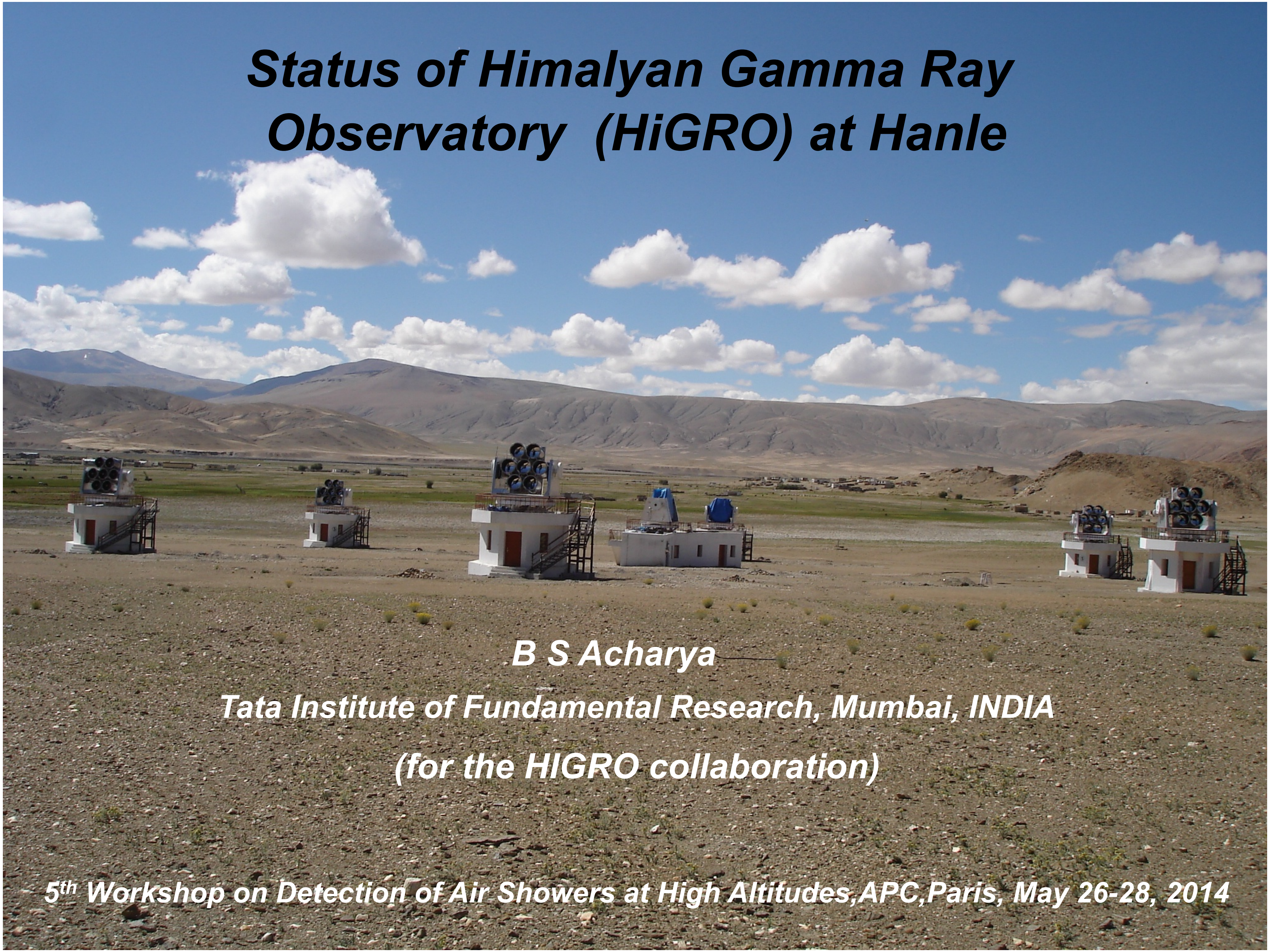


Status of Himalyan Gamma Ray Observatory (HiGRO) at Hanle

B S Acharya

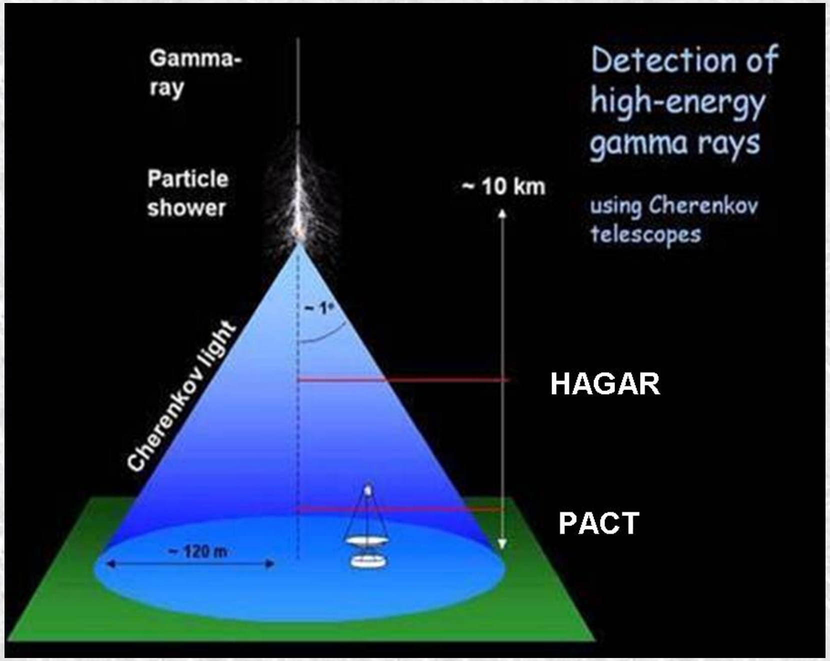
Tata Institute of Fundamental Research, Mumbai, INDIA

(for the HIGRO collaboration)

5th Workshop on Detection of Air Showers at High Altitudes,APC,Paris, May 26-28, 2014

Himalayan Gamma Ray Observatory, HiGRO @ Hanle

- **Hanle: a high altitude location in Himalayas**
- **Cost effective way of reducing energy threshold of atmospheric Cherenkov telescope**



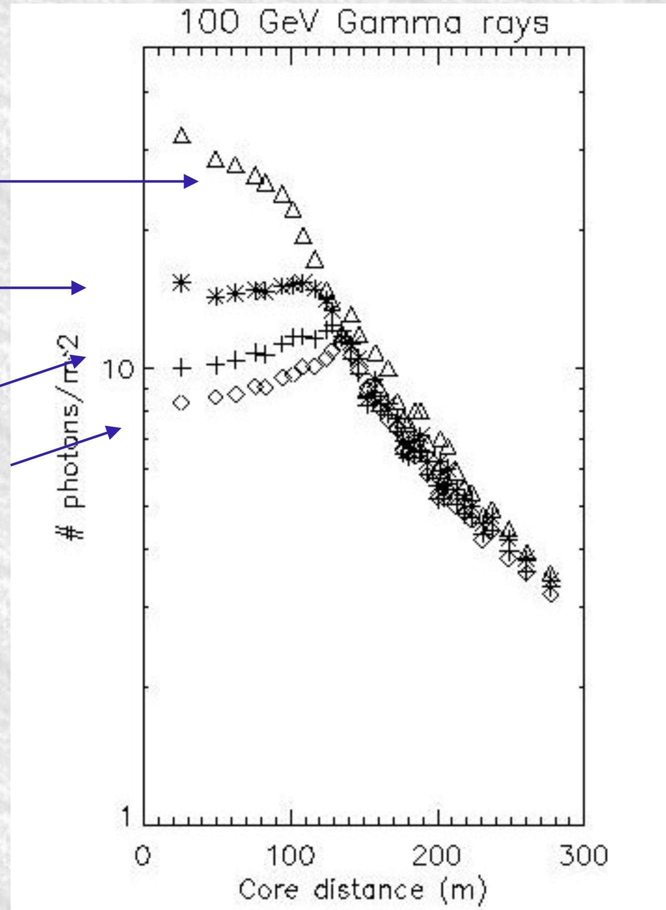
Lateral distribution from simulations

4.3 km

2 km

1 km

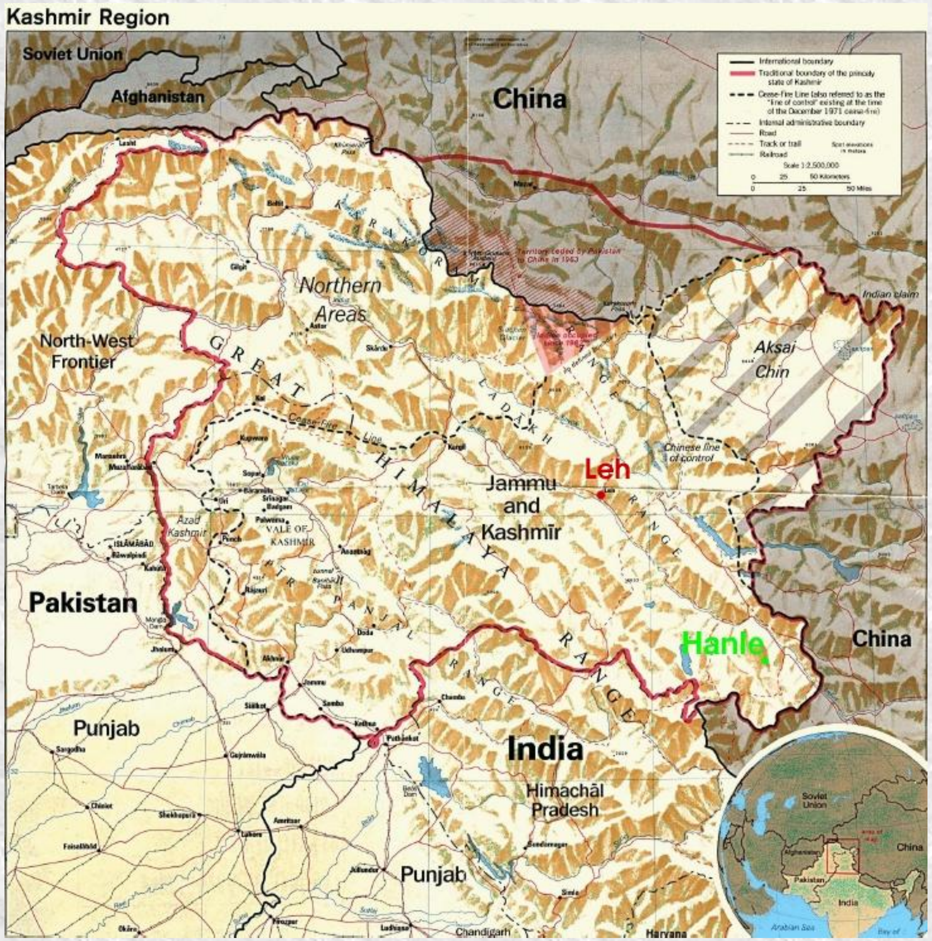
Sea level



Higher Cherenkov photon density and less atmospheric attenuation of Cherenkov photons at higher altitudes

Himalayan Gamma Ray Observatory (HiGRO)

- **Lower energy threshold using high altitude location**
- **Collaboration between BARC, IIA, TIFR and SINP**

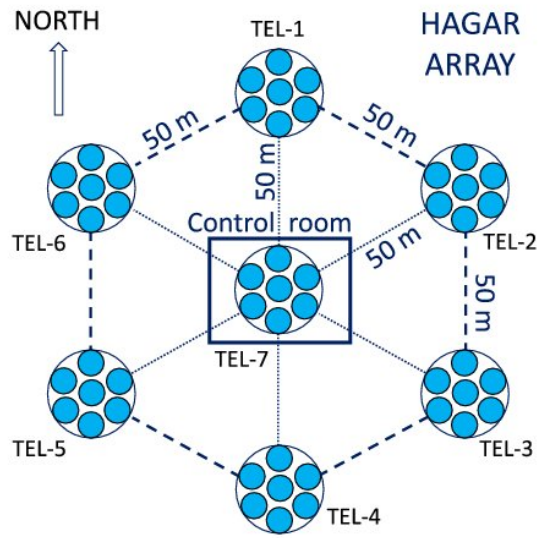


- **Located at Hanle in Himalayas**
  Latitude : 32^0 46' 46" N
  Longitude : 78^0 57' 51" E
  Altitude : 4270 m
- **Located at the base camp of Indian Astronomical Observatory of IIA**
- **260 spectroscopic nights/year**

- **Phase 1 : HAGAR**
  (array of 7 small telescopes)
- **Phase 2 : MACE**
  (21m diameter single telescope)

High Altitude GAmma Ray (HAGAR) Telescope Array

- An array of 7 telescopes based on wavefront sampling technique
- Arrival time of Cherenkov shower front recorded at various locations in Cherenkov pool using distributed array of telescopes



- 7 telescopes consisting of 7 para-axially mounted parabolic mirrors of diameter 0.9 m
- f/D ~ 1
- Photonis UV sensitive phototube (XP2268B) at the focus of each mirror
- Field of view : 3^0 FWHM

HAGAR Telscope Array

Installation during 2005-2008
IIA & TIFR
Fabricated at Bangalore by IIA
Optical system + DAQ by TIFR

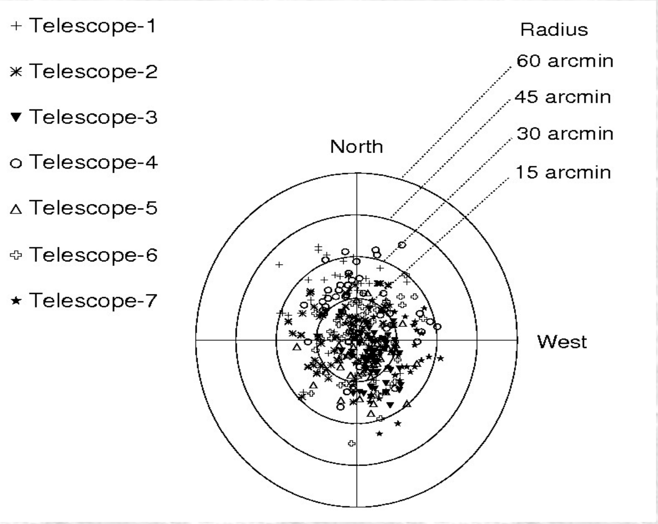
Tracking System

- Alt-azimuth mount, each axis driven by separate stepper motor
- Telescope movement control system consists of two 17 bit rotary encoders, two stepper motors with drivers and micro-controller based Motion Control Interface Unit (MCIU)
- Maximum zenith angle coverage upto 85°
- Steady state pointing accuracy of servo is ± 10 arc sec
- Maximum slew rate : 30°/min

MCIU

Pointing accuracy of a mirror : 12.5 arcmin (SD=6.95 arcmin)

Pointing offsets for 49 mirrors



K. S. Gothe et al., Experimental Astronomy, Vol. 35, p. 489-506, 2013

Data Acquisition System

- **High voltages given to individual PMTs are controlled through CAEN controller model (SY1527)**

- **PMT pulses are brought to control room through coaxial cables of type LMR-ultraflex-400 and RG213**

- **Data acquisition through CAMAC based instrumentation**

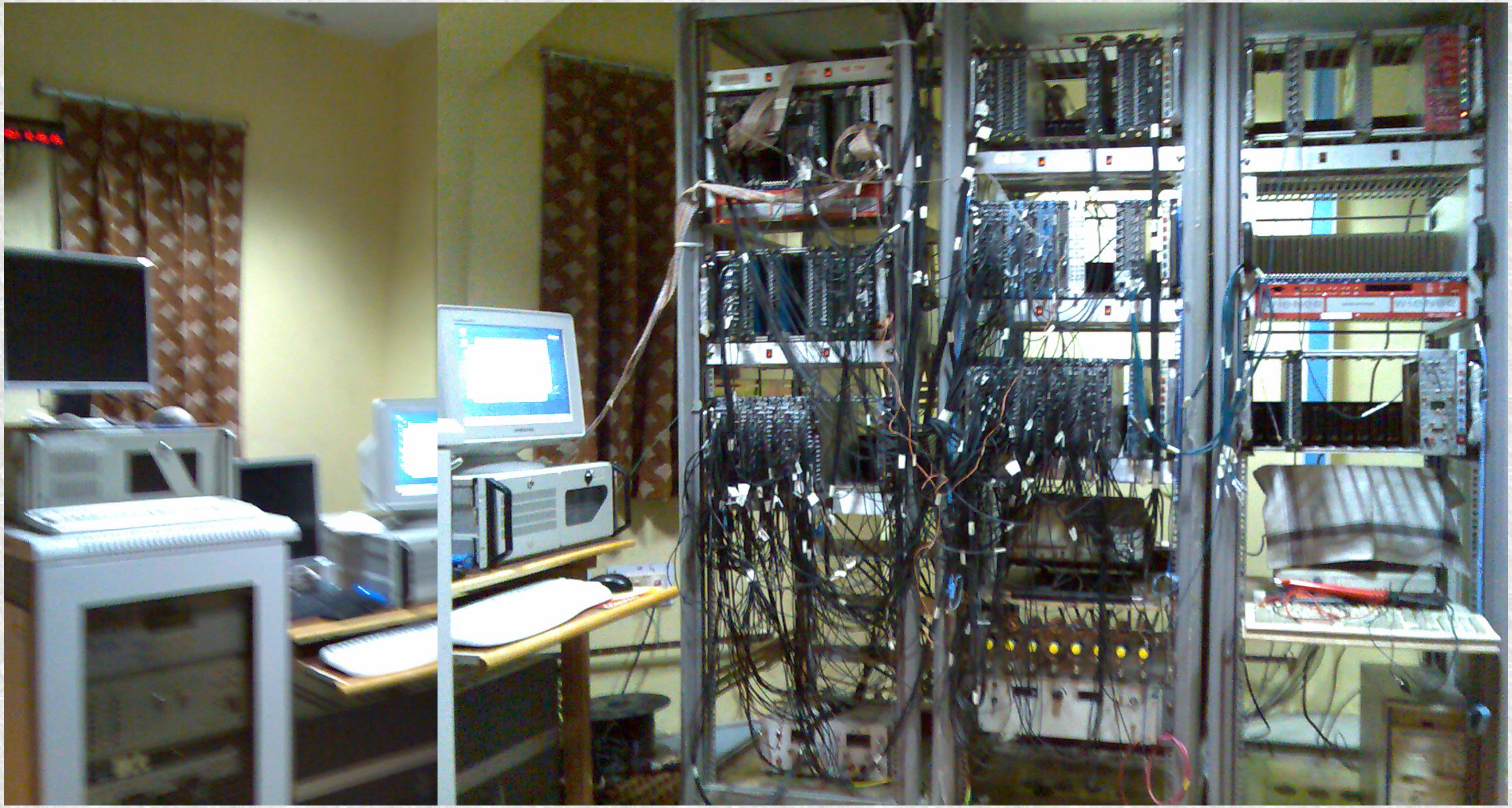
- **Event interrupt generated on coincidence of at least 4 telescope pulses**

- **Data recorded for each event:**
  relative arrival time of shower front at each mirror
  accurate to 0.25 ns using TDCs
  pulse height at each telescope using 12 bit ADC
  absolute event arrival time accurate to s

- **Various count rates recorded every second for monitoring purpose**

- **Cherenkov pulses from telescopes recorded using Acqiris waveform digitizer with sampling rate of 1GS/s**

Data Acquisition and Telescope Control System



CAMAC based => VME based + 8 ch Acqiris Digitiser

Modules Developed In-House

CAMAC controller

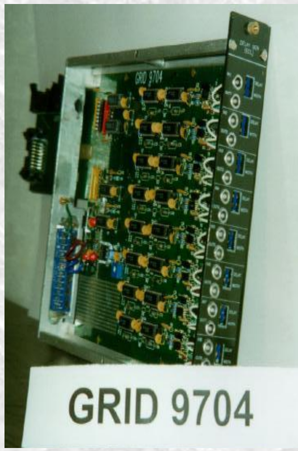
16 ch. CAMAC Latch

16 ch. CAMAC Scaler

CAMAC Real Time Clock

NIM to ECL Converter

ECL Delay Generator



Programmable Delay Generator

HAGAR Trigger Logic

Programmable Discriminator

Simulations for HAGAR

CORSIKA + Detector simulation program developed in-house

CORSIKA v. 6.720 :

VENUS, GHEISHA, EGS4, US standard atmospheric profile
- **Cherenkov photon wavelength range : 200-650 nm**
- **Impact parameter range : 0-300 m**
- **Viewcone : 0-4^0 for cosmic rays**
- **HAGAR geometry, geomagnetic field at Hanle**
- **Mirror reflectivity (80%), PMT quantum efficiency**

Type	Energy range	# of showers generated
Gamma rays	20-5000	1 x 10^6
Protons	50-5000	3 x 10^6
Alpha particles	100-10000	6 x 10^6
Electrons	20-5000	3 x 10^6

Detector simulation program :

NSB generation :
- **2×10^8 ph/cm^2/s/sr**

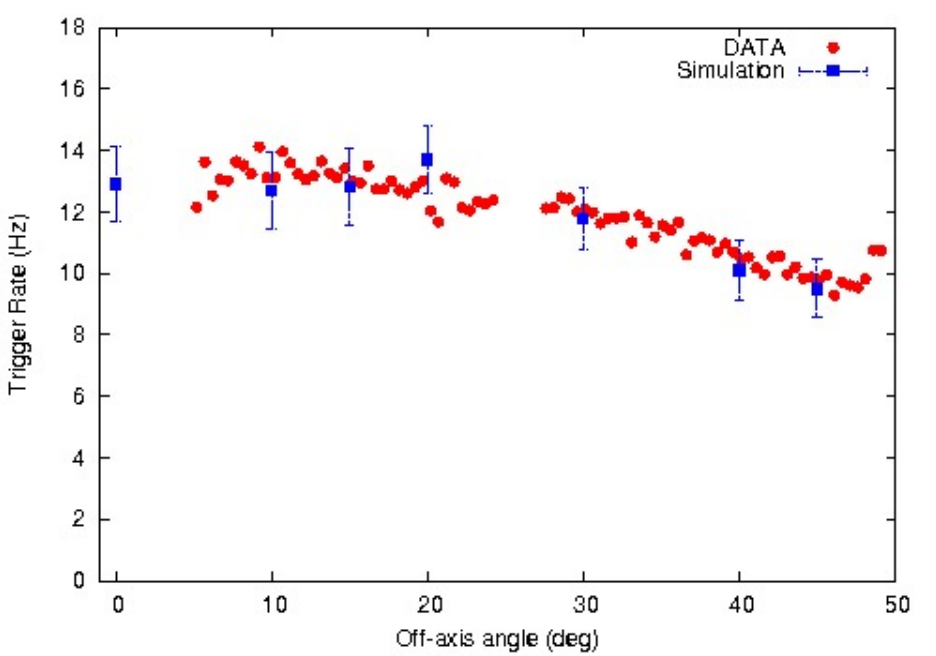
PMT response :
- **gain=6.8×10^6, Gaussian 3 ns rise time**

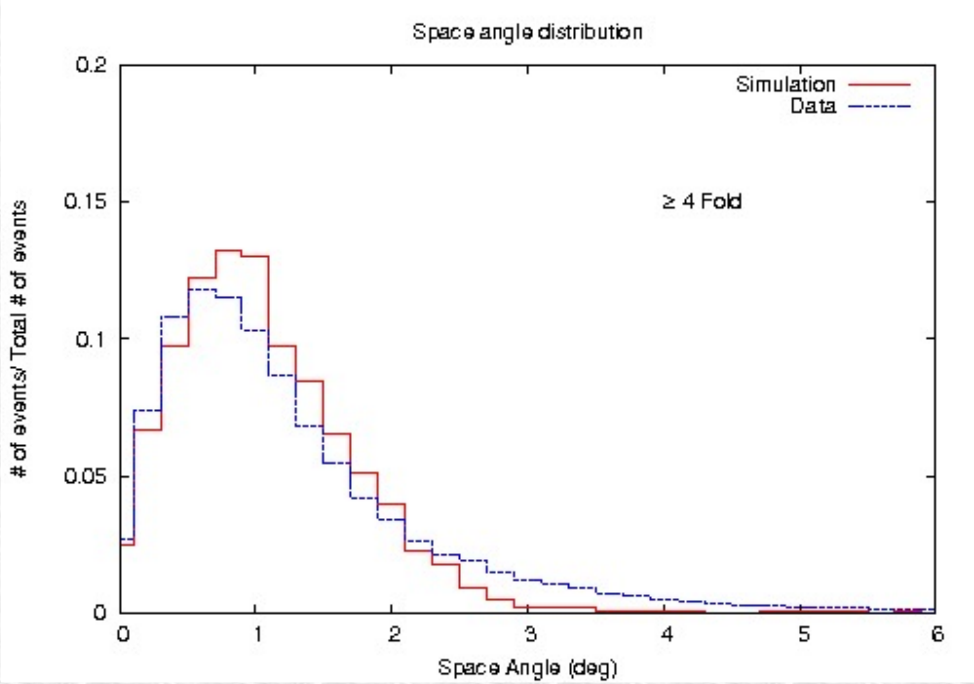
attenuation in coaxial cables :
- **LMR-ultraflex-400 + RG213**

trigger formation :
- **4 fold trigger with 150 ns coincidence window**

Comparison of Simulations with Observations

Variation of trigger rate with zenith angle →





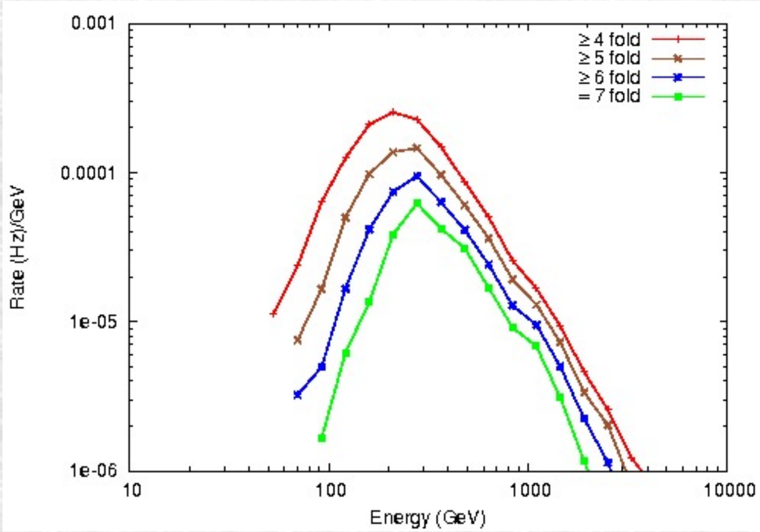
← **Space angle distributions from plane front fitting of Cherenkov shower front**

L. Saha et al. , Astroparticle Physics Vol. 42, p. 33-40, 2013

Performance Parameters of HAGAR

1. Trigger threshold : 17.5 photo-electrons/telescope

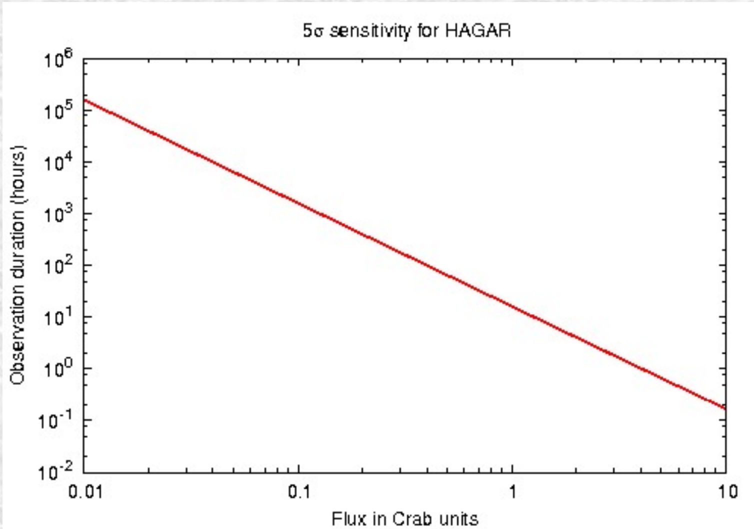
2. Trigger rate : Protons 9.2 Hz, α particles 3.7 Hz, Electrons 0.11 Hz
Total trigger rate ~ 13.0 Hz



3. Energy threshold :

208 GeV for vertical showers
For ≥4 telescopes triggering

4. Expected gamma ray rate from Crab like sources = 6.3/min



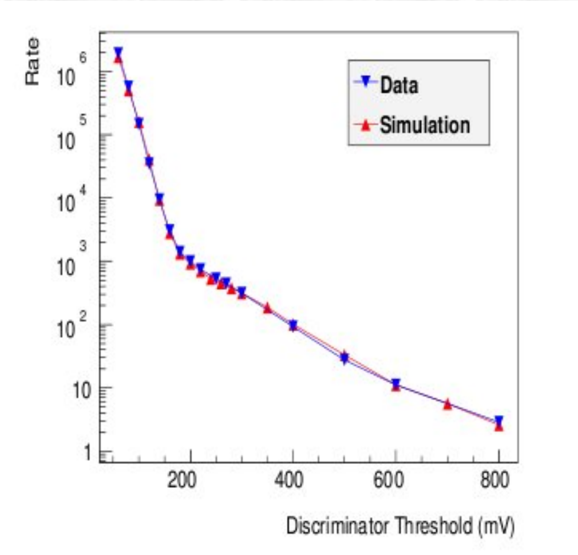
5. Collection area = 3.2×10^4 m^2

6. Sensitivity :
1.2σ/√(hour) for Crab like sources

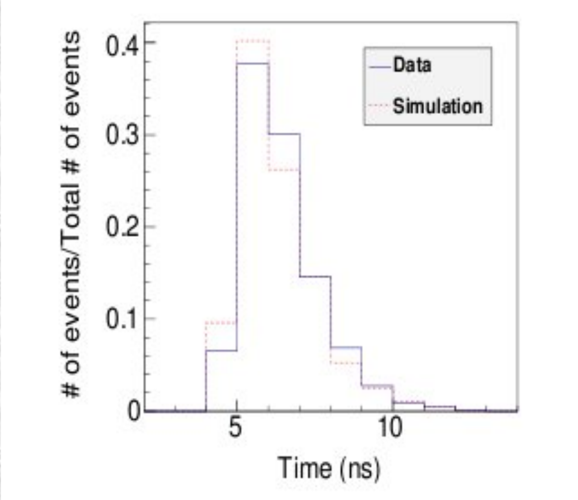
L. Saha et al. , Astroparticle Physics
Vol. 42, p. 33-40, 2013

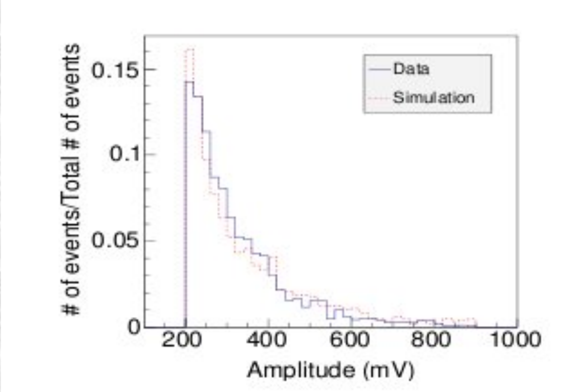
Comparison of Simulations with Observations

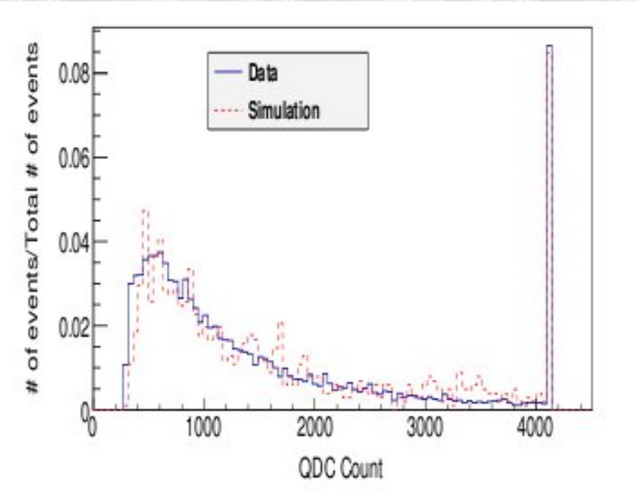
Rate-bias curve



Cherenkov pulse: width and amplitude







← **Charge in pulse**

E. Kundu et al., NSGRA-2013

HAGAR Observation Summary

➢ **Regular observational runs commenced in September, 2008**

Galactic sources

	ON (Hours)	OFF (Hours)
Crab	202.4	189.3
Geminga	126.3	76.1
Fermi pulsars	179.6	70.4
LSI+61 303	44.9	47.7
MGRO J2019+37	30.2	29.45

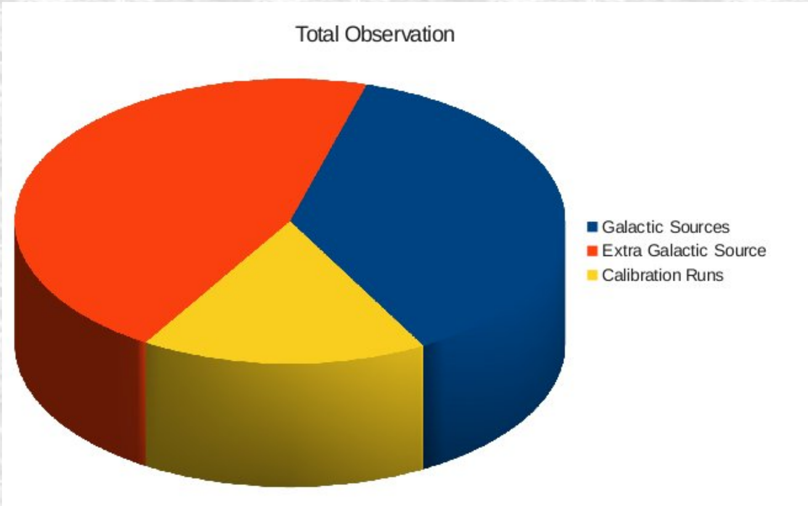
Extragalactic sources

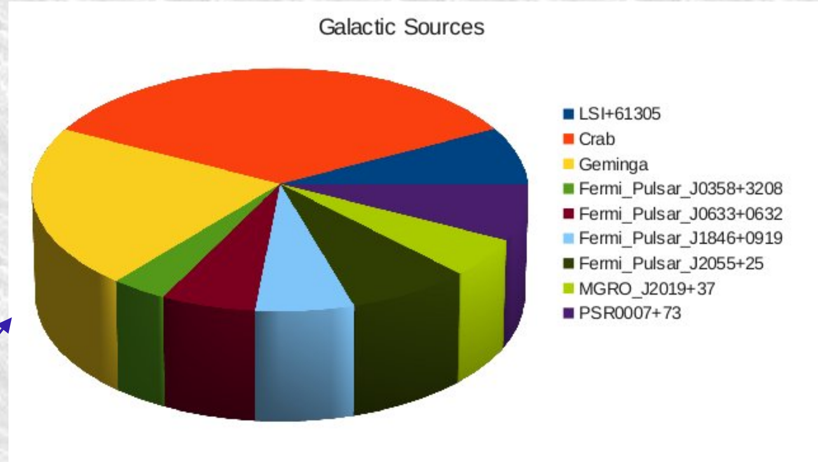
	ON (Hours)	OFF (Hours)
Mrk 421	196.1	227.1
1ES2344+514	114.0	131.0
Mrk 501	121.5	127.1
1ES1218+304	47.7	56.2
BL Lac	40.3	40.3
3C454.3	15.3	15.3
1ES1959+650	6.9	9.5
H1426+428	22.3	23.3
M87	2.0	2.7

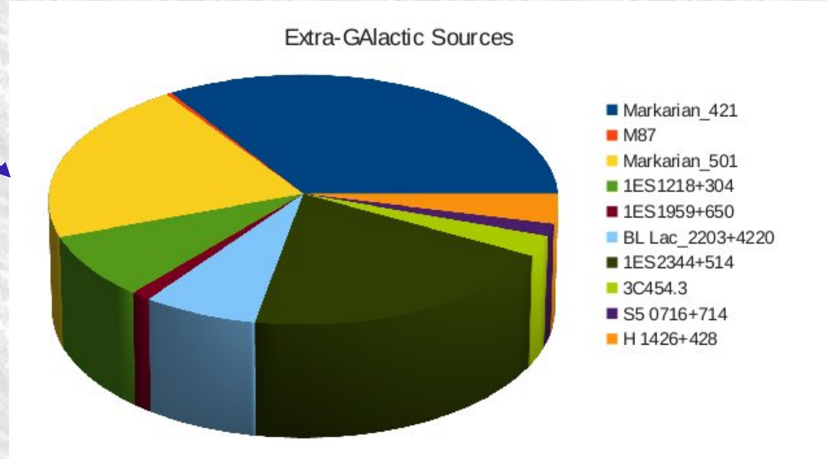
Calibration runs : 448.22 Hours

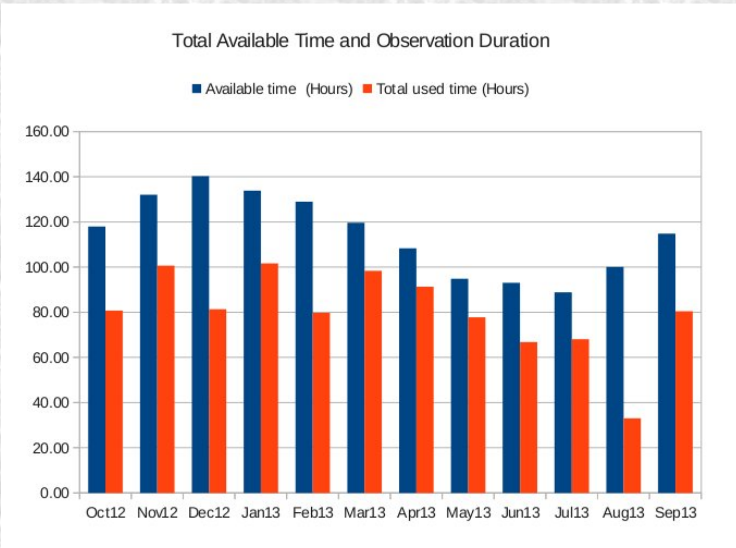
Total observation duration (during September, 2008 – September, 2013) : 2706.62 Hours

HAGAR Observation Summary





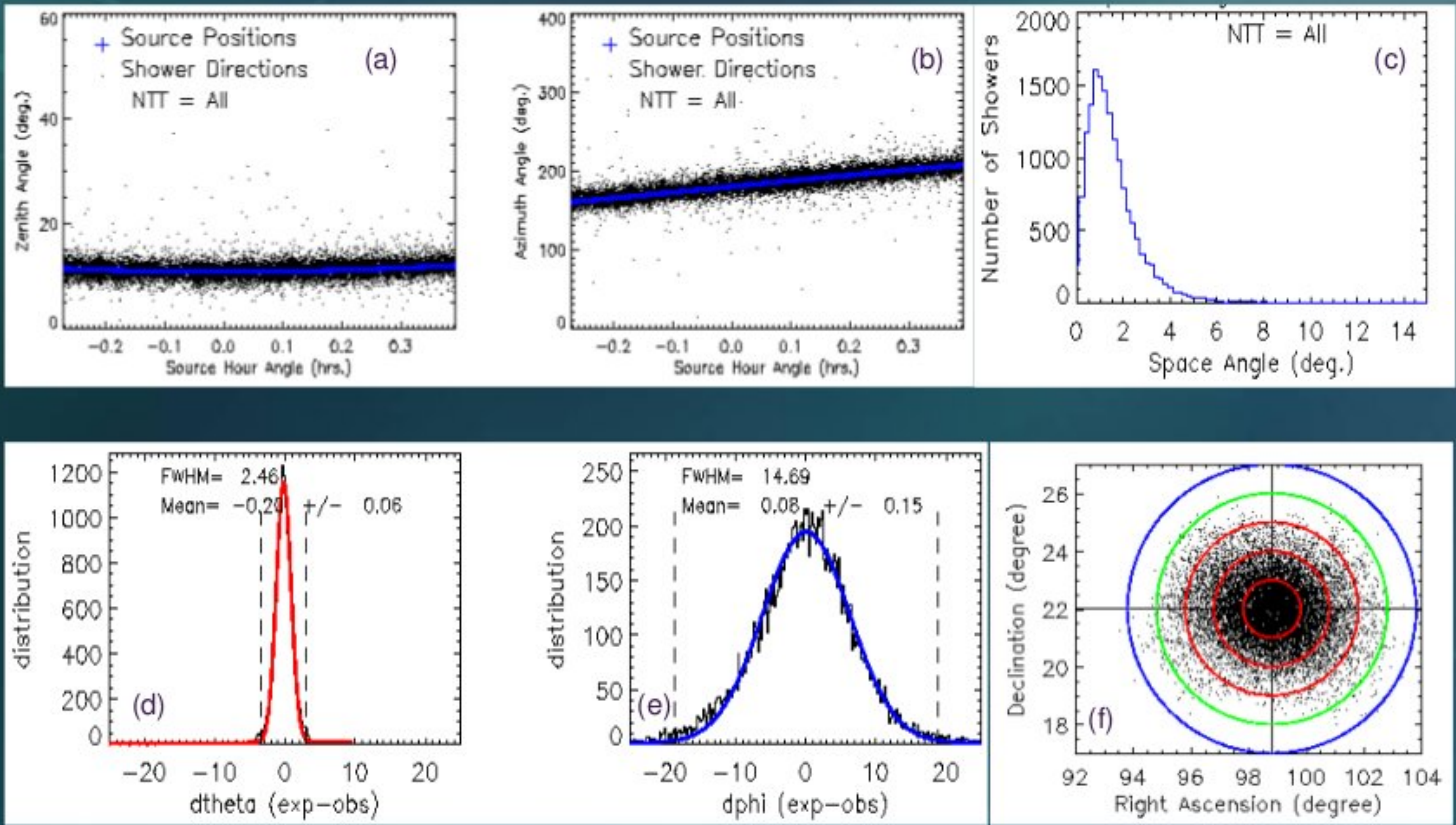




Seasonal variation of observation duration in Oct 2012 – Sept 2013

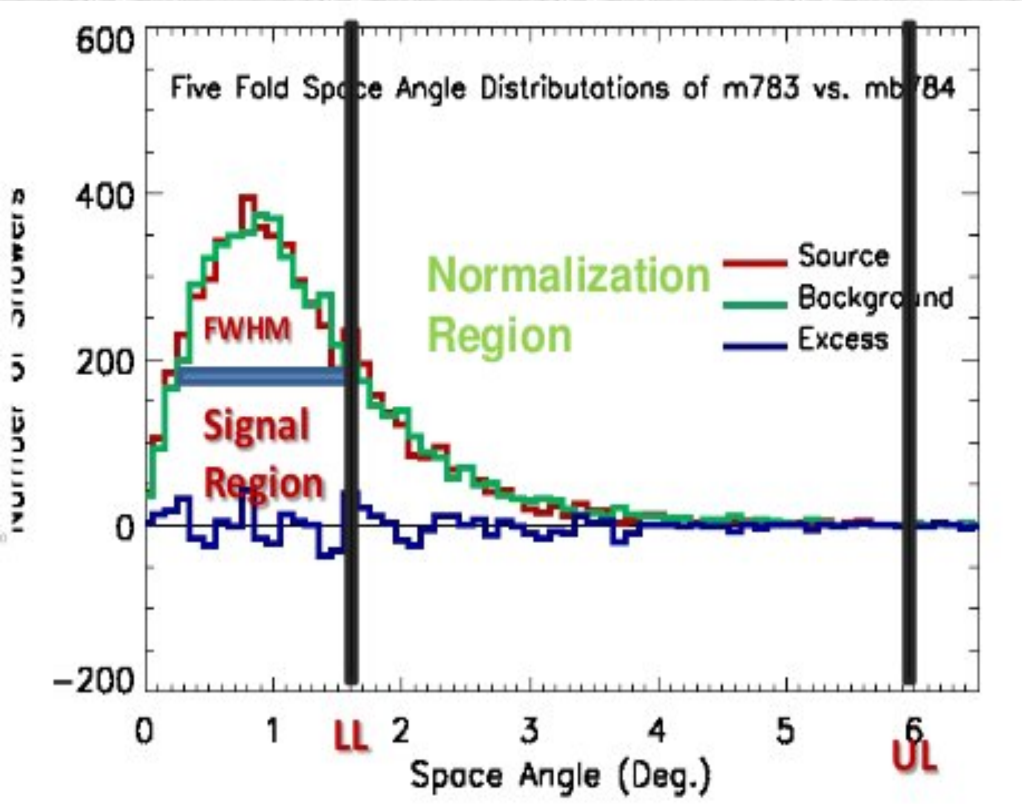
Data Analysis

(II) Event arrival direction profiles



Analysis Method

- Observations carried out in ON-OFF pairs of 40 minutes duration each
- Selection cuts applied based on data quality, stability of rates etc
- Arrival direction of a shower is determined by reconstructing the shower front using arrival time of Cherenkov shower front at each telescope
- Cherenkov shower front approximated by plane front
- Space angle : angle between normal to the plane front and source direction



- Background space angle distributions are normalized w.r.t. source distributions by comparing shapes in LL to UL window
- γ ray signal = excess events

no. Of γ-rays = $\sum$ (S-cB)

C : normalization constant

B. B. Singh et al., NSGRA-2013

Observations & Data

- ON-OFF pairs of 40 minutes duration
- Calibration runs for systematic checks

Source	Observation duration (hours)	Number of Run pairs
Crab	110	171
Dark region	35	53
Delta leo (star m=2.7)	23	34
Milky way	18	32

Data Analysis

Crab region : RA # 05:34:32
DEC # 22:00:52
Epoch # 2000

FoV of HAGAR : 3 degree

Crab nebula

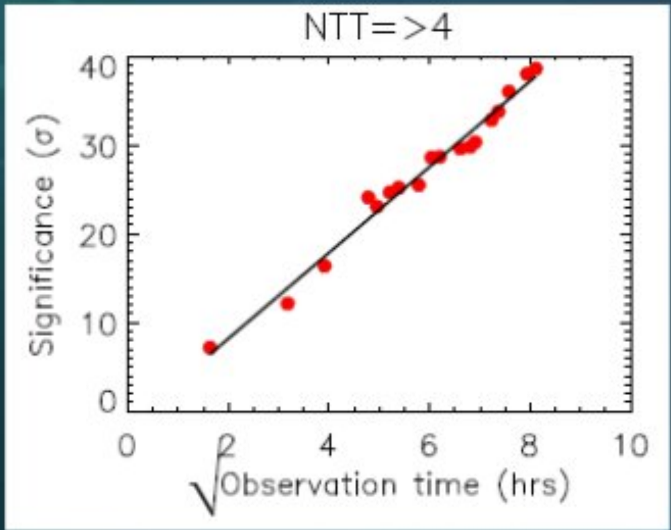
Milkyway

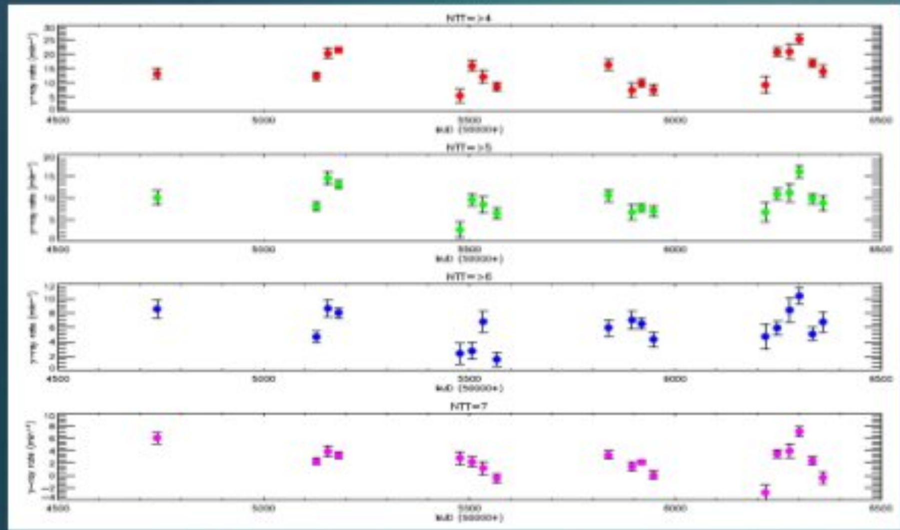
Zeta tauri star, m=3
RA # 05:37:38
DEC # 21:08:33
Epoch # 2000

Dark region

Data Analysis

Result – 1 : Crab region *vs* Dark region

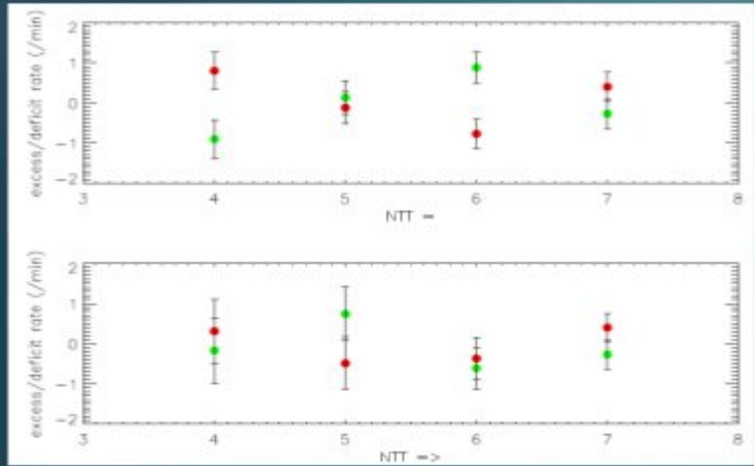




Crab region				Dark region	Milkyway	Star (δ-leo)	Crab	
Total Runs		108/171	Monte-Carlo simulation*					
Total duration (hours)		67.3/109						
NTT	Rate (min^{-1})	σ	Rate (min^{-1})					
≥ 4	15.4 ± 0.4	38.6	6.3					
≥ 5	9.7 ± 0.3	30.1	3.9					
≥ 6	5.9 ± 0.3	23.5	2.4					
≥ 7	2.5 ± 0.2	14.6	1.5					

Data Analysis

Result – 2 : Dark *vs* Dark region

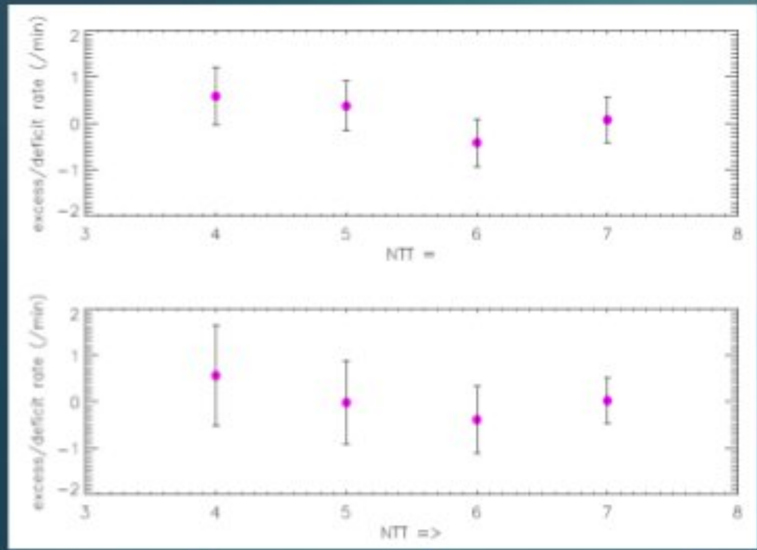


Crab region				Dark region	Milkyway	Star (δ-leo)	Crab
Total Runs		108/167	Monte-Carlo simulation*	40/53			
Total duration (hours)		67.3/109		26.1/34.6			
NTT	Rate (min^{-1})	σ	Rate (min^{-1})	Rate (min^{-1})			
≥ 4	15.4 ± 0.4	38.6	6.3	0.3 ± 0.8			
≥ 5	9.7 ± 0.3	30.1	3.9	-0.5 ± 0.7			
≥ 6	5.9 ± 0.3	23.5	2.4	-0.4 ± 0.5			
≥ 7	2.5 ± 0.2	14.6	1.5	0.4 ± 0.4			

Conclusion: No artificial signal is added if the sky brightness around ON-source and OFF regions are almost same.

Data Analysis

Result – 3 : Milky-way *vs* Dark region



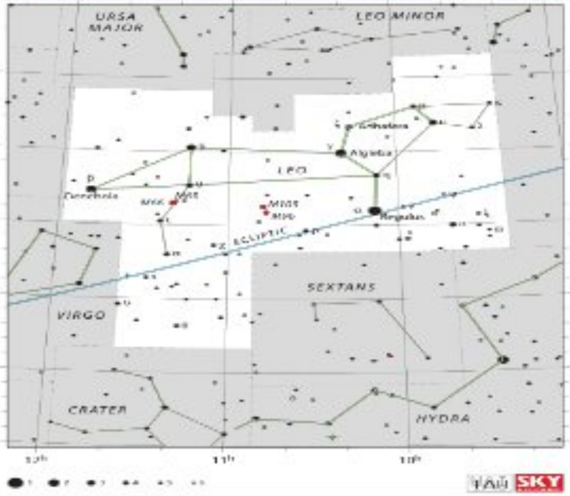
Crab region				Dark region	Milkyway	Star (δ-leo)	Crab
Total Runs		108/167	Monte-Carlo simulation*	40/53	20/32		
Total duration (hours)		67.3/109		26.1/34.6	11.5/17.6		
NTT	Rate (min^{-1})	σ	Rate (min^{-1})	Rate (min^{-1})	Rate (min^{-1})		
≥ 4	15.4 ± 0.4	38.6	6.3	0.3 ± 0.8	0.6 ±1.1		
≥ 5	9.7 ± 0.3	30.1	3.9	-0.5 ± 0.7	-0.1 ±0.9		
≥ 6	5.9 ± 0.3	23.5	2.4	-0.4 ± 0.5	-0.4 ±0.7		
≥ 7	2.5 ± 0.2	14.6	1.5	0.4 ± 0.4	0.1 ± 0.5		

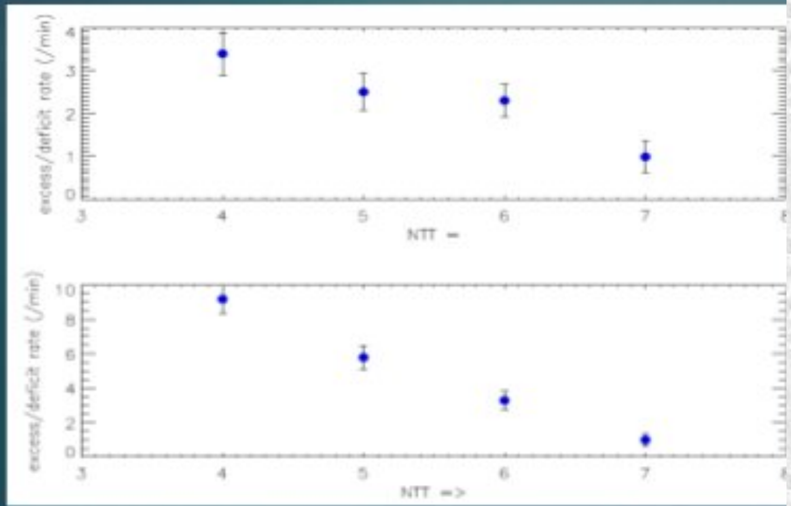
Conclusion: No systematic/artificial signal is added due to brightness of the milky-way.

Data Analysis

Result – 4 : Star *vs* Dark region

On-source : δ-leo
Off-source : dark region



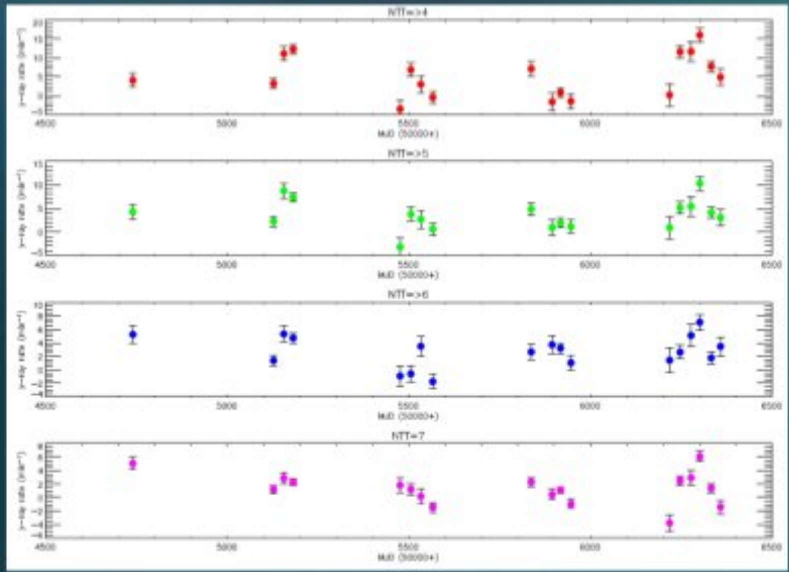


Crab region				Dark region	Milkyway	Star (δ-leo)	Crab
Total Runs		108/167	Monte-Carlo simulation*	40/53	20/32	24/34	
Total duration (hours)		67.3/109		26.1/34.6	11.5/17.6	17.3/22.7	
NTT	Rate (min^{-1})	σ	Rate (min^{-1})	Rate (min^{-1})	Rate (min^{-1})	Rate (min^{-1})	
≥ 4	15.4 ± 0.4	38.6	6.3	0.3 ± 0.8	0.6 ±1.1	9.2 ± 0.8	
≥ 5	9.7 ± 0.3	30.1	3.9	-0.5 ± 0.7	-0.1 ±0.9	5.8 ± 0.7	
≥ 6	5.9 ± 0.3	23.5	2.4	-0.4 ± 0.5	-0.4 ±0.7	3.3 ± 0.5	
≥ 7	2.5 ± 0.2	14.6	1.5	0.4 ± 0.4	0.1 ± 0.5	0.9 ± 0.4	

Conclusion: A star of magnitude 3 located at distance of 1 degree from a γ-ray source adds substantial systematic/artificial signal.

Data Analysis

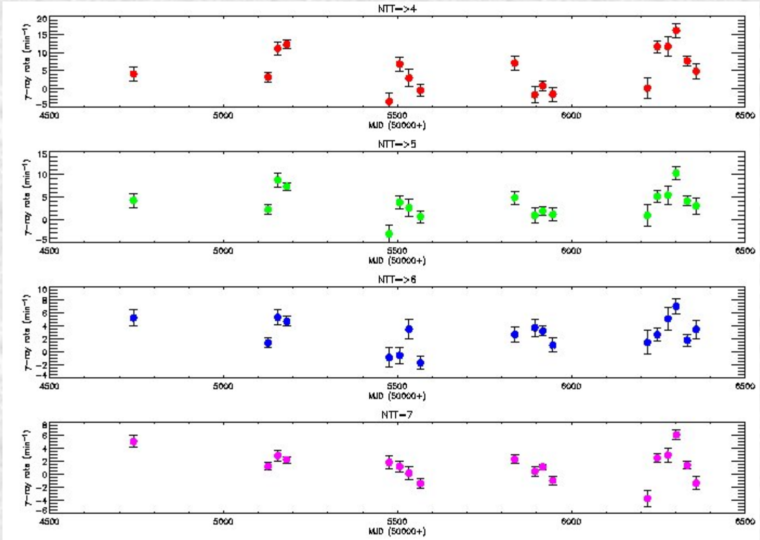
Result – 4 : Crab *vs* Dark region



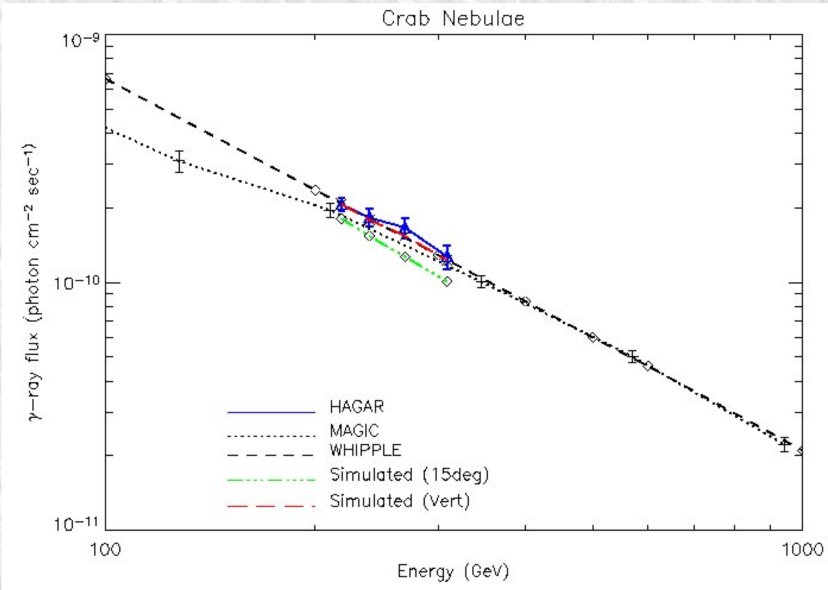
Crab region				Dark region	Milkyway	Star (δ-leo)	Crab	
Total Runs		108/167	Monte-Carlo simulation*	40/53	20/32	24/34		
Total duration (hours)		67.3/109		26.1/34.6	11.5/17.6	17.3/22.7		
NTT	Rate (min^{-1})	σ	Rate (min^{-1})	Rate (min^{-1})	Rate (min^{-1})	Rate (min^{-1})	γ (min^{-1})	σ
≥ 4	15.4 ± 0.4	38.6	6.3	0.3 ± 0.8	0.6 ±1.1	9.2 ± 0.8	6.2 ±0.4	15.5
≥ 5	9.7 ± 0.3	30.1	3.9	-0.5 ± 0.7	-0.1 ±0.9	5.8 ± 0.7	3.9 ±0.3	12.1
≥ 6	5.9 ± 0.3	23.5	2.4	-0.4 ± 0.5	-0.4 ±0.7	3.3 ± 0.5	2.6 ±0.3	10.4
≥ 7	2.5 ± 0.2	14.6	1.5	0.4 ± 0.4	0.1 ± 0.5	0.9 ± 0.4	1.6 ±0.2	8.9

HAGAR Results : Crab Nebula

- **Only runs near transit of the source selected**
- **Observation duration after applying data quality cuts for data collected in 2008-2013 = 67.3 hours**



#triggering telescopes	γ-ray rate (per minute)	Significance σ
≥4	6.18±0.40	15.5
≥5	3.90±0.32	12.1
≥6	2.61±0.25	10.4
=7	1.67±0.17	8.96



Crab flux = (2.07 ± 0.13) x10^{-10} ph/cm^2/s for threshold of 218 GeV

B. B. Singh et al. NSGRA-2013

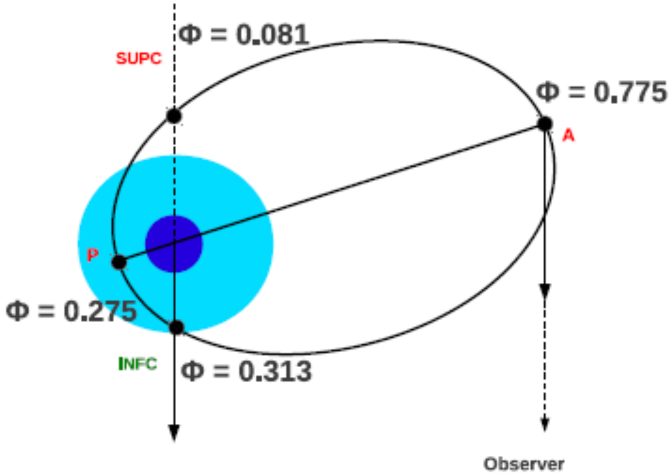


Figure 4.6: Orbital geometry of LSI 61+303. The phases for Inferior conjunction (INFC), Superior conjunction (SUPC), periastron (P), and apastron (A) are shown following Ref. [101] and they occur at orbital phases 0.313, 0.081, 0.275 and 0.775, respectively.

Figure 4.7: Location of LSI 61+303 (red circle with size 3 degrees; ON-source region) in the sky along with the two background regions (green circles with sizes 3 degrees; OFF-source regions).

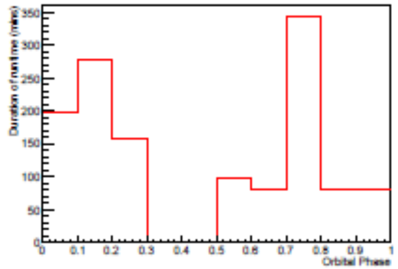


Figure 4.8: Distribution of orbital phase vs exposure time for the observation of LSI 61+303.

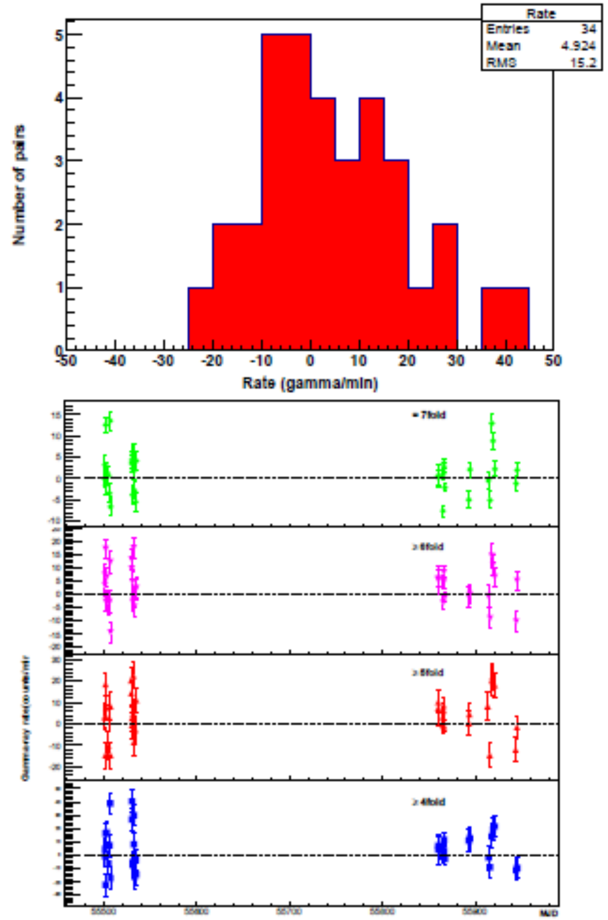


Figure 4.9: *Upper*: Distribution of gamma-ray rates for 34 pairs of LSI 61+303 for NTT ≥ 4. *Lower*: Light curve of LSI 61+303 for different trigger conditions.

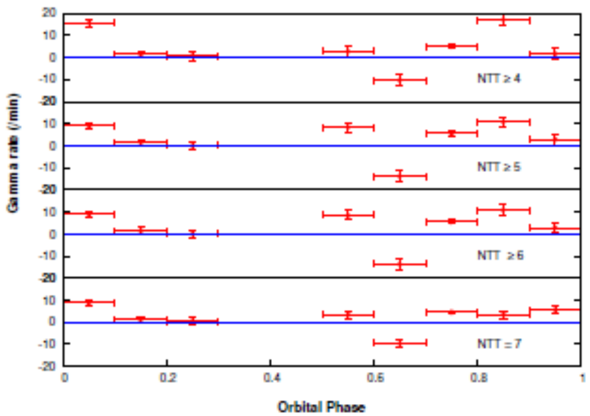
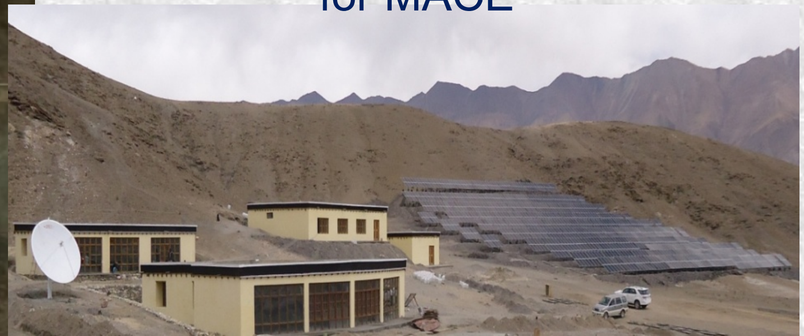


Figure 4.10: Gamma ray rates of LSI +61 303 as a function of orbital phase for different telescope trigger conditions.

Status at Hanle site

240 KWp Solar Power Plant
for MACE



Subsystems of the MACE telescope

Mechanical Structure (150T)

Mirror Panels (1564/4)

Mirror Alignment System

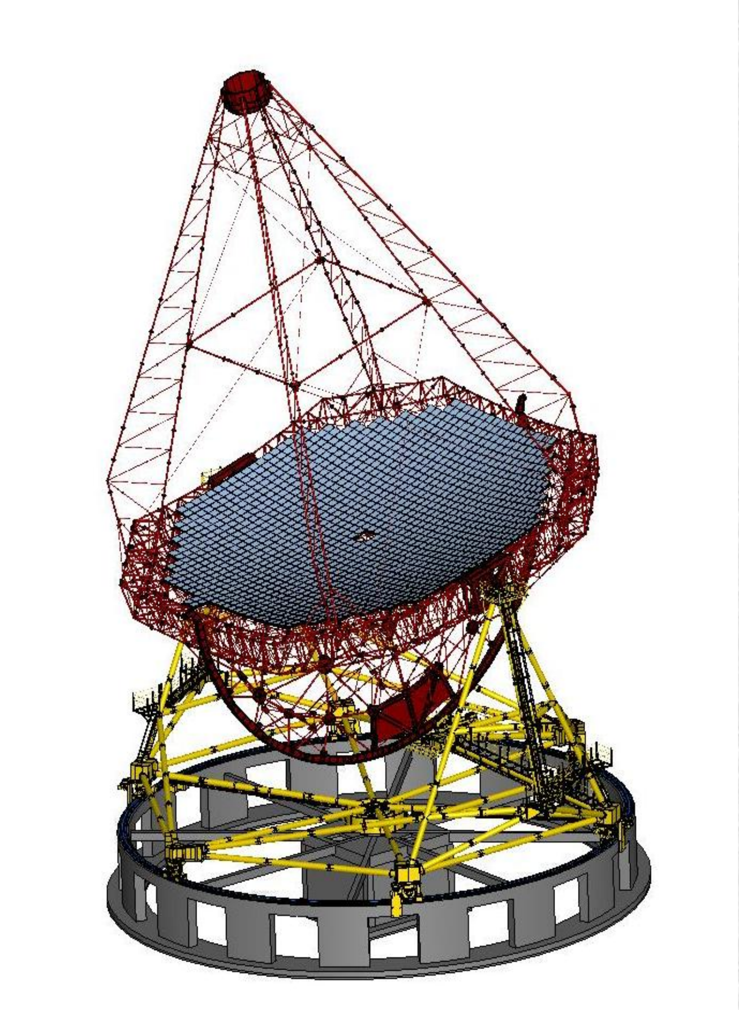
Bull Gear & Drive System

Modular Camera Electronics

Instrumentation Shelters

Data Connectivity

Data Archive



R. Koul et al. NSGRA-2013

Assembly status in Jan, March & May 2013

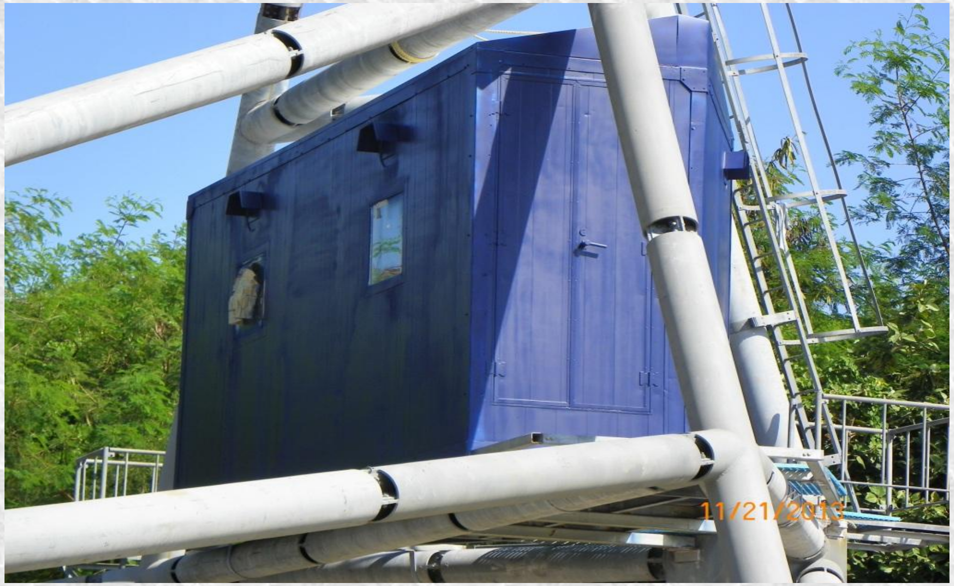
Transportation requirements (size < 5mx3m)

21m MACE PROOF ASSEMBLY PROGRESS AT AP&SD/ECIL ON 15.05.2014

TDU At Site

TDU RACK

Motorized AZ Axis Wheel



Shelter mounted on Structure

Mirror Assembly

1310 out of 1564 quality Diamond turned Al alloy mirror facets ready.

30 panels assembled & ready for deployment

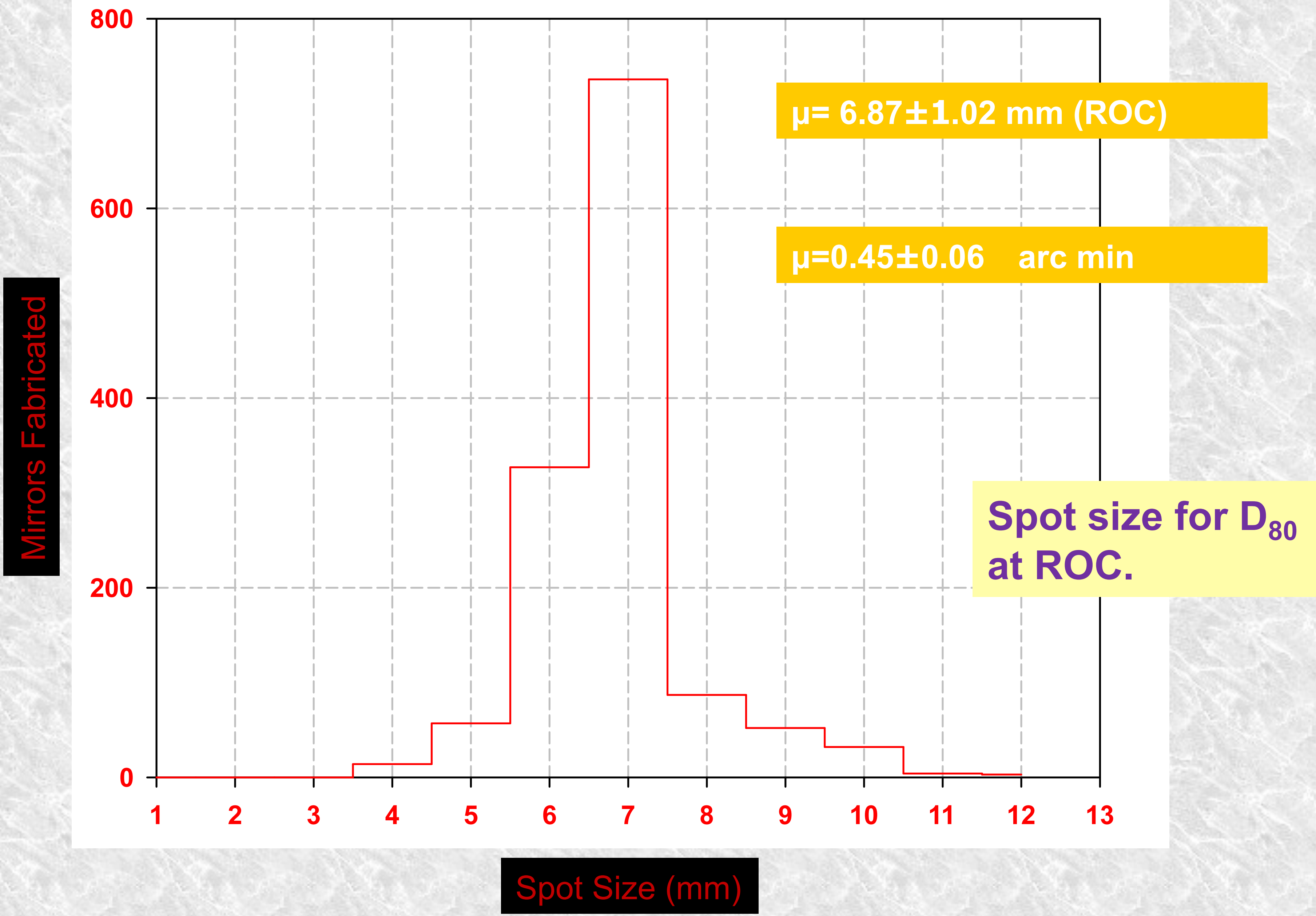
On-axis spot size of assembled panels measured < 5mm diameter

Storage and transportation boxes for panels

9-panel mirror alignment system assembled

Manufacture of Actuators

Spot-size distribution status after (**1310 mirrors**)



Alignment at mirror and at panel side procedure

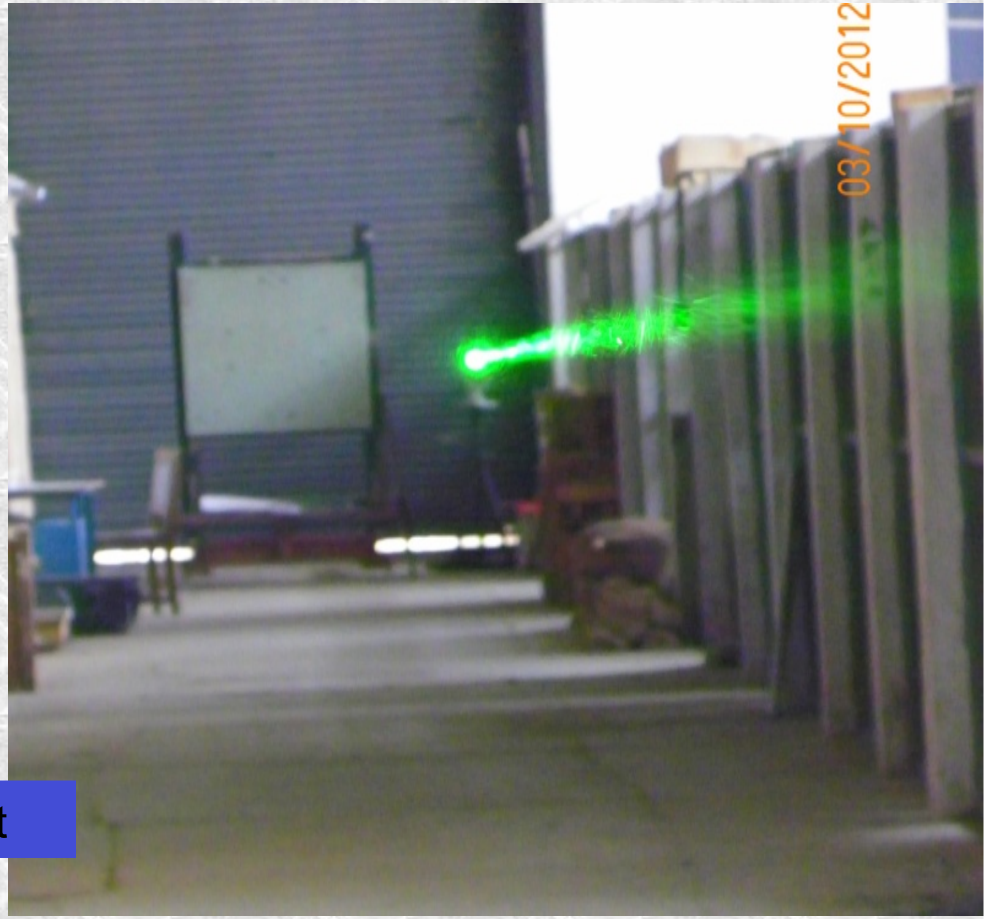
aligning 2 panels in a day,
to be speedup

Torque behind the mirror facets and
behind the panel

4 Aligned mirrors on Panel

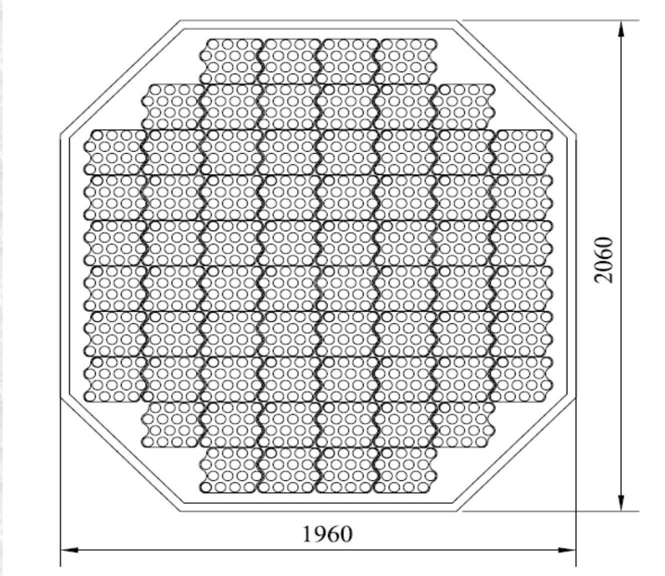
Panel re-arrangement

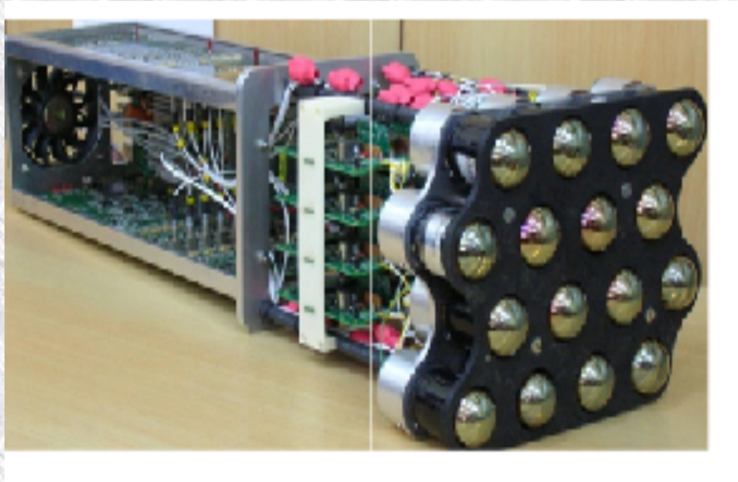
Laser & Screen



MACE Camera

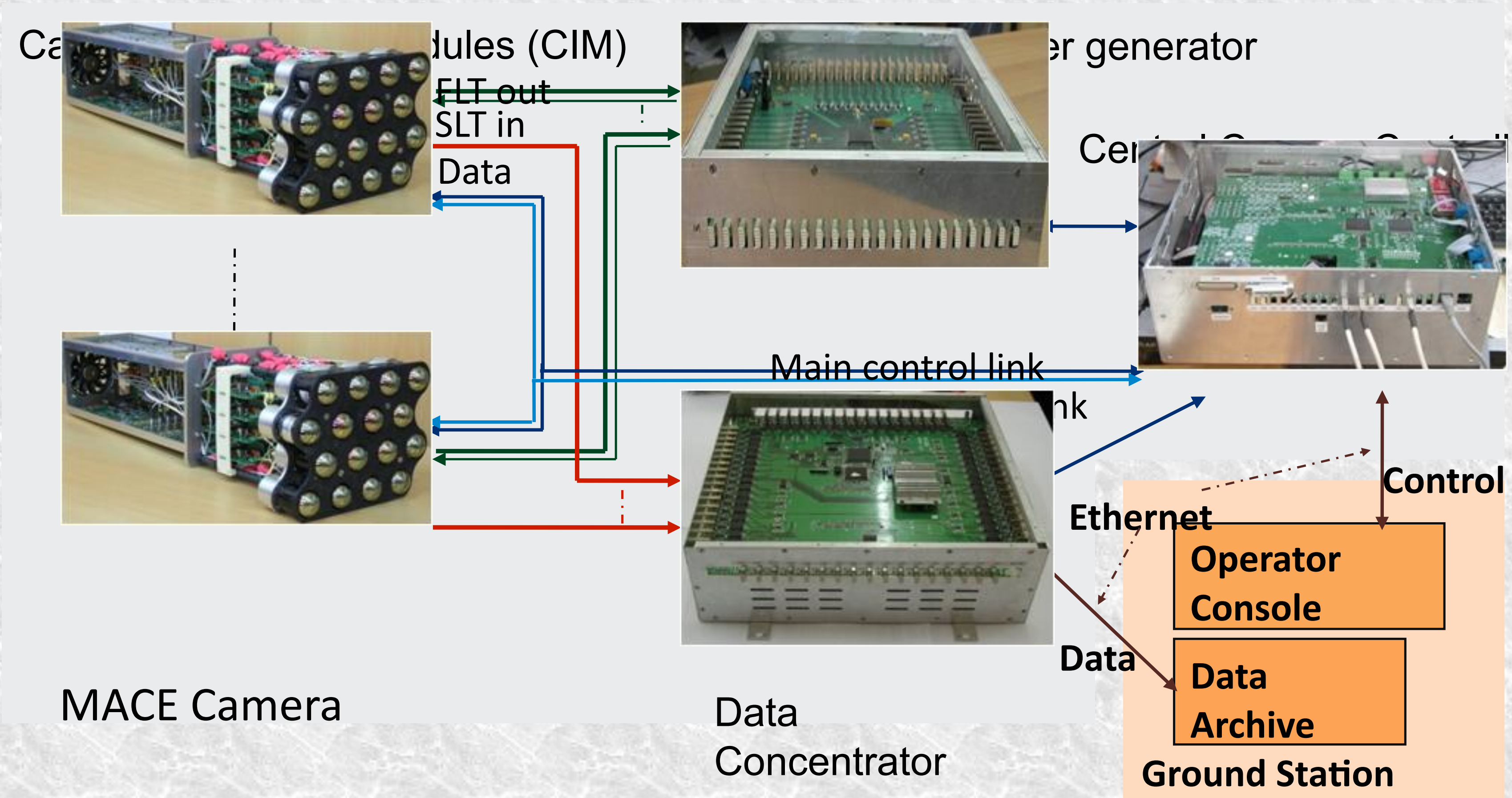
- 1088 PMTs (ETE 9117 WSB) with a uniform pixel resolution 0.125 deg.
- 16 PMTs are arranged in a Camera Integrated Module (CIM).
- PMTs are powered by Voltage Divider Network (VDN) .
- The socket, VDN and a pre-amplifier assembly is housed in a metallic enclosure.
- Programmable HV required for PMT gain matching is mounted close to PMT tubes.





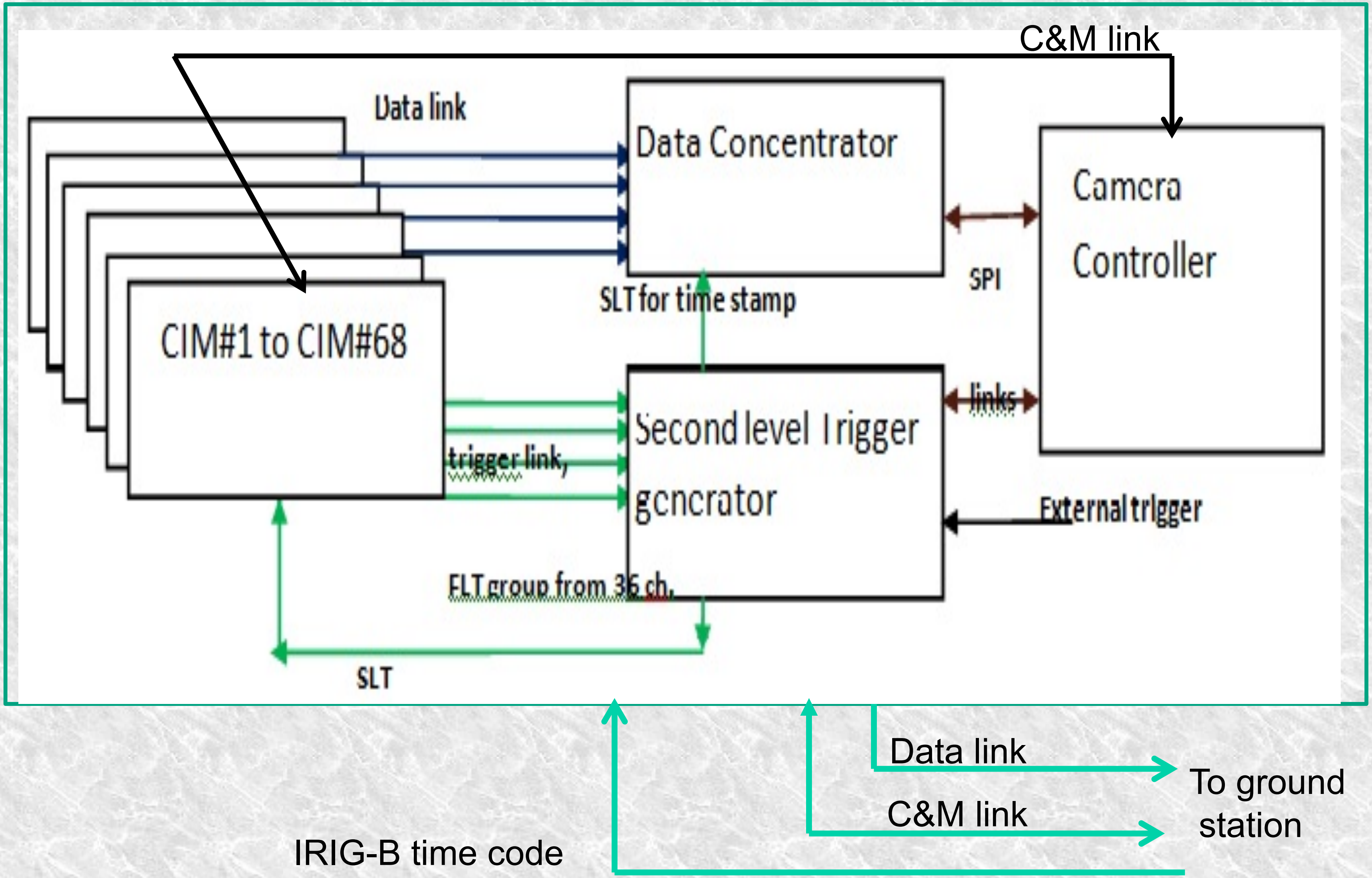
Picture courtesy: ED

Status: Integration of fully assembled 4 CIM modules with DC, CCC, SLTG, Console, Data Archive, Master Clock is completed. Performance evaluation in progress



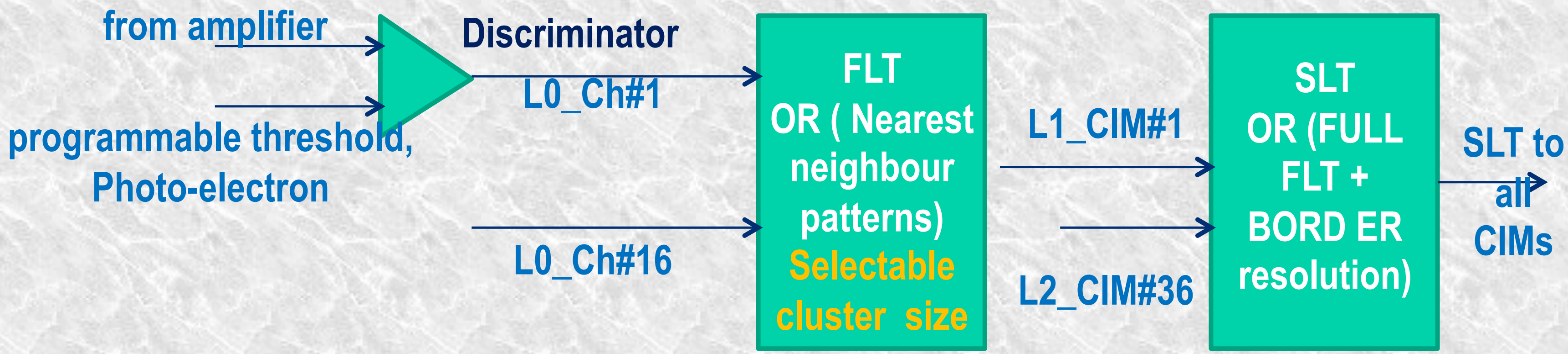
64 channel prototype camera housing

Overall architecture - Block diagram of camera electronics



Entire electronics on camera,
only power and communication cables to camera from ground station

Trigger generation, **MACE** telescope
– two stage, two phase pattern based coincidence



First Level Trigger -

- effective coincidence window ~ 5-6 ns
- pe threshold ~ 3-5 photo-electrons
- Selectable tight cluster pattern of 3 to 6 pixels
- Nearest neighbour FULL trigger and partial border triggers,
- Border strength - STRONG, MEDIUM, WEAK

Lower power, lower volume. Allows to compensate for PMT transit time variation with respect to high voltage bias

Camera Electronics

One 16 channel CIM tested extensively

Assembly of three additional modules

Integrated testing of 64 channels to start soon

Bulk production to start after 64 ch. testing

Data Archive – specifications finalised &

procurement initiated

Data connectivity – Anunet link

Revised time-line

Review of Telescope Structure assemby:June11-12, 2014

Alignment & Drive tests : from 15 June 2014

Dismantling of structure : 1 July 2014

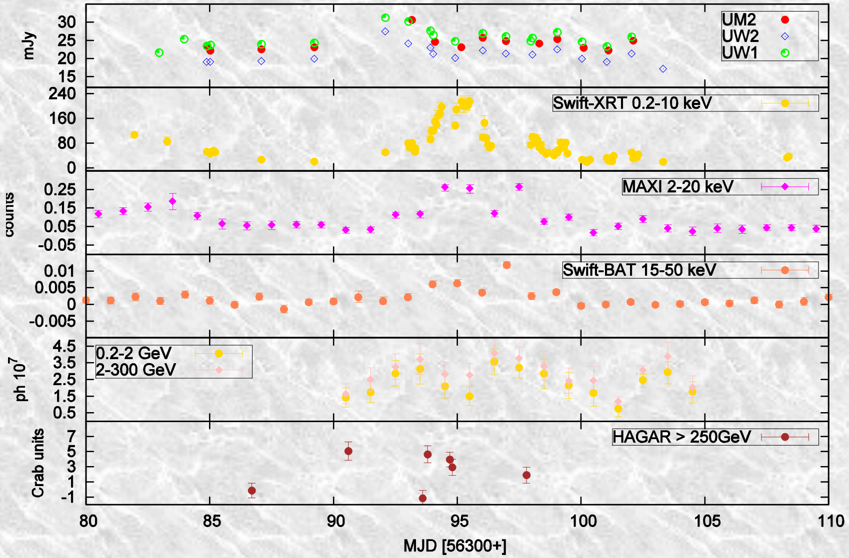
Transportation to Hanle : 1 Aug 2014

start Installation at Hanle: 1 Sept 2014

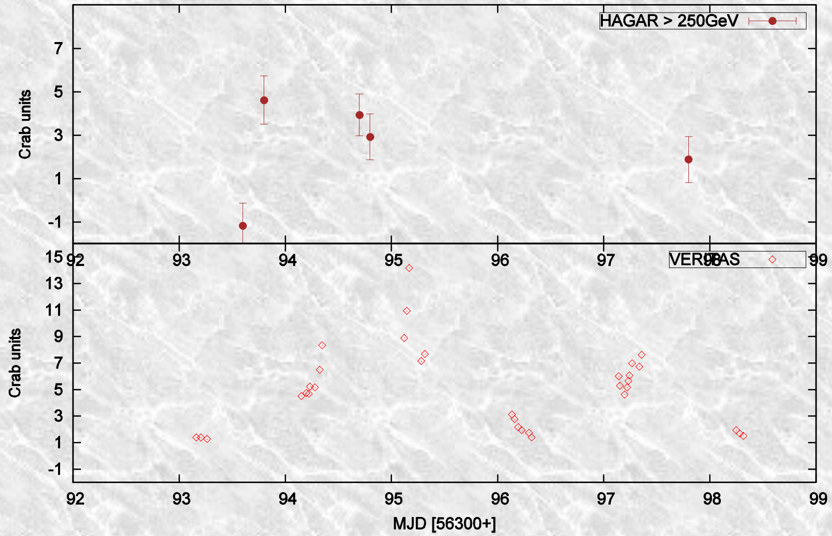
finish Installation by mid 2015


42
42
Thanks

Mkn421



mJy
UM2
UW2
UW1
Swift-XRT 0.2-10 keV
counts
MAXI 2-20 keV
Swift-BAT 15-50 keV
ph 10^7
0.2-2 GeV
2-300 GeV
Crab units
HAGAR > 250GeV
MJD [56300+]



HAGAR > 250GeV
Crab units
VERITAS
Crab units
MJD [56300+]

Figure 4.11: Location of the MGRO J2019+37 (3 degree red circle; ON-source region) in the sky along with the two background regions (3 degree green circles; OFF-source regions).

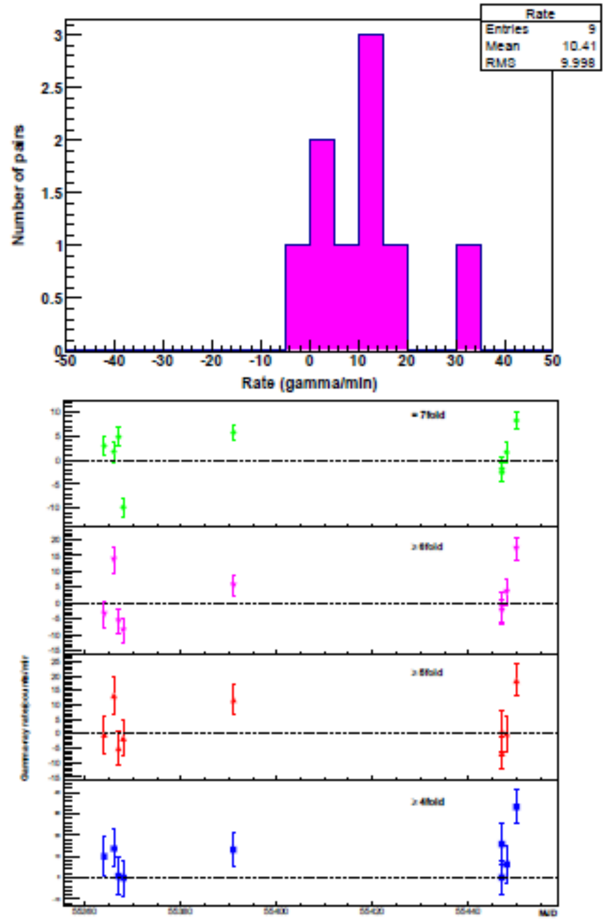


Figure 4.12: *Upper*: Distribution of gamma-ray rates for all 9 pairs for NTT ≥ 4. *Lower*: Light curve for MGRO J2019+37 for all 9 pairs for different telescope triggering conditions.