Distributed analysis for the ATLAS Experiment in the S.Co.P.E Project

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***Abstract*—ATLAS is a particle physics experiment that will operate, starting in spring 2009 throughout a ten years planned period, at LHC (Large Hadron Collider) at CERN. LHC will achieve a luminosity of 10^{34}cm^{-2}s^{-1} and will be able to explore a large amount of particle physics fields. Its main goal is to detect Higgs boson, the only Standard Model particle yet to be observed. ATLAS is a large international collaboration, made up of more than 2000 physicists from thousands of Research Institutes and Universities all over the world. This complexity requires a very cooperative distributed computing and data analysis model, so the emergent GRID Computing technology has been adopted. One of the main challenges of ATLAS computing model is to develop and to keep operative a system capable to manage some PetaBytes of data per year. Processing and analyzing data will need unprecedented efforts in terms of performance, scalability and robustness of distributed analysis tools, so the ATLAS experiment, in collaboration with two European projects, LCG (LHC Computing Grid) and EGEE (Enabling Grid for E-SciencE), is setting-up a complex set of tools and services for automated data distribution and processing. The goal is to guarantee to each user access to GRID resources, in order to analyze physics data and detector performances. ATLAS software has been installed on the S.Co.P.E prototype and different integration tests have been performed in order to evaluate at best the physics analysis workability degree. On the bases of these results, the job submission on the prototype by using the ATLAS Virtual Organization, the data transfer on the Storage Element and the configuration of the ATLAS specific tools have been performed in S.Co.P.E environment. In particular, the distributed analysis tool GANGA has been used in S.Co.P.E , which allows users to define, submit and monitor analysis jobs on the GRID, locate input data in the different storage sites and save output files in a coherent way.**

***Index Terms*—LHC, ATLAS, LCG, S.Co.P.E.**

I. INTRODUCTION

THE aim of this paper is to give an overview of ATLAS Distributed Computing Model and to explain how this model has been integrated in S.Co.P.E. Project.

II. LHC OVERVIEW

The CERN Large Hadron Collider (LHC) [1] is a high energy proton-proton collider installed in the existing 26.7 km tunnel about 100 m underground near Geneva constructed between 1984 and 1989 for the CERN Large Electron Proton (LEP) machine. A magnetic field of 8.5 Tesla enables the two proton beams to travel, in opposite direction, through two superconducting rings, each of 4.2 km radius. Each beam, composed of 2835 bunches containing 10^{11} protons, will achieve a energy of 7 TeV, in order to reach, in the collision, a center of mass energy of 14 TeV. The crossing rate of 40 MHz will produce a collision rate up to 10^9 Hz. Starting with a luminosity of 10^{33}cm^{-2}s^{-1}, LHC will reach in three years a luminosity of 10^{34}cm^{-2}s^{-1}.

In the four proton-proton colliding points (see fig.1) are placed four experiments: two "*omni purpose*" experiments, ATLAS [2] and CMS [3], and two dedicated experiments: LHCb [4] for B-physics studies, and one heavy ion experiment, ALICE [5].

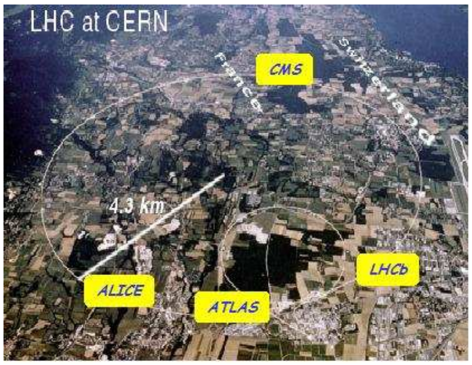

Fig. 1. LHC colliding points scheme.

A. LHC Physics Motivation

The unprecedent characteristics described above make LHC the largest high-energy physics project all over the world enabling the study in deep details of a large amount of particle physics items.

The model describing accurately elementary particles phenomenology is the Standard Model, formulated in 1967 by Glashow [7], Salam [8] and Weinberg [9]. In this model, describing for the first time both electromagnetic and weak interactions together, elementary particles are classified on the basis of the statistical laws they obey, distinguishable by their "intrinsic" spin angular momentum. Spin can be an integer number or a semi-integer number: in the first case particles are called "bosons", according to Bose-Einstein statistics, while in the second case particles are called "fermions", according to Fermi-Dirac statistics. Leptons and quarks are fermion particles, classified in three generations:

$$\text{Leptons:} \quad \begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

$$\text{Quarks:} \quad \begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

These particles interact via fundamental forces, mediated by bosons particles; in particular the eight strong force mediators are called gluons, while electro-weak unified force is mediated by a massless particle, the photon, and by three massive bosons: Z^0, W^+ e W^-.
Standard Model had a lot of experimental confirmations, but there are still some open questions. First of all, the determination of the origin of the electro-weak mass scale, operated by the Higgs boson [10], the only Standard Model particle yet to be observed. LEP experiments put a 95% C.L. lower limit on the Higgs mass at 114.4 GeV [11], and, in order to explore the whole mass range up to 1 TeV, a powerful machine such as LHC was needed. So the Higgs detection is the main goal of LHC research.
Moreover, the high value of the center of mass energy will allow LHC to search for new physics beyond the Standard Model, the more accredited model being Supersymmetry [12]. This theory [13] predicts the existence of new particles, "partners" of Standard Model particles, with equal properties but a spin differing by 1/2; this important characteristic establishes a new symmetry between fermions and bosons, i.e. between matter and force, and, if verified, will open new revolutionary fields in physics. In fact, Supersymmetry may solve some deep problems of the Standard Model and give an important answer to the Cosmology problem of the identification of the nature of Dark Matter.
It is remarkable to note that for a center of mass energy of 14 TeV, the total inelastic cross section is about 80 mb (see fig. 2), while for interesting processes such as Higgs or Supersymmetry particle productions the cross section is of the order of 1 pb. In terms of rates, the total inelastic rate is about 10^9

Hz, while Higgs production has a rate of the order of 1 Hz, which becomes about 10^{-2} Hz including the branching-ratio; this means that the selection power needed is of the order of 10^{11}. This is the real challenge of the LHC: to be able to identify and select such rare events in a background dominated by uninteresting events. For this purpose, very large and complex experiments have been designed.

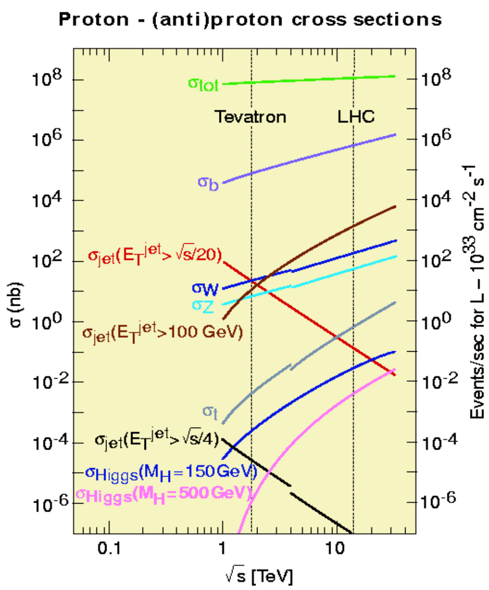

Fig. 2. LHC Cross Section.

III. ATLAS EXPERIMENT

ATLAS (A *Toroidal LHC ApparatuS*) is one of the four particle physics experiment at LHC, it is composed of more than 2000 physicists from hundreds of Research Institutes and Universities all over the world, and its layout has been set-up to exploit at best the LHC capabilities. Its technical characteristics will allow efficient reconstruction of charged particle tracks, photons and electrons identification and high precision measurements of muon momentum by using just the external muon spectrometer.

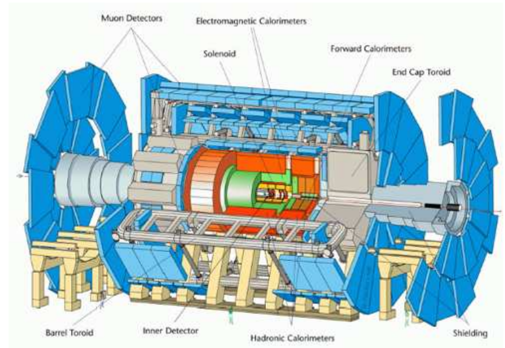

Fig. 3. ATLAS detector layout.

A. ATLAS layout

ATLAS experimental apparatus has a total volume of approximately 16000 m^3, a length of 46 m, a radius of 24 m, a weight of 7000 Tons and about 10^8 electronic channels. The layout [2] is shown in figure 3, where different regions can be singled out:

- the central region, called *barrel*, holds the sub-detectors, concentrically arranged compared to beams axis;
- two *end-cap* regions arranged at the ends of the *barrel*.

Proceeding form the inner to the outer, the *barrel* is composed by the following subdetectors:

1) the vertex tracker, surrounding the beam collision point;
2) the inner tracker, placed inside a solenoidal magnetic field;
3) the electromagnetic and hadronic calorimeters;
4) the muon spectrometer, placed such that particles which originate at the interaction point traverse three chamber stations inside a toroidal magnetic field.

In the *end-caps* are arranged, respectively:

1) the electromagnetic and hadronic calorimeters;
2) the forward calorimeters;
3) the muon spectrometer.

A schematic view of how particles are detected in ATLAS apparatus is represented in fig 4.

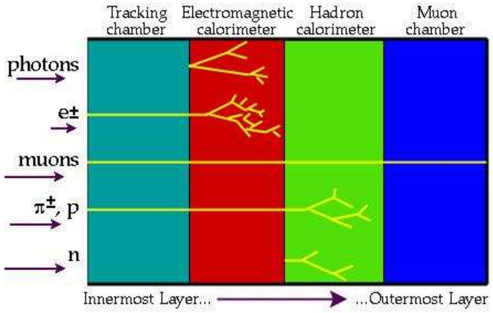

Fig. 4. Schematic view of particles detection in ATLAS

B. ATLAS Computing Framework

ATLAS software has been developed by using an *objected-oriented* model, based essentially on *C++* programming language, integrated with FORTRAN and Java components. A common *framework*, ATHENA [6], based on GAUDI [14], has been developed with an high level of abstraction; it provides all infrastructures needed to process data from the detector read-out to data simulation, reconstruction, event display and analysis. ATHENA is based on a set of software interactive packages called components which operate different algorithms. Components are coordinated and supervised by an *Application Manager*.
The main feature of such framework is that user can define components to be used and how they must interact on the base of his needs by using Python scripts called *Job-Options*.
The different software versions are called *ATLAS releases* [24], physically organized using the Concurrent Versions System (CVS). Once a software release suitable for production has been built and validated, a distribution kit is used to install the ATLAS offline software on sites worldwide. The Package Manager used to fetch and install the ATLAS software is Pacman [15].

C. ATLAS Distributed Computing Model

High Energy Physics experiments experienced, during the years, an exponential growth from both hardware and software point of view. The large dimension of the ATLAS experiment and the complexity of the events requiring a huge granularity of the detectors in order to identify "good events" in a large background environment, determine a very large size of the events: 1.6 MB for Raw data.

Moreover, LHC beam collisions will take place with a temporal interval of 25 ns, and every bunch-crossing will produce, at high luminosity, about 23 interactions. Therefore the foreseen input event rate in the ATLAS detector will be of the order of 1 GHz. The ATLAS trigger, arranged in three levels, reduces such a rate to 200 Hz; this means that in one year the amount of data will be approximately of the order of 2 PB. Same amount of derived data will be determined by the large-scale processing, reprocessing and analysis activities. The computing power required to process this huge amount of data is of the order of 10^5 CPUs full time.

The impossibility of concentrating the needed computing power and storage capacity in a single place required the development of a world-wide distributed computing system, which allows efficient data access and makes use of all available computing resources. Thus ATLAS Collaboration embraced a computing model [6] based on the Grid paradigm and on a high degree of decentralization and sharing of computing resources. The main difference with the previous CERN-based Computin Models is that off-site facilities play a vital role to the operation of ATLAS. In particular, since 2002 a complex set of tools and distributed services, enabling the automatic distribution and processing of the large amounts of data, has been developed and deployed by ATLAS in cooperation with LHC Computing Grid (LCG) Project [16], [17] and with the middleware providers of the three large Grid infrastructures: EGEE [18] in most of Europe and the rest of the world, NorduGrid [19] in Scandinavian countries and OSG [20] in the United States. The Computing Model designed by ATLAS is a hierarchical structure organized in different *Tiers* [6]. The Tier0 facility is based at CERN and is responsible for first–pass processing and archiving of the primary Raw data and their distribution to the Tier1s. The 10 Tier1 facilities word-wide distributed have to store and guarantee a long-term access to Raw and derived data and provide all the reprocessing activities. Each Tier1 heads up a set of Tier2 sites grouped in regional *Clouds*. Tier2s are the centres designed for the users analysis and provide all the Monte Carlo simulation capability. A scheme of ATLAS Cloud Model is represented in fig. 5. In particular, the Tier1 in Italy is located at INFN-CNAF in Bologna, while Tier2 facilities are four: Frascati, Milano, Napoli and Roma hosted by the local Universities and INFN Divisions.

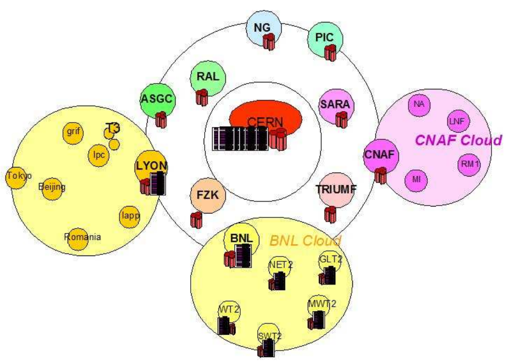

Fig. 5. ATLAS Tier Cloud Model

The main components of such system are described in the following.

1) ATLAS Virtual Organization: in order to access grid resources, ATLAS members are organized in *Atlas Virtual Organization*; the computing information and the privileges of all ATLAS members are stored in a VOMS database.

2) Distributed Data Management: Data distribution takes place through the Distributed Data Management (DDM) system [21]. Such system has two main tasks:

- to provide data replication in the collaboration sites by using the different data transfer protocols in a transparent way;
- keep tracks of data distribution in Data Catalogs.

A collection of files having similar characteristics compose a dataset; user requests of dataset replicas, called subscriptions, are provided by DDM system, which searches for data in the Catalogs and submits transfers. Information about data replicas are stored in a single database and one of the easier way to access such information is the ATLAS Dashboard portal [22]. The DDM software (DQ2) has been developed as a set of independent clients and services belonging to three categories:

- Central Services, which contain all information about content, configuration, replication and organization of data;
- Local Services, which consist of a set of agents interacting with Central Services in order to perform data transactions required;
- End User tools, which allow users to access data information, download or upload data, request subscriptions.

3) ATLAS Production System: a central system, ProdSys/Panda production system, schedules all organized data processing and simulation activities. The production System makes use of the computing resources enabled by the three different middlewares (LCG/EGEE, NDGF/Nordu-Grid and OSG/Panda) joining ATLAS VO; his workload is divided up into similar jobs, called tasks, which perform different data transformation (i.e. event generation, detector simulation, Monte Carlo digitization and reconstruction, etc.). These tasks are assigned to clouds by Panda according to a load-balancing scheme tuned to take into account workload, storage capacity and input data. Moreover, the system prevents potential inefficiencies in grids by trying each job a maximum number of times; if all the attempts fail, jobs enter in a stuck state and a await additional management operated by a team of experts.

4) ATLAS Monitoring System and User Support: This complex structure requires a continuous monitoring by all collaboration sites, as well as an efficient and monitored distribution of data and of the software needed for data processing. In particular, Production System, DDM and Central Services are monitored by a distributed team of shifters which make use of a set of quick and efficient tools providing an overview of the overall status of the system, a fast detection of the problems and an efficient ticketing system in order to solve them in collaboration to sites managers. In addiction, support for distributed tools is performed by developers and operators using specific forums which allow both solving problems and debugging softwares.

5) ATLAS Distributed Software: ATLAS software distribution [25], is provided by ATLAS Software Installation System for LCG/EGEE [23], [26], based on the Light Job Submission Framework for Installation (LJSFi), an independent job submission framework for generic submission and job tracking in EGEE. It is responsible for access, monitor, install, test e publish information about all resources made available to ATLAS Collaboration by LCG. The core system is based on the Installation DataBase which stores the information about the resources, the jobs and the software deployment status, while the command line interface is responsible of the interaction with the Grid middleware. The software installation is performed in 3 steps. First a pilot job is sent to each site where to install the software; if site checks have been successfully executed, the actual installation process may start. The installation actions are performed in the target nodes (Worker Nodes) by the software management script, handling installations and removals of the ATLAS software distribution kit with Pacman, and for each software release installed at a site, a tag is published to the corresponding Computing Element at the end of the installation task.

6) ATLAS Distributed Analysis Tools: ATLAS Computing Model provides also a series of useful tools for distributed data analysis. There are two official tools used by ATLAS collaboration: Pathena [27], mainly used in OSG, and GANGA [28], used in EGEE and NorduGrid. The main feature of GANGA is to provide a transparent command line or graphical interface between the user and the grid infrastructure, hiding grid technicalities to users; in fact, by setting few parameters in a Python script it provides access to file catalog, computing elements, ATLAS releases needed to process data, and retrieve output data. In GANGA each job is configured by a set of functional blocks (see fig. 6), each one with a well defined purpose, in order to define:

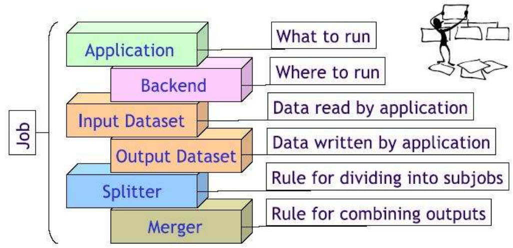

Fig. 6. GANGA functional blocks

- the application to run within the framework ATHENA or not;
- the preferred sites where to run, which may be local backends or all the other backends belonging to the three middlewares presently used by ATLAS;
- the input data needed by application, which may belong to local datasets or to DQ2;
- the output data to store;
- the task to split jobs into subjobs and to combine output.

IV. Napoli ATLAS Tier 2

Napoli ATLAS Tier2 started his operations as such in the first half of 2006 after many years of long experience as local computing farm. It provides resources and services to the whole ATLAS collaboration, and in particular to italian users, for Monte Carlo simulation and analysis. The main activities carried out by the Napoli and the other italian groups in the Tier2 are the Muon Triggers studies (LVL1 and Event Filter), Muon Reconstruction, RPC calibration and analysis and Supersymmetry searches. The computing resources at the end of 2008 consists of 50 Worker Nodes and 260 cores corresponding to a computing power of about 580 kSI2k, while storage resources, based on a SAN architecture, consist of 260 TB and 12 disk servers. Moreover, local services have been implemented to manage and monitor the whole system: the Computing Element, the Storage Elements, the Storage Resource Manager DPM, and the account server HLR.

Many tests, during which dummy datasets are shipped to Tier1s and Tier2s from the Tier0 and the other Tier1s, have been performed to optimize the configuration of the system and evaluate the its performance such as:

- Functional Tests, which periodically evaluate data transfer functionalities to sites;
- Throughput Tests which verify the foreseen data transfer speed;
- CCRC08 (Combined Computing Readiness Challenge 2009), the combined test with the other LHC experiment in order to verify the capability of the common service of sustaining their contemporaneous activities.
  performances with others LHC experiments.

Moreover, other tests called Job Priorities Test are used to evaluate the correct working of fair share mechanism, which allows site manager to define which percentage of the resources can by accessed by the different user categories[1] according to ATLAS VO policies, while Distributed Analysis Tests (Hammer Tests) control the correct functionality of GANGA on the different sites.
All these tests had excellent results, according to the general trend of other Tier2s.

A. PON S.Co.P.E. Project

S.Co.P.E. [29], [30] is a project of the University "Federico II" of Napoli whose aim is to set-up a general purpose super-computing infrastructure based on Grid model and on the most recent distributed computing technologies, in order to support the scientific activities of the research groups belonging both to Napoli University and to the Universities and Research Institutes of the PON joining the GriSù Project. On the bases of a pre-existing metropolitan network infrastructure, operating a gigabit connection between the most important research structures, S.Co.P.E. integrates the current computing and storage resources with new high performance hardware, in order to create a unique Grid platform integrated with national and international Grid infrastructures. Moreover, S.Co.P.E. project is promoting scientific development for fundamental research and technologic innovation in four research areas:

- Macrocosm and Microcosm Sciences,
- Matter and Environment Sciences,
- Life Sciences,
- Middleware,

and a large scientific community, in collaboration with INFN and other local and national research structures, is working for this purpose.

B. Napoli ATLAS Tier2 and S.Co.P.E.

ATLAS is one of the project belonging to S.Co.P.E. in the Macrocosm and Microcosm Sciences area. Its Tier2 is hosted both in the original INFN site in the Physics Department of the University and in the new S.Co.P.E. site (7). In order to ensure a fast and efficient

Fig. 7. S.Co.P.E. site.

connection of the computing resources, a 10 Gbps connection has been realized between the two sites.
Different ATLAS grid infrastructures have been implemented in order to allow ATLAS VO user to access, requesting ATLAS software installation and using GANGA on GRID-S.Co.P.E. resources. In particular, GRID MAP file has

[1] In ATLAS VO users may have different roles on the basis of the type of jobs they run on grid. For example, who submits central production has the 'production' role, while users who sends analysis jobs have 'none' role

been modified in order to allow ATLAS Napoli users to run their own jobs on a dedicated queue. ATLAS software Installation System has been readapted on the "Scope Atlas Installation System" and its correct working on S.Co.P.E. resources has been tested.

Finally, GANGA has been configured in order to use the S.Co.P.E.'s Computing Element and Resource Broker, and ATLAS jobs have been launched using this tool. A large production of simulated single muon events has been realized using the S.Co.P.E. resources. Since the interoperability between the ATLAS and the S.Co.P.E. Grid has been verified, the activities of the ATLAS experiment will exploit in future the resources of the Project accordingly to the fair share policies among the supported VOs.

V. Conclusion

The LHC Physics Program has a breakthrough discovery potential, will make an enormous number of precision measurements, and therefore is the leading component of the world High Energy Physics program from for the next 20 years. LHC will be taking data starting from next autumn over the whole next year. The ATLAS computing model had been defined in order to exploit the advantages of the GRID and the large amount of resources spread over the world. We have tested the functionality of the ATLAS software on the S.Co.P.E. and, thanks to the inter-operability, on the other PON resources.

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