International Symposium on the Recent Progress of Ultra-High Energy Cosmic Ray Observation
December 10-12, 2010 Nagoya, Japan

Microwave Detection of UHECR: R&D efforts

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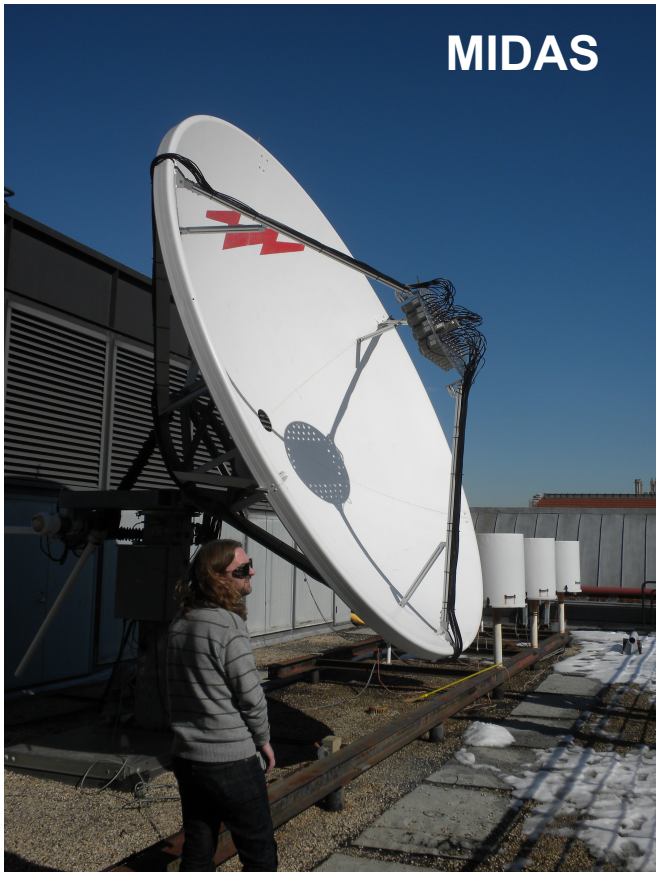
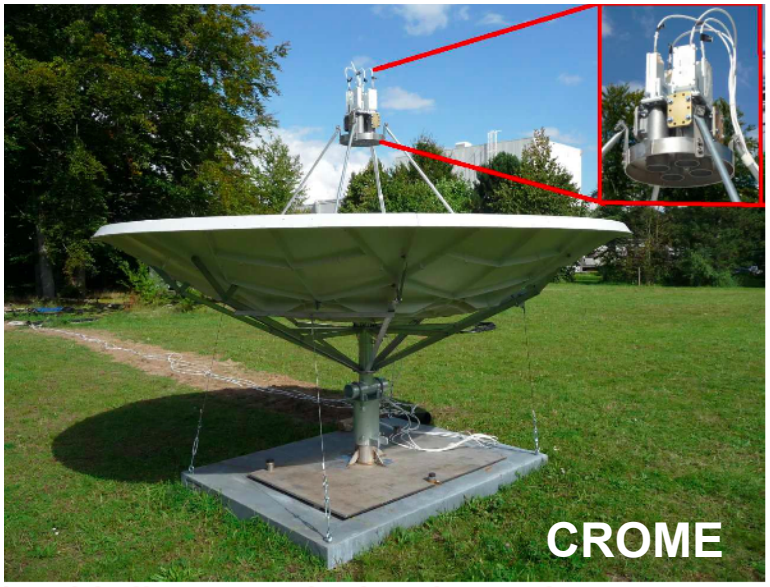




(Plausible) Microwave Emission Mechanism

EAS particles dissipate their E through ionization → A plasma of $T_e \sim 10^{4\text{-}5}$K created → The electrons of the plasma interact with the neutral molecules of the atmosphere producing bremsstrahlung emission in the microwave

Molecular bremsstrahlung (well known in astrophysical plasmas):

- Unpolarized and Isotropic → **FD-like detector** (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 equipment)

R&D on Microwave Detection

Following the pioneering work of AMBER (first measurements performed in Hawaii published in 2008), a collaborative R&D effort is ongoing:

- AMBER at Auger (covered by A. Connoly presentation)
  trigger by Auger SD
- MIDAS (MIcrowave Detection of Air Showers)
  a large field-of-view self-triggering antenna dish
- EASIER (Extensive Air Shower Identification using Electron Radiometer)
  feed horn on Auger tank
- CROME (Cosmic Ray Observation by Microwave Emission)
  antenna dish in coincidence with KASCADE

Also, new beam measurements are being planned

- AMY at Frascati Beam Test Facility (V. Verzi, INFN Roma 2)
- At Argonne Van de Graaf (P. Privitera)

Complementary approaches, common goal: establish microwave detection as a viable technique for enhancing existing experiments and building much larger aperture detectors for UHECR.

CROME Collaboration:

H. Blümer, R. Engel, A. Haungs, T. Huege, H. Klages, M. Kleifges, O. Krömer, M. Roth, F. Salamida, H. Schieler, R. Šmída, M. Unger, M. Weber, F. Werner, J. Wochele

Karlsruhe Institute of Technology

EASIER 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. Mariş, F. Montanet, M. Münchmeyer, R. Randriatoamanana, P. Stassi, A. Stutz

LPNHE, IPNO Orsay, LPSC Grenoble, UFRJ Rio, CAB Bariloche

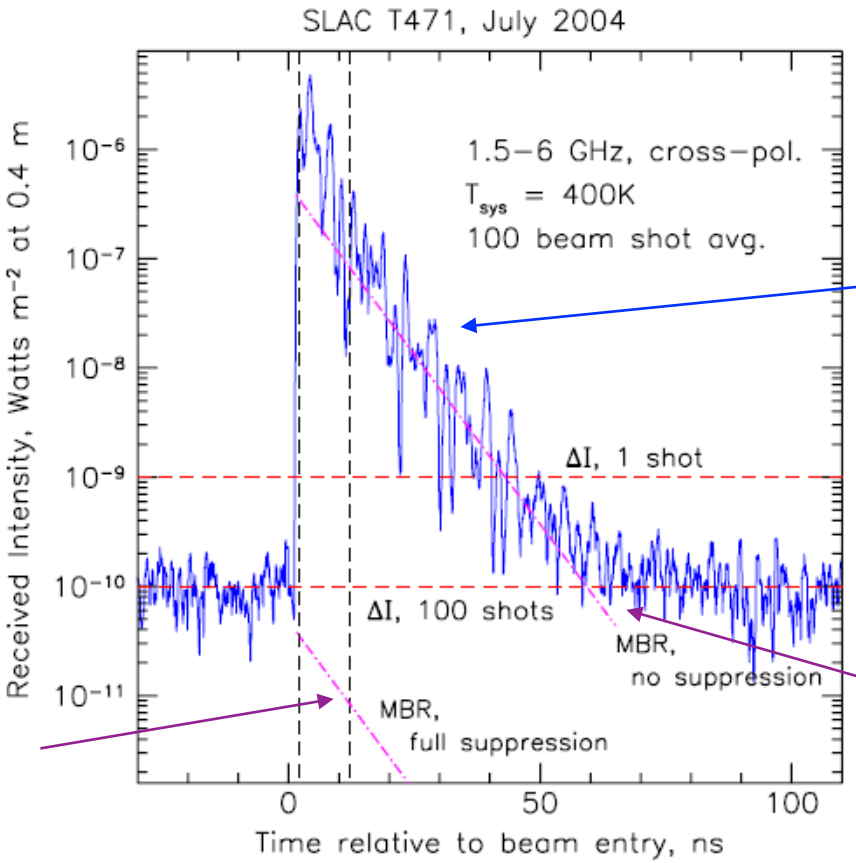
MIDAS Collaboration:

M. Bogdan, M. Bohacova, P. Facal, J.F. Genat, F. Ionita, M. Monasor, P. Privitera, L. Reyes, B. Rouille d'Orfeuill, C. Williams, J. Alvarez-Muniz, W. Carvalho, E. Zas, C.Bonifazi, J. de Mello, E. Santos, I. Allekote, X. Bertou

The University of Chicago, Universidad de Santiago de Compostela, Universidade Federal do Rio de Janeiro, Centro Atómico Bariloche and Instituto Balseiro

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

28 GeV electron beam showering on a target,microwave emission measured in the air volume of anechoic chamber



Measured signal attributed to molecular bremsstrahlung

Minimum signal level expected.

Expectation, emission enhanced by coherence

Depending on the plasma density parameters

→ **Each electron emission is independent** → RANDOM INTERFERENCE → $P_{tot} = N_e \times P_1$

Partial coherence possible

→ **Phase-space correlation of the individual emission** → COHERENCE → $P_{tot} = (N_e)^2 \times P_1$

Scaling to UHECR Air Showers

Flux density at 0.4 m

$I_{0,\,meas} = 4\ 10^{-16}$ W/m^2/Hz

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

@ 10 Km

$I = 2.8\ 10^{-24}$ W/m^2/Hz

Bunch equivalent energy

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

T_{sys}=100K A_{eff} = 10 m^2
Δt = 100ns Δf = 1GHz

$\Delta I = 1.6\ 10^{-23}$ W/m^2/Hz

Minimum detectable flux density

5σ detection threshold

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

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

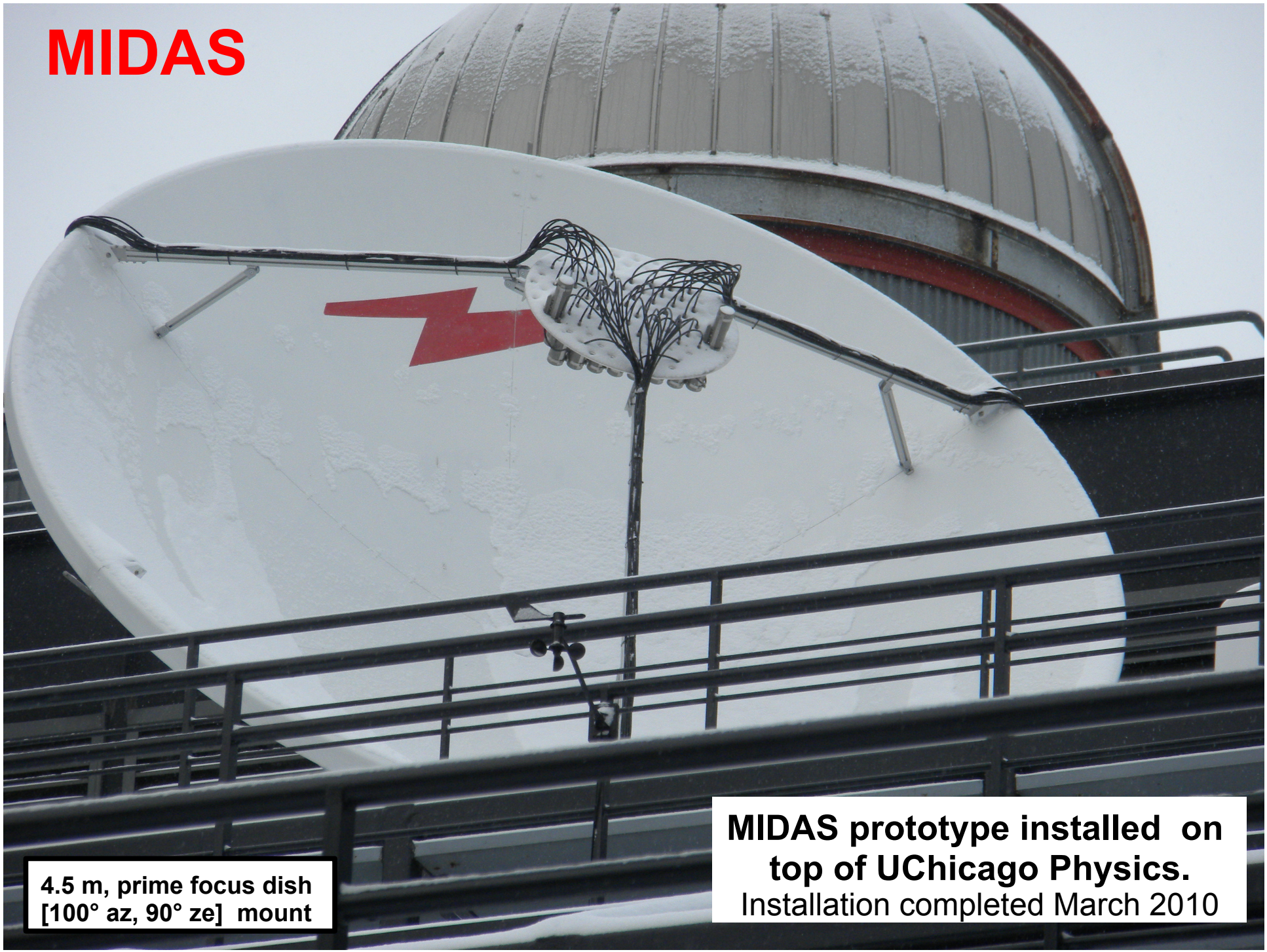
PROTOTYPE DETECTOR DESIGN PARAMETERS

Large collection area	~ 10 m^2	4.5m dish
Pixel field of view	~1.5°	Extended C-Band
Total field of view	~15°	~50 channels
Time domain	100 ns resolution	Fast power detector
Trigger for fast transient events		Flash ADC acquisition with FPGA trigger

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

(Wavelength, dish collection area and f.o.v. closely tied)

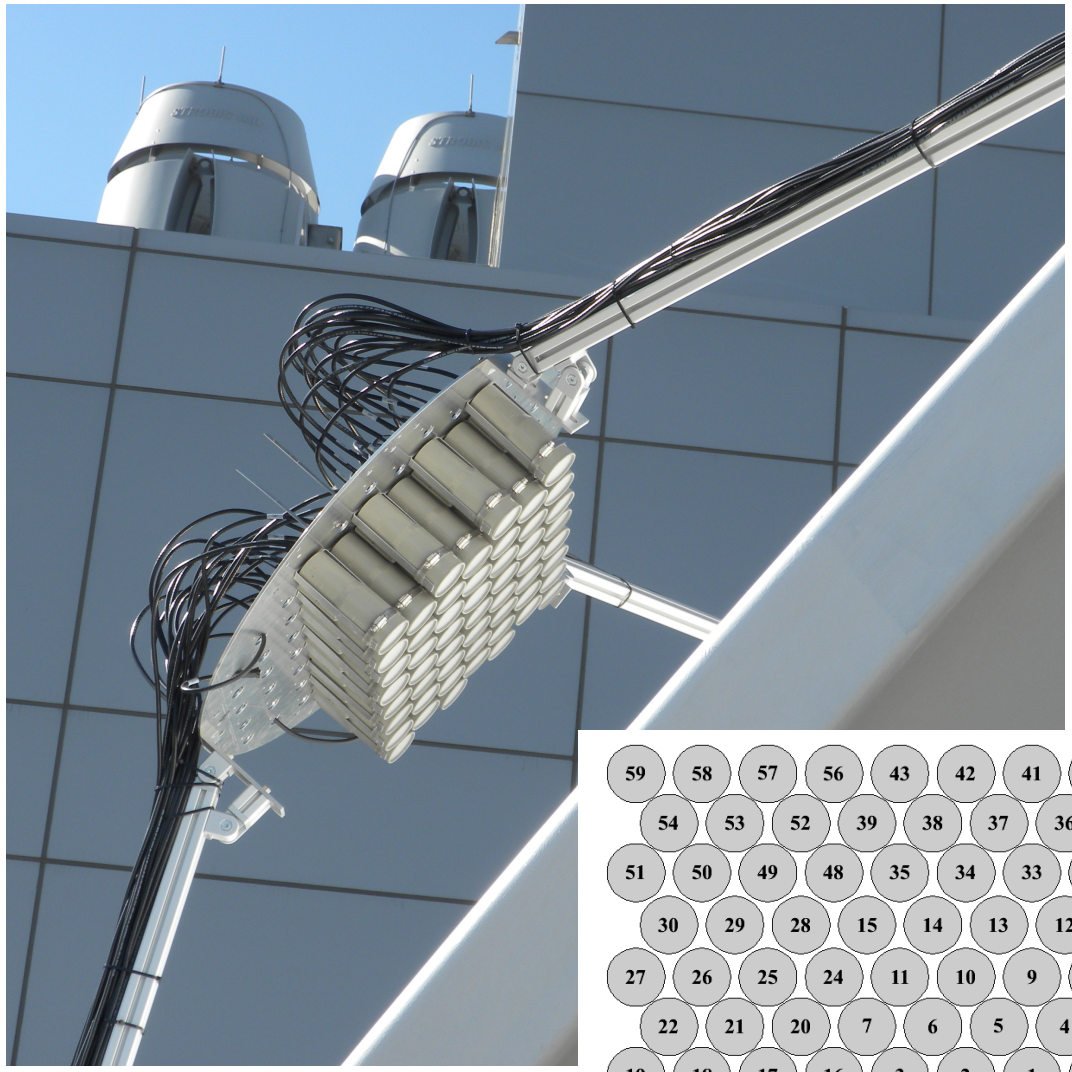
MIDAS

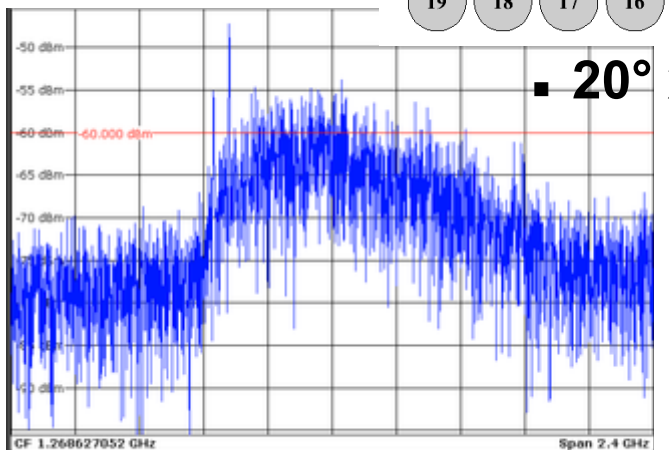


4.5 m, prime focus dish [100° az, 90° ze] mount

MIDAS prototype installed on top of UChicago Physics.
Installation completed March 2010

The MIDAS Camera

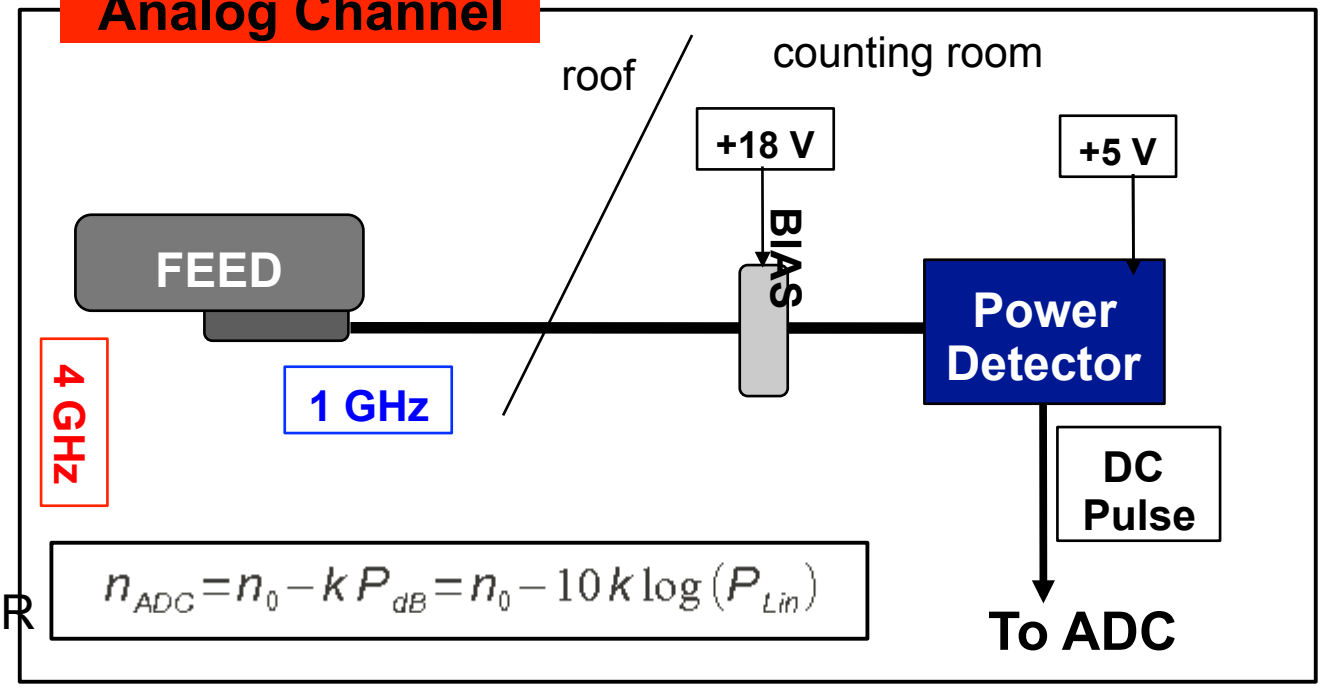




- 53 C-extended band [3.4,4.2GHz] commercial Satellite feeds
- Feed + amplifier + downconverter
- 13K noise, 70 dB amplification
- Output: Intermediate frequency ~ 1GHz
- 20° x 10° fov

MIDAS

Analog Channel

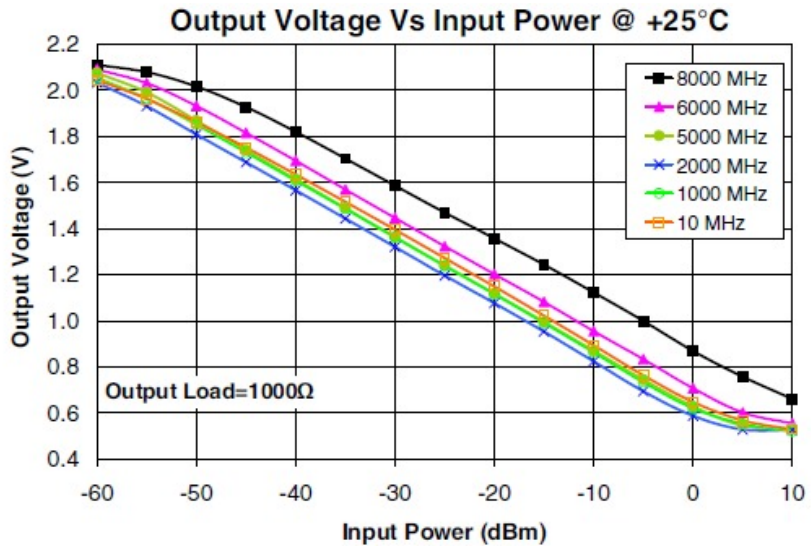


$$n_{ADC} = n_0 - k P_{dB} = n_0 - 10 k \log(P_{Lin})$$

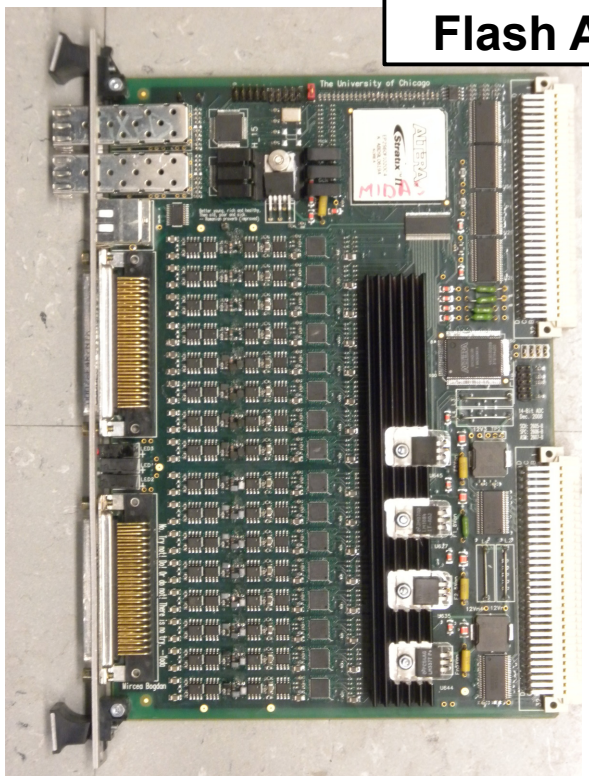
AMBER, EASIER and CROME

Power detector

0÷2 V DC output, log response
10MHz to 8GHz bandwidth
100 ns time resolution



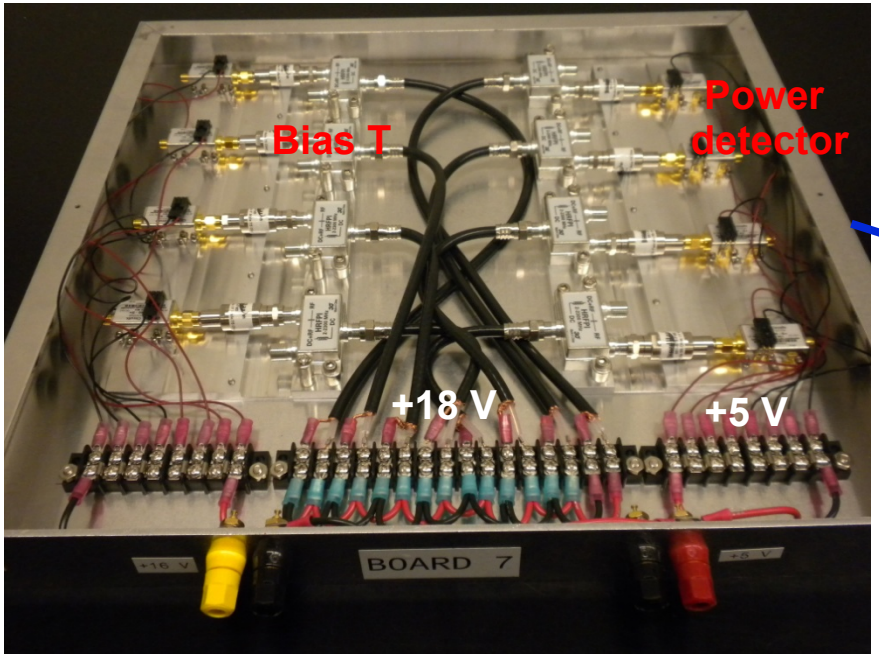
Flash ADC

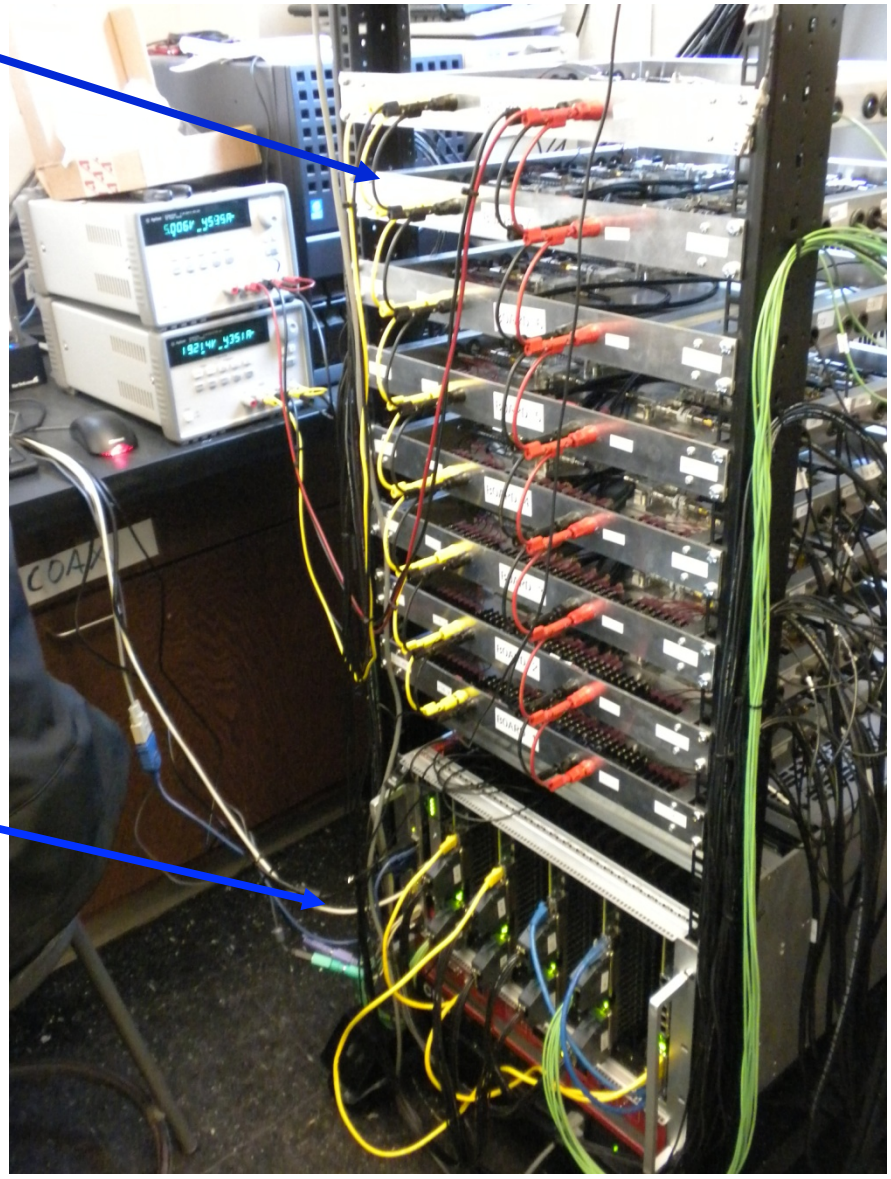


- 16 channels
- 14 bit
- 20 MHz
- FPGA trigger
- Developed @ EFI

MIDAS Control Room

Analog electronics enclosure





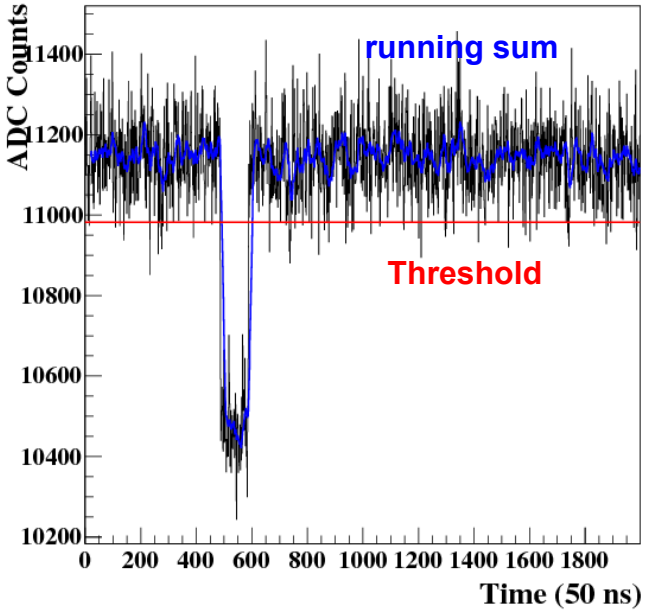
VME digital electronics:

- 4 ADC boards
- Master Trigger Board
- GPS board

Data acquisition:

- Event readout
- 1 second monitoring data

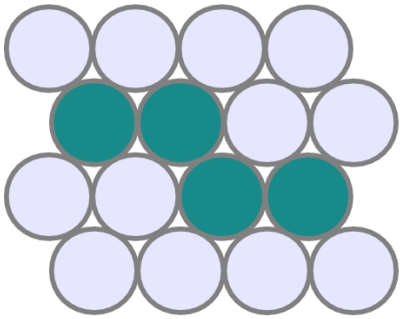
MIDAS Trigger Strategy a la FD



FIRST LEVEL TRIGGER

Pixel threshold trigger: the running sum of 1 μs is compared with a threshold self-regulating to maintain

100 Hz trigger rate



SECOND LEVEL TRIGGER

FLT pixels open a 20 μs gate: require topology (pattern) and time coincidence

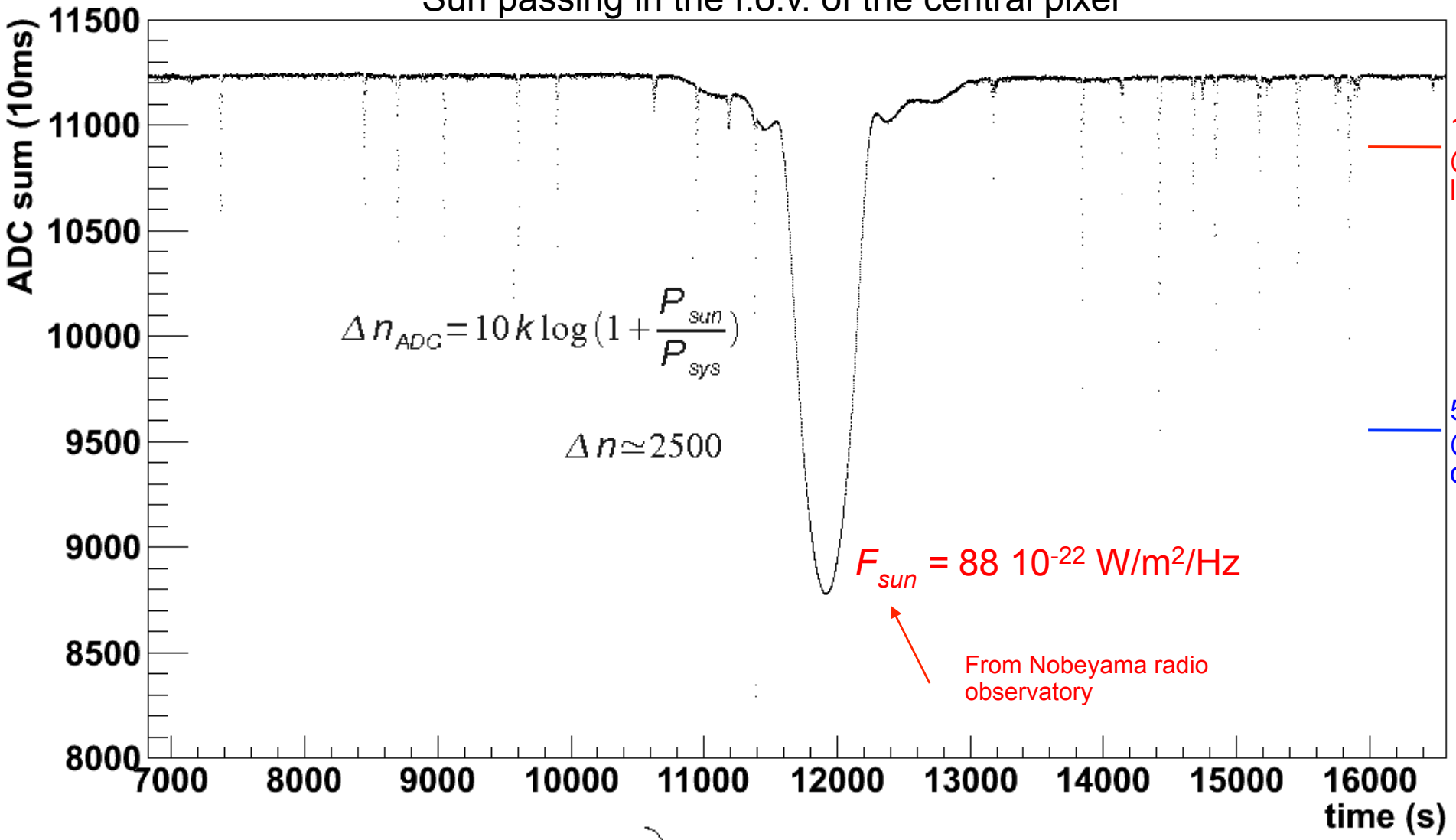
Accidental rate ~ 0.2 Hz

HIGH-LEVEL VETO

inhibits the SLT trigger when the rate is higher than a pre-set value, to filter *noise bursts*

Absolute Calibration and Sensitivity

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



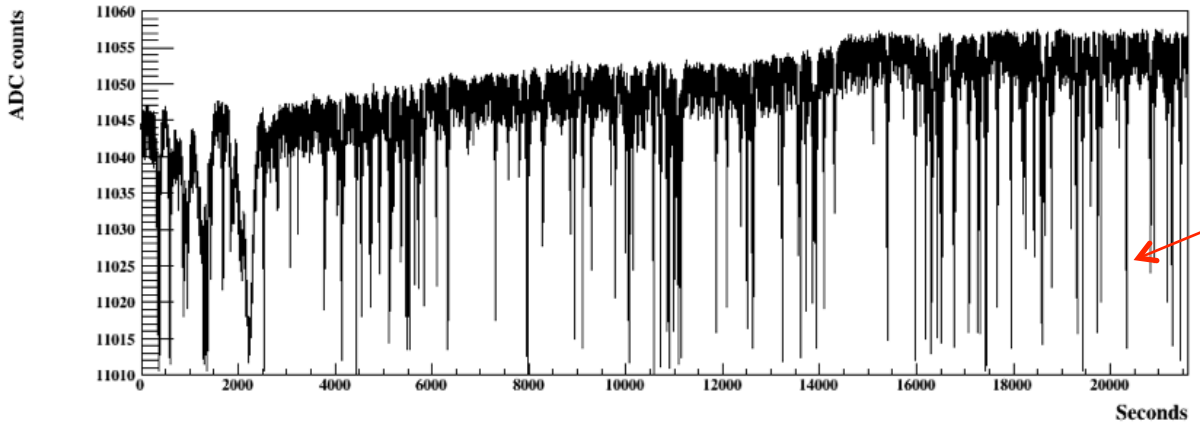
$$F_{sys} \simeq 3.3 \cdot 10^{-22}\, W/m^2/Hz$$

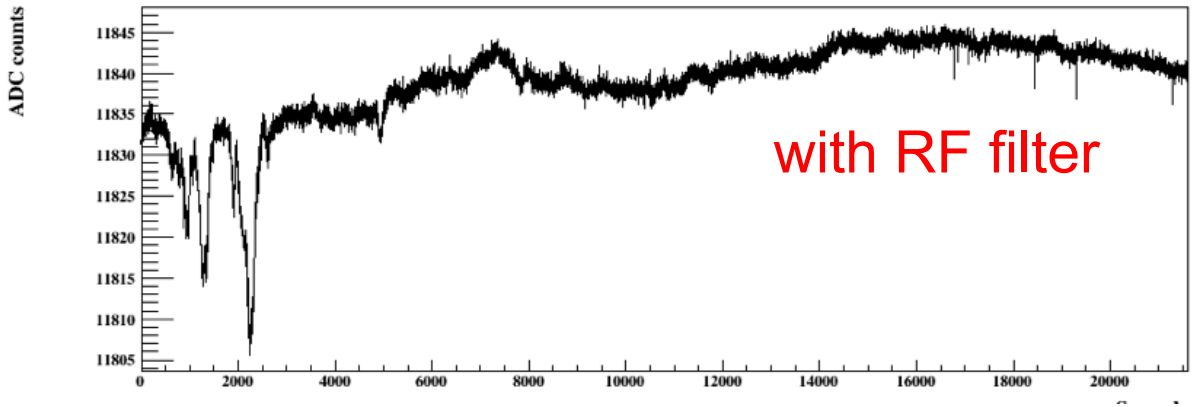
$$F_{sys} = \frac{2 k_B T_{sys}}{A_{eff}}$$

$$\Rightarrow T_{sys} \simeq 120 K$$

close to the design goal

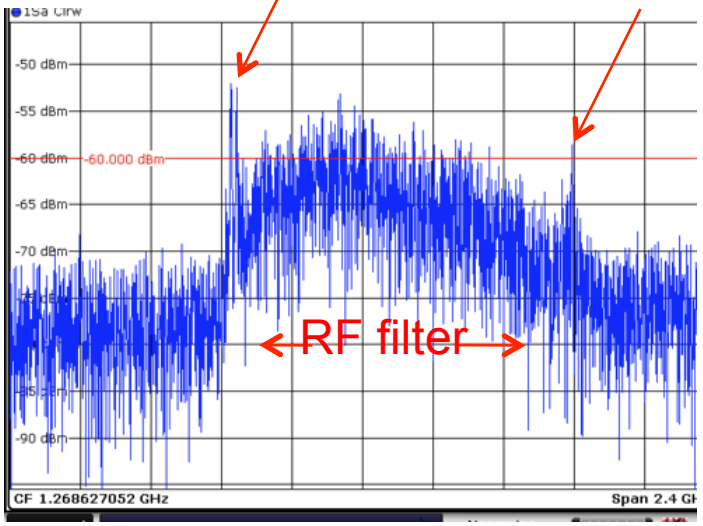
RFI and duty cycle

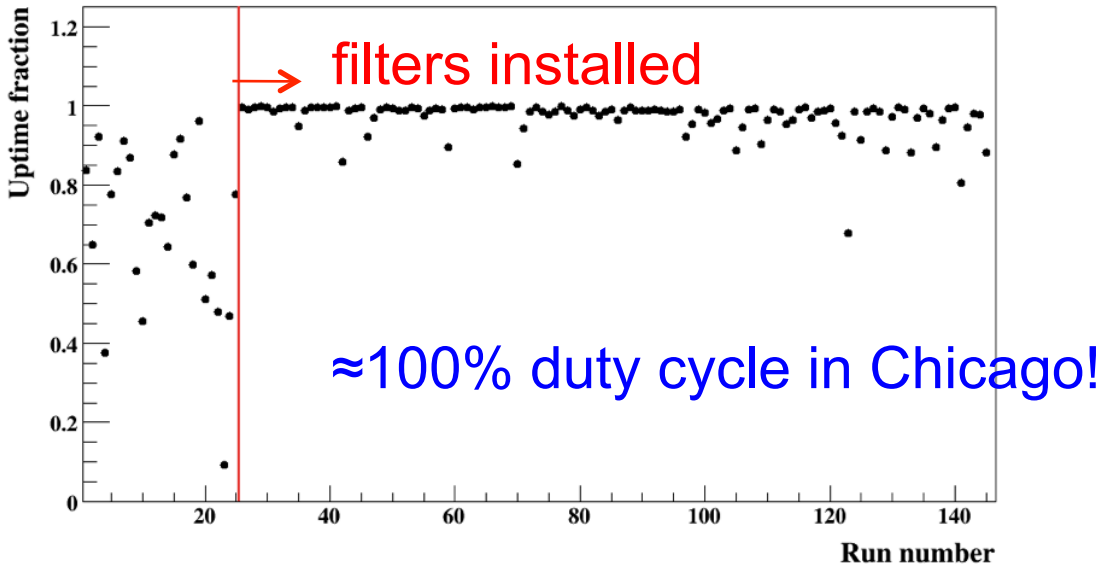


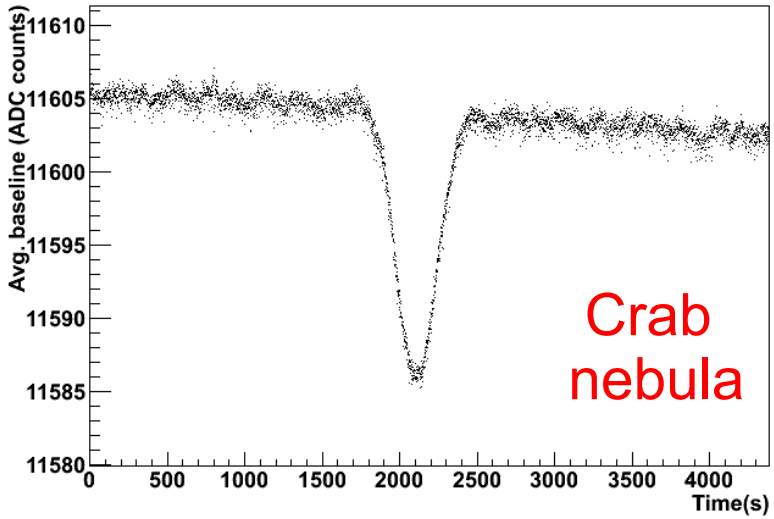


airplanes!

Cell. tower

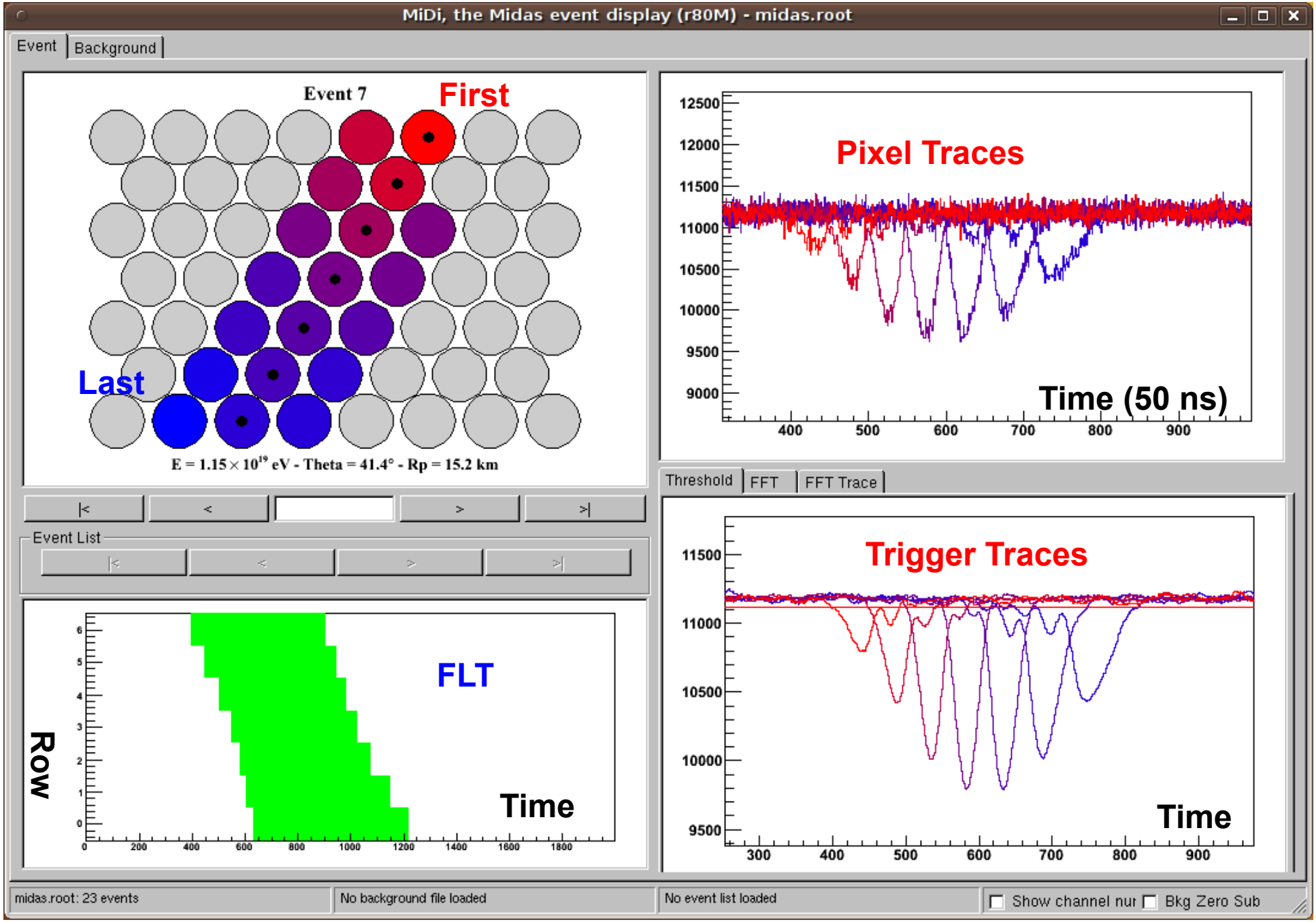






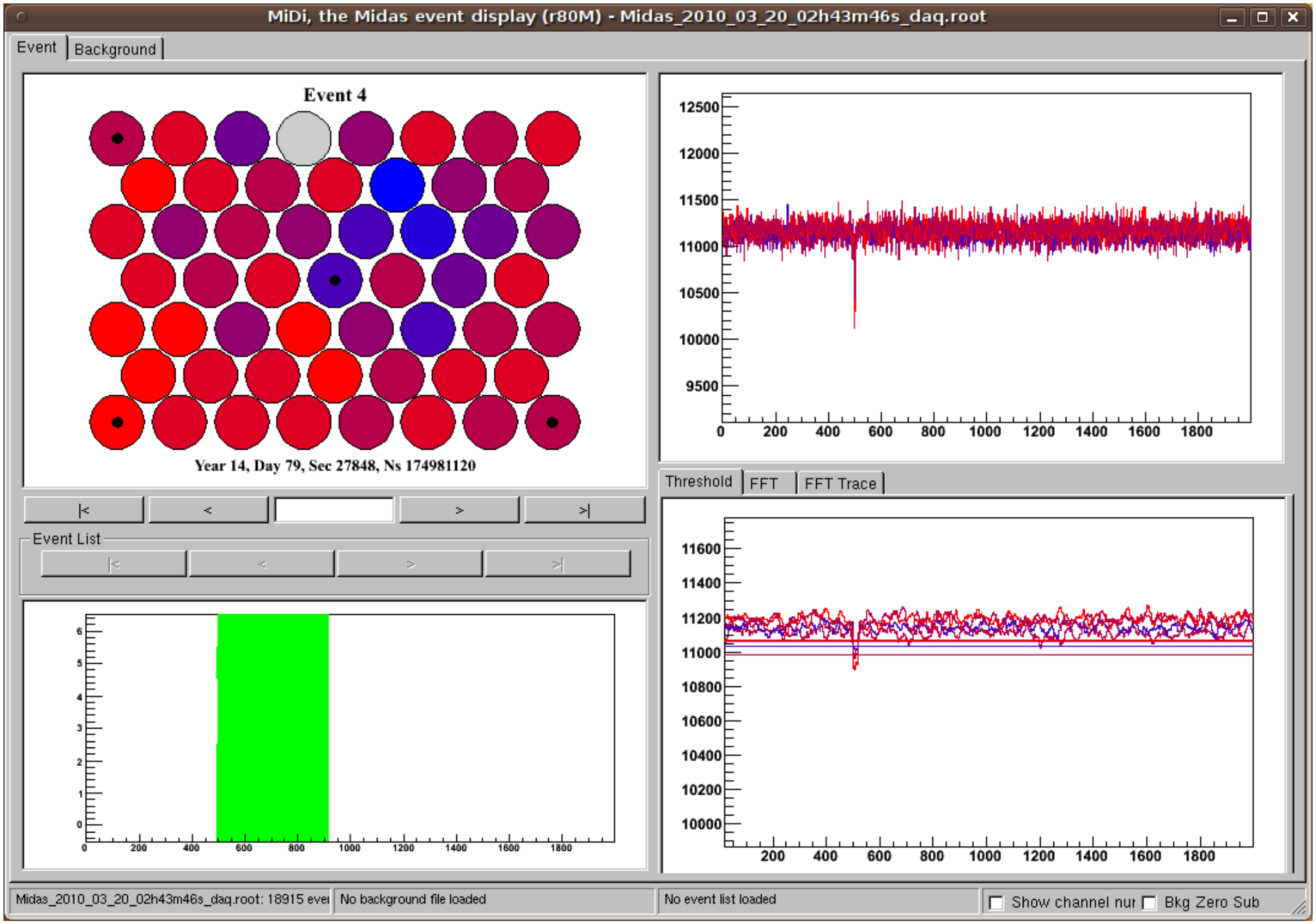
Monte Carlo Simulated MIDAS Event

QUADRATIC SCALING

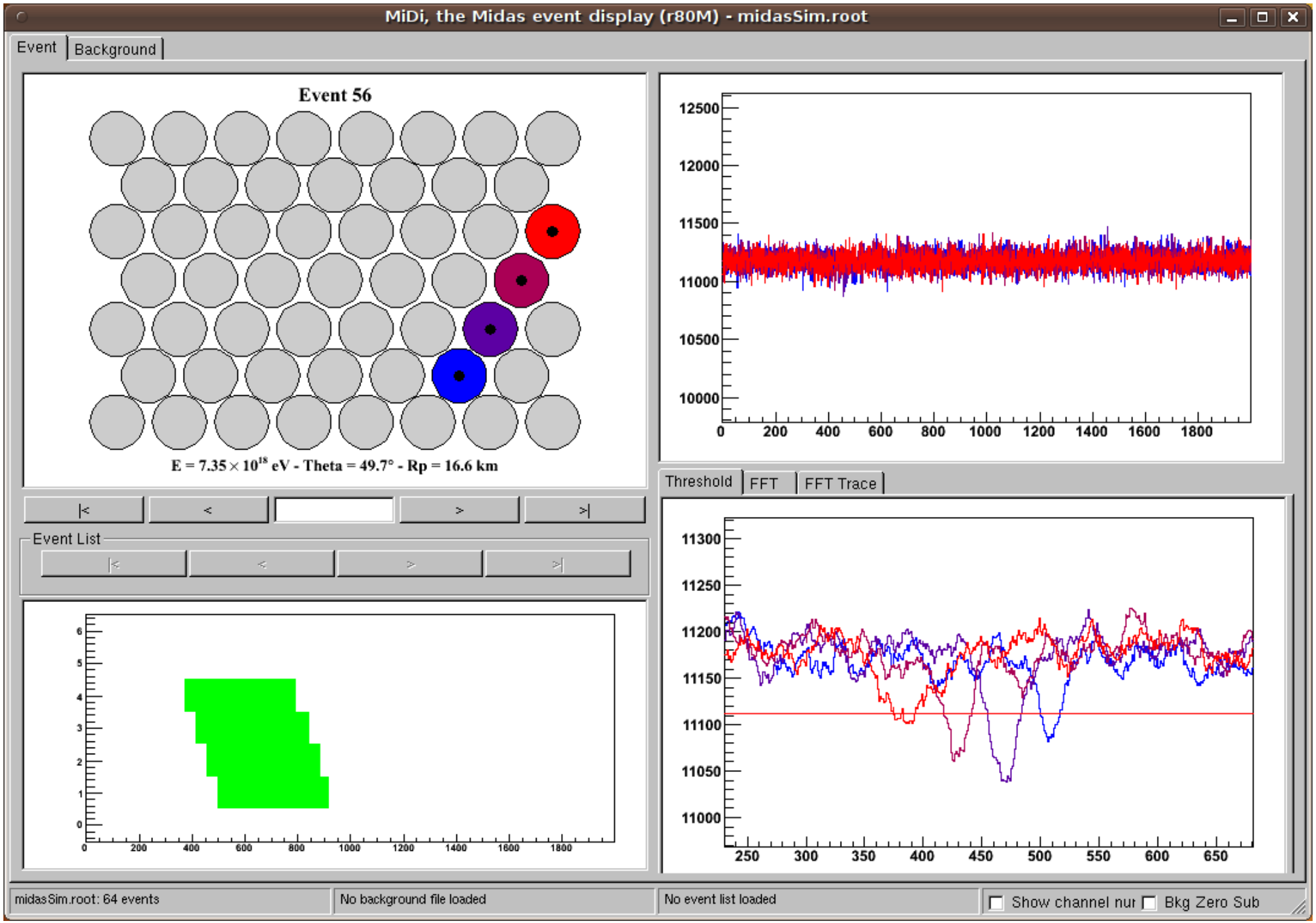


Noise event

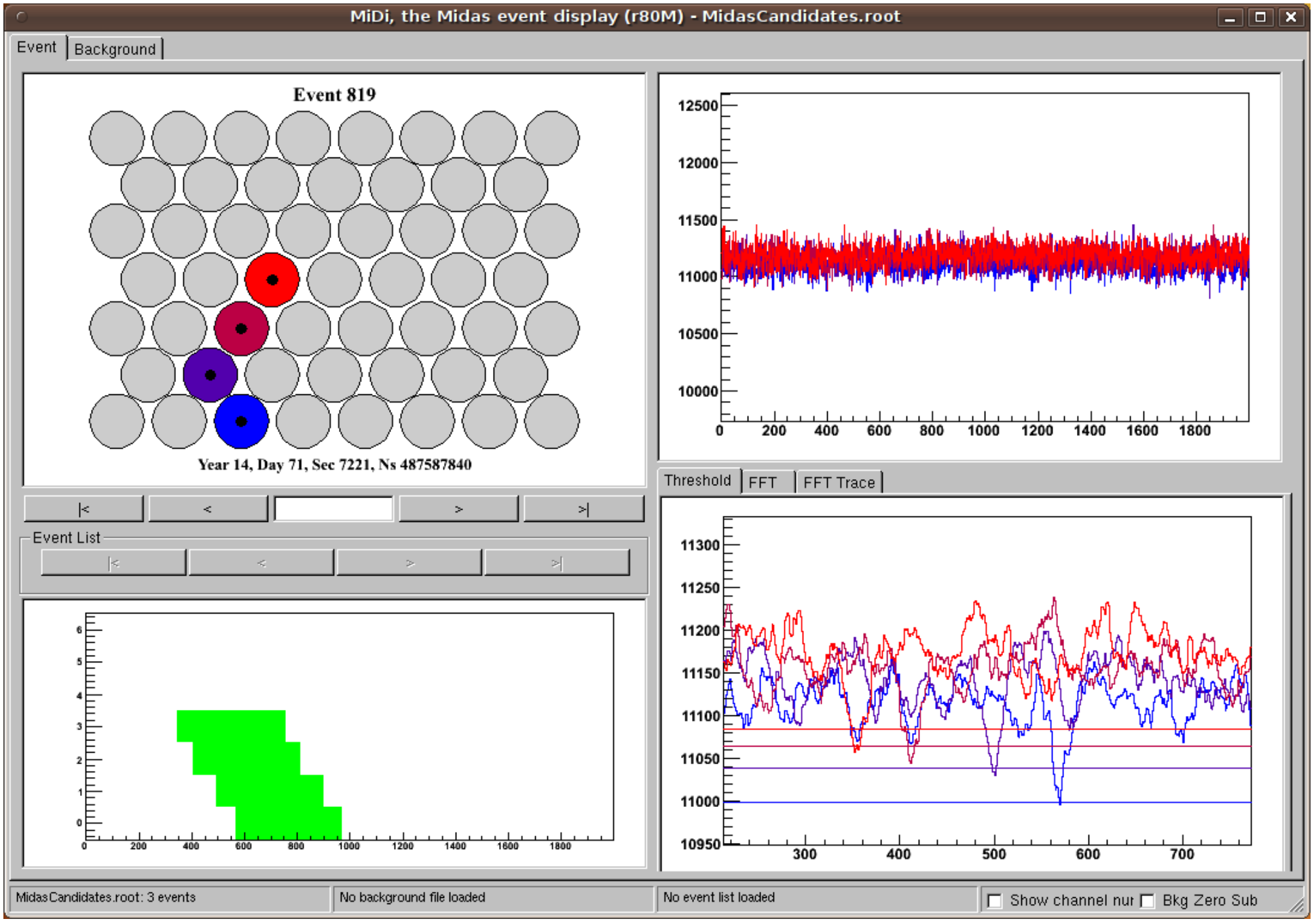
Clear signature, all pulses at the same time.



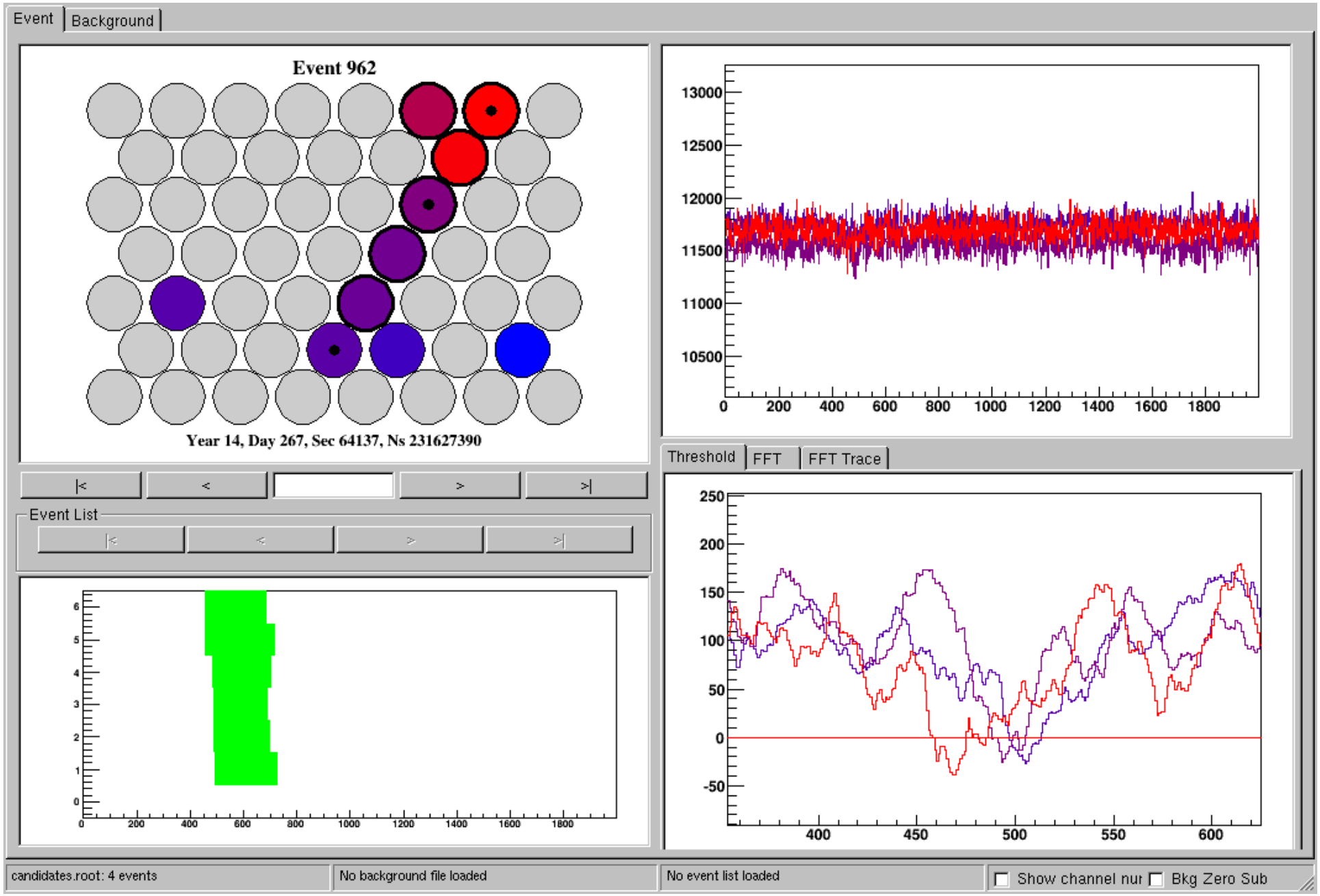
Monte Carlo Simulated MIDAS Event



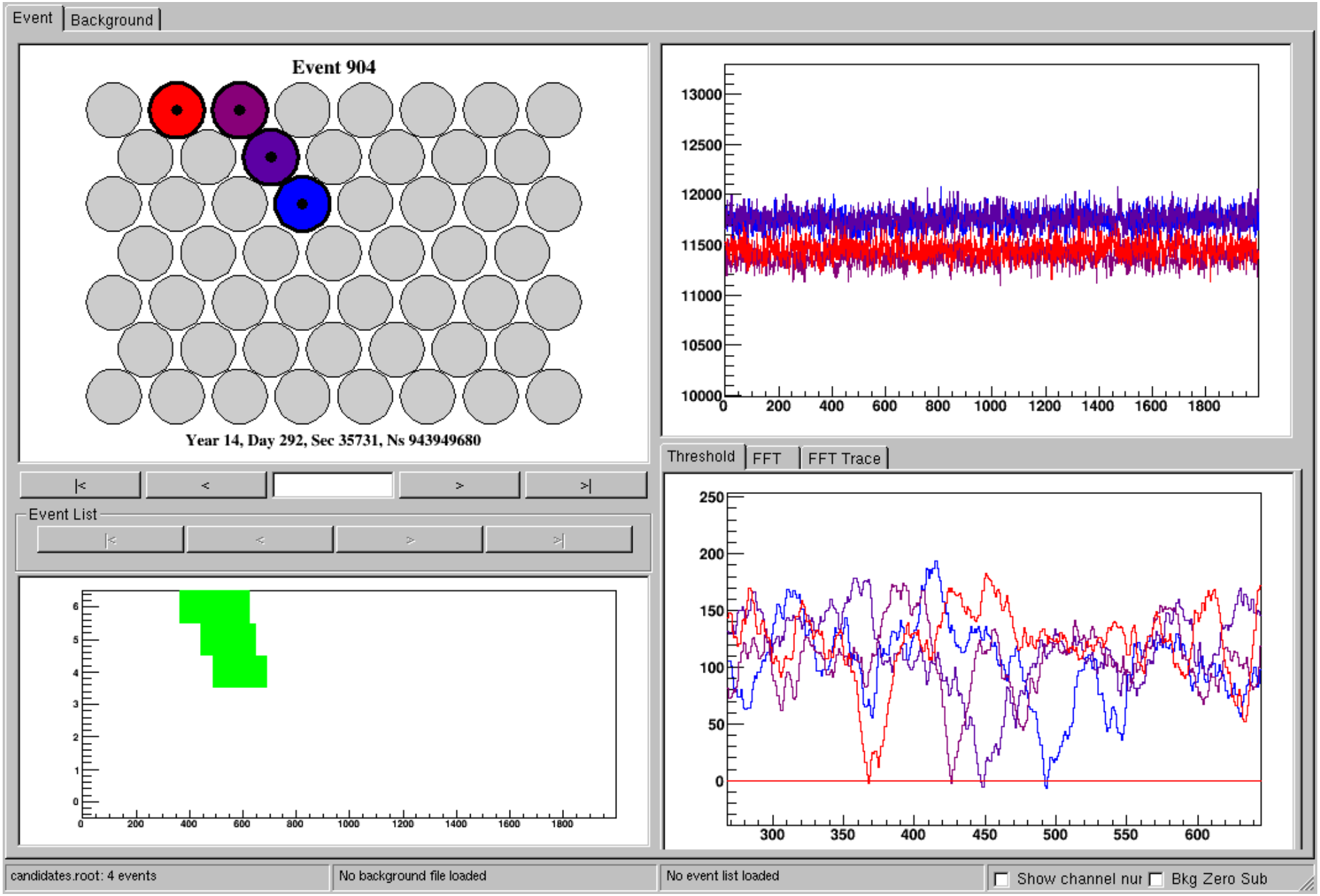
Event Candidate (April test run)



Event Candidate (October run)

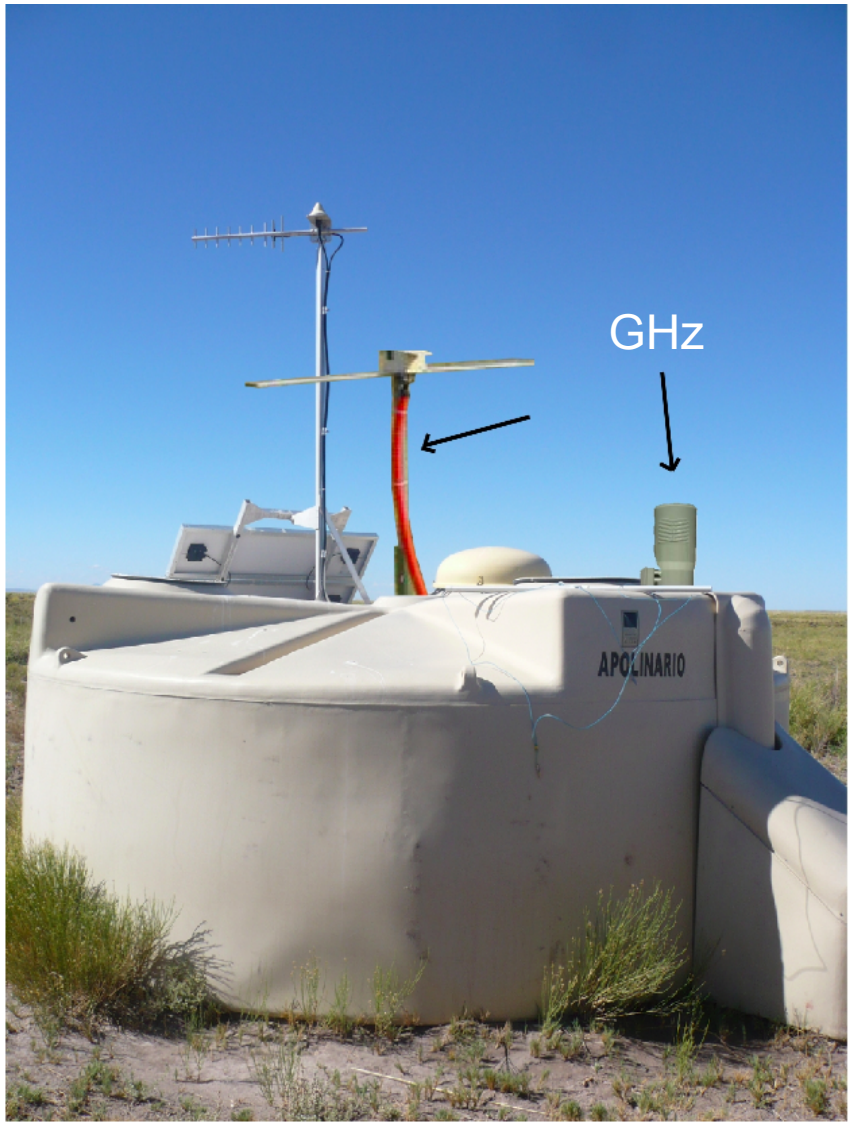


Event Candidate (October run)



We keep detecting (not striking) candidates. Coincidence measurement with Auger essential

EASIER concept



- Install GHz wide fov feed in each tank.

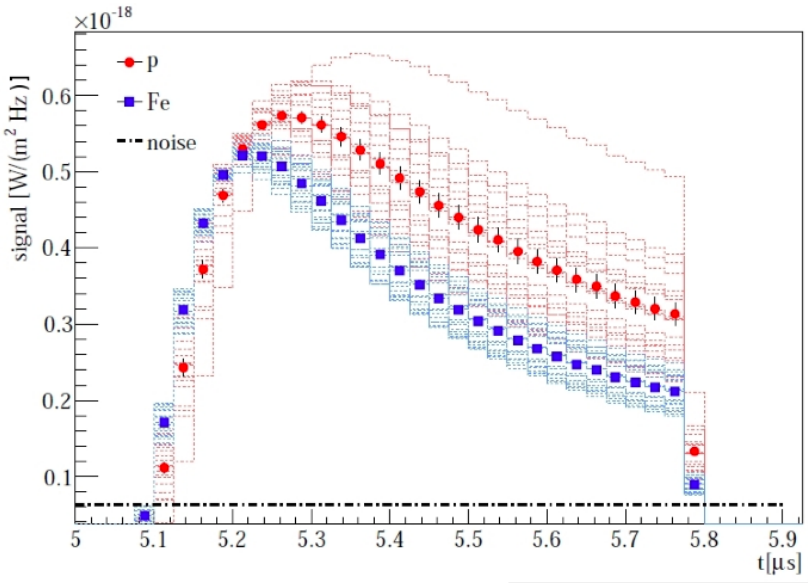
≈ 100% duty cycle with the coverage of a surface detector, integrated in the array (first test: equip one hexagon)

- Signal proportional to the EM energy

- Time shape related to the cascade evolution and X_{max}

- Muonic signal in the tank by subtraction

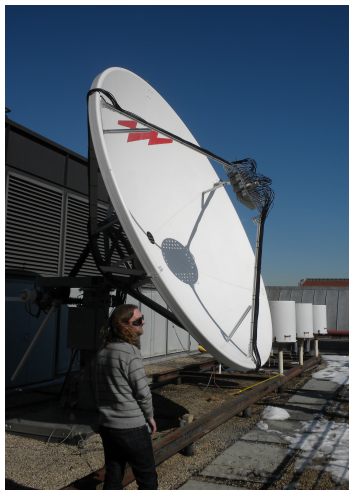
COMPOSITION!

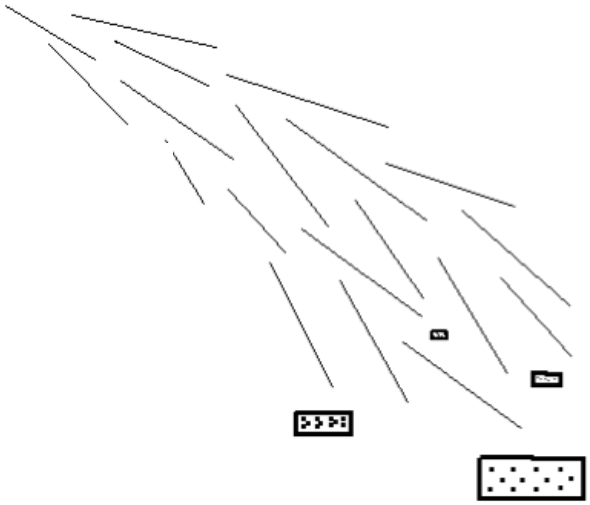


EASIER is easy

Why EASIER works

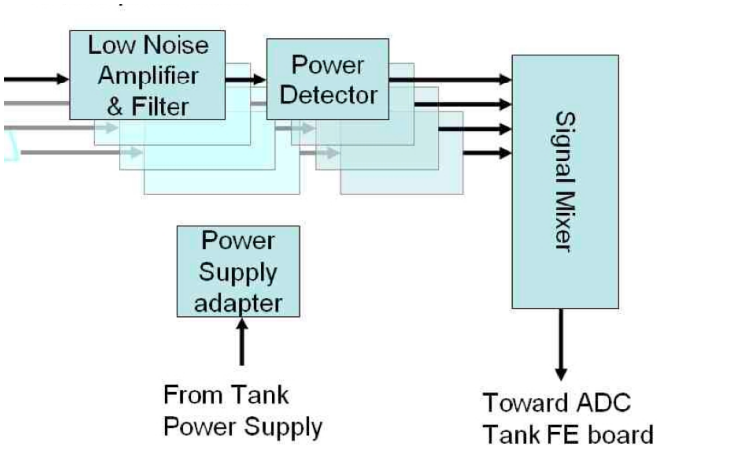
- EASIER will use the power and electronics available on the Auger tank. EASIER signal will be digitized, stored and broadcasted as a standard PMT channel. Minimal changes needed.
- Triggered by the tank

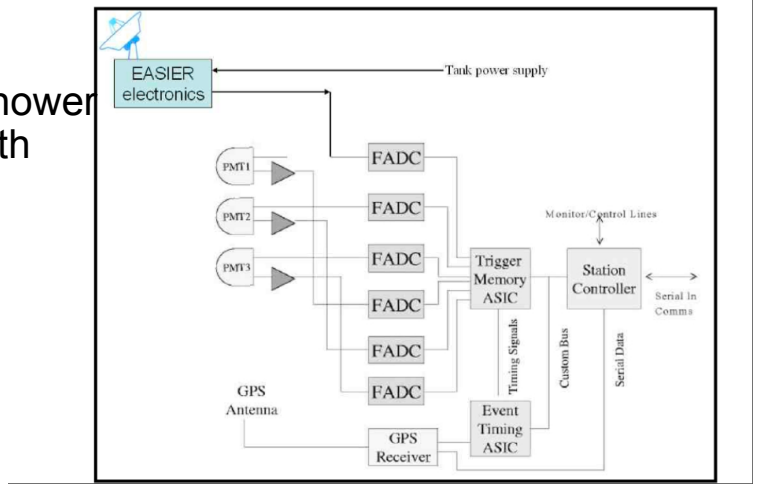




Large antenna area
10 km distance from shower
O(1 μs) pulse width

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

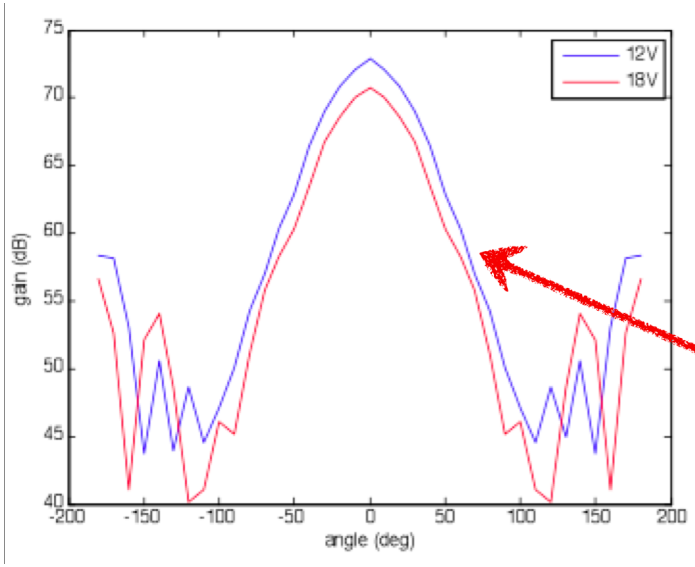


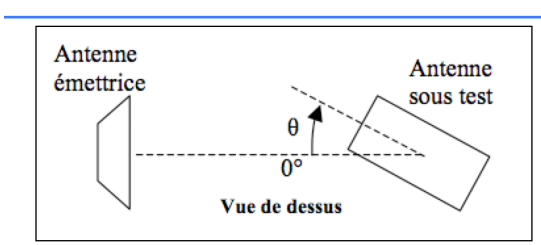


NOTE: EASIER vs MIDAS: the shower is closer and the signal is boosted by the geometrical time compression. Also, being triggered by the tank, better signal over noise by averaging over events. EASIER sensitivity close to large FD-like dish.

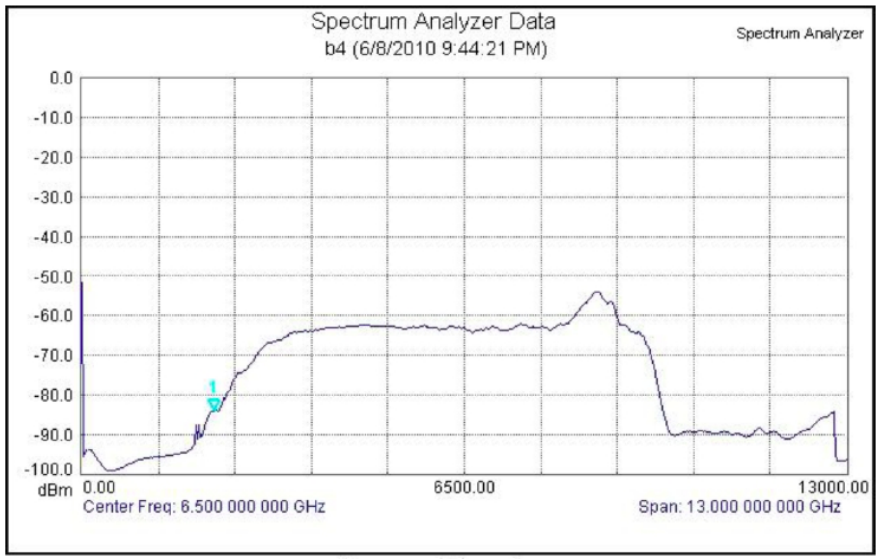
EASIER antenna and noise

Same MIDAS feed and power detector



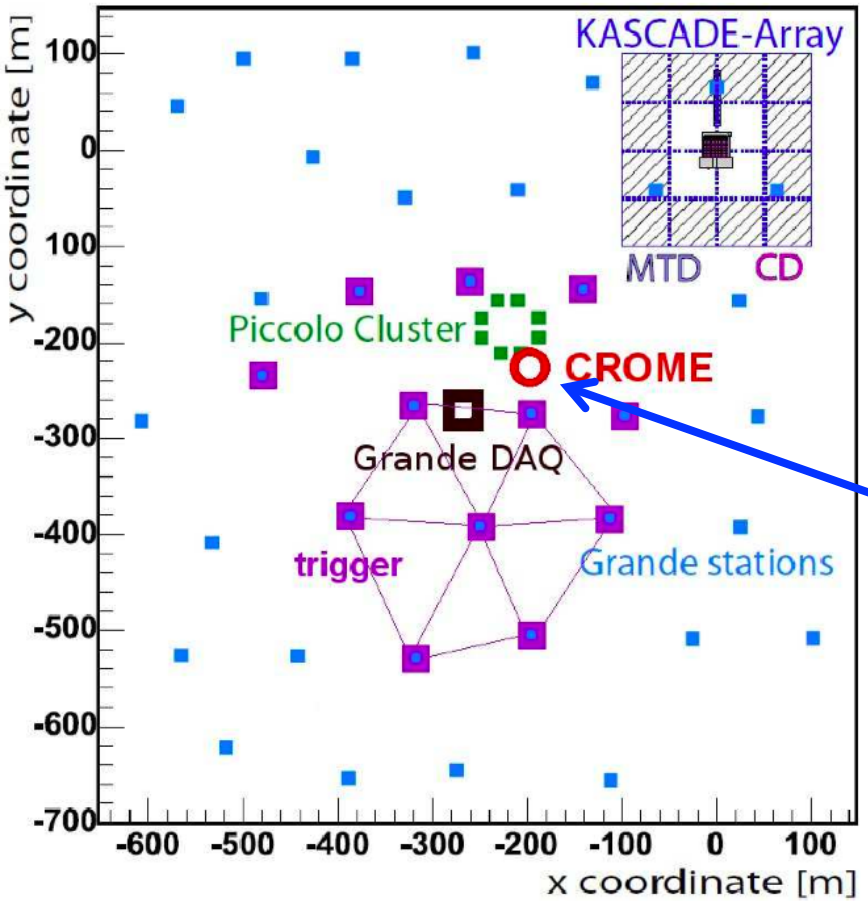


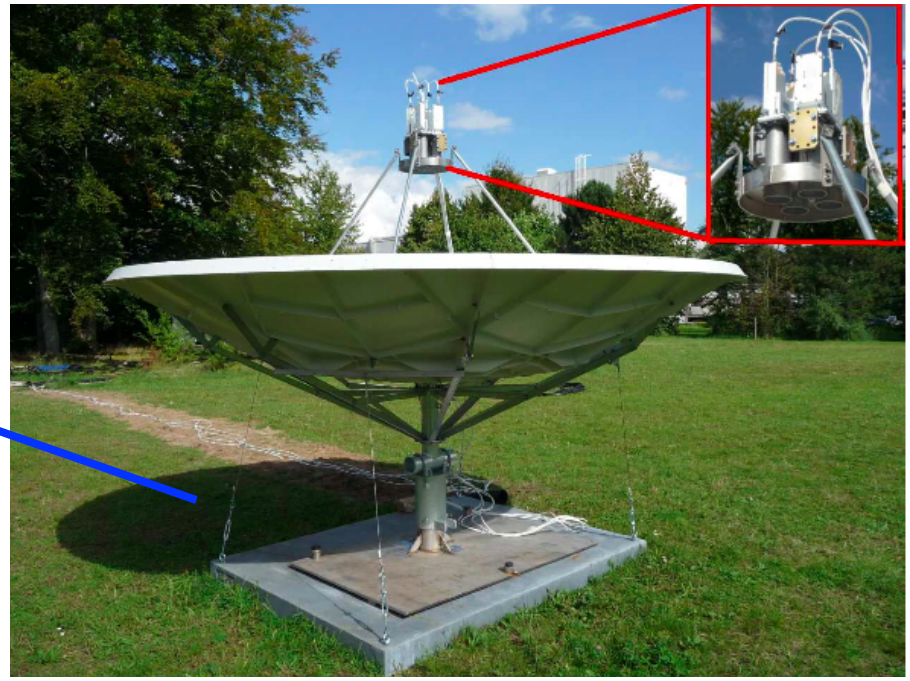
Anechoic chamber measurement at Valence



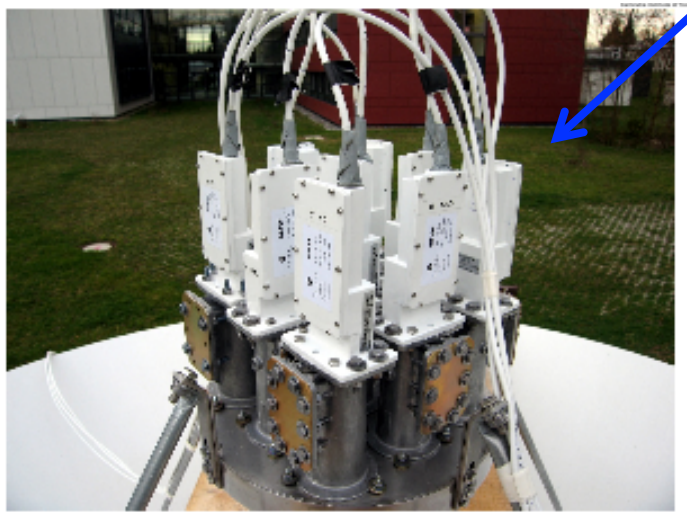
Noise in Auger site, very clean band 3 - 7 GHz

CROME





- 3.4 m diameter dish
- 4 C-band receivers 1.6° fov (now 8)

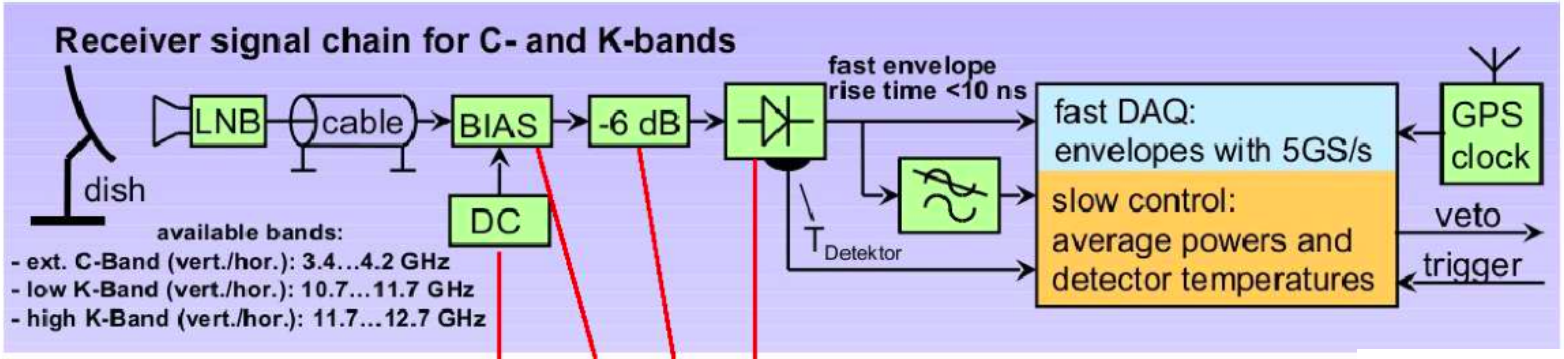


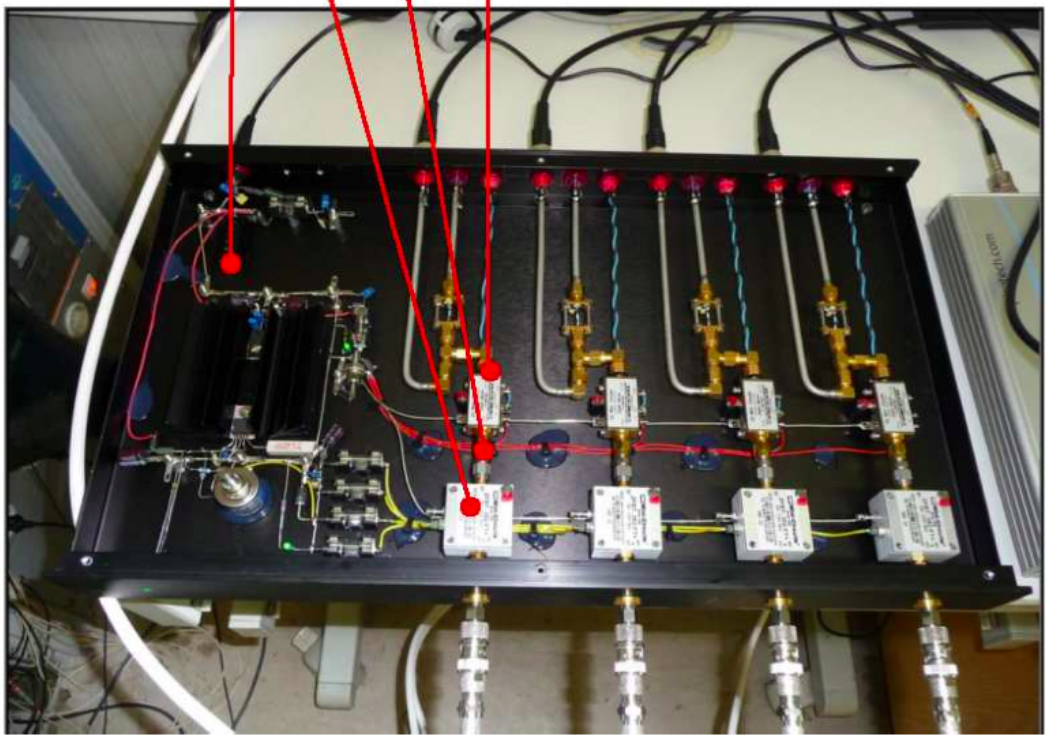
- Energy range: 10^{16} - 10^{18} eV

- Trigger for CROME requires 3 inner hexagons in KASCADE Grande

- Trigger rate 1 event each 5 minutes

CROME electronics

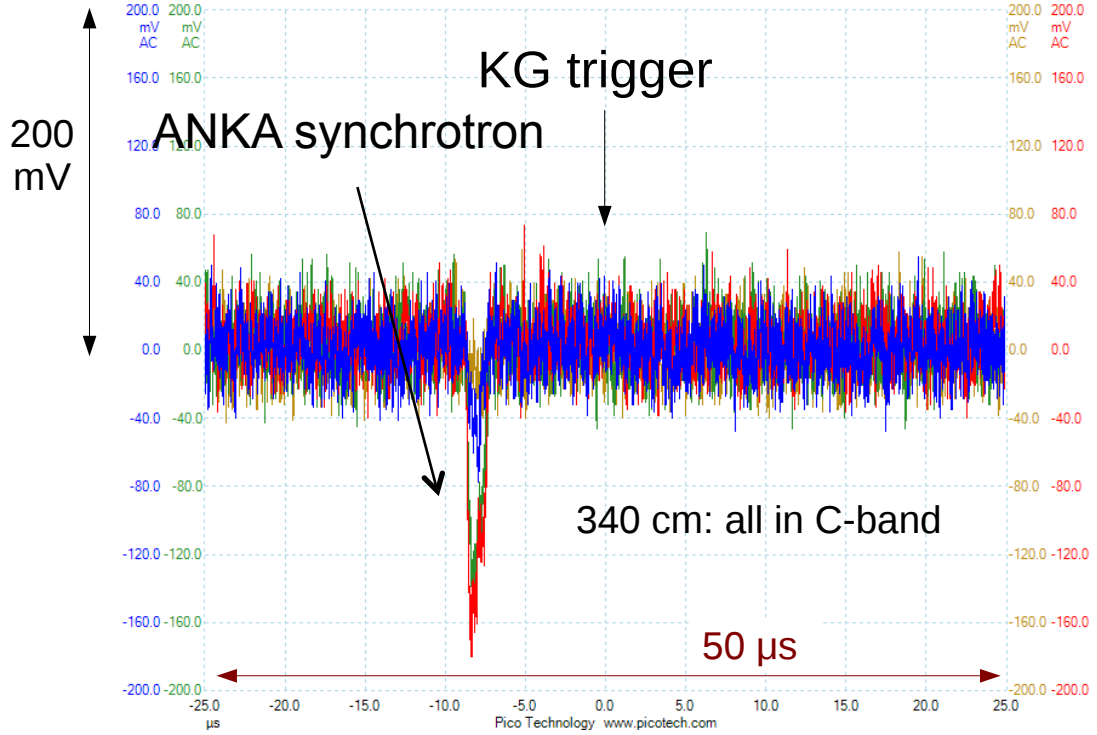


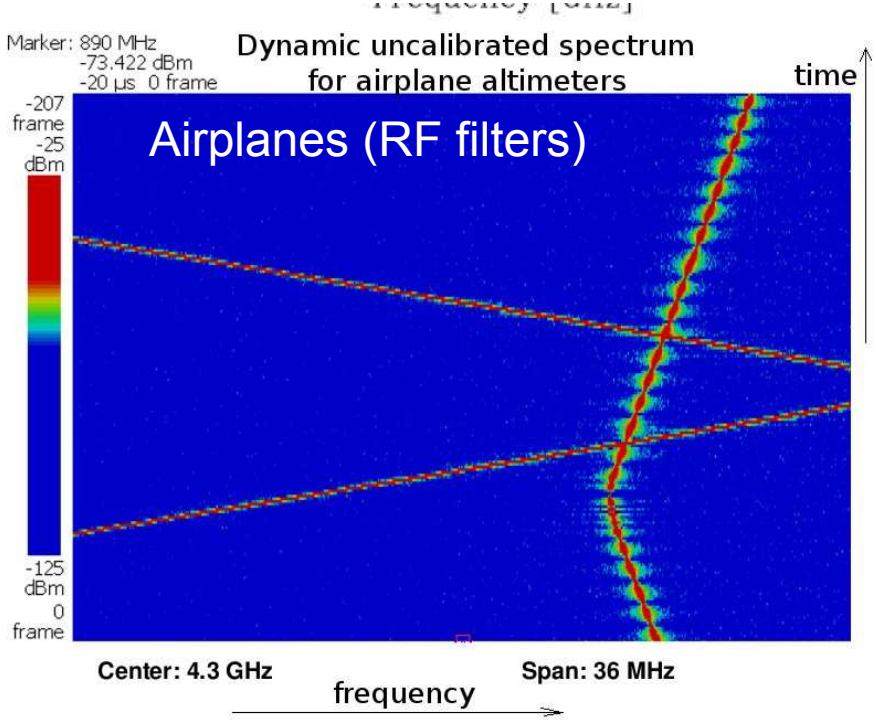


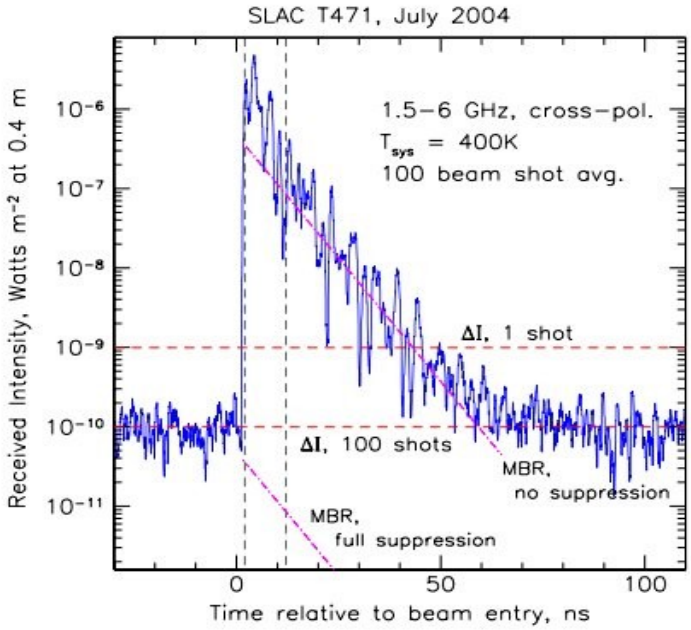
Digitizer Picoscope 6403:

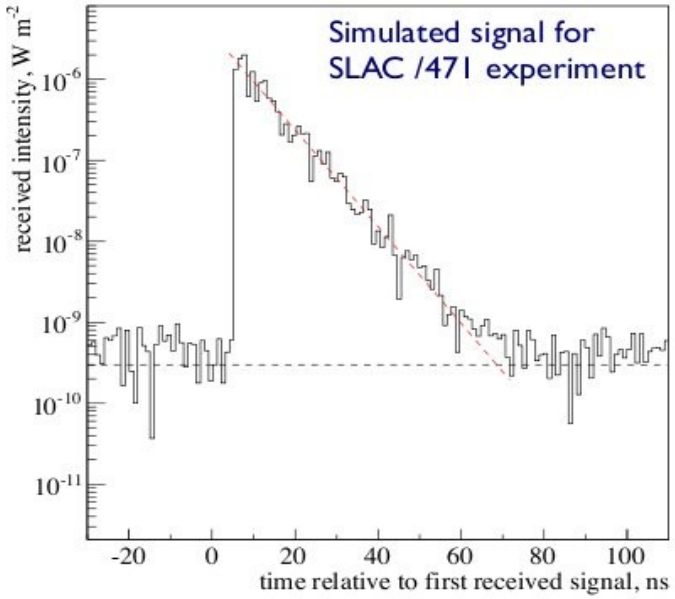
- 4 channels
- 350 MHz analog bandwidth
- Sampling rate up to 5 GS/s
- Vertical resolution is 8 bits

RFI in Karlsruhe



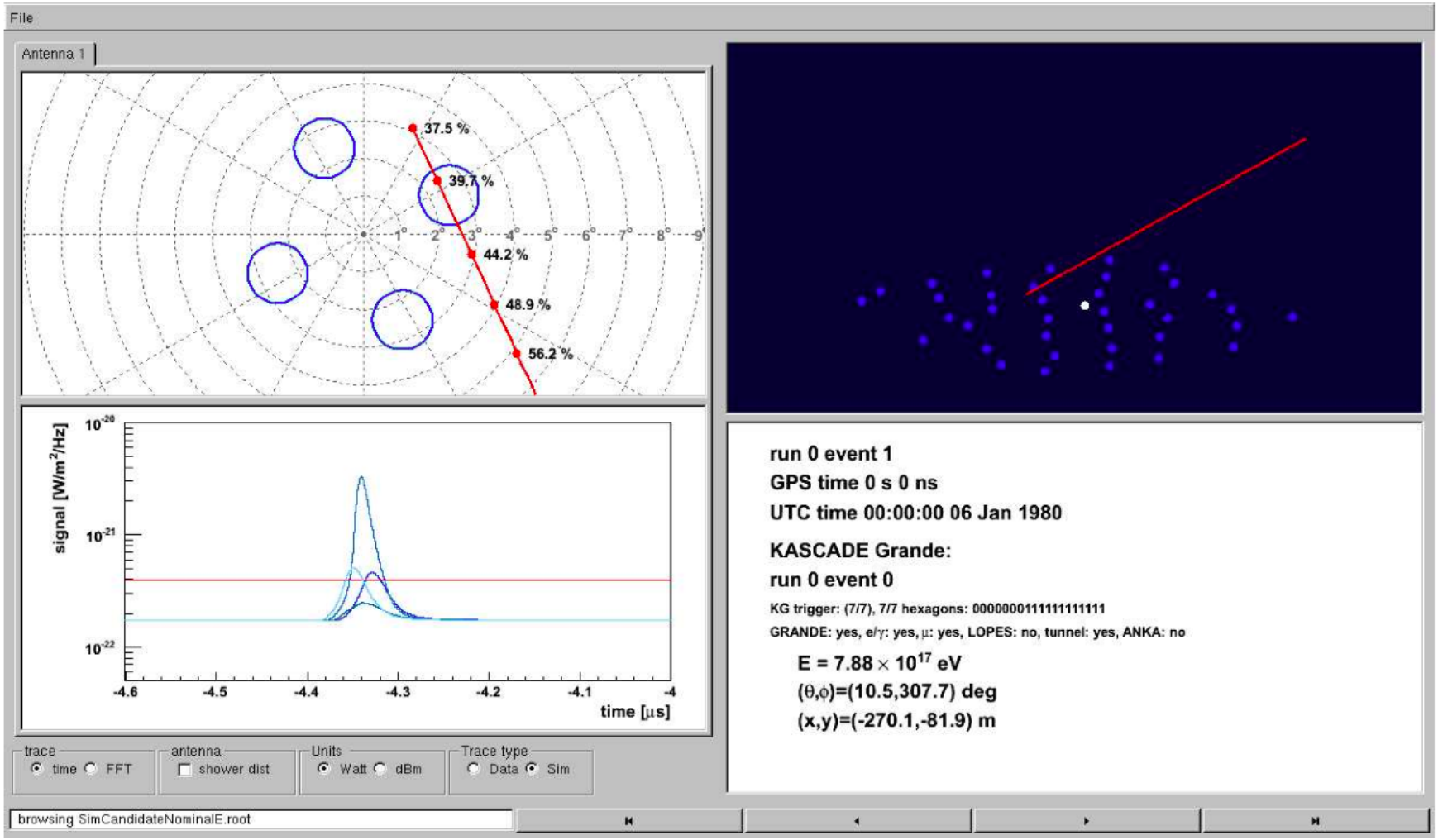






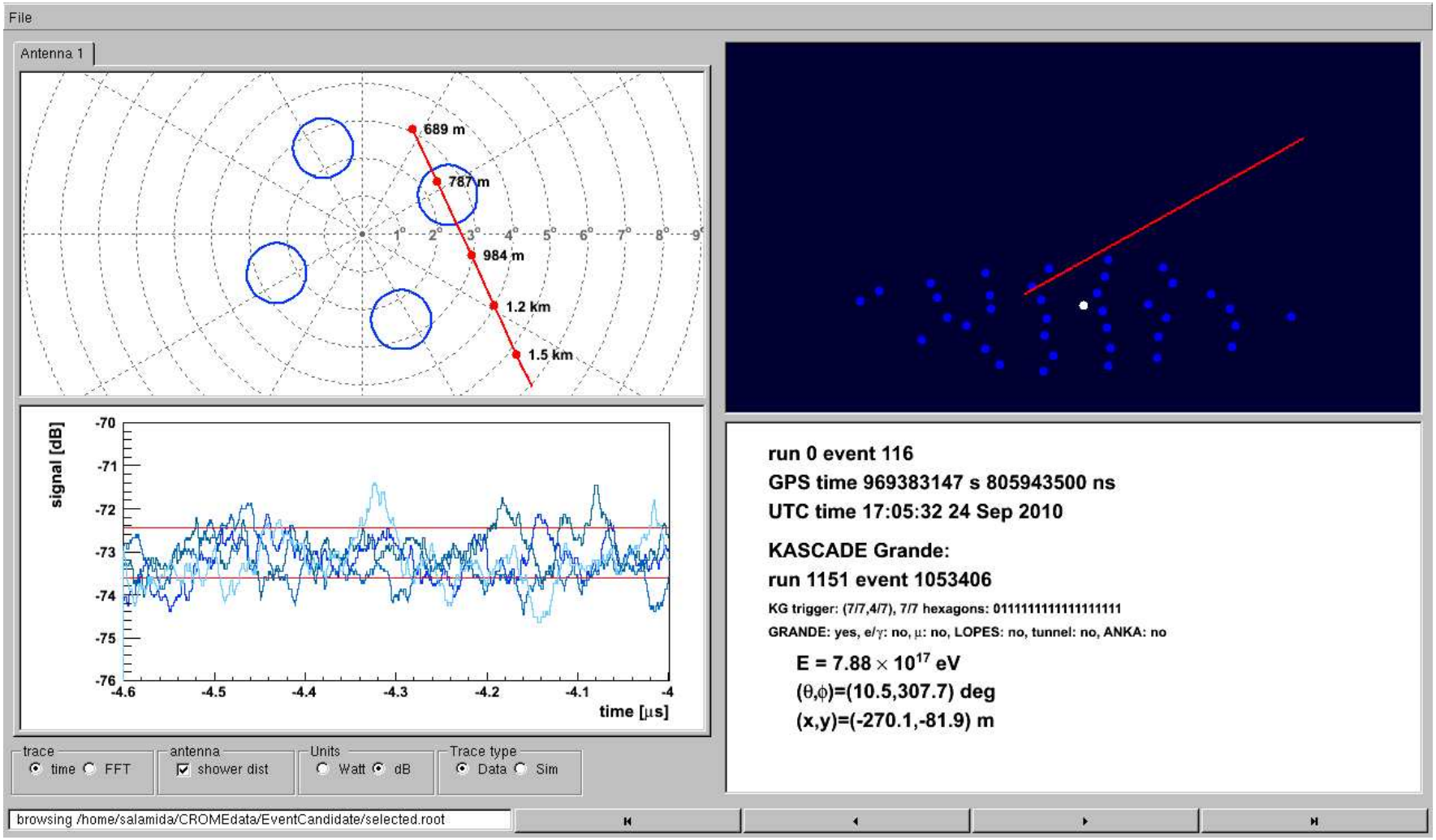
Microwave signal simulation

CROME simulated signal (from triggered KG event 10^{18} eV)



Linear scaling assumed in the simulation

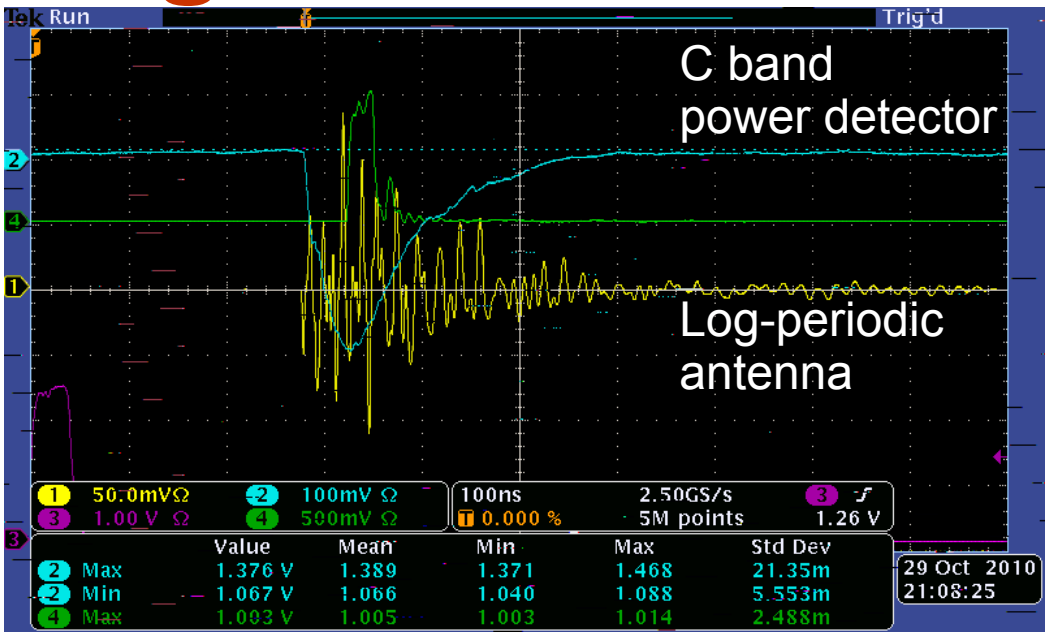
CROME corresponding signal



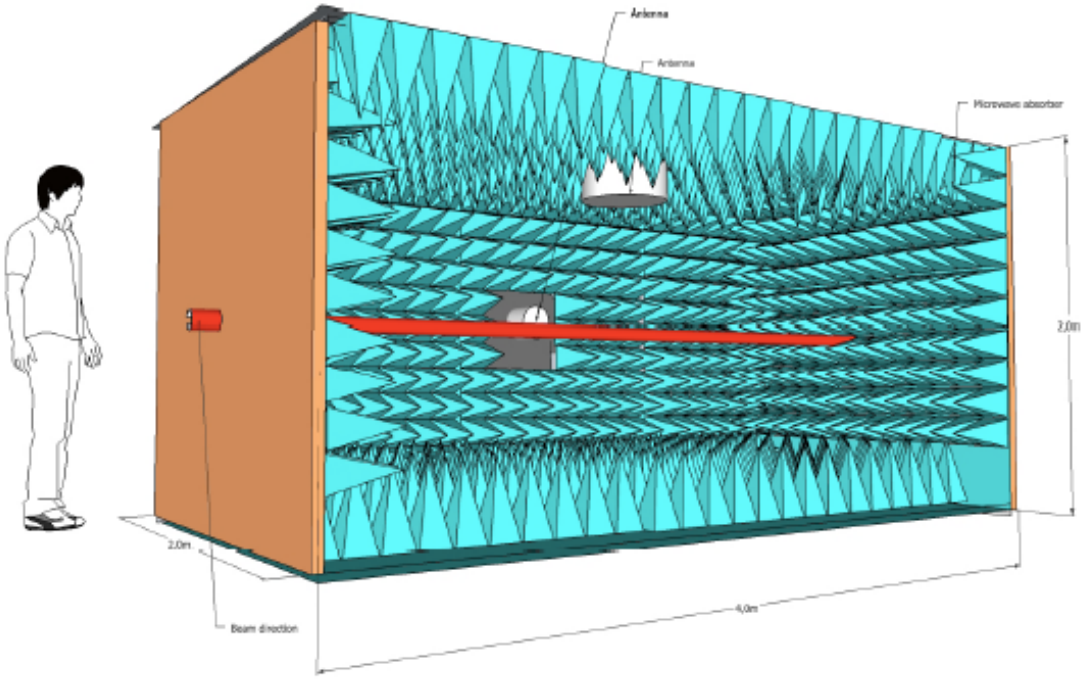
Analysis ongoing: KG shower reconstruction, KG-CROME trigger delay

First beam test @ Argonne

3 MeV electrons



Good RF background conditions. Signal in correspondence of beam observed.



AMY@ Frascati

700 MeV electrons

Outlook

- An extensive R&D program is undergoing to detect microwave emission from UHECR. Complementary approaches, including beam measurements, are pursued.

- MIDAS experience: microwave antenna calibration, mantainance and remote operation is much easier than UV-light FD. If technique successful, a very robust and low-cost detector can be built.

- AMBER, MIDAS, EASIER will be installed at the Auger Observatory in 2011. CROME will continue to take data and will be upgraded till KG operating. Expected rates (with linear scaling) few events per month.

- Quadratic scaling unlikely (MIDAS should have seen many large events in Chicago, also CROME). The potential of the technique will depend on the equivalent UHECR energy threshold.

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Stay tuned (to the microwave UHECR radio)