Preservation of the HERA-B Collaboration heritage

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Abstract. We present the concept of the data preservation developed for the HERA-B experiment which studied proton-nucleus interactions of the 920 GeV/c beam at HERA/DESY. The full analysis chain (starting from raw data) is to be preserved based on the rolling DPHEP model with open access to the data. We have frozen the full working analysis software environment using chroot-jail virtualization and report first experience of porting the software to a newer OS/compiler.

1. The Experiment

HERA-B [1, 2] was a multipurpose large-aperture spectrometer at the HERA storage ring at DESY. The experiment studied interactions of the 920 GeV/c protons on wire targets inserted in the halo of the HERA beam. The primary goal of the experiment initially was to study CP-violation and the design of the detector and trigger systems was optimized for efficient real-time filtering of the $b$-hadrons based on online reconstruction of $J/\psi$ mesons. After commissioning run in 2000, the physics programme has been revised and concentrated on studies of the QCD physics in $pA$ interactions.

Figure 1. Top view of the HERA-B detector

As shown in Figure 1, the detector included the target system for dynamic positioning of various nuclear wire targets (C, W, Ti, Al) in the halo of the proton beam, the Silicon-strip Vertex...
Detector, a dipole magnet, an extensive drift-tube Outer and MSGC/GEM Inner Tracking Systems, the Ring Imaging Cherenkov Counter, the sampling Electromagnetic Calorimeter and the Muon Detector.

The forward magnetic spectrometer possessed sensitivity to the full event within the acceptance region centered around midrapidity and extending into the backward hemisphere. HERA-B featured high resolution tracking and vertex reconstruction, good particle identification over a wide momentum range, and selective multi-level dilepton trigger. More detailed description of the detector can be found e.g. in [3] and references therein.

The main physics data sample was collected during the 2002/2003 HERA run with minimum bias and dilepton triggers using C, Ti, and W targets. The data sample has the following division between different triggers:

- 164\,M dilepton triggered events (\(\sim 300k\) \(J/\psi\) decays in \(\mu\mu\) and \(ee\) modes) collected in single- and double-wire configurations useful for \(A\)-dependence studies (Figure 2);
- 210\,M minimum bias events;
- 20\,M “hard photon” calorimeter-based trigger, \(E_T > 2\,\text{GeV}/c\) (C, Ti, W and Al targets);
- 100\,M “glueball trigger” with low charged track multiplicity (C and Al targets).

Analysis of the data produced about 20 physics publications in journals (last paper published in 2009), and 23 detector publications in NIM. The main results include unique measurement of the \(b\bar{b}\) cross-section at \(\sqrt{s} = 41.6\) GeV as well as other competitive results in charm, strange and exotic physics at the highest energy among the fixed-target experiments. The main physics topics covered by HERA-B analyses are listed below.

Dilepton-triggered data:
- \(J/\psi\) \(A\)-dependence, kinematic distributions and polarization
- Charmonium production ratios: \(\psi(2S)/J/\psi\) and \(\chi_c/J/\psi\)
- Bottomium production, and \(b\bar{b}\) production cross-section
- FCNC \(D^0 \rightarrow \mu\mu\) decay search

Minimum-bias data:
- open charm production and \(J/\psi\) production cross-section
- strangeness and hyperon production
- pentaquark search

Hard photon data:
- \(\pi^0\) and \(\eta\) differential production cross-sections, ratios and \(A\)-dependence
- jet-shape analysis

Most of analyses were performed with the dilepton triggered and minimum bias data. The “hard photon” and “glueball” triggered data received relatively less or no analysis. A few unfinished analyses are being continued by individual former members of the collaboration, such as cascade hyperon production, or analysis of the topological cross-section.

Figure 2. Invariant mass of \(\mu^+\mu^-\) pairs in the dimuon triggered sample after minimal cuts.
2. Data volume and software for preservation

The last OS version used by the Collaboration was a 32-bit SuSe Linux 7.2 (kernel 2.4.29), with GCC v2.95 compiler. In total the HERA-B analysis software contains $\sim 900$ kLOC in 6600 source files. About 2/3 of code is C/C++ (including headers), 1/6 is Fortran 77, 1/6 is Tcl/Tk, shell, assembler, perl etc.

External dependencies are: CERNLIB 2000, ROOT 3.03_09, CLHEP. In order to create an autonomous data preservation solution, all the external dependencies are included into the preservation bundle. The database software is custom-made based on the Berkeley DB package and is included in the source code tree. The total size of databases necessary for MC production, data/MC reconstruction and trigger simulation is $\sim 5$ Gb.

The total data size (not prepared for archiving) stored at DESY on tape is $\sim 250$ Tb in 850,000 files, see Table 1. This corresponds approximately to 10% of the full amount of data of the HERA experiments.

| Table 1. Data unprepared for archiving. |
|----------------------------------------|
|                                        |
| Data | MC | Archive | User | Rest |
|------|----|---------|------|------|
| 260 Mb | 570 Mb | 30 Mb | 70 Mb | 50 Mb |

3. Experience of migration to a newer OS and compiler

In this section we describe an attempt to migrate the code to the newer OS and compiler: the 32-bit distribution of SLC5(4) Linux, GCC v4.1(v3.7). About 3 FTE-months of a person familiar with the HERA-B software were spent, more than 600 modifications were made throughout the code.

- 3 Fortran (bad comment line, change in XOR, MIN, MAX functions)
- 10 C preprocessor syntax
- 1 incorrect loop optimization in the newer compiler
- 150 changes to the header files (deprecated “.h”, e.g. math.h, GNU_SOURCE)
- 170 invalid comparison/conversion between pointers and iterators
- 54 errors in function declaration
- 50 various small syntax errors (e.g. “default:” C++ tag without closing “;”)
- 210 C++ assignment of the arrays
- 20 problems with syntax in the usage of C++ templates

Many of the found incompatibilities of the original code with the newer compiler arose from the fact that the code is not fully compliant to the language standard while the newer compiler is more restrictive towards the standard.

The modifications allowed to compile successfully a basic set of libraries and build user application which can read HERA-B data and do the analysis.

Let us emphasize that any, even apparently harmless change to the original software requires very careful and meticulous testing and extensive comparison between results obtained with the original algorithms and their version ported to a newer compiler.

Although most of the HERA-B libraries could be compiled, the fraction of the libraries which can be tested by reading the DSTs is relatively small. It covers only the routines which are
actually invoked during the data read operations, which includes the basic routines responsible for database access, data I/O, event unpacking, and memory management. No physics simulation or reconstruction routines which often contain more sophisticated algorithms could be tested this way. Several libraries necessary for MC detector simulation and event reconstruction could not be ported so far at all.

The difficulty of porting the physics software comes from its complexity and the fact that it often involves expert knowledge. One should also recognize that the physicists developing the code were mainly focused on obtaining from it needed physical functionality. Therefore despite that the original software has been profoundly tested and proved to work correctly, the writers sometimes unconsciously relied on unspecified bugs/features of a particular version of the old compiler. The code often lacks comments and in some problematic places where the compiler finds non-compliant expressions, it is not always clear at all how the code was supposed to behave.

Another obstacle which we have met porting the software to the newer OS, was related to small corruptions which, as we found, had occurred in the contents of some of the database files. The corruptions appear to be very small, keep intact most of the data and not affect noticeably the work of the database servers. Nonetheless, they have manifested themselves by breaking the conversion procedure of the database files to the binary format of the new OS. We estimated that attempts to fix the corrupt databases or to make improvements to the conversion tool would have required much work so they were not done for this study.

4. “Frozen” solution based on chroot-jail virtualization

Taking advantage of the fact that all HERA-B software has been available for Linux OS (SuSe 7.2, kernel 2.4.29) and of the backward compatibility between the Linux kernels, we could virtualise the original HERA-B system in a “chroot jail” set up under a modern Linux (SLC4, kernel 2.6.x) which affords some independence of the operating system evolution.

A minimal environment able to compile and run user HERA-B analysis executable takes less than 3 Gb of space: ~ 1.6 Gb — tools and libraries still available at DESY AFS, including ~ 1.3 Gb — HERA-B software projects and ~ 300 Mb — gcc-2.95, tcl/tk, CLHEP, CERNLIB, ROOT, dcap-libraries; 70 Mb — necessary tools and libraries which were locally installed on the old system; ~ 1.2 — Gb minimal set of databases necessary for reading DST files.

The full installation takes ~ 8 Gb of space and allows to compile and run HERA-B analysis executables to perform complete analysis chain, including MC production, event reconstruction and trigger simulation. Compared to the minimal environment, the full one includes an extended set of necessary databases and for safety reasons a raw image of the old HERA-B Linux root filesystem instead of selected local binaries. The volume sharing is as follows: ~ 1.6 Gb — tarball with the tools and libraries from DESY AFS; ~ 1.5 Gb — raw image of the root filesystem of a typical old Linux work-group server; ~ 5.0 Gb — set of databases required for analysis as well as for MC production, event reconstruction, and trigger simulation.

The main steps taken to set up an old system “guest” in a chroot-jail on the host Linux system are as follows.

- The raw image of the old root filesystem is mounted as a loop device to a chosen directory,
- the host’s /tmp, /proc, and the directory with the old AFS binaries and database files are mounted in “bind” mode respectively into $guest/tmp, $guest/proc etc.,
- a few settings such as the host name in $guest/etc/hosts are fixed,
- finally, ‘chroot $guest’ is called to switch into the old system guest.

Among the advantages of the chroot-jail approach one can name its simplicity, the fact that virtualization provides exact bug-to-bug reproducibility of the original software (which is especially important for keeping it as a reference for any future development), and that it incurs...
no performance penalty compared to the full user-space virtualization solution. The main drawback comes from the dependence on the backward compatibility between Linux kernels, although this problem is characteristic to any presently available virtualization solution (namely, in the form of possible backward-incompatible developments of the virtualization platforms in the long term future).

Creation of the virtual environment allows to freeze an official working HERA-B release so that this frozen version could be used for running the analysis software “as is” as well as for testing the future migrations.

5. Preservation Model

Preservation of the data has not been considered during the active phase of the Collaboration. That could not but unfavourably influenced the quality of the code, the data formats and in particular lead to the overall lack of documentation.

As a guideline we take the level 4 model from DPHEP recommendations [4] for full software preservation. Full analysis chain and data starting from the raw DSTs are preserved. The model implies that the simulation/reconstruction/analysis is performed using modern OS, while keeping a frozen official release on an old OS for testing. The GRID is to be used as the computing resource. The access to the data is to be regulated via a reanimated VO, herab. The data can also be released in future (first in n-tuple format) for the outreach purposes.

While discussing preservation of the legacy scientific software, in our opinion it is worth to consider separately the more technical parts of the software such as I/O, inter-process communication and database services from the physics data simulation/reconstruction and analysis parts of the software. The technical libraries often can be relatively easily maintained or even reimplemented using modern compilers and more efficient techniques by a software specialist whereas the physics analysis parts of the software are highly specific for the given experiment and comprise a lot of expert-knowledge, in particular understanding of the physics and properties of the detector so that the support of the physical parts of the software requires work of an interested physicist deeply involved in doing the analysis using this software and taking the responsibility for the changes.

For example, as mentioned in the previous section, to provide a working environment it was not necessary to port the corrupted databases which can be run in a separate virtual machine running the old system. Furthermore, the data access being performed from the chroot-jail through the modern kernel calls automatically takes advantage of the updates in the hardware. Similarly, in a long-term future in case of backward-incompatible changes in the I/O interface to the mass storage system (currently the HERA-B software uses dCache and the standard local filesystem I/O operations), only a small part of the “technical” code responsible for the data I/O has to be changed without any need to update or port to a newer system the whole analysis software stack.

In our vision, the final object of the HERA-B data preservation model would be to grant an Open Access to the HERA-B data for public use. The organizational details and legal issues regarding the Open Access to the data are being discussed with the Collaboration and the DESY Laboratory.

The Open Access could be organized according to the following principles. The Collaboration would authorize the use of the data and software “as is” with no support or responsibility for produced results on the side of the Collaboration. The results of analysis would be signed by the authors of the analysis, not the Collaboration. Any publication should probably include an explicit acknowledgment stating that the data is used with the permission of the Collaboration and a disclaimer stating that the Collaboration has not reviewed the presented results and takes no responsibility for their reliability.

The modification to the code and the software support would be in hands of the community of
the users/analysts, while the data preservation crew would take care of storing the data, ensuring its availability by regularly running a set of standard tests, maintaining central repositories for software and documentation, possibly managing the VO and providing limited user training with installation and basic use of the software.

6. Conclusions
In the framework of the DESY data preservation project DESY-IT has initiated the work to preserve HERA-B data for the future use for possible (re)analysis, education and outreach purposes.

We described successful experience of porting a subset of libraries to a newer version of OS and compiler which allowed to compile an analysis executable sufficient for reading and analysing existing DSTs. Furthermore, a fully functional HERA-B analysis environment has been created based on the chroot-jail virtualization technique. Such a “frozen” system can be used as a reference for any future code migrations to newer operating systems as well as for doing analysis.

The preservation model of HERA-B is based on the level 4 DPHEP model with an Open Access. All the levels of data (starting from raw DSTs) and the full analysis chain are preserved. The road-map for the preservation has to be agreed between the Collaboration, DESY laboratory and DPHEP. Some important technical and organizational details such as usage of the GRID resources as well as the necessary legal steps regulating the access to the data have still to be settled.

In order to aid to work out the final solution and optimize it towards the needs of the future users of the preserved data, the readers interested in the analysis of the HERA-B data are kindly invited to contact the authors.

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