PROCEEDINGS OF SCIENCE

Cosmic@Web - Astroparticle learning platform for students

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Encouraging young people to actively participate in science is a longstanding and important priority at DESY. To provide high-school students with an opportunity to learn more about astroparticle physics, a number of simple experiments were developed at the DESY Zeuthen campus. Data from these experiments are published on the *Cosmic@Web* learning platform, along with a range of online analysis tools and introductory material. In addition to local experiments, data are provided from a global network of continuously-operating cosmic particle experiments. Diverse sites participate in this network, including the pole-to-pole research vessel Polarstern, the Antarctic Neumayer III station, as well as the high altitude research stations in Aragats, Armenia and Moussala, Bulgaria. Using *Cosmic@Web*, students without direct access to an experiment can analyse data in a classroom or at home. The learning platform can also be used to participate in the annual International Cosmic Day. With Cosmic@Web, students can work like real scientists and do their own astroparticle physics research. These developments form part of the German outreach network Netzwerk Teilchenwelt.

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1. Introduction

The astroparticle department at DESY has a longstanding tradition of supporting cosmic particle outreach programs. Offering insights into this research field for the public has long been an essential component of this mission. We have extensive experience in promoting direct contact between scientists and young scientific and technical talents.

Our primary outreach aims are:

- to bring our research closer to the general public, and to help them to understand how research is conducted;
- to promote enthusiasm about physics, and to attract the younger generation to scientific and technical careers before they lose interest in science;
- to convey the joy of physics.

The arrival of wide-scale internet access in almost every household has provided a unique opportunity to develop a digital outreach strategy. Using the internet, we can reach a significantly larger audience, who no longer need to be physically present at the institute. For this reason, we created the online platform *Cosmic@Web*, an effort to redesign physics learning with the aim of enabling authentic scientific work for young people. The platform, which we introduce here, has been successfully used by many students. It is supported by *Gesamtmetall - Nachwuchssicherung* [1] and forms part of the German outreach network *Netzwerk Teilchenwelt* [2].

2. Physics education in Germany today

In 2016, the German Physical Society (DPG) published a comprehensive study of physics education in Germany [3]. This study highlighted a broad social consensus on the importance of physics being taught at school, particularly given that Germany is a high-tech but resource-poor nation. However, there are disagreements about the extent to which physics should be taught in order for a person to become a responsible citizen in our country. It has become socially acceptable to say: "I've just always been bad at mathematics and physics". At the same time, the German economy is facing a massive shortage of scientific and technical specialists and corresponding trainees. How is it that, despite the recognised social importance of physics, it remains one of the most unpopular subjects? How can we communicate physics in a more engaging way? The study identifies and describes six problems physics education in schools faces today:

1. The desired standards and skills are not routinely achieved by students.
2. Material is taught in an isolated way, without establishing connections between topics.
3. Interest decreases with age, and this trend is especially pronounced in physics.
4. There are huge differences in performance levels within a class.
5. Girls lack self-confidence in physics and boys achieve significantly better results.

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6. Computer and information literacy is not satisfactory.

In line with the study's findings, we prioritised the following for the *Cosmic@Web* platform:

- Present natural science research as it is conducted and present a better and more realistic image of physicists.
- Choose diverse and problem-oriented tasks, recognize and promote special talents and inclinations.
- Break through the monotony of physics lessons by conveying the complexity and nuance of physics problems, which are often oversimplified in classes. Prioritise deeper understanding of selected concepts, rather than broad but superficial knowledge.
- Experiment more, introducing indispensable mathematical tools and specialist vocabulary step by step and as needed for the experiments.
- Promote reflective, critical handling of digital media and the Internet. Integrate simulations and animations.

3. *Cosmic@Web* in a Nutshell

With *Cosmic@Web*'s online analysis tools[1], young people can easily analyse real experimental data from a global network of cosmic particle detectors. Introductory materials and descriptions of the experiments can be found, in both English and German, on the accompanying websites[2]. The material is primarily aimed at students aged 14-18, and requires no programming knowledge. The platform aims to give students the opportunity to work like a scientist. With *Cosmic@Web*, they can choose a topic to investigate, study literature, define a hypothesis, analyse data, and summarise their results.

In our experience, a central challenge for online resources is in weighing up how much information should be provided. While the learner should not be overwhelmed by the excessive technical information, sufficient information must be provided to enable students to draw their own conclusions when analysing data. Different approaches are offered to understand the topic step by step, leaving room for discovery. Nevertheless, there must always be the possibility to receive assistance in the learning and cognition process and to deepen one's knowledge in the subject area. The *Cosmic@Web* online analysis tools are as intuitive as possible, leaving plenty of room for autonomous analysis of the provided data, but also giving guidance by setting reasonable default values. One of our aims is to ensure that the *Cosmic@Web* online analysis tools and the material provided are easily understandable for a wide audience. Technical concepts are simplified where possible, while maintaining scientific accuracy.

The main page at http://cosmic.desy.de introduces cosmic particle research with four key themes: scientific ("What are cosmic particles?"), historical ("How are cosmic particles studied?"),

[1] http://cosmicatweb.desy.de
[2] http://cosmic.desy.de

origin-based ("Where do cosmic particles come from?") and life-relevant ("How do cosmic particles affect our everyday lives?"). Following the introductory texts, readers are invited to consider questions covering each of the four aspects, with helpful links to further resources for additional research. This is particularly useful for German-speaking students, as there are few alternatives available. The links teach students to learn independently while assessing the quality of source material, a skill that German students often lack. This approach enables students to become increasingly familiar with cosmic particles, but also leaves room for independent reflection.

Raw data from several different experiments are provided, along with explanatory material and suggestions for possible analysis tasks. Unlike many school experiments, the data do not always clearly show the expected trends. Often systematic effects have to be identified and understood before the data can be properly interpreted, for example accounting for additional dependence on temperature or pressure. This is much closer to the way research is conducted by scientists. The complexity of interpreting real data allows space for discussion and room for interpretation, making the analysis more exciting.

For each experiment, an overview of the detector is given, along with a description of the data and example analyses. A glossary also explains basic terms that students might not be familiar with. An introduction to the scientific method is also provided, along with example reports from former pupils. These should help the young people to collect ideas for their own final report and for the "publication" of their findings.

4. How to use the *Cosmic@Web* online analysis tools

The *Cosmic@Web* online analysis tools can be run in a web browser with a computer or smartphone. The central analysis page is shown in Figure 1. Students can easily analyse data and plot results. The platform can be used either individually or as part of a team in school lessons, or alternatively during student internships in research institutions. Previous students have used *Cosmic@Web* to produce technical papers and posters. Students with varying levels of background knowledge have been able to successfully use the *Cosmic@Web* tools to analyse data and create professional plots summarising their results.

The website offers a user-friendly graphic interface. The following options should be specified to produce plots:

- The complexity level must be selected. There is a *Standard* setting for beginners, while advanced users can alternatively choose *Advanced*.
- Both the experiment and dataset must be selected.
- Variables must be selected for analysis.
- Cuts to reduce the data can be defined.
- The desired plot type must be selected (1D Histogram, XY Plot, 2D Histogram, Profile, Map)
- A function to fit to the data can be specified (Linear, Exponential, Gauss, Sine, Custom Equation)
- Additional stylistic options can be specified for plot design, and the file format.

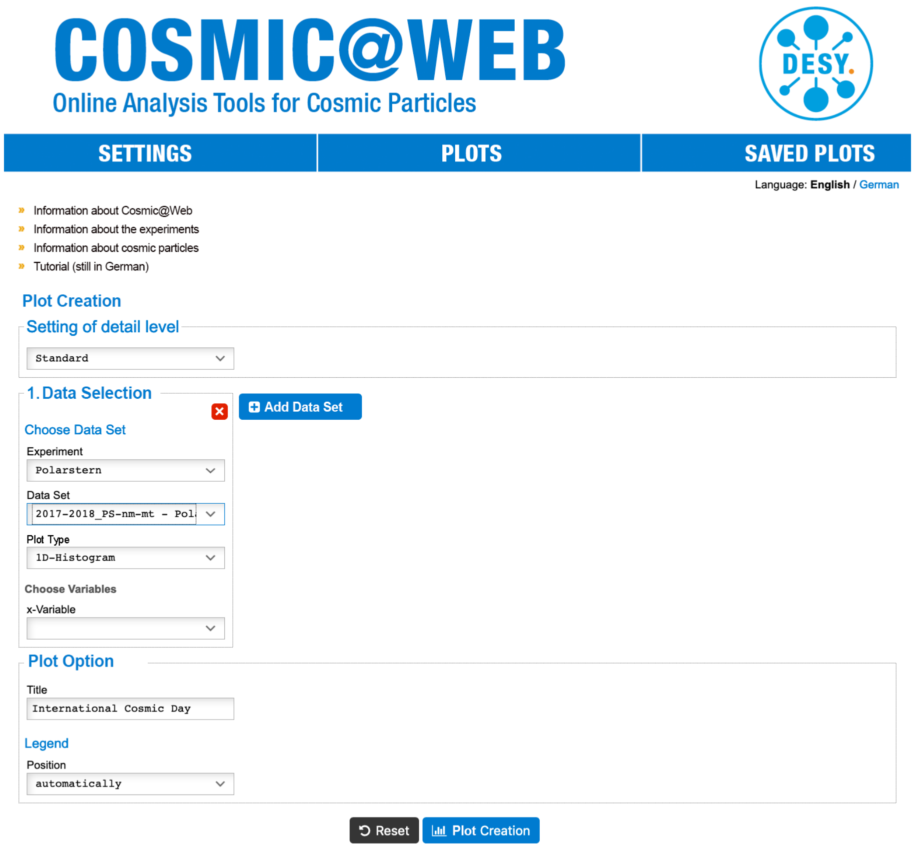

Figure 1: The *Cosmic@Web* online analysis tools welcome page.

5. Experiments and Analysis Suggestions

Datasets from several different experiments are available and we plan to expand this offering in the future. Most datasets have a livetime of several years, and are provided together with weather data to enable studies on the effects of atmospheric pressure and temperature on particle fluxes. There are currently three classes of experiments which can be analysed with *Cosmic@Web*:

- Experiments running continuously at the DESY campus in Zeuthen. These include the Trigger-Hodoscope (recording muons and particle showers), the CosMO Mill (for investigating the angular dependence of the muon rate), CosMO-muv (for measuring the velocity of muons), and LiDO (for measuring the lifetime of muons).
- A muon detector and a Mini Neutron Monitor (MNM) installed on the German research vessel Polarstern. Their data make it possible to investigate the shielding of the Earth's magnetic field against cosmic particles. A similar muon detector and MNM took data at the German Antarctic Station Neumayer III, to look for cosmic weather events caused by increased solar activity.
- Open access data from the SEVAN network [4], organized by the A. Alikhanyan National Lab in Yerevan, Armenia. Data from two SEVAN detectors are available: SEVAN Aragats

(3200 m altitude in Armenia) and SEVAN Moussala (2900 m in Bulgaria). The data can be used to study cosmic weather effects and the fluxes of muons, electrons, neutrons and gamma rays.

5.1 Data taken on board the RV Polarstern

The German research vessel (RV) Polarstern [5], operated by the Alfred-Wegener-Institute, is used for polar and environmental research. It cruises between the Arctic and Antarctic, with two Atlantic passages annually. The Polarstern also hosts guest experiments on board, such as a Mini Neutron Monitor (MNM) and a muon detector. Both experiments are jointly operated by DESY, Christian-Albrechts-UniversitaÌĹt Kiel and North-West-University Potchefstroom (South Africa). The MNM and muon detector measure the flux of secondary particles (neutrons and muons respectively) created in cosmic ray air showers. Those fluxes depend on the solar activity, as well as the Earth's magnetosphere. They also depend on meteorological parameters, such as the temperature and pressure. The Earth's magnetosphere changes with latitude, a trend which is reflected in the countrate of secondary cosmic rays. The sensitivity of the detectors can be studied by measuring the variation of the countrate over the latitudes covered during one passage. The study of solar activity effects are long-term, requiring several years of data from passages following the same routes. Both on board detectors operate autonomously: data are reduced on board and stored on a laptop, with the reduced data being sent to DESY along with meteorological data. Data from many years of Polarstern cruises are made available on the *Cosmic@Web* platform together with tools to analyse them. Students can explore how the countrate of cosmic rays is modulated by the latitude (i.e. the Earth's magnetic field) and local weather conditions, and also explore long-term trends due to solar activity. During the Fall 2018 passage [6], the collection of realtime meteorological data was upgraded.

6. International Cosmic Day

One application of *Cosmic@Web* has been for the International Cosmic Day (ICD)[3] [7], a global astroparticle physics outreach event for high-school students organised each year by DESY. Since 2012, students, teachers and scientists from all over the world have participated in an annual program to learn about cosmic particles and study atmospheric muons. The students typically gather in venues such as schools, universities or labs. They spend the day analysing muon data, working in groups to discuss their task. School groups can also participate in a joint video conference hosted by scientists, giving them the opportunity to present results to their peers. Proceedings are also published recording contributions from all participants. By participating in the ICD, students can fully experience the work of a scientist, which includes the measurements and data analyses as well as collaboration with international colleagues and the presentation of the results.

The physics goal of the ICD is to understand the zenith angle dependence of atmospheric muons, using two cosmic-ray detectors in coincidence. The main result is that the muon rate is lowest when the detectors are oriented horizontally. Trying to explain this trend leads to a discussion of the lifetime of the muons, their decay and their propagation through the atmosphere.

[3] https://icd.desy.de

Any cosmic ray detector can be used for the ICD, so each group can use a local setup or even build their own. Since 2018, it is now also possible to participate in the ICD using the data offered by *Cosmic@Web*. This means that students without access to a detector can still analyse muon data and present their results at the video call. Now that participation only requires access to a computer, it is much easier for schools to join. Using *Cosmic@Web* has widened access to the ICD, and the number of participants to the ICD has increased by $\sim 10\%$. As the Polarstern upgrade coincided with ICD 2018, the opportunity was used to also present that experiment and share the newest data taken on board with students participating in the ICD via satellite connection.

7. Summary and Outlook

Cosmic@Web provides an easy-to-use platform for students to access and analyse data taken by multiple cosmic ray experiments online. Data from these experiments are hosted on the platform, along with a range of online analysis tools and introductory material. *Cosmic@Web* enables students to experience how scientists work, and can be used for school projects or internships, or to participate in the ICD. Soon, students will be able to download the data directly in addition to using the online analysis tools. The *Cosmic@Web* platform will continue to grow as more experiments are added, and more explanatory material is provided.

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