Cosmic rays and research in schools: one school's experience

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ABSTRACT The High School Project on Astrophysics Research with Cosmics (HiSPARC) is an international project in which secondary schools and academic institutions join forces to form a network of detectors to measure cosmic rays with extremely high energy. We present results of research done by students at the King Edward VI High School For Girls, Birmingham, UK, and highlight the benefits of such projects in raising the profile of physics in schools.

Cosmic radiation

Our planet is continually being bombarded by high-energy particles from space. This cosmic radiation consists of neutrinos, protons and other heavier atomic nuclei, which originate from the Sun, shock waves around supernovae in our galaxy, and, for the most energetic particles, active galactic nuclei. These primary cosmic rays collide with air particles in our atmosphere to produce showers of secondary particles which include muons, electrons and photons (see Figure 1).

HiSPARC

In the High School Project on Astrophysics Research with Cosmics (HiSPARC; www.hisparc.nl/en), secondary schools and academic

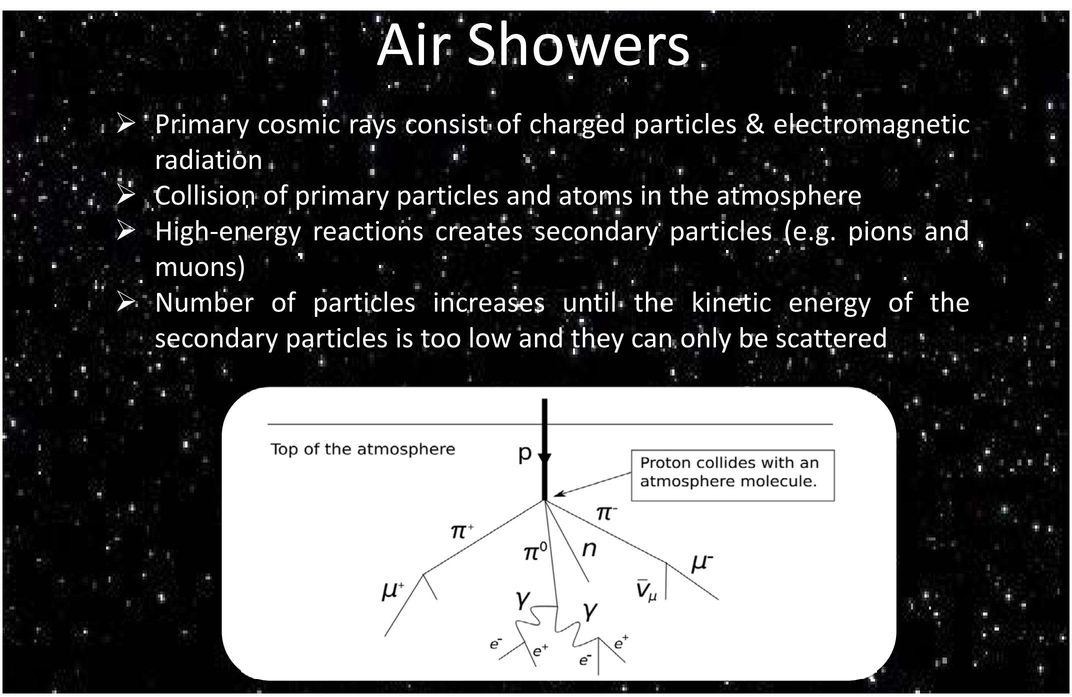

Figure 1 The interaction of a primary cosmic ray with the atmosphere (from a student presentation at the 4th Annual Student HiSPARC Cosmic Ray Conference at the University of Bristol, 2016; wikis.bris.ac.uk/display/HiSparc/4th+Annual+HiSPARC+conference)

institutions join forces to form a network of detectors to study the muons that reach the Earth's surface and thereby indirectly learn about cosmic rays of extremely high energy. The initial network of HiSPARC detectors was developed in the Netherlands in 2002–2003 and since then the network has been extended to other countries, including the UK. All the detectors are connected to a central computer server at the scientific institute Nikhef in the Netherlands via the internet.

The project was brought to the UK in 2012 by Dr Jaap Velthuis of the University of Bristol and in 2013 by Professor Cristina Lazzeroni of the University of Birmingham (www.birmingham.ac.uk/schools/physics/outreach/HiSPARCproject.aspx). There are now about 20 detectors in the UK, and the number is increasing rapidly.

King Edward VI High School For Girls (KEHS) in Birmingham, UK, joined the project in 2014, with assistance and guidance from the University of Birmingham. This article describes our involvement and how such initiatives have raised the profile of physics in the school.

The KEHS detector

Our first tasks on joining HiSPARC were to build a detector, and to connect it to the database via the internet. A group of sixth-form students (years 12 and 13; ages 16–17) set about the task with enthusiasm, as it involved use of power drills! Most of the items required to build the detector were supplied by the University of Birmingham, and guidance was generously provided by Dr Angela Romano and Professor Cristina Lazzeroni of the Particle Physics group of the University.

Figure 2 shows a schematic diagram of the HiSPARC detector.

- It consists of two rectangular scintillators that produce flashes of light when struck by muons.
- The light produced in a scintillator is guided to a photo-multiplier tube (PMT) via a triangular piece of scintillator.
- The analogue signals from the PMTs are fed to the HiSPARC box, which converts them to a digital signal which is then sent to a dedicated local computer.
- The latter is connected to the internet so that the data can be uploaded once a day to the HiSPARC database.
- A GPS receiver is also connected to the system so that the exact position of the detector is known and the time of muon arrival at each scintillator is determined to a very high precision.

In the first phase of the construction procedure (see Figure 3), the students cleaned the scintillators and light guides with alcohol and then wrapped them in aluminium foil (to trap the light in the

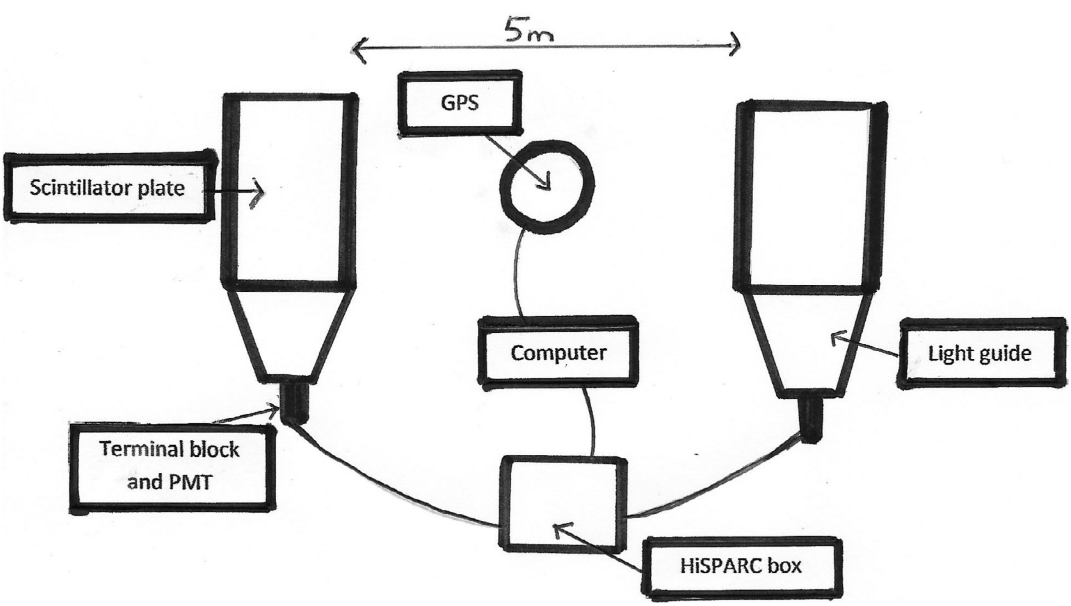

Figure 2 Schematic diagram of a HiSPARC detector

Figure 3 Sixth-form physics students (age 16–17 years) preparing the scintillator for the detector

scintillators), followed by black pond liner (to stop light entering the scintillators from outside). The light guides were glued onto the scintillators and the PMTs attached. Once the glue was dry, the detectors were tested to ensure that there were no light leaks and the PMTs were working efficiently.

In the second phase of the construction procedure, the scintillators were placed in ski boxes (car roof boxes) on the school roof (see Figure 4), making sure that the boxes were firmly attached to concrete slabs so that they were stable during wind and rain. Cables were fed into the school library below, where the HiSPARC box, computer and internet connection were situated (see Figure 5). Finally, a comprehensive series of tests was carried out to ensure that the system was working correctly. In real life, of course, the assembly did not always work according to plan. For example, faulty PMTs had to be replaced, a special type of glue had to be sourced, and negotiations were required to ensure that the project was funded and permission obtained for the installation. However, a working system was created over a few weeks, and different groups of students from years 10 and 11 (ages 14–15) started their analyses of real events.

A weather station was installed on the school roof near the HiSPARC detector, allowing the local atmospheric conditions such as temperature, air pressure and wind speed to be correlated with the cosmic ray flux received by our detector.

Results from the research

An event or coincidence is when a flash of light is detected in both scintillator plates within a time interval of 1.5 μs. Two scintillators are used so that real events can be distinguished from background noise in the electronics or signals due to background radiation. The detector continually counts the number of events, and a total count is recorded for each hour. Most projects involve statistical analysis looking for a correlation between this hourly rate and some other variable. Dr Maria Pavlidou of the University of Birmingham has produced of examples of initial projects and suggestions for analysis techniques (www.birmingham.ac.uk/schools/physics/outreach/HiSPARCproject.aspx); her guidance during the work described in this article has been invaluable.

Students have access to the data from their own detector as well as data from all the other detectors

Figure 4 The ski boxes containing the HiSPARC detector, fixed firmly to the school roof

Figure 5 The HiSPARC box and dedicated computer located in the library below the roof on which the detector is placed; year 10 researchers checking that the system is working correctly

in the Europe-wide network via the HiSPARC website data.hisparc.nl/show/stations_by_country.

Here we summarise four projects undertaken by groups of year 10 and 11 students and presented at the 2015 and 2016 annual HiSPARC conferences.

Latitude dependence

Two students investigated whether the number of events depended on the latitude of the detector. They hypothesised that the Sun's magnetic field should have an effect on the number of events, either by deflecting some cosmic rays away from the Earth's surface, so acting as a 'shield', or by guiding particles towards the Earth, so acting as a kind of 'lens' (see Figure 6); these effects should be greater near the Equator than near the Poles. They looked at data from five detectors, including one at Aarhus University in Denmark, at a latitude of 56.2°, and the Philips Van Horne 1 detector in the Netherlands, at a latitude of 51.3°. Using data from several months during 2013, they compared the number of events during a 5 hour period near midnight and a 5 hour period near midday for each detector. A statistically significant effect of latitude was not seen but this may have been because the differences in latitude for the detectors were only small (just 5°) and the time frames when all the detectors of interest were online were limited. Nevertheless, these students were awarded the gold medal for their presentation at the 2015 HiSPARC conference at the University of Birmingham (https://wikis.bris.ac.uk/display/HiSparc/HiSPARC+Annual+Conference+2015).

Solar cycle dependence

A group of six students was awarded the silver medal at the 2015 HiSPARC conference for showing an anticorrelation between the number of sunspots (a measure of solar activity) and the number of cosmic ray events (see Figure 7). They used 5 years' data (2009–2014) from a HiSPARC detector in the science park in Amsterdam covering a period from solar minimum to solar maximum (wikis.bris.ac.uk/display/HiSparc/HiSPARC+Annual+Conference+2015).

Atmospheric pressure dependence

Three students were awarded the bronze medal at the 2016 HiSPARC conference at the University

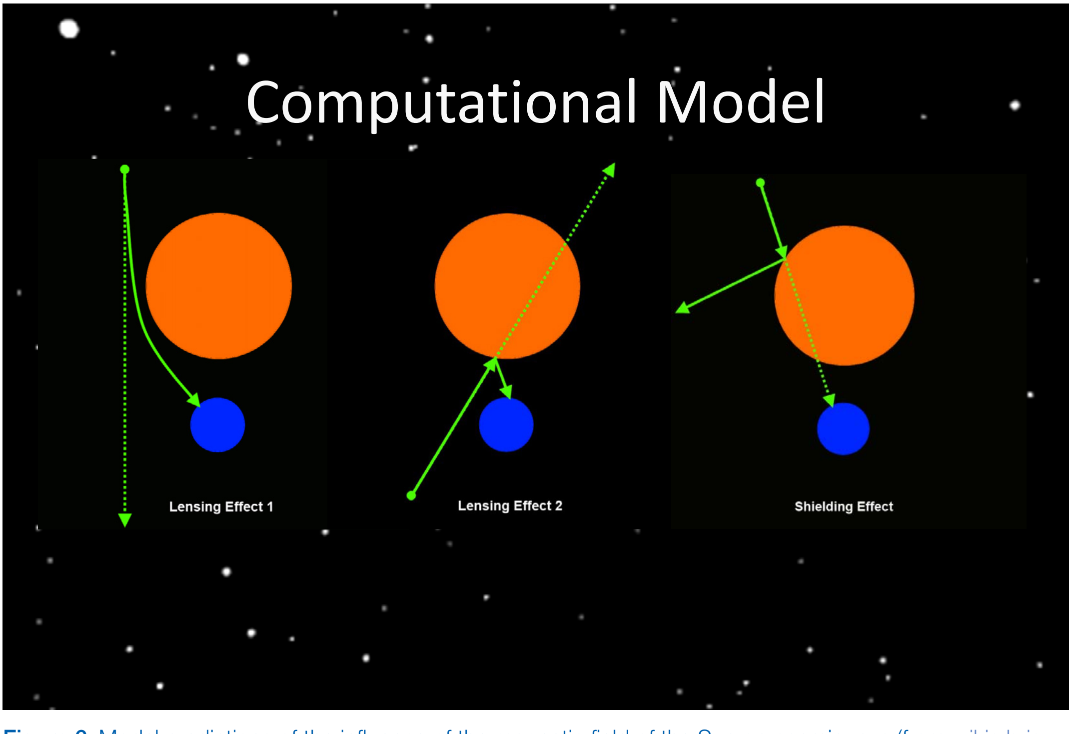

Figure 6 Model predictions of the influence of the magnetic field of the Sun on cosmic rays (from wikis.bris.ac.uk/display/HiSparc/HiSPARC+Annual+Conference+2015)

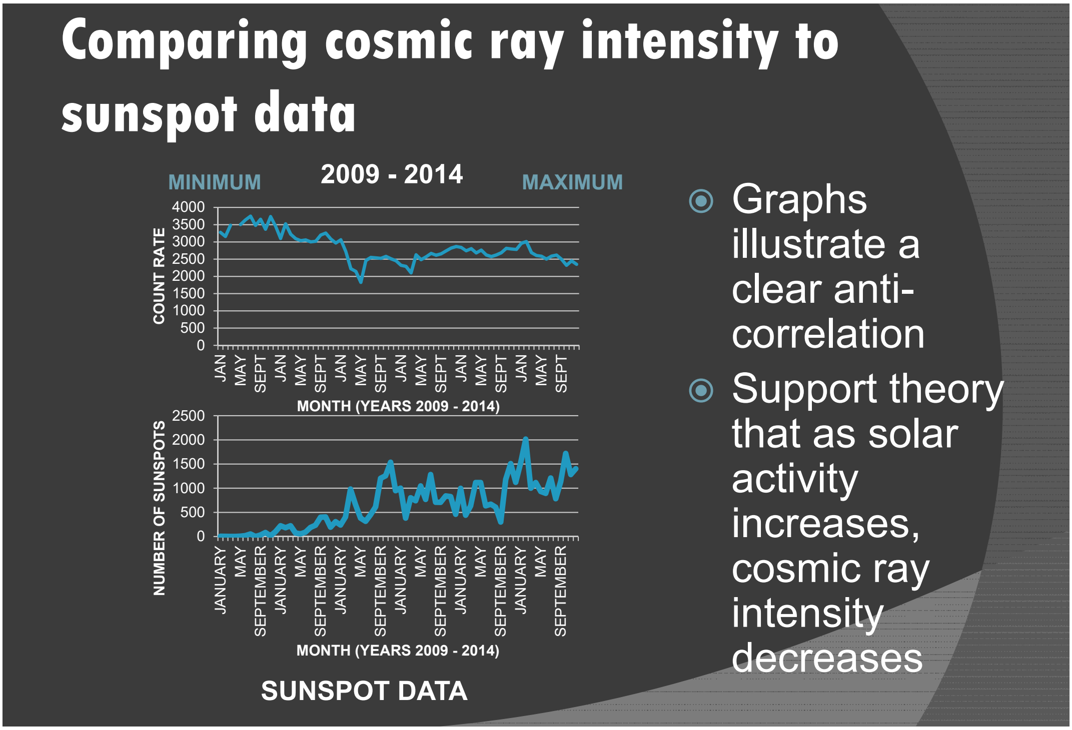

Figure 7 Demonstration that the number of cosmic ray events is inversely correlated with solar activity (wikis.bris.ac.uk/display/HiSparc/HiSPARC+Annual+Conference+2015)

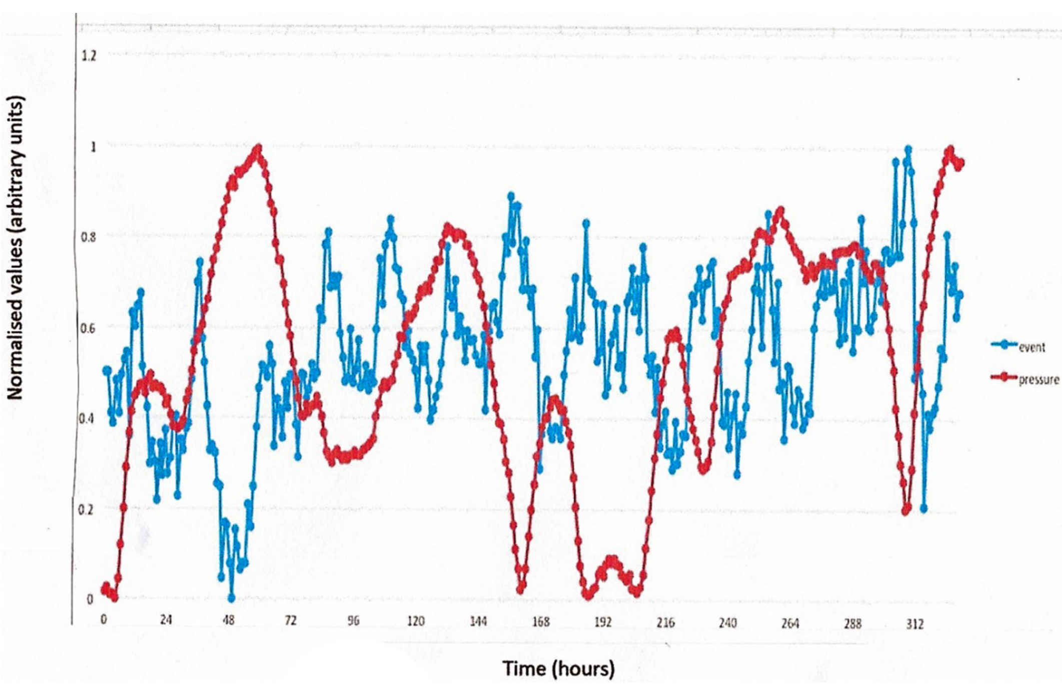

Figure 8 Evaluation of the effect of local atmospheric pressure on the number of cosmic ray events (wikis.bris.ac.uk/display/HiSparc/4th+Annual+HiSPARC+conference)

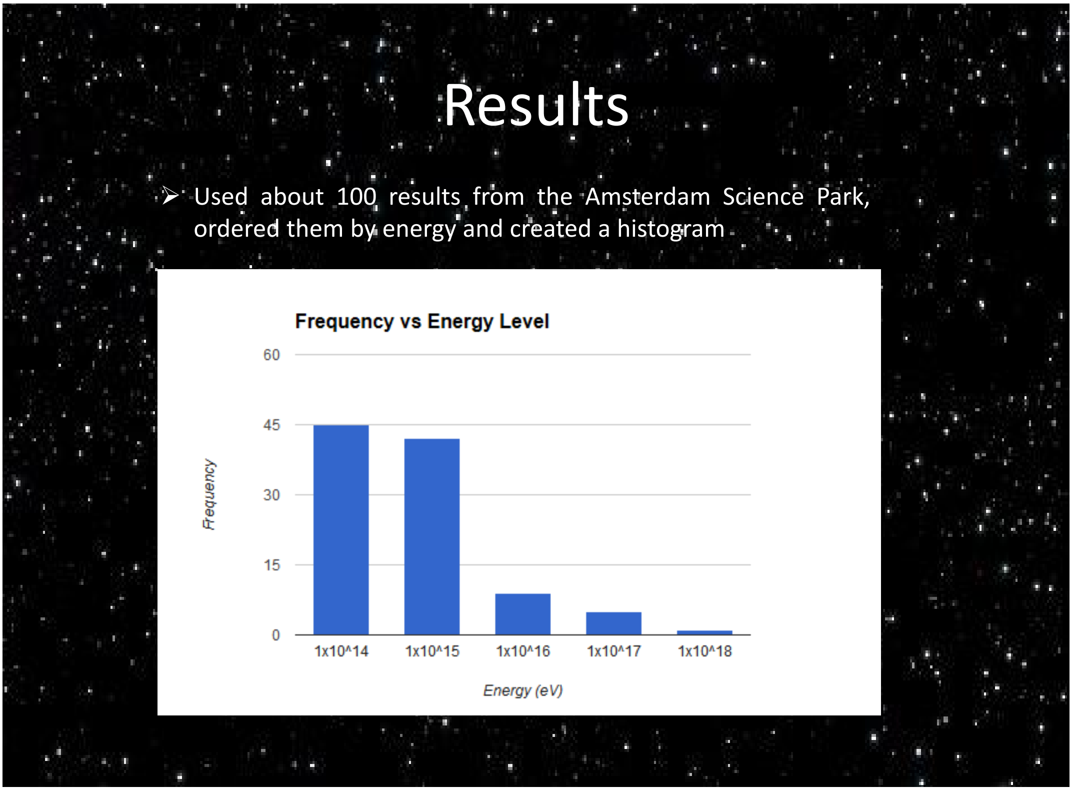

Figure 9 Calculated energies of the primary cosmic rays (wikis.bris.ac.uk/display/HiSparc/4th+Annual+HiSPARC+conference)

of Bristol for their investigation into the effect of atmospheric pressure (measured using the weather station on the school roof) on the number of cosmic ray events detected using the school's HiSPARC detector. An anticorrelation is expected: the higher the pressure, the greater the mass of air there is to deflect or absorb the cosmic particles, so they do not reach the ground to be detected. However, only a weak correlation was found (Figure 8), possibly because of the limited range of pressures in the 2 weeks of data analysed (wikis.bris.ac.uk/display/HiSparc/4th+Annual+HiSPARC+conference).

Determination of the energy spectrum of primary cosmic rays

Two students were awarded the gold medal at the 2016 HiSPARC conference for their use of the *jSparc* analysis software and data from three detectors located at the Amsterdam Science Park to determine the possible energies of the primary cosmic rays that give rise to the secondary muons (Figure 9). The *jSparc* software takes data from a number of detectors during one cosmic ray shower; it then uses a form of triangulation to calculate the likely location of the shower epicentre and from this can estimate the energy of the primary cosmic ray that caused the shower. The students found that the primary particles for the hundred showers analysed had energies in the range 10^{14}–10^{18} eV (wikis.bris.ac.uk/display/HiSparc/4th+Annual+HiSPARC+conference). For comparison, typical energies at the Large Hadron Collider are of the order of 10^{13} eV.

Benefits of participating in the HiSPARC project

Students gain many benefits from participating in the cosmic ray work:

- They develop independent research and ICT skills, in order to carry out fairly sophisticated statistical analysis of their data.
- They develop resilience, as things don't always go as expected: the available data sets may not be ideal; the expected correlations

may not be seen; or problems can arise with the detector or the associated computers.

- Students develop team building and time management skills
- Students had the opportunity each year to present their results at the annual HiSPARC conference. The conference consists of lectures from professional scientists on particle physics and related topics, as well as 15 minute student presentations of the research they have carried out during the year. Students needed to field questions from their peers and university researchers. Certificates were awarded to the three best student presentations.
- A significant benefit of the HiSPARC project is the opportunity for students to interact with professional scientists at the university, who, in our case, presented positive female role models. These contacts are important because students may soon outrun the experience and expertise of their teachers.
- A key strength of HiSPARC is that it is a real research project; even the experts at the university do not know all the answers.

Conclusion

HiSPARC is an international initiative that allows school students to undertake real research on high-energy cosmic rays by analysing data from a large network of detectors. Two years ago, our students built a HiSPARC detector, and, since then, groups of students have been actively involved in the project.

The number of girls in the UK who continue with physics after age 16 is modest compared with those taking biology and chemistry. Although numbers have improved in recent years through initiatives promoted by organisations such as the Institute of Physics, it remains a challenge for schools to encourage girls to take physics courses beyond GCSE. Happily, at KEHS our numbers have been fairly healthy in recent years, and initiatives such as HiSPARC have helped to raise the profile of the subject in the school.

Acknowledgements

We would like to thank our colleagues Cristina Lazzeroni, Maria Pavlidou and Angela Romano at the University of Birmingham; this work could not have been done without their kind assistance.

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