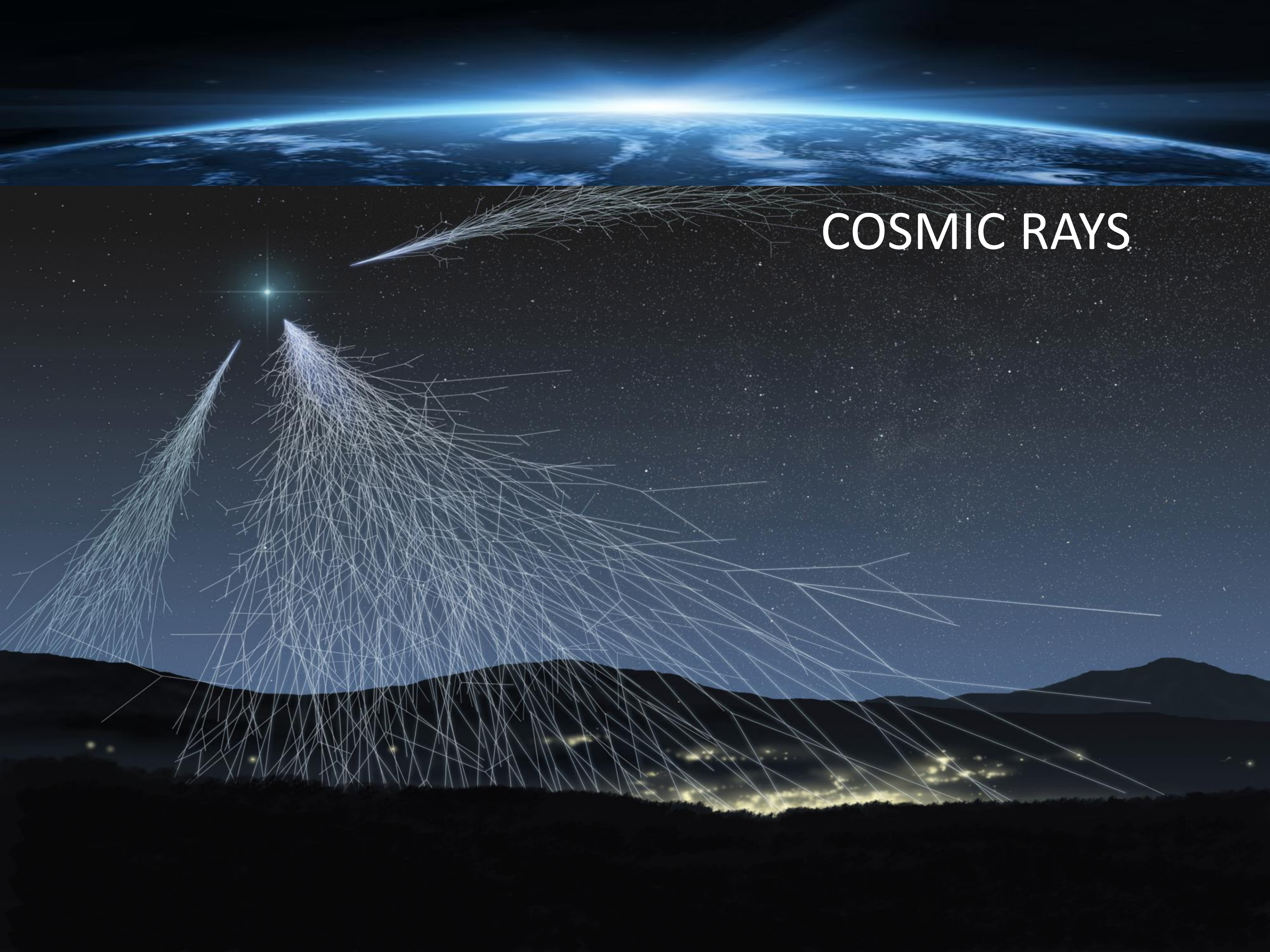
Cosmic Ray Detectors in Schools
The Extreme Energy Events project

Despina Hatzifotiadou
Istituto Nazionale di Fisica Nucleare (INFN) Sezione di Bologna Centro
Fermi – Roma
EP Department - CERN

Discover the Cosmos Summer School , Marathonas, Attica, 12 July 2017

Outline of session

- About cosmic rays
- The Extreme Energy Events Project – Science in the Schools
- A brief presentation of some cosmic ray projects and experiments in schools
- Measurement of cosmic muons due to time dilation
- Cloud Chamber (in theory..)


COSMIC RAYS

First studies of cosmic rays

In 1909 Theodor Wulf measured, using an electrometer, higher level of radiation at the top of the Eiffel Tower than at its base.

Victor Hess, using balloons, measured in 1912 atmospheric ionisation as a function of altitude. As he ascended to 5300 metres, he measured the rate of ionization in the atmosphere and found that it increased to some three times that at sea level. He concluded that penetrating radiation was entering the atmosphere from above. He had discovered cosmic rays.

What are cosmic rays

Very energetic charged particles coming from outer space that continually bombard the earth

- Protons (hydrogen nuclei) 89%
- Helium nuclei 10%
- Heavier nuclei 1%

When they collide with atoms in the earth's upper atmosphere, they create a shower of lower energy secondary particles, mainly pions.

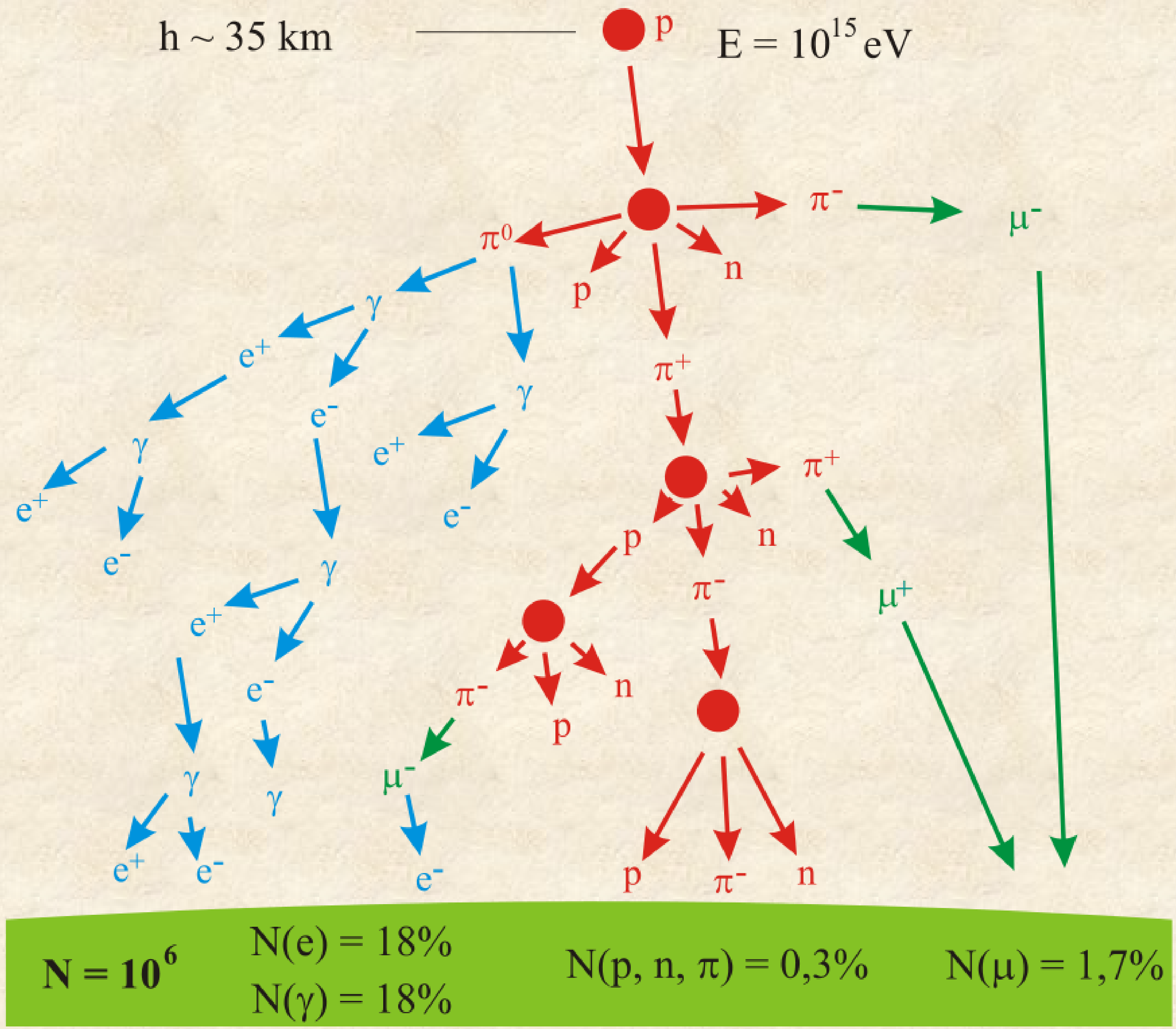
Pions swiftly decay emitting muons, which travel through the atmosphere and penetrate below ground.

A hundred of these secondary particles pass through our bodies every second.

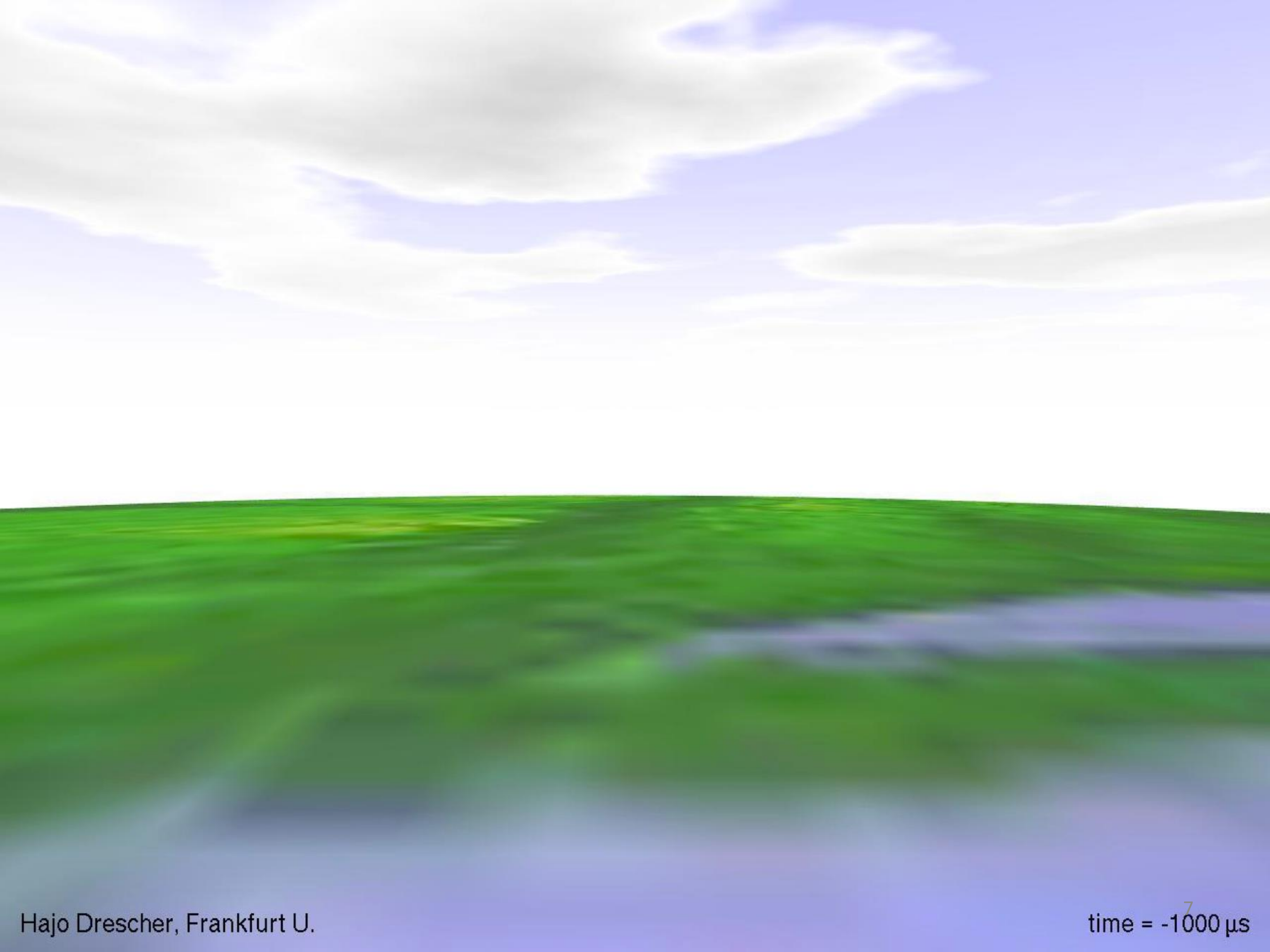
Energies of primary cosmic rays

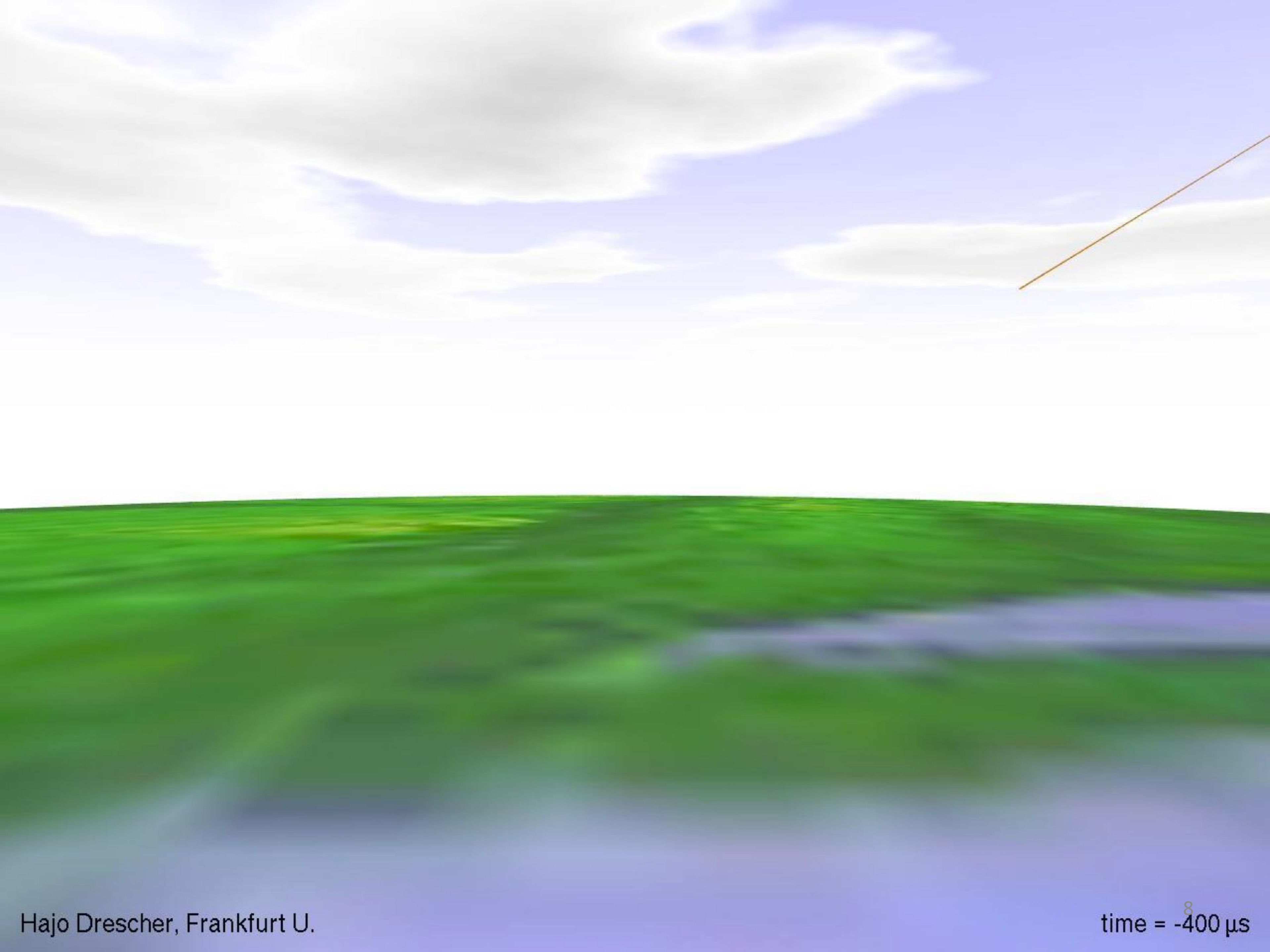
- from 1 GeV (rate : 10 000 / m^2s)
- up to 10^8 TeV (rate : < 1 /km^2century)

Very high energy cosmic rays generate huge showers of up to 10 billion secondaries spreading over areas of 20 km^2 at the surface of the earth

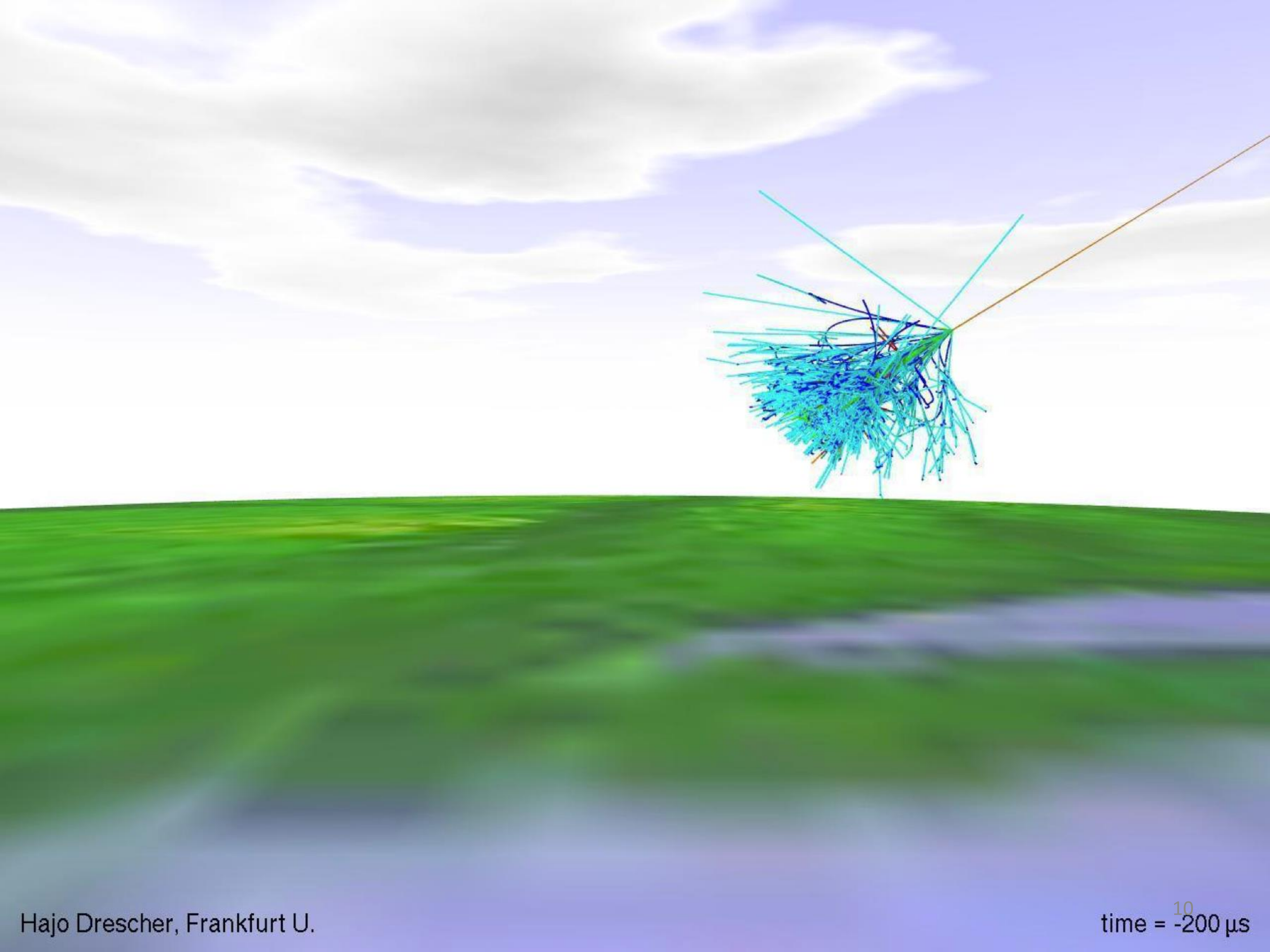


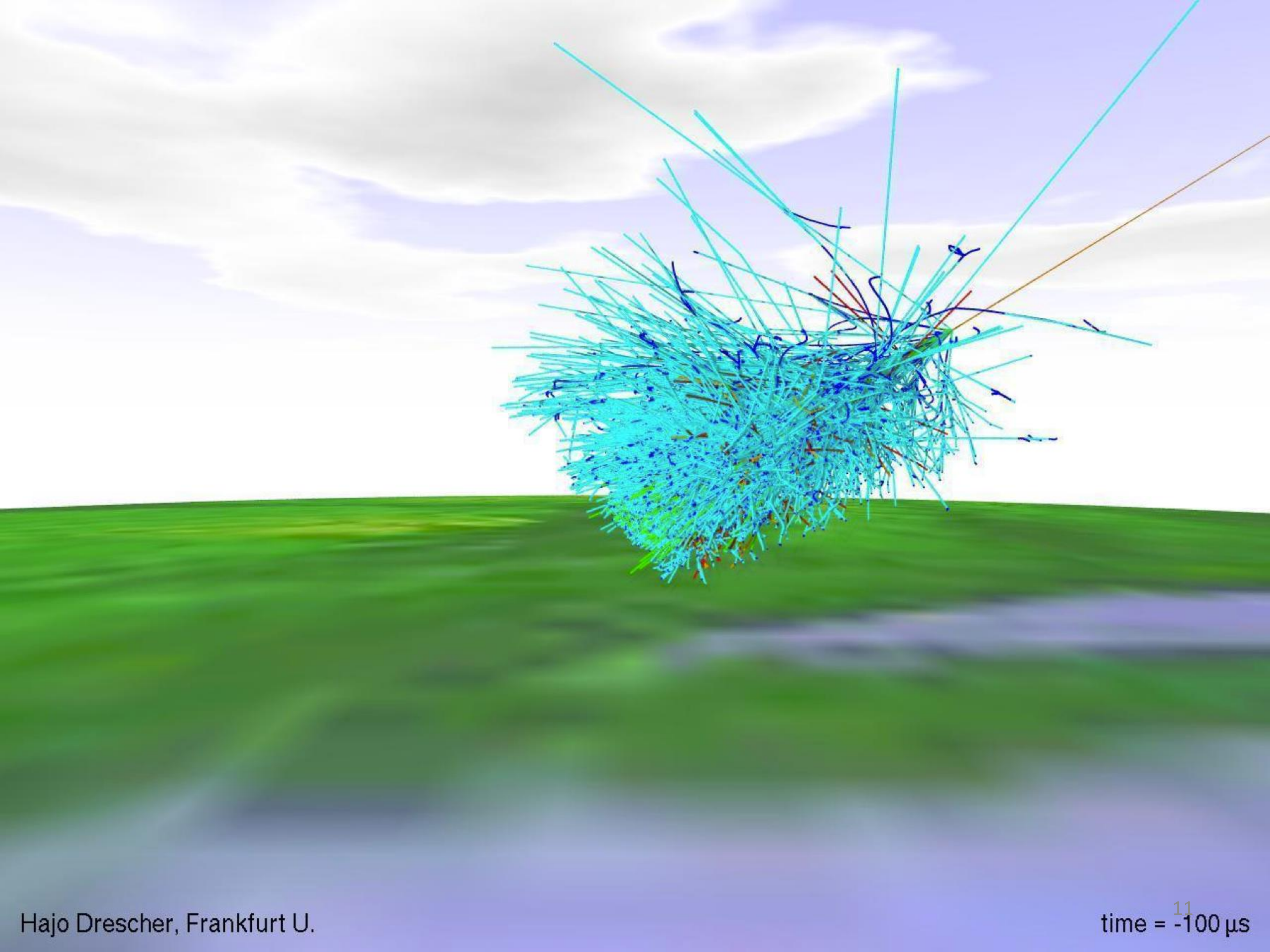
h ~ 35 km
p
E = 10^15 eV
π⁻
μ⁻
π⁰
p
n
γ
e⁺
e⁻
γ
π⁺
e⁺
γ
e⁻
e⁺
e⁻
π⁺
p
n
e⁻
γ
π⁻
μ⁺
e⁺
e⁻
π⁻
n
p
μ⁻
γ
γ
e⁺
e⁻
e⁻
p
π⁻
n
N = 10^6
N(e) = 18%
N(γ) = 18%
N(p, n, π) = 0,3%
N(μ) = 1,7%

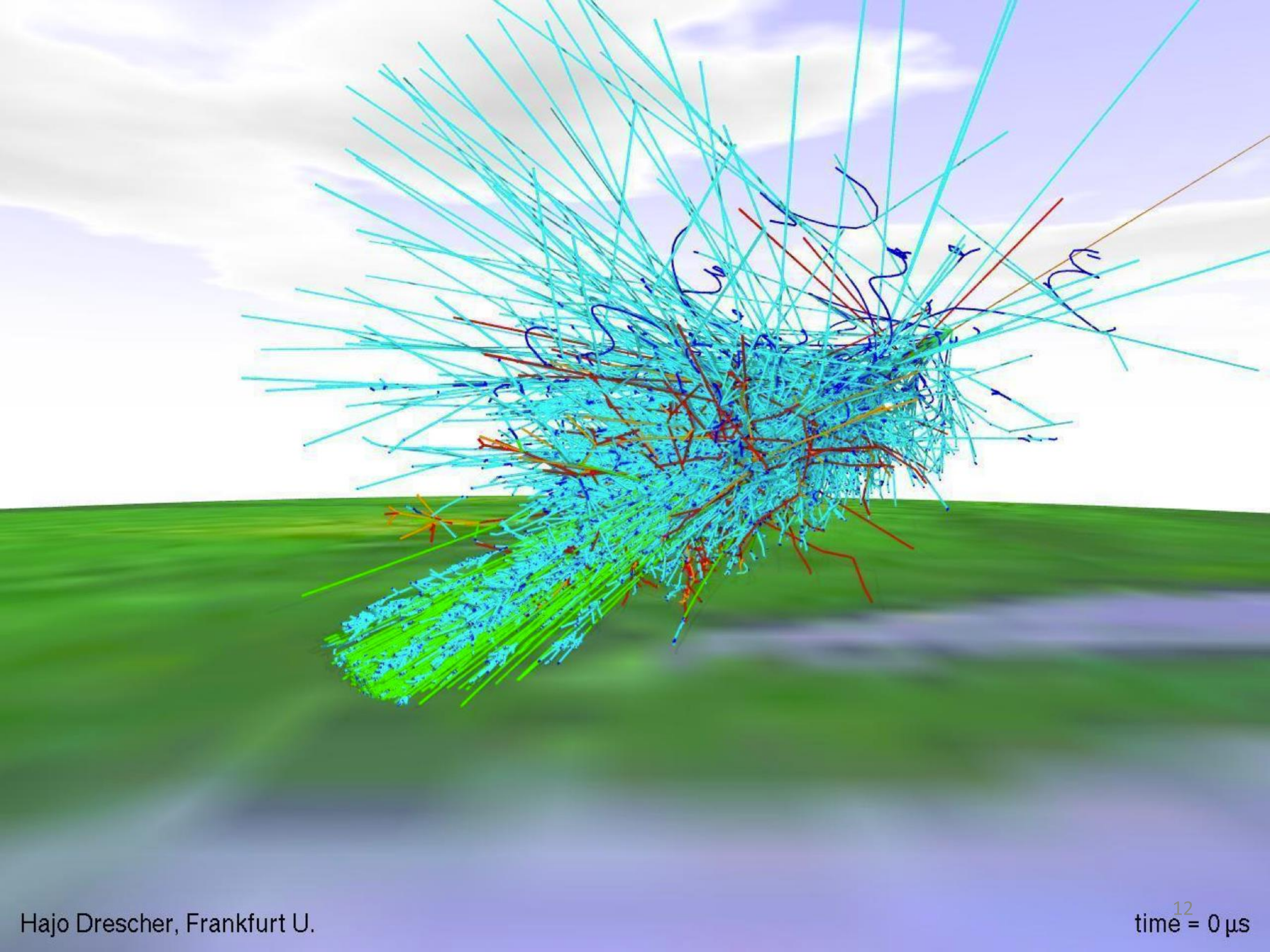

Hajo Drescher, Frankfurt U.
time = -1000 µs

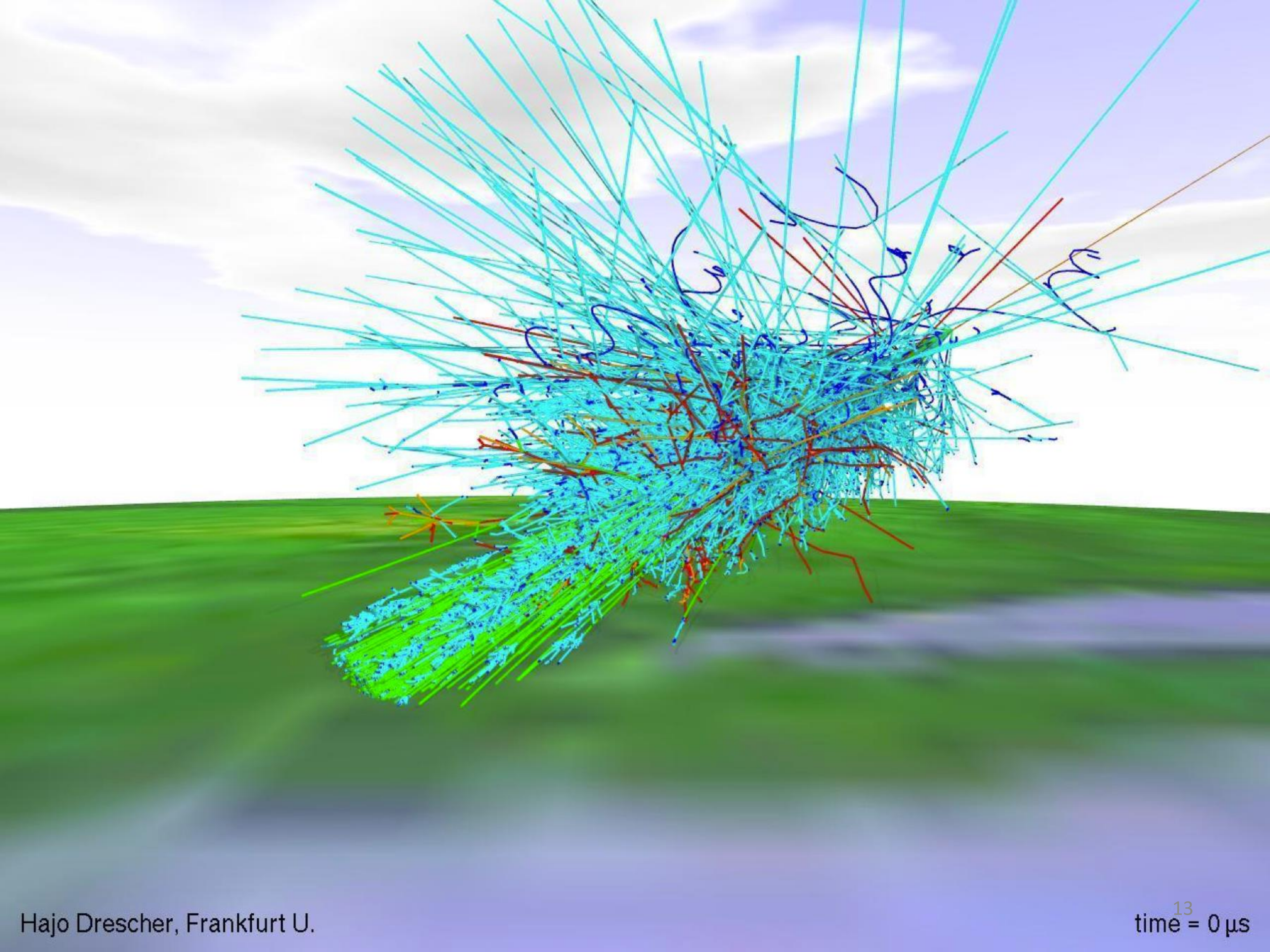

Hajo Drescher, Frankfurt U.
time = -400 µs


Hajo Drescher, Frankfurt U.
time = -300 µs


Hajo Drescher, Frankfurt U.
time = -200 µs


Hajo Drescher, Frankfurt U.
time = -100 µs


Hajo Drescher, Frankfurt U.
time = 0 µs


Hajo Drescher, Frankfurt U.
time = 0 µs

The Extreme Energy Events project
Science in the Schools

Cosmic ray physics experiment with double goal :
Educational / outreach and scientific research

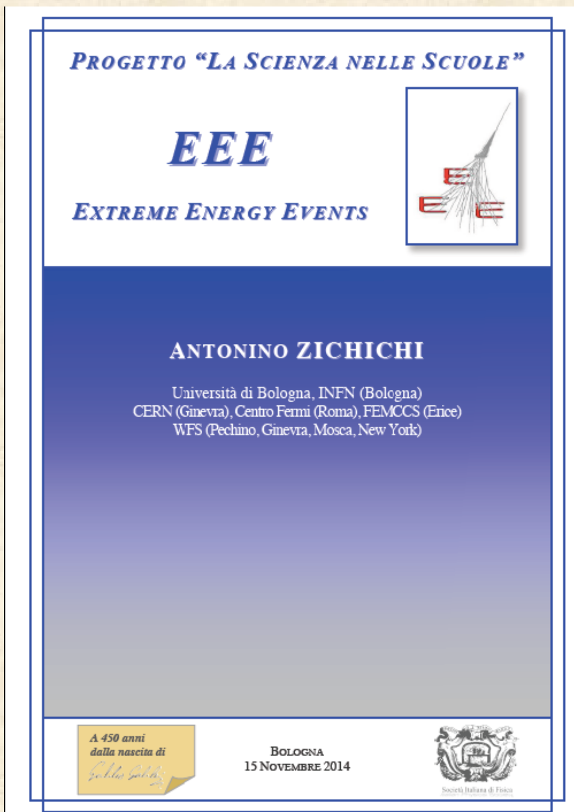
- hands-on activity for high-school students with the aim to stimulate their interest in science through their involvement in all stages of the project (detector construction, installation, comissioning, data-taking, analysis)
- research in cosmic ray physics

A collaboration of

- Centro Fermi – Roma Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi"
- INFN Istituto Nazionale di Fisica Nucleare
- MIUR Ministero dell' Istruzione, dell' Università e della Ricerca
- CERN European Organization for Nuclear Research

Some history..

Launch event : 3 May 2004
Webcast from CERN
Prof. A. Zichichi
Minister L. Moratti
watched by many Italian schools

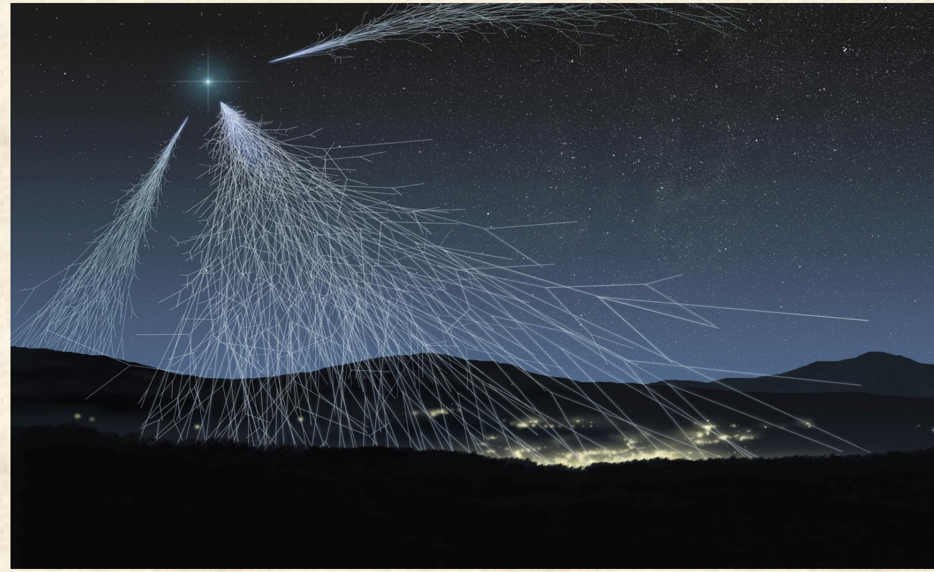


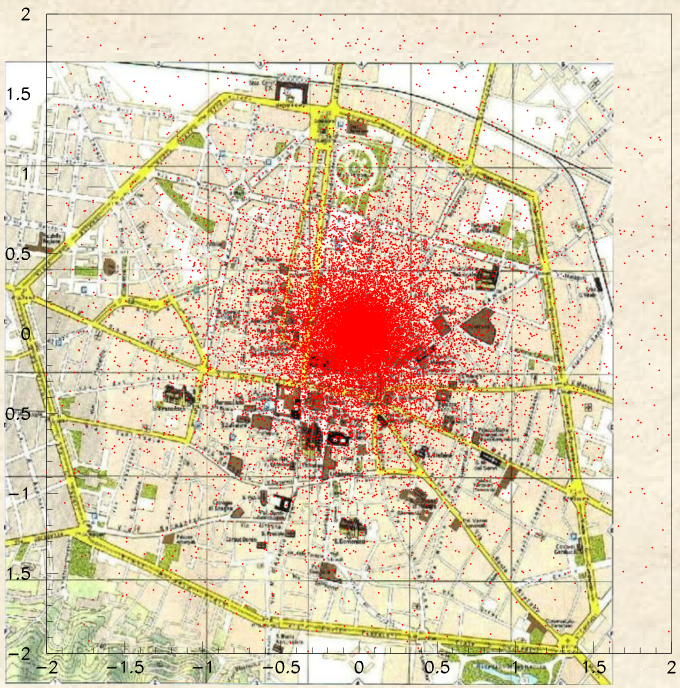
A. ZICHICHI, *Progetto "La Scienza nelle Scuole" EEE – Extreme Energy Events*
Società Italiana di Fisica (SIF), Bologna
1st Edition 2004; 2nd Edition 2005
3rd Edition 2012, 4th Edition 2014, 5th Ed. 2017

Aim of the EEE project

Look for extended air showers and extreme energy events

By detecting the muon component of the shower



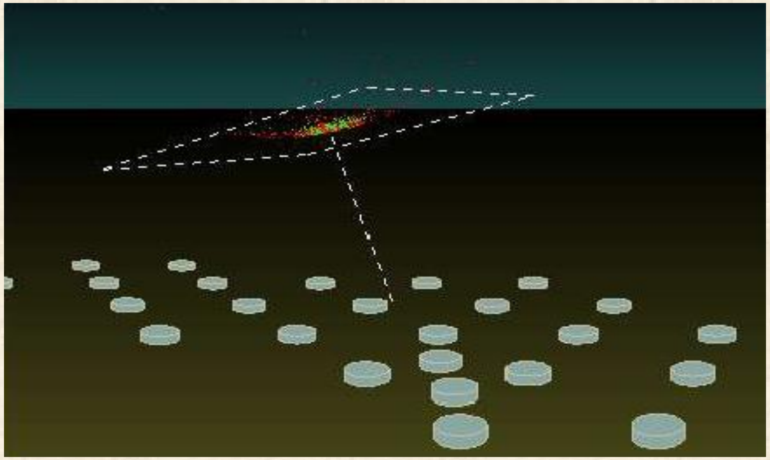


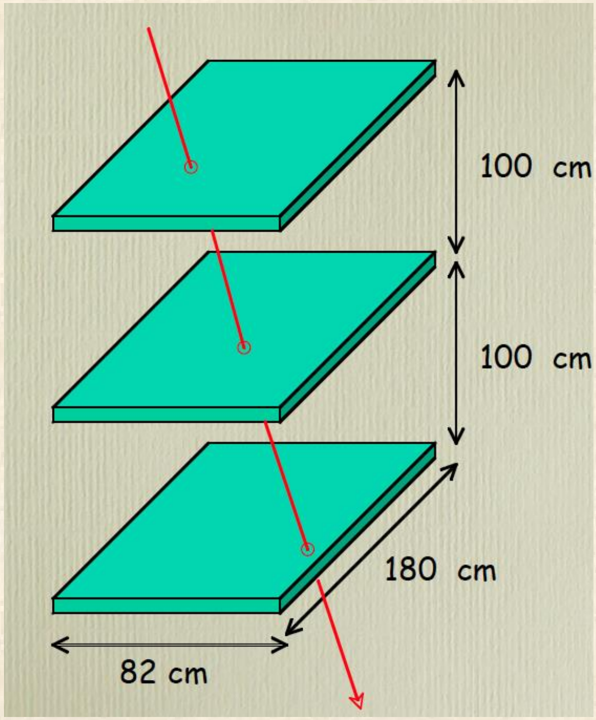
Simulation of a shower induced by a 10^{17}eV proton

(100 000 TeV, x20 000 > LHC energy)

At ground level 1 million muons arrive, over an area with radius at least 2 km.

- Place muon telescopes all over Italy in Italian High Schools
- Look for coincidences between telescopes





Key ingredient :
define direction of muon - so that we can point back to interaction point in atmosphere
check that muons belong to same shower and also get direction of incoming particle

An extended array of muon telescopes

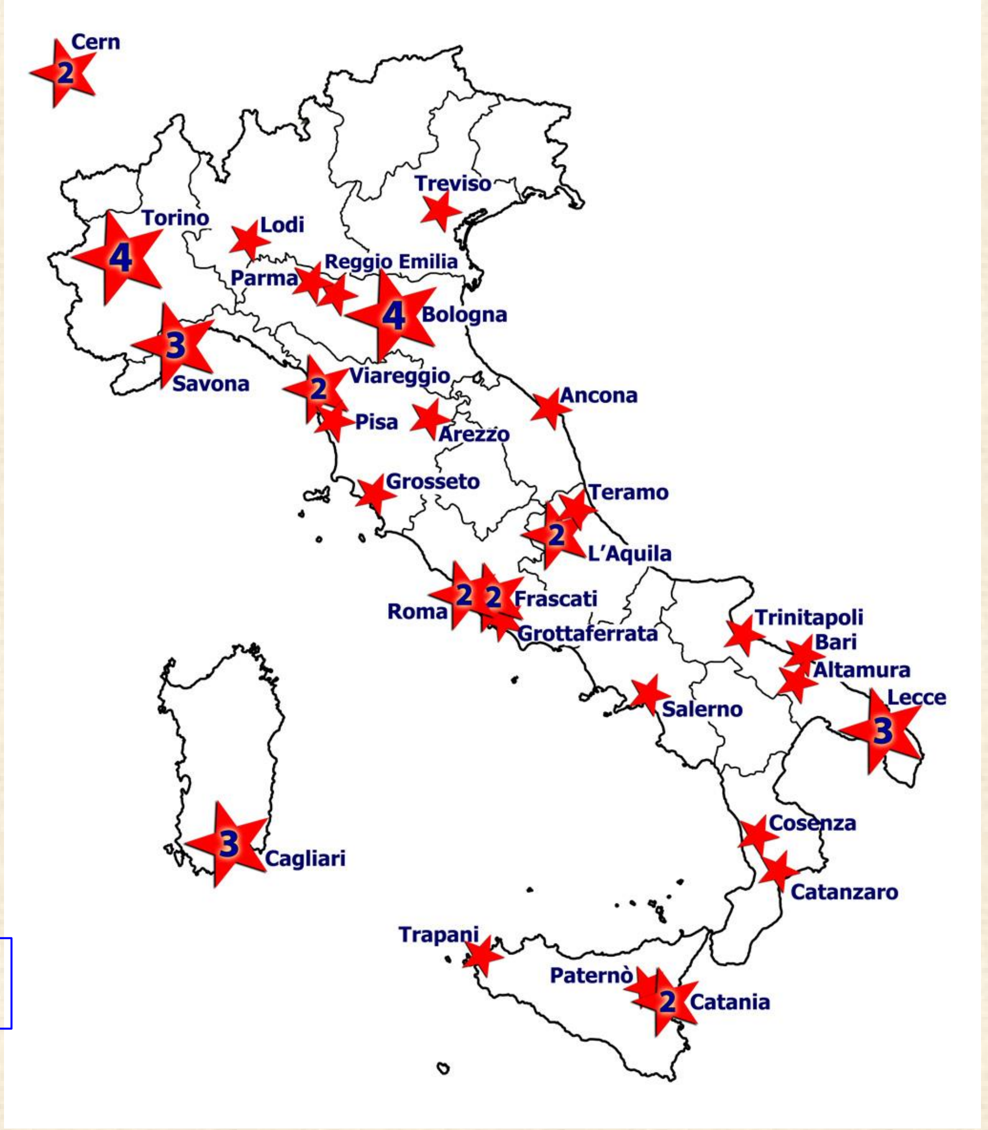
At present, a total of 53 telescopes

47 in Italian High Schools

They are mostly distributed in clusters in the whole Italian territory

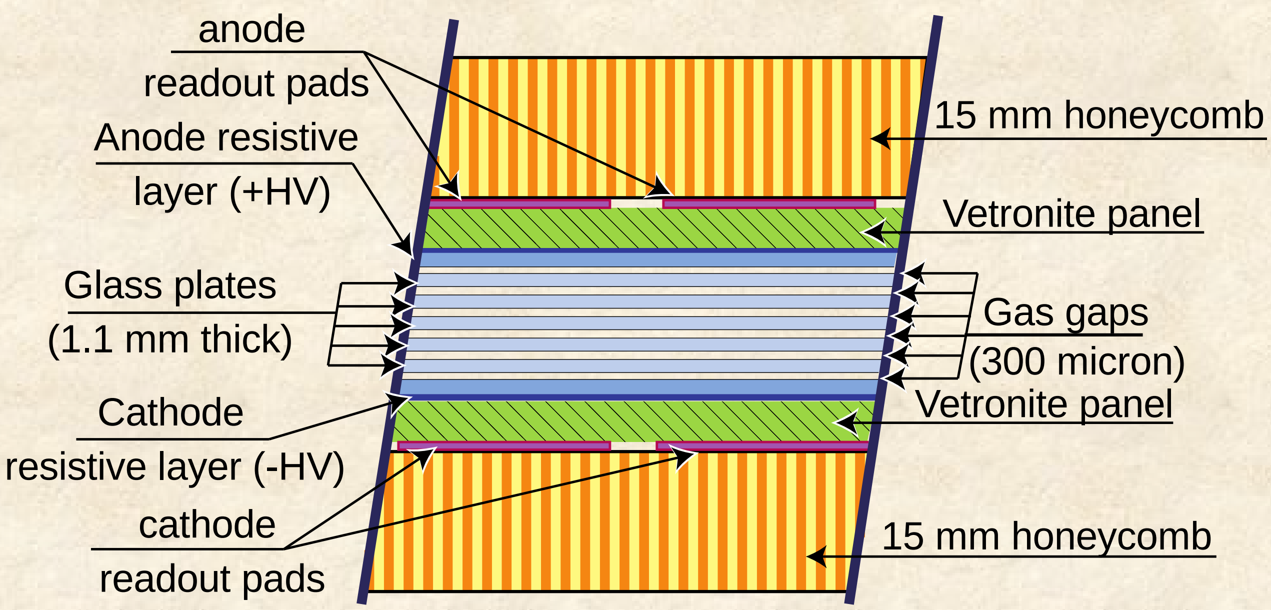
+ 2 telescopes at CERN
+ 4 in INFN Sections or Universities

~45 more schools on the waiting list



The experimental aparatus

The detector : 3 Multigap Resistive Plate Chambers (MRPC)

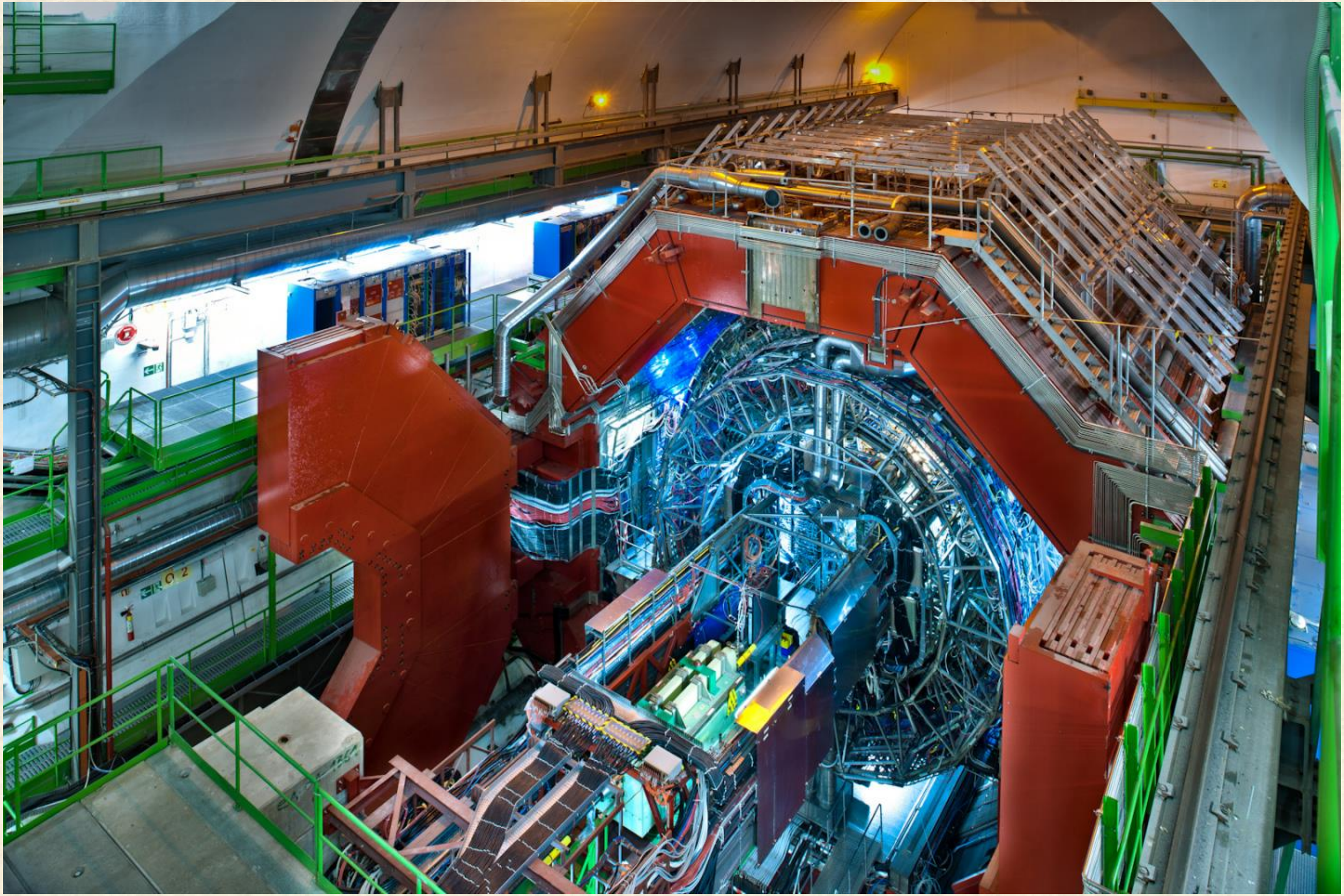


- 6 gas gaps of 300 microns each
- dimensions : 82 cm x 180 cm

➢ Requirements : reliable (long-term); easy to use; not expensive

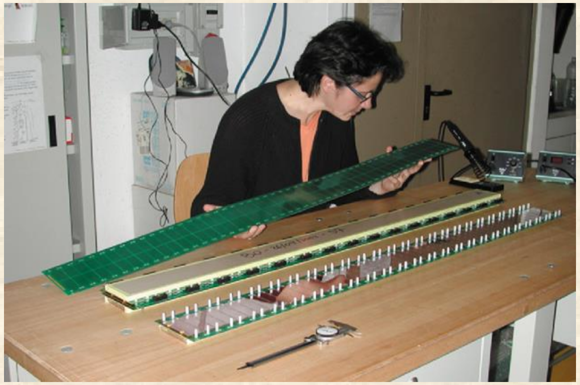
➢ Design based on the MRPCs of the ALICE Time Of Flight (TOF)

ALICE (A Large Ion Collider Experiment)



16 m x 16 m x 26 m 10 000 tons 60 m below ground @LHC @CERN

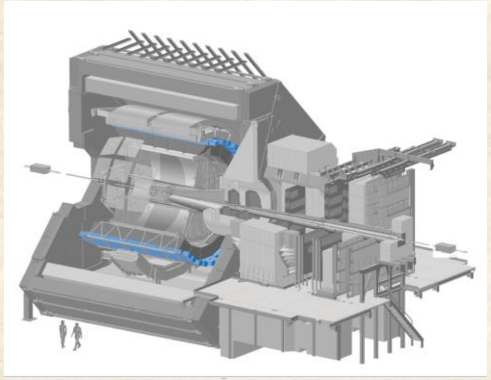
The ALICE Time Of Flight (TOF) detector

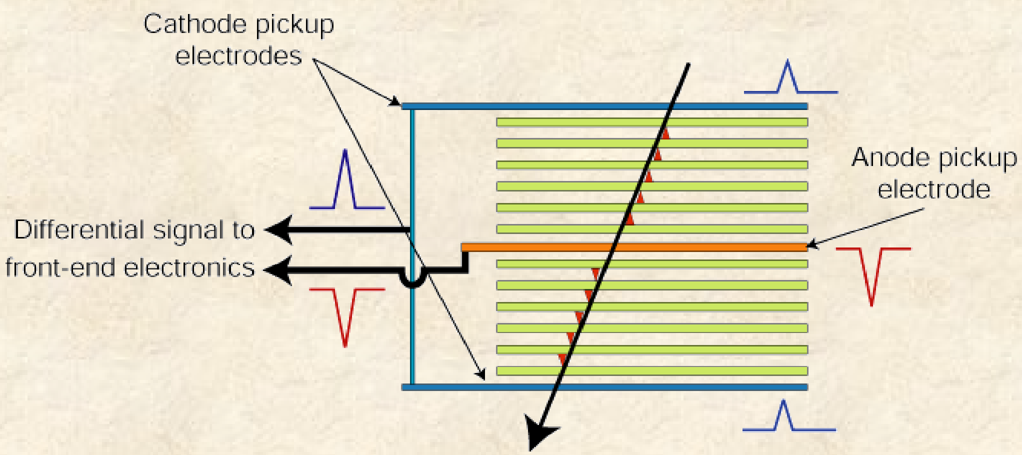


Provides charged particle identification

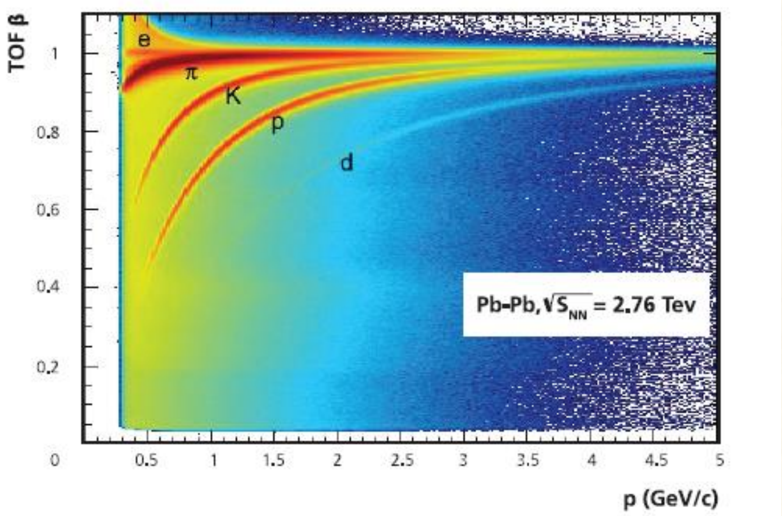
Multigap Resistive Plate Chamber
10 gaps of 250 microns each

Cylindrical array of 150 m^2 r=3.7 m
1600 MRPCs in 18 Supermodules



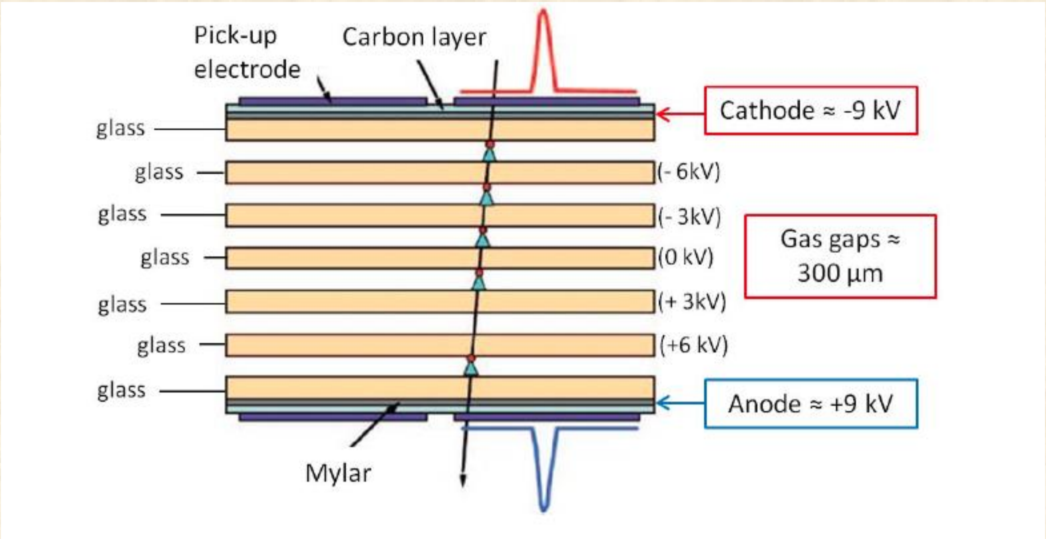


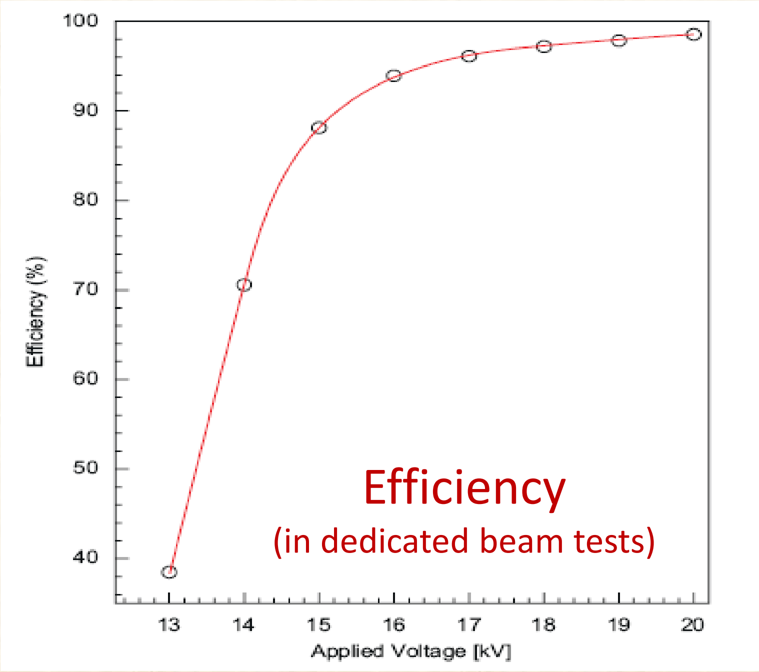
System time resolution σ = 70-80 ps



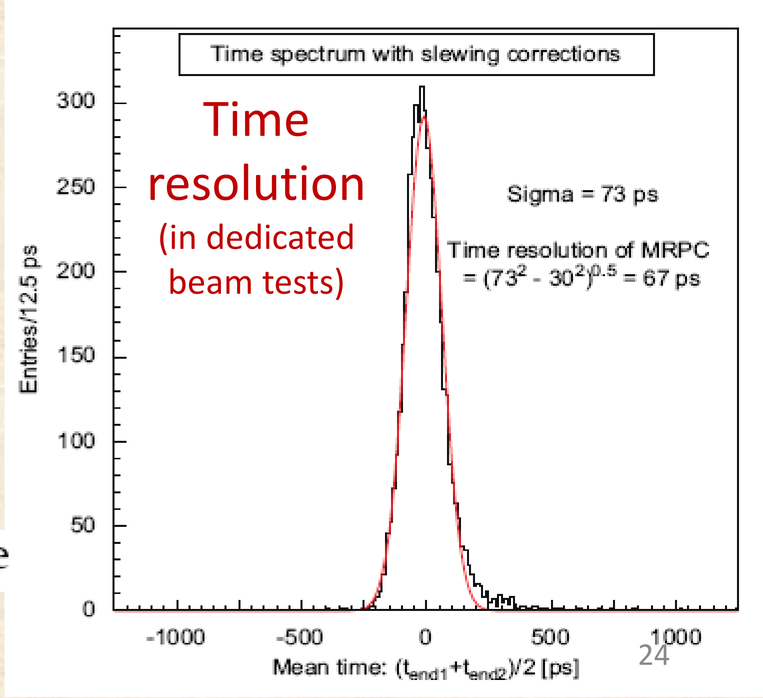
Correlation β = v/c versus momentum as observed by TOF in Pb-Pb collisions. Particle species are clearly separated in the intermediate p_T range

The EEE MRPC





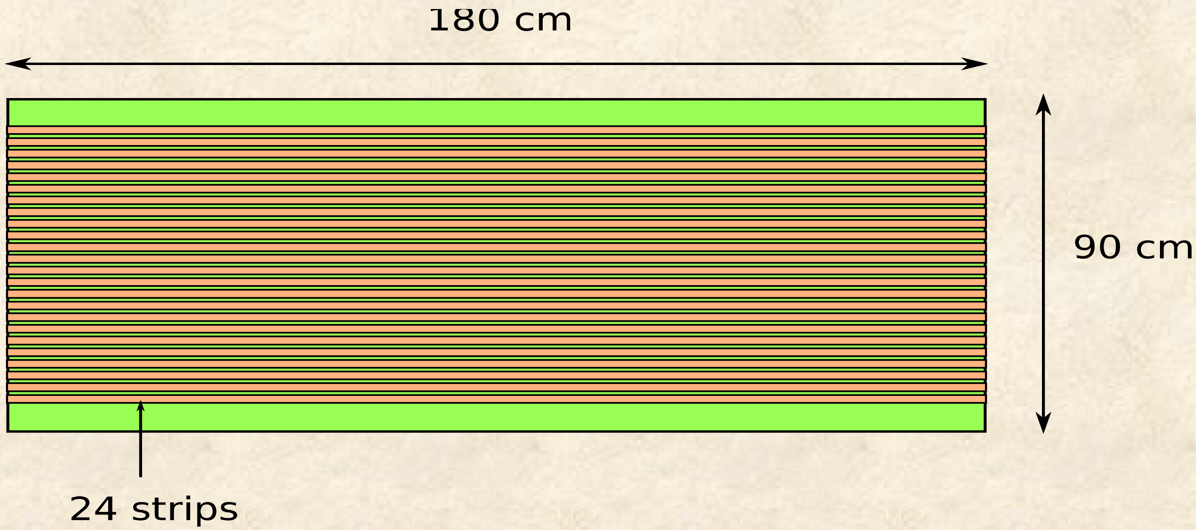
Operated with a mixture of 98 % $C_2H_2F_4$ – 2% SF_6



Performance of a six gap MRPC built for large area coverage

M. Abbrescia et al. / Nuclear Instruments and Methods in Physics Research A 593 (2008) 263–268

Signal readout

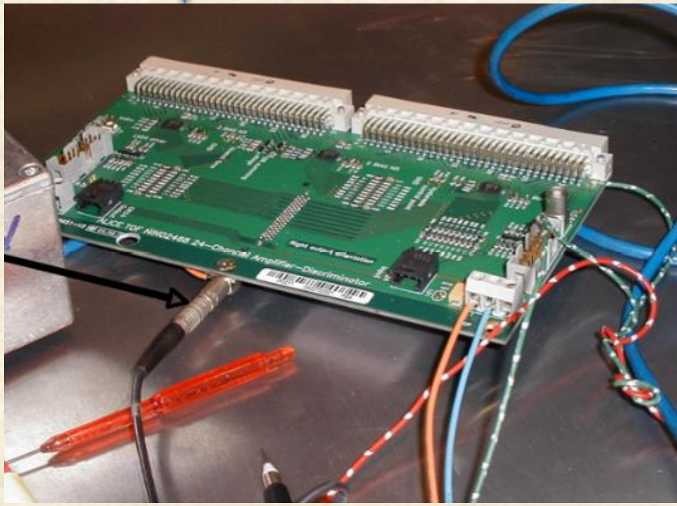


- 24 strips read out at both ends
- time difference : position of hit along the strip
- Anode & cathode readout plane : differential signal

adhesive copper tape on vetronite sheet
strip width : 2.5 cm; distance between strips : 0.7 cm
Pitch : 3.2 cm

FEA card
3 NINO asics / 24 channels
- Amplification
- Discrimination
- Stretching of pulse
- OR of 24 signals

2 FEAs per MRPC



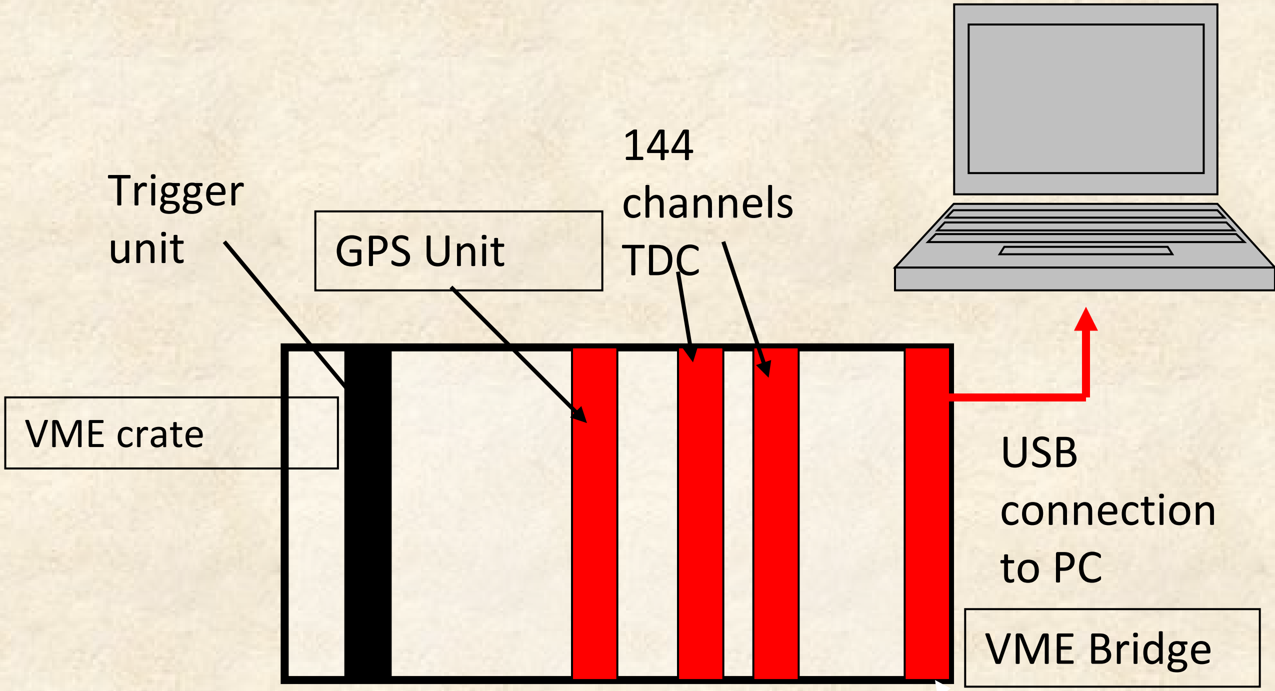
Space resolution in x and y : ~ 1 cm

Electronics

TDC TDC VME Bridge



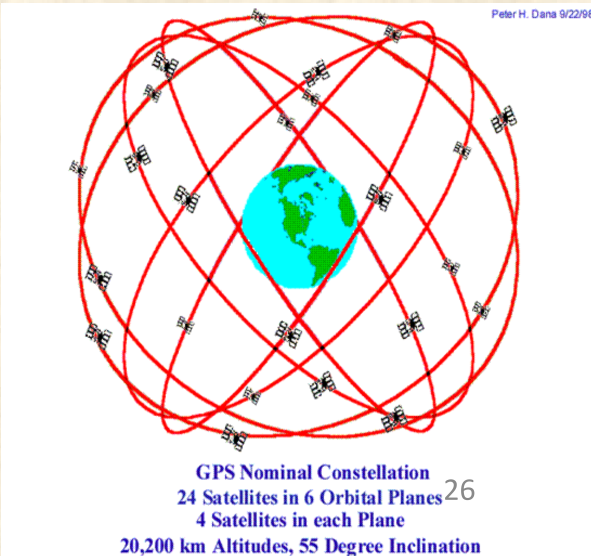
CAEN V1190A CAEN V1190B CAEN V1718



Data Acquisition and monitoring based on Labview

Trigger card
6-fold coincidence

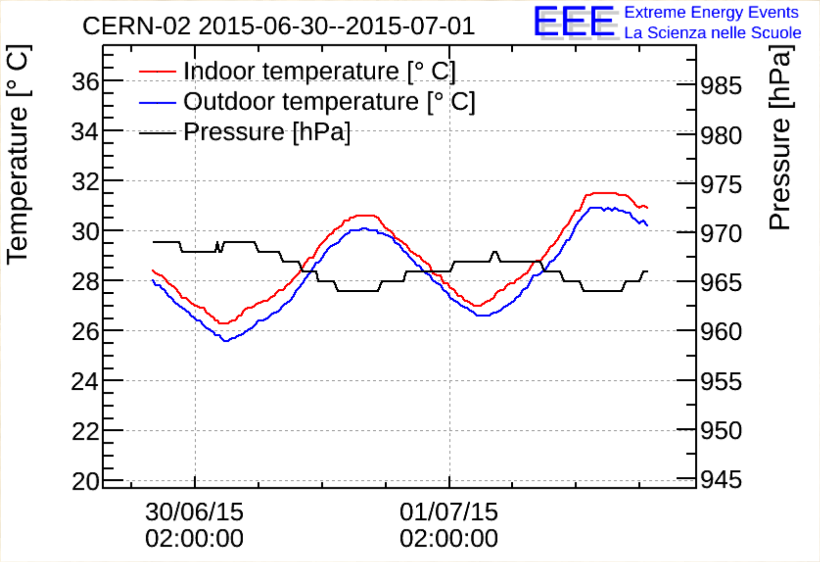
Hytec (or Spectracom) GPS to generate time stamps and synchronize stations at different location

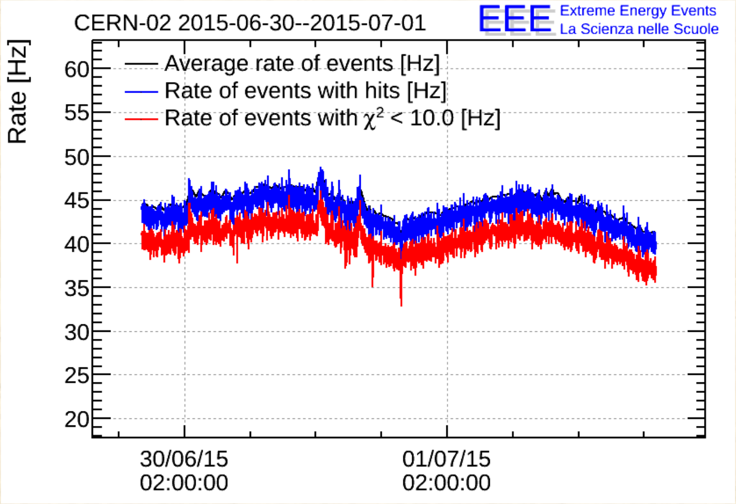


In addition

Weather station to monitor
- temperature
- pressure

read out by the DAQ

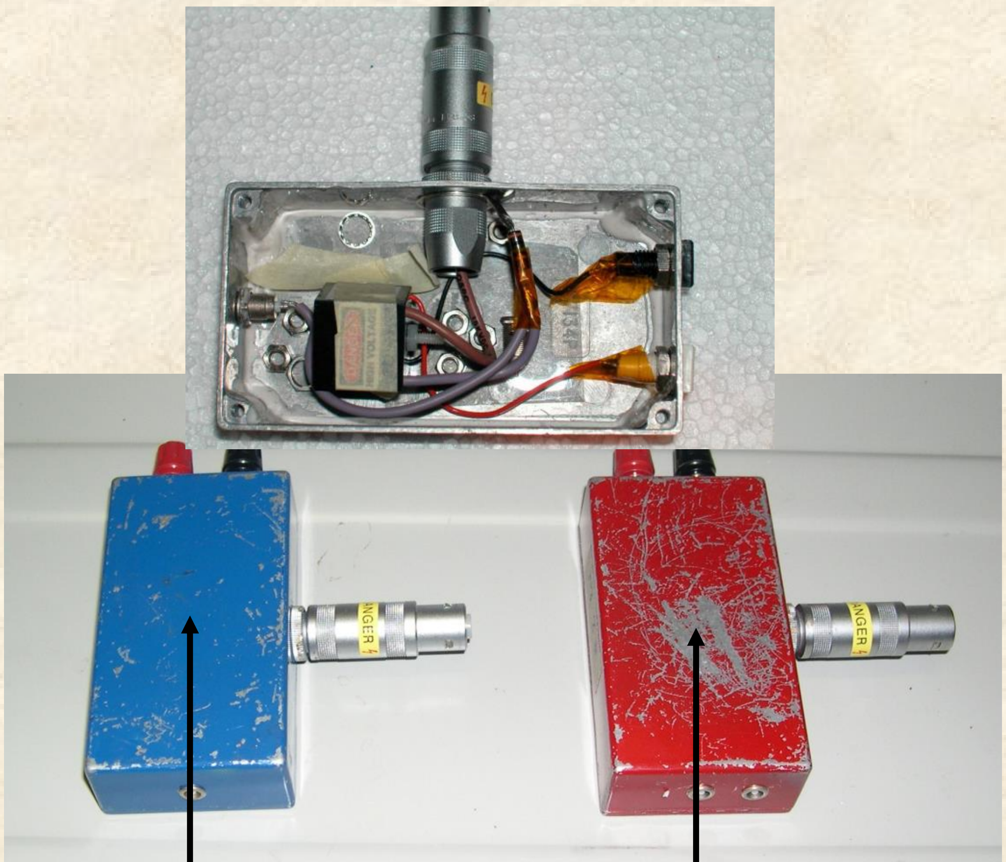




The HV system

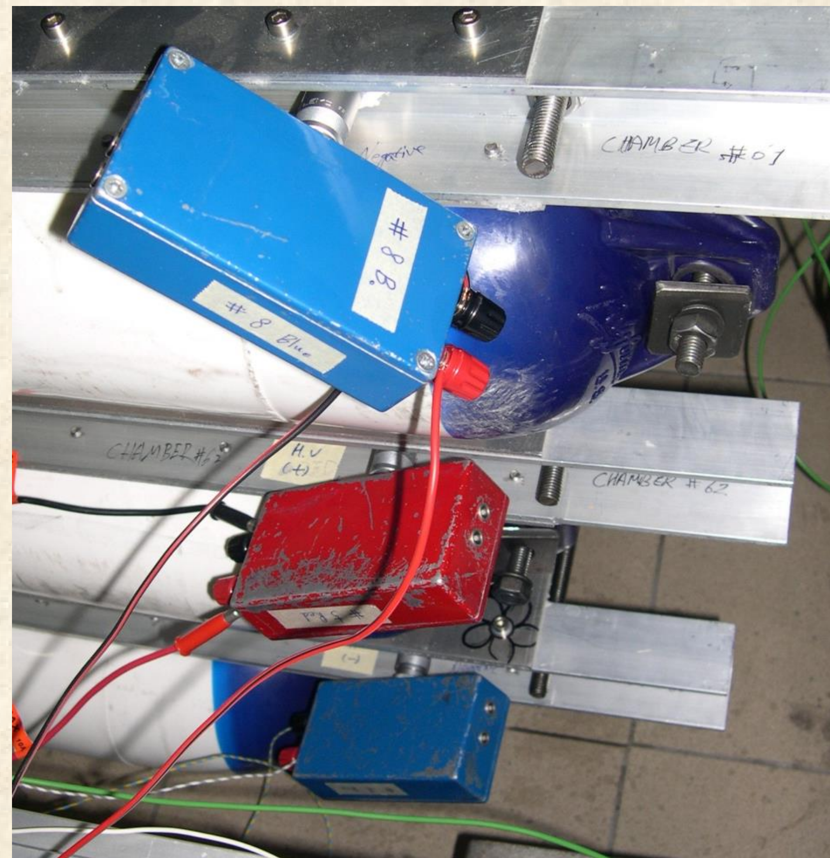
Working voltage for MRPCs : 18 - 20 kV

- DC-DC converters inside small boxes
- EMCO Q series converters providing an output voltage up to ±10 kV for 0-5 V input



-HV

+HV



The students' involvement

Phase I. Construction of muon detectors (MRPCs)

- Done by high-school students and teachers at CERN supervised by researchers*
- Each school sends 4-6 students accompanied by 1-2 teachers
- During their week-long stay at CERN they build 3 chambers

*Special agreement with CERN to allow children <18-years old to work in CERN labs

- 2005 7 schools (pilot)
- 2006 14 schools
- 2009 10 schools
- 2012 3 schools
- 2014 6 schools
- 2015 6 schools

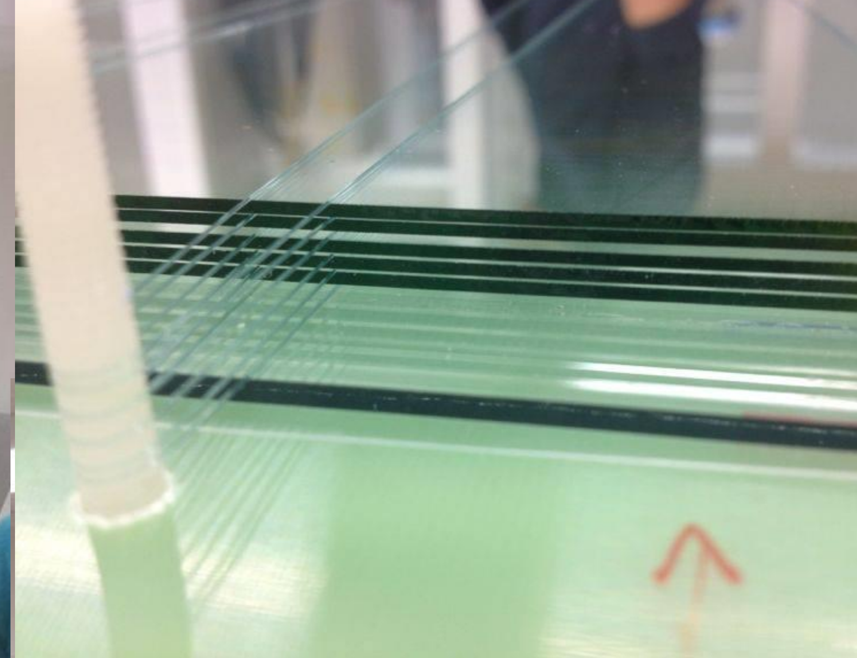
Total : 46 schools 250-300 students 50-80 teachers

- 2017 6 schools (telescopes will be installed until end 2017)

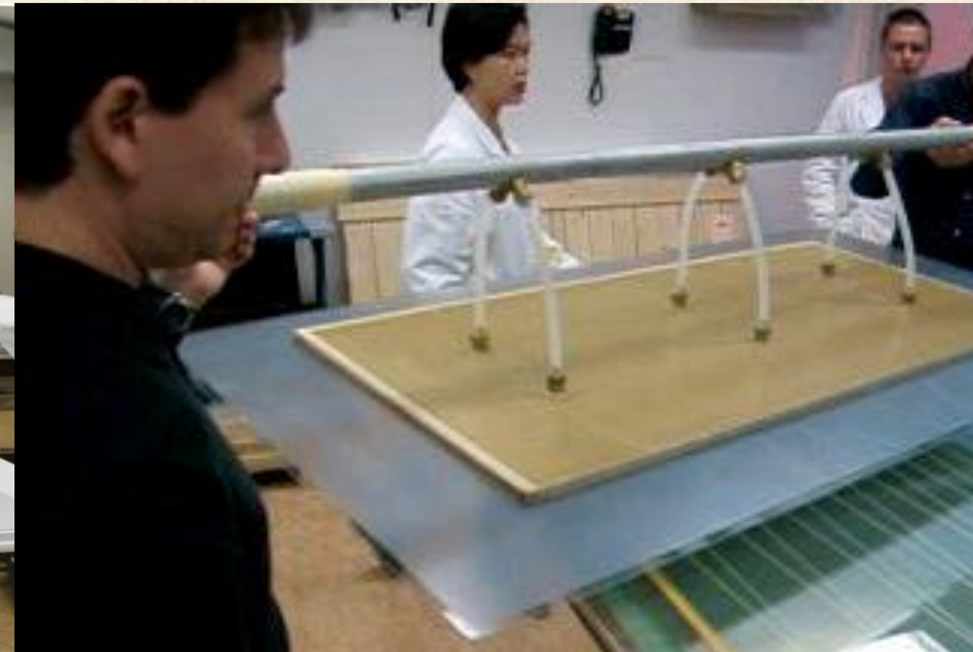
preparation of honeycomb panels

preparation of readout copper strips

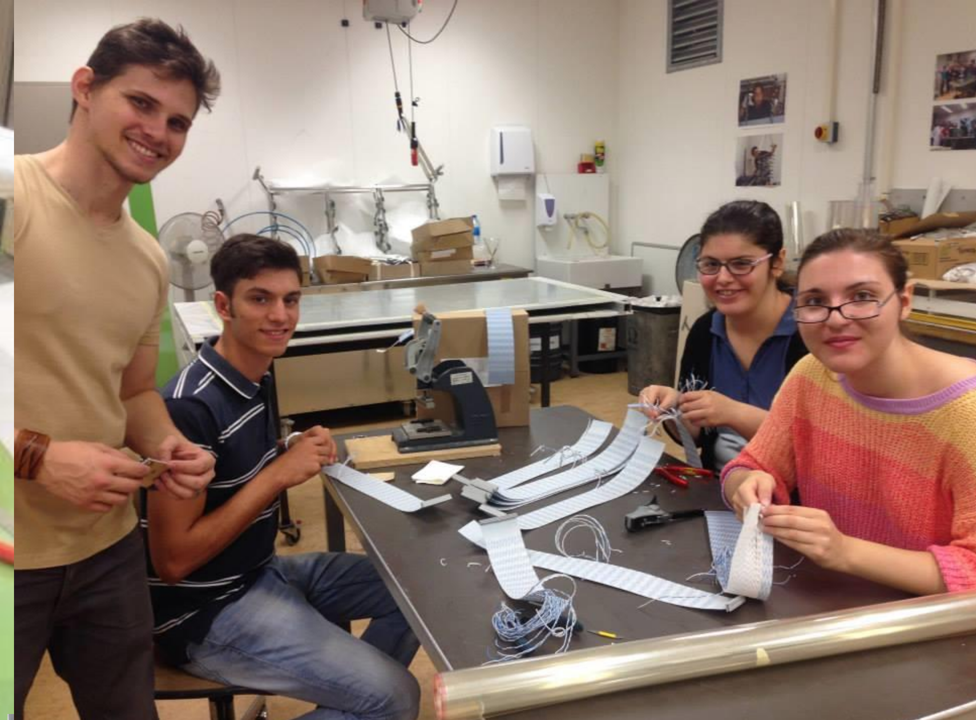
Fishing-line spacers

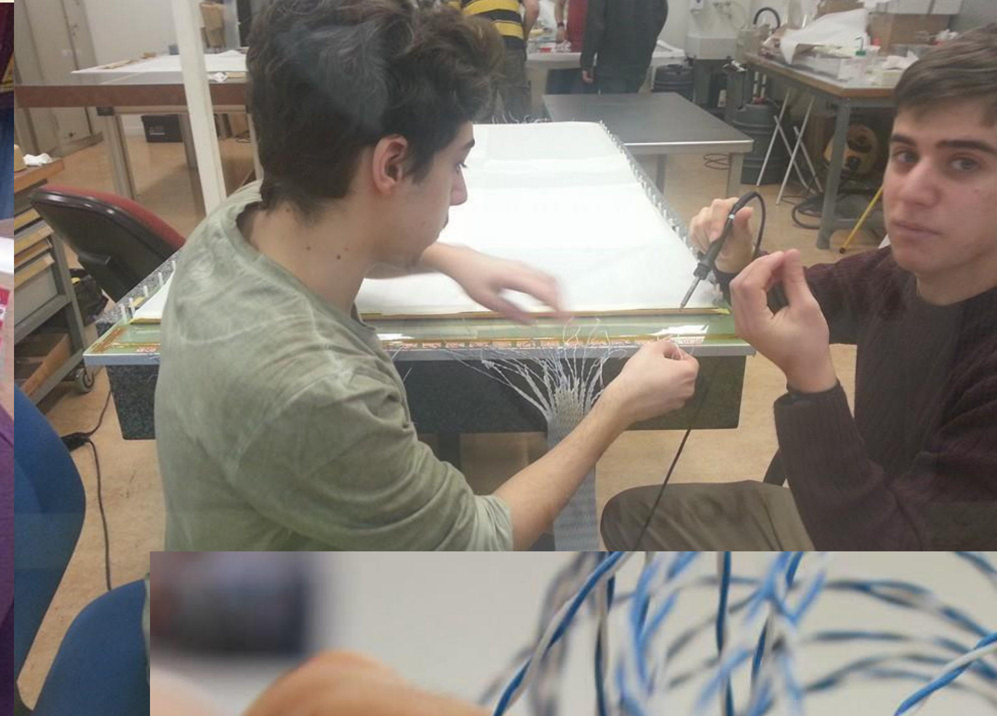


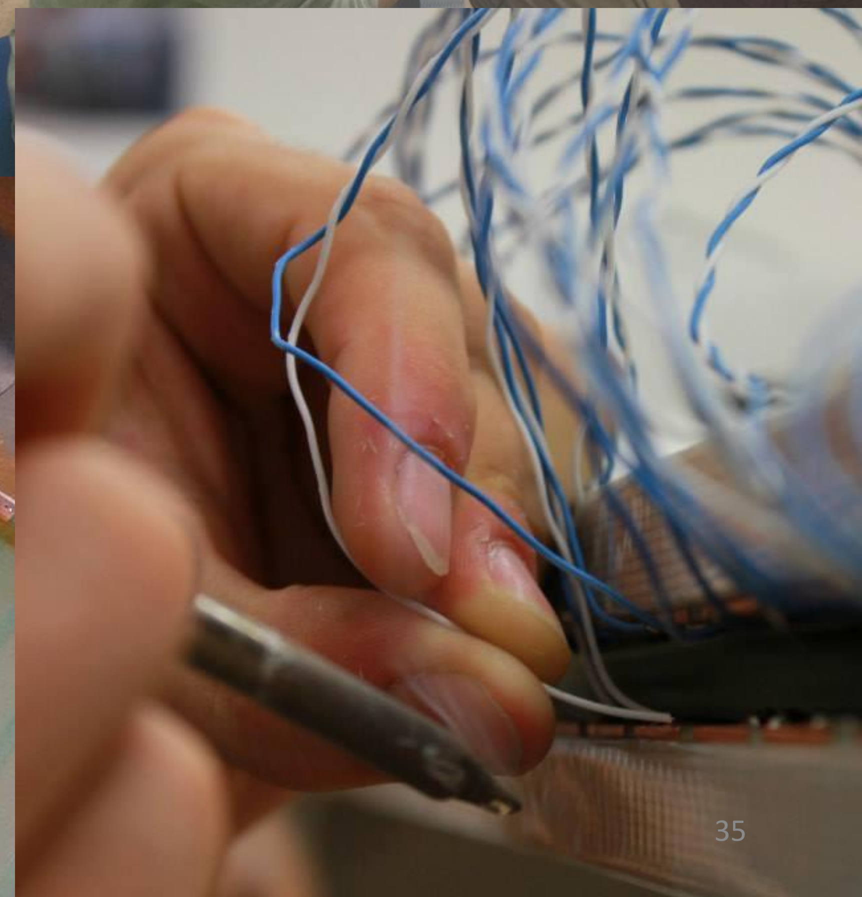

Cleaning glass panels



preparation of signal cables



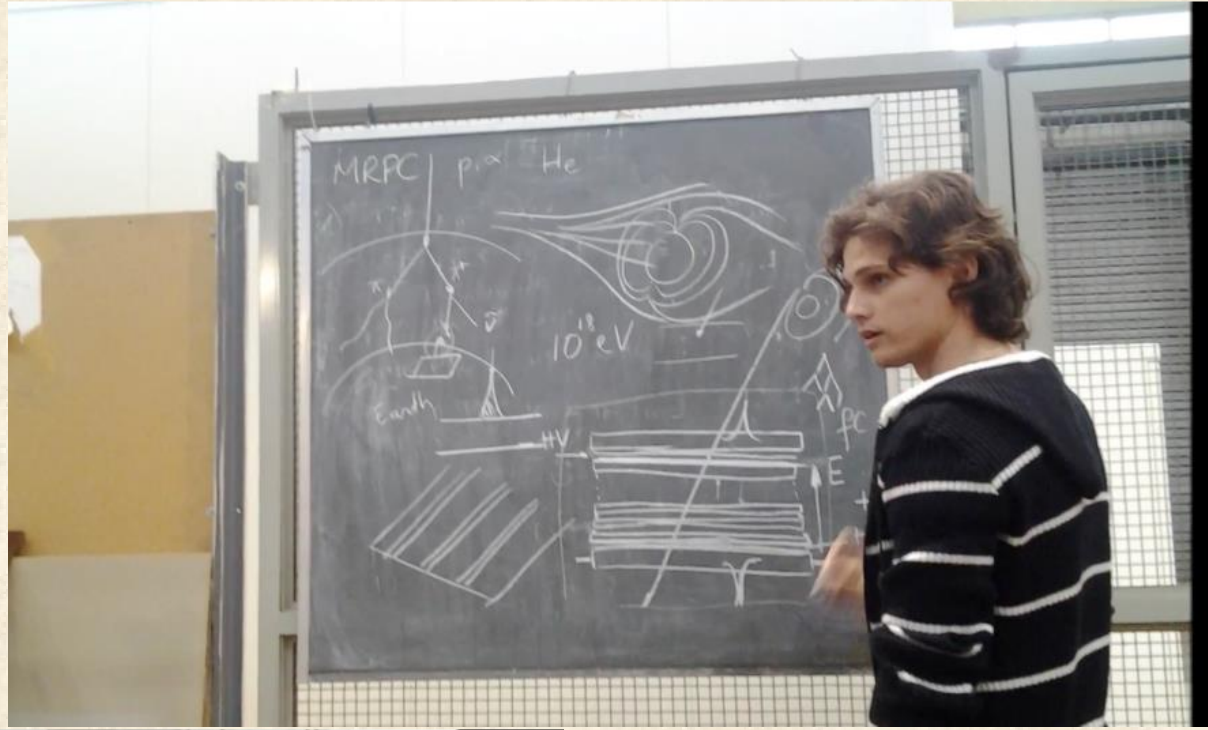




Soldering signal cables

Closing the gas box with the MRPC

Chambers under gas flow to test for leaks “lesson” on physics and operation of MRPCs



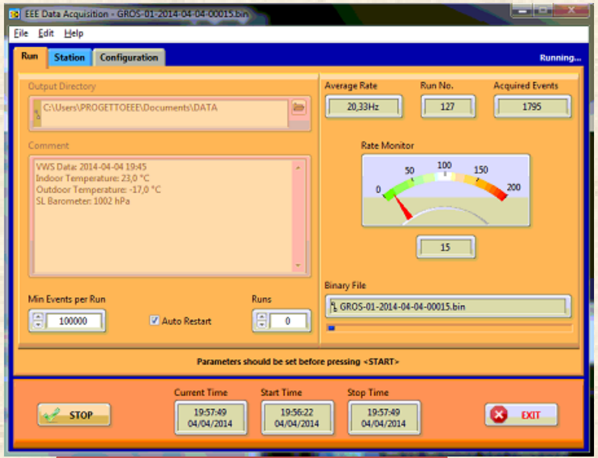
“lesson” on

- electronics
- readout
- data acquisition

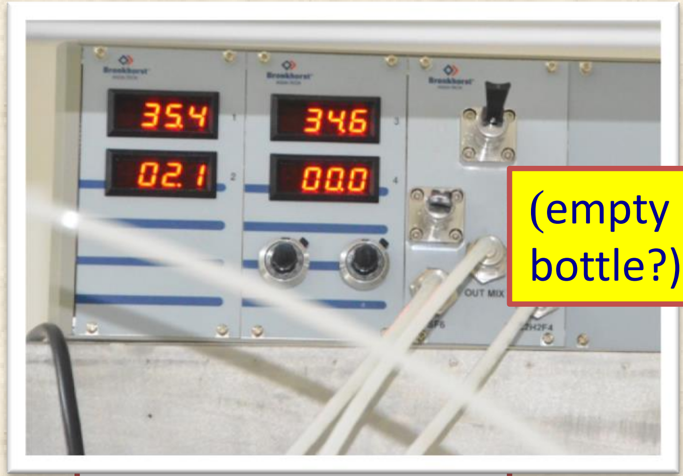
Chambers are shipped to Italy

Phase II: assembling the muon telescope

Phase III. Data-taking and monitoring



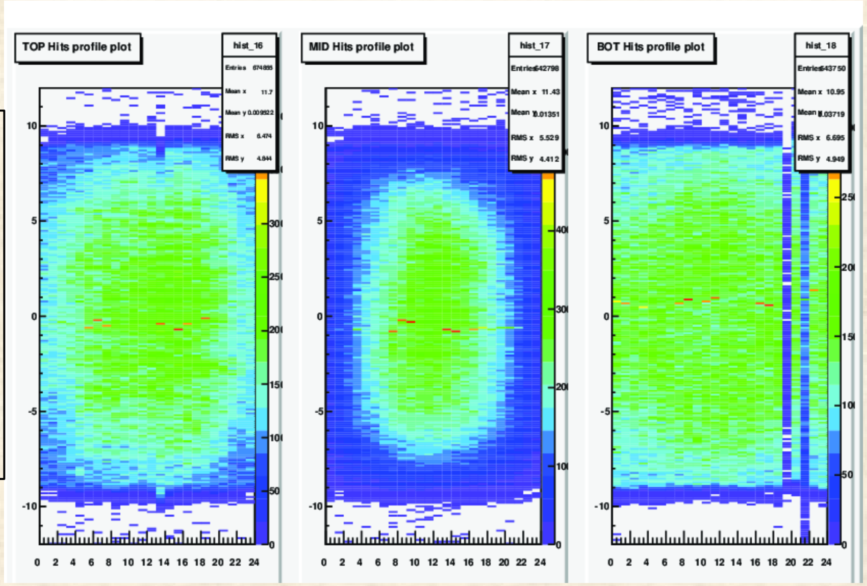
Check DAQ is ON



(empty bottle?)

Check GAS flow

The schools have the responsibility for keeping the telescope alive and ensure data-taking (with help from INFN and University researchers)

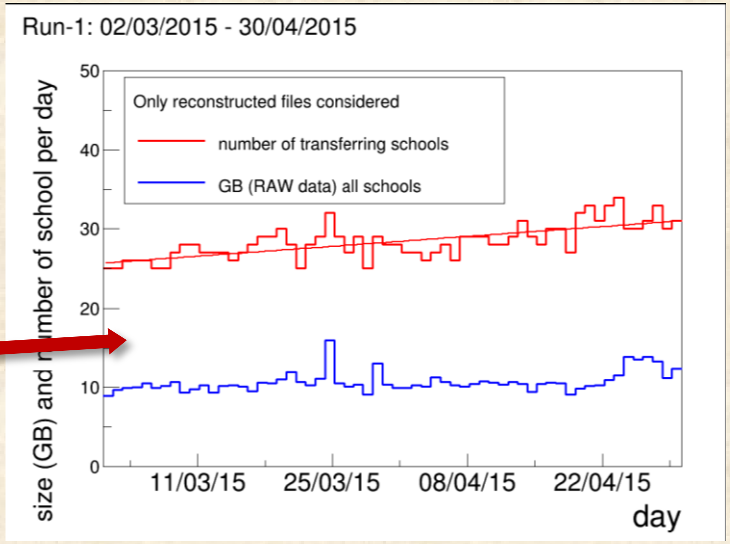


(dead channels?)

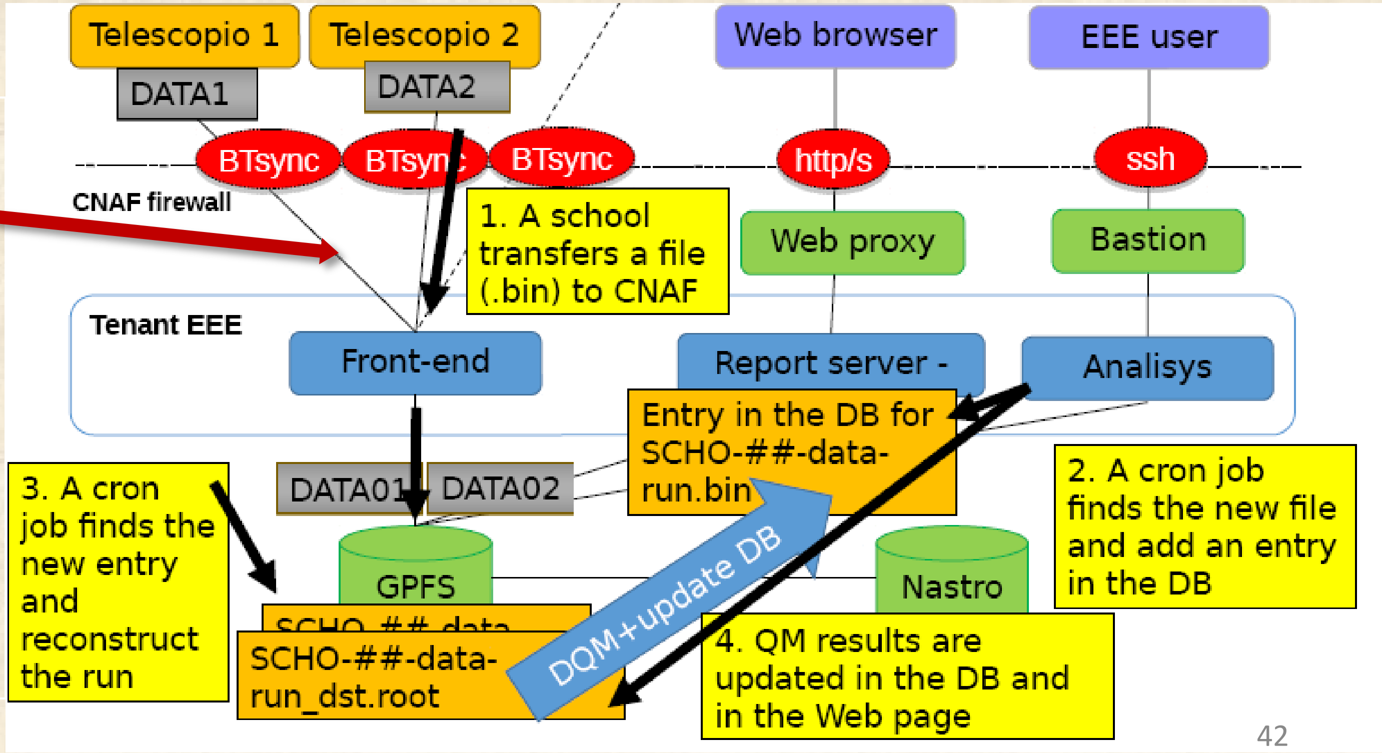
Check chamber hit distributions

EEE@CNAF

5-10 TB per year expected
Full statistics from Pilot run to Run-1:
~2.4 TB (raw: ~2 TB, reco: ~0.4 TB)
(+3 TB from past years)

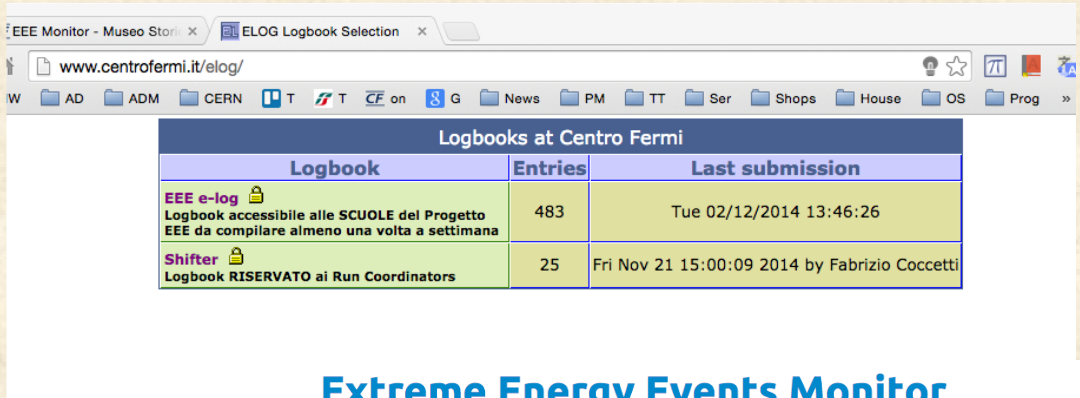


Data transferred fro each station to CNAF
A complex software architecture has been set-up to reconstruct the data and provide quasi-online (few hours) **histograms on the web for monitoring purposes**



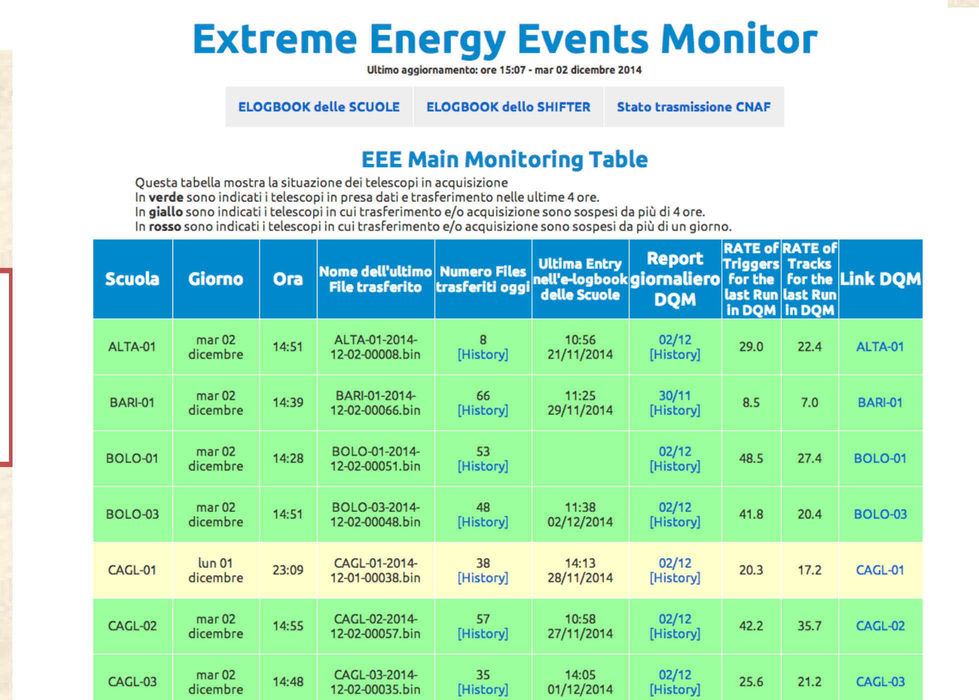
Phase IV: students' participation in coordinated run

Fill the e-logbook



Logbooks at Centro Fermi		
Logbook	**Entries**	**Last submission**
EEE e-log **Logbook accessibile alle SCUOLE del Progetto EEE da compilare almeno una volta a settimana**	483	Tue 02/12/2014 13:46:26
Shifter **Logbook RISERVATO ai Run Coordinators**	25	Fri Nov 21 15:00:09 2014 by Fabrizio Coccetti

Shifter :
Check the CNAF on-line monitoring system



Extreme Energy Events Monitor

Ultimo aggiornamento: ore 15:07 - mar 02 dicembre 2014

ELOGBOOK delle SCUOLE | ELOGBOOK dello SHIFTER | Stato trasmissione CNAF

EEE Main Monitoring Table

Questa tabella mostra la situazione dei telescopi in acquisizione
In **verde** sono indicati i telescopi in presa dati e trasferimento nelle ultime 4 ore.
In **giallo** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di 4 ore.
In **rosso** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di un giorno.

Scuola	Giorno	Ora	Nome dell'ultimo File trasferito	Numero Files trasferiti oggi	Ultima Entry nell'e-logbook delle Scuole	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	mar 02 dicembre	14:51	ALTA-01-2014-12-02-00008.bin	8 [History]	10:56 21/11/2014	02/12 [History]	29.0	22.4	ALTA-01
BARI-01	mar 02 dicembre	14:39	BARI-01-2014-12-02-00066.bin	66 [History]	11:25 29/11/2014	30/11 [History]	8.5	7.0	BARI-01
BOLO-01	mar 02 dicembre	14:28	BOLO-01-2014-12-02-00051.bin	53 [History]		02/12 [History]	48.5	27.4	BOLO-01
BOLO-03	mar 02 dicembre	14:51	BOLO-03-2014-12-02-00048.bin	48 [History]	11:38 02/12/2014	02/12 [History]	41.8	20.4	BOLO-03
CAGL-01	lun 01 dicembre	23:09	CAGL-01-2014-12-01-00038.bin	38 [History]	14:13 28/11/2014	02/12 [History]	20.3	17.2	CAGL-01
CAGL-02	mar 02 dicembre	14:55	CAGL-02-2014-12-02-00057.bin	57 [History]	10:58 27/11/2014	02/12 [History]	42.2	35.7	CAGL-02
CAGL-03	mar 02 dicembre	14:48	CAGL-03-2014-12-02-00035.bin	35 [History]	14:05 01/12/2014	02/12 [History]	25.6	21.2	CAGL-03

Data-taking

For many years: data taking « independent » ; data transferred to Erice server
Starting in 2014: Effort to centralise and coordinate data-taking

Pilot run : 27 October-14 November 2014
simultaneous and, for the first time, completely automatic acquisition, reconstruction and data storage from half (23) of the EEE telescopes at the INFN-CNAF computer centre of Bologna
Nearly 1 billion muon tracks collected in 3 weeks
Run 1 : February – April 2015
two thirds (35) of the EEE telescopes took part in the data taking:
More than 5 billion muon tracks collected in three months
Run 2 : November 2015 - May 2016
Run 3 : October 2016 - May 2017
Most EEE telescopes participated

~40 billion tracks collected in all Runs

… in addition

- The students follow seminars (at school or INFN or University) on
  - Cosmic rays, Particle Physics, Detectors, Electronics,…
  - They follow courses on ROOT
- Other cosmic ray related activities : building a cloud chamber
- They make videos and photos and post on social media, blogs, school's web site
- They participate in periodical local or national conferences and present their work

  Last one: National Conference of the EEE project, Erice, May 2017

  Next one : Erice, December 2017
- They participate in monthly video-conferences where they present the status of their telescope / data-taking /analysis
- Masterclasses on : telescope operation, monitoring, rate analysis
- Inauguration ceremonies in many schools with Prof. Zichichi, local authorities and media coverage

Some results

- Search for extended air showers
  Coincidences between muon telescopes
- Variation of muon flux in single EEE stations
  Observation of Forbusch decreases
- Study of upward-going particles
  electrons from μ-decay

First detection of extensive air showers with the EEE experiment

IL NUOVO CIMENTO

volume 125 B — serie 12 — numero 2 — febbraio 2010

NIFBAP 125(2) 129-254 (2010)

sommario di questo fascicolo

ISSN 2037-4895

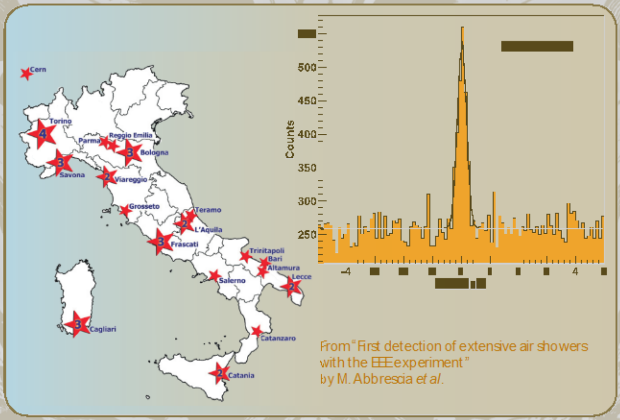
Società Italiana di Fisica
Bologna

IL NUOVO CIMENTO — VOLUME 125 B — 2 — 2010

2 125 B
febbraio 2010

IL NUOVO CIMENTO B
della Società Italiana di Fisica

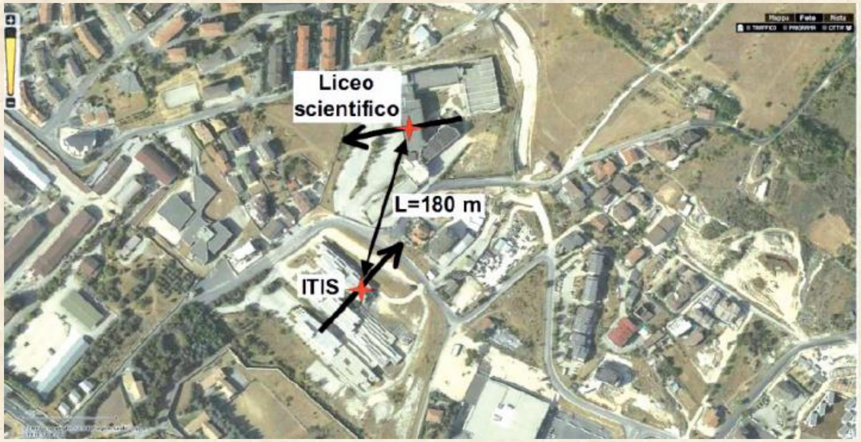
PROVANDO E RIPROVANDO



From "First detection of extensive air showers with the EEE experiment" by M. Abbrescia *et al.*

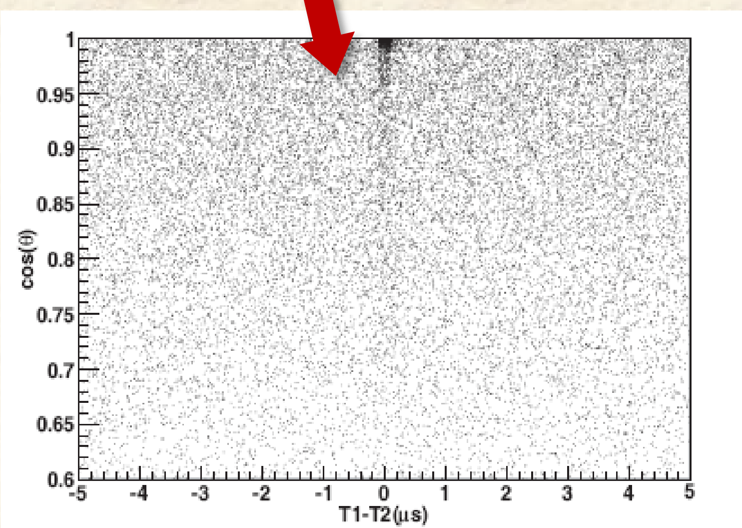
[redacted]

Available on line at www.sif.it



At L'Aquila, closest stations of the experiment

Angular correlations between "coincidences"

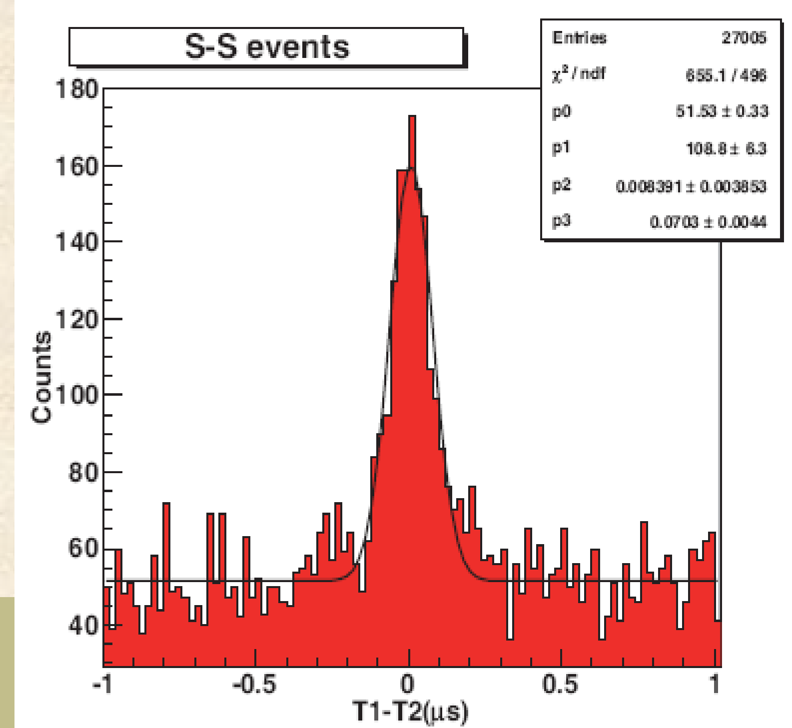


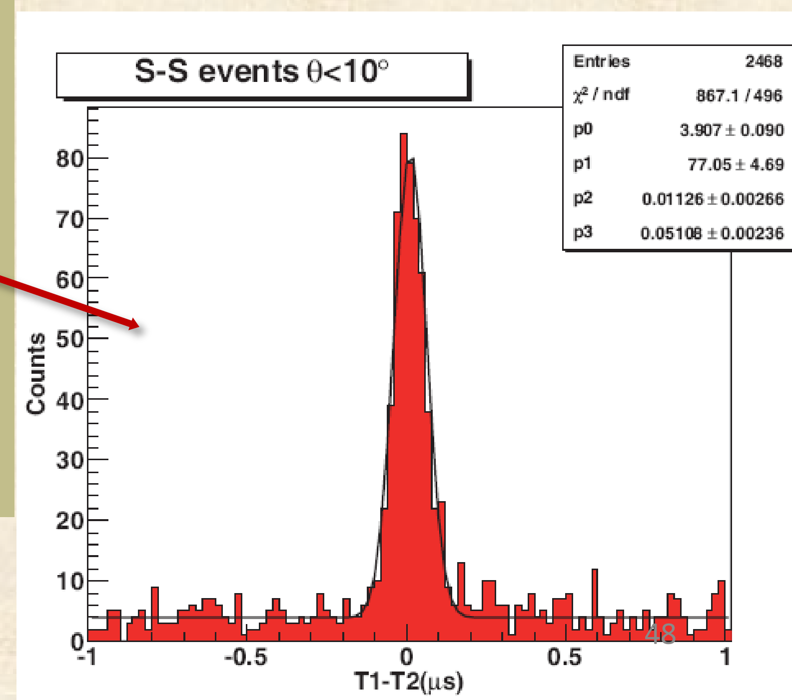
7.6 events/hour
Signal/Noise = 2

Angular cut (requiring quasi parallelism) improves S/N

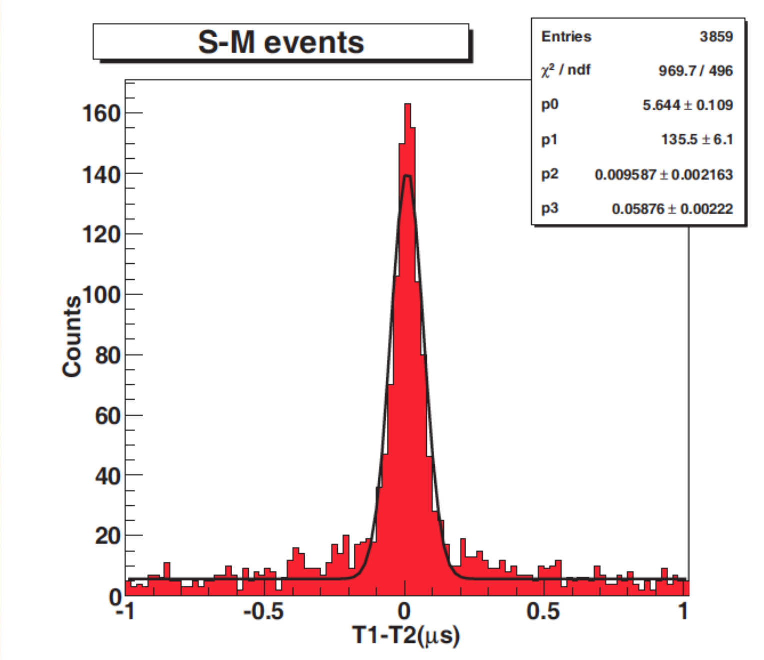
1.6 events/hour
Signal/Noise=18

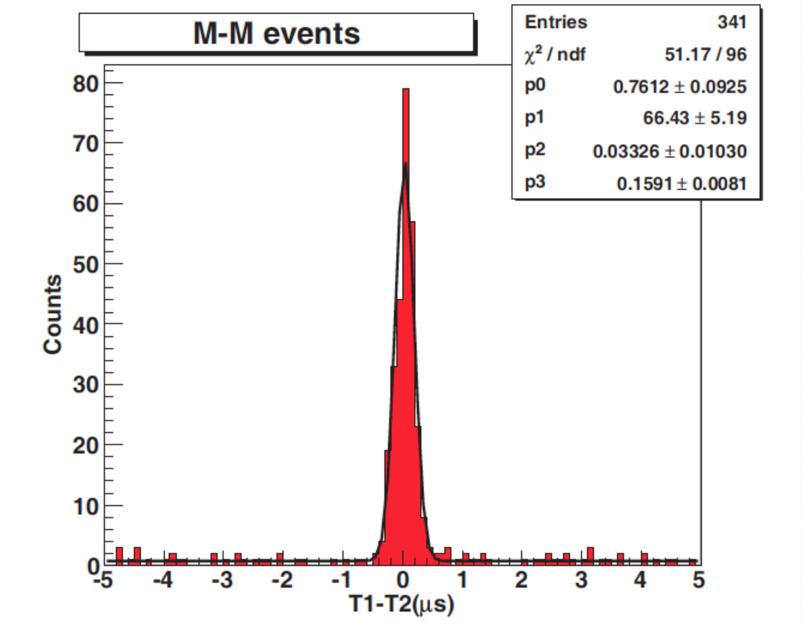
Time difference between events at the two stations





First coincidences detected

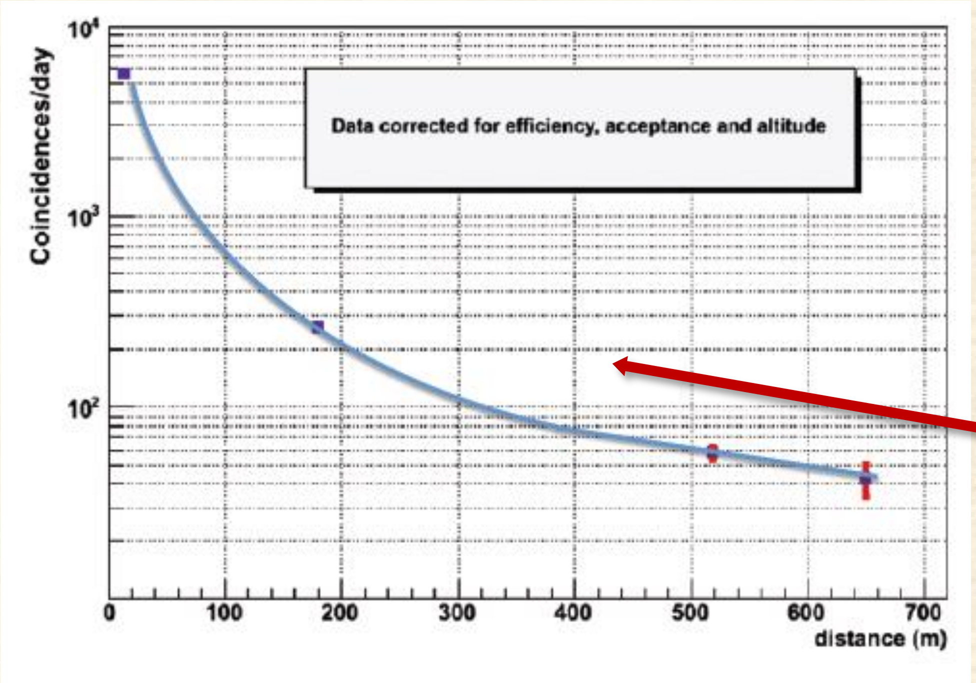




Single track in one school + multiple tracks in the other school
3.6 events / hour
Signal / Noise = 26.4

Multiple tracks in both schools
0.8 events / hour
Signal / Noise = 76

Coincidences up to 2012…



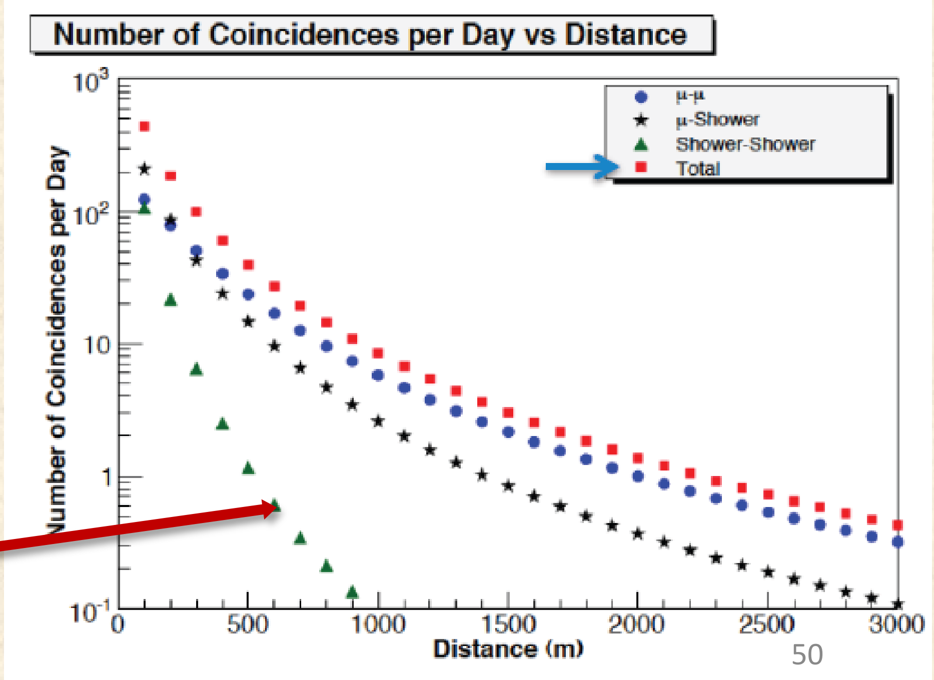
Number of coincidences per day, as measured by different telescope pairs of the EEE network, versus the relative distance between the two telescopes

Included in the plot: CERN-Geneva (15 m), L'Aquila (180 m), Cagliari (520 m) and Frascati (650 m)

Results consistent with Corsika and Cosmos Monte Carlo simulations

Few months to observe coincidences for distances > 1 km

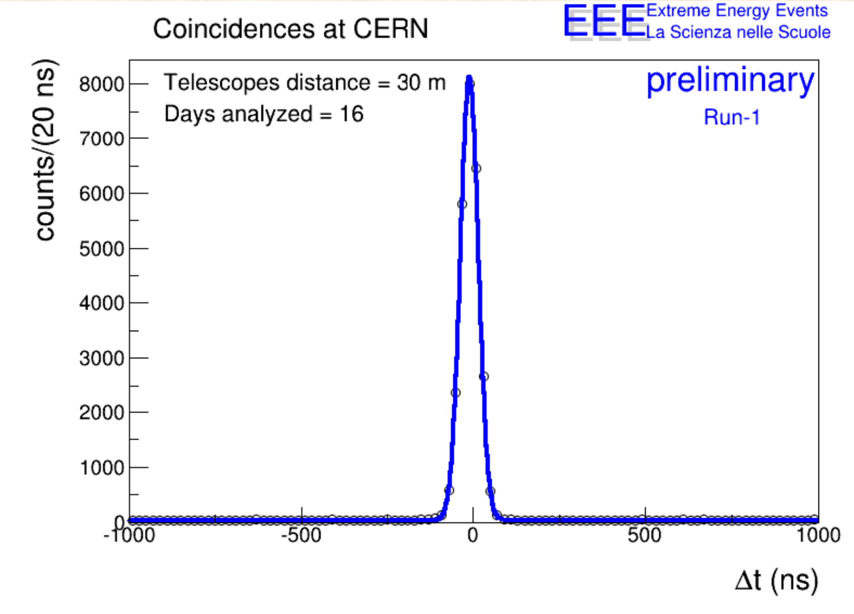
Corsika Monte Carlo simulations

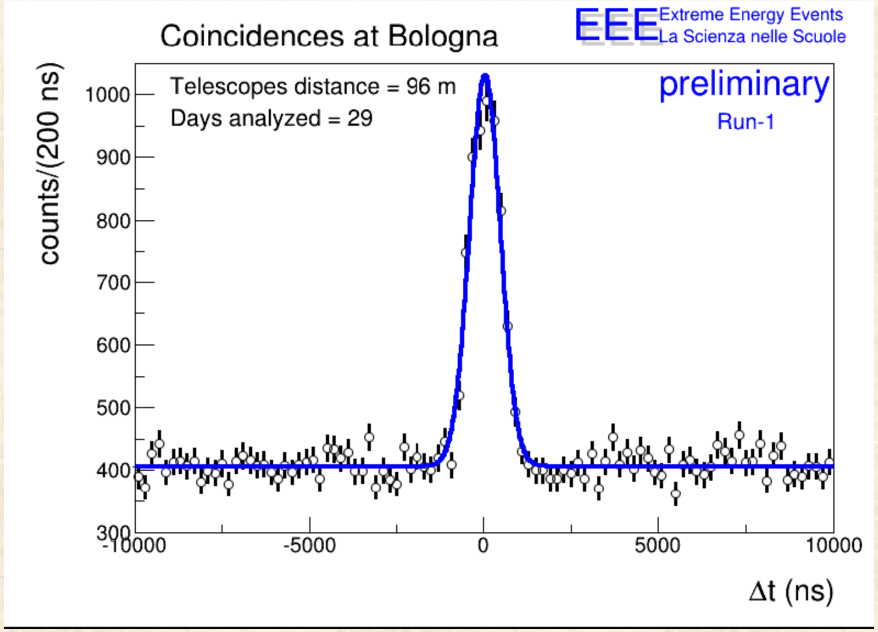


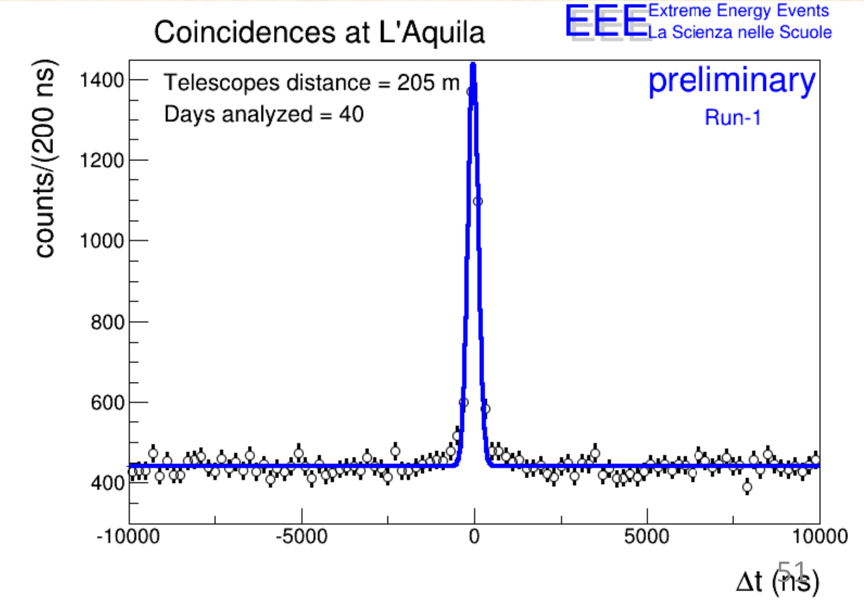
… coincidences during Run-1

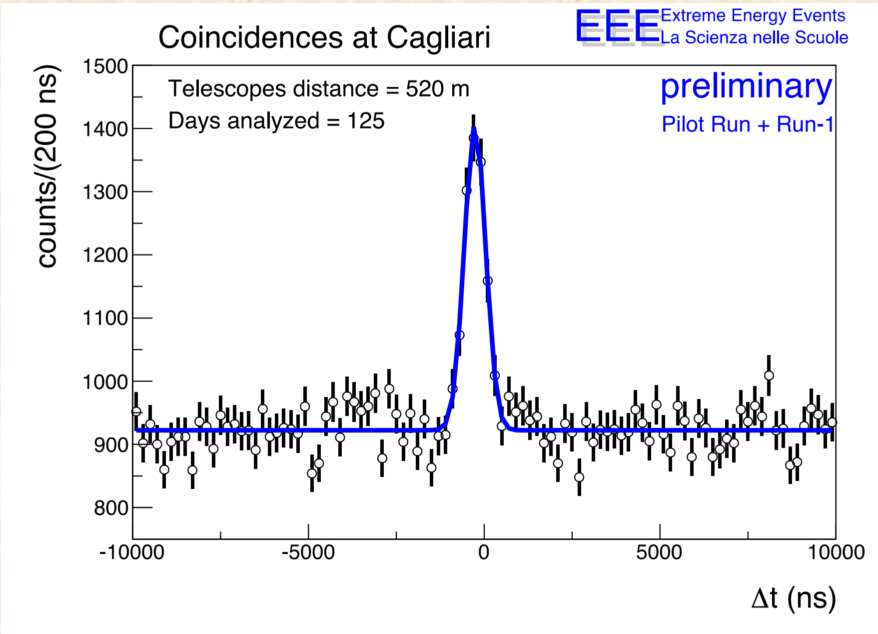
Coincidences were observed for several distances between telescopes : 15 m, 100 m, 200 m, 500 m, 1200 m

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

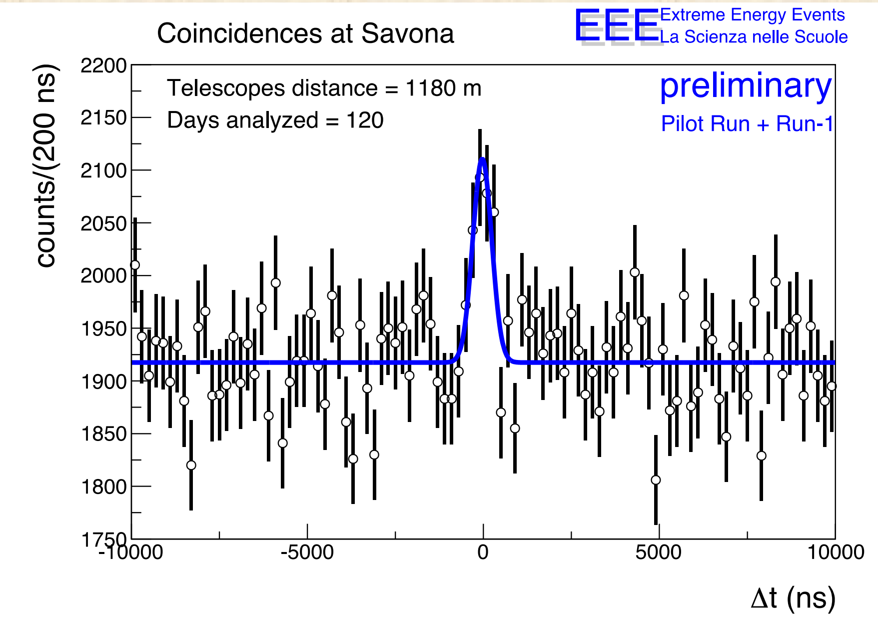








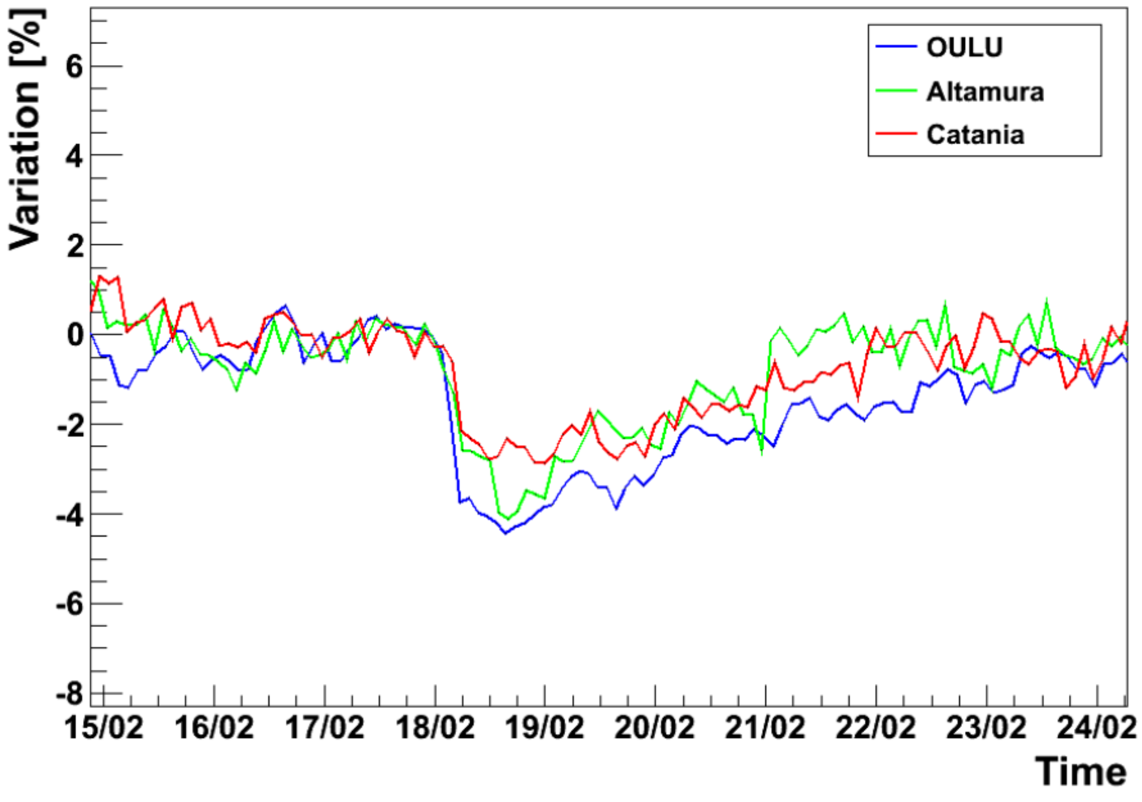
Coincidences at Cagliari
EEE Extreme Energy Events
La Scienza nelle Scuole
Telescopes distance = 520 m
Days analyzed = 125
preliminary
Pilot Run + Run-1
counts/(200 ns)
1500
1400
1300
1200
1100
1000
900
800
-10000
-5000
0
5000
10000
Δt (ns)



Coincidences at Savona
EEE Extreme Energy Events
La Scienza nelle Scuole
Telescopes distance = 1180 m
Days analyzed = 120
preliminary
Pilot Run + Run-1
counts/(200 ns)
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
-10000
-5000
0
5000
10000
Δt (ns)

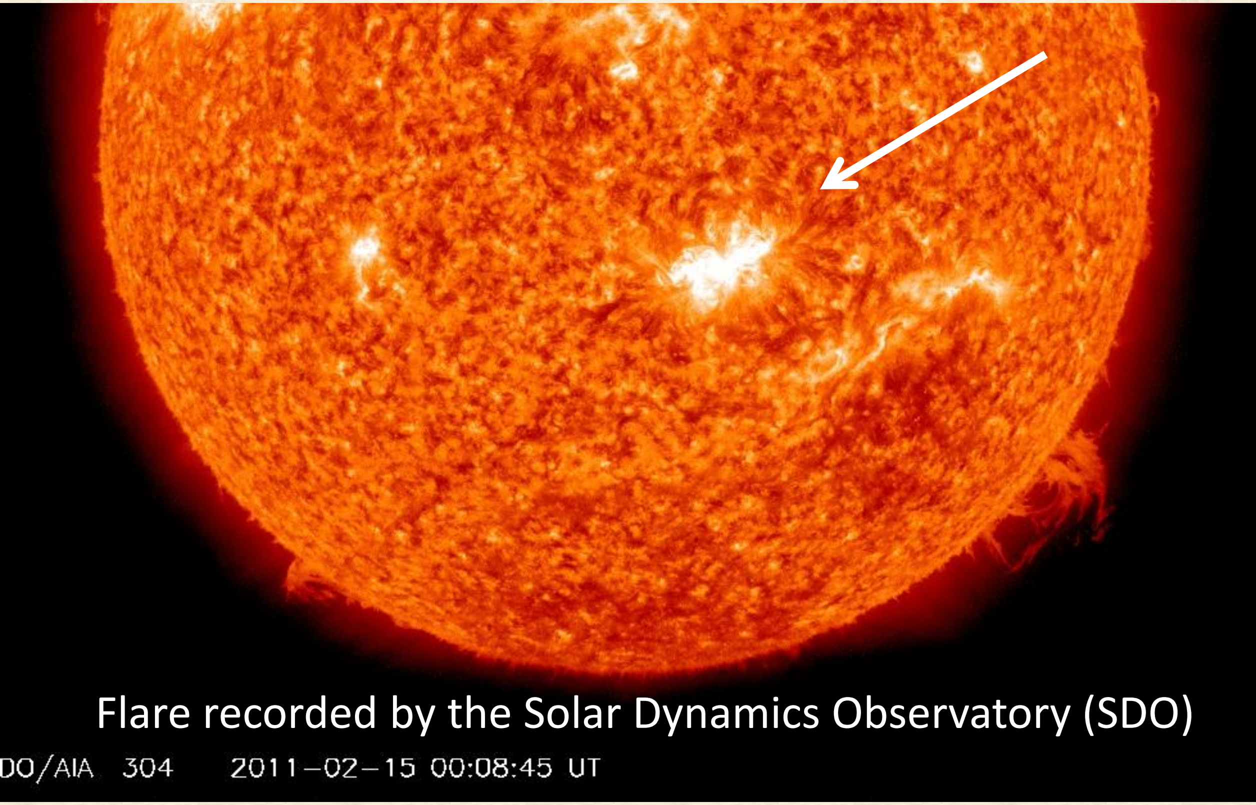
Forbush decrease 2011

- rapid variations of the cosmic rays flux over the course of a few hours associated to solar phenomena as CME (Coronary Mass Emission) and solar flares
- Decrease in muon flux reaching a minimum within hours
- Recovery lasts a few days
- comparison with Oulu neutron monitor station



2011 Valentine's Day Solar Flare

night between 14 and 15 February 2011



Flare recorded by the Solar Dynamics Observatory (SDO)

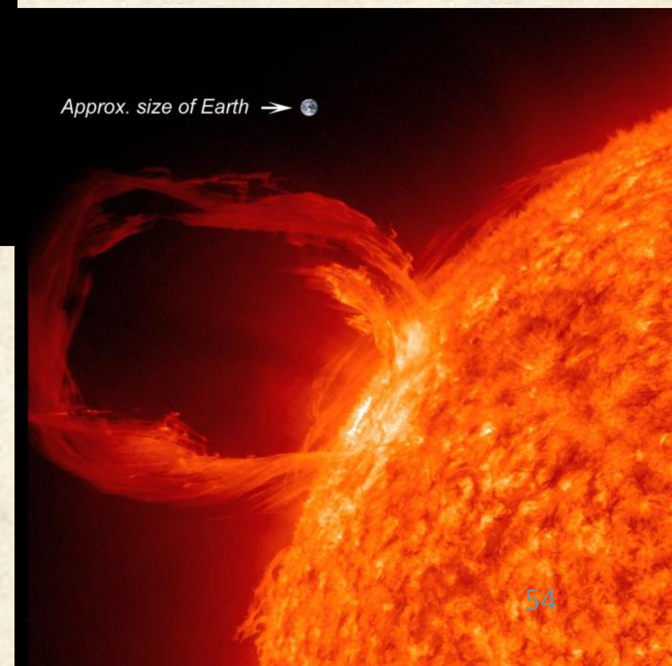
Solar flares: explosions on the sun, related to storage of energy in twisted magnetic fields -> burst of EM radiation (from radio waves to gamma rays)

Classification: according to intensity in wavelength range 0.1-0.8 nm

Solar flare, of category X2, followed by an important Coronary Mass Emission (CME)

Observable on earth a few days after the event

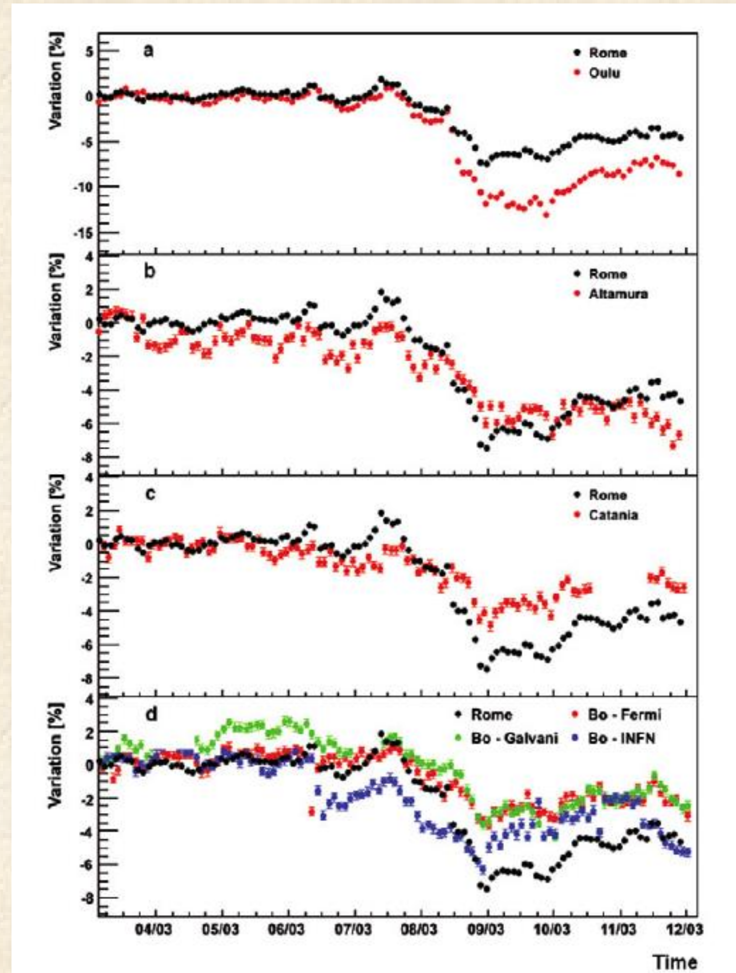
This kind of flares are constantly monitored since they may have relevant consequences on Earth



Forbush decrease 2012

Solar flare on March 6 2012 of category X5.4

- Neutron monitors in Oulu and Rome
- Liceo Gagnazzi – Altamura
- Liceo Galvani, Liceo Fermi – Bologna
- INFN Bologna
- Department of Physics – Catania

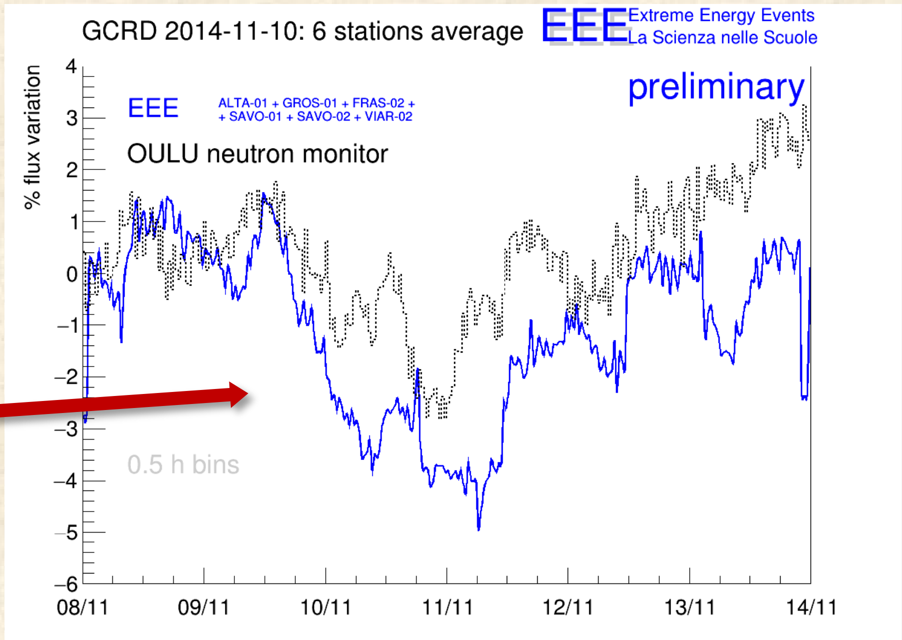


March 2012 flux decrease

Two more Forbusch decreases

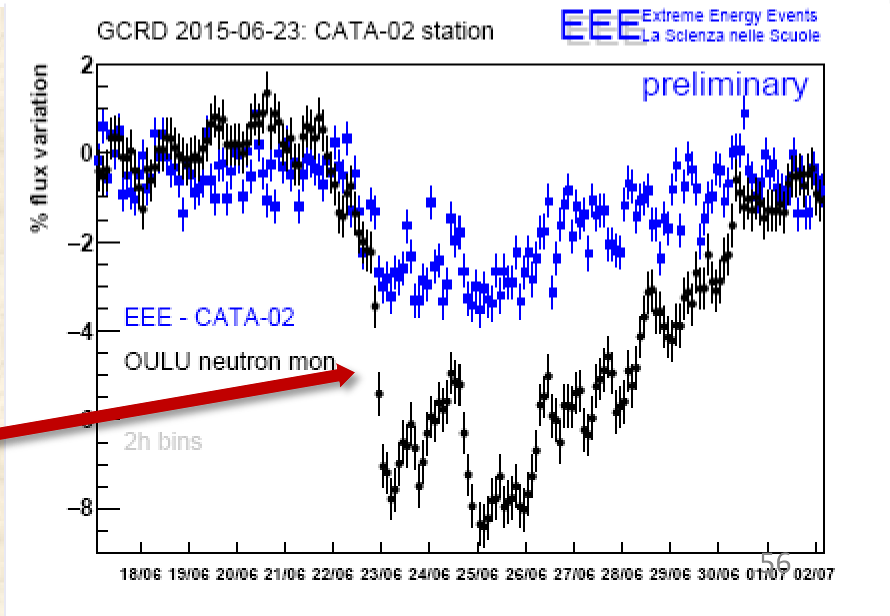
Immediately after the EEE Pilot run of 2014, a GCRD event was observed by 6 EEE telescopes: Altamura, Frascati, Grosseto, Savona (2), Viareggio

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



A GCRD occured on 23 June 2015 and was observed by 5 EEE stations, even though the array was under mantainance and upgrade.

Among the 5 active telescopes we chose for the preliminary analysis CATA-02, in comparison with the OULU data.



Upward-going events

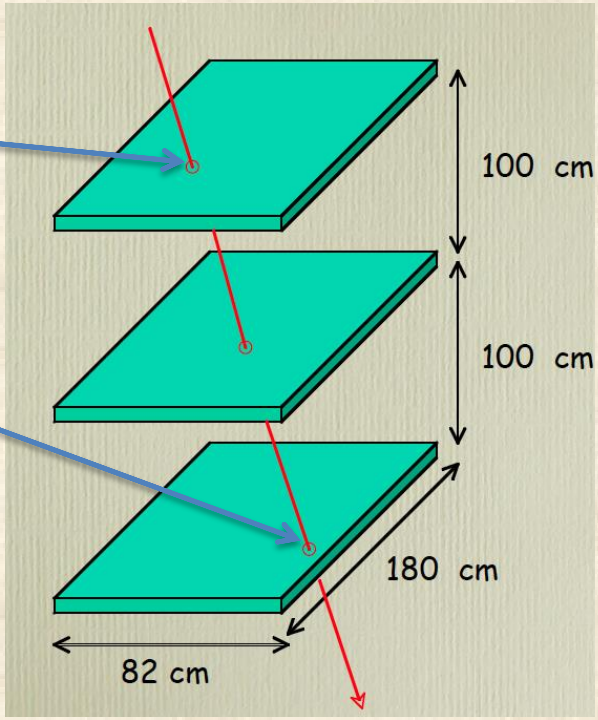
Time-Of-Flight (TOF) :
Time Bottom Chamber - Time Top Chamber*

TOF<0 : upward-going particle

Muons from (atmospheric) neutrino interactions with the earth ?

Too many upward-going events observed

intriguing!

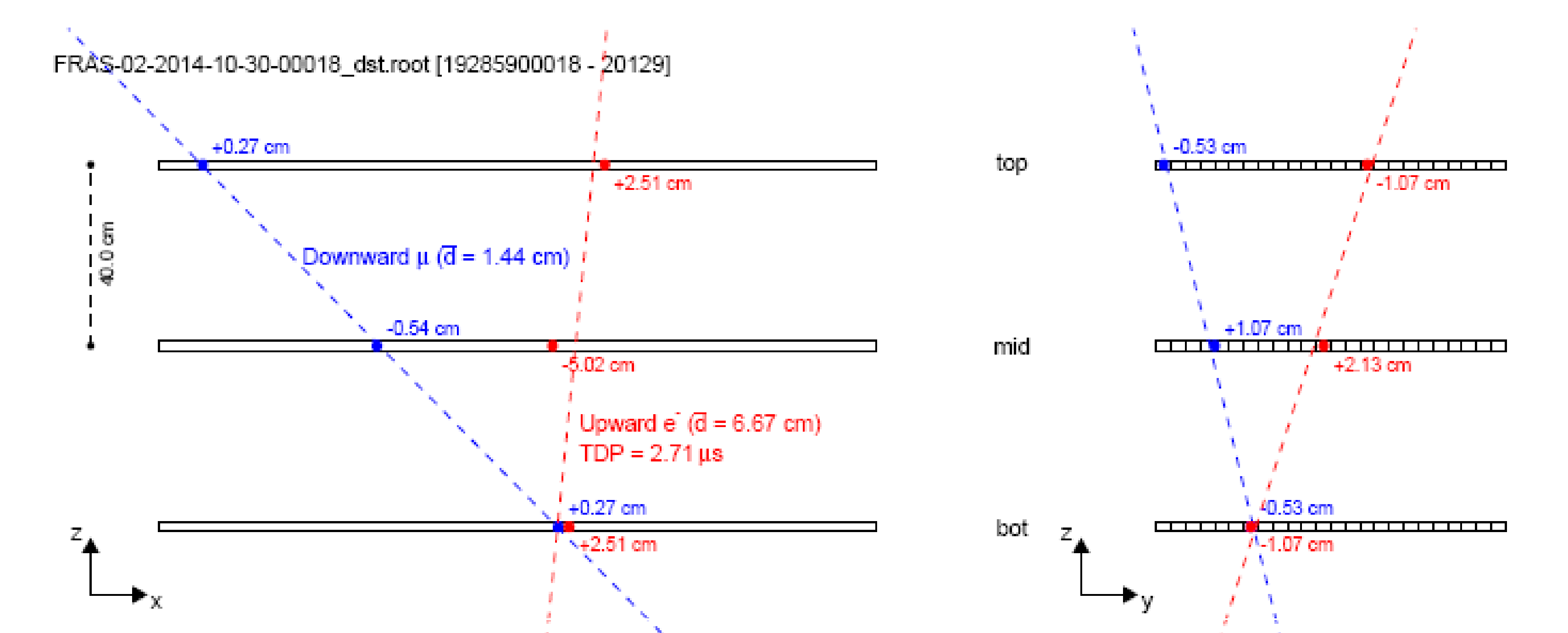


* Top and Bottom chambers are read out with the same TDC : same clock used

Upward-going events

About 1 event every 1000 observed goes in an upward direction

Some of them identified as electrons coming from muon decays (in the floor or in the bottom chamber), looking at their Time Difference with respect to the Previous (TDP) events



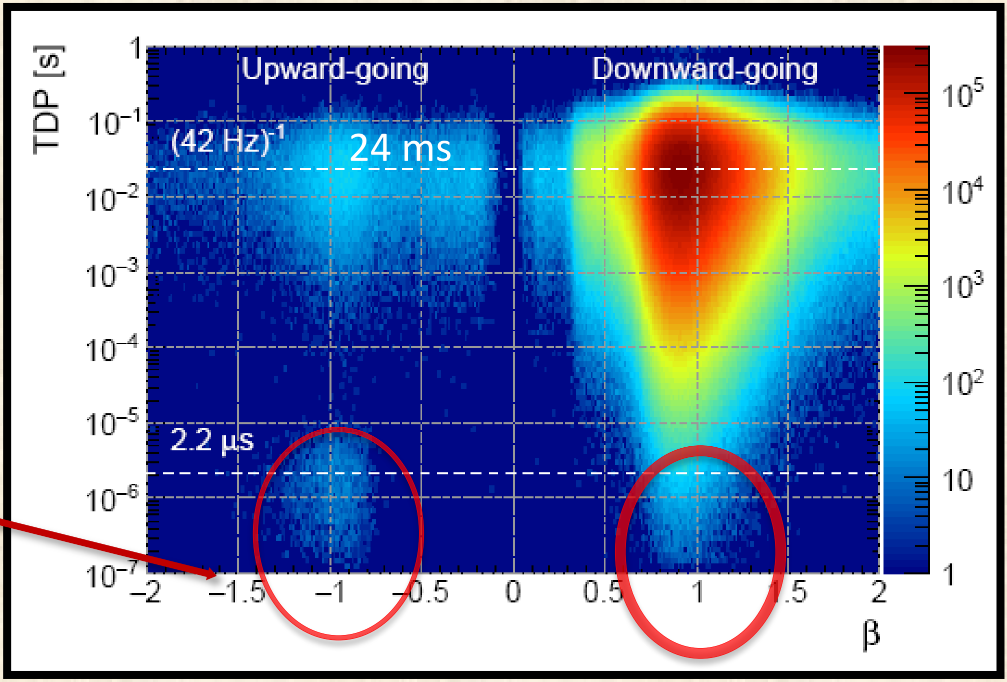
Event display (in the two projections)

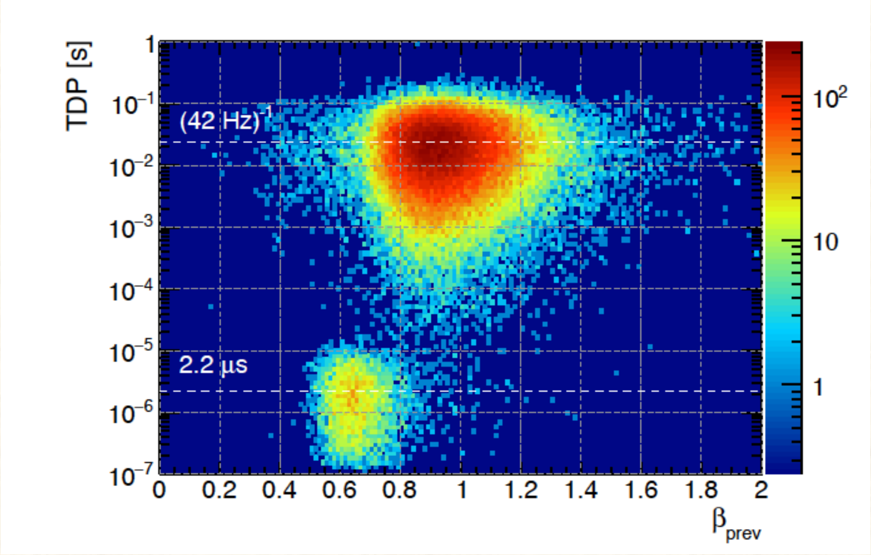
Tagged downward μ + upgoing electron

1.3 x 10^8 good tracks
7 x 10^4 TOF<0

β > 0 downward -going
β < 0 upward-going

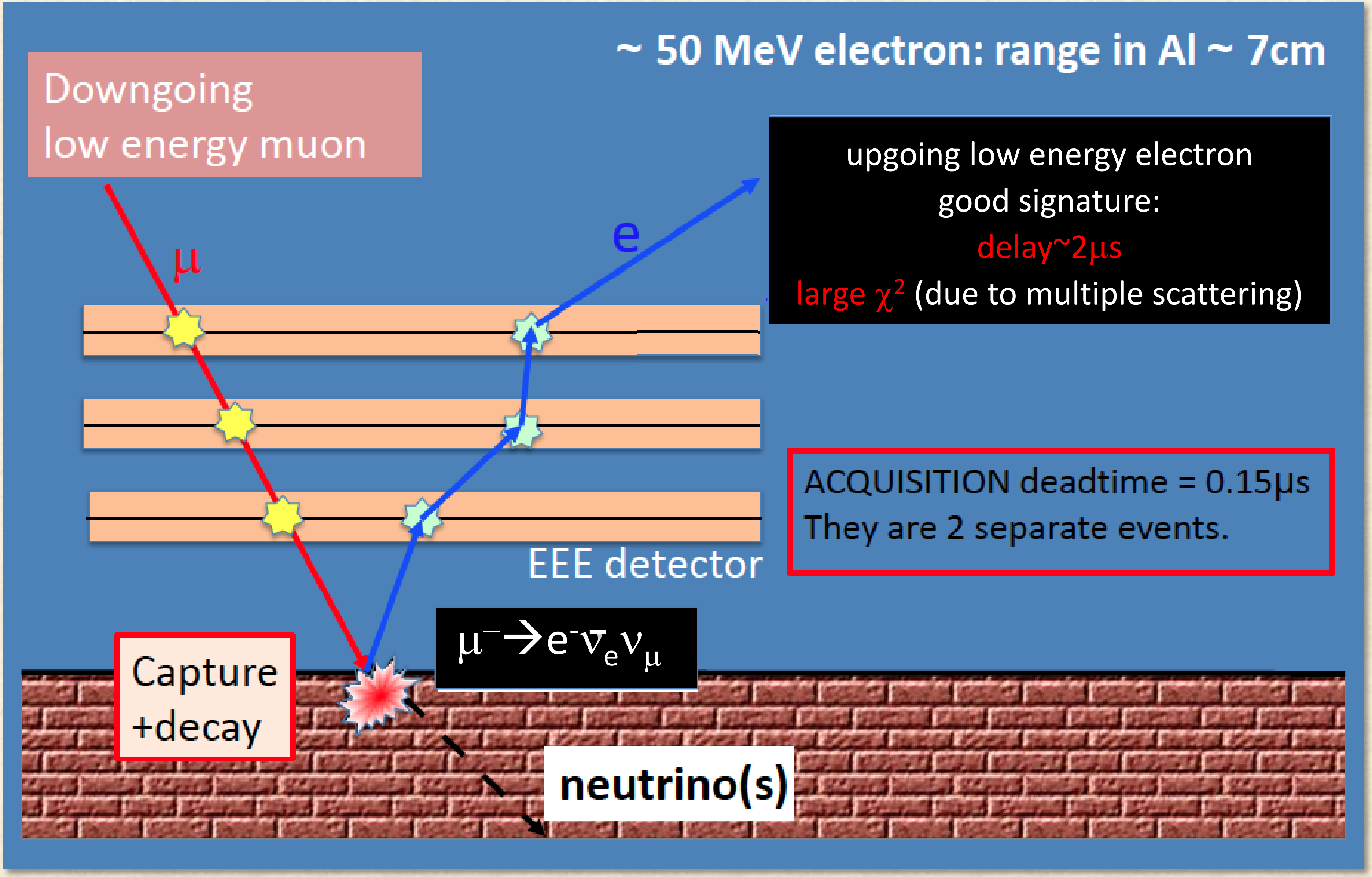
Identify electrons from muon decays (in the floor or in the bottom chamber): look at Time Difference with respect to the Previous (TDP) events versus velocity





Correlate TDP with velocity of previous particle : electrons come from decays of (slow) muons with 0.5<β<0.8
For β~0.65 range of muons in Al / concrete is 2-3 cm
Electrons from µ-decay, E=50 MeV, range in Al 7 cm

Muon decay



low energy electrons from muon decay are a robust explanation for upward-going particles

What is next

Future plans

- Next run scheduled to start in October 2017 and last until May 2018 (end of school year)
- Extend coincidence measurements to larger (>2 km) distances
- Look for long-range correlations
- Search for coincidences between telescopes located in different cities to look for exotic ("unexpected") high energy events
- Increase the number of EEE telescopes
    - from 50 to 100 High Schools (original project!)
- Include schools from other countries
    - School from Moscow (April 2017); school from Albania (next week)
- Involve schools without a muon telescope in data analysis

Search for the unexpected!!!

CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE

Progetto Extreme Energy Events (EEE) La Scienza nelle Scuole


Telescopio EEE del Liceo Classico Massimo D'Azeglio di Torino

Extreme Energy Events (EEE) - La Scienza nelle Scuole

dimensione font | Stampa | Email

Il Progetto EEE – La Scienza nelle Scuole consiste in una speciale attività di ricerca, in collaborazione con il CERN, l'INFN e il MIUR, sull'origine dei raggi cosmici, condotta con il contributo determinante di studenti e docenti degli Istituti Scolastici Superiori.

In ciascuna delle scuole aderenti al Progetto viene costruito un "telescopio" fatto con i più moderni e avanzati rivelatori di particelle (Multigap Resistive Plate Chambers, MRPC), da mettere in coincidenza tramite strumentazione GPS con i telescopi di altre scuole allo scopo di rivelare i muoni cosmici e gli sciami estesi, grandi anche quanto intere cittadine o più, prodotti dai raggi cosmici primari di più alta energia.

Ai ragazzi viene dato, inoltre, l'importantissimo compito della costruzione degli stessi rivelatori a partire da elementi di base, affinché si rendano conto di come si possa passare da materiali poveri a strumenti di altissima precisione. La costruzione dei rivelatori avviene nei laboratori del CERN, nei luoghi più esclusivi della ricerca più avanzata, che vengono resi a tale scopo accessibili ai ragazzi.

Attualmente risultano operative o prossime all'operatività tutte le stazioni realizzate (40) presso le scuole ed è in corso l'acquisizione dati volta, in particolare, alla ricerca di eventi coincidenti tra stazioni vicine e stazioni lontane.

The Project Extreme Energy Events - Science inside Schools (EEE), is a special research activity about the origin of cosmics rays, performed in collaboration with CERN, INFN and MIUR and carried out with the essential contribution of students and teachers of high schools.

EEE News

Gemellaggio tra gli studenti del Liceo Bafile de L'Aquila e del Liceo Galilei di Lanciano

L'esperimento EEE arriva a Mosca

Il progetto EEE alla Giornata dell'Arte

Liceo Carlo Rinaldini di Ancona al TG3 Marche

Cosmic Rays for outreach and science education

- ➢ Large scale experiments taking data continuously (outreach + research)

- ➢ Experiments in classroom using small scale cosmic ray detectors
- Measure azimuthal angle distribution
- Measure muon flux versus time, temperature,pressure, solar activity,…
- Measure muon velocity
- Measure muon lifetime

- ➢ Demonstrations (science exhibitions and museums, science festivals, ..)
- Spark chambers
- Cloud chambers

- ➢ Construction of cloud chambers in science workshops and observation of cosmic muons

Inside IPPOG (International Particle Physics Outreach Group) : effort to bring together different cosmic ray experiments in schools

- To get to know each other
- To exchange ideas
- To examine the possibility to make an « open data portal »
  Many experiments already have data in the public domain
  Common format?
- Look for coincidences between stations of different experiments?

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

Workshop on

HIGH SCHOOL COSMIC RAY EXPERIMENTS

Centro Fermi — Roma **15-16 February 2017**

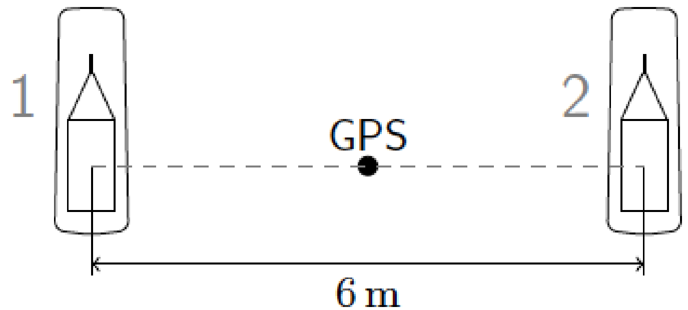
HiSPARC High School Project on Astrophysics Research with Cosmics

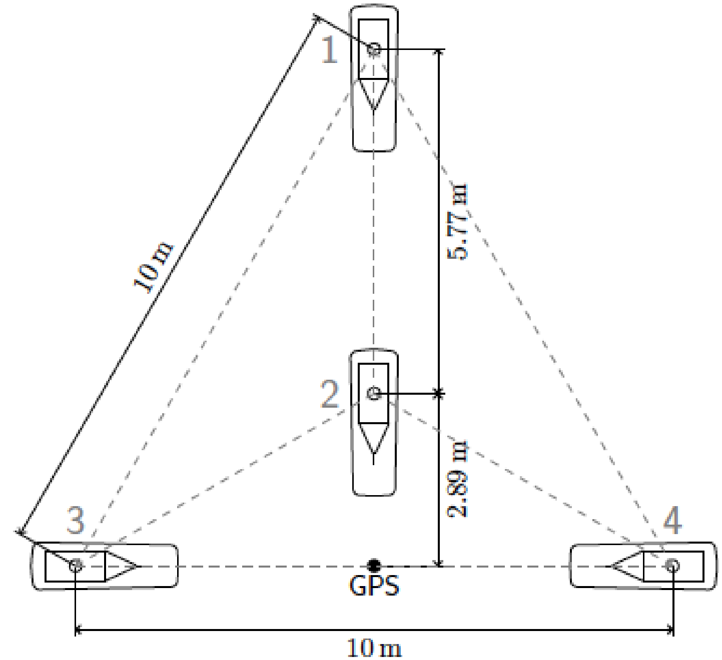
~ 100 detector stations in the Netherlands; ~ 20 in the UK + Denmark

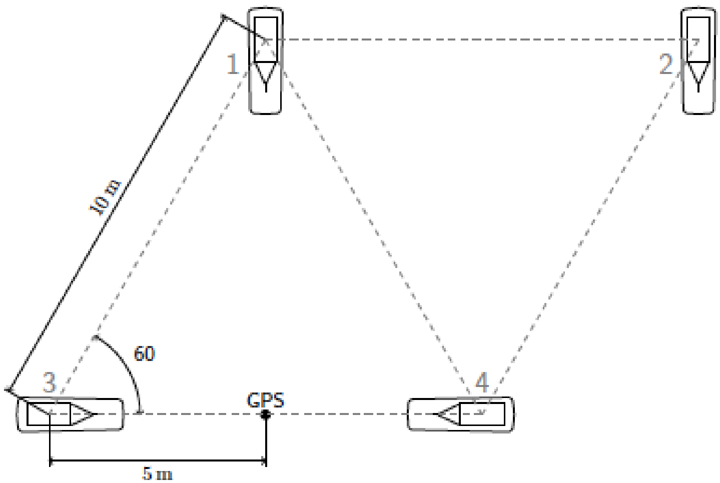
Detectors built by students ; installed on roofs of schools

Principle : If multiple detectors are hit within a narrow time window, these hits are deemed to be caused by particles from the same shower

HiSPARC Station

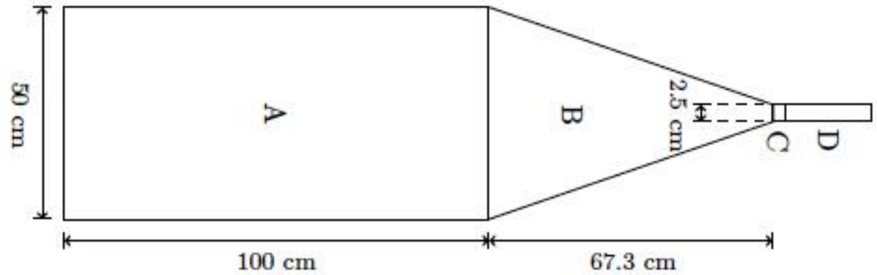






- Otherwise if no roof space available

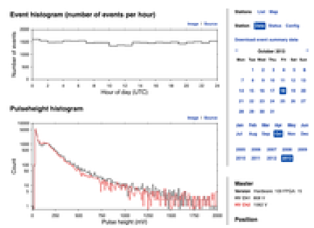
HiSPARC Detector



- A = Scintilator
- B = Lightguide
- C = Adaptor piece
- D = PMT

HiSPARC

Overviews

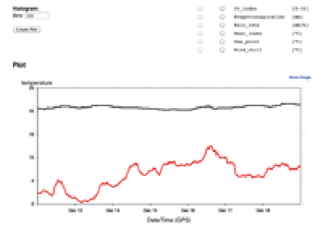


On the start page of the **HiSPARC Public Database** is an overview of all detector stations. Here the status of each station is indicated by colored status indicators. When choosing a station summaries of each day (from its first measurement up-to and including yesterday) will be shown in the form of graphs. A history of the configuration of the station can also be found here. As well as a page specifying the status of the station in more details, this can be useful to identify problems. The graphs also give insight in the quality of the data. Above each graph is a **Source** button that will provide a .csv (tab separated columns) file with the data points from graphs.

Data download

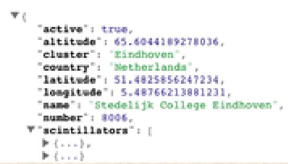
Through the page mentioned above you can also get to the **data download form**. Here a station, start and end date, and data type can be chosen. Then that data for this query can be downloaded as a .tsv file (a text file with tab separated columns) or viewed in a browser. The data is downloaded from the event summary database, this means that the data has already been partially analysed. The data contains information about the particle density in the detectors and the precise arrival times in each detector.

jSparc



jSparc is a JavaScript library which can use the data in the Public database. There are several web applications (**Analysis software** and **Data retrieval**) available that make use of this library and make it possible to analyse data in a browser. The source code of the jSparc library can be found on **GitHub**.

API



For programmers we also provide an **API** which makes it possible to easily retrieve metadata from the Public database. The API consists of a set of URLs that will always provide the latest up-to-date information. This way you can for instance check which stations measured data on a certain date or which stations are in a certain subcluster. It also provides access to the traces of the individual events. The API is usable by practically all programming languages. For Python and JavaScript it has been made easier, because functions have been added to the SAPPHiRE framework and the jSparc library to access the API.

COSMOS à l'École

COSMOS à l'École

- 46 educational institutions sharing 30 muon detectors
- From 25 regional education authorities (/30)
- 1700 pupils
- Once they have been trained, teachers train colleagues from their high school or from the local area (during dedicated teacher training sessions)
- Teachers get a « Cosmodétecteur» for 3 years (renewable) and usually make it circulate in their school and locally

Nicolas Arnaud

The cosmodetector apparatus

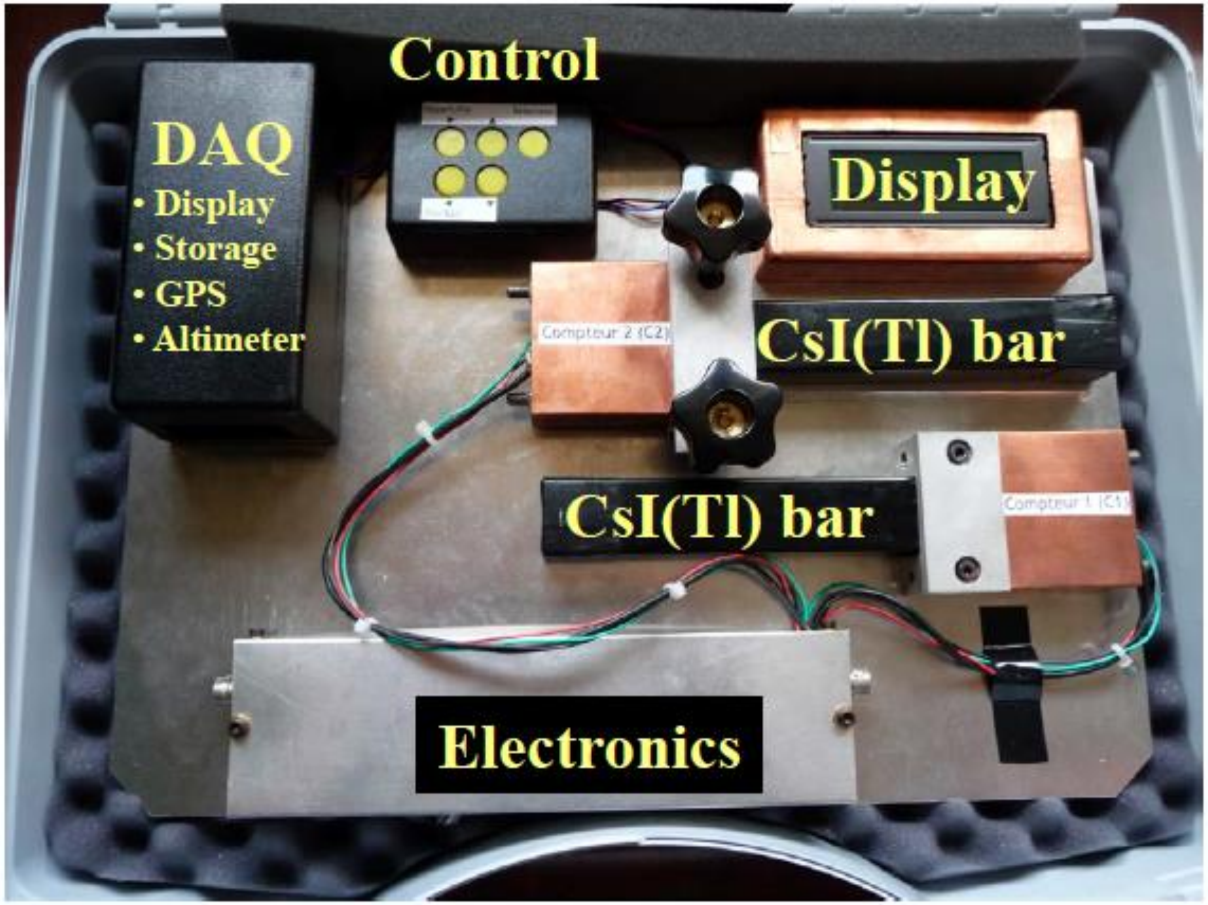
- 3 scintillator plates with a photomultiplier (PM) on top
- A DAQ system to trigger on 2-fold or 3-fold coincidences to remove background
- A Labview interface to steer the detector, monitor data taking and record data (ascii format, no GPS/accurate timing information)
- A movable « cosmic wheel » to look at the cosmic muon zenithal distribution

Laptop included – unit price: ~6-7 k€

Nicolas Arnaud

The « COSMIX » case

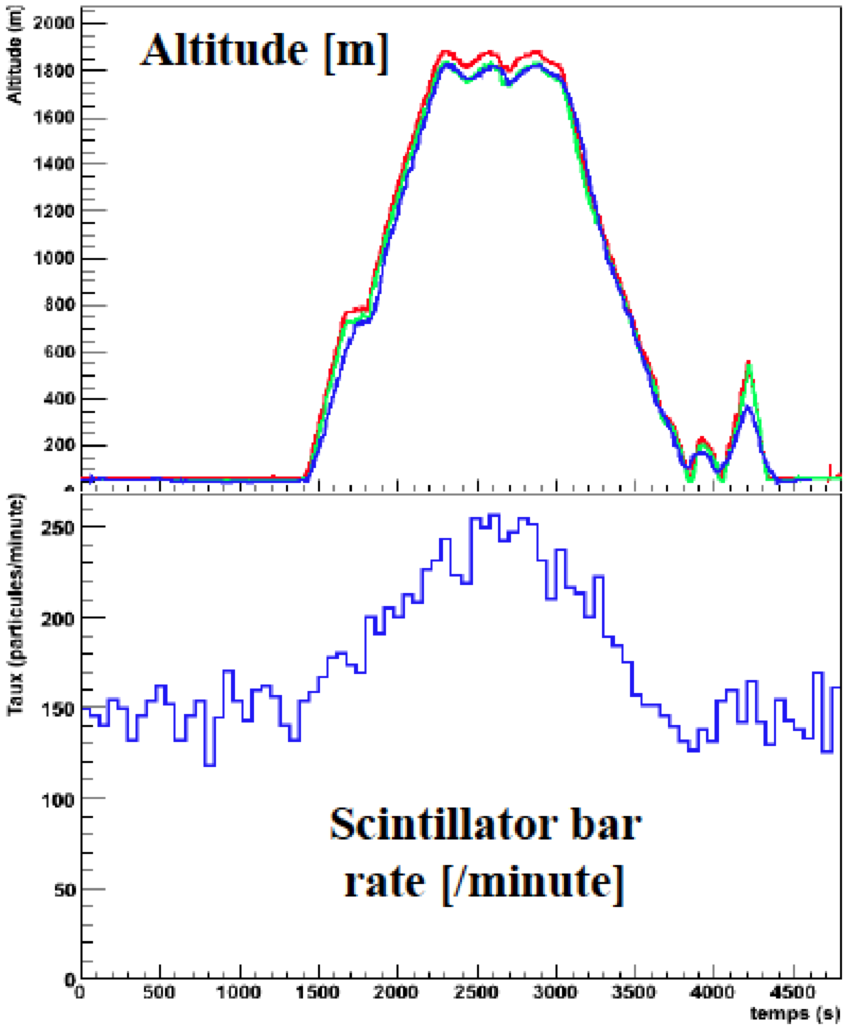
- Two l×w×h = 16×3×2 cm³ CsI(Tl) bars from Amcrys
- Hamamatsu PIN diodes
- Consumption ~300 mA
- 5V power (e.g. from laptop)
  - 7000 mAh battery for mobile measurements
- Unit cost ~2 k€
  - Half for the scintillator bars alone
  - → First detectors built using Fermi-GLAST spares
- Case
  - Weight < 4 kg
  - Dimensions: ~44×36×12 cm³



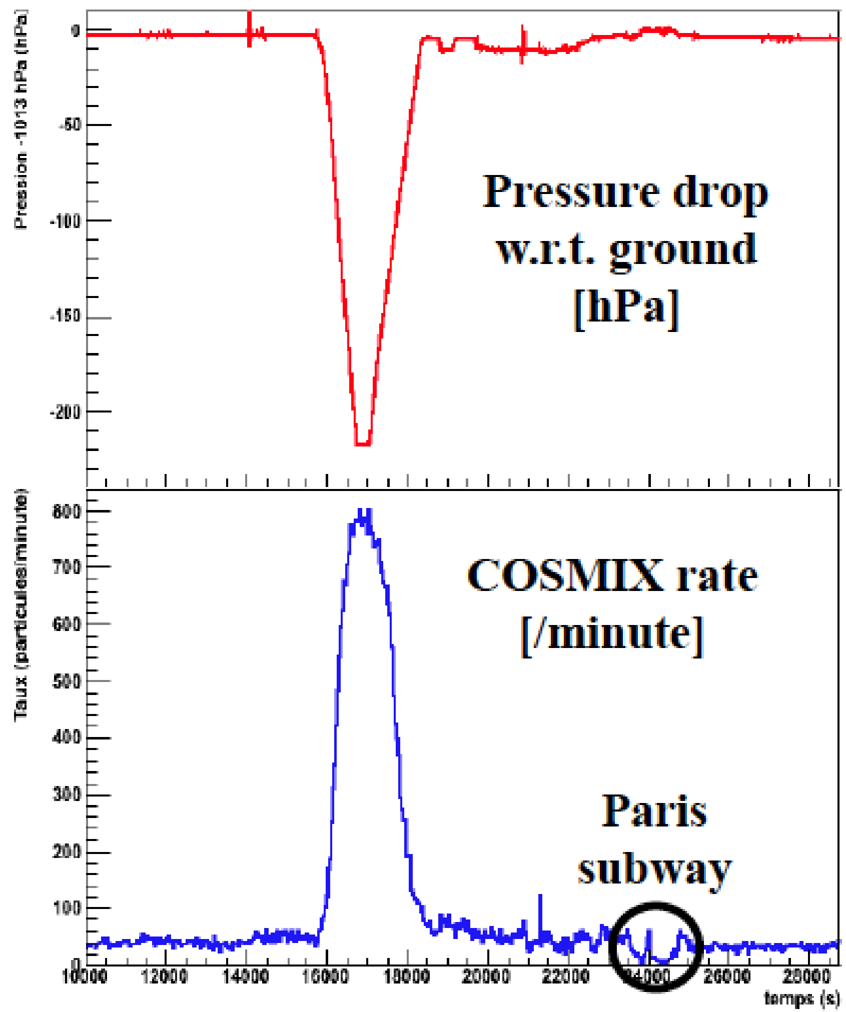
Nicolas Arnaud

Cosmic ray rates vs. altitude

Private plane flight up to 1,800 m



Commercial flight up to 10,000 m



Nicolas Arnaud

Detector Kit

4 counters w/PMTs
Power box (low voltage)
DAQ (developed by FNAL)
GPS w/antenna
Temperature & pressure sensors
Cables
(Raspberry Pi w/EQUIP)

DAQ creates formatted message sent to a computer & collected in text data file through USB interface. EQUIP computer commands set parameters for each investigation, monitor data stream & display parameter settings & other info.

QuarkNet

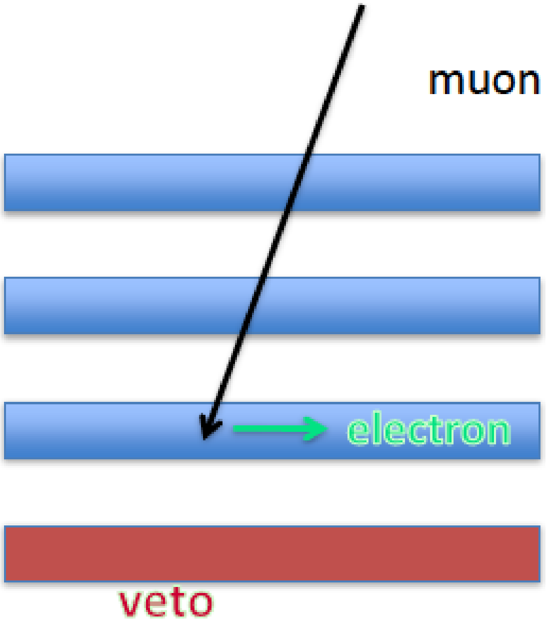
Where are the 840 DAQs?

- 260 detectors deployed in QuarkNet
- 450 in 32 countries:
  - Education - 294
  - Science
  - Museums - 13
- 130 in inventory

QuarkNet

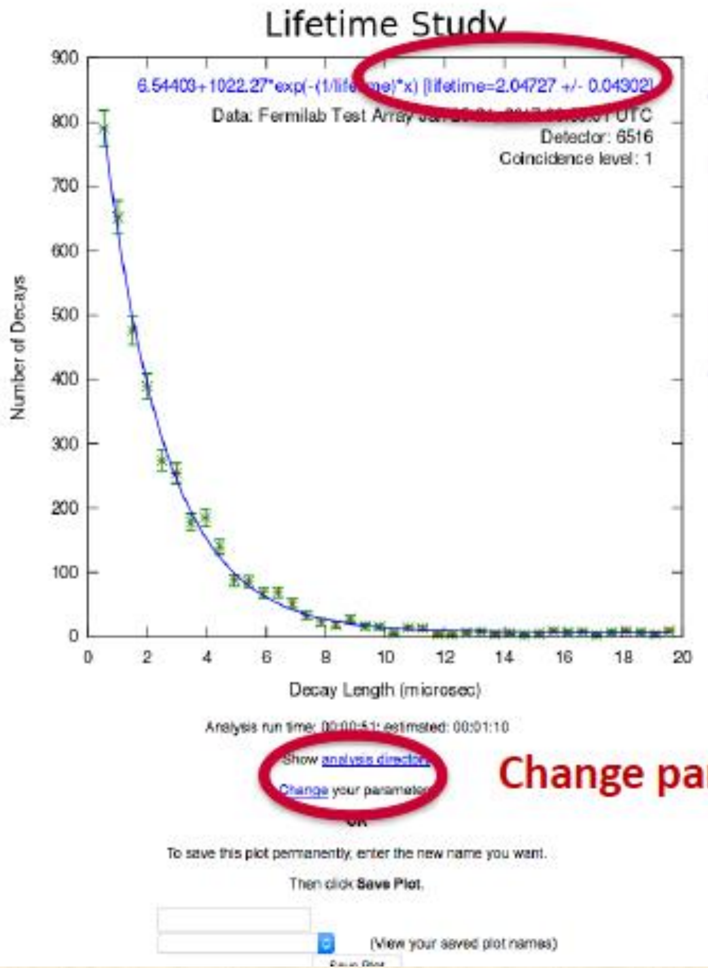
Muon Lifetime

- Stack four counters.
- Program DAQ: Require three top counters to fire and veto on bottom counter.
- Record data for one week.
- Upload data file to e-Lab.
- Select data file and run "lifetime" analysis to find time between muon and next signal (electron).



QuarkNet

Muon Lifetime Result



3500 muon decays in 7 days

(~1 decay every 1000 muons)

Lifetime 2.05 +- 0.04 microseconds

Random background 6.5 events per 500 ns bin

Change parameters and run again.

https://icd.desy.de/e49245/

Global Cosmic Ray Studies

Projects for High School Students

There are several projects around the world that address young people and teachers, to give them the opportunity to explore cosmic particles. These projects are presented below. For further information, please visit the web pages.

FINLAND

Callio Lab: Doing cosmic ray physics underground is something the young students are really interested in. The Centre for Underground Physics in Pyhäsalmi (CUPP) of Callio Lab, in Finland, has made it possible. The outreach program, established in 2010, is based on the cosmic ray experiment EMMA and particle physics. The emphasis is on the hands-on exercises with simple data and detectors. The workshops and theme days are well liked. The outreach is also taken out into the community by participating into annual town fair of Pyhäjärvi with general public lectures, and organizing theme weeks on physics topics together with science centre Tietomaa in Oulu. Website: Callio Lab

FRANCE

Cosmos à l'École: In France, a collaboration started several years ago between the "Institut National de Physique Nucléaire et de Physique des Particules" (IN2P3) of the CNRS and "Sciences à l'École", a project from the French Education Ministry which is promoting science in high schools and higher education. Large cosmic ray detectors called "Cosmodétecteurs" are built in the Marseille IN2P3 laboratory (CPPM) and given to high school teachers selected by "Sciences à l'École". These teachers are trained prior to receiving the detector – a one week-long seminar at CERN, part of the High School Teacher program, plus a technical course in Marseilleto learn how to use the apparatus. These teachers then exchange information through a dedicated internet forum and present the educational activities they develop with their Cosmodétecteur. There are currently 30 such detectors in France and 15 more will be released in 2017.
Website: Sciences à l'École

e-PÉRON: a virtual lab dedicated on cosmic rays.The Labex OCEVU (a cluster of 6 research laboratories located in the south of France) and the Observatoire Midi-Pyrénées offers the possibility for the teachers and their students, from high school to university to experiment cosmic ray physics for real on a dedicated platform online. Via a website, they could select their own experiment through several ones (muon lifetime, East/West effect, Rossi experiment, Auger experiment, cosmic ray network) and download the data during a choosen period. The experiments are located on the Pic du Midi de Bigorre in the French Pyrenees and are running continuously since may 2015. The use is in open access.
Website: e-PÉRON (the official website is under construction and will be available on June 2017)

GERMANY

Cosmic@Web: is a web platform that gatheres and provides the data of different experiments in the astroparticle physics. It allows students to analyse data on their own, without special programming skills and even write their own research papers. Website: Cosmic@Web

Netzwerk Teilchenwelt: On the track of the Big Bang. In the network "Netzwerk Teilchenwelt" one can enjoy particle physics and astroparticle physics to touch. At workshops in schools, student labs or museums, young people and teachers across the whole of Germany experience the world of Quarks, Elektron & Co. with real data from science or their own experiments. If you want to know more, join the network, develop your own projects and participate in workshops at CERN in Geneva, have a look at the website: Netzwerk Teilchenwelt

ITALY

Extreme Energy Events - Science inside Schools (EEE), is a joint educational and scientific initiative studying cosmic rays. This strategic project of Centro Fermi, Rome is conducted in collaboration with CERN, INFN and MIUR and carried out with the essential contribution of high school students and teachers. The physics research interests include the properties of the local muon flux, the detection of extensive air showers, and the search for possible long range correlations between far telescopes. The experiment is based on a network of "telescopes," the most advanced particle detectors (Multigap Resistive Plate Chambers, MRPC), built at CERN by teams of students and teachers. Telescopes are located in high schools distributed throughout Italy and are controlled by students. Currently, about 50 telescopes are taking data, and more than 90 institutes are analyzing data. Data from all telescopes are centrally collected, reconstructed and distributed to the students. Regular videoconferences, masterclasses, meetings and visits are organized with the involvement of all institutes. More than 50 billion tracks have been collected and are presently studied by students and professional researchers. The project is expanding with the construction of new telescopes. Website: EEE

POLAND

Cosmic-Ray Extremely Distributed Observatory (CREDO) is an expanding world wide network of cosmic ray detectors, utilising both professional observatories and public mobile devices such as smart phones. The main objective of CREDO is to look for cosmic ray events which are extended in both time and space and thus beyond the abilities of localised detectors to identify. Such events have interdisciplinary applications in areas such as geophysics and space weather as well as astrophysics. The involvement of non-professional science enthusiasts in CREDO is enhanced by Dark Universe Welcome where citizen scientists are invited to explore the cosmic ray events detected around the world, classify them and identify patterns.Website: CREDO, Dark Universe Welcome

RUSSIA

Showers of Knowledge is an open outreach educational project that aims to bring internet users worldwide to an analysis of data of the of real online cosmic-rays experiment. It is developed at Joint Institute for Nuclear Research (Dubna, Russia). The project consists of the distributed setup for researching cosmic rays RUSALKA ("mermaid"), comprising 11 stations located in the area of about 0.5 km in diameter; and the interactive internet portal livni.jinr.ru, where users can run a variety of pre-made data analysis scripts with their custom parameters. Our feature is the possibility for users to communicate with real particle physicists developing the project. Website: Showers of Knowledge

SPAIN

Cazadores de Rayos Gamma is a high energy astrophysics web application where students can analyse data from the MAGIC telescopes using a python programming environment. This outreach application combines a storytelling approach with science and programming challenges for the users. 4 PhD students introduce the user into high energy astrphysics research and the observations and analysis done with the MAGIC telescopes. The user will learn about fundamental physics related to Super Nova Remnants, Black Holes, Dark Matter,... and also about specific astronomical sources such as Casiopea A or the Crab Pulsar. The project was developed at the Institut de Física d'Altes Energies (IFAE) in Barcelona. At the moment only a spanish version is available. But soon it will be translated to other languages. Website: Cosmic@Web

SWEDEN

Cosmic ray outreach in Stockholm: The Royal Institute of Technology (KTH) and Stockholm House of Science offer high school projects on cosmic rays to Swedish students in the final year of high school. Muon detectors of different sizes are available for students to borrow, or use in our research labs. The participating students pose their own research questions, which they then test with one or more of our muon detectors. As part of this project a muon detector is launched on a weather balloon once a year to measure the cosmic ray flux at altitudes up to 35 000 km. The data from each flight is collected in a database which is freely available to anyone interested in collaborating with us. Website: Info kosmisk strålning

TAIWAN

QuarkNet-TW

QuarkNet-TW started in 2006. While we have worked with both high school and university students, most participants have been university students. We have prepared full usage of raspberry pi and python programs. (Using the QuarkNet detector is included in the senior course "Experiment for Modern Physics" by the Physics Department of National Cheng Kung University.) However, we are moving QuarkNet-TW to the Taipei Astronomical Museum (TAM) which is more practical for high school students. In addition to uploading data to e-Lab, students can analyze and view their data in real time. Extensions to astronomy become possible at TAM, and interested students can do some hands-on experiments related to electrical engineering.

UK

UNIVERSITY OF BIRMINGHAM

Detecting Cosmic Rays – possible student projects: Three portable scintillation telescopes, each comprising a pair of scintillators, have been constructed, following the QuarkNet design, in the School of Physics and Astronomy at the University of Birmingham. These telescopes can be set up and used conveniently by students to measure the flux of cosmic rays; its dependence on distance between the scintillators, on zenith angle and on height (e.g. on the successive floors of a building). Results can also be stored and analysed using standard QuarkNet software. These telescopes , with worksheets outlining possible investigations, can be borrowed by schools and colleges for student projects. For more information, please contact :

Website: Login as a guest to view Birmingham QuarkNet Project

HiSPARC

High School Project on Astrophysics Research with Cosmics (HiSPARC) is a project in which secondary schools and academic institutions join forces and form a network to measure cosmic rays with extremely high energy. HiSPARC offers students the opportunity to participate in real research, with the purpose of finding out more about these mysterious and rare cosmic particles. Schools purchase HiSPARC detectors and students install these on the roofs of their school. The HiSPARC project started in the Netherlands in 2002. The HiSPARC detectors are connected to a central computer at the scientific institute Nikhef in Amsterdam through the internet, forming a large network. The project is coordinated from Nikhef in Amsterdam. The project spread to the UK in 2012 with first the Universities of Bristol, Bath and Birmingham. The project has recently spread to the Universities of Cardiff and Sussex. Website: HiSPARC

QuarkNet Cumyru builds on existing STEM programmes linked with HiSPARC and QuarkNet and a programme to pilot the use of cosmic ray detectors in schools across South Wales. Since January 2016, the project has tried to enthuse secondary school students in STEM activities through engagement in real hands-on astrophysics experiments — measuring cosmic rays using detectors based in schools. Equipment is available for loan to those schools that need A level particle physics laboratory equipment. A website will eventually act as a repository of the resources for using the detectors in the classroom, and as a collaborative learning space where schools can upload their data and work together to analyse their results. Website: QuarkNet Cymru

USA

QuarkNet

Cosmic Ray e-Lab Studies: provide opportunities for high school students to conduct their own scientific investigations either with data they collected themselves or with data from their peers. QuarkNet teachers receive a kit to build a portable, configurable classroom detector; non-QuarkNet educators can purchase the DAQ with GPS, antenna and temperature and pressure sensors. They can buy the rest of the parts commercially. The browser-based e-Lab provides analysis tools for four different studies and a guided inquiry instructional tool complete with student and teacher pages. To access the e-Lab educators request accounts; they create accounts for their students. The Data Portfolio provides additional classroom activities that develop student knowledge and skills needed to complete their scientific investigation.

Websites: Login as a guest to view Cosmic Ray e-Lab and to access Data. | Data Portfolio | QuarkNet Project

https://icd.desy.de/e49245

Thanks a lot for your attention