Kavli Institute
for Cosmological Physics
at The University of Chicago

Microwave detection of air showers with MIDAS

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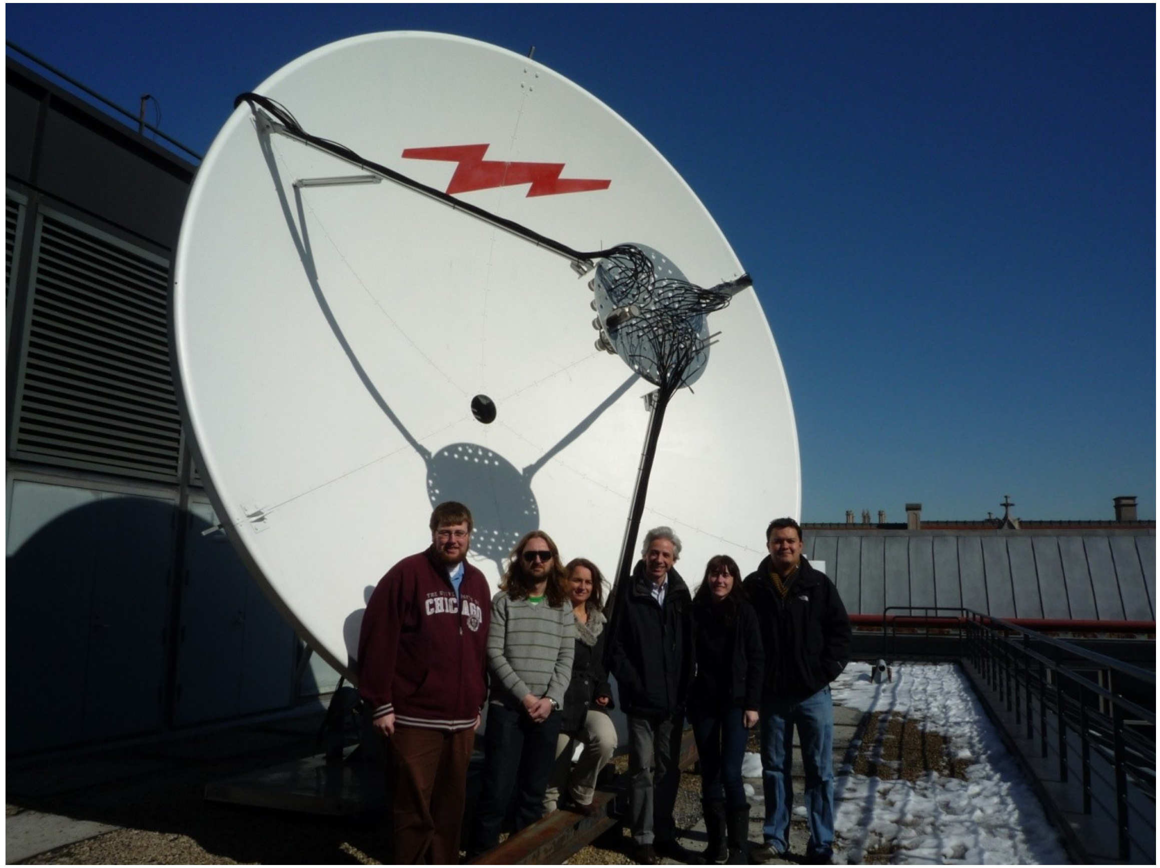
ARENA 2010 – NANTES
4th International Workshop on Acoustic and Radio EeV Neutrino detection activities
Tuesday, June 29, to Friday, July 2, 2010 – Université de Nantes, France



The University of Chicago
M. Bogdan, M. Bohacova, P. Facal, J.F. Genat, F. Ionita, M. Monasor, P. Privitera, L. Reyes, B. Rouille d'Orfeuill, C. Williams

Universidad de Santiago de Compostela
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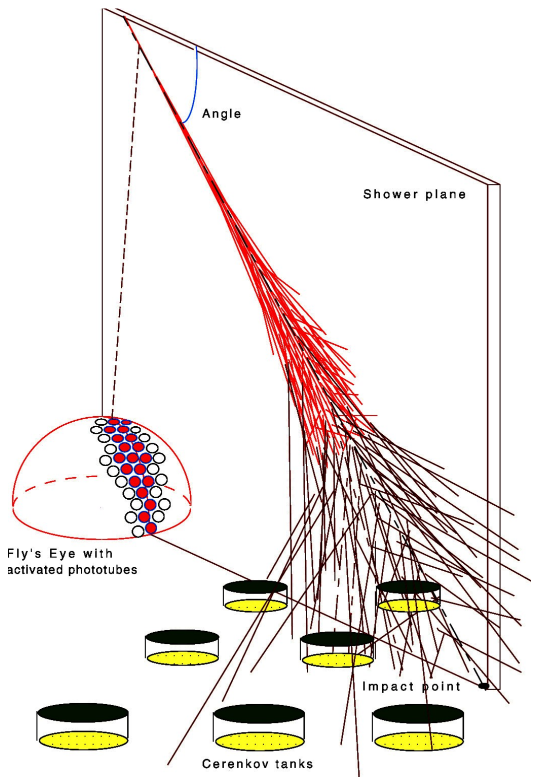
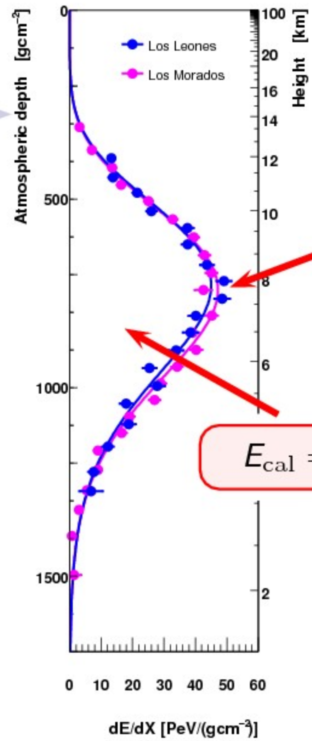
MIDAS is a prototype for an ultra high energy cosmic ray (and neutrino) detector, exploiting microwave bremsstrahlung radiation to build an 'FD-like' radio detector.





Fluorescence Detector

X_{max}

Depth of the shower maximum sensitive to mass composition

$E_{\mathrm{cal}} = \int \mathrm{d}X \, \frac{\mathrm{d}E}{\mathrm{d}X}$

Near calorimetric energy measurement (MC independent)

Clear moonless nights, 10% duty cycle

MIDAS OBJECTIVE

Confirm and characterize microwave emission as a viable detection technique for ultra high energy cosmic rays

Microwave emission from molecular bremsstrahlung

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 range

Molecular bremsstrahlung characterized by:

- Isotropic and un-polarized
- Microwave, measured 2-6 GHz
- Threshold for detection in UHECR would be below 10^{19} eV

Potential for an FD-like detector that observes the <u>longitudinal development</u> of the shower with <u>100% duty cycle</u>, <u>without atmospheric attenuation</u> and <u>low cost</u>.

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

Total radiation is the sum of the emission of the individual electrons

$$\vec{E} = \sum_{j=1}^{N_e} \varepsilon_1(\mathbf{v}) \exp(-i\vec{k}\cdot\vec{x})$$

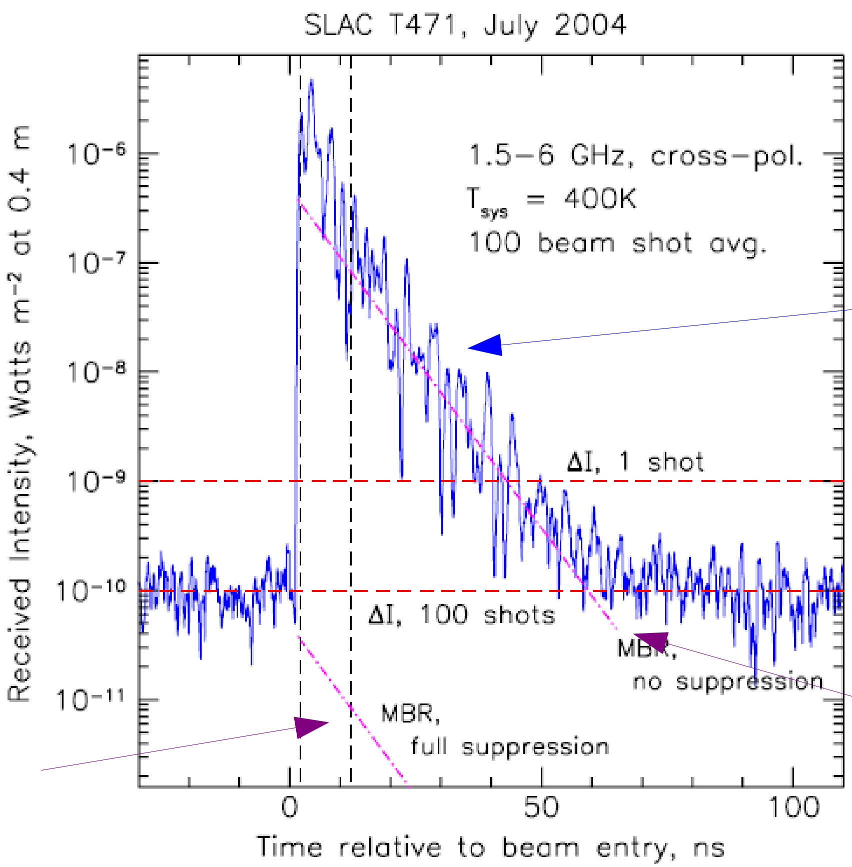
Depending on the plasma density parameters

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 → $P_{tot} = (N_e)^2 \times P_1$

Gorham measurement at SLAC

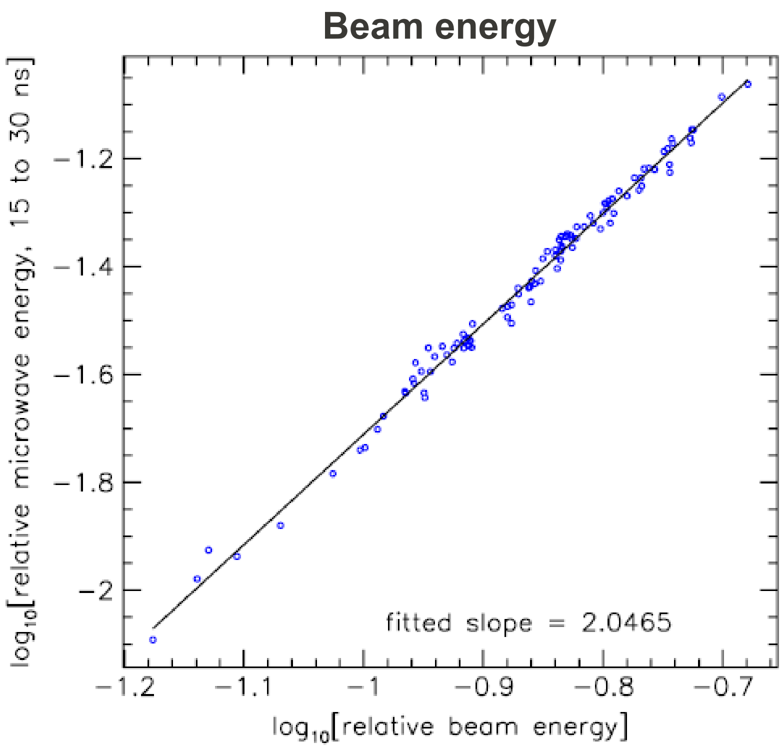


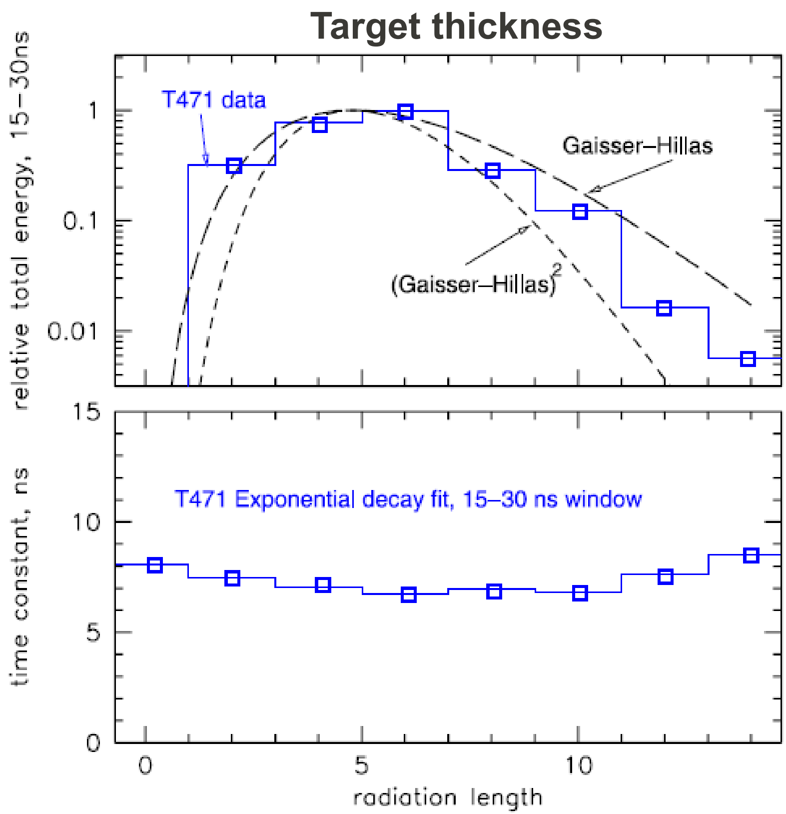
Measured signal attributed to molecular bremsstrahlung

Minimum signal level expected.

Expectation, emission enhanced by coherence

Measurements show some degree of coherence. Different values of the Debye length, electron density and plasma cooling could affect the scaling in an air shower





	BEAM	AIR SHOWER
Energy	$3.4\ 10^{17}$ eV	10^{19} eV
Plasma temperature	$10^{4.5}$ K	10^{4} K
Debye length	2 mm	7 cm
Electrons within Debye radius	10^{7}	10^{7}

The Debye length sets the expected correlation scale in the plasma

$I_{0,\,meas} = 4\ 10^{-16}$ W/m²/Hz

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

@ 10 Km → $I = 2.8\ 10^{-24}$ W/m²/Hz

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

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

5σ detection threshold

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

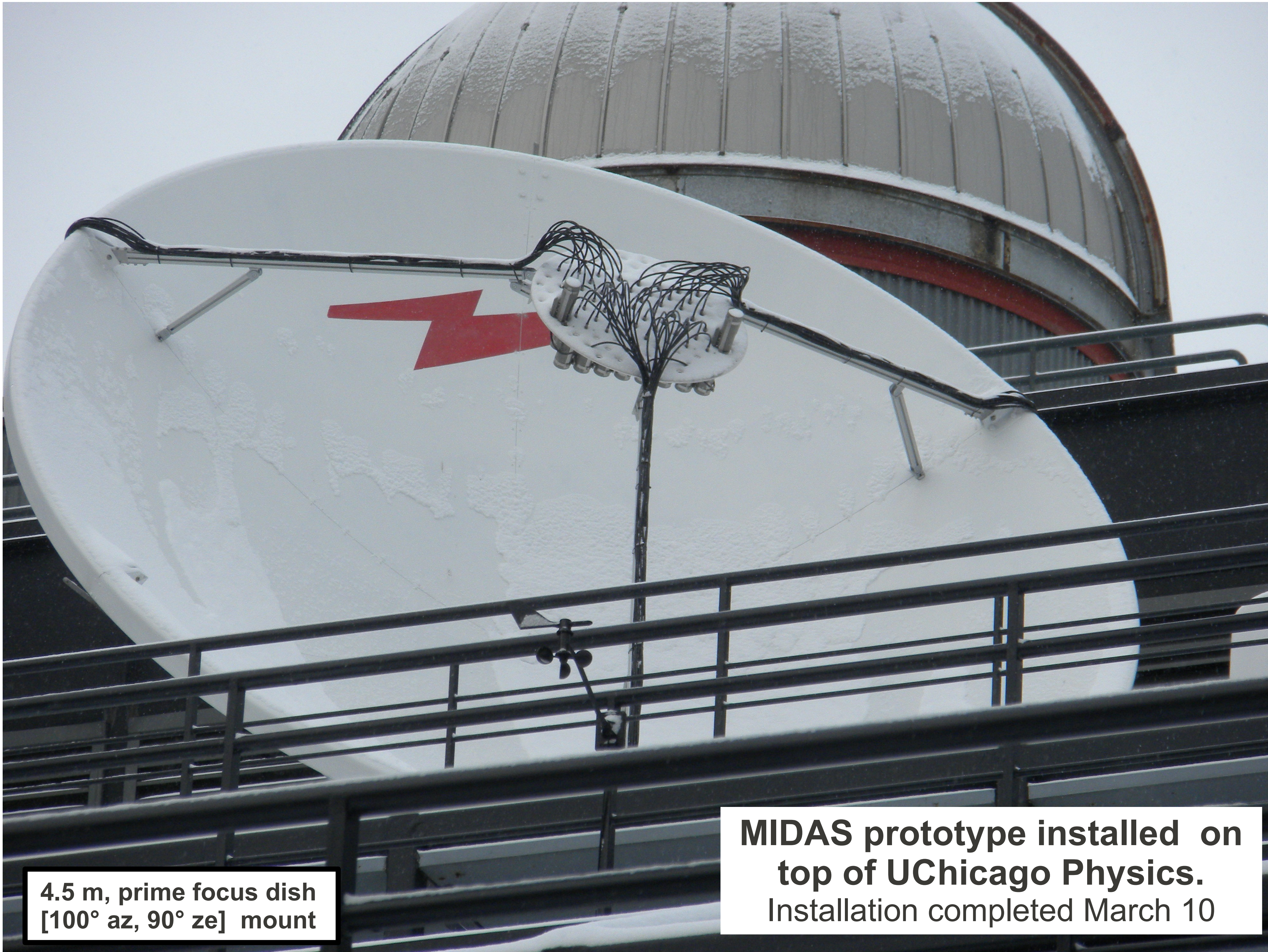
$E_{lin} \sim 10^{19}$ eV

DESIGN PARAMETERS

Large collection area	~ 10 m²	4.5m dish in campus
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

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

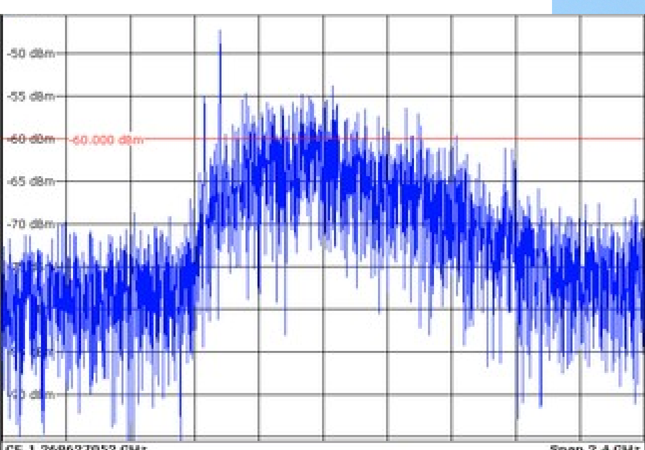
(Wavelength, dish collection area and f.o.v. closely tied)

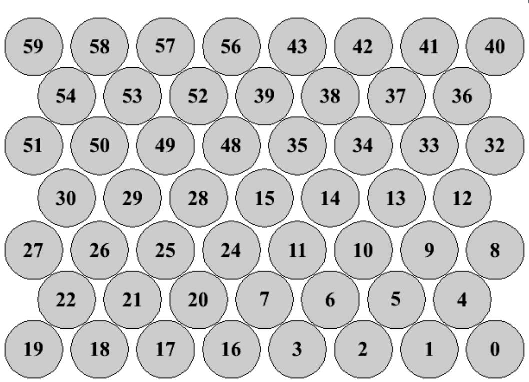

4.5 m, prime focus dish
[100° az, 90° ze] mount
MIDAS prototype installed on
top of UChicago Physics.
Installation completed March 10

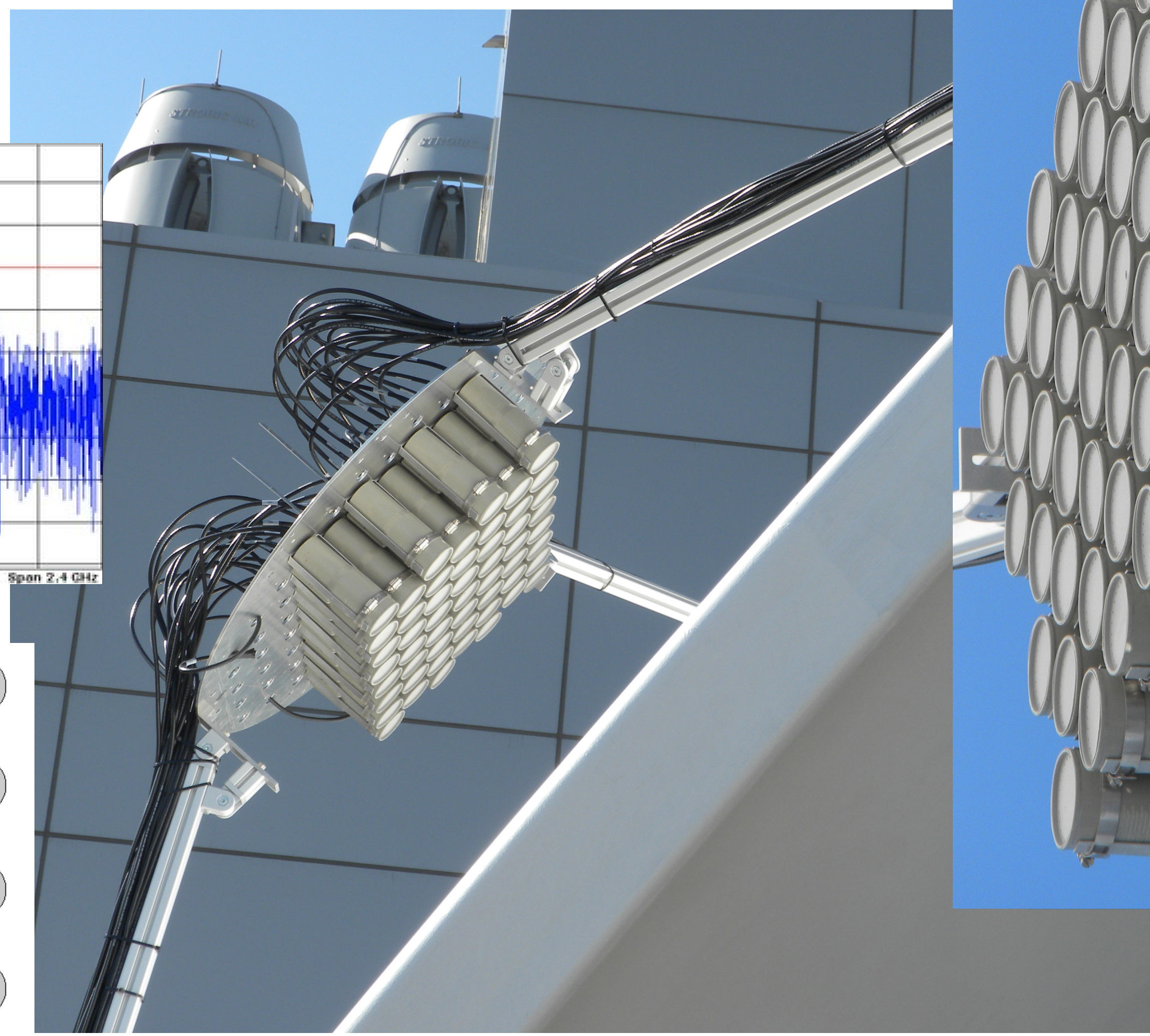
The Camera

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

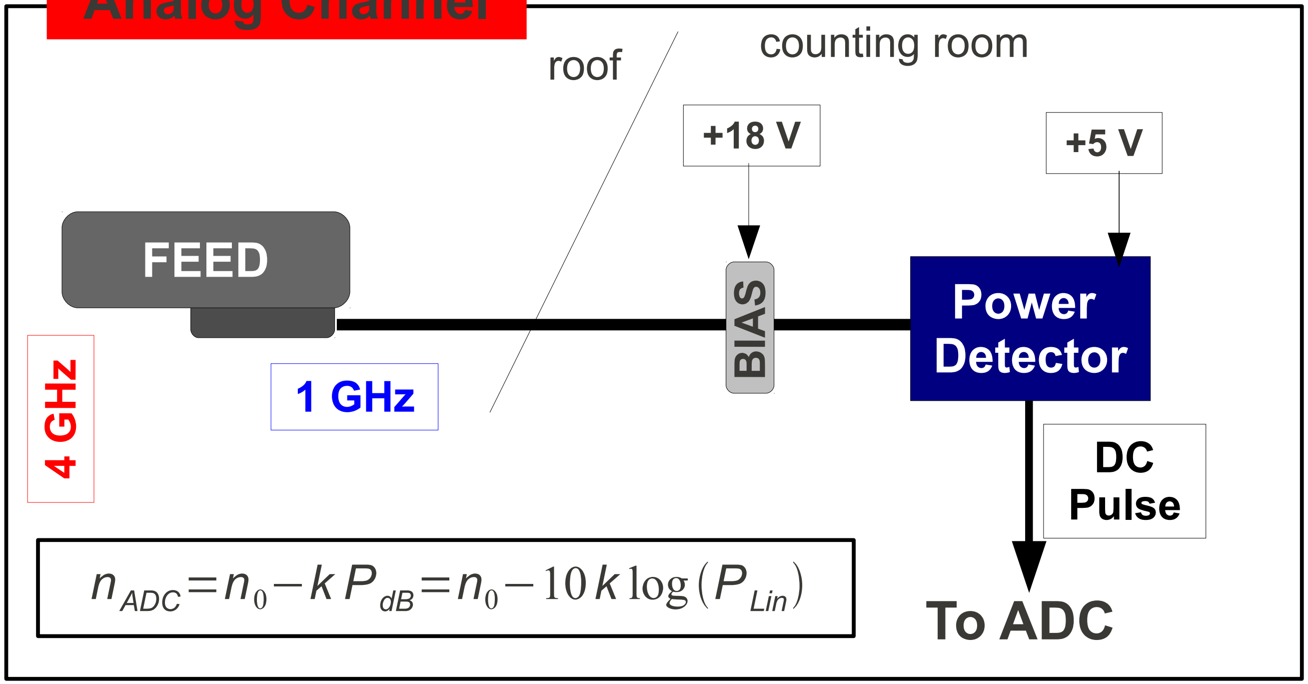
IF Spectrum





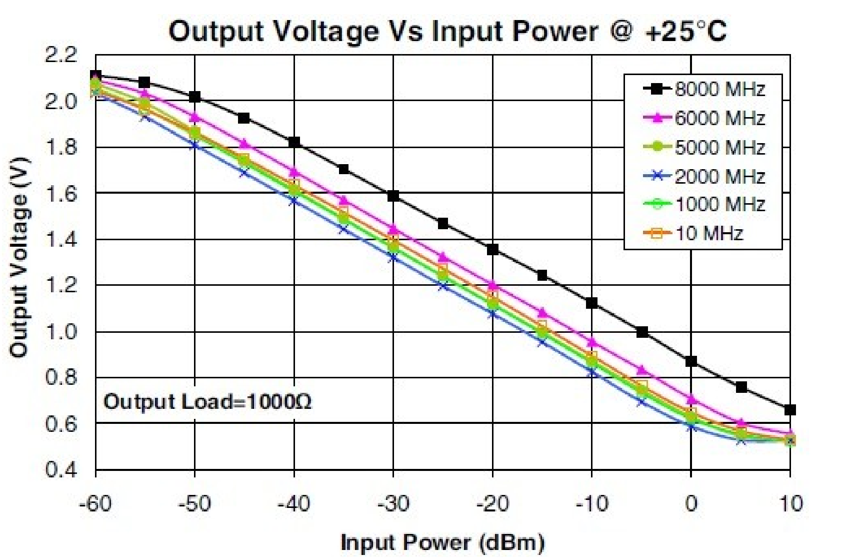


Analog Channel

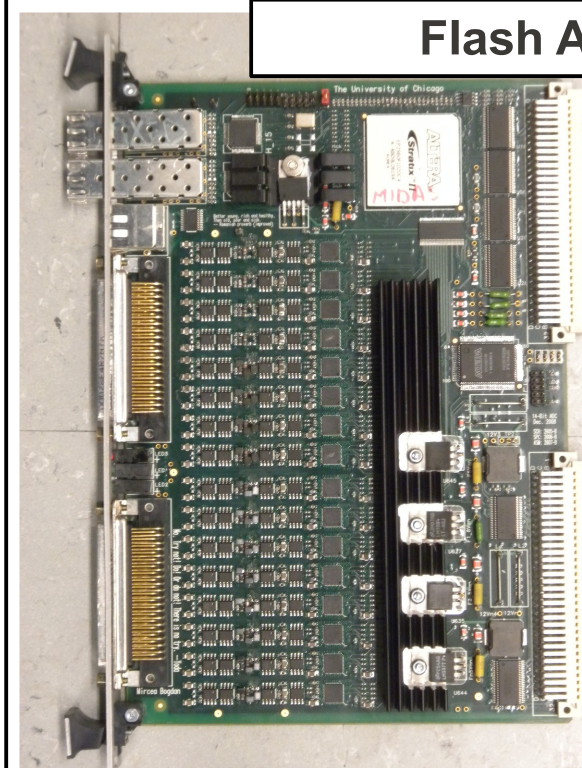


Power detector

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



Flash ADC



16 channels

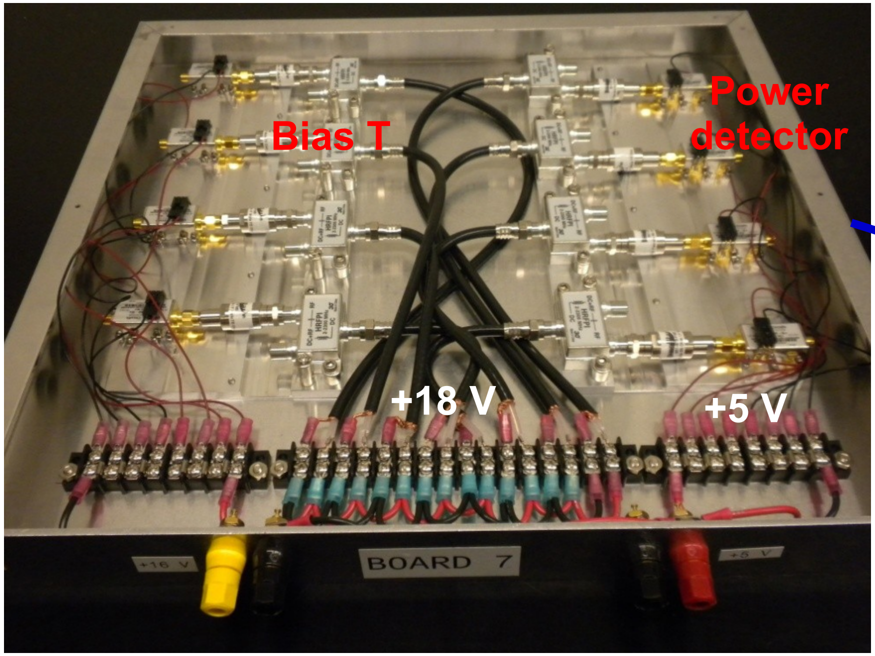
14 bit

20 MHz

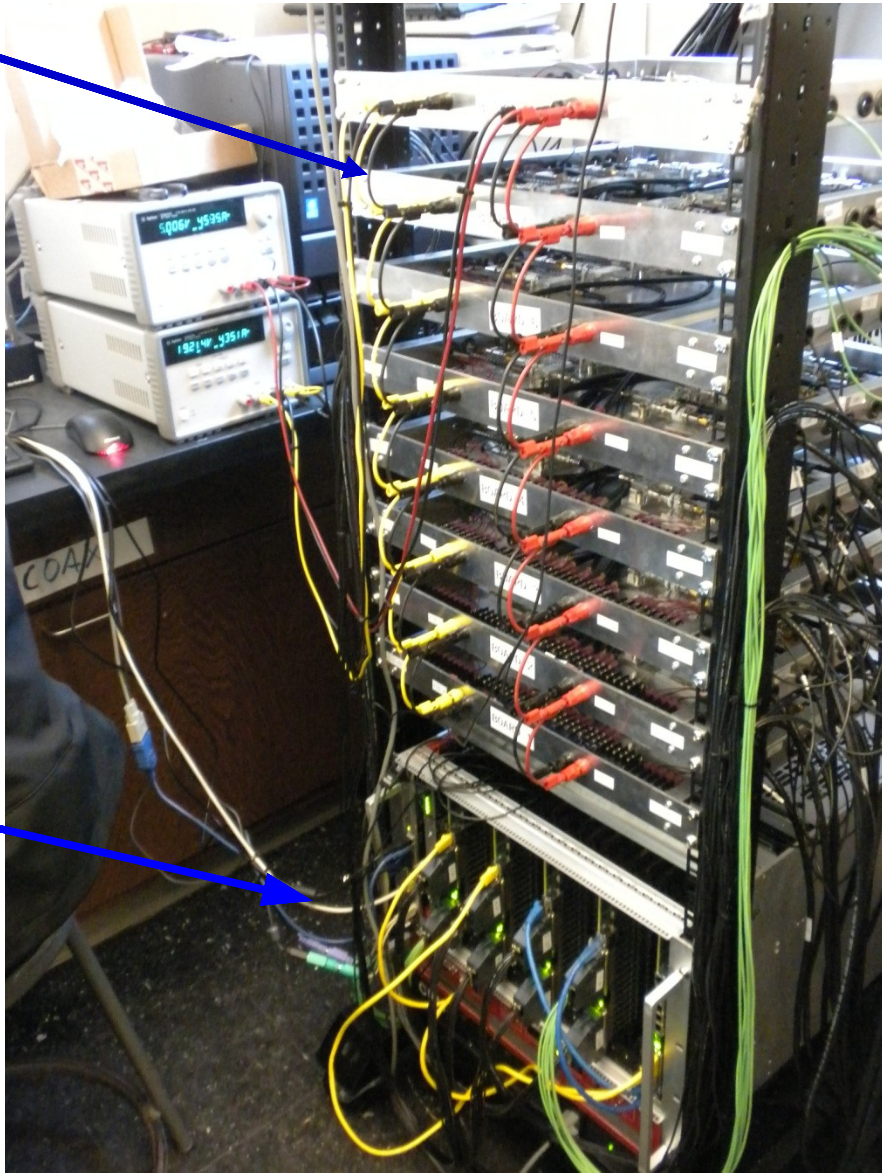
FPGA trigger

Developed @ EFI

Analog electronics enclosure



Control Room



VME digital electronics:

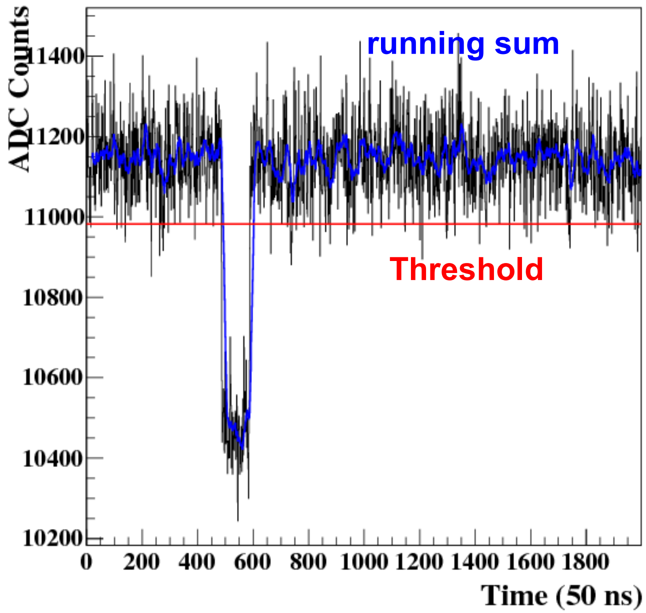
- 4 ADC boards
- Master Trigger Board
- GPS board

Data acquisition:

- Event readout
- 1 second monitoring data

Trigger Strategy

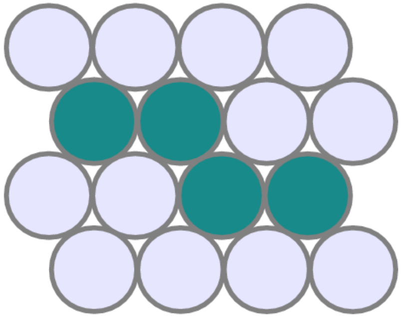
M. Monasor



FIRST LEVEL TRIGGER

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

100 Hz trigger rate by design



SECOND LEVEL TRIGGER

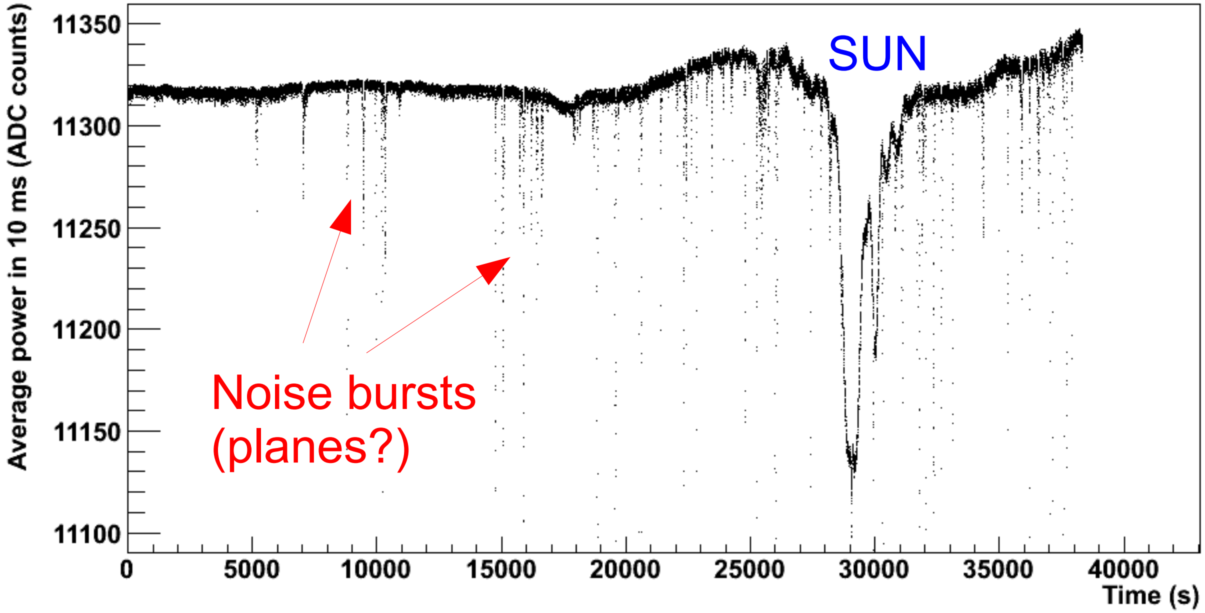
FLT pixels open a 20 μs gate: require topology (pattern) and time coincidence

Accidental rate ~ 0.2 Hz

HIGH-LEVEL VETO

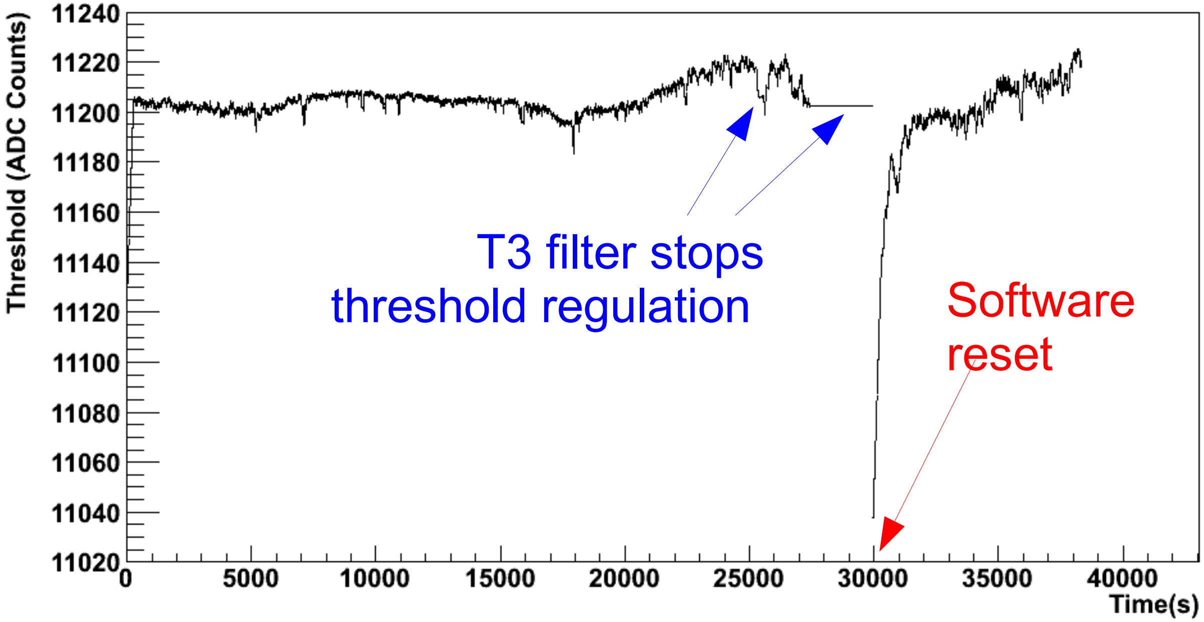
inhibits the SLT trigger when the rate is higher than a pre-set value, to filter *noise bursts*

BASELINE

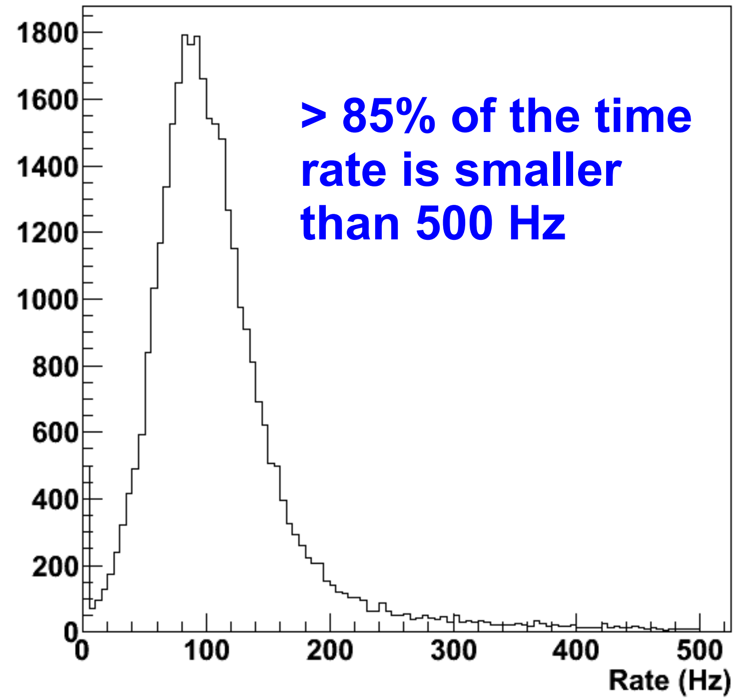


Average baseline (calculated in 10 ms,) threshold and rate recorded every second for detector monitoring.

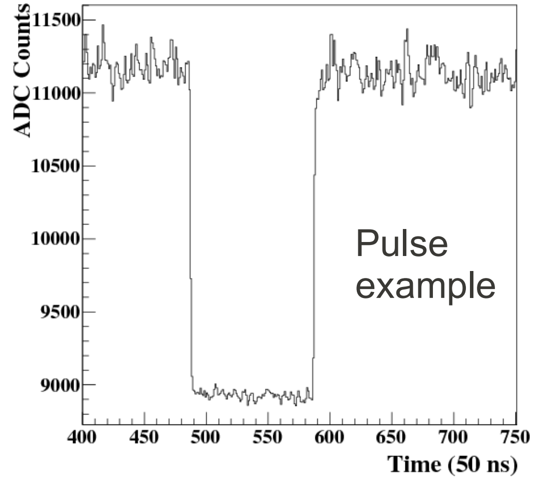
THRESHOLD



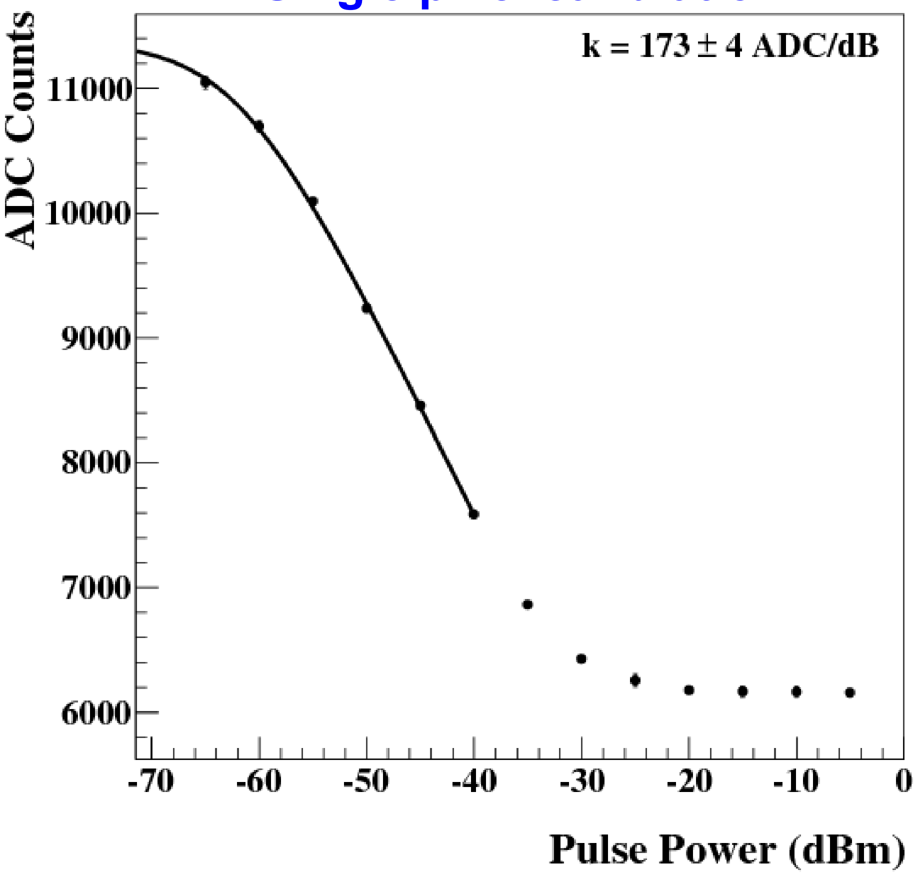
TRIGGER RATE



Relative calibration

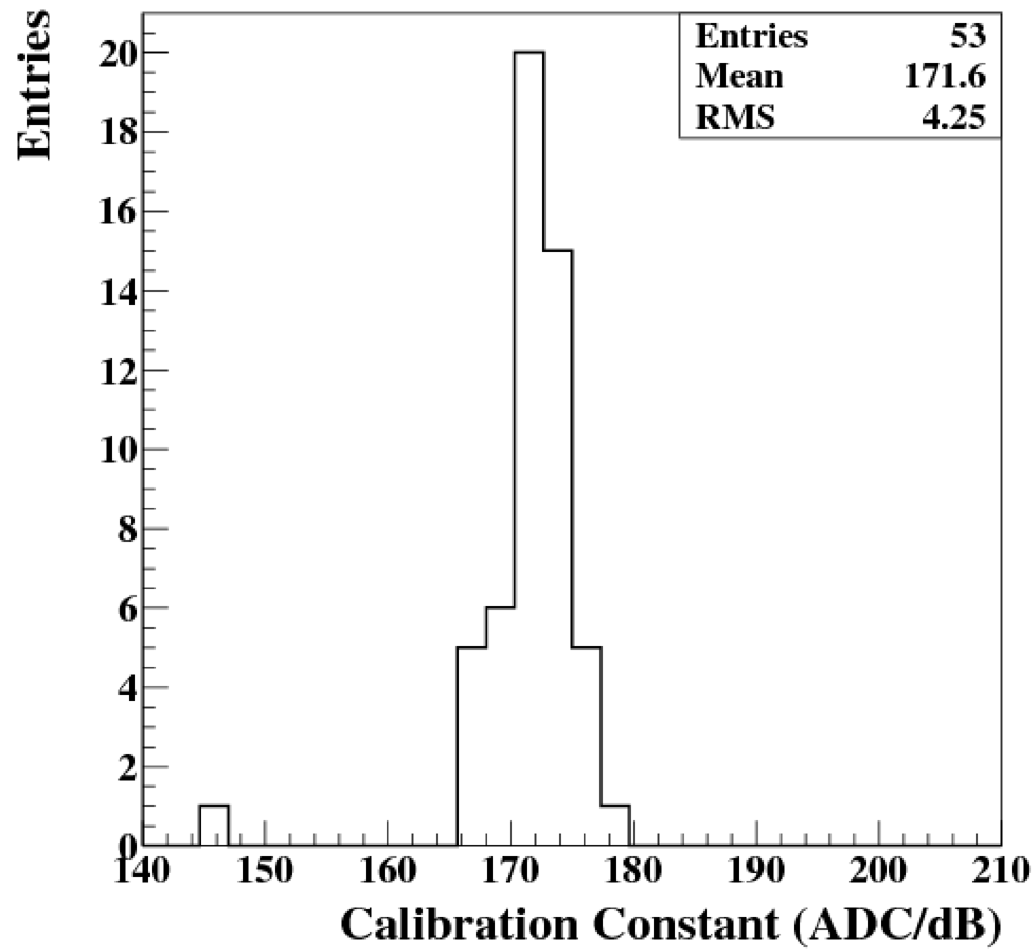


Single pixel calibration



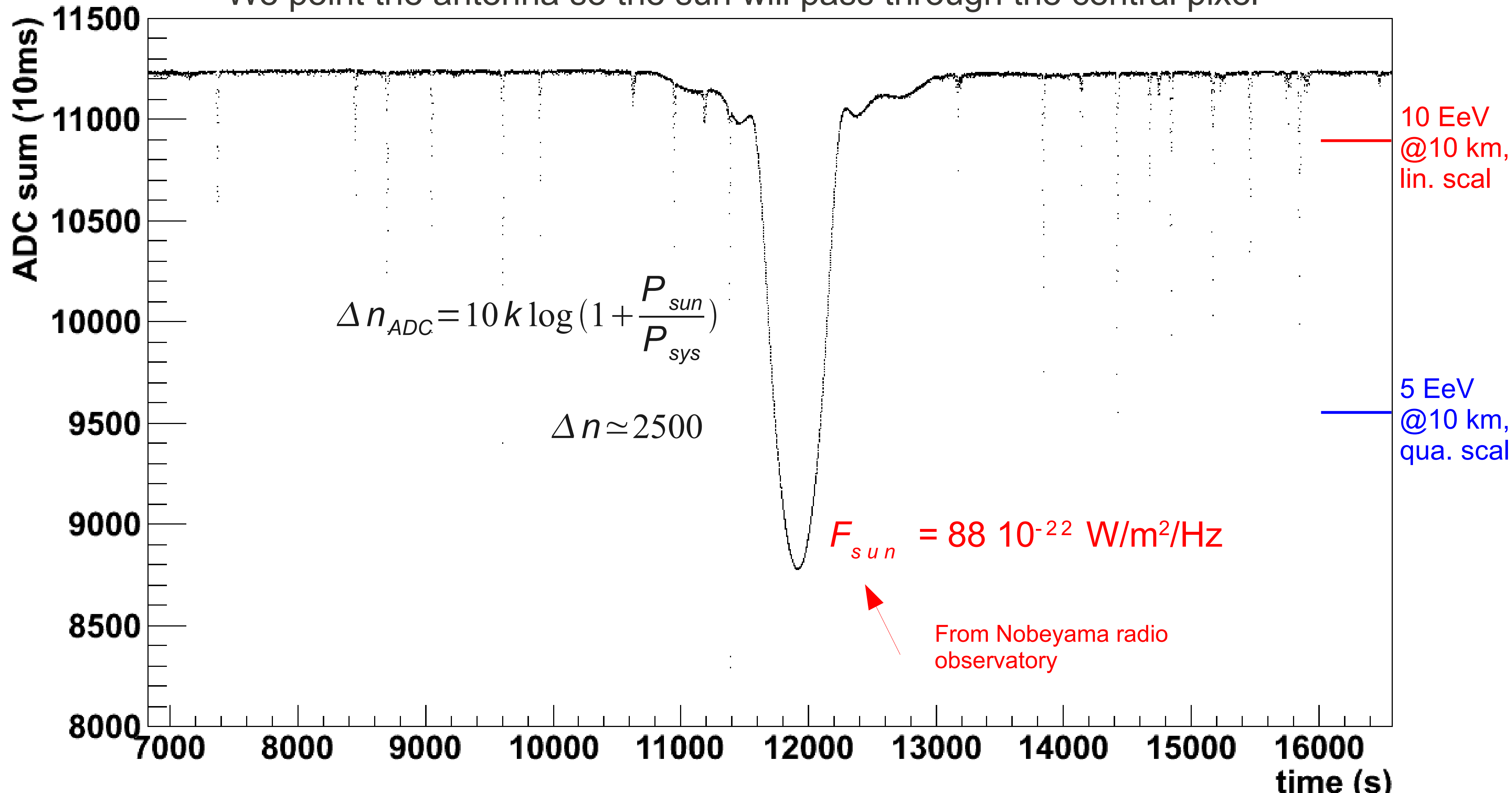
$$n_{ADC} = n_{sys} - 10\,k \log\left(1 + \frac{f}{P_{sys}} P_{Pulse}\right)$$

Calibration constants *(k)* distribution



Absolute calibration and sensitivity using the sun

We point the antenna so the sun will pass through the central pixel



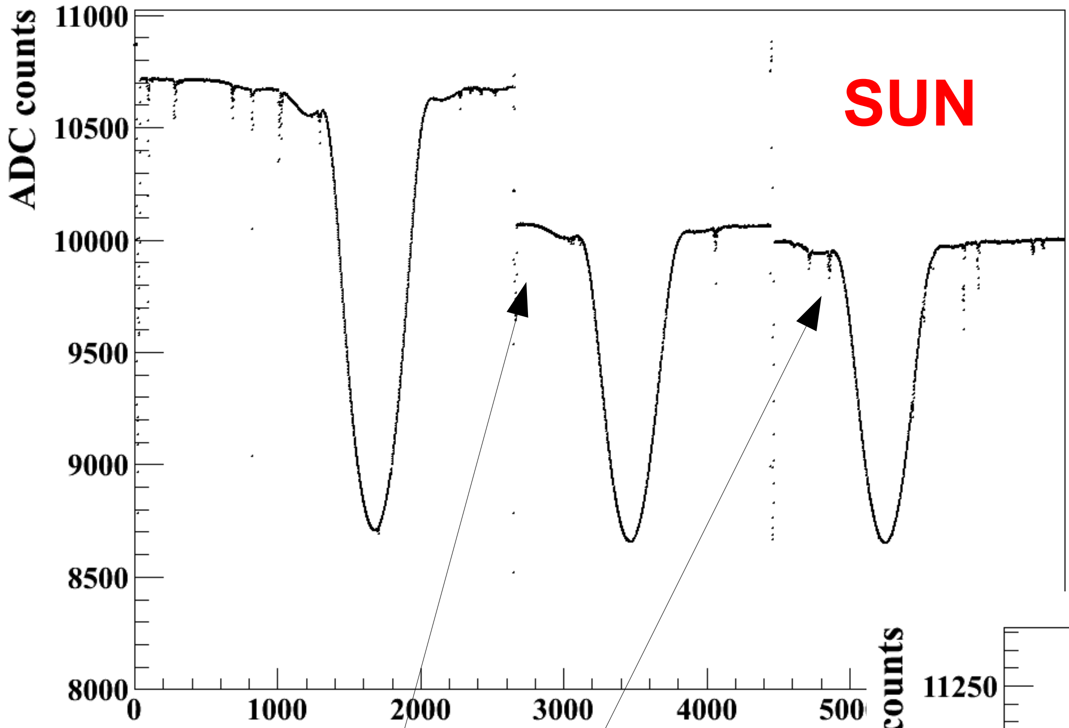
$$F_{sys} \simeq 3.3 \cdot 10^{-22}\, W/m^2/Hz$$

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

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

Fairly close to the design goal

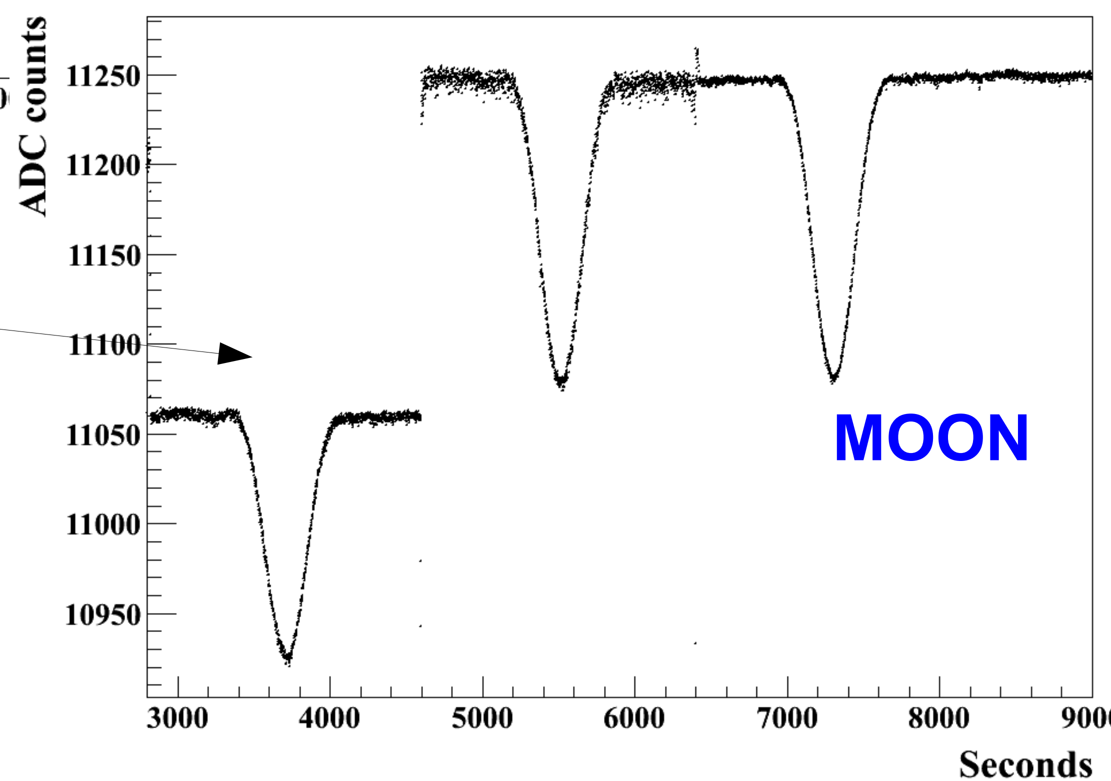
Tracking different sources



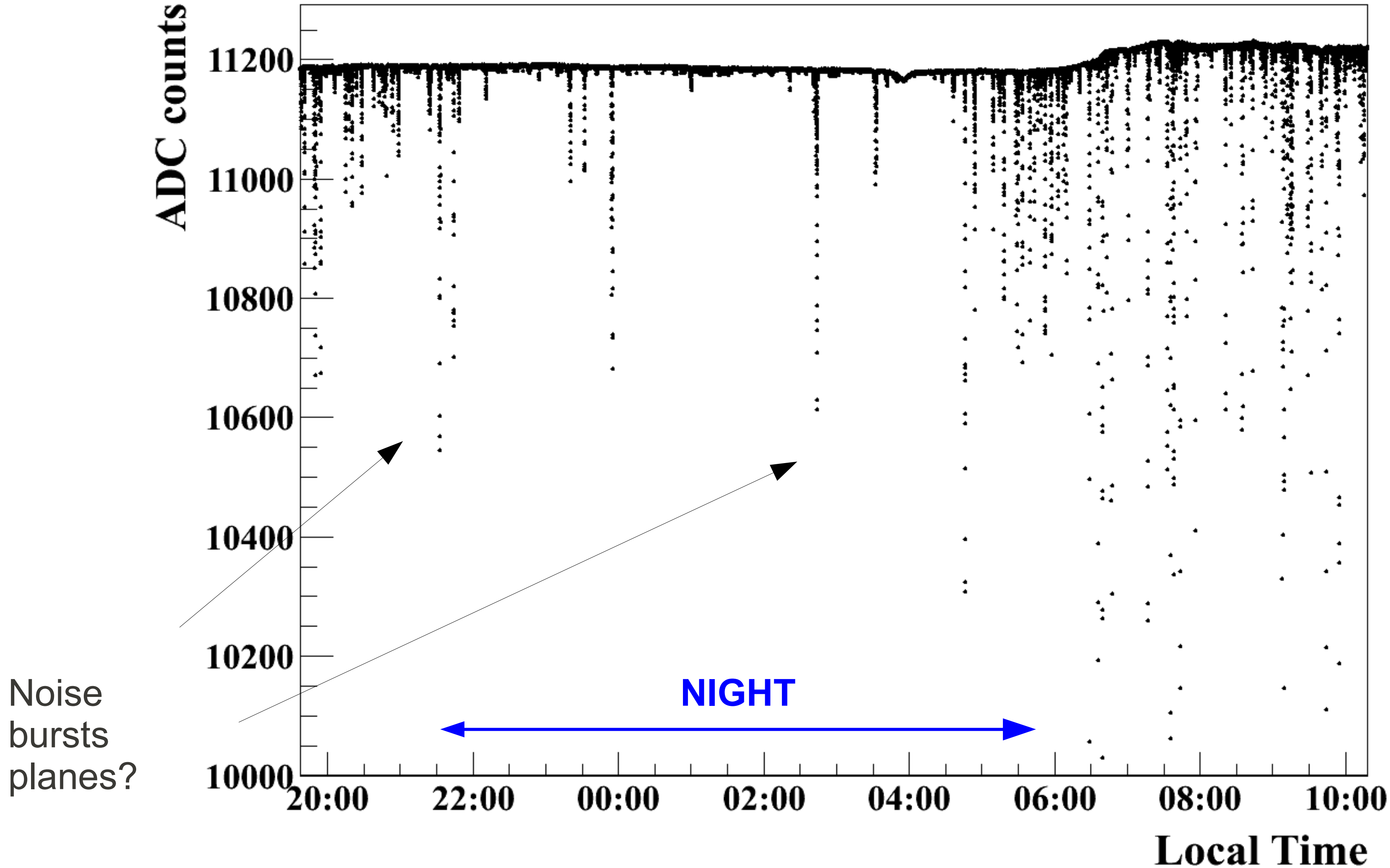
Tracking in half hour intervals, so the sun/moon passes through the center pixel several times in a row

Moon signal ~1/100 of the sun signal

Sidelobes hitting the wall of the building, system temperature increases



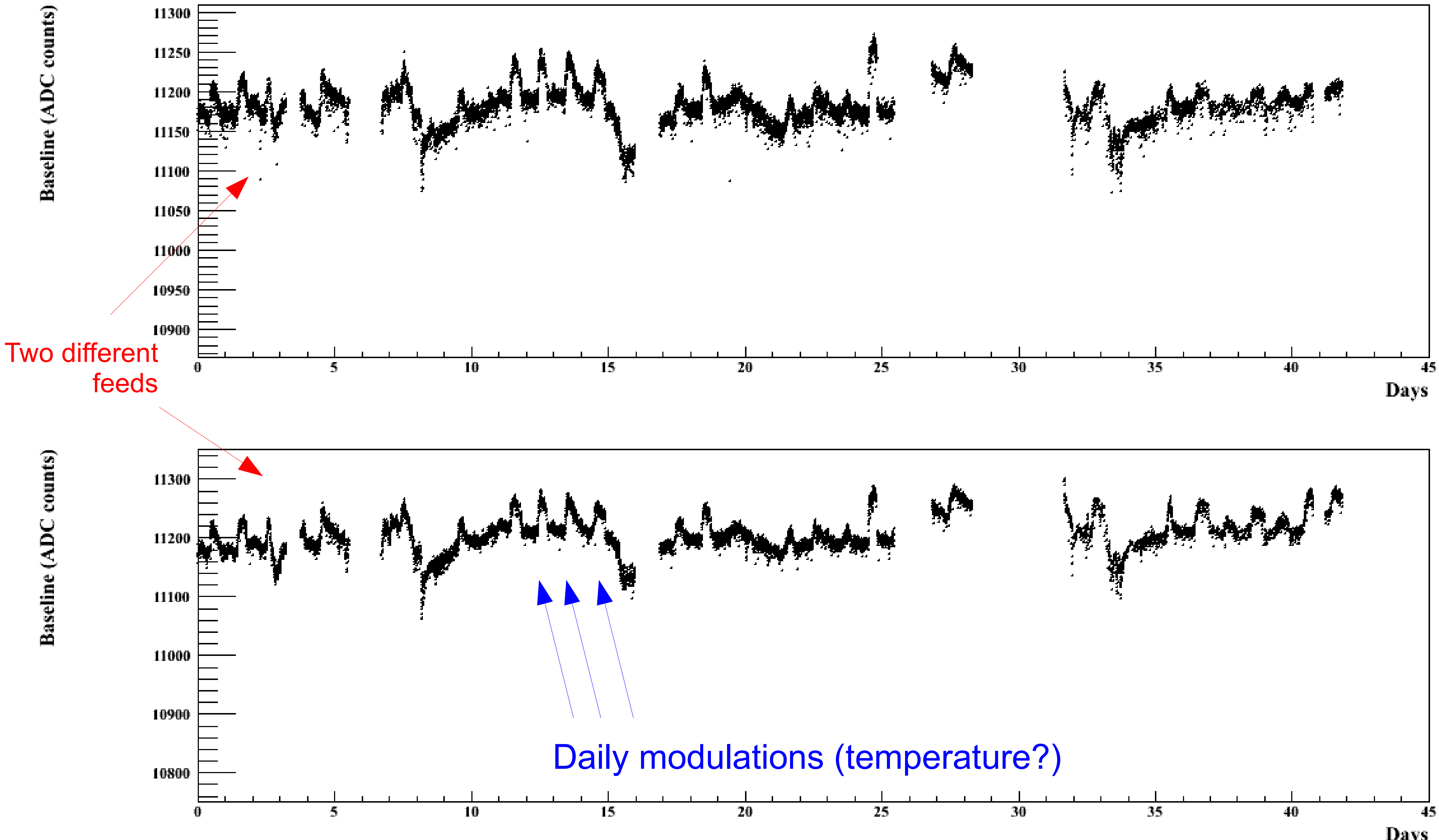
Data taking conditions (daily)



Clean periods (1s latency) between 95% and 50% of the total DAQ time (typical, we had days below 10%)

Event rate ≤ 0.5 Hz

Long term stability (40 days)



Baseline varies less than 1 dB over the period

MIDAS status and planned improvements

After commissioning in February we have focused on calibration, system characterization and also data taking.

Event search is in progress, a few candidates identified, nothing striking.

Data taking is fully automatic; manual intervention only needed in case of power supply or crate trip. We can also steer the antenna, track the sun, etc..., remotely.

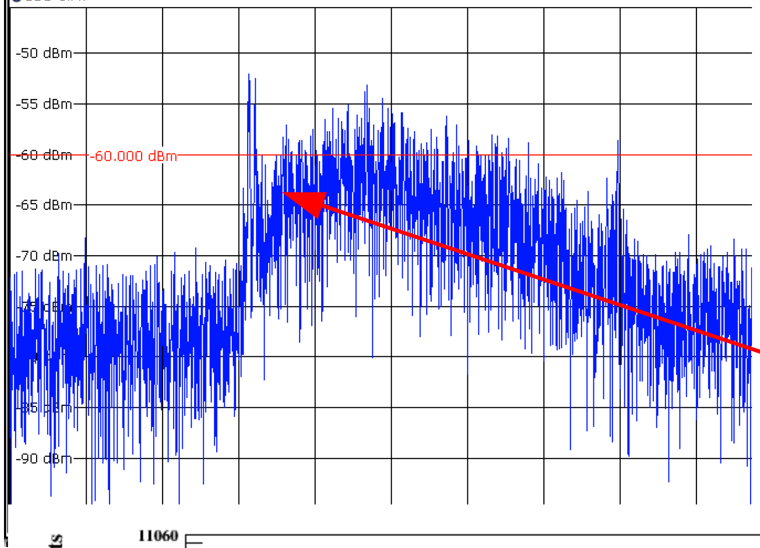
We have identified three upgrades that we want to introduce in the system (see next slides) in the next few weeks, namely:

New band-pass filter.

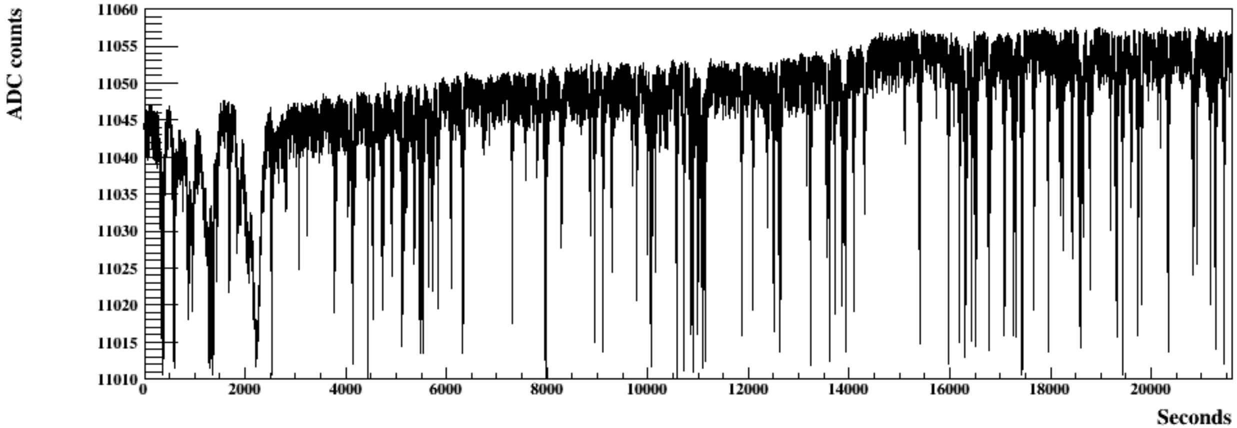
Fixed calibration antenna.

Implementation of a global camera trigger

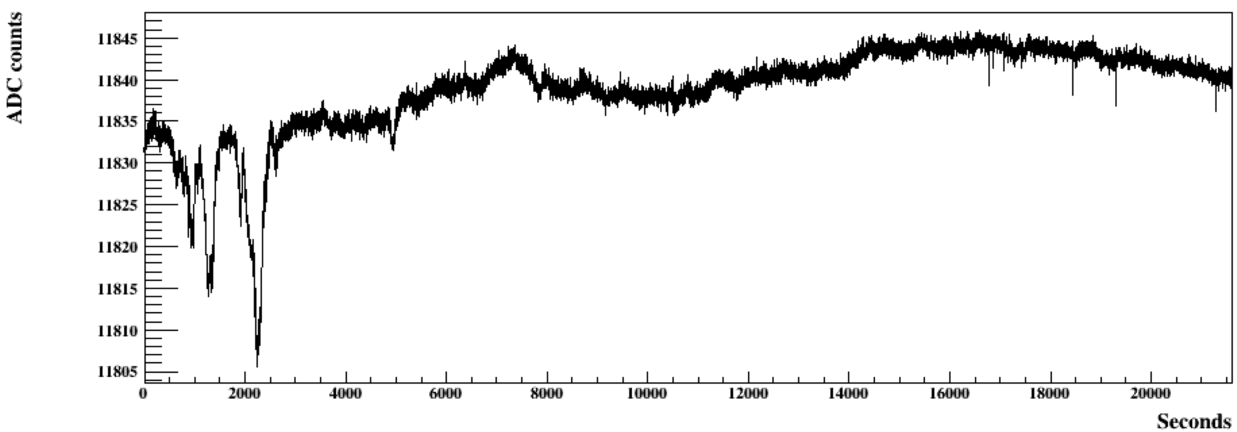
New band-pass filter



Lines associated with noise bursts.



Pixel without filter.
Noisy run



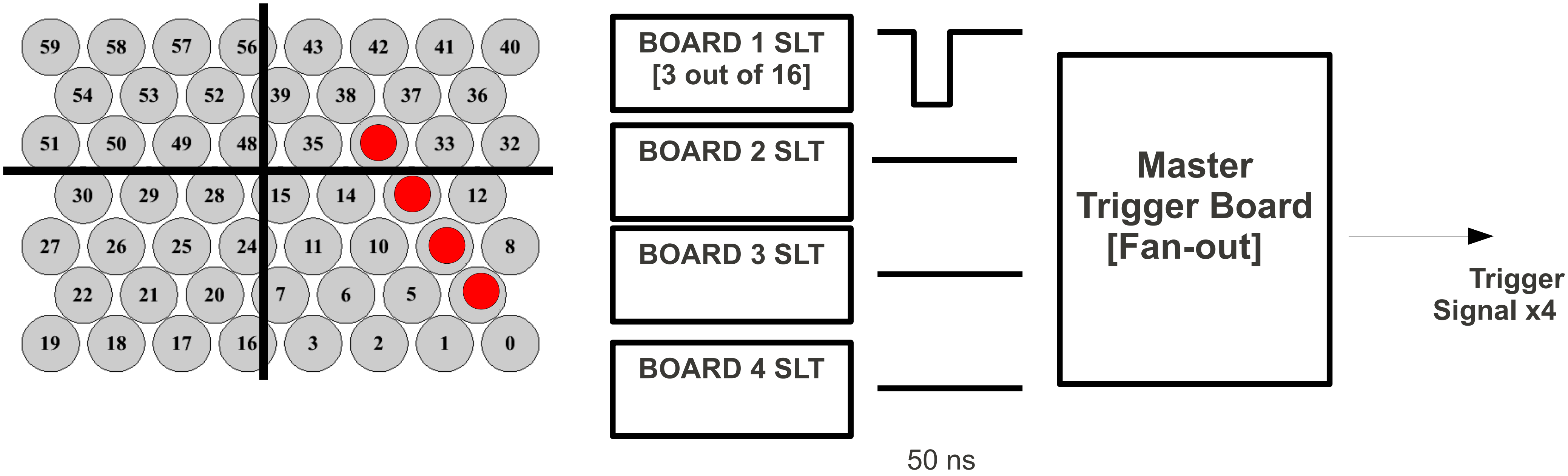
Same run in a pixel with a 1 GHz band pass filter installed.

Dead time due to trigger veto should be eliminated completely, so we increase effective DAQ time on are more stable system.

New relative calibration antenna

Low cost patch-panel antenna to be installed permanently at the center if the dish (in a removable plate).

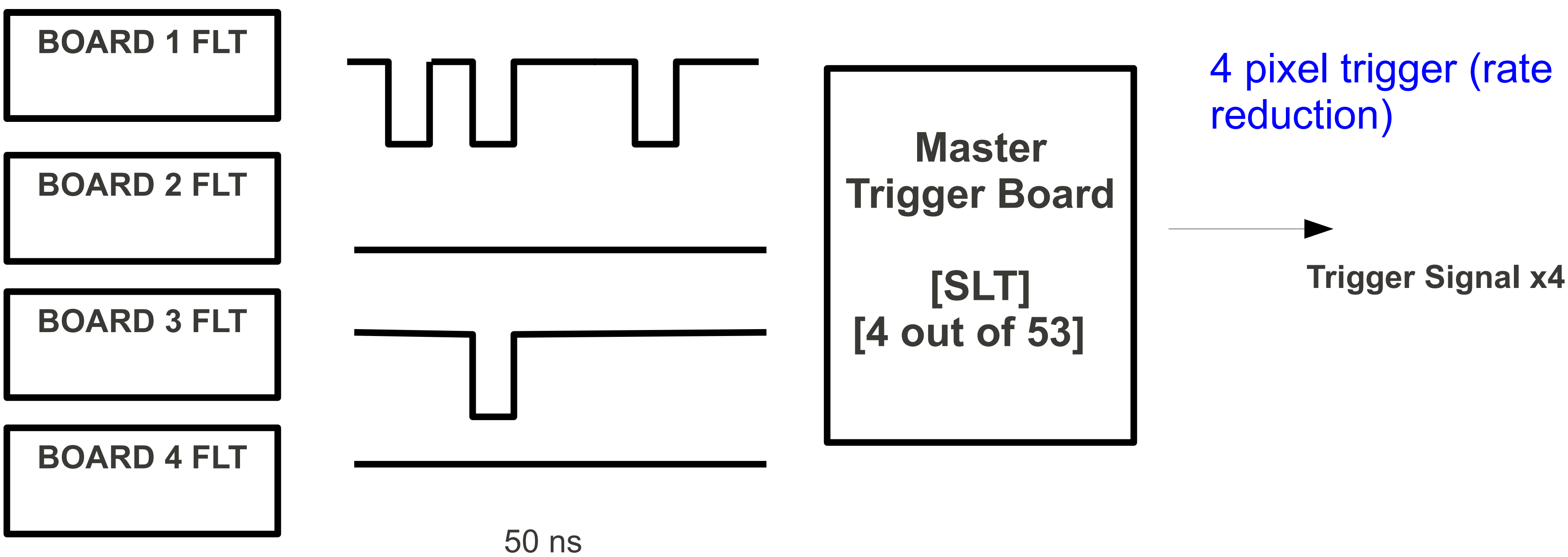
Fixed antenna to monitor system drifts and stability. Pulse generator inside the counting room will provide a periodic pulse.



New Camera trigger

Camera trigger
(reduce inefficiency)

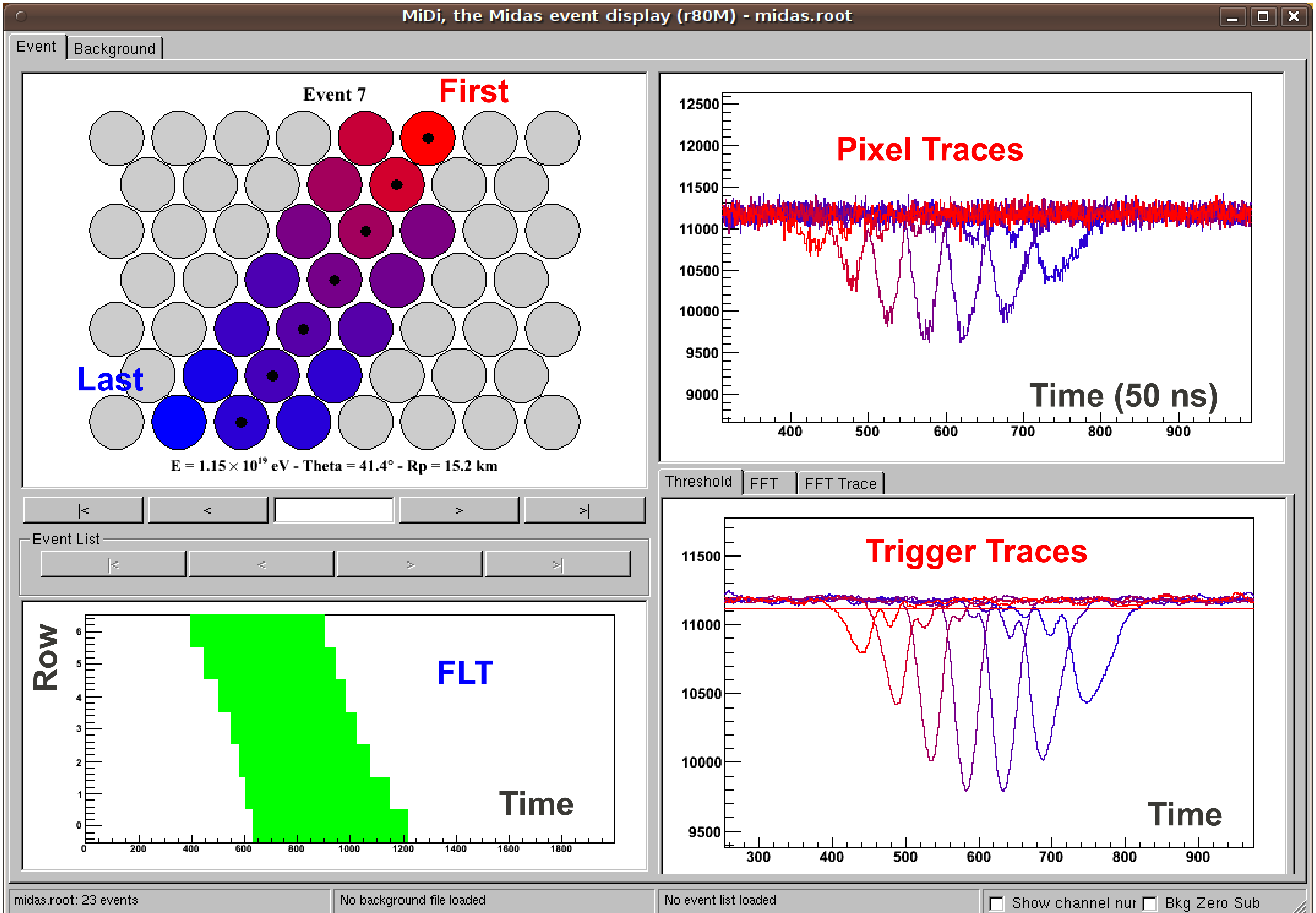
4 pixel trigger (rate
reduction)



M. Monasor, C. Williams

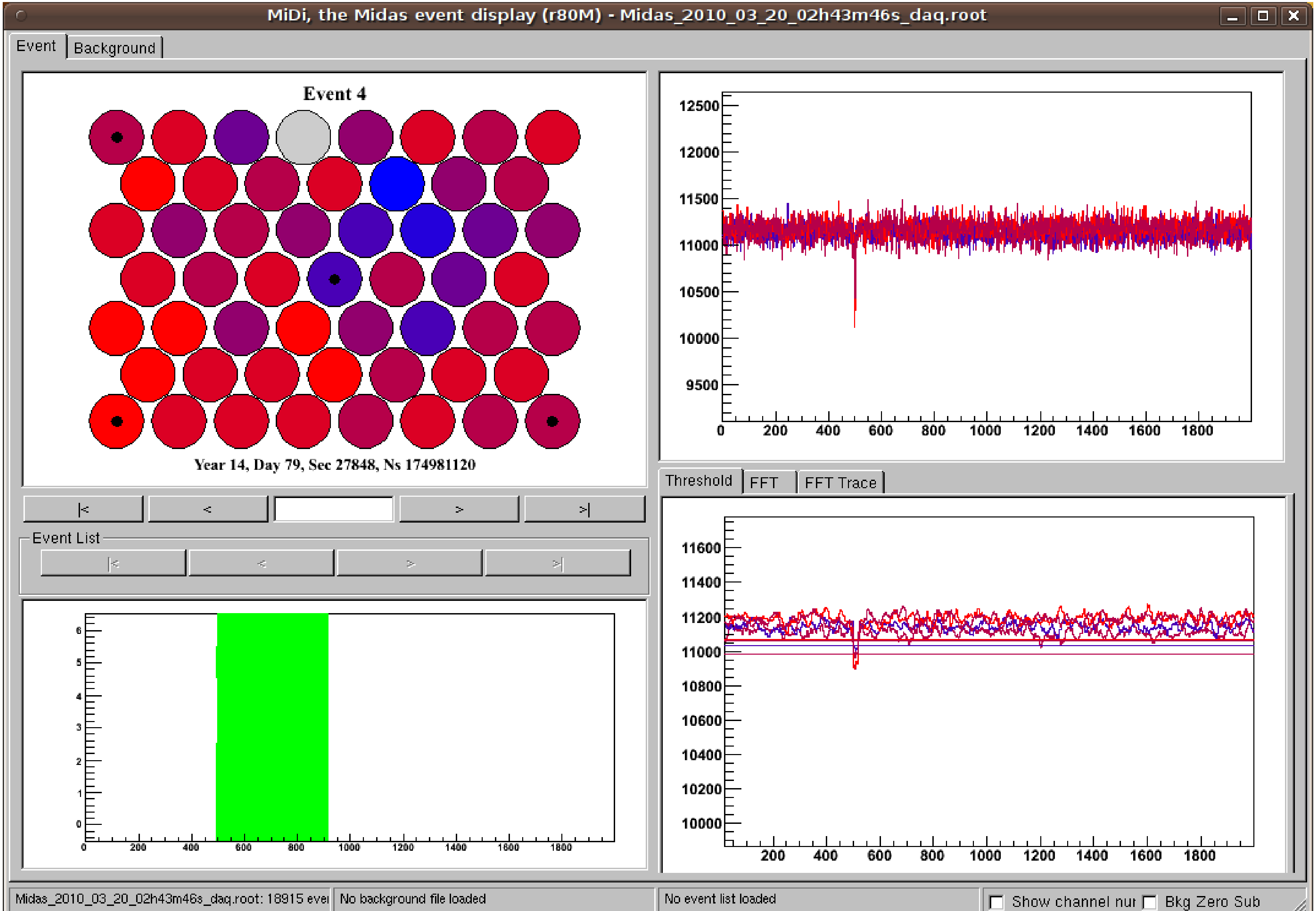
MC Simulated event

W. Carvalho

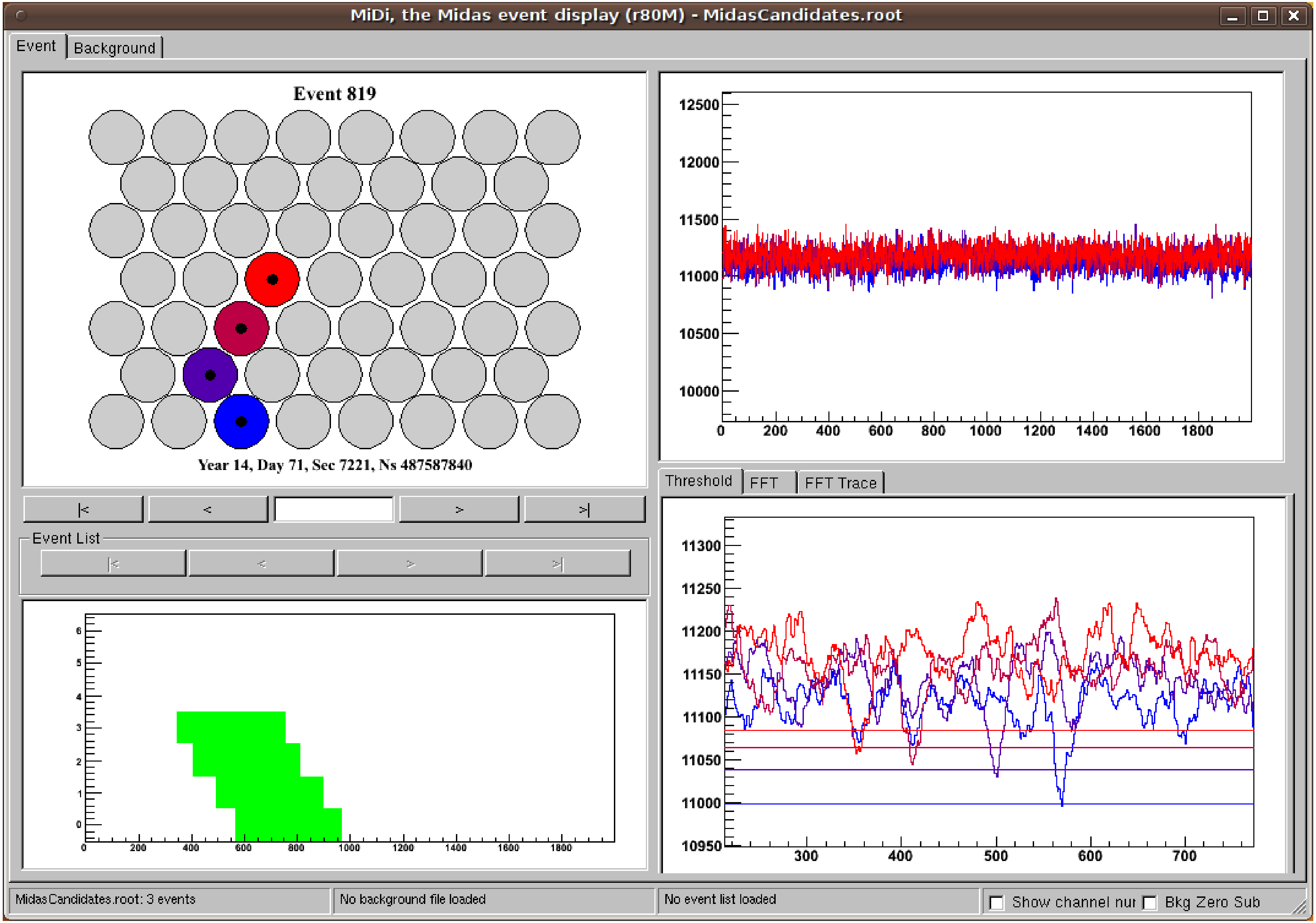


Event / Noise

Clear signature, all pulses at the same time.

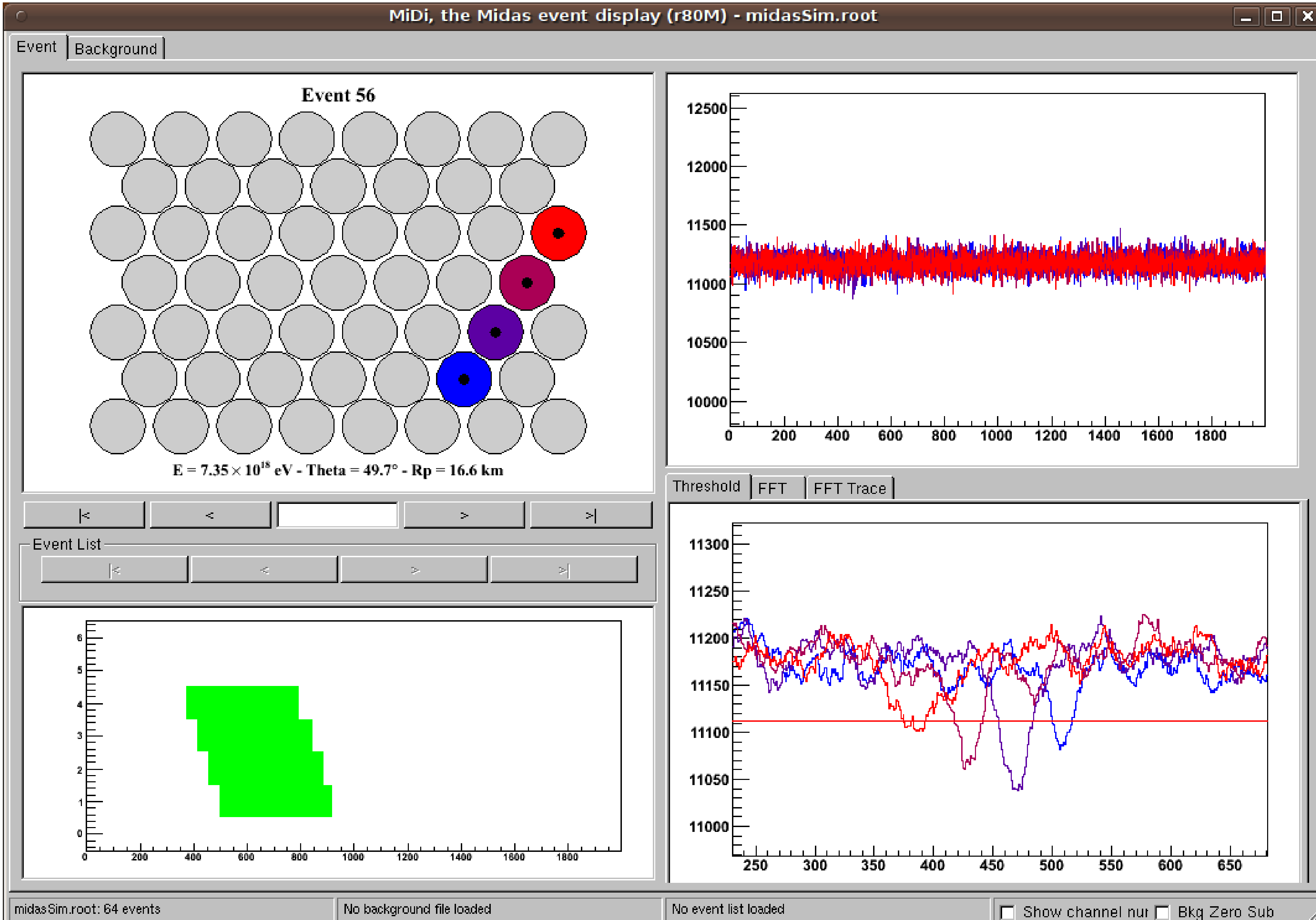


CANDIDATE



MiDi, the Midas event display (r80M) - MidasCandidates.root
Event
Background
Event 819
Year 14, Day 71, Sec 7221, Ns 487587840
Event List
Threshold
FFT
FFT Trace
MidasCandidates.root: 3 events
No background file loaded
No event list loaded
Show channel nur
Bkg Zero Sub

MC Simulated event (II)



Outlook

• MIDAS has been installed and data shows that behaves overall as expected. This first period of data taking focused on the understanding and commissioning of the detector and searching for first candidates.

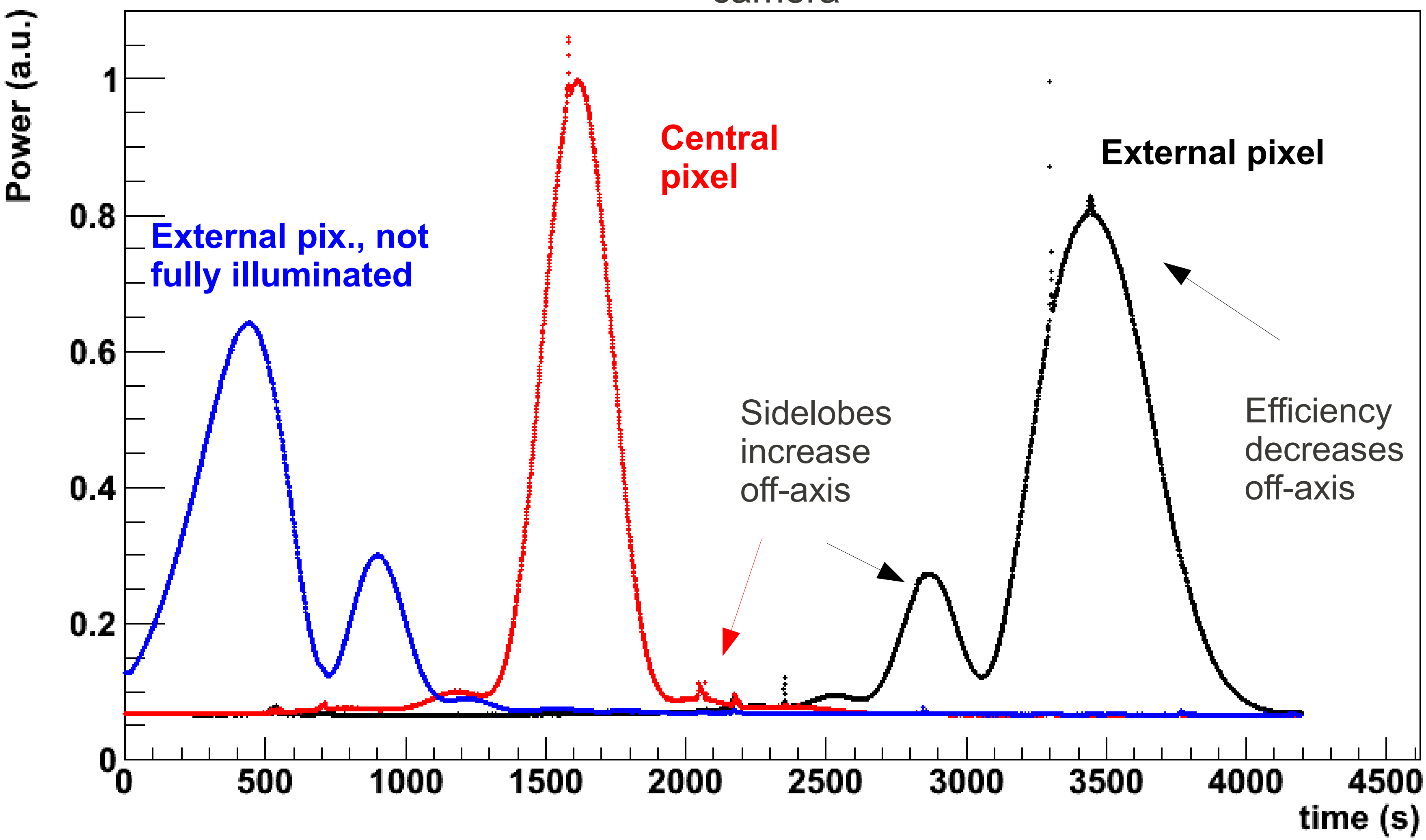
• Over the next weeks we will introduce some improvements in the system.

• Once we finish the upgrade we plan at least two months of stable data taking focused on event search.

• We plan to move the system to the Auger South site in Malargue. Some measurements of the background already performed and very encouraging [M. Bohacova, C. Bonifazi] .

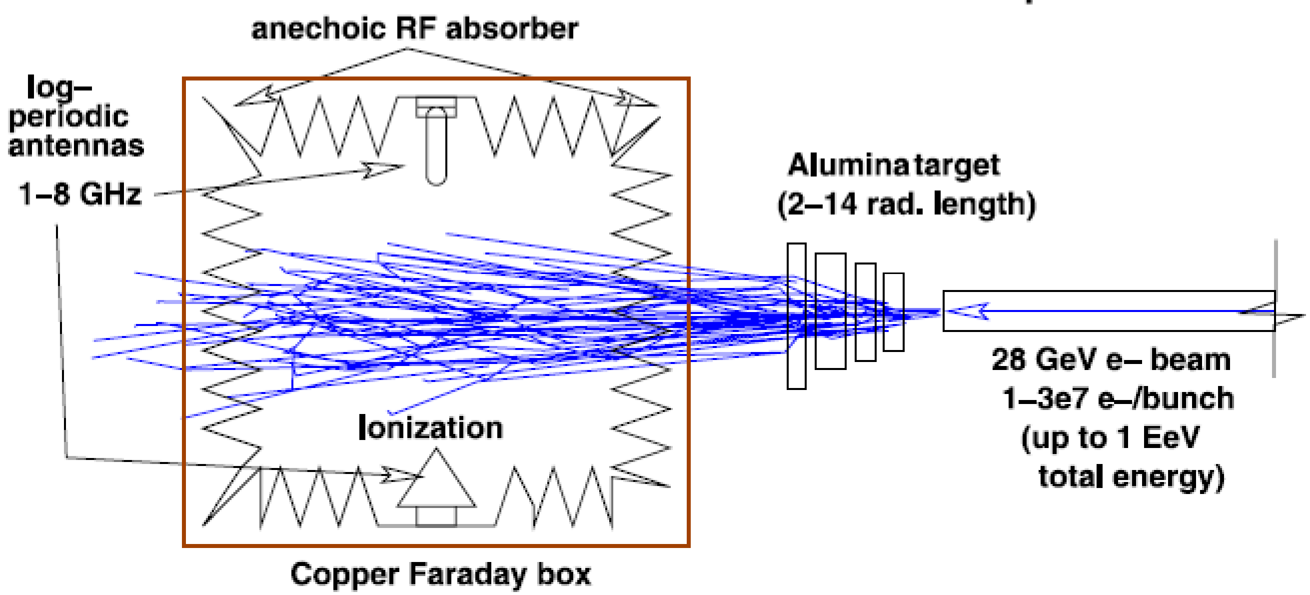
Focal plane efficiency

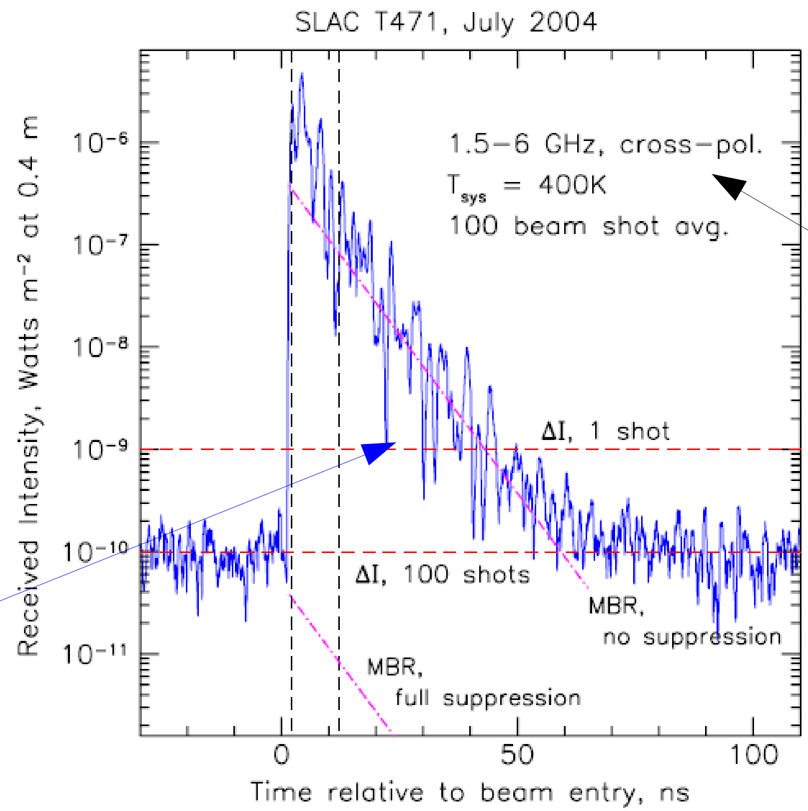
Analysis of the signal of the sun when crossing the field of view of the camera



Optics not optimized for wide angle coverage (aberrations)
Does not compromise shower observation, but trigger threshold increases off- axis (small effect).

SLAC T471 experiment



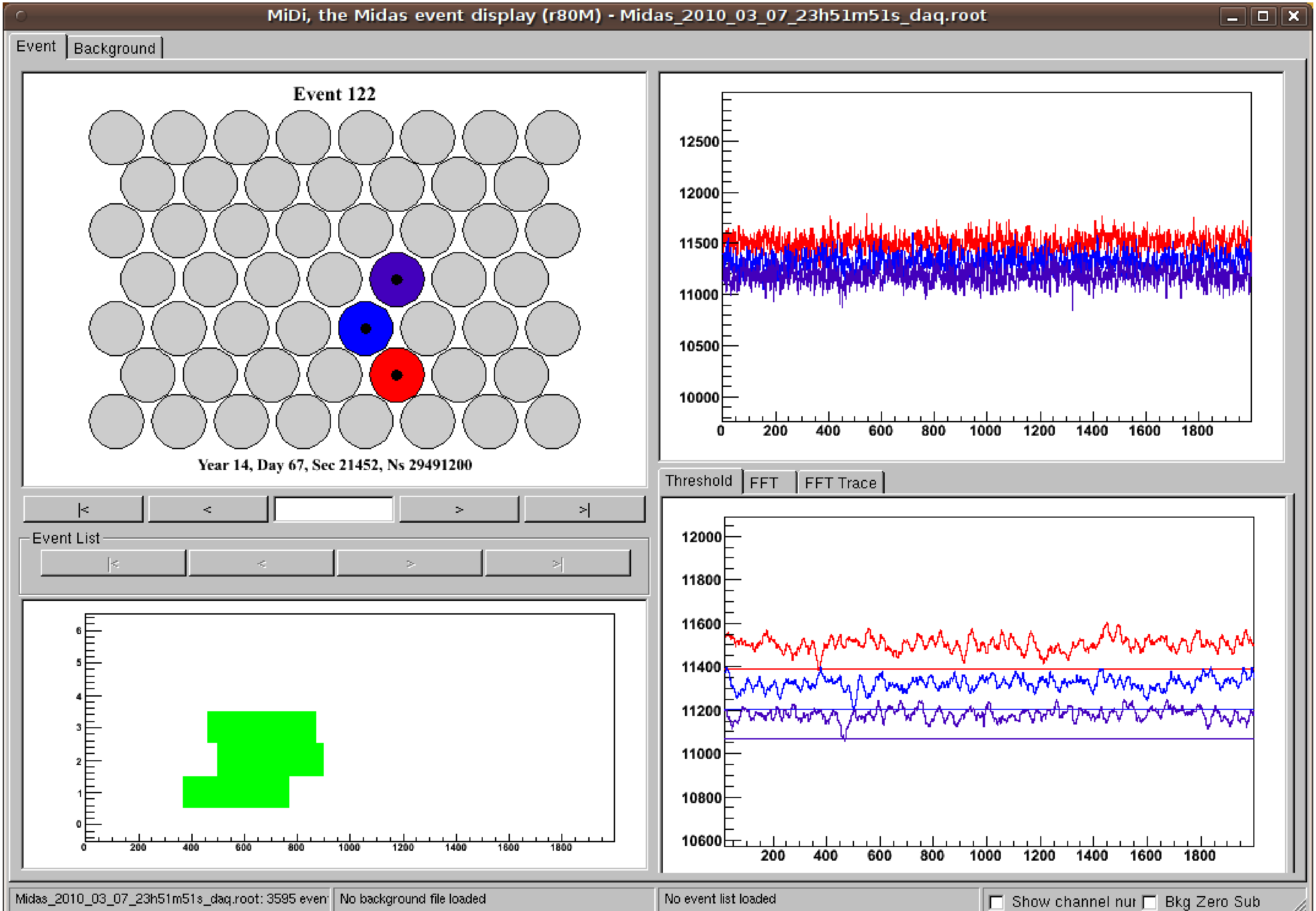


10 ns decay constant, compatible with plasma cooling.

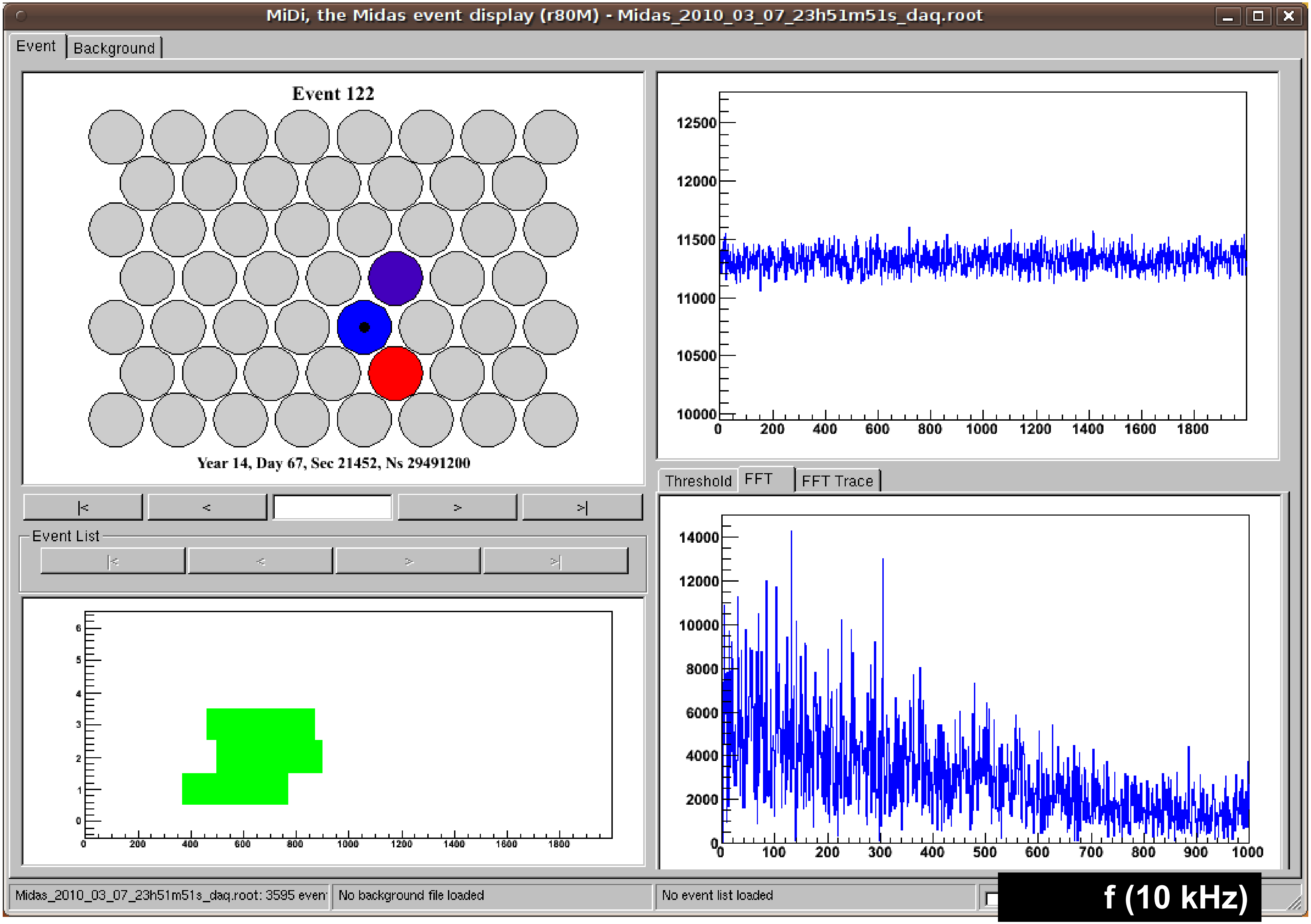
Insensitive to radio Cherenkov

P. Gorham et al..

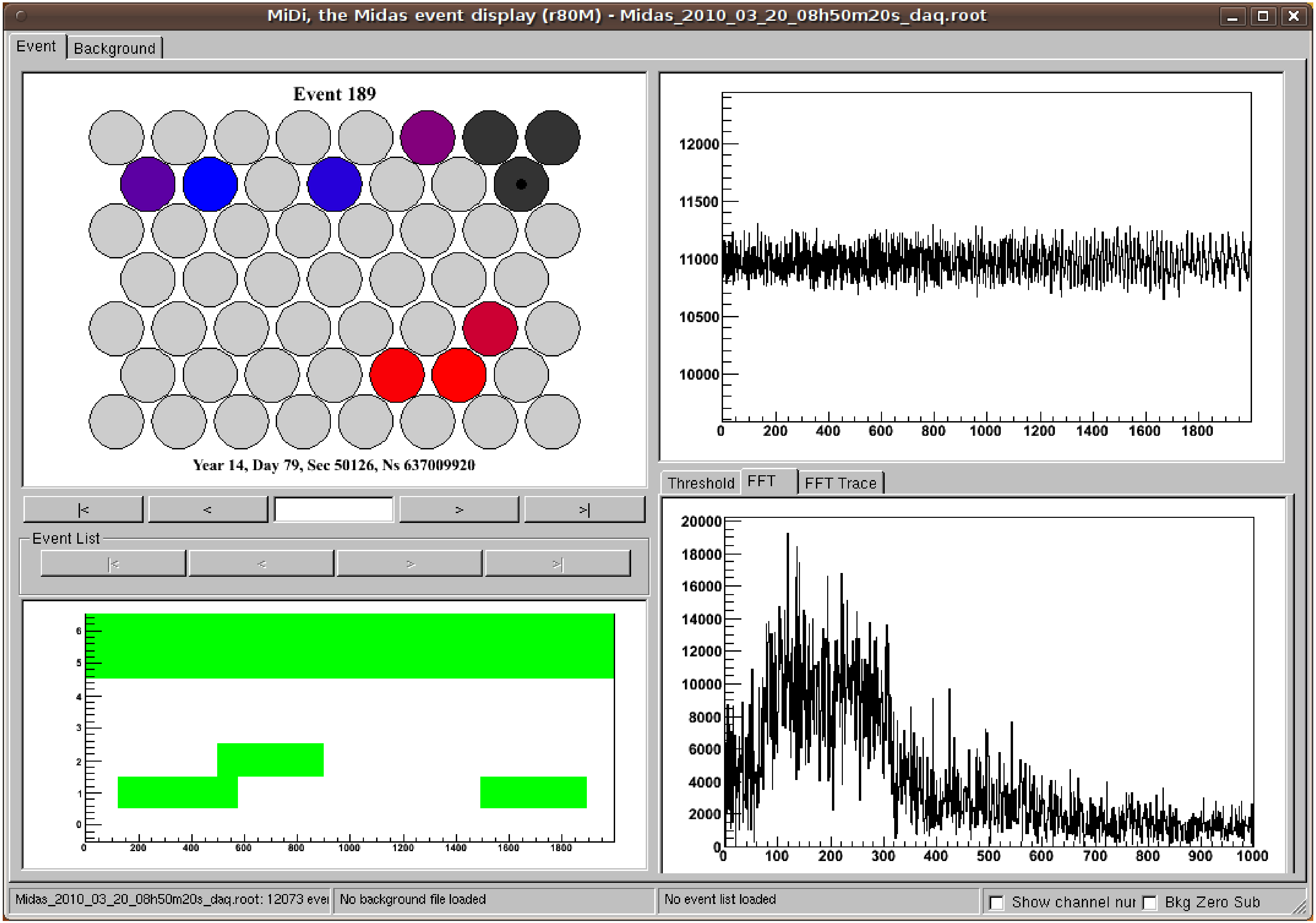
Event (Accidental)



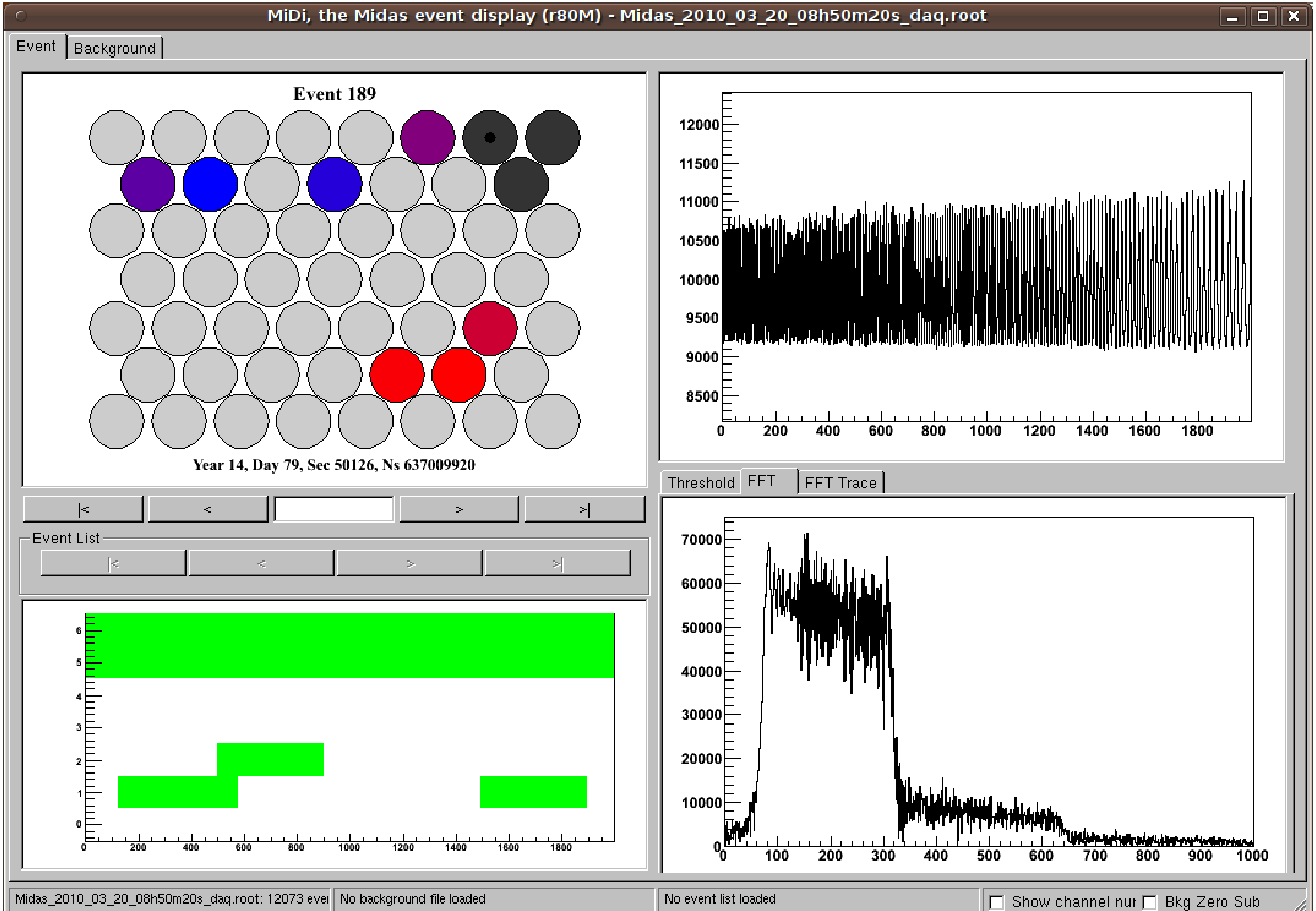
Noise spectral distribution



Noise Zoology (I)



Noise Zoology (II)



Noise Zoology (III)