

Particle Physics Outreach to Secondary Education

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HEP Outreach to Secondary Education

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1. INTRODUCTION

What is dark matter? What happened to the antimatter? How did the universe begin? How will it evolve? Are there extra dimensions of space? These unanswered questions stretch the imagination of particle physicists and students alike. There is remarkable worldwide interest, concern and opportunity to assist young people in seeking answers to these questions. Particle physicists find it rewarding and enjoyable to inspire today's students and tomorrow's scientists by bringing the world of modern physics into secondary classrooms in three basic ways: providing informal learning opportunities for students and support and resources to teachers, offering professional development for teachers, and offering research experiences for teachers and/or students. Most secondary students will not become scientists, but they do need an understanding of modern science—the ideas, the methodology, the people.

Effective activities are those that engage teachers and students with the science and help them develop an appreciation of the scientific enterprise. Findings about the impact these programs on participants come from studies of U.S. Department of Energy education programs, twelve years of evaluating QuarkNet (1), a U.S. particle physics community outreach program, research on web-based materials developed through the Interactions in Understanding the Universe (I2U2) project (2), and other science outreach programs. Observations, expert reviews and feedback from teachers, their students and scientists provide guidelines for the most effective way to support classroom teachers and reach their students. Feedback from participants in International Masterclasses and at the University of Stockholm House of Science school laboratory guide plans for activities that enthuse students.

We describe a few program exemplars, provide suggestions for practices that create effective programs based on research findings, and describe some methods for assessing programs whether

run by individual physicists or an entire research group or department (3). For information on U.S. assessment methodology, strategies and instrumentation, contact Jean Young, jyoung@dakotacom.net.

2. RESEARCH EXPERIENCES

Most particle physicists are familiar with undergraduate research internship programs. Some physicists hire high school physics teachers to work alongside undergraduates. It is difficult to overestimate the effect of this professional development opportunity, as teachers are welcomed to the scientific community. Perhaps, for the first time, they help develop scientific knowledge, engaging in scientific practices and discourse. Research experiences help teachers integrate the practices of science with the teaching of science. They begin to see how to create inquiry-based learning environments that provide in-depth engagement in science for their students. And their students get excited about science. They have opportunities to increase their scientific proficiency in particle physics, to interpret, evaluate and explain natural phenomena, to understand how scientific knowledge is developed and to engage in scientific practices and discourse.

In a few cases, high school students also hold internships. Summer programs run for about six weeks and may involve individual student appointments or appointments for student teams, along with a teacher to help as a supervisor. In academic-year programs, students meet with mentors once a week for approximately 17 weeks and continue their work as appropriate back at school. As with teachers, the experience of being welcomed into the scientific community has a profound impact on students, confirming their interest in a science, technology, engineering or mathematics (STEM) career and opening their eyes to possibilities in particle physics research.

Research internships are more than jobs. Mentors have reporting requirements. Teachers and students give talks at the end of their appointments. Participants may prepare research abstracts and,

in some cases, write their own papers. Others may be cited in professional papers of the groups or collaborations. Program assessment may include pre- post-tests to determine knowledge gains and surveys to determine participant satisfaction with aspects of the program.

Key mentor responsibilities include determining an appropriate, interesting and useful project that a student or teacher can complete in six to ten weeks and assigning backup support for those times when the mentor is away. In welcoming a participant into the group, a good mentor provides background information prior to the start date, sets reasonable expectations for work practices, particularly regarding safety, provides proper workspace and resources, and tracks progress on deliverables assuring completion at the end of the research period.

2.1. Teacher Research Programs

. . . through ongoing contact with practicing scientists, teachers gain self-esteem and confidence. They change their view of themselves and the view others—students and other adults—have of them. Thus they become professionalized. (Gerhard Salinger, National Science Foundation, Division of Research in Learning in Formal and Informal Settings)

The DOE/ACTS experience has been one of the greatest adventures in my life. Working with some of the smartest scientists in one of the greatest research laboratories (Fermilab) has demonstrated just how important of a job I have as a teacher. Collaborations with master teachers and top-notch scientists allow me to bring materials and resources back into my classroom that I would never have been able to have or know about. I can't wait to get back into the classroom this next year and share with students and teachers things I have learned.
(Martin Shaffer, Seaman High School, Topeka, KS)

The U.S. National Science Foundation (NSF) and the U.S. Department of Energy (DOE) as well as some local institutions fund summer teacher research appointments. Individual physicists volunteer as mentors. (In some cases, mentors must provide stipends from their own research funds.) DOE has an intensive, national program, the Department of Energy Academies Creating Teacher Scientists, DOE ACTS (4), that requires teachers and mentors to sign up for three years. As listed in *Core Principles*, the program has three overarching objectives:

1. Provide STEM educators (grades 5-12) with sustained, intensive professional development that is experientially based and effectively utilizes the unique resources that a national laboratory has to offer.
2. Integrate the principles of teaching STEM disciplines with the authentic practice of science. Participants' experiences in scientific research will be reflected in and transferable to classroom practice and will contribute to the reform of STEM education.
3. Create a conduit for shared ideas and improved collaboration between the scientific and education communities.

DOE ACTS includes three components—four- or eight-week summer research experiences, and leadership training and pedagogical applications that continue year-round. Teachers apply nationally and join an ACTS cadre at a DOE laboratory. With the exception of the Fermilab (5) program, physics teachers work alongside teachers of other disciplines during pedagogical and leadership activities. Teachers prepare a professional development plan, the foundation for translating DOE science to the classroom, improving personal teaching strategies and enhancing the teaching of colleagues. Physicists' responsibilities are limited to the mentorship with the caveat that they are expected to stay in touch with teachers during the academic year. The program developers hope this leads to sustained contact after the three years. Teachers receive a stipend, travel support

for one trip to and from the host laboratory, a housing allowance and opportunities to apply for mini-grant and professional development funds to support their plans.

The Office of Science: Office of Workforce Development for Teachers and Scientists runs DOE ACTS through laboratory education departments. Program management is handled via a comprehensive website with information, forms and materials for participants, mentors and staff. Lab staff and mentors collaborate to develop programs and select participants. Staff takes on the administrative tasks dealing with travel, housing, orientation, deliverables, social events and much more. While the program lasts four or eight weeks, teachers spend time in leadership and pedagogy sessions, so mentors must define research projects with that in mind. Labs must meet national reporting requirements and deliverables which may include an electronic portfolio, research papers and talks, poster presentations, pre- post-surveys, pre- post-tests and documentation of follow-up leadership activities.

2.2. Student Research Programs

QuarkNet has taught me that patience, common sense, and maturity will often serve you better than a book ever will. Through working on intellectually challenging activities, such as testing pods, programming software, and writing webpages, we learned that mistakes are not dead ends, but simply stepping stones. (Ting Wu, Illinois Mathematics and Science Academy, Aurora, IL)

In the U.S., QuarkNet, a national program offered at more than 50 centers associated with university and research laboratory particle physics groups for high school teachers, also supports summer research for high school student teams (see **Figure 1**). Although mentors have flexibility to organize the research, typically four students and a teacher collaborate for six weeks on one project. Teachers

and students receive weekly stipends. Students have built components of Fermilab's DZero detector and CERN's CMS detector and participated in research on various hardware projects for ATLAS, CMS, CDF and DZero. Recent research topics include: *Cosmic Ray Signals in Radar Echo, Fibers for Forward Calorimeter, The Effects of Impurities on Radio Signal Detection in Ice, Quartz Plate Calorimetry and RF Magnet Design, and Weak Lensing Mass Estimates of the Elliot Arc Cluster.*

Each year QuarkNet invites mentor physicists to propose research topic(s) for a student team. Staff reviews topics for consistency with national goals, accepts proposals accordingly and encourages but does not require mentors to select rising seniors for the team. These students return to high school where they can share their experiences with fellow students. QuarkNet keeps participant databases and has some ability to track students as they continue their education. Program requirements include student pre- post-tests, surveys for students and teachers and a team research abstract that is incorporated into the QuarkNet annual report. All documents are submitted via webforms. An outside evaluator receives completed documents and incorporates findings into an annual evaluation and metrics report. Information helps staff improve the program and provides evidence of program success to the funders. NSF and DOE fund QuarkNet with support from Fermilab, the University of Florida, the University of Notre Dame, the University of Washington and participating universities, laboratories and experiments.

2.3. What Works

The most important aspect of any research program for teachers, and it turns out for students as well, is being part of a scientific community. Because particle physics experiments involve hundreds, if not thousands, of people and extend for decades, the research experience of a teacher or student represents a small part of the experiment. Data from the former U.S. Department of Energy's Teacher Research Participation Program showed that teachers doing data analysis,

calibrating instruments or other aspects of research are effective when, and only when, they sit in on and contribute during planning/progress meetings where they are able to gain an appreciation of the entire research process.

Being a member of a community helps participants increase their scientific literacy and content knowledge of cutting-edge science. A strong mentor guides the research experience and exploration of subject matter. In addition, participants often benefit from working with a graduate or advanced undergraduate student who can best explain concepts and research procedures at their level of understanding. (Graduate and undergraduate students report they also learn from teachers.) Teachers participating in the Research-Based Science Education (RBSE) project (6) at the U.S. National Optical Astronomy Observatory commented that their level of expertise and content knowledge was most like that of a beginning graduate student.

A pedagogical expert (e.g., a teacher leader or education outreach expert) can help teachers transfer skills and cutting-edge science knowledge to their classrooms, as they do not automatically see how to parlay their research experiences into their classrooms. The community experience should not stop at the end of a summer workshop, research experience or other professional development. Follow-up support during the school year is especially important when student activities involve using instructional materials or instruments. Otherwise the materials remain on shelves unused.

Teachers working with QuarkNet's cosmic ray detectors rely on peers and a staff-run help desk for support. The same was true of solar telescopes provided through the RBSE program. These devices were simple, but teachers still needed expert guidance when the telescopes arrived at school misaligned or were unable to come up with ideas for making full use of them. Although trained in how to use instructional materials, including specific investigations for students, teachers struggled when using the materials/instruments for the first time.

External evaluators who have over ten years of QuarkNet data have developed a 10-point scale to rate the effectiveness of individual QuarkNet centers that provide teacher research experiences and/or professional development (**Table 1**). These success factors, including the extent to which they establish a community, provide a blueprint for achieving goals for scientific literacy, content and classroom transfer. (footnote or sidebar) Besides learning communities (category 10), other important factors are included such as strong mentor, teacher leader, classroom transfer, support and meaningful activities. In addition, teacher professionalism (category 9) contributes to the larger learning community, and the other factors act to maintain the centers.

Student research programs with specific characteristics have been shown to achieve the goals to increase students' understanding of scientific research and make them more scientifically literate. Preliminary data from the university-based RBSE using pre- and post-concept maps show that students gain an overall, more sophisticated and complete understanding of scientific inquiry by engaging in authentic ("meaningful") research. (footnote or sidebar) Applying the concept map method to QuarkNet's student research programs corroborated these data and provided further understanding of what works in student research. Since QuarkNet has many centers involving students at various levels and duration of science research experiences, analysis of the concept maps indicated: 1) There is a big difference between providing a research "experience" of a few to several days and engaging students in scientific research. Students in research programs for a month or more show statistically significant differences in their understanding of "scientific methodology" between pre- and post-participation while those who participate in programs a week or less show no such difference. 2) Students who experience all aspects of science processes discover the importance of such things as troubleshooting, calibration, use of journals or logbooks, where the hypothesis comes from, the importance of communicating ideas and results, why data are analyzed in a particular way, how conclusions are reached. The experience need not all be "Hands on"

because students learn as part of the research team. Students are unlikely to experience any of this in typical high school science classrooms.

Students also are more motivated and get more satisfaction out of their research experience when they report their findings in the form of presentations and abstracts as with the QuarkNet student research programs, posters as when students conduct QuarkNet cosmic ray studies, or contribute to something like the *RBSE Journal*, a reviewed publication. Motivation and satisfaction come from seeing their work being valued.

3. REAL DATA FOR STUDENTS

The scientist in me recognizes that while I (and other science teachers) do a great job in showing kids the 'wow' of science, we don't do good job in educating kids about real scientific research. (My students) had the chance to do real research. They were frustrated with me in the beginning because they encountered problems that they couldn't easily solve and I didn't have the answers to give them. They expected cookbook answers, but I was as in the dark as they were. At one point I said to them, "You have been taught the scientific method, now use it!" I wish you could have seen the astonished look on their faces. I have watched them transform from high school science students to research scientists. (Carol Baker, Alan Shepard High School. Palos Heights, IL writing about QuarkNet cosmic ray studies)

3.1. Accelerator-based Programs

Many of the world's largest physics experiments, primarily intended to study the intricacies and fundamental processes of matter, now make it possible for students and teachers to get close to the forefront of today's physics research. The aim is to give students and teachers the possibility to

explore particle data produced in high-energy particle collisions, and simultaneously enthuse students and teachers at school for modern physics in general and particle physics in particular. The Large Hadron Collider (LHC) at CERN (7) already reaches the highest collision energies ever achieved in the laboratory. To explore the particle collisions students and teachers use special analysis tools, very similar to the tools and methods the scientist use.

3.1.1. Hands on CERN. Data from the DELPHI experiment (8) at the CERN Large Electron Positron Collider (LEP) have been used for the last fifteen years in the innovative education project, Hands on CERN (9, 10). Using digitized DELPHI data, students can approach the physics frontline in the classroom and use the same scientific information as scientists to explore the fundamental building blocks of nature, quarks and leptons, and the fundamental forces in nature, such as the electroweak and strong force and their carriers, the Z^0 particle and the gluon.

The main education materials include background information about the Standard Model and the basics of particle accelerators and detectors, and the 3D event display of particle collisions, WIRED (11). The user can rotate and zoom into the virtual detector and introduce (and take away) different subdetectors as they identify particles produced in 1,500 DELPHI collisions. At a collision energy of 91 GeV, a Z^0 particle is produced in the electron positron collision. The Z^0 rapidly transforms into a quark and an antiquark, or a lepton and an antilepton, where the lepton is either an electron, a muon or a tau. Students determine the Z branching ratio.

Hands on CERN has been translated to 15 languages including the two original languages (Swedish and English). E.K. Johansson, project leader for Hands on CERN, received international attention culminating in the prestigious 2005 Webby Award in the Science category (12).

3.1.2. International Masterclasses. The International Particle Physics Masterclass (13) provides opportunities for students and teachers to participate in an annual authentic particle physics research exercise at a local university or research laboratory. High school students and teachers have the opportunity to interact with physicists in the field and learn how today's physics research is being done on an international level. High school students are invited to attend a one-day institute where they attend lectures and perform measurements on real data from particle physics experiments, using the same tools as the physicists (see **Figure 2**). Each year about 5,000-6,000 high school students in more than 20 countries visit close to 100 universities or research centers for a day in order to explore the intricacies of particle physics. Since the beginning, around 30,000 students in Europe and U.S. have taken part in an International Masterclass institute.

Real data of particle collisions are visualized using “event displays.” Introductory lectures teach the students the basics of particle physics, to identify different types of elementary particles and how to interpret the particle collisions. The students learn very quickly to use the event display and, for example, have no problems identifying the different decay modes of the Z particle in LEP data. The students perform their own measurements and determine many of the properties of the Z particle, which they discuss at the end of the day with other students via a videoconference organized from CERN or Fermilab.

QuarkNet has added features to the U.S. Masterclass to involve teachers in conducting the institutes. Teachers new to the masterclass attend an orientation session where they try out the analysis exercise and activities they can do with their students before the masterclass. Teachers engage students in a few activities to develop important prior knowledge. During the masterclass data analysis activity, teachers are actively assisting students. In addition, one teacher gives the lecture on identifying particles and interpreting particle collisions.

Before 2011, masterclass data came from the DELPHI and OPAL experiments at LEP, operational from 1989 to 2000. The Hands on CERN educational material was extensively used during all the International Masterclasses. In 2011 the masterclasses will use LHC data from ATLAS, CMS and ALICE.

3.1.3. Event Analysis. The ATLAS Event Challenge is an innovative program providing students with access to real and simulated data to explore the world of particles. The European Commission financed project "Learning with ATLAS@CERN" (14, 15) has been very important in making the ATLAS Event Challenge possible. Since the first LHC physics run at 900 GeV in December 2009, ATLAS can offer real particle collision events to students and teachers. These events contain the strange particles K^0 short with a lifetime of $0.9 \cdot 10^{-10}$ s and the Λ^0 particle with a lifetime of $2.6 \cdot 10^{-10}$ s and events with W and Z particles. These long-lived particles create an easily observed decay vertex (see **Figure 3**). Students can determine the mass and lifetimes of the K^0 and Λ^0 particles by measuring the momenta of the known particles produced in the decay. A minimum understanding of special relativity is needed to reconstruct the invisible particle from the decay products. Students quickly apply the concepts of relativity and understand how to spot the decaying particles using the event display.

An e-Lab (see Section 3.2.3.) provides students with data to check the CMS detector's calibration and participate in discovery science (as particle physicists do). Calibrating the detector to "rediscover" previous measured results is an important part of the early scientific activity at CMS. Currently, students have access to a limited amount of dimuon run data from which they can confirm J/Psi and Upsilon masses. With Monte Carlo data, and sometime in 2011 with run data, students can also confirm the Z mass. Soon CMS will release data that allow students to confirm the energy-momentum equivalence for low-mass particles. And much later, students will probe data

where physicists expect to find answers to questions at the heart of 21st century particle physics. The CMS e-Lab incorporates a 2D event display and the same 3D event display (**Figure 4**) upon which the CMS masterclass is based. Another analysis tool allows students to build histograms for statistical analysis of the data.

In an activity (16) that has been taught since 1996, students calculate the mass of the top quark by examining a DZero top/antitop production that took place on July 9, 1995. Taught when students are studying conservation of momentum, the activity builds on understanding of vector addition, explores the interdependency between mass and energy but depends upon only a small amount of particle physics explanation. Students work in teams with printouts of end views of four planar events, one real and three Monte Carlo, a protractor and ruler. Students create a vector diagram of particle momenta to find the missing neutrino momentum. When the class pools their results, they can come remarkably close to the value of the top mass.

3.2. Cosmic Ray Programs

When Mother Nature is the accelerator, the data source is cosmic rays. Projects worldwide provide opportunities for high school students to collect and analyze cosmic ray data. The scope of these efforts as represented by projects at meetings in October 2010 include the following: the United Kingdom and United States with four projects each, Canada three, Germany two, and the Czech Republic, France, Greece, Italy, the Netherlands, Portugal, Romania and Sweden with one each. Three basic themes on which the analysis is based include: 1) detecting ultra-high-energy cosmic rays with sparse, very large area networks; 2) detecting ultra-high-energy cosmic rays with radar-like technology and traditional scintillator detectors; and 3) student-designed investigations of cosmic ray flux, showers and muon lifetime. An annotated hardware list is in Section 5.2.

3.2.1. ALTA, HISPARC and Other Large-Area Arrays. ALTA, the Alberta Large-area Time-coincidence Array (17), in Canada and HISPARC, the High School Project on Astroparticle Research with Cosmics (18), in the Netherlands represent the most common approach to student cosmic ray research. The purpose of these projects is to conduct fundamental research into the nature of high-energy cosmic rays and provide an opportunity for high school students to participate in real research. The innovative aspect of these sparse arrays of simple detectors is their deployment on high school, college and possibly museum rooftops. Detectors are linked to Global Positioning System (GPS) satellites and university research centers. A collaboration of similar experimental clusters in North America, NALTA (19), has created a loose group of projects with similar goals. In these projects, students gain Hands on exposure to modern physics research processes and techniques, computer programming, data analysis, statistics and online videoconferencing. As ALTA PI Jim Pinfeld notes, this gives students a taste of science in action.

Typically, two to four detectors read out by a common electronics system are spaced meters apart in weatherproof rooftop boxes. A computer at the school provides local data acquisition and storage. Students maintain and operate the detectors; some upload data via a dedicated connection to a central server at the experiment where physicists or university students make searches for coincidences among events at different locations. In other cases the data upload is automatic.

At a given site a shower triggering individual detectors results in a local coincidence, which is time-stamped using the accurate GPS clocks. Knowing the timing difference between the individual detectors allows students to roughly point back along the track of the original cosmic ray. The GPS timing is accurate enough to allow pointing between different detector locations, which can be compared with the local pointing information to determine if one or more primaries were involved.

Projects offer workshops where teachers and students build detectors and electronics (**Figure 5**). In-depth workshops provide more information and experience for teachers who design teaching

materials, experiments and activities so students can learn to calibrate data acquisition electronics and analyze raw data. Physicists can present some of the latest information and theories about cosmic rays to the students. Students at different locations collaborate via the Internet. HISPARC has even developed a teachers-in-research component.

3.2.2. MARIACHI. The scientific goal of MARIACHI (20) is the detection of and collection of information about ultra-high-energy cosmic rays (UHECRs)—their rate of occurrence and origin. Located at Brookhaven National Laboratory, MARIACHI searches for UHECRs by detecting reflected broadcast TV or FM radio signals originating from distant transmitters. Detector sites around Long Island, New York are synchronized by the Global Positioning System and use grid computing to collect, display and analyze data. Once a signal is detected, scintillator arrays built and operated by high school students can confirm whether it is due to reflections from the ionization trails left by cosmic rays. Teacher and students developed the ground scintillator detector in a series of workshops. One teacher and several students can assemble one in a day (**Figure 6**).

A summer workshop covers all the elements of the grid-enabled MARIACHI data collection system, i.e., radio processing, scintillator ground detectors and cyber infrastructure. High school teachers participate with several of their students so they all can bring their expertise back to the classrooms. The one-week course combines lectures and seminars with practical experiments, which include the collection of signals using the radio receiver and basic signal processing.

Students participate in research projects, regular courses, workshops and other classroom activities where they learn to use MARIACHI tools. Once a detector is setup and running properly in a classroom, students evaluate various cosmic ray rates. Some students have developed Intel (21) projects under the supervision of MARIACHI researchers.

3.2.3. QuarkNet Cosmic Ray Studies. The QuarkNet classroom detector with components like today's large detectors at Fermilab and CERN provides real data for cosmic ray studies—student-led, teacher-guided investigations. Students gain their own understanding of low- to moderate-energy cosmic rays and may be fortunate enough to capture a rare high-energy shower. In addition to the classroom detector, QuarkNet offers a browser-based e-Lab (22) with Grid execution developed in collaboration with I2U2. Students without detectors can participate because all data uploaded to a common site is accessible through the e-Lab Student Home, allowing students to analyze a much larger body of data than those from their own detector.

These student investigations mirror scientific research as e-Lab project milestones (**Figure 7**) guide novice investigators through their work. Students learn the context of their upcoming project, determine a research question related to muon lifetime, flux or showers, set up the detector and check its performance before taking and uploading data to the e-Lab. The e-Lab provides students with analysis tools, an e-logbook to record their work and online posters to share their results. Using online tools, students can access the data and results of others, correspond with other research groups, post comments and questions, and respond to comments left by others on their own work. In general, these experiences of scientific collaboration are missing in most high school classrooms. As one student commented, cosmic ray studies were a "brilliant introduction to particle physics and analytical reasoning in general."

Through the Teacher Home, teachers have access to typical information on standards and prior knowledge and expected outcomes found in instructional units, an e-logbook, assessment tools and suggestions from other teachers for helping students start and navigate the e-Lab. A staffed help desk and online forum provide ongoing support.

3.3. What Works

U.S. Masterclasses differ from those in Europe because teachers provide about three hours of lessons related to conservation laws, colliders, detectors, basic particle physics concepts and the nature of scientific investigation. This preparation was added when evaluative data indicated students with only three hours of preparation, learned more and had higher rates of satisfaction than those who came unprepared. Pre- and post-test differences were statistically significant for the prepared students. In addition, evaluative data found that students enrolled in physics classes were most likely to have an effective and satisfying masterclass experience.

In Europe, appreciation of masterclasses was independent of the students' prior knowledge of particle physics. The perception of the lectures was an important factor for the appreciation of the masterclasses. A large majority of participants found the lectures interesting (81%) with a very clear correlation between interesting lectures and overall appreciation.

Surveys conducted in the U.S. (345 surveys from mainly high school students at 16 sites) and Europe (response of ~1,300 students 16 to 19 years old) showed that the majority of students liked masterclass much or very much (Europe, 82%), and U.S. students rated highly all aspects of masterclass (mean of 1.5 for most items from a possible “5”). U.S. students mostly “totally agreed” that they wanted to learn more physics after the masterclass, an important indicator of what might make more students consider a career in physics. They also reported learning all terms and concepts to a highly statistically significant degree ($>.001$).

Further studies of U.S. Masterclasses showed that: While some students found the lectures difficult to follow, it helped when presenters provided useful examples, relationships to everyday life and anecdotes. Students appreciated fewer, in-depth explanations over a lot of information given at once and liked the Hands on aspect of the exercises and working in groups. They appreciated working with real data “similar to what physicists do.” Most found the exercises easy to learn/do and fun. Several wanted more meaningful discussions before (e.g., how to; analyze together as a group) and after doing the exercise (e.g., discussing the significance of the data). Those who went on tours particularly liked seeing cutting-edge equipment and

technology. They liked seeing where research was being done and becoming more aware of different areas of physics. As one student reported, “[The tours] helped me better understand what my career in physics will entail.” Students liked the videoconference; they particularly liked talking with other students, especially those in other countries, getting their opinions, perspectives and sharing data. More details about the evaluation of the European masterclasses are found in reference 23.

QuarkNet cosmic ray studies are being subjected to rigorous evaluation as part of the current I2U2 NSF grant. Aspects of preliminary findings are applicable to other cosmic ray research projects. For example, findings indicate that a teacher workshop is essential if classroom implementation is to be effective. A minimum of three days is necessary to help teachers and student/teacher teams learn to use the detector. Mastery comes later with experience in the classroom. The QuarkNet workshop includes one full day to build and plateau a detector so that participants can take data overnight. The following two days put teachers in the position of their students as they learn how to use the e-Lab to guide their investigation from uploading and analyzing data to posting results. Survey data collected after each workshop showed that teachers “strongly agreed” that they increased their content knowledge, skills and became more comfortable using the e-Labs in their classrooms. They also “agreed” to “strongly agreed” that the workshop was well organized and effective. Notably they reported that they felt their questions were answered at their level of understanding.

Developing posters as the final stage in an e-Lab appears to help students better understand scientific research processes and provides an opportunity for them to write authentic reports to communicate their work. Rubric items to assess the posters include intended outcomes such as the extent to which students better understood the content, scientific research and the ability to communicate their ideas. The rubric scale is “not met,” “met” and “exceeded expectations.” A recent poster analysis indicated that 66% of students met or exceeded expectations overall. Students were most able to form a “Researchable question reflects and in-depth understanding of subject and

scientific research” and least able to provide “Evidence [that] supports claims made from the data; provide alternative explanations, suggest further inquiry.” While student poster scores appeared to depend to a large degree on their teacher, it was clear that students, overall, achieved intended outcomes to a large extent.

4. INFORMAL LEARNING FOR STUDENTS

I enjoyed WSHI [Westinghouse Science Honors Institute] because it brought the brightest thinkers and experimenters from all the local schools together to learn together and to grasp an idea of what to do with their lives. (Brandon Leckemby Somerset Area High School, Somerset, PA)

Programs at universities or labs can "rekindle the flame" among high school students. Programs, which may be a general science program or physics-only, range from a lecture series to a university science laboratory devoted entirely to schools. Such a laboratory is a model for universities that want to bridge the gap between school and higher education, to make physics at school more interesting or to introduce students to experimental physics in areas where it is uncommon at school.

4.1. Science Laboratories

The House of Science (24, 25, 26) in Stockholm is a university science laboratory for physics, astronomy, chemistry and biotechnology, entirely devoted to schools. The aim is to make modern science accessible to teachers, school classes and individual students. Natural science in general and

physics in particular, are often regarded as difficult subjects at school. This is where the House of Science at AlbaNova University center has an important role to play. The aims are to stimulate interest in natural science and technology, strengthen contacts between schools and the university and also show that university studies lead to interesting jobs. The main target groups are teachers, their school classes (12 to 19 year olds) and students doing their school project work (typically 17-19 years old).

In physics and astronomy some of the more advanced projects are studies of the galaxy in the microwave band (27), the sun (28), particle annihilation in a PET model (29), radon and radioactivity (30) and cosmic radiation. In biotechnology the sequencing of DNA is the most popular. Many of these projects are unique to House of Science and are not easy to perform in schools. At special occasions the general public is invited to take part in the laboratory exercises (31).

4.2. Saturday Morning Physics

Today, lecture series are commonly called Saturday Morning Physics (SMP) although the earliest one that can be documented, the Westinghouse Science Honors Institute (32), began in 1958. A late 2010 Google search unearthed 15 active programs in Canada, Germany and the United States. While most are student programs, three also welcome the general public. Activities vary from an hour lecture to a half-day program including a lecture, discussion sessions and tours.

SMP is a relatively modest effort by dedicated volunteers. But one should not underestimate the impact on students when they meet other bright, physics-oriented peers, encounter advanced topics not covered in school physics classes, network with physicists and gain insight into the world of physics.

Everyone benefits from SMP. The experience stimulates and excites students. Lecturers and discussion facilitators benefit from the joy of working with bright young people. They also may increase their own understanding as they think about the subjects in new ways for high school students. If more universities started such programs, the physics community could create small spheres of influence around university and lab hubs that would keep interest in science alive for many bright young students.

4.3. What Works

Around 85% of the students aged 12-15 who attended the House of Science say that what they remember most of their visit was the interesting experiments and being able to study living organisms. Those aged 16-18, most remember interesting experiments (50%) and new concepts that they confronted (30%). Most of them mentioned the contact with the young scientists manning the laboratory. Young university students and scientists are excellent in bridging the gap between school and university.

There are no SMP program guidelines; organizers should consider the number of sessions, activities to include, topics, scope and level of talks, if the program will be by registration or invitation, then whom to invite and how many invitations to send out. Whether SMP topics are all particle physics or not, the most important thing to get right is the level and degree of engagement in the lectures. Professors may be familiar with the work of Eric Mazur and Carl Wieman. Applying peer instruction (33) to a high school class could be facilitated with advice from some high school teachers.

Organizers recommend getting audience feedback, particularly from teachers. Keep lectures at a conceptual level and include a number of demonstrations. Lab tours provide places for more demonstrations. Handouts eliminate the need for note taking. Yale organizers recognized the

importance of interesting students rather than instructing them and offered a variety of unrelated topics that worked well (34). Fermilab noted a "shyness" of bright students to ask questions when among peers. Once over the hurdle, however, discussions became quite lively (35). A graduation ceremony, complete with certificates, refreshments and parents, is a great close to the program.

5. INSTRUCTIONAL RESOURCES

What makes it back to the classroom? Data, computer simulations, what high school students would call "sweet," an understanding and appreciation for particle physics. What are future payoffs? In the minds of high school students, information is powerful. Talented students become involved. Others read about physics in "popular" magazines . . . (Bob Grimm, Fremd High School, Palatine, IL)

5.1. Materials

"Classroom transfer" is, after all, everything. When we influence teachers' instructional practices, we can reach a generation of students. Some physicists are tempted to prepare "simple Hands on activities or lessons" to make it easier for teachers to include particle physics in their classrooms. However, there is a body of research-based practice for instructional materials development, which must vary from country to country. In the U.S. the current model developed by Grant Wiggins and Jay McTighe is called "Backward Design." (36) Physicists can provide the resources—demonstrations, labs, explanations, animations and more—that teachers can incorporate into their own lesson planning.

The ATLAS experiment has a well-developed outreach page (37) and the Learning with ATLAS website. Among the items on the outreach website are images and event displays, the latest news, run status, background information, e-tours, features, blogs, links to Twitter and YouTube,

blogs and more. Learning with ATLAS is the portal to an experimental laboratory for students, teachers and museum visitors mentioned in 3.1.3. These expanded resources provide challenging and authentic science experiences.

The US/LHC website (38) is repository of information and resources about the U.S. involvement in LHC research. Features for teachers and students include an event of the week, background on the physics questions LHC will address, information on how LHC works, links to data analysis projects for students and LHC live—links to Twitter, Facebook and blogs.

What do teachers do? Brigitte Blanchard, a High School Teachers at CERN Program (HST) (39) participant from France, organized cloud chamber building workshops for her students. These were so successful that she organized a parents evening at which students demonstrated their newly acquired knowledge and skills. At the same time she pioneered holding a Q&A videoconference between her students and a CERN physicist. Helena Howaniec, an HST participant from Poland, worked with her students on CERN-related projects in Lodz. Her school headmistress was so impressed she asked her to organize a CERN day for the students to present their results. She invited Mick Storr, HST Coordinator, who offered to attend if she invited other schools and teachers. She did better by also inviting local authorities and press and informing Polish particle physicists with contacts across the country. Deborah Roudebush, U.S. QuarkNet lead teacher, designed her physics course thematically around the search for the Higgs particle. She presented physics more coherently, increased emphasis on inquiry, incorporated more of what physics do, gave students more responsibility for their own learning and increased students' interest in science current events. Her final exam was based on particle physics. Helena and Deborah also brought their experiences to national level professional development organizations, and Brigitte's videoconference was the model for what has become a standard feature of CERN's education and outreach programs.

5.2. Classroom Detectors

More ambitious efforts involve physicists, sometimes in collaboration with teachers, developing detectors that allow students to explore particle phenomena at school. Here we provide an annotated list. Readers can find references available for constructing detectors in Related References. Contact developers for more details.

1. Do-it-Yourself Cloud Chamber: Built with readily available, inexpensive materials, cloud chambers help students visualize natural radiation—muons from cosmic ray collisions and background radiation from alpha, beta or gamma sources. A handy person can build a small cloud chamber rather easily. CERN version: Contact Mick Storr, mick.storr@cern.ch; Fermilab/QuarkNet version: Contact Bob Peterson, rspete@fnal.gov.
2. Portable Spark Chamber: A transportable spark chamber of robust construction, such as one at the University of Birmingham, UK, consisting of a stack of sixteen spark gaps, illustrates the trails of incident cosmic rays in a most striking fashion. As the noise of the sparking and the sight of the clearly visible tracks immediately attract the audience's attention, the spark chamber provides a fine introduction to talks and discussions of particle physics and of astrophysics. Over the last eight years, the Birmingham device has been demonstrated at about 20 schools a year in Central England and also has been shown at numerous open days and science fairs. Birmingham versions: Contact John Wilson, j.a.wilson@bham.ac.uk; EPPOG version: Contact H. Tiecke at NIKHEF, tiecke@nikhef.nl or C. Brouwer at Radboud University of Nijmegen, c.brouwer@hef.ru.nl.
3. Sparse, Very-Large-Area Cosmic Ray Detector Networks: These networks rely on placing detectors far from one another, on the rooftops of schools or colleges. ALTA outfits each installation with three $.36 \text{ cm}^2$ scintillators. The electronics use standard crate modules and

integrate PMT charge for energy determination. ALTA uses GPS for time synchronization between sites. A custom program with built-in graphs and simple statistical tools supports monitoring, automation and remote management. Data is automatically uploaded to a central computer. Students can override the automatic reset when they conduct their own experiments. Contact Jim Pinfold, jpinfold@ualberta.ca, for ALTA; Jan-William van Holten, v.hotlen@nikhef.nl, or Bob van Eijk, vaneijk@nikhef.nl, for HISPARC.

4. MARIACHI: A network of high school classroom-based scintillation detectors augment a system of stations based on bistatic radar technique that continuously listen to a radio frequency that illuminates the sky above. Each ground detector has four scintillators, 0.25 m² each, located in corners of a high school classroom, with an additional identical counter mounted in one of the corners. Signals from the five detectors feed into a dedicated electronics circuit with a field-programmable gate array that allows for programming of any desired logic among the counters. In particular, coincidence signals from the corner counter pair continuously monitor the local cosmic ray rate. Contact Helio Takai, takai@bnl.gov.

5. QuarkNet Cosmic Ray Detector: A high school classroom scintillation counter setup has been developed in collaboration with Fermilab technicians. Currently, the kit has a DAQ readout for four analog photomultiplier tube inputs, a four-channel time-to-digital converter, programmable trigger logic and local threshold time resolution of 1.25 ns. The detectors bind their local clocks to the GPS standard so that data across several independent locations can agree to better than 80 ns accuracy. Users upload raw data from these detectors to a web-based electronic laboratory, an e-Lab, where they inspect and analyze data from their own or other detectors. Contact Tom Jordan, jordant@fnal.gov.

6. CONCLUSION

The particle physics community has undertaken an impressive number of activities to improve and enhance science education at the secondary level. While formal education varies from country to country, physicists have developed programs that reach beyond the boundaries of schools to bring the excitement of current research to students and teachers. “Saturday Morning Physics” programs bring students to a university or research laboratory for a series of lectures on physics in general or particle physics in particular. Masterclasses bring students to a university or research laboratory for a one-day institute to analyze real data. In 2011, the students will be able to analyze LHC data!

A more extensive workshop program opens the door for teachers and students to have a cosmic ray detector at their school, thereby joining a science collaboration. Most collaborations study ultra-high-energy cosmic rays; QuarkNet provides a classroom detector kit and an e-Lab for students to design their own experiments with low- to moderate-energy cosmic rays, rediscovering what scientists already know but is new to students.

A different model brings students to a school laboratory at the university where modern science is accessible to school classes. And in a few cases, primarily in the U.S. where summer vacations are several months, teachers and students hold summer research internships working alongside particle physicists as part of the research team.

ATLAS is an exemplar among particle physics experiments that use the latest in Web technology to provide resources that not only give background information but also offer learning experiences. ATLAS has both an outreach page and a portal, Learning with ATLAS, to more extensive activities. Other resources include plans for inexpensive build-it-yourself cloud chambers, portable spark chambers and various cosmic ray detectors.

The next decades promise new discoveries that will advance our fundamental understanding of matter and energy. Along with that understanding will come new opportunities to expand the particle physics community’s education outreach activities. The dedication and creativity of

physicists and the teachers with whom they collaborate will provide unique opportunities for students and teachers to interact with particle physicists. From these interactions, teachers change their view of themselves becoming professionalized. Students are enthused when they "do science" rather than learn from a book.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding or financial holdings that might be perceived as affecting the objectivity of this review.

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Key Words

research experiences, data for students, instructional materials, classroom equipment, cosmic ray studies, research findings

Abstract (150 words)

This review summarizes exemplary secondary education and outreach programs of the particle physics community. We examine programs from the following areas: research experiences, HEP data for students, informal learning for students, instructional resources and professional development. We report findings about the impact on students and teachers from a variety of outreach programs and provide suggestions for practices that create effective programs from those findings. We also include some methods for assessing programs.

Key Terms/Definitions list

e-Lab: an online learning environment in which secondary students can participate in scientific investigations using data from professional databases. An e-Lab is problem-based, student driven and technology dependent. Where necessary, e-Labs use the power of grid computing and the Virtual Data System. Teaching tools help teachers guide student work.

List of important Abbreviations and Acronyms

I2U2: Interactions in Understanding the Universe Project

STEM: Science, Technology, Engineering and Mathematics

DOE ACTS: Department of Energy Academies Creating Teacher Scientists

RBSE: Research-Based Science Education Project

ALTA: Alberta Large-area Time-coincidence Array

HISPARC: High School Project on Astroparticle Research with Cosmics

NALTA: North American Large-area Time-coincidence Array

MARIACHI: Mixed Apparatus for Radar Investigation of Cosmic-rays of High Ionization

SMP: Saturday Morning Physics

HST: High School Teachers at CERN Program

Summary Points list

1. The particle physics community has an impressive record of education and outreach at the secondary level. Physicists provide informal learning opportunities for students and support and resources for teachers, offer professional development for teachers, and support research experiences for teachers and/or students.
2. Summer research experiences provide opportunities for secondary teachers and high school students to increase their scientific proficiency in particle physics, interpret, evaluate and explain natural phenomena, understand how scientific knowledge is developed and engage in scientific practices and discourse.
3. Some experiments make real data available to high school teachers and students. International masterclasses bring students to a local university or research laboratory for a one-day authentic experience where they attend lectures and perform measurements on real data. ATLAS and CMS event displays allow students to read the story of an individual collision and with the CMS e-Lab do statistical analyses on multiple events. Cosmic ray experiments provide detectors at schools so students can participate in real research and analyze cosmic ray data.
4. Making modern science accessible to students stimulates their interest in science and technology. Physicists offer informal lecture series, often called Saturday Morning Physics. In a more ambitious model, scientists set up a laboratory at Stockholm University dedicated to schools.
5. Websites, such as those from ATLAS and the US/LHC, have numerous resources that teachers can use to create their lessons and activities. Also available are plans for do-it-yourself cloud chambers, classroom cosmic ray detectors and portable spark chambers. All allow students to explore particle phenomena.

Future Issues list

1. Will the particle physics community be able to sustain and expand activities that improve and enhance science education at the junior and senior high school level in times of fiscal belt-tightening?
2. To what extent will people engaged in these activities take advantage of emerging technologies to enhance their programs and expand their reach?
3. To what extent will activities attract individuals traditionally underrepresented in science to particle physics?

Side Bar

To rate the programs: observers visit centers for two days during professional development/research experiences. They interview mentors, teachers and staff, sit in on meetings and lectures and sit with teachers as they conduct research. The main objective is to gather data that will support the ratings they subsequently submit to the center.

Concept map methodology: involves giving students a brief introduction to completing concept maps, providing concept maps with nine concepts and encouraging students to add appropriate concepts as they develop their maps. Data were analyzed using a modified Nowak and Gowin (*Learning How to Learn*, 1984) process.

Related Resources

CERN cloud chamber do-it-yourself directions:

<https://teachers.web.cern.ch/teachers/document/cloud-final.pdf>

Fermilab/QuarkNet cloud chamber do-it-yourself directions:

http://quarknet.fnal.gov/resources/QN_CloudChamberV1_4.pdf

Birmingham portable spark chamber information for people with little or no particle physics

background: **<http://www.hep.ph.bham.ac.uk/general/outreach/SparkChamber/>**

EPPOG portable spark chamber information:

<http://eppog.web.cern.ch/eppog/Resources/SparkChamber.html>

QuarkNet cosmic ray detector working documents:

http://www18.i2u2.org/cosmic/library/index.php/Cosmic_e-Lab

Figure Captions

Figure 1

Pictured are two 2010 QuarkNet summer research teams. One student-teacher team worked on using the MKK system to classify stellar spectra from the Sloan Digital Sky Survey. The other used and programmed robotic systems using LabVIEW. Credit: Fermilab VMS

Figure 2

Masterclass students at House of Science in Stockholm, Sweden working with Hands on CERN events. Credit: K.E. Johansson

Figure 3

Two views of a neutral K^0 particle decaying into two charged particles (in red) in the ATLAS detector. Copyright 2010 - The ATLAS Experiment@CERN

Figure 4

CMS e-Lab 3D browser-based event display showing a J/Psi decay. Credit: I2U2

Figure 5

Students get ready to wrap scintillating plastic for HISPARC counters at a detector workshop. Credit: NIKHEF

Figure 6

Students work with their teacher on a MARIACHI detector.

Figure 7

The Cosmic Ray e-Lab project map. The navigational tool provides novice science investigators hot spots along the main line for milestone seminars, opportunities for teachers to check student progress. Each project milestones on the four branch lines has a popup reference with background information, links to resources and an assignment for students to complete in their e-logbook.

Credit: I2U2

TABLE 1 Outreach Programs: Success Factors for Effective Professional Development

TABLE 1 Outreach Programs: Success Factors for Effective Professional Development											
Success Factors											
Center	1	2	3	4	5	6	7	8	9	10	Total
Center A	0	1	3	2	2	2	2	2	3	3	20
Center B	0	3	1	2	2	1	1	2	1	1	14
Center C	0	2	1	3	2	2	1	2	1	1	15
Center D	3	2	1	2	2	2	2	1	0	2	17
0 = none; 1 = minimal; 2 = satisfactory; 3 = outstanding											
1. Strong teacher leader											
2. Strong mentor who understands education and professional development											
3. Participants meet regularly.											
4. Meaningful activities—not just talks and trips; meaningful research experiences											
5. Directly address classroom implementation of activities for all teachers											
6. Specific support and/or follow-up from staff											
7. Money from more than one source such as additional grants											
8. Stable participant base											

9. Address teacher professionalism such as attending meetings of professional organizations.
10. Establish a learning community.



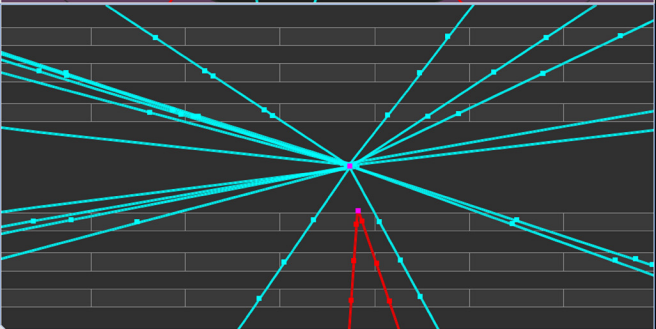




ATLAS EXPERIMENT

2009-12-06, 10:24 CET

Run 141749, Event 460665



**Detector Model** ?

- Tracker ☐
- ECAL Barrel ☐
- ECAL Endcap ☒
- ECAL Preshower ☒
- HCAL Barrel ☐
- HCAL Endcap ☒
- HCAL Outer ☒
- HCAL Forward ☒
- Drift Tubes (muon) ☐
- Cathode Strip Chambers (muon) ☐
- Resistive Plate Chambers (muon) ☐

Tracking ?

- Tracks (reco.)(89) ☐
- Electron Tracks (GSF)(0) ☒
- Clusters (Si Pixels)(480) ☐
- Clusters (Si Strips)(3722) ☐
- Rec. Hits (Tracking)(1088) ☐

ECAL ?

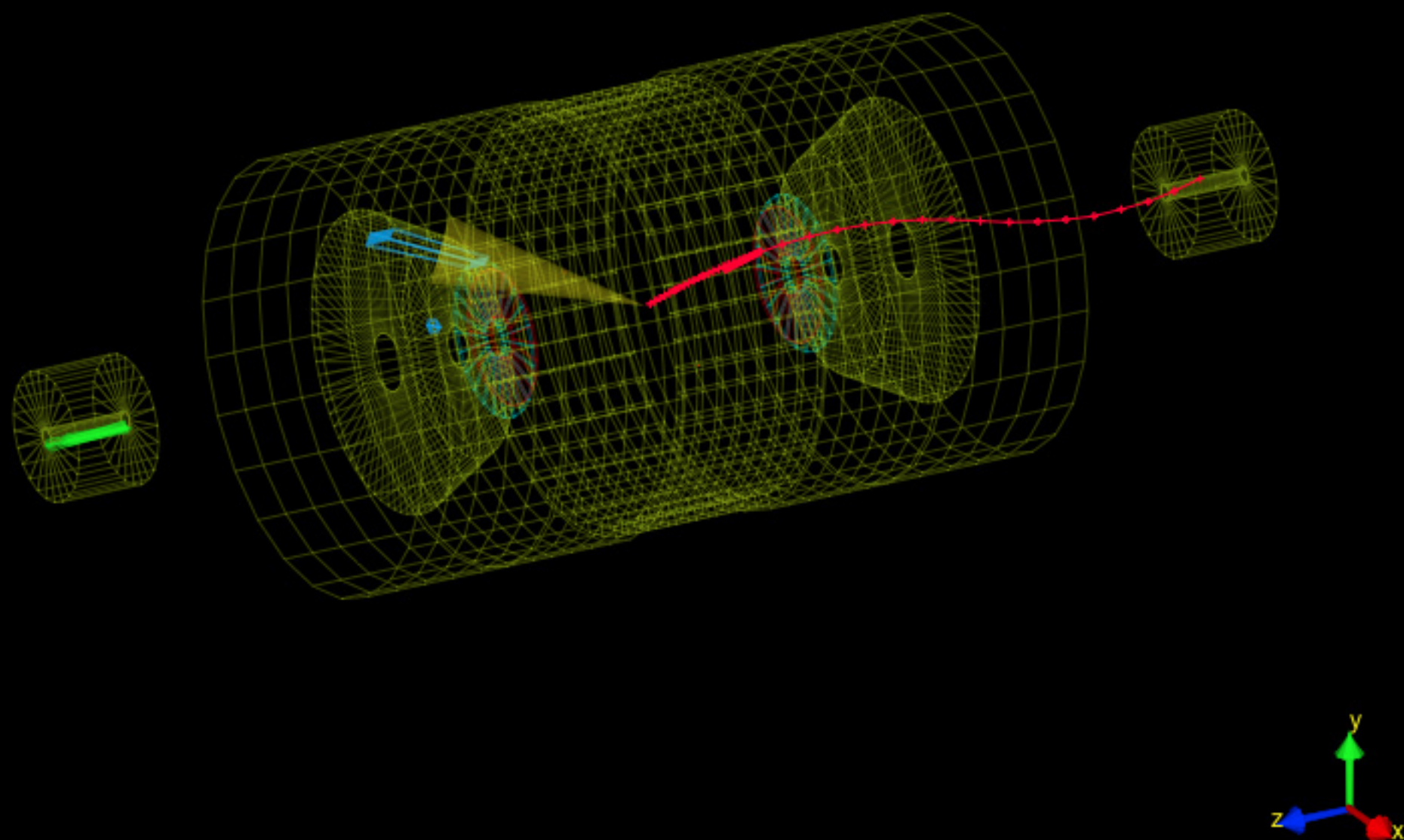
- Barrel Rec. Hits(931) ☒ ▶
- Endcap Rec. Hits(823) ☒ ▶
- Preshower Rec. Hits(561) ☐ ▶

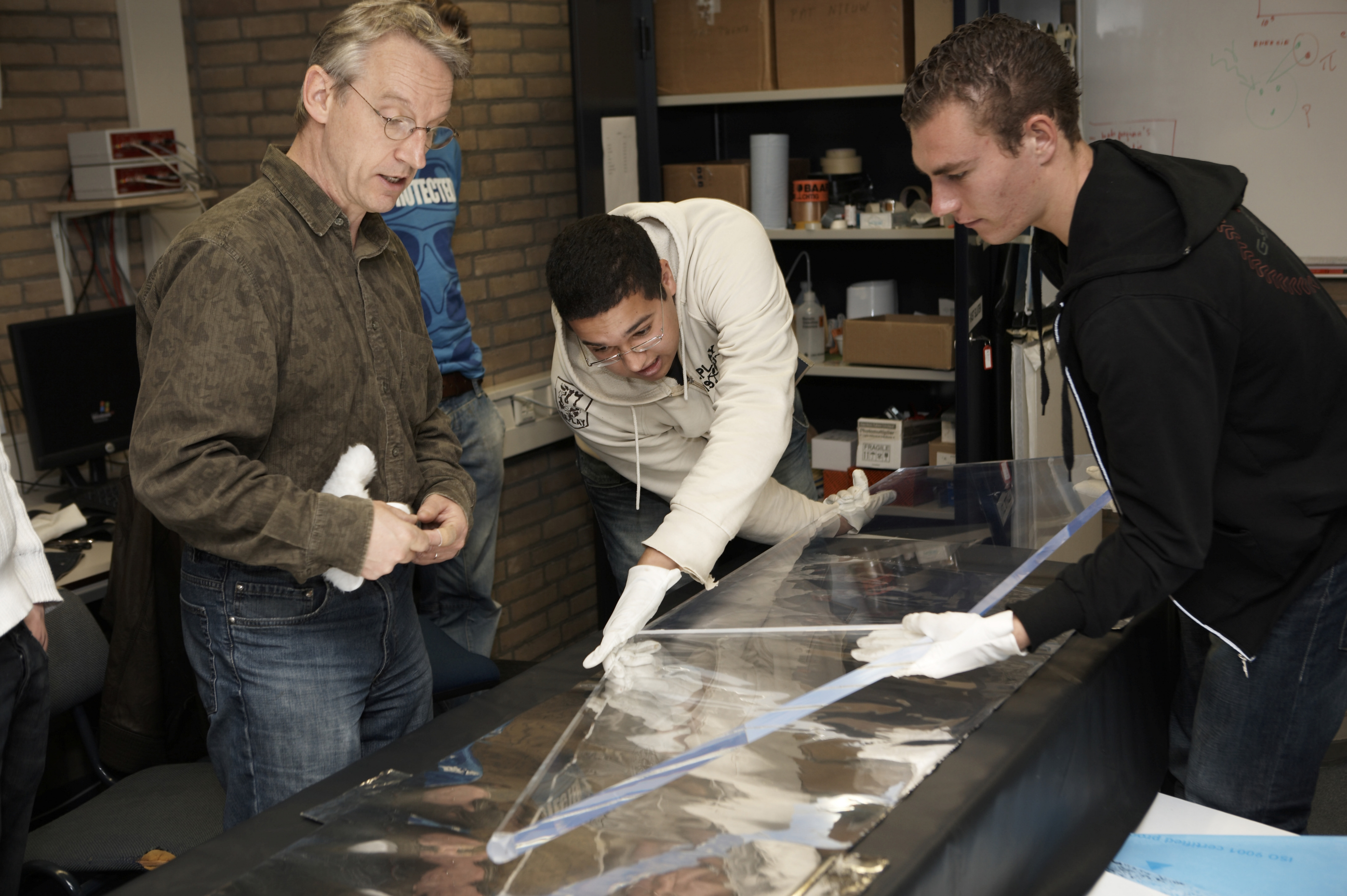
HCAL ?

- Barrel Rec. Hits(869) ☒ ▶
- Endcap Rec. Hits(233) ☒ ▶
- Forward Rec. Hits(385) ☐ ▶
- Outer Rec. Hits(393) ☐ ▶

Muon ?**Controls:**

- rotate
- Ctrl** + → pan x / y
- Shift** + → pan z







[Project Map](#)[Library](#)[Data](#)[Posters](#)[Site Map](#)[Assessment](#)[Text Version](#)[Cool Science](#)[About Us](#)

Home: Join a national collaboration of high school students to study cosmic rays.

Project Map: To navigate the Cosmic Ray e-Lab, follow the path; complete the milestones. Hover over each hot spot to preview; click to open. Along the main line are milestone seminars, opportunities to check how your work is going. Project milestones are on the four branch lines.

