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Computing Resources Scrutiny Group

R Aaij (The Netherlands), J Amundson (US), L Del Debbio (UK), K Dziedziniewicz (CERN, scientific secretary), D Elia (Italy), E Fede (France), D Gingrich (Canada), T Hartmann (Germany), J M Hernández (Spain, chair), J Kleist (Nordic countries), M Schulz (CERN)

1 Introduction

The Computing Resources Scrutiny Group (C-RSG) is responsible for evaluating the computing needs of the Large Hadron Collider (LHC) experiments, ALICE, ATLAS, CMS and LHCb, and providing recommendations to the Computing Resources Review Board (C-RRB) on the Worldwide LHC Computing Grid (WLCG) resources required by the Collaborations to support their approved physics programmes. The C-RSG has completed its Spring 2026 review, which evaluated computing resource usage in the calendar year 2025 and the final computing resource requests for 2027. This report summarizes the findings of this review and the recommendations for the experiments.

The C-RSG requested reports from each Collaboration detailing their computing resource utilization in 2025, anticipated usage in 2026, and proposed resource needs for 2027. These reports also addressed the recommendations issued following the most recent scrutiny in Autumn 2025 [1].

After reviewing the reports, the C-RSG submitted questions to each Collaboration to clarify specific points. Dedicated meetings were then held with Collaboration representatives, providing an opportunity for further discussion. These face-to-face meetings allowed the C-RSG to gain a well-informed understanding of the experiments' computing requirements.

The C-RSG also had an informal meeting with the LHCC WLCG referees on March 26th, 2026. This meeting allowed the LHCC and the C-RSG to confer on areas of common interest related to computer resources and utilization. Although the mandates of the two groups are different, the overlap in the evaluation and oversight of computing resources made for a helpful and informative discussion. The C-RSG thanks the LHCC referees for their participation in this discussion.

The C-RSG recommendations for 2027 resource provisioning by WLCG are provided in this report. They are based on the LHC schedule for 2026 and 2027 [2].

2 C-RSG Membership

The Spring 2026 scrutiny marked the first meeting in which Thomas Hartmann (DESY) represented the German funding agencies, succeeding Tigran Mkrtchyan (DESY). The C-RSG extends its sincere gratitude to Tigran for his many years of dedicated and highly valued contributions to the C-RSG and WLCG.

The chair thanks the C-RSG members for their commitment and expert advice.

The group sincerely appreciates the efforts of the Collaboration representatives in supporting the scrutiny process and addressing its previous recommendations.

3 Interactions with the Experiment Collaborations

All Collaborations submitted their reports by 10th February 2026. The C-RSG thanks the Collaborations for the timely submission of their detailed documents [3–7], which also contained responses to the findings and recommendations from the Autumn 2025 scrutiny round [1]. The group thanks the computing representatives of the Collaborations for their availability, their constructive responses to the questions raised by the C-RSG and responses to subsequent requests for further information. The dedicated meetings with experiment representatives were particularly helpful and greatly appreciated by the C-RSG.

Dedicated teams of C-RSG referees were assigned to review the ALICE and LHCb requests. As in previous years, and in agreement with the ATLAS and CMS managements, a single team of referees scrutinized the ATLAS and CMS reports and requests to ensure a consistent evaluation. The referees then presented their findings to the full C-RSG, which collectively developed the observations and recommendations outlined in this report. In preparation for the Autumn 2026 scrutiny, the C-RSG requests that the experiments submit their documents by Tuesday, September 1, 2026.

The C-RSG asks that the reports include the preliminary computing resource requirements for 2028 and that the Collaborations address both the general recommendations and those specific to their experiments as part of their submission.

4 Resource Usage in Calendar Year 2025

The C-RSG requested that the Collaborations provide a summary of their computing resource usage from January to December 2025. The 2025 data-taking year was highly successful for all experiments, with the LHC delivering record-breaking numbers of proton-proton (p-p) and lead-lead (Pb-Pb) collisions in a single year. The LHC also provided for the first time collisions between pairs of oxygen and neon nuclei, and between oxygen nuclei and protons. During an intensive 11-day campaign, experiments took full advantage of this short but valuable opportunity to study the formation of quark–gluon plasma in the largely unexplored regime of light-ion collisions. Despite the limited running time, the luminosity goals were exceeded by significant margins, thanks to the excellent availability of the accelerator complex and the high injector performance delivered by the LHC team.

Table 1 summarizes the RRB's approved baseline resource levels for 2025, categorized by tier level and resource type. The approved CPU power is close to 13 MHS23, while disk capacity exceeds 1.2 exabyte, and tape capacity approaches 2.5 exabytes.

	CPU [kHS23]	Disk [PB]	Tape [PB]	CPU [%]	Disk [%]	Tape [%]
Tier0	3243	259	1090	25%	21%	45%
Tier1	4353	497	1324	34%	40%	55%
Tier2	5146	496		40%	40%	
Total	12742	1252	2414	100%	100%	100%

Table 1 Baseline computing resource capacities approved by the RRB for WLCG sites in 2025. The last three columns represent the share of resources across the tier levels.

Table 2 shows the balance (in percentage) between the RRB's approved CPU, disk and tape resources for 2025 and those pledged by various funding agencies for each experiment, broken down by tier level. The data have been extracted from the WLCG CRIC information system [8].

With the exception of the Tier0, which provided exactly the approved resource levels, experiments faced moderate resource shortfalls at the Tier1 and Tier2 levels. The situation follows the same pattern as in recent years.

		ATLAS	CMS	ALICE	LHCb
Tier0	CPU	0	0	0	0
	Disk	0	0	0	0
	Tape	0	0	0	0
Tier1	CPU	0	6	-14	-8
	Disk	0	-6	-12	-1
	Tape	1	-8	-5	-7
Tier2	CPU	15	-4	3	3
	Disk	-4	-9	7	-13

Table 2 Balance (in percentage) between pledged and RRB-approved computing resources for 2025. Numbers in red highlight a shortfall in pledged resources, while numbers in green indicate a surplus.

The Collaborations efficiently utilized their allocated computing resources for processing, simulation and analysis of the collected data. Table 3 summarizes the CPU utilization, and Table 4 shows the CPU used by each of the experiments at the different tier levels, compared with the RRB's approved baseline values.

	RRB approved	WLCG used	WLCG / RRB	HLT used	HPC used	Total used	Total required	Total used / Total required
ATLAS	4626	6857	1.48	257	1399	8513	6526	1.30
CMS	4013	6296	1.57	434	554	7284	4363	1.67
ALICE	2045	2770	1.35	508	133	3411	2553	1.34
LHCb	1601	1764	1.10	688	76	2528	1701	1.49
Total	12284	17687	1.44	1887	2162	21736	15142	1.44

Table 3 CPU usage (in kHS23 years) per experiment from the different sources (WLCG, HLT, and HPC). The table also shows the RRB-approved baseline CPU for WLCG sites, calculated as a weighted average of the 2024 values (corresponding to the January–March 2025 period) and the 2025 values (corresponding to the April–December 2025 period). Total CPU requirements of the experiments, defined as the sum of the WLCG baseline and the expected contributions from HLT and HPC resources taken into account in the experiments' resource planning, are also shown.

	Tier0			Tier1			Tier2		
	Used	RRB	Used/RRB	Used	RRB	Used/RRB	Used	RRB	Used/RRB
ATLAS	1019	1059	0.96	1760	1605	1.10	4078	1962	2.08
CMS	1730	1130	1.53	1606	1058	1.52	2960	1825	1.62
ALICE	1149	660	1.74	696	675	1.03	925	710	1.30
LHCb	418	256	1.63	1024	839	1.22	322	468	0.69
Total	4316	3105	1.39	5086	4177	1.22	8285	4965	1.67

Table 4 CPU usage (in kHS23 years) by experiment and tier level in 2025, compared with the RRB-approved baseline values.

In 2025, total CPU usage reached 21.7 MHS23 years, marking an 11% increase compared to 2024. Experiments effectively leveraged CPU resources beyond pledged capacities, including idle time on High Level Trigger (HLT) farms (the O2 Event Processing Nodes (EPN) in the case of ALICE), additional availability at WLCG sites, and allocations at High Performance Computing (HPC) facilities. WLCG sites accounted for 81% of the total CPU consumption, with HLT/EPN farms contributing 9% and HPC facilities providing the remaining 10%.

WLCG sites provided close to 17.7 MHS23 years of CPU work, corresponding to 44% more CPU than the 12.3 MHS23 years baseline capacity approved by the RRB for 2025. It is worth noting that the experiments had accounted for the expected CPU contributions from HLT farms and HPC centres (2.8 MHS23 years in total) in their resource planning, thereby reducing the CPU requested from WLCG sites. Taking this into account, the CPU usage exceeded the experiments' total requirements by 44%, with 21.7 MHS23 years used compared to total requirements of 15.1 MHS23 years.

Figure 4 illustrates the annual CPU utilization of the experiments since 2017, highlighting individual contributions from WLCG sites, HLT farms and HPC facilities. The dashed black line represents the RRB-approved baseline CPU capacity for WLCG sites, while the blue line shows the experiments' CPU requirements, taking into account the expected contributions from HLT farms and HPC facilities in the resource planning. The significant contributions of CPU from the experiments' online farms and HPC facilities are evident, along with the over-pledged CPU provided by the WLCG sites.

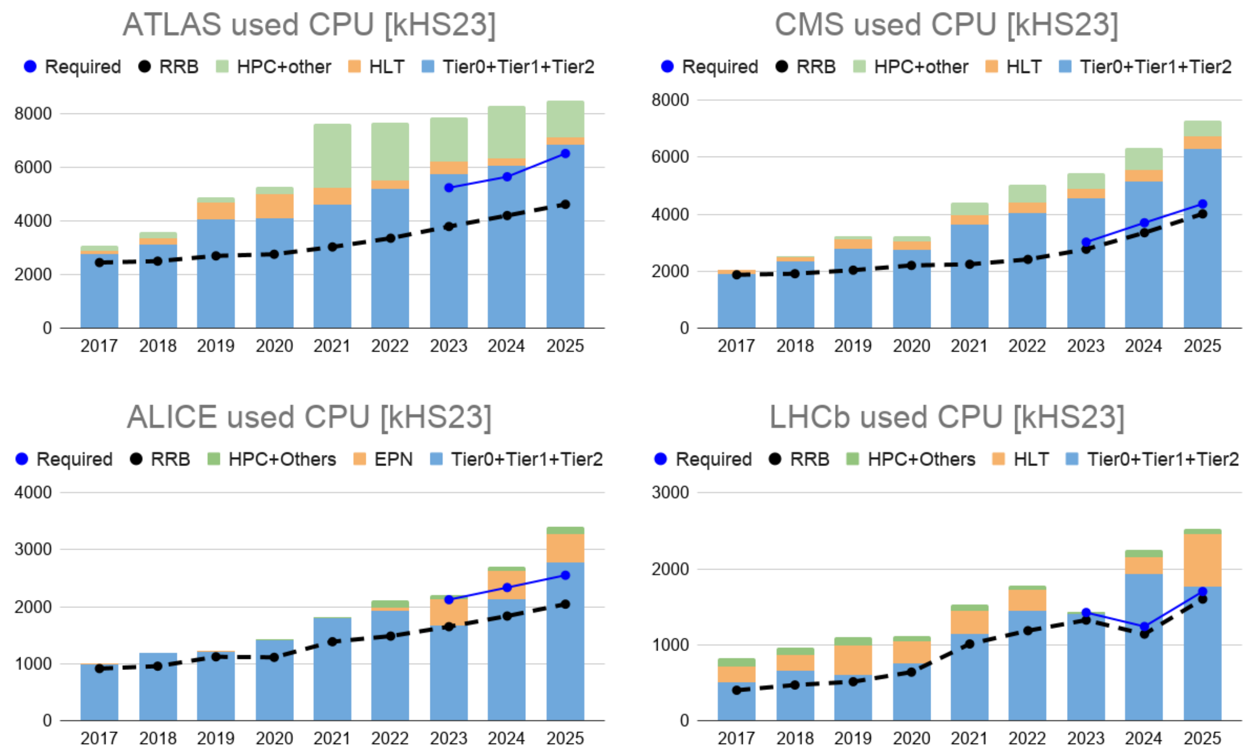

Figure 1 Annual CPU utilization of the experiments (in units of kHS23 years) with contributions from WLCG sites, HLT farms and HPC facilities stacked. The black dashed line represents the RRB's approved CPU baseline capacities for WLCG sites. The blue line shows the total experiments' CPU requirements anticipated in the resource planning.

Experiments utilized most of the non-pledged CPU resources to extend their Monte Carlo (MC) simulations, enhancing statistical precision and reducing systematic uncertainties in various physics analyses. The CMS experiment used part of these resources to promptly reconstruct parking data streams before archiving them to tape. ALICE used the EPN farm for calibration and data reprocessing.

Disk storage capacity grew by 20% from 1046 PB in 2024 to 1252 PB in 2025, while tape storage increased from 1897 PB to 2414 PB during the same period. Tier0 and Tier1 tape storage increased by 32% and 23%, respectively, reflecting the increase in Run-3 recorded raw data. Disk and tape utilization are adequate when considering the headroom required to effectively manage large data volumes.

Disk storage is the most expensive infrastructure component at WLCG sites. To optimise its use, the experiments aim to keep only frequently accessed data on disk. Accurate monitoring of disk usage and effective procedures for removing cold data are therefore essential for efficient resource management. The C-RSG has issued recommendations in this area in previous reports.

ATLAS stands out as the experiment with the most effective disk data management. Its procedures include detailed monitoring of data access patterns, the use of large and dynamic disk caches with automated eviction of unused data, and agile data placement policies that limit the lifetime of inactive datasets on disk. ATLAS reports that the fraction of cold data not accessed for 12 months is about 4% in the persistent and temporary disk areas, and only 0.4% in the large 100 PB disk cache. Persistent data is pinned on disk, temporary data is held while being processed but scheduled for later deletion, and cached data is used to optimise job brokering and can be removed when space is needed. We congratulate ATLAS on its excellent disk data management practices.

The other three LHC experiments perform significantly less well in the management of unaccessed data on disk. ALICE reports that 16% of its disk data has not been accessed for 12 months, while the corresponding figures for LHCb and CMS are 21% and 23%, respectively.

ALICE notes that the current level of cold data is affected by the transition from Run 2 to the Run 3 data format, during which some Run 2 datasets may appear less frequently accessed as analyses migrate to the new format. CMS currently lacks accurate monitoring of remote data access, and therefore, its reported level of cold data should be considered an upper limit.

The C-RSG will issue recommendations to ALICE, LHCb and CMS to encourage the adoption of best practices similar to those successfully implemented by ATLAS, and to enable more timely and effective data lifecycle management.

The Collaborations report significant progress in adapting their software applications for execution on GPUs, which offer a better performance-to-cost ratio than conventional CPUs for suitable workloads. However, not all algorithms can be efficiently ported to GPUs, making a hybrid approach, where applications run on CPUs while specific workloads are offloaded to GPUs, the most practical model. In addition, GPUs are becoming increasingly prevalent in large HPC facilities, making their adoption essential to fully exploit these potentially vast resources.

At a recent WLCG workshop on heterogeneous resources [9], the experiments reported substantial progress in porting software to GPUs, including MC event generation, Geant4 simulation, and reconstruction. However, no experiment is yet in a position to request or accept formal GPU resource pledges from WLCG federations.

Several key questions remain open, including the fraction of processing that can realistically be offloaded to GPUs, memory and CPU-to-GPU ratio requirements, optimal GPU deployment models, floating-point precision requirements, and other architectural considerations. Workflow management systems may also need to evolve to enable efficient co-scheduling of CPU and GPU workloads. Progress in these areas is expected between now and the start of Run 4.

A more detailed description of the computing resource utilization by the experiments in 2025 is provided in the following sections.

5 Resource Usage: ALICE

The report on the ALICE Collaboration's use of computing resources is based on the usage data and resource request provided by the ALICE experiment [3], a written set of responses to the C-RSG scrutiny questions, and a face-to-face meeting with the ALICE computing and physics coordinators. The ALICE report details the computing resources used from January to December 2025 and is summarised in Table 5. We thank the ALICE team for their willingness to provide additional information on request, some of this information had been already requested before. It would be appreciated if more detailed information and explanations could be incorporated in future reports, reducing the effort on both sides.

ALICE		2025				
		RRB approved	Pledged	Pledged / RRB	Used	Used / RRB
CPU	Tier0	680	680	100%	1149	169%
	Tier1	690	596	86%	696	101%
	Tier2	730	750	103%	925	127%
	Total	**2100**	**2026**	**96%**	**2770**	**132%**
	*EPN**				*508*	*38%*
	*Others**				*133.1*	*6%*
Disk	Tier0	78.0	78.0	100%	74.0	95%
	Tier1	79.0	69.1	87%	64.4	82%
	Tier2	77.0	82.5	107%	79.5	103%
	Total	**234**	**229.6**	**98%**	**217.9**	**93%**
Tape	Tier0	220.0	220.0	100%	196.7	89%
	Tier1	123.0	117.4	95%	100.8	82%
	Total	**343.0**	**337.4**	**98%**	**297.5**	**87%**

*: Percentage taken with respect to the total RRB approved CPU recommendation

Table 5 Summary of ALICE resource usage in 2025 and the comparison with RRB-approved and pledged resources. The CPU and storage resources are in units of kHS23 years and PB, respectively.

5.1 Data Taking and Processing

ALICE data taking during 2025 started with the first p-p data taking run from April 22nd to the beginning of the Technical Stop (TS) on June 18th. In this period, 10.2 pb^{-1} were recorded, corresponding to a data taking efficiency of 92%. After the TS and a run with light ions, proton-proton data were taken under different machine and experiment conditions, including a run with high interaction rates, testing the throughput of the DAQ system, and a low-field production phase with the intention to increase the reconstruction efficiency for low-momentum electrons and positrons. By the end of the 2025 pp programme, a total of more than 50 pb $^{-1}$ had been recorded, with an overall recording efficiency of 90%. In total, 192 PB of p-p compressed raw data have been recorded. Skimming reduced this to about 4.65% or 9 PB.

The second distinct campaign was dedicated to proton-oxygen (p-O), oxygen-oxygen (O-O) and neon-neon (Ne-Ne) collisions. The luminosity delivered exceeded the target, and with high efficiency, 0.33 PB, 1.8 PB, and 0.5 PB were recorded.

The Pb-Pb phase started on November 14th. To reduce losses due to space-charge fluctuations and field cage instabilities, the interaction rate was lowered to 23 kHz, roughly half of the rate in 2024. This increased stability and the resulting loss of integrated luminosity was limited to 30%. Out of the delivered 2090.9 μb^{-1}, 1989.8 μb^{-1} were recorded with an efficiency of 95%, corresponding to 50 PB.

Some data from 2022-2024 was reprocessed at the beginning of 2025. Work on the 2023 data could be finalised by May, and the AO2D samples for long-term physics analysis were produced. Throughout the year, calibration and reconstruction of the 2024 Pb-Pb run took place, in parallel with the processing of data recorded during the year. The final processing of the 2024 Pb-Pb data required a large fraction of the resources in 2025, encountering several technical challenges, mostly related to TPC distortions and the migration of data out of the disk buffer. Data taken with a reduced interaction rate showed a significant improvement in data quality.

First passes of the 2025 pp data have been completed. For the Light Ion datasets, the asynchronous processing has been completed by August. The work on the 2025 Pb-Pb started towards the end of the year.

The increased quality of the calibration mandated the production of MC data with high statistics. For p-p collisions, most of the effort was dedicated to 2023, 2024 and 2025 datasets. Combined, 36.79 billion events have been produced. For the 2023 and 2024 Pb-Pb runs, 550 million events, plus 12.4 million events for the low-energy period, have been produced. The creation of the 2025 MC data has started.

5.2 Resource Utilisation

JINR continued to pledge resources as a Tier2, however, due to uncertainties, these are used only opportunistically. JINR provided 1.5 PB of disk and 25 kHS23 of CPU. Resource losses at the other Russian sites amounted to 5.7 PB tape, 6.0 PB disk and 45.8 kHS23. It has to be noted that a potential loss of the JINR resources would not impact the core physics programme of ALICE.

Tape Usage Due to better than expected running conditions and the Light-Ion runs adding 3.68 PB, the data volume on tape increased to 323 PB. ALICE decided to keep two copies of the Light-Ion data. The Pb-Pb dataset was smaller than expected and required 26 PB less than estimated. Additional data archiving campaigns and moving data from the O2 disks required additional space. In 2026, ALICE will take data with an interaction rate of only 23 kHz, which will lead to a reduced need for tape storage.

Out of the 220 PB of Tier0 tape RRB-approved and pledged, ALICE used 89%. At the Tier1 sites, the RRB approved 123.0 PB and 117.4 were pledged, of which ALICE used 100.8 PB. Overall, the pledged tape remained with 337.4 PB, slightly below the approved 343.0 PB. With 297.5 PB tape usage, ALICE stayed well below the provided resources. These figures reflect the situation at the end of 2025. At the time of writing, ALICE has recorded 323 PB, 214 PB at the Tier0 and 109 PB at the Tier1s.

Disk Usage At all tiers, more disk space has been installed than pledged. For the Tier0 and Tier1s, the difference was relatively small. The Tier2s provided 91.54 PB out of which ALICE used 79.5 PB, which corresponds to 83% of the RRB-approved request. At the Tier0, 95% of the disk space has been utilised. At the Tier1s, the pledges have been at the 87% level of the approved capacity, and ALICE stayed with 64.4 PB, significantly below the pledged 69.1 PB. With 82.5 PB, the T2s pledged more disk space than recommended by the RRB, exceeding ALICE's use of 79.5 PB. ALICE reported on the data on disk not accessed for at least 12 months. The total space occupied by such data was 34 PB, corresponding to 16% of the overall data volume stored on disk. ALICE reported, on request, that 18 PB of legacy data have been identified for deletion in 2026. There are also plans to archive legacy ESD/AOD/MCAOD data in 2026. Concerning disk allocations, 35% of the space was dedicated to simulation samples, 60% to reconstruction datasets, and 5% was used for analysis data.

CPU Usage As shown in Table 5, the pledged resources for the Tier0 and the Tier2s have been very close to those approved by the RRB. The Tier1s pledged 86% of the approved CPU capacity. The CPU resources at the WLCG sites used by ALICE exceeded, at all tiers, the requests by a large margin. In total, 138% of the recommended CPU resources have been used, corresponding to 2770 kHS23 years.

In addition, the O2 Event Processing Nodes (EPN) contributed 508 kHS23 years in form of CPUs and GPUs, and other, non-pledged, resources provided an additional 133.1 kHS23 years. In total, ALICE used 162% of the CPU resources approved by the RRB.

The CPU efficiencies achieved have improved again, reaching now 88% at the Tier0, 81% at the Tier1s and 74% at the Tier2s. The overall wall time spent by failed jobs was 6.7% of the total wall time. Figure 3.4 of the ALICE report illustrates the CPU resource usage by the main workflows over the year. Like in 2024, the utilisation of the resources has not been continuous. There has been a significant reduction in all activities in June, caused by an issue related to the MC simulations, which required technical intervention.

CPU usage was distributed as follows: 54% for simulation, 26% for event reconstruction, and 20% for data analysis.

6 Resource Usage: ATLAS

The computing usage report of the ATLAS Collaboration is based on the information provided by the experiment [4], written responses to questions by the C-RSG, and a face-to-face meeting with the ATLAS computing coordinators.

ATLAS		2025				
		RRB approved	Pledged	Pledged / RRB	Used	Used / RRB
CPU	Tier0	1100	1100	100%	1019	93%
	Tier1	1635	1639	100%	1760	108%
	Tier2	1998	2297	115%	4078	204%
	Total	**4733**	**5036**	**106%**	**6857**	**145%**
	*HLT**				*257*	*5%*
	Others*				*1399*	*30%*
Disk	Tier0	56.0	56.0	100%	51.2	91%
	Tier1	186.0	186.7	100%	194.0	104%
	Tier2	227.0	218.9	96%	191.0	84%
	Total	**469.0**	**461.6**	**98%**	**436.2**	**93%**
Tape	Tier0	258.0	258.0	100%	268.0	104%
	Tier1	561.0	567.6	101%	560.0	100%
	Total	**819.0**	**825.6**	**101%**	**828.0**	**101%**

*: Percentage taken with respect to the total RRB approved CPU recommendation

Table 6 Summary of planned and used resources for ATLAS in the calendar year 2025. The CPU and storage resources are in units of kHS23 years and PB, respectively.

6.1 Overview of Activities

During 2025 ATLAS recorded 119 fb^{-1} of proton-proton collision data allowing to cumulate more than 500 fb^{-1} since the start of LHC. Early July proton-Oxygen, Oxygen-Oxygen and Neon-Neon collisions were recorded for the first time.

Data processing was correspondingly intensive, with prompt reconstruction at the Tier0 operating at full capacity during beam time, ensuring rapid availability of data for calibration and analysis. A substantial fraction of Tier0 resources was devoted to reconstruction and data handling, while the remainder supported calibration and alignment workflows essential for physics results. During periods without beam, Tier0 resources were efficiently reused for offline processing, contributing to MC production and other workflows.

The computing resources were fully and successfully utilised for Run 2 and Run 3 data (MC simulation, physics analysis) to ensure the best possible physics results.

By the end of 2025, the ATLAS Collaboration had published more than 1400 papers, some of which already included results based on 2024 data.

CPU Usage ATLAS consumed about 8.45 MHS23 years of CPU resources, representing a slight increase compared to 2024, with an overall CPU efficiency of around 84% across all resource types. All pledged resources were fully utilised, and ATLAS made extensive use of additional, non-pledged resources. In particular, the Tier0, Tier1 and Tier2 sites together provided about 136% of their pledged CPU capacity. Furthermore, opportunistic resources such as HPC systems, the HLT farm, and volunteer computing contributed roughly 25% of the total computing power used during the year.

A large fraction of resources was devoted to MC production, including event generation, simulation (both full and fast), and reconstruction. In addition, group production of analysis formats (DAODs) was the single largest consumer of compute resources in 2025, while user analysis accounted for about 12% of total CPU usage. Data processing at the Tier0, including prompt reconstruction and calibration, remained at a level comparable to previous years.

Data Usage Disk storage was also heavily utilised throughout the year. ATLAS maintained disk usage close to capacity, with active management through data deletion and replication policies to ensure sufficient operational headroom. The disk space was dominated by analysis-ready formats (DAODs) and reconstructed data (AODs), reflecting the needs of physics analysis. Despite continuous data taking, total disk usage remained relatively stable in the second half of the year due to efficient data management and replacement of older datasets.

ATLAS demonstrates a strong level of efficiency in managing cold data on disk through well-defined data lifecycle policies and continuous monitoring. While a sizeable fraction of disk-resident data may appear unaccessed over short time periods, detailed analysis shows that truly unused data, especially data that has remained on disk for more than a year, is relatively small.

Tape Storage Tape storage usage increased significantly, driven by the accumulation of new collision data and MC samples. At the CERN Tier0, tape occupancy grew substantially, with large contributions from 2025 proton–proton and heavy-ion data. Tier1 tape storage also expanded steadily, with about 120 PB of data written during the year. In addition to pledged tape at Tier0 and Tier1s, ATLAS also began exploiting opportunistic tape resources at Tier2 sites, storing on the order of 20 PB of additional replicas (mainly MC datasets), which is reported to have helped relieve pressure on Tier1 storage and support production workflows.

Data Transfer Activities Data transfers formed a major component of operations, with about half of all transfers related to production input staging and a significant fraction due to analysis activity. Efficient data management systems ensured that most data access occurred locally within sites, reducing the need for wide-area transfers and improving overall efficiency.

7 Resource Usage: CMS

The computing usage report of the CMS Collaboration is based on the information provided by the experiment [5], written responses to questions by the C-RSG and a face-to-face meeting with the CMS computing coordinators.

CMS		2025				
		RRB approved	Pledged	Pledged / RRB	Used	Used / RRB
CPU	Tier0	1180	1180	100%	1729	147%
	Tier1	1100	1166	106%	1606	146%
	Tier2	1900	1830	96%	2959	156%
	Total	**4180**	**4176**	**100%**	**6293**	**151%**
	*HLT**				*434*	*10%*
	*Others**				*657*	*16%*
Disk	Tier0	70.0	70.0	100%	56.3	80%
	Tier1	142.0	133.8	94%	123.0	87%
	Tier2	175.0	159.6	91%	139.1	79%
	Total	**387**	**363.4**	**94%**	**318.4**	**82%**
Tape	Tier0	442.0	442.0	100%	384.9	87%
	Tier1	445.0	411.5	92%	365.0	82%
	Total	**887.0**	**853.5**	**96%**	**749.9**	**85%**

*: Percentage taken with respect to the total RRB approved CPU recommendation

Table 7 Summary of planned and used resources for CMS in the calendar year 2025. The CPU and storage resources are in units of kHS23 years and PB, respectively.

7.1 Overview of Activities

The resource usage in 2025 reflects a year of highly intensive computing activity driven by successful data taking, large-scale MC production, and extensive user analysis. The CMS computing infrastructure operated efficiently across all tiers (Tier0, Tier1, Tier2, and opportunistic resources), with overall usage frequently exceeding pledged capacities. By the end of 2025, proton-proton run CMS had recorded 114.85 fb^{-1} with 91% efficiency.

CMS extended, in parallel with the legacy, the full proton-proton collision approach to transfer collision data directly from the Storage Manager to EOSCMS.

CPU Usage CPU resources were heavily utilized across all tiers, with usage frequently exceeding pledged capacities. At Tier0, CPU usage reached about 153% of the pledge, reflecting intensive prompt reconstruction and reprocessing workloads. Tier1 sites operated at around 121% of pledged CPU, with good efficiency (approx 81%), while Tier2 sites, which handle most user analysis, reached approximately 169% of their pledged capacity, albeit with lower efficiency (approx 64%) due to the nature of analysis jobs.

Because of a high utilization of opportunistic processing capacity, CMS reached a record peak usage of more than 682,000 CPU cores on 18 August 2025, including the new Tier1 at the National Centre for Nuclear Research (NCBJ), Poland.

Disk Usage Disk resources were consistently used at high levels throughout the year. At the Tier0, disk usage peaked at around 87% of capacity, while Tier1 sites averaged close to 90% utilization, indicating sustained pressure on storage systems. Disk usage was driven by the need to store large volumes of reconstructed data and analysis formats, as well as intermediate datasets required for processing workflows.

Tier2 disk resources supported large-scale user analysis and data access, with increasing demand due to a growing number of users and jobs. Overall, disk remained a critical and tightly managed resource, requiring careful balancing between data availability and storage constraints.

A significant fraction of data stored on disk remains unaccessed for extended periods, reflecting the challenges of balancing data availability with efficient storage usage. A notable portion of datasets, particularly older analysis formats and intermediate production outputs, are not accessed for many months, and in some cases are never accessed after creation.

This accumulation of "cold" data places increasing pressure on disk resources, as it occupies space that could otherwise be used for active datasets. To mitigate this, CMS must continue its effort to apply data management strategies such as dataset lifetime policies, automated deletion campaigns, and reduction of redundant replicas.

Tape Usage Tape storage was also heavily utilized, primarily for long-term data preservation. At the Tier0, tape usage reached about 87% of the pledged capacity, while Tier1 tape usage was around 89%, reflecting the accumulation of large datasets from ongoing data taking and simulation.

CMS continued to observe a shortfall in Tier1 tape capacity, highlighting the increasing demand for archival storage. Tape remains essential for storing raw and processed data, as well as large MC samples, and is a key component of the overall data management strategy. It is therefore encouraging to witness the establishment of a new CMS Tier1 in Poland, even though the site is not yet providing tape resources, and the work is ongoing in Serbia to also provide a Tier1.

8 Resource Usage: LHCb

The usage of computing resources in 2025 by LHCb was smooth and allowed for a successful recording of 11.81 fb^{-1} of integrated luminosity. As in previous years, the offline computing activities were dominated by MC production: 85% at the Tier0 and Tier1, and 95% at the Tier2. The number of events produced in full and fast simulation was about equal. Commendable activities in 2025 include significant efforts made to reduce disk usage following the 2024 storage pressure, particularly for the TURBO stream. Improvements in data compression, de-duplication, and physics selections reduced the average event size from 16 kB in 2024 to 11 kB in 2025. Reprocessing the 2024 TURBO data with these improvements also freed more than 8 PB of disk space.

Table 7 shows an overview of the LHCb resource usage in 2025, along with a comparison of the amount of resources approved by the RRB and the resources pledged by the sites. The CPU usage information is based on EGI accounting provided by the WLCG Accounting Utility (WAU) portal. The Tier0 disk usage is from EOS accounting, while disk usage at Tier1 and Tier2, and tape usage, are under DIRAC accounting, which is considered more trustworthy. The CPU from non-WLCG sites used DIRAC accounting scaled to EGI estimates.

LHCb		2025				
		RRB approved	Pledged	Pledged / RRB	Used	Used / RRB
CPU	Tier0	283	283	100%	418	148%
	Tier1	928	849	91%	1024	110%
	Tier2	518	535	103%	322	62%
	Total	**1729**	**1667**	**96%**	**1764**	**102%**
	*HLT**				*687*	*40%*
	*Others**				*77*	*4%*
Disk	Tier0	54.9	54.9	100%	42.1	77%
	Tier1	89.9	89.3	99%	84.7	94%
	Tier2	17.4	15.2	87%	13.4	77%
	Total	**162.2**	**159.4**	**98%**	**140.2**	**86%**
Tape	Tier0	170.4	170.4	100%	153.3	90%
	Tier1	194.8	181.2	93%	174.1	89%
	Total	**365.2**	**351.6**	**96%**	**327.4**	**90%**

*: Percentage taken with respect to the total RRB approved CPU recommendation

Table 8 Summary of planned and used resources for LHCb in the calendar year 2025. The CPU and storage resources are in units of kHS23 years and PB, respectively. The used CPU numbers are based on WLCG accounting as discussed below.

The WLCG sites provided 1764 kHS23 years of CPU work. The contribution from non-WLCG sites, including HLT and other centres, was 764 kHS23 years. The pledges were typically lower than requested. Pledged shortfalls of CPU and tape at the Tier1 were about 7-8% and disk at the Tier2 about 12%.

The Tier0 supplied 148% of its requested CPU. Although only 92% of the Tier1 CPU requested was pledged, it supplied 110% of its requested CPU. In addition, the HLT and other resources provide 30% of the total CPU used. This is a commendable use of the available resources.

However, the Tier2 CPU, which was to supply 28% of the requested CPU power, is a different story. Although 103% of the CPU was pledged, the average power used at the Tier 2 sites is 40% lower than pledged. A non-exhaustive list of nine sites with accounting issues was provided. It is not reasonable to make an estimate of what the numbers should be, but it is believed that the shortfall is due mainly to these accounting issues.

Only 88% of the Tier2 disk requested was pledged, but this is a small allocation compared to Tier0 and Tier1. Only 86% of the total disk requested was used, or 88% of pledged. By the end of the WLCG year, this is anticipated to only be 8% below pledge.

Only 93% of the Tier1 tape requested was pledged, and only 90% of the total tape requested was used. Of the tape pledged, 7% was not used. By the end of the WLCG year, the unused fraction is anticipated to be only 3% below the pledge, an acceptable amount.

An additional 7.5 PB of Tier0 tape buffer and 9.5 PB of user, detector studies and commissioning spaces are not visible in either DIRAC or WLCG storage accounting.

Approximately 20% of the data residing on disk has not been accessed in over a year. Discussions on this topic are planned for the Long Shutdown 3 in order to optimize the cold data fraction for Run 4.

9 Background for 2027 Resource Requests

During 2027, a year within the Long Shutdown 3 (LS3) period, the experiments plan to carry out extensive reprocessing campaigns of the data collected during Run 3, large MC production campaigns reflecting the final detector conditions, and intensive data analysis activities.

Given the expected availability of HLT/EPN farms and Tier0 resources for offline use, the experiments are not requesting increases in CPU resources, with the exception of ALICE. The substantial processing capacity of these resources has been factored into the resource request calculations, thereby reducing the CPU capacity required from WLCG sites.

The ATLAS HLT farm represents a significant resource, with around 1.8 MHS23 of compute power that is regularly used for offline processing when there are no LHC collisions. The servers comprising this resource will be relocated to a container at Point 8 in July 2026 and recommissioned for offline use for the duration of LS3. ATLAS conservatively assumes that the relocated HLT farm will deliver about 1 MHS23 for offline processing during 2027, based on power constraints in the container and availability from March to December 2027, rising to 1.3 MHS23 in 2028 and 2029.

CMS plans to relocate part of the Run 2 HLT farm to the ALICE Modular Data Centre in May 2026, preserving approximately 400 kHS23 for offline use until the end of Run 3. In addition, the Run 3 HLT farm, equipped with GPUs, is expected to remain available for most of 2027 as a reliable resource, providing about 860 kHS23 of CPU capacity.

In 2027, LHCb expects to obtain about 2700 kHS23 year of CPU from its HLT farm. This estimate is based on the past HLT farm offline contributions scaled to a full year and assuming 90% availability. This figure may change depending on power availability in the LHCb experimental area during 2027 and on planned maintenance of the HLT farm.

The ALICE EPN farm, with a CPU capacity of 385 kHS23 and equipped with GPUs, will be fully utilised in 2027 for the reprocessing of the Pb–Pb dataset collected in Run 3. An additional 107.8 kHS23 of CPU capacity from nodes with more powerful GPUs is currently reserved for testing, but may also become available for offline processing.

In previous scrutiny rounds, the C-RSG encouraged the experiments to estimate the amount of opportunistic resources, beyond the online farms, that could be available in 2027 and to include these in their resource planning. So far, only ATLAS and LHCb have done so. ATLAS expects to obtain about 800 kHS23 of additional capacity in 2027 from such resources, mostly from HPC facilities, while LHCb includes a more modest estimate of 100 kHS23 of CPU capacity from opportunistic resources.

It is worth noting that none of the four experiments has included contributions from beyond-pledge CPU resources at WLCG sites in their resource planning, despite the consistent provision of substantial additional capacity in recent years.

Regarding storage, the experiments request relatively modest increases in disk and tape capacity for 2027, below 10%, to accommodate newly reprocessed data and the production of MC samples.

The surge in hardware prices in 2026, driven by the insatiable demand for AI infrastructure and the effective sell-out of enterprise hard drives, threatens to impact resource provisioning for 2027. Fortunately, 2027 is a shutdown year, and the disk storage increases requested by the LHC experiments are modest. In addition, the absence of data taking in 2027 does not compromise critical data collection, and any resource shortages would mainly result in delays to MC production and data analysis. Nevertheless, the efficient use of resources is now more important than ever.

The following sections summarize the justification for the requests and the recommendations of the C-RSG.

10 Resource Requests: ALICE

The ALICE request for 2027 is shown in Table 9. 2027 will be the first of three years without new data taking. Therefore, the EPN resources will be fully available for processing from July 2026 onwards.

ALICE		2025			2026		2027		
		RRB approved	Pledged	Used	RRB approved	Pledged	Request	2027 req. / 2026 RRB	C-RSG recomm.
CPU	Tier0	680	680	1149	710	710	710	100%	710
	Tier1	690	596	696	720	626	720	100%	720
	Tier2	730	750	925	810	818	870	107%	810
	Total	**2100**	**2026**	**2770**	**2240**	**2154**	**2300**	**103%**	**2240**
	HLT			*508*					
	Others			*133*					
Disk	Tier0	78.0	78.0	74.0	90.0	90.0	94.2	105%	94.2
	Tier1	79.0	69.1	64.4	90.0	77.7	97.1	108%	93.6
	Tier2	77.0	82.5	79.5	89.0	94.5	98.9	111%	94.0
	Total	**234.0**	**229.6**	**217.9**	**269.0**	**262.2**	**290.2**	**108%**	**281.7**
Tape	Tier0	220.0	220.0	196.7	292.0	292.0	306.5	105%	306.5
	Tier1	123.0	117.4	100.8	155.0	156.6	169.5	109%	169.5
	Total	**343.0**	**337.4**	**297.5**	**447.0**	**448.6**	**476.0**	**106%**	**476.0**

Table 9 ALICE resource requests for 2027 and C-RSG recommendations. For reference, the 2025 utilization and 2026 pledged resources are also given. The CPU and storage resources are in units of kHS23 years and PB, respectively.

The main planned production campaigns will be dedicated in almost equal parts to the MC production and analysis of Run 3 data. Data processing will require only 5.2% of the total CPU. Overall, 2300 kHS23 of CPU capacity is requested. The Tier0 and Tier1s are not expected to increase their CPU pledges. The Tier2s are expected to provide an additional 7%. Out of the 290 PB of the requested disk storage, close to 30% is expected to store data related to Run 1 and Run 2. Globally, 59% of the space will be dedicated to real data AO2Ds, 35.2% to the equivalent MC data formats, and 5.5% are expected to be needed for analysis-related data. While the requested increase in CPU is only 3% globally, the requested space on disk has increased by 8%, with a larger growth of 11% expected to be provided by the Tie2s. Tape requests increased by 6% to 476 PB. A fraction of 79% of the total tape volume will be used for the archival of Run 3 data. Run 3 tape requirements are dominated by raw data.

The C-RSG considers that the requested CPU increase for ALICE in 2027 may not be necessary. The projected growth in analysis CPU appears conservative compared to previous shutdown periods. Additional CPU capacity from EPN nodes, not included in the Pb–Pb reprocessing estimates, may provide further flexibility. ALICE has also historically benefited from significant opportunistic resources (about 60% across Tier0, Tier1 and Tier2 in 2025). Moreover, past fluctuations in CPU availability, such as the temporary reduction in CPU utilisation observed in May–June 2025, attributed to issues affecting MC production, do not appear to have significantly impacted the physics programme. Taken together, these considerations suggest that the available resources are likely to be sufficient without a CPU increase.

Conclusions

The C-RSG recommends no increase in CPU capacity, as detailed in recommendation ALICE-2. In addition, the C-RSG recommends that the disk capacity increase at the Tier1 and Tier2 levels is limited to 50% of the current request, as detailed in recommendations ALICE-3 and ALICE-4. The remaining parts of the request are considered necessary to achieve the experiment's approved physics programme and recommend that the C-RRB arrange for pledges accordingly.

The C-RSG makes the following recommendation to the ALICE Collaboration:

ALICE-1 The C-RSG recommends that the additional information requested through questions and recommendations be addressed not only in the written responses but also incorporated into the next report, including the relevant points raised during the face-to-face meeting.

ALICE-2 The C-RSG recommends no increase in CPU resources for ALICE in 2027. The other three LHC experiments are not requesting additional CPU for 2027, given the absence of data taking and the expected availability of online farms and Tier-0 resources for offline processing. The C-RSG understands that ALICE is in a comparable situation.

ALICE-3 The C-RSG recommends that ALICE continue its efforts to reduce the fraction of cold data residing on disk and not accessed for extended periods. In this context, the C-RSG encourages the adoption of best practices, such as those successfully implemented by ATLAS, including detailed monitoring of data access patterns, the use of large and dynamic disk caches with automated eviction of unused data, and agile data placement policies that limit the lifetime of inactive datasets on disk. A reasonable target would be to ensure that the fraction of data not accessed for a year is reduced to below 10%. While recognising that, in some cases, data deletion requires consultation with the physics community, the C-RSG recommends that these procedures be streamlined to enable more timely data lifecycle management.

ALICE-4 The C-RSG recommends, in line with the previous recommendation on improving disk usage efficiency, that the disk capacity increase requested by ALICE for 2027 at the Tier1 and Tier2 levels be limited to 50% of the current request, with the remaining needs to be met through the deletion of cold data.

ALICE-5 The C-RSG recommends that ALICE provide long-term projections of resource needs, including for Run 4, to support long-term funding planning and interactions with the funding agencies.

11 Resource Requests: ATLAS

Table 10 shows the resource requests submitted by the ATLAS Collaboration for 2027, the resources used in 2025, and the pledged resources for 2025 and 2026 along with the C-RSG recommendations.

The ATLAS resource request for 2027 reflects a year with computing activities focused on finalising Run 3 processing, large-scale MC production, and preparations for HL-LHC. In particular, 2027 will include the completion of partial reprocessing of the final Run 3 data, significant event generation and simulation campaigns for Run 3 datasets (especially for 2025–2026 data), and an increasing production of new simulation samples for HL-LHC studies. At the same time, analysis activity is expected to grow rapidly as the full Run 3 dataset becomes available, driving sustained production of reduced analysis formats such as DAOD_PHYS and DAOD_PHYSLITE.

The total CPU requirement for 2027 is estimated to be slightly lower than the 2026 pledge (about 4% reduction), mainly due to the absence of data taking and improvements in software performance,

ATLAS		2025			2026		2027		
		RRB approved	Pledged	Used	RRB approved	Pledged	Request	2027 req. / 2026 RRB	C-RSG recomm.
CPU	Tier0	1100	1100	1019	1265	1265	1265	100%	1265
	Tier1	1635	1639	1760	1802	1827	1802	100%	1802
	Tier2	1998	2297	4078	2202	2381	2202	100%	2202
	Total	**4733**	**5036**	**6857**	**5269**	**5473**	**5269**	**100%**	**5269**
	HLT			*257*					
	Others			*1399*					
Disk	Tier0	56.0	56.0	51.2	65.0	65.0	65.0	100%	65.0
	Tier1	186.0	186.7	194.0	199.0	198.3	214.0	108%	214.0
	Tier2	227.0	218.9	191.0	243.0	239.6	262.0	108%	262.0
	Total	**469.0**	**461.6**	**436.2**	**507.0**	**502.9**	**541.0**	**107%**	**541.0**
Tape	Tier0	258.0	258.0	268.0	302.0	302.0	312.0	103%	312.0
	Tier1	561.0	567.6	560.0	692.0	695.2	741.0	107%	741.0
	Total	**819.0**	**825.6**	**828.0**	**994.0**	**997.2**	**1053.0**	**106%**	**1053.0**

Table 10 ATLAS Collaboration resource requests for 2027 and C-RSG recommendations. For reference, 2025 and 2026 pledged resources are also given. The CPU and storage resources are in units of kHS23 years and PB, respectively.

particularly in simulation. A substantial fraction of the required computing power is expected to be provided by non-WLCG resources, including the CERN Tier0, the relocated Run 3 HLT farm, and opportunistic resources. After accounting for these contributions, ATLAS does not request any increase in pledged CPU resources for 2027 across Tier0, Tier1, or Tier2 sites.

In contrast, storage requirements continue to grow. Disk storage is requested to increase by about 7% overall, reaching 541 PB. This growth is driven primarily by MC production, as well as the need to store analysis-ready datasets and maintain sufficient data replicas. The increase is distributed between Tier1 and Tier2 sites, while Tier0 disk capacity remains unchanged after optimisation of buffer usage.

Tape storage is also requested to increase, reaching about 1053 PB in total, corresponding to a growth of 6%. This reflects the need for long-term archival of both Run 3 data and large MC samples. The increase is mainly at Tier1 sites, with a smaller addition at Tier0 to retain flexibility for storing additional derived data products.

Overall, the ATLAS 2027 request is characterised by stable CPU requirements enabled by software improvements and significant use of opportunistic resources, combined with moderate but necessary increases in disk and tape storage to support ongoing simulation, data preservation, and analysis activities in a post–data-taking environment.

Conclusions

The C-RSG considers that the ATLAS experiment's resource requests for 2027, shown in Table 10, are necessary to achieve the experiment's approved physics program and recommends that the C-RRB arrange for pledges correspondingly.

The C-RSG makes the following recommendation:

ATLAS-1 The C-RSG requests that the ATLAS Collaborations work on quantifying the benefits and long-term expectations of having opportunistic tape at Tier 2 sites.

12 Resource Requests: CMS

The planned CMS activities for 2027 focus primarily on consolidating the full Run 2 and Run 3 datasets into a coherent legacy dataset for physics analysis. This involves large-scale reprocessing campaigns, including the re-reconstruction of Run 3 data from 2022 to 2024 using improved algorithms, as well as the regeneration of reduced data formats such as MiniAOD and NanoAOD for both Run 2 and Run 3 data. Heavy-ion datasets will also be reprocessed to incorporate improved reconstruction techniques.

In parallel, a major MC production campaign will be carried out to match the reprocessed data. This includes completing the 2026 MC production, generating new samples for Run 3 analysis, and producing additional samples for earlier datasets and new physics studies. Both full simulation and fast simulation will be used, with fast simulation enabling large parameter scans and systematic studies.

The experiment will also continue preparations for the HL-LHC, including the production of new simulation samples and further development of software and workflows. Data analysis activities in 2027 will concentrate on the full Run 2 and Run 3 datasets, with resource usage expected to remain at levels similar to previous years.

To support these activities, CMS plans to make extensive use of available computing resources, including the Run 3 HLT farm and opportunistic resources. These resources will be particularly important for MC production, allowing Tier1 facilities to focus on data reprocessing and analysis workflows.

CMS relies on XRootD for remote data access. However, the current XRootD data access monitoring is not sufficiently reliable to accurately track the input datasets accessed by CMS workflows. As a result, some datasets that are accessed remotely may appear as unused and therefore be incorrectly classified as cold data on disk. CMS is working with the XRootD development team to address these monitoring limitations.

While the C-RSG supports this effort, the current deployment timescale—about one year for the monitoring improvements, followed by an additional year to accumulate sufficient access statistics to identify cold datasets—appears rather long. The C-RSG therefore encourages CMS to explore ways to accelerate both the development and deployment phases of this work.

In addition, the C-RSG suggests exploring simpler interim solutions to track dataset access and to identify datasets that have never been accessed on disk. For example, the CMS workload management system (WMAgent and CRAB) could be used to track the input datasets of submitted production and analysis tasks, thereby providing a practical way to distinguish between accessed and unaccessed datasets.

Regarding the resource request for 2027, CMS does not request any increase in CPU resources compared to 2026, as existing capacity, including the HLT farm, is expected to be sufficient. However, an increase in storage is requested. Disk storage is requested to grow by about 9% (an additional 38 PB), driven by the need to store reprocessed datasets and make analysis-ready data widely available. Tape storage is requested to increase by about 8% (an additional 88 PB), primarily to support long-term archival of reprocessed data and large MC samples.

The newly established Polish Tier1 is still in its build-up phase and will not yet contribute significant resources, but together with the potential of a Tier1 in Serbia, it is an important step towards solidifying the number of CMS Tier1 sites. This is particularly important as the long-term prospect of the resources delivered by Russia remains unclear.

Conclusions

Table 11 shows the CMS Collaboration's resource request for 2027 along with the C-RSG recommendation. The C-RSG recommends that the disk capacity increase at the Tier1 and Tier2 levels is limited

CMS		2025			2026		2027		
		RRB approved	Pledged	Used	RRB approved	Pledged	Request	2027 req. / 2026 RRB	C-RSG recomm.
CPU	Tier0	1180	1180	1729	1350	1350	1350	100%	1350
	Tier1	1100	1166	1606	1200	1270	1200	100%	1200
	Tier2	1900	1830	2959	2000	1939	2000	100%	2000
	Total	**4180**	**4176**	**6293**	**4550**	**4559**	**4550**	**100%**	**4550**
	HLT			*434*					
	Others			*657*					
Disk	Tier0	70.0	70.0	56.3	81.0	81.0	81.0	100%	81.0
	Tier1	142.0	133.8	123.0	164.0	154.6	180.0	110%	172.0
	Tier2	175.0	159.6	139.1	198.0	176.3	220.0	111%	209.0
	Total	**387.0**	**363.4**	**318.4**	**443.0**	**411.9**	**481.0**	**109%**	**462.0**
Tape	Tier0	442.0	442.0	384.9	515.0	515.0	533.0	103%	533.0
	Tier1	445.0	411.5	365.0	540.0	503.9	610.0	113%	610.0
	Total	**887.0**	**853.5**	**749.9**	**1055.0**	**1018.9**	**1143.0**	**108%**	**1143.0**

Table 11 CMS Collaboration resource requests for 2027 and C-RSG recommendations. For reference, 2025 and 2026 figures are also given. The CPU and storage resources are in units of kHS23 years and PB, respectively.

to 50% of the current request, as detailed in recommendations CMS-6 and CMS-7. The remaining parts of the request are considered necessary to achieve the experiment's approved physics programme and recommend that the C-RRB arrange for pledges accordingly.

The C-RSG makes the following recommendations:

CMS-1 The C-RSG requests that the CMS Collaboration continue reporting on efforts to improve monitoring of data access, particularly with respect to identifying unaccessed datasets, and provide a timeline for the availability of proper data access monitoring.

CMS-2 The C-RSG also requests a more detailed analysis of the sources and types of cold data on disk, including, for example, data pending migration to tape, the relative popularity of miniAOD versus AOD datasets, and the distribution of cold data between detector and MC samples.

CMS-3 The C-RSG recommends that the CMS Collaboration assess whether the large amount of locally managed disk space at Tier2 sites, outside central Rucio control, is adequately sized or could be further reduced.

CMS-4 The C-RSG requests that the CMS Collaboration conduct an in-depth study of the causes for the CPU inefficiency of analysis jobs and initiate work on improvements. The C-RSG suggests that the collaboration consider adopting a setup where jobs are executed in a structured way, instead of the execution of submitted jobs by individual users.

CMS-5 The C-RSG observes that the CPU request for 2027 analysis activities is drastically reduced compared to previous resource requests, and the experiment, as a result, expects that there should be sufficient opportunistic CPU resources available to compensate. The C-RSG considers the approach to carry an inherent risk should the opportunistic resources fail to materialise and asks the CMS Collaboration to consider developing a fallback plan.

CMS-6 The C-RSG recommends that CMS continue its efforts to reduce the fraction of cold data residing on disk and not accessed for extended periods. In this context, the C-RSG encourages the adoption of best practices such as those successfully implemented by ATLAS, including detailed monitoring of data access patterns, the use of large and dynamic disk caches with automated eviction of unused data, and agile data placement policies that limit the lifetime of inactive datasets on disk. A reasonable target would be to ensure that the fraction of data not accessed for a year is reduced to below 10%. While recognising that, in some cases, data deletion requires consultation with the physics community, the C-RSG recommends that these procedures be streamlined to enable more timely data lifecycle management.

CMS-7 In line with the previous recommendation on improving disk usage efficiency, the C-RSG recommends that the disk capacity increase requested by CMS for 2027 be limited to 50% of the current request, with the remaining needs to be met through the deletion of cold data.

13 Resource Requests: LHCb

The computing resources requested by the LHCb Collaboration and the C-RSG recommendations for 2027 are shown in Table 12. Also shown for reference are the RRB-approved and pledged resources for 2025 and 2026, as well as the resources used in 2025. The 2026 pledges are taken from the WLCG by the C-RSG.

LHCb		2025			2026		2027		
		RRB approved	Pledged	Used	RRB approved	Pledged	Request	2027 req. / 2026 RRB	C-RSG recomm.
CPU	Tier0	283	283	418	344	344	324	94%	324
	Tier1	928	849	1024	1127	1016	1063	94%	1063
	Tier2	518	535	322	629	608	594	94%	594
	Total	**1729**	**1667**	**1764**	**2100**	**1968**	**1981**	**94%**	**1981**
	HLT			*687*					
	Others			*77*					
Disk	Tier0	54.9	54.9	42.1	70.9	70.9	73.4	104%	73.4
	Tier1	89.9	89.3	84.7	107.1	107.1	104.8	98%	104.8
	Tier2	17.4	15.2	13.4	20.7	17.3	20.3	98%	20.3
	Total	**162.2**	**159.4**	**140.2**	**198.7**	**195.3**	**198.5**	**100%**	**198.5**
Tape	Tier0	170.4	170.4	153.3	202.2	202.2	206.0	102%	206
	Tier1	194.8	181.2	174.1	233.7	219.7	246.1	105%	246.1
	Total	**365.2**	**351.6**	**327.4**	**435.9**	**421.9**	**452.1**	**104%**	**452.1**

Table 12 LHCb Collaboration resource requests for 2027 and C-RSG recommendations. For reference, 2025 and 2026 resources are also shown. The CPU and storage resources are in units of kHS23 years and PB, respectively.

The total LHCb computing resource needs for 2027 show a 1.7x increase in CPU, while disk and tape remain essentially unchanged. The increase is primarily driven by Run 3 simulation production. Assuming full availability of the HLT farm (2,700 kHS23·years) and opportunistic contributions at 100 kHS23·years, the effective WLCG CPU request remains unchanged from 2026.

Relative to the 2026 WLCG pledges, LHCb requests for 2027 correspond to 99% CPU, 102% disk, and 107% tape; values would be slightly lower relative to the 2026 RRB-approved figures. The constant WLCG CPU reflects the expected HLT resource increase (about 4.5x higher than available in a data-taking year). The CPU request is also reduced compared to the preliminary Autumn 2025 projection of a 123% increase, thanks to compiler optimisations and the use of the actual 2025 integrated luminosity in the calculation of the MC production needs.

Full simulation remains the dominant consumer of CPU resources in LHCb. In recognition of this, additional fast simulation workflows are being developed, including the use of shower libraries and machine-learning techniques to parametrise the calorimeter response. Several fully parametric simulation approaches are also under development, with varying levels of maturity.

The simulation is being adapted for multi-threaded execution, significantly reducing the memory footprint and enabling the use of HPC resources and many-core architectures with lower memory per core than typical grid nodes. Further stress testing and detailed validation are required before production deployment.

The disk capacity is expected to be a constant 139.3 PB for real data, 30.0 PB for simulated data (an increase of 3.0 PB relative to the 2026 RRB-approved level), and 29.2 PB for others (a decrease of 1.5 PB relative to the 2026 RRB-approved level).

The expected data volumes on tape are a constant 82.9 PB for Run 1 and Run 2 real and simulated (archived) data, and 369.2 PB for Run 3 collision data, heavy-ion and fixed target data, minimum bias/no-bias stream and simulated data, an increase of 16.2 PB relative to the 2026 RRB-approved level.

Conclusions

The C-RSG considers that the LHCb Collaboration's resource requests for 2027 are necessary to achieve the experiment's physics programme.

The following recommendations are made:

LHCb-1 The C-RSG requests LHCb to continue to investigate the high average CPU work per fully simulated event in 2025 and work with the physics groups to reduce it in future years. For the Fall 2026 report, it is requested to present the spread in CPU work per fully simulated event for various simulated processes.

LHCb-2 The C-RSG requests that LHCb investigate the reasons for the near-equal production of full and fast simulation events in 2025, compared to the design ratio of 1:2. The C-RSG recommends that LHCb strengthen engagement with the physics groups to prioritise the validation and adoption of fast simulation. Increasing the use of fast simulation, while ensuring adequate physics performance, will be critical to contain the CPU requirements associated with large-scale simulation production.

LHCb-3 The C-RSG requests LHCb to work with the WLCG accounting team to clarify and address the site accounting issues that resulted in an apparent under-utilisation of CPU resources in 2025. While recognising that DIRAC accounting may sometimes be preferred, the C-RSG recommends that such figures be converted to WLCG accounting units when presented, to ensure consistency and facilitate comparisons.

LHCb-4 The C-RSG recommends that LHCb continue its efforts to reduce the fraction of cold data residing on disk and not accessed for extended periods. In this context, the C-RSG encourages the adoption of best practices such as those successfully implemented by ATLAS, including detailed monitoring of data access patterns, the use of large and dynamic disk caches with automated eviction of unused data, and agile data placement policies that limit the lifetime of inactive datasets on disk. A reasonable target would be to ensure that the fraction of data not accessed for a year is reduced to below 10%. While recognising that, in some cases, data deletion requires consultation with the physics community, the C-RSG recommends that these procedures be streamlined to enable more timely data lifecycle management.

14 Comments and Overall Recommendations

The C-RSG completed this scrutiny round impressed by the vast amount of data collected by the experiments in 2025 and the remarkable scale of data processing, simulation and analysis activities undertaken. The experiments have demonstrated an exceptional ability to leverage a substantial volume of beyond-pledge and opportunistic CPU resources, approximately 44% more than their total requirements in 2025.

Comprehensive plans for computing resource utilisation in 2026 and 2027, along with the estimated computing resources required for the planned processing, simulation and analysis of the collected data, have been established.

Figure 2 (left) shows the evolution of WLCG computing resource capacities, aggregated across the four experiments and broken down by resource type (CPU, disk, and tape). Figure 2 (right) shows the corresponding annual increases in these resources. The reduction in resource growth from 2026 onwards, associated with Long Shutdown 3, is clearly visible.

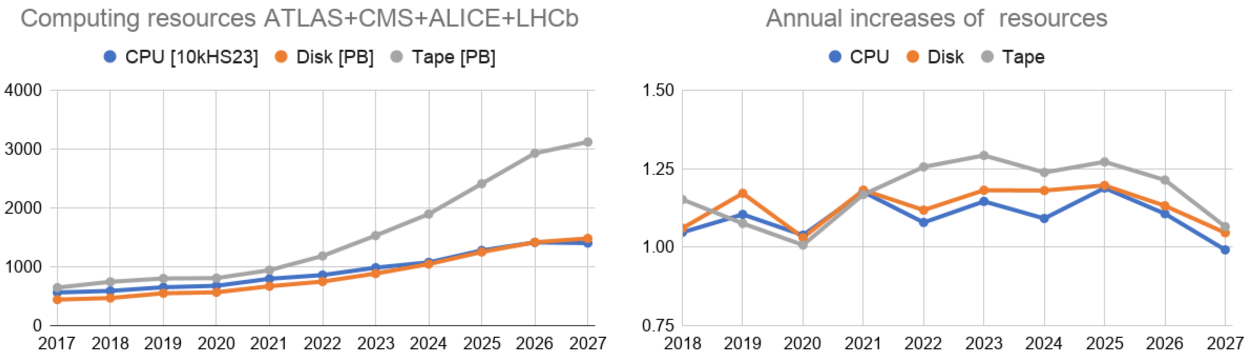

Figure 2 Left: Evolution of the RRB's approved overall baseline capacities for the WLCG computing resources (CPU in units of 10 kHS23, storage in PB). Right: annual resource increases. The 2027 values reflect the recommendations of the C-RSG.

Given the expected availability of online farms and Tier0 resources for offline use in 2027, the experiments are not requesting CPU increases, with the exception of ALICE, which requested a 7% increase (+60 kHS23) at the Tier2 level. Considering the large uncertainties in ALICE's CPU projections for 2027, particularly for data analysis, the current volatility in server markets with rapidly rising prices, the potential availability of additional EPN farm capacity beyond Pb–Pb reprocessing, and the likely availability of beyond-pledged resources at WLCG sites (30% at Tier-2 and 74% at Tier0 for ALICE in 2025), the C-RSG recommends that ALICE should not increase its CPU allocation for 2027.

The production of MC simulation samples remains by far the largest consumer of CPU resources in the experiments' workflows. The C-RSG recommends that the experiments continue their efforts to accelerate full MC simulation and to expand the use of fast simulation techniques wherever appropriate. In this context, we issue the following Recommendations:

ALL-1 The C-RSG recommends that the experiments continue to prioritise efforts to improve the performance of simulation and reconstruction software, as gains in software efficiency will be critical to compensate for the slowing growth of computing resources under flat funding. To monitor progress in this area, the C-RSG requests that the experiments provide, at each review, a plot showing the CPU work per event (in HS23 s) for the full simulation chain as a function of major software versions, including the historical evolution where available, and using a representative physics process as a consistent reference benchmark.

ALL-2 The C-RSG recommends that the LHC experiments strengthen their efforts on physics corrections, calibrations, and validation activities needed to enable the broader use of fast simulation. This work requires strong engagement from the physics community beyond the computing domain and is expected to have a significant impact on reducing overall CPU requirements.

The efficient use of CPU resources, as measured by the CPU efficiency metric, has been one of the areas closely monitored by the C-RSG. We now request that the experiments also report an additional metric, the amount of CPU time wasted by failed jobs, i.e., jobs that do not produce any useful output:

ALL-3 The C-RSG requests that all four LHC experiments report an additional efficiency metric in their computing utilisation reviews, namely the fraction of total CPU resources consumed by failed jobs. This information will help improve the assessment of resource efficiency and support efforts to optimise workload performance and reliability.

As mentioned in Section 4, with the exception of ATLAS, which demonstrates very effective disk data management, keeping the fraction of data not accessed within one year below 4%, the other experiments could further strengthen their data management practices to better control the lifetime of inactive datasets on disk. The C-RSG considers that a reasonable objective would be to reduce the fraction of data not accessed for one year to below 10%. While recognising that, in some cases, data deletion requires consultation with the physics community, the C-RSG encourages the streamlining of these procedures to support more timely data lifecycle management.

In this context, the C-RSG suggests limiting the requested disk capacity increases by ALICE, CMS and LHCb at the Tier1 and Tier2 levels to 50% of the requested amounts. The remaining needs (8.4 PB for ALICE and 19 PB for CMS) could potentially be accommodated through the progressive removal of cold data, whose total volume is considerably larger. Although LHCb is not directly affected by this reduction, as it is not requesting additional disk capacity at Tier-1 or Tier-2 sites for 2025, the identification and removal of cold data is also recommended.

The management of user and physics analysis group data is also a matter of concern for the C-RSG, as the usage of these datasets is typically not systematically monitored and the data placement policies that limit the lifetime of inactive datasets on disk often do not apply to them. We therefore put forward the following Recommendation:

ALL-4 The C-RSG requests that the experiments report on the utilisation and management of user and analysis-group data on disk, including the total volume and its fraction of the total disk space, the monitoring of data access and usage patterns, and the policies governing its retention and lifecycle management.

In response to our recommendation that the experiments provide long-term projections of their computing resource needs, aimed at supporting funding agencies in defining the most effective investment strategies, CMS and LHCb have provided such projections.

CMS has just released its Offline Software and Computing for HL-LHC Conceptual Design Report, including the resource projections [10]. For CMS, the start of the HL-LHC phase in Run 4 is expected to require a sharp increase in resources, significantly exceeding the growth achievable under constant budget scenarios. However, anticipated improvements resulting from ongoing R&D activities are expected to substantially mitigate these requirements.

ATLAS plans to release updated long-term resource projections in its forthcoming HL-LHC Software and Computing Technical Design Report. This document is expected to be available in time to inform the preliminary 2028 resource requests to be discussed this summer.

For LHCb, the running conditions in Run 4 will be similar to those in Run 3. However, projections for disk usage [7] indicate that growth beyond what could be sustained with flat budgets will likely be required.

ALICE has not yet provided long-term resource projections, and the C-RSG has requested that these be made available.

The C-RSG considers it important that resource projections continue to be updated regularly and therefore issues the following recommendation:

ALL-5 The C-RSG recommends that the LHC experiments regularly publish projections of their computing resource needs covering the Long Shutdown 3 and Run 4 periods, as this information is essential to support the long-term planning of funding agencies. These projections should be updated whenever significant changes occur, and in particular ahead of Run 4, when the results of ongoing R&D activities are expected to enable more robust estimates.

References

[1] Computing Resources Scrutiny Group. C-RSG autumn 2025 report. *CERN-RRB-2025-074*, 10 October 2025.

[2] CERN. LHC Schedule. http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm.

[3] ALICE Collaboration. ALICE Computing Resources Usage January through December 2025, Resource Requirements for 2027. 1 February 2026.

[4] ATLAS Collaboration. ATLAS computing status and plans – Report to the C-RSG – April 2026. 9 February 2026.

[5] CMS Collaboration. Spring 2026 scrutiny – CMS utilisation report 2025 and resource request for 2027. 28 February 2026.

[6] LHCb Collaboration. Utilisation of LHCb offline computing resources in 2025. *LHC-PUB-2026-002*, 10 February 2026.

[7] LHCb Collaboration. LHCb computing resources: Final 2027 requests. *LHC-PUB-2026-001*, 4 March 2026.

[8] WLCG CRIC. Computing Resource Information Catalogue. http://wlcg-cric.cern.ch.

[9] WLCG. Heterogeneous Architectures in WLCG. https://indico.cern.ch/event/1526077, 3-5 December 2025.

[10] CMS Collaboration. CMS Offline Software and Computing for HL-LHC Conceptual Design Report. https://cds.cern.ch/record/2957472, 25 March 2026.