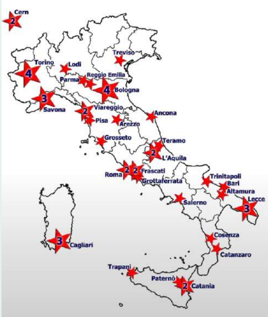
The Extreme Energy Events HECR array status and perspectives

Extreme Energy Events
Centro Studi e Ricerche "E. Fermi" (Roma)
Istituto Nazionale di Fisica Nucleare (To/Al/Bs)
University of Bari, Pisa, Siena, Torino, Cagliari
Bologna, Roma Tor Vergata, Salerno
CNAF (Bologna)
ICSC World Laboratory (Geneva)
CERN (Geneva)
JINR (Dubna)

European Cosmic Ray Symposium, 2016, September 5-9, Turin (Italy)

The Experiment

The Extreme Energy Events is a project started in 2004

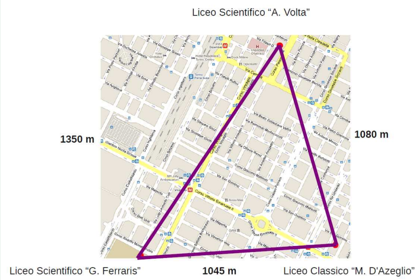


for studying
Low and High ECR
and related phenomena
by measuring
muons and electrons
in showers
with a broad and sparse
telescope array

keeping also educational and outreach parallel mission

EEE Scientific program - short/long baseline correlations

Telescopes are arranged in clusters with typical distances 100 m to 6 km.
Each cluster size shows different energy thresholds:
i.e. 3 station - 1 km clusters
$E_{th} \sim 10^{17}$ eV.
Clusters are 30 - 1000 km far away.



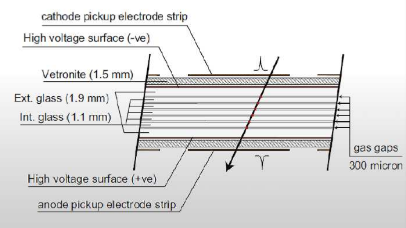
+ solar activity survey, effects on climate etc.

The Telescopes

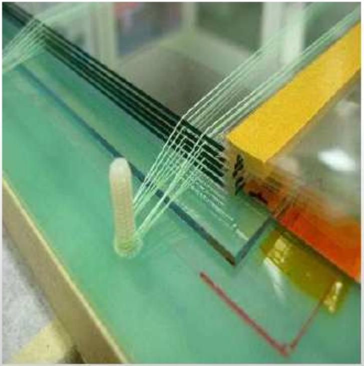
The Multigap Resistive Plate Chambers

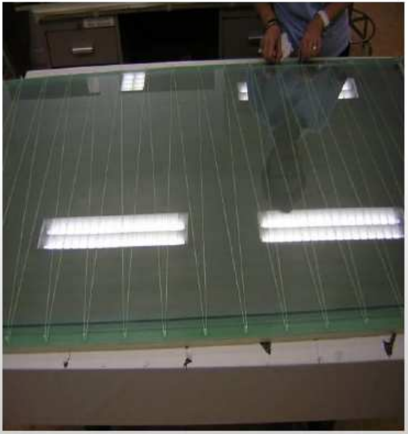
EEE chamber is an extended version of ALICE TimeOfFlight modules

- 6 gas gaps: 2 glass plates with their external surfaces painted with resistive paint; 5 floating glass plates (spaced by 300 μm)
- $C_2H_2F_4$ (98%) and SF_6 (2%) continuously fluxed by (3l/h)



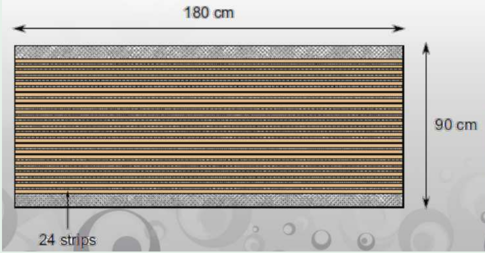
The Fishing line is used as a simple spacer (300 μm) between glasses





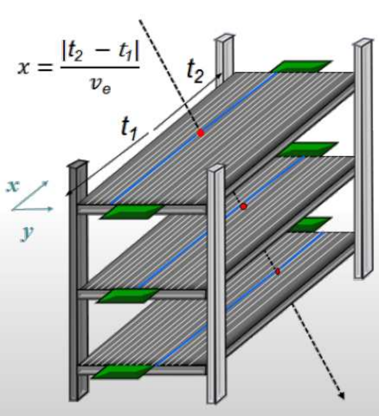
The avalanche detection and pitch

- 24 readout copper strips mounted on both sides of the stack of glass plates (i.e. cathode and anode read-out strips) ⇒ a differential signal is obtained by reading out both anode and cathode
- Strip pitch of 3.2 cm
- HV up to 20 kV (avalanche mode) supplied by 2 DC/DC converters

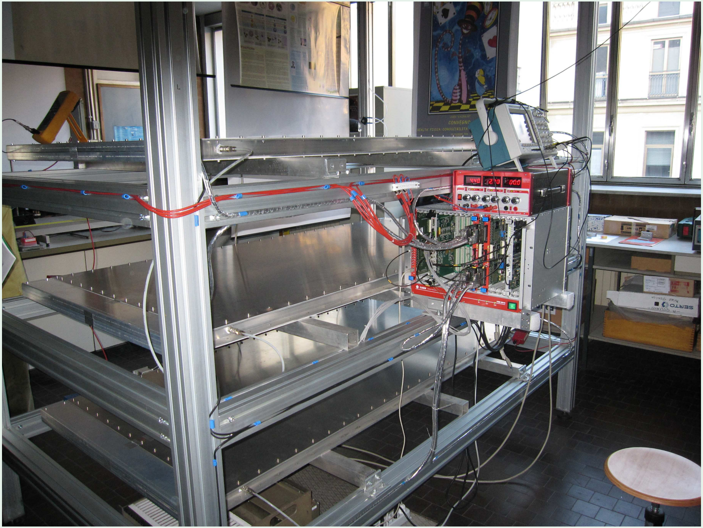


The Telescope

- Each telescope: 3 MRPC modules, 160 x 80 cm
- 6 Fast amplifier/discriminator NINO ASIC
- GPS
- VME-based data acquisition
  2 Multi-hit TDCs
  (100 ps resolution)
- Weather Station



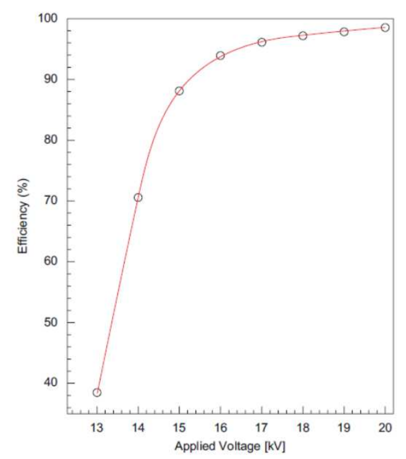
The telescope equipment



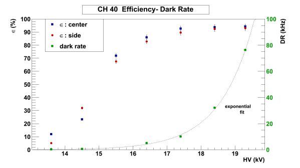
The Station Performances

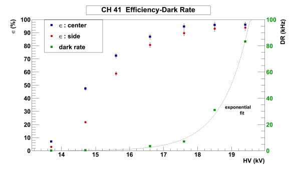
Chamber Efficiencies and Dark Count

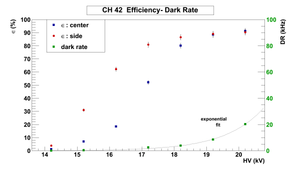
Test beam @ CERN PS



@ schools with CRs





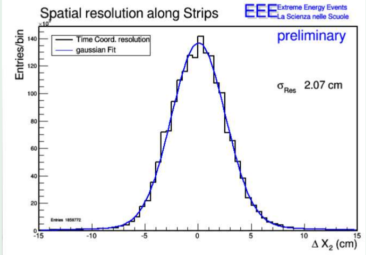


Spatial resolution along strip direction

$$\Delta X = \frac{X_{BOT}+X_{TOP}}{2} - X_{MID} \Rightarrow \sigma_X = \sqrt{\frac{2}{3}}\sigma \sim 2.1 \text{ cm}$$

Several factors affects X resolution:

- Chambers alignment
- Multiple scattering
- Strip calibration
- Propagation of signal along strips
- TDC resolution

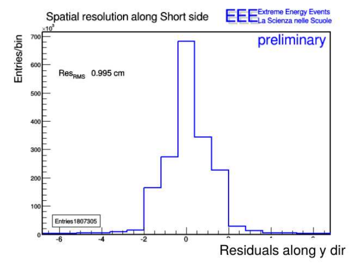


Spatial resolution across strip direction

$$\Delta Y = \frac{Y_{BOT}+Y_{TOP}}{2} - Y_{MID} \Rightarrow \sigma_Y = \sqrt{\frac{2}{3}}\sigma \sim 1 \text{ cm}$$

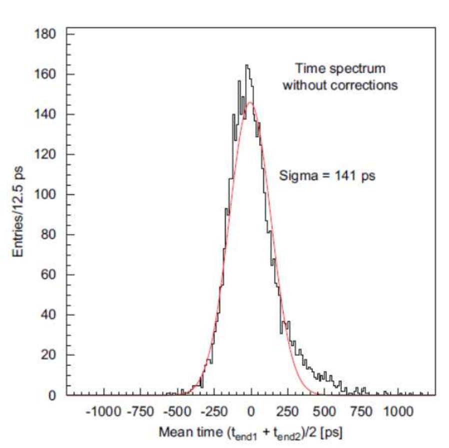
which is compatible with expected resolution

- $\sigma_Y = \frac{3.2}{\sqrt{12}} \sim 0.9$ cm



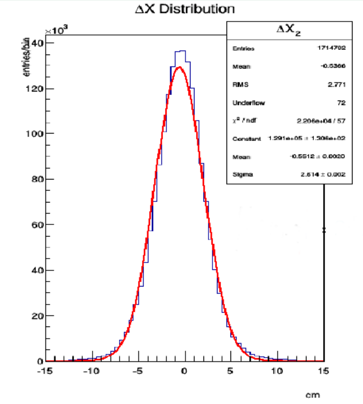
Time Resolution

@ CERN Test Beam



$\sigma_X \sim 141$ ps

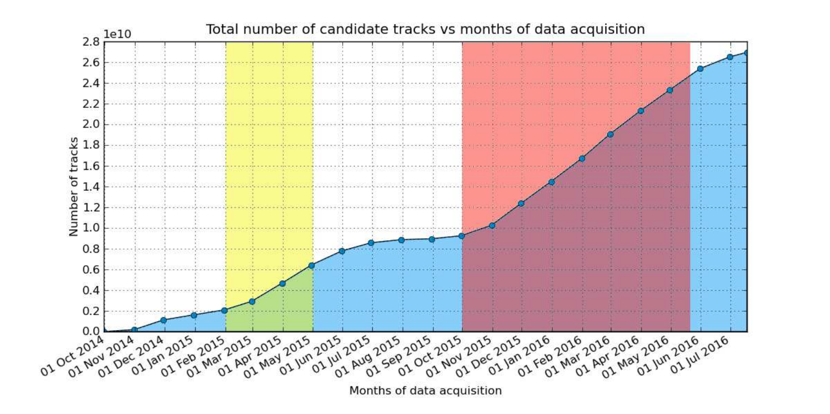
with Cosmic Rays



$\frac{2}{3}\sigma_X \sim 210$ ps

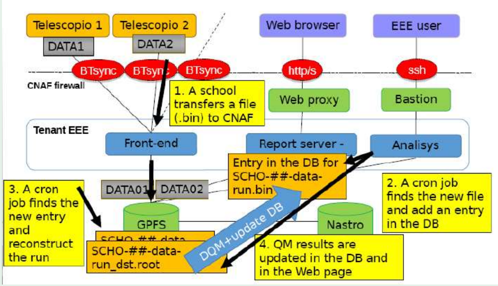
The Data Taking, Concentration, Reconstruction Philosophy

Data Taking and Coordinated Runs



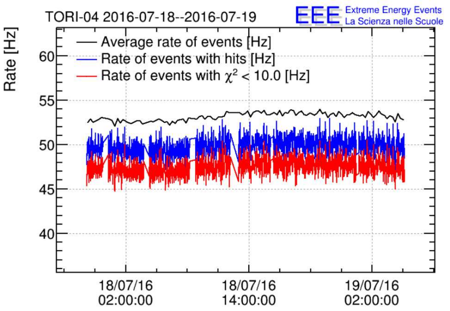
Data Transfer and automatic reconstruction @ CNAF

- Data are stored at the INFN-CNAF computer centre of Bologna
- A complex software architecture has been set-up to reconstruct the data and provide quasi-online (few hours) Data Quality checks on the web for monitoring purposes.



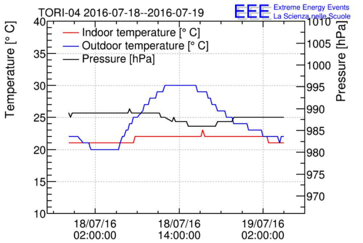
Data Quality Monitor

Rate Monitor



Daily and Run by Run based trending fluxes are provided in a few hours and published online

Environment

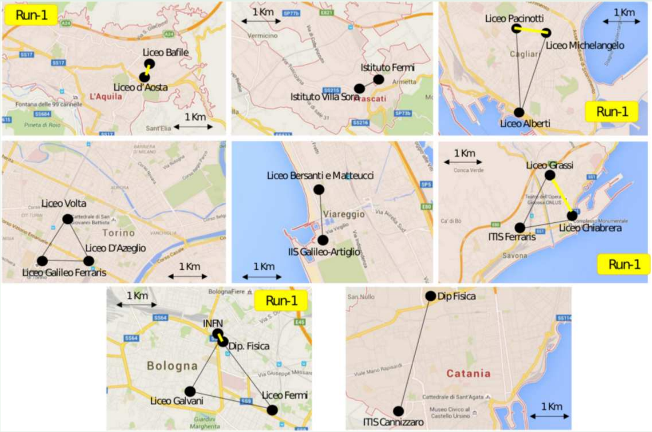


Pressure, Temperature and Humidity Data are also collected and made available for corrections and analysis.

Analysis and first results

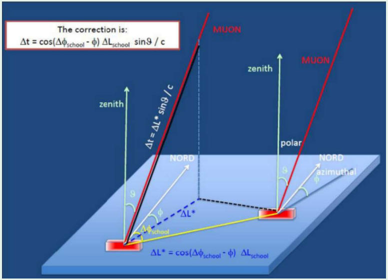
Coincidences and showers

Available Clusters during RUN-2



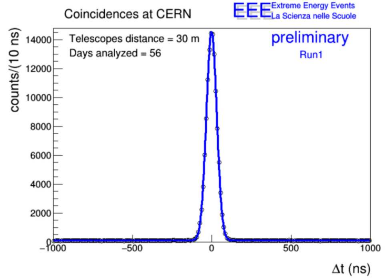
The Path corrections and coincidences

Tracks Angular correction



Tracks time are corrected by path differences

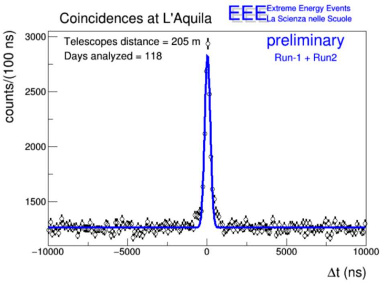
30 m double coincidences



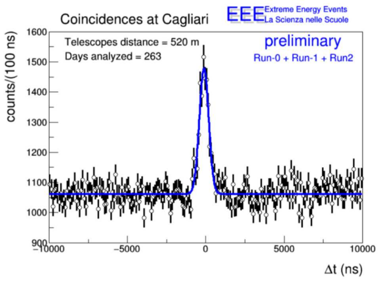
The EEE closest telescope pair at CERN

The Coincidences with increasing cluster size

205 m double coincidences



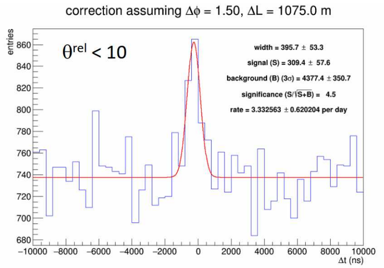
520 m double coincidences



The Coincidences with increasing cluster size

1.075 km double coincidences

at TURIN



MC vs data comparison

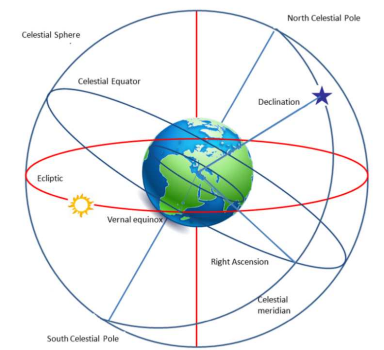
Preliminary corrected coincidences rates agree with MC expectations (COSMOS and CORSIKA)

Analysis and first results

Anisotropies at subTev scale

$\Rightarrow$ (single station analysis)

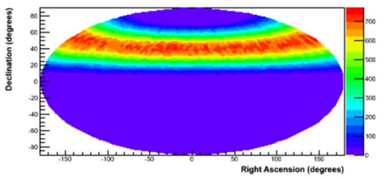
Near Universe CR Anisotropies



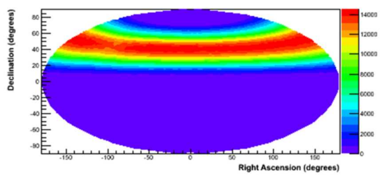
In the near Universe, anisotropies at 10^{-3}–10^{-5} scales for TeV scale CR were measured.
They were expected because of local non-uniformity of intergalactic magnetic fields (Compton getting effect due to e.g. Earth rotation around the Sun).

Shuffling corrections and first Aitoff maps

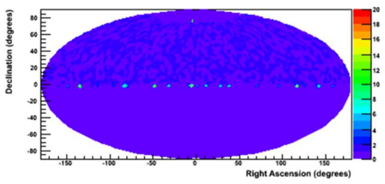
RAW DATA



SHUFFLE CORRECTIONS



Corrected Map



equatorial dots are border effects

Shuffling statistical approach was used to correct for time exposure and acceptance. No anisotropies observed at the level of $5{\cdot}10^{-3}$-10^{-2} scale.

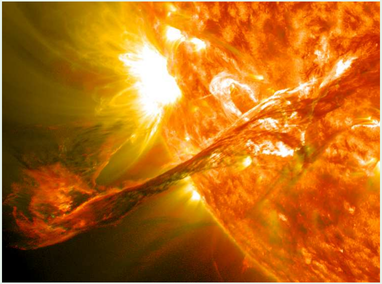
Analysis and first results

Upward particle flux
… understanding the feasibility of a measurement upward going ν

Analysis and first results

CR flux modulation

Forbush decreases and sun-related phenomena



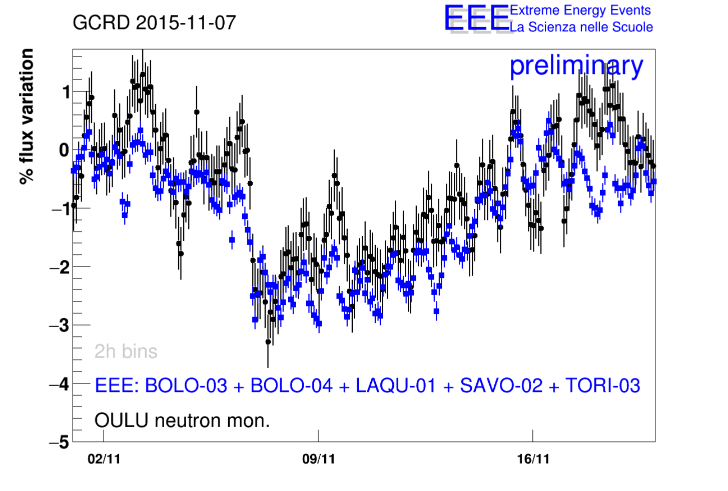
Forbush decreases are prompt CR flux decrease correlated to CME and Flares on Sun.

Flares are prompt e.m. flashes at $\sim 10^{25}$ J ($P_s un \sim 10^{26}$ W).

Coronal Mass Ejections are proton burst at $\sim 10^{23-24}$ J with speed 20-2000 km/s.

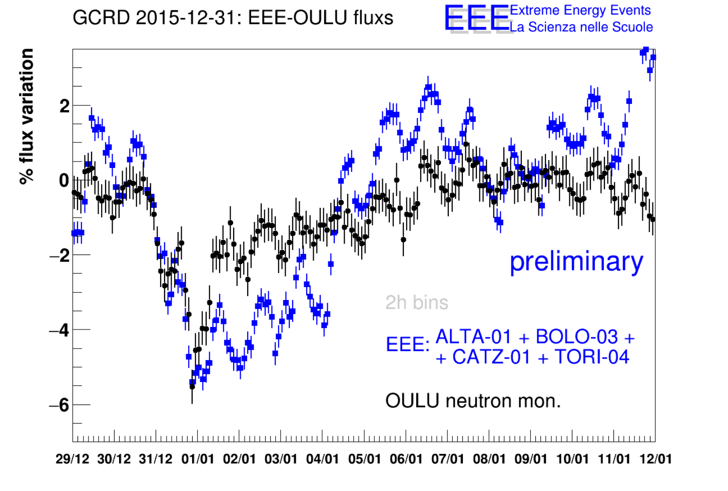
A complete understanding of both Flares, CME and Forbush is not yet available.

Forbush 2015-11
very good correlations with Neutron Monitors



Forbush 2015-12

low correlations with Neutron Monitors and two-step recovery mechanisms



- Pressure, Temperature corrections have to be deeply studied in order to perform a robust correction to the non-CR realted modulation effects
- Latitude and Longitude dependance studies are possible also with the EEE detectors (10 degrees in lat and long coverage)
- crossing the data with NM net is on the way
- ...
- after stabilizing the telescopes, long term studies on solar cycle survey are feasible.

Summary and Conclusions

The Educational and Outreach activities

- Telescopes are built at CERN
- by students and teachers
- installed in high schools
- monitored by students
- $>$ 500 students involved
- ...growing

- Masterclasses
- Lectures
- Trainings on detectors
- Analysis
- Schools
- Events

Conclusions

- EEE is a wide tracking telescope array
    - 52 telescope already working
    - $>$ 25 in construction
- high time resolution
- tracking capabilities
- 10 degrees in latitude and longitude coverage
- suitable both for studies at energies below and above the knee
- multipurpose array
    - HECR
    - CR flux modulation
    - local anisotropies (with conincences also higher energies available)
    - studying the feasibily of upward flux identification
- Environmental Studies
- $+$ educational purposes

> 2015 Articles

- EEE coll.: Looking at the sub-TeV sky by cosmic muons detected in the EEE MRPC telescopes"
  - EPJ-Plus (2015), 130:187
- EEE coll.: A study on upward going particles with the Extreme Energy Events telescopes
  - Nucl. Instr. and Meth. A 816 (2016) 142:148
- ... and preparing
- "The EEE Telescope performances"
- "An extended study of subTeV anisotropies with the EEE array"
- "A study of multistation coincidences at the km scale with the EEE array"
- "A Forbush decrease survey with the EEE telescopes"

Backup

EEE Scientific program - single station

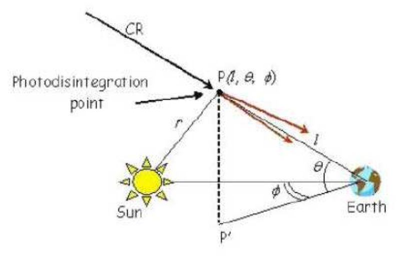
- Anisotropies (subTeV)
- Upward particle flux (mainly background)
- Rare events
  - high multiplicity
  - non random events
- long term solar activity correlation
- prompt solar events
- effects on atmosphere and climate

EEE Scientific program - long baseline correlations

Search for rare correlations due to:

- primaries photodisintegration nearby the Sun
- GZK-like effect
- interaction with interstellar medium
- ....
- possible astronomy? to be investigated

$\Rightarrow \geq 2$ high energy correlated secondaries



EEE Telescope distributions

The array is regularly extended:

- Since 2004 Pilot Phase with 7 telescopes in Lecce, Bologna, Cagliari, Catania, Frascati, L'Aquila, Torino
- At present 52 telescopes arranged both in clusters and single station, installed in High Schools (47), at CERN (2) and inside INFN sections (3)
- ... growing

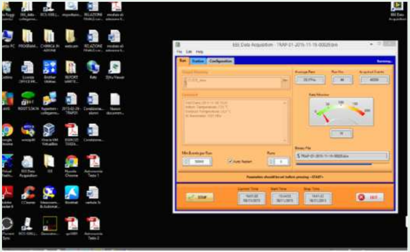
The Requirements and the solutions to address these topics

- Extended array ($>10^5$ km^2)
- Telescope clusters with variable geometry
- Long term operation (survey physics)
- High efficiency (rare events)
- High time resolution (Upward-Downward)
- Tracking capabilities on secondaries
- reasonable costs

$\Rightarrow$ Multigap Resistive Plate Chambers

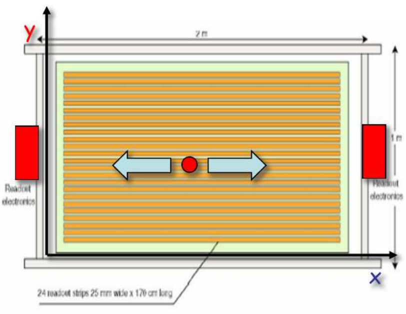
Stations are far away, thus remote control is fundamental

- HV-LV systems
- DAQ
- Weather station
- Data Transfer
- Gas system



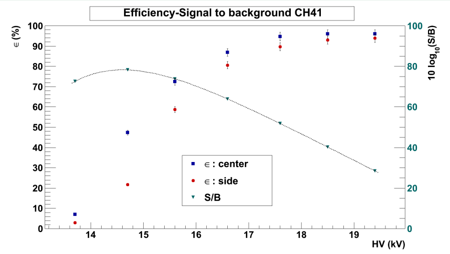
Each module provides a two-dimensional position information with efficiency close to 100% and a good spatial resolution.

- x coordinate: difference of signal arrival times at the strip ends measured by TDCs
- y coordinate: # of fired strip or weighted average of strip cluster



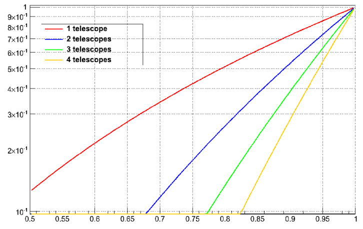
Chamber Signal/Background and Station efficiency

S/B



At plateau the S/B is ∼ 5 orders of magnitude

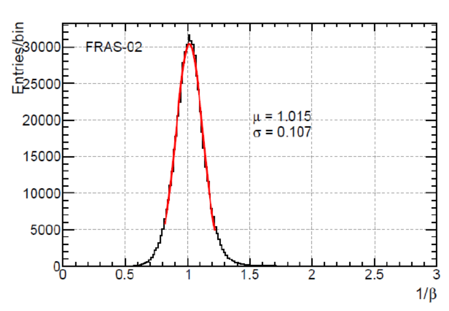
Telescope Cluster Efficiency



High efficiency is fundamental for clusters total efficiency if looking to ∼ few events/years

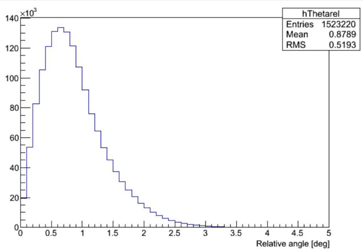
Angular and speed resolution

$1/\beta$ distribution



Slow muons and electrons tails can be tagged with χ^2 (next slides)

Tracks Angular residuals



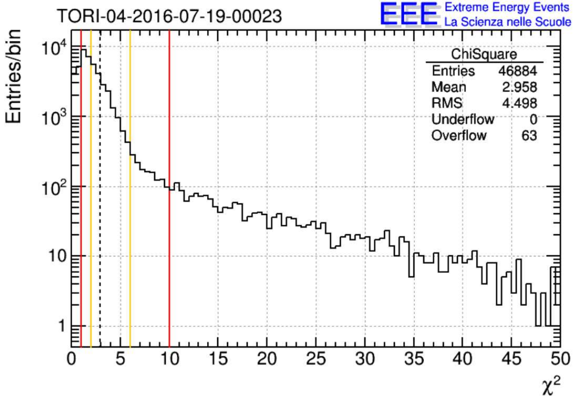
Geometrical simulation: evaluation of the relative angle between a simulated track and the track reconstructed with the telescope.

Data Taking and Coordinated Runs

The main challenge in coordinated Data Taking is related to the sparse and far away geometry of the array (up to 1000 km of distance)

- **Pilot-run**: first simultaneous acquisition of half (23) of the EEE telescopes.
  - Nearly 1 billion events i.e. muon tracks collected in the period 27 October-14 November 2014
- **Run-1**: 35 EEE telescopes took part in the data taking.
  - More than 5 billion events i.e. muon tracks collected in about three months (2 February-30 April 2015)
- **Run-2**: $\sim$40 EEE telescopes in acquisition from the end of October 2015 till mid May 2016.
  - More than 15 billion events i.e. muon tracks collected.

Data Quality Monitor



Data Quality Monitor

PLOT	ALARM	STATUS	OUTPUT	LIMITS
RateHitEvents	y_values	Clean	52.34 +- 0.94	[4 / 8 – 80 / 100]
DeltaTime	exp_fit_lambda	Clean	50.05 +- 0.23	[4 / 8 – 80 / 100]
HitMultTop	x_average	Clean	1.0928 +- 0.0021	[0.500 / 0.750 – 2 / 3]
HitMultMid	x_average	Clean	1.1306 +- 0.0026	[0.500 / 0.750 – 2 / 3]
HitMultBot	x_average	Clean	1.1043 +- 0.0022	[0.500 / 0.750 – 2 / 3]
HitMultTotal	x_average	Clean	3.3150 +- 0.0059	[1.50 / 2.50 – 6 / 9]
ClusterMultTop	x_average	Clean	1.0933 +- 0.0021	[0.500 / 0.750 – 2 / 3]
ClusterMultMid	x_average	Clean	1.1307 +- 0.0026	[0.500 / 0.750 – 2 / 3]
ClusterMultBot	x_average	Clean	1.1048 +- 0.0023	[0.500 / 0.750 – 2 / 3]
ClusterMultTotal	x_average	Clean	3.3289 +- 0.0059	[1.50 / 2.50 – 6 / 9]
ChiSquare	x_average	Clean	2.958 +- 0.021	[1 / 2 – 6 / 10]
RateTrackEvents	y_values	Clean	49.83 +- 0.92	[4 / 8 – 80 / 100]
FractionTrackEvents	y_values	Clean	0.9631 +- 0.0036	[0.400 / 0.800 – 1 / 1]
Phi				
Theta				
TimeOfFlight				
TrackLength				

A set fo monitoring parameters and distributions are automatically evaluated and alarms are generated.

This study is for understanding the feasibility of a measurement upward going ν, both atmospheric and extraterrestrial.

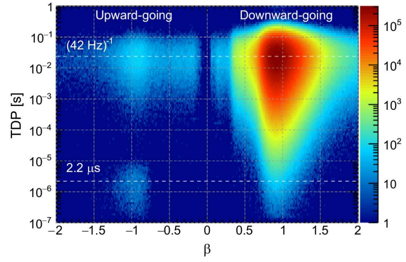
The total upward/downward flux ratio is $2{\cdot}10^{-3}$.

This means we have S/B $\sim 10^{-7}$ to be resolved (S/B $\sim 10^{-10}$ expected for atm. ν).

A component with $\sim 2\mu$s TDP is clearly evident.

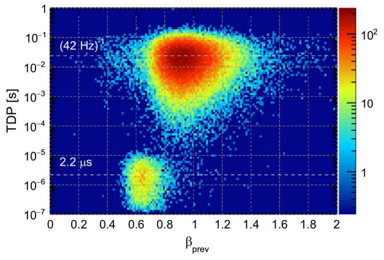
The population at TDP$\sim$23 ms is related with uncorrelated time-adiacent events.

Time Daughter-Parent vs β

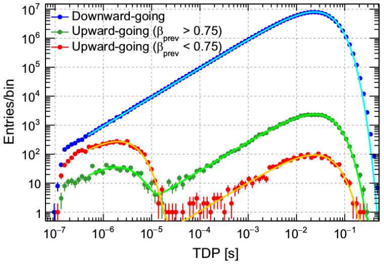


Events at TDP$\sim$23 ms are related to parent slow muons

TDP vs parent muon β



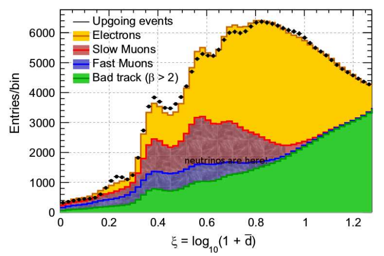
Exponential fit - particle Lifetime



μ decay population with $\tau \sim 2.2\mu$s

First step done, now increasing statistics for deeper studies

Identified upward populations

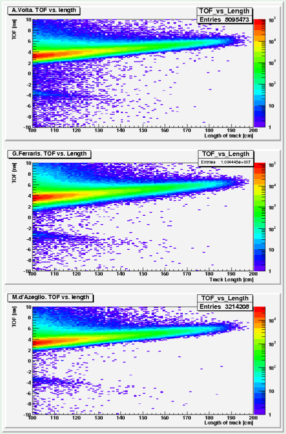


Only 6% of the upward flux is identified as electrons from μ decay.

The upward flux apparently uncorrelated to previous muons contains electrons and backscattered muons with untriggered parent muons.

These components are now the ones to be investigated, since they mimic genuine upward muon flux.

The EEE TOF measurements allows to tag upward flying particles

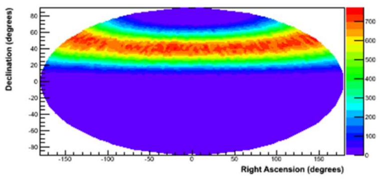


The study of Upward flux is of interest for understanding the feasibility of a measurement of upward going neutrinos converting in the Earth crust, both atmospheric and extraterrestrial.

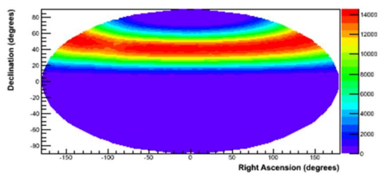
The expected down/upward ratio for EEE telescopes is $<10^{-10}$ just for atmospheric components.

Shuffling corrections and first Aitoff maps

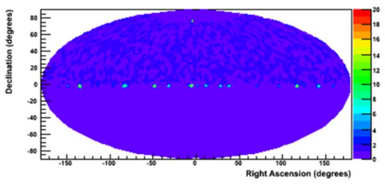
RAW DATA



SHUFFLE CORRECTIONS



Corrected Map

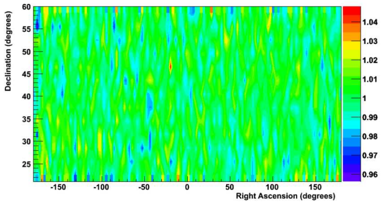


equatorial dots are border effects

Shuffling statistical approach was used to correct for time exposure and acceptance. Each real event correspond to 20 false events randomized over 24 h.

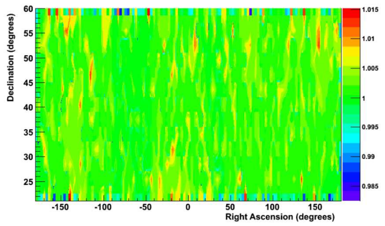
First Results ⇒ (Eur. Phys. J. Plus (2015) 130: 187)

TRIN-01 corrected



Trinitapoli telescope Aitoff Map corrected usign the shuffling method.

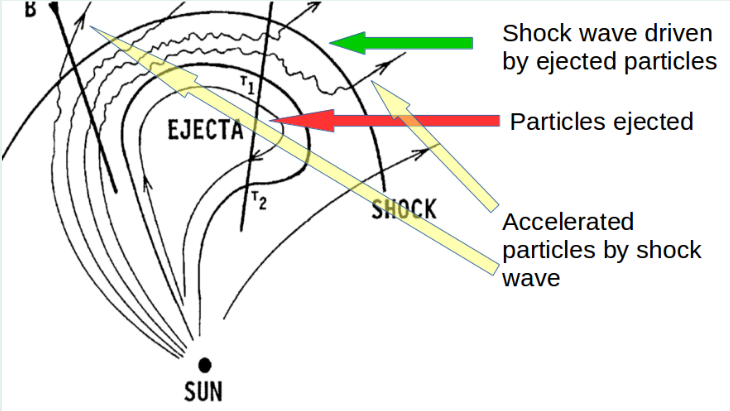
4 Stations Average



Weighted average of the corrected maps for the TRIN-01, CAGL-01, SAVO-01, CATA-01 telescopes. No anisotropies observed at the level of $5 \cdot 10^{-3}$-10^{-2} scale.

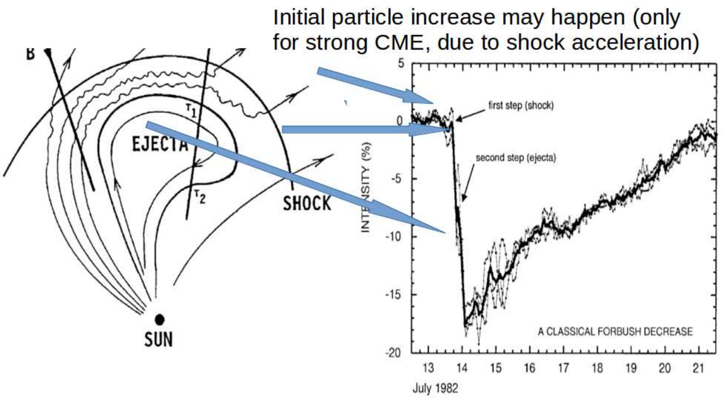
The most reliable scenario is a two step mechanism which involves

- the magnetic line disruption via plasma thermal pressure, with a proton burst emission
- magnetic line reconnection and reheating with a flare emission

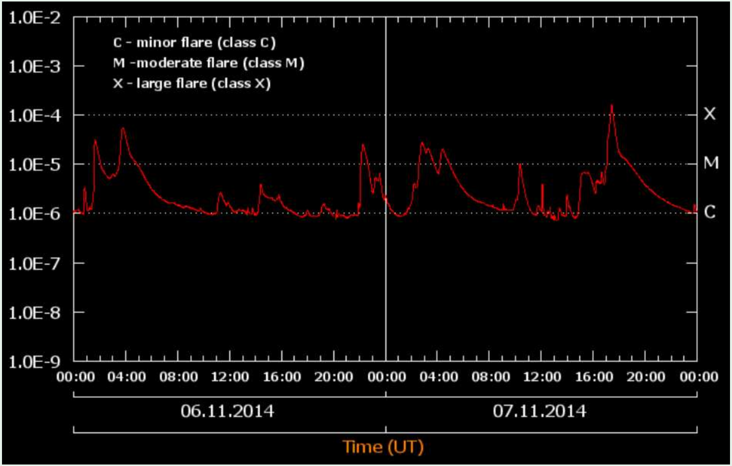


Interplanetary magnetic field and low energy CR are

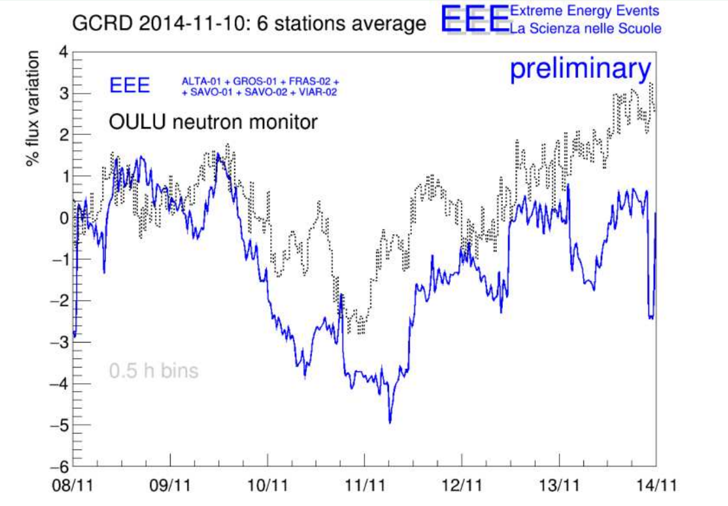
- first swept and compressed by the shock wave
- then again disturbed by the proton burst



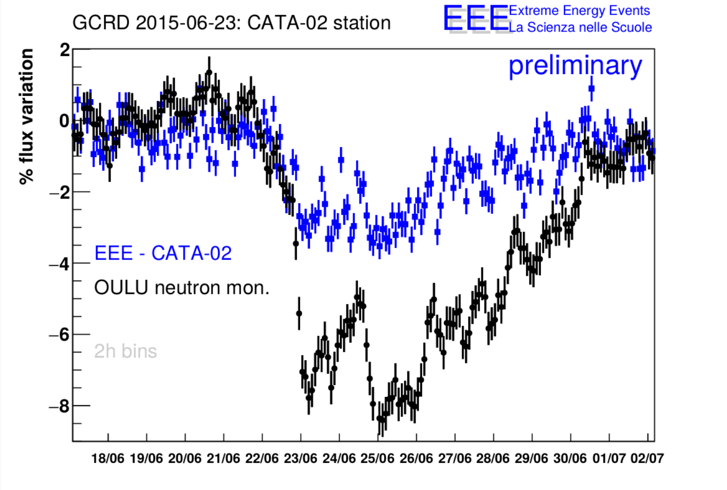
Flare 2014-11: X Class
few days waiting for the effects on Earth...



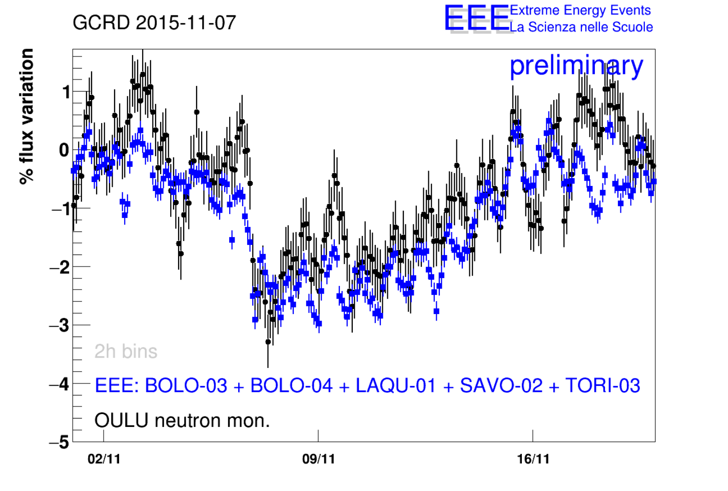
Forbush 2014-11
good correlations with Neutron Monitors
but muon amplitude a factor $\sim$ 2 higher



Forbush 2015-06
good correlations with Neutron Monitors
but muon amplitude a factor ~ 2 lower

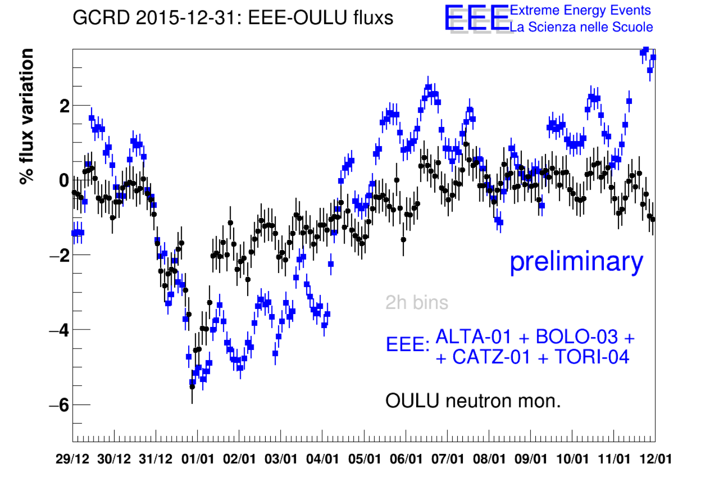


Forbush 2015-11
very good correlations with Neutron Monitors



Forbush 2015-12

low correlations with Neutron Monitors and two-step recovery mechanisms



- the different CR Forbush effects on muon and neutron component is not understood (and not confirmed)
- Pressure, Temperature corrections have to be deeply studied in order to perform a robust correction to the non-CR realted modulation effects
- Latitude and Longitude dependance studies are possible also with the EEE detectors (10 degrees in lat and long coverage)
- crossing the data with NM net is on the way
- ...
- after stabilizing the telescopes, long term studies on solar cycle survey are feasible.

2015 Conferences

- Frontier detectors for Frontier Physics (13th Pisa Meeting on advance detectors)
  $\Rightarrow$ Nucl. Instr. & Meth. A
  - M. P. Panetta: The EEE Project: an extended network of muon telescopes for the study of cosmic rays
  - F. Noferini: The computing and data infrastructure to interconnect EEE stations
- International School of Subnuclear Physics Erice 2015
  - L. Cifarelli: The EEE Project of the Enrico Fermi Centre
- 34th International Cosmics Rays Conference ICRC 2015 (The Hague)
  $\Rightarrow$ Proceedings of Science
  - I.Gnesi: Results from the observations of Forbush decreases by the Extreme Energy Events experiment
  - F. Pilo: First results from Run-1 of the Extreme Energy Experiment

2015 Conferences

- Cosmic Ray Internation Seminars 2015
  $\Rightarrow$ Nuclear and Particle Physics Proceedings
  - De Gruttola: First results from coordinated data taking by the Extreme Energy Events experiment
- Topics in Astroparticle and Underground Physics 2015
  - L. Perasso: EEE Extreme Energy Events: an astroparticle experiment in italian high schools
- Congresso SIF 2015
  - M. Abbrescia: Run-1 of the Extreme Energy Events experiment
  - E. Bossini: Test and characterization of Multigap Resistive Plate Chambers for the EEE Project.
  - M. P. Panetta: Distribuzioni angolari di muoni cosmici osservati dai Telescopi del Progetto EEE.

2016 Conferences

- 14th Vienna Conference on Instrumentation 2016
  - P. La Rocca: "Operation and performance of the EEE network array for the detection of cosmic rays
- The XIII workshop on Resistive Plate Chambers and related detectors
  - M. P. Panetta: "Recent results and performance of the EEE Project MRPCs network
- + 4 more within the end of the year