The ARGO-YBJ experiment and the potential of Resistive Plate Chambers for Cosmic Ray physics

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“The future of research on Cosmic Gamma Rays”

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The purpose

- The purpose of this talk is to show the potential of the Resistive Plate Chamber for the ground based Cosmic Ray detection
- Argo was the first application in this direction
- The results of this experiment are deeply related to the RPC features and to their optimization for the detection of cosmic showers
- The experience made with Argo is a solid starting point to extrapolate the performance of a second generation experiment based on a substantially upgraded type of RPC
- A special emphasis is put on the detection of gamma rays in the energy range down to 100 GeV, having in mind a possible proposal of a wide FoV gamma-ray detector, to be located in the Southern Hemisphere

The ARGO-YBJ experiment

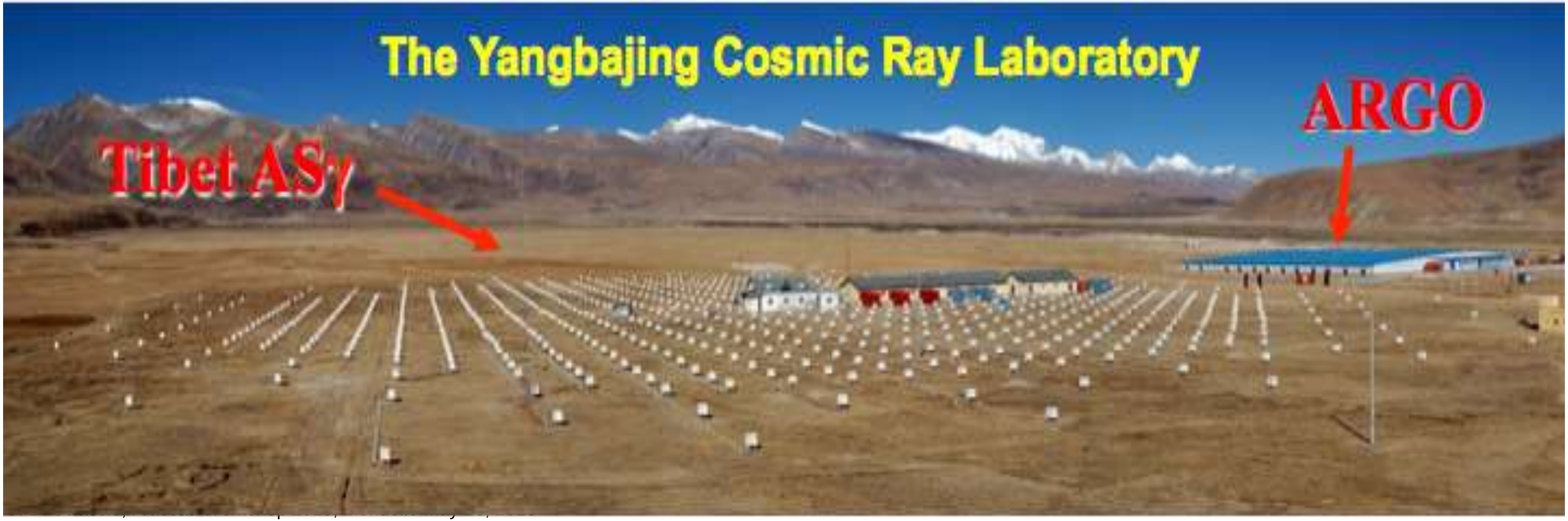
Longitude: 90º 31’ 50’’ East
Latitude: 30º 06’ 38’’ North

90 km North from Lhasa (Tibet)

4300 m above sea level $\sim$ 600 g/cm^2

INFN

IHEP/CAS



The basic concepts

…for an unconventional air shower detector

❖ HIGH ALTITUDE SITE (YBJ - Tibet 4300 m asl - 600 g/cm2)

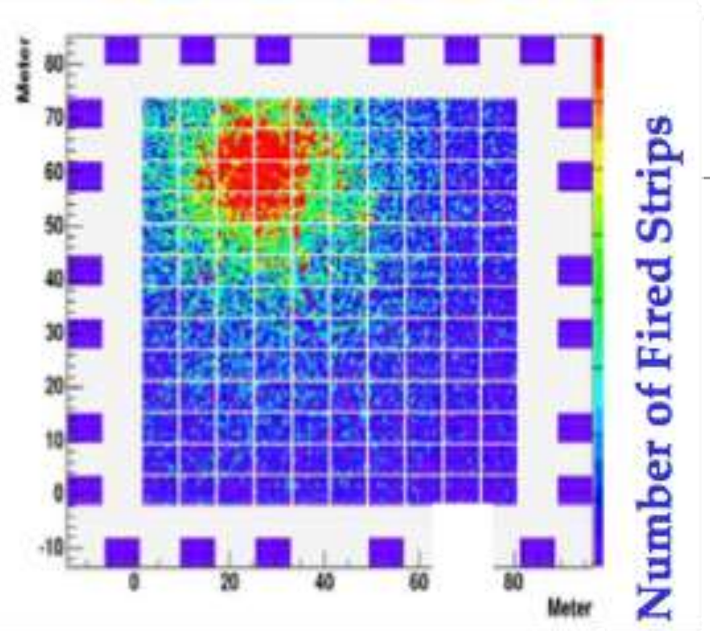
❖ FULL COVERAGE (RPC technology, 92% covering factor)

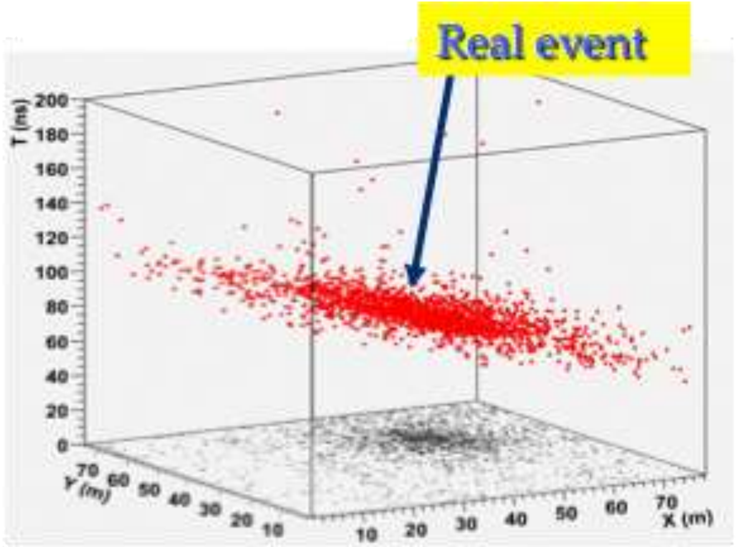
❖ HIGH SEGMENTATION OF THE READOUT (small space-time pixels)

Space pixels: 146,880 strips (7×62 cm^2)
Time pixels: 18,360 pads (56×62 cm^2)

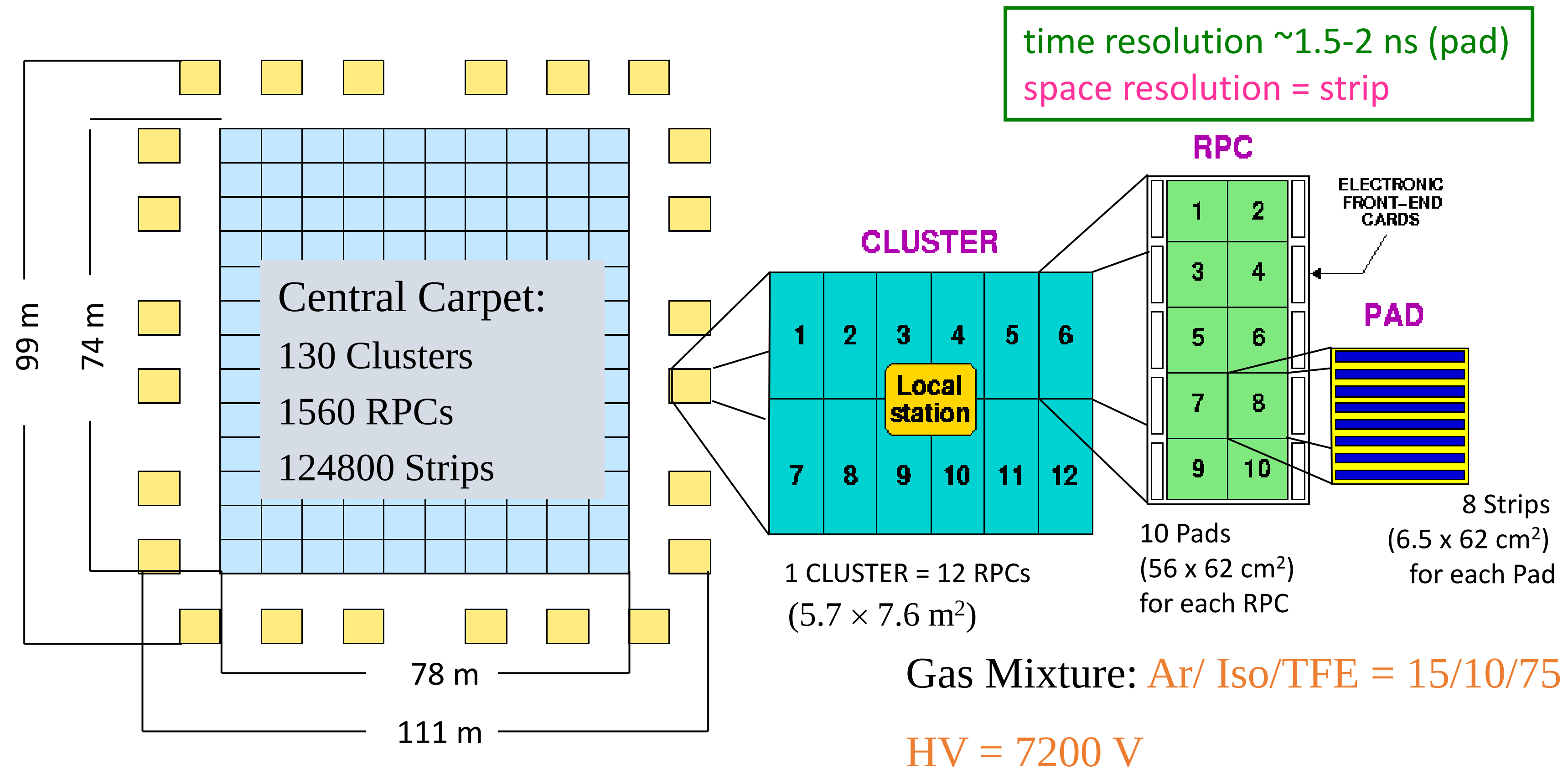
… in order to

- image the shower front with unprecedented details
- get an energy threshold of a few hundreds of GeV





The Argo detector

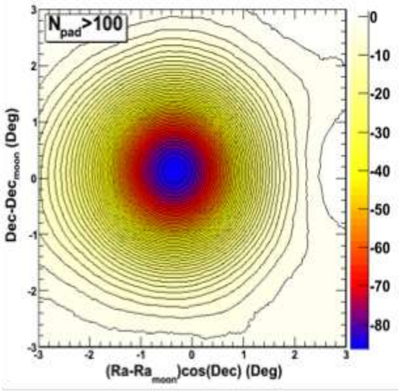


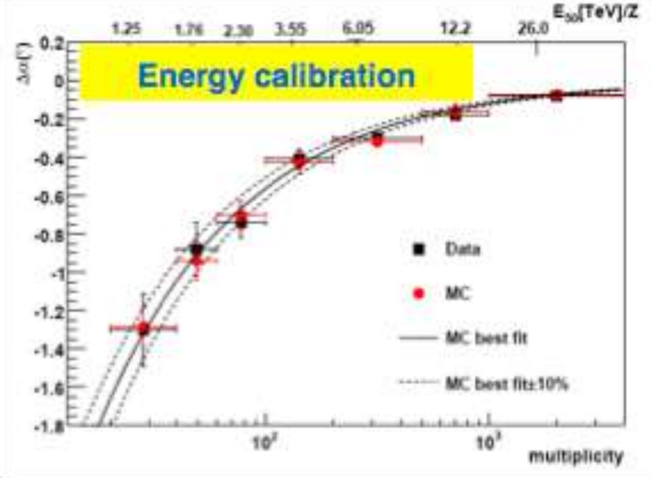
Single layer of Resistive Plate Chambers (RPCs)
with a full coverage (92% active surface) of a large area (5600 m^2)
+ sampling guard ring (6700 m^2 in total)

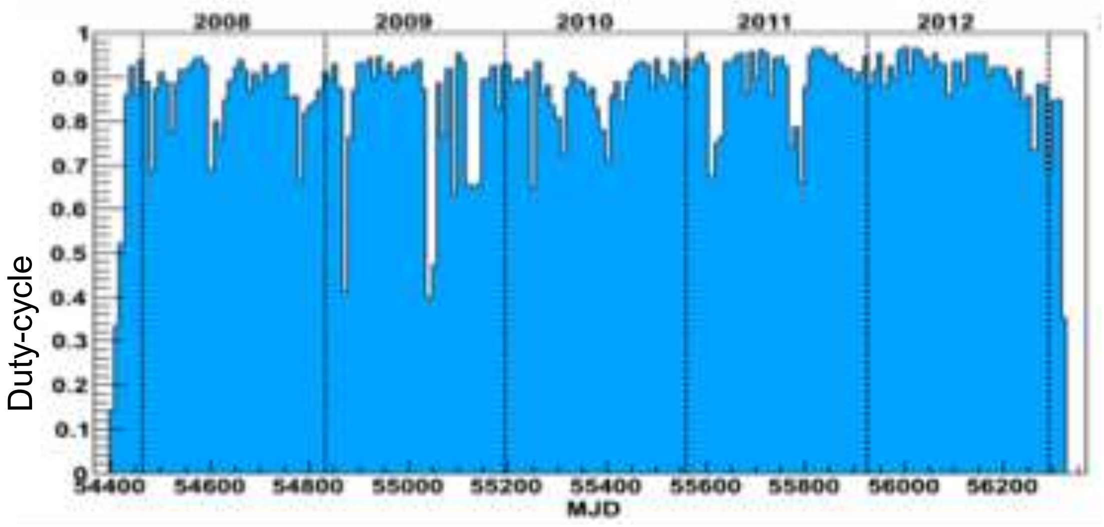
Status and performance

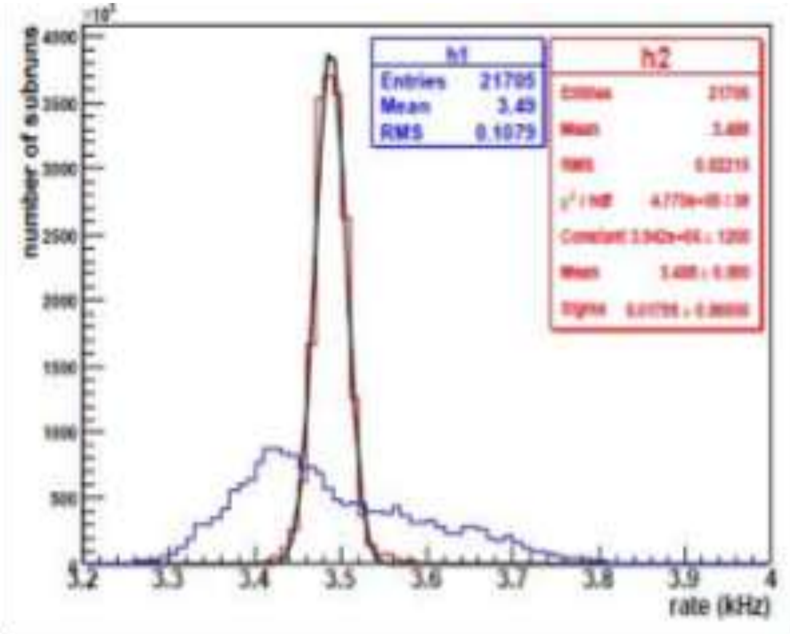
- In observation since July 2004 (with small portions of the detector)
- Stable data taking since November 2007
- End/Stop data taking: January 2013
- Very modest maintenance in a hostile environment

- Average duty cycle ~87% Dead time mostly due to frequent cuts of electric power
- Trigger rate ~3.5 kHz @ 20 pad threshold
- N. recorded events: ≈ $5 \cdot 10^{11}$ from 100 GeV to 10 PeV
- 100 TB/year data



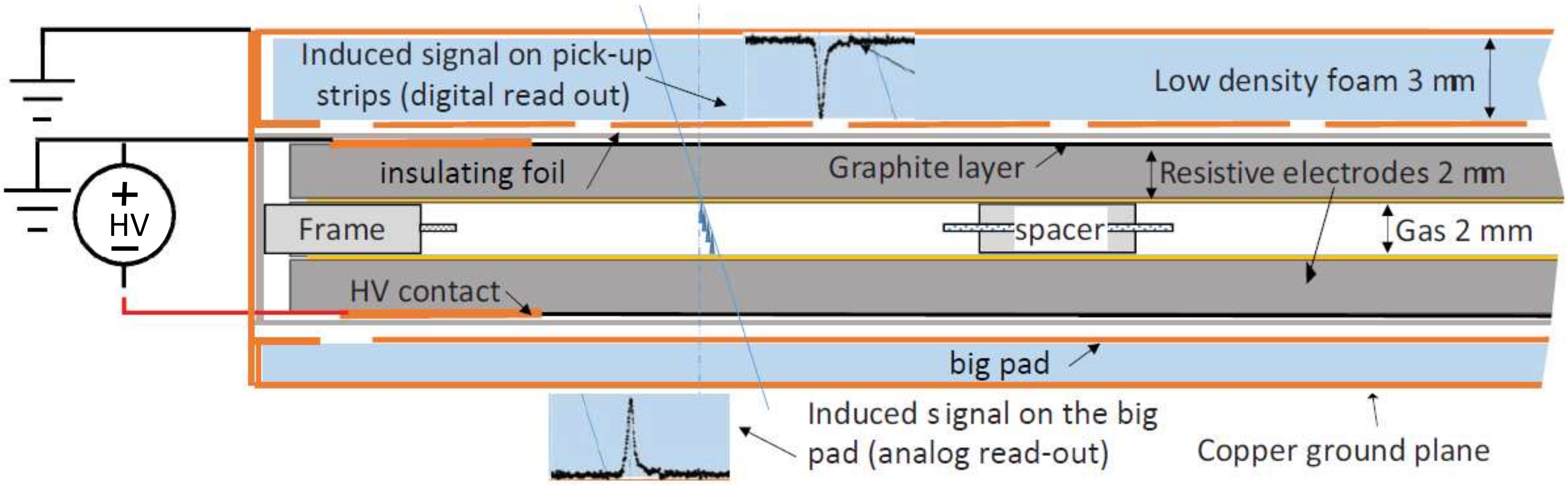






Intrinsic Trigger Rate stability 0.5% (after corrections for T/p effects)

Schematic cross section of a Argo RPC

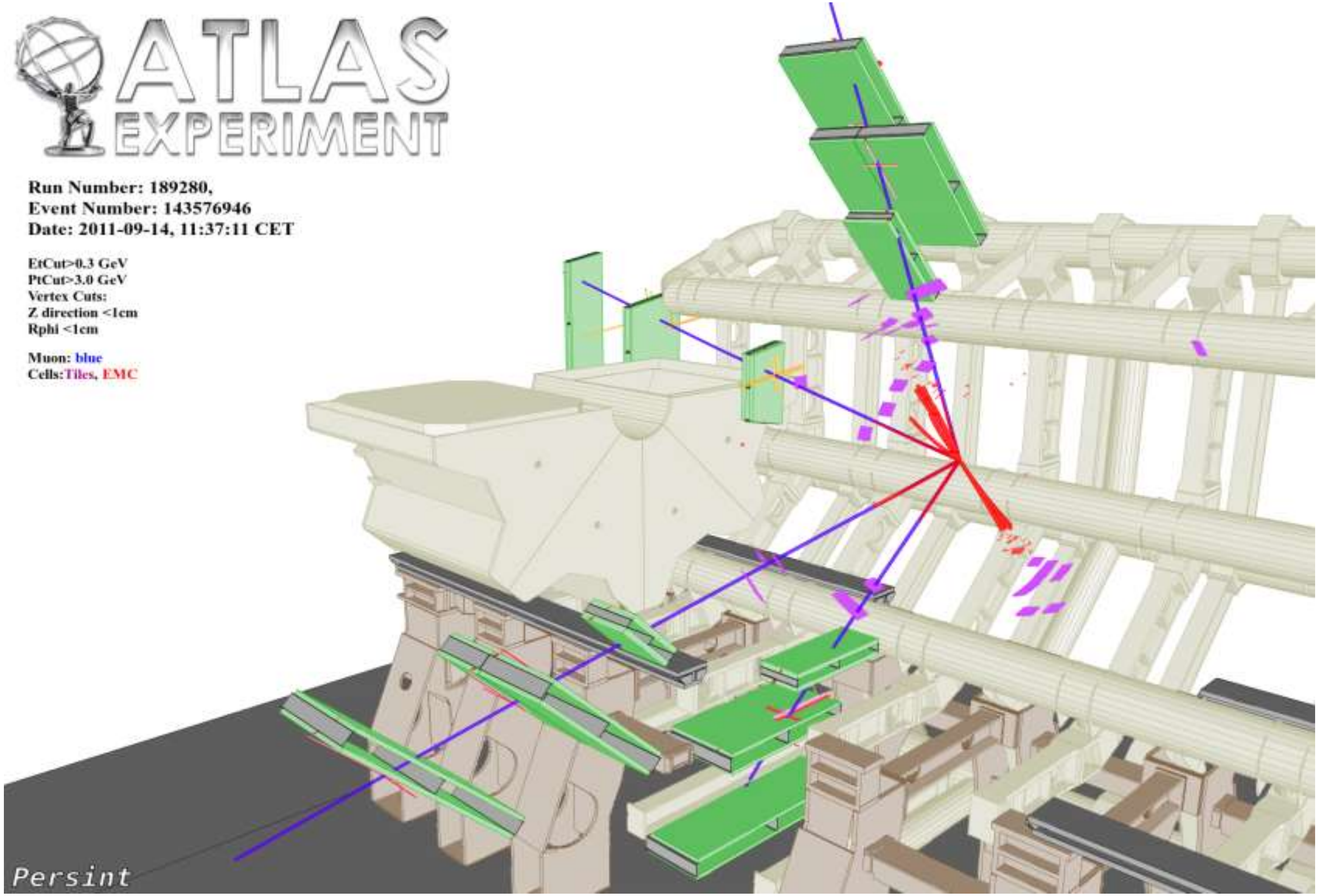


- A RPC is just a gas filled plane capacitor with high resistivity electrodes
- External signal pick up electrodes can be easily tailored with any shape
- Argo gas mixture: $C_2H_2F_4/Ar/iC_4H_{10}$ = 75/15/10 Time resolution ~ 1.5 ns

The RPC wide range of applications

- The RPCs found a wide range of applications. They are used as muon trigger detectors in 3 out of the 4 LHC main experiments
- They are also used, in the multigap configuration, as Time of Flight detectors for mass identification, with a time resolution of 50 ps
- Due to their simplicity and robustness they were used as Cosmic Ray detectors in Argo.
- On the other hand it has also to be stressed that a wide range of applications is essential for the production of components, like eg a full custom front-end circuit, that is only possible on a large scale base

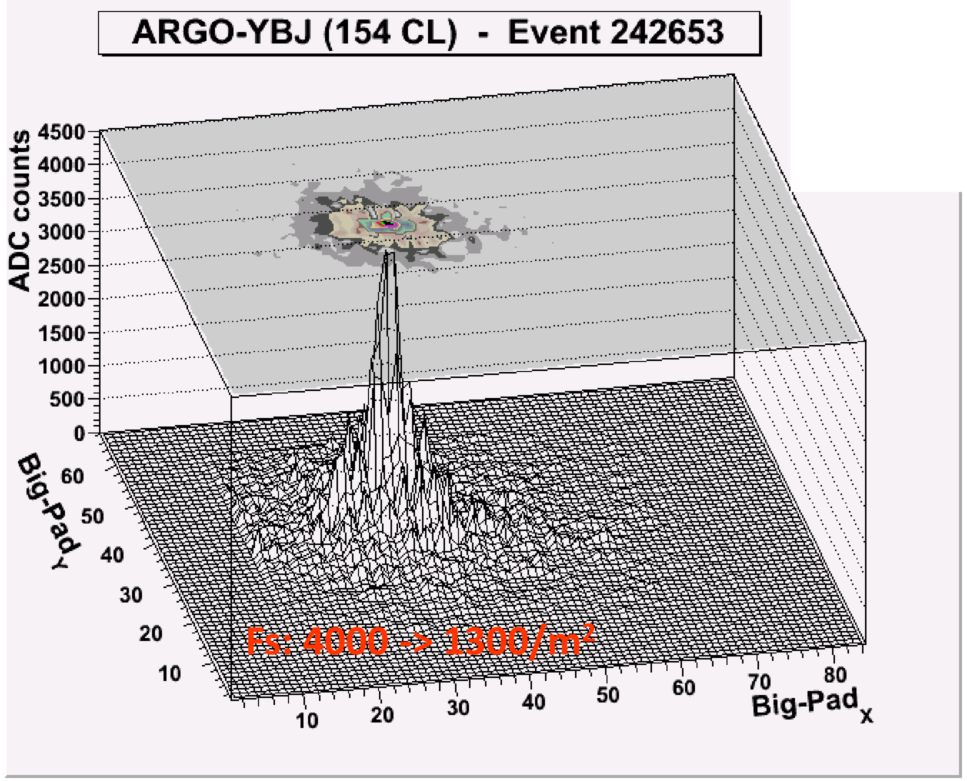
Higgs boson 4 muons decay in Atlas

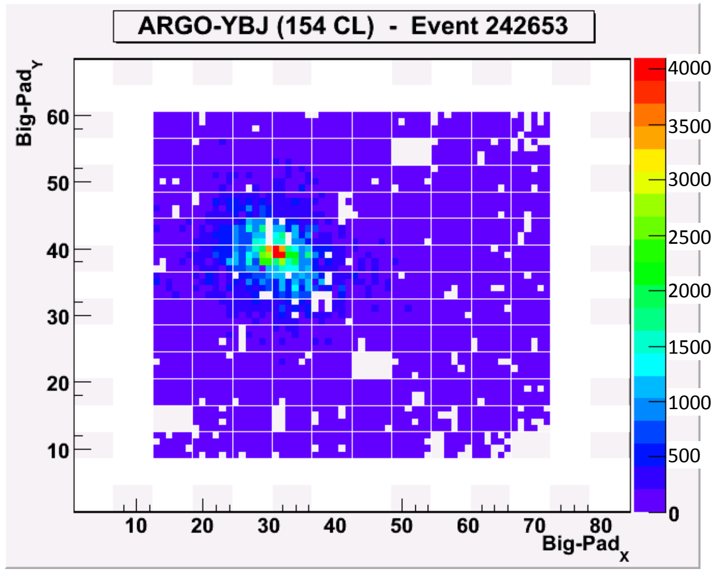


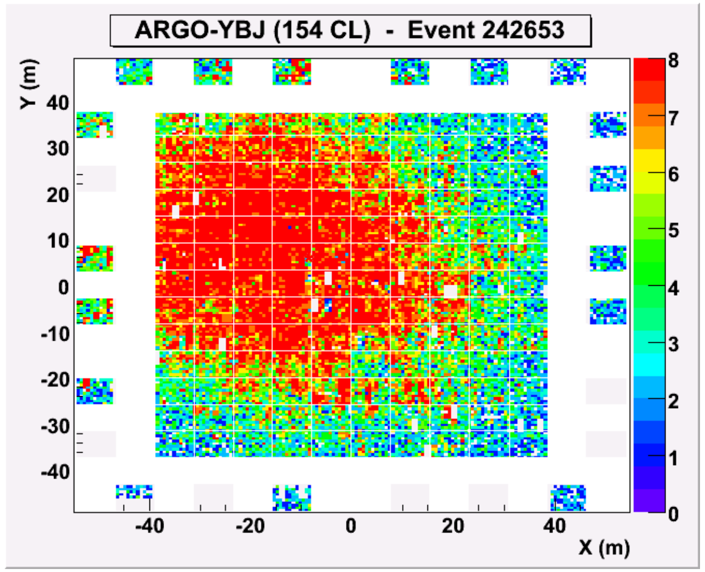
The RPC analog readout
Extending the dynamical range up to PeV

- Is crucial to extend the covered energy range above 100 TeV, where the strip read-out saturates
- Max digital density ~20/m^2 Max analog dens ~10^4/m^2
- Access the LDF in the shower core
- Sensitivity to primary mass
- Info/checks on Hadronic Interactions

ARGO event



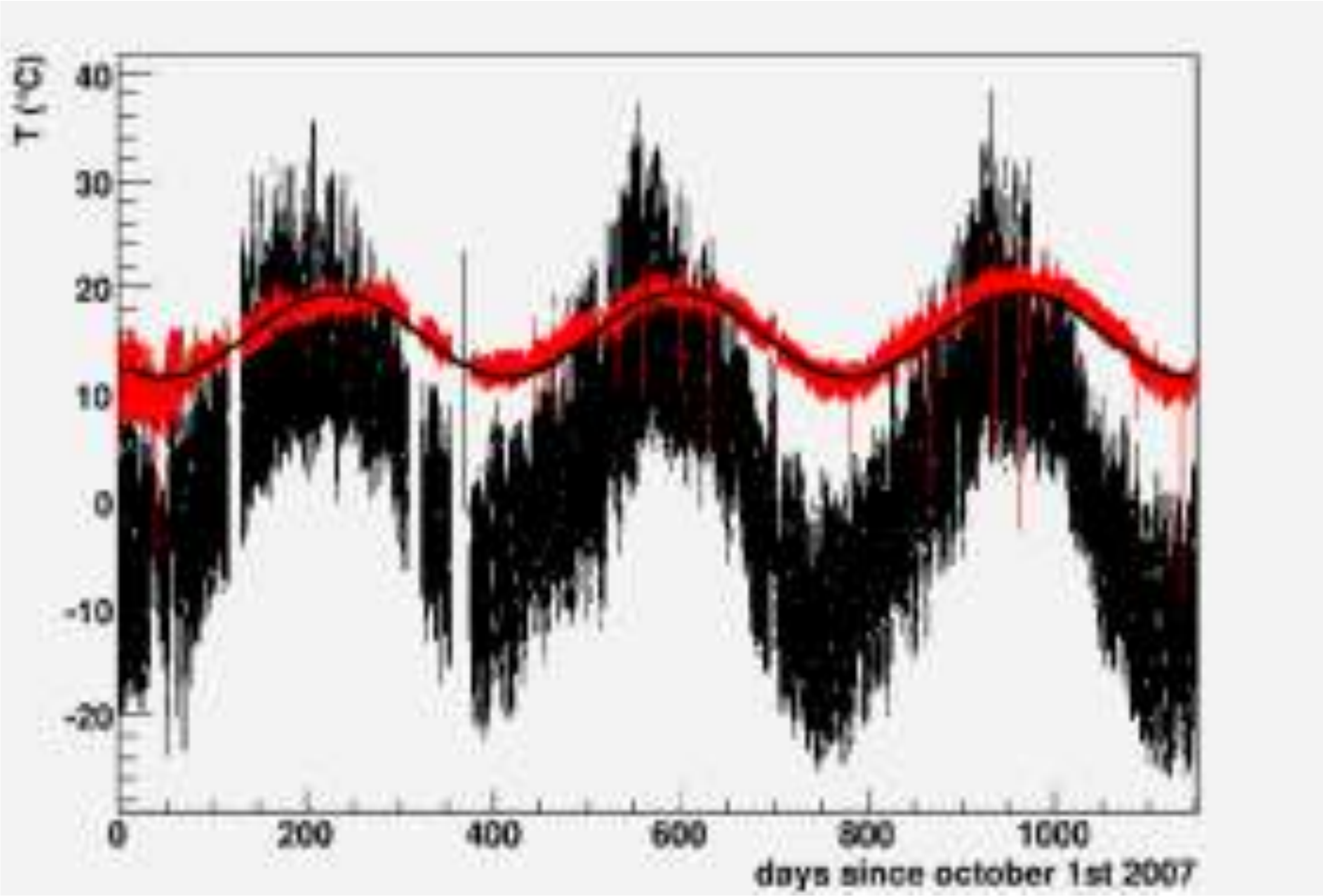




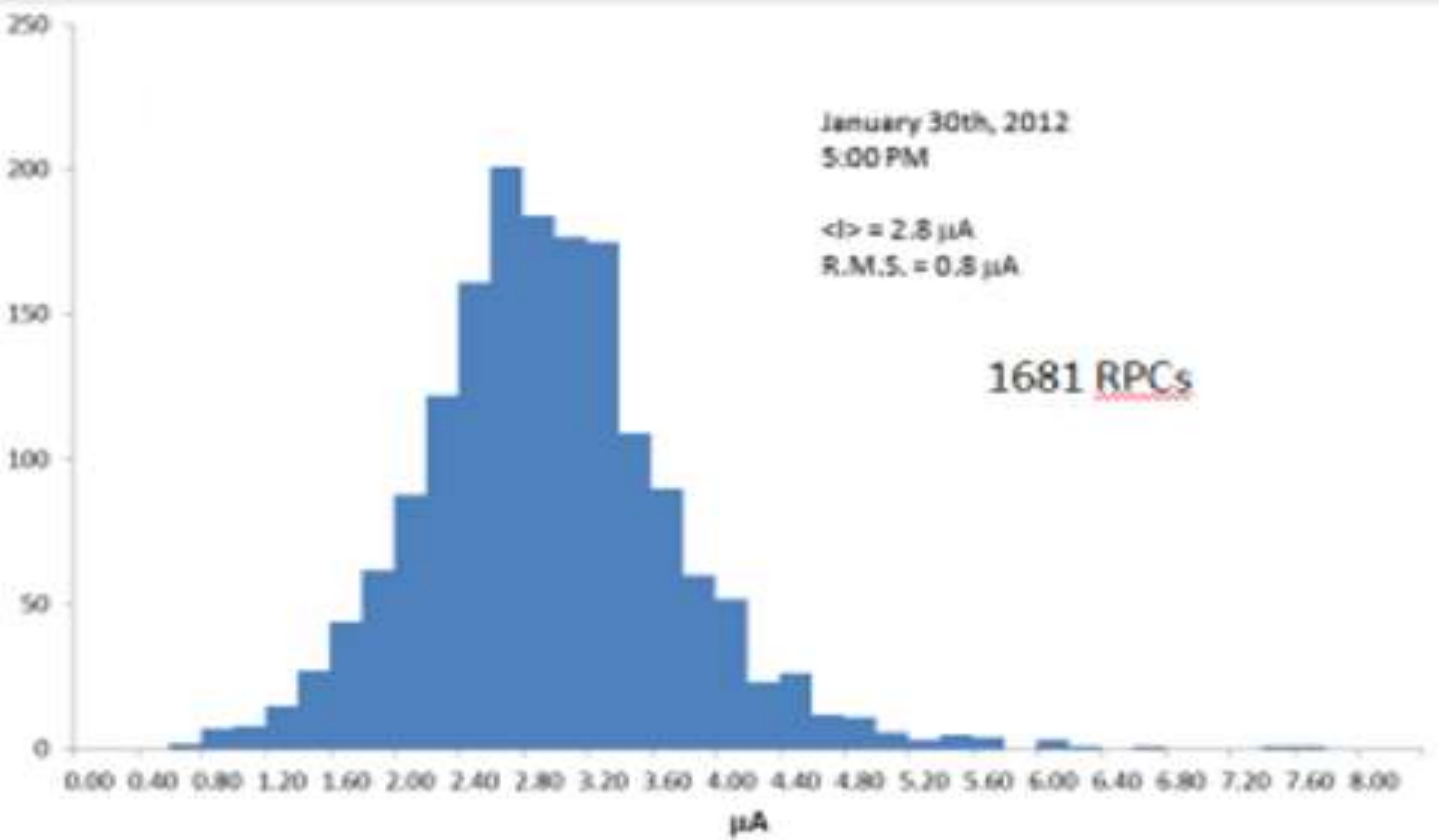
Operating a large size detector at 4300 m asl

- Efficient detector control system (DCS) to monitor
  - External temperature and pressure
  - Detector temperature
  - Operating currents of each chamber
  - Trigger rate

Temperature annual oscillations



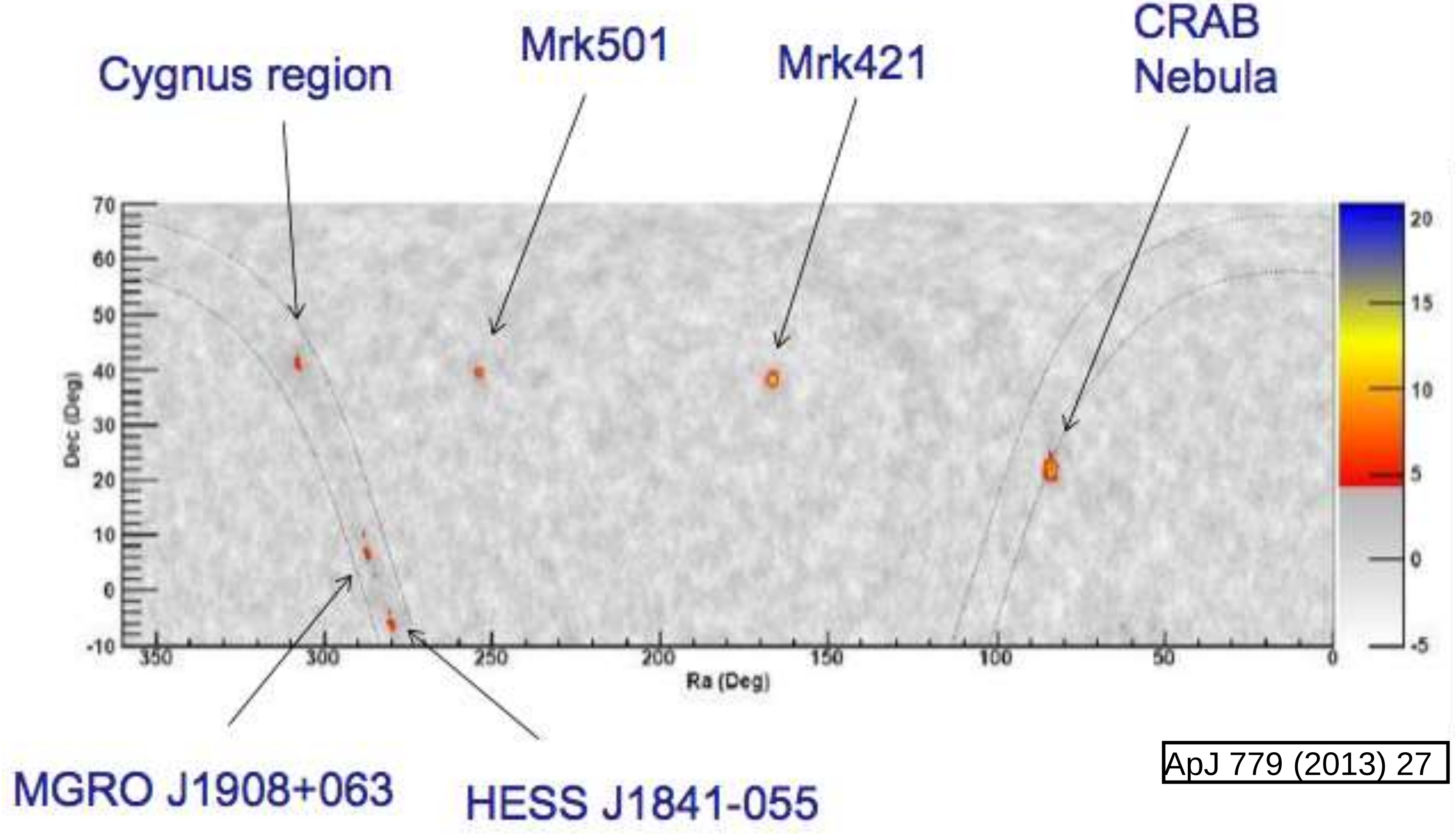
Operating current distribution for the 1681 RPCs (3.5 m^2 each)



Gamma-ray Astromomy ARGO-YBJ 5-years survey of the Northern Sky

- Integrated sensitivity in 5 y at ~1 TeV: 0.25 Crab for dec 15° - 45°

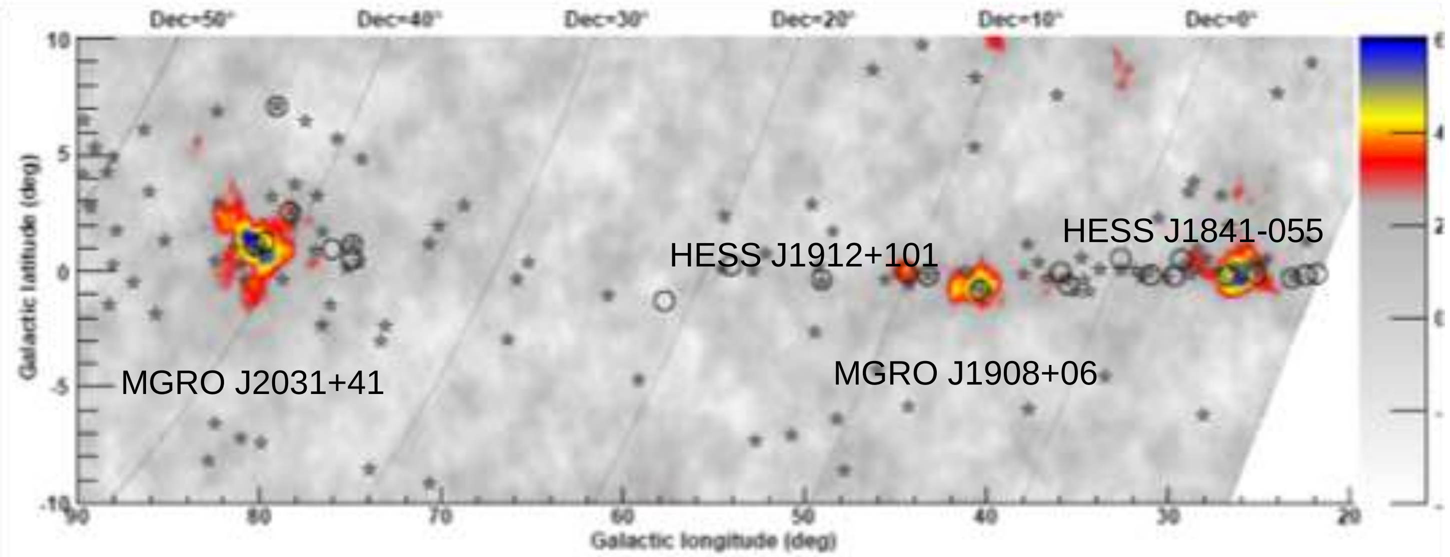
Gamma-ray astronomy



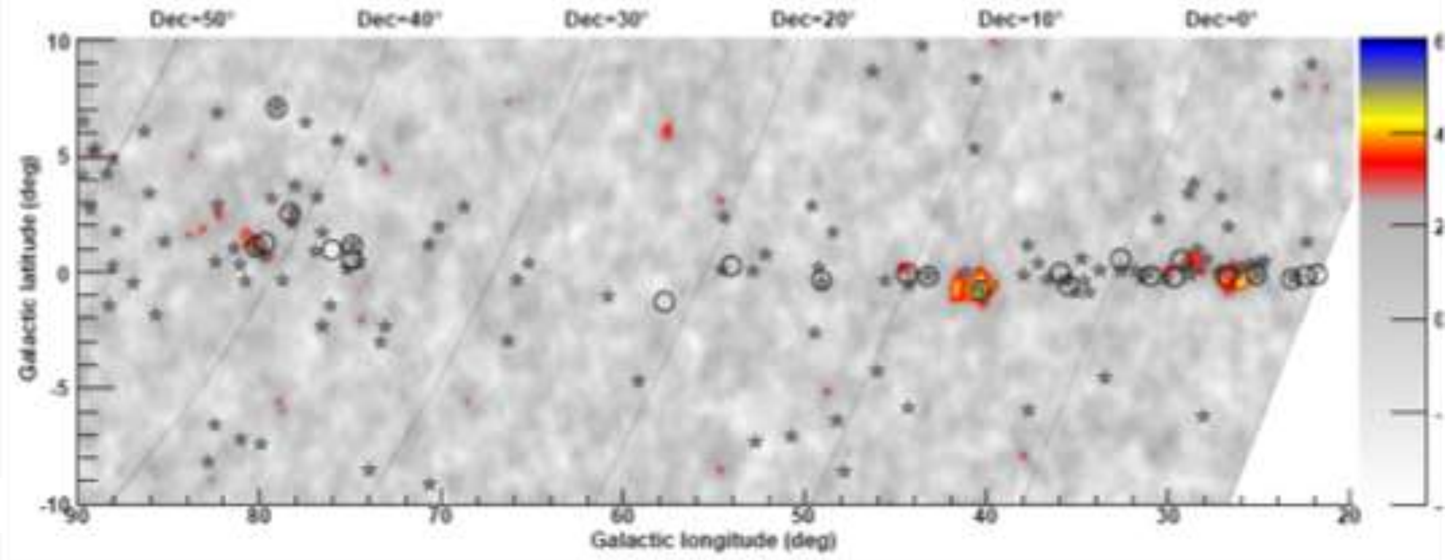
ApJ 779 (2013) 27

ARGO-YBJ 5-years Survey of Inner Galactic Plane

$20^\circ < l < 90^\circ$, $|b| < 10^\circ$



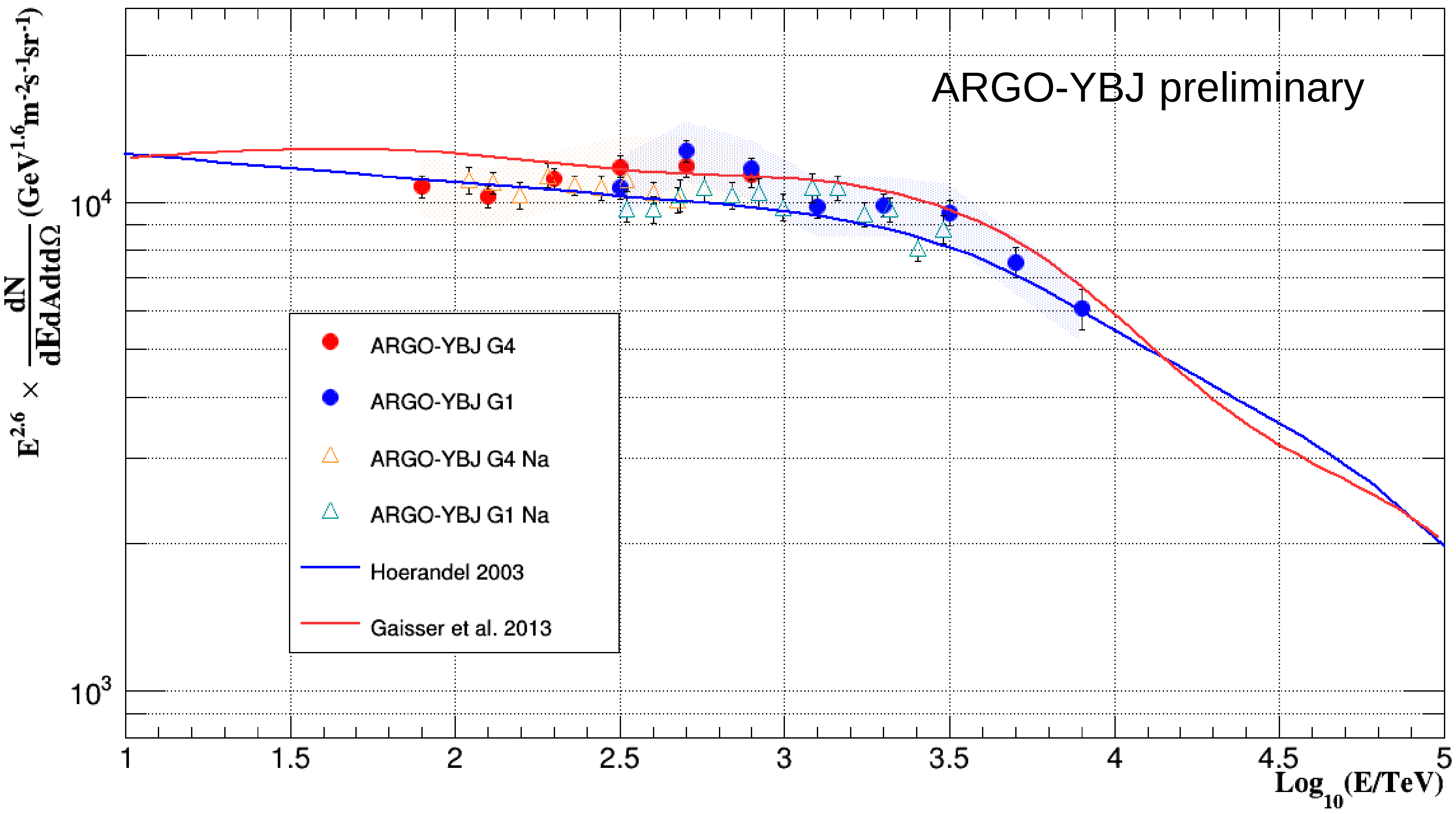
$E_{50} \approx 0.7$ TeV



$E_{50} \approx 1.8$ TeV

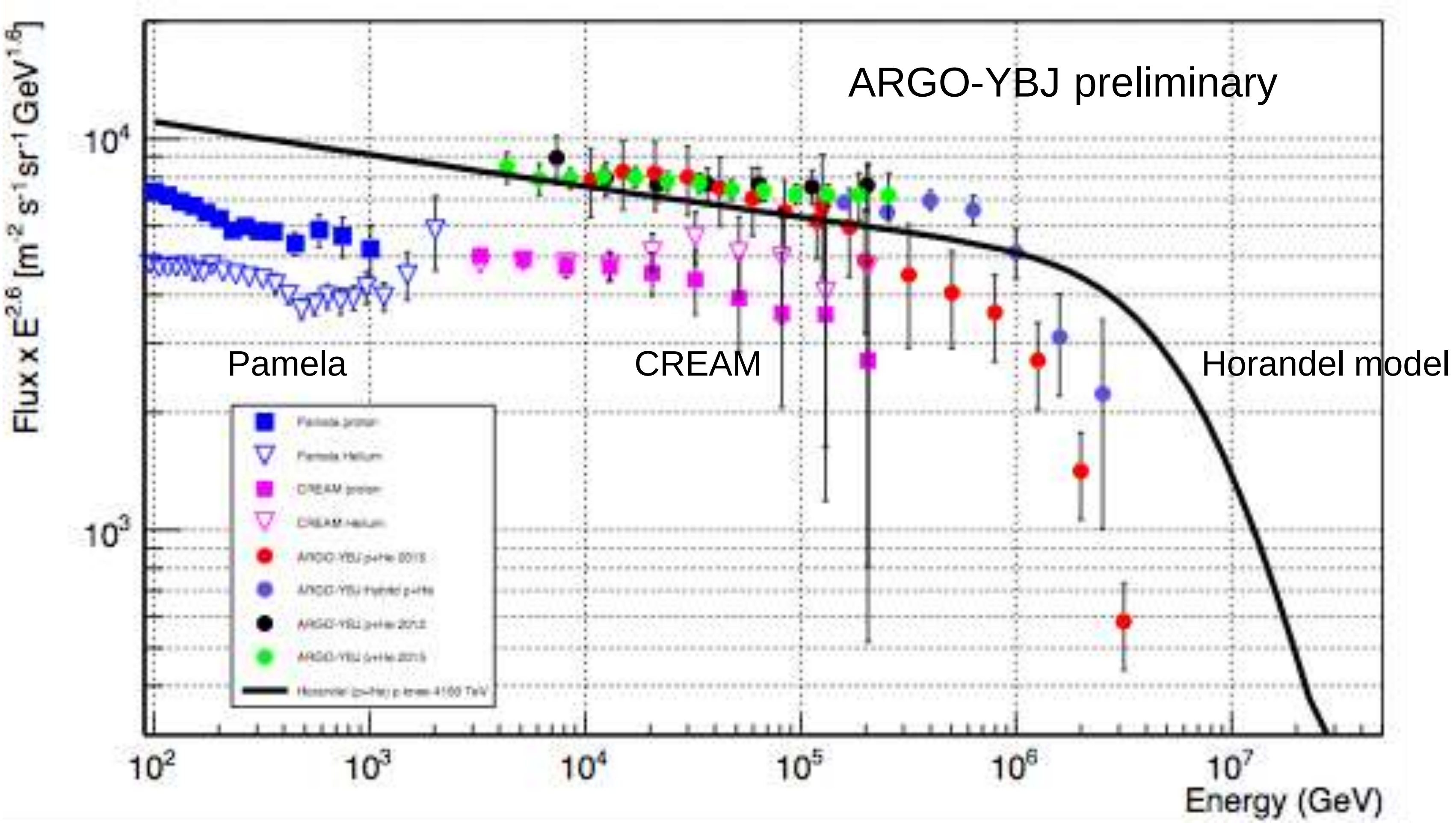
Cosmic ray physics All-particle spectrum by ARGO-YBJ

ARGO-YBJ reported evidence for the all-particle knee at the expected energy



Light component spectrum (3 TeV - 5 PeV) by ARGO-YBJ

ARGO-YBJ reported evidence for a proton knee starting at about 650 TeV
and not at 4 PeV (“standard model”)



A look to the future

Based on the Argo experience, a number of relevant upgrades can be conceived to improve the sensitivity of a similar detector, in particular for low energy gamma rays

Upgrades: larger detection area and Photon conversion

The results of Argo in gamma ray astronomy and CR physics were achieved with a substantially **downgraded** detector with respect the proposal, which was based on

- A RPC carpet of 120x120 m^2
- A $1X_0$ Pb converter on top of it

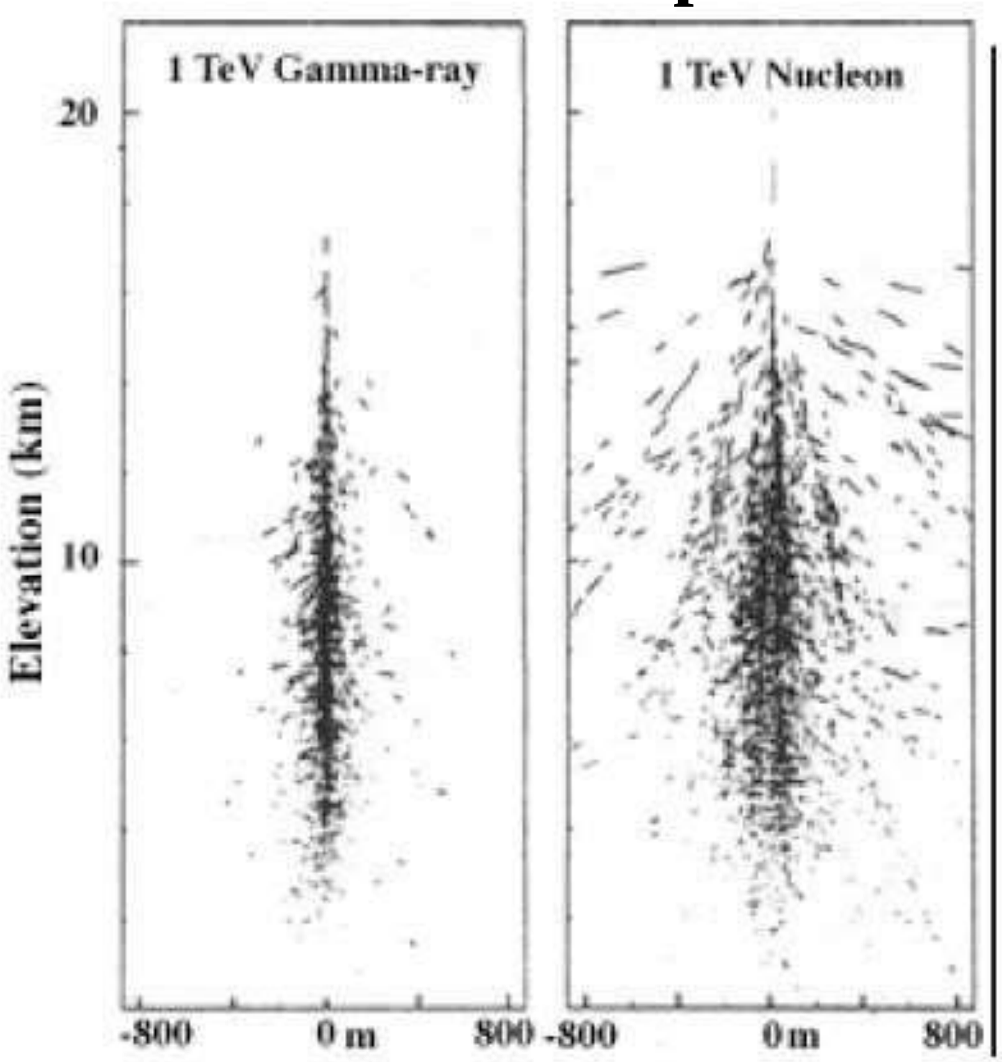
The real detector was a carpet of 5600 m^2 without any photon converter on top.

An obvious upgrade:

- increase the area to 10 000-20 000 m^2
  - Much higher statistics
  - **photon-hadron discrimination** possible (the small size of Argo did not allow this discrimination)
- A $1X_0$ Pb photon converter would **increase the number of detected shower particle by a factor ~ 5!!**

Gamma vs Hadronic shower

concentrated **sparse**

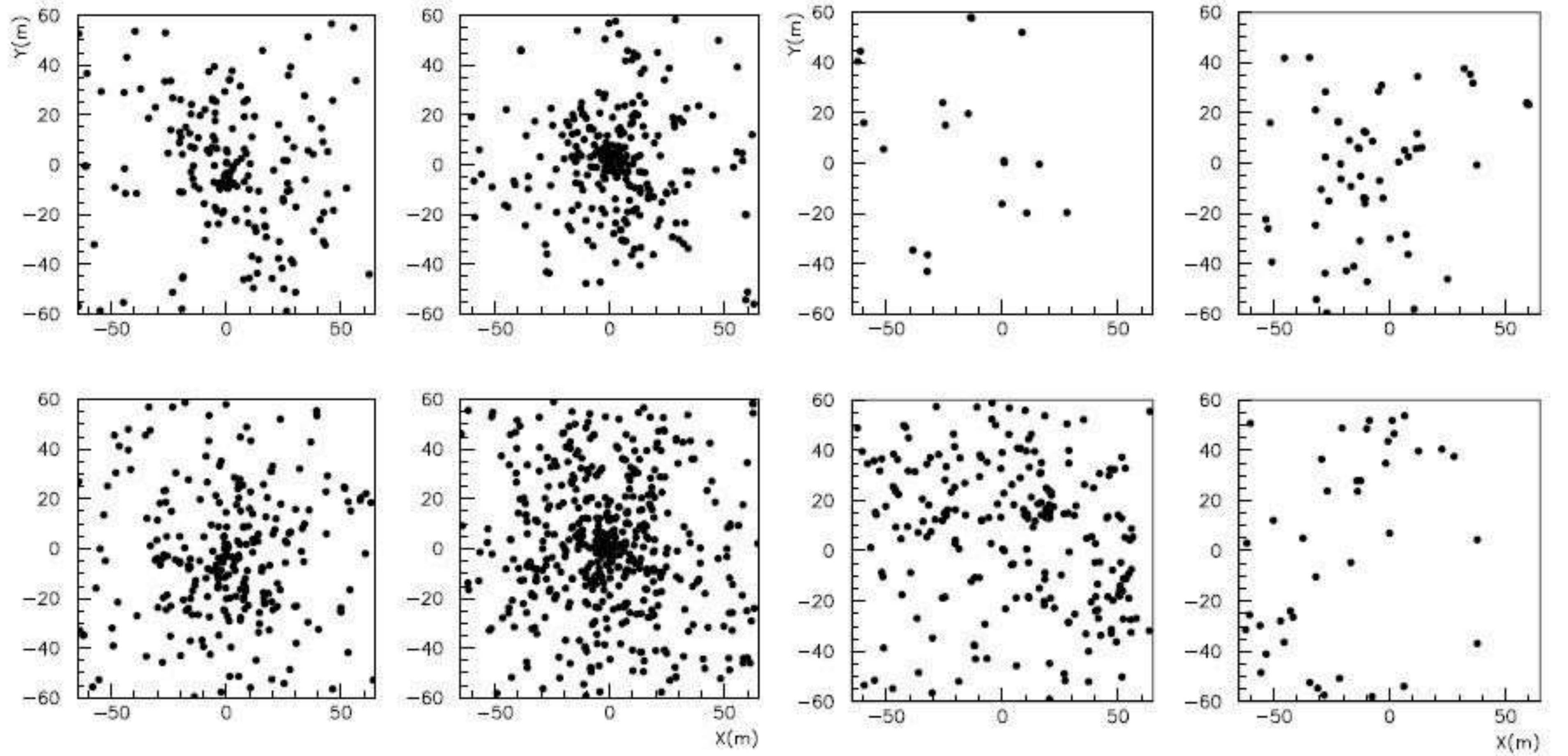


Large spread of arrival times

Gamma-proton shower discrimination

1 Tev photons

1 Tev protons



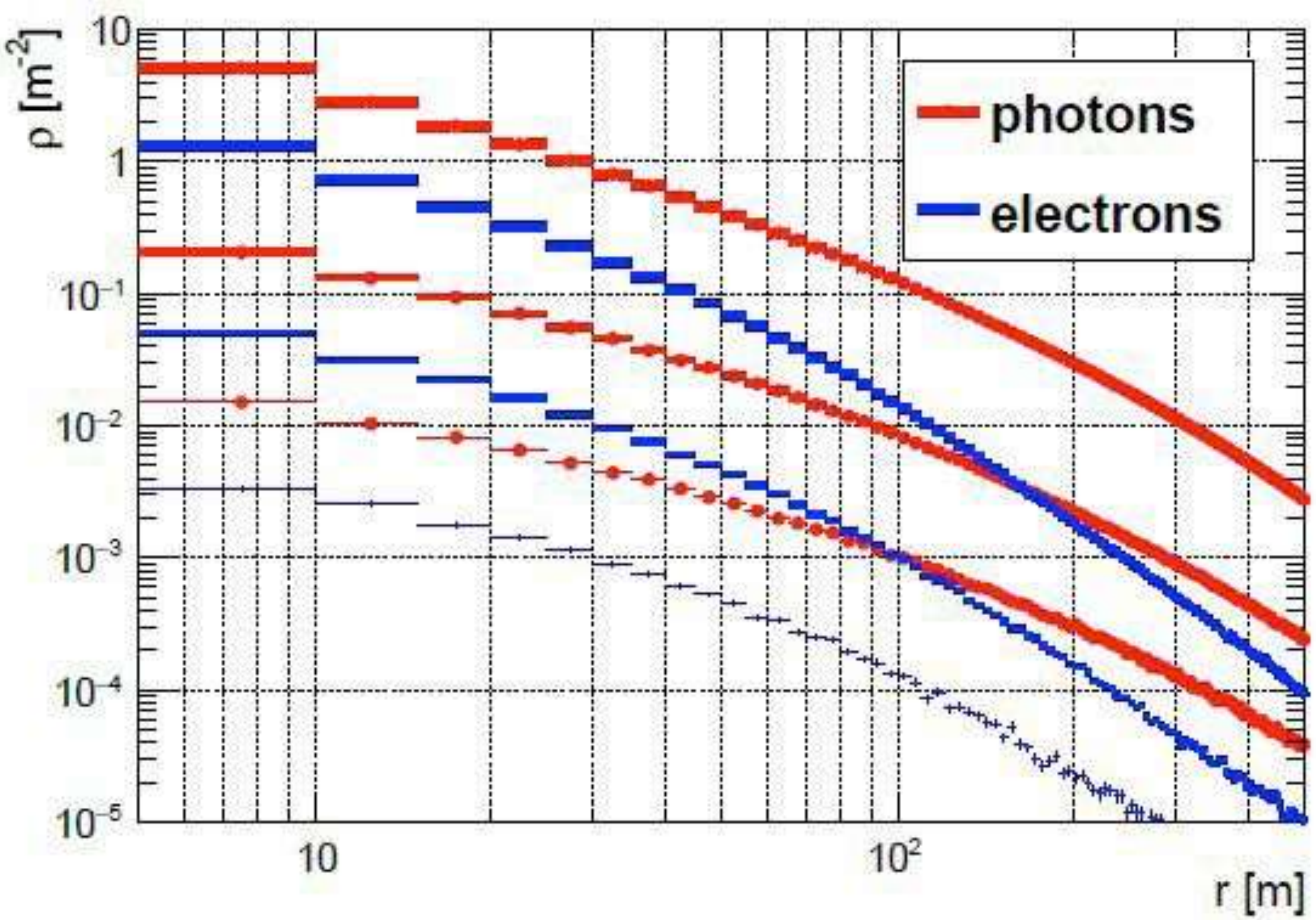
Primary photons of 100 GeV, 500 GeV and 5 TeV at 5000 m asl

<u>Photons are the main component of the shower</u>

6 part/m²

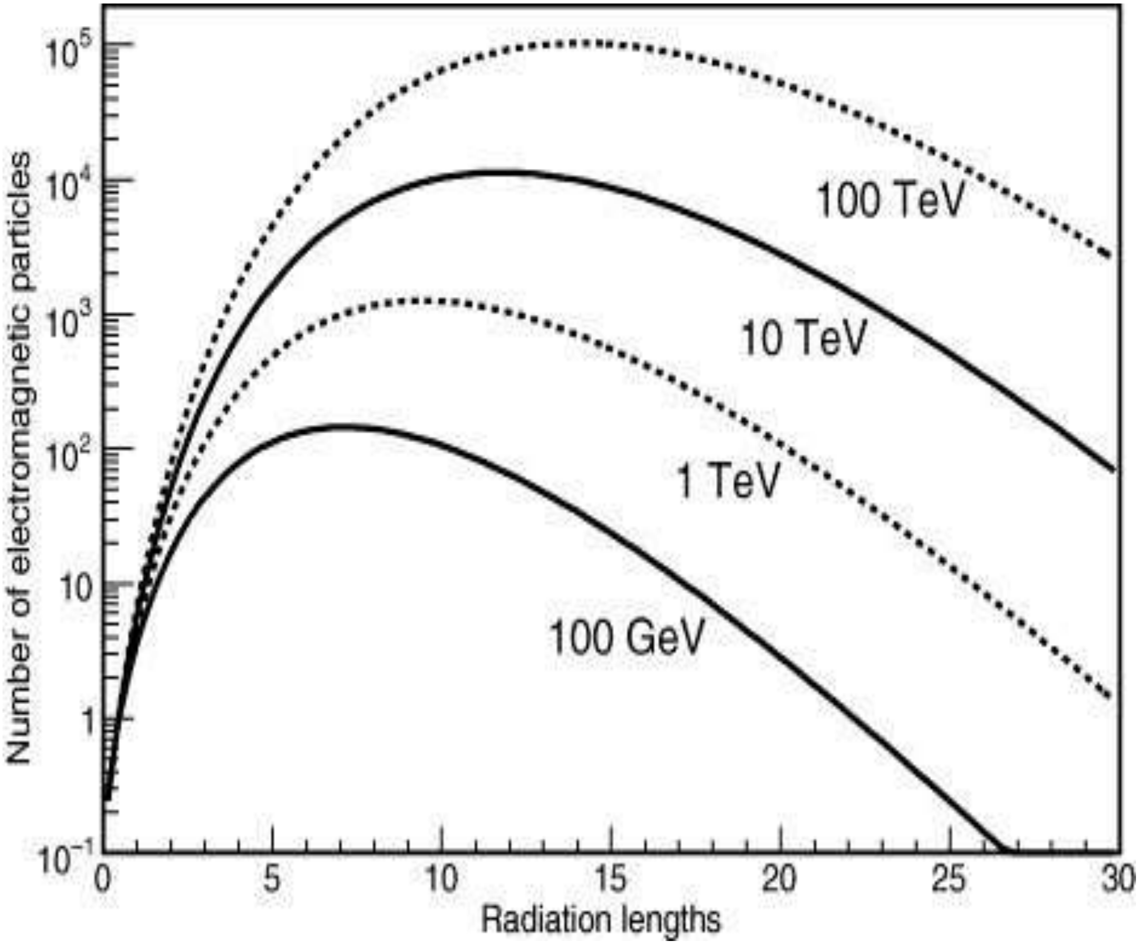
0.3 part/m²

0.02 part/m²



Upgrades:

Operation at higher altitudes



- Operating at higher altitudes, ~5000 m, would be a further important advantage, mainly for low energy photons
- Extrapolation **from 4300 m to 5000 m** (about -1.4 X_0) gives an **increase of almost a factor of 2 for the number of particles** produced by a 100 GeV primary photon

Upgrades:
Improving the detector performance (1)

- Fully analog read out
  - The experience with Argo suggests that for a shower detection the analog read out is more effective than the digital one and should be extended from the "big pad" to the full signal read out
  - With this approach, squared pick up electrodes of area e.g. 30x30 cm^2 or 40x40 cm^2, would be more effective than substantially longer strips. The signal amplitude recorded by ADCs would substantially improve the amount of information
  - 1 TDC + 1 ADC per pad
  - → Space-time sampling of the shower front with an unprecedented detail !
- Avalanche mode operation (Argo was operated in streamer)
  - Lower delivered charge and lower operating current → lower gas consumption
  - Much wider dynamic range of the analog read out
  - Should allow to resolve a very closed e+e- pair produced by a photon annihilation, its signal amplitude being twice the m.i.p.
  - Better timing. Sub-nanosecond resolution possible but should be compared with the intrinsic shower front fluctuations
- A relevant investment of simulation is crucial to test different ideas of optimization

Upgrades:
Improving the detector performance (2)

- Front end electronics
  - A new full custom front end circuit, dedicated to the RPCs, is under development (by R. Cardarelli) and will replace the one used for Argo
  - Final front end electronics optimized for the avalanche mode operation
  - The full custom circuit **will integrate the ADC and TDC functions**
  - The output for each fired pad will be a **shaped signal**, suitable for coincidence logics, **equipped with two numbers digitizing the Amplitude and the Time** respectively
  - A crucial solution to avoid a huge complexity of interconnected circuits needed to discriminate and to digitize the input signal

- A relevant investment of simulation is crucial to test different upgrade ideas and to optimize the detector, balancing performance and complexity
- Collaborators interested to a full detector simulation would be highly welcome

Upgrades:
the gas system

- The Argo Gas system was operated in open flow. The operation in closed loop, foreseen in the proposal, remained at the prototype level and was never implemented
- A gas recirculation/purification system would make the running cost negligible thus creating the best conditions for a very long term data acquisition

Conclusions

- The combination of high altitude site, full coverage and high segmentation of the read out, made Argo a unique experiment, which achieved relevant results even beyond the expectations of the proposal
- To extend this original approach to a new upgraded experiment, taking fully into account the experience made with Argo, will offer a relevant discovery potential
- A substantial upgrade of the performance is possible thanks to a number of well identified parameters/operations:
  - Increased detector area
  - Addition of a photon converter
  - Higher altitude site
  - RPC avalanche mode operation with improved timing and **fully analog read out**
  - New front end full custom circuit **integrating the ADC and TDC functions**
  - Gas closed loop

Conclusions (cont.)

- All these improvements allow to sample the shower front with a space-time resolution of about 10 cm x 1 ns or better.
- However a full simulation is needed to find the required optimal resolution, taking into account the intrinsic fluctuations of the shower front. This simulation can profit of the Argo experience as a solid reference point to extrapolate the performance of a new detector.
- A RPC wide FoV gamma-ray detector, in the energy range 100 GeV-10 TeV, located in the Southern Hemisphere, would be unique and complementary to other experiments planned to take data in the next decade
- We (G Di Sciascio, R. Santonico and M.Tavani) propose to organize a meeting of interested groups, to be held in Rome 2 at the beginning of December, dedicated to discuss this exciting idea