An innovative wide FoV gamma-ray detector in the South Hemisphere

Ricap2016 – Villa Tucolana

By R Santonico

- The purpose of this talk is to extrapolate some 10 years of experience made with data taking and analysis of **Argo-YBJ,** to an improved detector of the same type
- The main challenge should be the detection of gamma rays in the energy range down to 100 GeV and, at the same time, to study cosmic rays trough the shower core, up to about 10-20 PeV.
- A wide FoV gamma-ray detector, with the above characteristics, located in the Southern Hemisphere, would have a great discovery potential

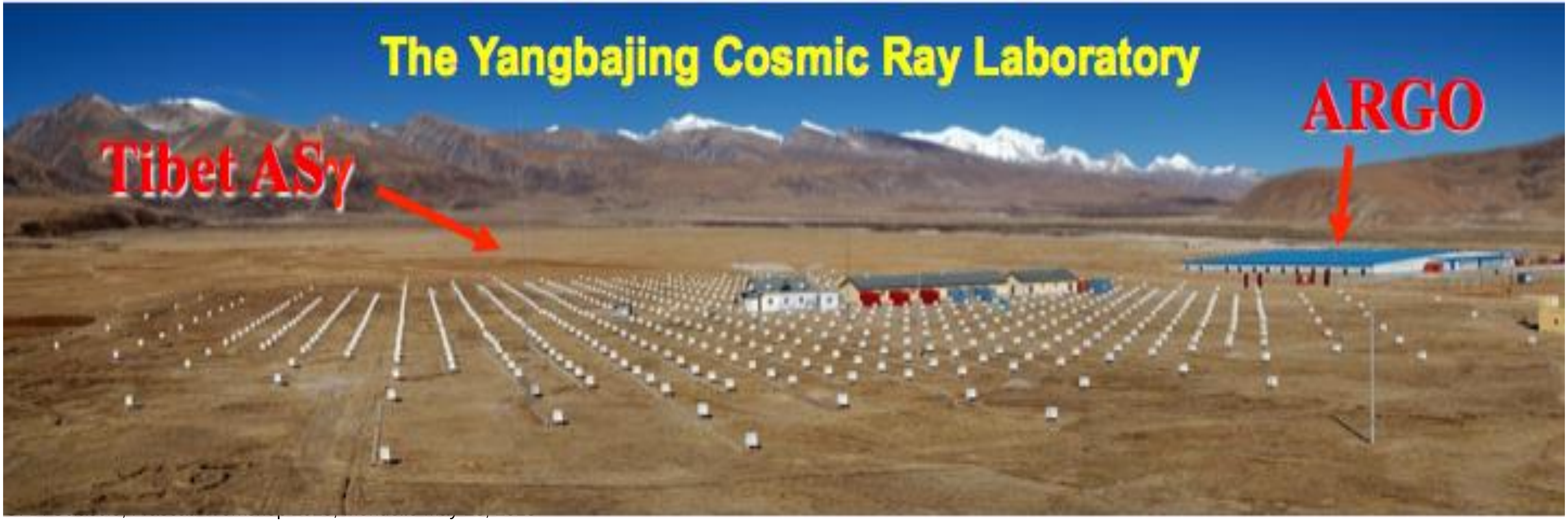
The ARGO-YBJ experiment

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

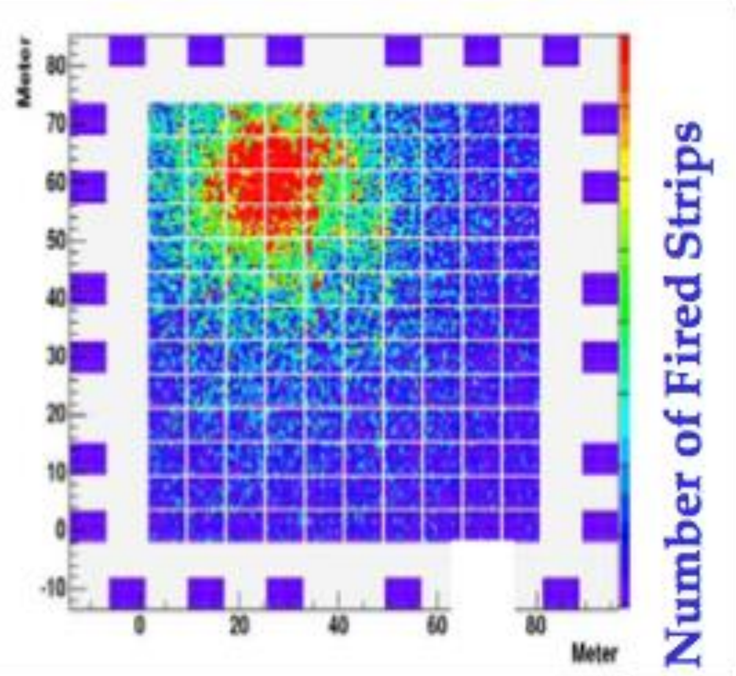
4300 m above sea level ∾ 600 g/cm^2

INFN IHEP/CAS

90 km North from Lhasa (Tibet)



Basic concepts for an unconventional air shower detector



❖ HIGH ALTITUDE SITE

(YBJ - Tibet 4300 m asl – 600 g/cm2)

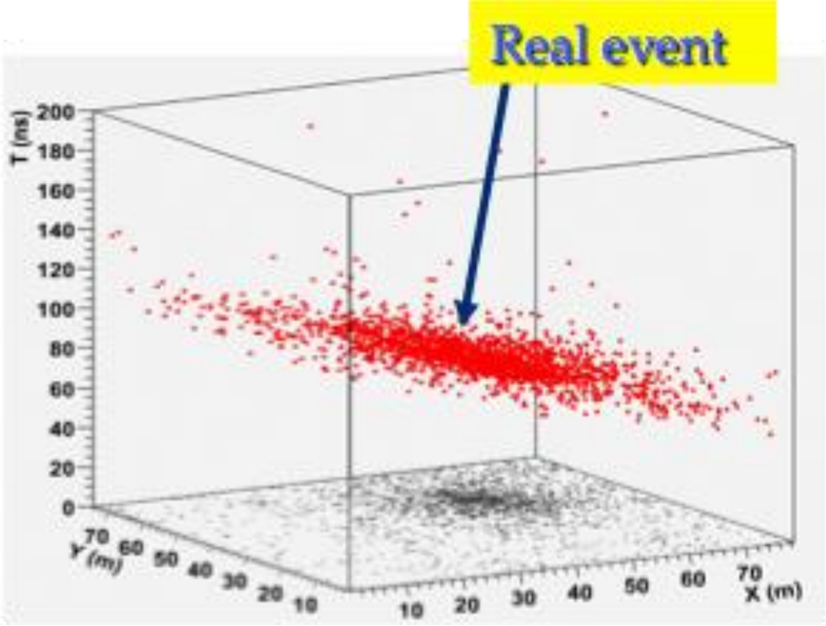
❖ FULL COVERAGE

(Resistive Plate Chambers, 92% coverage)

❖ HIGH READOUT SEGMENTATION

Space pixels: 146,880 strips (7×62 cm^2)

Time pixels: 18,360 pads (56×62 cm^2)

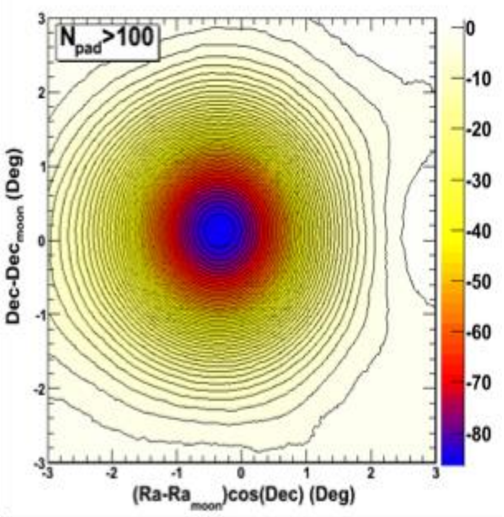


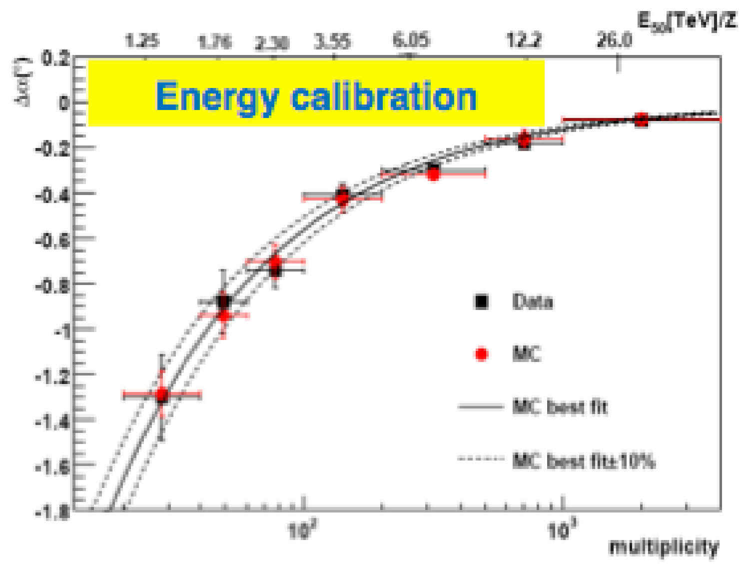
→ image the shower front with unprecedented details

→ get an energy threshold of a few hundreds of GeV

Status and performance

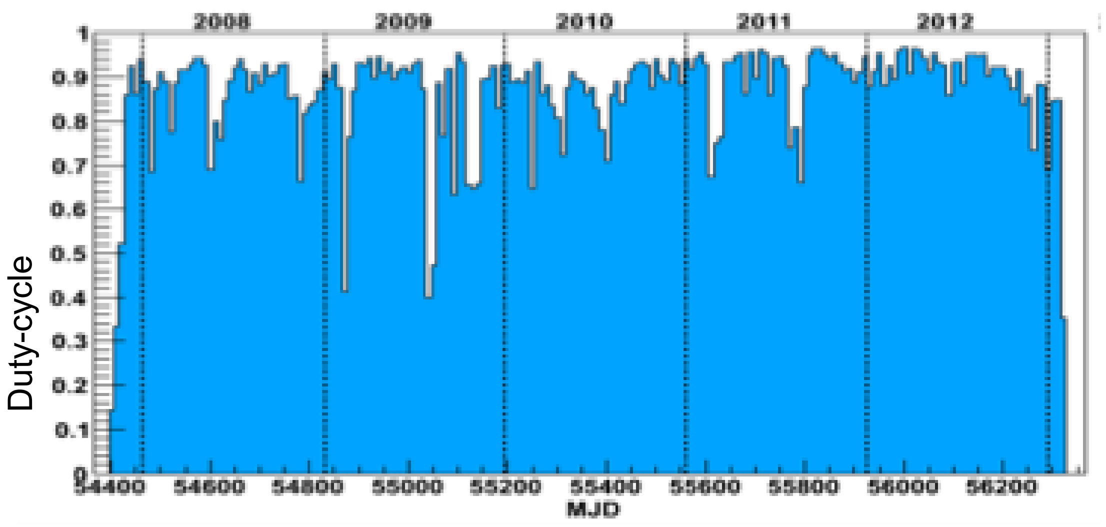
- In observation since July 2004 (with incresing portions of the detector)
- Stable data taking since November 2007
- End/Stop data taking: January 2013
- Very modest maintenance in a hostile environment
- Average duty cycle ~87% Dead time mostly due to frequent cuts of electric power
- Trigger rate ~3.5 kHz @ 20 pad threshold
- N. recorded events: ≈ $5\cdot10^{11}$ from 100 GeV to 10 PeV
- 100 TB/year data

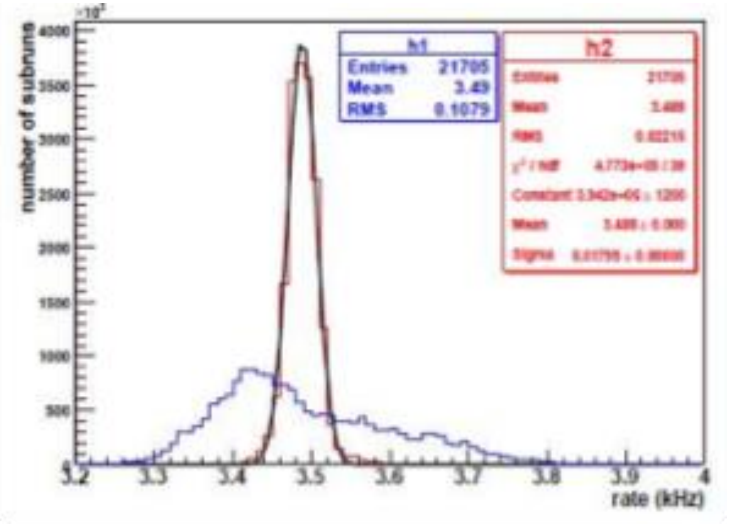




$N \approx 21 \cdot (E_{TeV}/Z)^{1.5}$

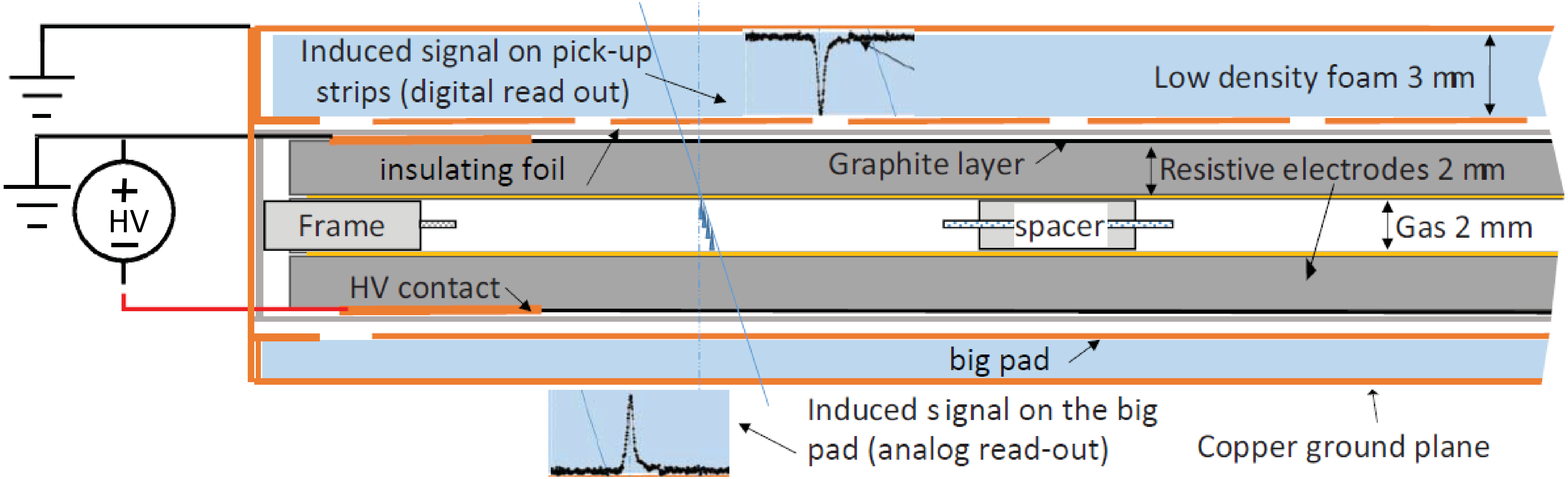
10% uncertainty estimated in the energy range 1 – 30 (TeV/Z)





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

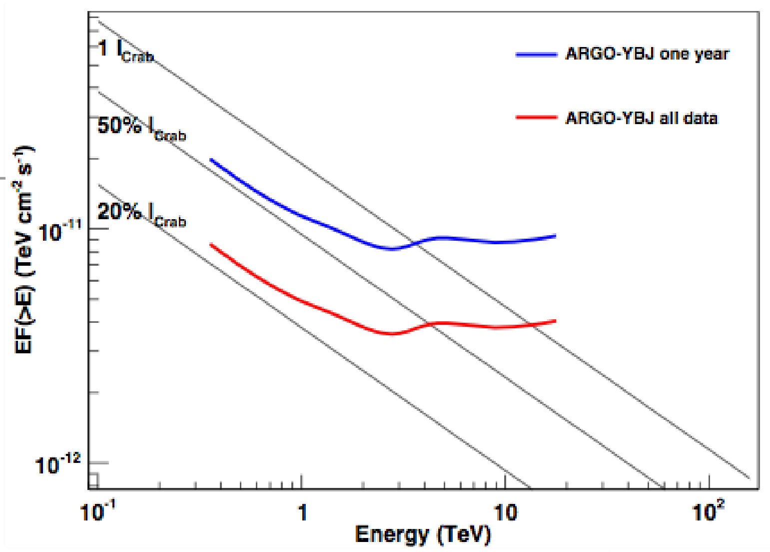
Scheme of the Argo Resistive Plate Chamber

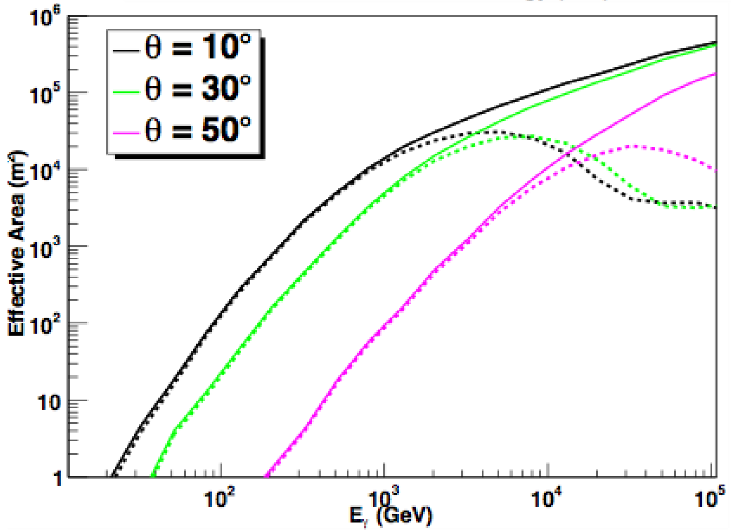


- A RPC is just a gas filled plane capacitor with high resistivity electrodes
- External signal pick up electrodes can be easily tailored with any shape
- Chamber size: 1.25x2.80 m2; Time resolution ~ 1.5 ns
- Argo gas mixture: $C_2H_2F_4/Ar/iC_4H_{10}$ = 75/15/10; Operated in Streamer Mode
- Two “big pads” of 1.25x1.40 m2 allows the analog readout

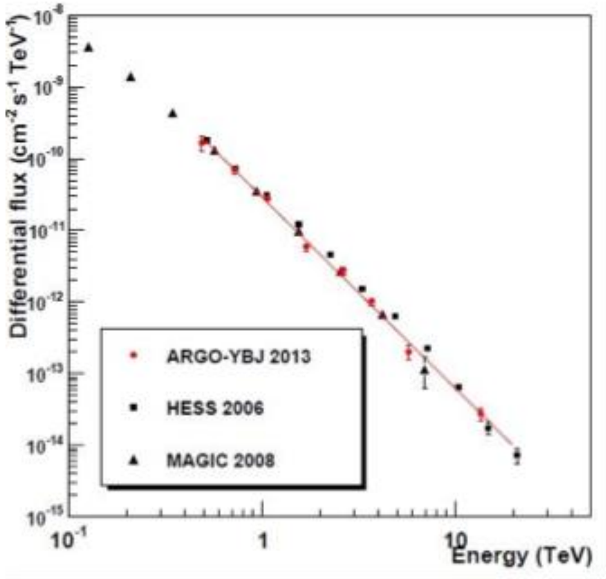
Gamma-Ray Astronomy with ARGO-YBJ

- Energy threshold: few hundreds of GeV
  → Overlaps with Cherenkov detectors
- Large duty cycle: 86%
- Large field of view: ~2 sr
- Declination band from -10° to 70°
- Integrated sensitivity in 5 y at ~1 TeV:
  0.25 Crab for dec 15° - 45°





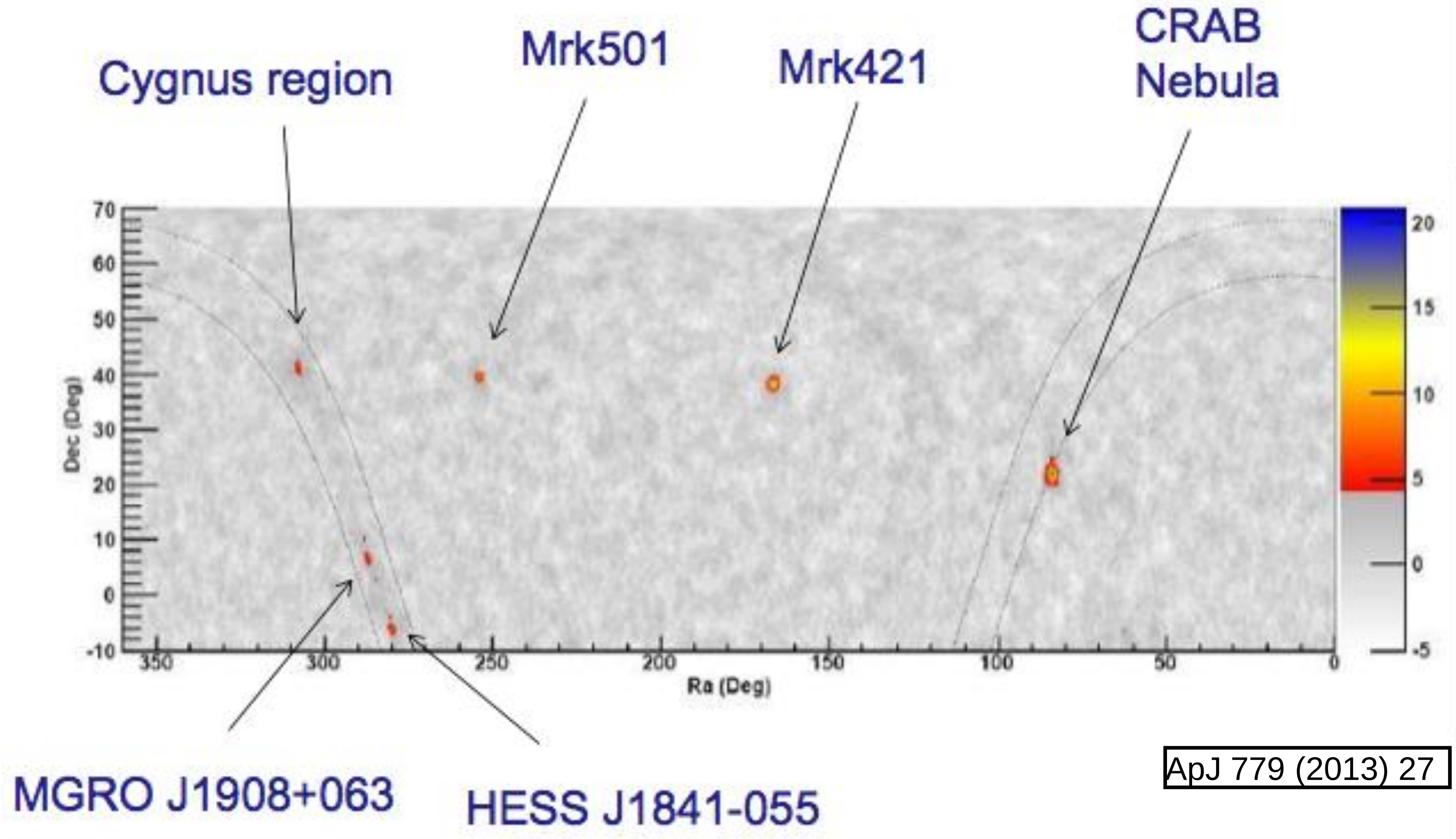
Crab Nebula 5 years data



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

Gamma-ray astronomy

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



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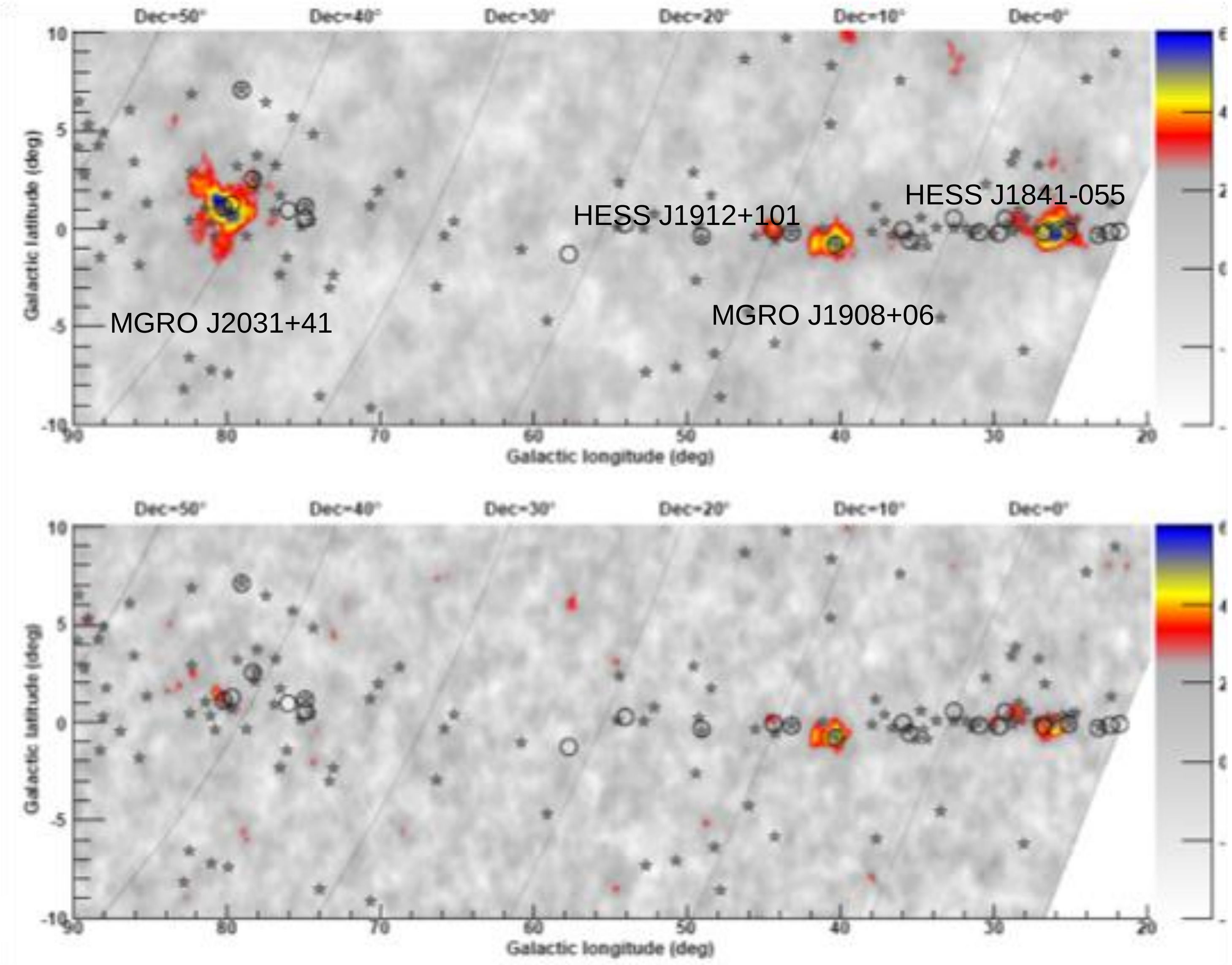
ARGO-YBJ 5-years Survey of Inner Galactic Plane

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



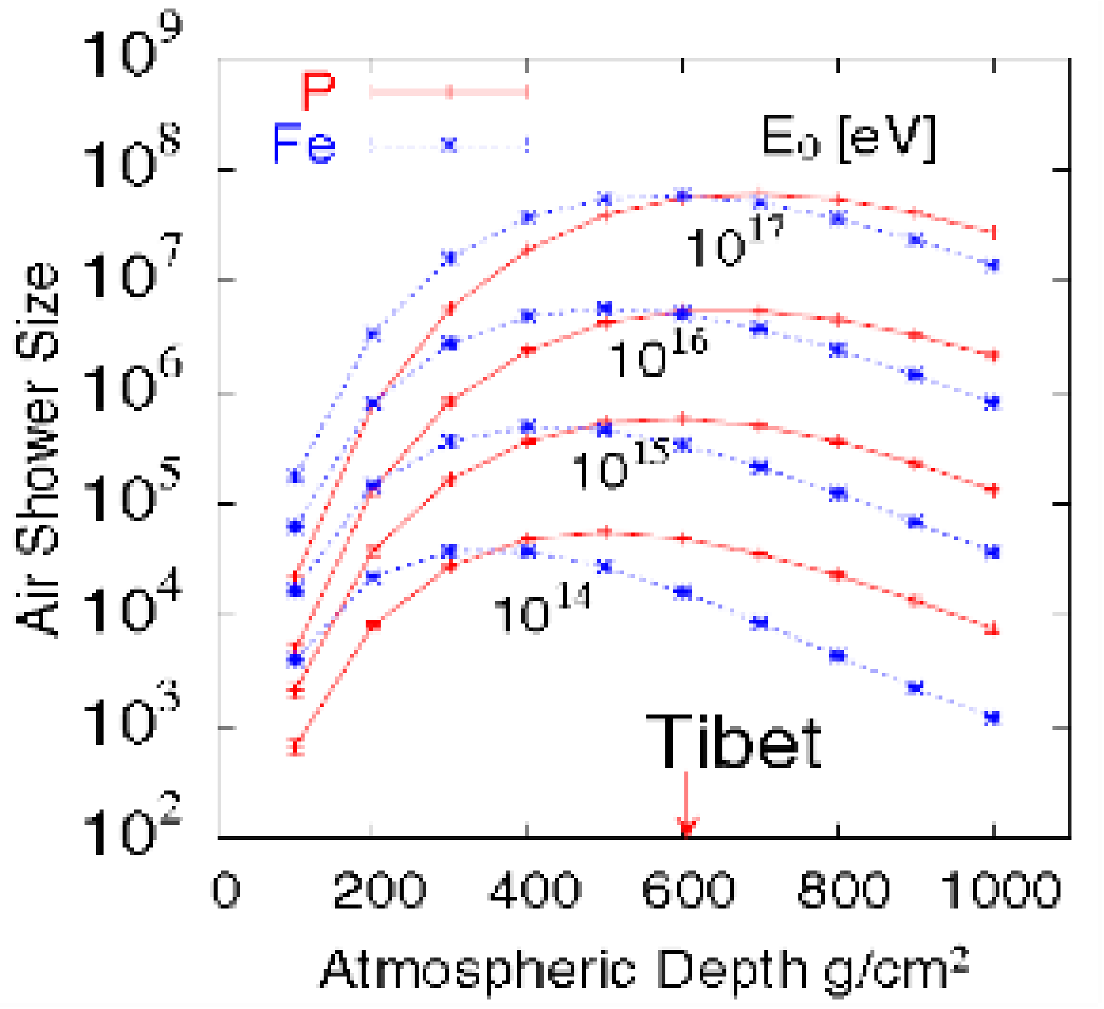
$E_{50} \approx 0.7$ TeV

$E_{50} \approx 1.8$ TeV

CR energy spectrum

- One of the most interesting Argo results concerns the measurement of the CR spectrum up to several PeV energy
- This was possible thanks to the analog readout of the signals which allowed to observe the shower core density with an unprecedented detail
- Working at high altitude (4300 m asl) offered the following advantages
    1. Small fluctuations: near the shower maximum
    2. p and Fe produce showers with similar size
    3. Low energy threshold

Absolute energy scale calibration with the Moon Shadow technique and overposition with direct measurements

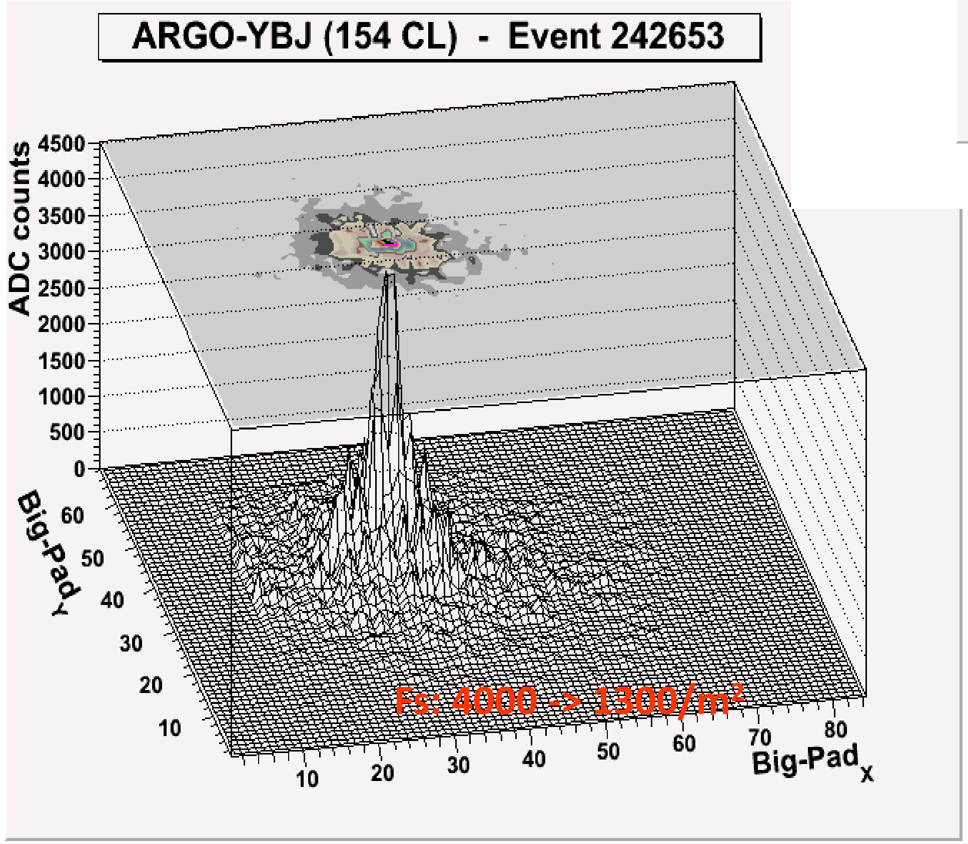


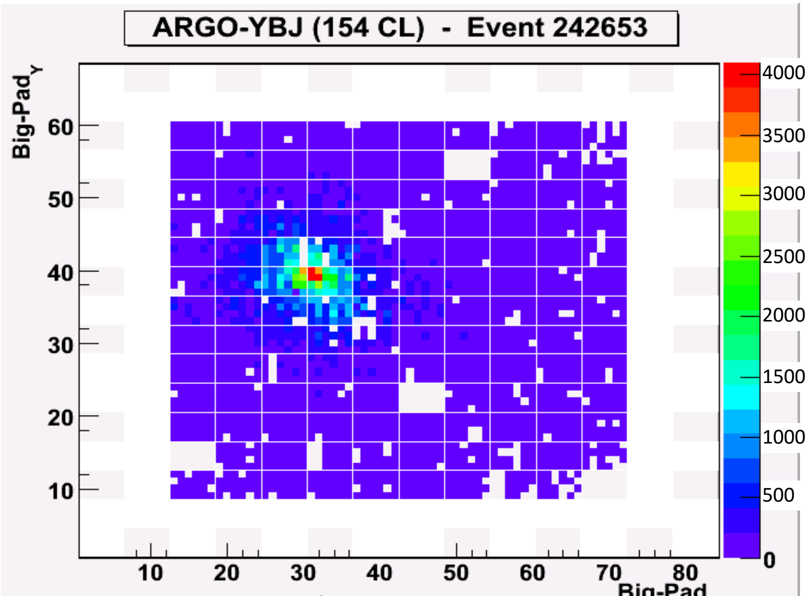
The RPC analog readout

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





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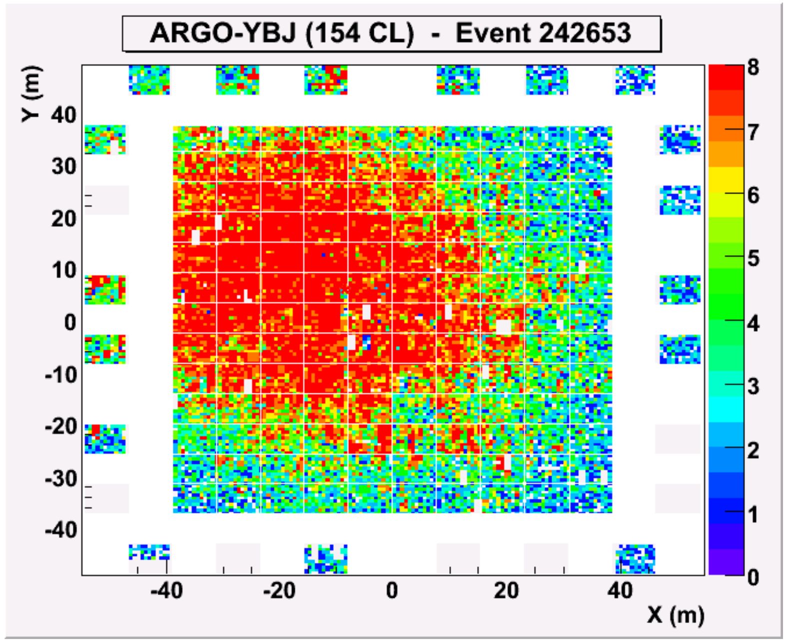
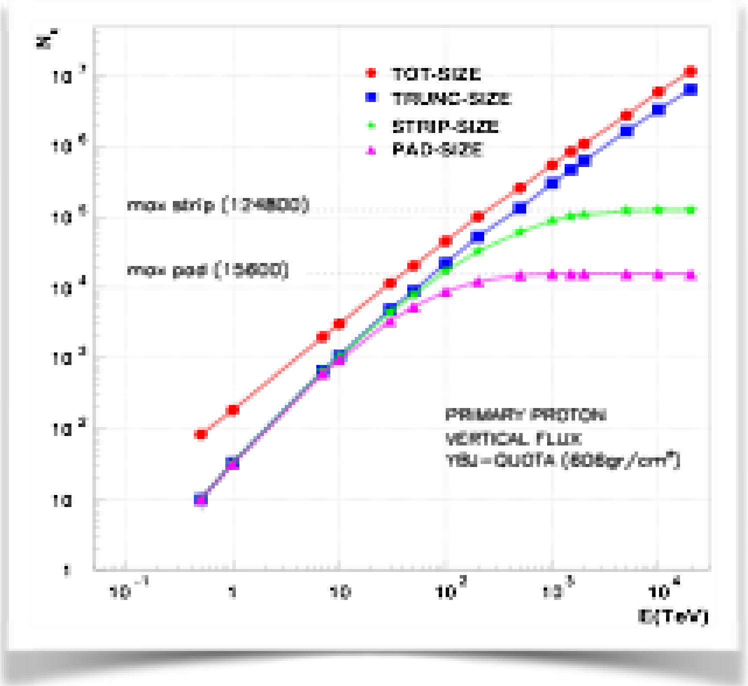
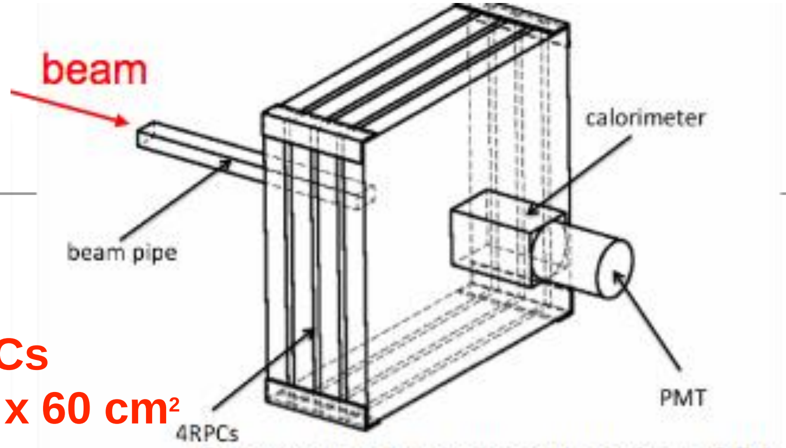




Intrinsic linearity: test at the BTF facility

Linearity of the RPC @ BTF in INFN Frascati Lab:

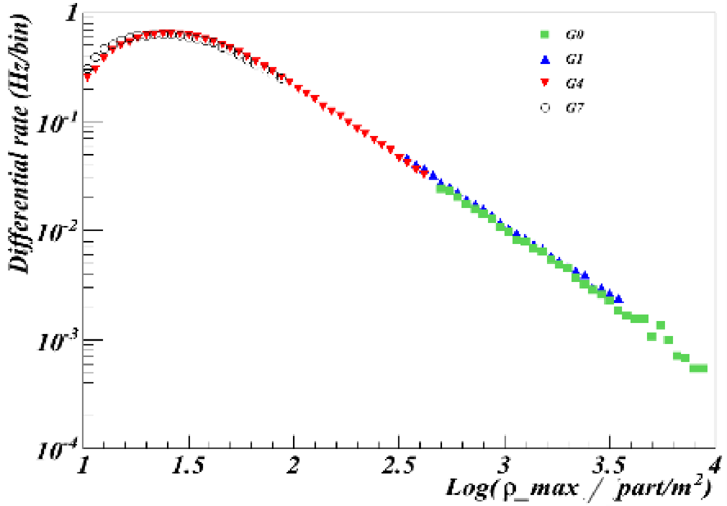
- *electrons (or positrons)*
- *E = 25-750 MeV (0.5% resolution)*
- *<N>=1÷10^{8}particles/pulse*
- *10 ns pulses, 1-49 Hz*
- *beam spot uniform on 3$\times$5 cm*



4 RPCs 60 x 60 cm^2

Calorimeter: lead glass block from OPAL, PMT a Hamamatsu R2238.

Good overlap between 4 scales with the maximum density of the showers spanning over three decades



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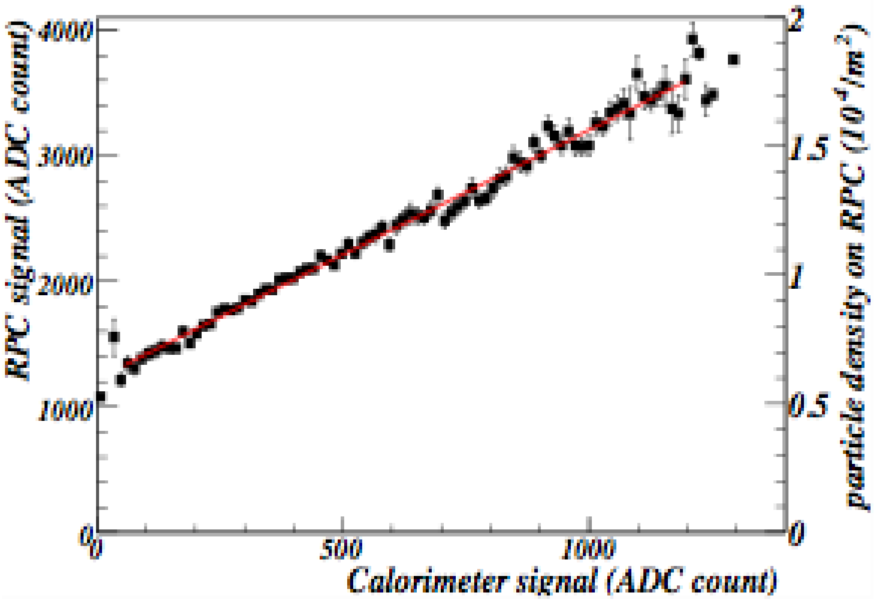
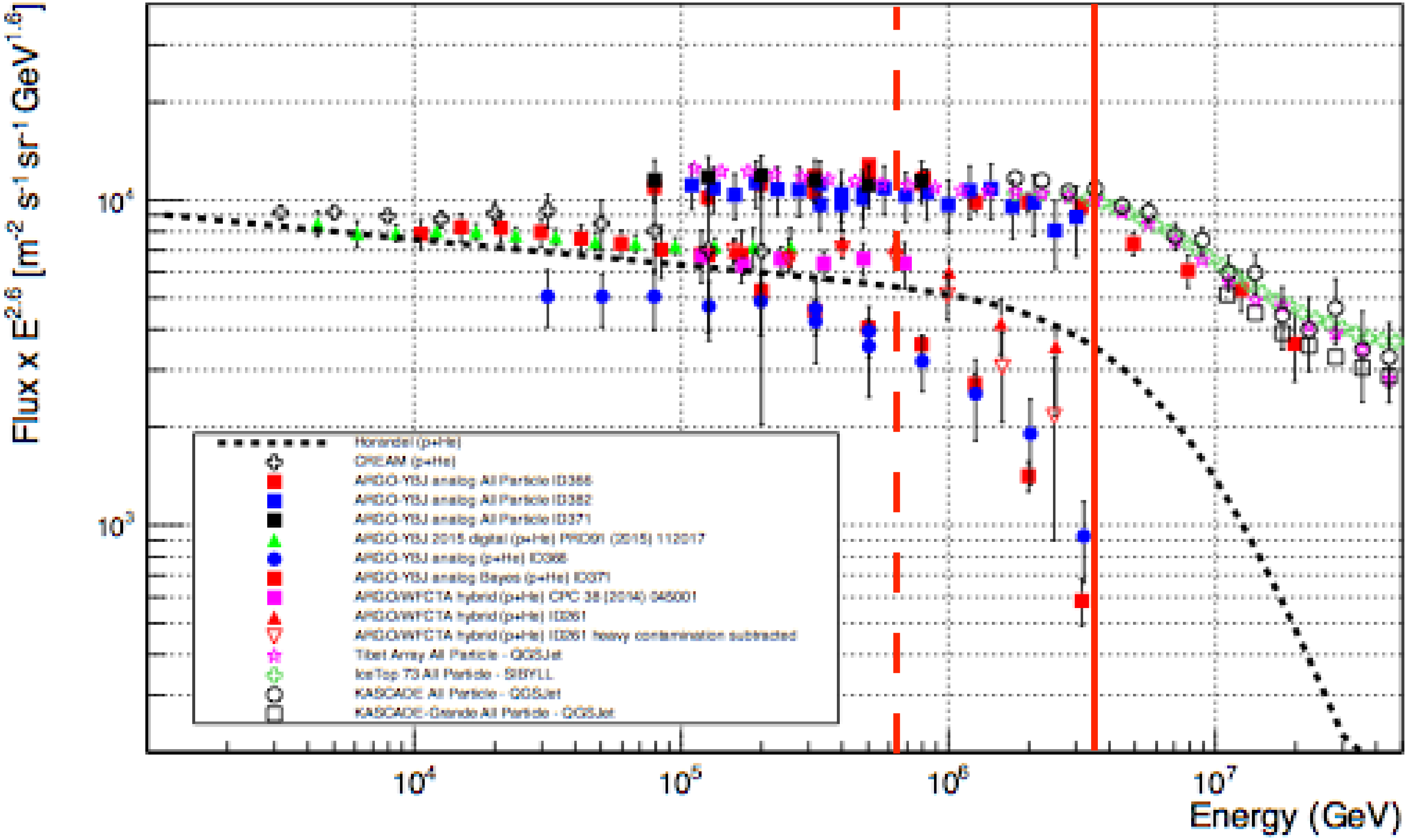
The RPC signal vs the calorimeter signal



➔ Linearity up to ≈ 2 · 10^4 particle/m^2

Light component (3 TeV - 5 PeV) and all particles spectrum



A look to the future: motivation for a Southern experiment

- The results of 5 years running with Argo suggest that this approach to the ground based CR detection is very promising and should continue with a second generation experiment
- Moreover, 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
- There are strong reasons for a Southern Experiment
  - **Southern sky is extremely rich and important for astrophysics**
  - No large-FOV TeV experiments in the South
  - Good opportunity today for an ambitious project in the South based on the convergence of different groups.
- The collaboration LATTES (Brasil, Portugal…) is already proposing an RPC Cosmic Ray detector to be located in a high altitude site in the South hemisphere

Southern TeV Astrophysics & Cosmic Rays Experiment: STACEX

A Wide FoV Detector for Gamma-Ray Astrophysics in the Range 100 GeV - 10 TeV in the Southern Hemisphere

G. Di Sciascio, R. Santonico, M. Tavani

March 9, 2015

Abstract

We present the concept of a new wide-FoV high-altitude detector in the Southern hemisphere dedicated to gamma-ray astronomy in the range 100 GeV - 10 TeV. The new instrument is based on large-area particle detectors (Resistive Plate Chambers, RPCs) already tested and implemented in the ARGO shower array experiment. The new experiment will have a sensitivity better than 10% Crab Nebula flux per year at 100 GeV with a very good angular resolution. It will be unique and complementary to CTA-South

Upgrades suggested by the Argo experience in view of a future experiment:

The results of Argo in gamma ray astronomy and CR physics were achieved with a **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 substantially **increase the number of detected shower particle**

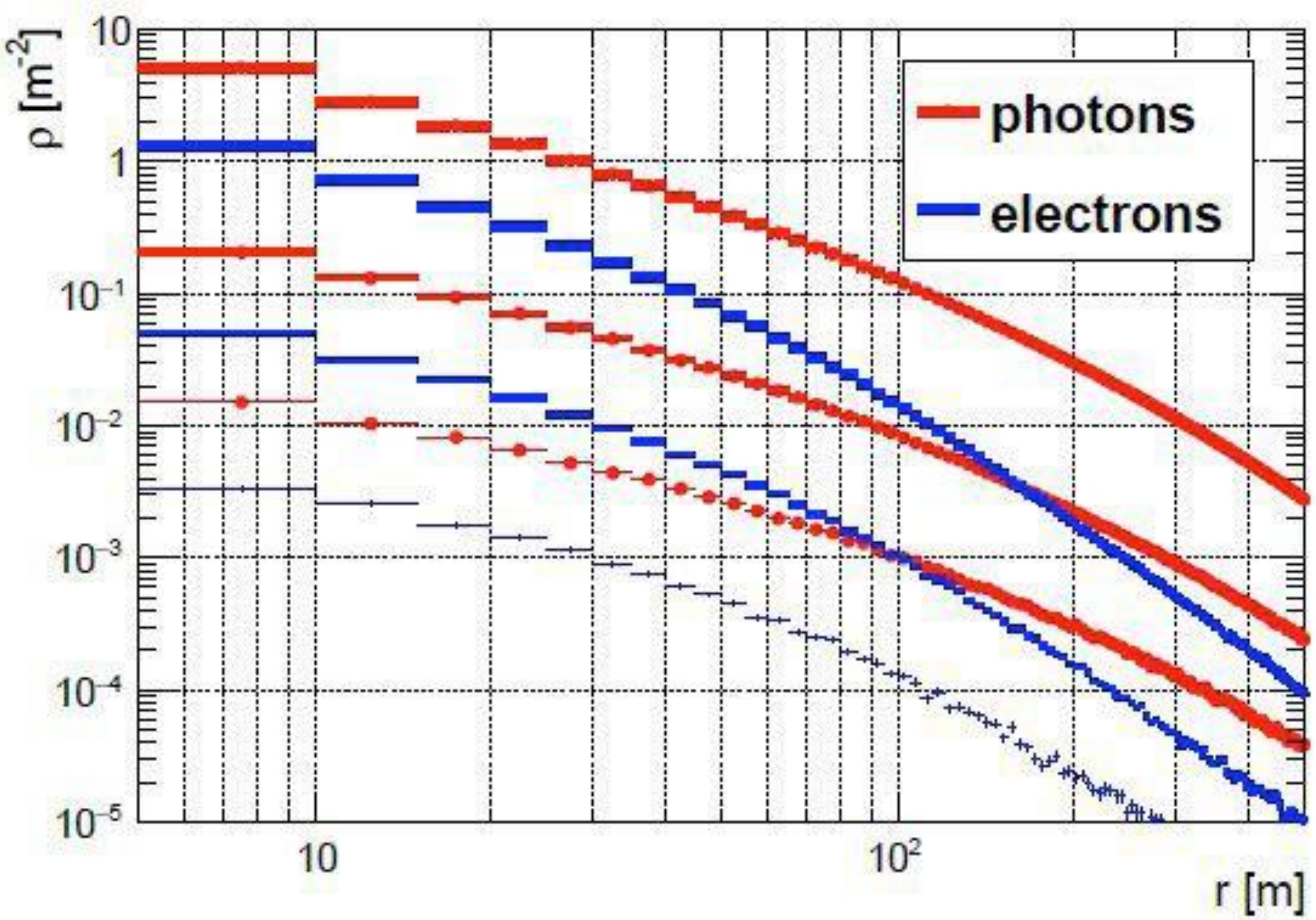
Primary photons of 100 GeV, 500 GeV and 5 TeV at 5000 m asl

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

6 part/m²

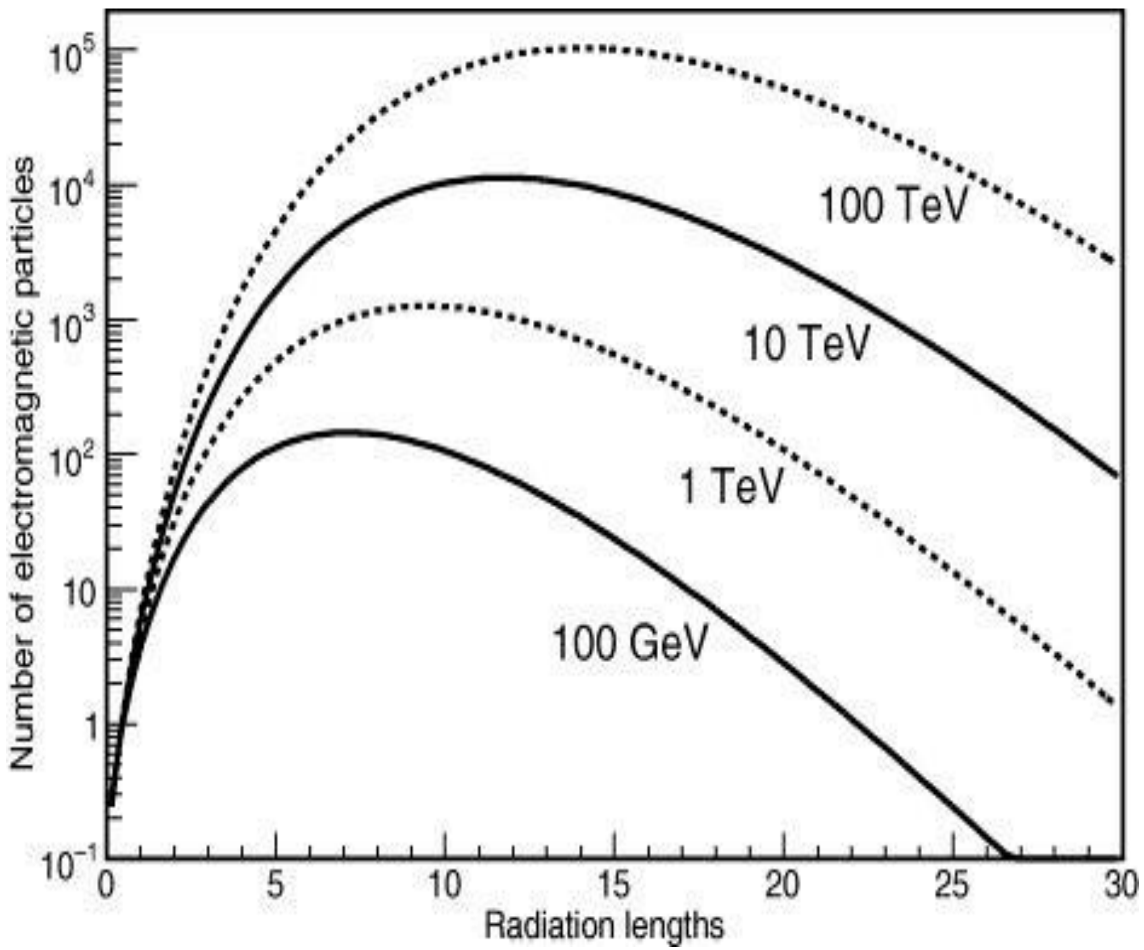
0.3 part/m²

0.02 part/m²



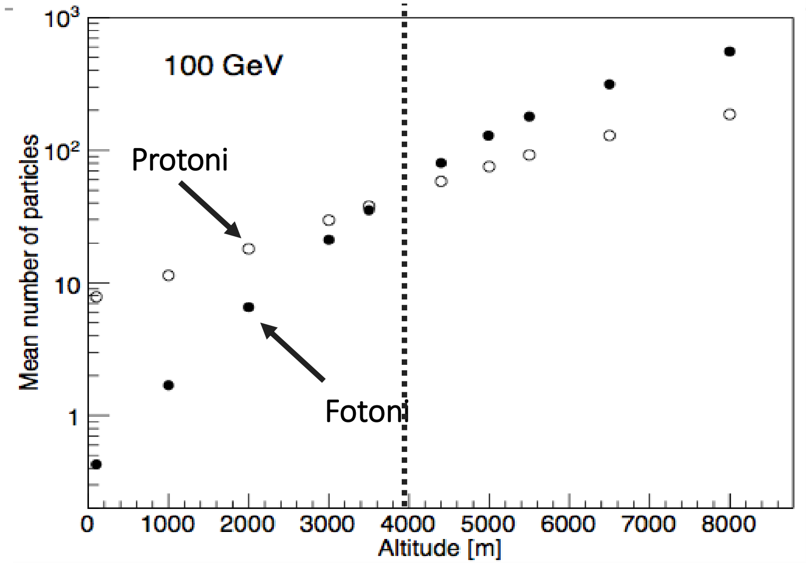
Upgrades:

Operation at higher altitudes



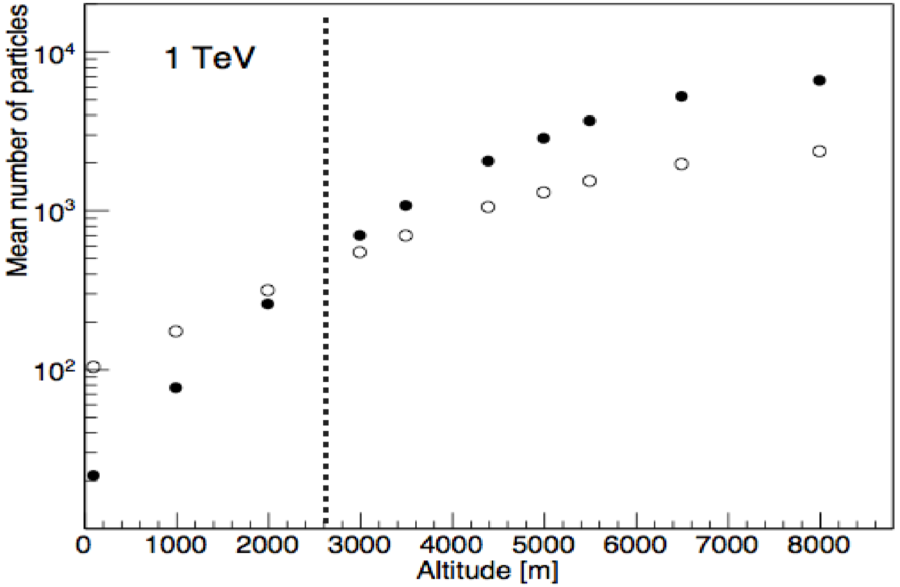
- Operating at higher altitudes, ~5000 m, would be a further important advantage, mainly for low energy photons
- Extrapolation **from 4300 m (YBJ-lab) to 5000 m** (about -1.4 X_0) gives an **increase of almost a factor of 2 for the number of particles** produced by a 100 GeV primary photon

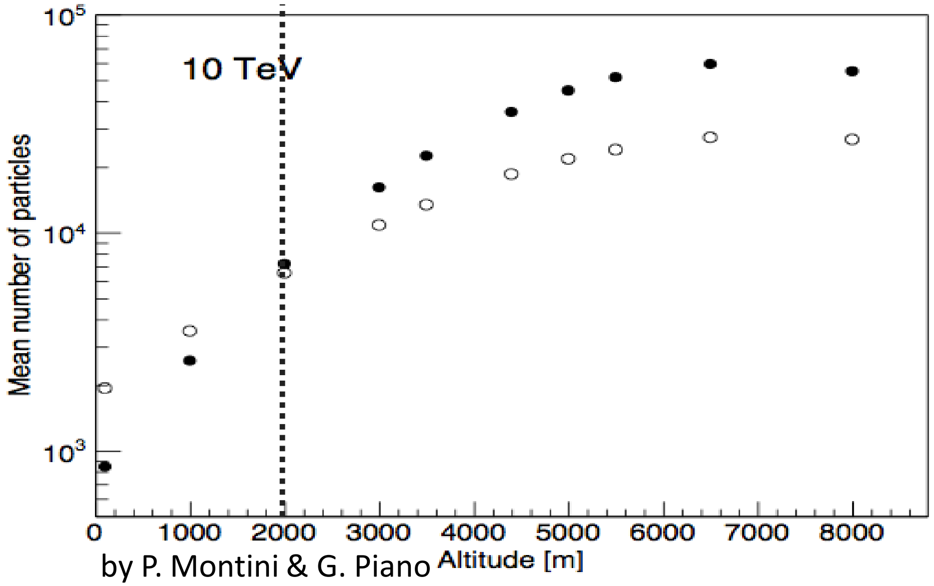
Proton vs Photon showers at different altitudes



Started discussions about different ideas for new experiment at higher altitude.
The goal is to lower the energy threshold in the 100 GeV range:

HAWC-South
LATTES: RPCs + water Cherenkov
STACEX: layers of RPCs
ALPACA: scintilator array + water pond





by P. Montini & G. Piano

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
  - Pick up electrodes of e.g. 20x20 cm^2, equipped with 1 TDC + 1 ADC per pad would substantially improve the amount of information
- Avalanche mode operation (Argo was operated in streamer)
  - 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
  - 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 solution avoiding 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

Upgrades:
the gas system (3)

- 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

Ideas about a future detector. Summary

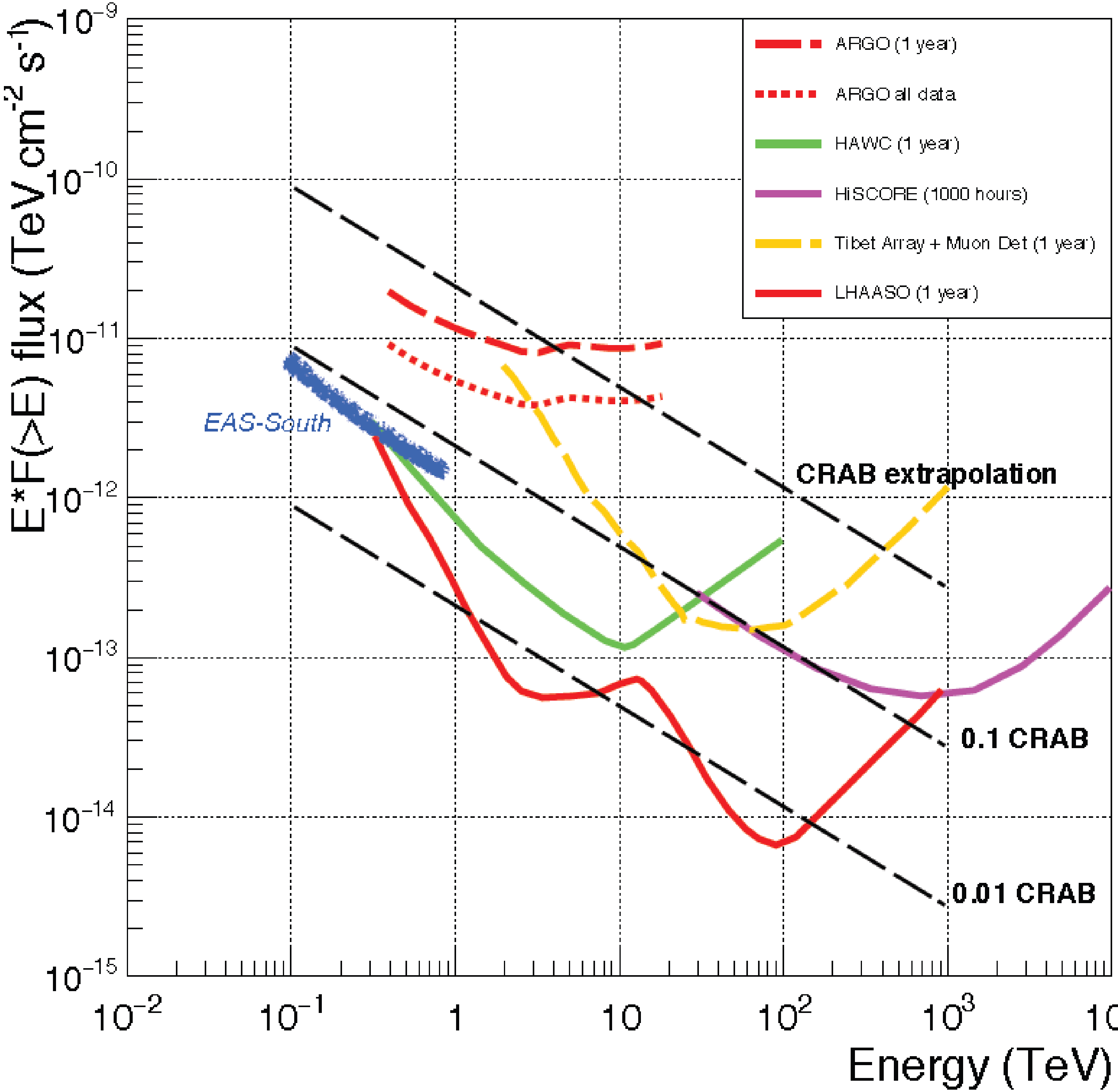
- Lay out
  - A central carpet 120x120 m^2 hosted inside a very light and cheap building
  - Surrounded by a sampling array of similar sensitive area but spread on an area some 10 times larger. Some experience has been already achieved on the “outside door” RPC operation
- Read out
  - Fully analog read out with pads of area about 20x20 cm^2
  - “big pads” of about 1 m2 for very high multiplicities
  - New front end full custom circuit integrating the time and amplitude digitization
- RPC operation
  - Avalanche mode with
  - Gas properly chosen for avalanche operation
- Gas system
  - Closed loop with a few volumes/day flux inside door
  - Open loop outside door with minimal gas supply (to be checked)
- Altitude: > 5000 m

The challenge of 100 GeV threshold and the site choice

- It is a big challenge requiring a careful evaluation of all parameters determining the detector sensitivity
- The laboratory altitude is, to some extent, the most important parameter fto detect low energy gammas. Evaluate:
  - The human limits: → to be included in the project optimization like other technological parameters
  - Strong requirements on the technology to minimize the permanence of the personnel at the experiment site.
  - A support laboratoty close to the experiment but lovcated at lower level would be very important for the final testing of the modules before installation. Local manpower might be crucial in the set up of the experiment.

Argo-Stacex comparison

	Argo:
• STACEX site: **5000 m altitude or more.**	4300 m
• RPC detectors eventually with Pb;	no Pb
• Area: **14,000 m^2** (full coverage); surrounded by a comparable sampling array	6000 m^2 full cov + 1000 m^2 guardring
• Energy ranges:	
• Photons: **100 GeV – > 20 TeV**	300 GeV – 10 TeV
• CRs: **300 GeV – 20 PeV**	600 GeV – 5/10 PeV
• 1-year gamma-ray sensitivity (@ 1 TeV): **50 mCrab**	½ Crab



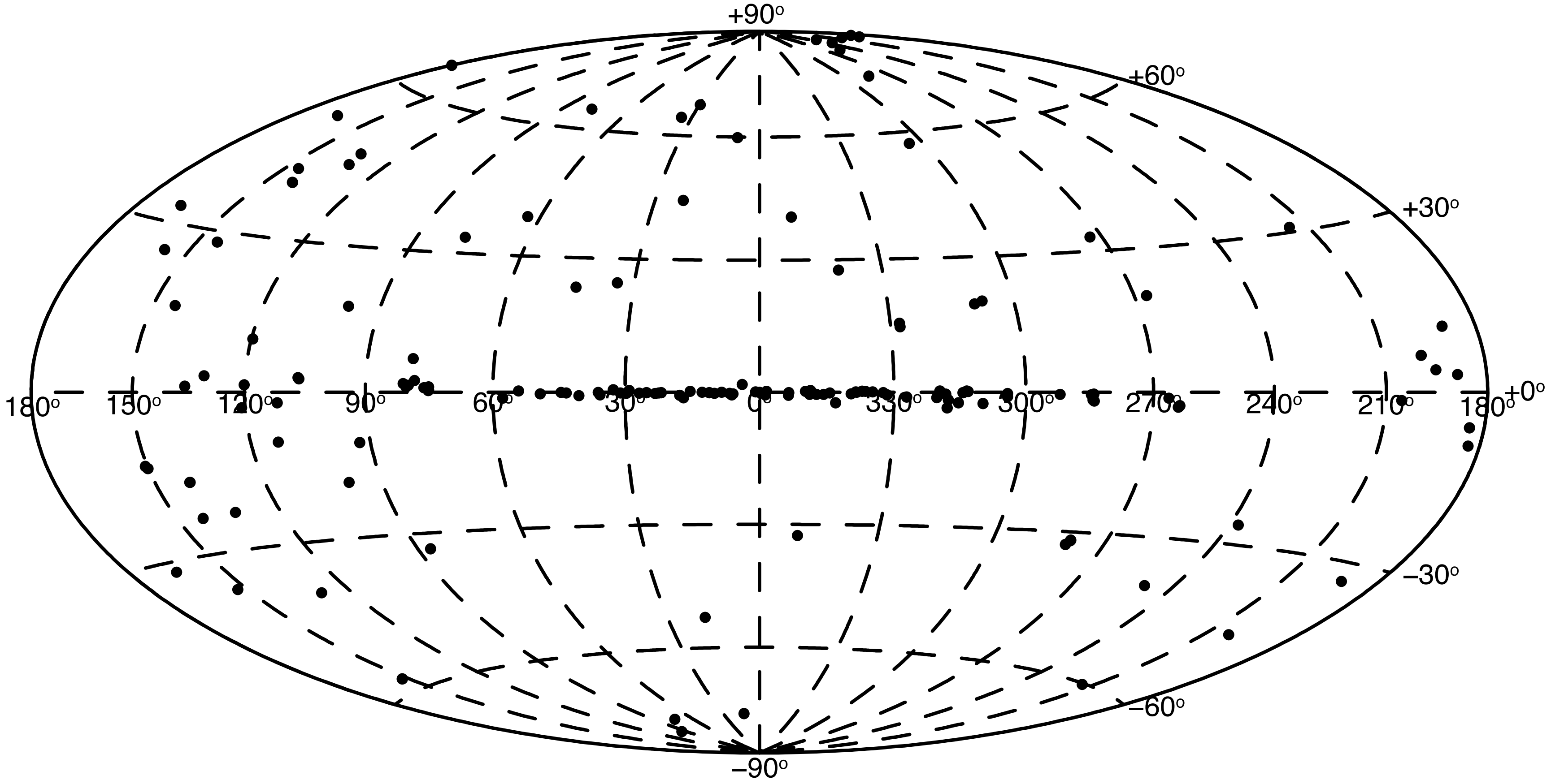
ARGO (1 year)
ARGO all data
HAWC (1 year)
HiSCORE (1000 hours)
Tibet Array + Muon Det (1 year)
LHAASO (1 year)
EAS-South
CRAB extrapolation
0.1 CRAB
0.01 CRAB
E*F(>E) flux (TeV cm^{-2} s^{-1})
Energy (TeV)
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}

Recent results from Fermi at Energies E > 50 GeV confirm the importance of a low energy threshold

The VHE sky (IACTs)

F > ~ 10 mC.U.

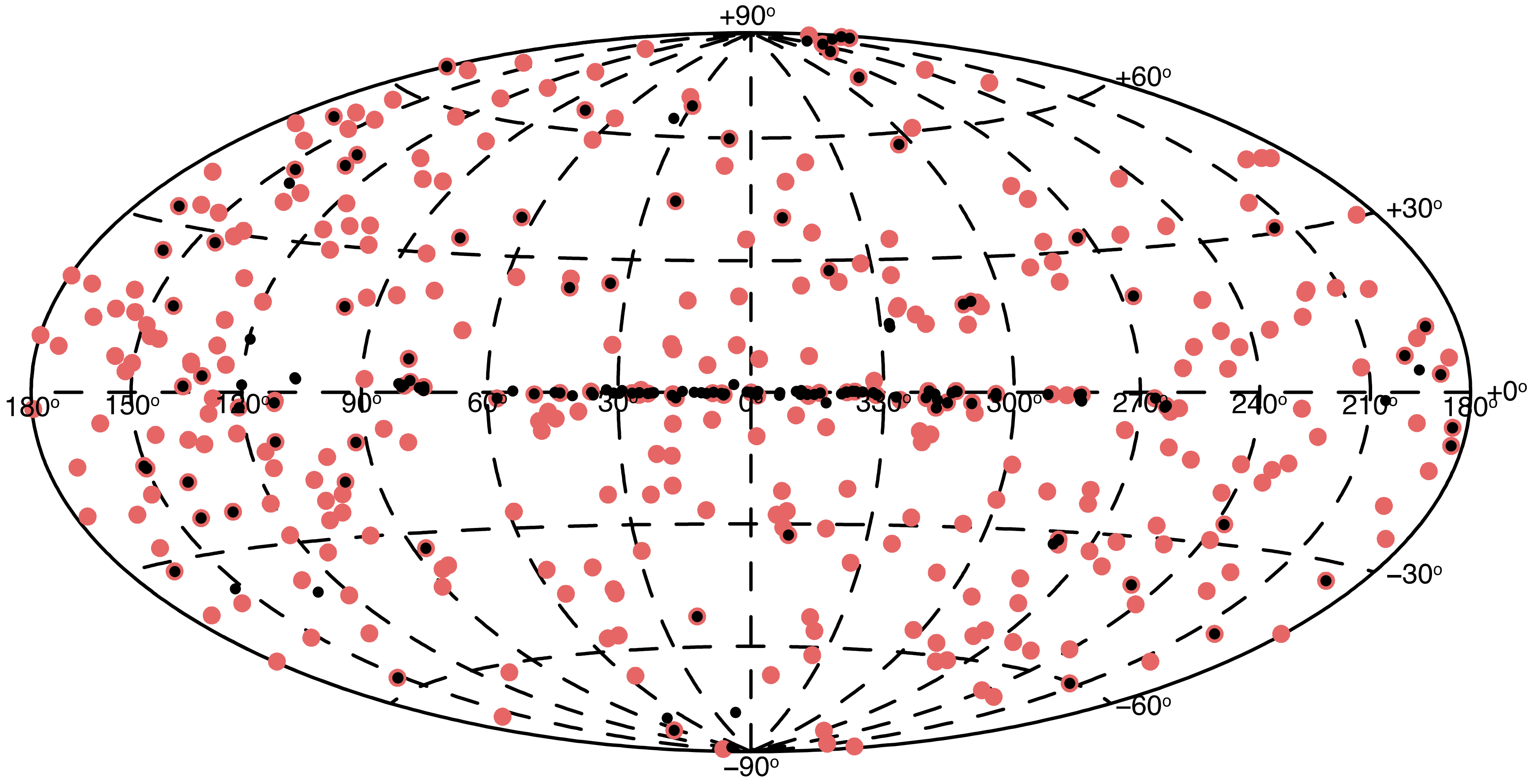
TeV sources (HESS, MAGIC, VERITAS) (courtesy of P. Giommi)



The VHE sky (IACTs+Fermi 2FHL)

F > ~ 10 mC.U. F > ~ 10 mC.U.

E > 50 GeV sources (Fermi-LAT, 2FHL)
(courtesy of P. Giommi)



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 will offer a relevant discovery potential
- A RPC wide FoV gamma-ray detector, in the energy range 100 GeV-20 TeV, located in the Southern Hemisphere, would be unique and complementary to other experiments planned to take data in the next decade
- The experience of Argo has clearly identified a list of improvements for a future experiment: higher altitude site, increased area, addition of a photon converter, RPC avalanche mode operation with improved timing and **fully analog read out achievable with a new front end electronic**
- Two collaborations, Lattes, Stacex, are already considering this possibility. A common proposal can create a very ambitious project with a large international participation
- Several collaboration items can be found even in the short-middle term: computer simulation, site choice and preparation of a pilot test to be performed in the chosen site