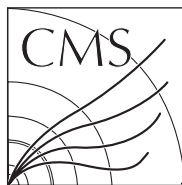


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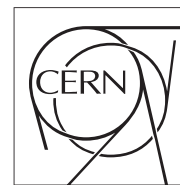
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The Compact Muon Solenoid Experiment

Conference Report

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14 May 2009

CMS Usage of the Open Science Grid and the US Tier-2 Centers

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Abstract

The CMS experiment has been using the Open Science Grid, through its US Tier-2 computing centers, from its very beginning for production of Monte Carlo simulations. In this talk we will describe the evolution of the usage patterns indicating the best practices that have been identified. In addition to describing the production metrics and how they have been met, we will also present the problems encountered and mitigating solutions. Data handling and the user analysis patterns on the Tier-2 and OSG computing will be described.

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CMS Usage of the Open Science Grid and the US Tier-2 centers

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Abstract. The CMS experiment has been using the Open Science Grid, through its US Tier-2 computing centers, from its very beginning for production of Monte Carlo simulations. In this talk we will describe the evolution of the usage patterns indicating the best practices that have been identified. In addition to describing the production metrics and how they have been met, we will also present the problems encountered and mitigating solutions. Data handling and the user analysis patterns on the Tier-2 and OSG computing will be described.

1. The Open Science Grid (OSG)

The CMS [1] experiment at the Large Hadron Collider (LHC) has extensive computing needs and has adopted a computing model which involves resources distributed world-wide, which are integrated as the world-wide LHC computing grid (WLCG) [2]. The Open Science Grid [3] is a consortium of software, service and resource providers and researchers, from universities, national laboratories and computing centers across the U.S., and is a part of WLCG. It aims to promote discovery and collaboration in data-intensive research by providing a computing facility and services that integrate distributed, reliable and shared resources to support computation at all scales. OSG brings together computing and storage resources from campuses and research communities into a common, shared grid infrastructure over research networks via a common set of middle-ware. It offers participating research communities low-threshold access to more resources than they could afford individually, via a combination of dedicated, scheduled and opportunistic alternatives. In the OSG model of operation, resource owners register their resource with the OSG and scientific researchers gain access to these resources by registering with one or more Virtual Organizations (VOs). The VO administrators register their VOs with the OSG and all approved members of the VO are allowed to access OSG resources, subject to the policies of the resource owners.

The LHC experiments CMS and ATLAS are among the many VOs that use OSG for their day-to-day operations. OSG provides packaged, tested and supported collections of software for installation on the compute and storage nodes at the participating sites. These software packages allows sites to monitor the usage and collect data to create accounting information regarding site availability, batch jobs, wall clock hours, usage of site resources by the VOs, storage allocation, data transfer over the grid etc. Figure 1 shows some of the accounting information of CMS operations on OSG from June through November 2008. The total usage (in hours) of OSG resources by different VOs from April 2008 until March 2009 is shown in Figure 2, indicating that CMS is amongst the largest users of the OSG. The CMS usage in OSG consists of MC

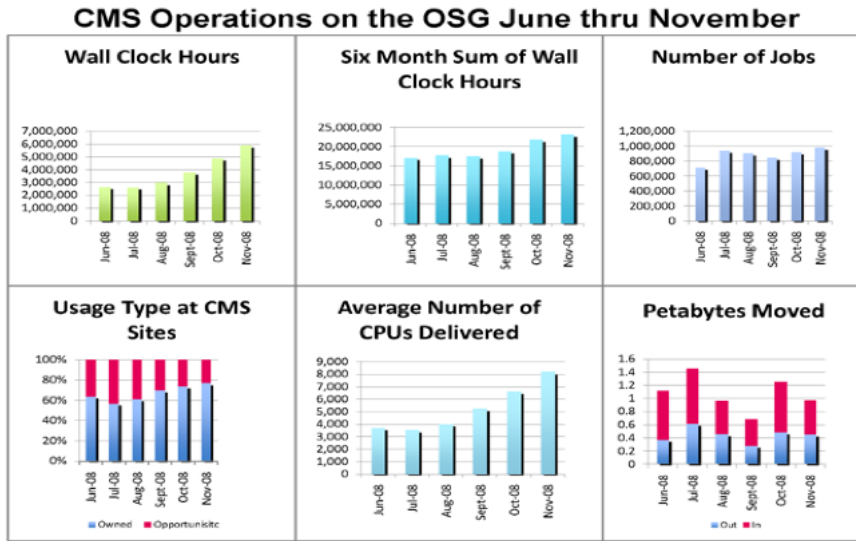


Figure 1. Accounting information regarding site availability, batch jobs, wall clock hours, usage of site resources by the VO, storage allocation, data transfer over the grid during June through November 2008.

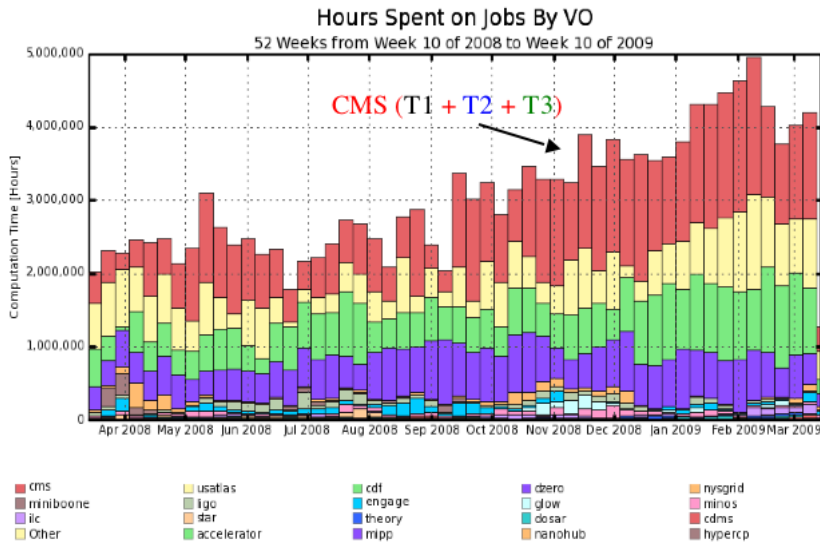


Figure 2. Total number of CPU hours used by many VOs (CMS, ATLAS, CDF, D0 etc.) in OSG. The portion of CMS usage is due to MC production and user analysis jobs at the CMS dedicated Tier-1, Tier-2 and Tier-3 centers and some opportunistic resources in the US.

production and user analysis performed at the CMS dedicated Tier-1, Tier-2 and Tier-3 center and some opportunistic sites.

2. CMS MC Production in OSG

The CMS experiment at CERN requires a large amount of Monte Carlo (MC) events to study and make predictions about the physics potentials of the experiment. This task is accomplished by the CMS data operations (DataOps) group that is responsible for the production and delivery of the billions of MC events in a timely manner. The computational workload for this “official production activity” is generated and tracked by a software package called ProdAgent [5]. The ProdAgent consists of several autonomous components that communicate with each other through persistent messages, to prevent that a crash of one component will bring the whole production agent down. Several components also communicate with external (to ProdAgent) elements such as the Data Bookkeeping Service (DBS), the CMS data transfer system (PhEDEx), and the production monitoring tool (ProdMon) to complete the production task for each workflow.

The production process follows the installation of the CMS software (CMSSW) at the participating WLCG institutions in Europe (EGEE) [4] and the US OSG [3] sites. Several ProdAgents instances are setup and managed by production teams based at CERN and Wisconsin to cover the Tier-2 sites in EGEE and OSG respectively. The CMS Tier-2 sites in EGEE and OSG are grouped into 8 Tier-2 regions with each of the 8 CMS Tier-1 centers assigned as the home (custodial) site for at least one of the Tier-2 regions where the MC data is stored in tape for archival purpose. MC samples received from the physics groups are distributed among the Tier-2 regions based on the available job slots at the Tier-2 sites and the available tape space at the corresponding (home) Tier-1 centers. The operations tasks are then handled by the production teams which include ProdAgent setup and configuration, work-flow management, tracking production failures/problems at the level of software, grid-middle-ware, at OSG/EGEE sites, migration of produced data to DBS, and initiating the data delivery via PhEDEx.

3. Routing of CMS jobs to OSG and Monitoring

Appropriate versions of the production software is periodically installed/updated in the computing server at UW Tier-2 facility. Production jobs are created and submitted to the Condor [6] batch system software equipped in the server. The jobs are then distributed to the OSG sites dynamically by the Condor JobRouter [7] with the help of a configurable “routing table” which maps jobs of varying types to OSG sites at a rate approximately equal to the rate at which jobs are able to occupy available batch slots at the respective site. The JobRouter is capable of dynamic routing (and re-routing) of jobs to sites based on dataset priorities, available resources and site productivity. A scheme of the JobRouter is shown in Figure 3.

The total number of jobs at any site at any given time is controlled by setting a threshold value on the parameters “running jobs” and “idle jobs” in the routing table. This prevents sites from being overloaded with excess number of jobs at any point in time. Until the number of idle jobs at the site go below the “idle” threshold Job Router stops routing any more jobs to that site. In this way, it can adapt to fluctuations in the availability of grid resources using direct evidence (idleness of a small number of jobs) rather than having to face the complex task of evaluating remote queue prioritization policies and resource usage in order to estimate availability of resources for making scheduling decisions.

The JobRouter relies upon feedback from the site (via the grid middle-ware) about the status of the job in the remote batch system. It incorporates the mechanism to respond to the situation where sites suddenly start to fail most or all jobs (caused by, for example, shared file-system failure, storage element failure, and unexpected state in the pre-installed application repository, a malfunctioning worker node) rapidly, refereed to as site-level “blackhole”. The JobRouter applies a throttle to the number of routing jobs to stabilize this situation which works very effectively against a complete failure of many small work-flows. For individual worker-node

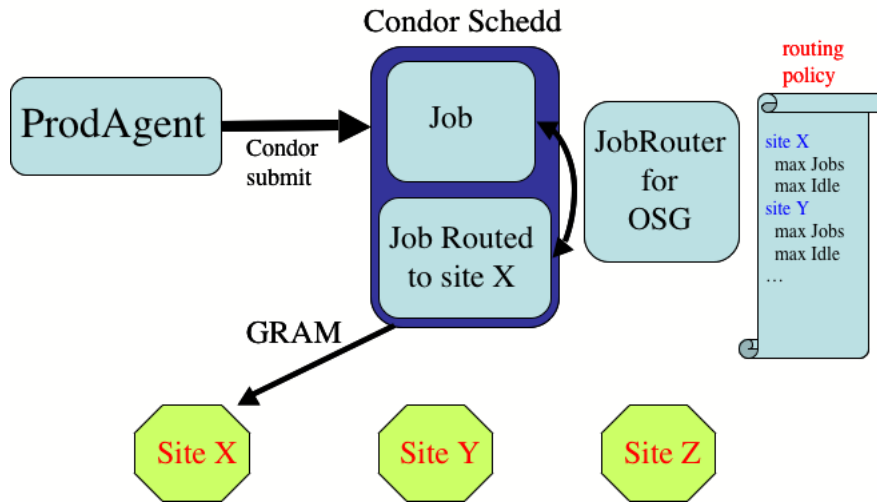


Figure 3. The JobRouter scheme used for MC production in OSG.

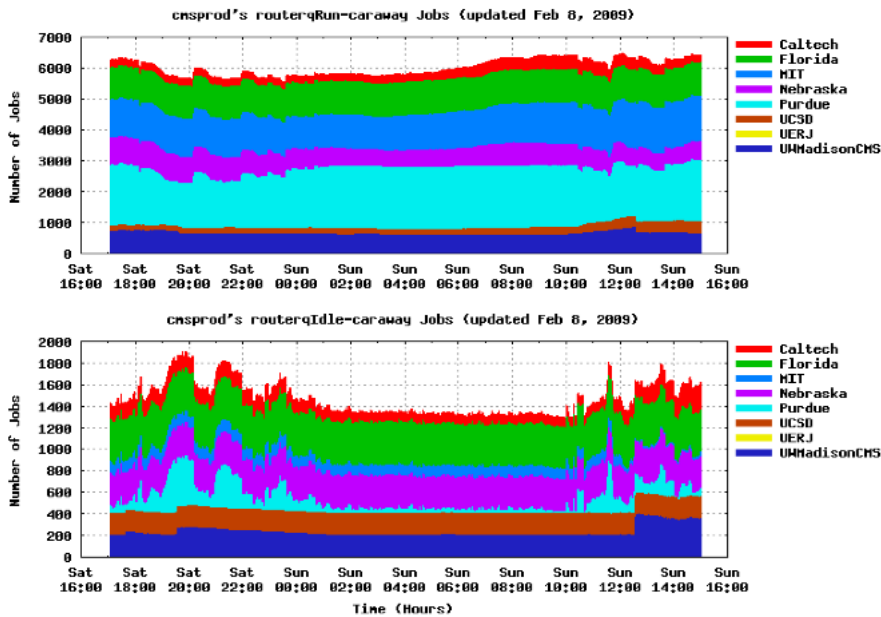


Figure 4. Monitoring of running/idle MC production jobs in OSG.

black holes, a simple approach is used in ProdAgent to limit the rate of failures on the node in order to prevent rapid consumption of all jobs waiting in the queue at the site in question.

The routing table may either be hand-coded or it may be generated by a plug-in that polls some external information source such as the OSG Resource Selection Service. The details are best left for the manual, but a simple routing table depicted in Table 3 gives the flavor of how it works.

The status of running and idle jobs from the JobRouter are monitored frequently as shown in Figure 4 and any job routing issues are addressed promptly with the help of site responsible.

```

[ name = "Florida";
  GridResource = "gt2 iogw1.hpc.ufl.edu/jobmanager-pbs";
  Requirements = other.WantJobRouter;
  MaxIdleJobs = 10;
  MaxJobs = 100;
  set_GlobusRSL = "(maxwalltime=1440)(jobType=single)";
]
[ name = "Purdue";
  GridResource = "gt2 osg.rcac.purdue.edu/jobmanager-condor";
  Requirements = other.WantJobRouter;
  MaxIdleJobs = 10;
]
[ name = "Caltech";
  GridResource = "cit-gatekeeper.ultralight.org/jobmanager-condor";
  Requirements = other.WantJobRouter;
  MaxIdleJobs = 10;
]

```

Table 1. The routing table specifying the scheduling policy and job transformation rules.

4. MC Production status and Quality in OSG

Most of the OSG sites (all CMS Tier-2s and few Tier-3s) used for production has been very reliable over the past year, but unexpected failures related to cooling, network, storage, and computing resources at sites have affected their usability for hours or days until they are resolved. The performance of the grid middle-ware (that handles the job submissions and transports files back and forth between the submit host and the sites over the grid) has remain steady over past couple of years. Intermittent problems such as user authentication, expired host or VO certificates at the sites, network connections etc., have dropped compared to previous years due to significant improvement in the operations strategy, monitoring and timely detection of issues by the site admin(s). The biggest chunk of time in running MC production is spent on the operations steps in ProdAgent that needs manual intervention by the operators and constantly watching for job failures due to various reasons.

As part of the normal production procedure, all production issues are communicated to the appropriate sources (ProdAgent, grid, sites, DBS, PhEDEx etc.) promptly whenever they are experienced and every effort is made to resolve them as soon as possible. Effective communication with the site admins regarding site related job failures (failed job logs are made available quickly at Wisconsin Tier-2 web space for sites to look at) and prompt response from them has significantly improved the production quality and reduced the possible wastage of resource usage.

With all the improvements to the ProdAgent software, enhanced scalability of the Condor batch system including improved job routing, reliability of grid-middle-ware and operational stability at sites, the performance of MC production on OSG in 2008 has increased very significantly compared to the previous years. As a result, during the period January 2008 to Feb 2009, more than 1.2 Billion (350 datasets) events (includes simulation and reconstruction) were produced using the CMS Tier-2 (and some Tier-3) sites in OSG. The contribution from various production teams is shown in Figure 5, and the contribution from the OSG sites are shown in Figure ???. Most of the MC production was done between September and Dec 2008, labeled as “Summer08” MC production. The quality of Summer08 production at all the CMS Tier-2 sites were excellent as shown in Figure 7. The empty (white) spaces in the plot corresponds to the

Merge events written (Sum: 1987268676)

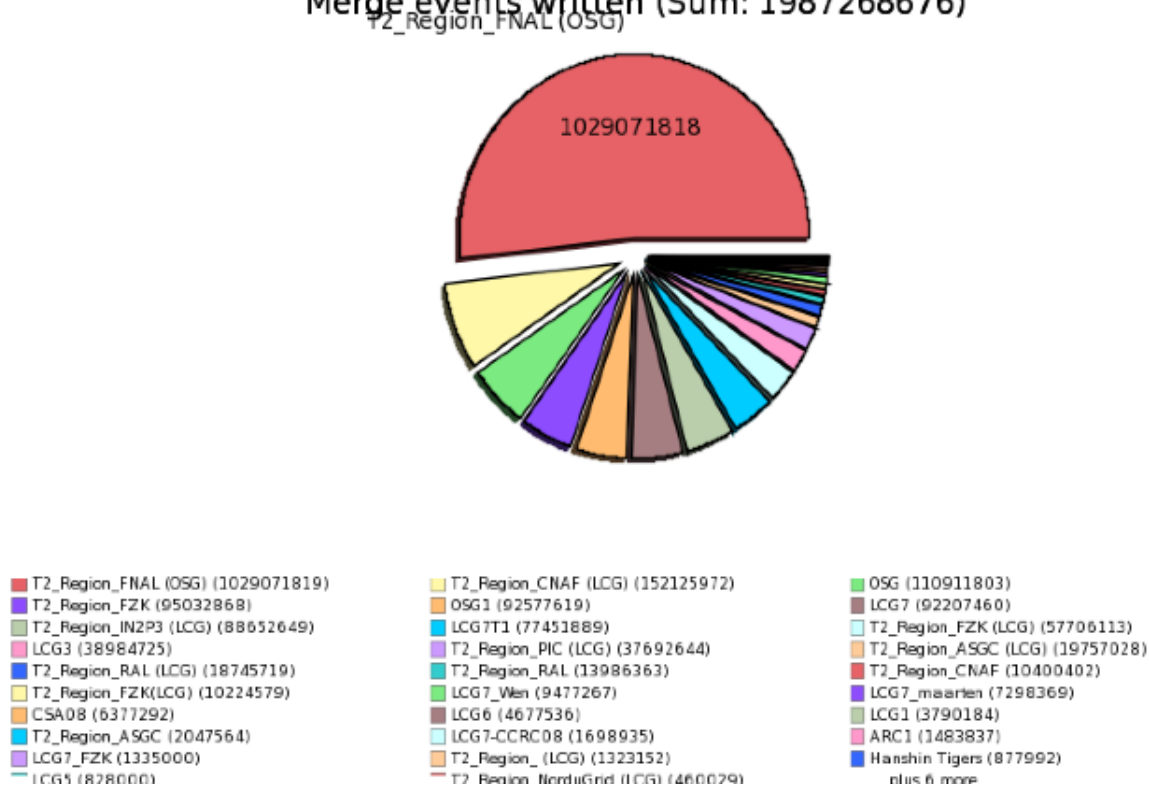


Figure 5. Simulation Events Statistics by all teams (“T2_Region_FNAL (OSG)”, “OSG”, and “OSG1” labels represent the same ProdAgent instance of OSG Tier-2 regions at different times between Jan 2008 and Feb 2009).

time when no jobs were submitted to the sites either due to planned resource maintenance or lack of production work-flows.

While the goal of CMS MC production is to produce and deliver the datasets to the users in a timely manner, every effort is made to maximize the utilization of all available computing resources at sites in a consistent manner over time. But the inevitable requirement to process the simulation, reconstruction, and skimming steps separately makes this process inefficient due to the extra intermediate steps that have to be manually performed between them. In addition multiple ProdAgent instances need to be deployed in different production servers to perform the steps independent of each other to keep the work-flows separate and avoid work-flow priority mix-ups, even though the same computing resources are shared to accomplish the task. In order to eliminate this multi-step processing, reduce the delay in data delivery time and improve the production efficiency significantly, a new approach called “Chained Processing” has been established and successfully tested. In this approach all the necessary processing tasks/tiers will be performed in a single step where the simulation, reconstruction and skim jobs will be chained together. A smaller fraction of the Summer08 production was done using the chained work-flows and no problems were found during the operation.

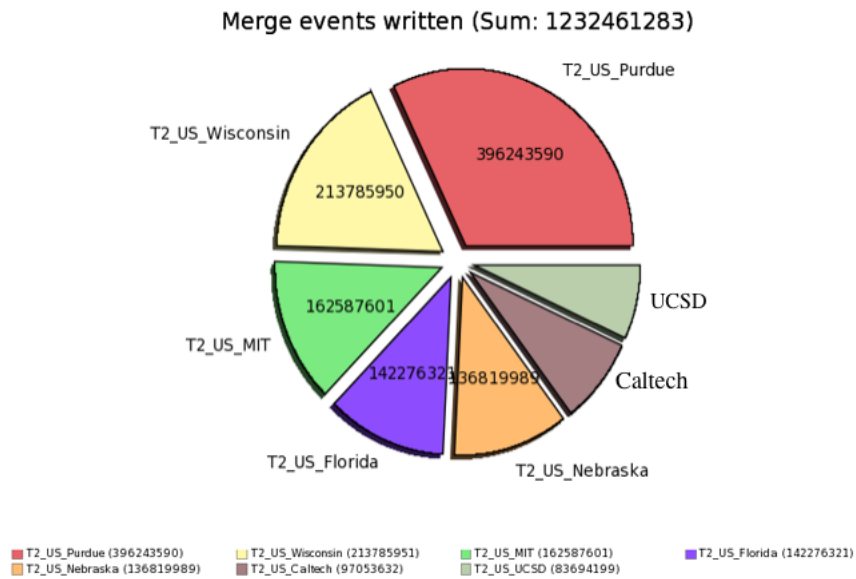


Figure 6. Production Statistics at OSG Sites (Jan 2008 until Feb 2009).

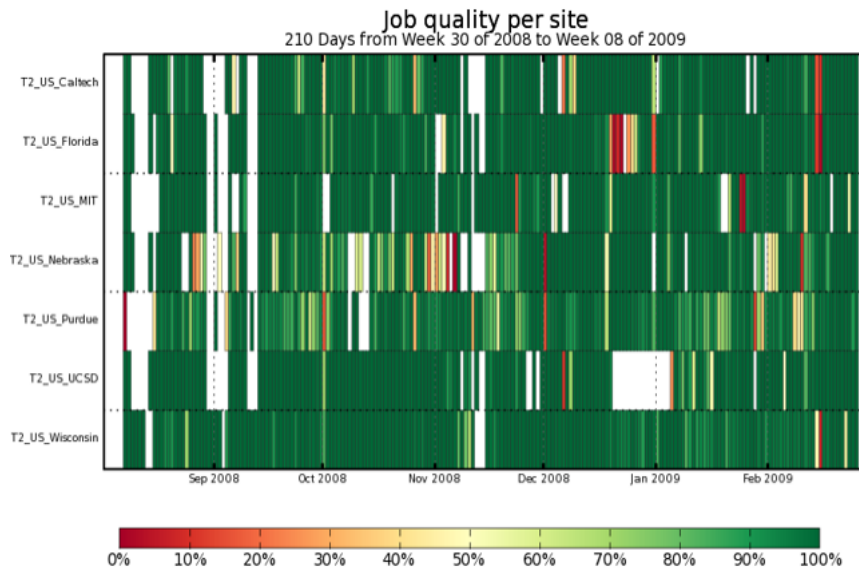


Figure 7. Summer08 production job quality at the US CMS Tier-2s.

5. CMS Data Model and Analysis @ US Tier-2 sites

The CMS computing model defines that the data collected by the CMS on-line data acquisition system is sent to the Tier-0 center at CERN where raw data is archived. A prompt reconstruction is performed and a first version of the Analysis Object Data (AOD) is produced. All the high-level physics objects are stored in the AOD together with the information sufficient to support typical analysis. Raw and first pass reconstructed events are distributed from the Tier-0 to a Tier-1 center which takes custodial responsibility for those while the AOD are also transferred to all Tier-1 sites. The Tier-1 sites provide services for data archiving, re-processing, calibration, skimming and other data-intensive analysis tasks. All AOD are transferred to the Tier-2 centers which provide resources for physics analysis.

According to the computing model each Tier-2 is associated with a certain number of physics analysis groups (PAGs). At present, in the absence of the real collision data from the CMS detector, mainly the MC samples and the cosmic muon data are subscribed by the various physics groups to the Tier-2 sites they are associated with for user analysis. Due to the distributed nature of data placement and location of the Tier-2 sites, it is inevitable that the analysis of this data has to be performed in a distributed way using the grid infrastructure by the CMS users scattered around the world. CRAB (CMS Remote Analysis Builder) [8] is a specific tool, designed and developed by the CMS collaboration to accomplish this task. It allows the end users (physicists) to access this distributed data in a transparent way by hiding the complexity of the Grid infrastructure. In this model, the user runs interactively over small data samples in order to develop and test his/her code using CMSSW. Once ready, the user submits his/her jobs through CRAB using a simple configuration file and from a User Interface to access the necessary data available at all remote sites. The configuration file contains all the needed parameters such as : the dataset that the user wants to access, the name of CMSSW specific configuration file, the job splitting parameters and procedure to manage the produced output, etc. The work-flow covered by CRAB consists of the following steps :

- The Data Discovery step, interacting with the CMS data management system (DBS) to find out whether the required data are available and the location(s);
- The interaction with CMSSW on the submit machine, so that the identical environment can be reproduced on the remote resources;
- The Grid specific step, where all tasks from job submission to output retrieval are performed;

Other useful functionalities such as complete job management (i.e. job killing, resubmission, failure analysis, etc.) are also handled by CRAB. Analysis jobs are directly submitted by the users to a set of CRAB servers which then distributes the jobs to the remote Tier-2 sites in EGEE and OSG using the steps as outlined above. The interoperability of the grid middle-ware used in the EGEE and OSG specific grid infrastructure allows user jobs to run and delivers the output in a transparent way.

Besides the use of CRAB for analysis by remote users, the local user community at each Tier-2 site have the liberty to use custom designed analysis tools to make use of the site resources more efficiently via local access without having to go through the grid. While the official MC production in CMS are done using the ProdAgent software, users can produce their private MC samples using CRAB and publish the samples to the Data Bookkeeping Service (DBS) for global access.

With the large amount of computing and storage resources, the CMS Tier-2 sites in OSG have been contributing heavily to both MC production and user analysis. Figure 8 shows the data volume at the CMS Tier-2 sites in OSG as of Feb 2009 and the number of terminated analysis jobs (as reported by CMS dashboard [9]) from June 2008 until Feb 2009 is shown in Figure 9. A compromise between the volume of MC production and user analysis at some of the sites are clearly indicated. An effective and reliable usage of the site resources has been possible

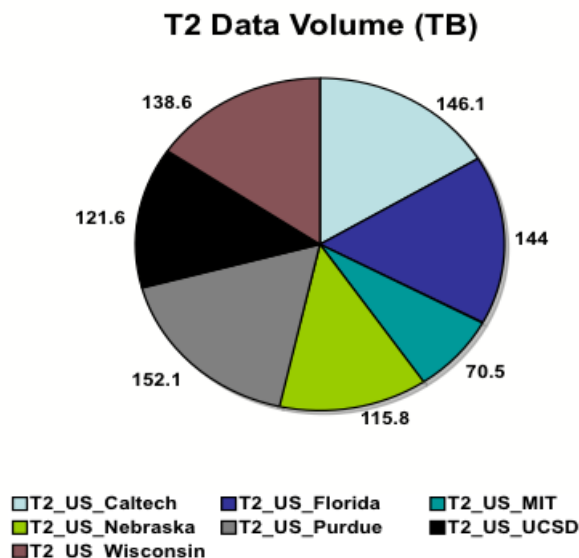


Figure 8. The volume of MC data hosted by the CMS Tier-2s in the US as of March 2009.

so far with a strong support and timely response at/from the sites and significantly more effort in this regard is already on the way as CMS moves towards the data taking in the fall of 2009.

6. Conclusion

Since its existence in 2007 the Open Science Grid has been very successful in providing a much needed infrastructure for users to accomplish their goal through distributed computing on the grid. It is evolving rapidly and expanding its services through the energetic, committed and sustained collaboration across the scientists and researchers, computing resource and software providers, and other grid infrastructures such as the worldwide LHC computing grid. It is continuously working with the user and grid communities to ensure uniform and transparent interfaces to the application layers and users to support the submission of jobs, the transport and storage of data, the monitoring and tracking of the usage. As a result, both CMS MC production and user analysis has been highly benefited from the usage of OSG for past 2 years. As the OSG facility/infrastructure continues to expand with the integration of new sites, the installation of new resources, the joining of new member communities, a greater usage of both the CMS dedicated and opportunistic resources in OSG is envisioned for future CMS operations.

Acknowledgments

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References

- [1] The CMS Experiment, <http://www.opensciencegrid.org>
- [2] LCG Project, <http://lcg.web.cern.ch/>
- [3] OSG Project, <http://www.opensciencegrid.org>
- [4] EGEE Project, <http://public.eu-egee.org/>
- [5] Evans D, Fanfanib A, Kavkac C, van Lingend F, Eulisse G, Bacchib W, Codispotib G, Masona D, De Filipisf N, and Hern JM, *Nuclear Physics B - Proceedings Supplements* **177-8** p285-6.

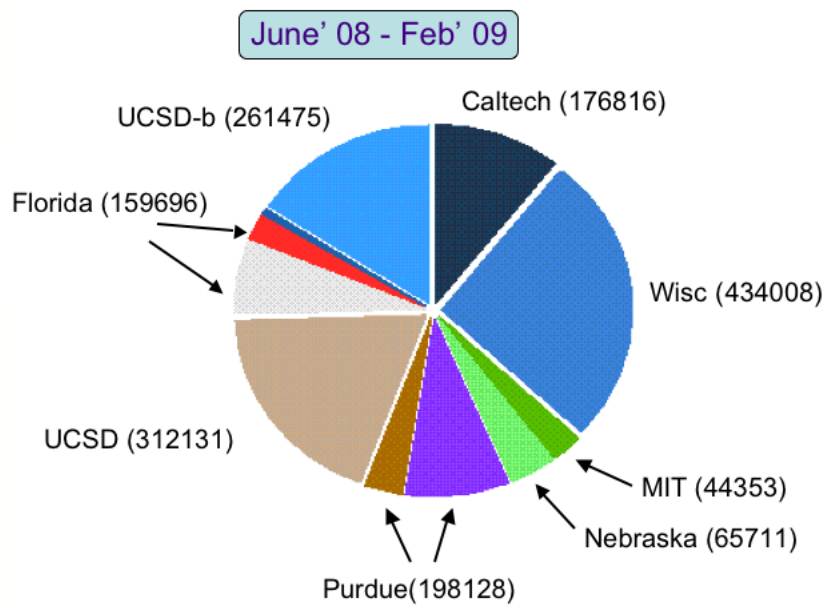


Figure 9. Number of terminated user analysis jobs at the CMS Tier-2 sites in the US from June 2008 until Feb 2009, according to the CMS dashboard.

[6] Condor Project, <http://www.cs.wisc.edu/condor/>

[7] D. Bradley et al., "Condor enhancements for a rapid-response adaptive computing environment for LHC", Abstract #400, CHEP 2009, Prague, CZ, March 2009.

[8] <https://twiki.cern.ch/twiki/bin/view/CMS/SWGGuideCrab>

[9] The CMS Dashboard, <http://arda-dashboard.cern.ch/cms/>