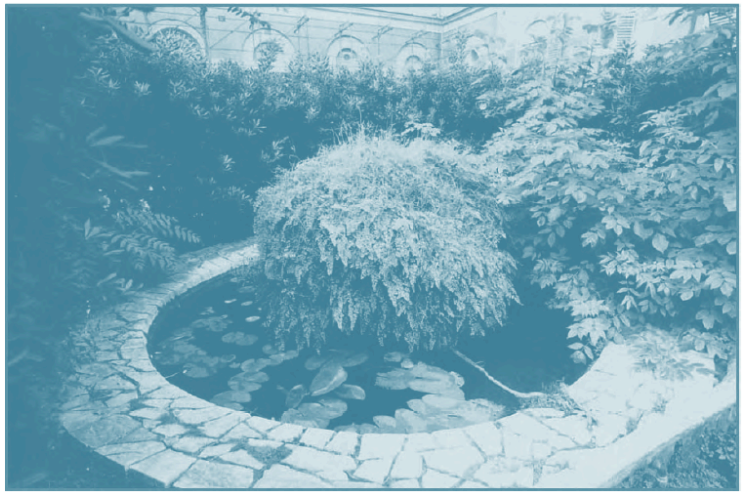
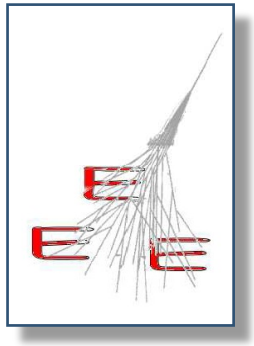
"Ettore Majorana" Foundation and Centre for Scientific Culture
International School of Subnuclear Physics
53rd Course: THE FUTURE OF OUR PHYSICS INCLUDING NEW FRONTIERS

The EEE – Extreme Energy Events Project of the Enrico Fermi Centre





LUISA CIFARELLI — Centro Fermi, Rome (IT)
Italian Physical Society
University & INFN, Bologna (IT)

CENTRO FERMI
Museo Storico della Fisica e
Centro Studi e Ricerche Enrico Fermi

Erice, 29 June 2015

Mission of the Enrico Fermi Centre – CENTRO FERMI

CENTRO FERMI is a research institution established in 2001 and devoted to interdisciplinary studies.

It aims to integrate the knowledge generated in different fields, and to promote discussion among top scientists with different areas of expertise, in order to create what Enrico Fermi would have liked to establish in Italy:

a centre dedicated to frontier research in physics and to its wide applications for the benefit of humankind.

Main Activities

The activities of CENTRO FERMI characterize its uniqueness:

1. Grants, for "New Talents" and Senior/Junior researchers, to study original and interdisciplinary research topics;

2. Research Projects, including those defined as Strategic Projects, for the realization and promotion of interdisciplinary original research;

3. Activities for the Dissemination of Scientific Culture and Historic Memory, through the restoration of the "Monumental Complex" of Via Panisperna, the old Institute of Physics which has an extraordinary historical value, to be used in part for the Museum.

Strategic Research Projects

1. Extreme Energy Events (EEE) – Science inside Schools

2. Quark-Gluon Coloured World (QGCW) – ALICE and beyond

3. Advanced Techniques for Biomedical Applications

4. Energy

5. Environment and Cultural Heritage

6. Fundamental Physics, History of Physics & Complexity

Dissemination of Scientific Culture & Historic Memory

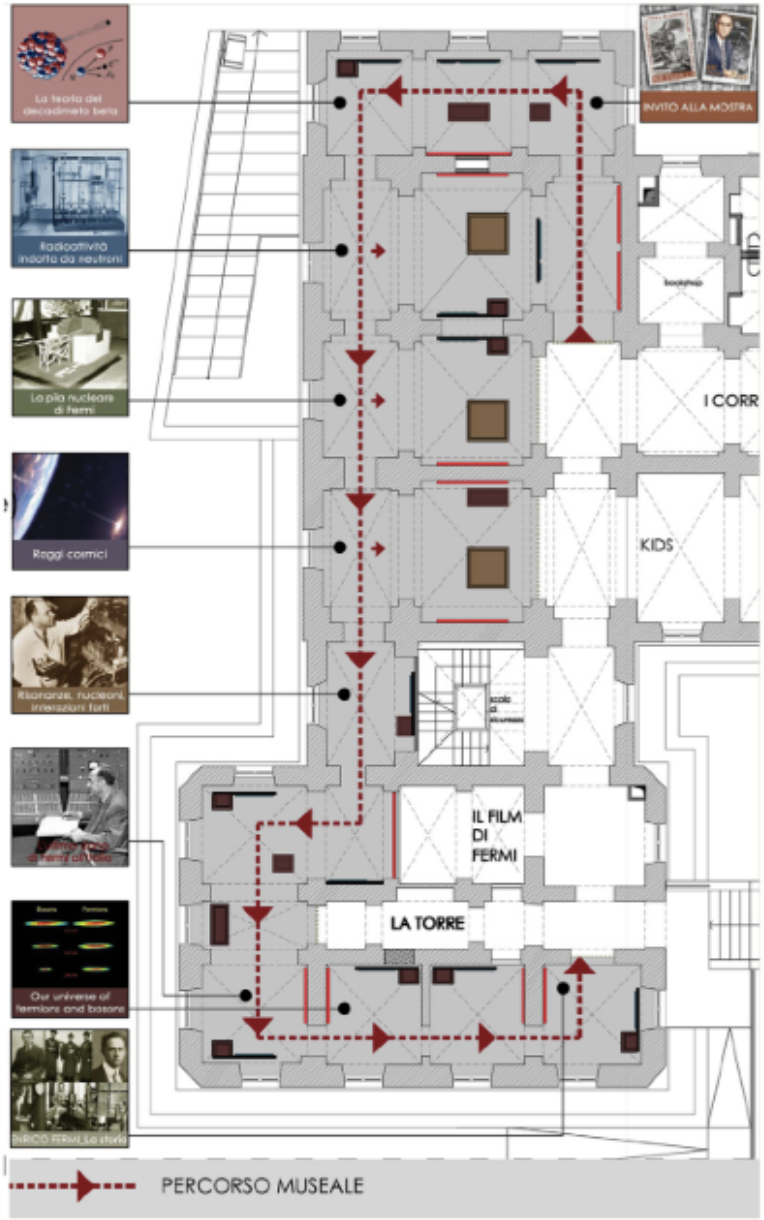
- Refurbishing of the historical building of the Institute of Physics (1880) at Via Panisperna in Rome started in 2010

- Fermi Fountain inaugurated as the 1st Historic Site of the European Physical Society (EPS) in 2012 in the presence of the President of the Italian Republic Giorgio Napolitano

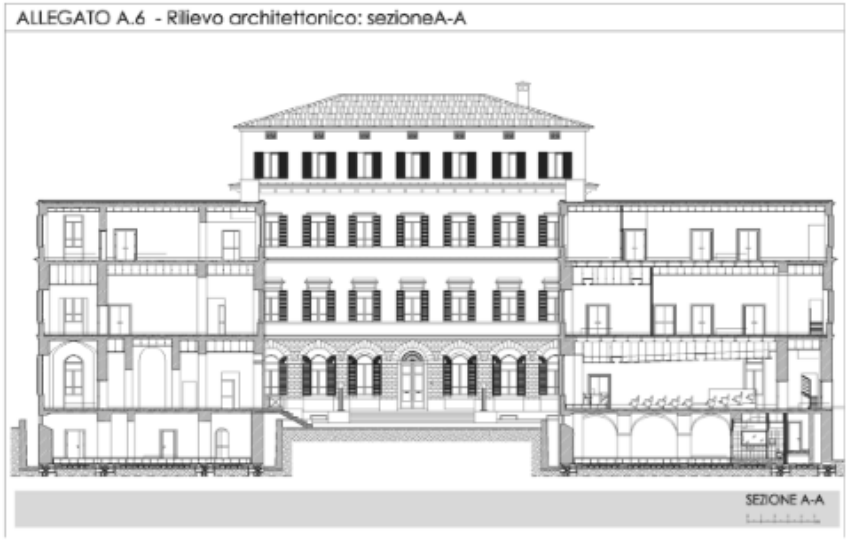
Fermi Fountain
1st Historic Site of the European Physical Society
April 2012

Fermi Museum

- MoUs established / to be established with:
  - Sapienza University (Rome)
  - Domus Galieiana (Pisa)
  - Fermilab (Chicago)
  - Fermi Institute, University of Chicago
  - Chicago Library
- MUSEO FERMI working group operative since early 2013
- Presentation of MUSEO FERMI Project in 2014
- Inauguration of MUSEO FERMI at Via Panisperna in … 2016 (??)
- Inauguration of *Fermi Exhibition* in 2015 on the occasion of IYL2015 and 90th anniversary of the discoveries that led Fermi to the Nobel Prize



Ipotesi di percorso museale in una parte del piano terreno della sede istituzionale del *Centro Fermi*.



Sezione dell'edificio di Via Panisperna, visto dal lato dell'ingresso al *Centro Fermi*, ossia dal lato del giardino dove si trova la storica fontana di Fermi.

L'edificio di Via Panisperna in fase di restauro (giugno 2015).

THE EEE – EXTREME ENERGY EVENTS PROJECT

SCIENCE INSIDE SCHOOLS
SCIENCE IN THE HEART OF THE YOUNG

A. ZICHICHI, *Progetto "La Scienza nelle Scuole"*
EEE – Extreme Energy Events
Società Italiana di Fisica (SIF), Bologna
1st Ed. 2004; 2nd Ed. 2005
3rd Ed. 2012, 4th Ed. 2014

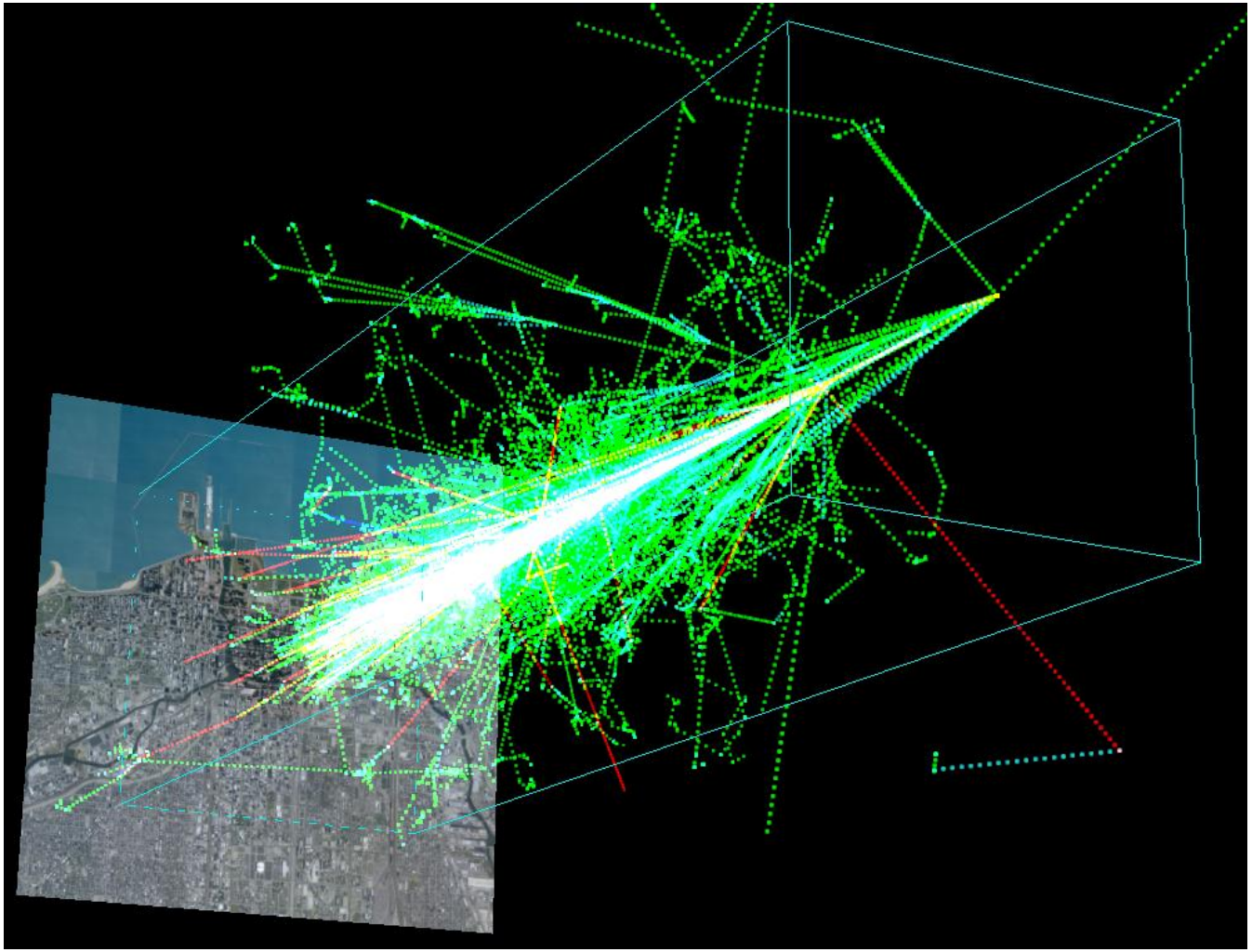
Collaboration project

Centro Fermi
CERN
INFN
MIUR
SIF

Launch event on 3 May 2004 at CERN

R. Aymar – CERN DG
L. Moratti – Minister of Science & Education
A. Zichichi – Centro Fermi President

Physics goal of EEE Project:
Detect atmospheric showers of very high / extreme energy by detecting secondary muons on ground coming from very high energy primary cosmic rays



How?

By equipping a large number of Italian High Schools with a large EEE telescope:

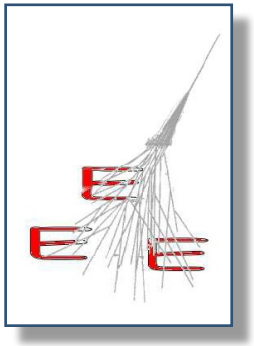
a very sophisticated particle tracking detector
with outstanding timing capablities

→ The EEE Project has a dual role:

- Education instrument for students
  together with their tutors & teachers
- Scientific instrument for physicists
  which involves students
  in a forefront research experiment

It is indeed a physics experiment !

The EEE Project



Since 2004 …

Pilot project with 7 EEE telescopes in High Schools
(Bari, Bologna, Cagliari, Catania, Frascati, L'Aquila, Torino)

→ In 2015: > 50 EEE telescopes

42+5 in High Schools

+5 in Labs

across an overall area of ≈ 0.5 x 10^6 km^2

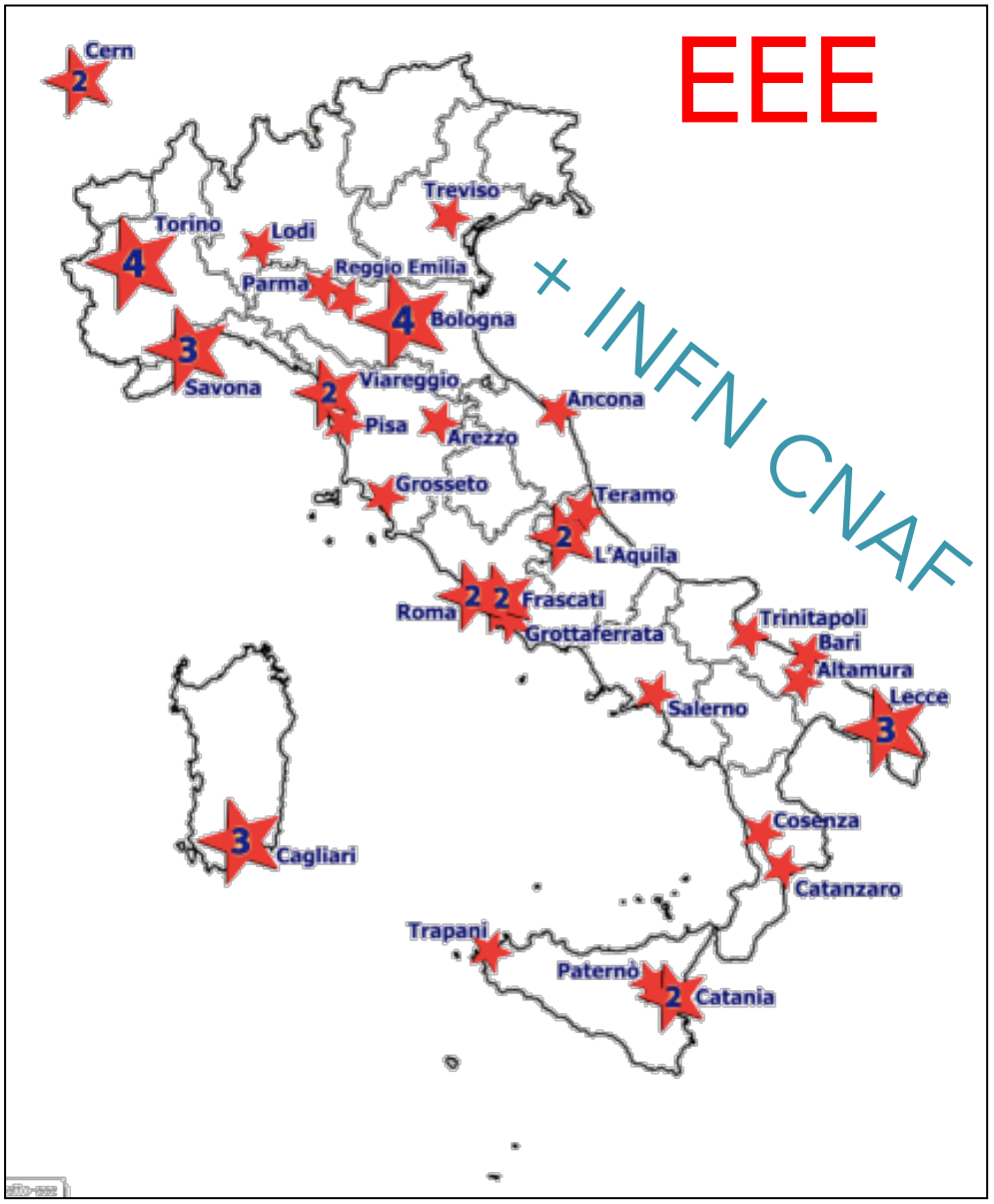
At present, 47 High Schools are involved:
42 + 5 new High Schools in 2015

They are mostly distributed in clusters in the whole Italian territory

+ 2 telescopes at CERN
+ 3 in INFN Units

Total: 52 telescopes

→ 3 new High Schools in 2016 → 50 !!!



… 25 High Schools in waiting list !!!

After initial MIUR & INFN funding in 2004 → Extra MIUR funding in 2012-2013

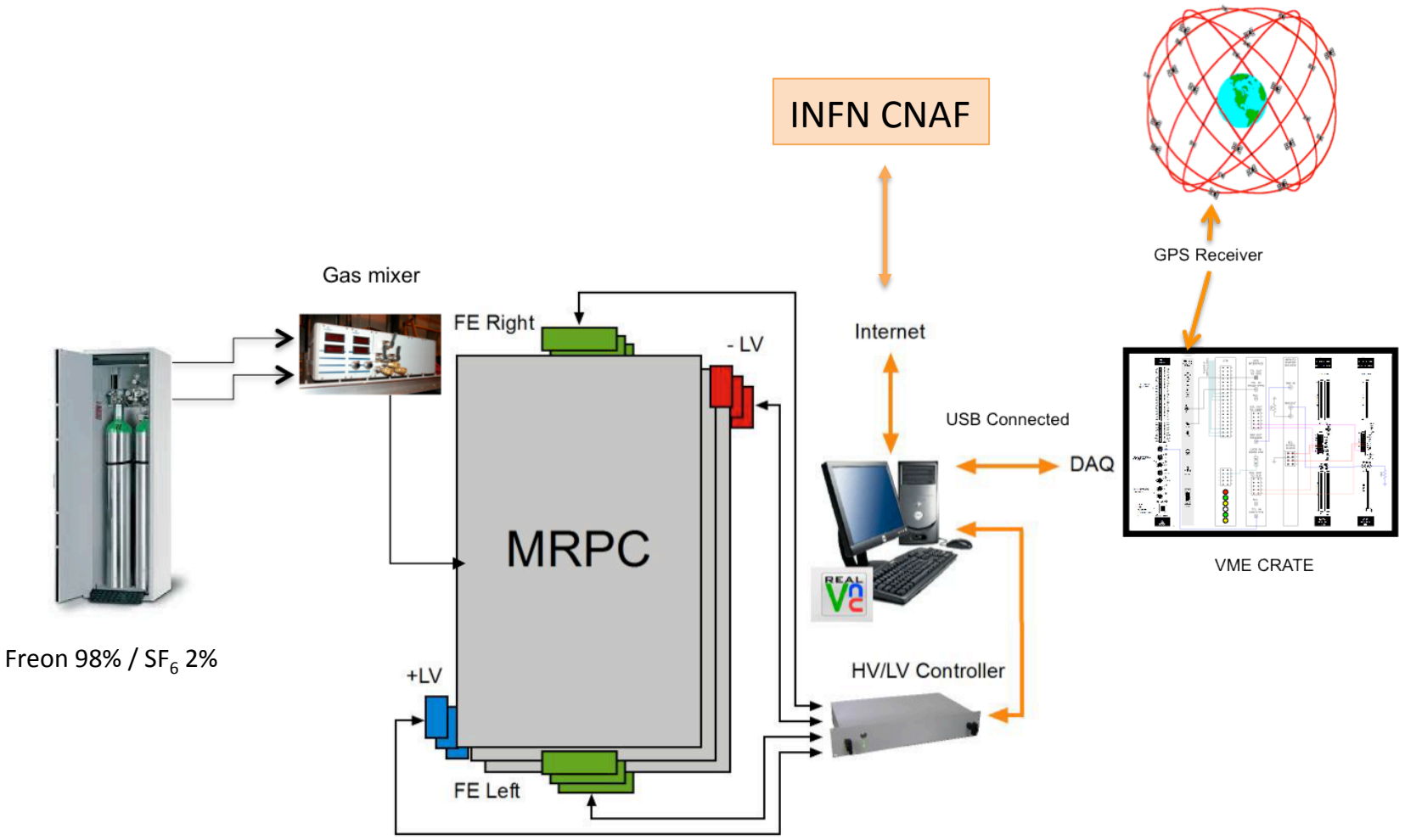
- Progetti Premiali 2012 (7% of FOE) for 2013-2014
  CF as PI (Principal Investigator) – 1 year
  - EEE (Extreme Energy Events) – An Italy-Wide Observatory of Cosmic Rays for Astrophysical Research and Advanced Scientific Training
    CF with INFN

- Progetti Premiali 2013 (7% of FOE) for 2014-2015
  CF – 1 year
  - EEE (Extreme Energy Events)
    CF

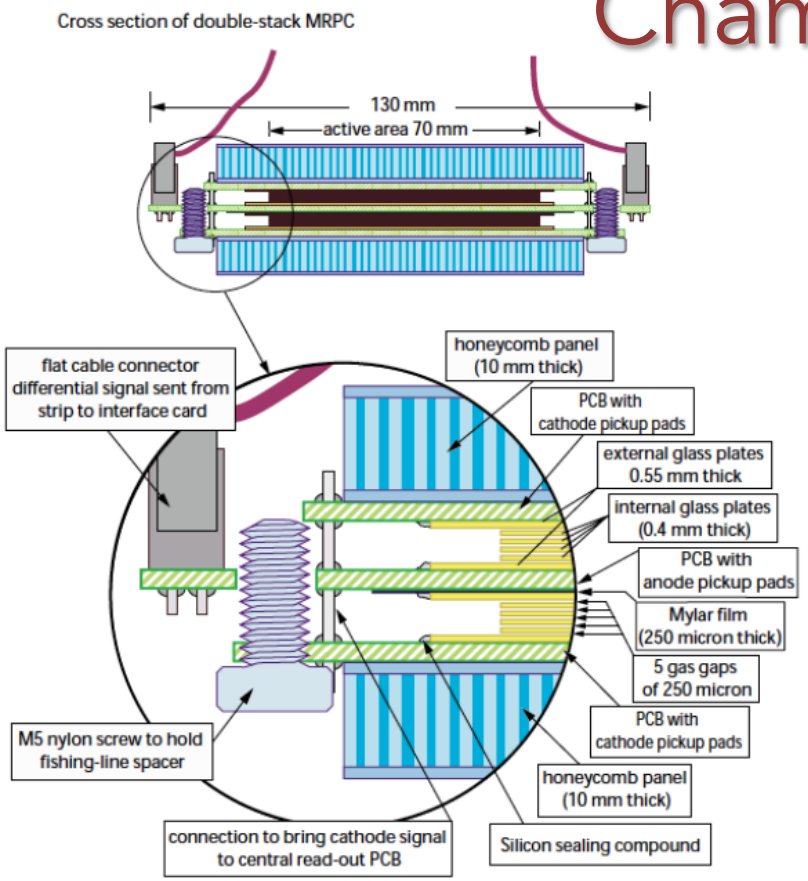
New boost of the EEE Project
thanks to the introduction of
automatic – simultaneous – direct
data transfer to **INFN-CNAF**
computer centre

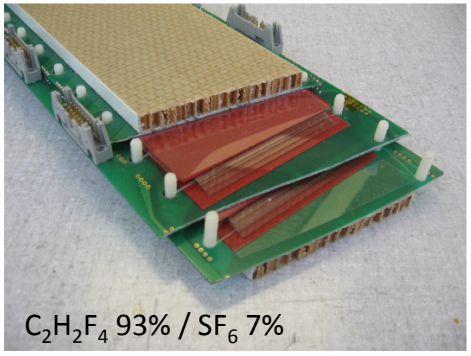
→ **high statistics** of cosmic muons
→ **immediate** data reconstruction & storage

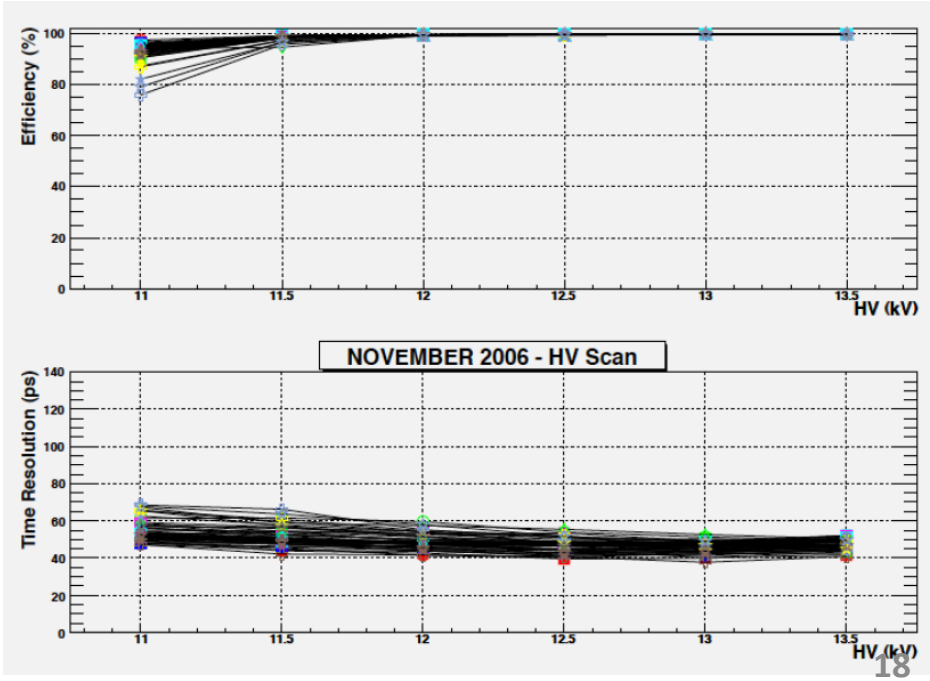
EEE telescope with 3 MRPCs and relative system



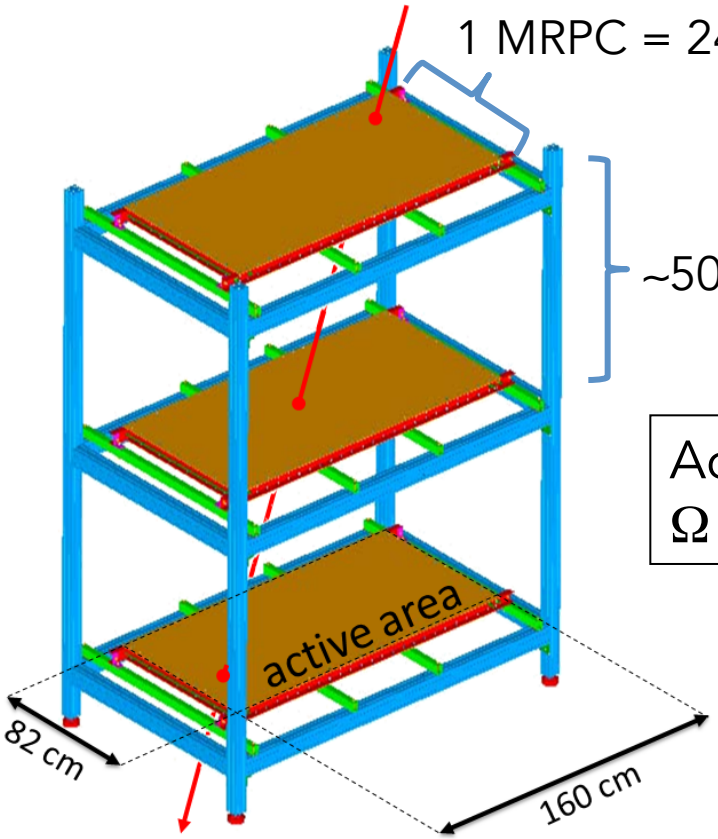
ALICE-TOF Multigap Resistive Plate Chamber (MRPC)





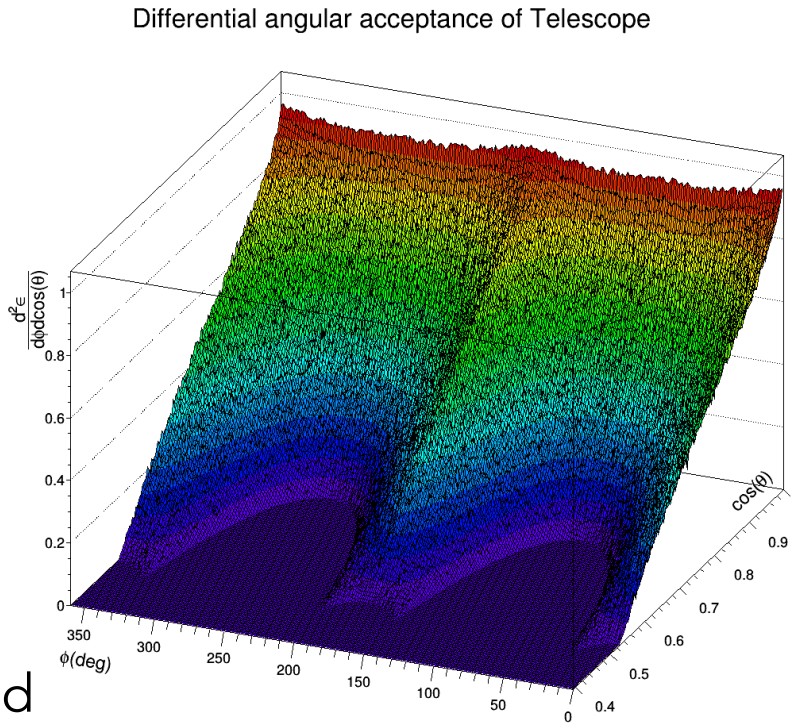


The EEE telescope



MRPC chambers are built by High School students at CERN (starting from 2004)
and maintained by them under the supervision of EEE researchers

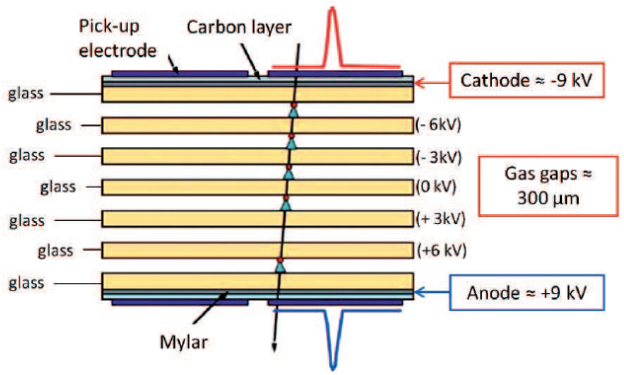
Acceptance
Ω = 1.6 sr



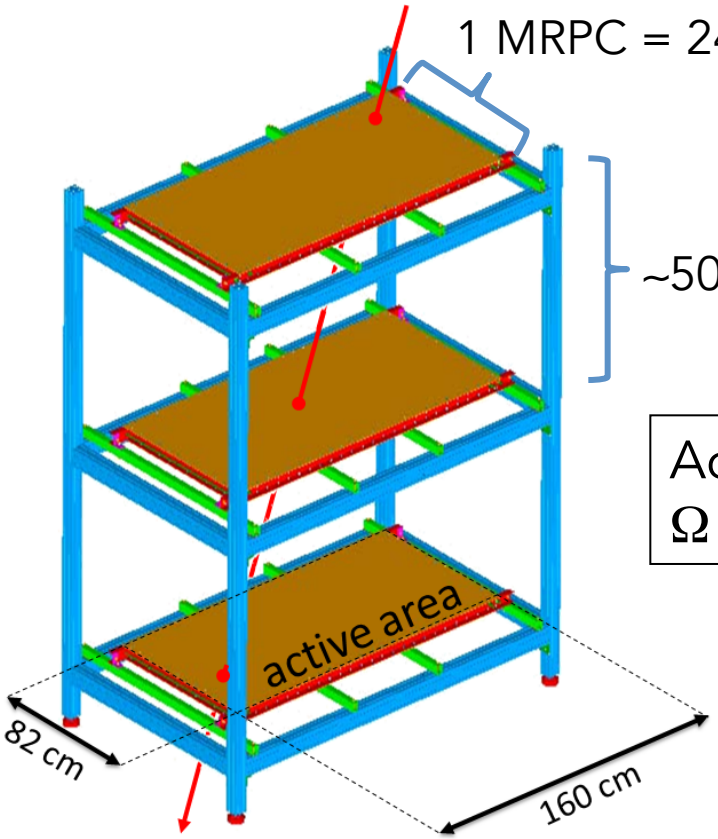
3 MRPC planes with 24 strips each read at both ends → 144 readout channels

- The trigger requires a hit signal on each end of the 3 MRPCs within a ±500 ns window
- Cosmic muons are tracked & reconstructed

EEE Project
MRPC construction



The EEE telescope



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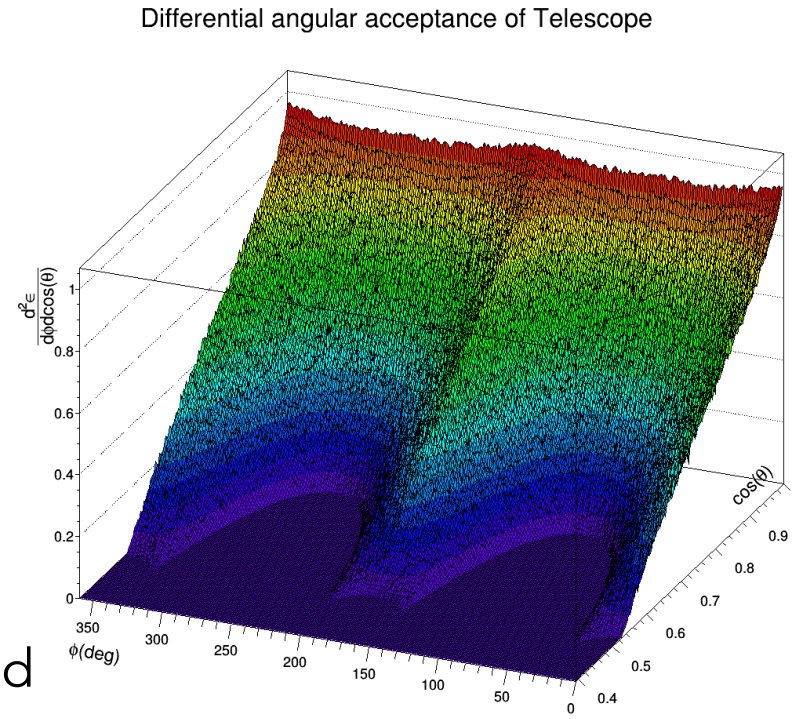

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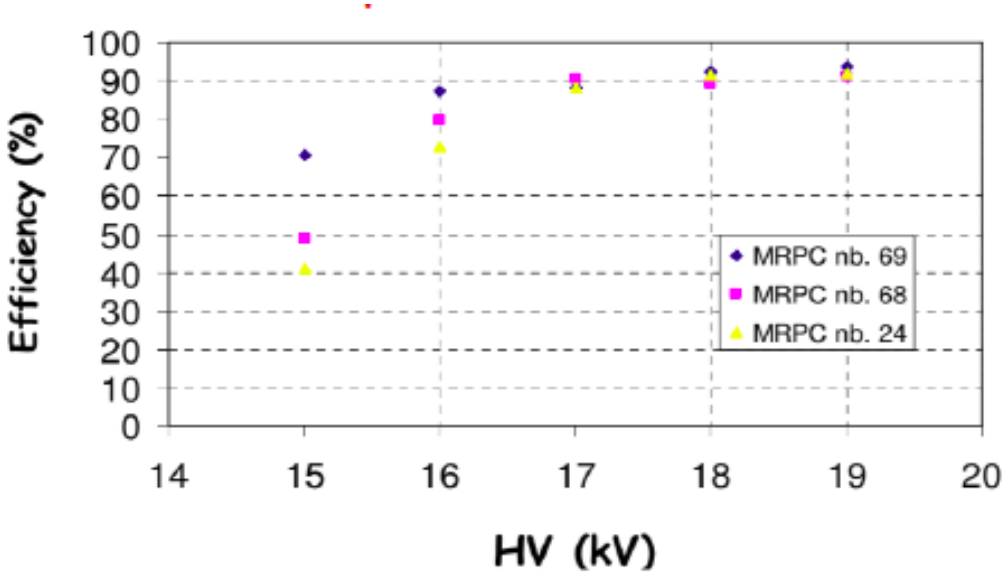
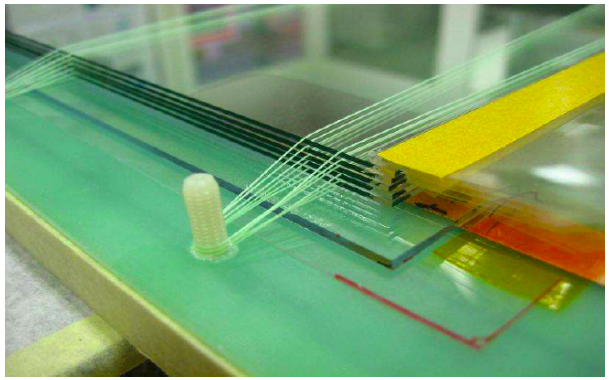
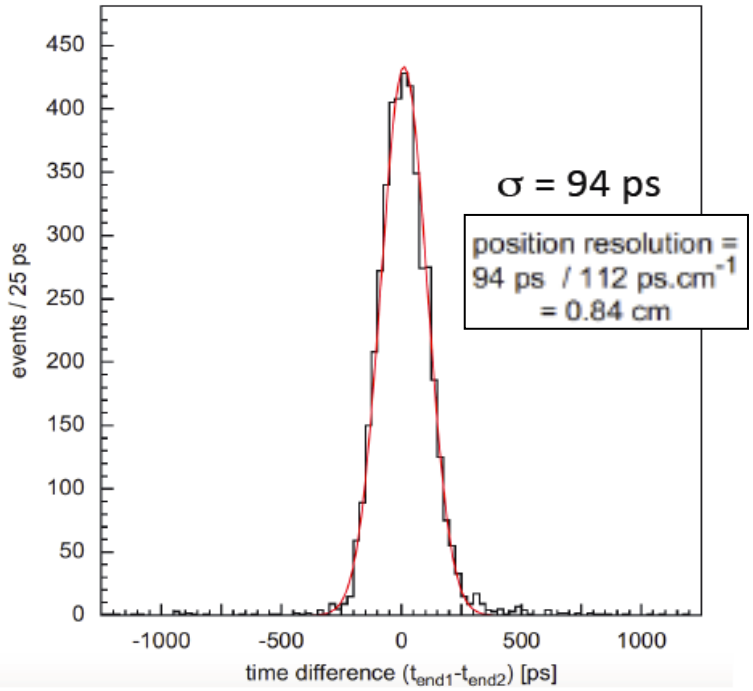
The EEE MRPC

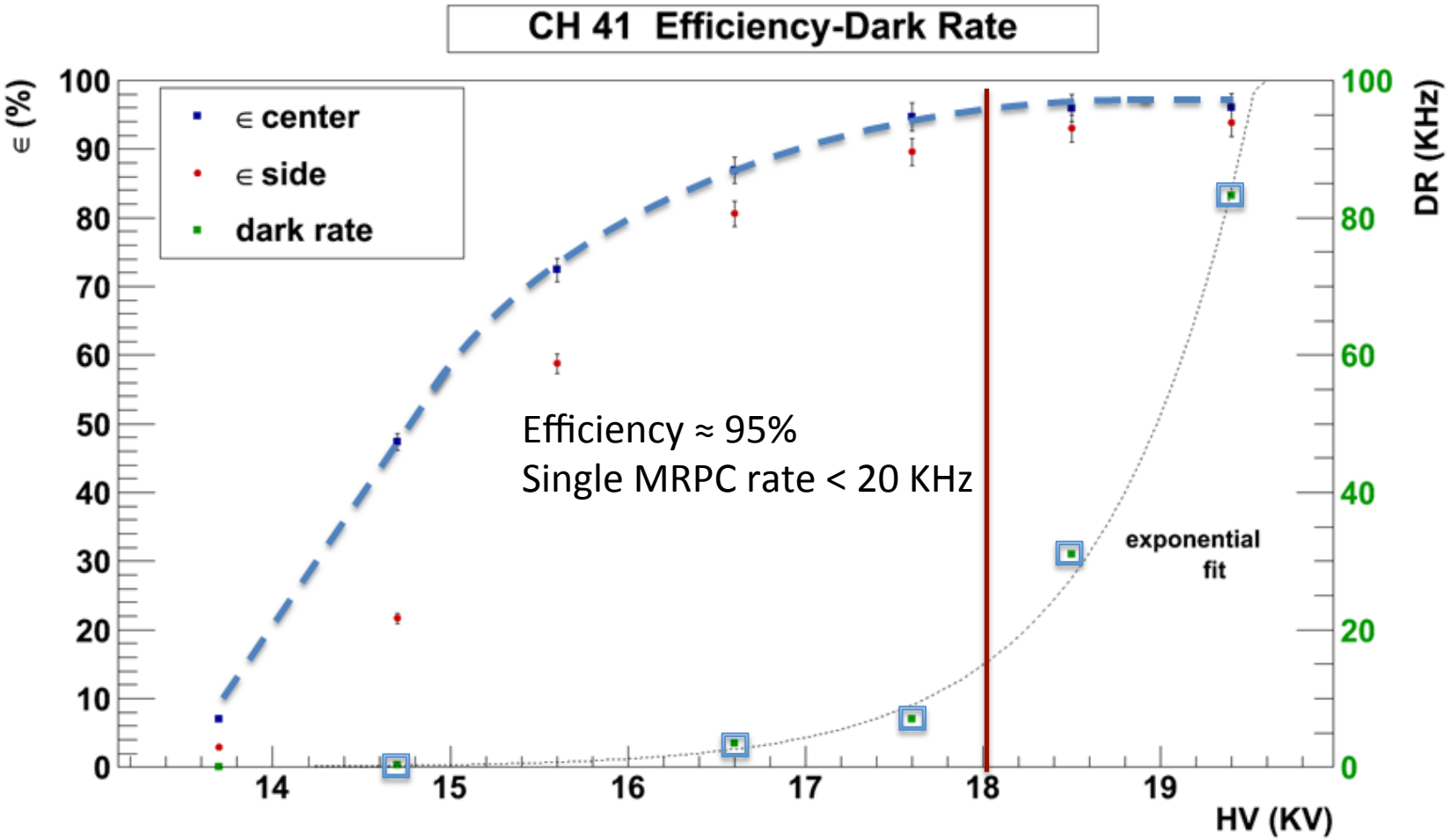




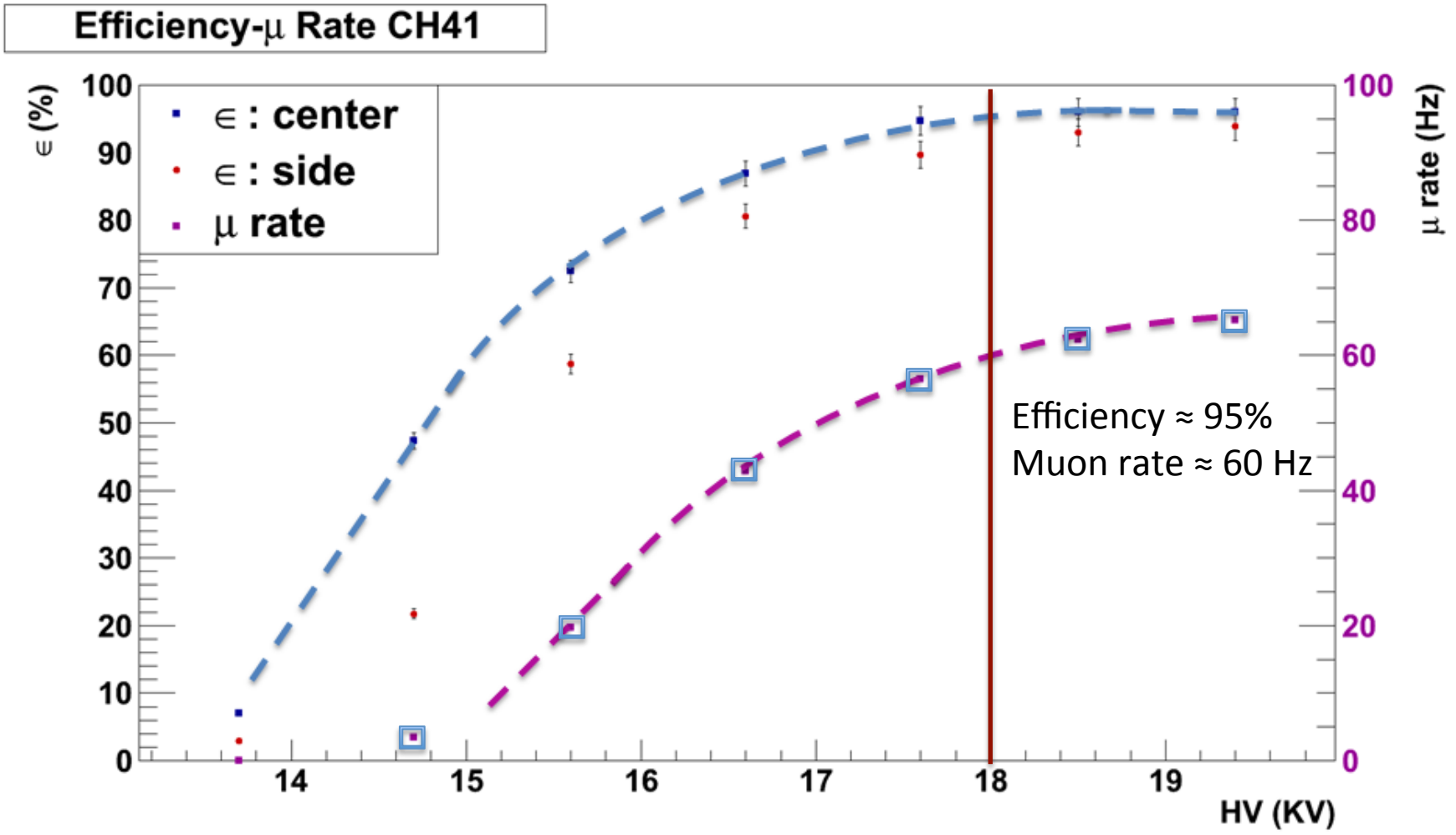


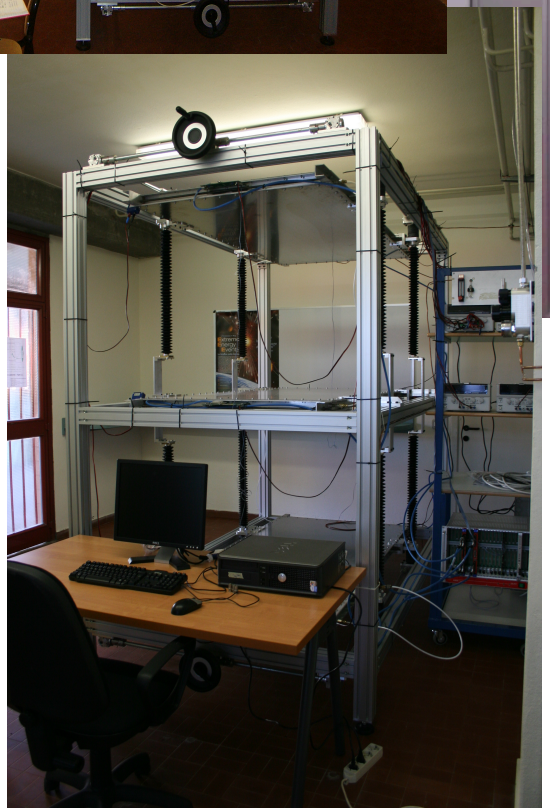
The time resolution of the MRPC is better than 100 ps, allowing to reconstruct the position along the strip with a precision of 0.84 cm

Efficiency vs. Noise



Efficiency vs. Muon rate (3-MRPC coincidence rate)





EEE telescopes installed inside High Schools

The "event time" measurement

Each telescope is equipped with a GPS to measure the UTC time with very high precision (GPS resolution ~100 ns)

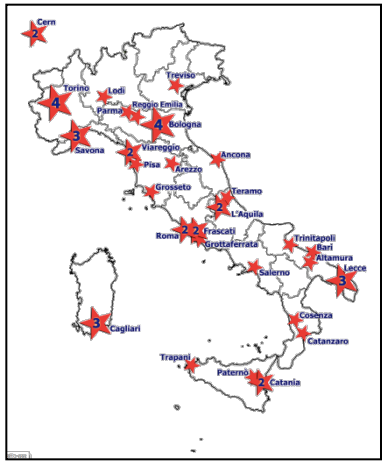
The GPS cannot provide directly a time when a telescope trigger signal is obtained

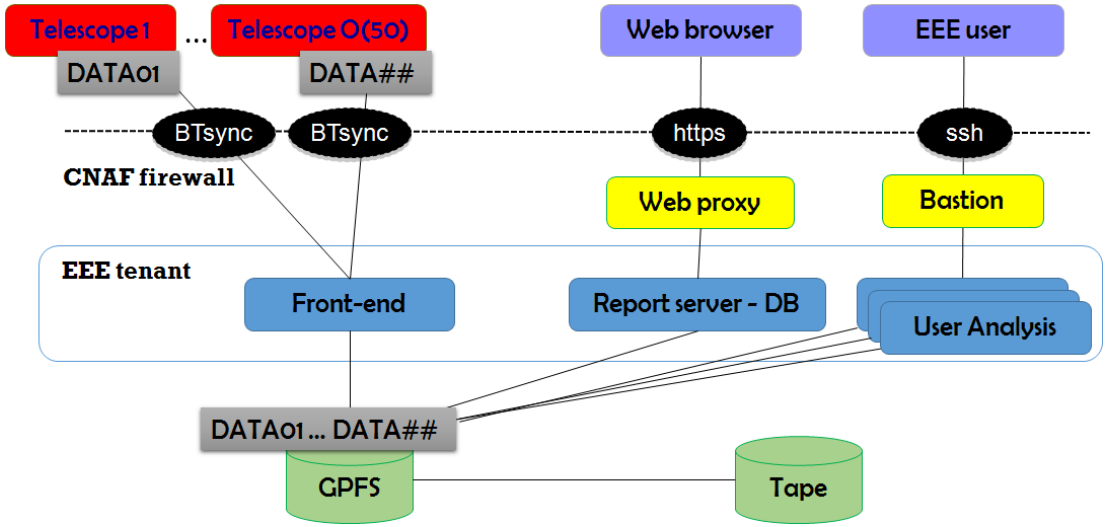
→ The GPS provides a signal once per second and it resets a TDC counter which is devoted to count time (TDC bin ~25 ns) in between two GPS signals

→ The TDC counts are read & associated to the event when the telescope trigger signal is obtained

The GPS time is crucial to study coincidences between near and far telescopes → extensive air showers → extreme energy events

The computing and data infrastructure to interconnect EEE telescopes





The Extreme Energy Event (EEE) experiment is devoted to the search of high-energy cosmic rays through a network of telescopes installed in about fifty high schools distributed throughout the Italian territory.

One of the main goals of the project is to involve young students in a high-level scientific enterprise.

Therefore the experiment is very peculiar and requires new solutions for the data management.

Data are collected (all Schools → CNAF) and automatically reconstructed

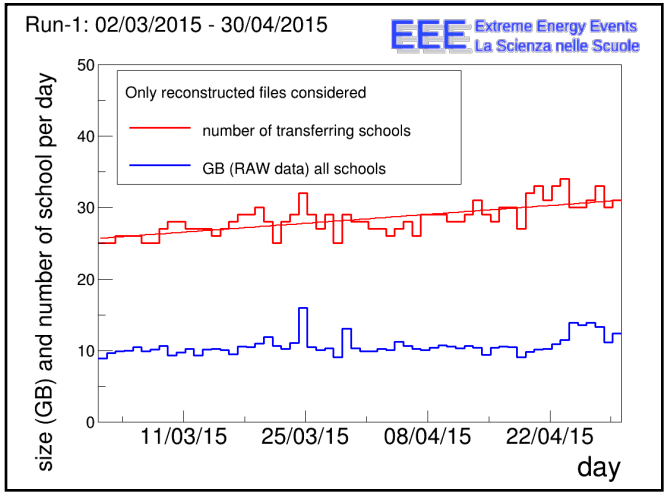
The EEE Project
2014 Pilot run
&
2015 Run-1

- In 2014, a Pilot run involving the simultaneous and, for the first time, completely automatic acquisition and data storage of EEE events from half (23) of the EEE telescopes at the INFN CNAF computer centre of Bologna has been performed
  → Nearly 1 billion events i.e. muon tracks collected in nearly one month (27 October-14 November)

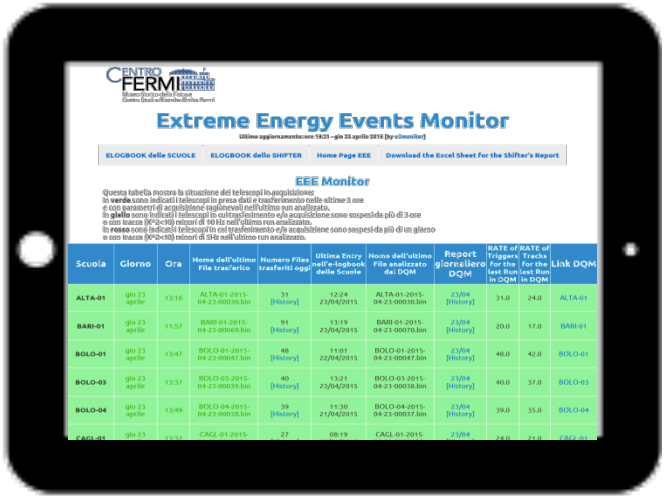
- In 2015, for Run-1, two thirds (35) of the EEE telescopes were ready to efficiently participate
  → Over 5 billion events i.e. muon tracks collected in about three months (2 February-30 April)

Data Transfers and Run-1 stats

- So far 35 telescopes connected to INFN CNAF and transferring data using *bittorent sync*
- A CNAF front-end is dedicated to receive all the data with a required bandwidth of 300 kB/s
- A *btsync client* is installed in each School (Win OS)
- 5-10 TB per year are expected
- Full statistics from Pilot run* to Run-1*: ~2.4 TB (raw: ~2 TB, reco: ~0.4 TB) corresponding to
  ~7 billion cosmic rays
  (+3 TB from past years)



Run-1 day-by-day statistics.



EEE monitor with information in real time
https://www.cnaf.infn.it/eee/monitor/

*Pilot run from 27-10-2014 to 14-11-2014
Run-1 from 02-03-2015 to 30-04-2015

Quasi online monitor

CENTRO FERMI
Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

Extreme Energy Events Monitor

Ultimo aggiornamento: ora 09:42 - dom 28 giugno 2015 [by e3monitor]

ELOGBOOK delle SCUOLE | ELOGBOOK dello SHIFTER | Home Page EEE | Download the Excel Sheet for the Shifter's Report

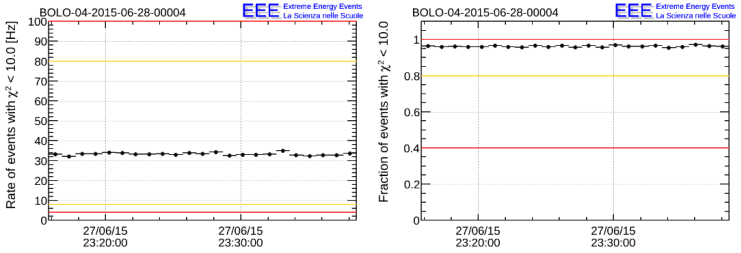
EEE Monitor

Questa tabella mostra la situazione dei telescopi in acquisizione:
In **verde** sono indicati i telescopi in presa dati e trasferimento nelle ultime 3 ore
e con parametri di acquisizione ragionevoli nell'ultimo run analizzato.
In **giallo** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di 3 ore
o con tracce (X^2<10) minori di 10 Hz nell'ultimo run analizzato.
In **rosso** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di un giorno
o con tracce (X^2<10) minori di 5Hz nell'ultimo run analizzato.

Scuola	Giorno	Ora	Nome dell'ultimo File trasferito	Numero Files trasferiti oggi	Ultima Entry nell'e-logbook delle Scuole	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	lun 11 maggio	14:31	ALTA-01-2015-05-07-00029.bin	0 [History]	11:25 27/04/2015	ALTA-01-2015-05-07-00028.bin	08/05 [History]	31.0	23.0	ALTA-01
BARI-01	sab 13 giugno	11:45	BARI-01-2015-06-13-00016.bin	0 [History]	14:00 22/05/2015	BARI-01-2015-06-13-00015.bin	14/06 [History]	20.0	17.0	BARI-01
BOLO-01	dom 28 giugno	09:17	BOLO-01-2015-06-28-00026.bin	27 [History]	09:24 05/05/2015	BOLO-01-2015-06-28-00025.bin	28/06 [History]	38.0	28.0	BOLO-01
BOLO-03	lun 22 giugno	17:14	BOLO-03-2015-06-22-00003.bin	0 [History]	10:14 26/05/2015	BOLO-03-2015-05-26-00034.bin	27/05 [History]	36.0	32.0	BOLO-03
BOLO-04	dom 28 giugno	09:33	BOLO-04-2015-06-28-00025.bin	26 [History]	12:31 04/05/2015	BOLO-04-2015-06-28-00023.bin	28/06 [History]	37.0	34.0	BOLO-04
CAGL-01	dom 28 giugno	08:58	CAGL-01-2015-06-28-00013.bin	14 [History]	11:16 26/06/2015	CAGL-01-2015-06-28-00012.bin	28/06 [History]	17.0	14.0	CAGL-01
CAGL-02	dom 28 giugno	09:29	CAGL-02-2015-06-28-00022.bin	23 [History]	09:34 24/04/2015	CAGL-02-2015-06-28-00020.bin	28/06 [History]	33.0	27.0	CAGL-02
CAGL-03	dom 28 giugno	09:22	CAGL-03-2015-06-28-00020.bin	20 [History]	08:06 10/06/2015	CAGL-03-2015-06-28-00019.bin	28/06 [History]	22.0	18.0	CAGL-03

Run by run (50000 events) quality monitor (real time)

EEE DQM run report

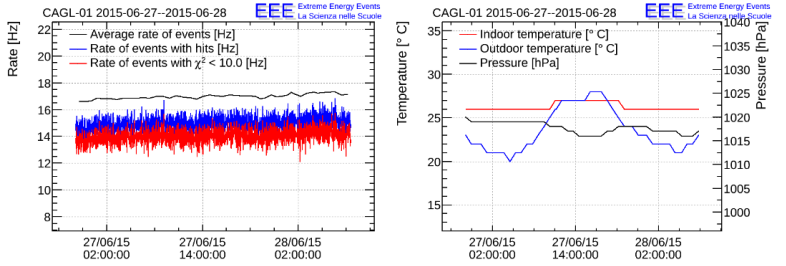


RUN SUMMARY

- DST file path: /home/analisi/eeetmp/BOLO-04-2015-06-28-00004_dst.root
- Unique run identifier: 8310000004
- Smallest event timestamp: 2678837347.038 s UTC
- Largest event timestamp: 2678838712.109 s UTC

Daily summary (trending infos available for analyses)

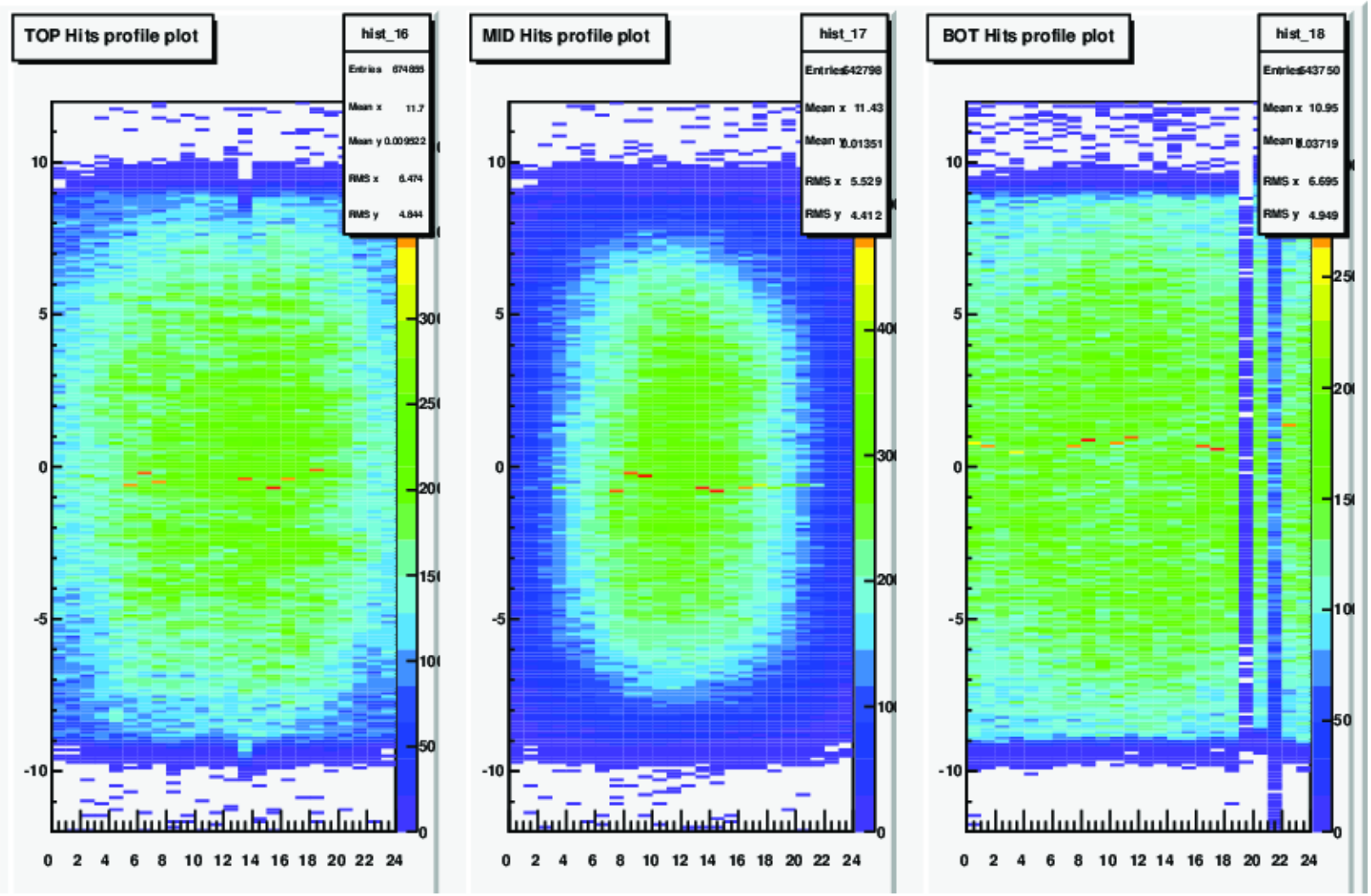
EEE DQM summary report



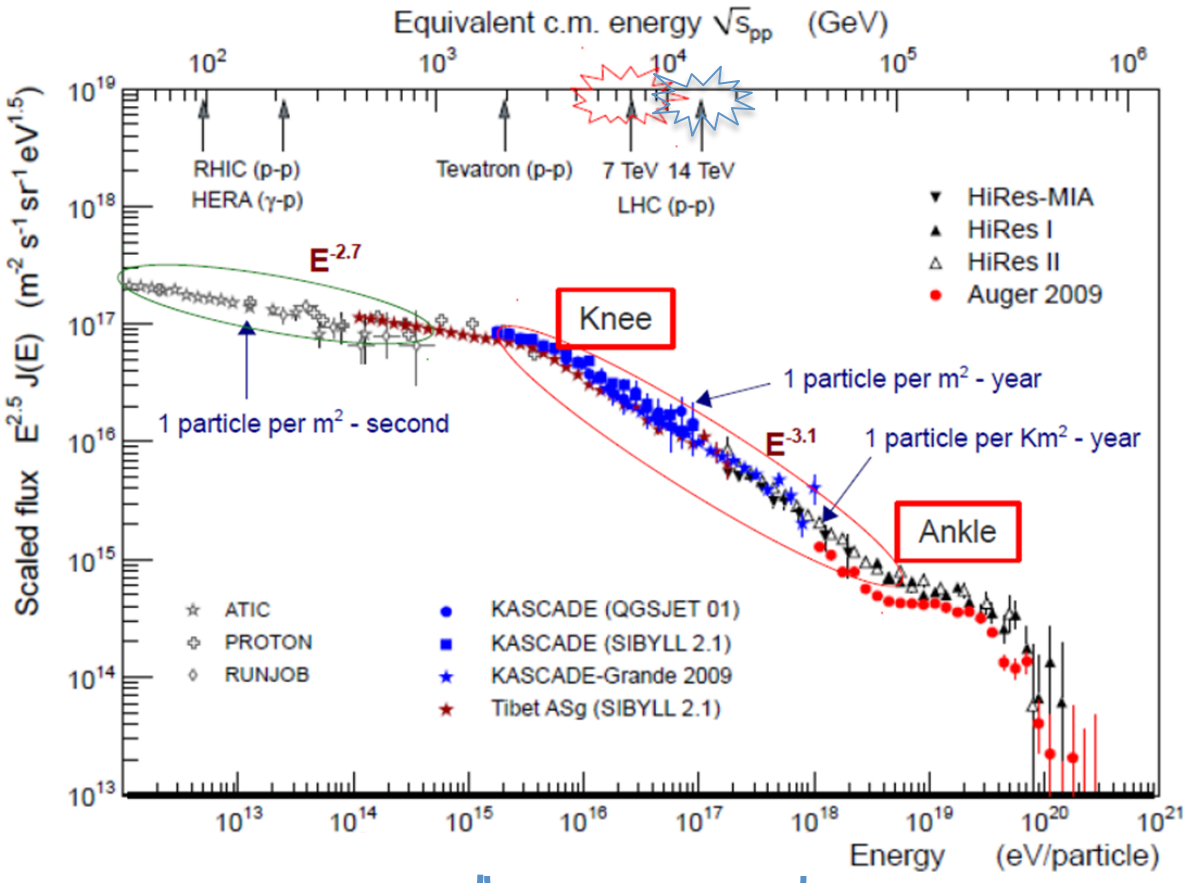
SUMMARY

- Station: CAGL-01
- Time period: 2015-06-27--2015-06-28
- Number of runs processed: 46
- Total number of events: 2099422

MRPC hits


TOP Hits profile plot
hist_16
Entries 674885
Mean x 11.7
Mean y 0.009522
RMS x 6.474
RMS y 4.844
MID Hits profile plot
hist_17
Entries 642798
Mean x 11.43
Mean y 0.01351
RMS x 5.529
RMS y 4.412
BOT Hits profile plot
hist_18
Entries 643750
Mean x 10.95
Mean y 0.03719
RMS x 6.695
RMS y 4.949

Cosmic rays flux and EEE



Single telescope sensitivity

Multi-telescope analyses

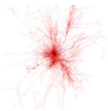
EEE telescopes collect secondary muons coming from primary cosmic rays of over 10^{11} eV

Coincidences between telescopes allow to select primary energies above 10^{15} eV (thousands of TeV)

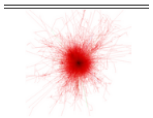
High energy events

Density of secondaries at sea level

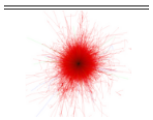
$E = 10^{11}$ eV



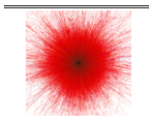
$E = 10^{12}$ eV



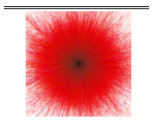
$E = 10^{13}$ eV



$E = 10^{14}$ eV

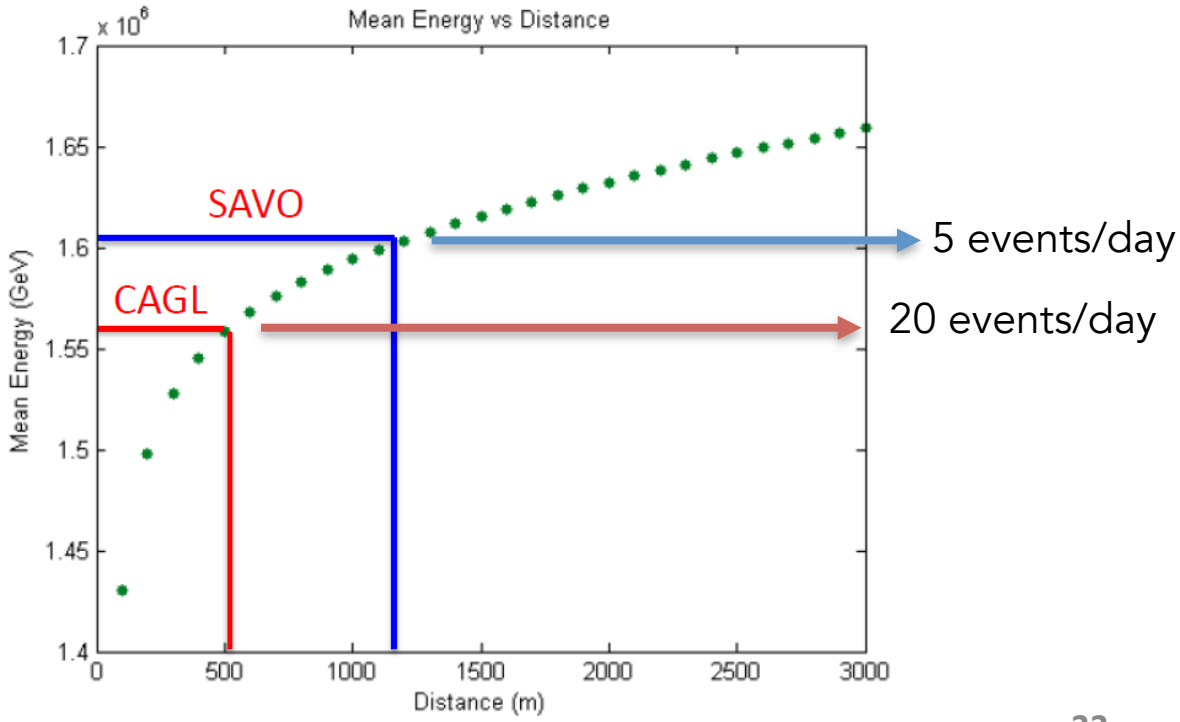


$E = 10^{15}$ eV



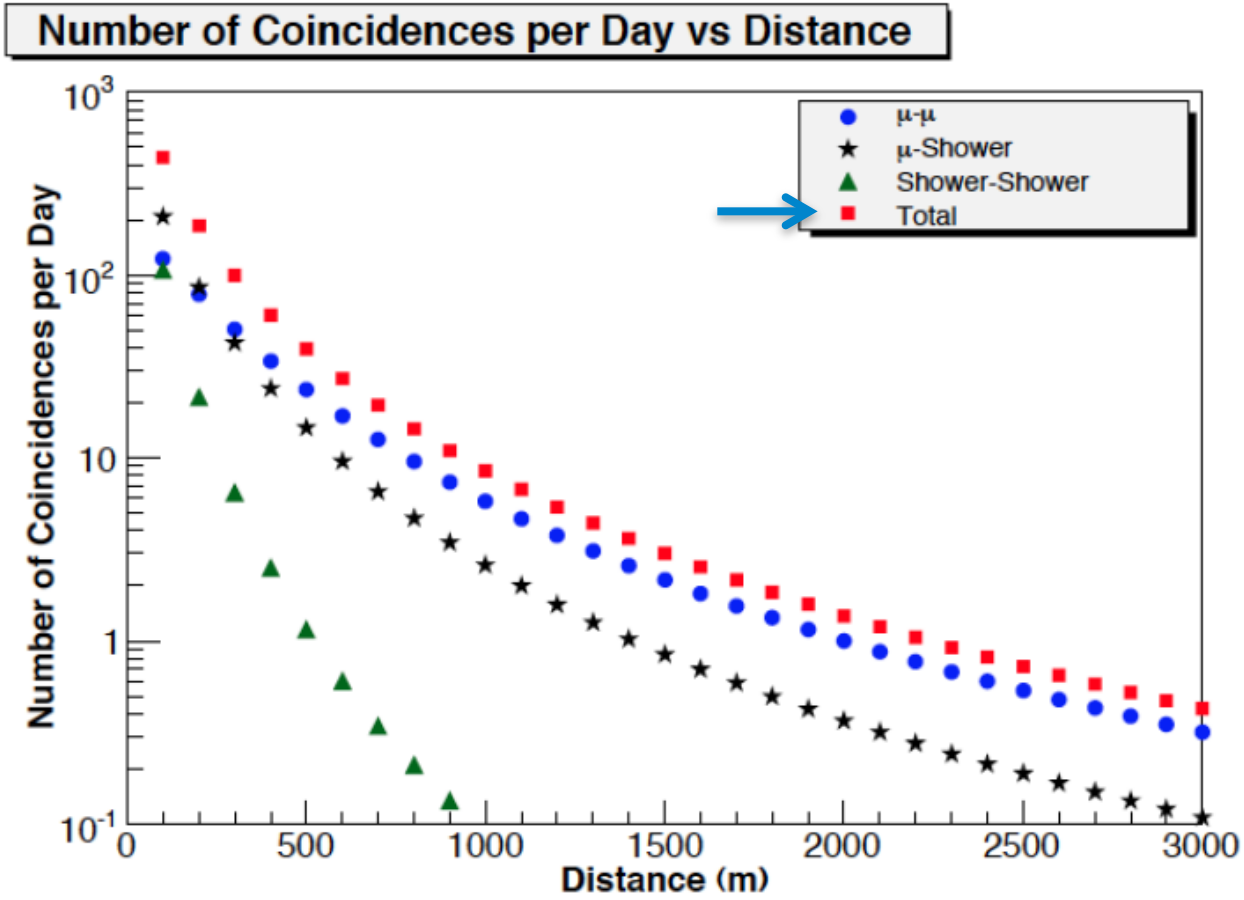
Increasing the distance between telescopes the energy of the primary observed increases as well

The flux of primaries depends on the energy
→ many days of operation needed for very large distances



Corsika MC simulations

MC simulations for EEE telescopes



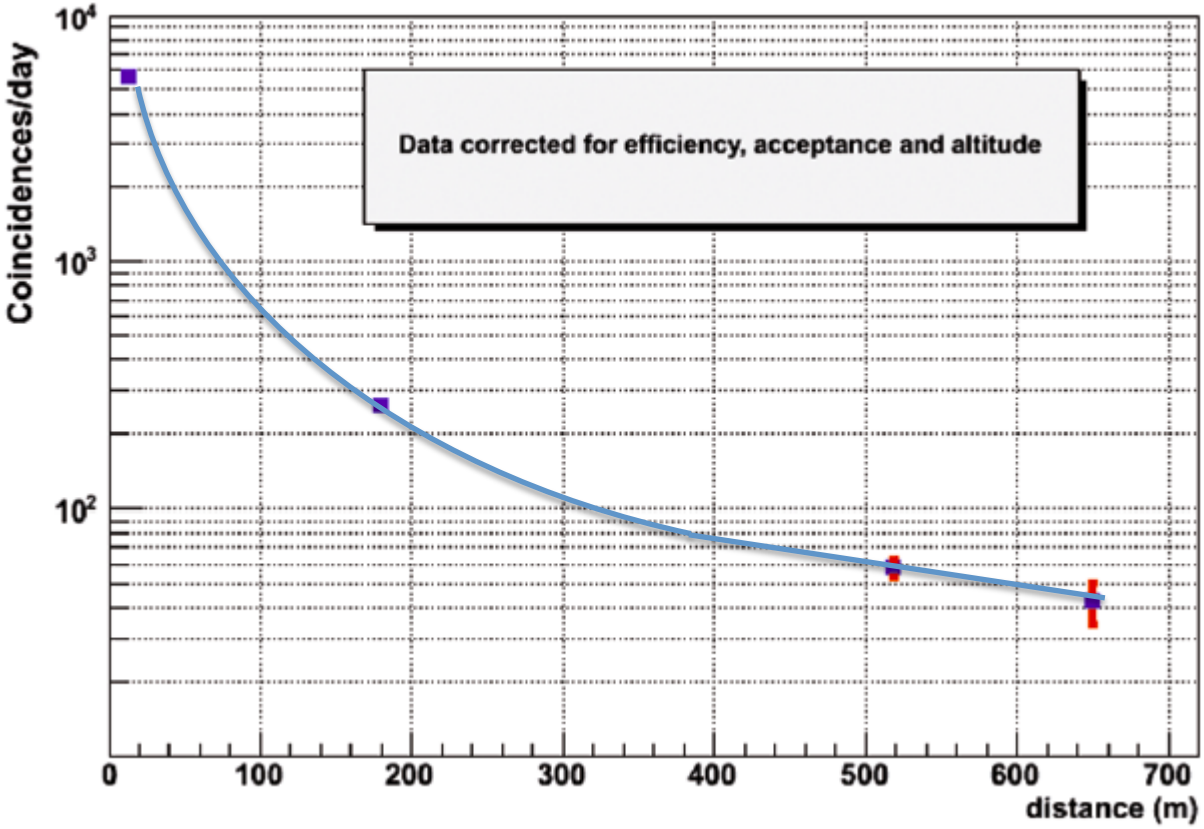
Coincidences expected per day between EEE telescopes as a function of the distance

→ Few months required to observe coincidences at 1 Km

Corsika MC simulations

First results in 2012 for coincidence events

Eur. Phys. J. Plus (2013) **128**: 148



Number of coincidences per day, as measured by different telescope pairs of the EEE network, as a function of the relative distance between the two telescopes

Data from the following sites are included in the plot: CERN-Geneva (15 m), L'Aquila (180 m), Cagliari (520 m) and Frascati (650 m)

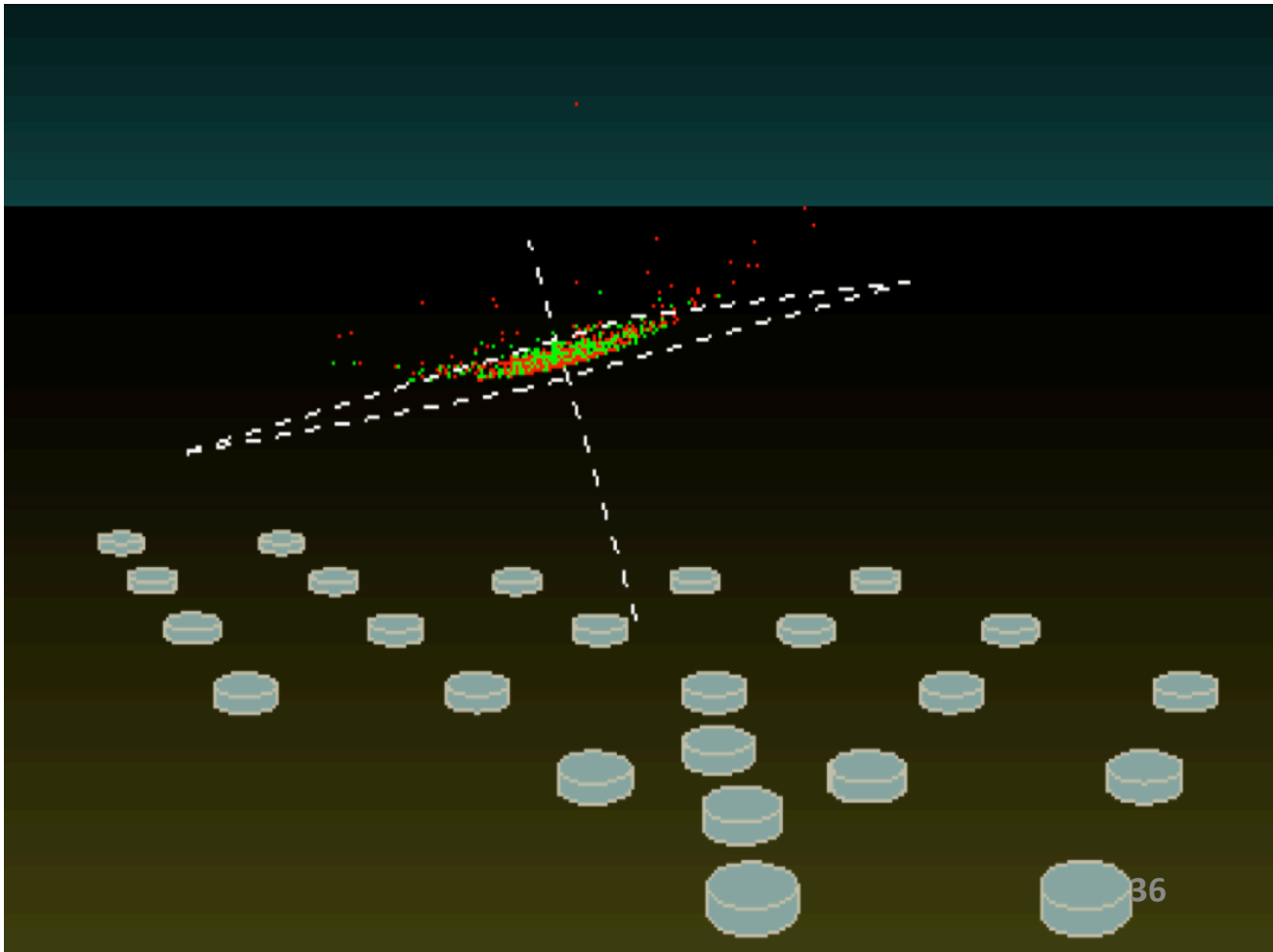
Consistent with Corsika & Cosmos MC simulations

As from 2014

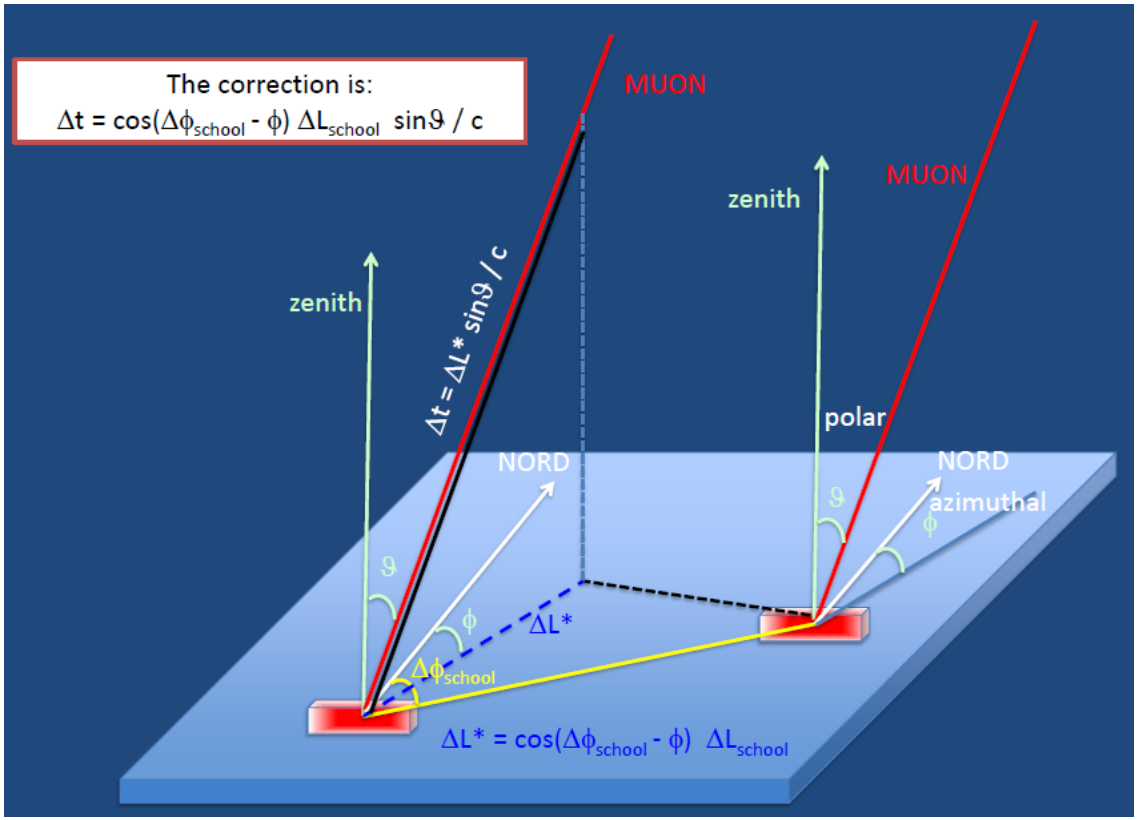
– with more statistics

– taking advantage of the tracking capablity of the telescopes to select different impact angles and apply angular & time corrections

→ the search for coincidence events from near and distant telescopes is successfully ongoing



Reconstruction of the primary cosmic ray direction

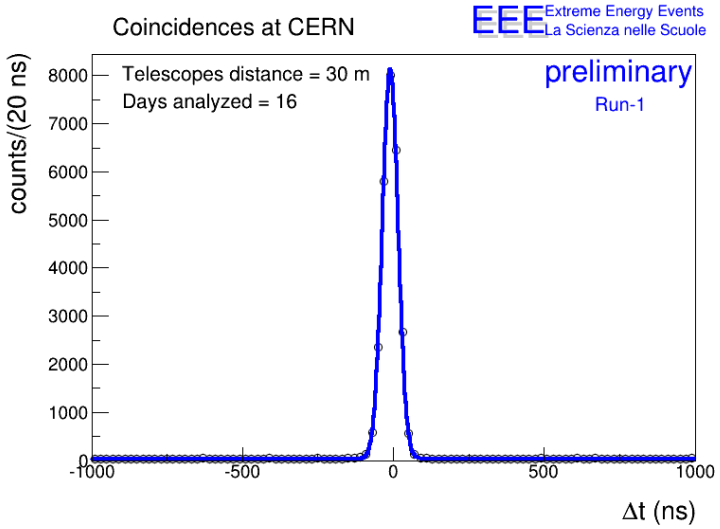


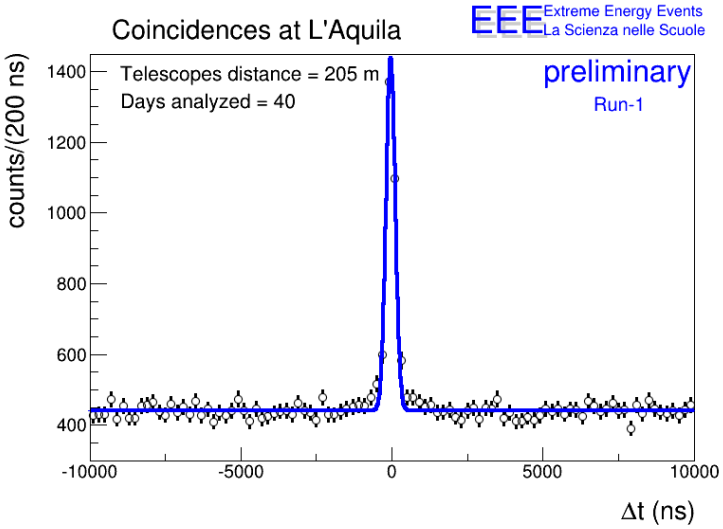
EEE telescopes allow to reconstruct the direction of the shower secondaries, i.e. of the shower axis

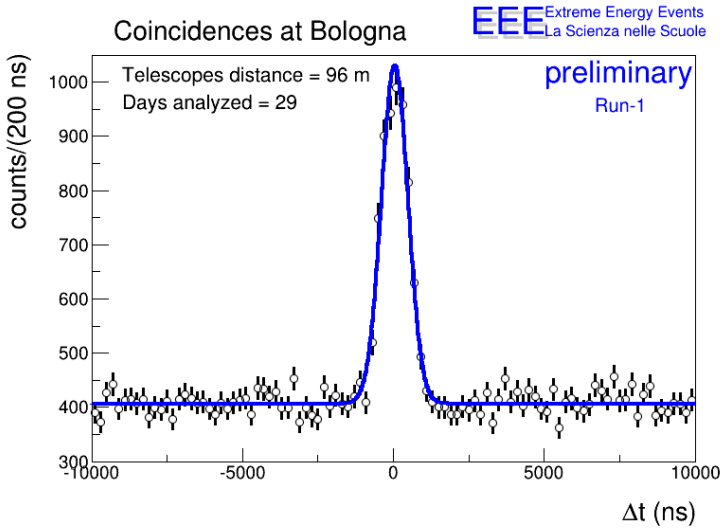
Such a feature allows to correct, event by event, the time delay between two telescopes because of the propagation of the wave front of the shower

This is very important when looking at coincidences at very large distances since above 1 Km the time delay may be of the order of few microseconds

Preliminary results from Run-1 (2015)



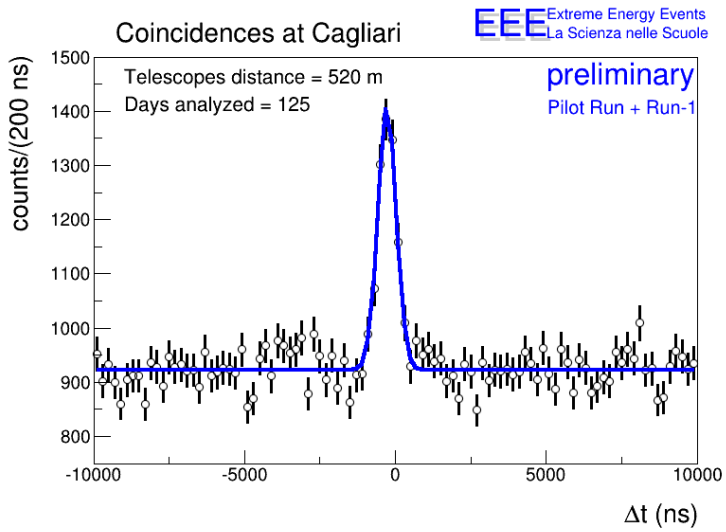


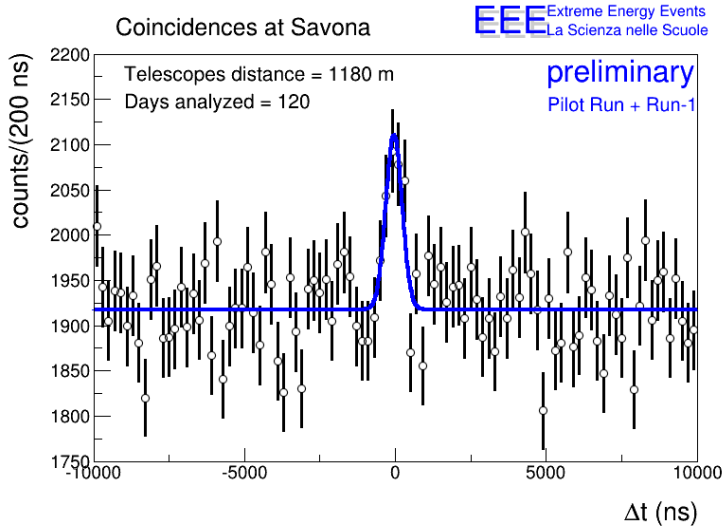


Coincidences were well reconstructed for several distances between telescopes (15 m, 100 m, 200 m, 500 m, 1200 m)

The width of the reconstructed peak is usually of the order of 200-250 ns (CERN and Bologna cases differ because of particular GPS setups)

Preliminary results from Run-1 (2015)





For the first time coincidences were observed between two telescopes installed in High Schools at a distance greater than 1 Km (significance $S/\sqrt{(S+B)} = 5.1$)

The statistics used here includes also the data acquired in the Pilot run of 2014

→ One of the goals for next year is to extend such measurements to larger distances (up to 2 Km) and to extend the study to telescopes located in different cities to look for exotic ("unexpected") high energy events

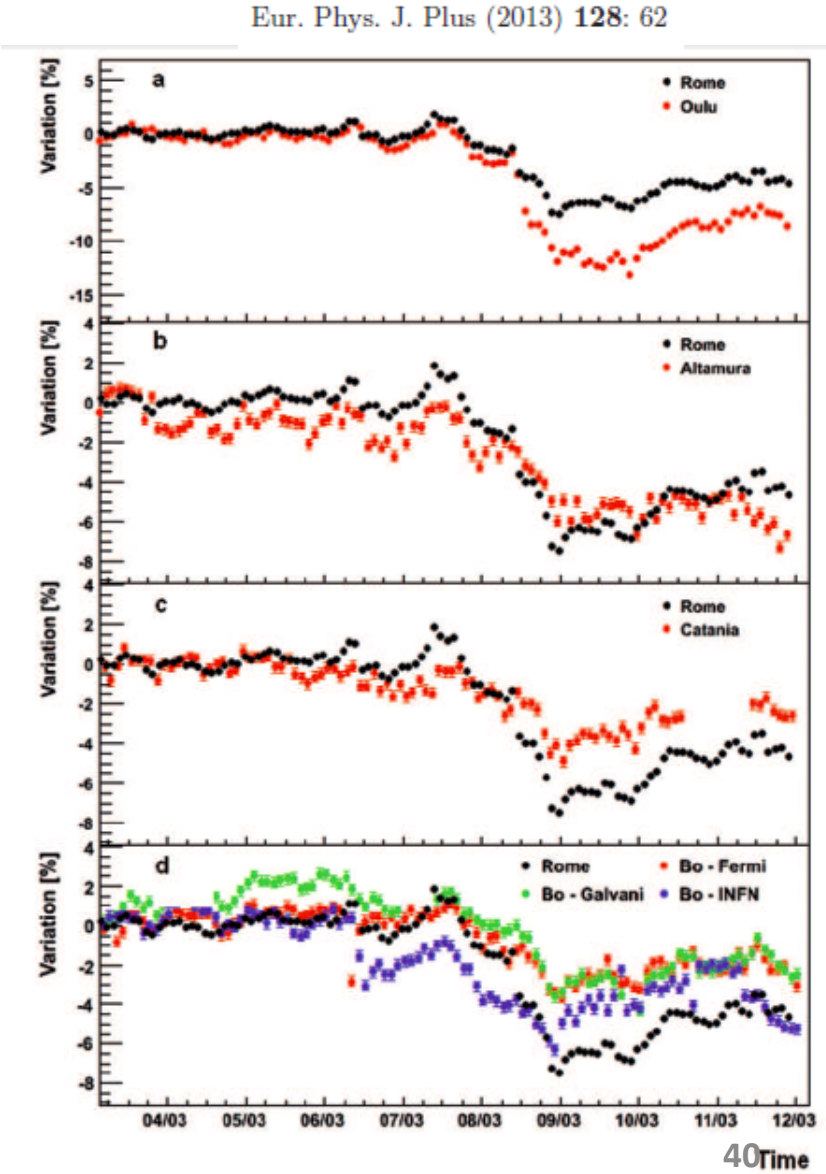
Galactic Cosmic Ray Decrease (GCRD)

Among the non-periodic intensity variations, rapid decreases of the galactic cosmic-ray (GCR) flux due to solar activity (the so-called Forbush decreases) are the most common and the most interesting

GCRD events consist of an impressive transient change in the cosmic-ray intensity

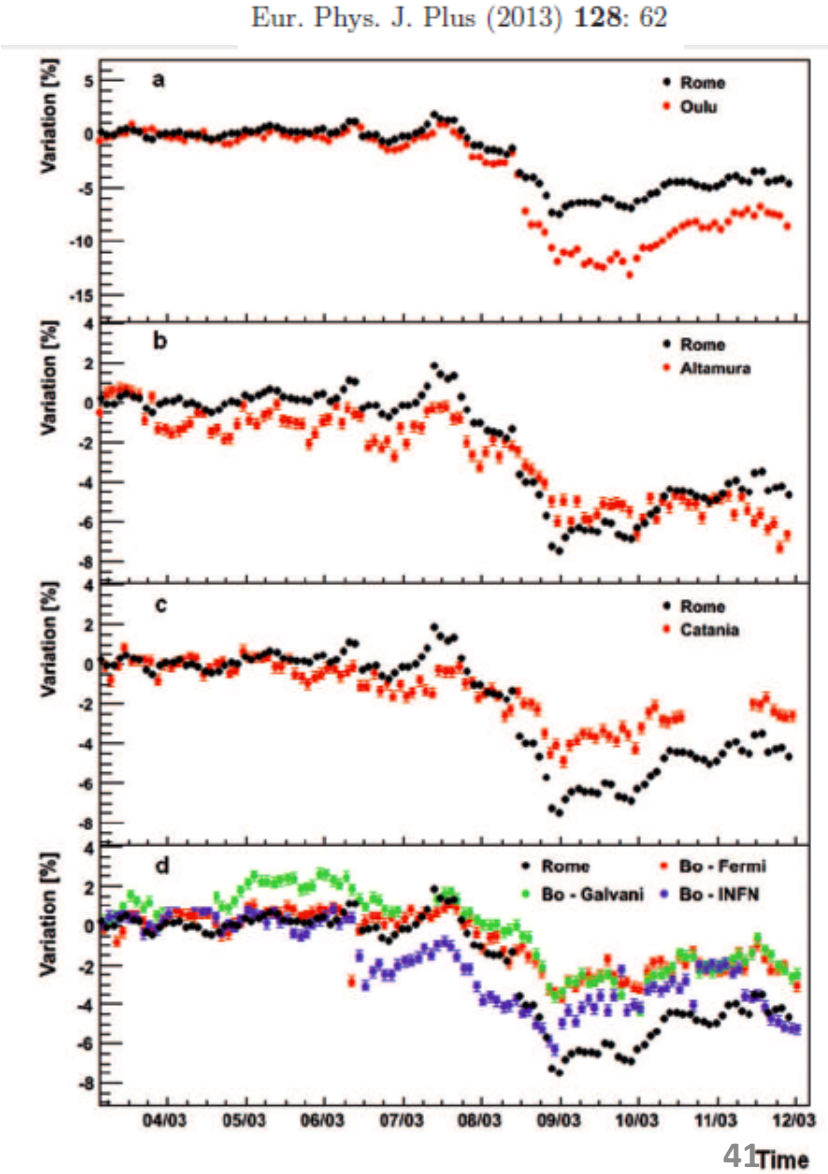
They are characterized by a rapid (a few hours) intensity reduction, followed by a slow recovery in a few days time range

Such strong variations are probably related to solar flares and the associated geomagnetic disturbances



Galactic Cosmic Ray Decrease (GCRD)

In 2012 a GCRD event observed by the Oulou (Finland) and Rome detectors of the Neutron Monitor Network,
was also observed for the first time by 5 EEE telescopes: Altamura, Bologna (3), Catania



Galactic Cosmic Ray (GCR) flux variation due to solar activity

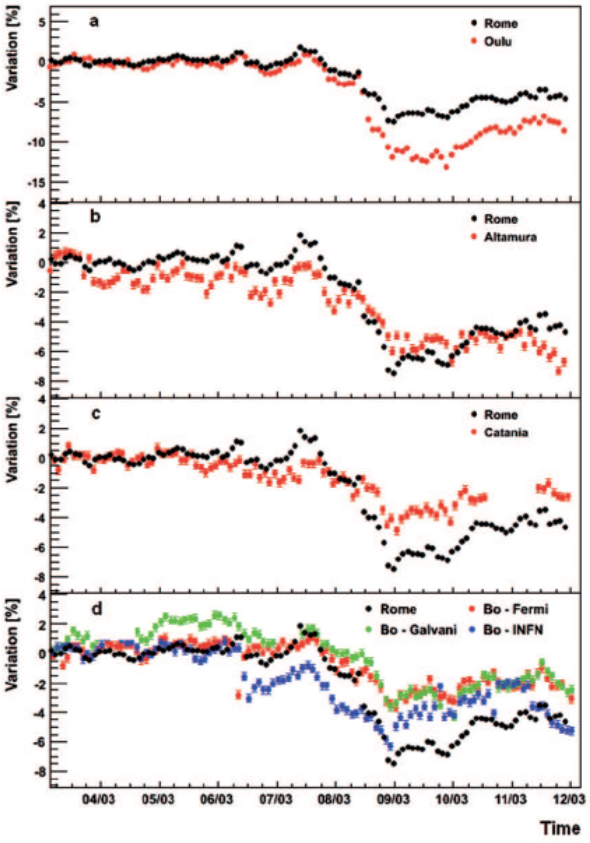
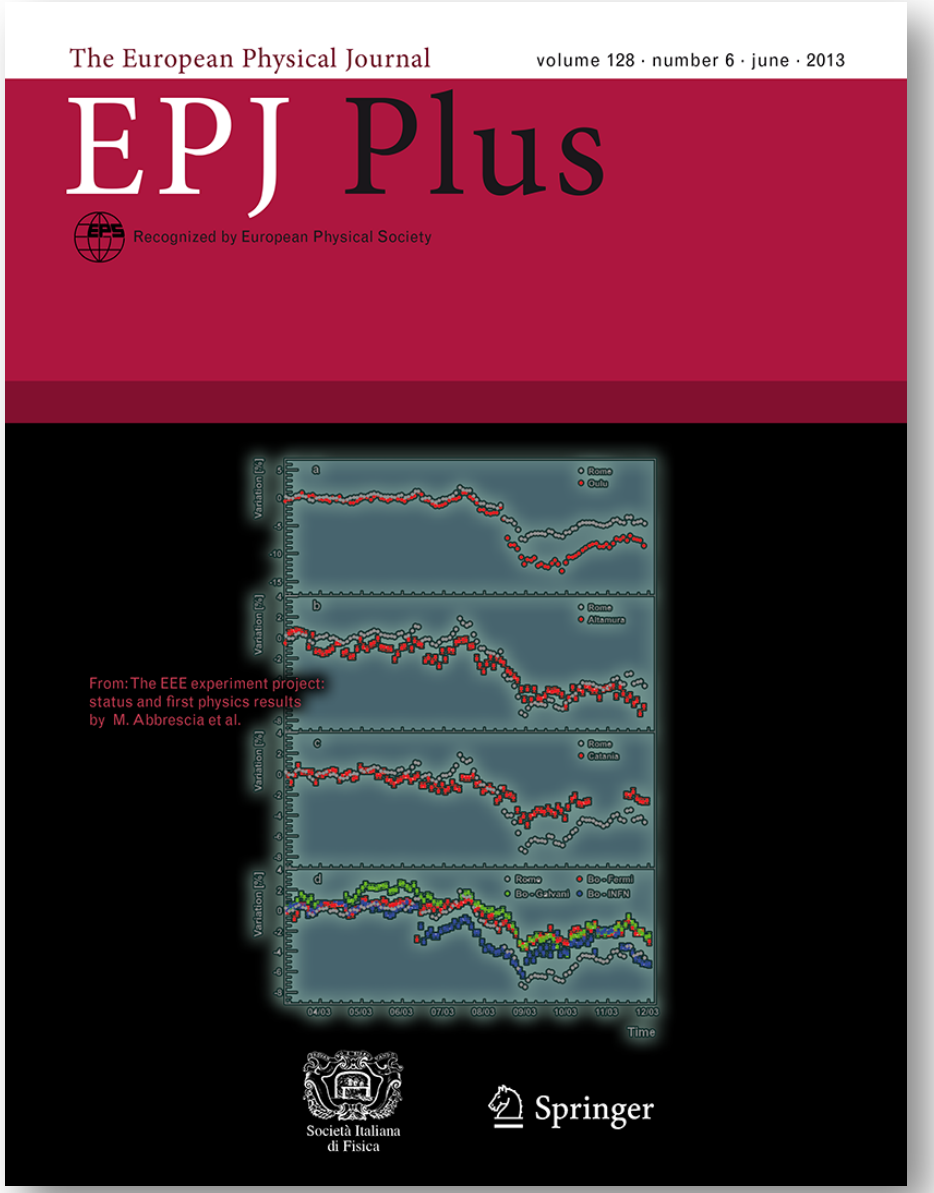
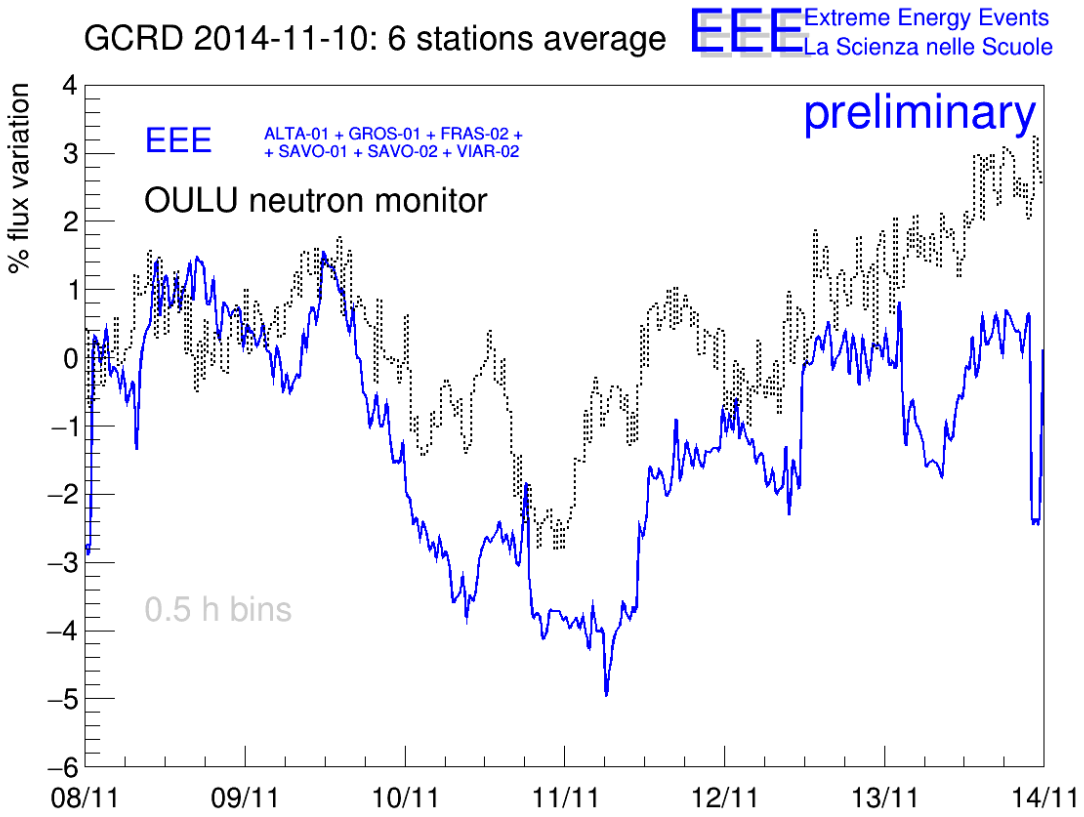


Fig. 5. The March 2012 GCR decrease, as observed by (a) the Oulu and Rome detectors of the Neutron Monitor Network and by (b) the Altamura, (c) Catania, and (d) Bologna EEE telescopes. For an easier comparison, the EEE measurements are superimposed to the Rome data.



Unprecedented with muons in High Schools !!!

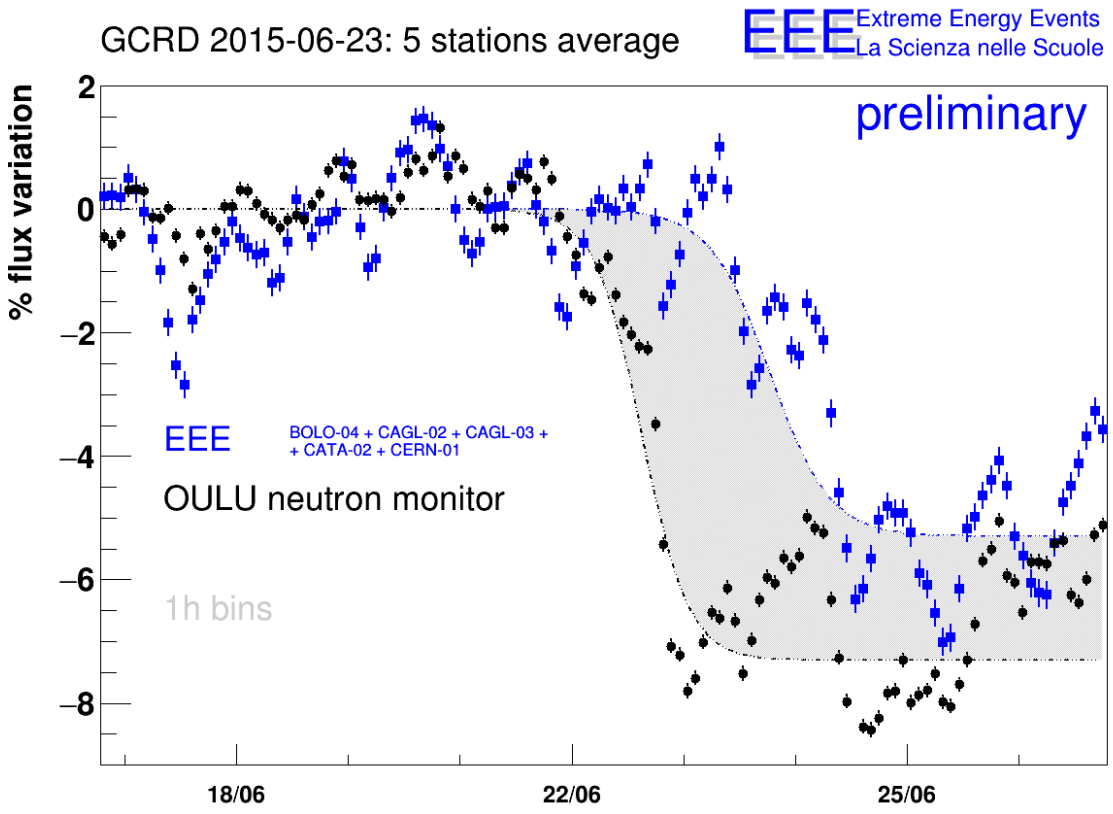
A recent GCRD



Immediately after the EEE Pilot run of 2014, a GCRD event was observed by 6 EEE telescopes: Altamura, Frascati, Grosseto, Savona (2), Viareggio

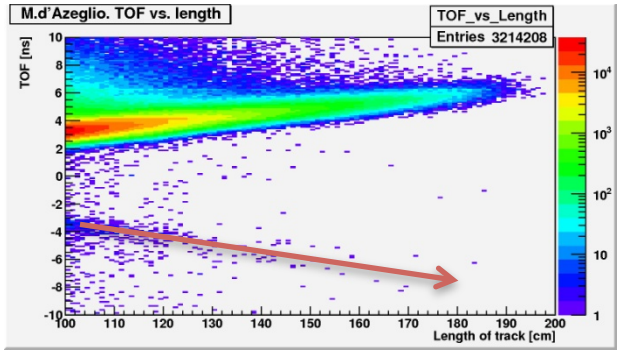
Muon rates averaged over 6 EEE telescopes and Neutron rates from the Oulu station, Finland, during the GCRD associated to X class solar flare on 7 November 2014

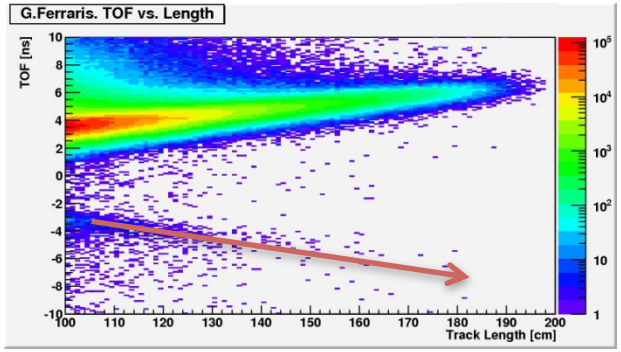
A GCRD during this School !!

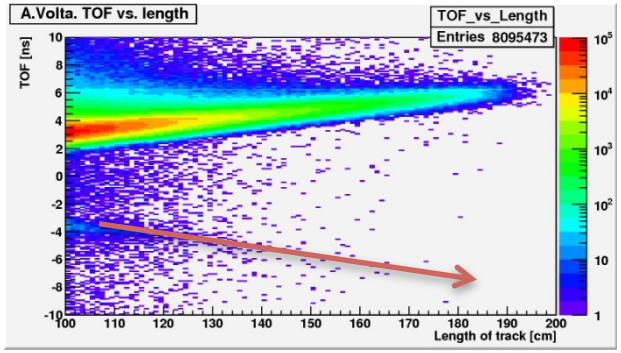


GCRD event observed by 5 EEE telescopes: Bologna, Cagliari (2), Catania, CERN-Geneva

Upgoing events





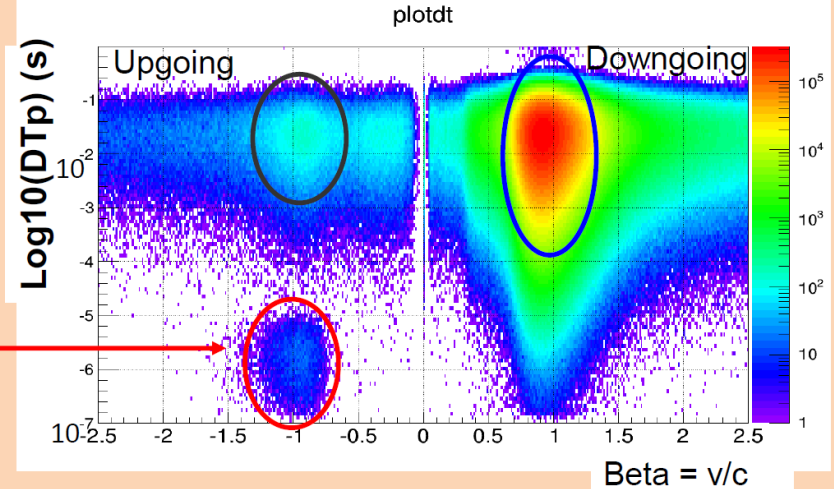


Few upgoing events are observed (1/2000) in EEE telescopes

The nature of such events is under investigation

A fraction of them can be clearly identified as electrons coming from muon decays (in the floor under the telescope), looking at their time correlation with previous events (~ 2 μs)

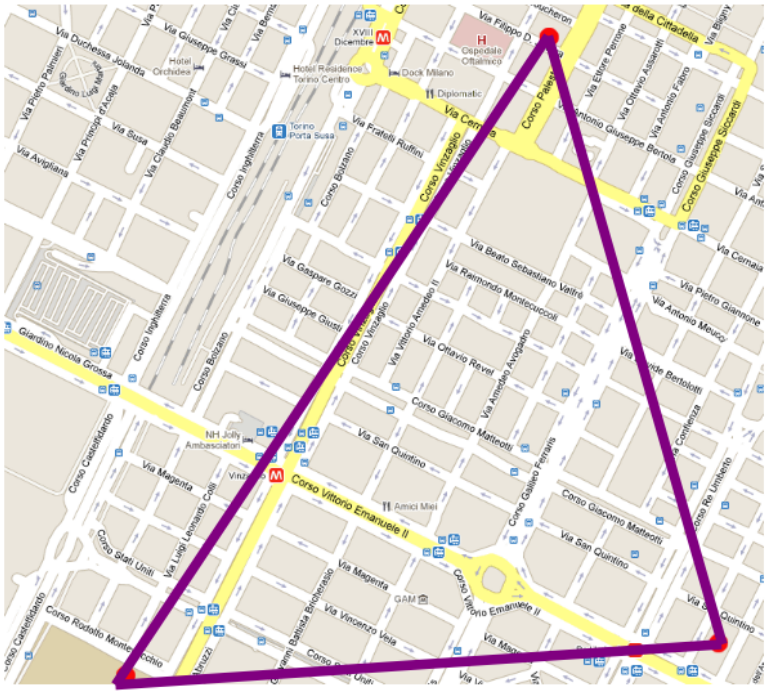
DTp = time delay from previous event



Muon decay Delayed ~2μs

Upgoing electron delay of ~ 2μs wrt parent Muon

Three-telescope coincidences



Coincidence studies will be extended also to the case of three telescopes

Advantages

- The energy of the primary is expected to be higher
- Background from accidental combinations is strongly suppressed

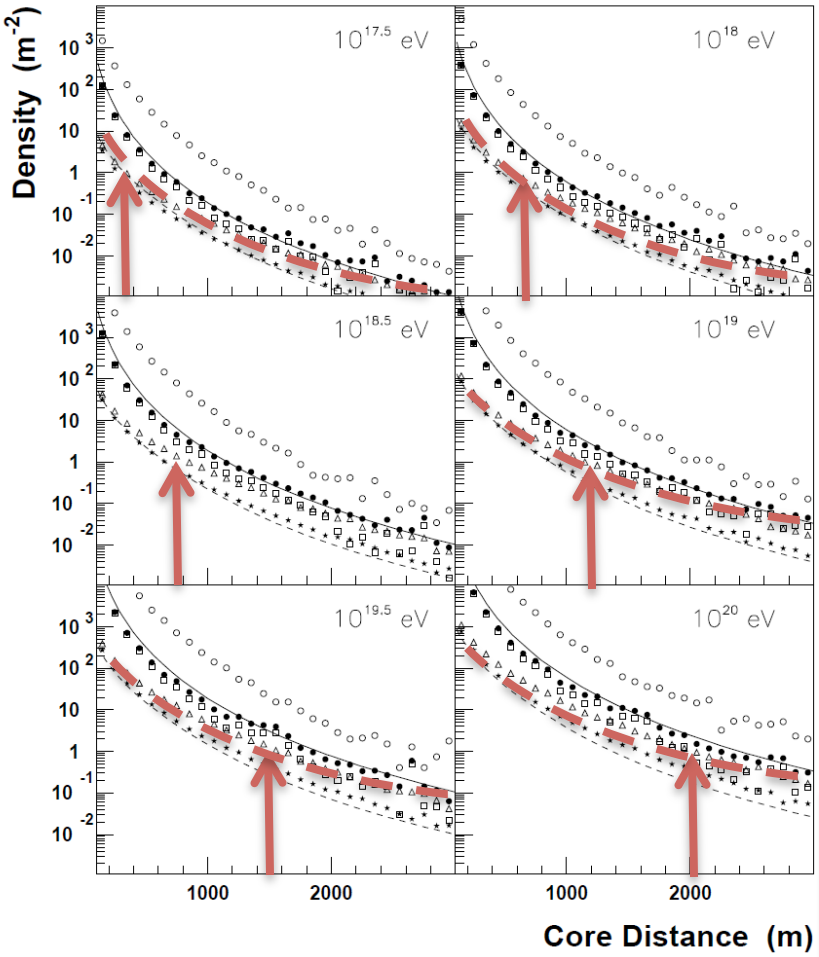
Disadvantages

- The rate expected is much lower than in the two-telescope case

→ more data taking needed

Lateral distribution of secondaries

Astropart. Phys. 13, 277-294 (2000)



The lateral distributions of photons (open circles), electrons (open squares) and muons (open triangles) above 10 MeV energy and muons (stars) above 1 GeV simulated with Corsika MC

Charged particles in addition to electrons and muons above 10 MeV energy are also plotted (full circles)

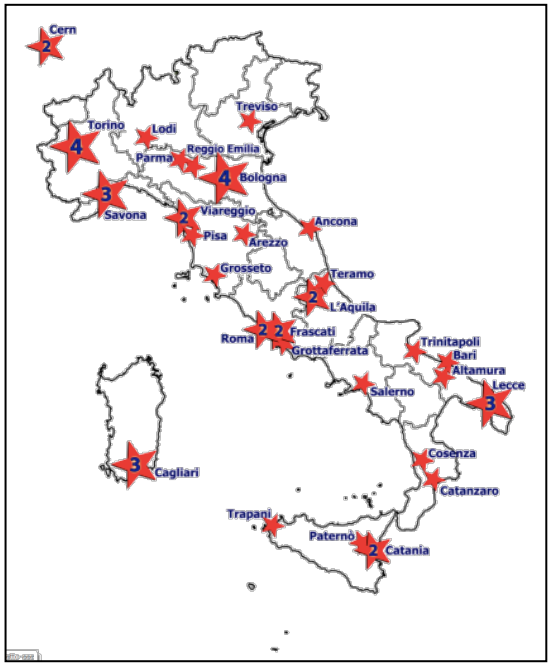
Below the distance indicated by the red arrows the muon density is expected to be larger than $1/m^2$

→ multi-track events in single EEE telescopes could allow to select by telescope coincidences showers of even higher energy

What next

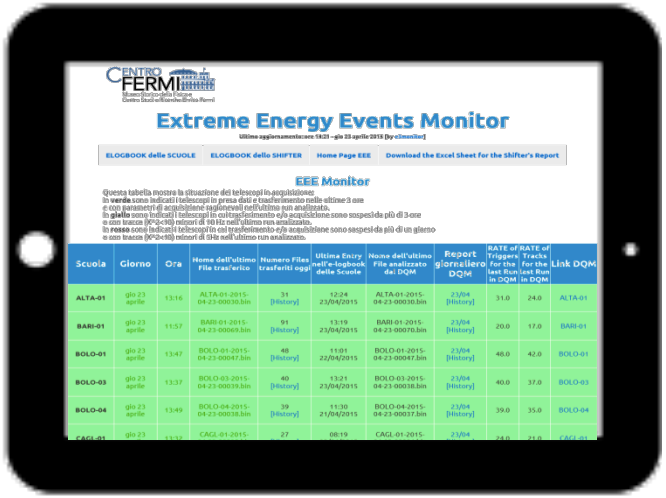
- Increase the number of EEE telescopes from 50 to 100 High Schools (original project!)
- Increase the statistics of two-telescope coincidences and search for three-telescope coincidences within the same city
- Include multi-track telescope analysis in the search
- Search for coincidences of clusters of telescopes between different cities
- Search for upgoing events in single telescopes and in two-telescope coincidences
- Test the pointing capabilities of telescopes

→ SEARCH FOR THE UNEXPECTED …



The EEE Open Data Project

Tablets to 75 EEE High Schools
(50 with + 25 without telescope)
→ Remote & continuous monitor
of EEE telescopes and access to data
even for Schools without telescopes



In collaboration with IPOGG (International Particle Physics Outreach Group) the EEE Project – Italy is participating in the newborn

GLOBAL HIGH SCHOOL COSMIC RAYS PROJECT

involving similar projects in Czech Republic, Denmark, France, Germany, Greece, The Netherlands, UK, USA and more

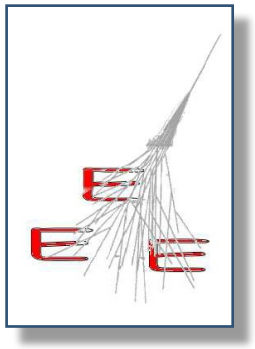
GLOBAL HIGH SCHOOL COSMIC RAYS PROJECT

- Establish a "universal" portal through which successful cosmic ray studies programs can reach out to teachers and students around the world
- This web portal would be the entry point for an international network of cosmic ray projects for education
- Students with a School detector could contribute data to a global project
- Students who are interested but without a detector could analyze data and/or participate in special events

→ magnified outreach potential for the EEE Project !!

Marcello Abbrescia	marcello.abbrescia@ba.infn.it
Roberta Antolini	roberta.antolini@lngs.infn.it
Carlo Avanzini	carlo.avanzini@pi.infn.it
Luca Baldini	luca.baldini@pi.infn.it
Rinaldo Baldini Ferroli	rinaldo.baldini@lnf.infn.it
Giovanni Batignani	giovanni.batignani@pi.infn.it
Giovanni Bencivenni	giovanni.bencivenni@lnf.infn.it
Edoardo Bossini	edoardo.bossini@pi.infn.it
Elisa Bressan	elisa.bressan@bo.infn.it
Emilio Chiavassa	chiavassa@to.infn.it
Corrado Cicalò	corrado.cicalò@ca.infn.it
Luisa Cifarelli	luisa.cifarelli@bo.infn.it
Eugenio Coccia	eugenio.coccia@lngs.infn.it
Alessandro Corvaglia	alessandro.corvaglia@le.infn.it
Daniele De Gruttola	Daniele.De.Gruttola@cern.ch
Salvatore De Pasquale	depasquale@sa.infn.it
Adriano Di Giovanni	adriano.digiovanni@lngs.infn.it
Marco D'Incecco	marco.dincecco@lngs.infn.it
Marco Dreucci	marco.dreucci@lnf.infn.it
Franco L. Fabbri	franco.fabbri@lnf.infn.it
Enrico Fattibene	enrico.fattibene@cnaf.infn.it
Andrea Ferraro	andrea.ferraro@cnaf.infn.it
Richard Forster	richard.forster@cern.ch
Vladimir Frolov	vladimir.frolov@cern.ch
Piero Galeotti	galeotti@to.infn.it
Marco Garbini	marco.garbini@bo.infn.it
Gianluca Gemme	gianluca.gemme@ge.infn.it
Ivan Gnesi	gnesi@to.infn.it
Stefano Grazzi	stefano.grazzi@ge.infn.it
Carlo Gustavino	carlo.gustavino@lngs.infn.it
Despina Hatzifotiadou	despina.hatzifotiadou@cern.ch
Paola La Rocca	paola.larocca@ct.infn.it
Sha Li	sha.li@cern.ch
Angelo Maggiora	maggiora@to.infn.it
Gaetano Maron	gaetano.maron@lnl.infn.it
Barbara Martelli	Barbara.Martelli@cnaf.infn.it
Mario Nicola Mazziotta	Marionicola.Mazziotta@ba.infn.it
Silvia Miozzi	silvia.miozzi@lnf.infn.it
Marco Panareo	marco.panareo@le.infn.it
Maria Paola Panetta	mariapaola.panetta@le.infn.it
Riccardo Paoletti	riccardo.paoletti@pi.infn.it
Laura Perasso	laura.perasso@ge.infn.it
Federico Pilo	federico.pilo@pi.infn.it
Guido Piragino	guido.piragino@to.infn.it
Francesco Riggi	franco.riggi@ct.infn.it
Giancarlo Righini	giancarlo.righini@centrofermi.it
Adrian Rodriguez Rodriguez	adrian.rodriguez.rodriguez@cern.ch
Gabriella Sartorelli	gabriella.sartorelli@bo.infn.it
Eugenio Scapparone	eugenio.scapparone@bo.infn.it
Angelo Scribano	angelo.scribano@pi.infn.it
Marco Selvi	marco.selvi@bo.infn.it
Sergio Serci	sergio.serci@ca.infn.it
Elisabetta Siddi	elisabetta.siddi@ca.infn.it
Sandro Squarcia	sandro.squarcia@ge.infn.it
Mauro Taiuti	mauro.taiuti@ge.infn.it
Giuseppe Terreni	giuseppe.terreni@pi.infn.it
Flavio Tosello	tosello@to.infn.it
Maria Cristina Vistoli	cristina.vistoli@cnaf.infn.it
Lucia Votano	lucia.votano@lngs.infn.it
Crispin Williams	crispin.williams@cern.ch
Stefano Zani	stefano.zani@cnaf.infn.it
Antonino Zichichi	antonino.zichichi@cern.ch
Raman Zuyeuski	roman.zouevski@cern.ch

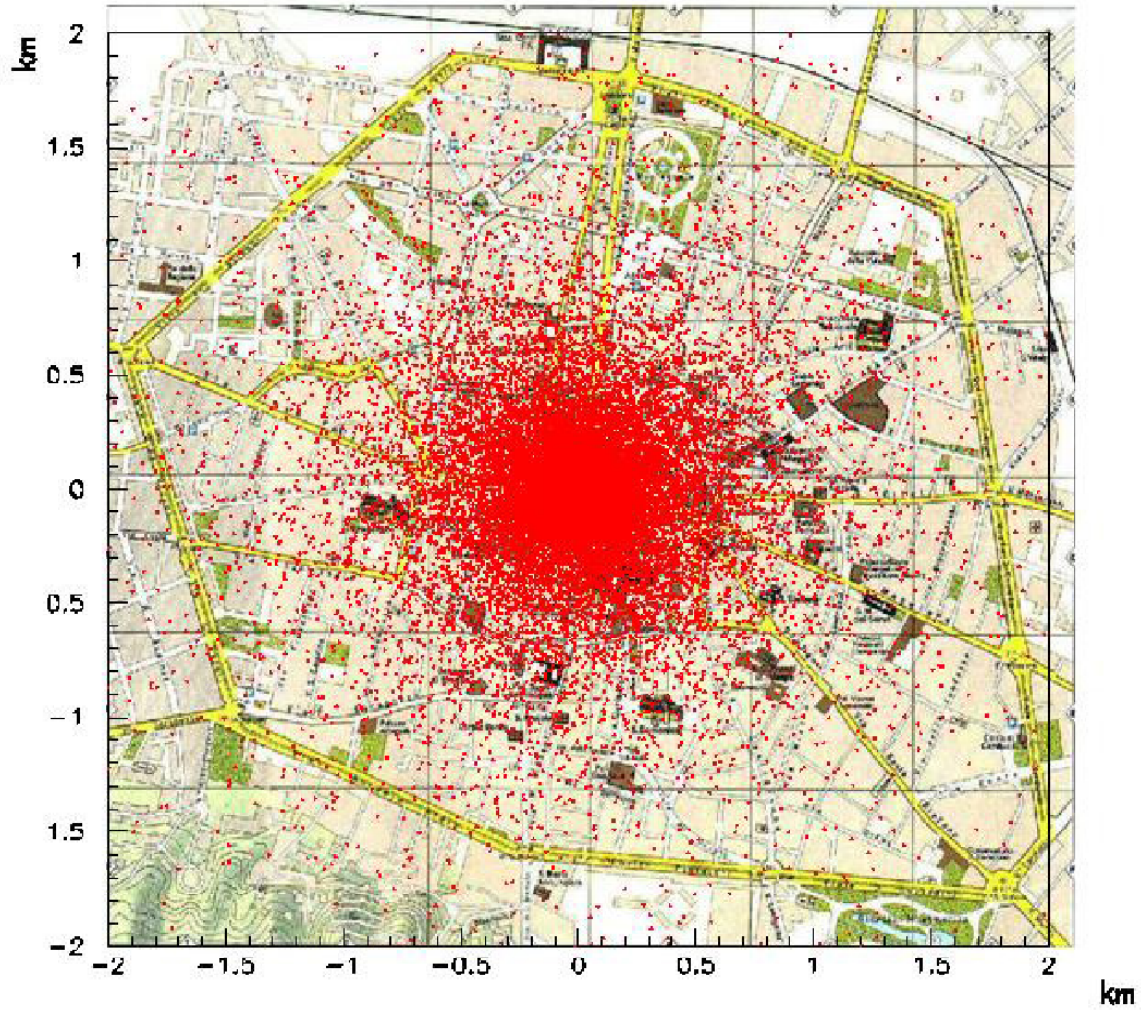
THE EEE COLLABORATION



Thanks to those to whom
I have borrowed/stolen slides

And thank you all for the attention

Primary cosmic proton of 10^{17} eV interacting at 15 km altitude → shower with 10^6 muons on the city of Bologna



EEE Physics Publications until 2014

- - Abbrescia M. et al. (EEE Collaboration), *Cosmic rays Monte Carlo simulations for the Extreme Energy Events Project*, Eur. Phys. J Plus 129 (2014) 166
- - Abbrescia M. et al. (EEE Collaboration), *Time correlation measurements from extensive air showers detected by the EEE telescopes,* Eur. Phys. J Plus 128 (2013) 148
- - Abbrescia M. et al. (EEE Collaboration), *The EEE experiment project: status and first physics results,* Eur. Phys. J Plus 128 (2013) 62
- - Abbrescia M. et al. (EEE Collaboration), *The EEE Project: cosmic rays, multigap resistive plate chambers and high school students*, JINST, 7 (2012) P11011
- - Abbrescia M. et al. (EEE Collaboration), *The EEE experiment: cosmic rays, multigapresistive plate chambers and high school students*, XI Workshop on Resistive Plate Chambers and Related Detectors, PoS (RPC2012) 012
- - Abbrescia M. et al. (EEE Collaboration), *Observation of the February 2011 Forbush decrease by the EEE telescopes*, Eur. Phys. J. Plus 126 (2011) 61
- - Abbrescia M. et al. (EEE Collaboration), *First detection of extensive air showers with the EEE experiment*, Il Nuovo Cimento B-Basic Topics in Physics 125 (2010) 243-254
- - Abbrescia M. et al. (EEE Collaboration), *Towards the installation and use of an extended array for cosmic ray detection: The EEE Project*, Nuclear Physics B (Proc. Suppl.) 190 (2009) 38-43
- - Abbrescia M. et al. (EEE Collaboration), *Performance of a six gap MRPC built for large area coverage,* Nuclear Instruments and Methods in Physics Research A, 593 (2008) 263-268
- - Abbrescia M. et al. (EEE Collaboration), *Extreme Energy Events Project: Construction of the detectors and installation in Italian High Schools*, Nuclear Instruments and Methods in Physics Research A, 588 (2008) 211-214
- - Abbrescia M. et al. (EEE Collaboration), *Multigap Resistive Plate Chambers for EAS study in the EEE Project*, Proceedings of the 30th International Cosmic Ray Conference, Vol. 5, HE part 2 (2008) 1565–1568
- - An S. et al. (EEE Collaboration), *Multigap resistive plate chambers for EAS study in the EEE Project*, Nuclear Instruments and Methods in Physics Research A, 581 (2007) 209-212
- - Antolini R. et al. (EEE Collaboration), *The EEE Project: status and perspectives*, Nuclear Physics B (Proc. Suppl.), 165 (2007) 333-340