HILLAS SYMPOSIUM

Heidelberg, Germany

December 10 - 12

Different aspects of Air Cherenkov Technique and Michael Hillas

Razmik Mirzoyan

Max-Planck-Institute for Physics

Munich, Germany

Cherenkov Shower Imaging using Image Intensifiers (1960-65) and Stereo Detectors (1972-76)

Image Intensifier Pictures of Cherenkov light Image from Cosmic Ray Air Shower.
On short time-scale images are brighter than bright star (Vega).
Work by David Hill (M.I.T.) and Neil Porter (U.C.D.) in 1960

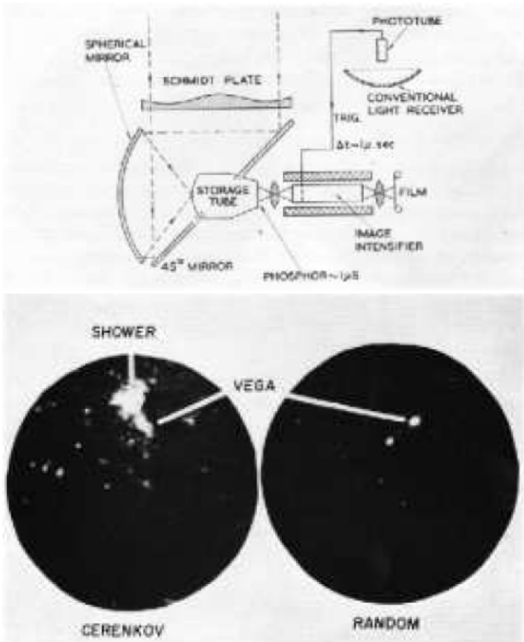
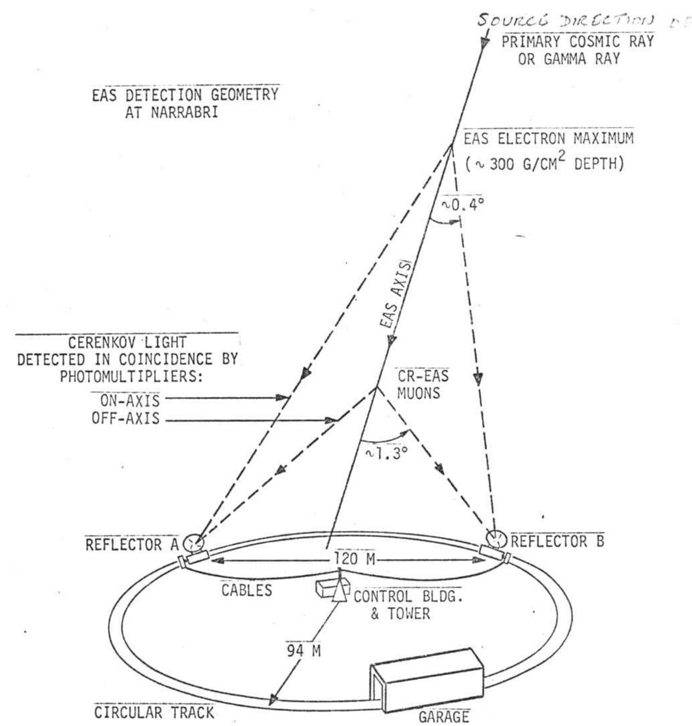


Figure 5. **Top:** Image Intensifier used by Hill and Porter to record the images of cosmic ray air showers [24]. **Bottom** Images of the night-sky triggered by an ACT (left) and triggered randomly (right). The field of view was ±12.5°.



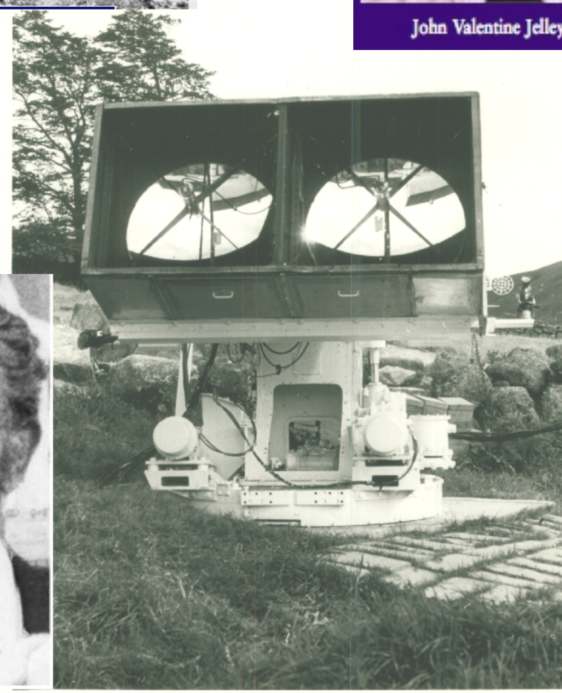
Josh Grindlay demonstrates value of stereo imaging with two-pixel system (Double Beam Technique) at Mt. Hopkins and Narrabri (1972-76)

Early Atmospheric Cherenkov Detectors

A. Chudakov
Crimea, Ukraine
1959-64

existing light receiver installation at A.E.R.E., Harwell. The bank of three-foot f/0·5 mirrors is mounted equatorially for drift scans.

John V. Jelley
U.K. A.E.R.E., Harwell, UK



Neil Porter
Glencullen, Ireland
1962-66

An interesting experimental work has been performed by the Chudakov's team.
The technique and the instrument were well-understood, below some excerpts from a paper from 1964

А К А Д Е М И Я Н А У К С С С Р

1964 ТРУДЫ ФИЗИЧЕСКОГО ИНСТИТУТА им. П. Н. ЛЕБЕДЕВА Том XXVI

А. Е. ЧУДАКОВ, В. Л. ДАДЫКИН, В. И. ЗАЦЕПИН, Н. М. НЕСТЕРОВА

ПОИСКИ ФОТОНОВ С ЭНЕРГИЕЙ $\sim 10^{13}$ *эв* ОТ ЛОКАЛЬНЫХ ИСТОЧНИКОВ КОСМИЧЕСКОГО РАДИОИЗЛУЧЕНИЯ

В данной статье описываются методика и результаты эксперимента, в котором сделана попытка обнаружения потока фотонов высокой энергии от некоторых космических объектов (и в первую очередь от объектов Лебедь А и Телец А). Эти наблюдения велись в течение четырех летних сезонов 1960, 1961, 1962 и 1963 гг. Предварительные результаты работы были доложены на международных конференциях по космическим лучам в Японии [1] и Боливии [2] и на Всесоюзной конференции по космическим лучам в Якутске.

Методика эксперимента была основана на регистрации широких атмосферных ливней в небольшом телесном угле (порядка нескольких тысячных стерадиан) по создаваемому ими в атмосфере Земли черенковскому излучению и сравнении интенсивности частиц высокой энергии, идущих от различных точек небесной сферы. Для этой цели была разработана телескопическая аппаратура большой светосилы, способная регистрировать вспышки черенковского света от ливней относительно небольшой начальной энергии ($\sim 2 \cdot 10^{12}$ *эв* при наблюдении на уровне моря). Благодаря большой эффективной площади регистрации ливней таким методом темп счета ливней (по направлениям, близким к вертикали) мог быть доведен до 200—250 в минуту и соответственно получена хорошая статистическая точность в сравнении интенсивностей от различных участков неба.

Окончательный результат всех четырех серий наблюдений оказался отрицательным. Во всех случаях с точностью около 1% не обнаружено возрастания интенсивности вблизи обследованных объектов. Придавать реальное значение эффектам порядка 1%, наблюдавшимся для объекта Лебедь А, оказалось невозможным. Таким образом, получен верхний предел возможной интенсивности фотонов. Для энергий фотонов $E \gtrsim 5 \cdot 10^{12}$ *эв*, этот предел составляет $5 \cdot 10^{-11} см^{-2} \cdot сек^{-1}$.

Введение

В последнее время все большее внимание исследователей уделяется задаче экспериментального обнаружения фотонов высокой энергии в составе первичных космических лучей. При этом предполагается, что фотоны с энергией от 10^8 *эв* и сколь угодно выше должны возникать при столкновениях частиц космических лучей с ядрами атомов разреженной среды (благодаря генерации π^0-мезонов и последующему их распаду). Поэтому

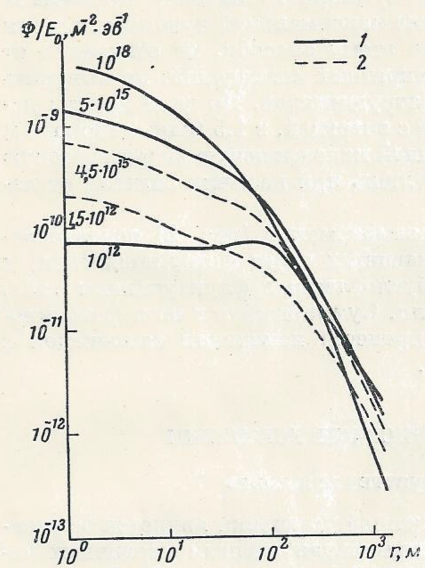


Рис. 3. Пространственное распределение интенсивности черенковского света в широких атмосферных ливнях на уровне моря

1 — первичные фотоны; 2 — первичные протоны; цифры у кривых показывают энергию первичных частиц в *эв*

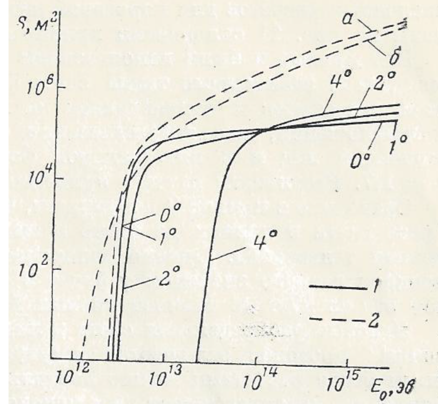


Рис. 11. Зависимость эффективной площади регистрации ливней от энергии

1 — для телескопов с углом зрения 1,75° для случая ливней от локального источника фотонов (цифры у кривых — угол между оптической осью телескопов и направлением на источник); 2 — для светоприемников с неограниченным углом зрения; а — для случая ливней от фотонов, б — для случая ливней от протонов

По оси ординат отложены значения площади $S, м^2$, по оси абсцисс — энергия первичных частиц в *эв*; масштаб по осям логарифмический

Таблица 1

Астрономический объект и период наблюдений	Часовой угол	Склонение	Число сеансов	$\delta \pm \sigma$, %	
				$\vartheta_{эф} \approx \pm 1°$	$\vartheta_{эф} \approx \pm 3°$
Дискретные радиоисточники					
Телец А (Крабовидная туманность)					
1960	$5^h 32^m$	$+22°00'$	15	$-0,15 \pm 1,32$	$+1,30 \pm 0,95$
1961			13	$-0,70 \pm 1,20$	$-0,60 \pm 0,84$
1962 *			19	$-1,40 \pm 0,82$	$-0,45 \pm 0,54$
Кассиопея А					
1962	$23^h 21^m,6$	$+58°35'$	8	$+0,60 \pm 0,93$	$-0,47 \pm 0,56$
1962 *			12	$-0,36 \pm 1,10$	$-0,77 \pm 0,66$
Лебедь А					
1960	$19^h 58^m,4$	$+40°32'$	19	$+1,60 \pm 0,92$	$+1,60 \pm 0,80$
1961			70	$+0,22 \pm 0,35$	$+0,67 \pm 0,28$
1962			62	$+0,15 \pm 0,63$	$-0,65 \pm 0,52$
1962 *			20	$+0,50 \pm 0,76$	$+0,60 \pm 0,54$
1963 *			20	$+1,16 \pm 0,77$	$+0,97 \pm 0,53$
Дева А					
1961	$12^h 28^m,9$	$+12°38'$	10	$-0,23 \pm 3,0$	$-0,14 \pm 2,10$
1962			10	$+0,37 \pm 1,0$	$+0,54 \pm 0,70$
Персей А 1962	$3^h 14^m$	$+42°24'$	4	$-1,80 \pm 2,30$	$-2,00 \pm 1,24$
Стрелец А 1963	$17^h 43^m,3$	$-28°58'$	7	—	$+10,5 \pm 20$
Скопления галактик					
Большая Медведица II 1962	$10^h 54^m$	$+56°30'$	1	$-5,0 \pm 2,9$	$-3,0 \pm 1,24$
Северная корона 1962	$15^h 22^m$	$+27°24'$	2	$+3,3 \pm 2,1$	$+1,9 \pm 1,4$
Волосы Вероники 1962	$12^h 55^m$	$+28°41'$	1	$+1,5 \pm 3,4$	$+1,7 \pm 2,4$
Волопас 1962	$14^h 33^m$	$+31°16'$	1	$+2,4 \pm 6,9$	$+6,6 \pm 4,7$

* Звездочкой отмечены измерения с компенсацией тока от неба.

- A multitude of sources have been observed and serious statistical treatment of data has followed

- Except for some small fluctuations no significant flux has been observed
$\geq$ 3.5-5 TeV,
Flux upper limit:
5×10^{-11} ph/cm²s

- They turned down the too optimistic prediction of Cocconi about 1000:1 S/N

SOVIET PHYSICS JETP VOLUME 20, NUMBER 2 FEBRUARY, 1965

THE ANGULAR DISTRIBUTION OF INTENSITY OF CERENKOV RADIATION FROM EXTENSIVE COSMIC-RAY AIR SHOWERS

V. I. ZATSEPIN

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor $\boxed{\text{March 2, 1964}}$

J. Exptl. Theoret. Phys. (U.S.S.R.) 47, 689-696 (August, 1964)

The angular distribution of intensity is calculated for the Cerenkov radiation produced in the terrestrial atmosphere by extensive air showers of cosmic rays. Calculations are made for showers arriving from the zenith and for conditions of observation at sea level and at an altitude of 3860 m above sea level. Photographic observation of the shape of the flash of light against the celestial sphere, as obtained in [2,3] is evidently in satisfactory agreement with the calculations.

1. INTRODUCTION

In the registration of extensive air showers (EAS) by means of Cerenkov counters,[1,2] a knowledge of the angular distribution of the Cerenkov radiation is important primarily from the methodological point of view (choice of the angle subtended by

motion. Neither the scattering of the light by density inhomogeneities in the air nor absorption of the light is taken into account.

2. STATEMENT OF PROBLEM AND METHOD OF CALCULATION

Victor Zatsepin, celebrated his 90 years birthday last October

In 1960‘s Victor Zatsepin well-
-understood all the main features of the air Cherenkov technique

- I learned from him that in 1960‘s he was seriously considering a key question about how one could measure multiple images of showers (or more precisely, which kind of cameras can do that ?)
- He performed simulations of air showers in 1961-64 (computer simulation in early 1960‘s !)
- „URAL“ was the name of the russian computer that was operated by a specially trained staff.

Those who analyze data from IACTS, looks familiar, isn't it ?

V. Zatsepin 1965

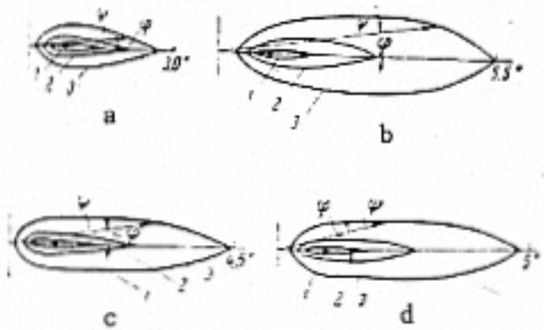


FIG. 6. Contours of equal intensity in light flashes from showers from primary protons and primary photons of various energies, for sea level and R = 100 m from the axis. The curves 1, 2, 3 correspond to intensity values $10^{-1}\,I_{max}(100)$, $10^{-2}\,I_{max}(100)$, and $10^{-3}\,I_{max}(100)$. Diagrams a and b correspond to primary photons of energies 10^3 and 5×10^6 BeV, and diagrams c and d to primary protons of energies 1.5×10^3 and 4.5×10^6 BeV.

primary photons. For lower energies of the primary particles ($E_0 \approx 10^{12}$ eV) the situation is somewhat better (Fig. 6). Here the shape of the line $I = 10^{-3} I_{max}$ in showers from photons differs appreciably from that of the corresponding line in showers from protons. This difference, however, is entirely due to the difference in the shapes of the cascade curves. If we allow for the fact that

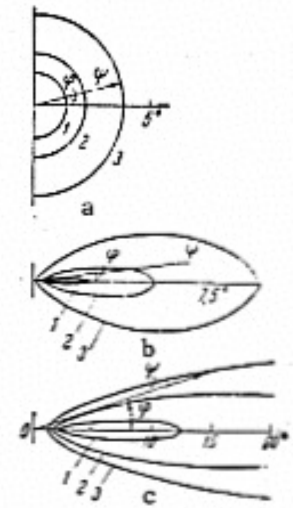


FIG. 8. Contours of equal intensity in the light flash at various distances from the axis of a shower arising from a primary proton with $E_{0p} = 4.5 \times 10^6$ BeV (3860 m above sea level). Curves 1, 2, and 3 correspond to the intensities $10^{-1}\,I_{max}(R)$, $10^{-2}\,I_{max}(R)$, and $10^{-3}\,I_{max}(R)$, and diagrams a, b, and c are for distances 0, 100, and 400 m from the axis of the shower.

with $E = 4.5 \times 10^{15}$ eV is considerably larger than that from such a shower at sea level. This difference is mainly due to the different distance of the registering device from the maximum of the

One of the 1st Statements in the Literature on the Potential of the Stereo Imaging

CONCLUSION

The calculations that have been made enable us to draw the following conclusions:

1. Since the maximum intensity of the light from a shower does not coincide with the direction of arrival of the primary particle, in researches in which the determination of the angular coordinates of the primary particle is made by photographing the light flash from the shower one should seek improved accuracy in this determination by photographing the shower simultaneously from several positions.

2. If the distance from the axis of the shower to the detector is determined from independent data, then an analysis of the shape of the light flash from the shower and its total intensity gives information both about the initial energy of the primary particle and about the position in the atmosphere of the maximum of the shower, and can thus be used for the analysis of fluctuations in the development of showers in the atmosphere.

In conclusion I regard it as my pleasant duty to express my gratitude to A. E. Chudakov for suggesting this topic and for helpful discussions.

THE ASTROPHYSICAL JOURNAL, 175:L117–L122, 1972 August 1

DETECTION OF HIGH-ENERGY GAMMA RAYS FROM THE CRAB NEBULA

G. G. FAZIO, H. F. HELMKEN, E. O'MONGAIN, AND T. C. WEEKES
Smithsonian Astrophysical Observatory, Cambridge, Massachusetts
Received 1972 May 11; revised 1972 May 26

ABSTRACT

By means of the ground-based atmospheric Cerenkov technique, observations of the Crab Nebula, averaged over a 3-year period, indicate that a flux of γ-rays ($4.4 \pm 1.4 \times 10^{-11}$ photons cm^{-2} s^{-1}) with energy $\geq 2.5 \times 10^{11}$ eV has been detected at the 3.1 σ level. This flux corresponds to an emission of 6×10^{33} ergs s^{-1}, significantly less than the continuous X-ray emission. The γ-ray flux may vary with time, with the most significant flux ($1.21 \pm 0.24 \times 10^{-10}$ photons cm^{-2} s^{-1}) occurring 60–120 days after a major spin-up of the pulsar NP 0532. This increase was observed on three different occasions, and if the flux in only these intervals is used, the effect is at the 5 σ level. The total γ-ray energy observed on each occasion was $\sim 10^{41}$ ergs, an energy approximately equal to the energy of the pulsar spin-up.

THE ASTROPHYSICAL JOURNAL, 174:L9–L17, 1972 May 15

DETECTION OF PULSED GAMMA RAYS OF $\sim 10^{12}$ eV FROM THE PULSAR IN THE CRAB NEBULA

J. E. GRINDLAY
Smithsonian Astrophysical Observatory and Harvard College Observatory, Cambridge, Massachusetts
Received 1972 March 10

ABSTRACT

The previous evidence we have given for the detection of pulsed γ-rays of $\sim 10^{12}$ eV from NP 0532 has been confirmed by an additional 99 drift scans on the Crab in 1971 November and December. Again, only those extensive air showers detected to be possibly initiated by γ-rays showed a 4.5 σ excess at the phase of the optical interpulse. The sum of these data and those reported previously yielded a 5.5 σ peak at the interpulse and a 3.5 σ peak at the main pulse, consistent with a pulsed flux $F(E_\gamma \geq 6.8 \times 10^{11}$ eV) $\simeq 1.25 \times 10^{-11}$ photons cm^{-2} s^{-1}. The ratio of interpulse to primary pulse is $\sim$3.5 : 1, and the spectrum appears consistent with an extrapolation from the X-ray data. Some implications of these results are discussed.

Finally, from figure 3 it is obvious that we have not detected any continuous flux from the Crab Nebula. That is, the excess of the γ-event mean (9) above the background (6.4) is entirely due to the pulsar effect in bins 4, 8, 9. The flux upper limit for a detection greater than 3 σ would then be $F(E_\gamma \geq 6.8 \times 10^{11}$ eV) $< 1.2 \times 10^{-11}$ photons cm^{-2}, which would not affect previous limits (Grindlay and Hoffman 1971) on the nebular magnetic field and thus the pulsar field or radius.

Investigation on the effectiveness of VHE Gamma ray astronomy Techniques Based on Imaging of Cherenkov Flashes

Plyasheshnikov, Bignami, 1985

Introduction.

The search for very-high-energy (VHE) cosmic gamma-rays is performed with the method of registration of the Čerenkov light flashes generated in the atmosphere by the extensive atmospheric showers (EAS) initiated by such quanta. As noted in the review ([1]), the existence of 5 such sources is established with very high level of confidence. There is one source of extragalactic origin among them. Recently, two X-ray binary systems, Vela X-1 and Her X-l, have been reported to be sources of VHE gamma-radiation (3,3).

([1]) A. A. Stepanian: *Adv. Space Res.*, **3**, No. 10-12, 123 (1984).

39

IL NUOVO CIMENTO VOL. 8 C, N. 1 Gennaio-Febbraio 1985

Investigation on the Effectiveness of VHE Gamma-Ray Astronomy Techniques Based on Imaging of Čerenkov Light Flashes.

A. V. PLYASHESHNIKOV (*) and G. F. BIGNAMI

Istituto per Ricerche in Fisica Cosmica e Tecnologie Relative - Via Bassini 15, 20133 *Milano*

(ricevuto il 27 Settembre 1984)

Summary. — A high-velocity Monte Carlo method is applied to very-high-energy gamma-ray astronomy techniques. The discrimination effectiveness against the cosmic-ray background is investigated for the technique based on the two-dimensional imaging of the Čerenkov light flashes created by the extensive air showers in the atmosphere. It is shown that previously proposed discrimination methods using the difference in the Čerenkov light flash shape of gamma-rays- and background-induced showers have low effectiveness. Two new discrimination methods are proposed, based on the difference in the orientation of Čerenkov light spot and fluctuations of the light density. The combination of these methods allows us to increase the «signal/noise» ratio by 4-5 times.

PACS. 94.40. – Cosmic rays.

A very interesting paper from A. Plyasheshnikov and G. Bignami from 1985

It claims that the orientation parameter α can provide a gamma hadron separation

Introducing α parameter; it can discriminate hadrons

Plyasheshnikov, Bignami, 1985

3'3. *Discrimination method using the light spot orientation.* – It follows from the analysis presented above that the effectiveness of discrimination methods based on the difference in the Čerenkov-light angular-distribution shape is low. One has, therefore, to resort to use as a basis of the discrimination the difference in some other properties of g- and p-showers. One such property is the orientation of the light spot in the focal plane of the installation.

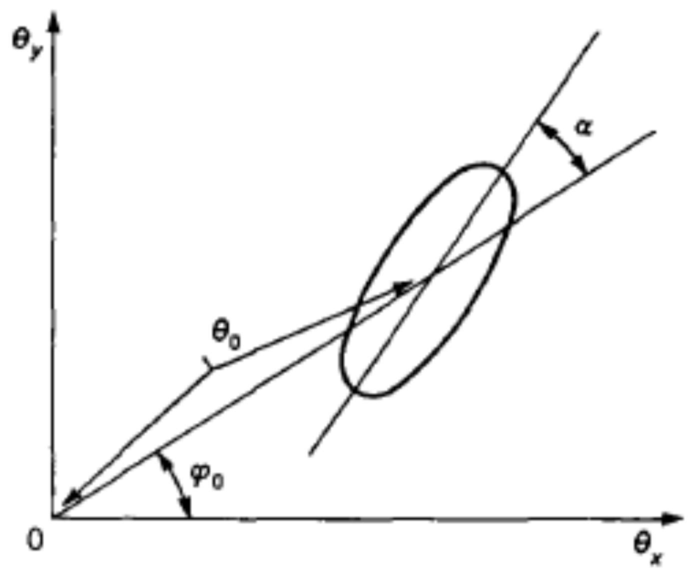


Fig. 4. – Determination of the light spot orientation in the focal plane. The zero of the co-ordinate system corresponds to the γ-shower axis direction, θ_0, φ_0 determine the maximum position, α determines the major axis orientation.

Plyasheshnikov, Bignami, 1985

3·4. *Discrimination based on differences in the cascade development fluctuations.* – Paper ([20]) deals with an analysis of the discrimination methods against the cosmic-ray background for a heavy calorimeter placed aboard the satellite for measuring the cosmic electron flux. For discrimination, the difference in the fluctuations and correlations of the longitudinal development of e- and p-showers in the calorimeter substance is used, and high values of effectiveness are obtained.

We tried to reproduce the approach of ([20]) for our conditions, and analysed the effectiveness of a simple discrimination method using the difference in the fluctuations of the Čerenkov-light spot density integrated along the small axis. For this purpose, the following construction of the discrimination parameter was used:

a) The central part of Čerenkov light spot was divided in the focal plane into strips of width $\Delta\theta$ ($\Delta\theta = 0.2°$ in our case) perpendicular to the major axis. The disposition of these strips with respect to the spot maximum position was chosen to be uniform for all cascades.

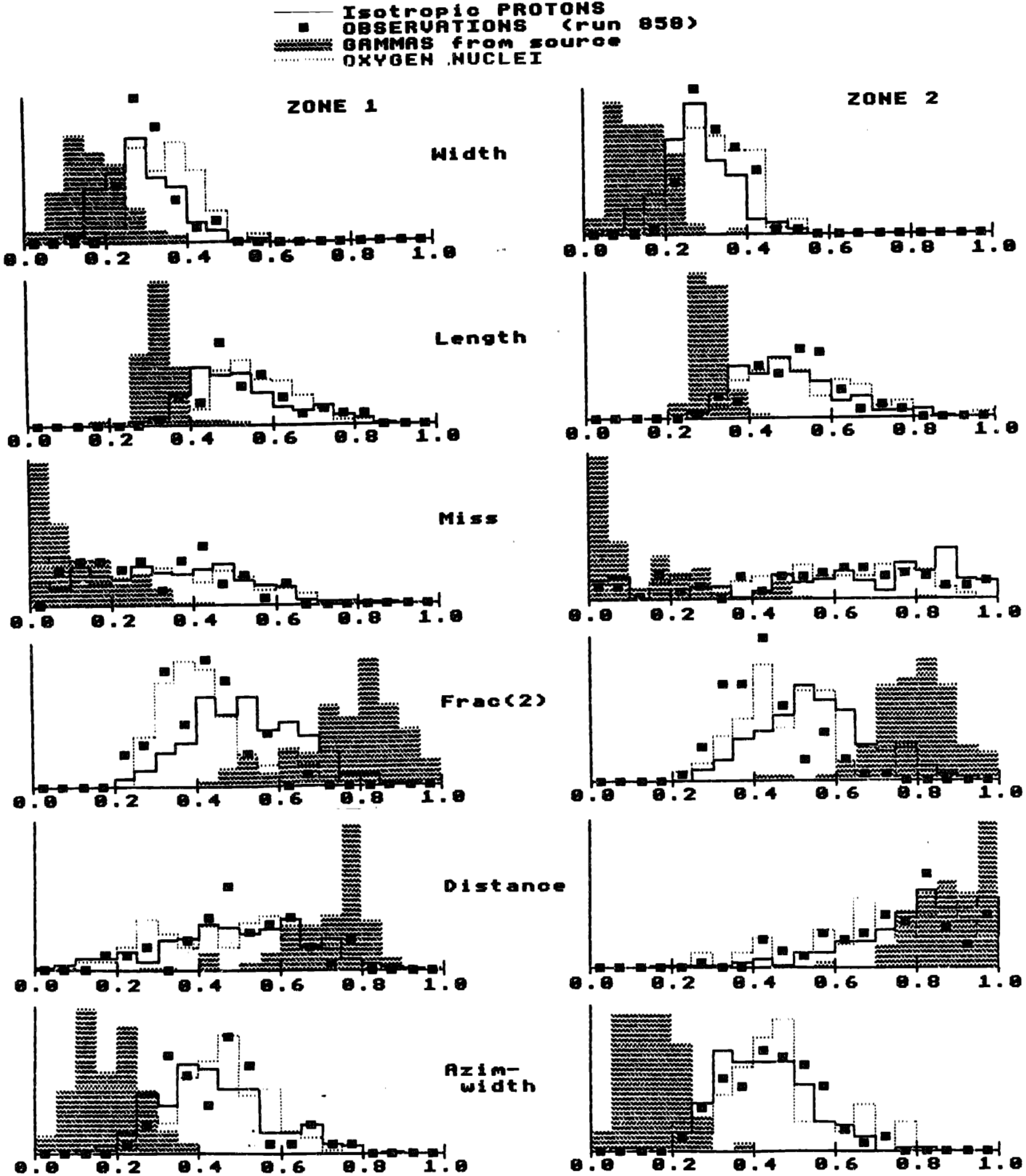
b) The relative amount of Čerenkov light v_i ($i = 1, \ldots, n$; n is the number of strips) was counted for each strip.

c) The mean values $\bar{v}_{\gamma i}$ and the mean square deviations $\sigma v_{\gamma i}$ were calculated for the γ-shower case.

d) A statistical criterion of agreement

a) The parameter χ^2 can provide a high enough value of discrimination effectiveness (up to 2). A combination of this parameter with α can increase the « signal/noise » ratio for the installation by about 4-5 times.

([20]) R. M. Golynskaya, L. A. Hein and V. L. Zatsepin: *Proceedings of the XVIII International Cosmic Ray Conference*, Vol. **5** (Bangalore, 1983), p. 324.



Hillas, ICRC La Jolla, 1985

"Hillas" parameters

Interesting to note that although the parameters *AZWIDTH* and *MISS* include information on parameter *a*, it is not explicitly defined by M. Hillas

SAO/NASA Astrophysics Data System (ADS)

Title: HERCULES - A Giant Step Forward for TeV Astronomy
Authors: Lamb, R. C., Weekes, T. C., & Hillas, A. M.
Journal: Bulletin of the American Astronomical Society, Vol. 18, p.664
Bibliographic Code: 1986BAAS...18R.664L

3.04

HERCULES - A Giant Step Forward for TeV Astronomy

R.C. Lamb (ISU), T.C. Weekes (SAO), and A.M. Hillas (Leeds).

An improved atmospheric Cerenkov detector, operating in the 10^{11}-10^{14} eV energy range, is described. The apparatus, symbolized by the acronym HERCULES (High Energy Radiation Cameras Using Light Emitting Showers) should improve the sensitivity of present day instrumentation by more than a factor of 10, allowing perhaps as many as a 100 new TeV sources to be studied. The proposed apparatus will consist of two 10-meter diameter reflectors, separated by 120 meters, at the site of the Whipple Observatory's present 10-meter reflector. Each reflector will contain a high resolution Cerenkov camera (pixel spacing 0.25°) covering a 4° field-of-view. The arrival direction of an individual air shower will be reconstructed from the two stereoscopic views. The predicted improvement in sensitivity is based on the Whipple Observatory's experience with a single camera with a 0.5 pixel spacing and recent simulations of gamma-ray and cosmic-ray air showers (Hillas 1985).

The number „0“ workshop on IACTs took place in Crimea in 1989 (before the 1st one in Paris in 1992)

Proceedings of the International Workshop on

VERY HIGH ENERGY GAMMA RAY ASTRONOMY

Crimea, USSR

April 17 - 21, 1989

Edited by

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Yerevan Physics Institute, USSR
*Crimean Astrophysical Observatory, USSR

Abstract

A Čerenkov imaging telescope being under construction for investigation of TeV primary γ-rays is described.

The present stage of investigations of cosmic VHE and UHE γ-rays is characterized by high requirements to the reliability of fluxes from point sources as well as to identification of "γ-events". Development of the background-suppressing techniques seems the most promising way to achieve these aims. In the energy range 10^{11}-10^{13}eV, the main hopes are connected with the possibility for an analysis of the Čerenkov radiation images of atmospheric showers [1]. Efficiency of this method has been successfully demonstrated recently by detection of γ-ray fluxes at the 9σ level from the Crab Nebula with the Wipple observatory 10-meter imaging Čerenkov γ-ray telescope [2].

In 1989, at the cosmic ray station of Yerevan Physics Institute, near the Byurakan optical observatory (40.18° N latitude and 44.5° E longitude) at an altitude of 1900m, we have begun the construction of an atmospheric Čerenkov imaging telescope, which

mirrors is very important, especially for further improvement of the

The Inherent Accuracy of Cerenkov Shower Images for Resolving Point Sources ()

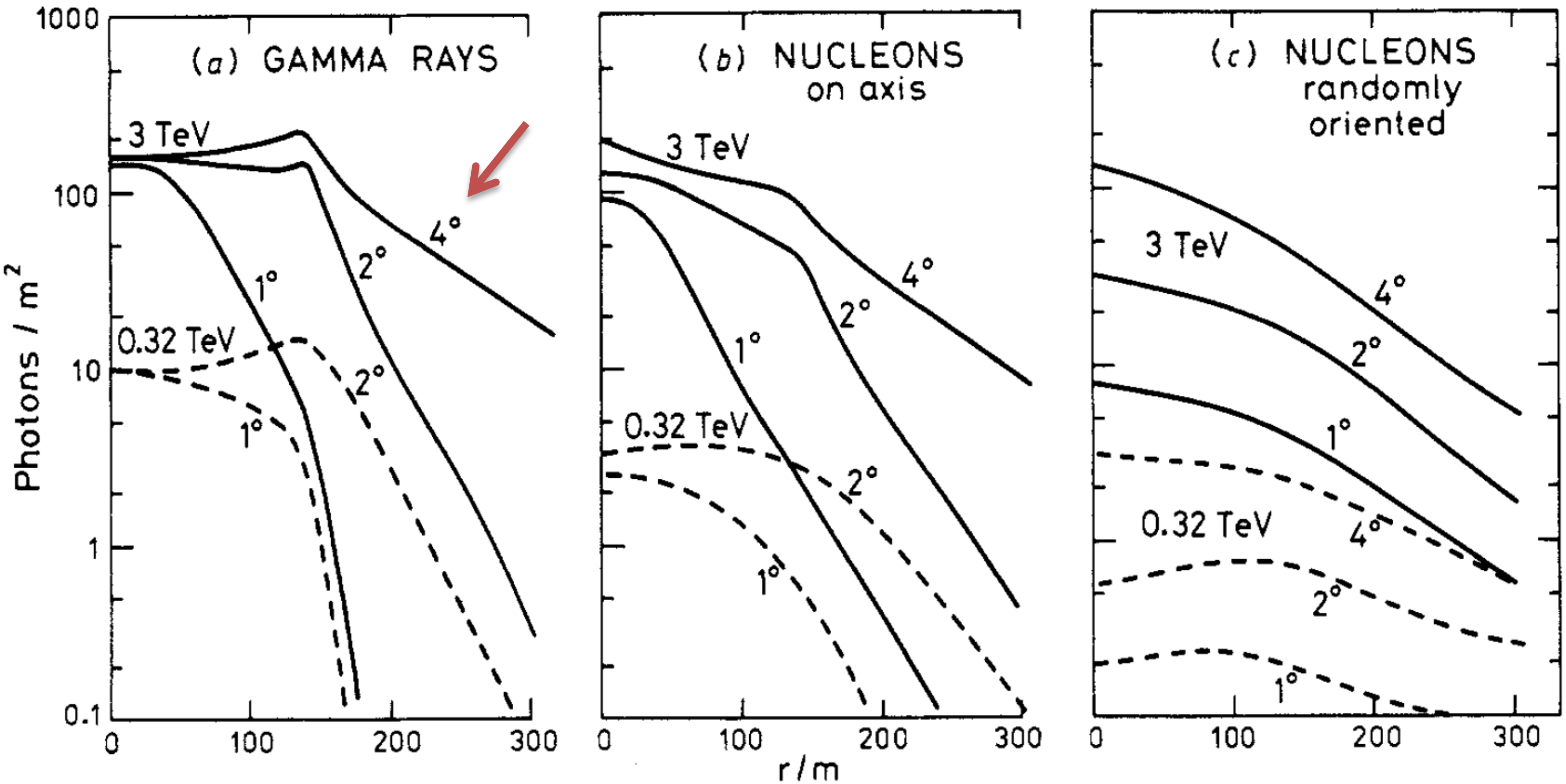
Hillas, A. M.

Publication	Very High Energy Gamma Ray Astronomy, Proceedings of the International Workshop held 17-21 April, 1991 in Crimea, USSR. Edited by A.A. Stepanian, D.J. Fegan and M.F. Cawley., p.134
Pub Date:	1989
Bibcode	1989vheg.conf..134H

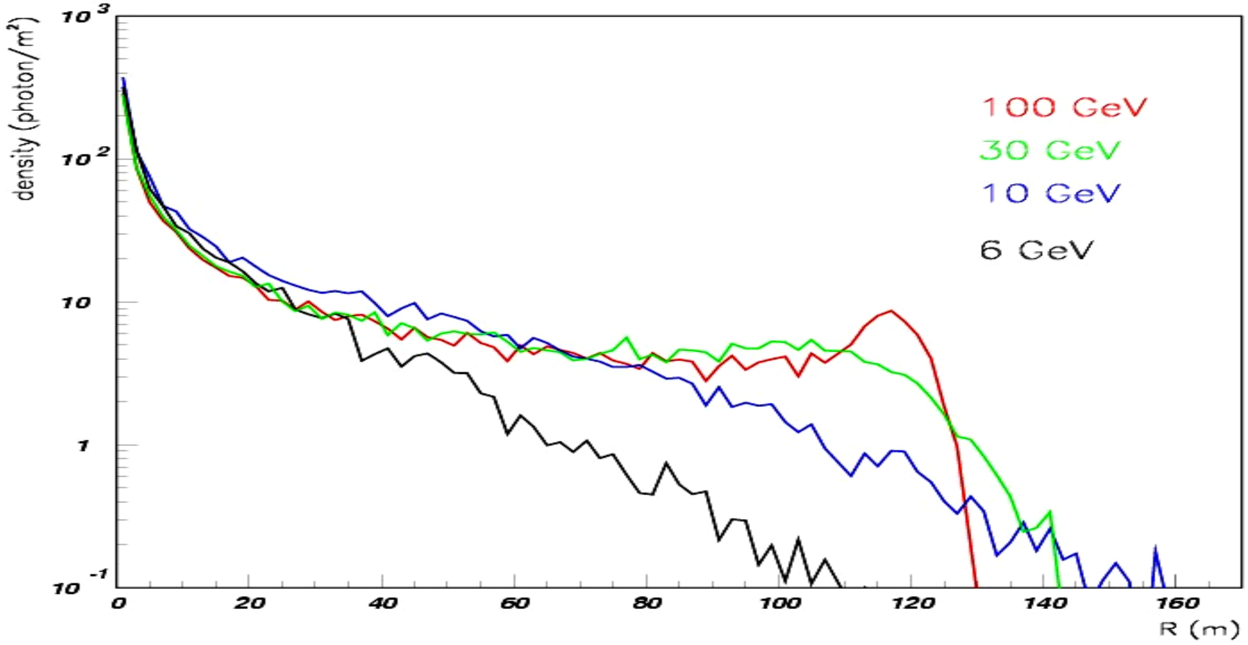
M. Hillas showed that with an infinite array of IACTs one can achieve an angular resolution of 2’

Effect of limiting the FoV of the telescope on the shape of the average lateral distributions and hence the collection area

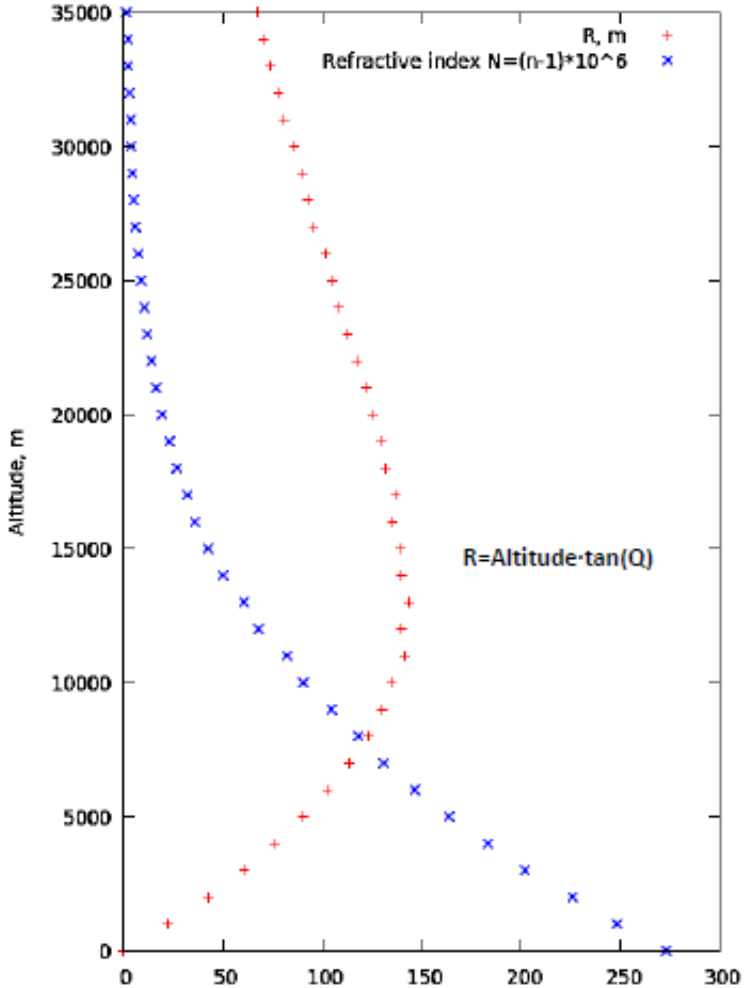
Hillas, Patterson, *J. Phys. G: Nucl. Part. Phys.* 16 (1990) 1271

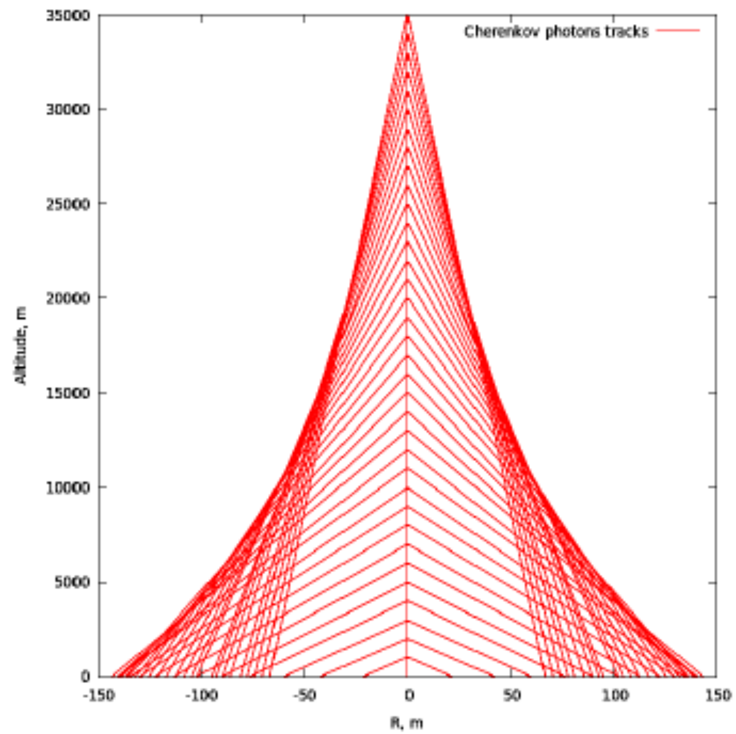


Lateral distribution of Cherenkov light emission from a single μ



Index of Refraction and Cherenkov Emission Angle versus Altitude

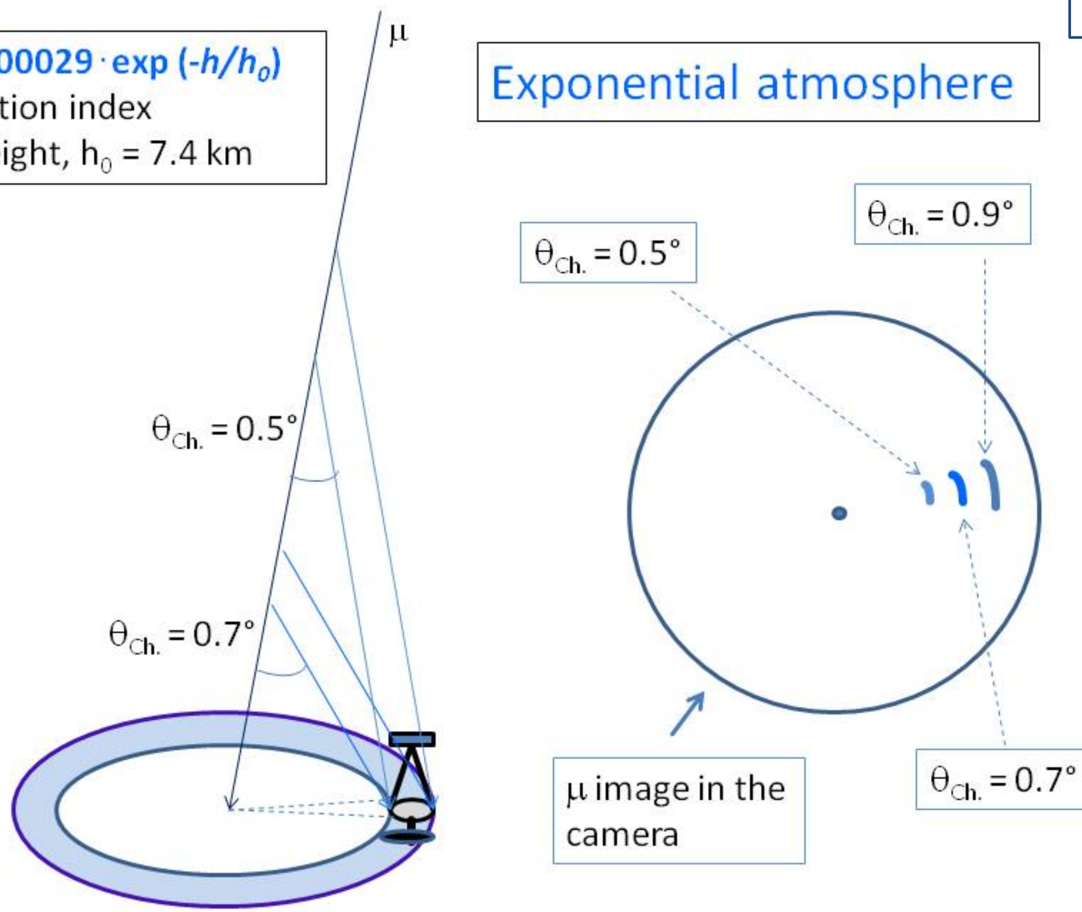




VHE γ-astrophysics with IACTs is possible thanks to exponential atmosphere

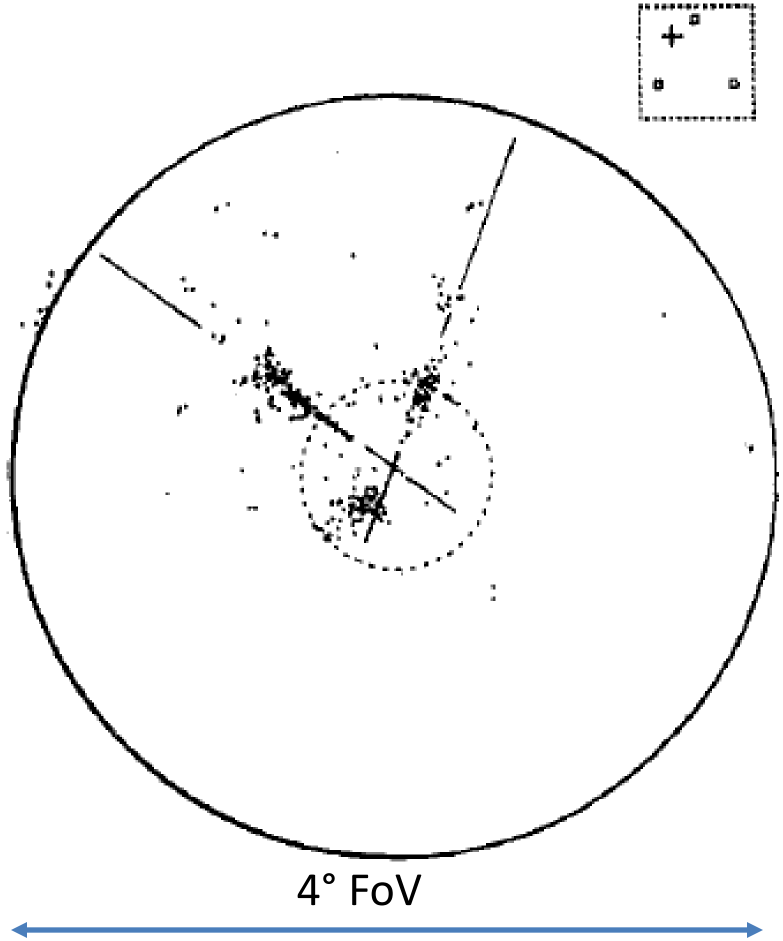
Mirzoyan, 2014

$n(h) = 1 + 0.00029 \cdot \exp(-h/h_0)$
n(h) – refraction index
h_0 – scale height, h_0 = 7.4 km



Superimposed images of a 320 GeV shower from 3 telescopes of 10m diameter

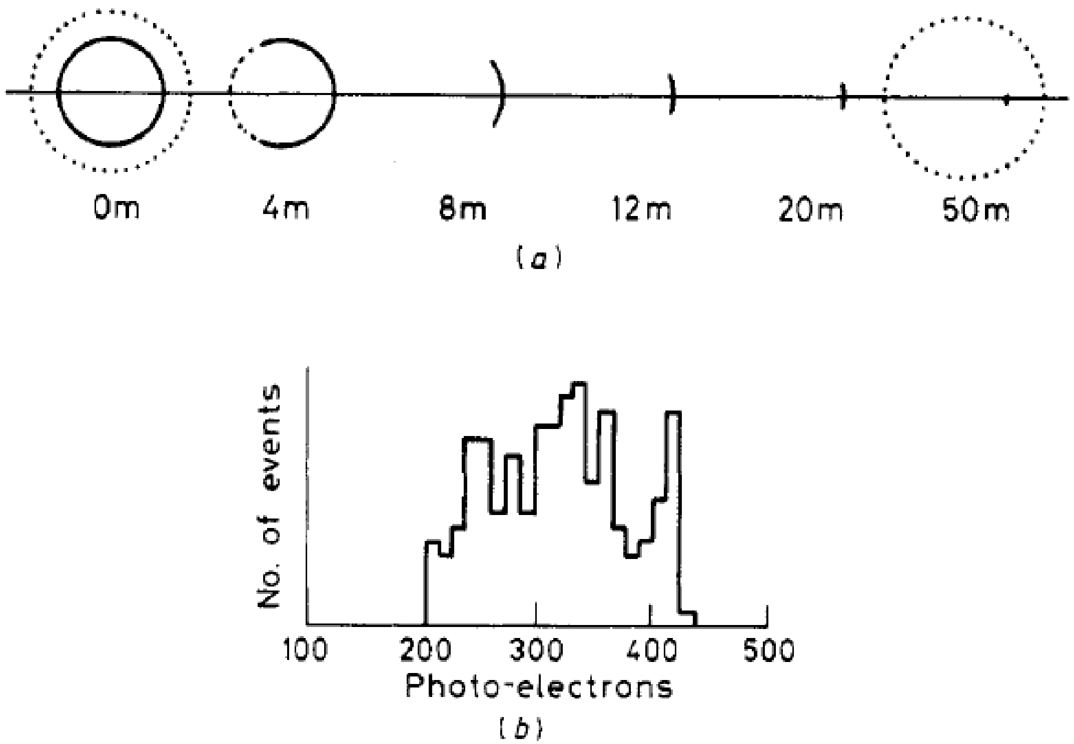
Hillas, Patterson, *J. Phys. G: Nucl. Part. Phys.* 16 (1990) 1271



- Persistently almost in all simulations a 4° FoV is used for point sources
- The inner circle is 1°

Cherenkov image from a 20 GeV μ at various distances from a 10m telescope; can be used for calibration

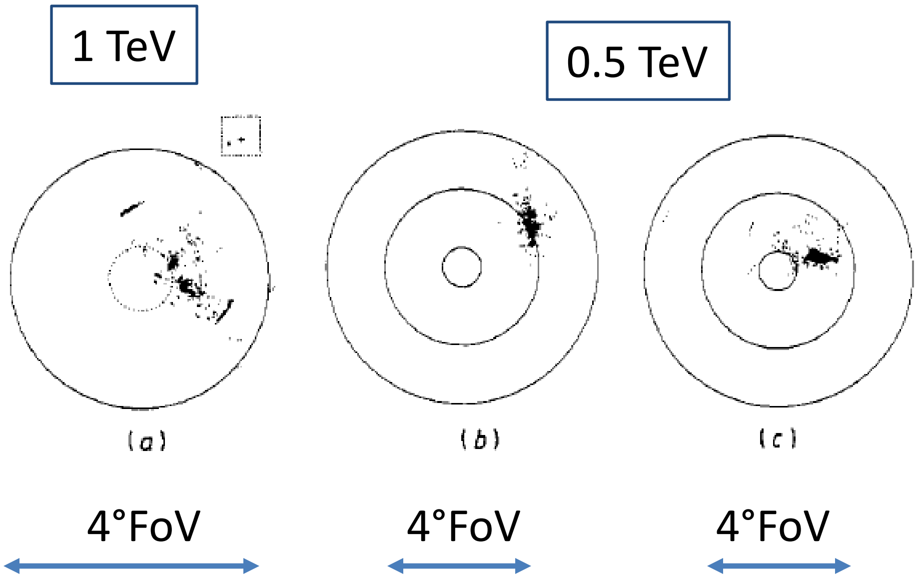
Hillas, Patterson, *J. Phys. G: Nucl. Part. Phys.* 16 (1990) 1271



It is possible that short muon arcs, not very curved, might at times be mistaken for narrow images of gamma showers.

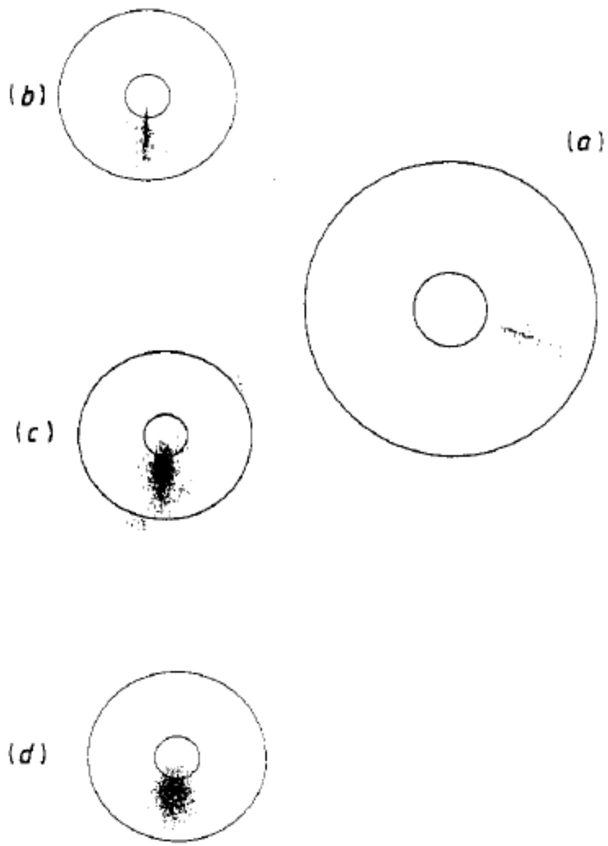
TeV proton showers sometimes can mimic gammas

Hillas, Patterson, *J. Phys. G: Nucl. Part. Phys.* 16 (1990) 1271



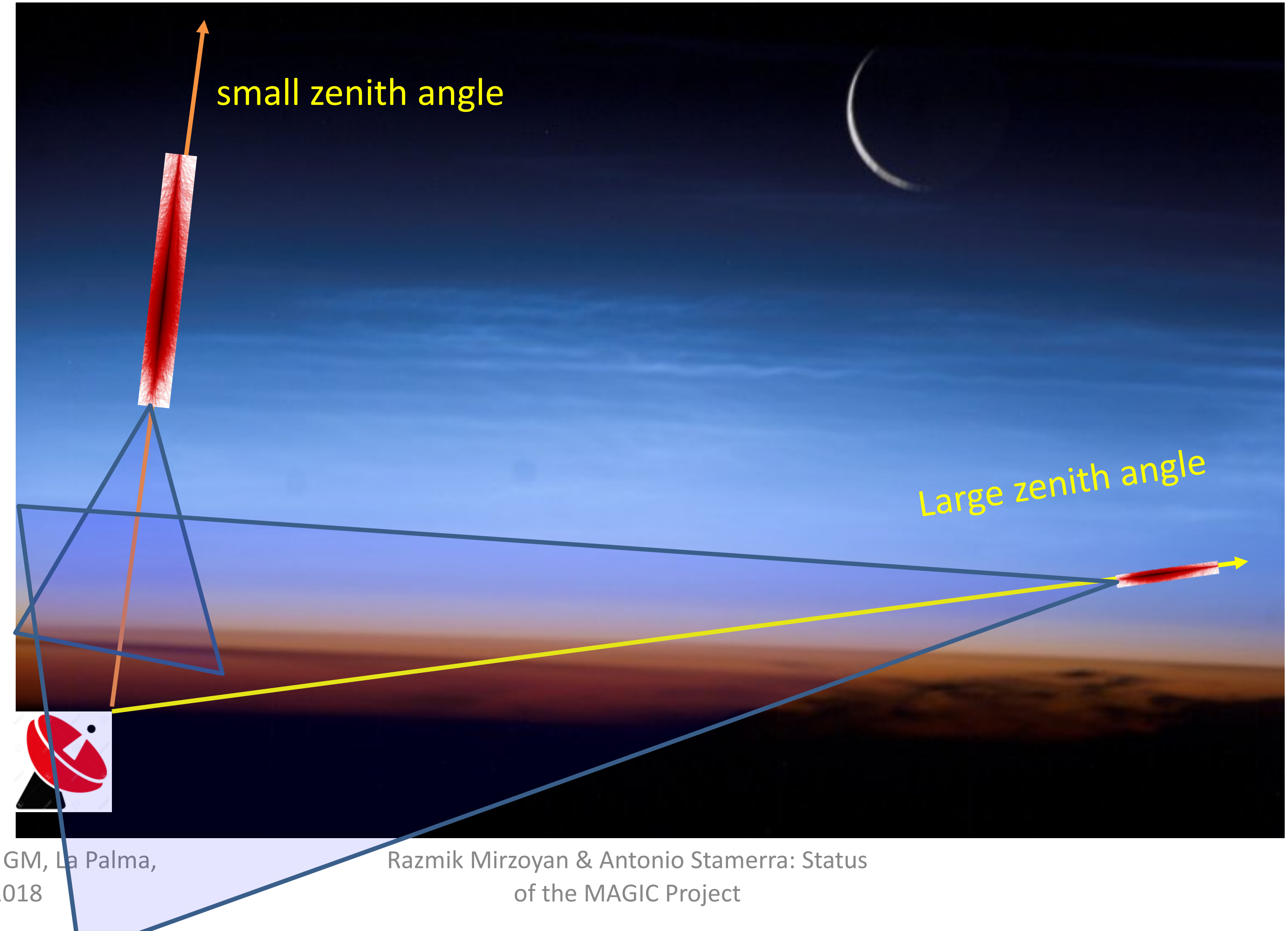
- Only occasionally, by accident, is the major axis aligned with the source, since they belong to an isotropic population.

Gamma showers under large zenith angle

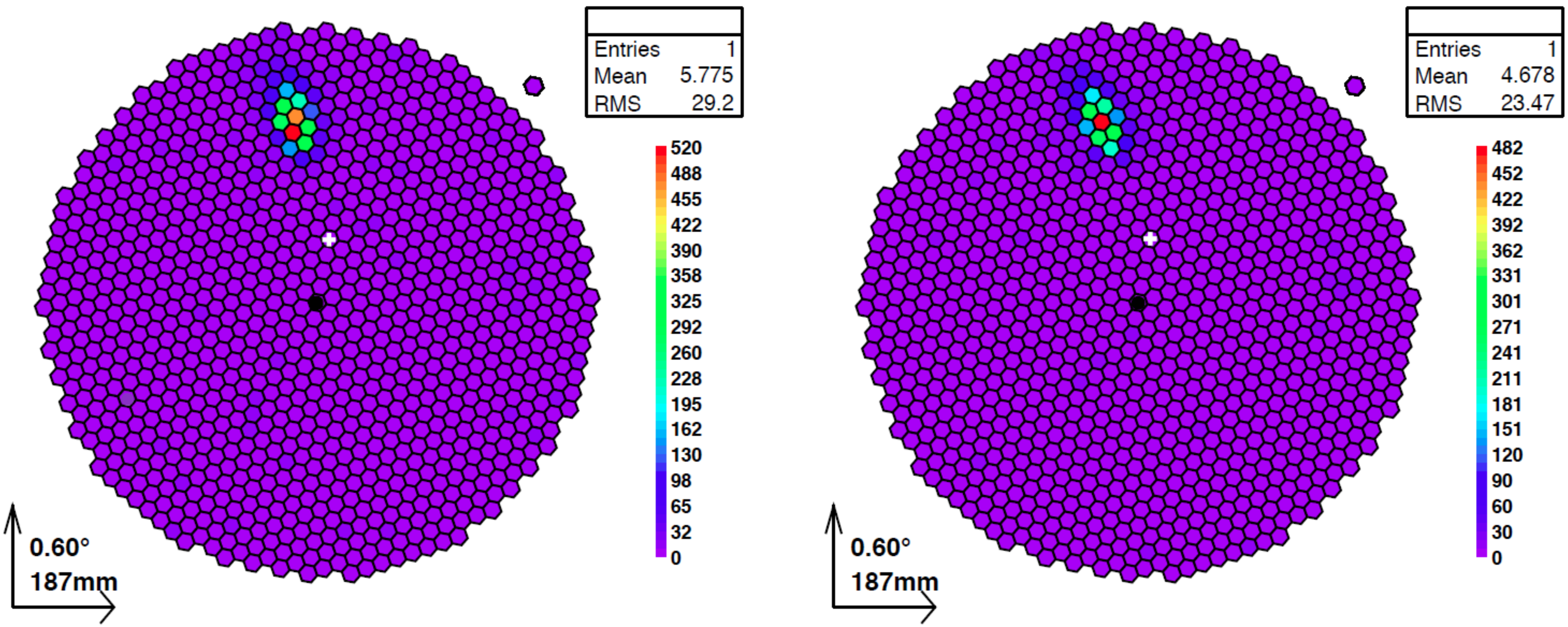


- **(a) A** gamma ray image at low elevation **(15°)** typical of the Sommers-Elbert method **of** observation. The energy is 100TeV and the core distance is - 900 m from the mirror. These images are very narrow and no longer than normal images.
- ***(b-d)*** show varying amounts of aberration using a Gaussian point spread function on an 11TeV gamma ray shower, at vertical incidence and at a core distance of 135m. ***(b)*** is an ideal image, **(c) U** = 0.3° and ***(d) 0*** = **0.6°.** Clearly with such narrow images, high angular resolution can be usefully employed.
- Circles are 1°, 4°.

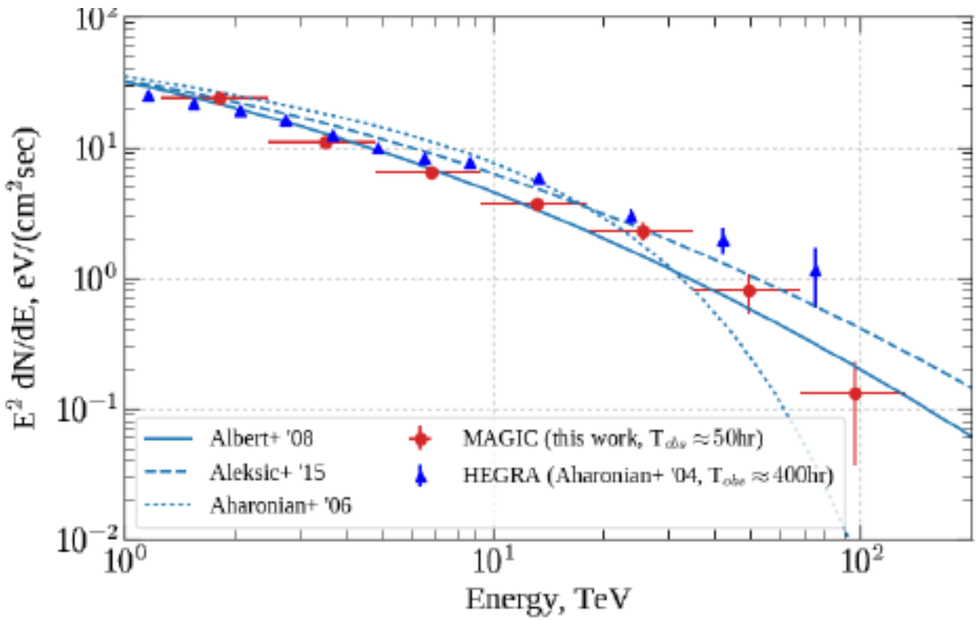
Cartoon on longer path length in atmosphere for an EAS @ large zenith angle observations



A gamma-ray candidate event observed by MAGICs from Crab under the zenith angle of 77.8°; the estimated energy is 144.4 TeV



MAGIC observations of Crab extended into the zenith angle range 70° - 80°



Older MAGIC spectrum suggests:
alpha = 2.47 + 0.24*log10(4/1) ~ 2.61
beta = 0.24

CombUnfold:
f_0 = (6.88 +/- 0.45) x 10^{-13} 1/(cm*sec*TeV)
alpha = -2.78 +/- 0.11
beta = -0.20 +/- 0.17

Fold:
f_0 ~ 7.0 x 10^{-13} 1/(cm*sec*TeV)
alpha ~ 2.59
beta ~ 0.30

The measured spectrum is consistent with older results within uncertainties.

Conclusions of the paper by A.M. Hillas & J.R. Patterson

Hillas, Patterson, *J. Phys. G: Nucl. Part. Phys.* 16 (1990) 1271

- There are clearly a number of characteristic differences between conventional gamma ray and nucleon-produced images and light pools. The most useful appear to center around the small widths and pointing alignments of gamma ray images, particularly when stereo images can be combined.
- In order to delineate the detailed information contained in an image, resolutions 2' would be advantageous

VHE γ-ray workshop at 22nd ICRC, Dublin, 1991

→ Mirzoyan

Report on Workshop on Very High Energy Gamma Ray Astronomy at the 22nd ICRC, August 14, 1991.

I promised I would circulate the one page summaries of the workshop to all interested parties. I am enclosing a copy of the summaries received and some personal comments. Arnold Stepanian was unable to attend until later in the conference but sent his comments for presentation; since I only received them a few minutes before the workshop I opted not to present them, but enclose them here.

The workshop was, I think, a success. This was in no small part due to our able chairman, John Jelley, to whom we all owe a debt of gratitude. I had hoped that by convening representatives of all the active groups we could get some agreement on the relative merits of the various versions of the technique now being used; in particular I had hoped that some of the criticisms of various techniques which are said in private might be voiced in public so that they could be discussed and analysed. In this we were only partly successful in that all groups were not represented and those present seemed largely uncritical of their colleagues' experiments.

It appears that there are two distinct schools of thought re assigning sensitivities. One school bases its derivation entirely on the measured response to hadronic showers; the other school uses absolute calibrations and simulations and ignores the hadronic response. There are some who use some intermediate method. Techniques which bias heavily against the detection of hadronic showers obviously cannot use the hadronic response to calibrate their response to gamma rays. Groups which do not have reliable Monte Carlo simulations prefer to use the measured response. However there does not seem to be any strong feeling that either method is seriously in error and it appears that differences in measured fluxes (and upper limits) must arise from causes other than the defined sensitivities. In this sense we have made no progress.

I am sorry the program was so crowded; obviously we should have scheduled more time for the workshop. I am particularly sorry that we did not have time to get on to the second topic of the workshop, "Overlapping observations with GRO" and apologise to Neil Gehrels for leaving no time for his presentation. He has kindly provided a one page summary of the GRO observing schedule.

Please note that the Whipple Observatory group has agreed to distribute information pertaining to GRO that is of interst to ground-based gamma-ray observers by e-mail (this includes non-GRO specific programs that may be of interest to the community); we will be happy to include you on the e-mail distribution if you will send us your address. Our BITNET address is "GAMMA@ARIZRVAX".

Thanks for helping make the workshop a success; from the large attendance there is obviously a lot of interest in the topic,

TCW

Trevor C. Weekes Sept. 11, 1991

Final Program for the Very High Energy Gamma Ray Workshop

Wednesday Evening, August 14, Dublin

Chairman: J.V.Jelley

Program

(a) Atmospheric Cherenkov Telescope Sensitivities.

Speaker	Group	Summary
C.Raubenheimer	Potchefstroom	Yes
B.S.Acharya	Tata/Pachmari	Yes
No representative	Durham/Narrabri	No
G.Sembrowski	Haleakala/South Pole	Yes
P.Goret	Saclay/Themis	No
G.Thornton	Adelaide/Woomera	Yes
P.Edwards	Tokyo/Cangaroo	Yes
R.C.Lamb	Iowa/Whipple	Yes
A.A.Stepanian (absent)	Crimea	Yes
W.Stamm/A.K.Konopelko	Yerevan/HEGRA	No

(b) Observing Programs, GRO Overlap (No discussion)

N.Gehrels, GRO Project Scientist	GRO Status and Program	Yes

2. ENERGY THRESHOLD

(a) how defined : defined as the average energy of a gamma ray event to trigger the telescope
(b) how estimated : The average trigger rate (per minute) for the source direction is obtained from the data. Using the well measured Cosmic ray spectrum, this rate is converted to the Cosmic ray energy threshold. The relevant solid angle factor and the average zenith angle are used as inputs to this calculation. Finally, the gamma ray threshold is taken as half the Cosmic ray energy threshold.

3. COLLECTION AREA

(a)how defined :defined to be within the radius of 100 meters with the telescope as the centre.
(b)how estimated: circles of 100 meter radius are drawn around each telescope . The collection area for the whole array is computed considering the fact that some area will be common to all telescopes.

THE UNIVERSITY OF ADELAIDE'S VHE GAMMA RAY TELESCOPE AT WOOMERA (aka BIGRAT)

Thornton

Description

The Woomera telescope is located at 31° 06′ S, 136° 47′ E at an elevation of 160m. It consists of three twelve square metre composite mirrors on a common alt-azimuth mount. At each focus (f=2.7m) there are three 51mm phototubes providing a ~2° field of view. The tubes are arranged in a triangle with the centroid on axis. The anode signals are ac-coupled, without amplification, to discriminator inputs. The discrimination level is 25 photo-electrons (nominal). We currently run the tubes at ~2–3 kHz singles rates on the night sky, padded to 5 kHz by computer controlled LEDs. An event trigger is formed by a triple coincidence between the corresponding tubes at the three foci. The vertical trigger rate is ~7 Hz.

Energy threshold

As our definition of E_{th} we use the modal energy of triggering showers from an $E^{-2.1}$ differential spectrum of Hillas monte carlo gamma-rays. For vertical showers

$$E_{th} = 500GeV \qquad (E_{median} = 800GeV)$$

Collecting area

We do not explicitly define the collecting area. A value can be calculated by requiring consistency between the event rate, the field of view and m.c. parameters (see next item).

THE CANGAROO COLLABORATION 3.8m TELESCOPE AT WOOMERA

Edwards

Description.

The 3.8m telescope is located 100m east of the University of Adelaide telecope (BIGRAT) at 31° 06′ S, 136° 47′ E, 160m a.s.l. The 3.8 m telescope is a composite mirror on a alt-azimuth mount. The central 1.7m diameter section of the mirror is made from aluminized duralumin. The six outer segments are canigen coated aluminium alloy. In the focal plane (f=3.8m) is an imaging camera of (64/)256/500 photomultipliers, providing an aperture of 3.2°/4.0° diameter. The anode signals are amplified with a gain of 100, allowing low, stable tube gains, before discrimination. A specially designed circuit containing 16 channel amplifiers, discriminators, ADCs, TDCs and single count scalers has been developed. The TDCs aid in night sky background rejection. An event trigger is formed from analog sums and hit

Energy threshold

An energy threshold at the zenith of ~500GeV is believed possible, depending on the final triggering conditions. This corresponds to an event rate of ~10 Hz.

between the event rate, the field of view and m.c. parameters (see next item).

$$A_c \approx 1.1 \times 10^9 cm^2 \qquad (i.e.\ R = 190m)$$

where I_{CR} is the cosmic ray flux and S/B is the ratio of the signal to the cosmic ray background.

Background rejection/ Future plans

We currently employ no background rejection techniques but we are about to install a 37 pixel camera in place of one of the detector triplets. This should be in place by December 1991. We are experimenting with a pulse shape digitizing system which should provide some gamma/nucleon discrimination.

References

Clay R.W. *et al.*, 1989, Proc. Astron. Soc. Australia, **8**, 41

Hillas A.M. & Patterson J.R., 1990, J. Phys. G, **16**, 1271

Patterson J.R. & Hillas A.M., 1989, Nucl. Inst. Meth. **A278**, 553

Protheroe R.J., 1987, 20th ICRC, **8**, 21

Wonderful review of M. Hillas "Evolution of ground-based gamma-ray astronomy from the early days to the Cherenkov Telescope Arrays"

A.M. Hillas, ApP, 43 (2013) 19–43

- When one considers the incredible 4.8-h periodicities extracted even in underground experiments, I am made to remember that my Harwell mentor, T.E. Cranshaw, once explained to me that a physicist's apparatus gradually learns what is expected of it.
- This is the best explanation I know of at present for this episode (and happily convenient, blaming the apparatus for a dog-like desire to please).

HILLAS SYMPOSIUM

Heidelberg, Germany

December 10 - 12

Our deep appreciation and admiration is with the great scientist