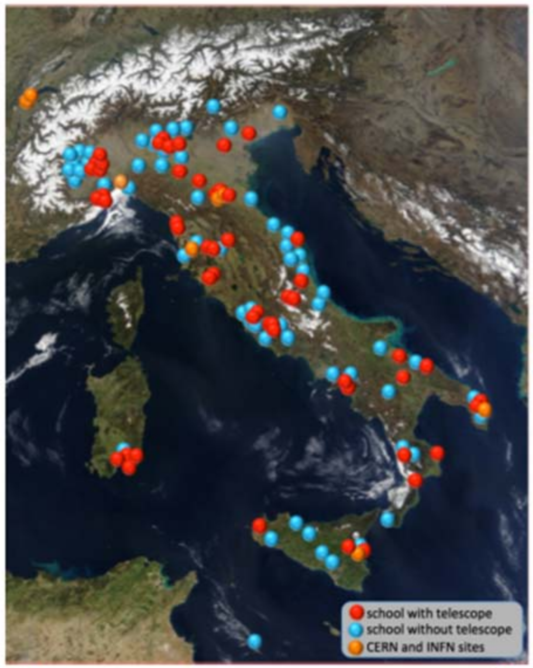
The ecological transition of the EEE experiment

Marcello Abbrescia

Extreme Energy Events
Science inside Schools

The EEE experiment

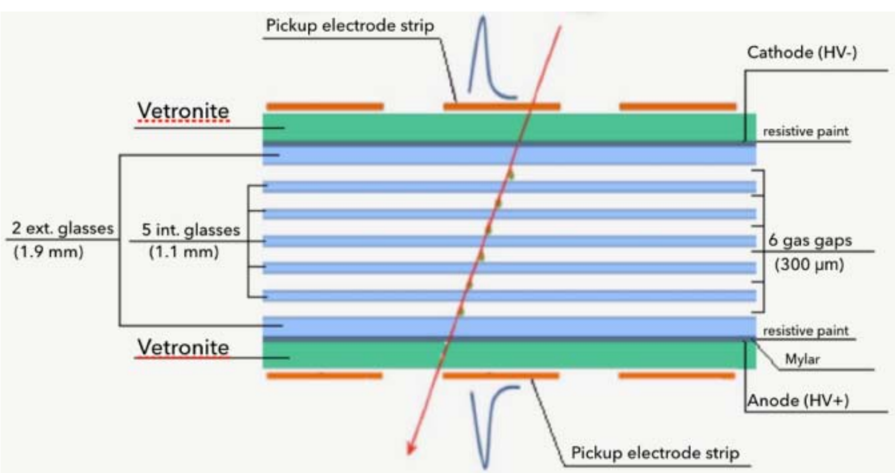


11 deg Latitude

3 Multigap Resistive Plate Chambers (MRPCs) to detect and track cosmic muons with the aim to study Extensive Atmospheric Showers.

55 EEE Stations in school buildings
5 at INFN sections
2 at CERN

62 EEE telescopes



✓**Low trigger rate:**
on the average ≈30 Hz per telescope

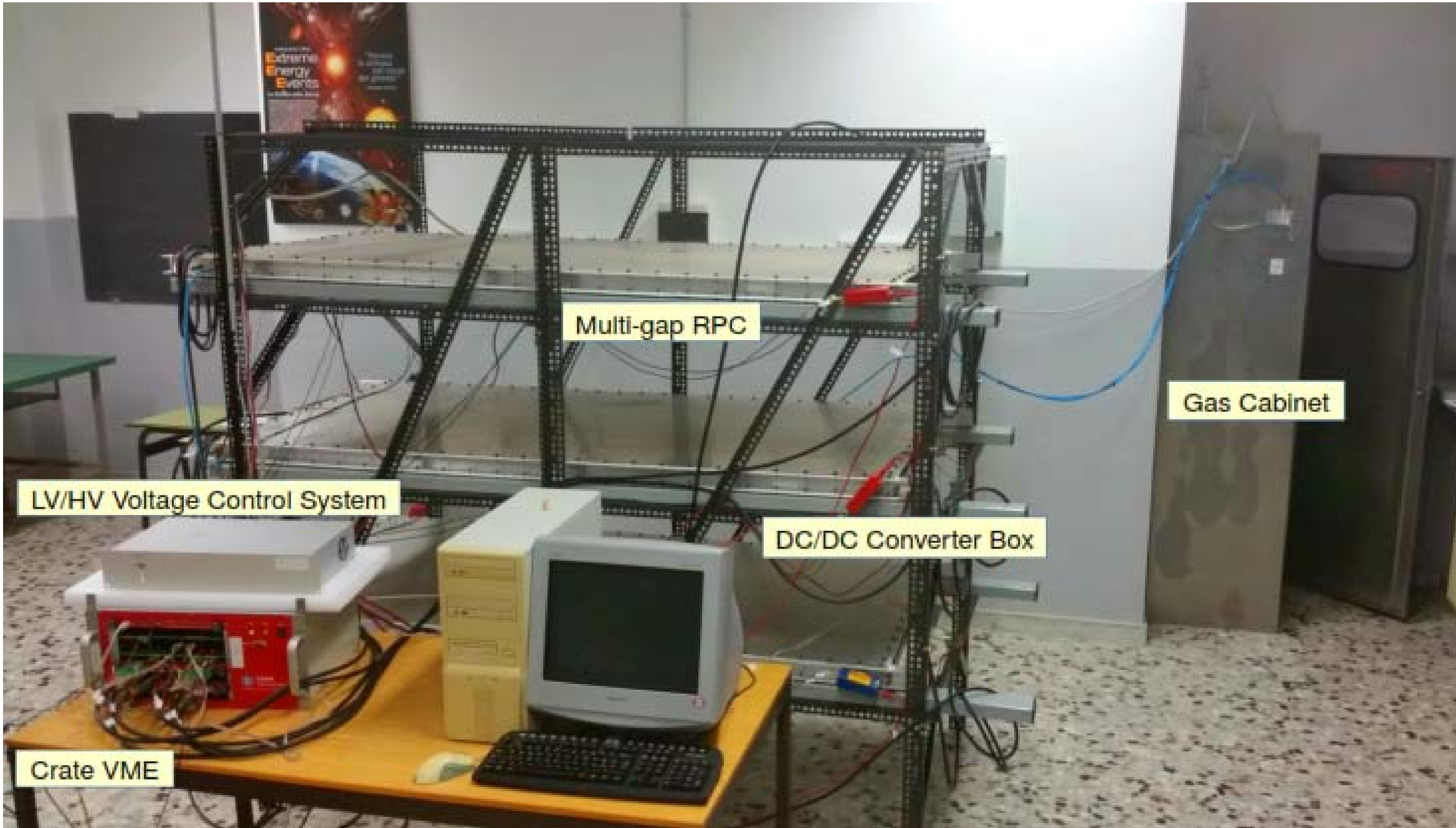
✓**Large size, low cost MRPCs:**
1.58×0.82 m^2, readout copper strips;

✓**6 gas gaps: 300 μm, spaced by fishing line**
From 2018: 55 new Chambers → 250 μm gaps:

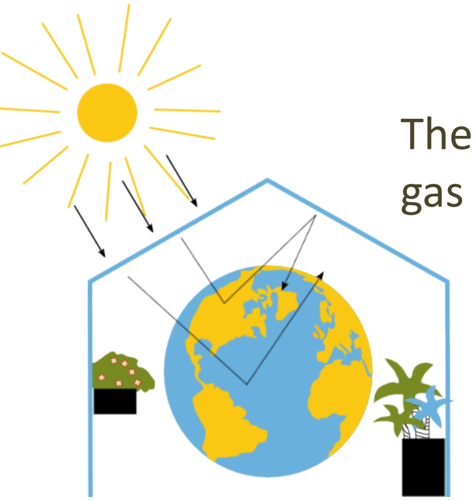
✓**A mixture of $C_2H_2F_4$ (R134a) and SF6 98/2**
flowed in daisy chain at atmoshperic pressure, with a flow of ≈ 2-3 l/h

Extreme Energy Events
Science inside Schools

The EEE telescopes



The GAS issue in EEE



The Global Warming Potential measures the **« greenhouse effect »** of a gas normalized to CO_2.

Mixture used in the EEE MRPCs :
R134a /SF_6 98/2 → GWP ≈1880

62 telescopes with a flow of 2 l/h → ≈ 10^6 l/year

EEE strategies to reduce the greenhouse gas emissions from the EEE MRPC array

The EEE Collaboration has started 3 important actions:

- Gas flow reduction
- Gas recirculation system
- Eco-friendly gas mixtures

EEE gas flow reduction campaign

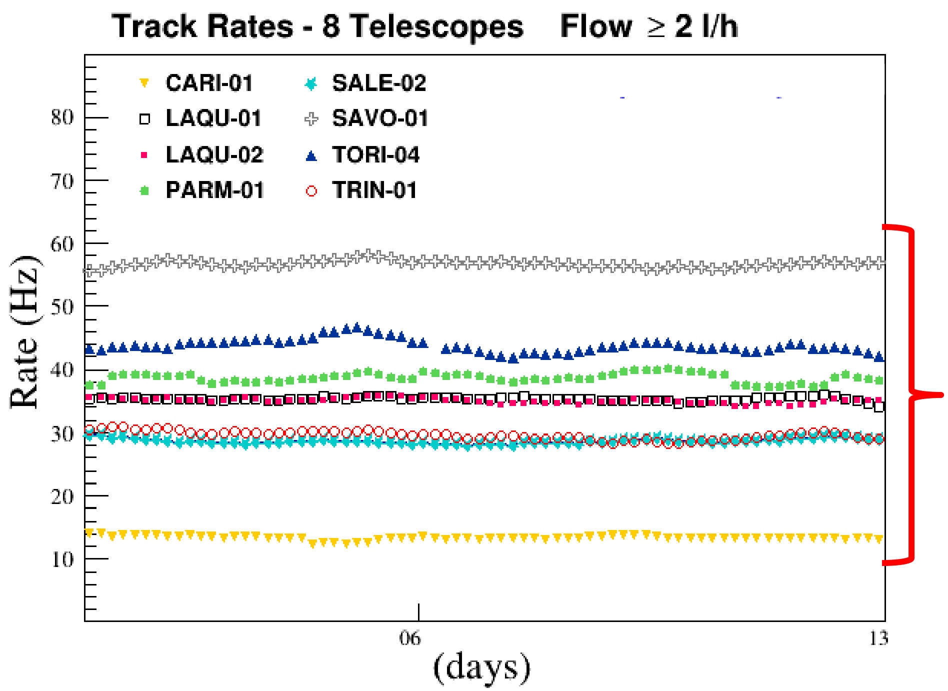
The flow reduction campaign started in September 2019 → stopped in March 2020

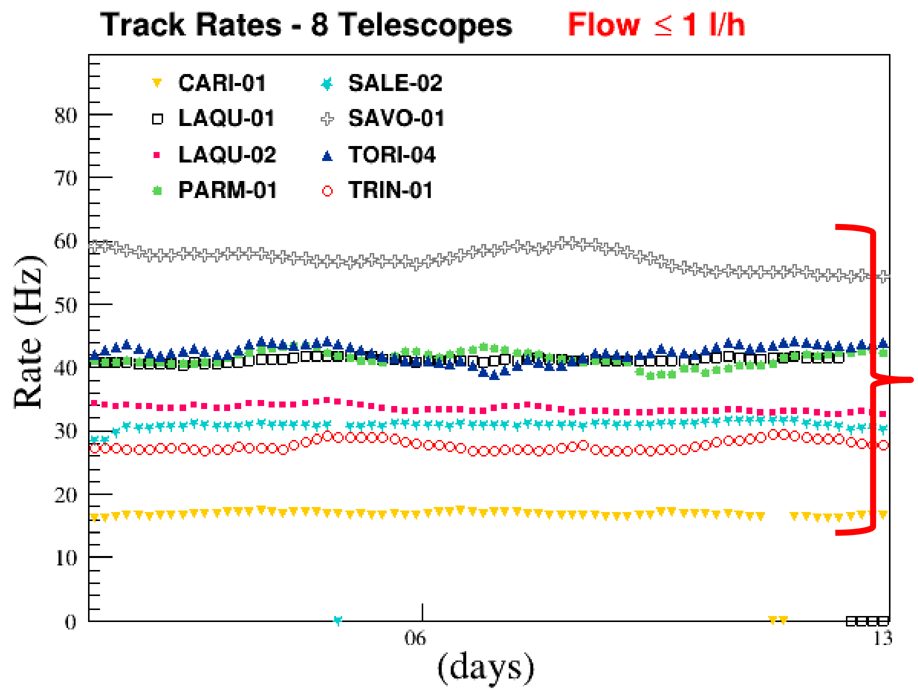
from 2-3 l/h -> 1 l/h

When about 60% of the EEE telescopes was able to operate with a ≈ 1 l/h gas flow

The MRPCs for tracking cosmic muons can operate at a lower flow, and their performance is not affected by flow reduction

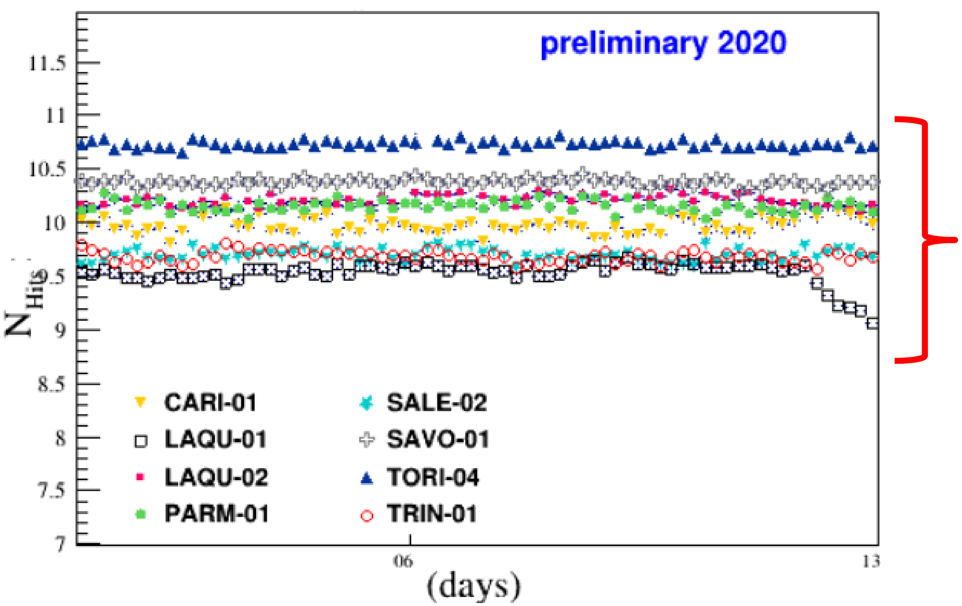
Muon track rate: comparison before/after

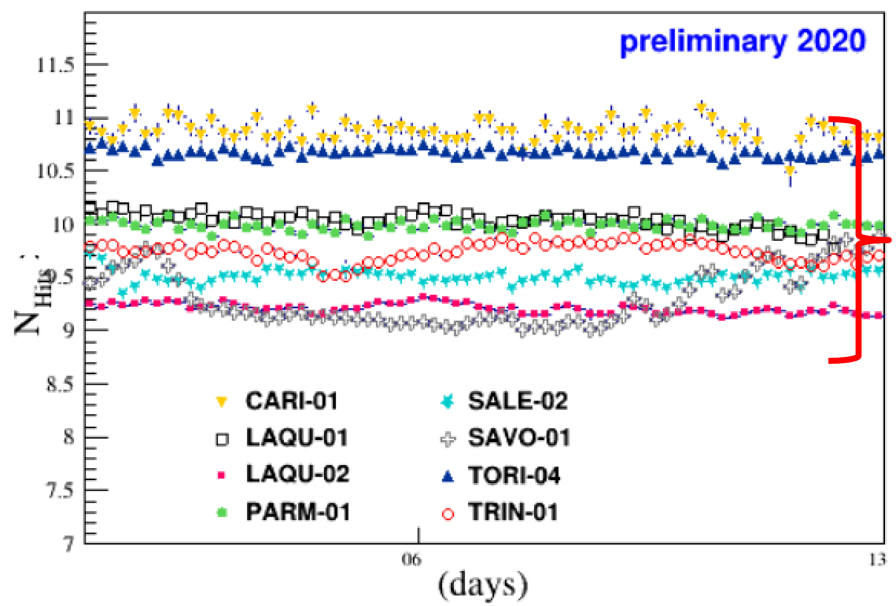




Gas flow reduction campaign

Strip multiplicity (whole telescope): comparison before/after





Remarkable stability considering the different conditions in: **Temperature, external pressure, efficiency fluctuations** in a time lapse of **a year between the two data samples.**

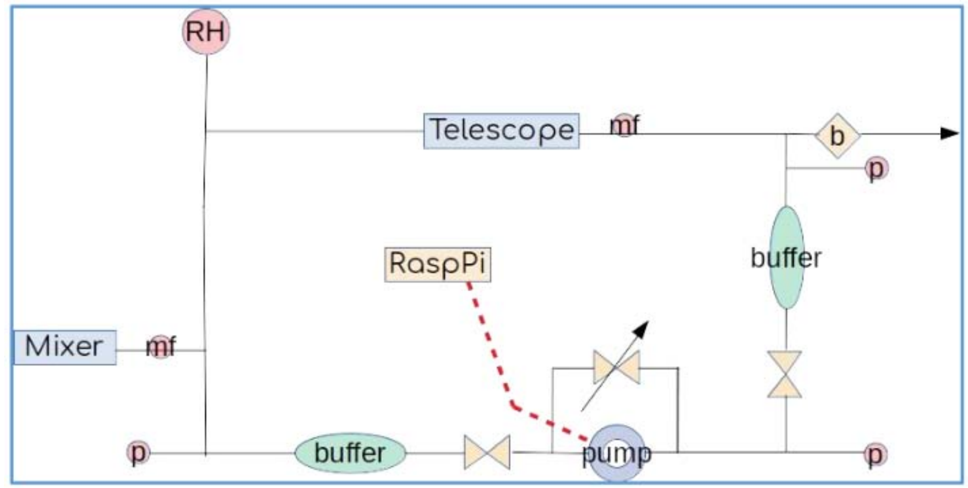
Average value	*Flow ≥ 2 l/h*	*Flow ~ 1 l/h*
Time Resolution σ_t	237 ± 67 ps	238 ± 40 ps
Longitudinal Res. σ_x	1.48 ± 0.04 cm	1.4 ± 0.1 cm
Trasversal Res. σ_y	0.92 ± 0.01 cm	0.93 ± 0.05 cm

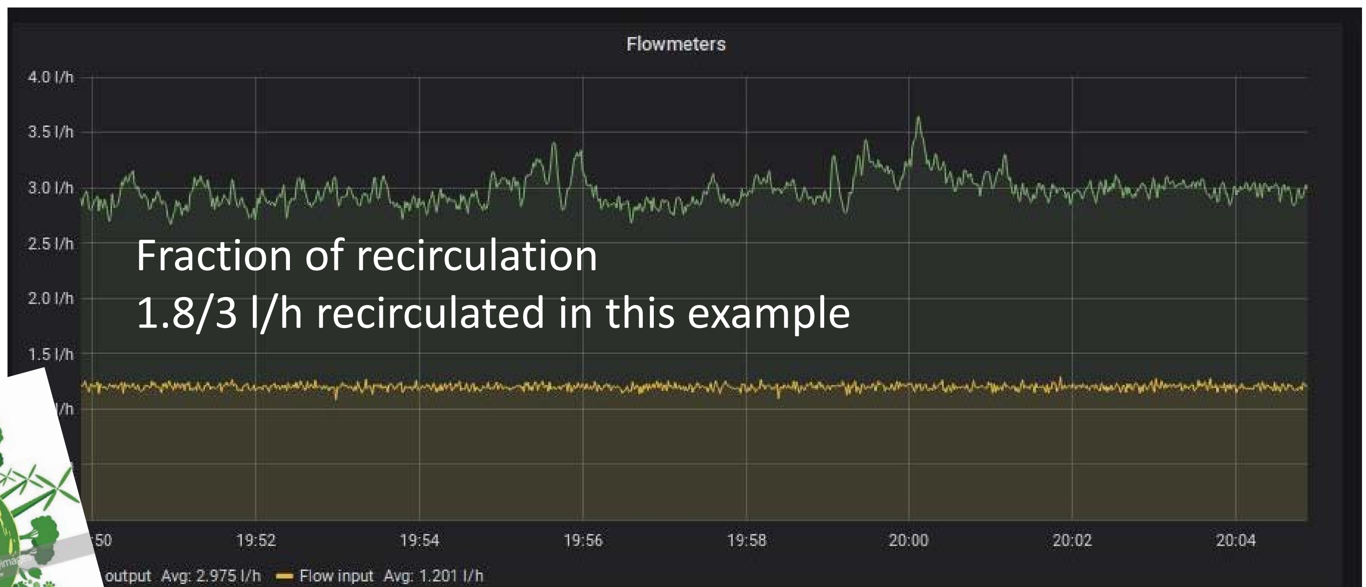
Spatial and Time resolutions not affected by gas flow reduction.

The EEE gas recirculation system prototype

A recirculation system was installed and studied on a EEE Telescope at CERN
* thanks to CERN Gas Group

OUR GOAL:
A simple, small, easy-to-use, low cost system to be eventually installed in each EEE Station





At present the prototype can reuse a flow fraction ≈ 60%

Some numbers on equivalent CO_2 production

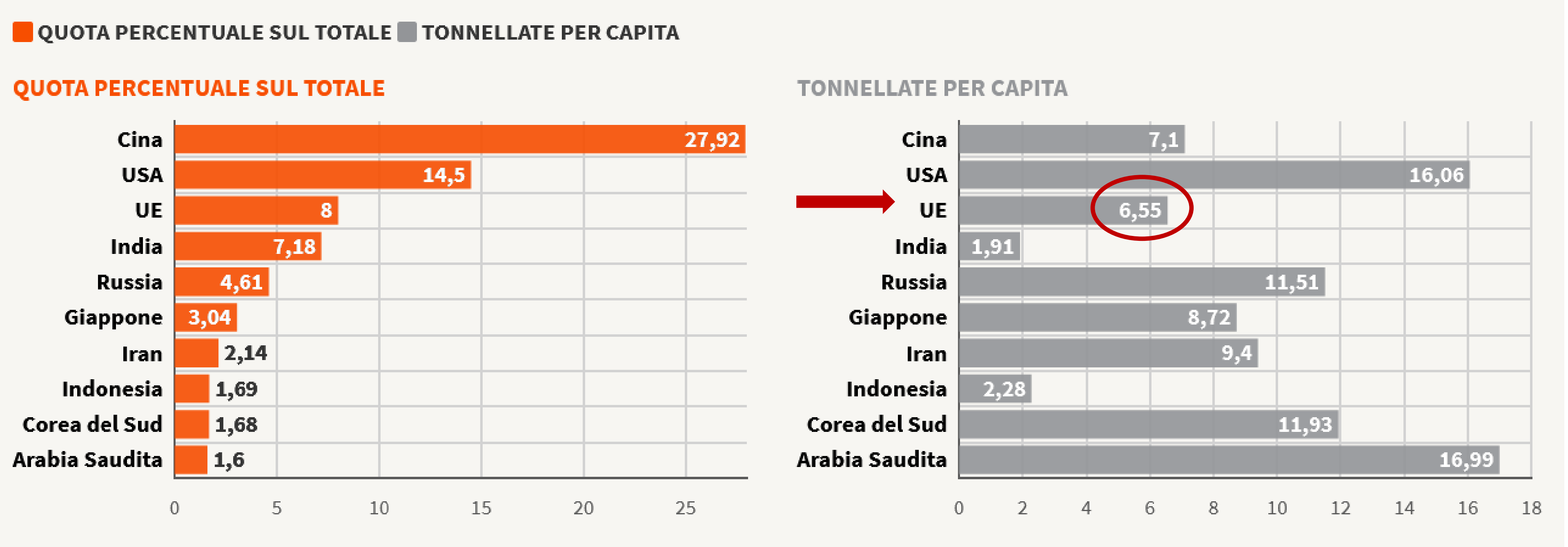
1 EEE telescope uses about 1 l/h of $C_2H_2F_4/SF_6$ 98/2 gas mixture
→**8760 liters per year** (when continuously operating, h24, even during August, Christmas, etc.)

Since the densities of $C_2H_2F_4$ = 4.25 kg/m^3 and of SF_6 = 6.17 kg/m^3, this corresponds to inject into the atmosphere, each year:
36.5 kg of $C_2H_2F_4$ and 1.1 kg of SF_6

However, the Global Warming Power (GWP) of $C_2H_2F_4$ is 1430 the one of CO_2 (namely 1 ton of $C_2H_2F_4$ injected warms the Earth like 1430 of CO_2), and GWP(SF_6) = 23900

So, one EEE telescope injects into the atmosphere gas, for a GWP equivalent to **78.5 tonnes of CO_2 per year:**
36.5 kg x 1430 + 1.1 kg x 23900 = 52200 kg + 26300 kg = 78500 kg

Amount of CO_2 produced in the world



An EU citizen injects about 6.55 tons/year in the atmosphere
→ One EEE telescope roughly emits the CO_2 equivalent to 12 **(twelve) people**

New ecofriendly mixtures in EEE: a BIG problem

For the EEE telescopes we are limited to:

-**Use binary mixtures,** since we have just two flowmeters

  -Not possible (too expensive to add another mass flowmeter to the whole EEE network)

  -An easier solution could be found using ternary or quaternary mixtures

- Mixtures that have a **working point close to the present ,** < 20 kV

  -Not possible (too expensive) to replace the present HV power supply in the whole network

The new EEE **binary** gas mixture must have:

✓a low GWP

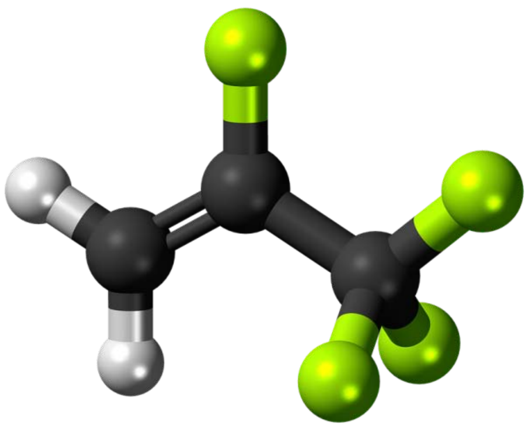
✓guarantee spatial and time resolutions compatible with physics

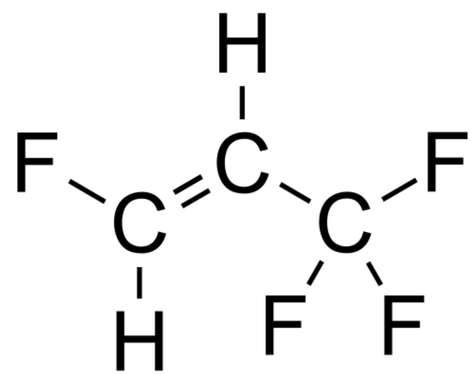
✓must be safe (we cannot use hydrocarbons)

✓must have a similar cost wrt. present one

Basic trendlines in EEE

- Research trendlines are concentrated around the idea of replacing:
- $C_2H_2F_4$ (GWP=1430)→ $C_3H_2F_4$ze (GWP=4)
- SF_6 (GWP=23900) → CO_2 (GWP=1) or He (GWP<1)





-$C_3H_2F_4$ze (HFOze for the sake of brevity) is the most similar molecule to $C_2H_2F_4$ but with a low GWP;

- He and CO_2 are used to reduce the operating voltage with respect to pure HFO → main drawback: less quenching with respect to standard mixture

Extreme Energy Events
Science inside Schools

Would it be a solution?

A mixture made out of $C_3H_2F_4$ /He 50/50 would have **GWP=2.5**

→ An EEE telescope would inject in the atmoshpere a gas whose GWP would be equivalent to **89.5 kg/year of CO_2**

→ This would roughly correspond to the CO_2 injected yearly by **0.014 human beings living in the EU**.

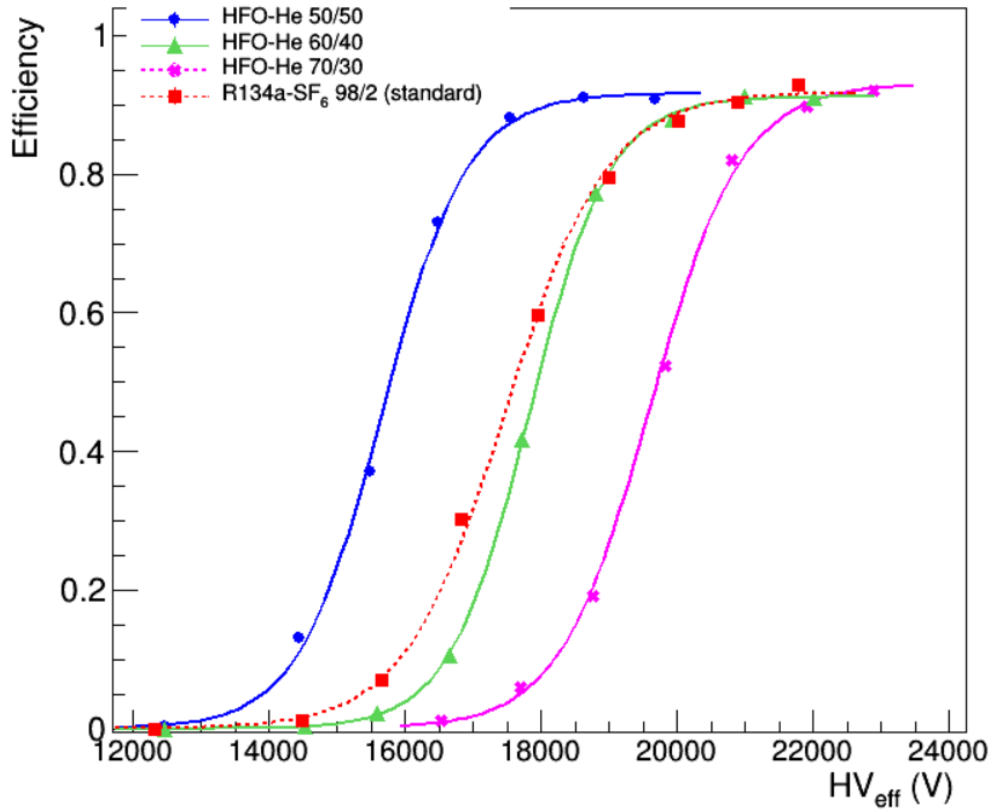
The EEE collaboration started:
-a series of tests at the:
- Rende, Pisa sites → HFO/He
- Bologna, CERN sites → HFO/CO_2

Once the tests completed on HFO/He mixtures, standard data taking (with the telecope **completely filled** with new gas mixture) started both in Rende and Pisa, for several months now.

Rende tests on HFO/He

Basic idea is that **He does not take part in the multiplication processes**

It reduces the partial pressure of the active mixture component, and **the effective operating voltage.**



At Rende, telescope made of 10 years old 300 μm chambers, two used for trigger and tracking, the other filled with the new mixture.

Offline event selection based on data from the 2 trigger chambers:

- β of reconstructed particle in the 0.85-1.25 range
- extrapolated intercept point within the fiducial area on test chambers
- track zenithal angle θ < 25

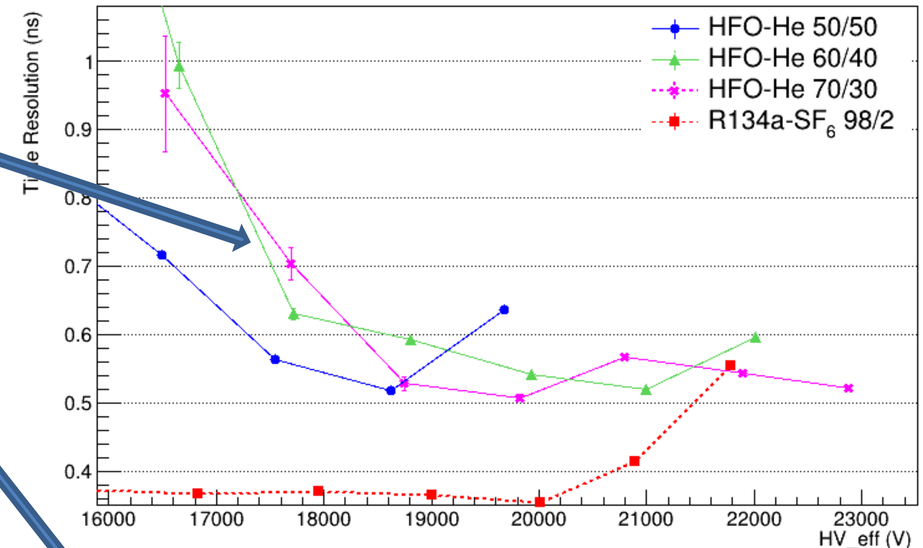
Chamber considered efficient if a cluster is found within 10 cm from the extrapolated intercept point.

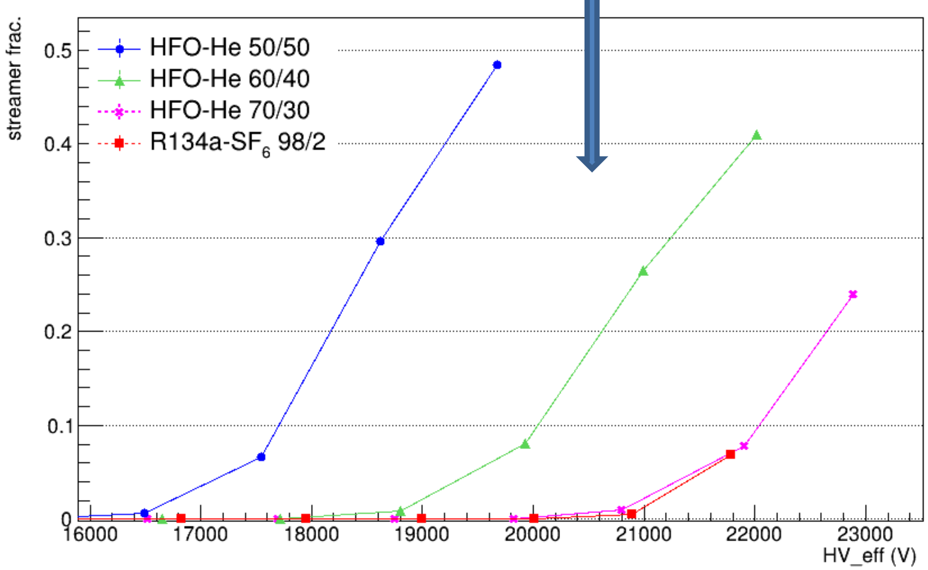
Rende tests with HFO/He

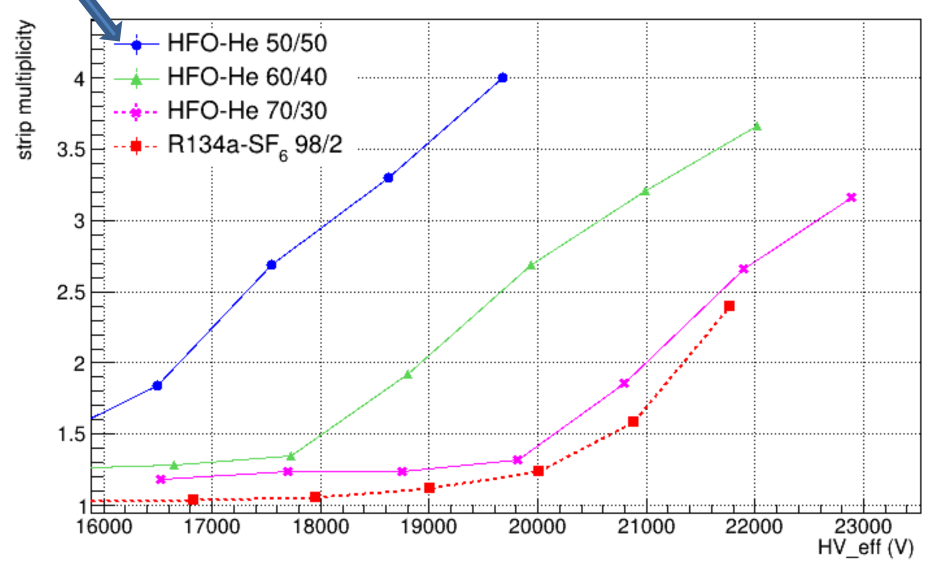
Time resolution: generally worse wrt. standard mixture (lower electron drift velocity)

Strip multiplicity: generally larger wrt. standard mixture (lower electron drift velocity)

Streamer fraction: generally larger wrt. standard mixture (less quenching)





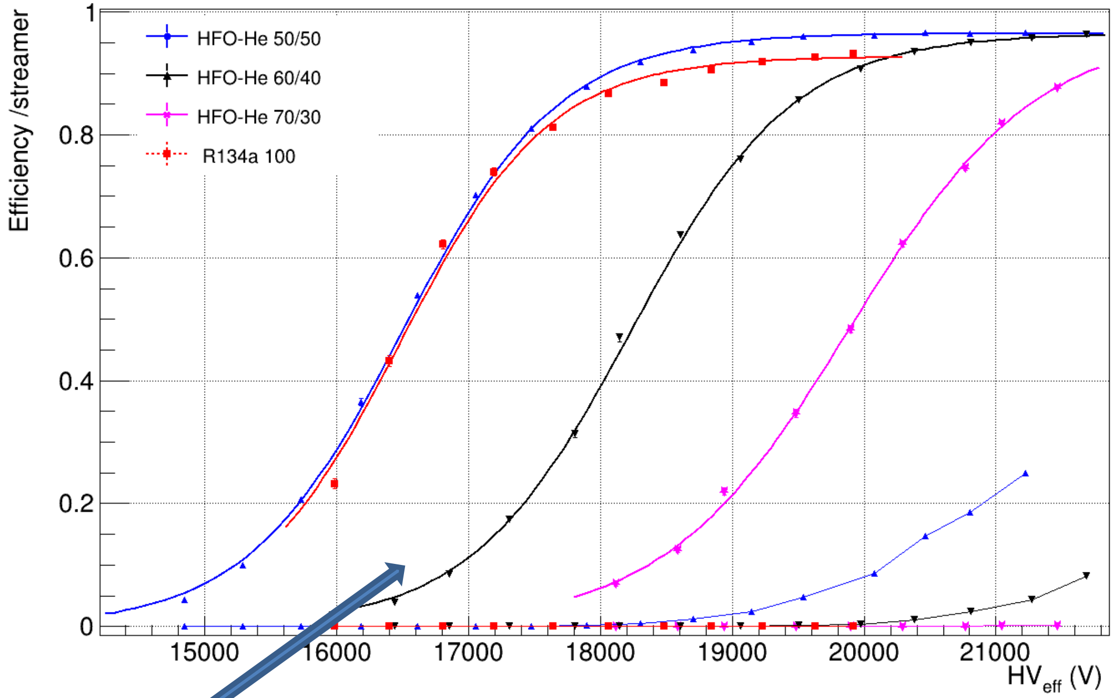


Pisa tests with HFO/He

In Pisa performed similar tests to Rende:
For "historical" reasons comparison done to a mixture TFE 100.

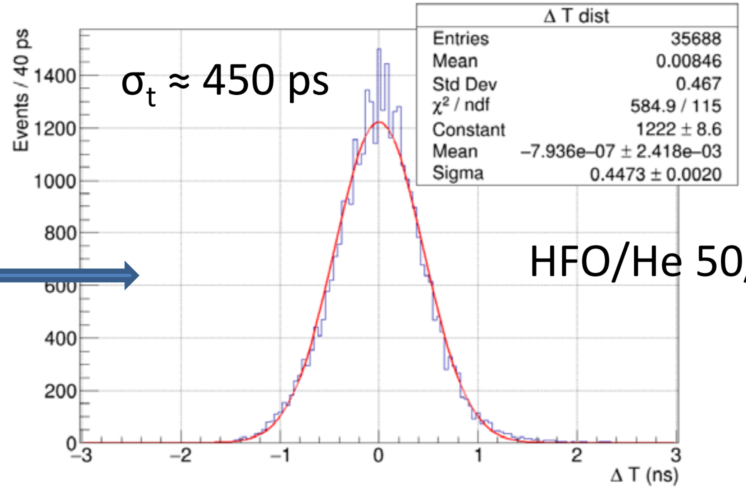
✓HFO/He 50/50 give similar results wrt. TFE 100

✓HFO/He 60/40 give similar results wrt. TFE/SF_6 98/2 (Rende) → expected



Efficiency and streamer fraction

Time distributions

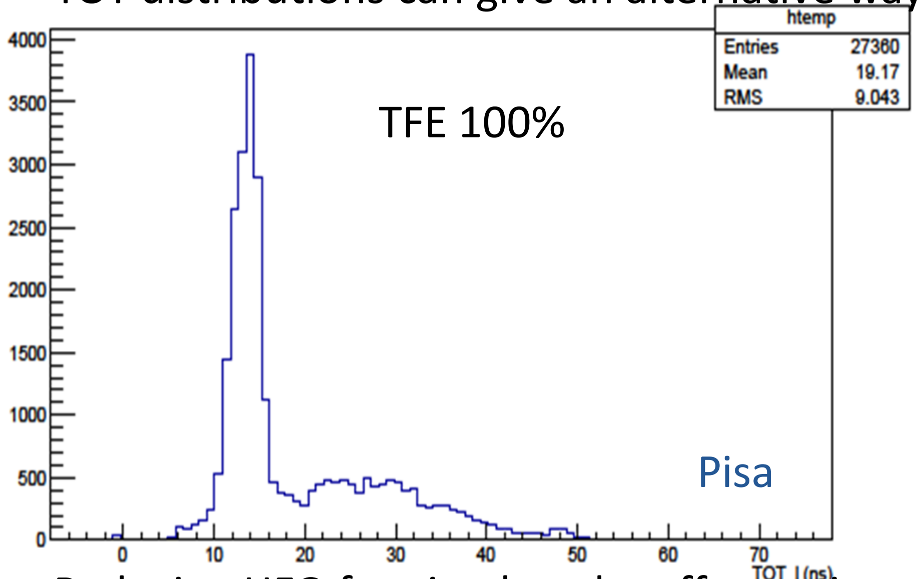


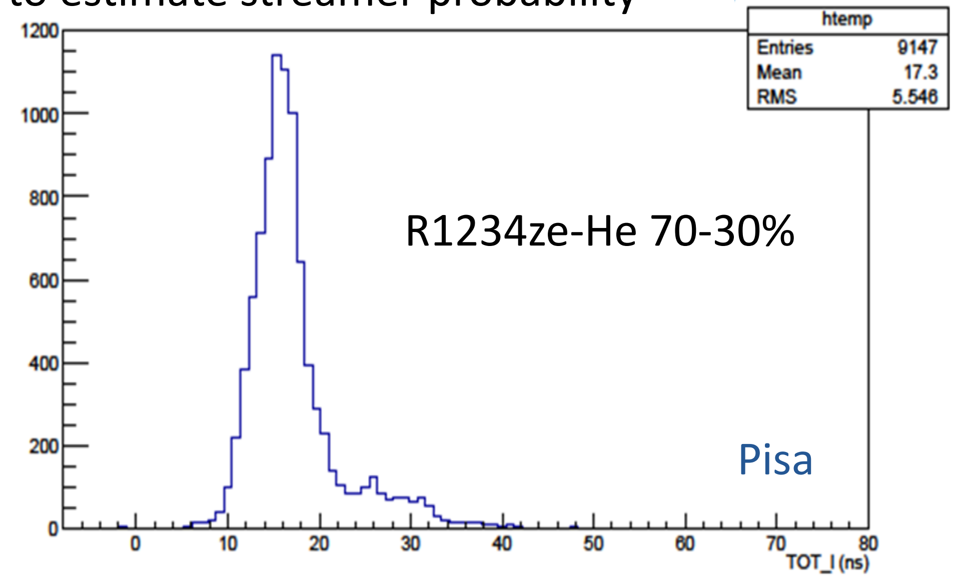
$\sigma_t \approx 450$ ps

HFO/He 50/50

Time Over Threshold comparison

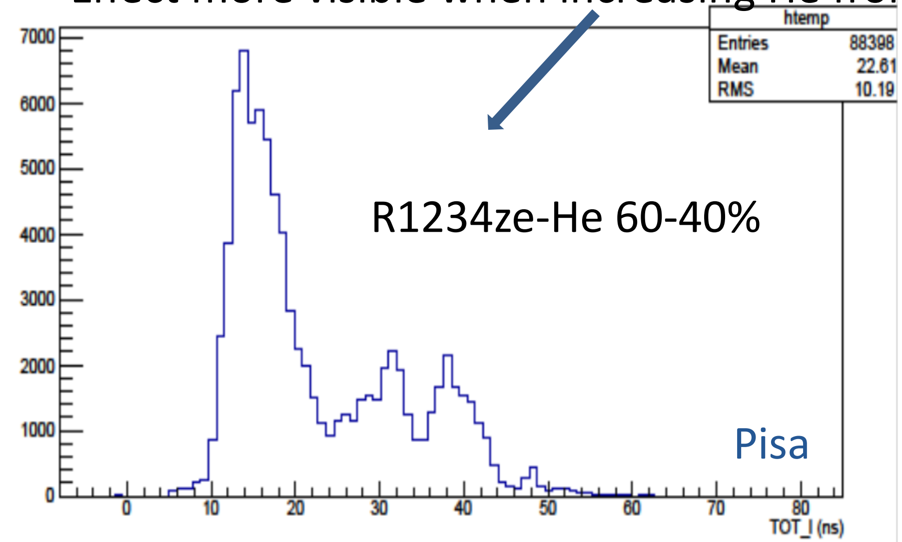
TOT distributions can give an alternative way to estimate streamer probability

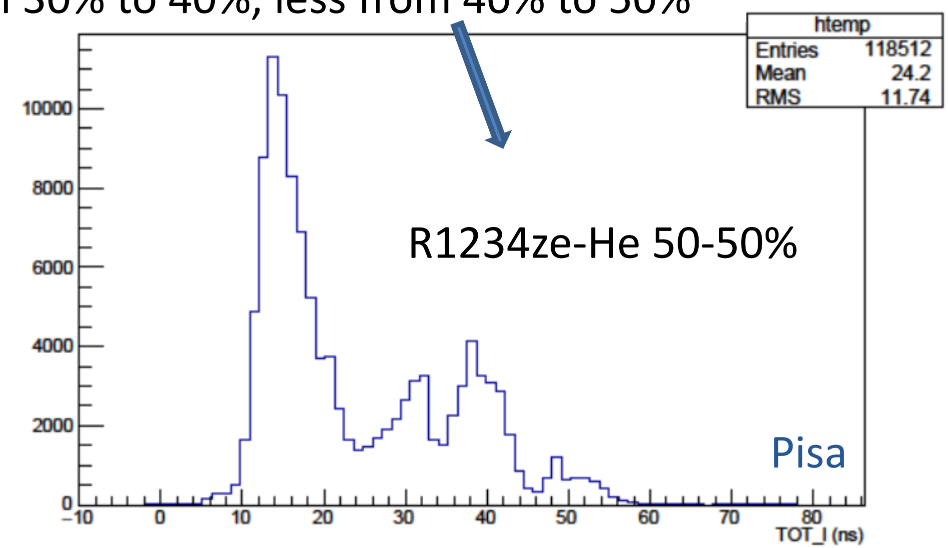




Reducing HFO fraction has the effect to increase the percentage of large TOT events

- Effect more visible when increasing He from 30% to 40%, less from 40% to 50%





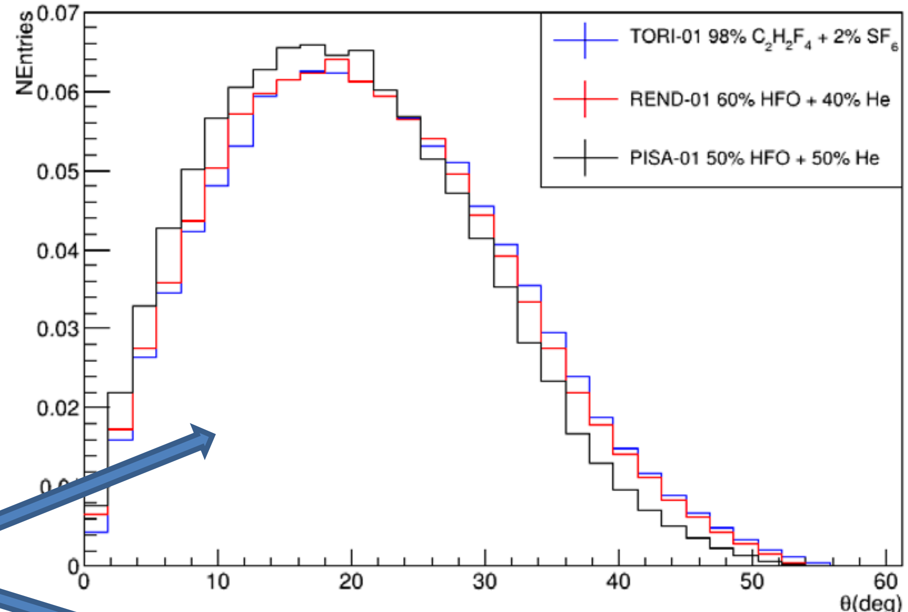
Long term data taking with HFO/He

All three chambers of both telescopes (Rende and Pisa) filled with HFO/He mixtures in different percentages

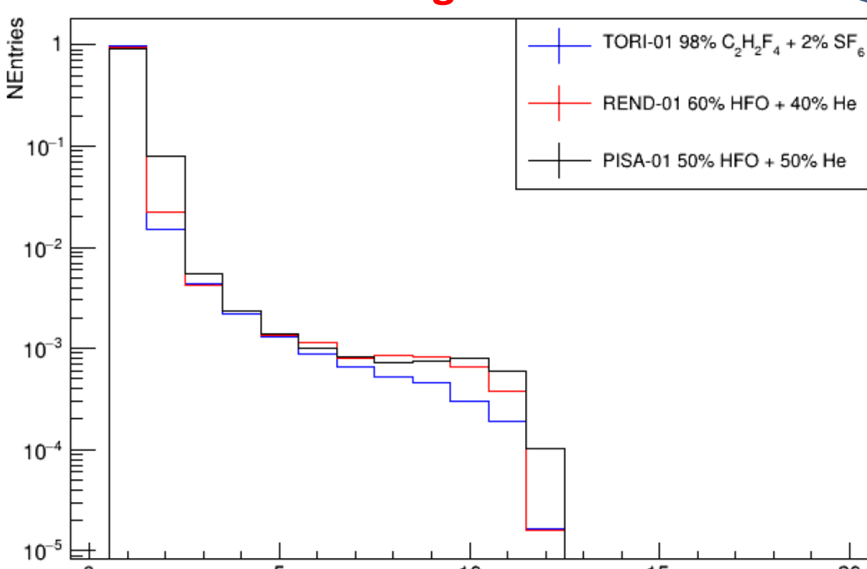
Data taking going on:

-**since beginning of 2022** and continuing at Rende (HFO/He 60/40)

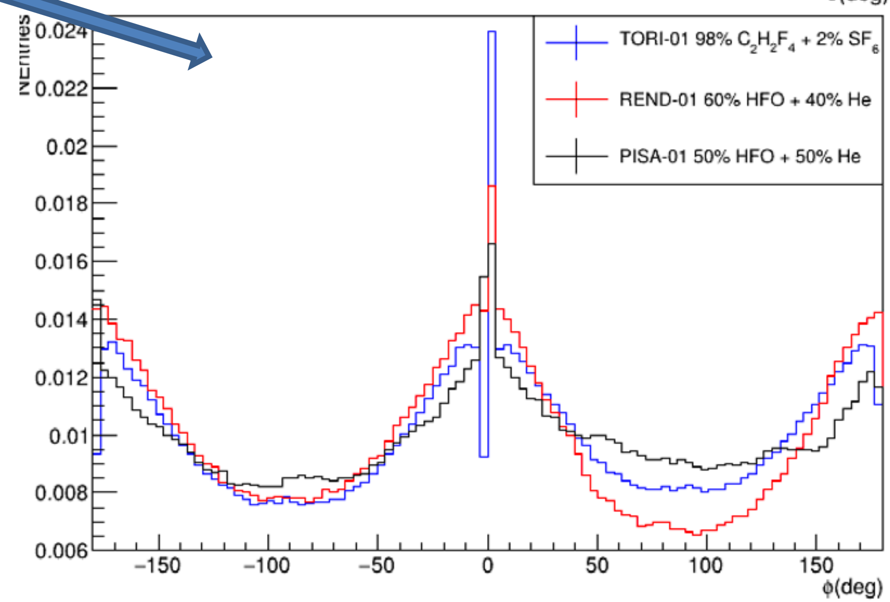
-**Since March 2022** and stopped in June 2022 for an electronic problem at Pisa (HFO/He 50/50)



Muon tracks angular distributions



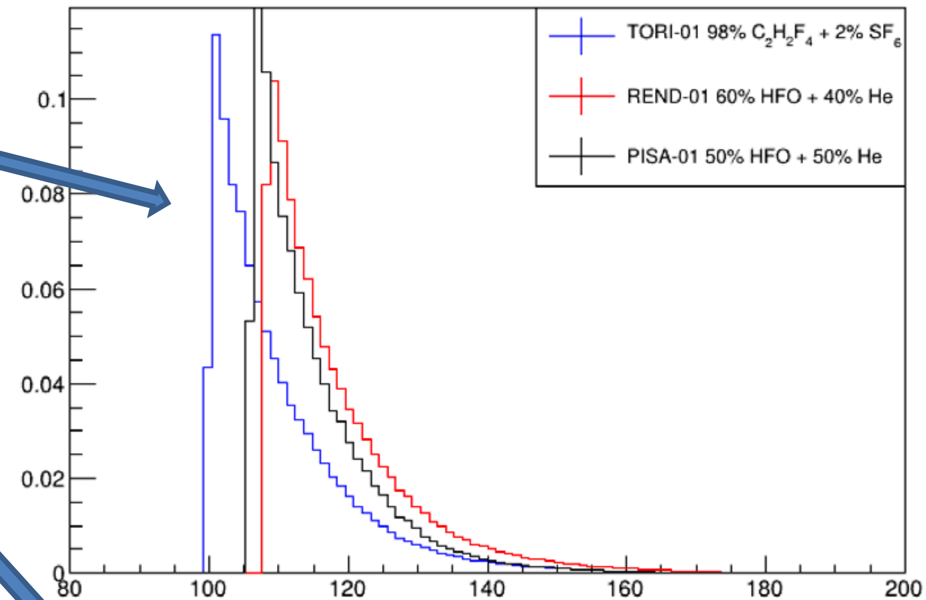
# of reconstructed tracks per trigger



Data taking with HFO/He

Reconstructed muon track lenght:

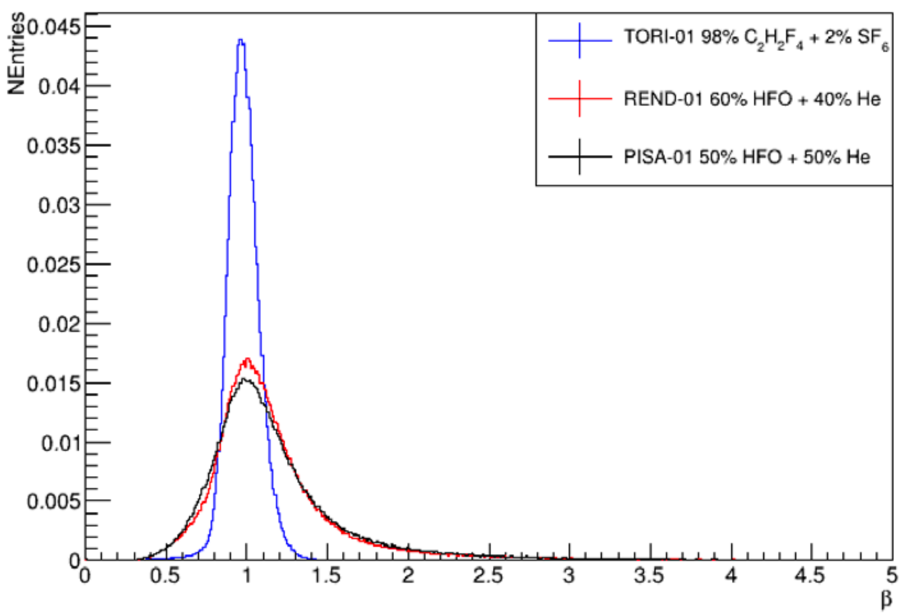
- Minimum track length related to distance between top and bottom chambers: TO 1 m, RN and PI 1.05 m

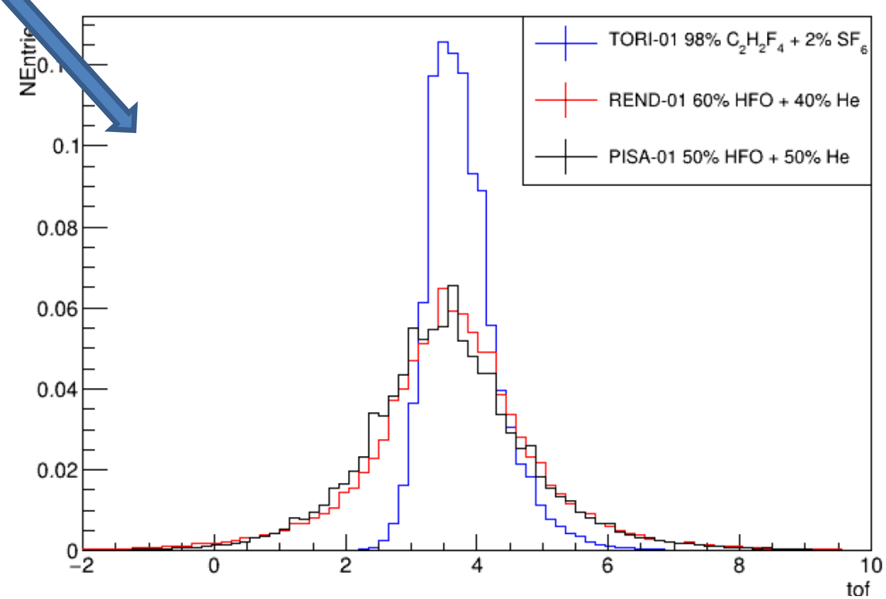


Time Of Flight between top and bottom chambers:

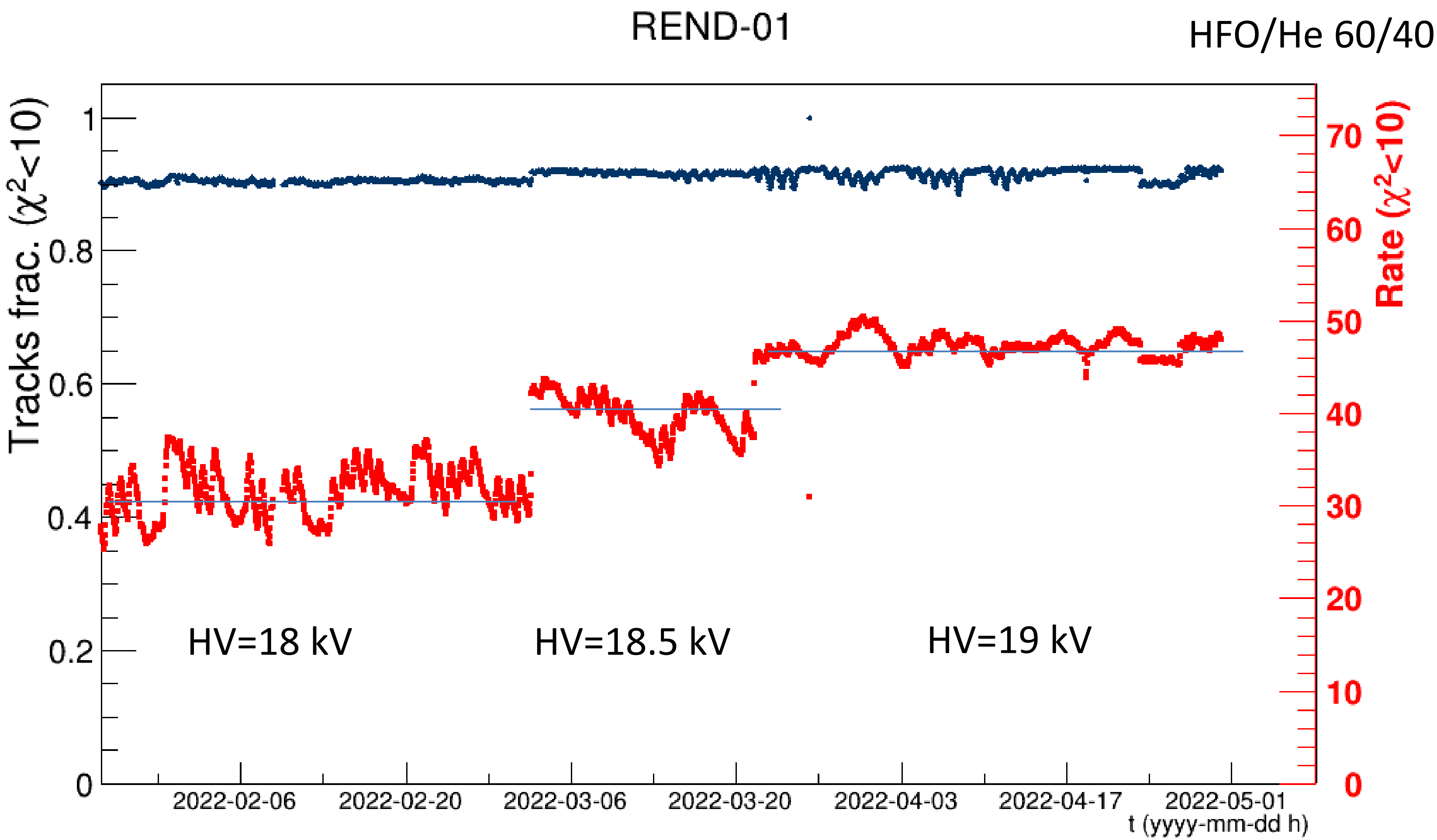
- Larger distribution due to worse time resolution

β of reconstructed muon tracks





Long term data taking with HFO/He

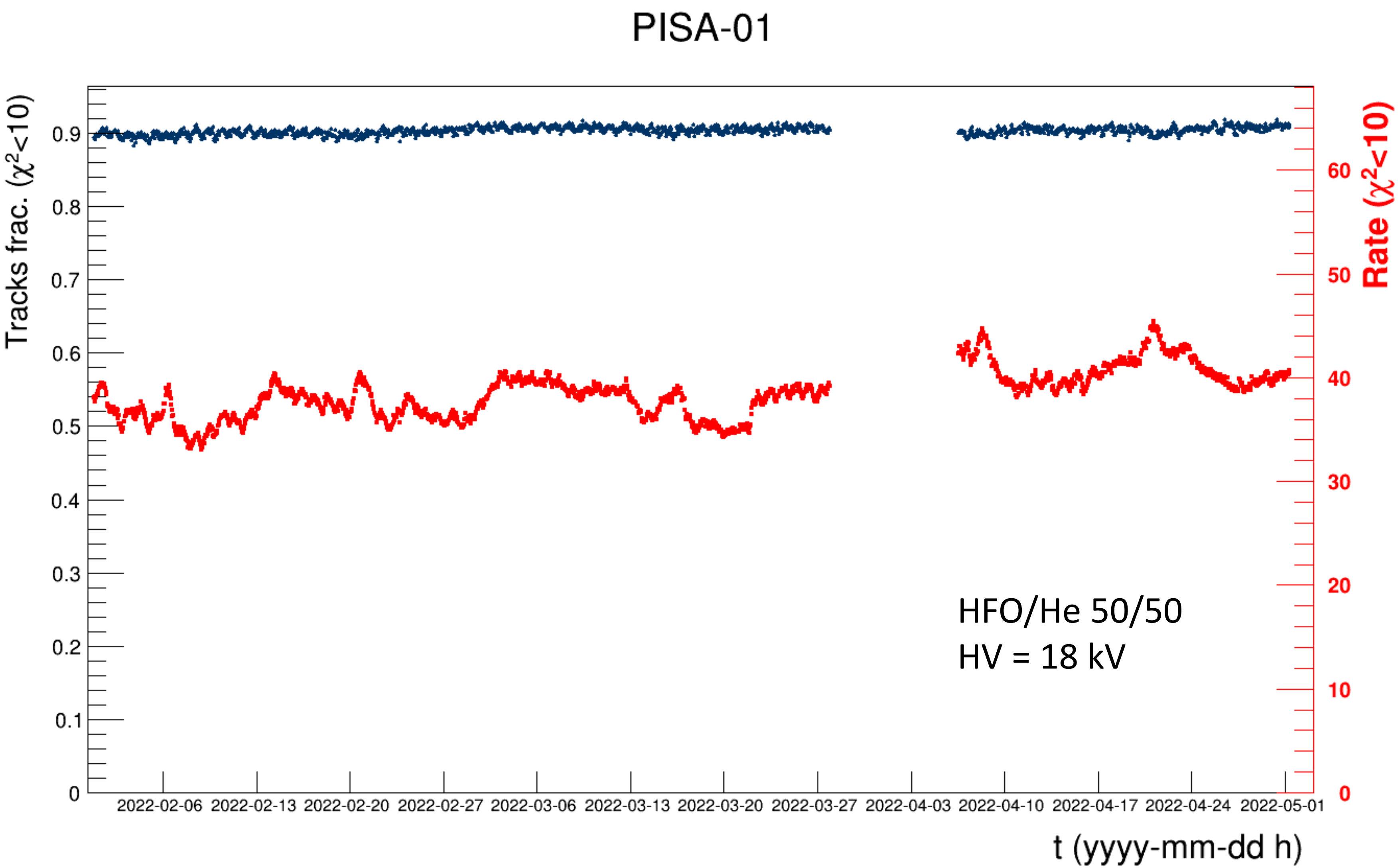


Oscillations due to **temperature variations** inside the hut where the telescope is located

- Oscillations reduced when HV deeper in the efficiency plateau

Apart from that, **remarkable stability**

Long term data taking with HFO/He



Extreme Energy Events
Science inside Schools

Tests with HFO/CO_2

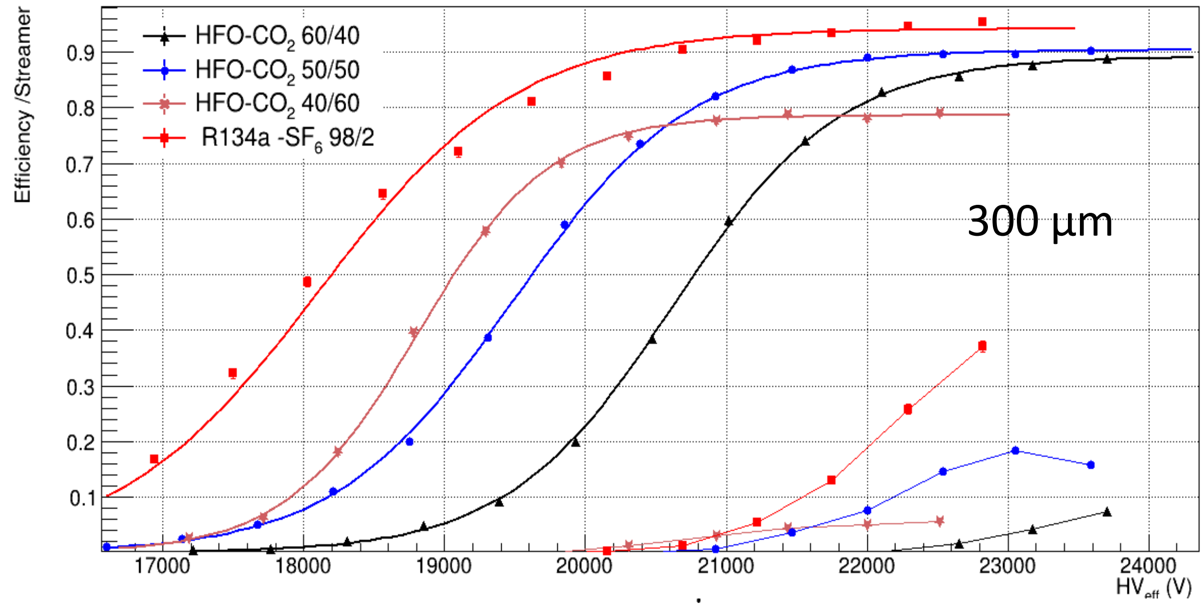
Tests with both 300 (older) and 250 (newer) µm chambers
- CERN and Bologna

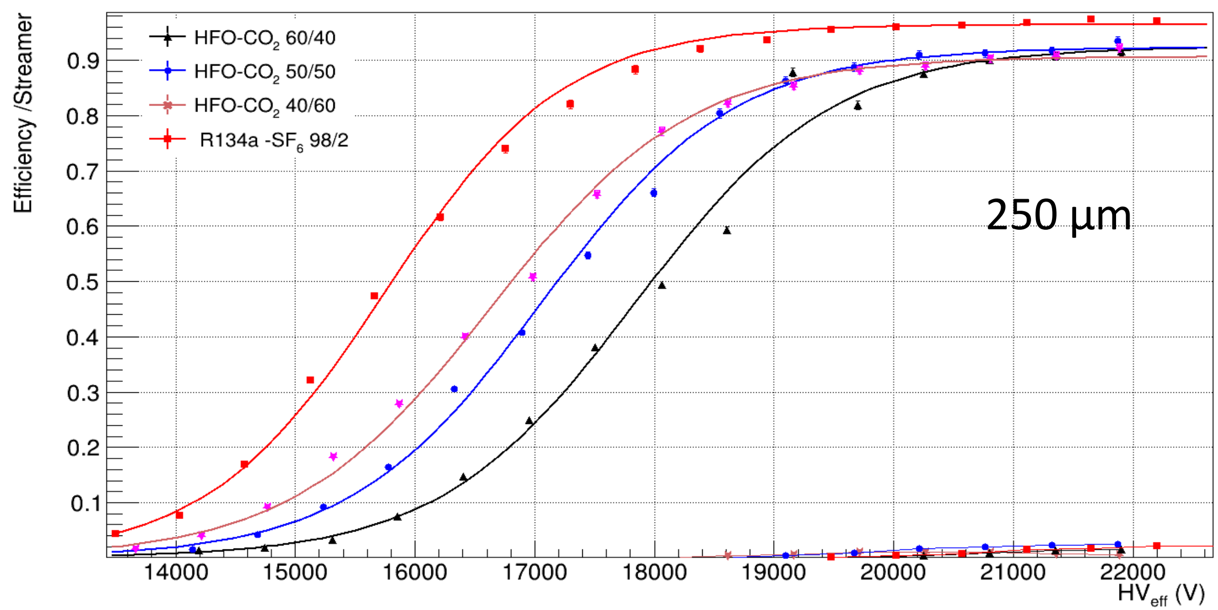
In general a slightly lower efficiency measured with HFO/CO_2 mixtures
- Evident with HFO/CO2 40/60

Higher working point wrt. to HFO/He mixtures (with same percentage of HFO)

Slightly lower streamer probability at the same efficiency
- **Quite low with 250 µm chambers**

Analysis ongoing
- Many tests done

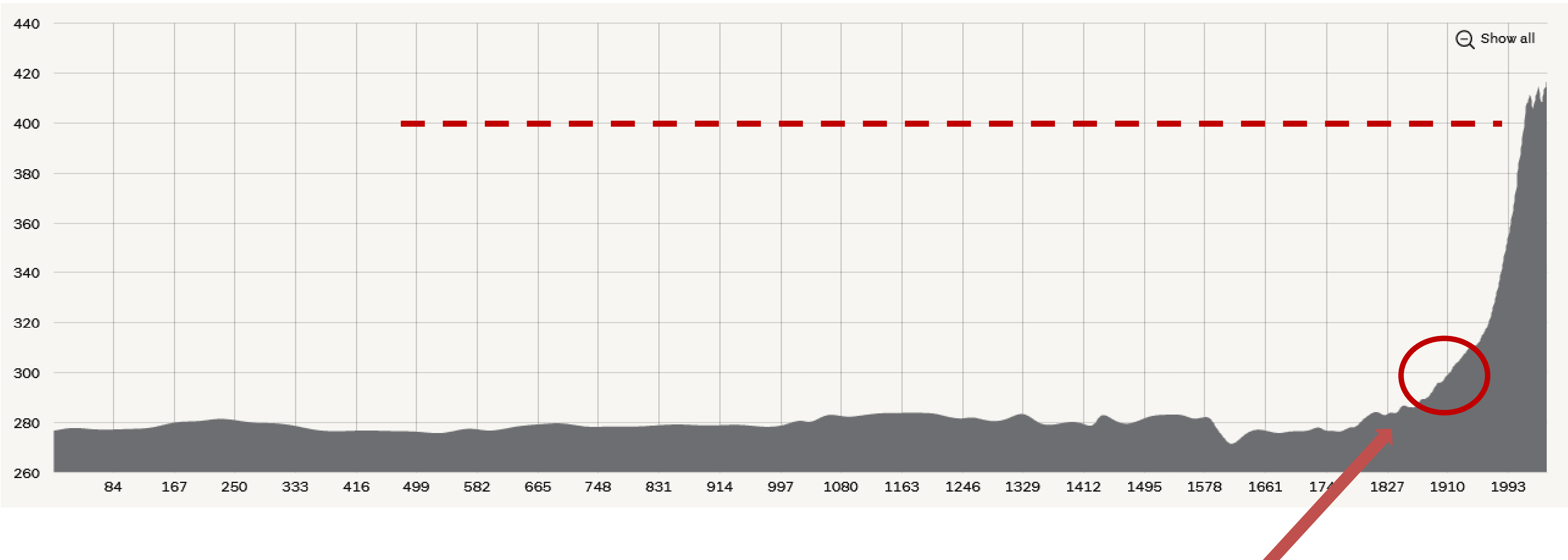




Conclusions

- ✓ The EEE experiment is on the eve **of its ecological transition**.
- ✓ Tests with HFO/He mixtures completed satisfactorily
  - ✓Reasonable efficiency at low HV;
  - ✓Larger cluster size and streamer fraction;
  - ✓Worse time resolution.
- ✓Long term data acquisition with telescopes completely filled with ecofriendly gas mixtures showed **performance completely satisfactory for the physics aim of the experiment**
- ✓Other stations being equipped with new eco-friendly gas an underway for restart
- ✓Achieved a **complete replacement of greenhouse gases with an ecofriendly gas mixture**
  - ✓EEE is running with a fully ecofriendly gas mixture.
- ✓Tests with HFO/CO_2 still on going

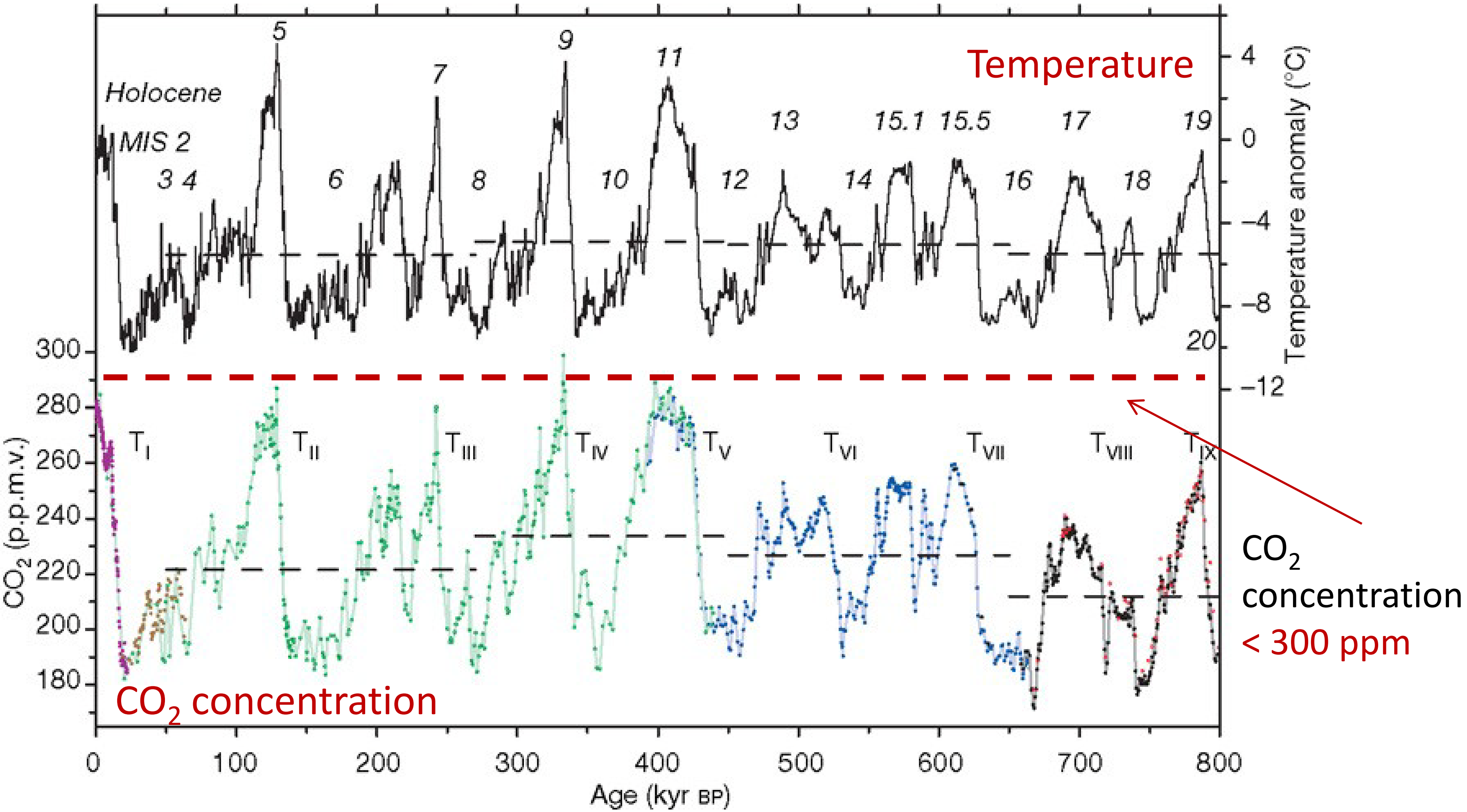
CO_2 concentration: last two thousand years



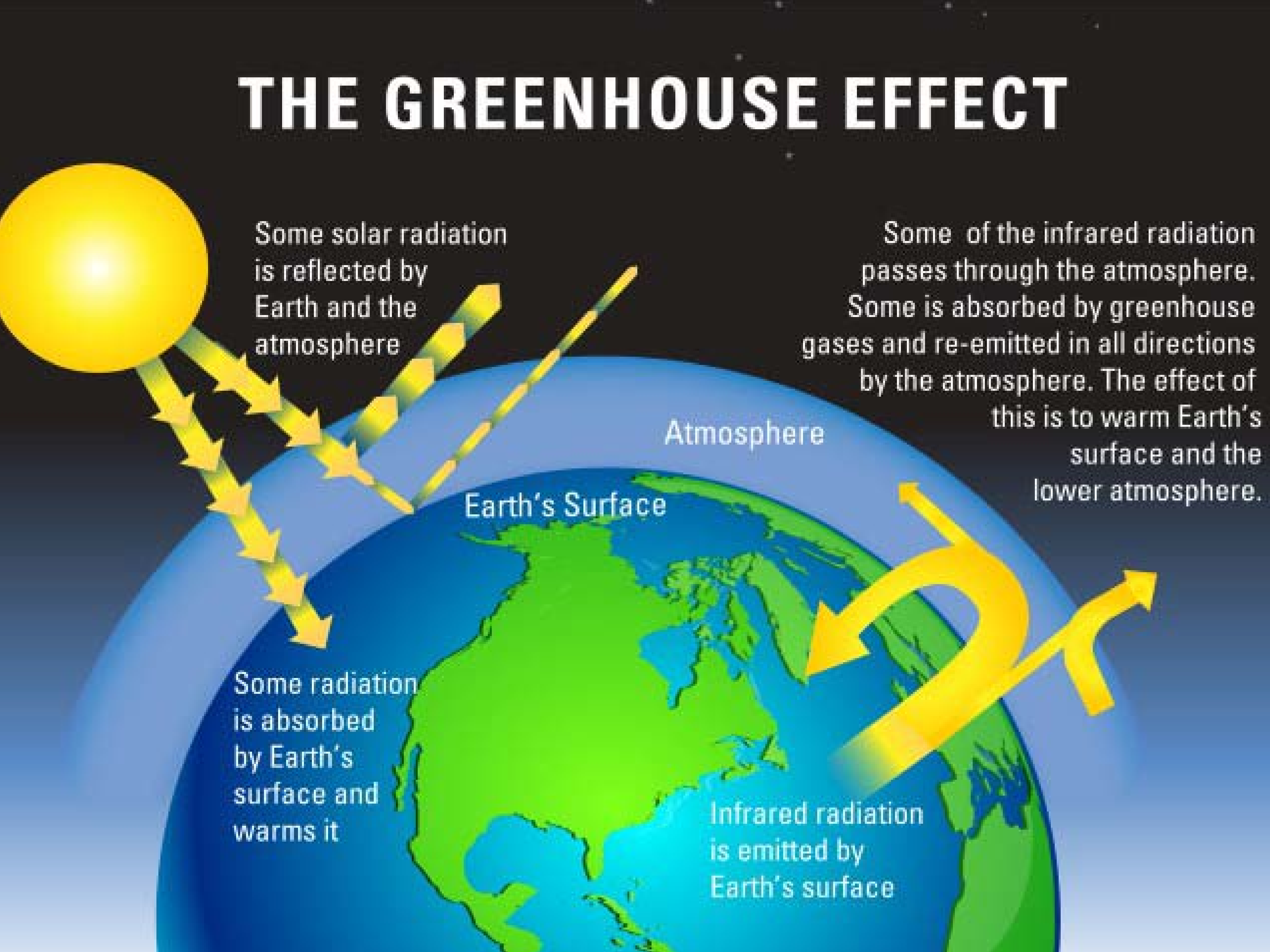
The first time in human history that atmospheric CO_2 exceeded 300 ppm was about the time the **Titanic sank (1912)** in the North Atlantic Ocean. Now, the crossover to concentrations that stay above 400 ppm CO_2 is nearly complete.

An interlude: CO_2 concentration: last million year

Lüthi, D., Le Floch, M., Bereiter, B. *et al.* High-resolution carbon dioxide concentration record 650,000–800,000 years before present. *Nature* **453**, 379–382 (2008). https://doi.org/10.1038/nature06949



We know that atmospheric CO_2 has ranged between 172 and 300 part per million (ppm) for the past 1 million years.


THE GREENHOUSE EFFECT
Some solar radiation is reflected by Earth and the atmosphere
Some of the infrared radiation passes through the atmosphere. Some is absorbed by greenhouse gases and re-emitted in all directions by the atmosphere. The effect of this is to warm Earth's surface and the lower atmosphere.
Atmosphere
Earth's Surface
Some radiation is absorbed by Earth's surface and warms it
Infrared radiation is emitted by Earth's surface