LHCb Computing
Resource usage in 2015 (II)

LHCb Public Note
Issue: First version
Revision: 0
Reference: LHCb-PUB-2016-004
Created: 4th February 2015
Last modified: 15 February 2016
Prepared By: LHCb Computing Project
C. Bozzi/Editor
Abstract

This document reports the usage of computing resources by the LHCb collaboration during the period January 1st – December 31st 2015.

The data in the following sections has been compiled from the EGI Accounting portal: https://accounting.egi.eu. For LHCb specific information, the data is taken from the DIRAC Accounting at the LHCb DIRAC Web portal: http://lhcb-portal-dirac.cern.ch.
Table of Contents

1. INTRODUCTION ........................................................................................................................................... 1

2. COMPUTING ACTIVITIES DURING 2015 ................................................................................................. 2

3. USAGE OF CPU RESOURCES ....................................................................................................................... 3

   3.1. WLCG ACCOUNTING ............................................................................................................................... 4

   3.2. LHCb DIRAC CPU ACCOUNTING .......................................................................................................... 7

4. USAGE OF STORAGE RESOURCES ............................................................................................................. 14

   4.1. TAPE STORAGE ........................................................................................................................................ 14

   4.2. DISK STORAGE ....................................................................................................................................... 17

   4.3. DISK AT TIER2S ..................................................................................................................................... 20

5. DATA POPULARITY ......................................................................................................................................... 22

6. COMPARISON BETWEEN USED STORAGE AND PREVIOUS FORECAST ............................................. 25

7. THROUGHPUT RATES .................................................................................................................................... 26

8. SUMMARY ..................................................................................................................................................... 27
List of Figures

Figure 3-1: Summary of LHCb computing activities (used CPU power) from Jan 1<sup>st</sup> to Dec 31<sup>st</sup> 2015. The line represents the 2015 pledge, rescaled in order to match the difference between CPU power measurements in EGI and DIRAC (see footnote 4 in Section 3.2). .................................................................................................................. 3

Figure 3-2: Summary of LHCb site usage (used CPU power) from Jan 1<sup>st</sup> until Dec 31<sup>st</sup> 2015.................................................................................................................................................. 4

Figure 3-3: Monthly CPU work provided by the Tier1s (and Tier0) to LHCb from Jan 1<sup>st</sup> until December 31<sup>st</sup> 2015.............................................................................................................................................. 5

Figure 3-4: Monthly CPU work provided by the Tier2s to LHCb from Jan 1<sup>st</sup> until December 31<sup>st</sup> 2015.............................................................................................................................................. 6

Figure 3-5: CPU time consumed by LHCb during Jan 1<sup>st</sup>—Dec 31<sup>st</sup> 2015 (in days), for WLCG sites, excluding the HLT farm (top, per country), and non-WLCG sites, including the HLT farm and commercial clouds (bottom, per site). .................................. 8

Figure 3-6: Usage of LHCb Tier0/1s during Jan 1<sup>st</sup> — Dec 31<sup>st</sup> 2015. The top plot shows the used CPU power as a function of the different activities, while the bottom plot shows the contributions from the different sites. ................................................................. 9

Figure 3-7: Usage of LHCb resources outside Tier0 and Tier1s during Jan 1<sup>st</sup>— Dec 31<sup>st</sup> 2015. The top plot shows the used CPU power as a function of the different activities, while the bottom plot shows the contributions from the different sites. MC simulation jobs at commercial cloud sites are further detailed in Figure 3-8. User jobs (shown in magenta in the top plot) are further detailed in Figure 3-9................................. 10

Figure 3-8: Running simulation jobs on commercial cloud sites in November-December 2015................................................................. 11

Figure 3-9: Running user jobs on sites other than Tier1s (top) and Tier-2D sites (bottom) during Jan 1<sup>st</sup> – Dec 31<sup>st</sup> 2015........................................................................................................................................ 12

Figure 3-10: CPU time as a function of the job final status for all jobs (top), and as a function of activity for stalled jobs (bottom) ........................................................................................................ 13

Figure 4-1: Tape space occupancy for RAW data, January-December 2015 ................. 14

Figure 4-2: Tape space occupancy for RAW data collected in 2015, grouped by activity........ 15

Figure 4-3: Tape occupancy for RDST data, January-December 2015........................ 15

Figure 4-4: Tape occupancy for RDST data corresponding to 2015 data taking .......... 16

Figure 4-5: Tape occupancy for derived data, January-December 2015..................... 16

Figure 4-6: Usage of Disk resources at CERN and Tier1s from Jan 1<sup>st</sup> to December 31<sup>st</sup> 2015. Real data and simulated data are shown in the top and bottom figures. ........ 18

Figure 4-7: Usage of buffer disk from January 1<sup>st</sup> to December 31<sup>st</sup> 2015............... 19

Figure 4-8: Usage of disk resources reserved for Users from January 1<sup>st</sup> to December 31<sup>st</sup> 2015................................................................. 19

Figure 4-9: Usage of disk space at Tier-2D sites from Jan 1<sup>st</sup> to December 31<sup>st</sup> 2015, for real data (top) and simulated data (bottom). ................................................................. 21
Figure 5-1: Disk occupancy for derived data in the second half of 2015, grouped by activity.

Figure 5-2: Volume of accessed datasets as a function of the number of accesses in the last 13 weeks.

Figure 5-3: Volume of accessed datasets as a function of the number of accesses in the last 26 weeks.

Figure 5-4: Volume of accessed datasets as a function of the number of accesses in the last 52 weeks.

Figure 6-1: Forecast and used tape in 2015, by category.

Figure 6-2: Forecast and used disk in 2015, by category.

Figure 7-1: Throughput rates for exports of RAW data from the online farm to the CERN Tier0 (top) and from the Tier0 to Tier1s (bottom).
List of Tables

Table 1-1: LHCb estimated resource needs for 2015 (September 2014). .........................1
Table 1-2: Site 2015 pledges for LHCb.................................................................1
Table 3-1: Average CPU power provided to LHCb during Jan-Dec 2015 (Tier0 + Tier1s).5
Table 3-2: Average CPU power provided to LHCb from Jan 1st until December 31st 2015, in WLCG sites other than the Tier0 and Tier1s..................................................6
Table 4-1: Situation of Disk Storage resource usage as of December 31st 2015, available and installed capacity as reported by SLS, and 2015 pledge. The contribution of each Tier1 site is also reported. .................................................................17
Table 4-2: Available and used disk resources at Tier-2D sites on December 31st 2015. 20
1. Introduction

As part of the WLCG resource review process, experiments are periodically asked to justify the usage of computing resources that have been allocated to them. The requests for the 2015 period were presented for the first time in LHCb-PUB-2014-014, and confirmed in LHCb-PUB-2014-041. Table 1-1 shows the requests to WLCG. For CPU, an additional power of 10kHS06 and 10kHS06 were deemed to be available from the HLT and Yandex farms, respectively.

<table>
<thead>
<tr>
<th></th>
<th>CPU (kHS06)</th>
<th>Disk (PB)</th>
<th>Tape (PB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 0</td>
<td>36</td>
<td>5.5</td>
<td>11.2</td>
</tr>
<tr>
<td>Tier 1</td>
<td>118</td>
<td>11.7</td>
<td>23.7</td>
</tr>
<tr>
<td>Tier 2</td>
<td>66</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Total WLCG</td>
<td>220</td>
<td>19.1</td>
<td>34.9</td>
</tr>
<tr>
<td>Non WLCG</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1-1: LHCb estimated resource needs for 2015 (September 2014).*

The last update to the pledge of computing resources for LHC from the different sites can be found in: [http://wlcg-rebus.cern.ch/apps/pledges/resources/](http://wlcg-rebus.cern.ch/apps/pledges/resources/). The LHCb numbers for 2015 are summarized in Table 1-2.

<table>
<thead>
<tr>
<th></th>
<th>CPU (kHS06)</th>
<th>Disk (PB)</th>
<th>Tape (PB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 0</td>
<td>36</td>
<td>5.5</td>
<td>11.2</td>
</tr>
<tr>
<td>Tier 1</td>
<td>139</td>
<td>14.0</td>
<td>28.1</td>
</tr>
<tr>
<td>Tier 2</td>
<td>61</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Total WLCG</td>
<td>236</td>
<td>21.5</td>
<td>39.3</td>
</tr>
</tbody>
</table>

*Table 1-2: Site 2015 pledges for LHCb.*

The present document covers the resource usage by LHCb in the period January 1st – December 31st 2015. It is organized as follows: section 2 presents the computing activities; section 3 shows the usage of CPU resources; section 4 reports on the usage of storage resources. Section 5 shows the results of a study on data popularity. A comparison of storage usage with the initial forecast is given in Section 6; throughput rates are discussed in Section 7. Finally everything is summarized on Section 8.
2. Computing activities during 2015

The usage of offline computing resources involved: (a) the production of simulated events, which runs continuously; (b) the legacy stripping of Run1 data and the regeneration of micro-DST from the MDST.DST\(^1\) related to this legacy stripping; (c) a “swimming”\(^2\) cycle of the Run 1 dataset; (d) running user jobs; (e) processing data taken in Run2 in proton, ion, and proton-ion collisions.

Activities related to data taking were tested at the end of May and started at the beginning of the LHC physics run at the end of June. They ramped up during autumn, when most of the data were collected and the full processing chain was successfully exercised.

LHCb has implemented in Run2 a new trigger strategy, by which the high level trigger is split in two parts. The first one, synchronous with data taking, writes events at a 150kHz output rate in a temporary buffer. Real-time calibrations and alignments are then performed and used in the second high-level trigger stage, where event reconstruction algorithms as close as possible to those run offline are applied.

Events passing the high level trigger selections are sent to offline, either via a “FULL” stream of RAW events which are then reconstructed and processed as in Run1, or via a “TURBO” stream which outputs the results of the online reconstruction in a micro-DST format which does not require further processing and can be used right away for physics analysis.

The LHCb computing model is assuming 10kHz of FULL stream and 2.5kHz of TURBO stream in proton collisions. In 2015, rates of up to 18kHz and 5kHz were measured for FULL and TURBO, resulting in a throughput rate of up to 1.4GB/s and a transfer rate to the Tier0 of up to 750MB/s. Given the LHC live time in 2015 being considerably lower than initially foreseen, the offline resources were enough to cope with these higher rates. Plans are currently under way in order to reduce these rates in 2016 to those foreseen in the computing model.

In 2015, the RAW data associated to the TURBO stream were written to storage for validation reasons. However, it is planned to drop these RAW data already for data taking in 2016, when the TURBO stream will be fully validated.

Other than proton collisions, LHCb also took data in ion collisions during the last weeks of 2015, and proton-ion collisions in a fixed-target configuration. The associated datasets account for less than 20% of the total.

As in previous years, LHCb used successfully resources at Tier 2 sites with disk (T2D), and continued to make use of opportunistic resources, which are not pledged to WLCG, which significantly contributed to the overall usage.

---

1 The MDST.DST is a DST stream out of the stripping, containing all events selected by micro-DST streams. It can be used to regenerate micro-DSTs without rerunning the stripping in case analysts miss some important information.

2 The swimming procedure allows to determine and correct for acceptance biases due to the LHCb trigger when performing time-dependent analyses.
3. Usage of CPU Resources

The number of running jobs is generally consistent with the 2015 pledges. The CPU usage increased due to activities related to data taking in the last four months of 2015, when the LHC provided more stable running conditions.

Computing activities (see Figure 3-1) were dominated by Monte Carlo production. Figure 3-1 also shows a continuous contribution due to user jobs and periods where Stripping and Swimming were performed. Reconstruction of collision data was performed while taking data from July onwards. After Technical Stop 2, the ramp up of the LHC luminosity provided the bulk of data accumulated by LHCb in 2015. Most of the data were taken from proton collision. These data were subsequently stripped and made available to the analysts, following the computing model. The remainder was taken from proton-ion collisions in a fixed-target configuration and, for the first time in LHCb, from ion collisions.

The production of simulated events has been somewhat decreasing during summer. A new simulation cycle is currently undergoing its final validation phase and will start soon, with a corresponding increase in the usage of CPU resources.

Figure 3-1: Summary of LHCb computing activities (used CPU power) from Jan 1st to Dec 31st 2015. The line represents the 2015 pledge, rescaled in order to match the difference between CPU power measurements in EGI and DIRAC (see footnote 4 in Section 3.2).
The jobs were split in the various centers, according to the computing resources offered to LHCb (Figure 3-2). The Tier0 and seven Tier1s contribute about 60%, the rest is due to Tier2s, with significant amounts from Tier-2D with disk, and unpledged resources (the Yandex farm and commercial clouds among them).

The LHCb Online HLT farm was the site running the fifth largest number of jobs. Due to the preparation for the 2015 data taking, it was no longer available after May. It became available again after the end of data taking in December, when it was used for Monte Carlo production.

![Normalized CPU usage by Site](image)

**Figure 3-2:** Summary of LHCb site usage (used CPU power) from Jan 1st until Dec 31st 2015.

### 3.1. WLCG Accounting

The usage of WLCG CPU resources by LHCb is obtained from the different views provided by the EGI Accounting portal. The CPU usage is presented in Figure 3-3 for the Tier1s and in Figure 3-4 for Tier2s. The same data is presented in tabular form in Table 3-1 and Table 3-2.

---

3 Including WLCG Tier2 sites that are not pledging resources to LHCb but are accepting LHCb jobs.
The average power used at Tier0+Tier1 sites is about 15% lower than the pledges. The average power used at Tier2s is about 30% higher than the pledges.

The average CPU power accounted for by WLCG (including Tier0/1 + Tier2) amounts to \((154+84) = 238 \text{ kHS06}\), to be compared to 240 kHS06 estimated needs quoted in Table 1-1. Additional computing power was used at the LHCb HLT farm and non-WLCG sites, for an estimated contribution of about 40 kHS06 on average (see Figure 3-5). Therefore the used CPU resources were 15% higher with respect to initial estimations.

Less CPU power than anticipated was used at the Tier0. The Tier1s usage is generally in line with the pledges. The discrepancy for the RAL Tier1 is overcompensated by the CPU used at the UK Tier2s, the largest one being located also at RAL. In general, the LHCb computing model is flexible enough to use computing resources wherever available.

![LHCb Tier0/1 Accounting 2015](image)

*Figure 3-3: Monthly CPU work provided by the Tier1s (and Tier0) to LHCb from Jan 1st until December 31st 2015.*

<table>
<thead>
<tr>
<th>&lt;Power&gt;</th>
<th>Used (kHS06)</th>
<th>Pledge (kHS06)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-CERN</td>
<td>17.9</td>
<td>36</td>
</tr>
<tr>
<td>DE-KIT</td>
<td>17.0</td>
<td>19.6</td>
</tr>
<tr>
<td>ES-PIC</td>
<td>8.5</td>
<td>7.7</td>
</tr>
<tr>
<td>FR-CCIN2P3</td>
<td>30.2</td>
<td>23</td>
</tr>
<tr>
<td>IT-INFN-CNAF</td>
<td>28.1</td>
<td>23.6</td>
</tr>
<tr>
<td>NL-T1</td>
<td>16.3</td>
<td>15.7</td>
</tr>
<tr>
<td>RRC-KI-T1</td>
<td>14.0</td>
<td>14.2</td>
</tr>
<tr>
<td>UK-T1-RAL</td>
<td>21.8</td>
<td>35.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>153.8</strong></td>
<td><strong>175.2</strong></td>
</tr>
</tbody>
</table>

*Table 3-1: Average CPU power provided to LHCb during Jan-Dec 2015 (Tier0 + Tier1s).*
Figure 3-4: Monthly CPU work provided by the Tier2s to LHCb from Jan 1st until December 31st 2015

<table>
<thead>
<tr>
<th>&lt;Power&gt;</th>
<th>Used (kHS06)</th>
<th>Pledge (kHS06)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>1.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>France</td>
<td>17.4</td>
<td>12.9</td>
</tr>
<tr>
<td>Germany</td>
<td>1.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Israel</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Italy</td>
<td>6.2</td>
<td>7.9</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>Poland</td>
<td>7.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Romania</td>
<td>1.3</td>
<td>4.9</td>
</tr>
<tr>
<td>Russia</td>
<td>7.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Spain</td>
<td>8.2</td>
<td>3</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1.9</td>
<td>7</td>
</tr>
<tr>
<td>UK</td>
<td>29.1</td>
<td>13.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>84.1</strong></td>
<td><strong>61.2</strong></td>
</tr>
</tbody>
</table>

Table 3-2: Average CPU power provided to LHCb from Jan 1st until December 31st 2015, in WLCG sites other than the Tier0 and Tier1s.
3.2. LHCb DIRAC CPU Accounting

The sharing of CPU time (in days) is shown in Figure 3-5. The top chart reports the CPU time per country provided by WLCG sites, including the ones not providing a pledge for LHCb, and excluding the HLT farm. The bottom chart shows the CPU time per site provided by non-WLCG sites. The HLT farm at CERN and the Yandex farm in Russia are dominant contributors as usual. Other farms (Ohio Supercomputing Center and Zurich) provide sizeable computing. A small contribution also comes from commercial cloud resources procured by CERN (Deutsche Boerse Cloud Exchange and Microsoft Azure), which were used by LHCb in November and December 2015.

The CPU power used at Tier0/1s is detailed in Figure 3-6. As seen in the top figure, simulation jobs are dominant (70% of the total), with user jobs contributing about 13% to the total, the incremental stripping of Run1 data stripping contributing significantly in January, and the rest being used for activities related to the 2015 data taking.

The contributions from the Tier2s and other non-WLCG sites are shown in Figure 3-7. It shows that their contribution is mostly dedicated to simulation (93%) and user jobs (6%). In 2015, LHCb introduced the concept of “mesh processing”, which allows Tier2 sites to dynamically contribute to workflows related to real data (i.e. reconstruction and stripping). In this way, work can be distributed across sites and tier levels in a very flexible way. Jobs related to mesh processing, and contributing to nearly 1% of the total jobs at Tier2s, are visible in Figure 3-7 in October and November 2015.

Figure 3-8 shows the number of MC simulation jobs on commercial clouds procured by CERN (DBCE and Azure). The contribution of these sites to the total CPU was relatively small, but their integration in LHCb workflows was a useful experience in view of the upcoming exploitation of additional cloud resources in 2016, such as those expected from the 3rd round of commercial cloud procurement at CERN and from the HNSciCloud project. In particular, the LHCb job execution workflow was successfully modified to allow the efficient exploitation of multi-processor virtual machines in the DBCE cloud, by allowing the concurrent execution of multiple single-processor jobs within separate pilots.

Figure 3-9 shows the number of user jobs per site for sites other than Tier1s (top) and at Tier-2D sites (bottom). They typically consist of fast parameterized simulations or final selections/fits, which do not need input data, but there are also user jobs running on stripped (micro)DSTs placed on Tier-2D disks.

Figure 3-10 shows pie charts of the CPU days used at all sites as a function of the final status of the job (top) and as a function of the activity when jobs are stalled (bottom plot). About 93% of all jobs complete successfully. The major contributors to unsuccessful jobs are “stalled” jobs, which are mostly killed by the site where the jobs are executed. By looking at the bottom plot of Figure 3-10, one can see that stalled jobs are due to user jobs in 50% of the cases. This was generally due to a handful of individual users. The other 50%, happens in Monte Carlo simulation, and is typically due to failures in getting the

---

4 There is a long-standing difference between the CPU power measured in DIRAC and the one measured in EGI. An analysis of data obtained from the two accounting systems results in an average scaling factor of 1.31 to be applied to the DIRAC accounting in order to match the EGI accounting.
proper size of a batch queue, or in evaluating the CPU-work needed for an event (and thus over evaluating the number of events the jobs can run).

Figure 3-5: CPU time consumed by LHCb during Jan 1st—Dec 31st 2015 (in days), for WLCG sites, excluding the HLT farm (top, per country), and non-WLCG sites, including the HLT farm and commercial clouds (bottom, per site).
Figure 3-6: Usage of LHCb Tier0/1s during Jan 1st – Dec 31st 2015. The top plot shows the used CPU power as a function of the different activities, while the bottom plot shows the contributions from the different sites.
Figure 3-7: Usage of LHCb resources outside Tier0 and Tier1s during Jan 1st — Dec 31st 2015. The top plot shows the used CPU power as a function of the different activities, while the bottom plot shows the contributions from the different sites. MC simulation jobs at commercial cloud sites are further detailed in Figure 3-8. User jobs (shown in magenta in the top plot) are further detailed in Figure 3-9.
Figure 3-8: Running simulation jobs on commercial cloud sites in November-December 2015
Figure 3-9: Running user jobs on sites other than Tier1s (top) and Tier-2D sites (bottom) during Jan 1st – Dec 31st 2015
Figure 3-10: CPU time as a function of the job final status for all jobs (top), and as a function of activity for stalled jobs (bottom)
4. Usage of Storage resources

4.1. Tape storage

Tape storage grew by about 6 PB. Of these, 4PB were due to RAW data taken in the last four months of 2015. The rest was equally shared among RDST and ARCHIVE, the latter due to the archival of Monte Carlo productions, the legacy stripping of Run 1 data, and new Run2 data. The total tape occupancy as of December 31st 2015 is 21.6 PB, 10 PB of which are used for RAW data, 5.6 PB for RDST, 6 PB for archived data. The tape efficiency factor of 0.85, included when determining the requests, is dropped in the reported tape occupancy.

![PFN space usage by StorageElement](image)

Figure 4-1: Tape space occupancy for RAW data, January-December 2015
**Figure 4-2:** Tape space occupancy for RAW data collected in 2015, grouped by activity

**Figure 4-3:** Tape occupancy for RDST data, January-December 2015
Figure 4-4: Tape occupancy for RDST data corresponding to 2015 data taking

Figure 4-5: Tape occupancy for derived data, January-December 2015
4.2. Disk storage

The evolution of Disk usage during 2015 is presented in Figure 4-6, separately for real data DST and MC DST, Figure 4-7 for buffer space, and Figure 4-8 for user disk. The buffer space is used for storing temporary files such as RDST until they are stripped or DST files before they are merged into large (5 GB) files. The increase of the data volumes during data taking periods results in a corresponding increase in the buffer space in the Tier0 and all Tier1s.

The real data DST space increased due to the legacy stripping (1 PB) at the beginning of the year. The recent removal of datasets unused since a long time allowed us to recover 1.2PB of disk space in August, which was subsequently used for storing Run2 datasets. A slight increase due to the 2015 data taking is visible in July.

Space used for simulation has increased at a regular pace of about 100 TB per month.

Table 4-1 shows the situation of disk storage resources at CERN and Tier1s, as well as at each Tier1 site, as of December 31st 2015. The used space includes derived data, i.e. DST and micro-DST of both real and simulated data, and space reserved for users. The latter accounts for 666TB in total.

<table>
<thead>
<tr>
<th>Disk (PB)</th>
<th>CERN</th>
<th>Tier1s</th>
<th>CNAF</th>
<th>GRIDKA</th>
<th>IN2P3</th>
<th>PIC</th>
<th>RAL</th>
<th>RRCKI</th>
<th>SARA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHCb accounting</td>
<td>3.98</td>
<td>11.46</td>
<td>2.40</td>
<td>1.92</td>
<td>1.56</td>
<td>0.71</td>
<td>3.13</td>
<td>0.55</td>
<td>1.20</td>
</tr>
<tr>
<td>SLS T0D1 used</td>
<td>4.08</td>
<td>11.48</td>
<td>2.43</td>
<td>1.91</td>
<td>1.56</td>
<td>0.71</td>
<td>3.12</td>
<td>0.55</td>
<td>1.20</td>
</tr>
<tr>
<td>SLS T0D1 free</td>
<td>0.72</td>
<td>2.37</td>
<td>0.17</td>
<td>0.22</td>
<td>0.22</td>
<td>0.08</td>
<td>0.06</td>
<td>0.71</td>
<td>0.35</td>
</tr>
<tr>
<td>SLS T1D0 (used+free)</td>
<td>0.91</td>
<td>3.23</td>
<td>2.72</td>
<td>0.14</td>
<td>0.03</td>
<td>0.01</td>
<td>0.20</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>SLS T0D1+T1D0 total</td>
<td>5.61</td>
<td>17.08</td>
<td>5.32</td>
<td>2.27</td>
<td>1.81</td>
<td>0.80</td>
<td>3.94</td>
<td>1.35</td>
<td>1.58</td>
</tr>
<tr>
<td>Pledge ’15</td>
<td>5.50</td>
<td>14.04</td>
<td>2.72</td>
<td>2.34</td>
<td>1.88</td>
<td>0.76</td>
<td>3.51</td>
<td>1.26</td>
<td>1.57</td>
</tr>
</tbody>
</table>

Table 4-1: Situation of Disk Storage resource usage as of December 31st 2015, available and installed capacity as reported by SLS, and 2015 pledge. The contribution of each Tier1 site is also reported.

The SLS used and SLS free information concerns only permanent disk storage (T0D1). The first two lines show a good agreement between what the site reports and what the LHCb accounting (first line) reports, except for small discrepancies at CERN and CNAF.

The total allocated space is 3PB above the 2015 pledges, 2.7PB of which are due to an artifact in the assignment of buffer space at CNAF. The available disk space (about 2.8PB, if the CNAF buffer space is not considered) is sufficient to cover the various activities foreseen until the end of the 2015 WLCG year. We anticipate that, due to the reduction in the LHC live time with respect to the one used to calculate the requests, the available disk space will not be completely used.

---

5 This total includes disk visible in SRM for tape cache. It does not include invisible disk pools for dCache (stage and read pools).
Figure 4-6: Usage of Disk resources at CERN and Tier1s from Jan 1st to December 31st 2015. Real data and simulated data are shown in the top and bottom figures.
Figure 4-7: Usage of buffer disk from January 1st to December 31st 2015.

Figure 4-8: Usage of disk resources reserved for Users from January 1st to December 31st 2015.
4.3. Disk at Tier2s

The available disk at Tier-2D is now 2.56 PB, 1.54 of which is used. Table 4-2 shows the situation of the disk space at the Tier-2D sites. Figure 4-9 shows the disk usage at Tier-2D sites.

Table 4-2: Available and used disk resources at Tier-2D sites on December 31st 2015.

<table>
<thead>
<tr>
<th>Site</th>
<th>SLS free disk (TB)</th>
<th>SLS used disk (TB)</th>
<th>SLS total disk (TB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBPF (Brasil)</td>
<td>52</td>
<td>69</td>
<td>121</td>
</tr>
<tr>
<td>CPPM (France)</td>
<td>49</td>
<td>61</td>
<td>110</td>
</tr>
<tr>
<td>CSCS (Switzerland)</td>
<td>85</td>
<td>205</td>
<td>290</td>
</tr>
<tr>
<td>IHEP (Russia)</td>
<td>7</td>
<td>58</td>
<td>65</td>
</tr>
<tr>
<td>LAL (France)</td>
<td>50</td>
<td>60</td>
<td>110</td>
</tr>
<tr>
<td>LPNHE (France)</td>
<td>58</td>
<td>72</td>
<td>130</td>
</tr>
<tr>
<td>Manchester (UK)</td>
<td>98</td>
<td>204</td>
<td>302</td>
</tr>
<tr>
<td>NCBJ (Poland)</td>
<td>109</td>
<td>201</td>
<td>310</td>
</tr>
<tr>
<td>NIPNE (Romania)</td>
<td>195</td>
<td>173</td>
<td>368</td>
</tr>
<tr>
<td>RAL-HEP (UK)</td>
<td>139</td>
<td>311</td>
<td>455</td>
</tr>
<tr>
<td>UKI (UK)</td>
<td>174</td>
<td>126</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1021</strong></td>
<td><strong>1540</strong></td>
<td><strong>2561</strong></td>
</tr>
</tbody>
</table>
Figure 4-9: Usage of disk space at Tier-2D sites from Jan 1st to December 31st 2015, for real data (top) and simulated data (bottom).
5. Data popularity

Dataset usage patterns, routinely monitored in LHCb since some years, are used to purge a significant amount of disk space. Rather old datasets that were still used in the first half of 2014, mostly for completing the analysis based on 2011 data, were no longer accessed since a few months. Therefore, they were archived in August (Figure 4-6, top plot), and the recovered disk space could be used to store datasets produced on 2015 data from proton collisions, without increasing the disk space occupancy (Figure 5-1).

Figure 5-1: Disk occupancy for derived data in the second half of 2015, grouped by activity.

Figure 5-2, Figure 5-3, and Figure 5-4 show the physical volume of disk of the accessed datasets as a function of the number of accesses in the last 13, 26, and 52 weeks. The number of usages of a dataset over a period of time is defined as the ratio of the number of files used in that dataset to the total number of files in the dataset. The first bin indicates the volume of data that were generated before and were not accessed during that period (e.g. 3.5 PB in the last 52 weeks). The last bin shows the total volume of data that was accessed (e.g. 9.0 PB in the last 52 weeks). The total amount of disk space used by the derived LHCb data is 12.7 PB. The datasets accessed at least once in 13, 26 and 52 weeks, occupy respectively 46%, 58% and 70% of the total disk space in use, respectively.

The volume in each bin is not weighted by the number of accesses.

Since this number is computed by explicitly excluding files that are not usable for physics analysis, e.g. RDST or temporary unmerged files, it is not directly comparable to the used resources mentioned in Section 4.
The dataset classifier mentioned in our previous report has been further developed and improved. The next step will be to use the estimators provided, and additional information for each storage site (space used by each dataset, total space, free space) and upcoming space needs in order to provide hints for the best placement strategy.

![Number of Disk dataset usages (last 13 weeks)](image1)

*Figure 5-2: Volume of accessed datasets as a function of the number of accesses in the last 13 weeks.*

![Number of Disk dataset usages (last 26 weeks)](image2)

*Figure 5-3: Volume of accessed datasets as a function of the number of accesses in the last 26 weeks.*
Figure 5-4: Volume of accessed datasets as a function of the number of accesses in the last 52 weeks.
6. Comparison between used storage and previous forecast

The storage usage shown in the previous sections can be compared to the forecast presented in LHCb-PUB-2014-041. Figure 6-1 and Figure 6-2 show the results of such comparison for tape and disk. The 2015 WLCG year will end on March 31st.

Lower usage of both disk and tape with respect to the forecast is mainly due to the LHC live time being considerably shorter than anticipated.

For tape, the reduction is also due to some changes in the LHCb computing model, aimed at mitigating tape growth during Run2, which would otherwise exceed what can be reasonably assumed to be available. First, it was decided to save only one copy of derived data, since it is possible to regenerate them from the RDST in case of tape loss with reasonable operational costs. Then, FULL.DSTs have been replaced by RDST, which no longer contain the RAW banks, in 2015 data. Therefore their size is about halved with respect to Run1 data.

Part of the 15% deficit in disk usage will be partly reduced by the re-stripping of Run2 data, by an incremental stripping of Run1 data, and by Monte Carlo production.

<table>
<thead>
<tr>
<th>Tape storage in 2015 (PB)</th>
<th>Forecast (LHCb-PUB-2014-041)</th>
<th>Usage (31/12/2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Data</td>
<td>12.7</td>
<td>10.0</td>
</tr>
<tr>
<td>FULL.DST</td>
<td>8.7</td>
<td>5.6</td>
</tr>
<tr>
<td>MDST.DST</td>
<td>1.8</td>
<td>6.0</td>
</tr>
<tr>
<td>Archive – Operations</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>Archive – Data preservation</td>
<td>3.1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34.9</strong></td>
<td><strong>21.6</strong></td>
</tr>
</tbody>
</table>

*Figure 6-1: Forecast and used tape in 2015, by category*

<table>
<thead>
<tr>
<th>Disk storage in 2015 (PB)</th>
<th>Forecast (LHCb-PUB-2014-041)</th>
<th>Usage (31/12/2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stripped Real Data</td>
<td>7.3</td>
<td>6.6</td>
</tr>
<tr>
<td>Simulated Data</td>
<td>8.2</td>
<td>7.3</td>
</tr>
<tr>
<td>User Data</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>MDST.DST</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>RAW and other buffers</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19.1</strong></td>
<td><strong>16.9</strong></td>
</tr>
</tbody>
</table>

*Figure 6-2: Forecast and used disk in 2015, by category*
7. Throughput rates

RAW data were exported from the pit to the CERN Tier0, and onwards to Tier1s, at the design Run2 throughput rates (Figure 7-1). Further optimization of the overall workflow is possible by merging small files at the pit, before transfer, in order to have less files and higher throughput with the FTS transfer service.

Figure 7-1: Throughput rates for exports of RAW data from the online farm to the CERN Tier0 (top) and from the Tier0 to Tier1s (bottom).
8. Summary

The usage of computing resources in the 2015 has been quite smooth for LHCb.

The legacy stripping of the Run1 dataset was completed at the end of January. A “swimming” activity was run shortly afterwards. The workflow for the Run2 data taking was exercised in the spring, and successfully put to work as soon as LHC started providing collisions.

The ramp-up of the LHC luminosity resulted in a corresponding increase of the data throughput to offline resources. Due to somewhat relaxed trigger thresholds, throughputs of up to 1.3GB/s were input to the offline system, which was able to keep up without major problems.

Simulation has been running at almost full speed using all available resources, being the dominant activity in terms of CPU work. Additional unpledged resources, as well as clouds, on-demand and volunteer computing resources, were also successfully used.

Storage resources are not a concern. It is likely that the storage resources provided to LHCb will not be saturated by the end of the WLCG year in March 2016, due to the reduced LHC live time with respect to the initial expectations.

The usage of datasets produced for physics analysis is constantly monitored, the subsequent analysis of data popularity having allowed LHCb to free a significant amount of disk space.