A Validation Framework for the Long Term Preservation of HEP Data.

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DPHEP: Data preservation in high energy physics

The problem of data persistence and preservation is not new, but is becoming more prominent with the advent of so called big data, in particular within the applied sciences. However, until recently high energy physics (HEP) had little or no tradition or clear model of long term preservation of data in a meaningful and useful way, and the data from the majority of older experiments have simply been lost. Attempts to preserve previous data sets have in general not been a planned initiative by the original collaboration but a push by knowledgeable people, usually at a later date. This is despite several clear scenarios where preservation of HEP data is beneficial for a number of reasons including: to allow the re-analysis of data taken at a unique centre of mass energy and/or with unique initial state particles, especially if new theoretical predictions or analysis techniques become available; to aid the combination of data sets between similar experiments; for possible verification of new phenomena found by another HEP experiment; and to allow the use of real HEP data in scientific training, education and outreach.

The DPHEP Collaboration

The start of the 21st century saw the end of operation of several particle colliders including LEP (e+e−, where data taking ended in 2000), HERA (e± p, 2007), PEP-II (e+e−, 2008), KEKB (e+e−, 2010) and the Tevatron ($p\bar{p}$, 2011), providing unique data sets in terms of initial state particles or centre of mass energy or both. As the experiments at each of these colliders continued to publish their final results and conclude their core physics programmes, the question of what should be done with the data naturally presented itself.

Inspired by a lack of concrete solutions or guidelines to the problem of data preservation in HEP, an international study group on data preservation and long term analysis in high energy physics, DPHEP, was formed at the end of 2008 to address the issue in a systematic way. The composition of the group was initially driven by BaBar and the HERA experiments H1, ZEUS and HERMES, who were soon joined by Belle, BES-III and the Tevatron experiments CDF and DØ. The LEP experiments are also represented in DPHEP and the LHC experiments ALICE, ATLAS, CMS and LHCb joined the study group in 2011. The laboratories and associated computing centres at BNL, CERN, DESY, Fermilab, JLAB, KEK and SLAC are also all members of DPHEP, in addition to several funding agencies. A series of seven workshops have taken place since 2009 and DPHEP is officially endorsed with a mandate by the International Committee for Future Accelerators, ICFA.

The initial findings of the study group are summarised in a short interim report released in 2009 and a full status report was published in 2012 (arXiv:1205.4667). The report contains: a tour of data preservation activities in other fields; an expanded description of the physics case; a guide to defining and establishing data preservation principles; and updates from experiments and joint projects, as well as person-power estimates for these and future projects. After many decades of neglect with respect to other scientific disciplines, data preservation is now a rapidly emerging field in HEP, where DPHEP is established as the coherent multi-laboratory, multi-experiment body to examine this issue.

The DPHEP Study Group is now moving to a new organisational model, the DPHEP Collaboration and the formal signing procedure of the Collaboration Agreement has now commenced. In addition to the DPHEP Chair, a Project Manager position has now been established, which is initially based at CERN.

Preservation models

If one thing may be learned from previous enterprises, it is that the conservation of tapes is not equivalent to data preservation, and that not only the hardware to access the data but also the software and environment to understand the data are the necessary and more challenging aspects. In addition to the data, the various software, such as simulation, reconstruction and analysis software need to be considered. If the experimental software is not available the possibility to study new observables or to incorporate new reconstruction algorithms, detector simulations or event generators is lost. Without a well defined and understood software environment the scientific potential of the data may be limited. Just as important are the various types of documentation, covering all facets of an experiment. Considering this inclusive definition of HEP data, a series of data preservation levels has been established by the DPHEP Collaboration, as summarised in the table below. The levels are organised in order of increasing benefit, which comes with increasing complexity and cost. Each level is associated with use cases, and the preservation model adopted by an experiment should reflect the level of analysis expected to be available in the future.

	Preservation Model	Use Case
1	Provide additional documentation	Publication related info search
2	Preserve the data in a simplified format	Outreach, simple training analyses
3	Preserve the analysis level software and data format	Full scientific analysis, based on the existing reconstruction
4	Preserve the reconstruction and simulation software as well as the basic level data	Retain the full potential of the experimental data

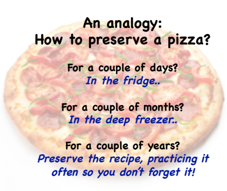
The four levels represent three different areas, which represent complementary initiatives: documentation (level 1), outreach and simplified formats for data exchange (level 2) and technical preservation projects (levels 3 and 4). Whereas most collaborations involved in DPHEP pursue some form of level 1 and 2 strategies, levels 3 and 4 are really the main focus of the data preservation effort: to maintain usable access to analysis level data, Monte Carlo and the analysis level software, in addition (in the case of level 4) to the reconstruction and simulation software.

Previous data preservation experiences in HEP indicate that new analyses and complete re-analyses are only possible if all the necessary ingredients to retrieve, reconstruct and understand the data are accounted for. Only with the full flexibility does the full potential of the data remain, equivalent to level 4 preservation.

Level 4 solutions

Most experiments in DPHEP plan for a level 4 preservation programme, although different approaches are employed concerning how this goal should be achieved. One option, typically realised using virtualisation, is to freeze the current system to keep the software and environment alive as long as possible. Although this will provide a workable solution for the medium-term future, the operability of the software and correctness of the results are not guaranteed. If changes are needed it will will become more difficult the longer software is frozen and future compatibility issues may arise, in addition to the inevitable security concerns.

The alternative approach employed at DESY is to adapt and validate the software and environment to future changes as and when they happen. In this way, the working version of the experimental software is actively migrated to more modern platforms and future-proof resources, substantially extending the lifetime of the software, and hence the data, whilst retaining the flexibility to apply any necessary changes. The success of such migrations depends on having a robust and complete set of validation tests. Virtualisation techniques are again used, in this case to provide a coherent platform to build and validate software and environments created according to the recipes provided by the experiments.



An analogy:
How to preserve a pizza?

For a couple of days?
In the fridge..

For a couple of months?
In the deep freezer..

For a couple of years?
Preserve the recipe, practicing it often so you don't forget it!

The software preservation system at DESY

A generic validation suite, which includes automated software build tools and data validation, has been developed at DESY to automatically test and validate the software and data of an experiment against such changes and upgrades to the environment, as well as changes to the experiment software itself. Technically, this is realised using a virtual environment capable of hosting an arbitrary number of virtual machine images, built with different configurations of operating systems (OS) and the relevant software, including any necessary external dependencies. Such a framework is by design expandable and able to host and validate the requirements of multiple experiments, and can be thought of as a tool to aid migration that will detect problems and incoherence, as well as identifying and reporting the reasons behind them.

Inputs to the preservation system and workflow

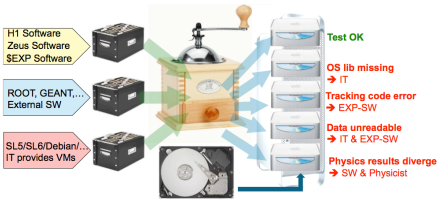
Three distinct catagories are identified as separate inputs to the validation system, as illustrated in the main picture on the left: the experiment specific software, any external software dependencies and finally the operating system and compiler. The workflow of the validation framework, called the **sp-system**, is then as follows:

1. In an initial, preparatory phase, the experimental software should be consolidated, the OS migrated to the most recent release, and any unnecessary external dependencies removed. Any remaining, well-defined necessary dependencies are then also incorporated. Analysis and data validation tests should then be defined and prepared, examining each part of the experimental software deemed necessary in the preservation model adopted.

2. A regular build of the experimental software is done automatically according to the current prescription of the working environment, and the validation tests are performed. At regular intervals, new OS and software versions will then be integrated into the system, under the supervision of experts from the host IT department and experiment.

3. If the validation is successful, no further action must be taken. If a test fails, any differences compared to the last successful test are examined and problems identified. Intervention is then required either by the host of the validation suite or the experiment themselves, depending on the nature of the reported problem.

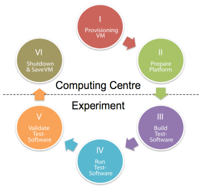
4. The final phase occurs either when no person-power is available from the experiment or IT side or the current system is deemed satisfactory for the long-term need or stable enough. At this point the last working virtual image is conserved and constitutes the last version of the experimental software and environment. It should be noted however, that this now frozen system is unlikely to persist in a useful manner much beyond this point.



The basic validation cycle employed by the system is illustrated below. Note the separation of the computing centre and experimental phases, reflecting the separate responsibilities of the sp-system provider and the client experiment.

Current configurations supplied by DESY-IT

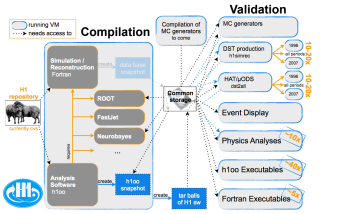
Within the current sp-system there are virtual machines with five different configurations: SL5/32bits with gcc4.1 and gcc4.4, SL5/64bits with gcc4.1 and gcc4.4, and SL6/64bits with gcc4.4. In addition, the set of external software required by the experiments is also installed, for example the ROOT versions used by the experiments: 5.26; 5.28; 5.30; 5.32; 5.34. The sp-system is designed and constructed in a such a way that a new configuration (as a virtual machine or a normal physical machine like a batch or grid worker node) can easily be added. The only requirement of a new machine is to have access to the common sp-system storage where the tests from the experiments as well as the test results are stored, in addition to the ability to run a cron-job on the client machine.



Validation tests as defined by the experiments

In addition to the common infrastructure provided by the IT division, the development and implementation of the tests by the participating experiments requires significant investment, even if basic validation structures already exist. As a first step, the number and nature of the experimental tests is surveyed, the level of which reflects the DPHEP preservation level aimed at by the participating collaboration.

The figure below details the results of this evaluation by the H1 Collaboration, which is implementing a full level 4 preservation programme. The structure of the tests is divided into two parts. Firstly the compilation of approximately 100 individual H1 software packages and the identified external dependencies is carried out, where the resulting binaries are stored as tar-balls on the common storage within the sp-system. Secondly, a series of validation tests is performed on the full spectrum of the H1 software, using the compiled software. Whereas some of these tests examine the results of stand alone executables and are run in parallel, many are run sequentially and form discrete parts in one of many full analysis chains: from MC generation and simulation, through multi-level file production and ending with a full physics analysis and subsequent validation of the results.



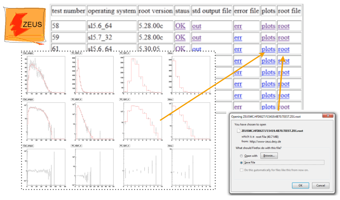
What the sp-system does *not* do

The sp-system is designed for software verification, validation and migration support only. Neither the hardware resources nor the interface are designed for mass production or large scale analysis. The framework is rather used to establish the latest working version of the computing and software environment and it can help to prepare a production system by supplying the successfully validated recipe of the latest configuration. If a production system is required, then this recipe should be deployed on a suitable resource at the time: an institute cluster, grid, cloud, sky, quantum computer, and so on.

Validation Results

Each test-job started in the sp-system is typically assigned a unique ID, and all scripts and input files used in the test as well as all output files are kept. This allows the validation of all versions against each other and ensures reproducibility of previous results. In addition to this unique ID, validation jobs may be tagged with a description, indicating which software versions were used, and the Unix timestamp of the execution to aid the book-keeping.

Script-based webpages are used to record and display available validation runs for a given description and indicate the status of the compilation for the individual packages or tests within table cells, which are linked to a corresponding output file. This file may be a simple yes/no, a text file, a histogram, a root file or even a link to a further page, depending on the nature of the test. An example from the ZEUS Collaboration is given below, showing a series of validation tests with various OS configurations and ROOT versions.



test number	operating system	root version	staus	std output file	error file	plots	root file
58	sl5.6_64	5.28.00c	OK	out	err	plots	root
59	sl5.7_32	5.28.00c	OK	out	err	plots	root
61	sl5.6_64	5.30.05	OK	out	err	plots	root
					err	plots	root
					err	plots	root
					err	plots	root
					err	plots	root
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Opening ZEUSMC.HFDX627.F15419.4B70.TEEST.Z01.root

You have chosen to open

ZEUSMC.HFDX627.F15419.4B70.TEEST.Z01.root

which is a: root File (40.7 MB)

from: http://www-zeus.desy.de

What should Firefox do with this file?

○ Open with [Browse...]

● Save File

□ Do this automatically for files like this from now on.

[OK] [Cancel]

Operating System	SL5 32bit	SL5 64bit									SL6 64bit
External Dependencies		ROOT				Cernlib		Fastjet	Neuro-bayes	Neuro-bayes	
Process		5.26	5.28	5.30	5.32	2005	2006	2.3.3	2008 0312	3.3.0	
Accessing cNtuples (Data/MC)	🟩	🟩	🟩	🟩	🟩						🟩
Creating cNtuples (Data/MC)	🟩	🟩									🟩
ZMCSP (simulate/reconstruct MC)	🟩	🟩				No dependence					🟩
Validation	🟨	🟨	🟨	🟨	🟨						🟨
Compilation of s/w	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	▨	🟨
Generating MC files	🟩						🟩				🟩
Producing DST files (Data/MC)	🟩						🟩				🟩
Producing h1oo files (Data/MC)	🟩	🟩	🟩	🟩	🟩	No dependence	🟩	🟩	🟩	▨	🟩
Accessing h1oo files (Data/MC)	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	▨	🟩
Accessing ndb snapshot	🟩						🟩				🟩
Validation	🟨	🟨	🟨	🟨	🟨		🟨	🟨	🟨	▨	🟨
Compilation of s/w	🟩	🟩	🟩	🟩	🟩	🟩					🟩
Accessing uDST (precompiled s/w)	🟩	🟩	🟩	🟩	🟩	🟩					🟩
Reconstruction (precompiled s/w)	🟩					🟩		No dependence			🟩
Producing uDST (precompiled s/w)	🟩					🟩					▨
Validation	🟨	🟨	🟨	🟨	🟨	🟨					🟩

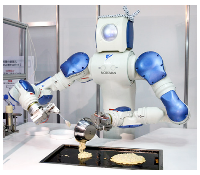
Putting it all together

In total more than 300 runs over sets of pre-defined tests have been performed within the sp-system by the HERA experiments. A summary of the current status of the validation tests is displayed in the above diagram, showing a coarse breakdown for ZEUS (orange), H1 (blue) and HERMES (red) tests and the different dependencies. The experiments are in the process of migrating to SL6/64bit, and the tests performed so far using the sp-system have already identified and helped to solve several long standing bugs. The next challenges include testing the SL7 environment and checking the compatibility of the experiments software with ROOT 6.

Next steps and possible expansion

The HERA experiments are still in the process of defining and implementing the complete set of validation tests for the whole chain of software to be preserved. Due to the limited manpower availability and unclear long-term support for the HERA experiments, this will take at least one more year to complete.

From the IT side, the current version of the sp-system is very light for the user tests implemented so far. The common storage allows the communication between the system and the experiment tests using only a few shell variables, which describe for example the location of the input file of the tests, the test outputs and the external software on the client. Using the thin layers of scripts it is possible to envisage a complete separation of the user part from the details of the sp-system. This will allow easier transformation of already existing user tests into the sp-system as well as the porting of the tests developed within the sp-system to other test platforms, in case there will be no long term support for the current implementation.



The sp-system at DESY is able to host validation initiatives from other experiments as well as support for the migration of already existing tests into the sp-system.

The scale of the current sp-system is probably not adequate for the LHC experiments, but the concept is nevertheless applicable. In the case of expansion of the system to non-DESY experiments, work would be needed in the area of the input of the tests for people outside of DESY IT environment, as well as improving the presentation of the test results, which is currently done mostly by the experiments themselves, using the raw output of the sp-system.

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