Extreme Energy Events Project (EEE)

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Introduction

The main scientific goal of the EEE project [1,2] is the **detection of extensive air showers (EAS)** produced by the impact of primary cosmic rays of **energy greater than 10^{14}eV** on the Earth's atmosphere. Devised as a joint scientific and educational initiative by Centro Fermi in collaboration with INFN, CERN and MIUR (the Italian Ministry of Education, University and Research), the EEE project is strongly contributing at **introducing a large number of high-school students to the methods of particle and astroparticle physics**: the school buildings have been chosen as detector sites, and teams of students are directly involved in the construction, installation, operation and data analysis of the experiment, under the supervision of researchers from scientific institutions.

EEE Network

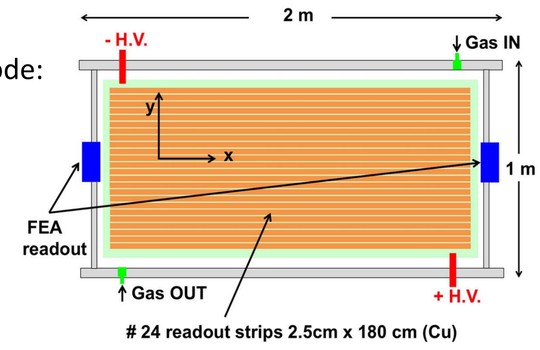
- **2008**, 7 pilot sites;
- **2016**, 52 operative sites (**47 in high schools** and 5 in Labs) across **area larger than 5×10^5 km^2**:
  - Single stations;
  - City clusters (2-4 telescopes):
    - Coincidences studies;
    - Relative distances **from a few hundred meters to more than 1000 m.**

Distribution of telescopes over Italian territory

Detector & Performances

EEE telescope [3]:

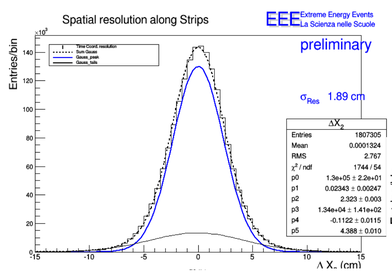
- **3 MRPC chambers** (160×80 cm^2) in avalanche mode:
  - **High efficiency, reconstruction tracks muons with good angular and spatial resolution;**
  - 24 strips (3.2 cm pitch and 168 cm of length) read out at front-end cards;
  - Gas mixture (98% $C_2F_4H_2$, 2% SF_6);
  - **Coordinates:**
    - Y → fired strip;
    - X → signal time difference on strip.
  - 24 OR signals of strips used in coincidence trigger logic;
  - 144 LVDS signals in 2 TDCs (100 ps resolution).
- **GPS receiver:**
  - Reset TDC and telescopes **UTC synchronization (50 ns resolution).**



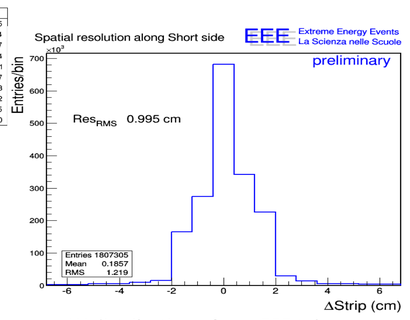
MRPC top view with its x-y reference system

Performance [4]:

- **Spatial resolution**:
  - **1.9 cm** along strips (X);
  - **1 cm** in short direction (Y).
- **Time resolution → 210 ps.**



ΔX distribution of one EEE telescope



ΔY distribution of one EEE telescope

CNAF, Coordinate RUN & Monitor

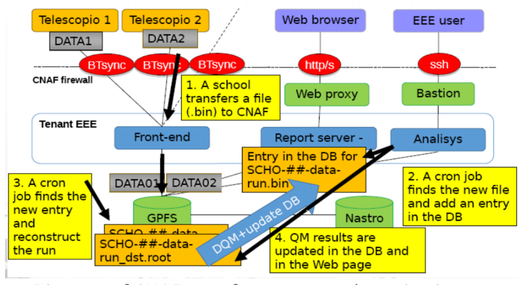
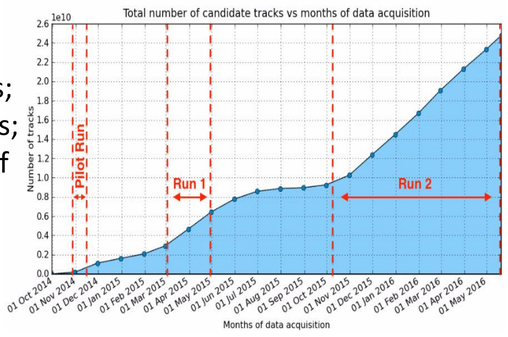


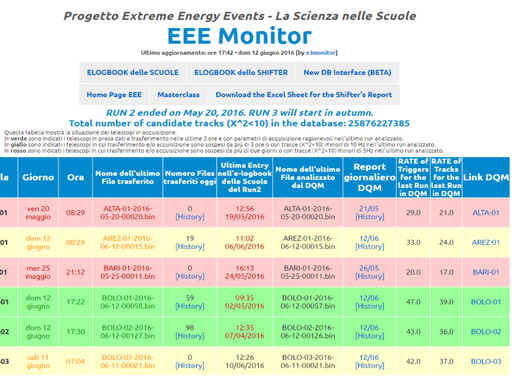
Diagram of CNAF transfer system and monitoring

- **Data transferred directly from single stations to CNAF servers and automatically reconstructed** since 2014 [5].

- **3 coordinated Run completed, 1 in planning:**
  - Pilot-Run (27/10-14/11/2014), 10^9 candidate tracks;
  - Run-01 (02/03-30/04/2015), 5×10^9 candidate tracks;
  - Run-02 (07/11/2015-20/05/2016), triple number of candidates tracks and 43 station participating;
  - **Run-03, start in September/October 2016, objective to double total statistic.**



Number of candidates traces from beginning of transfers to the CAF with highlighted periods of coordinated Run



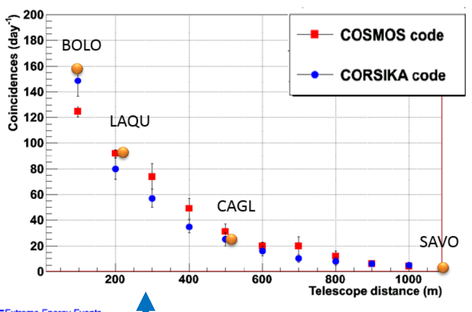
Scuola	Giorno	Ora	Nome dell'ultimo File trasferito	Numero Files trasferiti oggi	Ultima Entry nell'e-logbook delle Scuole del Run2	Nome dell'ultimo File analizzato dal DQM	Report giornaliero DQM	RATE of Triggers for the last Run in DQM	RATE of Tracks for the last Run in DQM	Link DQM
ALTA-01	ven 20 maggio	08:29	ALTA-01-2016-05-20-00020.bin	0 [History]	12:56 19/05/2016	ALTA-01-2016-05-20-00020.bin	21/05 [History]	29.0	21.0	ALTA-01
AREZ-01	dom 12 giugno	08:29	AREZ-01-2016-06-12-00015.bin	19 [History]	11:02 06/06/2016	AREZ-01-2016-06-12-00015.bin	12/06 [History]	33.0	24.0	AREZ-01
BARI-01	mer 25 maggio	21:12	BARI-01-2016-05-25-00011.bin	0 [History]	16:13 24/05/2016	BARI-01-2016-05-25-00011.bin	26/05 [History]	20.0	17.0	BARI-01
BOLO-01	dom 12 giugno	17:22	BOLO-01-2016-06-12-00058.bin	59 [History]	09:35 02/05/2016	BOLO-01-2016-06-12-00057.bin	12/06 [History]	47.0	39.0	BOLO-01
BOLO-02	dom 12 giugno	17:30	BOLO-02-2016-06-12-00127.bin	98 [History]	12:35 07/04/2016	BOLO-02-2016-06-12-00126.bin	12/06 [History]	43.0	36.0	BOLO-02
BOLO-03	sab 11 giugno	07:04	BOLO-03-2016-06-11-00021.bin	0 [History]	12:26 10/06/2016	BOLO-03-2016-06-11-00021.bin	12/06 [History]	42.0	37.0	BOLO-03

Web Page of EEE Monitor.

- **Comprehensive monitoring system**, in a web site [6]:
  - **easy to access and use for students;**
  - immediately check status of telescopes;
  - many link with analyzed data and didactical materials.

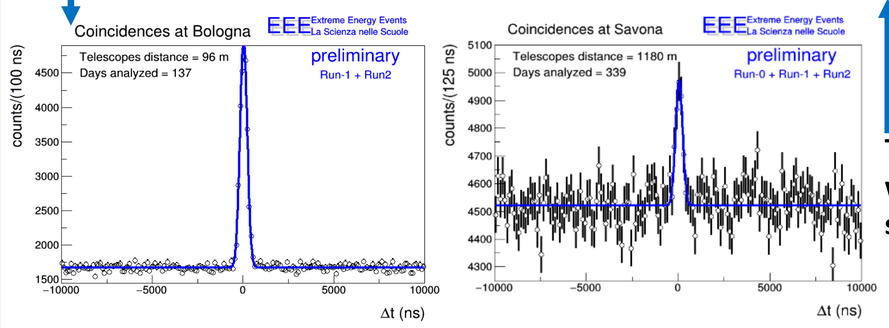
Study of coincidences between telescopes

- EAS particles arrival time difference for coincidences verification depend on stations distances [7];
  - angular position from the axis shower;
  - axis shower direction's angle.
- **Distance correction reduces accidental coincidences background** (S/N and σ).



Coincidence rates among telescopes compare with MC simulation.

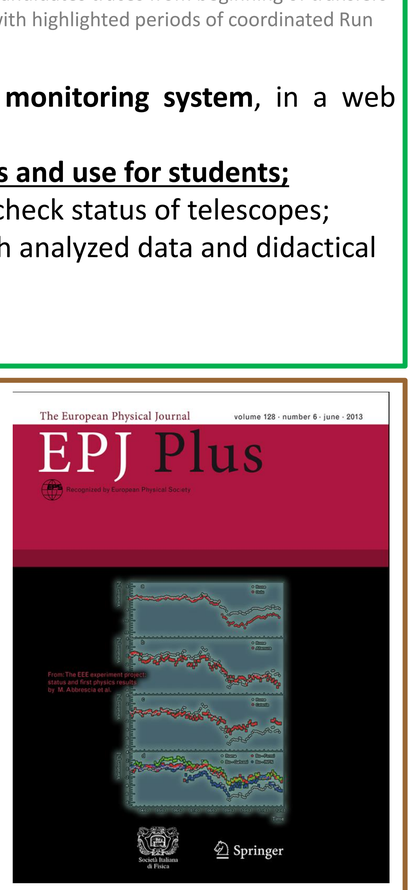
The results in agreement with Monte Carlo simulations [8].



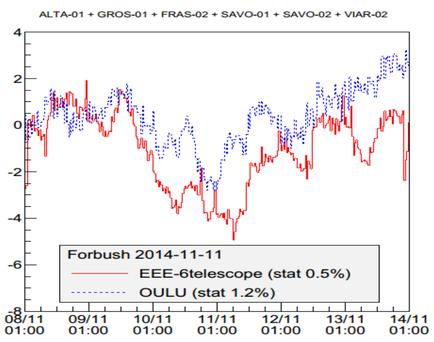
Observations of coincidences between stations: a) On left, telescope at 100 m in Bologna, one of nearest distances. B) On right, telescopes at 1200 m in Savona, actually farthest distances.

Observation of Forbush decrease

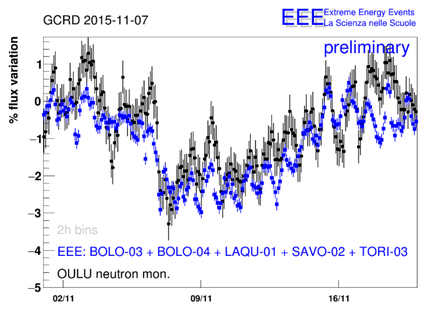
- **Forbush decrease**,
  - Transient variation of cosmic ray flux observed on Earth, caused by solar flares.
  - Observed by neutron monitor stations around world.
- **EEE Observations:**
  - **February 2011** [9], few stations;
  - **2012** [10], data published on EPJ Plus (and cover);
  - **2013-2016**, observations repeated with more stations.



EPJ Plus 2012 cover with results of EEE project in study of Forbush decrease



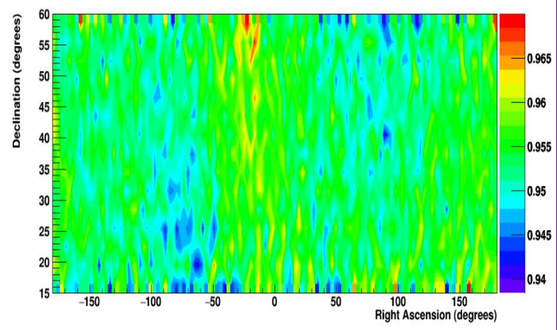
Two data comparison of Forbush decrease between EEE-Telescopes and OULU Neutron Monitor. In up-left, an events of 2014. In down-right, an events of 2015.



- Data selected and compared with neutron monitors of OULU (easy access to data), in Finland.
  - **Data of EEE network in agreement with neutron monitor data.**

Search of Anisotropy at sub-TeV scale

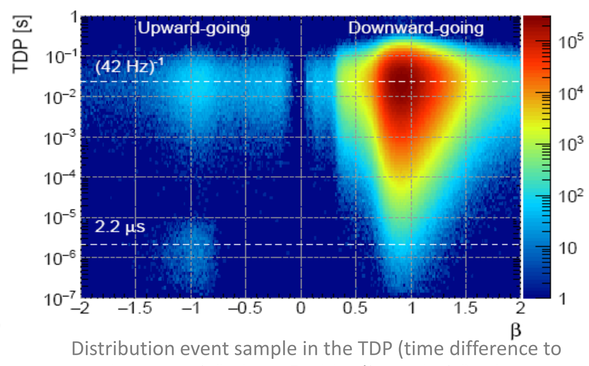
- Coordinates of muon track transformed:
  - from local (θ, φ, t) to equatorial (Right Ascension, Declination);
    - take into account Earth motion [11].
- Analyzed 10^9 events from 23 EEE sites:
  - **some evidence of small anisotropies (few 10^{-3}).**



Combined result from 5 EEE sites with some anisotropy

Muon decay in Up-going events

- 1.3×10^8 events with good track [12];
  - 2 populations with negative β (upward-going events) clearly identified:
    - **one is characterized by TDP of the order of μs.**
- **Identified muon decay in 0.005% of all events** (<6% of upgoing tracks).



Distribution event sample in the TDP (time difference to previous event)-β plane. Positive/(negative) β values correspond to downward/(upward)-going events.

Reference:

[1] Centro Fermi web site: http://www.centrofermi.it/eee.
[2] A. Zichichi, Progetto "La Scienza nelle Scuole" - EEE: Extreme Energy Events, SIF (2004)
[3] M. Abbrescia et al. (EEE Collaboration), JINST 7 (2012) P11011 .
[4] M. P. Panetta et al. (EEE Collaboration), RPC2016.
[5] F. Noferini et al. (EEE Collaboration), Nucl. Instrum. Meth. A 820 (2016) 329-300.
[6] https://www1.cnaf.infn.it/eee/monitor/
[7] M. Abbrescia et al. (EEE Collaboration), Nuovo Cimento 125 (2010) 243.
[8] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2014) 129, 166.
[9] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2011) 126, 61.
[10] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2013) 128, 62.
[11] M. Abbrescia et al. (EEE Collaboration), Eur. Phys. J. Plus (2015) 130, 187.
[12] M. Abbrescia et al. (EEE Collaboration), Nucl. Instrum. Meth. A 816 (2016) 142-148.

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