Microwave detection of cosmic ray air showers at the Pierre Auger Observatory, an R&D effort

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for the
Pierre Auger Collaboration

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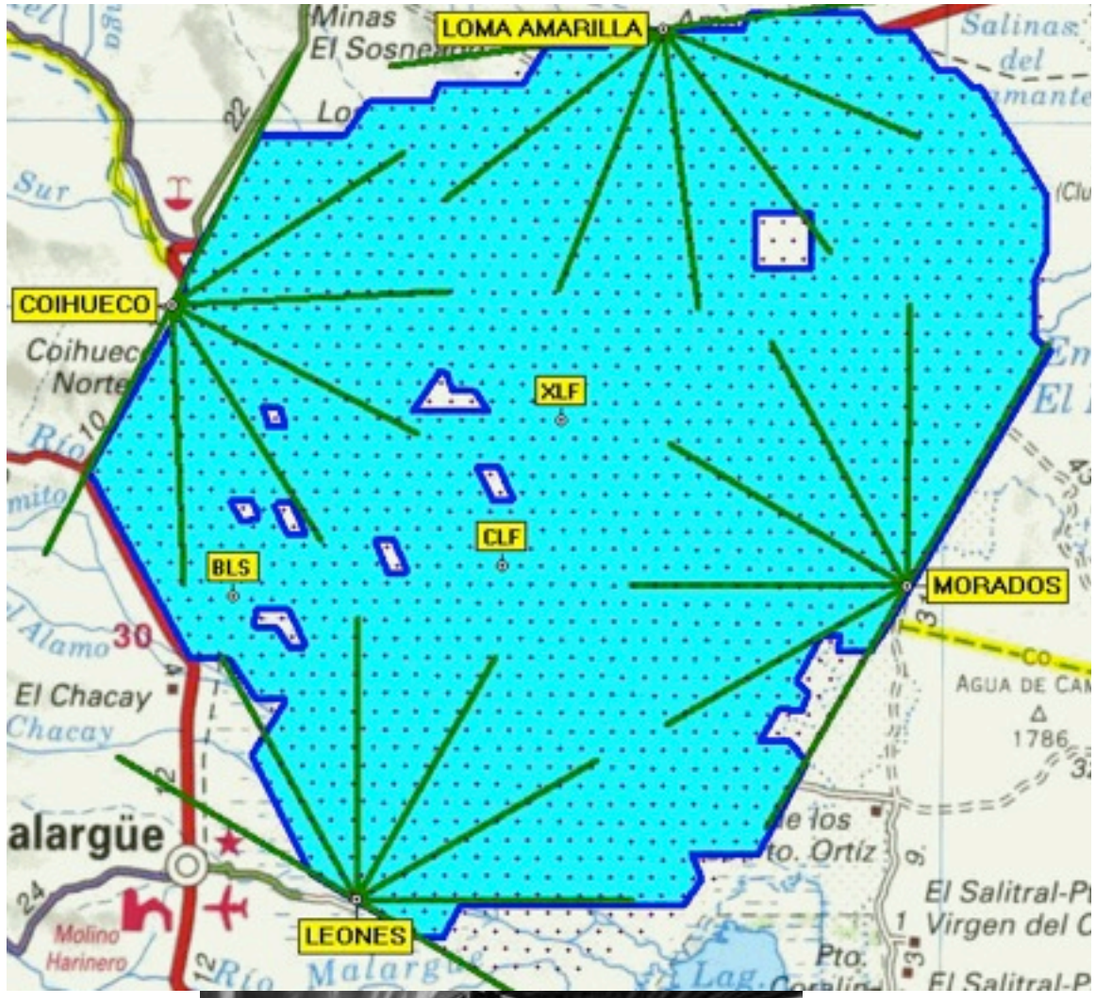
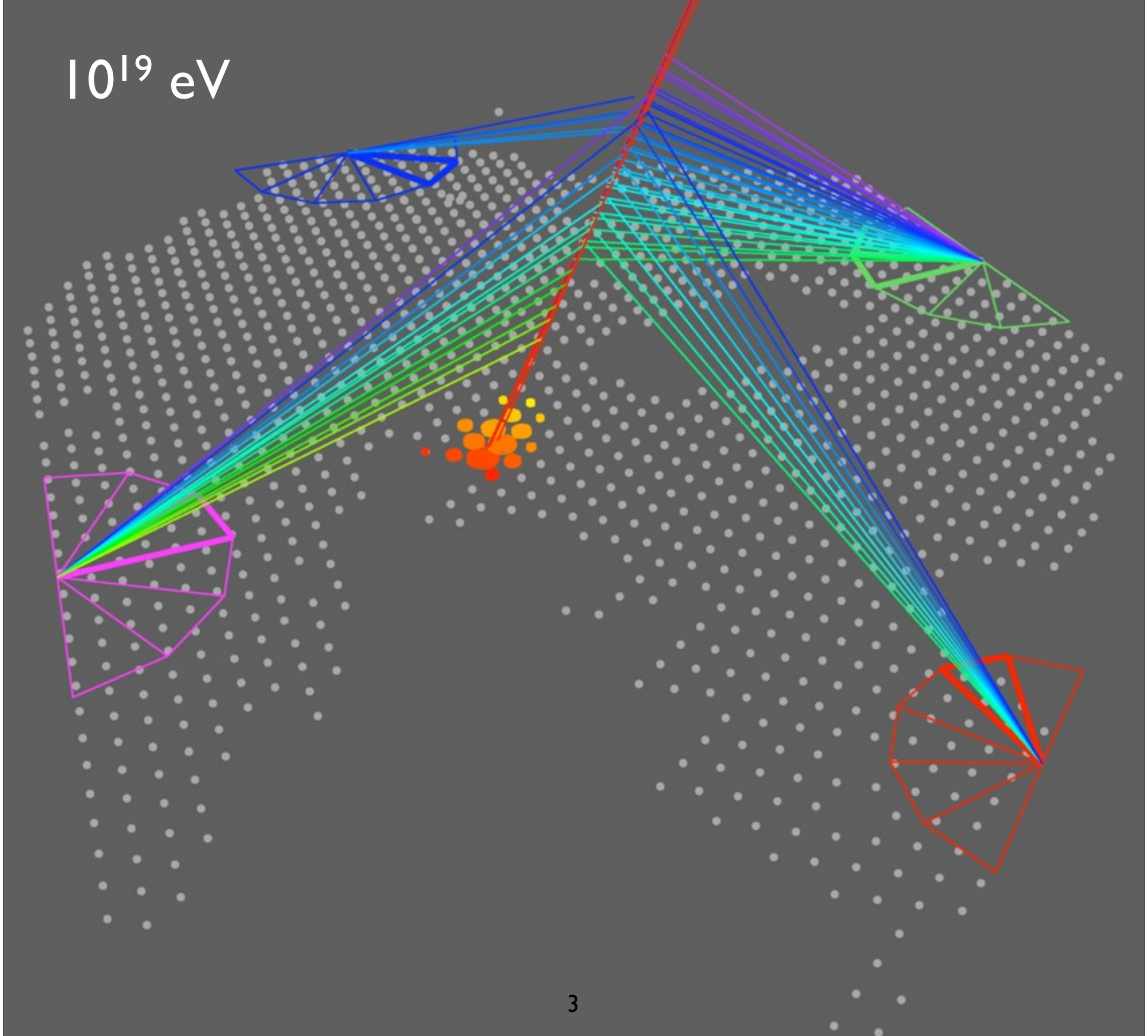
Pierre Auger Observatory

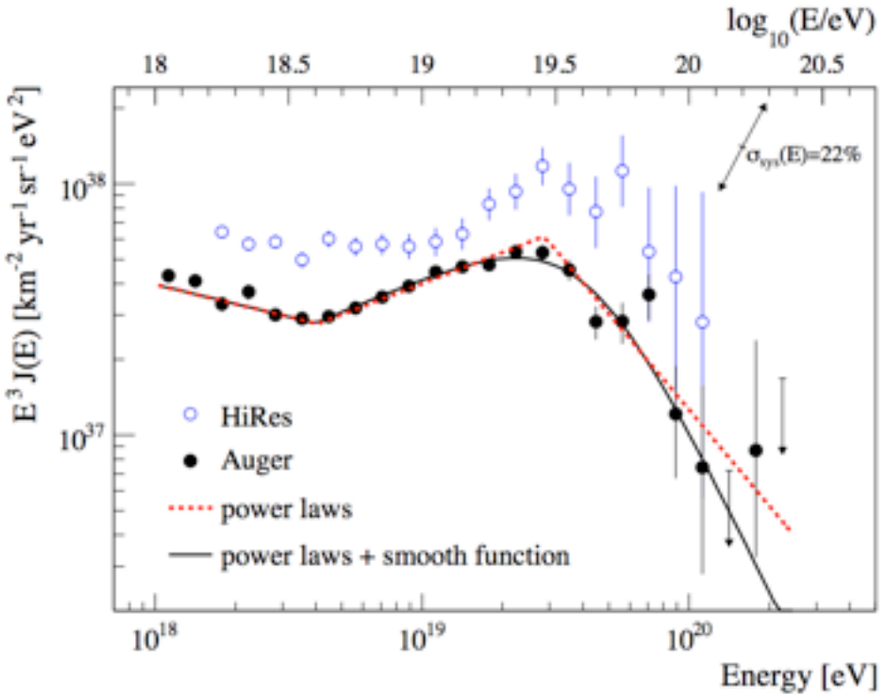
- Hybrid Detection Technique, Covering 3000km^2
- Surface Detector (SD) of 1600 Cherenkov water detectors
  Drawback: Difficult to get longitudinal development
- 24 Fluorescence Telescopes (FD),
  Drawback: 10% duty cycle, Atmospheric effects



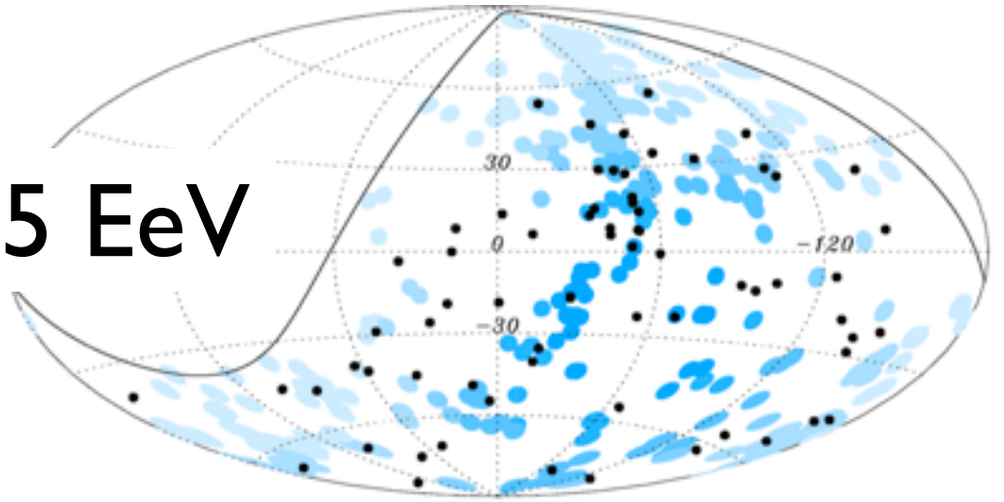

10^{19} eV

Pierre Auger Observatory

Key Science

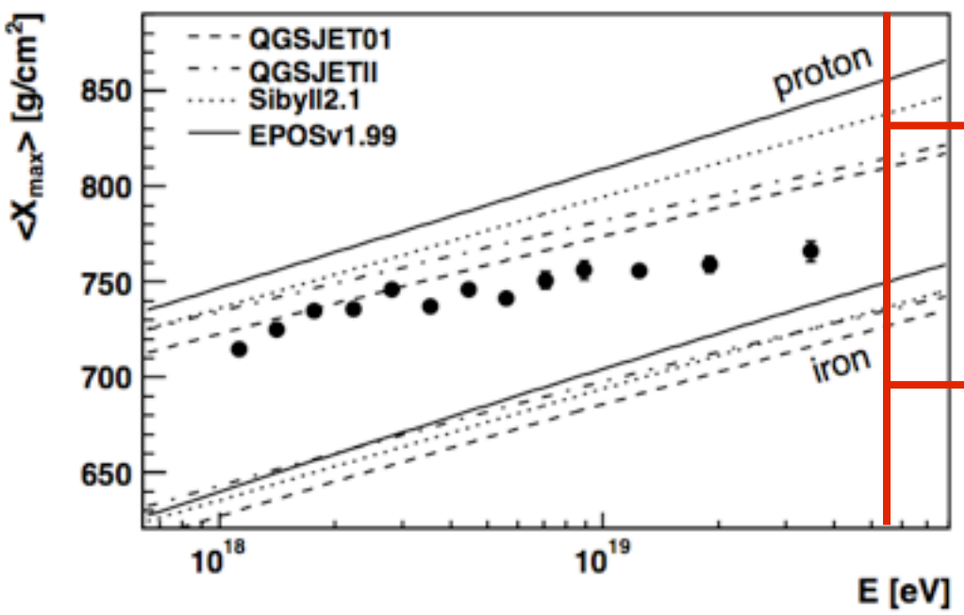


Observed spectral break at $10^{19.5}$ eV, consistent with GZK effect.



Spatial anisotropy of events above 55 EeV

55 EeV



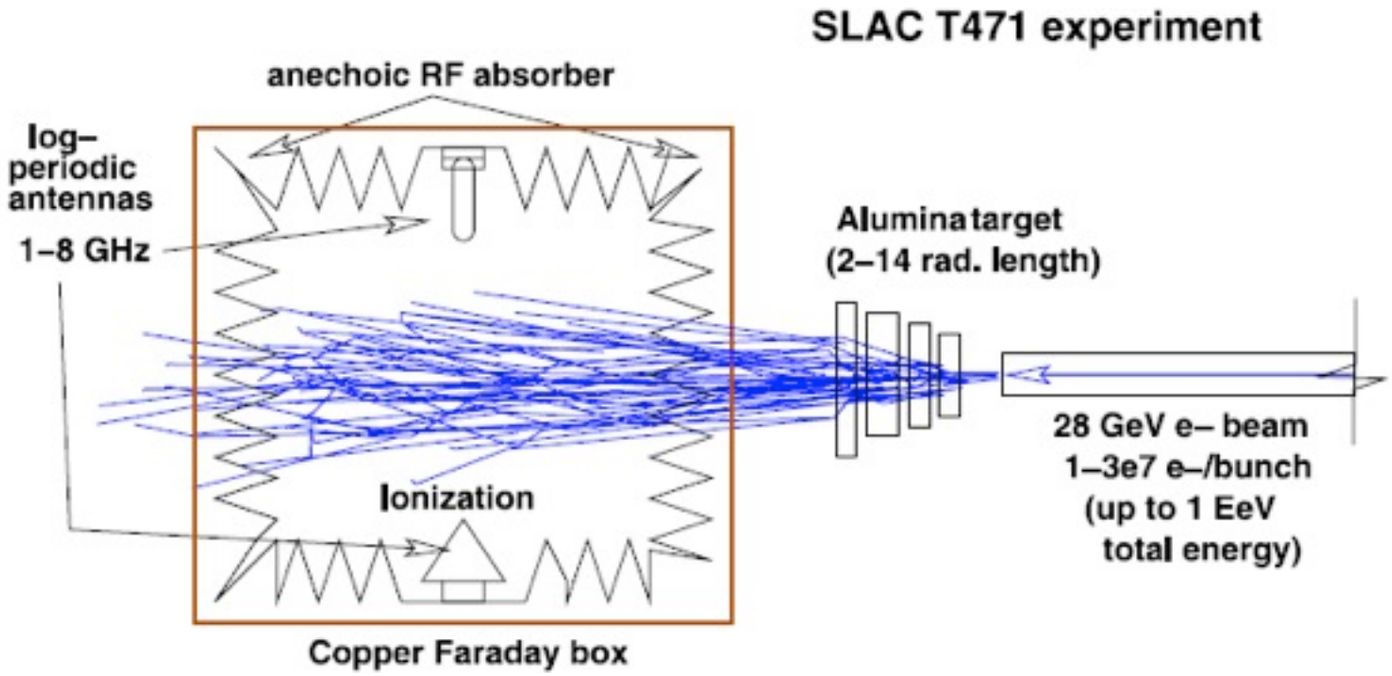
Measurements of shower maximum suggests change in UHECR composition or a change of interaction cross section

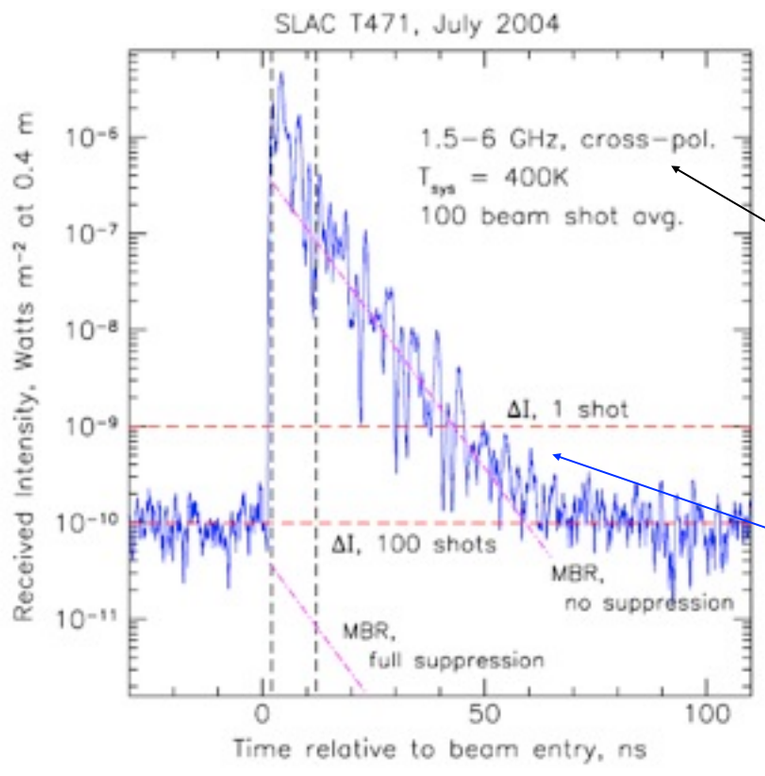
Molecular Bremsstrahlung Emission

- 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 longitudinal development with nearly 100% duty cycle, limited atmospheric effects and low cost (ability to cover large area)

Beam Measurements





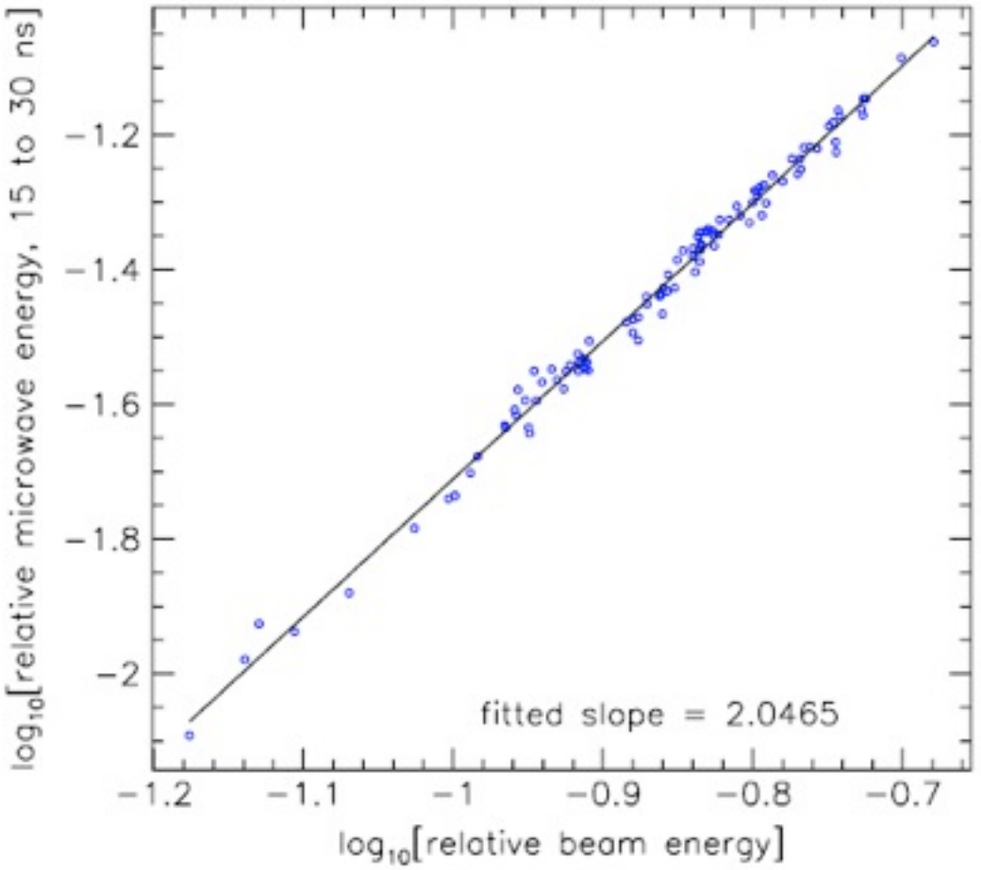
Insensitive to radio Cherenkov

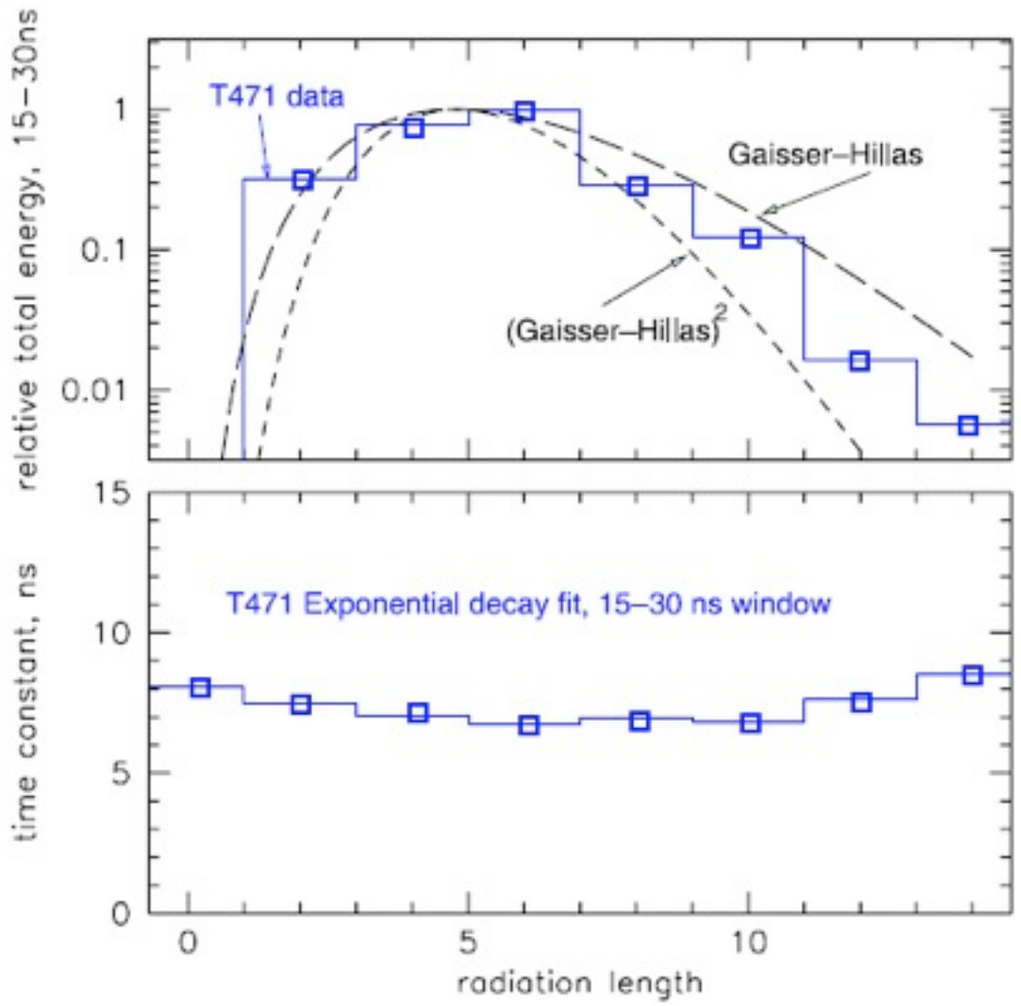
10 ns decay constant, compatible with plasma cooling.

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

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

MIcrowave Detection of Air Showers

- Imaging telescope similar to FD, Prototype at University of Chicago
- 4.5m parabolic reflector with 53 commercial extended C-band (3.4-4.2GHz) LNBFs, 20°x10° FOV

16 channels

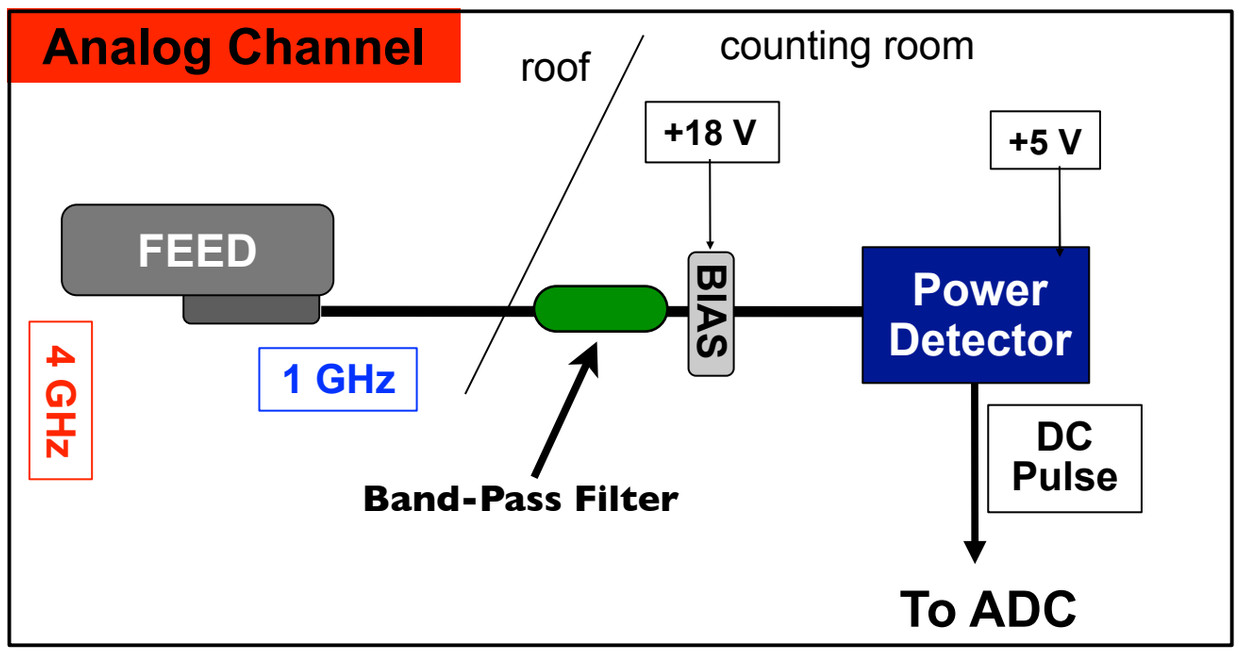
14 bit

20 MHz

FPGA trigger

Developed @ EFI

- Analog power detection and filtering
- Custom FPGA/ADC for triggering

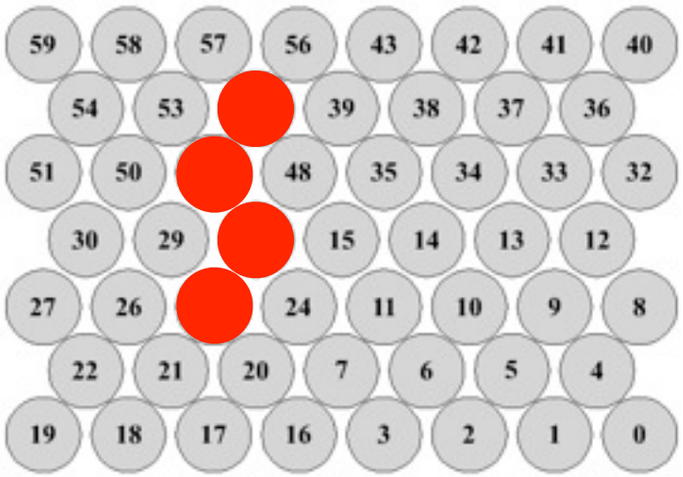


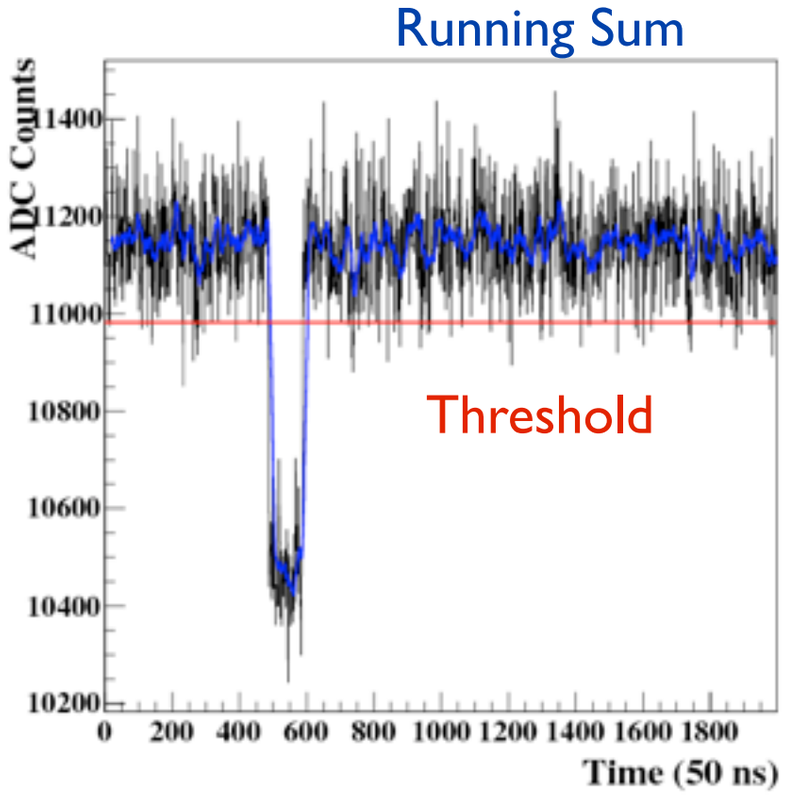
MIDAS

MIcrowave Detection of Air Showers

FLT: 1 μs running sum, over threshold trigger

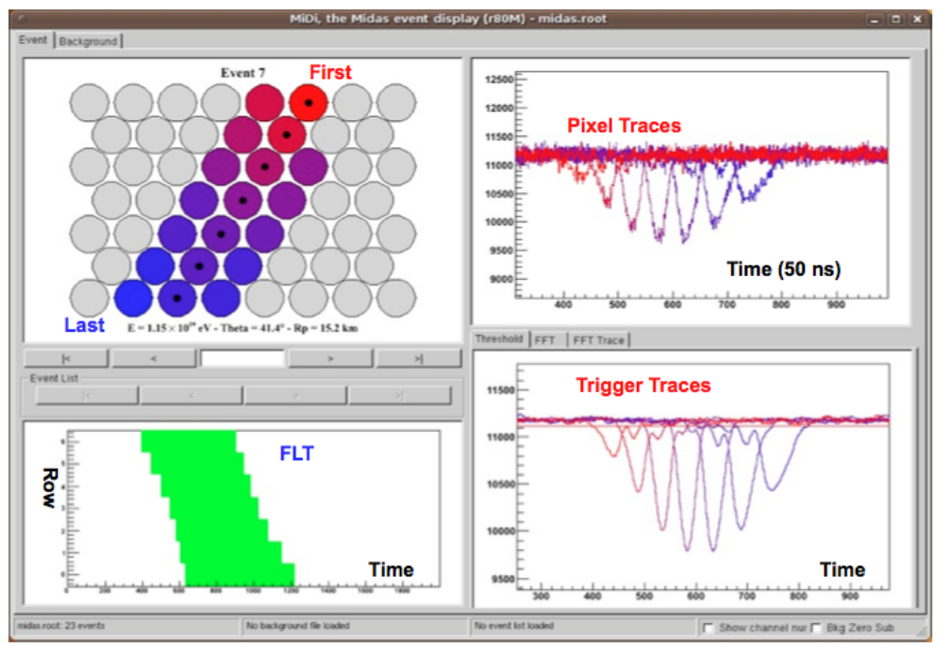
Each feed has self-regulated threshold to hold rate at 100Hz





SLT: require 4 FLT within 10 μs for specified pixel patterns

End-to-end Monte Carlo developed for detector, calibrated with on telescope pulsing antenna and astrophysical sources



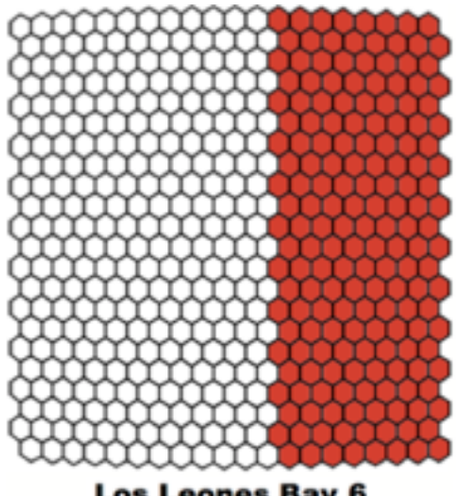
AMBER

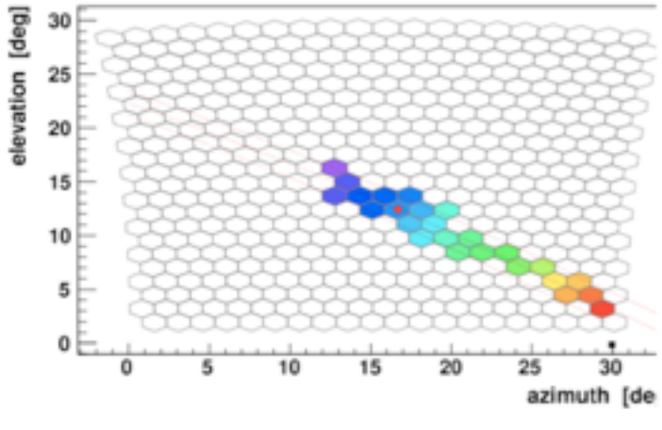
Air-shower Microwave Bremsstrahlung Experimental Radiometer

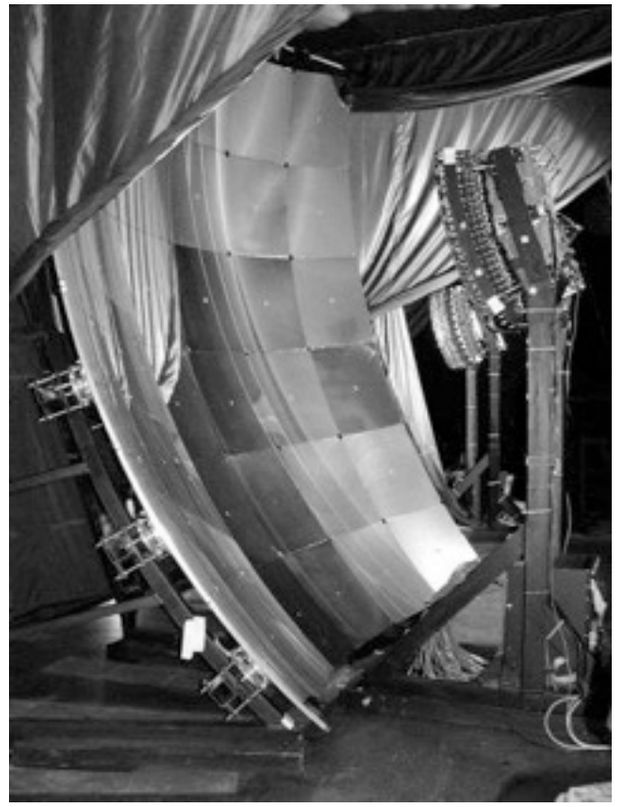
- 2.4m off-axis parabolic reflector
- 12 Single polarization C-band feed horns, 4 dual polarized dual band feed horns (C-band and Ku-band 10.95-14.5GHz), 7°x7° FOV
- Signal is passed through analog power detector, digitized at 100MHz, and held in a very large circular buffer (~5s)
- Triggered by external trigger from Auger SD

FDWave

- Use empty PMT pixels at Los Leones FD site to hold Ku-band INBFs
- FD mirror is 3.4m spherical reflector constructed out of polished aluminum, perfect for RF reflection
- Use existing FD electronics for Digitizing, but run passively with FD
- Has advantage of observing events in FD and radio simultaneously

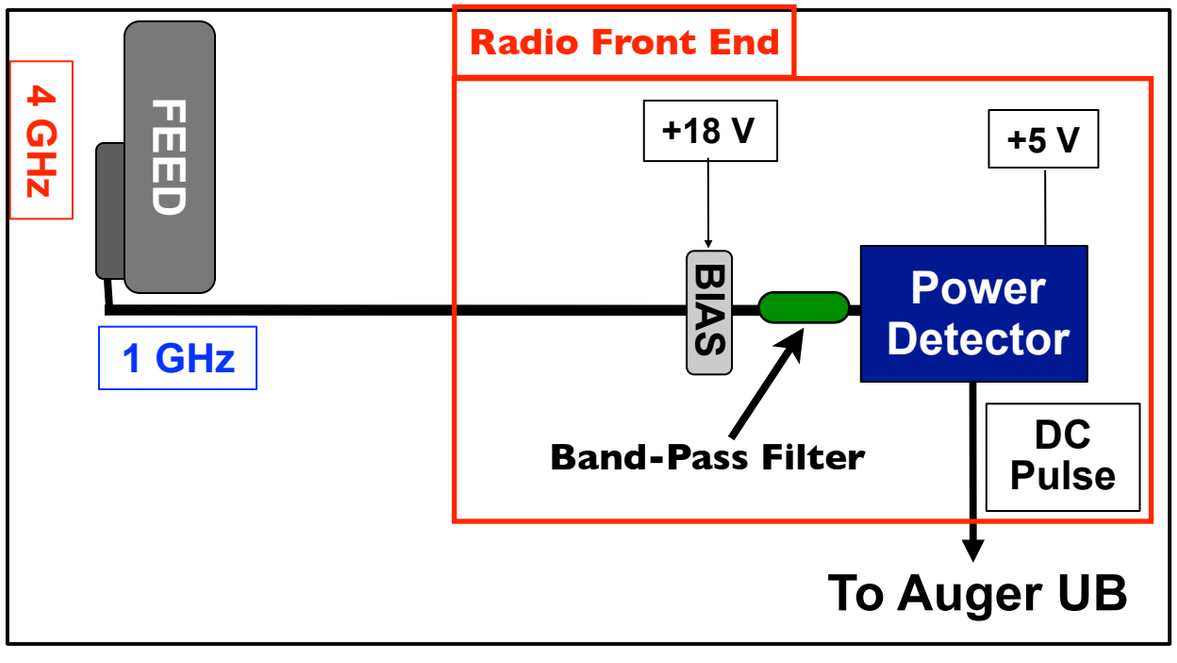






EASIER

Extensive Air Shower Identification using Electron Radiometer



- Exploring 2 detection techniques: MHz (geosynchrotron) and GHz
- GHz uses commercial C-band LNBF similar to MIDAS with no reflector, 60° FOV around zenith
- LNBF mounted on Auger SD tank, shares the SD PMT electronics for ADC, timing, and triggering
- Detects showers which are very nearby ~3km, signal time compression and external trigger make up for small effective area of antenna

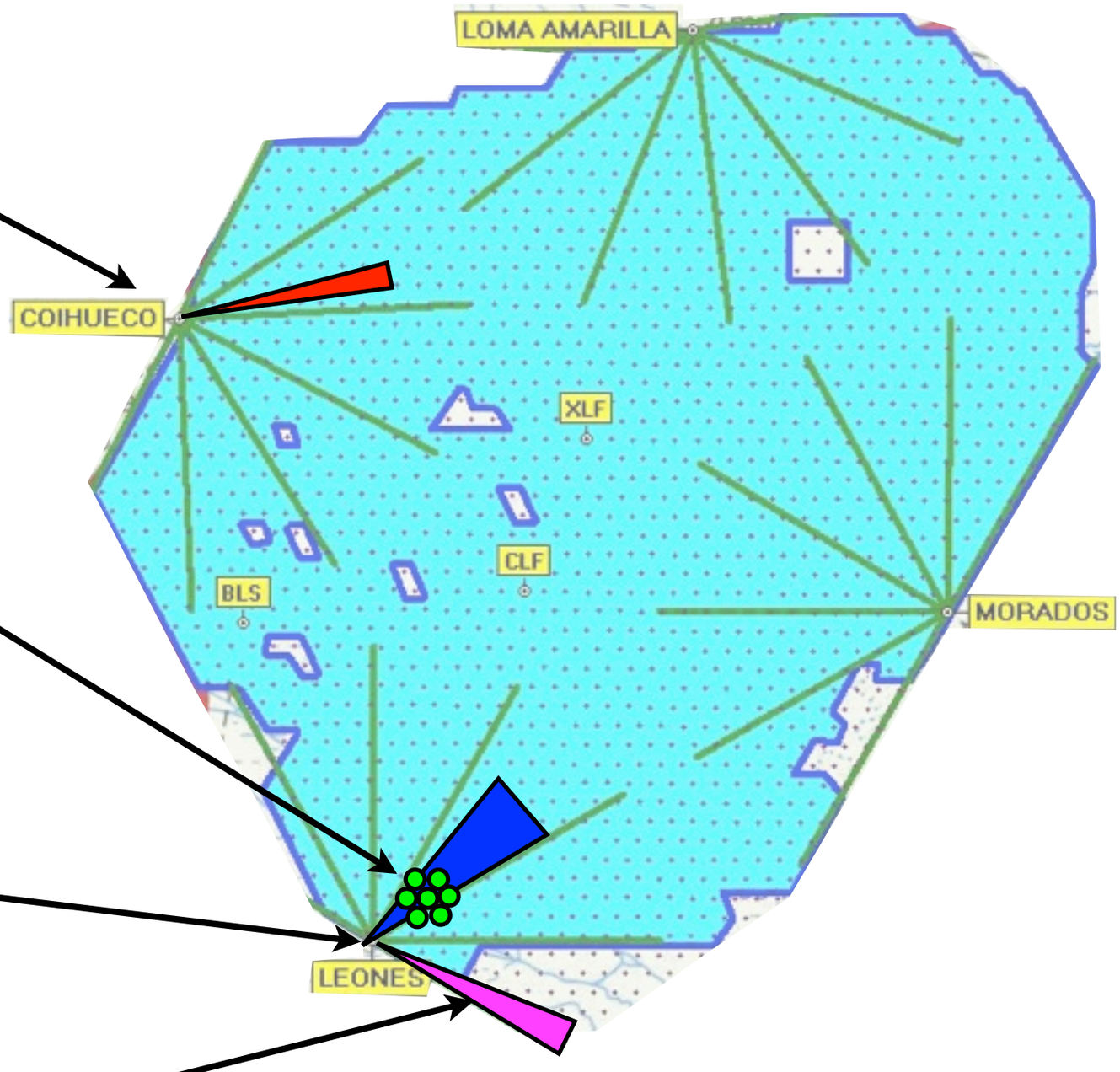
Future Outlook

AMBER: Installed and taking data

EASIER: Installed and taking data

MIDAS: Chicago run finished, preparing for shipment

FDWave: Contacting manufacturers and waiting for funds



Conclusions

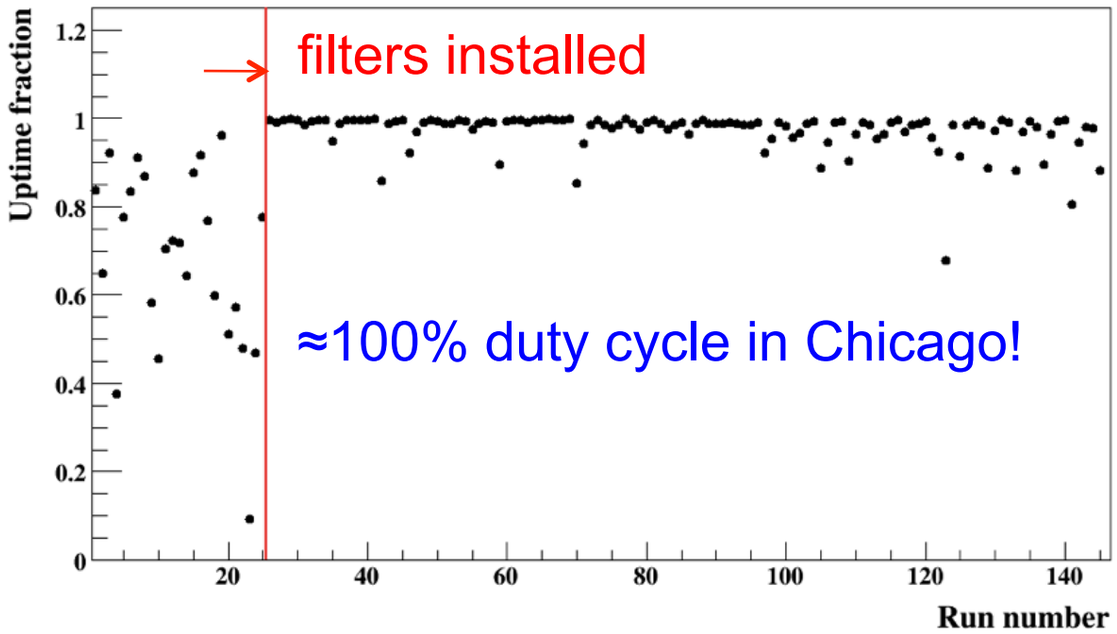
- 4 unique GHz detectors in the process of being installed at the Auger site
- Each design has unique set of systematics
- Prepared to explore new detection technique with the advantages of coincident detection using the FD and SD

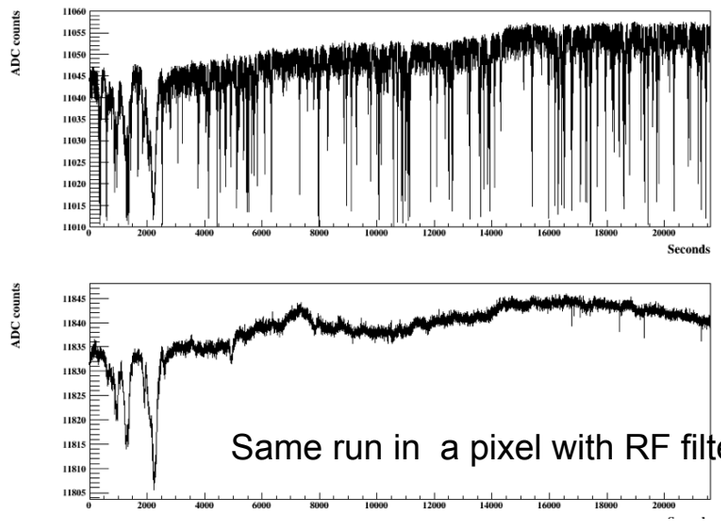
Extra Slides

MIDAS

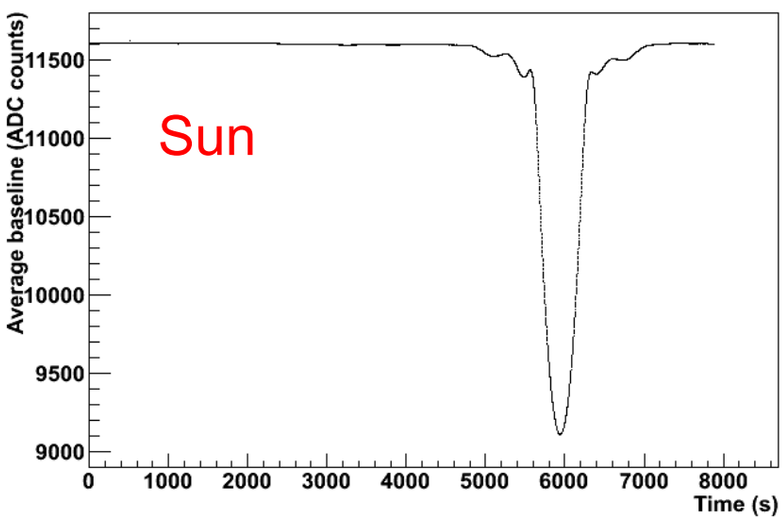
MIcrowave Detection of Air Showers

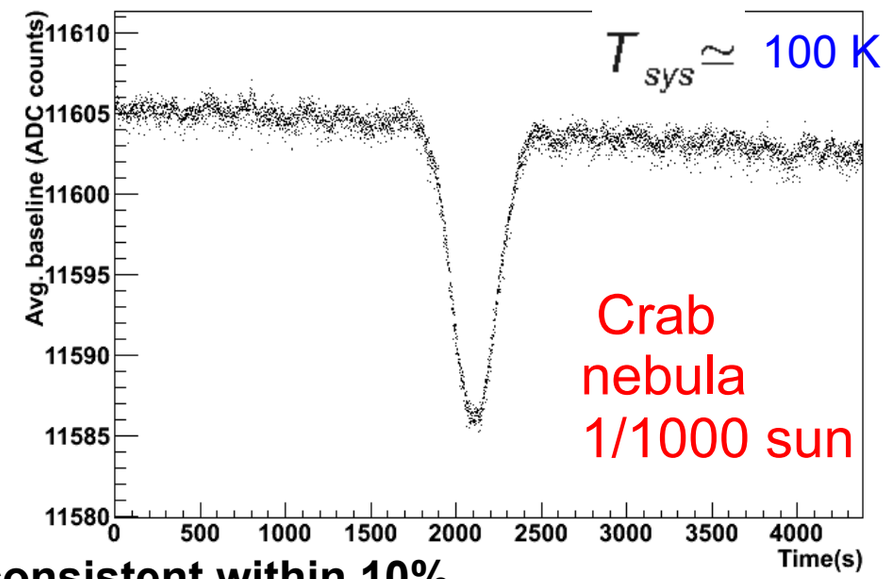
RFI and duty cycle





Absolute Calibration



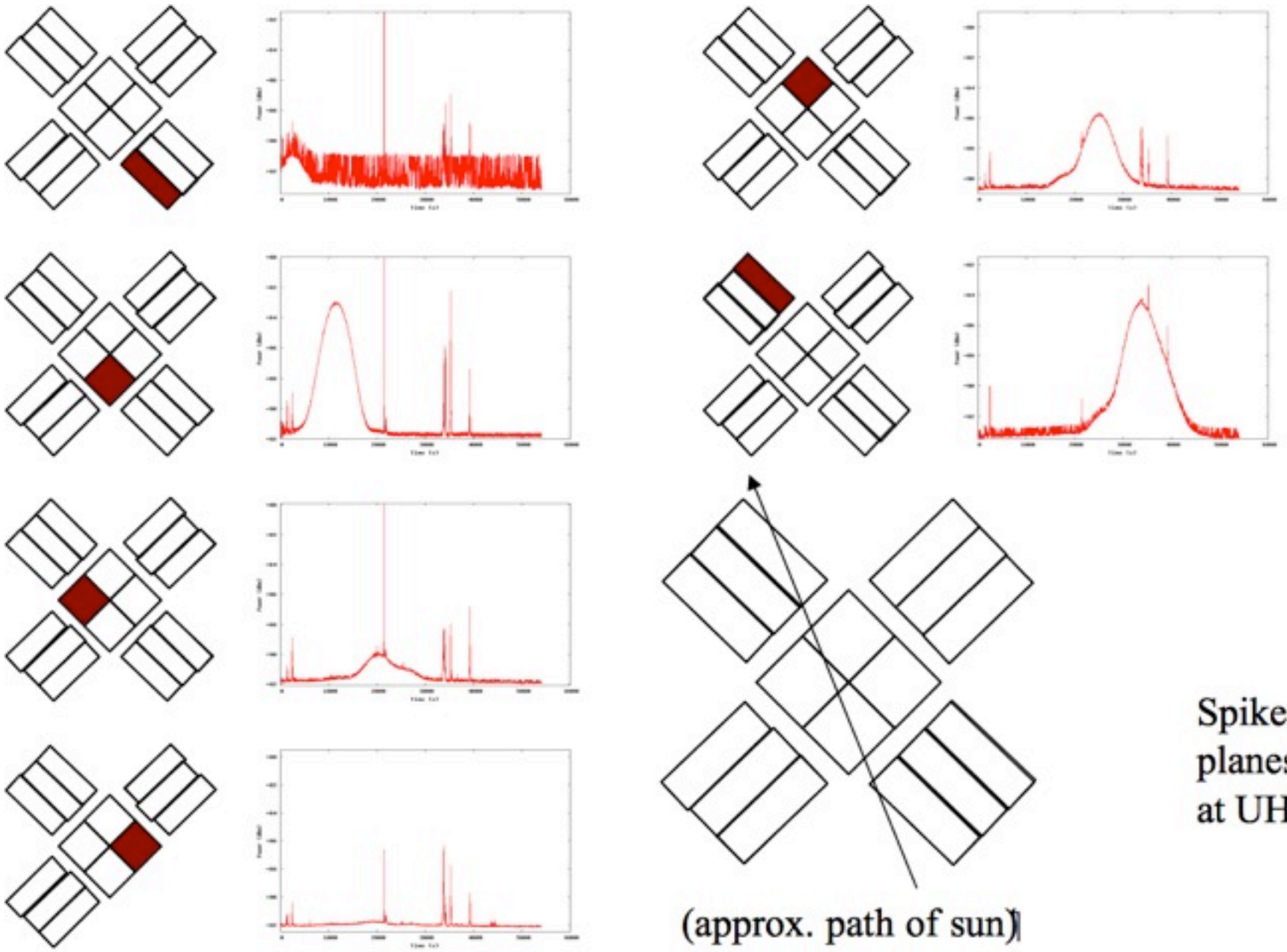


NOTE: Calibrations with Sun, Moon and Crab consistent within 10%

AMBER

Air-shower Microwave Bremsstrahlung Experimental Radiometer

Sun Crossing



(approx. path of sun)

Spikes/noise due to planes/nearby RF sources at UH

EASIER

Extensive Air Shower Identification using Electron Radiometer

MHz Event