

Puerto Vallarta, Jalisco, Mexico  
Hilton Hotel Feb 19-23, 2018

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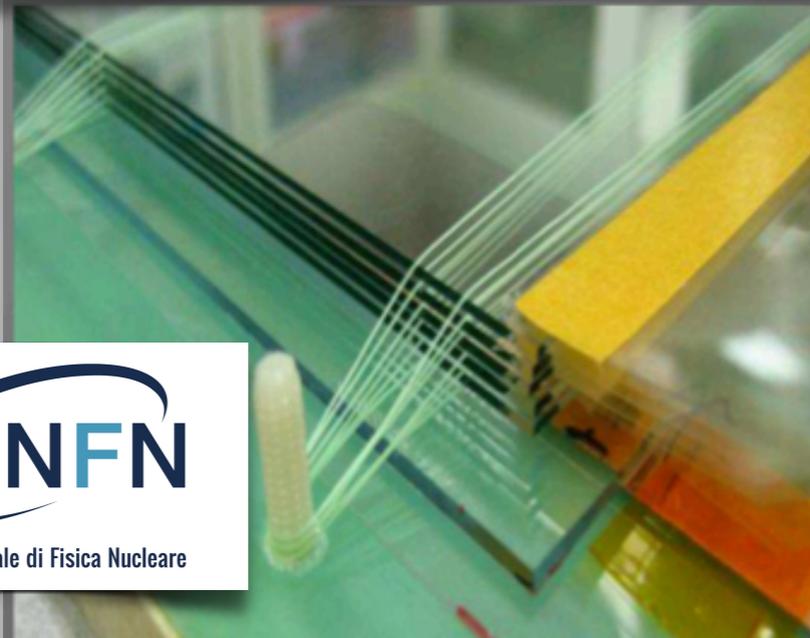
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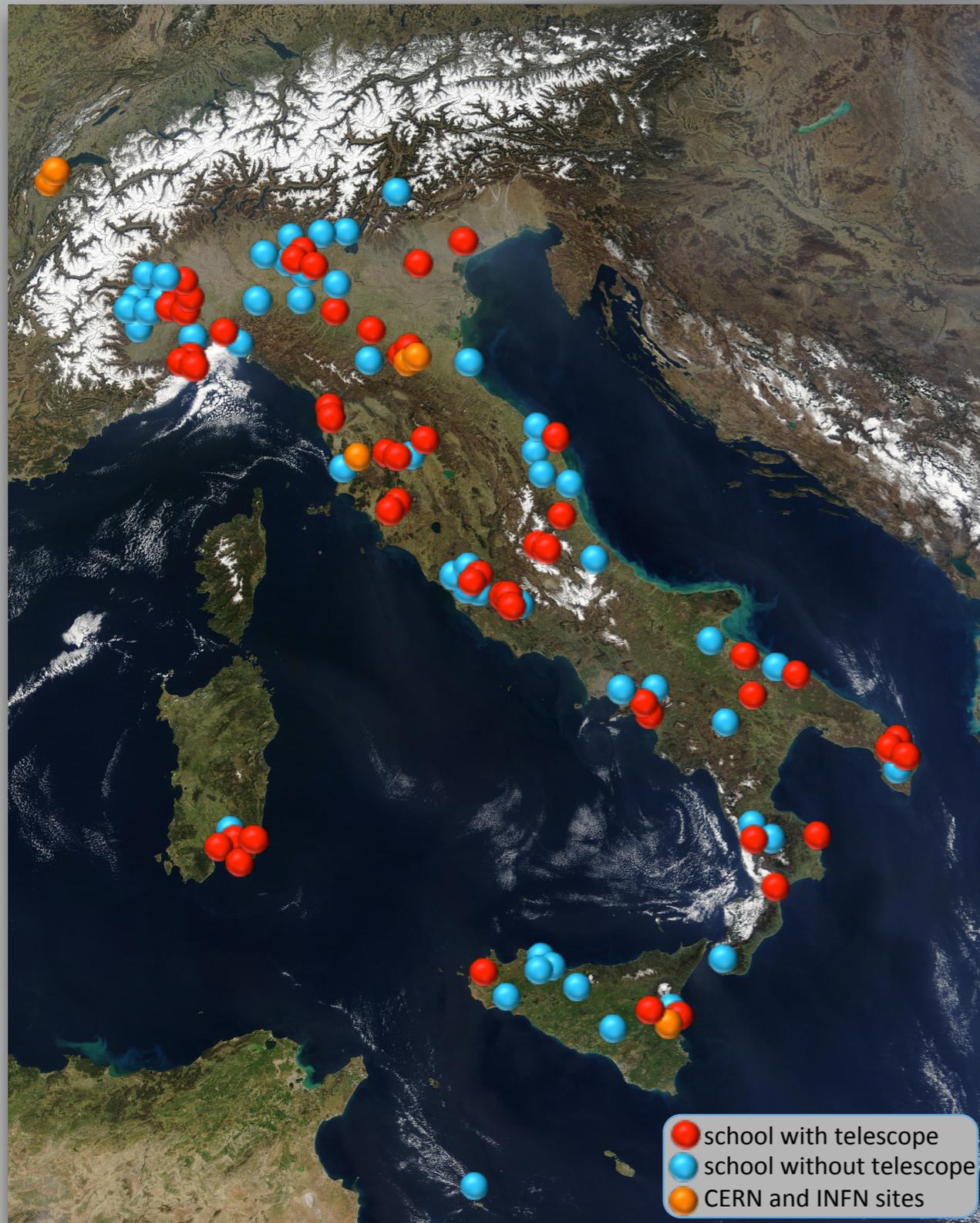
# Performance of the Multigap Resistive Plate Chambers of the Extreme Energy Events Project

D. De Gruttola\* for the EEE Collaboration

\* Centro Fermi, Rome and Salerno INFN - Italy



# Extreme Energy Events (EEE) Project



- ✓ array of MRPC telescopes covering more than  $3 \cdot 10^5 \text{ km}^2$
- ✓ clusters and standalone stations
- ✓ stations are hosted in Italian Secondary Schools, INFN sections and CERN
- ✓ each station is made of 3 MRPC chambers
- ✓ project started in 2004
- ✓ array composed of 56 telescopes at the moment (continuously growing) (see *M. Abbrescia's talk about the EEE upgrade*)
- ✓ long-living MRPC-based system (14 years)
- ✓ 60 billion tracks currently collected
- ✓ *unconventional working sites:*
  - mainly school buildings
  - non-professional electrical lines
  - non-controlled environmental parameters
  - heterogeneous maintenance conditions

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working sites:

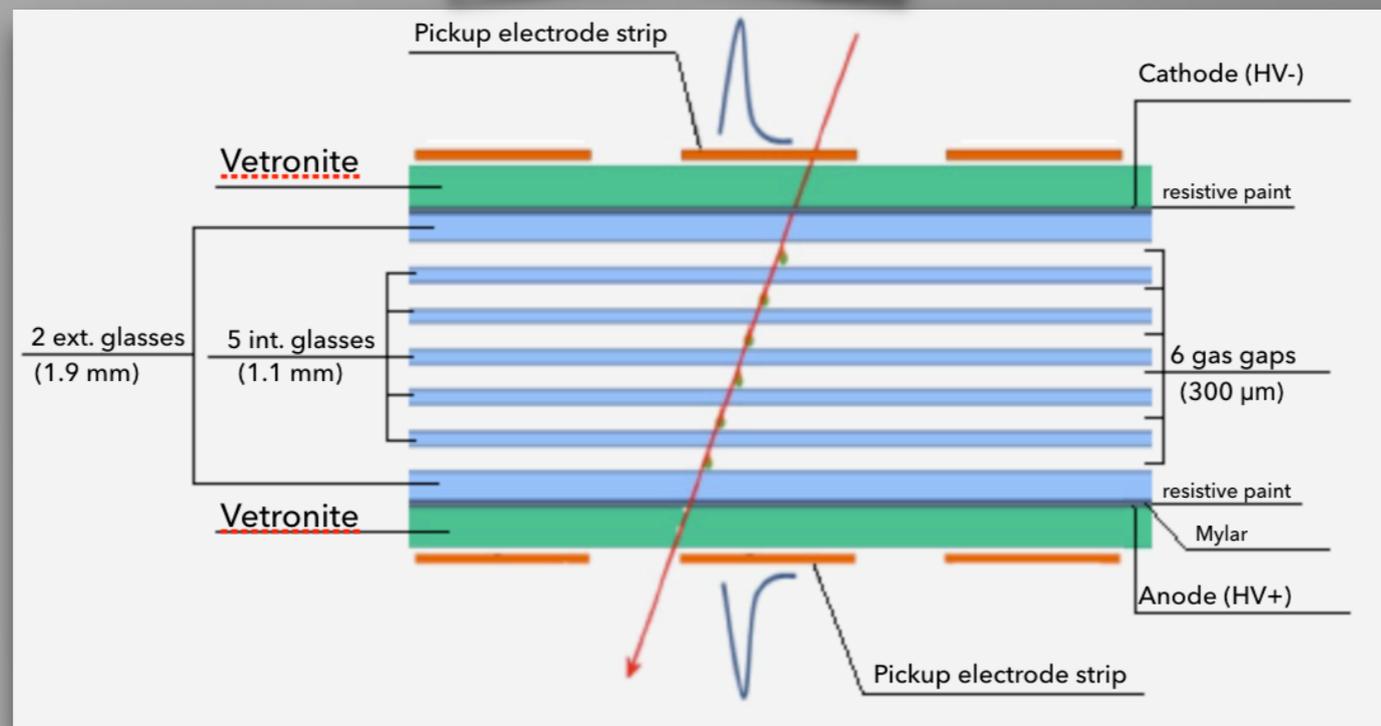
mainly school buildings

non-professional electrical lines

non-controlled environmental parameters

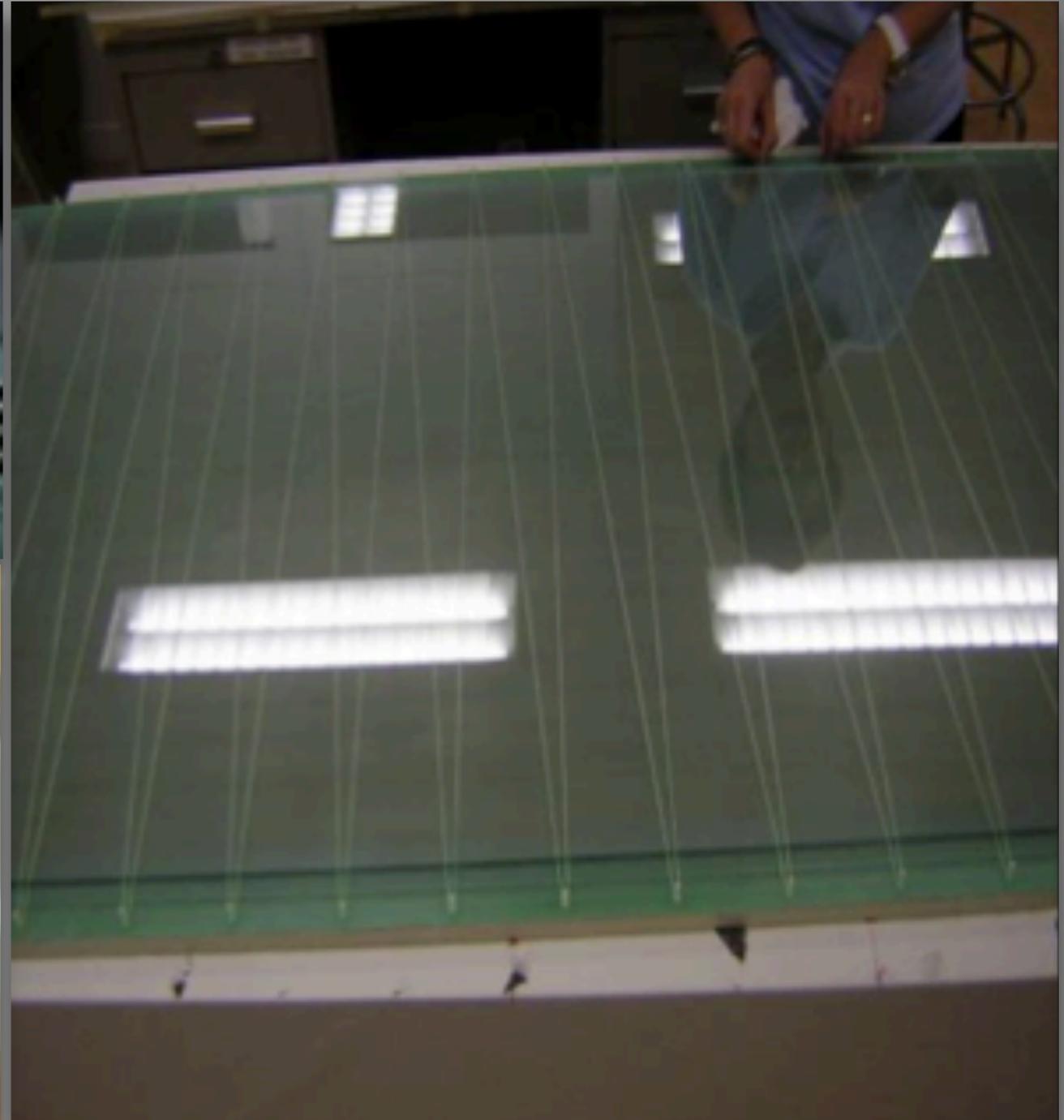
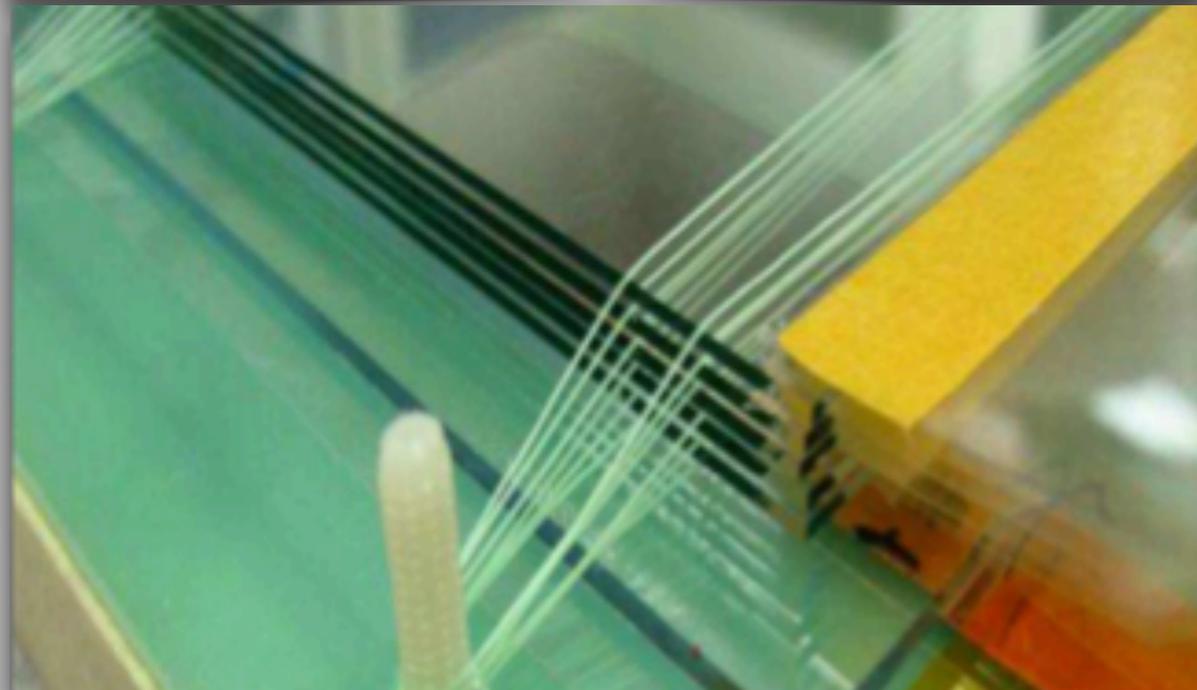
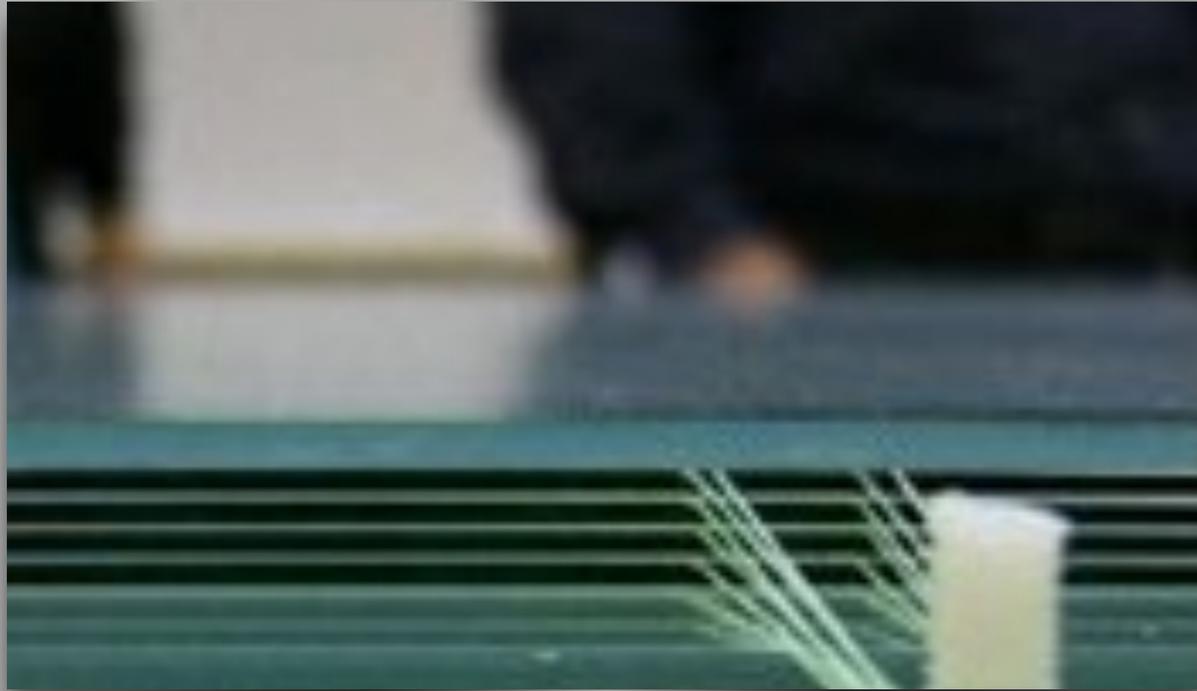
heterogeneous maintenance conditions

# EEE MRPC



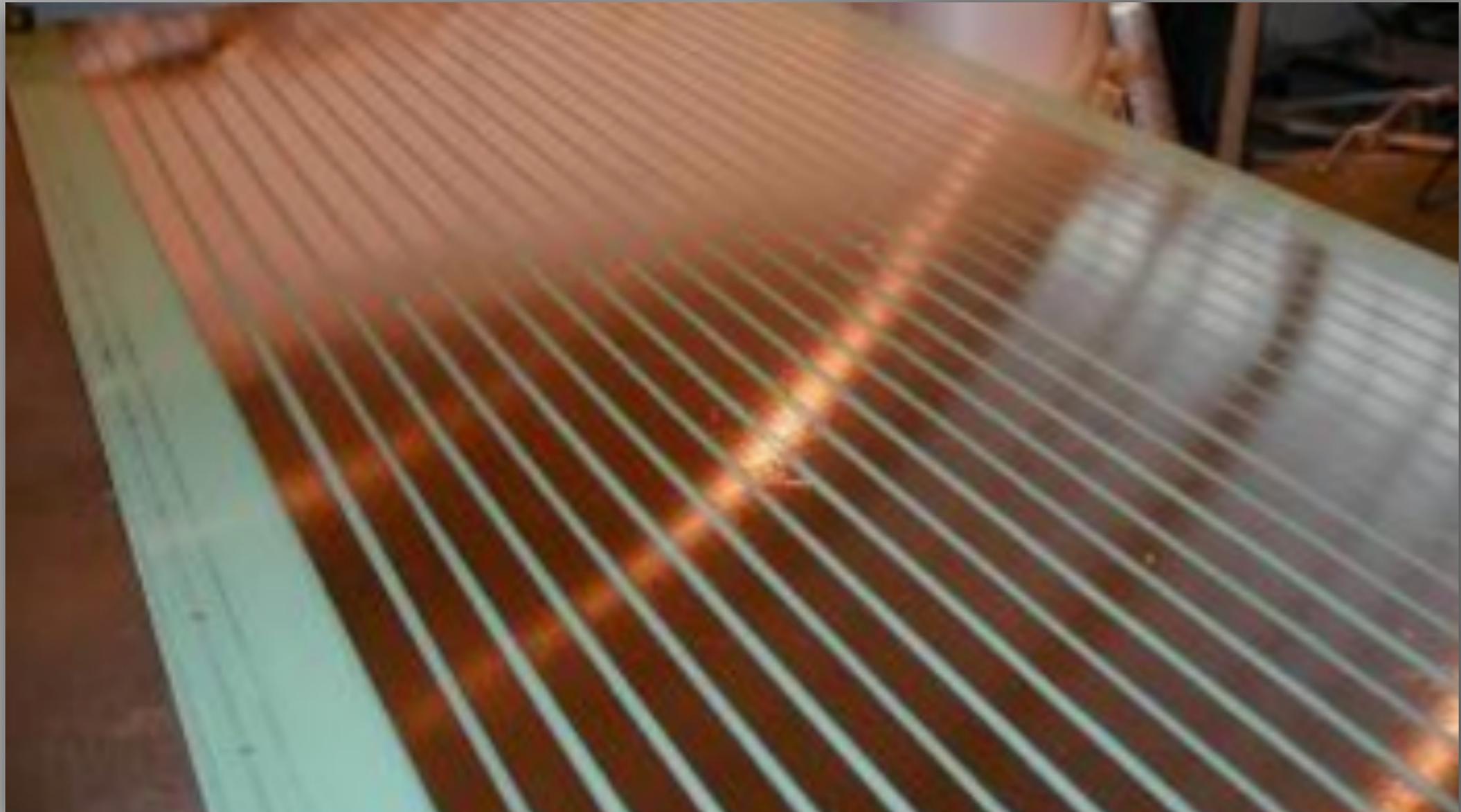
- ✓ 6 gas gaps (300 μm)
- ✓ 2 external glass sheets (anode and cathode) – 160 cm x 85 cm, 1.9 mm thick (resistive paint 5-20 MΩ/□)
- ✓ 5 intermediate (electrically floating) glass sheets - 158 cm x 82 cm, 1.1 mm thick
- ✓ 24 copper strips (anode and cathode) to pick up the signal – 158 cm x 25 cm, spaced by 7 mm
- ✓ honeycomb panels to ensure mechanical stability – 182 cm x 90 cm
- ✓ gas-tight aluminum box – 200 cm x 100 cm
- ✓ gas mixture 98% R134a (C<sub>2</sub>F<sub>4</sub>H<sub>2</sub>) - 2% SF<sub>6</sub>  
(see S. Pisano's talk about new gas mixtures)
- ✓ HV up to 20 kV (avalanche mode) supplied by 2 DC/DC converters

# EEE MRPC



## MRPC details:

- ✓ glasses
- ✓ 300  $\mu\text{m}$  fishing line as spacer to create gas gaps
- ✓ vetronite panel

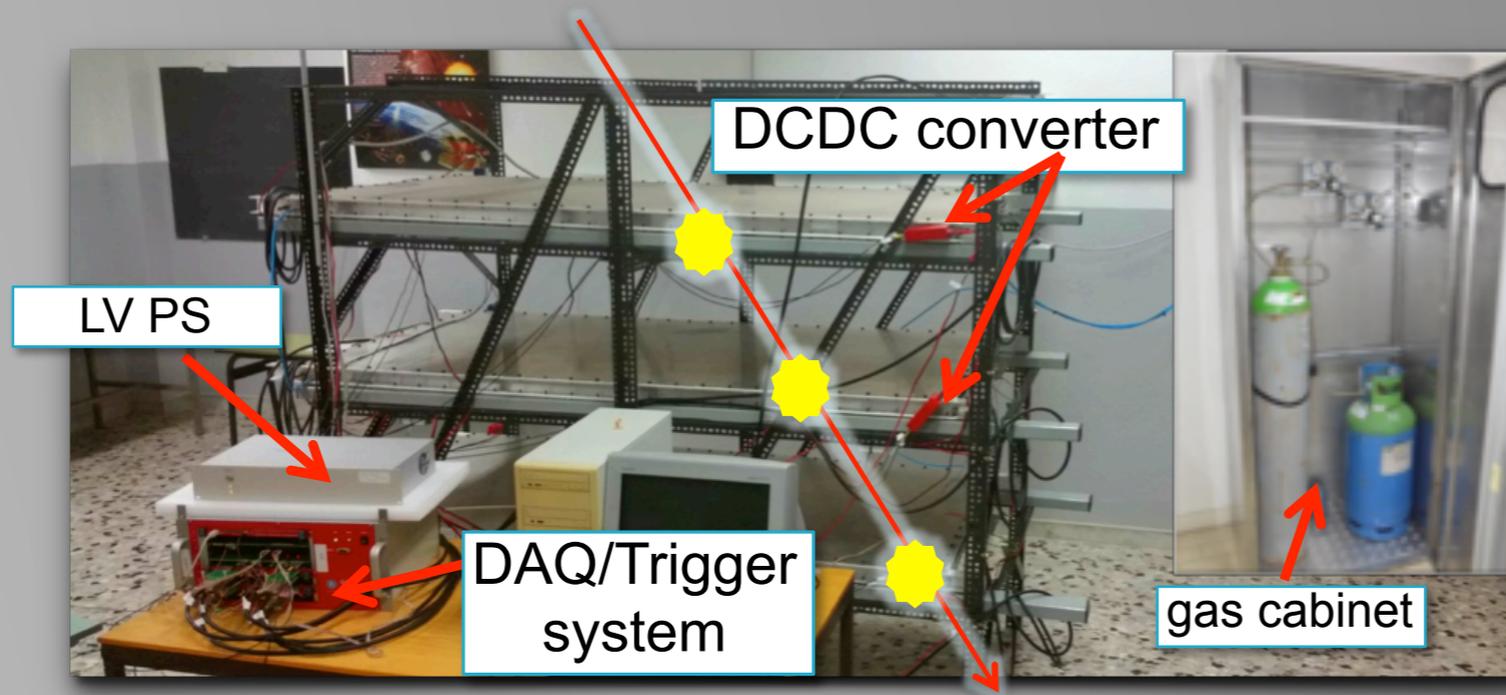


MRPC details:

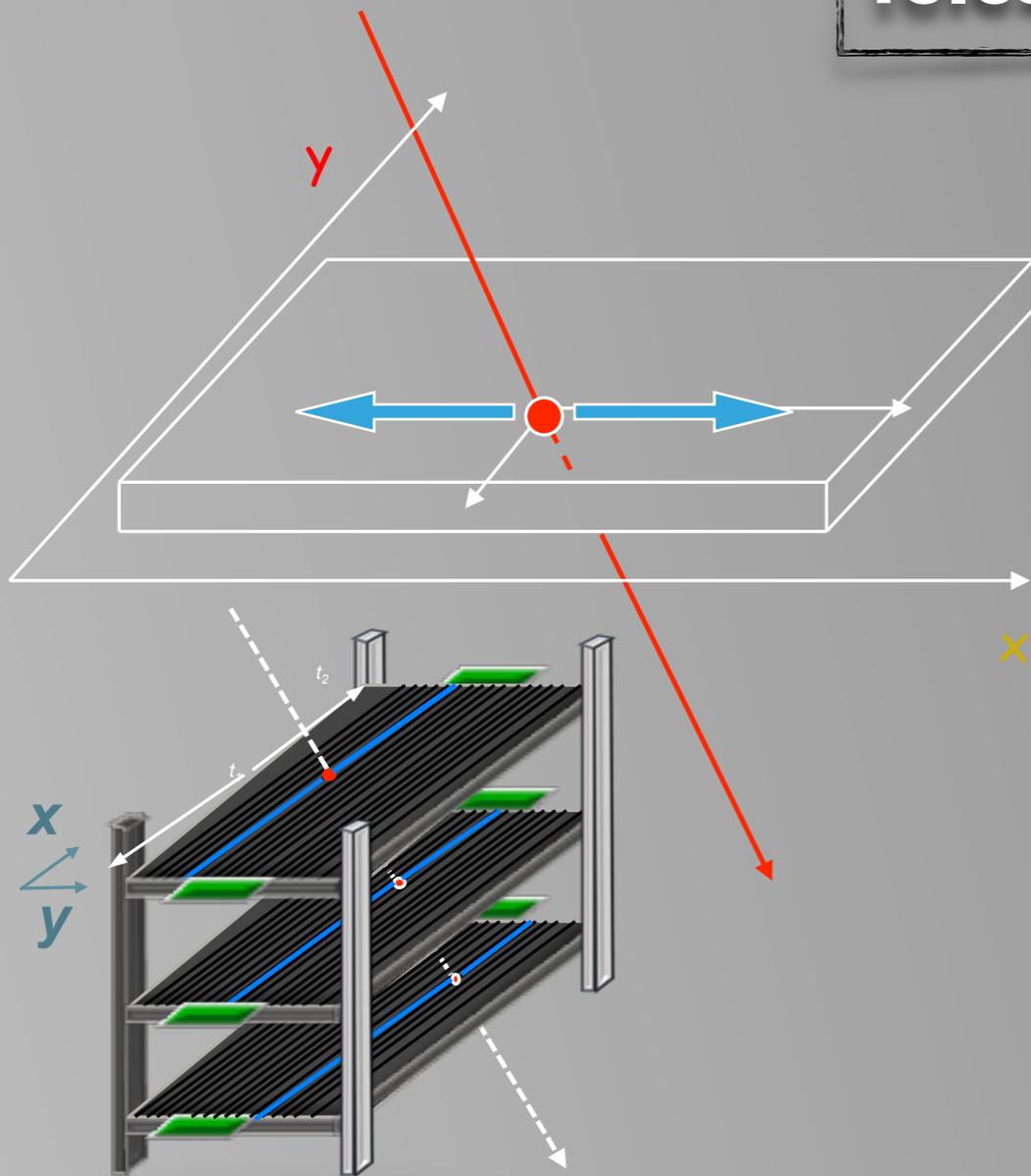
- ✓ 24 copper strips to pickup the signal
- ✓ pitch 3.2 cm

# Telescope and electronics

- ✓ 6 Front-End boards (FEAs) with 24 channels to process readout signal (pre-amplification + discrimination)
- ✓ 2 Multi-hits Time to Digital Converters (TDCs 128 + 64 channels)
- ✓ 1 Trigger Card: a six-fold coincidence of both FEAs of the three MRPCs generates the Data Acquisition (DAQ) trigger
- ✓ GPS unit provides the event time stamp (UTC time) to record and synchronize information
- ✓ weather station to monitor the temperature and the pressure inside and outside the telescopes building

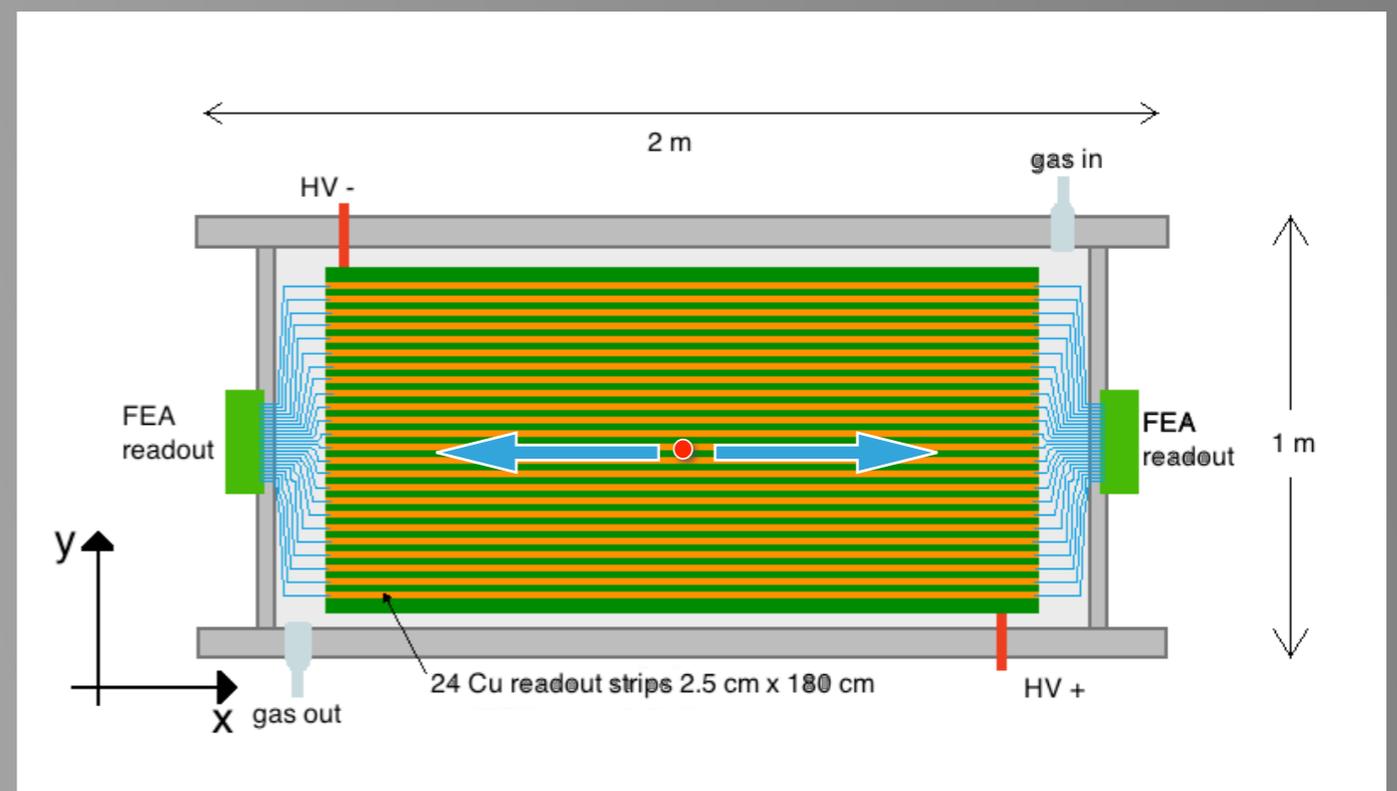


# Telescope and electronics



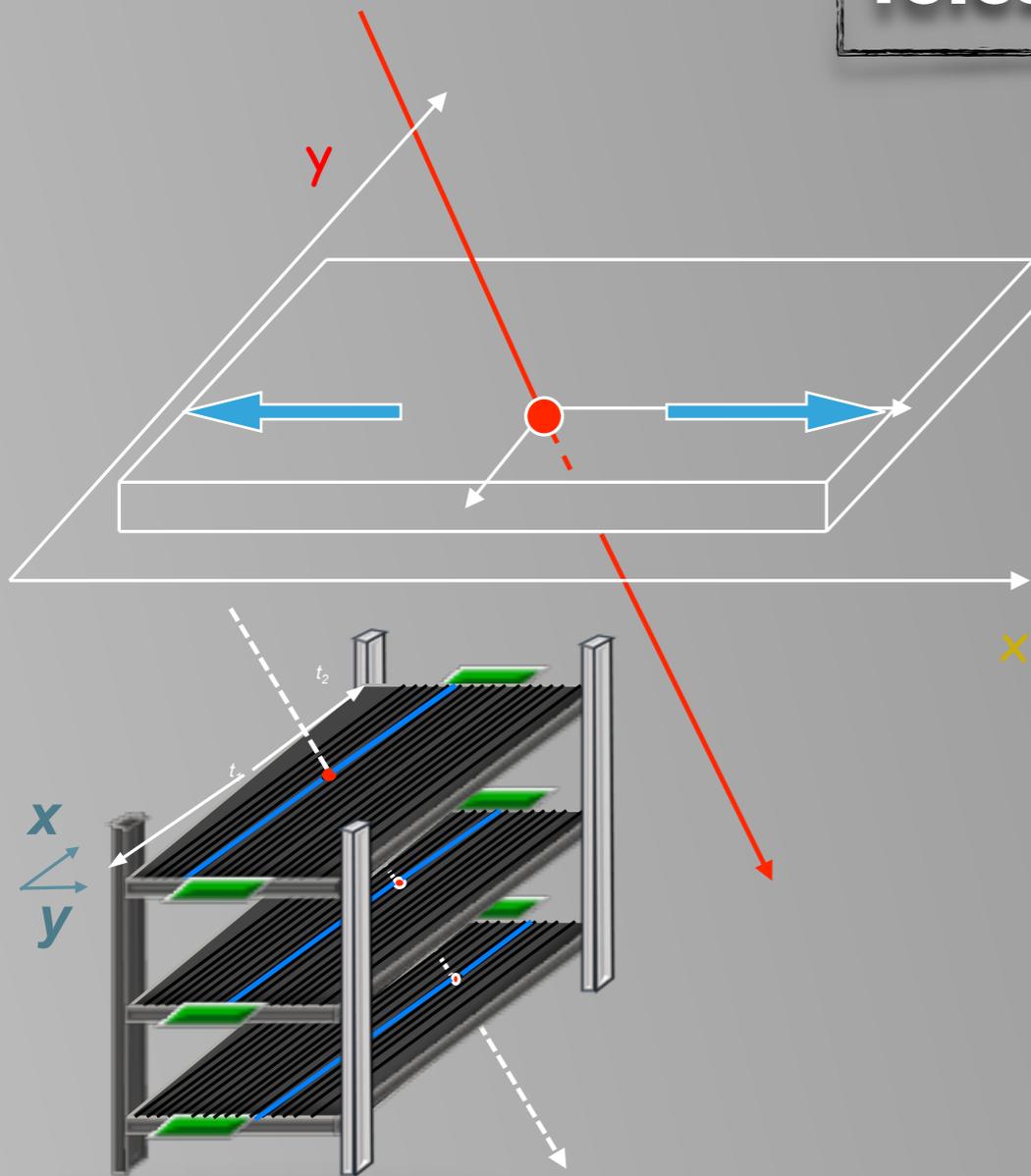
particle impact point reconstructed by:

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



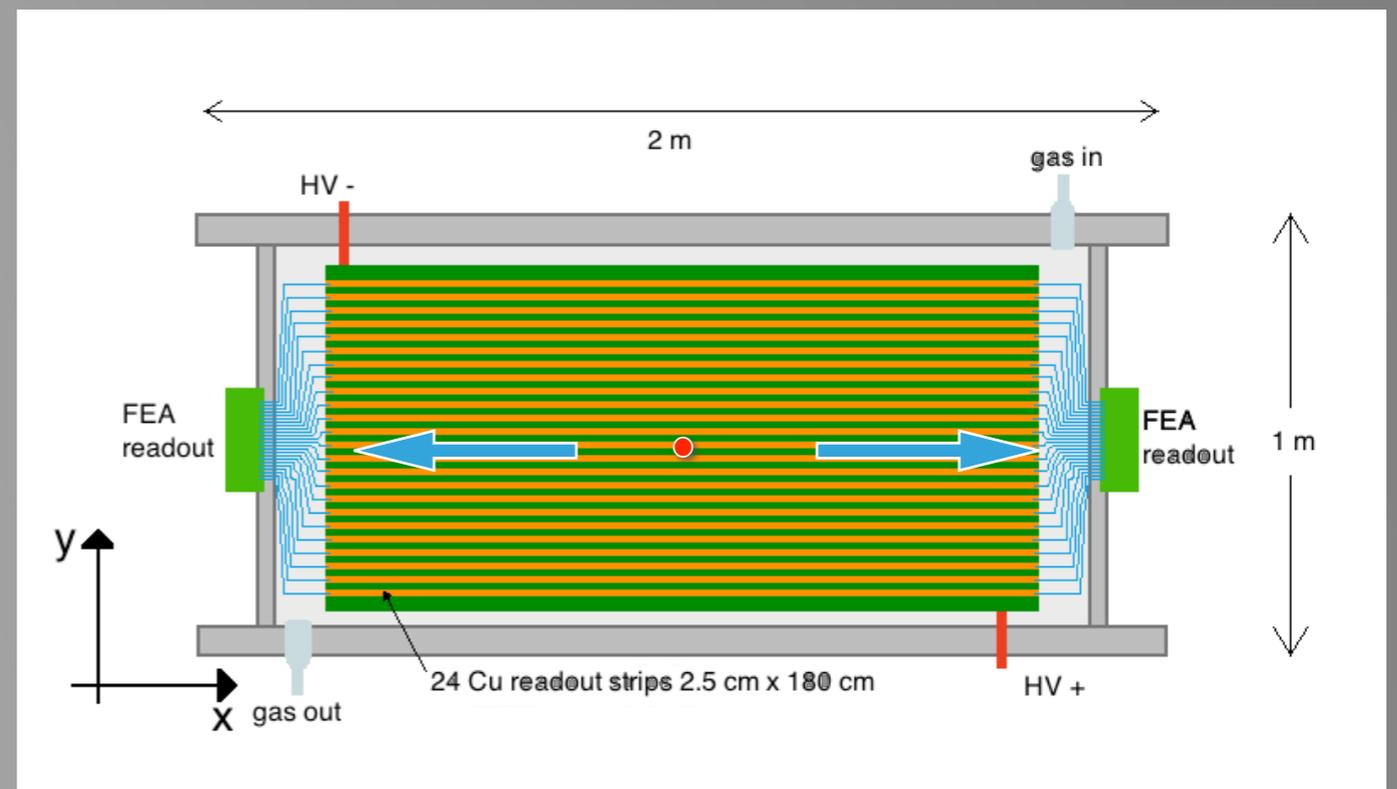
- ✓ 100 ps **time resolution** of the **TDC** bin
- ✓ ~1 cm **spatial resolution** along both coordinate
- ✓ > 95% MRPC **efficiency** at the operating voltage of 18 kV
- ✓ few tens ns **GPS time resolution**

# Telescope and electronics



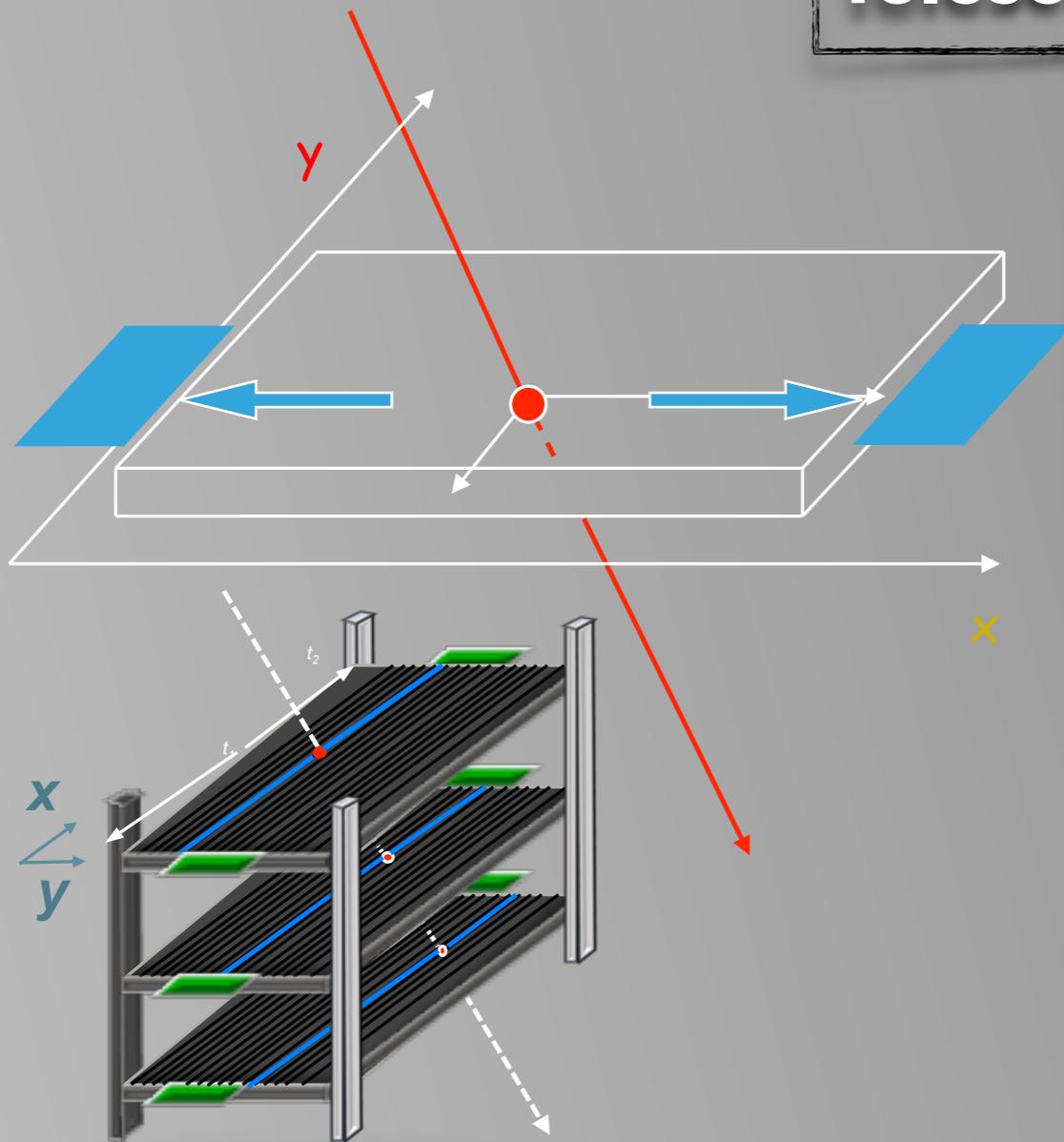
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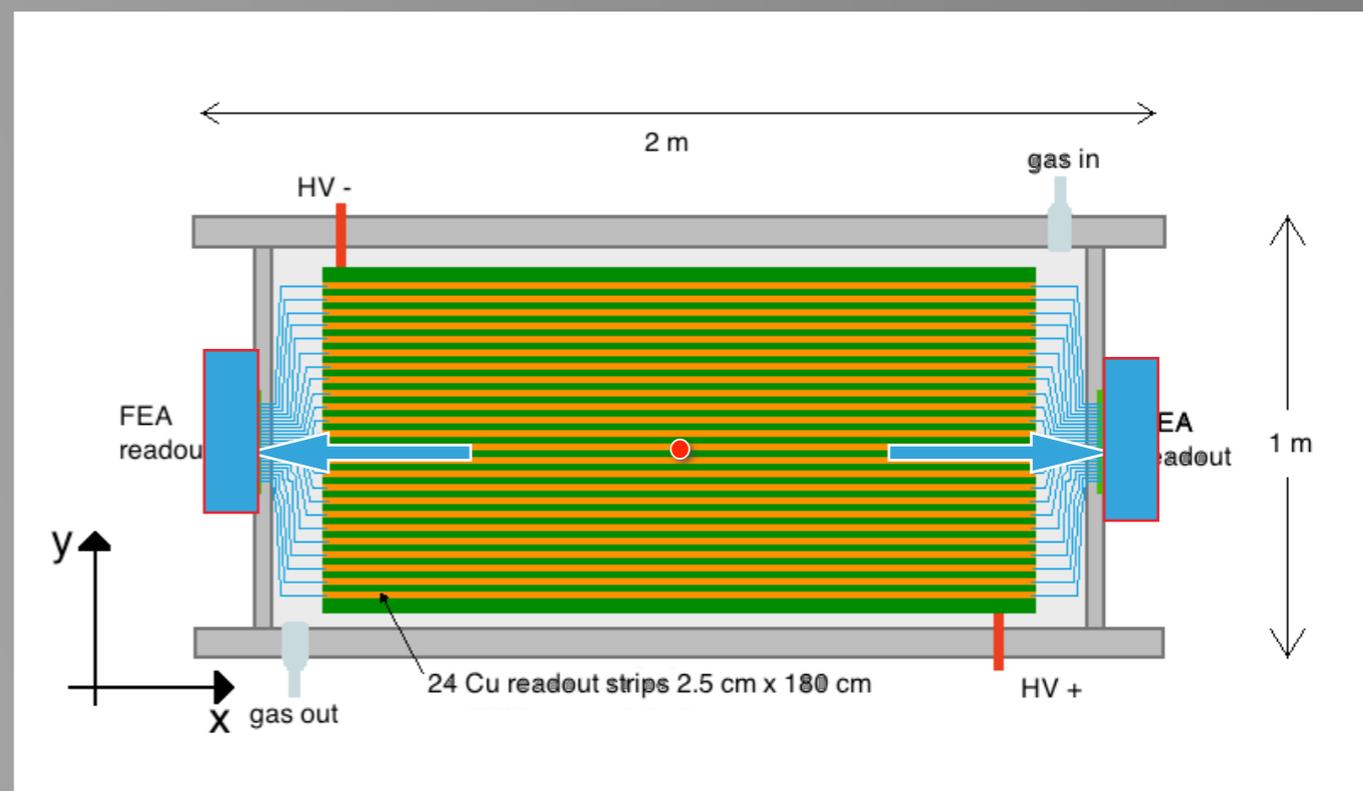
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# Telescope and electronics



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# Students involvement

- ✓ one week to build 3 chambers (activity at CERN)
- ✓ secondary school students work under researchers' supervision (activity at CERN)
- ✓ setup of the telescope (activity at school)
- ✓ chamber efficiency measurements (activity at school)
- ✓ all chambers are correctly working in each single telescope (daily monitor)

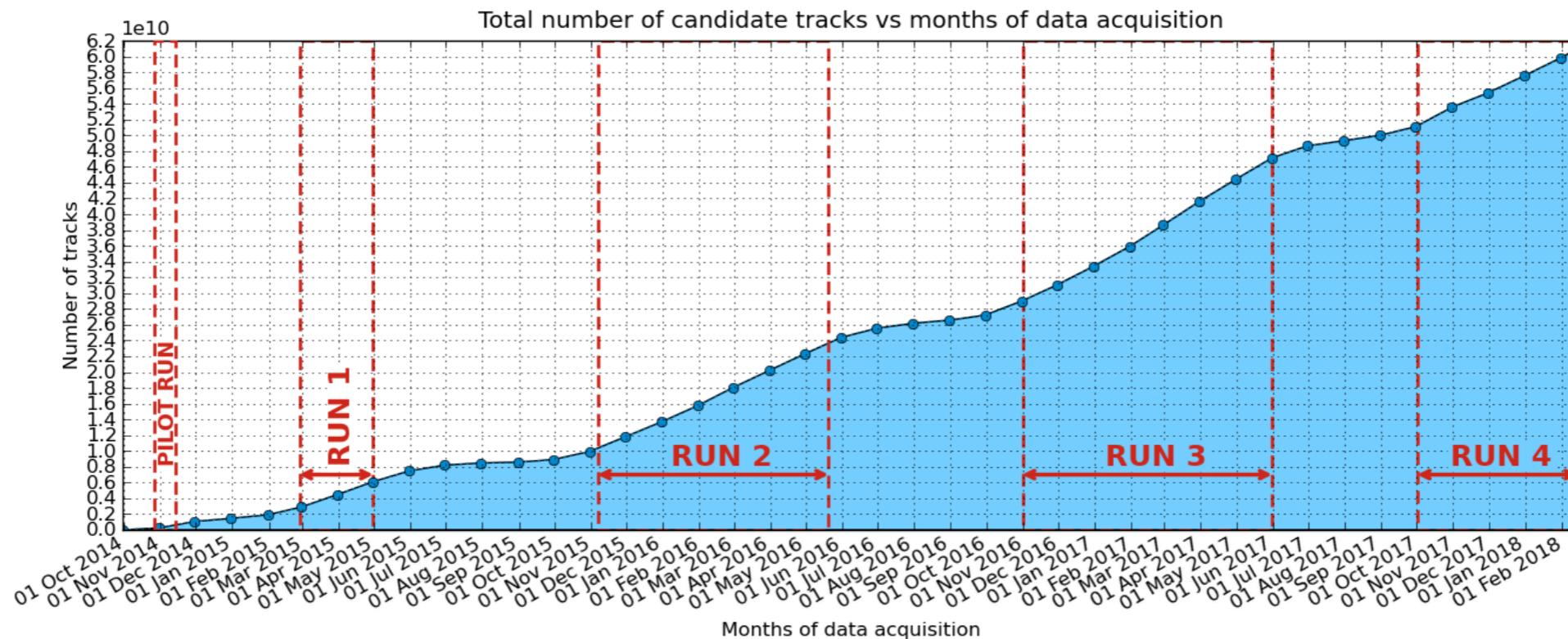


- <10 students + 2-3 teachers per school involved in the chamber construction at CERN
- thousands of students and hundreds of teachers participating to the project

# Performance

# Data taking

- ✓ periodic coordinated data taking periods (**Runs**) are performed
- ✓ all telescopes take data, with a central system of online shift and **data quality monitor**
- ✓ *Pilot Run, Run 1, Run2, Run 3 have been completed in the last 4 years*
- ✓ **Run 4** ongoing
- ✓ data are sent to **CNAF** (data storage center in Bologna, Italy) to be stored, reconstructed and analyzed
- ✓ **60 billion** tracks collected



# Time resolution

✓ cut on reconstructed tracks  $\chi^2 < 10$

✓ results will be published soon

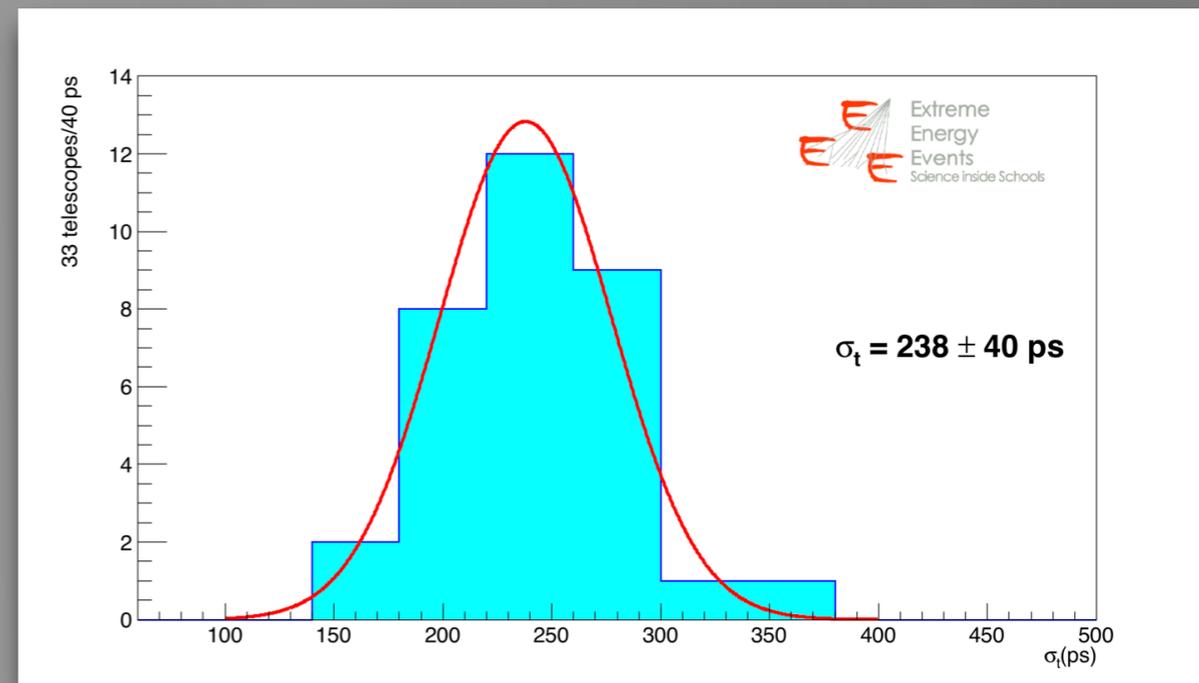
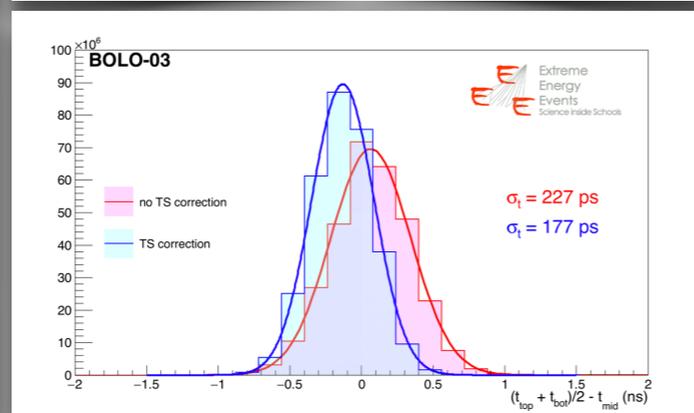
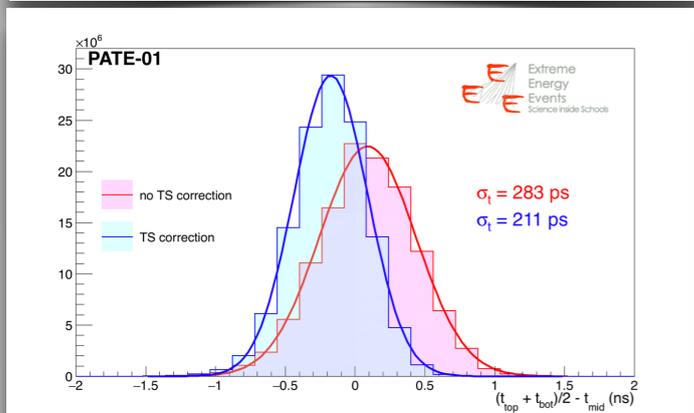
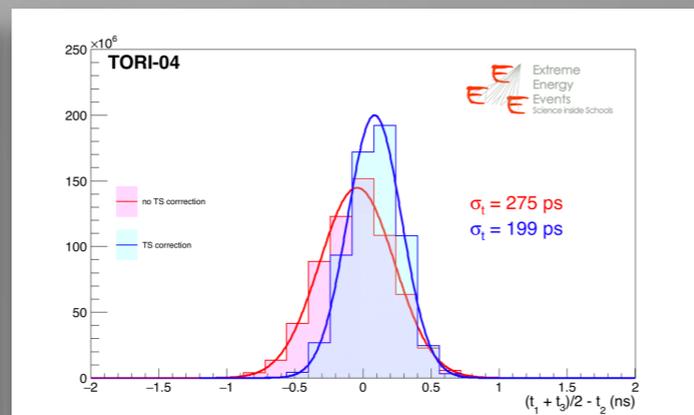
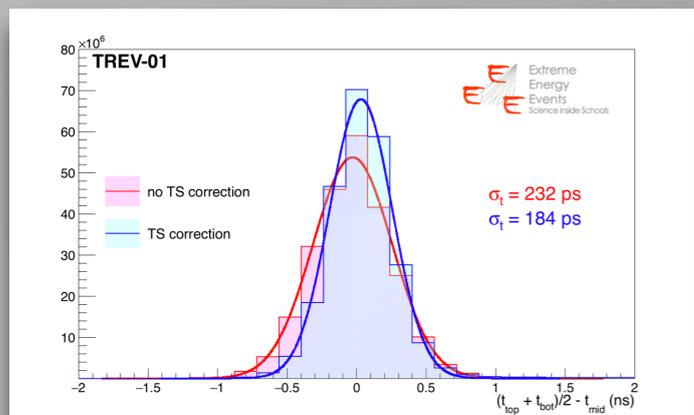
Time Slewing correction:

- the hit time depends on the signal amplitude, or equivalently the Time Over Threshold (TOT)
- the effect of its jitter has to be corrected in order to get the real hit time

✓  $\Delta t_{\text{hit}} = (t_{\text{bot}} + t_{\text{top}})/2 - t_{\text{mid}}$

✓  $\sigma_t = \sqrt{3/2} \sigma_{\Delta t} \sim 240 \text{ ps}$

✓ time slewing correction to be applied (soon)



✓ average time resolution  $\sim 240 \text{ ps}$

✓ resolution within expectations (order of  $10^2 \text{ ps}$ ) and compatible with requirements

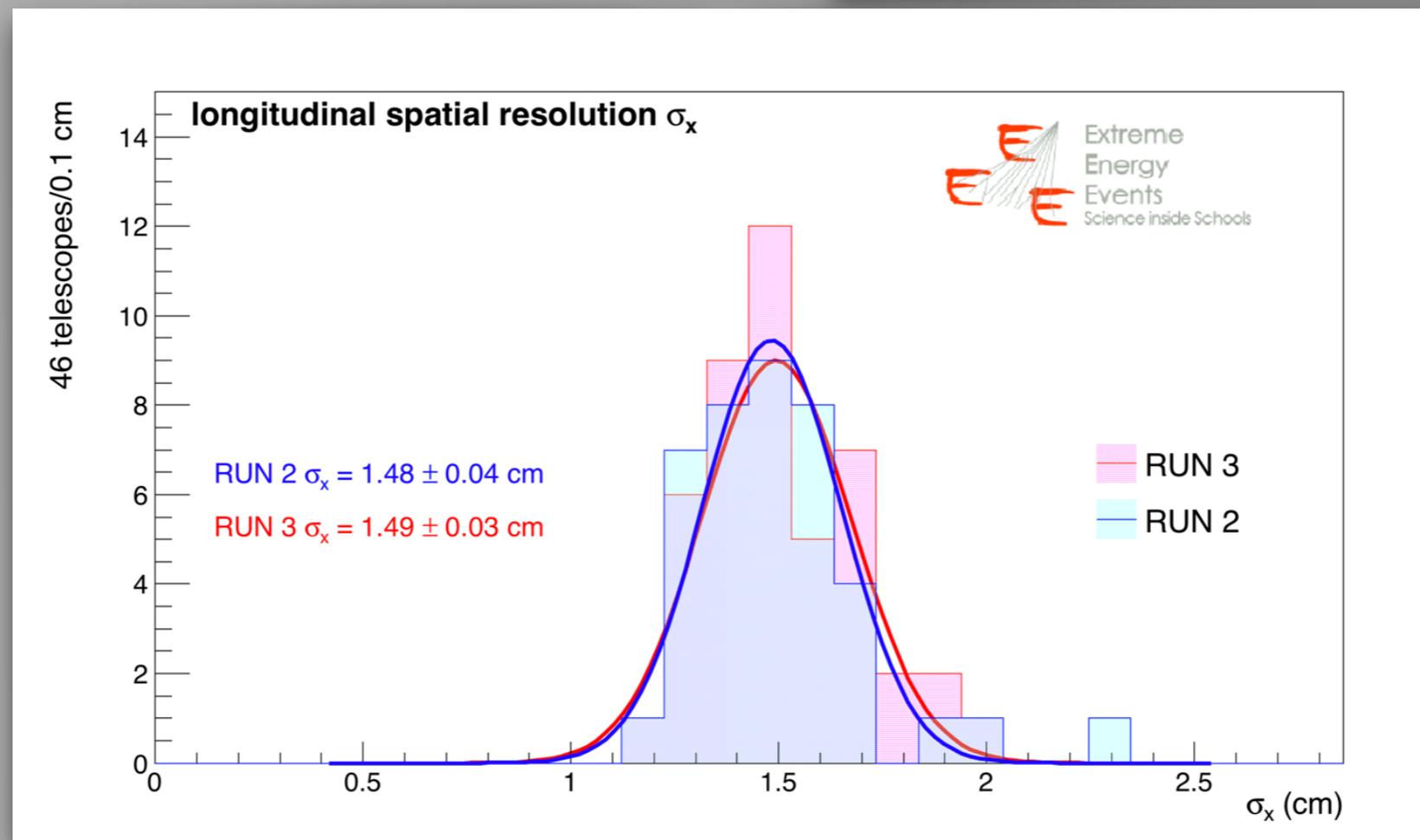
# Spatial resolution (long side)

- ✓ cut on reconstructed tracks  $\chi^2 < 10$
- ✓ results will be published soon

$$\checkmark \Delta x = (x_{\text{bot}} + x_{\text{top}})/2 - x_{\text{mid}}$$

$$\checkmark \sigma_x = \sqrt{3/2} \sigma_{\Delta x} \sim 1.49 \text{ cm}$$

$$\checkmark \sigma_{x\text{exp}} \sim \sqrt{\sigma_{TDC}^2 + \sigma_{TDC}^2 v_{\text{drift}} / 2} \sim 1.1 \text{ cm}$$



- ✓ average spatial resolution (long side) 1.49 cm
- ✓ resolution compatible with requirements

# Spatial resolution (short side)

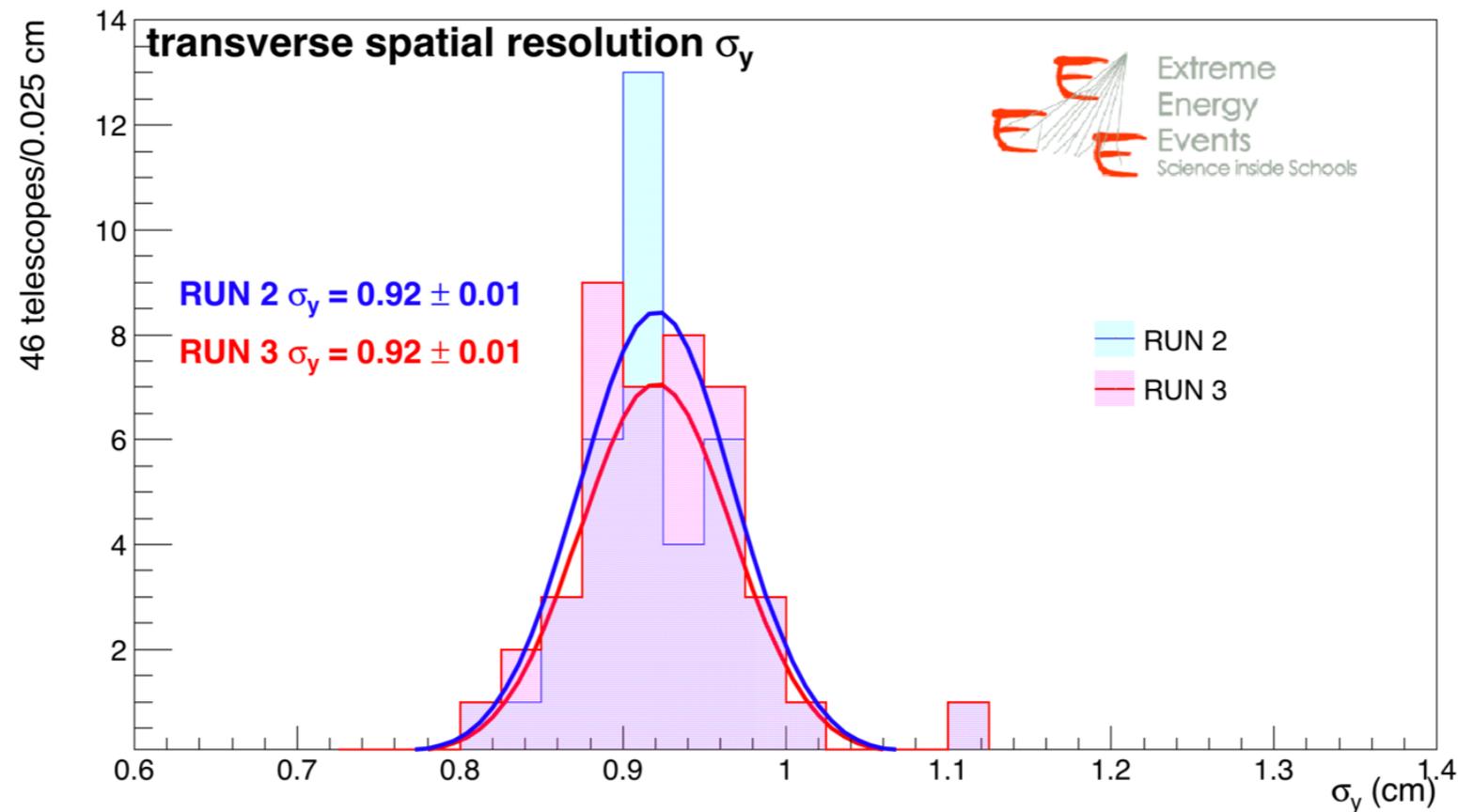
✓ cut on reconstructed tracks  $\chi^2 < 10$

✓ *results will be published soon*

✓  $\Delta y = (y_{\text{bot}} + y_{\text{top}})/2 - y_{\text{mid}}$

✓  $\sigma_y = \sqrt{3/2}\sigma_{\Delta y} \sim 1 \text{ cm}$

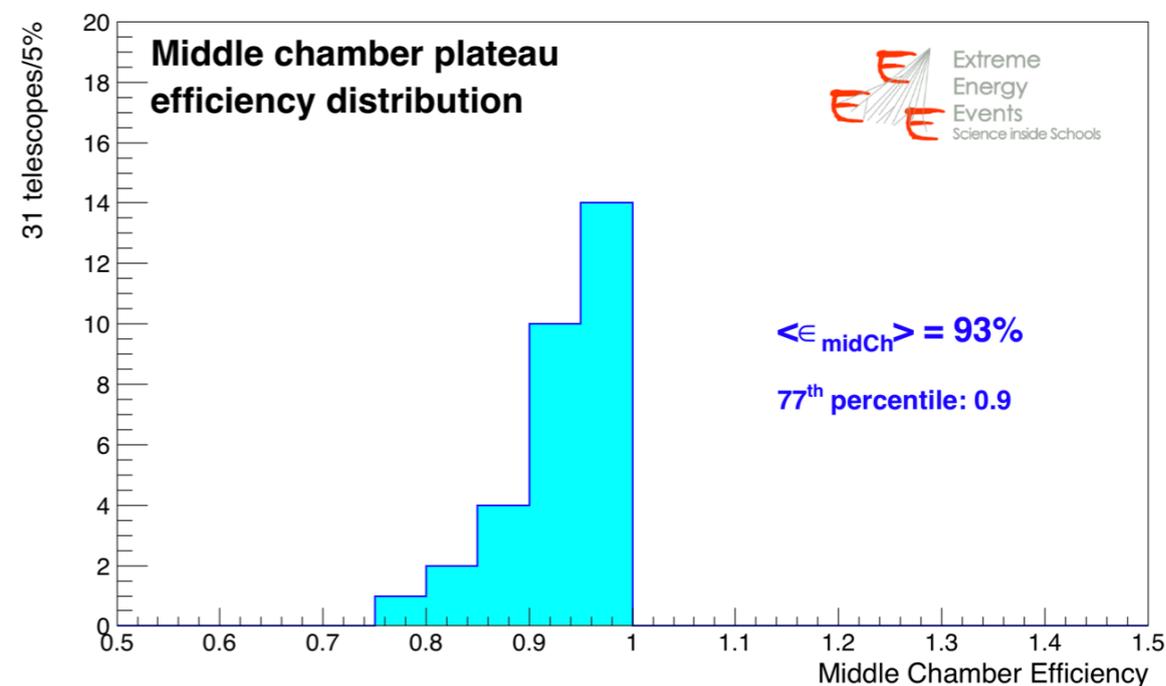
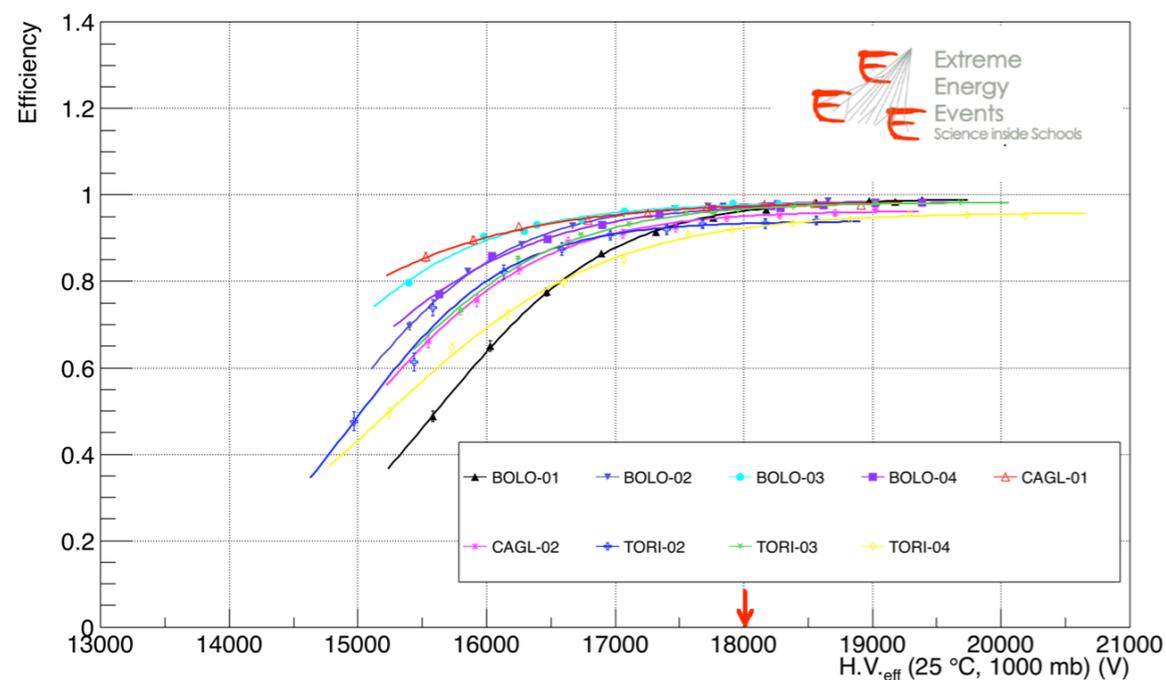
✓  $\sigma_{y\text{exp}} \sim \text{pitch}/\sqrt{12} \sim 0.92 \text{ cm}$  (pitch 3.2 cm)



✓ average spatial resolution (short side) 0.92 cm  
✓ resolution compatible with requirements

# Efficiency

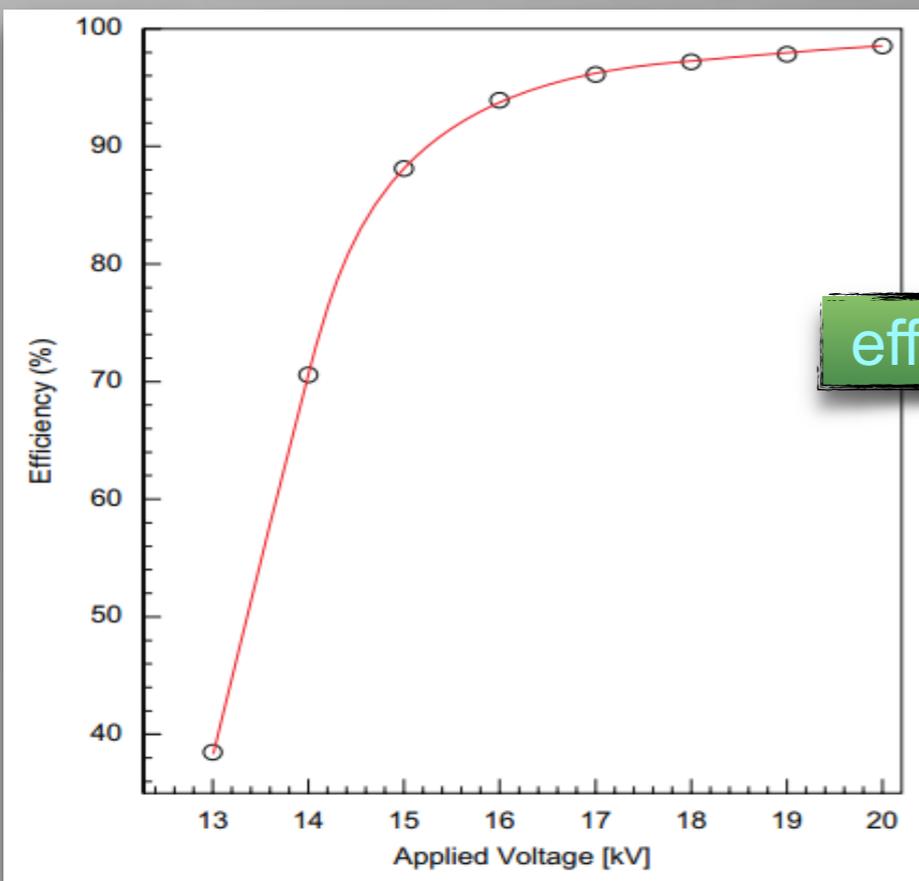
- ✓ external chambers used as trigger
- ✓ efficiency of the middle chamber measured on all telescopes
- ✓ students involved in the measurement (well defined procedure for the HV scan)
- ✓ procedure to measure efficiency of the external chambers ready (and applied in a few cases)



- ✓ average efficiency of the telescope network ~93 %
- ✓ compatible within expectations and with the results from beam-tests performed at CERN
- ✓ efficiency better than 93 % is reached by 77% of the network

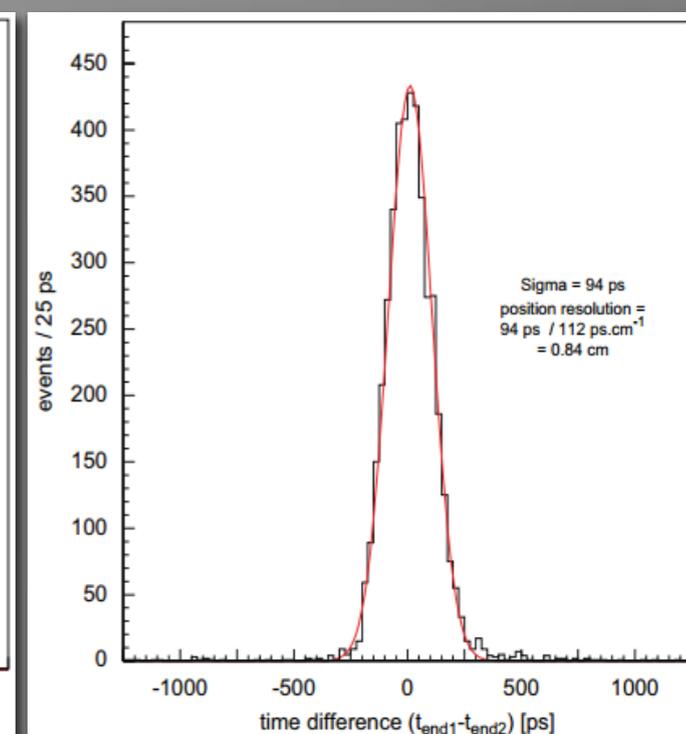
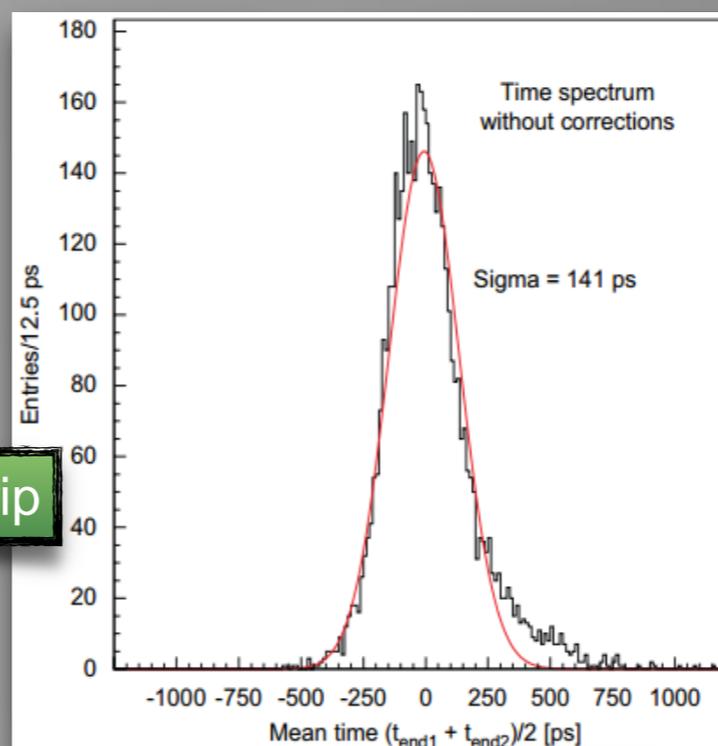
# Results from beam-tests at CERN

- ✓ efficiency vs HV for a single MRPC chamber
- ✓ events triggered by scintillators



efficiency plateau ~100%

TDCs 25 ps bins, scintillators system time resolution 30 ps

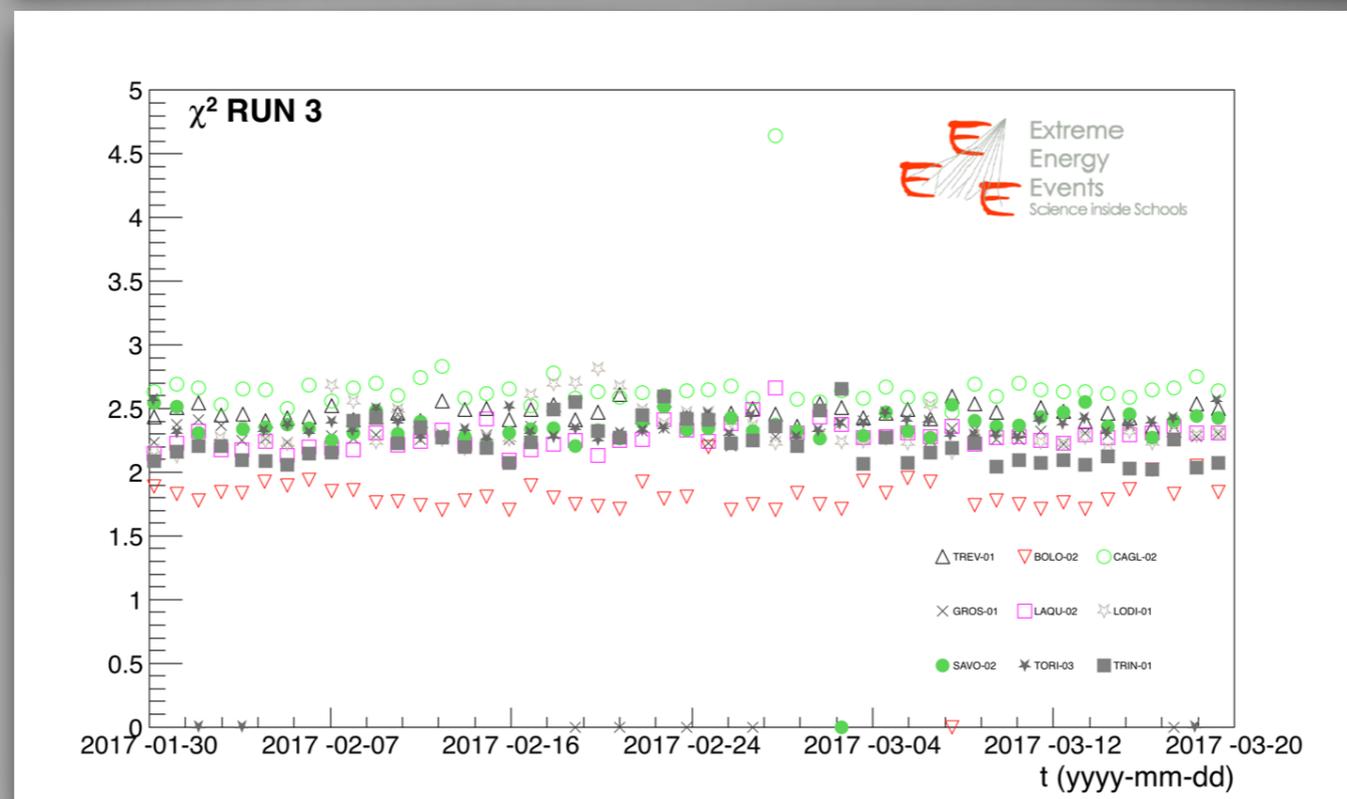
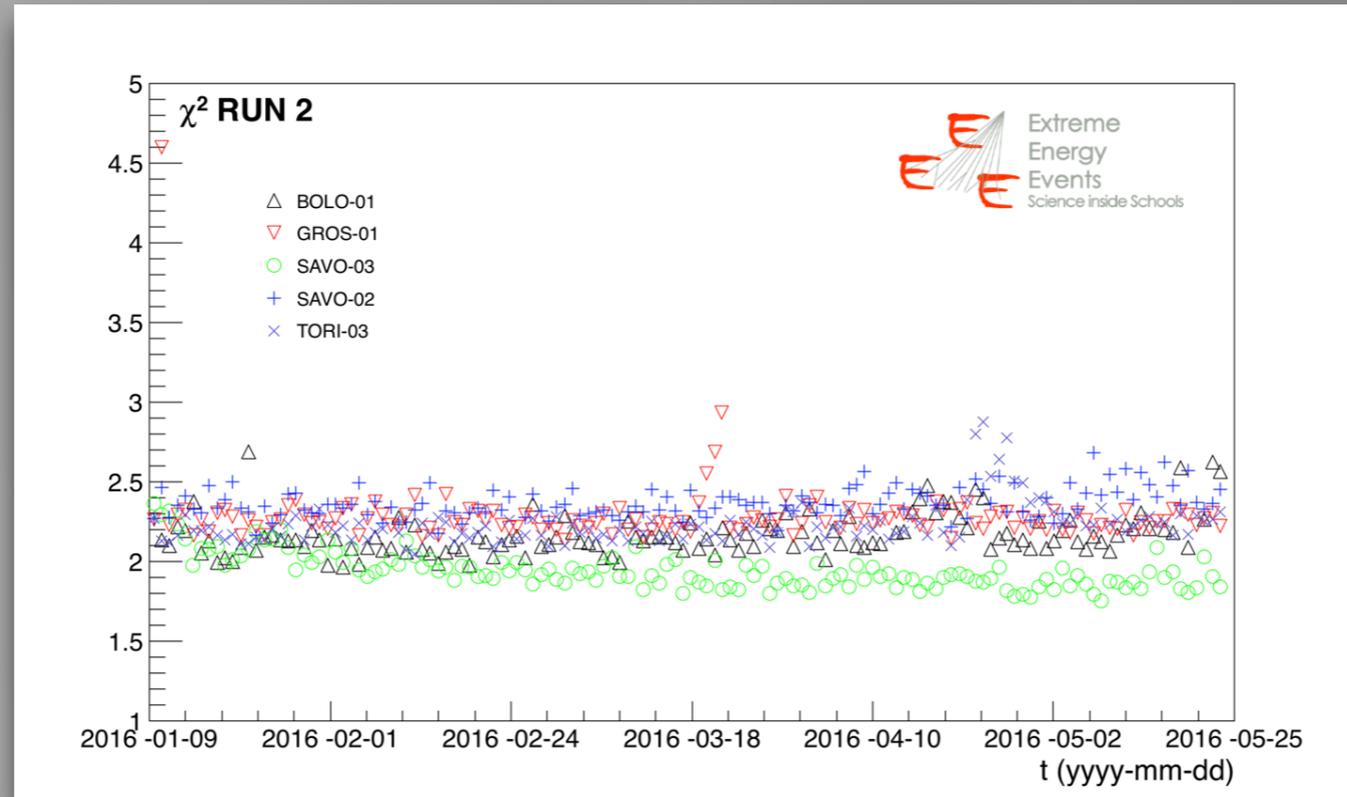


$\sigma_t \sim 100$  ps in the center of the strip

spatial resolution along the strip 0.8 cm

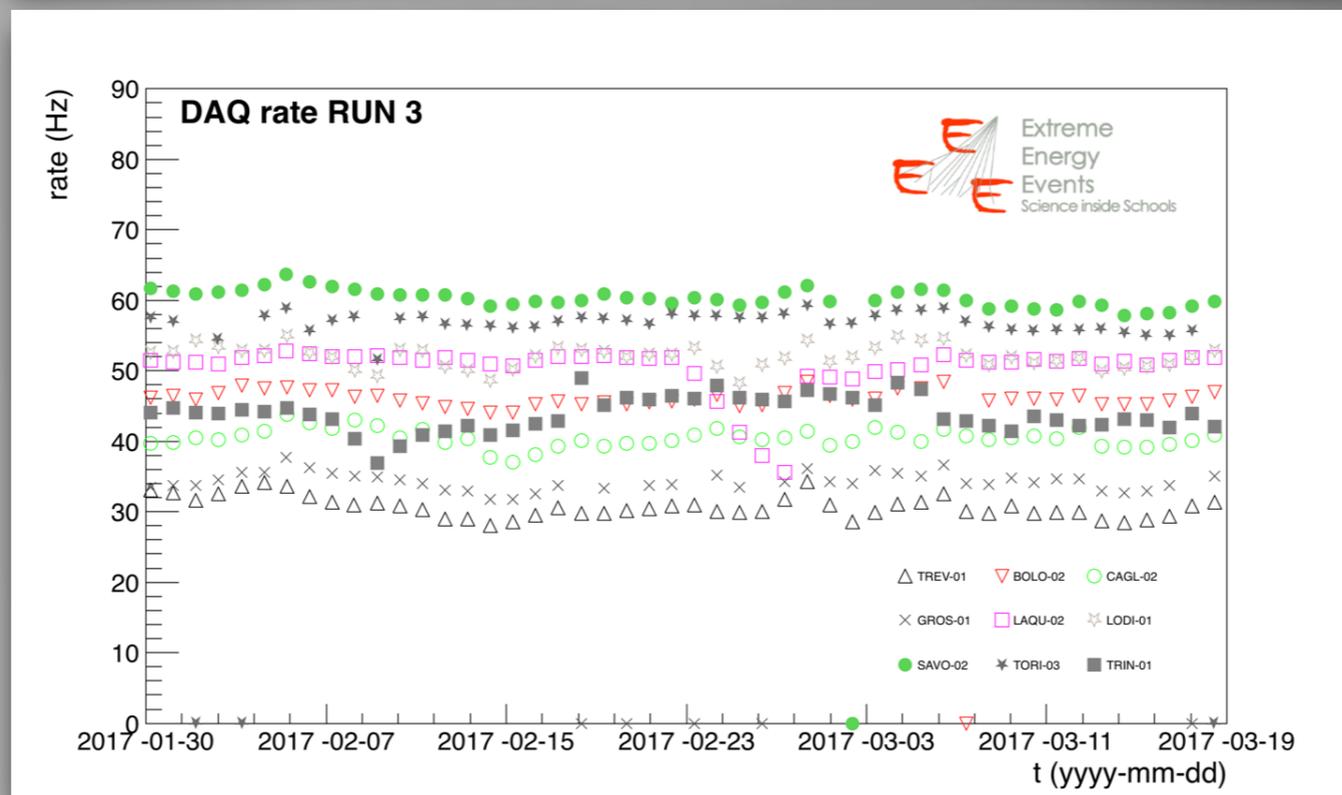
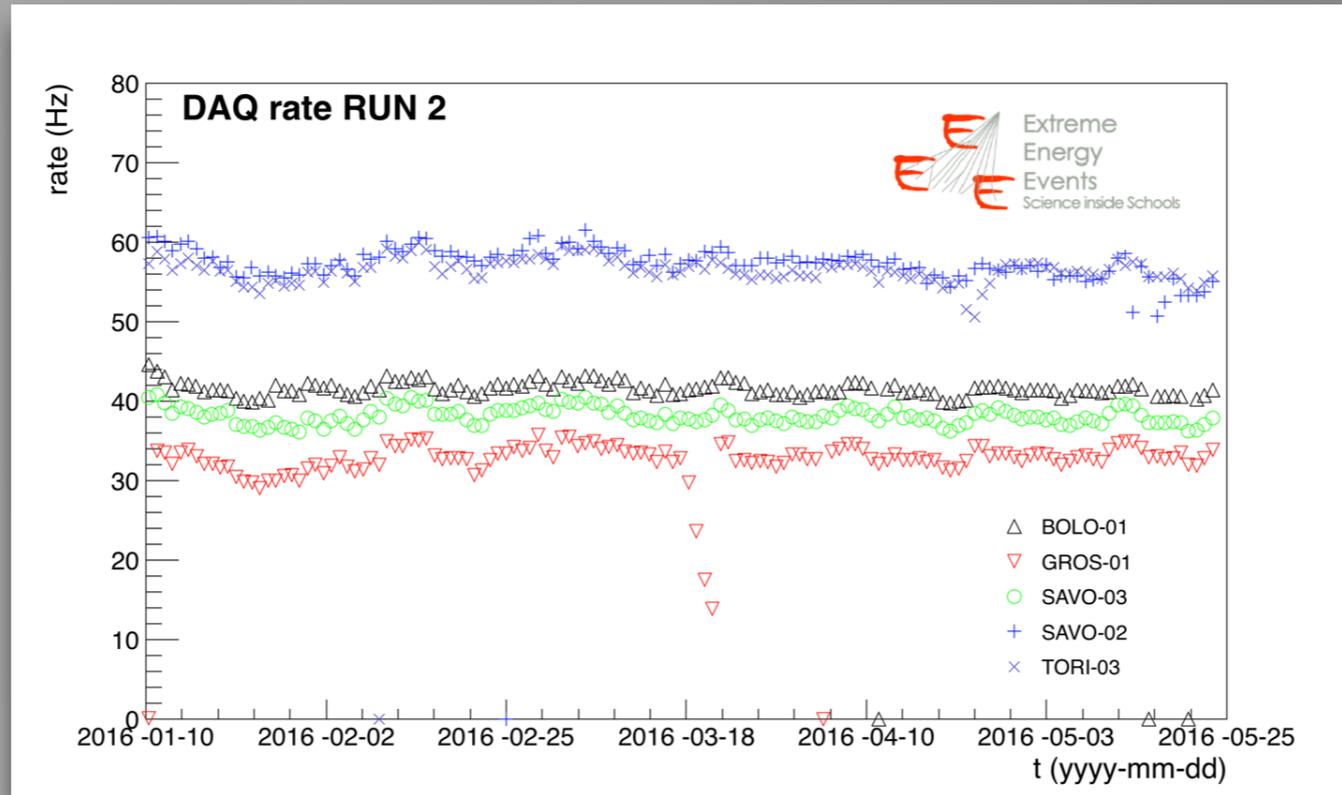
# Long term stability

average track  $\chi^2$  – computed as the best track in the event if at least one hit on each chamber is recorded



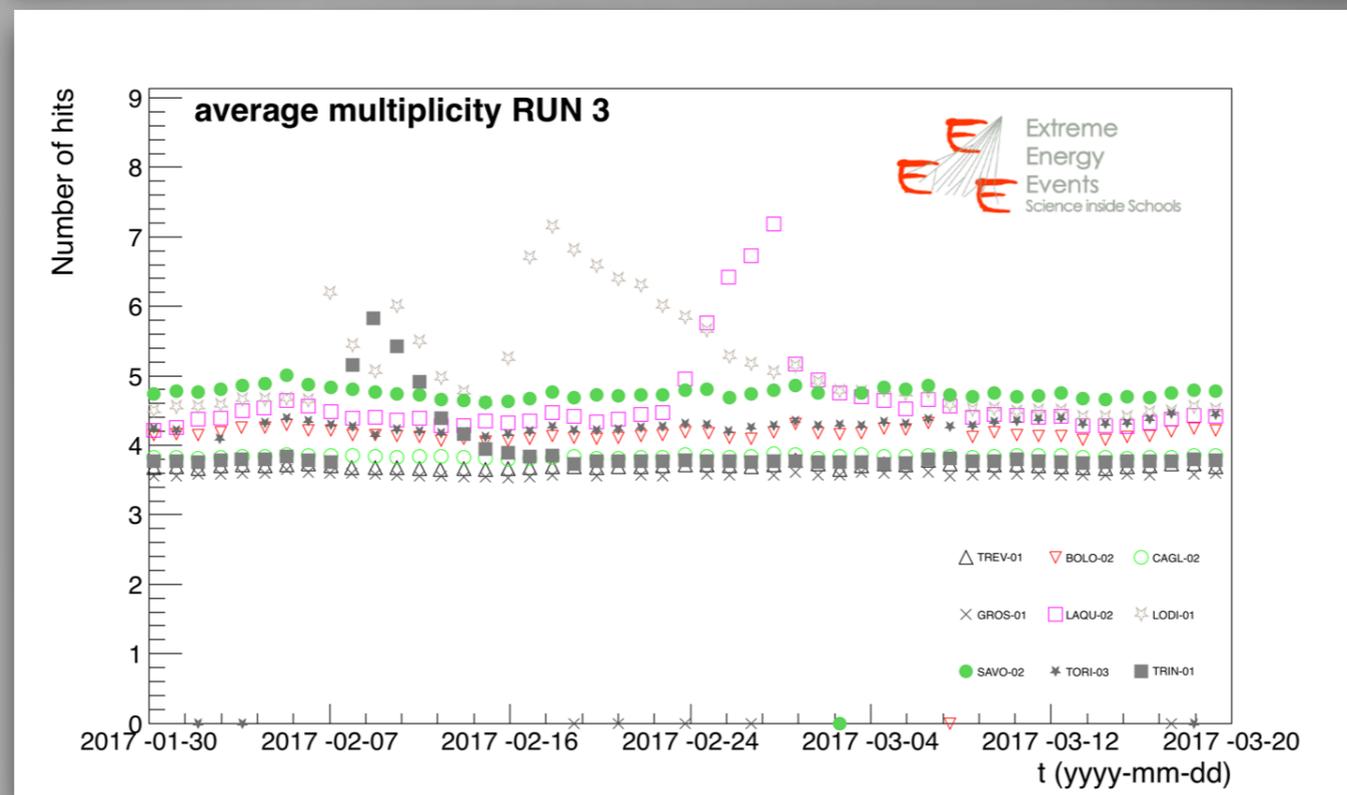
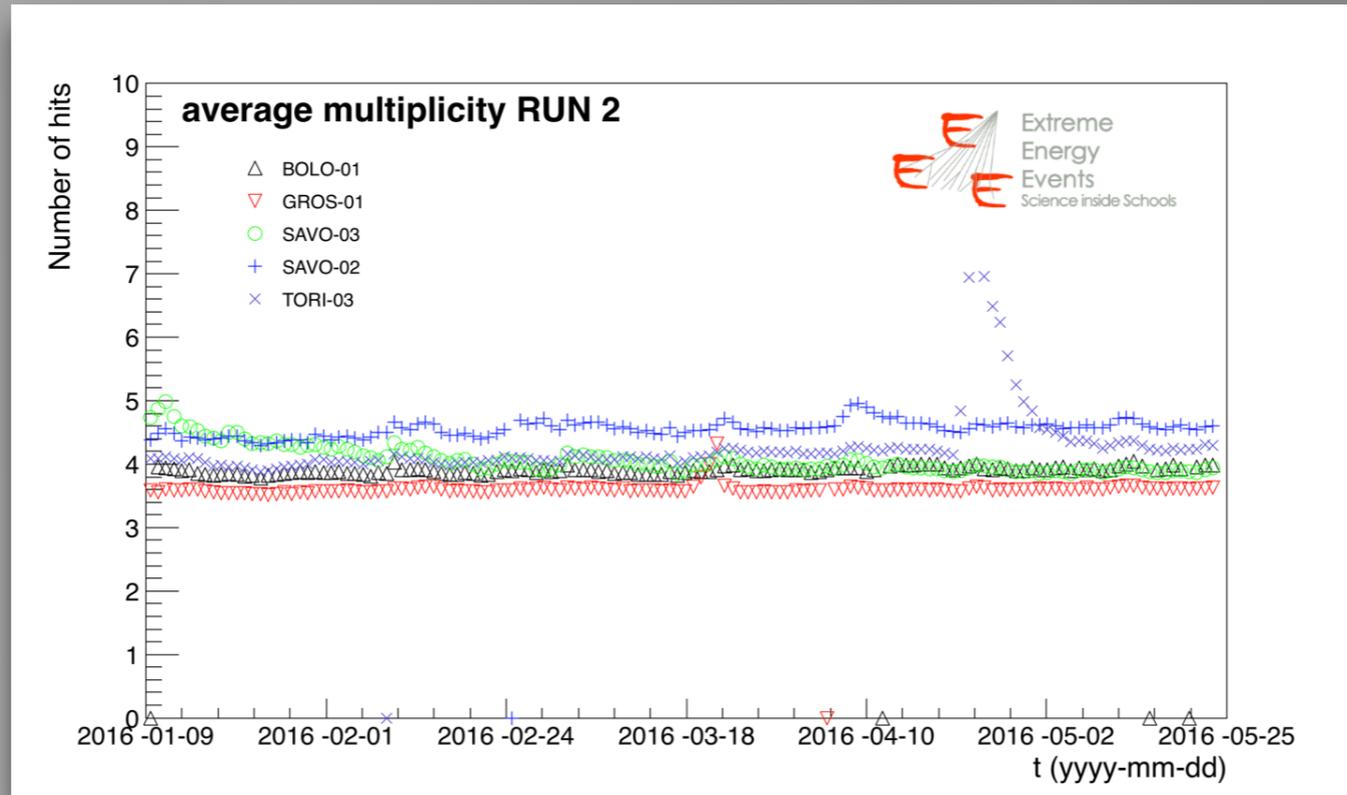
# Long term stability

DAQ rate – raw acquisition rate



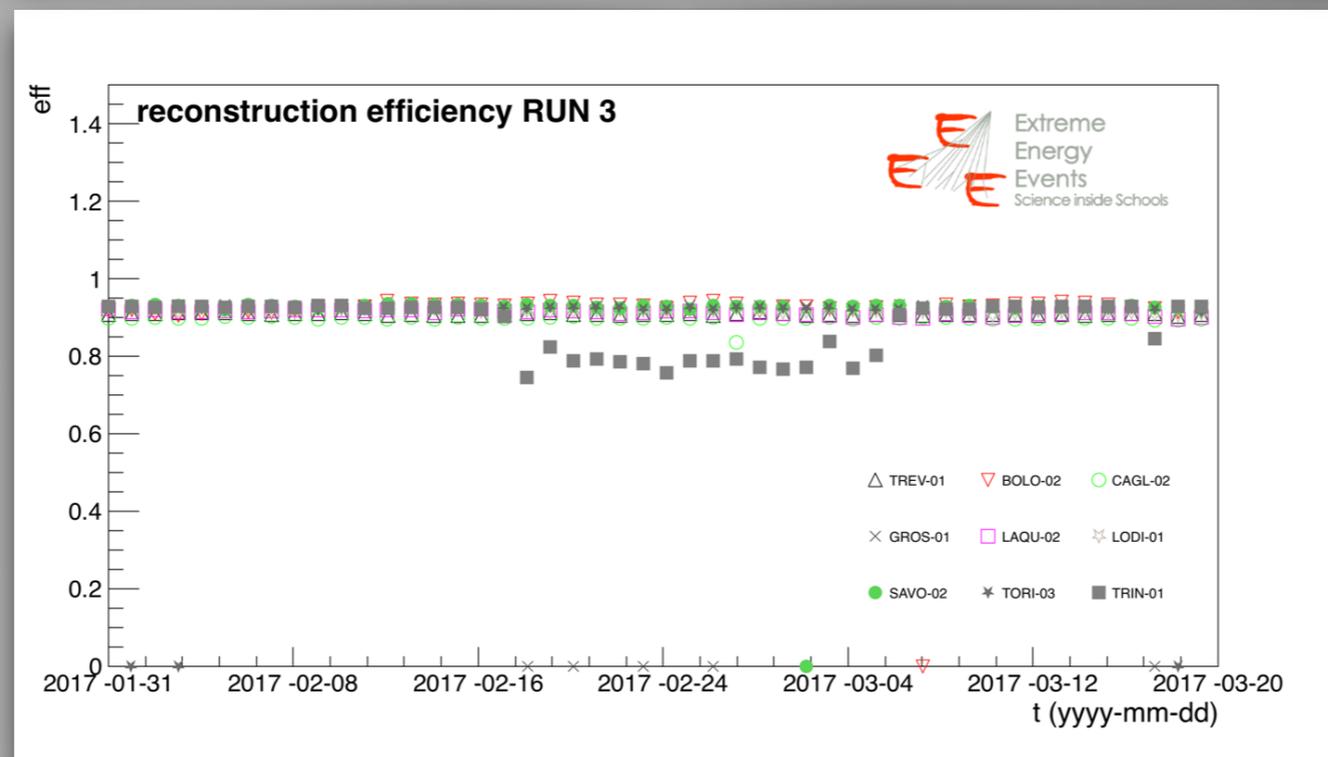
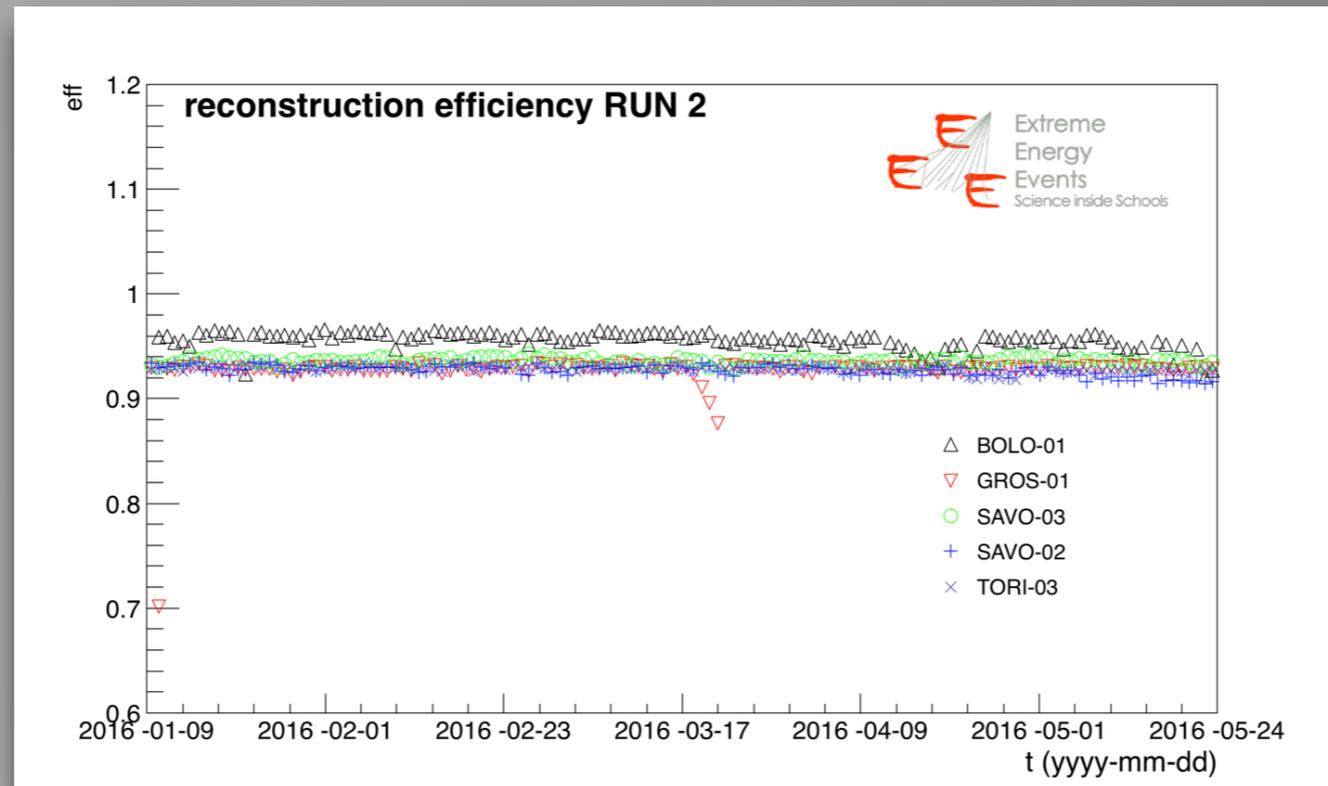
# Long term stability

multiplicity – average number of hits on the three chambers for each event



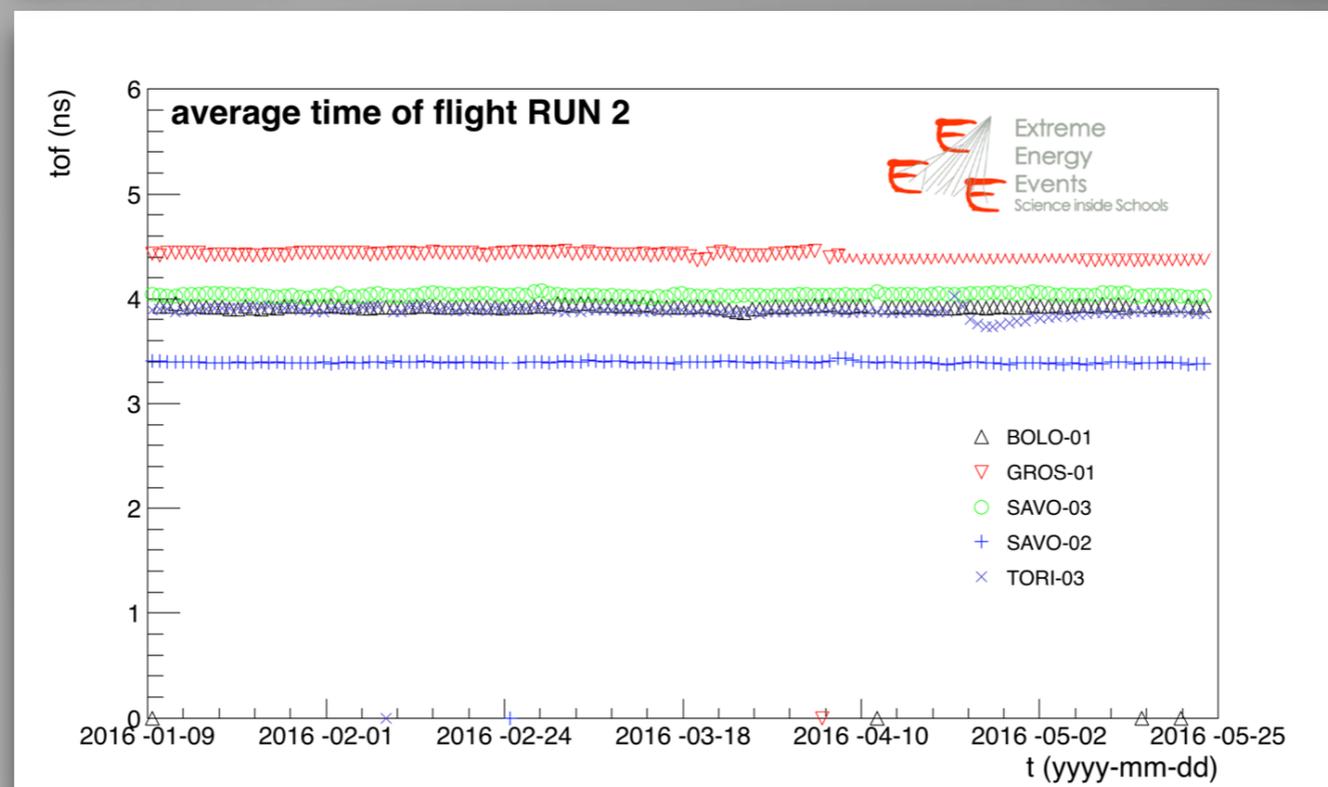
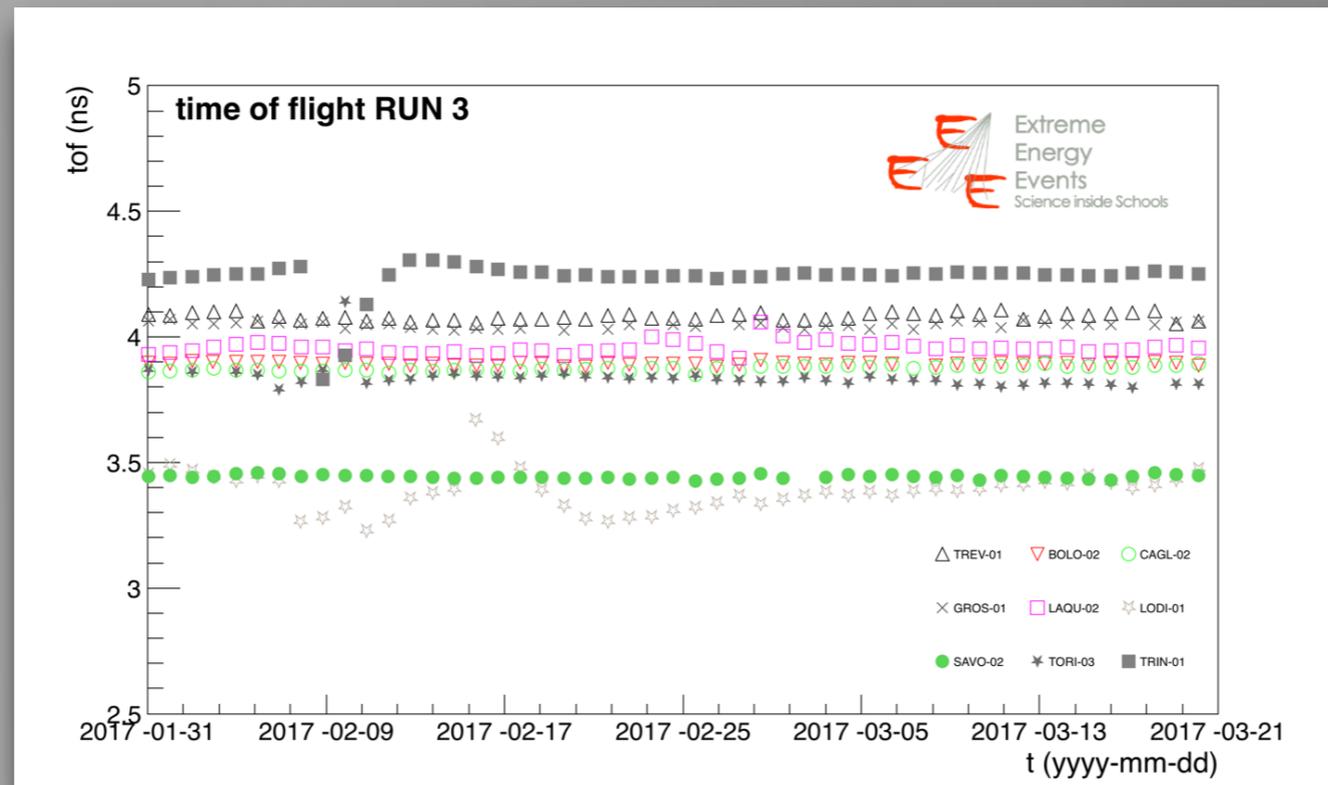
# Long term stability

reconstruction efficiency – percentage of raw events where at least one candidate track has been found



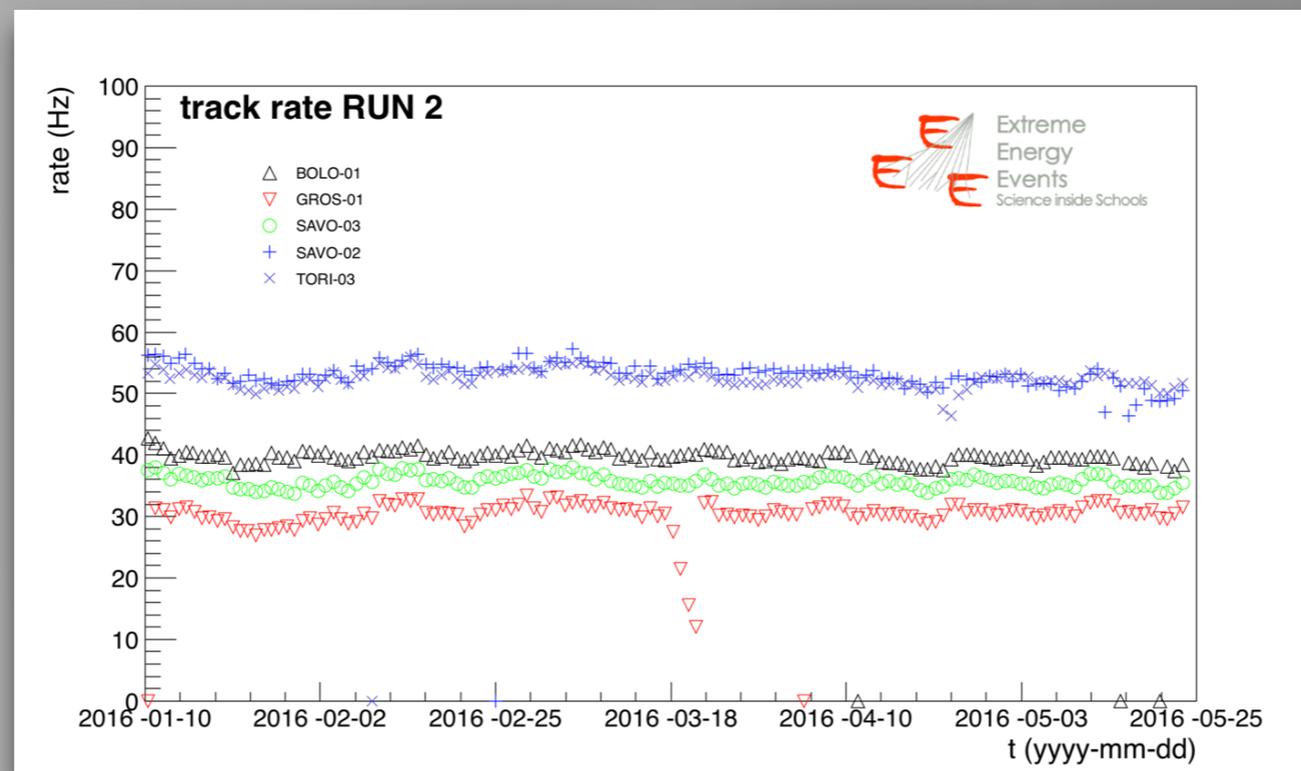
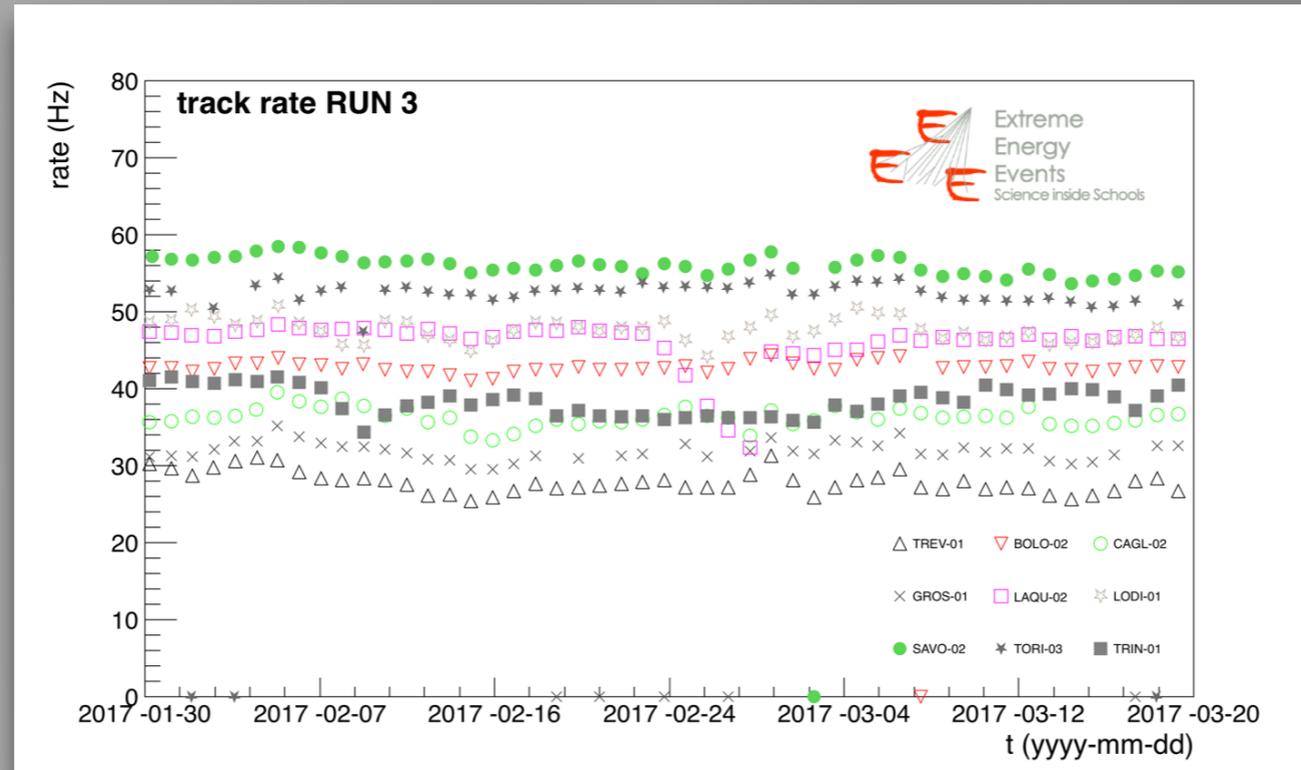
# Long term stability

Time Of Flight – average track TOF between top and bottom chambers

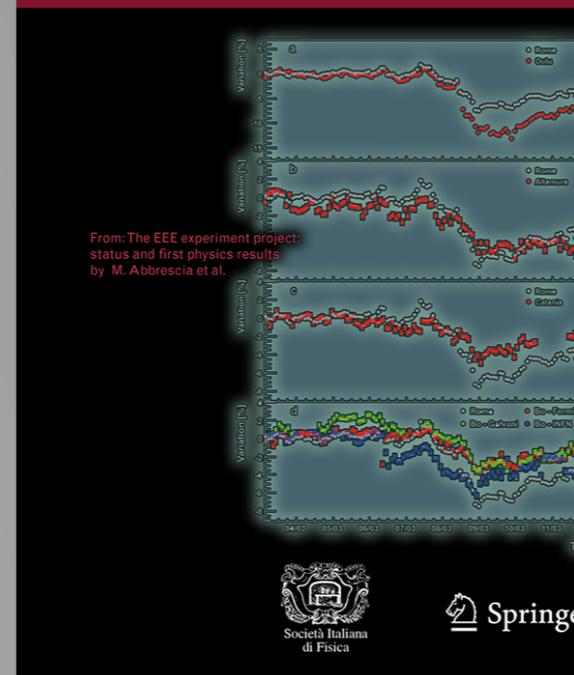
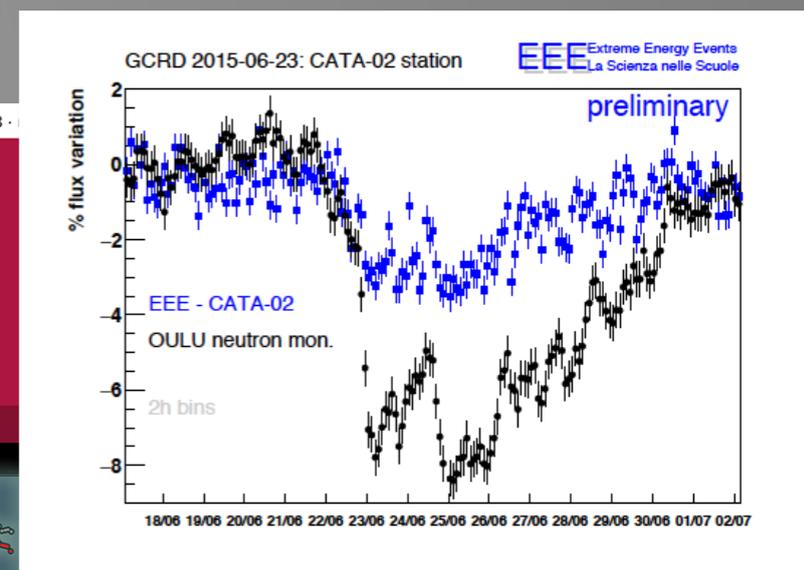
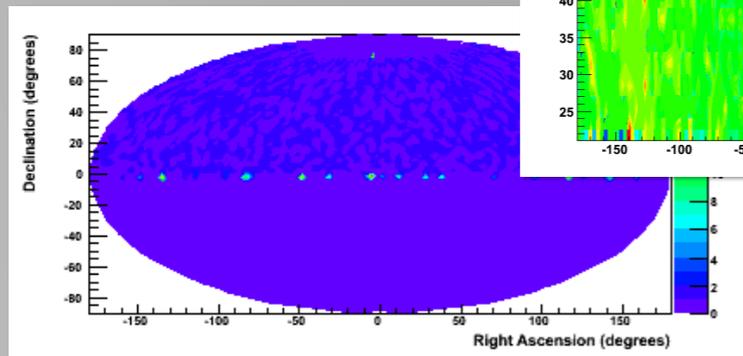
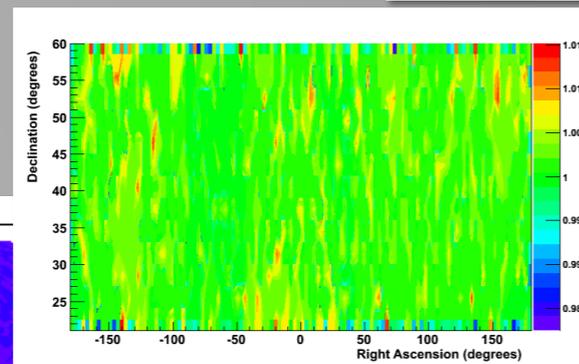
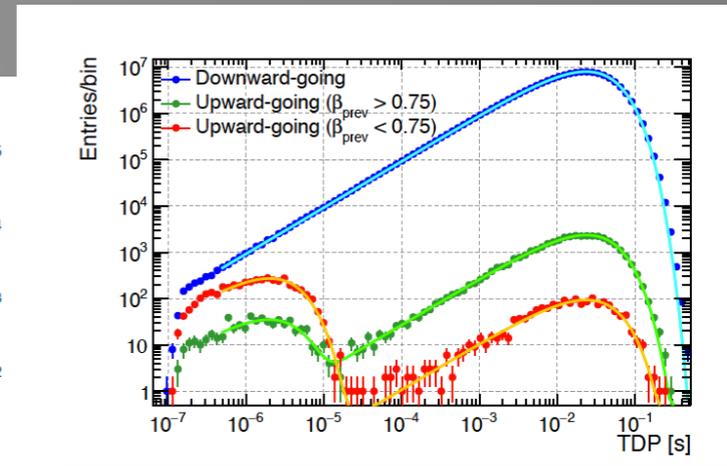
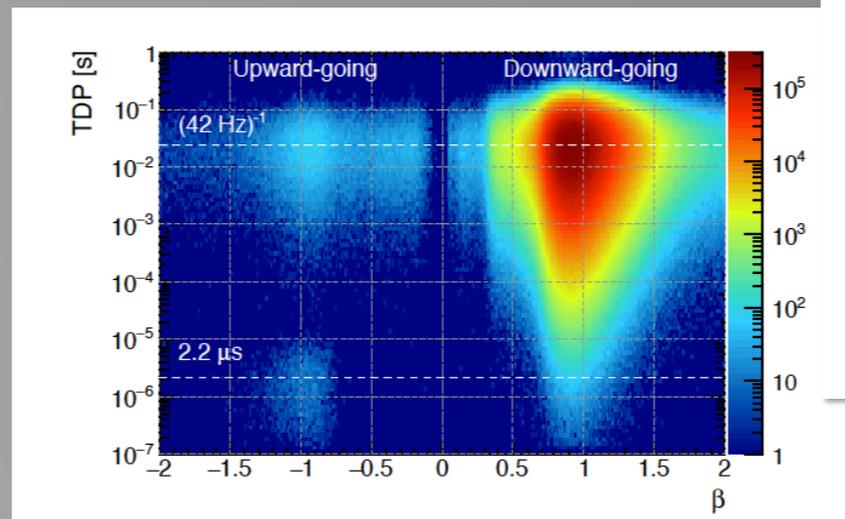
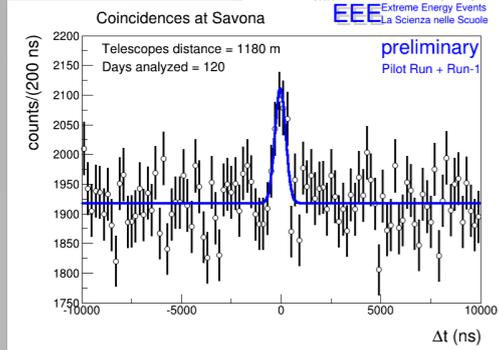
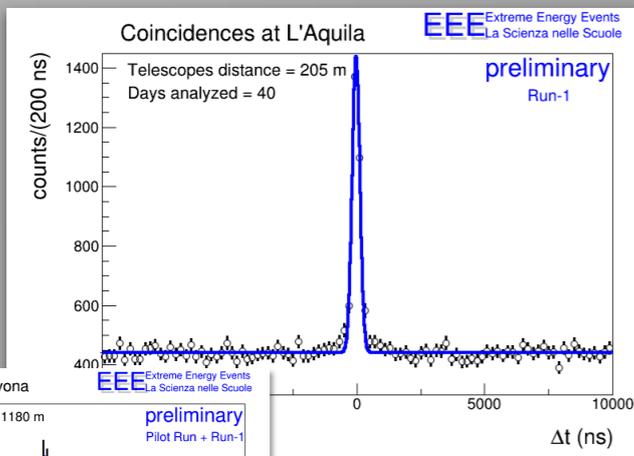


# Long term stability

track rate – rate of events with at least one candidate track



# Analysis



- ◆ telescope coincidences
- ◆ search for anisotropies
- ◆ Forbush decrease
- ◆ muon decay
- ◆ long distance coincidences
- ◆ many others

# Conclusions

- ✓ network continuously growing and successfully operating since 14 years
- ✓ excellent performance in terms of time and spatial resolution
- ✓ very high efficiency
- ✓ High School students strongly involved in the Project
- ✓ coordinated data taking periods ongoing (central data storage and reconstruction)
- ✓ more than 60 billion tracks collected

	Pilot Run	Run 1	Run 2	Run 3
starting date	27/10/2014	27/02/2015	07/11/2015	01/11/2016
ending date	14/11/2014	30/04/2015	20/05/2016	31/05/2017
number of days	19	63	196	212
tracks/day (M)	~ 27	~ 53	~ 69	~ 85
<i>purity</i> (%)	75	84	83	80

Table 1: Statistics from the four coordinated runs. The number of active telescopes in Pilot Run, Run 1, Run 2 and Run 3, is respectively 15, 28, 38 and 46. The purity is calculated as candidate tracks/triggers.