January 15, 2005

Research-Oriented Teaching of Particle Physics[§]

G. Dissertori*

Institute for Particle Physics, ETH Zurich, Switzerland

Abstract

We present a realization of the concept of research-oriented teaching in the particular case of particle physics. Our approach is based on the deployment of modern e-learning tools in order to give students easy access to data of modern particle physics experiments. It has been implemented in the form of a novel course at ETH Zurich, which relies on a Web site developed within the "Interactive Physics and Education Project (IPEP)" at the Institute for Particle Physics. We give a summary of the goals of this project, the didactical advantages of our approach and the experience gained so far.

[§]Presentation given at the 9th Workshop on Multimedia in Physics Teaching and Learning, Graz, Austria, 2004.

*guenther.dissertori@cern.ch

1 Introduction

During recent years, new media and e-learning tools for teaching at the University level have found ever more attention and wide-spread use. The possibilities for applying these new tools cover a very large spectrum, from the simple publication of lecture notes on the World Wide Web to the development of very sophisticated, often multi-media enhanced, web sites.

It is rather clear that a University, with its two-fold mandate of research and education, should efficiently use its resources and unique position by offering the best-possible preparation of its students for their later activities as researchers. Thus its education system should have an important component of research-oriented teaching, besides the more standard and traditional collection of classes and courses.

At the Institute for Particle Physics at the Swiss Federal Institute of Technology (ETH) in Zurich we have made an attempt to combine the two aspects mentioned above, namely the advent of new media and the importance of research-oriented teaching, by offering a new course to students interested in the analysis techniques of modern particle physics. The basis of this course is a newly developed web site which allows students to gain easy access to the (in general rather complex) data of a variety of modern particle physics experiments. Thus our approach to research-oriented teaching consists in web-aided data analysis, web-based search for original publications and the preparation of scientific presentations by the students with the help of modern presentation tools, which are the current standard in the scientific community.

In the following we present the "Interactive Physics and Education Project" (IPEP), by which the above-mentioned course was initiated. Next we describe the issue of teaching particle physics, in particular regarding data analysis, and our technical solution to this problem. Then the experience gained so far at ETH Zurich is summarized, followed by a proposal for further applications of our tool. Finally, some conclusions are given.

2 The project IPEP

The Interactive Physics and Education Project was initiated in 2001 by Prof. F. Pauss at the Institute for Particle Physics of ETH Zurich. IPEP proposed a strategy for making physics goals, experimental techniques and real hands-on computational aspects of particle physics accessible to students as well as to a larger community. The main objective was that students shall get their first hands-on experience with modern analysis methods using real data from particle physics experiments, without having to learn technical details such as data access. This has the didactical advantage that students can concentrate on the physics content and techniques of the data analysis.

A pilot project was set up in order to prepare a novel course at ETH, called "Computational Methods in Data Analysis : Particle Physics Examples" [1]. In particular, the preparation of the courses' web site as well as of the necessary data bases was carried out during this first phase, followed by the actual course given for the first time in spring 2002. The follow-up project then concentrated on improvements of and additions to the courses' contents and its web site.

The main challenge of this project consisted in setting up a transparent and user friendly data access, where transparent means that data from different experiments at different particle accelerators should be accessible in the same manner. The fact that this is not a trivial task is explained below.

2.1 The problem at hand

The primary objective of particle physics is the understanding of the basic building blocks of matter and the fundamental forces which act between them. In order to pursue this goal, particles have to be accelerated to high energies and brought into collisions with other particles. The outcomes of these interactions are measured and compared to theoretical predictions. Altogether this needs complex accelerator infrastructures on the one hand and typically very large and complicated detector systems on the other hand. Usually the detector systems have to read out millions of electronic channels at very high frequency, leading to rather involved and large data sets.

These experiments are carried out in the framework of large international collaborations at the leading research centres in Europe, the USA and Japan. Among others, the Institute of Particle Physics at ETH Zurich is involved in large-scale experiments at CERN (Geneva) and DESY (Hamburg). The basic issue regarding teaching is that every experiment stores the data in a particular data format and develops its own software environment for the later retrieval and analysis of these data. These environments and analysis tools can be rather complex, which often leads to steep learning curves for diploma and doctoral students joining the research groups. Obviously, the time needed for learning all these data formats and software environments is prohibitive for a direct application in a one-semester course which extends over 14 weeks at ETH Zurich.

In particular, access to data from different experiments at different particle colliders was envisaged, such as ALEPH, DELPHI and L3 at LEP, NOMAD at the SPS, H1 at HERA, CMS at LHC. Besides the general introductory courses on particle physics and possible "Semesterarbeiten", previously there was no such direct insight offered to the world of particle physics for students at ETH. The skills acquired during the course would also be relevant for other fields, where concepts such as data mining and statistical analysis or the extraction of relevant information out of a large data sample are of importance.

Since our goal was to let the students concentrate on the physics content of a selected data analysis, it was clear that a generic interface to the data had to be developed. We concluded that a Web interface for analyzing complex data from high energy physics represents a more than adequate medium, since not having to introduce the students to experiment-specific software tools increases considerably the working efficiency as well as the chance to achieve the didactical objectives. We expected the students to gain experience with independent and autonomous solving of scientific problems, as well as to acquire skills in preparing high-standard scientific presentations. For the teaching staff it should allow to get major insights into new e-learning techniques. Finally, the re-useability of the infrastructure and contents constituted an important aspect.

2.2 The technical solution

The web site of the course is structured according to the experiments/analyses which can be carried out and accessible via a main introductory page, `http://ihp-lx2.ethz.ch/CompMethPP/`. For every project, first a short description of the underlying physics as well as of the detector and accelerator at hand is given. The students have to follow several steps, which are indicated by links to the specific web pages, cf. Fig. 1. These steps are i) scanning of event displays of particle interactions (Fig. 2), in order to get a feeling for the event topologies involved and thus to lay out the later analysis strategy, ii) data analysis by submitting queries to a data base and interpreting the results which are returned in the form of histograms, iii) further data interpretation, such as parameter fits to selected data distributions. In addition, specific web pages contain further information needed for the analyses, as well as links to the lecture notes, to frequently asked questions and to a groupware system (BSCW [2]) for collaborative actions (students work in groups), such as data storage and communication.

Regarding the scanning of event displays, task i), two solutions have been adopted. The analysis of Z boson decays at LEP, registered with the DELPHI detector, is implemented as an interactive tool based on JAVA and developed at CERN (WIRED [3]), whereas for the other experiments the scanning consists in simply browsing through images stored on the server.

The technically most challenging task was the interface to the data, needed for step ii), which has to be user friendly, flexible and which should not cause large network load. The data are stored in a POSTGRES (SQL) [4] data base on a Web server (Linux PC) and accessed via a Web form with SQL statements for data selection. Graphics rendering is performed on the server side, using a JAVA based package developed at SLAC (Stanford) for high energy physics data visualization (JAS [5]).

The data base represents a compressed data set and contains simple high-level variables of several different experiments. Any detailed detector-specific data have been discarded in the original skimming process. The Web-interface for the interactive data queries (Fig. 3) allows to choose between experiments at different accelerators, to select a specific event variable to be histogrammed, to define a set of selection criteria (SQL statements) and finally to submit the query to SQL tables containing real data and/or simulations based on specific physics and detector models. An application, which runs on a central server, takes the query, scrutinizes the data base, generates the graphics and sends the latter back to the client (the Web browser), as seen in Fig. 4. This architecture renders the client particularly light-weight and minimizes the amount of data transfer across the network. In addition, no special software is required to access the data, a standard Web browser is sufficient. Further data analysis such as histogram fitting, task iii), can be performed, again via a Web interface (Web form), with the CERN package ROOT [6] running on the server side and only the resulting graphics sent to the client.

3 Experience gained so far

The course "Computational Methods in Data Analysis : Particle Physics Examples" has been offered on a regular basis since 2002 (during every spring term) to students from ETH Zurich as well as from the University of Zurich. It is given in English. This constitutes a preparation of the students to their imminent entry into the world of research, where English is the standard. The course covers two hours of lectures and one hour of exercises. However, the actual time dedicated to purely lecturing and to active work at computer terminals varies throughout the term. The didactical approach is the following: First basic concepts and methods, such as particle detectors and statistics, are taught in a rather classical style. Then these concepts and methods are implemented by the students via team-work on concrete projects/problems, under supervision of the lecturer and the assistants. Finally, the aspect of adequate and modern presentation techniques for scientific results is brought into discussion, with concrete presentations to be prepared and given by the students at the end of the course.

The lectures and the student projects cover physics topics such as the analysis of the Z line shape and the determination of the number of light neutrino families, Higgs search at LEP, cross section measurements at HERA and the study of neutrino interactions with the NOMAD detector. The students use the Web site with the interface to the data described above. Groups of 2-3 students work together on one physics topic of their choice. Group discussion sessions on technical and topical issues are organized, as well as a presentation session at the end of the course. With this group work we are able to enhance teamwork and social competence. Apart of the work with computers in the lecture hall students are expected/encouraged to work off-time by accessing remotely the Web site.

The transparent data access, avoiding the learning of experiment-specific analysis tools, has allowed the students to quickly enter the physics aspects and problems of the data analysis. Within the limited amount of time they have been able to complete the exercises, i.e. perform the required measurements and to prepare scientific talks (typically with POWERPOINT) in order to summarize their work. Thus our basic didactical goal has been achieved. In addition, their independent hands-on experience with real data, as well as the usage of original scientific literature (in English) has given them valuable insight and taste for the later scientific work. Overall the students' experience turned out to be extremely positive so far, indicated first by a direct course evaluation in form of a questionnaire and second by the fact that an overwhelmingly large fraction (above 80%) of the students have later chosen to carry out their diploma and PhD thesis work at our Institute.

It is worth noting that the students appreciated very much the introduction to techniques of giving modern high-standard scientific presentations, which was missing from the curriculum so far.

4 Project status and further applications

Encouraged by the positive feedback obtained during the last three years, we will continue to offer this course regularly during the upcoming years. It is planned to include further physics topics in the near future, such as analyses of simulated and real data at the future LHC collider at CERN. We have also been approached by interested colleagues from other Universities (e.g. from Pisa and Florence in Italy) in order to obtain our tool and integrate it into their own curriculum.

In parallel, we have prepared a down-scaled version of our Web site [7], with enhanced documentation, necessary for offering it as a tool to high-school teachers and students. In order to understand the requirements of this type of "client", we have organized dedicated workshops with teachers from Switzerland as well as from Austria and northern Italy. First experience could be gained with a dedicated class given at a school in Switzerland, as well as with a high-school student who has carried out a "Matura-Arbeit" on the study of Z boson decays by using our simplified Web tool.

Not surprisingly it turns out that still a substantial effort and dedication by the teacher is required for a successful deployment of the tool. Concentrating on a limited group of interested and highly-motivated students is also beneficial. Nevertheless, the idea of offering direct insight into the fascinating world of modern research in particle physics by analyzing real (!) data, in general seems to be a good approach of bringing fundamental research to the schools. It is the personal experience which gives the additional value. Therefore we believe that our work can be the basis for future outreach activities, now targeting the general public.

5 Conclusions

We have presented an approach to the problem of research-oriented teaching of particle physics, based on the development of a Web tool which allows for a simple access to real data of modern particle physics experiments. During the last three years, a dedicated course, based on this Web tool, has been successfully given at ETH Zurich. Motivated by this experience, first attempts have been made to adapt the tool also to the interests and needs of high-school teachers and students. The possibility of even addressing the general public in the future is foreseen.

Acknowledgements

The Interactive Physics and Education Project has been funded by the Rector's Fonds FILEP at ETH Zurich. I would like to express my acknowledgements to Prof. F. Pauss who has initiated this project, as well as to my colleagues Dr. Ch. Grab, Dr. A. Holzner, Dr. F. Behner, Dr. B. List, Dr. P. Herrmann and M. Bischofsberger for the successful collaboration and realization of the project. Finally, I would like to thank the organizers of the MPTL9 Workshop for the invitation and the very pleasant and stimulating atmosphere at the conference.

References

[1] `http://ihp-lx2.ethz.ch/CompMethPP/`

[2] `http://bscw.fit.fraunhofer.de/`

[3] `http://wired.freehep.org/index.html`

[4] `http://www.postgresql.org/`

[5] `http://jas.freehep.org/`

[6] `http://root.cern.ch/`

[7] `http://ihp-lx2.ethz.ch/CompMethPP/outreach`

Appendix : Screen Shots

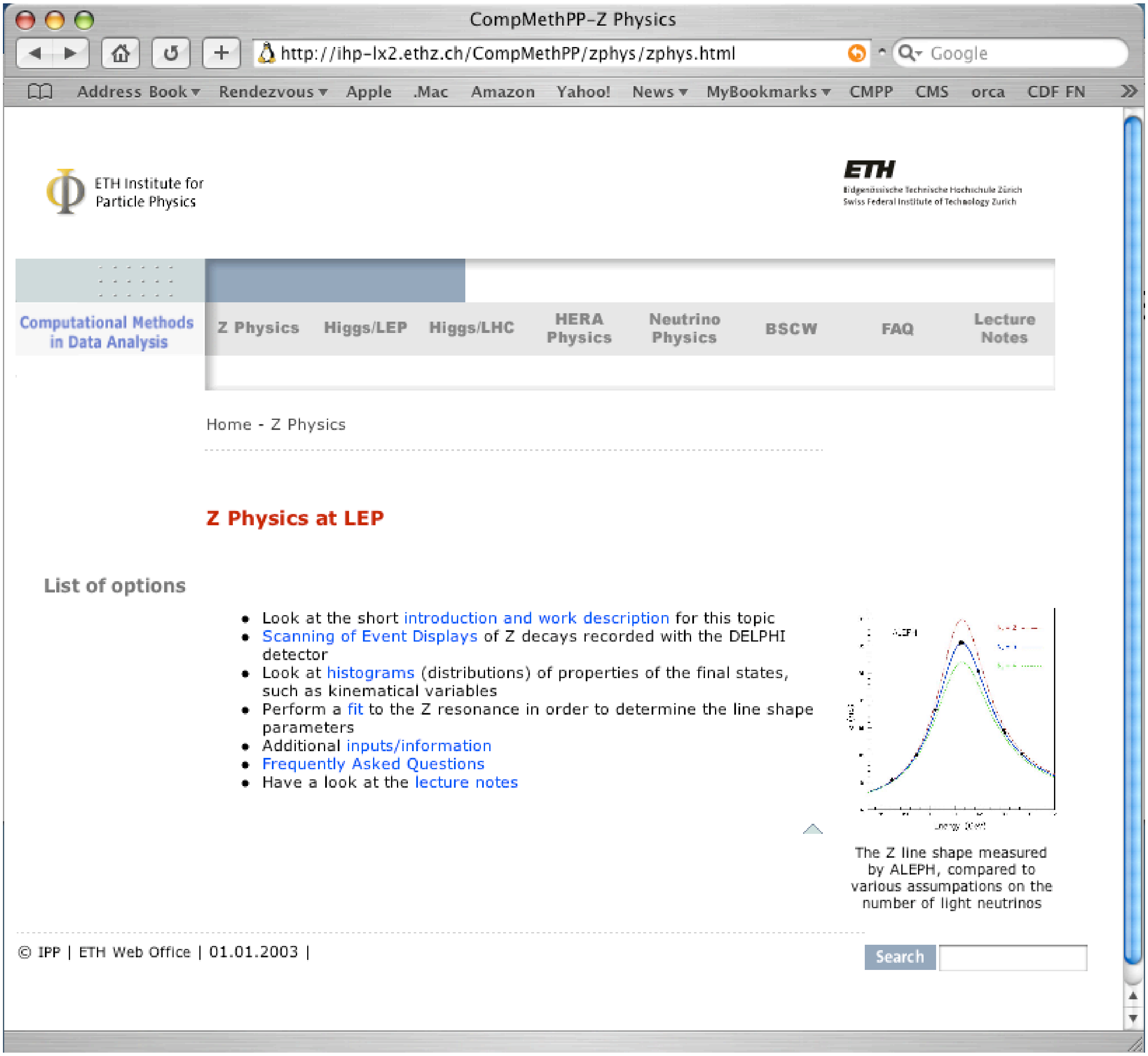

Figure 1: Screen shot of the main entrance page to a specific student project.

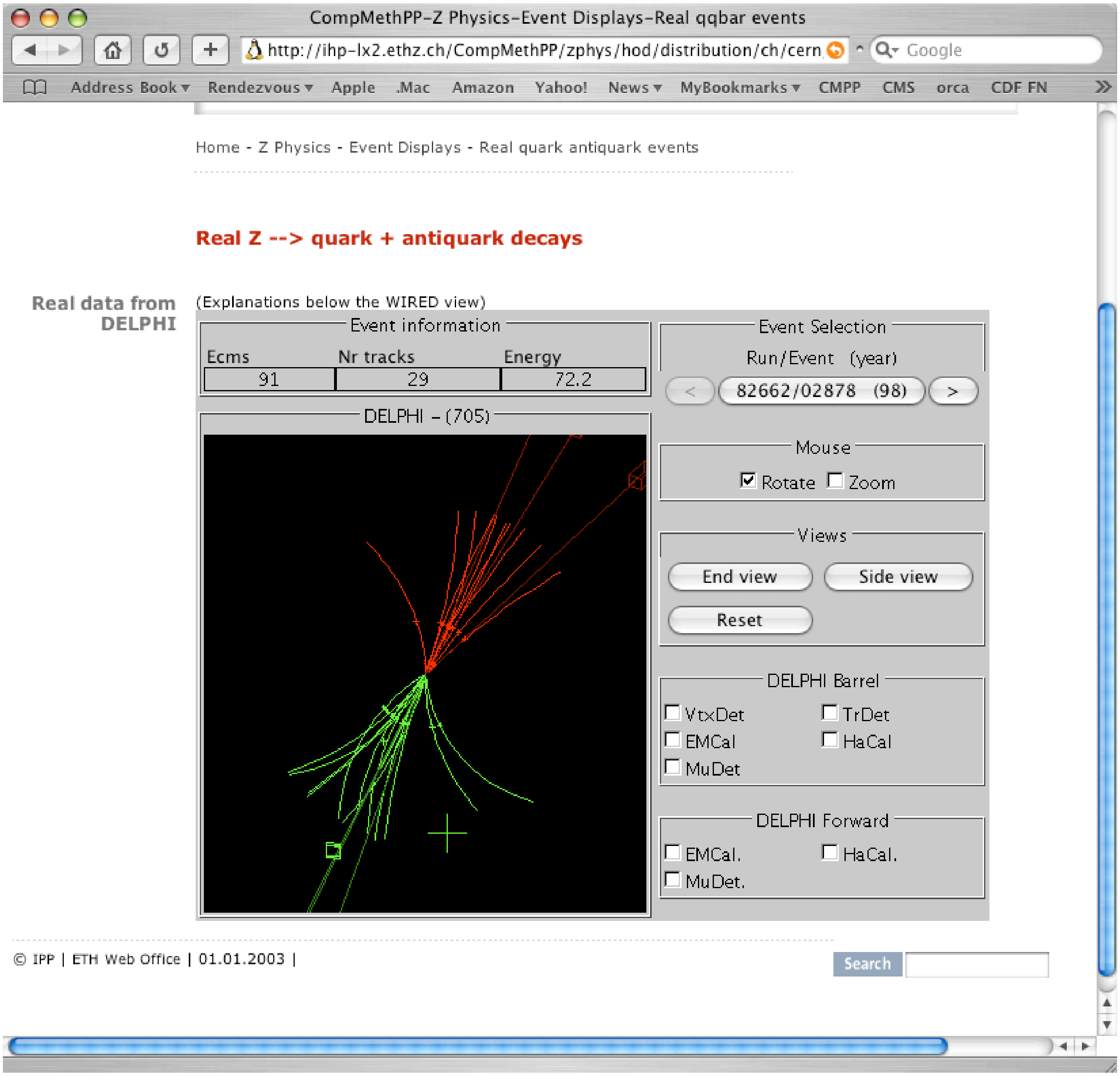

Figure 2: Screen shot of the web page with the event scanning tool for Z boson decays.

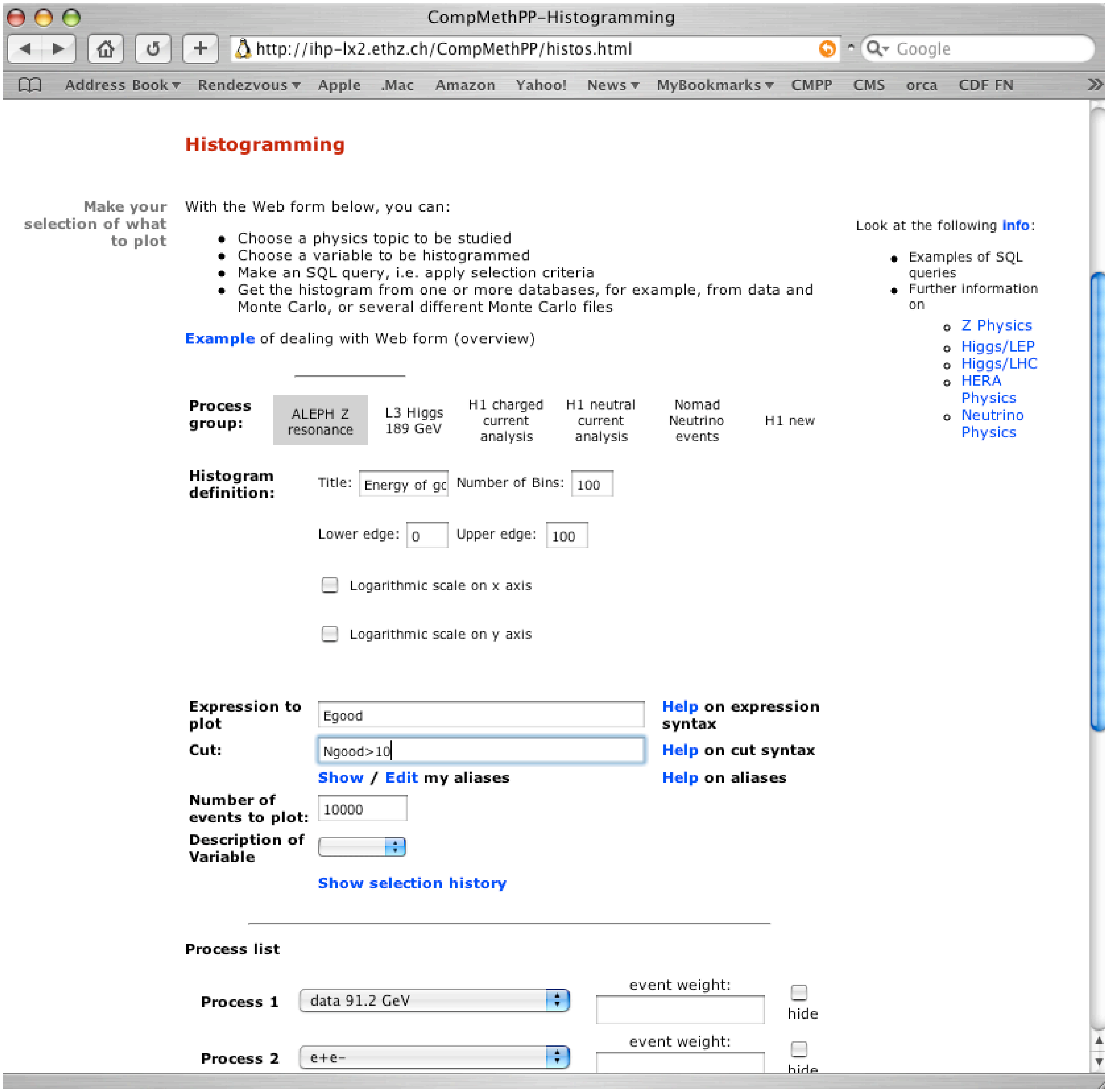

Figure 3: Screen shot of the web page with the web form for choosing the data to be analyzed and the histogram to be created.

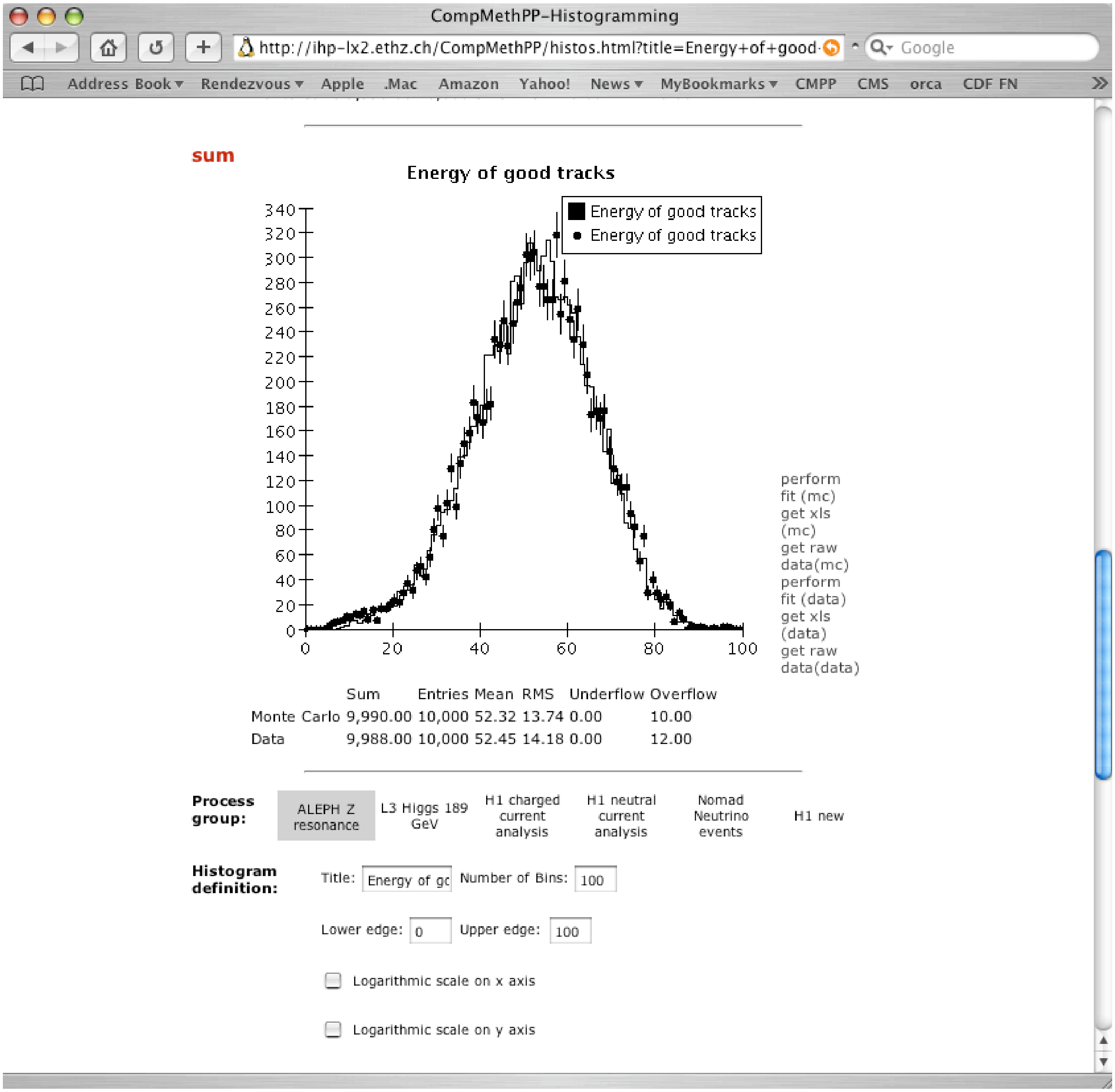

Figure 4: Screen shot of a web page containing the result (histogram) of a query to the data base.