New RPC readout for EAS mapping in ground based cosmic ray detectors

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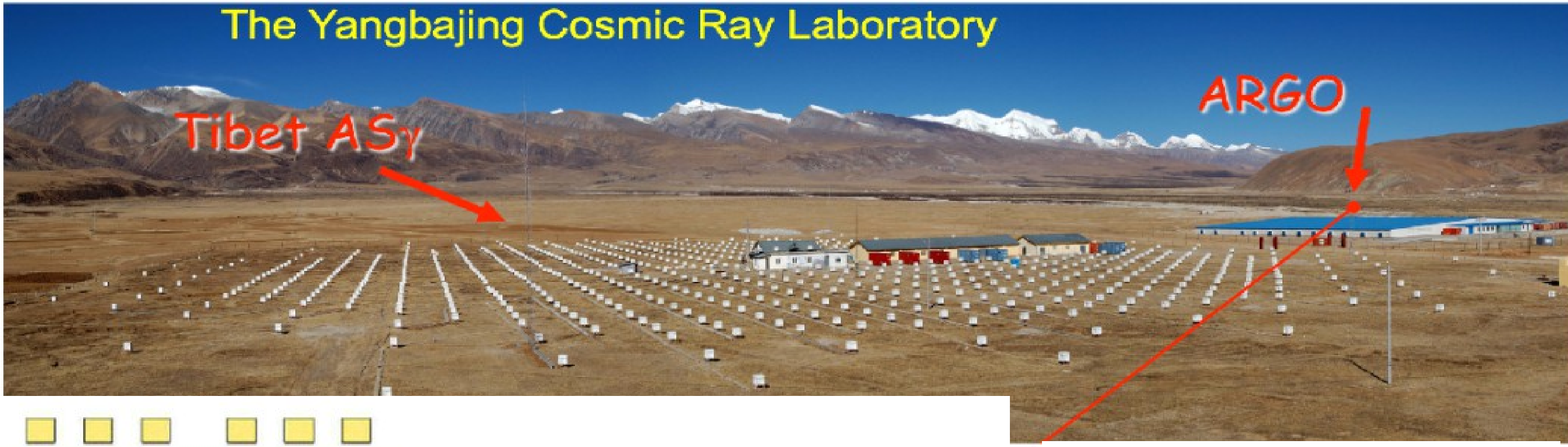
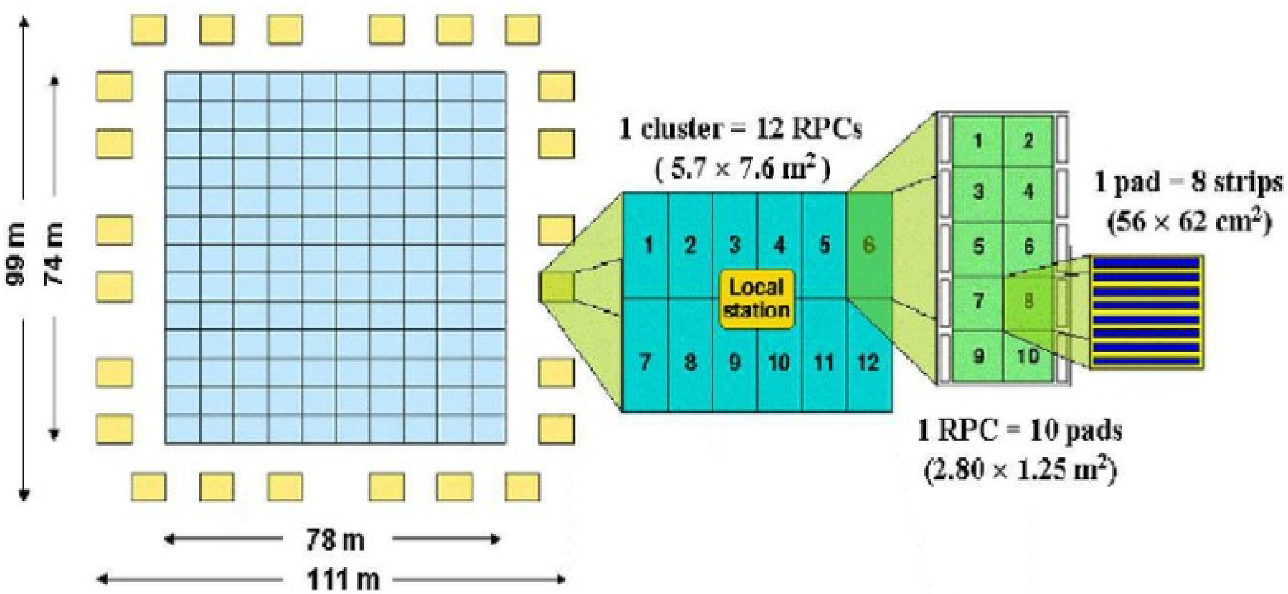
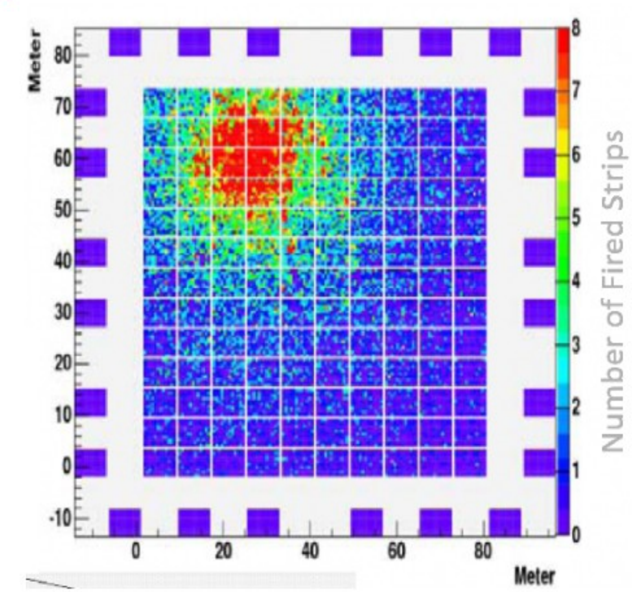
ARGO experiment



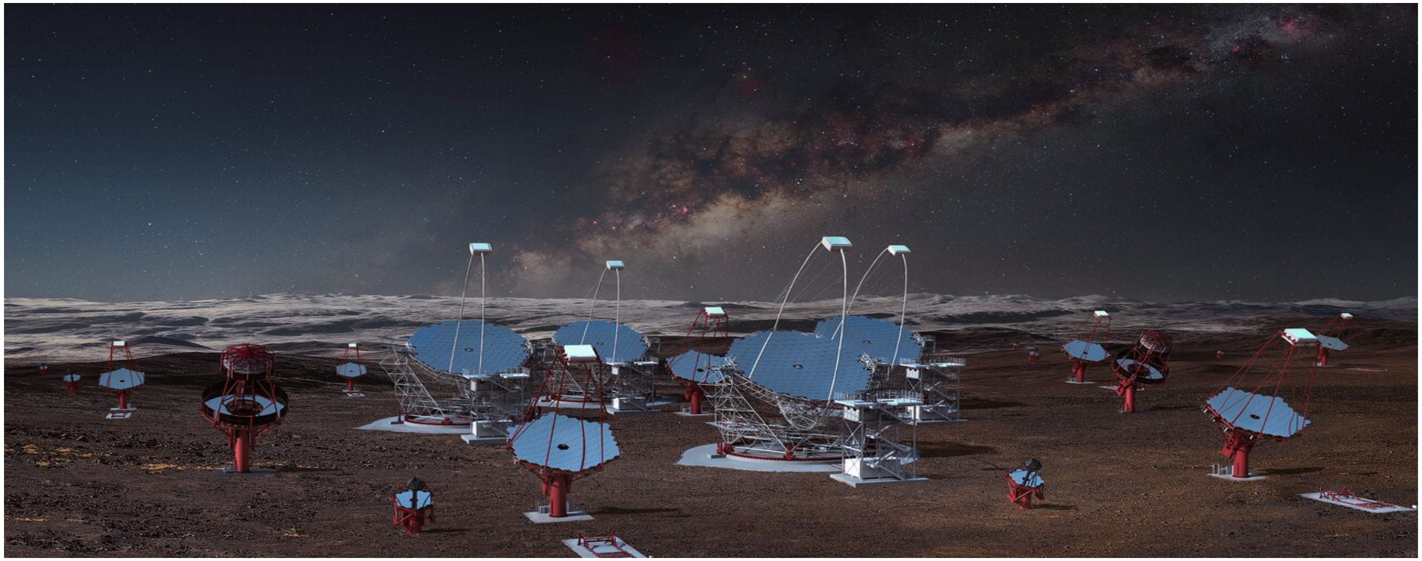




ARGO @ YBJ γ shower detector:
Data taking with very low maintenance from 2007 to 2012:
100*100 m^2 RPC carpet with full coverage at 4000 m a.s.l. (100 GeV < E < 10 PeV)
Shower energy from fired pad multiplicity,
Direction from shower time profile (0.5^o @ 1 TeV)

Other γ ray shower detectors

Cerenkov telescope arrays (CTA) are leading technique, but low duty cycle (5%) and telescopes need to be pointed.

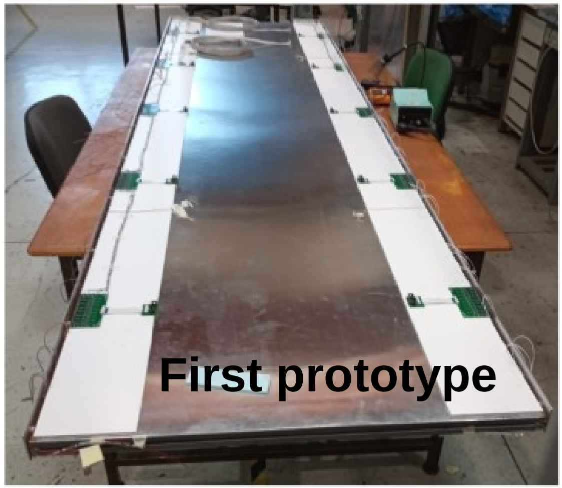


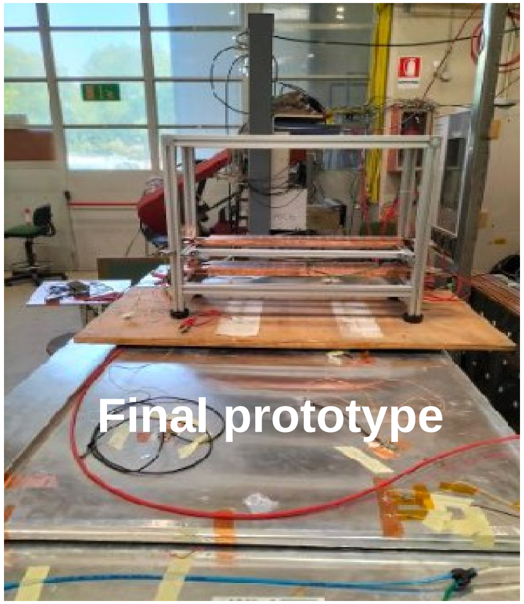
Ground extensive air shower (EAS) detectors are complementary.
EAS detectors main techniques: RPC carpet (ARGO) Cerenkov tank arrays (HAWK, LHASO).

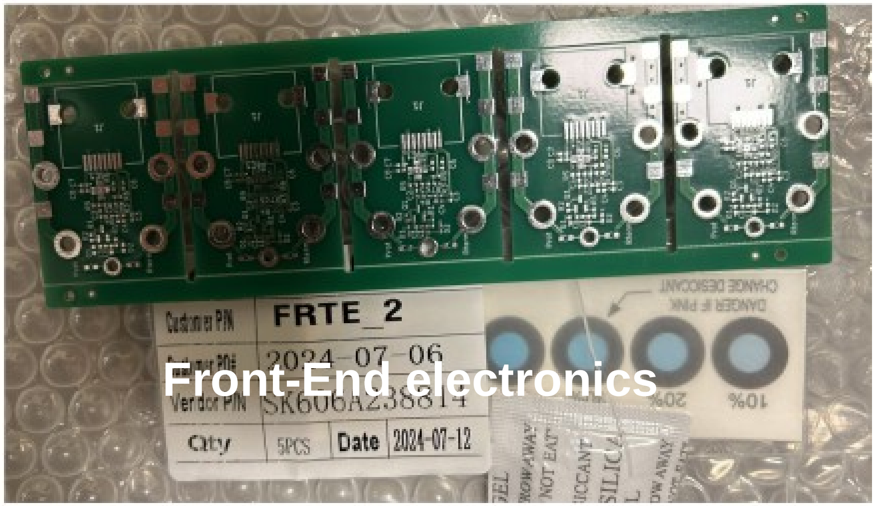
RPCs in γ ray shower detectors

Proposal for complementing the two techniques:
RPCs with better energy resolution and lower energy threshold on shower,
Cerenkov pool better angular resolution and γ/p shower separation.

European funds PNRR CTA+ to INAF include working package 1520 for the realization of a hybrid RPC+WC demonstrator of 100 m^2 area.
Activity carried in the framework of SWGO as a possible upgrade.
Tenders for detectors and electronics placed at the end of 2023.


First prototype


Final prototype



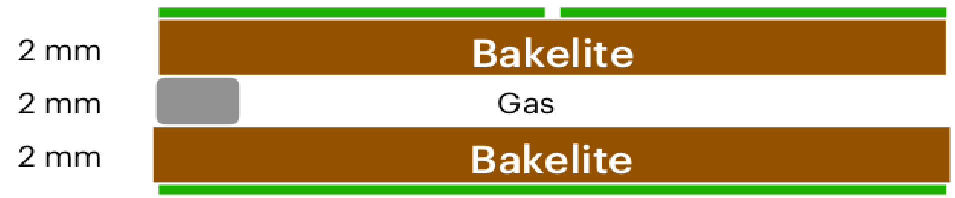
Front-End electronics

Milestones:
1) First chambers already available. Full production by middle 2025
2) Integration tests RPC+WC end of 2024 – first half of 2025
3) Installation and operation at high altitude starting at the end of 2025

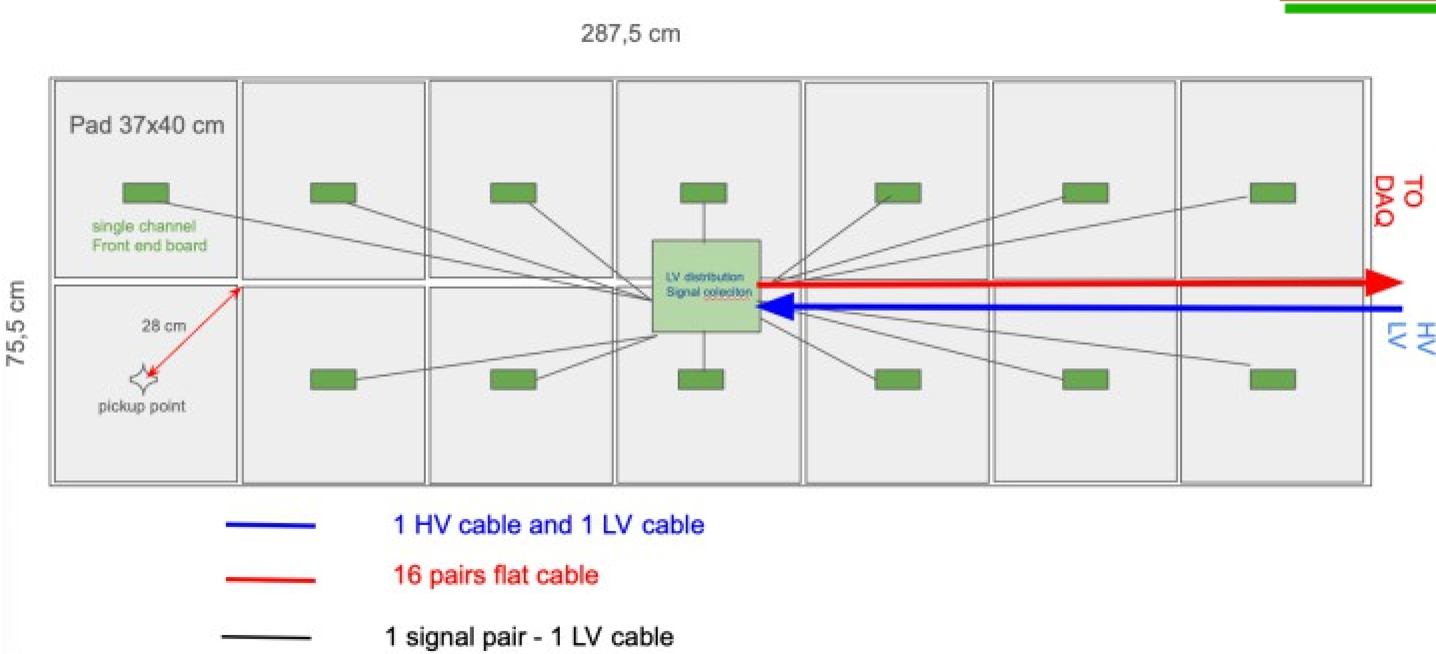
New RPC design

Detector challenges:
High altitude o(4000 m a.s.l.) operation (P~0.6 bar)
High temperature excursion
Little maintenance possible

Pad read-out



Big Pad read-out

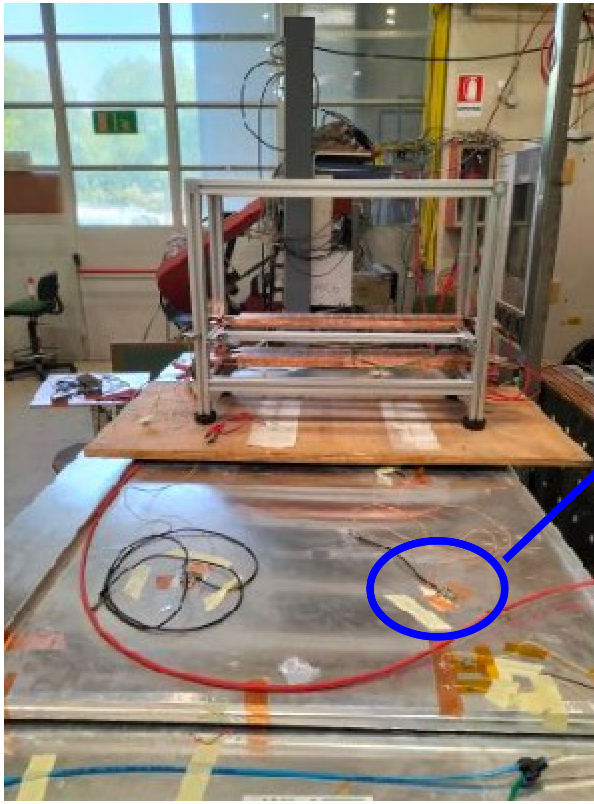


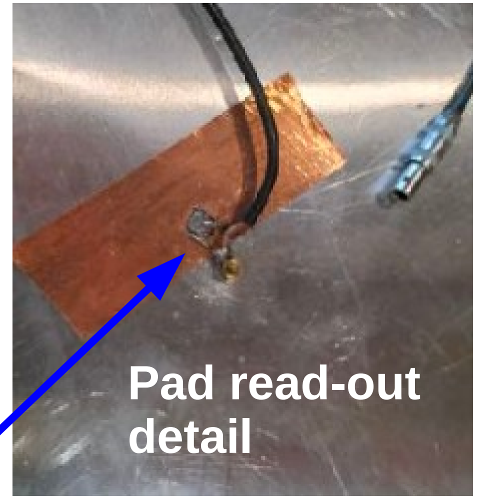
ATLAS-like design:
2 mm bakelite electrodes
2 mm single gas gap

But $\rho \sim 10^{11}$ Ωcm

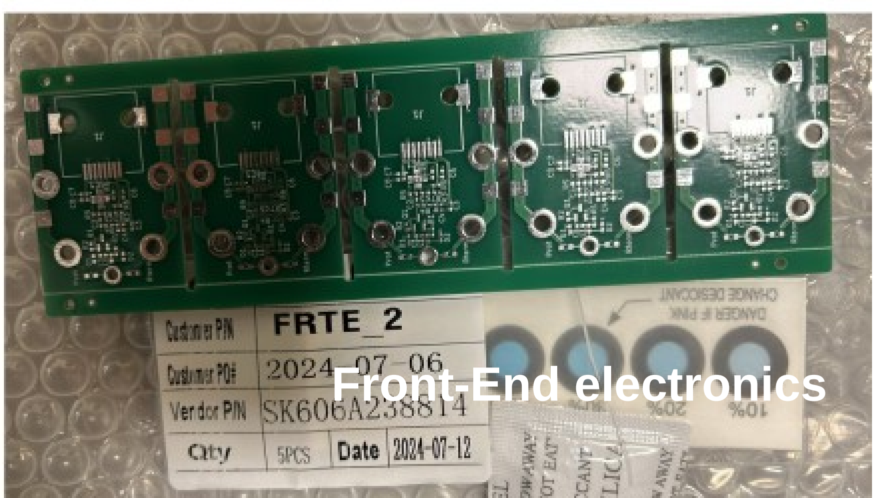
RPC improvements:
Avalanche operation to improve linearity ($10^4 \rightarrow 10^7$ particles/m^2)
Read-out by 14 pads (37*40) cm^2
Additional Read-out by 2 big pads ARGO-like (for high multiplicity)
Eco-friendly gas mixtures + gas tightness (highly profiting from LHC RPC R&D)
Detector construction techniques to improve robustness and simplicity
Acquisition of Pad digital signal and time + Big Pad signal amplitude/charge

New RPC design





The pads will be read-out in the central position,
for symmetry reason.
R&D needed to understand signal formation and propagation.
Pad signal will be amplified.



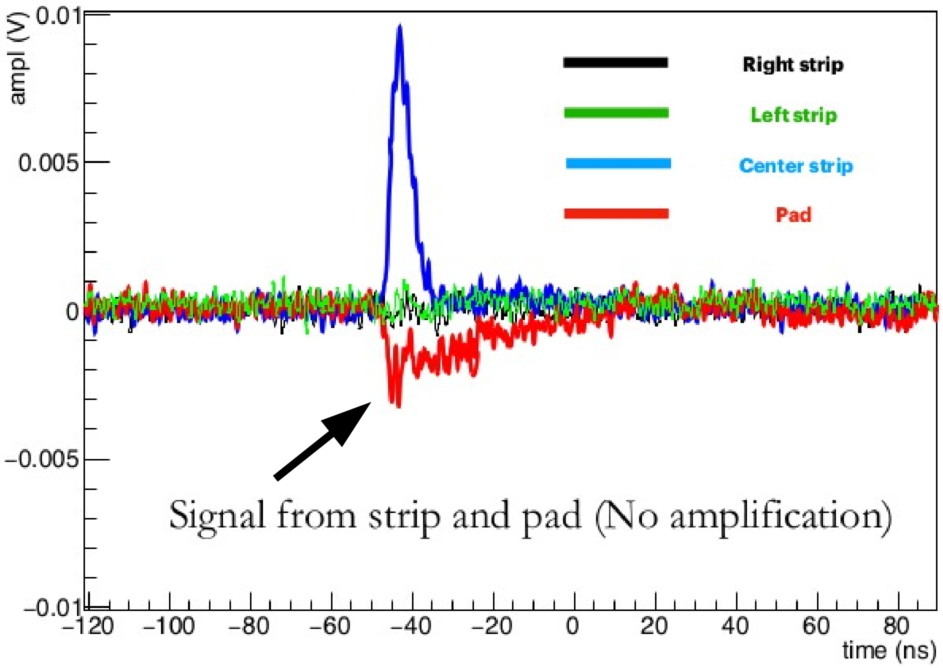
Bjt transimpedance amplifier + High-Speed
commercial comparator with LVDS Output

Supply Voltage 3 – 5 Volt
Isupply@5V = 0,011A
Vth = 1 – 5 Volt → Discriminator threshold 5 -28 mV
Peaking time = 2 ns
Minimum Input detectable signal = 0.05 pC
(test pulse rise time 2ns fall= 5ns R=50 Ohm)

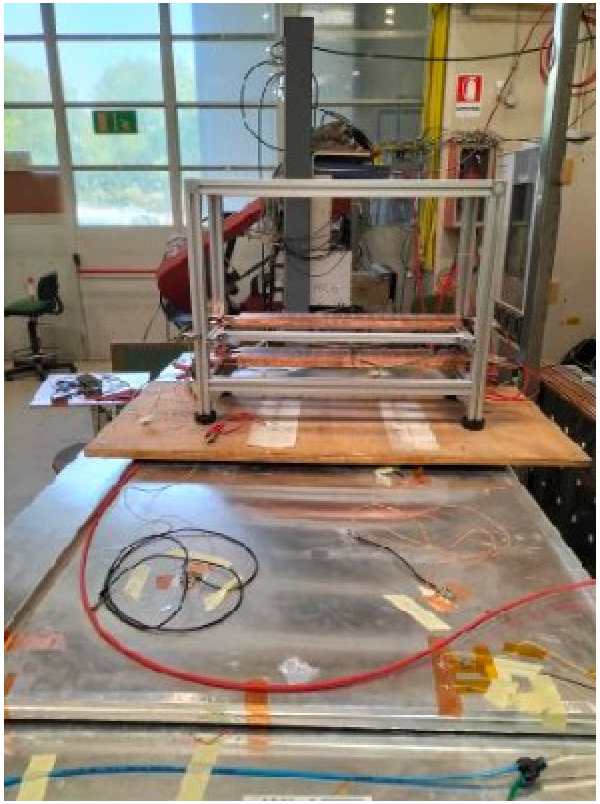
Big pad read-out

For EAS detection it is important to measure the particle density profile.
For low multiplicities use of strips/small pads.
Big pad integrates the signal at high multiplicities (already used in ARGO experiment).
The number of particles is proportional to the signal amplitude and charge.
Long tail dependent on big pad capacitance and input impedance at read-out.

Example of big pad signal on first RPC prototype equipped with strips:

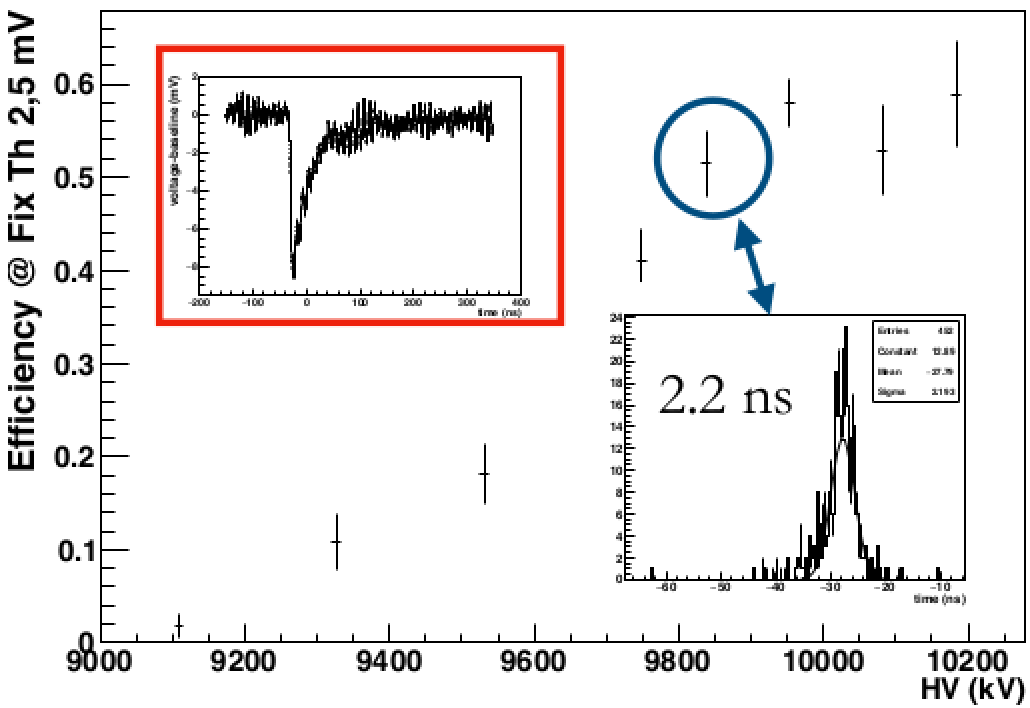


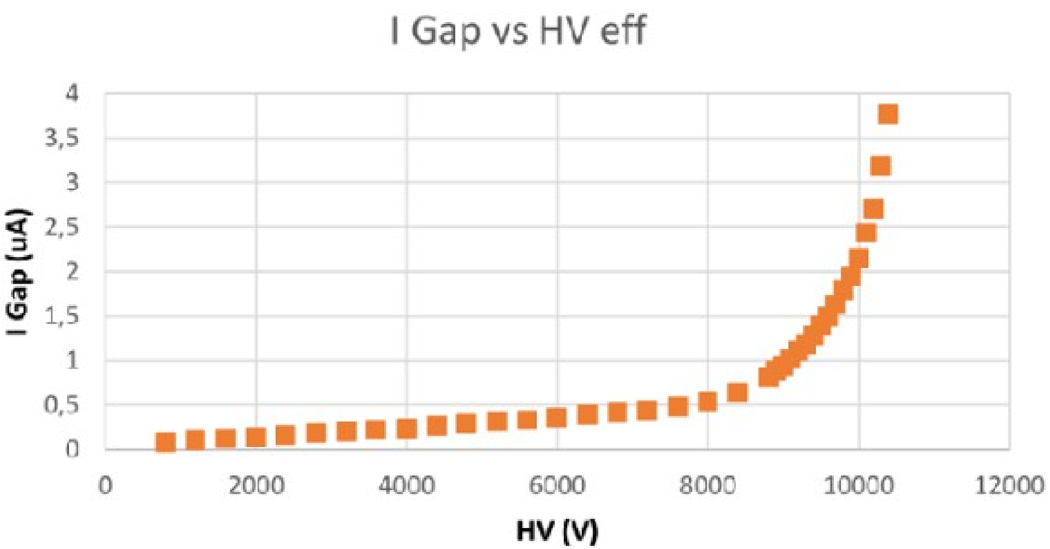
Final prototype first tests



ATLAS like gas mixture.
RPC based trigger, but triggered area greater than single pad.
Single pad signal acquired on scope without amplifier.
Time resolution (spoiled by trigger) < 2.2 ns.
Noise observed on oscilloscope ~ 1 mV.
Near future tests on signal formation in different positions.

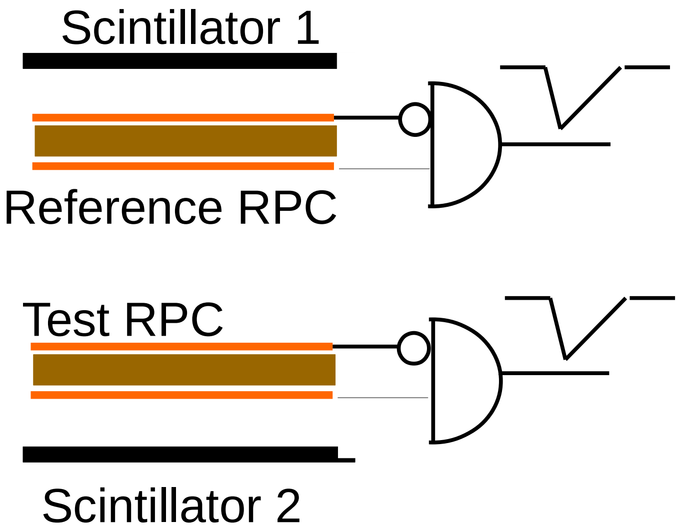
Single pad performance (not full acceptance).



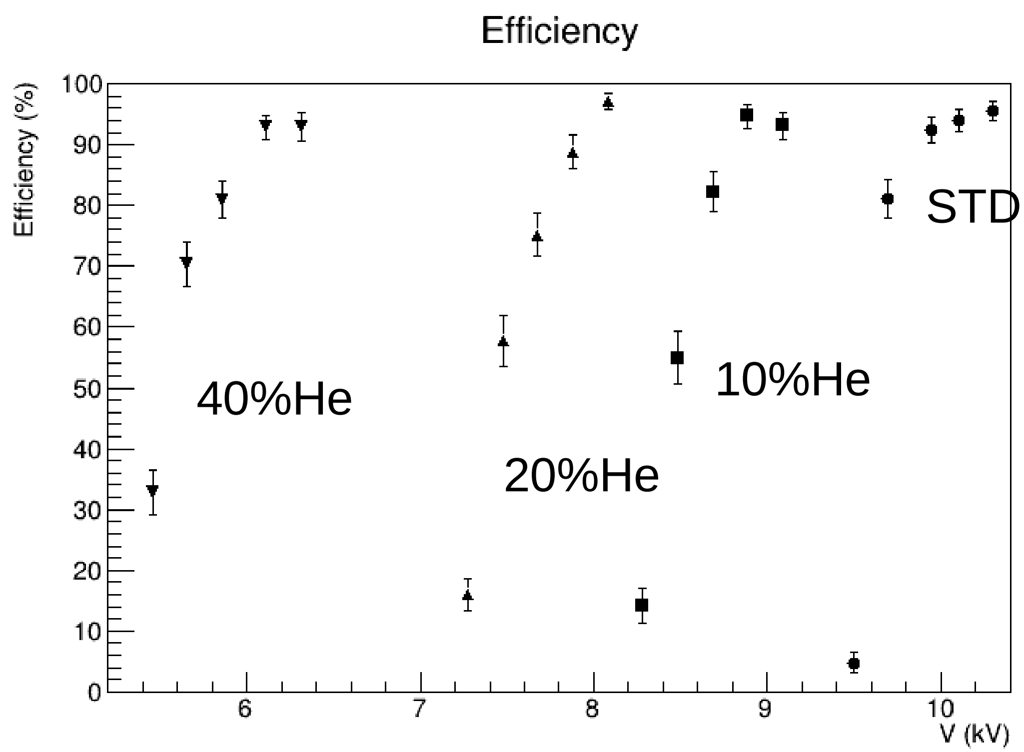


Low pressure simulation tests

Low pressure emulation:
Cosmic rays triggered by two scintillator tiles
2 RPCs of 50*50 cm2 area read-out by single pads (no amplifier)
Signals from 2 RPCs acquired by obscilloscope
One of them is used as a reference at fixed voltage
Standard CMS mixture (STD) as baseline
Addition of He, inert gas to emulate lower pressure

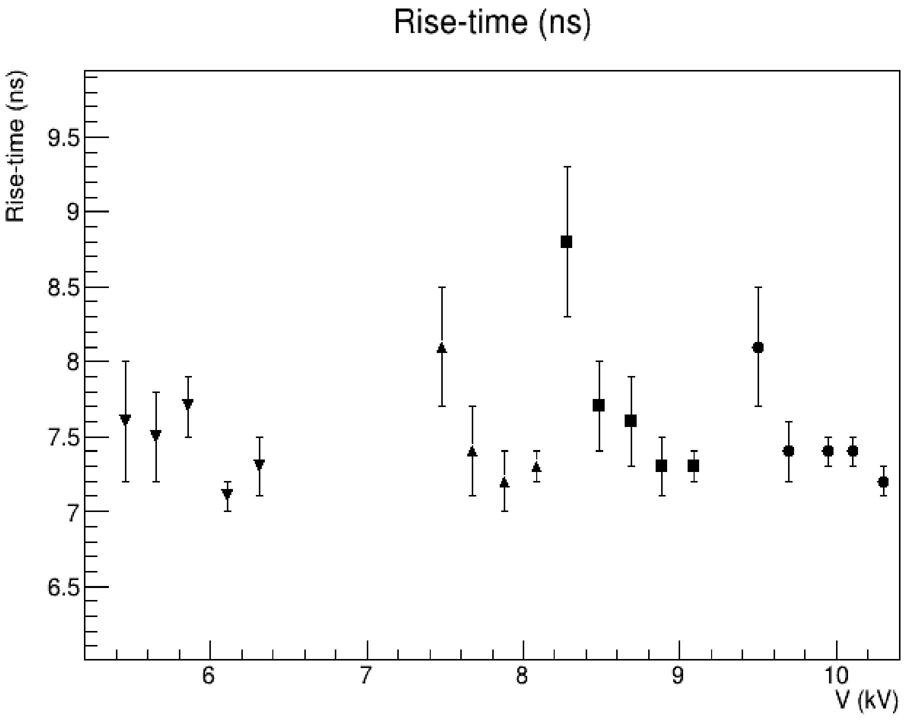


Four mixtures considered:
STD, 90%STD+10%He, 80%STD+20%He, 60%STD+40%He
Discrimination threshold = 2 mV



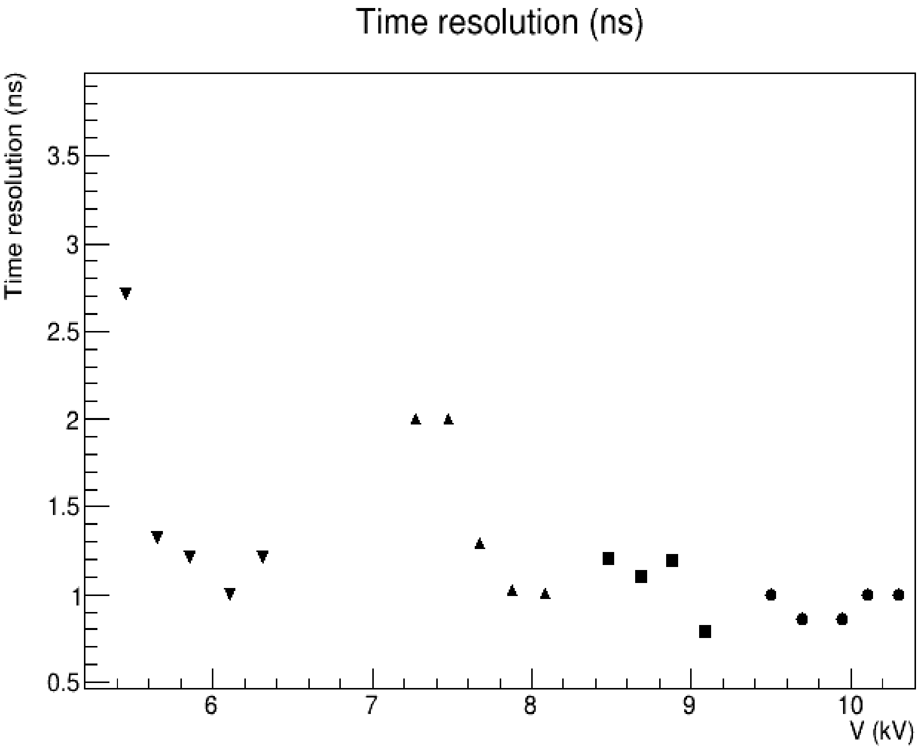
With 40% He operating voltage ~4 kV lower.
Lower efficiency plateau value expected.

Low pressure simulation tests

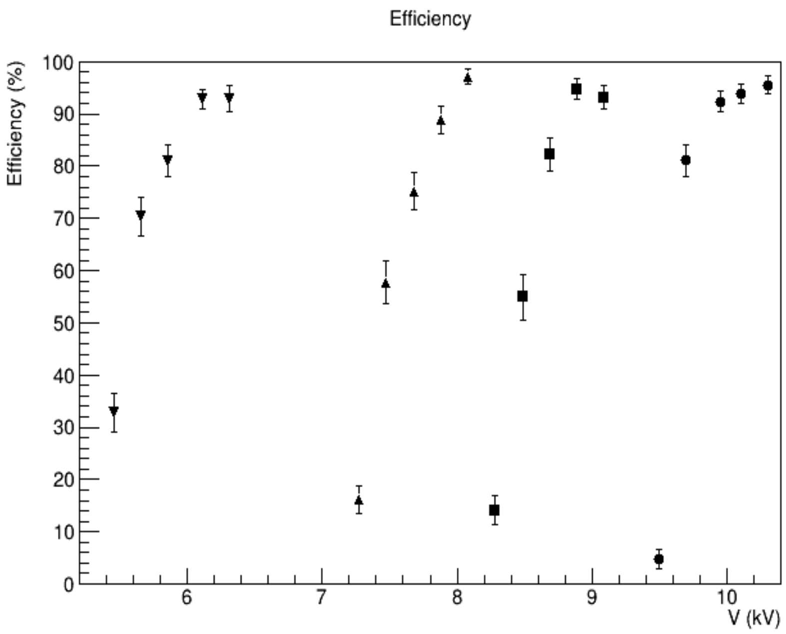


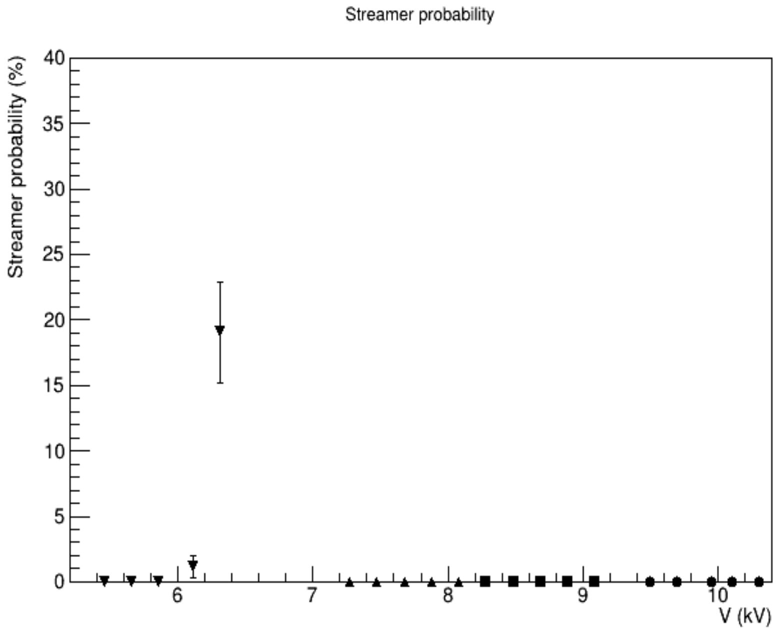
Rise time (10% → 90% of amplitude) at operating voltage ~7ns for each mixture. Due to pad read-out ?

Time resolution estimated from time of flight distribution between two RPCs. Values ~ 1 ns are obtained.



Low pressure simulation tests





Only one concern: streamer-less plateau with 40% He, i.e. at 0.6 bar, much shortened.
To be verified whether due to He addition or to lower pressure.

Further studies:
Change isobutane/SF6
Studies with green mixtures
Final FE electronics with amplifier.

Conclusions and outlook

RPCs in the past have been used for cosmic ray detection (ARGO for extensive air showers).

New window of opportunity to use them together with Water Cerenkov arrays for the same purpose because of complementary performances.

However we need a new design (easiness of construction, robustness, economicity) due to harsh environment conditions.

New readout design with pads to be used in avalanche mode (ARGO was operated in streamer).

Waiting for results of studies on signal formation on 40*40 cm2 pads, promising results in terms of noise (1 mV) and time resolution (~ ns), but the effect of the atmospheric pressure on streamer onset needs further investigations.