Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

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The MIDAS Experiment: A New Technique for the Detection of Extensive Air Showers

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<u>MI</u>crowave <u>D</u>etection of <u>A</u>ir <u>S</u>howers

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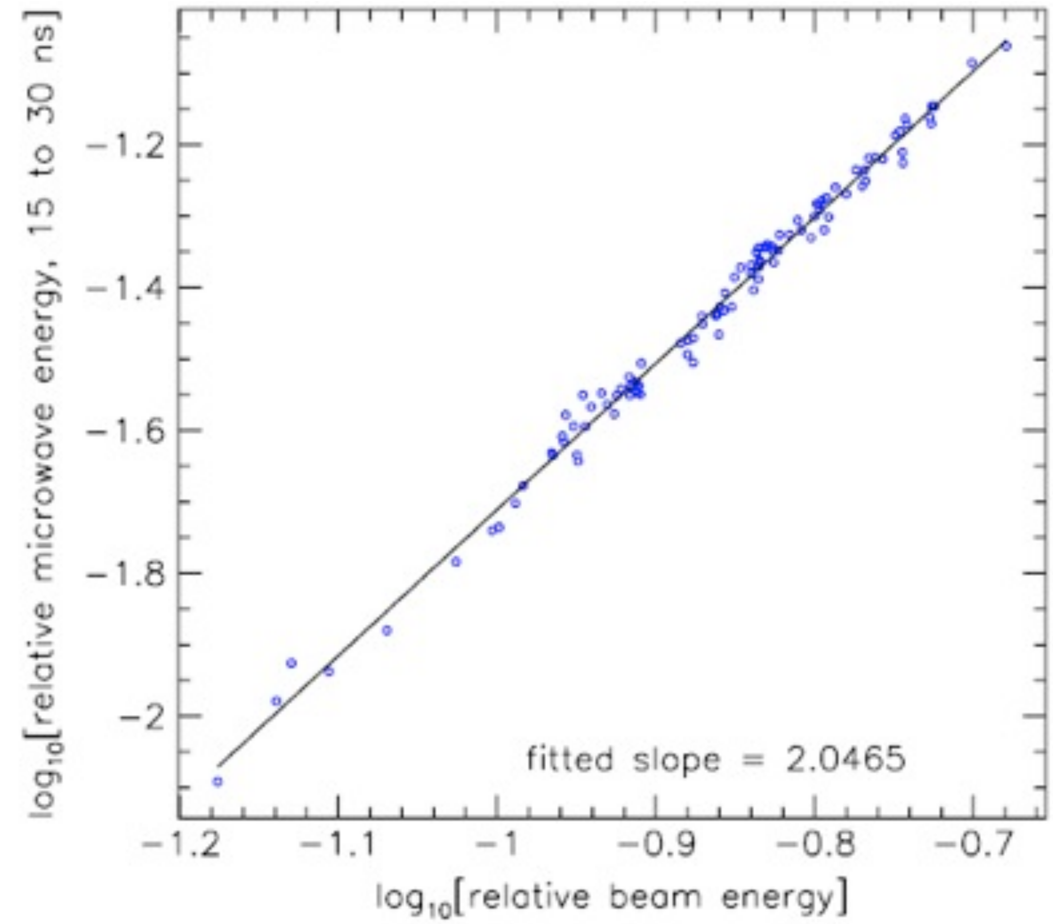
Molecular Bremsstrahlung Emission

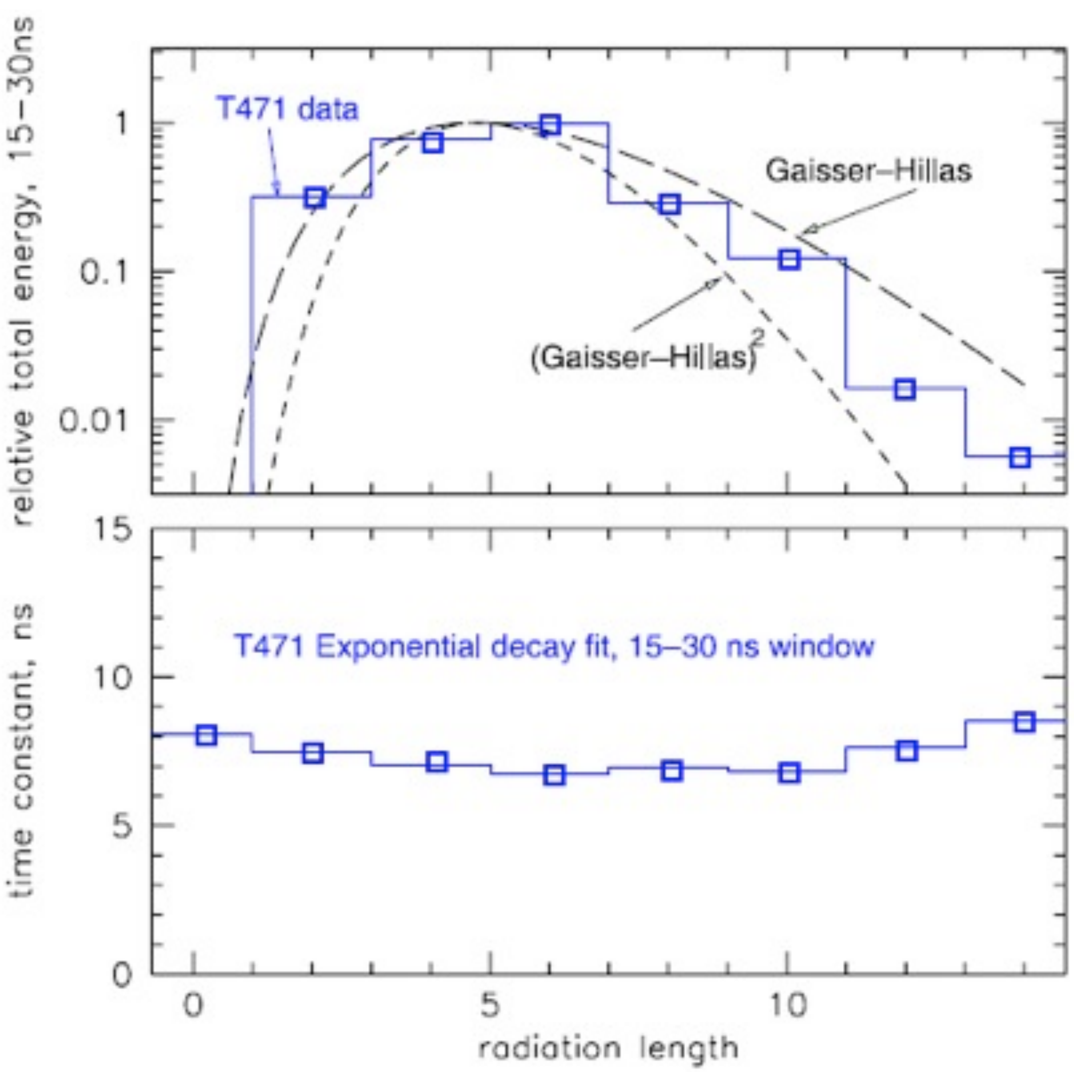
- EAS particles dissipate energy through ionization
- Produces plasma with $T_e \sim 10^4$-10^5K
- Free electrons produce Bremsstrahlung emission in microwave regime from interaction with neutral air molecules
- Emission is unpolarized and isotropic

Potential exists for an FD-like detection technique capable of measuring the shower's <u>longitudinal development</u> with <u>nearly 100% duty cycle</u>, limited atmospheric effects and <u>low cost</u>

Plasma density determines level of signal coherence

Fully coherent plasma: $P_{tot}=(N_e)^2 \times P_1$
Incoherent plasma: $P_{tot}=N_e \times P_1$





Beam tests results suggest coherent emission

However, due to large physical extent of shower plasma, EAS emission has an unknown level of coherence

G-H fits suggest the plasma scaling in the beam may not match EAS scaling

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

MIDAS Prototype system

$I_{0,\,sh} = 2.8\ 10^{-16}$ W/m²/Hz
$E_0 = 3.4\ 10^{17}$ eV

→ @ 10 Km → $I = 2.8\ 10^{-24}$ W/m²/Hz

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

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

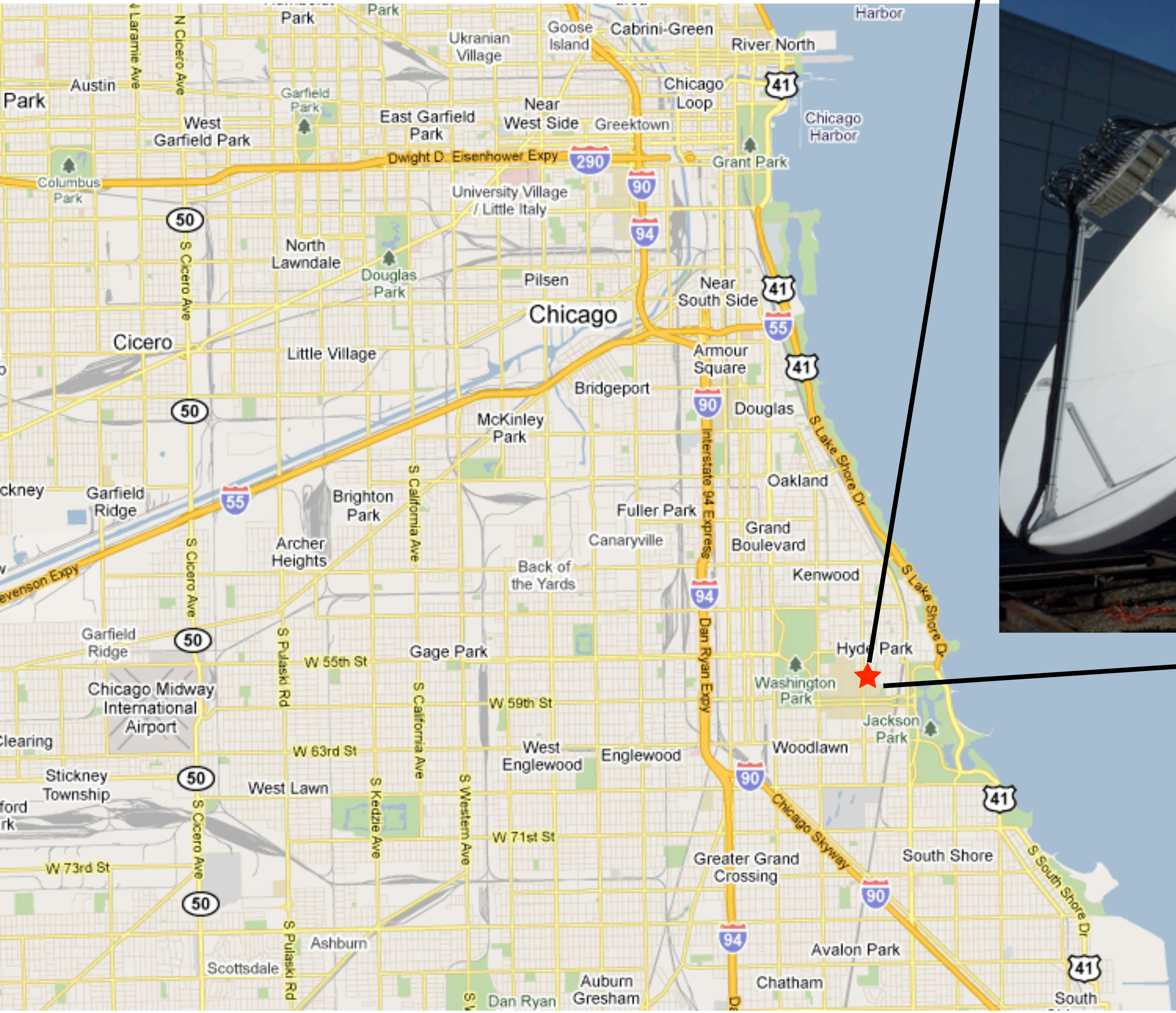
Detection Threshold

$E_{quad} \sim 2\ 10^{18}$ eV
$E_{lin} \sim 10^{19}$ eV

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

Large collection area	~ 10 m²	Use 4.5m dish already installed at U of C
Pixel field of view	~1.5° ~ λ/D	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

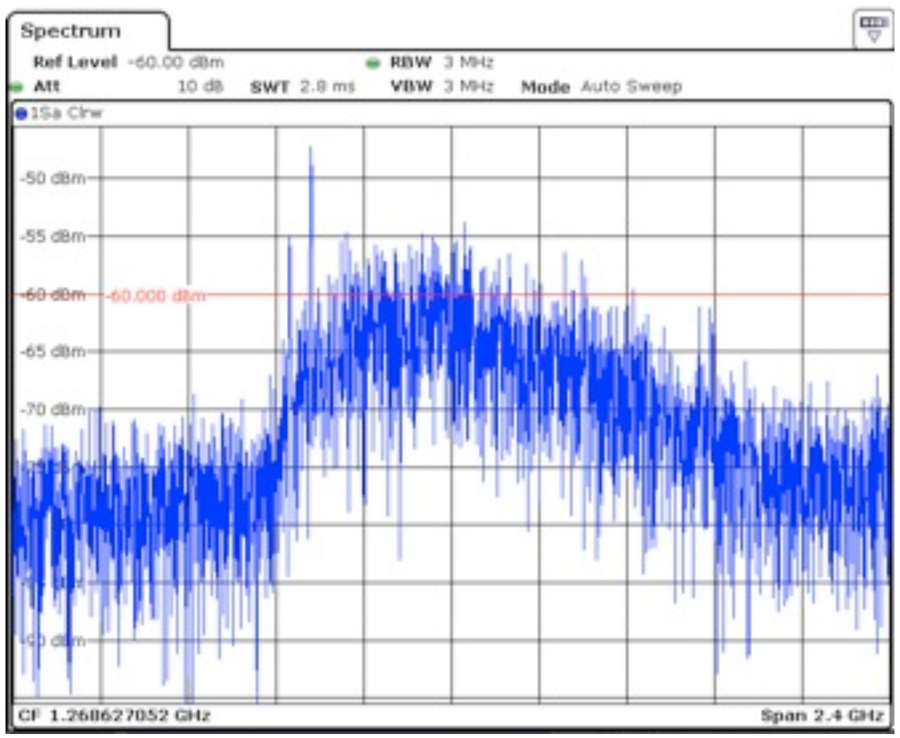
4.5 Meter Prime Focus Parabolic Reflector

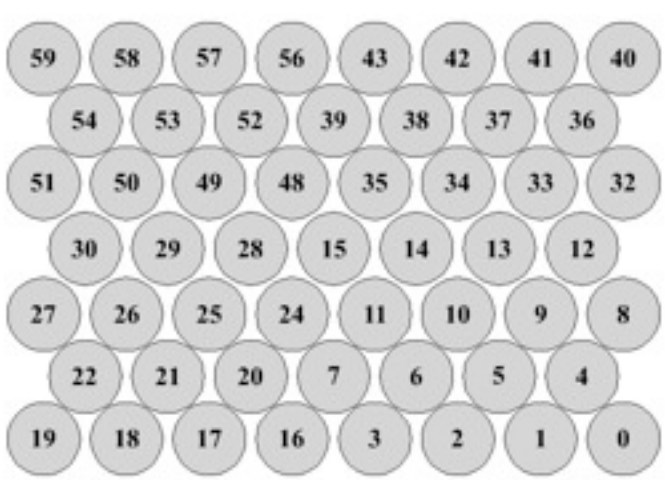


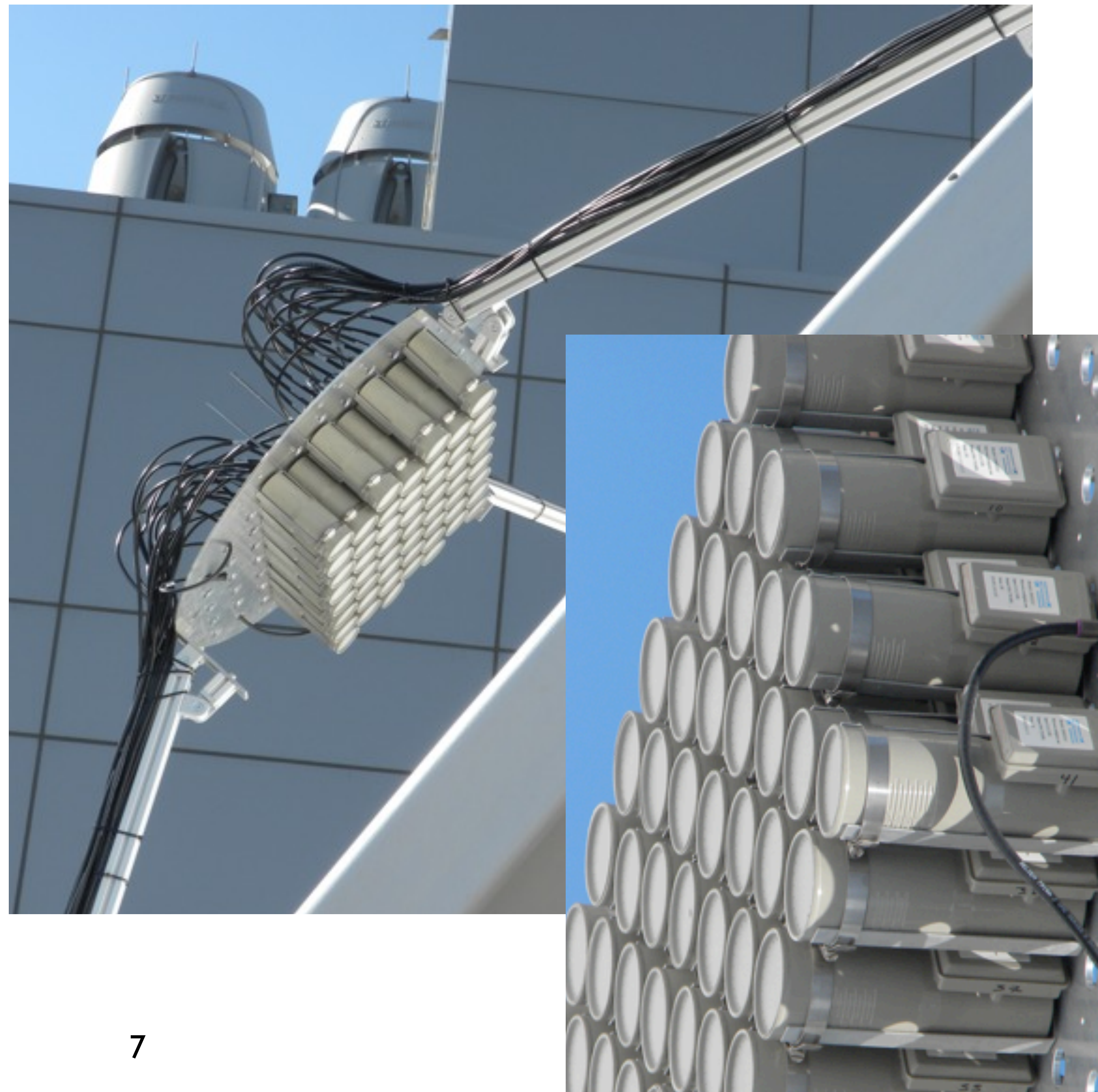
90° Alt
100° Az

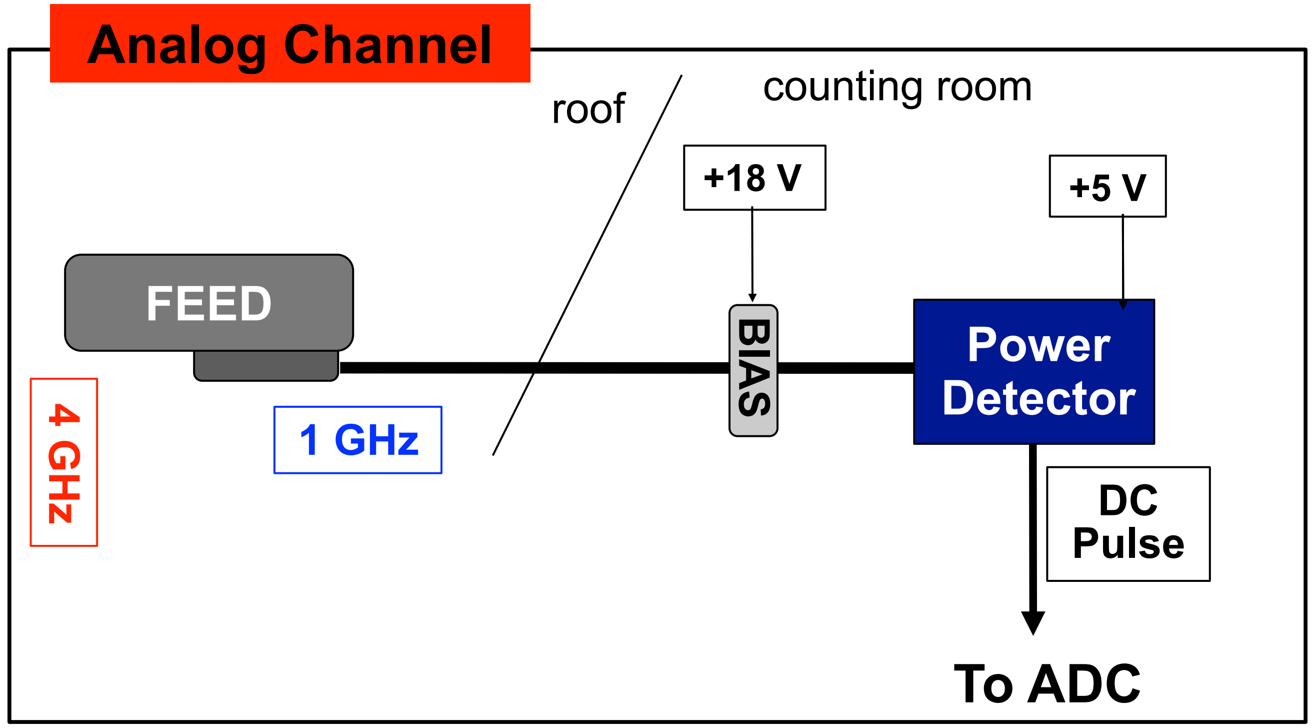
Camera

- 53 Commercial Extended C-Band Feeds
- Feed Horn + LNA + Down Converter (3.4-4.2 GHz to ~ 1GHz)
- 13K noise floor, 70 dB amplification
- 20° x 10° FOV





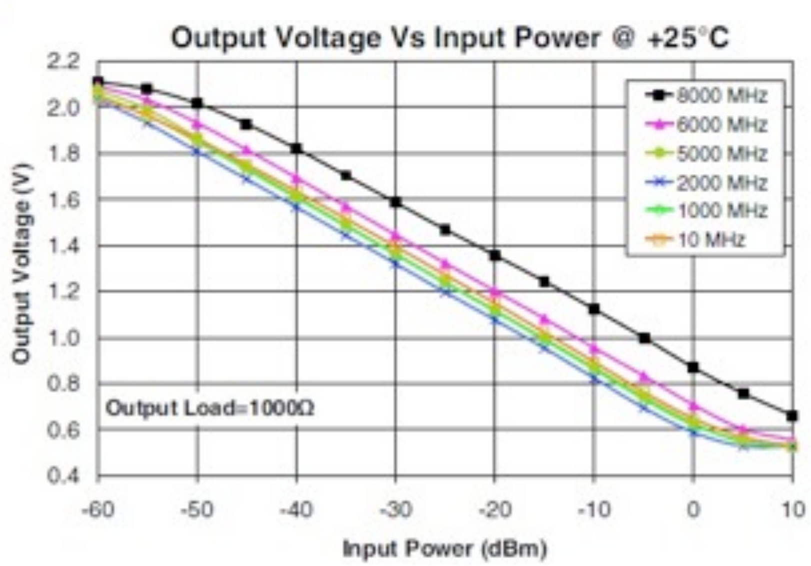




$$n_{adc} = n_0 - k\, P_{dB} = n_0 - k\, \log(P_{lin})$$

Power detector

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



Flash ADC

16 channels

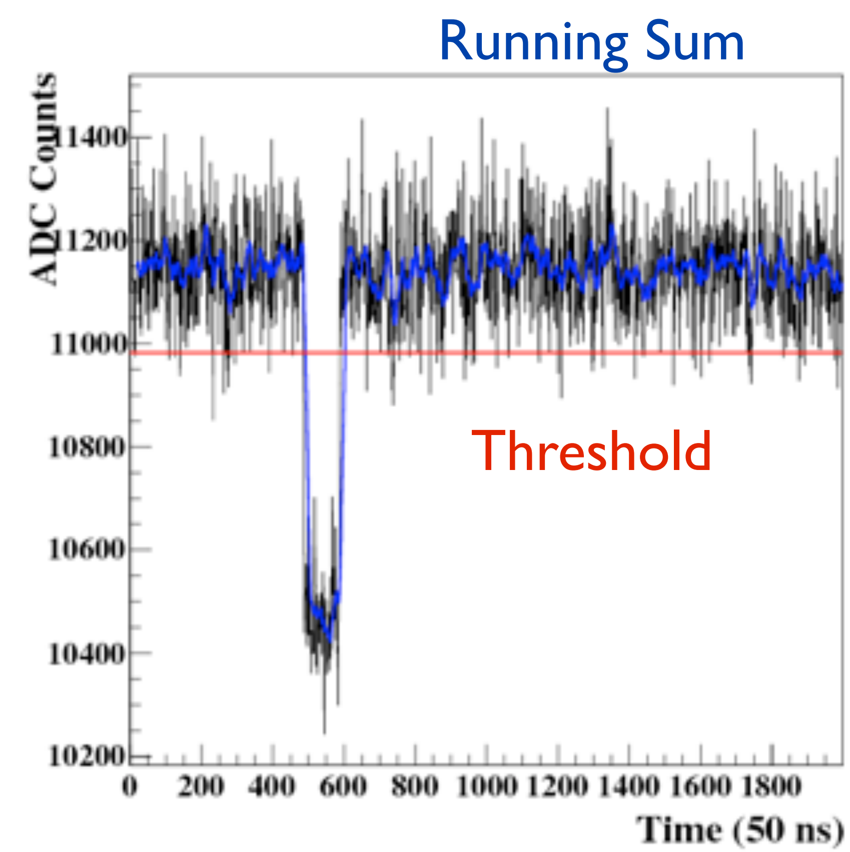
14 bit

20 MHz

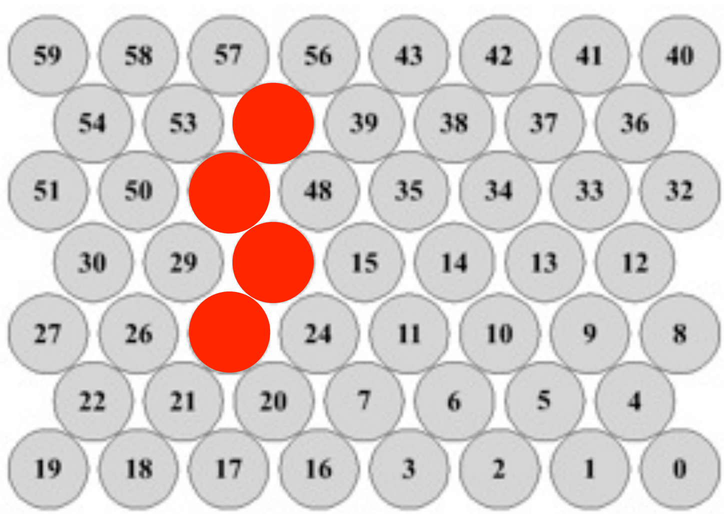
FPGA trigger

Developed @ EFI

Trigger



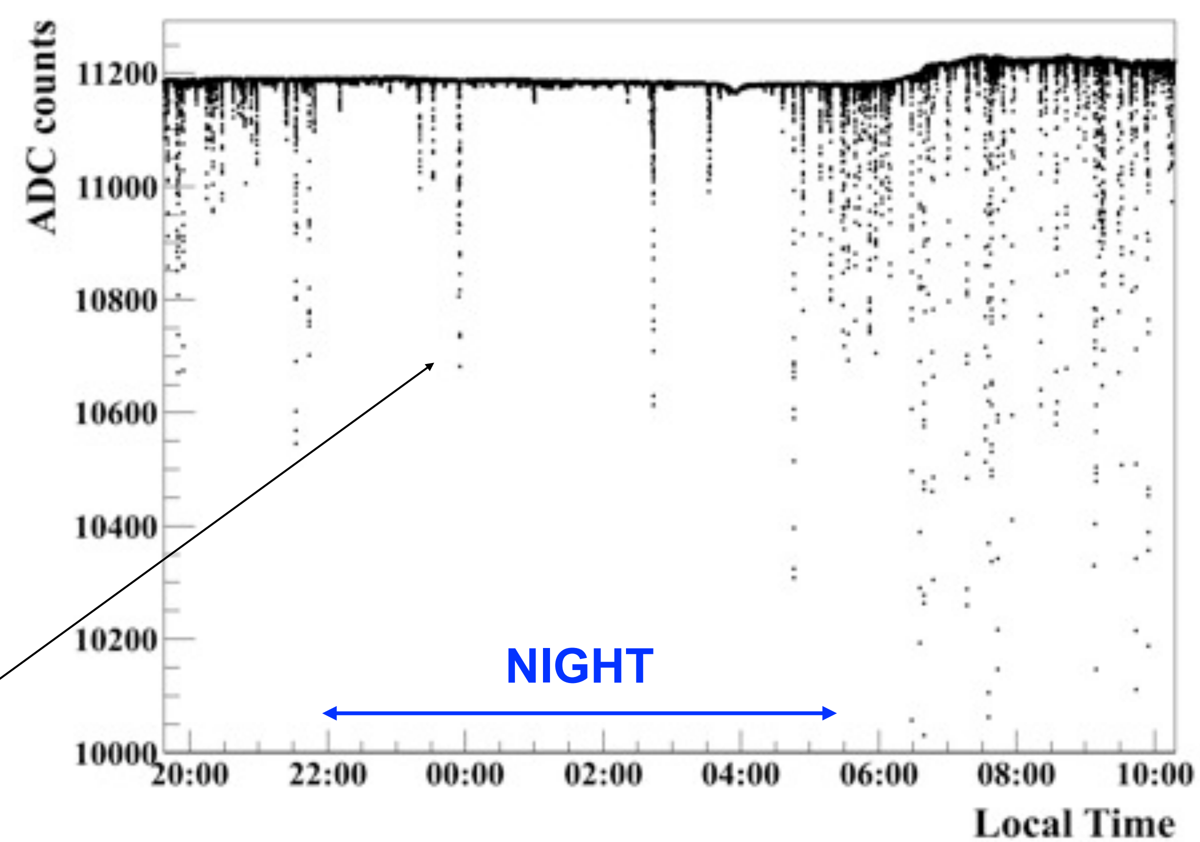
FLT: 1 μs running sum, over threshold trigger
Each feed has self-regulated threshold to hold rate at 100Hz



SLT: require 3 FLT within 20 μs for specified pixel patterns, noise rate 0.2Hz

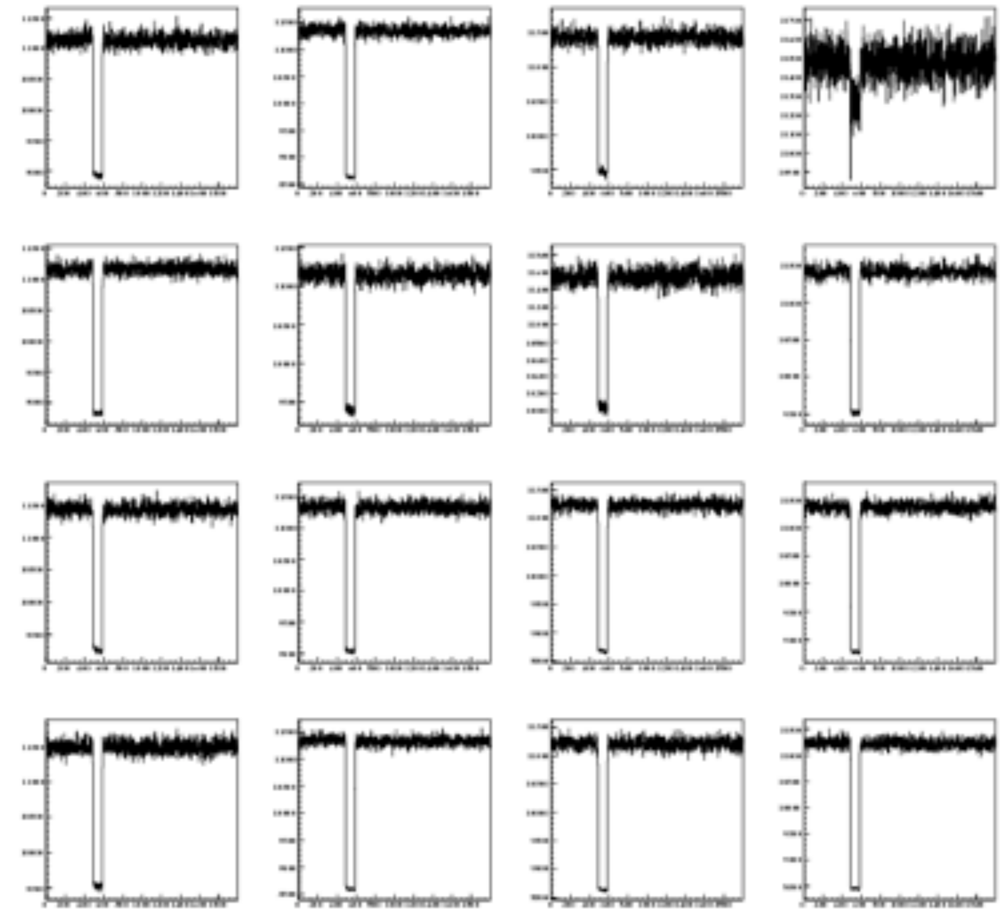
High-Level Veto: Inhibits trigger when SLT exceeds preset value. Filters periods of noise bursts improving livetime.

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



Noise bursts

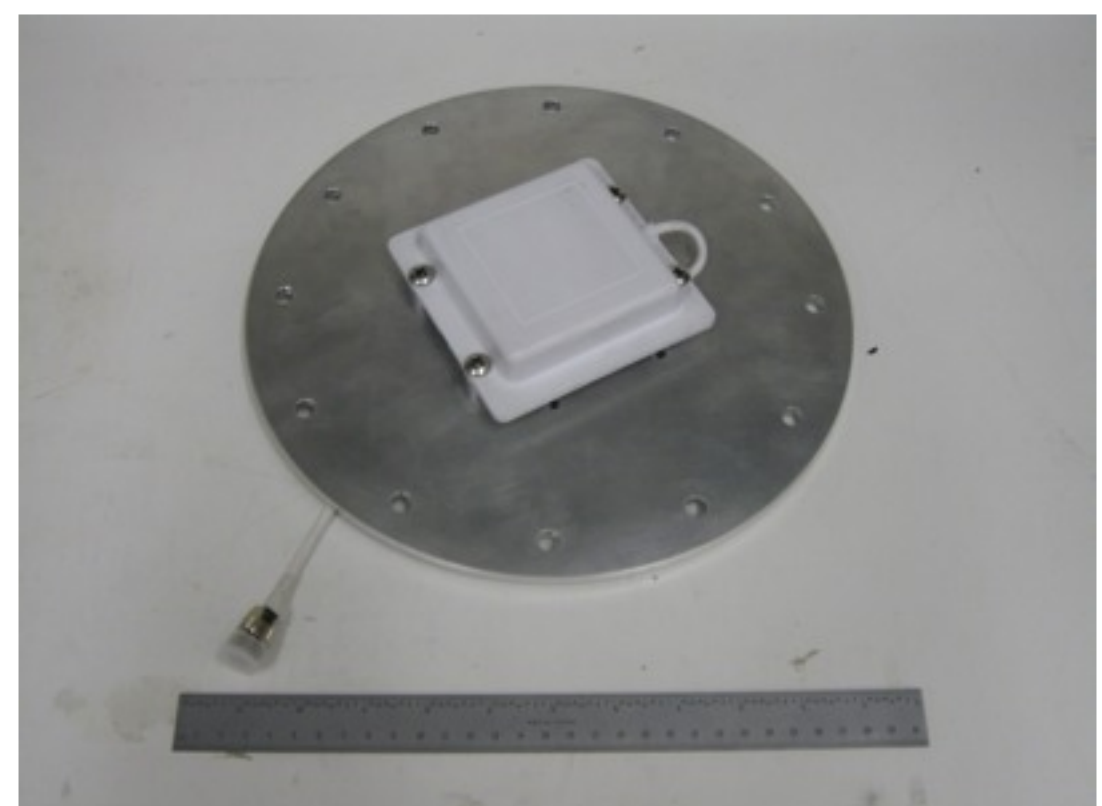
Calibration



Log periodic antenna is directed at feeds sending 5 μs pulses

Allows for relative calibration, test of synchronization, and system timing

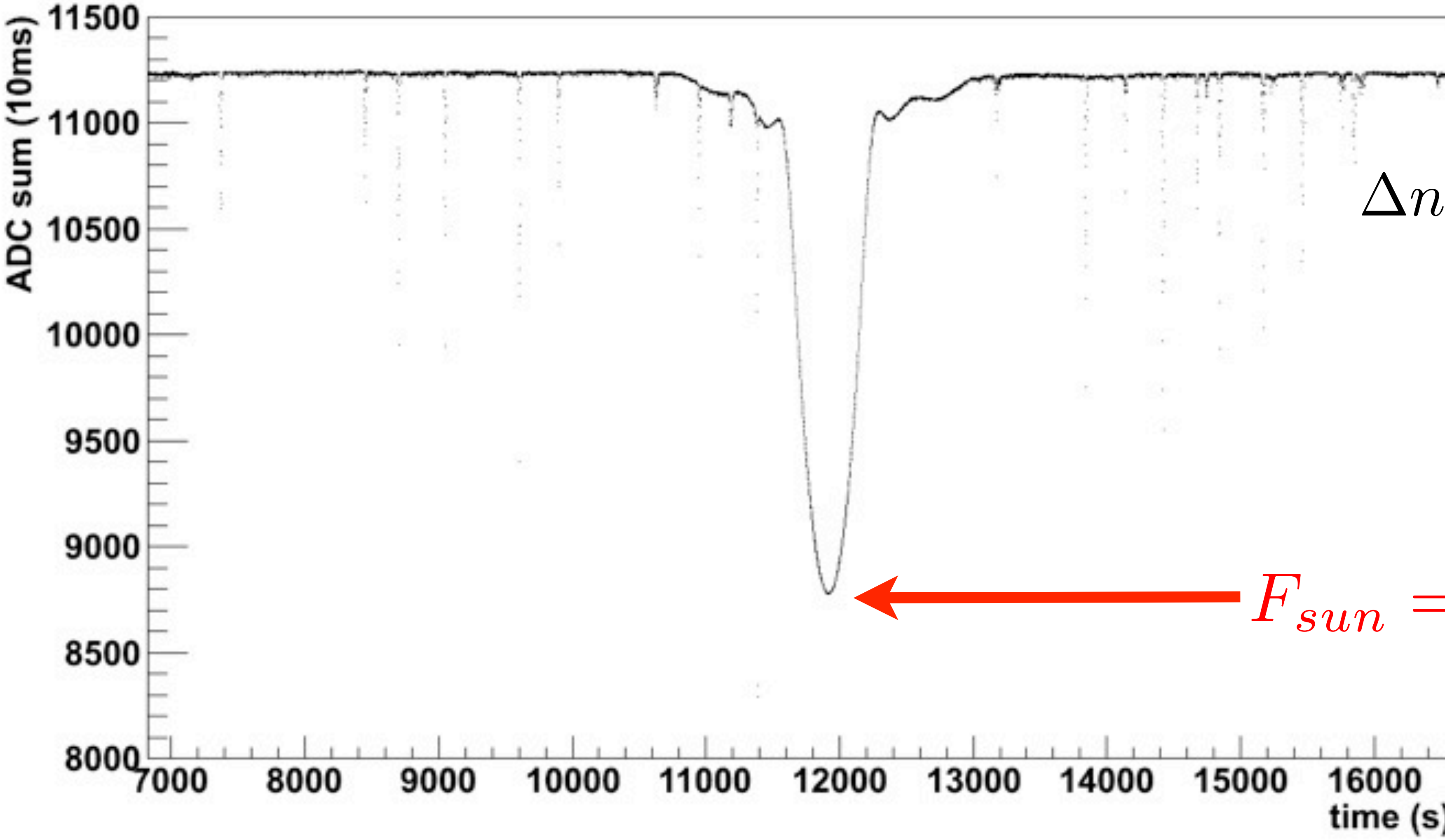
Soon we will deploy a low cost patch antenna permanently on the telescope for continued long term calibrations



Calibration

Astrophysical sources provide a calibration of system temperature

Sun



$$\Delta n_{adc} = 10\ k\ log(1 + \frac{P_{sun}}{P_{sys}})$$

$$\Delta n_{adc} \simeq 2500$$

$$F_{sun} = 88 \times 10^{-22} W/m^2/Hz$$

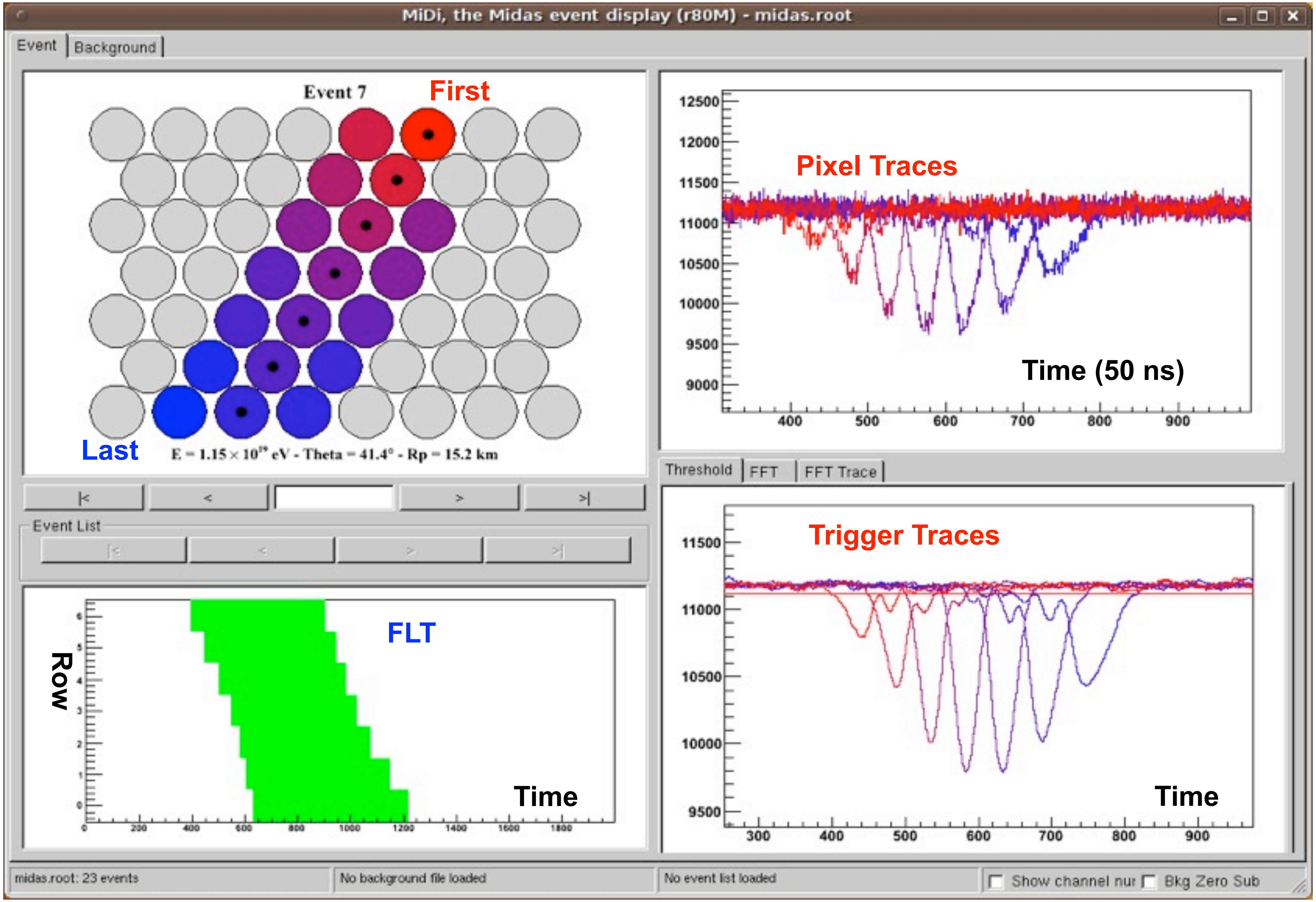
Nobeyama Radio Observatory

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

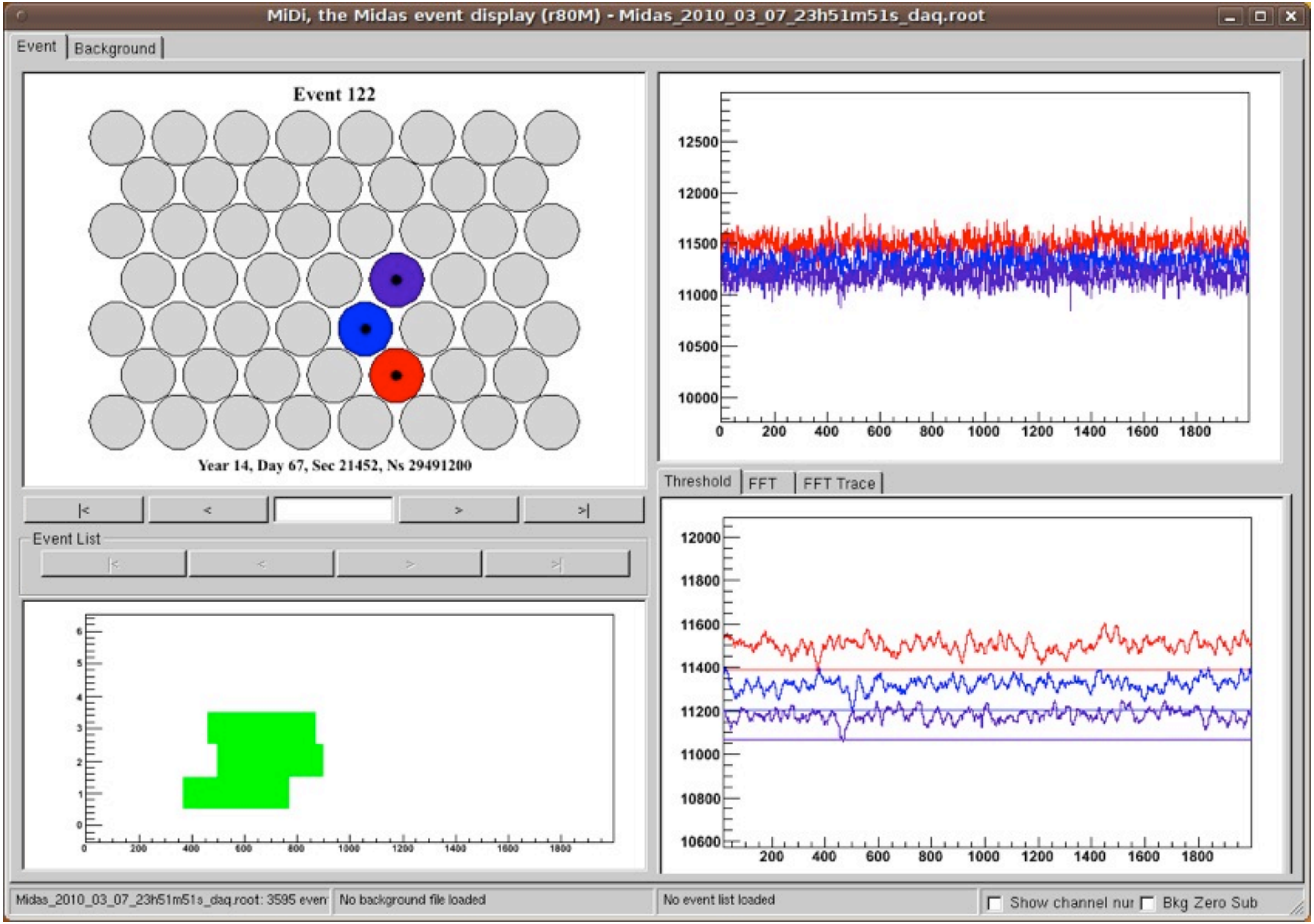
$$F_{sys} = \frac{2 k_B T_{sys}}{A_{eff}} \longrightarrow T_{sys} = 120K$$

also have observed moon (sun/100) and crab nebula (sun/1000)

MC Simulated Events

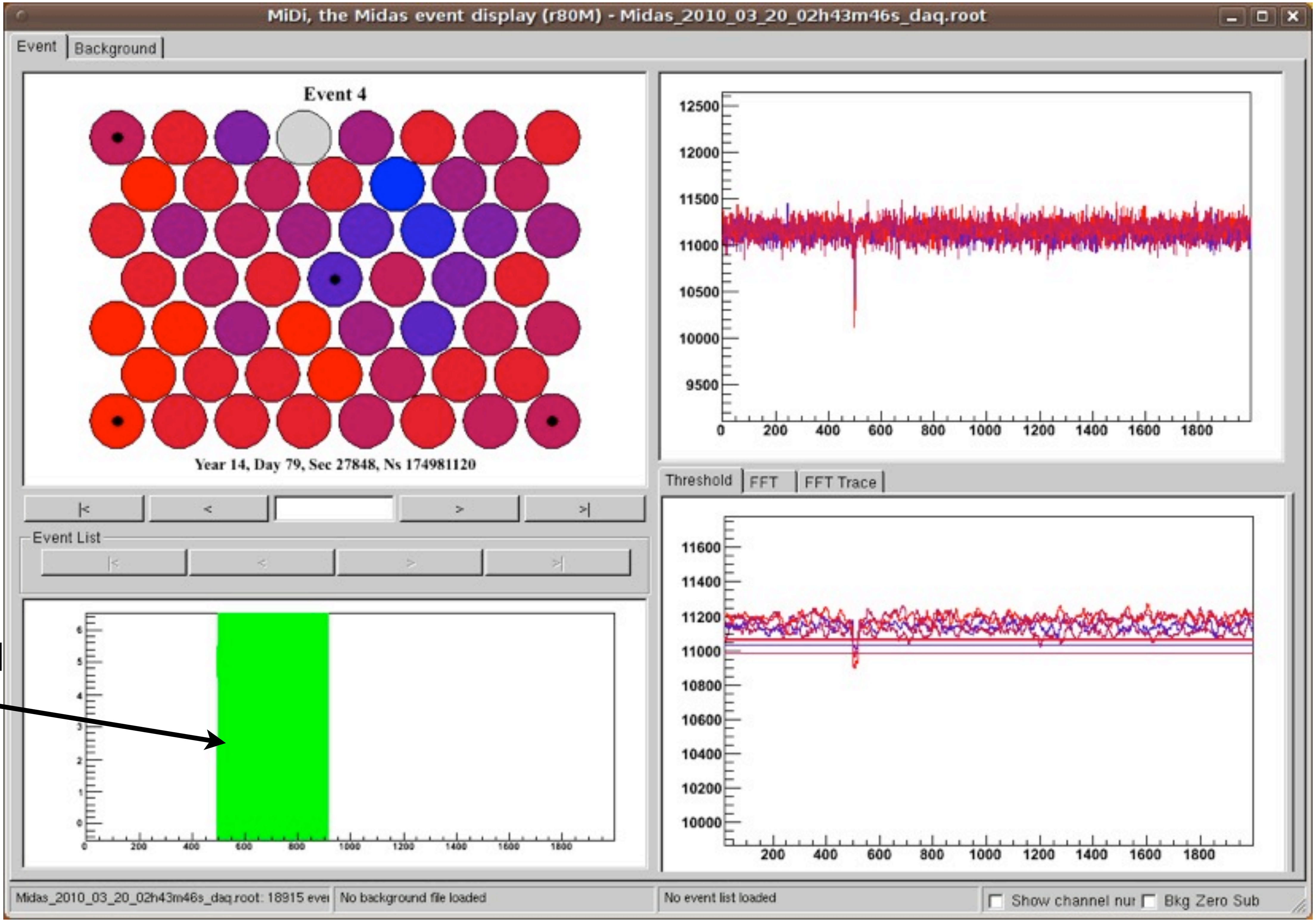


Event (thermal noise)



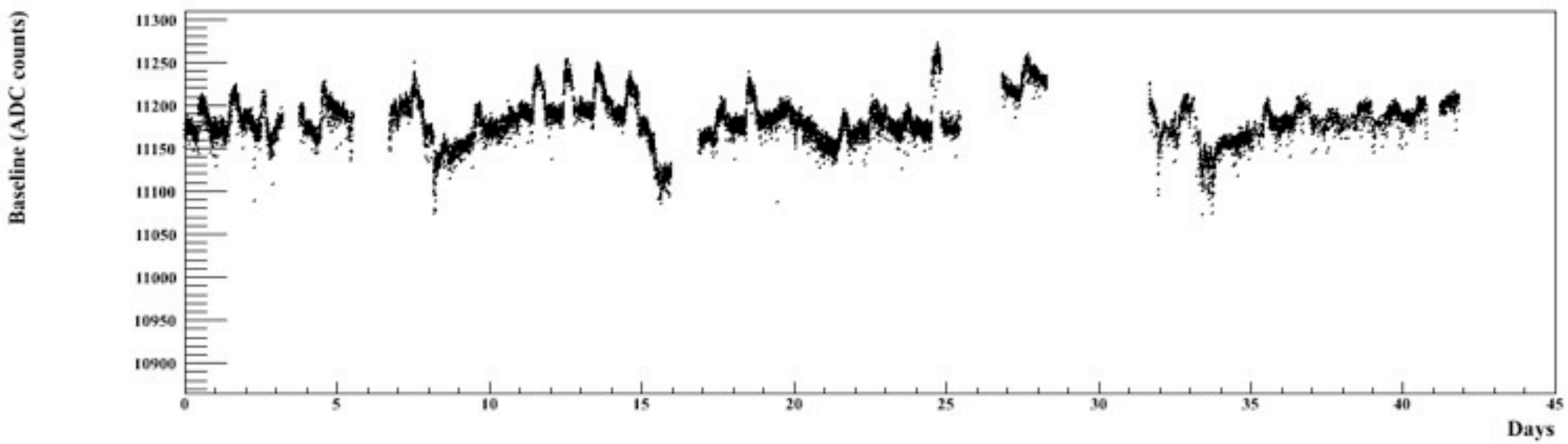
Noise Event

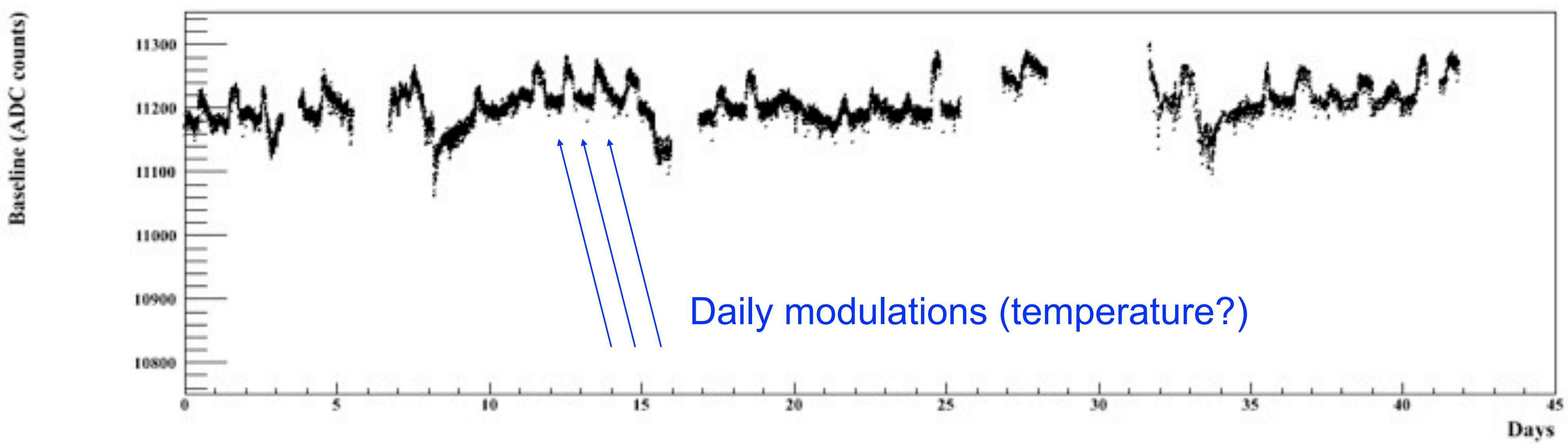
noise is likely due to aviation interference



All rows triggered simultaneously

Baseline for two channels over ~40 days of data taking

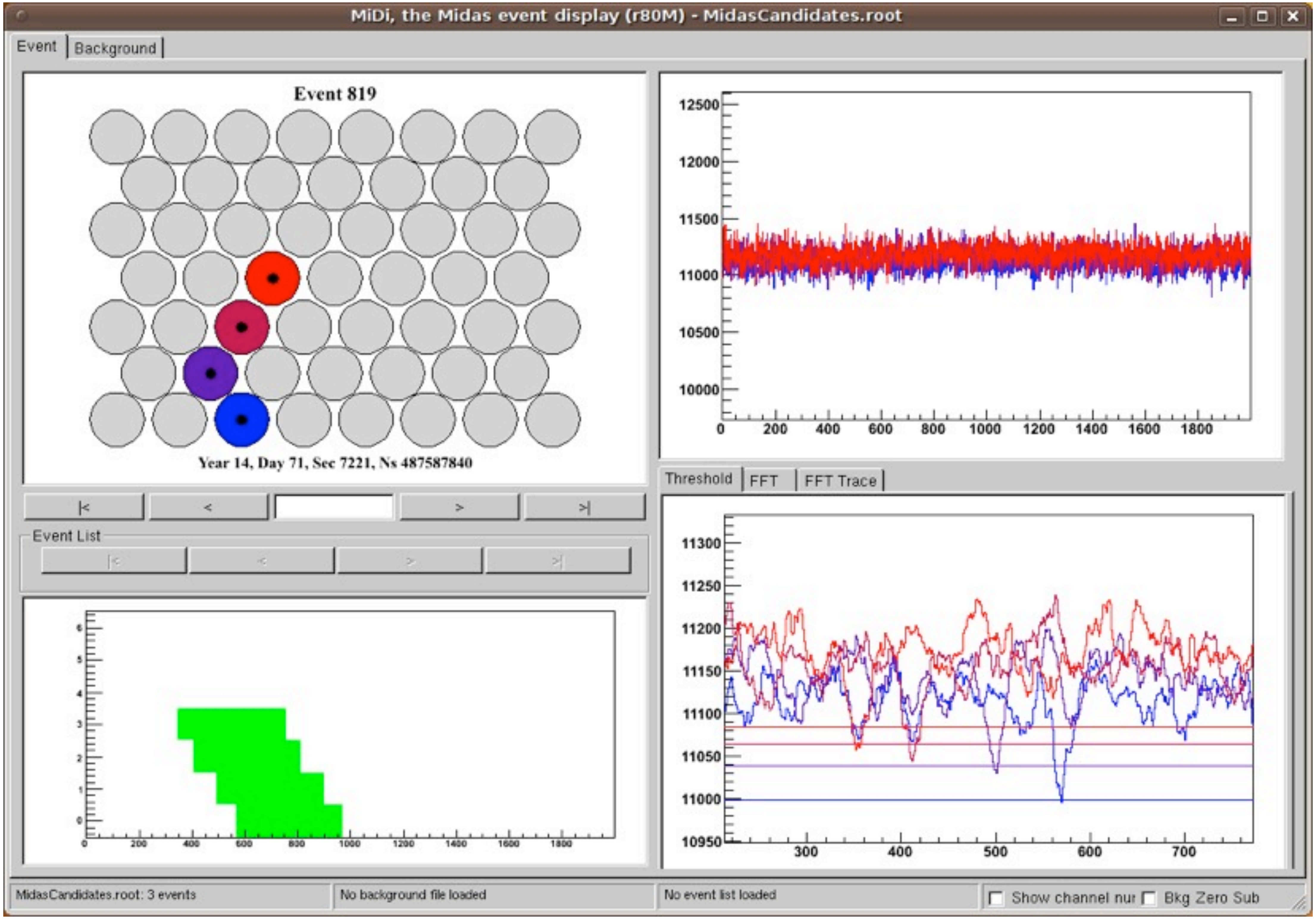




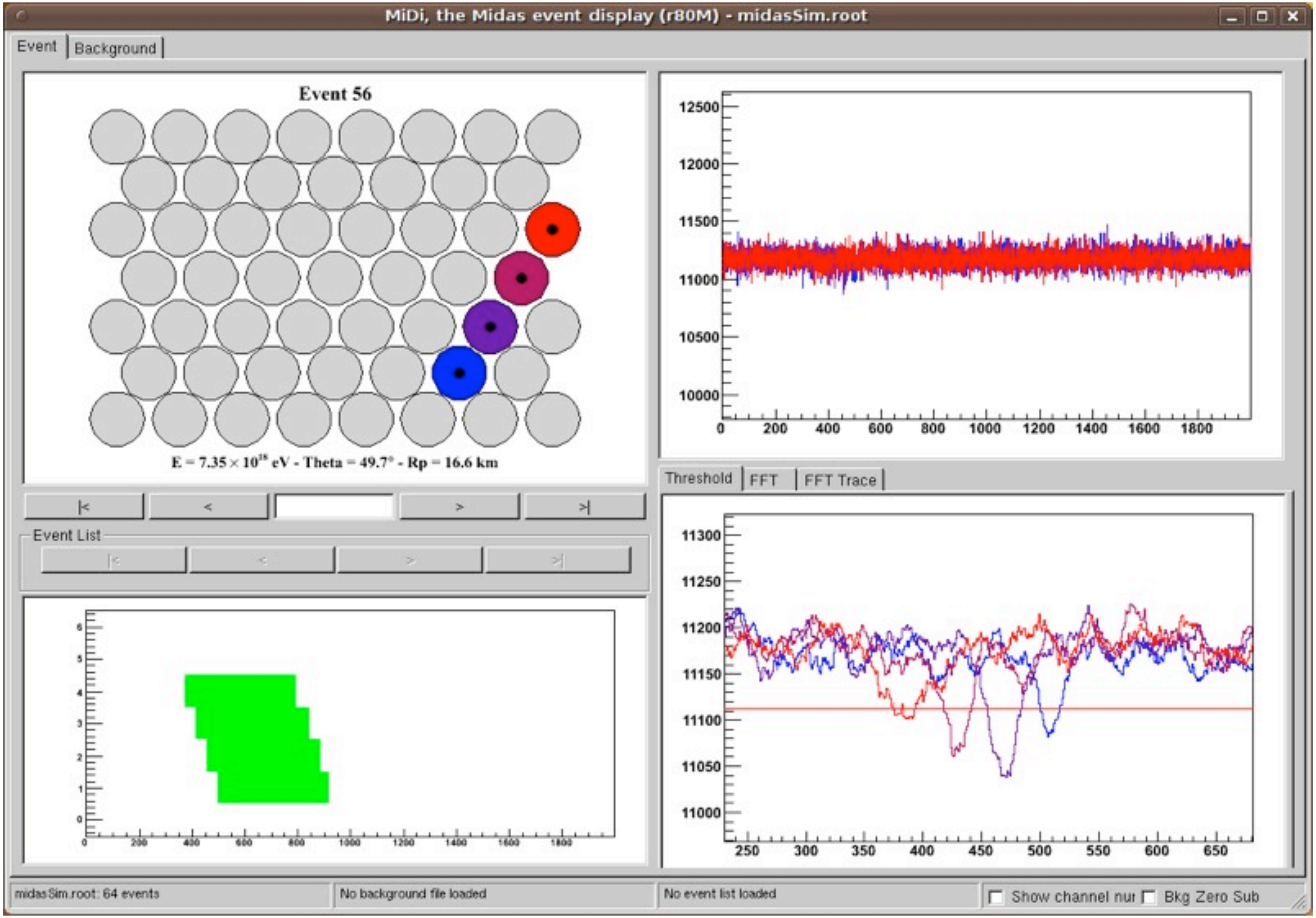
Baseline varies less than 1 dB over the period

Continued calibration with patch antenna will help explain the periodic fluctuations

Candidate Event



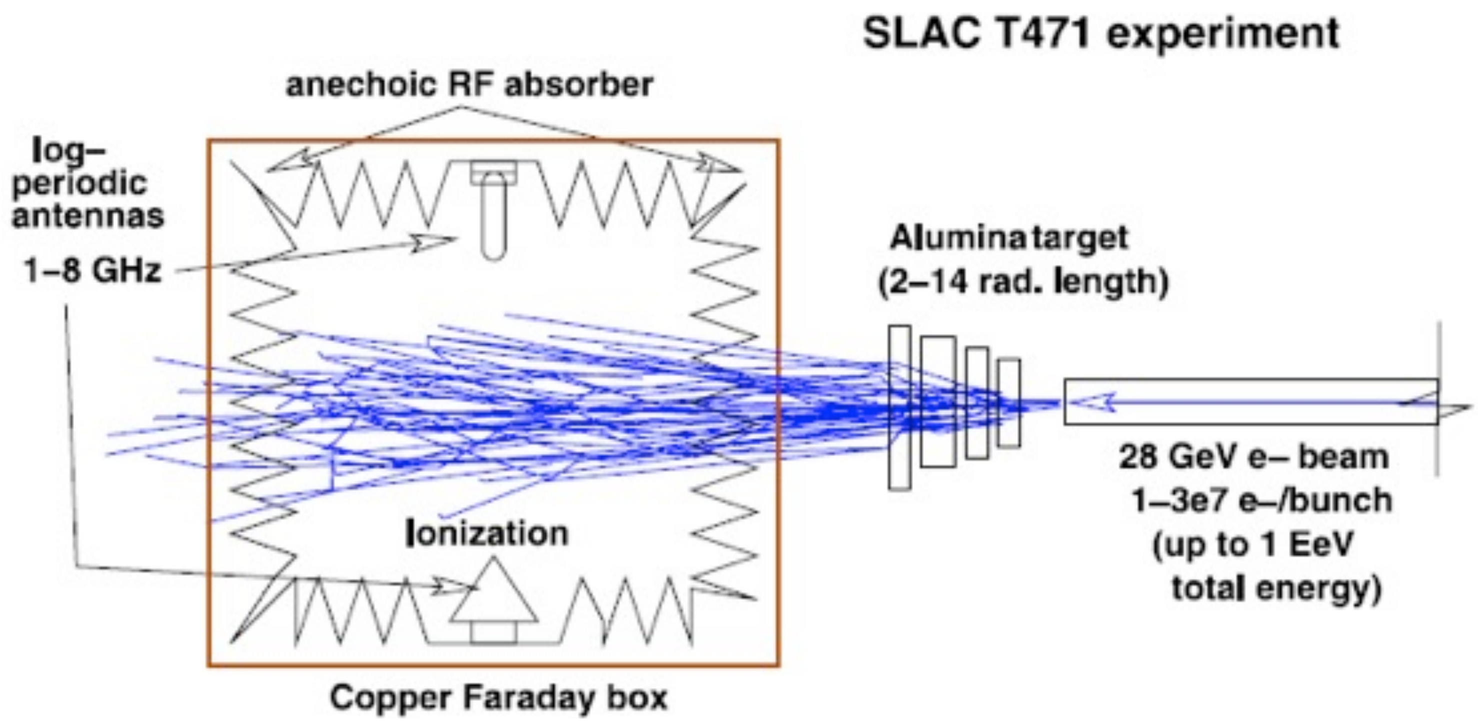
MC Event

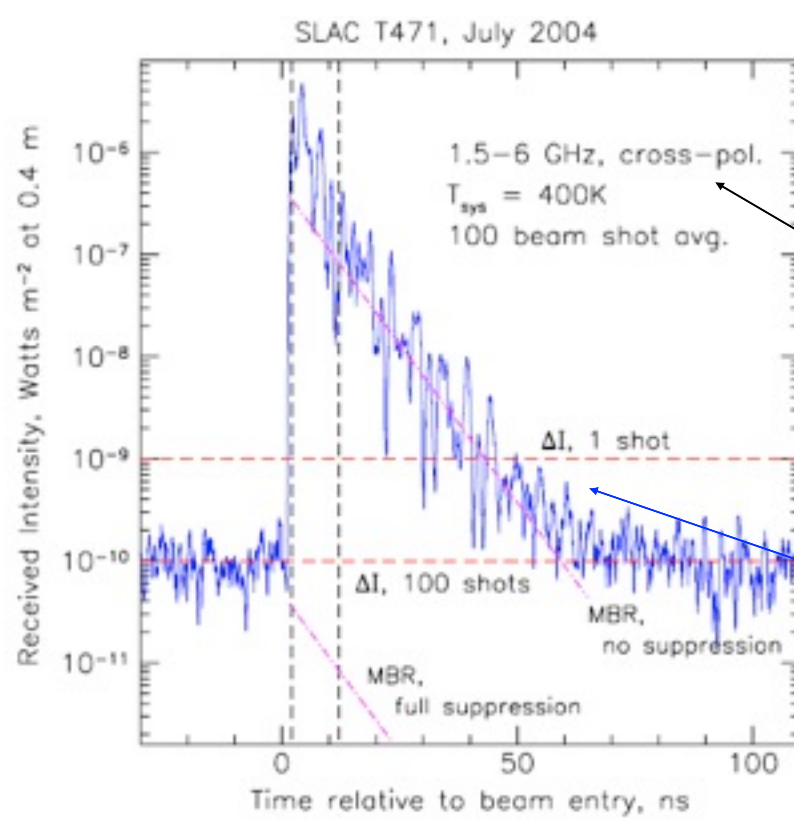

MiDi, the Midas event display (r80M) - midasSim.root
Event
Background
Event 56
E = 7.35 × 10^18 eV - Theta = 49.7° - Rp = 16.6 km
Event List
Threshold
FFT
FFT Trace
midasSim.root: 64 events
No background file loaded
No event list loaded
Show channel nur
Bkg Zero Sub

Conclusions

- Developed a self-triggering FD analog to explore the molecular bremsstrahlung emission in EAS
- Improvements currently underway:
  - Modifying trigger to better match patterns seen in MC
  - Addition of 1GHz band-pass filter to deal with noise bursts
  - Installation of patch antenna for continued calibration
- Plan to install the set-up in Argentina at the Pierre Auger Observatory to look for coincident detections

Extra Slides

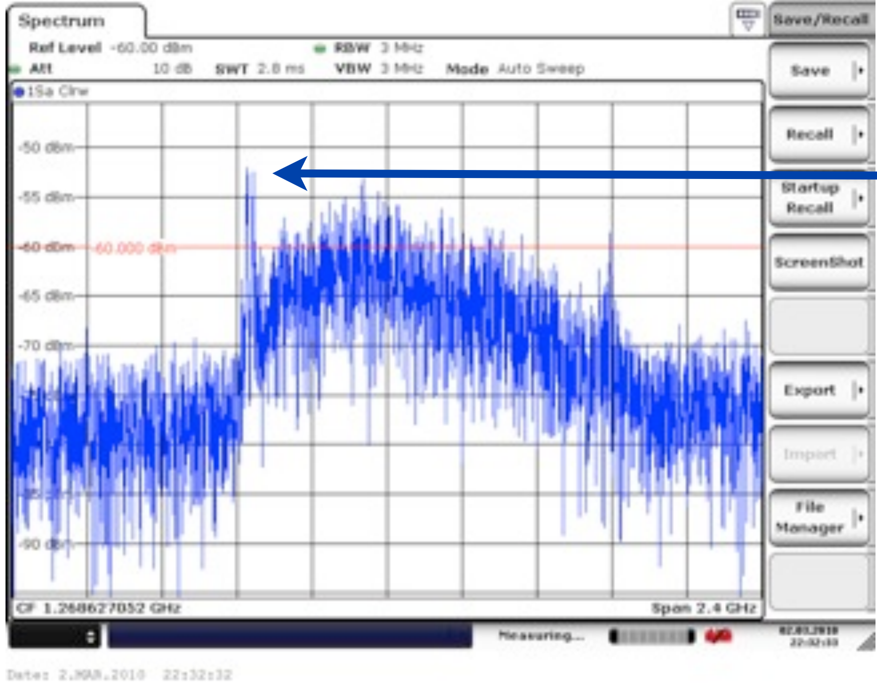




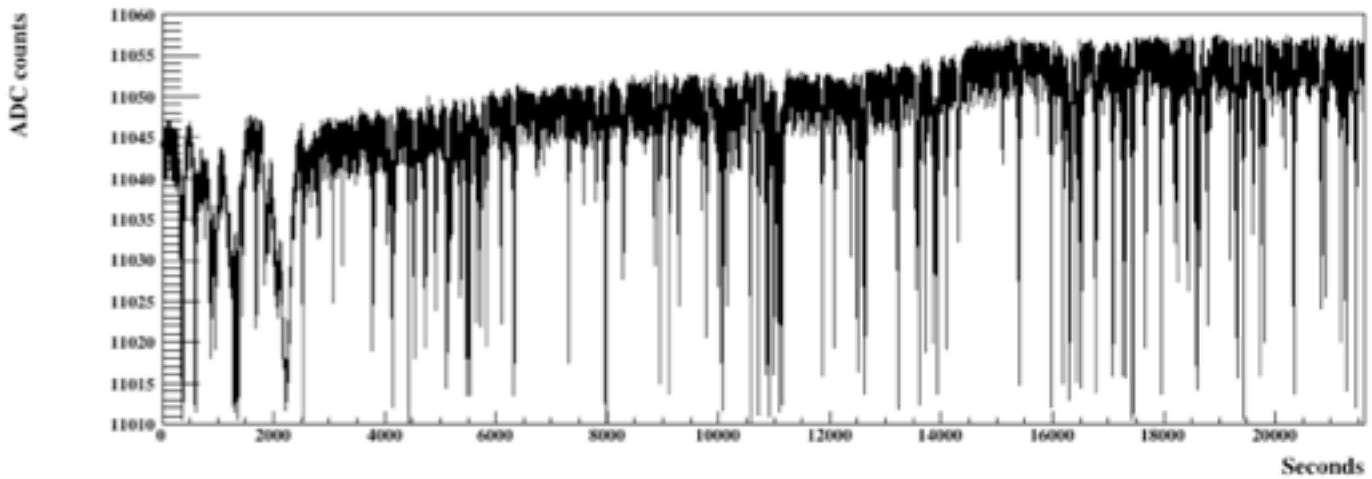
Insensitive to radio Cherenkov

10 ns decay constant, compatible with plasma cooling.

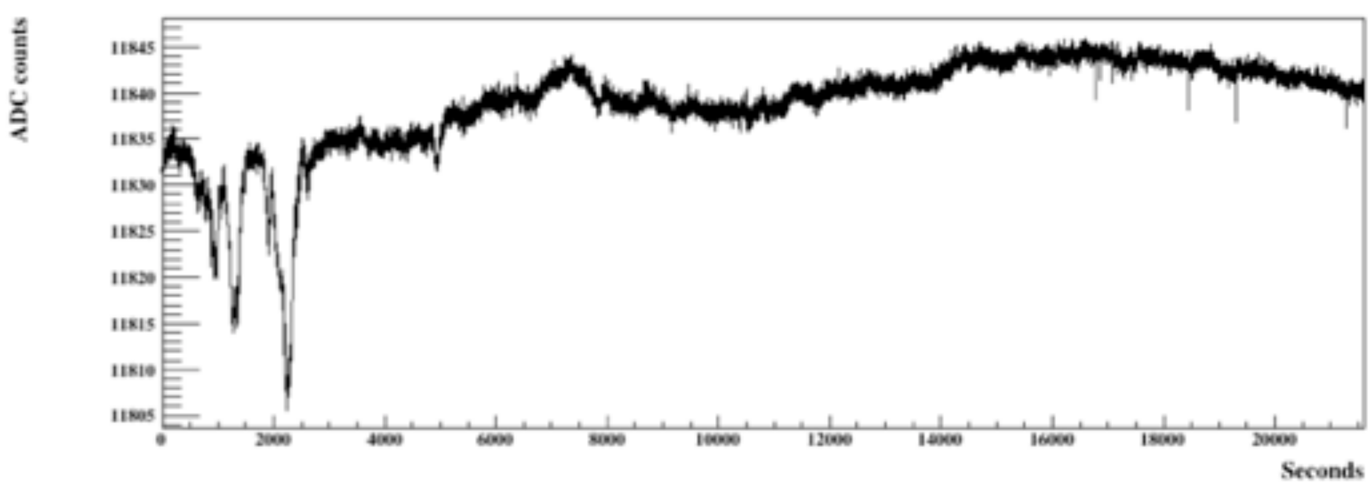
P.W Gorham *et al.,* "Observations of microwave continuum emission from air shower plasmas", Phys. Rev .D. **78**, 032007 (2008)



Installed a 1GHz band-pass filter, greatly reduced power in bursting lines



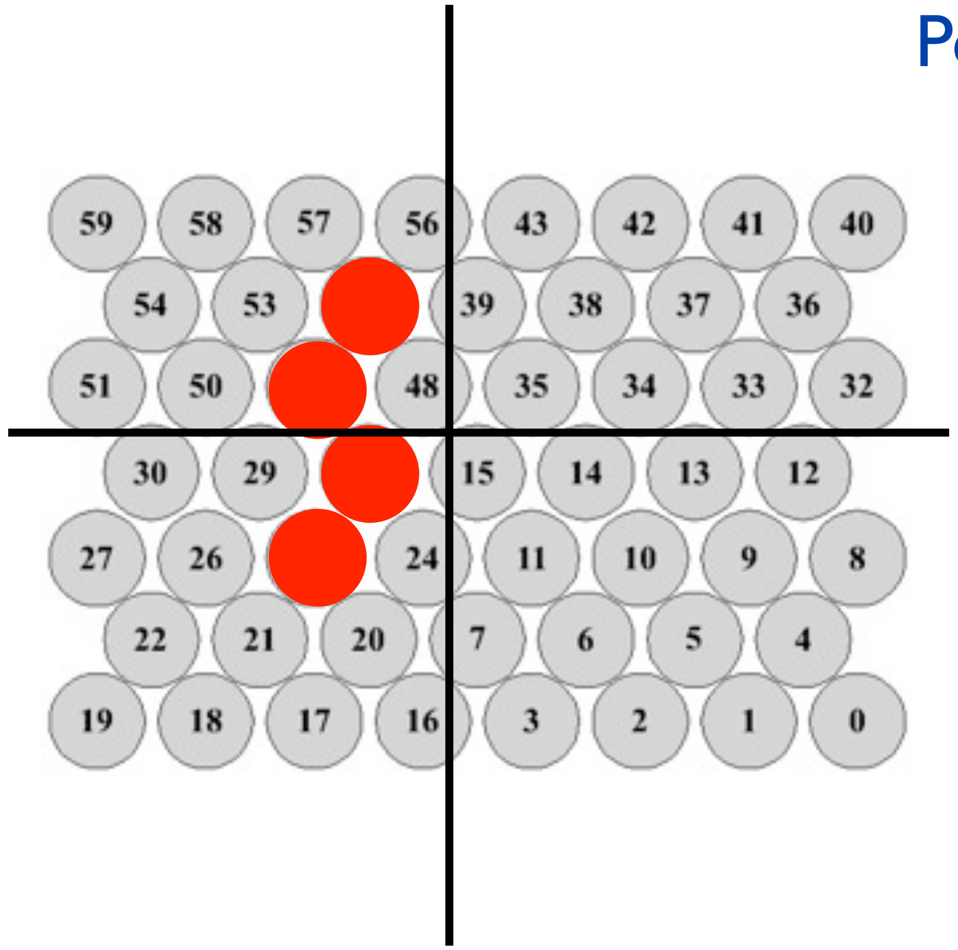
Pixel without band-pass filter



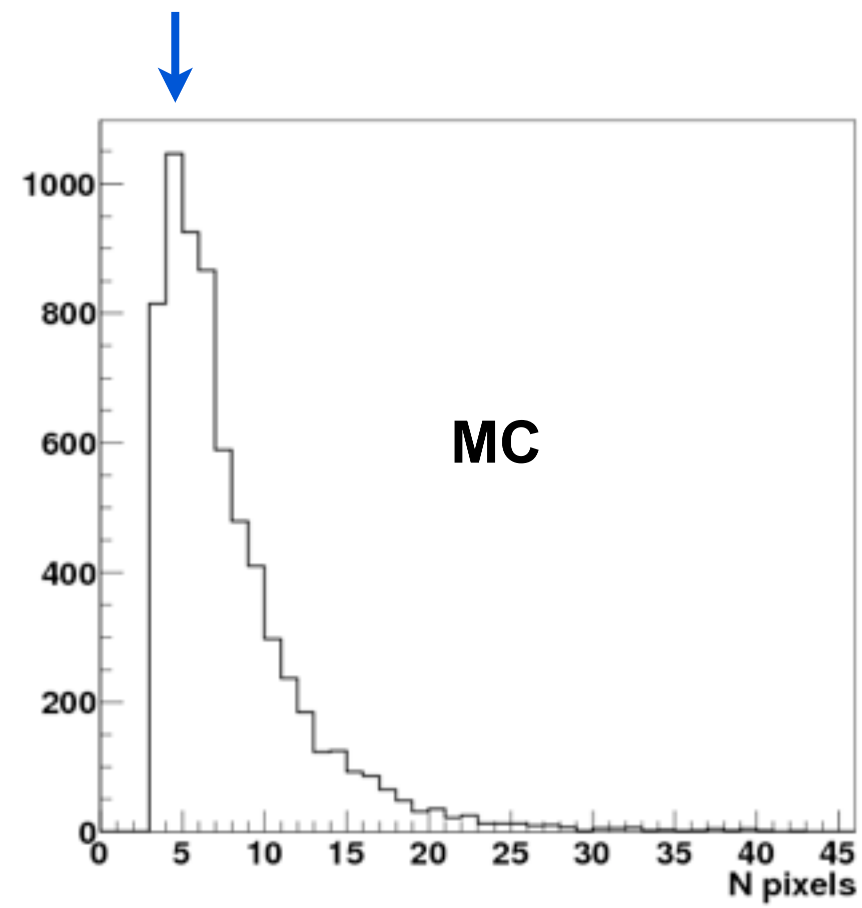
Pixel with band-pass filter same run

Should eliminate periods of deadtime due to noise bursts and make the system more stable

Trigger Improvements



Peak at 4 pixels triggered, 3 pixel events have low SNR



4-Pixel Patterns across the whole camera

Reduces noise events significantly
Better match for MC data