# Astroparticle Detector Array, an educational project on Ultra High Energy Cosmic Rays

**Abstract:** ADA (Astroparticle Detector Array) is an educational project finalized to detect high energy cosmic rays named UHE (Ultra High Energy). Its working process is the same as that used in professional cosmic ray observatories and indeed it consists of simple detectors spread over the whole national territory and beyond. The detectors are hosted among high schools, associations and private astronomical observatories. ADA was brought about with the intention of promoting astroparticle physics to any given level of divulgation. Furthermore, ADA is becoming an interesting tool not only for teachers but also for independent and keen scientists.

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## THE ADA PROJECT

ADA (Astroparticle Detector Array) is a project meant for the detection of cosmic rays, particularly the high energy ones called UHECR. One of the main purposes of this project is to shed knowledge in astroparticle physics on the public at large and to get high school students involved in learning this subject. Experiments similar to ADA already exist in other countries, but for some features ADA can be considered unique; one of its features is that each detector has its own dedicated web section with a plotted graphic data in real time and, furthermore, all data is stored online where it is freely accessible: (http://www.astroparticelle.it/public/ada/). Currently the project is in use with several detectors placed among schools and amateur observatories in Italy and Switzerland (Figure 1).

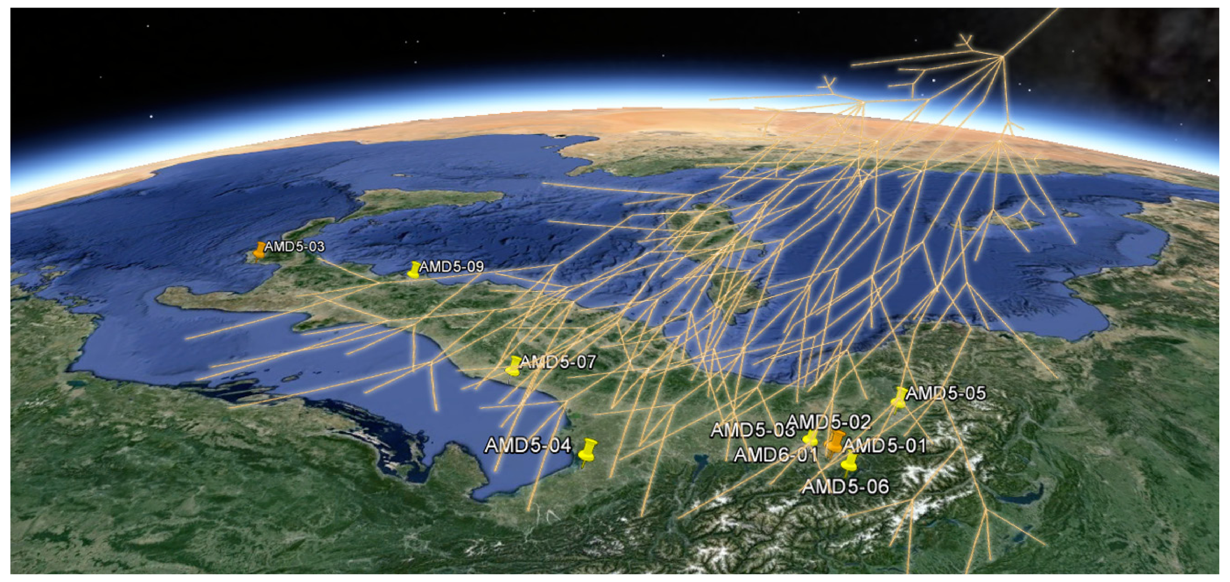


Figure 1 - Artistic image, deployment of the AMD5 detectors in Italy and in the neighbouring Switzerland. List of leaders and respective detector places: R.Crippa, Osservatorio FOAM13 di Tradate (VA) - M. Arcani, 'laboratorio Astroparticelle', Venegono I. (VA) - D. Liguori, Istituto di Istruzione Superiore IIS CARIATI (CS) - A. Tegon, Astrofili di Mestre e Santa Maria di Sala (VE) - F. Poglio, Liceo Scientifico Statale Piero Gobetti, Torino - F. Arcidiacono, Polo scolastico 2 Torelli, Fano (PU) - G.Luvini, Osservatorio M.te Lema, Vernate CH - M. Canali, Liceo E. Majorana Desio (MB) - E. Rubino, Associazione Arma Aeronautica, Reggia di Caserta *(credit Google Map)*.

ADA constantly measures the flux of cosmic rays with the aim of detecting - in the same unit of time - signals of ultra high energy particles in detectors located several kilometres away.

The advantage of having detectors coordinated with a comparison of the data (on screen) in real time, is that of guaranteeing the possibility of revealing "unusual" astronomical events. Indeed if an anomaly in the flux is evidenced only in one isolated detector (Figure 2) it may have no specific meaning, but if a significant variation is detected simultaneously around the array of detectors it could be a signal of high-energy particles and would be followed up with a thorough analysis.

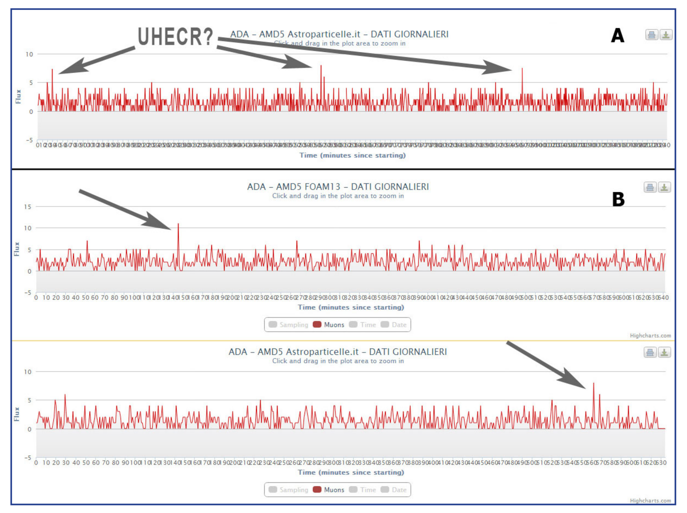


Figure 2 - (A) Anomaly in cosmic rays flux recorded by one of the detectors; in the peaks the muons flux increased beyond 4σ. (B) Some variation in the flux on 5th March 2014; both detectors have reported significant changes but at several hours from each other. If they had happened at the same time it would have been a signal of high-energy events *(M. Arcani, R. Crippa)*.

The project uses detectors called AMD5 (Figures 3 and 4). Each instrument becomes a valuable piece of an array that sends data to a web-server. The "astroparticle portal" (www.astroparticelle.it), works as a concentrator that collects data from each server, makes a first analysis and allows any user connected to the world wide web to consult it.

## AMD5 DETECTOR & ASTRORAD SOFTWARE

AMD5 (Astroparticle Muon Detector) is a cosmic ray detector ideal for use as a cell in a matrix system because it has proven reliability and both its use and construction are quite simple.
This instrument is usually constructed inside an empty personal computer case. The functioning of AMD5 is based on two Geiger-Müller tubes (GMT) working in coinciding unison, thereby allowing the discrimination of many cosmic rays from other less energetic particles.
Signals left in the detector by particles are processed by our software AstroRad; the data produced by the software include the counting of the flux of particles per unit of time, the frequency and time of arrival of the particles (with accuracy within one thousandth of a second) and dosimetry.
The data is uploaded online, plotted on screen and simultaneously recorded in tables. In this way it is also possible to export the data at the end of the measurements and to analyse them with any analysis software.
In addition to particle counting, it is possible to carry out other interesting tasks with this equipment. One of these is, for example, the absorption of cosmic rays in materials, which consists in superimposing thicker and thicker metal slabs and plotting the data of the results, so by obtaining the well-known Rossi curves.
Another example is the comparison between the flux of muons detected and the flux of the solar wind, to highlight how the activity of our Sun, in particular the Forbush effect, influence cosmic rays on earth. The East/West effect is another example and consists in orientating the detector (and hence GMT) to south-north and tilting it gradually towards east and then west, in order to demonstrate and understand the geomagnetic effect.

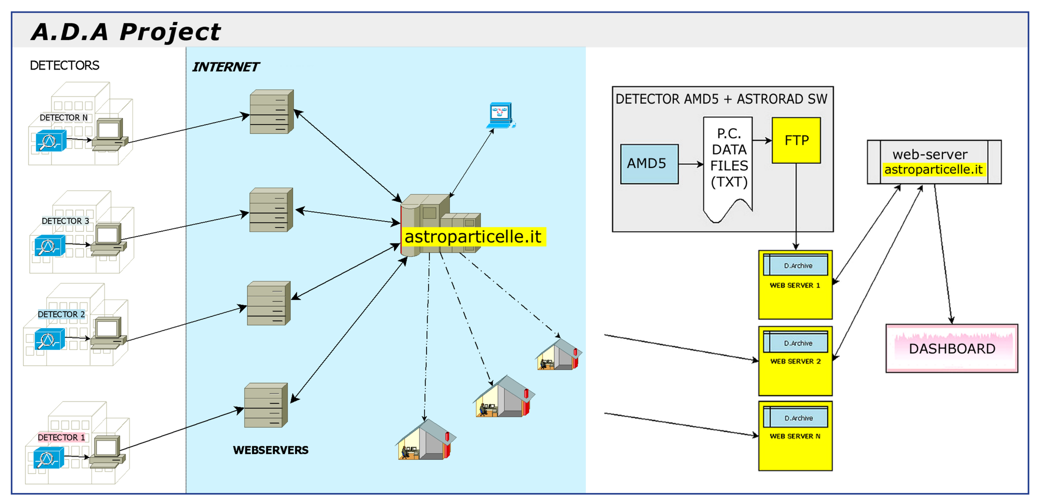


Figure 3 - Block diagram of the ADA project; each AMD5 detector sends its data to a web-server via FTP, opening a preset webpage on the astroparticelle.it portal (http://www.astroparticelle.it/public/ada/) the system automatically creates all the graphics in real time).

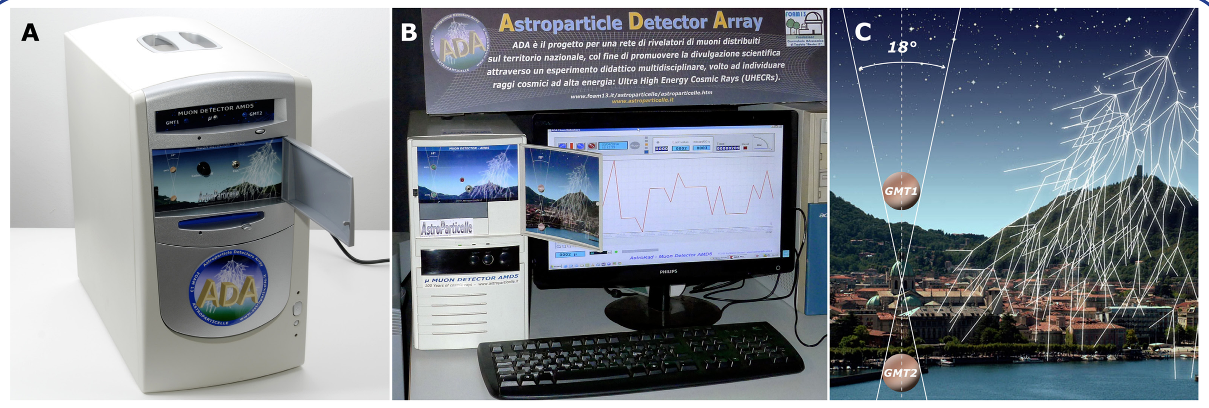


Figure 4. (A) One of the AMD5 detectors (2015). (B) AMD5 detector installed at the FOAM13 Observatory. (C) The position of the two Geiger tubes also assigns an "optical" geometry in the instrument; as the GMT is spaced by 6 centimetres, the visible sky window is about 18° or about 0,5 sr *(M. Arcani, R. Crippa)*.

## SOCI ADA SOFTWARE

Every day each detector connected to the ADA network generates several text files containing all the data recorded throughout the whole day. Each file contains thousands of strings on cosmic ray activity. This data is accumulated day in day out and it is easy to calculate that in one year millions of pieces of numerical data are created. All this brings about a cost - in terms of time - dedicated to data analysis.
When there is a count of cosmic rays (muons) that exceeds an arbitrarily threshold, the ADA system sends an e-mail to the leaders of each detector. At that point those interested in checking the progress of the data should download the files of the day from the server and analyse them with software (e.g. Excel, Maxima, SciLab, Matlab, Mathematica...).
The SOCI-ADA software (Seeker Of Coincidences In ADA) has been designed to simplify the task of data analysis. This program perfectly solves the problem of looking for coincident events in the ADA array.
At this moment SOCI-ADA can extract from a single file only events that exceed the average value added by the value of 'n' times δ (SD), with 'n' freely configurable (default 3).
In this way it is easy to verify coincidences among detectors and to plot the related results onto a graph (Figure 5).

### THE ADA '*APP*'

This application, designed for mobile devices (Android only, sorry), shows the data of the detectors associated with the ADA project. The idea is to immediately inform the ADA users of possible UHECR events. One future development will also be that of using the flux of muons to make predictions, for example forecasting solar activities through the Forbush effect, a kind of dedicated space weather.
Some links to websites around the world that deal with astroparticle physics are also included in the 'app', including a link to the graphs reported by the ADA detectors that are surfable through the browsers of every mobile device.

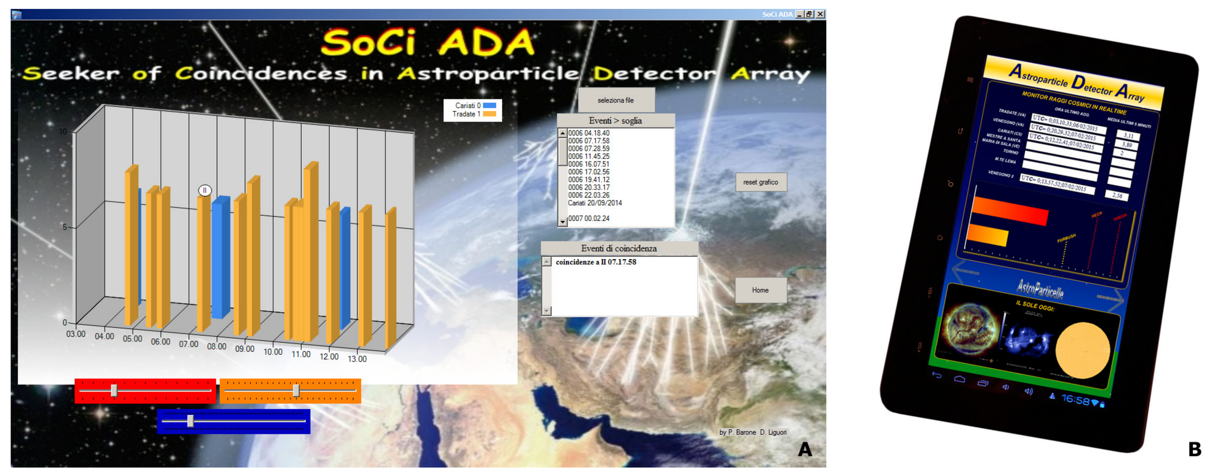


Figure 5 - (A) Screen-shot of the SOCI software *(D.Liguori, P. Barone)*. (B) The ADA *app* installed on a mobile device.

## CORSIKA SIMULATION AND THE SUPERNOVA HYPOTHESIS

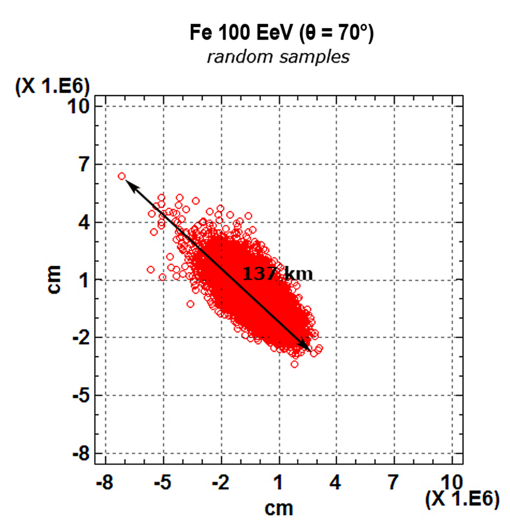


Figure 6 - Simulation of a shower from an iron nucleus entering in atmosphere with a zenith angle of 70° *(M. Arcani)*.

CORSIKA [1] is a simulation model based on the Monte Carlo methods developed at the Karlsruher Institut für Technologie (KIT) in Germany. Originally intended for studies related to the KASKADE Observatory in Germany, CORSIKA is used to simulate cosmic rays in the atmosphere and is now used in all professional observatories around the world, including Auger in Argentina. CORSIKA has been used here to figure out what should be the maximum distance between two or more detectors belonging to the same shower. In relation to the known values of flux and energy of the primary cosmic rays we have found that for detecting secondary particles - belonging to the same shower - the distance between two different detectors should be in the order of a few tens of km for vertical particles (zenith angle equal to zero) and up to 100-150 km for particles with a very inclined trajectory towards the angle of zenith (Figure 6).

However the ADA project was born with the idea to revealing extraordinary events. In the history of cosmic ray so far no one observatory has ever seen a supernova event (or similar) that occurred in our Galaxy. Astronomers think that the rate of supernova should be one per century and the very last was seen by Kepler in 1604 (Figure 7); we are therefore in credit of four supernovas at least. In the case of a supernova event in the Milky Way, if this were to occur with the expected features, we are confident in thinking that bunches of primary particles could arrive at the same time from the source and generate contemporary showers in different areas. This would lead to measuring a flux of particles (muons) much higher in the same unit of time, regardless of the distance between the detectors. For this reason it is important to have the largest number of detectors in the ADA network and be prepared in case such an opportunity were to come about.

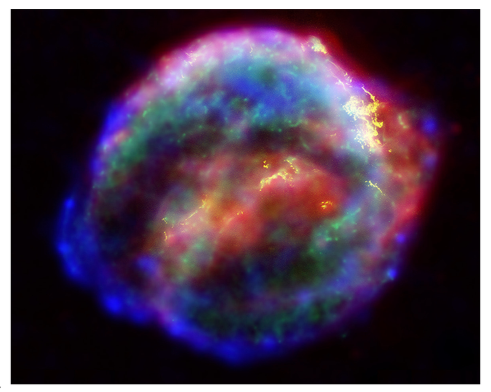

Figure 7 - The supernova 1604, the very last supernova exploded inside our Galaxy *(credit HST, NASA)*.

## ADA AND ITS DETECTORS AT WORK

### Dependence on Zenith angle

Between June and August 2014 an ADA detector was used to measure the flux of cosmic rays in relation to the zenith angle of the direction of incoming particles. Varying inclination and orientation, day by day, at the end of the measures the data produced a "photograph of the cosmic rays in the sky." The result is a snapshot of the average distribution of the flux of secondary cosmic rays that hit the ground at our latitudes.
The three-dimensional image (Figure 8) shows both the clear dependence of cosmic rays upon the zenith angle and the geomagnetic effect which enlightens much more the western part (in this specific case the North-West).

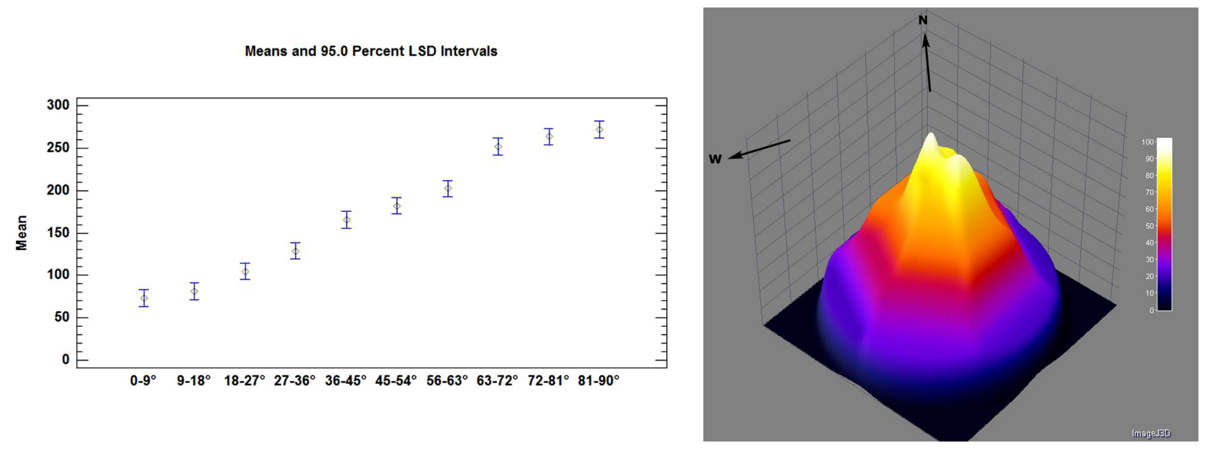


Figure 8 - (A) Total number of particles measured in relation to the angle of the zenith in over two months. (B) The three-dimensional image is obtained by assigning the values of cosmic ray data to the RGB channels *(M. Arcani)*.

### The FORBUSH effect

One of the most visible effects in the array of ADA is certainly the solar activity that modulates the cosmic ray flux at Earth (Forbush effect). The graph below was obtained from measurements made on 10 and 11 April 2014 (doy 101) from the AMD5 detectors in operation at that time. The average of secondary particles measured during the Forbush event decreases from 3.68 to 2.71 per minute (Figure 9).

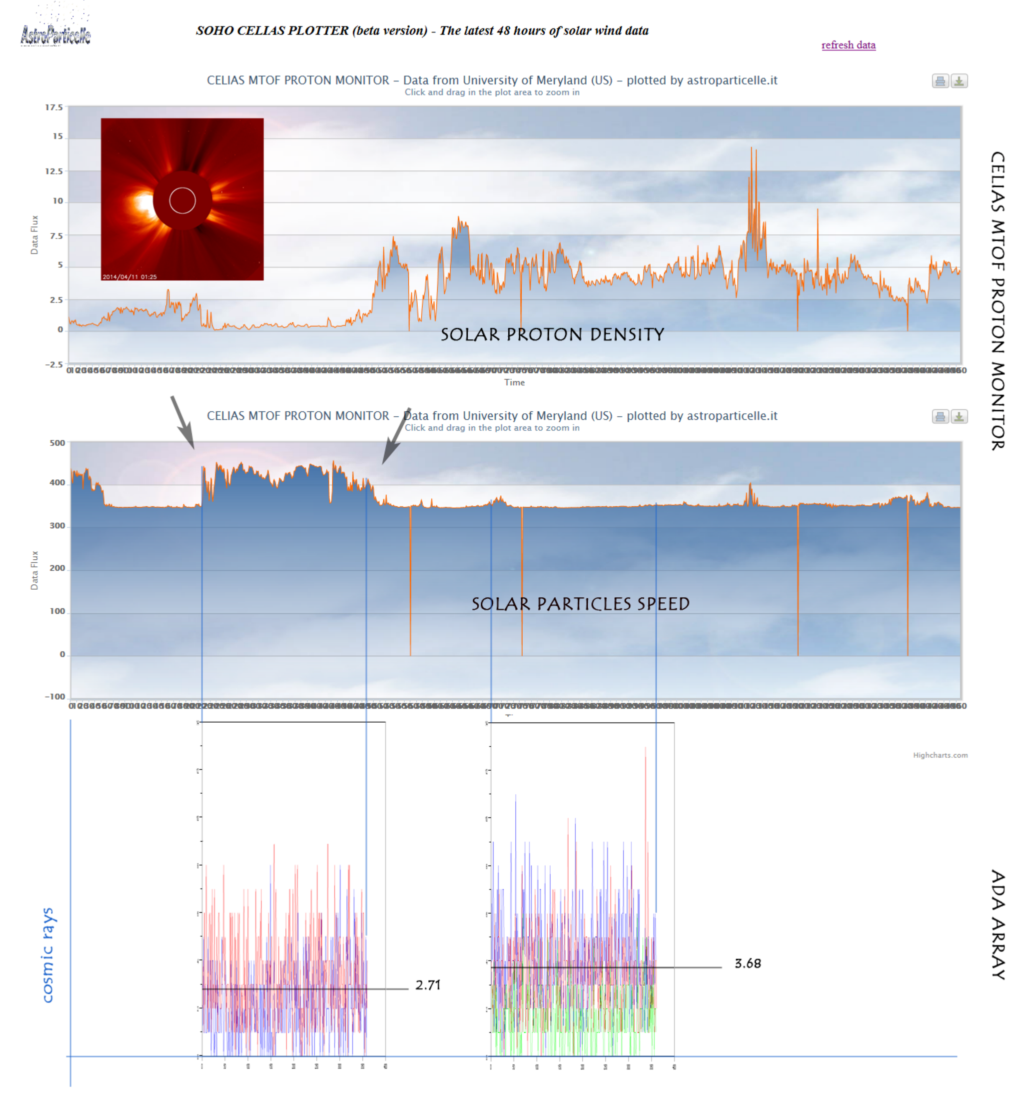


Figure 9 - Above, solar wind data, below ADA cosmic rays detected in the period of time considered. *(M. Arcani, R. Crippa, D. Liguori)*.

### The East-West effect

As shown at Asmara by Bruno Rossi in 1933, the flux of particles coming from the West is greater than that from the East [2].
For this measure several AMD5 from different locations have been used; from our latitudes (39-45 °N) it is very difficult to measure the ratio of the particles coming from the west or from the east even when recording data for a long time. The problem of long term data analysis is that it would be necessary to consider the atmospheric and solar parameters which could modulate the muon flux in the atmosphere thereby influencing the results. One of the most satisfactory results was obtained in a week. As far as the atmospheric values are concerned, it was assumed that in the course of a week the effects are negligible; the solar activity on the other hand has been kept under constant surveillance by monitoring the activities of Celias (Charge, Element, and Isotope Analysis System) on the spacecraft SOHO (http://umtof.umd.edu/pm/) and, for verification purposes, a mean of Celias data over the considered period was taken.

The comparison with the solar wind in the considered days does not suggest that it has influenced the detections. As can be seen from the graph of Figure 10, the prevalence from the west is not always confirmed, sometimes the values from the East exceed those from the West, so, in essence, there is not a unique indication.
At the end of the recordings we have: From EAST: 3.29 ± 0.03 From WEST: 3.32 ± 0.06. However taking the percentage of the average, a difference of 0.9% is obtained, with a predominance of particles coming from West.
Note that a measurement made with the same detector (AMD5) from the Teide Park (28° N at 2000 m) in Tenerife (Sp) showed instead a clear ratio of 21.52%.

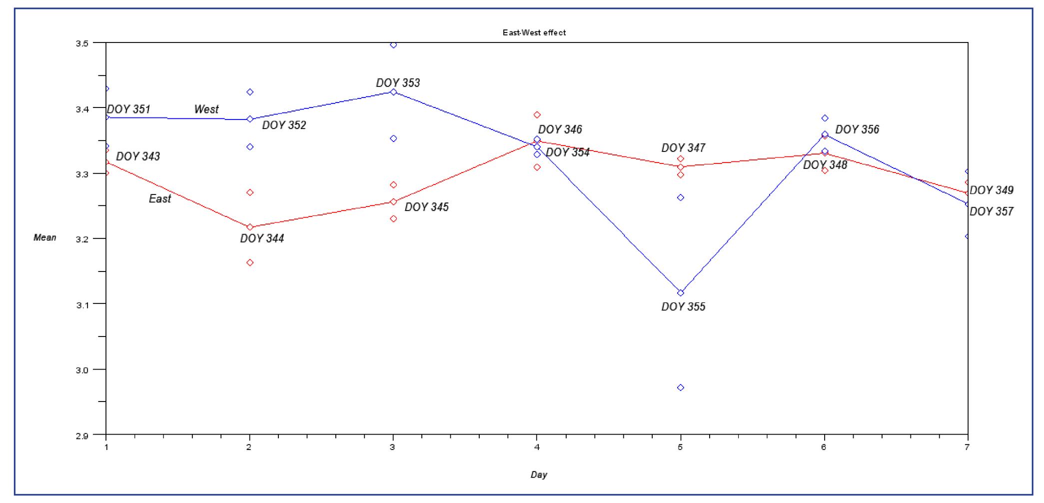


Figure 10 - Cosmic rays coming from West (blue line) and East (red line), AMD5 45.7°N 8.55E @ 350 m *(M. Arcani)*.

### Influence of atmospheric and Heliophysics parameters on cosmic ray flux

The atmospheric parameters, such as temperature, pressure and air humidity may modify the development of particle showers and consequently the detected signal. The graph in Figure 11 shows the data relating to: the average trend of cosmic ray counts, the temperature, the pressure and the humidity detected for all months in the year 2014.

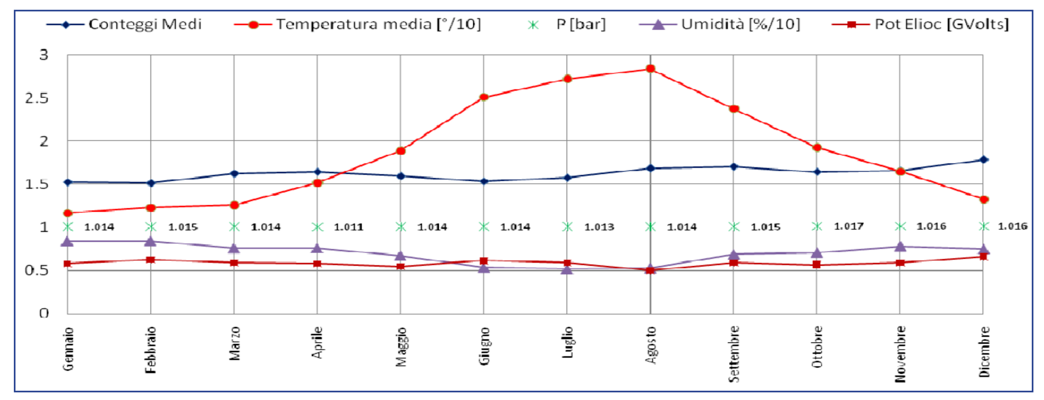


Figure 11 - Comparison among the c.r. count trend and the atmospheric parameters trend in the 12 months of 2014 *(D. Liguori, P. Barone)*.

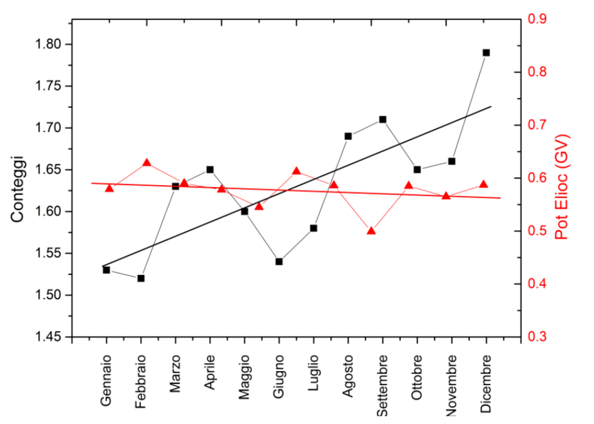


Figure 12 - Comparison among the count trend and the heliocentric potential [3] trend in the 12 months of 2014 *(D.Liguori, P. Barone)*.

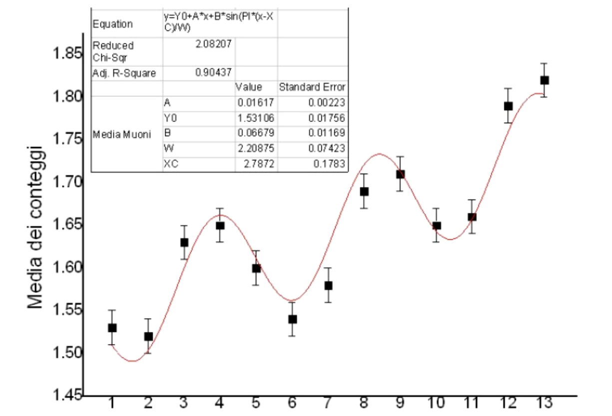


Figure 13 - Mean of monthly trends for c.r. counts throughout the year 2014. The data relative to January 2015 as month number 13 has been also added. *(D. Liguori, P. Barone)*.

The graph in Figure 12 shows the trend of the mean counts of cosmic rays and the heliocentric potential [3] for all the months of the year 2014. Note the oscillatory seasonal effect. In order to give an explanation, at least a qualitative explanation, for the trend in the graph of Figure 11 we have to remember the link between solar activity and the change in the flux of cosmic rays arriving on Earth. Making graphs of the cosmic ray flux - month by month throughout 2014 - in relation to solar activity synthesized in the value of the heliocentric potential, one can see that (see Figure 12) an average increase in solar activity corresponds to an average drop in the cosmic ray flux detected and vice versa. The oscillatory behaviour of the cosmic ray flux was fitted with the equation curve:

$$y = y_0 + Ax + B\sin\left[\frac{\pi(x - x_c)}{w}\right]$$

with a value equal to 0.9 for the Adjusted R2 (see Figure 13). It may be noted that this oscillation has a period of about four and a half months (2w) and an increase in slope (fitted from the straight line of equation y = y0 + Ax with A equal to about 0.02) justifiable, at least qualitatively, with the mean trend of the slight decrease in the variation of the solar activity, highlighted by the heliocentric potential trend (see trend lines) shown in figure 12.

## CONCLUSIONS

Taking into account the simplicity of the instruments used and the small sensitive surface of the detectors, the results obtained - in more than two years of running - look incredibly good. So we think that the ADA project and its particle detectors AMD5 are a great tool that should be present in school laboratories and in astronomical observatories, both to project young students in the world of astroparticle physics and to ensure the disclosure of a scientific discipline as yet unknown at popular level.

References:

[1] D. Heck et al., Report FZKA 6019 (1998), Forschungszentrum Karlsruhe; http://web.ikp.kit.edu/corsika/physics_description/corsika_phys.html
[2] Alessandro De Angelis, L'enigma dei raggi cosmici. Le più grandi energie dell'universo, Springer Verlag 2011.
[3] http://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/heliocentric/