A RPC based GRB hunter

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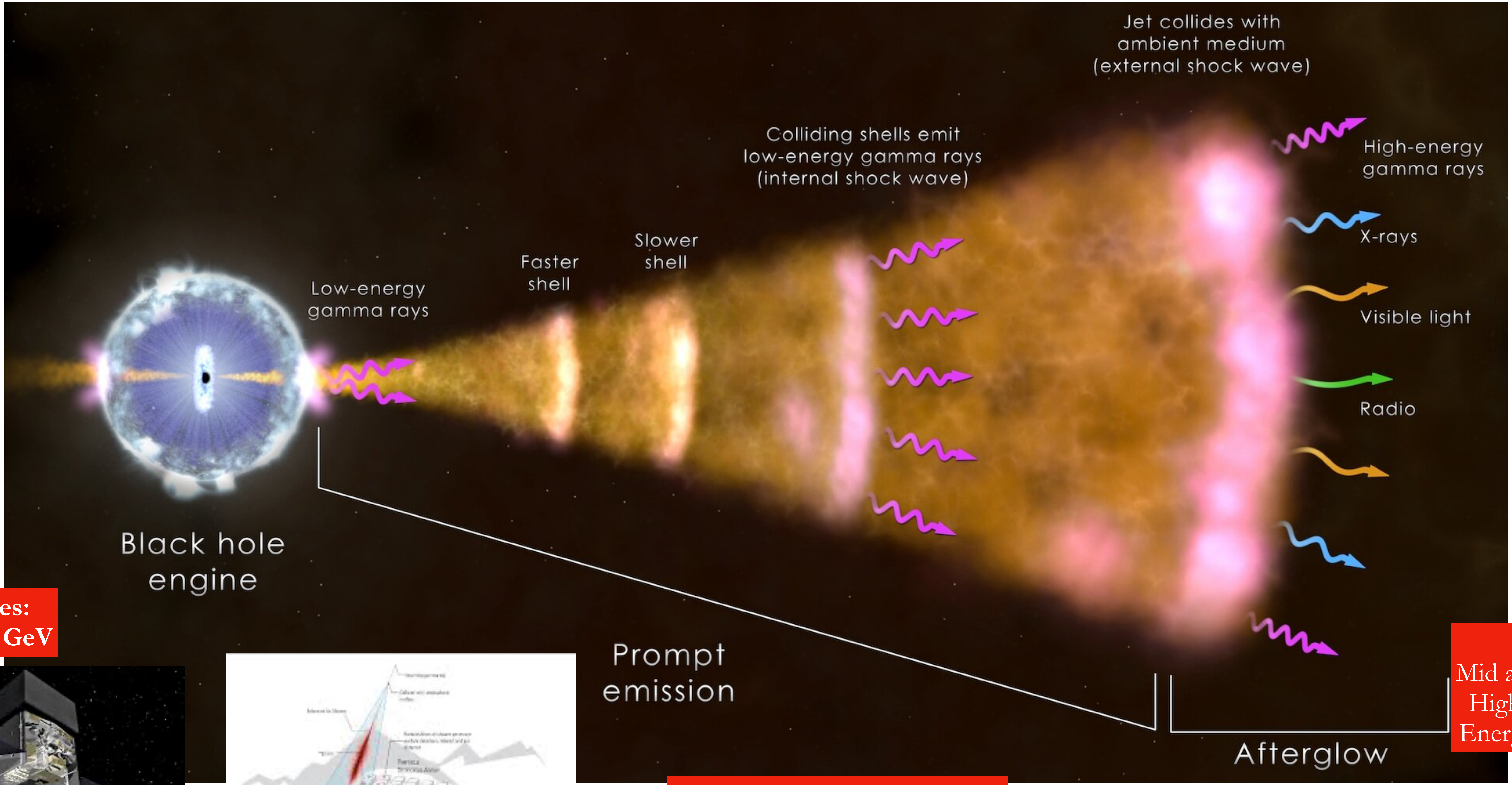
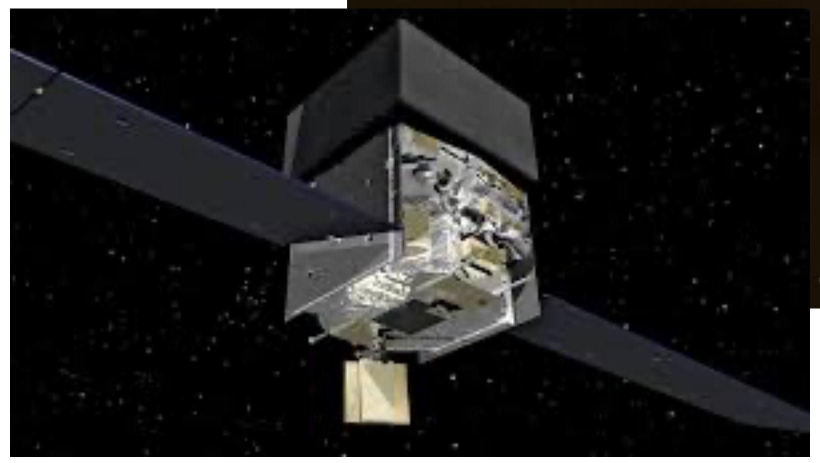
C) **Università Tor Vergata**
D) **INAF**

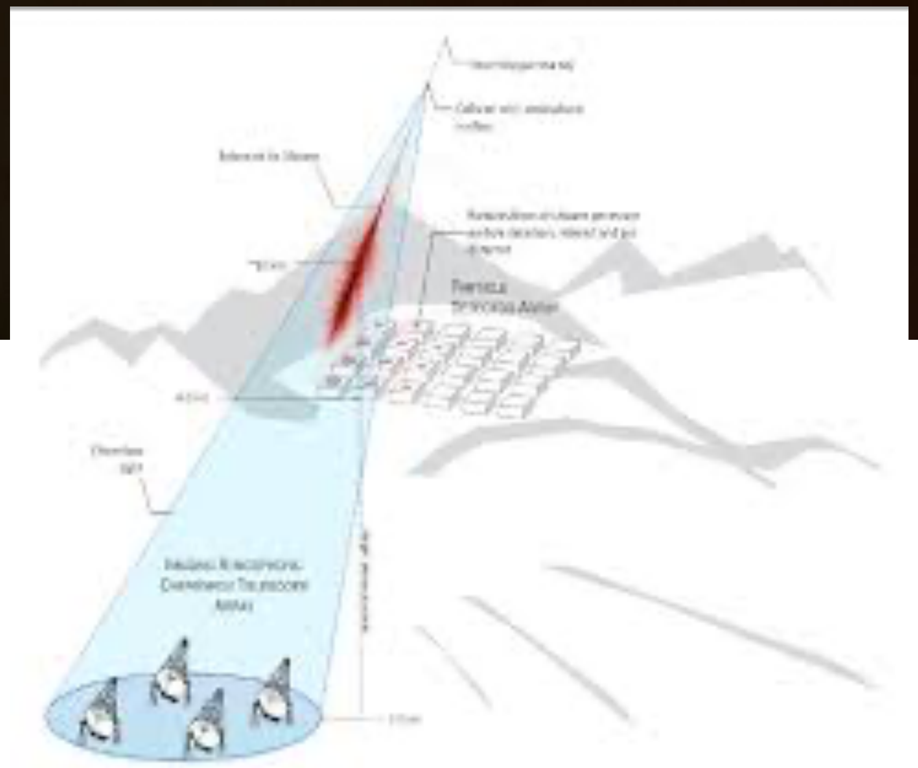
GRBs and detection with EAS



Satellites:
up to **100 GeV**



186 GRBs from.
FERMI/LAT
29 GRBs with emission
above **10 GeV**



IACT:
good angular/energy resolution
Low duty cycle - lower FOV

6 GRBs from TeVCat

Air Shower Arrays
Mid angular/energy resolution
High duty cycle - large FOV
Energy range: 100 GeV - PeV

LHAASO observed the GRB221009A:
extraordinarily bright and very energetic GRB
detecting more than 5,000 photons above 500 GeV

GRBs and detection with Air Shower Arrays

From an experimental point of view, the sampling of secondary particles at ground can be realized with two different approaches

(1) ***Particle Counting***. A measurement is carried out with thin (≪ 1 radiation length) counters providing *a signal proportional to the number of charged particles* (as an example, plastic scintillators or RPCs). *The typical detection threshold is in the keV energy range.*

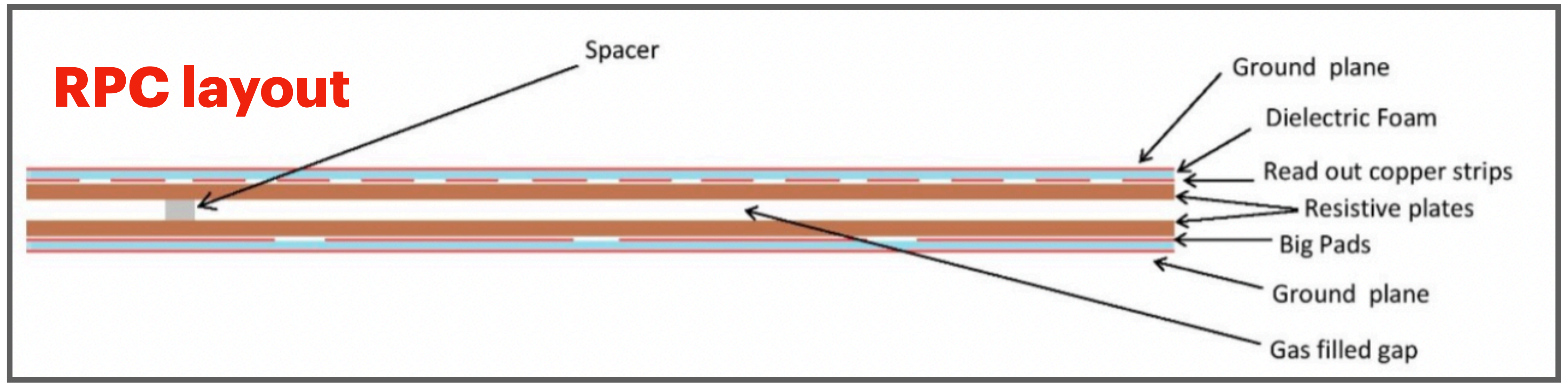
(2) ***Calorimetry***. *A signal proportional to the total incident energy of electromagnetic particles* is collected by a thick (many radiation lengths) detector. An example is a detector constituted by many radiation lengths of water to exploit the Cherenkov emission of secondary shower particles. The Cherenkov threshold for electrons in water is 0.8 MeV and the light yield ≈320 photons/cm or ≈160 photons/MeV emitted at 41°.

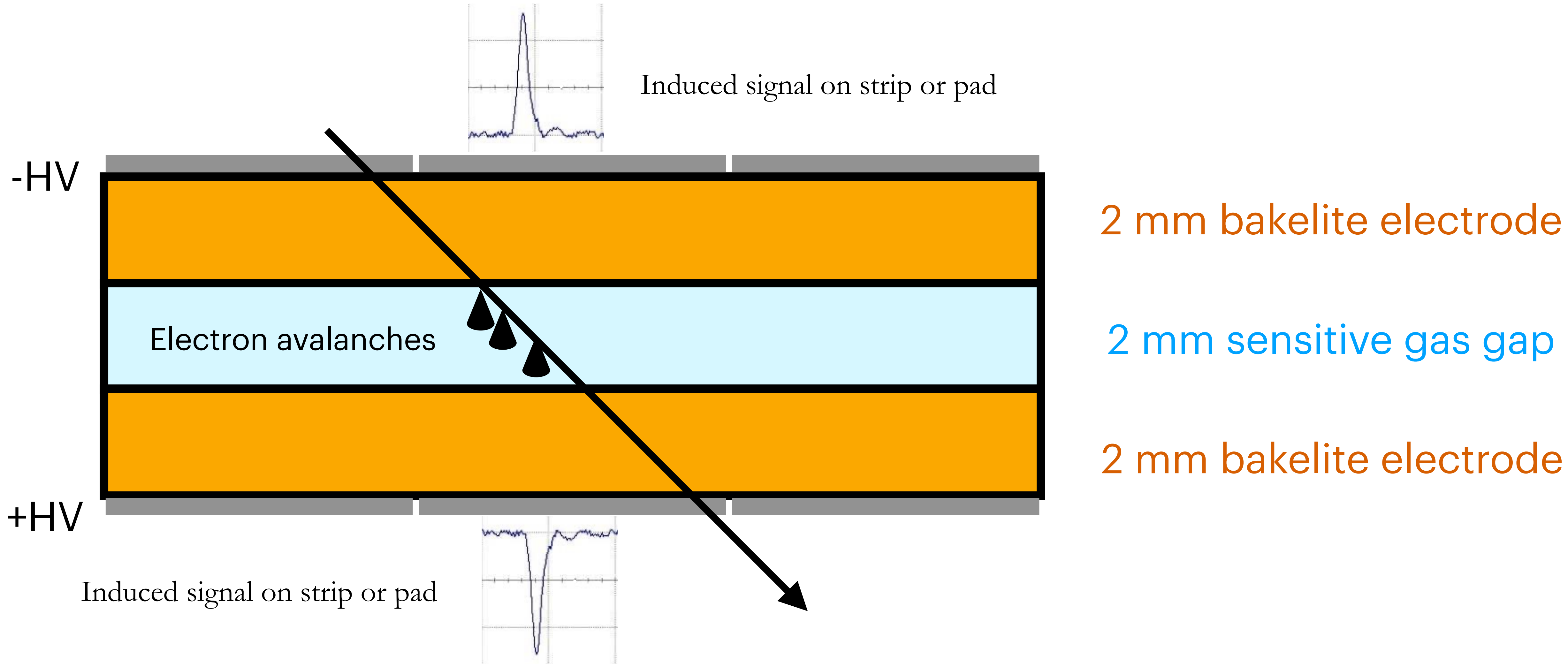
The critical parameters of a detector are the *time* and the *amplitude resolutions*.

"Detecting gamma-rays with moderate resolution and large field of view: Particle detector arrays and water Cherenkov technique"
Michael A. DuVernois, Giuseppe Di Sciascio
Chapter for "Handbook of X-ray and Gamma-ray Astrophysics" (Eds. C. Bambi and A. Santangelo, Springer Singapore) arXiv:2211.04932

In this talk we will consider the particle counting approach with **Resistive plate Chambers**

Resistive Plate Chambers (RPCs)





Particle detection in 2 mm gap width
Only 2 mm bachelite thickness before gas

Low threshold for charged particle detection (KeV range)

Detector:
Single Gap RPC: 2 mm gas gap
Gas mixture: $C_2H_2F_4$ - C_4H_{10} - SF_6 (95.2% - 4.5% - 0.3%)

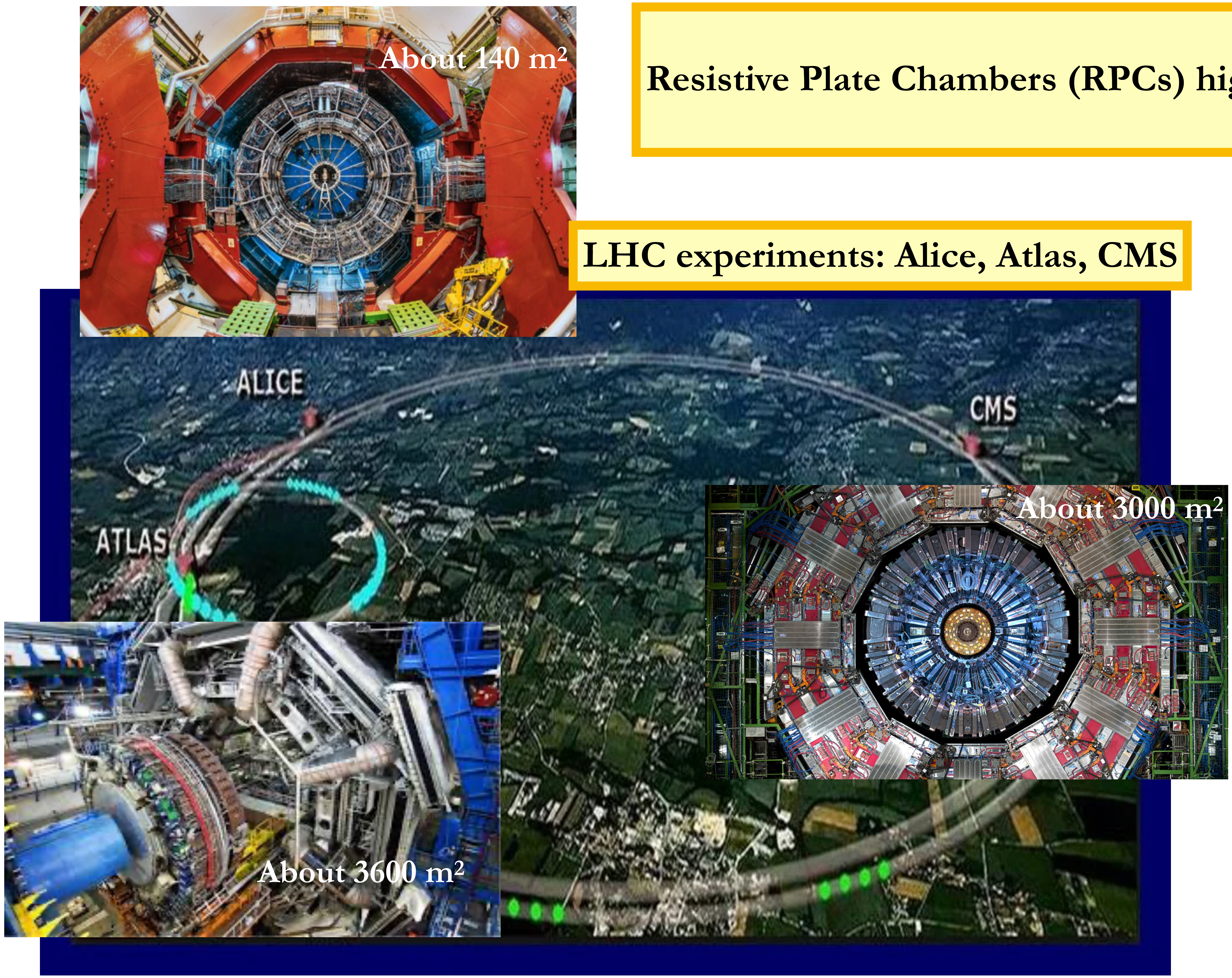
New generation of RPCs:
- Operated in avalanche mode (lower charge)
- Imporved Front-end electroncis

Advantages of avalanche operations:
- Lower charge: improved linearity up to O(10^7) particles/m^2 (10 PeV primaries)
- Lower charge: lower gas flow needed (less expensive, lower maintenance)
- Lower signals: easier control of cross talk and noise

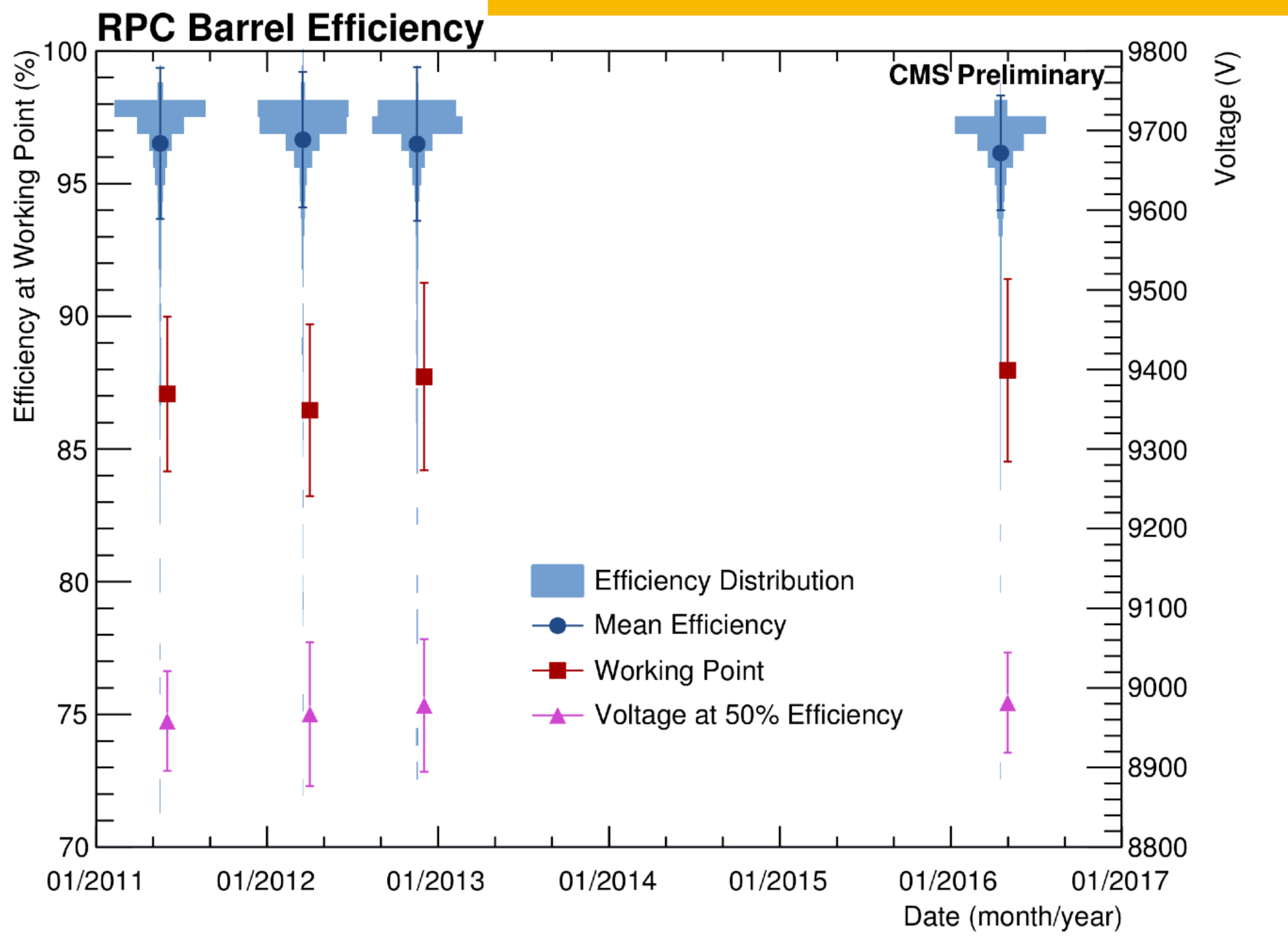
RPC in high energy physics

Resistive Plate Chambers (RPCs) highly used in high energy physics

LHC experiments: Alice, Atlas, CMS



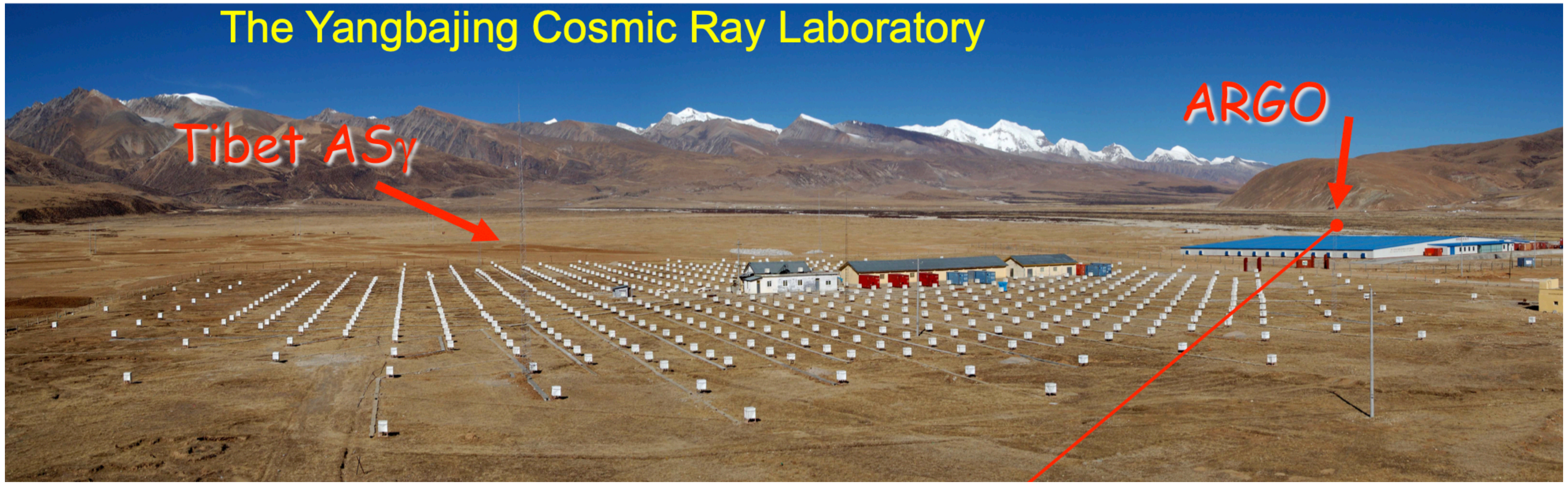
RPC CMS performance vs time



High detection efficiency: around 97 %
Excellent time resolution: 1-2 ns
Reasonable cost

RPC for cosmic ray physics

ARGO experiment

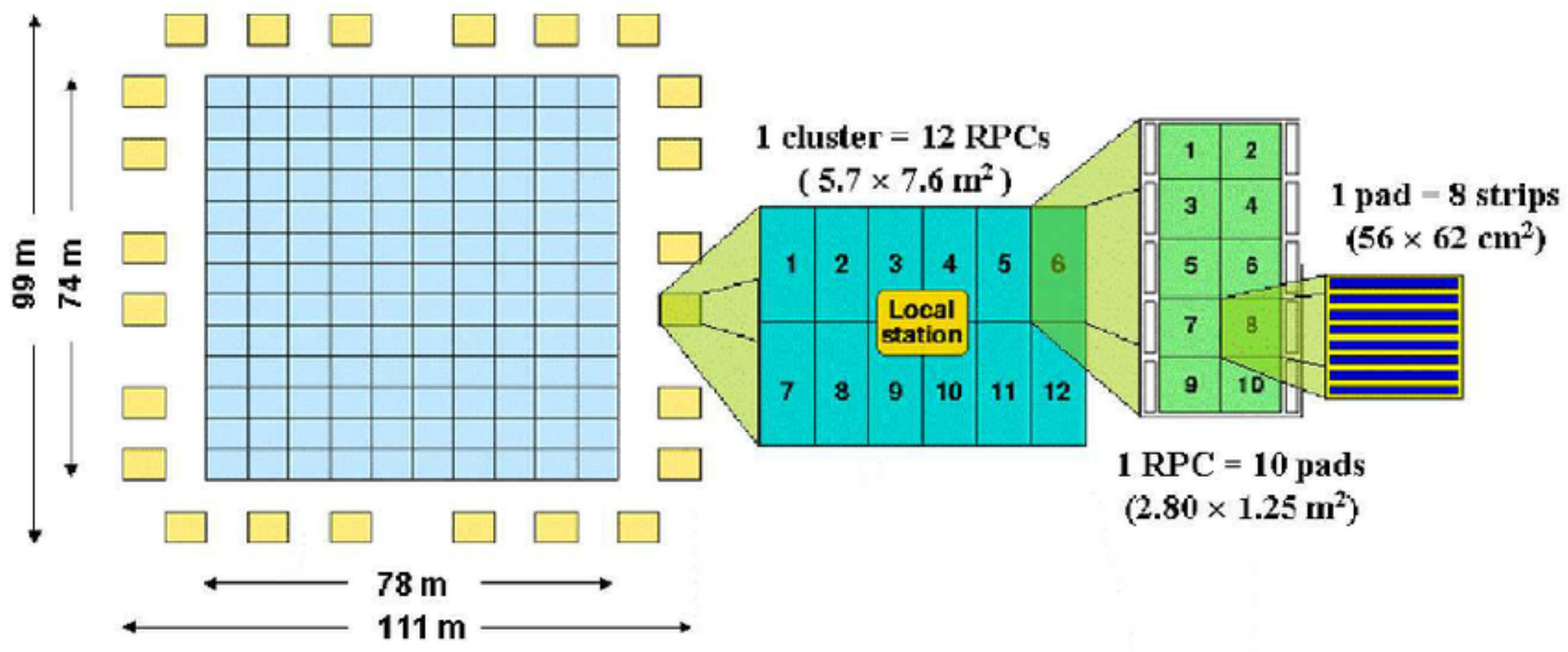


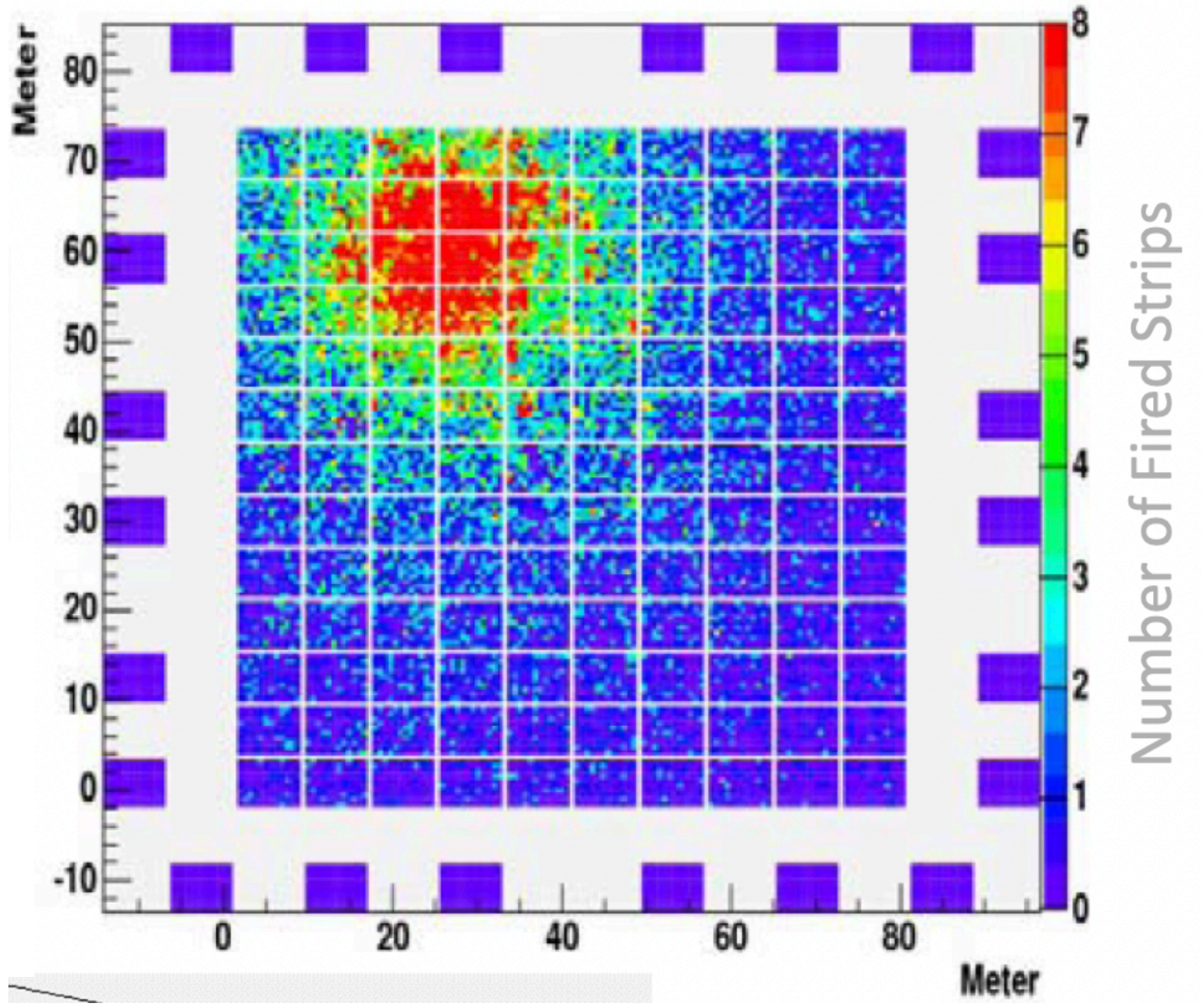
- Data taking with Very low maintenance: **2007 -2012**

Angular resolution **0.5° at 1 TeV** (shower front projection with time measurement)

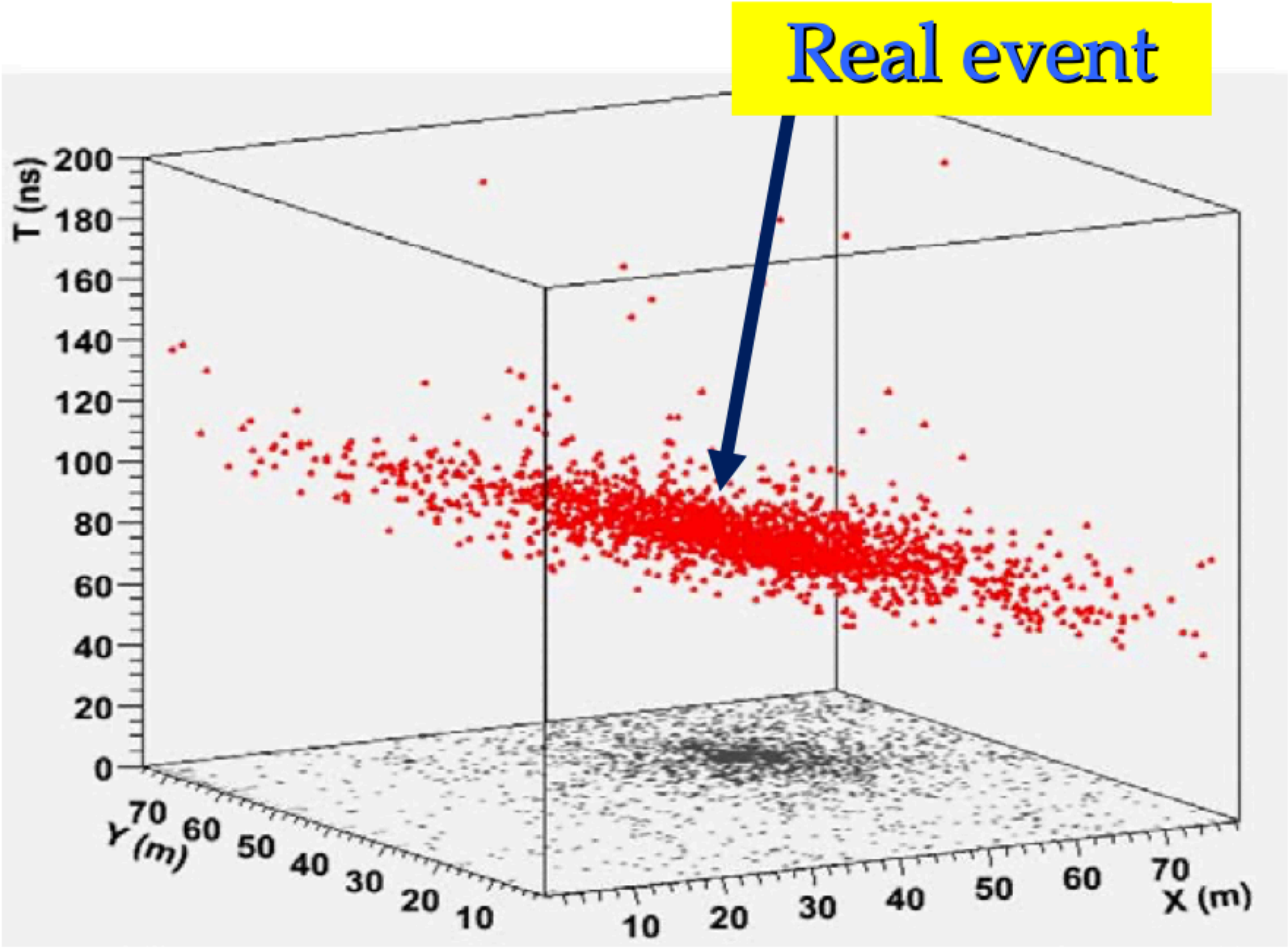
Energy Range: **100 GeV - 10 PeV**

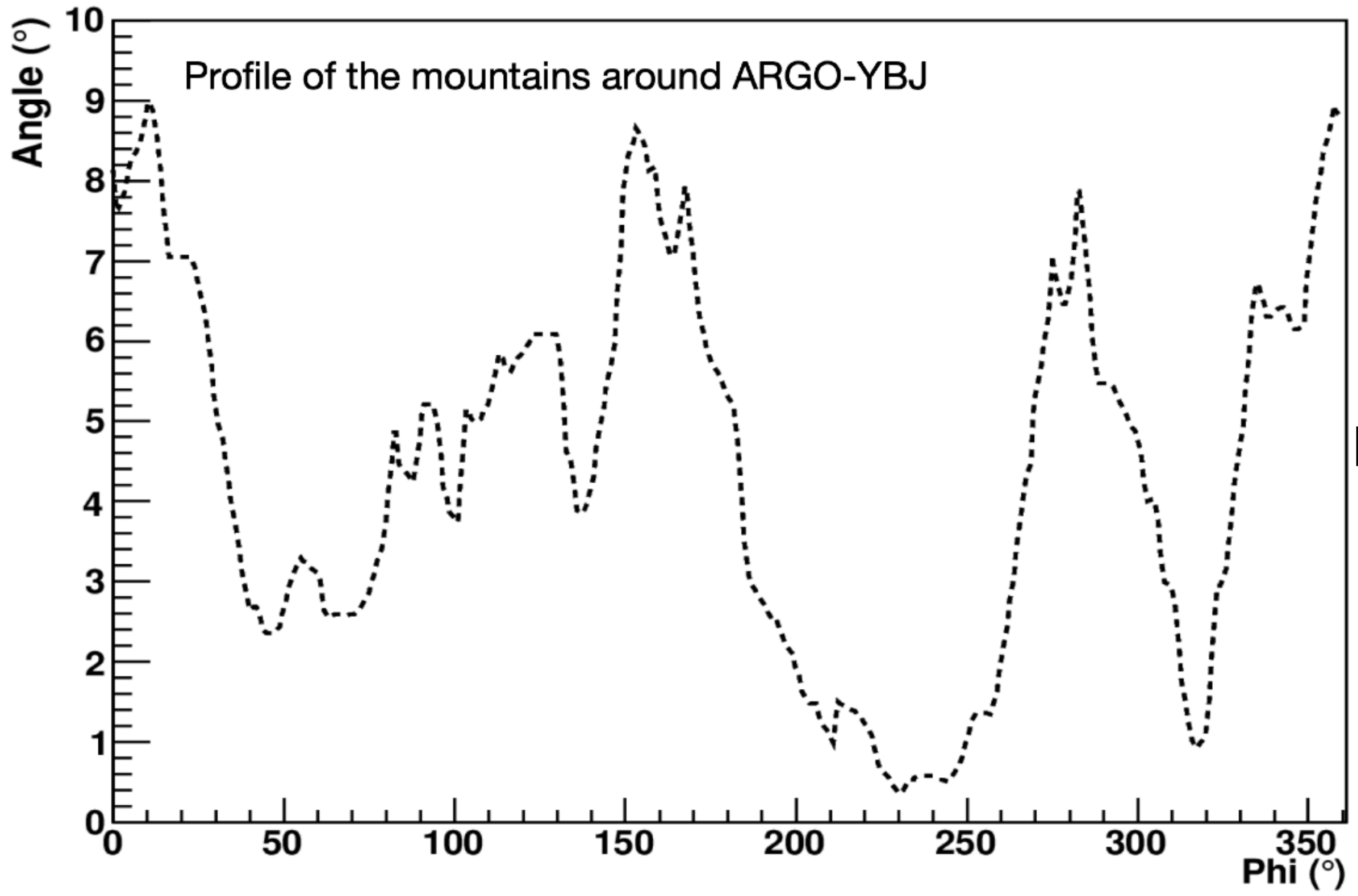
5600 m² of active area + **1100 m²** guard ring

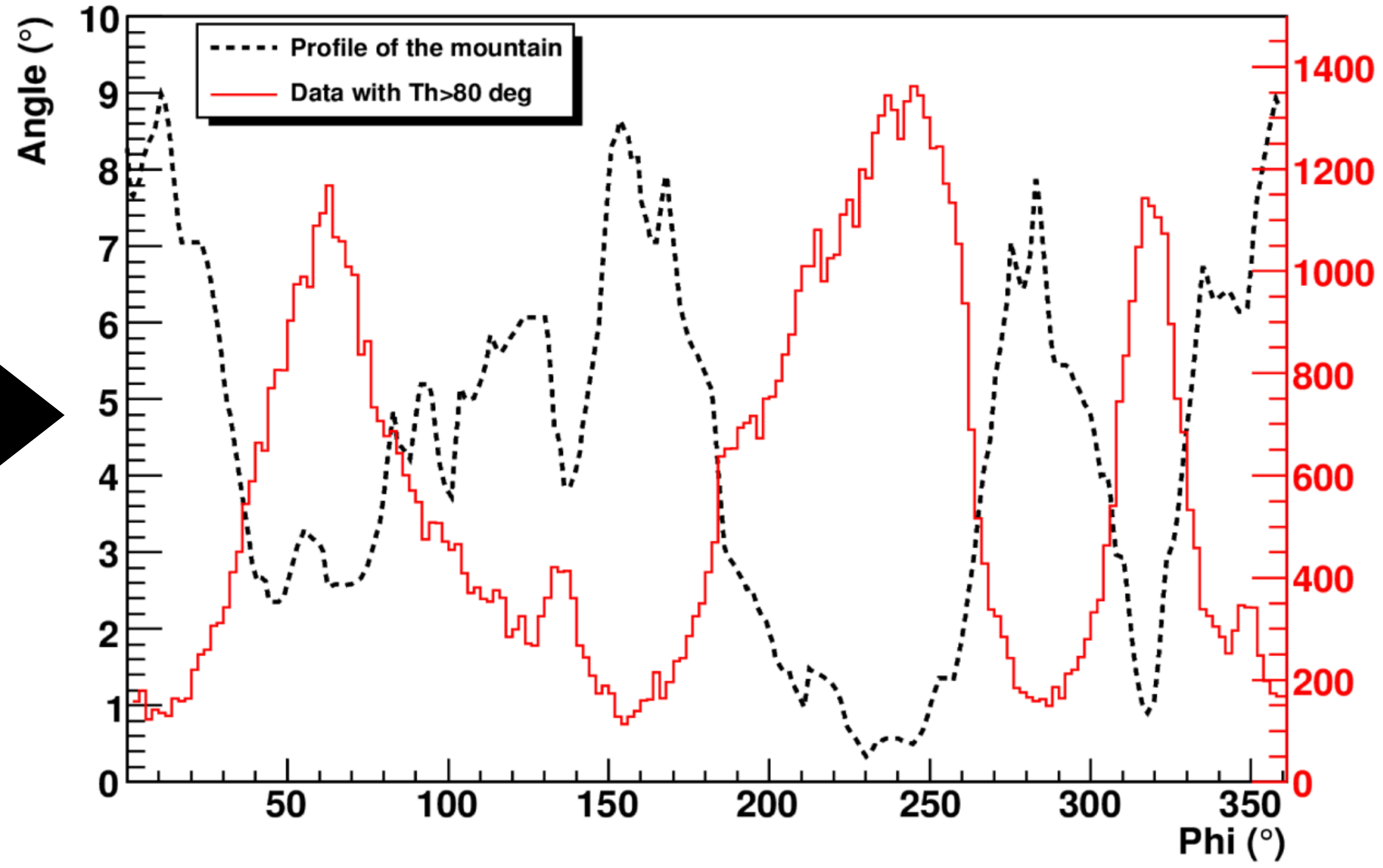




RPC in the ARGO experiment







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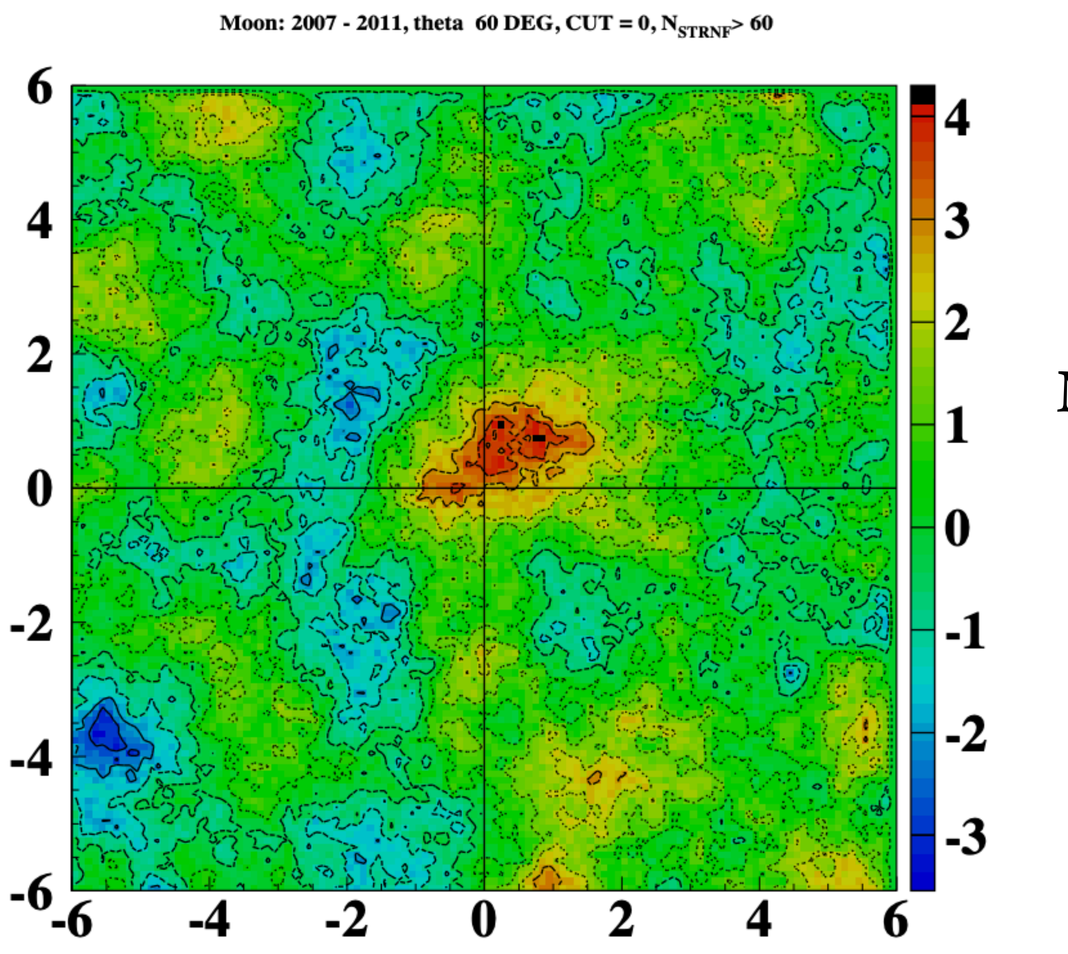


MOON shadow
EAS above
60 degrees

Fig.4: Moon shadow significance map. The event multiplicity is N>60 and the zenith angle is $\theta > 60°$. The color scale gives the statistical significance in standard deviations.

Triggering at low energy threshold

A RPC carpet allows to exploit a high granularity read-out crucial for a flexible trigger logic.

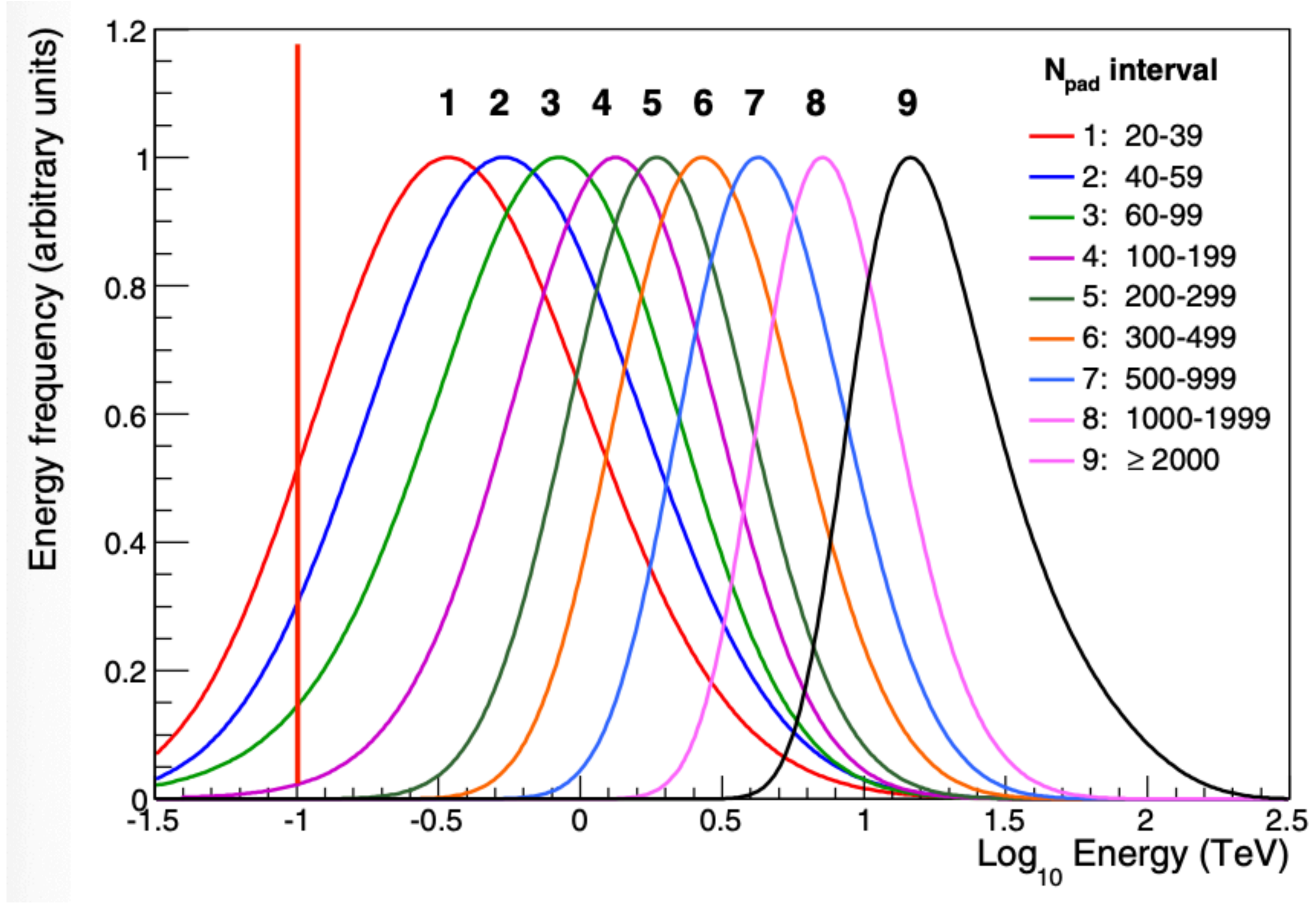
Very silent detector (380 Hz/pad, a half from soil radioactivity) and a particle multiplicity built up correlating at different time scales increasing portions of the carpet

ARGO - YBJ data:
Inclusive trigger by a majority of 20/15600 pads *accidental free*
Median energy of first multiplicity bin: 340 GeV

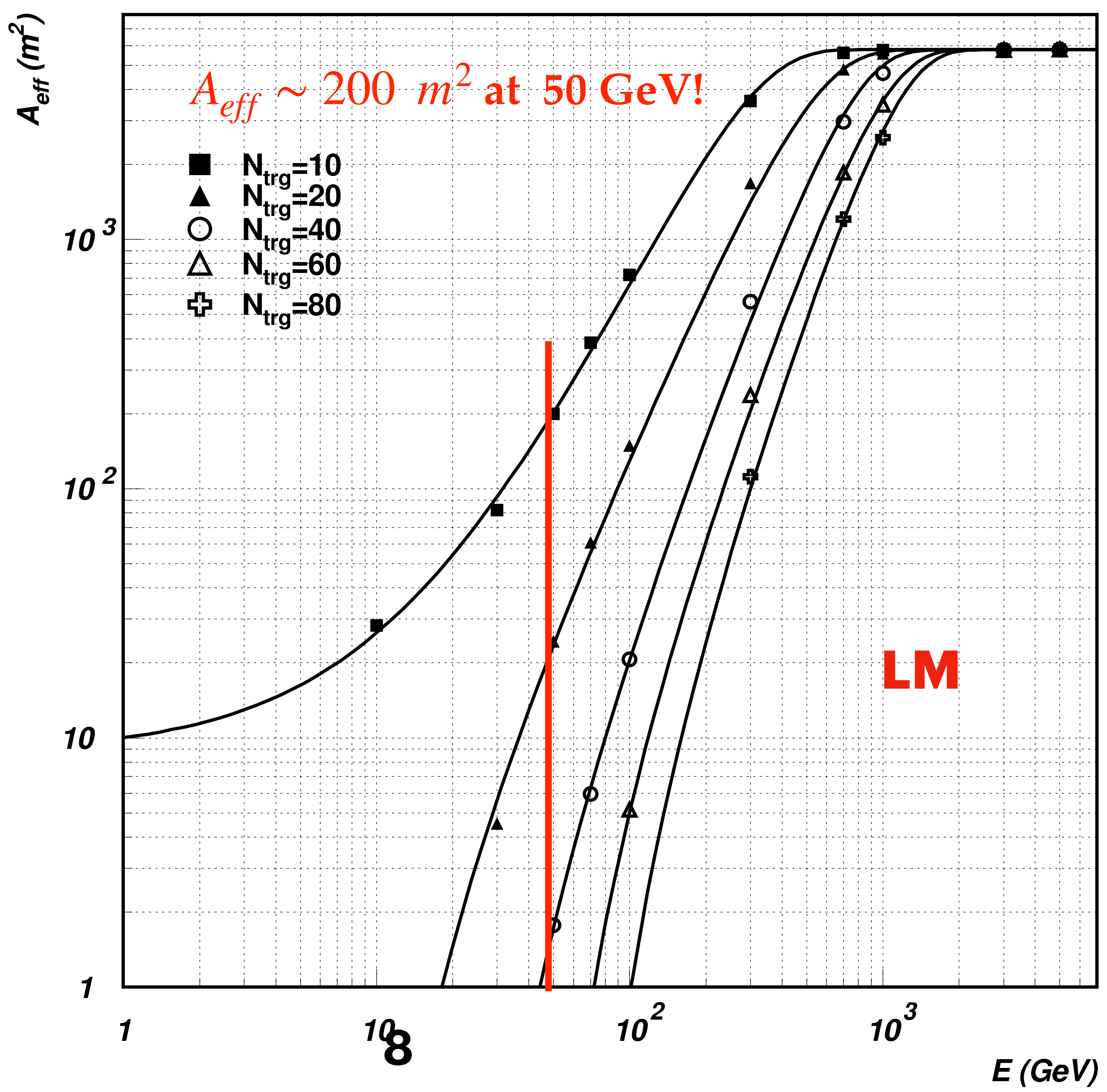
Different algorithm were exploited or tested

- **Single Particle Technique (SPT)**
- **Low Multiplicity Trigger (LM)**
- **High Multiplicity Trigger (HM)**
- **FAST Trigger**

ARGO High Multiplicity trigger



ARGO Low Multiplicity trigger



R&D for a hybrid RPC-WCD detector

RPC have been already presented in the past as a possible option for gamma ray physics in south hemisphere.

NEW: After the pandemic crisis, with the **National Recovery and Resilience** Plan (PNRR) the European Commission funded many projects in Italy in response to the crisis and to jumpstart the economy

In the framework of PNRR CTA+, Working Package 1520, INAF

INFN will support the construction and test of an hybrid RPC + Water-Cerenkov of about 100-200 m^2

Rome TorVergata group lead the RPC construction project starting from the Argo experience

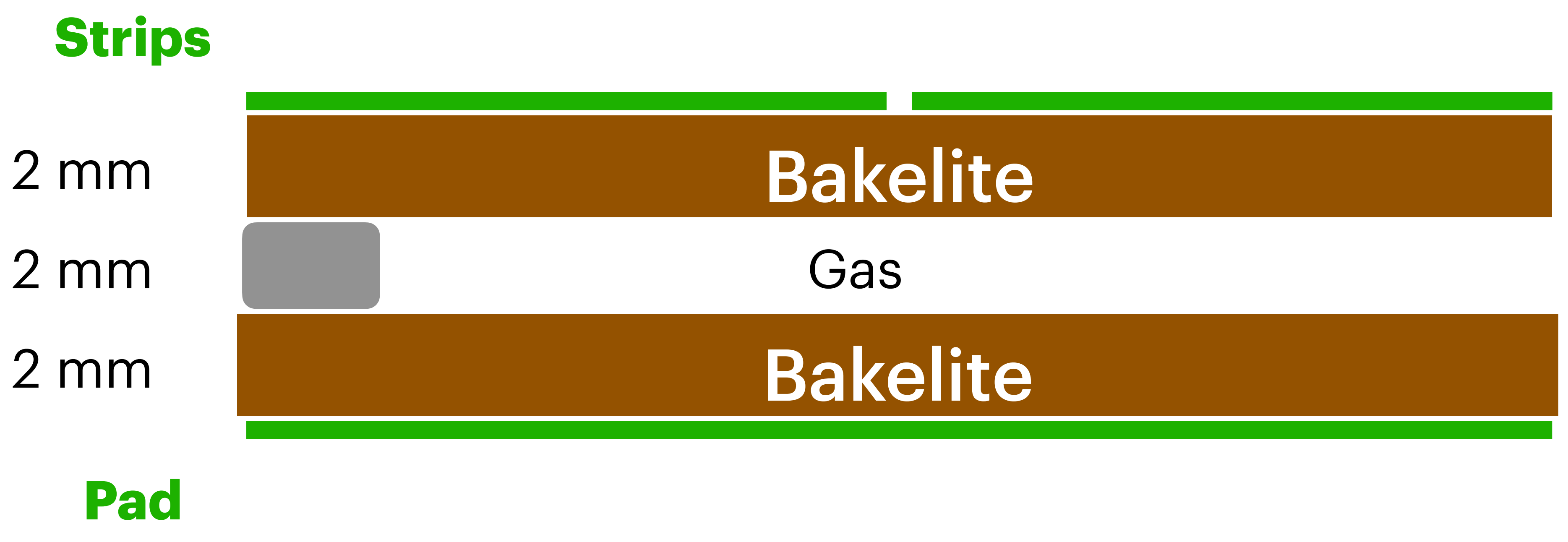
Timeline for the project:

- Tenders closed by the end of 2023:
  1) Front-End Read-Out per RPC production
  2) HPL electrodes production for RPC
  3) HV, LV e Read Out systems
  4) **Fully assembled RPCs production-> N^o 32 RPC total area 73 m^2 + additional 25 m^2 already available**

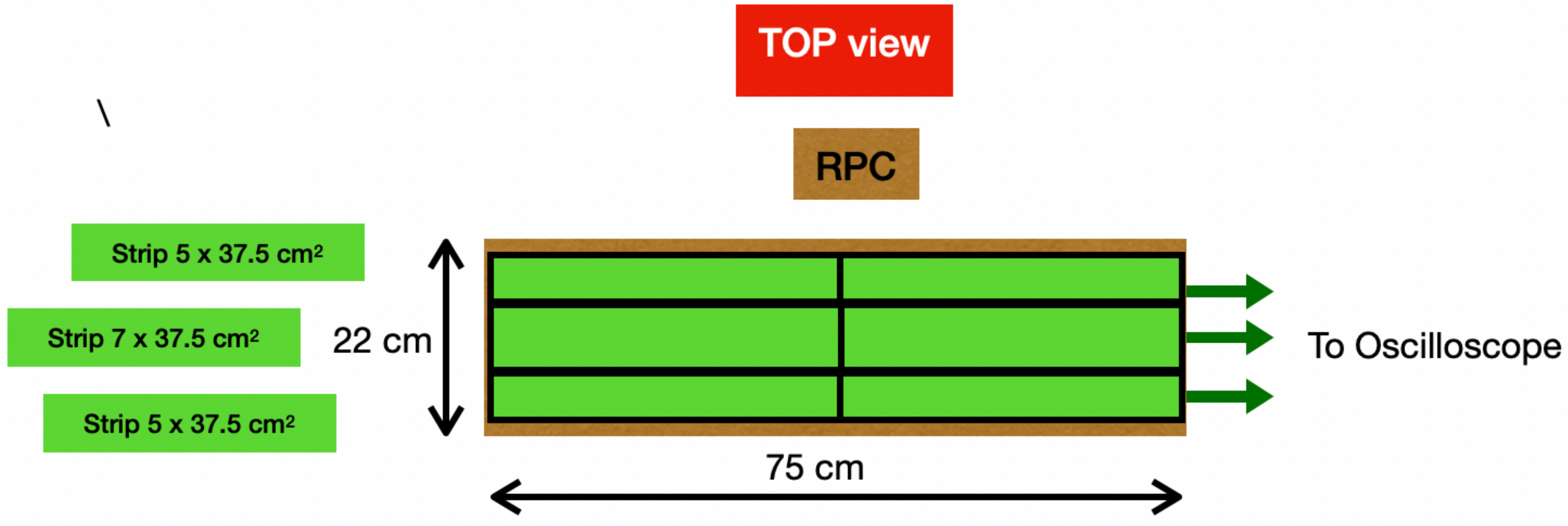
  Note: 1 Cluster of Argo 50 m^2 produced physics results (Astroparticle Physics 17 (2002) 151–165)
- RPC Production and test: first chambers already available. Full production middle of 2025.
- Integration test RPC+WCD tank end of 2024-first half 2025
- Installation and operations at high quote starting at the end of 2025
- **To complete this project we asked to carry on these activities inside the SWGO Collaboration to build a small demonstrator for a possible future upgrade.**

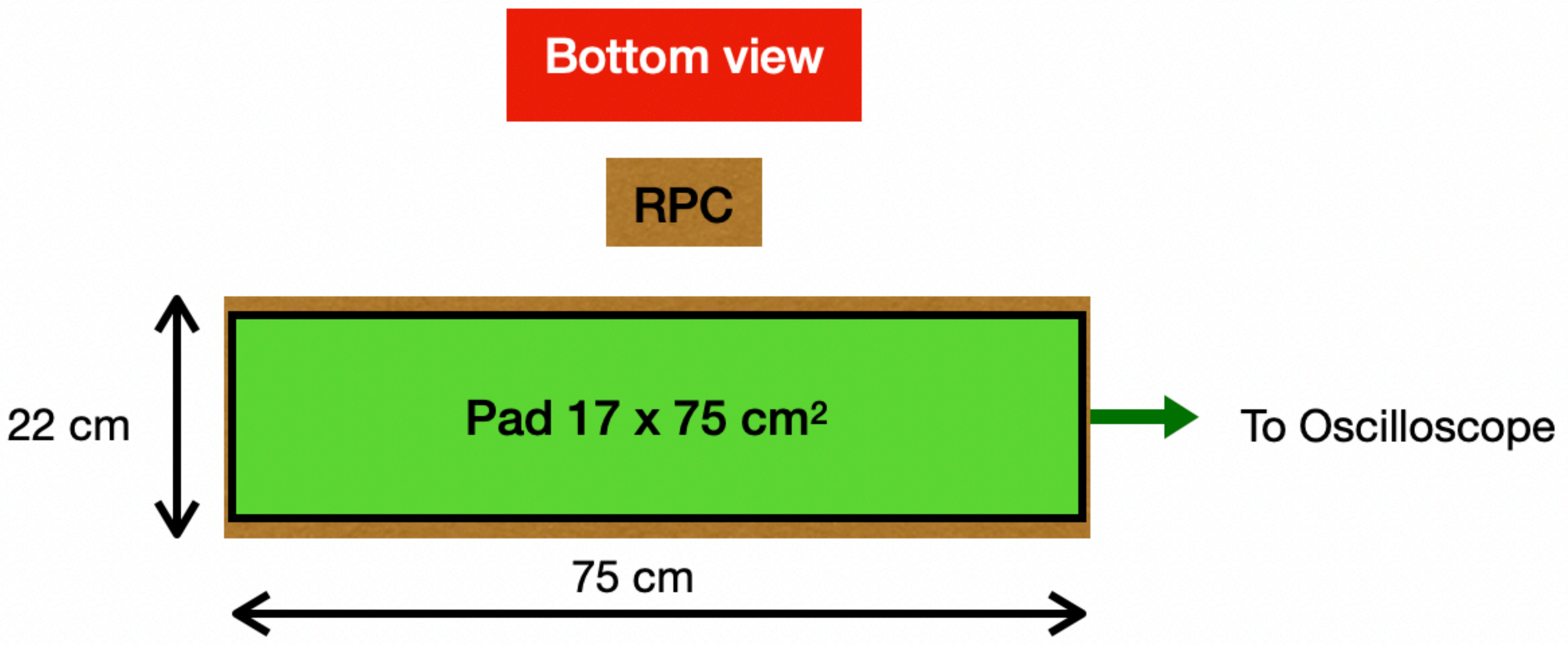
Laboratory test: small chamber (6 strips)

2 mm gap RPC Not in scale



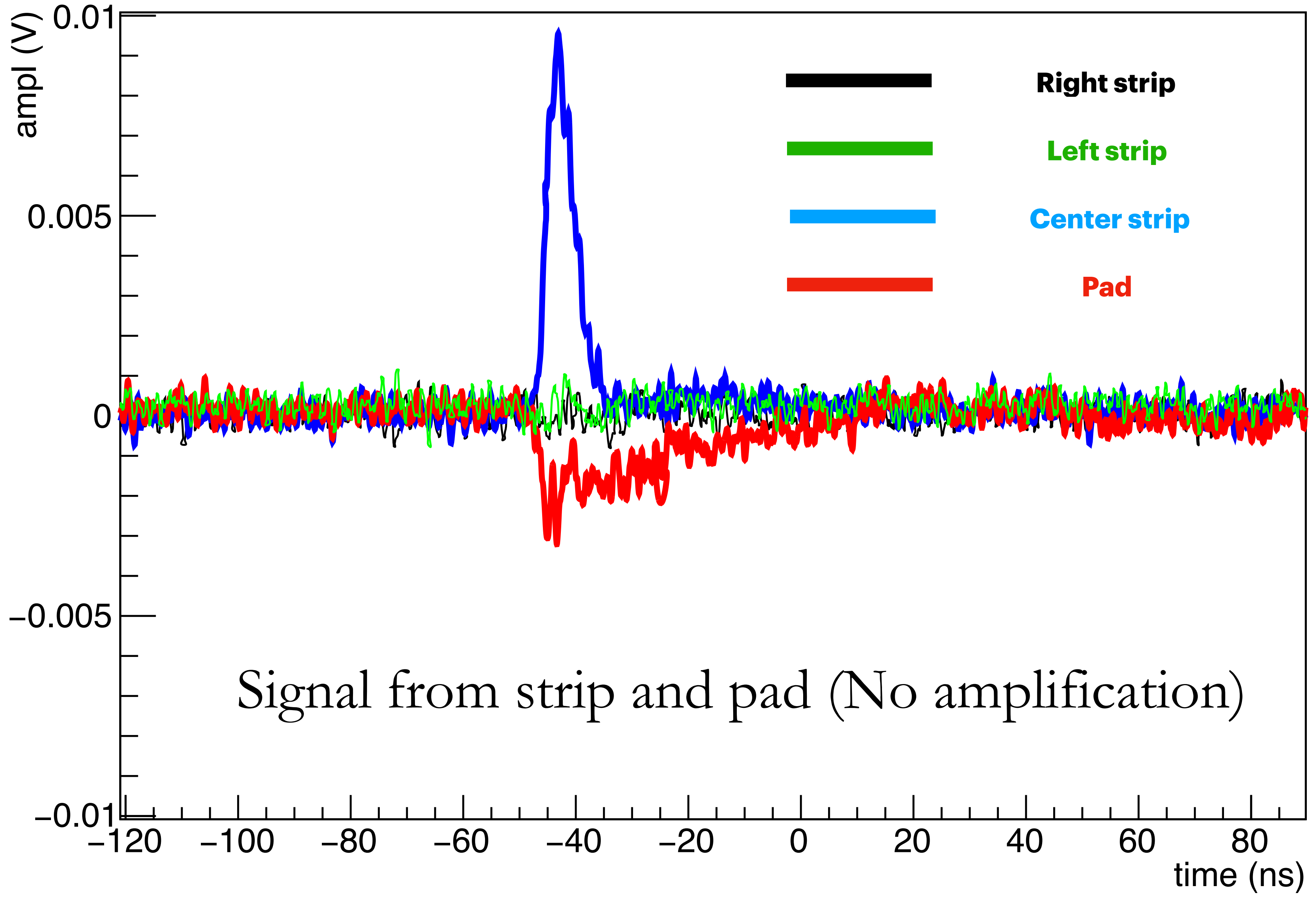
Detector:
Single Gap RPC: 2 mm gas gap
Gas mixture: $C_2H_2F_4$ - C_4H_{10} - SF_6 (95.2% - 4.5% - 0.3%)

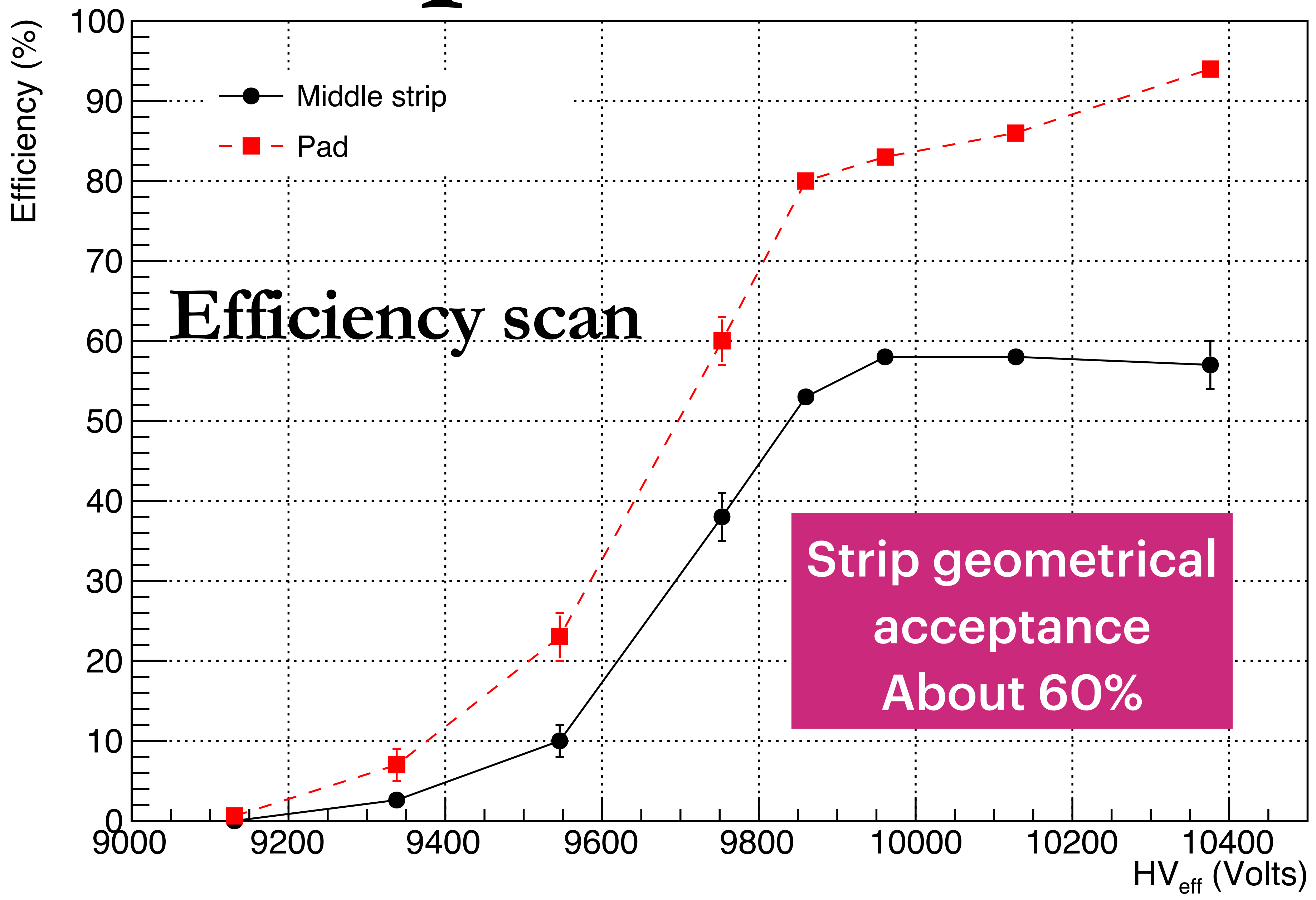




Readout:
3 strips to oscilloscope from one side
3 strips to front end electronic from the other side (still not used)
1 bigger pad to oscilloscope

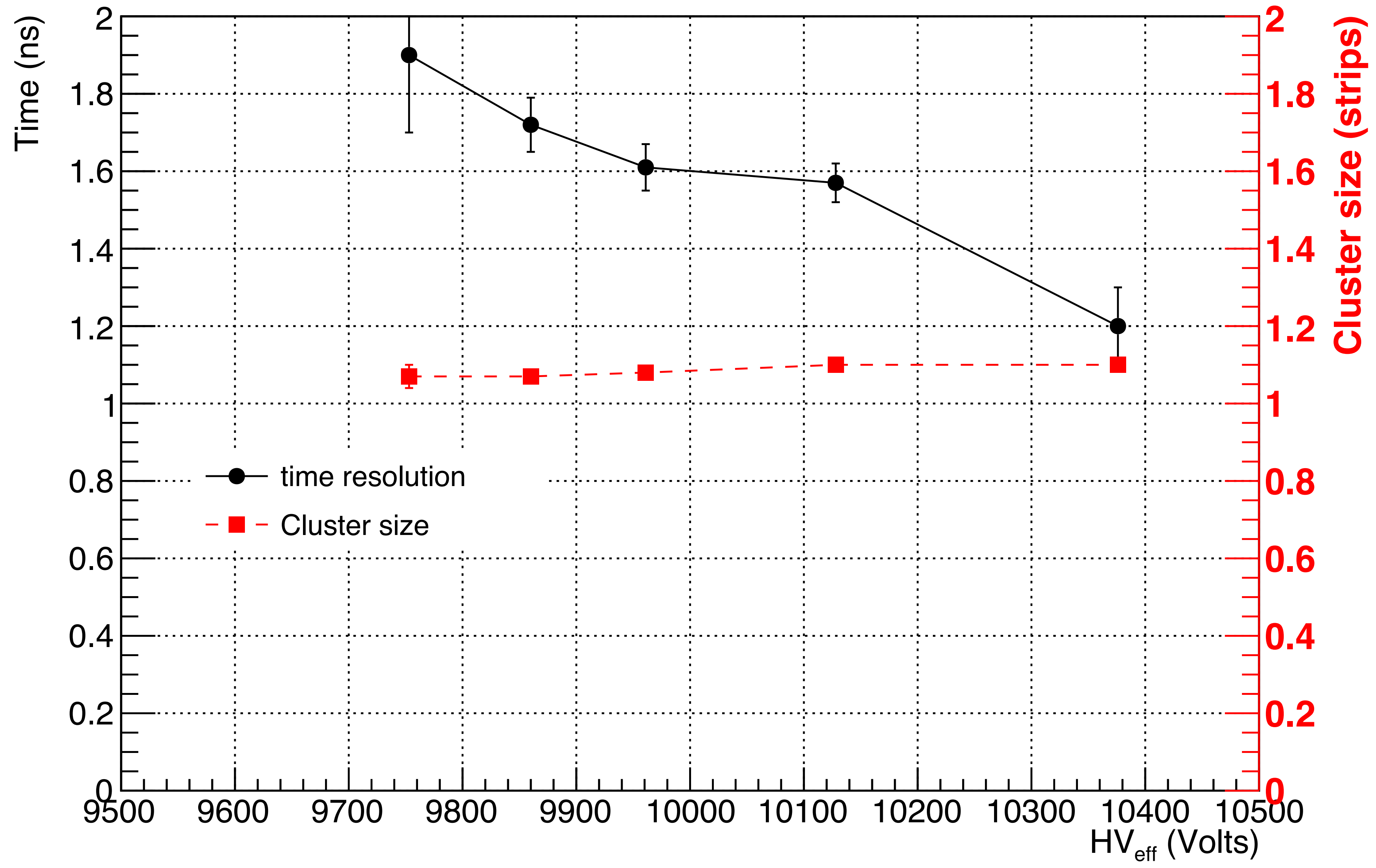
Small chamber performance



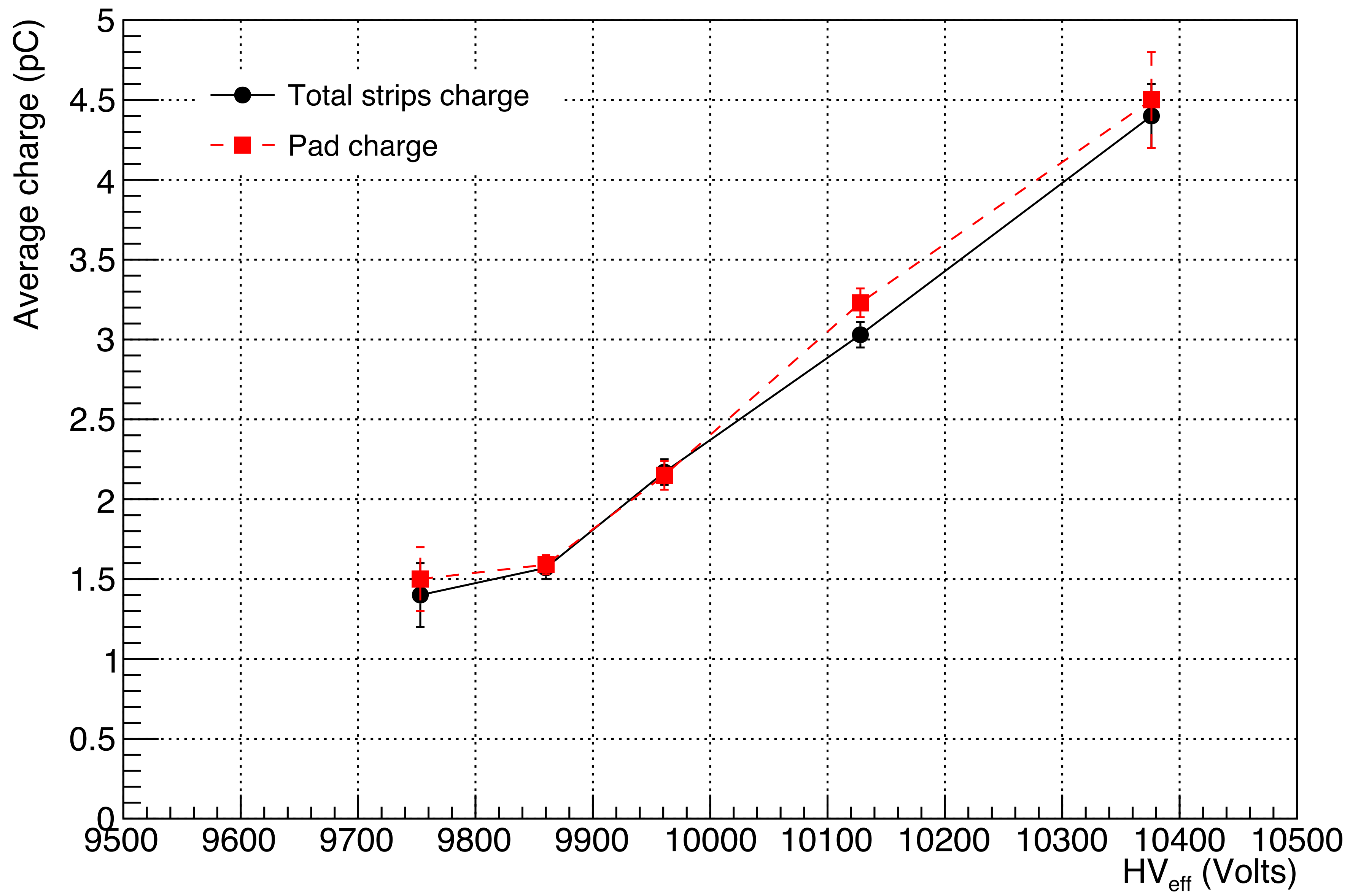


HV normalized at
P_0 = 1010 mbar
T_0 = 20°

Time resolution, cluster size



Charge vs HV

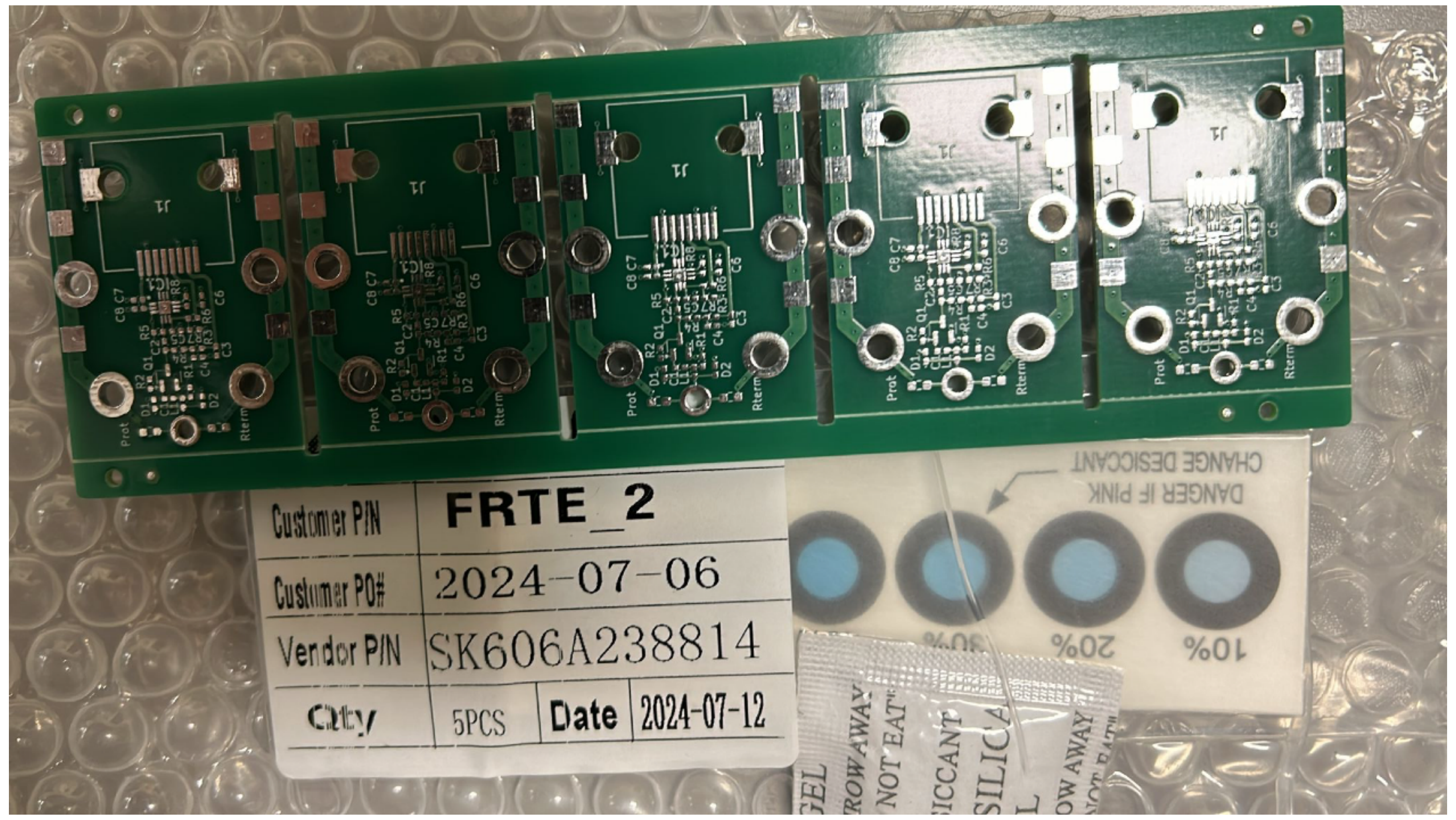


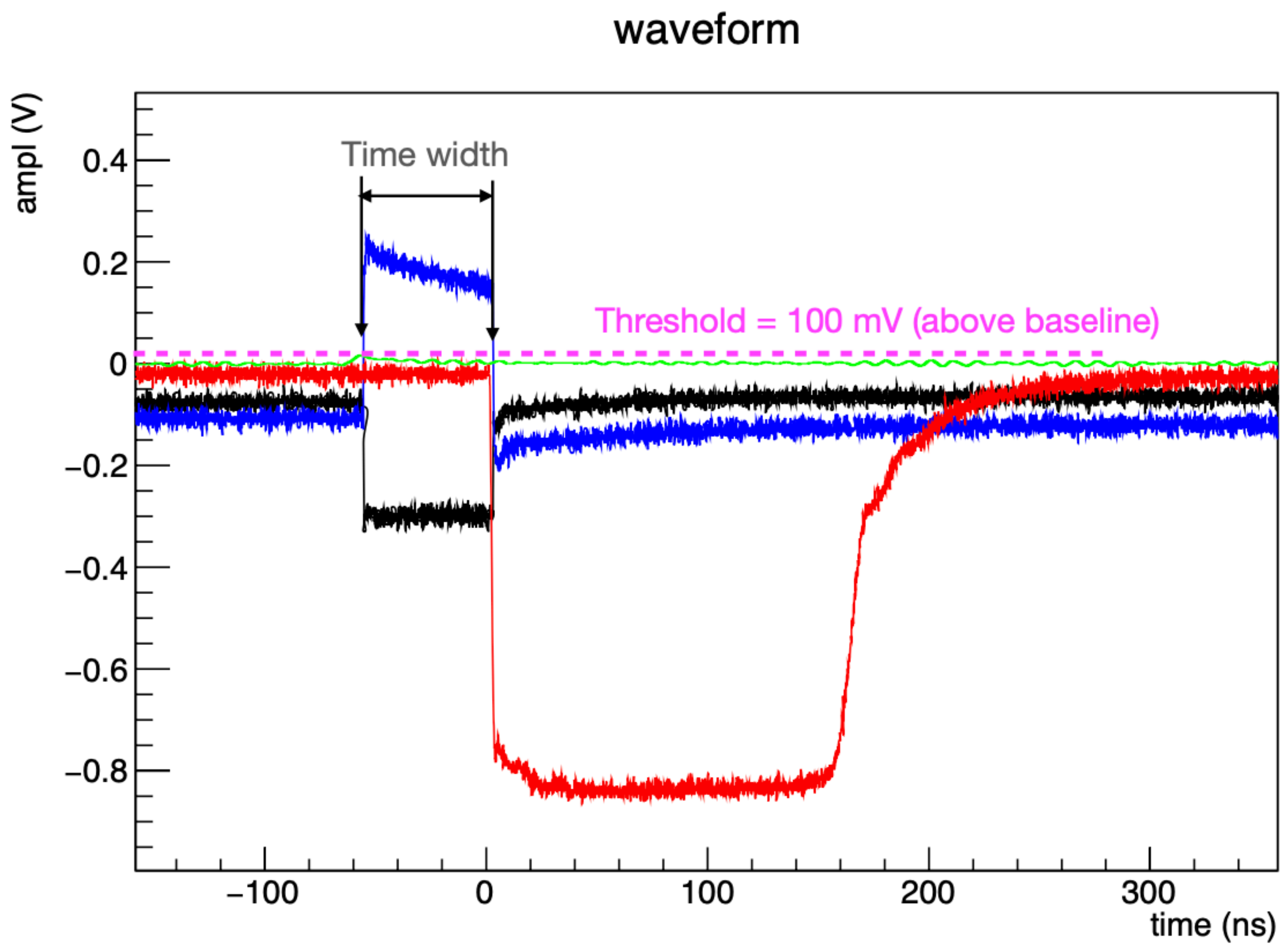
Front end electronics

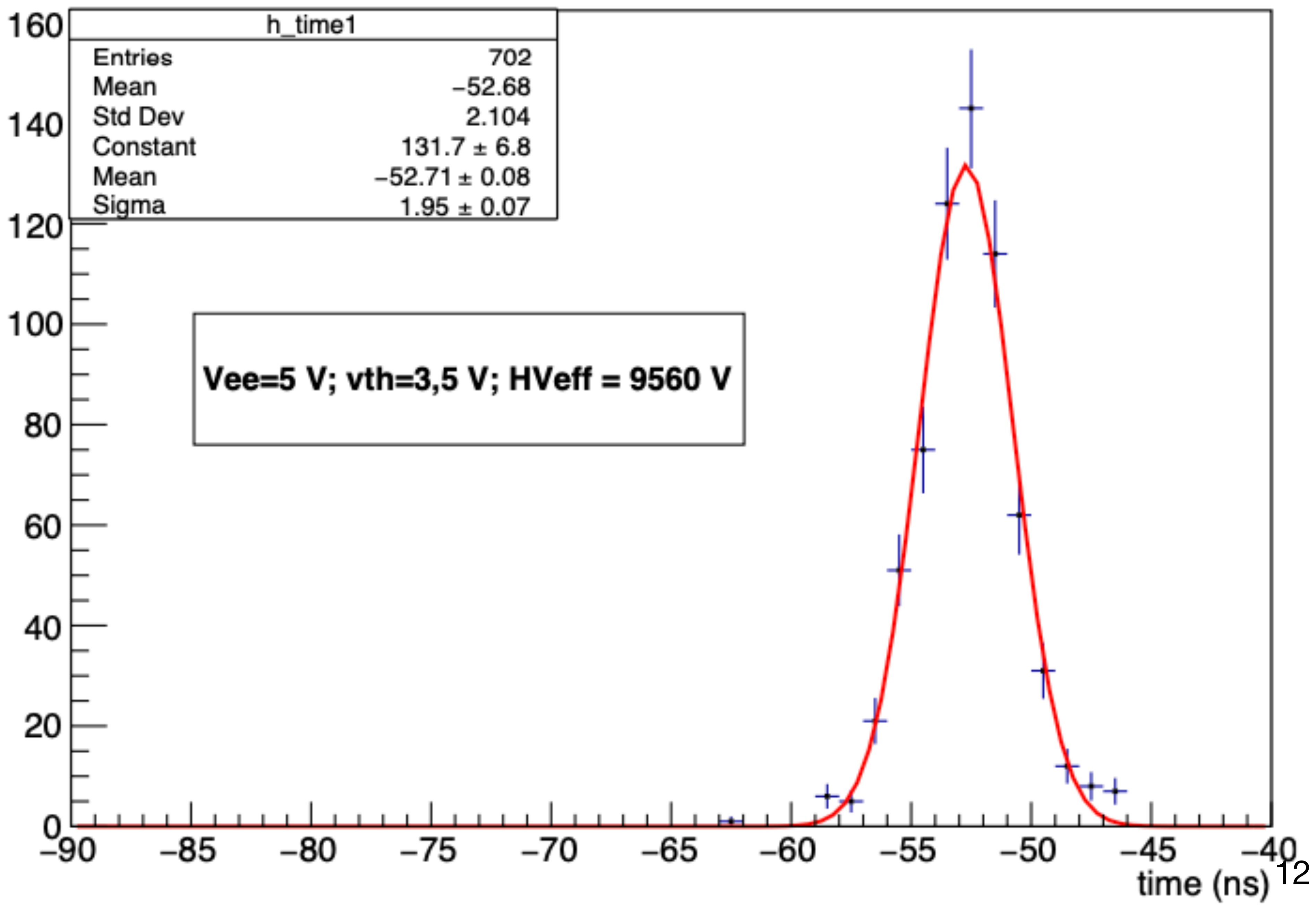
First prototype of front end electronics tested on the small chamber with strips

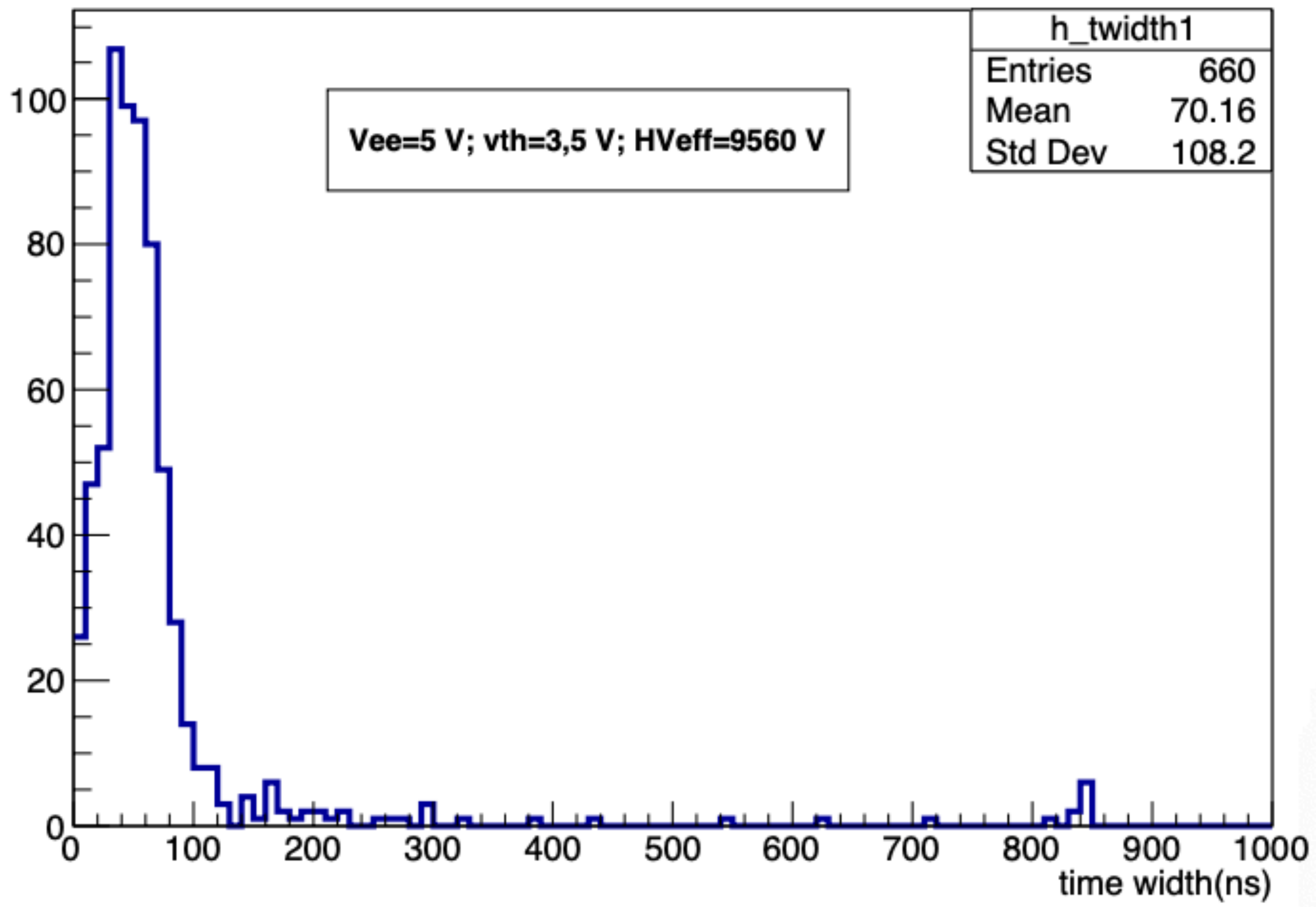
Front end board characterization ongoing:
- Efficiency improved
- Time resolution preserved

Plan to test it on big chamber and large pads

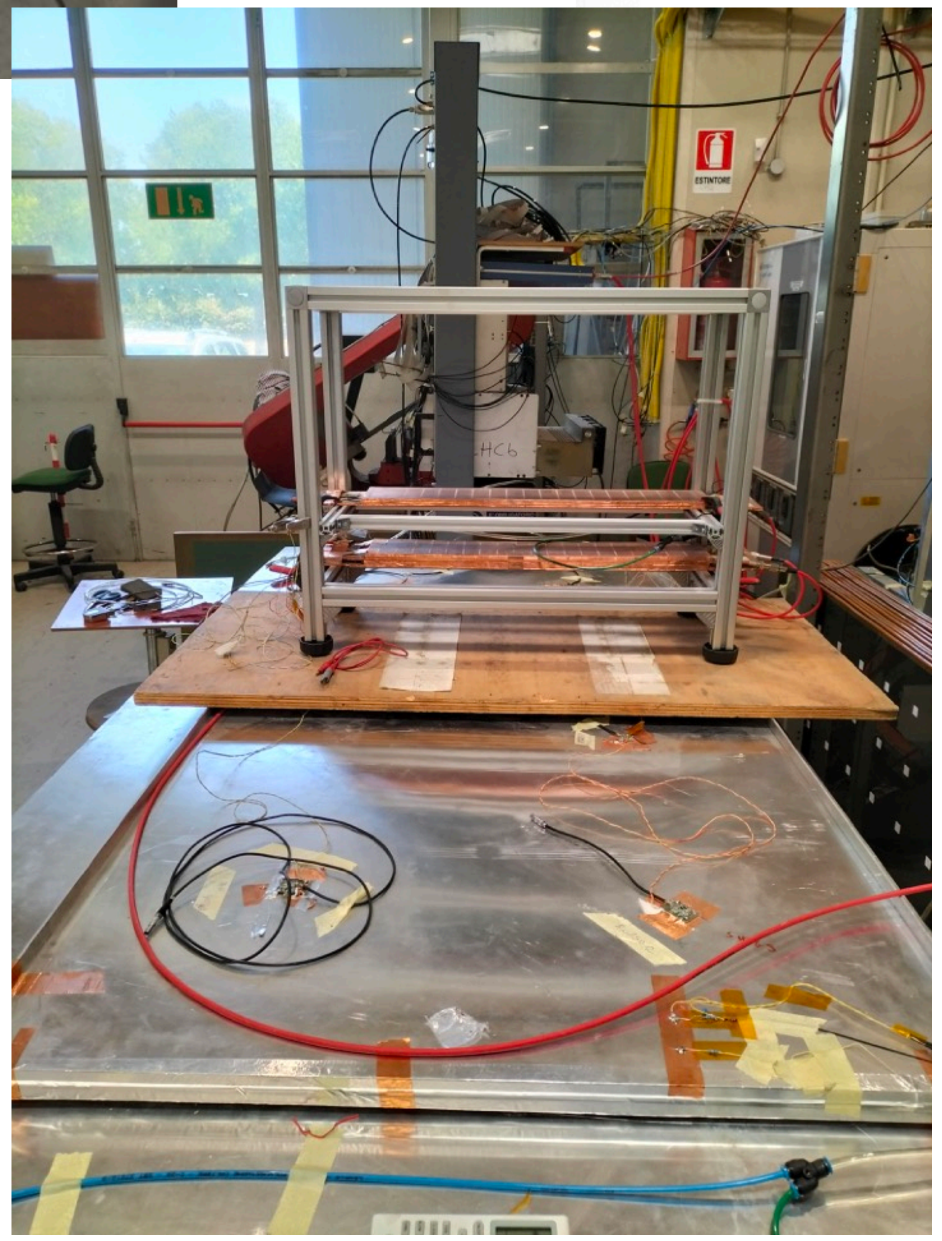


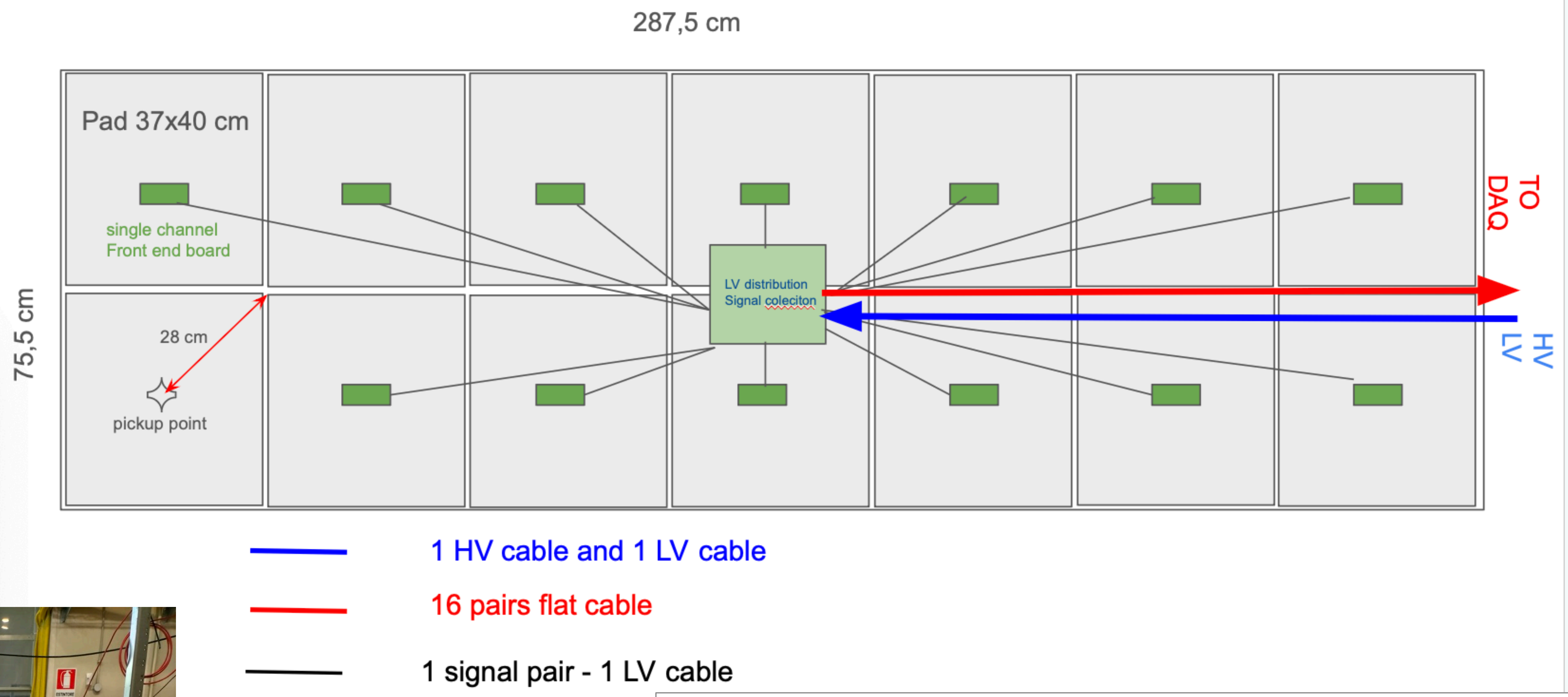


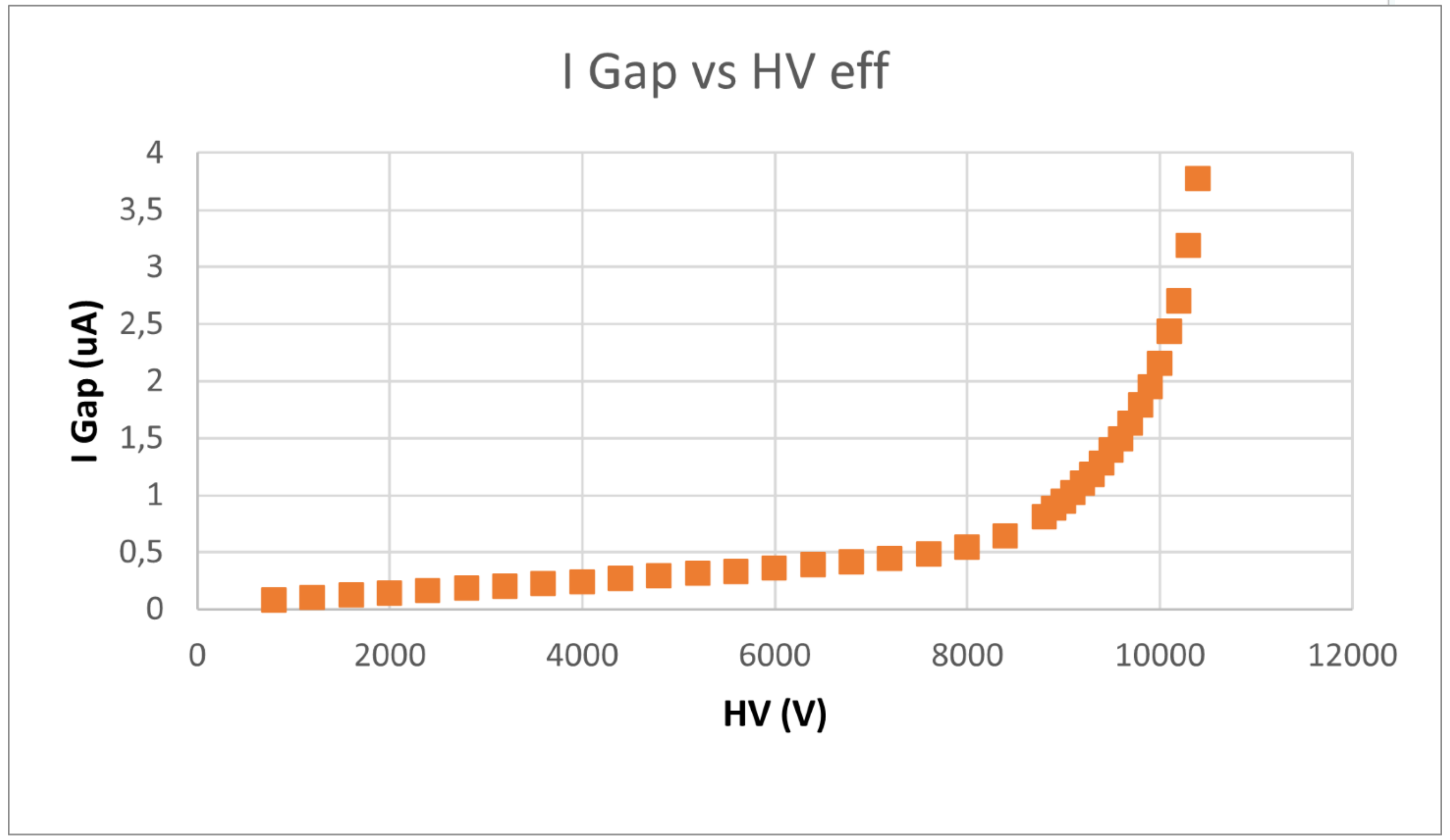




Detector optimization: full chamber prototype

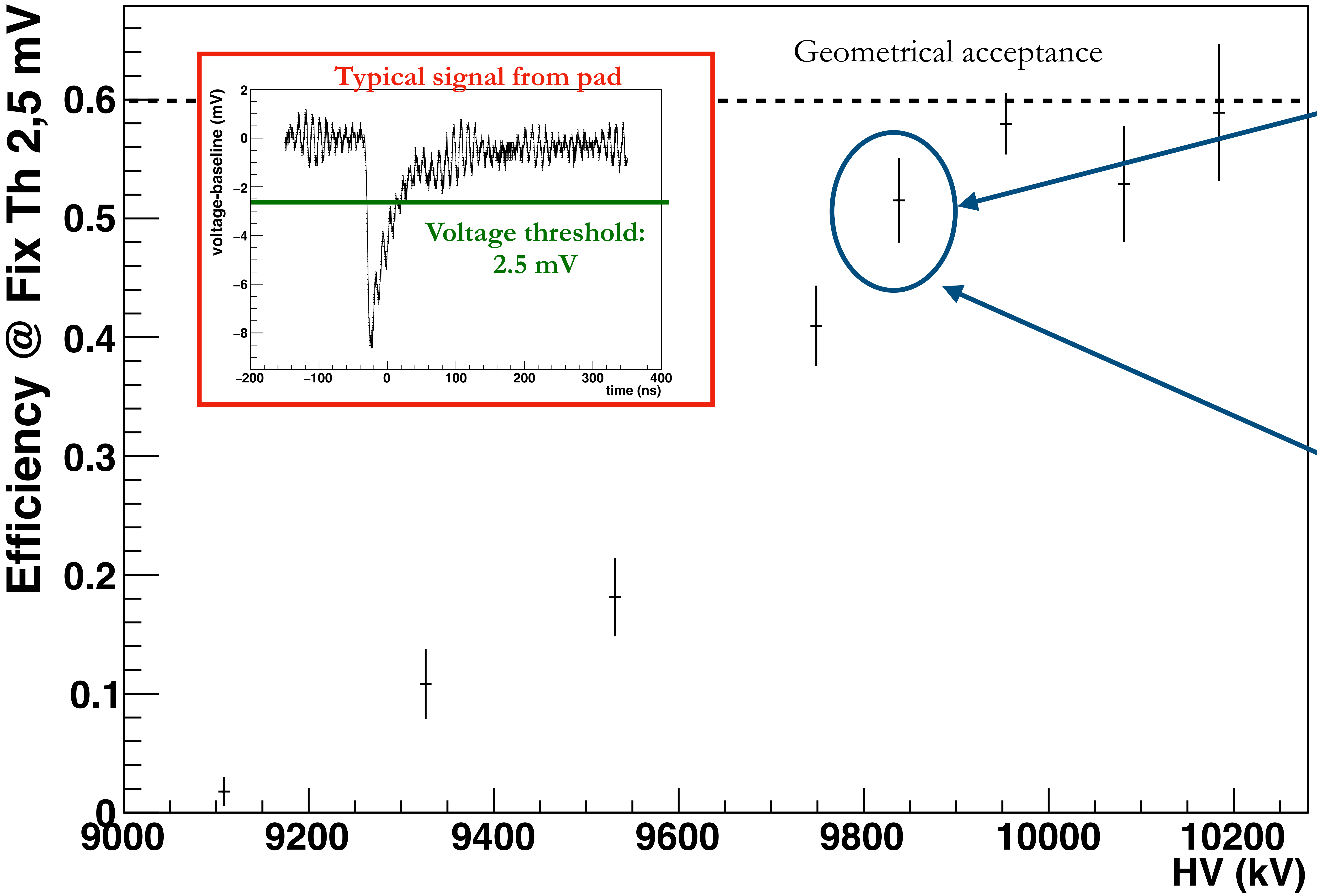


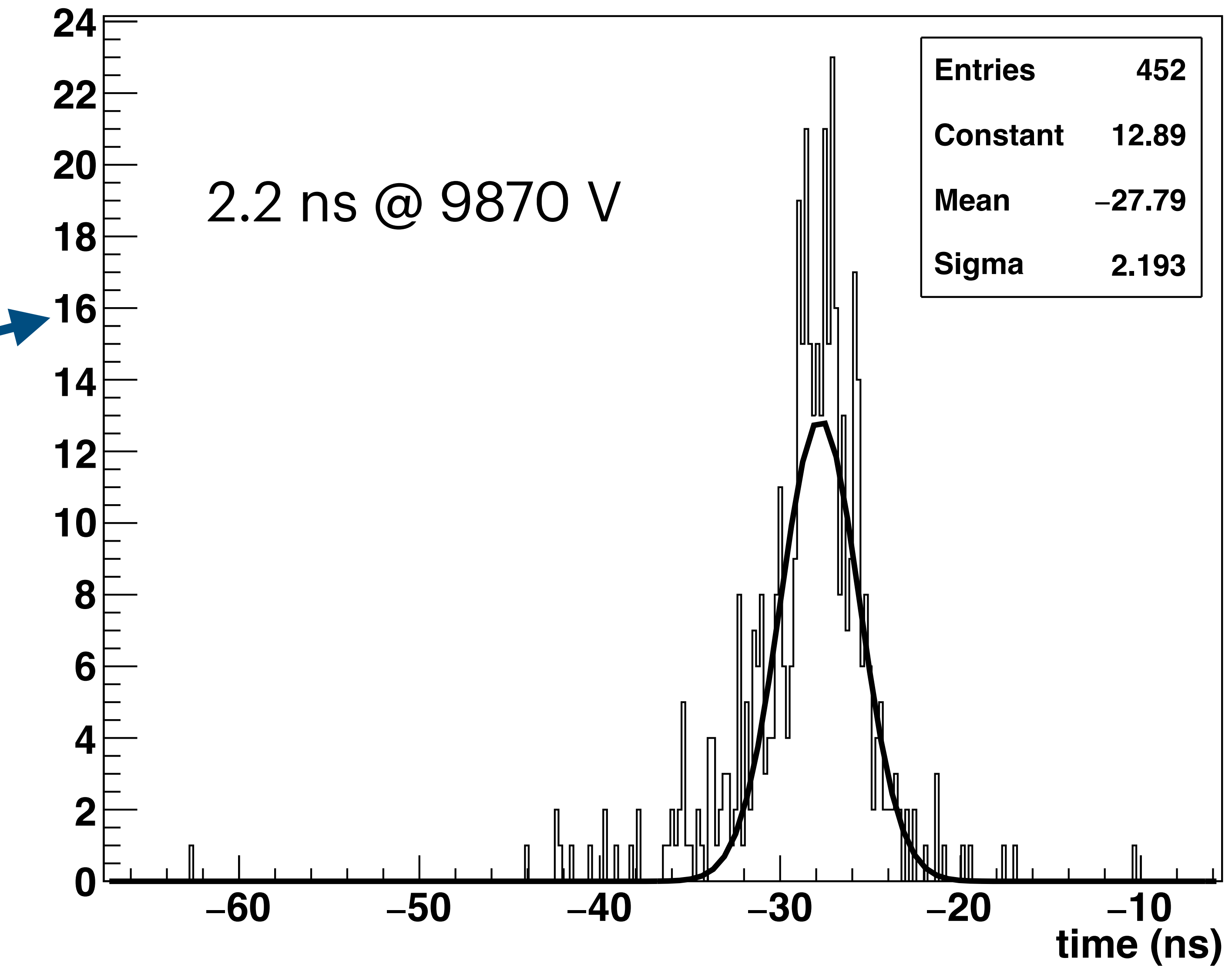


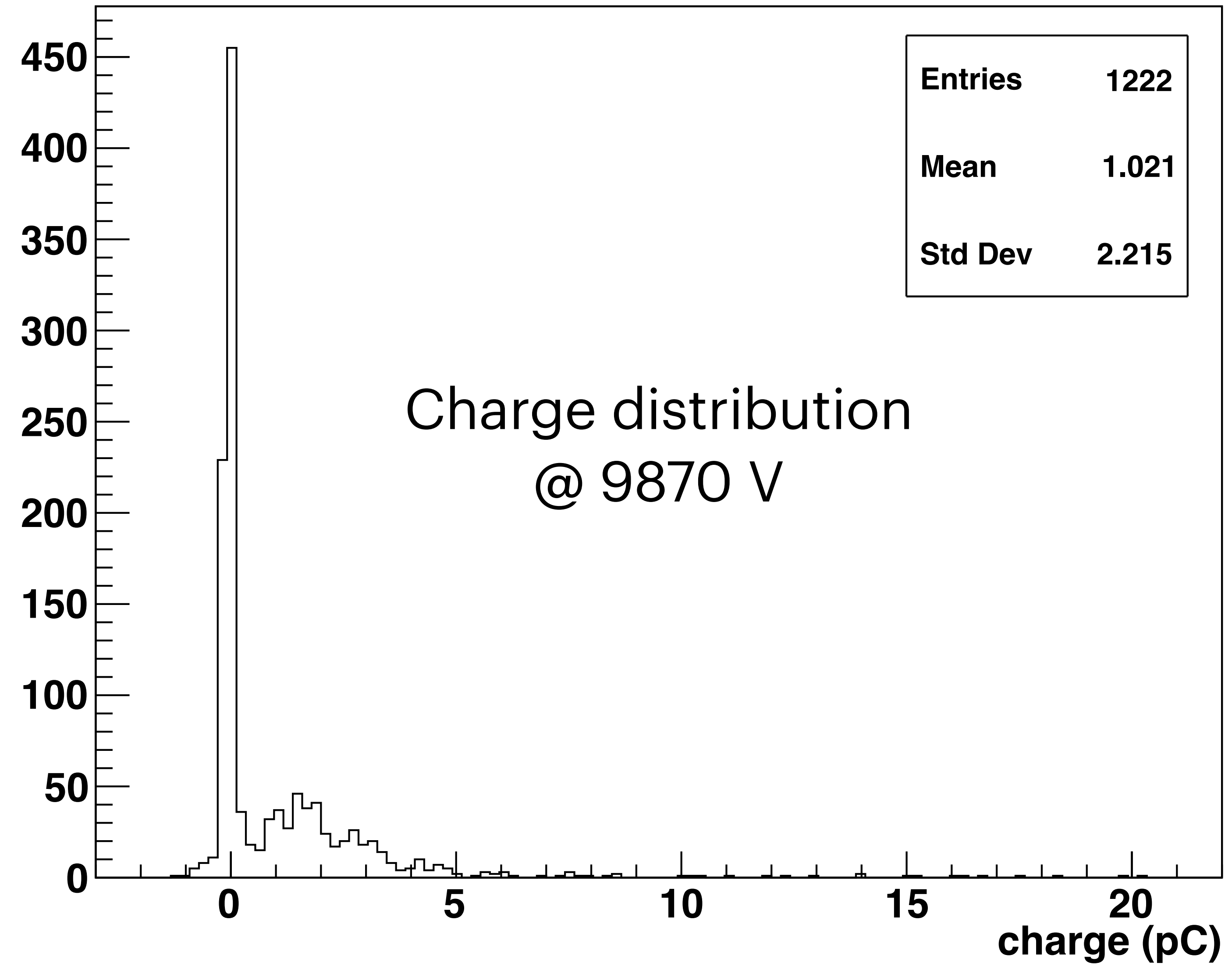


Big chamber performance

HV normalized at
P_0 = 1010 mbar
T_0 = 20°

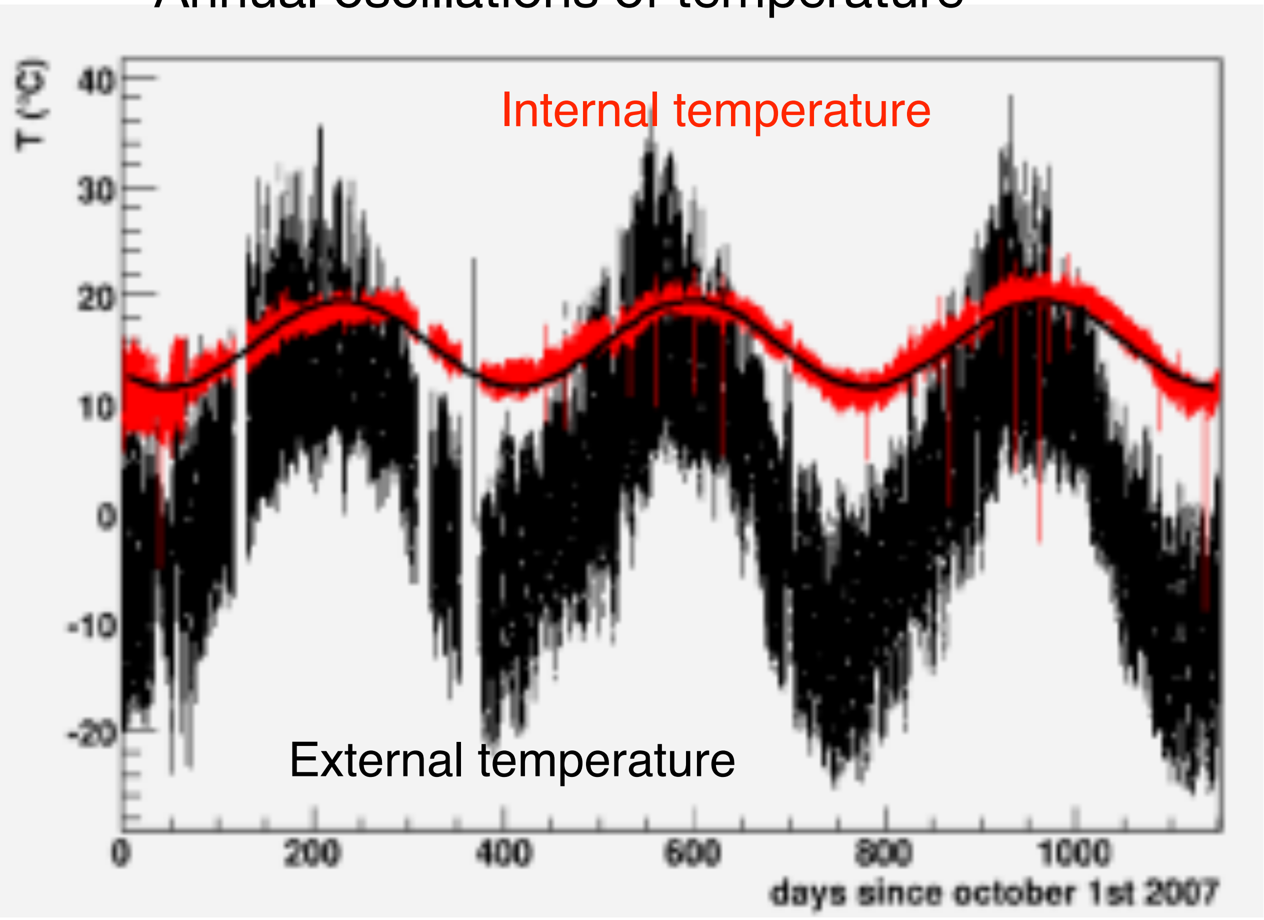




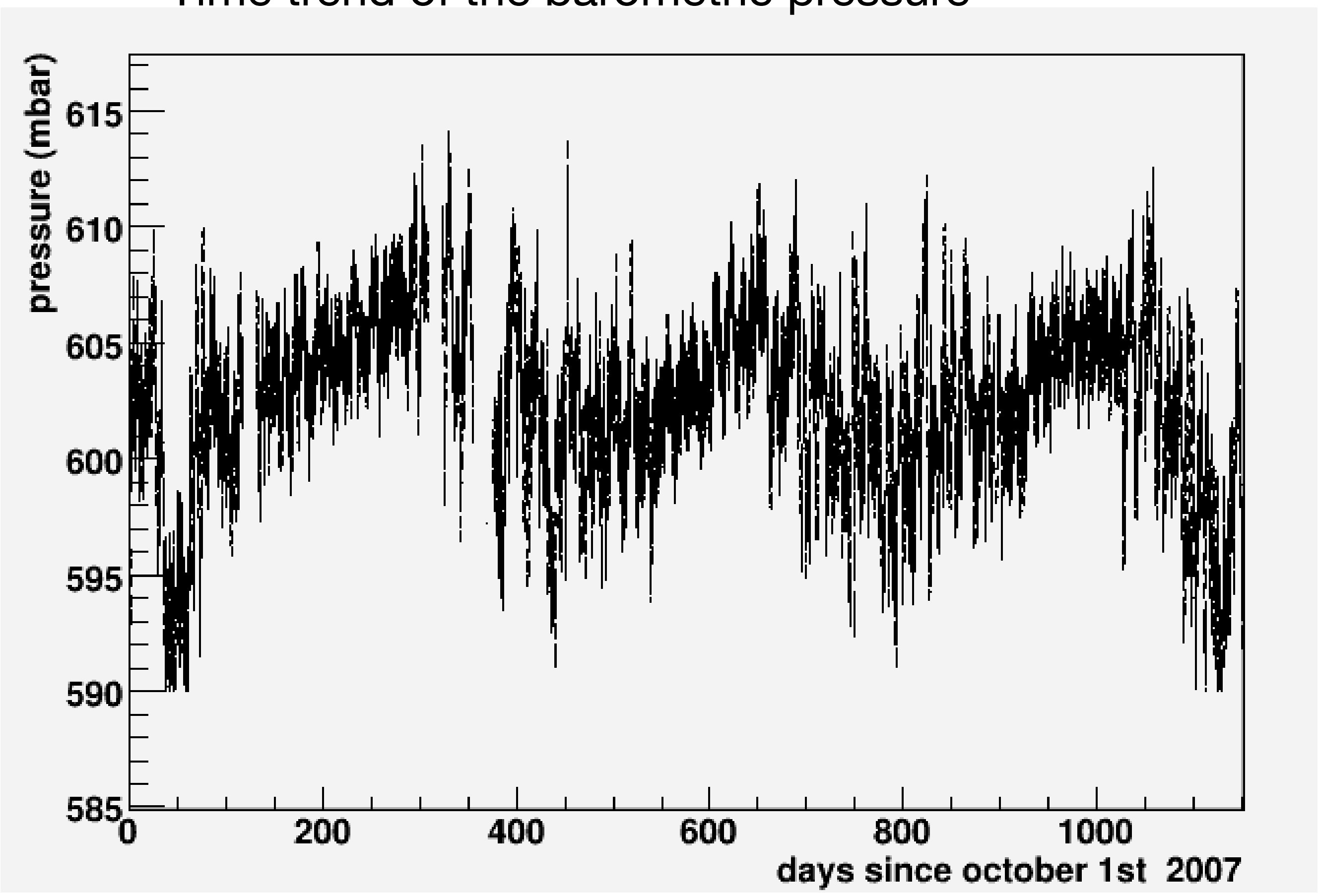


Operations at high quote: ARGO experience vs T and P

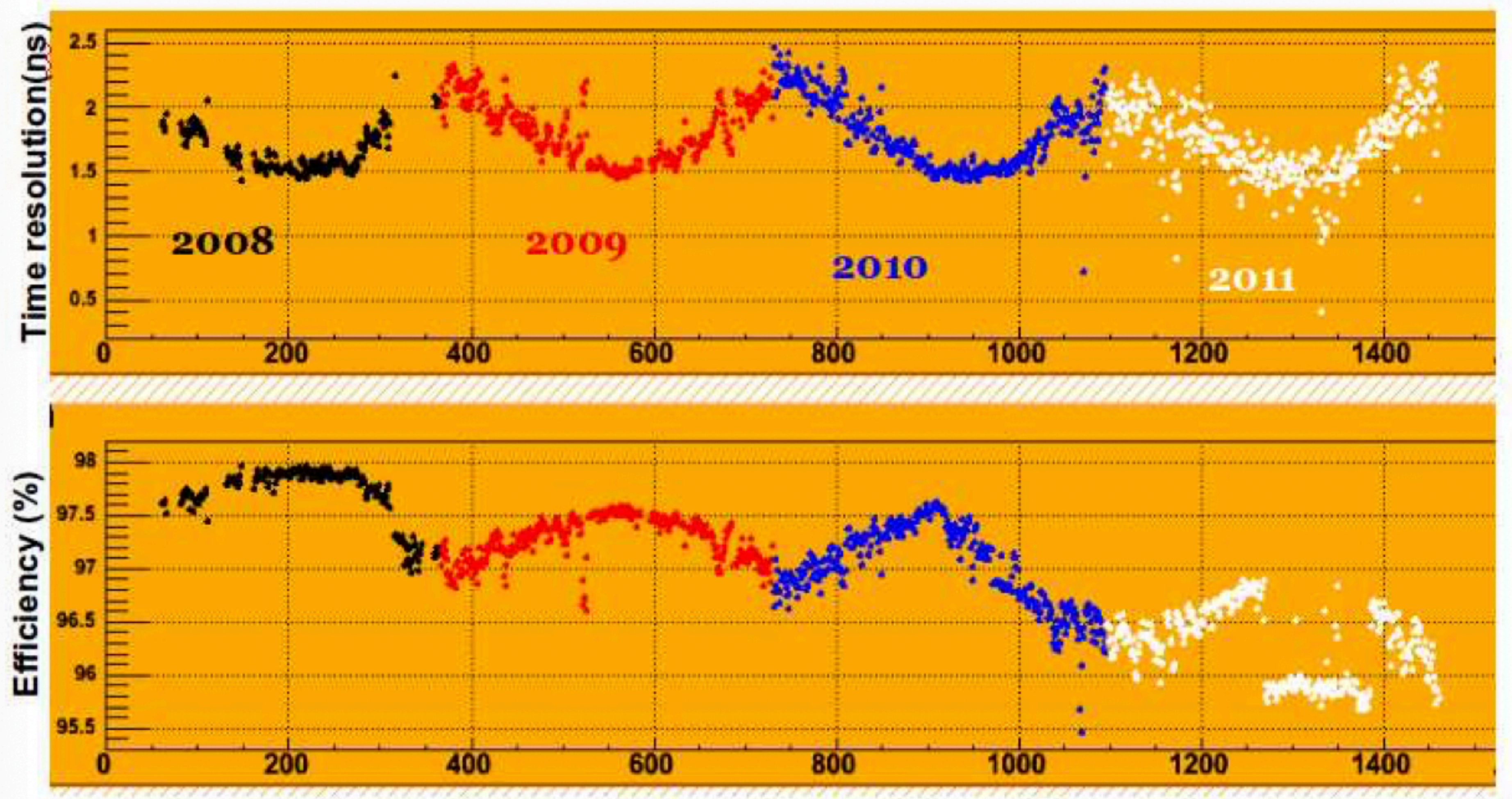
Annual oscillations of temperature



Time trend of the barometric pressure



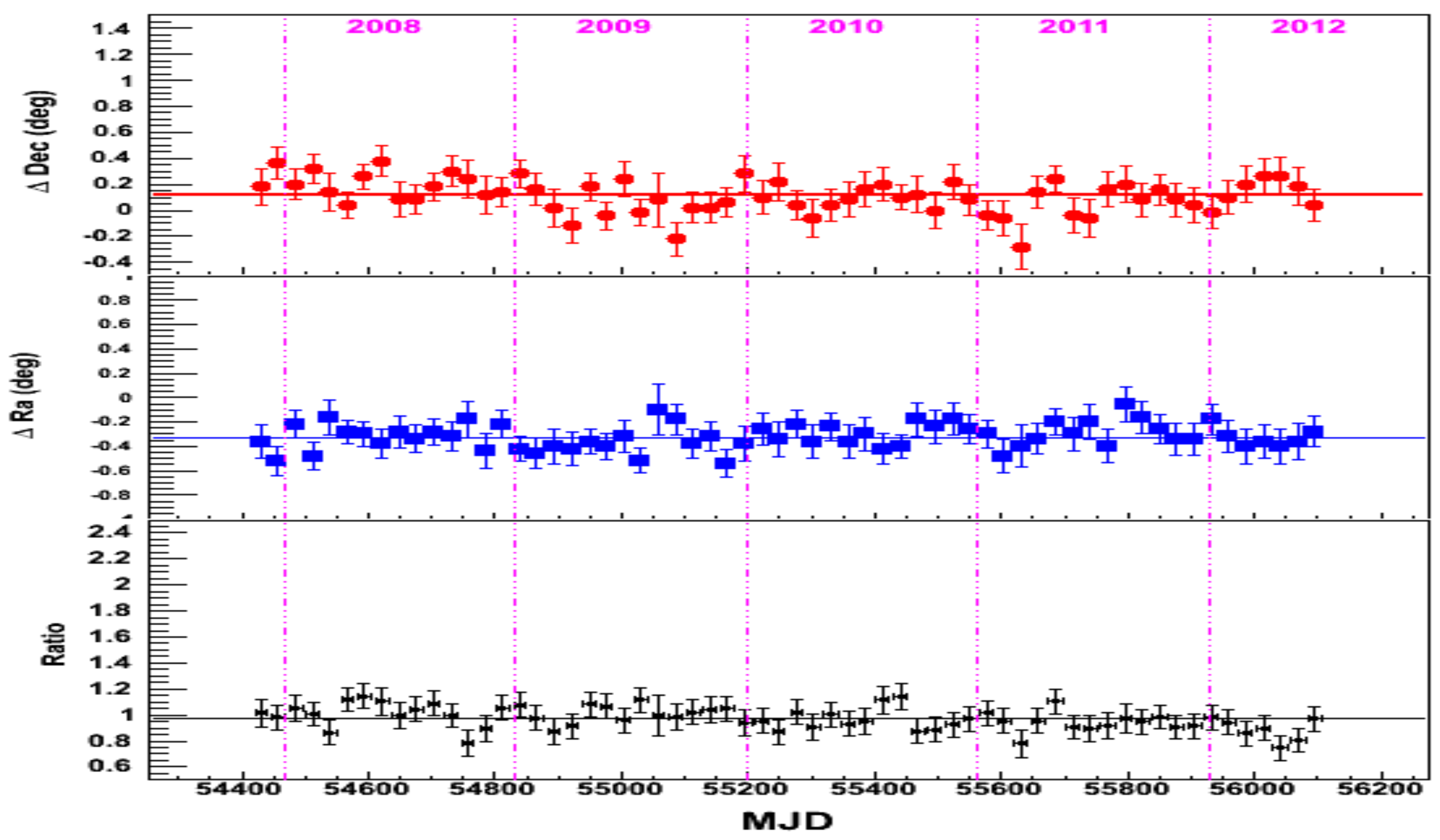
The yearly average value is about 600 mbar



days since January, 1st 2008

Neverthless

Stability of angular resolution and pointing accuracy (TeV)



High energy experiments shown the possibility to further control small T/P variations

$$V_{eff} = V_{app}\frac{T}{T_0}\frac{p_0}{p}$$

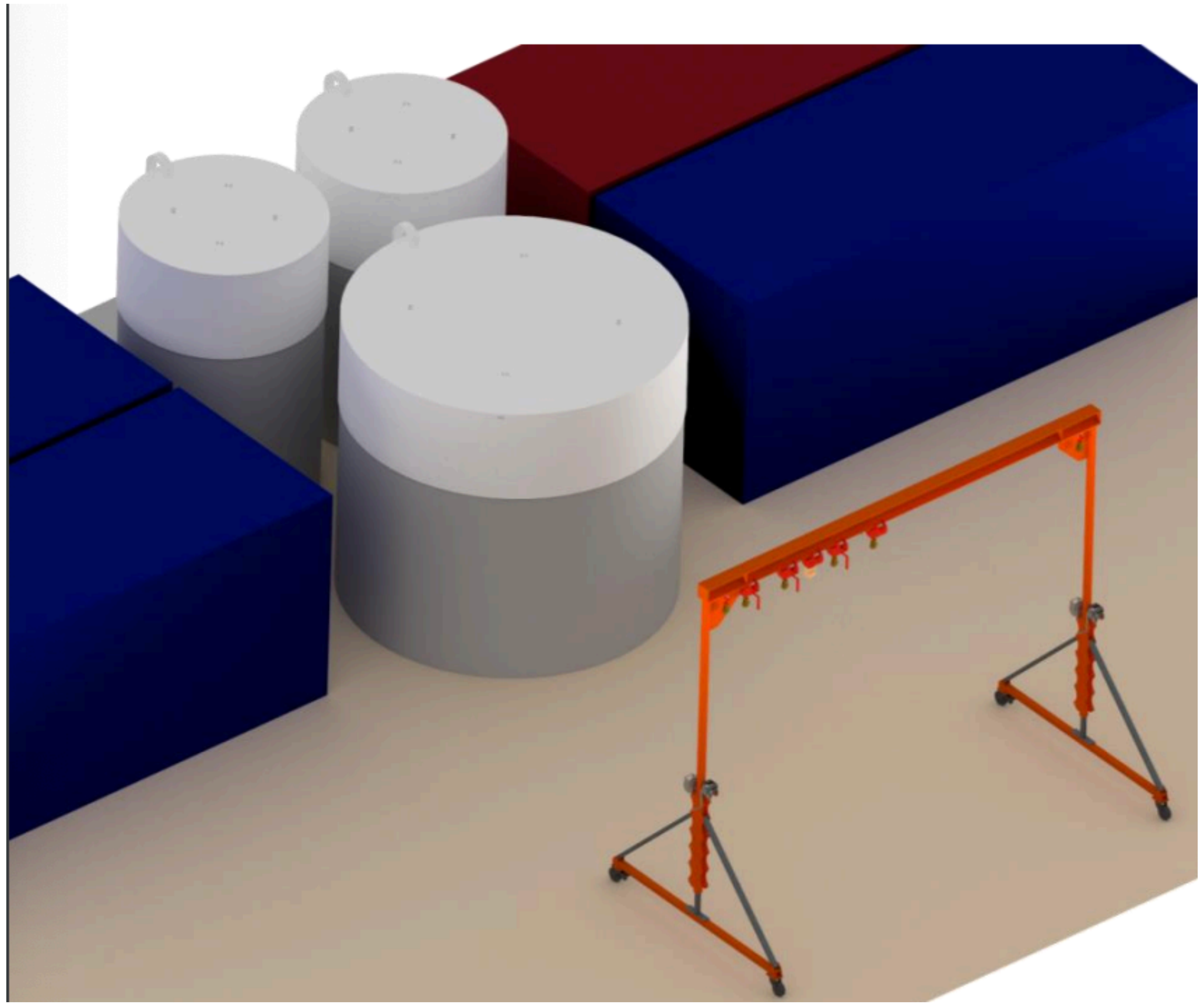
Test in progress to study the performance with extreme environmental conditions:

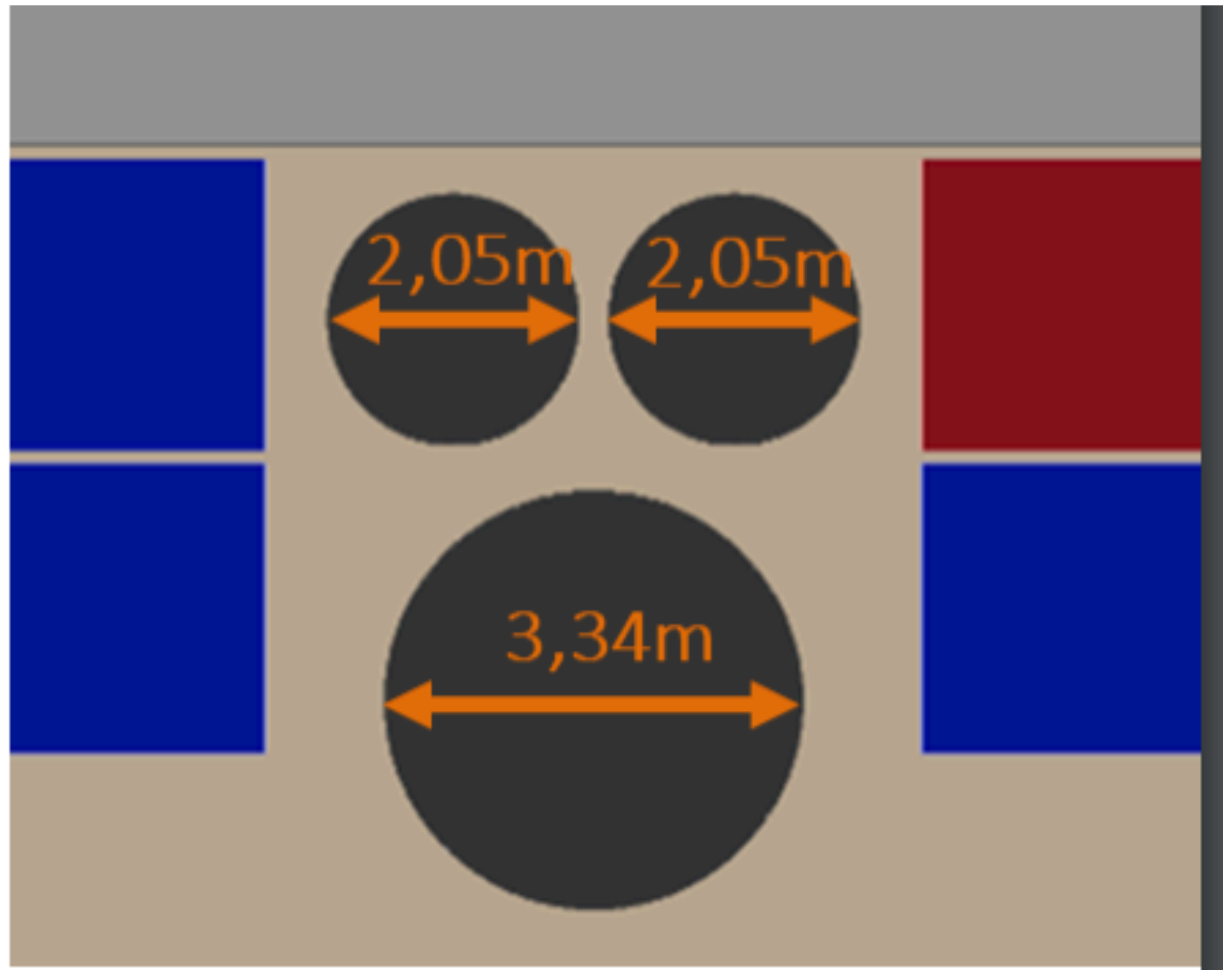
- Temperature cycles
- Performance at low pressure

Mechanical integration with SWGO tank in Milano

Diego Sartirana – Mechanical Engineer Istituto Nazionale di Fisica Nucleare (INFN) – section of Turin
diego.sartirana@to.infn.it

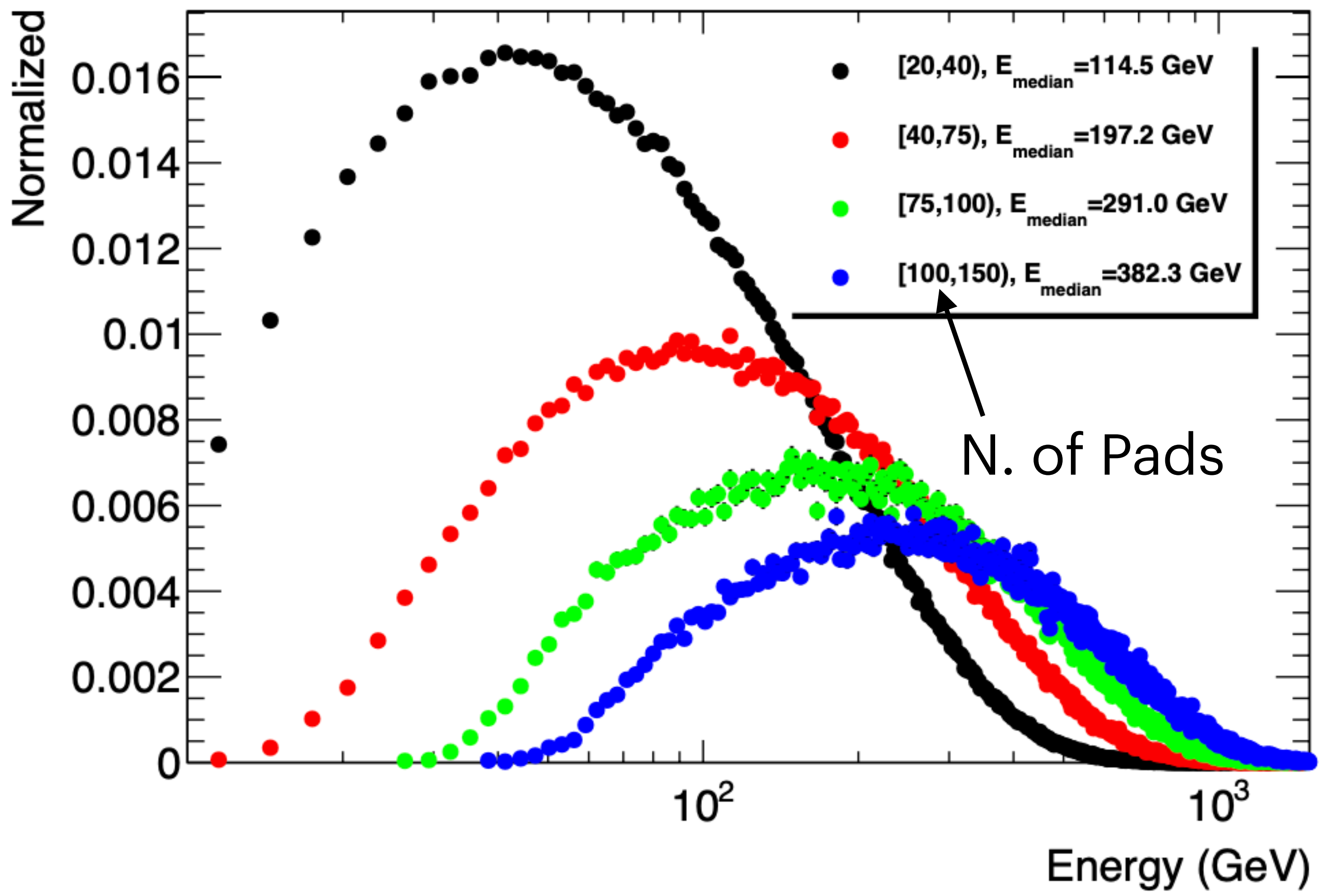
Plans for a joint test WCD tank + RPC Chamber by the end of 2024:
- meccanico integration
- Common DAQ
- Comparison RPC vs WCD performance

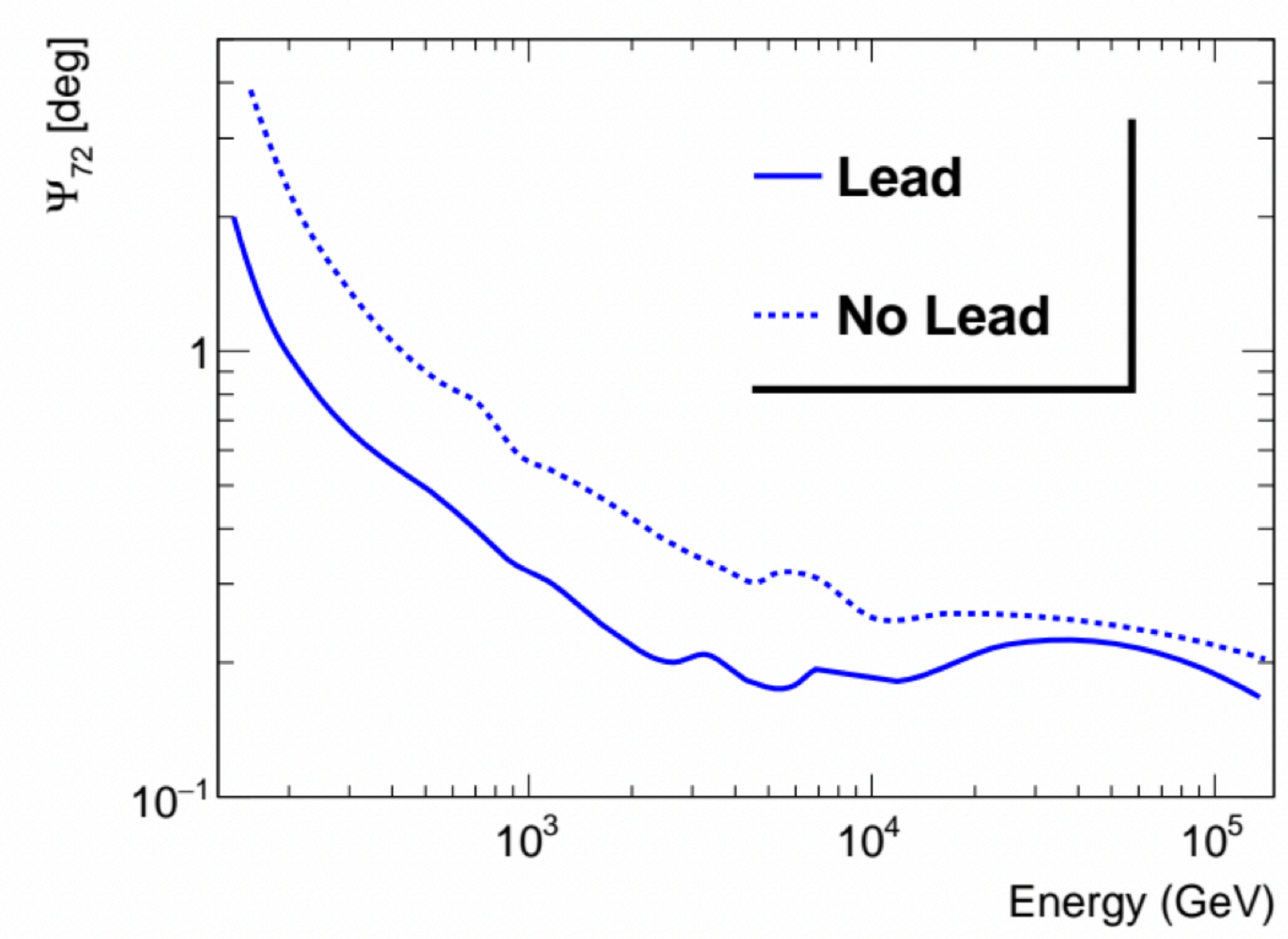




1 or 2 Large size RPCs on top of WCD tank

RPC simulation





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Standalone performance of a carpet of RPCs with pad segmentation 55.6 x 61.8 cm²

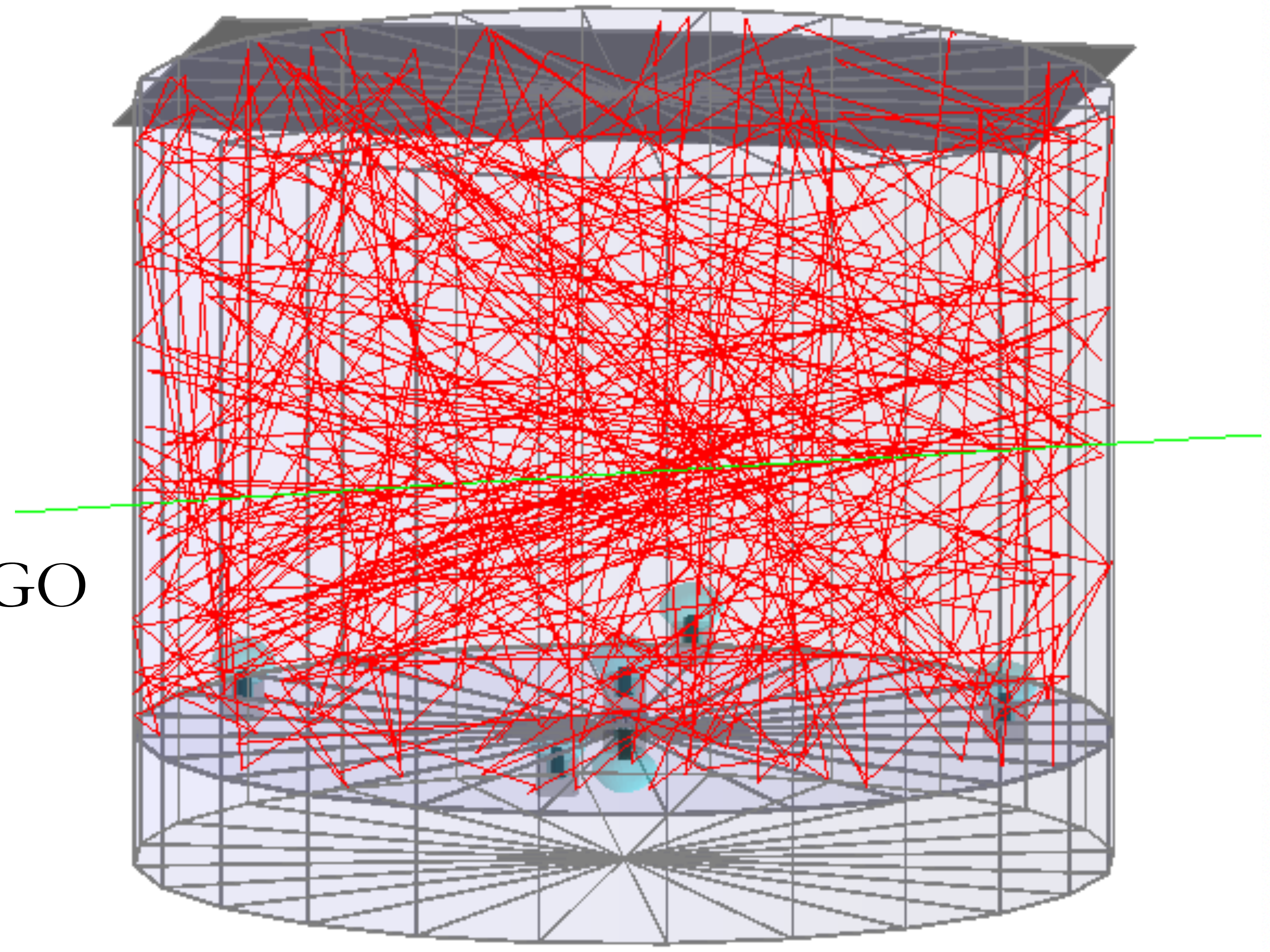
Arrival resolution:

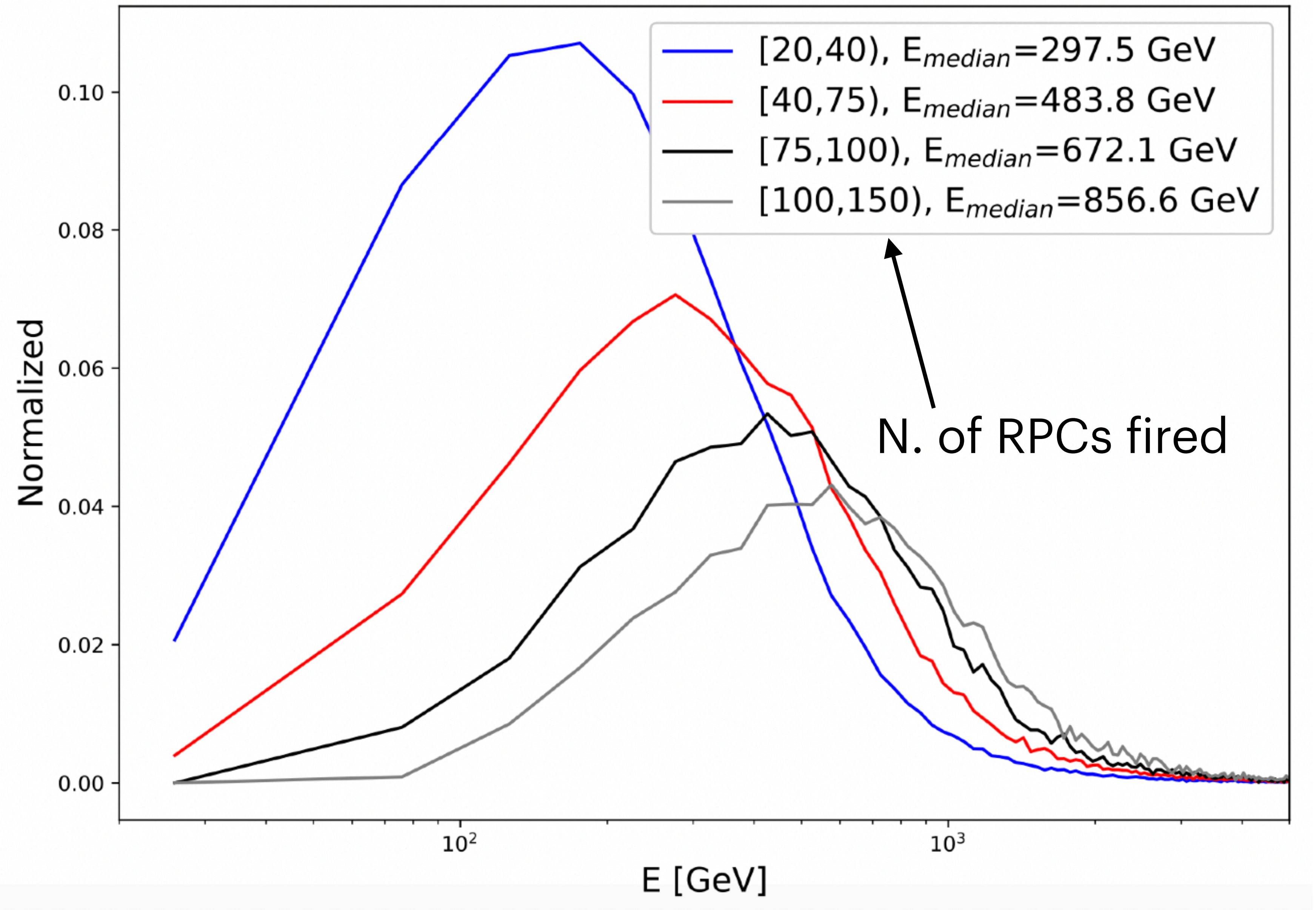
5.7° (2.9°) @ 100 GeV without (with) lead converter
0.5° (0.32°) @ 1 TeV without (with) lead converter

NEW: Preliminary integration of RPC geometry in the SWGO software

Plans to fully integrate the RPC detector in SWGO software and to study:

- Interplay among WCDs and RPCs
- Performance of RPCs standalone
- Use of RPCs as calibration for WCDs





Conclusions

The low detection threshold of the RPCs and the flexibility to merge the informations from the highly segmented pad readout, makes this detector very useful to hunt GRBs lowering the **Energy threshold down to 100 GeV (or less)**.

The ARGO experience already shown the possibility to have good performance

A project to build about **100 m^2 of RPCs** to be tested in an hybrid system with WCD tanks has been funded inside the Italian National **National Recovery and Resilience** Plan (PNRR).

Work is in progress to build and test the chambers and to develop a R&D plan to optimize this detector for operations at high quote in synergy with WCD detectors.

The R&D plan and performance simulations are under development inside the SWGO Collaboration with the goal to build a **small (100 m^2) demonstrator** to be tested at high quote for a possible future upgrade of the experiment.

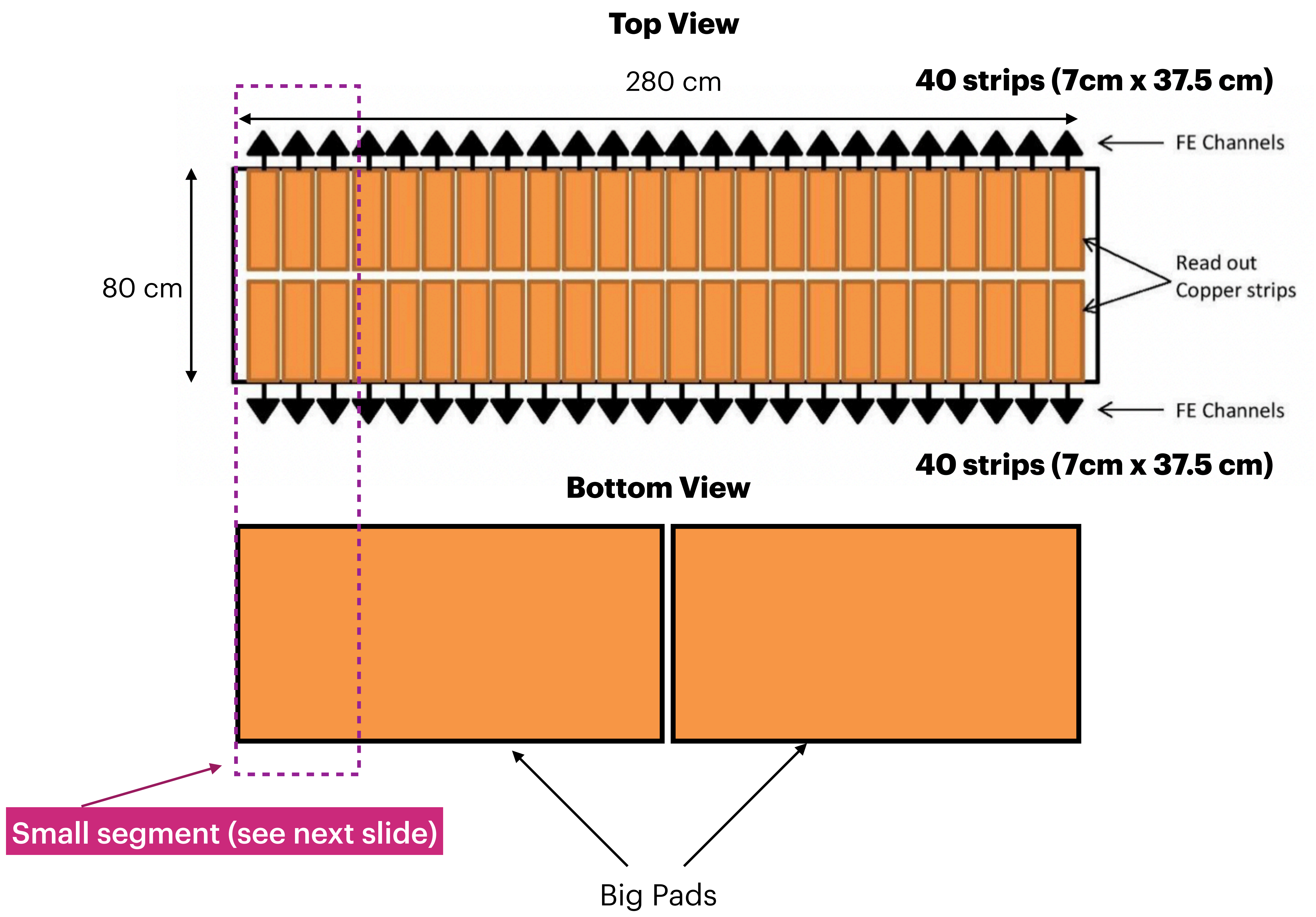
Several laboratory tests are ongoing to characterize the best layout and electronics.

An integration (mechanics+DAQ) test of RPC + WCD tanks is planned in Milano in the next year and possibly at high quote afterwards.

Backup

Detector optimization: RPC R&D ongoing

- **RPC chamber deisgn**



Goal of R&D in laboratory
- Evaluate performance (efficiency and time resolution) with large strips
- Optimization of Front-end readout
- Mechanical layout evaluation

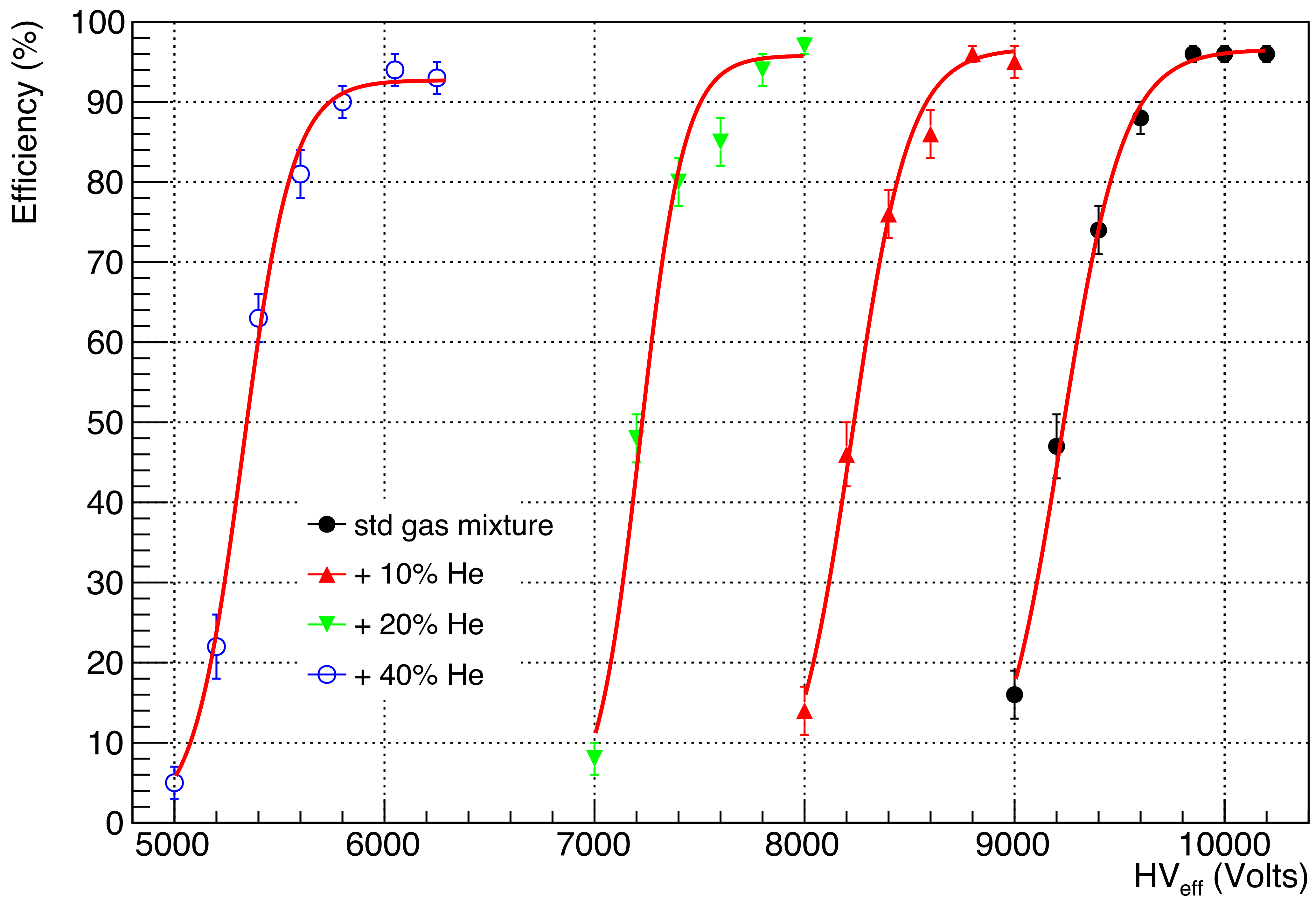
Operations at high quote: Low pressure performance expected

Expected pressure at high quote: 600 mbar

Effective Voltage is lower with respect to sea leve

$$V_{eff} = V_{app}\frac{T}{T_0}\frac{p_0}{p}$$ ⟶ HV_{50} From 9220 V (@ 990 mbar) to 5588 V (@ 600 mbar)

In first approximation the low pressure environment can be simulated adding an inert gas such as Helium



		Results from fit		
Gas mix	$P_{eqivalent}$ (mbar)	HV_{50} (V)	Effmax (%)	Streamer fraction at max voltage(%)
STD	990	9220 +/- 15	97 +/- 1	2.3 @ 10200 V
90 % STD + 10% He	902	8220 +/- 16	97 +/- 1	
80 % STD + 20% He	792	7217 +/- 12	96 +/- 1	
60 % STD + 40% He	594	5325 +/- 14	93 +/- 1	40 @ 6200 V

Not fully in agreement with T/P formula

STD gas mixture measured at 990 mbar

90% STD + 10% He equivalent to 0.9 * 990 = **900** mbar
80 % STD + 20% He equivalent to 0.8 * 990 = **792** mbar
60% STD + 40% He equivalent to 0.6 * 990 = **594** mbar

Efficiency above 93 % also at low pressure -> with final electronics 95% expected

Low pressure operations increase streamer fraction-> tuning of the gas mixture ongoing

Test in progress to replace tetrafluorethane with tetrafluoropropane (Low GWP)

RPC plans for Italian PNRR demonstrator

- Main subject of this work
  - Detector optimization
    - RPC layout
    - RPC readout
  - Integration with WCD
    - WCD tank - RPC mechanical and DAQ integration (test expected in Milan at the end of 2024)
    - studies of performance of the hybrid system: interplay WCD-RPC response
  - Operations/performance at high quote
    - scheme to flow chambers on larger area (Recirculation systems)
    - RPC operations and performance at low pressure, high temperature range.
  - Simulation of the impact of RPCs in particular for GRB detection

- We are planning these activities inside the SWGO Collaboration (Our WCD colleagues in the PNRR project are already part of SWGO)
  - Plan: a **small scale joint test RPC prototypes + WCD tanks**
  - Participation to the **engineering array of SWGO** to test the possible integration of RPCs and WCD
  - Verify the goals of the **R&D at high altitude**