PIERRE AUGER OBSERVATORY

Status of the program for microwave detection of cosmic rays at the Pierre Auger Observatory

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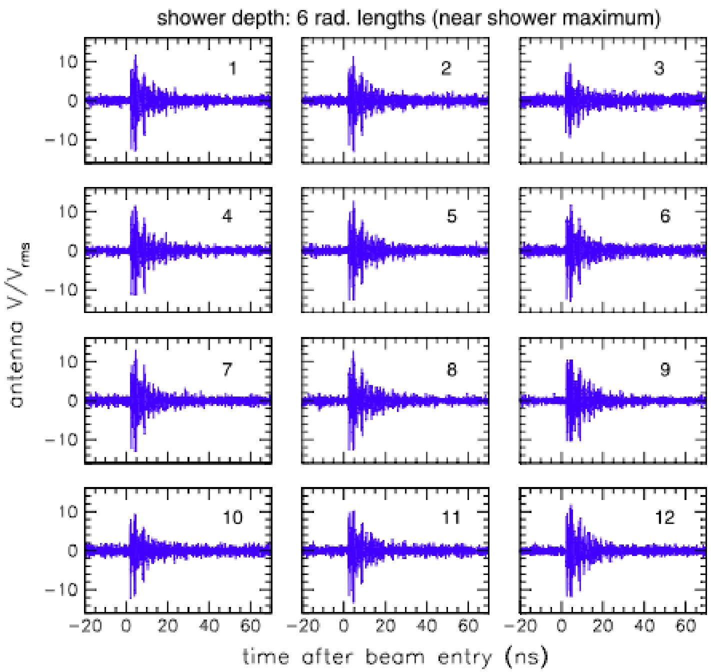
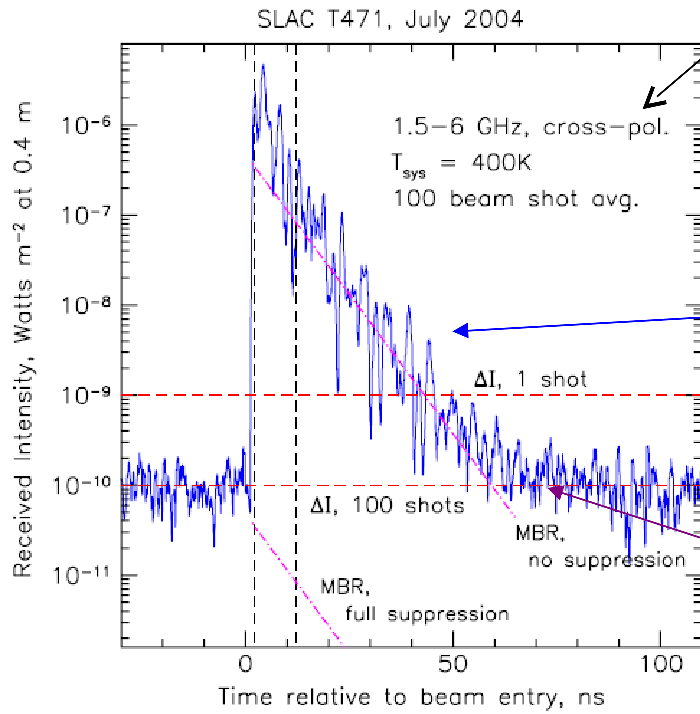
The University of Chicago, Kavli Institute for Cosmological Physics and Enrico Fermi Institute, USA

International Symposium on Future Directions in UHECR Physics, 13-16 February 2012 CERN

Motivation





Insensitive to radio Cherenkov

Measured signal attributed to molecular bremsstrahlung

Expectation, emission enhanced by coherence

P.W Gorham *et al.*, "Observations of microwave continuum emission from air shower plasmas" Phys. Rev .D. **78**, 032007 (2008)

Golden channel for UHECR detection

Unpolarized and isotropic

Calorimetric energy and longitudinal profile

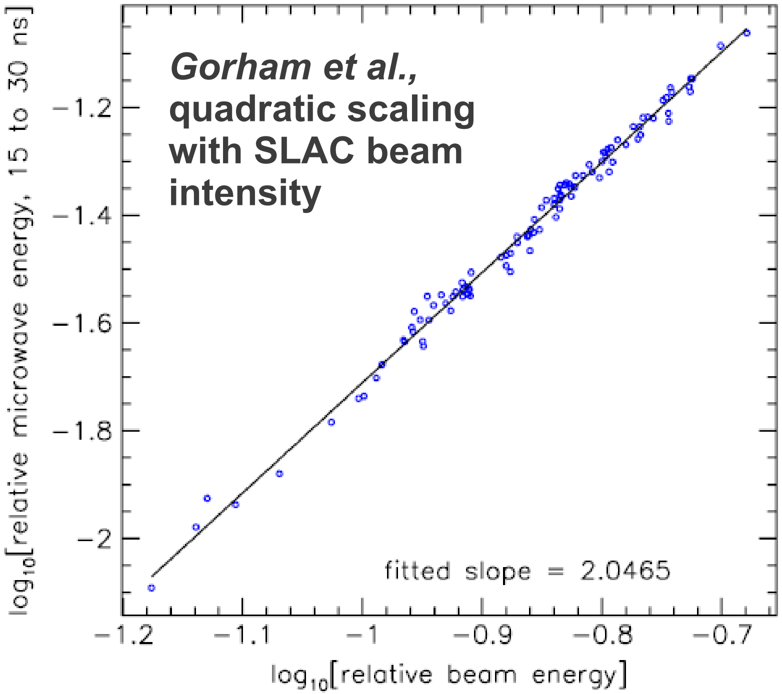
Microwave, GHz range, flat in frequency

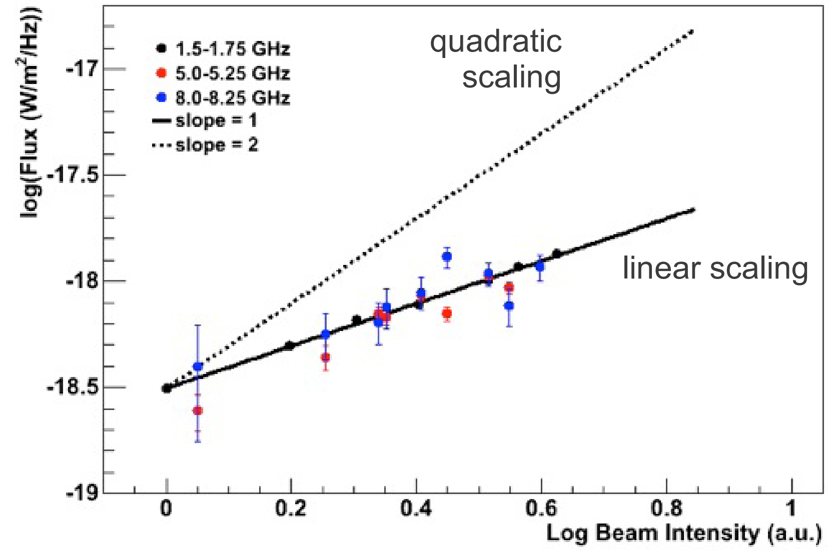
100% duty cycle

Minimal atmospheric attenuation
(even with clouds and rain)

Low cost
(satellite TV equipment)

From the lab to air showers: signal level and scaling can depend on the characteristics of the plasma.





MAYBE (C. Williams, previous talk), linear scaling with beam intensity

Scaling the *Gorham flux:*

Flux density at 0.4 m

$I_{0,\,meas} = 4\ 10^{-16}$ **W/m²/Hz** → **@ 10 Km** → $I = 2.8\ 10^{-24}$ **W/m²/Hz**

$E_0 = 3.4\ 10^{17}$ **eV**

Bunch equivalent energy

$$\Delta I = \frac{k\,T_{sys}}{A_{eff}\sqrt{\Delta t\,\Delta f}}$$

→ **T_{sys}=100 K A_{eff} = 10 m² Δt = 100ns Δf = 1GHz** → $\Delta I = 1.6\ 10^{-23}$ **W/m²/Hz**

Minimum detectable flux density

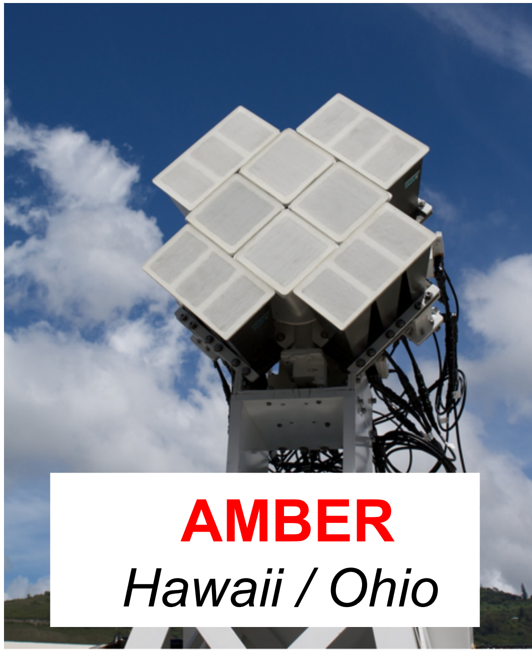
5σ detection threshold

$E_{qua} \sim 2 \cdot 10^{18}$ eV

$E_{lin} \sim 10^{19}$ eV

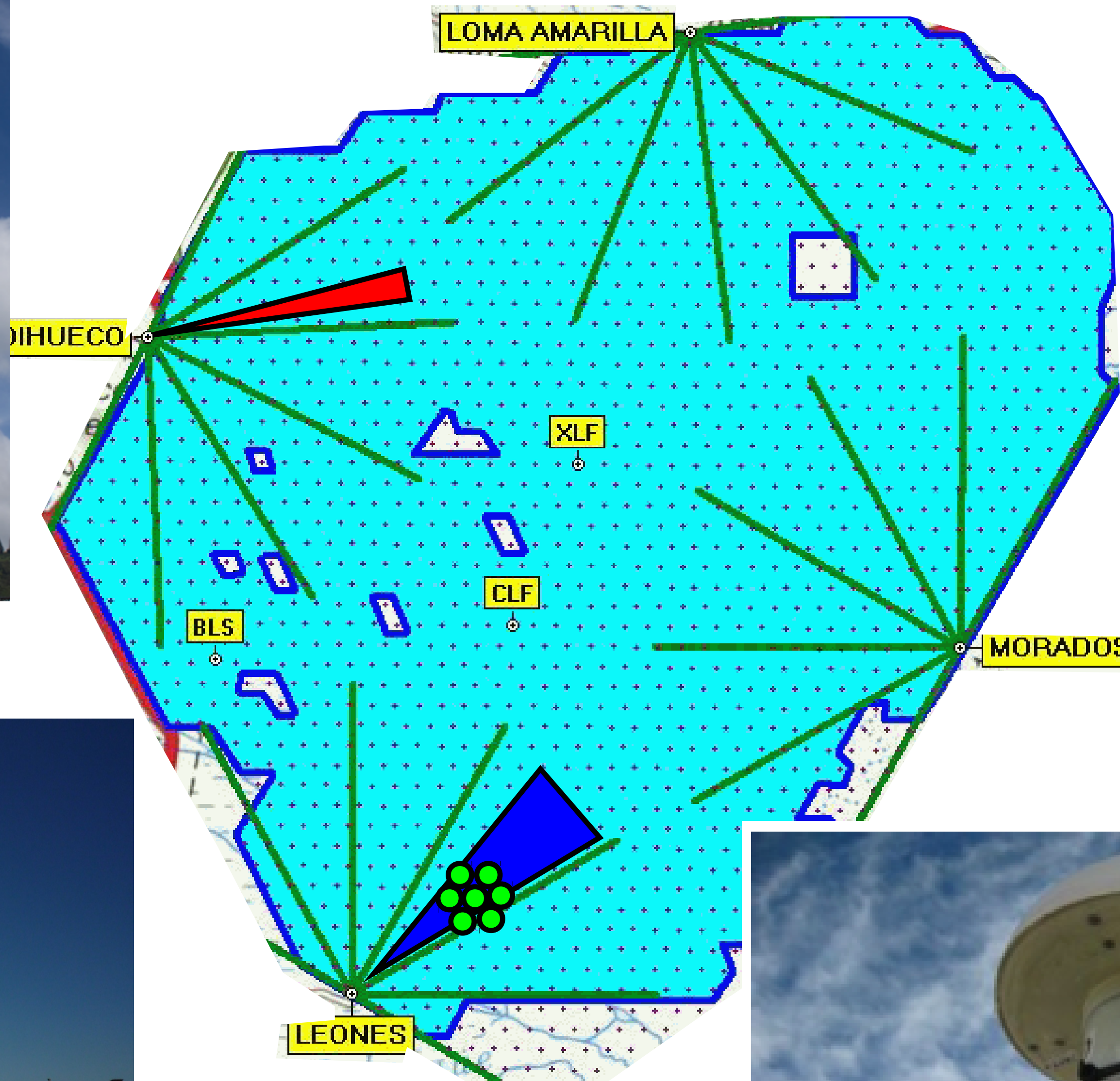
Feasible with realistic detector

GHz R&D at the Auger Observatory



AMBER

Hawaii / Ohio



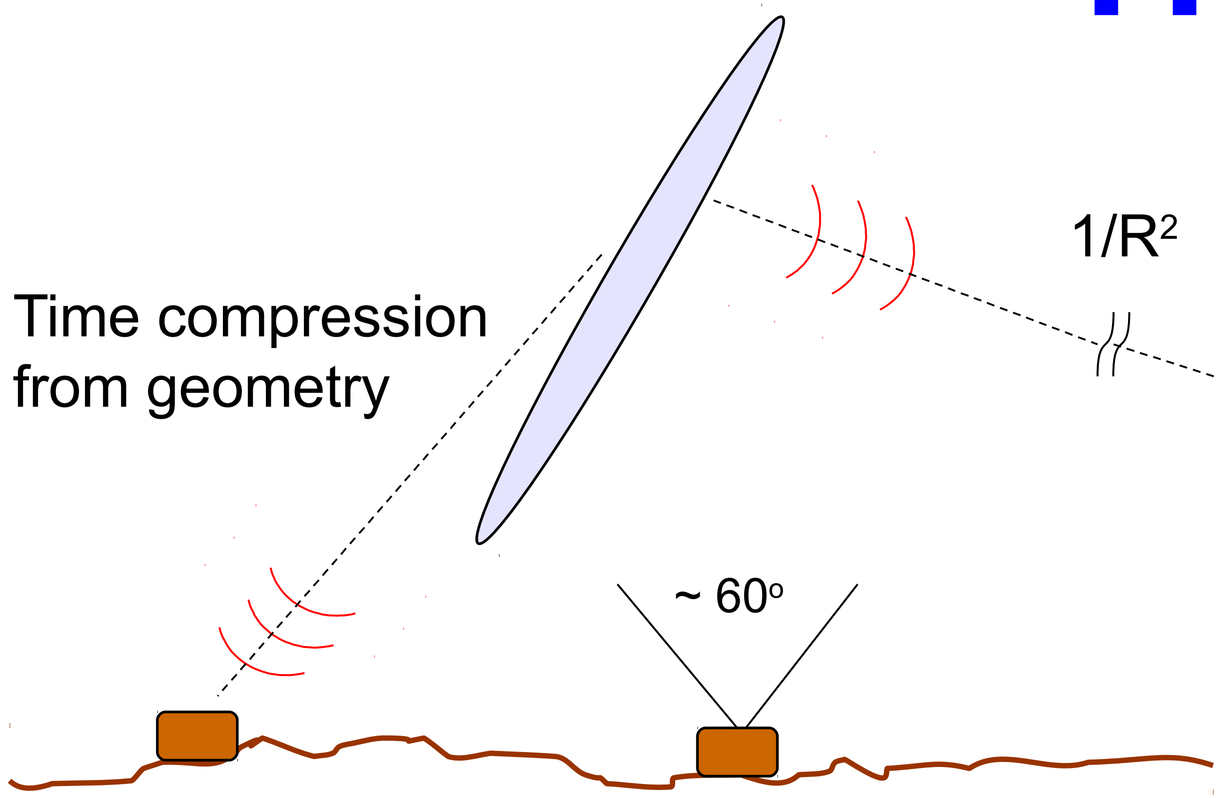
MIDAS

Chicago/Rio/Bariloche/USC

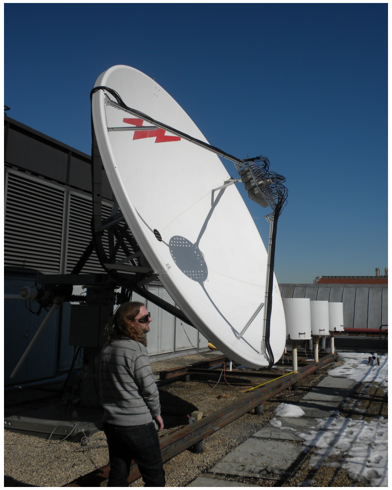
EASIER

LPHNE/Grenoble/Orsay/Rio

Two different approaches



~ 10 m² antenna effective area
10 km distance from shower
O(1 μs) pulse width



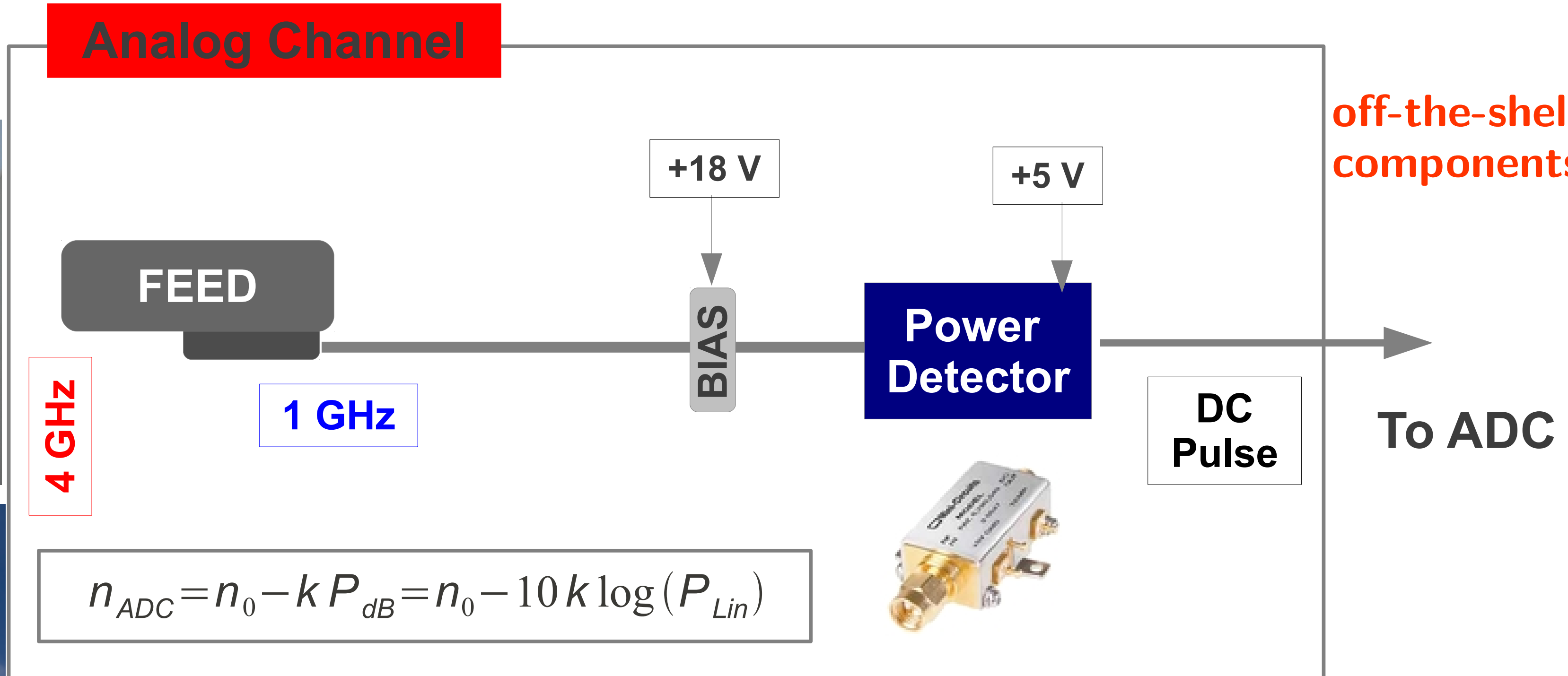
0.003 m² antenna effective area
Large field-of-view
1 km distance from shower
O(100 ns) pulse width

EASIER: install a wide aperture antenna at the Surface Detector stations

MIDAS/AMBER: use a parabolic dish reflector instrumented with an array of feeds, 'Radio fluorescence'.

NOTE: EASIER vs MIDAS/AMBER: the shower is closer and the signal is boosted by the geometrical time compression. Also, being triggered by the tank, better signal over noise by averaging over events. EASIER sensitivity close to large FD-like dish.

.. but basically the same instrumentation to detect GHz radiation



Two main elements:

Feed+LNB or LNBF: antenna element (C-Band 4 GHz) , high gain amplifier and downconverter

Power detector: provides a DC pulse proportional to the log of the power in the microwave signal. Time response 10-100 ns depending on configuration.

AMBER

FD-like detector

2.4 m off-axis parabolic dish instrumented with 16 C-band (~ 4 GHz) feeds and 4 K_u band (~ 10 Ghz feeds).

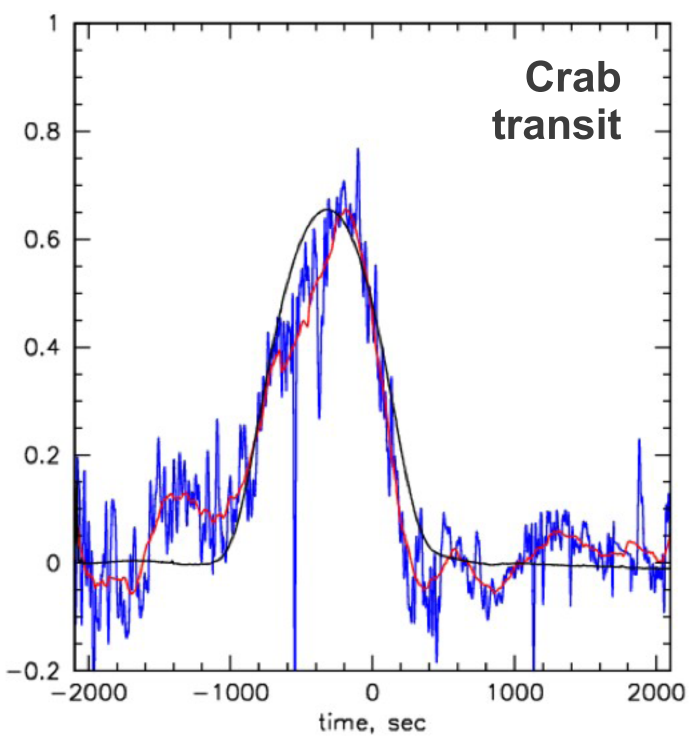
Some feeds instrument both polarizations, 28 channels in total.

SD-triggered: local buffer is circa 5 seconds deep to account for latency.

When a trigger is received 100 μs of data are stored for analysis.

During commissioning, cross-check of telescope pointing, alignment and focus.

System temperature C-Band ~ 60 K



AMBER installed overlooking low energy 'infill' array in May 2011.

Data analysis underway, looking for coincidences with the SD.

MIDAS

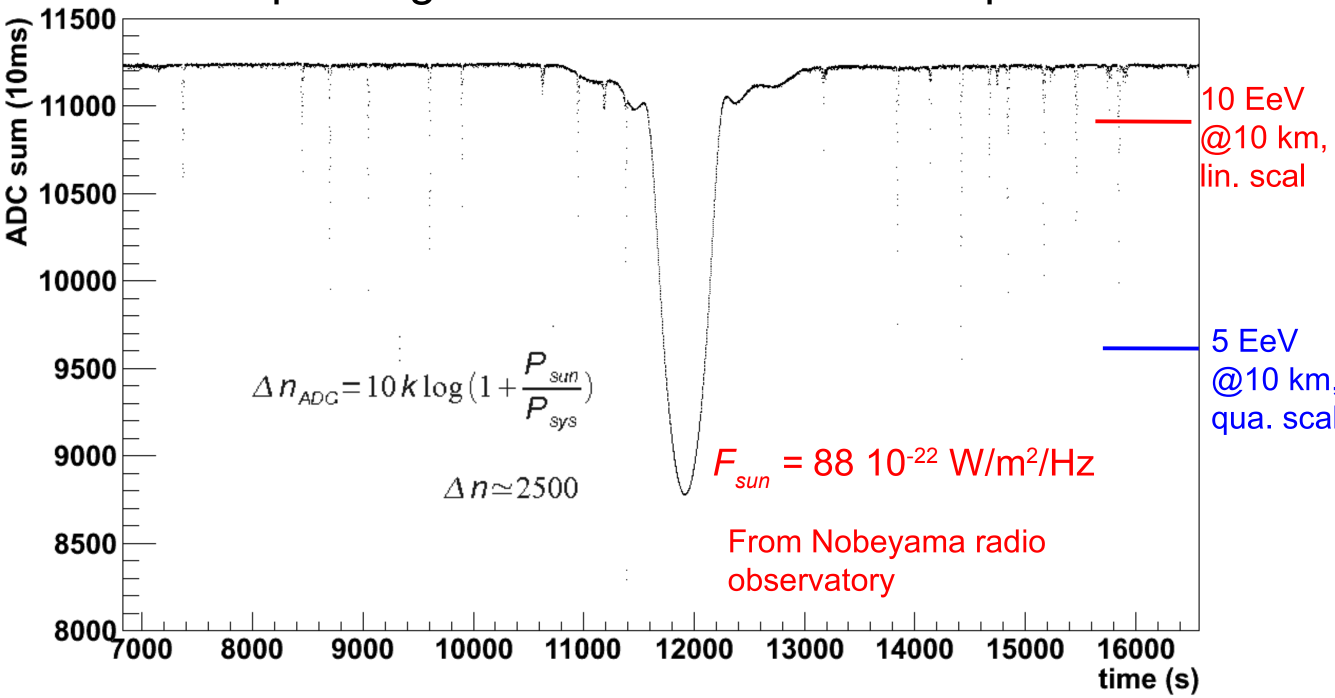
4.5m dish, 53 channels, 20x10° field of view.

Self triggered, pixel threshold trigger (regulated for constant rate) + topological second level trigger.

Commissioning and data run in Chicago

Waiting to be installed in Malargüe

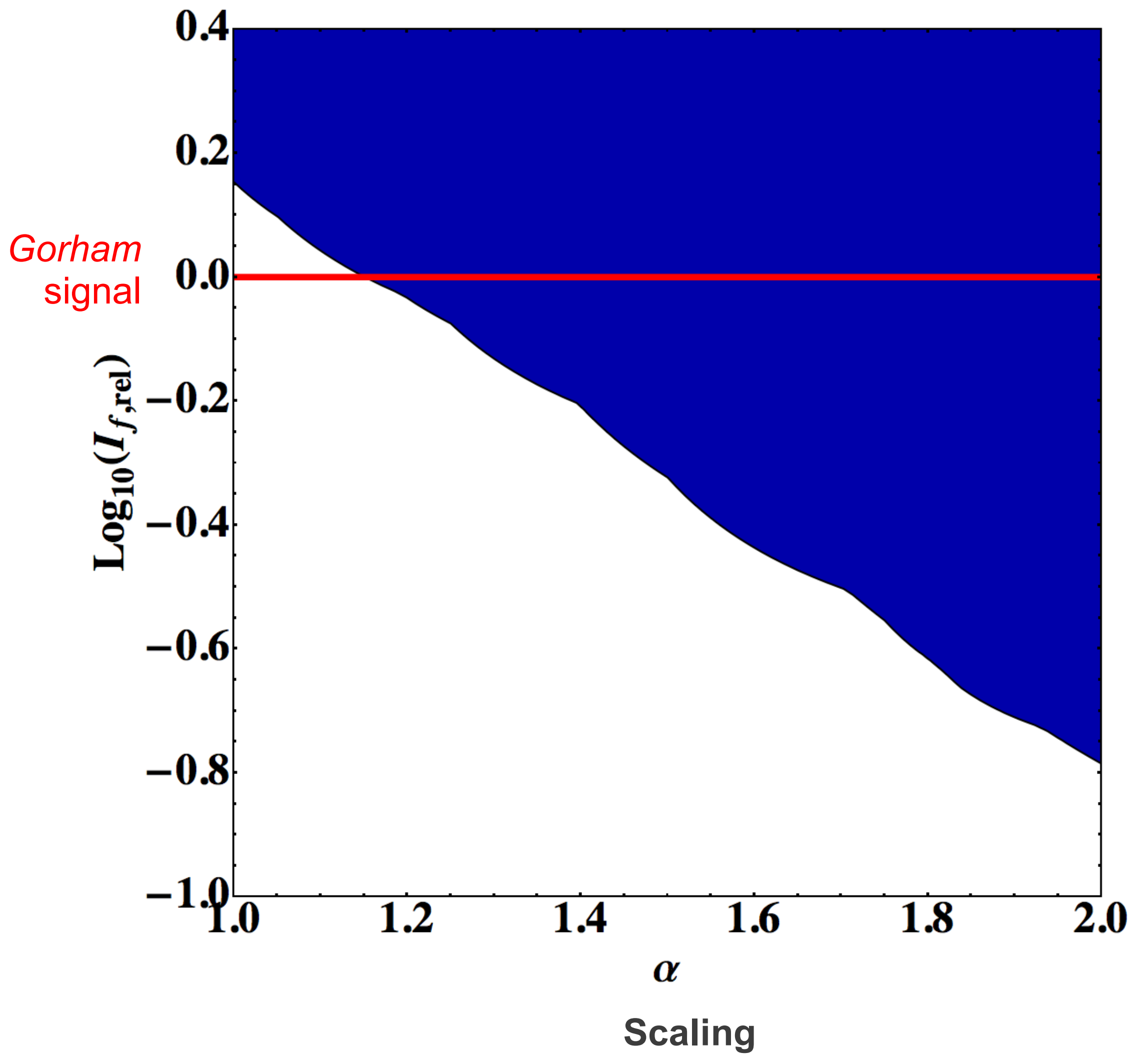
Sun passing in the f.o.v. of the central pixel



Absolute calibration and sensitivity using the signal from the sun

$T_{SYS} \sim 120$ K

MIDAS: limit on the GHz emission



3 months data taking in Chicago:

- Event candiates with 5 pixels not observed, rule out Gorham signal with quadratically scaling.

- Some 4 pixels candidates but background estimation is difficult: coincidence with particle detector needed.

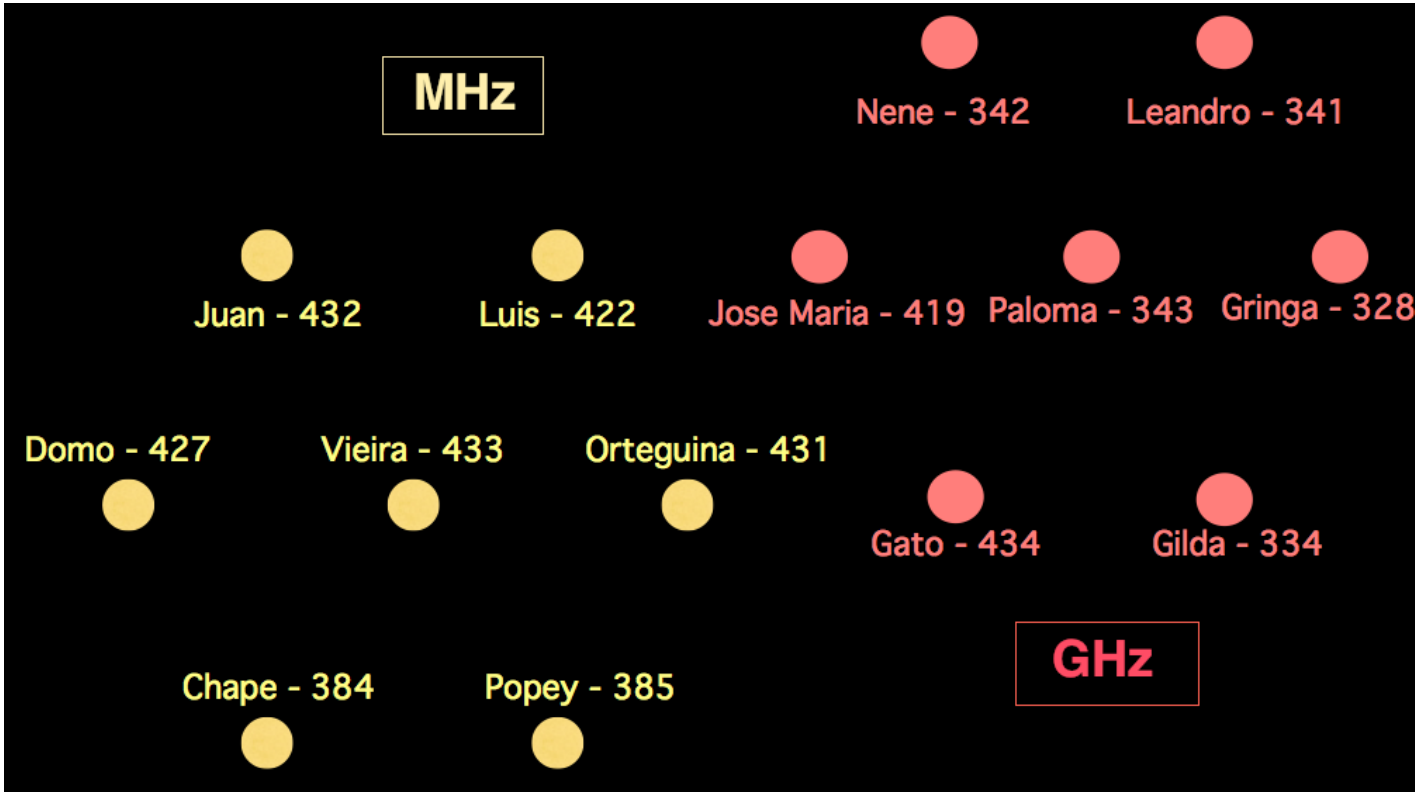
Expected rate at Malargue (linear scaling) ~ 1 ev/month

EASIER

Simple set-up: one antenna (MHz or GHz) in an SD tank, connected to one of the FADC channels.

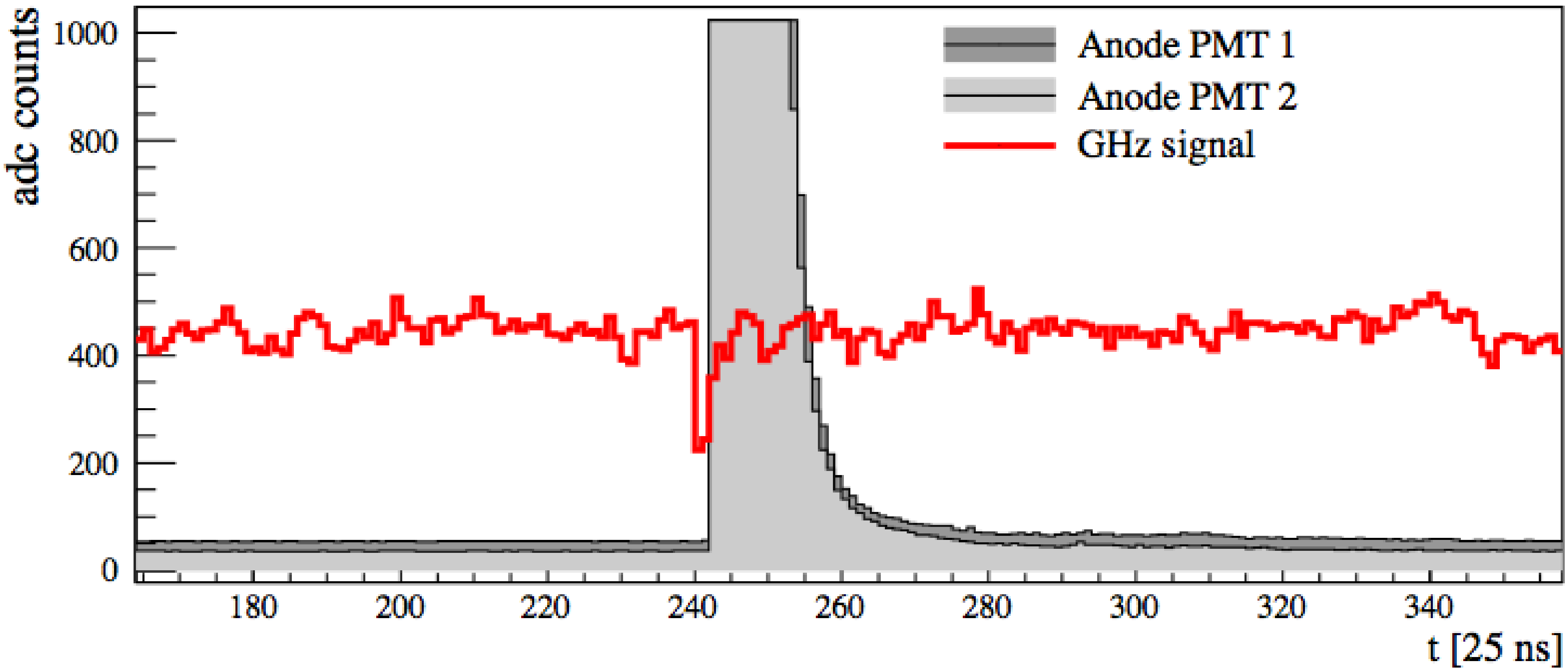
Small collection area but boost from geometry.

Antennas are read-out when the SD triggers, and data is integrated in the SD data stream.



AIM: Auger South upgrade with 100% duty cycle electromagnetic detector (see Antoine LS talk, friday)

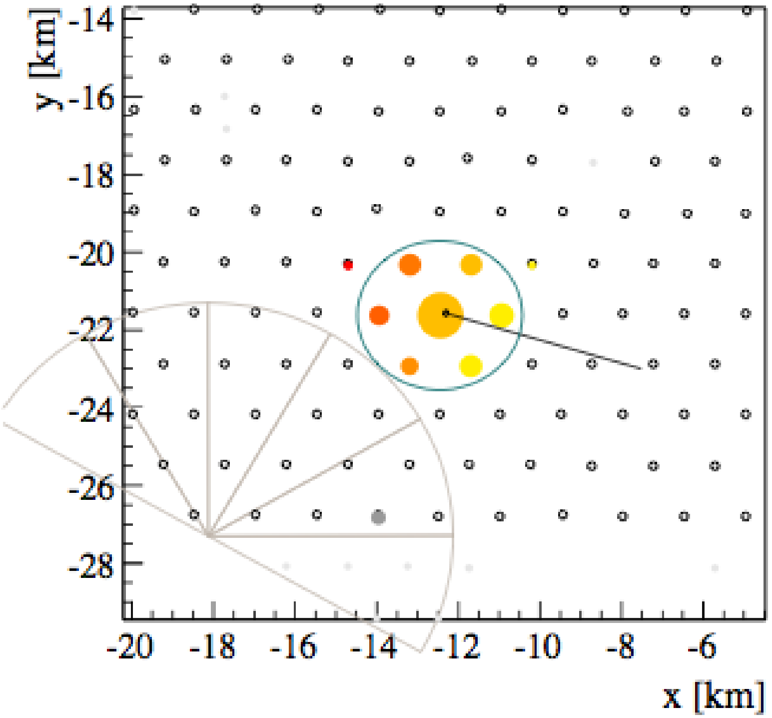
EASIER GHz candidate

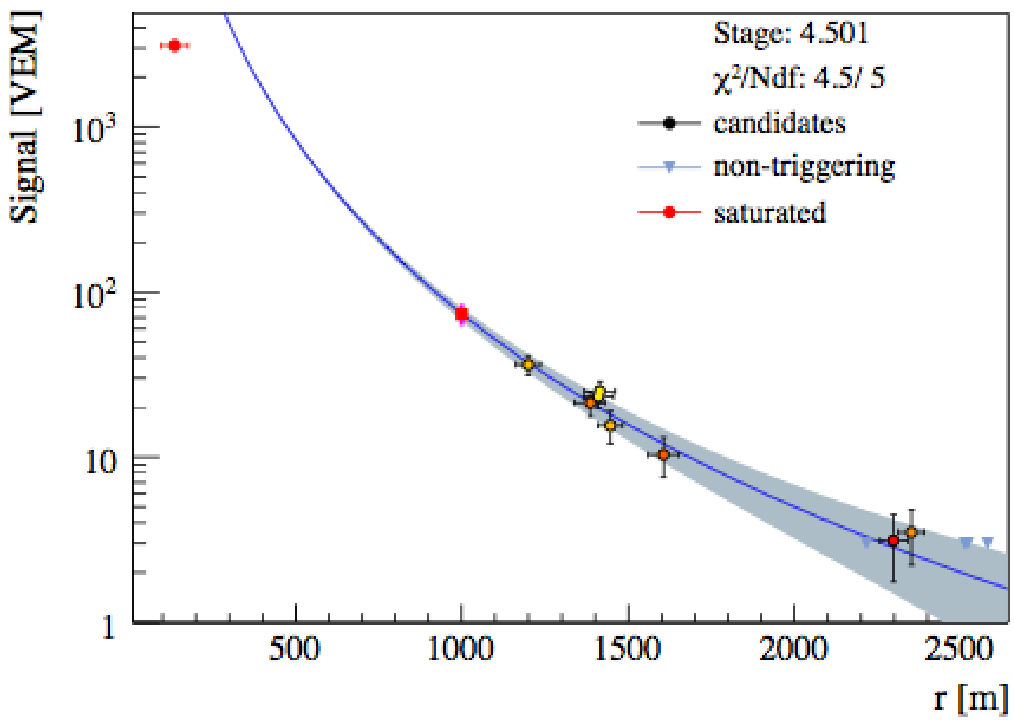


First evidence of GHz radiation from an air shower

Detection time of GHz signal (before PMT signal) excludes possibility of emission from PMT itself

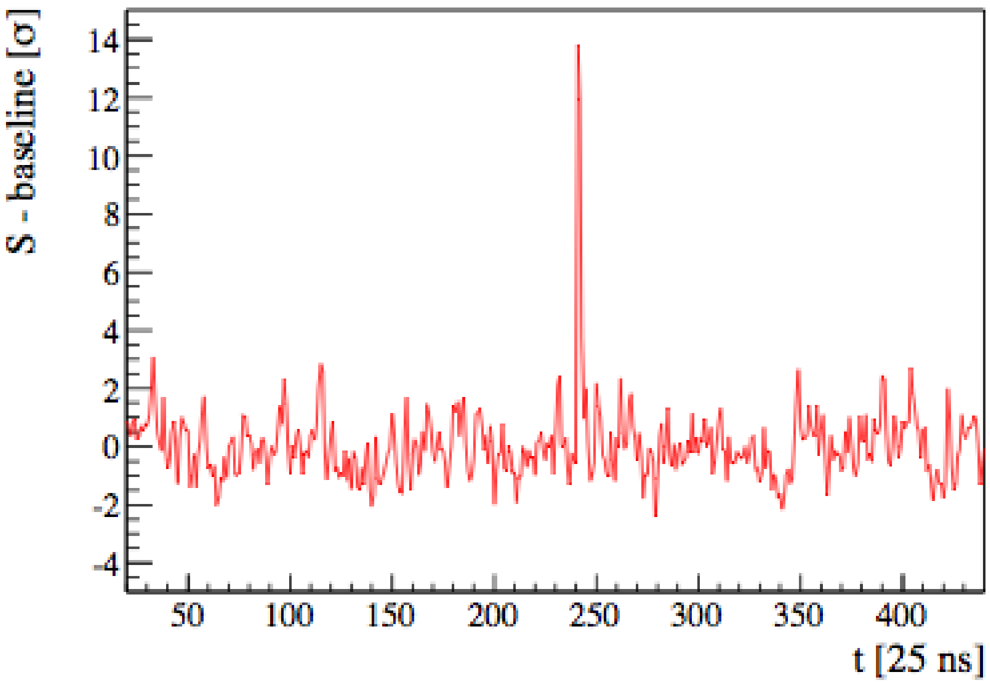
First EASIER GHz candidate



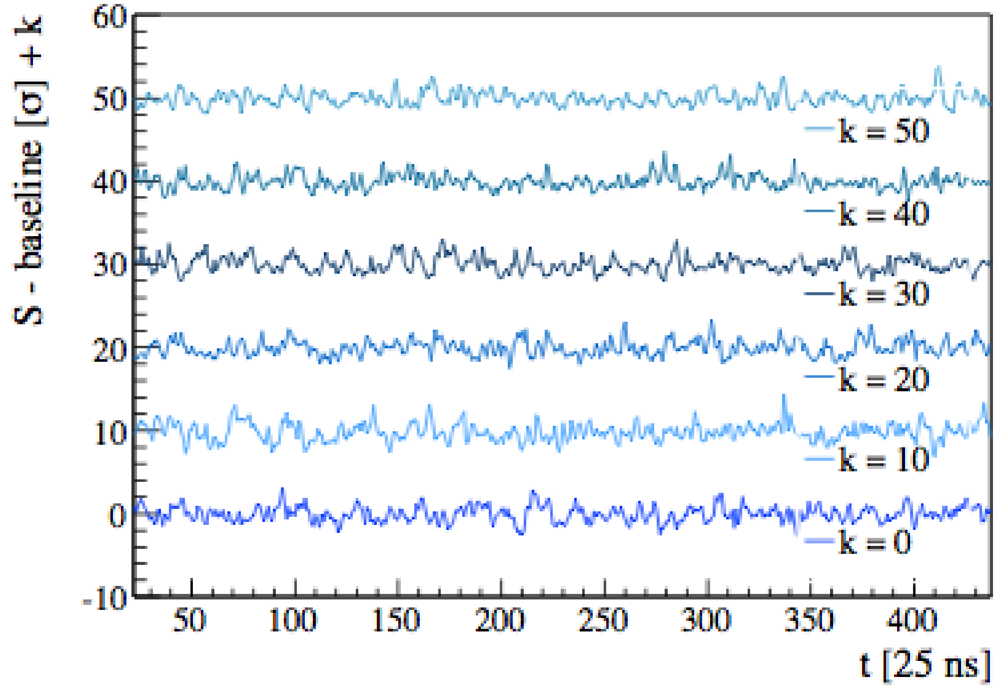


- A very large energy shower E = 14 EeV, zenith angle ≈ 30^{o}
- Shower core very close to Nene (≈ 140 m), PMT saturated

First EASIER GHz candidate



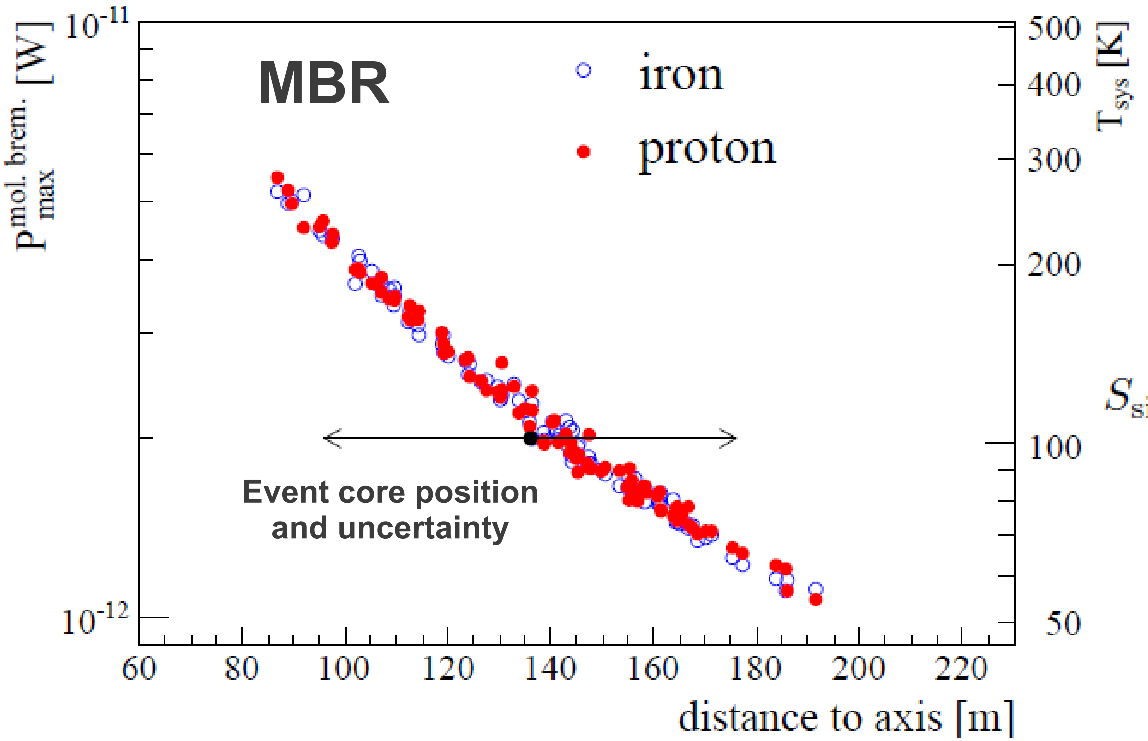
14 σ significance on the detected signal



No signal detected on the other tanks in the hexagon

Difficult to extract conclusions from a single shower, still we can compare it with the expectations from MC simulations

EASIER event: simulation

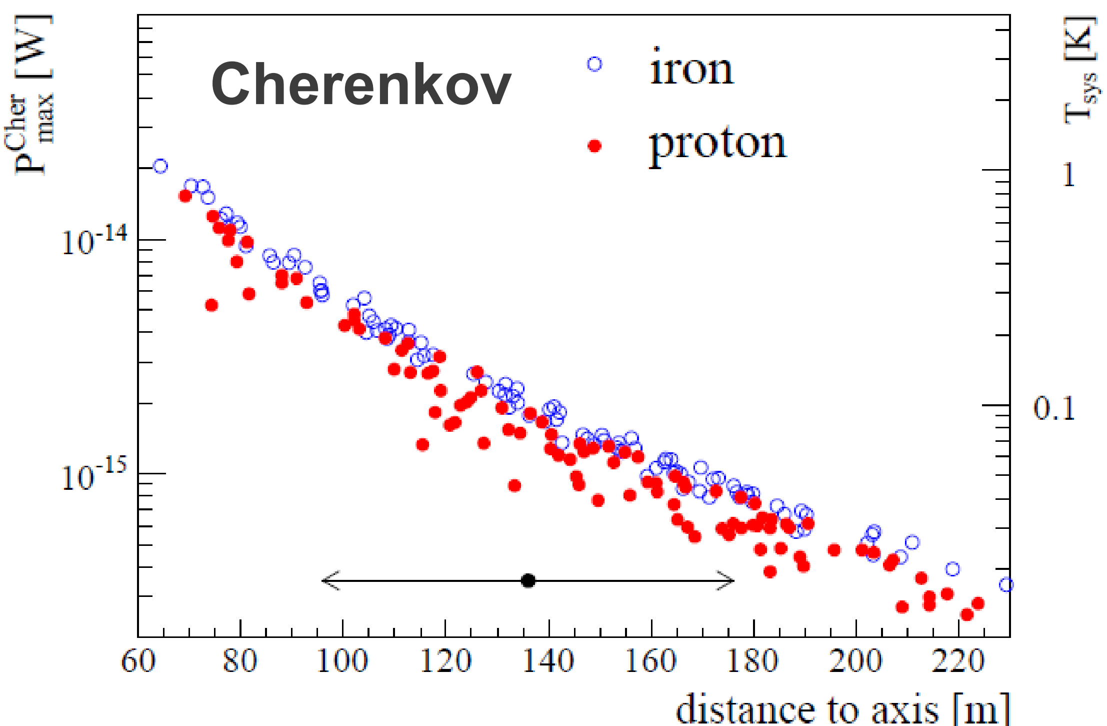


System temperature for a 14 σ detection

$$\Delta T = \frac{1}{\sqrt{\Delta f \cdot \tau}} T_{\rm sys} = \alpha \cdot T_{\rm sys},$$

$$S_{\rm sim} = k_B \Delta T \Delta f = n \cdot \sigma = n \cdot k_{\rm B} \cdot \alpha \cdot \Delta f \cdot T_{\rm sys},$$

T_{SYS}~ 100 K, compatible with MBR.

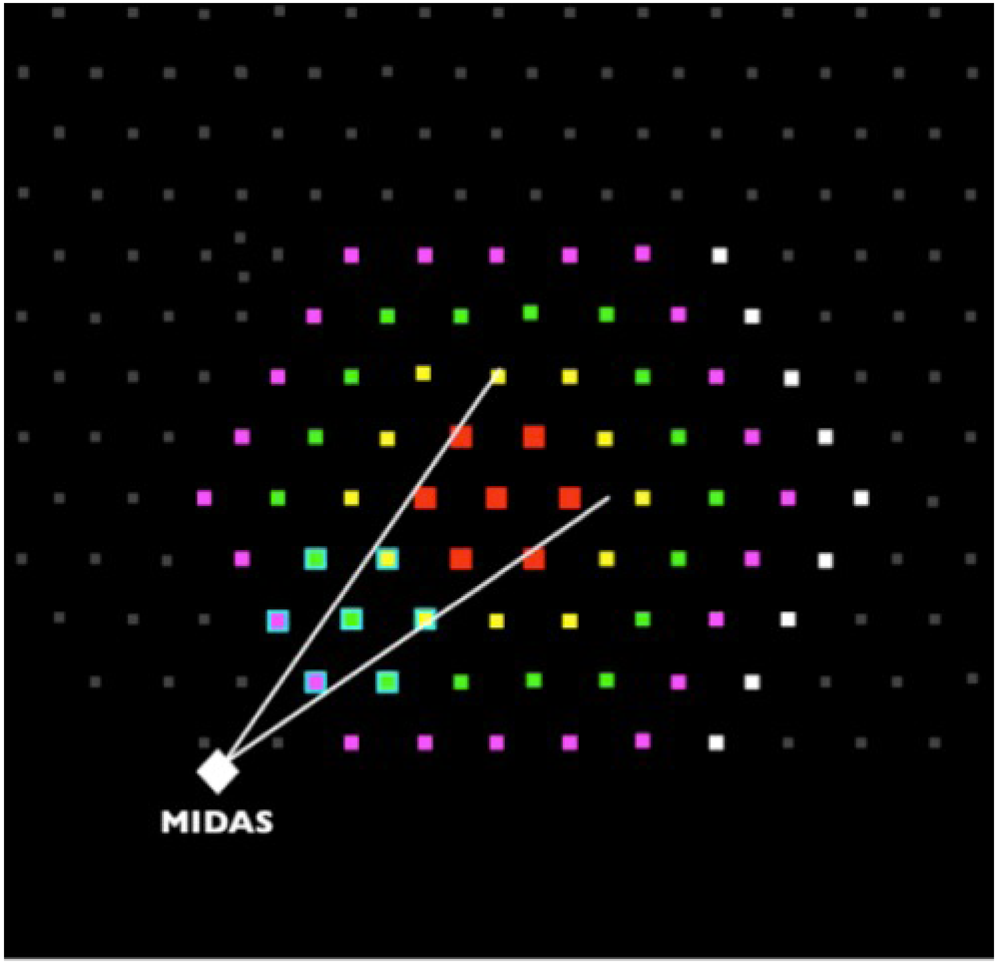


Cherenkov can not account for observed signal level.

We can not exclude a coherent emission that enhances the signal in the forward region

EASIER Extension

61 SD stations equipped with Hz instrumentation for a ~10-fold increase in the expected event rate.

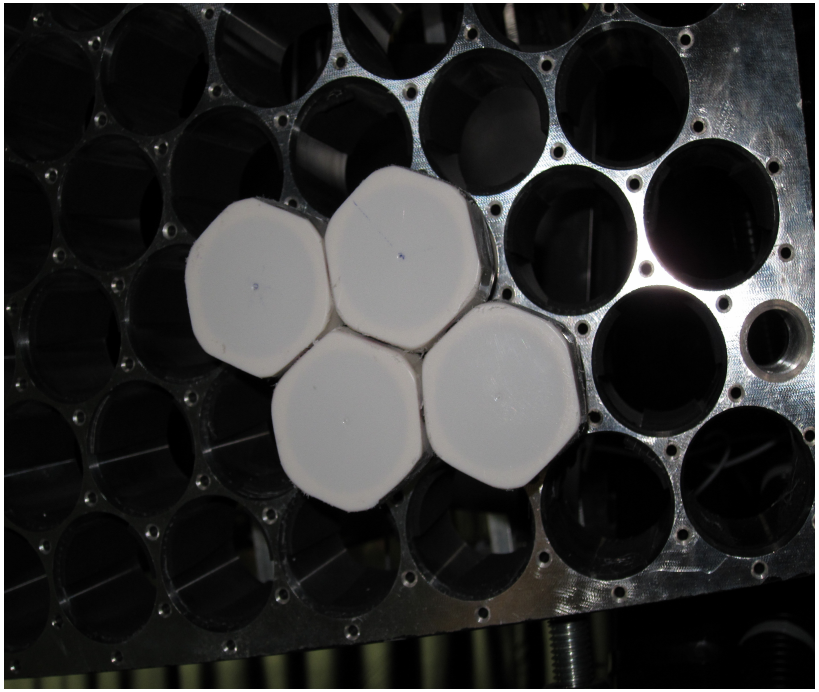


Expected rate:
1 ev/month

Coming soon

In the field of view of MIDAS: discrimination between isotropic and forward enhanced emission

More GHz activities <u>inside</u> Auger...



FDWave

Use empty PMT positions in an FD camera to place GHz receivers, with the output signal integrated in the fluorescence detector DAQ

PROS: FD trigger lowers threshold, plus allows integration over many events.
CONS: higher system temperature.

Under development, to be installed this year/

...and outside

- CROME (see R. Smida talk, next)

- Smaller set-ups: Bariloche, Lecce,...

Test beams:
- MAYBE (C. Williams talk)

- AMY (see poster session) Frascati BTF, 500 MeV high intensity electron beam

Outlook

- Microwave radiation at GHz frequencies: 'calorimetric' detection at the highest energies with a 100% duty cycle and low cost. Potential as a standalone detector or complementing existing arrays.

- Strong program within Auger dedicated to establish the feasibility of the technique

- Results already here: first detection of GHz radiation from an extensive air shower, with EASIER

- More results: quadratic scaling of the *Gorham* signal seems unlikely (both from EAS data and from accelerator measurements).

- Characterizing the signal (emission mechanism, scaling, angular distribution,...) will likely require the combination of data from different air shower detectors and test beam measurements.

- Much more data coming (EASIER extension, MIDAS@Malargue, AMY test beam).

STAY TUNED!