# Observations with the *High Altitude GAmma-Ray* (HAGAR) telescope array in the Indian Himalayas

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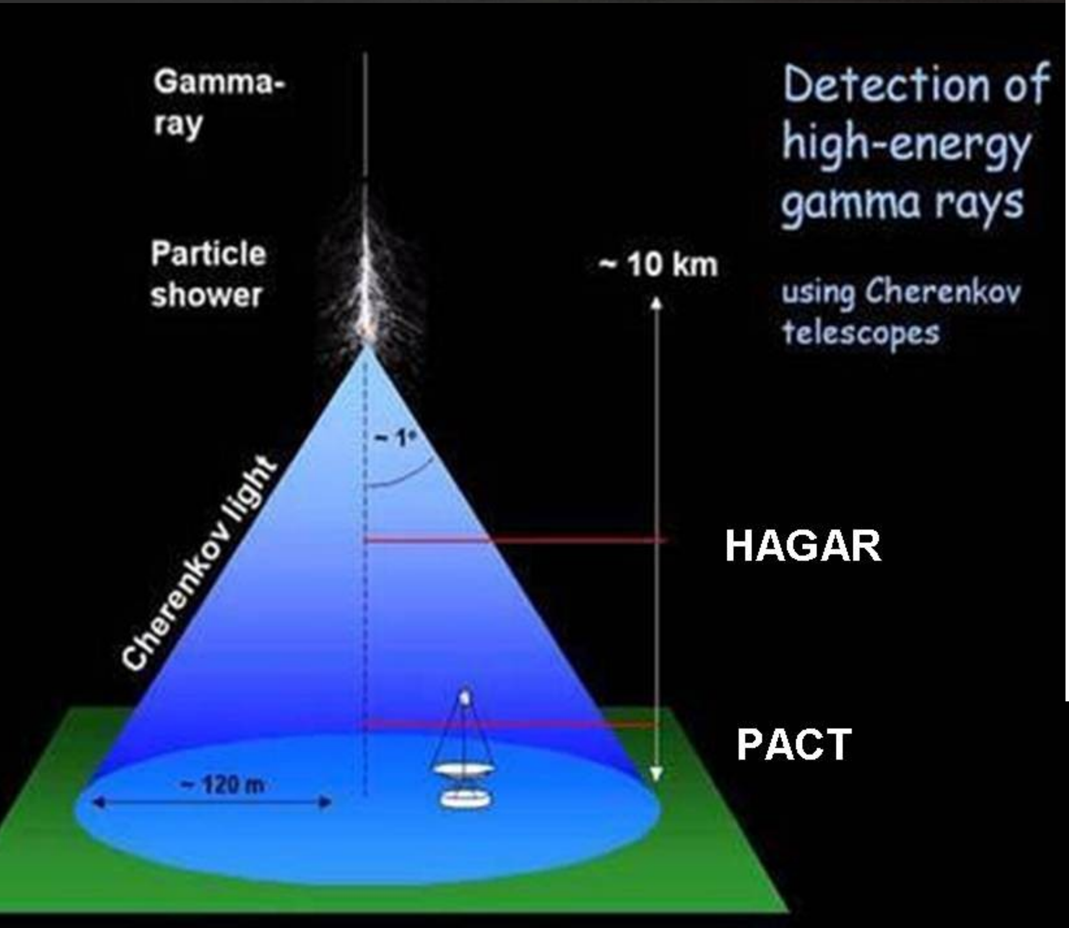
# Outline

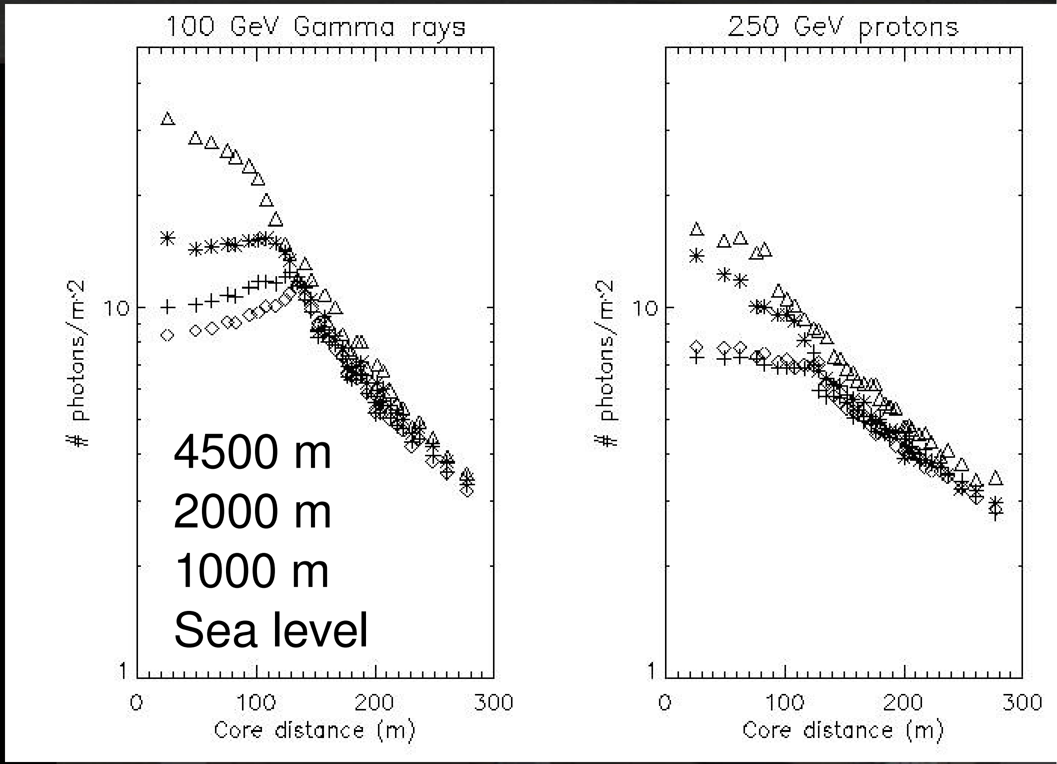
- The HAGAR experiment
- Observations & analysis method
- Preliminary results & expected improvements
- The MACE project
- Summary

## Lowering energy threshold with atmospheric Cherenkov experiments at high altitude

- Maximize Cherenkov photon density on the mirrors

- Minimize atmospheric attenuation




--> Significant reduction in energy threshold at higher altitudes

# HImalayan Gamma-Ray Observatory (HIGRO)

Collaboration between BARC & TIFR (Mumbai), IIA (Bangalore) & SINP (Kolkata)


**Phase 1:** HAGAR (IIA+TIFR) 7 element wavefront sampling array (non-imaging);
Now operating

**Phase 2:** 21 m Dia MACE (BARC) imaging Tel.
Expected in 2012

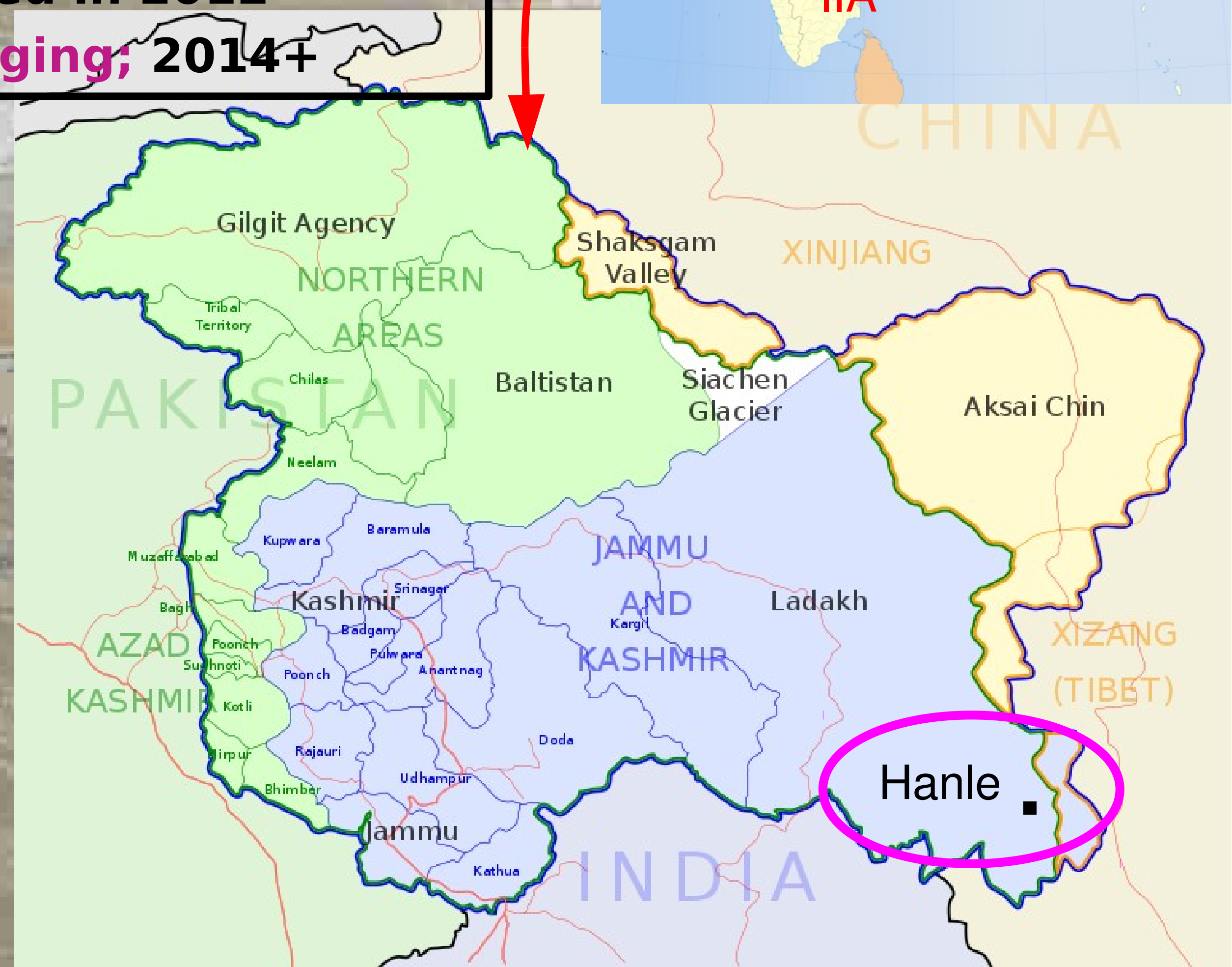
**Phase 3:** MACE-II Stereo imaging; 2014+

## Location :

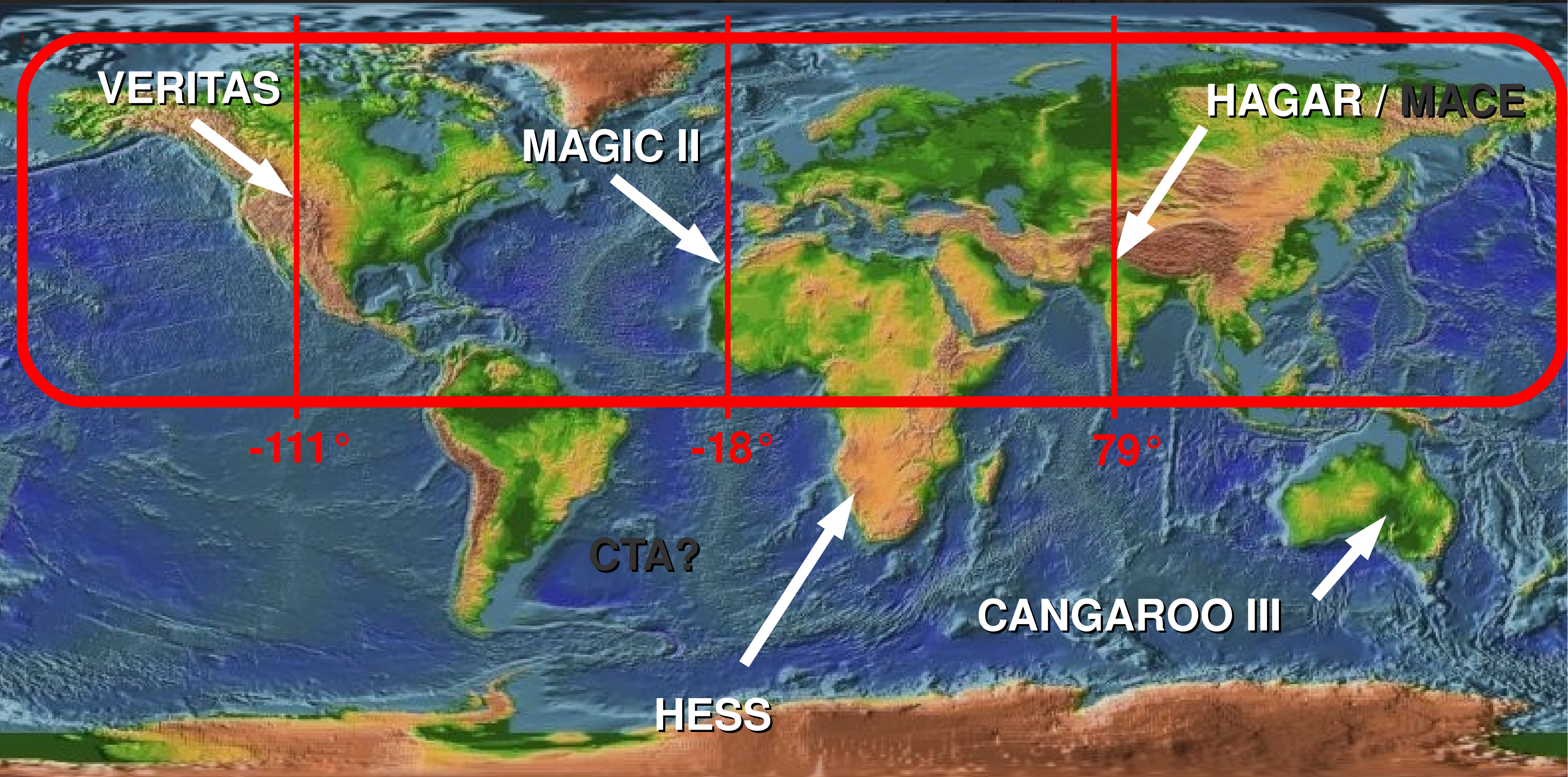
- Latitude: 32° 46' 46'' N
- Longitude: 78° 57' 51'' E
- Altitude : 4300 m

## Site Characteristics :

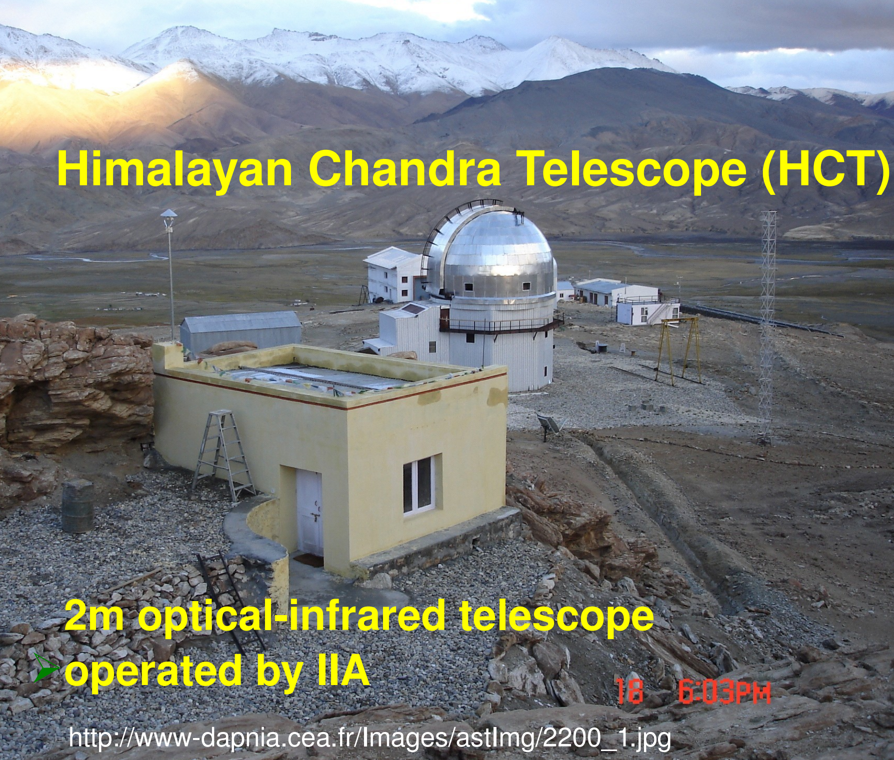
- Low sky brightness
- Low humidity
- Easy accessibility
- Observations throughout ~ 10 lunar periods / year



# The sites of the 4 world largest gamma-ray experiments + HAGAR / MACE



# HAGAR: High Altitude Gamma-Ray




Himalayan Chandra Telescope (HCT)

- 2m optical-infrared telescope operated by IIA

http://www-dapnia.cea.fr/Images/astImg/2200_1.jpg

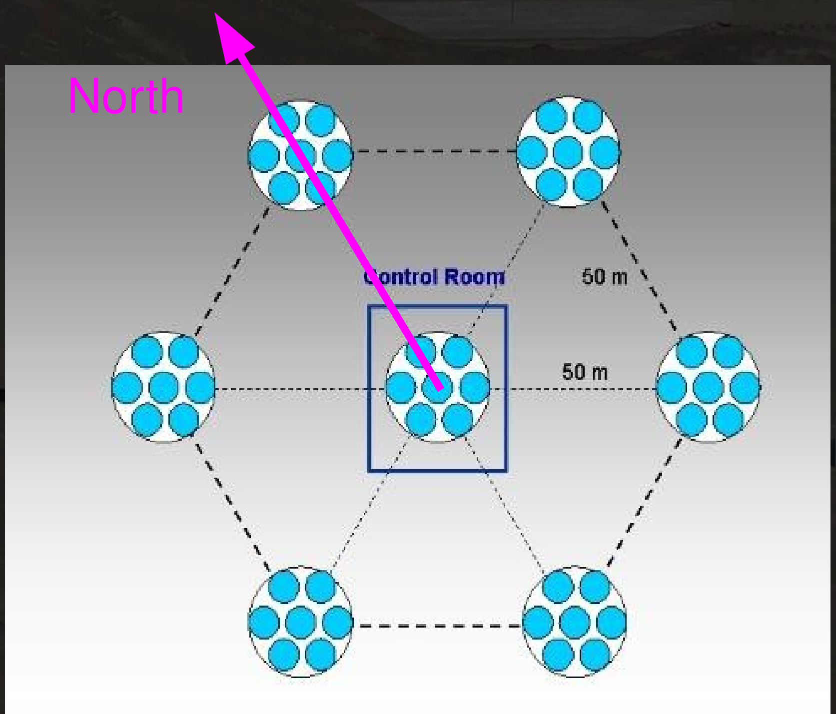


HAGAR telescope array @ 4300 m amsl

# High Altitude GAmma Ray (HAGAR) Experiment

- Experiment based on wavefront sampling technique
- Completely indigenously designed and assembled
  Civil and mechanical : IIA, Optics and DAQ : TIFR

**31 $m^2$ of mirrors for the 1st experiment using atmospheric Cherenkov technique at a so high altitude (4300 m – SHALON: 3300 m)**



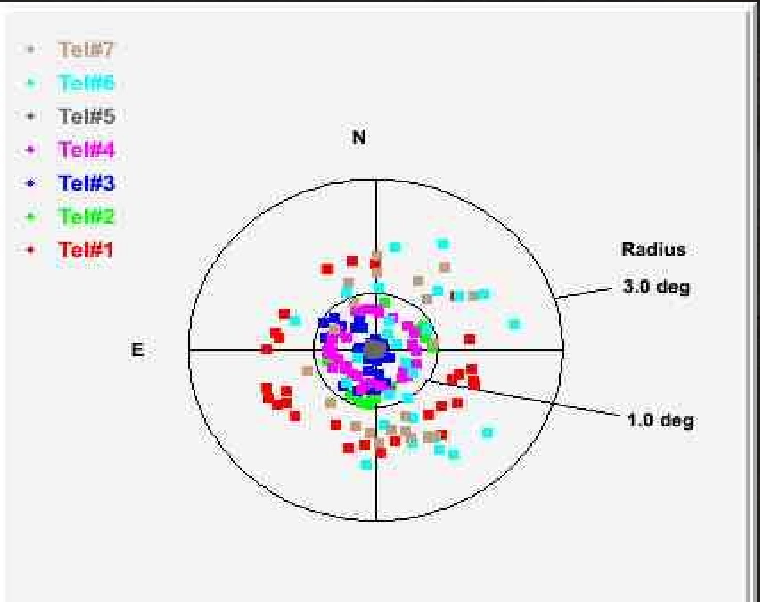

- 7 telescopes consisting of 7 para-axially mounted parabolic mirrors of diameter 0.9 m
- f/D ~ 1
- Photonis UV sensitive phototube (XP2268B) at the focus of each mirror
- Field of view: 3° 17' diameter
- Angular resolution expected ~0.2°

# Telescope alignment

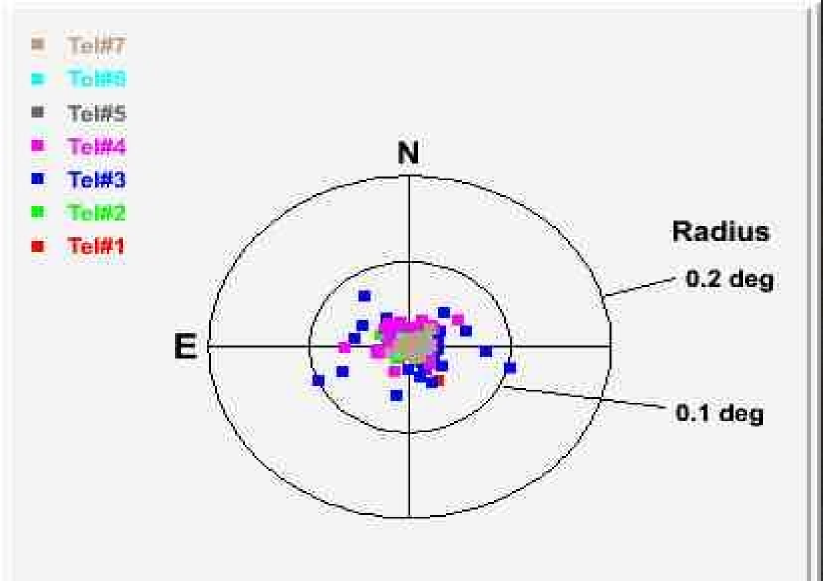
## Telescope pointing

For each telescope pointing model is worked out sighting large no. of stars

Star offsets relative to telescope axis

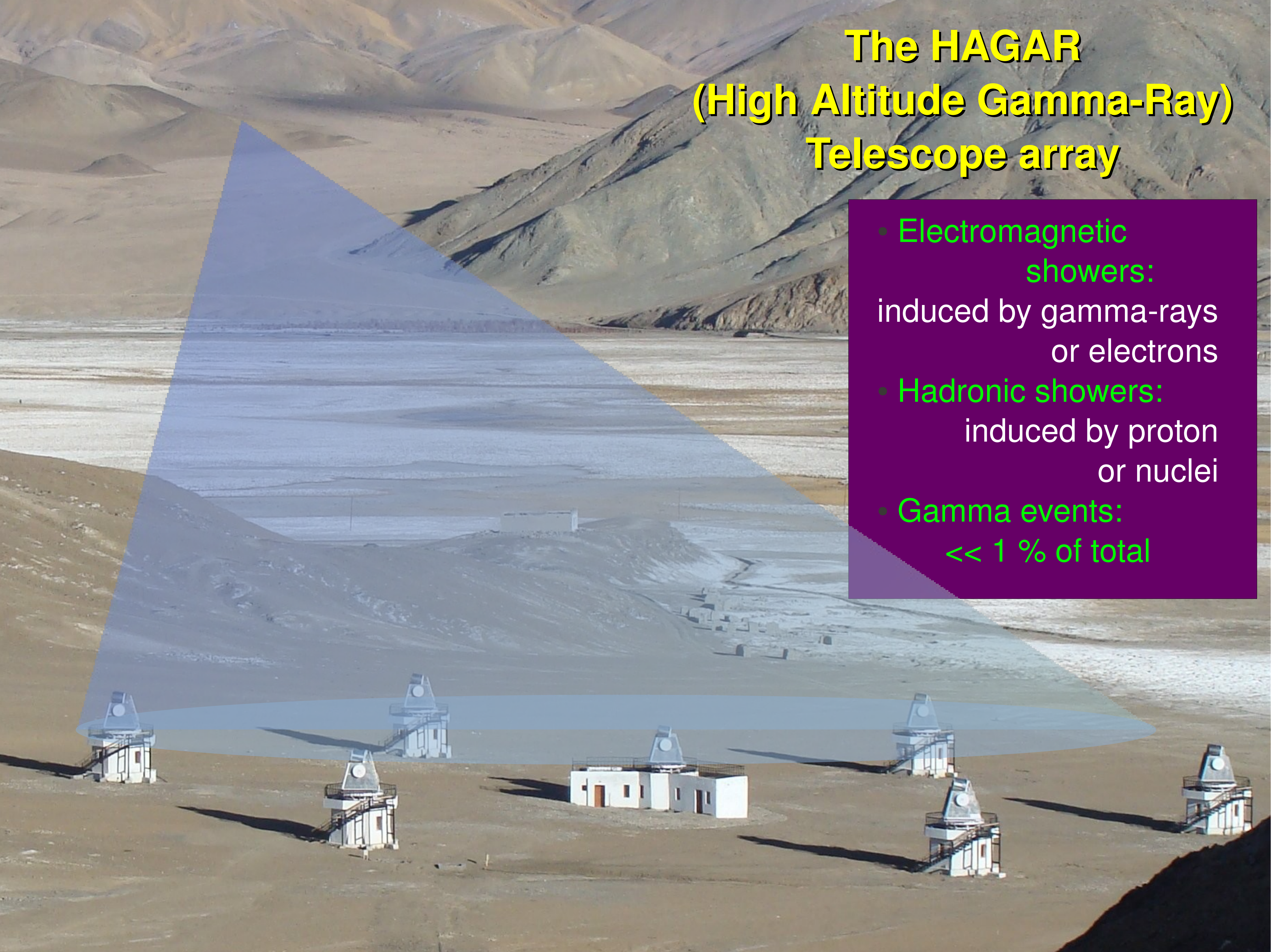



Before pointing model



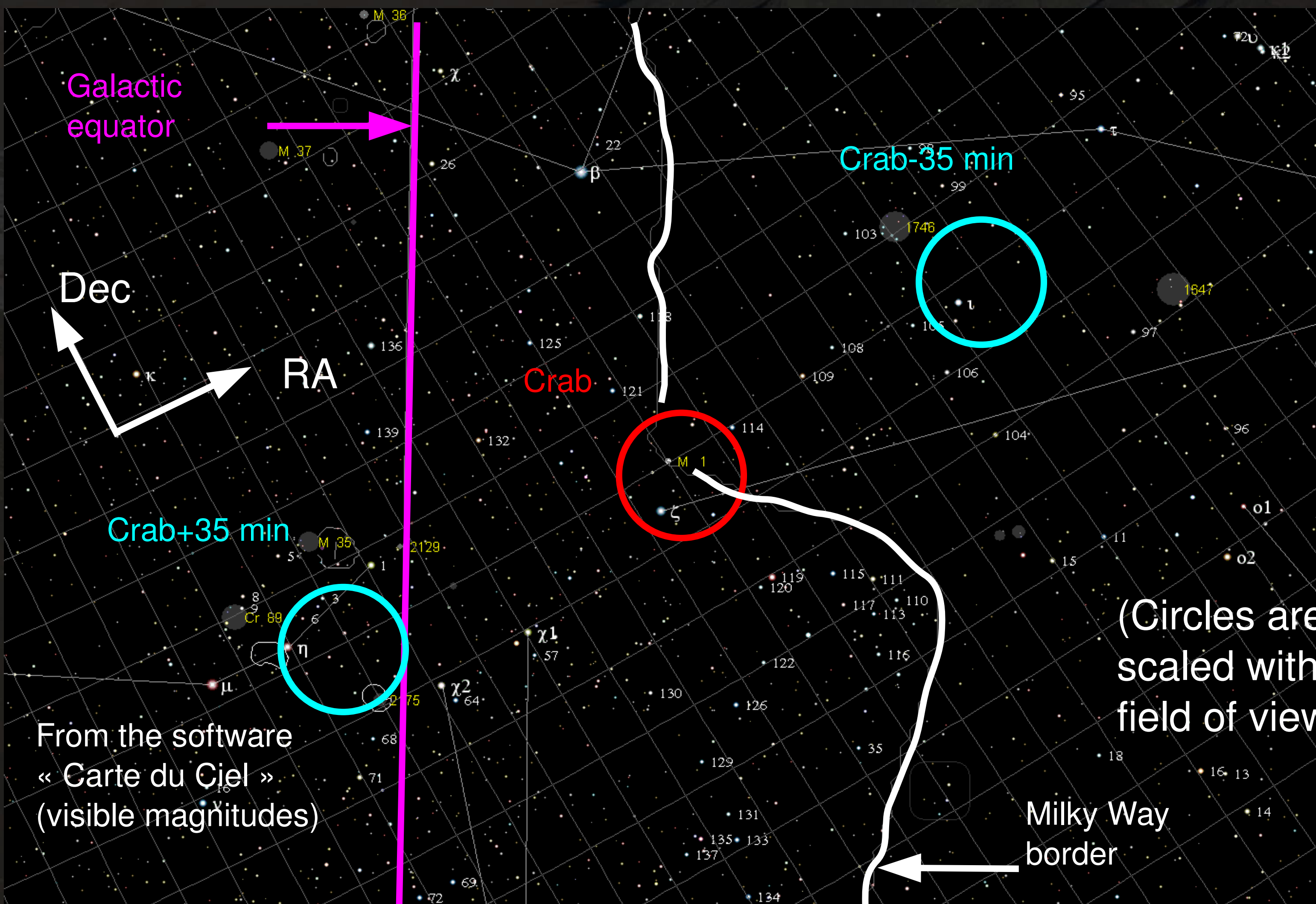

After application of pointing model

Overall pointing accuracy
Including mirror alignment :
0.2°±0.1°


The HAGAR
(High Altitude Gamma-Ray)
Telescope array
Electromagnetic showers:
induced by gamma-rays or electrons
Hadronic showers:
induced by proton or nuclei
Gamma events:
<< 1 % of total

# The ON – OFF observation startegy

Comparing the source region with a off-source region at same local coordinates on the sky, where only isotropic background is expected.




Exemple of Crab nebula observations

(Circles are not scaled with HAGAR's field of view)

signal + bckg ] (ON) - bckg (OFF) = signal

# HAGAR observation log
## (Sept 2008 - Nov. 2009)

| | Duration | (hour) |
|---|---|---|
| *Source name* | **ON** | **OFF** |
| **Galactic** | | |
| Crab nebula & pulsar | 68 | 59 |
| Geminga pulsar | 42 | 18 |
| LSI +61 303 | 8 | 7 |
| **Extragalactic** | | |
| Mkn 421 | 19 | 24 |
| Mkn 501 | 18 | 18 |
| 1ES2344+514 | 50 | 36 |
| 3C454.3 | 11 | 10 |
| **Dark regions** | | 74 |

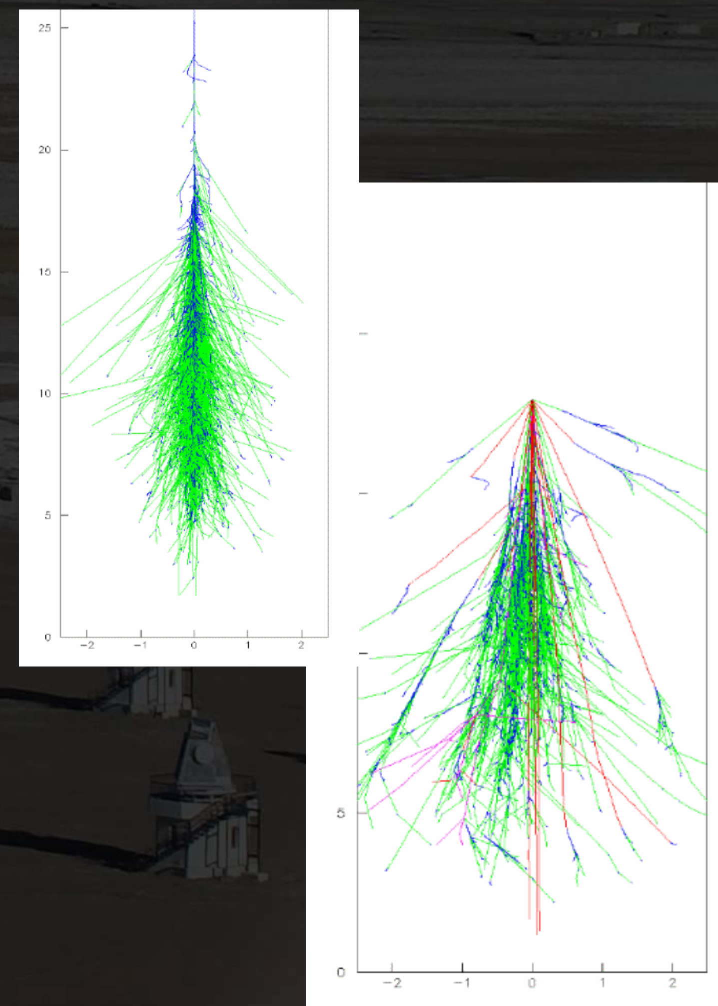
**All 7 telescopes commissioned**
**Regular source data since september 2008**

# Simulations for HAGAR

- - Simulations of extensive air showers using CORSIKA

- Detecto- r Simulation using a in-house developped IDL program: Site and instrument related parameters

- Atmospheric attenuation of Cherenkov photons
- Reflectivity of mirrors
- Phototube response
- Attenuation of pulse in coaxial cables
- Discriminator thresholds
- Trigger generation criteria



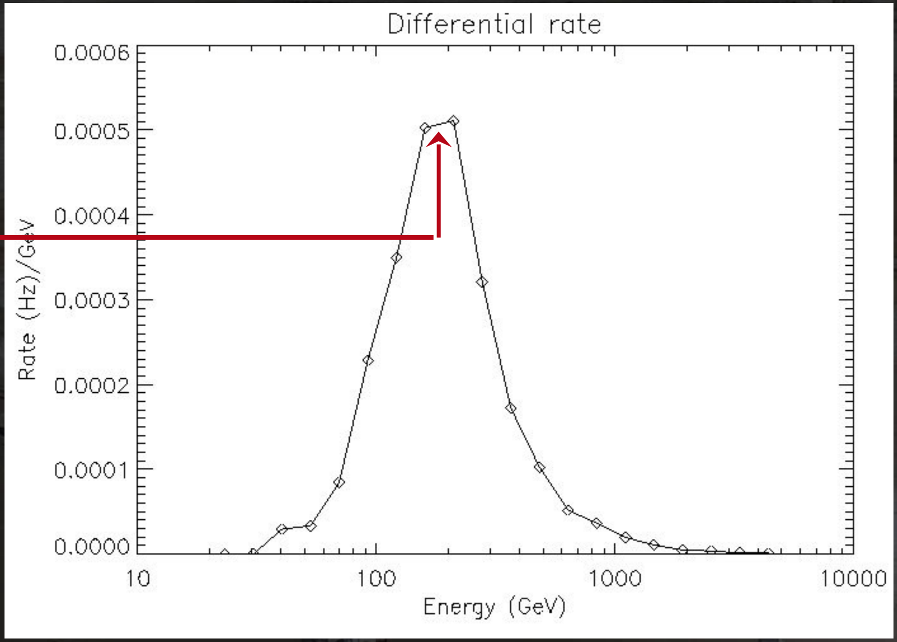
## Performance Parameters

- Trigger rate : protons 9.9 Hz
  nuclei 3.6 Hz,
  Electrons 0.16 Hz
  Total = 13.7 Hz

- Energy threshold at zenith :

**$E_{th}$ = 185 GeV**

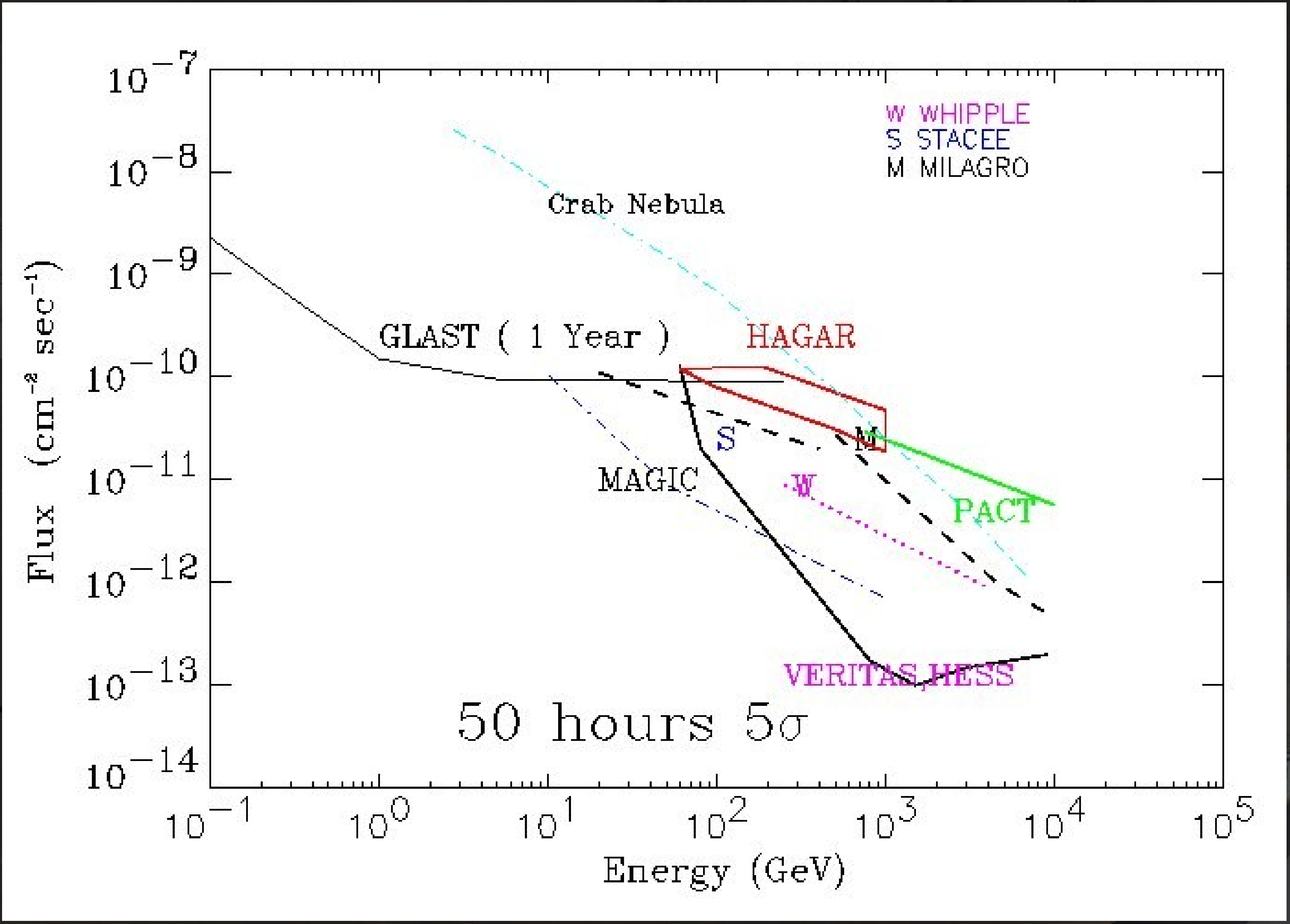
More than 4 times less than the PACT energy threshold!



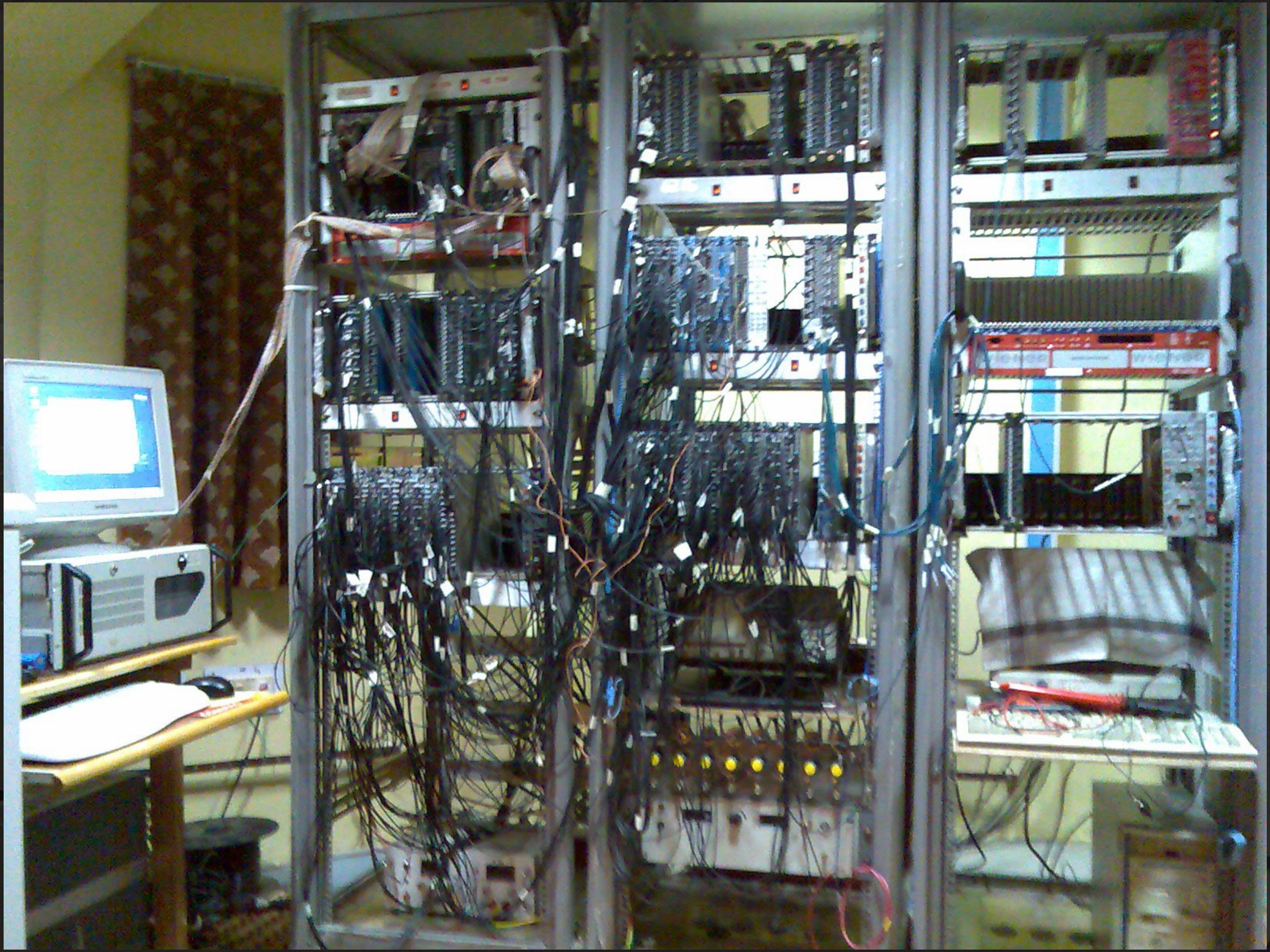

- Expected gamma-ray rate from Crab Nebula ~ 9.6 counts /min

- **Effective collection area = $4 \times 10^4$ m$^2$**

# Sensitivity of Various gamma-ray Experiments



# Data Acquisition and Telescope Control



# Data Acquisition System (before Flash-ADCs)

- 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 generated on coincidence of at least 4 telescope pulses above a preset threshold within 200 / 300 ns

- Data recorded for each event:

  relative arrival time of shower front at each mirror
  accurate to 0.25ns using TDCs

  pulse integration at each mirror using 12 bit QDCs

  absolute event arrival time accurate to micro-sec

- Various count rates recorded every second for monitoring purpose

# Analysis method (for each run)

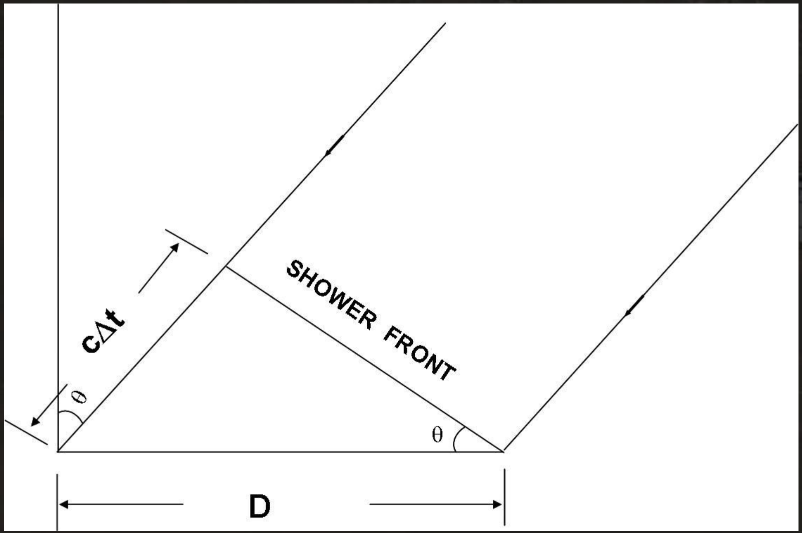
- Selection cuts based on data quality (trigger rates, ...) and analysis parameters

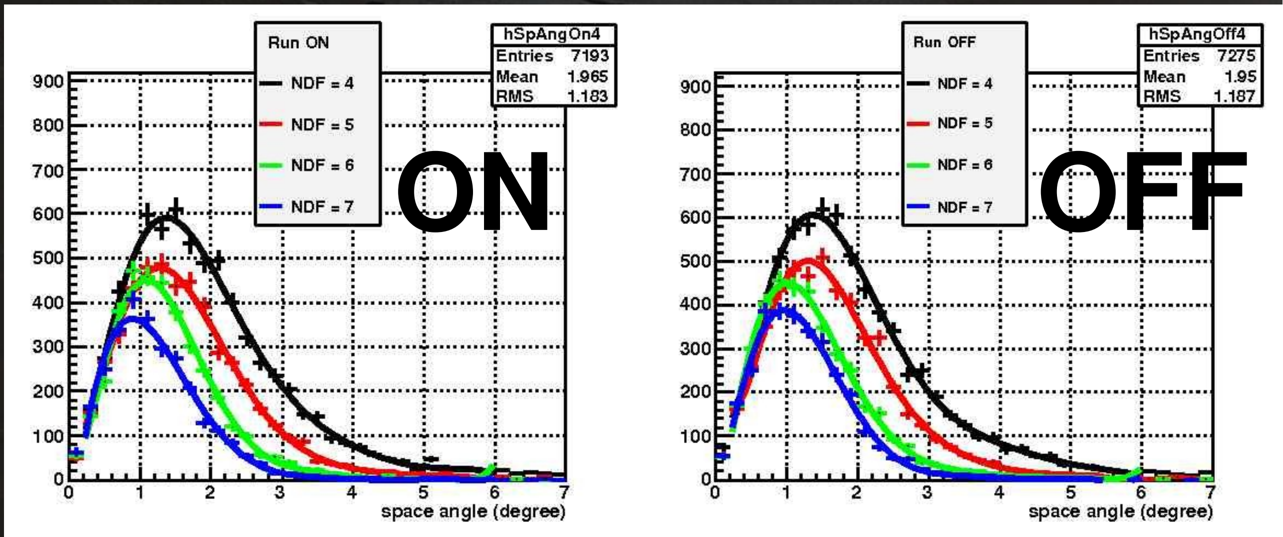
- Computing of T0 (fine-tunning transit time through electronic (PMTs to TDCs), using fix angle runs)

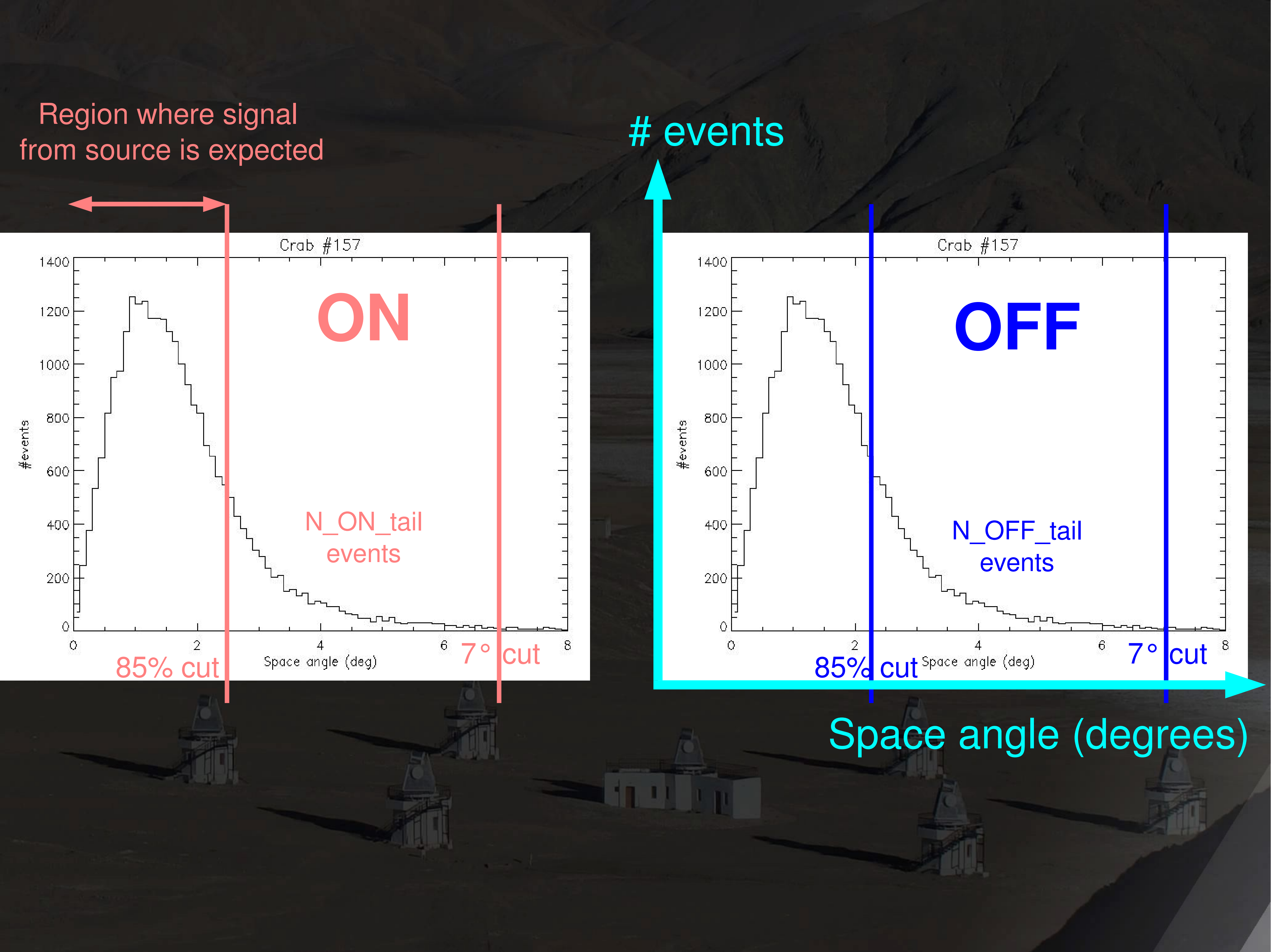
- Fit of the Cherenkov wavefront with a plane, using “royal sum” TDC data

  Normal to this plane gives arrival direction of the shower, measured by *space angle*, angle between normal and source direction.

- Because the signal comes from central area of the telescope field of view, gamma-ray events are expected at small value of the space angle.



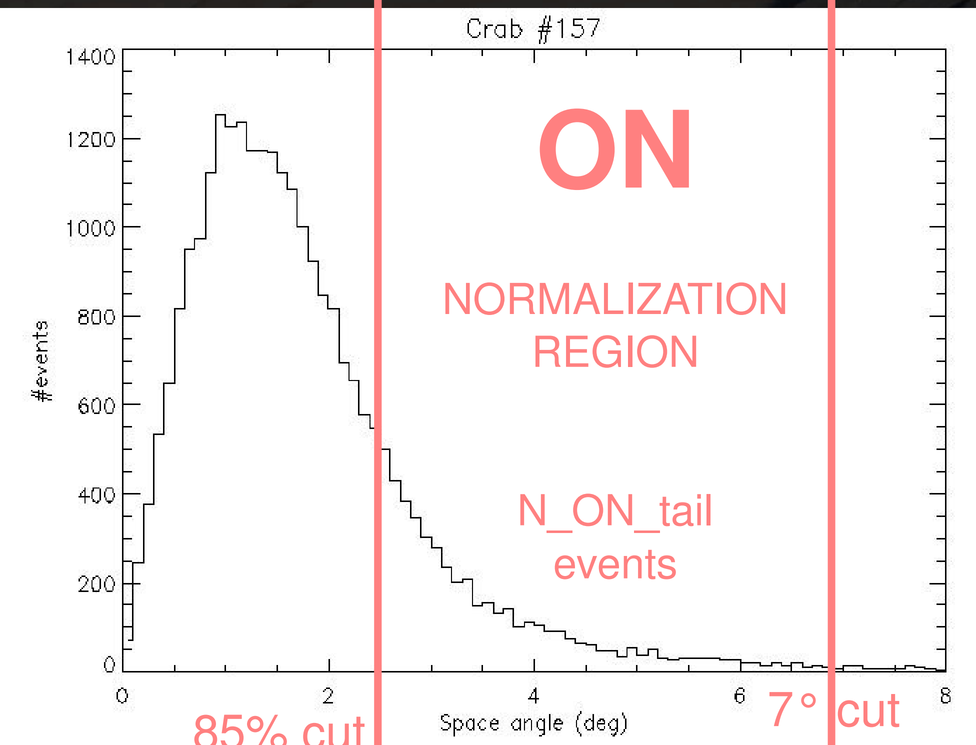



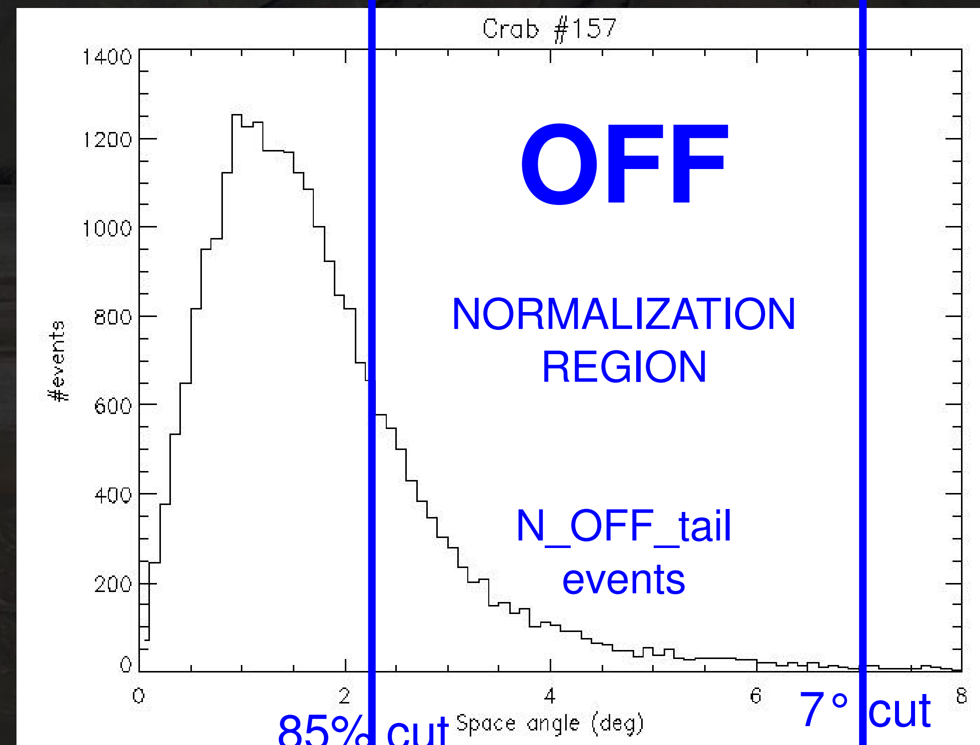


Region where signal
from source is expected
# events
Crab #157
ON
N_ON_tail
events
85% cut
7° cut
Space angle (deg)
#events
Crab #157
OFF
N_OFF_tail
events
85% cut
7° cut
Space angle (deg)
#events
Space angle (degrees)

Region where no signal from source is expected

Calculation of the normalization constant “C”, for each run, and for each NDF.



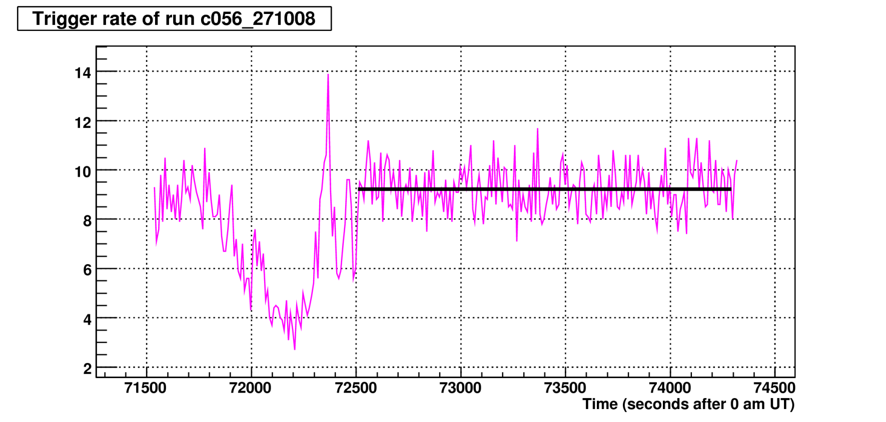




C = N_ON_tail / N_OFF_tail

**Excess < 85 % cut = N_ON – C x N_OFF**

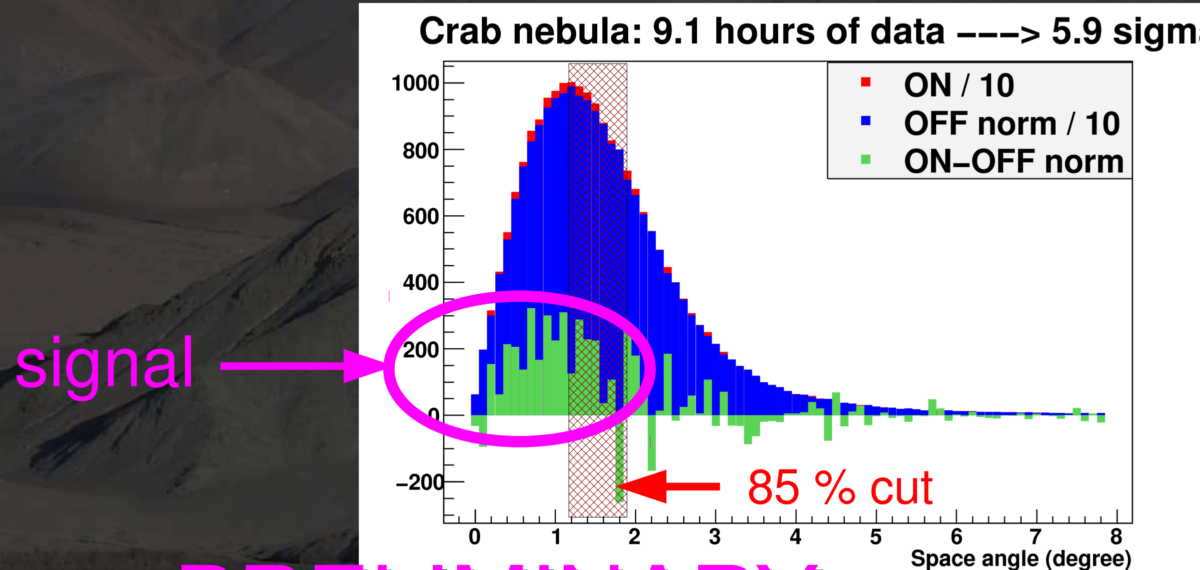
# Data selection

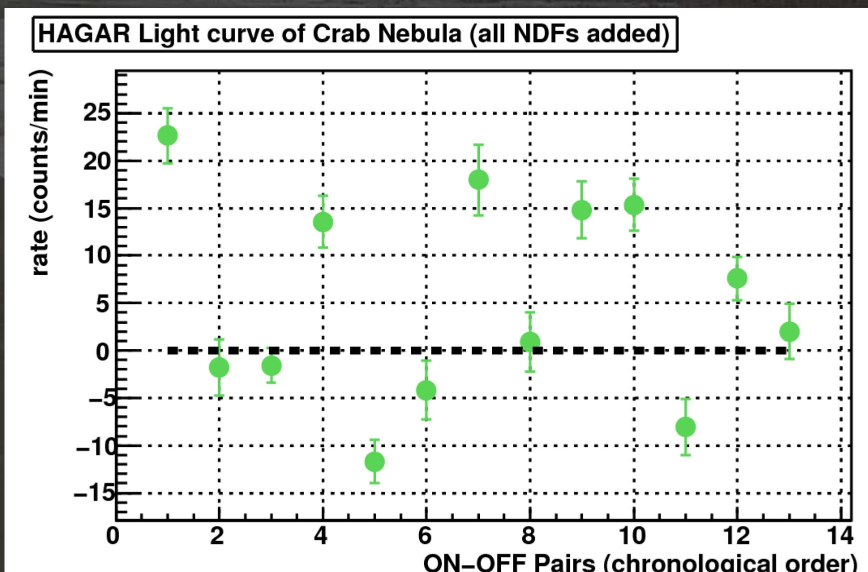
- Run selection:
  - Trigger rate stability

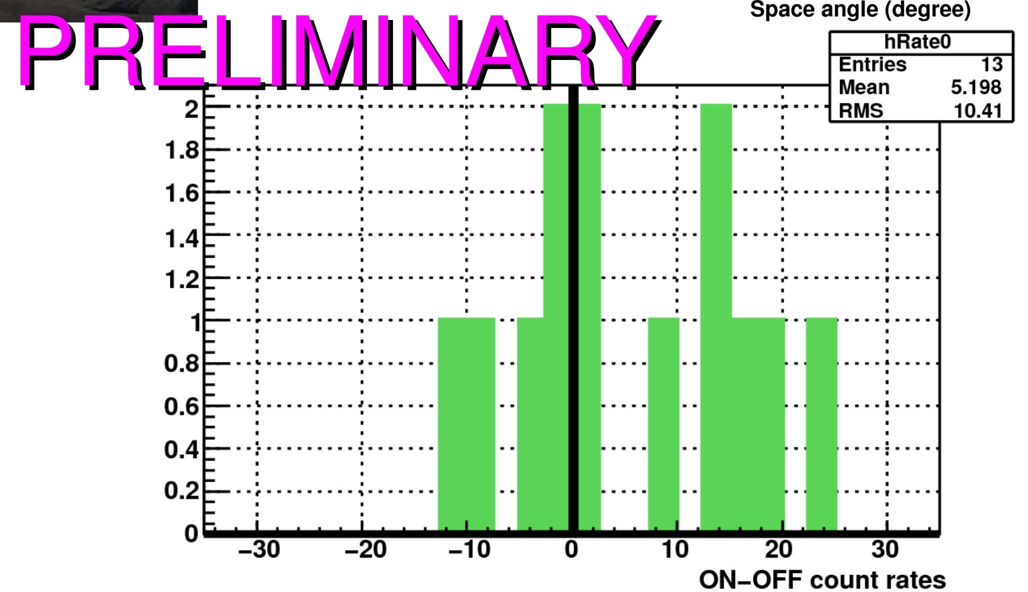



- Pair selection
  - Differences in trigger rates (< 2 Hz)
  - ON/OFF ratio per telescope (~ 1)
  - Differences in parameters of the space angle distribution shape
  - Value of the normalization constant C (~ 1)
  - Differences in variables related to NSB rates

# Preliminary result on Crab nebula




*For Crab nebula:*

Effective area ~ 5 x $10^4$ $m^2$

$E_{threshold}$ ~ 200 - 220 GeV

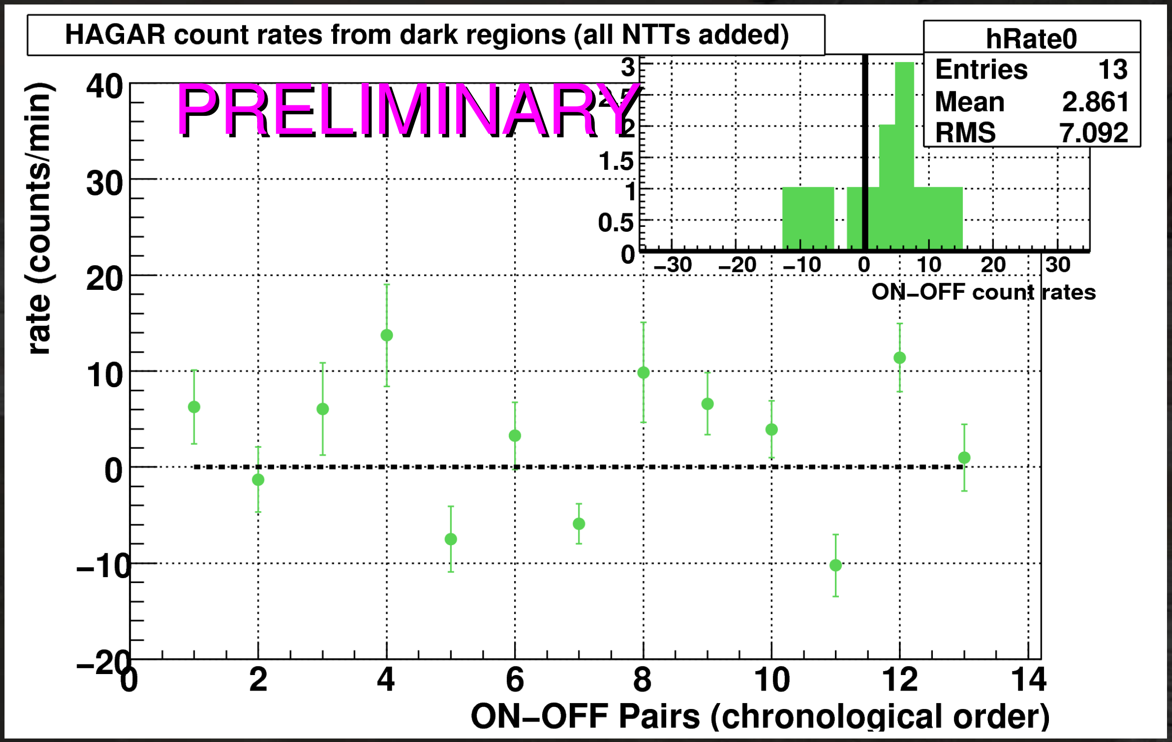
13 pairs / 9.1 hours

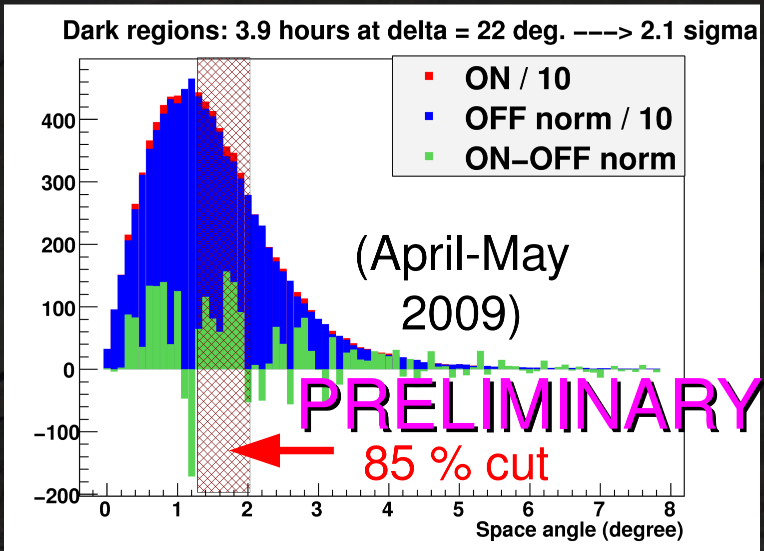
$N_\sigma = 6.0$

4.1 ± 0.7 gamma / min

==> Integral flux = 1.4 x $10^{-10}$ ph. $cm^{-2}s^{-1}$

# Preliminary result on Dark regions (OFF-OFF)



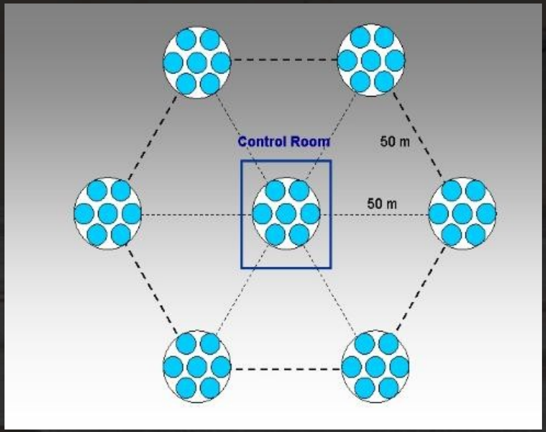

13 pairs ; 6.6 hrs ; $N_\sigma < 2.2$ ---> No signal

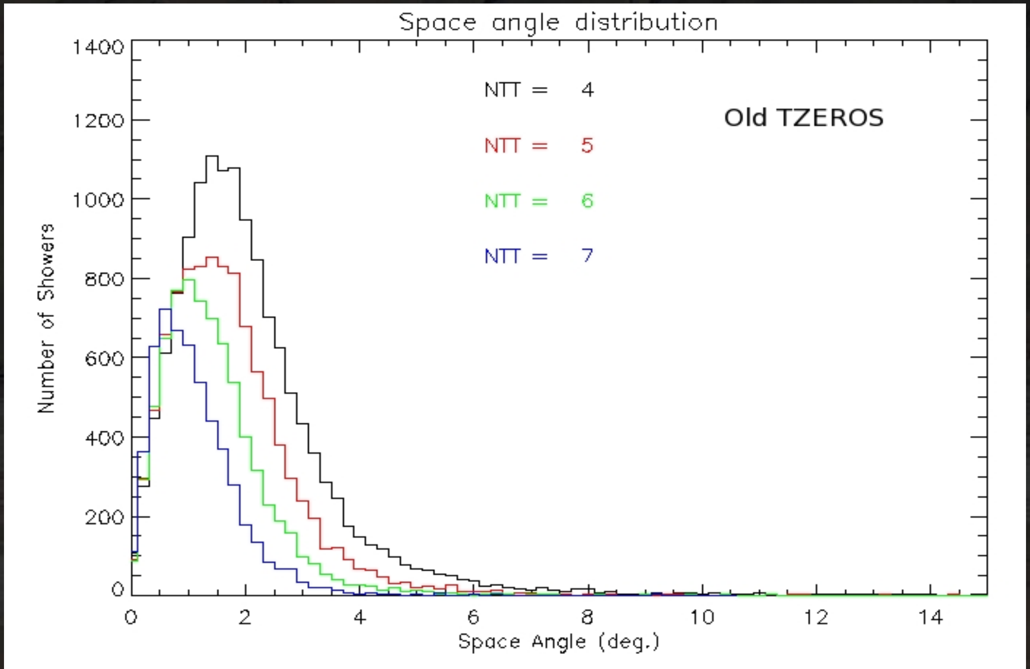
More data is required,

but preliminary result do not show dramatic systematic effect

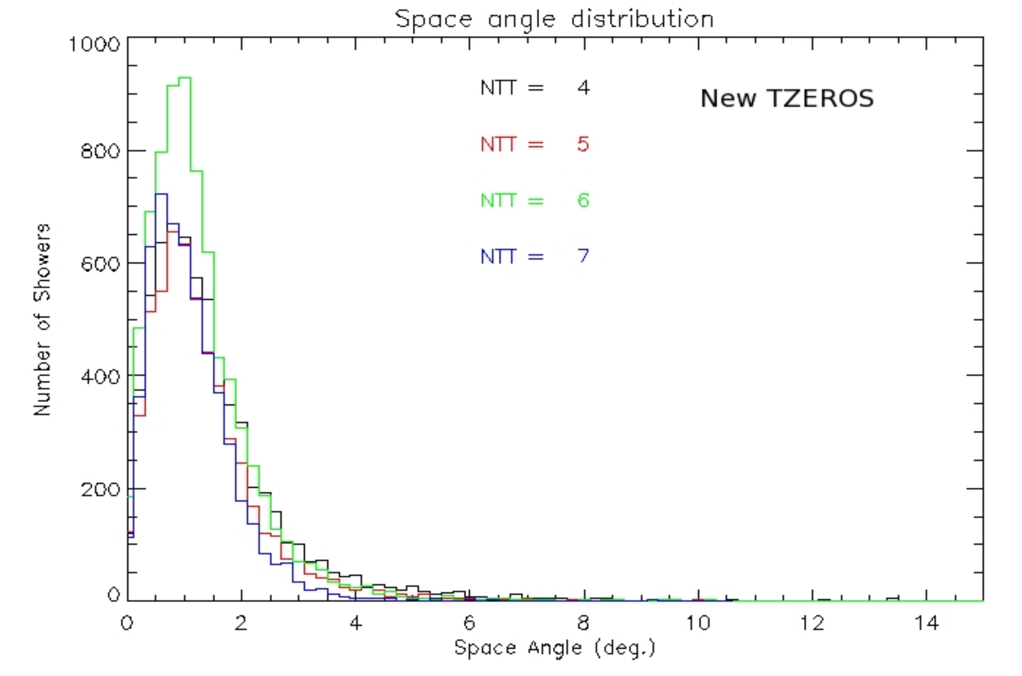
“The Tzero issue”
Cherenkov light from nuclei
What are the arrival times w.r.t. the central telescope?

# New T0's (April 2010)




19 different configurations:
-> 19 sets of T0's!




4 fold triggers: 1234, 2345, 1456, etc.
5 fold triggers: 12345, 34567, etc.
6 fold triggers: 123456, 134567, etc.
7 fold triggers: 1234567 only

# Gamma/hadrons discrimination

**Standard analysis cuts**

separate cuts on variables to maximise hadronic rejection

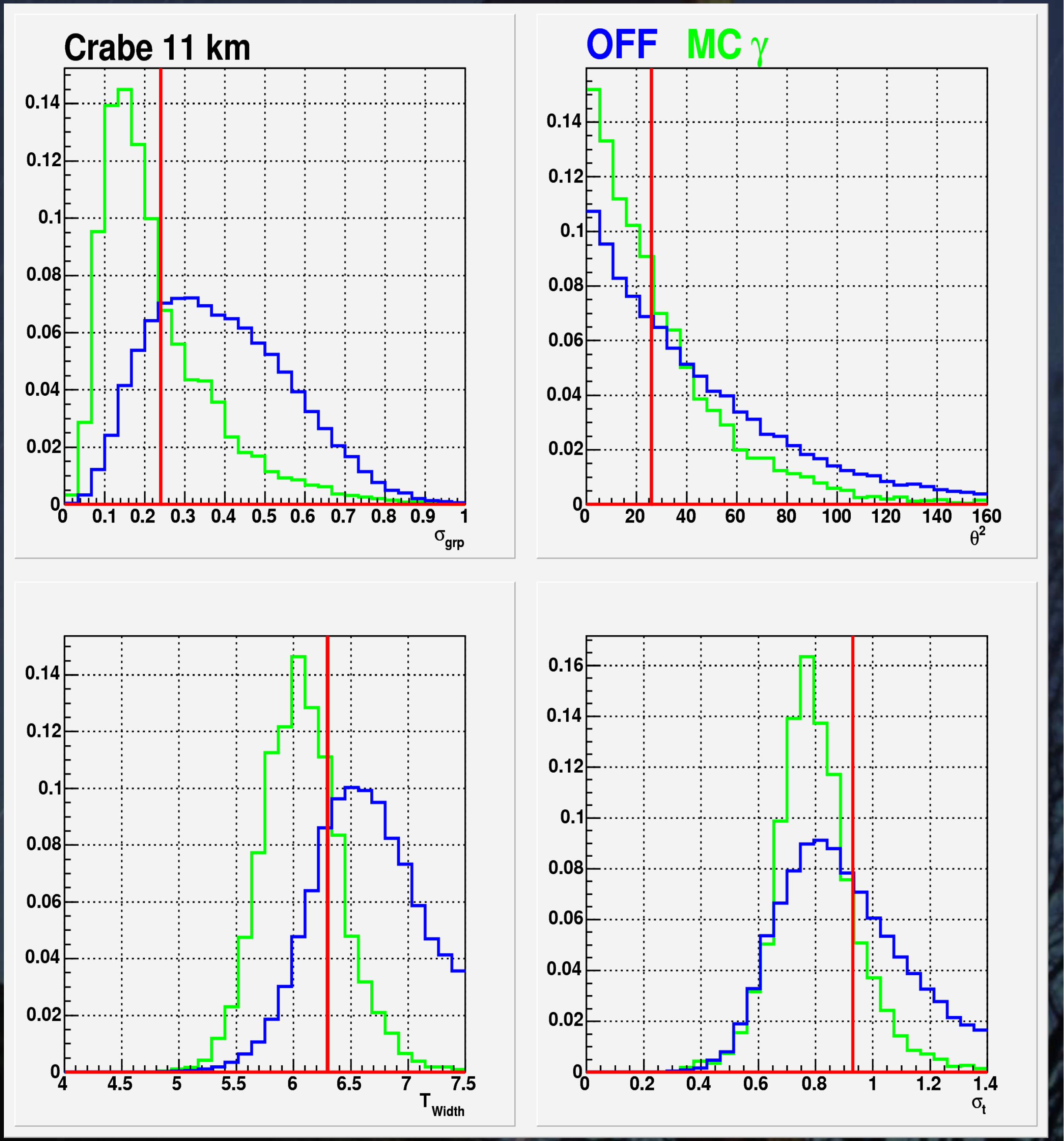
# Gamma/hadrons discrimination

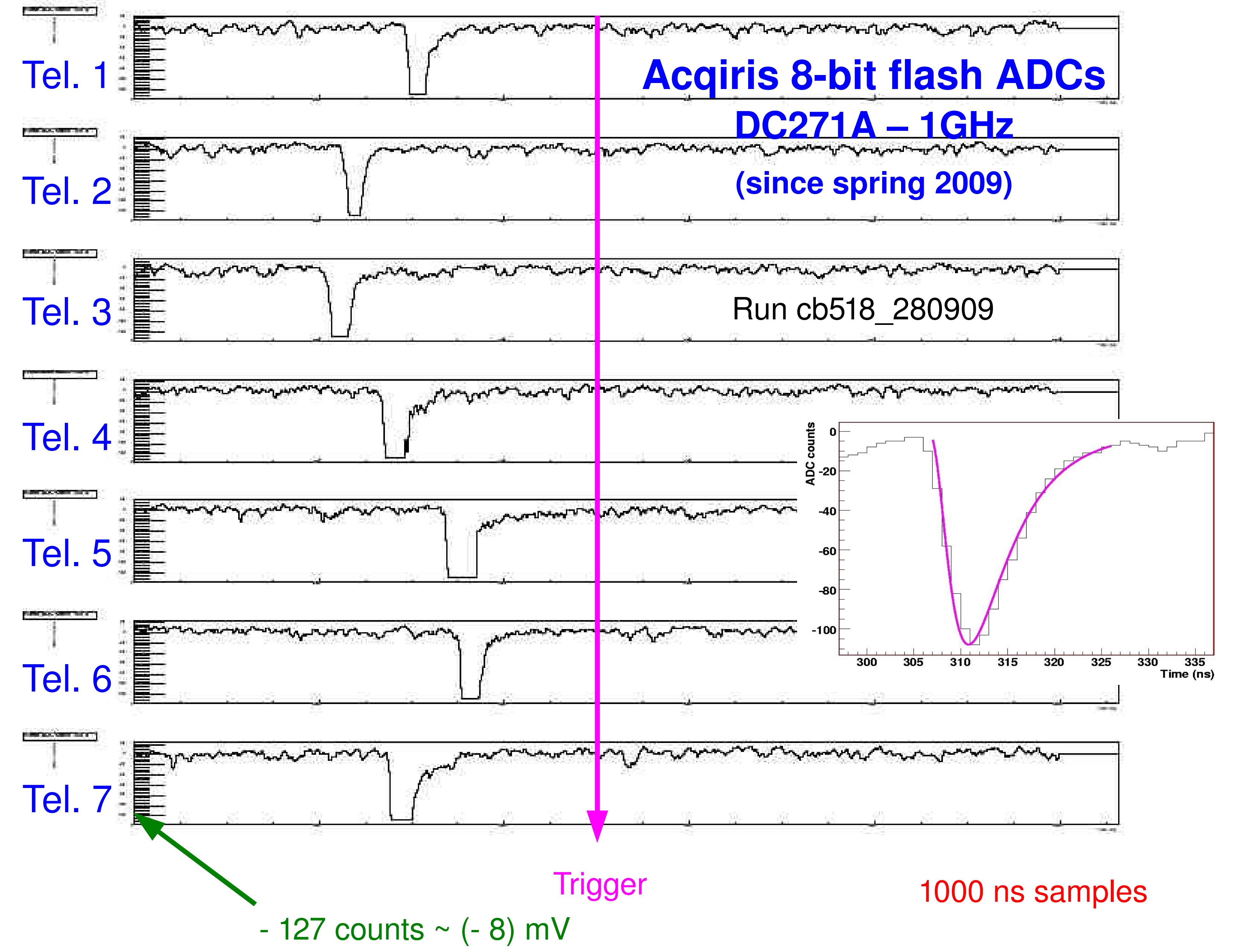
Standard analysis cuts

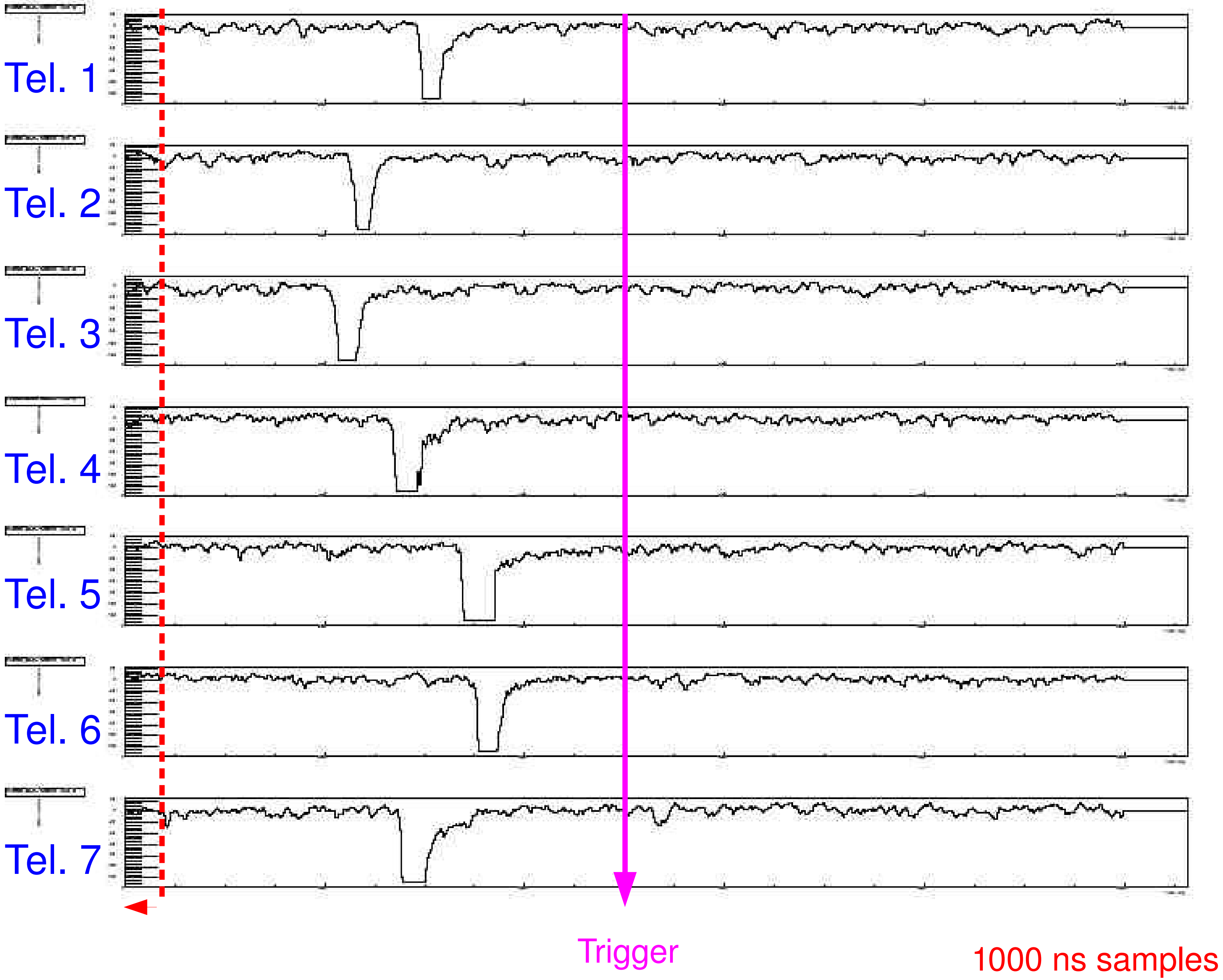
separate cuts on variables to maximise hadronic rejection

Example of Crab data (mirrors pointing at 11 km above the observatory):

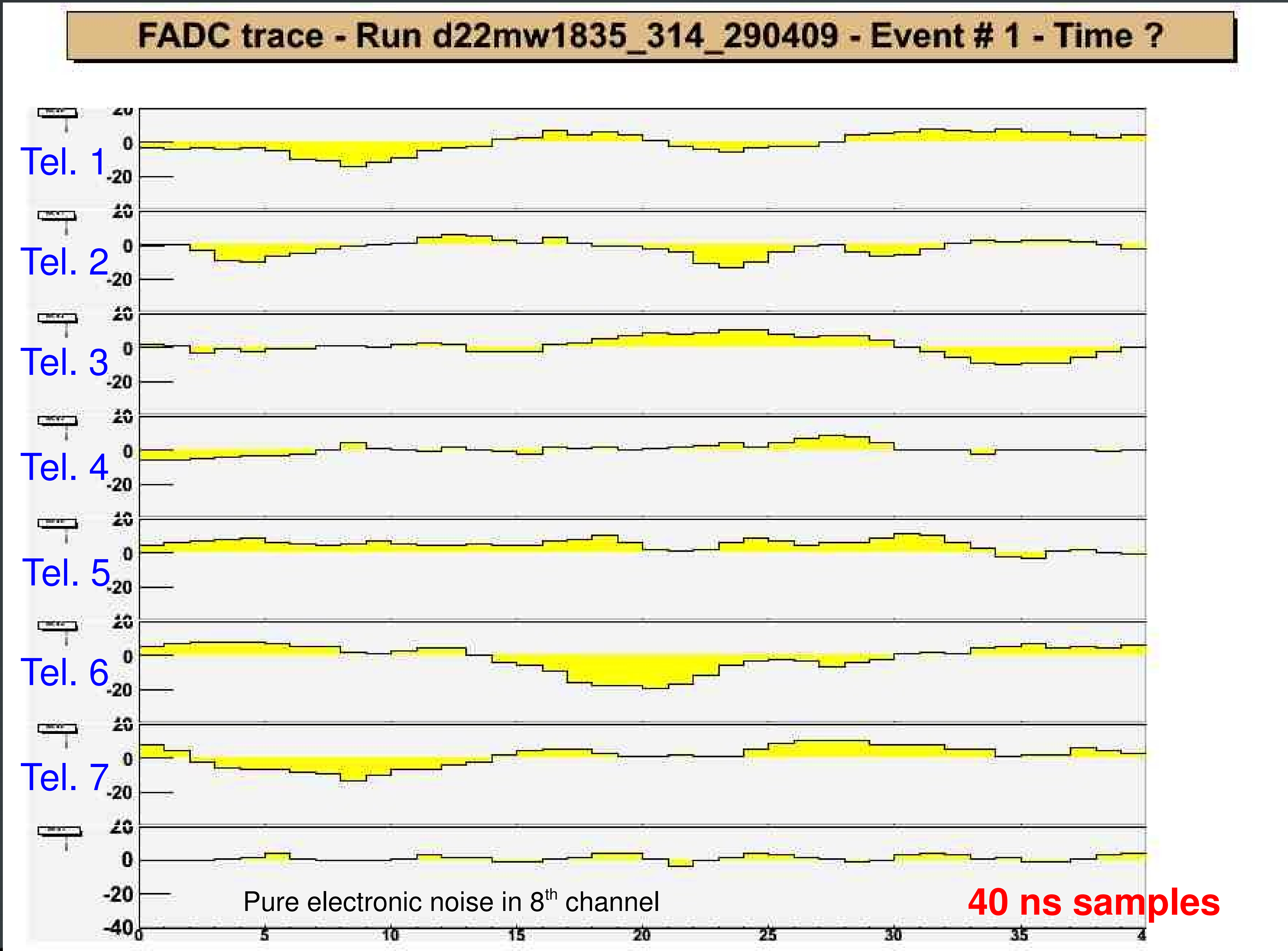
- γ MC
- OFF (mostly hadronic events)



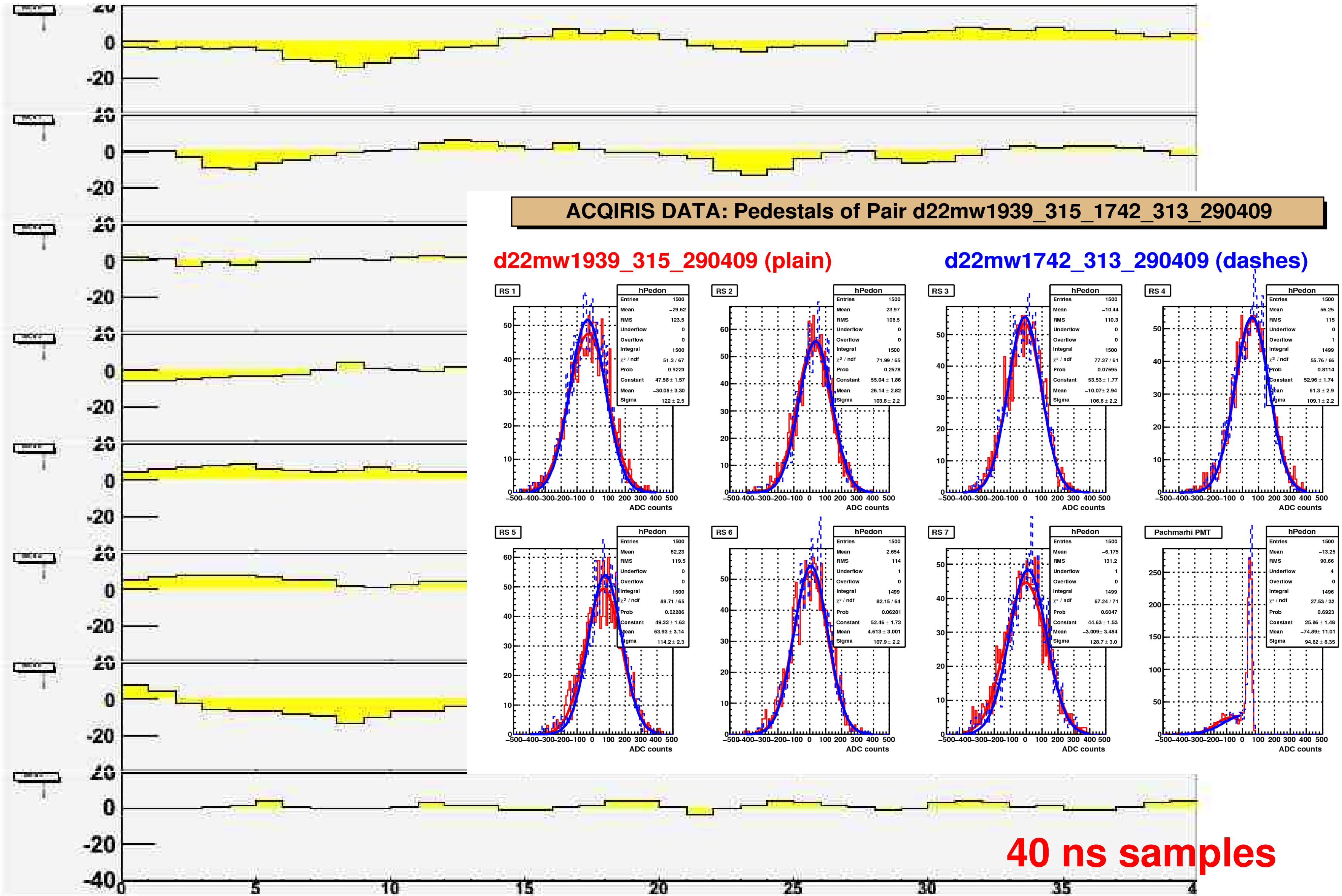

Acqiris 8-bit flash ADCs
DC271A – 1GHz
(since spring 2009)
Run cb518_280909
Tel. 1
Tel. 2
Tel. 3
Tel. 4
Tel. 5
Tel. 6
Tel. 7
ADC counts
0
-20
-40
-60
-80
-100
300
305
310
315
320
325
330
335
Time (ns)
Trigger
1000 ns samples
- 127 counts ~ (- 8) mV




Extracting noise only (for each channel and each event)


FADC trace - Run d22mw1835_314_290409 - Event # 1 - Time ?
Tel. 1
Tel. 2
Tel. 3
Tel. 4
Tel. 5
Tel. 6
Tel. 7
Pure electronic noise in 8th channel
40 ns samples
20
0
-20
-40
0
5
10
15
20
25
30
35
4

# FADC trace - Run d22mw1835_314_290409 - Event # 1 - Time ?



# Recent upgrades on hardware (July 2010)

**- Hardware upgrade for monitoring:**

- A meter is introduced for monitoring the night sky clarity (brightness)
- Home made Progammable discriminator unit which will aid to monitor the rate vs threshold of all telescope pulses

**- Hardware upgrade for trigger logic:**

Trigger circuit was modified and upgraded. Further upgradation in trigger circuit to linearly add all telescope pulses is planned which could reduce the energy threshold (Grand Sum).

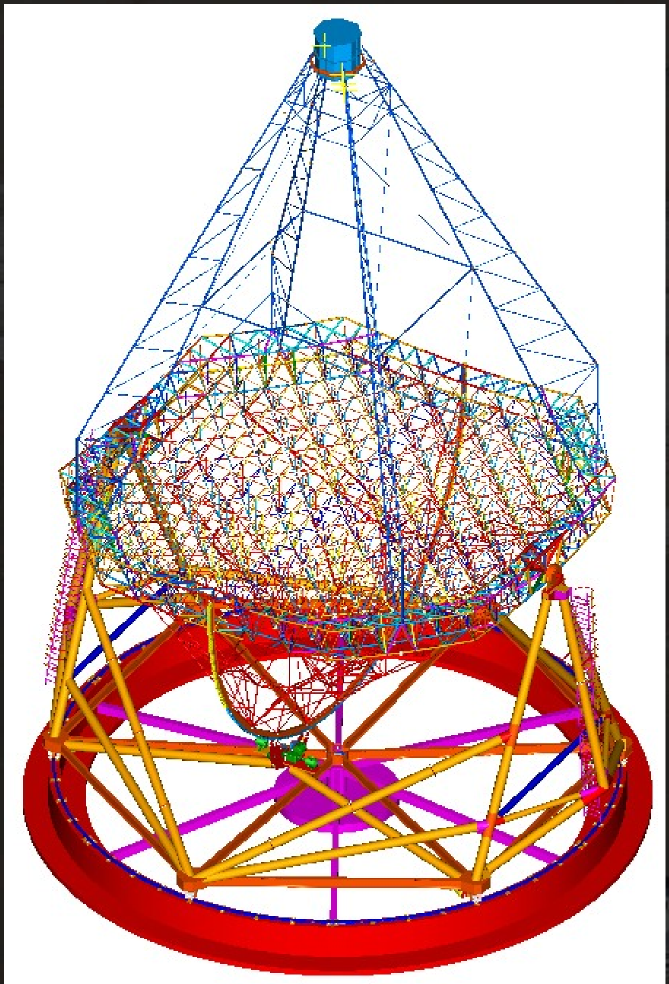
**- Software upgrade:** new data format for additional house keeping informations like discriminator thresholds for royal sum pulses

# Improvements in analysis

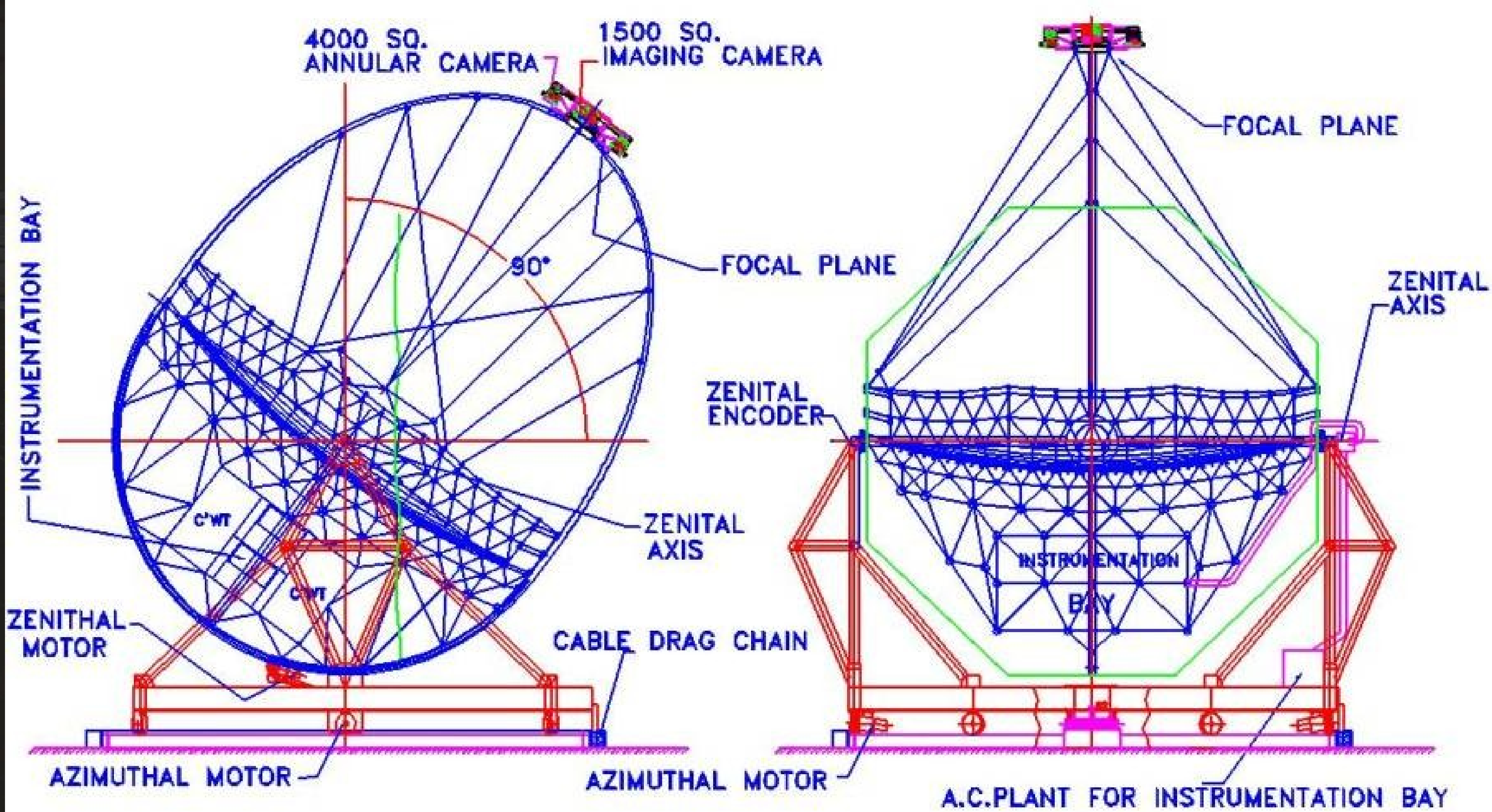
- Getting rid off a normalization constant
  - software padding
  - cutting low charge events
- Parabolic or spherical front fitting
- Analysis at mirror level (not only at telescope level)
- Focus on flash ADC analysis

## Future Prospects at HIGRO

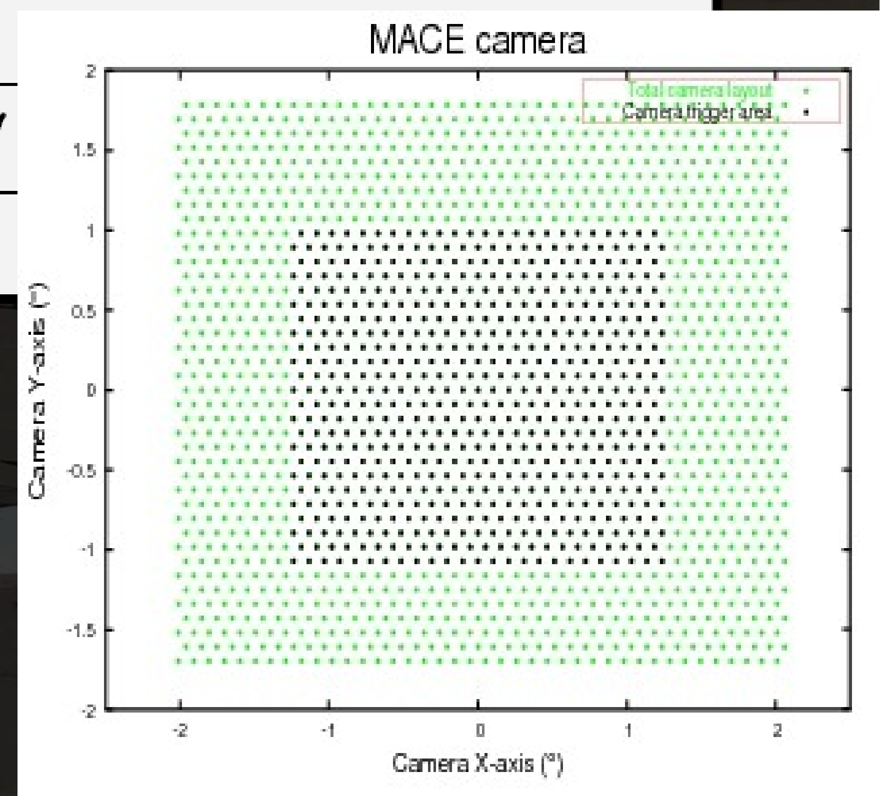
## Major Atmospheric Cherenkov Experiment (MACE)



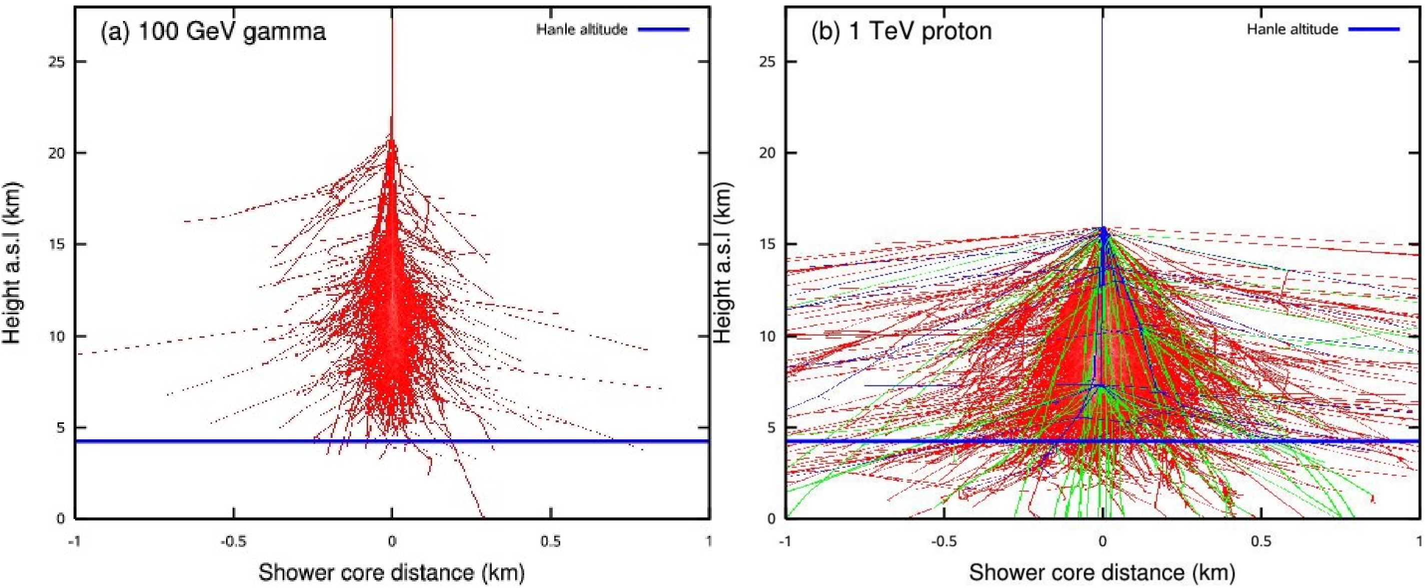
- Second stage of HIGRO collaboration (IIA, BARC and TIFR)
- Initially single imaging telescope of dia 21 m
  - ➔ lower energy threshold of 30 GeV
  - ➔ Sensitivity : 5 sigma Crab in 13 min > 200 GeV
    43 min > 55 GeV
  - ➔ located near HAGAR : common events
  - ➔ first light expected in 2012
- Will be augmented by two more similar elements by 2014 to enable stereoscopic operations


4000 SQ.
ANNULAR CAMERA
1500 SQ.
IMAGING CAMERA
FOCAL PLANE
90°
INSTRUMENTATION BAY
C'WT
C'WT
ZENITAL
AXIS
ZENITHAL
MOTOR
CABLE DRAG CHAIN
AZIMUTHAL MOTOR
AZIMUTHAL MOTOR
FOCAL PLANE
ZENITAL
AXIS
ZENITAL
ENCODER
INSTRUMENTATION
BAY
A.C.PLANT FOR INSTRUMENTATION BAY

| | | | |
|---|---|---|---|
| Light Collector | Aperture (d) | : | 21 m |
| | Area | : | ~ 330 m$^2$ |
| | Mirror | : | 356 panels (4 × 50cm × 50cm) |
| | F-ratio | : | f/1.2 m (f ≅ 25 m) |
| Camera | FoV | : | 4$^{\circ}$ × 4$^{\circ}$ |
| | Pixels | : | 1088 |
| Trigger | FoV | : | 2.4$^{\circ}$ × 2.4$^{\circ}$ |
| | Pixels | : | 576 |
| | Threshold Energy | : | 30 GeV |
| | First Light | : | 2012 |



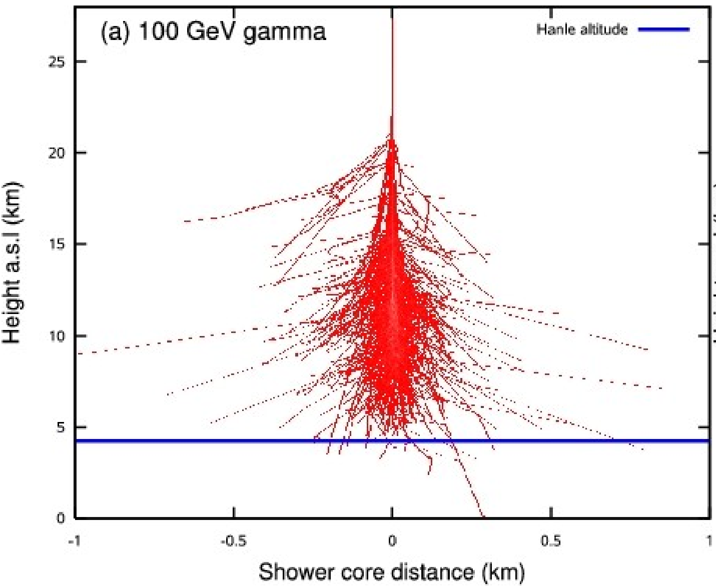
# Eas at hanle

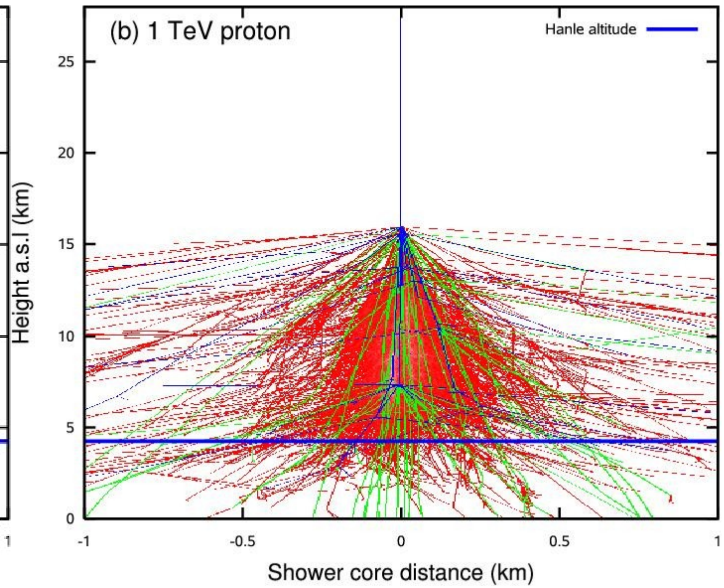


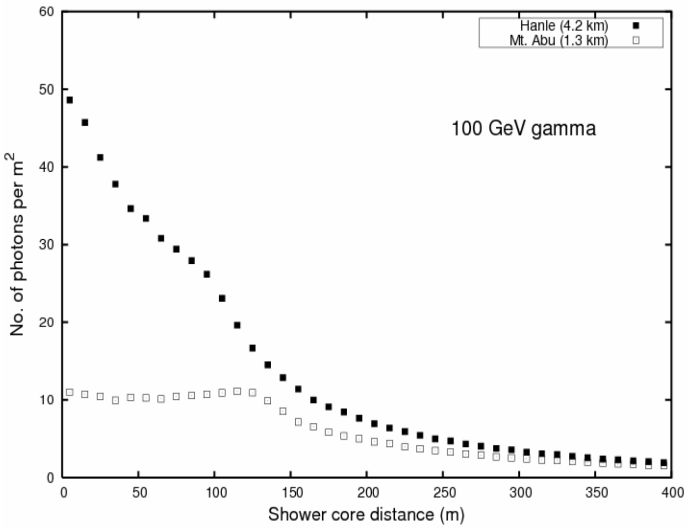

Simulations with CORSIKA

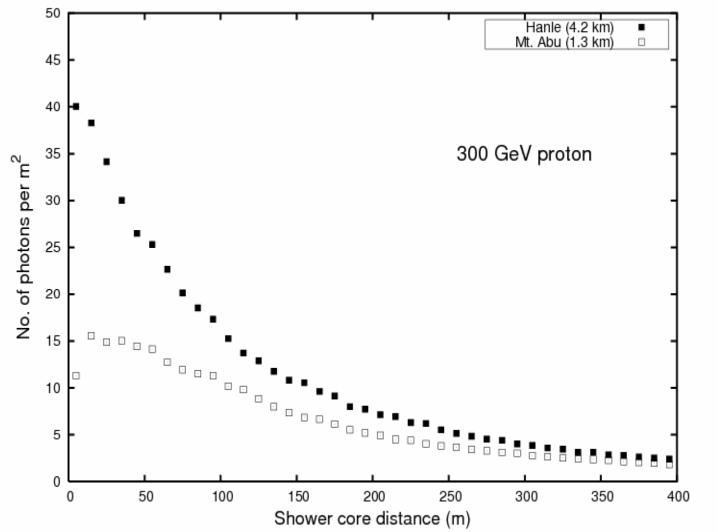
| | Gamma | Proton | Electron | Alpha |
|---|---|---|---|---|
| Energies (GeV) | 1 – $10^4$ | 10 – $10^4$ | 5 – $10^4$ | 10 – $10^4$ |
| Scatter Rad. (m) | 400 | 500 | 400 | 500 |
| Viewcone Angle | -- | $4^o$ | $4^o$ | $5^o$ |
| # showers | ~ $10^6$ | | | |
| Zenith Angles | $0^o$ , $20^o$ , $40^o$ , $50^o$ , $60^o$ | | | |

# Eas at hanle

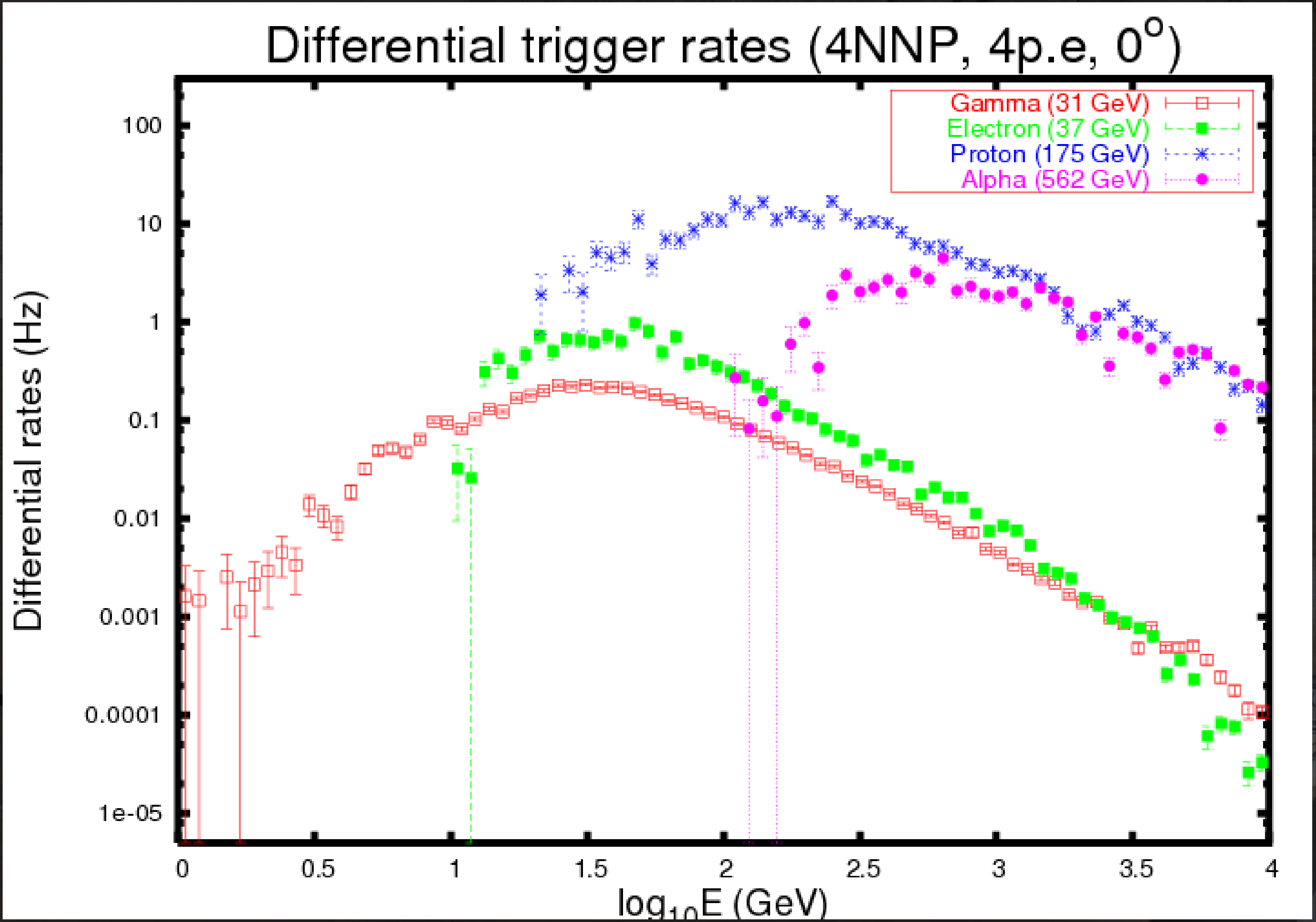

(a) 100 GeV gamma
Hanle altitude
Height a.s.l (km)
Shower core distance (km)


(b) 1 TeV proton
Hanle altitude
Height a.s.l (km)
Shower core distance (km)

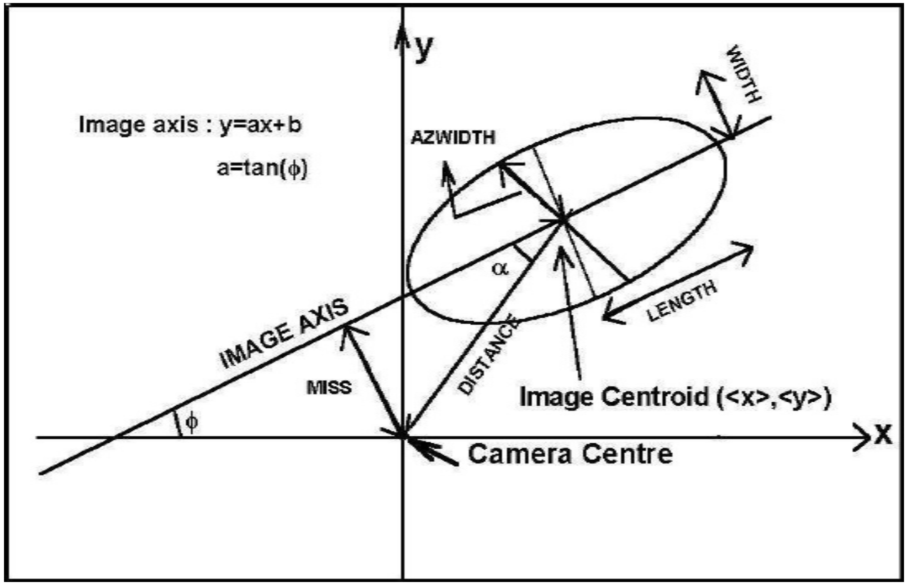

Hanle (4.2 km)
Mt. Abu (1.3 km)
100 GeV gamma
No. of photons per m2
Shower core distance (m)

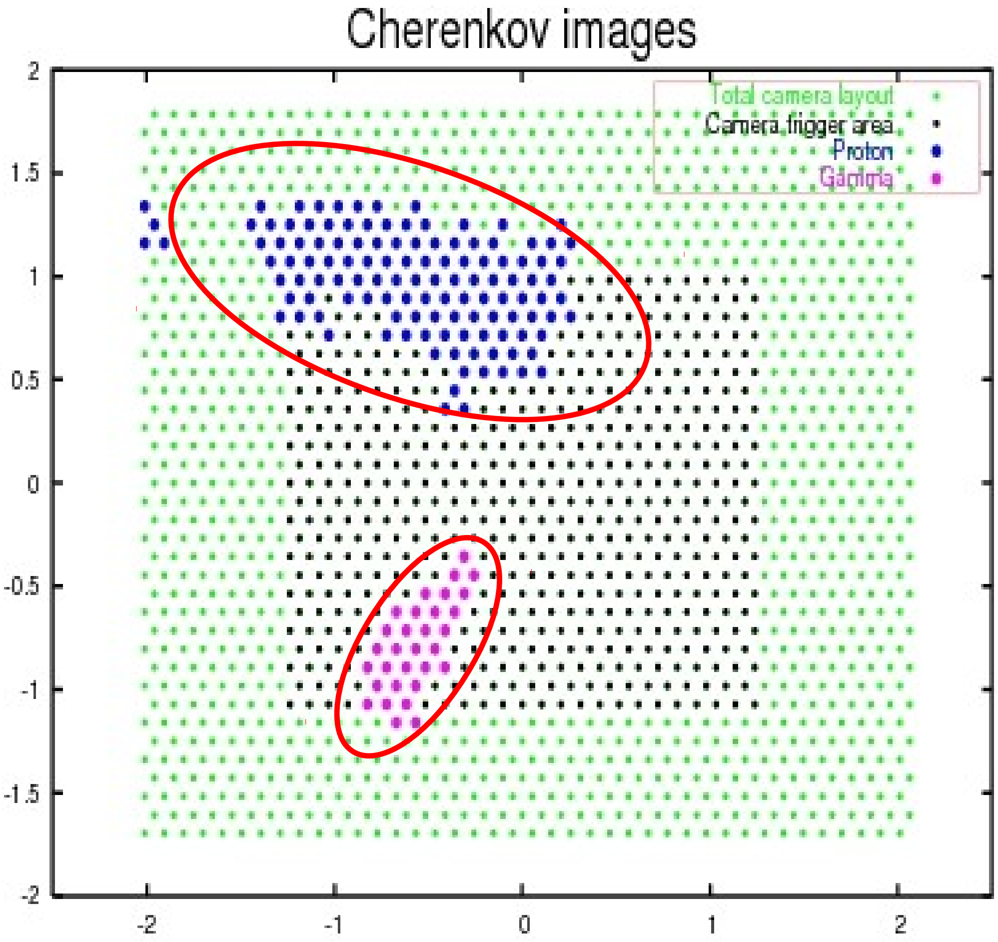

Hanle (4.2 km)
Mt. Abu (1.3 km)
300 GeV proton
No. of photons per m2
Shower core distance (m)

# Differential Rate & Energy threshold Estimate



# Hillas parameters



# Advantages of multiple elements and MACE-II

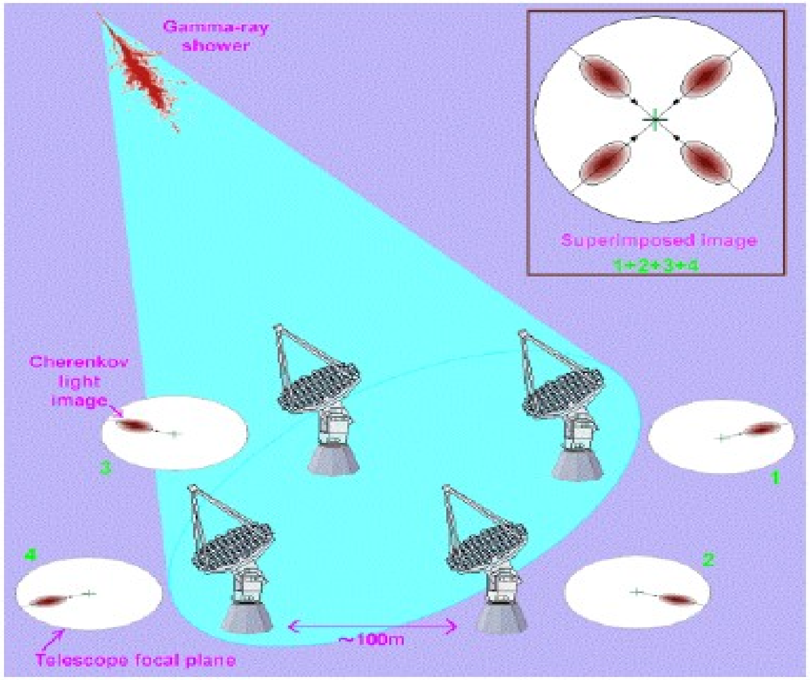
- Showers seen from different angles – better gamma/hadron rejection

. Impact parameter determination

- Angular resolution
  ~ arc minutes

- Energy resolution ~ 10%

- Muon discrimination



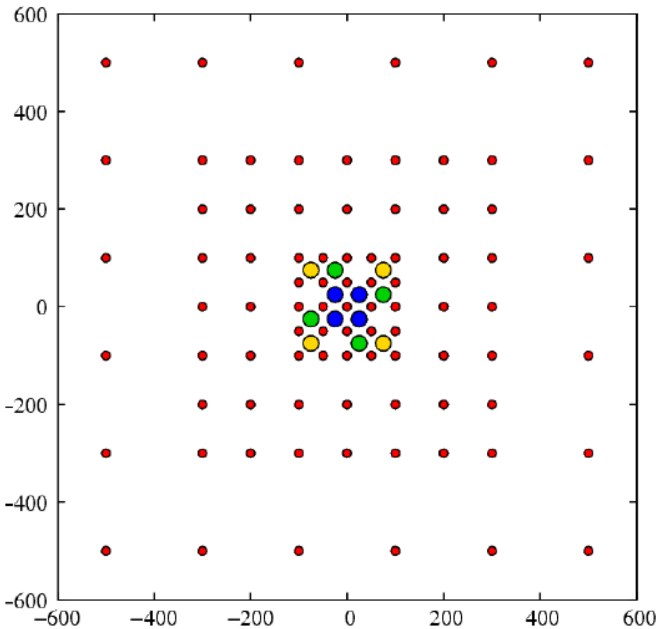

* A complete array of at least 3 telescopes is already accepted... (if we do good science with one...)

# MACE Fabrication

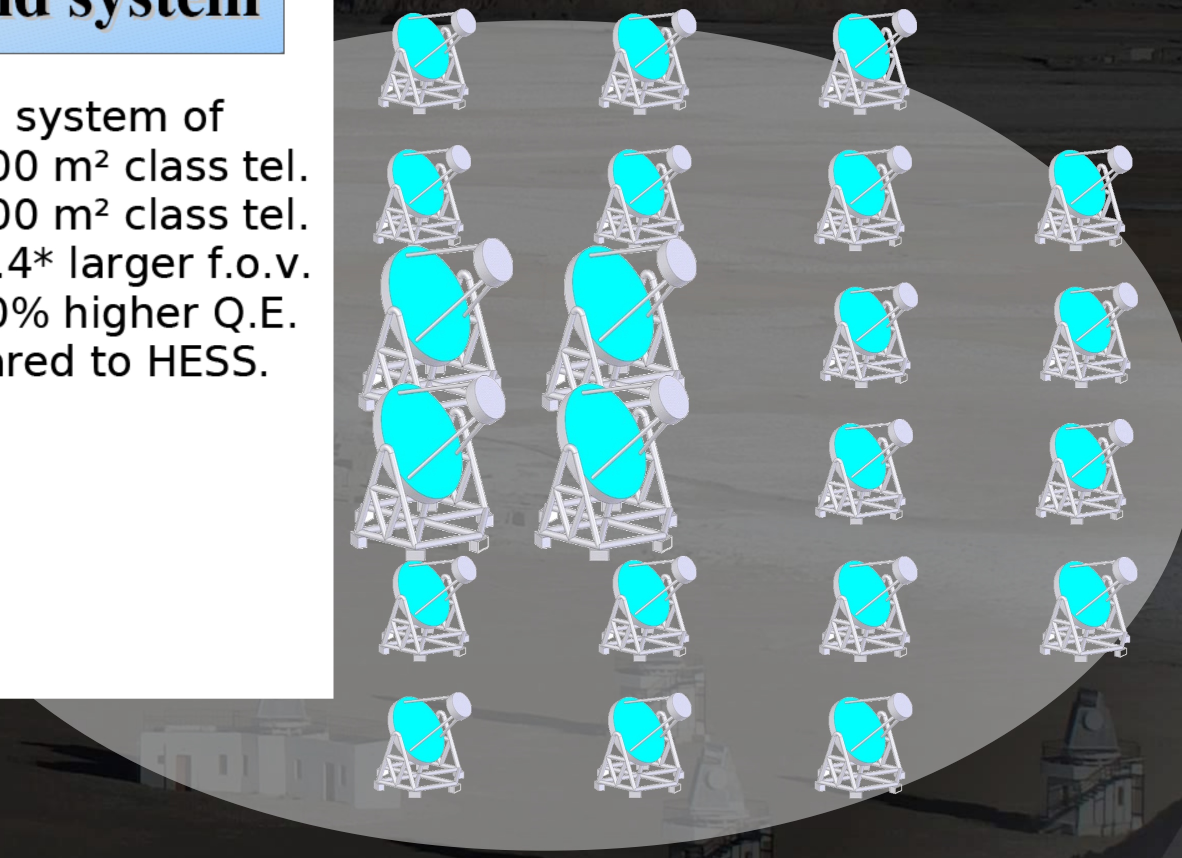


# Cherenkov Telescope Array (CTA)

## Configurations: 97 tel. hybrid system




Hybrid system of
- 12 600 m² class tel.
- 85 100 m² class tel.
with 1.4* larger f.o.v.
and 50% higher Q.E.
compared to HESS.



# Summary

- We report a preliminary results on Crab nebula and showed that statistical fluctuations from ON-OFF method are not significant (dark regions), in spite of a small hadronic rejection

On-going and future work:

- Improving shower direction recontruction (~ spherical wavefront fit) and timing calibration (T0's and laser)
- Analysis of FADC data (Acqiris DC271A – 1GHz)
- *Software padding* (balancing NSB differences between ON & OFF)
- Implementing GHS parameters (similar to CELESTE's)
- Present main effort to reduce the energy threshold (Grand Sum)
- More simulations to determine more precisely energy threshold and sensitivity, and to draw space angle and other variables
- Analysis of the large amount of data!!!
- MACE is coming soon (2012)!!!

## * Tata Institute of Fundamental Research, (TIFR), Mumbai (Bombay) :

Present members :

B.S. Acharya, R.J. Britto, V.R. Chitnis, A.I. D'souza, N. Dorji, K.S. Gothe, B.K. Nagesh, N.K. Parmar, Sandeep Kumar, S.K. Rao, S.K. Sharma, B.B. Singh, P.V. Sudersanan, S.S. Upadhya, S. Vishwakarma

Past members : P.N. Bhat, D. Bose, A. Naidu, M.S. Pose, P.N. Purohit, L. Rapsal, A.J. Stanislaus, P. Majumdar

## * Indian Institute of Astrophysics (IIA), Bangalore :

Present members :

G.C. Anupama, R.Cowsik, F. Gabriel, P.U. Kamat, P.M. Kemkar, J.P. Lancelot, P.K. Mahesh, J. Manoharan, T.P. Prabhu, R.R. Reddy, F. Saleem, A.K. Saxena, A. Shukla, G. Srinivasulu, P.R. Vishwanath + Staff from *Indian Astronomical Observatory*, Hanle

Past members : J.K. Pendharkar, R. Srivatsan, R. Srinivasan

## * Bhabha Atomic Research Centre (BARC), Mumbai (Bombay) (ApS Division) :

R. Koul, R.C. Rannot, A.K. Tickoo, K. Yadav, N. Bhatt, A. Mitra, K.K. Singh, ...

## * Saha Institute of Nuclear Physics (SINP), Kolkata (Calcutta) :

P. Bhattacharjee, L. Saha

# Back up slides

# Genesis of gamma-ray astronomy

http://heasarc.gsfc.nasa.gov/docs/history/

- **1895: Röntgen discovers x-rays.**
- **1900: Villard discovered gamma rays (on Earth)**
- **1912**: Victor Hess discovered cosmic ionizing radiation
- **1914**: Rutherford and Andrade measured gamma-ray wavelenth
- **Long debate**: CRs are photons (Millikan) or particules (Compton)?
- **1933**: Chadwick, Blackett & Occhialini observe that gamma rays passing through matter can generate electron-positron pairs.
- **1934**: Three independent experiments (by Johnson, Alvarez & Compton and Rossi) measure the East-West effect and find that the intensity of cosmic rays is greater from the west, which implies that the **majority of primary cosmic rays are positively charged particles.**
- **1948**: Feenberg and Primakoff predict that gamma rays are produced in interstellar space due to Compton up-scattering of low-energy photons off high-energy electrons.
- **1952**: Hayakawa & Hutchinson predicted that cosmic gamma rays may be produced by CRs interacting with matter.
- **1952**: Hayakawa predicts the existence of diffuse Galactic gamma-ray emission due to the decay of neutral pions that are liberated when cosmic-ray nuclei collide with interstellar gas.

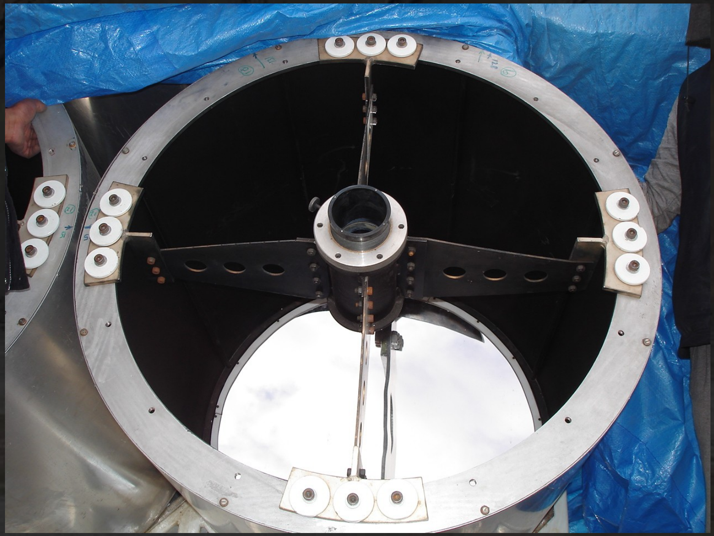
# Genesis of gamma-ray astronomy

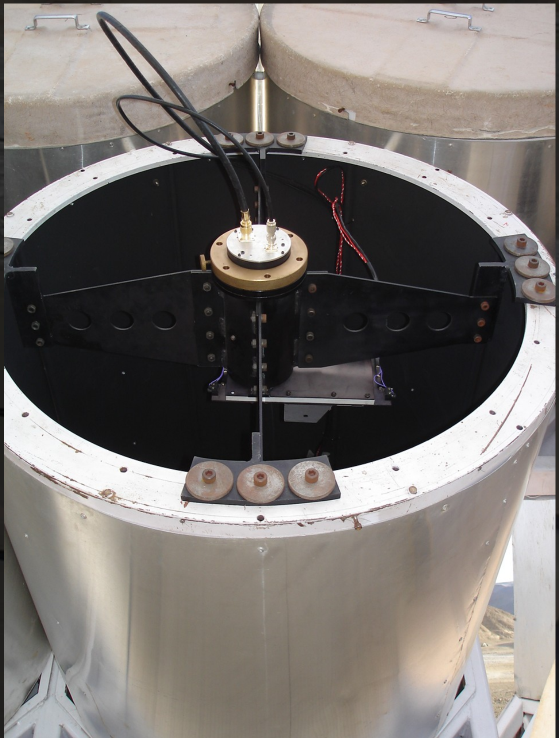
http://heasarc.gsfc.nasa.gov/docs/history/

- **1958**: **Morrison summarizes several encouraging predictions regarding the emission of gamma rays from a variety of celestial sources**
- **1953**, by British Atomic Energy Research Establishment in Harwell (UK): **FIRST ATMOSPHERIC CHERENKOV DETECTION**, with a 30 cm parabolic mirror with a PMT + array of proportional counters
- **1960-1963** at Katsiveli, Crimea, USSR (Ukraine), **FIRST ATMOSPHERIC CHERENKOV ARRAY**: up to 12 parabolic mirrors (dia: 155 cm , focal length= 60 cm) on 4 independent rotating frames. Mirrors were viewed by one PMT of 4.5 cm dia + correcting lens for improving the angular characteristics of Telescope.
- **1961**: satellite EXPLORER XI detected ~ 20 isotropic gamma-ray photons.
- **1967**: OSO-3 satellite detected 621 gamma-ray photons from the Galactic plane
- **1967**: First detection of a Gamma-Ray Burst by Vela 4a & 4b satellites

  (published in 1973)
- **1972**: satellite SAS-2 – **FIRST SIGNIFICANT GAMMA-RAY DETECTION!**

# HAGAR Telescope



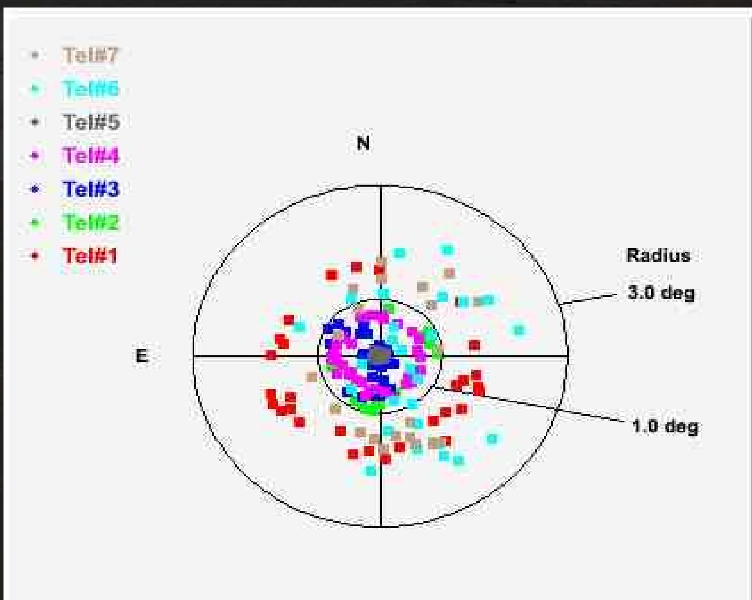


# Telescope alignment

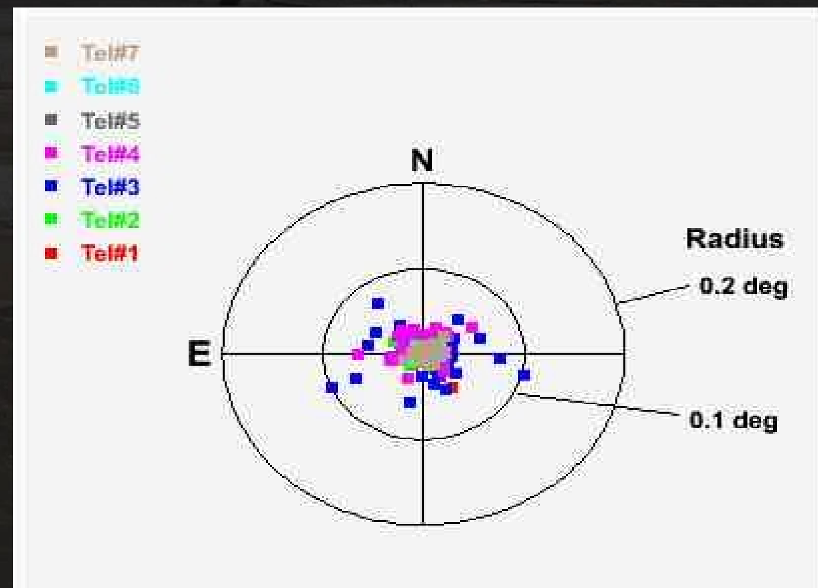
## Telescope pointing

For each telescope pointing model is worked out sighting large no. of stars

**Star offsets relative to telescope axis**




Before pointing model




After application of pointing model

Then star scans →

Overall pointing accuracy Including mirror alignment : 0.2°±0.1°

# *Gamma Ray Band*

**Terminology :**

1 MeV : $10^6$ eV 1 GeV : $10^9$ eV
1 TeV : $10^{12}$ eV 1 PeV : $10^{15}$ eV

- Low Energy (LE) : ≤ 30 MeV
- High Energy (HE) : 30 MeV – 30 GeV
- Very High Energy (VHE) : 30 GeV – 30 TeV
- Ultra High Energy (UHE) : 30 TeV – 30 PeV
- Extremely High Energy (EHE) : ≥ 30 PeV

# *Gamma Ray Band*

**Terminology :**

1 MeV : $10^6$ eV    1 GeV : $10^9$ eV
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- Extremely High Energy (EHE) : ≥ 30 PeV

# Detector Simulation

## Site and instrument related parameters

- Atmospheric attenuation of Cherenkov photons
- Night sky background : $1.5 \times 10^8$ ph cm$^{-2}$ s$^{-1}$ sr$^{-1}$
- Field of view : 3° FWHM
- Reflectivity of mirrors : ~ 80%
- Phototube response :
  Gain = $2.2 \times 10^6$, Quantum efficiency : peak = 24% at 400 nm
  Pulse shape : Gaussian with rise time 2 ns and width 3.3 ns
- Attenuation of pulse in coaxial cables :
  30 m LMR-Ultraflex-400, 55m RG213
- Pulse amplification : factor of 10
- Discriminator thresholds : ~180 mV for telescope pulses
- Trigger generation criteria : at least 4 telescope pulses out of 7 crossing threshold

## *CORSIKA*

**Inputs :**

- **Primary type and energy**
- **Arrival angle of primary**
  - **gamma-rays : vertical**
  - **Cosmic rays : within 3° around vertical**
- **Impact parameter : 0-200 *m***
- **Altitude of observation level and geomagnetic field**
  - **Hanle altitude : 4.3 *kms***
- **Telescope array geometry**
- **Wavelength range : 270-650 *nm***

**Output :**

**Arrival time, direction and position of Cherenkov photons hitting telescopes**

➢ ***Detector Simulation:*** **Site and instrument related parameters**

➢ **Program developped in-house**

- Atmospheric attenuation of Cherenkov photons
- Reflectivity of mirrors
- Phototube response
- Attenuation of pulse in coaxial cables
- Discriminator thresholds
- Trigger generation criteria

## *Details of Spectral Shapes Used for Simulations*

- **For γ-rays :** *(20 GeV – 5 TeV)*

$$J(E) = 3.2 \times 10^{-7} (E_{TeV})^{-2.49}\ m^{-2}\, s^{-1}\, TeV^{-1}$$

- **For protons :** *(50 GeV – 5 TeV)*

$$J(E) = 0.0867 (E_{TeV})^{-2.7}\ m^{-2}\, s^{-1}\, sr^{-1}\, TeV^{-1}$$

- **For α particles :** *(100 GeV – 10TeV)*

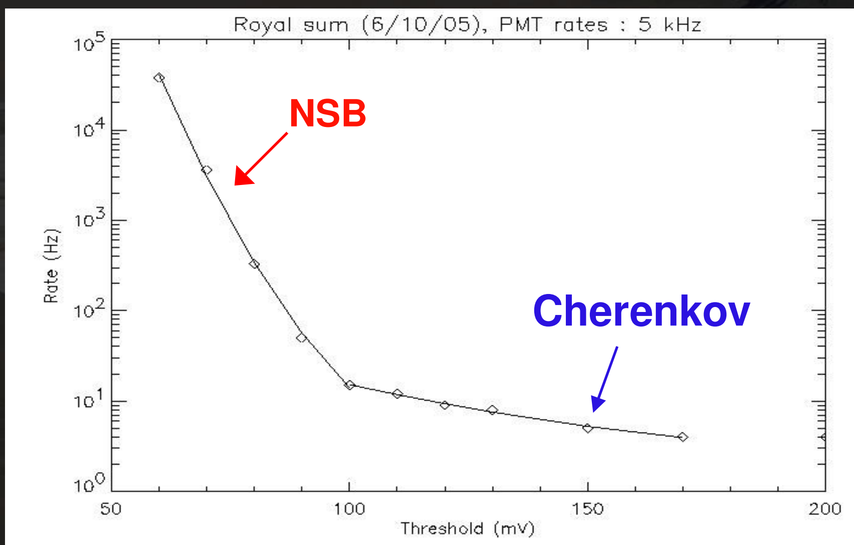
$$J(E) = 0.0595 (E_{TeV})^{-2.7}\ m^{-2}\, s^{-1}\, sr^{-1}\, TeV^{-1}$$

- **For electrons :** *( 50 GeV – 5 TeV)*

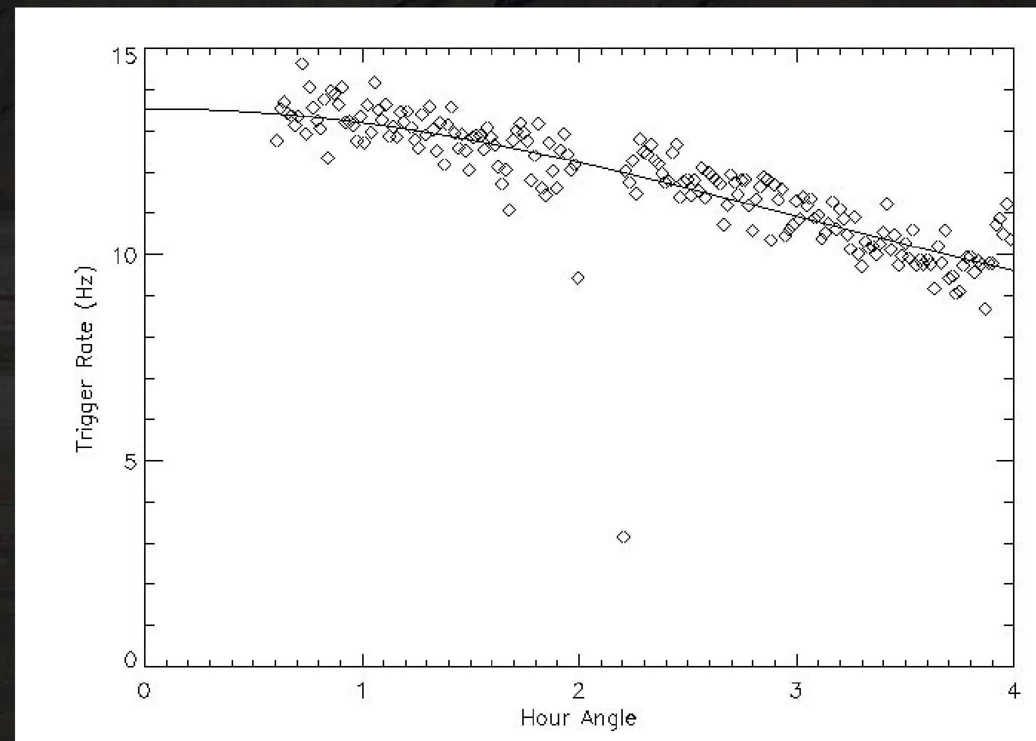
$$J(E) = 638.97 (E_{GeV})^{-3.3}\ m^{-2}\, s^{-1}\, sr^{-1}\, GeV^{-1}$$

# *Preliminary Tests*

## Rate-bias curve

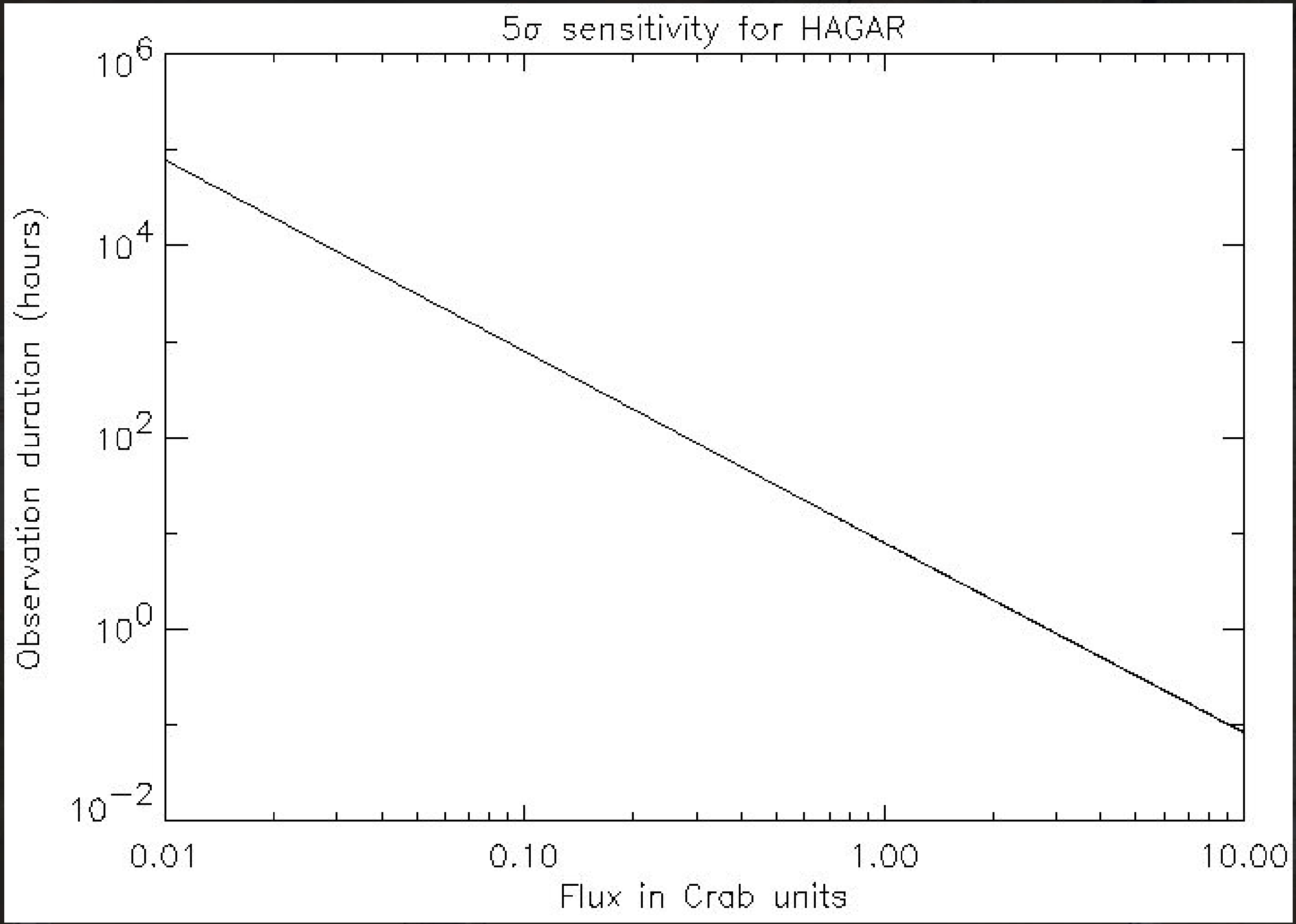



## Dark region tracking




## PMT rate stability, fixed angle runs etc

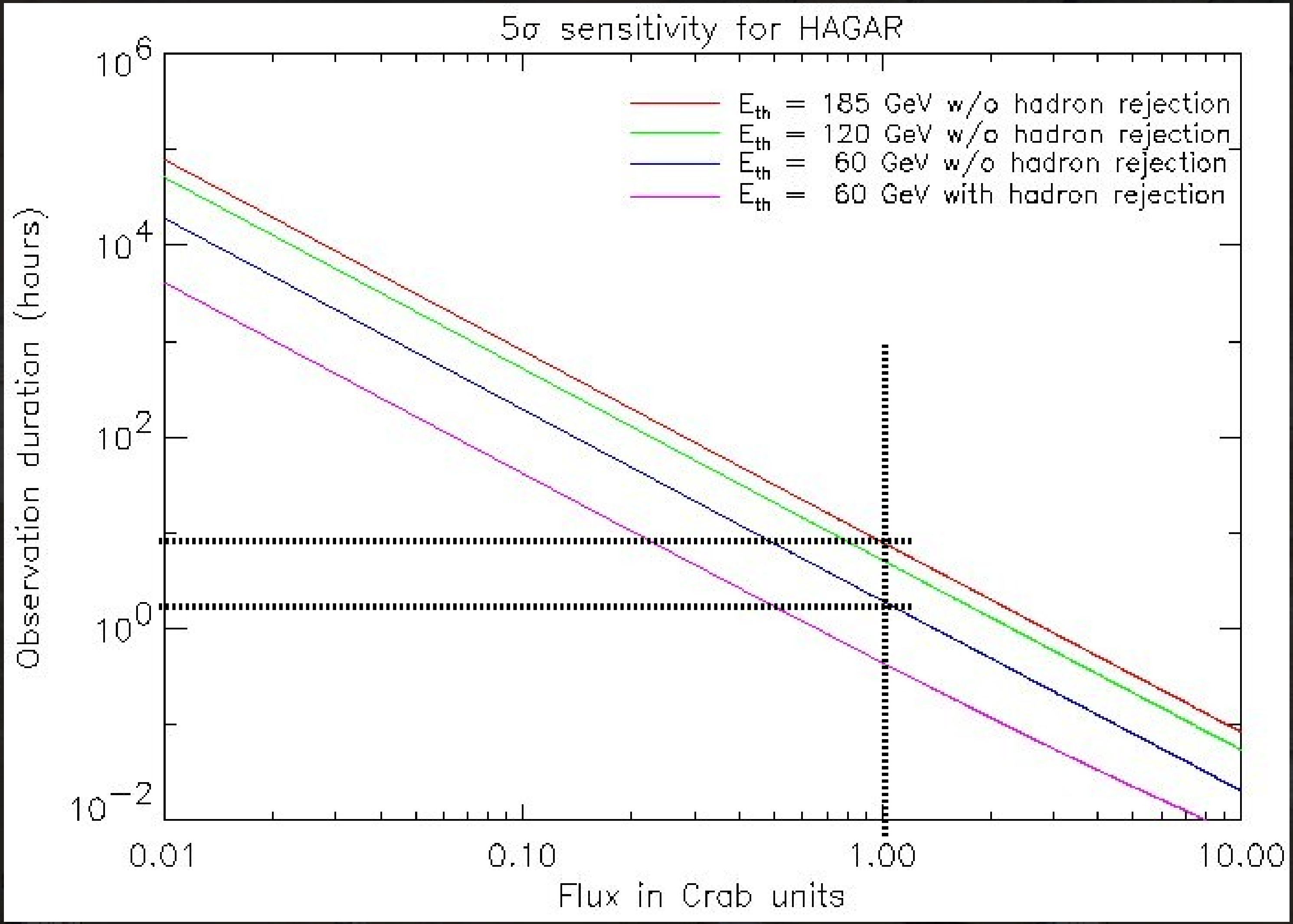
# Sensitivity of HAGAR




**Raw sensitivity of HAGAR : 1.8 sigma/√hr for Crab like sources**

**Improvement in sensitivity : Off-axis rejection**
**Gamma-Hadron Separation parameters**

# Sensitivity of HAGAR




**Assuming 98% rejection for cosmic ray showers and 35% acceptance for gamma-rays, sensitivity for energy threshold of 60 GeV ~ 7.6 sigma / √hour for Crab**

## Reconstruction of Arrival Direction

**If the $x_i$, $y_i$, $z_i$, are the co-ordinates of the ith telescope, l, m, n, the direction cosines of shower axis and $t_i$ is the arrival time of photons at this telescope then equation relating them**

$$lx_i + my_i + nz_i + c\left(t_i - t_0\right) = 0$$

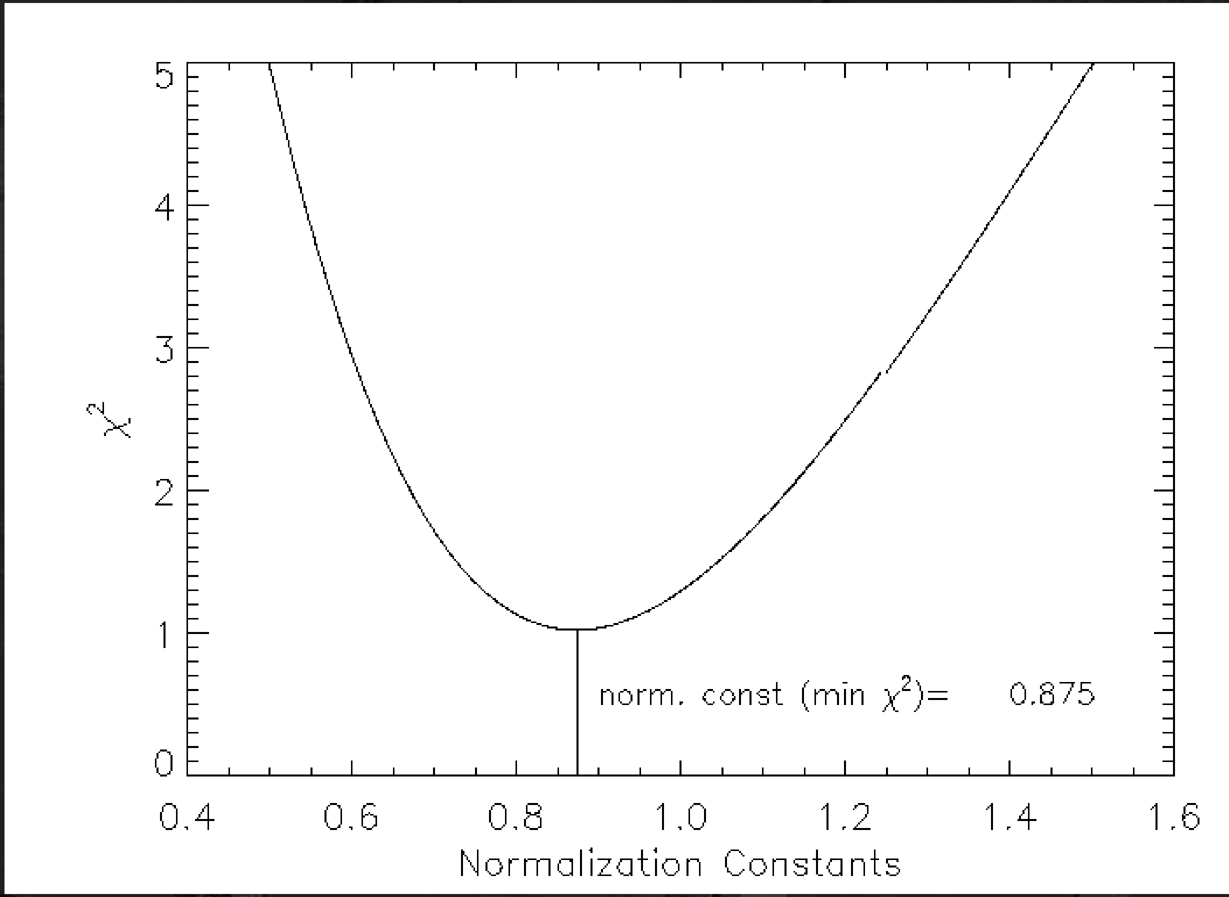
**Where $t_0$ is the time at which the shower front passes through the origin of the co-ordinate system. Then the arrival direction can be estimated by $\chi^2$ minimization**

$$\chi^2 = \sum_{i=0}^{n} \omega_i \left(lx_i + my_i + nz_i + c\left(t_i - t_0\right)\right)^2$$

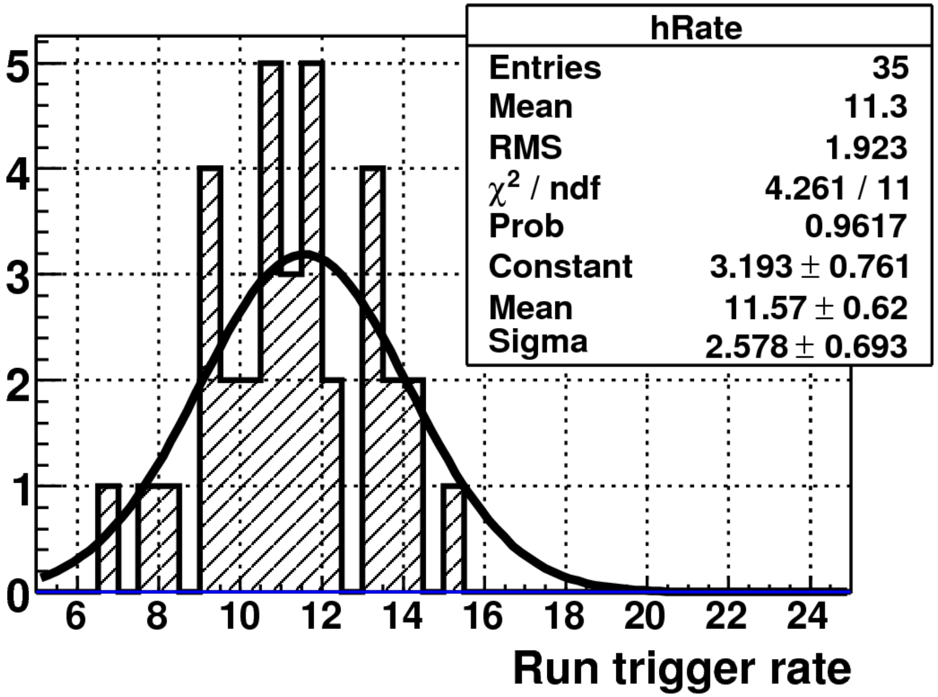
**The value of l, m, n, and $t_0$ are calculated using following eqns**

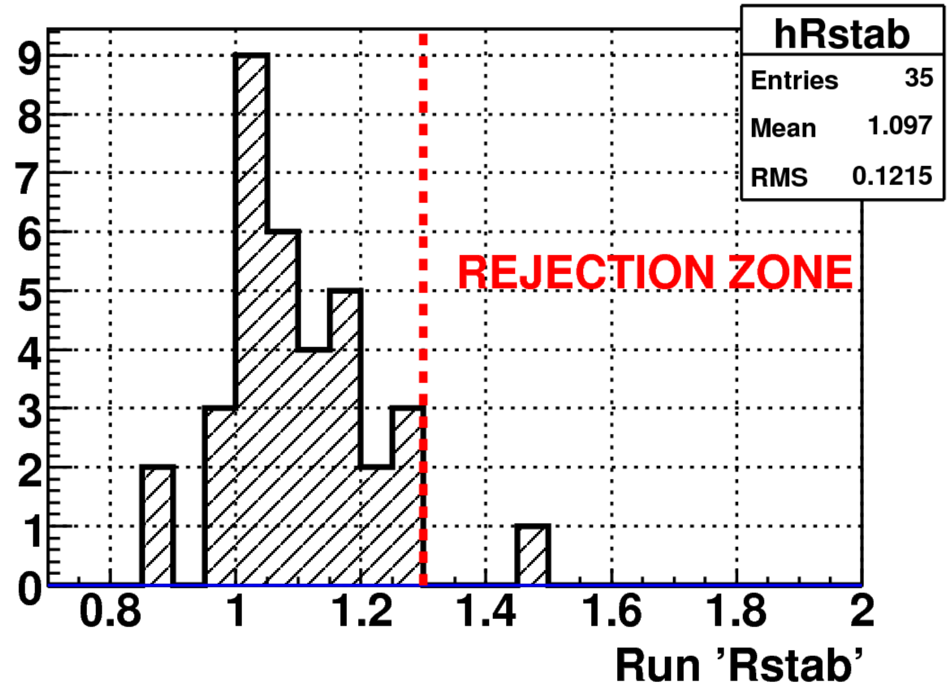
$$\frac{\partial \chi^2}{\partial l} = 0, \quad \frac{\partial \chi^2}{\partial m} = 0, \quad \frac{\partial \chi^2}{\partial t_0} = 0, \quad l^2 + m^2 + n^2 = 1$$

$$excess = \Sigma_{i=0}^{2.5}(Si - c_k B_i)$$

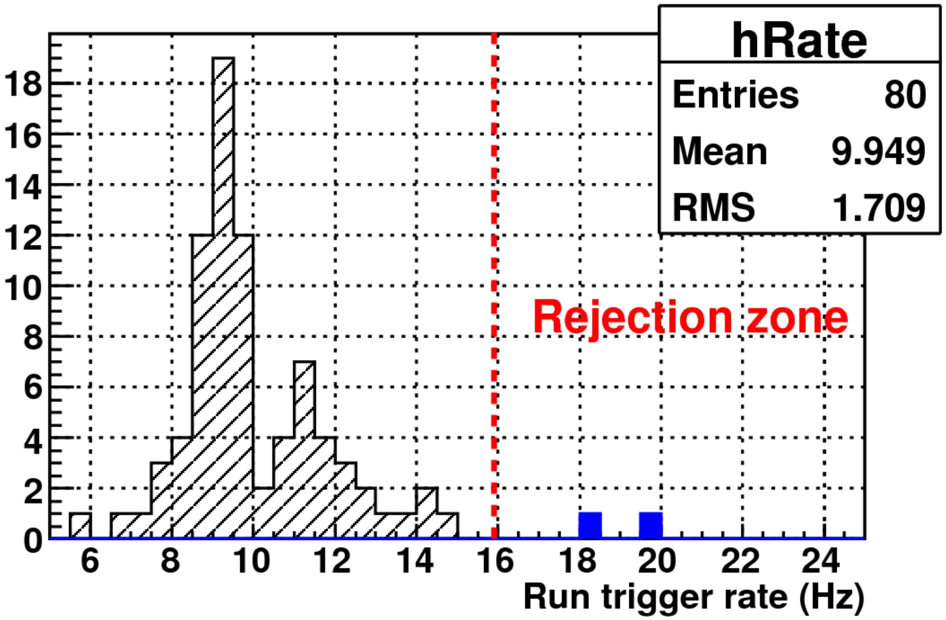


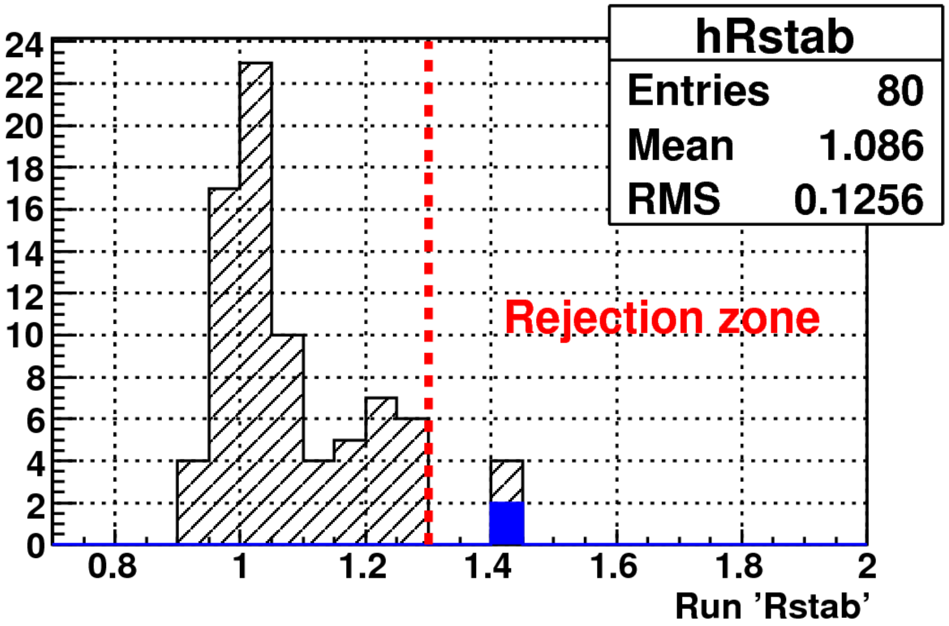
# Dark regions “d22mw” and OFF Crab:



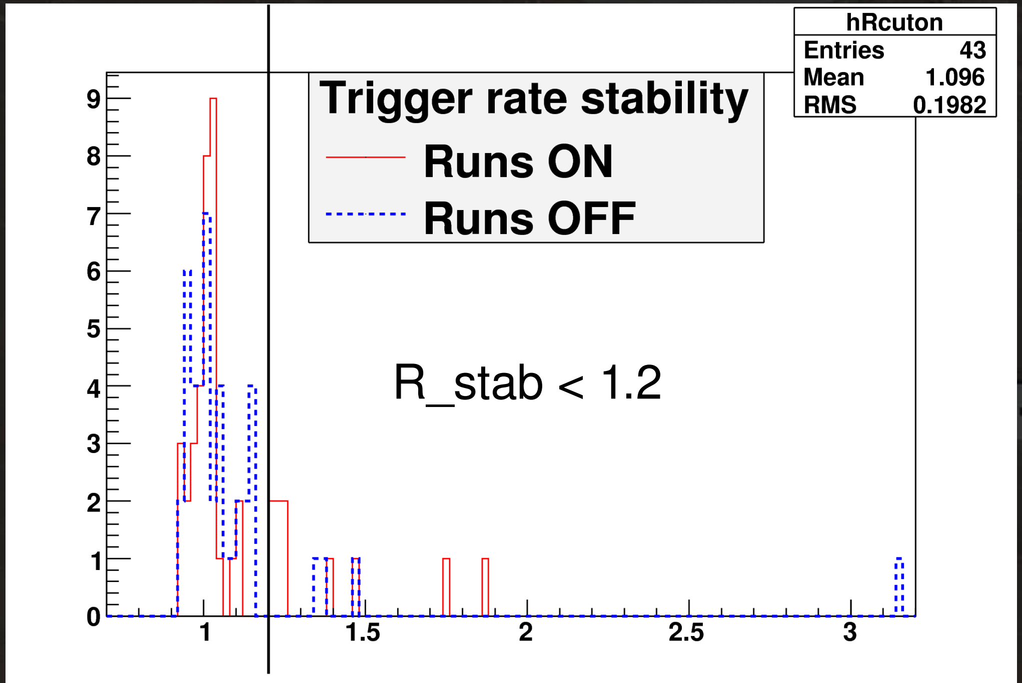

# Crab nebula:

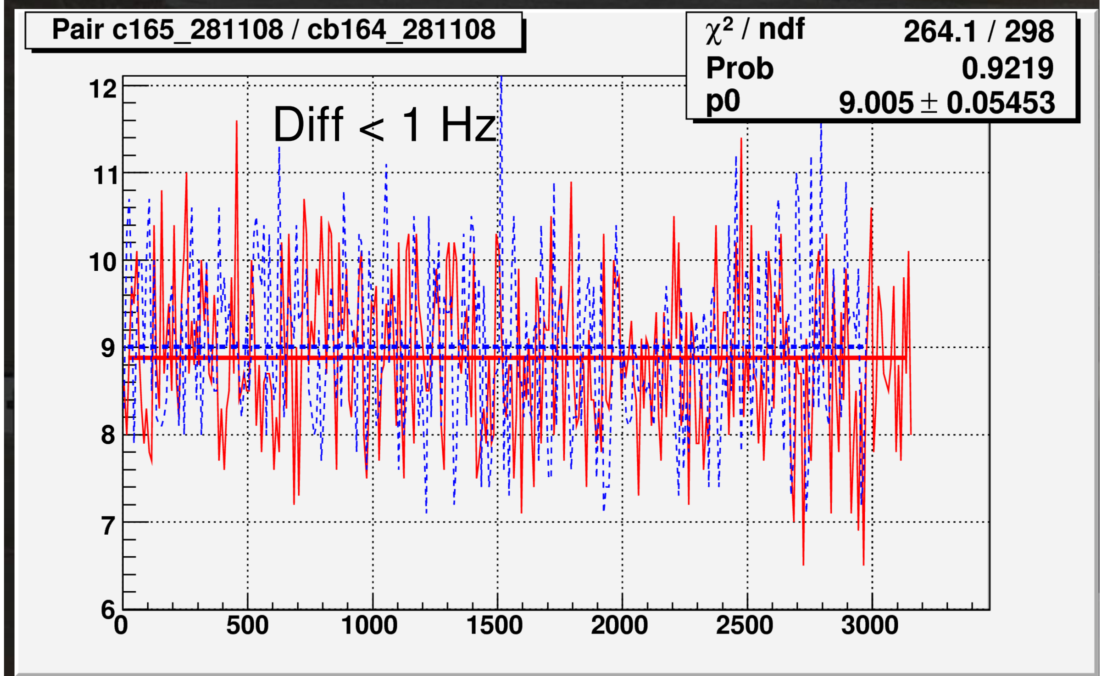


# Trigger rate of selected events

- Events are rejected if
  - TDC values out of range
  - Large chi ² in plane front fitting
- Trigger rate parameter computed again to check no biais due to analysis procedure



# Current status of TDCs/QDCs

- 7 telescopes with 7 mirrors ---> 49 PMTs
- 49 individual + 7 “royal sum” TDC channels
- 7 QDC “royal sum” channels (module for the 49 individual QDC channels are installed)
- Now, only the 7 royal sum TDC channels are used for signal extraction.

## Additional event selection:

* Common hour angle

* Chi $^2$ < mean + 1 sigma

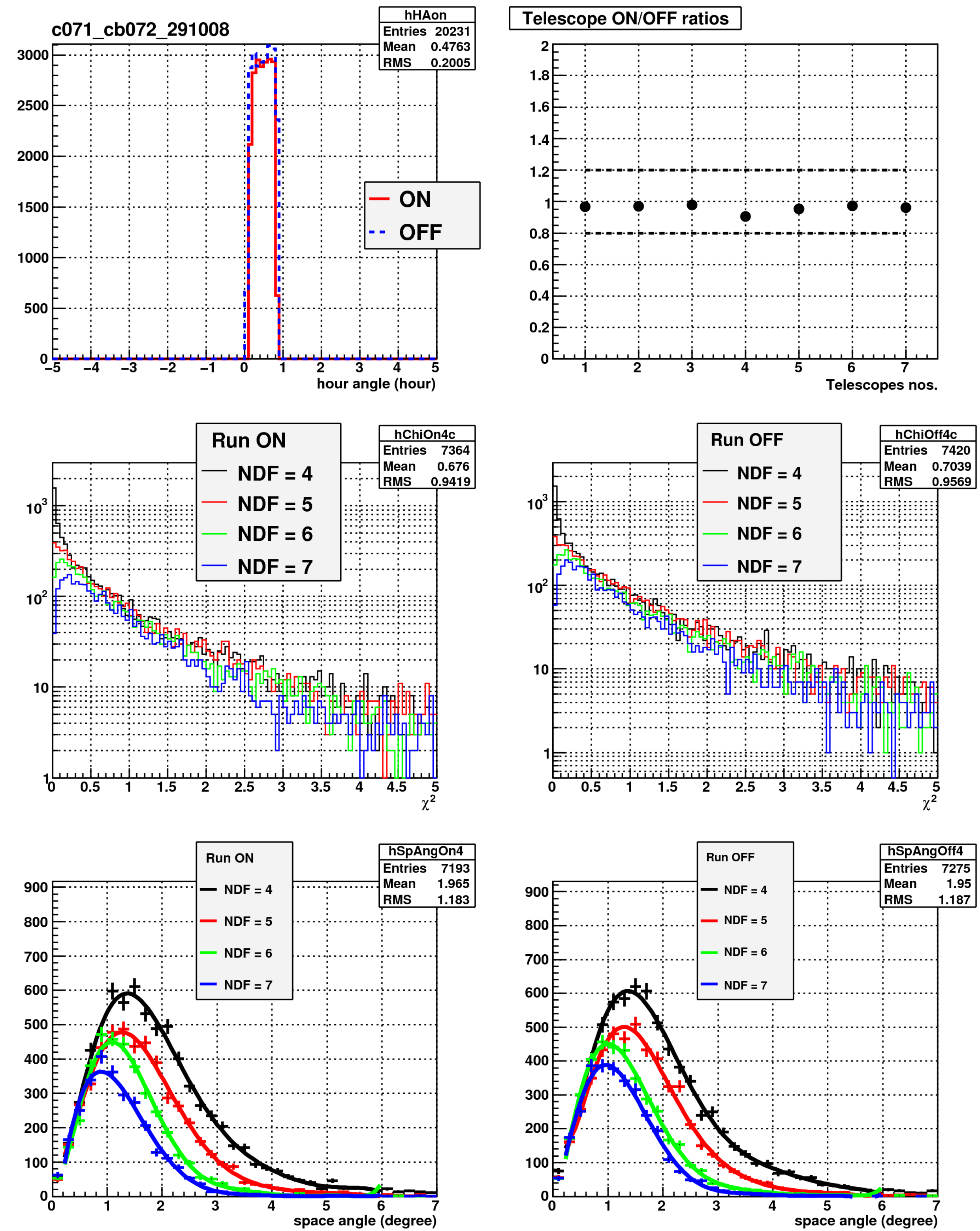
## Pair selection:

* ON/OFF ratio per tel at 1.0 +/- 0.2

* Space angle distribution parameters:

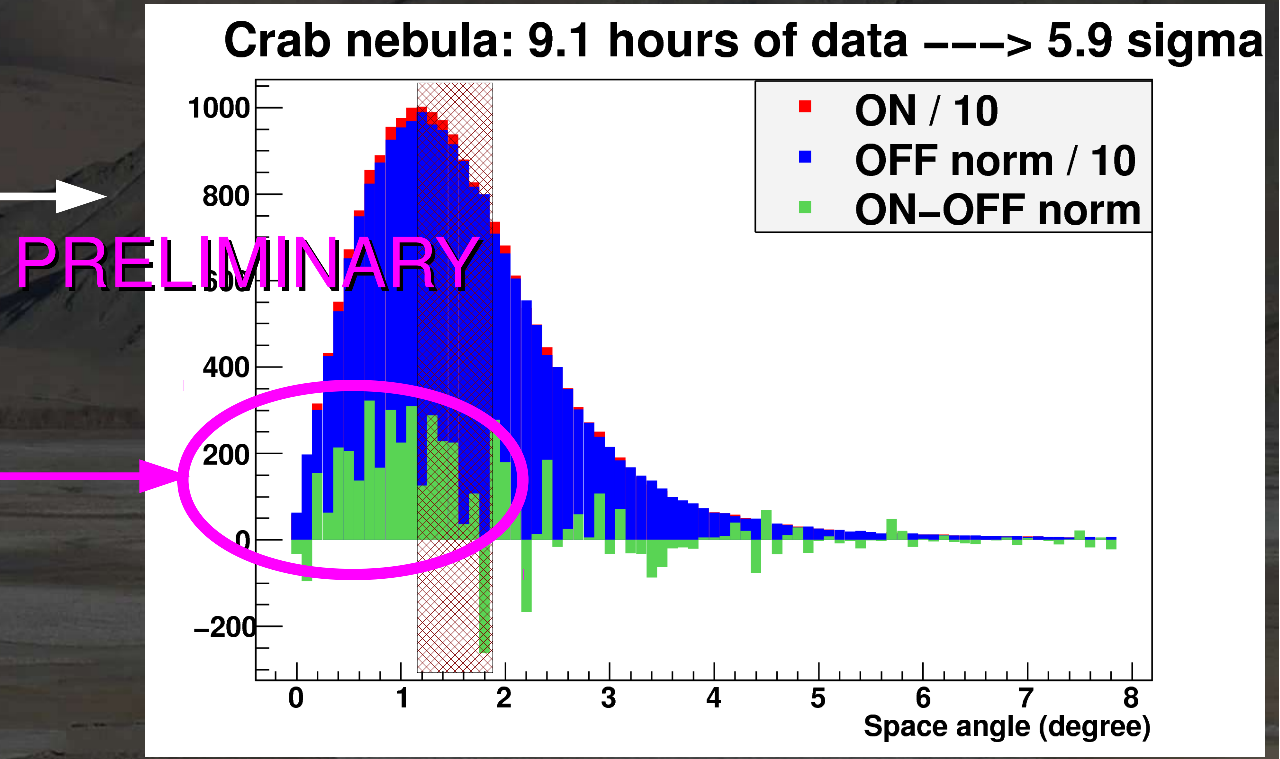
- 85 % cut
- peak value
- FWHM

Differences < 0.15°



# Crab nebula

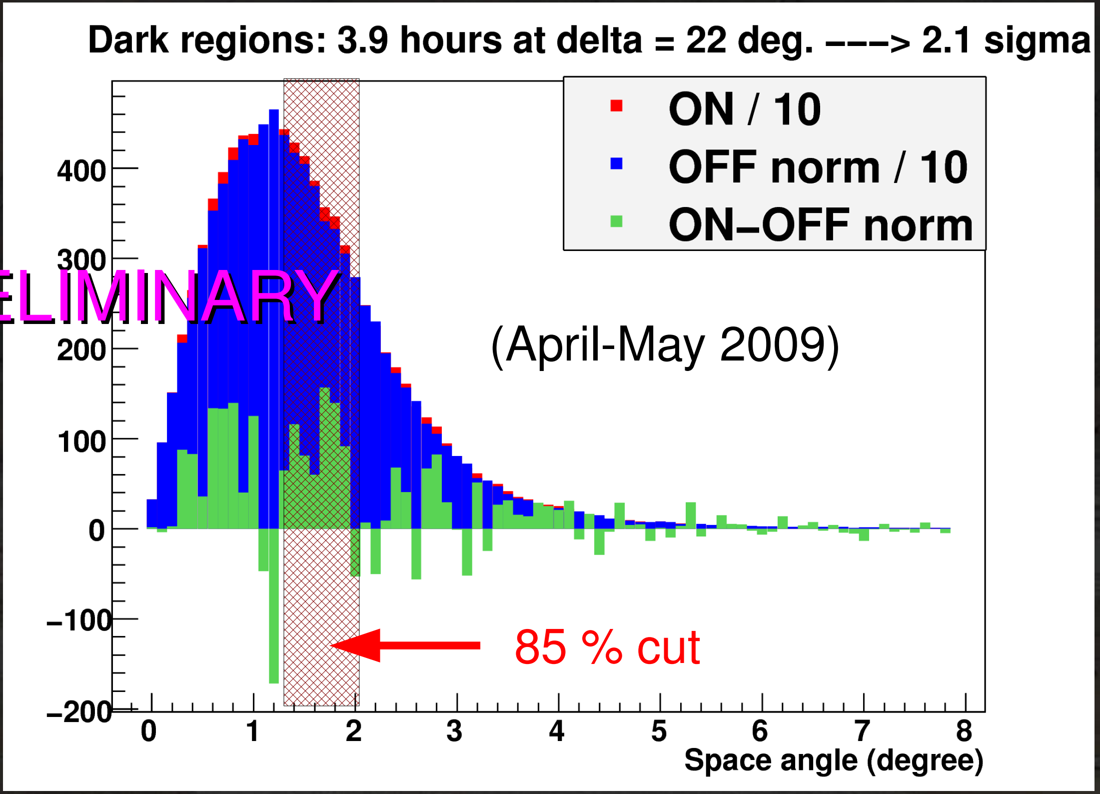
All pairs together
All NTT together




| NTT | No. selected pairs (initially 43) | duration (hour) | $N_{ON}$ | $N_{OFF}$ | excess | rate (count(s)/min) | significance (no. of $\sigma$) |
|---|---|---|---|---|---|---|---|
| All tel. | 13 | 9.1 | 99000 | 100430 | 2604.5 ± 437.9 | 4.1 ± 0.7 | 6.0 |
| 4 tel. | 9 | 6.5 | 31855 | 31587 | 1460.4 ± 247.2 | 5.9 ± 0.6 | 5.9 |
| 5 tel. | 12 | 8.6 | 28486 | 29152 | 455.8 ± 235.7 | 1.9 ± 0.5 | 1.9 |
| 6 tel. | 10 | 7.5 | 18517 | 18832 | -238.0 ± 192.9 | -1.9 ± 0.4 | -1.2 |
| 7 tel. | 12 | 8.5 | 20142 | 20859 | 926.2 ± 194.2 | 1.8 ± 0.4 | 4.8 |

# Dark regions:

All pairs together
All NTT together




| NTT | No. selected pairs (initially 25) | duration (hour) | $N_{ON}$ | $N_{OFF}$ | excess | rate (count(s)/min) | significance (no. of $\sigma$) |
|---|---|---|---|---|---|---|---|
| All tel. | 13 | 6.6 | 81164 | 80199 | 867.8 ± 402.3 | 2.64 ± 0.95 | 2.2 |
| 4 tel. | 9 | 4.8 | 25121 | 24848 | 81.1 ± 224.6 | 0.28 ± 0.78 | 0.7 |
| 5 tel. | 10 | 5.1 | 19475 | 19332 | -46.7 ± 198.1 | -0.15 ± 0.64 | -0.2 |
| 6 tel. | 12 | 6.1 | 17056 | 16984 | 39.4 ± 184.9 | 0.11 ± 0.51 | 0.2 |
| 7 tel. | 11 | 5.4 | 19512 | 19035 | 794.1 ± 195.0 | 2.45 ± 0.60 | 4.1 |

## HAGAR RESULTS ON CRAB NEBULA

* Excess for NDF >= 4
* Excess for NDF = 4
* Excess for NDF = 5
* Ecxess for NDF = 6
* Excess for NDF = 7

**NDF >=4: 13 pairs = 9.1 h**
4.12 +/– 0.70 $\gamma$ / min ––> 5.95$\sigma$

**NDF = 4: 9 pairs = 6.5 h**
3.72 +/– 0.63 $\gamma$ / min ––> 5.91$\sigma$

**NDF = 5: 12 pairs = 8.6 h**
0.88 +/– 0.46 $\gamma$ / min ––> 1.93$\sigma$

**NDF = 6: 10 pairs = 7.5 h**
–0.53 +/– 0.43 $\gamma$ / min ––> –1.23$\sigma$

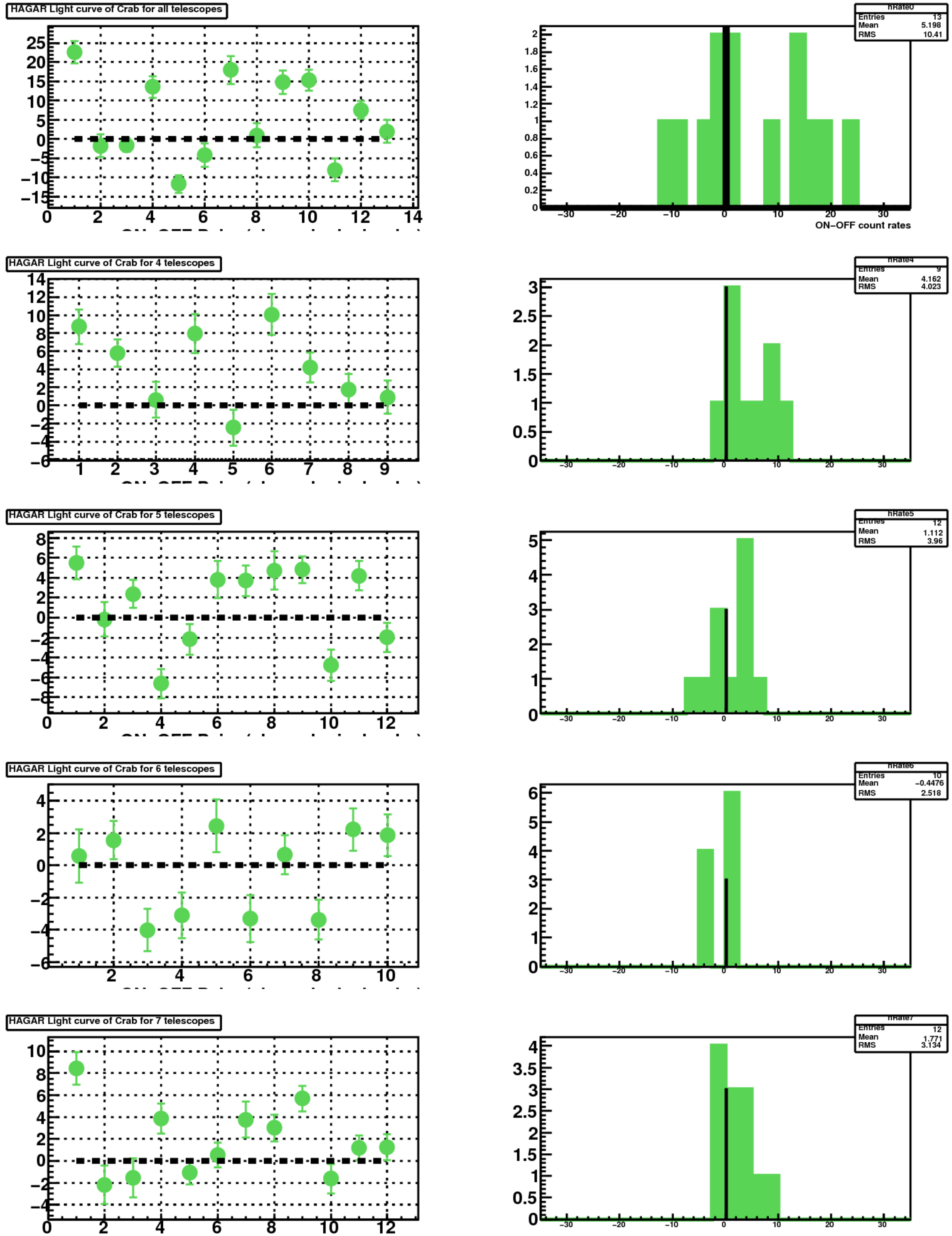
**NDF = 7: 12 pairs = 8.5 h**
1.81 +/– 0.38 $\gamma$ / min ––> 4.76$\sigma$

## RUN/PAIR SELECTION:

* | Diff Trigger rate | < 1.0 Hz
* Rcut (rate stab.) < 0.00
* 0.8 < Tel Ratios (1 to 7) < 1.2
* | Diff Space Angle Cut | < 0.0
* | Diff Space Angle Peak | < 0.0
* | Diff Space Angle FWHM | < 0.0
* 0.85 < norm Const (85 %) < 1.15

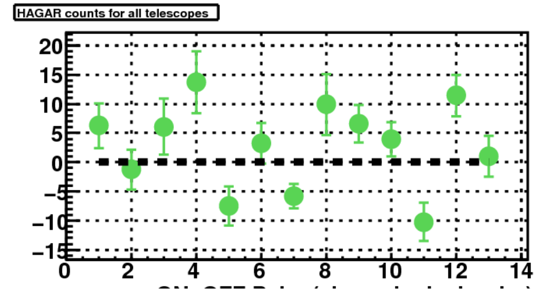
## MAIN ANALYSIS CUTS:

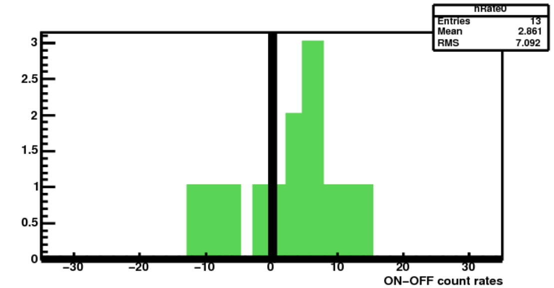
* TDC ranges
* common hour angle
* $\chi$^2 on plane front fitting
* Space Angle Cut = 85 %



## HAGAR RESULTS ON cb_Israel

* Excess for NTT >= 4
* Excess for NTT = 4
* Excess for NTT = 5
* Ecxess for NTT = 6
* Excess for NTT = 7

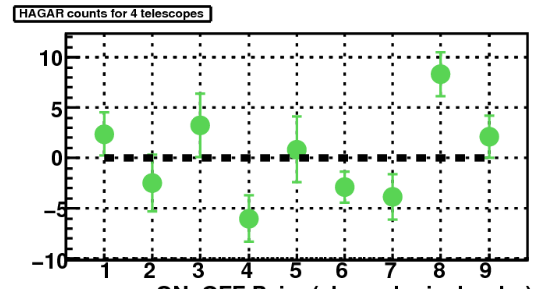


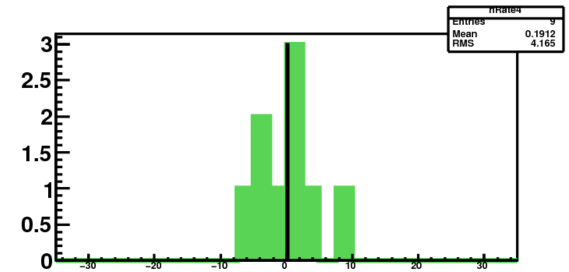




**NTT >=4: 13 pairs = 6.6 h**
**2.64 +/– 0.95 $\gamma$ / min --> 2.16 $\sigma$**

**NTT = 4: 9 pairs = 4.8 h**
**0.28 +/– 0.78 $\gamma$ / min --> 0.36 $\sigma$**

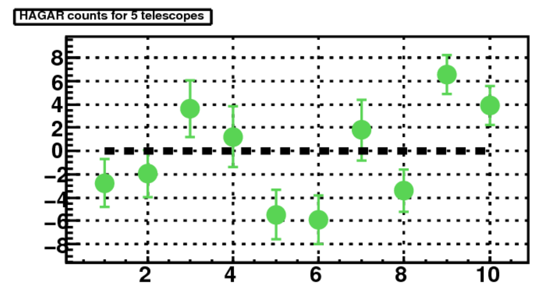
**NTT = 5: 10 pairs = 5.1 h**
**–0.15 +/– 0.64 $\gamma$ / min --> –0.24**

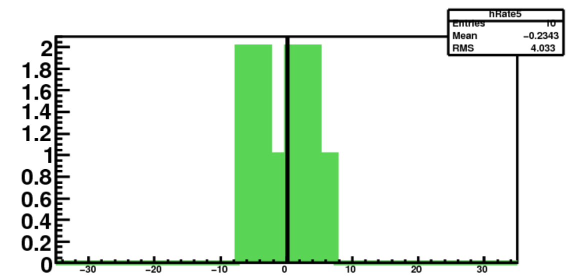



**NTT = 6: 12 pairs = 6.1 h**
**0.11 +/– 0.51 $\gamma$ / min --> 0.21 $\sigma$**

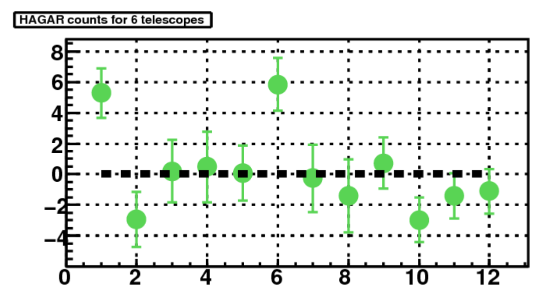
**NTT = 7: 11 pairs = 5.4 h**
**2.45 +/– 0.60 $\gamma$ / min --> 4.07 $\sigma$**

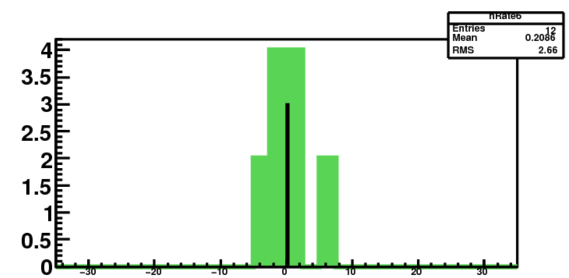



## RUN/PAIR SELECTION:

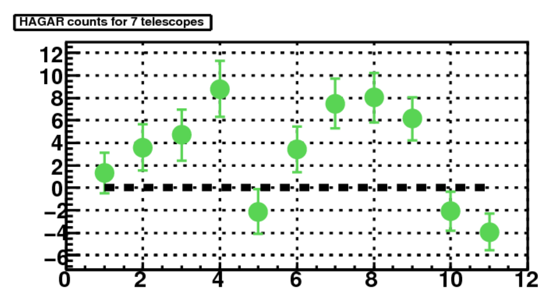
* | Diff Trigger rate | < 1.0 Hz
* Rcut (rate stab.) < 0.00
* 0.8 < Tel Ratios (1 to 7) < 1.2
* | Diff Space Angle Cut | < 0.0
* | Diff Space Angle Peak | < 0.0
* | Diff Space Angle FWHM | < 0.0
* 0.85 < norm Const (85 %) < 1.15

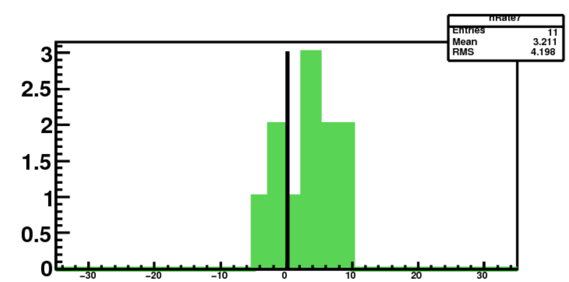



## MAIN ANALYSIS CUTS:

* TDC ranges
* common hour angle
* $\chi$^2 on plane front fitting
* Space Angle Cut = 85 %



## HAGAR RESULTS ON d22mw

* Excess for NTT >= 4
* Excess for NTT = 4
* Excess for NTT = 5
* Ecxess for NTT = 6
* Excess for NTT = 7

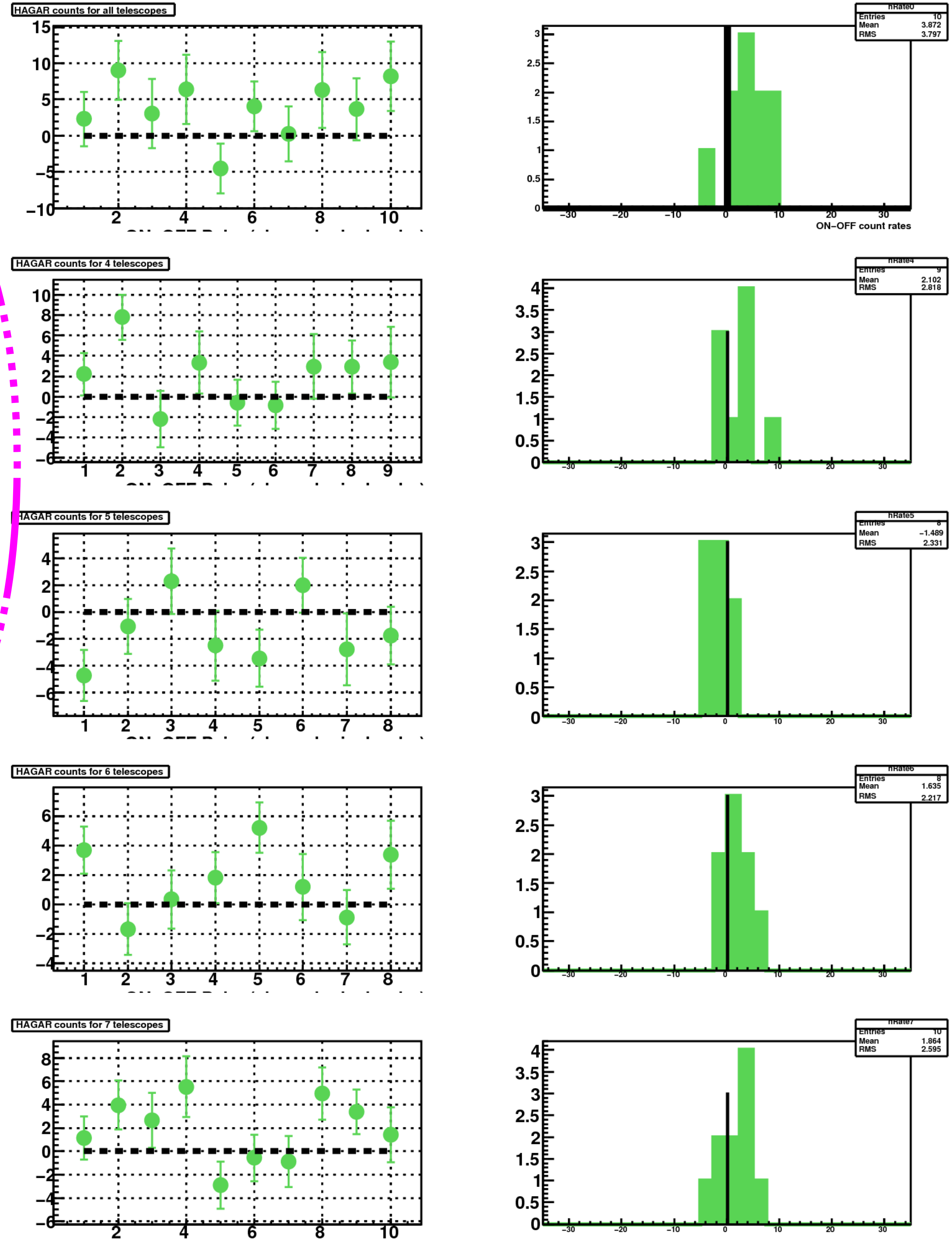
**NTT >=4: 10 pairs = 4.6 h**
3.38 +/– 1.21 $\gamma$ / min --> $2.72\sigma$

**NTT = 4: 9 pairs = 4.1 h**
2.15 +/– 0.87 $\gamma$ / min --> $2.47\sigma$

**NTT = 5: 8 pairs = 3.7 h**
–1.56 +/– 0.79 $\gamma$ / min --> $-1.99\sigma$

**NTT = 6: 8 pairs = 3.7 h**
1.52 +/– 0.66 $\gamma$ / min --> $2.28\sigma$

**NTT = 7: 10 pairs = 4.6 h**
1.74 +/– 0.68 $\gamma$ / min --> $2.57\sigma$



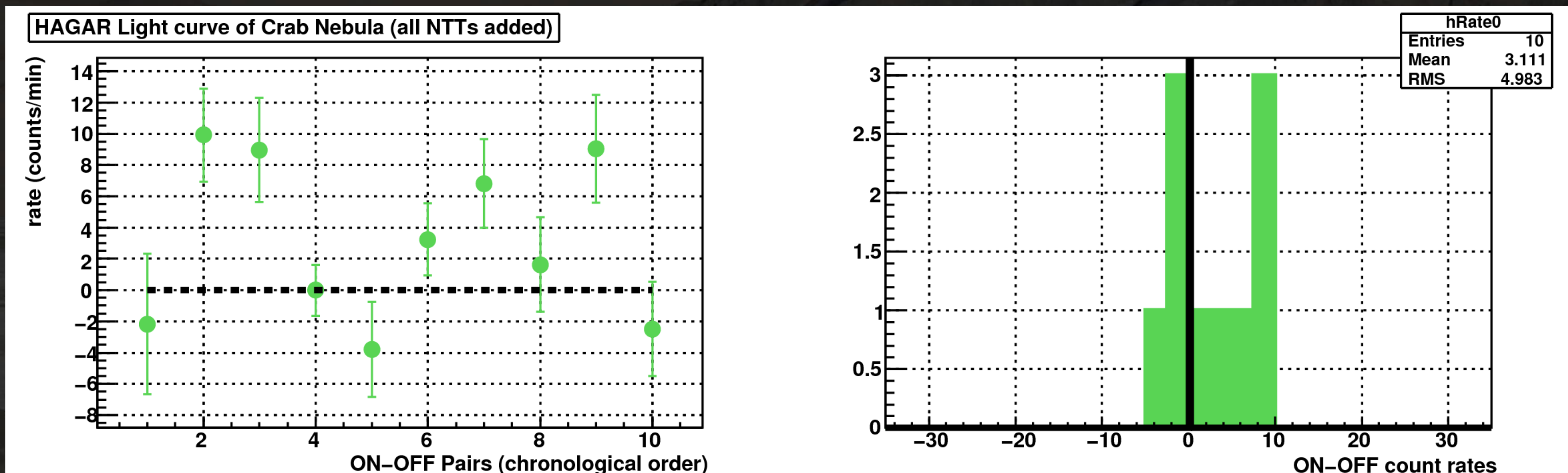

## RUN/PAIR SELECTION:

* | Diff Trigger rate | < 1.0 Hz
* Rcut (rate stab.) < 0.00
* 0.8 < Tel Ratios (1 to 7) < 1.2
* | Diff Space Angle Cut | < 0.0
* | Diff Space Angle Peak | < 0.0
* | Diff Space Angle FWHM | < 0.0
* 0.85 < norm Const (85 %) < 1.15

## MAIN ANALYSIS CUTS:

* TDC ranges
* common hour angle
* $\chi$^2 on plane front fitting
* Space Angle Cut = 85 %

# Crab 2009 (Nov-Dec)

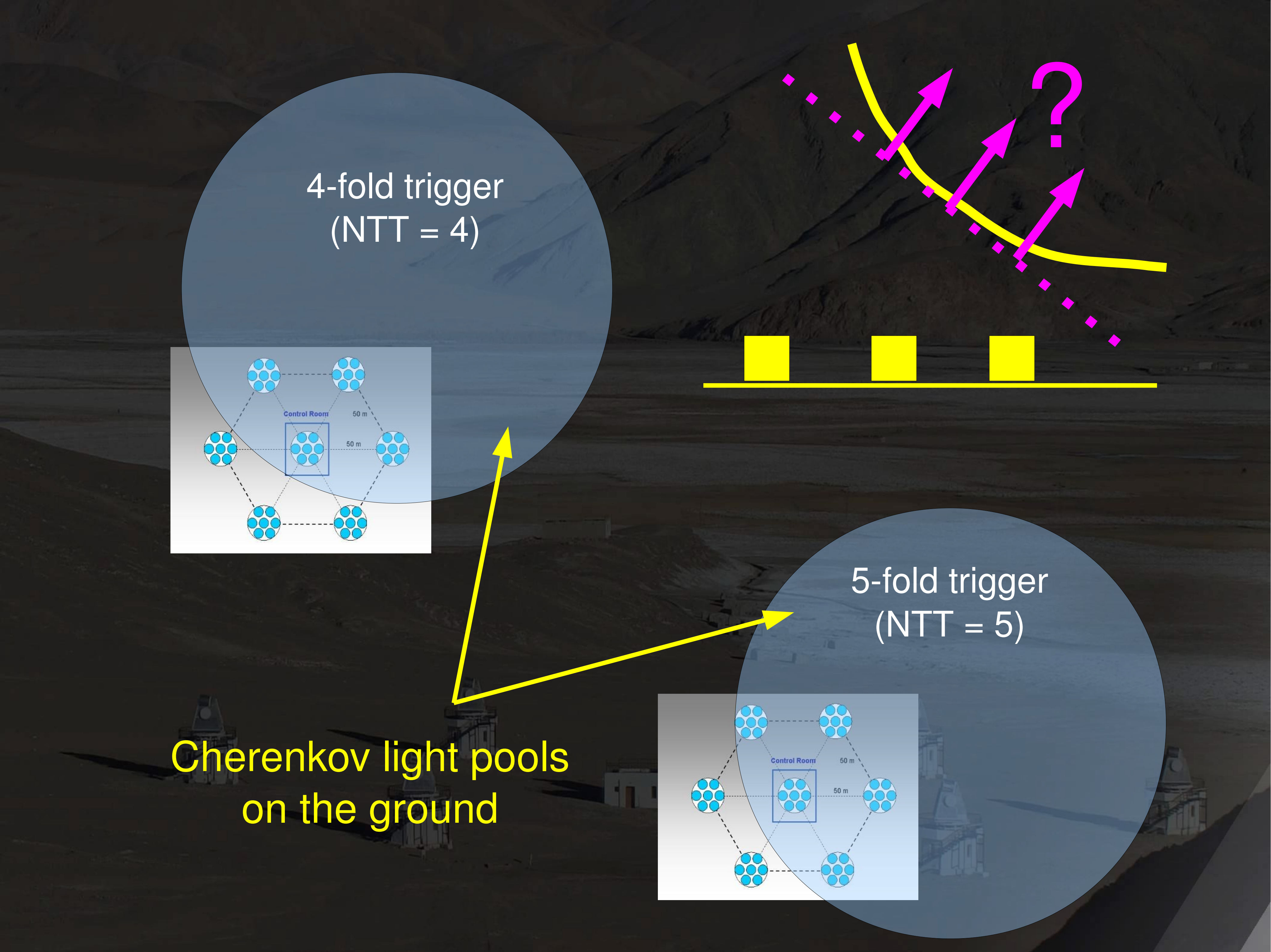


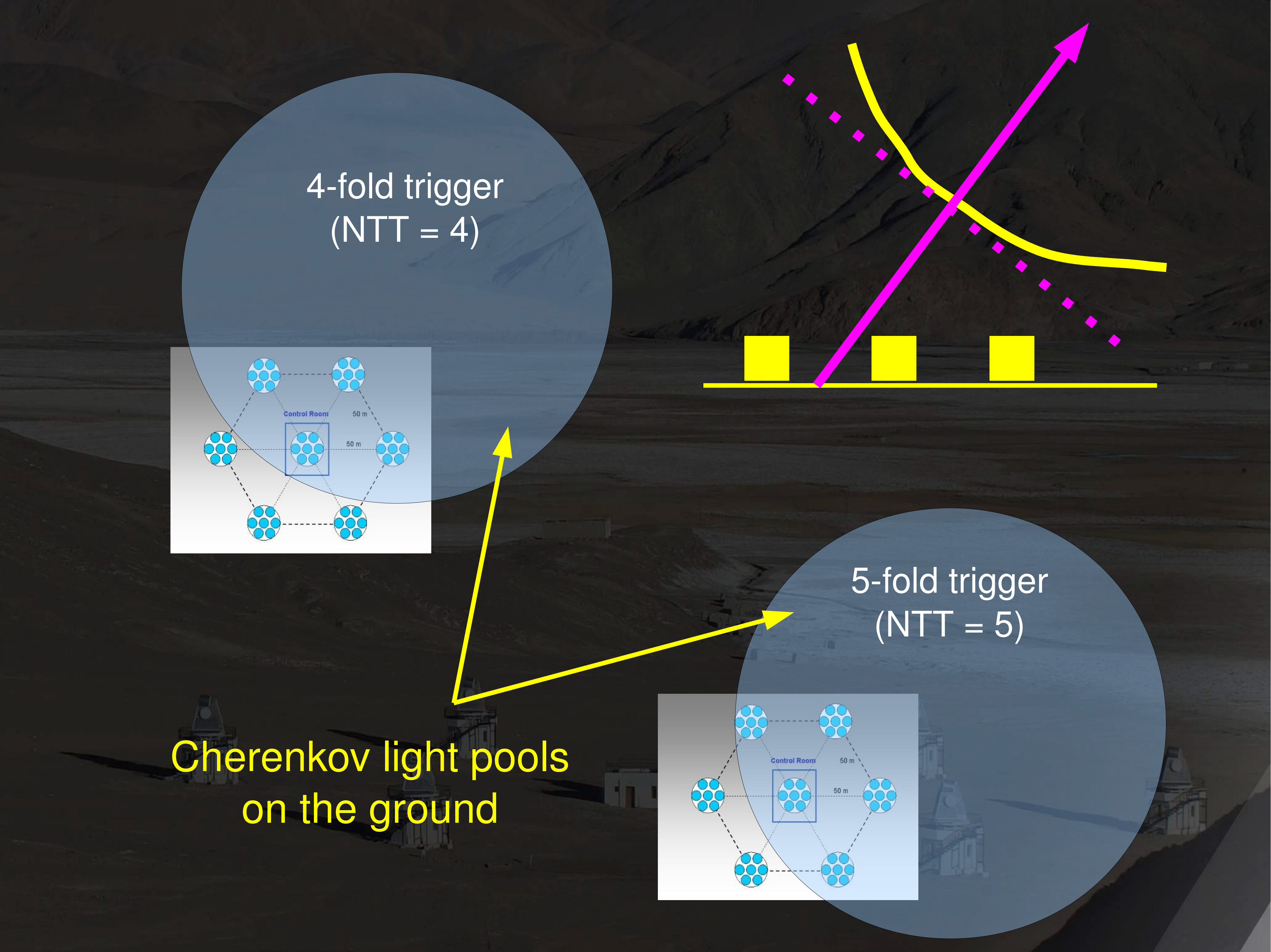

With loose cuts

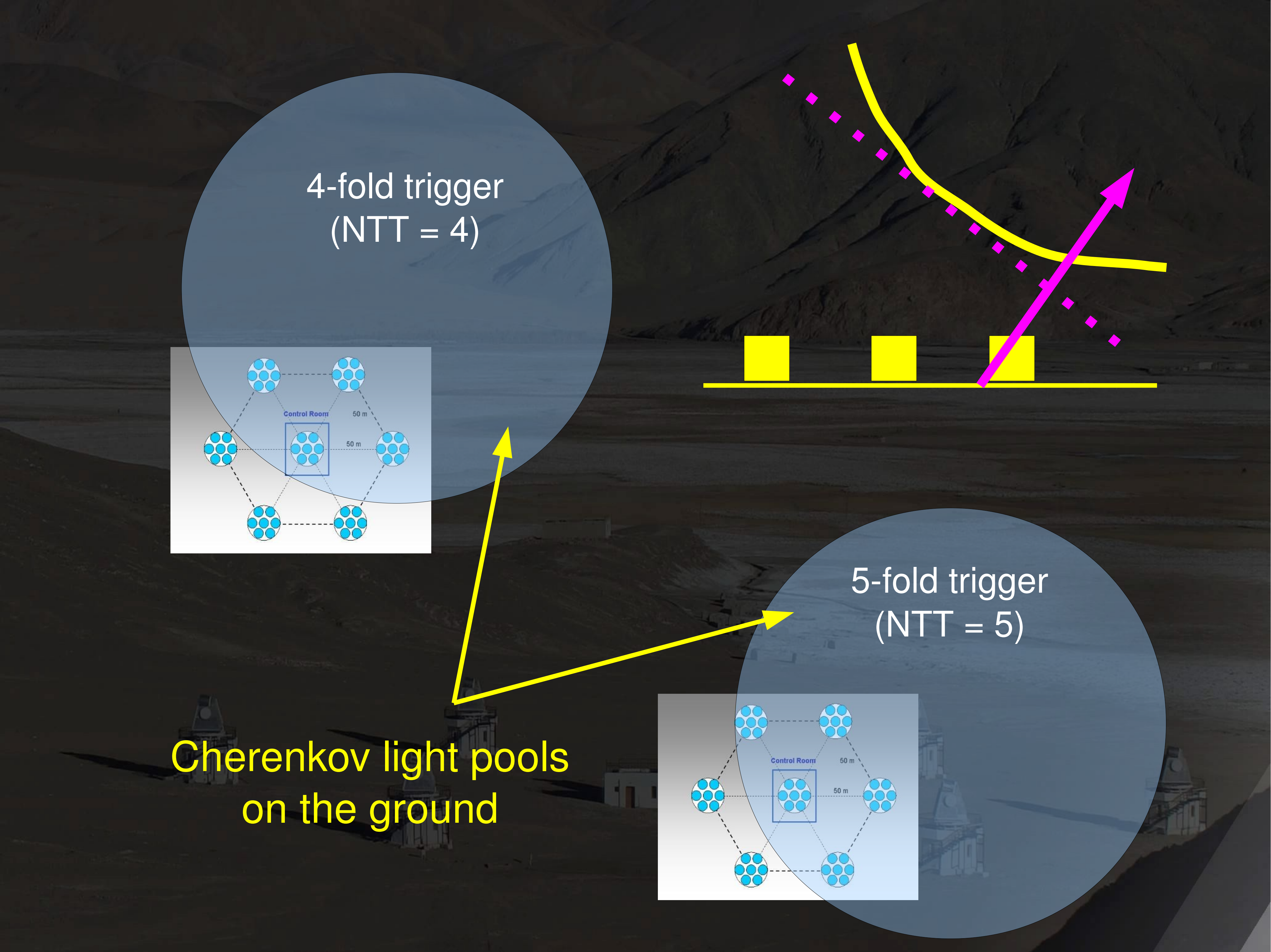
| | | |
|---|---|---|
| 5.7 hrs | NTT 4-5-6-7 | 3.3 sigma |
| | NTT 5-6-7 | 5.0 sigma |

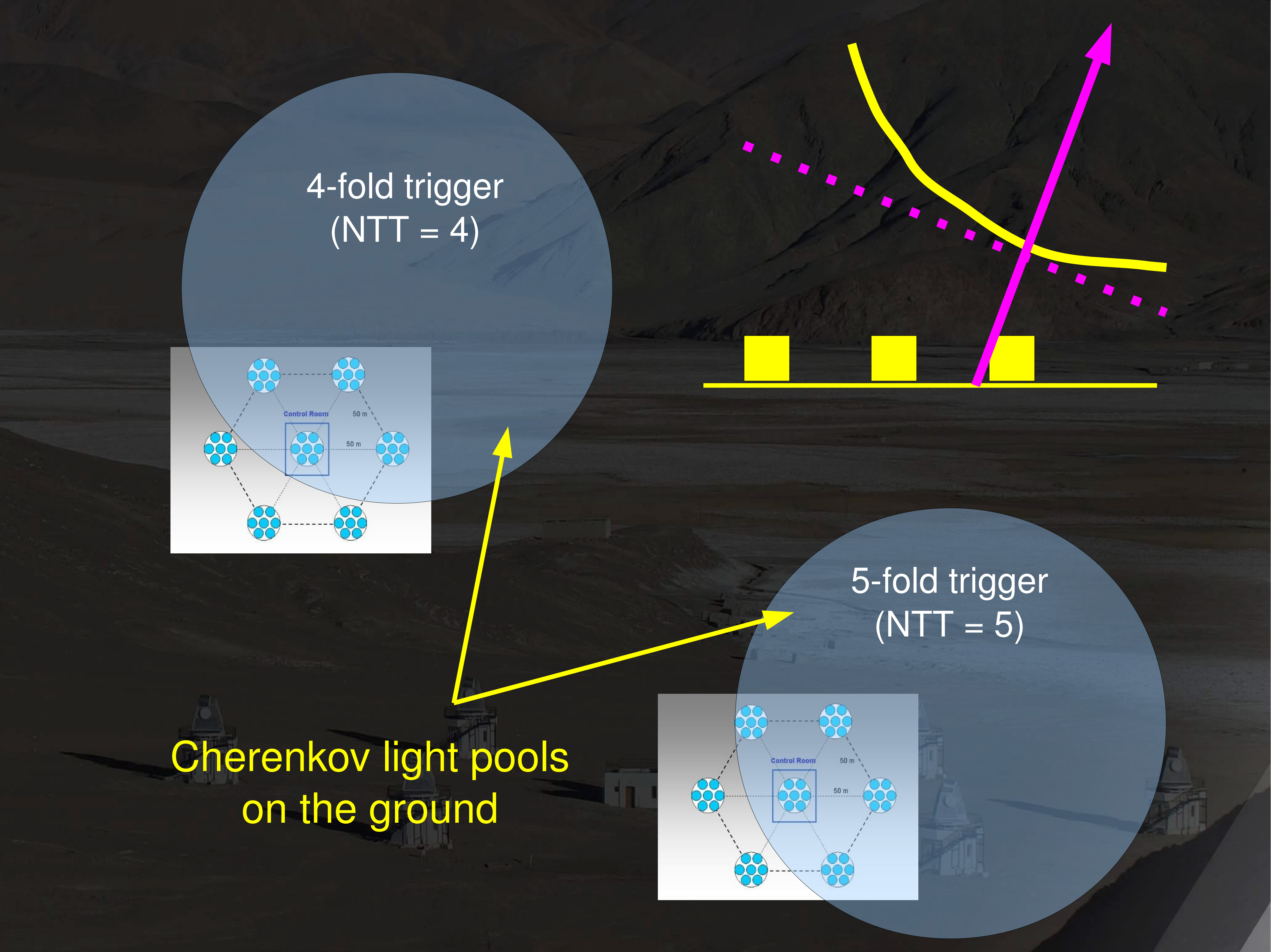
VERY PRELIMINARY!!!

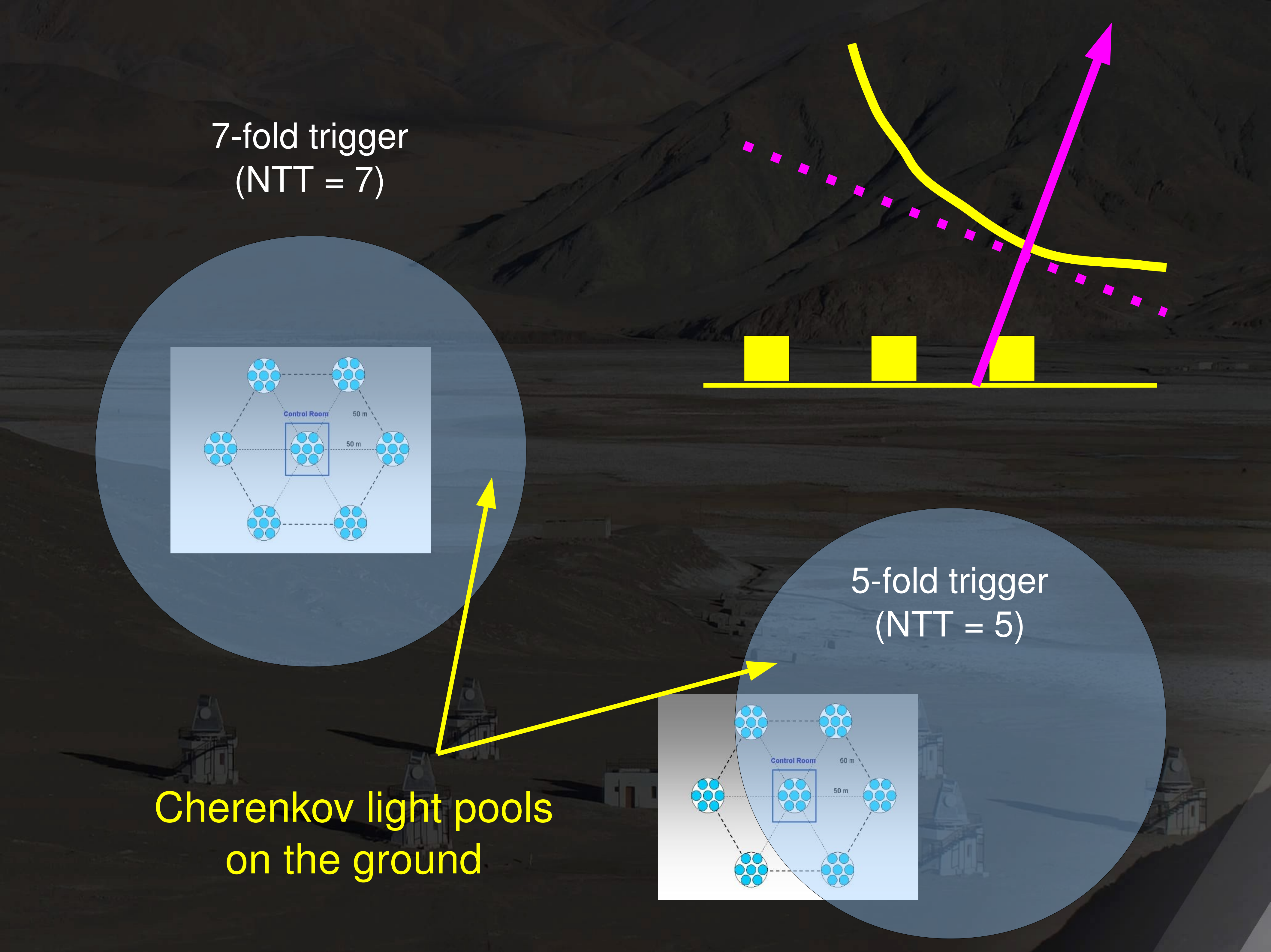
---> urgence of continuing improvement in analysis


4-fold trigger
(NTT = 4)
5-fold trigger
(NTT = 5)
?
Control Room
50 m
50 m
Control Room
50 m
50 m
Cherenkov light pools
on the ground

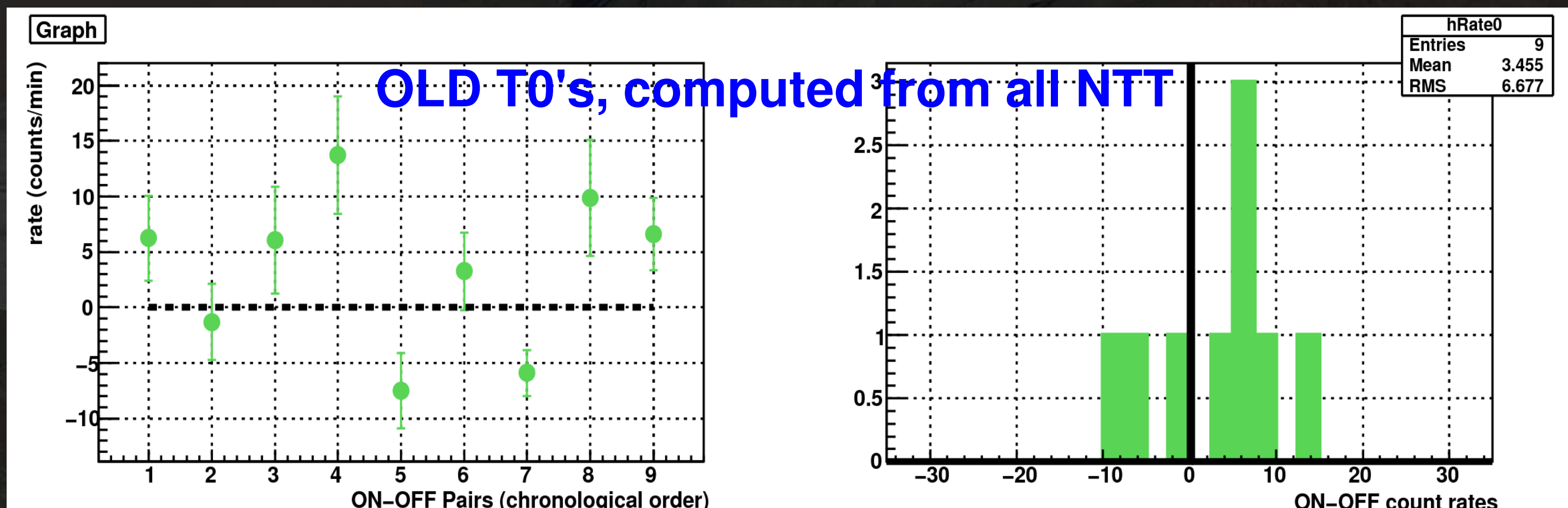

4-fold trigger
(NTT = 4)
Control Room
50 m
50 m
5-fold trigger
(NTT = 5)
Control Room
50 m
50 m
Cherenkov light pools
on the ground

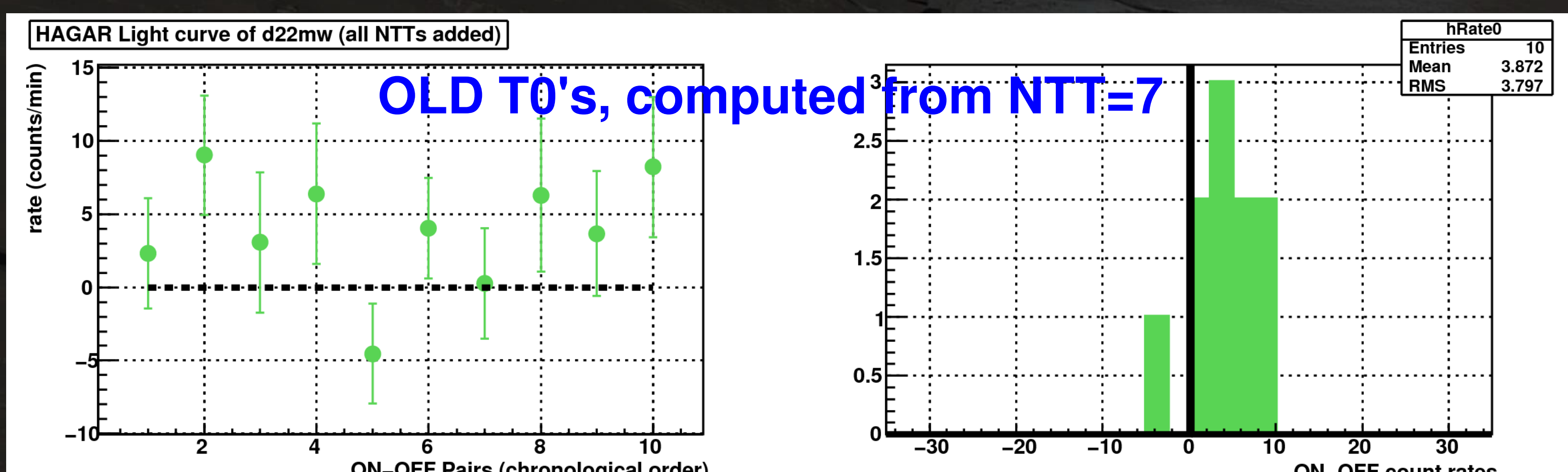

4-fold trigger
(NTT = 4)
Control Room
50 m
50 m
5-fold trigger
(NTT = 5)
Control Room
50 m
50 m
Cherenkov light pools
on the ground

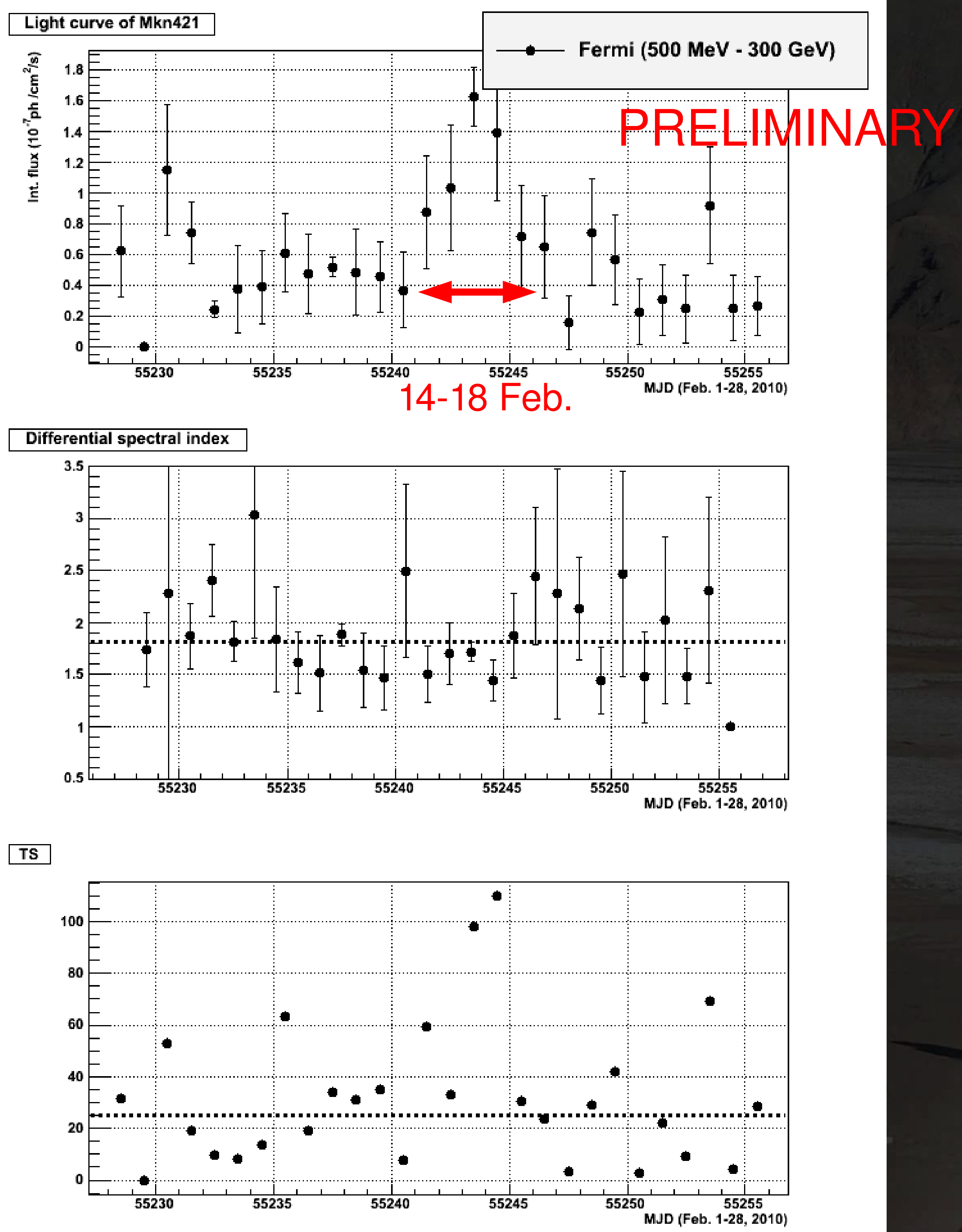

4-fold trigger
(NTT = 4)
Control Room
50 m
50 m
5-fold trigger
(NTT = 5)
Control Room
50 m
50 m
Cherenkov light pools
on the ground


7-fold trigger
(NTT = 7)
Control Room
50 m
50 m
5-fold trigger
(NTT = 5)
Control Room
50 m
50 m
Cherenkov light pools
on the ground

# Dark regions with different T0's sets



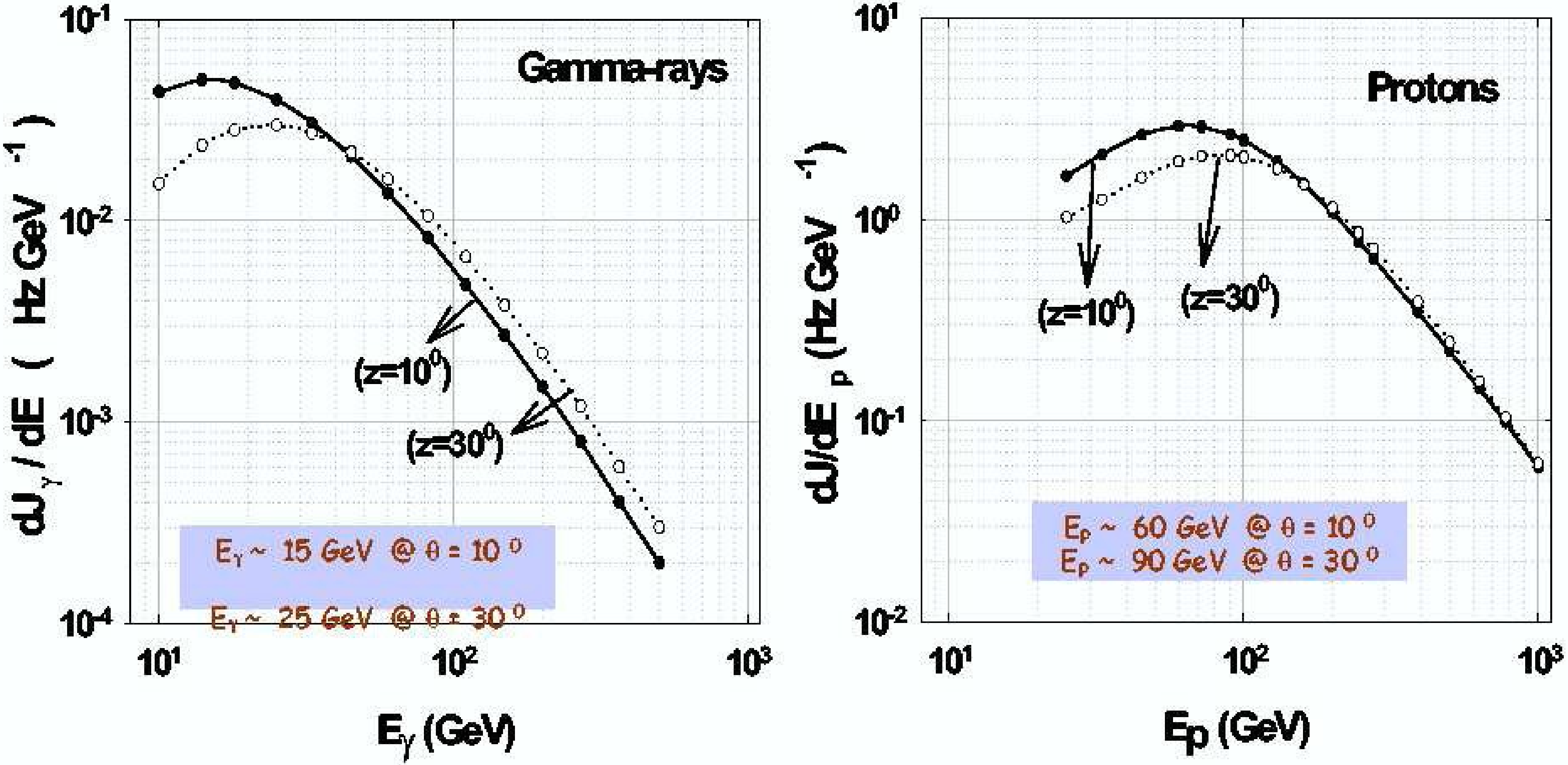


Light curve of Mkn421
Fermi (500 MeV - 300 GeV)
PRELIMINARY
Int. flux ($10^{-7}$ph/cm$^2$/s)
MJD (Feb. 1-28, 2010)
14-18 Feb.
Differential spectral index
MJD (Feb. 1-28, 2010)
TS
MJD (Feb. 1-28, 2010)

# Improvements in Analysis

## 3. Other improvements

* Software padding for balancing NSB in ON and OFF regions
* FADC expected to improve energy estimate of primary



Gamma-rays
Protons
(z=10⁰)
(z=30⁰)
Eγ ~ 15 GeV @ θ = 10⁰
Eγ ~ 25 GeV @ θ = 30⁰
Ep ~ 60 GeV @ θ = 10⁰
Ep ~ 90 GeV @ θ = 30⁰
dJγ / dE ( Hz GeV -1 )
dJ/dE p (Hz GeV -1)
Eγ (GeV)
Ep (GeV)

# MACE sub-systems

| | |
|---|---|
| Mechanical structure | ~155 tons, 45m high, 27m dia track |
| Alt. Azm. Mounting | Track and wheel type for azm. Movememt ( tracking accuracy < 1 arc-min) |
| Optics and alignment system | 356 panels each with 2 actuators for active mirror control |
| Camera and data acquisition | 1088 pixels, HV, GHz digitization, all signal processing electronics within the camera of 2m x 2m x 2m |
| Relative and absolute gain calibration system | Multi color LEDs, Fast light flashers , calibrated PIN diodes |
| Two trigger generation system | On-line rejection of cosmic ray / muon/ chance events |
| Timing system | GPS based |
| Data Acquisition and control system | LYNUX based, capable of handling event rates upto few kHz. ( data volume 25 GB/ night ) |
| Tracking accuracy and sky condition monitoring | CCD cameras |