EAS direction reconstruction with HiSPARC

High-School Project on Astrophysics Research with Cosmics (HiSPARC)

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HiSPARC

HiSPARC is a research and outreach project already operating for more than 10 years. The HiSPARC network currently consists of over 100 detection stations. Stations are located at high schools and research institutes in the Netherlands, United Kingdom and Denmark [1, 2].

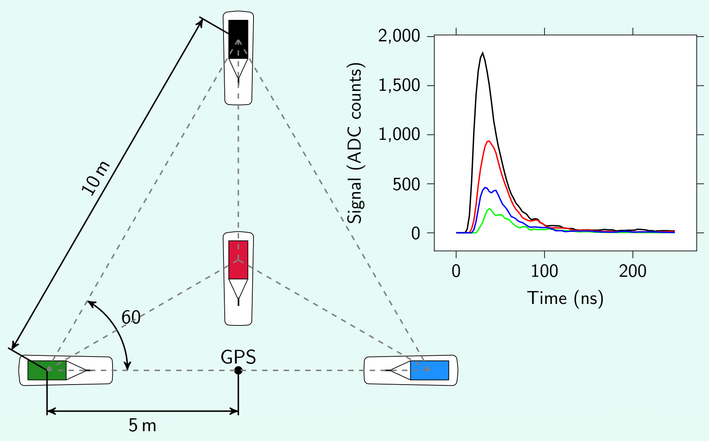
HiSPARC network, each circle is one station [3].

Detection station

A single station consists of:

- Two or four plastic scintillators (100 x 50 x 2 cm).
- One photomultiplier tube per scintillator.
- 4-channel 12-bit ADC, 2.5 ns sampling.
- GPS for station position and synchronised timing.

The station triggers when at least 2 scintillators simultaneously detect a minimum ionising particle (MIP). All events are sent to data storage at Nikhef and then publicly accessible through a web interface [4] and API [5].



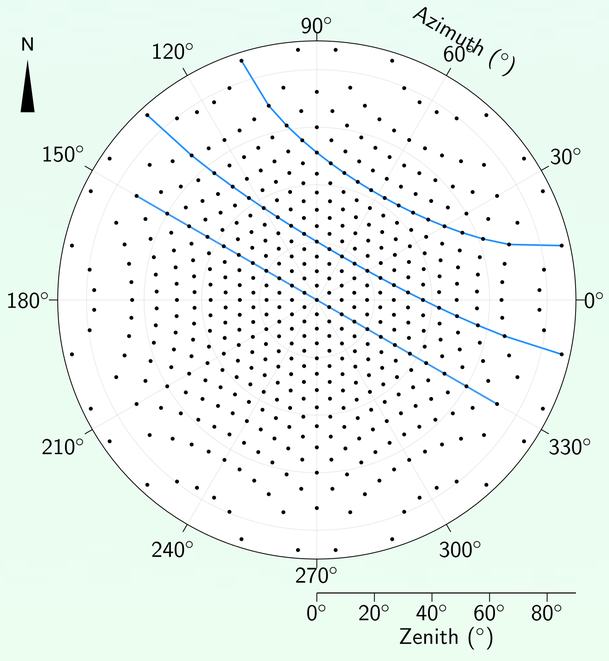
Station layout and event readout example.

Shower direction

Analytical formulae for azimuth and zenith for a thin and flat shower front define the shower direction $\boldsymbol{n}$:

$$\tan\phi = \frac{n_y}{n_x} = \frac{(\mathbf{u}\times\mathbf{v})_y \pm v_y\sqrt{v^2-u^2}}{(\mathbf{u}\times\mathbf{v})_x \pm v_x\sqrt{v^2-u^2}}$$
$$\cos\theta = n_z = \frac{(\mathbf{u}\times\mathbf{v})_z \pm v_z\sqrt{v^2-u^2}}{v^2} \qquad (1)$$

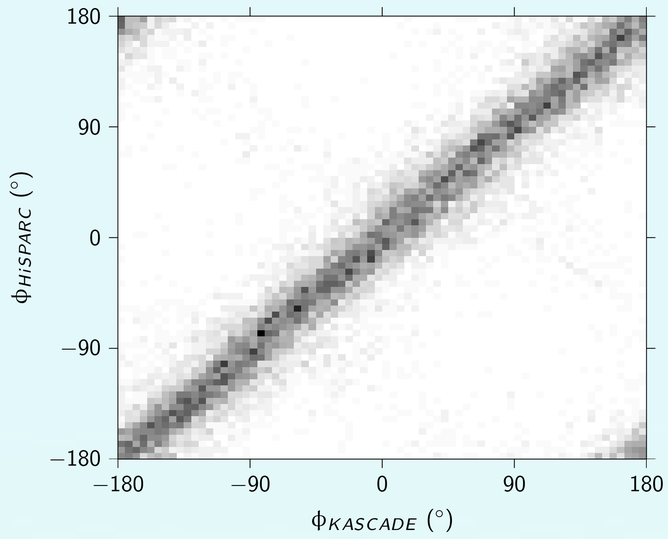
The equations give two solutions; the one with shower direction under the horizon is discarded. Due to the 2.5 ns ADC sampling the direction reconstruction results in a discrete distribution:



Discrete azimuth and zenith angles for the three outer scintillators of the station. The lines connect angles for fixed timestamps in two scintillators while the third varies.

KASCADE

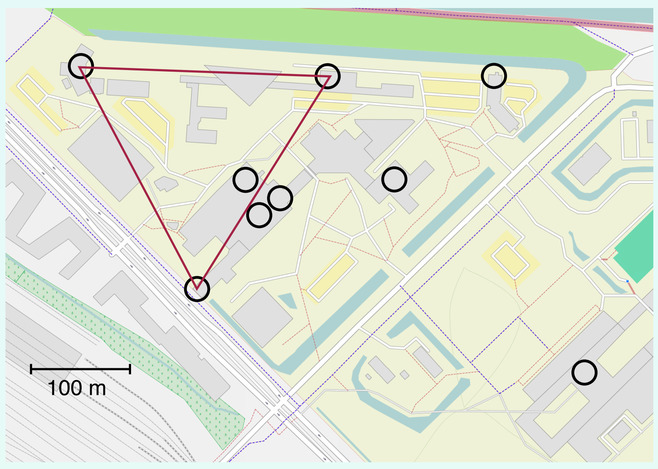
A HiSPARC station was integrated in the KASCADE experiment [6] for calibration. The shower direction reconstructed by the HiSPARC station was compared with that of the KASCADE array and shows excellent agreement:



Azimuthal angle from KASCADE versus HiSPARC.

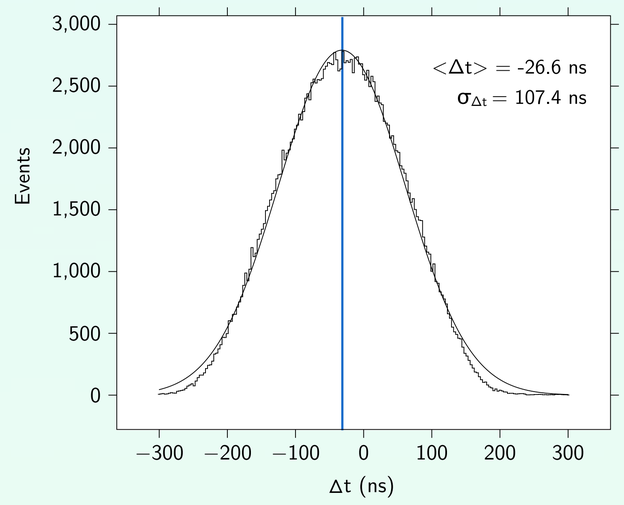
Science Park cluster

At the Amsterdam Science Park 9 HiSPARC stations are clustered:



HiSPARC – 4-scintillator – stations at Amsterdam Science Park.

The cluster detects showers with energy >10^{15} eV triggering three or more stations. This requires calibration of each GPS. The GPS offset between stations is determined. The offset is defined as the mean of the time difference distribution:



Typical GPS time differences (Δt) between stations satisfies a normal distribution. The width of the distribution increases with station distance.

For more than three stations in coincidence formulae (1) generalise to:

$$\sum_i^k \left(\Delta x_i n_x + \Delta y_i n_y + \Delta z_i n_z + c\Delta t_i\right)^2 \qquad (2)$$

This expression is minimised to derive the direction of the shower. Reconstruction was tested using full simulation of detection stations with air showers generated by CORSIKA [7]. Various timing uncertainties and detector response resolutions are taken into account.

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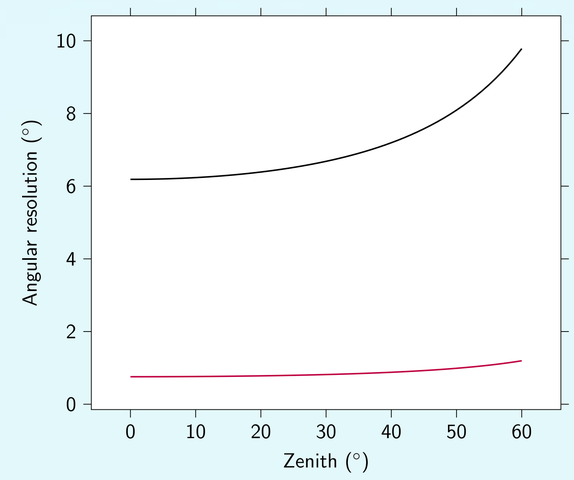
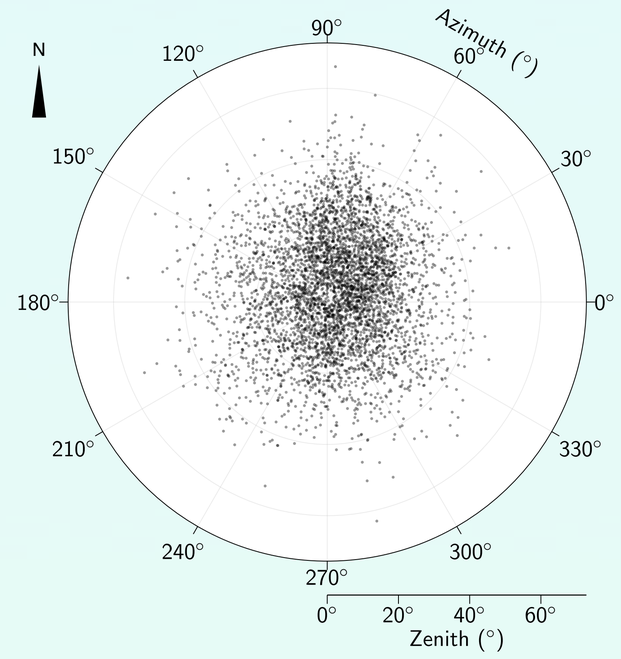
Reconstruction

The angular resolution for reconstructed events as a function of zenith is:



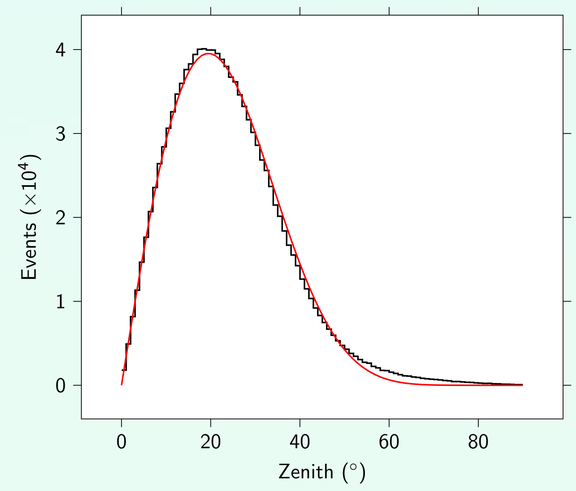
For a single station (black) with $\sigma_t = 1.8$ ns and the combination of three stations shown on the map (red) with $\sigma_t = 5.5$ ns for $N_{MIP} \geq 2$. 66% of the events are within this error.

For the following reconstructions 4½ years of shower data from the Science Park cluster has been used. Reconstructed angles for events which triggered any combination of 7 stations are shown:



Azimuth and zenith for showers that hit 7 or more Science Park cluster stations.

The reconstructed zenith distribution follows the expected distribution:



Histogram of zenith reconstructions for events that hit at least 3 stations. Expected zenith distribution as given by Rossi is in red.

Summary

HiSPARC is a sparse network of compact and affordable stations allowing high school students to meet science. As all data and tools are publicly available events can be analysed in the classroom.

With a single station we achieve reasonable angular resolution on the cosmic shower direction, when we include more stations we observe a significant improvement.

References

[1] Fokkema, D.B.R.A. The HiSPARC Cosmic Ray Experiment. PhD thesis. Universiteit Twente (2012).
[2] de Laat, A.P.L.S. PhD thesis (work in progress).
[3] Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under CC BY SA.
[4] HiSPARC Public Database, http://data.hisparc.nl .
[5] Fokkema, D.B.R.A. and de Laat, A.P.L.S. SAPPHiRE: A frame work for HiSPARC, http://docs.hisparc.nl/sapphire .
[6] Antoni, T. *et al.* The Cosmic-Ray Experiment KASCADE. *Nucl.Instr. and Meth. A513*, 490-510 (2003).
[7] Heck, D. *et al.* CORSIKA: a Monte Carlo code to simulate extensive air showers. *FZKA 6019* (1998).