MAGIC

(the Major Atmospheric Gamma Imaging Cerenkov telescope)

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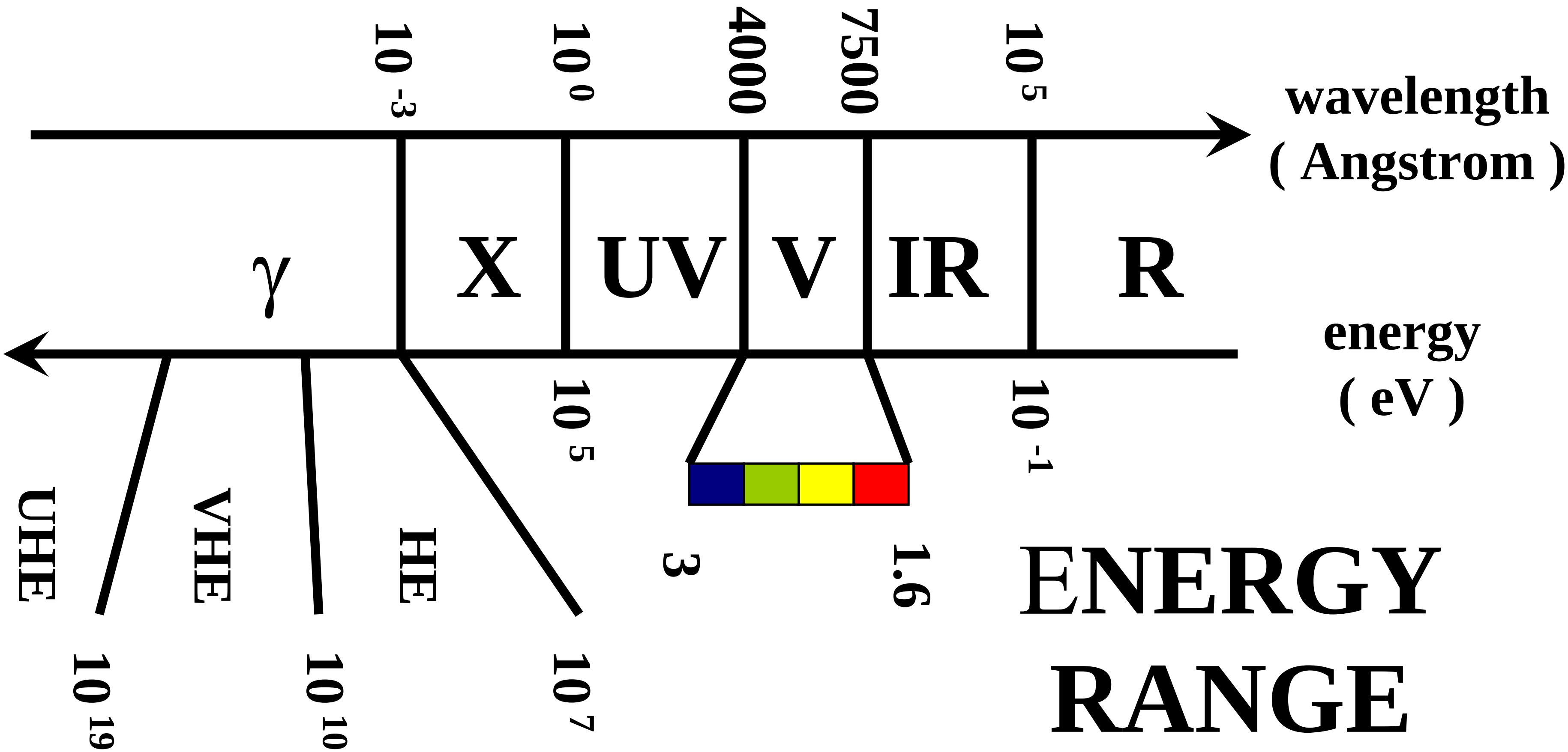
for the MAGIC Collaboration

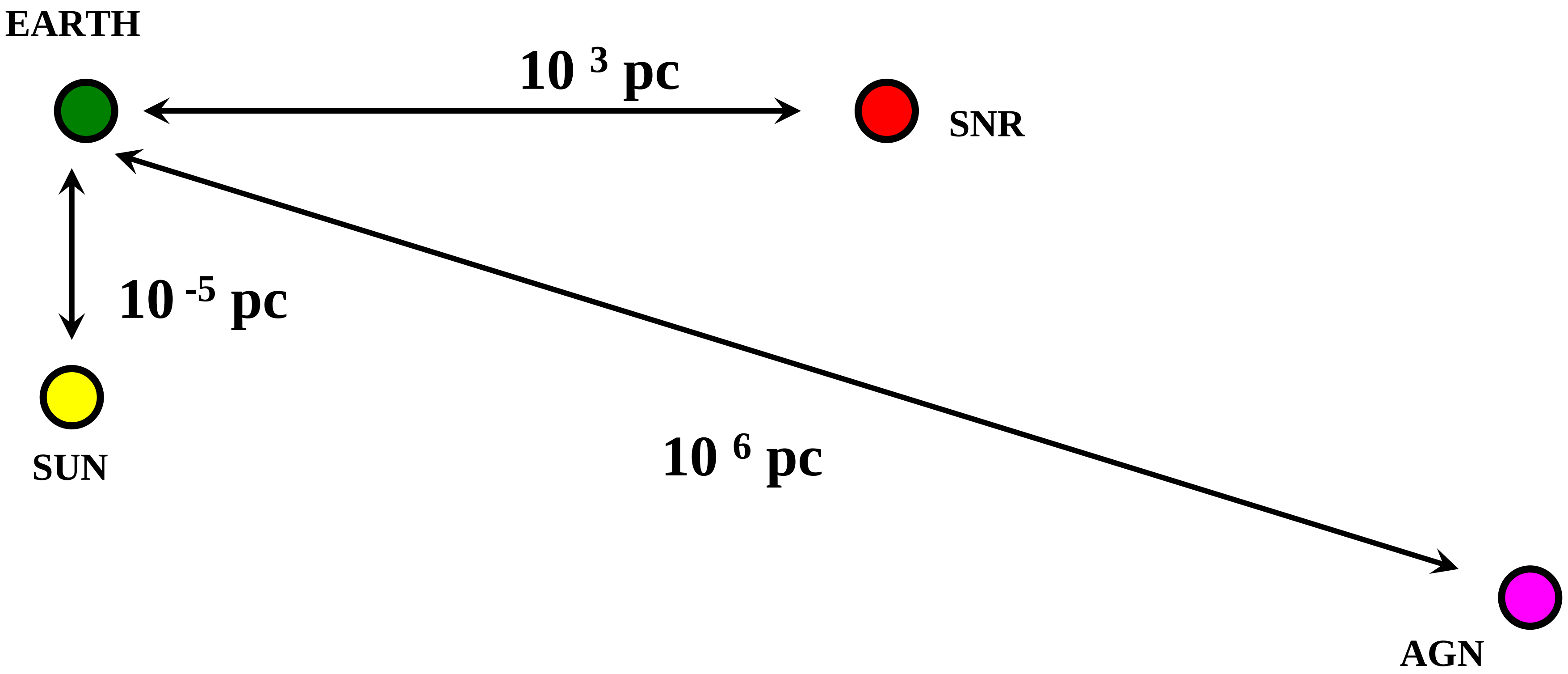
γ-ray astrophysics : energy



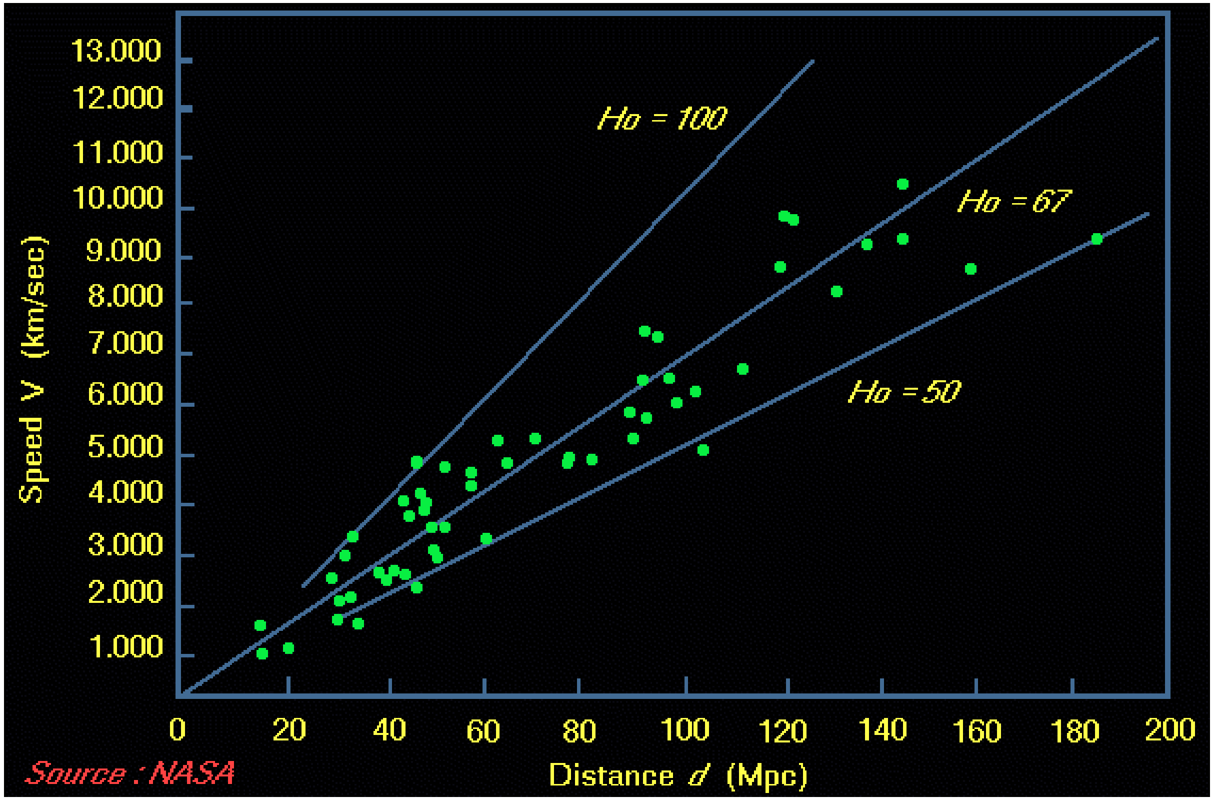
ENERGY RANGE

γ-ray astrophysics : distance

PARSEC $1\ \text{pc} = 10^{18}\ \text{cm}$



γ-ray astrophysics : redshift

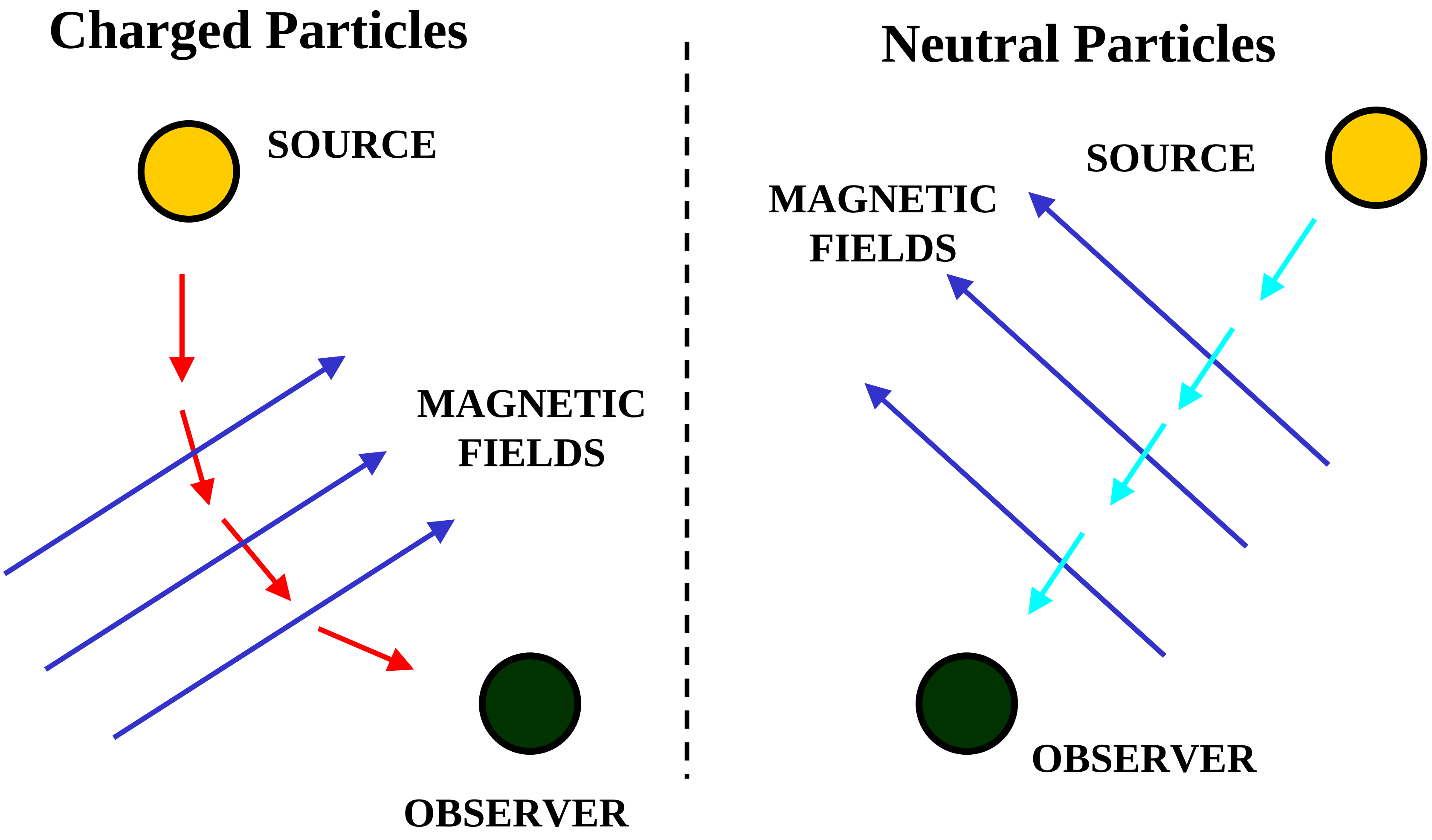


Hubble law
V ∝ d

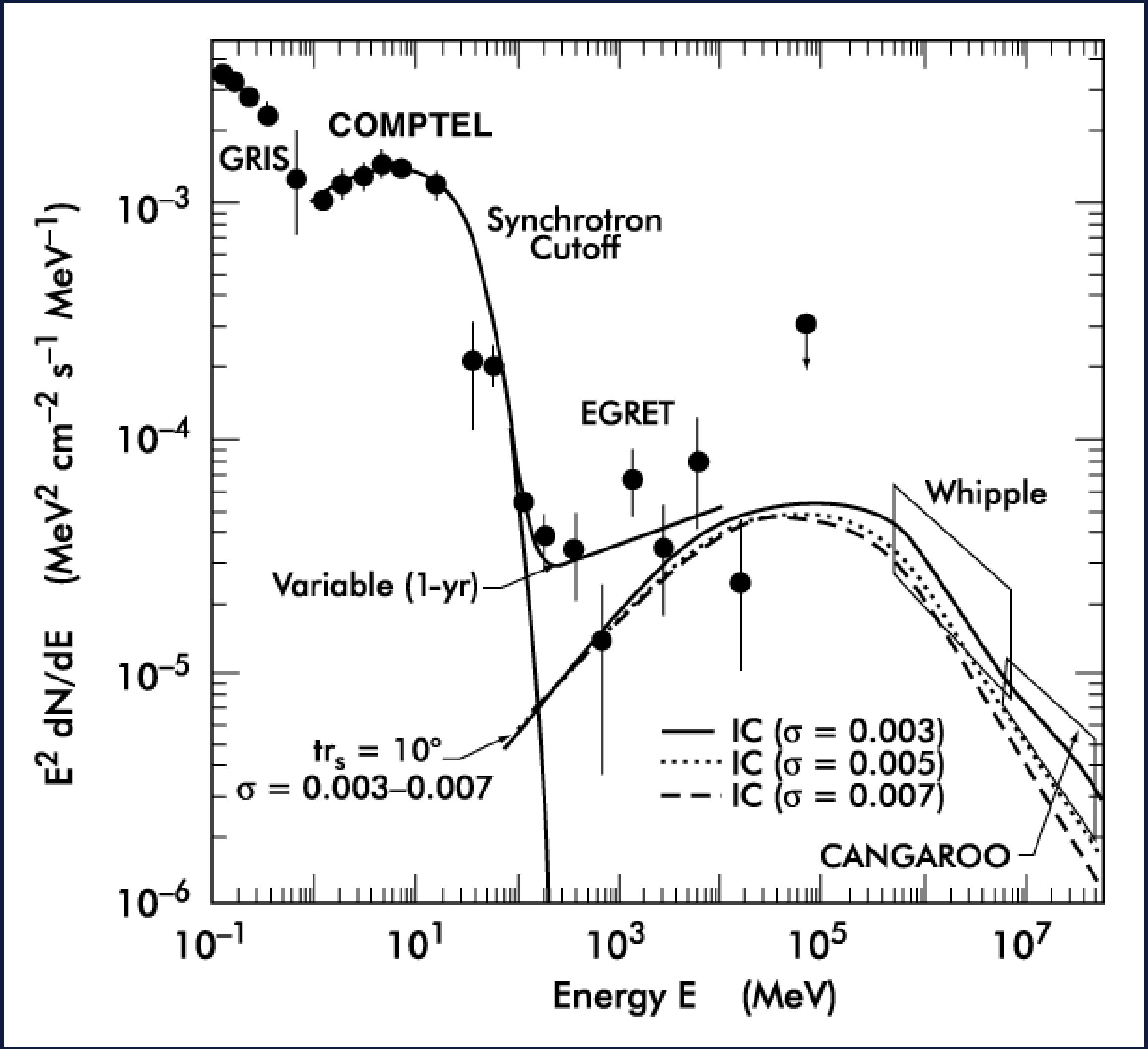
Doppler Effect
z ∝ V

DISTANCE
z ∝ d

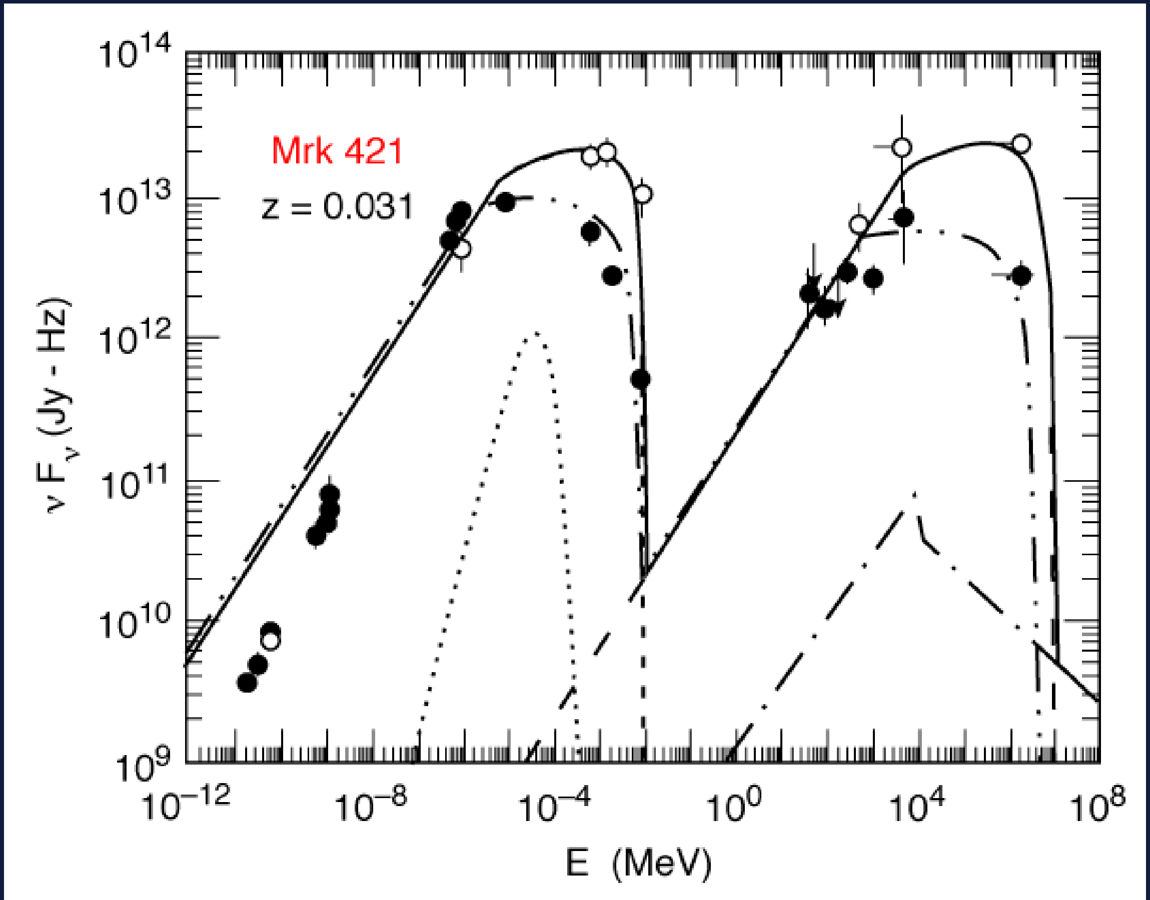
γ-ray astrophysics : direction



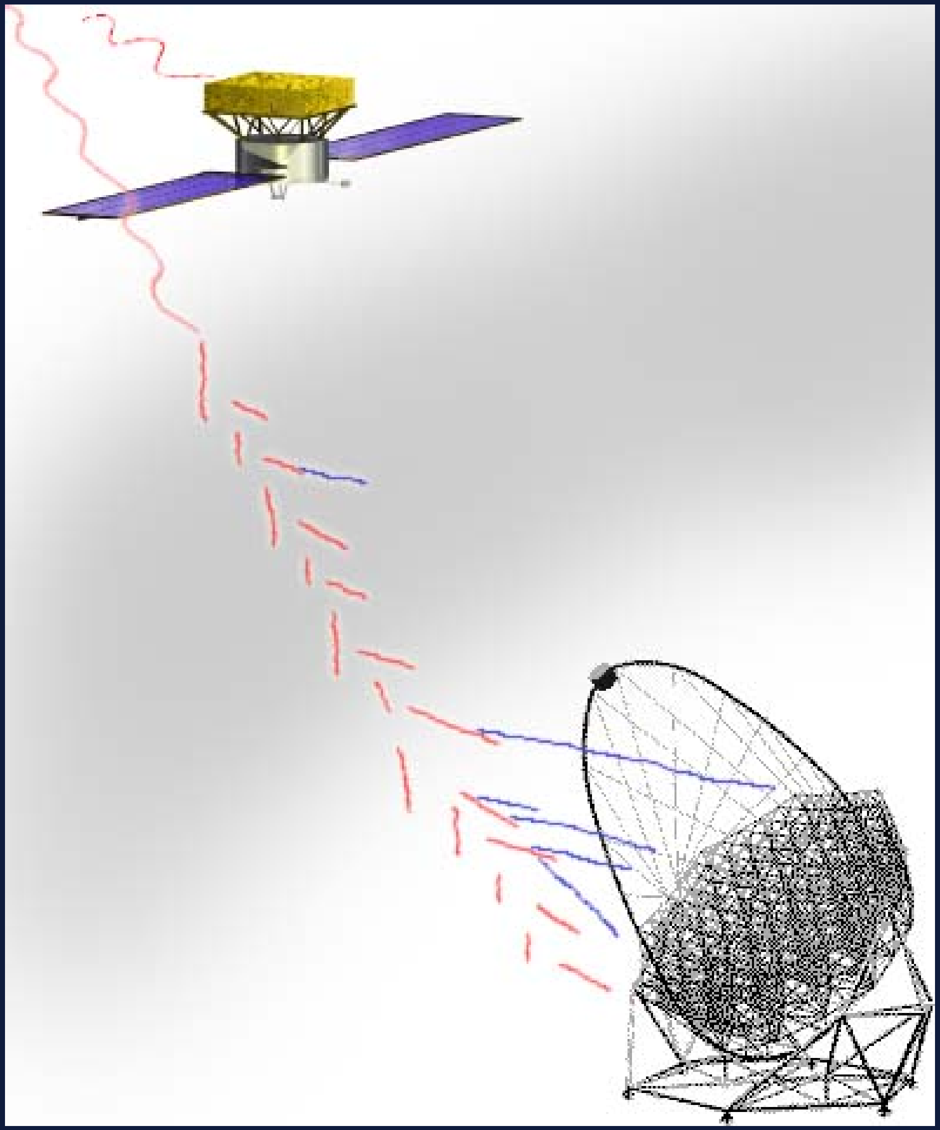
Energy Spectrum (CRAB)



Energy Spectrum (MRK 421)



Cosmic Ray Detection Approaches



Space detectors
Large field of view
Small collection area (~1 m^2)
Energy sensitivity up to ~100 GeV

Ground detectors
Small field of view
Large collection area (~$3 \cdot 10^4$ m^2)
Energy sensitivity from ~10 GeV

$\Rightarrow$ **Large Cherenkov Telescope**

Optimised for:
- low threshold: $E_\gamma < 30$ GeV
- fast repositioning: $t_R < 30$ s.

Many new technological elements

Atmospheric showers

QuickTime™ and a
MPEG-4 Video decompressor
are needed to see this picture.

Air Showers

Air showers induced by cosmic rays

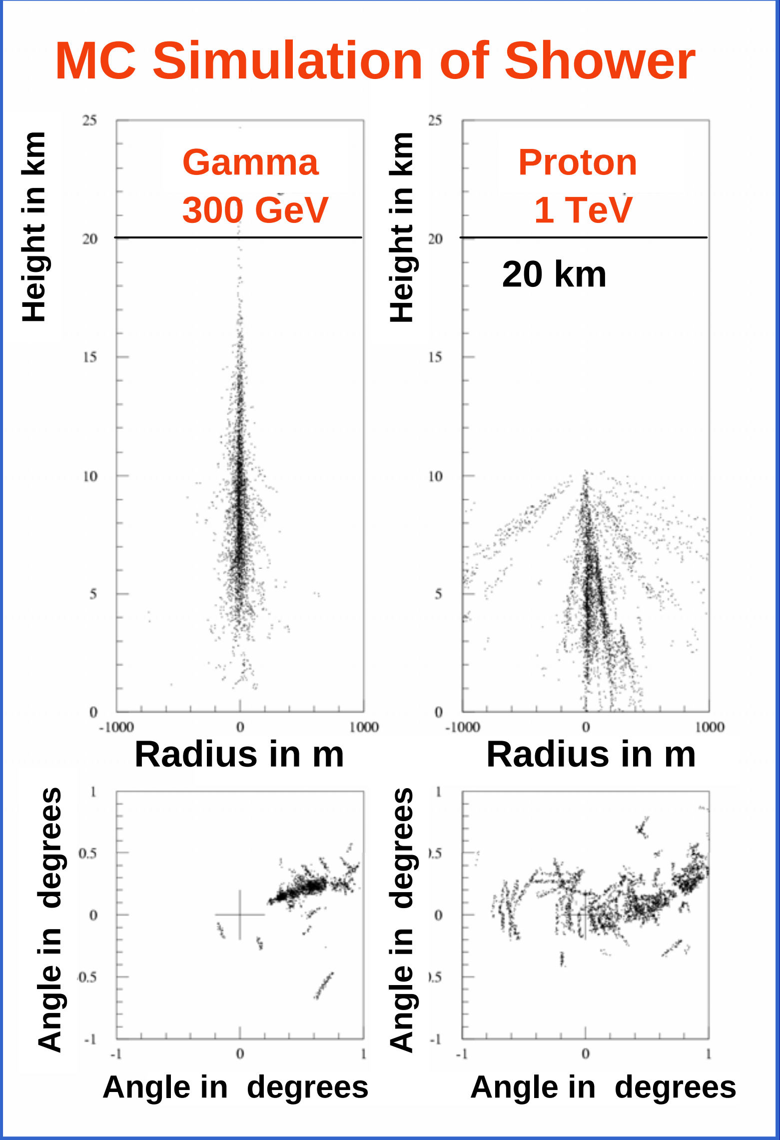
air shower

hadronic

gamma photons

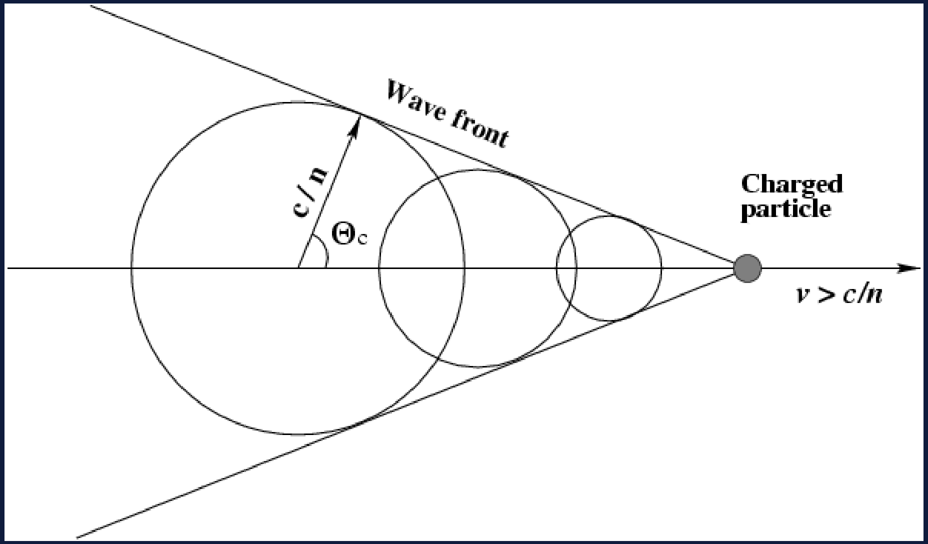
differently

Cherenkov light



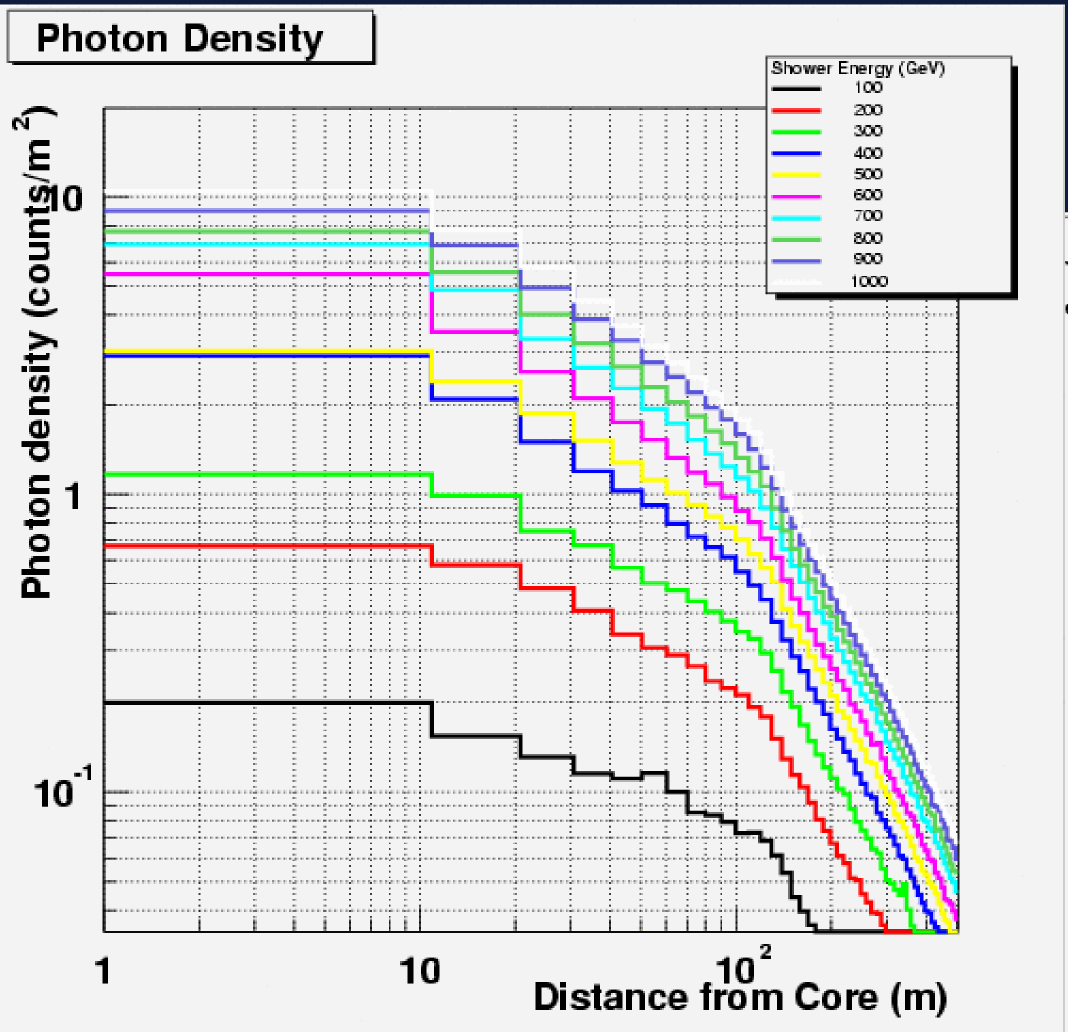
QuickTime™ and a
Video decompressor
are needed to see this picture.

CERENKOV EFFECT

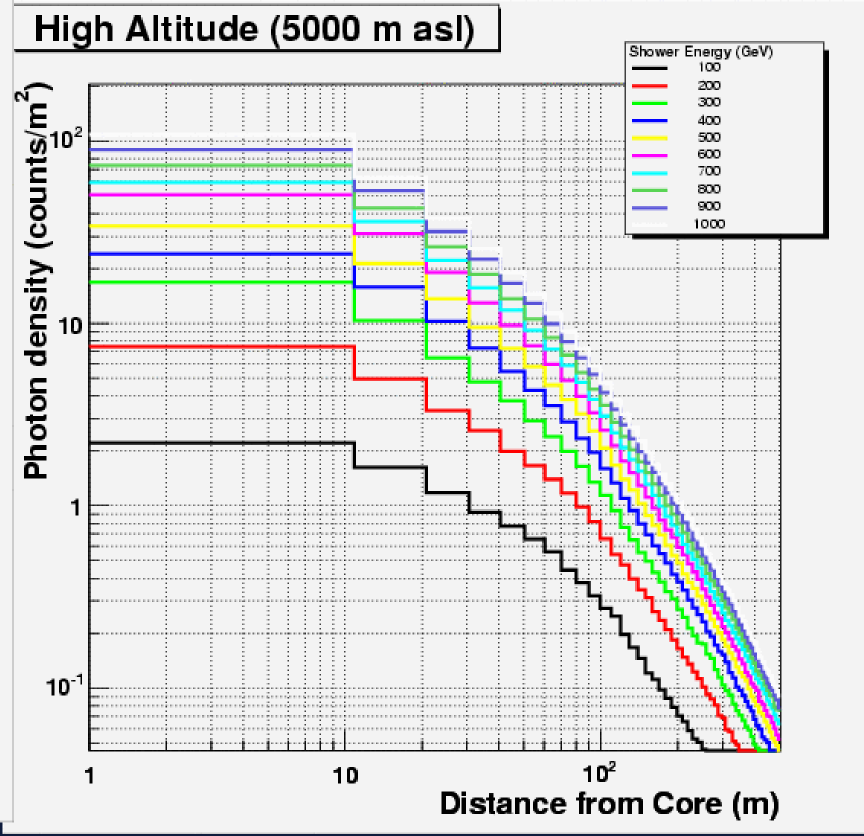


Atmospheric showers and Cerenkov light

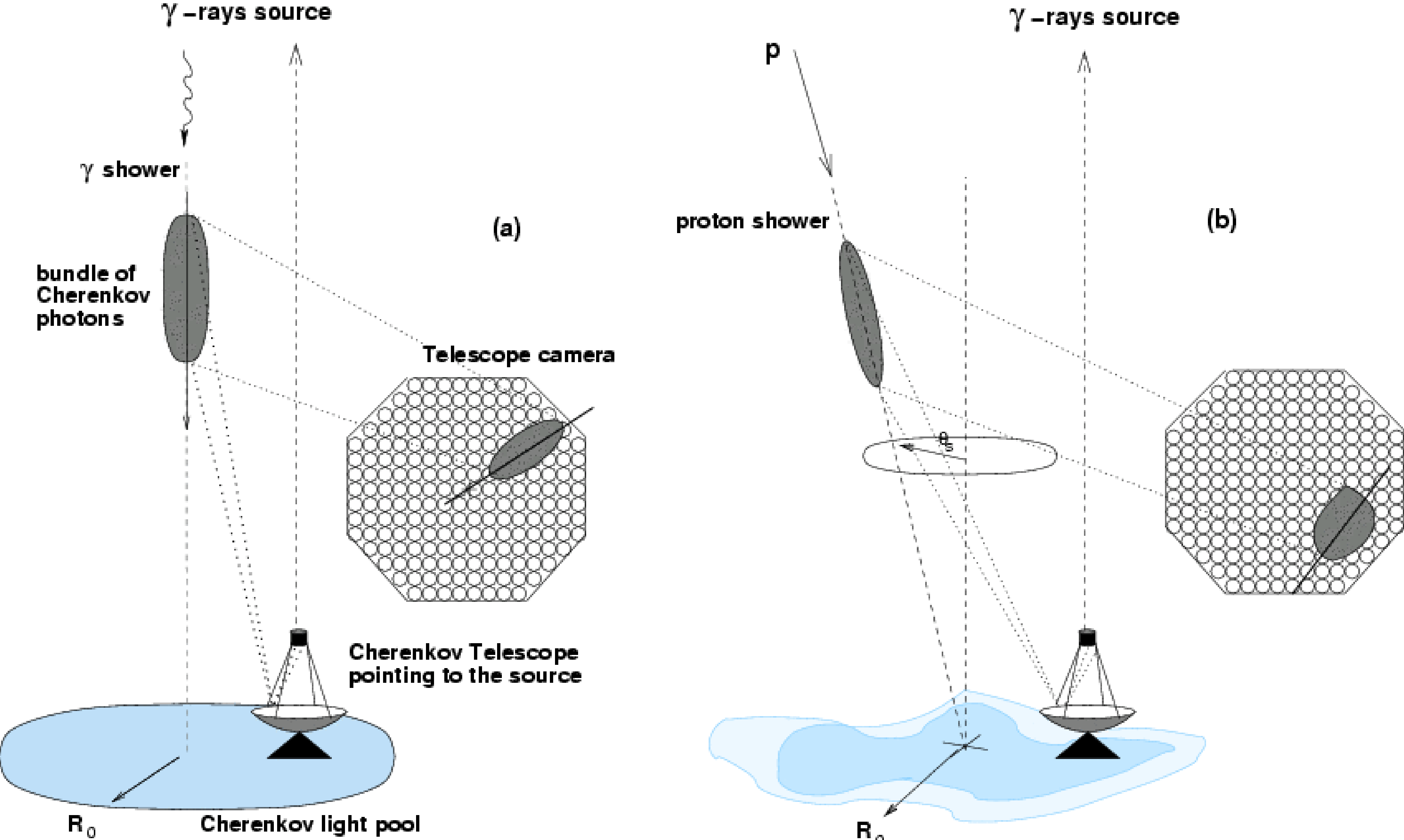
QuickTime™ and a
MPEG-4 Video decompressor
are needed to see this picture.



Photon Density
Shower Energy (GeV)
100
200
300
400
500
600
700
800
900
1000
Photon density (counts/m 2)
10
1
10^{-1}
1
10
10^{2}
Distance from Core (m)



High Altitude (5000 m asl)
Shower Energy (GeV)
100
200
300
400
500
600
700
800
900
1000
Photon density (counts/m 2)
10^{2}
10
1
10^{-1}
1
10
10^{2}
Distance from Core (m)

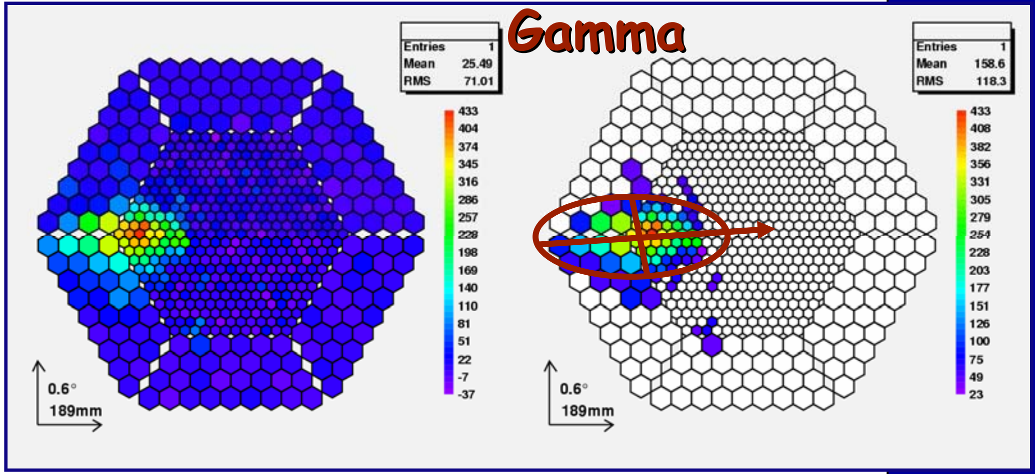

γ -rays source
γ shower
bundle of
Cherenkov
photons
(a)
Telescope camera
Cherenkov Telescope
pointing to the source
R0
Cherenkov light pool
p
γ -rays source
proton shower
(b)
R0

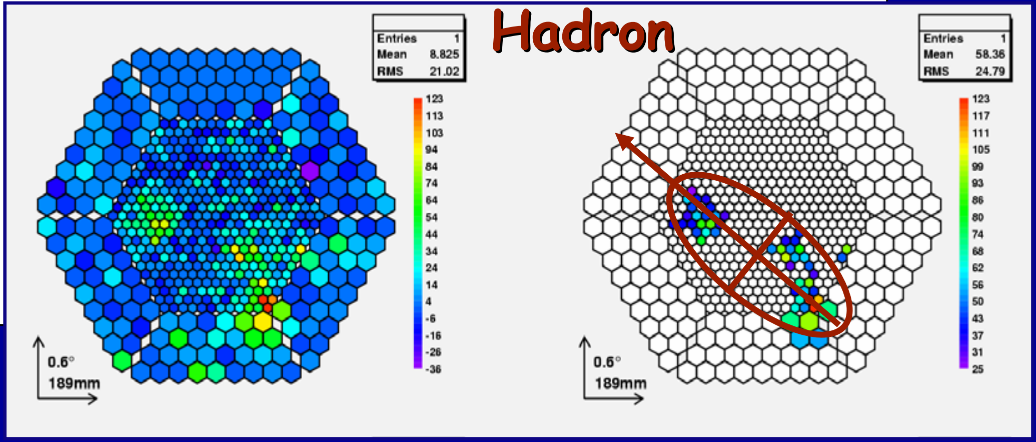
Analysis

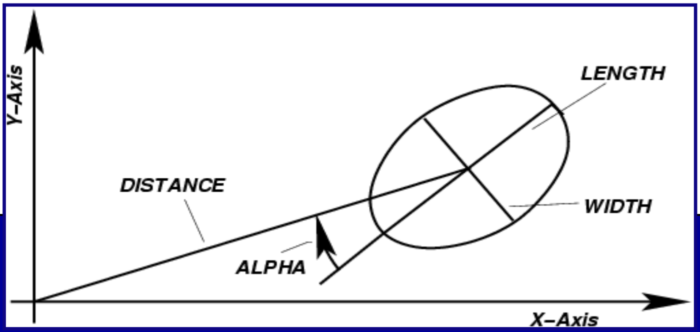
‚Hillas parameters‘

reduction

- Source in center







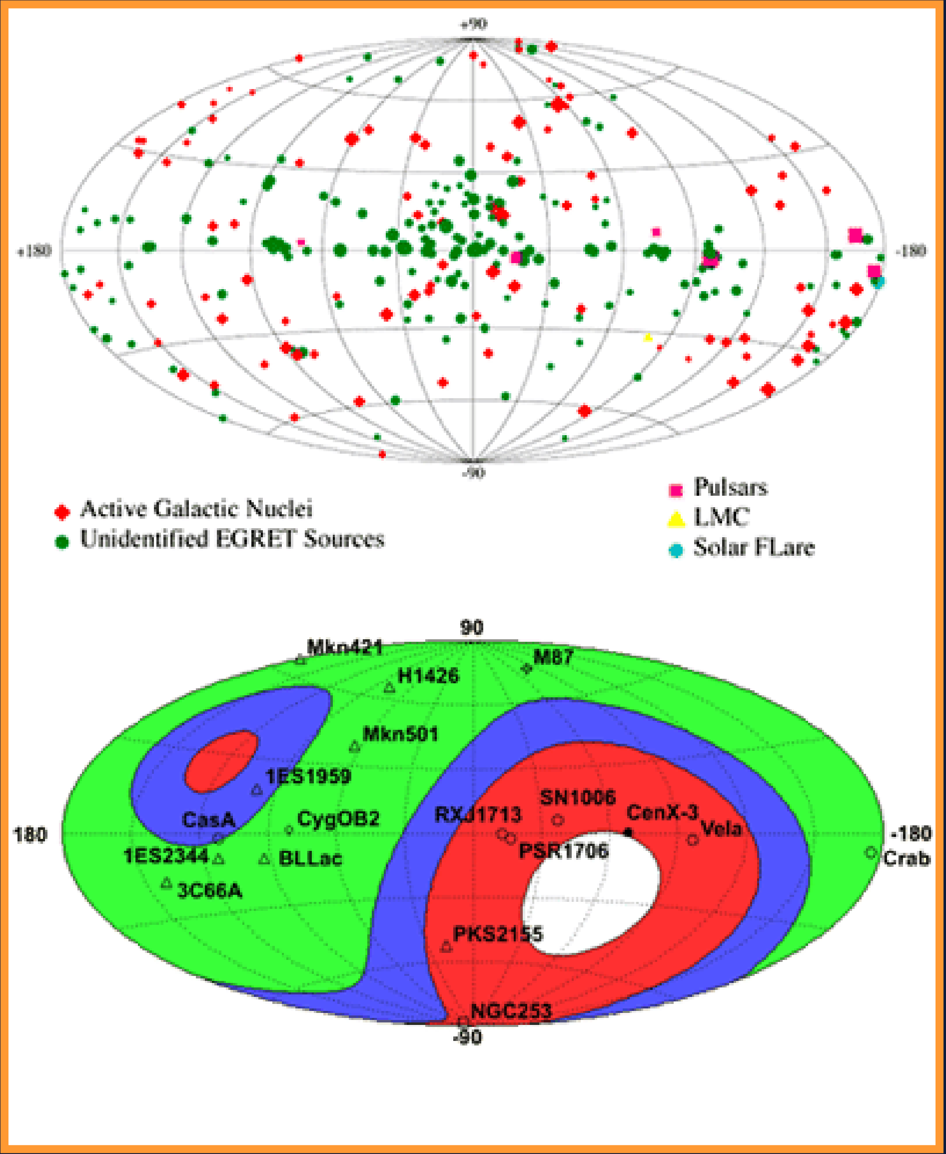
IACT PARAMETERS

- Angular resolution

  Energy Threshold

  Sensitivity

The Gamma Ray Universe



EGRET

- 100 MeV < Eγ < 10 GeV
- A ~ 0.15 m²

> 270 sources (170 unidentified)

First Generation IACTs

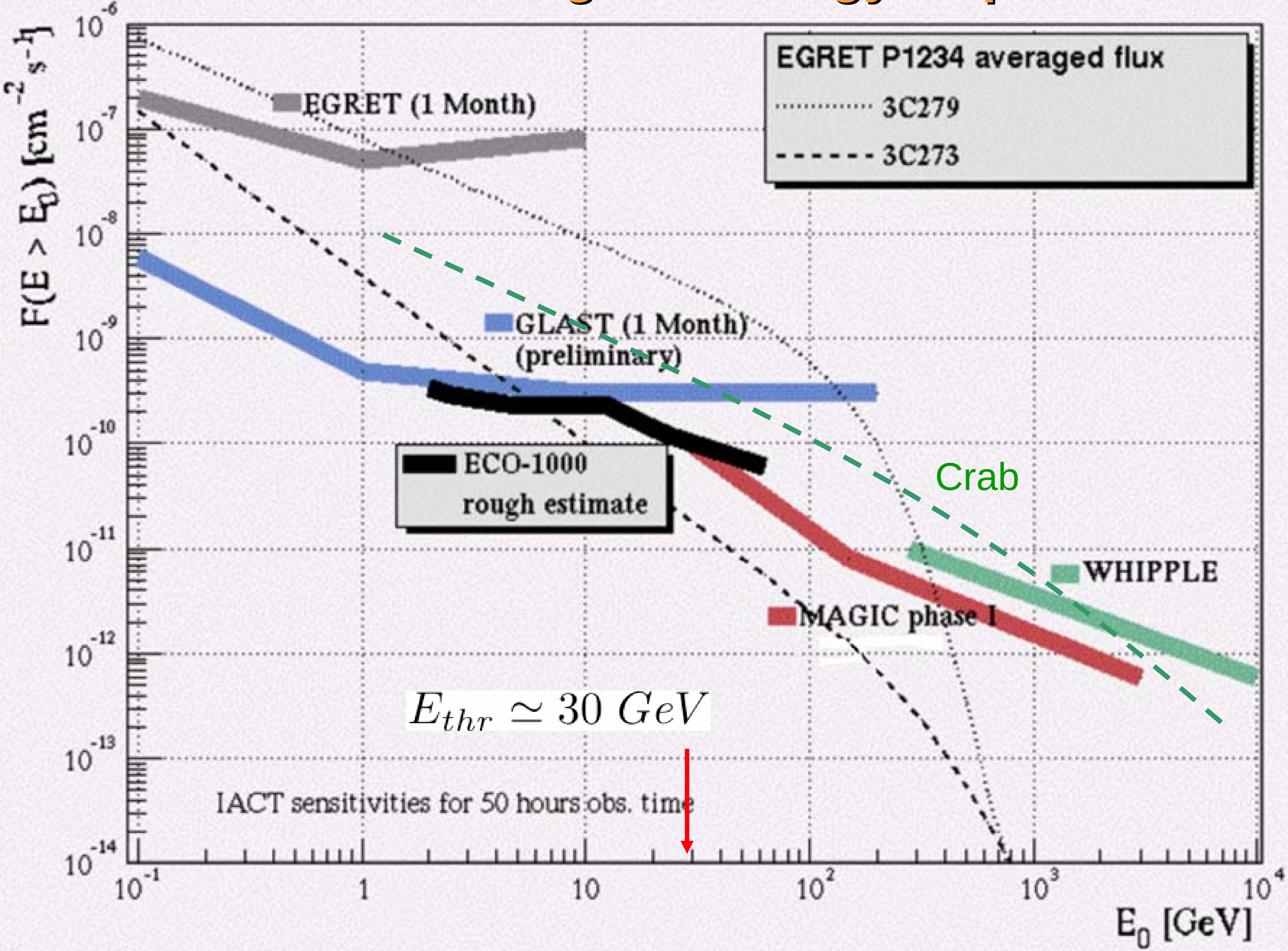
- Eγ > 300 GeV
- A ~ 40000 m²

~ 10 sources

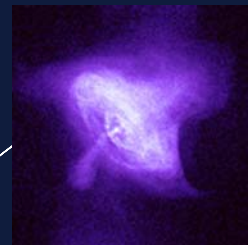
Something must happen in

10 GeV < Eγ < 300 GeV

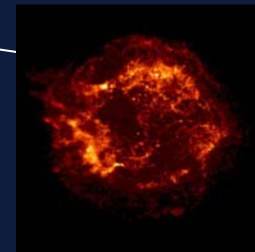
Covering the Energy Gap



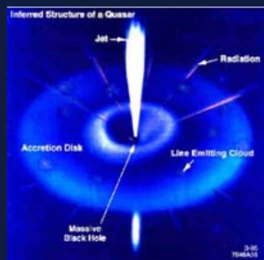
MAGIC Physics Targets



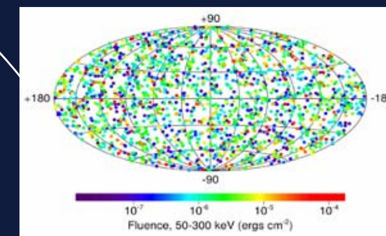
Pulsars



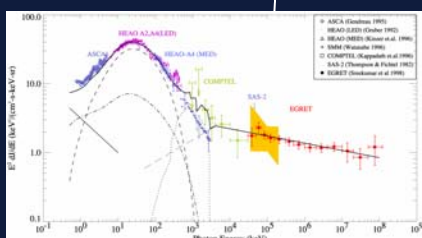
SNRs



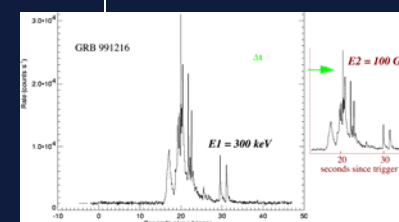
AGNs



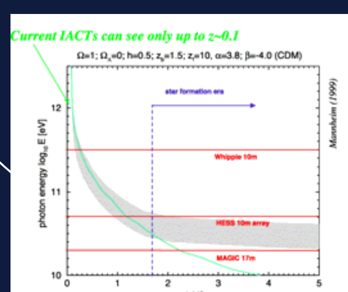
GRBs



Diffuse γ Background



Quantum Gravity



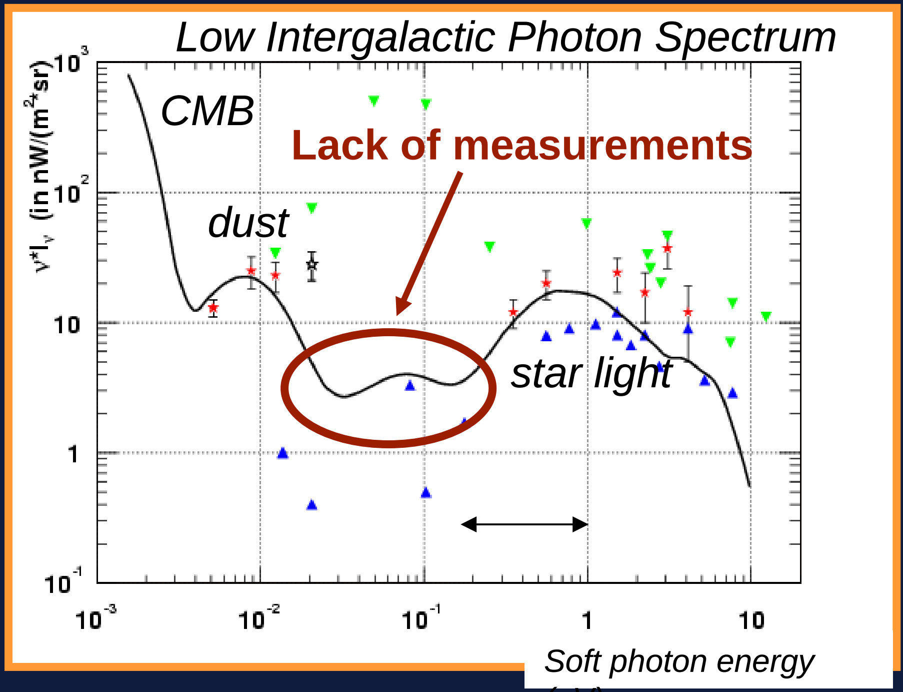
Cosmological γ Horizon

Cold Dark matter

Optical Depth and Gamma Ray Horizon (GRH)

High energy γ-rays traversing cosmological distances are expected to be absorbed through interaction with **EBL**:

$$\gamma_E \, \gamma_\epsilon \longrightarrow e^+ e^-$$



Stecker, De Jager: astro-ph/9501065

Kneiske, Mannheim, Hartmann: Astron. Astrophys. 386 (2001) 1

Absorption is modeled by:

$$\frac{dN}{dE} = K E^{-\Gamma} \cdot e^{-\tau(E,z)}$$

The Gamma Ray Horizon is defined by:

$$\tau(E,z) = 1$$

Optical Depth

$$\tau(E,z) = \int_0^z \frac{d\ell}{dz'} dz' \int_0^2 \frac{x}{2} dx \int_{\frac{2m^2c^4}{Ex(1+z')^2}}^{\infty} n(\epsilon, z') \, \underbrace{\sigma \left[2xE(1+z')^2 \right]}_{\text{Bethe-Heitler cross section}} \, d\epsilon$$

Bethe-Heitler cross section

Measurement of Cosmological Parameters

The GRH is a distance estimator based on the absorption, depends on:

- the γ–ray path
- the Hubble constant and the cosmological densities

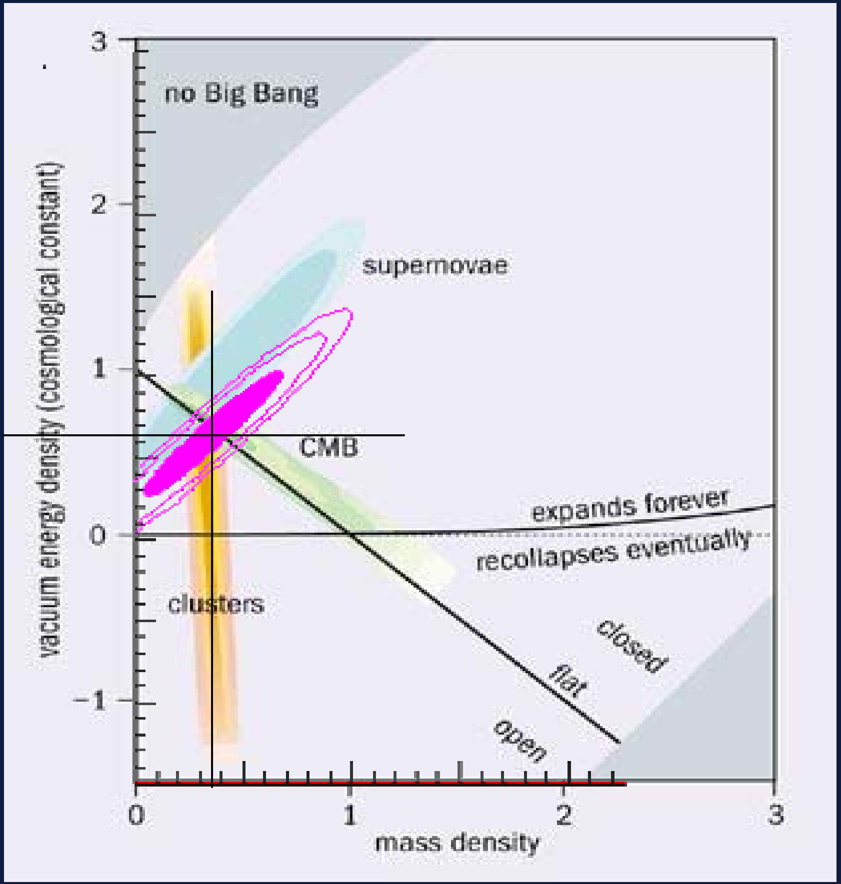
$$\frac{d\ell}{dz} = c \cdot \frac{1/(1+z)}{H_0 \left[\Omega_M (1+z)^3 + \Omega_K (1+z)^2 + \Omega_\Lambda\right]^{1/2}}$$

Ho known at the level of 4 km/s/Mpc (Hubble project)

$$\begin{aligned} H_0 &= 68.5 \pm 1.6 \text{ km/s/Mpc} \\ \Omega_M &= 0.35^{+0.21}_{-0.20} \\ \Omega_\Lambda &= 0.65^{+0.24}_{-0.25} \end{aligned}$$

MINOS

$\Rightarrow$ The $\Delta\chi^2$=2.3 *2-parameter contour* improves by more than a factor 2 the present Supernovae combined result !

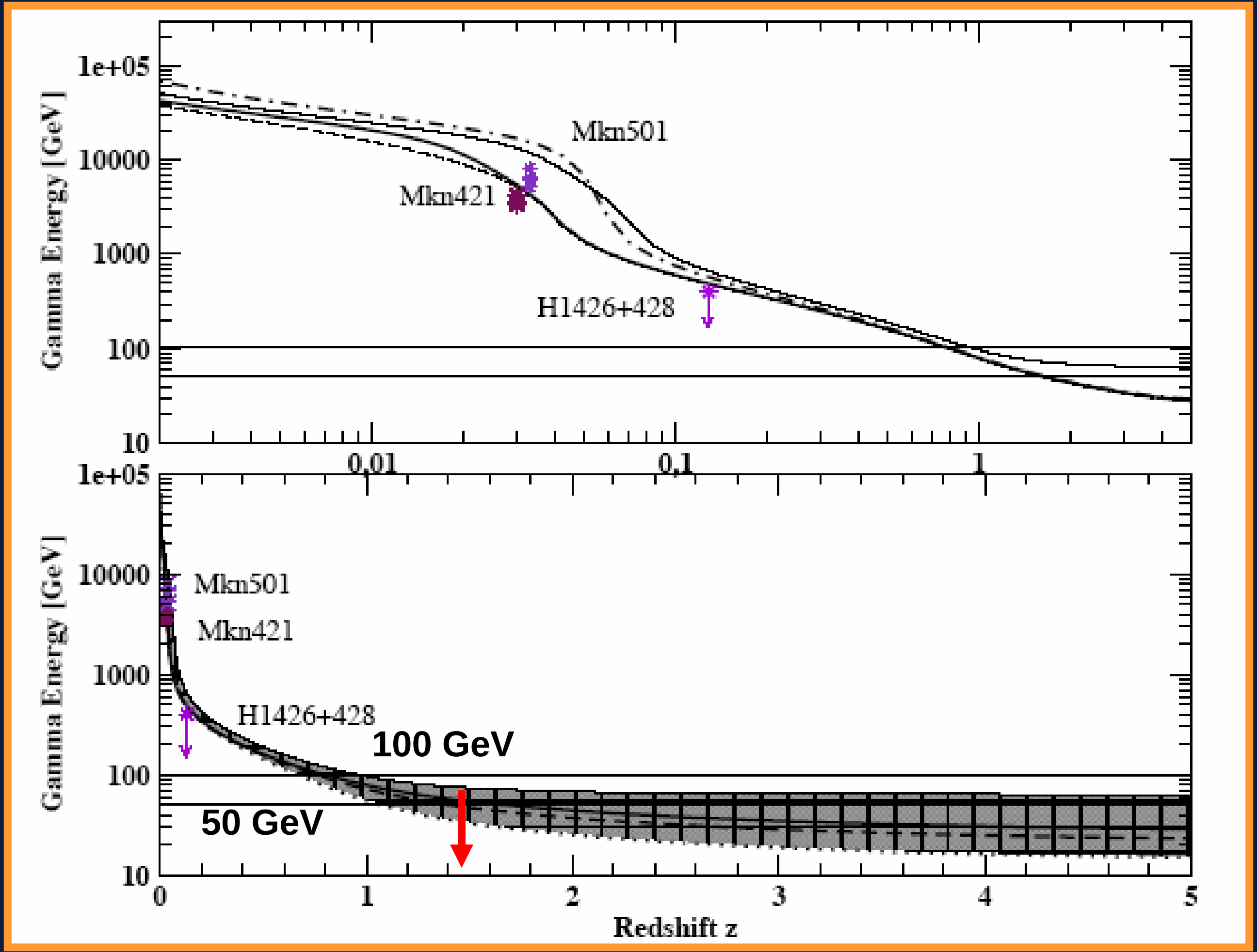


O. Blanch, M. Martinez - ICRC 2003

Fazio-Stecker Relation

Measuring the Fazio-Stecker relation is of great diagnostic value for:

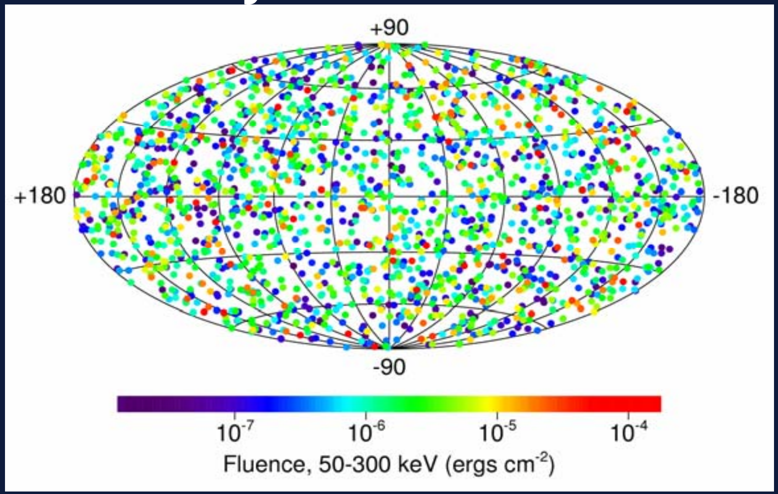
- star formation in optically-obscured IR galaxies
- stellar sources of UV radiation at high *z*
- star formation rate at high *z (~1.5)*



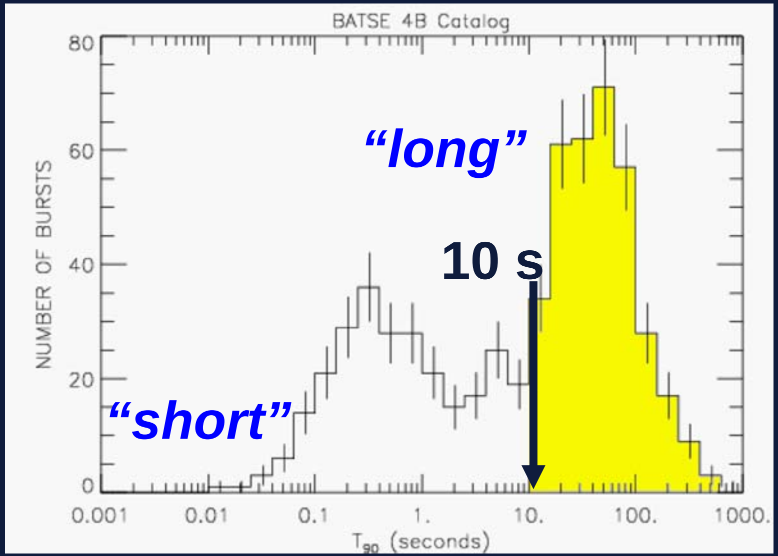
Kneiske et al. astro-ph/0309141

Gamma Ray Bursts

Uniformity



Pulse Duration



- Origin of GRBs
  - Galactic
  - Cosmological
- Theoretical Emission Models:
  - Standard fireball model
  - Internal Shocks model
  - External Shock model
- Multiwavelength study
- GeV studies possible if:
  - **fast repositioning ~10 s**
  - **low E threshold ~30 GeV**
- From BATSE catalog ~50/year
  - Expected signal rate 6÷600 Hz (in [10s,T] assuming T~20s)
  - 2÷3 "long" GRBs detectable/year

What do we need to study GRBs ? Alert System

High Energy Observations

"Faint" Objects → Large Effective Area

Rapid Variable Phenomena → Short Dead Time ~ 100 μs

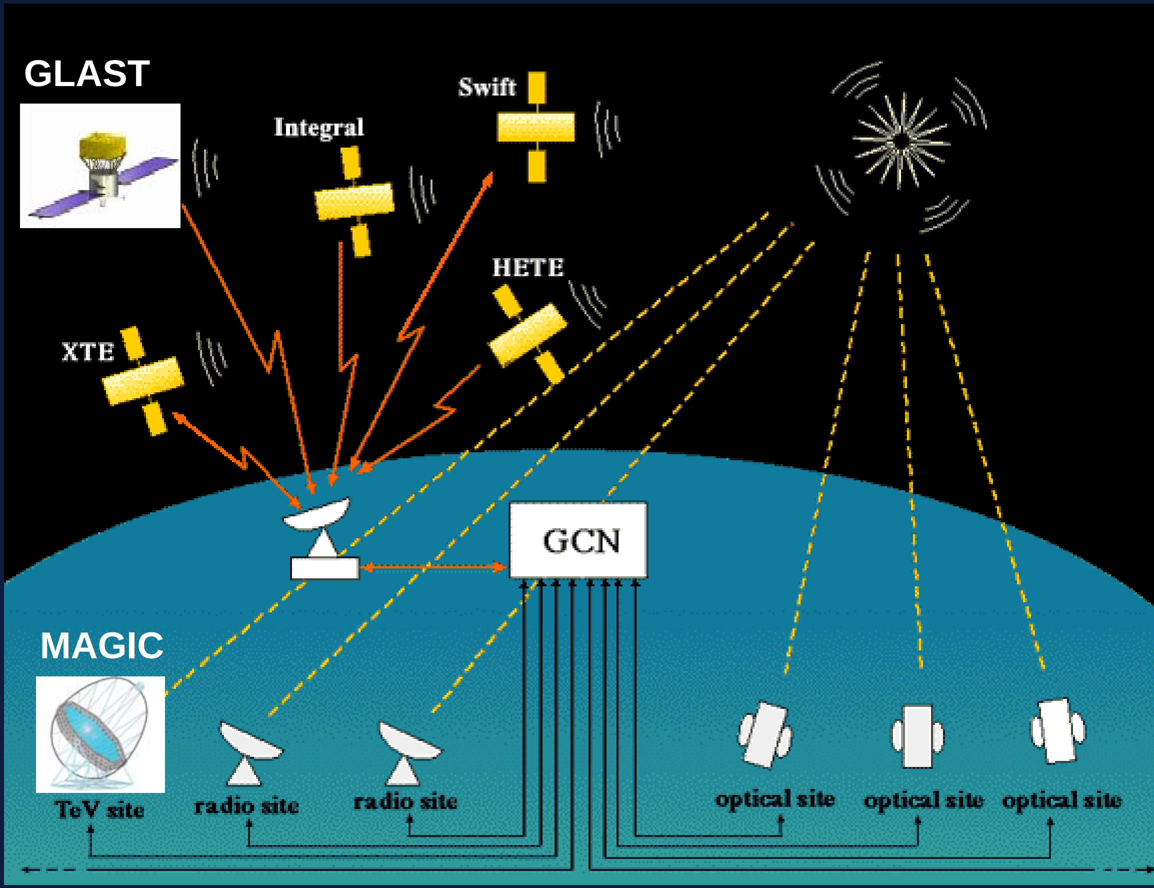
Large Field Of View → High Acquisition Rate

Broad Band Observations

Connection between
Ground & *Space* Telescopes

- Rapid Response
- Good Localization
- Rapid Repositioning

→**Global Coordinate Network**



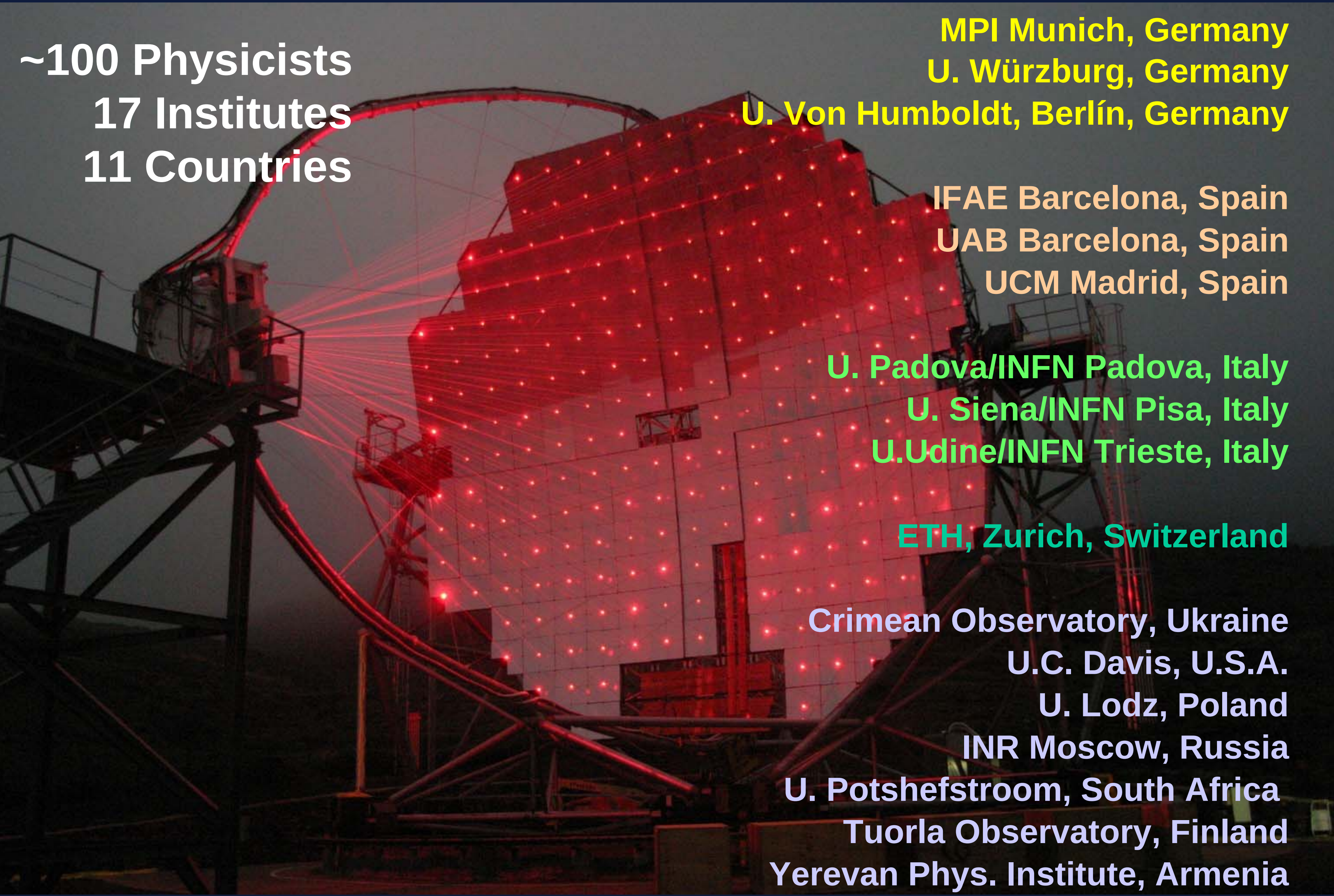
What do we need to study GRBs? Telescope Fast Movement

Mean Repositioning Time ~ 20 s

Point ANY place in the sky in ~30 s

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

The MAGIC Collaboration



~100 Physicists
17 Institutes
11 Countries

MPI Munich, Germany
U. Würzburg, Germany
U. Von Humboldt, Berlín, Germany

IFAE Barcelona, Spain
UAB Barcelona, Spain
UCM Madrid, Spain

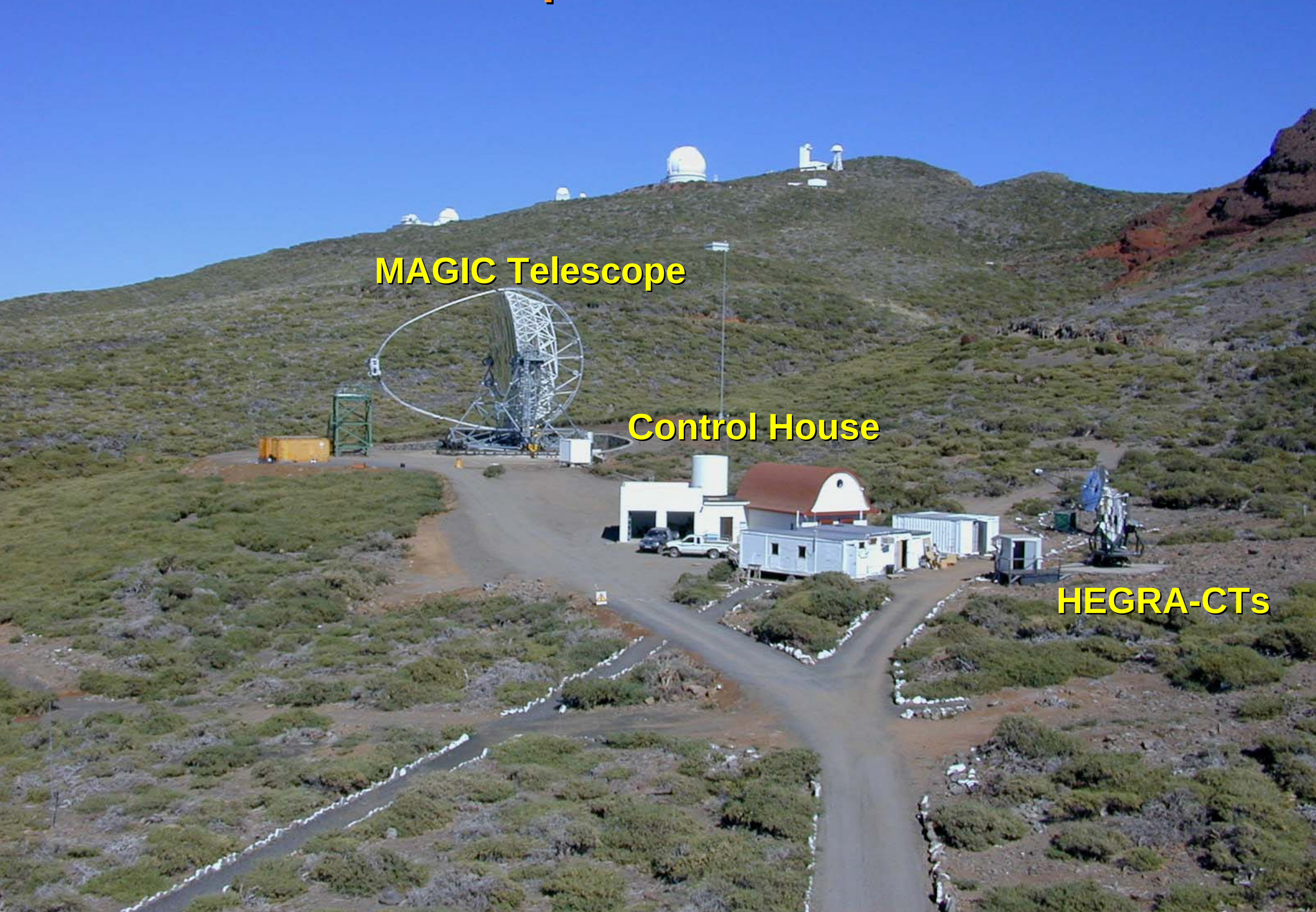
U. Padova/INFN Padova, Italy
U. Siena/INFN Pisa, Italy
U.Udine/INFN Trieste, Italy

ETH, Zurich, Switzerland

Crimean Observatory, Ukraine
U.C. Davis, U.S.A.
U. Lodz, Poland
INR Moscow, Russia
U. Potshefstroom, South Africa
Tuorla Observatory, Finland
Yerevan Phys. Institute, Armenia

The Site: Roque de Los Muchachos

The Site: Roque de Los Muchachos



Lowering the Energy Threshold

Energy Threshold

$$E \propto \sqrt{\frac{\phi\Omega\tau}{A\epsilon}}$$

Ω - Pixel Solid Angle
τ - Integration time

A - Mirror Area
ε - Quantum Efficiency

Lowering the Energy Threshold

Energy Threshold

$$E \propto \sqrt{\frac{\phi \Omega \tau}{A \varepsilon}}$$

Mirror Area

17 m diameter

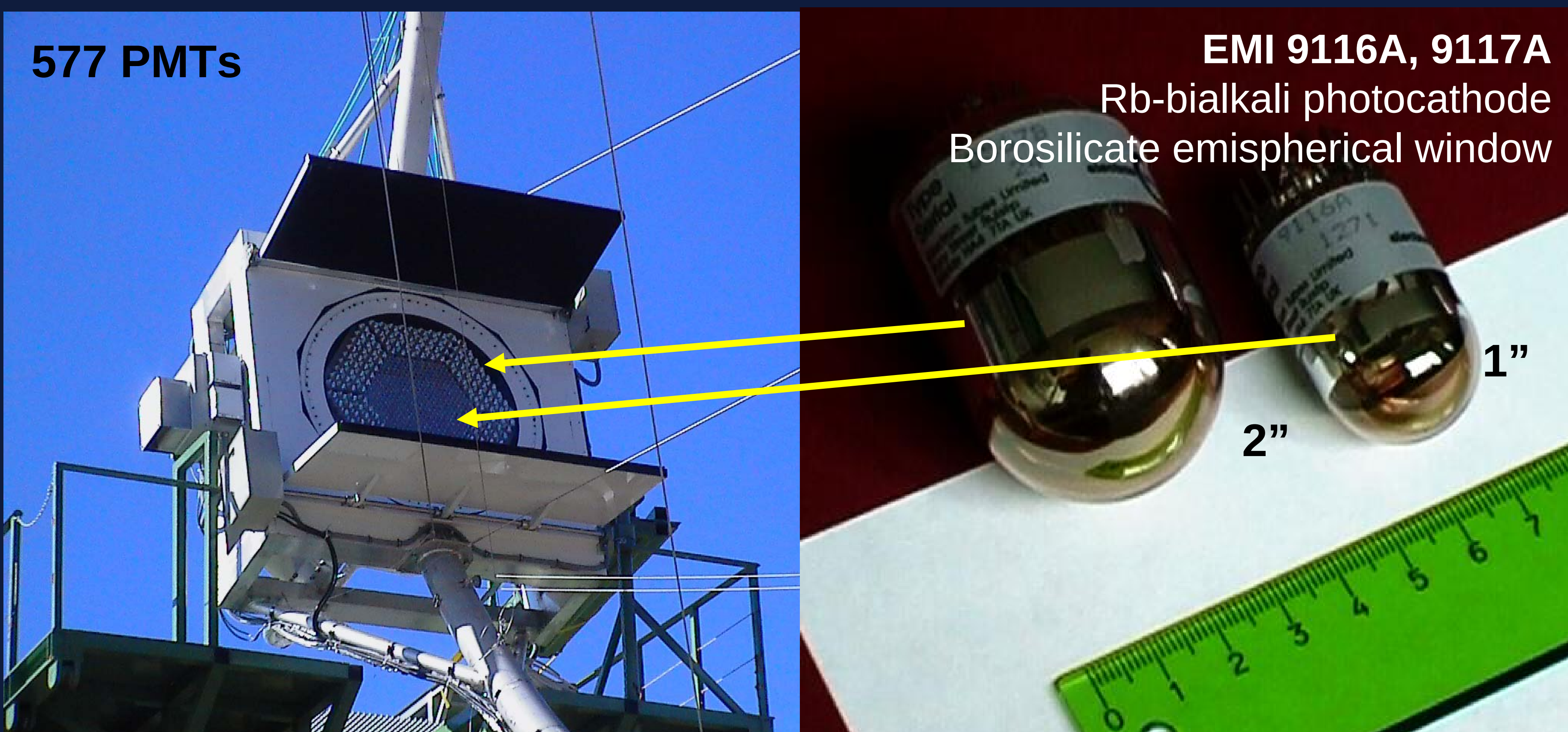
240 m^2 diamond milled Al

85%-90% reflectivity

Built by MERO (F)

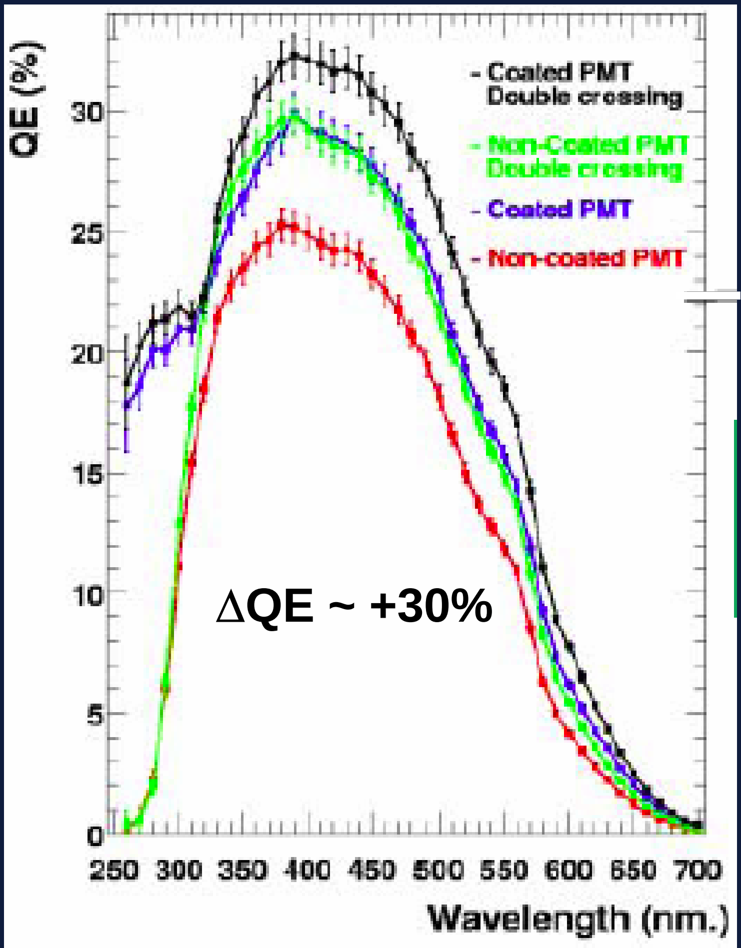
Lowering the Energy Threshold

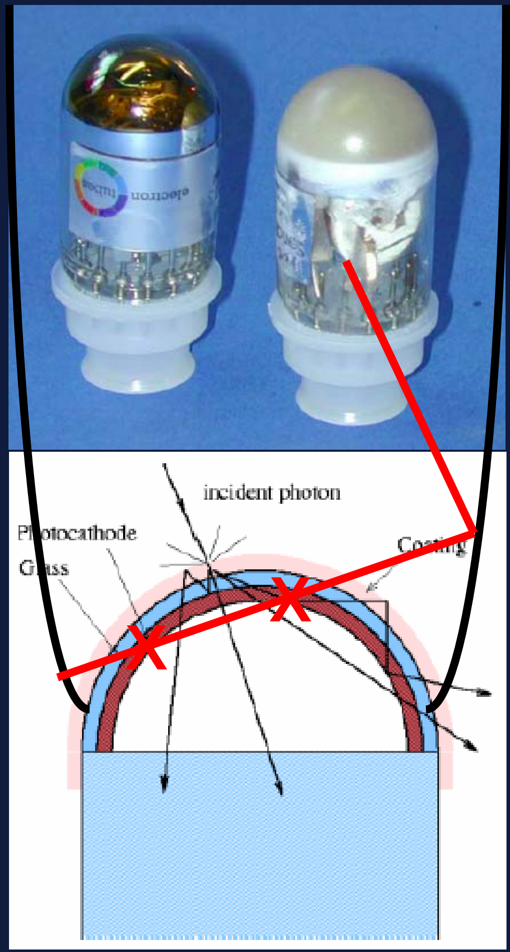
Energy Threshold $$E \propto \sqrt{\frac{\phi\Omega\tau}{A\epsilon}}$$ **Pixel Solid Angle**



Lowering the Energy Threshold

Energy Threshold $$E \propto \sqrt{\frac{\phi \Omega \tau}{A \epsilon}}$$ **Quantum Efficiency**





Lacquer

PTP+B-72
+Dichloromethane

1. Increase γ path length
2. Light collector to cross twice the photocathode

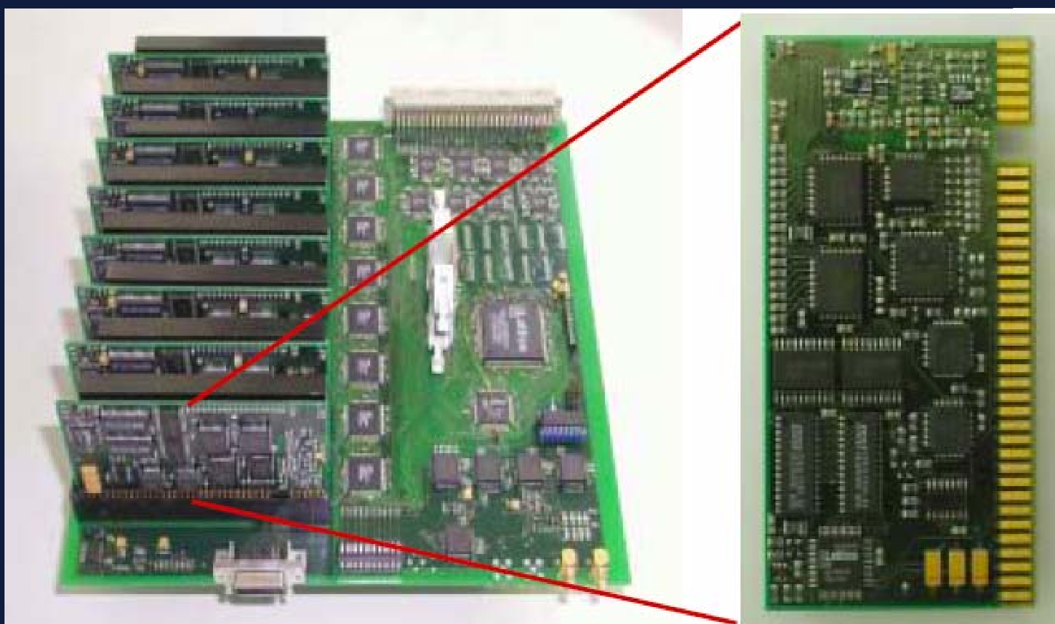
Lowering the Energy Threshold

Lowering the Energy Threshold

Energy Threshold $$E \propto \sqrt{\frac{\phi\Omega\tau}{A\epsilon}}$$ **Integration time**

Flash ADC @ 330 MHz, 8 bit

High/Low gain (x5)



First Calibration Event

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Low Gain

High Gain

Dynamic range: 2000 (high/low gain)

DAQ: Continuous ~20 Mbytes/sec ➔ ~1% deadtime @ 1 kHz

Internal FIFO for 150 000 events (>20 kHz) ➔ Gamma Ray Bursts

The Trigger Architecture

Discriminators

# of photoelectrons

↓

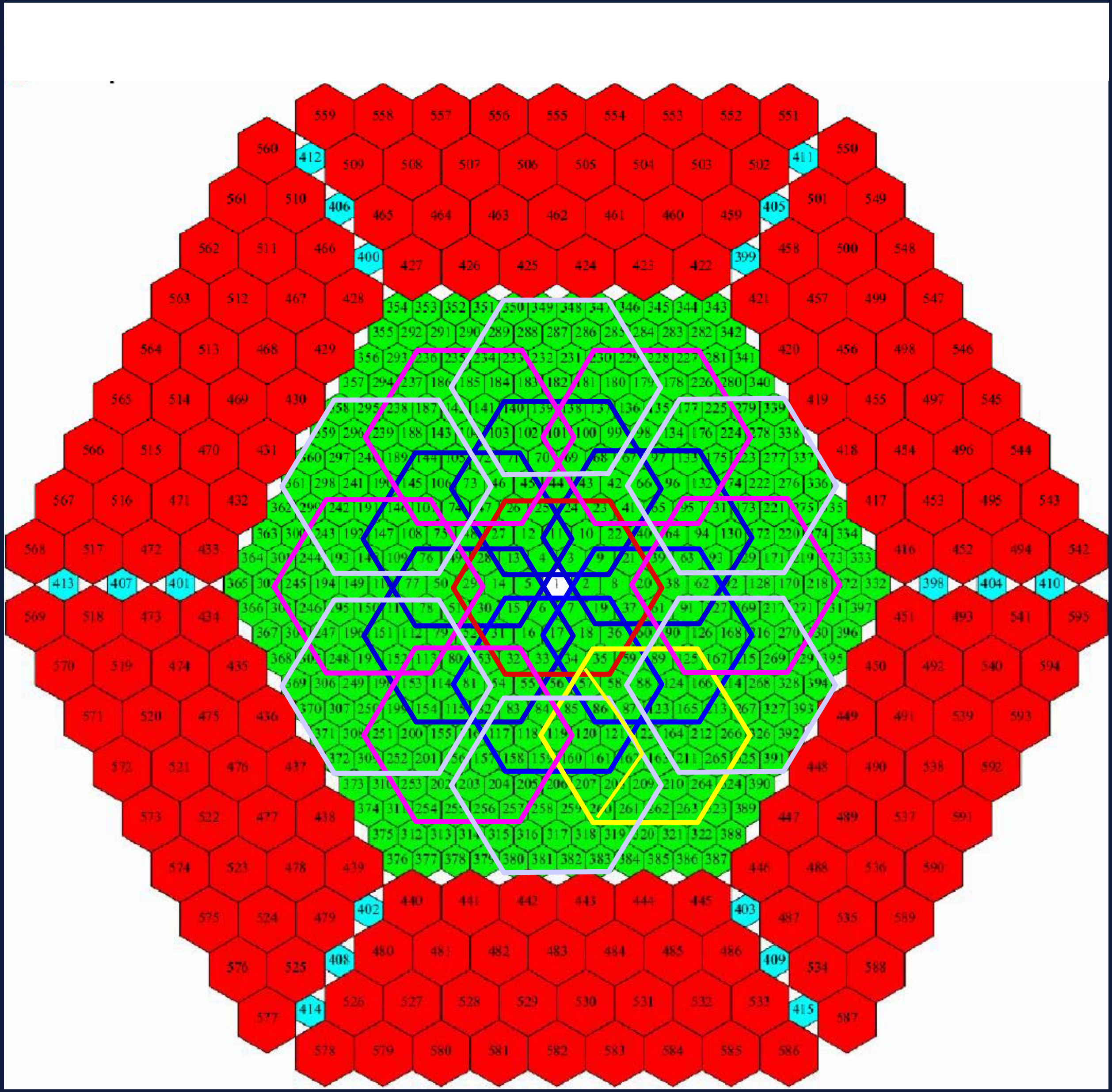
Level 1

tight time coincidence

↓

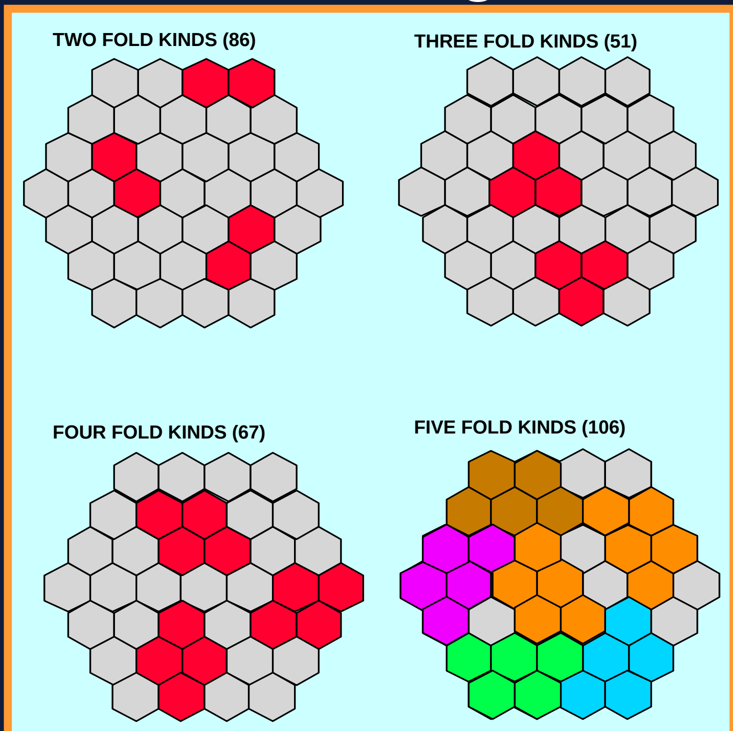
Level 2

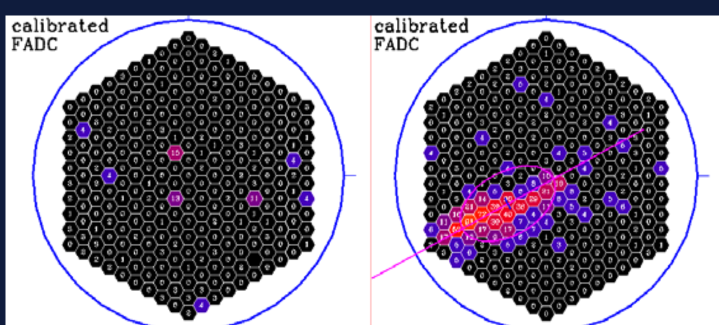
advanced pattern recognition



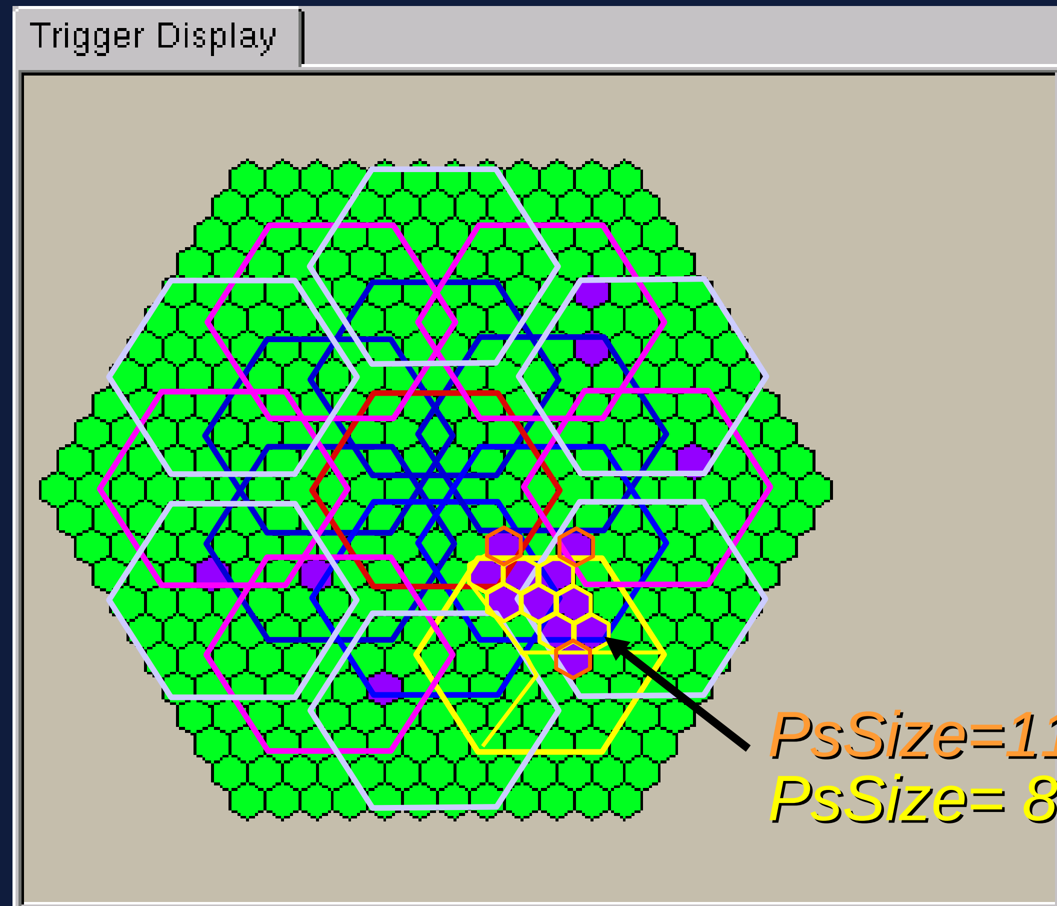
The Trigger Selection

Level 1 Logic





Level 2 Logic



Perform a <u>pattern recognition</u> and apply topological cuts.

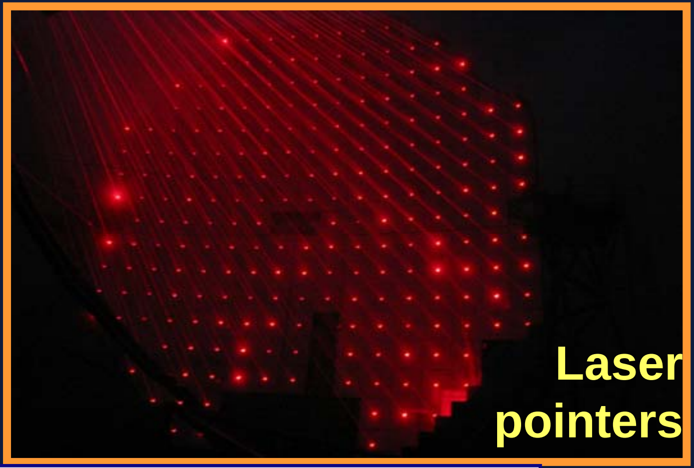
The cluster size can be <u>computed at trigger level</u> - “pseudosize”.

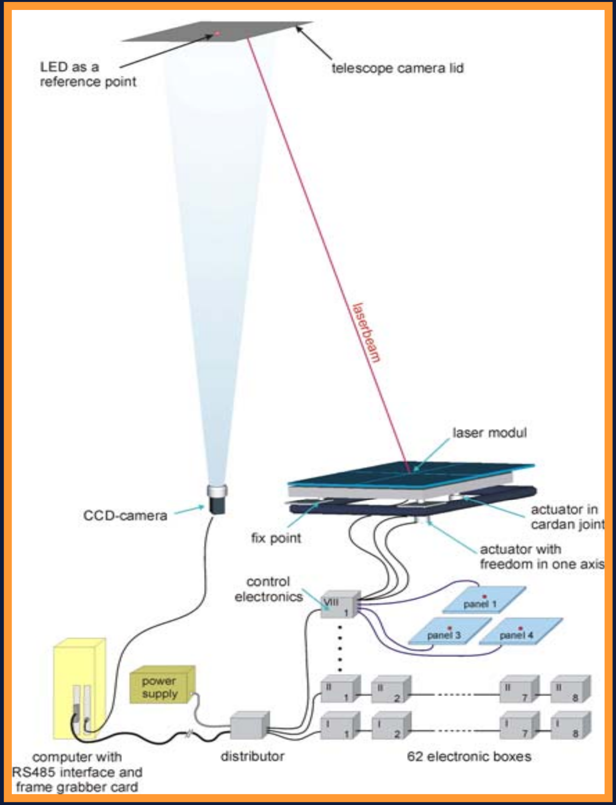
NIM A461(2001)521, NIM A518(2004)554

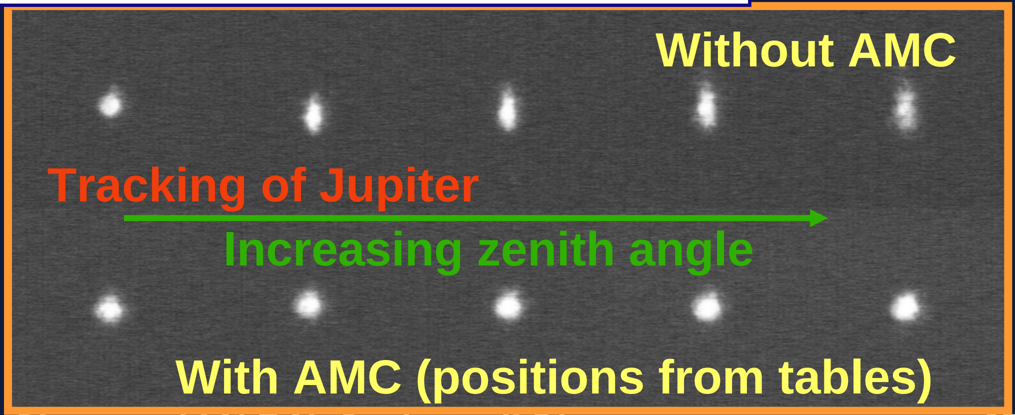
Active Mirror Control

A) Optimize focus on lamp (920 m)

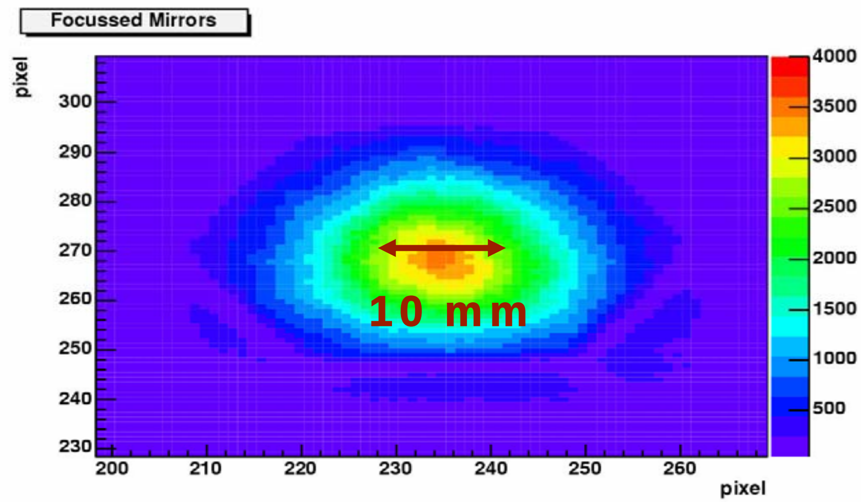
B) Memorize panel & laser positions ➔ PSF

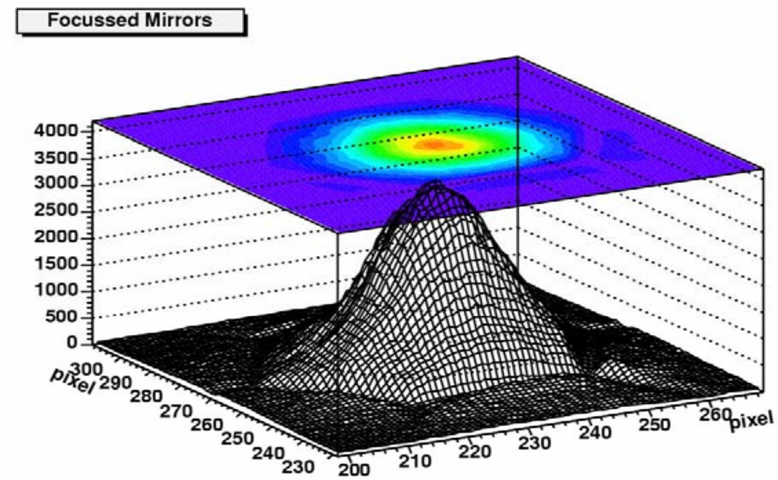


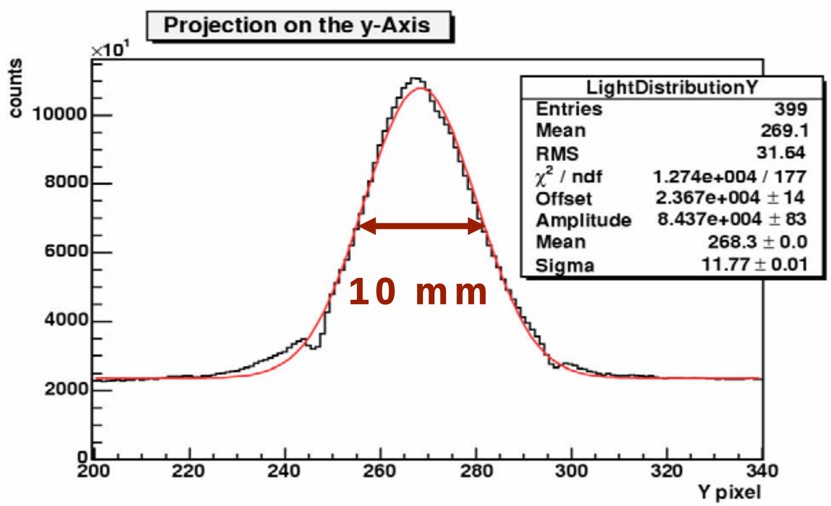




Point Spread Function







- Lightspot recorded with CCD camera
- 80% within 10 mm=1/3 pixel
- Limited by CCD camera

Camera Calibration

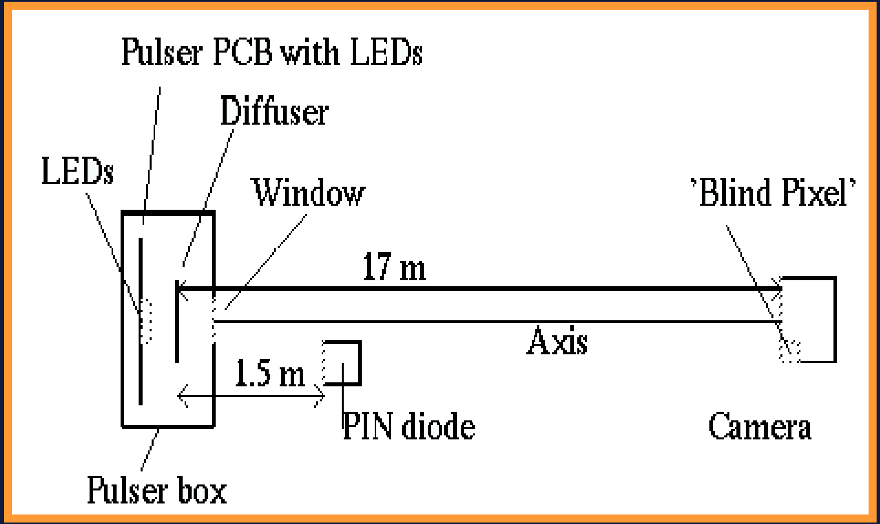
Strong LED pulser with avalanche transistors and 3 different colors

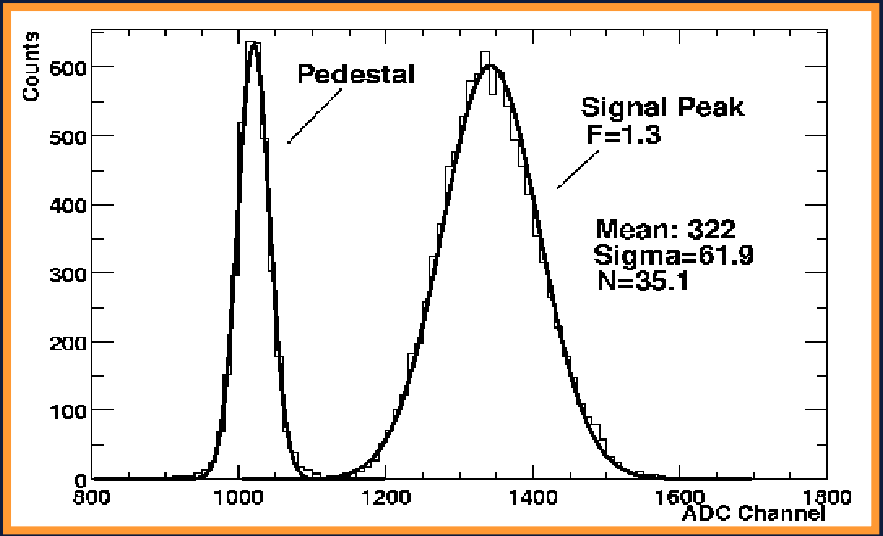
Light pulse amplitudes up to 2000 PhE/pixel ~ 3-4 ns

Pulser flux measurement by

- PMT
- PIN diode
- Excess noise method

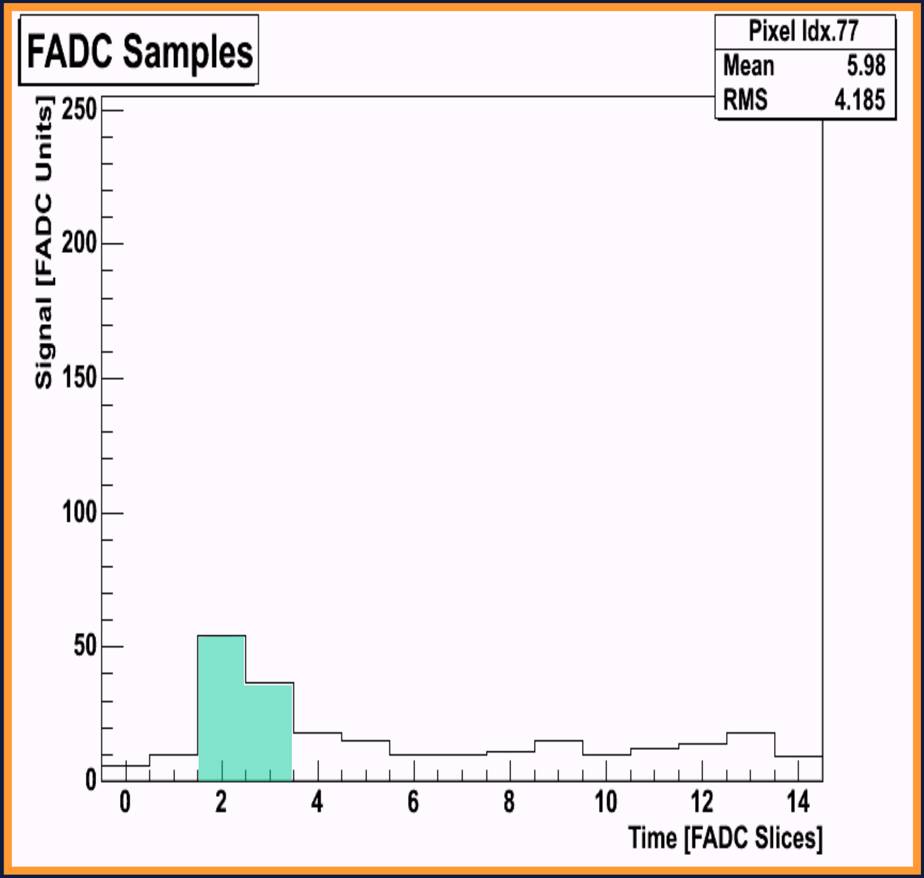
Calibration by muon rings

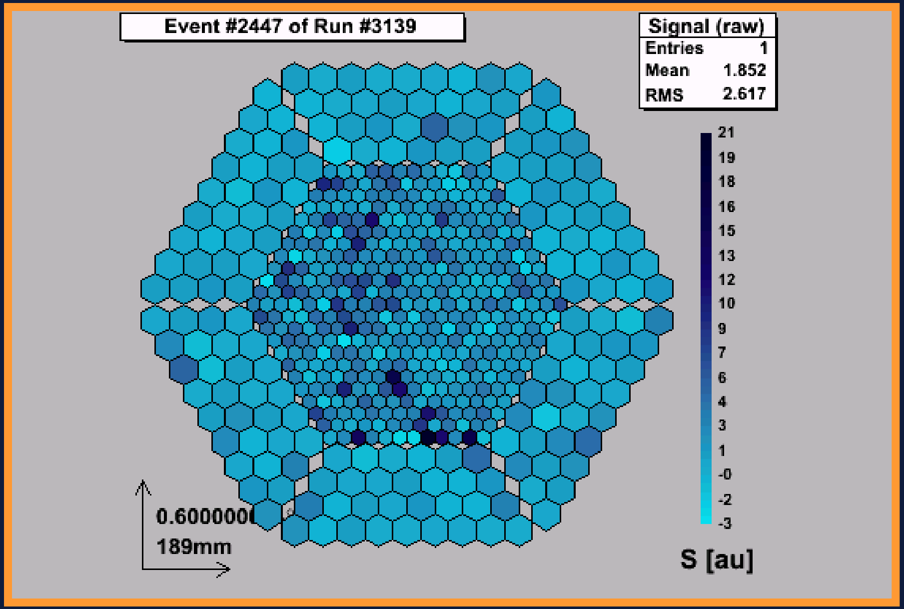


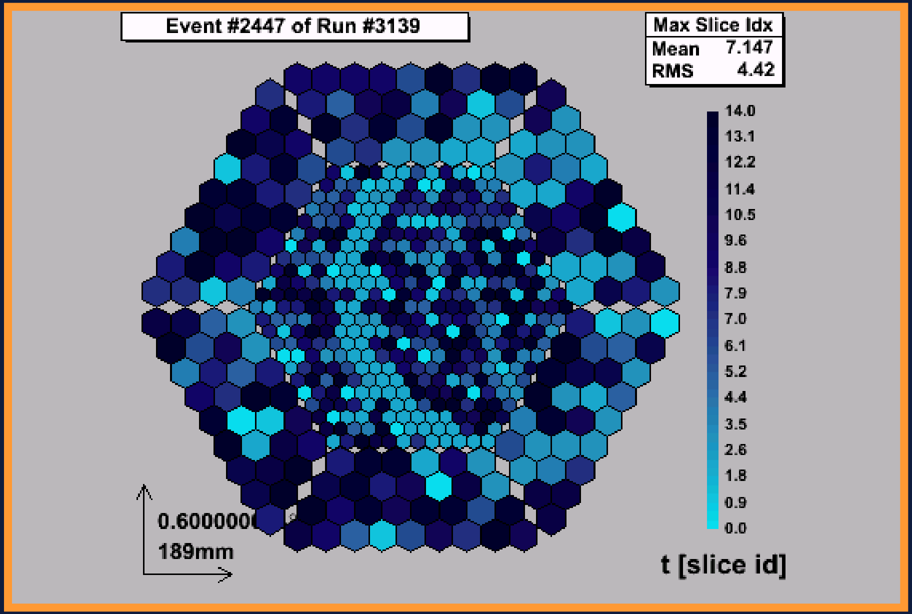


Muon rings

Add time information to tag muons in events
Help in gamma/hadron separation







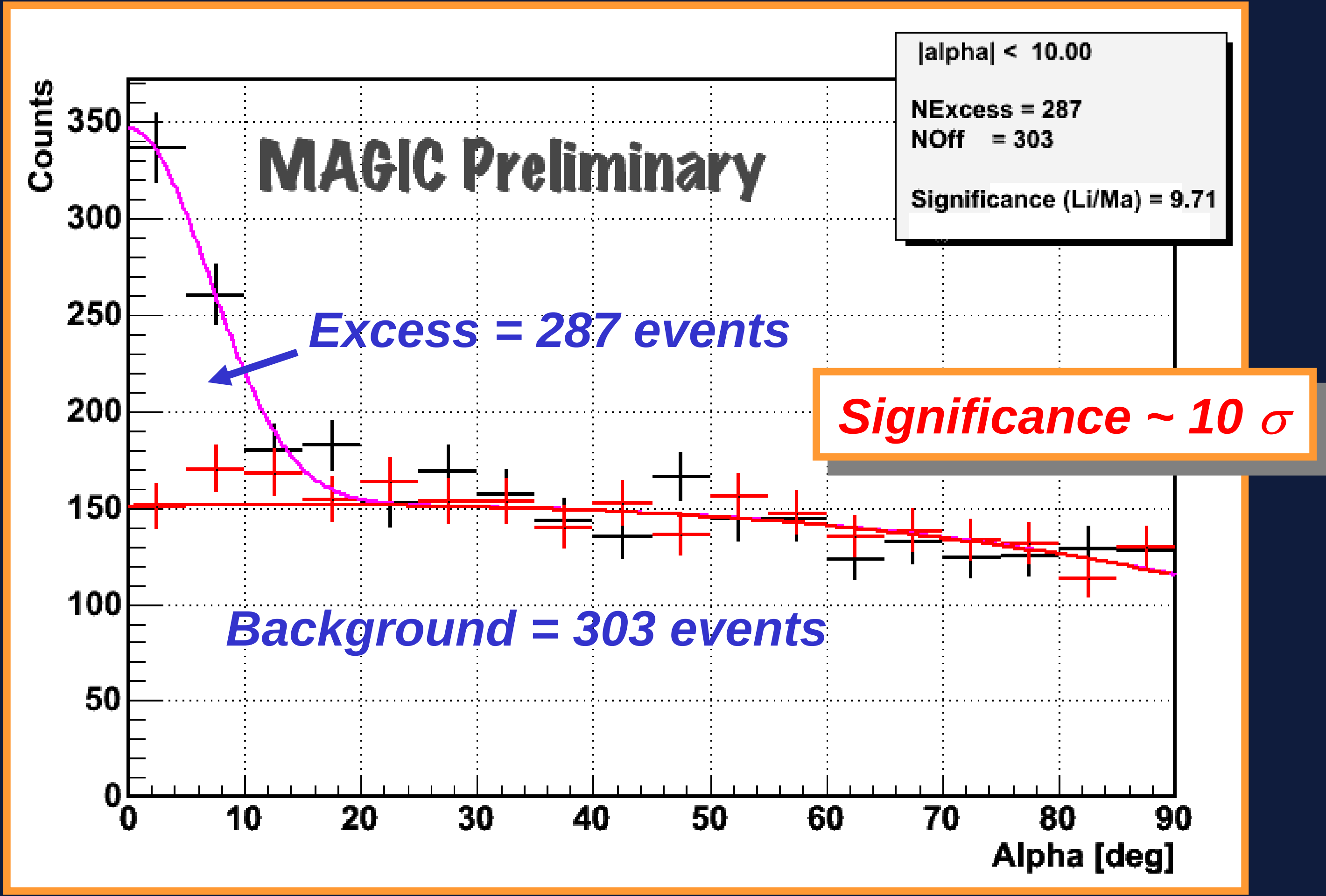
Preliminary results: Crab

Crab nebula (pulsar wind)

Steady Gamma emission (standard candle): useful for calibration

Very first look: **~50 minutes** observation time ➔ **detection !**

~ **8.0 events/minute** after simple cuts

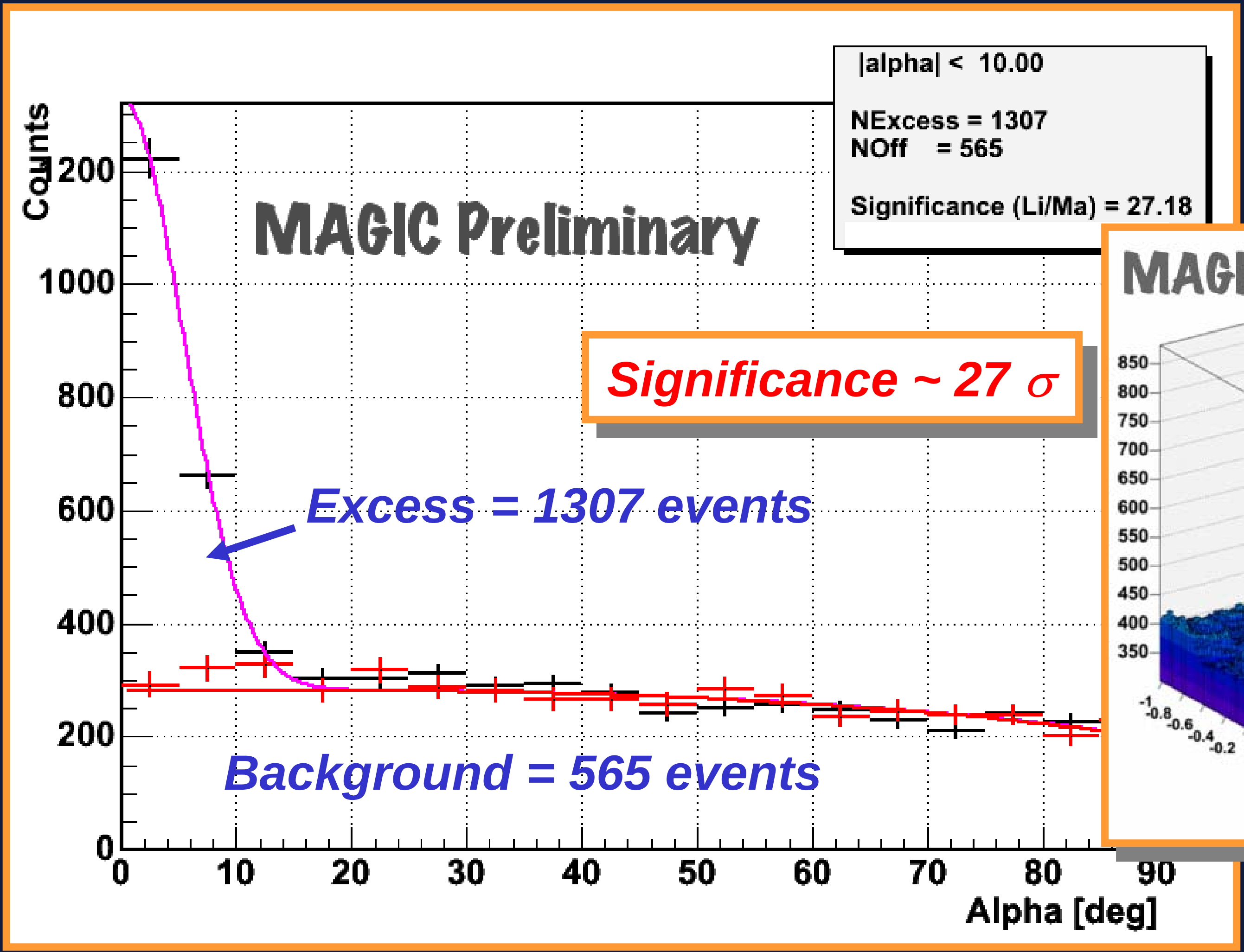


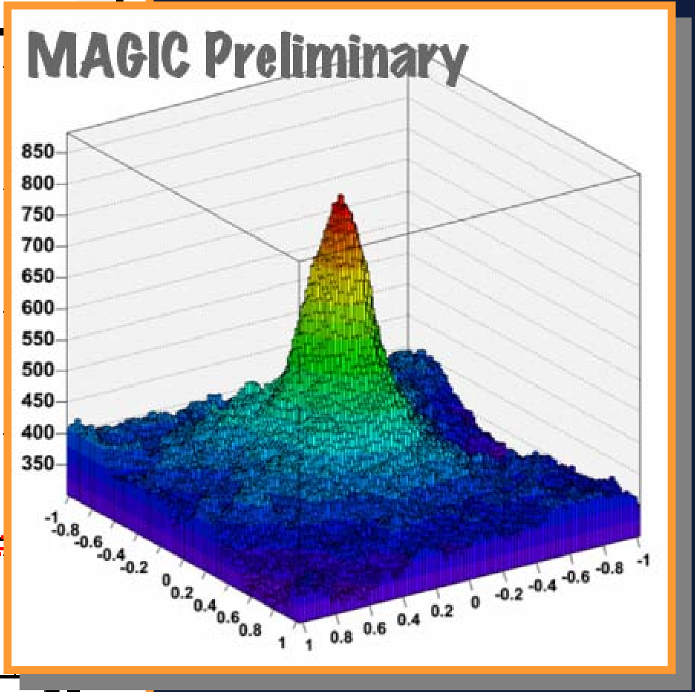
Preliminary results: Mrk 421

Mrk 421 (BL Lac, z=0.031) was **flaring in February**

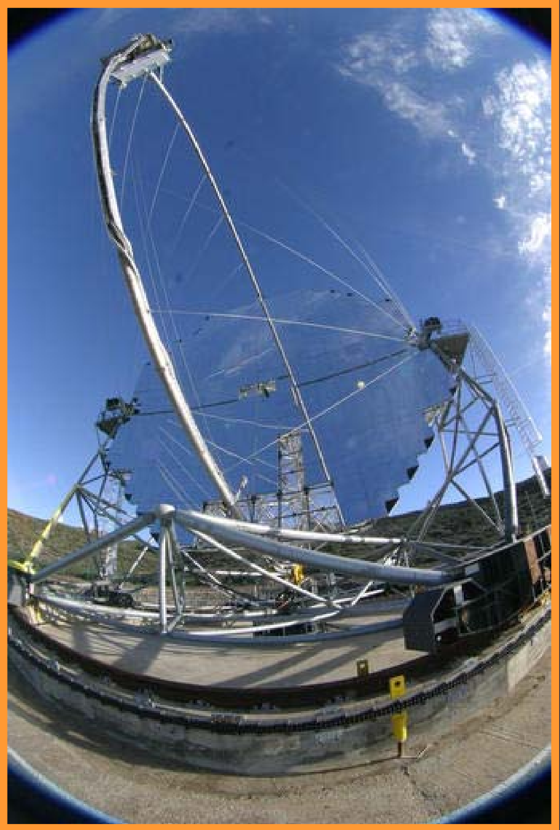
Observation time **~100 minutes**

27 sigma significance after simple cuts





Future Prospects and Developments



Build a second telescope
⇒ Same mechanical structure
⇒ Test bench for technical developments

Design Study for a 34m telescope astro-ph/0403180

REFERENCES

- High energy astrophysics (Longair)

Cosmic Ray and Particle Physics (Gaisser)

Very high energy gamma ray astronomy (Weekes)

http://www.pi.infn.it/magic

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