



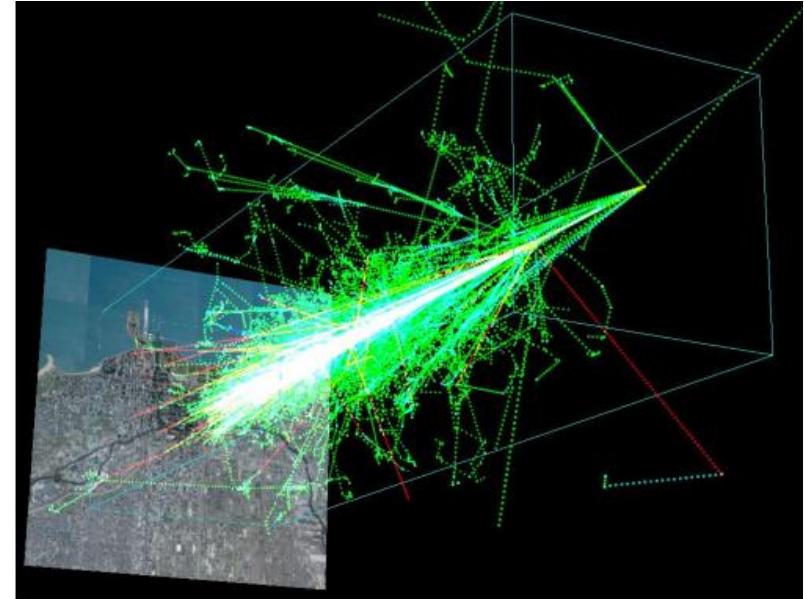
A study of the Extreme Energy Events sparse array performance during Run2 and Run3

M. P. Panetta
for the EEE Collaboration



The EEE Project

The Extreme Energy Events (EEE) Project is an experiment for the detection of Extensive Air Showers.



It is a joint **scientific** and **educational** initiative by CENTRO FERMI in collaboration with



and



The EEE Project

The detection of an EAS is achieved by measuring the coincidences recorded at the different sites of the EEE Telescopes Array. It consists of tracking detectors hosted in **High Schools** spread on the Italian territory, each made of 3 **Multigap Resistive Plate Chambers** (MRPCs).

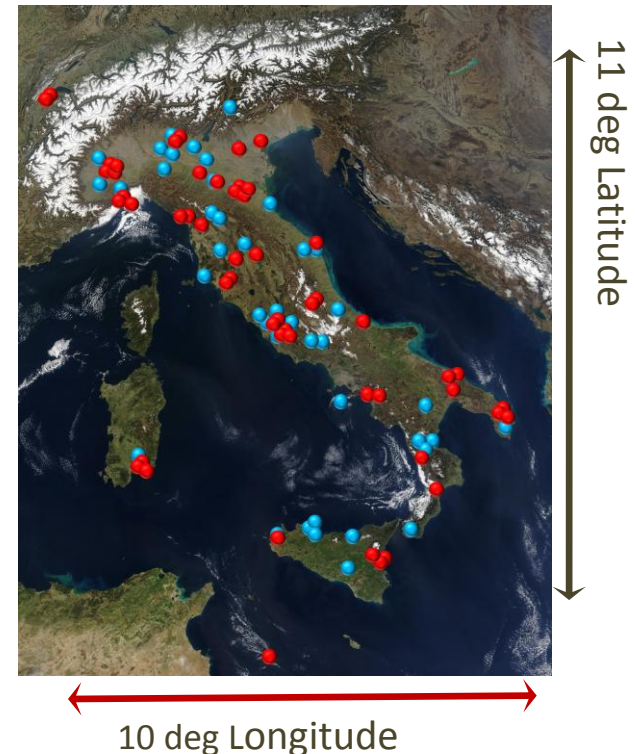
In 2004 \Rightarrow Pilot project: 7 towns with EEE telescopes in High Schools

In 2016 \Rightarrow >52 EEE telescopes across an overall area of $\sim 3 \times 10^5 \text{ km}^2$

In 2017 \Rightarrow 20 new stations (10 in construction)

- 48 EEE Station in school buildings
- 4 at INFN sections
- 2 at CERN

Telescopes are organized in clusters (10m -4 km d.) and single telescope stations



The EEE Project : a dual role



Education instrument for students

The MRPCs are built and managed at CERN by small teams of students and teachers.

In their schools ~ 500 students and 100 teachers are directly involved in operating and monitoring EEE stations, with the aim to introduce them in an advanced physics research.

Impacts in didactic and science awareness of the Extreme Energy Events Observatory.

Grazzi Stefano, Centro Studi e Ricerche 'Enrico Fermi'
SIF 2017, 11-14/09/2017, Trento



S. Grazzi talk



The EEE Project : a dual role

Scientific instrument for physicists

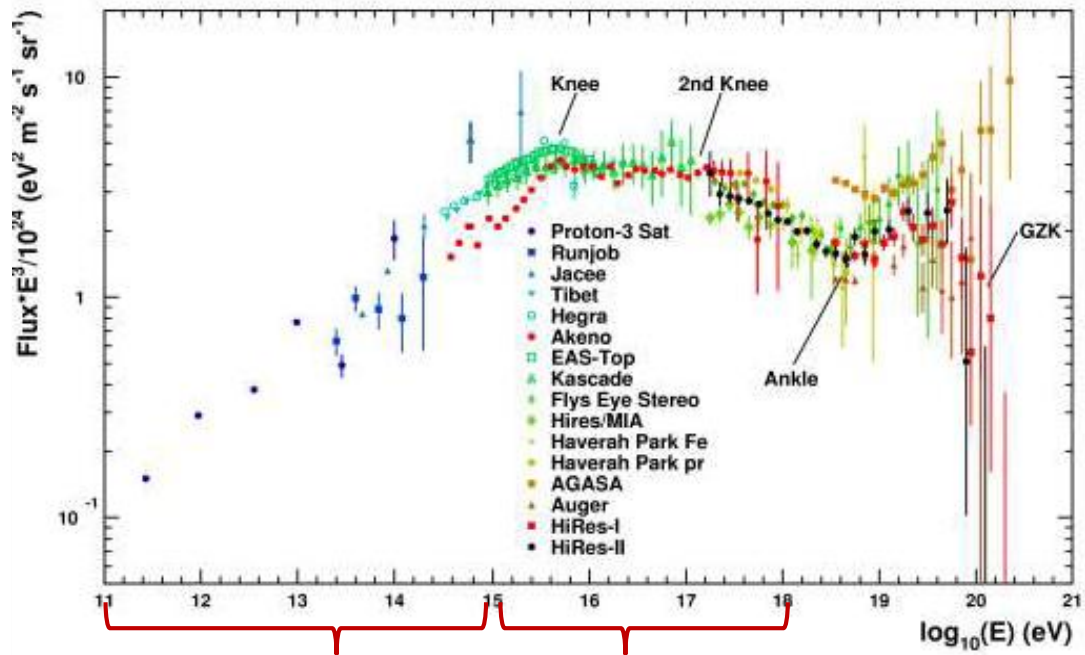
EEE Collaboration involves ~ 70 physicists. Many different topic in the cosmic ray physics:

Search of coincidences, Long distance correlation
Correlations to solar activity, Upgoing tracks, Large scale anisotropy, ...

As a single detector : the EEE telescope is a high precision tracking detector that can study the flux of secondary cosmic muons.

As telescopes cluster: in the same town, it aims to study the properties of the EAS in which muons are originated,

As an array using sites far apart: it makes possible to investigate time correlations between different EAS events (es. *Gerasimova-Zatsepin effect*)



Single telescope
sensitivity

Multi-telescope
analyses



The EEE Project : a dual role

Scientific instrument for physicists

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Correlations to solar activity, Upgoing tracks, Large scale anisotropy, ...

I. Gnesi talk



The Extreme Energy Event network Status and Perspectives

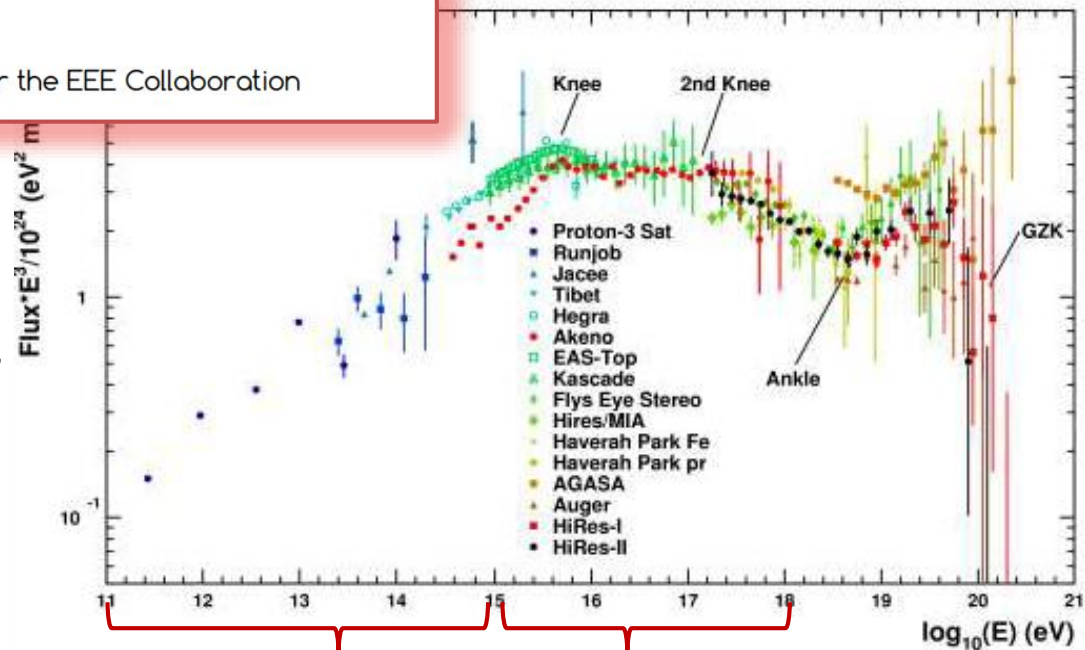
Ivan Gnesi for the EEE Collaboration

As a single detector

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Single telescope sensitivity

Multi-telescope analyses



The EEE Project : a dual role

Scientific instrument for physicists

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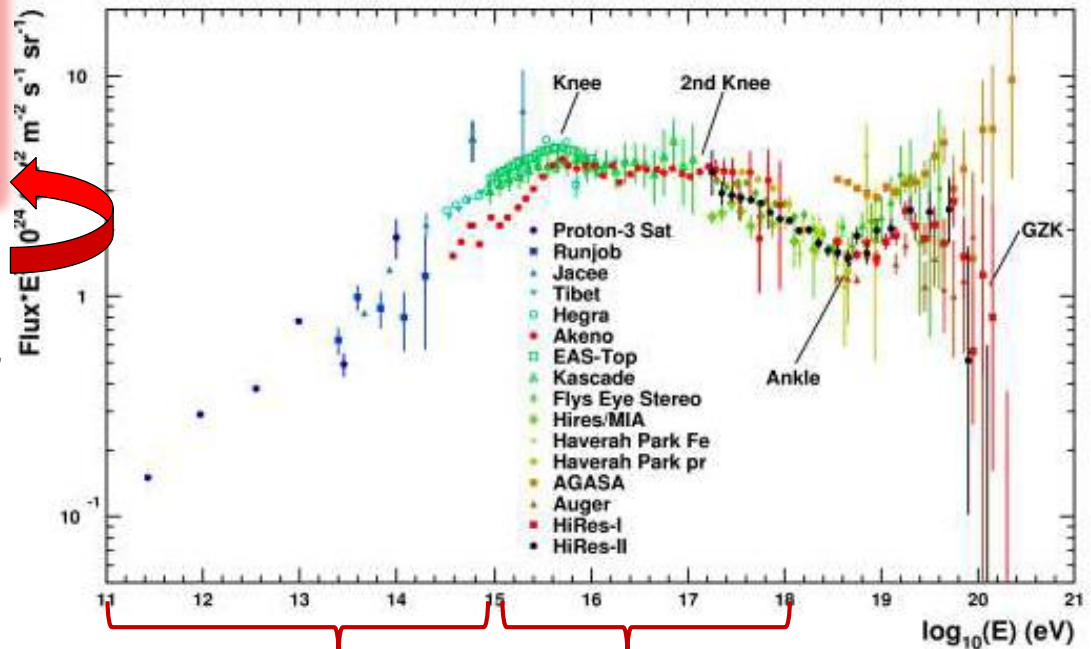
- Search of coincidences, Long distance correlation
- Correlations to solar activity, Upgoing tracks, Large scale anisotropy, ...

F. Coccetti talk

Monte Carlo simulation chain of the Extreme Energy Events Project for EAS detection

F. Coccetti for the EEE Collaboration

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Single telescope sensitivity

Multi-telescope analyses

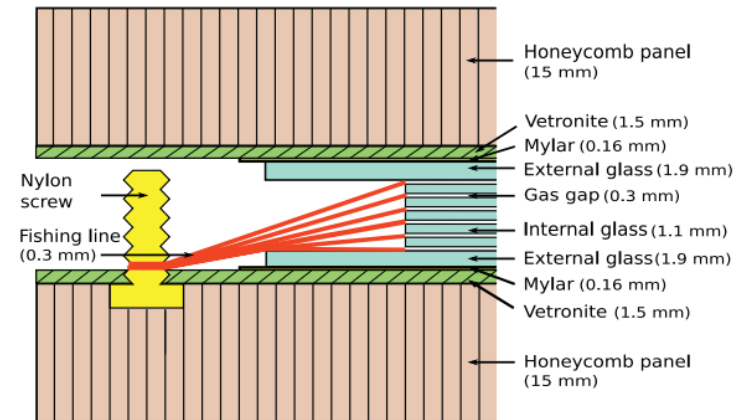
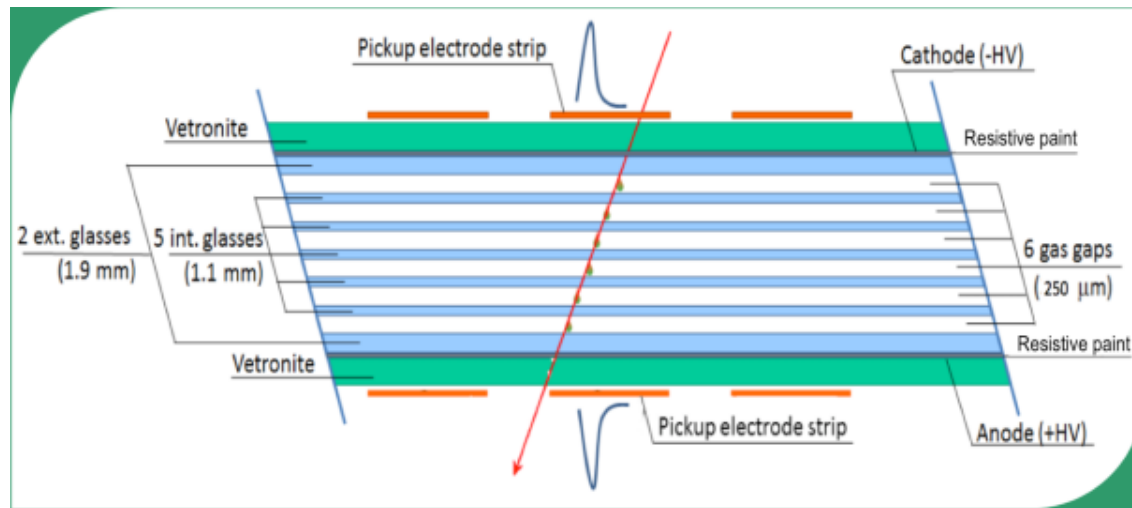


The Multigap Resistive Plate Chambers

Three MRPC Layers for tracking particles

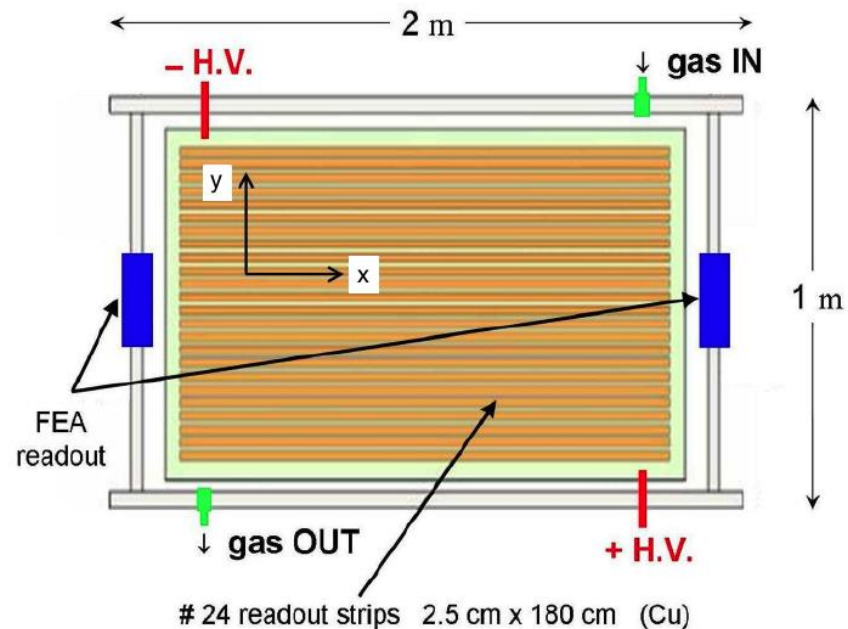
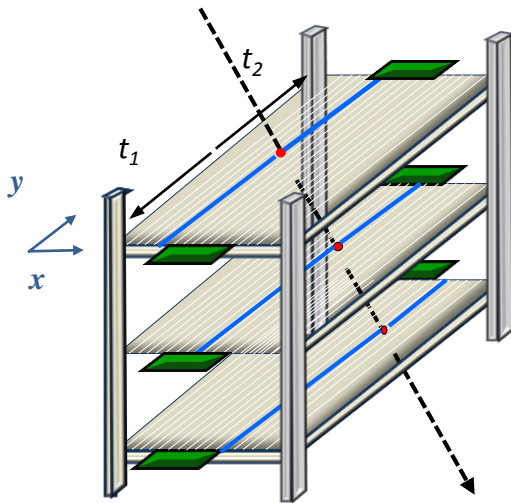
Three Multi-Gap Resistive Plate Chambers (MRPCs) of $1.60 \times 0.80 \text{ m}^2$, with similar operation characteristics to the ones built for the Time Of Flight array of the ALICE experiment

- 6 Gas Gaps: 2 vetronite panels with 5 floating glass plates, $300 \mu\text{m}$ spaced by fishing line
- $\text{C}_2\text{H}_2\text{F}_4$ (98%) and SF_6 (2%) continuously fluxed by (3l/h)



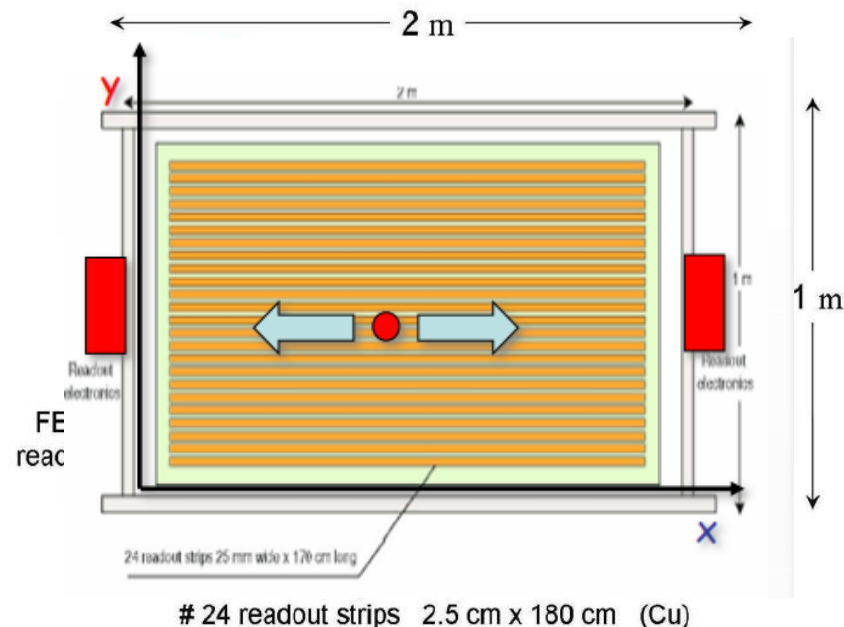
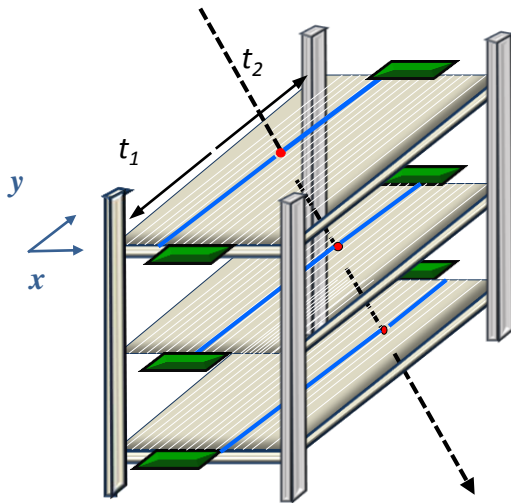
The EEE Telescopes

- ❑ **THREE MULTI-GAP RESISTIVE PLATE CHAMBERS** (MRPCs) of 1.60x0.80 m², for tracking particles
- ❑ **6 FRONT-END BOARDS** (FEAs) with 24 channels to process readout signal
- ❑ **VME BRIDGE**. DAQ connected to a PC via USB, controlled by LabView program
 - 1 MULTI-TRIGGER CARD**: a six-fold coincidence of both FEAs of the 3 MRPCs generates the Data Acquisition (DAQ) trigger
 - 2 MULTI-HITS TIME TO DIGITAL CONVERTERS** (TDCs 128 + 64 channels) to reconstruct the particle impact point
- ❑ **GPS** unit provides the event time stamp (UTC time) to record and synchronize informations
- ❑ **VOLTAGE CONTROLS SYSTEM** (VCS) in the MRPCs DC/DC Converters and FEAs
- ❑ **WEATHER STATION** to monitor the temperature and the pressure inside and outside the telescopes building



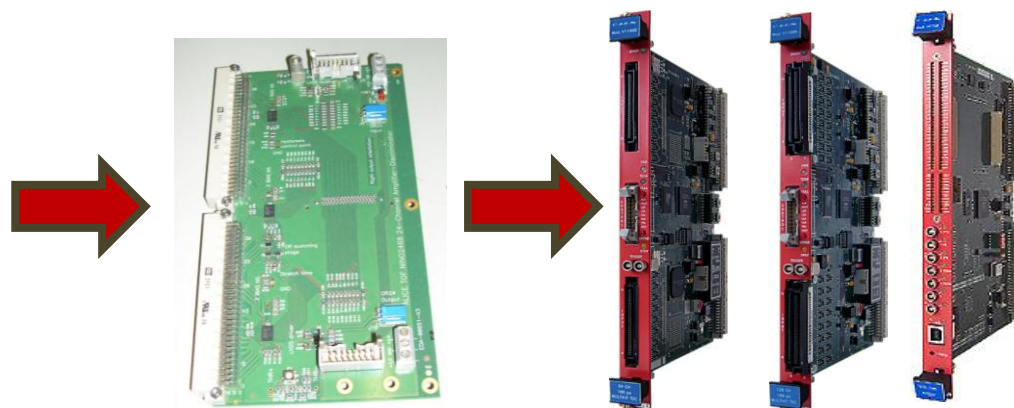
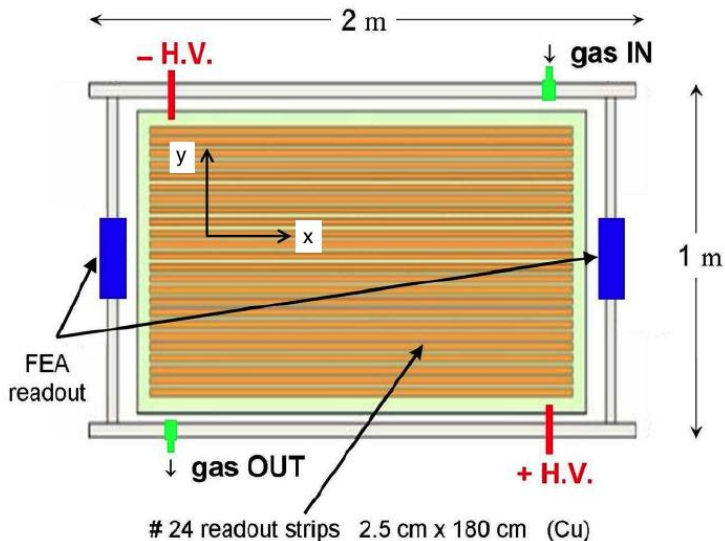
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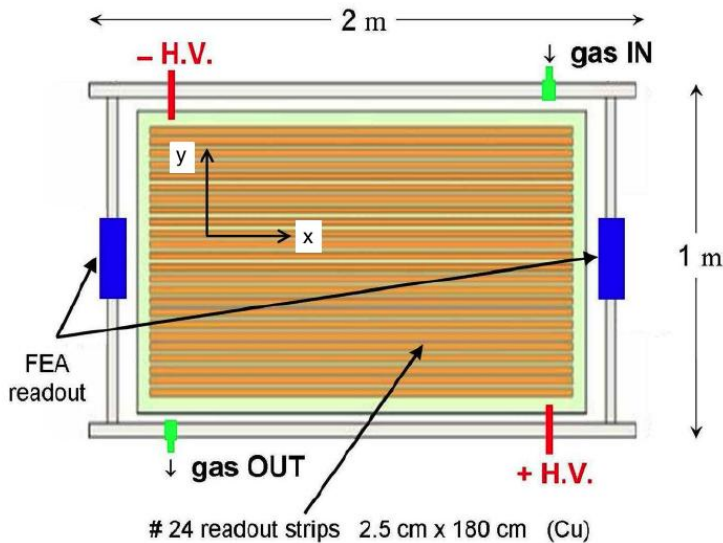
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A. Corvaglia talk

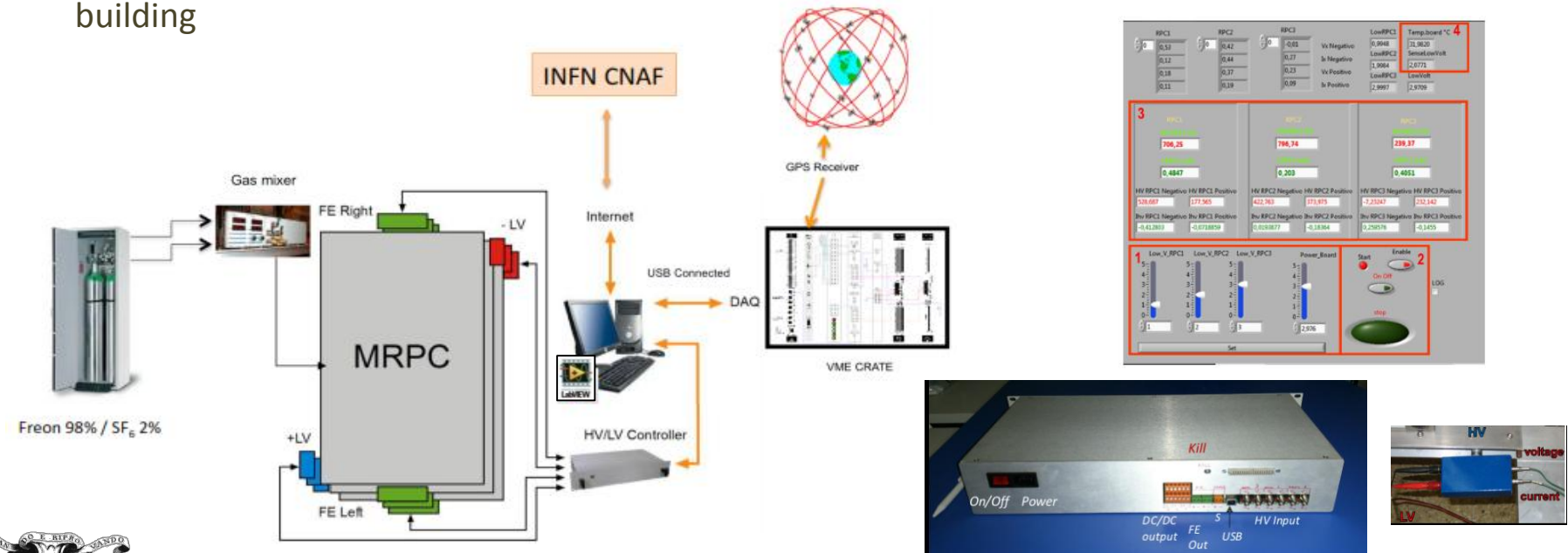
Scheda di trigger-GPS per l'Osservatorio
Extreme Energy Events

A. Corvaglia for the EEE Collaboration



The EEE Telescopes

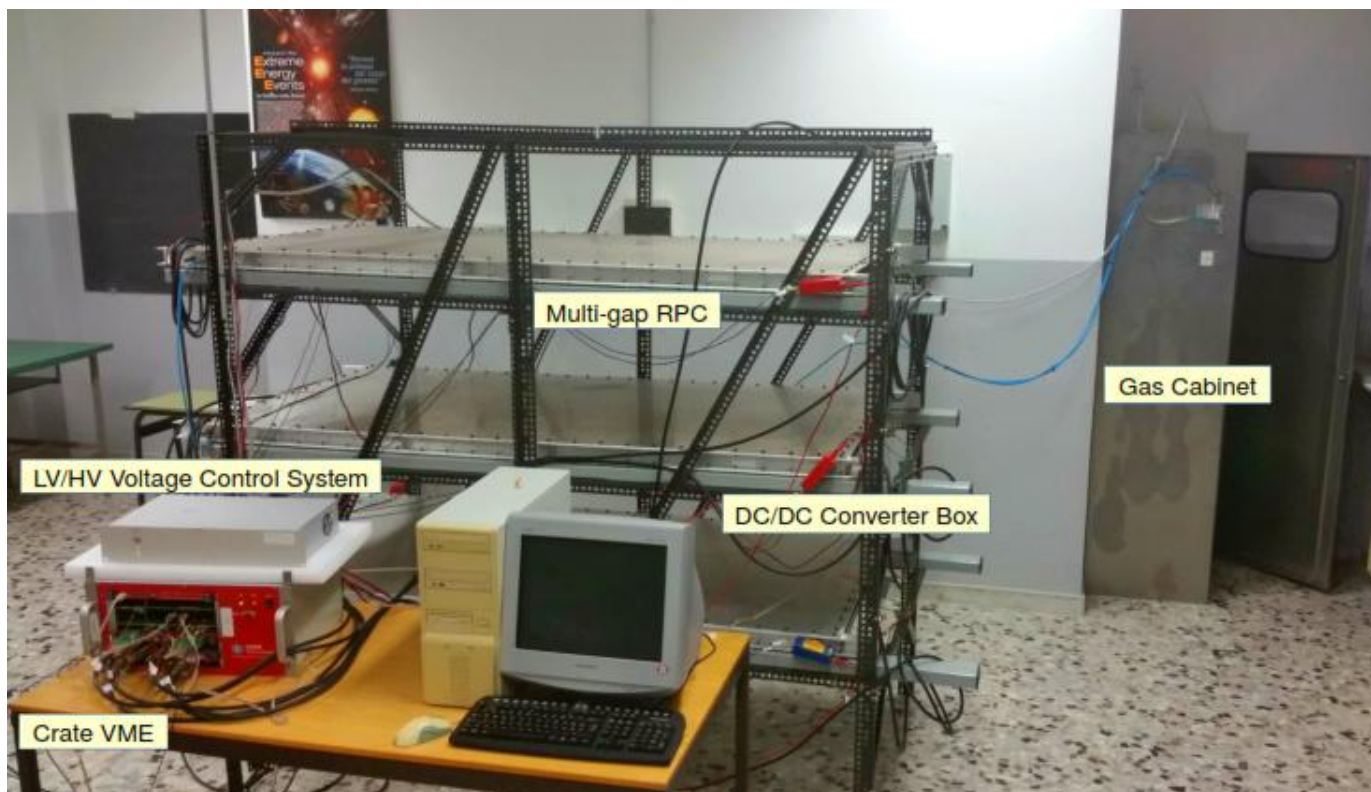
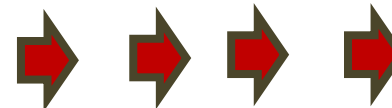
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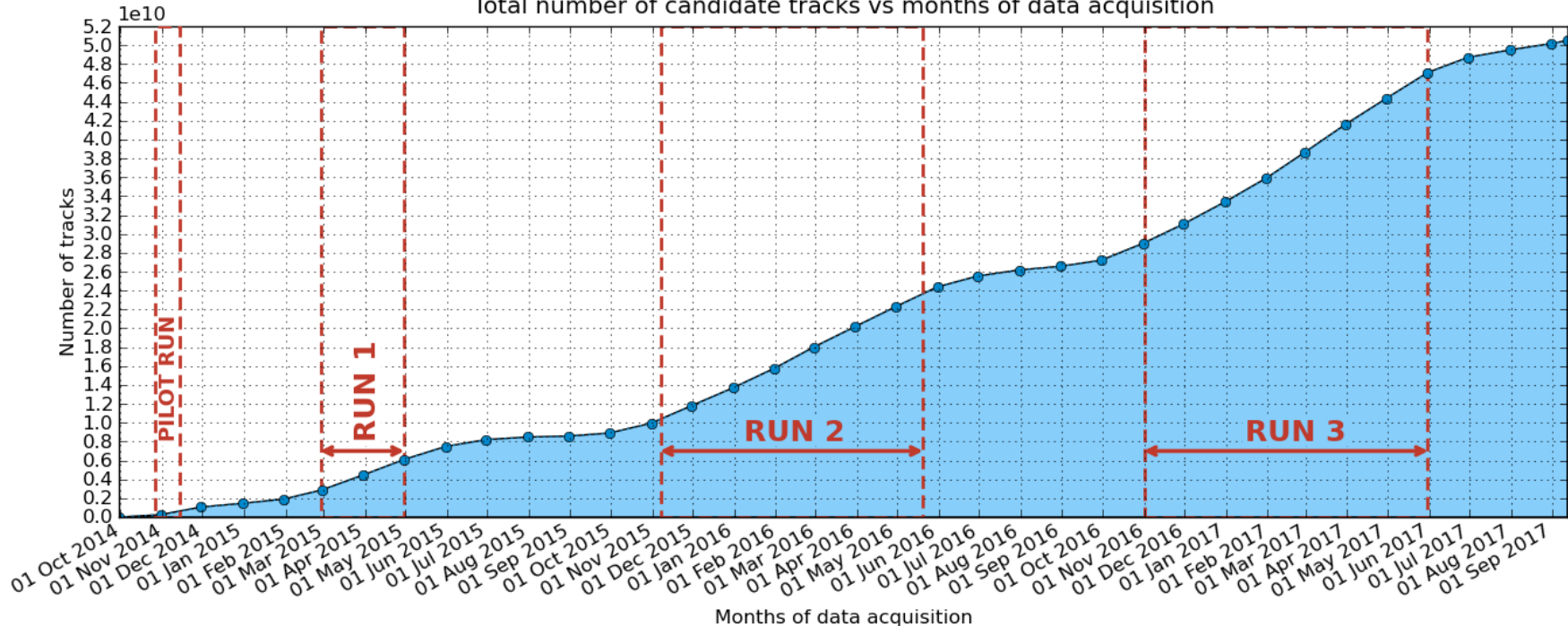
Data are sent to **CNAF** to be stored, reconstructed and analysed



Run : the coordinate DATA acquisition

Since November 2014

Total number of candidate tracks vs months of data acquisition




Progetto Extreme Energy Events - La Scienza nelle Scuole
EEE MONITOR
 Home Page EEE | Masterclass | Download the Excel Sheet | New DB Interface | Connectivity Report

- **41** telescopes
- **15** billions tracks collected
- **46** telescopes
- **25** billions tracks

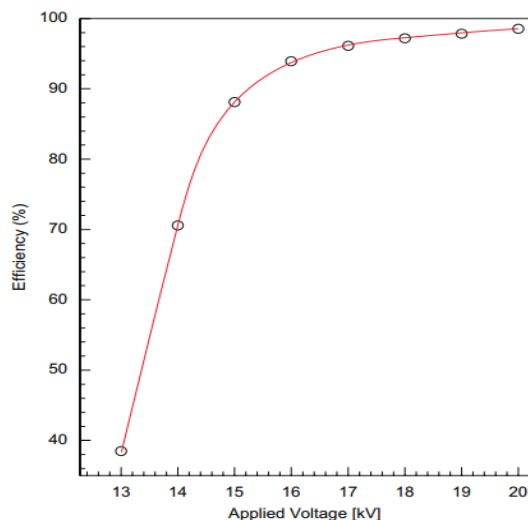
Scuola	Classe	Ora	Nome dell'attività	Numero di studenti	Uffici Extra	Report giornaliero	Rate of tracks per telescope	Rate of tracks per km ² per day	Link DQM
ATA-01	5B-18	14:37	ATA-01-2017-09-10-00013333	18	ATA-01-2017-09-10-00013333	10/10	0.0	0.0	ATA-01
ANCO-01	5B-18	11:29	ANCO-01-2017-09-10-00013333	18	ANCO-01-2017-09-10-00013333	10/10	2.0	0.0	ANCO-01
AREC-01	5B-18	11:30	AREC-01-2017-09-10-00013333	32	AREC-01-2017-09-10-00013333	10/10	23.0	29.0	AREC-01
BARI-01	5B-18	14:36	BARI-01-2017-09-10-00013333	8	BARI-01-2017-09-10-00013333	10/10	23.0	23.0	BARI-01
BOLD-01	5B-18	14:30	BOLD-01-2017-09-10-00013333	32	BOLD-01-2017-09-10-00013333	10/10	40.0	37.0	BOLD-01
BOLD-02	5B-18	14:30	BOLD-02-2017-09-10-00013333	32	BOLD-02-2017-09-10-00013333	10/10	47.0	43.0	BOLD-02
BOLD-03	5B-18	14:31	BOLD-03-2017-09-10-00013333	32	BOLD-03-2017-09-10-00013333	10/10	47.0	43.0	BOLD-03
BOLD-04	5B-18	14:32	BOLD-04-2017-09-10-00013333	32	BOLD-04-2017-09-10-00013333	10/10	40.0	41.0	BOLD-04



Study of the EEE MRPC Telescopes Performance



Single MRP Chamber



TEST BEAM at CERN

Efficiency vs HV for a single MRP Chamber (Triggered by scintillators)

Efficiency plateau **~100%**

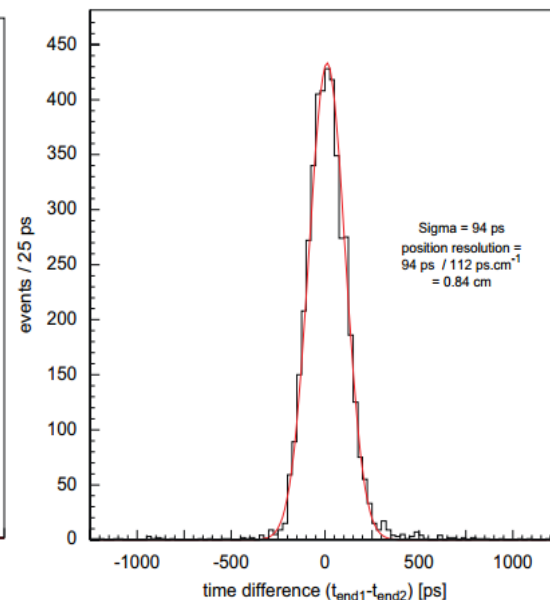
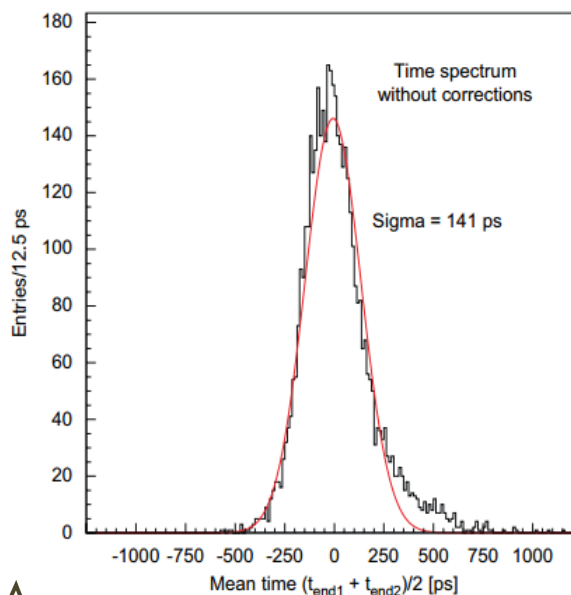
TDCs 25ps bins , scintillators system time resolution 30 ps

In the middle of the strip length
Time resolution **~141 ps**

+ corrections

(slewing -Time over Threshold- correction , scint. time res.)

Time resolution **~94 ps**



Spatial resolution along strips **~ 8 mm**



MRPC Telescopes

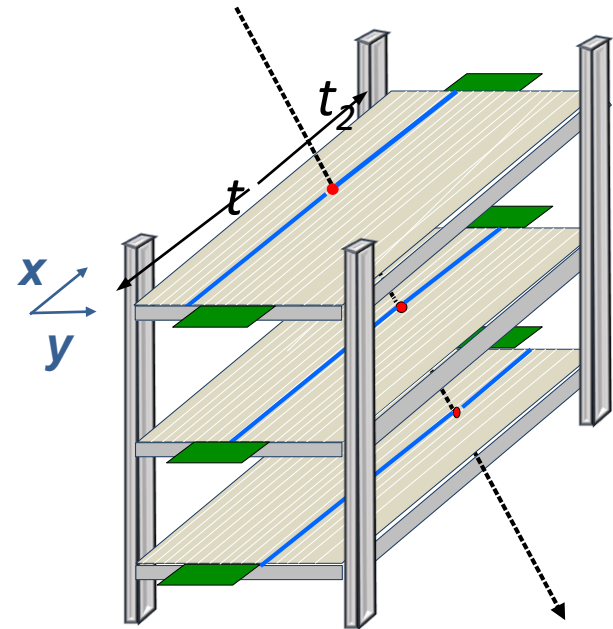
At CNAF where an all data reconstruction algorithm is applied to all telescopes raw data.

Tracking procedure: "Good" events are selected by quality cuts: lowest χ^2 , track length, ToF

The particle impact point is reconstructed by :

- the fired strip (y)
- the difference of signal arrival times at the strip ends measured by TDCs (x)

$$x = \frac{T_{Left} - T_{right}}{2 v D_{rift}}$$



The impact time in each MRPC is reconstructed as the average of signal arrival times at the strip ends (*RIGHT* and *LEFT SIDE*)

$$T_{Hit} = \frac{T_{RIGHT} + T_{LEFT}}{2}$$



MRPC Telescopes

The **EEE MRPCs Telescopes** performance measured with cosmic particles in the EEE stations **inside school building**

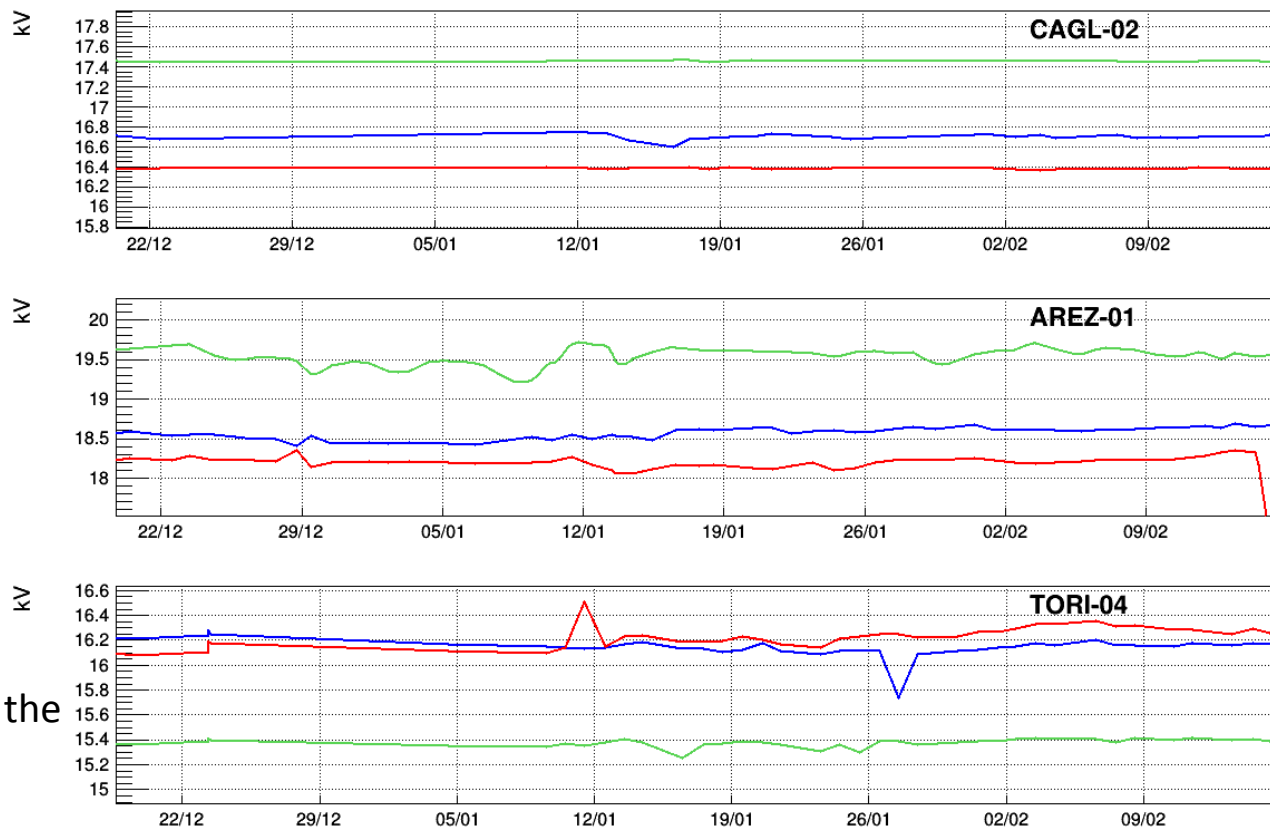
Time vs HV

HV > 17 kV

~

$\Delta V = 200-300$ V

High voltage time-trend across the RUN3 in the 3 MRPC

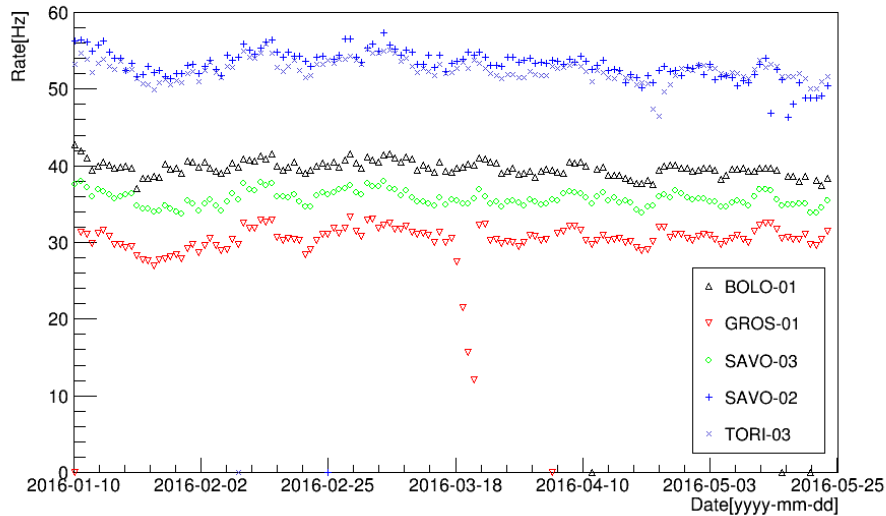


MRPC Telescopes

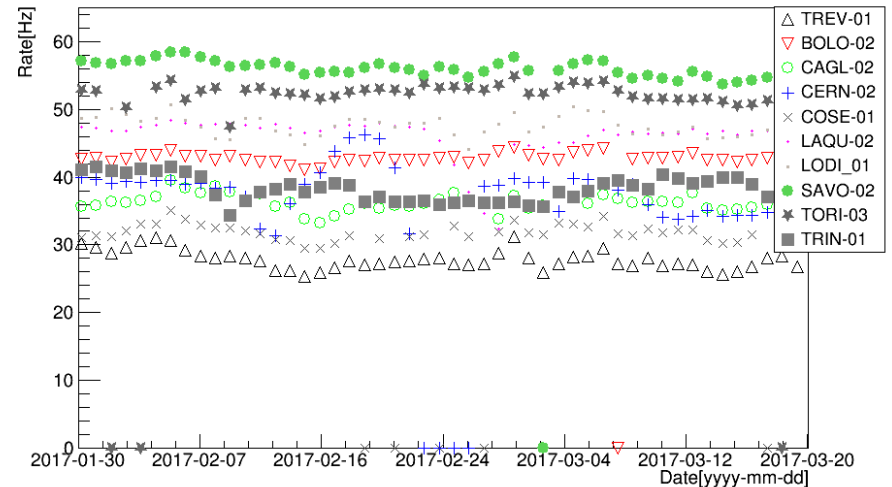
Long term performance stability: Tracks rate

Detectors are hosted in schools, monitoring T and P, not in a controlled environment

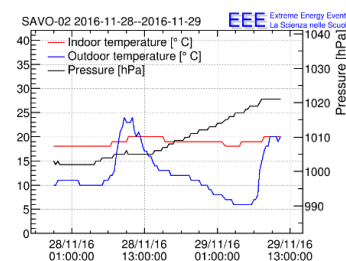
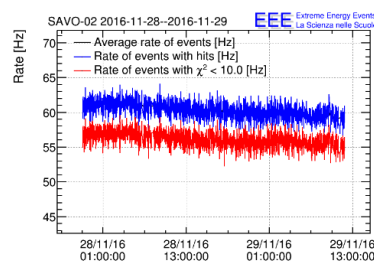
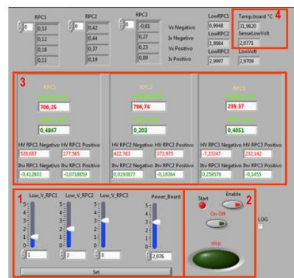
TrackRate-Run2



TrackRate-Run3



Data Quality Monitor & Voltage Control System



Param	Value	Status	Unit	Units
RateHitEvents	y-values	Clean	29.69 ± 0.52	[4 / 8 - 80 / 100]
DeltaTime	exp_fit_lambda	Error	1.0 ± 0.0	[4 / 8 - 80 / 100]
HitMultTop	x_average	Clean	1.1696 ± 0.0027	[0.500 / 0.750 - 2 / 3]
HitMultMid	x_average	Clean	1.2463 ± 0.0031	[0.500 / 0.750 - 2 / 3]
HitMultBot	x_average	Clean	1.2824 ± 0.0032	[0.500 / 0.750 - 2 / 3]
HitMultTotal	x_average	Clean	3.6957 ± 0.0068	[1.50 / 2.50 - 6 / 9]
ClusterMultTop	x_average	Clean	1.0687 ± 0.0018	[0.500 / 0.750 - 2 / 3]
ClusterMultMid	x_average	Clean	1.0807 ± 0.0020	[0.500 / 0.750 - 2 / 3]
ClusterMultBot	x_average	Clean	1.0845 ± 0.0020	[0.500 / 0.750 - 2 / 3]
ClusterMultTotal	x_average	Clean	3.2339 ± 0.0048	[1.50 / 2.50 - 6 / 9]
ChiSquare	x_average	Warning	1.748 ± 0.021	[1 / 2 - 6 / 10]
RateTrackEvents	y-values	Clean	27.45 ± 0.50	[4 / 8 - 80 / 100]
FractionTrackEvents	y-values	Clean	0.9308 ± 0.0044	[0.400 / 0.800 - 1 / 1]
Phi				
Theta				
TimeOfflight				
TrackLength				

Extreme Energy Events (EEE) is powered by eJOP version 3.0.0.
This page validates an HTML 4.01 strict and css level 3.
Generated on Friday, May 14 2017 at 05:15:47:00Z



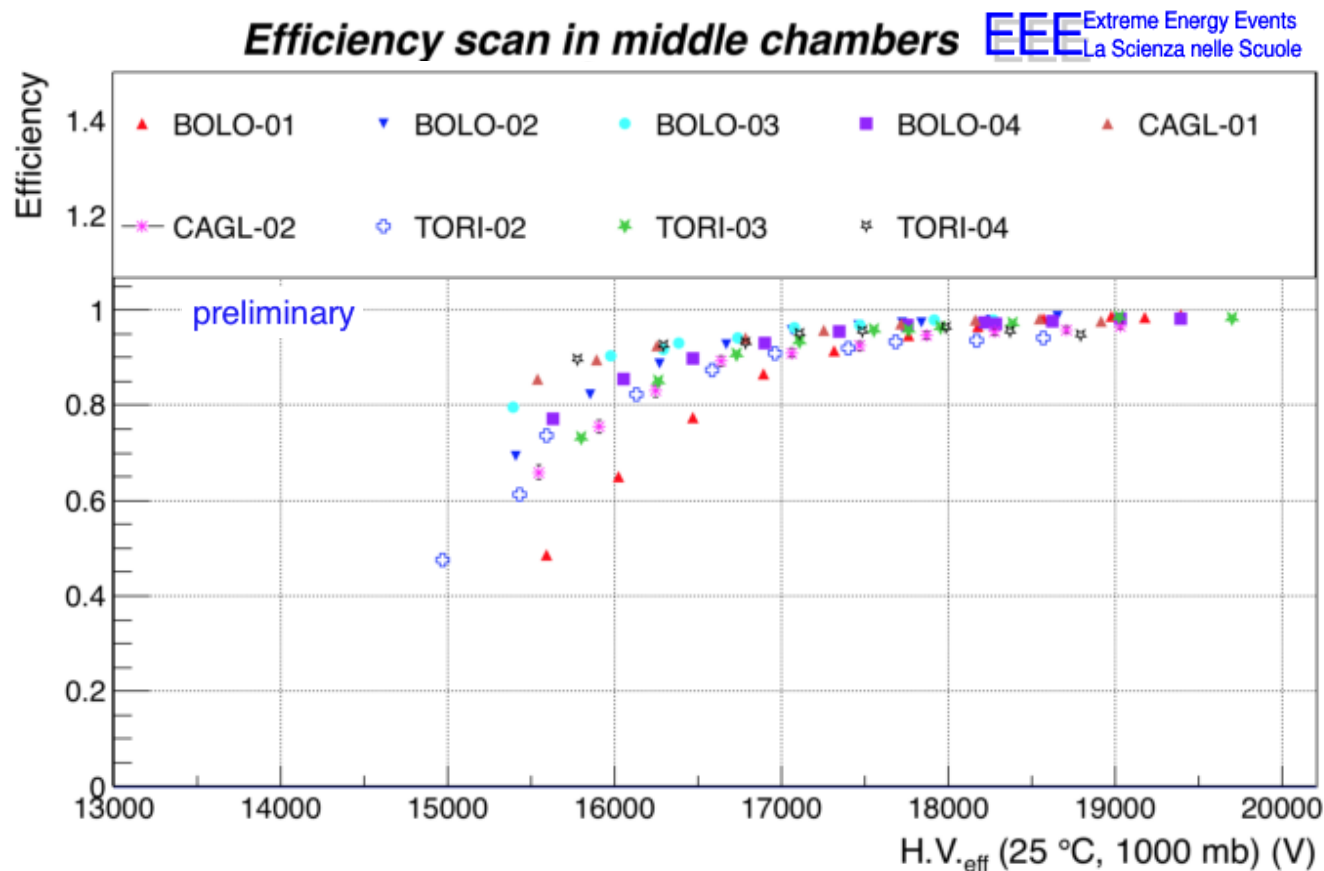
MRPC Efficiency

The EEE MRPCs Telescopes performance measured with cosmic particles in the EEE stations inside school building

Efficiency vs HV

HV > 17 kV ~ 95%

Using the 2fold coincidence. To reduce the noise due to the trigger condition we use events with 2-hit clusters in both the triggering chambers (5% of the events) and check the middle chamber.

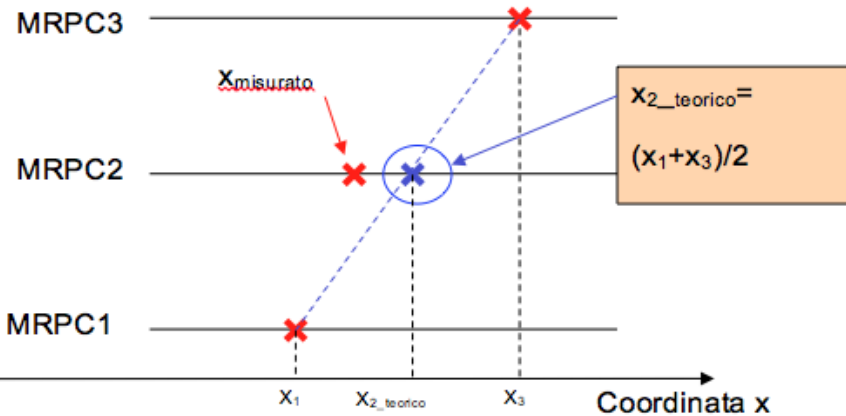


Spatial Resolution

Longitudinal Spatial Resolution for the 3 MRPCs

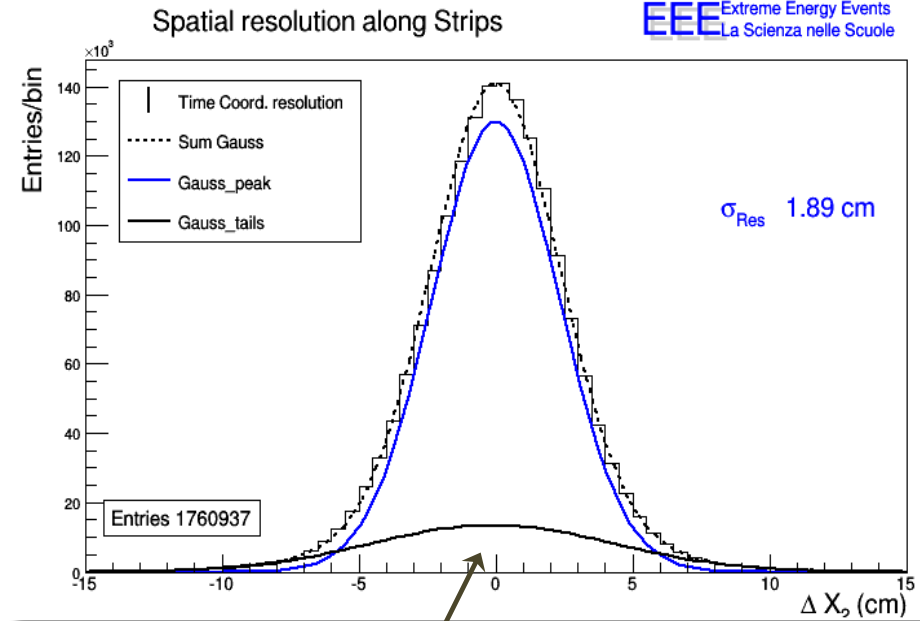
measured with cosmic particles in the EEE stations

X coordinate: the direction longitudinal to the strips chambers



$$\Delta X_2 = \frac{X_{1Bot} + X_{3Top}}{2} - X_{2Mid}$$

$$\sigma_{X Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta X} \sim 1,89 \text{ cm}$$



Fit with 2 contributions

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



Spatial Resolution

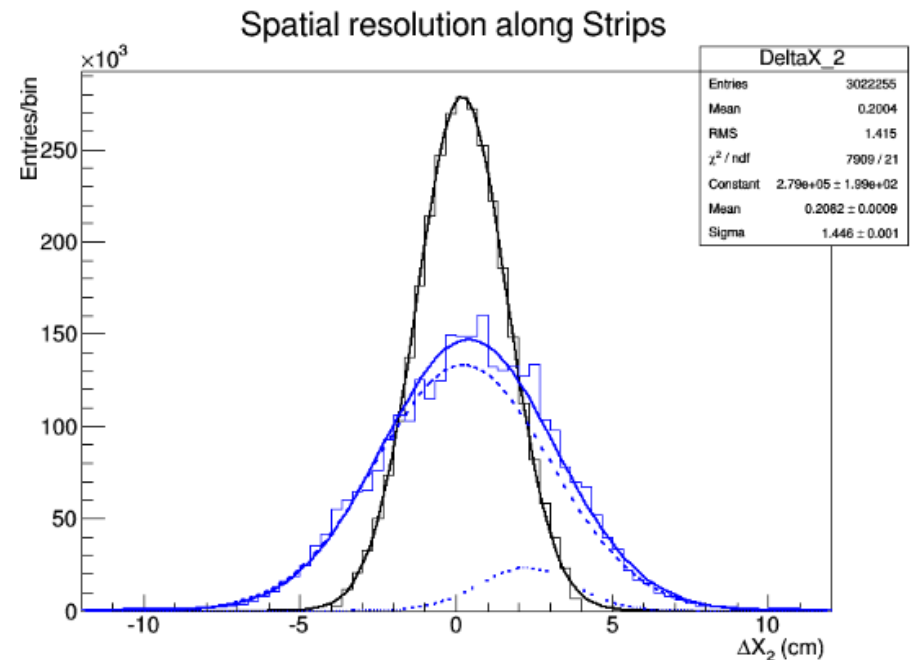
Longitudinal Spatial Resolution

The x distribution on each strip appears not centered at zero, as the distribution $\delta_T = T_{Left} - T_{right}$, because of some differences in the single signal paths in the FEA, in the TDC channels, or in the amphenol cables

$$\Delta X_2 = \frac{X_{1Bot} + X_{3Top}}{2} - X_{2Mid}$$
$$\sigma_{X Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta X} \sim 1,2 \text{ cm}$$

Strip by strip calibration

In each datafile an histogram for each strip is built and its mean value M_{strip} is used for compensating the x-position on the strip $x_{corr} = x_i - (79 - M_{strip})$



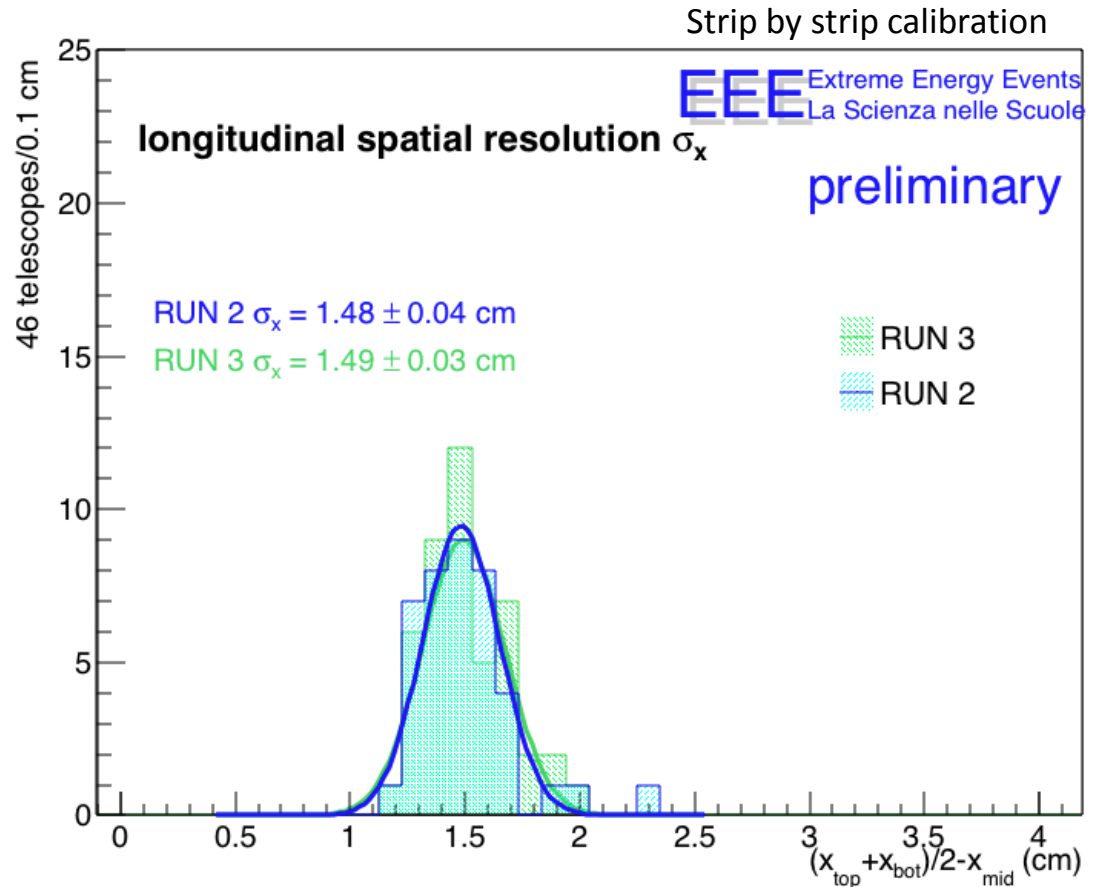
Spatial resolution improved of 40%



Spatial Resolution

Longitudinal Spatial Resolution RUN2 + RUN3 (Data sample = 3×10^9)

$$\Delta X_2 = \frac{X_{1Bot} + X_{3Top}}{2} - X_{2Mid}$$
$$\sigma_{X ALL.} = \sqrt{\frac{3}{2}} \sigma_{\Delta X} \sim 1,5 \text{ cm}$$



Spatial Resolution

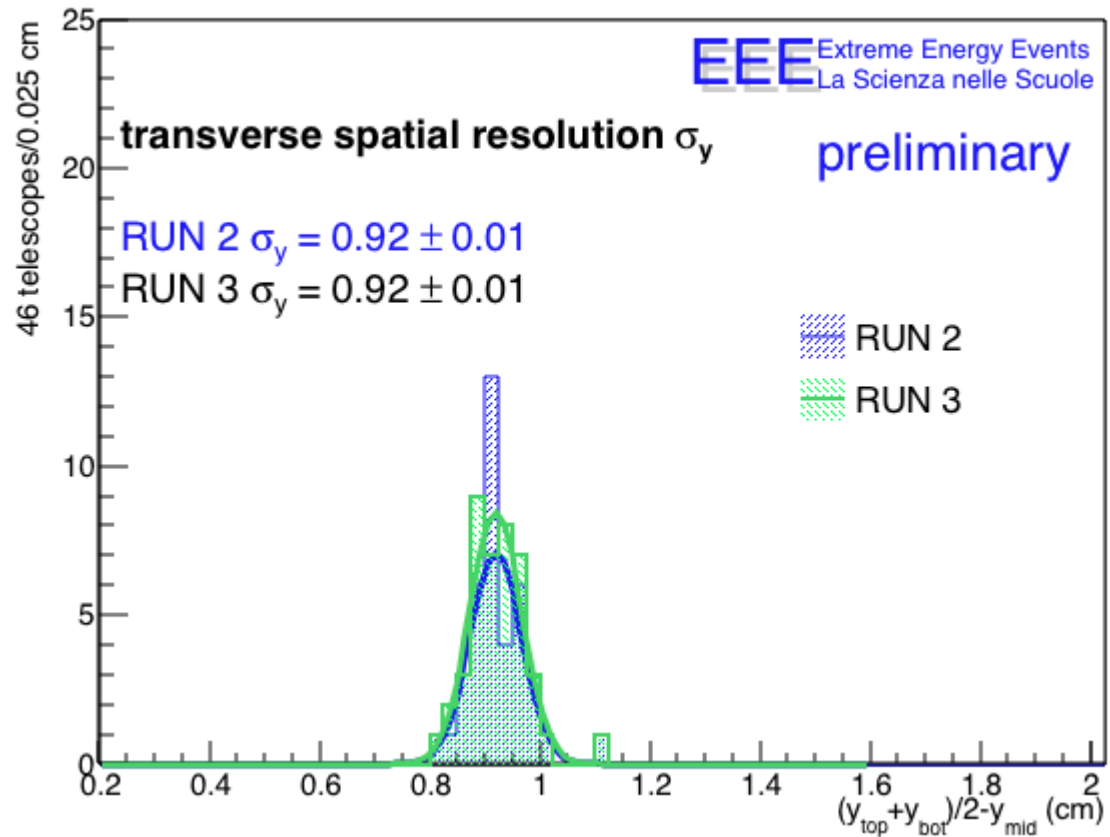
Transverse Spatial resolution for the 3 MRPCs RUN2 + RUN3 (Data sample = 3×10^9)

measured with cosmic particles in the EEE stations

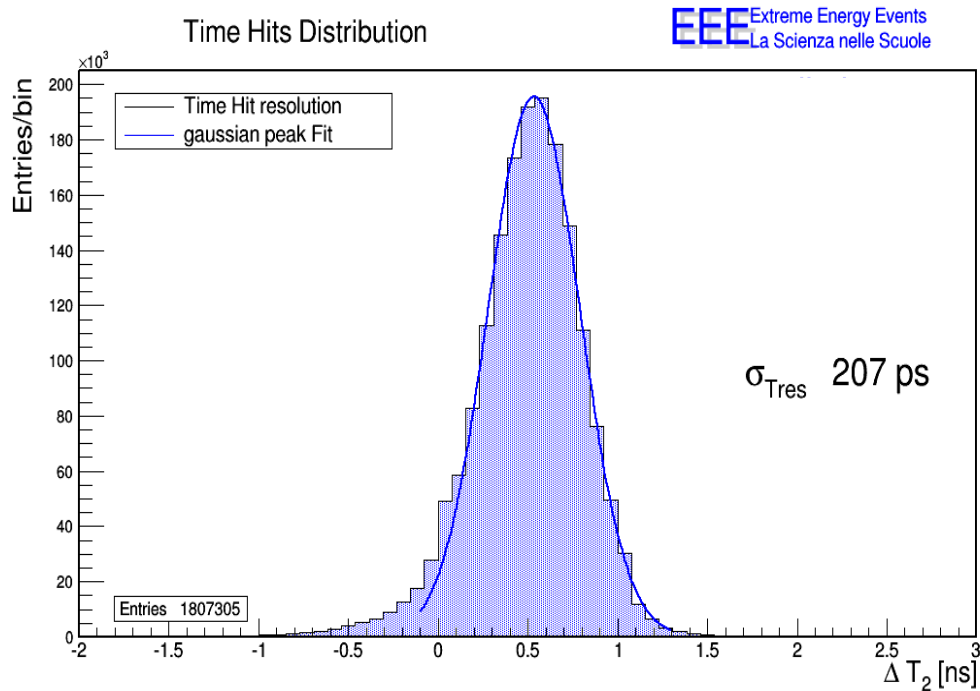
Y coordinate: the direction transverse to the strips chambers

$$\Delta Y_2 = \frac{Y_{Bot} + Y_{Top}}{2} - Y_{Mid}$$
$$RMS_{Y Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta Y} = 0,92 \text{ cm}$$

Expected spatial resolution
 $\sim 3.2 \text{ cm} / \sqrt{12} = 0.9 \text{ cm}$



Time Resolution



Time resolution for the 3 MRPCs

measured with cosmic particles in the EEE stations inside school building

$$\Delta T_{Hit} = \frac{T_{H_Bot} + T_{H_Top}}{2} - T_{H_Mid}$$

$$\sigma_{Time Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta T} \sim 220 \text{ ps}$$

TDCs 100 ps

Time calibrations

Propagation of the signal along the strips



Time Resolution

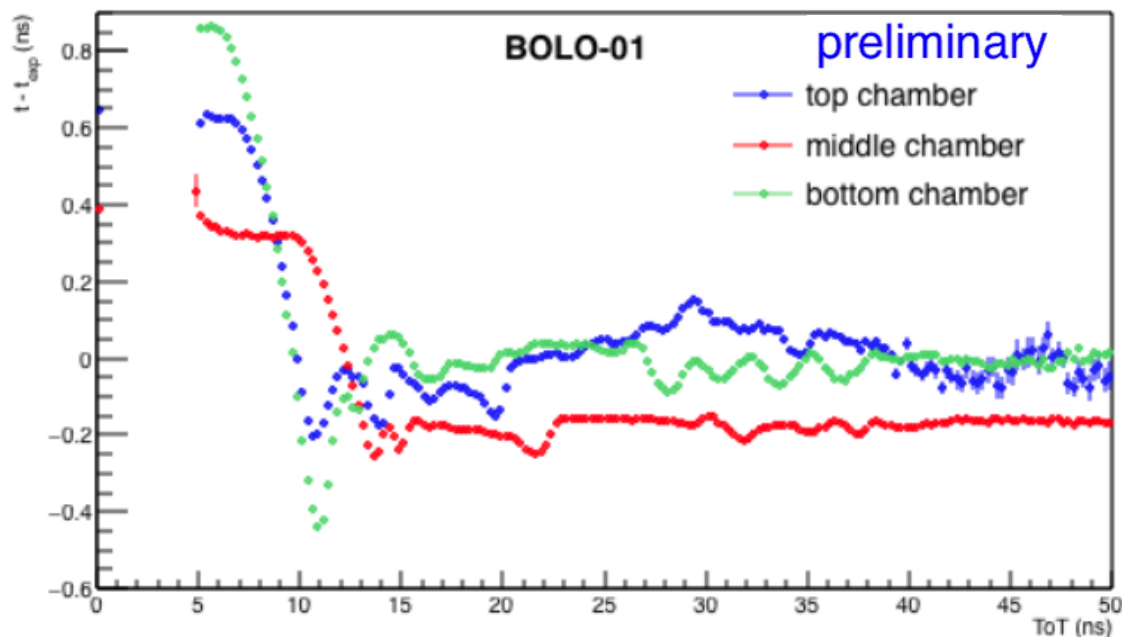
Time slewing corrections

Correlation between TOT and the different $T_{exp} - T_{corr}$, fitted by a polynomial (5th)

Time resolution for the 3 MRPCs

$$\sigma_{Time Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta T} \sim 220 ps$$

EEE Extreme Energy Events
La Scienza nelle Scuole



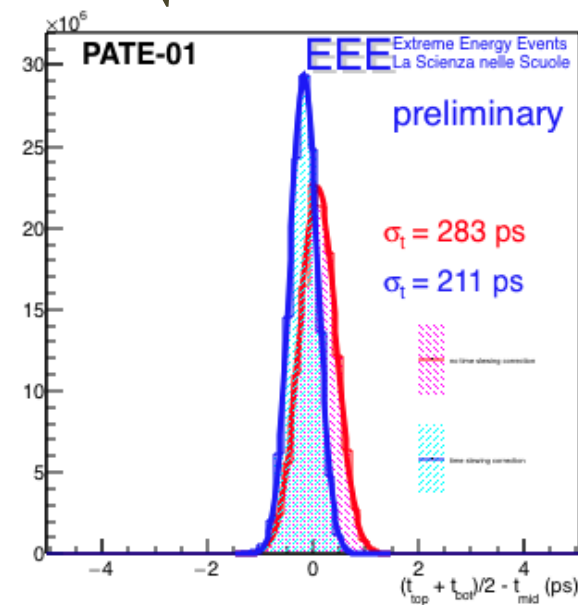
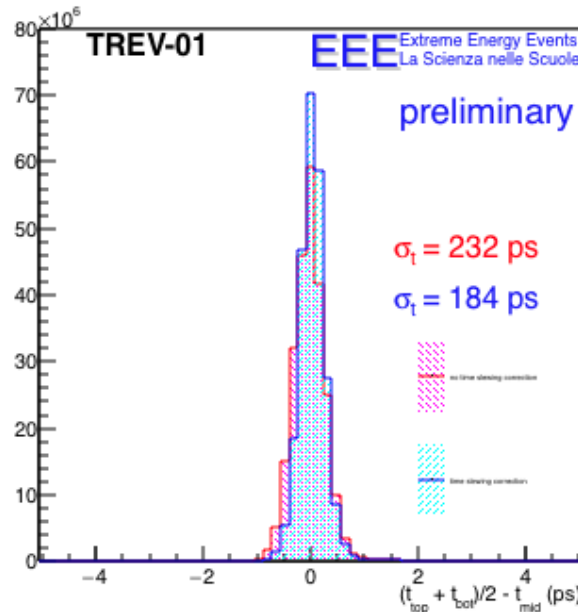
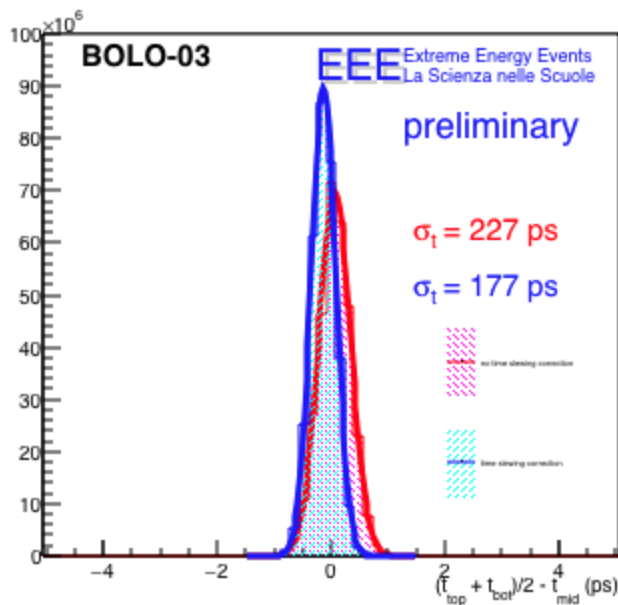
Time Resolution

Time slewing correction

Correlation between TOT and the different $T_{exp} - T_{corr}$, fitted by a polynomial (5th)

Time resolution for the 3 MRPCs

$$\sigma_{Time Res.} = \sqrt{\frac{3}{2}} \sigma_{\Delta T} \sim 180 \text{ ps}$$



20% improvements.

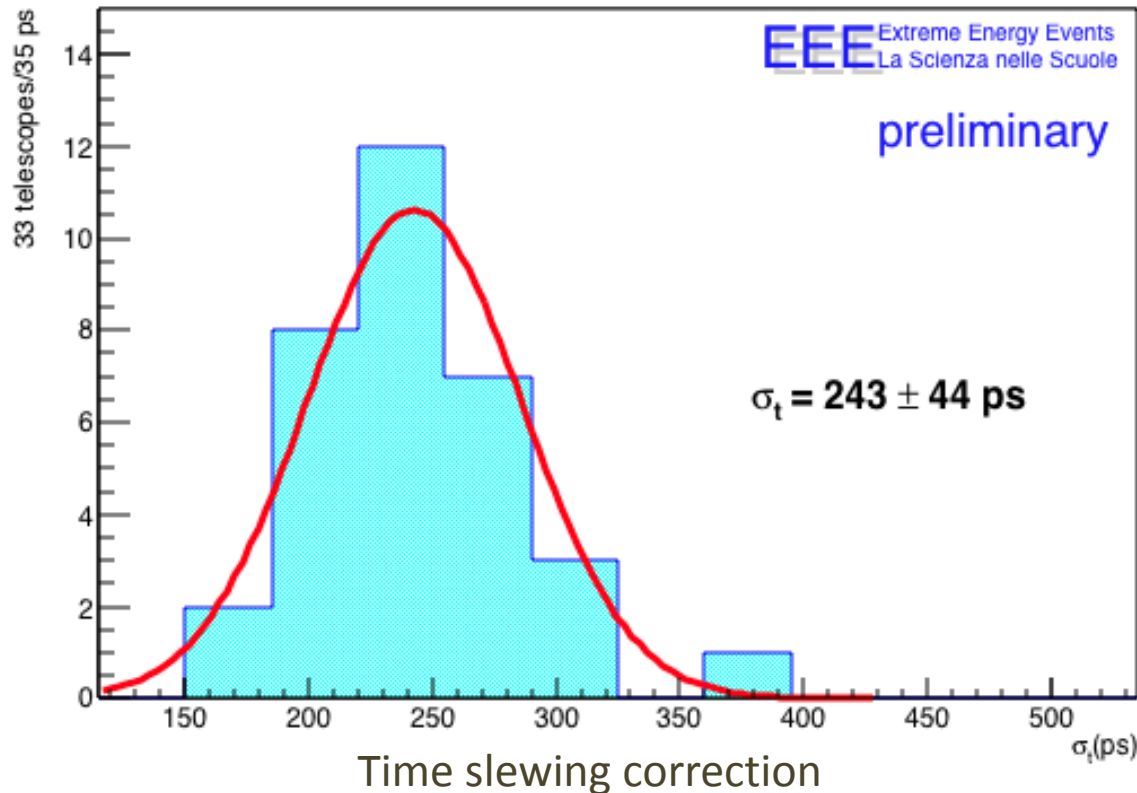
Resolution range from 175 to 290 ps



Time Resolution

Time resolution for the 3 MRPCs (33 Telescopes **RUN3**)

$$\sigma_{T \text{ ALL}} = \sqrt{\frac{3}{2}} \sigma_{\Delta T} \sim 243 \pm 44 \text{ ps}$$



Study of the EEE MRPC Telescopes Performance

Performance measured with cosmic particles in the EEE stations inside school building

- ✓ Stable efficiency vs HV HV > 17 kV **95%**
- ✓ Corrections improve the space and time resolution

Fully compatibility RUN2 +Run3

Strip by strip calibration + **Time slewing corrections**

MRPC vs EEE Telescopes

(Test beam) (Cosmic rays)

- TDCs resolution
- Chambers alignment
- Multiple scattering
- Strip calibrations
- Propagation of the signal along the strips

EEE MRPC Performance: a paper in preparation

The Extreme Energy Events Observatory: an overview of the MRPC telescopes performances.

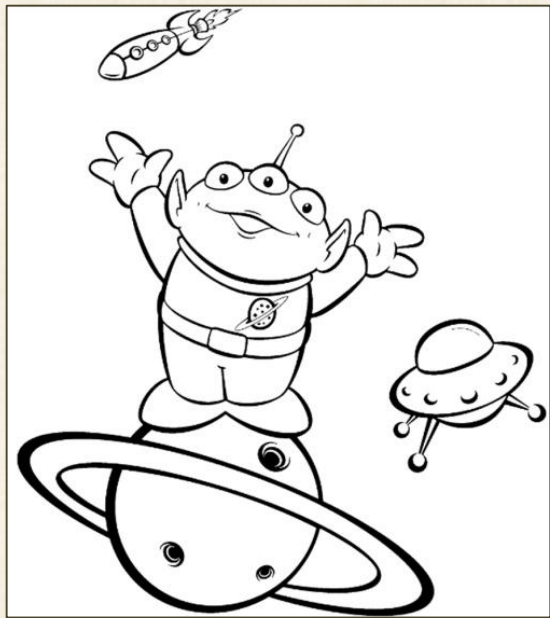
The EEE Collaboration

Received: date / Accepted: date

Abstract The muon telescopes of the Extreme Energy Events (EEE) Project [1] are based on Multigap Resistive Plate Chamber (MRPC) technology. The EEE array is composed, so far, of 50 telescopes, each made of three MRPC planes, spanning more than 10 degrees in latitude and 11 in longitude, organized in clusters and single telescope stations distributed all over the Italian territory and installed in High Schools. The study of Extensive Air Showers (EAS) requires excellent performance in terms of time and spatial resolution, efficiency, tracking capability and stability. The data from two recent coordinated data taking periods, named Run 2 and Run 3, have been used to measure these quantities and the results are described, together with a comparison with results from beam test performed in 2006 at CERN.



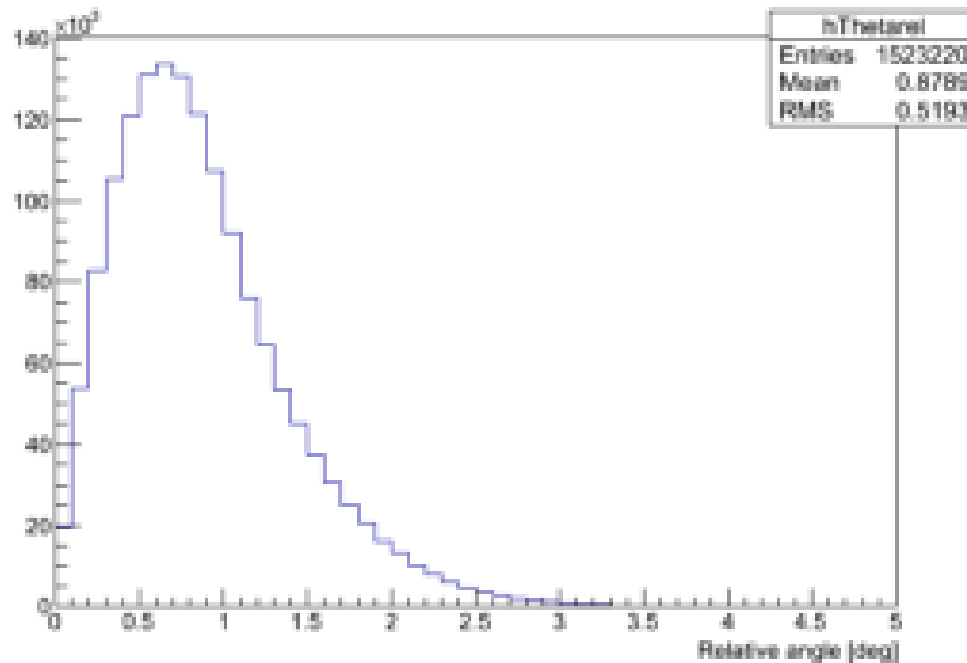
THANKS FOR YOUR ATTENTION



...*SPARE*

Performance of the EEE MRPC Telescope

The direction of cosmic particles passing through the telescope is reconstructed with a precision that depends on the MRPC spatial resolution.



TDCs 100 ps

$\Delta X_2 = 0,92$ cm

$\Delta\theta = 0,88^\circ$

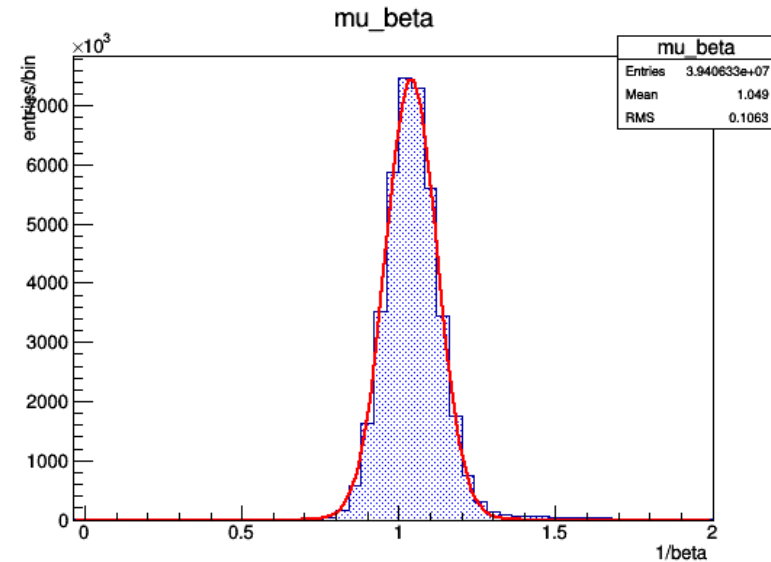
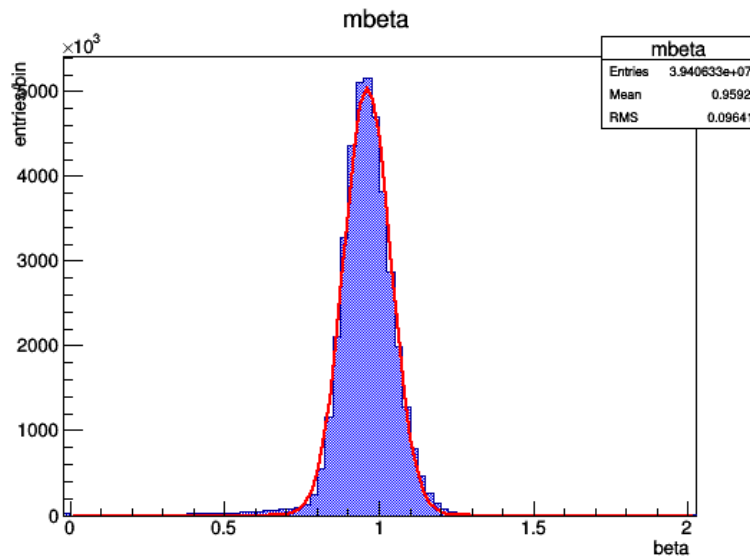
Geometrical simulation: evaluation of the relative angle between a simulated track and the track reconstructed with the telescope



The MRPC Telescopes

β for the 3 MRPCs $\beta = \frac{L_{track}}{ToF c}$

CAGL-02

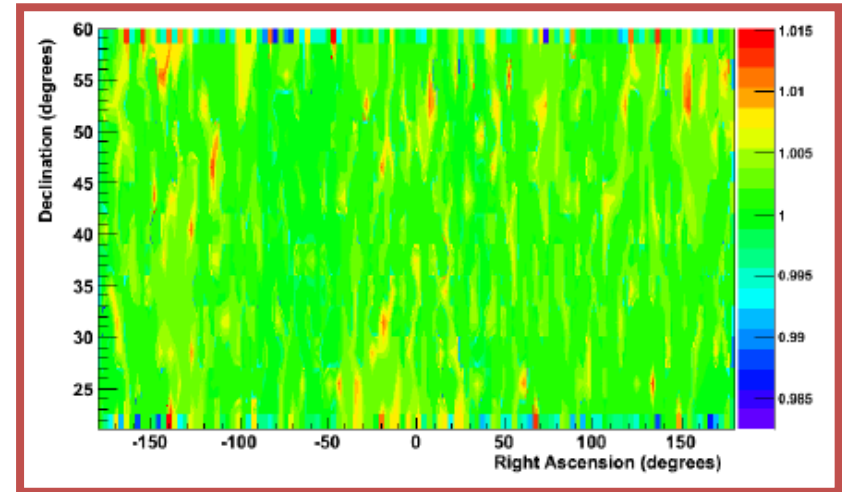


Resolution on $1/\beta$ measurement
around 10%



Looking at the sub-TeV sky with cosmic muons detected in the EEE MRPC telescopes

- **4 EEE sites included**
- **Set of 110 M events analyzed**
- **2D Right Ascension-Declination maps**
- **No anisotropy probed at the level of $\approx 1\%$**



EEE Site (Location)	Geographical location	Number of analysed events
SAVO-01 (Savona)	44° 18.366' N, 8° 28.078' E	48.6 M
CAGL-01 (Cagliari)	39° 13.767' N, 9° 7.084' E	16.6 M
TRIN-01 (Trinitapoli)	41° 21.167' N, 16° 5.004' E	20.2 M
CATA-01 (Catania)	37° 31.501' N, 15° 4.046' E	19.3 M

- ✓ results obtained from each day in a single telescope station were summed together, with a weight proportional to the number of collected events in each day
- ✓ due to the geometrical acceptance of the telescopes, the range between 20° and 60° was considered, to avoid border effects where statistics is low

Some Physics Results

Scientific instrument for physicists

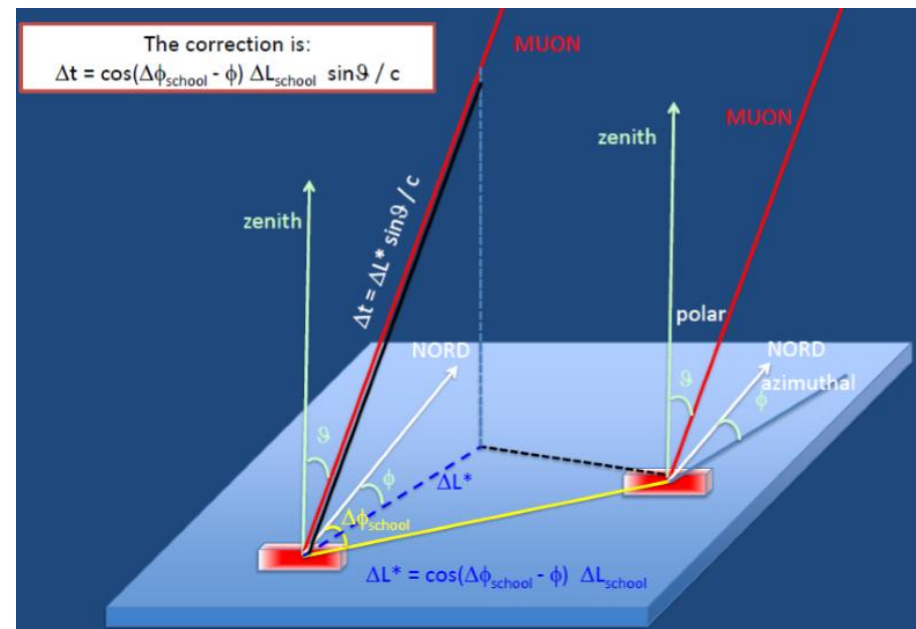
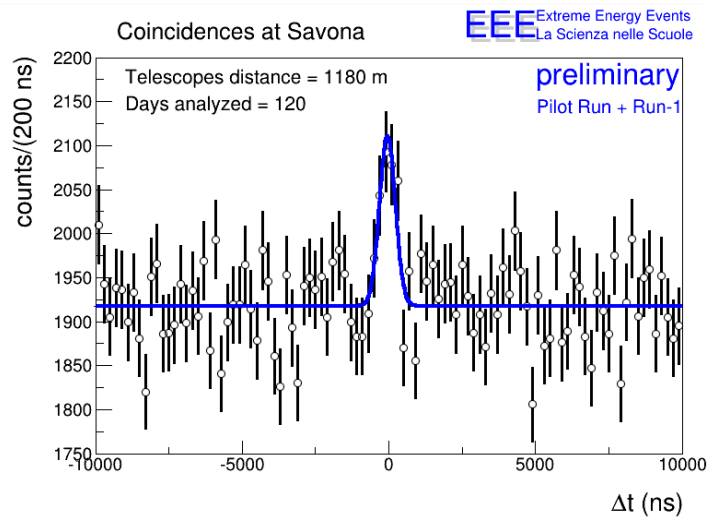
Many different topic in the cosmic ray physics:

Search of coincidences,

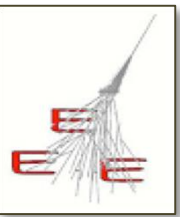
Correlations to solar activity,

Upgoing tracks,

Search of anisotropy



Some Physics Results



Scientific instrument for physicists

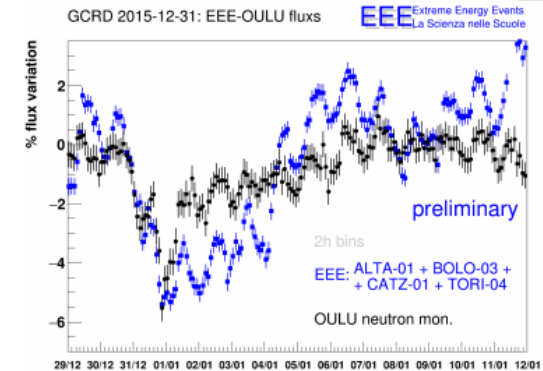
Many different topic in the cosmic ray physics:

Search of coincidences,

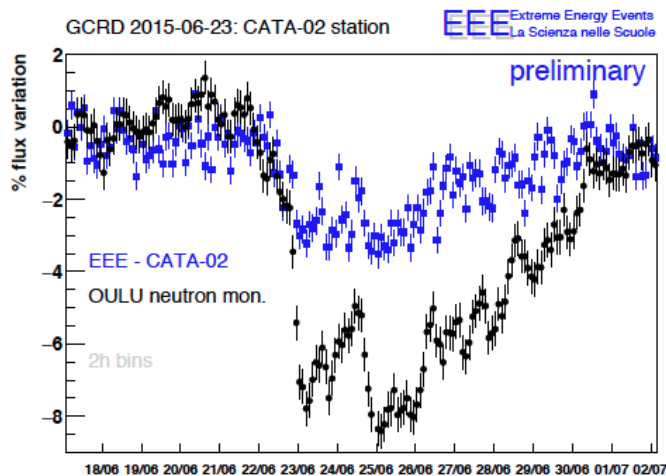
Correlations to solar activity,

Upgoing tracks,

Search of anisotropy



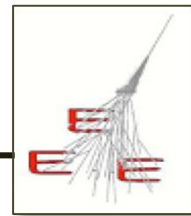
Flux decrease as observed by 6 stations
(adding up data set from different stations reduce the
signal/noise value)



Flux decrease as observed by the CATA-02 station
(Forbush June 2015)

Rapid decreases (Forbush decreases) of
the galactic cosmic-ray flux, associated to
solar phenomena are detected by the
EEE stations in good agreement with
neutron monitor stations

Some Physics Results



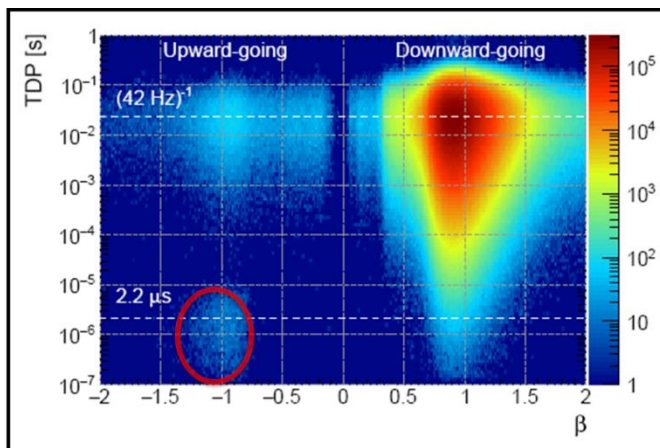
Scientific instrument for physicists

Many different topic in the cosmic ray physics:

Search of coincidences,
Correlations to solar activity,

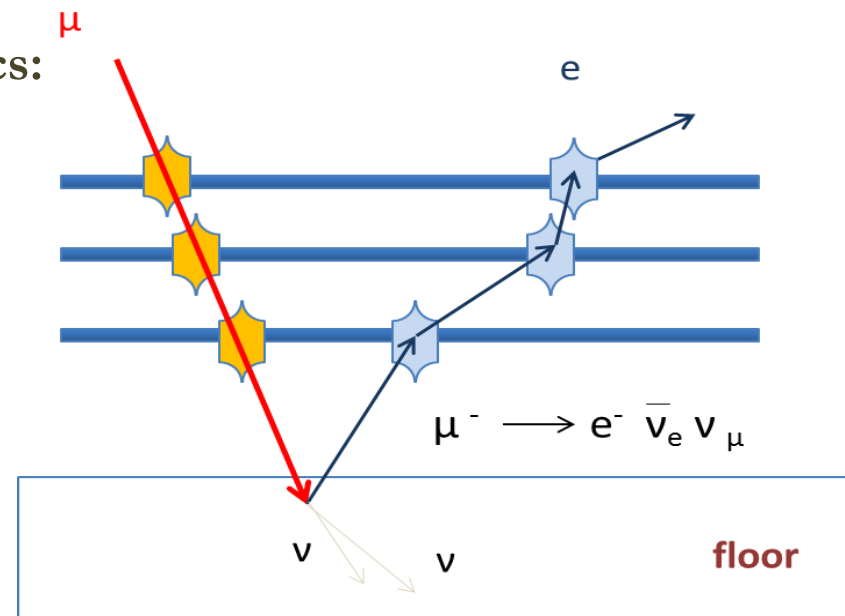
Upgoing tracks,

Search of anisotropy



Upgoing low energy electron
Good Signature: **delay ~ 2 μs**
+ large χ^2

ACQUISITION deadtime = 0.15 μs
They are 2 separate events.



Upgoing events are observed ($\sim 1/2000$) in EEE telescopes.

A fraction of them can be clearly identified as electrons coming from muon decays, by means of a time correlation with previous events ($\sim 2 \mu\text{s}$)