The Pierre Auger Observatory Enhancements

Carla Bonifazi for the Pierre Auger Observatory

3rd Roma International Conference on Astro-particle Physics

Pierre Auger Observatory

The collaboration

~ 400 scientists ~ 90 institutions from 19 countries

The experiment

Large aperture > 7000 km^2 sr @10^{19} eV

Uniform exposure

Angular resolution ~1° @ 10^{19} eV

Calorimetric calibration in energy

Primary particle discrimination (light, heavy, γ, ν)

Data taking since Jan 2004

Construction completed in mid 2008

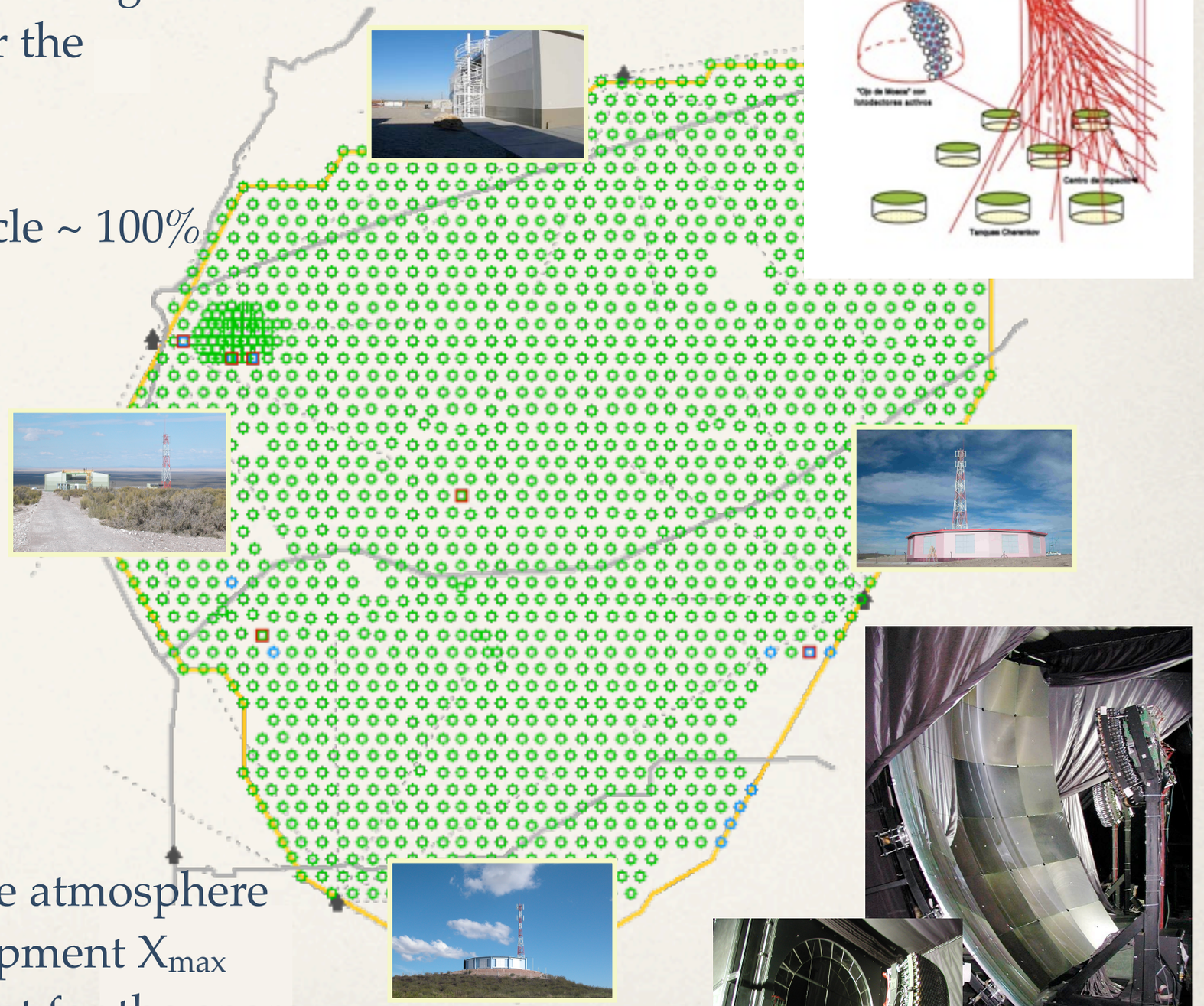
"To make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side"

V.H.Hess, Nobel lecture, December 1936

The hybrid concept

Surface Detector (SD)

- Lateral distribution of the particles on ground
- Energy estimator + correction for the attenuation in the atmosphere
- Calibration with the FD energy
- Total area of 3000 km^2 – Duty cycle ~ 100%



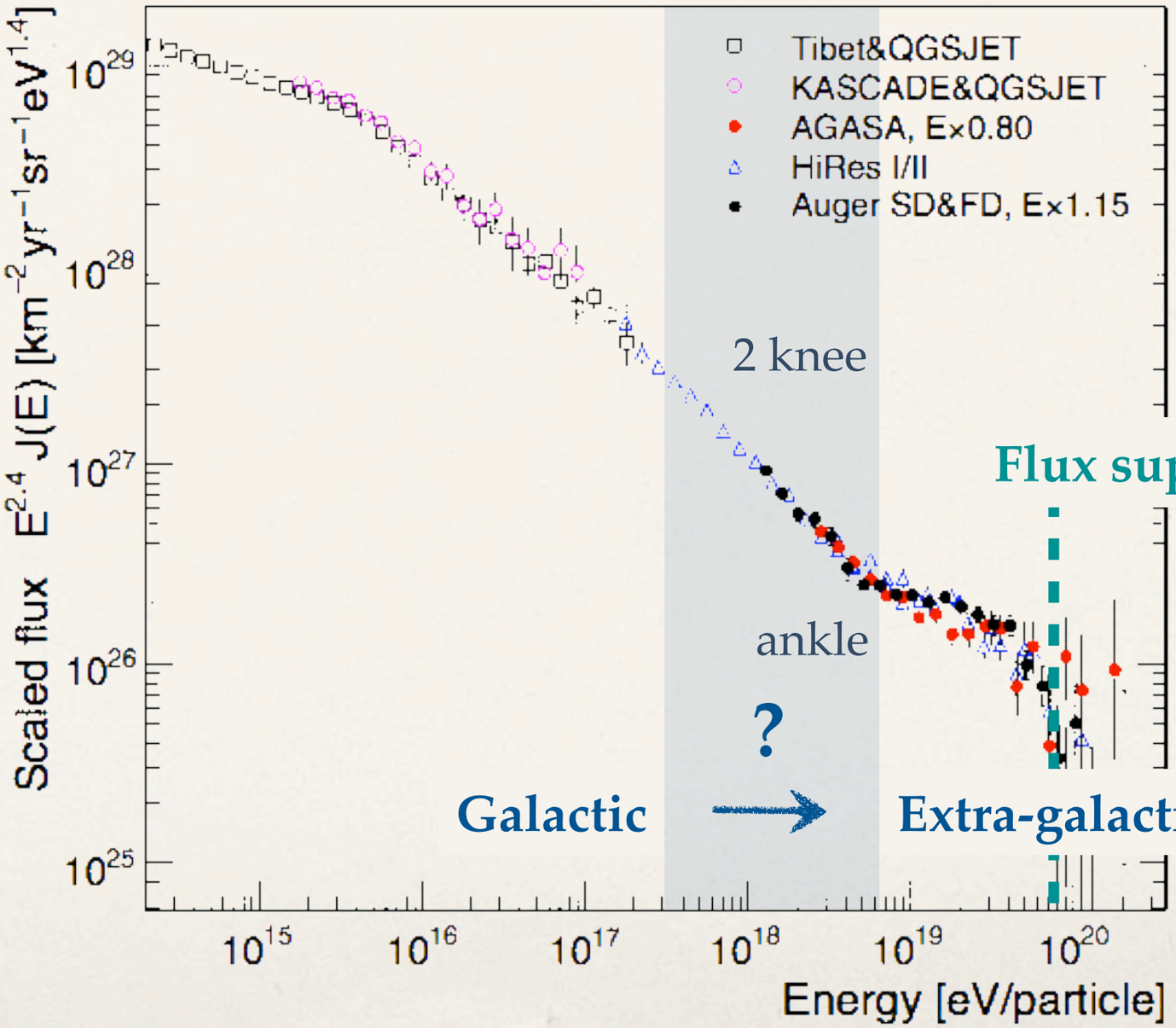
Fluorescence Detector (FD)

- Longitudinal development in the atmosphere
- Maximum of the shower development X_{max}
- Almost calorimetric measurement for the energy
- Duty cycle ~ 10%

Current knowledge...

Spectral features:

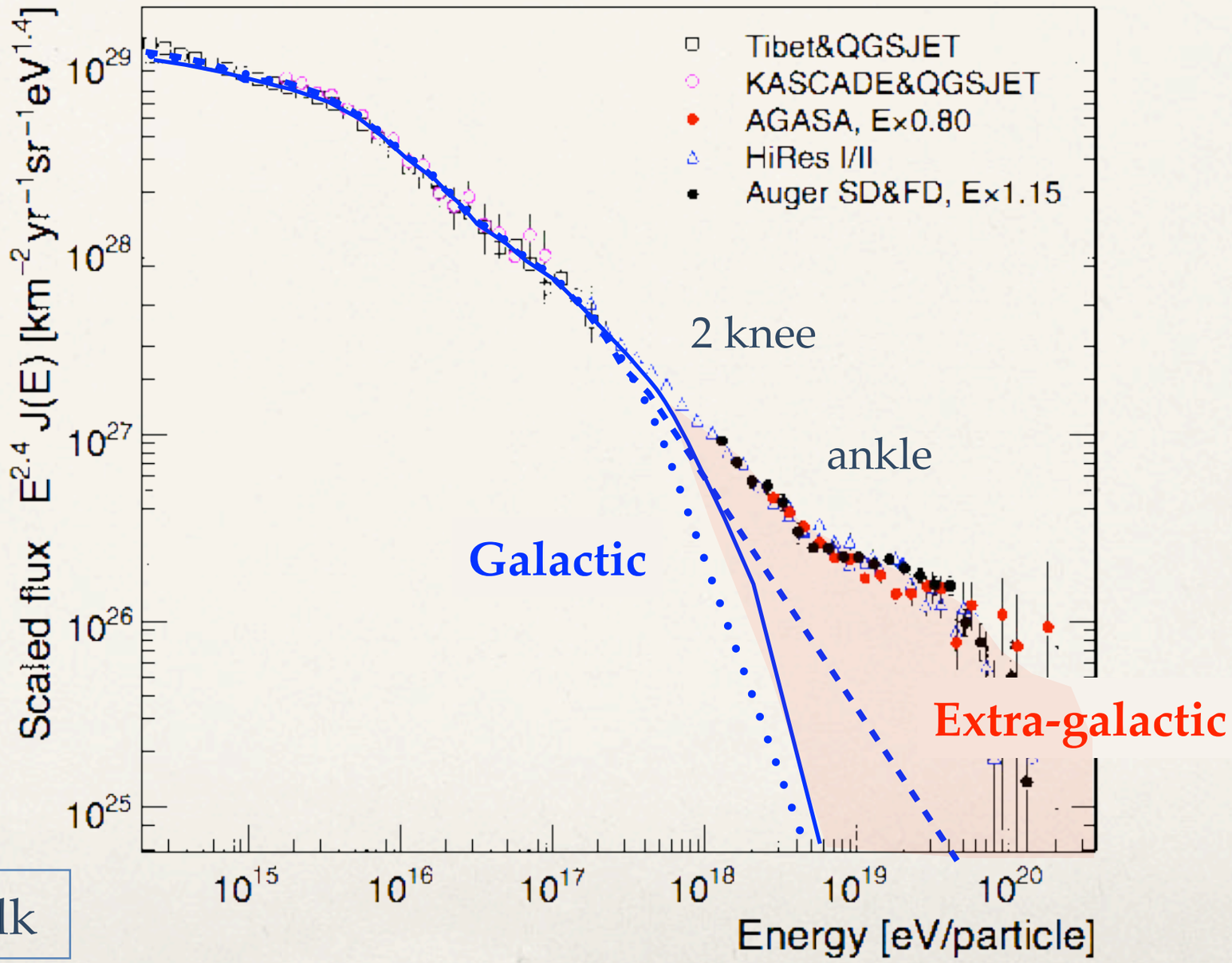
Acceleration or propagation effects?



Current knowledge...

Several models can fit the spectrum

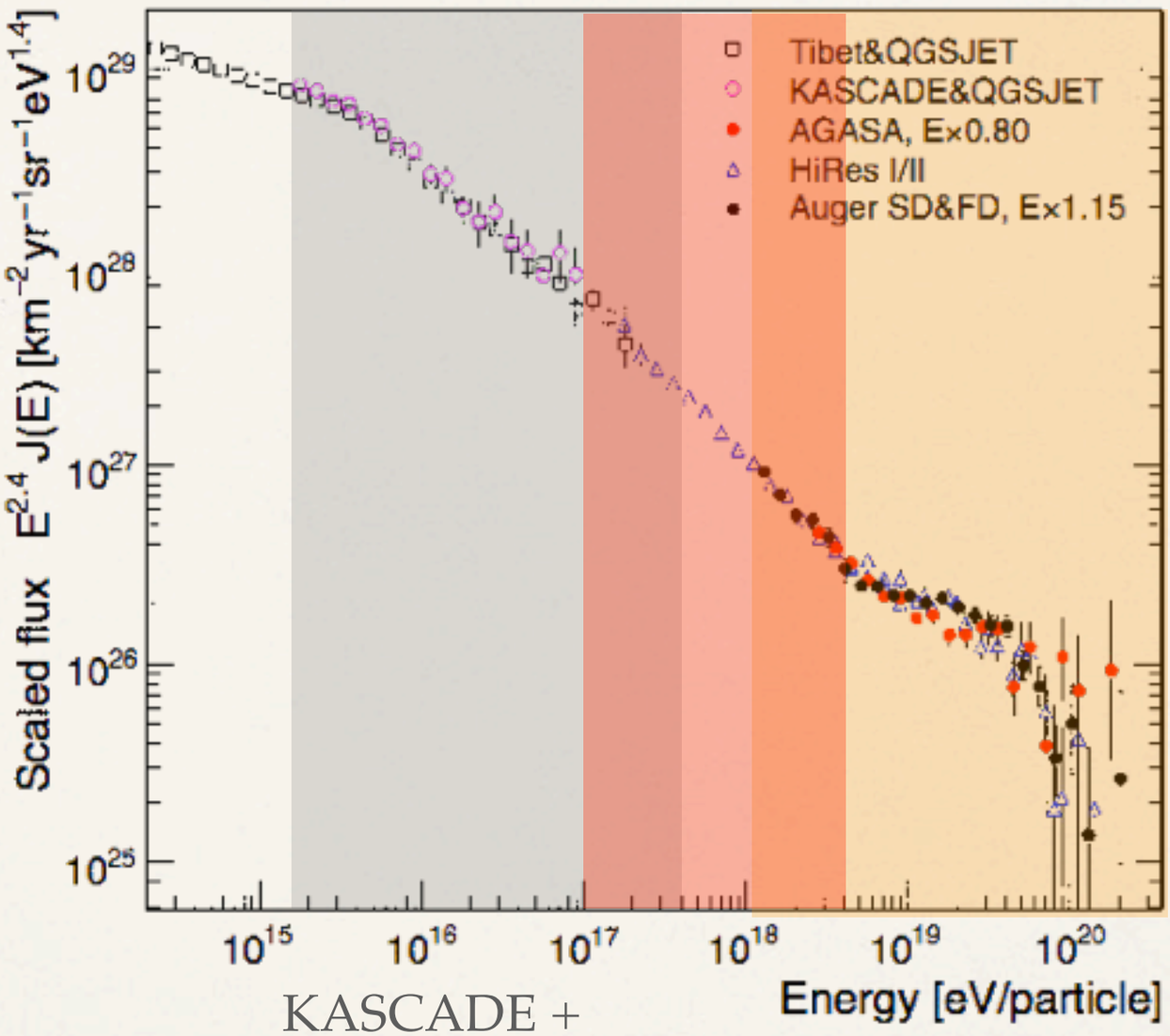
Mass composition measurement **required** !



See Raffaella's talk

Enhancements: low energy

HEAT / AMIGA AUGER

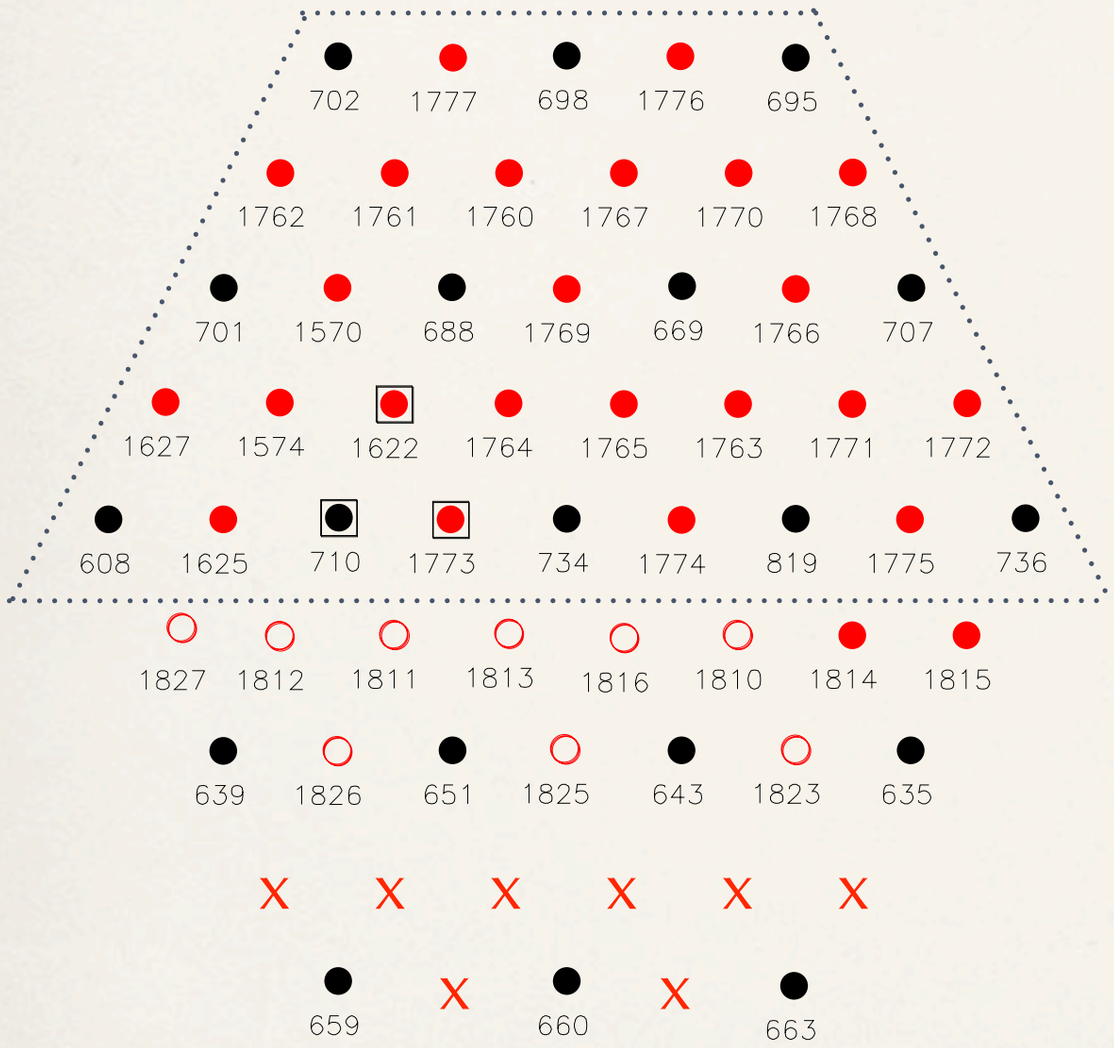


KASCADE +
K-GRANDE

Auger extensions:

61 infill stations at 750 m spacing + muon counters (AMIGA)
3 additional telescopes with extended field of view (HEAT)

AMIGA
Auger Muons & Infill for the Ground Array



- ● 1500 m grid stations
- ● 750 m grid stations (infill stations)
- ○ infill stations just installed
- □ associated muon detectors
- X 8 missing infill stations

Total area: 23.5 km^2

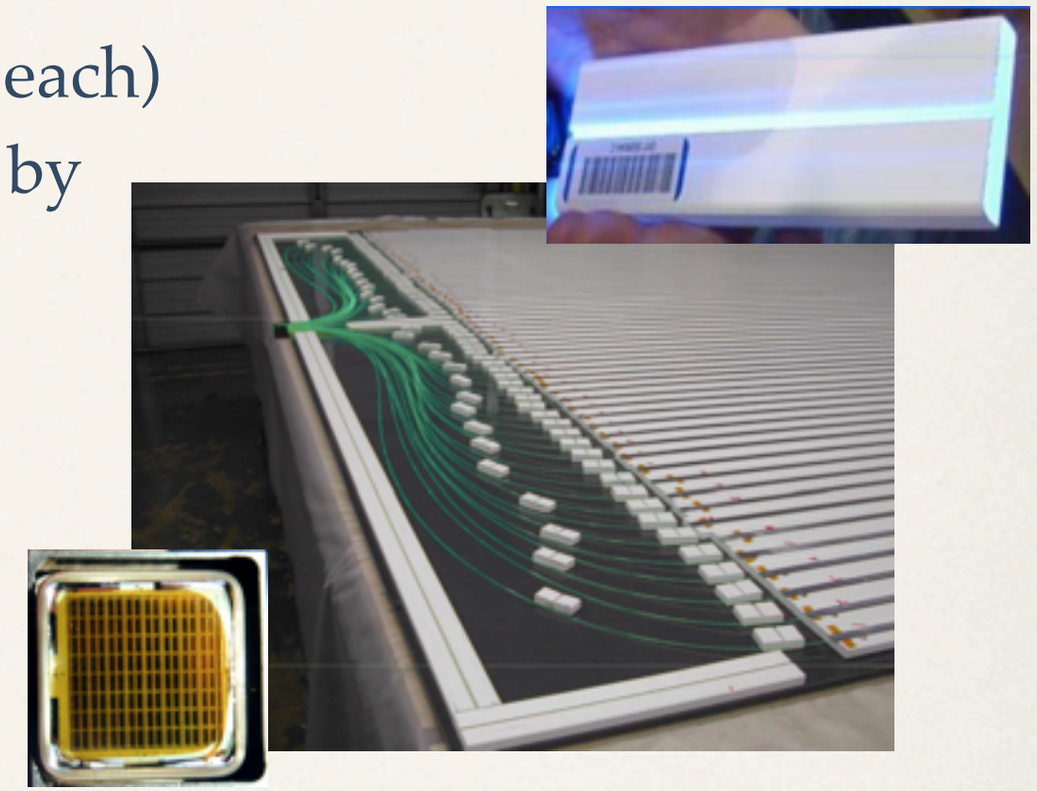
Near future:
+24 stations in a 433 m grid ~ 5.9 km^2

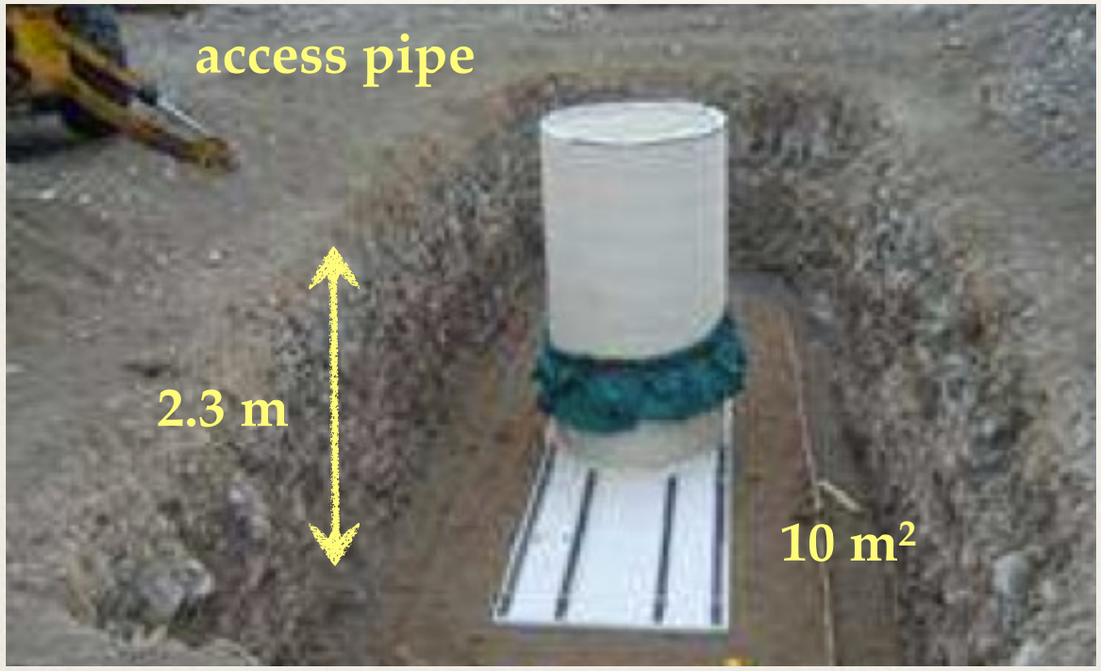
Data taking since August 2008

Water Cherenkov detectors: electromagnetic component + muons
Muon detectors: muons

AMIGA
Auger Muons & Infill for the Ground Array

- 30 m^2 muon counters (3 modules of 10 m^2 each)
- Each module contains 64 strips connected by optic fiber to a 64 multi-anode PMT
- Buried 2.3 m underground
- Muons with energy to cross > 540 g/cm^2





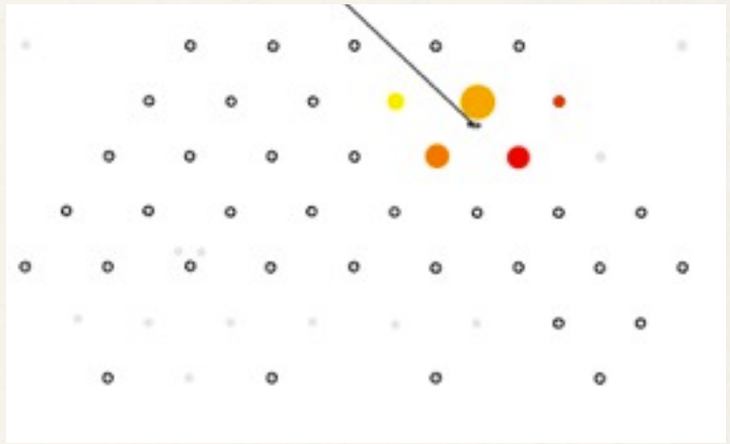
- Each muon counter is triggered by its associated surface detector
- Muon signal sample at 320 MHz
- Digital logical signal above the threshold

Infill event example

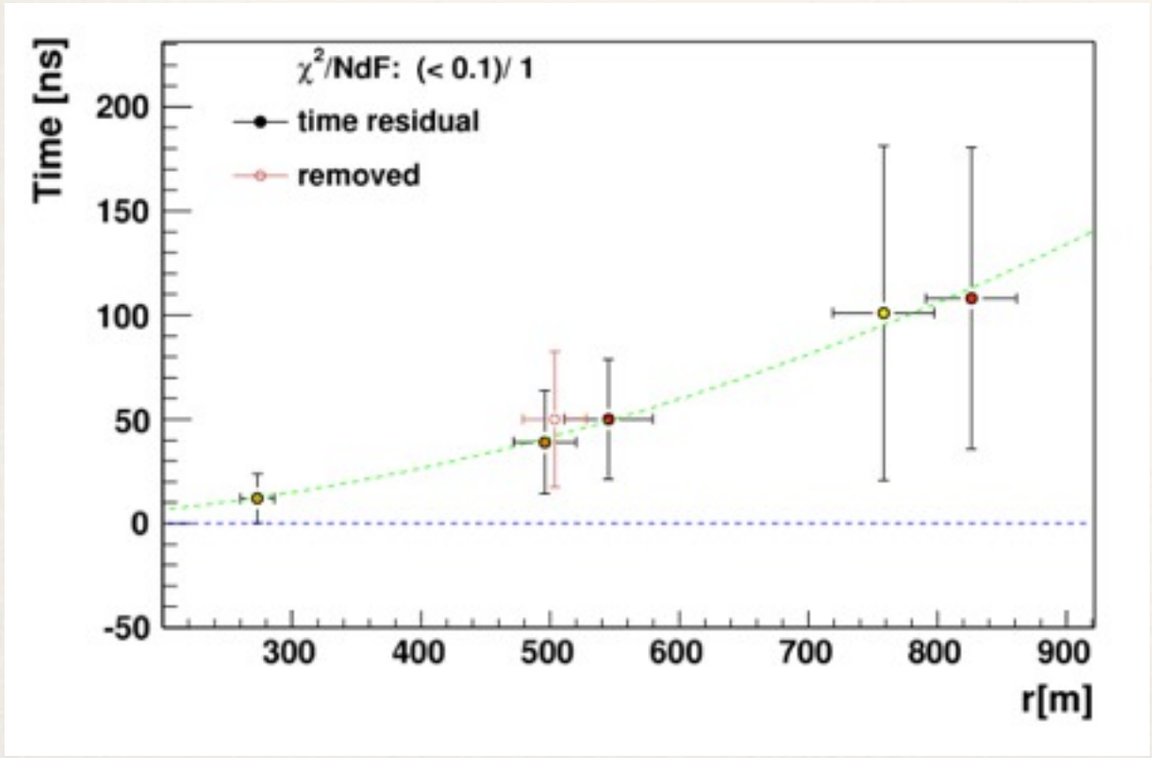
Data set:

- 1 Aug 2008 – 31 Mar 2011
- $\theta < 55^{o}$
- Fiducial cut: hottest station surrounded by 6 active stations (T5)

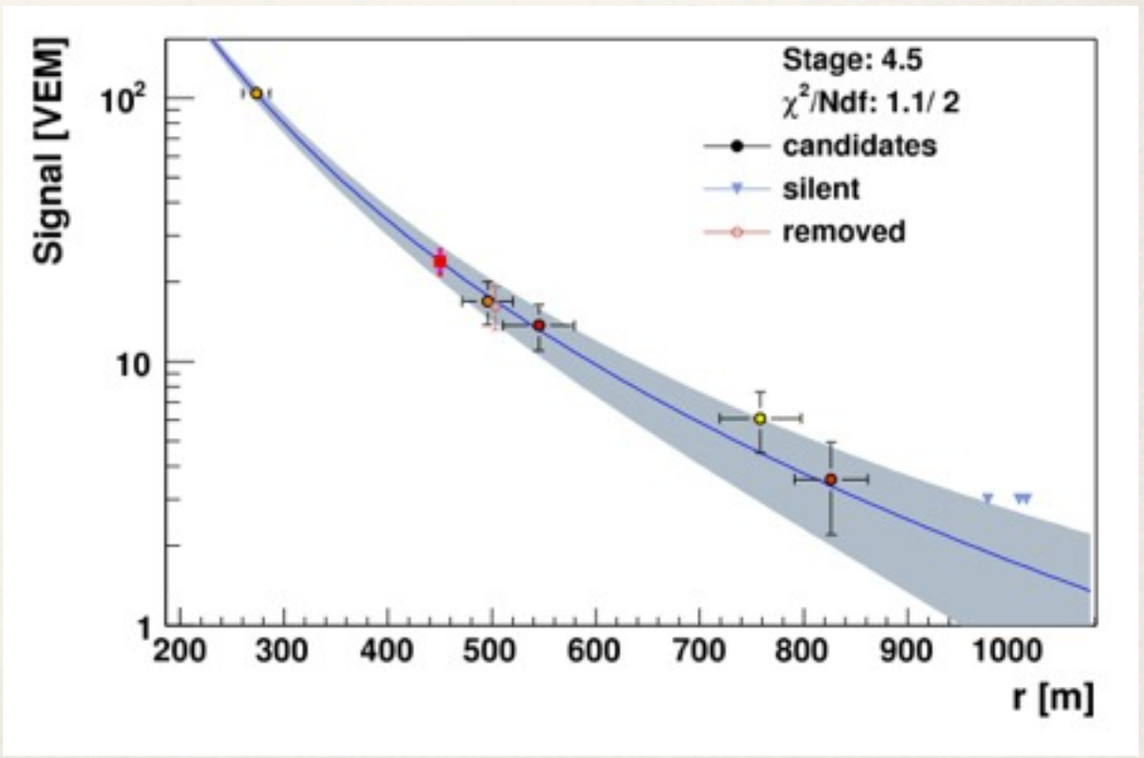
5-fold T5 event – E ~ 3 10^{17} eV



Geometrical reconstruction

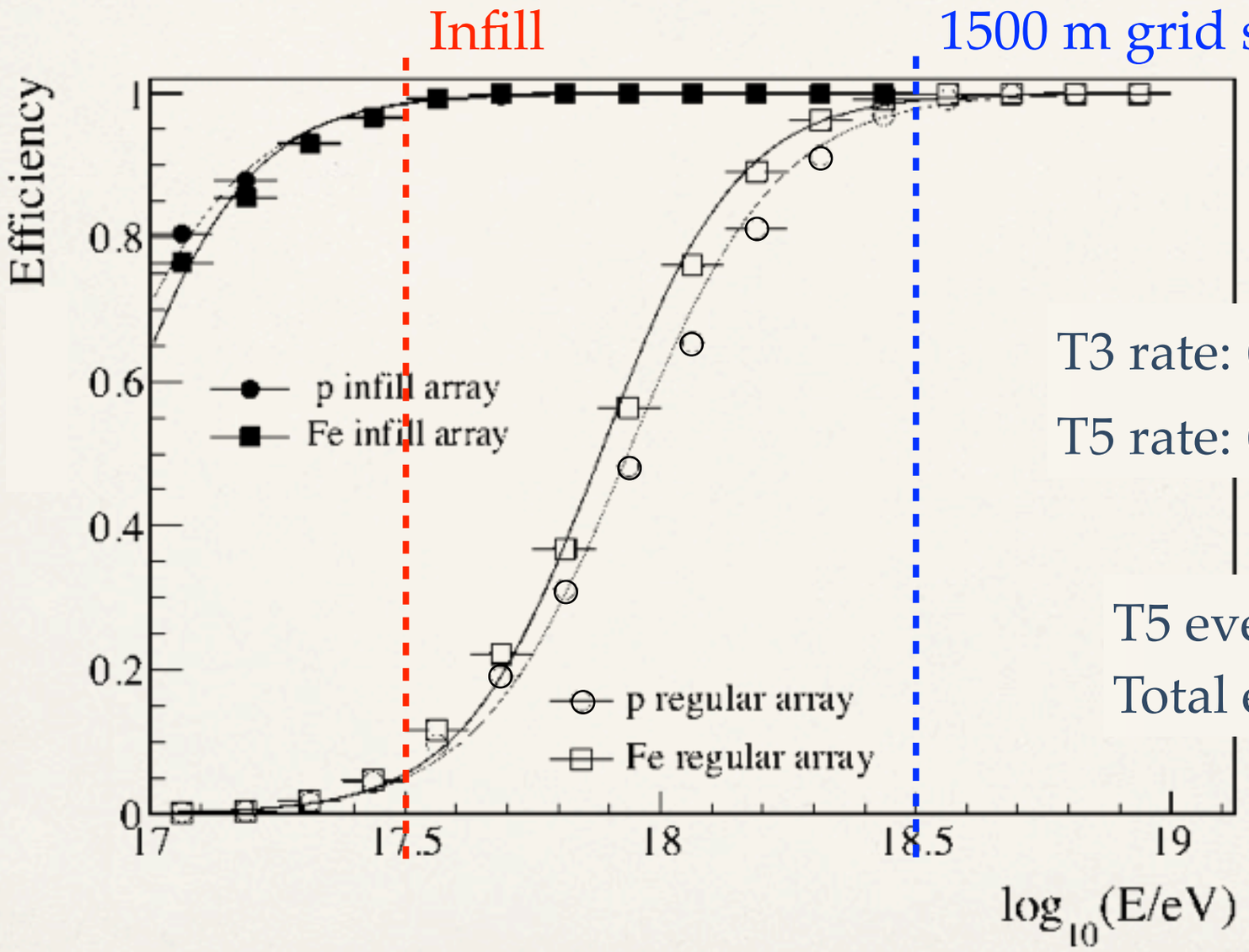


Lateral distribution function



Trigger efficiency

E > 3 10^{17} eV the array is 100% efficient for cosmic rays at θ < 55°



T3 rate: (55 ± 6) events/hexagon/day

T5 rate: (28 ± 3) events/hexagon/day

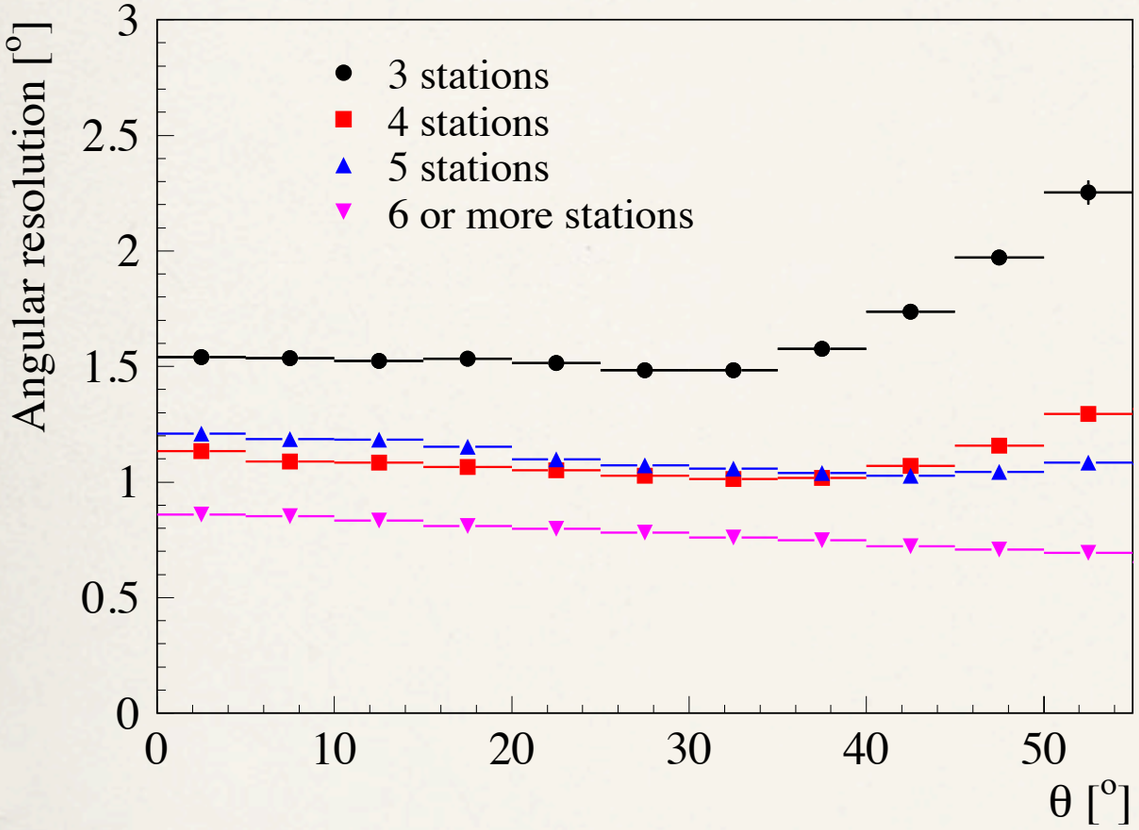
T5 events: (390 ± 70) / day

Total events: ~260.000

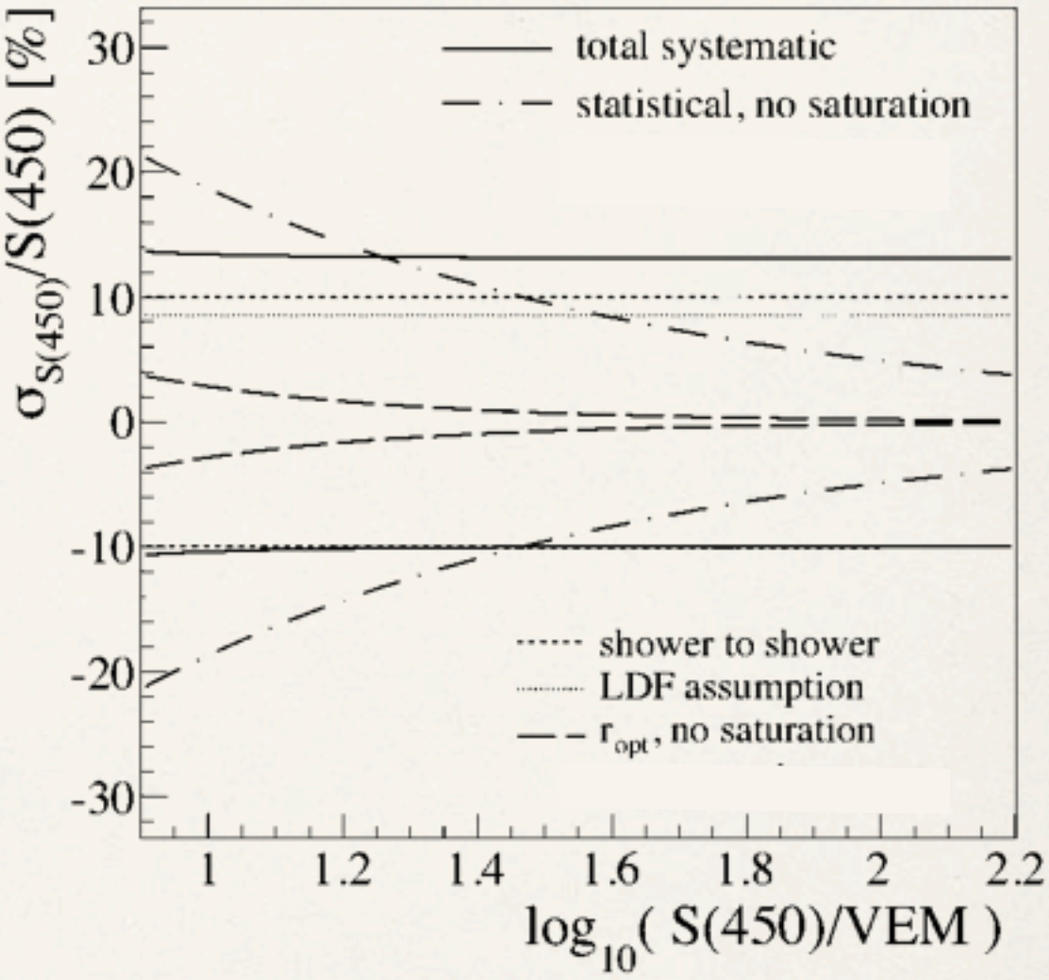
Total acceptance (1 Aug 2008 – 31 Mar 2011): (26.4 ± 1.3) km² yr sr

Infill Performance

Angular resolution

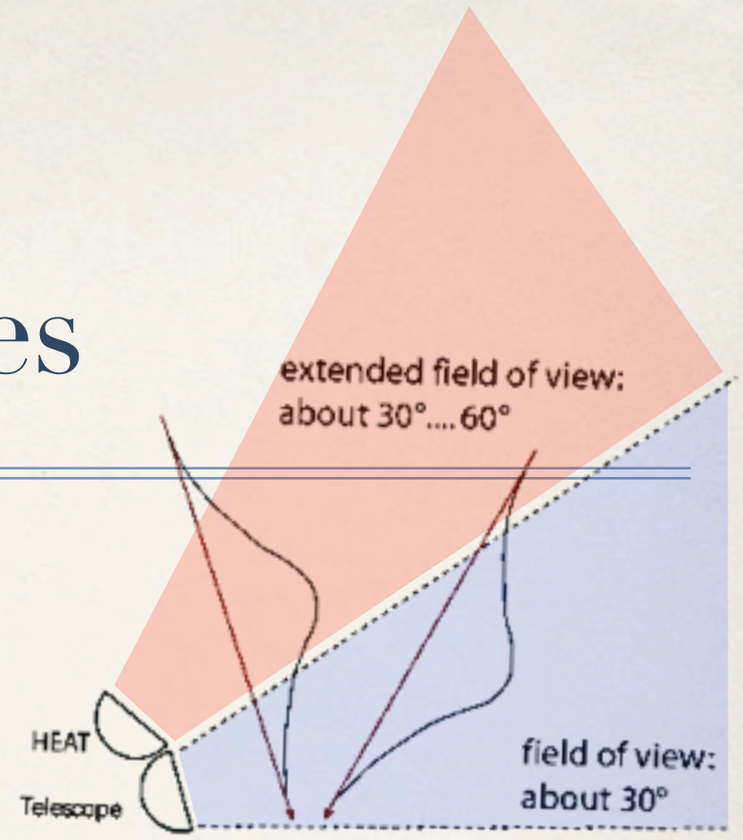


S(450) uncertainties

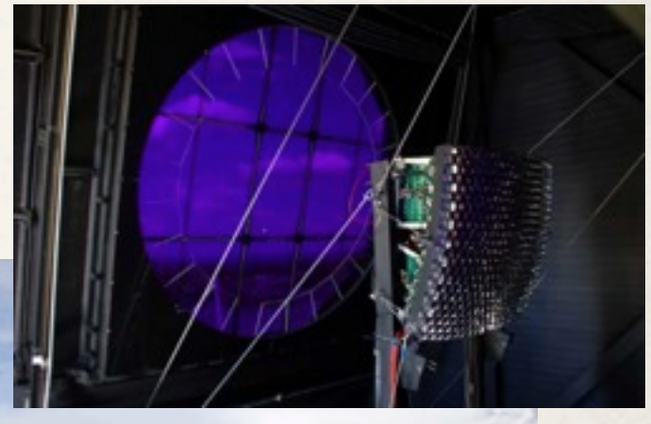


- Angular resolution ~ 1° for events with 6 or more stations ($E \geq 5\ 10^{17}$ eV)
- R_{opt} = 450 m LFD fluctuations are minimized
- Statistical uncertainties of S(450): 20% @ 10 VEM – 5% @ 100 VEM (saturation +10%)
- LDF parameterization (LLP or NKG): ~9% (it cancels in the final energy calibration – FD)
- 10% shower-to-shower fluctuations

HEAT
High Elevation Auger Telescopes



- Low energy showers develop higher in the atmosphere
- 3 "standard auger" telescopes pivot-mounted for 30° to 58° elevation
- New improved electronics: faster sampling & read out
- Hybrid mode together with AMIGA – E ~ 10^{17}eV



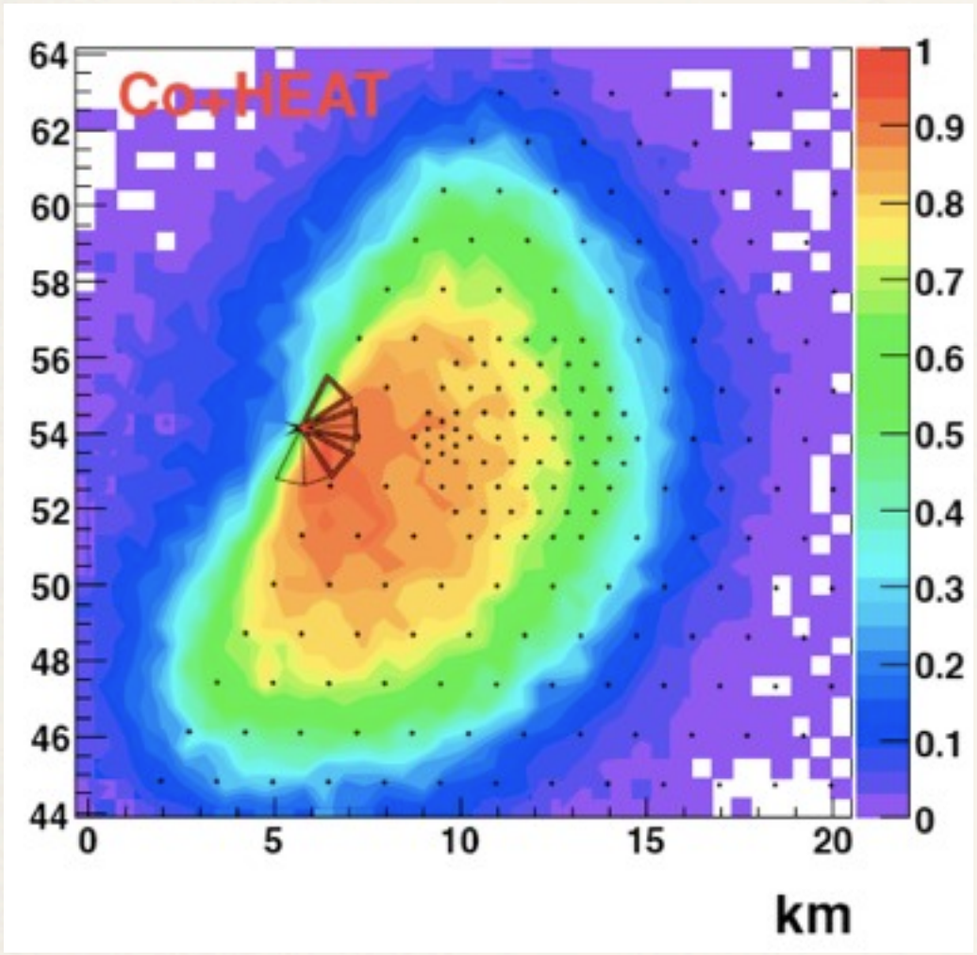
First telescope working since Jan 2008

HEAT was completed in Sep 2009

Data taking since June 2010

HEAT event example

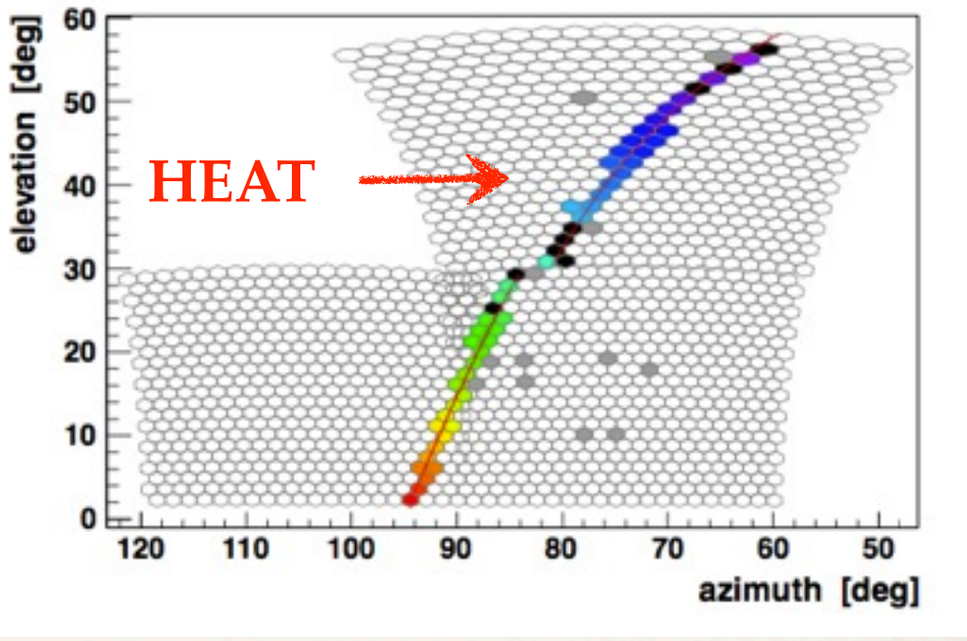
Trigger efficiency E ~ 3 10^{17} eV

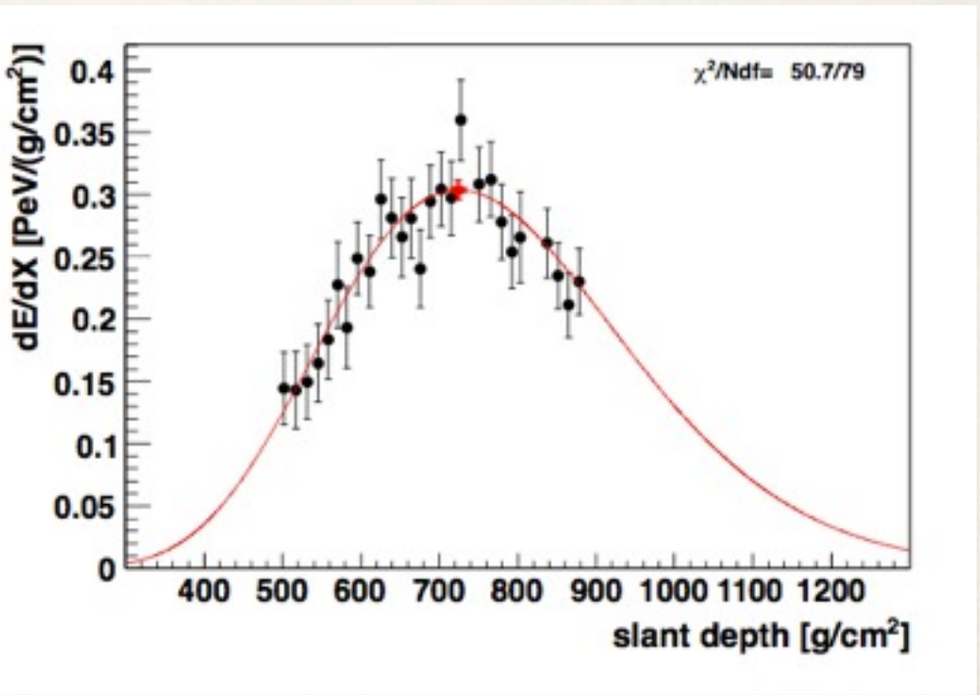


Monte Carlo simulation

- Good accuracy of energy and X_{max} determination
- X_{max} in the FOV

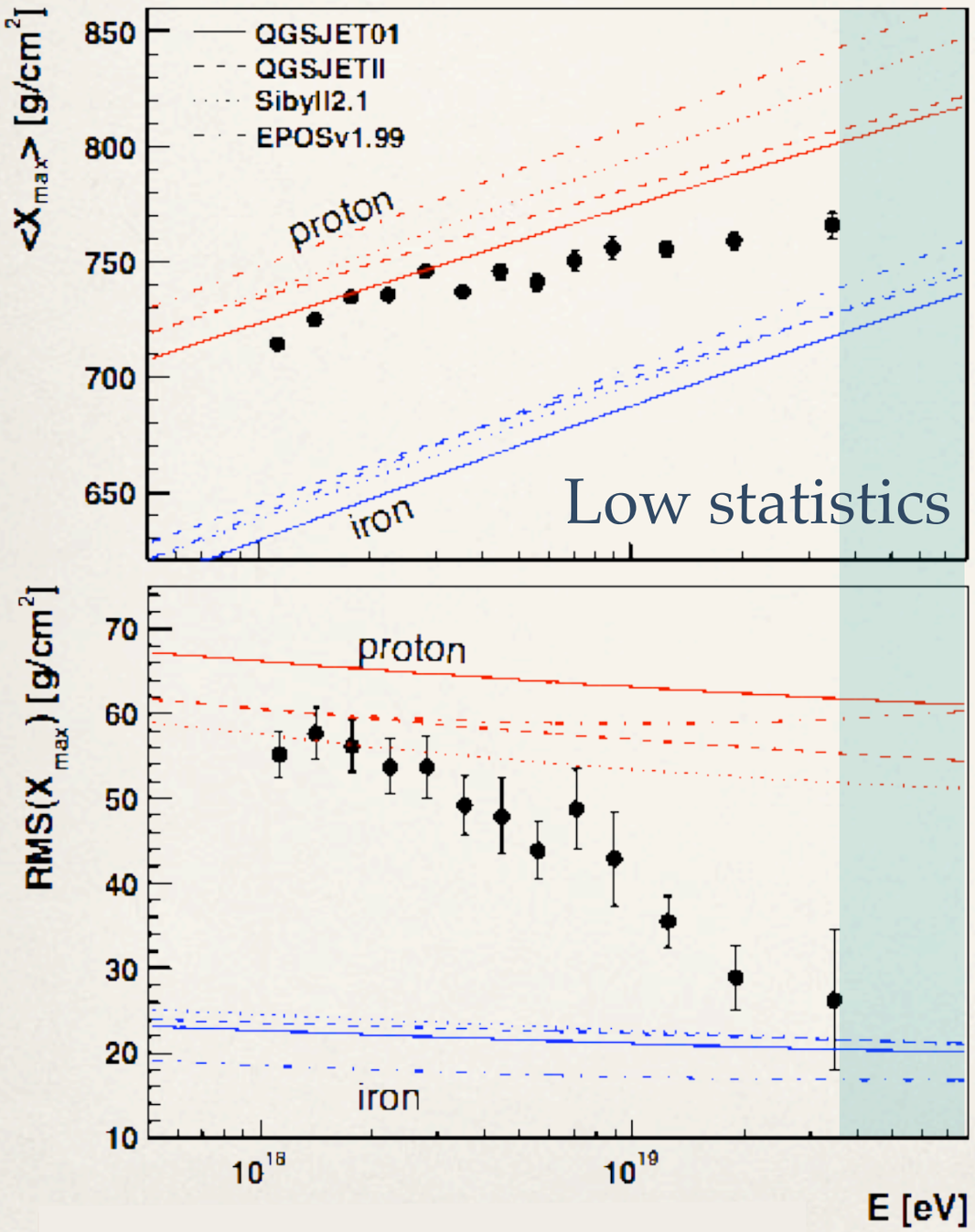
Low energy event ~ 2 10^{17} eV



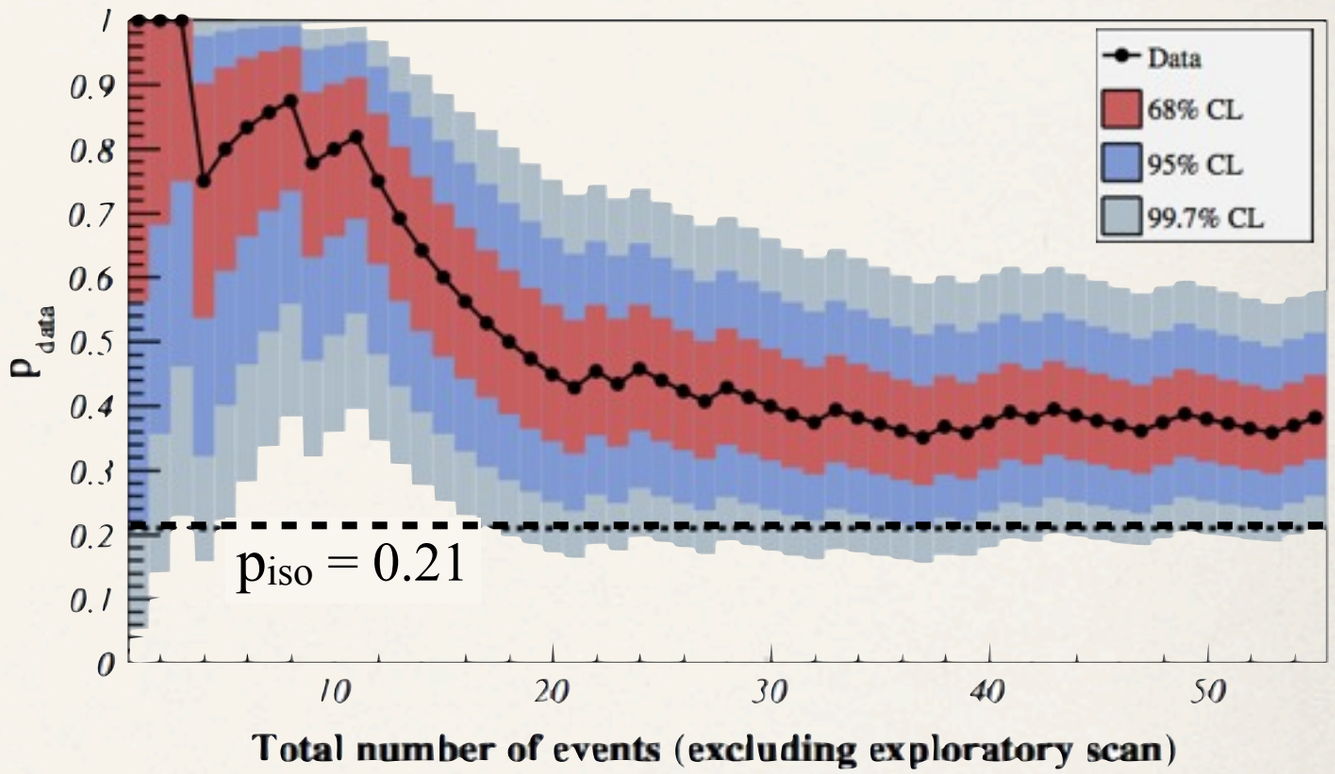


Current knowledge...

X_{max} for composition studies



Correlation of the UHECR with the nearby AGNs



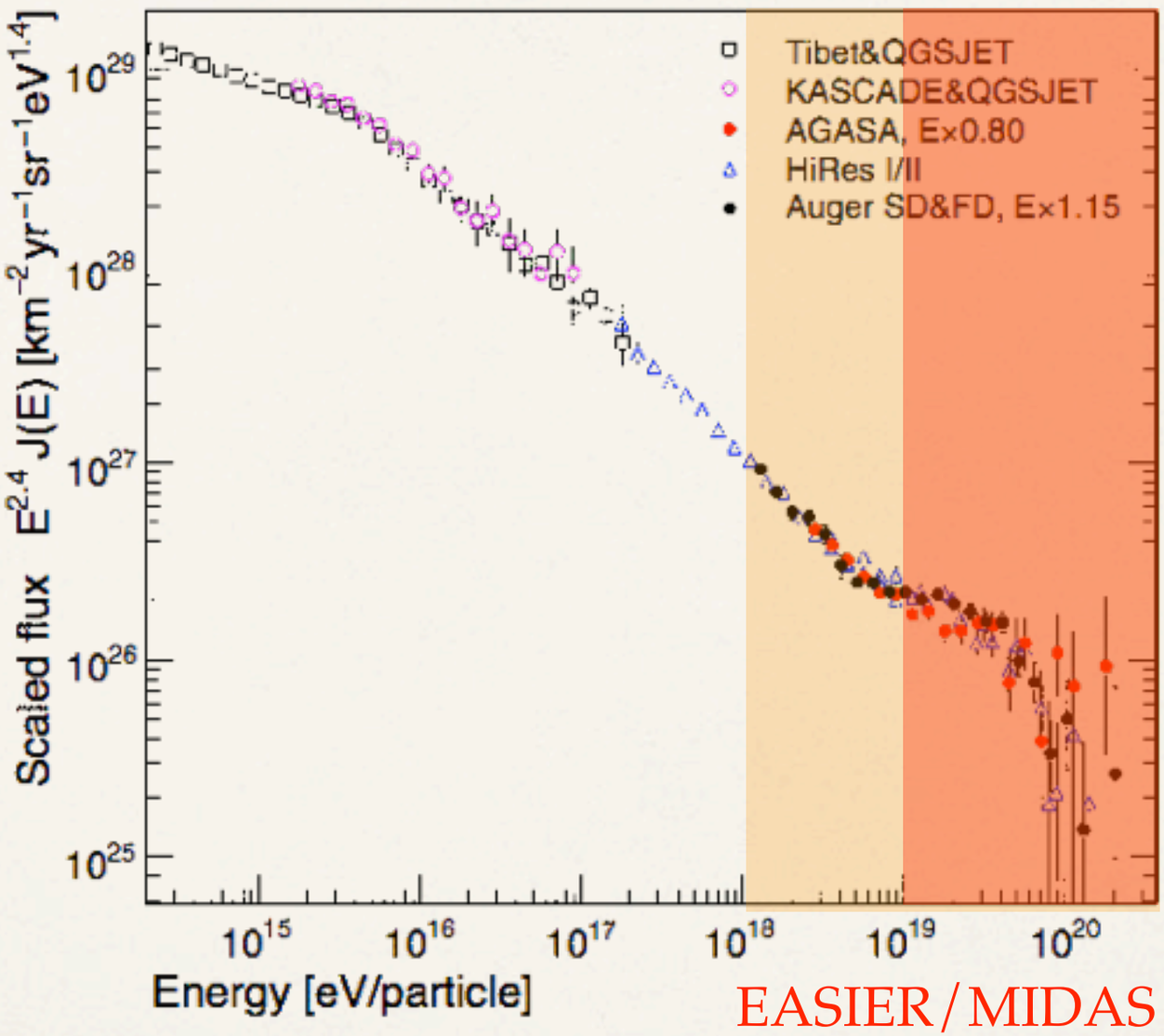
Needs:

Composition for events $E > 5\ 10^{19}$ eV (X_{max} measurements)

On an event-by-event basis if possible

Enhancements: high energy

AUGER



EASIER/MIDAS

Auger new techniques:

Radio (MHz)/Microwave (GHz) signal in each surface detector (EASIER)
Microwave antenna – similar to the florescence detection (MIDAS)

Radio / Microwave detection

Geosynchroton Radiation

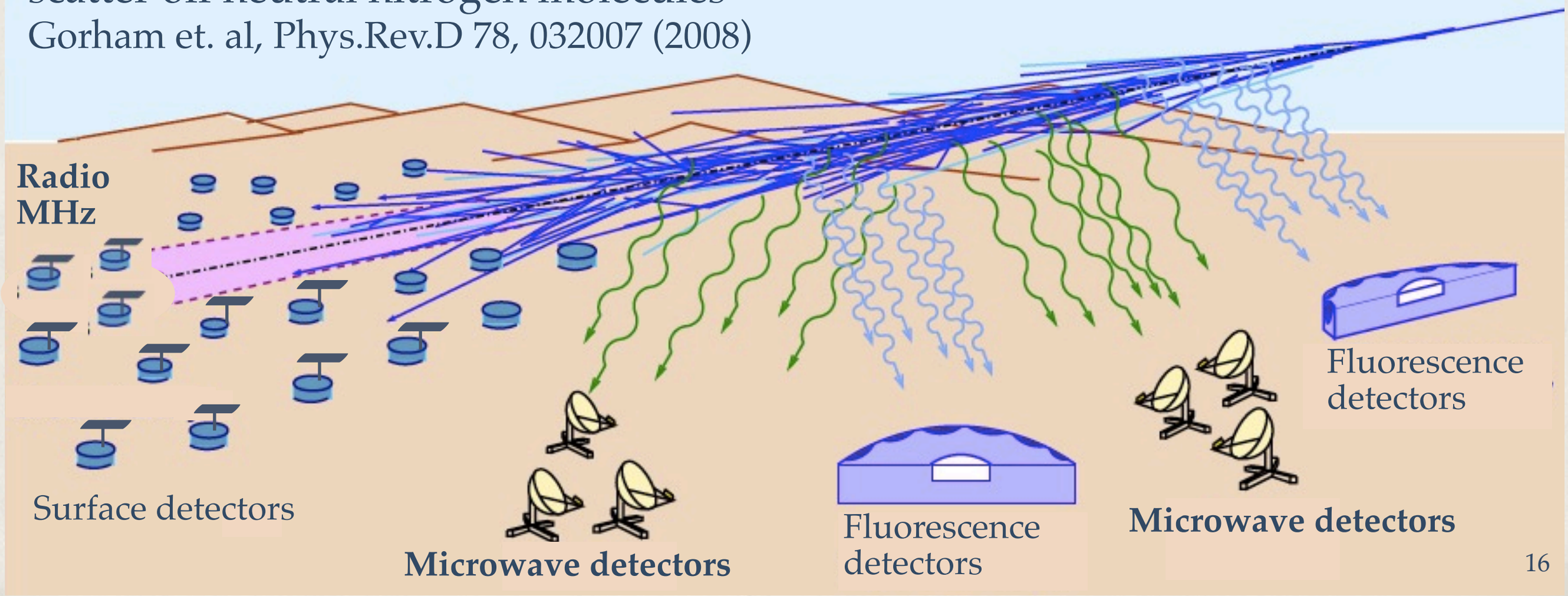
Extensive air showers (EAS) induced by cosmic rays produce secondary particles that emit a detectable electric field in the MHz range

See Benjamin's talk

Molecular Bremsstrahlung Radiation (MBR)

The weakly ionized plasma created in the atmosphere after the passage of the EAS gives rise to the emission of continuous radiation (MBR) as free electrons scatter off neutral nitrogen molecules

Gorham et. al, Phys.Rev.D 78, 032007 (2008)



EASIER
Extensive Air Showers Identification with Electron Radiometers

Detection principles:

- Detection of the radio emission of the EM cascade
- Two possible bands: VHF (30 – 80 MHz) and C-band (3.4 – 4.2 GHz)
- Sensor integrated in the array
- Trigger and timing via the surface detector DAQ

Observables:

- Signal proportional to the EM energy
- Time shape related to the cascade evolution and X_{max}
- Muonic signal in the surface detector by subtraction (S_μ)

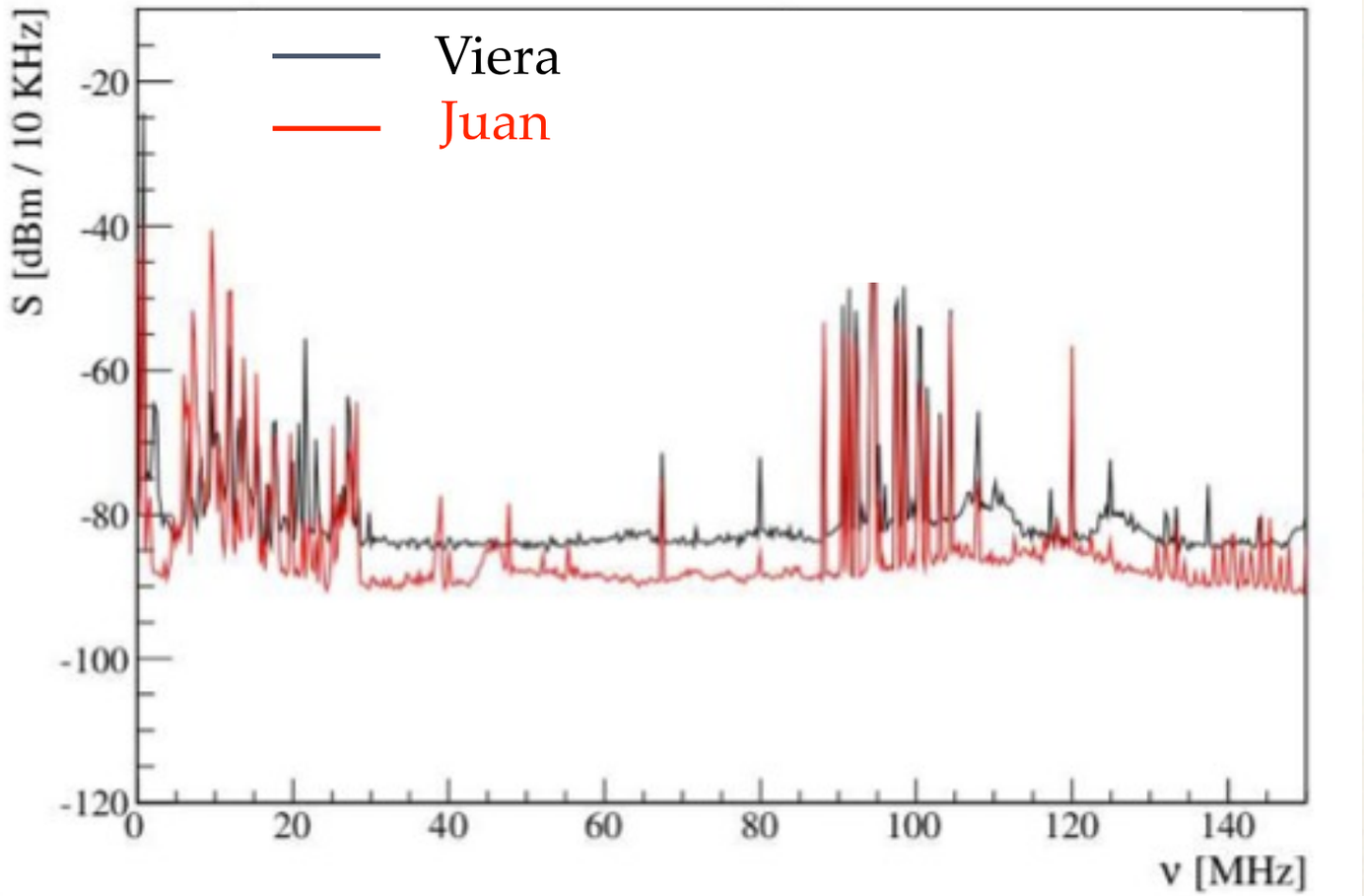
~ 100% duty cycle telescope with the coverage of a surface detector, integrated in the array

VHE – First test hexagon

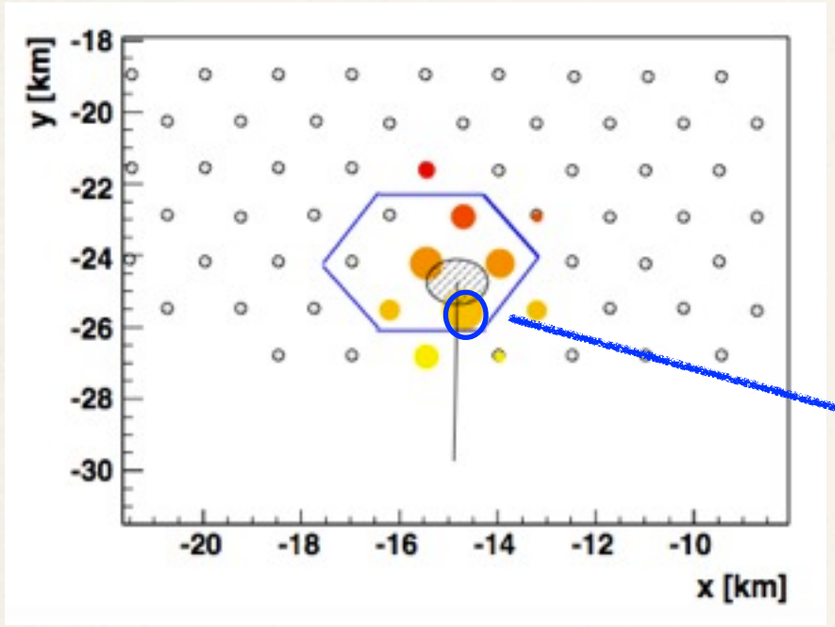
VHE (30 – 80 MHz)

Geosynchroton emission

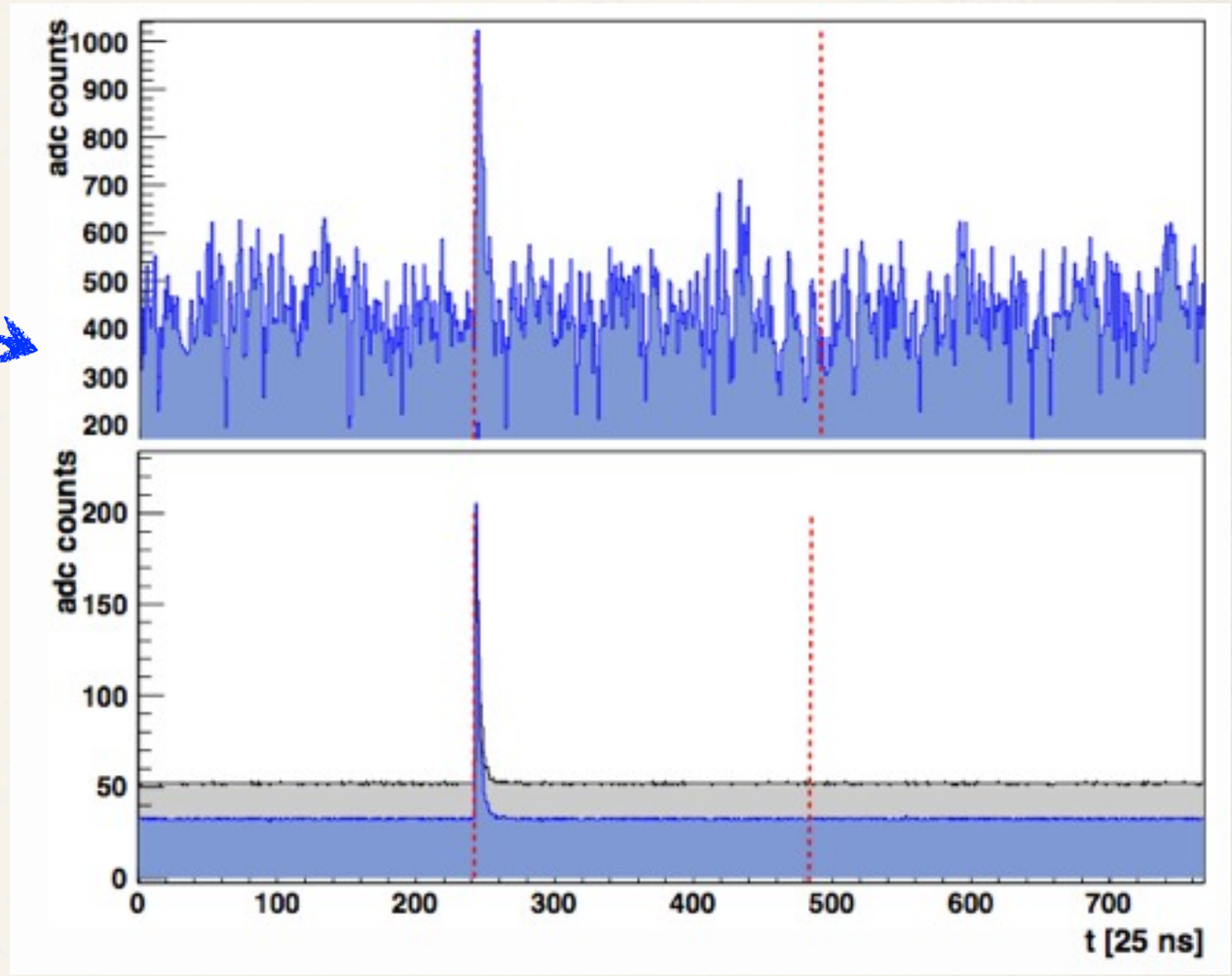
Installed in March 2011

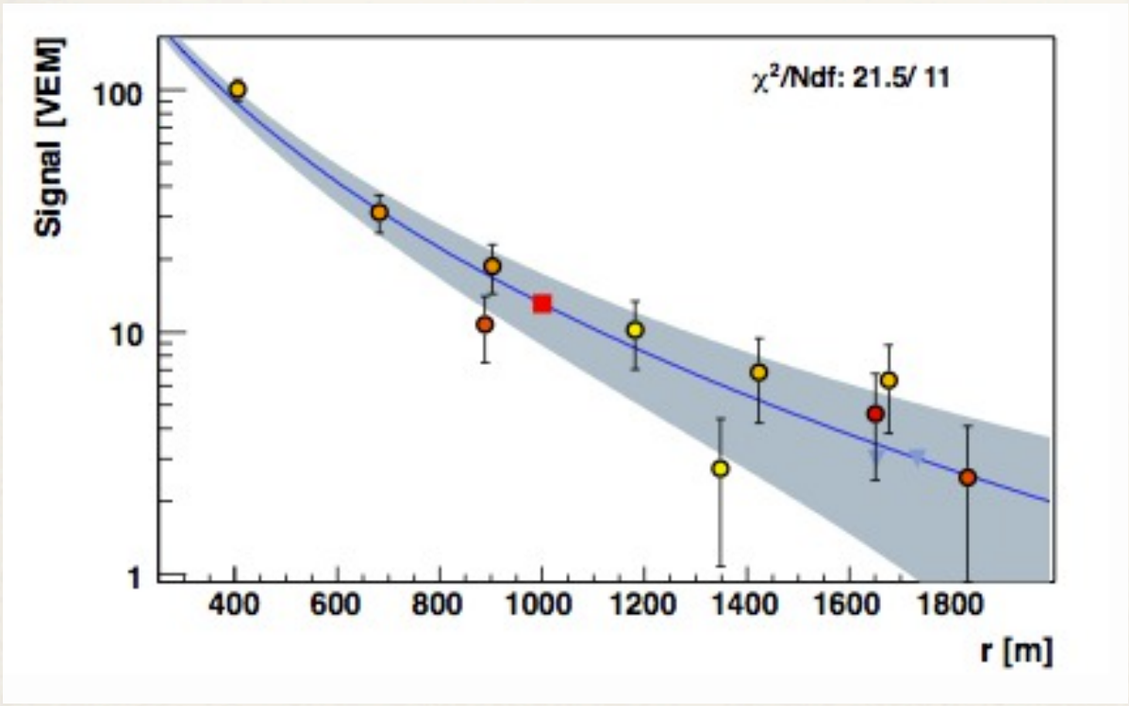


VHE: First event



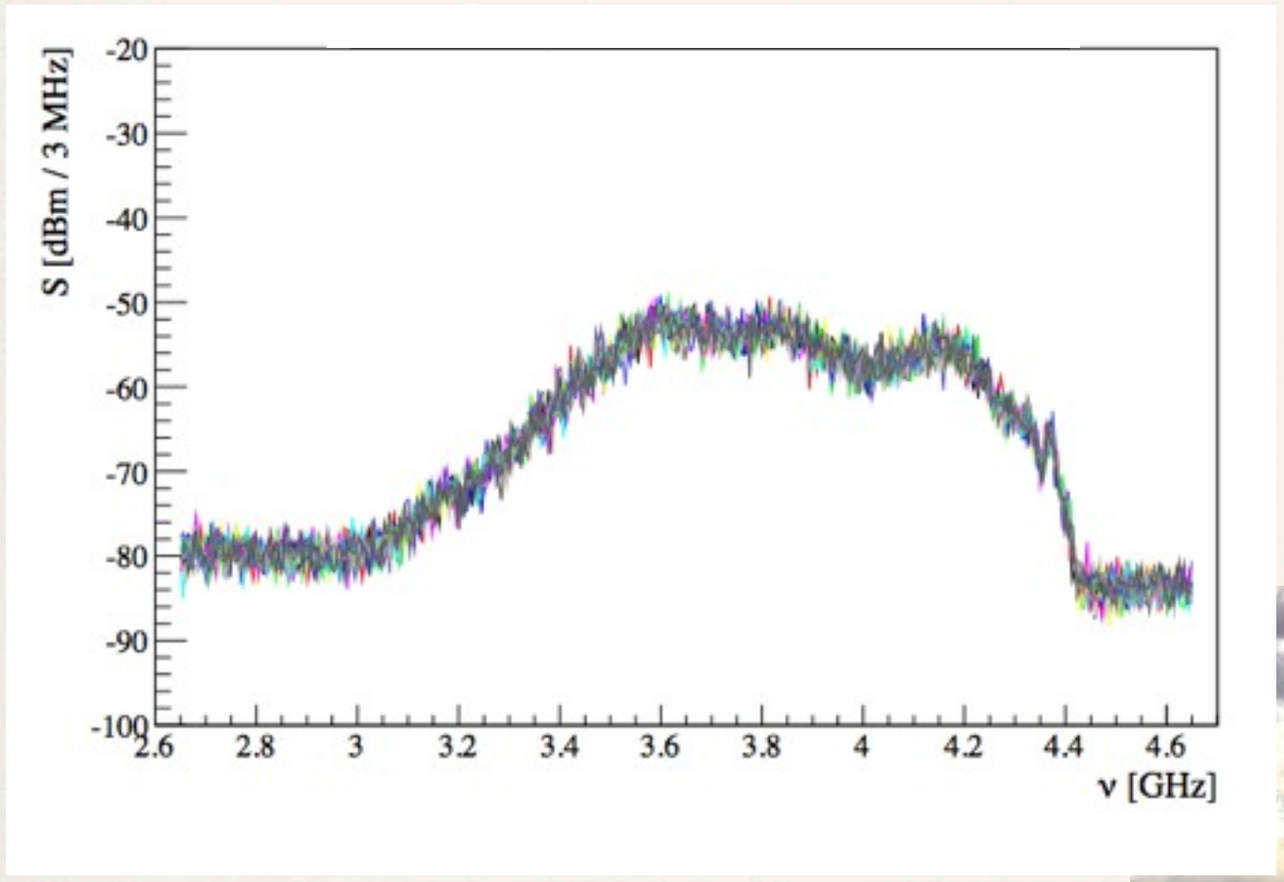
400 m to the core





GHz – First test hexagon

Microwave (3.4 – 4.2 GHz)
Installed in April 2011



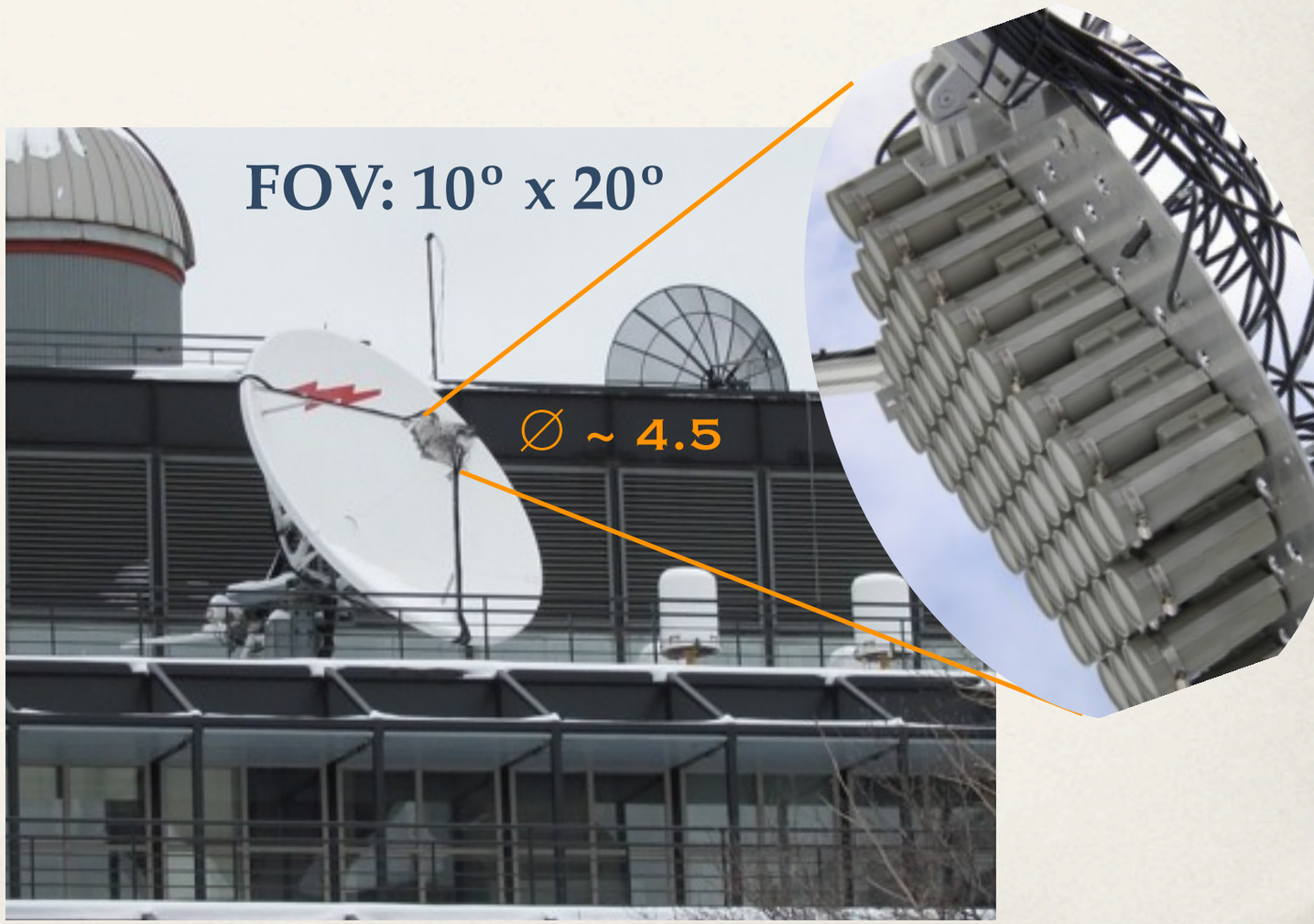
Ongoing analysis
- Calibration, noise level
- Signal search

MIDAS
Microwave Detection of Air Shower

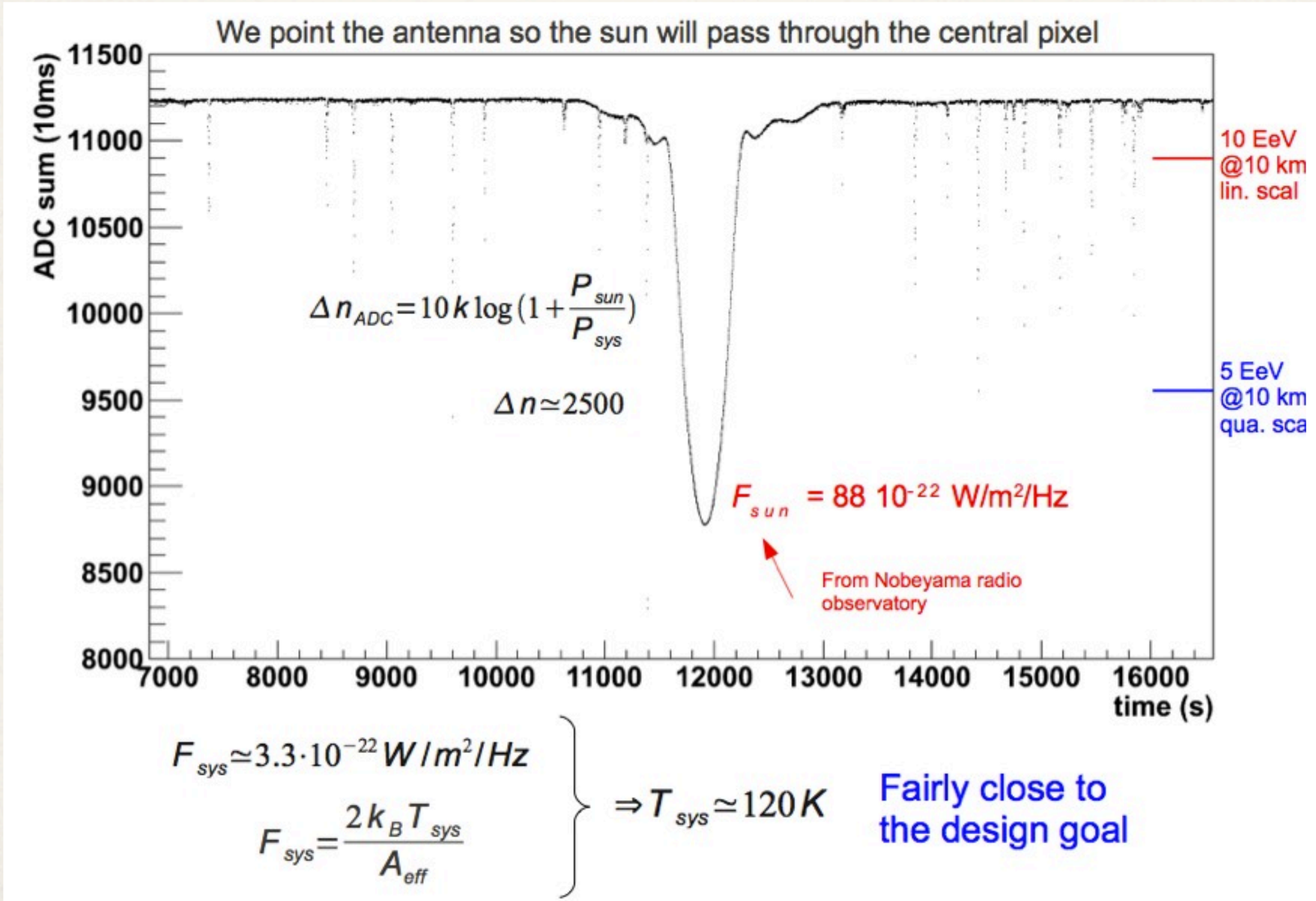
MIDAS is an R&D effort to detect EAS in the microwave band due to MBR

Prototype detector @ UChicago was designed to make an FD-like detection and reconstruction of the shower

- Camera with 53 C-band feeds
  - Frequency 3.4 – 4.2 GHz
  - 13 K noise
  - 70 dB amplification
- Feed central on the focus
- 4.5 m diameter parabolic dish
- Movement:
  - 90º zenith
  - 100º azimuth



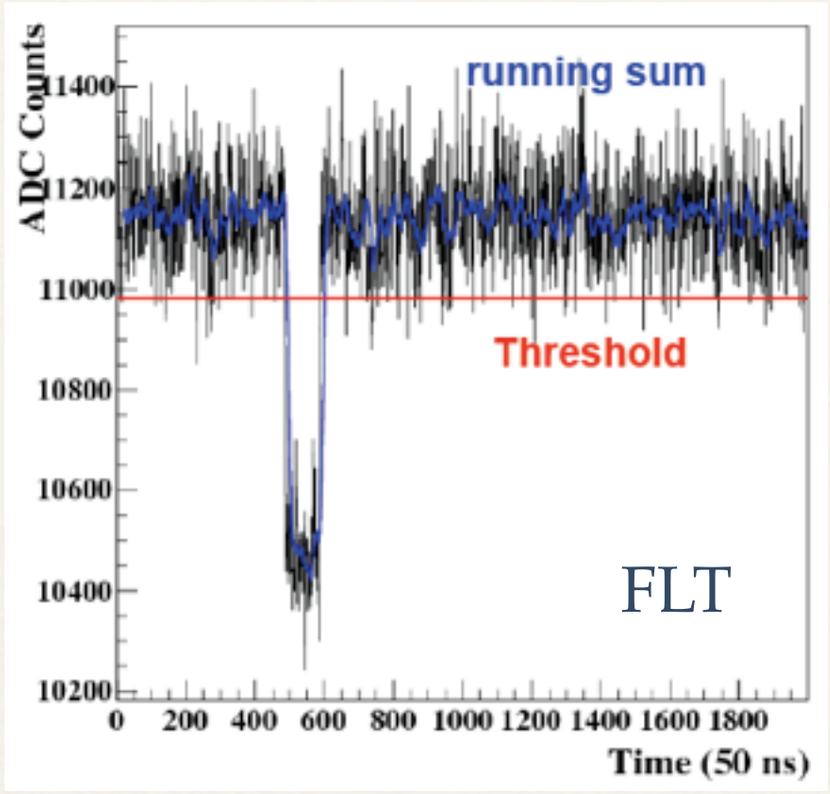
Calibration with the Sun

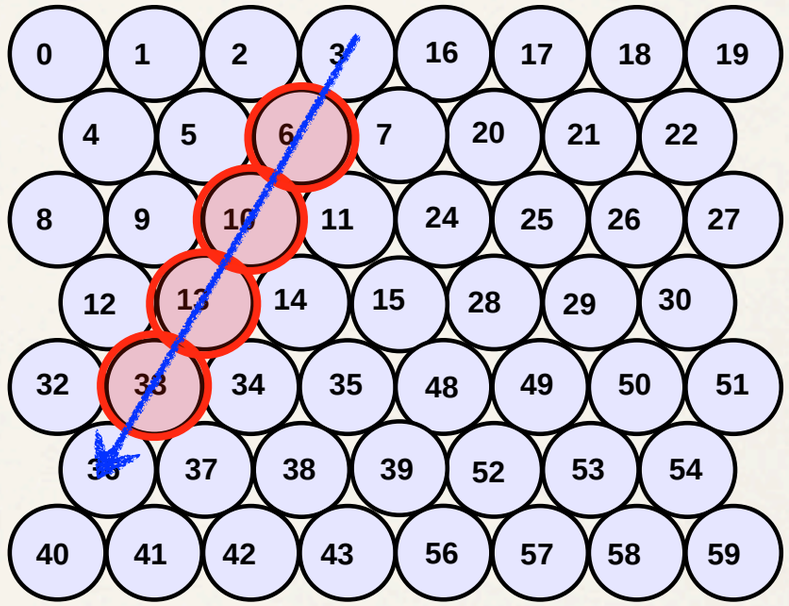


MIDAS: Trigger

Level 1 (FLT):
1 μs ADC sum compared to self adjusted threshold (100 Hz per design)

Level 2 (SLT):
FLTs windows of 20 ms + topology + time coincidences (accidental rate ~ 0.2 Hz)





Total of 1-2 events/month above 3 10^{18} eV
Antenna will be installed in Auger Observatory (September 2011)

Summary

Enhancements to Auger baseline configuration are currently being made to decrease the minimum energy to an order of magnitude below its original design and to improve the quality of the data at the highest energies

- HEAT is taking data since June 2010
- AMIGA is in a very advanced state
  85% of the infill array installed and taking data since August 2008
  3 muon counters already installed
- EASIER has the two test hexagons installed and taking data
- MIDAS has more than one year of the antenna working at the University of Chicago and will be moved to the Auger Observatory (near EASIER)

The Pierre Auger observatory is in a very exciting moment

More @ ICRC 2011

Thanks !