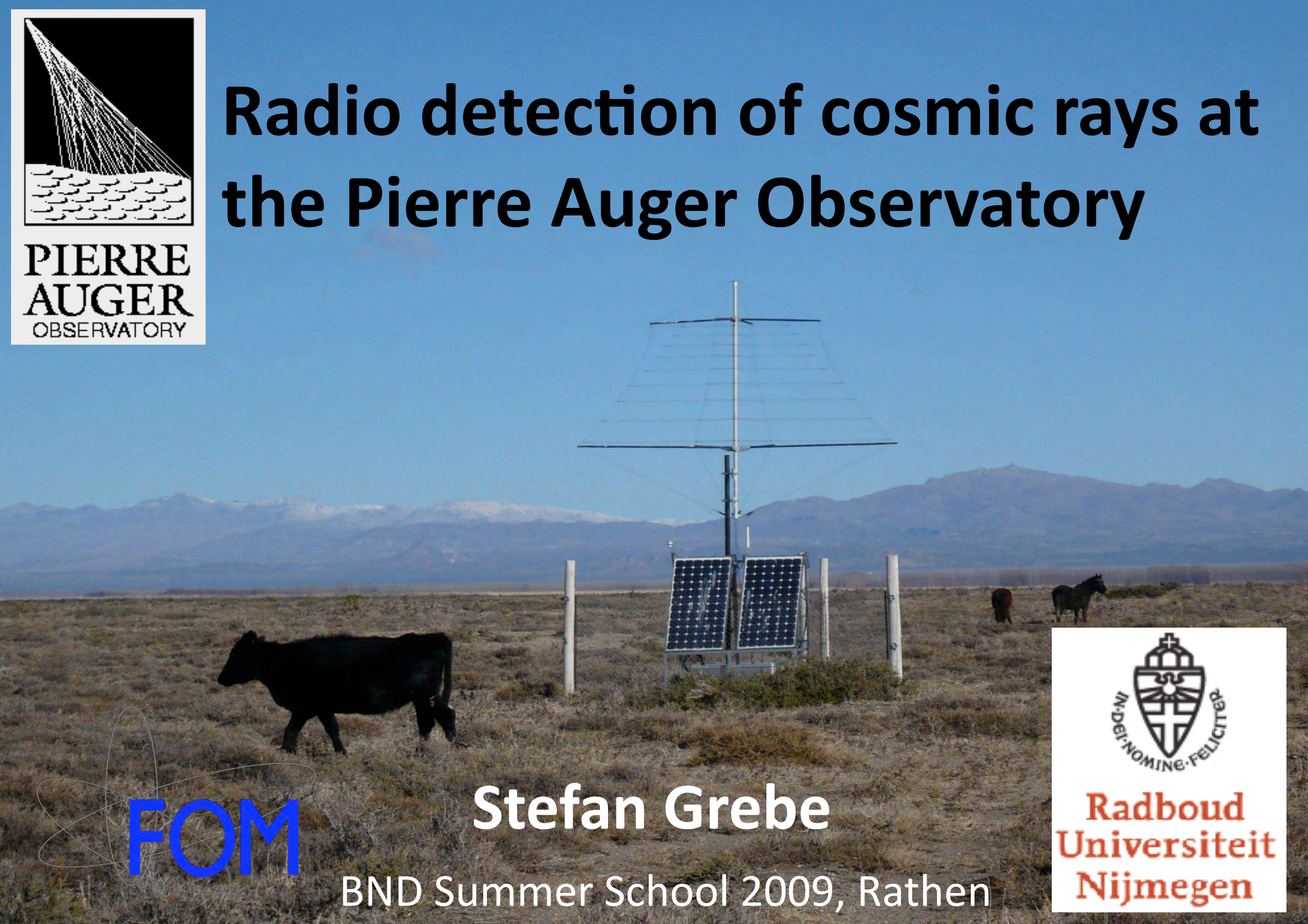
Radio detection of cosmic rays at the Pierre Auger Observatory



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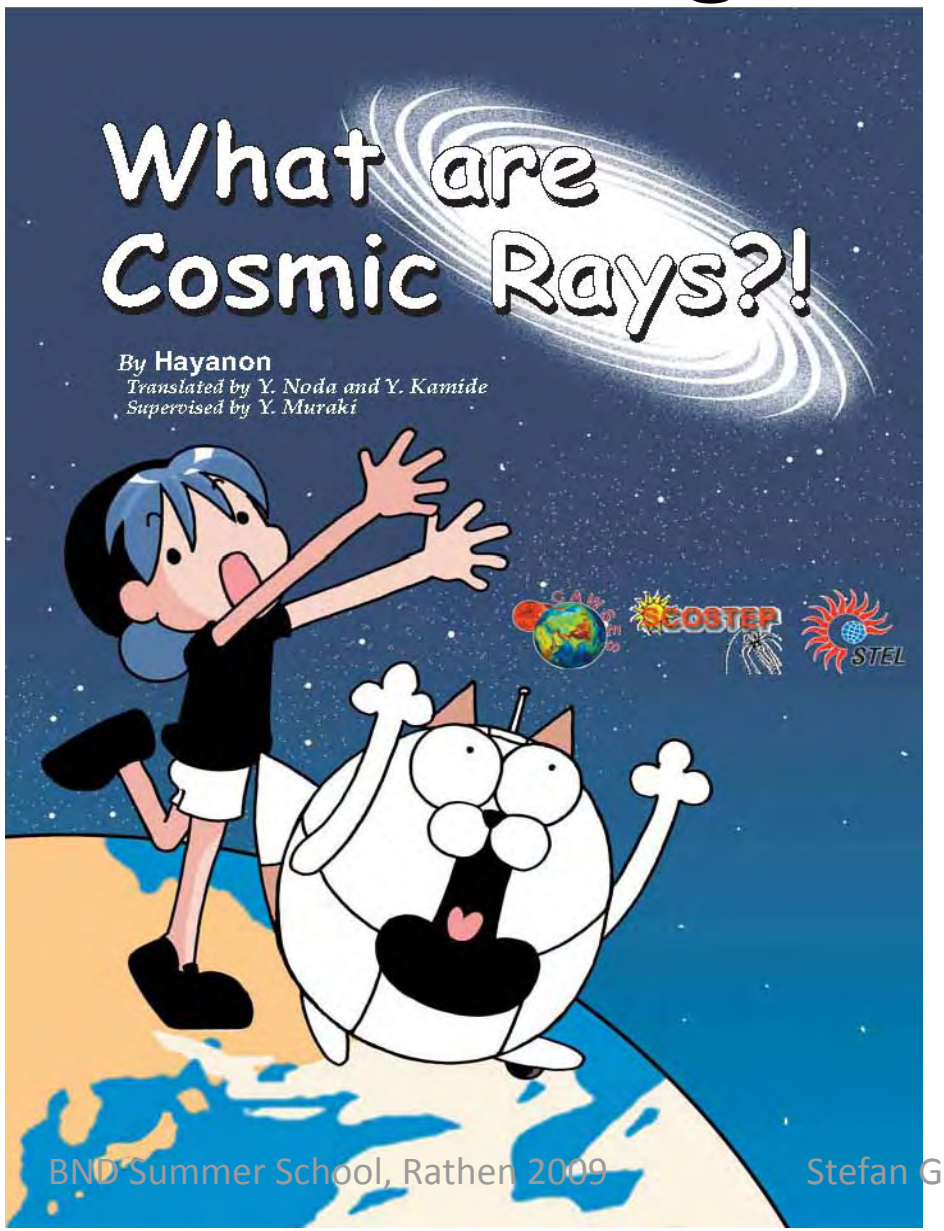
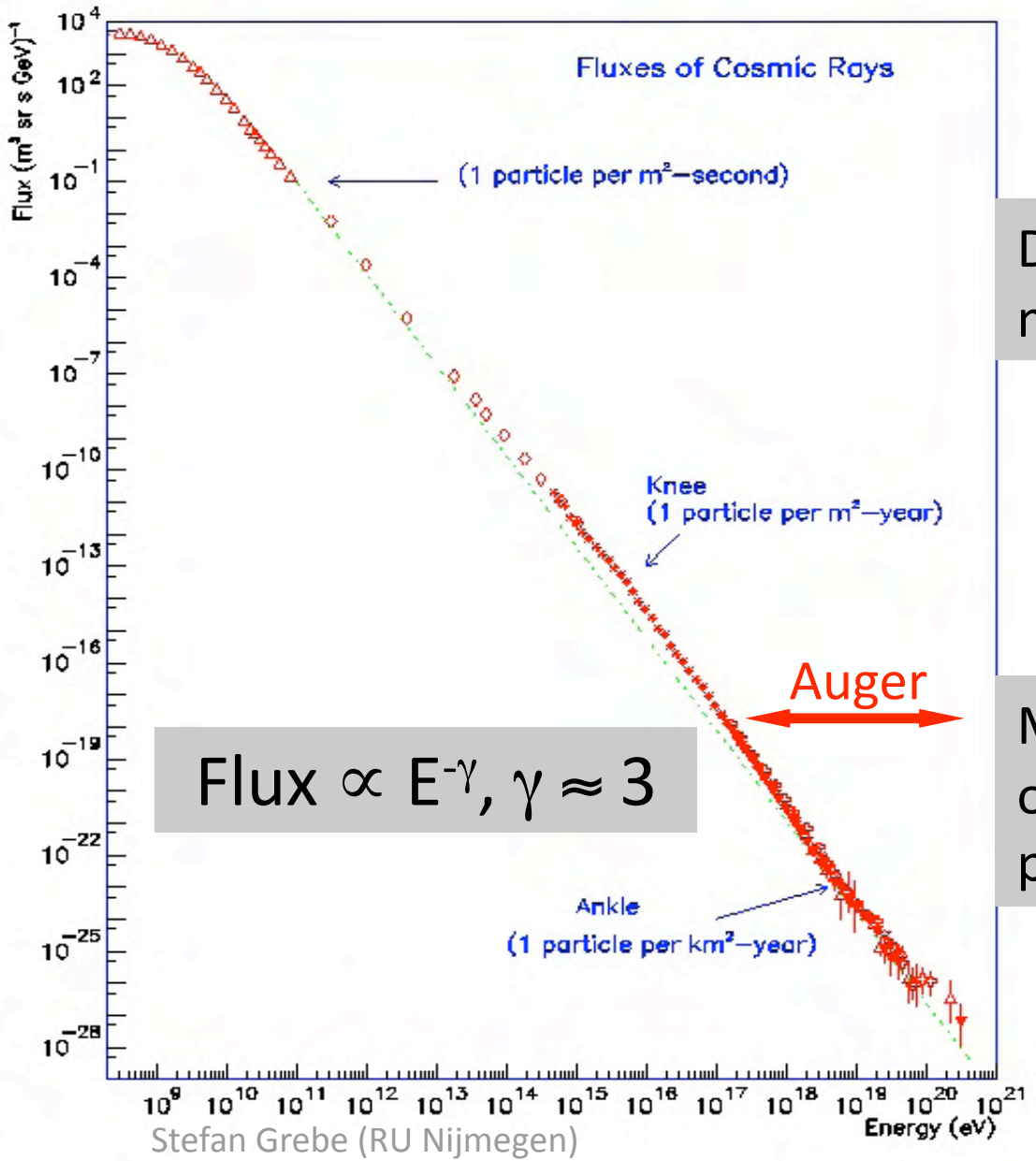
Open questions about the highest energetic cosmic rays?



- Mass composition?
- Sources ?
- Acceleration mechanisms?
- Propagation along astronomical distances?
- Deflection by magnetic fields?

Energy spectrum

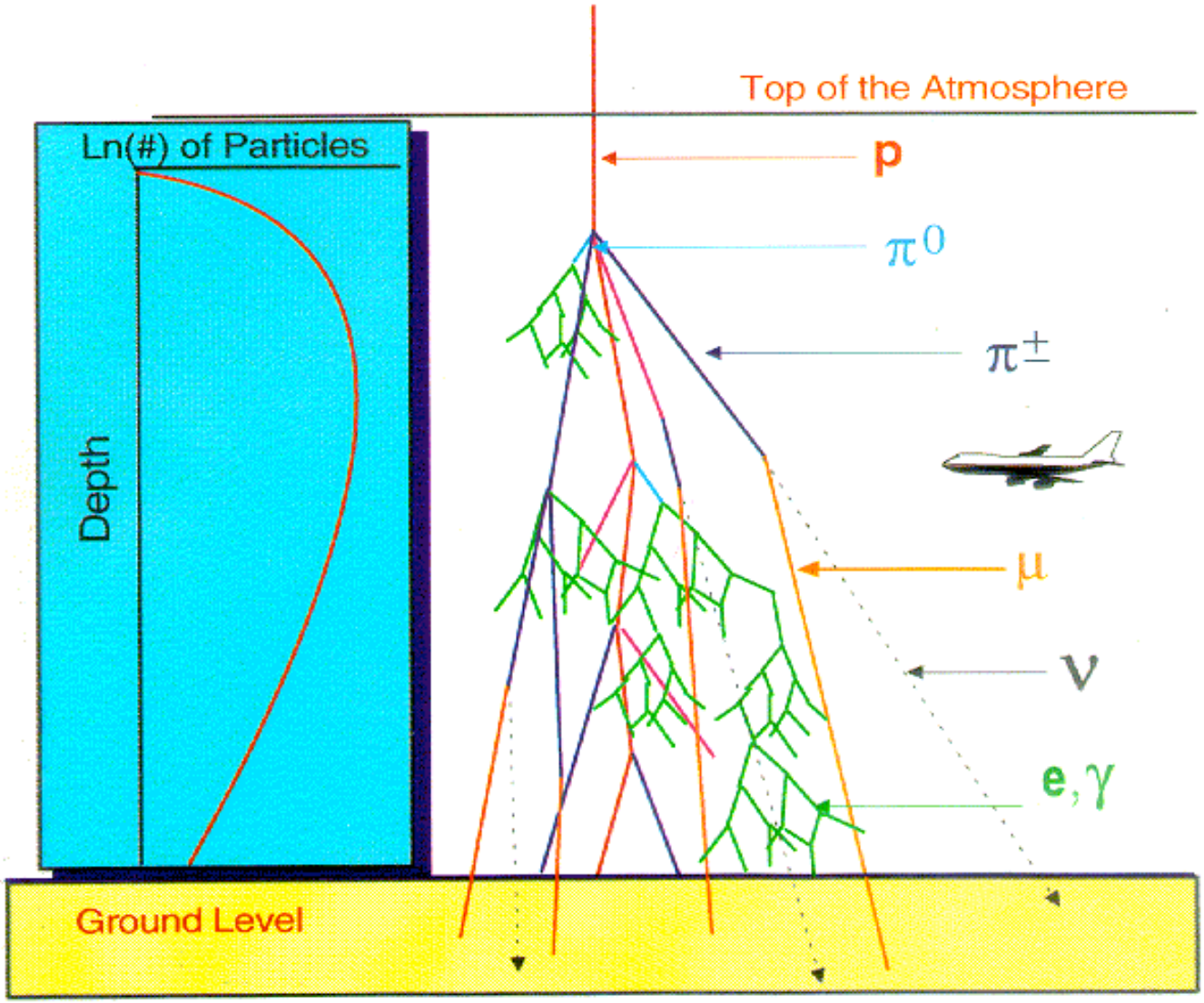


Flux $\propto E^{-\gamma}$, $\gamma \approx 3$

Direct measurement

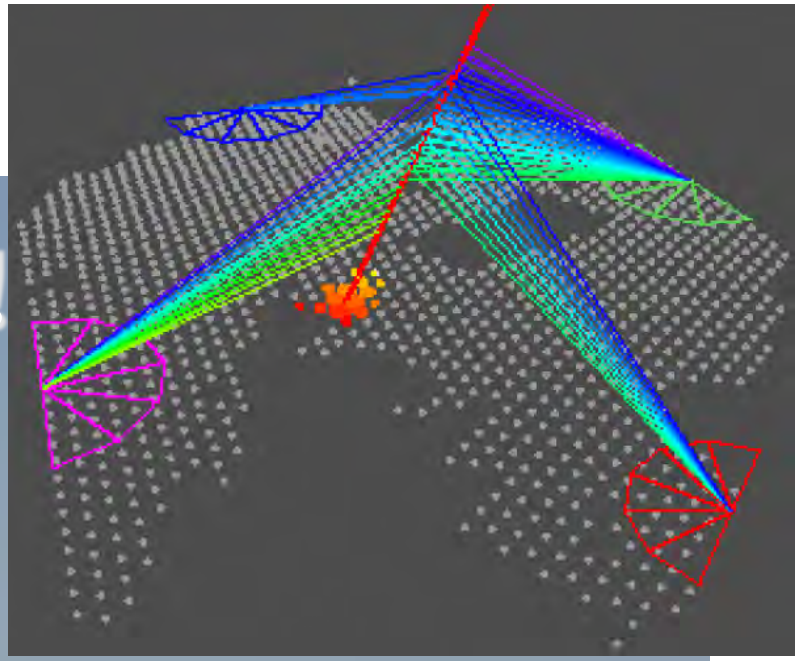
Measurement of secondary particles

Extensive air showers



Extensive Air Showers

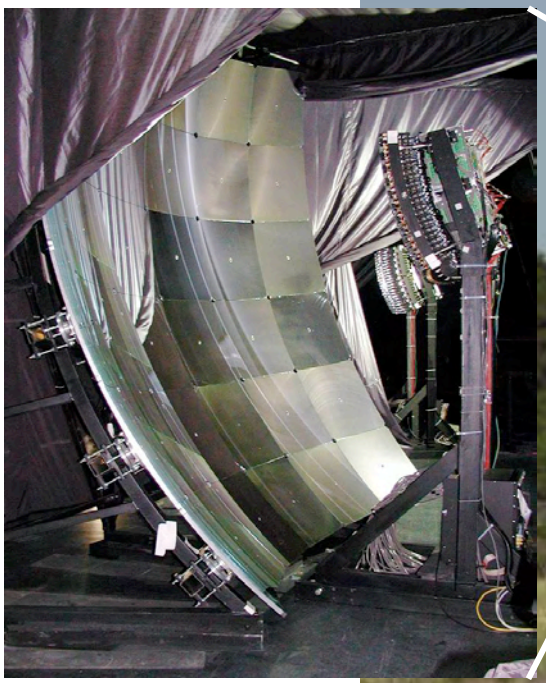
Detection techniques



Hybrid Operation!

Fluorescence Detectors

Longitudinal development of the air shower



Surface Detectors

Lateral distribution of secondary particles

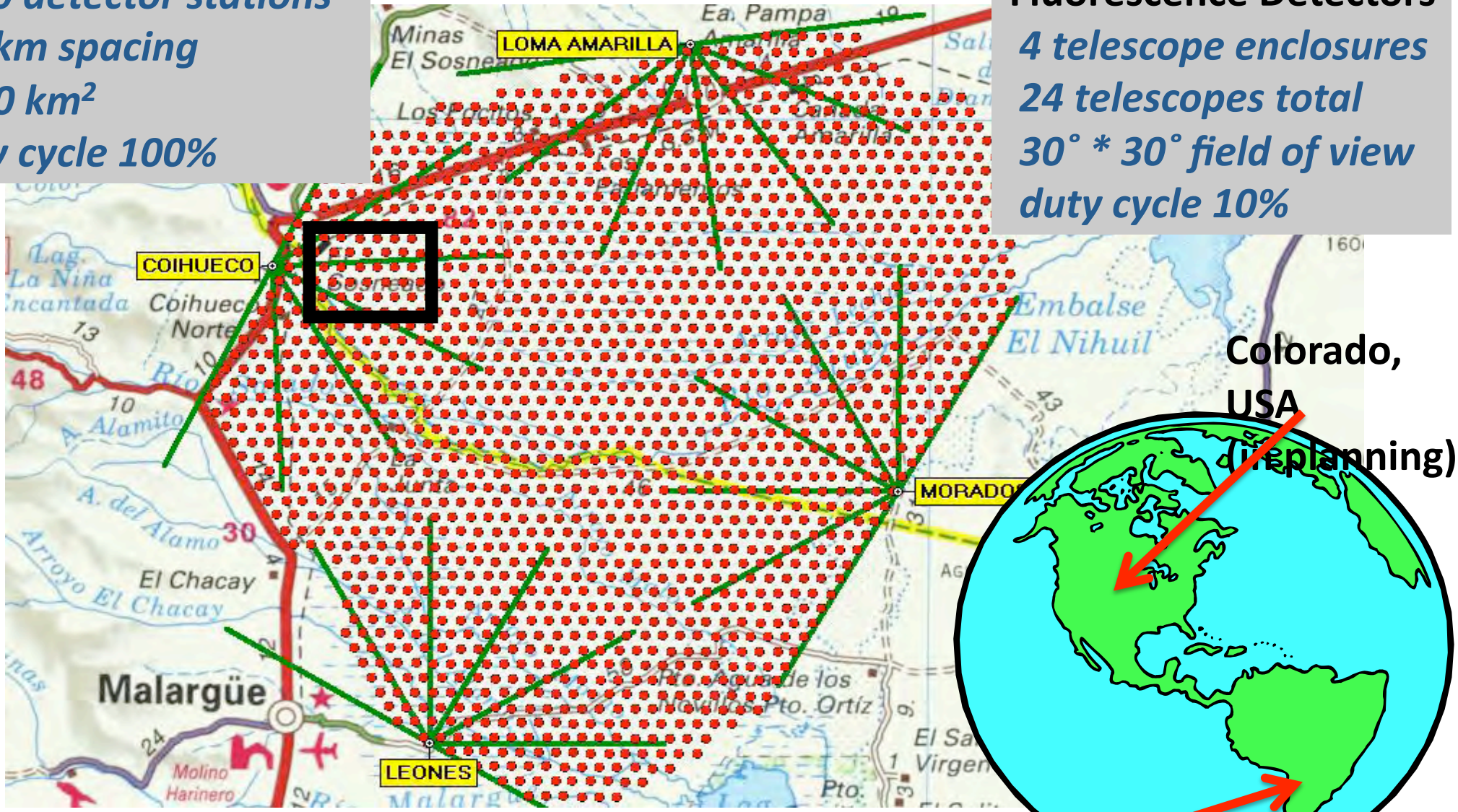
The observatory

Surface Array

1600 detector stations
1.5 km spacing
3000 km²
duty cycle 100%

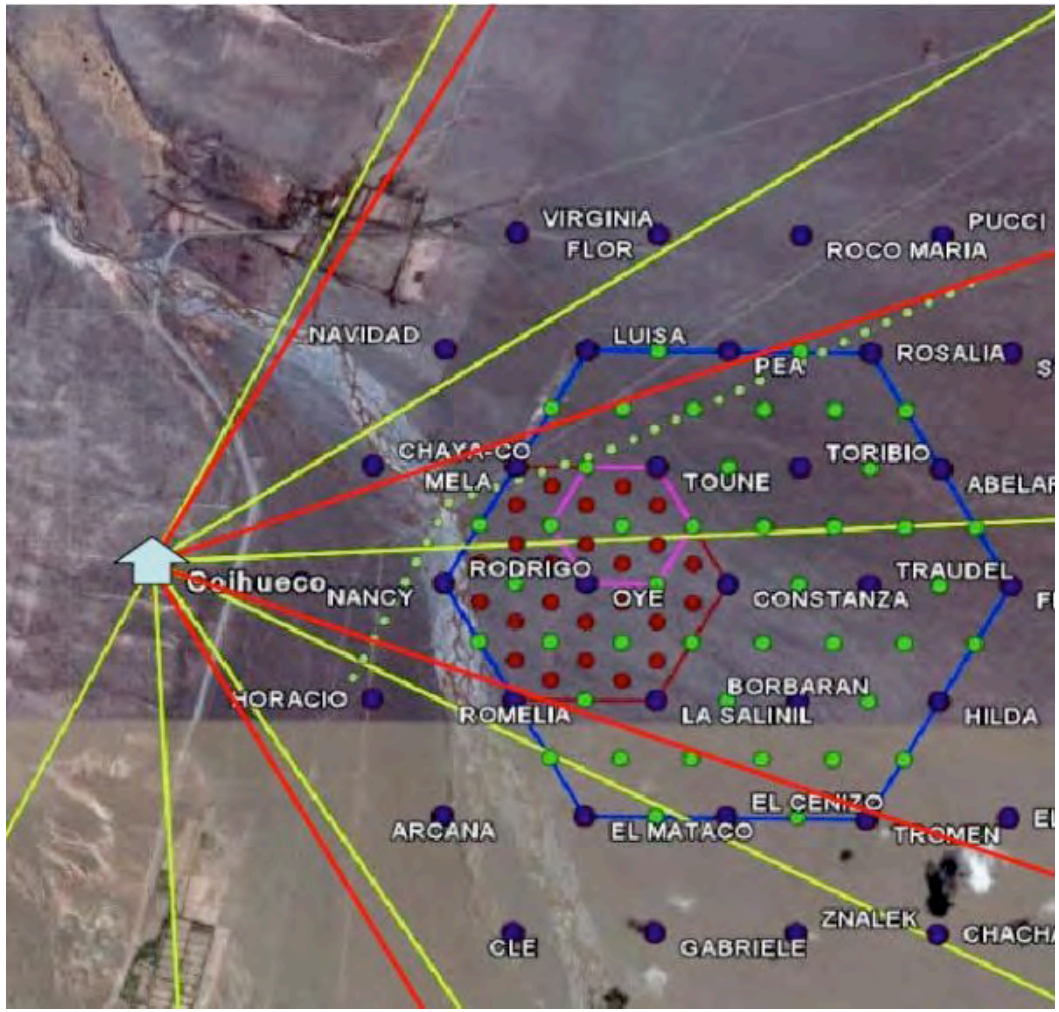
Fluorescence Detectors

4 telescope enclosures
24 telescopes total
*30° * 30° field of view*
duty cycle 10%



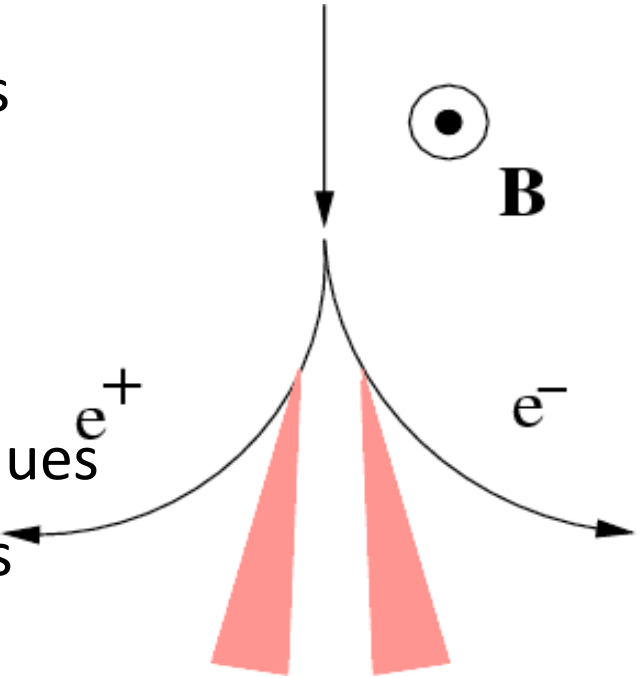
Enhancements to lower energies

- AMIGA - Auger Muons and Infill for the Ground Array
  - Additional tanks with smaller spacing
  - Buried muon counters
- HEAT - High Elevation Auger Telescopes
  - Field of view from 30˚ to 60˚ above the horizon
  - Regular telescopes: 1˚ to 31˚
- **AERA – Auger Engineering Radio Array**

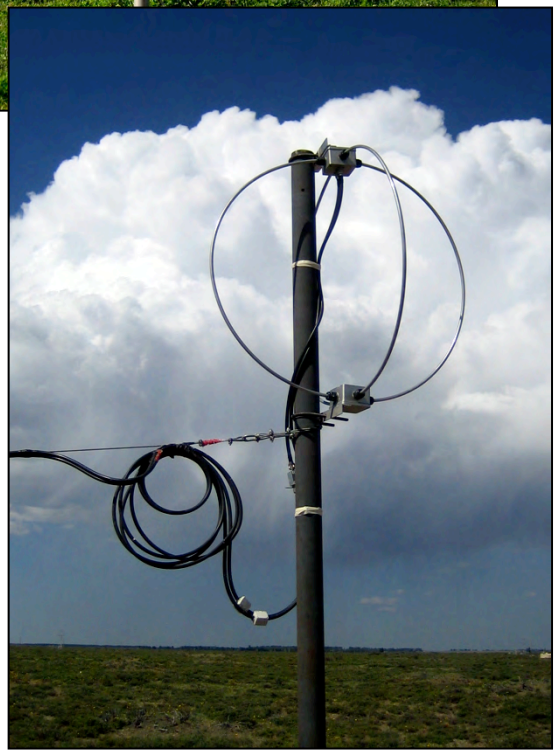


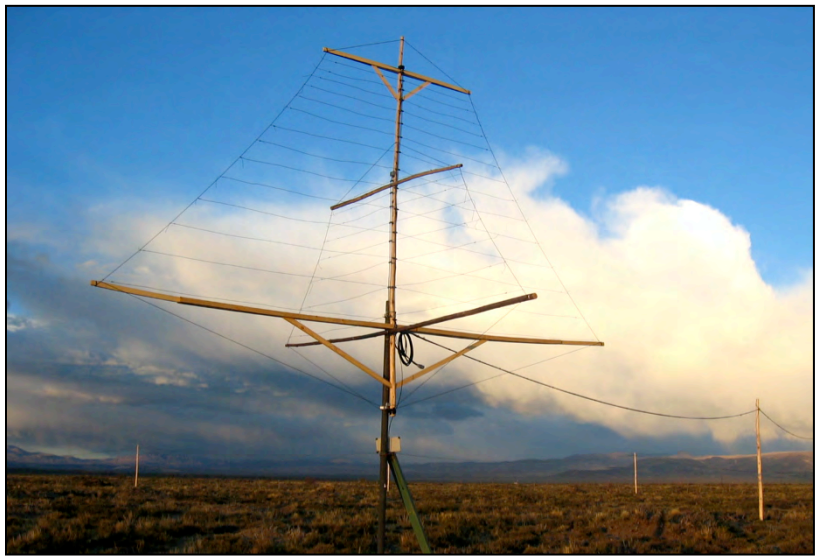
Radio emission and detection

- Cosmic ray air showers emit pulsed radio signals
  - Geomagnetic deflection of electrons and positron
  - Coherent in frequency range < 100 MHz
- Ideal complement for existing detection techniques
  - Sensitive to number of electrons / positrons
  - Measurement of two polarizations
  - 24 hours/day operation (10 x fluorescence)
  - Hybrid operation with surface detectors
  - Reconstruction of shower maximum -> study mass composition



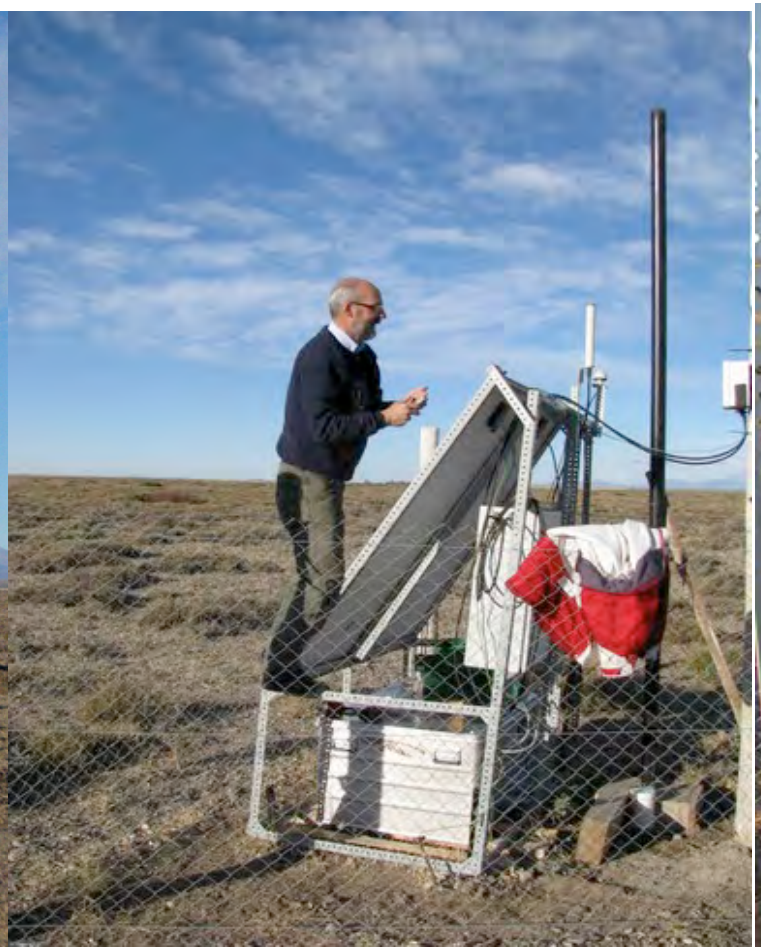
Prototype antenna designs





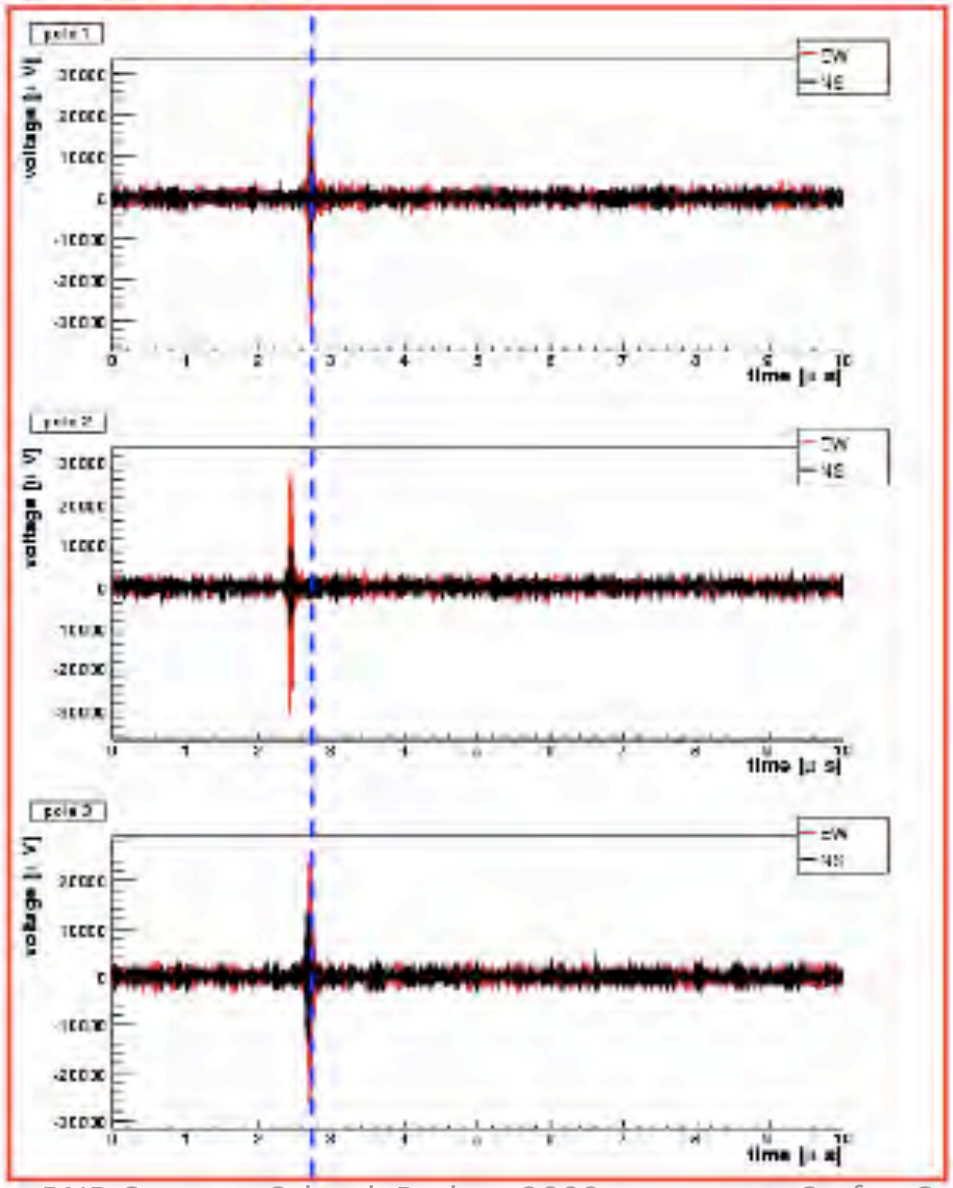
Dutch MAXIMA setup

- 4 stand alone stations close to a surface detector station
- Self and external triggering possible (scintillators)

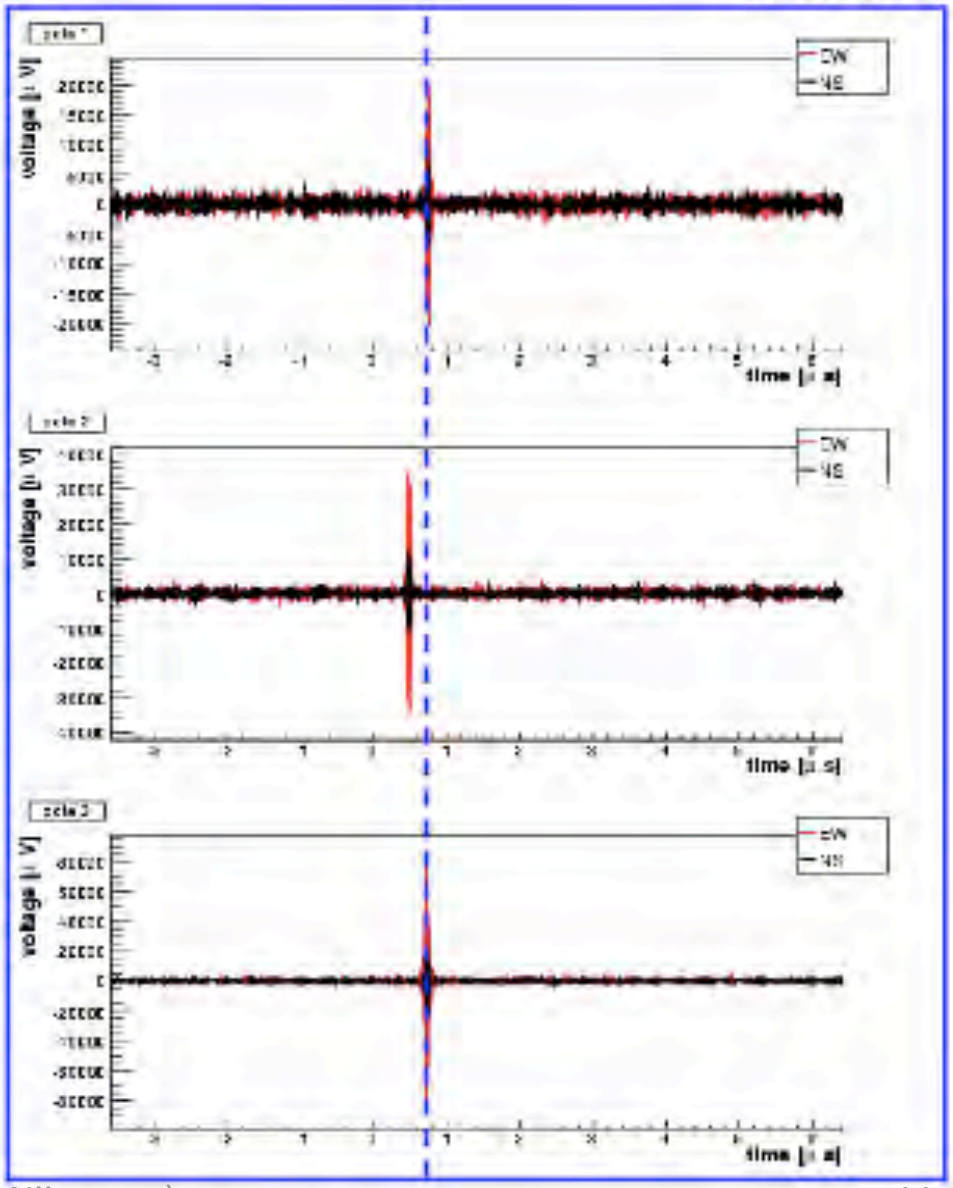


Example event

Measured:



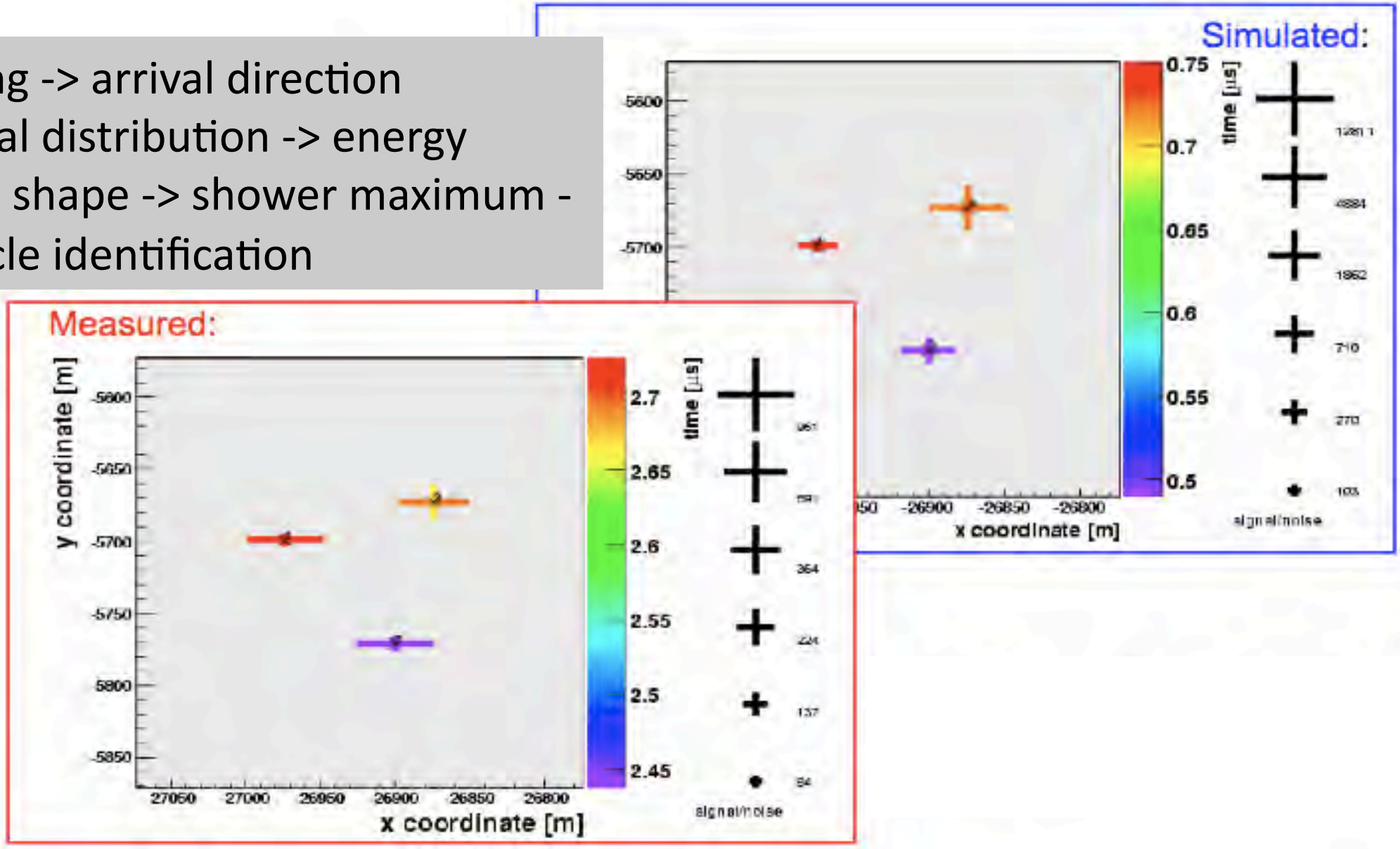
Simulated:



Reconstruction strategy

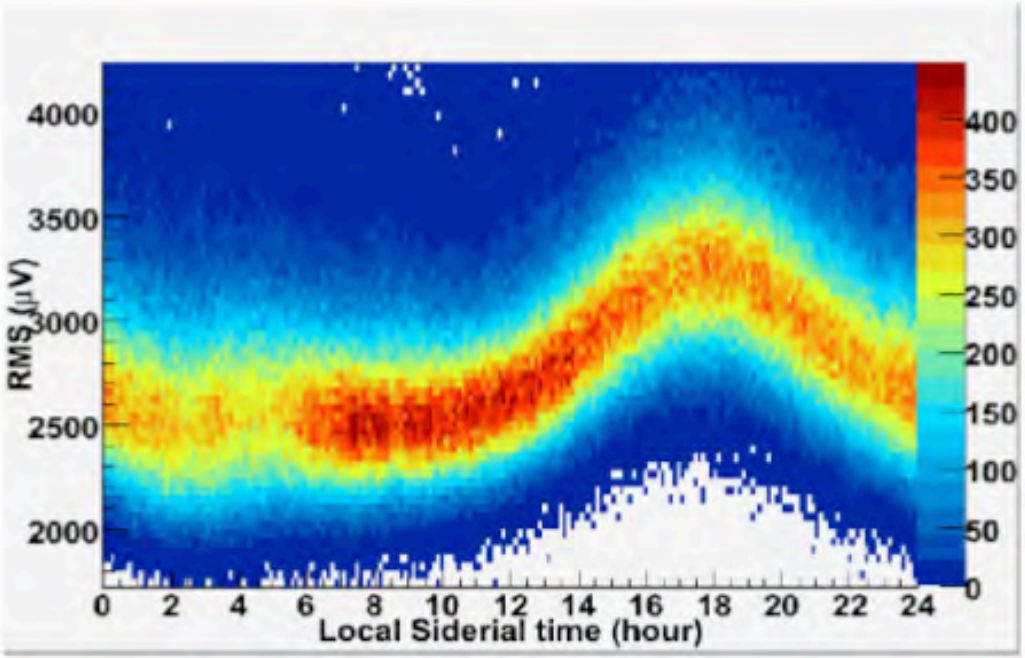
- Timing -> arrival direction
- Lateral distribution -> energy
- Pulse shape -> shower maximum -

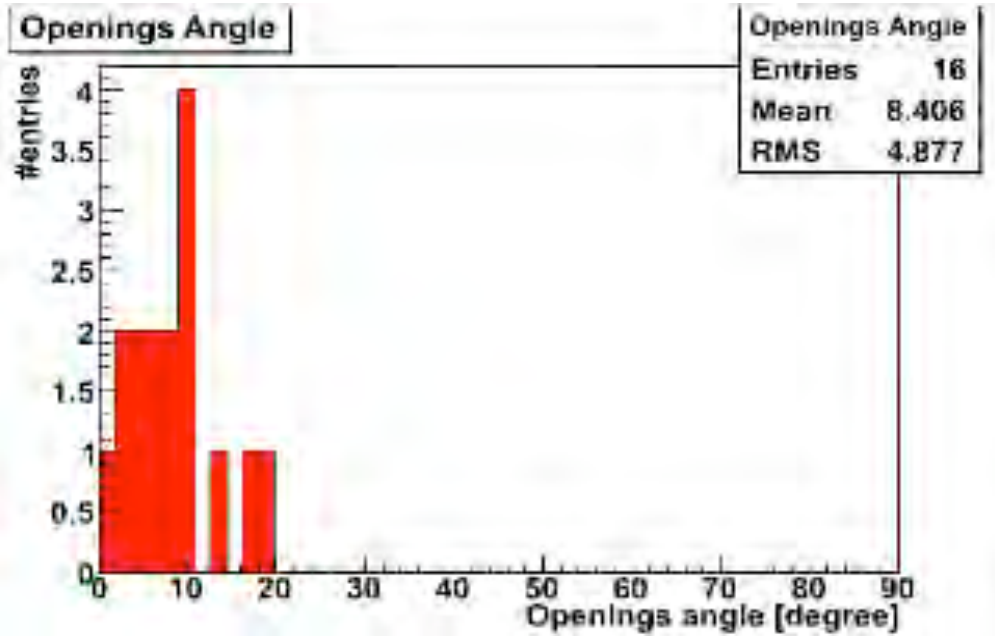
> particle identification



Some results

- Galactic background
  - Study antenna pattern
  - Compare polarizations

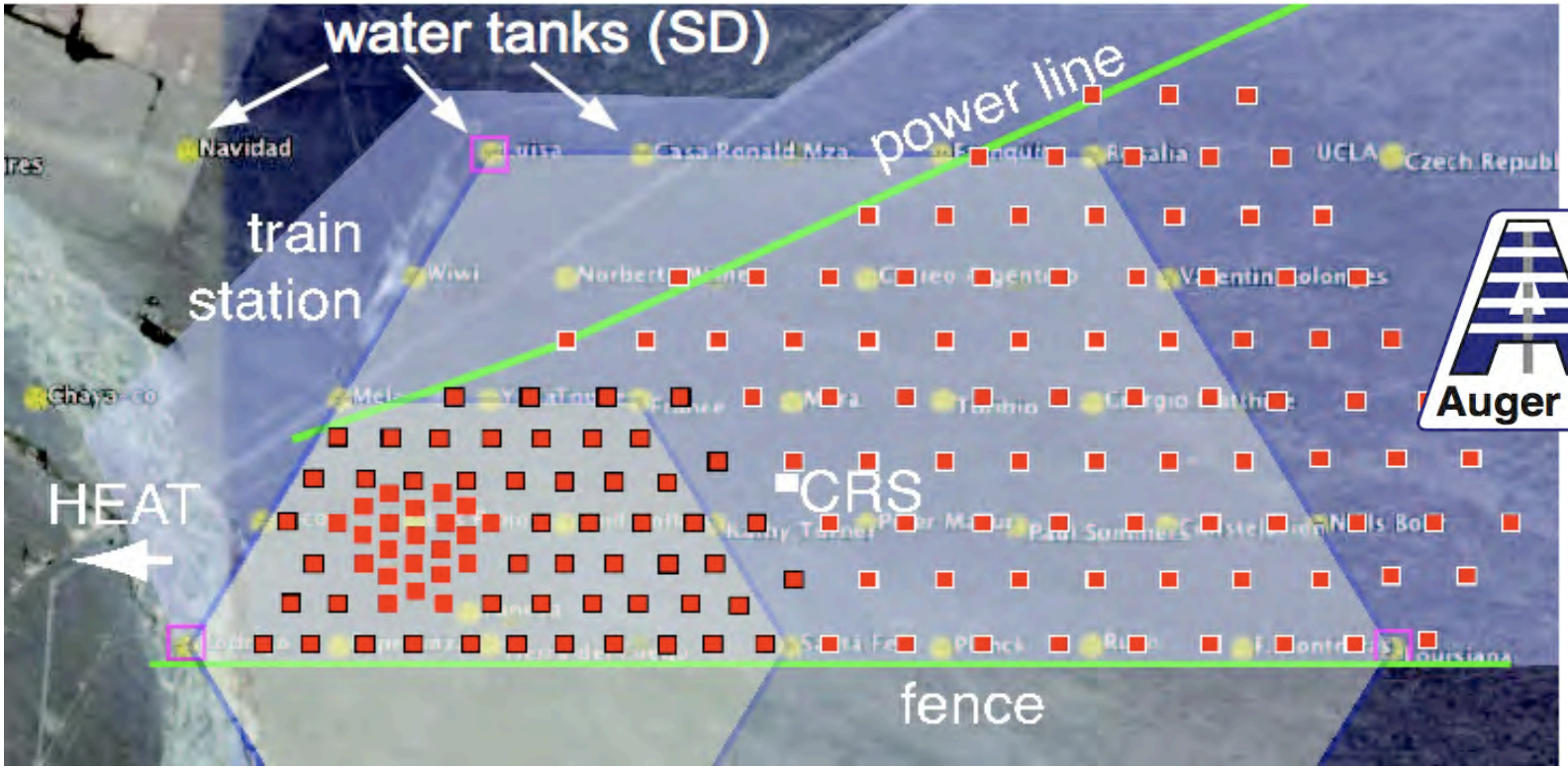




- Angular deviations to surface detector reconstruction
  - Full (preliminary) reconstruction chain in software framework
  - Compare data with simulations

Auger Engineering Radio Array

- Accepted proposal
- 150 detectors on 20 km^2 (largest cosmic ray radio detector ever built)
- Co-located with low-energy extensions of other Auger detectors
- Expect ~ 800 cosmic ray events per year with E > 10^{18} eV



AERA
Auger Engineering Radio Array

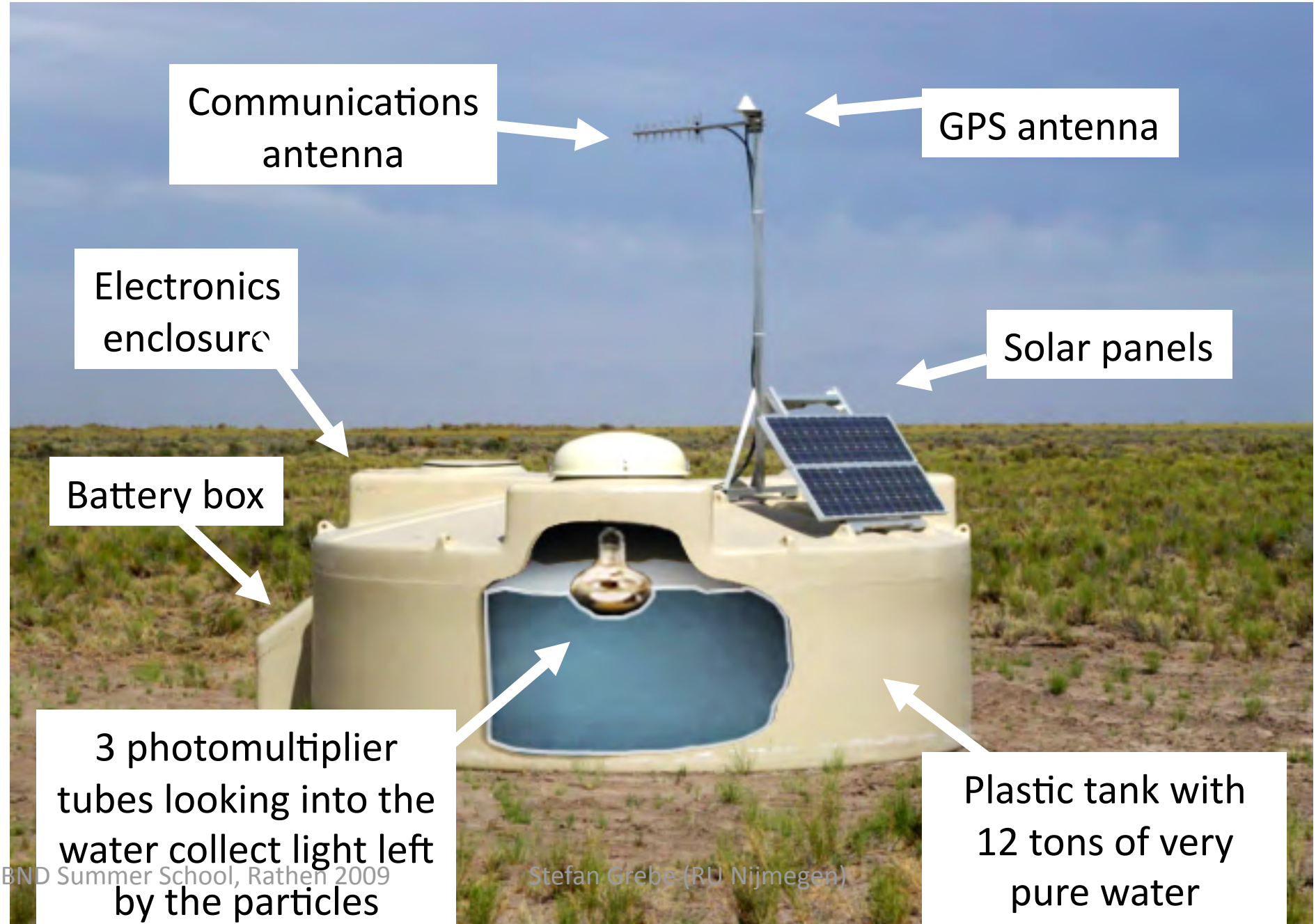
Summary and outlook

- Principle feasibility of radio detection has been showed
- First results are very promising
- This year 4 more MAXIMA stations
- Start of AERA next year

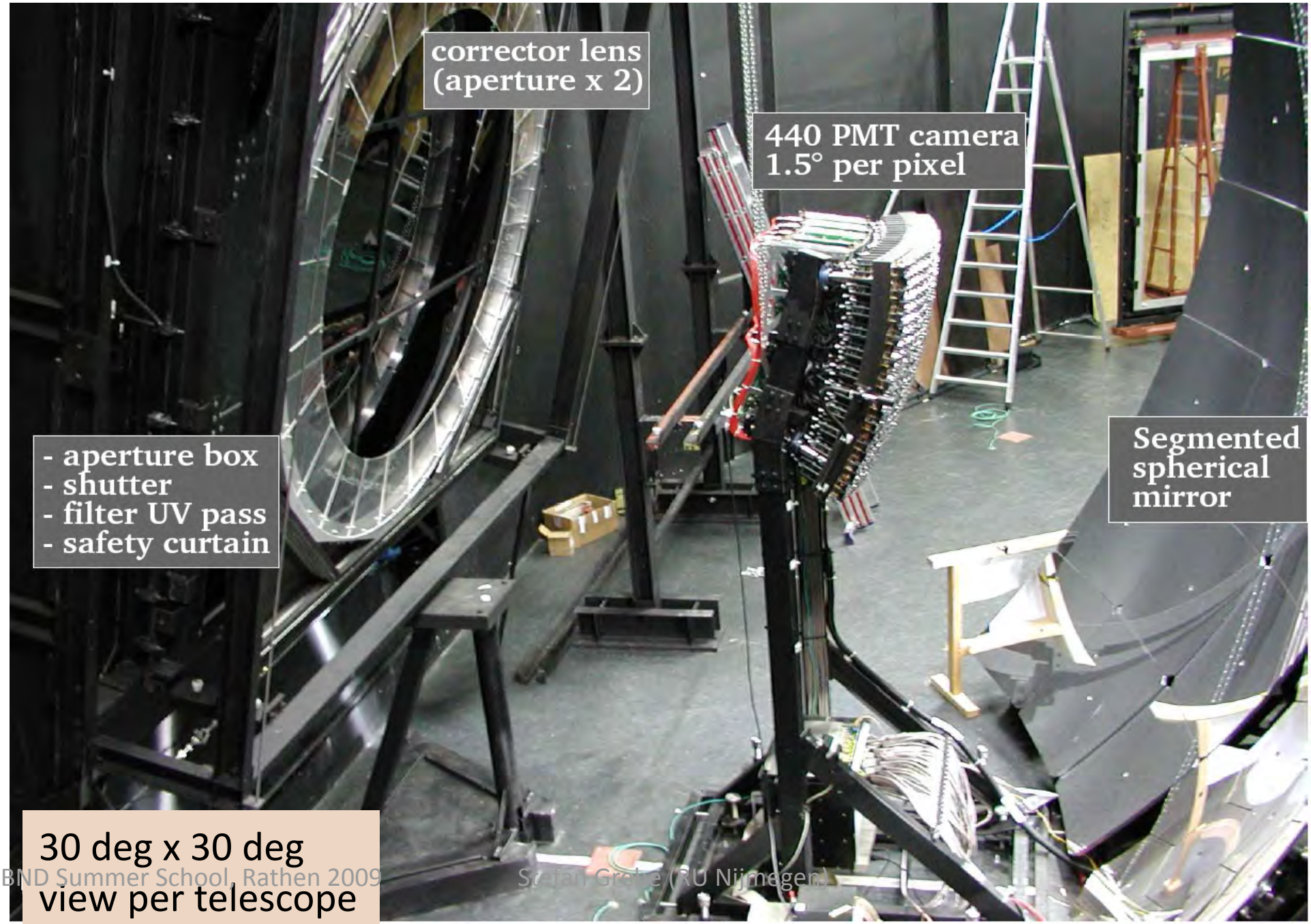
- Precision measurements with:
  - Surface detector (small spacing) and muon counters
  - Fluorescence from 0˚ to 60˚
  - Radio

Institutions participating in AERA

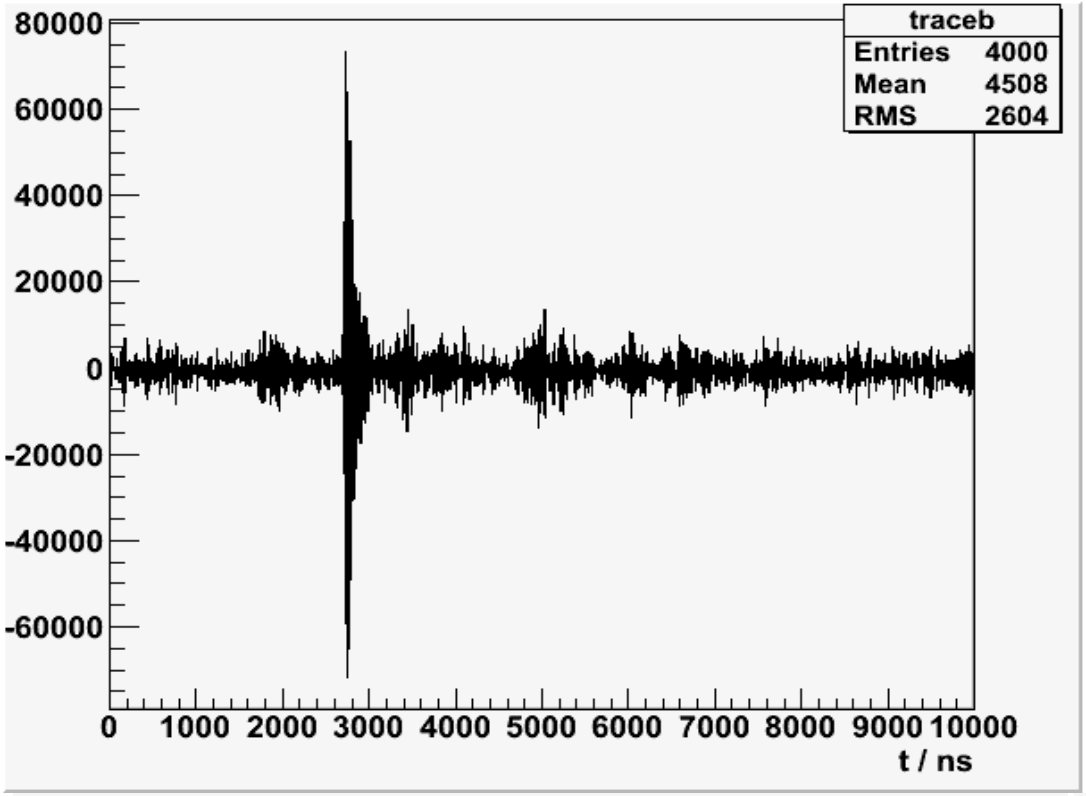
A surface detector station

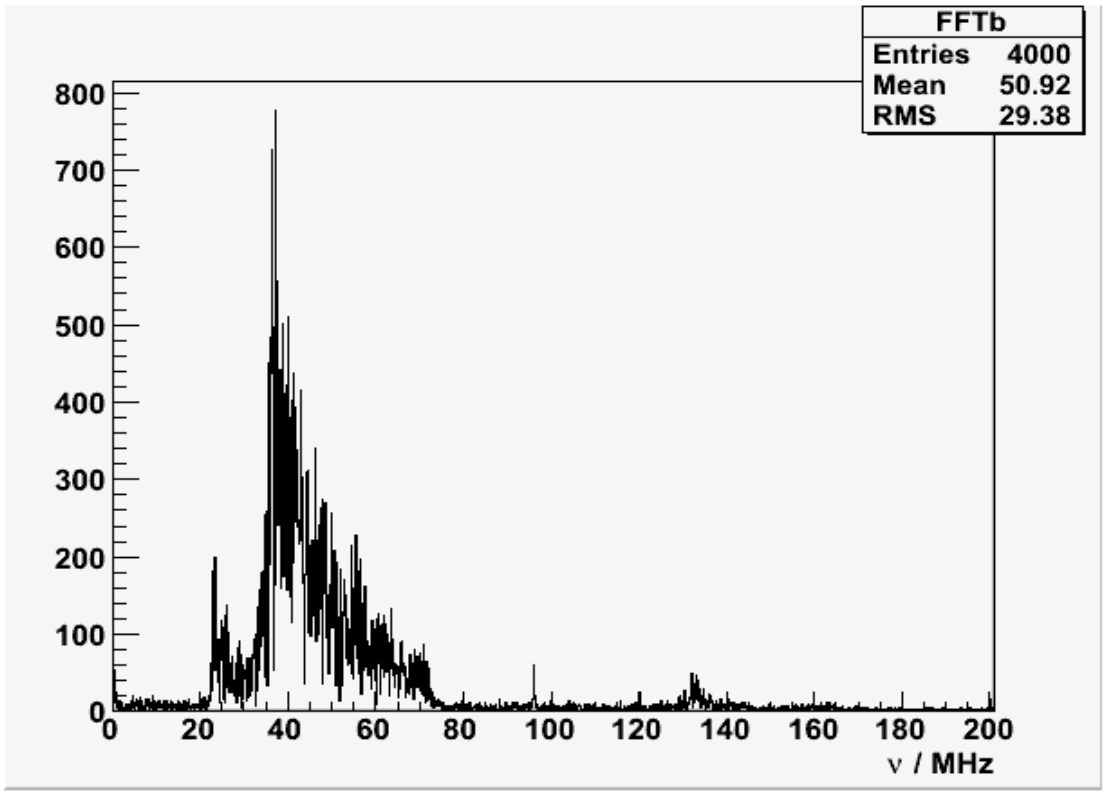


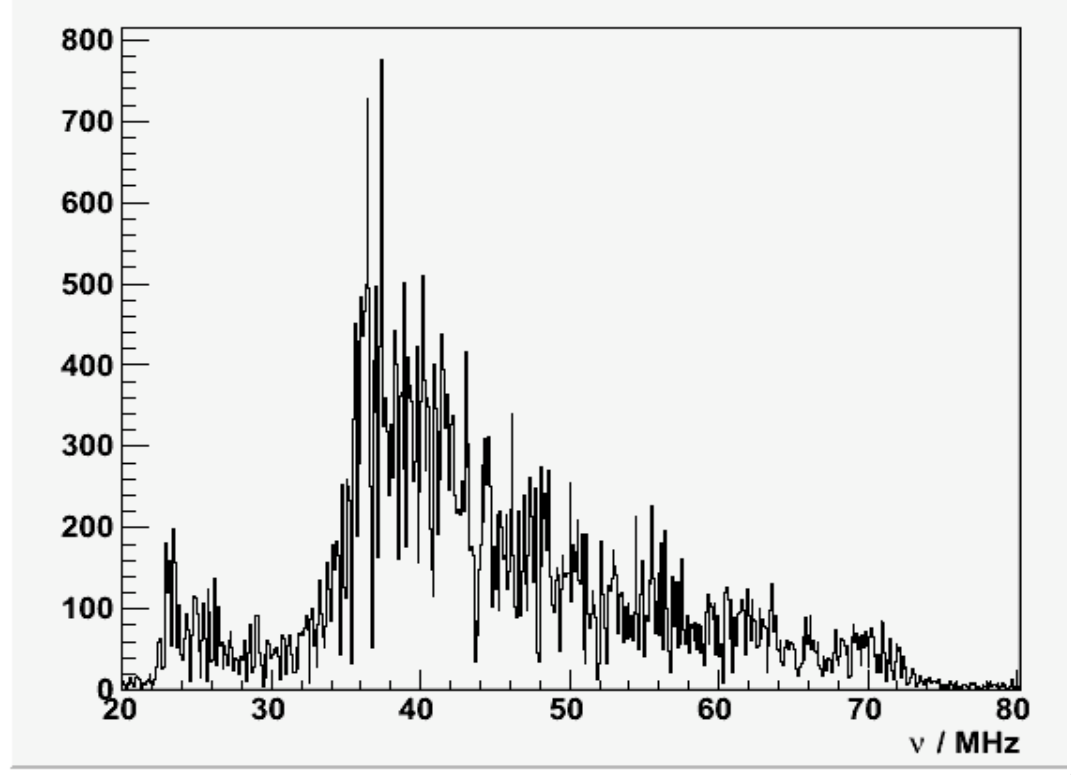
A fluorescence telescope

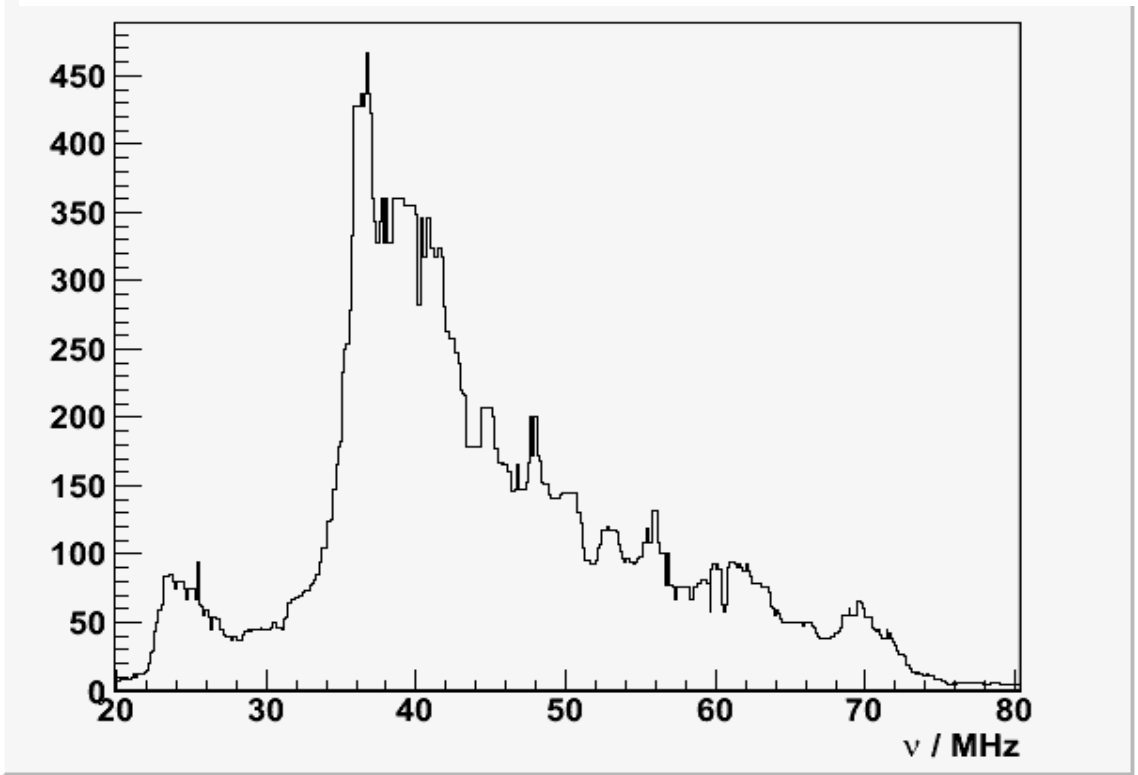


30 deg x 30 deg
view per telescope


traceb
Entries 4000
Mean 4508
RMS 2604
80000
60000
40000
20000
0
-20000
-40000
-60000
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
t / ns


FFTb
Entries 4000
Mean 50.92
RMS 29.38
800
700
600
500
400
300
200
100
0
0 20 40 60 80 100 120 140 160 180 200
ν / MHz


800
700
600
500
400
300
200
100
0
20 30 40 50 60 70 80
ν / MHz


450
400
350
300
250
200
150
100
50
0
20 30 40 50 60 70 80
ν / MHz