FATA2025

Timing performance of the Multigap Resistive Plate Chambers for the cosmic ray telescopes of the EEE Project

Marika Rasà* on behalf of the EEE Collaboration

* University and INFN – Catania, Centro Fermi (Rome)

Extreme Energy Events
Science inside Schools

CENTRO RICERCHE ENRICO FERMI

Università di Catania

INFN CATANIA

The EEE project

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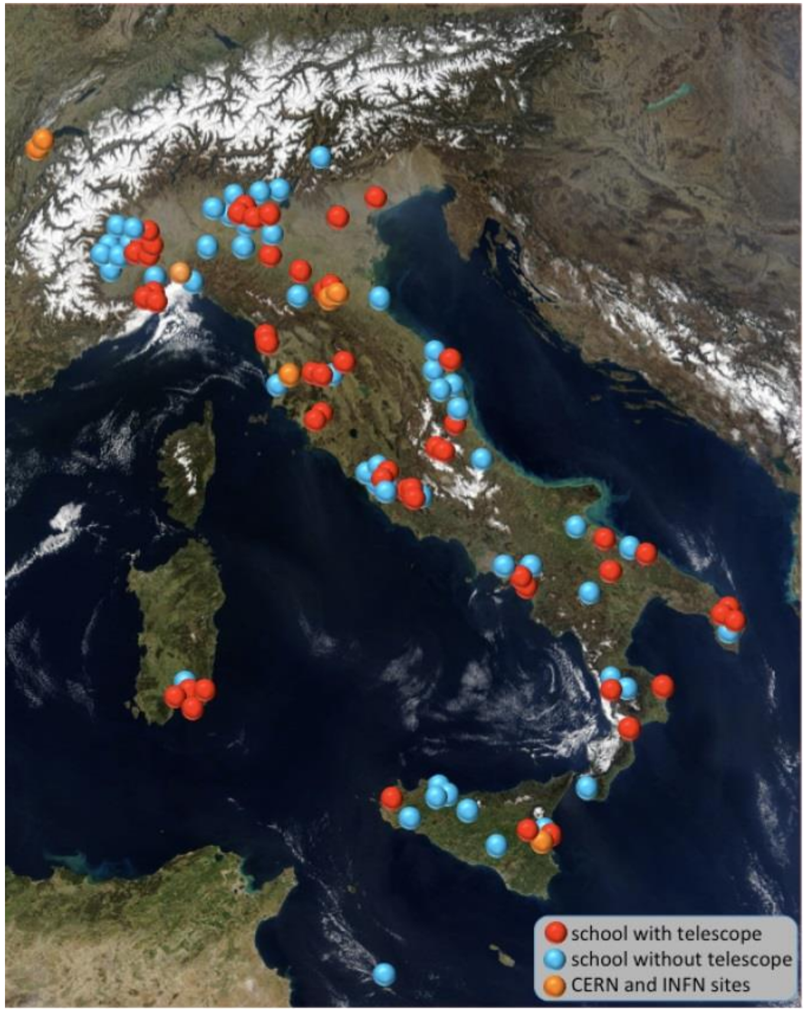
- The **EEE** (**E**xtreme **E**nergy **E**vents) Project was conceived in 2004 as a collaboration of Centro Fermi, INFN, CERN, MIUR
- It aims at the detection of cosmic ray muons by means of a sparse array of telescopes, distributed over all the Italian territory
- Network of ~ 60 telescopes based on Multi-gap Resistive Plate Chambers (MRPC) plus ancillary detectors installed in Italian high schools, CERN and INFN sites
- 4 scintillator detectors (POLA-R): 3 at Ny Ålesund + 1 mobile
- More than 80 High Schools participating in the project (both with and without telescope)



The EEE project – physics goals

The EEE project can investigate different physical effects, such as:

- Cosmic ray flux variation
- Search for anisotropies of the secondary component
- Latitude dependance
- Forbush decreases
- Upward going particles
- Detection of Extensive Air Showers
- Long distance correlations
- …

More details on EEE page:
https://eee.centrofermi.it/it/ricerca/pubblicazioni

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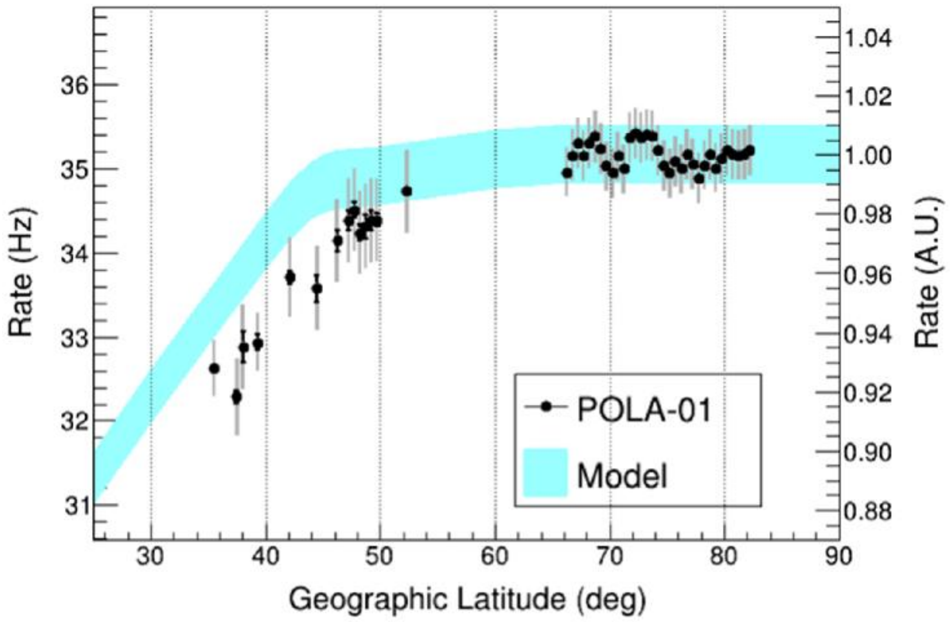

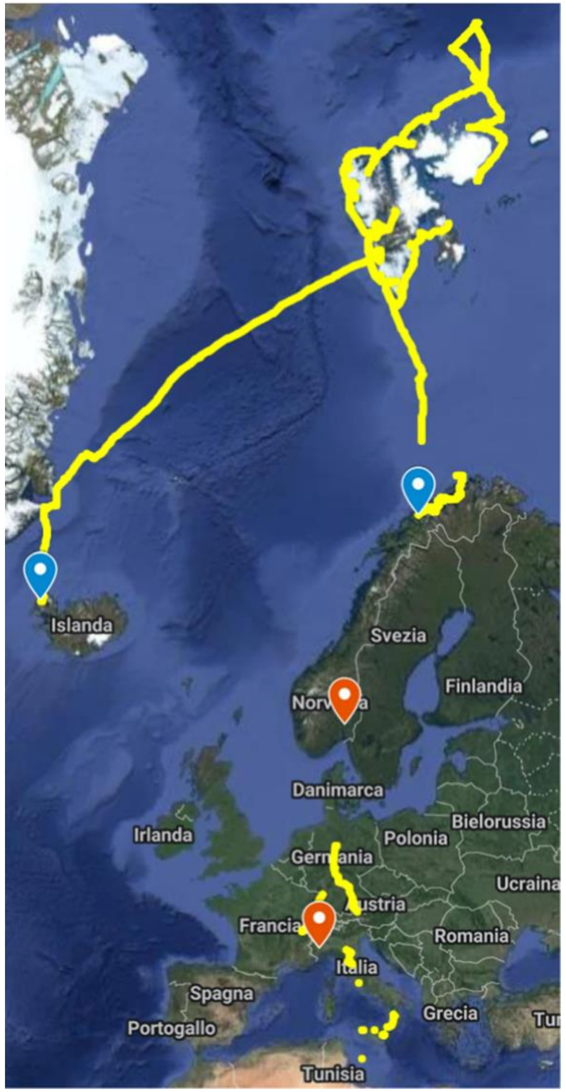

M. Abbrescia et al. (The EEE Collaboration), Eur. Phys. J. C 83 (2023) 293

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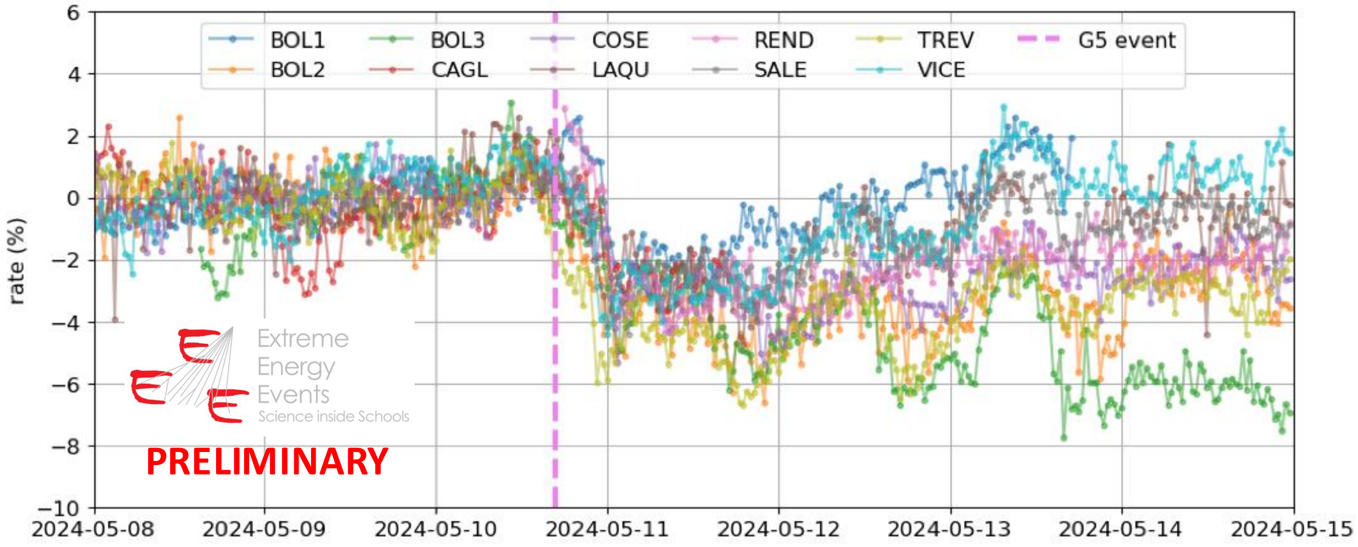

EEE Collaboration, *Observation of the May 2024 Forbush event with the EEE detectors operated with an eco-friendly gas mixture*, submitted

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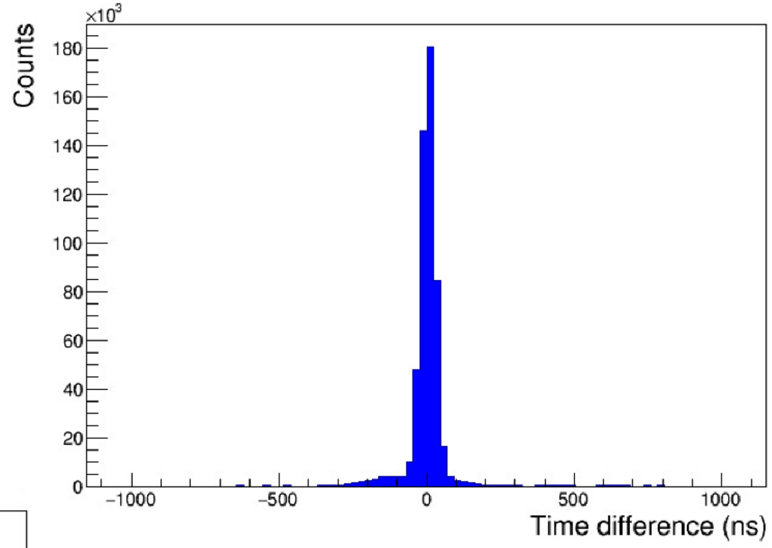
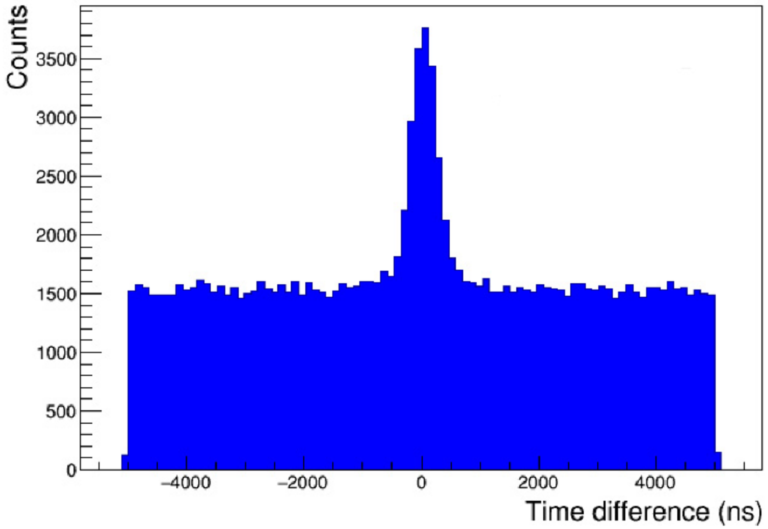


CERN telescopes, 15 m

L'Aquila telescopes, 200 m



M. Abbrescia et al. (The EEE Collaboration), Eur. Phys. J. Plus (2018) 133-134

The EEE project – educational aspects

- The *only program* where students are involved for multiple years, with different project performed during school activities

The EEE project – educational aspects

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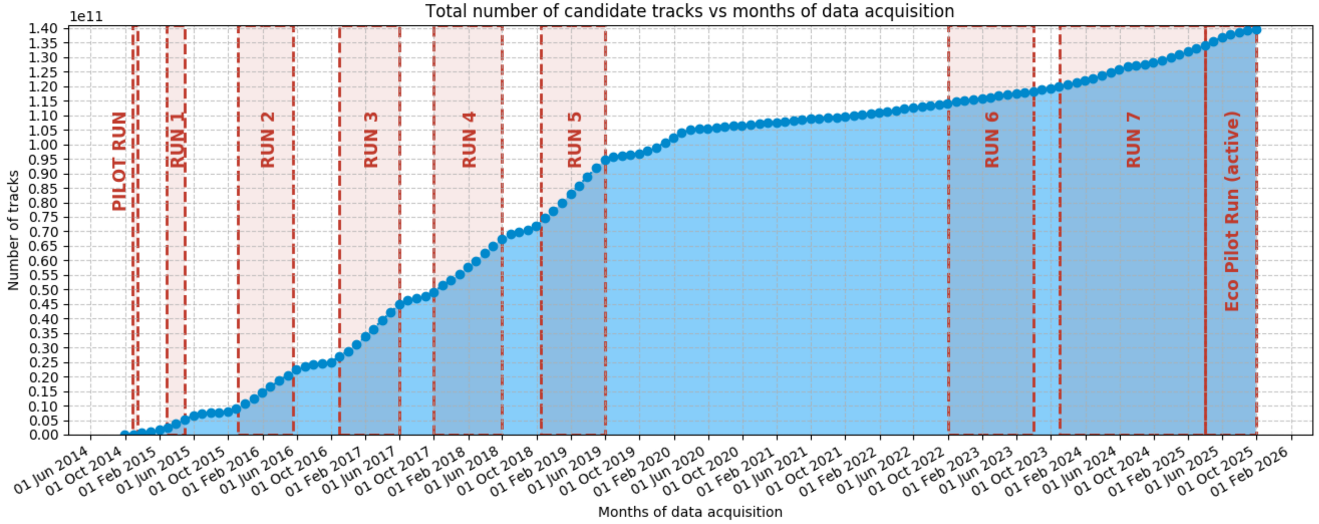
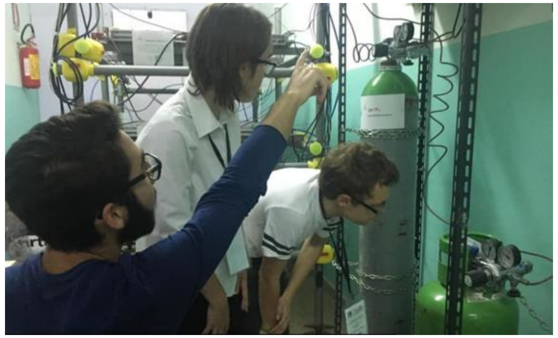
- The *only program* where students are involved for multiple years, with different project performed during school activities
- High school students and teachers have built their own telescope at CERN and take care of the data taking





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- Online and in presence meeting, with the opportunity to present different experimental activities

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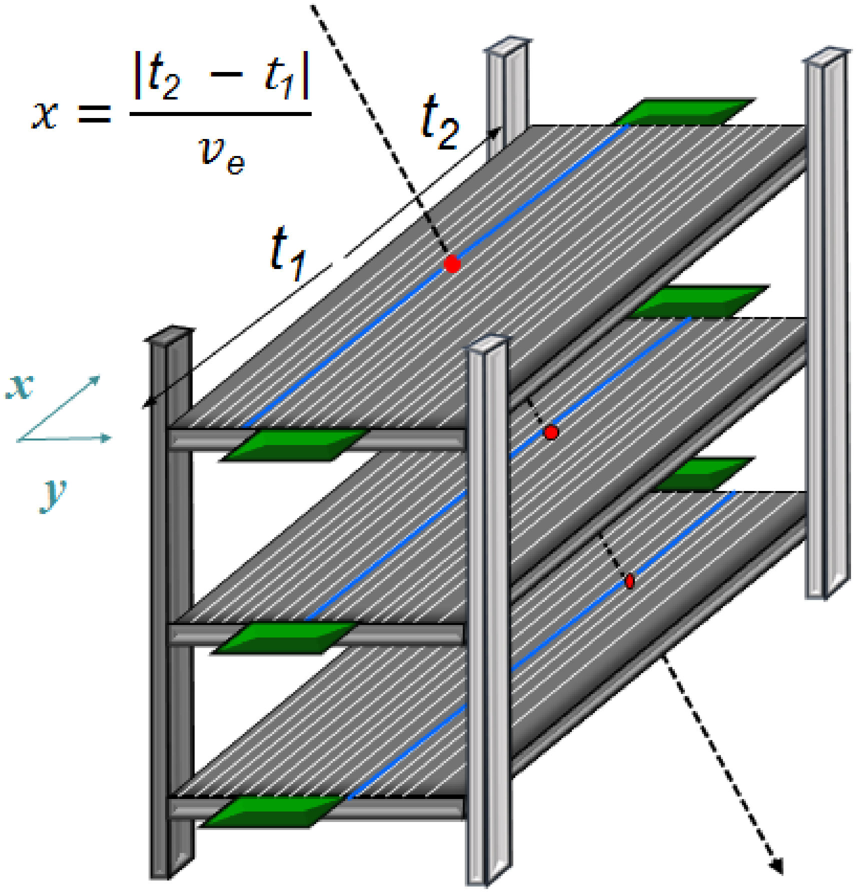
- High school students and teachers have built their own telescope at CERN and take care of the data taking
- Online and in presence meeting, with the opportunity to present different experimental activities
- Participation to International Cosmic Day (masterclasses, data analysis, etc)

The MRPC telescope

EEE station: telescope of 3 MRPC chambers (~ 80 x 160 cm^2) separated by 50 cm

Needed characteristics:

- Easy to find and to work materials
- Reasonable cost
- Able to handle different environmental conditions (different buildings, no professional electrical lines…)
- Long term operation required
- Efficiency close to 100 %
- Reconstruction of muon orientation
- Good time resolution → expected TOF measurements ~ ns



Technology chosen: a larger (~1.5 m^2) and simpler version of the Multi gap RPC developed for the ALICE TOF

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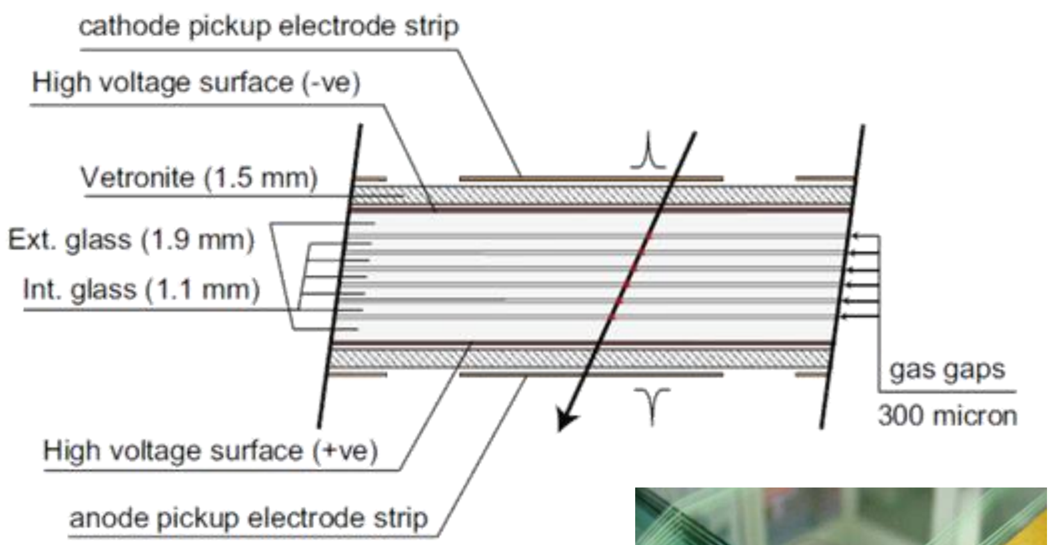
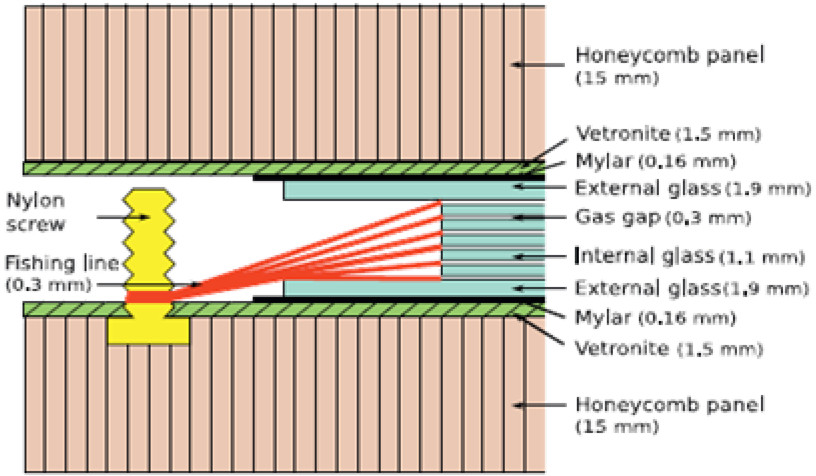
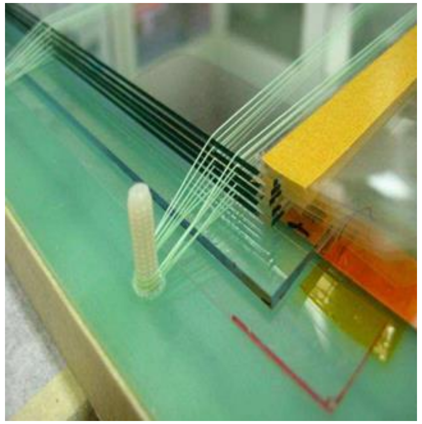
Technology chosen: a larger (~1.5 m^2) and simpler version of the Multi gap RPC developed for the ALICE TOF

The EEE MRPC

- 6 gas gaps of 300 µm (250 µm after upgrades)
- 2 external glass sheets (160 cm x 85 cm, 1.9mm thick) with their external surfaces painted with resistive paint (5-20 MΩ/□)
- 5 intermediate glass sheets (158 cm x 82 cm, 1.1 mm thick), spaced using fishing line
- Mylar foil (175 cm x 86 cm, 0.16mm thick) on vetronite panels (175 cm x 86 cm, 1.5 mm thick) to insulate the readout strips from the cathode/anode







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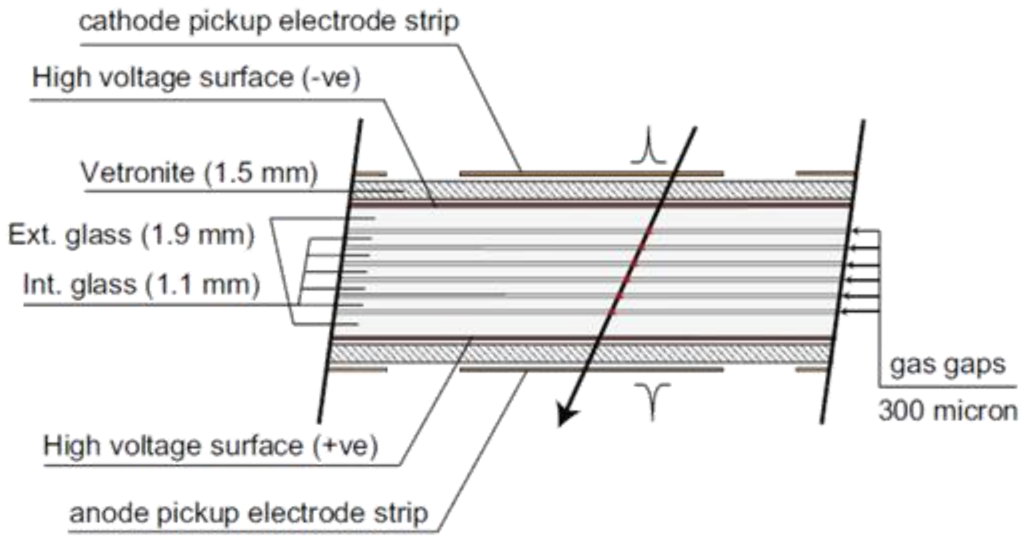

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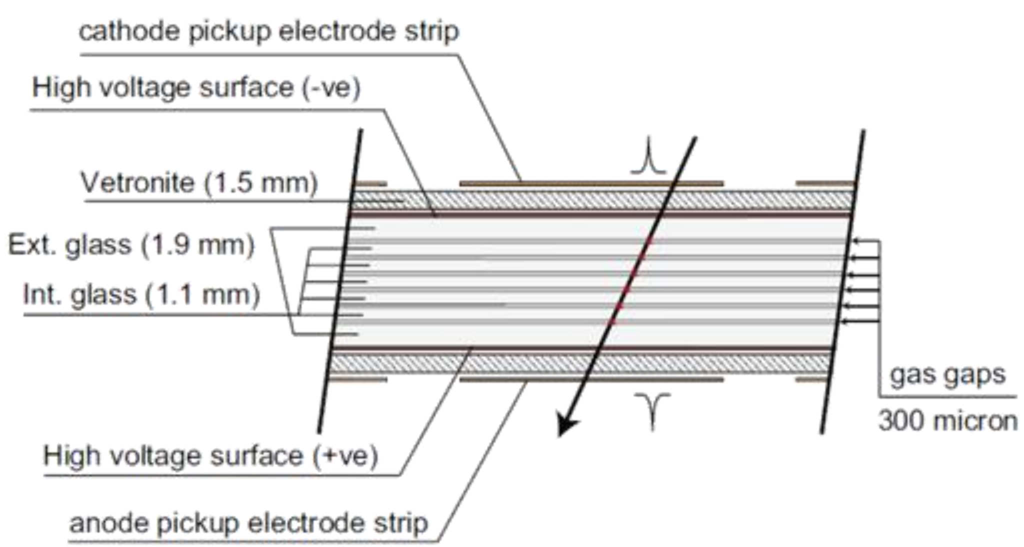
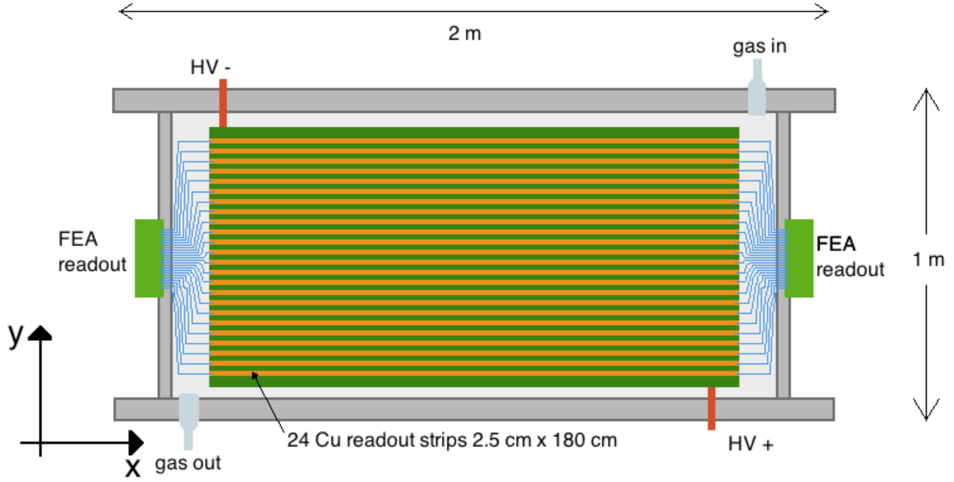
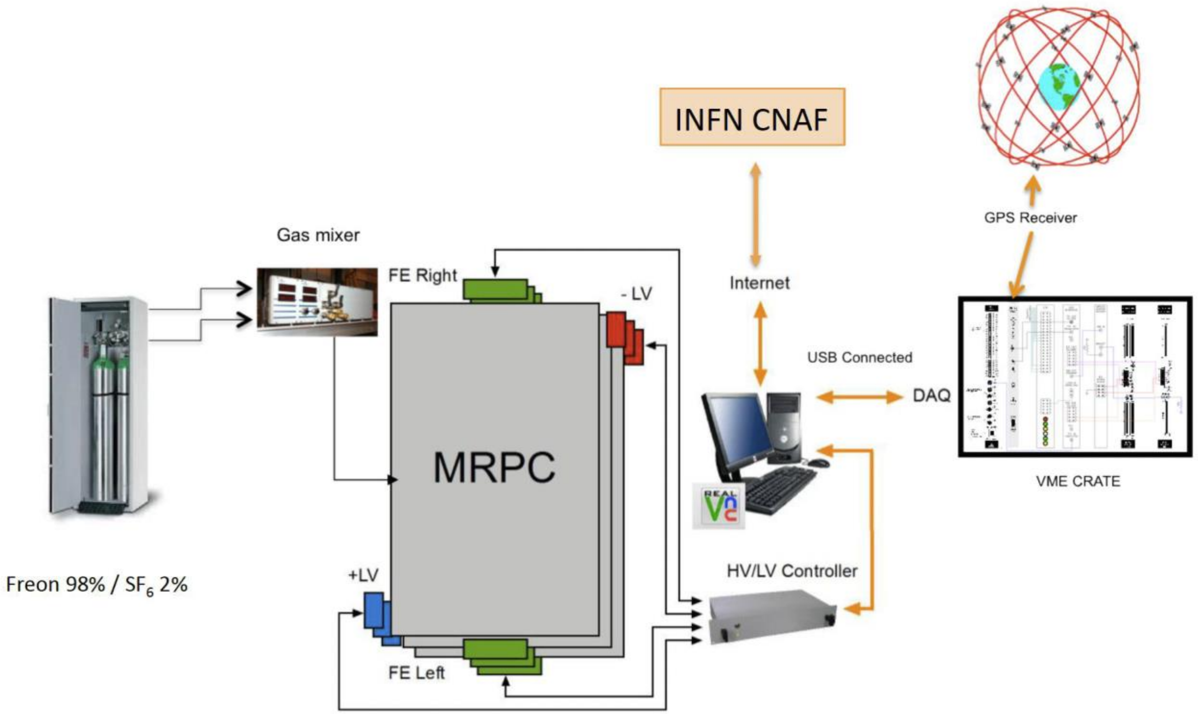
- Readout strips made using copper tape (24 strips 180 cm x 2.5 cm spaced by 7mm)
- Honeycomb panels (180 cm x 90 cm) complete the mechanics
- All mounted inside a gas tight aluminum box (200 cm x 100 cm)
- $C_2H_2F_4$(98%) and SF_6(2%) continuously fluxed (2-3l/h)





Telescope equipment

- 6 FEE cards (with NINO chips) for readout and trigger
- Stand-alone LV power supplies, both commercial or custom engineered
- DC/DC converters for HV (±20 kV) to chambers
- GPS time-stamp of the collected events (40ns precision)
- VME-based data acquisition (Trigger card + Multi-hit TDCs)
- Gas flow provided by a commercial mixing system that fills the chambers in daisy chain
- Weather Station



Timing performance: test beam

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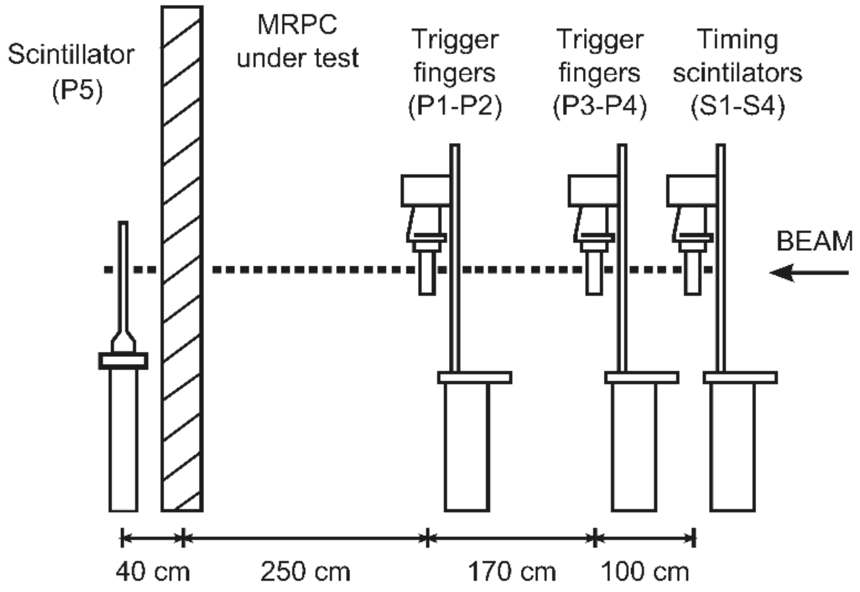
- First steps: validate the performances of the technology, due to the peculiarity of the construction techniques

- First test with beams @ CERN-PS T10

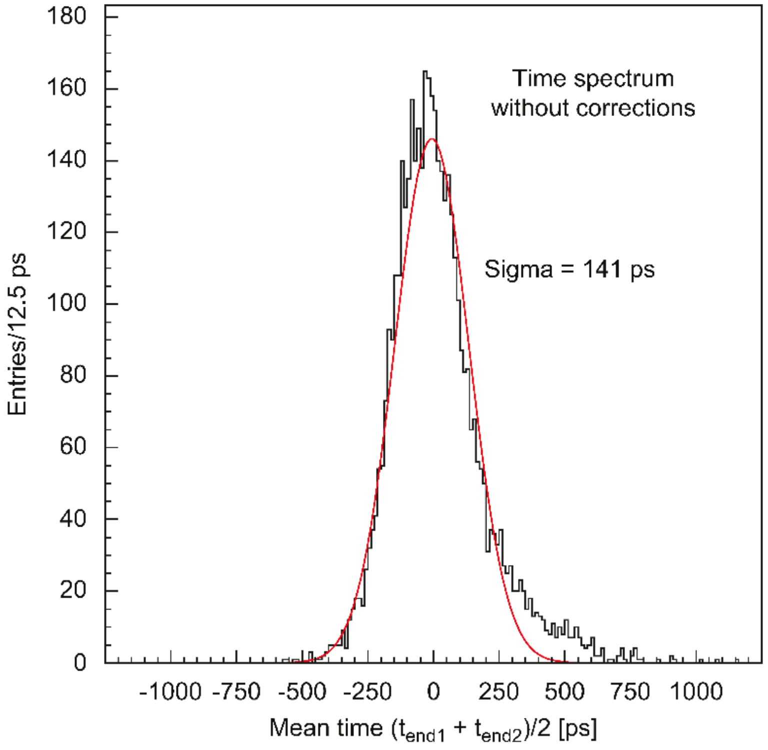
- Experimental setup:
  - Two pairs (P1-P2 and P3-P4) of scintillator used to provide the trigger.
  - P5: scintillator added to ensure that the particles pass through the MRPC
  - S1-S4: two scintillator bars ortogonal to each other read by 4 photomultiplies discriminated by CDF to provide accurate time reference
    - Estimated time resolution of this system is 30ps, subtracted quadratically when quoting the time resolution of the MRPC
  - Flux of $C_2F_4H_2$ (98%) + SF_6 (2%) at 5l/h



M. Abbrescia et al. (The EEE Collaboration), Nucl. Instrum. Meth A 593 (2008) 263

Timing performance: test beam

- Beam centered in the middle of the strip
- Signal measured at both end of the strip → mean time independent on the position
- Long tail due to the different impedence of the MRPC (100 Ω) and the cards adjusted to match the ALICE-TOF MPRCs (50 Ω) → reflection of the signal
- Time slewing in the discriminators to be corrected
  - Input charge of the signal, leading and trailing edges measured → the width is used to correct the slewing



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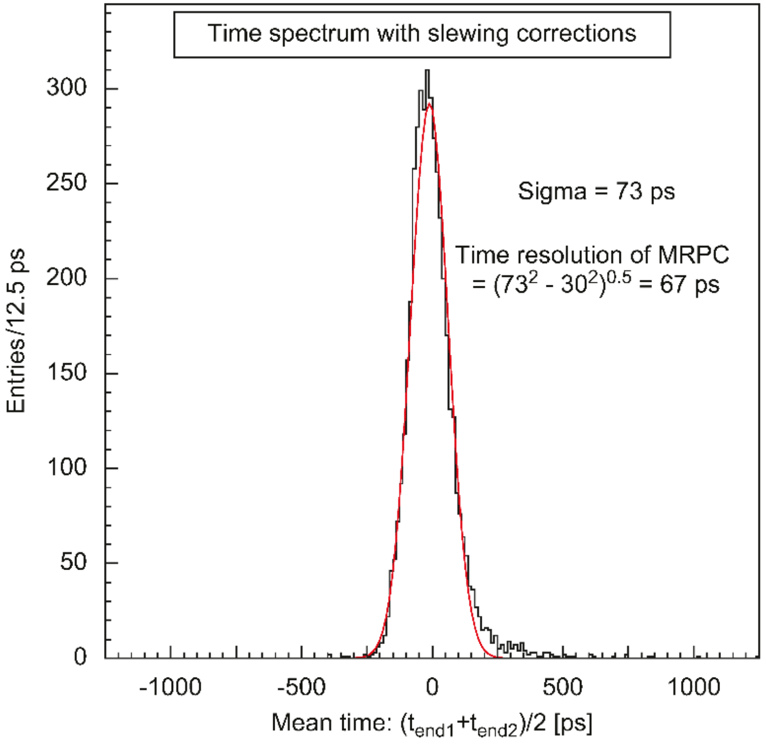
- Time resolutions after slewing and scintillator jitter corrections is ***67 ps***



M. Abbrescia et al. (The EEE Collaboration), Nucl. Instrum. Meth A 593 (2008) 263

Timing performance of the telescopes with cosmic rays

- Timing resolution of the MRPCs in the EEE network measured in two different periods:
  - Run 2 (Nov 2015 – May 2016) only using TORI-03 and PISA-01 telescopes. Track data sample: 8×10^9
    - Telescope equipped with dedicated board which distributed a common clock to the TDCs
  - Run 3 (Nov 2016 – May 2017) using 33 telescopes. Track data sample: 31×10^9
    - All telescopes now equipped with the dedicated boards
- Common approach: measuring the time information of the upper and lower chambers to evaluate the middle one, that is compared with the measured one
- Time residuals defined as:

$$\Delta t = \frac{t_{top} + t_{bot}}{2} - t_{mid}$$

- Width of the distribution proportional to the time resolution of the telescope

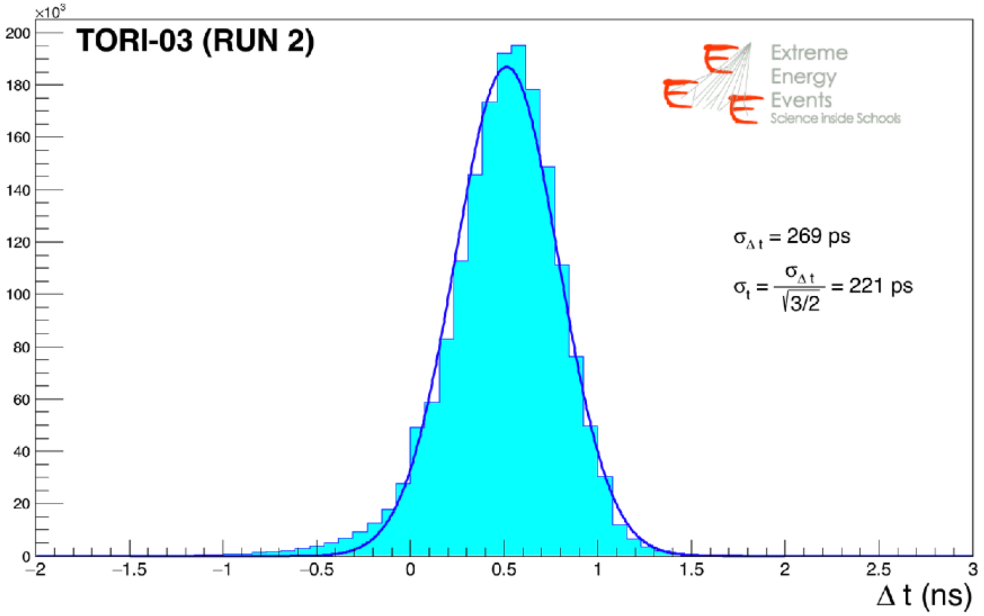
M. Abbrescia et al. (The EEE Collaboration), JINST 13 (2018) 08026

Timing performance of the telescopes with cosmic rays

- Distribution fitted with a Gaussian function with $\sigma_{\Delta t}$ = 269 ps
- Assuming similar timing performances of the three chambers, than the single chamber has a time resolution of:

$$\sigma_t = \sigma_{\Delta t} / \sqrt{\frac{3}{2}} = \boldsymbol{221\ ps}$$

- Similar results for the PISA-01 telescope, with a $\boldsymbol{\sigma_t = 270\ ps}$
- No time slewing correction applied
- Distribution shifted due to missing calibrations (i.e. z displacement of the middle chamber, cables length, electronics delay)



M. Abbrescia et al. (The EEE Collaboration), JINST 13 (2018) 08026

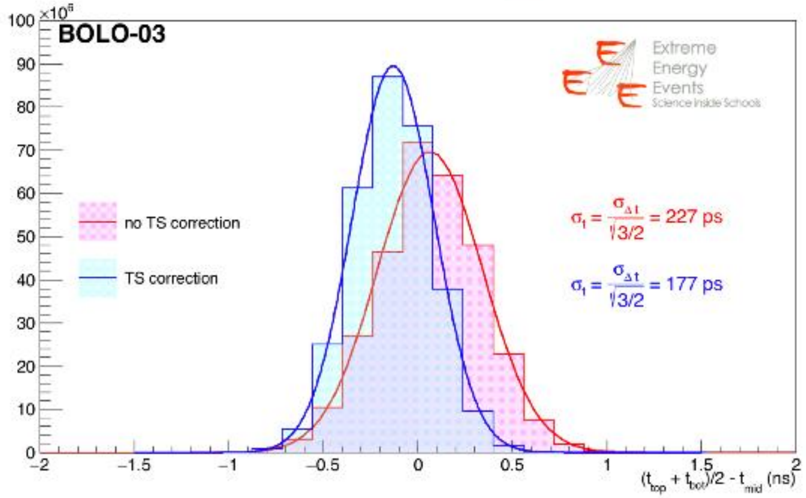
Timing performance of the telescopes with cosmic rays

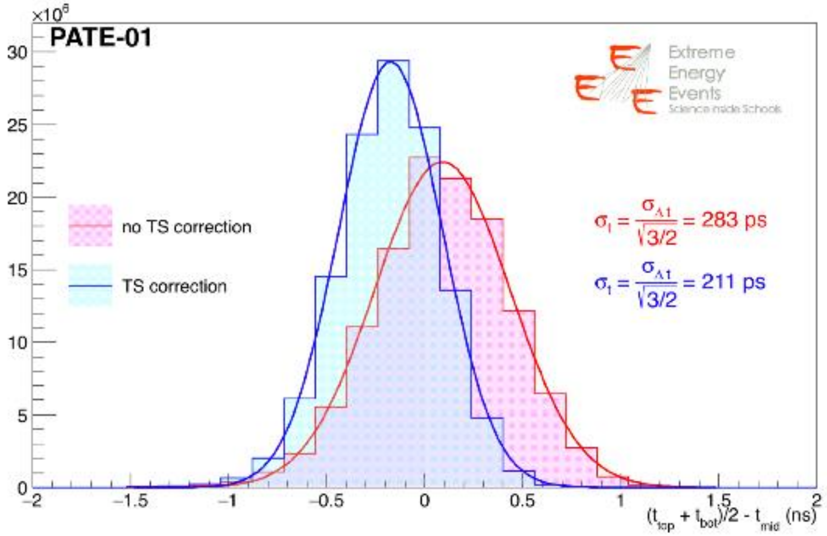
- Time slewing correction estimated for each chamber using the Time Over Threshold (TOT) → 20% improvement

- Depending on the telescope, σ_t ranges between ***140 and 380 ps***

- Different values can be explained by three factors:
  - Missing optimization of the detector working point
  - Possible inhomogeneities in MRPC constructions
  - Possible not optimal calibration for some strips

- Distribution shifted due to missing calibrations (i.e. z displacement of the middle chamber, cables length, electronics delay)





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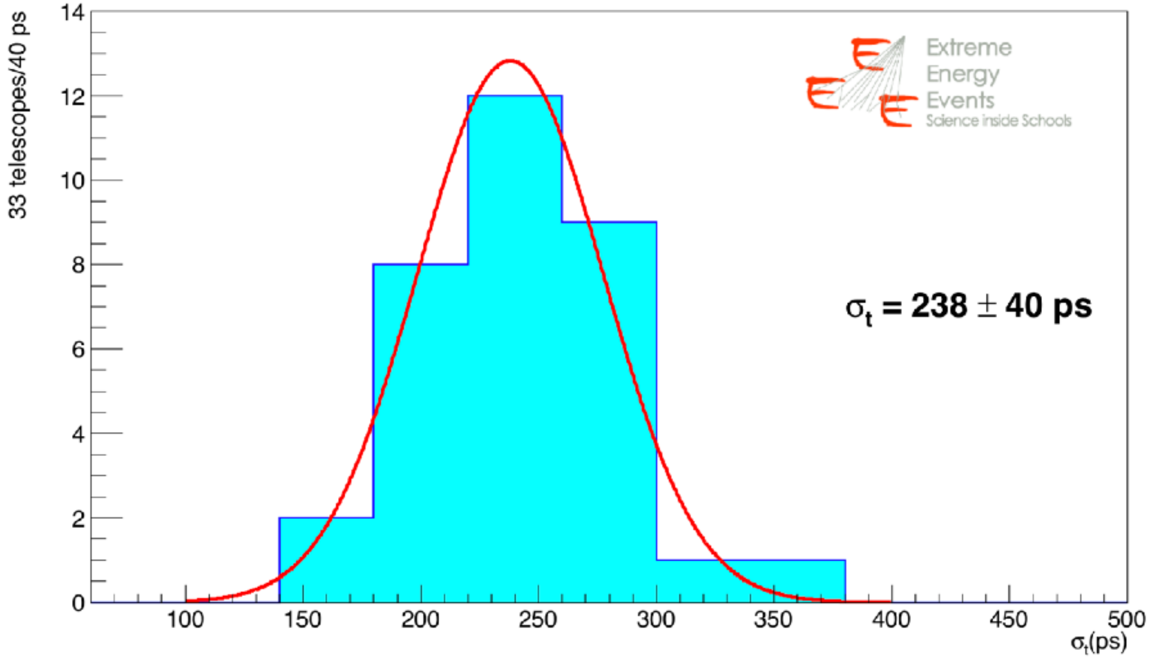
- Average resolution with 33 telescopes $\boldsymbol{\sigma_t}$ ***= 238 ps ± 40 ps***
- Larger value with respect to test beam results: expected due to different conditions (no focused, monochromatic and collinear beam)



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The ecological transition

- Global Warming Potential (GWP) measures the greenhouse effect of gas normalized to CO_2
- EU regulations set an upper limit to GWP allowed in gas-operated devices
  - GWP > 150 have been banned
- The GWP of EEE standard mixture is ~ 2030
- Even if the standard mixture is still suitable for scientific purposes, the EEE Collaboration decided to reduce the greenhouse gas emissions from the EEE telescopes
- R&D with new eco-gas mixtures carried out during COVID stop

The ecological transition

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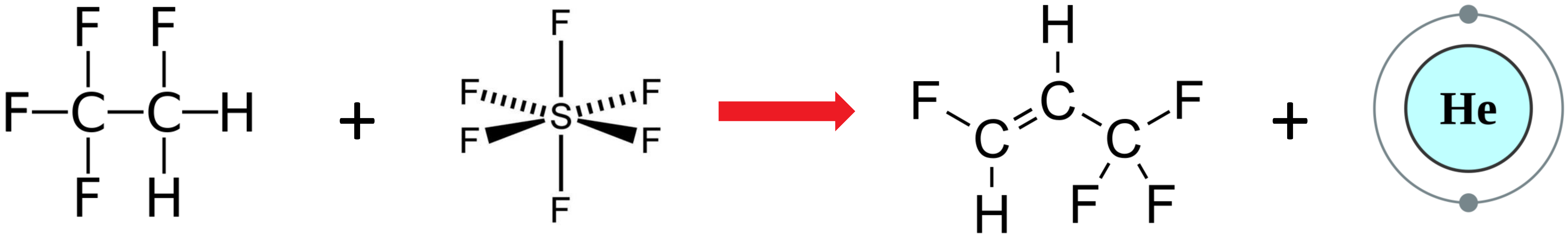
Main features required:

- Lower GWP with respect to the standard mixture
- Only non flammable, non toxic gases allowed
- Only binary mixtures
- The detector must be able to operate with a maximum bias voltage of 20kV
- FEE must be able to handle the new signals
- Performance of the detector should not have any negative impact on the physics programme
- Cost of the mixture in line with the previous one



$C_2H_2F_4$	SF_6	$C_3H_2F_4$	He
Tetrafluoroethane	Sulfur hexafluoride	Tetrafluoropropane (or HFO)	Helium
GWP = 1430	GWP = 23900	GWP = 6	GWP < 1

Timing performance with new eco-mixture

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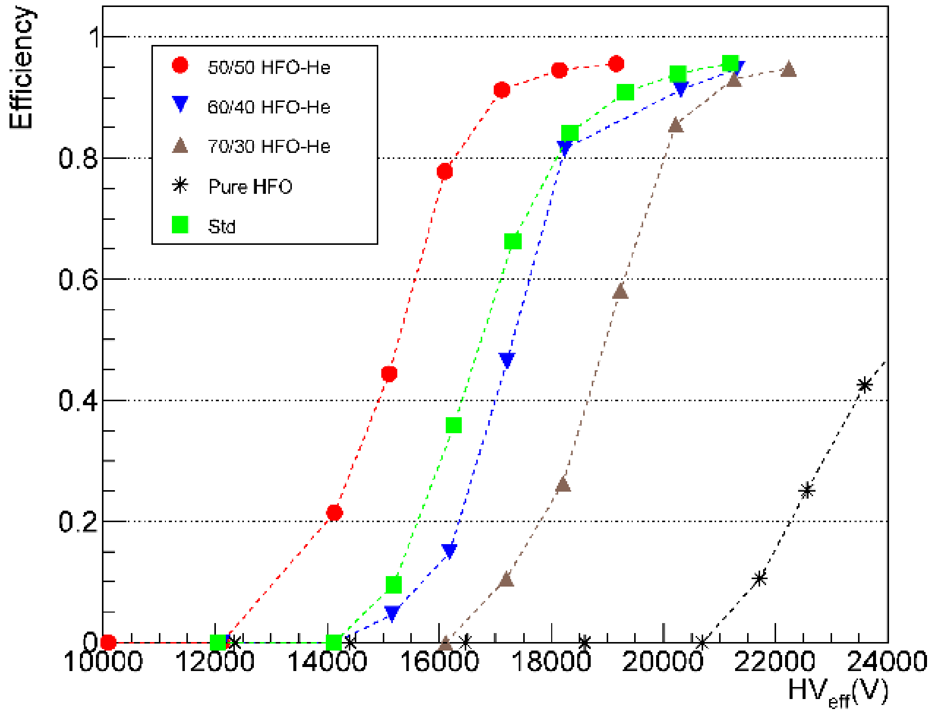
- R&D program reported here obtained testing the middle chamber with the HFO-He mixture, while operating the two outher chambers with the standard mixture
- Different HFO and He percentage explored with a flux of 1l/h. Voltages selected to obtain a 95% efficiency

M.Abbrescia et al. (EEE Collaboration), JINST19(2024)P11003



$$HV_{eff} = HV \times \frac{P_{ref}}{P} \times \frac{T_{ref}}{T}$$

$$P_{ref} = 1010\ mbar, T_{ref} = 293.15\ K$$

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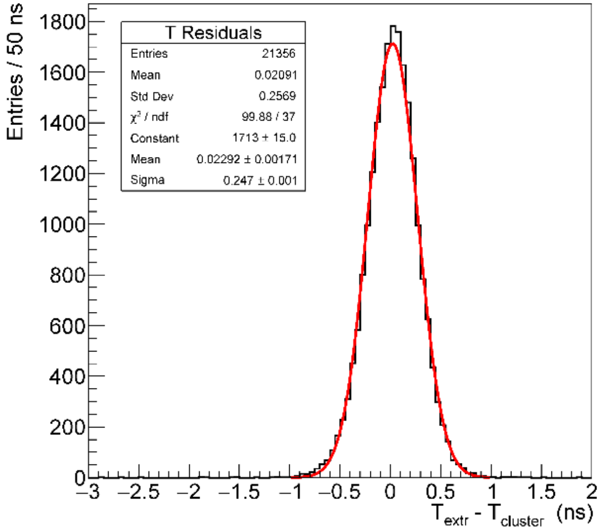
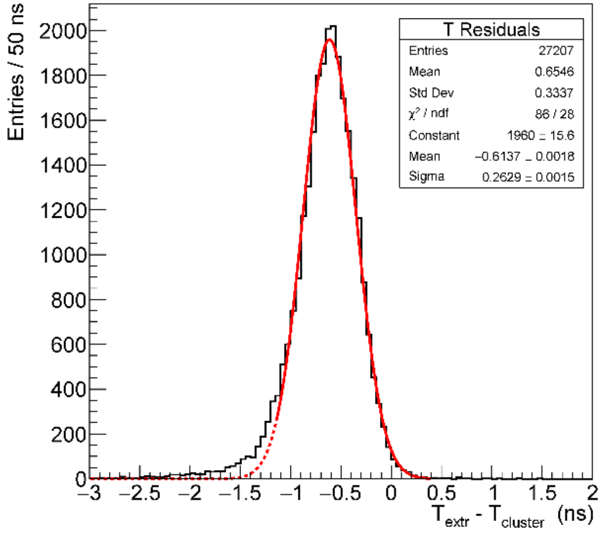
- Time residual techique applied, with a strip by strip calibration to correct possible time offset generated by the setup (gas independent)
- Left tail in the new mixture, not present in the standard one
- Time residuals are slightly larger with respect to the standard mixture, suggesting a slightly lower time precision
  - Possible causes: different drift speed, different Townsend coefficient, larger spread in signal total charge, etc

M.Abbrescia et al. (EEE Collaboration), JINST19(2024)P11003



(a) Std

$\sigma_{\Delta t}$(std) = 247 ps
$\sigma_{\Delta t}$(70/30) = 263 ps



(b) 70/30

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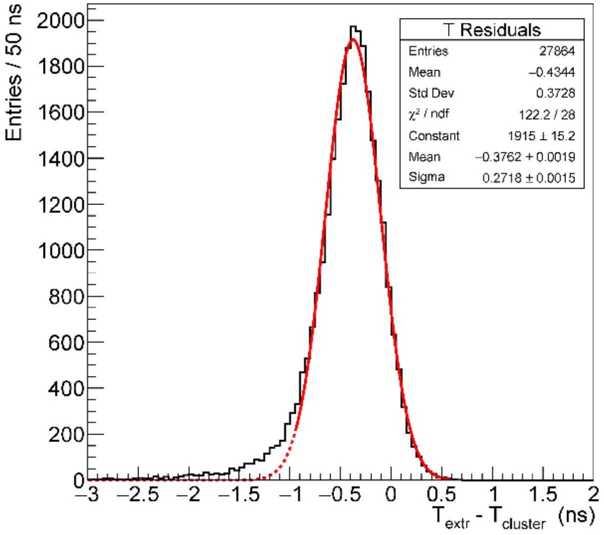
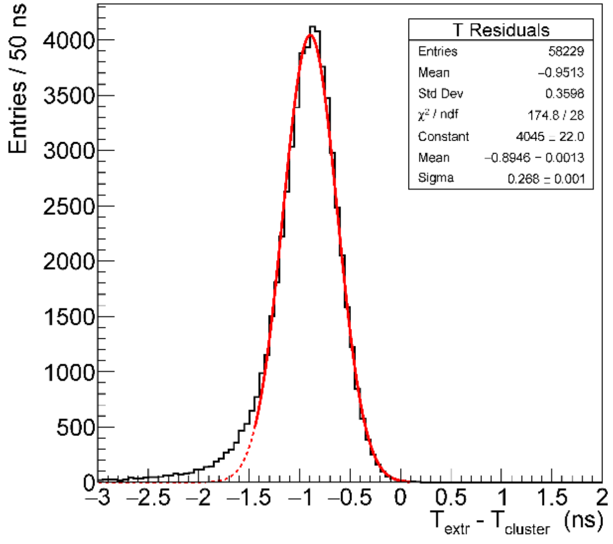


(c) 60/40

M.Abbrescia et al. (EEE Collaboration), JINST19(2024)P11003

$\sigma_{\Delta t}(60/40) = 271$ ps
$\sigma_{\Delta t}(50/50) = 268$ ps



(d) 50/50

Conclusions

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- The EEE network is one the largest surface, largest area of MRPC and long-living network of cosmic ray detectors
- Challenge in the detector building and operations
- Dual role of the project: research and educational, with young students involved
- MRPC timing performance tested with beam, cosmic rays and with new eco-friendly gas mixture
- Very good timing resolution for the MRPC chambers, ~ 200 ps, fully compatible with the experiment requirements

Thank you for your attention!