# 66th INFN ELOISATRON WORKSHOP:
# New gas mixtures for RPC and MRPC detectors

# THE EEE PROJECT: TEST AND DATA TAKING WITH ECOGAS

**C.Ripoli*** on behalf of the EEE Collaboration

*University and INFN of Salerno

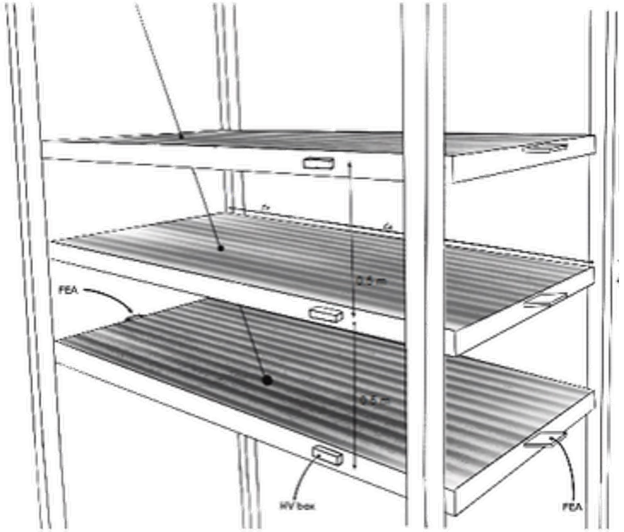
November 21 -23, 2022
Ettore Majorana Foundation and Centre for Scientific Culture

# EEE Project Ecological Transition

The EEE Collaboration started actions to reduce the GHG emissions

**2017 – 2020**

- Gas leak reduction campaign
- Gas flow reduction campaign
- Re-circulation system prototype  test
- Test and analysis data on alternative mixtures (several  % combination)



**2021 – 2022**

- Choice of ecofriendly gas mixtures adopted
- Long term studies to validate the stability
- Ecofriendly gas mixtures deployment
- Data taking with complete replacement of GHG with an ecofriendly gas mixture

# Gas leak reduction

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The gas flow reduction has been preceded by a MRPCs Gas Tightness Test campaign

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


HV connectors, gas connectors, gas pipes, screws and MRPC edges checked and repaired

# Gas flow reduction

Started in September 2019 and stopped in March 2020 due to Covid-19

## Flow reduction 2-3 l/h → 1l/h

~ **65%** EEE detectors work with a flow ~ 1 l/h

## Gas waste decreased by **50%** thanks to flow reduction

The MRPCs for cosmic muons tracking can operate at lower flows, with no impact on performance

**Spatial and Time resolutions not affected by gas flow reduction**

| Resolution avarage value | Flow $\geq$ 2l/h | Flow~1l/h |
|---|---|---|
| Time ($\sigma_t$) | $(237 \pm 67)$ ps | $(238 \pm 40)$ ps |
| Longitudinal ($\sigma_x$) | $(1.48 \pm 0.04)$ cm | $(1.40 \pm 0.10)$ cm |
| Trasversal ($\sigma_y$) | $(0.92 \pm 0.01)$ cm | $(0.93 \pm 0.05)$ cm |

# Gas flow reduction campaign

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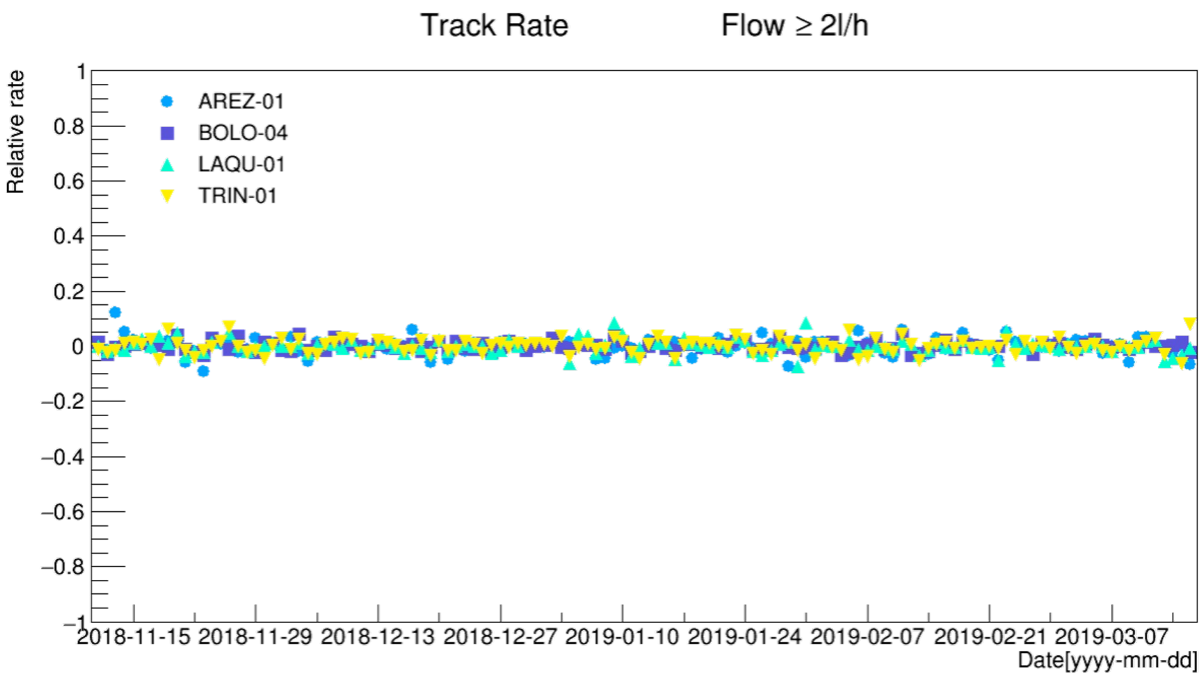
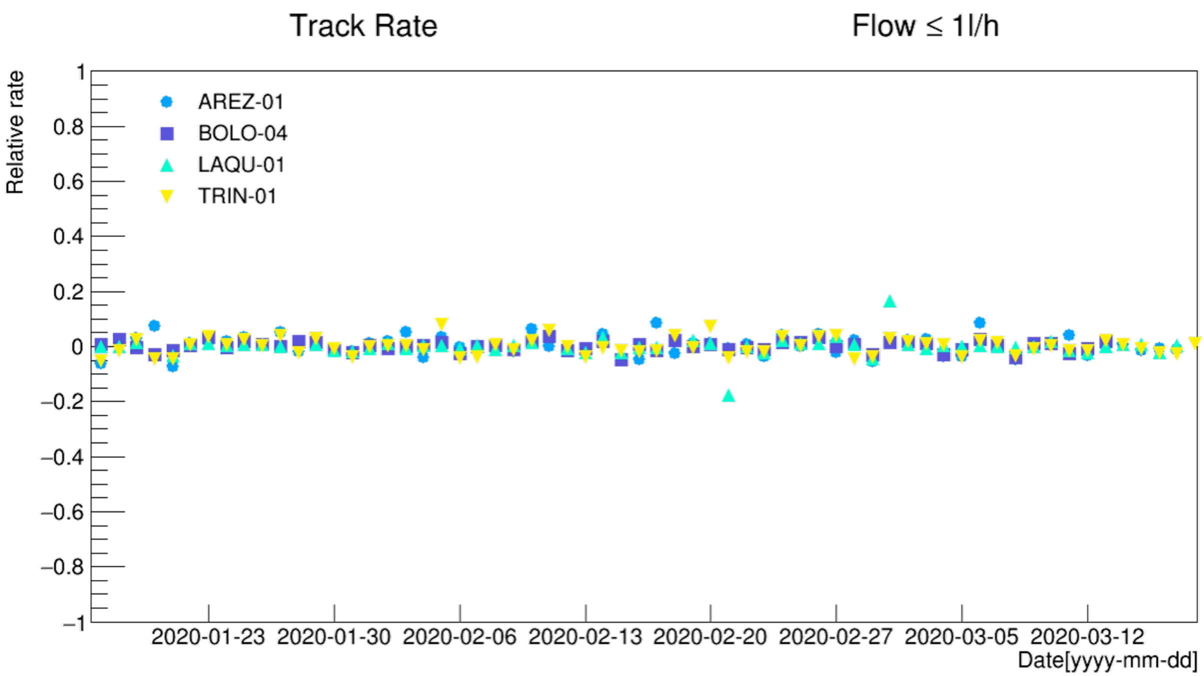
Muon track rate before and after the flow reduction




**Remarkable stability**

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

# The EEE gas re-circulation system

A recirculation system was installed and studied on a EEE Telescope at CERN

*** thanks to CERN Gas Group**

The consumption of gas in the EEE array could be reduced by recycling the gas mixture thanks to this gas recirculation system

**Last test with prototype can reuse a flow fraction ≈ 60%**

**The idea:**

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

# Eco-friendly gas mixtures

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## New mixture main features required:

- Lower GWP compared to the standard mixture
- Similar performance in terms of:

  → Working point < 20 kV
  (as per the current HV power supply )
  → Spatial and time resolutions compatible with physics

- Safety hydrocarbons cannot be used due to flammability issues.
  It could be unsafe and leaks in the current MRPC system would need to be detected adding complexity to the system
- Cost saving
- Binary EEE telescopes have just 2 flowmeters
  The number of flowmeters in EEE Telescope array cannot be changed

# Eco-friendly gas mixtures

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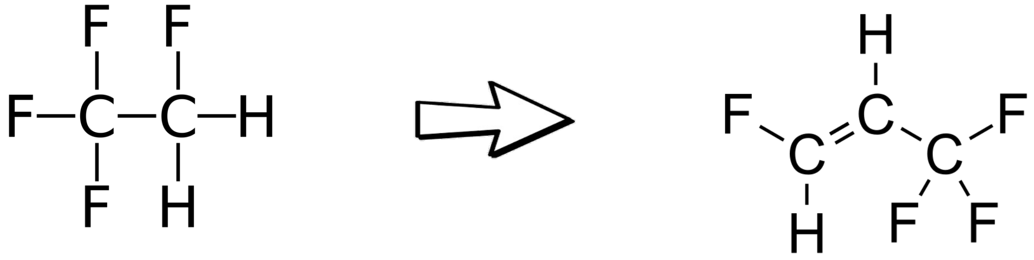
*Standard* mixture adopted in the MRPC EEE telescopes
$C_2H_2F_4$ (98%) + $SF_6$ (2%)
GWP of ~ **1880**

98% $C_2H_2F_4$ + 2% $SF_6$

Just one carbon!



$C_2H_2F_4$
Tetrafluoroethane
GWP = 1430

$C_3H_2F_4$
Tetrafluoropropene
GWP = 6

**$C_3H_2F_4$**
is a good candidate to replace
**$C_2H_2F_4$**

✓ $C_3H_2F_4$ is a good quencher
✓ Too high operating voltage

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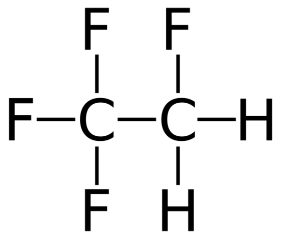

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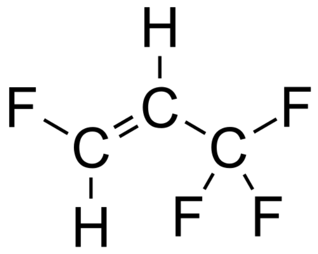

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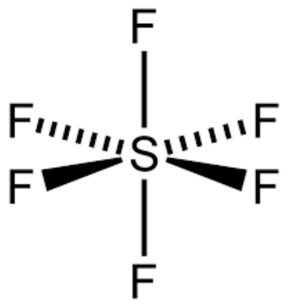
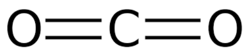


$SF_6$
Sulfur hexafluoride
GWP=23900

He
GWP<1



$CO_2$
GWP=1

✓ He and $CO_2$ are used to reduce the operating voltage wrt pure HFO
✓ Less quenching wrt standard mixture

# Eco-friendly gas mixtures

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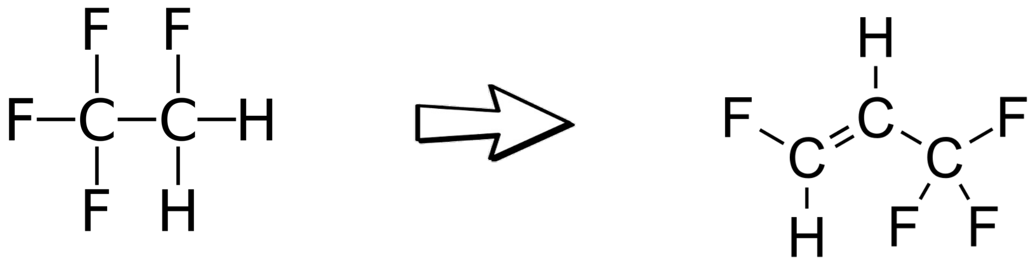

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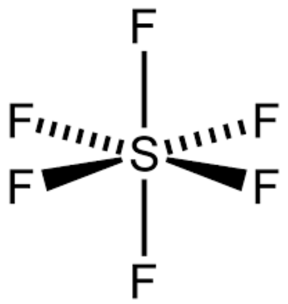

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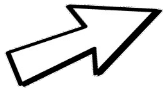
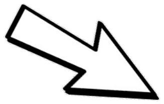
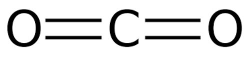


He
GWP<1





$CO_2$
GWP=1


✓ He and $CO_2$ are used to reduce the operating voltage wrt pure HFO
✓ Less quenching wrt standard mixture

# HFO-1234ze based gas mixtures

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Mixtures based on $C_3H_2F_4$ with different percentages of He and $C0_2$ have been tested in order to optimize the HV curve.

***Chosen mixtures based on performed tests***

***$C_3H_2F_4$ + He***

***$C_3H_2F_4$ + $CO_2$***

| Percentage of gas (%) | | | | |
|---|---|---|---|---|
| **$C_3H_2F_4$ + He** | | **$C_3H_2F_4$ + $CO_2$** | | **Pure $C_3H_2F_4$** |
| 90 | 10 | 60 | 40 | 100 |
| 70 | 30 | 50 | 50 | |
| 60 | 40 | 40 | 60 | |
| 50 | 50 | | | |

$C_3H_2F_4$ is a good quencher the streamer percentage is under control, but..

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

**Telescopes involved in gas test**

| TELESCOPE | MIXTURE |
|---|---|
| REND-01 | $C_3H_2F_4$ + He |
| PISA-01 | $C_3H_2F_4$ + He |
| CERN-01 | $C_3H_2F_4$ + $CO_2$ |
| BOLO-01 | $C_3H_2F_4$ + $CO_2$ |

# R&D studies on ecofriendly gases

# Test on ecofriendly gases

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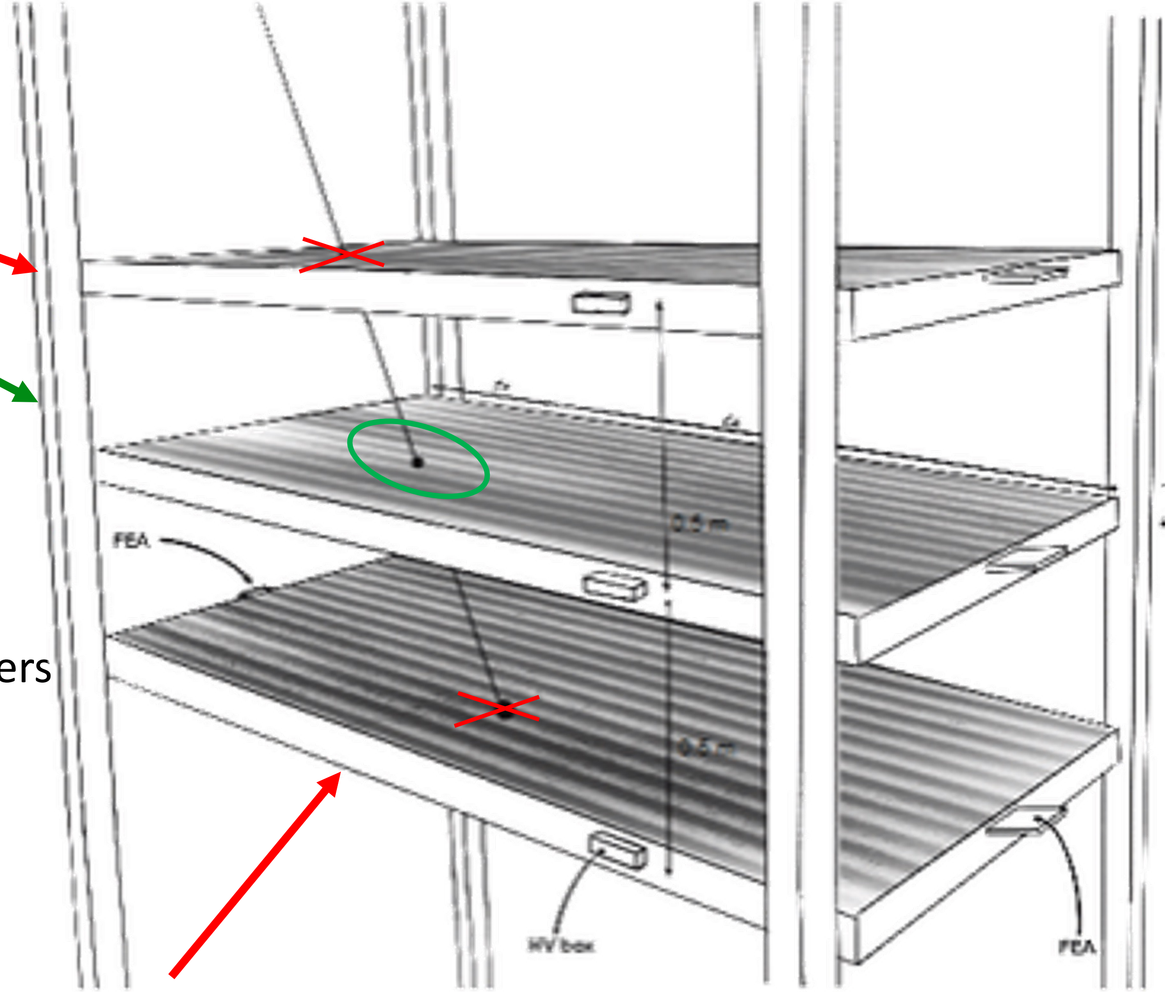
**3 MRPC chambers**:

- two used for trigger and tracking
- one filled with new mixture (under test)



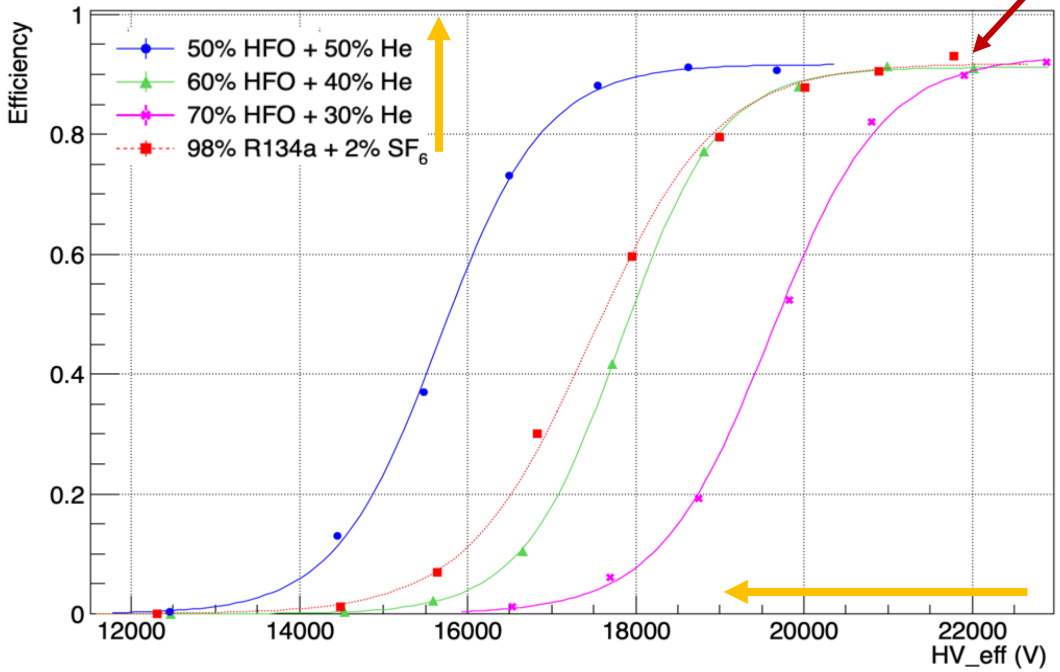

**Offline event selection based on data from the 2 trigger chambers:**
- β of reconstructed particle in the 0.85-1.25 range
- extrapolated intercept point within the fiducial area on test chambers
- track zenithal angle θ < 25

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

# HFO + He test

REND-01
300 μm gap

Higher HV working point ~ 21/22 kV
with respect to standard mixtures




**WORKING POINT**

The WP decreases

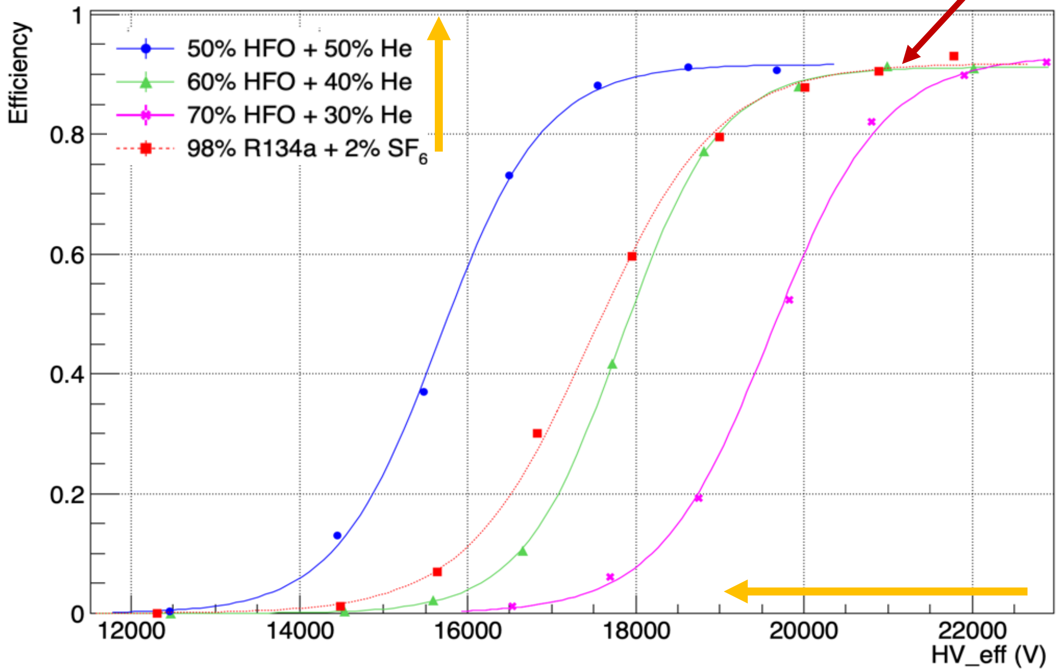
as the He fraction increases

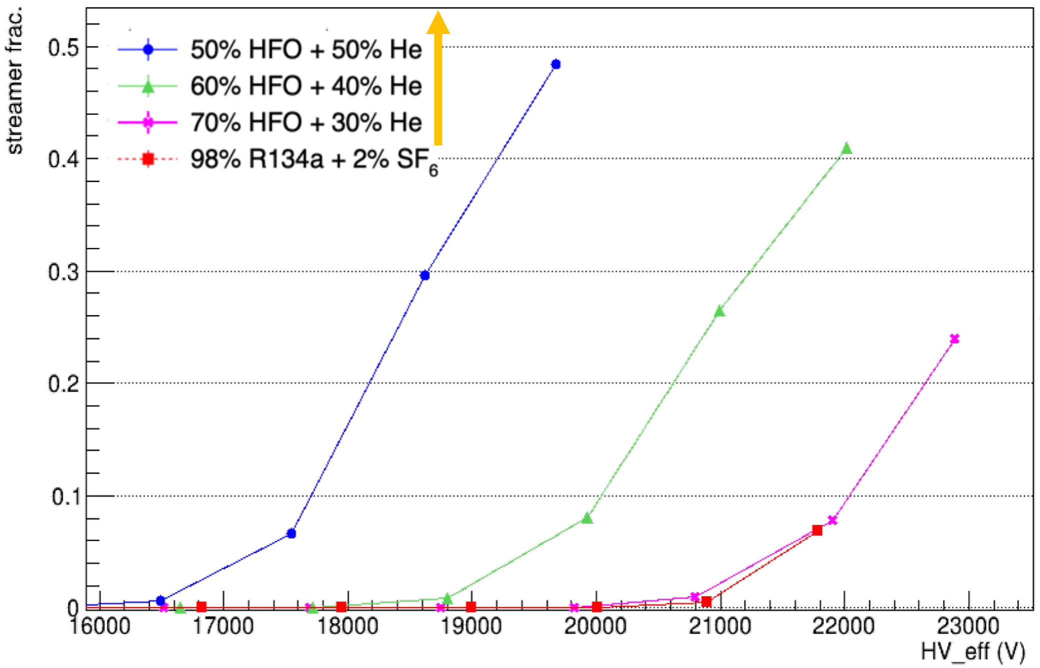
# HFO + He test

The mixture made out of
50% $C_3H_2F_4$ + 50% He
would have **GWP < 3.5**

REND-01
300 µm gap

Higher HV working point ~ 21/22 kV
above the upper HV limit




The str fraction increases as the He fraction increases

**WORKING POINT**

The WP decreases

as the He fraction increases

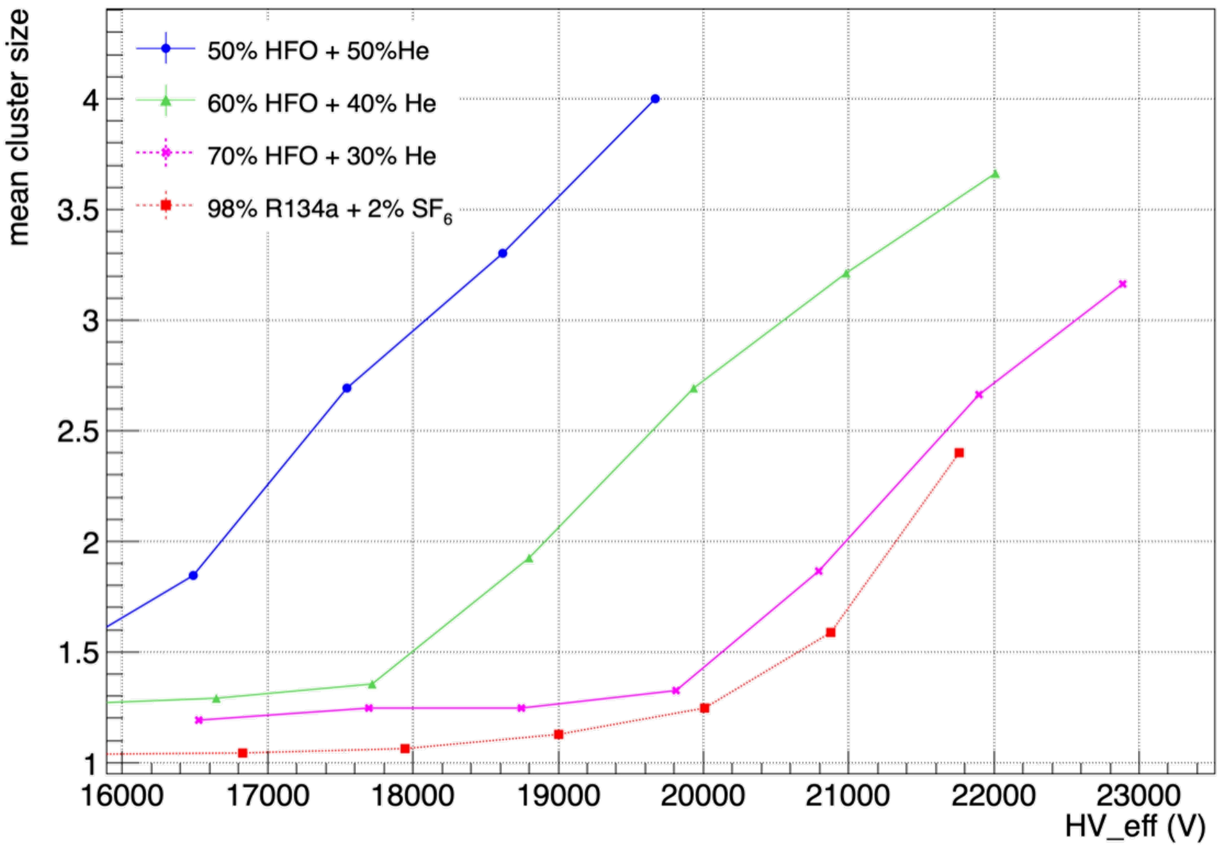
**STREAMER FRACTION**

The str fraction is comparable of the different %
It is larger wrt. standard mixture (less quenching)

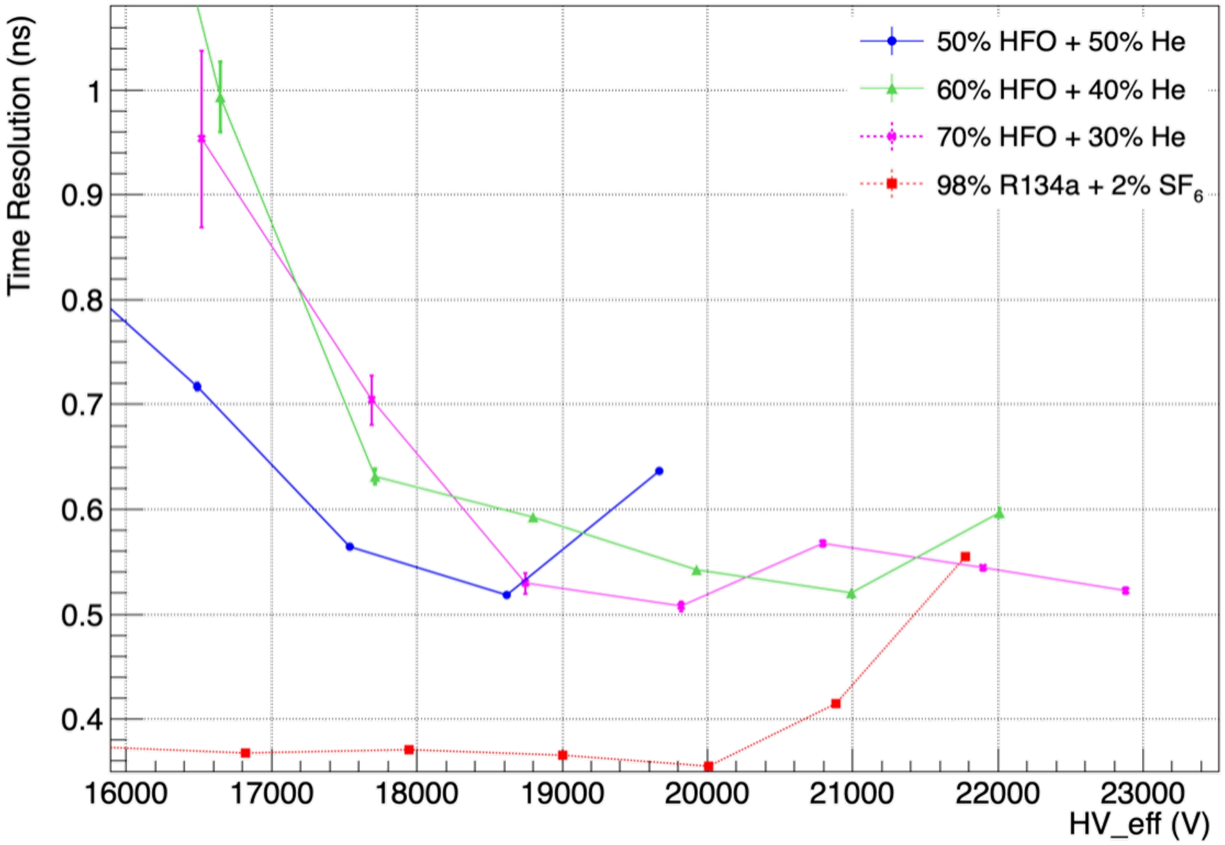
REND-01
300 µm gap

# HFO + He test

**Strip multiplicity**



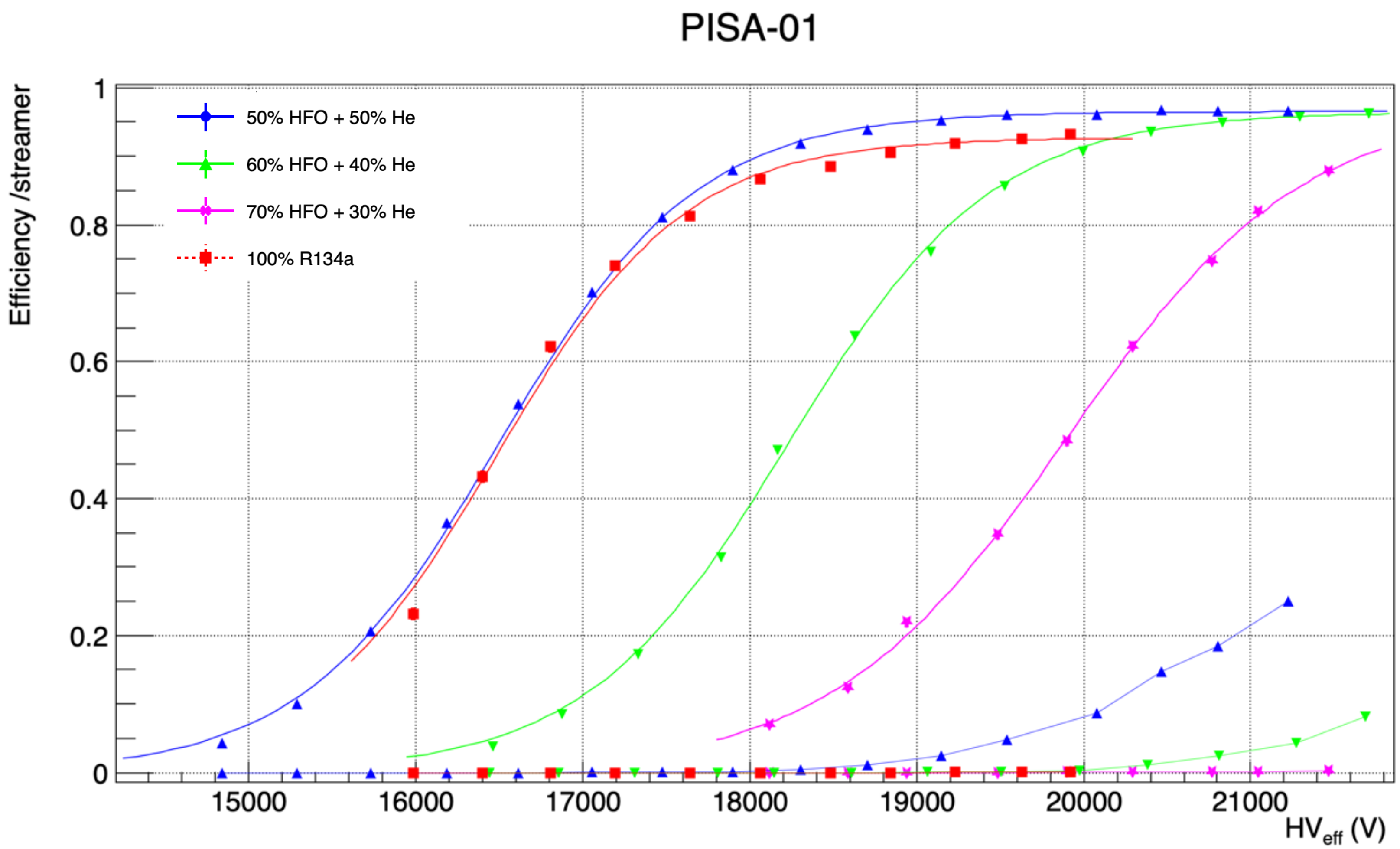

**Time resolution**




Generally worse wrt standard mixture
(lower electron drift velocity)

PISA-01
300 µm gap

# HFO + He test




The mixture made out of
50% $C_3H_2F_4$ + 50% He
would have **GWP < 3.5**

Operating the telescope with $C_3H_2F_4$+He gives the same efficiency at the same operating voltage as the "standard" mixture

Similar results wtr Rende for WP and streamer fraction

# HFO + $CO_2$ test

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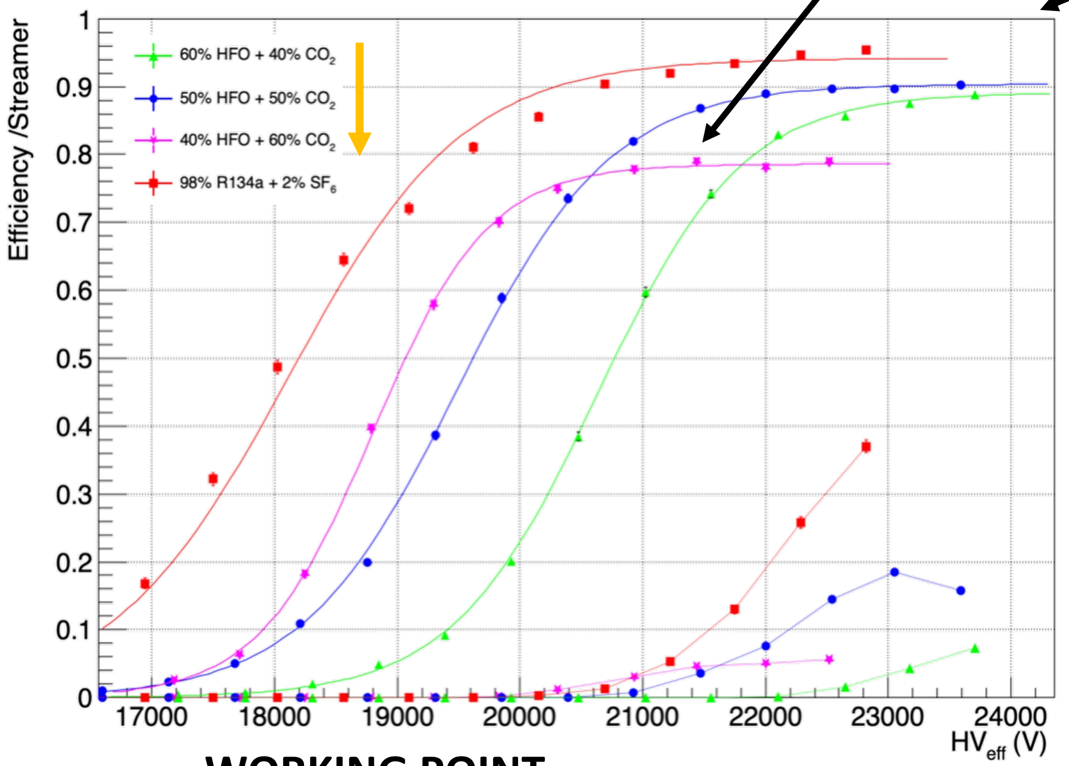
Mixtures with $CO_2$ shows a slightly lower efficiency
More evident with the higher % of $CO_2$

Higher working point wrt HFO+He mixtures
(with same percentage of HFO)

CERN-01 – 300µm




**WORKING POINT**

The WP decreases as the
$CO_2$ fraction increases

The mixture made out of
50% $C_3H_2F_4$ + 50% $CO_2$
would have **GWP = 3.5**

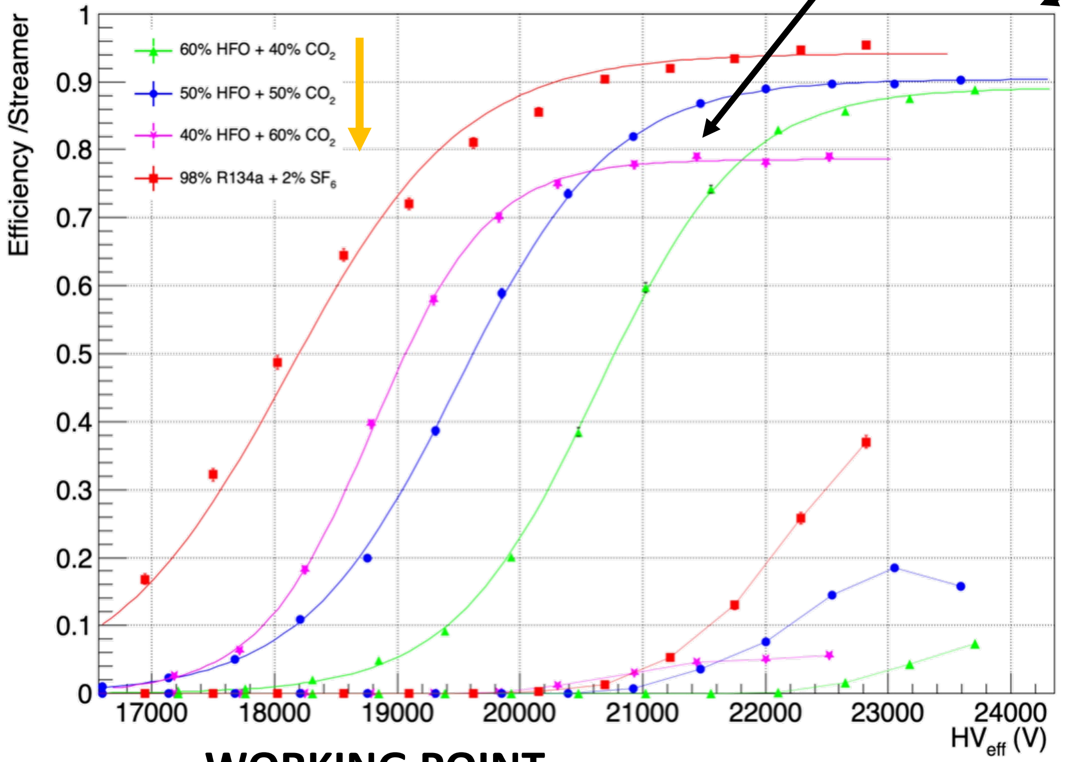
# HFO + $CO_2$ test

Tests with 300 and 250 µm chambers (upgrade after 2017)

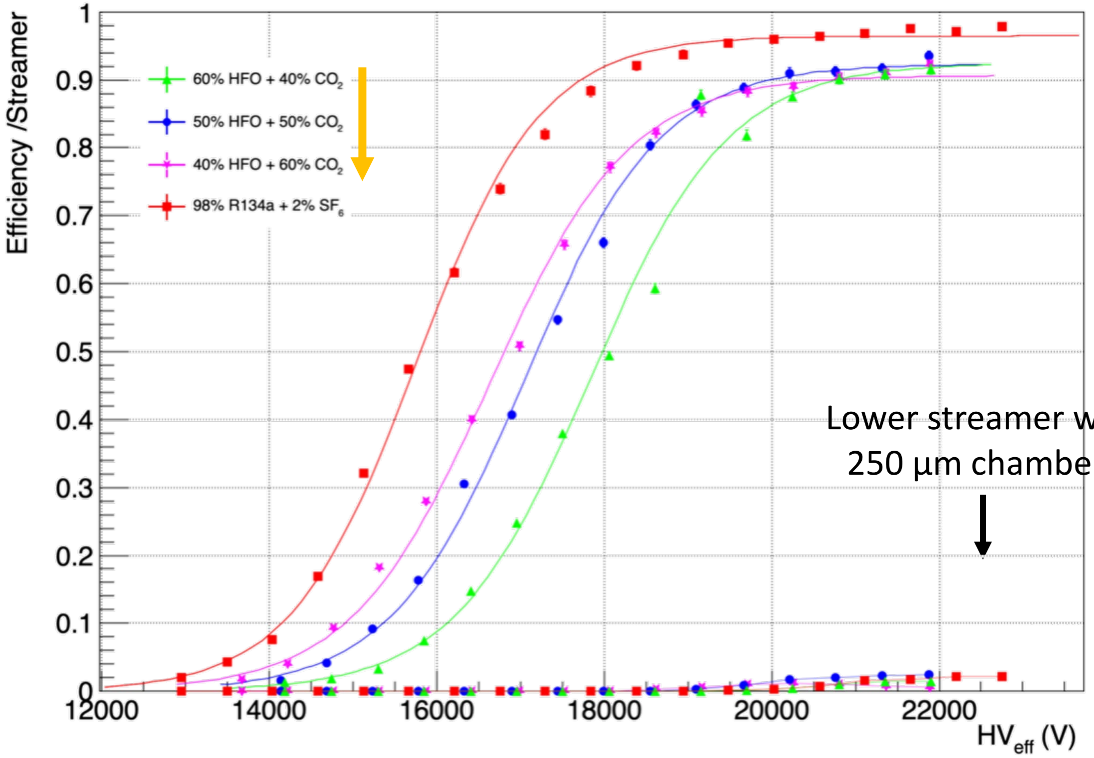
Mixtures with $CO_2$ shows a slightly lower efficiency wrt std mixture
More evident with the higher % of $CO_2$

Higher working point wrt HFO+He mixtures
(with same percentage of HFO)

CERN-01 – 300µm




CERN-01 – 250µm




Lower streamer with
250 µm chambers

**WORKING POINT**
The WP decreases as the
$CO_2$ fraction increases

Slightly lower streamer probability
by adding $CO_2$

The mixture made out of
$50\% \ C_3H_2F_4 + 50\% \ CO_2$
would have **GWP = 3.5**

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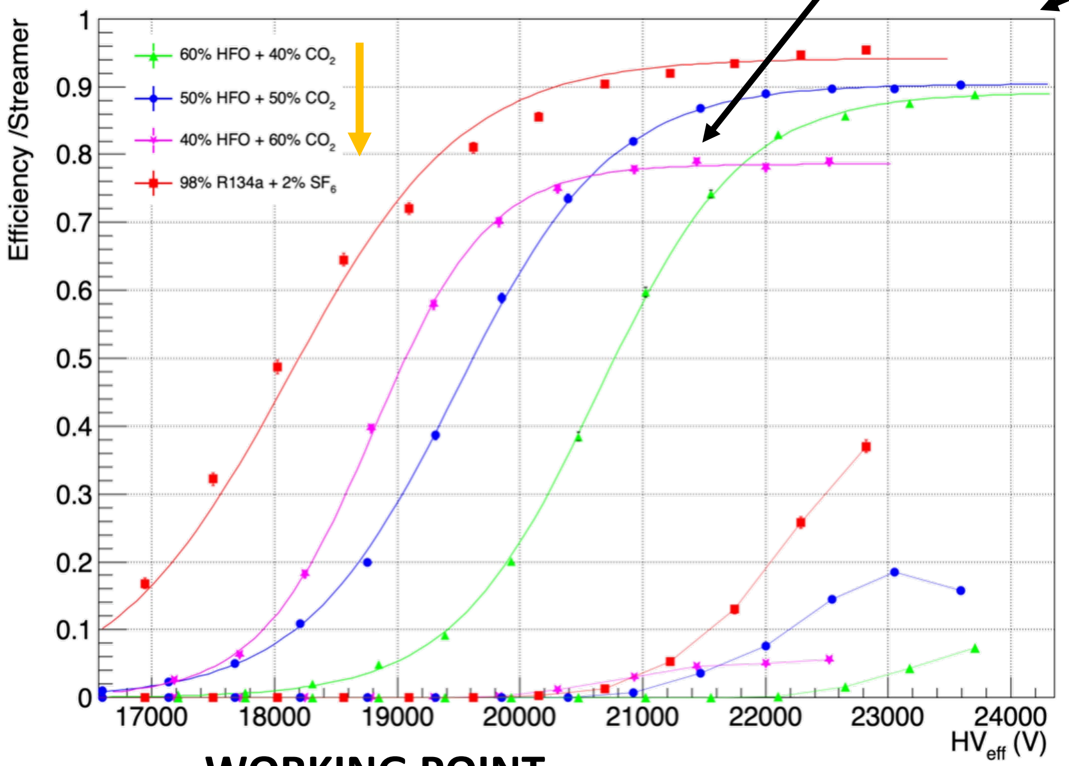
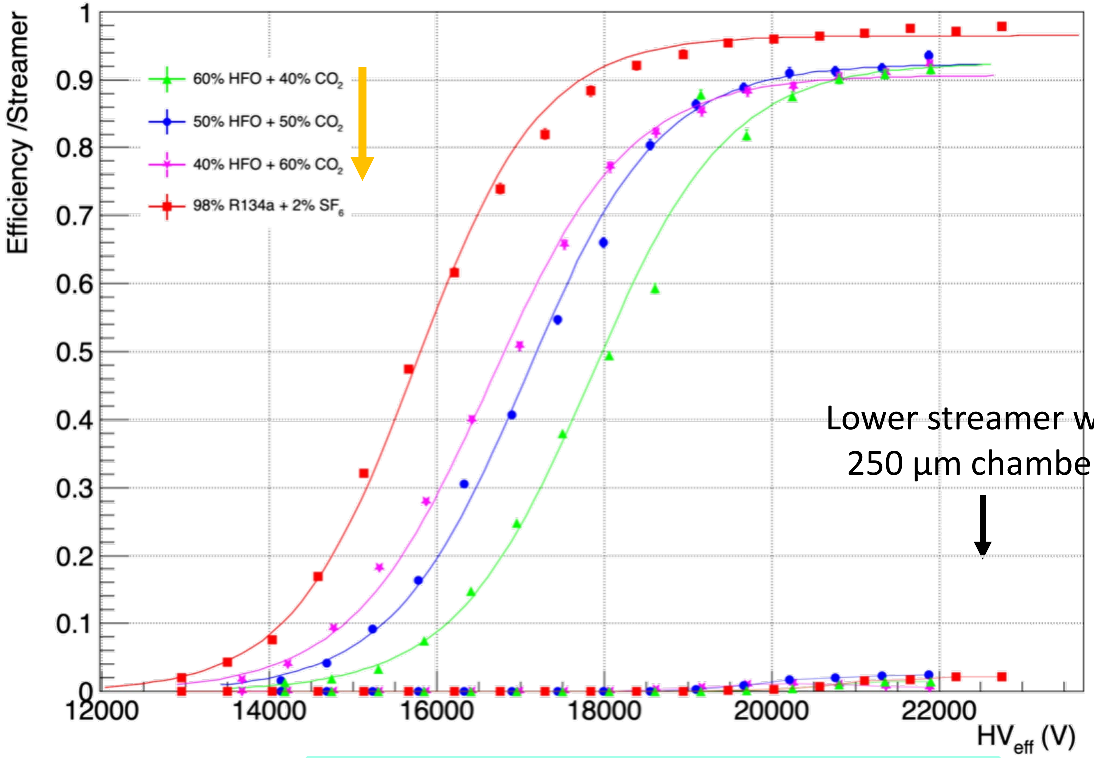



CERN-01 – 250µm




Lower streamer with
250 µm chambers

**WORKING POINT**
The WP decreases as the
$CO_2$ fraction increases

Slightly lower streamer probability
by adding $CO_2$

WORK IN PROGRESS with $CO_2$
Many tests done
Analysis ongoing

# Data taking

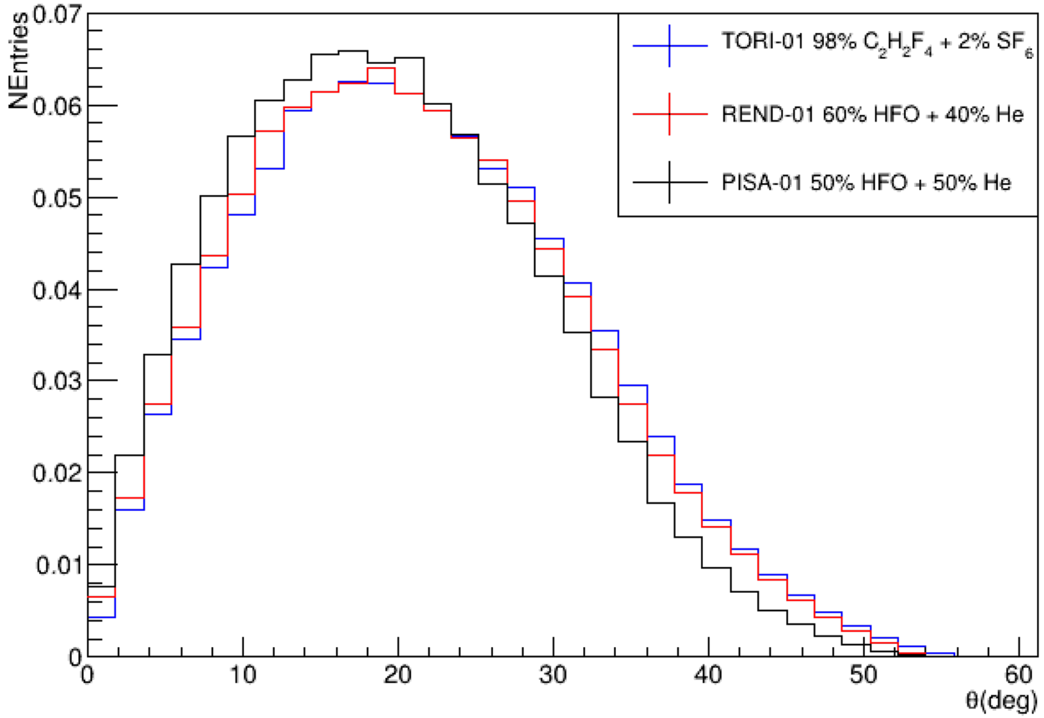
## HFO + He

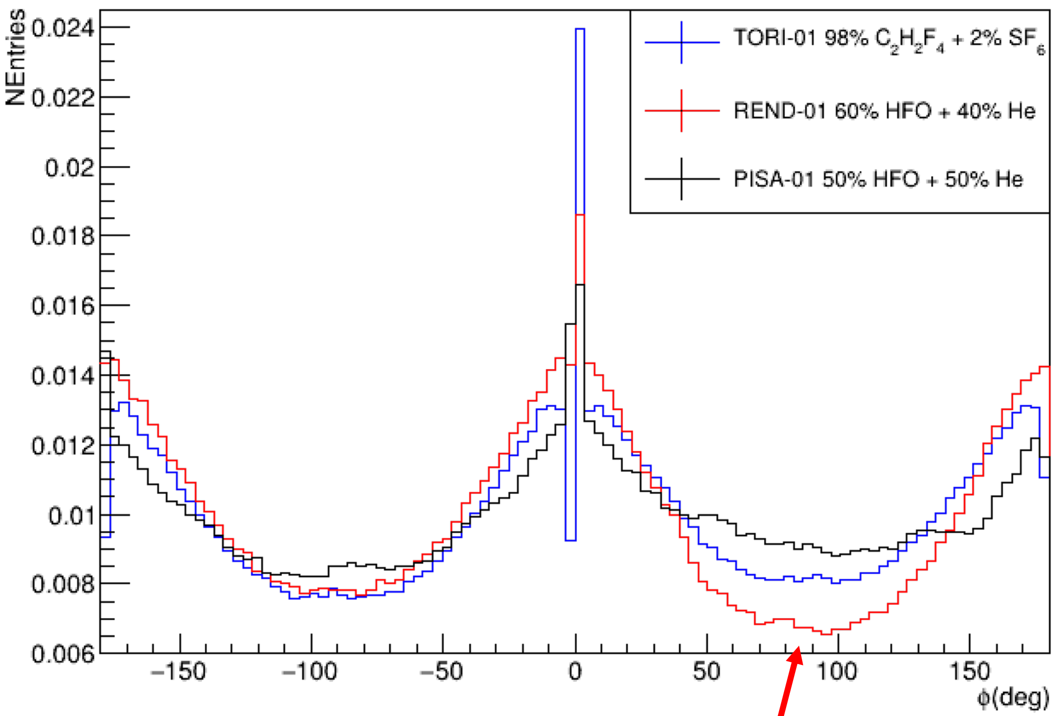
## (ECOGAS in all 3 chambers)

# Muon tracks triple data taking - HFO + He

## Angular distributions

Two telescopes REND-01 and PISA-01 with all 3 chambers filled with HFO + He mixtures in different percentages



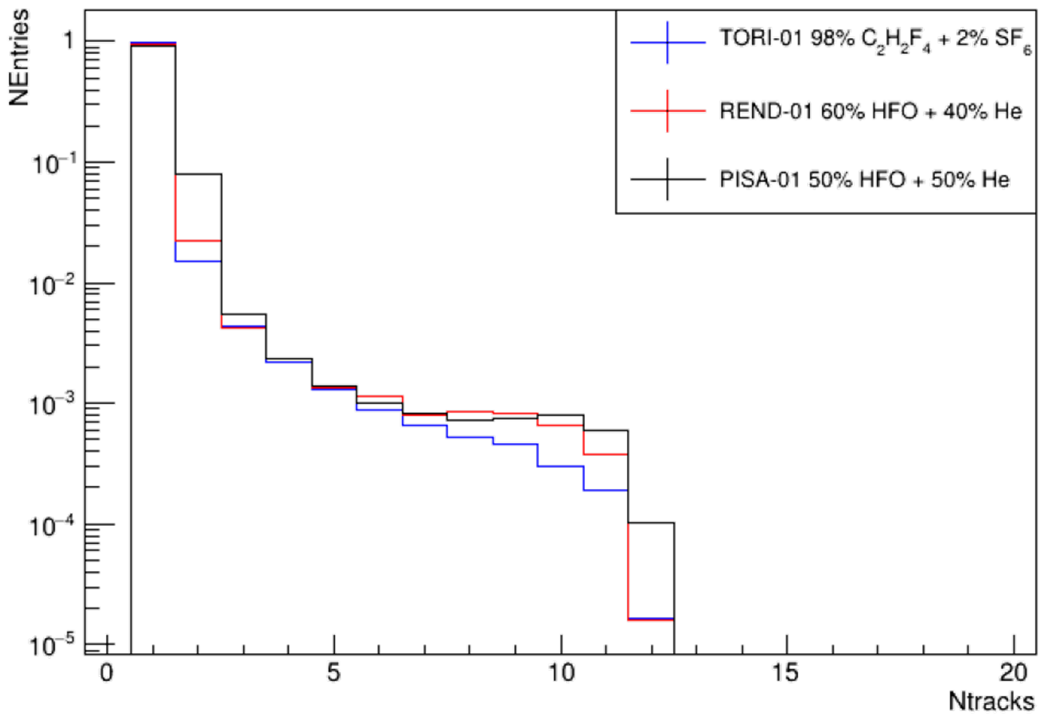

**LONG term data taking:**

- REND-01 from the beginning of 2022 to now (11 months)
- PISA-01 from March 2022 to June 2022 (4 months) for an electronic problem

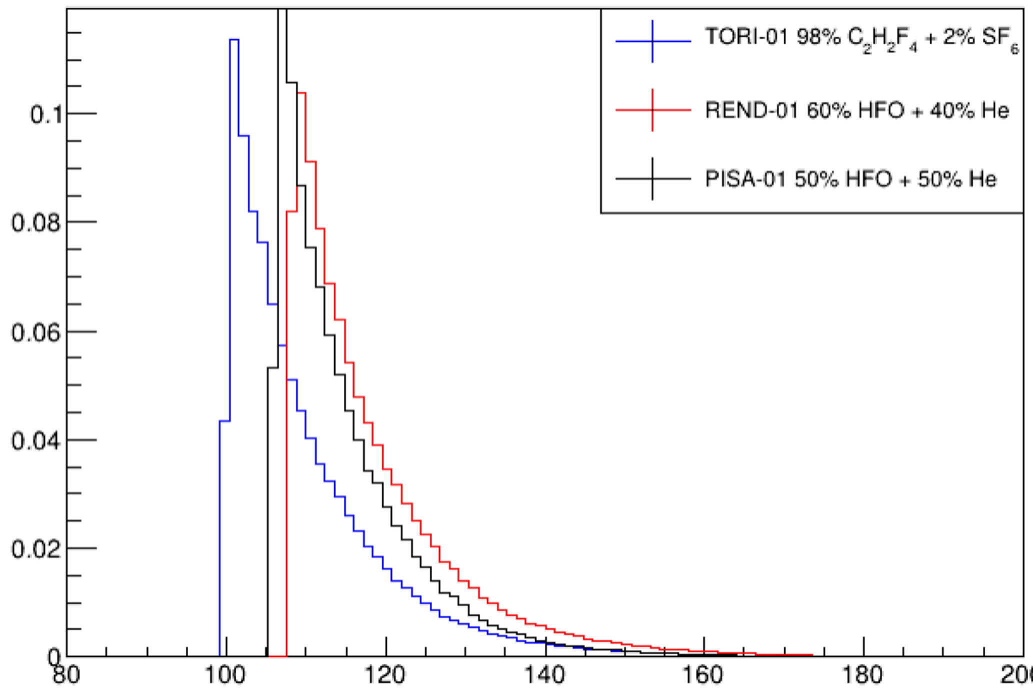
The telescope detect the presence of a close six floor building

# Muon tracks triple data taking - HFO + He

**# of reconstructed tracks per trigger**




**Reconstructed muon track lenghts**

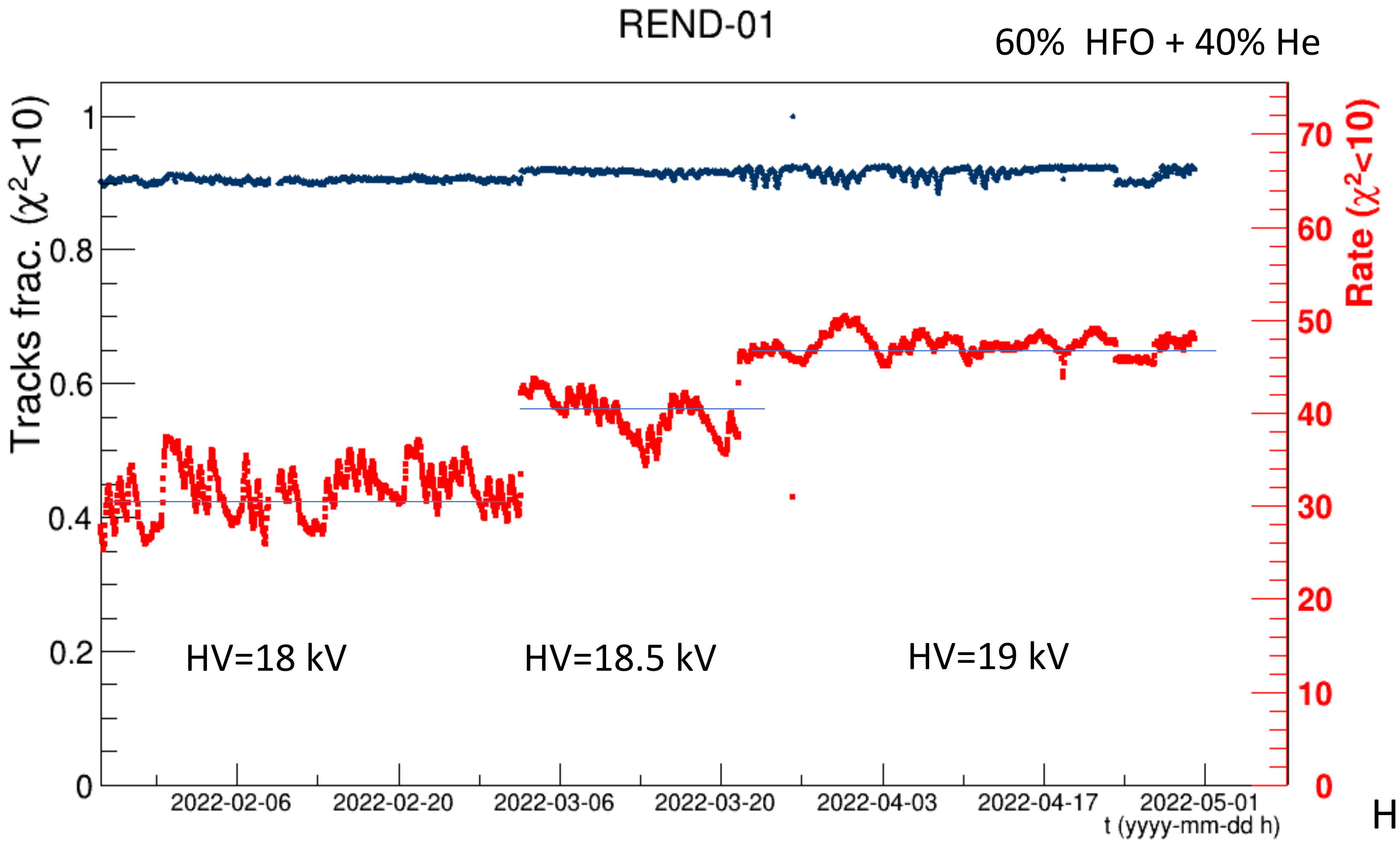



Minimum track length related to distance between top and bottom chambers:

TORI-01 → 1 m

REND-01 and PISA-01 → 1.05 m

# Track rate stability REND-01 triple data taking - HFO + He



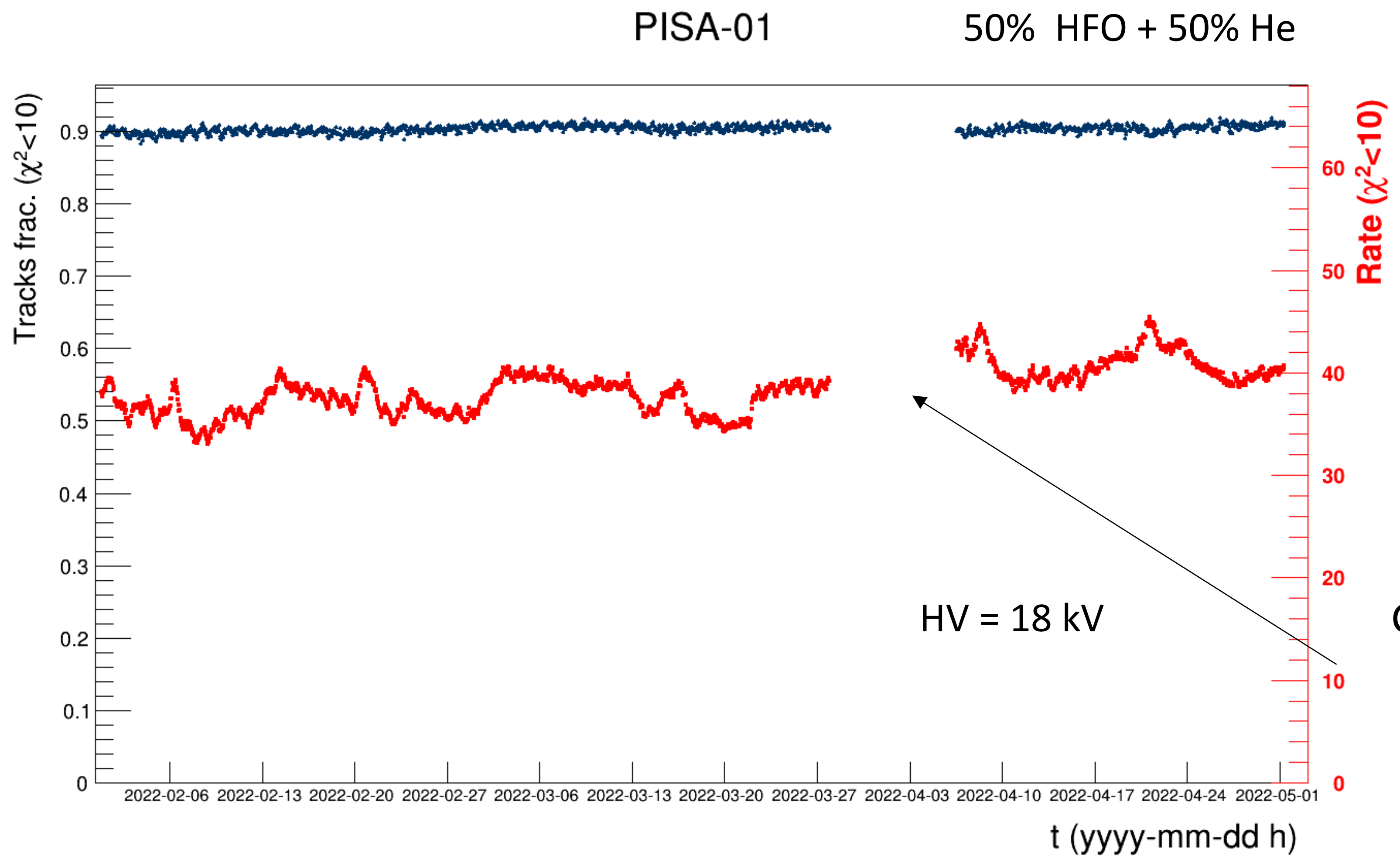

Test telescopes fluxed for more than three months

All chambers filled with new mixture (50% HFO + 50% He)

**Oscillations** are due to *temperature variations* depending on where the telescope is located

Oscillations reduced when HV deeper in the efficiency plateau

# Track rate stability PISA-01 triple data taking - HFO + He




Test telescopes fluxed for more than three months

All chambers fluxed with new mixture (50% HFO + 50% He)

Gap is due to efficiency study and telescope maintenance

# Track rate stability PISA-01

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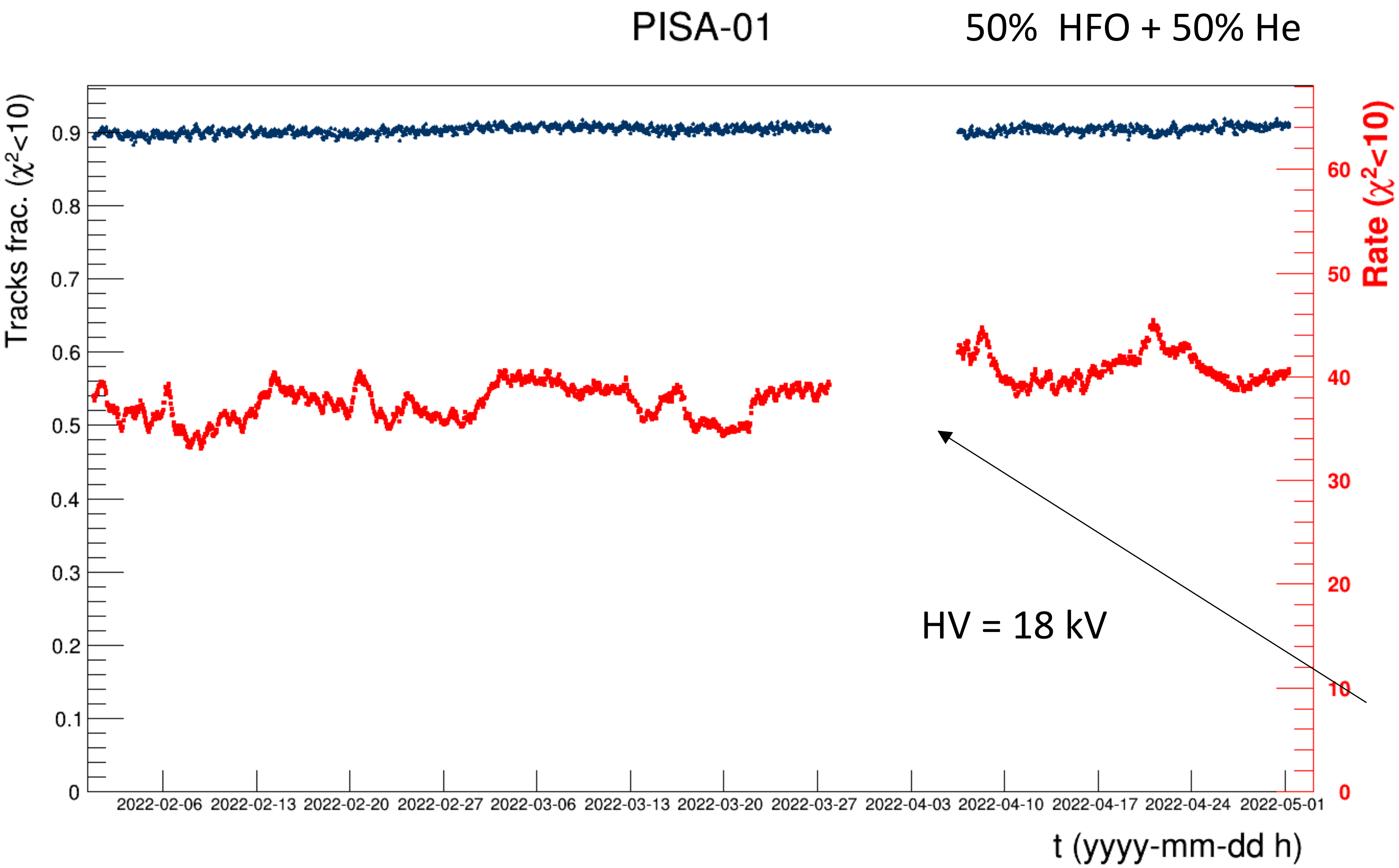



Test telescopes fluxed
for more than three months
All chambers fluxed with new mixture
(50% HFO + 50% He):

Interruptions due to efficiency
study and telescope maintenance

**HFO + He** → Great long term stability and no degrade of performance

# RESTARTING for EEE telescopes

**Test phase completed - new data acquisition**

**Telescopes completely filled with: HFO + He**

| TELESCOPE | MIXTURE |
|---|---|
| *CAGL-01 | 50% $C_3H_2F_4$ + 50% He |
| *CARI-01 | 65% $C_3H_2F_4$+ 35% He |
| PISA-01 | 50% $C_3H_2F_4$ + 50% He |
| REND-01 | 60% $C_3H_2F_4$ + 40% He |
| *SALE-02 | 50% $C_3H_2F_4$ + 50% He |

→ 250 μm

*New test in schools planned!

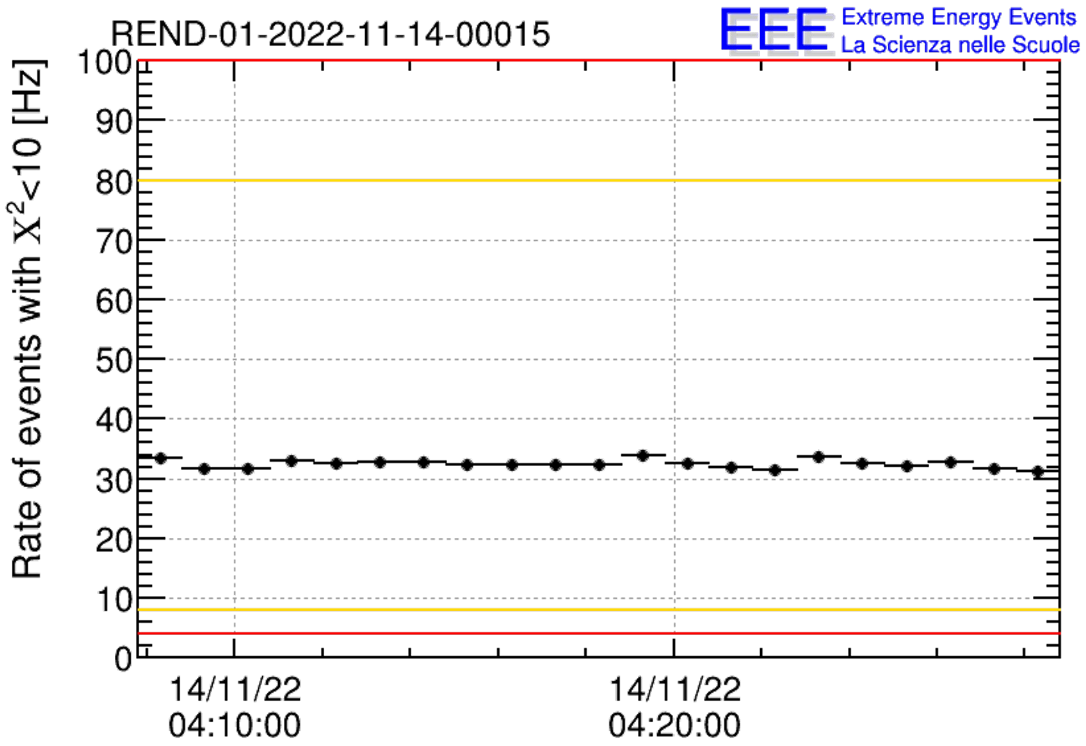
**Telescopes completely filled with: HFO + $CO_2$**

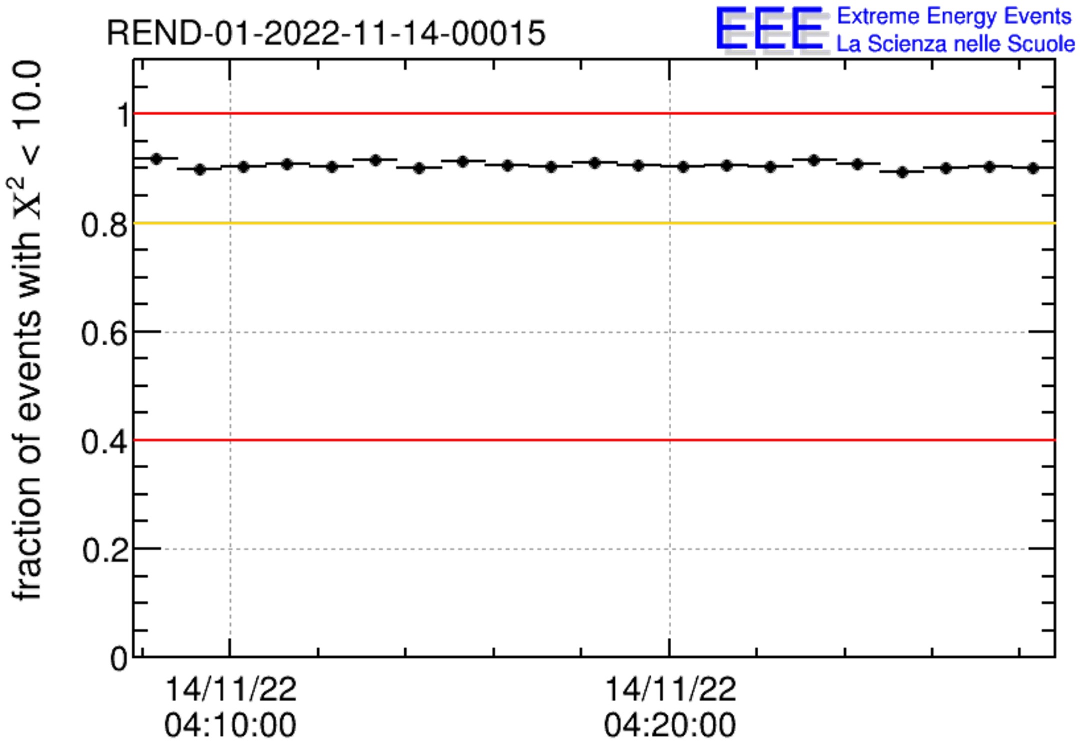
| | |
|---|---|
| *LECC-01 | 50% $C_3H_2F_4$ + 50% $CO_2$ |
| *BOLO-05 | 60% $C_3H_2F_4$ + 40 % $CO_2$ |
| *CAGL- 02 | 50% $C_3H_2F_4$ + 50% $CO_2$ |
| CERN-01 | 50% $C_3H_2F_4$ + 50% $CO_2$ |
| BOLO-01 | 50% $C_3H_2F_4$ + 50% $CO_2$ |

→ 300/250 mμ

# RESTARTING for REND-01 telescope

**Telescope:** REND-01 Rende (Calabria)
**Term data taking:** from february 2022 to now
**Mixture:** $60\%\ C_3H_2F_4 + 40\%\ He$
**HV:** 19 kV
**Flow:** 0.9 l/h



# RESTARTING for REND-01 telescope

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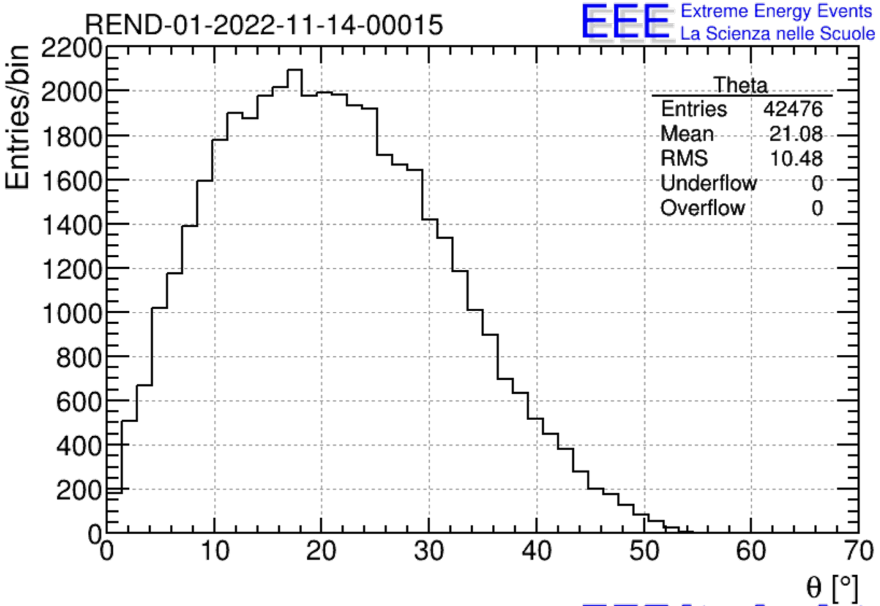
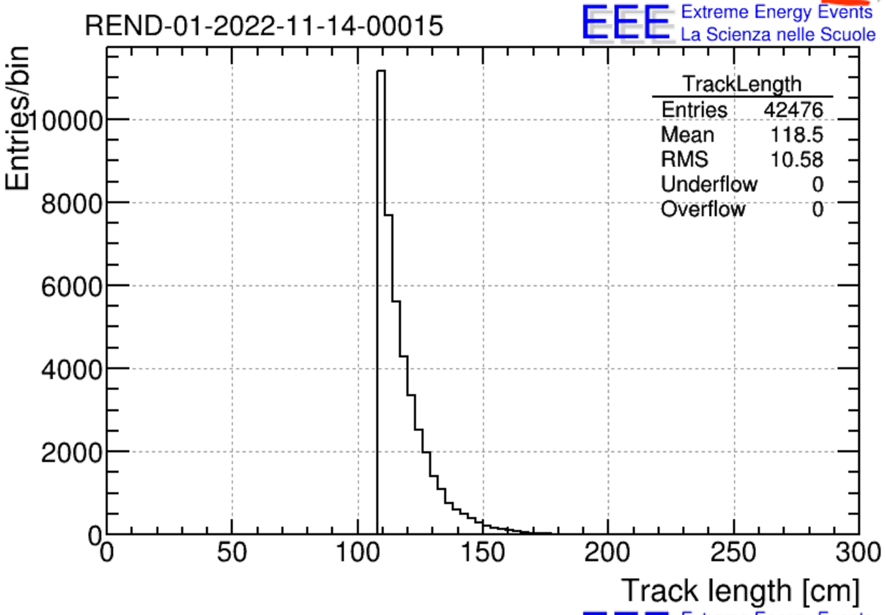
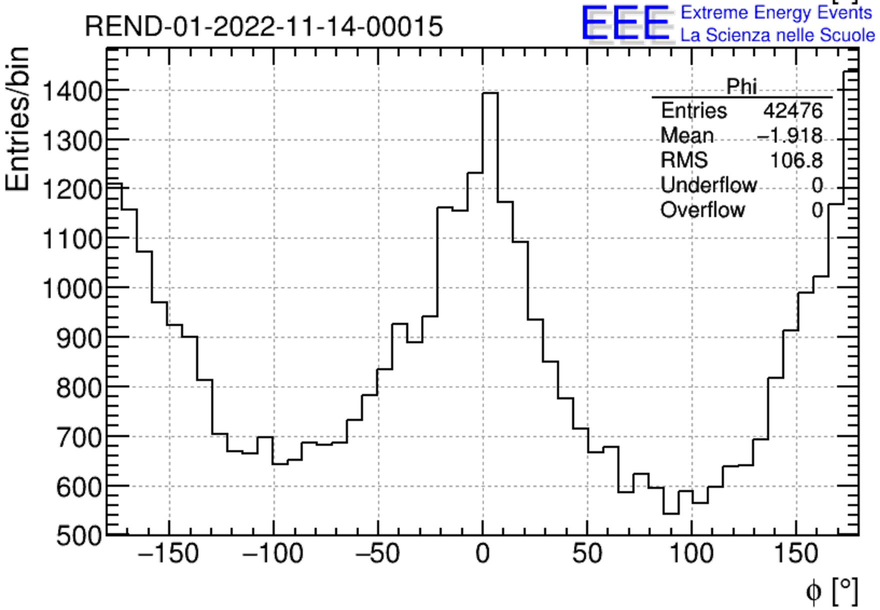
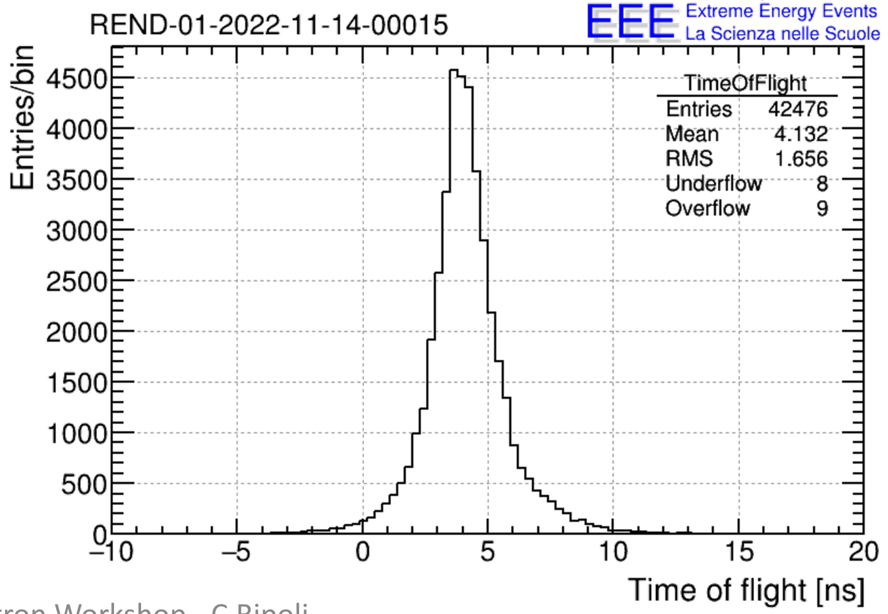


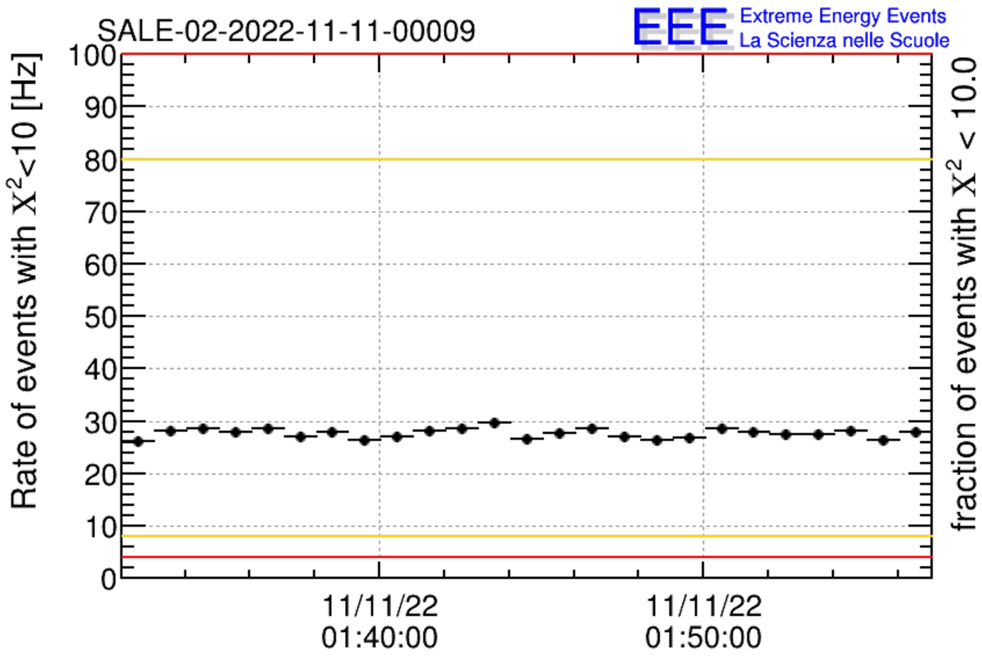



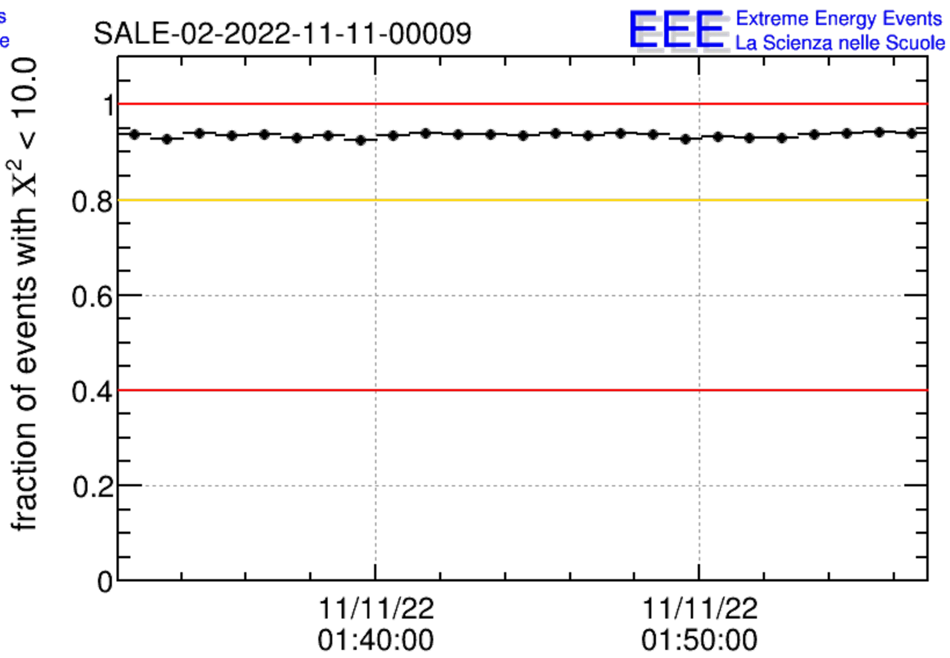




Raw data

# RESTARTING for SALE-02 telescope

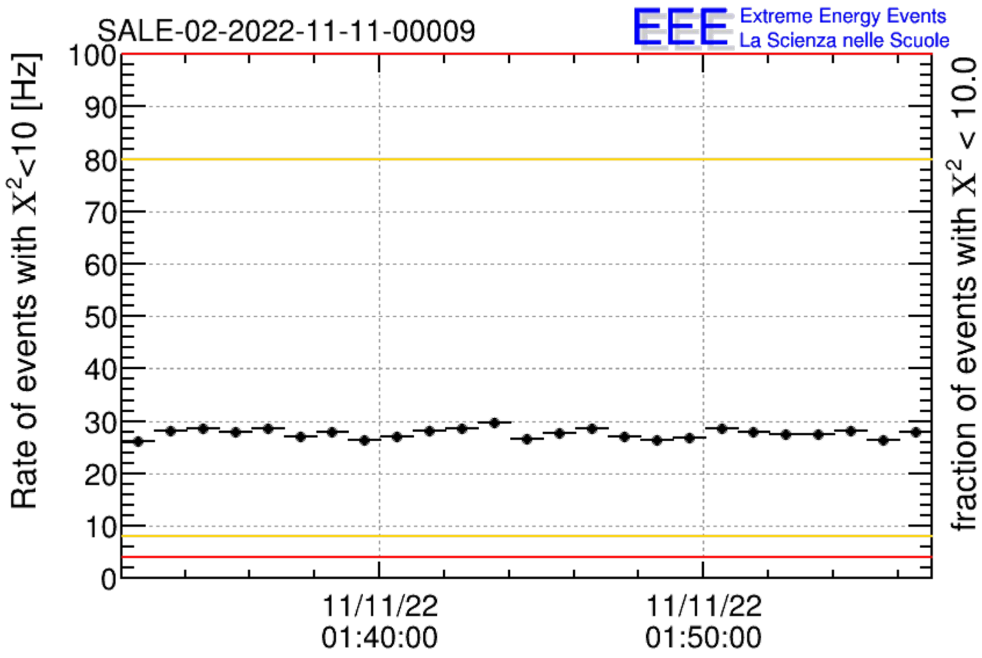
**Telescope: SALE-02 Salerno (Campania)**
**Term data taking:** from october 2022 to now
**Mixture:** **50% $C_3H_2F_4$ + 50% He**
**HV:** 19kV
**Flux:** 1.2 l/h

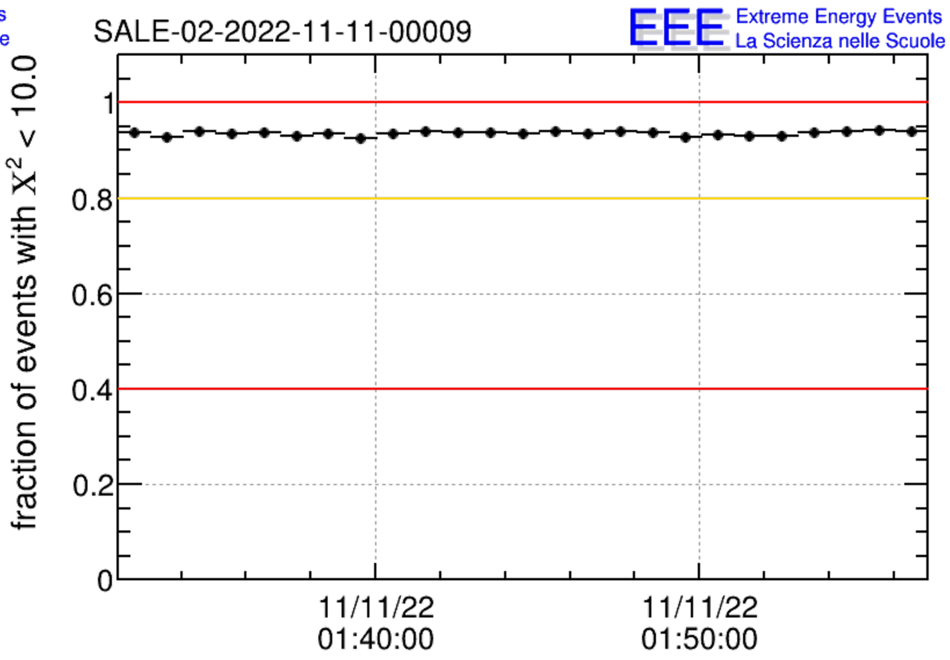


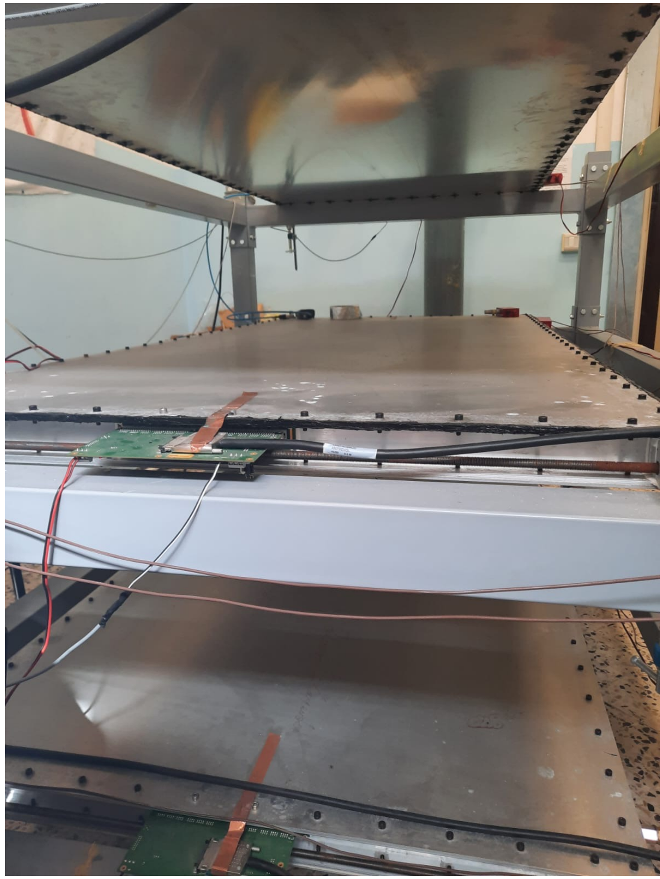
# RESTARTING for SALE-02 telescope

**Telescope: SALE-02 Salerno (Campania)**
**Term data taking:** from october 2022 to now
**Mixture:** **50% $C_3H_2F_4$ + 50% He**
**HV:** 19kV
**Flow:** 1.2 l/h

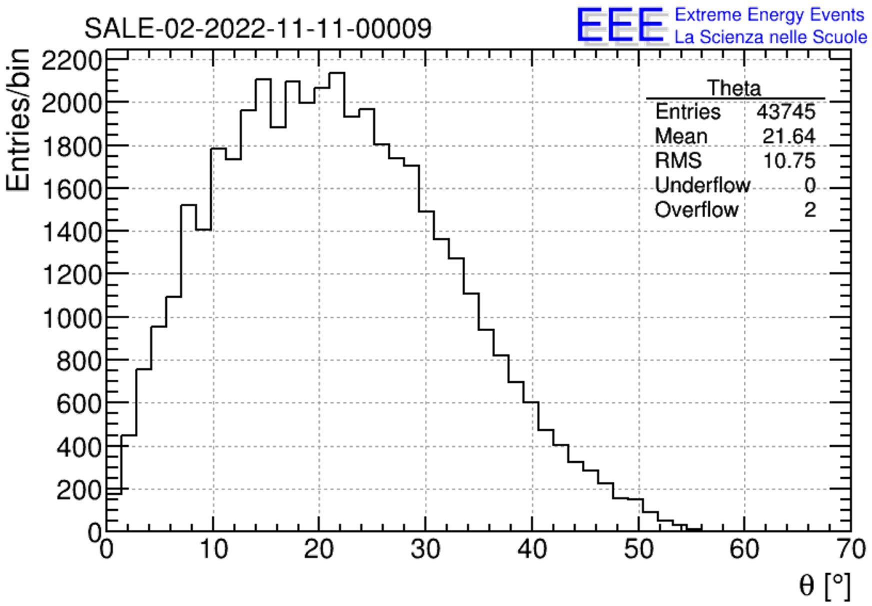


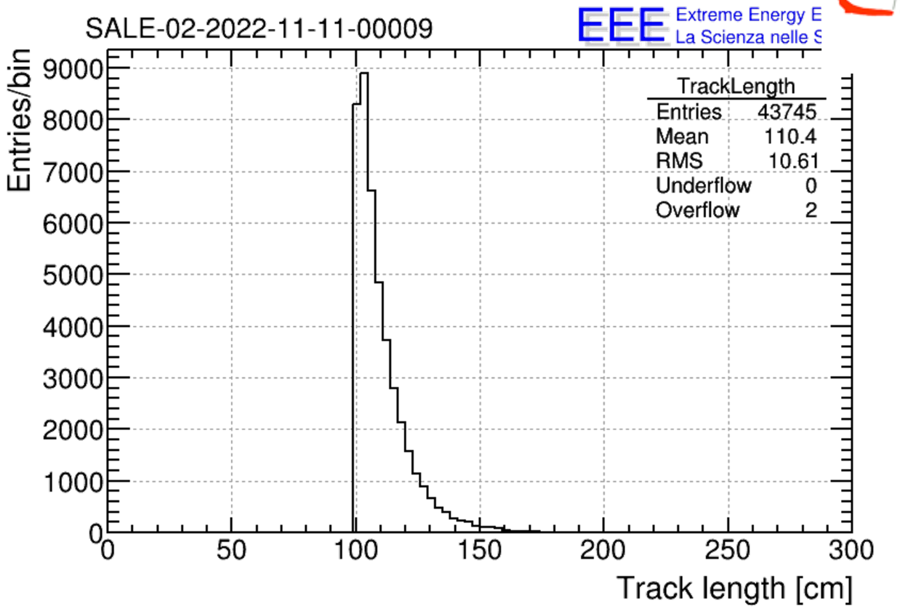



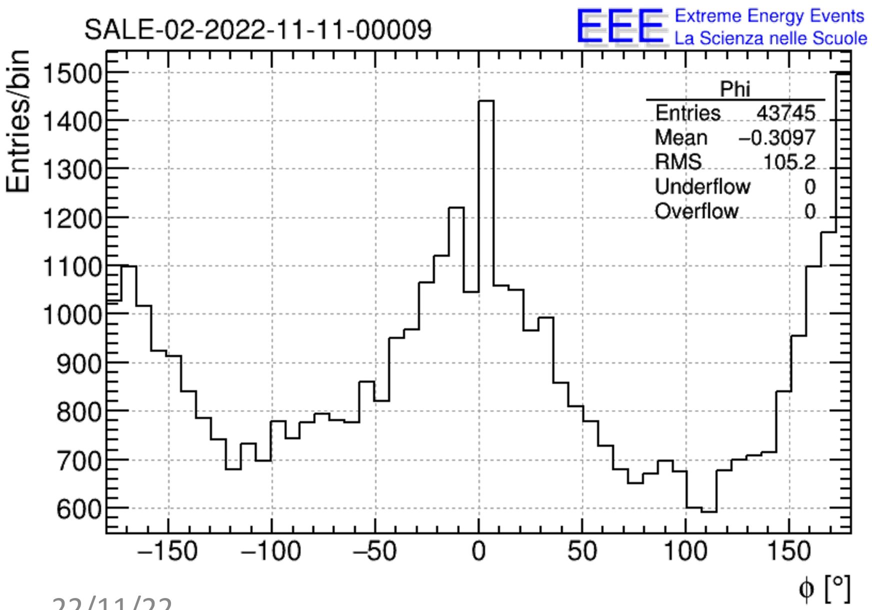

**First restarting in a school!**

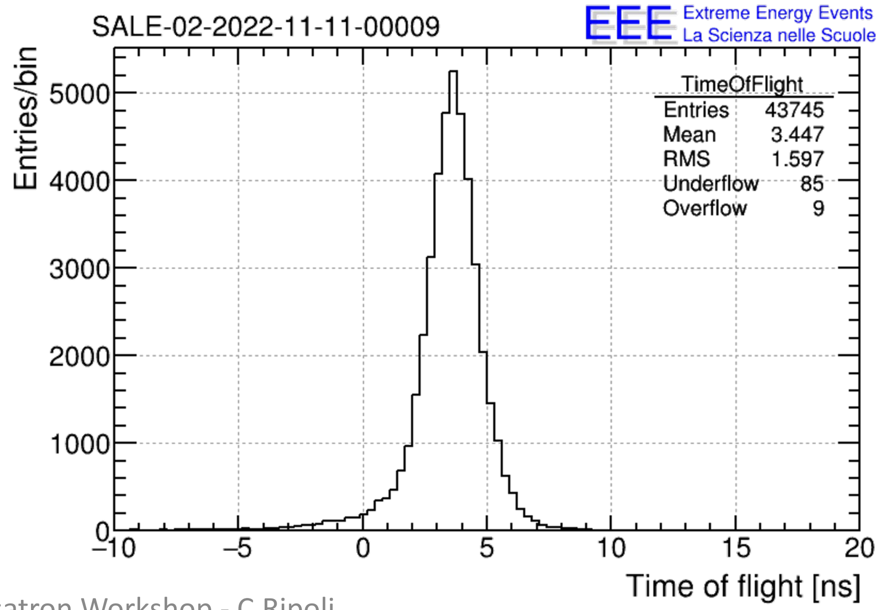


# RESTARTING for SALE-02 telescope



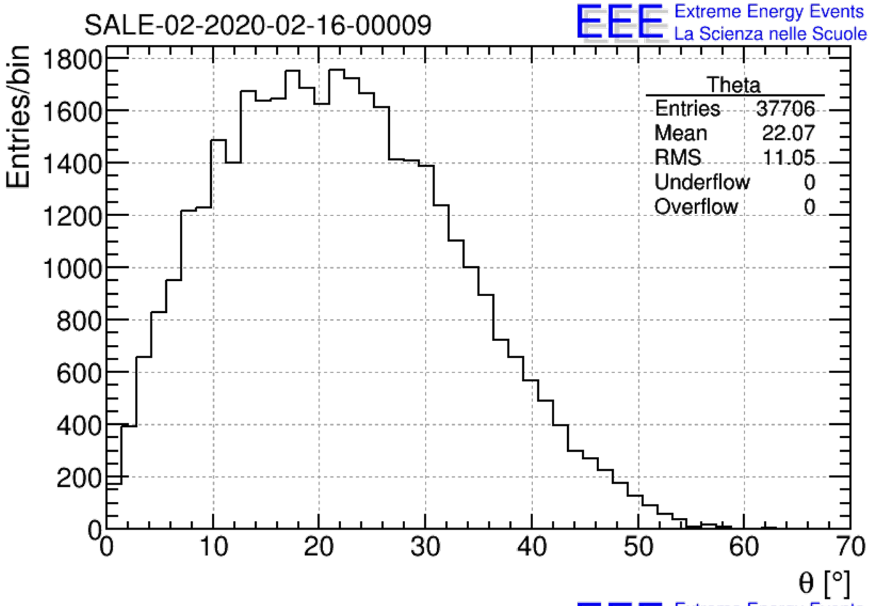



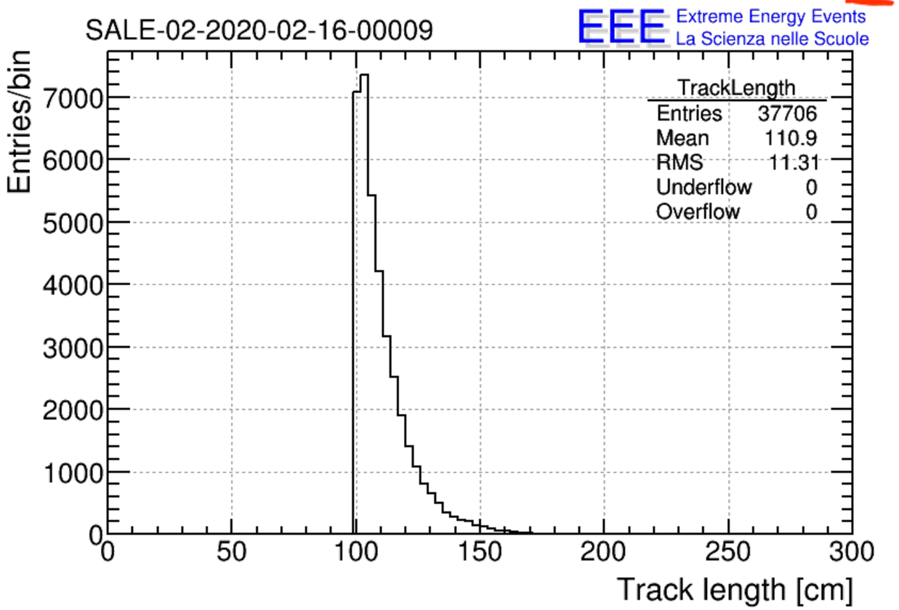



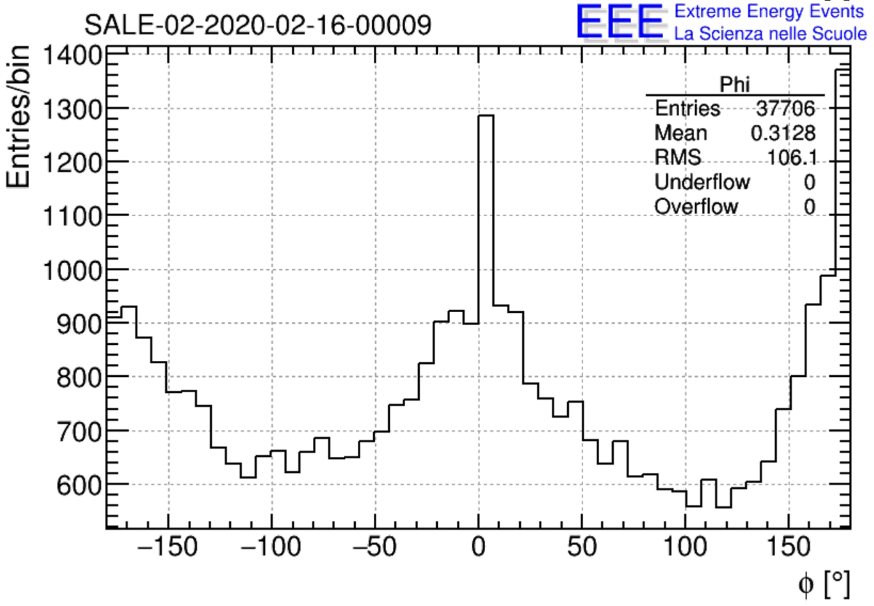

ECOGAS
Raw data

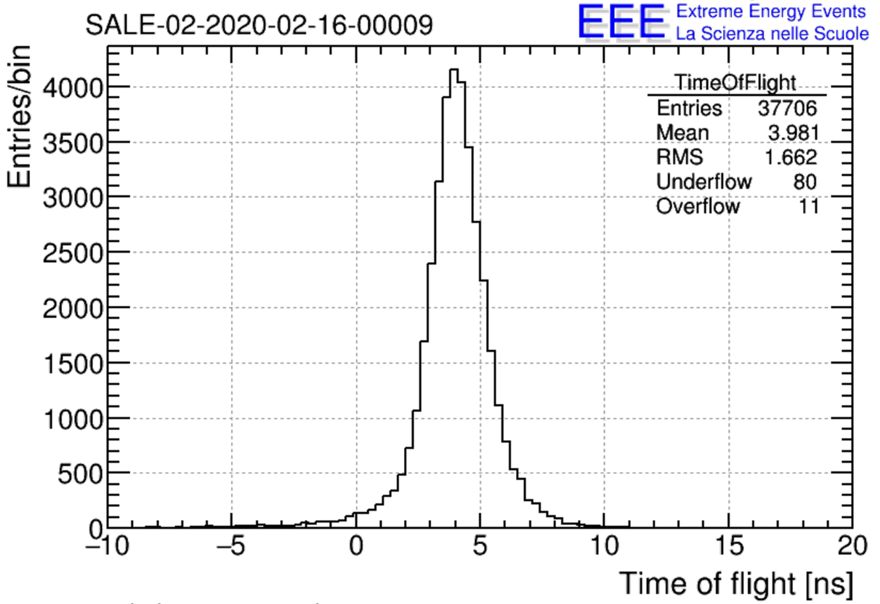
# RESTARTING for SALE-02 telescope

Extreme Energy Events
Science inside Schools




STANDARD MIXTURE
Raw data

# RESTARTING for SALE-02 telescope

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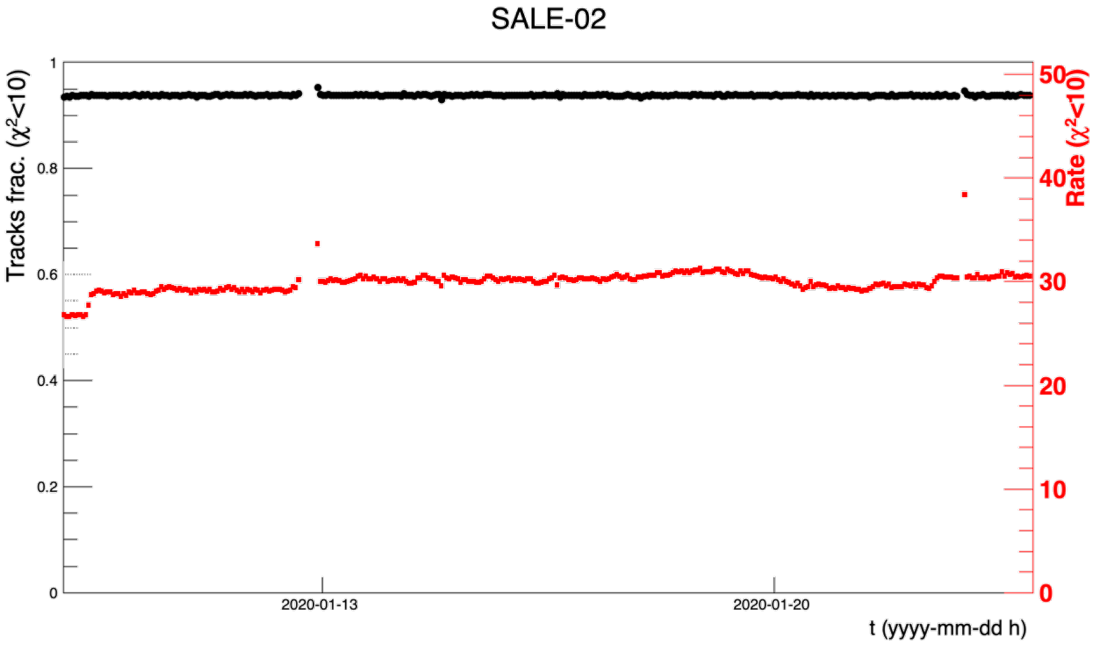
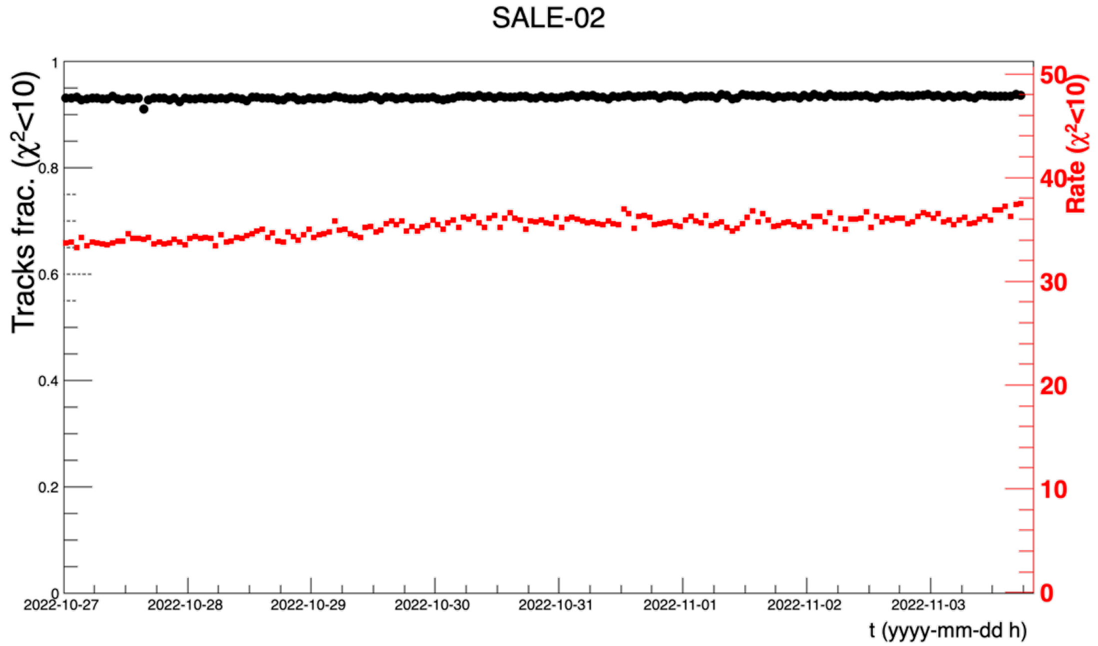
2020 standard mixture




2022
New ecofriendly mixture




**Stable rate**
**WORK IN PROGRESS!**

# Conclusion

Extreme Energy Events
Science inside Schools

The EEE experiment started the ***ecological transition***

- New mixtures chosen : HFO + He and HFO + $CO_2$
- Tests with HFO + $CO_2$ still ongoing
- Tests with HFO + He mixtures **completed satisfactorily**
  - Reasonable efficiency at low HV
  - Larger cluster size and streamer fraction
  - Time resolution worse wrt standard mixture

  } but good enough for the aims of the project
- **Satisfactory performance** for the physics aims of the experiment with telescopes completely filled with ecofriendly gas
- Other stations equipped with new eco-friendly ready to restart
- Long term data acquisition **ongoing**

# Thank you!

Extreme
Energy
Events
Science inside Schools

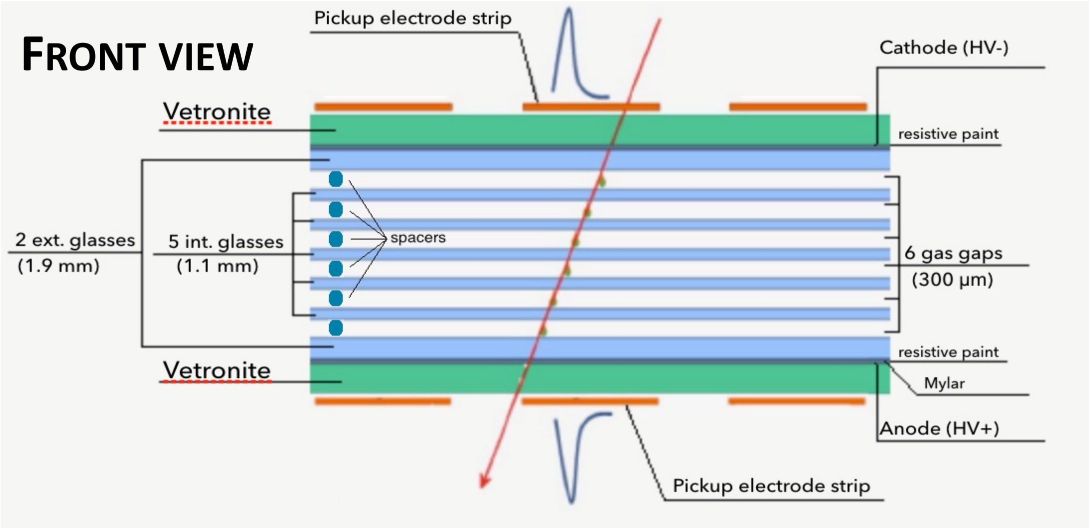
# Backup

# EEE telescope

Extreme Energy Events
Science inside Schools

Each telescope is composed of

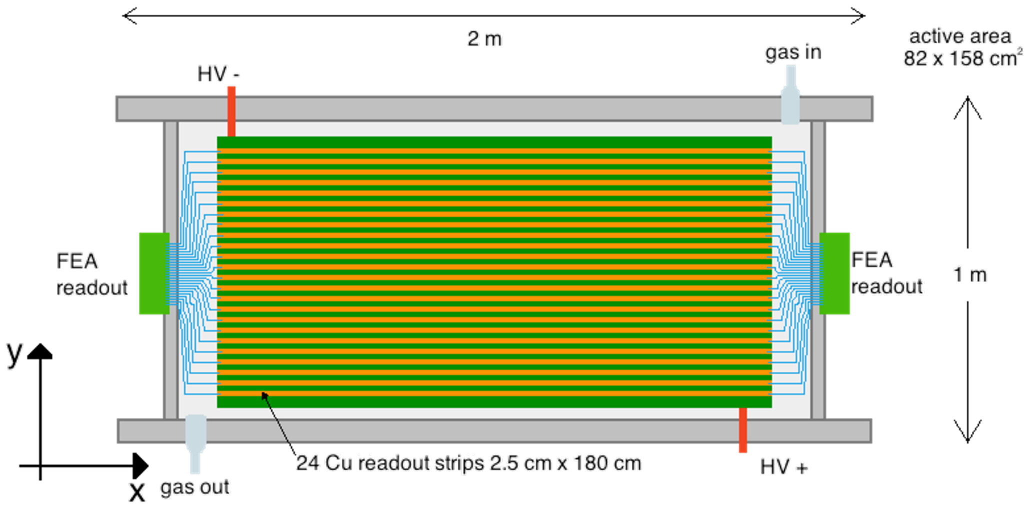
3 large area (1.58 × 0.82 m$^2$) **MRPCs**




Each chamber has **six 300 μm gas gaps**
(250 μm in EEE upgrade after 2017)
equipped with **24 readout copper strip electrodes**
(180 cm x 2.5 cm spaced by 7 mm)

**High Voltage (HV)** up to **20 kV** (avalanche mode)
provided by 2 DC/DC converters

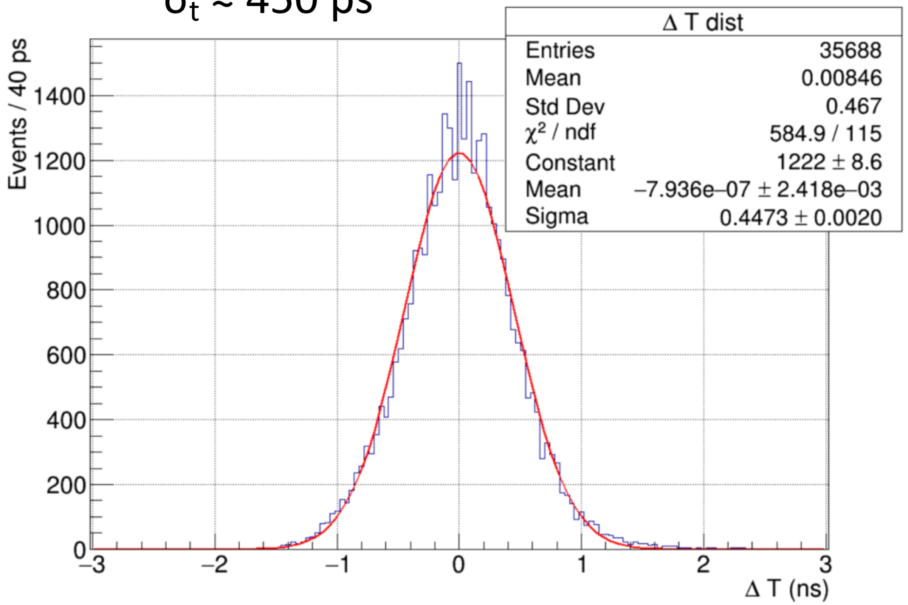
**y** determined by the strip on which the signal is induced




**x** determined by measuring the difference between the arrival time of the signal at the two ends of the strip

Time resolution with new gas ECOgas

$\sigma_t \approx 450$ ps




50% HFO +50% He

# Time Over Threshold comparison

Extreme Energy Events
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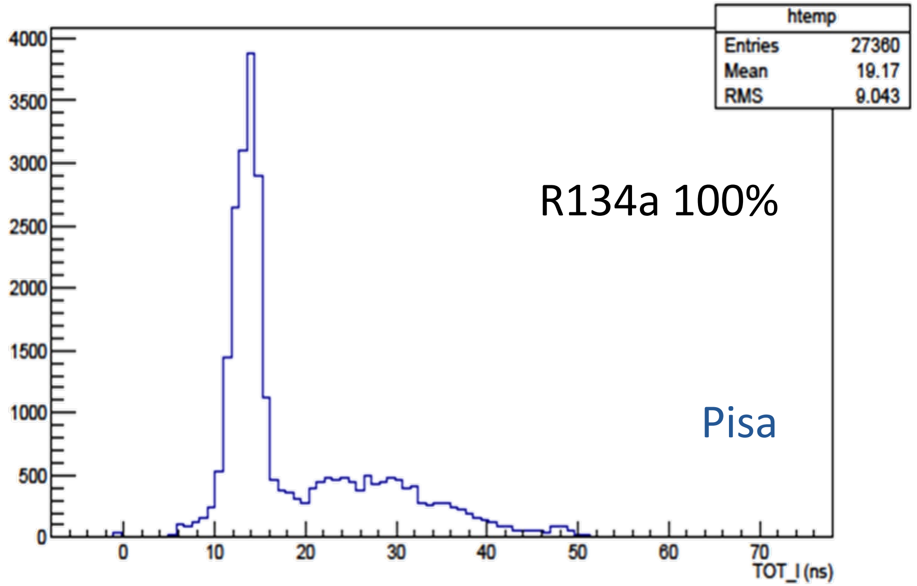
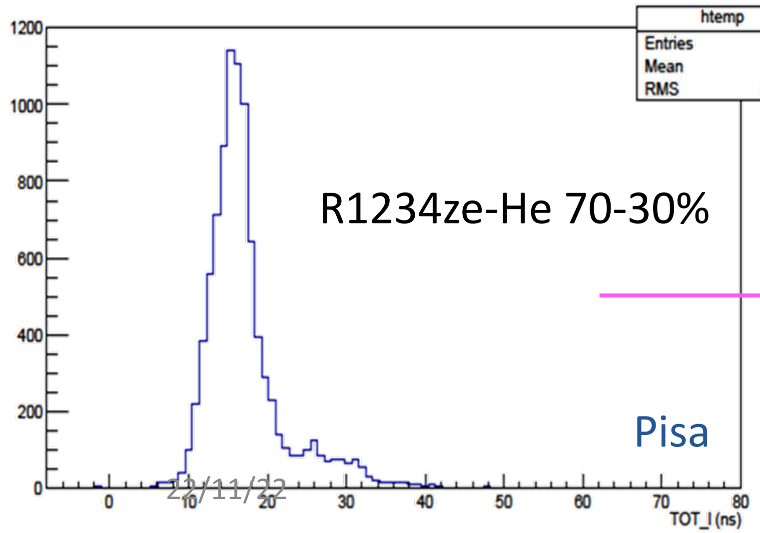
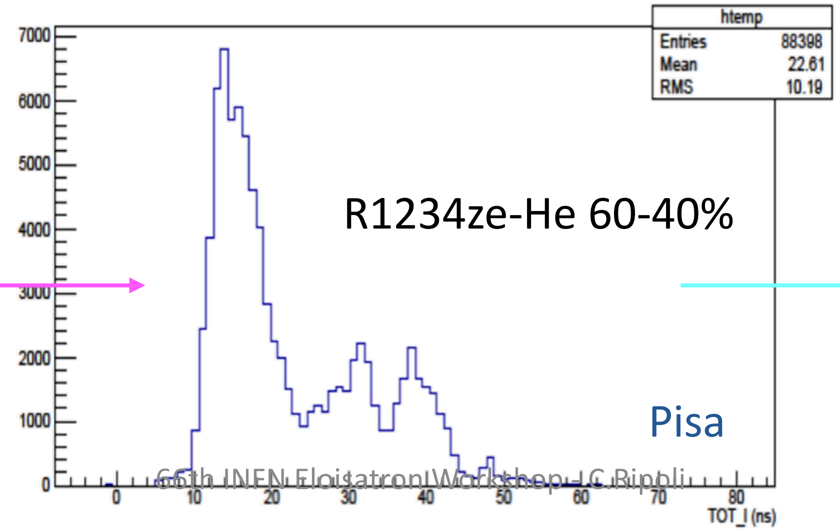
TOT distributions can give an alternative way to estimate streamer probability

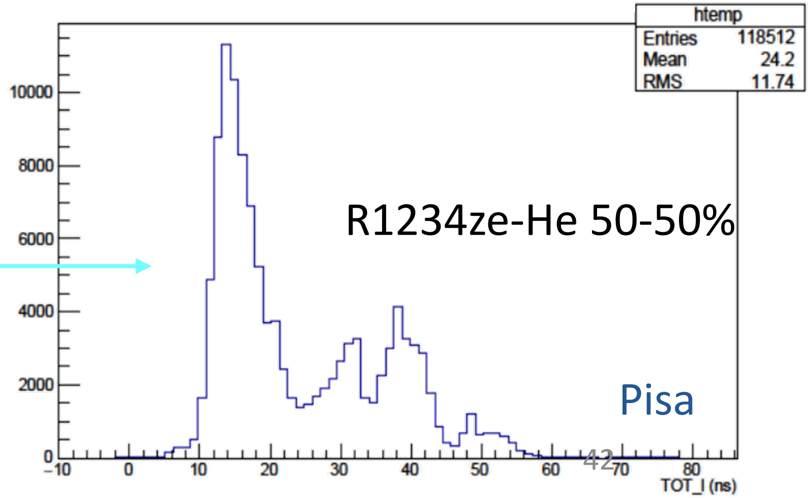



Reducing HFO fraction has the effect to increase the % of large TOT events

Increasing He :
- from 30% to 40% more visible effect
- from 40% to 50% less visible



- Pressure and temperature correction:

$$HV_{eff} = HV \frac{p_0}{p} \frac{T}{T_0} \qquad (p_0=1010 \text{ mb}, T_0=293.15 \text{ K})$$