The EEE Project: an extended network of muon telescopes for the study of cosmic rays

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Frontier Detectors for Frontier Physics

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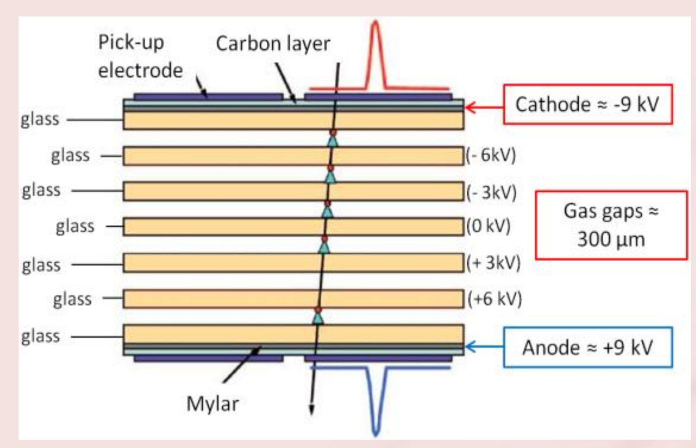
The EEE (Extreme Energy Event) Project [1] is an experiment to study high energy extensive air showers (EAS) over a very large area, using an array of muon telescopes, based on position-sensitive Multigap Resistive Plate Chambers (MRPCs) and distributed over a total area of 3 x 10^5 km^2. The stations are installed inside Italian high school buildings, INFN sections and at CERN, and most of them have been independently taking data since several years. Young students are directly involved in assembling and monitoring the telescopes, with the aim to introduce them to advanced physic research [2]. A new combined run (RUN 1) has started in February 2015, with more than 30 telescopes taking data simultaneously and it has collected about 4 x 10^9 reconstructed events.

The EEE Telescope

Three MRPCs for particle traking

Single MRPC :

- 6 gas gaps: 2 vetronite panels with 5 floating glass plates, 300μm spaced
- ~10^{13}Ωcm³ volume resistivity - Licron resistive paint on the outside glass plate s
- $C_2H_2F_4$(98%) and SF_6 (2%) continuously fluxed by (3l/h)
- 24 readout copper strips as electrodes, pitch of 3.2 cm
- HV up to 20 kV (avalanche mode) supplied by 2 DC/DC converters



When a charged particle traverses the gas it creates, along its path, ion-electron pairs which are amplified in the Townsend avalanche process. The glass plates terminates the avalanches development in each gaps. The induced signals, sum of the electric charges in all of the gaps, are picked up by the copper strips on both vetronite panels [3] [4].

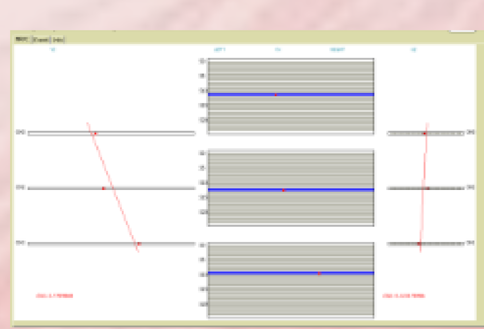
The EEE Station

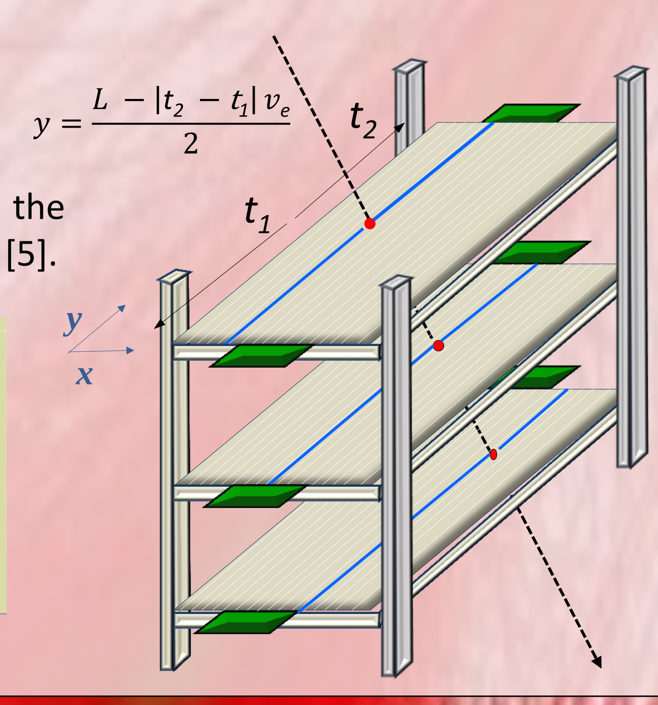
- 6 FRONT-END BOARDS (FEAs) with 24 channels to pick up readout signals on the strips
- 2 MULTI-HITS TIME TO DIGITAL CONVERTERS (TDCs 128 + 64 channels) to reconstruct the particle impact point.
- TRIGGER CARD. A six-fold coincidence of both front-end cards of the three MRPCs generates the data acquisition Trigger.
- GPS UNIT gets the event time stamp (UTC time) to record and synchronize informations
- VME BRIDGE. DAQ connected to a PC via USB, controlled by LabView program
- VOLTAGE CONTROL SYSTEM (VCS) in the MRPCs DC/DC Converters and FEBs
- WEATHER STATION measures the temperature and the pressure inside and outside the telescopes building

Performance

The particle impact point is reconstructed by the hit strip (x) in one direction and by the difference of signal arrival times at the strip ends (y) measured by TDCs in the other direction [5].

- ✓ 100ps time resolution of the TDCs
- ✓ ~ 7 mm spatial resolution along both coordinates
- ✓ > 95% MRPC efficiency at the operating voltage of 18 kV
- ✓ ~ 100 ns GPS time resolution





RUN 1

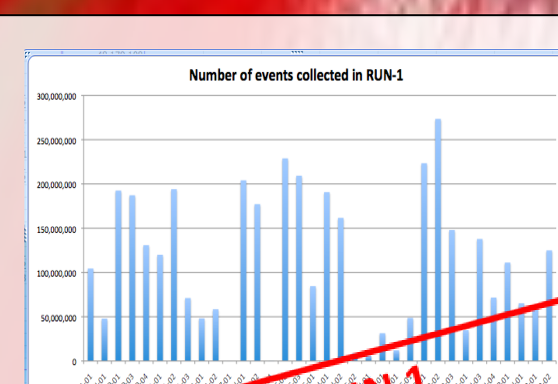
45 days Run

23 February 2015 – 30 April 2015

For the first time a large number of telescopes have been contemporaneously taking data

- 35 telescopes
- 20 –40 Hz muon rate in each one.
- Data are transferred and stored to CNAF where events and tracks are analyzed
- Tracking procedure: "Good" events are selected → Cuts χ^2 < 10 , length , ToF
- Particle polar and azimuthal angles of the event are reconstructed

4 x 10^9 GOOD TRACKS have been collected

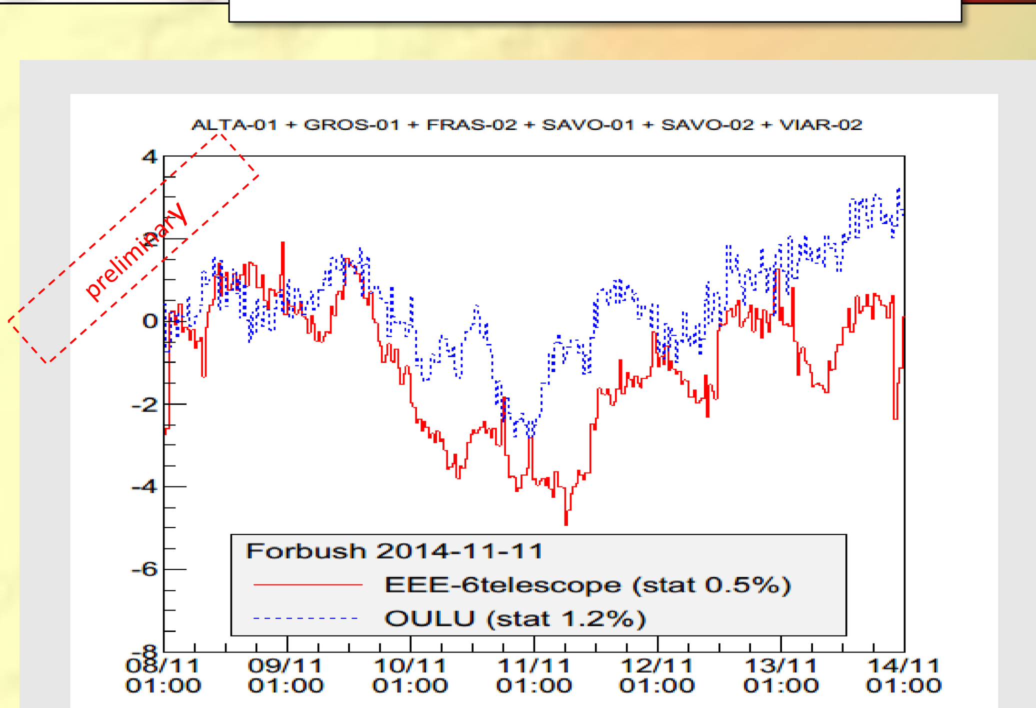


RUN 1

See also poster by F. Noferini

Since the beginning of their operation the single EEE telescopes and their clusters in a same metropolitan area have been able to produce significant scientific outcomes. **At the present, data transfer to CNAF**, allowing a direct way to store and access all data, **makes it easier to analyse contemporaneously all the EEE network results**

Study of cosmic rays flux



Muon rates averaged on 6 EEE telescopes (red) , Neutron rates from the Oulu station, Finland (blu), during the FD associated to solar flare on the date 7-11-2014

Local value of temperature and pressure influence both cosmic ray flux at the sea level and gas density in the MRPC. Therefore muon rates $R_{measured}$ in each telescope need to be normalized to the effctive rate R_{eff} by means of a barometric coefficient β evaluated in each different environment.

$$R_{eff} = (1 - \beta\Delta p)\, R_{measured}$$

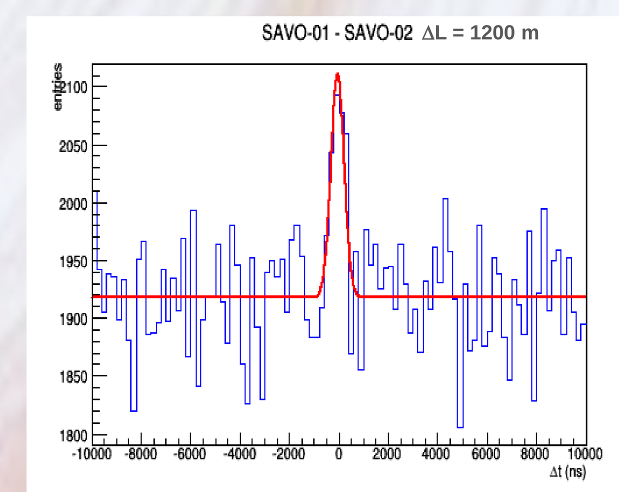
Δp is the variation of atmospheric pressure with respect to the average value

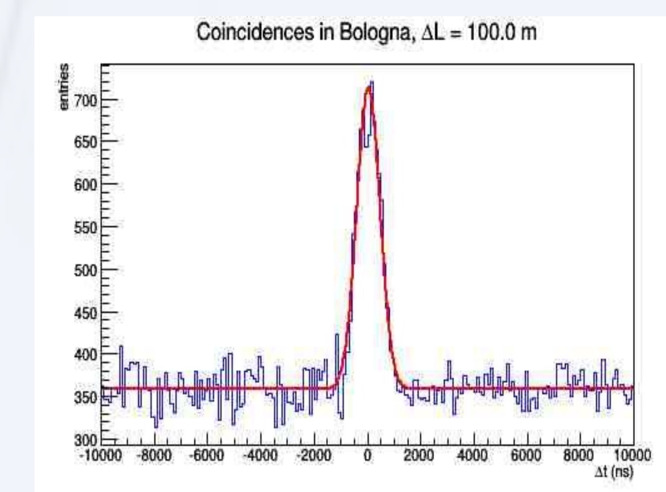
Forbush decreases (FDs) are rapid variations of the cosmic rays flux that take place over the course of a few hours, and are associated to solar phenomena as CME and solar flares. FDs have been already observed by single EEE telescopes [8] [9], and also by different telescopes contemporaneously. Adding up data set from different station allows to reduce the *Signal/Noise* value.

Search for Coincidences

Extensive Atmospheric Shower (EAS) Detection

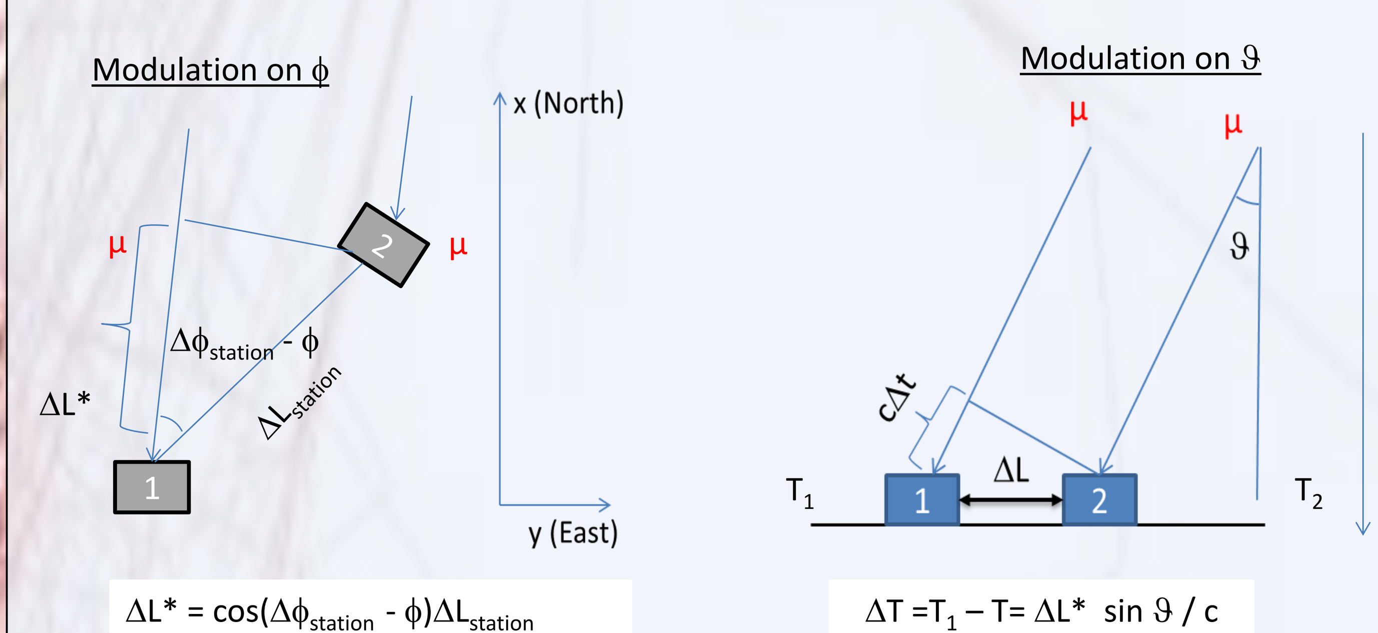
The telescopes relative distances are ranging from a few hundred meters for clusters of 2, 3 and 4 telescopes in the same city, to more than 1000 km for the farthest stations. Muons from the same EAS are detected by different stations [6].





Distance corrections

Arrival time difference of particles in the same EAS depend on their own angular position from the axis shower and on the axis shower direction. Therefore time intervals for checking out muon coincidences are correlated to the distance between the different stations [7].



$$\Delta T = \cos(\Delta\phi_{station} - \phi)\, \Delta L_{station} \sin\vartheta / c$$

$\Delta L_{station}$. Relative distance between Telescopes

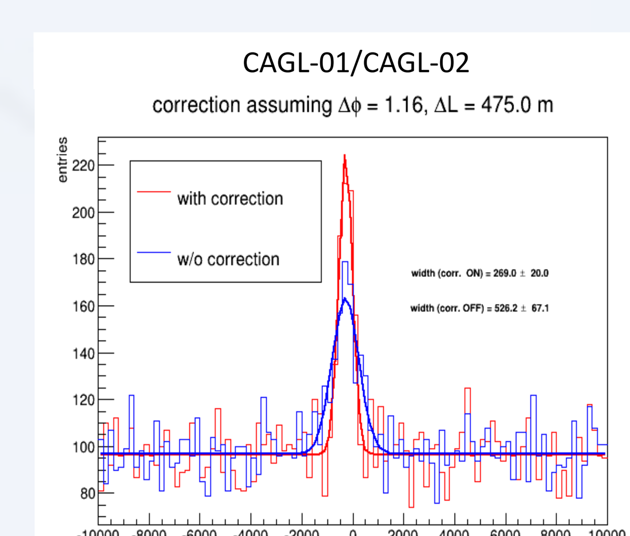
ϑ. Polar angle of the EAS axis

ϕ. Relative azimuth angle between telescopes and the North

$\Delta\phi_{station}$. Relative azimuth angle between stations

GPS resolution $\sigma_{GPS} \times \sqrt{2}$ ~ 140 ns

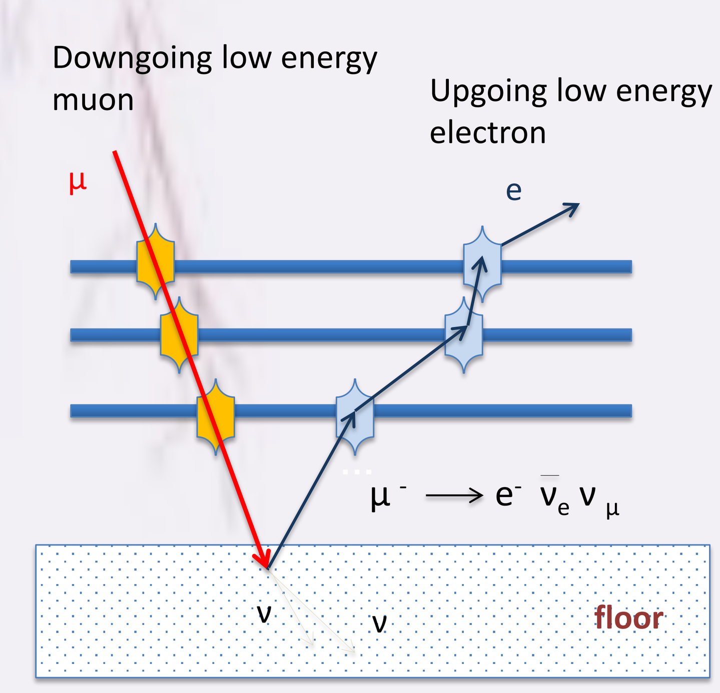
Distance correction reduces background due to accidental coincidences (S/N and σ) These corrections are important for High Energy EAS research among faraway telescopes (>2km) since coincidences peak width is proportional to ΔL.



and beyond…

Upgoing tracks

Most of them might be electrons from μ-Decay…



Some open questions

How to evaluate the telescopes time exposure and acceptance? Could be possible to search local anisotropy in primary cosmic ray through the EEE network?

References

[1] Centro Fermi web site: http://www.centrofermi.it/eee.

[2] M. Abbrescia et al, Nucl. Instrum. Meth.A 593 (2008) 263 268.

[3] A. Zichichi, Progetto "La Scienza nelle Scuole" - EEE: Extreme Energy Events (Societa Italiana di Fisica, Bologna, 2004) 2nd edition (2005), 3rd edition (2012).

[4] A. Akindinov et al., Nucl. Instrum. Methods Phys. Res. A 456, 16 (2000)

[5] M. Abbrescia et al. (EEE Collaboration), Nucl. Instrum. and Meth A 588(2008) 211

[6] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2013) 128, 148.

[7] M. Abbrescia et al. (EEE Collaboration), Nuovo Cimento 125(2010) 243

[8] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2011) 126,61.

[9] M. Abbrescia et al. (EEECollaboration), Eur. Phys. J. Plus (2013) 128, 62.