PROCEEDINGS OF SCIENCE

An IceTop module for the IceCube Masterclass

The IceCube Collaboration[1]

[1] *http://icecube.wisc.edu/collaboration/authors/icrc15_icecube*

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The IceCube Masterclass for high school students is an outreach project developed for the South Pole IceCube Neutrino Observatory. The Masterclass is designed to provide an authentic astrophysics research experience by demonstrating typical elements of IceCube research. It is a full-day event, consisting of engaging activities, educational talks, and scripted analyses, where students reproduce some of the main IceCube science results using real data. A highlight of the analysis activities are interactive applications, which run directly in standard web browsers and offer opportunities for students to intuitively develop insights into data processing. This contribution describes a new analysis module which reproduces the measurement of the cosmic ray energy spectrum with IceTop, the surface component of IceCube. The module features a web application that allows students to interactively fit representative IceTop events to determine the direction and energy estimator S_{125} from the raw data.

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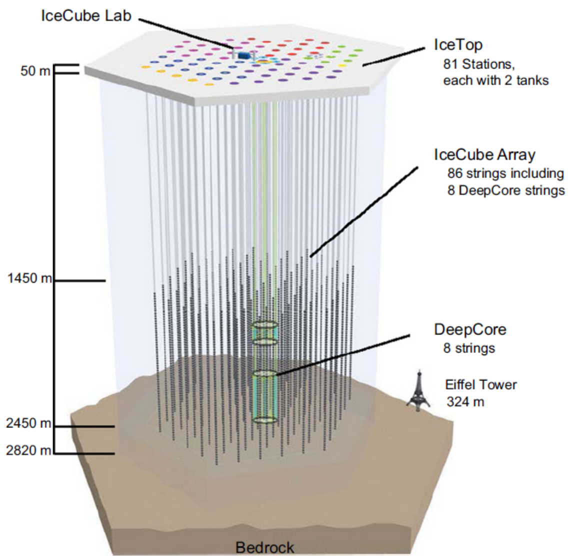

Figure 1: Schematic view of the IceCube experiment. The bulk of the light detectors are buried under 1.5 km of ice and form the in-ice detector. The in-ice detector is used mainly for neutrino astronomy and neutrino physics studies. The IceTop sub-detector consists of 81 pairs of ice-filled tanks at the surface. They serve two purposes: vetoing particles from cosmic-ray induced air showers that reach the in-ice detector (non-neutrino events), and studies of cosmic rays.

1. IceCube and the Masterclass

The IceCube Neutrino Observatory, shown in Fig. 1, is a cubic-kilometer neutrino detector located at the geographic South Pole. It has a rich physics program, including the study of extra-terrestrial neutrinos, neutrino oscillations, searches for dark matter, and studies of the cosmic-ray spectrum, composition, and angular distribution. Its surface component, IceTop [1], located at 2835 m above sea level, is an excellent detector for probing cosmic rays [2], which are detected through secondary air shower particles produced during interactions in Earth's atmosphere.

In 2014, the IceCube Collaboration launched the IceCube Masterclass [3], a new educational program that gives high school students the opportunity to learn about cosmic rays and neutrinos, and what they tell us about the universe. Students discover that IceCube is a unique, extreme experiment, both because of its location and the phenomena studied. The IceCube Masterclass program was inspired by the International Masterclasses program, started in 2005 by the International Particle Physics Outreach Group [4], and supported in the USA by QuarkNet [5].

The IceCube Masterclass invites high school students, and accompanying teachers, to join an IceCube institute for one day. They experience real research in an authentic environment, including performing an analysis using IceCube data, meeting active physicists, and linking up in person and virtually with student peers from the U.S. and several countries in Europe. A highlight is the live interactive webcast with IceCube personnel at the South Pole station.

Each Masterclass leads students through one IceCube analysis, focusing on the fundamental aspects of astrophysical measurement. Preselected data sets are used to teach how to distinguish between signal and background events, develop the art of event selection, calculate an observable from data and determine the significance of a result. The technicalities of handling large amounts of data are avoided.

The first edition, held on May 2014, included around 100 students visiting five IceCube institutions in the U.S. and Europe. The second edition took place in March 2015 with 175 students in the U.S., Germany, Belgium and Denmark, at a total of ten institutions.

2. The IceTop module

In November 2014, the Education and Outreach Group and the Cosmic Ray Group decided to add a new analysis activity to increase the variety of topics available in the IceCube Masterclass, which so far focused on the observation of extraterrestrial neutrinos [6]. The measurement of the cosmic-ray flux with the IceTop sub-detector [2], an important result for investigating cosmic rays that is relatively accessible, was selected as the topic for the new activity.

The measurement of the cosmic-ray flux can be split into four steps. Step 1 is the reconstruction of air shower events from the raw data measured by the IceTop detector array, in particular the shower size S_{125}. This observable, which is the equivalent signal strength at a radial distance of 125 m from the shower axis, is a proxy for the energy of the incident cosmic ray. Step 2 is the selection of well-reconstructed events above the detection threshold of the detector, around 1 PeV. Step 3 is the conversion of the shower size S_{125} into an equivalent cosmic-ray energy; this assignment uses air shower simulations. The final step 4 is the computation of the cosmic-ray flux from a histogram of the measured cosmic-ray energies. The flux is obtained by dividing the event count per bin through the respective energy interval covered by the bin and the exposure of the detector over the time of data taking.

For the non-expert, data are numbers without meaning; they are abstract entities. Illustrating a complex data analysis, such as a measurement of the cosmic-ray flux from data, is the main educational challenge of the Masterclass. We address this challenge with dedicated interactive data visualizations, designed to make the concepts and processes underlying the analysis accessible to the students.

These applications create a playground for students to explore. Interaction with the visualization allows them to quickly build an intuitive understanding of the physics, the methods and the techniques, without requiring previous knowledge of the mathematics or programming skills needed to handle large data sets. This simple but deep approach aims to create a positive experience for the students – a feeling that they can be an IceCube researcher – that could have an impact on their future perception of and interest in science.

The new IceTop exercise followed this approach and was designed in two parts. An interactive analysis of real and simulated IceTop events formed the first part (step 1). The events presented to students were already pre-selected to simplify the exercise (step 2 described above is skipped).

The reconstruction of showers from raw data is rather intuitive. Students estimated S_{125} using the interactive fitting application shown in Fig. 2. To do so, they also had to reconstruct the direction and location of the shower axis. The fitting application runs inside current web browsers and is built on standard web resources; HTML, SVG, and JavaScript. The design focus was on simplicity and consistency. All interactive elements were given the same blue-gray color, to make them easily recognizable. Large round knobs invite the user to drag them around. Markers that represent signals have the same size and color in all three plots, and react immediately in unison when the orientation or location of the shower axis is changed.

In the second part of the IceTop analysis, students were guided to perform a simple measurement of the cosmic-ray flux based on the fitted S_{125} values from the first part. They learned how energies are assigned to air shower events (step 3), and how counting events in narrow energy bins leads to an estimate of the cosmic-ray flux that arrives at Earth (step 4).

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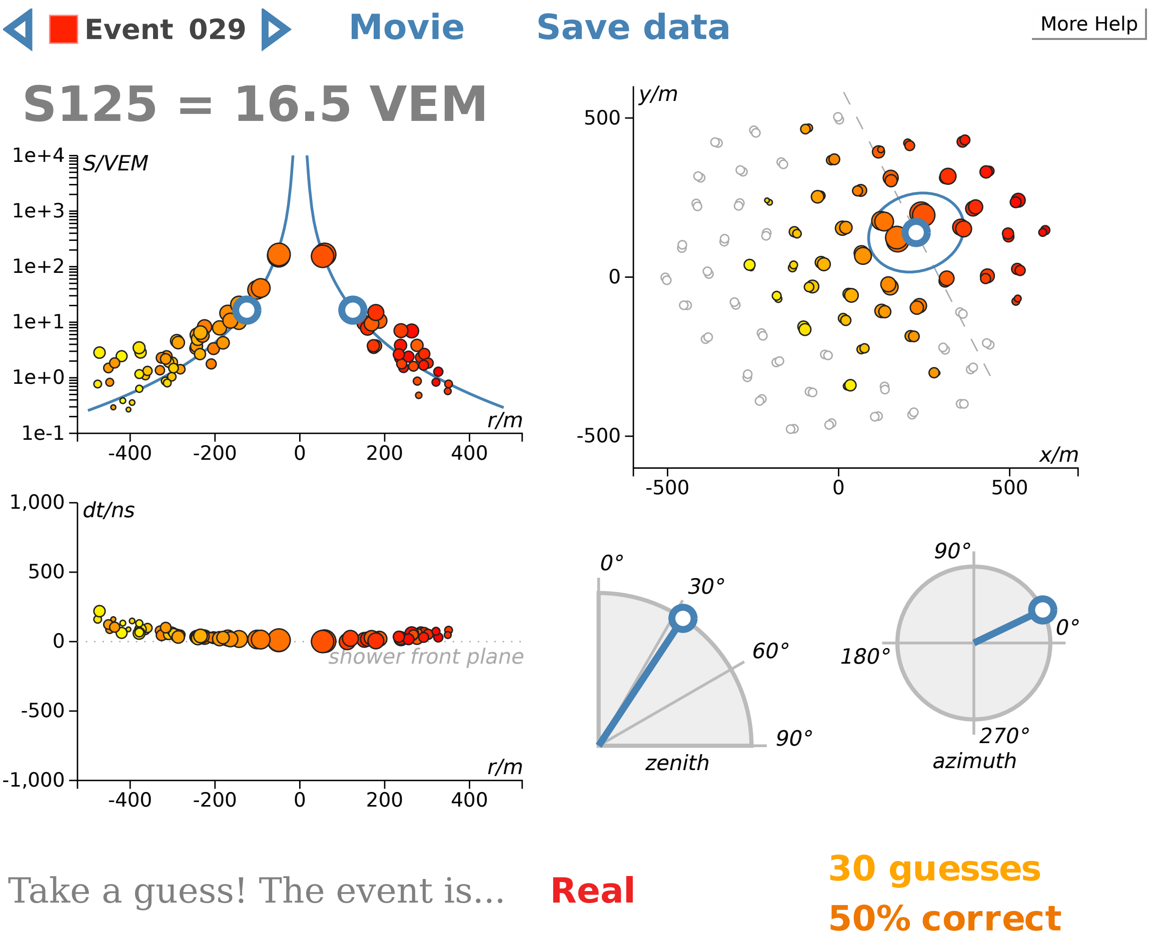

Figure 2: The interactive fit of an air shower event in IceTop, as it appears on the Masterclass website [7]. Recorded signals (colored dots) are characterized by arrival time, encoded in the color, and their charge left in the detectors, encoded in the dot size. All blue-gray elements are interactive and can be clicked or dragged. A detailed explanation of the application can be found on the website.

The second part of the analysis activity used spread sheet-templates to perform calculations. Students first determined the relationship between S_{125} and the known cosmic-ray energy in simulated events by fitting a straight line in a double-logarithmic plot of the energy of the cosmic ray and the reconstructed value of S_{125}. Then they assigned this calibration to the real events in the set, which had been weighted beforehand to reflect their relative abundance in a full day of data. These weighted events were filled into an energy histogram. At this point, the cosmic-ray flux was computed using the given bin sizes in energy and the pre-determined exposure of the detector for one day of data.

An example result from the students is shown in Fig. 3 and compared with the published spectrum. The agreement is good, considering the extreme simplifications (only 15 weighted events, manual event reconstruction). The discrepancy in the first bin is caused by the low resolution of the energy assigned by the students in small shower events. It is difficult for humans to assess

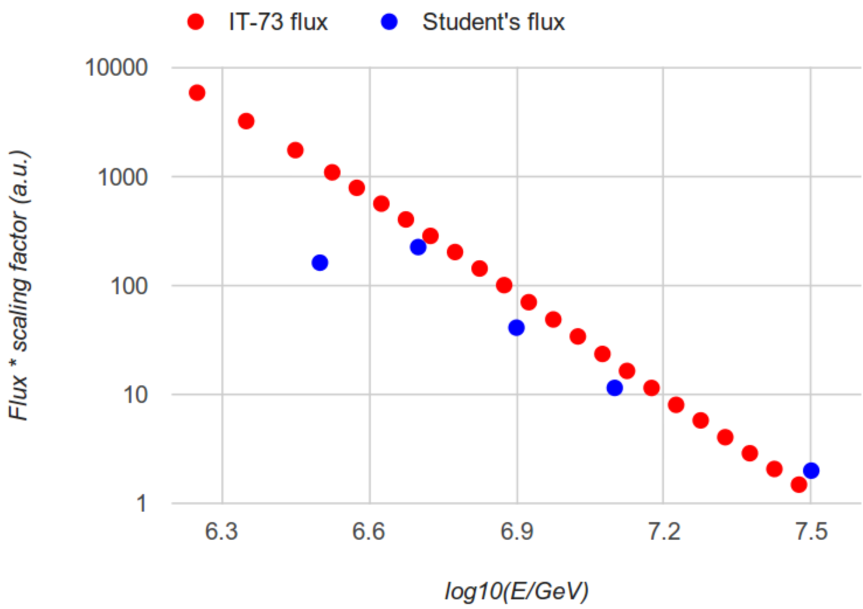

Figure 3: The cosmic-ray flux from the IT-73 publication [2] (red dots) and the flux estimated by the students in the exercise (blue dots). The student estimate scatters around the official result, because the estimate is derived from only 15 weighted events. The main features are nevertheless apparent, the power law shape and the rapid decrease with increasing energy. Both fluxes were scaled by a constant factor to have the y-axis run from 1 to 1000 in arbitrary units.

the shower size S_{125} in showers with few recorded signals. Low energy events, whose energy was interpreted as too low, fall outside of the histogrammed range, and thus create the dip in the first bin.

Students performed these tasks in groups of two to three, each with an independent set of 15 real and 15 simulated events. Using independent data sets allowed the students to combine their results in the end, to obtain an improved estimate of the cosmic ray spectrum by computing the average. Initially, students were asked to guess if each event was real or simulated data, and the truth was only revealed after the guess. The idea of this game was to convey that simulated and real data are virtually indistinguishable. The students responded very well to the game and it turned out to be an entertaining element, creating a positive form of suspense and competition between the groups.

3. Feedback and evaluation

A detailed pre- and post-evaluation of the Masterclass is performed by the students as part of each year's Masterclass. The evaluations are used to track the satisfaction of the students with the different aspects of the program. Since the purpose of the Masterclass is to raise interest in astroparticle physics, this is an important measure.

Results for this year's activities are shown in Fig. 4 for the two participating U.S. institutes. The activities got good response in general. The analysis activities differed between Wisconsin and

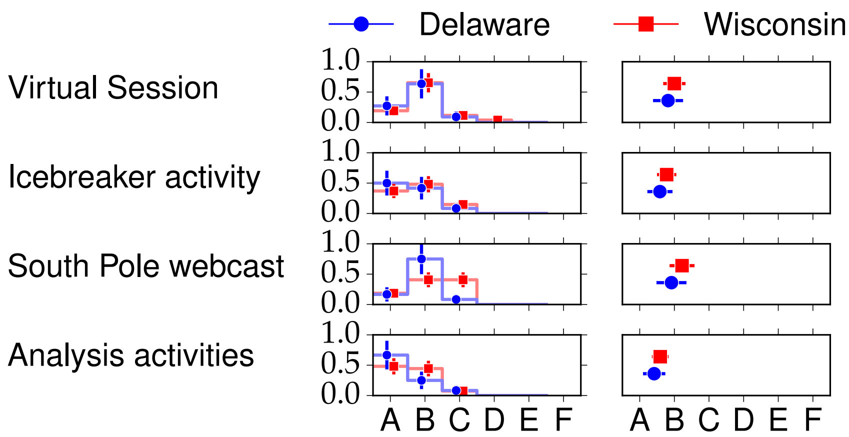

Figure 4: Student evaluation of the activities during this year's Masterclass for WIPAC, University of Wisconsin-Madison, and University of Delaware. The scale follows the U.S. grading system, where A is the most positive grade, and F the most negative. *Left*: Evaluation histograms with Poisson uncertainties. *Right*: Average grade. The IceTop module was used only in Delaware.

Delaware. The new IceTop module was used only in Delaware, which replaced an analysis activity related to finding an anisotropy in the neutrino flux.

The students expressed special preference for the interactive parts, like the analysis activities and the Icebreaker activity.

4. Ideas for future development

The IceTop module got positive feedback and will remain part of the IceCube Masterclass program in following years. The IceTop analysis could also be used by new undergraduate researchers as a gentle introduction to this research field. Further development of supporting educational resources will also enable its use as a research-based activity in classrooms.

The first part of the module, the interactive fit of IceTop events, could also be used in other contexts. It is an intuitive challenge, similar to solving a puzzle. The application could be part of the activities during an Open House Day at the university. A computer could be set up for visitors to interact with IceTop events. Also, physics institutes working on IceTop could link to the application on their websites to illustrate how the experiment works.

A stand-alone version is planned for these uses. To increase its appeal to a more general audience, the stand-alone version is planned to incorporate a passive demonstration mode – serving as a tutorial – and a ranking list for participating users could serve as a reward system. Rankings could be based on the achieved total χ^2-value of the fits, and the percentage of correct guesses on the origins of the events.

References

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