Data Preservation in High Energy Physics – why, how and when?

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Abstract

Long-term preservation of data and software of large experiments and detectors in high energy physics is of utmost importance to secure the heritage of (mostly unique) data and to allow advanced physics (re-)analyses at later times. Summarising the work of an international study group, motivation, use cases and technical details are given for an organised effort to secure and enable future use of past, present and future experimental data. As a practical use case and motivation, the revival of JADE data and the corresponding latest results on measuring $\alpha_s$ in NNLO QCD are reviewed.

Keywords: data preservation, JADE experiment, measurement of $\alpha_s$

1. Introduction

Analyses of data from large scale projects in experimental particle physics are usually pursued for a typical time period of 5 years after close-down of the experiments. After this time of post-mortem analyses, the number of active members of large collaborations deteriorates to zero, as does the active maintenance of data and software which is needed to efficiently analyse these data. While the data, as e.g. those obtained from 11 years of running of the electron-positron collider LEP, or from 16 years of running of the lepton-hadron collider HERA, remain to be of unique importance and relevance for the field of high energy particle physics, the long-term storage of these data and - especially - the possibility to summarise these data using the mandatory software packages and know-how of detector particularities is, in almost all cases, not warranted after a relatively short period of time. In fact, at this time, the data of many past collider projects are already lost, or are in an unusable state, and as this contribution is being written up, data e.g. from LEP experiments continue to become lost forever.

An international study group for data protection and future use of high energy physics data, DPHEP, has formed and has presented its first assessments of possible use cases and the technicalities of data and software preservation. In the following, the physics case for data preservation and re-analysis will be given, and will be demonstrated by recent physics results obtained from data of the JADE experiment which operated from 1979 to 1986 at the $e^+e^-$ collider PETRA at DESY. Some details of preservation models will also be summarised.

2. Physics case

The most important scientific reasons for long-term data protection and future use of data from past experiments are the following:

- long term completion and extension of the scientific program of the project:
  The original program of a large scientific project is usually not completed at times of shutdown of the experiment(s), and is not completely finalised even after a period of a few additional years of data analyses, when availability and usability of data and software deteriorate due to the fast development of storage and computer hard- and software systems, and due to the fading availability of expert knowledge and personnel.

- cross collaboration analyses:
  maximum value and sensitivity of the data of large collider projects can be achieved by combining the data statistics of several experiments which operated on these facilities. Such combinations, however, are often not completed, or not even started at the time when projects end.

- data re-use:
  due to the general development of scientific knowledge, new questions may arise and/or new theoretical models and experimental methods may become available which make re-analyses of old data mandatory, if no such data are available from newer or active projects.

- training, education and outreach:
  there are many examples for successful use of data and analysis tools from past experiments to train and
educate students and even pupils on modern scientific questions and methods; data, results and simulations of past experiments are often used for outreach purposes since the “owner’s rights” on public access to such data are usually less restrictive after close-down of the project.

3. The JADE experiment at PETRA: past and presence

One of the few practical examples of successful usage of data from a large experiment, up to 30 years after the data have actually been taken, is the preservation and reanalysis of data from the JADE experiment [2] which operated at the PETRA $e^+e^-$ collider [3] at the DESY laboratory at Hamburg.

JADE was one of the first symmetric and maximally hermetic multi-purpose, electronic particle detectors, comprising a high resolution gas tracking (jet) chamber, placed in a hermetic solenoidal magnetic field of 0.5 Tesla, surrounded by an electromagnetic calorimeter and a hermetic muon filter and muon detector system. PETRA delivered electron-positron collisions at centre of mass energies from 12 to 46 GeV. In total, about 200 pb$^{-1}$ of high quality collision data was taken by JADE during its lifetime, corresponding to about 45,000 well reconstructed multi-hadronic final state events [2].

JADE, together with 4 other experiments at PETRA, took data from 1979 to 1986, when the PETRA collider was shut down and construction work for the HERA collider began. The data and software files continued to be actively used for few more years, until 1990/1991, when the last analysis results were published. After that time, the data, residing on archive tapes, where physically removed from the DESY computer centre and stored in aluminium boxes. Space limitations at DESY imposed physical destruction of these tapes by 1997.

The source code of the JADE software framework was collected and stored on private computer accounts which were maintained until the IBM main frame computer was phased out at DESY in 1997. The JADE collaboration had no plan nor model for further data preservation and future use of their data.

The post-mortem project of JADE data and software revival is due to the interest and initiative of a few individual previous JADE members, which started in 1995 to 1997, just in time to prevent inevitable loss of data and software.

In 1997, about 1 TB of raw and calibrated data and MC production were moved from a few thousand archived round tapes (160 MB per tape) to 600 IBM 3490 tapes (800 MB per tape). A second copy of the data was made on 200 Exabyte cartridges (2.5 GB each) [4]. No MC generated data files were preserved at that stage. In 2005, the exabyte cartridges travelled to Munich, were transferred to disk, and are now a (very small) part of the ATLAS data storage at the LHC Tier-2 centre of the Max Planck Society computing centre at Garching.

The reactivation of the software was successfully completed in 1999 [2]. It required adapting the JADE software code, originally consisting of FORTRAN-IV, but also partly of SHELTRAN, MORTRAN and Assembler code, to UNIX platforms and modern FORTRAN compilers.

Today, the generation of model collision events, using modern physics Monte Carlo Generators with full detector simulation, is possible again, and simulated as well as real data events can be examined using a revived version of the original JADE event display with enhanced options like colour (which was not available during JADE running time). The revived JADE software runs on IBM AIX machines, relying on the fact that these systems utilise the same byte order as the IBM 370 did. The revitalisation, details of emulation routines and the usage of the software packets and data files is documented in a respective JADE computing note [6].

The complexity of the software code and the data structures, of the detector hardware and its simulation, however, still requires the knowledge of experts for analysing these data. This knowledge is currently maintained at the Max-Planck-Institute for Physics at Munich and at DESY. The data and usage thereof is still “owned” by the original JADE collaboration, such that no general “open access” to these data is granted.

4. Physics benefits: new results from old data

Improvements motivating reanalyses of the JADE data, due to advanced theoretical knowledge and analysis methods compared to those being available at PETRA times, are summarised, with special attention to the study of hadronic final states, in Table 1. Enhanced and more profound theoretical knowledge, more sophisticated Monte Carlo (MC) and hadronisation models, improved and optimised experimental observables and methods, and a much deeper understanding and precise knowledge of the Standard model of electroweak and strong interactions make it mandatory and beneficial to reanalyse old data and to significantly improve their scientific impact.

In general, these benefits can be used to

- re-do previous measurements, with increased precision and reduced systematic uncertainties;
- perform new measurements, at Energies and processes where no other data are available today;
- if new phenomena are found today: go back and check at lower energies.

4.1. JADE data and LEP parametrisation: universality of hadronisation

One of the first surprises when starting to reanalyse JADE data was to realise that newly generated Monte Carlo
model events, based on modern QCD shower models like JETSET, HERWIG and PYTHIA, using parameters as optimised much later by the experiments at the LEP collider, described the JADE data, at much smaller c.m. energies than at LEP, to a degree never obtained at PETRA times \( \frac{E}{ \sqrt{s}} \). In detail, hadronic event shape distributions are correctly described at all energies, down to 14 GeV, by the models without the need to re-adjust model parameters at each c.m. energy (see Fig. 1) - a fact never achieved at PETRA times, where models required significant retuning of parameters at each major energy.

There is an important physics result behind this observation: the process of hadronisation as implemented in these models does not depend on the c.m. energy, such that studies of physical parameters, like the size and the energy dependence of the strong coupling constant, \( \alpha_s \), can be pursued with a minimum of systematic uncertainties. Moreover, using the JADE data sample, such measurements can be done in the entire PETRA energy range, where the energy dependence of \( \alpha_s \) is expected to be much larger than at the higher energies of LEP. Note that at PETRA times, the insufficient quality of modelling the lowest energy data, around 14 and 22 GeV, prevented significant studies of those data.

### 4.2. The running coupling \( \alpha_s \) in NNLO QCD

The latest study and re-use of JADE data \( \frac{E}{ \sqrt{s}} \) demonstrates the physical value of old data at times far after the active time of the experiment: measurements of the coupling parameter of the strong interaction, \( \alpha_s \), can now be pursued with much higher precision and considerably smaller systematic uncertainties than at the times of PETRA. All of the facts listed in Table 1 apply and improve the significance of such measurements today, using the data of the past.

The status of \( \alpha_s \) measurements at the time of PETRA was reviewed e.g. in \( \frac{E}{ \sqrt{s}} \). It can be summarised by quoting \( \alpha_s(35 \text{ GeV}) = 0.14 \pm 0.02 \), where the error was largely dominated by hadronisation and QCD uncertainties.

The results of reanalysing the JADE data \( \frac{E}{ \sqrt{s}} \), using modern event shape and jet distributions and the most recent and advanced predictions in resummed next-next-to-leading order (NNLO) of QCD perturbation theory \( \frac{E}{ \sqrt{s}} \), are shown in Figure 2 as a function of the c.m. energy. Also shown is the prediction of the running \( \alpha_s \) in 3-loop QCD perturbation theory, for the central fit value of \( \alpha_s(M_Z) \) to all JADE data,

\[
\alpha_s(M_Z) = 0.1172 \pm 0.0020(\text{exp}) \pm 0.0046(\text{th}) .
\]

The results are also compared to a similar analysis using LEP data \( \frac{E}{ \sqrt{s}} \).

The value of reusing JADE data is obvious: \( \alpha_s \) runs with energy as predicted by QCD, which is significantly proven by the JADE data alone, manifesting the concept of Asymptotic Freedom \( \frac{E}{ \sqrt{s}} \) (see \( \frac{E}{ \sqrt{s}} \) for a recent review of measurements of \( \alpha_s \)). No other such results are currently available in this energy regime. They are, due to many improvements in the field during the past 20 years, significantly more precise than what has been achieved during and shortly after the actual running of PETRA.

### 5. International effort of data preservation: DPHEP

While the JADE example is one of the only existing examples of preserving and reusing data and software of a complex experiment in high energy physics, it is known that the data of many other experiments are already lost inevitably, and/or cannot be used any more due to the lack of functional software and analysis environment. The LEP experiments, more than 10 years after active data taking, report occasional analyses until today, however it is known that the data, as well as the corresponding software environments, are beginning to fade away, and some losses of data (archive tapes) were already communicated.

In 2009, an international initiative to preserve data in high energy physics (DPHEP) has formed and worked out arguments, technical details and governance policy for a concerted effort to preserve and re-use data of recent and current large-scale high energy physics experiments. In particular, 4 different levels of data preservation models have been defined, as summarised in Table 3. These levels are inclusive, i.e. higher levels include the details of those before. In general, they differ in their overall purpose, in their degree of flexibility and in the amounts of efforts necessary to maintain these levels.

While levels 1 and 2 are realised in a number of projects and cases, they do not allow to perform new or improved analyses (compared to what was published in the past). Level 3 provides some limited means for new analyses. Only level 4, however, gives the flexibility which provides full future potential of data analysis. It is also the most intricate model, as it requires significant and sustained efforts of preparation, maintenance and validation.
Table 2: Data preservation models and different use cases as worked out by the DPHEP study group.

| Level | Preservation model | use case |
|-------|--------------------|----------|
| 1     | provide additional documentation | publication-related information search |
| 2     | preserve the data in simplified format | outreach, simple training analyses |
| 3     | preserve the analysis level software and data format | full scientific use based on existing reconstruction |
| 4     | preserve reconstruction and simulation software and basic level data | full potential of experimental data |

A typical time-line of a level-4 data preservation model is given in Figure 3. It relates the times of data taking, of collaboration life time, of data preservation R& D, of long term analysis and a possible and final “open access” period with the new organisation of physics supervision and resources needed to pursue such a project (in units of FTE’s, as a function of the number of years). Further details on the questions of technologies, facilities, funding, governance, supervision and authorship rights are elaborated and given in [1].

Future usability and preservation of data of large HEP experiments is mandatory, both on grounds of scientific importance and of sustainment of publicly funded heritage. While extra resources must be identified to pursue active data preservation, the necessary amount of such resources is only at the level of very few percent of the original investments. Failing to do so, i.e. accepting the loss of data and their scientific usability, may be regarded to be a crime, given the large amounts of expenses and manpower which were invested in the original experimental programs.

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Figure 1: Distributions of 1-T data at c.m. energies from 14 to 44 GeV. The data are compared to model predictions with hadronisation parameters optimised at LEP.

Figure 2: Measurements of $\alpha_s(Q)$ from JADE data, in the energy range from $Q = 14$ to 44 GeV, using event shapes and QCD predictions in resummed NNLO&NNLA perurbation theory. The results from a similar analysis of OPAL data (preliminary) are also included.

Figure 3: Timeline and need of resources for a data preservation model at level 4, i.e. maintaining full flexibility for future and long-term use of the data of a HEP experiment after its termination.