Computing Resources Scrutiny Group Report

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for the C-RSG

April 27-28, 2026

CERN-RRB-2026-10

C-RSG membership

Name	Funding agency	Institution	Review Team
Josva Kleist	Northern Countries	NORDUnet	CMS/ATLAS
Roel Aaij	The Netherlands	NIKHEF	CMS/ATLAS
Eric Fede	France	IN2P3-Villeurbanne	CMS/ATLAS
Domenico Elia	Italy	INFN and Univ. Bari	CMS/ATLAS
Markus Schulz	CERN	CERN	ALICE
James Amundson	USA	Fermilab	ALICE
Thomas Hartmann	Germany	DESY	ALICE
Douglas Gingrich	Canada	University of Alberta	LHCb
Luigi Del Debbio	UK	Edinburgh University	LHCb
José Hernández	Spain	CIEMAT	LHCb, Chair
K Dziedziniewicz-Wójcik		CERN	Scient. Secret.

- Thomas Hartmann (DESY) succeeds Tigran Mkrtchyan (DESY) as the German funding agency representative, and joins the ALICE review team
- Luigi del Debbio (University of Edinburgh), representing the UK funding agency, moves from the ALICE to the LHCb review team

Spring 2026 Scrutiny Process

- LHC Collaborations submitted report on
  - 2025 computing resource usage
  - Computing activities and plans for 2026
  - Final resource requests for 2027
- C-RSG responded with written questions
  - Met with Collaboration computing representatives
  - Provided Collaborations with draft report for any corrections of facts
- C-RSG made recommendations regarding requests and plans
- C-RSG also met with LHCC WLCG referees and chair
  - Identified a number of issues of common concern
- 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

WLCG computing resources approved and pledged for 2025

Resources **approved** by RRB for 2025

	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%

- ~12.7 MHS23 CPU (~1.5M cores)
  ~1.25 EB disk,
  ~2.4 EB tape
- **Under-pledges at Tier1 and Tier2 levels**
  - Some strain on storage
  - Same pattern as previous years

Balance (**Pledged**-RRB)/RRB [%]

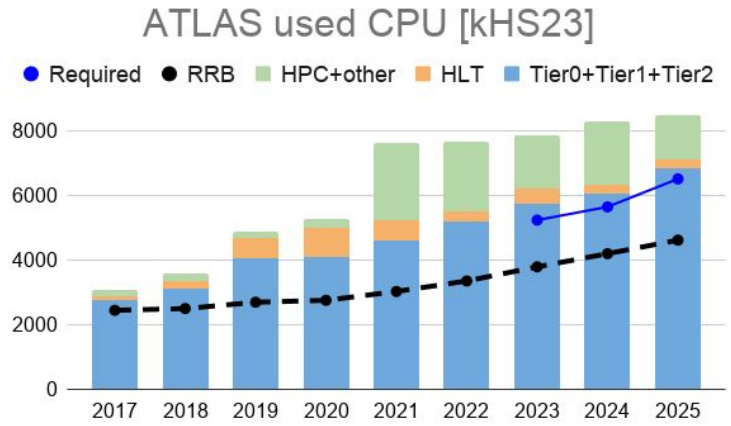
		ATLAS	CMS	ALICE	LHCb
Tier0	**CPU**	0	0	0	0
	Disk	0	0	0	0
	Tape	0	0	0	0
Tier1	**CPU**	0	6	-14	-8
	Disk	0	-6	-12	-1
	Tape	1	-8	-5	-7
Tier2	**CPU**	15	-4	3	3
	Disk	-4	-9	7	-13

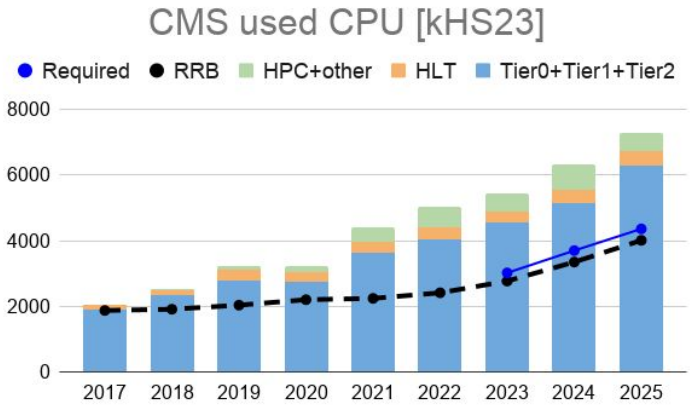
CPU utilization in 2025

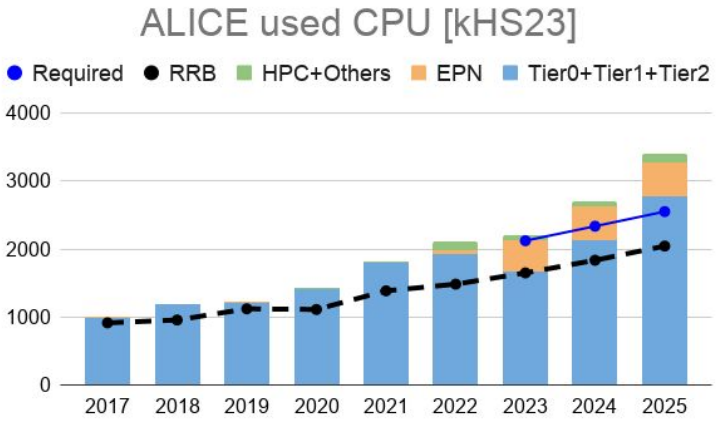
CPU in kHS23 units	RRB approved	WLCG used	WLCG / RRB	HLT used	HPC used	Total used	Total required	Total used / Total required
ATLAS	4626	6857	1.48	257	1399	8513	6526	1.30
CMS	4013	6296	1.57	434	554	7284	4363	1.67
ALICE	2045	2770	1.35	508	133	3411	2553	1.34
LHCb	1601	1764	1.10	688	76	2528	1701	1.49
Total	12284	17687	1.44	1887	2162	21736	15142	1.44

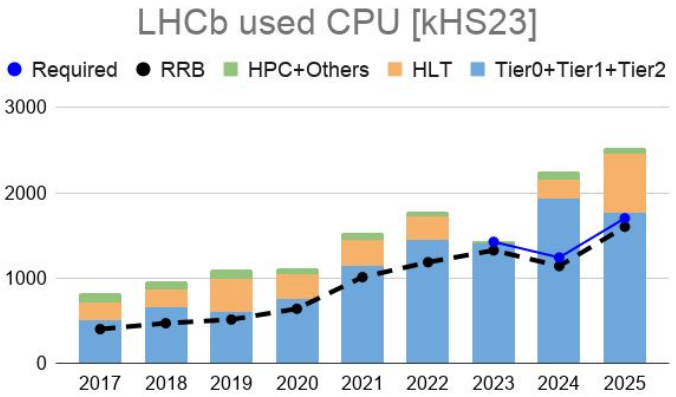
- **Substantial beyond-pledge CPU at WLCG sites:** $Used_{WLCG}/Approved_{RRB} = 144\%$
- Additional CPU from HLT farms and HPC facilities used in planning and reducing CPU requested to WLCG sites: $Used_{total}/Required_{total} = 144\%$
- CPU contributions: WLCG 81%, HLT farms 9%, HPC facilities 11%
- Extra CPU used to extend MC simulations; CMS for promptly reconstructing parked data stream as well

CPU utilization history









Storage utilization in 2025

- Disk storage capacity grew by 20% in 2025 (1.25 EB) and tape storage by 27% (2.4 EB)
  - Utilization in 2025 at the level of 90% (some headroom required for operations)
- Disk and tape limited to pledged resources at WLCG sites
  - **No beyond-pledge or “opportunistic” storage**
- 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

2027 computing resource requests: CPU

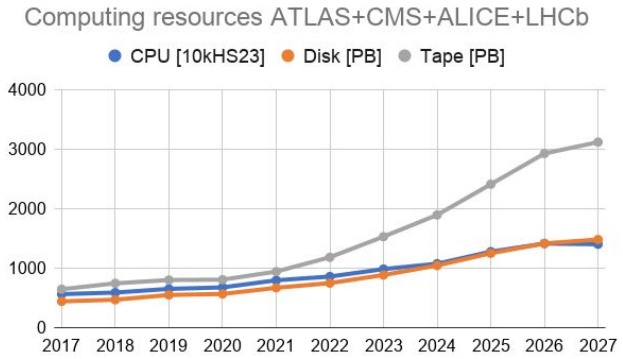
- During 2027, the experiments plan to carry out extensive processing
  - Extensive reprocessing campaigns of the data collected during Run 3
  - Large MC production campaigns reflecting the final detector conditions
  - Intensive data analysis activities
- Being 2027 a year within the LS3, online farms and Tier0 resources will be available for offline use
  - No CPU increase in WLCG sites for 2027
- Additional CPU from HPCs expected
  - ATLAS 800 kHS23, and LHCb 100 kHS23 included in their resource plans
- Additional beyond-pledge CPU resources likely available at WLCG sites
  - No experiment includes them in their resource plans

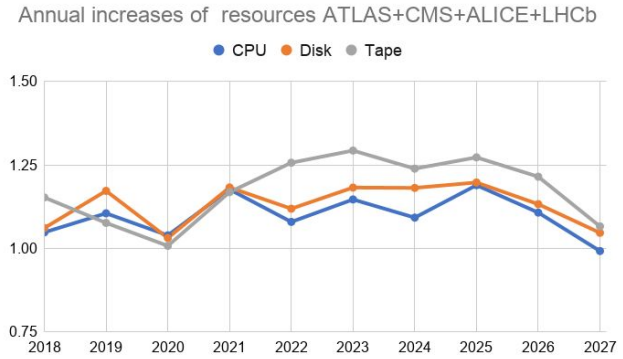
2027 computing resource requests: storage

- Modest increases in disk and tape capacity for 2027, below 10%
  - To accommodate newly reprocessed data and the production of MC samples
- Surge in hardware prices in 2026, driven by the insatiable demand for AI infrastructure
  - Sell-out of enterprise hard drives, threatens to impact disk 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

2027 computing resource requests

		ALICE			ATLAS			CMS			LHCb		
		2027 Request	2027 req. / 2026 RRB	2027 req. - 2026 RRB	2027 Request	2027 req. / 2026 RRB	2027 req. - 2026 RRB	2027 Request	2027 req. / 2026 RRB	2027 req. - 2026 RRB	2027 Request	2027 req. / 2026 RRB	2027 req. - 2026 RRB
CPU [kHS23]	Tier0	710	100%	0	1265	100%	0	1350	100%	0	324	94%	-20
	Tier1	720	100%	0	1802	100%	0	1200	100%	0	1063	94%	-64
	Tier2	870	107%	60	2202	100%	0	2000	100%	0	594	94%	-35
	Total	**2300**	**103%**	**60**	**5269**	**100%**	**0**	**4550**	**100%**	**0**	**1981**	**94%**	**-119**
Disk [PB]	Tier0	94.2	105%	4.2	65	100%	0	81	100%	0	73.4	104%	2.5
	Tier1	97.1	108%	7.1	214	108%	15	180	110%	16	104.8	98%	-2.3
	Tier2	98.9	111%	9.9	262	108%	19	220	111%	22	20.3	98%	-0.4
	Total	**290.2**	**108%**	**21.2**	**541**	**107%**	**34**	**481**	**109%**	**38**	**198.5**	**100%**	**-0.2**
Tape [PB]	Tier0	306.5	105%	14.5	312	103%	10	533	103%	18	206.0	102%	3.8
	Tier1	169.5	109%	14.5	741	107%	49	610	113%	70	246.1	105%	12.4
	Total	**476.0**	**106%**	**29.0**	**1053**	**106%**	**59.0**	**1143**	**108%**	**88.0**	**452.1**	**104%**	**16.2**





2027 computing resource recommendations by CRSG

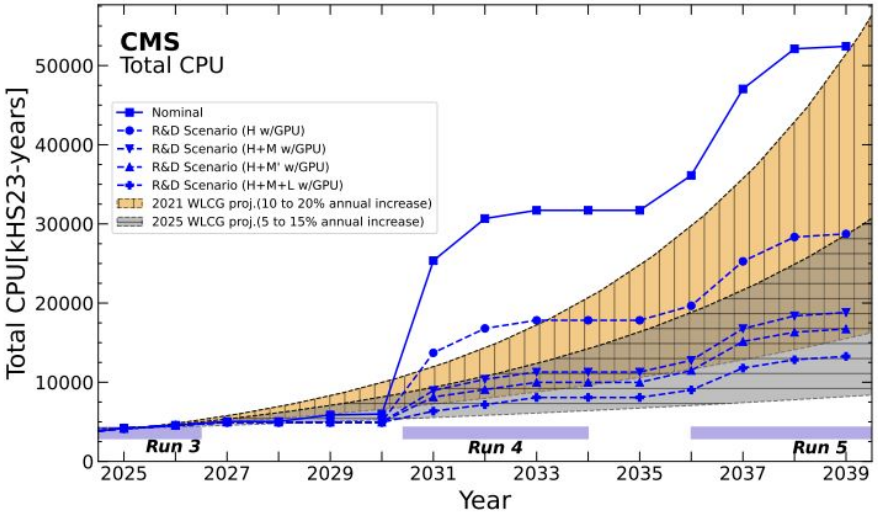
		ALICE			ATLAS			CMS			LHCb		
		2027 CRSG	2027 CRSG / 2026 RRB	2027 CRSG - 2026 RRB	2027 CRSG	2027 CRSG / 2026 RRB	2027 CRSG - 2026 RRB	2027 CRSG	2027 CRSG / 2026 RRB	2027 CRSG - 2026 RRB	2027 CRSG	2027 CRSG / 2026 RRB	2027 CRSG - 2026 RRB
CPU [kHS23]	Tier0	710	100%	0	1265	100%	0	1350	100%	0	324	94%	-20
	Tier1	720	100%	0	1802	100%	0	1200	100%	0	1063	94%	-64
	Tier2	810	100%	0	2202	100%	0	2000	100%	0	594	94%	-35
	Total	**2240**	**100%**	**0**	**5269**	**100%**	**0**	**4550**	**100%**	**0**	**1981**	**94%**	**-119**
Disk [PB]	Tier0	94.2	105%	4.2	65	100%	0	81	100%	0	73.4	104%	2.5
	Tier1	93.6	104%	3.6	214	108%	15	172	104%	8	104.8	98%	-2.3
	Tier2	94.0	106%	5.0	262	108%	19	209	106%	11	20.3	98%	-0.4
	Total	**281.8**	**105%**	**12.8**	**541**	**107%**	**34**	**462**	**104%**	**19**	**198.5**	**100%**	**-0.2**
Tape [PB]	Tier0	306.5	105%	14.5	312	103%	10	533	103%	18	206.0	102%	3.8
	Tier1	169.5	109%	14.5	741	107%	49	610	113%	70	246.1	105%	12.4
	Total	**476.0**	**106%**	**29.0**	**1053**	**106%**	**59.0**	**1143**	**108%**	**88.0**	**452.1**	**104%**	**16.2**

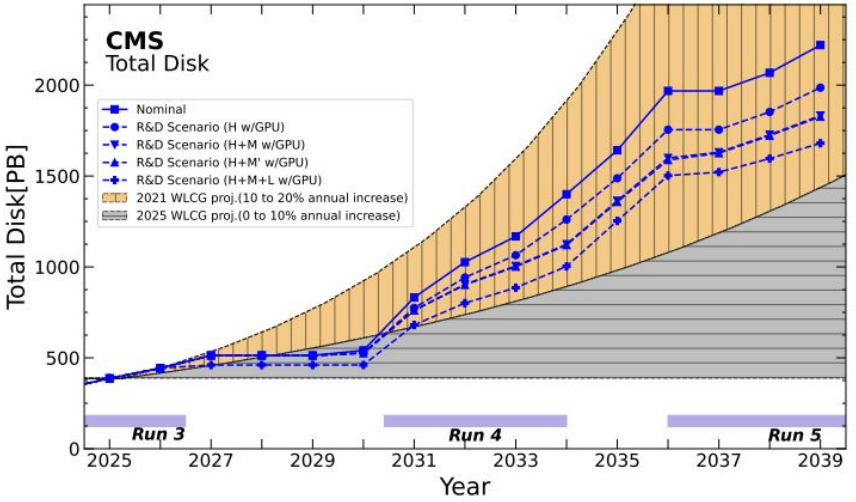
- No CPU increase recommended for all experiments
  - ALICE requested a 7% CPU increase (+60 kHS23) at Tier2 level
- Recommend to cap requested disk increase to 50% at Tier1 and Tier2 levels
  - Recover rest of the requested increase by deleting cold data on disk
  - Affecting ALICE and CMS
    - Very low level of cold data in ATLAS; LHCb does not request disk increases for 2027
- Recommend to grant requested tape increases for all experiments

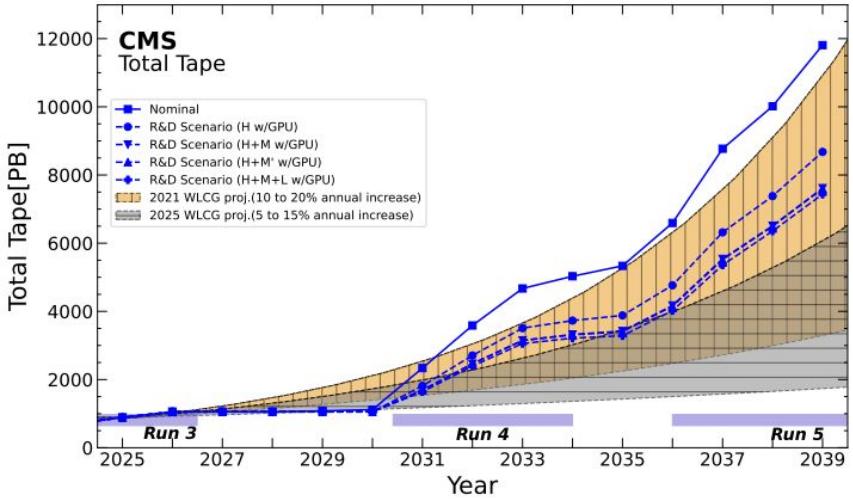
Long-term resource projections

- The CRSG had recommended 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 has provided his resource projections in the recently published Computing & Offline software for HL-LHC Conceptual Design Report
- LHCb has provided the resource projections in the 2027 resource request document (LHC-PUB-2026-001)
- ATLAS plans to release updated long-term resource projections in its forthcoming HL-LHC Software and Computing Technical Design Report
- We have requested ALICE to provide the resource projections

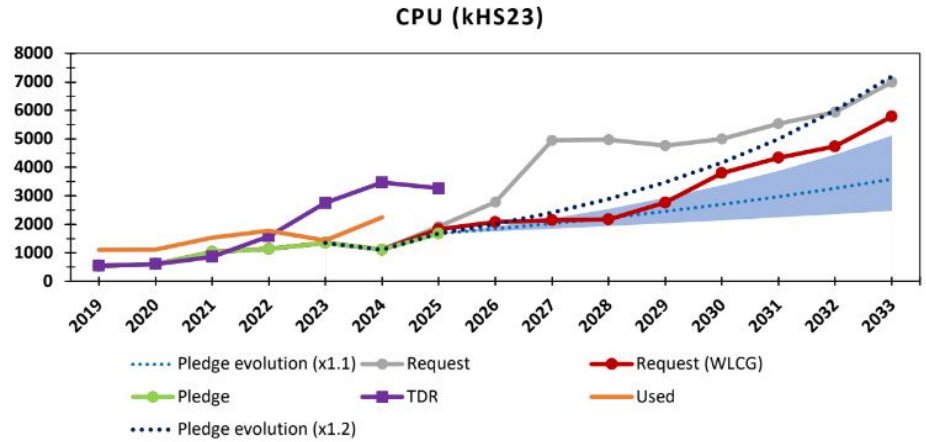
Long-term resource projections: CMS

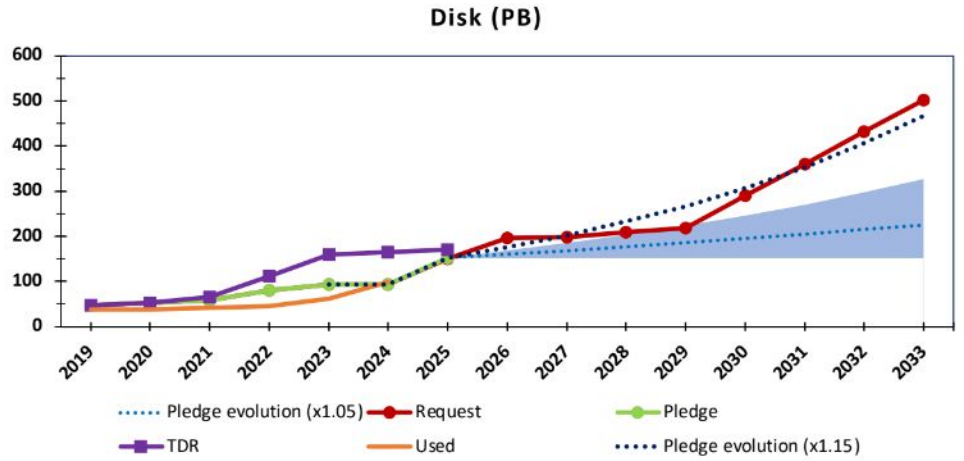


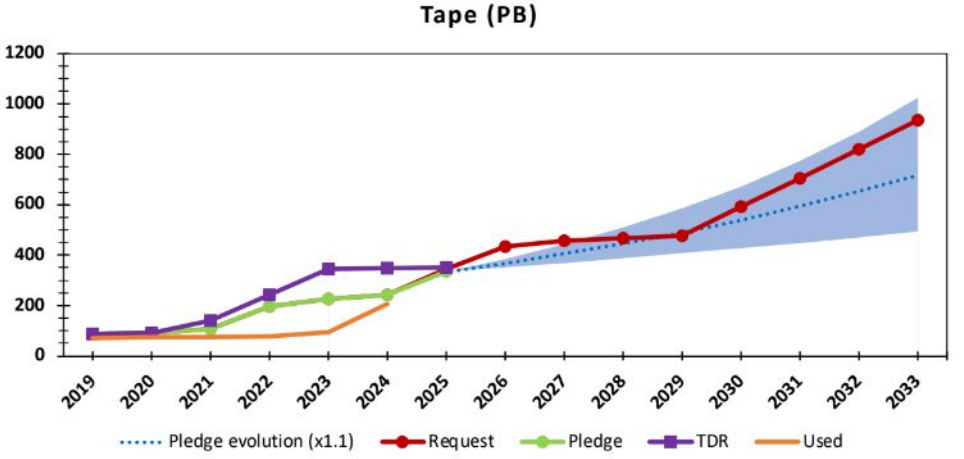




Long-term resource projections: LHCb







ALICE recommendations summary

1. Include more detailed information in resource usage and request documents
2. No increase of CPU resources in 2027
3. Reduce the volume of cold data on disk
   - Adopt best practices for access monitoring and data management
   - Target: data not accessed by one year <10% of the total data volume on disk
   - Streamline procedures with physics community to enable more timely data lifecycle management
4. Disk capacity increase requested for 2027 at Tier1 and Tier2 levels limited to 50% of the current request
5. Provide long-term projections of resource needs

ATLAS recommendations summary

1. Quantify the benefits and long-term expectations of having opportunistic tape at Tier 2 sites

CMS recommendations summary

1. Report on improvements on data access monitoring, particularly with respect to identifying unaccessed datasets
2. Provide detailed analysis of the nature of cold data on disk
3. Review locally managed disk space at Tier2 sites
4. Study CPU inefficiencies of analysis jobs; consider managed execution
5. CPU requested for analysis activities drastically reduced for 2027, relying on opportunistic CPU: risky approach; provide fallback plan
6. Reduce the volume of cold data on disk
   - Adopt best practices for access monitoring and data management
   - Target: data not accessed by one year <10% of the total data volume on disk
   - Streamline procedures with physics community to enable more timely data lifecycle management
7. Disk capacity increase requested for 2027 at Tier1 and Tier2 levels limited to 50% of the current request

LHCb recommendations summary

1. Work in reducing CPU requirements for full simulation
   - Investigate reasons for being a factor of two higher than the planned value for 2027 resource requests
2. Low proportion of fast vs full simulation productions (1:1 vs 2:1 design)
   - Strengthen engagement with the physics groups to prioritise the validation and adoption of fast simulation
3. Clarify CPU accounting issues at Tier2 sites
4. Reduce the volume of cold data on disk
   - Adopt best practices for access monitoring and data management
   - Target: data not accessed by one year <10% of the total data volume on disk
   - Streamline procedures with physics community to enable more timely data lifecycle management

Summary of global recommendations

MC simulation is the primary driver of CPU consumption: the C-RSG recommends accelerating full MC simulation and expand the use of fast simulation techniques

1. Prioritize efforts to improve performance of simulation
   - Provide historical evolution of performance
2. Strengthen their efforts on physics corrections, calibrations, and validation activities needed to enable the broader use of fast simulation
   - Requires strong engagement from the physics community

The efficient use of CPU resources has been closely monitored by the C-RSG

3. Request reporting the fraction of total CPU resources consumed by failed jobs

Summary of global recommendations

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

4. Report utilisation and management of user and analysis-group data on disk
    - Volume, data access and usage patterns, retention and lifecycle management policies

The C-RSG considers it important that resource projections continue to be updated regularly as this information is essential to support the long-term planning of funding agencies

5. Update projections covering the Long Shutdown 3 and Run 4 periods whenever significant changes occur

Summary

- The C-RSG is 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 resource
- The management of unused data on disk should be improved
  - Already subject to recommendations in previous C-RSG reports
  - ATLAS is the exception
- Modest increase of resources requested for 2027
  - No increase in CPU recommended by the C-RSG
  - Limit requested disk increases at Tier1 and Tier2 levels to 50% (except for ATLAS)
  - The C-RSG recommends to grant the requested tape increases

Backup slides

ALICE recommendations

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
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 recommendations

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-R recommends that these **procedures be streamlined** to enable more timely data lifecycle management

ALICE recommendations

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

ATLAS recommendations

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**.

CMS recommendations

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.
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.
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 recommendations

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.

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 recommendations

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-R recommends that these **procedures be streamlined** to enable more timely data lifecycle management
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 l**imited to 50%** of the current request, with the remaining needs to be met through the deletion of cold data.

LHCb recommendations

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.
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 recommendations

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 recommendations

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-R recommends that these **procedures be streamlined** to enable more timely data lifecycle management

Overall recommendations

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 f**ast simulation** techniques wherever appropriate.

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.
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.

Overall recommendations

Efficient use of CPU resources: monitor wasted CPU by failed jobs in addition to CPU efficiency (wallclock time over CPU time)

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.

Overall recommendations

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.

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.

Overall recommendations

Long-term projections of computing resource needs important to support funding agencies in defining the most effective investment strategies

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.