The STACEE Ground-Based Gamma-Ray Detector

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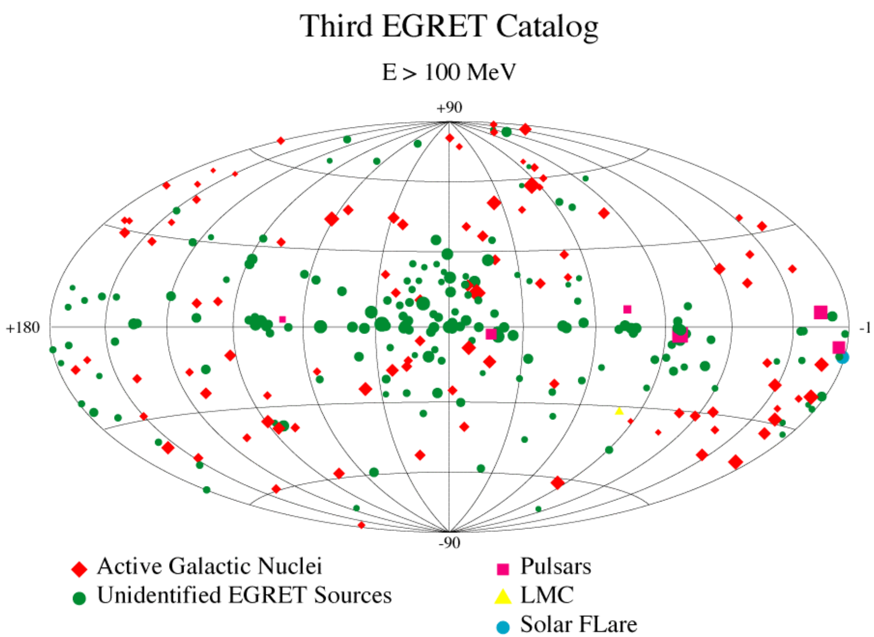
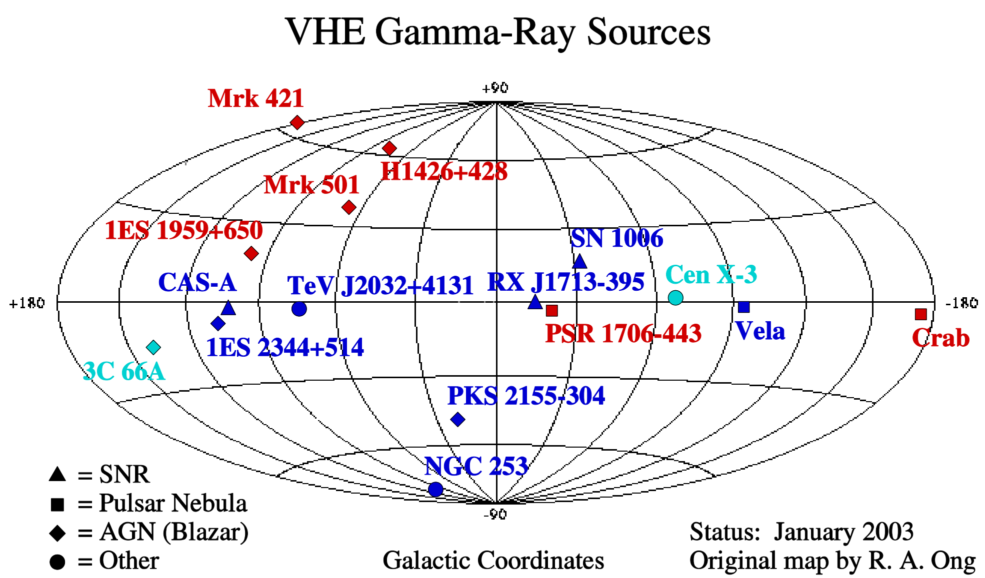
Gamma-Ray Sources





Satellite observations

100 MeV < E < 10 GeV

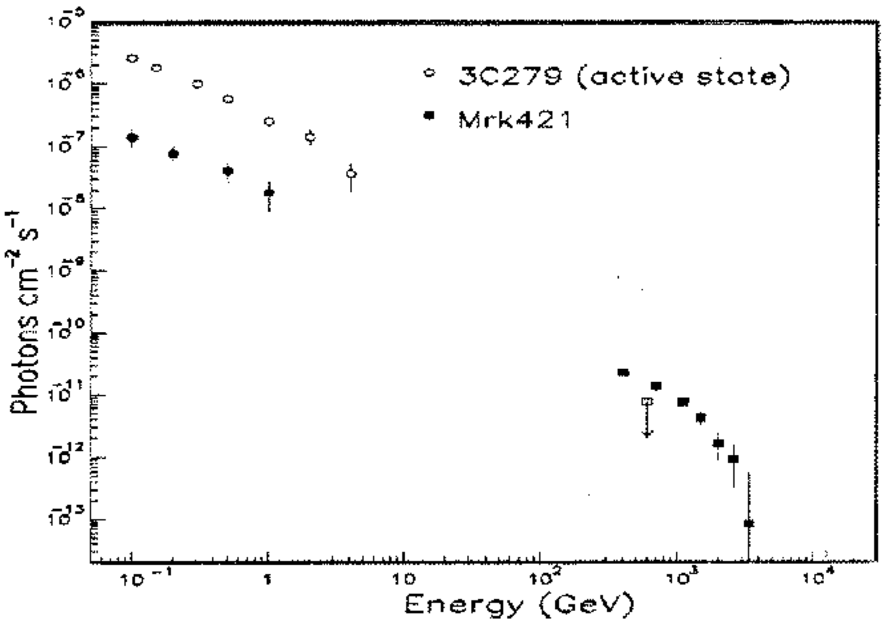
Ground-based observations

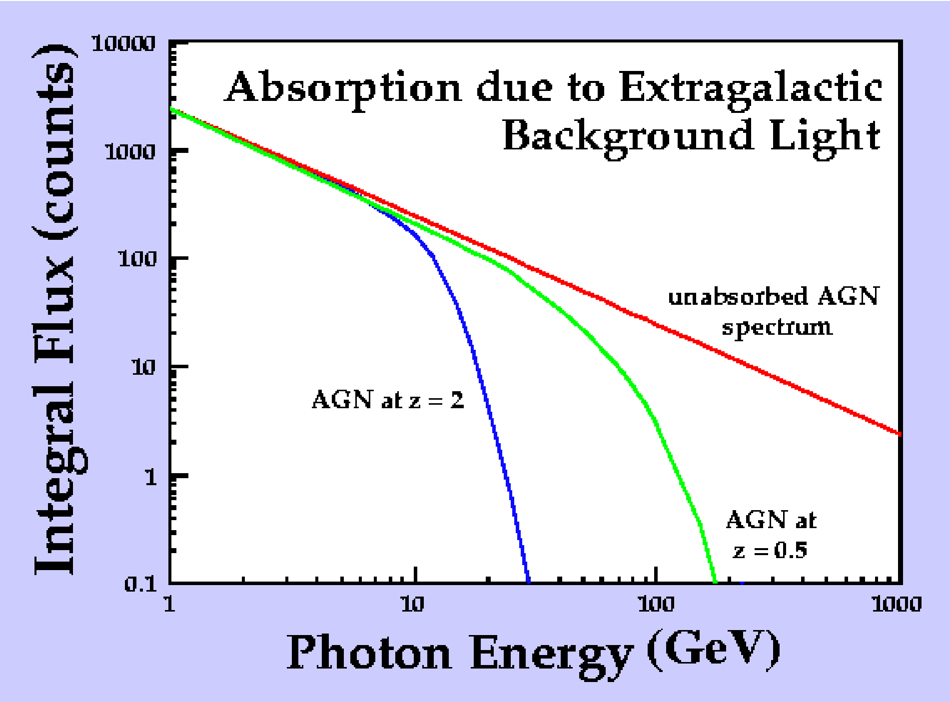
E > 250 GeV

Galactic objects: plerions, pulsars, supernovae

Extragalactic objects: AGN (active galactic nuclei), GRB (gamma-ray bursts)

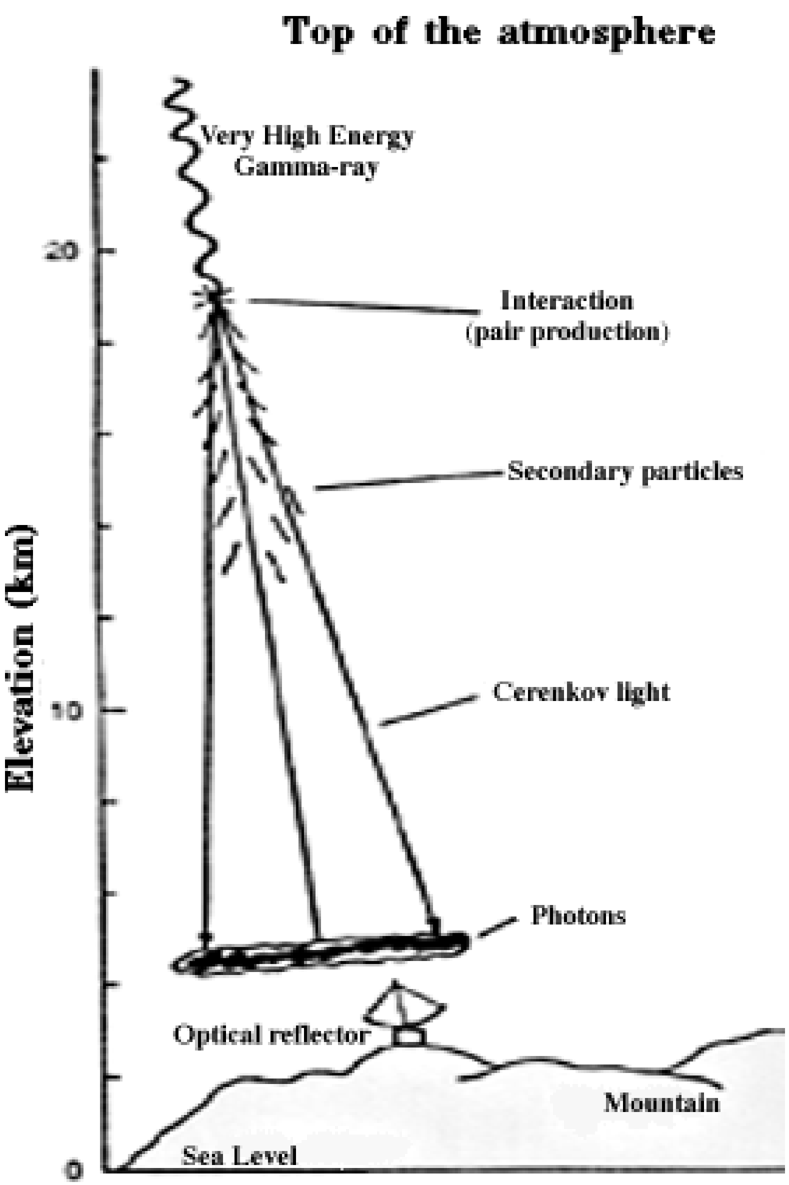
Gap in Spectrum





- Spectral cut-off between 10-250 GeV.
- Perhaps high energy gamma-rays are attenuated by photon-photon interactions due to intergalactic infrared (IR) background.
- IR background determined by nature of galaxy formation and composition of dark matter.
- The measurement of an intrinsic break of the spectrum in the unexplored region could constrain theoretical models of gamma-ray generation within AGNs.

Atmospheric Cherenkov Effect



- Enter earth's atmosphere and interact to produce extensive air showers (EAS) of highly relativistic charged particles.
- Charged particles emit Cherenkov radiation (light pool about 125 m radius at ground level).
- Amount of Cherenkov light proportional to energy of progenitor.
- Density of photons on ground decreases with decreasing energy.
- Difficulties in using atmospheric Cherenkov technique at energies below 100 GeV:
  - Significant fluctuations in the photon yield on the ground caused by variation in the position of first interaction of the gamma-ray.
  - Cherenkov photon yield drops off rapidly with increasing zenith angle due to atmospheric attenuation.

Energy Threshold

$$E_{TH} \propto \sqrt{\frac{\phi_{BKG}\Omega\tau}{A\eta}}$$

ϕ_{BKG} : photo flux of night-sky background,

Ω : field-of-view,

τ : trigger gate width,

A : mirror collection area,

η : efficiency for converting photons striking heliostat into photoelectrons in PMT (technology limited).

- WHIPPLE observatory has lowest energy threshold (about 250 GeV) for 78 m^2 mirror.
- Energy threshold limited by total mirror collection area:

  large mirrors → low energy threshold.
- Several approaches:
  - Multiple large reflectors, each one having its own camera array.
  - One (or more) large fixed hemispherical mirrors ("bowls").
  - Use large mirror area available at solar power plants.

National Solar Thermal Test Facility

Located at Sandia National Laboratories on grounds of Kirtland Air Force Base, 15 km southeast of Albuquerque, New Mexico.

STACEE Collaboration and History

Group of about 16 Scientists

- University of Alberta/TRIUMF

  D.M. Gingrich
- University of California, Santa Cruz

  L.M. Boone, D.A. Williams
- Barnard College, Columbia University

  D. Bramel, R. Mukherjee
- McGill University

  P. Fortin, D.S. Hanna, J. Kildea, T. Lindner, C. Mueller, K. Ragan, C.G. Theoret
- University of California, Los Angeles

  J. Carson, A. Jarvis, J.A. Hinton, R.A. Ong, J.A. Zweerink
- Case Western Reserve University

  C.E. Covault, R.A. Scalzo

History and Future

1994: Discussed instrumenting a solar power plant for astrophysics.

1994-95: Tests to detect Cherenkov light at Barstow in California.

1996: Tests to detect Cherenkov light at Sandia in New Mexico.

1996-98: Built $\frac{1}{2}$ a detector at Sandia in New Mexico.

1998-99: Took data with $\frac{1}{2}$ detector and detected Crab nebula.

1999-01: Completed $\frac{3}{4}$ detector.

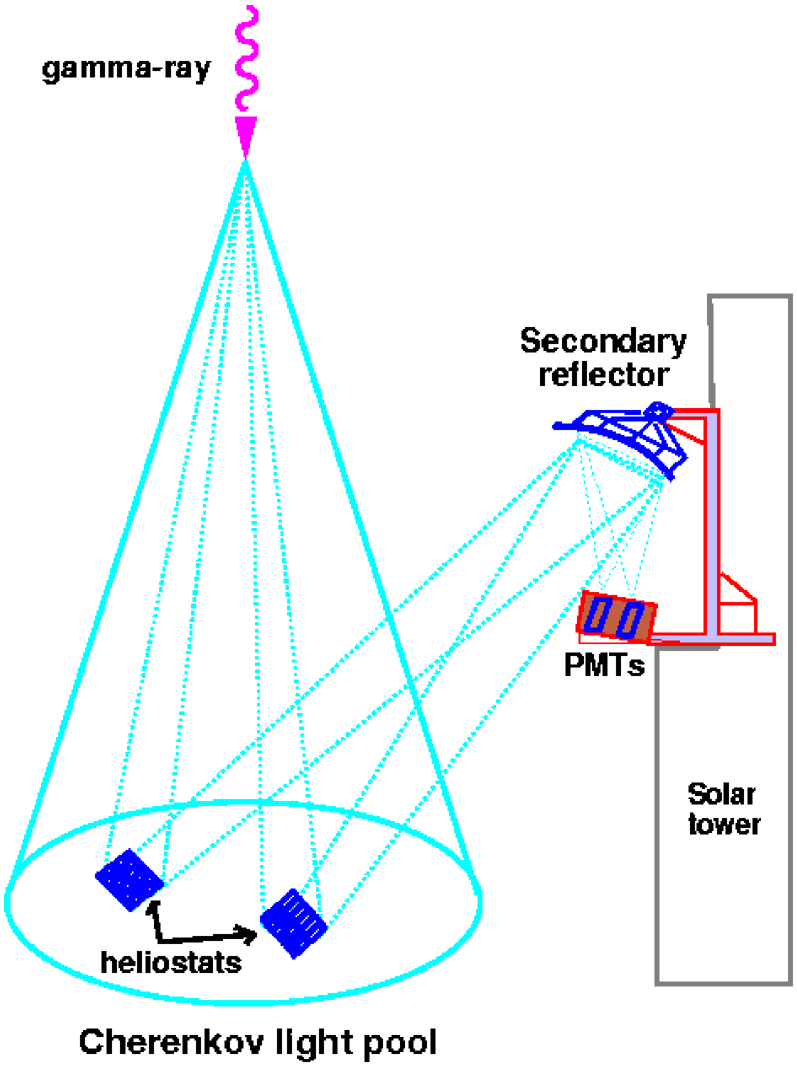
2000-01: Took data with $\frac{3}{4}$ detector and detected Mrk 421

2001-02: Completed full detector.

2002-04: Observations and upgrades.

2004-06+: Observations.

Solar Tower Concept

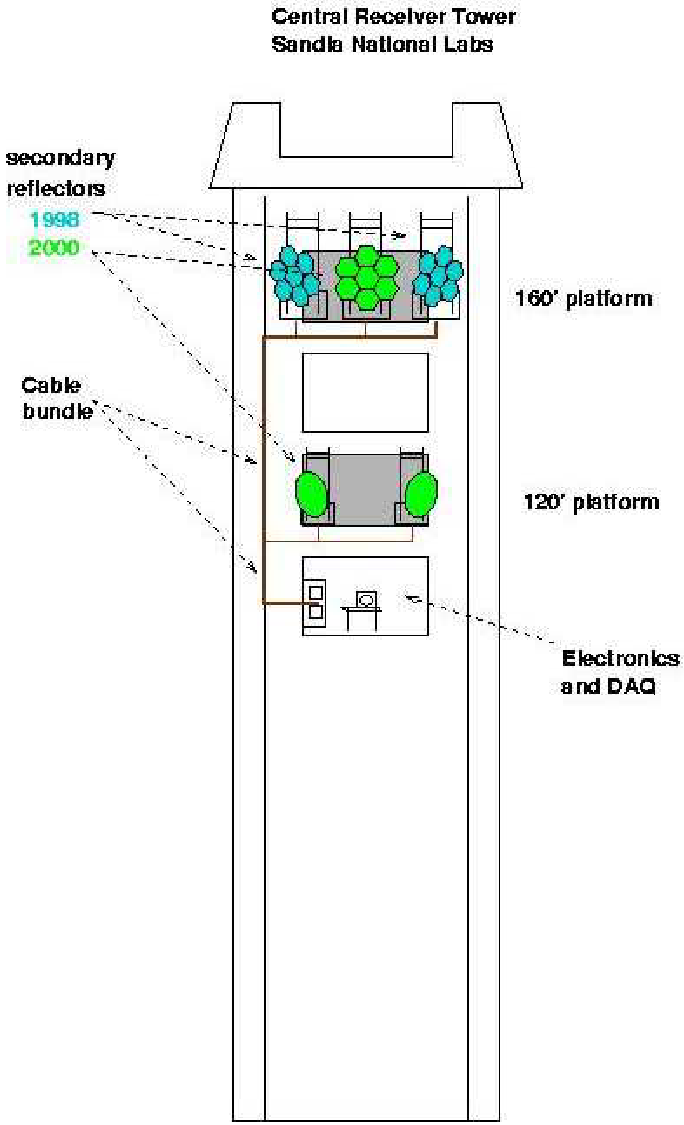


- Field size 150 m × 300 m, using 64 heliostats.
- Cherenkov light from showers in atmosphere is reflected by heliostats to secondary mirrors on the central receiving tower.
- Secondary mirrors focus light onto photomultiplier tube cameras, with light from each heliostat directed to a separate photomultiplier tube.

Heliostats (large steerable mirrors)

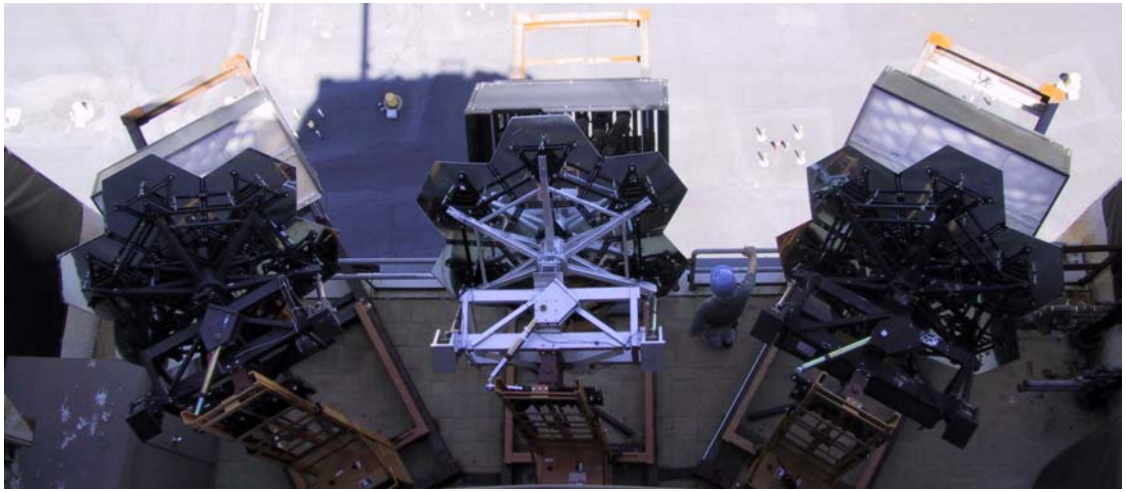
- Each mirror 37 m^2: 25 square mirror facets (1.2 m on a side)
  - ➔ about 2300 m^2 total area.
- 80% reflectivity for visible light.
- Each heliostat accurate to 0.05 degrees (tracking stability).
- Average heliostat field of view is 0.7 degrees.

Solar Tower



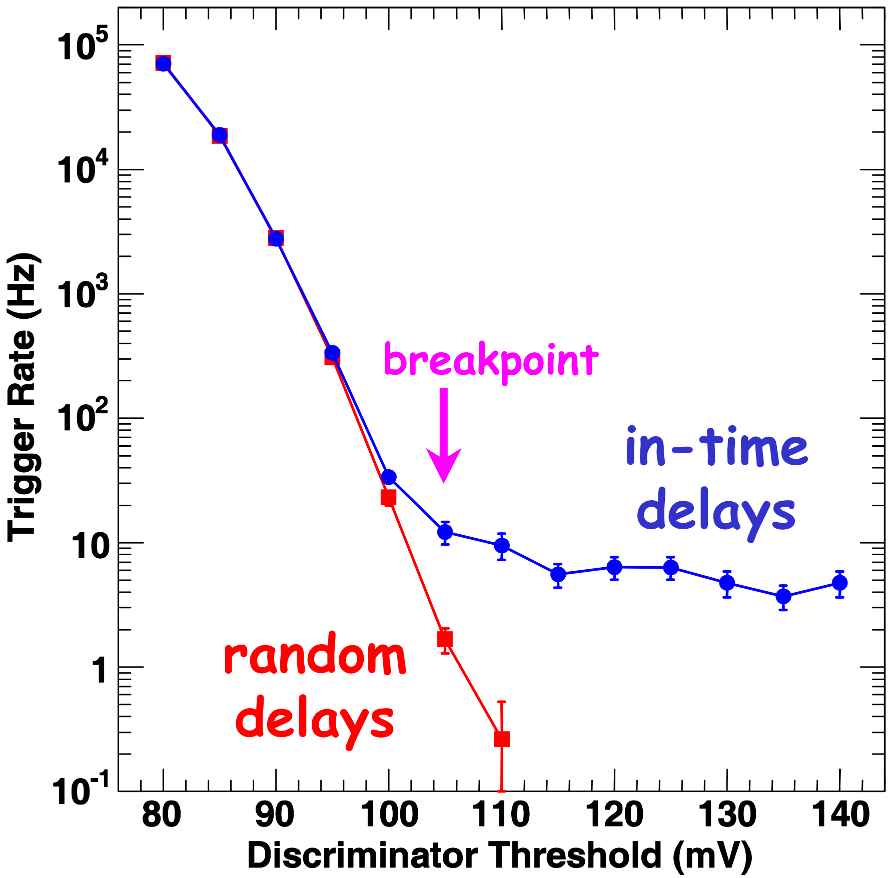
Central Receiver Tower
Sandia National Labs
secondary
reflectors
1998
2000
160' platform
Cable
bundle
120' platform
Electronics
and DAQ

Secondary Mirrors and PMT Camera



- Secondary mirrors image light onto PMTs (each PMT sees light from one heliostat).
- Optical spot size 1 cm
- Optical cross-talk (light from more than 1 heliostat reaches PMT)
  - < 5% (negligible after timing cuts),
  - no cross-talk between non-adjacent heliostats.

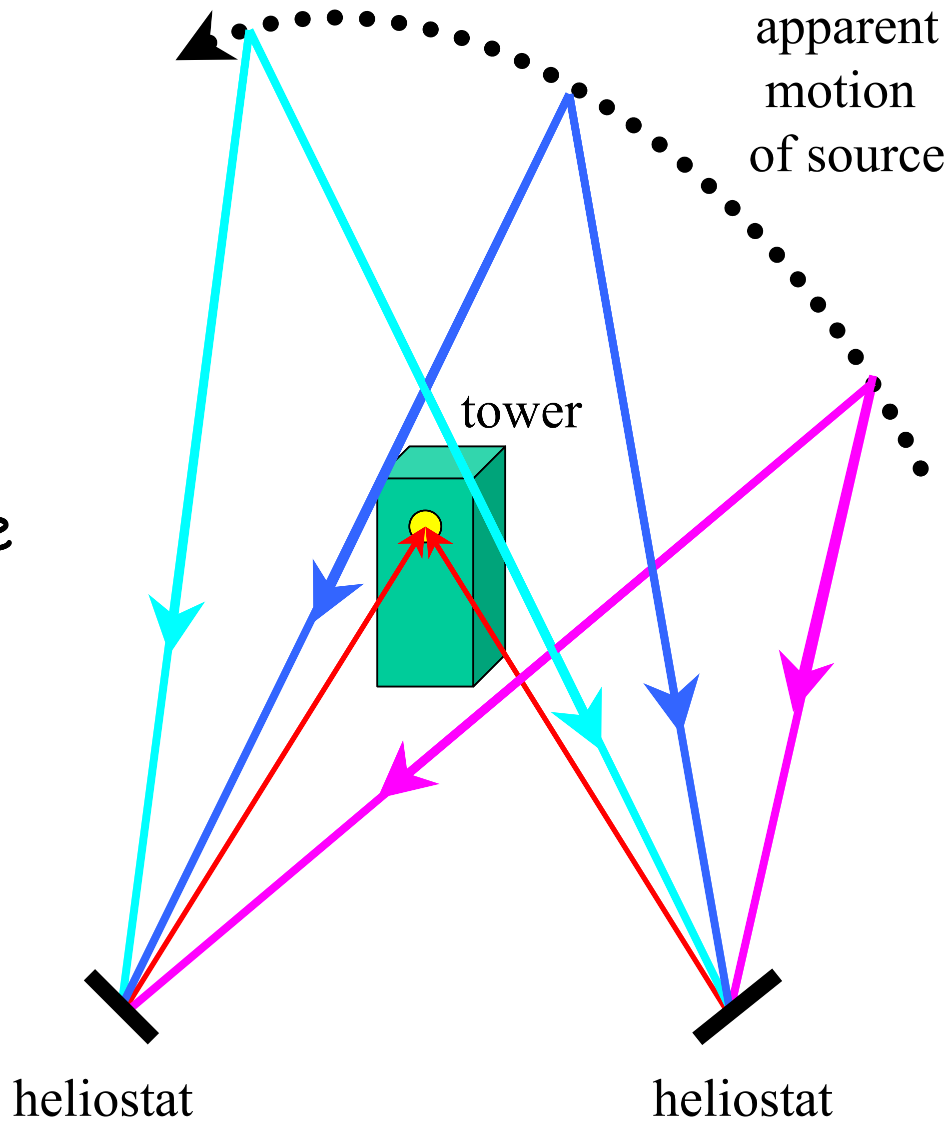
Front-End Discriminators



- In-time delays appropriate for Cherenkov triggers.
- Random delays show contribution from accidental coincidences caused by night-sky background.
- Set discriminator thresholds 15-20 mV above breakpoint.

Programmable Delays

- Form coincidence over 64 heliostats.
- Propagation times of the reflected light from the heliostats to the central tower vary, depending on the heliostat position, the shower inclination angle, and apparent motion of source across the sky.
- Delay signals in pipelines with dynamically changing delay times.



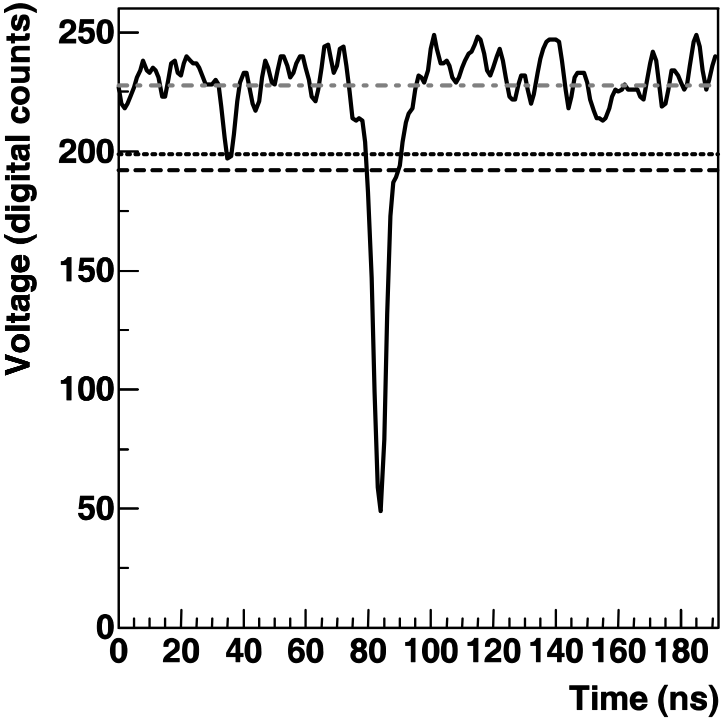
Delay and Trigger System

- Custom-built VME delay and trigger system based on FPGAs.
- Delays in 1 ns steps for a range which allows 45° of zenith.
- Two-level trigger system:
  1) 8 PMTs assigned to a subcluster,
  2) 8 subclusters in global trigger.
- Select multiplicity based on rejection of hadronic showers using Monte Carlo simulations.
- Programmable multiplicity, example:
  1) 5 of 8 PMT in a subcluster,
  2) 5 of 8 subclusters in trigger.

Cluster board (1 of 8)

FADC System

- Reconstruct energy and direction of primary gamma ray.
- Allows various new methods to reject cosmic rays while retaining gamma-ray initiated events.
- 1 GS/s with 8-bit resolution and dynamic range 1 V.



Summary

- STACEE is a complete ground-based Cherenkov wavefront sampling gamma-ray telescope.
- Uses heliostat mirrors of a solar energy research facility.
- Cherenkov light from air showers collected onto a set of 64 heliostats with collective area of 2300 m^2.
- STACEE achieves a low-energy threshold of about 100 GeV.
- Complete detector operating since the spring of 2002.
- Data acquired on Crab nebula, and the AGNs 3C66A, OJ+287, W-Comae, Markarian 421, H1426.