XV Workshop on Resistive Plate Chambers and Related Detectors
RPC2020

RPC2020

10-14 February 2020

Strategies to reduce the Global Warming Impact in the MRPC Array of the EEE Experiment

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for the EEE Collaboration

Extreme Energy Events
Science inside Schools

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The EEE Project

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The Extreme Energy Events (EEE) Project is an experiment for the detection of Extensive Air Showers (EAS). It is a joint scientific and educational initiative by CENTRO FERMI in collaboration with INFN and CERN

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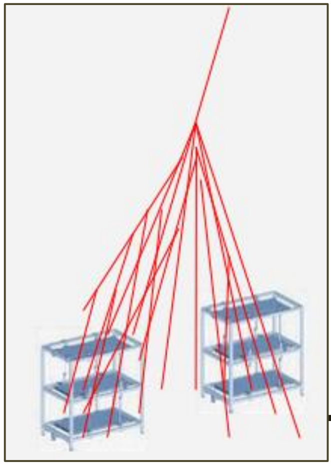
The detection of an EAS is achieved by measuring the coincidences recorded at the different sites of the EEE Telescopes Array. It consists of **tracking detectors** hosted in High Schools each made of 3 **Multi-gap Resistive Plate Chambers** (MRPCs).

The Project started in 2004 → > **62 EEE telescopes** across an overall area of ~ 3 x 10^5 km^2

In 2019 → 8 new stations



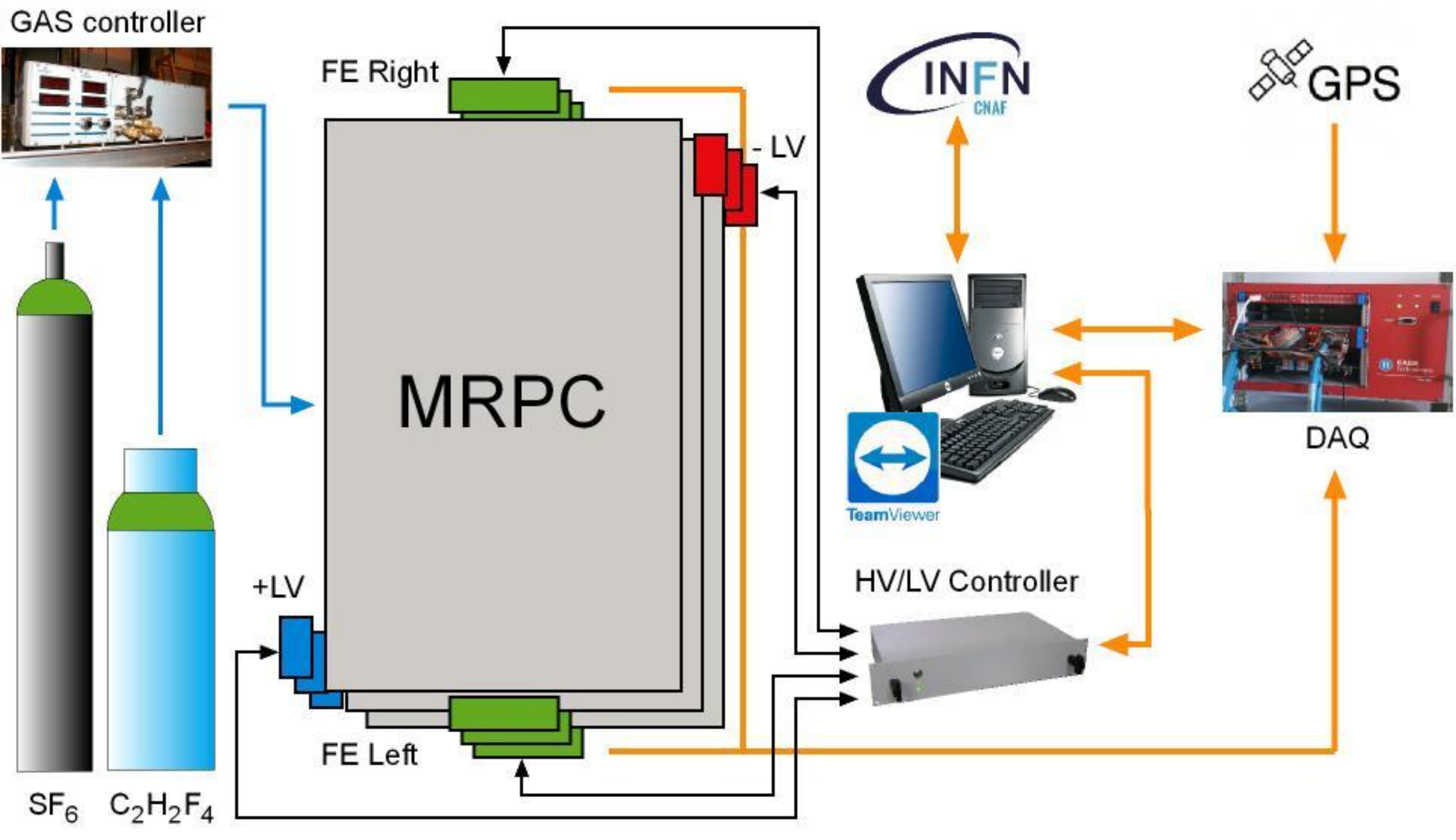
- 55 EEE Station in school buildings
- 5 at INFN sections
- 2 at CERN

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

11 deg Latitude

10 deg Longitude

The EEE Telescopes

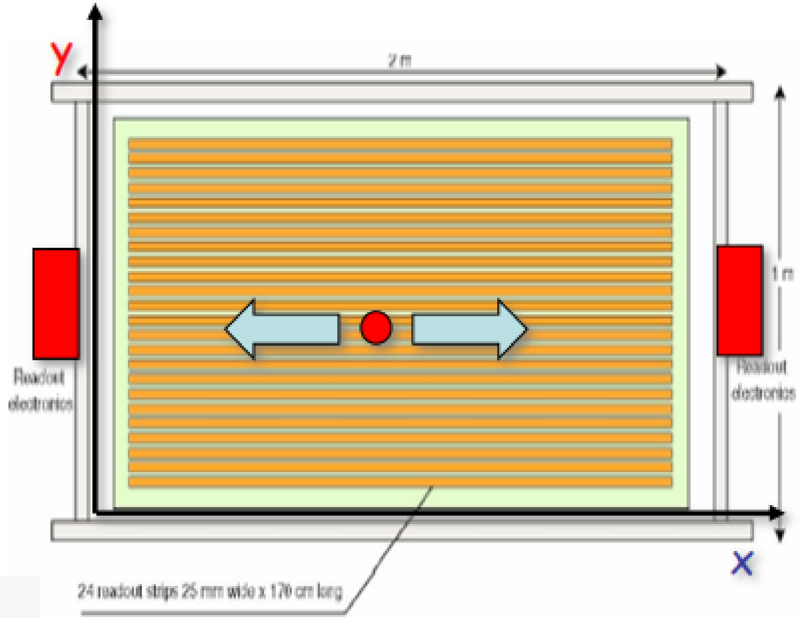


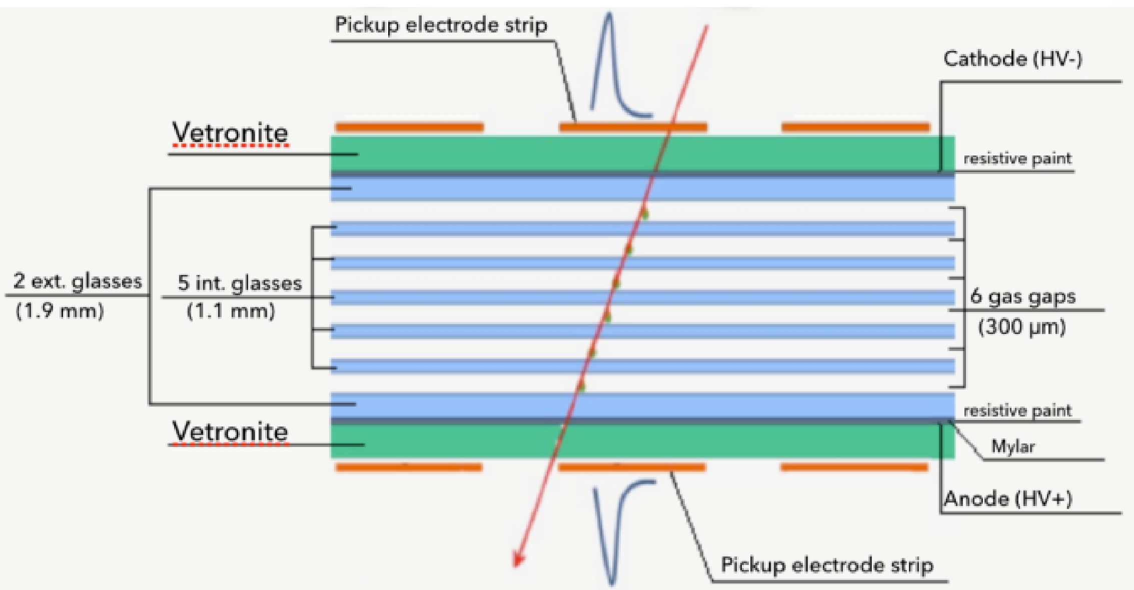
The EEE Telescopes

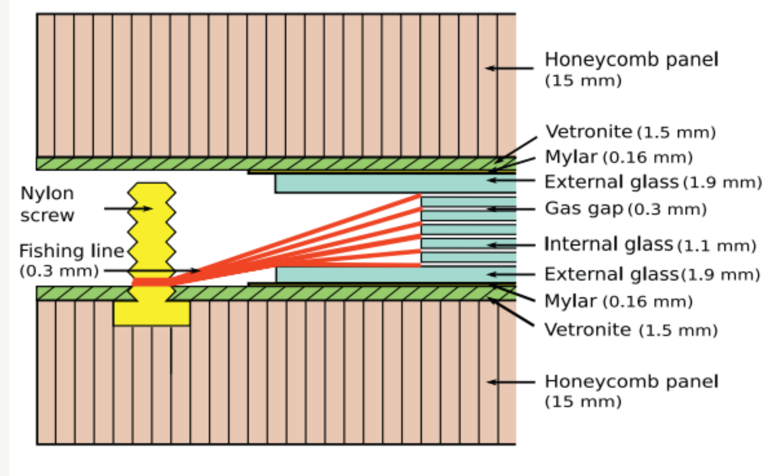
3 Multigap Resistive Plate Chambers (MRPCs) for tracking particles

Large chambers 1.58x0.82 m^2

- 24 readout copper strips 1.58 m x 25mm, spaced 7 mm
- 6 Gas Gaps: 2 vetronite panels with 5 floating glass plates, 300µm spaced by fishing line
  from 2018 : 50 New Chambers → 6 Gas Gaps, 250µm spaced
  (13 new telescopes + spare MRPCs)
- Two external glass sheets, anode and cathode, covered with resistive paint (5-20 MΩ/m^2)







The EEE Telescopes

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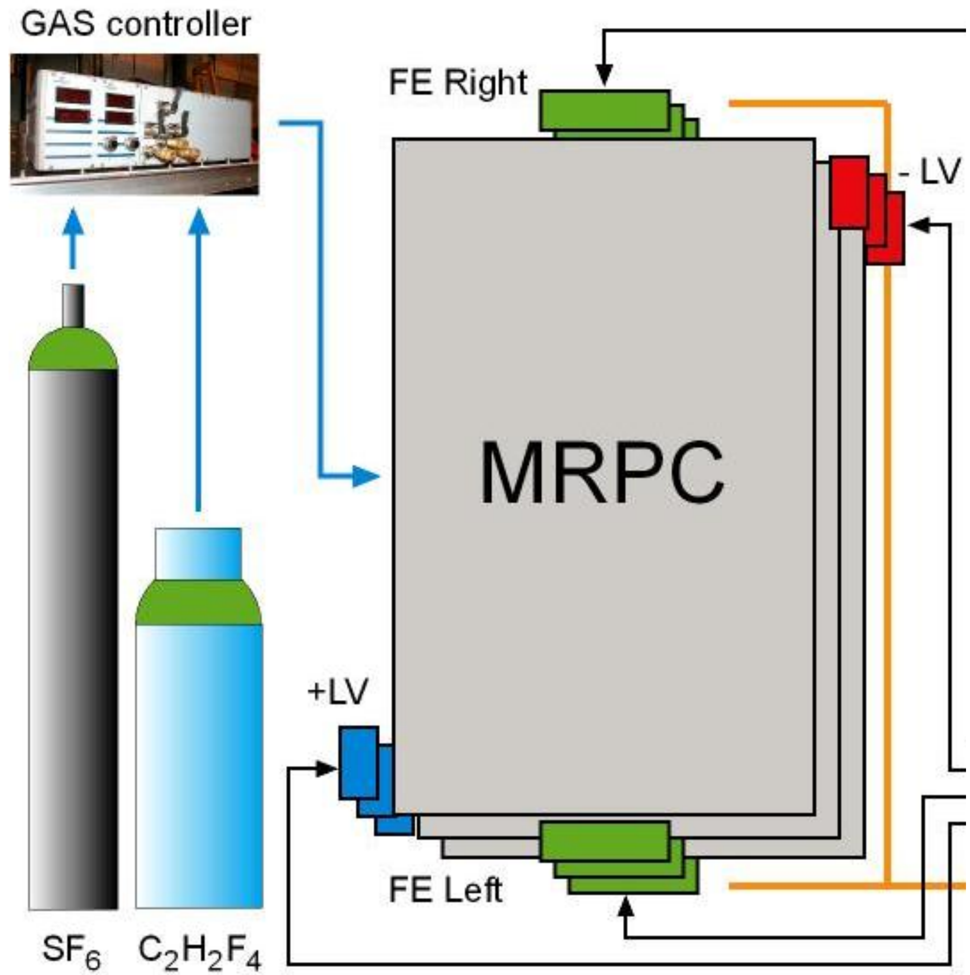
3 Multigap Resistive Plate Chambers (MRPCs) for tracking particles

Large chambers 1.58x0.82 m^2

- **HV working point around 18 kV in avalanche mode** supplied by 2 DC/DC converters (up to 20 kV)
- **Mean muon rate in the telescopes 30 Hz**
  → **100 10^9 tracks** collected during 5 coordinated data taking in the last 5 years
- **A mixture of $C_2H_2F_4$ (R134a) and SF_6**
  98% 2%
  continuously flowed in daisy chain at the **atmospheric pressure** with **a flow ~ 2 - 3 l/h**



The GWP reduction

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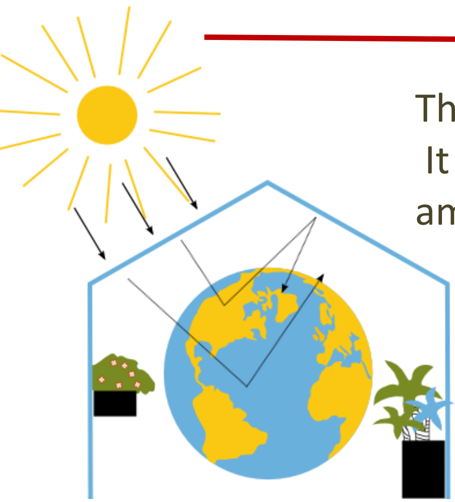

The Global Warming Potential is a measure of the **« greenhouse effect ».**
It compares the amount of heat trapped by 1 kg of a gas in the atmosphere to the amount of heat trapped by 1 kg of CO_2 . GWP(CO_2) is standardized to 1.

EU decides to ban the gas mixture with GWP > 150 (2015 → 2020)

Mixture adopted in the EEE MRPCs :
R134a (98%) + SF_6 (2%) → GWP ~ 1880

56 telescopes with a flow of 2 l/h → ~ 10^6 l/year, 3t /year

(These gases will continue to be available for research purposes but due to the reduced interest from industry their cost largely increased → until to 5 times more expensive ~ 100k euro/y)

Our strategies to reduce this Global Warming Impact in the EEE MRPC array

The EEE Collaboration has started 3 important actions:

- Gas flow reduction **short-term**
- Gas recirculation system **long-term**
- New Eco-friendly gas mixtures

Gas flow Reduction

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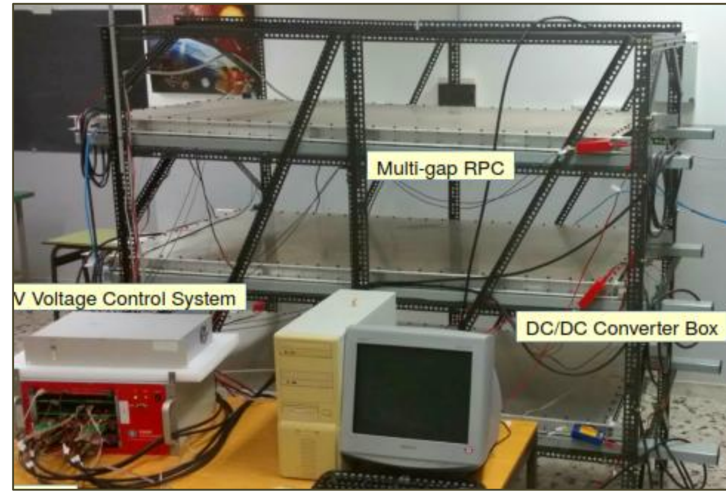
OUR TARGET : The MRPCs can operate at a lower flow

Gas tightness of the MRPCs was checked with the help of teachers and students!



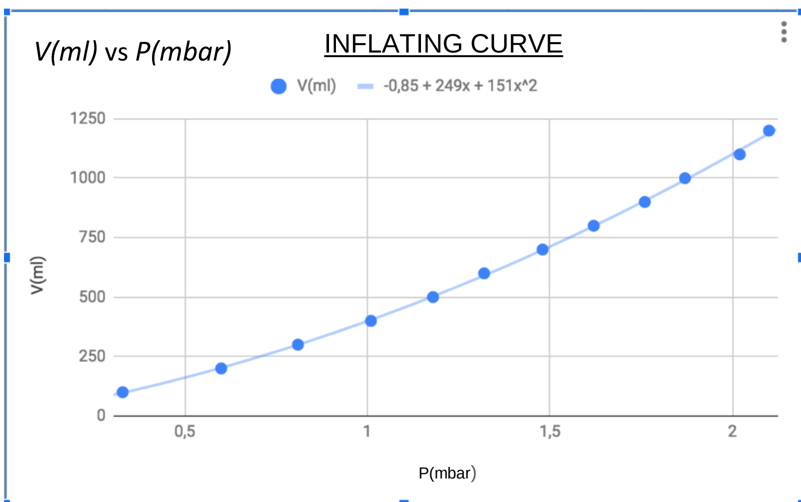
MRPC Tightness Gas Test

The tightness measurement is performed by applying a pressure drop technique:

- A known volume of air V_c is gradually injected in the MRPC to obtain a calibration curve. After, the subsequent pressure drop in the chamber is measured during ~1 hour. The gas tightness is evaluated as the volume leakage ***k*** (l/h) at an overpressure of $P_d = 1\ mbar$

A chamber is accepted if the leakage rate at ΔP_{atm} ~1 mbar is lower than the maximum value: **0.1 l/h**

MRPCs with a leakage rate > 0.1 l/h have been cured

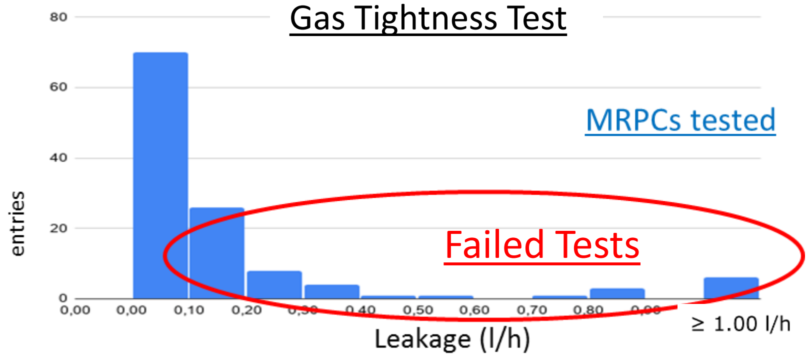


The EEE Telescope array are able to operate at an overall flow ~ 1 l/h

REDUCTION OF 50% of the GAS WASTE

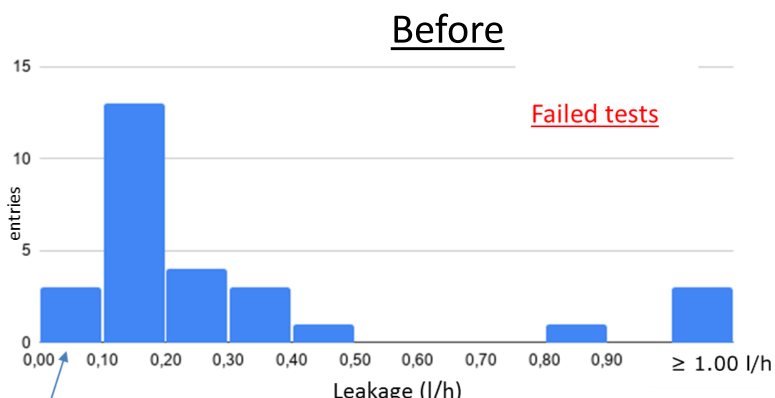
Gas Flow Reduction

This flow reduction campain is still ongoing. At present:

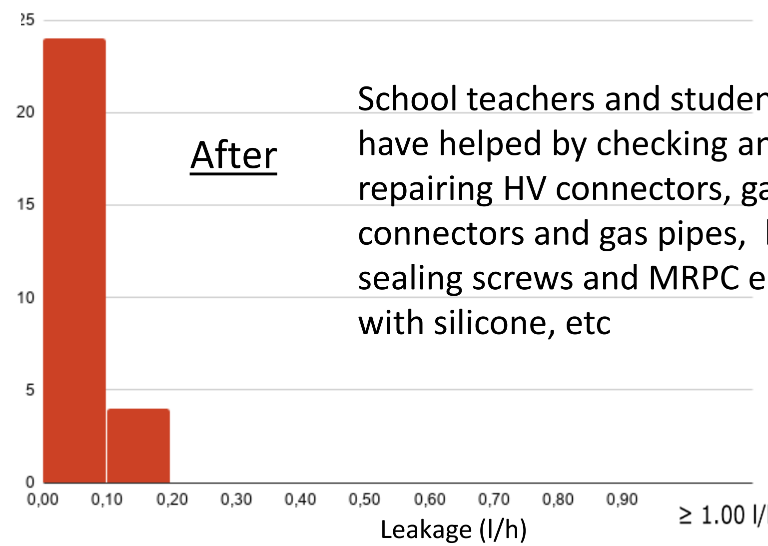


120 MRPCs were tested,
46 MRPCs do not pass the tightness test
28 MRPCs were cured in order to reach the leakage allowed < 0.1 l/h
18 MRPCs are waiting to be repaired or re-tested

MRPCs cured



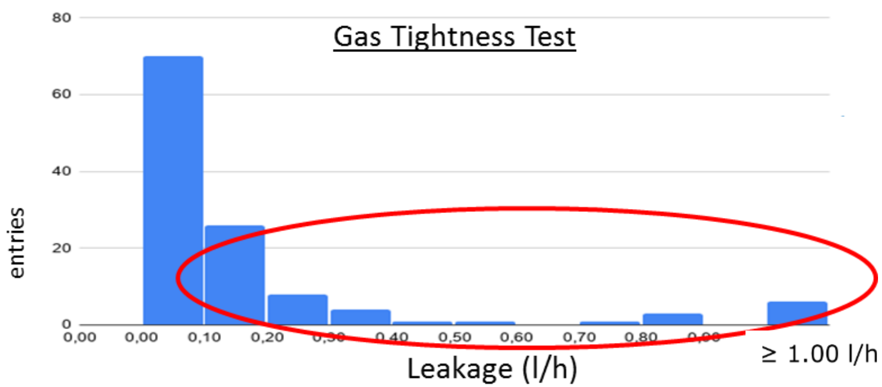
(in some case, MRPCs with leakage > 0,08 l/h are also cured)



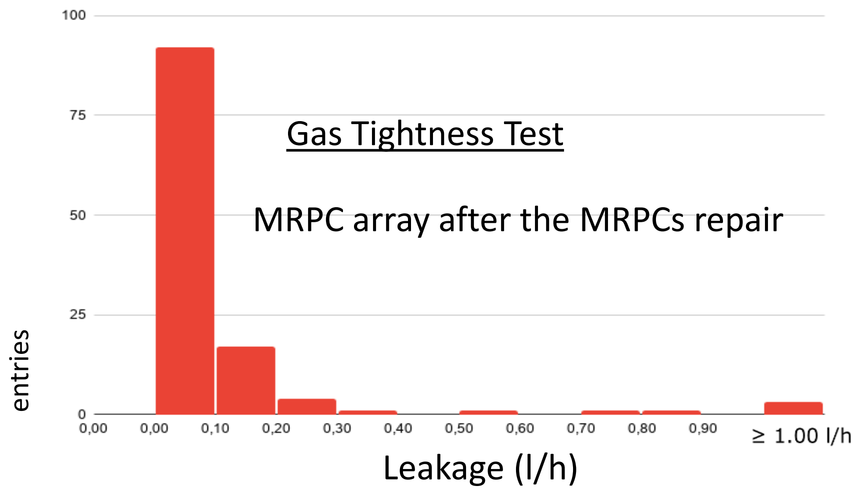
School teachers and students have helped by checking and repairing HV connectors, gas connectors and gas pipes, by sealing screws and MRPC edges with silicone, etc

Gas Flow Reduction

MRPC array **before** the flow reduction campaign



MRPC array **after** the flow reduction campaign



This flow reduction campain is still ongoing.

At present:

120 MRPCs were tested,

112 MRPCs passed the tightness test with a leakage value ≤ 0.1 l/h

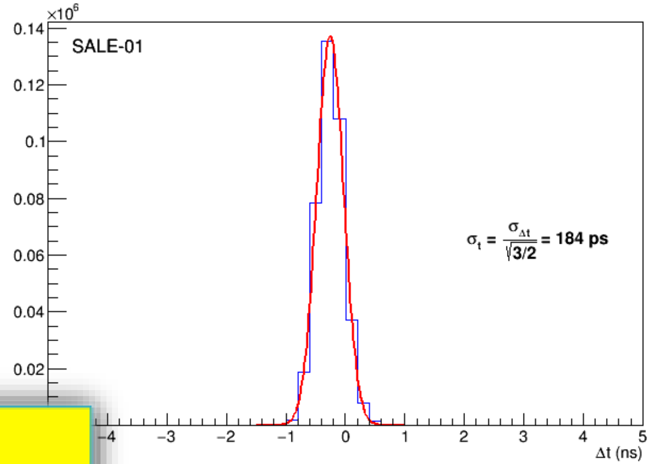
65% of the EEE Telescope array are already able to use an overall flow ~ 1 l/h

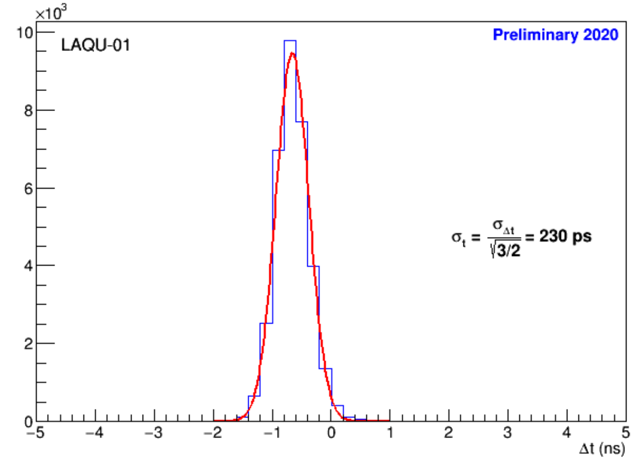
Gas Flow Reduction

Telescopes performance with a flow ~ 1 l/h

Time Resolution measured with cosmic rays

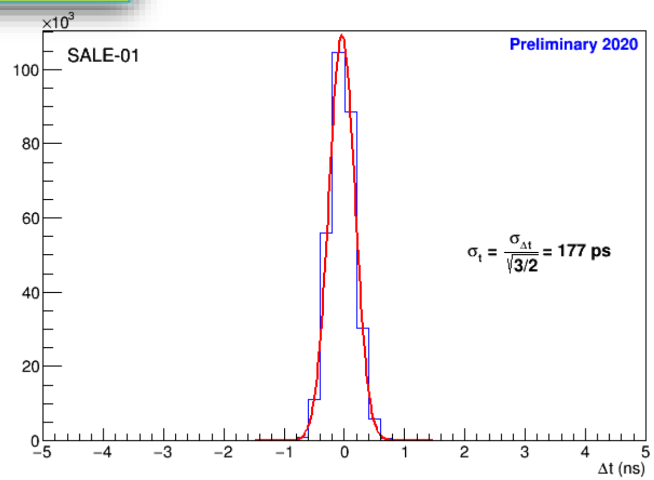
Run5 flow ≥2l/h

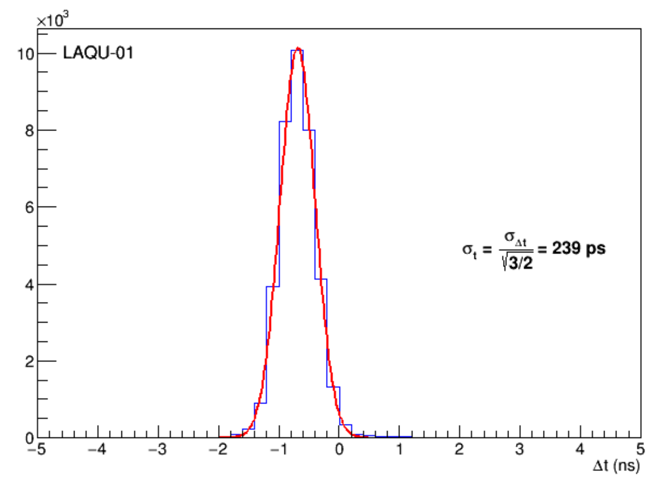




- ✓ $\Delta t_{hit} = (t_{top} + t_{bot})/2 - t_{mid}$
- ✓ $\sigma_t = \sqrt{3/2}\sigma_{\Delta t}$
- ✓ time slewing correction applied

flow ~ 1 l/h





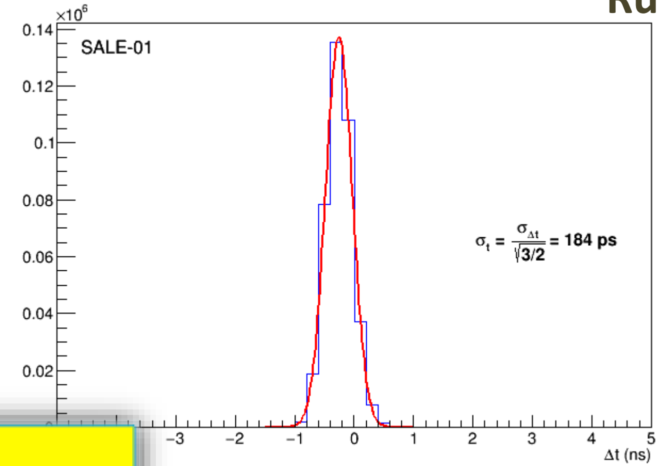
Gas Flow Reduction

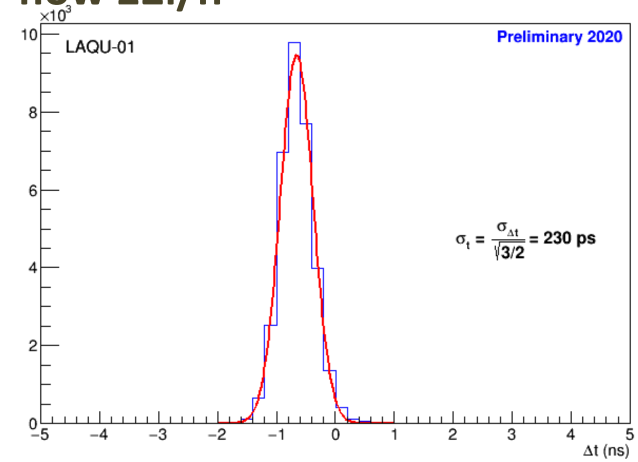
Telescopes performance with a flow ~ 1 l/h

Longitudinal space resolution measured with cosmic rays

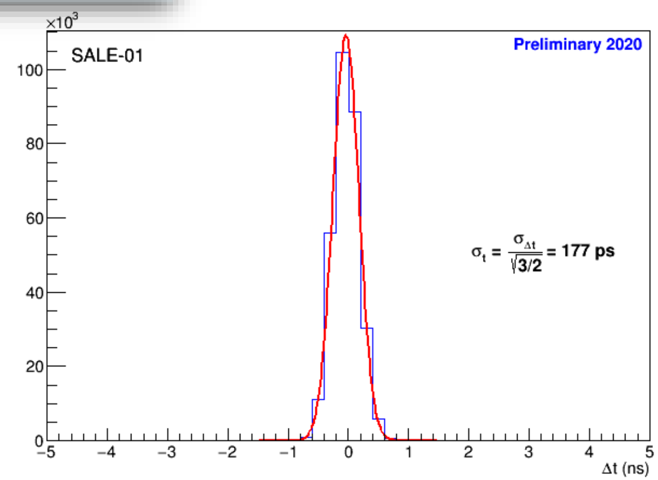
- ✓ $\Delta x = (x_{bot} + x_{top})/2 - x_{mid}$
- ✓ $\sigma_x = \sqrt{3/2}\,\sigma_{\Delta x}$
- ✓ $\sigma_{xexp} \sim \sqrt{\sigma^2_{TDC} + \sigma^2_{TDC} v_{drift}} / 2$

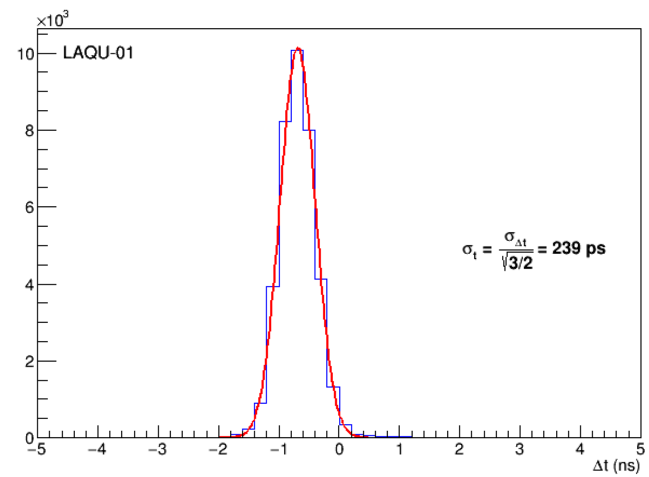
Run5 flow ≥2l/h





flow ~ 1 l/h





Gas Flow Reduction

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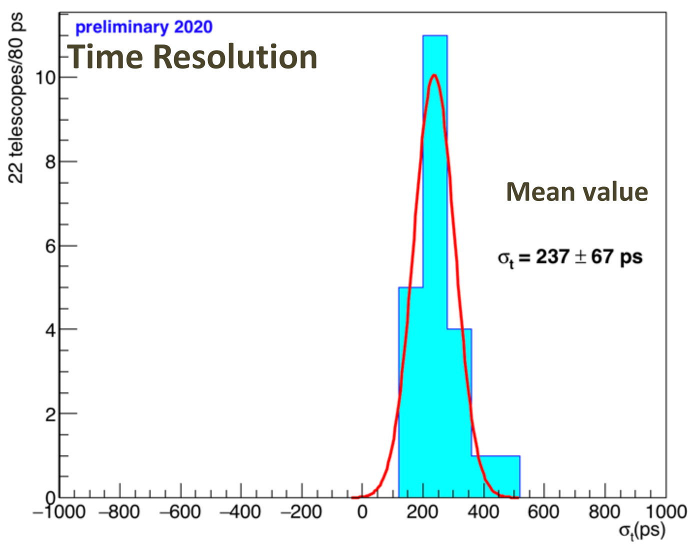
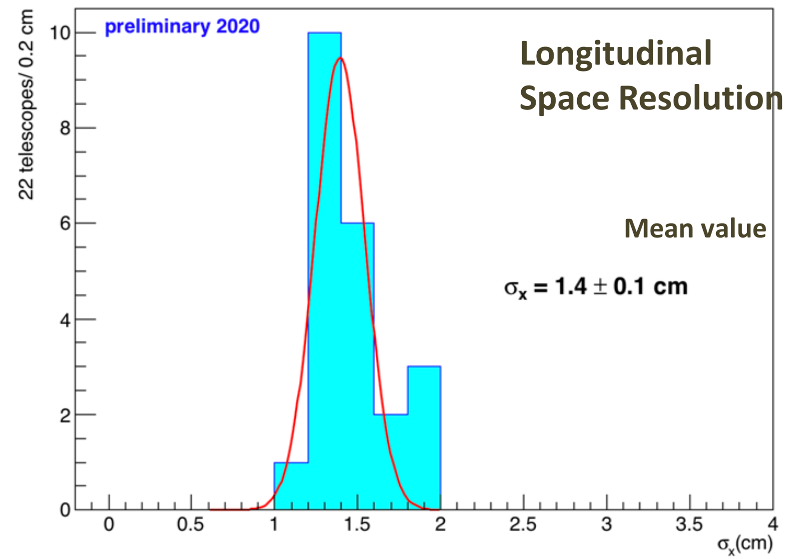
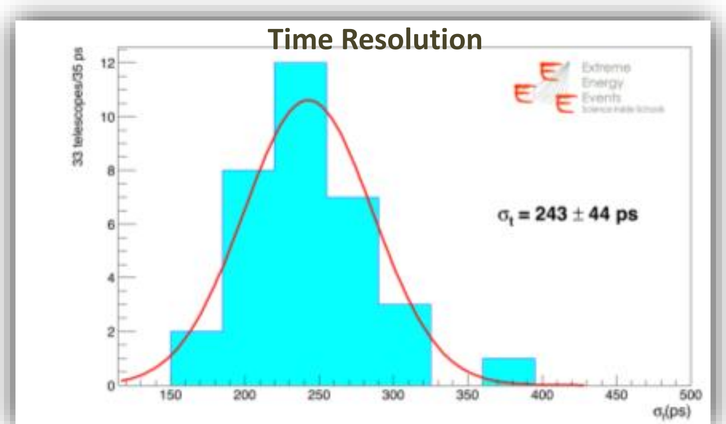
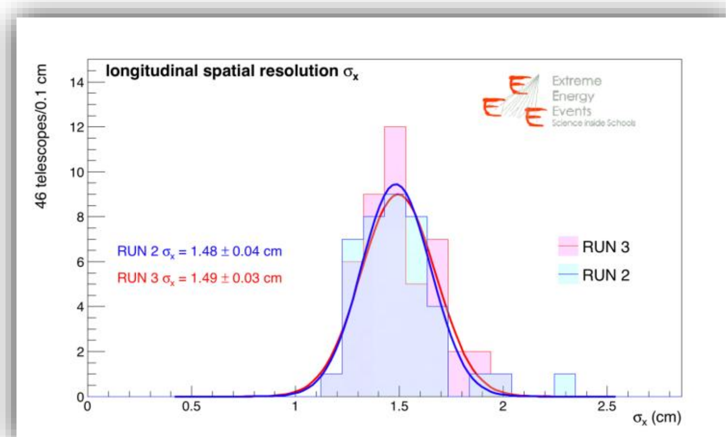
Telescopes performance with a flow ~ 1 l/h using a sample of 22 Telescopes





The sample resolutions at ~ 1 l/h are compatible with the array resolutions using a flow ≥2 l/h,





Gas Recirculation System

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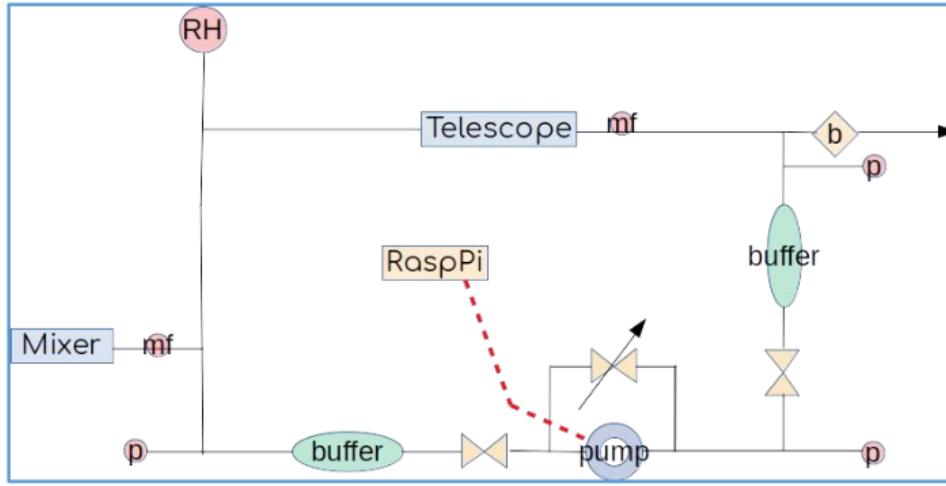
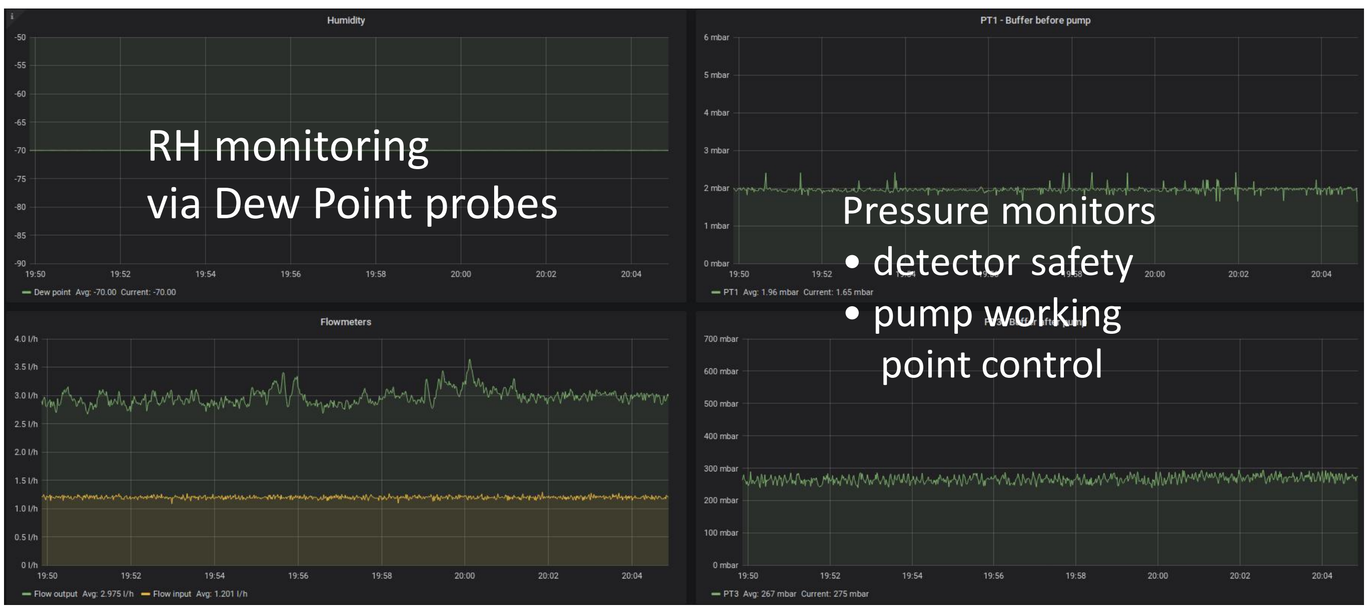
A recirculation system is installed and under study on a EEE Telescope at CERN

OUR GOAL:
A simple, small, easy-to-use system to be eventually installed in each EEE Station, to be monitored by school teams

The cost of a prototype is ~ 2 keuro → our target is < 1 keuro,





Gas Recirculation System

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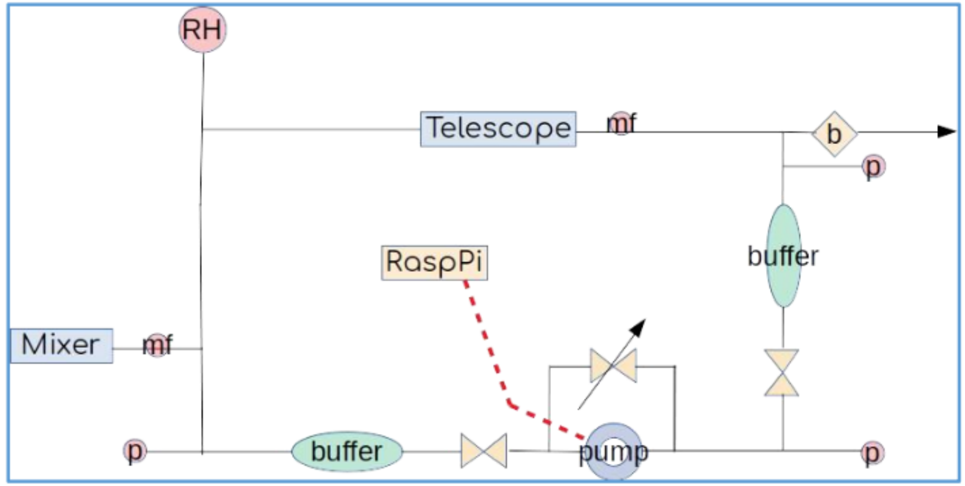

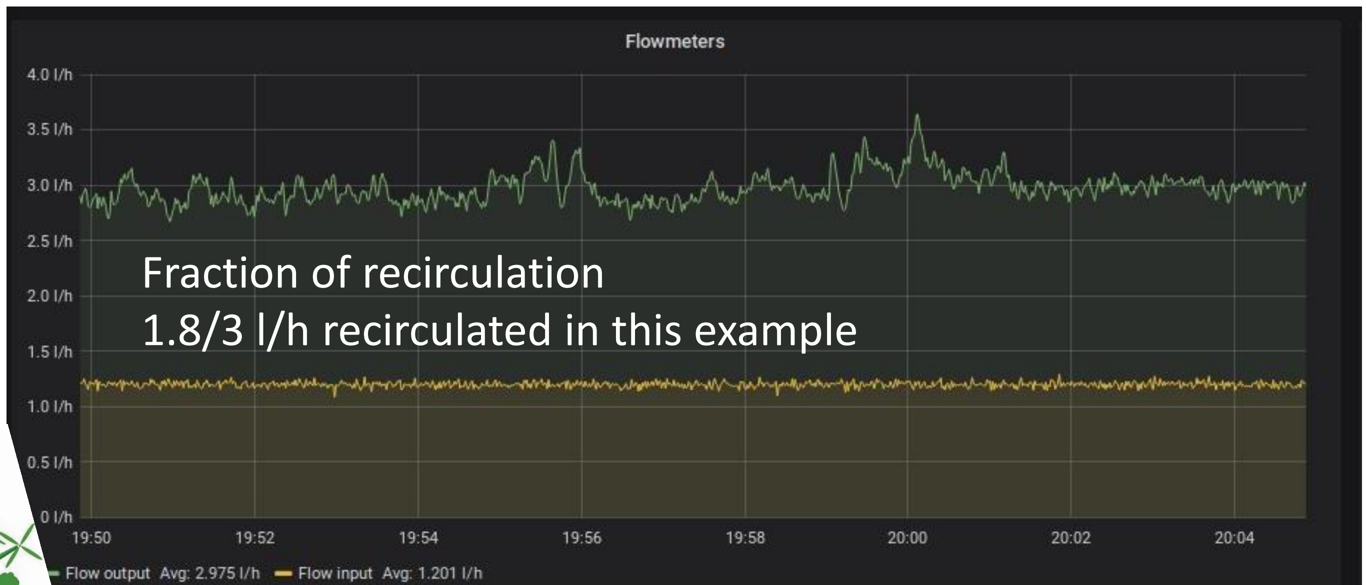

At present the prototype can reaused a flow fraction ~60%

Eco-Friendly Gases

To support this GWP reductions, several gas mixtures have been tested in the EEE Telescope, with a new **MRPChamber using cosmic muons** (→ low rate ~30 Hz)

The **MRPC efficiency, current, cluster size** has been studied with different **« ecofriendly »** mixtures as a function of applied high voltage

- Pure $C_3H_2F_4$ (R1234ze)
- R1234ze + CO_2
- R1234ze + SF_6
- Pure CO_2
- CO_2 + SF_6

The promising gas mixtures are:

- Pure $C_3H_2F_4$ (R1234ze)
- R1234ze + CO_2
- R1234ze + SF_6

100% Tetrafluoropropene $C_3H_2F_4$

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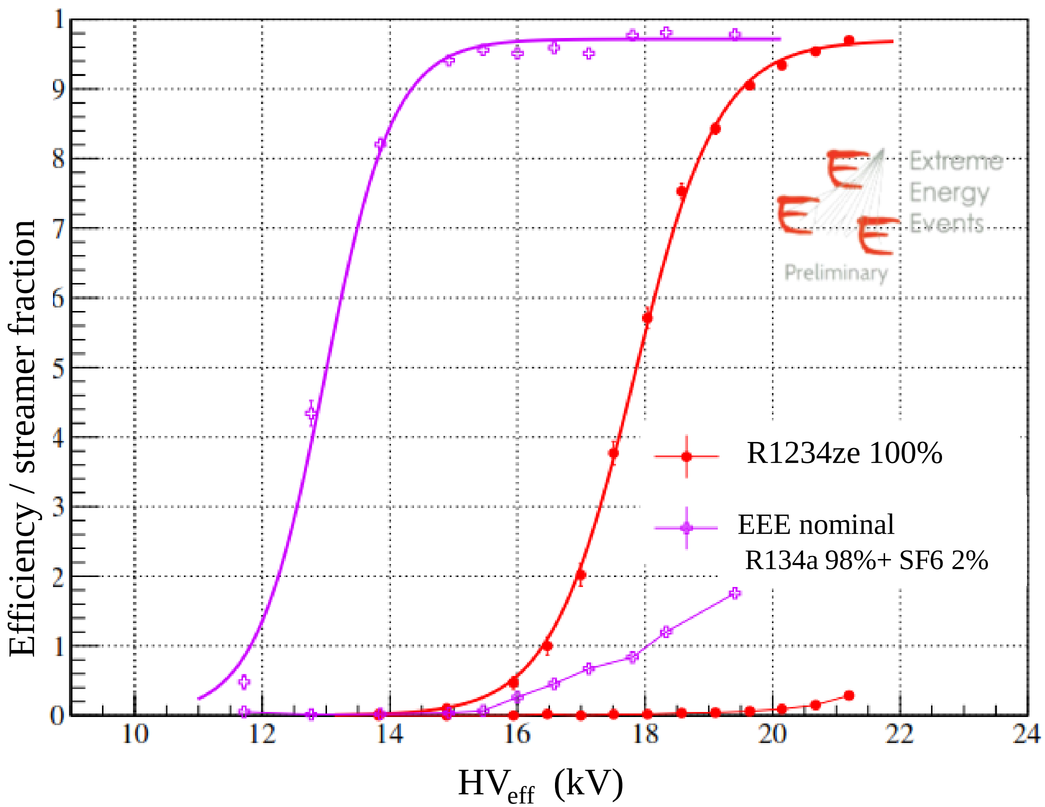
Tetrafluoropropene $C_3H_2F_4$ (R1234ze or HFO) with **GWP = 4** could be a good candidate to substitute R134a ($C_2H_2F_{4,}$ GWP = 1300)

High rate measurements (in RPCs) show good results with mixtures of R1234ze …

Pure R1234ze



- Efficiency vs HV_{eff}
- Streamer fraction :

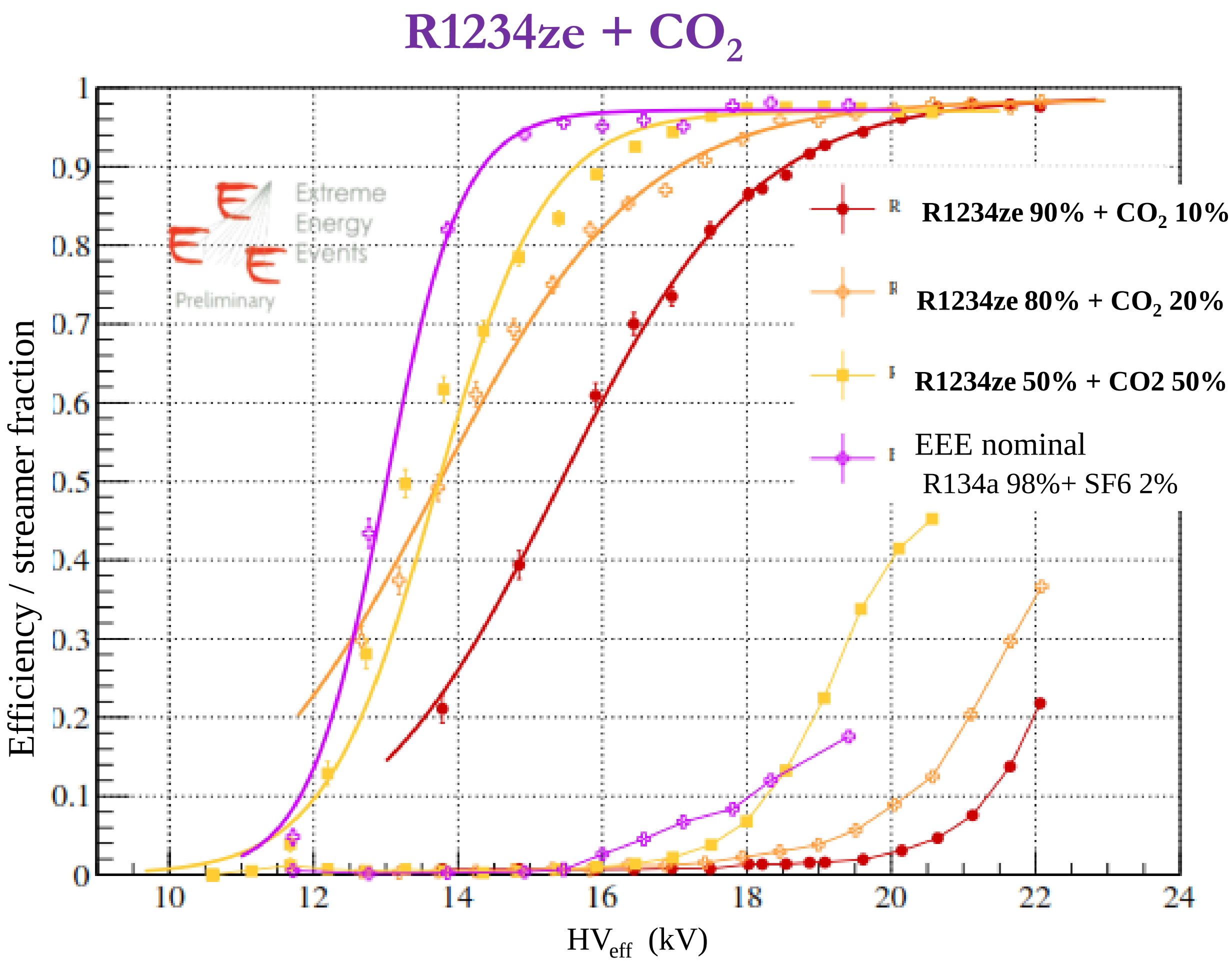
$$S = \frac{\#\,TOT\ Hits\ \ with\ cluster\ size{>}5\ strips}{\#\,TOT\ Hits\ in\ the\ chambers}$$

Lower dark currents
Streamers < 5 % → **good quencher**

HV working point, around 21 kV, **is higher** than the EEE nominal mixture (mean value 16-17 kV with new 250µm-MRPC).
It is close to the upper HV limit supplied by DC/DC converters.

R1234ze + CO_2

Mixtures based on Tetrafluoropropene and CO_2 and have been tested in order to limit the working voltage [very low GWP mixtures: GWP $_{R1234ze}$ = 6 , GWP $_{CO2}$ = 1]



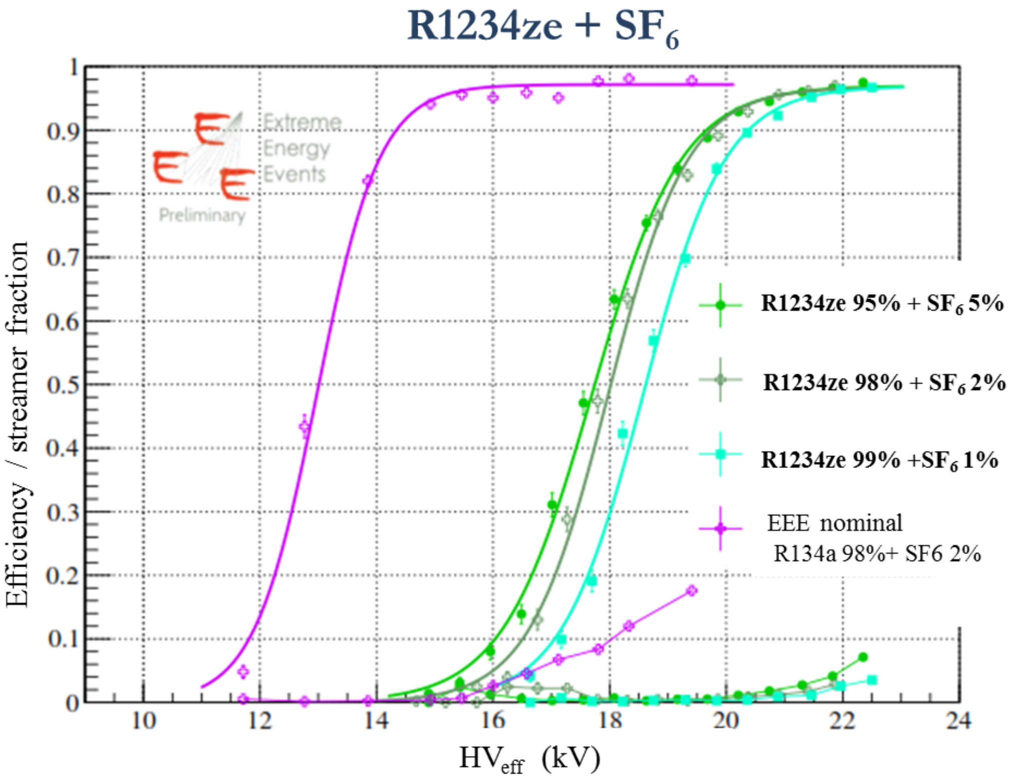
- Efficiency vs HV_{eff}
- Streamer fraction :

$$S = \frac{\#\,TOT\ Hits\ \ cluster > 5\ strips}{\#\,TOT\ Hits}$$

The efficiency plateau decreases as the CO_2 fraction increases. For mixture R1234ze **50% +** CO_2 **50%** → 18 kV

The streamer percentage increases.

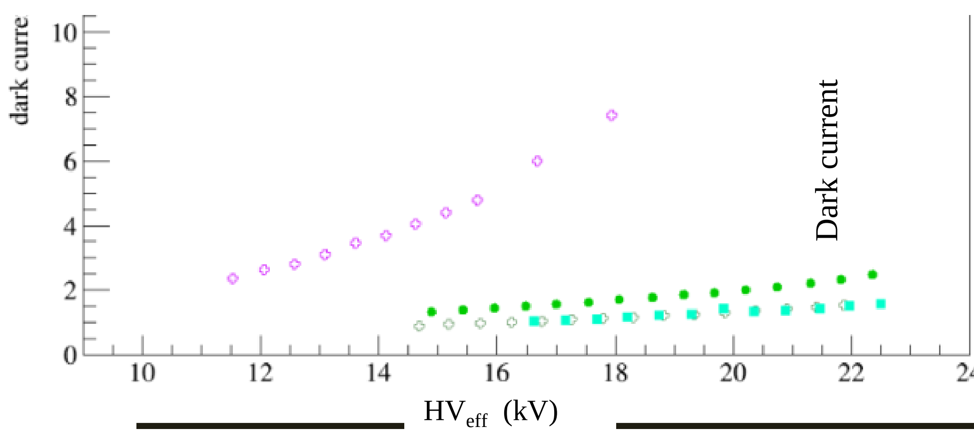
R1234ze + SF_6



SF_6 is a very effective quencher also in a small percentage , but due its very high GWP value (GWP = 23900) , its fraction should not exceed 0.5%

- Efficiency vs HV_{eff}
- Streamer fraction :

$$S = \frac{\#\ TOT\ Hits\ \ cluster>5\ strips}{\#\ TOT\ Hits}$$



High value of the HV setting point, above the upper HV limit supplied by DC/DC converters.

Noisy is highly suppressed by SF_6.

Eco-Friendly Gases

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To support this GWP reductions, several gas mixtures have been tested in the EEE Telescope, with a new **MRPChamber using cosmic muons** (→ low rate ~ 30 Hz)

The **MRPC efficiency, current, cluster size** has been studied with different **« ecofriendly »** mixtures as a function of applied high voltage

The promising gas mixtures:

- Pure $C_3H_2F_4$ (R1234ze) → **High cost for** R1234ze ~ R134a
- R1234ze + SF_6 → High GWP value
- R1234ze + CO_2 → better than pure R1234ze but already expensive

Updates on Gas Studies:

New test mixtures are ongoing using Ar/CO_2 : 93/7, 95/5, 90/10, 80/20.

- Promising : Largely used on MPGD
- very high charge

cheap 30 euro / m^3

Summary

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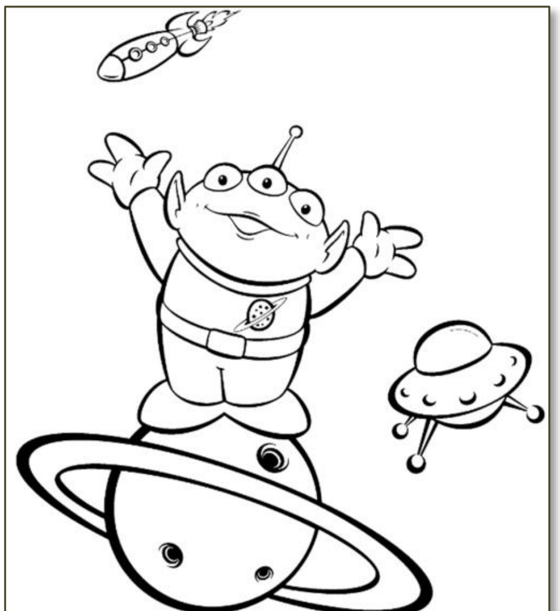
The EEE Collaboration actions:

- Gas flow reduction → **~ 40 EEE Telescopes are taking data with a flow ~ 1 l/h**
- Gas recirculation system → **Our prototype can reaused a flow fraction ~60%**
- Eco-friendly gas mixtures → **Pure $C_3H_2F_4$ (R1234ze) & R1234ze + CO_2**
  New test mixtures ongoing using Ar/CO_2

THANKS FOR YOUR ATTENTION



…SPARES

The EEE Project : a dual role

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Scientific instrument for physicists

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

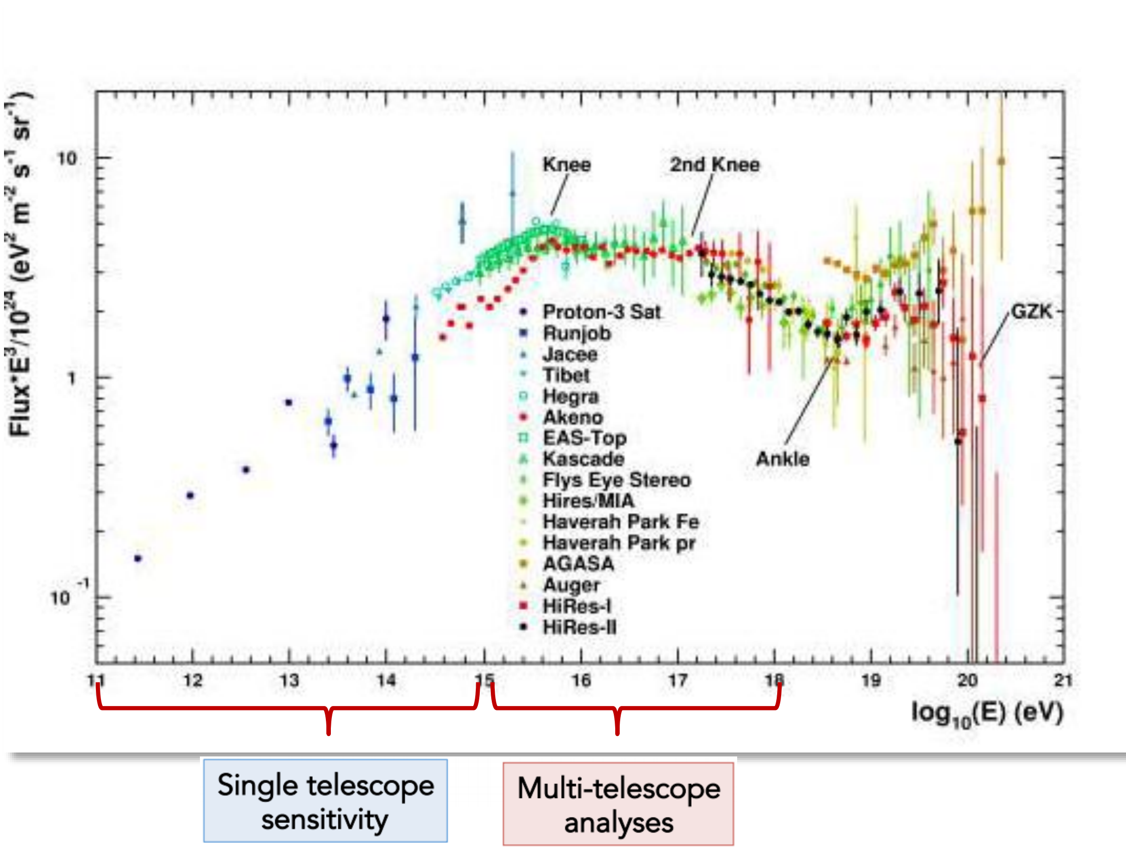
Search of coincidences, Long distance correlation

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

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

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

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



The EEE Project : a dual role

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Education instrument for students

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

In their schools hundreds of students with their teachers are directly involved in operating monitoring EEE stations, with the **aim to introduce them in an advanced physics research.**

The EEE Telescopes

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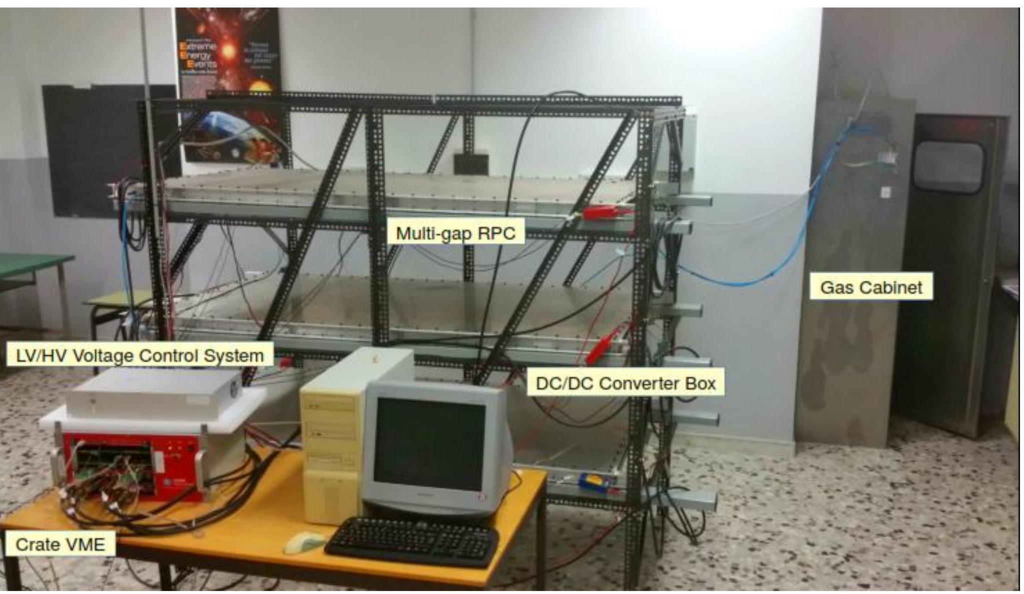
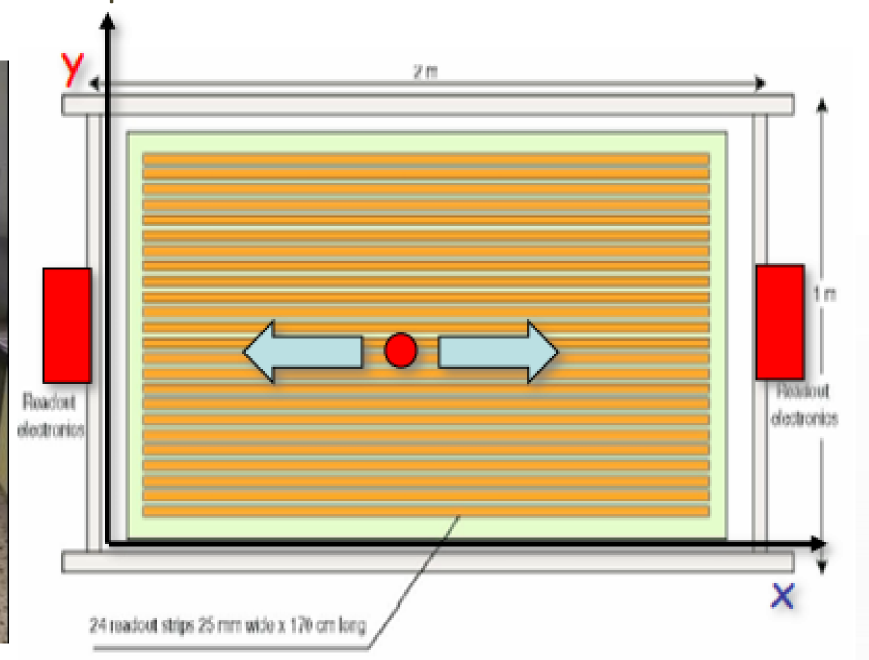
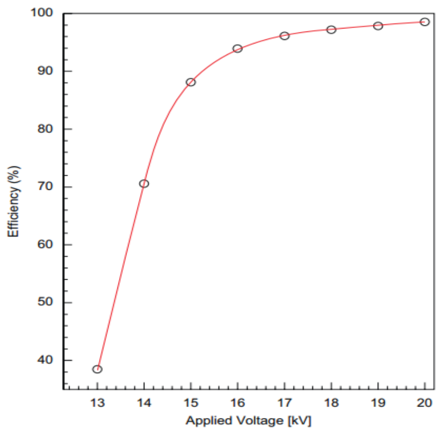
- **THREE MULTI-GAP RESISTIVE PLATE CHAMBERS** (MRPCs)
- **6 FRONT-END BOARDS** (FEAs) with 24 channels to process readout signal
- **VME BRIDGE.** DAQ connected to a PC via USB, controlled by LabView program
  - **1 MULTI-TRIGGER CARD:** a six-fold coincidence of both FEAs of the 3 MRPCs generates the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





Single MRP Chamber



TEST BEAM at CERN

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

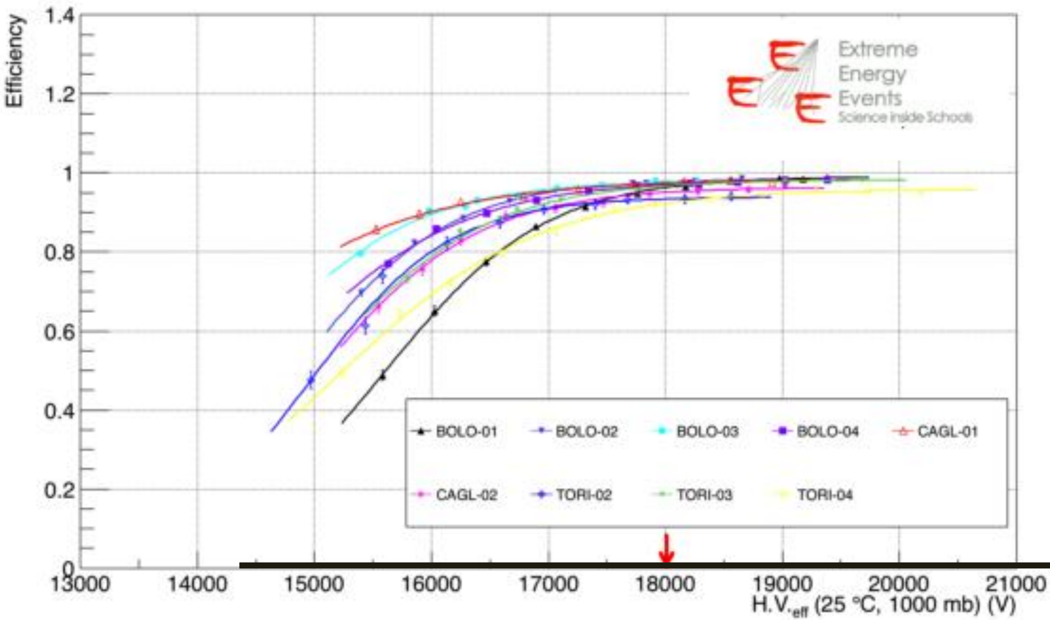
Efficiency plateau ~**100%**

TDCs 25ps bins , scintillators system time resolution 30 ps
In the middle of the strip lenght

Time resolution ~141 ps
+ corrections ~94 ps ⇨ **Spatial resolution along strips** ~ 8 mm

Performance for the EEE telescope

measured with cosmic particles in the EEE stations inside school building



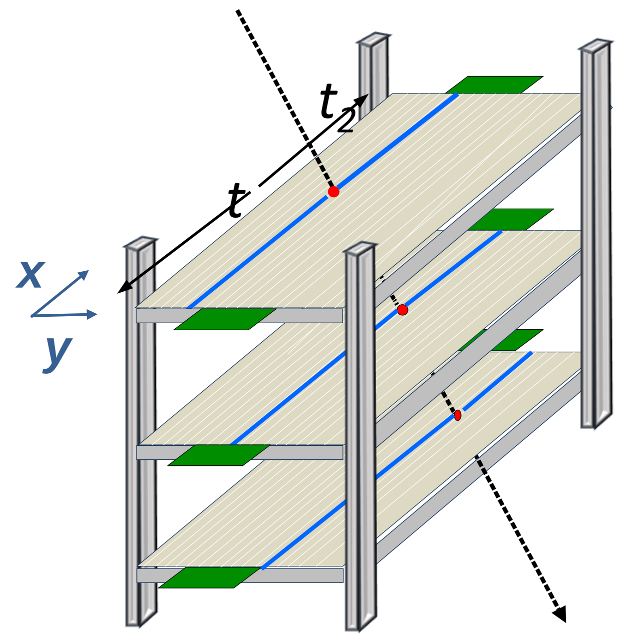
Efficency vs HV

HV~18 kV → **95%**

Longitudinal Spatial resolution ~1.5 cm
Time resolution ~ 240 ps

The MRPC Telescopes

At CNAF where an all data reconstruction algorithm is applied to all telescopes raw data.
Tracking procedure: "Good" events are selected by quality cuts: lowest $\chi 2$, track length, ToF



The particle impact point is reconstructed by :

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

$$x = \frac{T_{Left} - T_{right}}{2} v_{Drift}$$

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

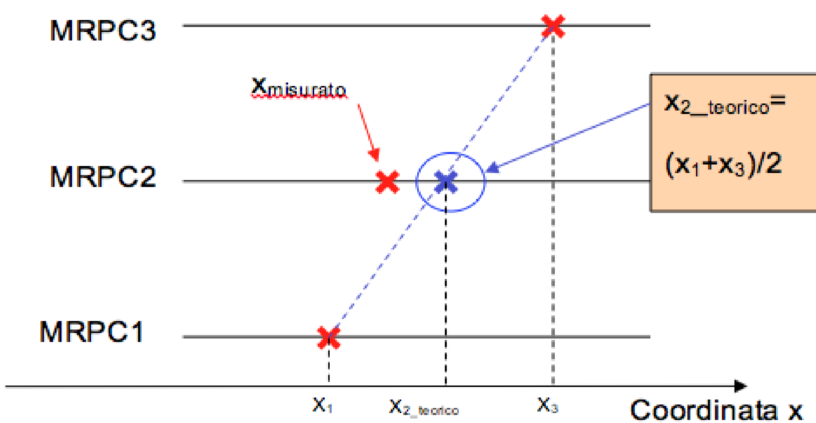
$$T_{\mathrm{Hit}} = \frac{T_{RIGH} + T_{\mathrm{LEFT}}}{2}$$

The MRPC Telescopes

Spatial resolution for the Telescopes

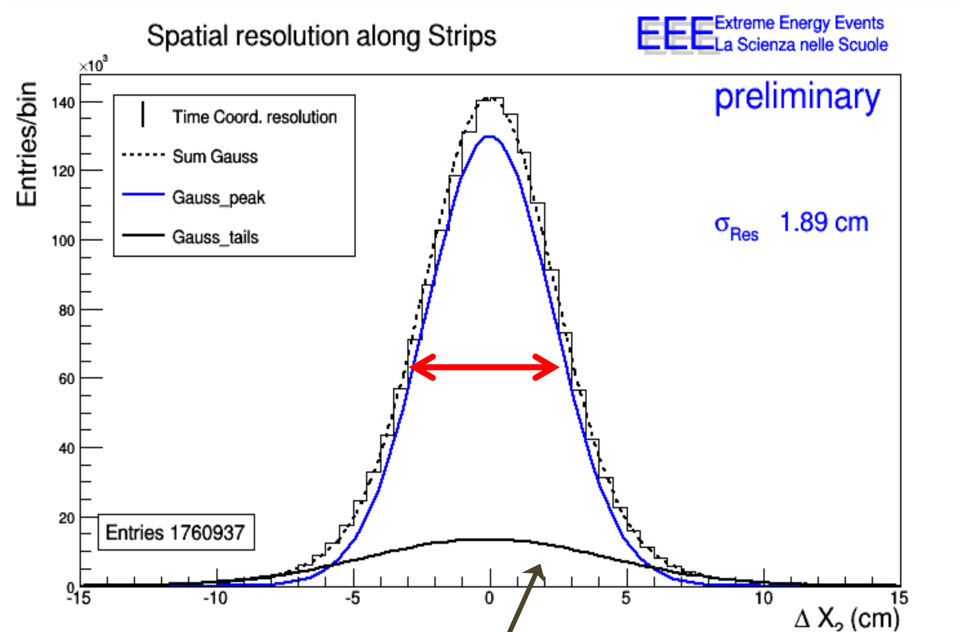
measured with cosmic particles in the EEE stations

Long side Chamber coordinate (X)



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

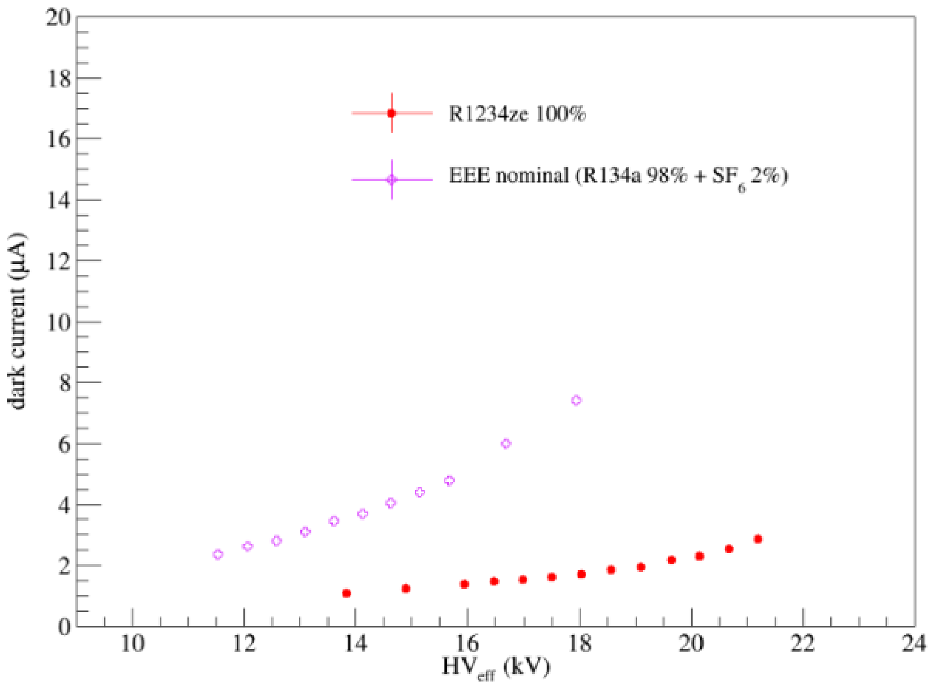
$$\sigma_{\Delta X} = \sigma_{X\,Res.}\sqrt{\frac{3}{2}} \;;\quad \sigma_{X\,Res.} = \sqrt{\frac{2}{3}}\sigma_{\Delta X} \sim 1{,}89\ cm$$

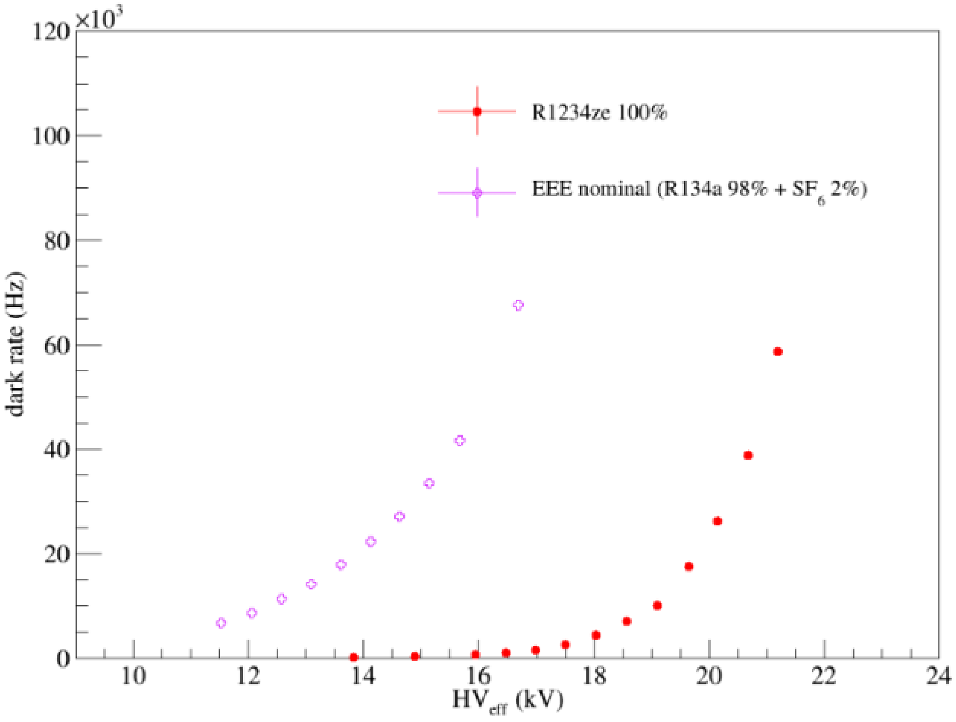


Fit with 2 contributions

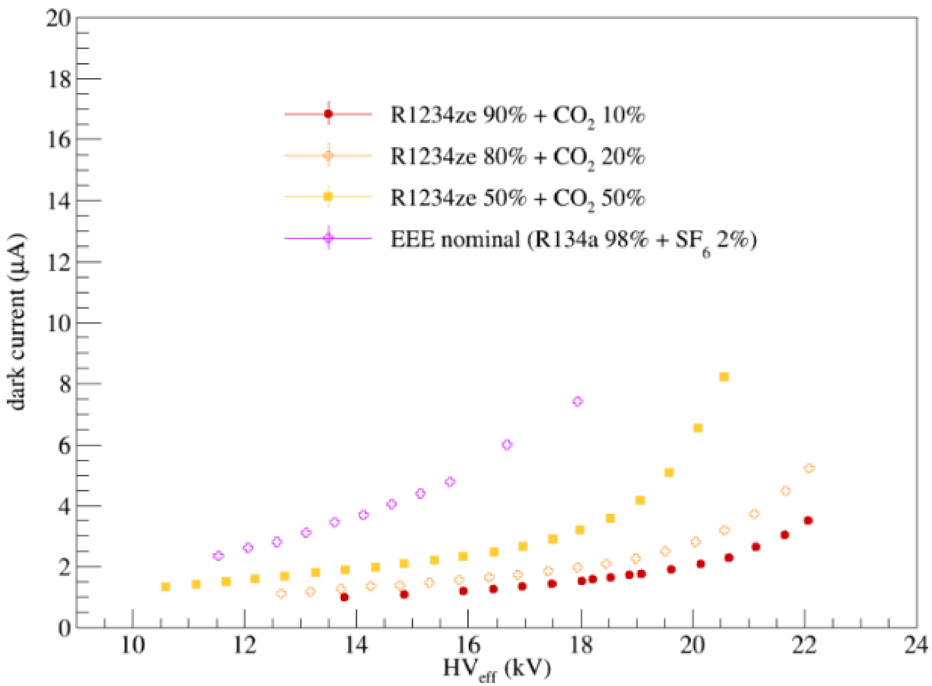
- **TDC resolution**
- Chambers alignment
- Multiple scattering
- Strip calibration
- Propagation of the signal along the strips

Pure R1234ze

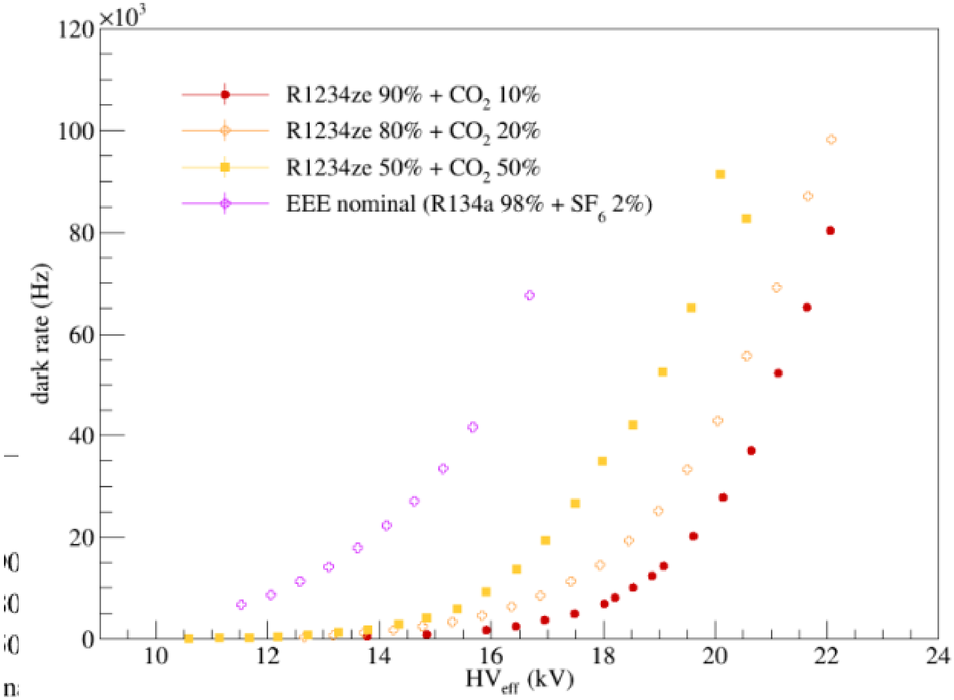




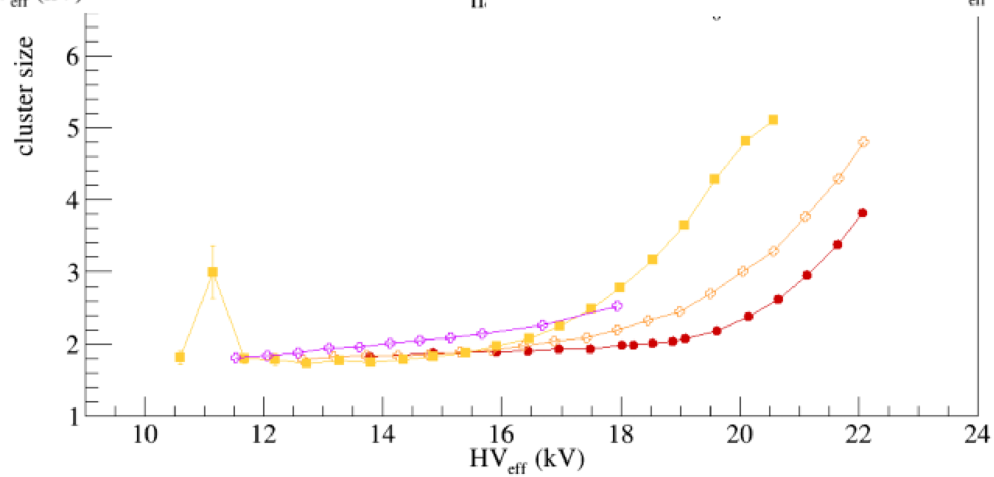
R1234ze + CO_2



R1234ze 90% + CO2 10%
R1234ze 80% + CO2 20%
R1234ze 50% + CO2 50%
EEE nominal (R134a 98% + SF6 2%)
dark current (μA)
HVeff (kV)



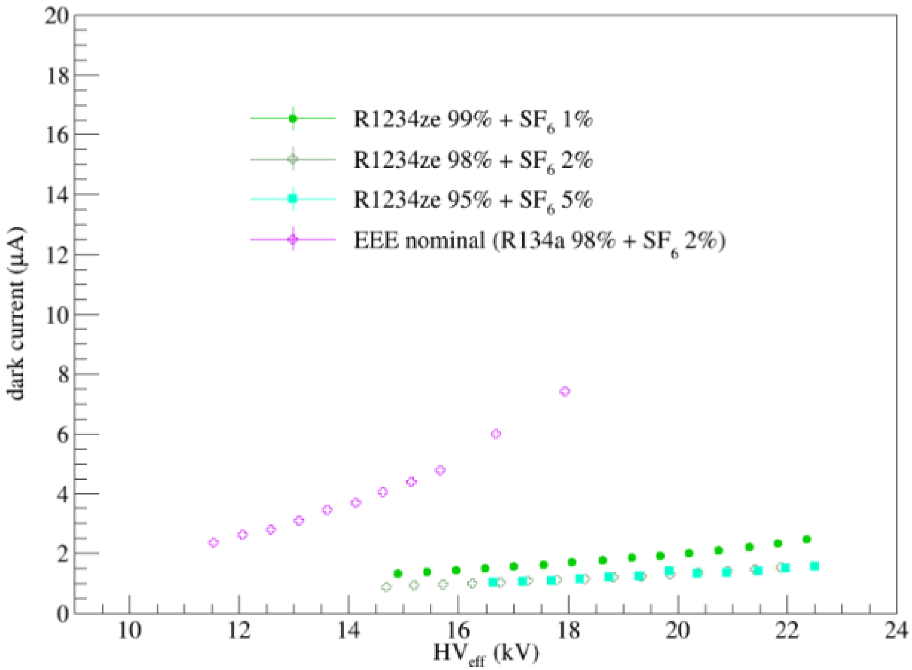
×10³
R1234ze 90% + CO2 10%
R1234ze 80% + CO2 20%
R1234ze 50% + CO2 50%
EEE nominal (R134a 98% + SF6 2%)
dark rate (Hz)
HVeff (kV)

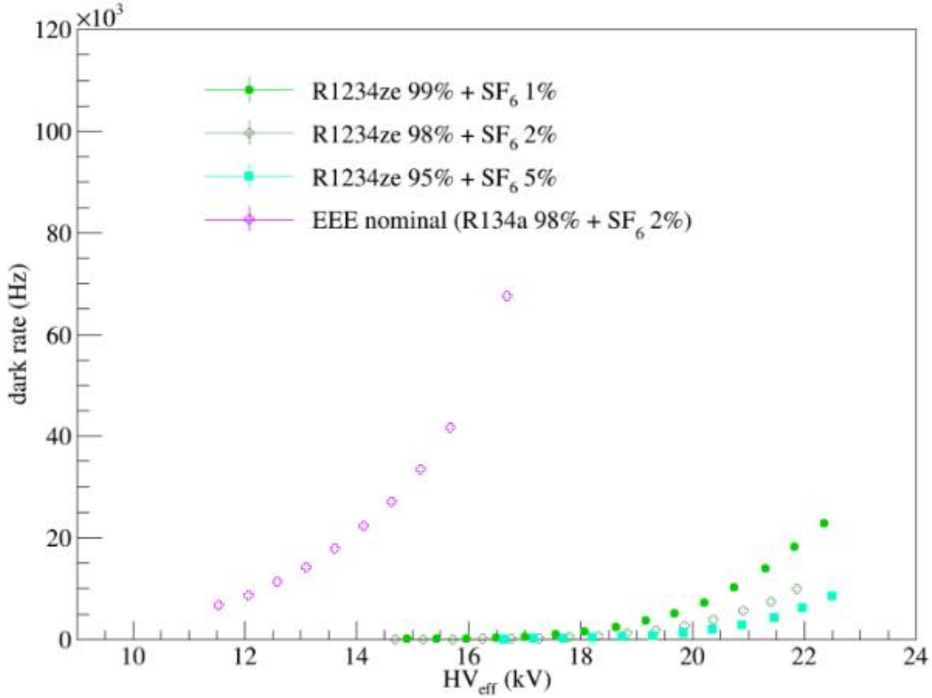


cluster size
HVeff (kV)

R1234ze + SF_6

Extreme Energy Events
Science inside Schools





CO_2 based mixtures