The MAGIC Telescope(s)

– Nicola Turini –

Univ. of Siena & INFN PISA

- The MAGIC Telescope
- Galactic sources
- Extragalactic sources
- MAGIC II

TeV 2007 Venezia 30 Aug 2007

MAGIC: The Collaboration

IFAE, UAB, IEEC, U Barcelona, Inst Astrof Andalucía, Inst Astrof Canarias, UC Madrid, MPI München, U Würzburg, HU Berlin, U Dortmund, Desy, INFN/U Pd, INFN/U Si, INFN/U Ud, INAF, UC Davis, ETH Zürich, U Lodz, Tuorla Obs, Yerevan Ph Inst, INR Sofia

Many World Records:

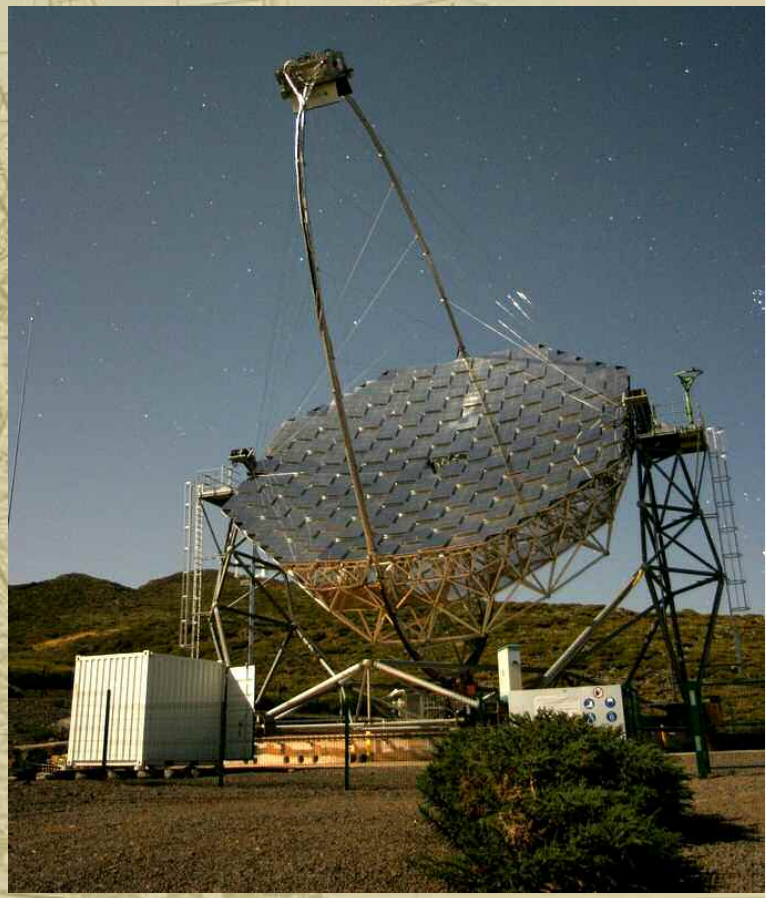
- 1st working system of analogue transmission via optical fibres
- 1st light weight carbon fiber frame
- 1st sub-μs topological trigger

among Cherenkov detectors:

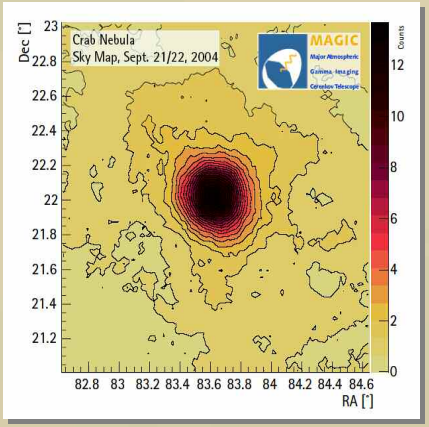
- widest refl. surface (236 m^2, 17 m ∅)
- lowest energy threshold
- fastest slewing system (40 s for 360° azimuth turn)

Main features:

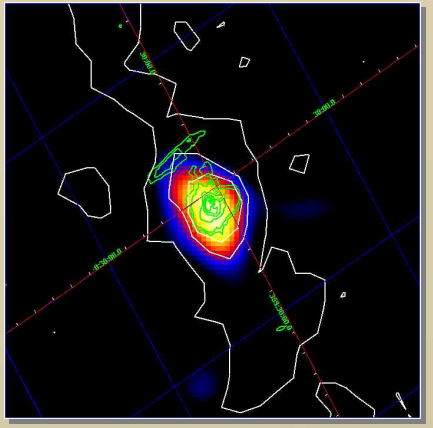
- 3.5° FoV Camera, 576 enhanced QE PMTs
- Trigger threshold: 50 GeV (can be lowered at 30 GeV with L2 trigger)
- Sensitivity: 2.5% Crab @50 hrs
- Energy res: 20÷30%
- Ang. res (γ PSF): 0.1°



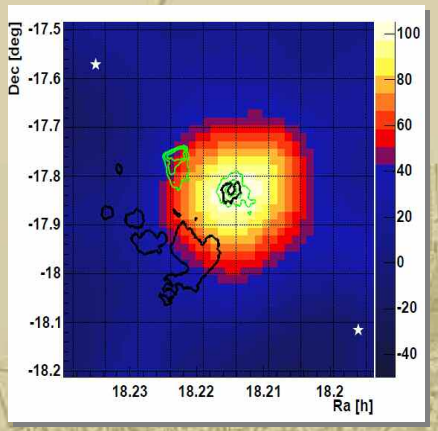
MAGIC: Galactic Sources



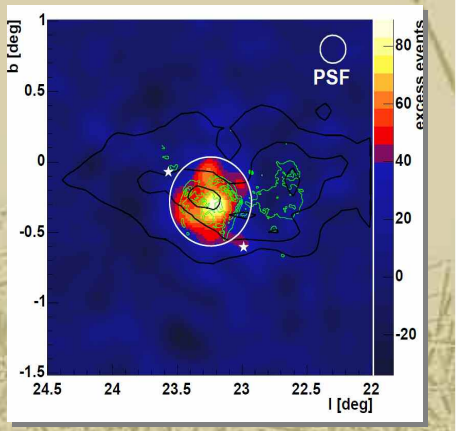
The Crab Nebula



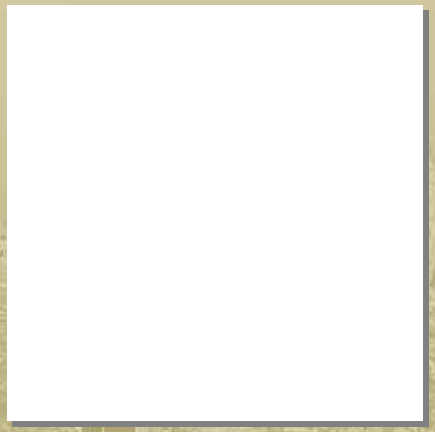
The Galactic Centre



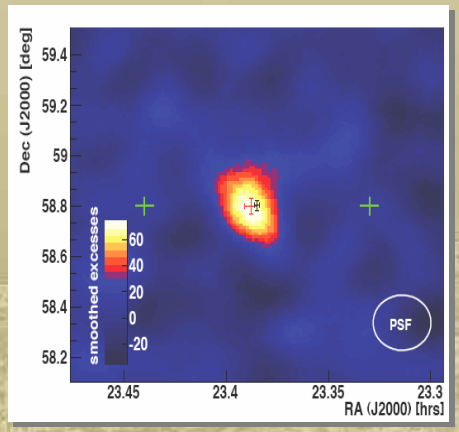
HESS J1813



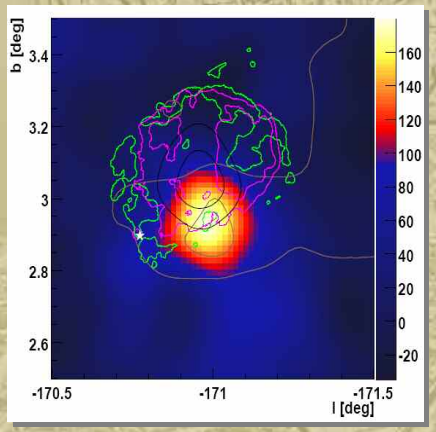
HESS J1834



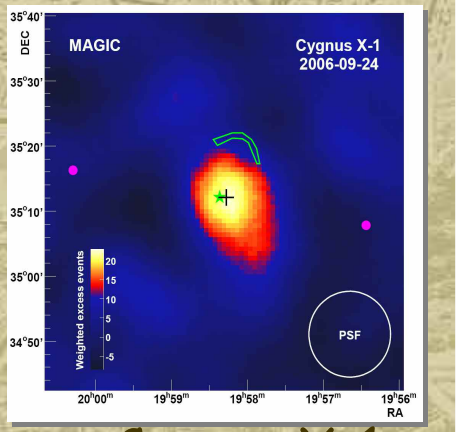
LS I+61



Cas A

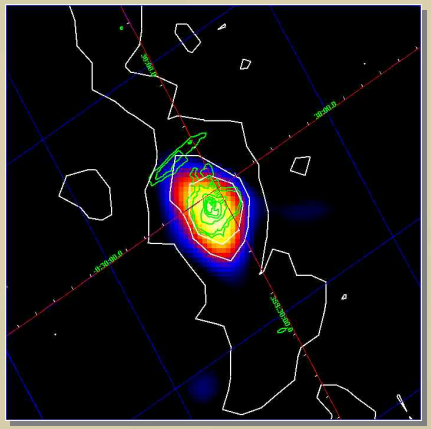


MAGIC J0616+225
→ IC 443



Cygnus X-1

Galactic Sources: overview



The Galactic Centre

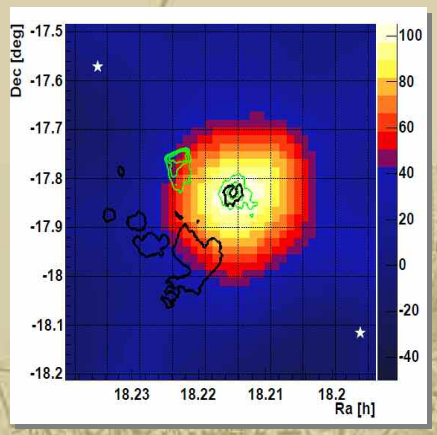
ApJ 638 L101 2006

→ E_{th} ~600 GeV

Spct. idx: 2.2 ± 0.2

compatible w/HESS

No variability



HESS J1813-178

ApJ 637 L41 2006

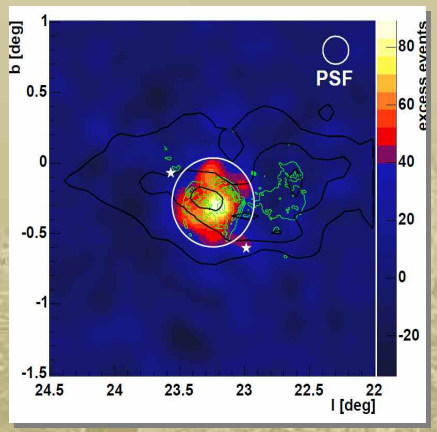
→ E_{th} ~400 GeV

Spct. idx: 2.15 ± 0.3

compatible w/HESS

more data needed

Lept/had discrim.



HESS J1834-087

ApJ 643 L53 2007

→ E_{th} ~150 GeV

Spct. idx: 2.5 ± 0.2

compatible w/HESS

LS I+61

Sci 312 1771 2006

→ E_{th} ~200 GeV

Spct. idx: 2.6 ± 0.2

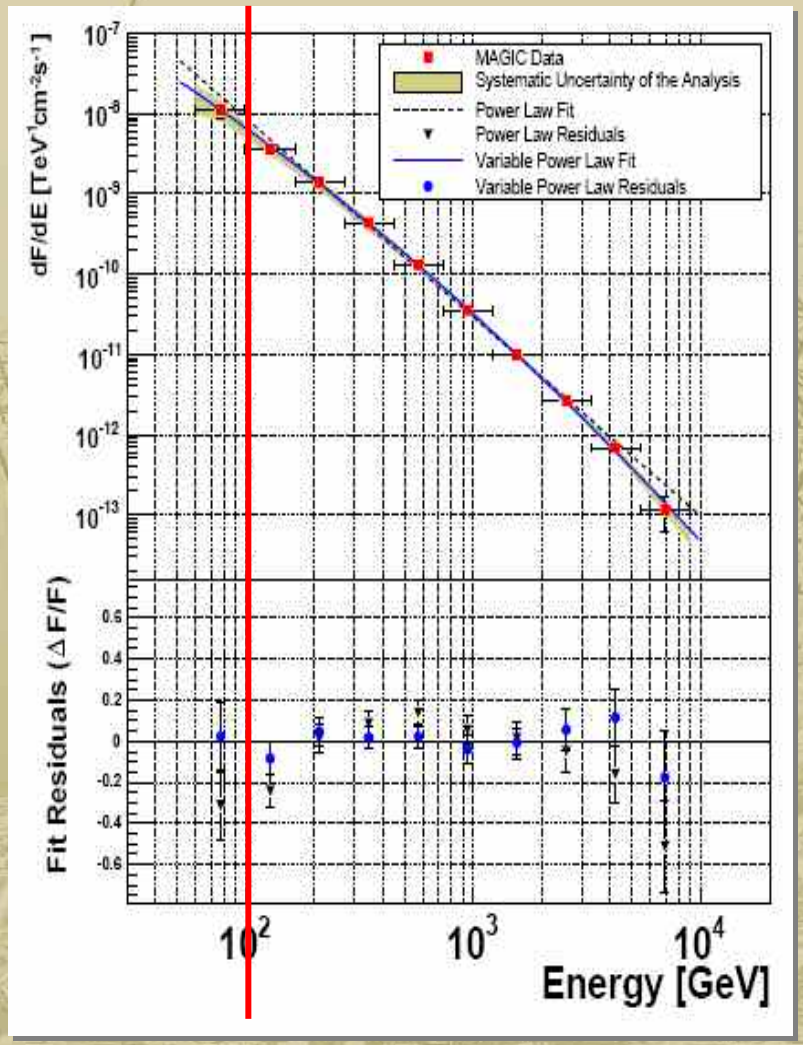
Variable!

Miniature AGN

The Crab Nebula: toward the Compton Peak

Submitted to ApJ

- Zenith angle < 20° @LE
- Spectrum measured between 60 GeV and 9 TeV
- Spectral idx ≈ 2.31
- Spectrum shows a clear peak at 77 ± 47 GeV
- Spectrum steady
- Source pointlike
  1st measure below 100 GeV with Cherenkov!

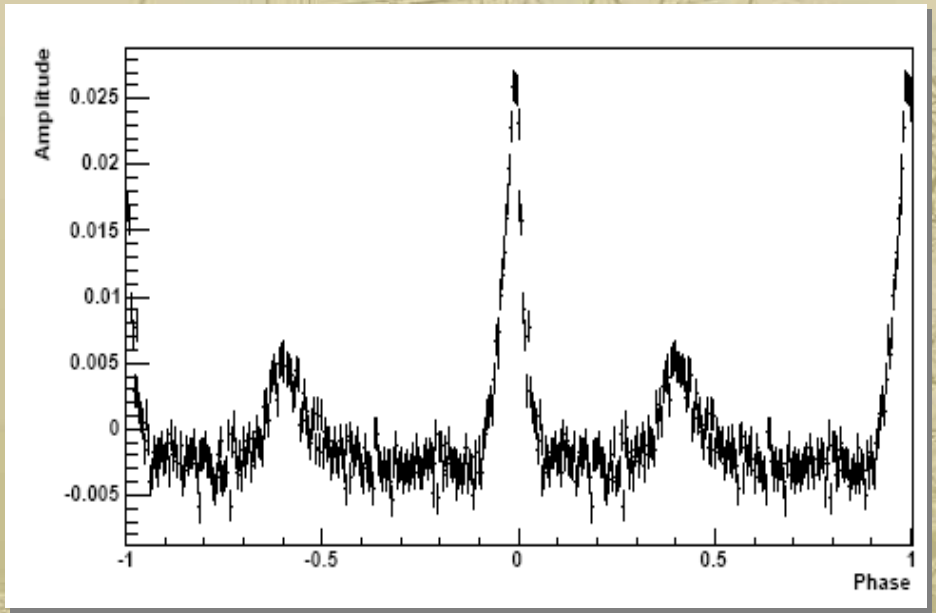


The Crab Pulsar

- Steady emission coincident with pulsar
- Optical phaseogram read on-site"
- No evidence of pulsation
- Constraints set

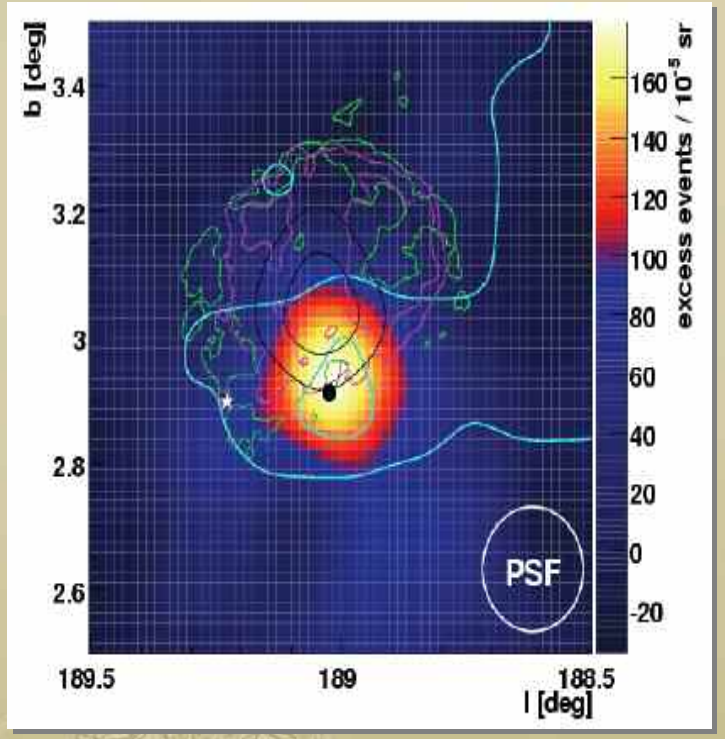
⇨ exponential cutoff
< 27 GeV

⇨ supra-exp cutoff
< 60 GeV



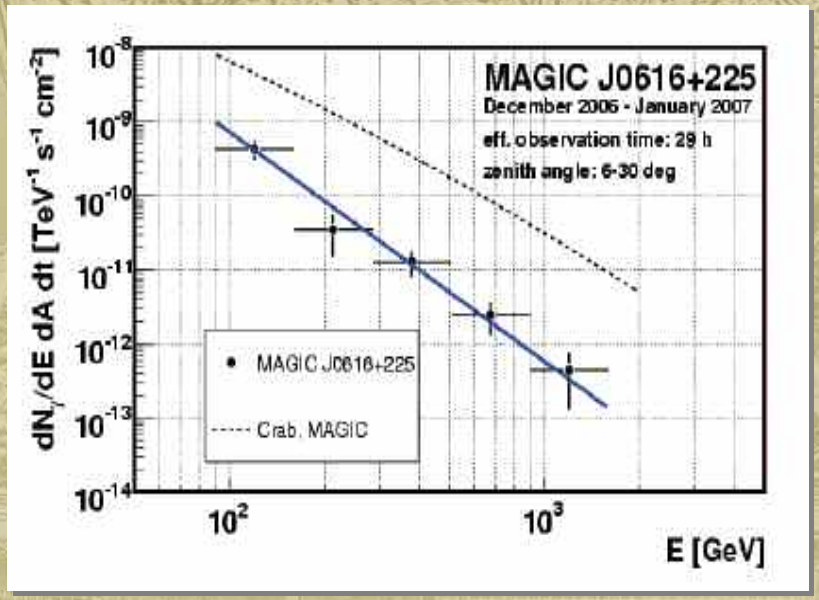
Optical phaseogram @MAGIC

MAGIC J0616+225 (in IC443)



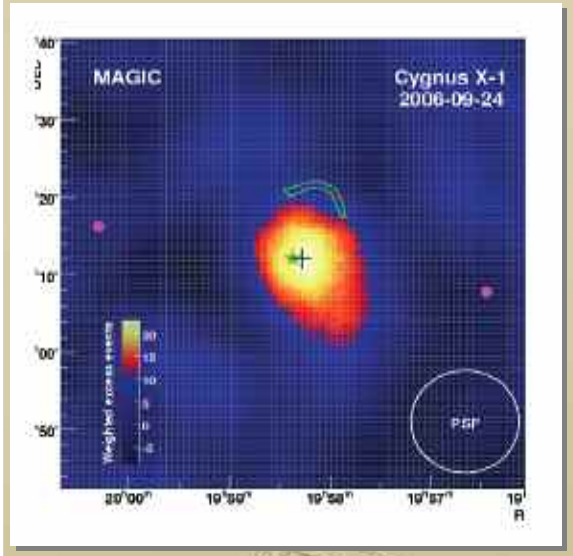
- 6.5% CU @100GeV, 3% CU @300GeV
- spct. idx 3.1 ± 0.3
- no flux variations
- pointlike emission
- correlated w/ mol. clouds (10^4 $M_\odot$)
- well corr. w/1720 MHz maser (shock?)
- alternative: PWN displaced emission?

^{12}CO emission (cyan), 20 cm VLA (green)
ROSAT (purple), EGRET (black),
CXOU J061705.5+222127 (white star),
1720 MHz OH maser (black dot)



Cygnus X1: THE Black Hole

1st evidence of BH in VHE



Submitted to ApJ

42.6 hrsa in 26 night

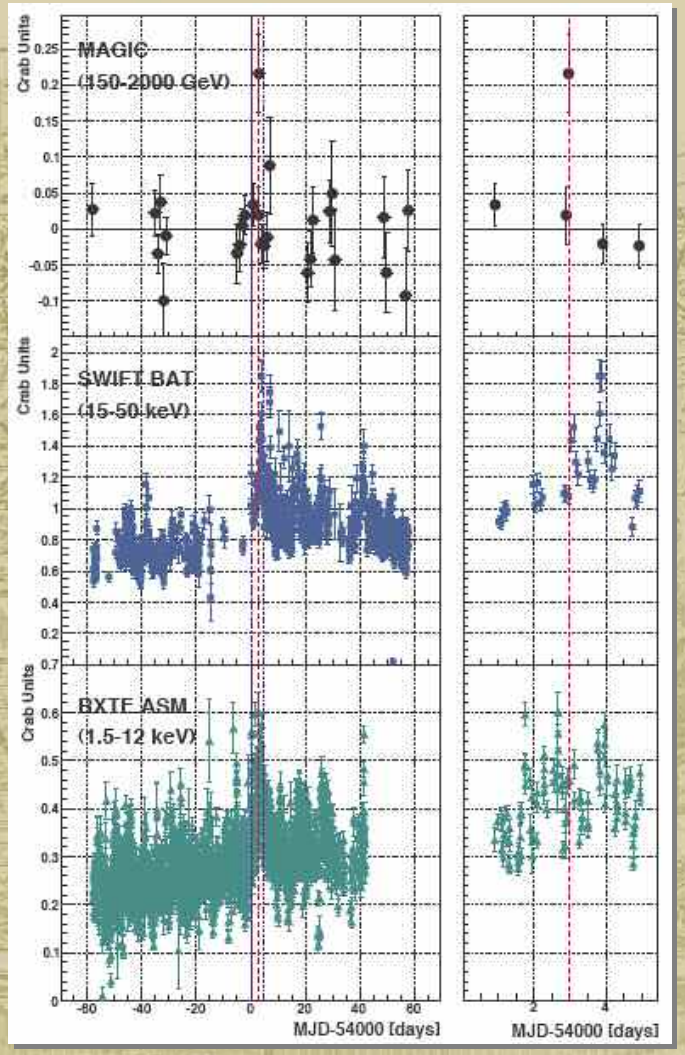
UL @ 1÷5% CU

26/09/2006: 4.0σ

27/09/2006: 4.9σ

Coincident with CygX1

Coinc. w/ hard X flare



Cygnus X1, BH X-ray binary:

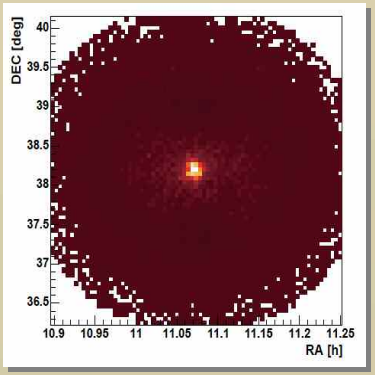
BH 21 $M_{\odot}$ + O9.7 40 M⊙

- 5.6 days period
- X ray flaring activity well known
- arclike from jet-ISM interaction

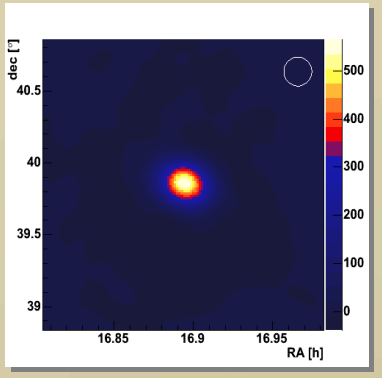
Extragalactic Sources in VHE energies

Source	Redshift	Sp.	Types	Discovery	Observation
M 87	0.004	2.9	FR-I	HEGRA	HESS
Mkn 421	0.031	2.2	HBL	Whipple	many
Mkn 501	0.034	2.4	HBL	Whipple	many
1ES 2344+514	0.044	2.9	HBL	Whipple	MAGIC
Mkn 180	0.045	3.3	HBL	MAGIC	
1ES 1959+650	0.047	2.4	HBL	7TA	many
PKS 0548-322	0.069		HBL	HESS	
BL Lac	0.069	3.6	LBL	MAGIC	
PKS 2005-489	0.071	4.0	HBL	HESS	
PKS 2155-304	0.116	3.3	HBL	Durham	many
1ES 1426+428	0.129	3.3	HBL	Whipple	HEGRA
1ES 0229+200	0.139		HBL	HESS	
H 2356-309	0.165	3.1	HBL	HESS	
1ES 1218+304	0.182	3.0	HBL	MAGIC	VERITAS
1ES 1101-232	0.186	2.9	HBL	HESS	
1ES 0347-121	0.188		HBL	HESS	
1ES 1011+496	0.212	4.0	HBL	MAGIC	
3C 279	0.538		FSRQ	MAGIC	
PG 1553	?	4.0	HBL	HESS/MAGIC	

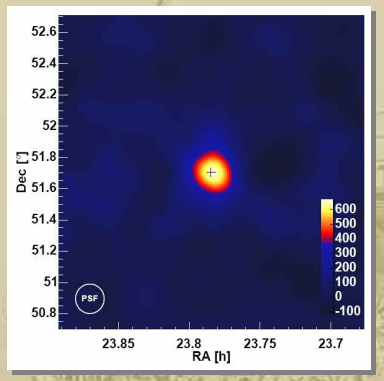
MAGIC: Extragalactic Sources



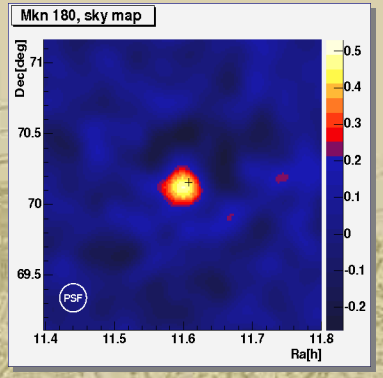
Mrk 421 (0.031)



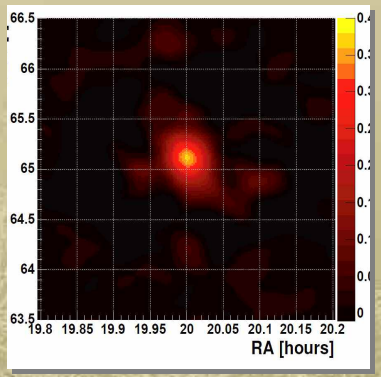
Mrk 501 (0.034)



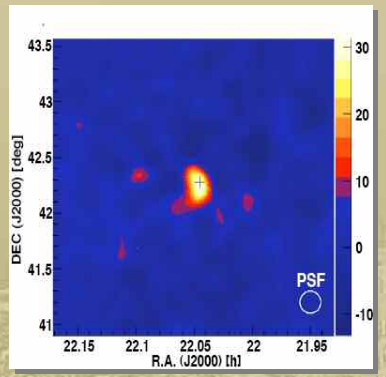
1es2344 (0.044)



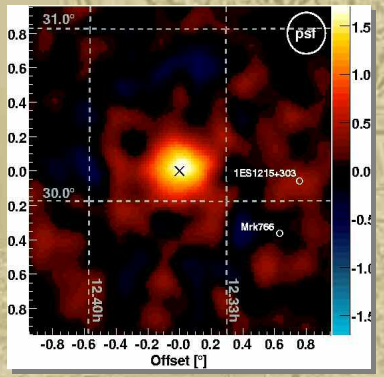
Mrk 180 (0.045)



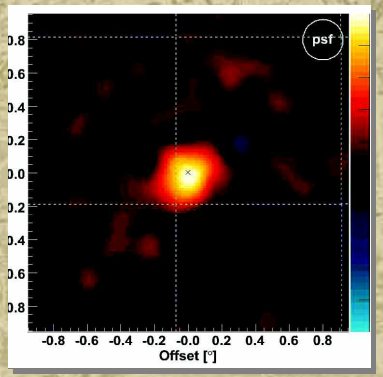
1es1959 (0.047)



BL Lac (0.069)

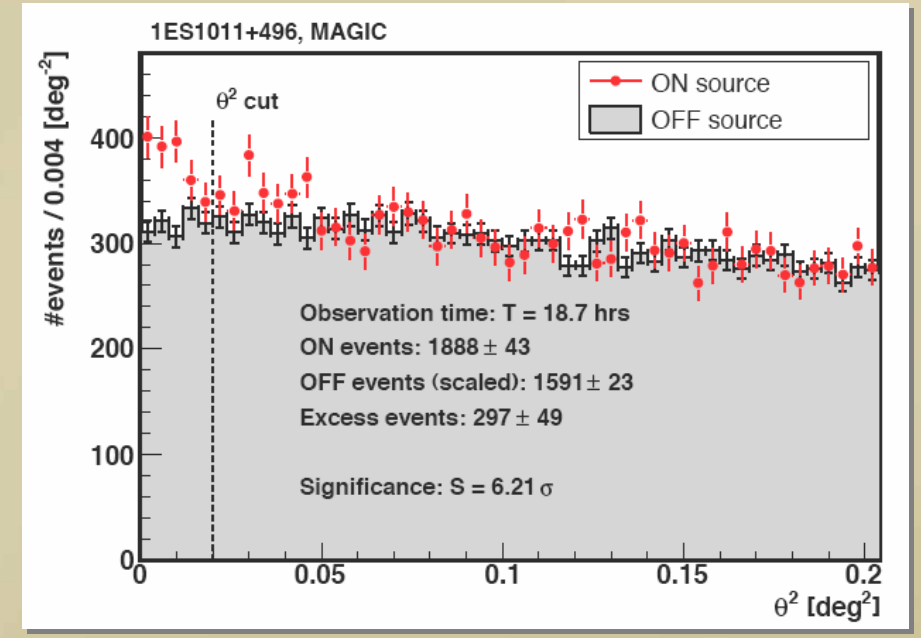


1es1218 (0.18)

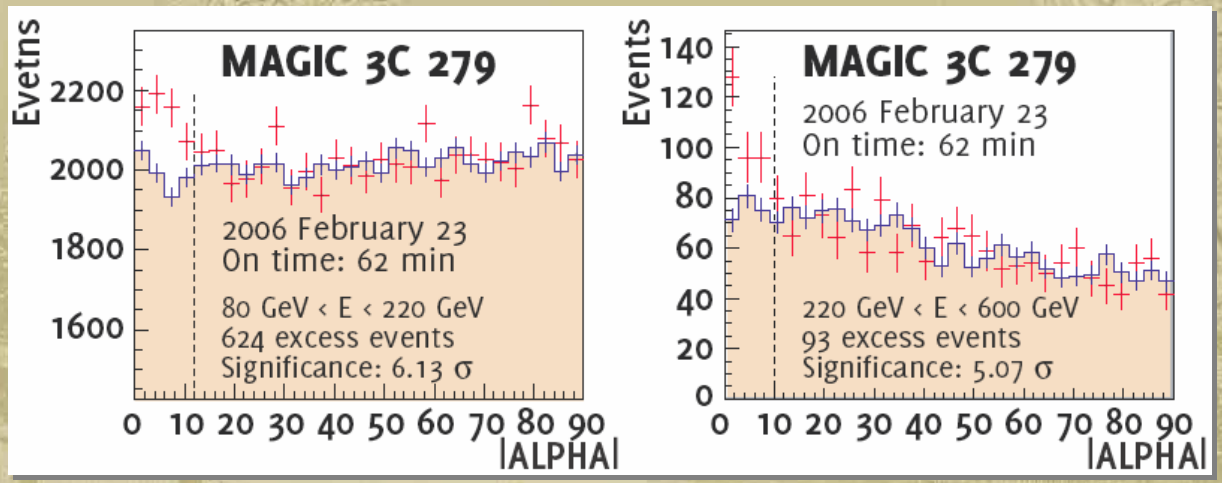


PG1553 (>0.25)

New large Z sources

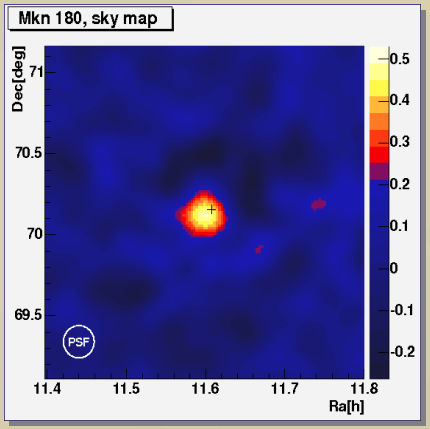


BLLac Object 1ES1011+496 (0.212)
Triggered by an optical outburst
Subm APJ 29 jun 2007



Quasar 3C 279 (0.536)
Flare seen
Feb 23rd 2006

Extragalactic Sources: overview



ApJ 648 L105 2006

→ E_{th} ~200 GeV

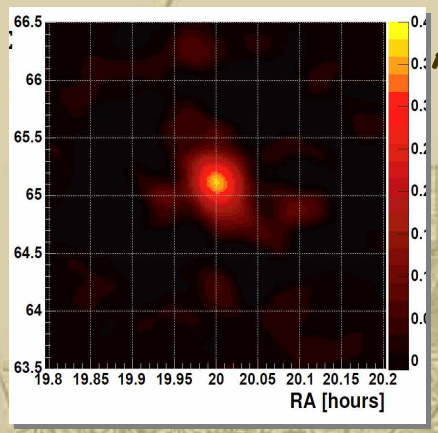
Spct. idx: 3.3 ± 0.7

MAGIC discovery!

Trig. by Opt+X-ray

11% Crab

Mrk 180 (0.045)



ApJ 642 L119 2006

→ E_{th} ~180 GeV

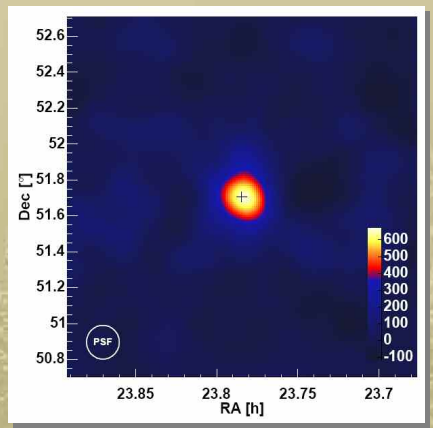
Spct. idx: 2.9 ± 0.2

Orphan flare

1st obs quiescent!

11% Crab

1es1959+650 (0.047)



ApJ 662 892 2007

→ E_{th} ~350 GeV

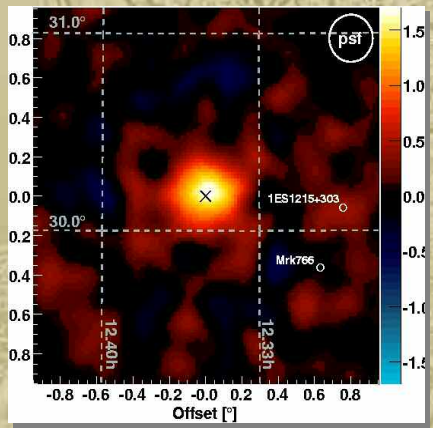
Spct. idx: 2.95 ± 0.2

W+H evidence

W: in flare @0.6CU

5% Crab!

1es2344+514 (0.044)



ApJ 639 761 2006

→ E_{th} ~120 GeV

Spct. idx: 3.0 ± 0.4

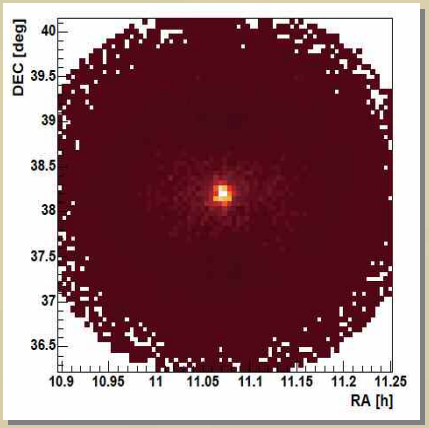
MAGIC: 13% CU

W: $\Phi_{>350GeV} < 8\%$CU

H: $\Phi_{>750GeV} < 12\%$CU

1es1218+304 (0.18)

Extragalactic Sources: overview



Mrk 421 (0.031)

ApJ 663? 2007

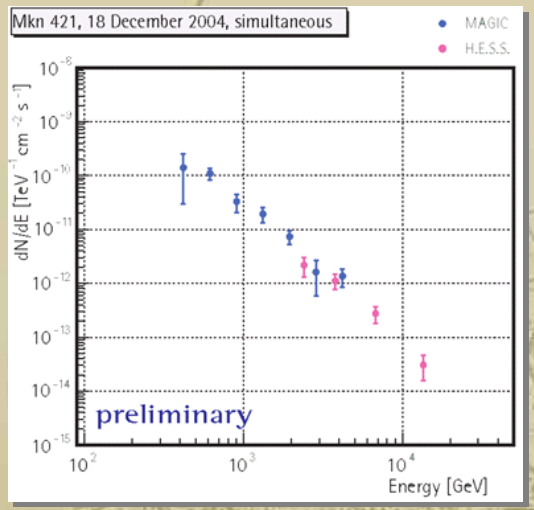
→ E_{th} ~150 GeV

Spct. idx: 2.2 ± 0.2

<evts> ≈5 min^{-1}

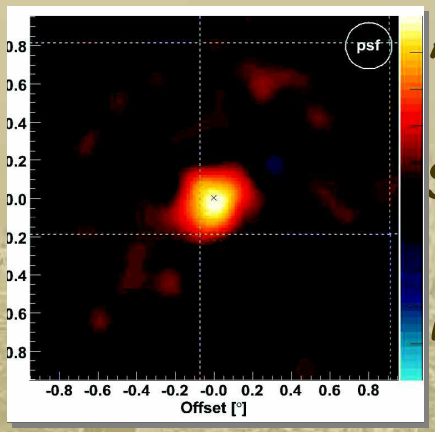
good VHE/X corr.

0.5 ÷ 2 Crab



Simultaneous observation with HESS

- Cross-calib
- Wider energy coverage



PG1553+113 (z>0.25)

ApJ 654 L119 2007

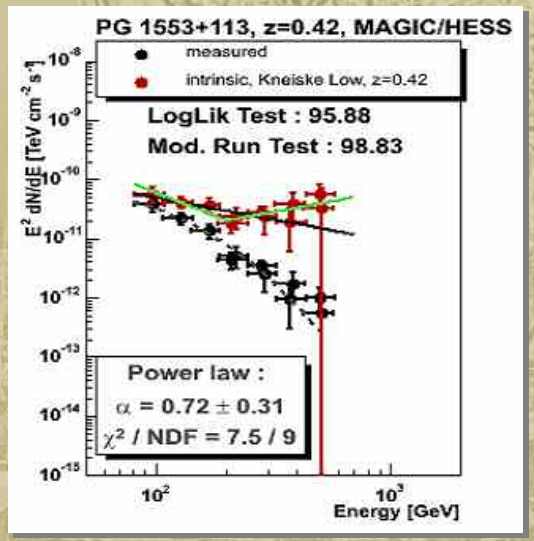
→ E_{th} ~150 GeV

Spct. idx: 4.21±0.25

Evidence by HESS

MAGIC detection

2% Crab



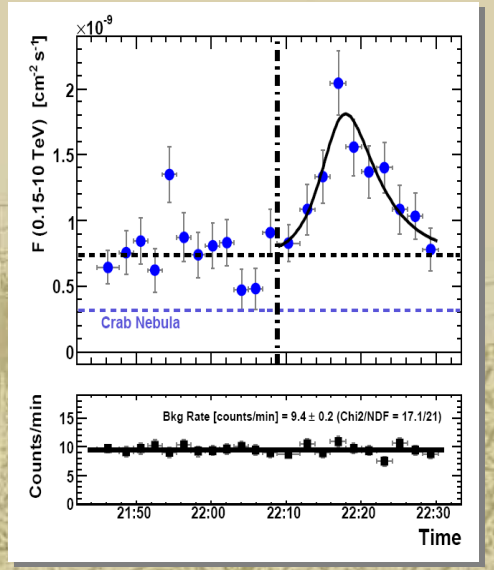
z limit by IACTs

- Conserv. EBL
- dN/dE~ $E^{-\gamma}$, γ>1.5

New preliminary UL: z<0.42

Markarian 501: Fast variability (subm. Apj)

- 24 nights: Φ < 0.5 CU and Φ > 1 CU
- for 2 nights: Φ > 3 CU $T_{2\times} \approx$ **2 min**
- harder spectra @ harder fluxes
- Variability increased with energy

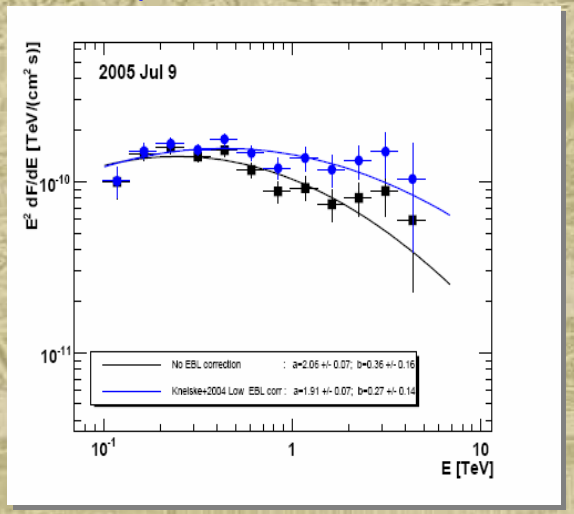


Curved spectrum:

$$\frac{dN}{dE} = \left(\frac{E}{300\ GeV}\right)^{-1.9-0.27\log_{10}(E/300GeV)}$$

$\Rightarrow$ SSC: δ=25÷50, B=0.1÷0.5 G

July 9th, 2005



Markarian 501: Time lag

- Evident 4±1 min Time Lag between $\Phi_{<250GeV}$ and $\Phi_{>1.2TeV}$
- May be explained by the particle acceleration process
- BUT, if photons at diff. E emitted simultaneously:

Lorentz invariance violation?

$\Delta T \sim 4$ min, $\Delta E \sim 1$ TeV

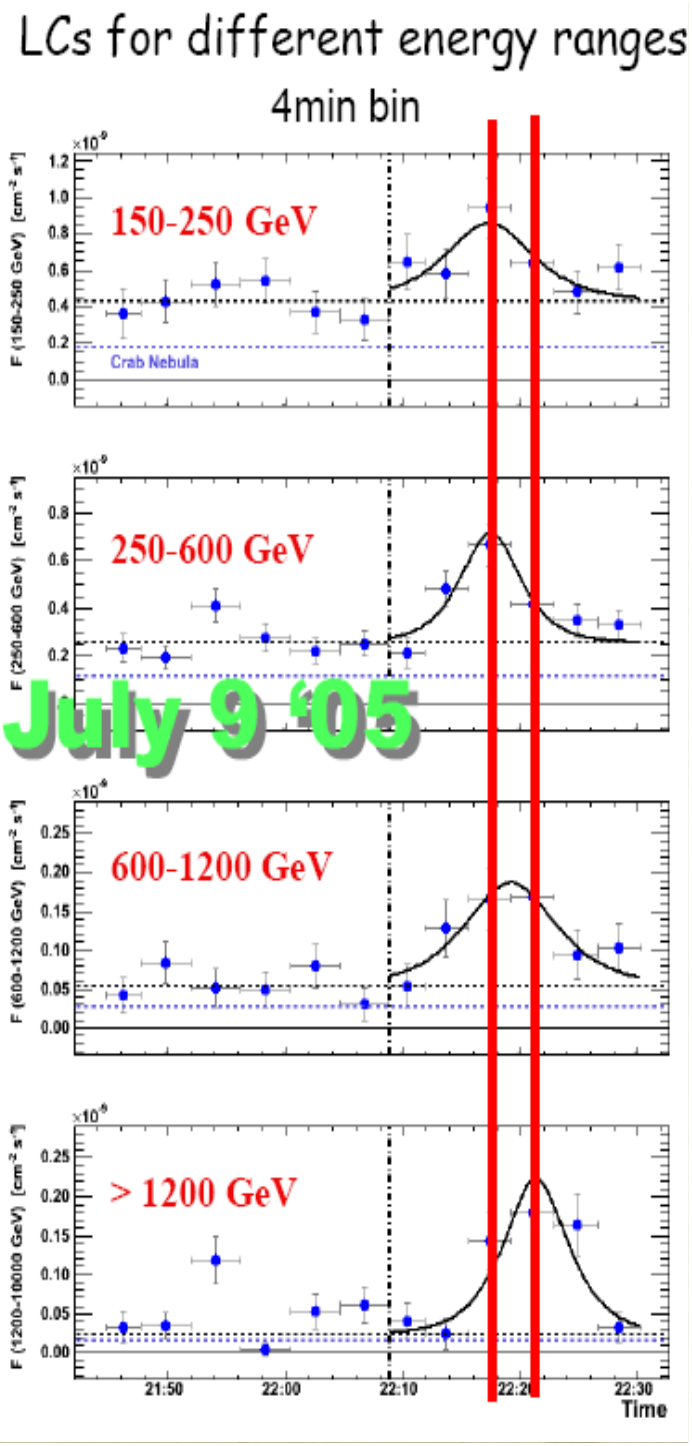
$\Rightarrow$ $M_{QG1} \sim 0.4 \times 10^{18}$ GeV or

$M_{QG2} \sim 0.6 \times 10^{11}$ GeV

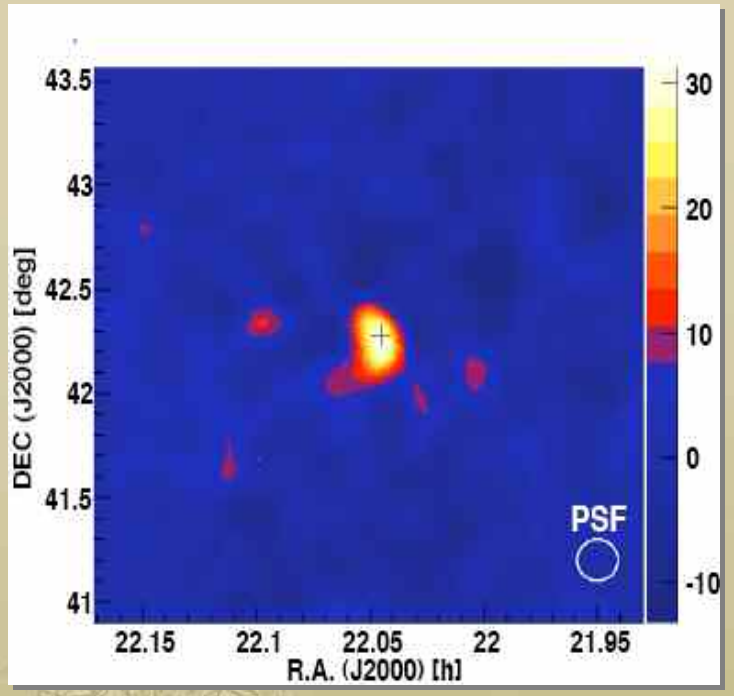
probe a vacuum refractive index

$\simeq 1 - (E/M_{QGn})^n$, n = 1, 2

Sub Apj 21 aug

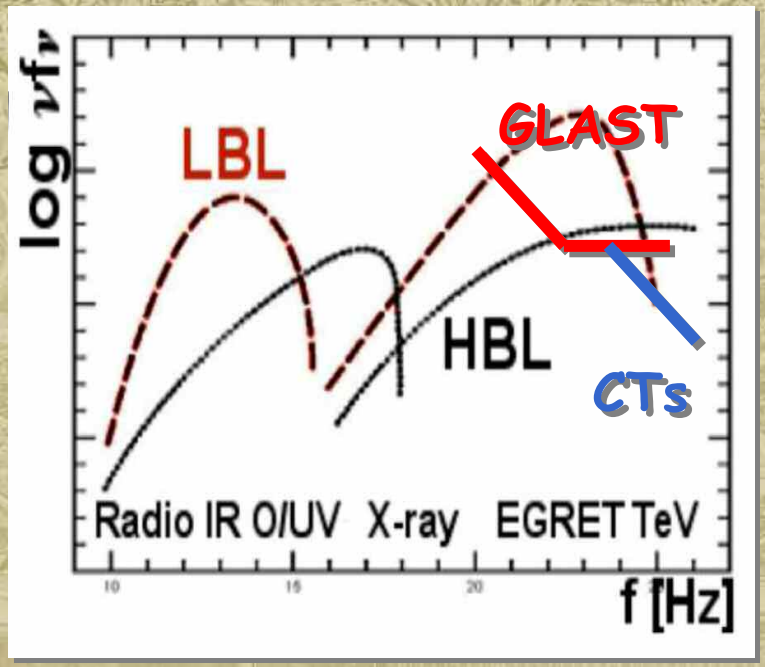


BL Lac: new source and new class (LBL)

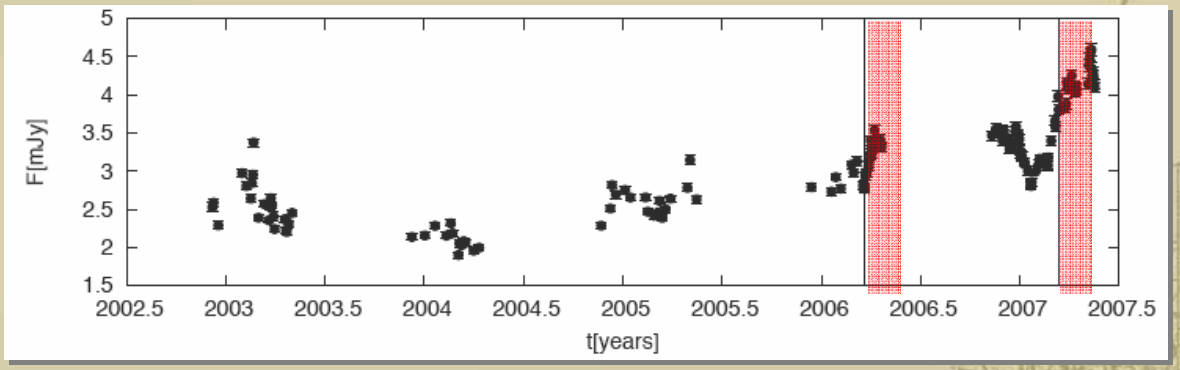


From Aug to Dec 2005 (22 hrs)
→ 3% Crab @200 GeV, idx: -3.6± 0.5
no flux variation
From Jul to Sept 2006 (26 hrs)
→ NO EXCESS!
Follows the trend in optical activity

LBL: low frequency BL Lac
For Cherenkov telescope:
low energy threshold
For GLAST: easier to detect

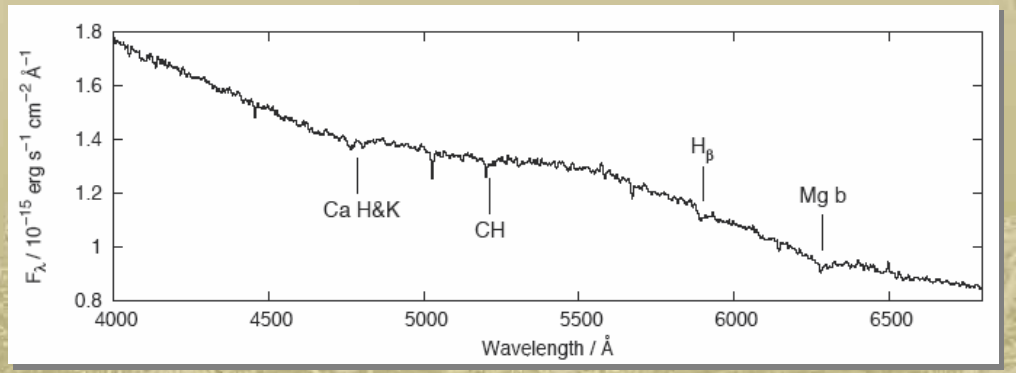


HBL 1ES 1011 +496 (0.212)

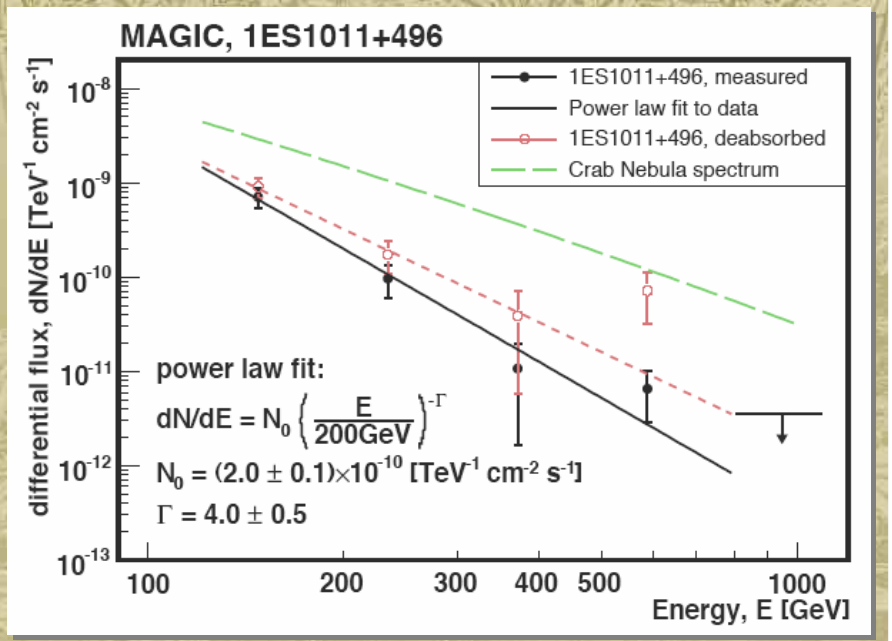


Optical light curve (KVA)

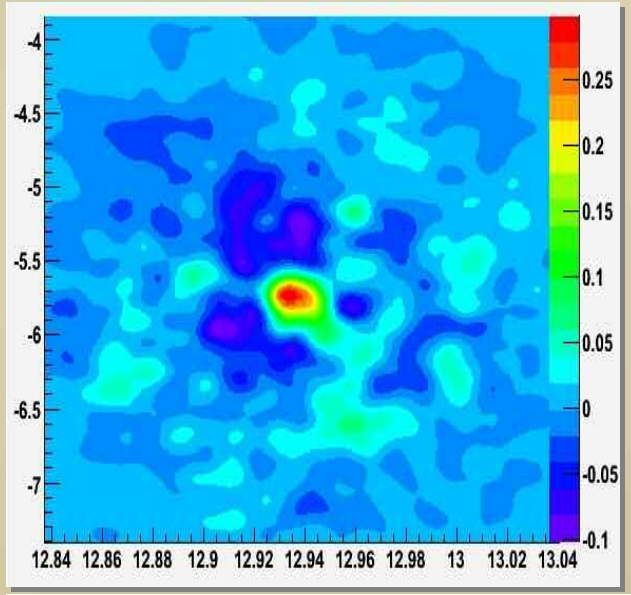
Magic observations triggered by optical light curves at KVA



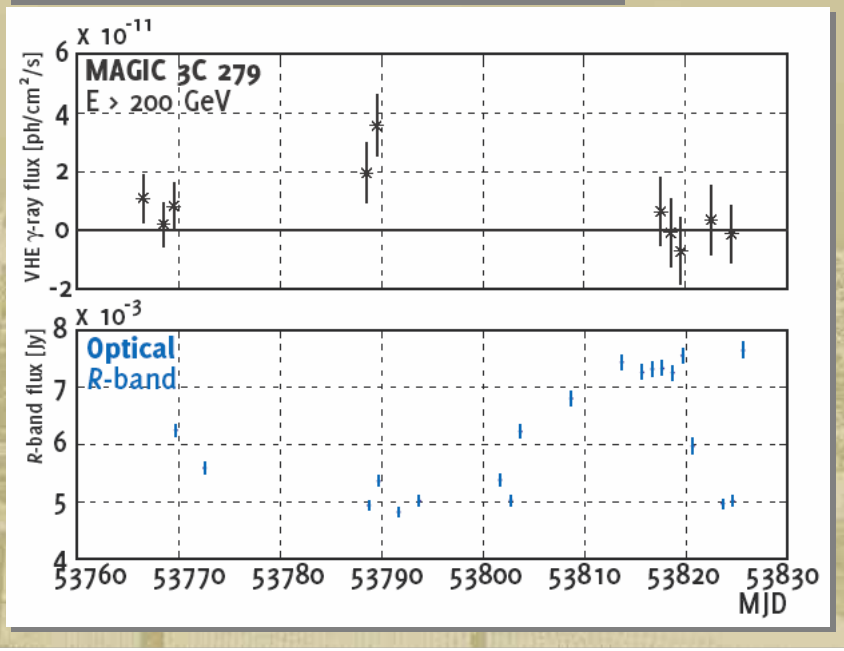
Host galaxy spectrum give Z=0.212

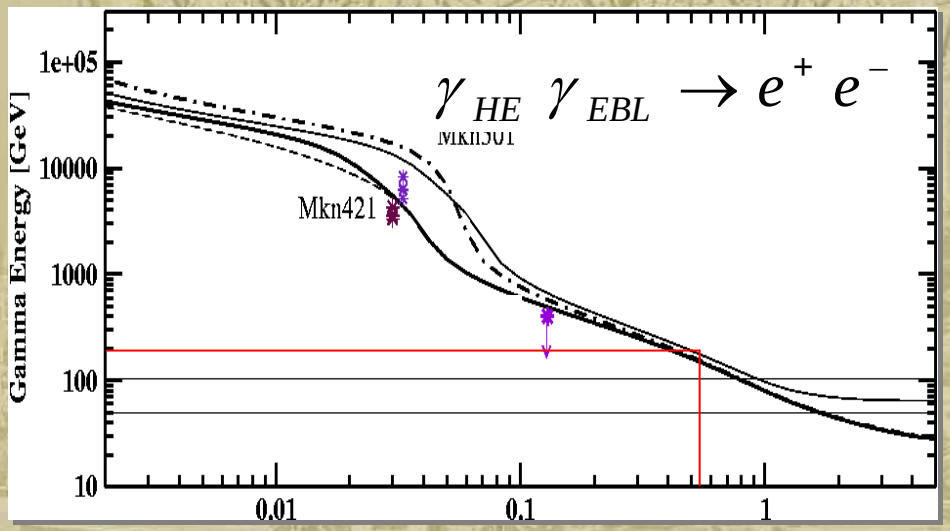


FS Radio Quasar 3C279 (0.536)



The source was detected in one night (Feb 23rd 2006) in high state with 6.1 σ signal at energies <200 Gev and 5.1 σ at higher energies.
It is the farthest object observed at these energies





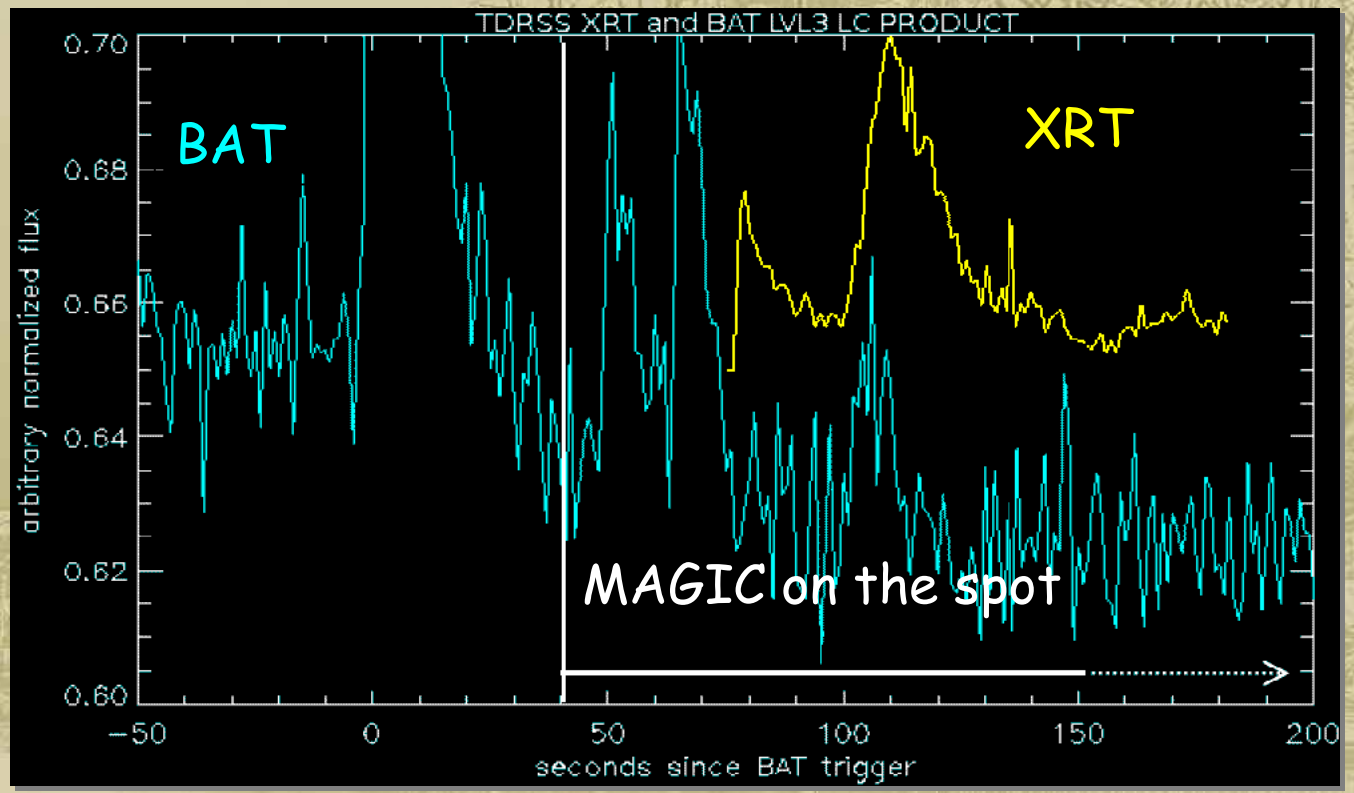
Kneiske, Mannheim, Hartmann: Astron. Astrophys. 386 (2002)

EBL Absorption

GRB Observations

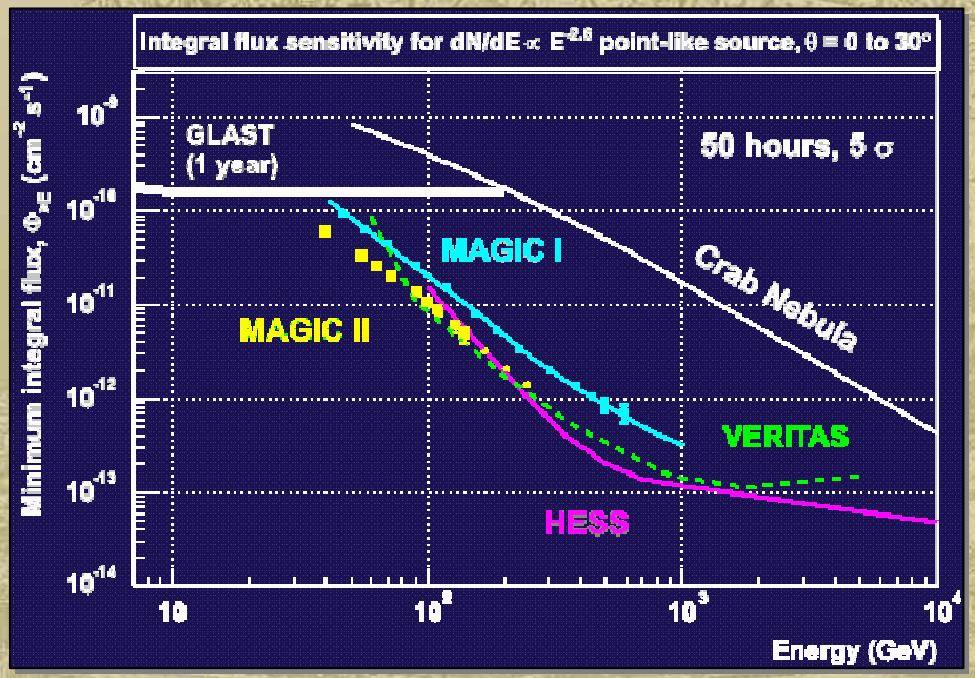
- 22 GRBs follow-up: 2 even while during the prompt emission
- UL ≈ 80 GeV
- Analysis results sent via GCN asap!
- Need a closer GRB

- GRB 050713a ApJ 641 L9 (2006)
- 1st DC: ApJ 667n2



The future: MAGIC II

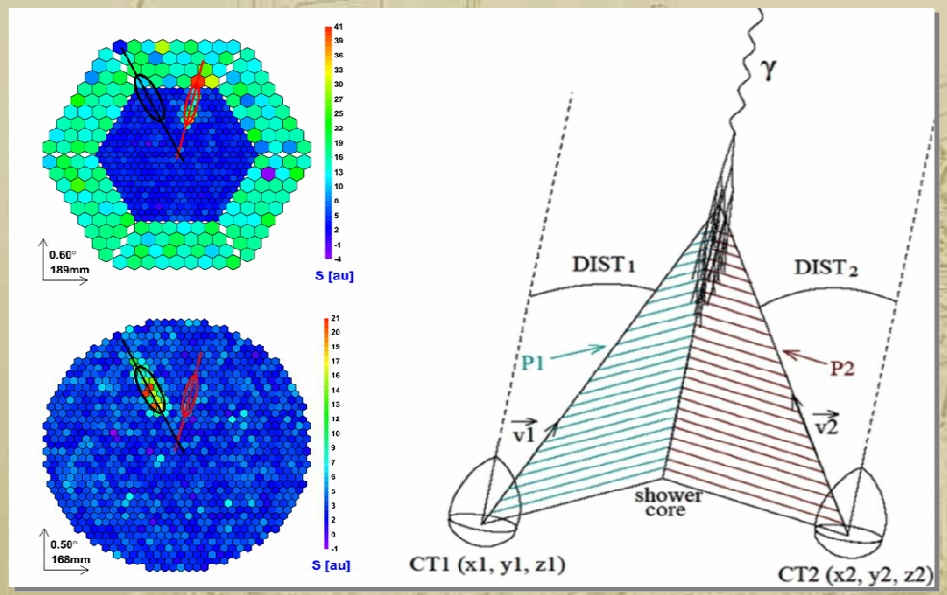
- Mirror redesign: 0.5×0.5 m^2 → 1×1 m^2
- Better sealing of mirrors
- Faster DAQ:
  300 MHz → 2 GHz
- Better DAQ:
  lower dead time
- Higher QE PMT (2×)
- Stereo observation



MAGIC II Monte Carlo Studies

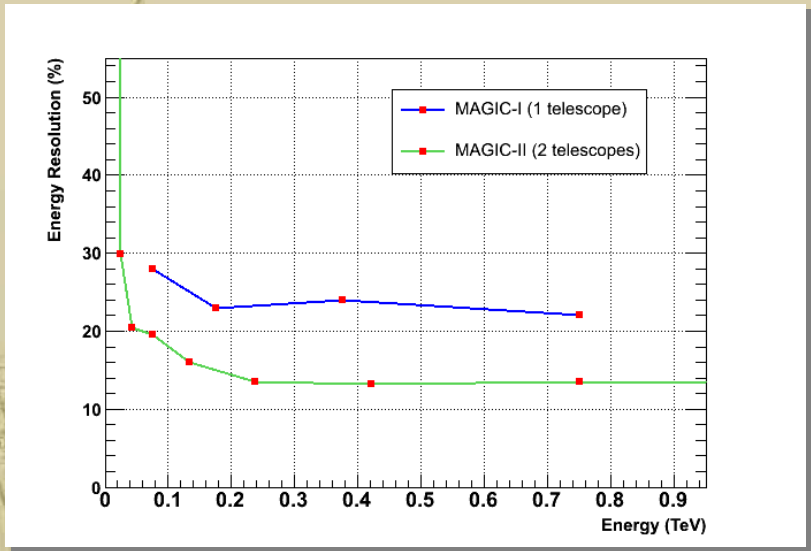
Stereo Analysis:

- observe shower simultaneously with 2 telescopes
- 3D shower reconstruction
- Additional shower parameters:
  - Impact parameter
  - Shower maximum (h_{max})
  - Eliminate ambiguity on arrival direction
- Better reconstruction of energy and arrival direction
- Improved background rejection

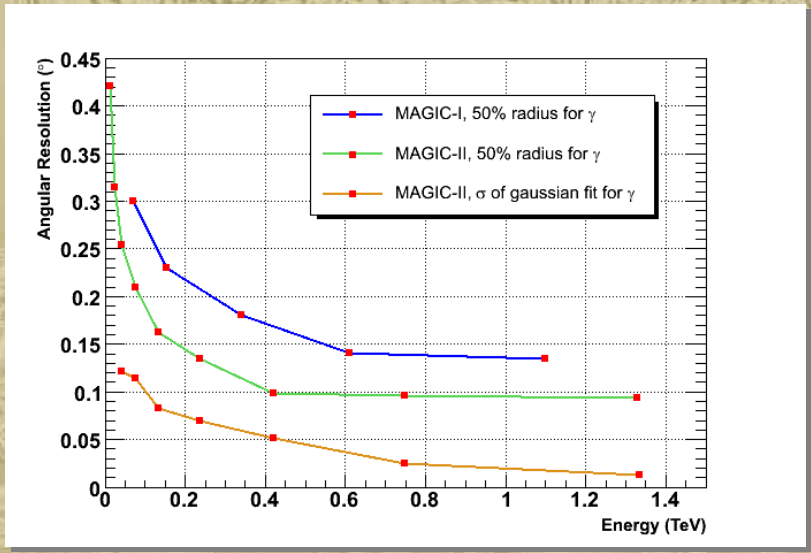


Improved Reconstruction

- Energy resolution
  - MAGIC-I: ~25%
  - MAGIC-II: 14-20% (2 telescopes)



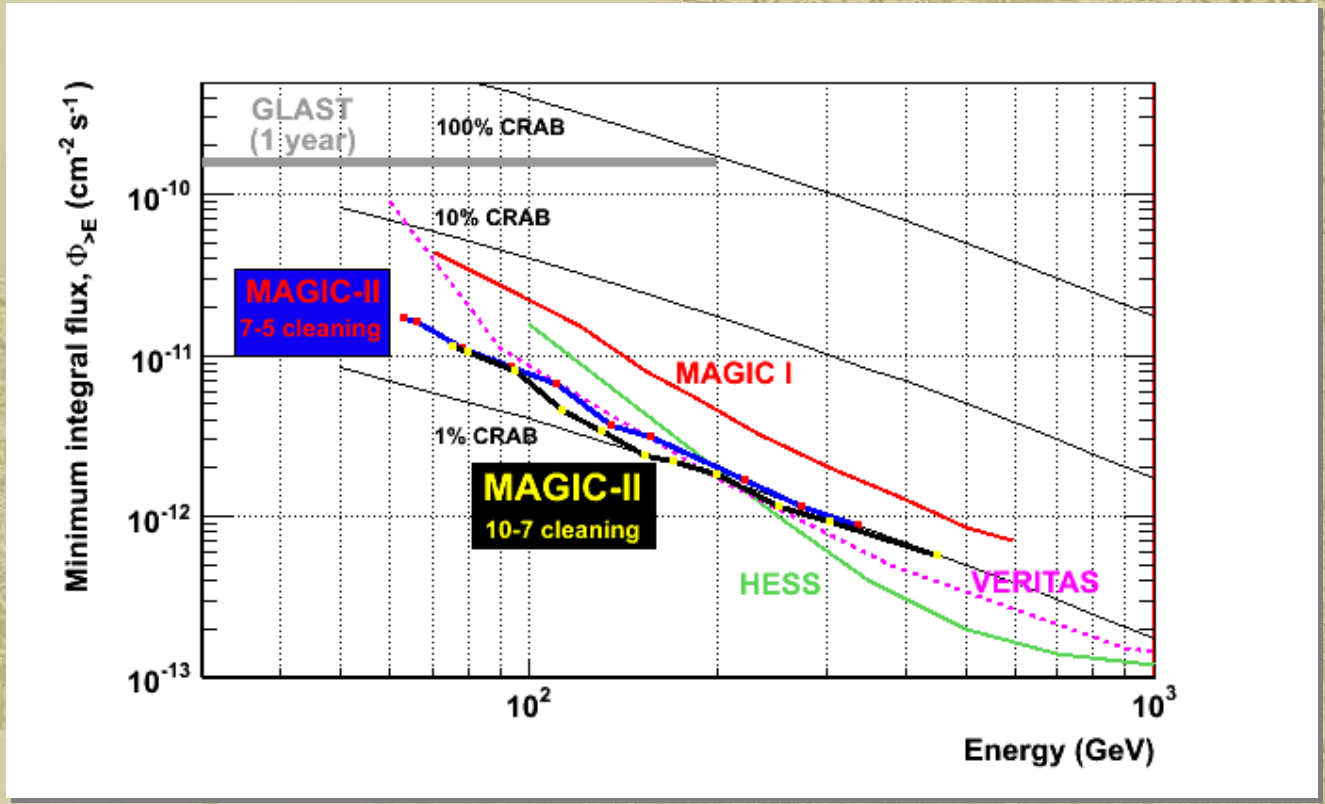
- Angular resolution
  - Substantial (~50%) improvement since source position is obtained from intersection point of both showers



Improved Sensitivity

using Stereo Analysis

- better **background rejection** down to low energies
- **increase sensitivity by up to factor 3**
  => reduce observation time by factor 9
- Large gain in sensitivity at low energies (< 100 GeV)

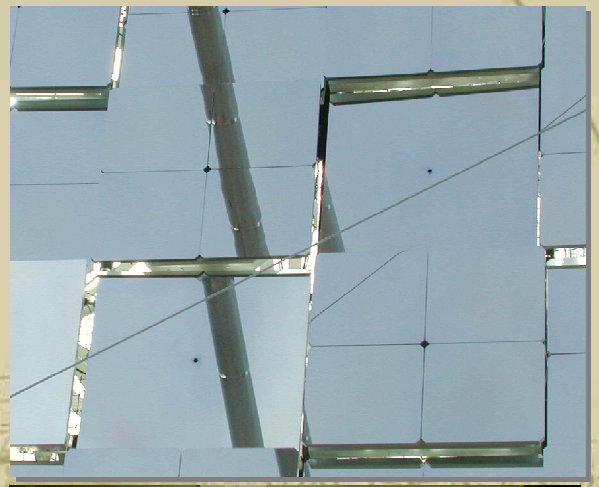


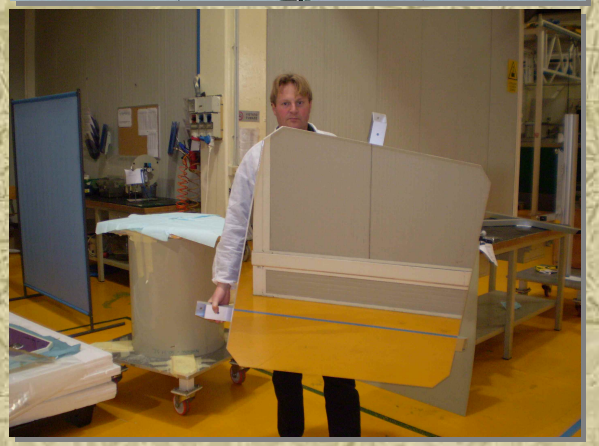
Mirrors

- Parabolic tessellated reflector
- 249 spherical **1 m² mirror** elements
- Active mirror control

2 technologies:

- All aluminum mirrors
  - MAGiC-I technology
  - Diamond milled Al surface
  - Excellent focal spot
  - ~87% reflectivity
- Glass mirrors
  - New technology
  - 2 mm glass plates
  - Al honeycomb layer
  - Quality and robustness under investigation

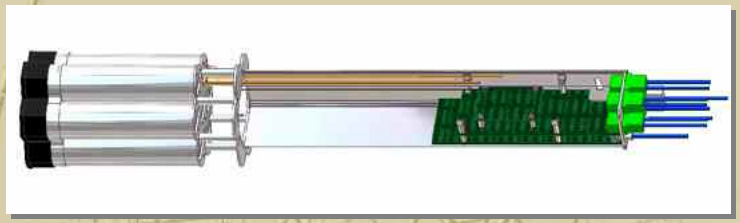




Camera

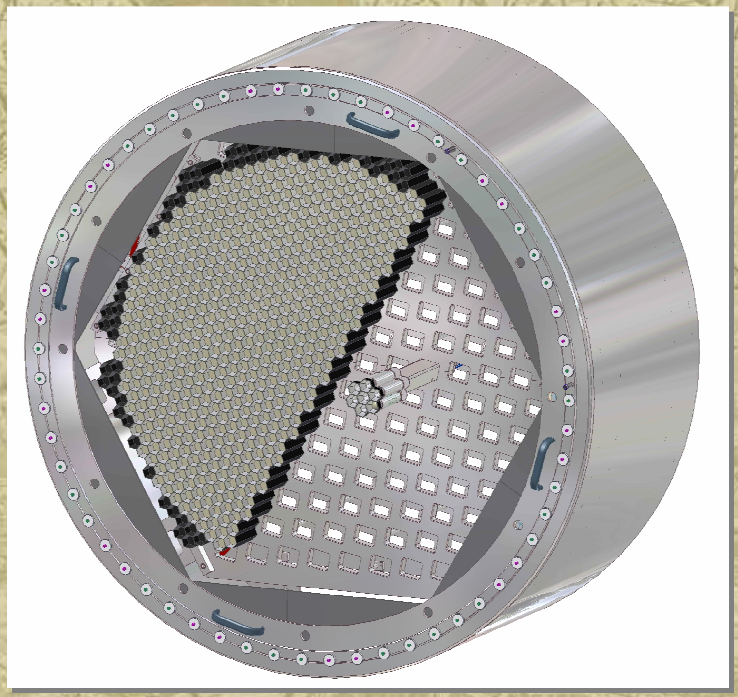
Design criteria:

- High Photon detection efficiency
- 500 MHz bandwidth for entire signal chain



Modular design

- Clusters of 7 pixels
  => easy replacement
  => upgrade possibility to higher QE photosensors

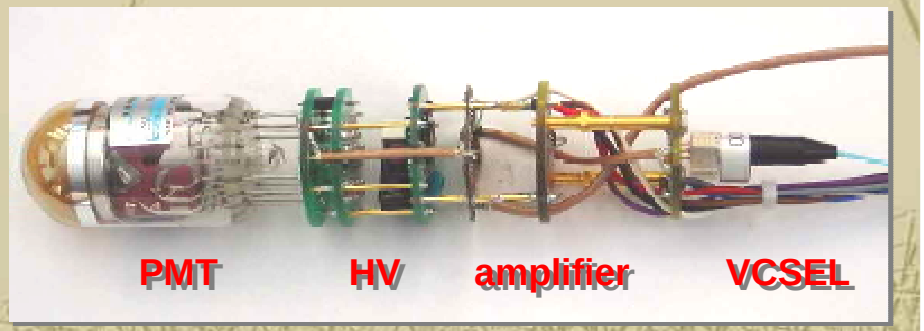


Field of View (FoV)

- 1039 identical 0.1° FoV pixels
- Round configuration
- Total FoV: d=3.5° (similar to MAGIC-I)

Light Sensors

Phase 1
- Hamamatsu R10408 PMTs
- Peak QE typically 34%
- Fast 1 ns signals
- 0.3-0.4% afterpulse (@ 4 ph.e.)
- Cockroft-Woltan HV generator in PMT socket



Phase 2
- Upgrade inner camera with HPDs
- Peak QE ~ 50%
- Use outer camera corners for field test

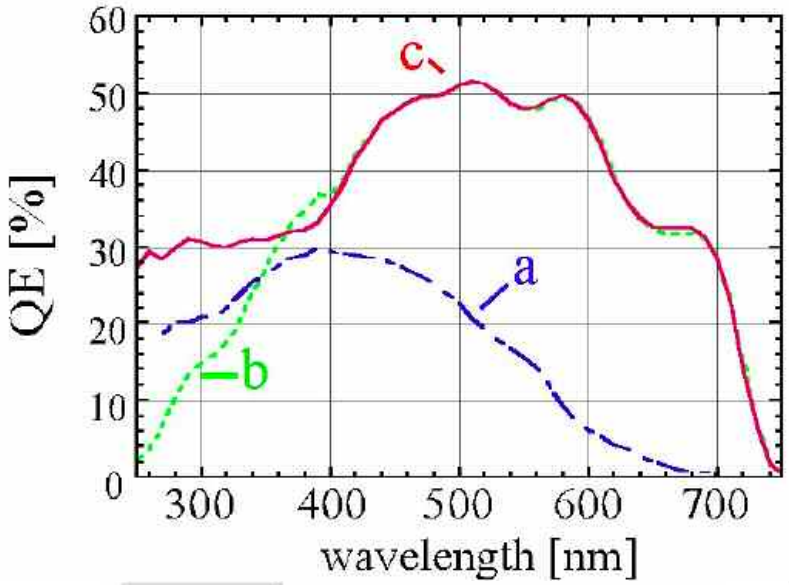
=> Increase sensitivity for low energy showers

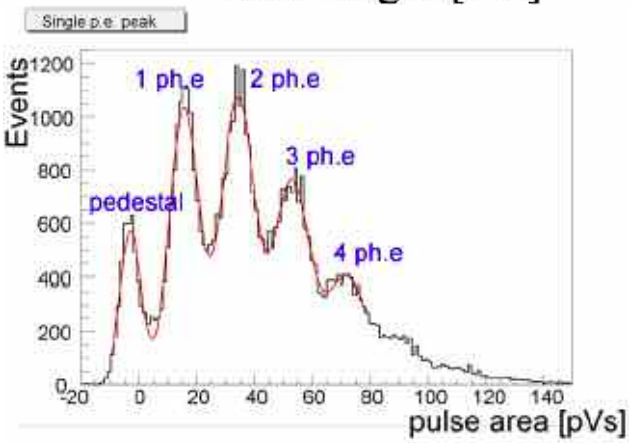
New High QE Photosensors

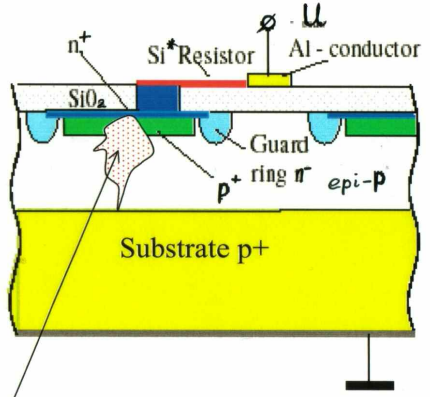
GaAsP HPD

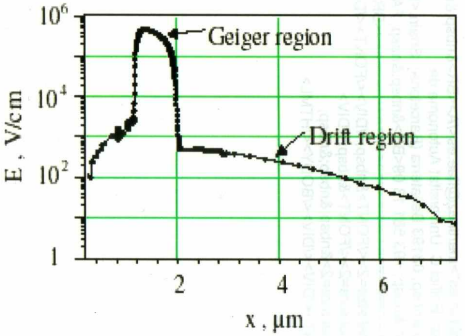
SiPm

QE from 40%
up to 60/70%
for backilluminated

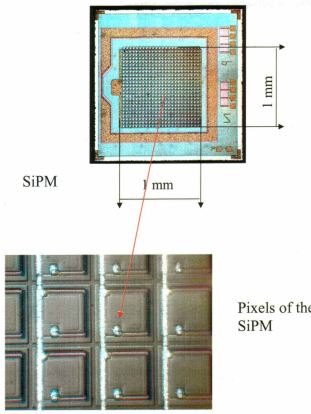


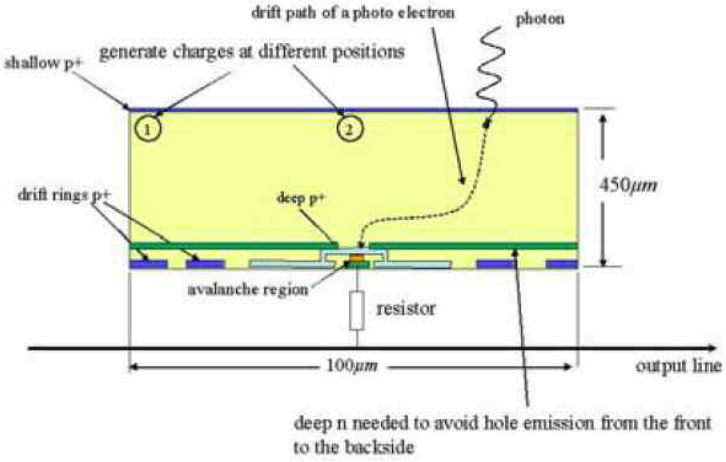






Geiger discharge due to Avalanche ionisation by electorns and holes





Trigger

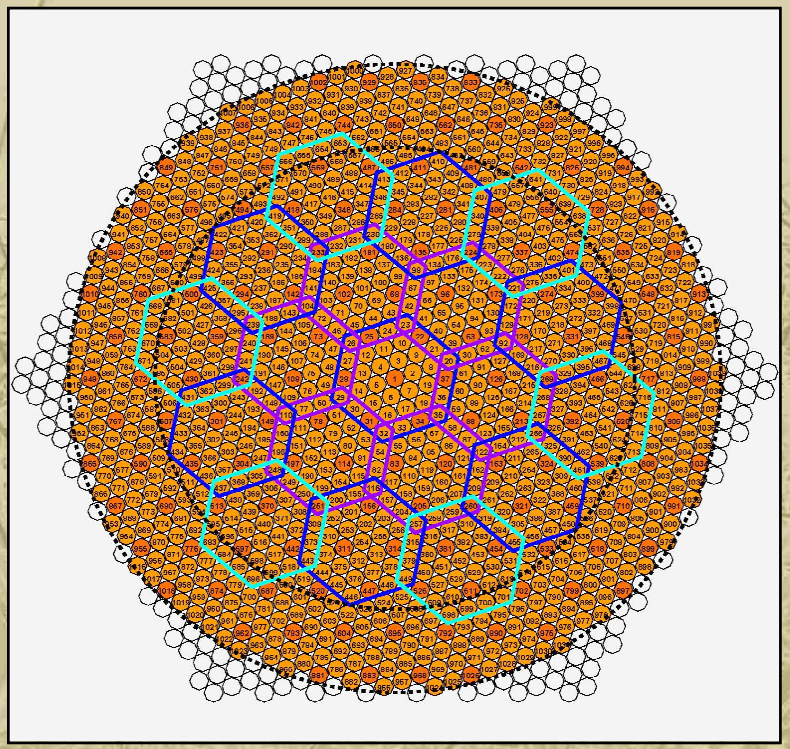
Increase trigger area:

- d=1.9° => d=2.5°

=> Larger effective FOV

=> Improved sensitivity for

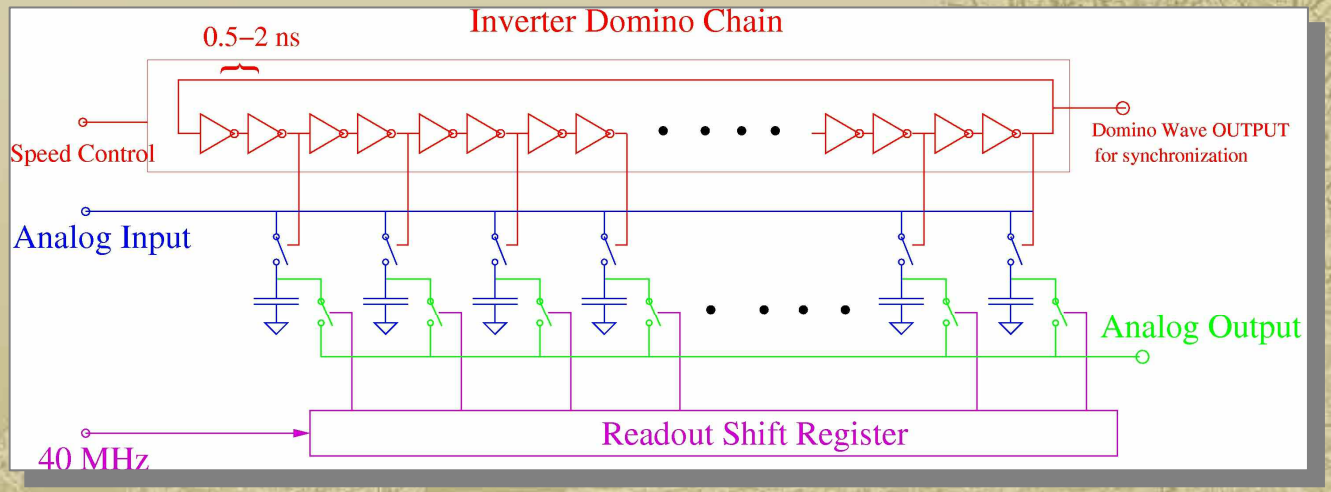
- Sky scan
- Extended sources
- Wobble mode observation

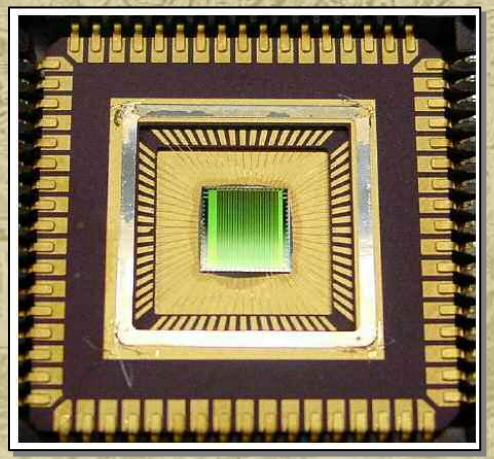


2 telescope coincidence trigger

Fast digitization: Domino Ring Sampler

- 2 up to 7 GSamples/s analog sampling in a series of 1024 capacitors
- 400 MHz bandwidth improved to 500Mhz in version III and IV
- 12 channels per chip
- slow (40 MHz) readout and external 12 bit digitization





Design: Stefan Ritt
Paul Scherrer Institute
(Villigen,CH)

- low cost
- low power consumption
- very flexible and compact

Magic II upgrade summary

- MAGIC-II operational first half of 2008 (inauguration Sept 2008)

- High QE camera
- Fast signal processing

- Improve sensitivity by factor ~3
- Lower analysis threshold

Conclusions

MAGIC scientific campaign (1+0.7 years):

>>> VHE Physics @ 2% Crab level <<<

- 4 new extragalactic sources
- 3 new galactic sources

Among them:

- Variable source (binary LSI +61 303)
- Short term flux and spct. variability (Mrk 501)
- New "VHE-loud" classes (LBL, BHs)

A MAGIC Catalogue of 21? sources after 2 years

Data cycle 3 has just started:

>>> MAGIC 2 completion and physics below 1% Crab <<<