs/node
- Functions
  - Data aggregation (Detector STFs to global CTF)
  - Synchronous global reconstruction
  - Calibration and data volume reduction
  - Quality control
  - Asynchronous (offline) reconstruction
- Containers house a backup EOS storage in case of network interruption to CC

Synchronous data processing

- Goal - to compress the RAW data by about factor 35 (3.5TB/s -> 100GB/s)
- Through zero suppression, clusterization, tracking, optimized data format
    - ***Mandatory use of GPUs (40x faster than CPUs)***
    - All synchronous level software is written for GPUs for all detectors

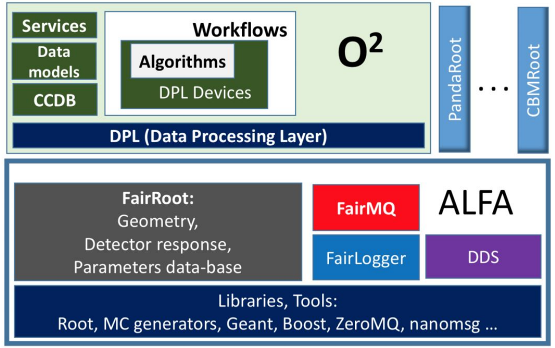


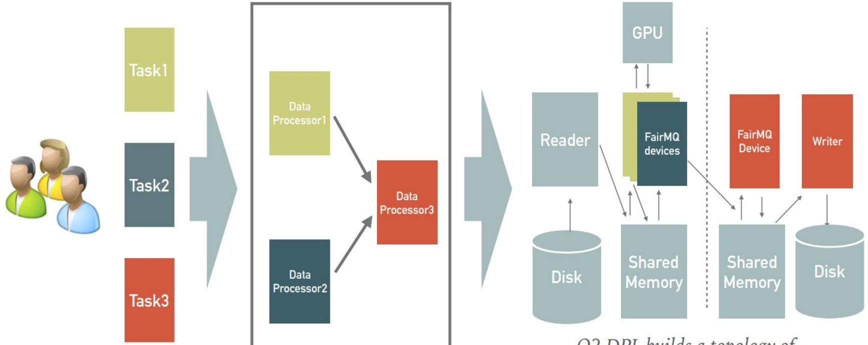
Pb-Pb @50 kHz IR
2 ms drift time
TPC reconstructed tracks from different colour-coded events



Unassigned clusters (noise) Reconstructed tracks
Removed clusters Failed fits

O2 Software framework





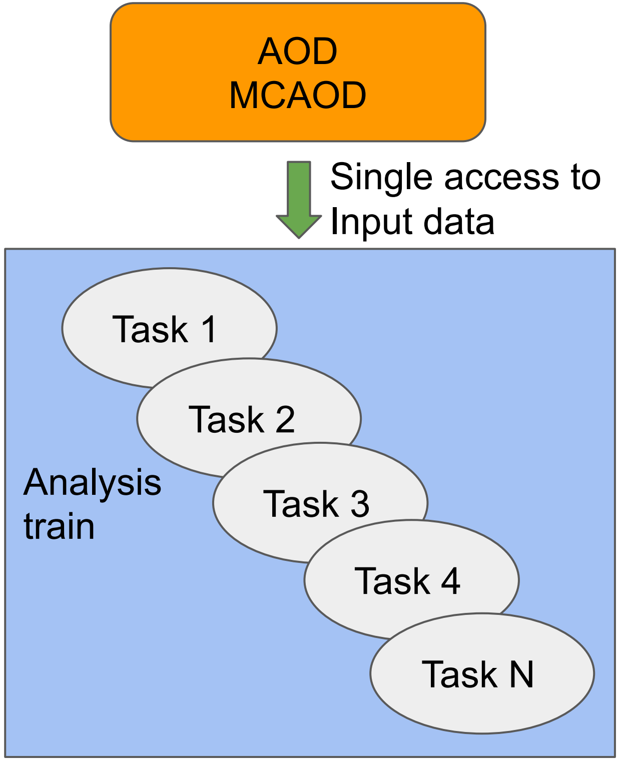
Users define tasks and their dependencies

O2 DPL builds a workflow (DAG) out of the specified tasks

O2 DPL builds a topology of FairMQ devices and maps tasks on it into account available resources

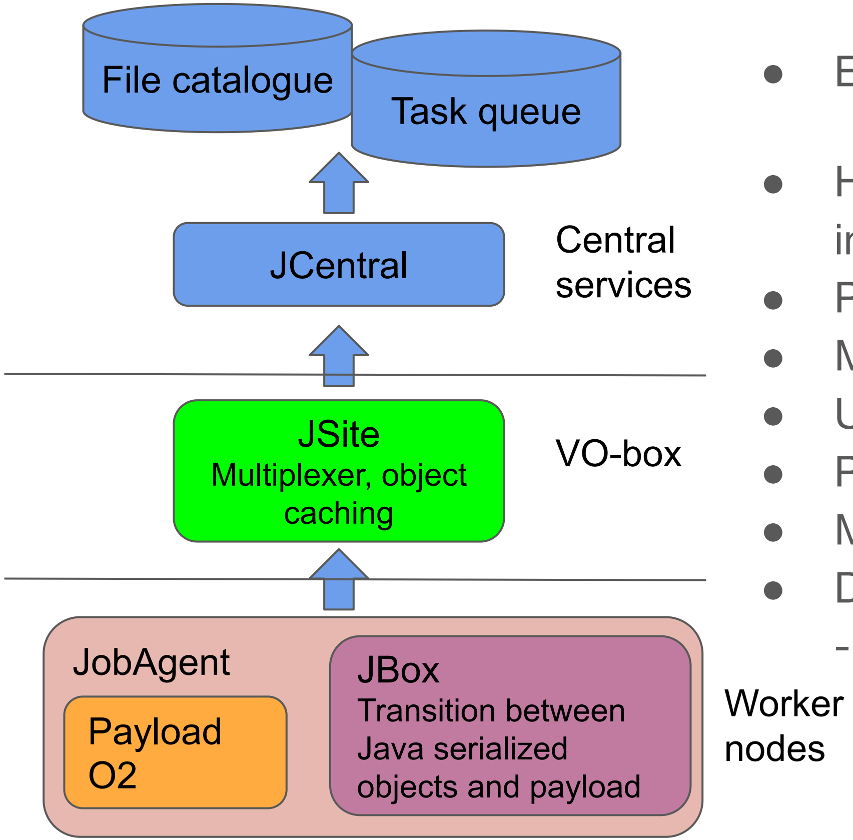
- Developed by ALICE in collaboration with the FAIR group at GSI Darmstadt
- Three major parts
  - Transport layer, based on FairMQ - message passing toolkit
  - Data model - ALICE-specific object description and content
  - Data processing layer - set of data processors implicitly organized in a logical dataflow for data transformation
- Trivially parallel and integrates tools for GPU offloading
- Natural use of multicore processing and shared memory - ***move to multicore***

Analysis facilities (AFs)



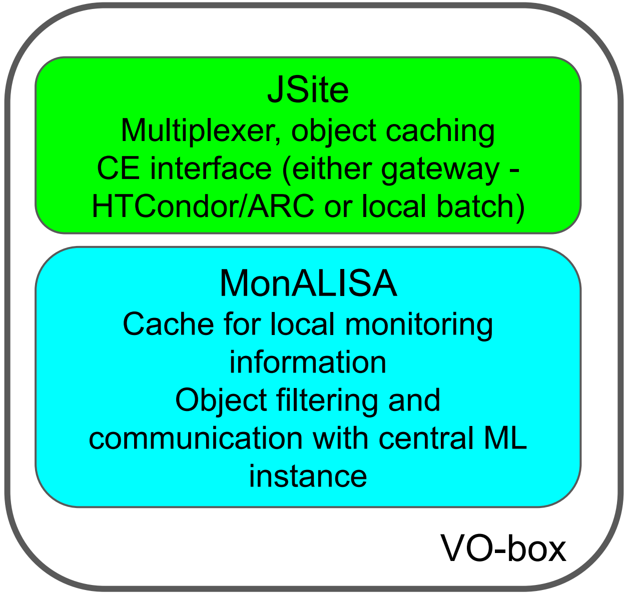
- New element of the computing model
- Data transferred to AF from T0/T1s/T2s
- Goals
    - Provide a location with comprehensive data samples from asynchronous and MC data processing at ~10% statistics
    - Fast tuning of analysis algorithms - once ready, run on full sample on the Grid
    - First data and low statistics analysis (if compatible)
- Incorporated in the Grid framework
- Sites tuned for fast I/O between storage and CPU
    - Approximate total size 6-8k cores, 10PB storage
    - ~15MB/s/core throughput
- As of today - GSI Darmstadt and KFKI Budapest (⅔ of the AF target, looking for more suitable sites)

Grid middleware development - JAliEn



- Evolution of the AliEn middleware
  - Refactored and rewritten in Java
- Highly efficient and scalable communications infrastructure
- Persistent, compressed, SSL channels
- Multiplexing and object caching
- Use of Java serialized objects
- Platform independent
- Multi-core enabled, HPC ready
- Deployed gradually on the existing infrastructure - no interference with operations

Site services evolution



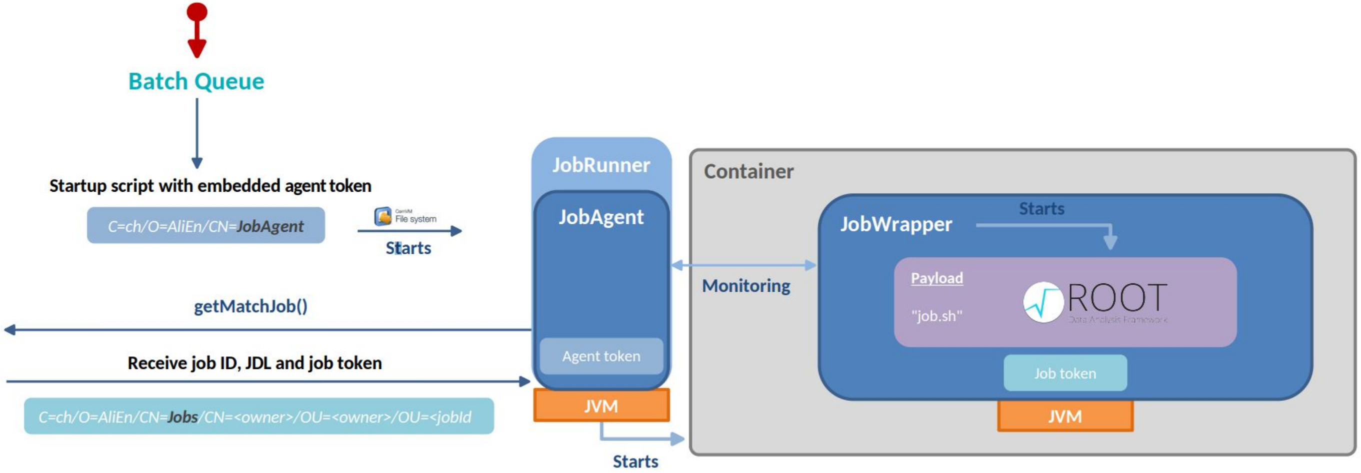
JSite
Multiplexer, object caching
CE interface (either gateway - HTCondor/ARC or local batch)

MonALISA
Cache for local monitoring information
Object filtering and communication with central ML instance

VO-box

- New middleware for sites - simplification of operation
- JAliEn was installed gradually and in combination with the local CE updates
- From 5 services to 2
  - The remaining services are quite reliable and effectively do not require site manager intervention
- Automatic updates to new version of VO-box services
- Monitoring of all relevant info for the site is provided on a single page here

JobRunner, JobAgent and JobWrapper

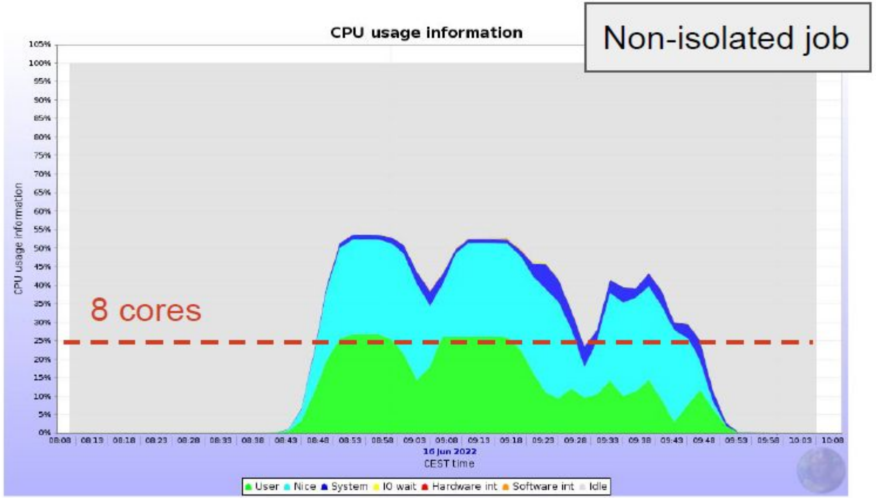


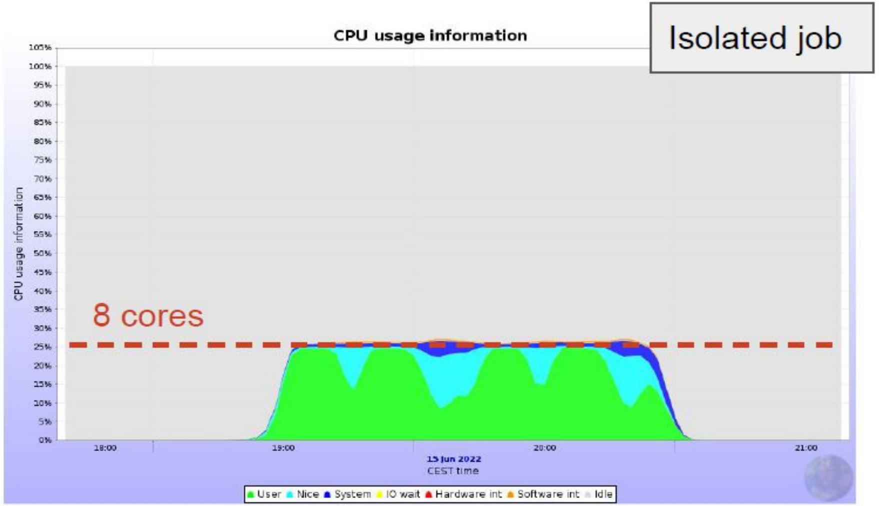
- Entirely new method for both resources and job control
- Fully containerized workload
- Ability to run multiple jobs within the control of the same JobRunner
    - Effective control of any set of resources provided

Payload containers

- By default, all jobs are wrapped in a CentOS 7.9 container
- Other images are available
  - Rocky 8.6: For newer payloads and ***GPUs*** (special for the EPN cluster)
  - Rocky 9.0 + RHEL 9: Already certified
  - Debug containers, for example with vtune, strace
- GPUs are supported in Apptainer (formerly Singularity)
- All of the above allows for fulfilling various job requirements, independent of the underlying OS
- Allows for use of HPCs or other specialized clusters (for example EPNs)

Job isolation and control - applying `taskset`



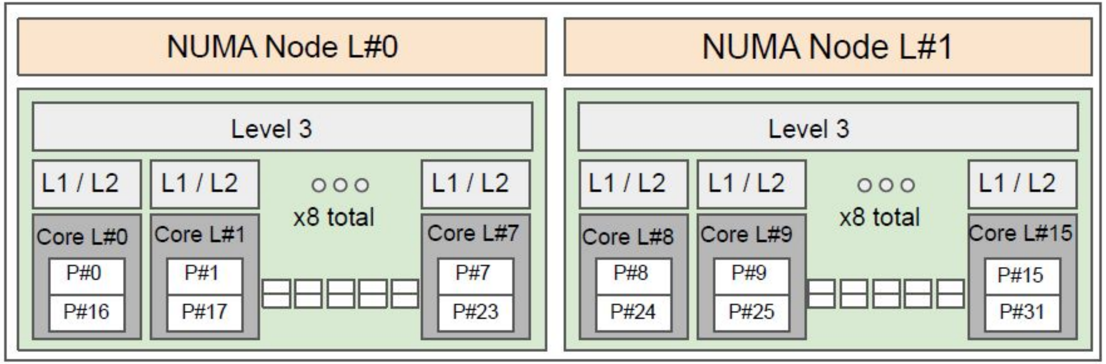


- Total CPU usage goes above the requested 8 cores

- CPU consumption is limited with `taskset`
- Total CPU usage is flat at 8 cores

- Applicable for sites with non-constrained resources and full node submission

Improving job efficiency through CPU pinning

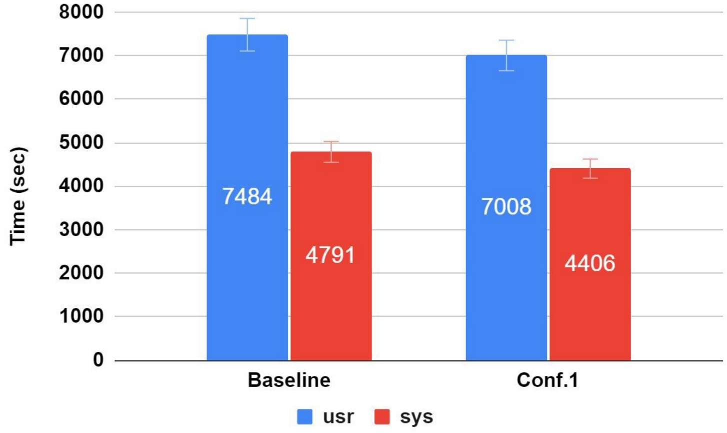


Sample host CPU architecture

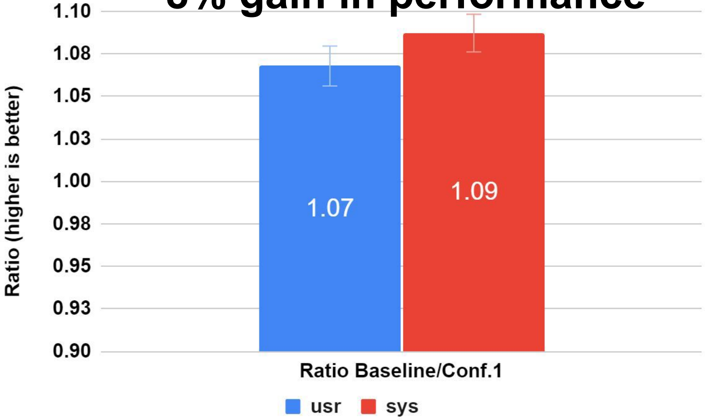
- Various core/cache pinning configurations possible
  - Same NUMA Node and independent L1,L2 cache
  - Different NUMA Nodes and independent L1,L2 cache
  - Same NUMA Node and sharing L1,L2 cache
  - Random core assignment
  - No pinning

Improving job efficiency through CPU pinning

- Most efficient configuration - same NUMA node, independent L1/L2 cache - compared to no pinning
- Only possible if full control of the CPU - whole node
- Already in production at LBNL - Lawrencium HPC

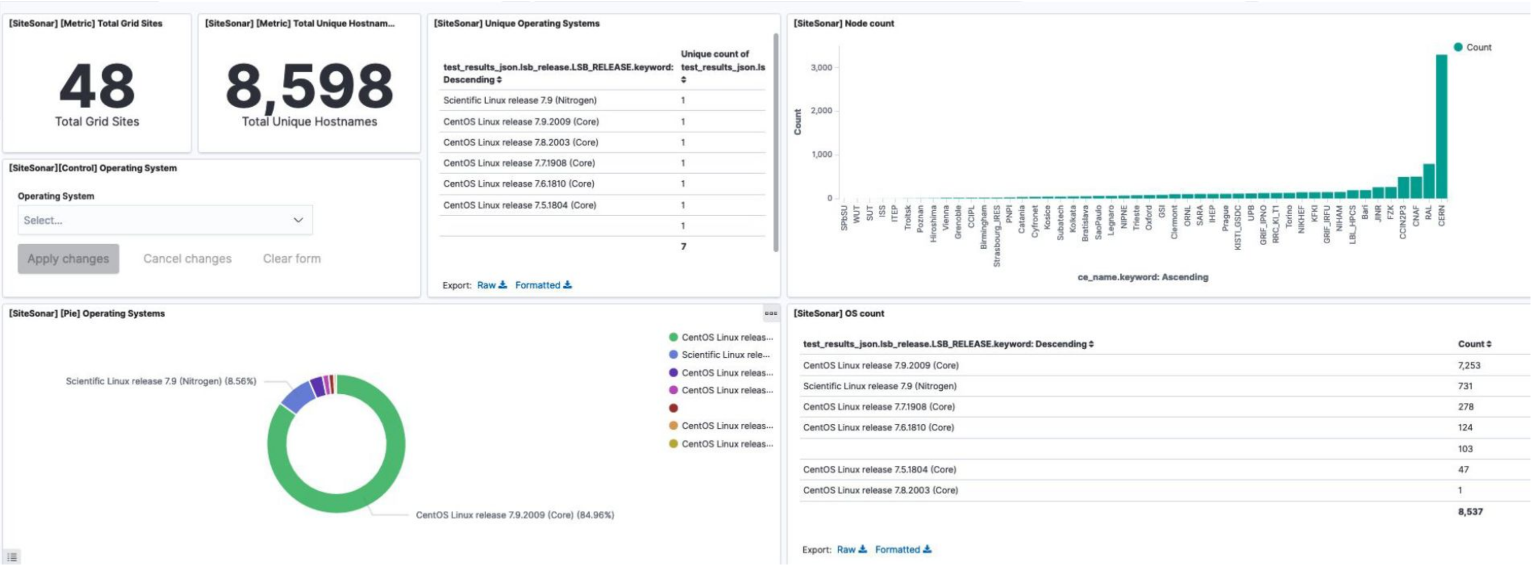


8% gain in performance



New tools and monitoring - SiteSonar

- Tool to evaluate site capabilities and installations - probes invoked at the beginning of execution
  - Collects data from ~10K Grid nodes daily



[SiteSonar] [Metric] Total Grid Sites

48
Total Grid Sites

[SiteSonar] [Metric] Total Unique Hostnam...

8,598
Total Unique Hostnames

[SiteSonar][Control] Operating System

Operating System: Select...

Apply changes | Cancel changes | Clear form

[SiteSonar] Unique Operating Systems

test_results_json.lsb_release.LSB_RELEASE.keyword: Descending ⇕	Unique count of test_results_json.ls ⇕
Scientific Linux release 7.9 (Nitrogen)	1
CentOS Linux release 7.9.2009 (Core)	1
CentOS Linux release 7.8.2003 (Core)	1
CentOS Linux release 7.7.1908 (Core)	1
CentOS Linux release 7.6.1810 (Core)	1
CentOS Linux release 7.5.1804 (Core)	1
	1
	7

Export: Raw Formatted

[SiteSonar] Node count

[SiteSonar] [Pie] Operating Systems

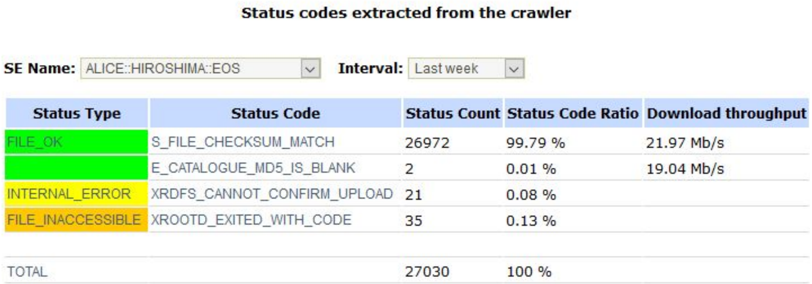
[SiteSonar] OS count

test_results_json.lsb_release.LSB_RELEASE.keyword: Descending ⇕	Count ⇕
CentOS Linux release 7.9.2009 (Core)	7,253
Scientific Linux release 7.9 (Nitrogen)	731
CentOS Linux release 7.7.1908 (Core)	278
CentOS Linux release 7.6.1810 (Core)	124
	103
CentOS Linux release 7.5.1804 (Core)	47
CentOS Linux release 7.8.2003 (Core)	1
	8,537

Export: Raw Formatted

Storage performance - FileCrawler

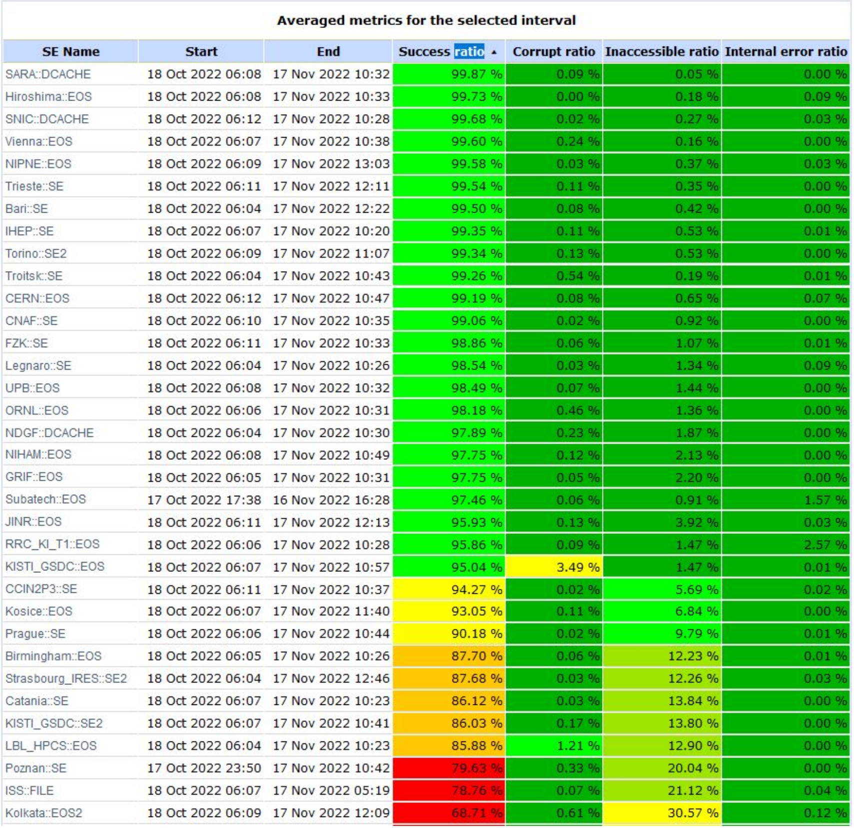
- Checks storage integrity on sites by mimicking normal jobs
- Random files, proportional to the storage size
- Reporting on file health, throughput and accessibility
- Early detection of storage issues



Status codes extracted from the crawler

SE Name: ALICE::HIROSHIMA::EOS **Interval:** Last week

Status Type	Status Code	Status Count	Status Code Ratio	Download throughput
FILE_OK	S_FILE_CHECKSUM_MATCH	26972	99.79 %	21.97 Mb/s
🟩	E_CATALOGUE_MD5_IS_BLANK	2	0.01 %	19.04 Mb/s
INTERNAL_ERROR	XRDFS_CANNOT_CONFIRM_UPLOAD	21	0.08 %	
FILE_INACCESSIBLE	XROOTD_EXITED_WITH_CODE	35	0.13 %	
TOTAL		27030	100 %	



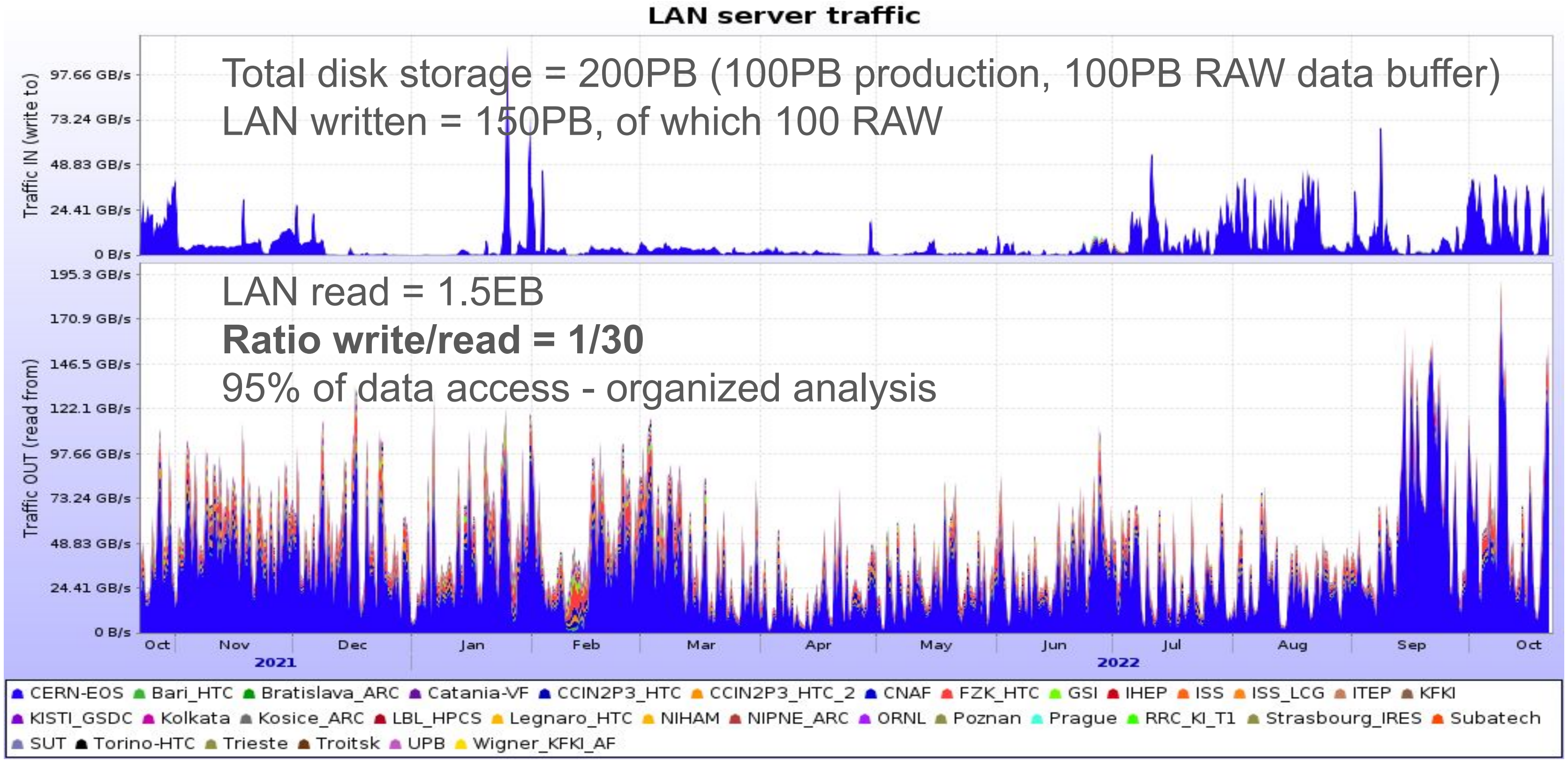
Averaged metrics for the selected interval

SE Name	Start	End	Success ratio ▲	Corrupt ratio	Inaccessible ratio	Internal error ratio
SARA::DCACHE	18 Oct 2022 06:08	17 Nov 2022 10:32	99.87 %	0.09 %	0.05 %	0.00 %
Hiroshima::EOS	18 Oct 2022 06:08	17 Nov 2022 10:33	99.73 %	0.00 %	0.18 %	0.09 %
SNIC::DCACHE	18 Oct 2022 06:12	17 Nov 2022 10:28	99.68 %	0.02 %	0.27 %	0.03 %
Vienna::EOS	18 Oct 2022 06:07	17 Nov 2022 10:38	99.60 %	0.24 %	0.16 %	0.00 %
NIPNE::EOS	18 Oct 2022 06:09	17 Nov 2022 13:03	99.58 %	0.03 %	0.37 %	0.03 %
Trieste::SE	18 Oct 2022 06:11	17 Nov 2022 12:11	99.54 %	0.11 %	0.35 %	0.00 %
Bari::SE	18 Oct 2022 06:04	17 Nov 2022 12:22	99.50 %	0.08 %	0.42 %	0.00 %
IHEP::SE	18 Oct 2022 06:07	17 Nov 2022 10:20	99.35 %	0.11 %	0.53 %	0.01 %
Torino::SE2	18 Oct 2022 06:09	17 Nov 2022 11:07	99.34 %	0.13 %	0.53 %	0.00 %
Troitsk::SE	18 Oct 2022 06:04	17 Nov 2022 10:43	99.26 %	0.54 %	0.19 %	0.01 %
CERN::EOS	18 Oct 2022 06:12	17 Nov 2022 10:47	99.19 %	0.08 %	0.65 %	0.07 %
CNAF::SE	18 Oct 2022 06:10	17 Nov 2022 10:35	99.06 %	0.02 %	0.92 %	0.00 %
FZK::SE	18 Oct 2022 06:11	17 Nov 2022 10:33	98.86 %	0.06 %	1.07 %	0.01 %
Legnaro::SE	18 Oct 2022 06:04	17 Nov 2022 10:26	98.54 %	0.03 %	1.34 %	0.09 %
UPB::EOS	18 Oct 2022 06:08	17 Nov 2022 10:32	98.49 %	0.07 %	1.44 %	0.00 %
ORNL::EOS	18 Oct 2022 06:06	17 Nov 2022 10:31	98.18 %	0.46 %	1.36 %	0.00 %
NDGF::DCACHE	18 Oct 2022 06:04	17 Nov 2022 10:30	97.89 %	0.23 %	1.87 %	0.00 %
NIHAM::EOS	18 Oct 2022 06:08	17 Nov 2022 10:49	97.75 %	0.12 %	2.13 %	0.00 %
GRIF::EOS	18 Oct 2022 06:05	17 Nov 2022 10:31	97.75 %	0.05 %	2.20 %	0.00 %
Subatech::EOS	17 Oct 2022 17:38	16 Nov 2022 16:28	97.46 %	0.06 %	0.91 %	1.57 %
JINR::EOS	18 Oct 2022 06:11	17 Nov 2022 12:13	95.93 %	0.13 %	3.92 %	0.03 %
RRC_KI_T1::EOS	18 Oct 2022 06:06	17 Nov 2022 10:28	95.86 %	0.09 %	1.47 %	2.57 %
KISTI_GSDC::EOS	18 Oct 2022 06:07	17 Nov 2022 10:57	95.04 %	3.49 %	1.47 %	0.01 %
CCIN2P3::SE	18 Oct 2022 06:11	17 Nov 2022 10:37	94.27 %	0.02 %	5.69 %	0.02 %
Kosice::EOS	18 Oct 2022 06:07	17 Nov 2022 11:40	93.05 %	0.11 %	6.84 %	0.00 %
Prague::SE	18 Oct 2022 06:06	17 Nov 2022 10:44	90.18 %	0.02 %	9.79 %	0.01 %
Birmingham::EOS	18 Oct 2022 06:05	17 Nov 2022 10:26	87.70 %	0.06 %	12.23 %	0.01 %
Strasbourg_IRES::SE2	18 Oct 2022 06:04	17 Nov 2022 12:46	87.68 %	0.03 %	12.26 %	0.03 %
Catania::SE	18 Oct 2022 06:07	17 Nov 2022 10:23	86.12 %	0.03 %	13.84 %	0.00 %
KISTI_GSDC::SE2	18 Oct 2022 06:07	17 Nov 2022 10:41	86.03 %	0.17 %	13.80 %	0.00 %
LBL_HPCS::EOS	18 Oct 2022 06:04	17 Nov 2022 10:23	85.88 %	1.21 %	12.90 %	0.00 %
Poznan::SE	17 Oct 2022 23:50	17 Nov 2022 10:42	79.63 %	0.33 %	20.04 %	0.00 %
ISS::FILE	18 Oct 2022 06:07	17 Nov 2022 05:19	78.76 %	0.07 %	21.12 %	0.04 %
Kolkata::EOS2	18 Oct 2022 06:09	17 Nov 2022 12:09	68.71 %	0.61 %	30.57 %	0.12 %

Network and data processing

- Jobs are dispatched to the Grid sites that already have the data
  - Minimizes WAN traffic and RTT efficiency penalty
- Grid site local file access (95%), remote (5%)
  - Remote access due to local SE issues, usually temporary
- Multiple replicas sorted topologically: apps first access local replica, then the next closest
  - Sorting by network topology, availability, network quality, geo-location and other metrics
- Storing multiple replicas
  - One replica is written to the local storage element
  - The other replicas are written to the remote (but close) storage elements
  - Remote writes might go through LHCOPN / LHCONE

Data access - LAN



Total disk storage = 200PB (100PB production, 100PB RAW data buffer)

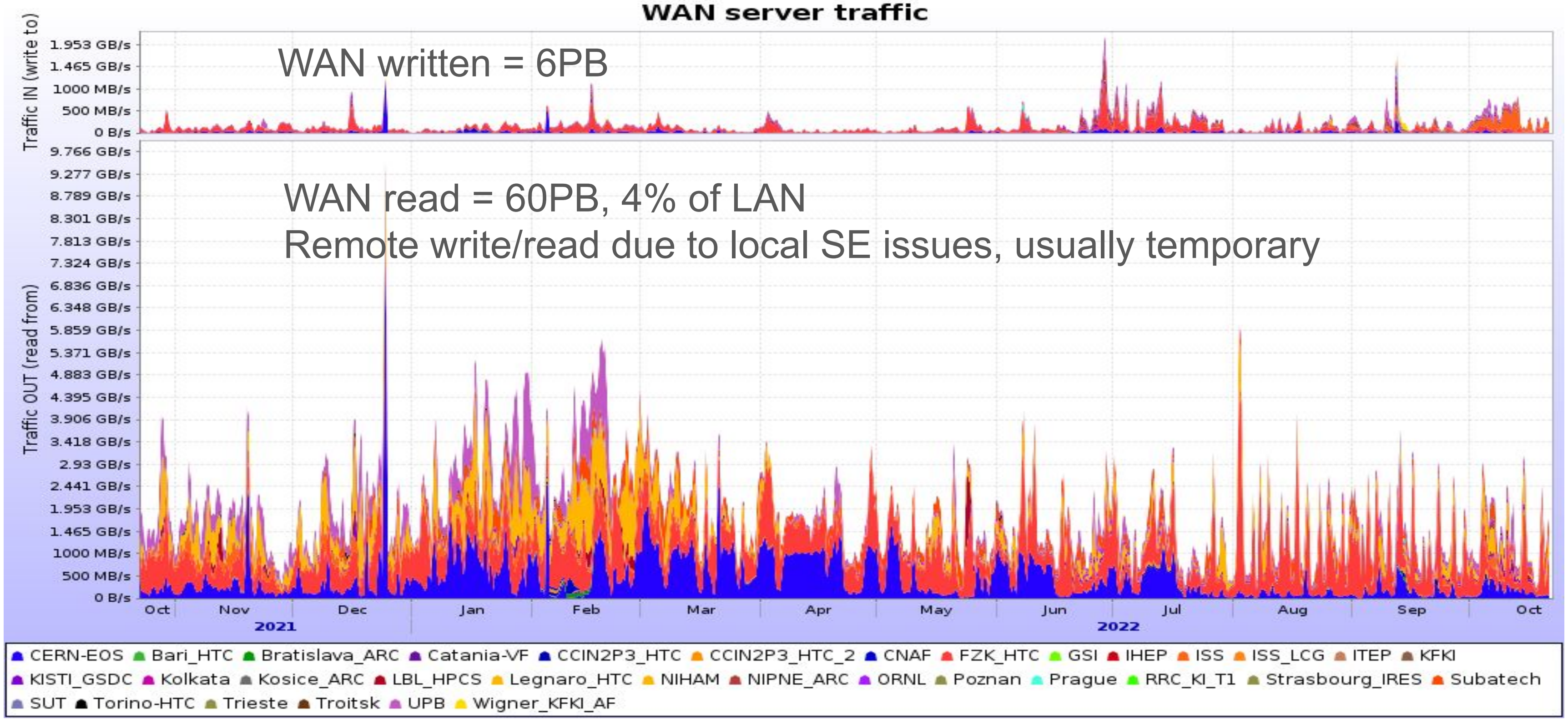
LAN written = 150PB, of which 100 RAW

LAN read = 1.5EB

Ratio write/read = 1/30

95% of data access - organized analysis

Data access - WAN (LHCONE/LHCOPN)



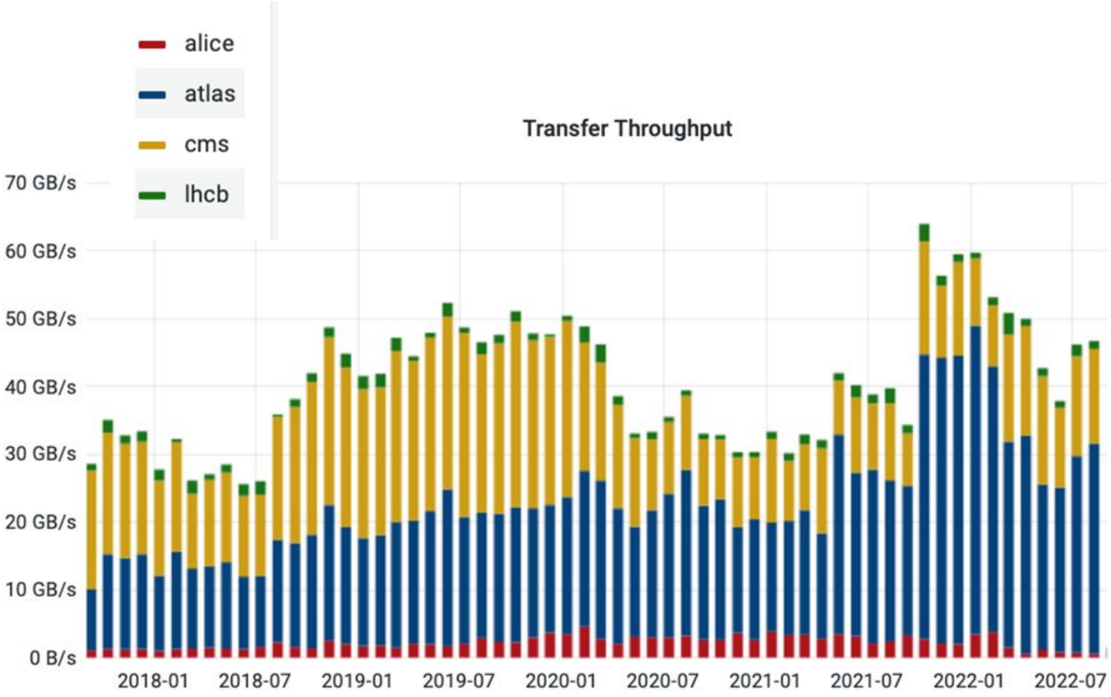
WAN written = 6PB

WAN read = 60PB, 4% of LAN

Remote write/read due to local SE issues, usually temporary

ALICE in the big picture - WLCG data transfers

- Includes RAW data distribution and other LHCONE/LHCOPN transfers
- ALICE computing model and network use is beneficial to remote sites
- Network requirements are mild and well within the capabilities of regional T2s

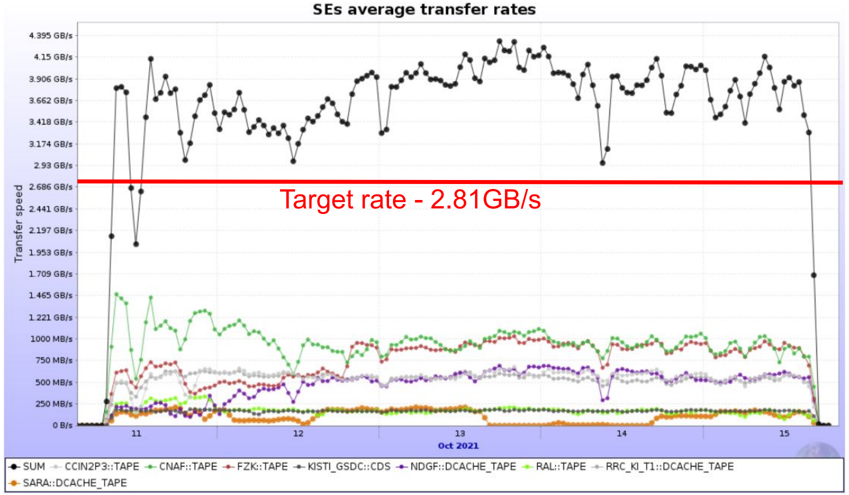


Expected data rates in Run3 - replication of RAW

T1 Centre	Target rate GB/s	Achieved rate GB/s
CNAF	0.8	0.94 (116%)
IN2P3	0.4	0.54 (130%)
KISTI	0.15	0.16 (106%)
GridKA	0.6	0.76 (123%)
NDGF	0.3	0.47 (144%)
NL-T1	0.08	0.1 (122%)
RRC-KI	0.4	0.53 (128%)
RAL	0.08	0.17 (172%)

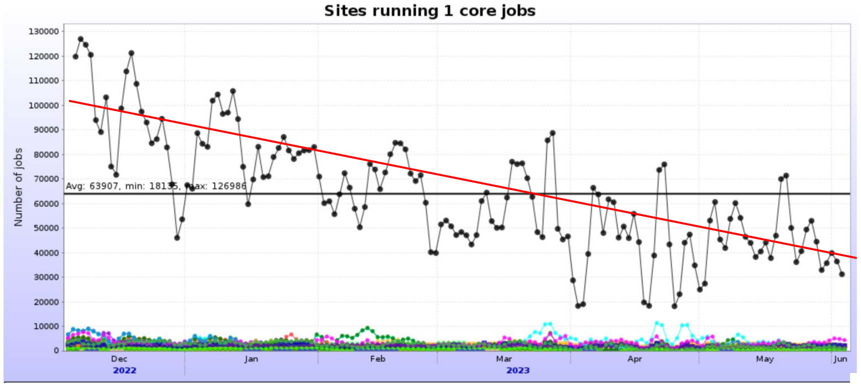
Sum 2.81GB/s

- Full traffic simulated during data challenge
- Channels tuned to slightly above the target rate, within reasonable limit
- The bulk of the bandwidth will be used after the Pb-Pb data taking period, for ~3 months
  - Since there is no Pb-Pb this year, we remain at the level of data challenges



Target rate - 2.81GB/s

Multicore use

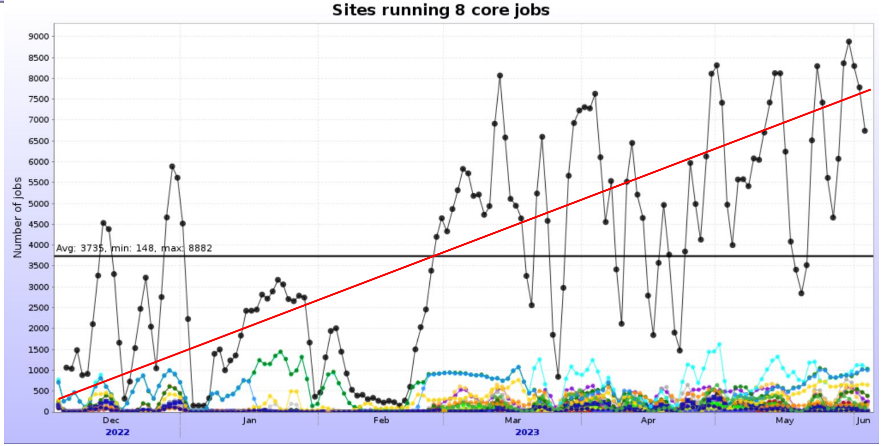


Steady decline of single-core payloads

- Legacy analysis and MC

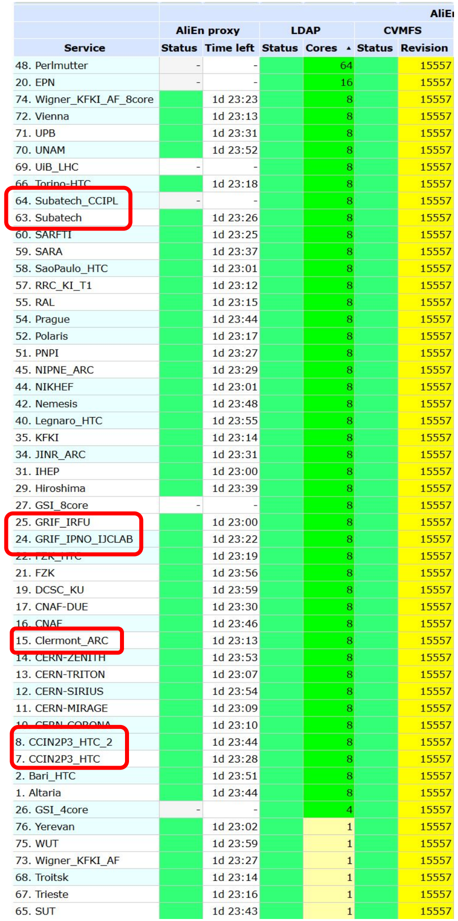
Proportional increase of multicore

- 2022 and 2023 data processing
- MC
- New organized analysis (Hyperloop)



Site upgrade to 8-core

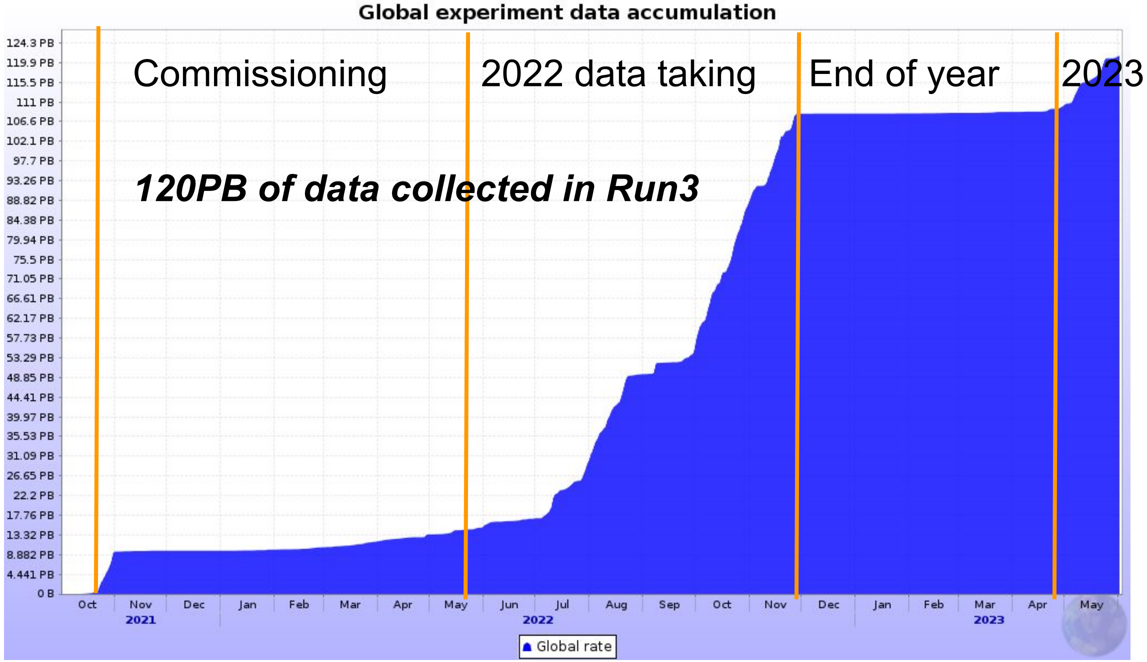
- Site conversion to 8 cores ongoing
  - ~90% of Grid capacity already there
  - 100% of FR sites on 8 core queues
- Good experience with whole node submission
  - Steady running (LBNL Lawrencium, Perlmuter) + ORNL + GridKA (in progress) + KISTI
  - All HPC resources are whole-node, use will expand
  - Possibility to improve job performance
    - ~8% reduction in execution time through optimal NUMA assignment
    - More flexibility with CPU vs. I/O intensive tasks



	AliE					
	AliEn proxy		LDAP		CVMFS	
Service	Status	Time left	Status	Cores ▲	Status	Revision
48. Perlmutter	-	-	🟩	64	🟩	15557
20. EPN	-	-	🟩	16	🟩	15557
74. Wigner_KFKI_AF_8core	🟩	1d 23:23	🟩	8	🟩	15557
72. Vienna	🟩	1d 23:13	🟩	8	🟩	15557
71. UPB	🟩	1d 23:31	🟩	8	🟩	15557
70. UNAM	🟩	1d 23:52	🟩	8	🟩	15557
69. UiB_LHC	-	-	🟩	8	🟩	15557
66. Torino-HTC	🟩	1d 23:18	🟩	8	🟩	15557
64. Subatech_CCIPL	-	-	🟩	8	🟩	15557
63. Subatech	🟩	1d 23:26	🟩	8	🟩	15557
60. SARFTI	🟩	1d 23:25	🟩	8	🟩	15557
59. SARA	🟩	1d 23:37	🟩	8	🟩	15557
58. SaoPaulo_HTC	🟩	1d 23:01	🟩	8	🟩	15557
57. RRC_KI_T1	🟩	1d 23:12	🟩	8	🟩	15557
55. RAL	🟩	1d 23:15	🟩	8	🟩	15557
54. Prague	🟩	1d 23:44	🟩	8	🟩	15557
52. Polaris	🟩	1d 23:17	🟩	8	🟩	15557
51. PNPI	🟩	1d 23:27	🟩	8	🟩	15557
45. NIPNE_ARC	🟩	1d 23:29	🟩	8	🟩	15557
44. NIKHEF	🟩	1d 23:01	🟩	8	🟩	15557
42. Nemesis	🟩	1d 23:48	🟩	8	🟩	15557
40. Legnaro_HTC	🟩	1d 23:55	🟩	8	🟩	15557
35. KFKI	🟩	1d 23:14	🟩	8	🟩	15557
34. JINR_ARC	🟩	1d 23:31	🟩	8	🟩	15557
31. IHEP	🟩	1d 23:00	🟩	8	🟩	15557
29. Hiroshima	🟩	1d 23:39	🟩	8	🟩	15557
27. GSI_8core	-	-	🟩	8	🟩	15557
25. GRIF_IRFU	🟩	1d 23:00	🟩	8	🟩	15557
24. GRIF_IPNO_IJCLAB	🟩	1d 23:22	🟩	8	🟩	15557
22. FZK_HTC	🟩	1d 23:19	🟩	8	🟩	15557
21. FZK	🟩	1d 23:56	🟩	8	🟩	15557
19. DCSC_KU	🟩	1d 23:59	🟩	8	🟩	15557
17. CNAF-DUE	🟩	1d 23:30	🟩	8	🟩	15557
16. CNAF	🟩	1d 23:46	🟩	8	🟩	15557
15. Clermont_ARC	🟩	1d 23:13	🟩	8	🟩	15557
14. CERN-ZENITH	🟩	1d 23:53	🟩	8	🟩	15557
13. CERN-TRITON	🟩	1d 23:07	🟩	8	🟩	15557
12. CERN-SIRIUS	🟩	1d 23:54	🟩	8	🟩	15557
11. CERN-MIRAGE	🟩	1d 23:09	🟩	8	🟩	15557
10. CERN-CORONA	🟩	1d 23:10	🟩	8	🟩	15557
8. CCIN2P3_HTC_2	🟩	1d 23:44	🟩	8	🟩	15557
7. CCIN2P3_HTC	🟩	1d 23:28	🟩	8	🟩	15557
2. Bari_HTC	🟩	1d 23:51	🟩	8	🟩	15557
1. Altaria	🟩	1d 23:44	🟩	8	🟩	15557
26. GSI_4core	-	-	🟩	4	🟩	15557
76. Yerevan	🟩	1d 23:02	🟩	1	🟩	15557
75. WUT	🟩	1d 23:59	🟩	1	🟩	15557
73. Wigner_KFKI_AF	🟩	1d 23:27	🟩	1	🟩	15557
68. Troitsk	🟩	1d 23:14	🟩	1	🟩	15557
67. Trieste	🟩	1d 23:16	🟩	1	🟩	15557
65. SUT	🟩	1d 23:43	🟩	1	🟩	15557

2022 + 2023 data collection and processing

- After a period of detector commissioning in 2021-2022
- Steady p-p data taking in 2022
- Dec 2022 to Apr 2023 - calibration and processing, followed by skimming
- 2023 has started well and is the first year with Pb-Pb beam (looking forward to it)


Commissioning

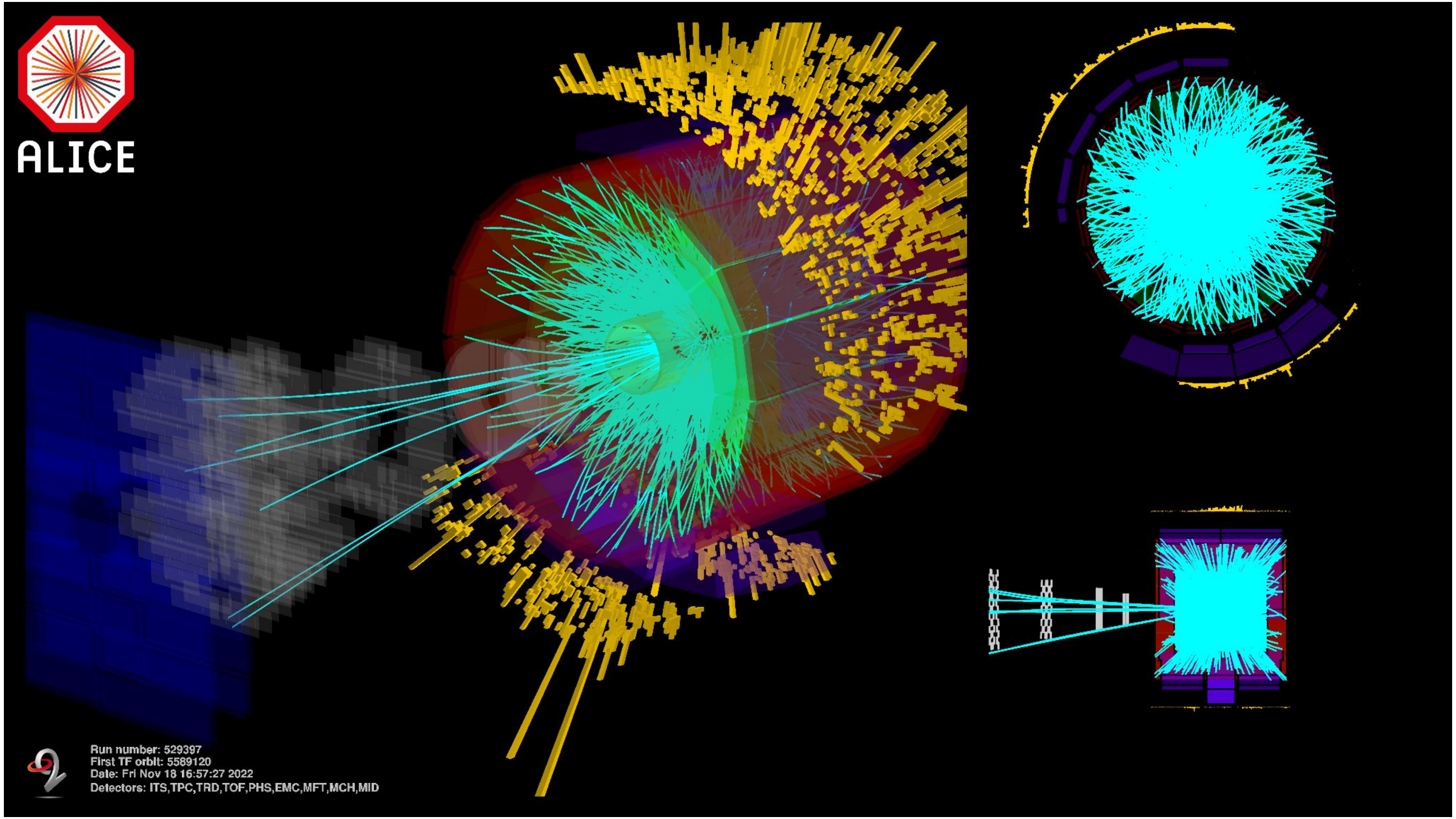
2022 data taking

End of year

2023

120PB of data collected in Run3

Event from 18 Nov 2022, low IR Pb-Pb@5.36TeV



Run number: 529397
First TF orbit: 5589120
Date: Fri Nov 18 16:57:27 2022
Detectors: ITS,TPC,TRD,TOF,PHS,EMC,MFT,MCH,MID

Summary

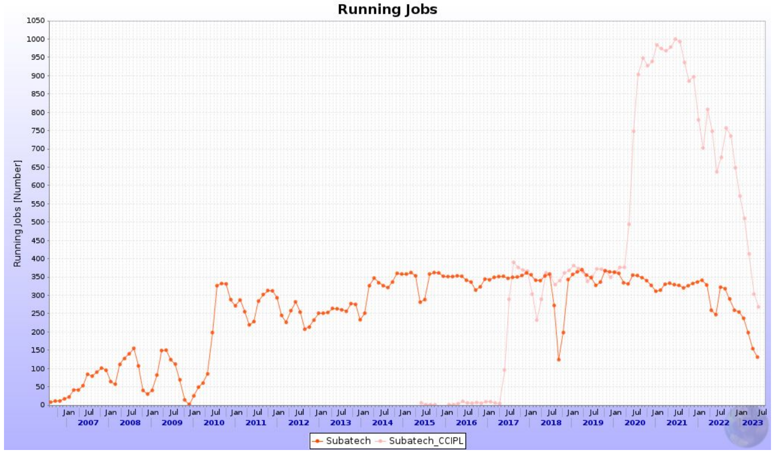
- During the LHC shutdown ALICE upgraded the detector and entire software stack
- Change of physics focus, triggerless readout, up to 100x event rate
  - Requires online compression and offline filtering
  - To stay within the resources envelope of WLCG
  - Steady data taking and processing since start of Run3 (2022 onward)
- New O2 software - multiprocess/shared memory, multicore
- New central GRID software
  - Entirely rewritten in Java
- JAliEn keeps the logic and functionality of AliEn
  - It is faster and simpler to deploy and operate
  - Much easier to maintain and to add new features
  - Incorporated support for GPUs and HPCs
- Site operation is simplified and made more reliable
  - Lowers the threshold for new sites joining (not the current trend…)

Thank you!

- To the entire French GRID community for the excellent and steady support

- ***Farewell to Subatech as GRID site***
- Special thanks to the team and especially to ***Jean-Michel Barbet***

- In the ALICE Grid since the start of operation many years ago…
- One of the first sites to adopt, test and debug new software or principles of operation
- We are very sorry to see it go… and wish JM Happy Trails!


Running Jobs
Running Jobs [Number]
Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul Jan Jul
Subatech
Subatech_CCIPL