Report on PhD activity: EASIER

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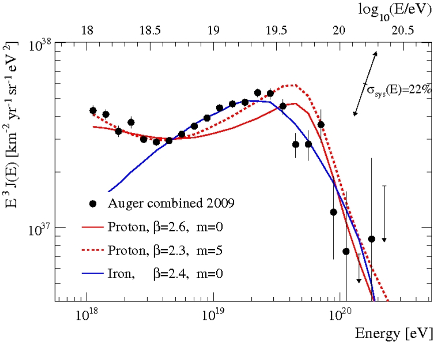
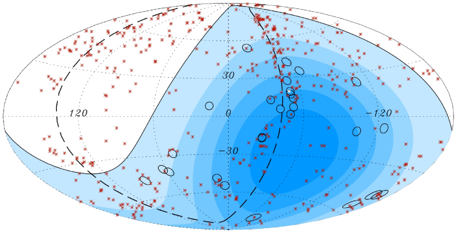
Outline

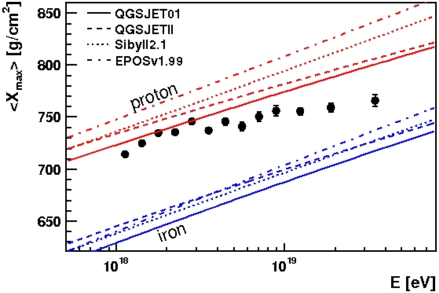
- Introduction to EASIER
- The prototype detector
- Noise measurements
- Expected signal
- Future plans

The collaboration: J. Aublin, M. Avenier, C. Bérat, X. Bertou, P. Billoir, C. Bonifazi, J. Chauvin, O. Deligny, Silvia Gambetta, P. Ghia, H. Lebbollo, D. Lebrun, I. Lhenry-Yvon, A. Letessier-Selvon, C. Macolino, I. Mariș, F. Montanet, M. Münchmeyer, R. Randriatoamanana, P. Stassi, A. Stutz

Auger results



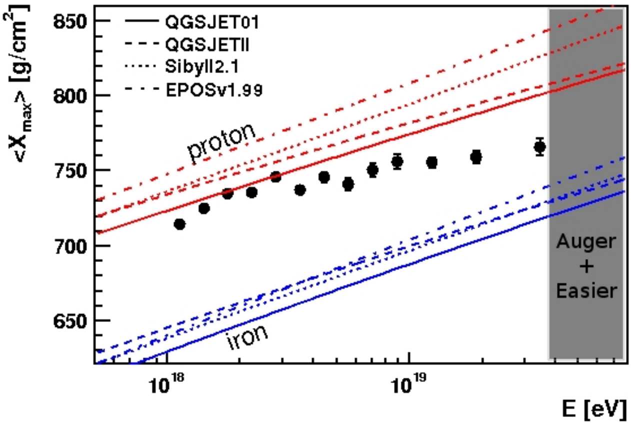




- GZK suppression: mass composition important
- $< X_{max} >$: composition shows a trend towards heavy nuclei
- Data up to March 2009: 38% correlate

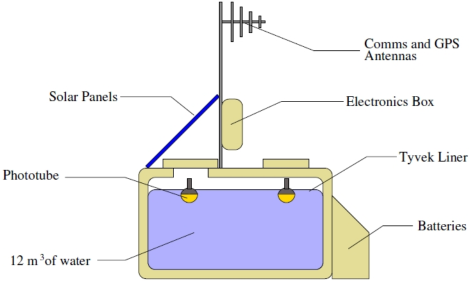
EASIER's goal

- Improve particle indentification of UHECR
- Measure UHECR composition at higher energies
- Measure hadronic cross section at higher energies
- Constraints and parametrization of interaction models



The detector

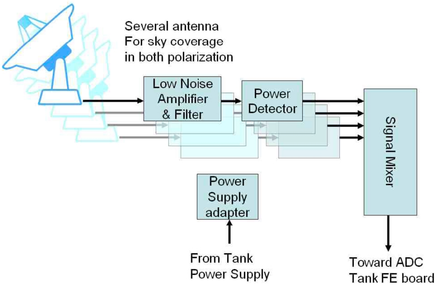
Extensive Air Shower Identification using Electron Radiometer

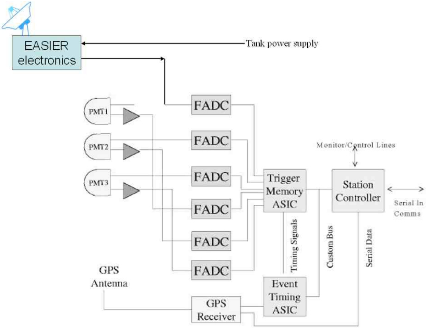


- Integrated radio receiver
- EM component of the shower
- Power trace
- Local DAQ

Summary

- Detection of **radio emission** of the EM cascade
- **Two** possible bands: VHF (10-100 MHz) and C+K (1-10 GHz)
- **Trigger and timing via tank DAQ**





- Signal proportional to the EM energy
- Time shape related to the cascade evolution and X_{max}
- Muonic signal in the tank by sustraction

$\approx$ 100% **duty cycle telescope with the coverage of a surface detector, integrated in the array**

Plan

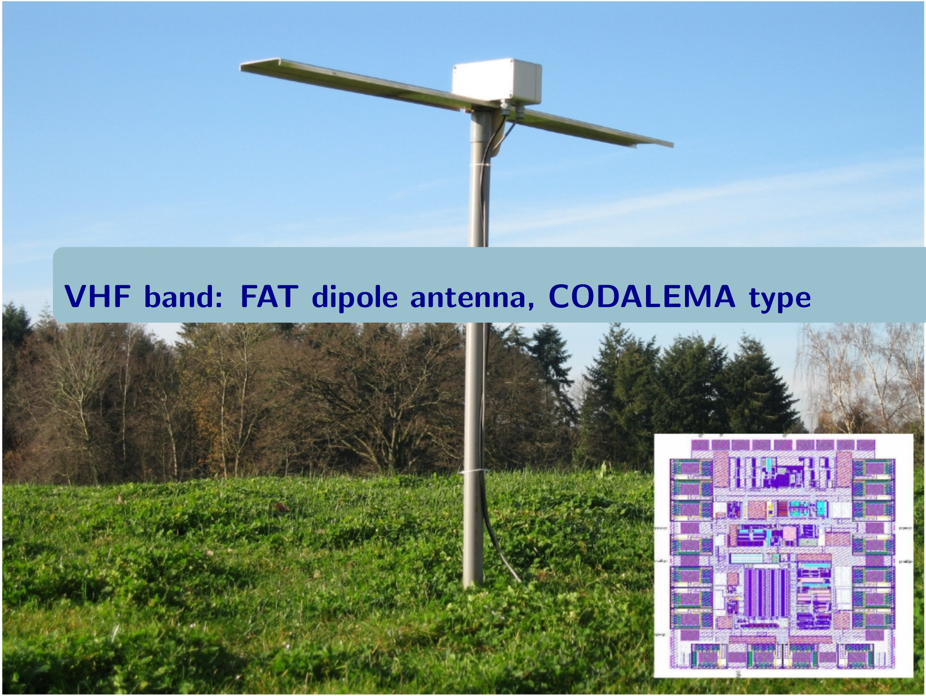
VHF band:

- Antenna's selection and test
- Noise evaluation
- Test of the acquisition chain
- Prototype installation
- Data taking and analysis

C+K band:

- Find the best antenna
- Test the whole receiving system and tank connection
- Signal simulations
- Prototype installation
- Data taking and analysis

VHF band: FAT dipole antenna, CODALEMA type



Radio physics

Signal: **geosynchrotron radiation**

$$\mathbf{E}\,[\mu\mathrm{V/m}] = 178\frac{E_0}{10^{17}\,\mathrm{eV}}(-\mathbf{v}\times\mathbf{B})\cos\theta\exp(\frac{-d}{D_0(\theta)})$$

State of art in the detection:

- Collimated radiation
- Main experiments: LOPES, CODALEMA, AERA
- Large areas at low cost
- Problems in trigger setup
- Actual detectors few hundred meters apart

External trigger can overcome these difficulties

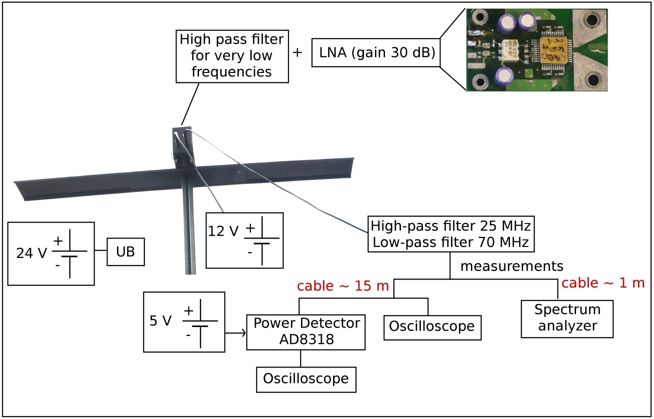
Plan of noise measurements

Noise measurements:

- Environmental noise
- Constant noise from the tank electronics
- Noise from PMTs signal
- Test of our acquisition chain
- Measurement sensitivity
- Trigger rate

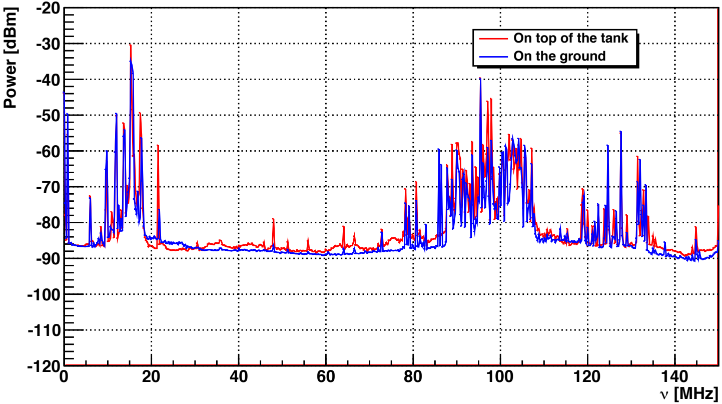
Measurements taken in Orsay (Paris) at the Auger prototype tank

Experimental setup



- FAT dipole antenna from the CODALEMA collaboration
- LNA from CODALEMA, gain $\sim 30\,\mathrm{dB}$
- Power Detector

Environmental noise

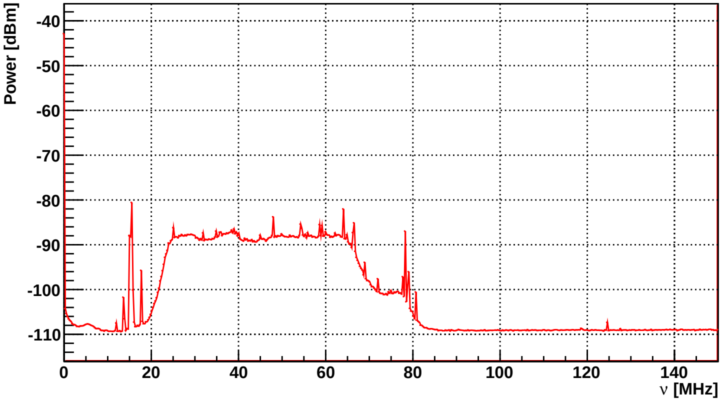


- Noise level on top of the tank of $-128\,\mathrm{dBm/Hz}$
- Difference between the spectra of: $(1.17 \pm 0.17)\,\mathrm{dBm}$

Antenna lobes not influenced by the position with respect to the tank

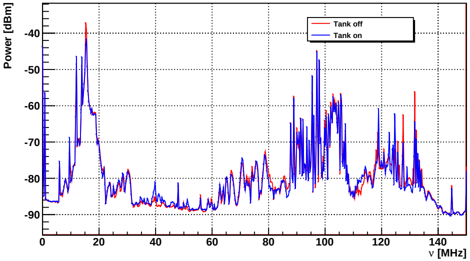
Electric field

Spectrum on top of the tank with filters (25-70 MHz)

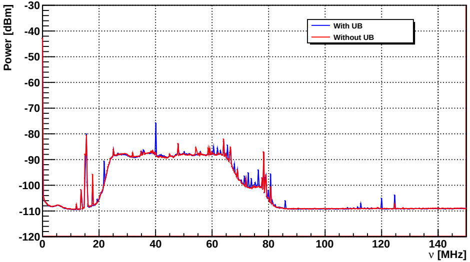


$$P = 7.61 \cdot 10^{-9}\,\mathrm{W} \qquad E = \frac{U_{out}}{l_{eff}} = 4.11 \cdot 10^{-5}\,\mathrm{V/m}$$

Constant noise from the tank



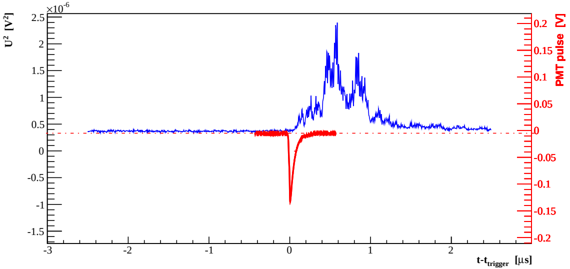
- No emission visible from the PMTs



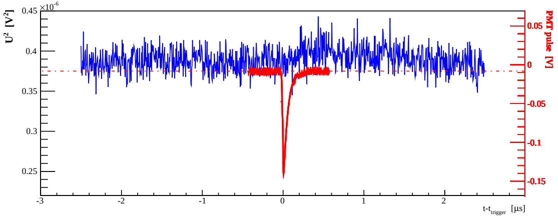
- Noise at 40 MHz from the UB

Noise from PMTs

Antenna close to a PMT

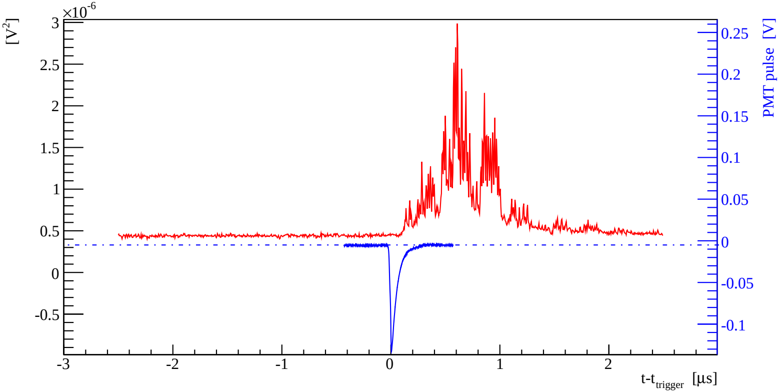


Antenna on top of the tank



- 2000 traces enrigestered
- Squared averaged signal
- Peak value: power in a 1 μs window
- Peak value: power in a 100 ns window
- **Antenna on top of the tank is a good configuration**

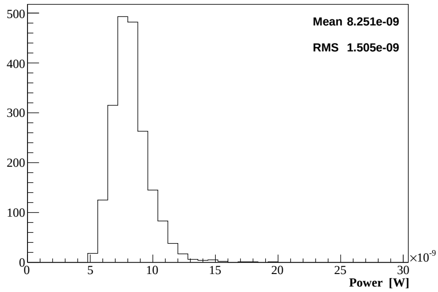
Power detector measurement



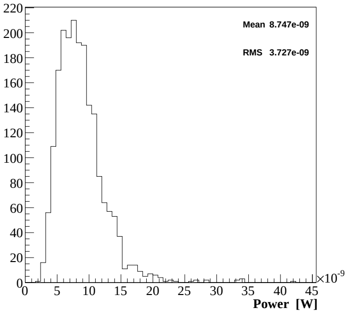
- Averaged traces
- Same response obtained without the Power Detector
- Same observables considered to estimate the noise

Sensitivity

- Distribution of the values of the average power measured in a chosen time window for 2000 traces
- The sensitivity is the variance of the distribution
- Two parameters computed for two different windows: $1\,\mu\mathrm{s}$ $100\,\mathrm{ns}$
- Parameters computed before the trigger and around the maximum



baseline: $\sigma_{1\,\mu\mathrm{s}} = 1.50\,\mathrm{nW}$



around maximum: $\sigma_{100\,\mathrm{ns}} = 3.73\,\mathrm{nW}$

Summary of noise measurements in the VHF band

- **The best configutation for EASIER is the antenna on top of the tank**

position	signal quantity	E [$\mu V/m$]	P [dBm]
top of tank	baseline	54.39	-48.76
top of tank	1 μs maximum	55.67	-48.55
top of tank	100 ns maximum	56.14	-48.48

Noise from the PMTs for the 1 $\mu\mathrm{s}$ window: **0.19 dB**
Noise from the PMTs for the 100 ns window: **0.28 dB**

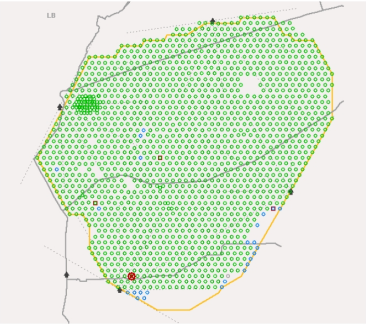
- Sensitivity

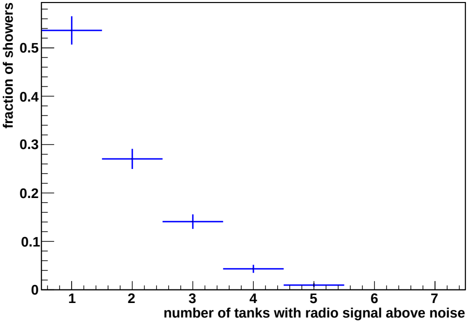
Measurement	σ_W [nW]	σ_E [μV/M]
1 μs baseline	1.50	4.95
100 ns baseline	3.61	11.97
1 μs peak	1.71	5.55
100 ns peak	3.73	11.96

Expected trigger rate

Event number expected in the Vieira hexagon:

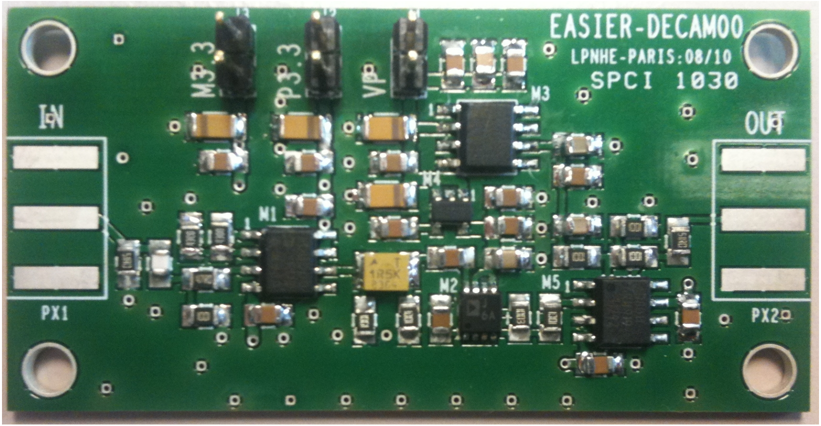
- SD events from May to August 2010
- Quality cut: T5
- Corresponding electric field higher than sensitivity





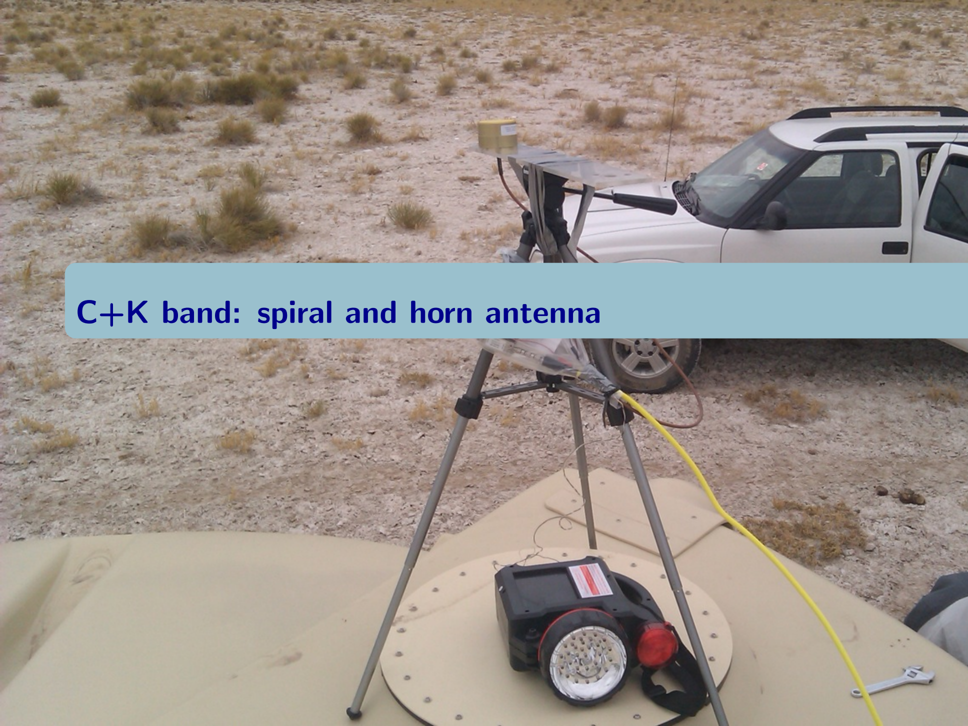
5 events/day in our hexagon

Stage of the VHF



Board with all the components just arrived in Paris!
Ready to complete the tests of the acquisition chain with the Auger UB

C+K band: spiral and horn antenna



The Molecular Bremsstralhung Radiation

Starting point: **Gorham et al. "Observation of microwave continuum emission from air shower plasmas", Phys.Rev.D78,2008.**

- EAS particles dissipate their energy through ionization
- A plasma of $T_e \simeq 10^{4-5}\,\mathrm{K}$ is created
  - Secondary electrons excite $N_2 \Rightarrow$ **fluorescence radiation**
  - Secondary electrons themselves produce their own emission like **bremsstralhung in field of neutral molecules: EMISSION IN THE MICROWAVE RANGE**

Characteristics:

- Isotropic radiation $\Rightarrow$ FD like detector
- Around 100% duty cycle
- Minimal atmospheric attenuation (even with clouds and rain)

State of art:

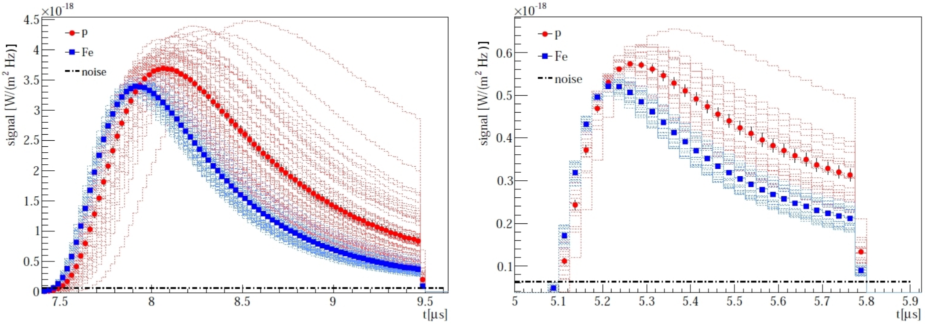
- Observed in laboratory at accelerator experiment
- Never observed in field
- Main experiments: AMBER, MIDAS, CROME

Again the slave trigger helps improving problem of detectability due to signal to noise ratio

Signal calcualtion

Scaling of the accelerator data from the Gorham paper taking into account the shower development and antenna FOV. Expected intensity:

- Coherent emission $I \propto N_e^2$
- Uncoherent emission $I \propto N_e$



Traces expected at 900 m, for $\theta = 38\,^{o}$

Expected signal

Rescaling of Gorham signal:

$S(1000)_{Ne} \simeq -170\,\mathrm{dBm}$
$S(1000)_{Ne^2} \simeq -155\,\mathrm{dBm}$

Detector design parameters:

$$A_{eff} \cdot \Omega = \lambda^2$$

Effective area	$0.007\,m^2$
Field Of View	$\pi/2$
λ	10 cm
$\Delta\nu$	1 GHz
Δt	25 ns

Minimum detectable signal:

$$\Delta I = \frac{k_B \cdot T_{sys}}{A_{eff}\sqrt{\Delta t \Delta f}}$$

For $T_{sys} \simeq 10\,\mathrm{K} \Rightarrow \Delta I \simeq -174\,\mathrm{dBm}$

The signal rescaled is above the thermal noise!

Challenge: lower T_{sys} as much as possible

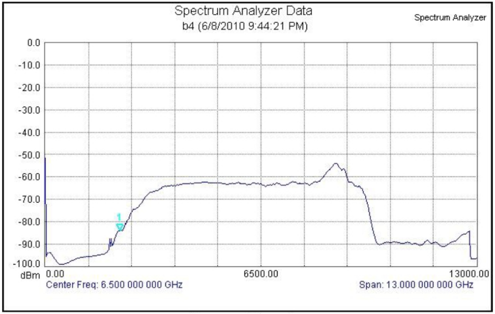
Experimental setup

- Spiral antenna
- Commercial horn antenna
- Low noise cables
- Spectrum analyzer

Measures with the spiral

Measurements taken in Argentina to study the environmental noise:

- Spiral antenna
- Two LNA: $G = 38\,\mathrm{dB}$, $N = 2\,\mathrm{dB}$, $B = 2 - 9\,\mathrm{GHz}$



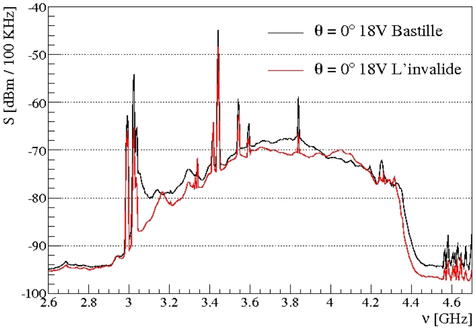
Clean band: 3-7 GHz

Thermal noise dominated by the LNA noise

Measures with the horn

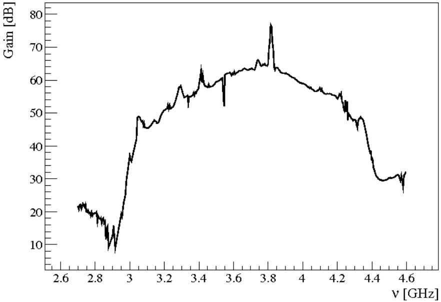
Measurements taken in Paris:

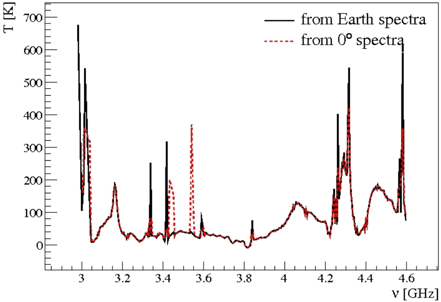
- Horn antenna
- Integrated LNB



Horn characterization: gain and temperature

Preliminary characterization:





- $P = k_B \cdot T \cdot \delta\nu \cdot G$
- $T_{ground} = 300\,\mathrm{K}$, $T_{sky} = 10\,\mathrm{K}$
- System temperature computed inverting the equation: $T \sim 20\,\mathrm{K}$

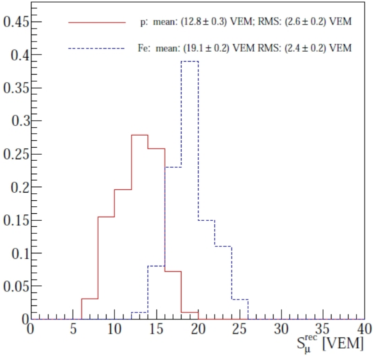
Summary of the C+K

- Signal calculation from Gorham paper
- Two antennas tested: spiral and horn
- Horn antenna seems more promising
- Background measurements in Argentina
- Preliminary characterization of the horn antenna

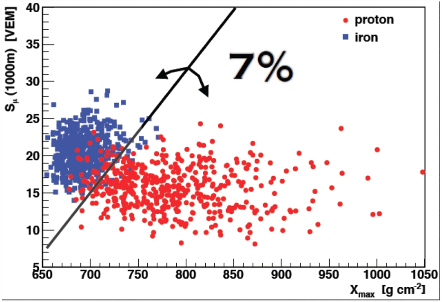
$\Rightarrow$ **work in progress**

Analysis tools

Study of shower universality to recover the muonic signal from the electromagnetic signal detected by EASIER



S_μ by substraction of the S_{em} measured by EASIER



Anti-correlation between X_{max} and S_μ from simulated showers

Study of the recovery of muonic signal from Golden Hybrids events

Conclusions and future plans

VHF band

Done:

- Antenna chosen and tested
- Acquisition chain partially tested
- Noise from the tank evaluated
- Expected trigger rate computed

To do:

- Test of the complete acquisition chain

First deployment foreseen in november

C+K band

Done:

- Different types of antenna tested
- Signal and noise calculation

To do:

- Choice of the antenna
- Evaluation of the system temperature
- Take into account the antenna response in simulations

First deployment foreseen in december

Final configuration

Moving towards a more complete detection of EAS