CACTUS

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Outline

- Solar Two facility and CACTUS.
- Instrument:
  -250 channel (effective) camera.
- Simulations and Calibrations
  -optics & noise
  -energy response
  -Crab
- The Dark Matter problem & Draco
  -Data & Preliminary analysis.

Future prospects - Dwarf spheroid survey.

The Solar 2 Heliostat Array

Located 15 miles outside Barstow, CA

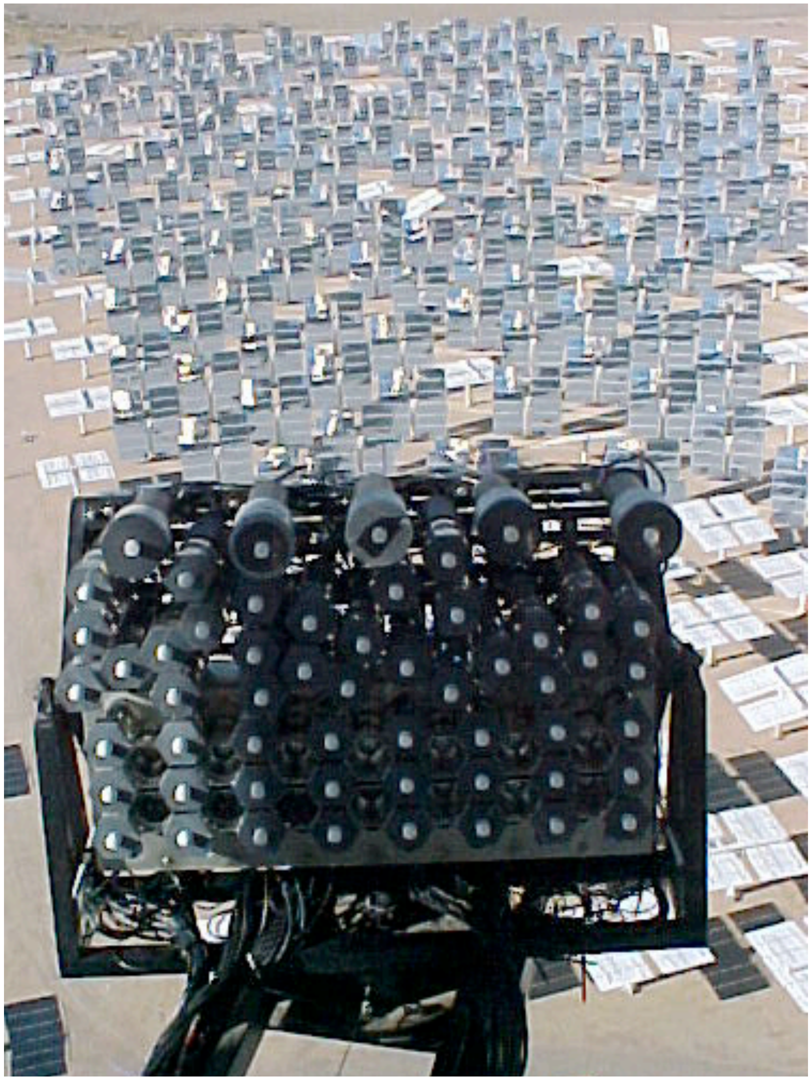
Over 1,900 42m^2 heliostats. The largest array in the world.

We have ~160 heliostats in the FOV of our camera.

Collection area = ~64,000 m^2.

80 channel camera

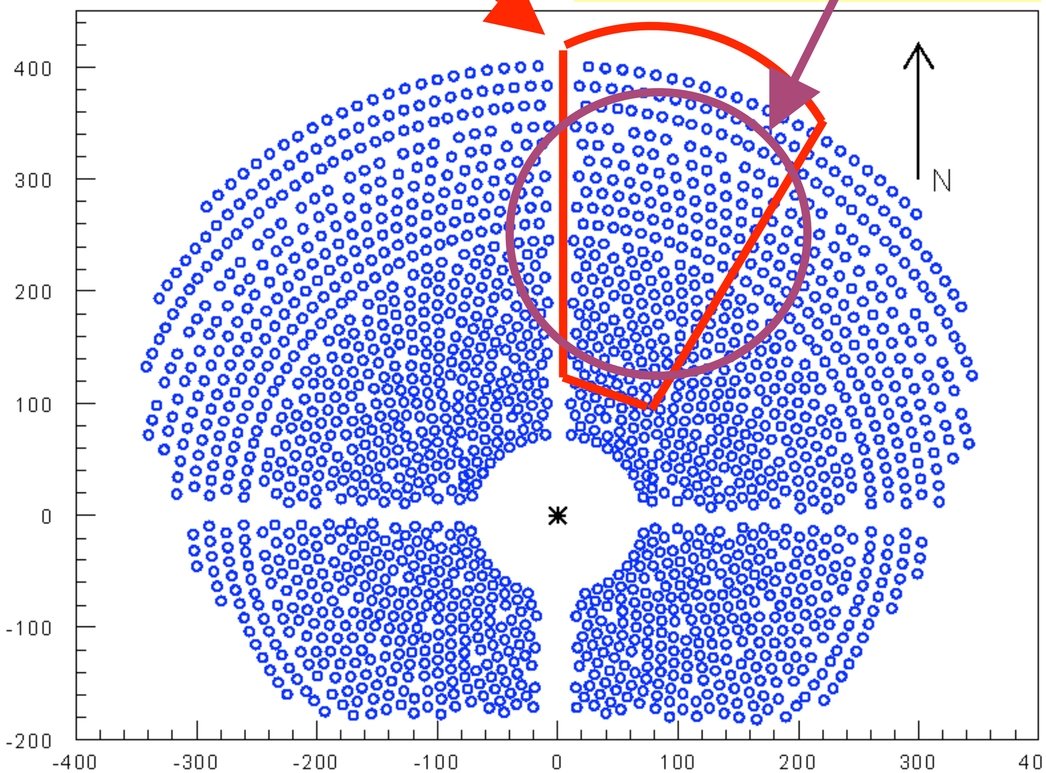
Heliostat Field



Part of the field being used. 160 heliostats* available. 140 used in this campaign.

*limited by aperture

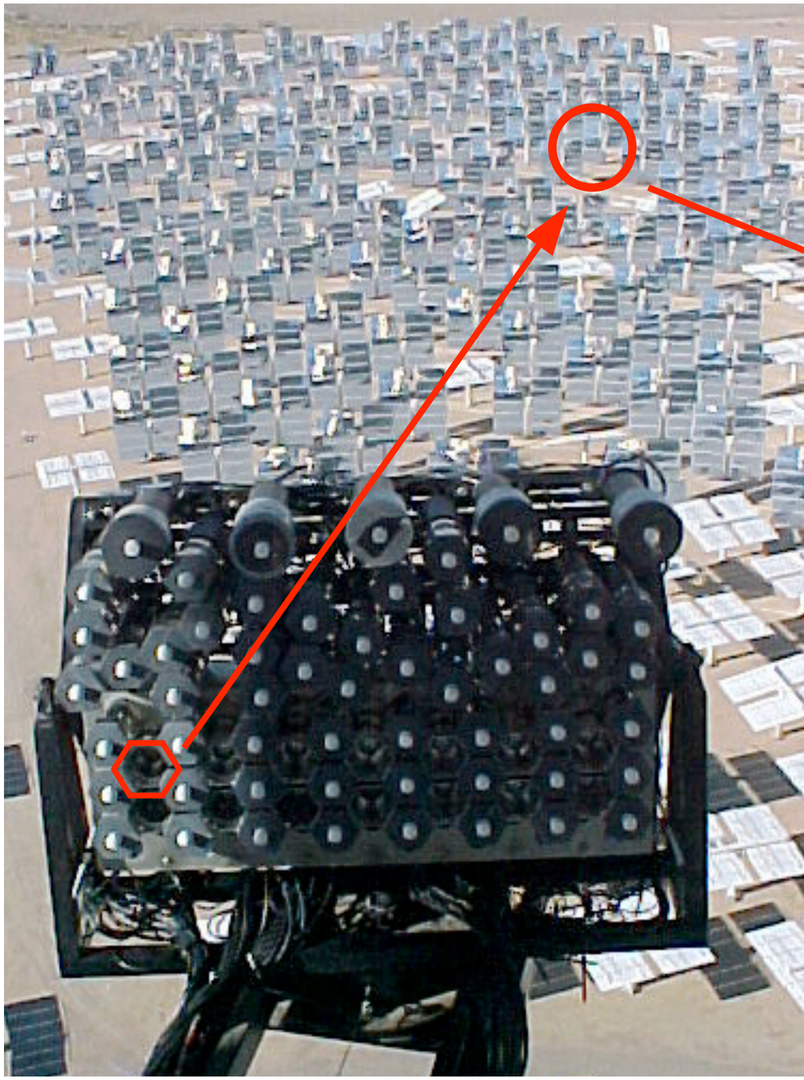
CACTUS is capable of collecting nearly the entire Cherenkov light pool

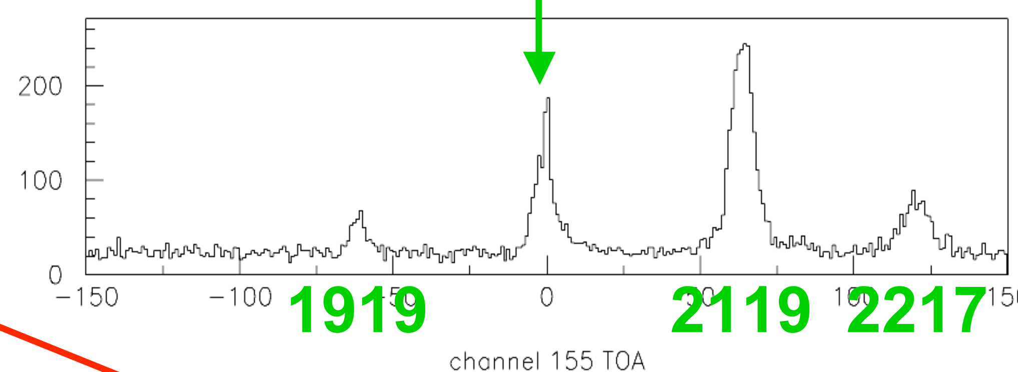


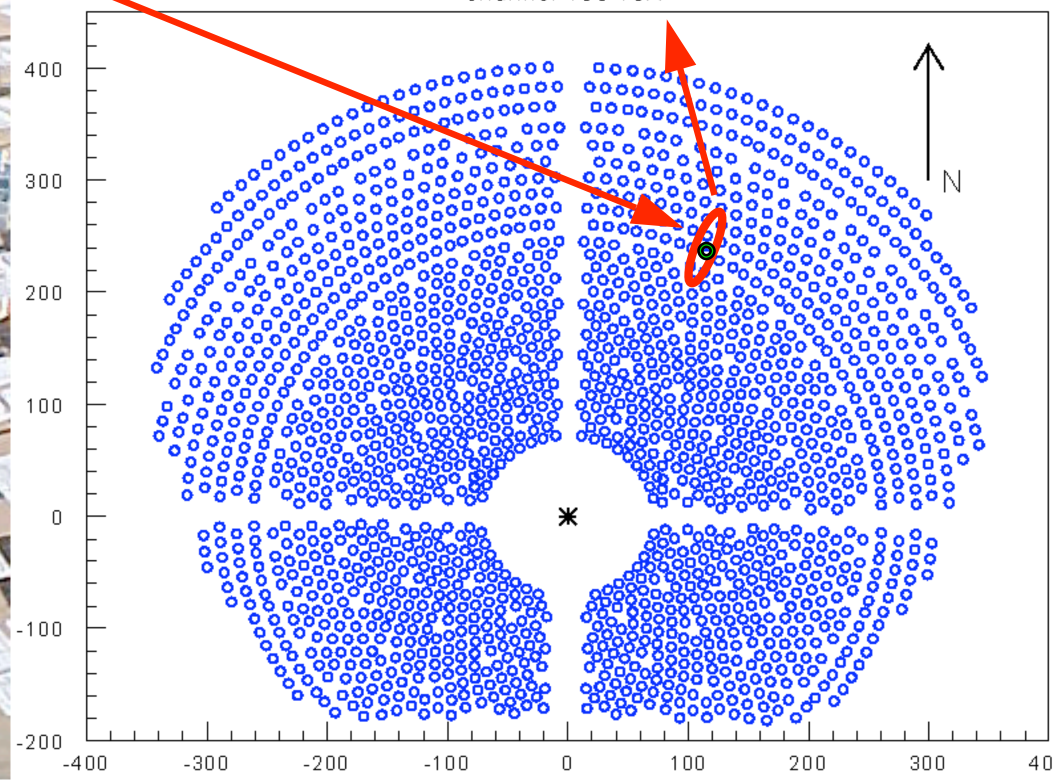
80 channel camera

Heliostat Field

Time expected for heliostat 2017.







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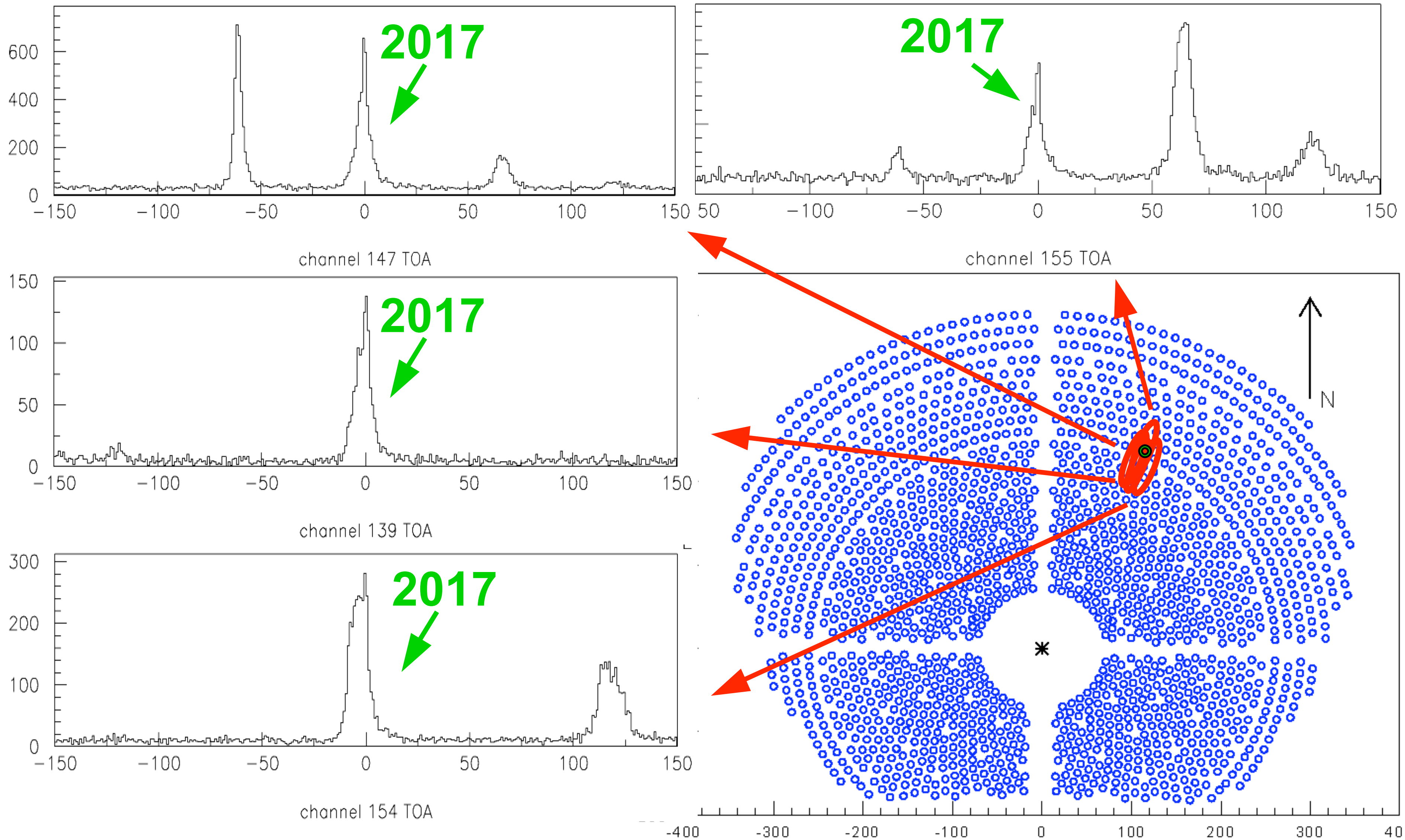
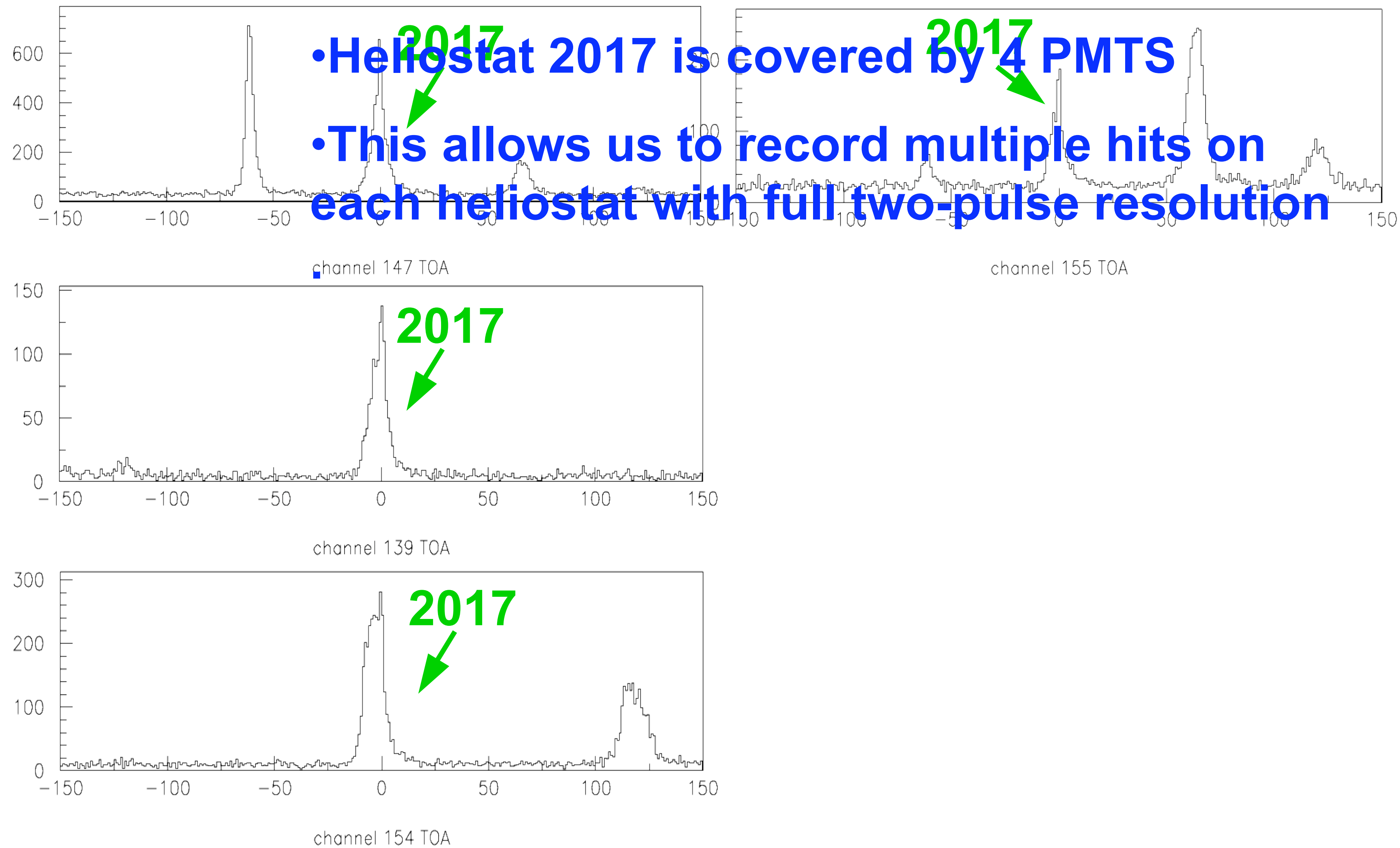
Channel Multiplicity



Heliostat Multiplicity

- **Heliostat 2017 is covered by 4 PMTS**
- **This allows us to record multiple hits on each heliostat with full two-pulse resolution**



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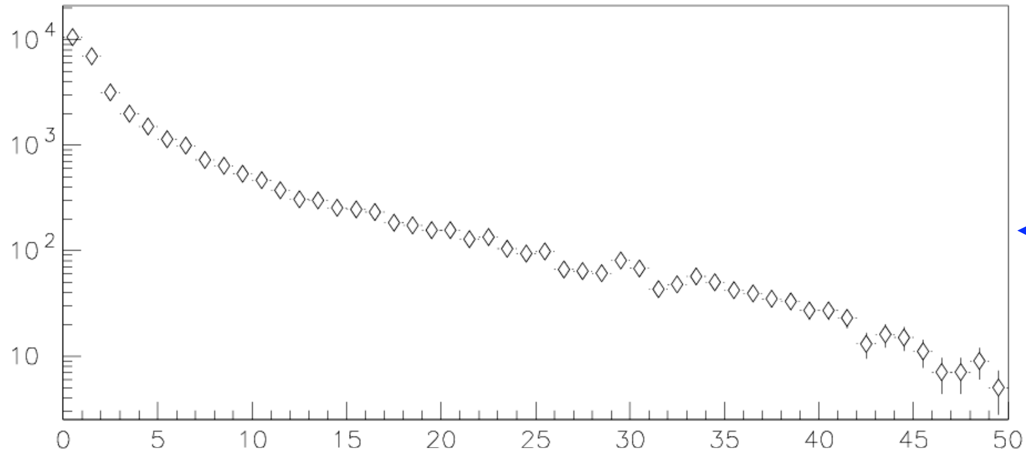
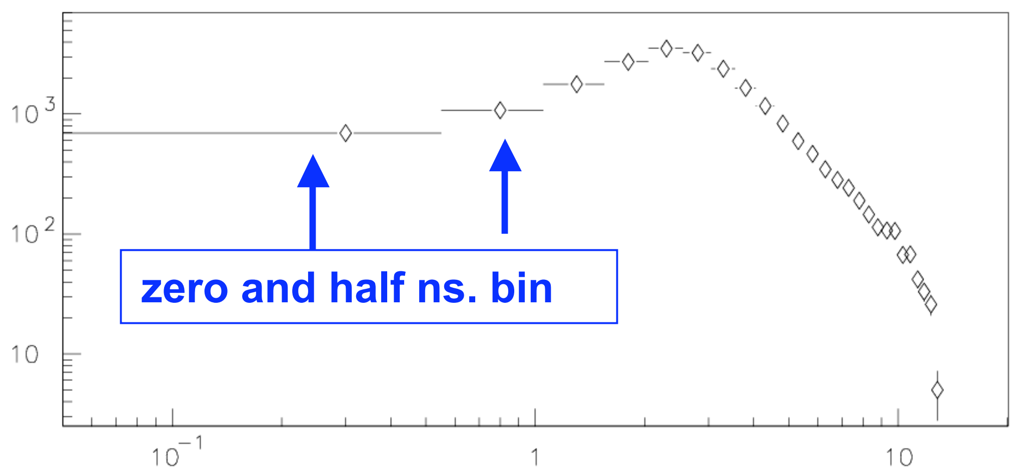
Heliostat Multiplicity



Number of Helios with Multiple Hits per Event

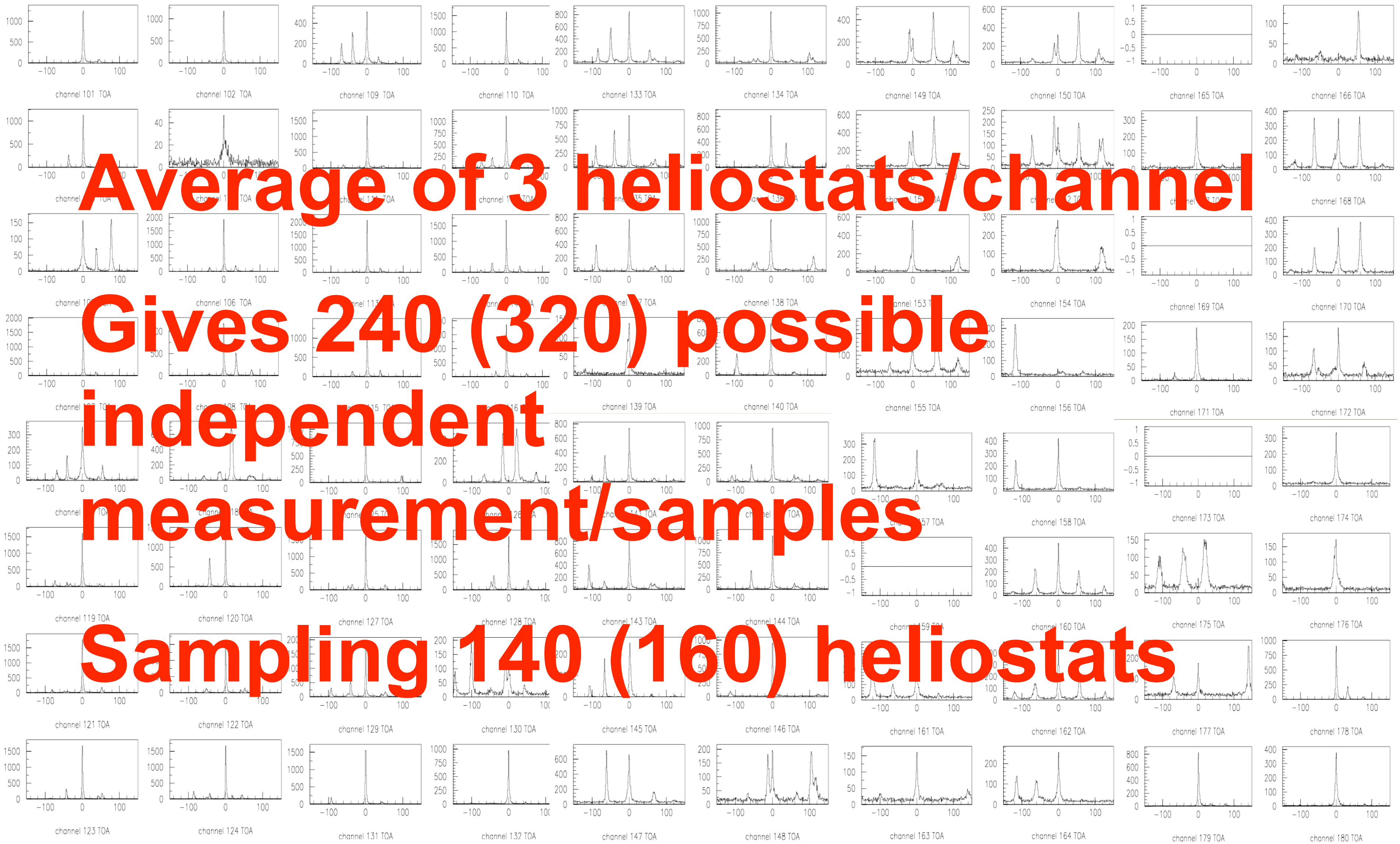
Most events contain multiple hits in each heliostat.



Average Time between multiple hits (ns)

We can record multiple hits with 0.5 ns resolution without any pile-up.

Heliostat Multiplicity

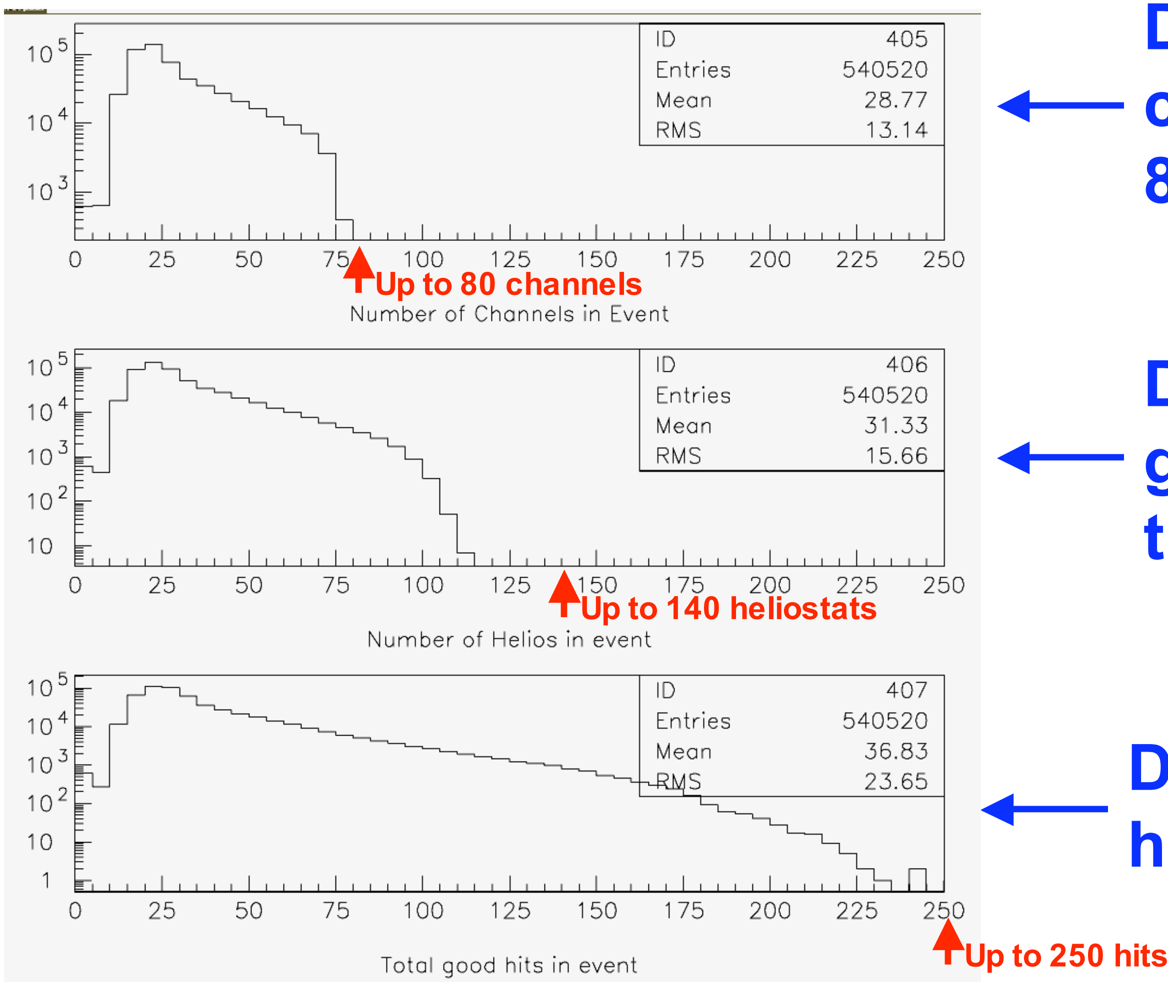


Average of 3 heliostats/channel

Gives 240 (320) possible independent measurement/samples

Sampling 140 (160) heliostats

Heliostat Multiplicity



Dynamic range if 80 channels mapped to 80 heliostats.

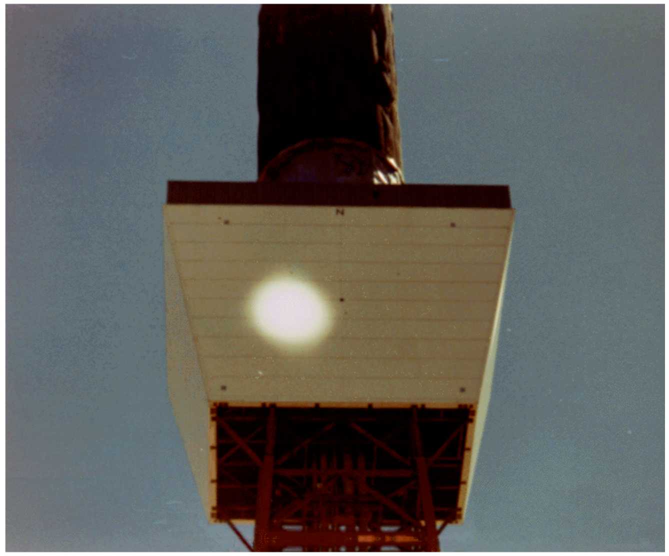
Dynamic range gained by using more than 80 heliostats.

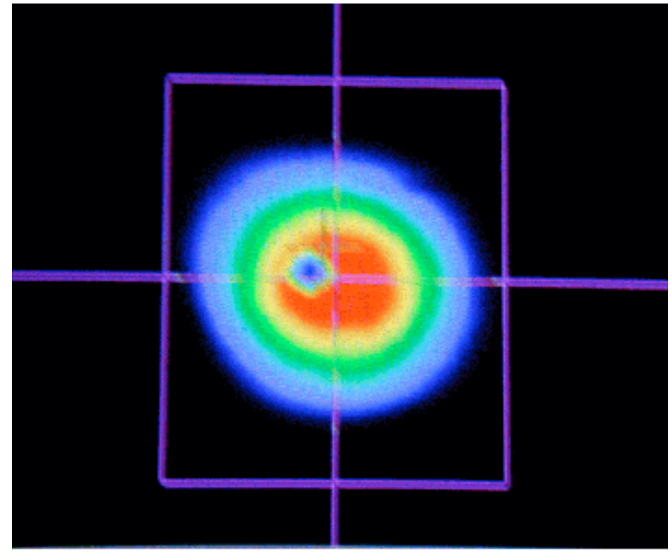
Dynamic range using heliostat multiplicity.

Calibrations and Simulation

Heliostat Alignment and MC Calibration

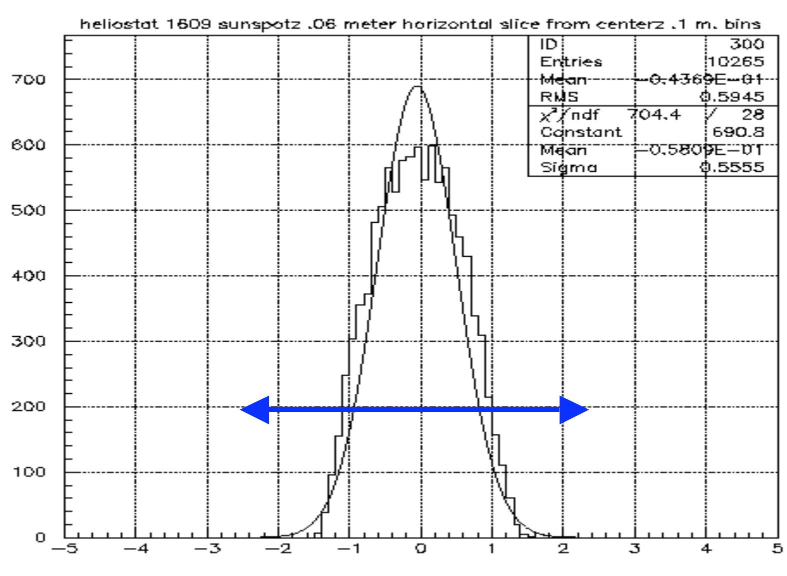
The heliostats are aligned using a sunspot projected on the tower face.
An infrared CCD camera is used to measure the sun spot and maximize the brightness at the

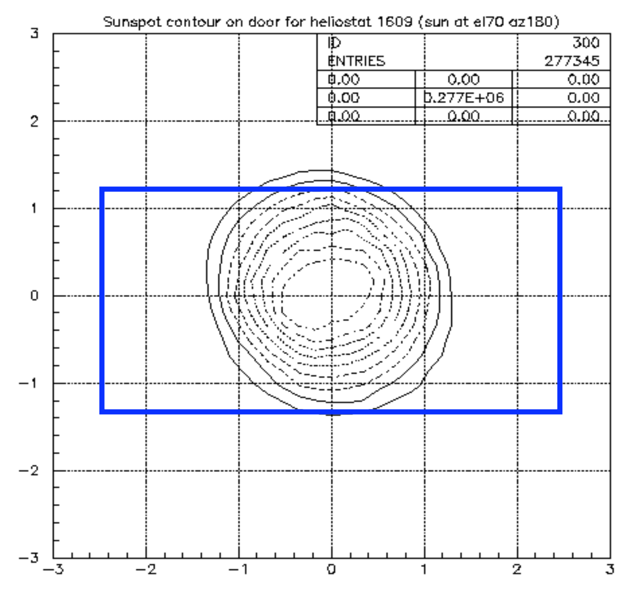




Simulated Sunspots

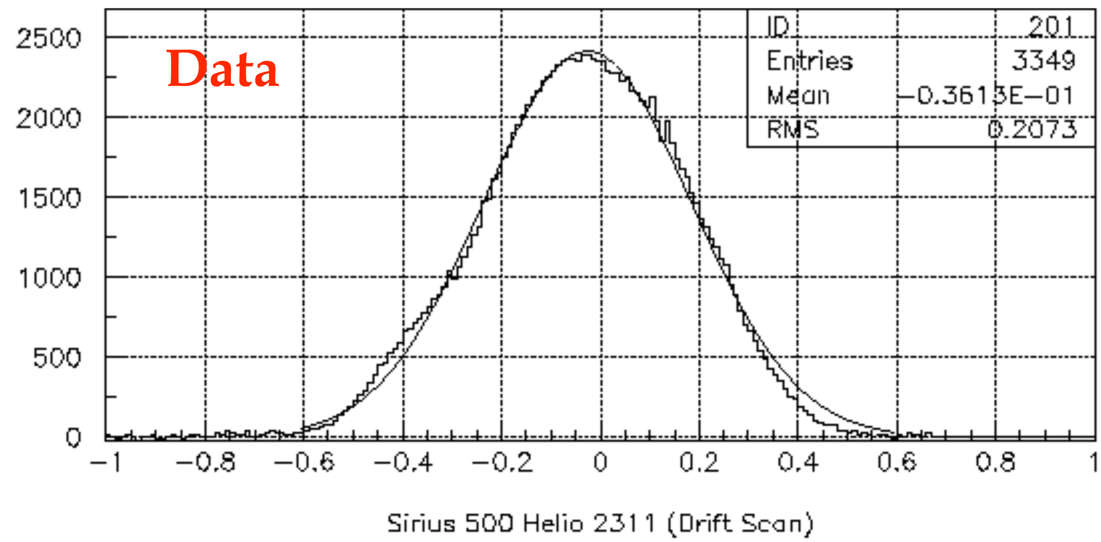
Heliostat facet parameters were optimized to match the CCD images

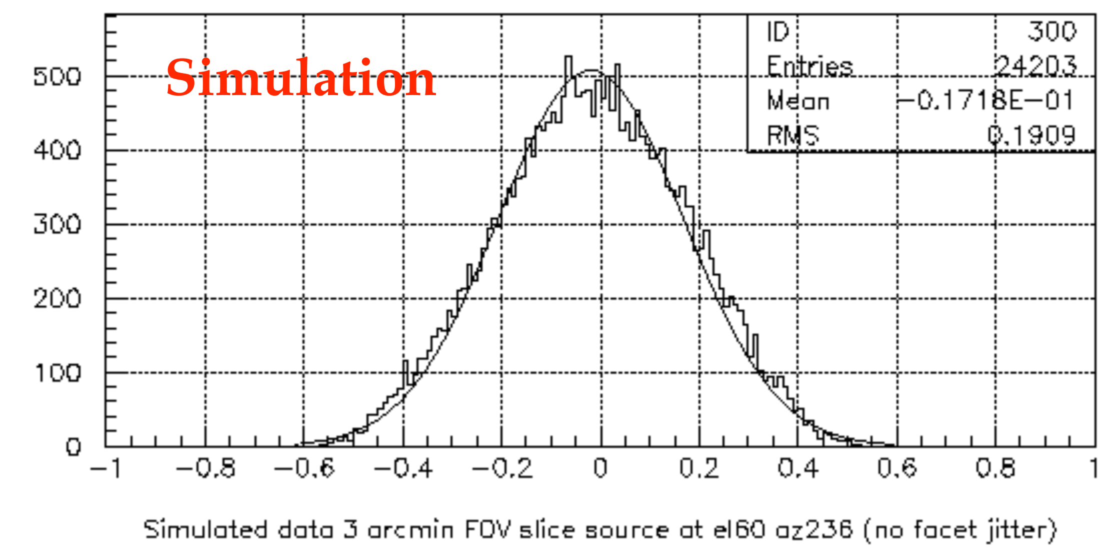




Calibrations and Simulation

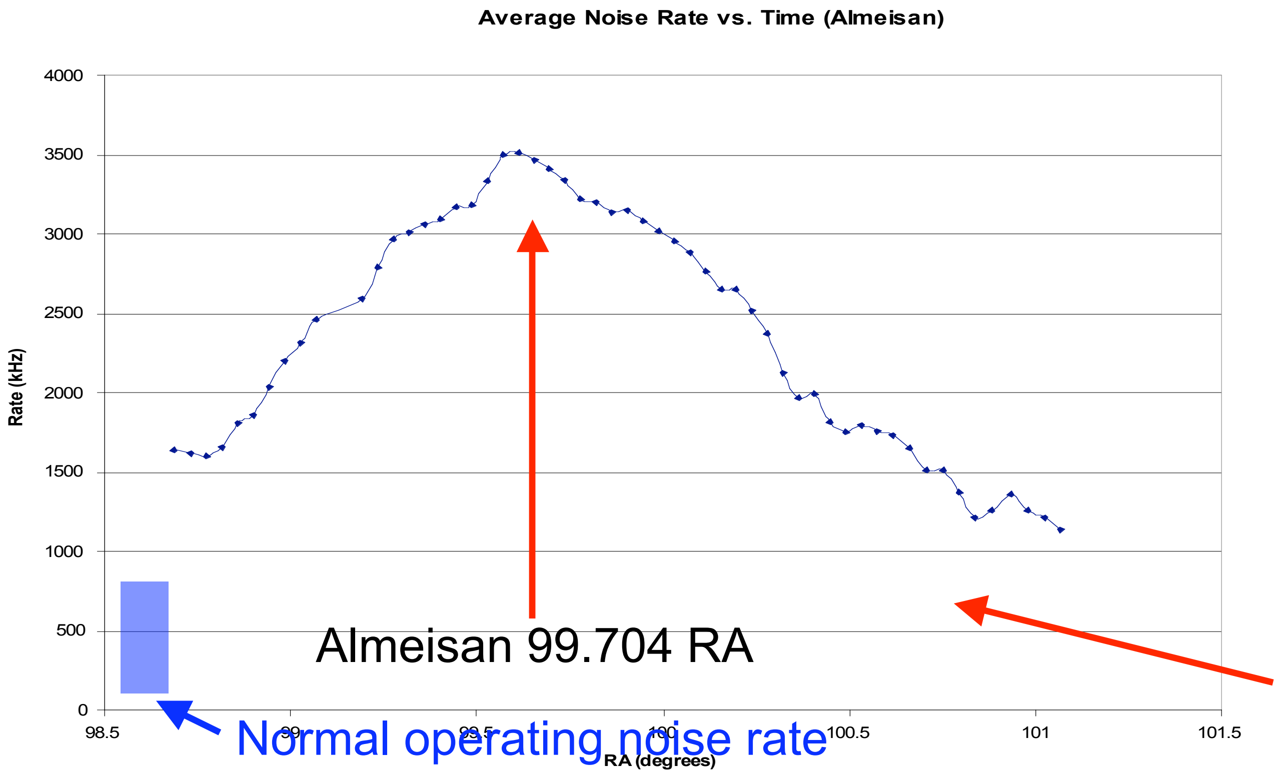
Calibrating with starlight: Drift scan of Sirius





Drift scan of Sirius across one heliostat compared with a detailed simulation of all the optical elements involved.

Almeisan Noise Drift Scan

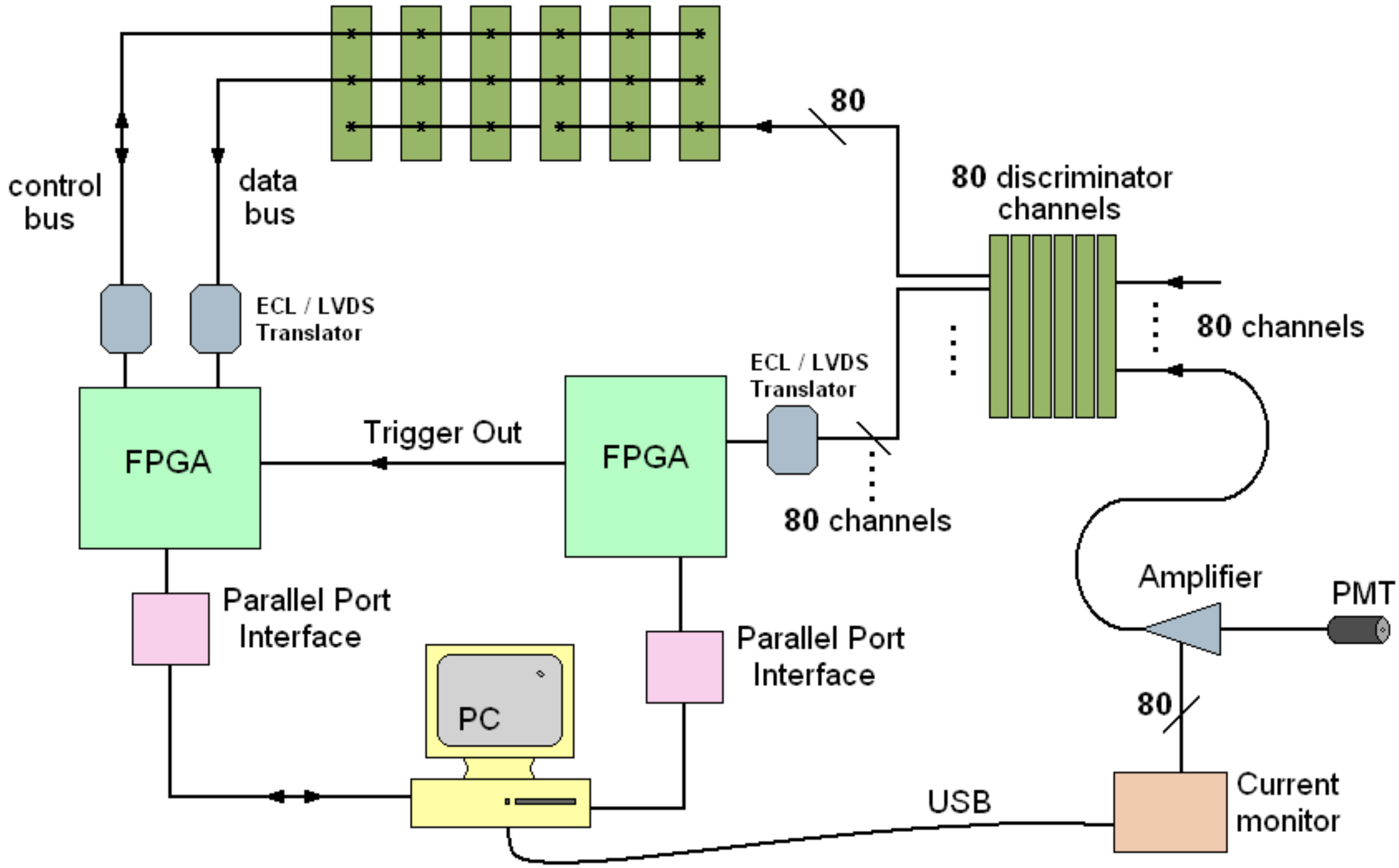


Background Noise Rates as the star Almeisan drifts across our field of view.

Rates are calculated from noise regions of 2 μsec tdc window.

We are within normal noise rates 1 degree from a neighboring star.
(Almeisan is magnitude 7)

Electronics Chain



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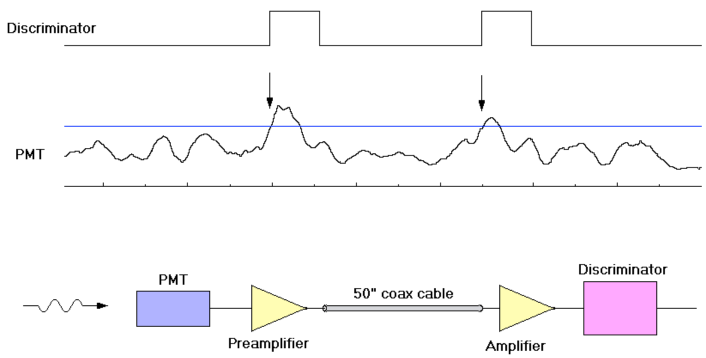
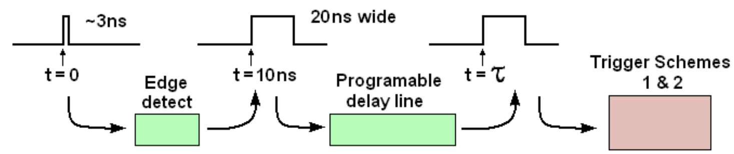
Electronics Chain and Trigger

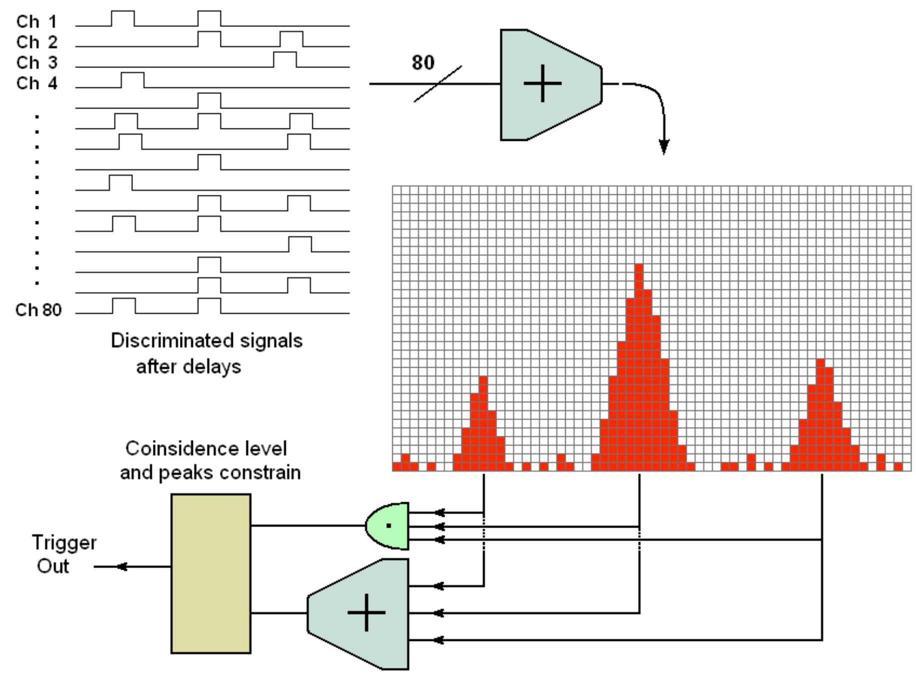


Analog input stage



Trigger Scheme 1: Add all 80 channels and triggers at a given coinsidence level.

Trigger Scheme 2: Add all 80 channels and look for a pattern of one central peak with two side peaks, then it ask for a coinsidence level to trigger.

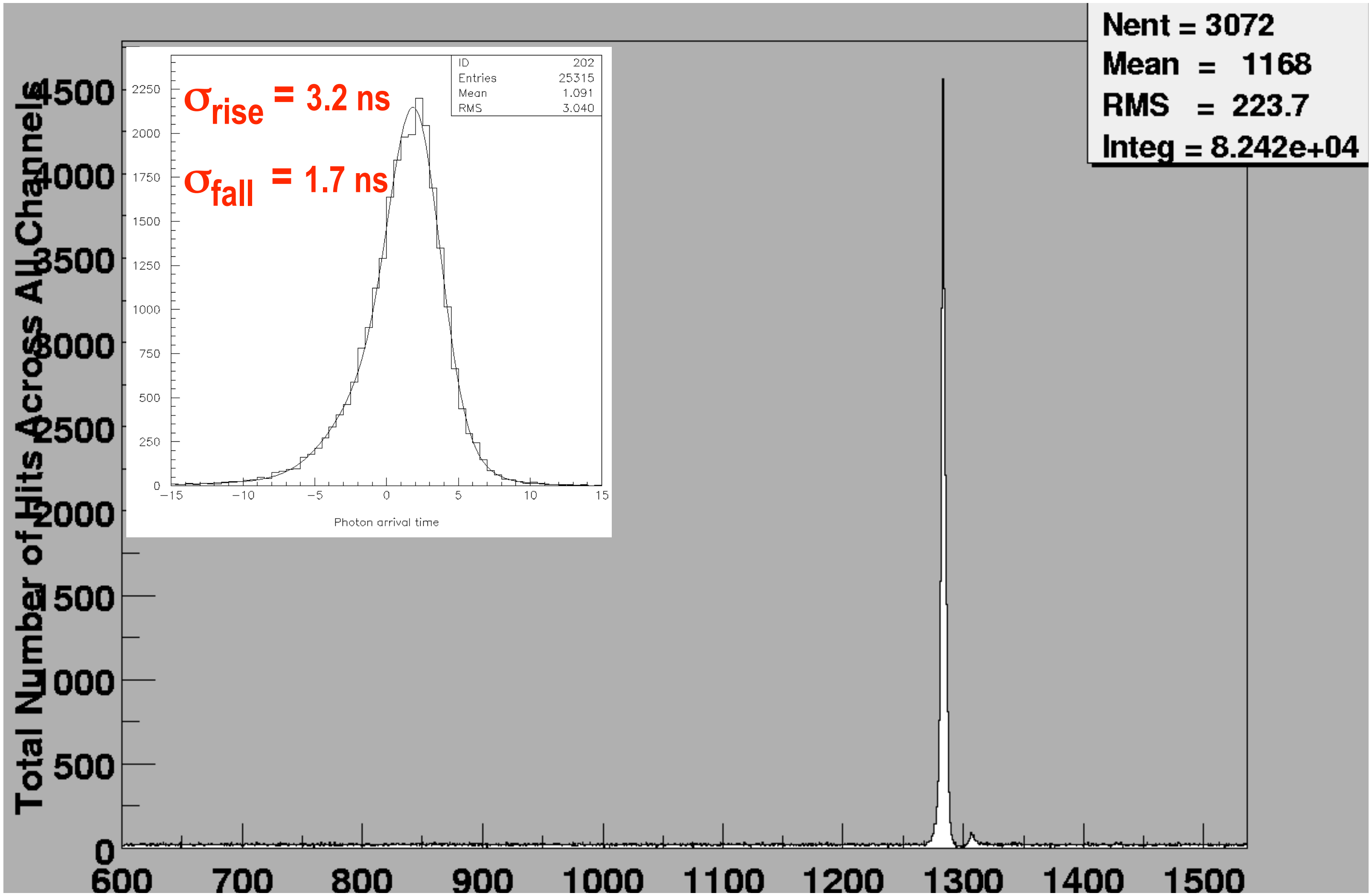


Trigger decision schemes. An FPGA based system allows us to implement several types of trigger.

Data this season was taken with trigger scheme 1, a simple sum of 80 channels.

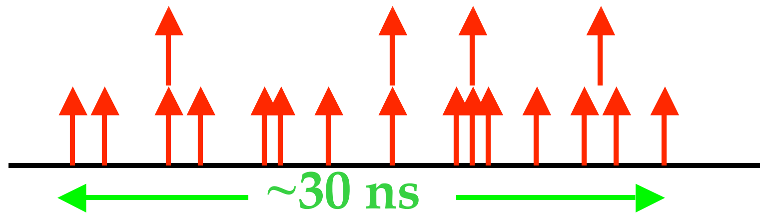
We have also implemented a 3-tap scheme to bring more heliostats into the trigger

Data are recorded in multi-hit TDCs with a time-of-arrival resolution of 0.5 ns. The signal to noise ratio for Cherenkov wavefront detection is excellent.

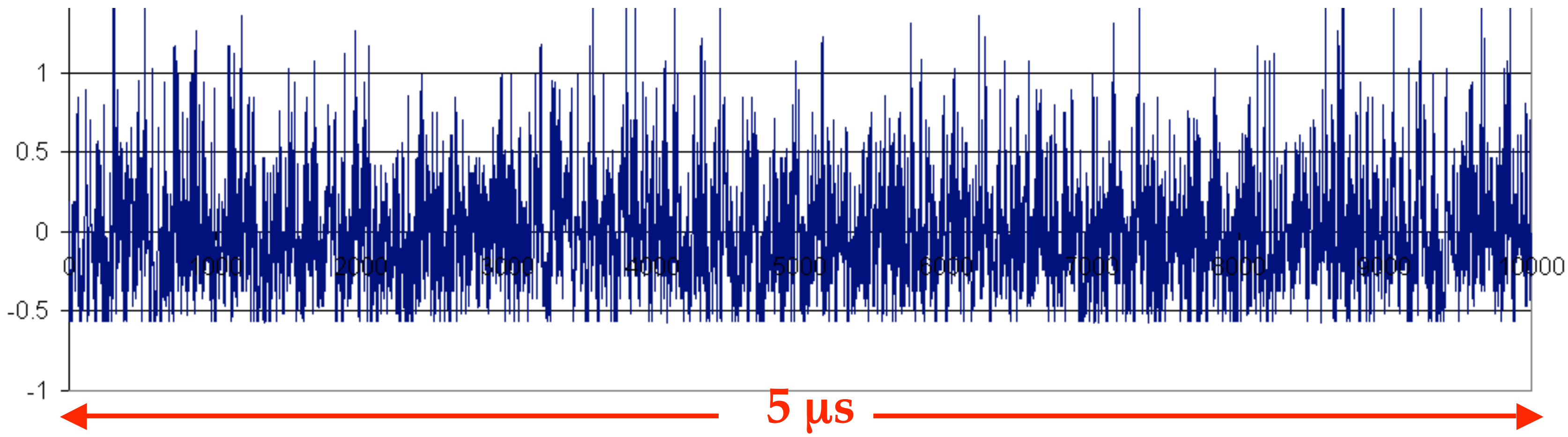


Simulation of Electronic Response

1. Background starlight is simulated by random insertion of photoelectrons. Each p.e. is ascribed a pulse shape based on measurements and with appropriate gain variations.



2. The a.c. component of the piled up p.e.'s is then used as background noise. The agreement with measured noise is excellent.



3. A threshold is applied and digital signals are recorded for comparison with measured rates.

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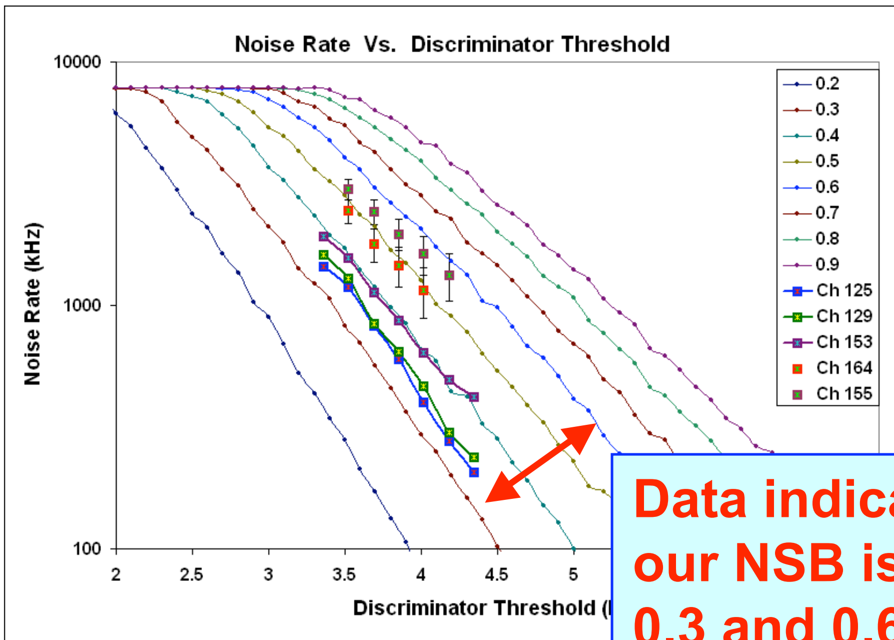
Understanding the NSB

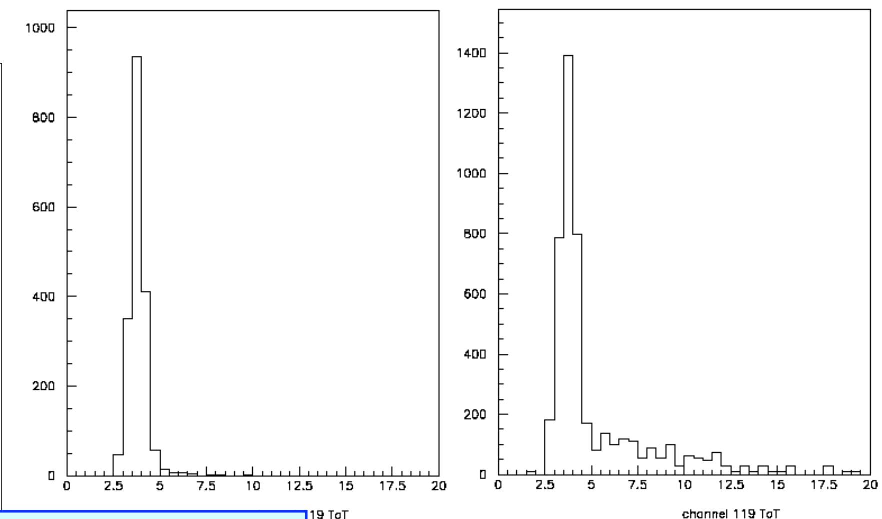
Several simulations were created to understand noise response of our system. Optical and electrical noise were input into a simulated channel and the response was compared to actual data.

… by changing Noise and Gain, we can also match simulated TOT to TOT taken from data.



Data indicates that our NSB is between 0.3 and 0.6 P.E./ns

Figure 1. Five typical channels are being fit to different noise curves

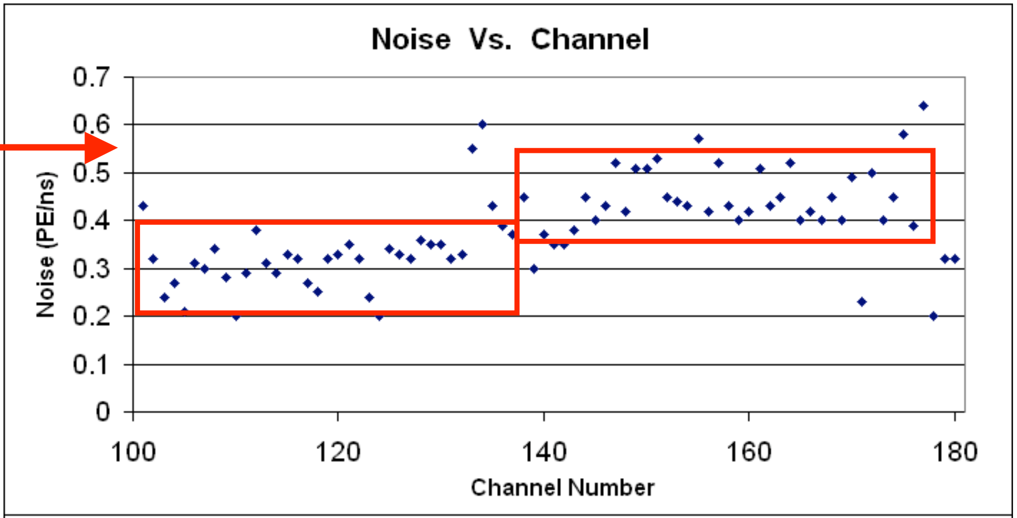


…ting data noise to simulated …ise. The plot on the left is pure …mulated noise, and the plot on …e right is noise plus real showers. For TOT fitting purposes, only the peak at ~3ns needs to be tuned.

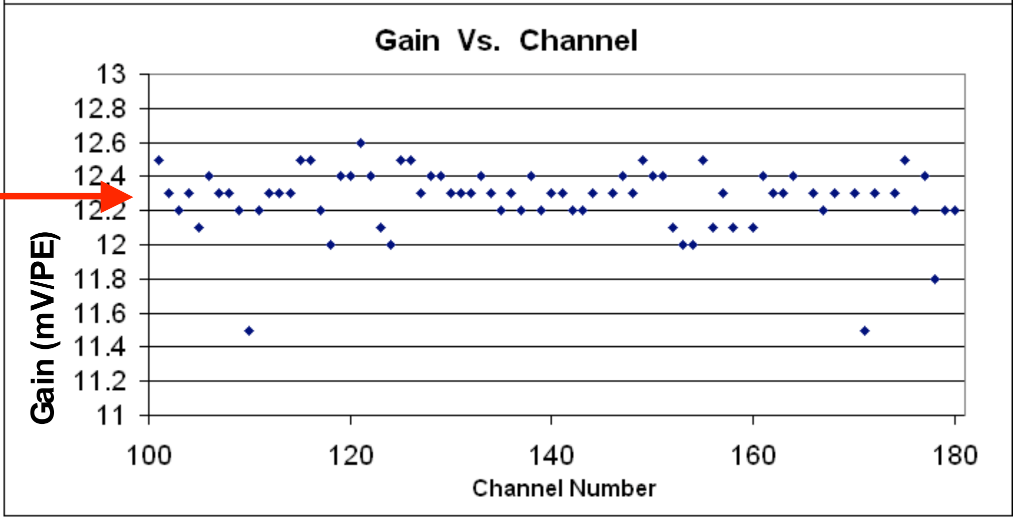
Simulating Night Sky Background

Simulations indicate that our threshold is 4.0 PE

Two levels of noise caused by number of helios entering the channel. The first 32 are nearly 1 to 1 and the rest are close packed

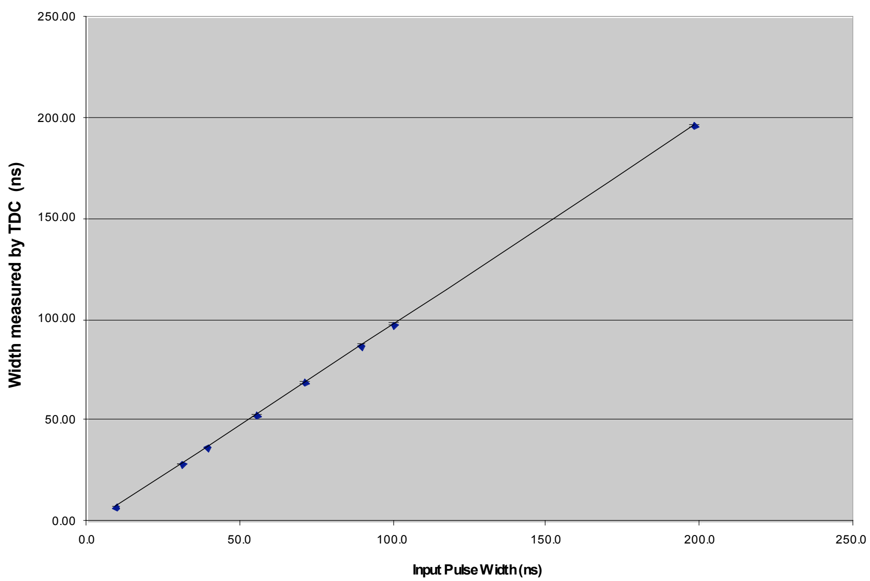


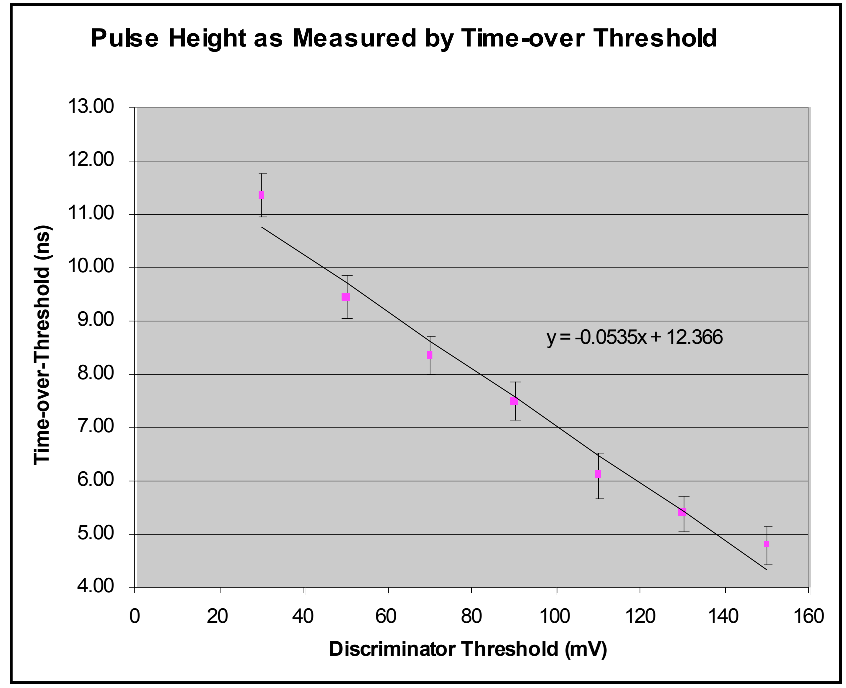
Gains are stable



Fit is to Mkn 421 background which is low compared to the Crab NSB

Time Over Threshold Calibration



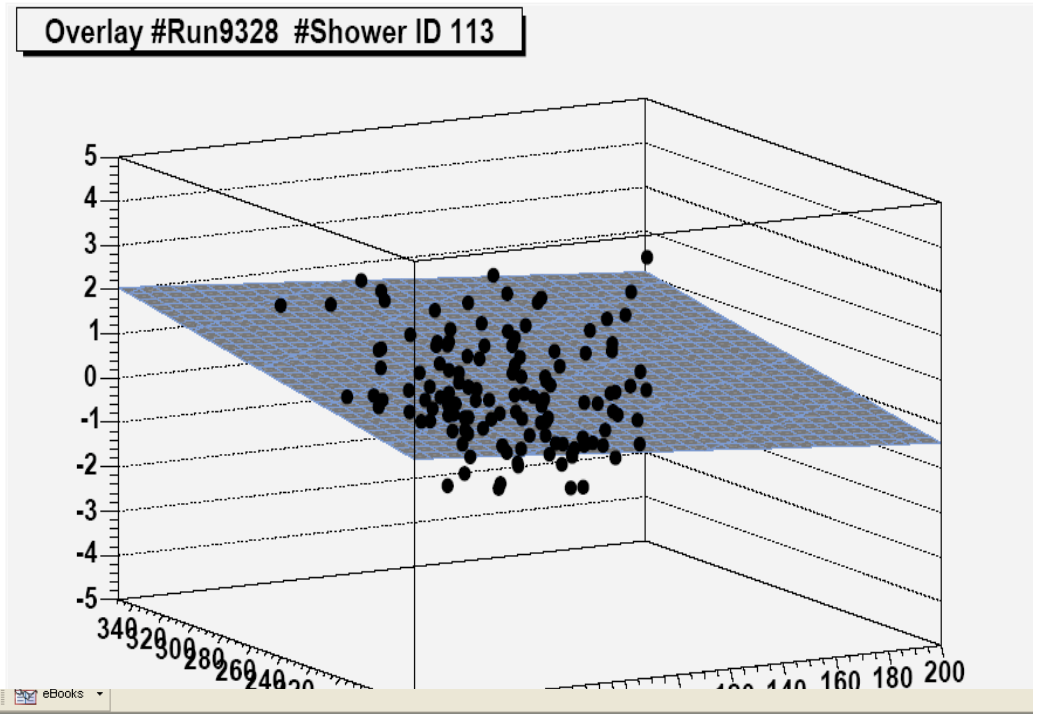


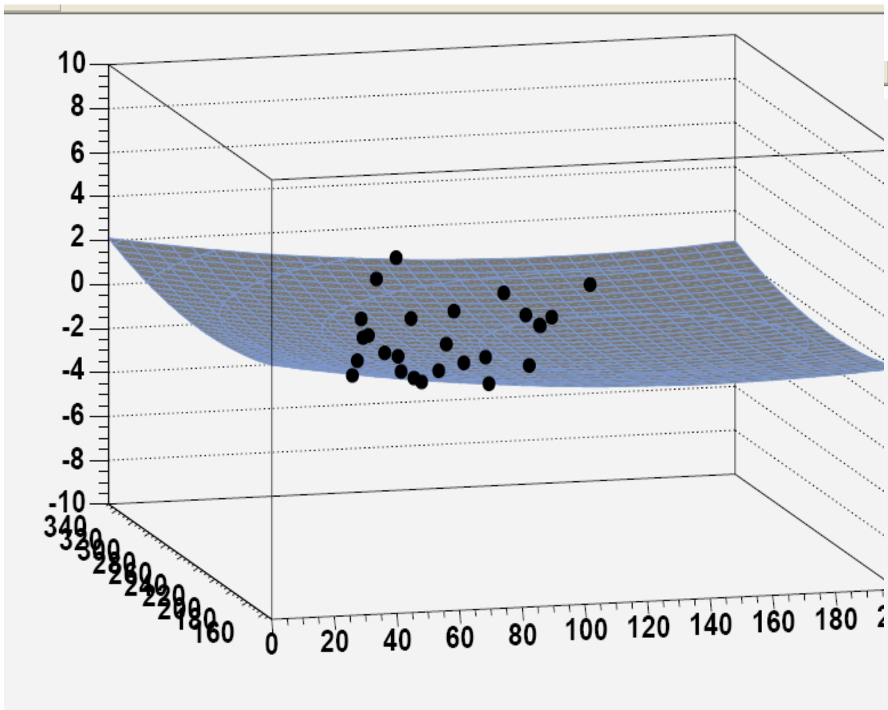
Average Pulse-width (100 samples) measurements on a 12 ns pulse as a function of discriminator threshold.

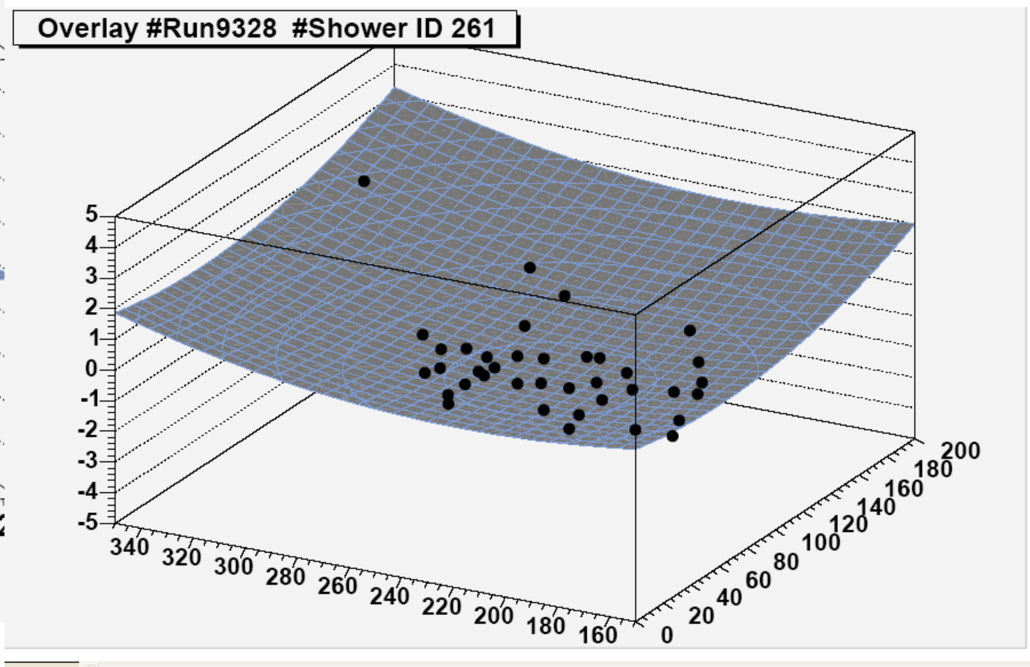
Effective resolution is
~50 ps/mV. Hence,
For a 0.5 ns TDC resolution on each edge an effective ToT resolution of ~0.7 ns is achieved.

For a 1V dynamic range, this provides a 6-bit digitization.

Typical events with a fitted wavefront overlaid on the hits.





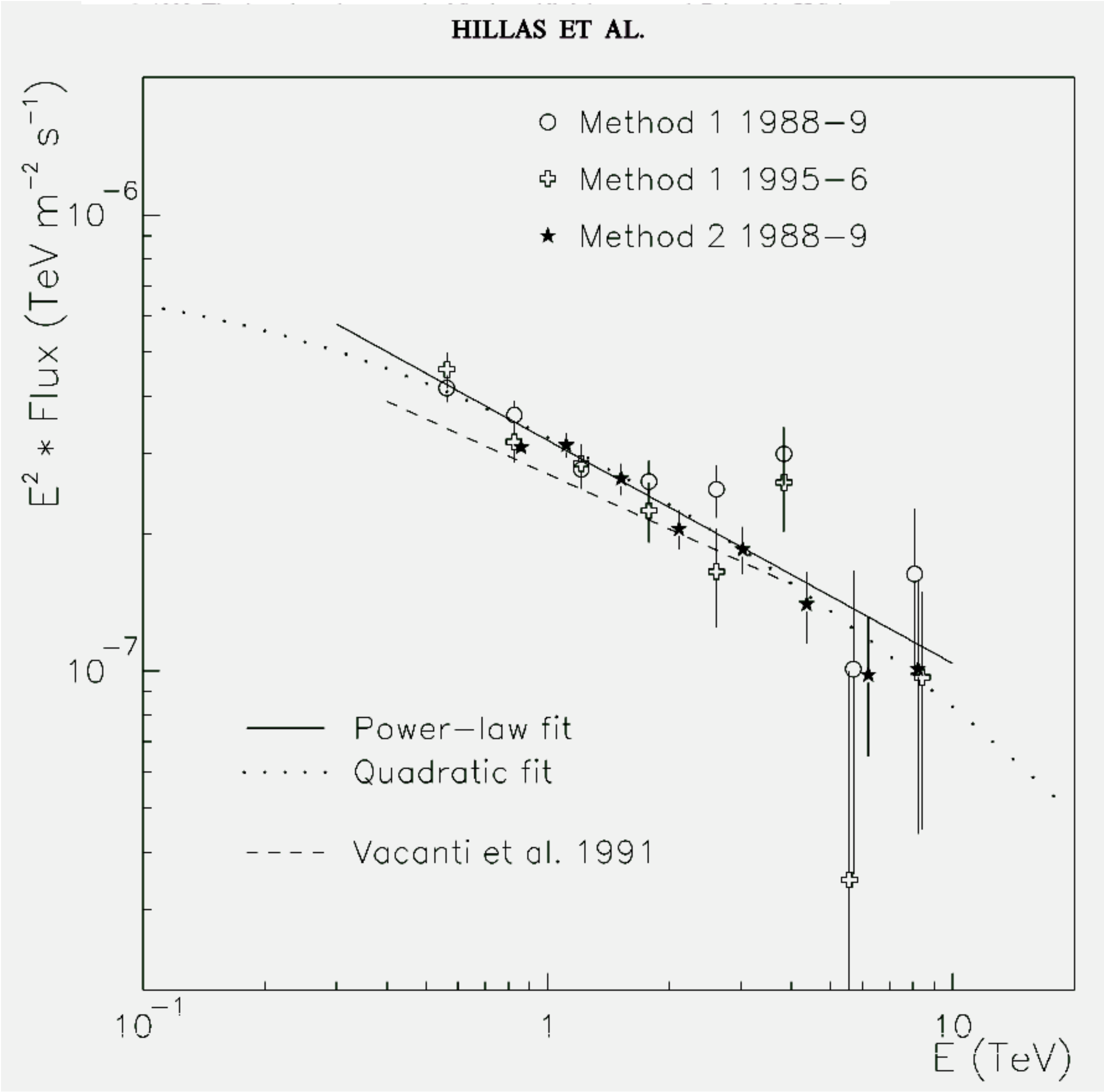


Calibrations using the Crab Nebula

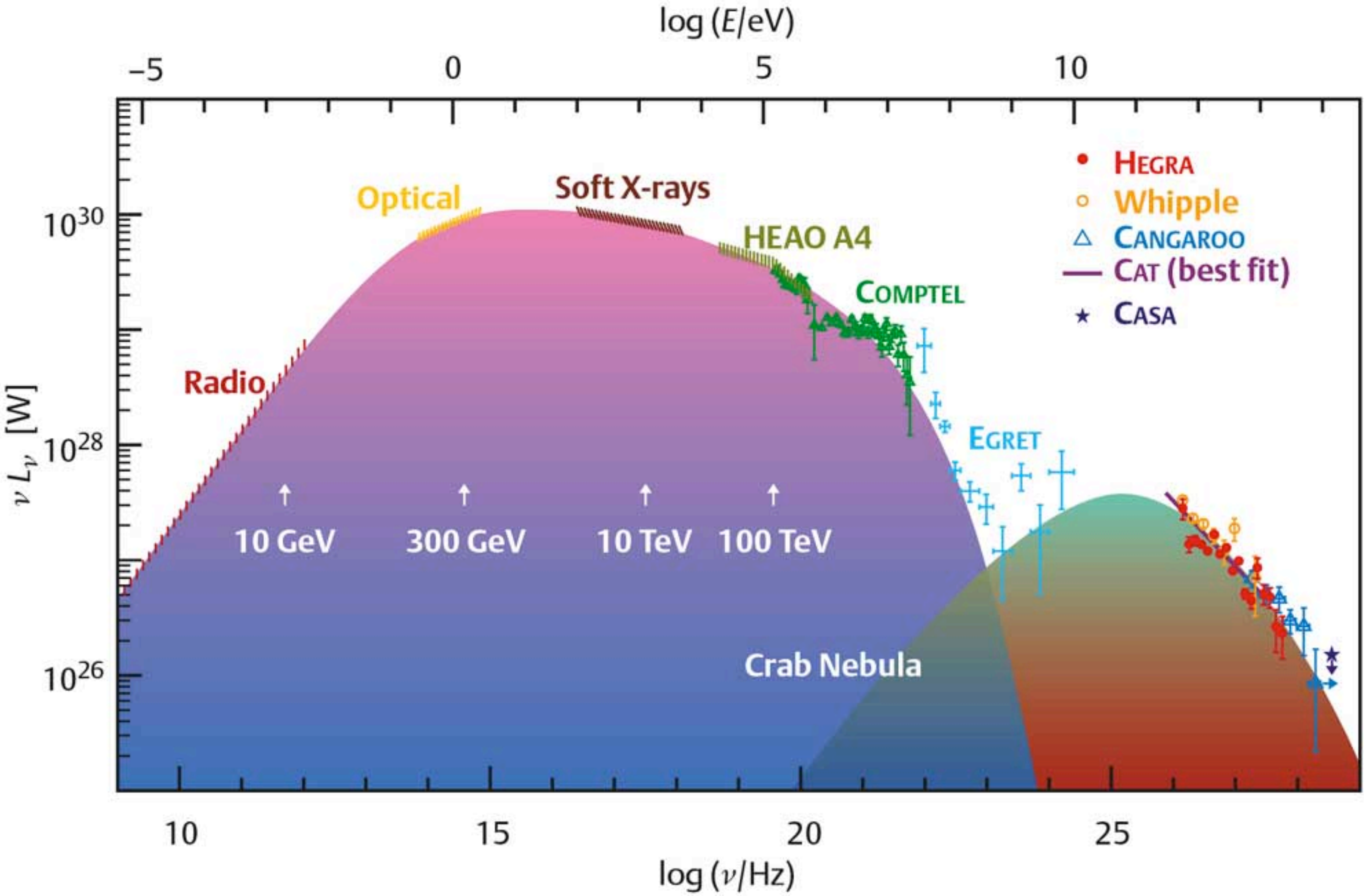
The standard candle of gamma-ray astrophysics, the Crab has been studied extensively and is now believed to have a well known and stable spectrum above ~300 GeV.

THE ASTROPHYSICAL JOURNAL, 503:744–759, 1998 August 20

HILLAS ET AL.



Crab Spectrum: The spectrum has not been established in the 10-100 GeV region, thus making it difficult to use the Crab as a standard candle in this regime. We have to rely on simulations.

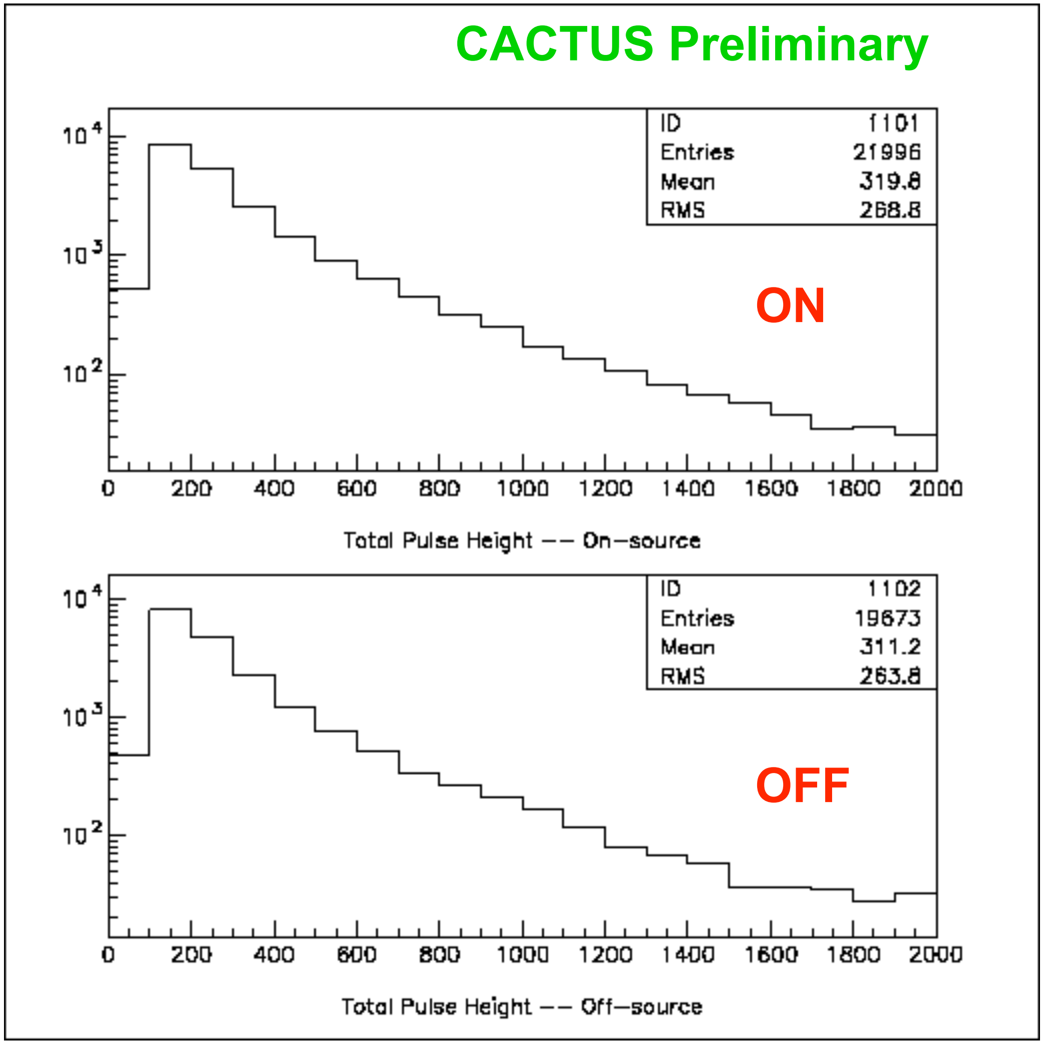


CRAB: The observed distribution in Total Pulse-Height.

Data are recorded in ON-source (heliostats track the Crab) and OFF-source (heliostats revert and track a point 30 mins away from the Crab) pairs of 28 minute duration each.

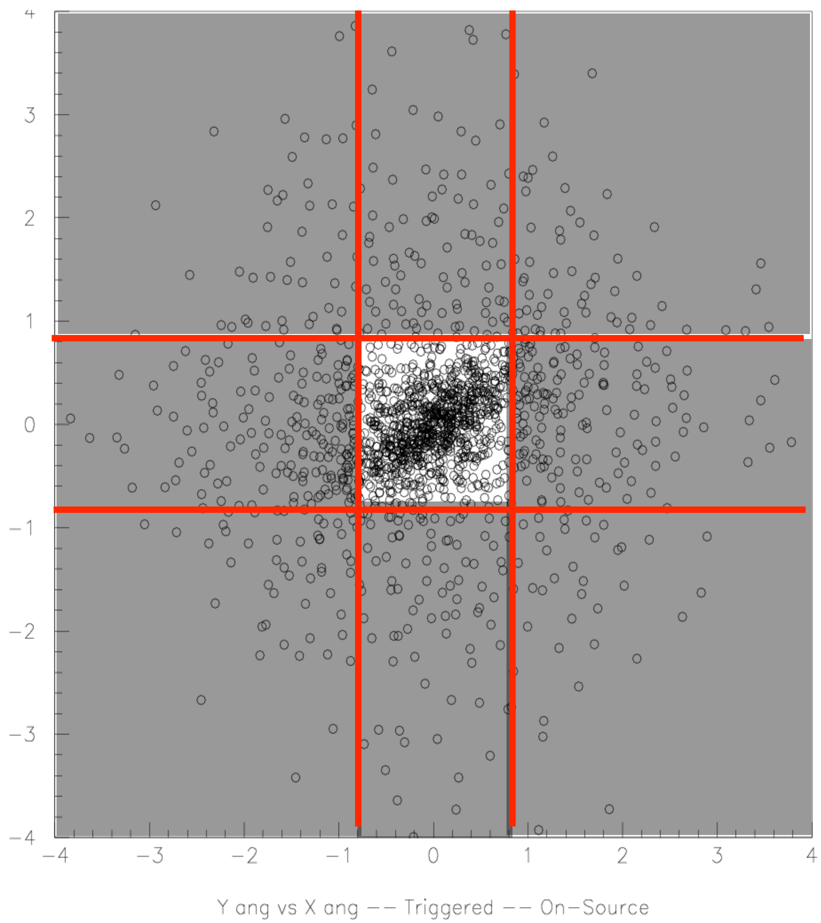
We require >20 channels in a 13 ns window for the event to be considered in our offline sample.

Further fiducial cuts are applied on the measured centroid and angle to restrict the sample to well contained events (next slide).

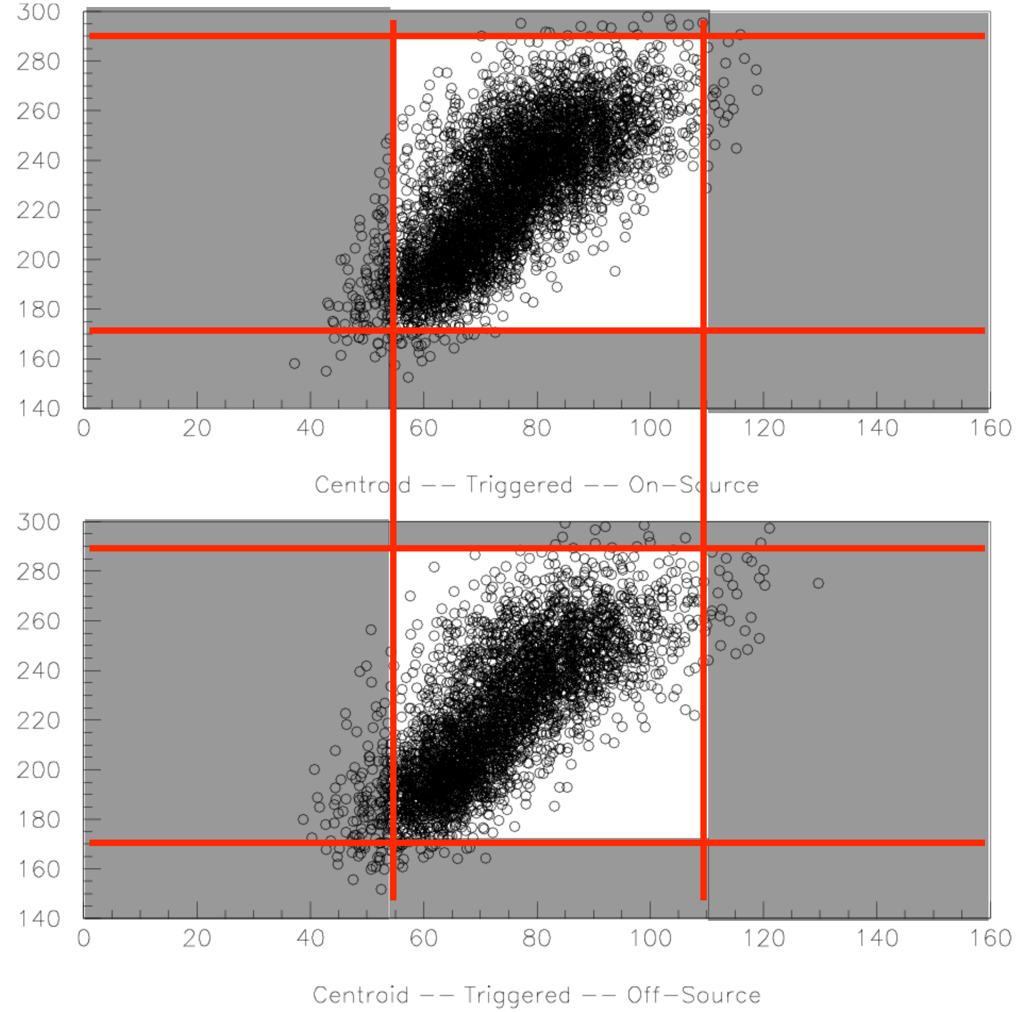


Fiducial Cuts

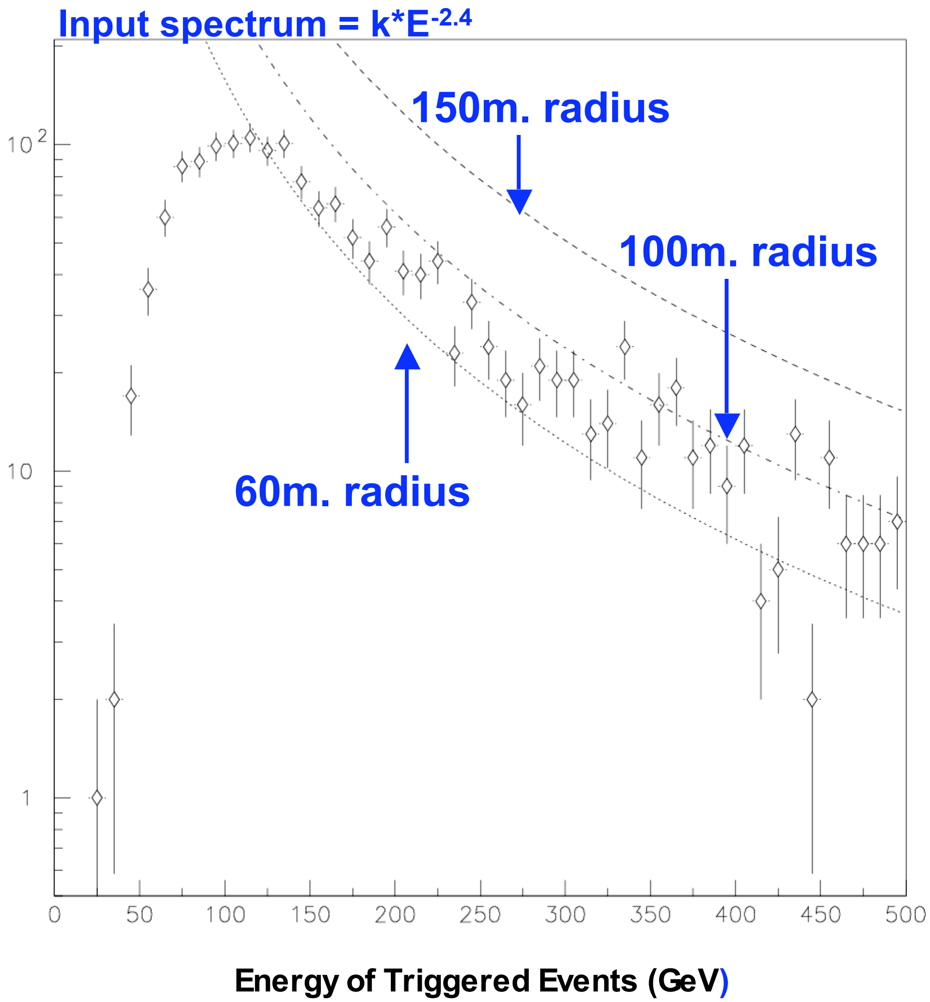
First Planar Angle Fit

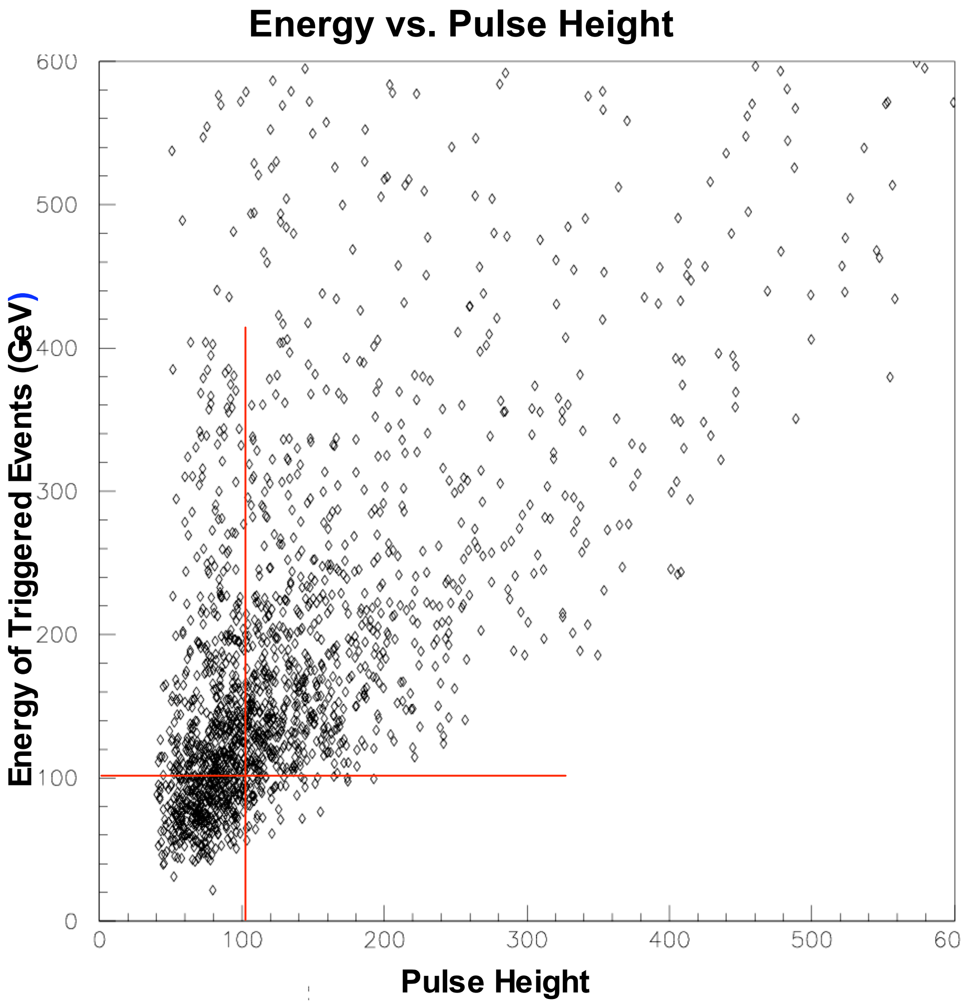


X/Y Shower Centroids



Simulated Energy Response



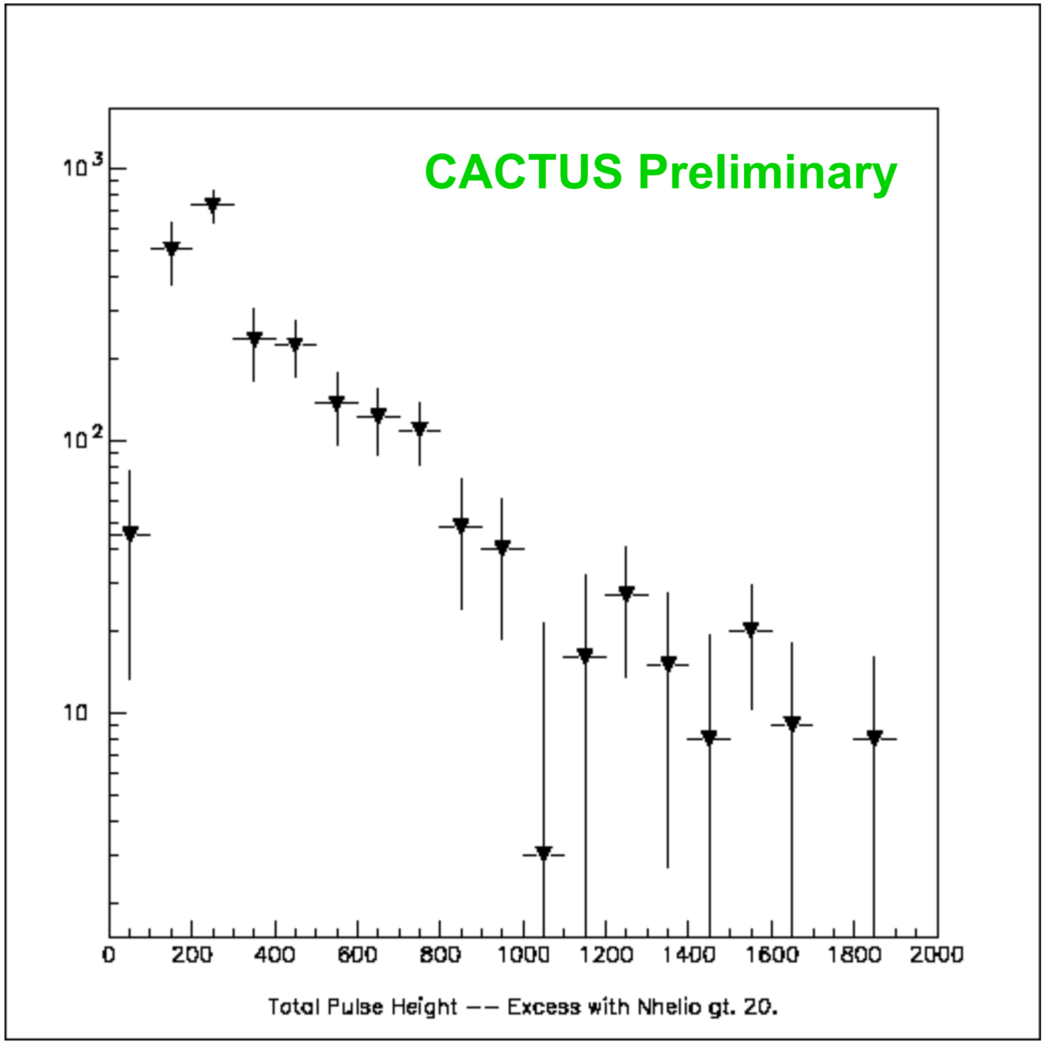


CRAB: Measured spectrum for "high energy" events

This sample from the Crab represents an excess rate of 12/min.

The horizontal scale is "total measured pulse height" which is closely related to the incoming energy.

The range of measurements here represent an energy range of ~ 50-2000 GeV.



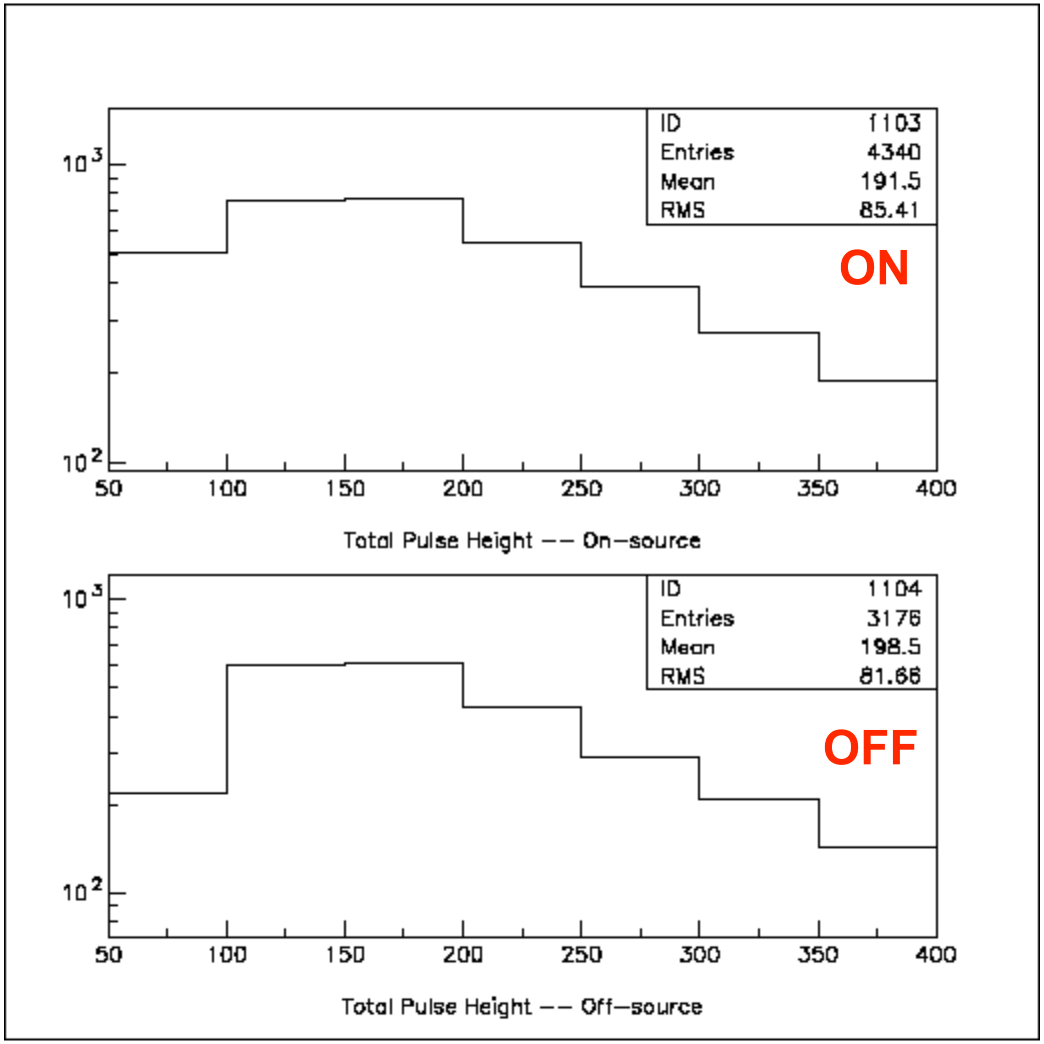
CRAB: Attempt at understanding the low energy regime

Lower the requirement for Number of channels in the trigger (>15).

Same fiducial cuts as before.

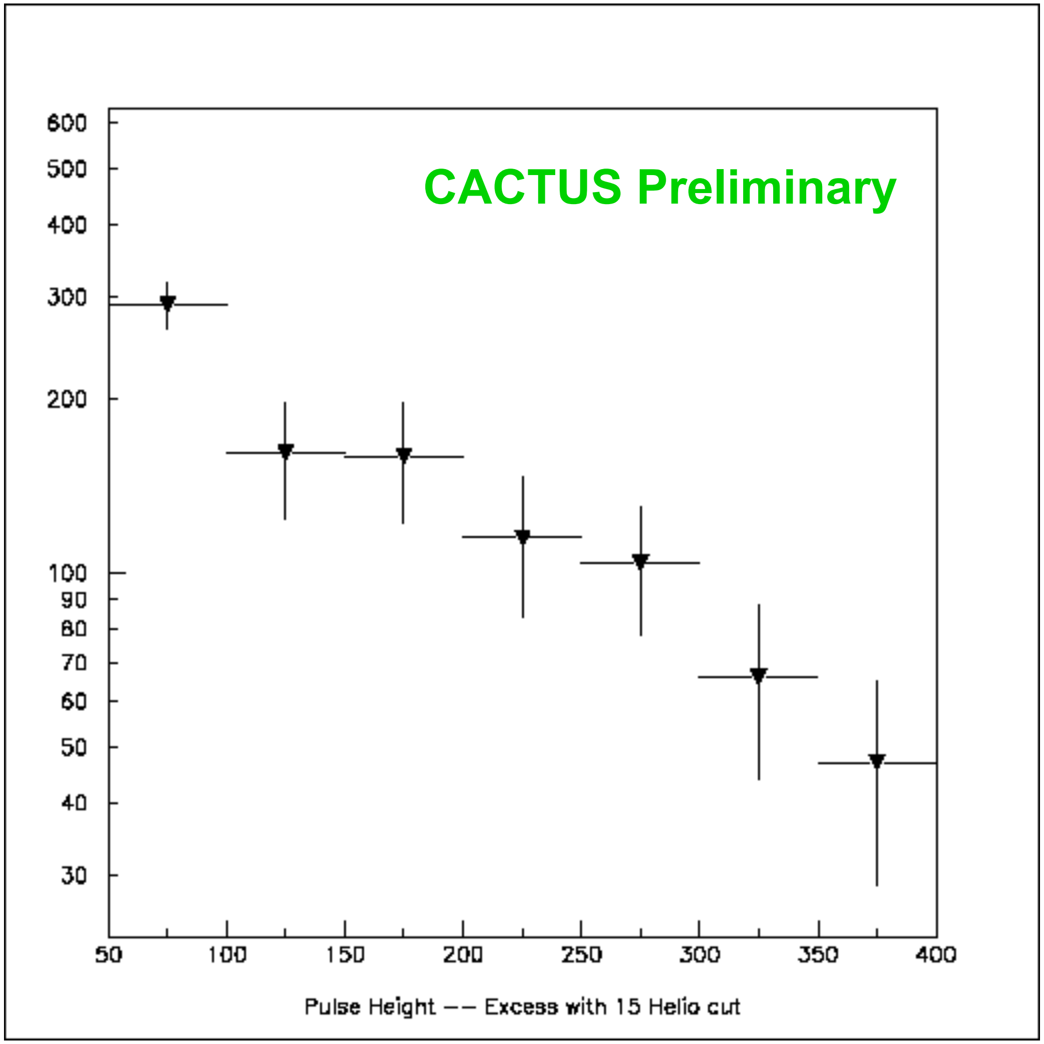
Restrict the data set to one on/off pair (28 mins) to avoid weather related differences.

Observed excess of events after cuts = **42/min**.



CRAB: Measured spectrum for "low energy" events

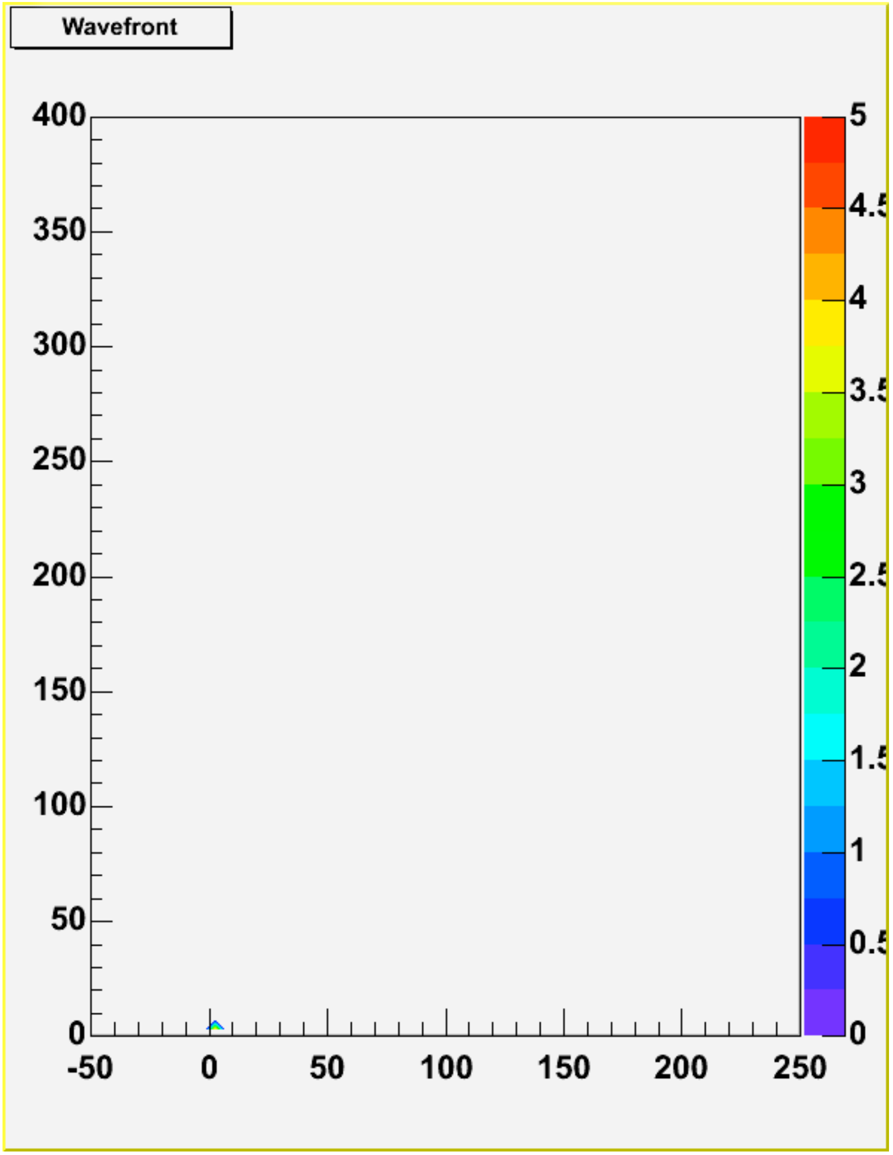
Crab low energy excess: Rate of ~ 42/min!

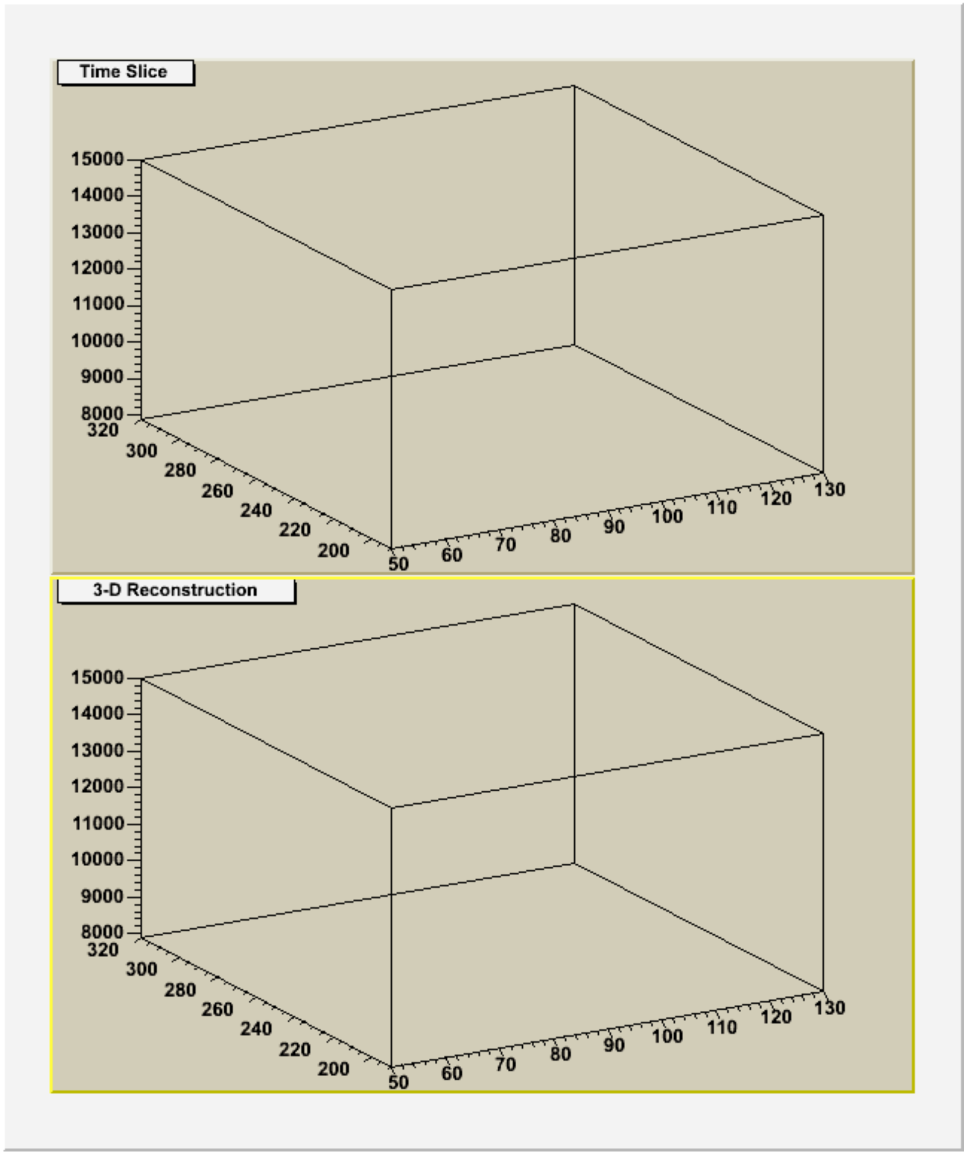


The significance of this detection of Crab in 28 mins is 13 σ .

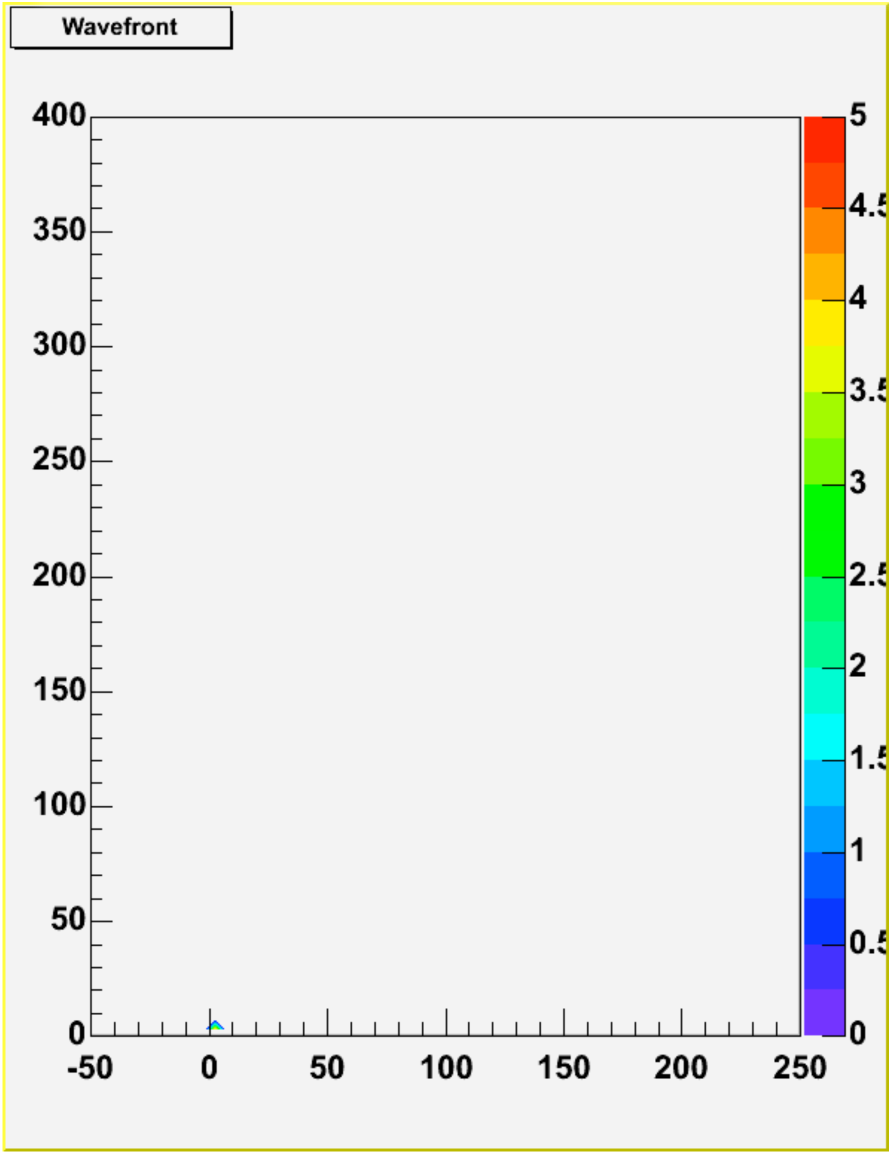
Much work remains to be done to extract a flux measurement.

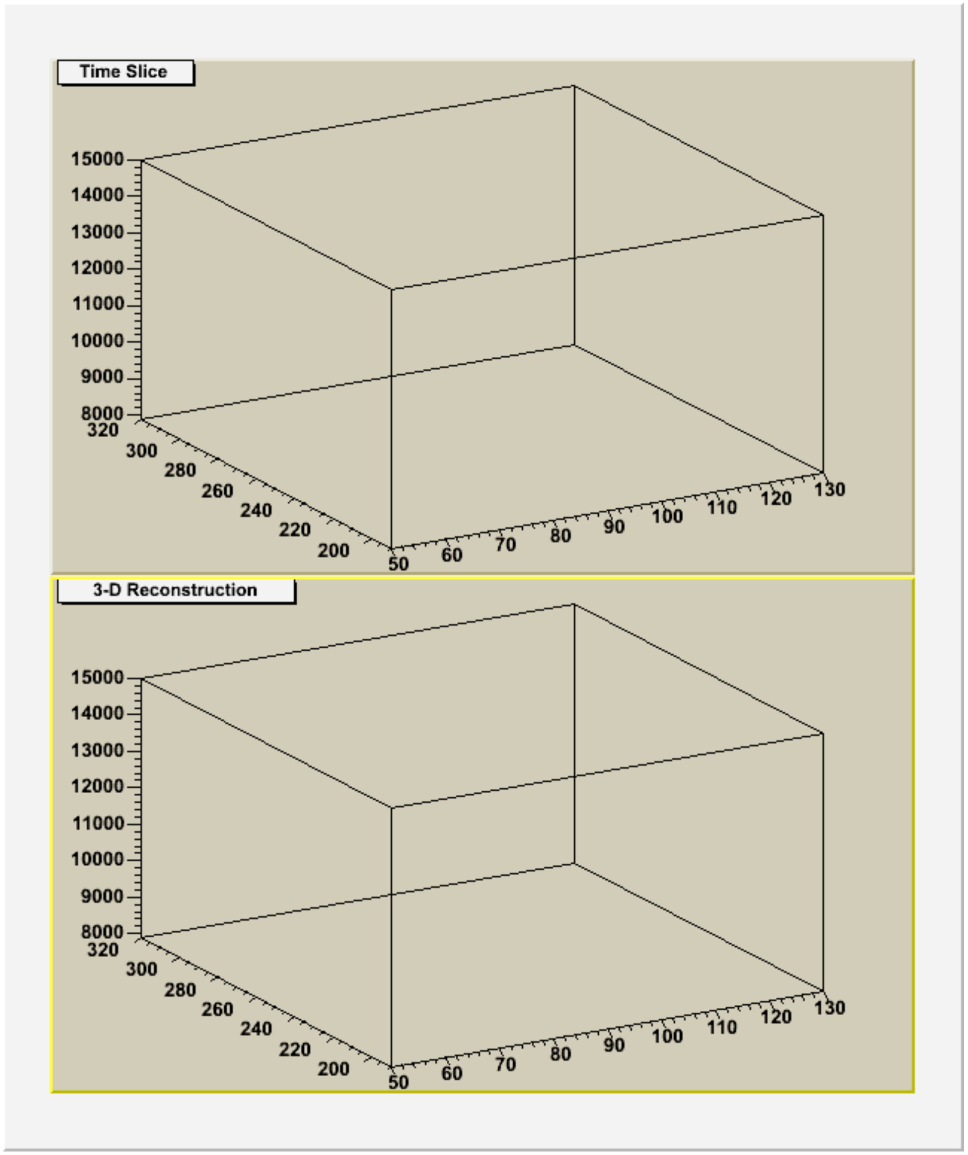
Time Projection Reconstruction





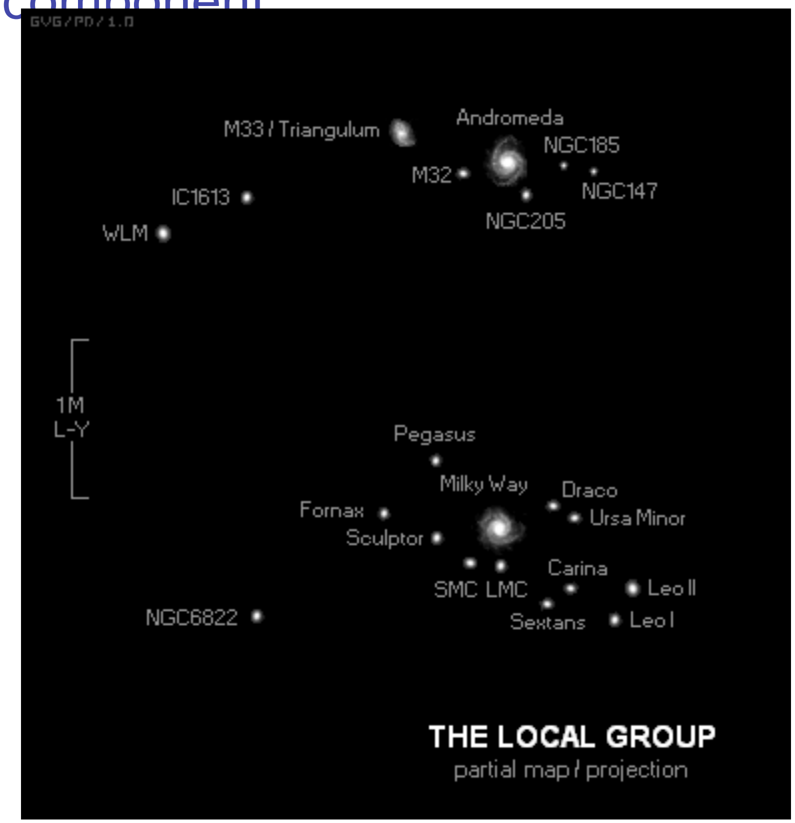
Time Projection Reconstruction





Draco and Dark Matter

Draco is a dwarf spheroidal galaxy in the vicinity of the milky way. Its estimated total mass of is ~0.3 - 8 x 10^7solar masses and, given the low luminosity of ~2 x 10^5 Lsolar, the global mass-to-light ratio anywhere in the 10-100 range. This requires that Draco contain a dominant dark matter component



Draco is about 0.5 degrees across. It is very faint in the optical.

Integrated magnitude ~11 making it an ideal candidate for ACT observations.

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Neutralinos: Previous attempts at understanding Draco.

Neutralinos are the lowest mass supersymmetric particles in the Minimum SUSY Model. Since they are stable, they are a popular candidate for Cold Dark Matter.

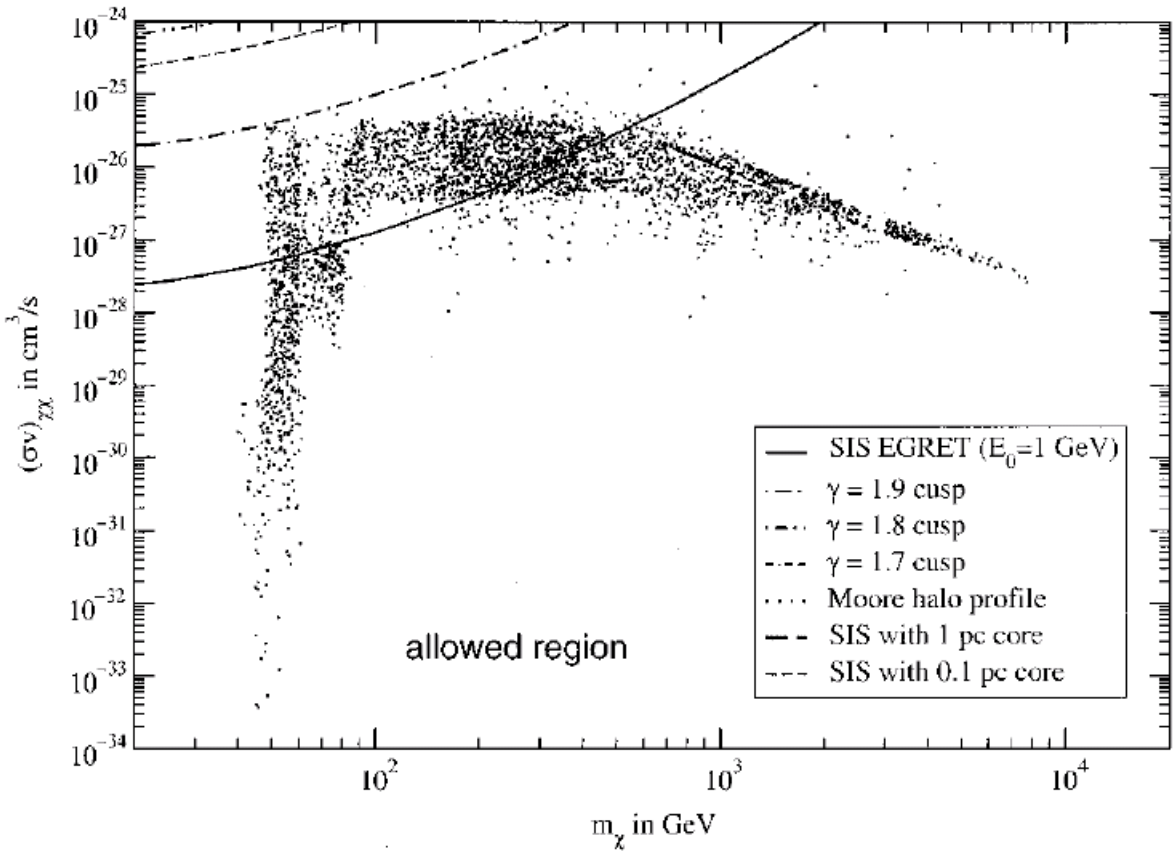
Neutralinos can annihilate into quark and anti-quark pairs. The resulting hadron jets will contain gammas from neutral pion decays.

The rate will depend on ρ^{2}, where $\rho \sim r^{-\gamma}$ is the density profile of the neutralinos.

PHYSICAL REVIEW D **66**, 023509 (2002)

Particle dark matter constraints from the Draco dwarf galaxy

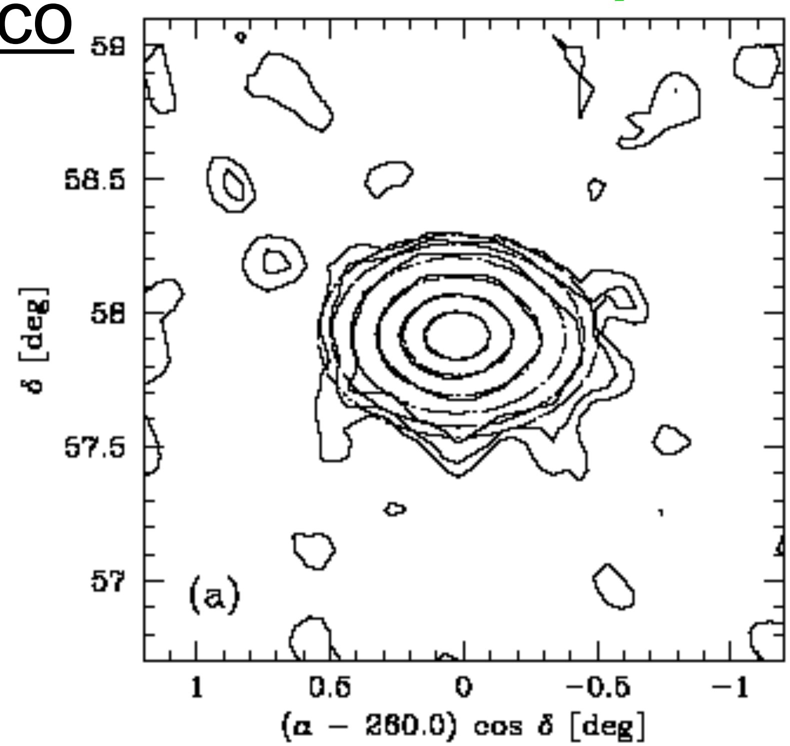
Craig Tyler*
Department of Astronomy & Astrophysics, The University of Chicago, Chicago, Illinois 60637
(Received 18 March 2002; published 3 July 2002)

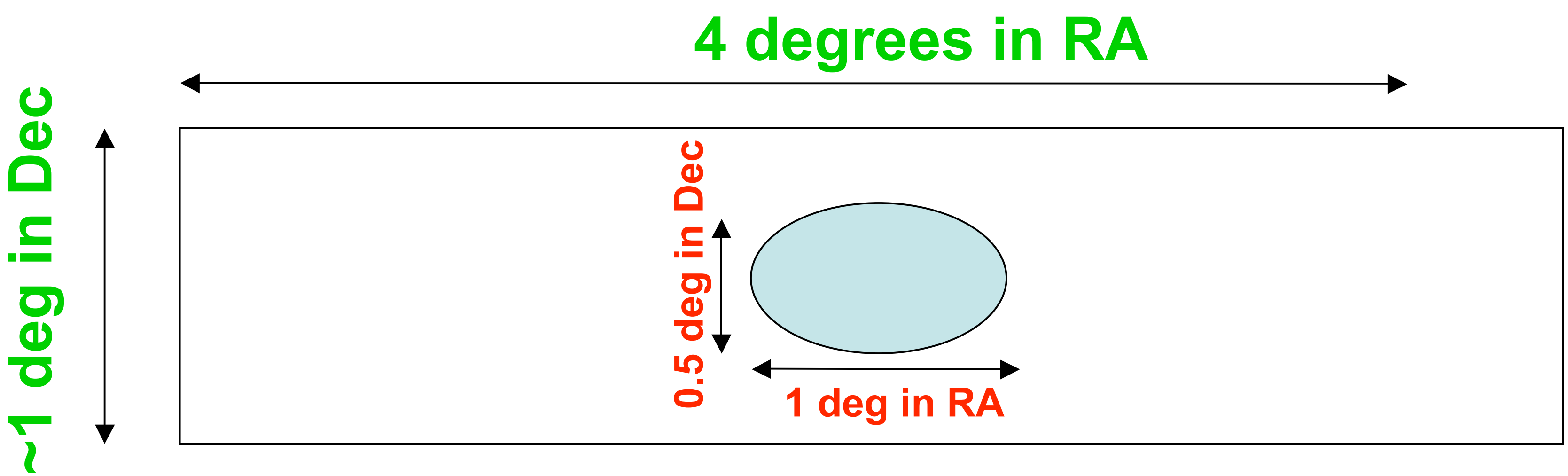


CACTUS Observations of Draco

- Drift scans: +- 2 degrees in RA.
- Background check using Draco minus 1 degree in Dec.

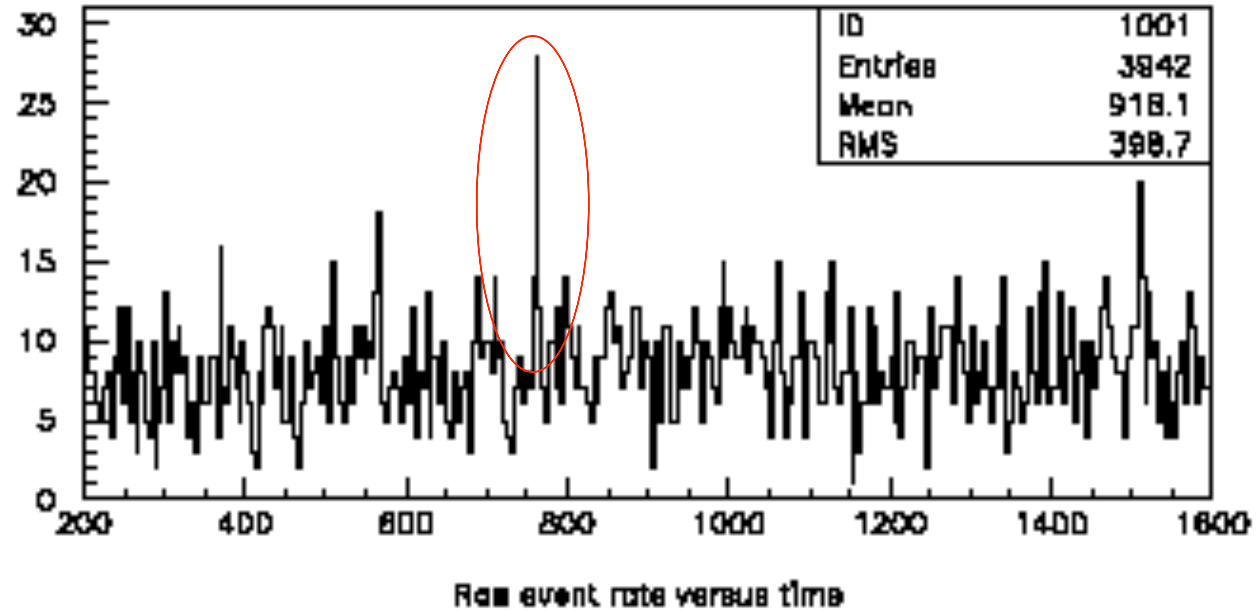
SDSS map



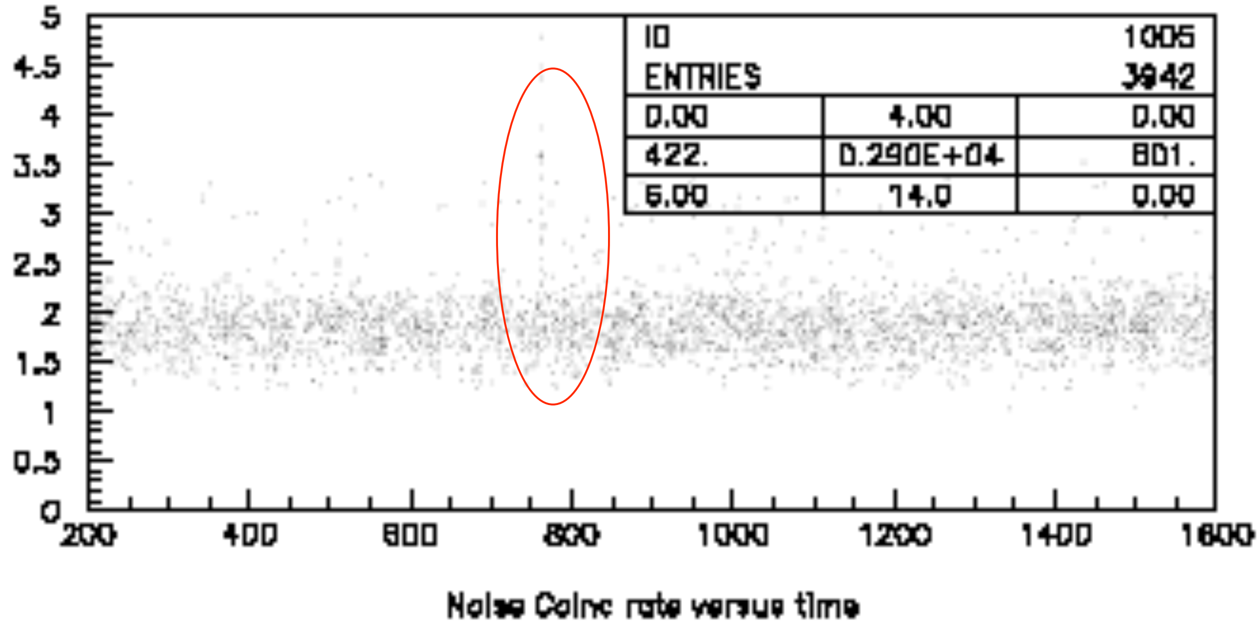


Typical Scan lasting 30 minutes

The data-acquisition consists of recording time of arrival and pulse heights for each channel. In addition, background noise rates are recorded for 1 microsecond preceding the triggering event.



Noise spikes due to fluctuations and/or meteorites, airplanes etc can be tracked in the background noise rate which is otherwise very stable.

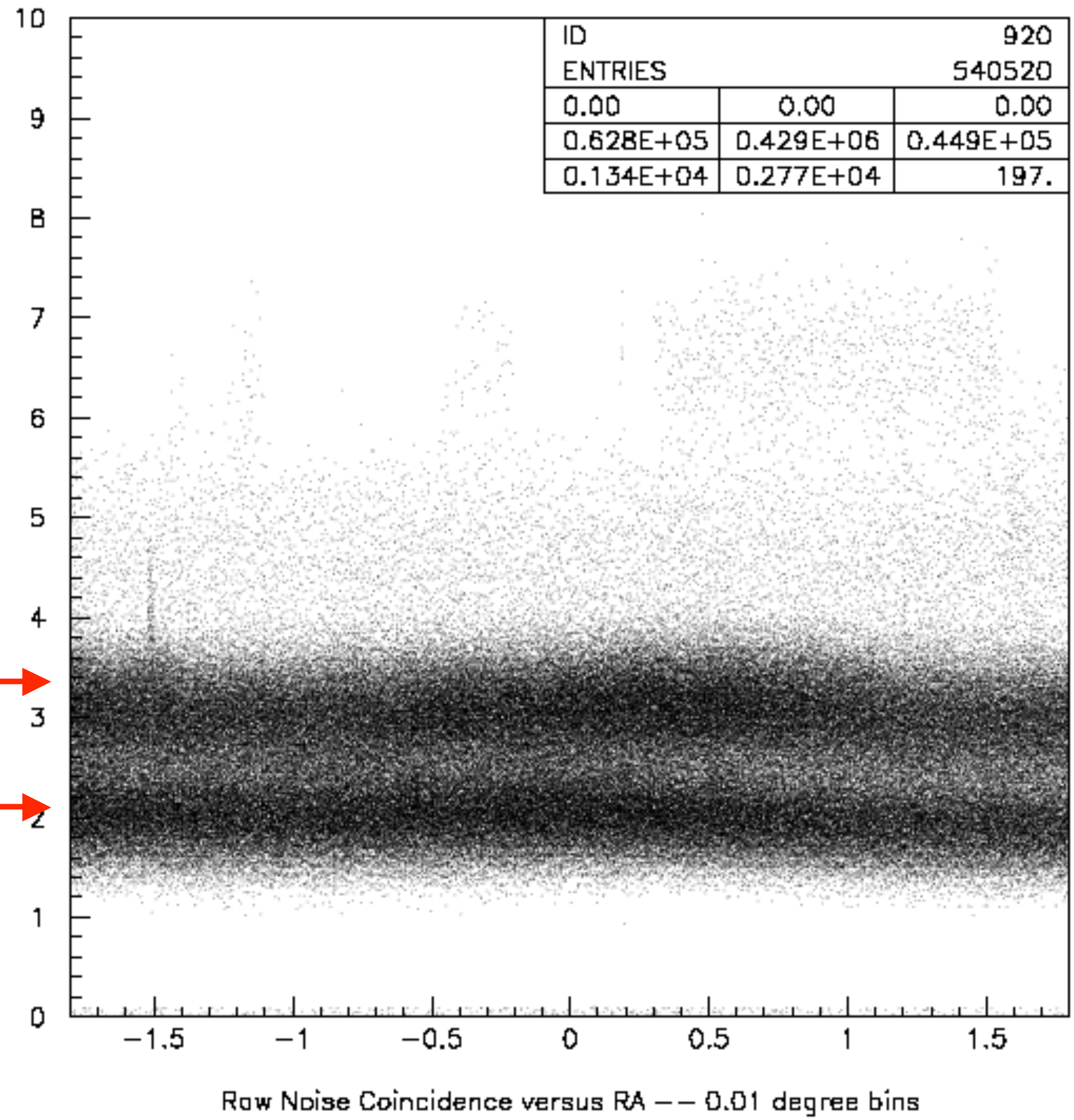


Integral of 44 scans

During the 10 days of observing the night sky had a small shift in transparency. The noise coincidence rate went up and the trigger was adjusted to accommodate this change.

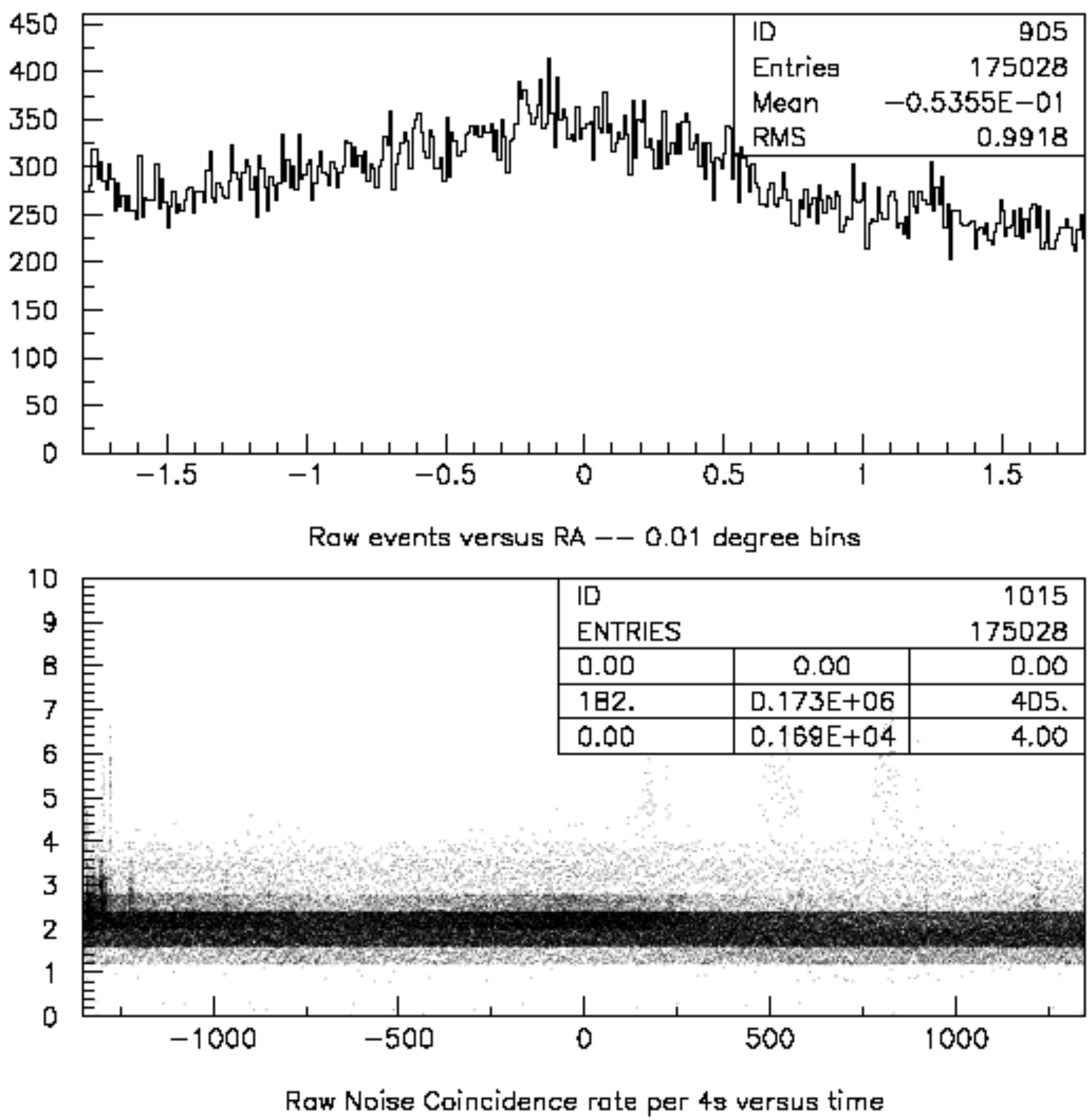
Trigger on >13 channel coincidence

Trigger on >11 channel coincidence



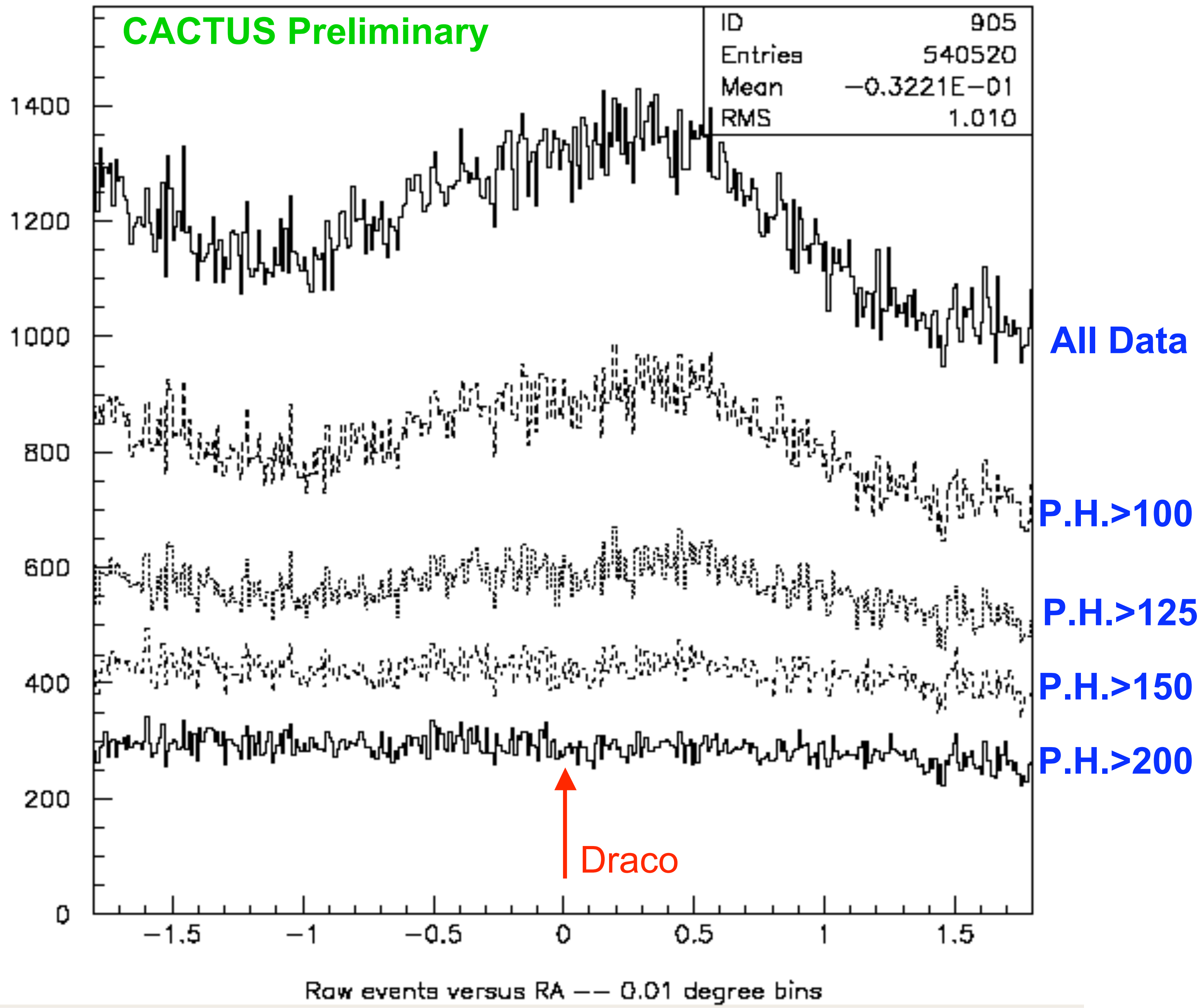
Sum of 7 scans taken during low background rate conditions.

The background is stable, while the scan data show a feature.



Integral of 44 scans

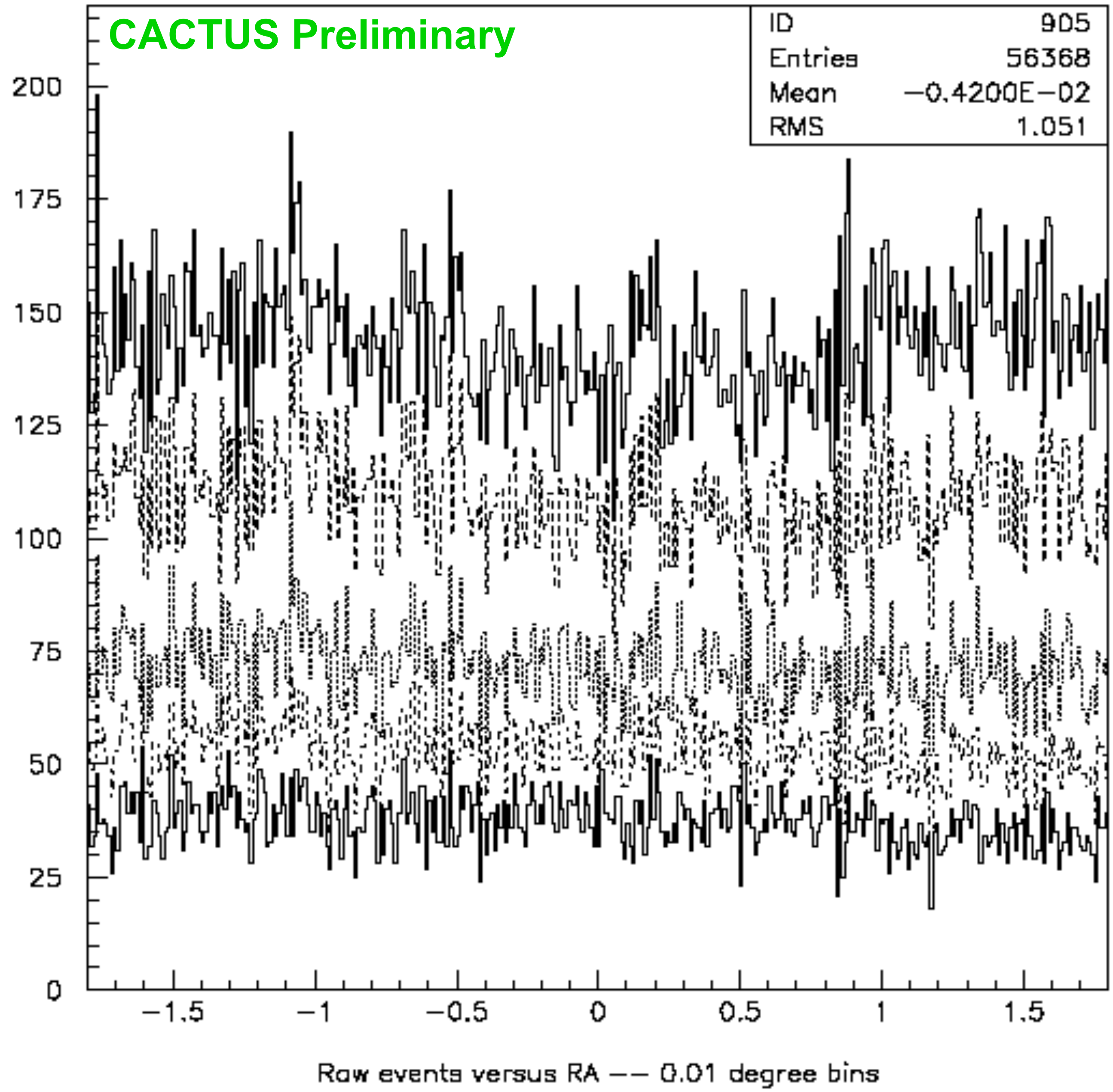
Placing cuts on the total Pulse Height in the event (~energy) reveals that the excess is not visible above about 150, which is ~150 GeV.



Scan of Draco -1 in Dec

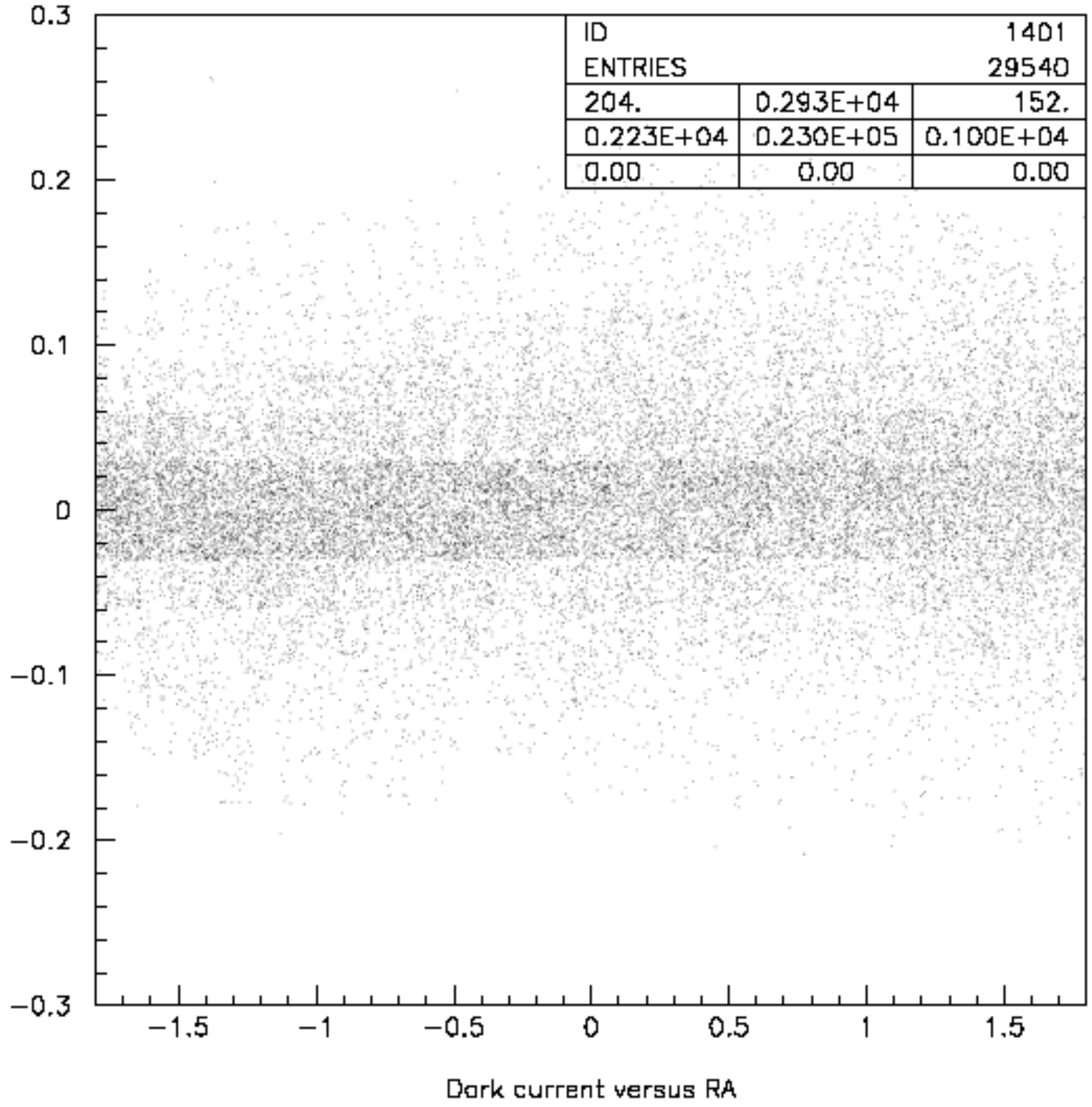
A similar set of scans in RA but offset by 1 degree in Dec show flat distributions in all energy bins.

A total of 6 scans are integrated here. The scaled rates agree with the background in 44 Draco scans.



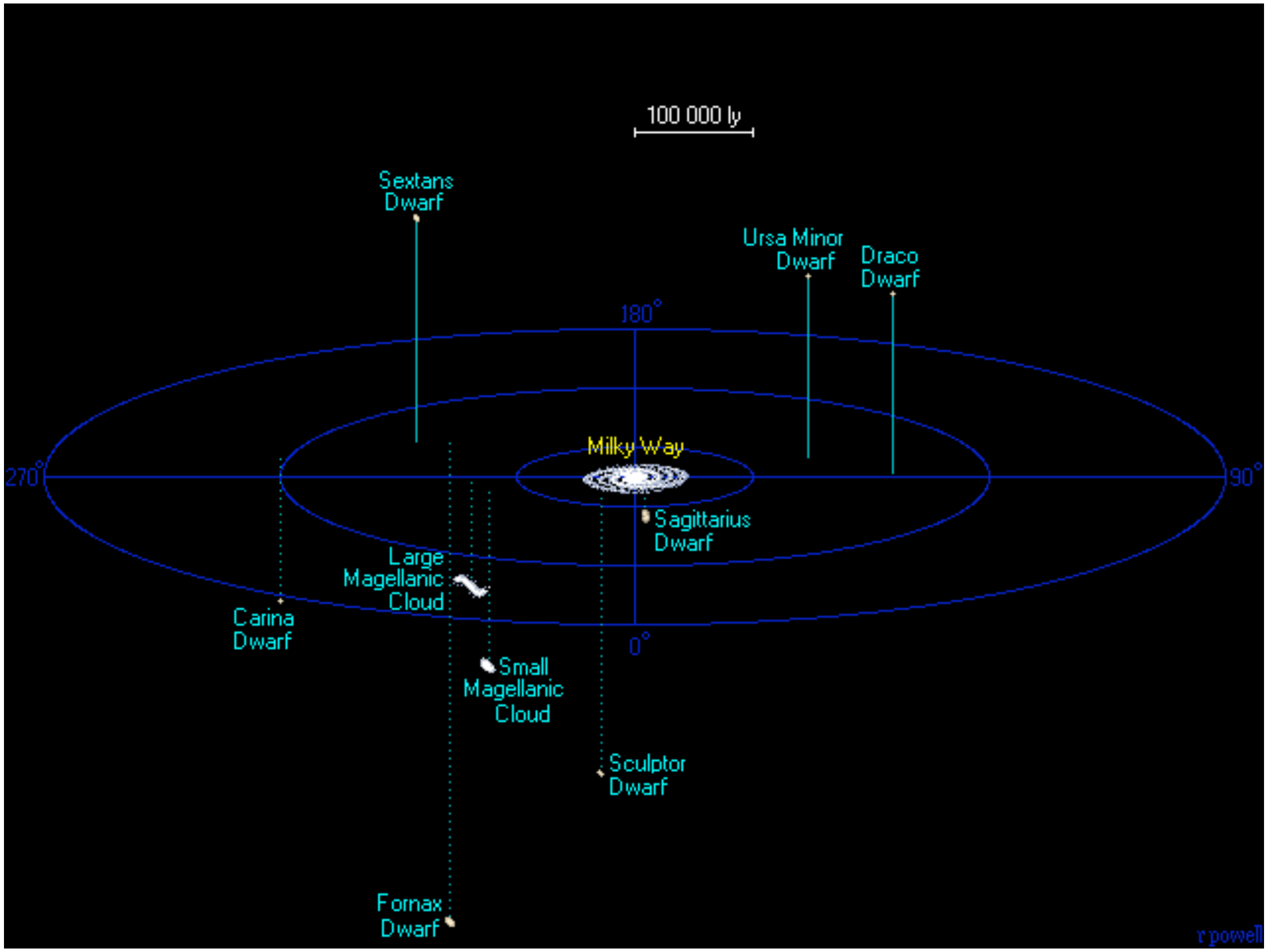
Dark Currents were also quite stable for the duration of the scans.

Shown here is the deviation from the baseline average dark currents recorded during 1 minute prior to the scan.



Dwarf Spheroid Survey

Our future plans include a survey of Sextans dwarf and a return to Draco in March 2006 to confirm the excess seen in this observing period.



Summary

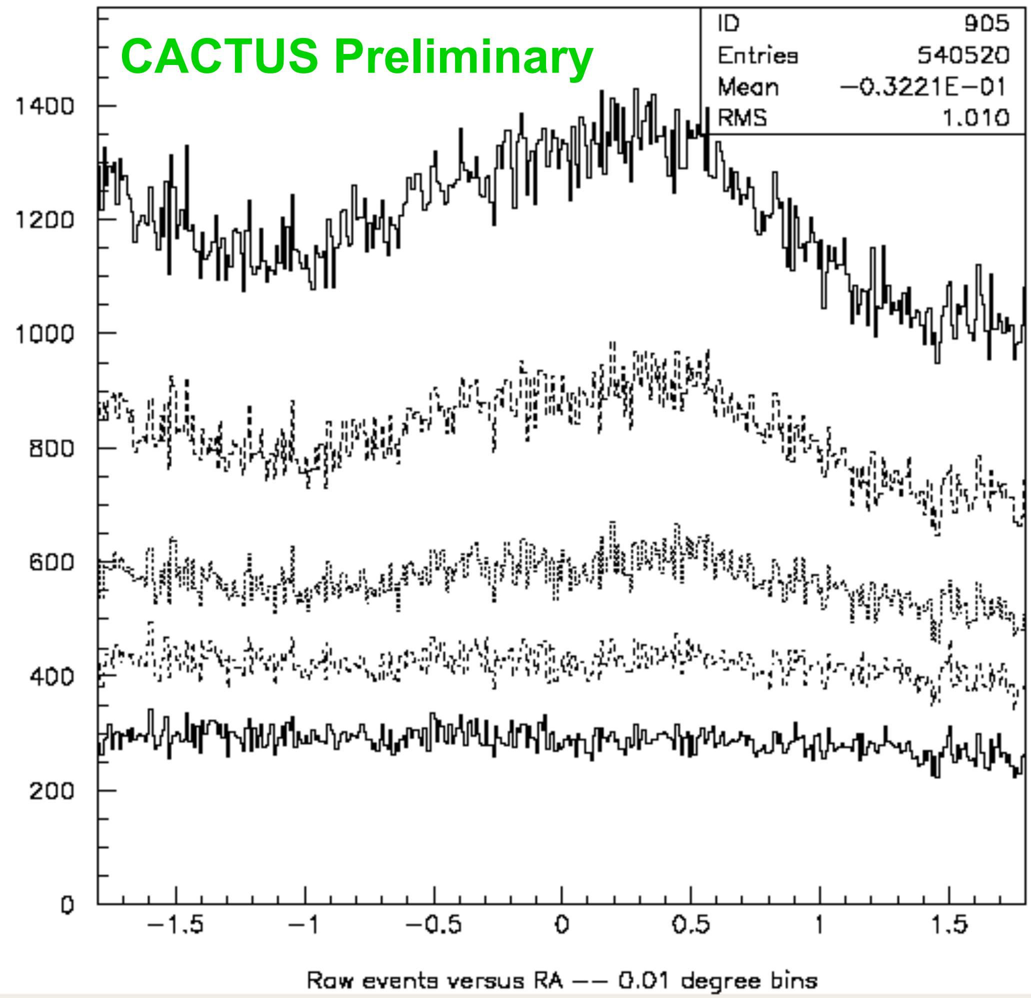
We have to test the robustness of the excess. Work to be done:

1. Full shower fit analysis.
2. More detailed energy scale simulations and comparison with world data on Crab.
3. Trigger threshold analysis.

Observe Sextans in the Fall.

Return to the Crab in the Fall for further calibration.

Implement time-imaging technique for improved gamma/cosmic ray discrimination.



Updates at ICRC, TAUP and other venues.

We welcome collaborators.

Acknowledgements

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- We thank the Office of the President of the University of California for supporting us with a grant for the development of the electronics for CACTUS.
- We are indebted to Southern California Edison, and Mr. Judd Kilminik in particular, for allowing us to use the Solar-2 site.
- An original grant from the Keck Foundation and Dr. Tumer from UCR paid for the mechanical and civil engineering aspects of converting Solar-2 into an ACT.
- The senior Electronics Engineer at UC-Davis, Mr. Britt Holbrook, takes a large part of the credit for the successful conversion and operation of CACTUS.
- We also wish to acknowledge the efforts of numerous undergraduate and graduate students who worked part time in the desert to make CACTUS into a reality.
- We are grateful to Prof. Alan Zych of UCR for loaning 50 phototubes to us.

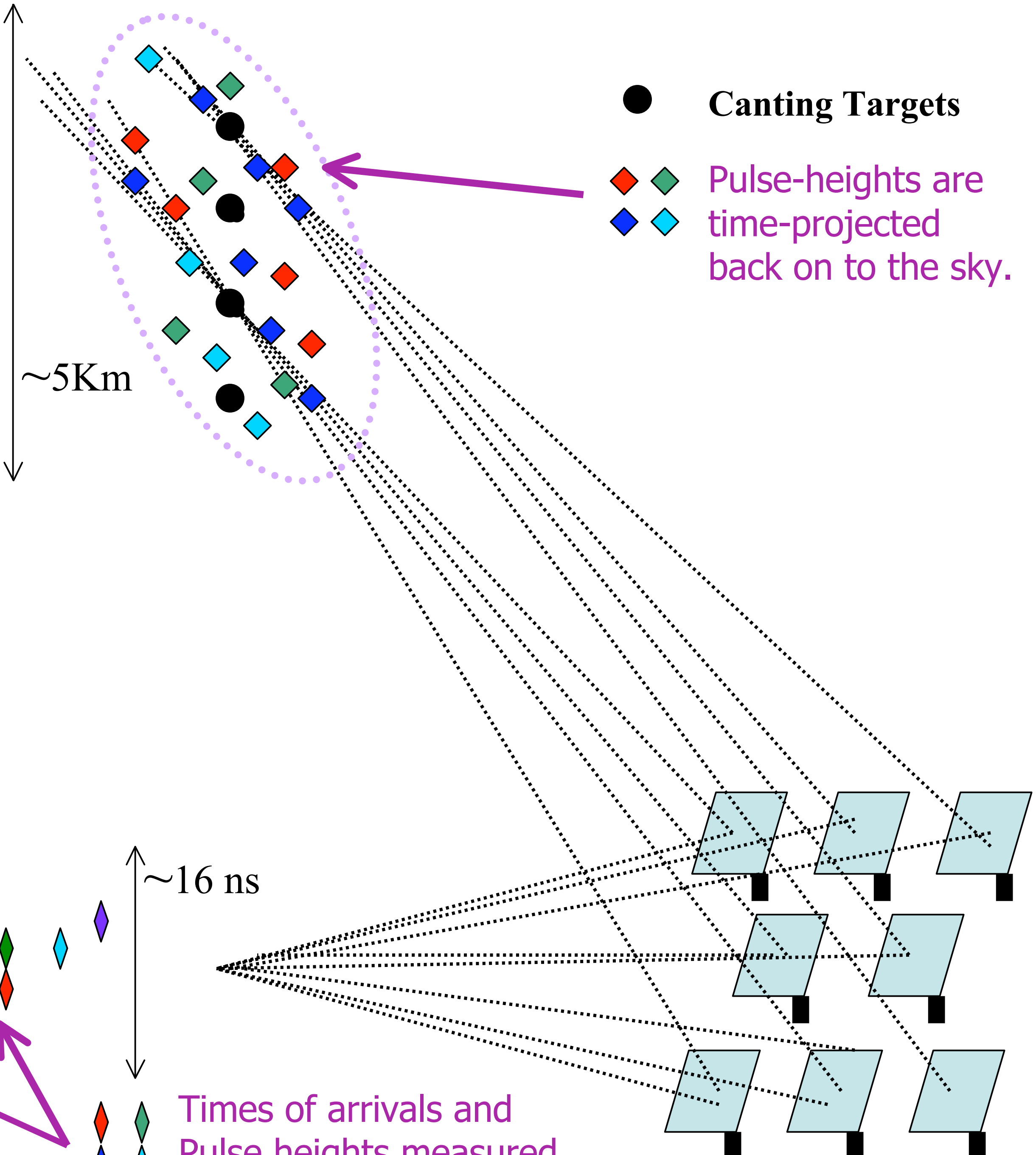
Time-Projection Imaging

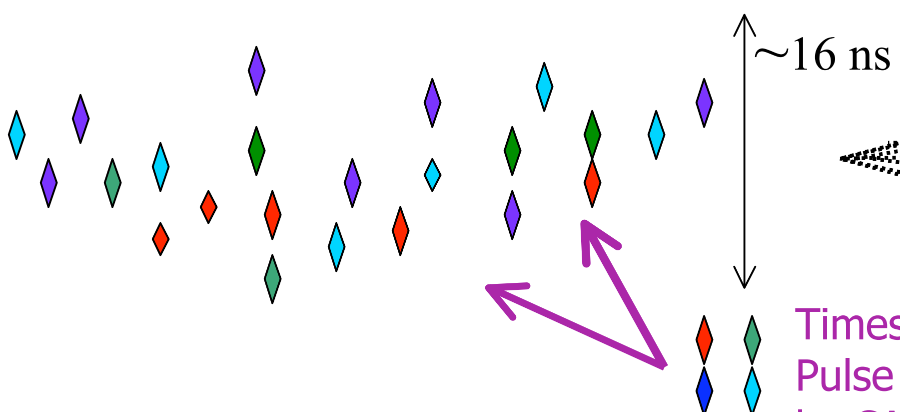
CACTUS records multiple hits and pulse-heights per Heliostat. The time-of arrival difference between these pulses can be correlated to height of emission.

$\Delta h \sim c\, \Delta T/(n-1)$

For, $|1-\beta| \sim |n-1| \sim 10^{-3}$

$\Delta T = 16$ ns => $\Delta h \sim 5$ Km





Mani Tripathi, UC-Davis.

2 degree scans (37) with varying noise conditions due to haze.