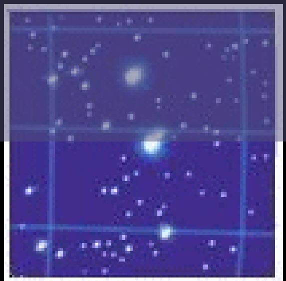


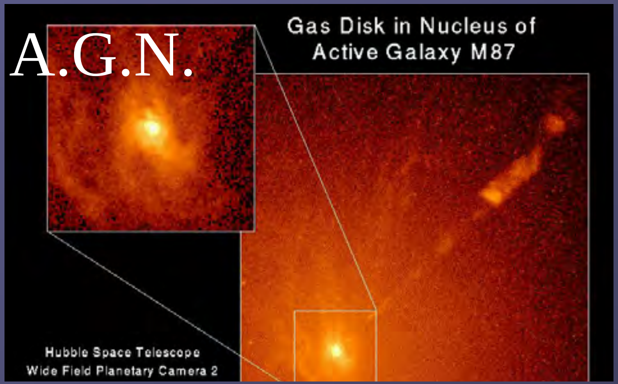
Physics with MAGIC

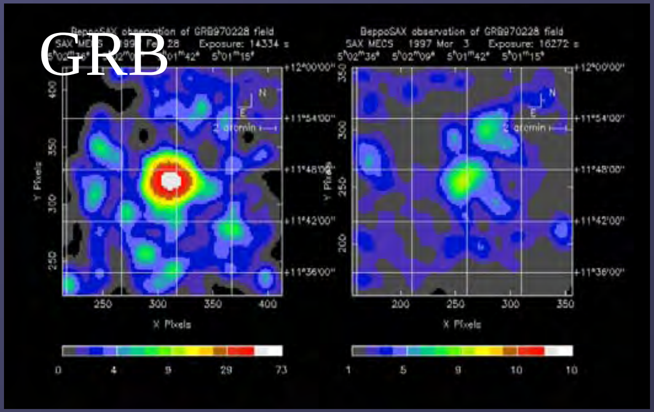
M.Teshima

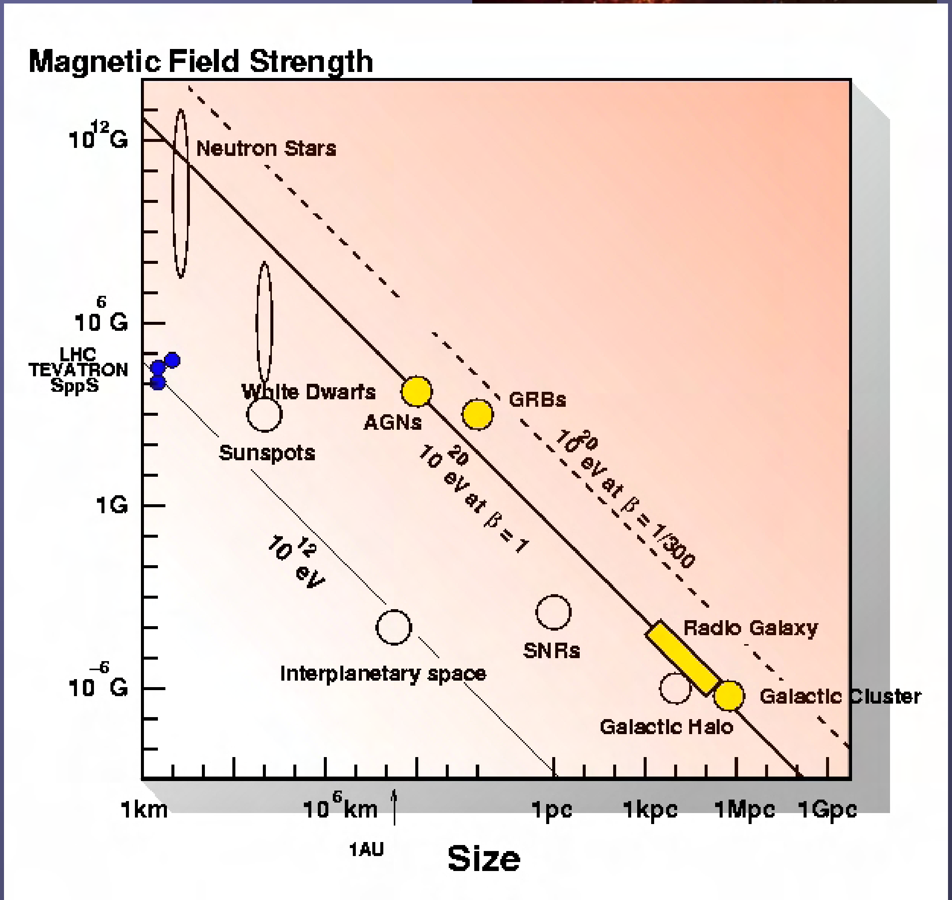
MPI für Physik, München

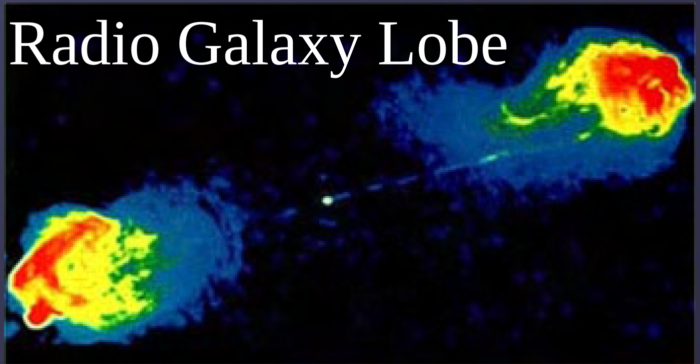
(Werner-Heisenberg-Institut)

Gamma ray sources = Cosmic Ray Accelerators



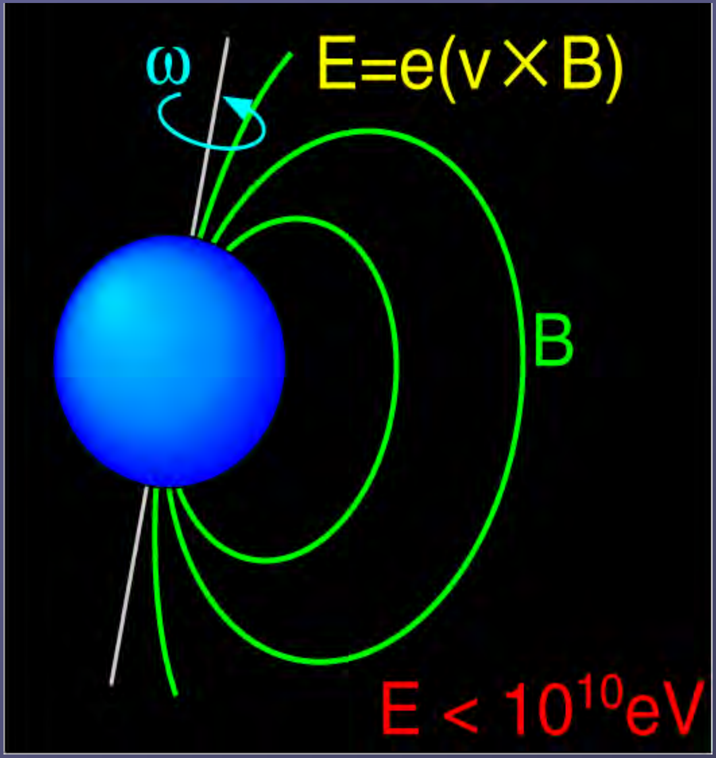




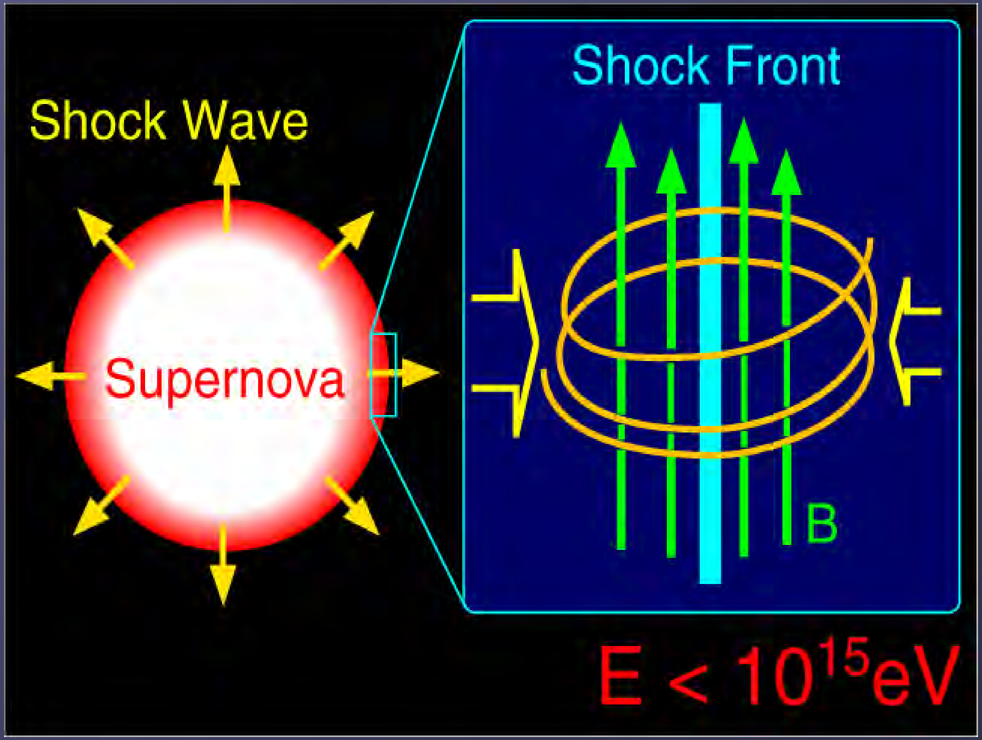


Cosmic Accelerators

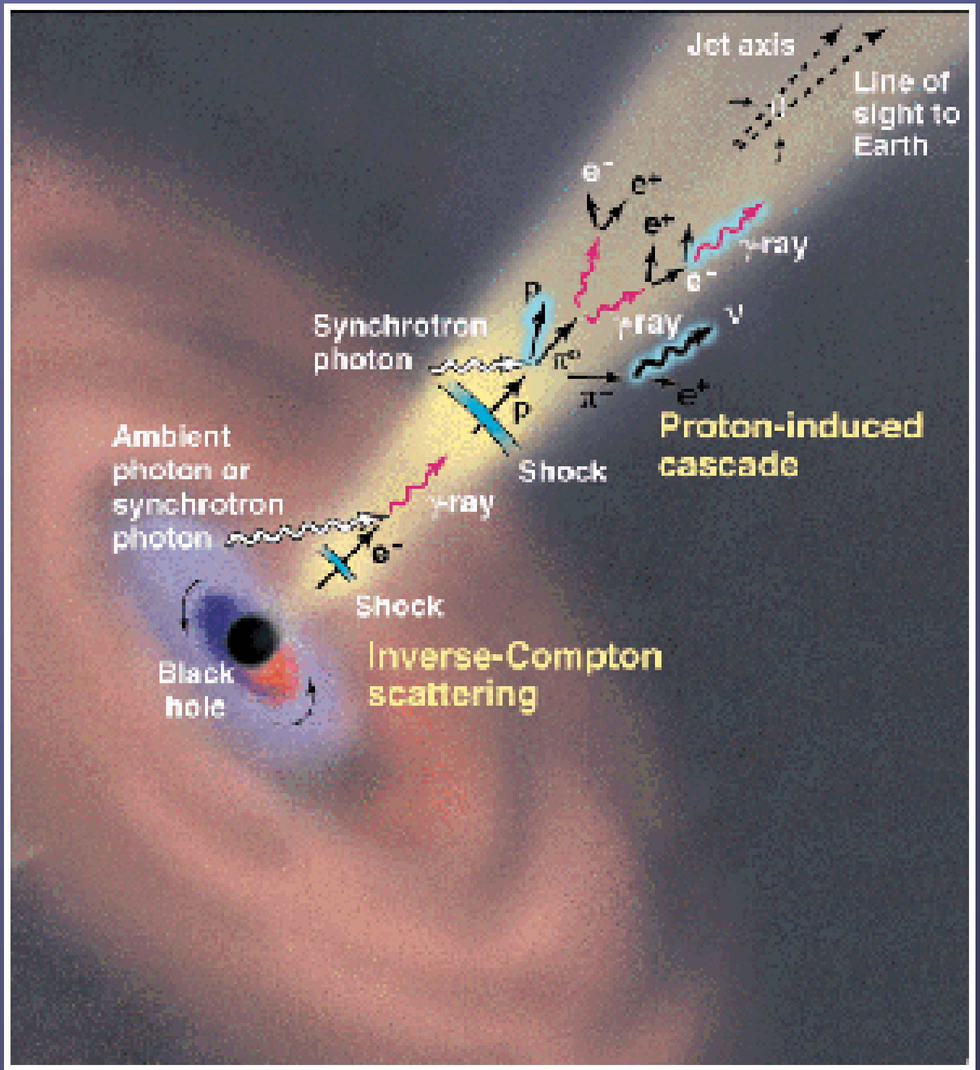
High Electrostatic field (one shot)

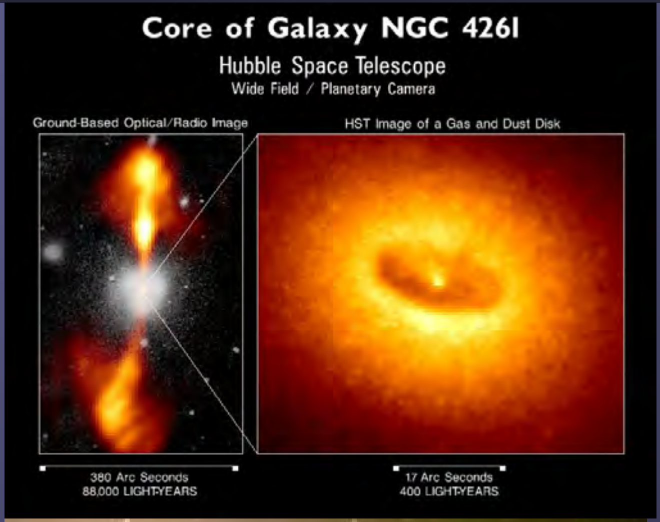


Repetition in Magnetic field

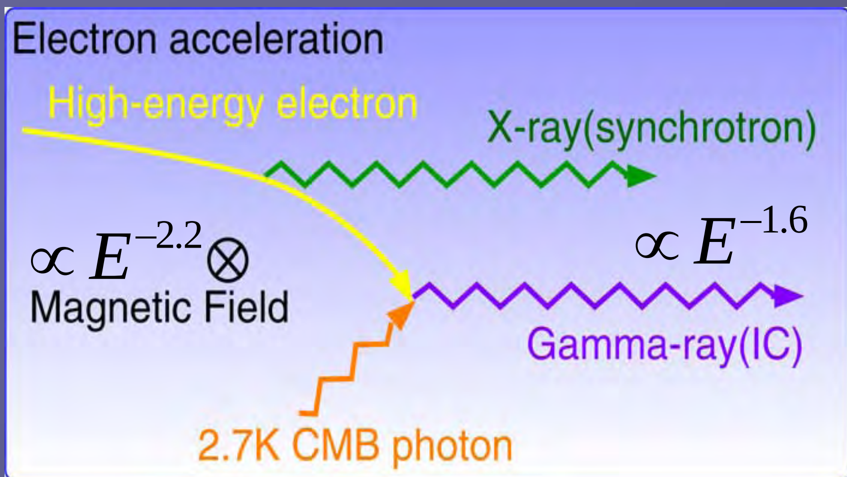


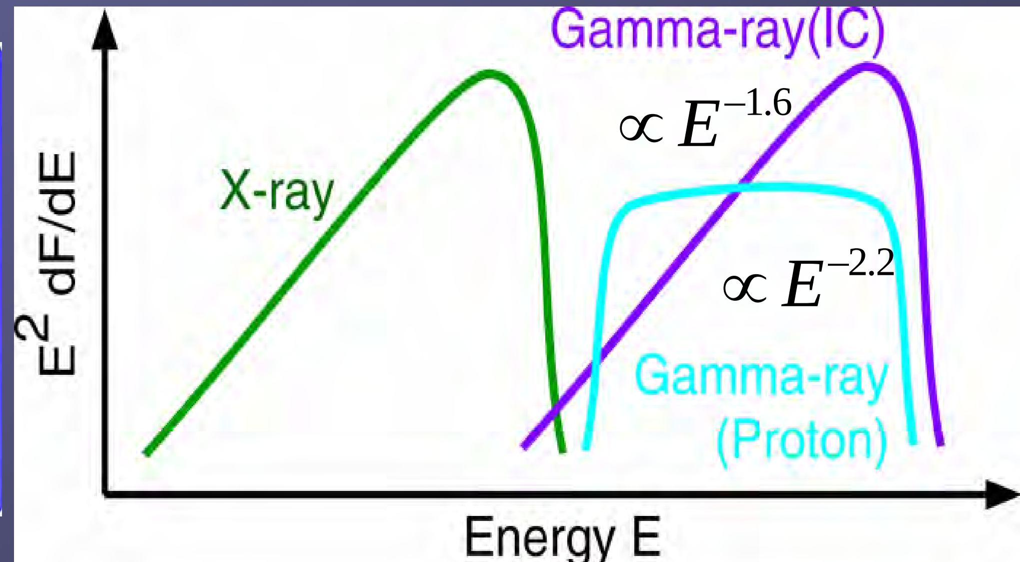
Cosmic Ray accelerator AGNs

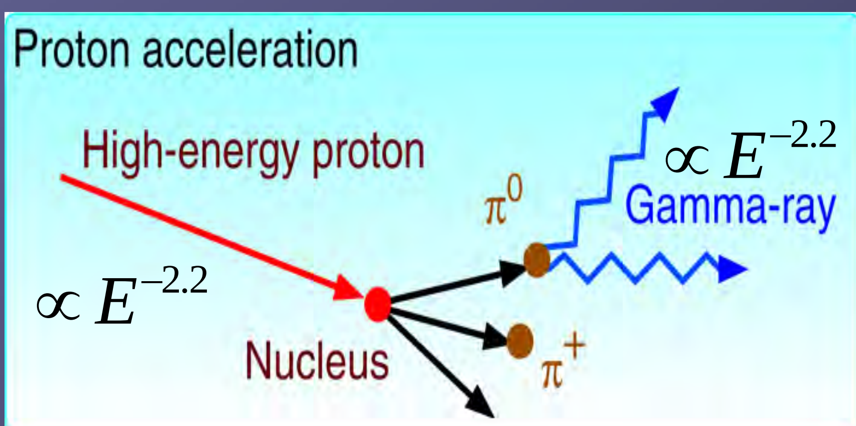




Gamma-Ray Emission Processes







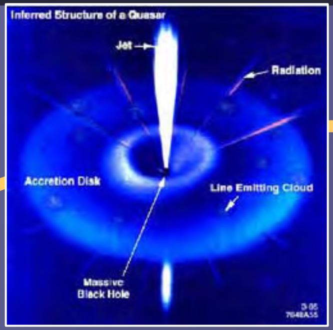
$$\left(\frac{dE}{dt}\right)_{\mathrm{I.C.}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\,\gamma_{\max}^{2}\,\mathrm{U}_{\mathrm{photon}}$$

$$\left(\frac{dE}{dt}\right)_{\mathrm{Sync}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\,\gamma_{\max}^{2}\,\frac{B^{2}}{2}$$

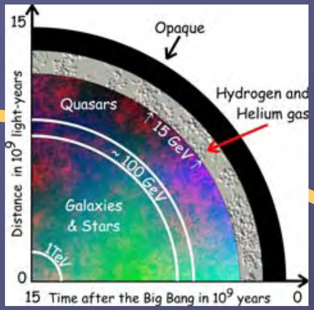
Physics & Astrophysics with MAGIC

MAGIC Physics Objectives

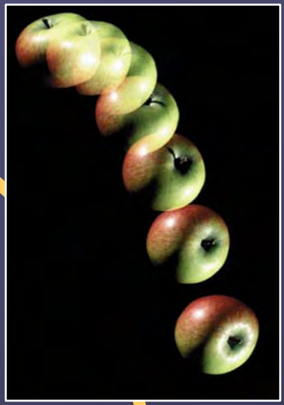
Pulsars



AGNs

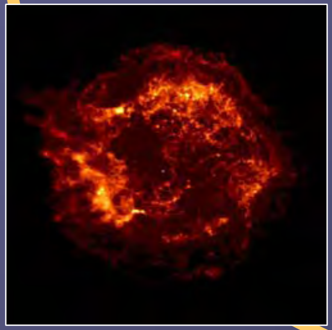


Cosmological γ-Ray Horizon

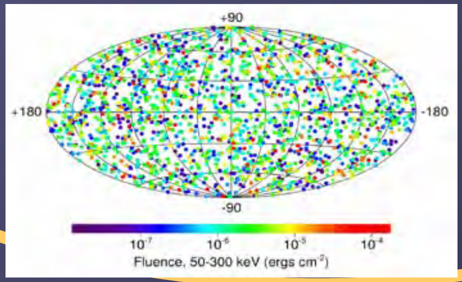


Quantum Gravity

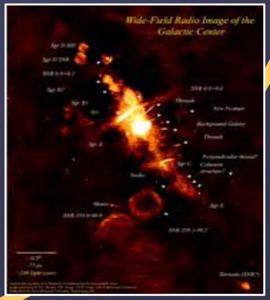
Origin of Cosmic Rays



SNRs



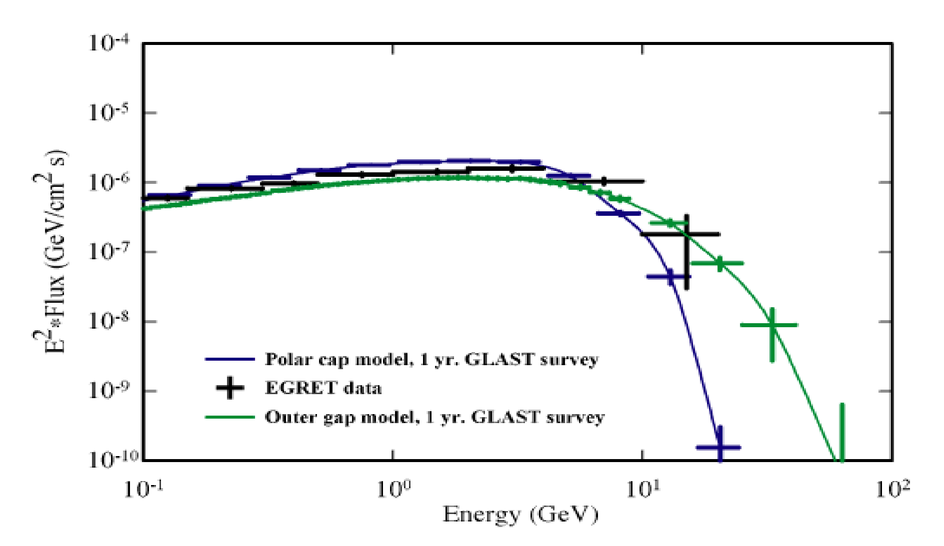
GRBs

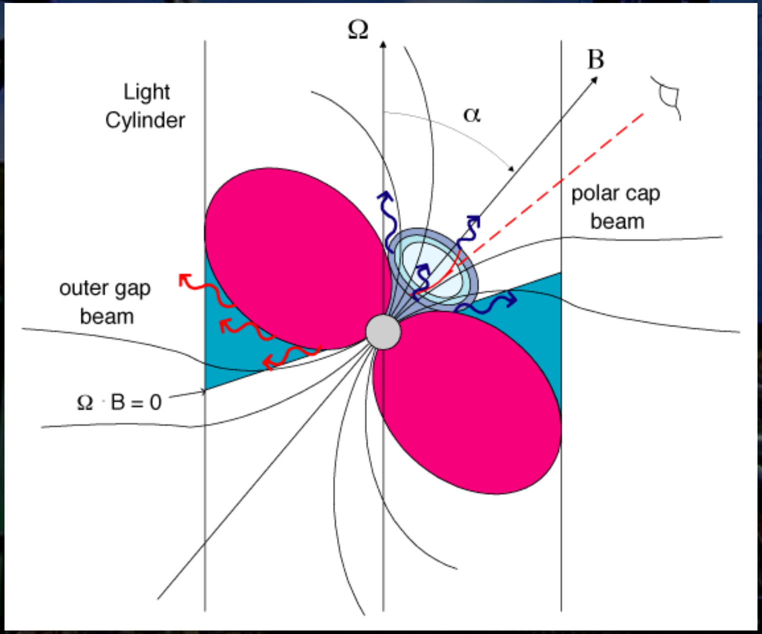


Cold Dark Matter

Pulsars

- 7 γ-ray pulsars seen by EGRET (E_γ < 10 GeV)
- Only upper limits from present IACTs for pulsed emission (spectral cut-off)

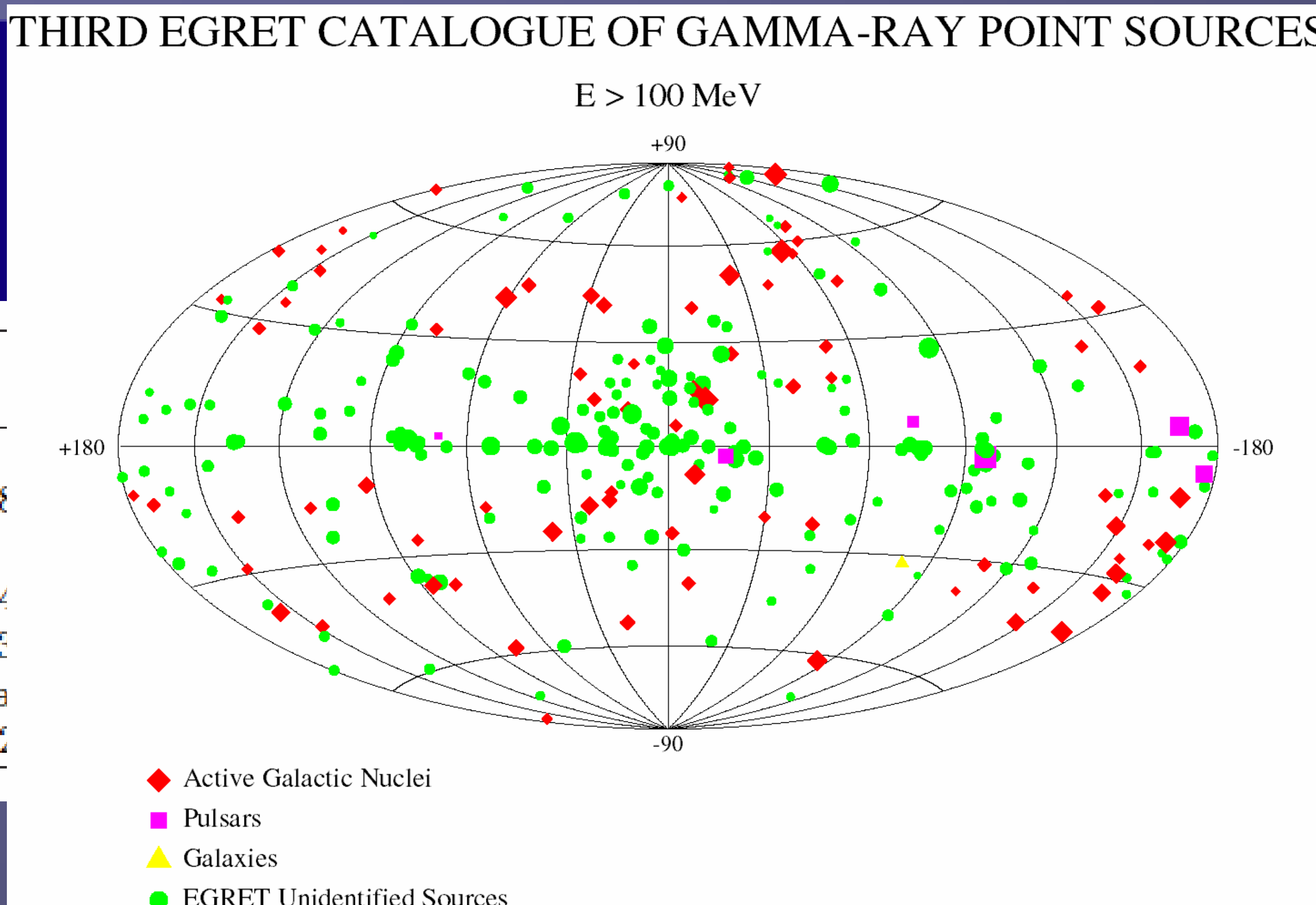




- Where do γ-rays come from? Outer gap or polar cap?
- 30 – 100 GeV decisive energy range

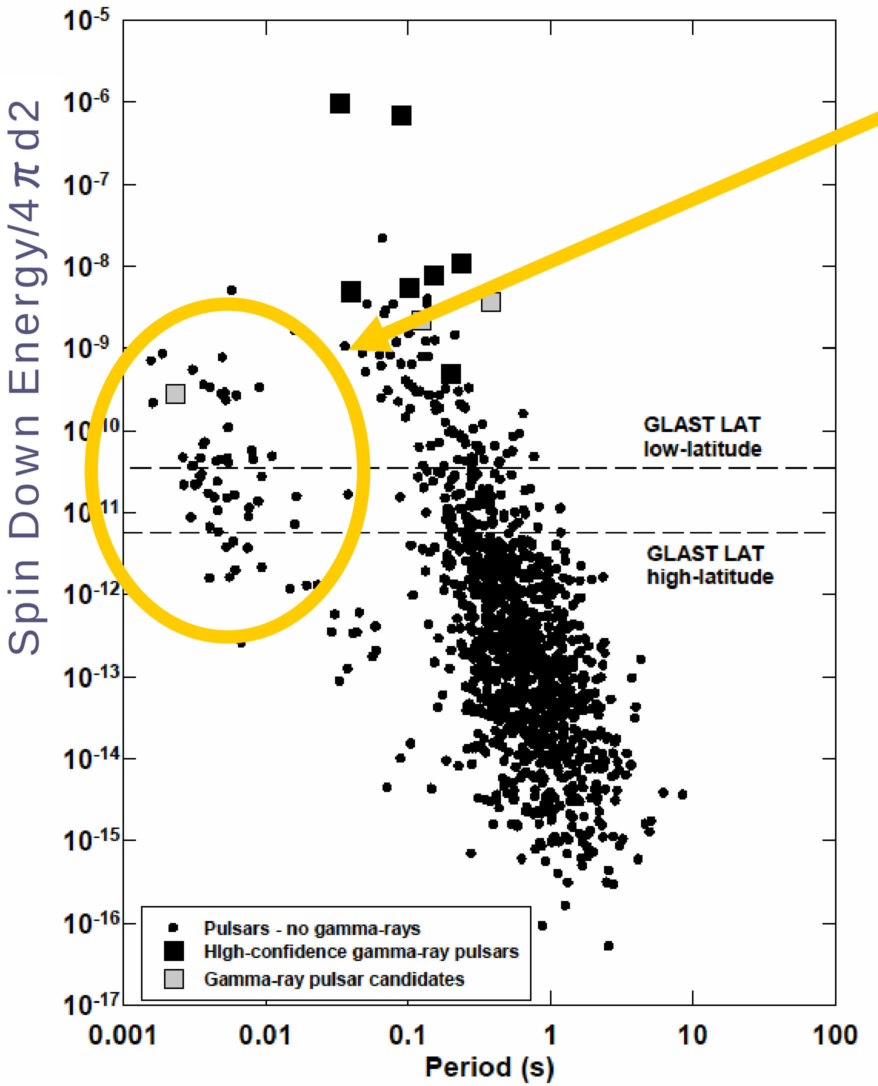
Pulsars

Name	η ... > 1eV)
Crab	).001
B1509-58	).009
Vela	).003
B1706-4	).020
B1951+3	).007
Geminga	).029
B1055-52	).207

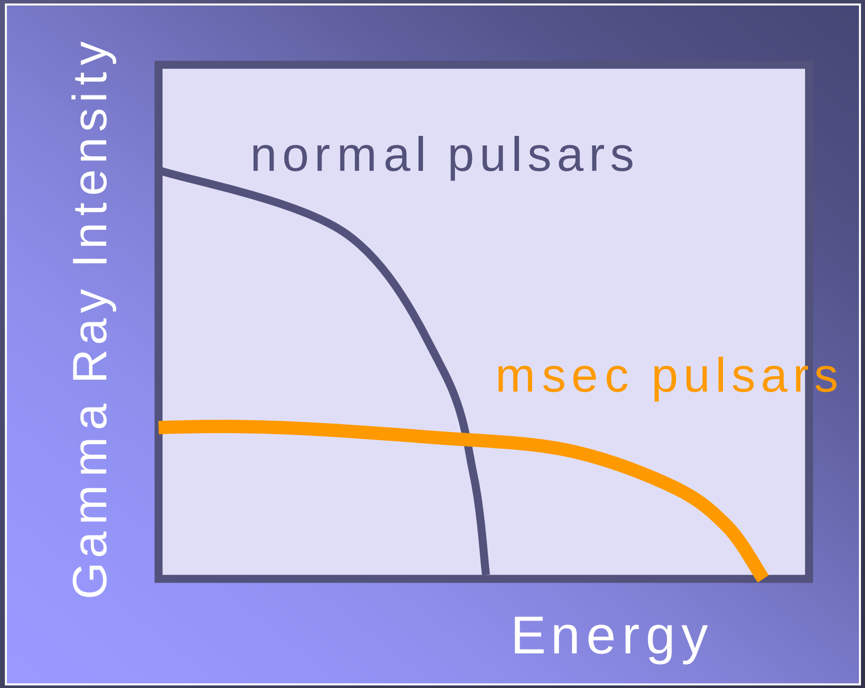


- Old pulsars have hard energy spectrum (gamma ray rich)
- Some of EGRET un-ID sources are believed to be old pulsars. Identification by MAGIC high statistics data

Gamma Ray visibility

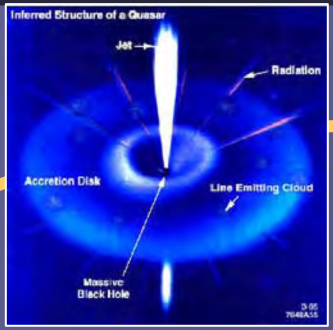


msec pulsars are good candidates for VHE gamma sources

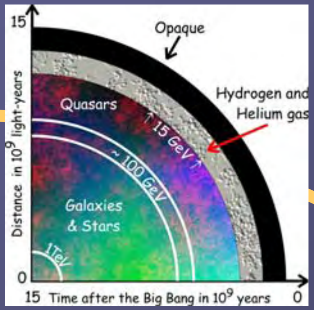


MAGIC Physics Objectives

Pulsars



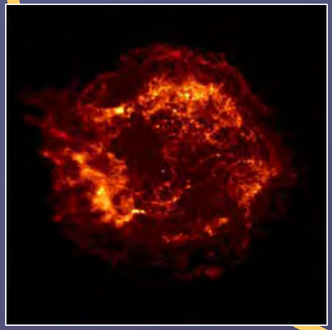
AGNs



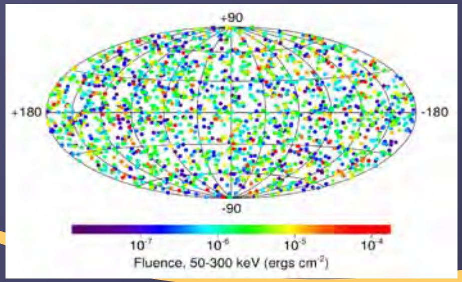
Cosmological γ-Ray Horizon

Quantum Gravity

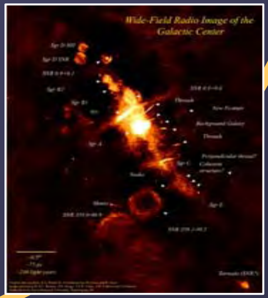
Origin of Cosmic Rays



SNRs

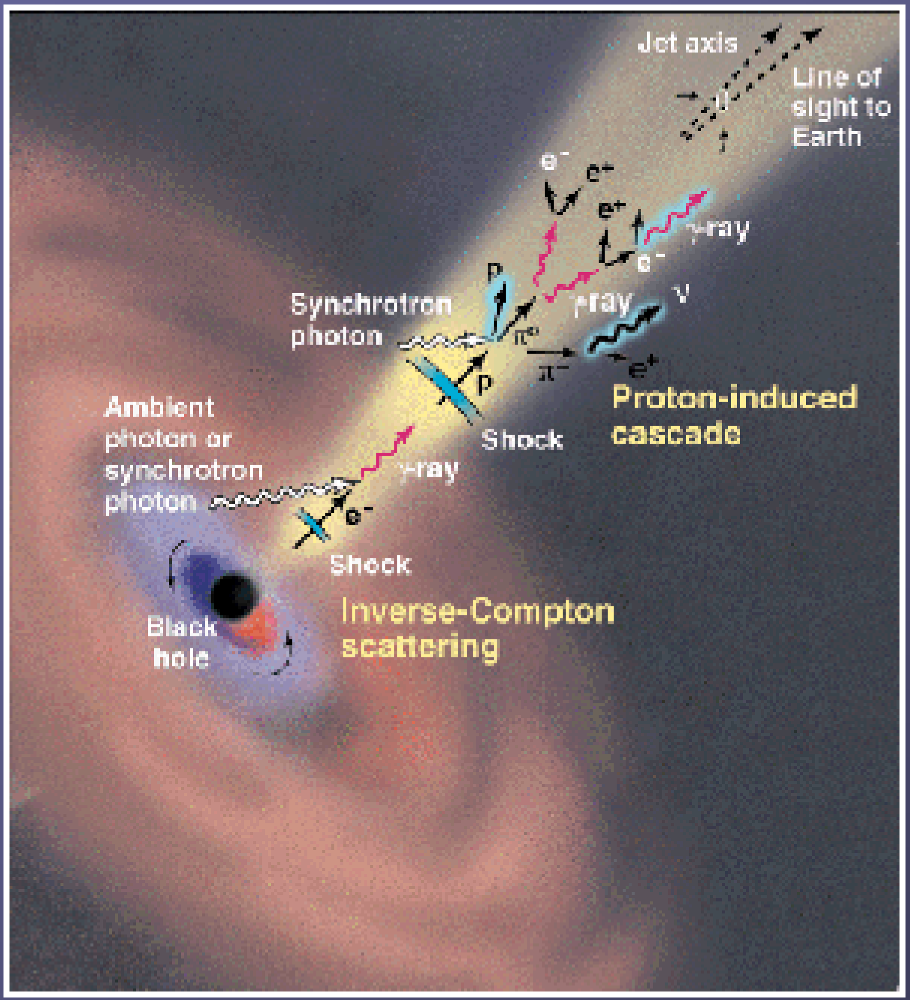


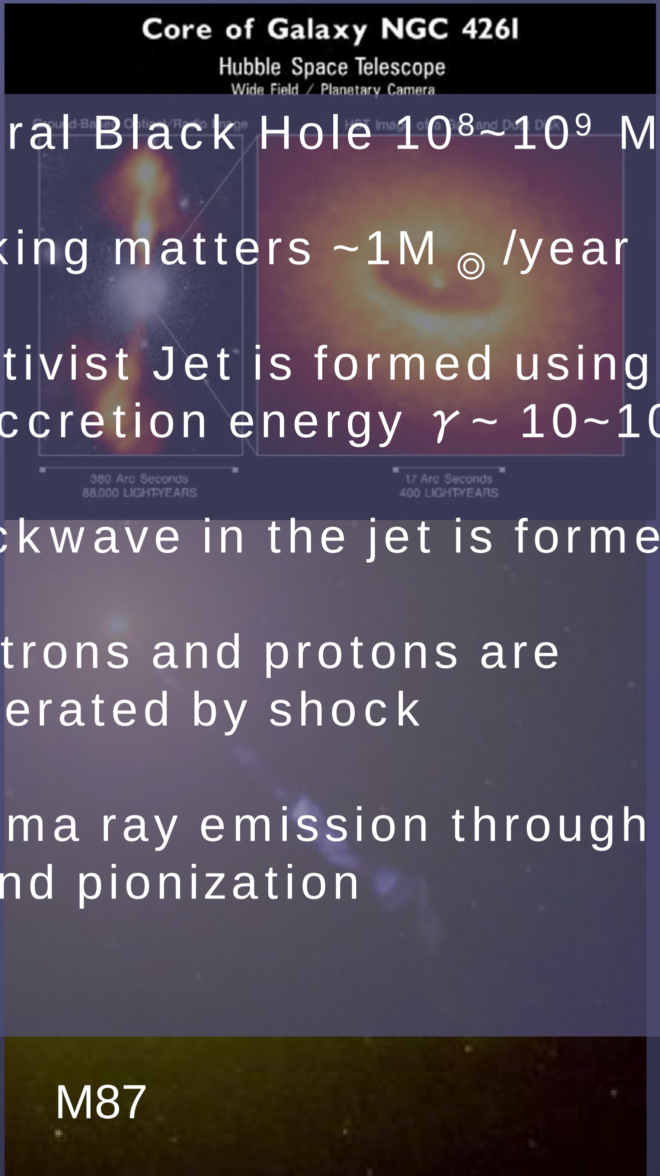
GRBs



Cold Dark Matter

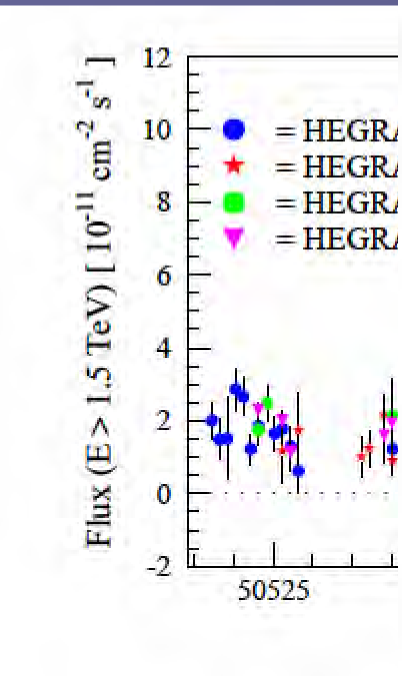
Active Galactic Nucleis





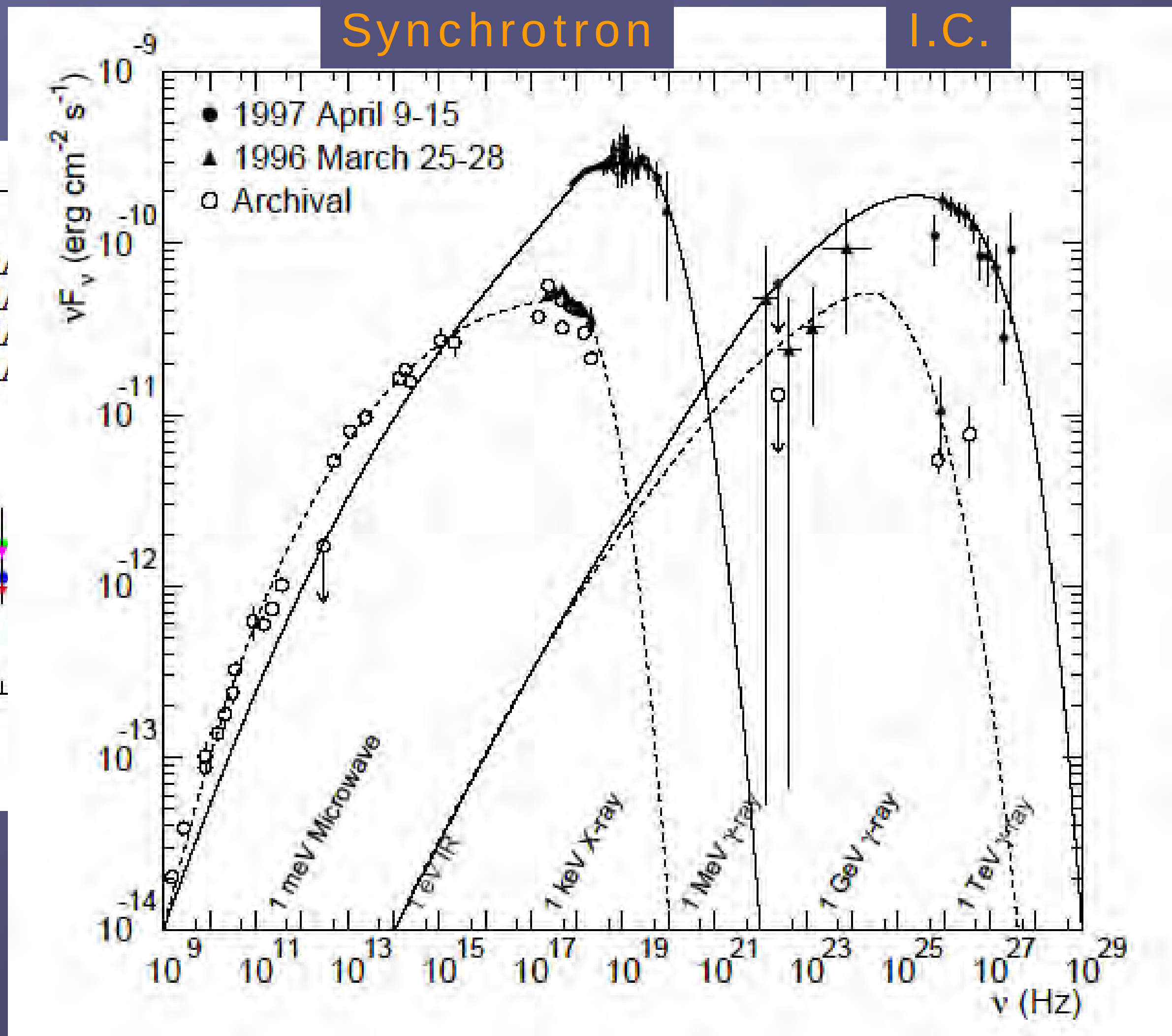
- Central Black Hole 10^8~10^9 $M_\odot$
- Sucking matters ~1$M_\odot$ /year
- Relativist Jet is formed using the accretion energy γ~ 10~100
- Shockwave in the jet is formed
- Electrons and protons are accelerated by shock
- Gamma ray emission through I.C. and pionization

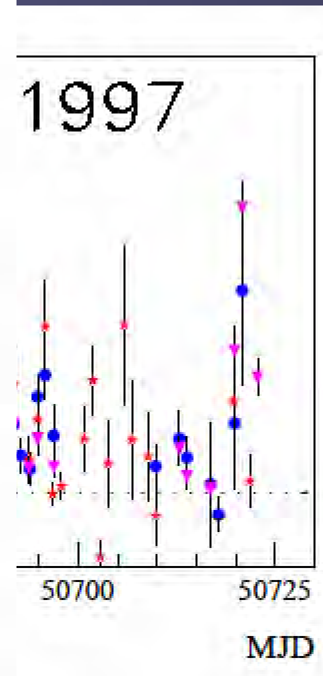
Mrk501 by HEGRA



Synchrotron

I.C.





Emax(e) became higher

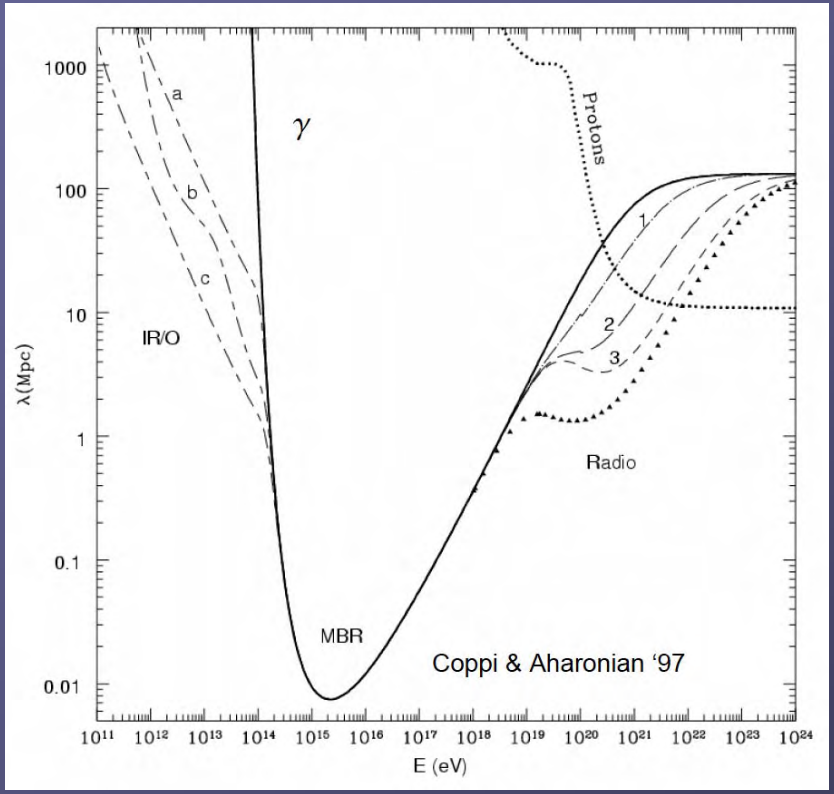
TeV Blazars

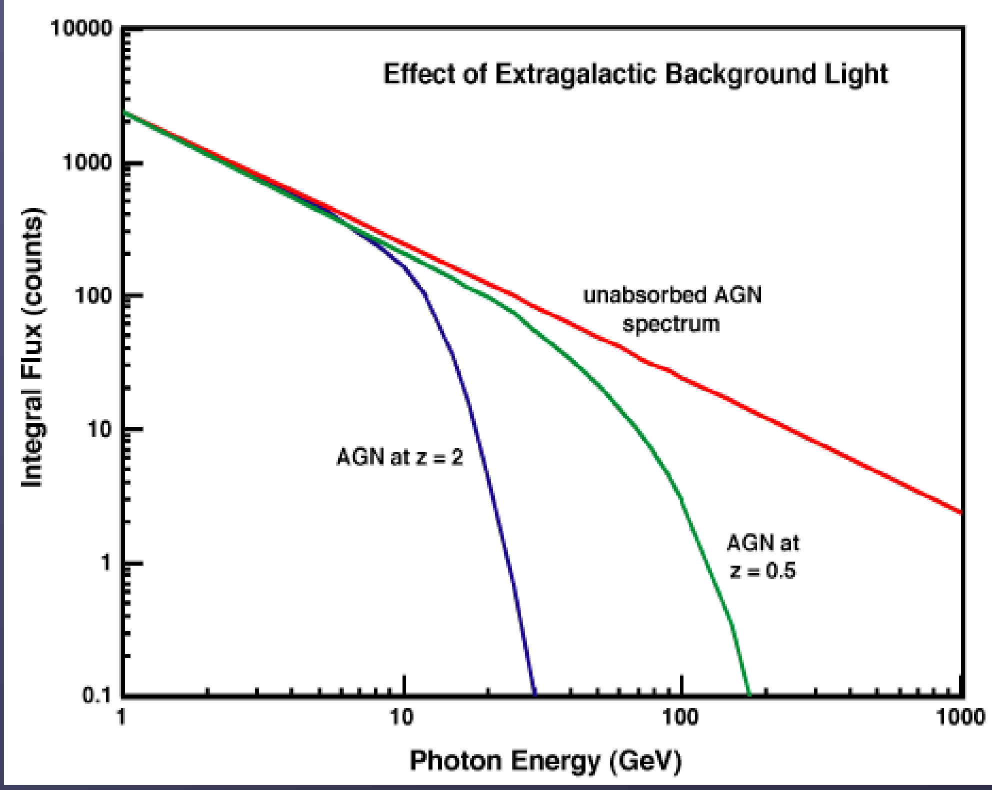
Most of sources are nearby Z<0.1

Catalog Name	Source	Classification	Redshift
TeV 0219+4248	3C66A	BL Lac (LBL)	0.444 ??
TeV 1104+3813	Mrk 421	BL Lac (HBL)	0.031
TeV 1429+4240	H1426+428	BL Lac (HBL)	0.129
TeV 1654+3946	Mrk 501	BL Lac (HBL)	0.033
TeV 2000+6509	1ES1959+650	BL Lac (HBL)	0.048
TeV 2159−3014	PKS2155−304	BL Lac (HBL)	0.116
TeV 2203+4217	BL Lac	BL Lac (LBL)	0.069 ??
TeV 2347+5142	1ES2344+514	BL Lac (HBL)	0.044

Absorption of gamma rays in the universe

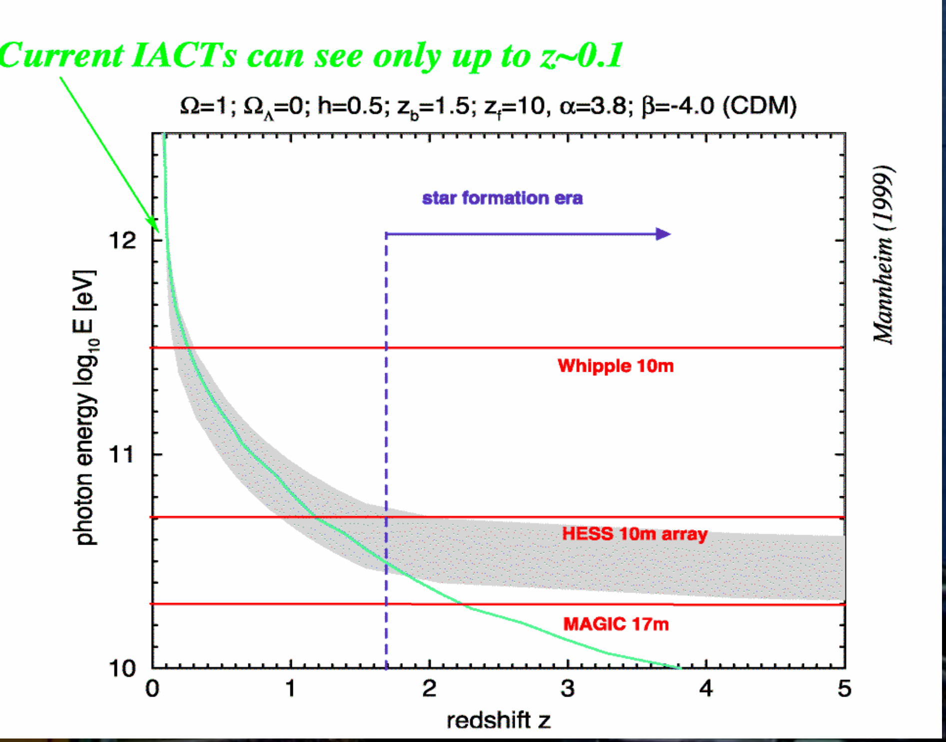
Pair Creation; $\gamma + \gamma \rightarrow e^+ + e^-$

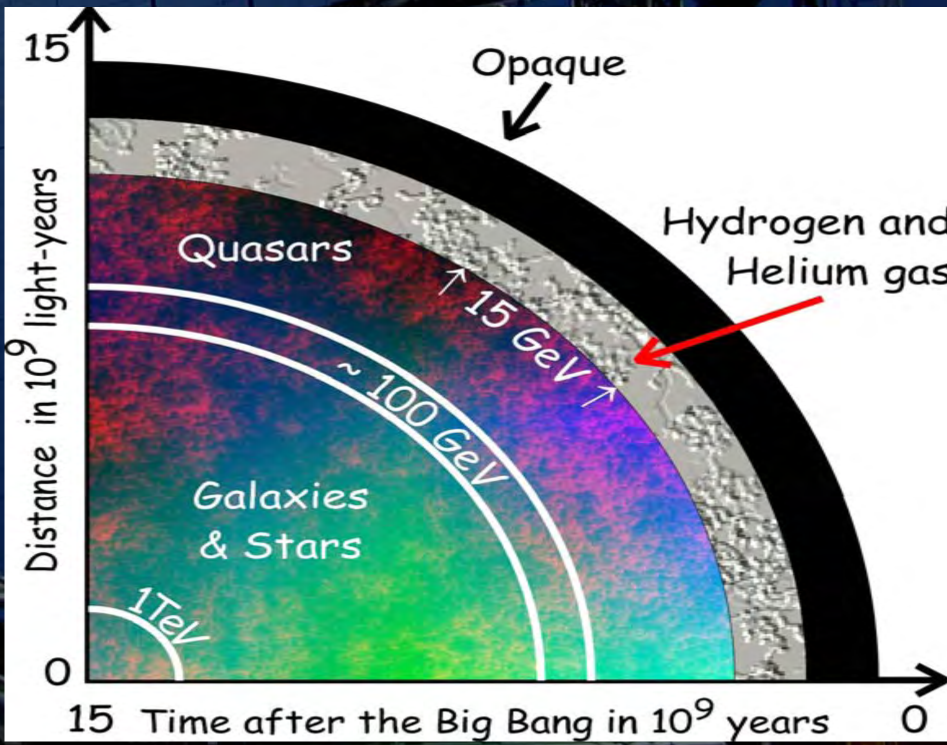




Gamma Ray Horizon

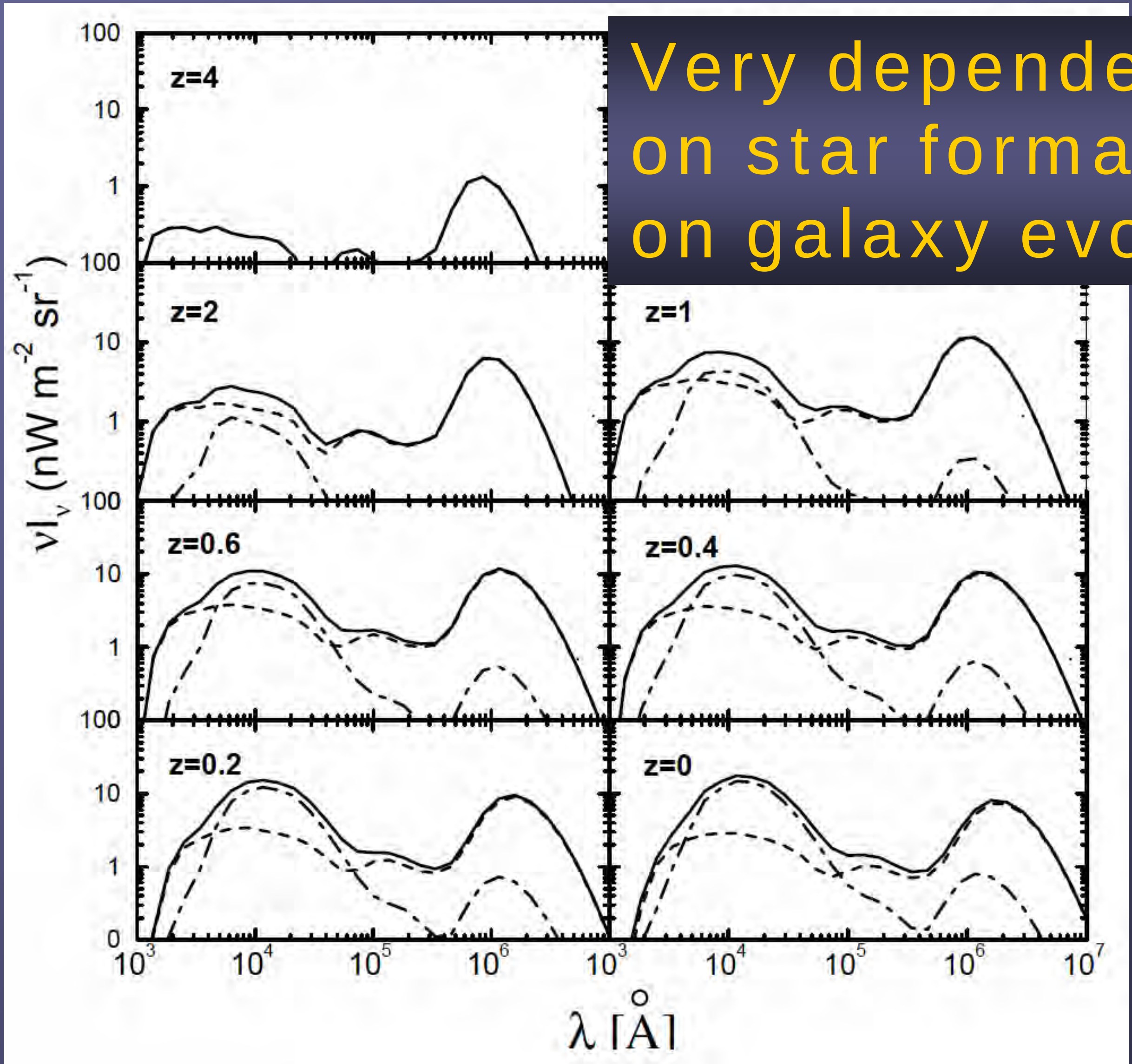
A lower energy thresholds allows a deeper look into the universe





Evolution of EBL

by T.M. Kneiske et al.



Very dependent
on star formation and
on galaxy evolution

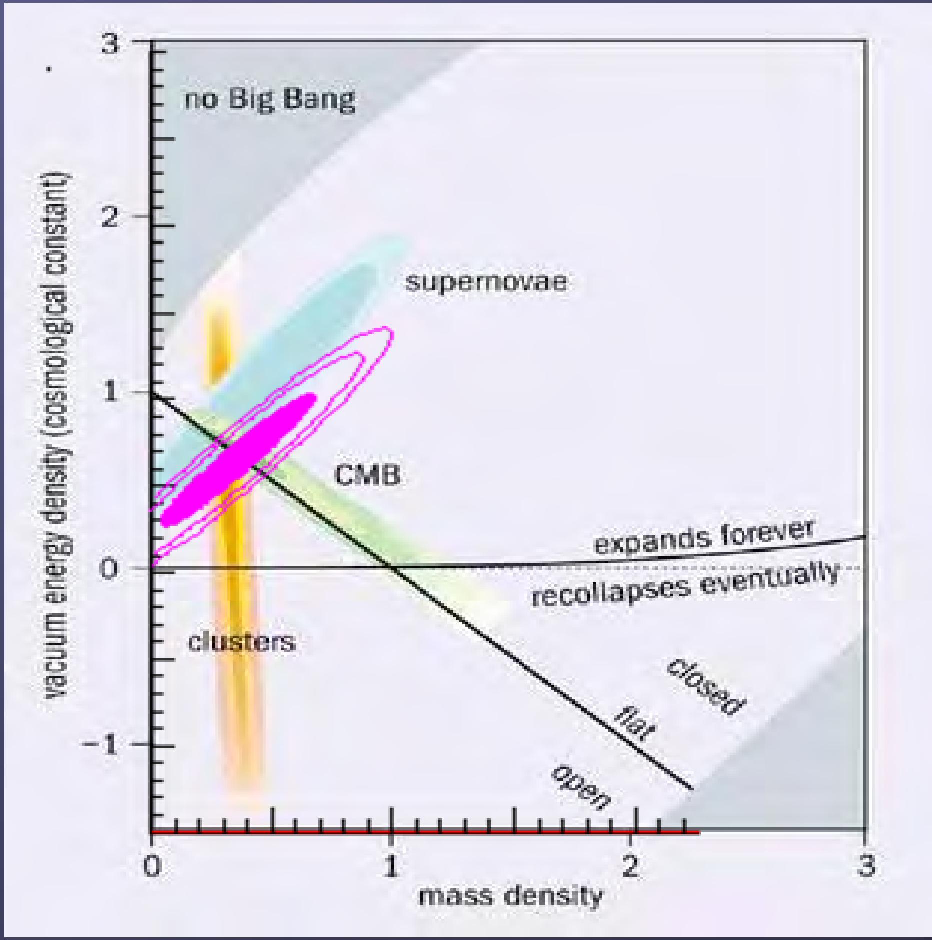
Gamma Ray Horizon and Cosmology

Gamma ray horizon gives us

1. Gamma ray path length
2. IR, optical photon density

Path length ←→ z (red shift)

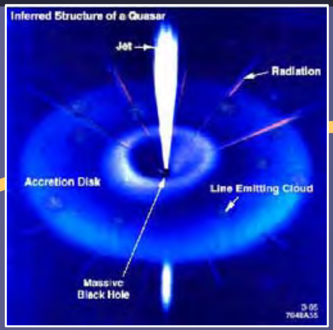
$$\frac{d\ell}{dz} = c \cdot \frac{1/(1+z)}{H_0\left[\Omega_M(1+z)^3 + \Omega_K(1+z)^2 + \Omega_\Lambda\right]^{1/2}}$$



O. Blanch, M. Martinez - ICRC 2003

MAGIC Physics Objectives

Pulsars



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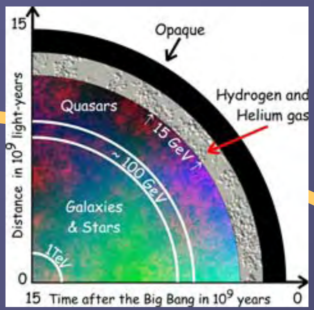
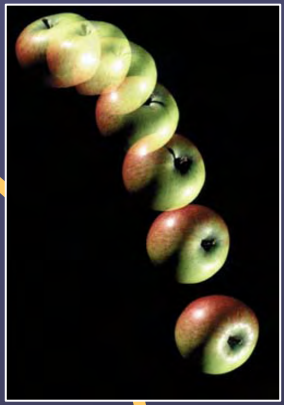
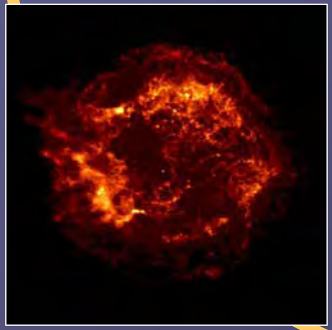


Cosmological γ-Ray Horizon

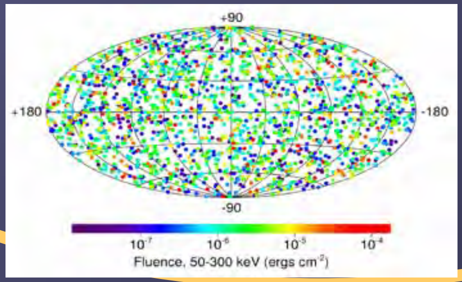


Quantum Gravity

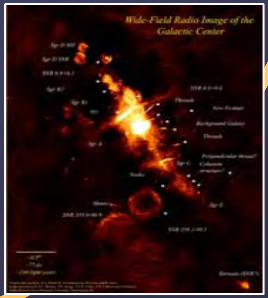
Origin of Cosmic Rays



SNRs



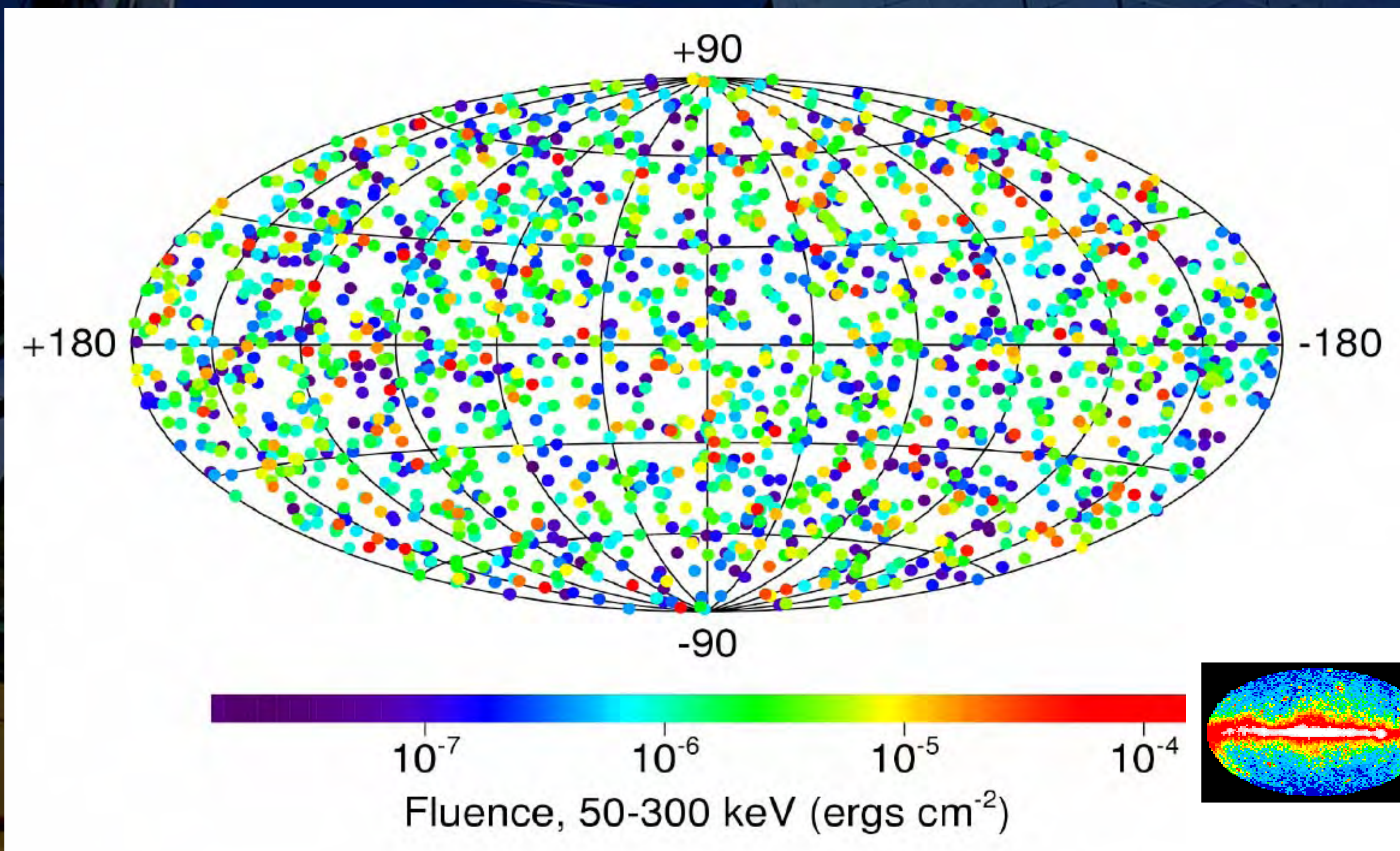
GRBs

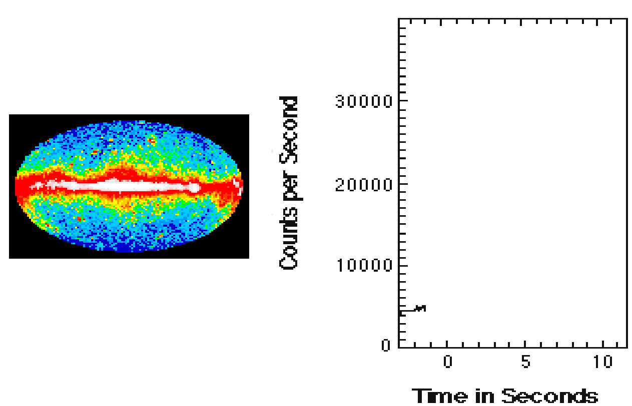


Cold Dark Matter

Gamma Ray Bursts

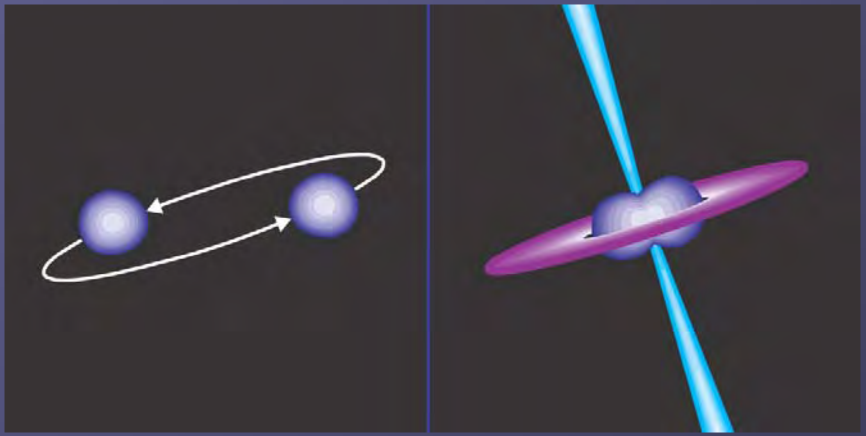
MAGIC has a chance to see a few GRBs/year





Gamma ray bursts

Hypernova!

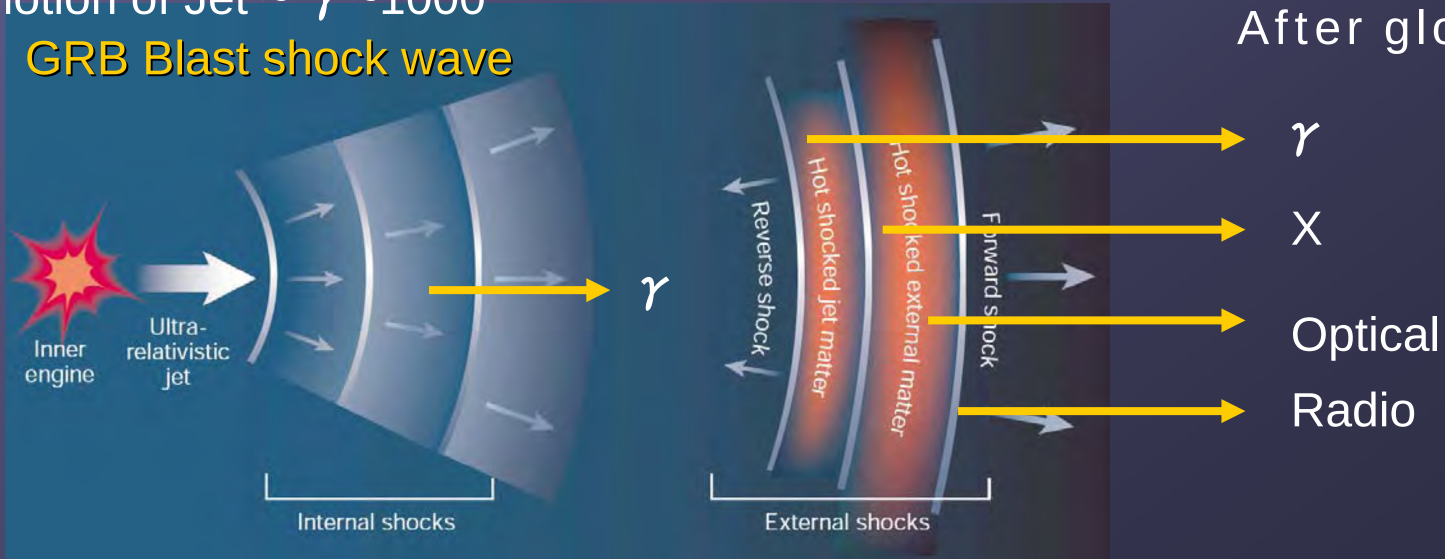


Binary neutron stars

Relativistic Bulk motion of Jet ~ γ ~1000

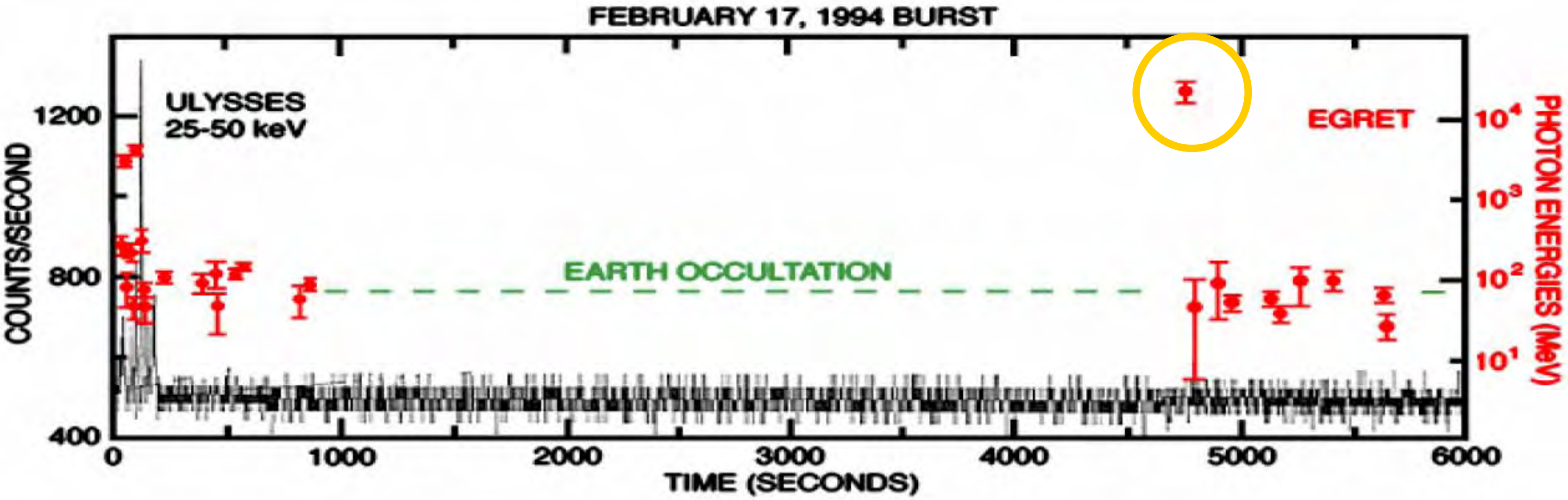
GRB Blast shock wave

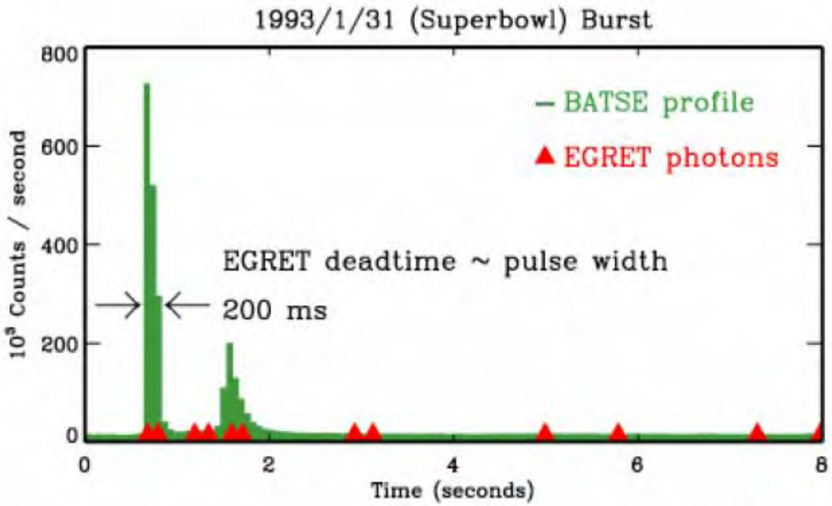
After glow



Two EGRET Bursts

18GeV photon





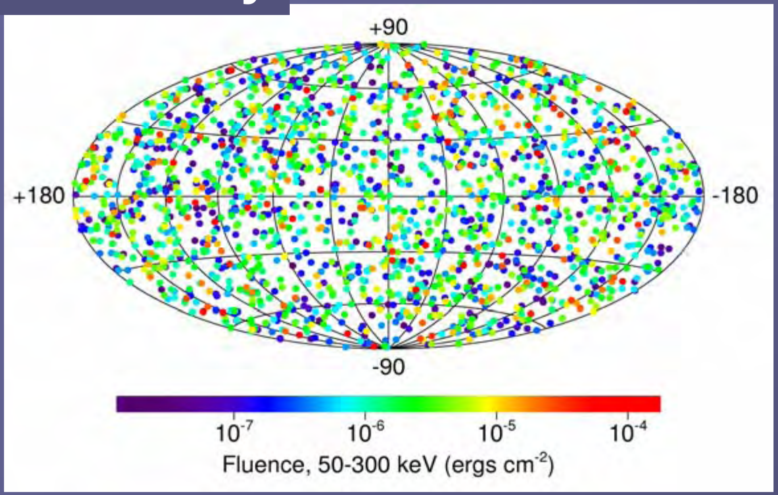
- >10 GeV photons can last for > 1 hr,

  start w. MeV trigger
- Considerable energy

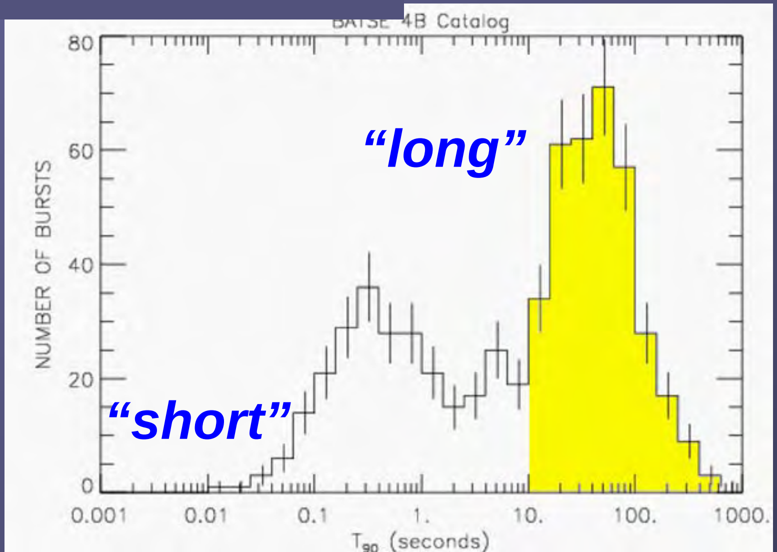
  at 100 MeV-10 GeV

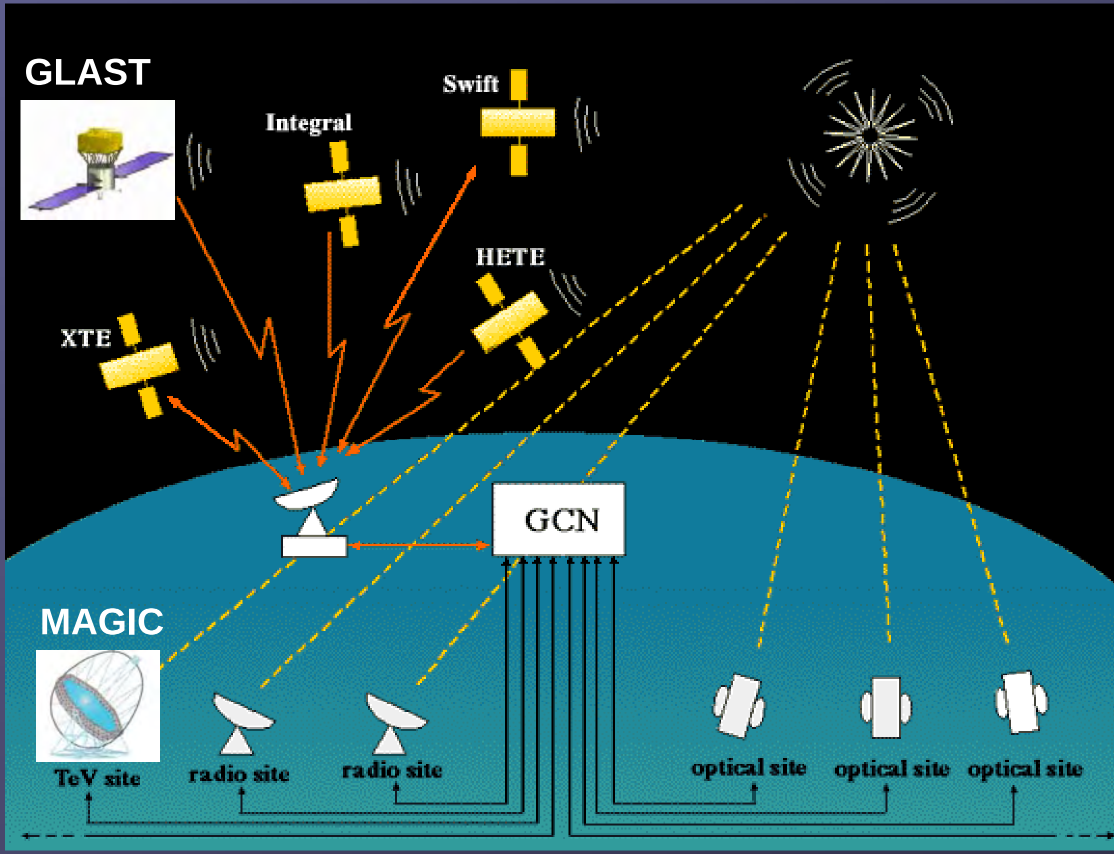
GRB observation by MAGIC

Uniformity



Pulse Duration





~10sec GRB trigger Satellite to MAGIC
<20sec MAGIC slewing time

GRB observation by MAGIC

- A few GRBs/year will be detectable by MAGIC
- Typical gamma ray flux at 10-50GeV
  - $Rate_{exp}$ = 100~1000Hz assuming E^{-2} power law spectrum

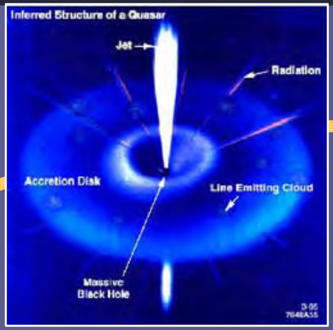
- Test for Quantum Gravity
  - ~10sec time delay are expected at ~100GeV energy from cosmological GRBs
  - Cosmological distance!! High Energy!! High statistics!!
  - Energy dependence, Distance dependence (we need several samples at least)

$$\Delta t \simeq \xi \frac{E}{E_{QG}} \frac{L}{c}$$

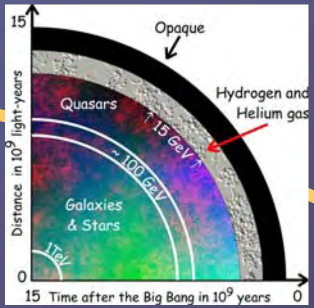
E_{QG} ~10^{19}GeV

MAGIC Physics objectives

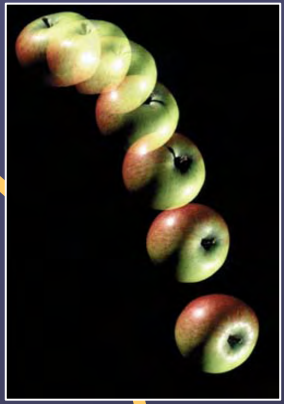
Pulsars



AGNs

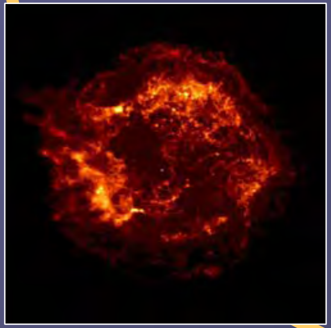


Cosmological γ-Ray Horizon



Quantum Gravity

Origin of Cosmic Rays



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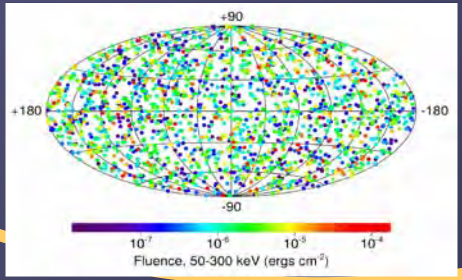
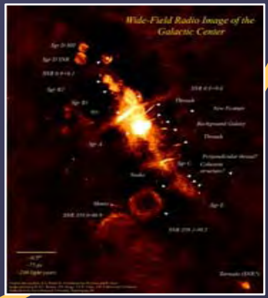
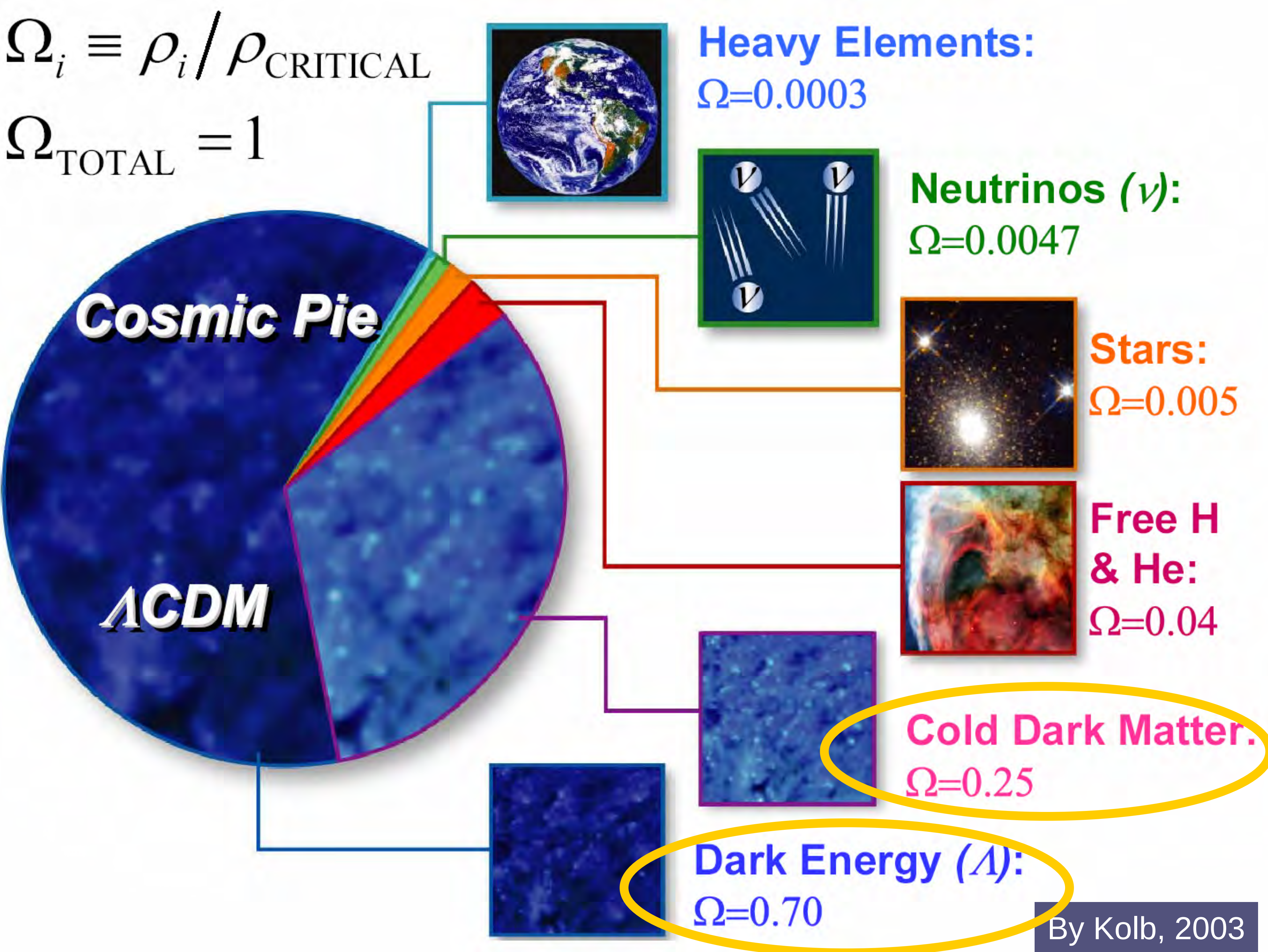


GRBs



Cold Dark Matter


$\Omega_i \equiv \rho_i / \rho_{CRITICAL}$
$\Omega_{TOTAL} = 1$
Cosmic Pie
ΛCDM
Heavy Elements:
Ω=0.0003
Neutrinos (ν):
Ω=0.0047
ν
ν
ν
Stars:
Ω=0.005
Free H
& He:
Ω=0.04
Cold Dark Matter:
Ω=0.25
Dark Energy (Λ):
Ω=0.70
By Kolb, 2003

Total Photon Spectrum from Neutralino annihilation (Bergstroem et al. 1998)

Best Candidate; LSP Neutralino
R-Parity conservation

$$(100\,GeV \leq m_\chi \leq 1\,TeV)$$

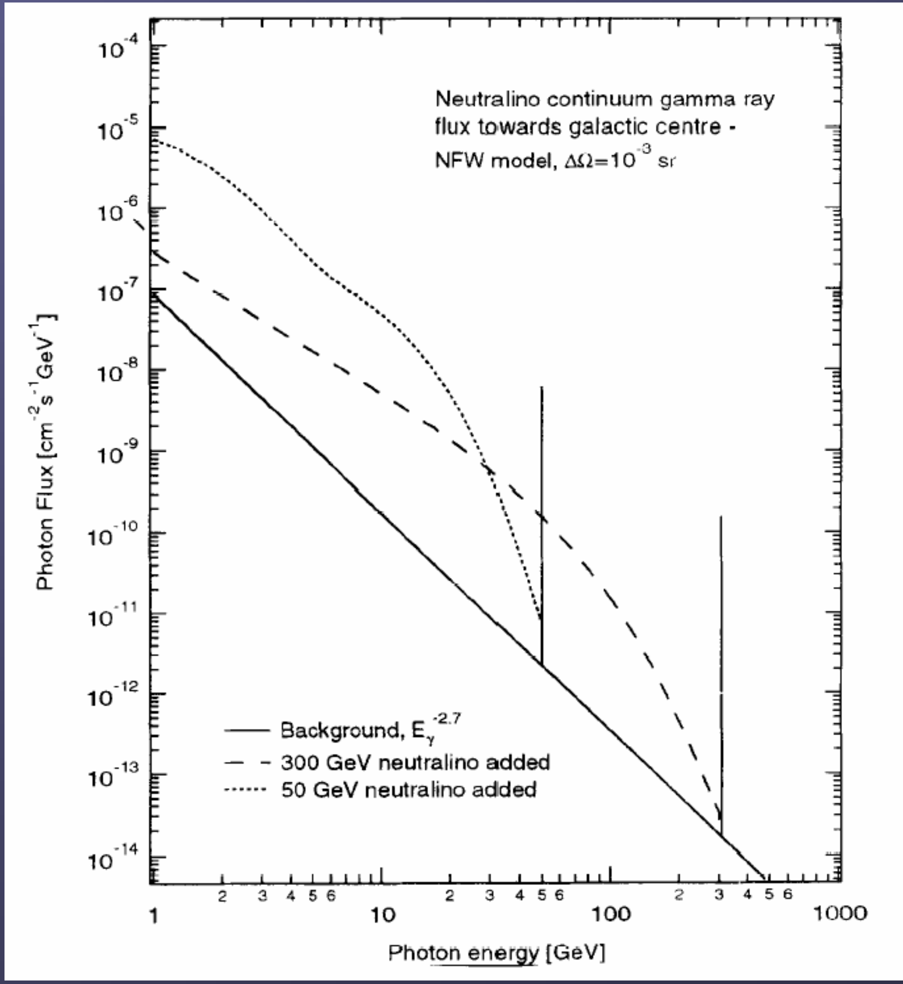
Neutralino Annihilations
→ gamma rays

$$\chi\chi \rightarrow \gamma\gamma \Rightarrow \gamma\text{-line} \;\; E_\gamma = m_\chi$$

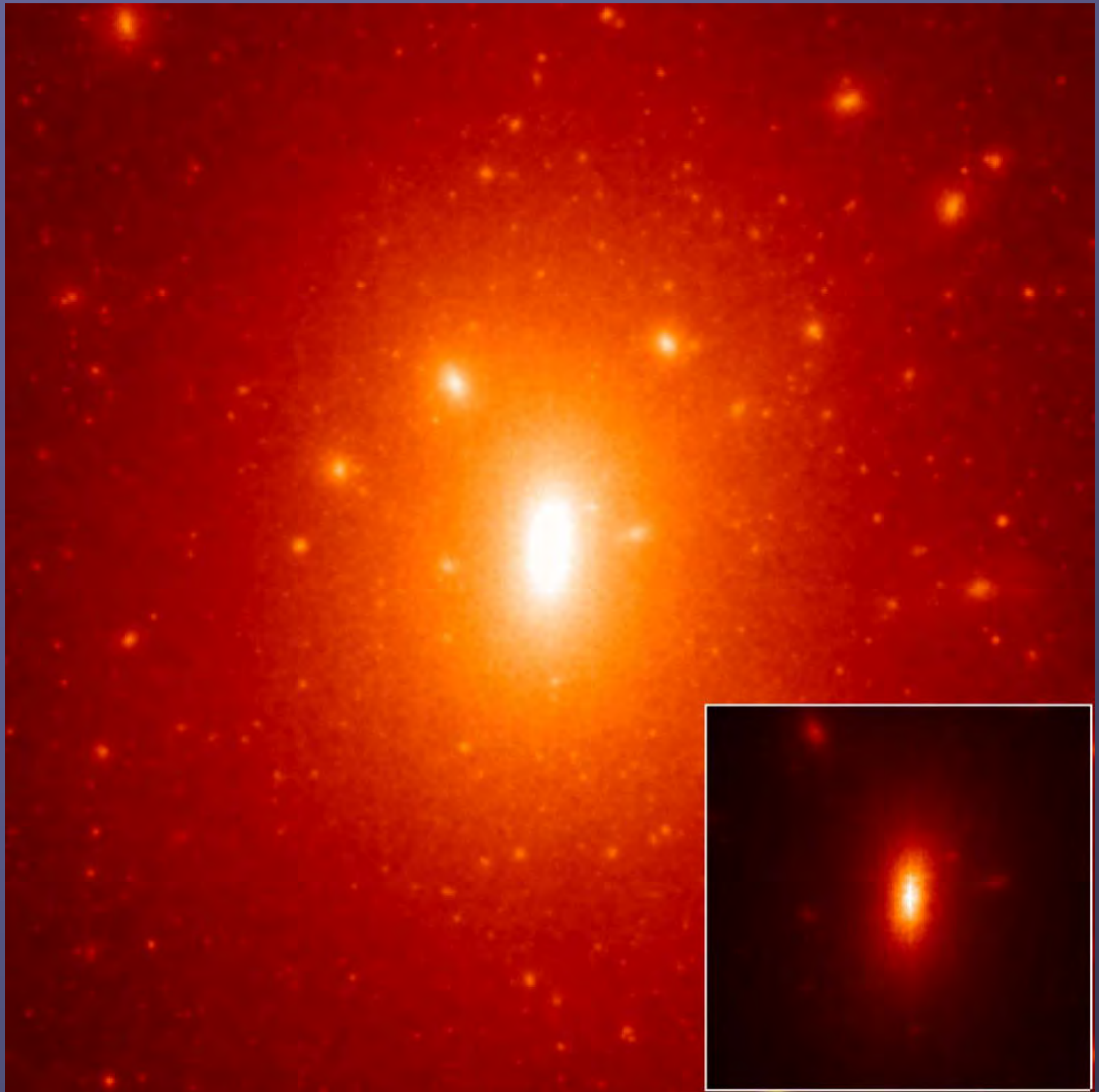
$$\chi\chi \rightarrow \gamma Z \Rightarrow \gamma\text{-line} \;\; E_\gamma = m_\chi - m_Z^2/4m_\chi$$

$$\chi\chi \rightarrow \bar{q}q \Rightarrow \gamma \text{ continuum}$$

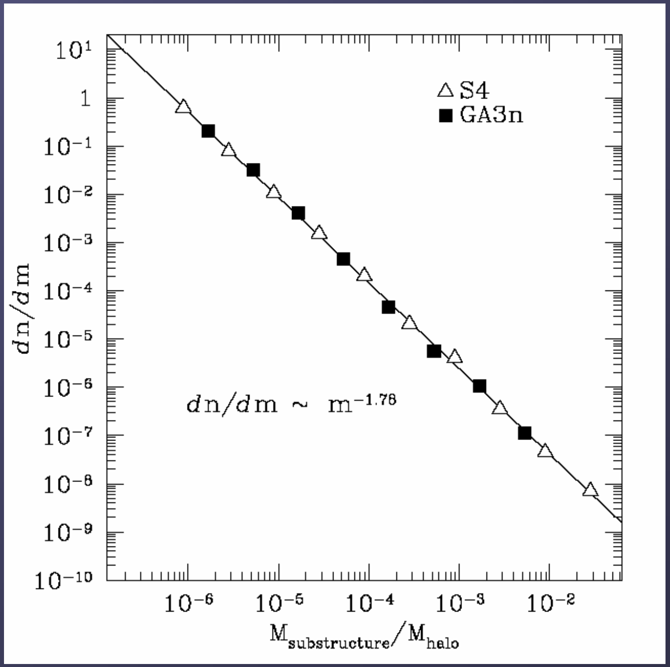
$$\Phi_\gamma(\Omega) = \frac{N_\gamma v\sigma}{4\pi \cdot M_\chi^2} \cdot \int \rho_{DM}{}^2(l)\,dl(\Omega)$$



Galactic Center distribution of DM
Stoehr et al. 2003

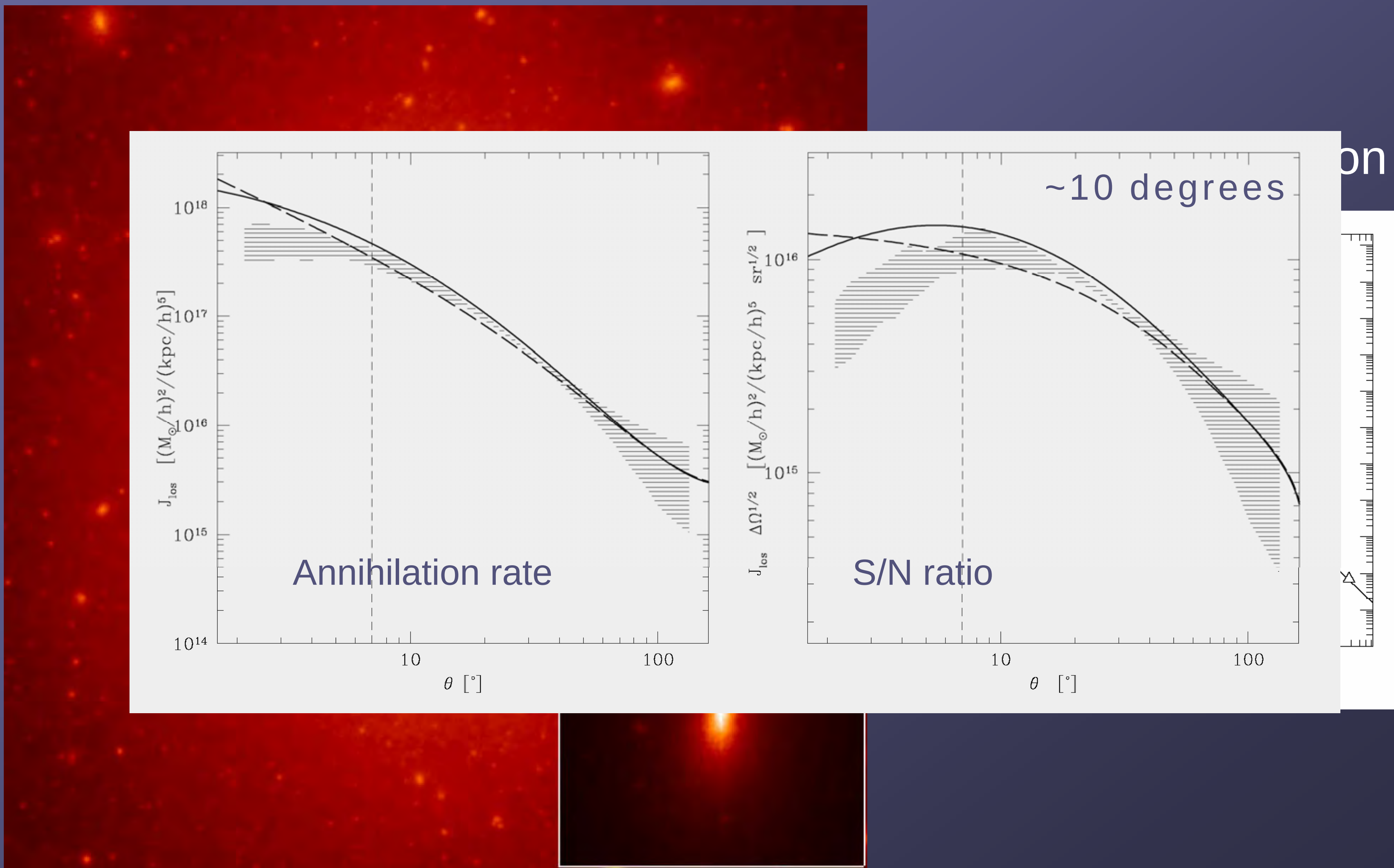


Subhalo mass function



Galactic Center distribution of DM

Stoehr et al. 2003



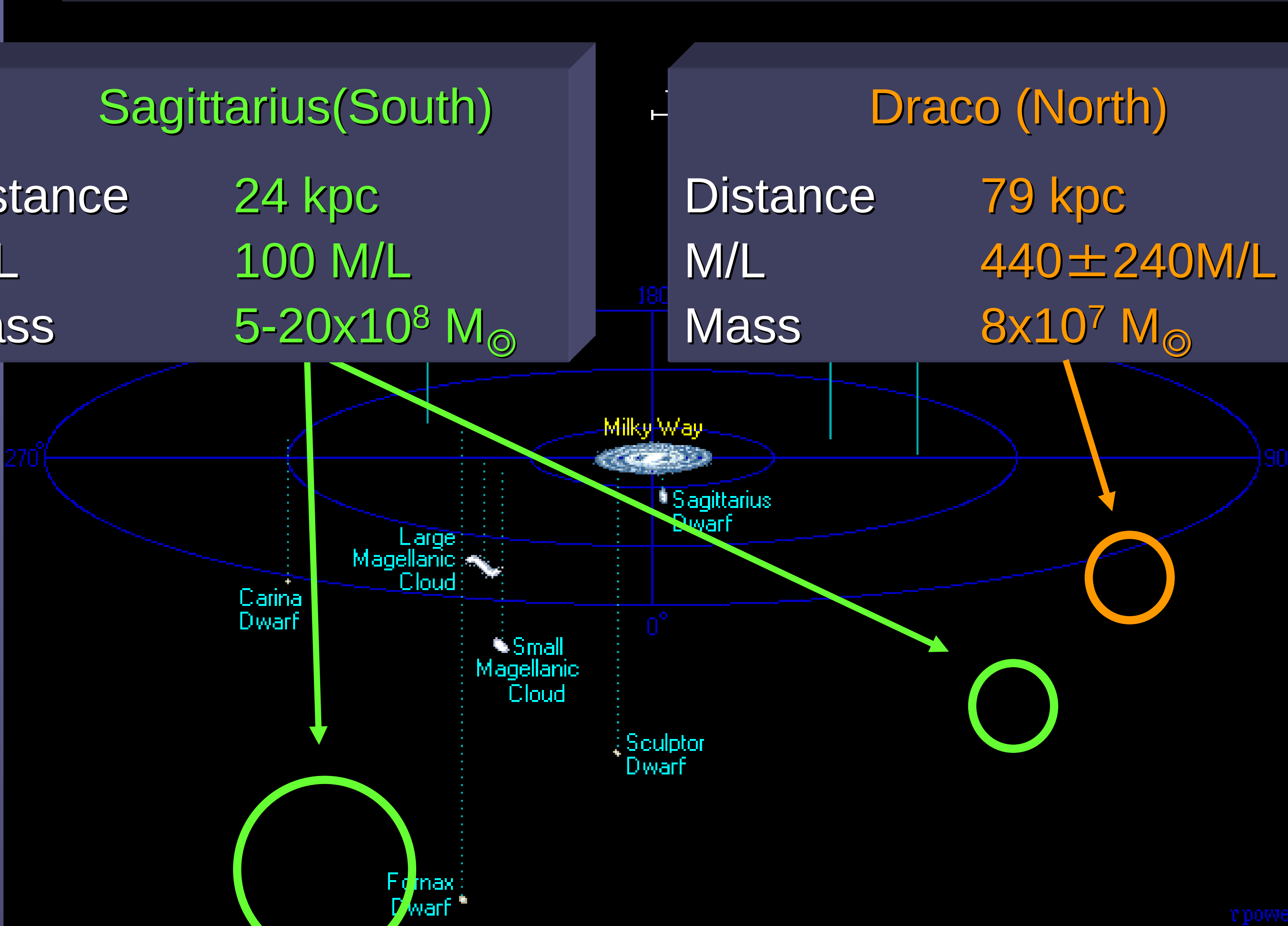
Nearby Dwarf Galaxies

Sagittarius(South)

Distance	24 kpc
M/L	100 M/L
Mass	5-20x10^{8} $M_{\odot}$

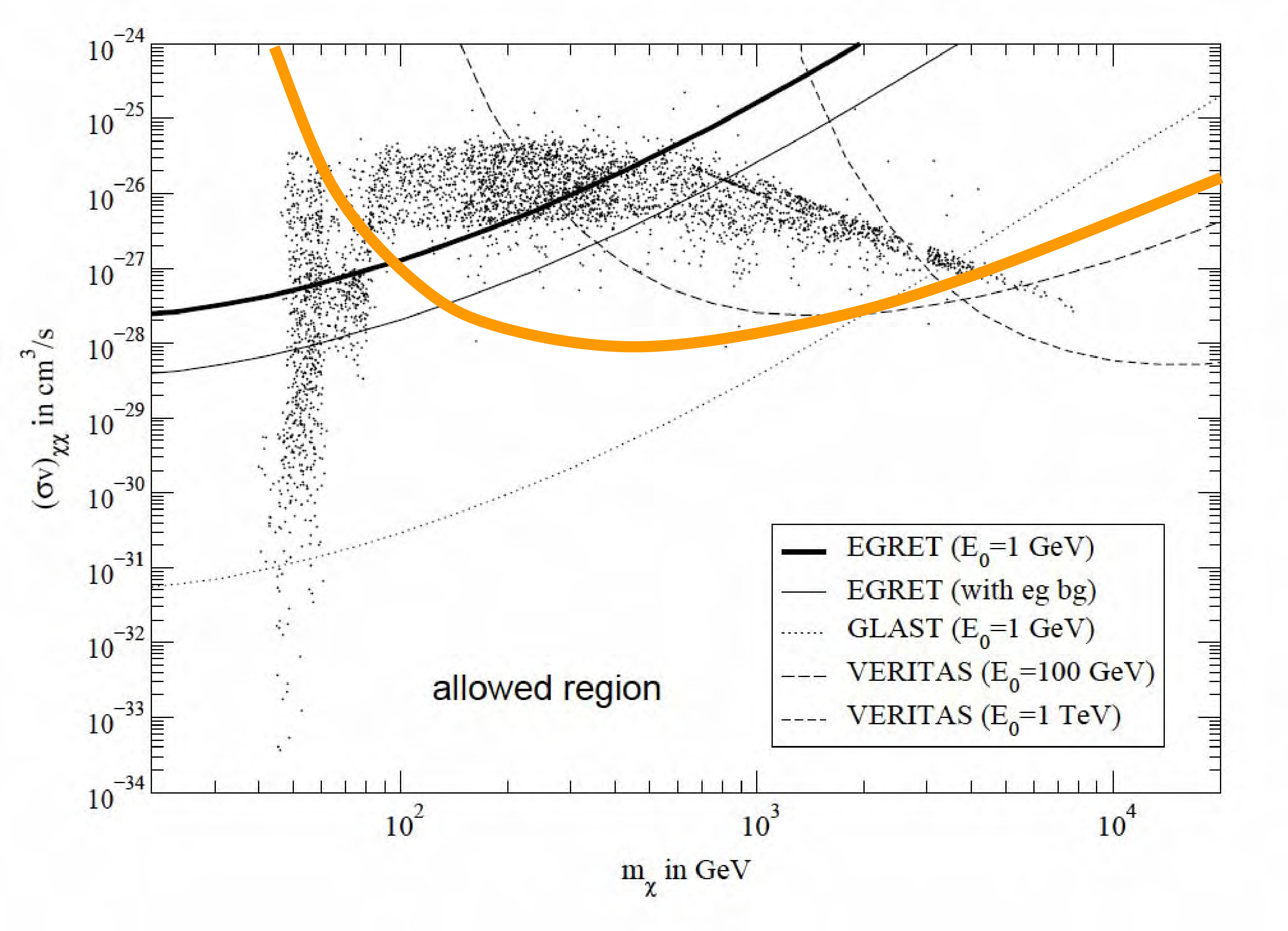
Draco (North)

Distance	79 kpc
M/L	440±240M/L
Mass	8x10^{7} $M_{\odot}$



Draco Dwarf Galaxy

C.Tyler 2002



WIMPZILLA footprints:

Isocurvature modes: CMB, Large-scale structure

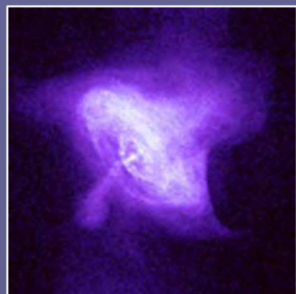
Decay: Ultra High Energy Cosmic Rays

Annihilate: Galactic Center, Sun

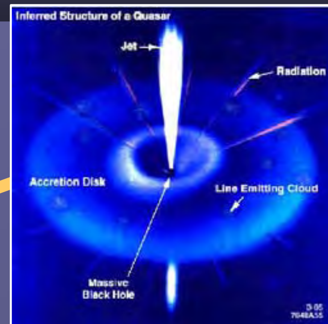
Direct Detection: Bulk, Underground Se

By Kolb, 2003

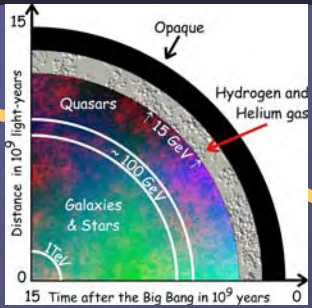
MAGIC Physics Objectives



Pulsars



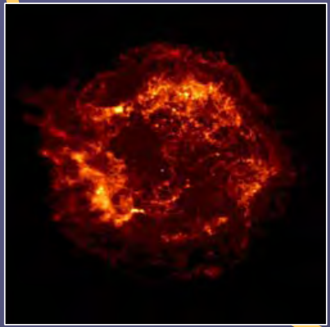
AGNs



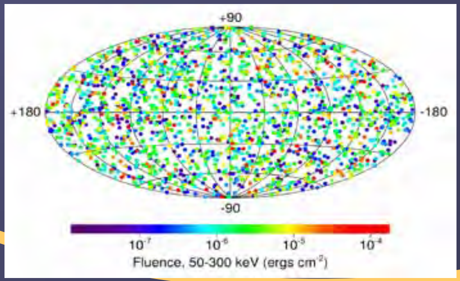
Cosmological γ-Ray Horizon

Quantum Gravity

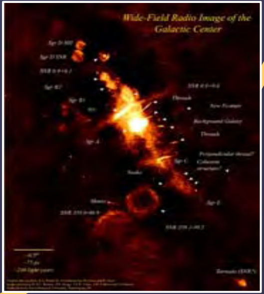
Origin of Cosmic Rays



SNRs



GRBs

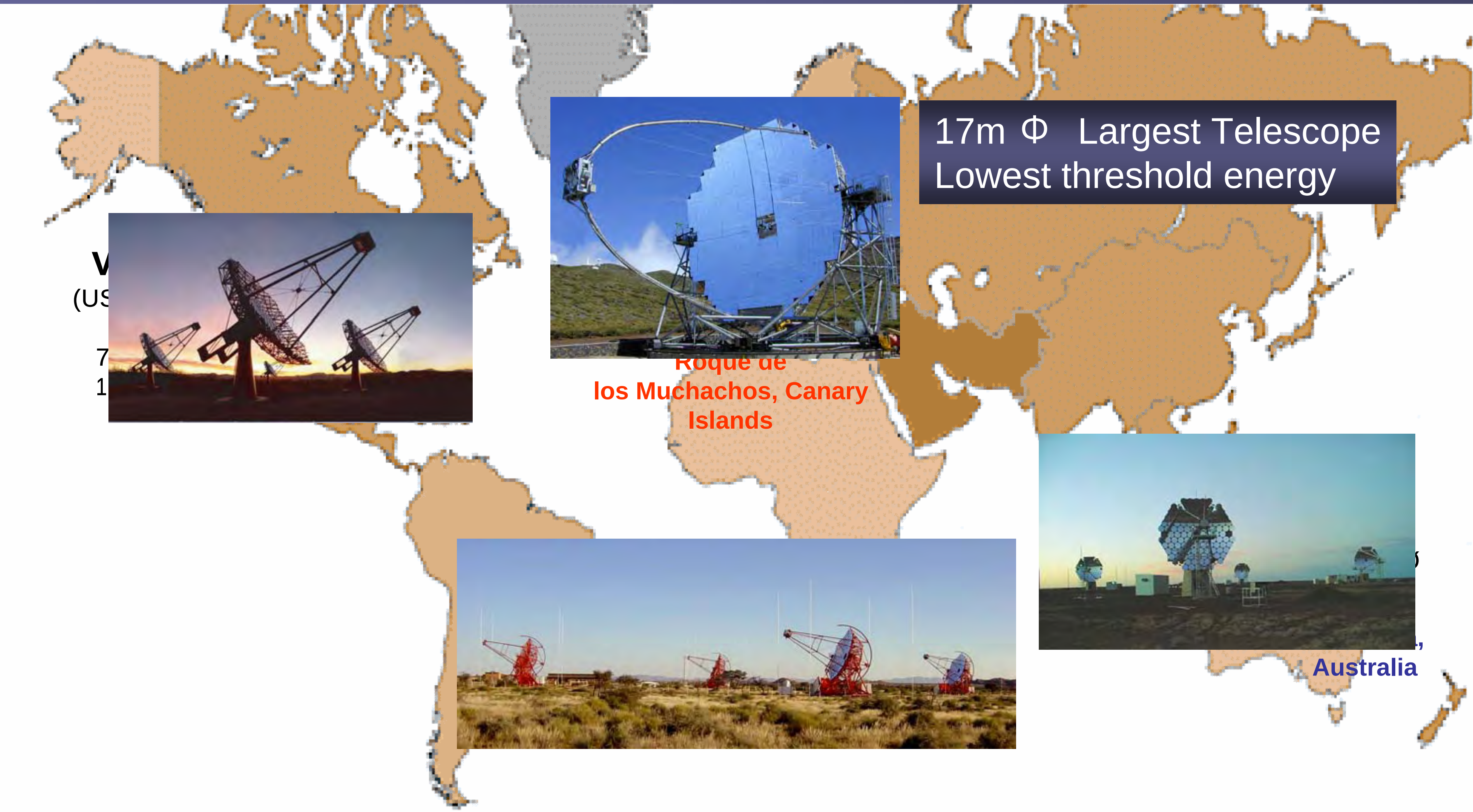


Cold Dark Matter

Gamma Ray Detectors

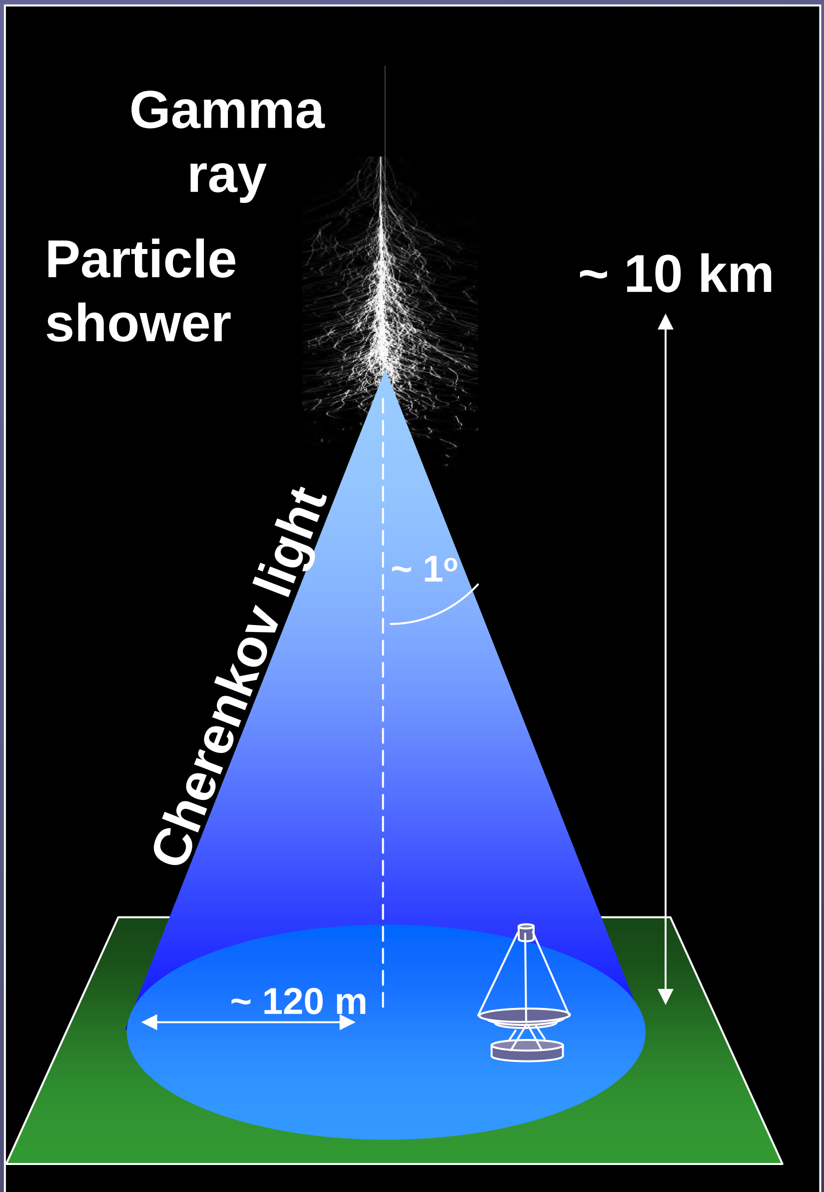
Imaging Air Cherenkov Telescopes

Ground based gamma ray astronomy
Big Four!!



17m Φ Largest Telescope
Lowest threshold energy

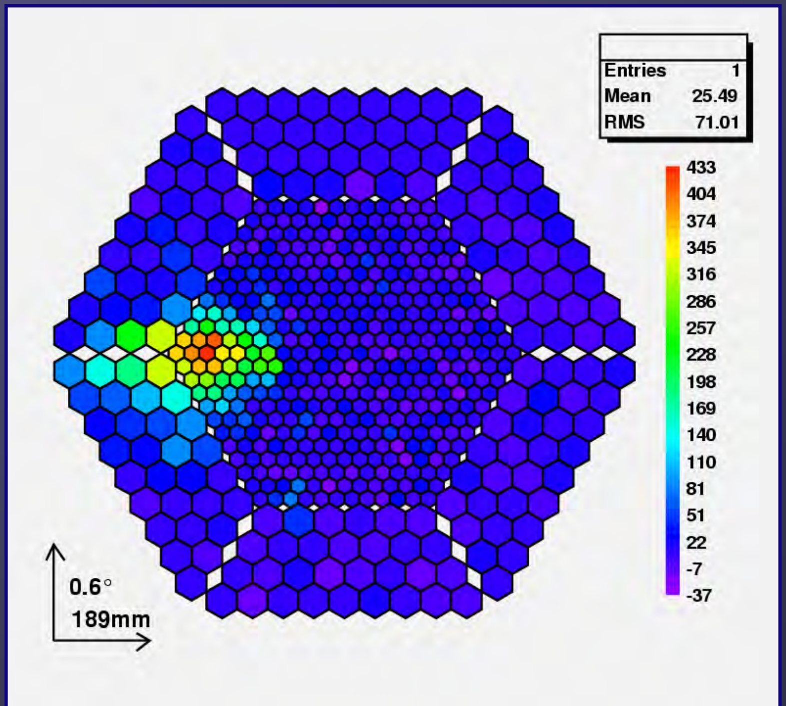
Atmospheric Imaging Cherenkov Telescope



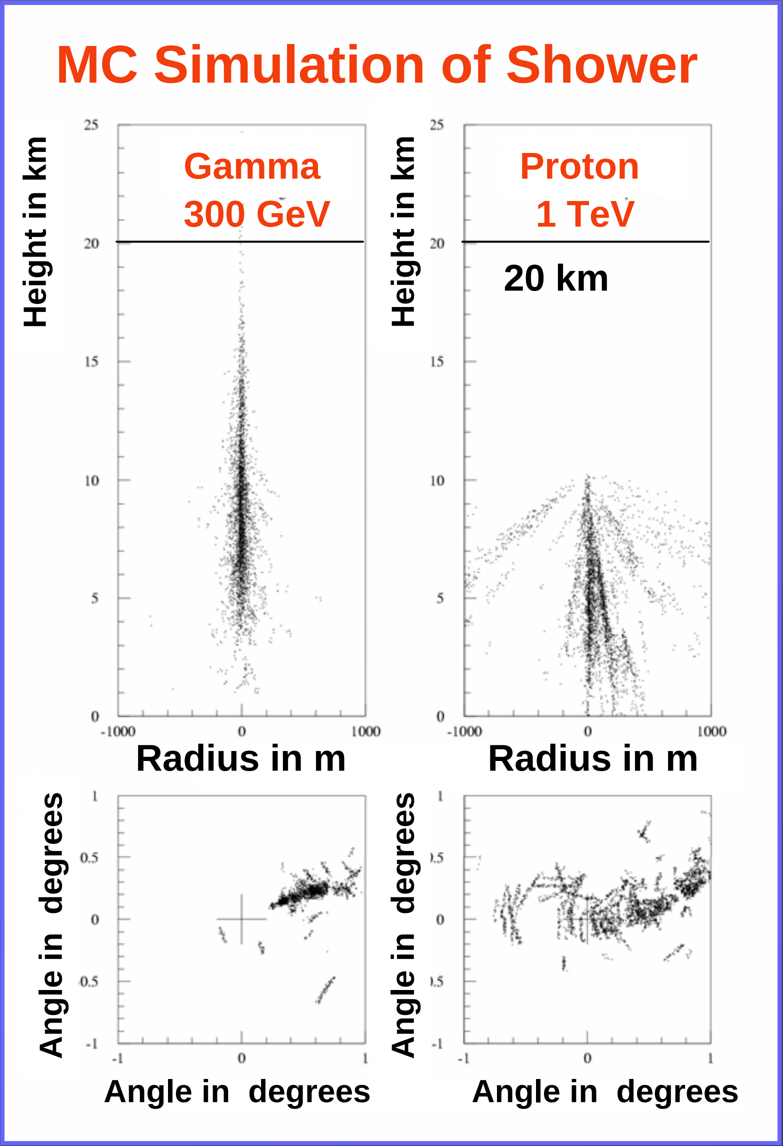
Cherenkov light from gamma ray showers

~100 photons/m^2 @1TeV gamma
➔ Photon hungry experiment

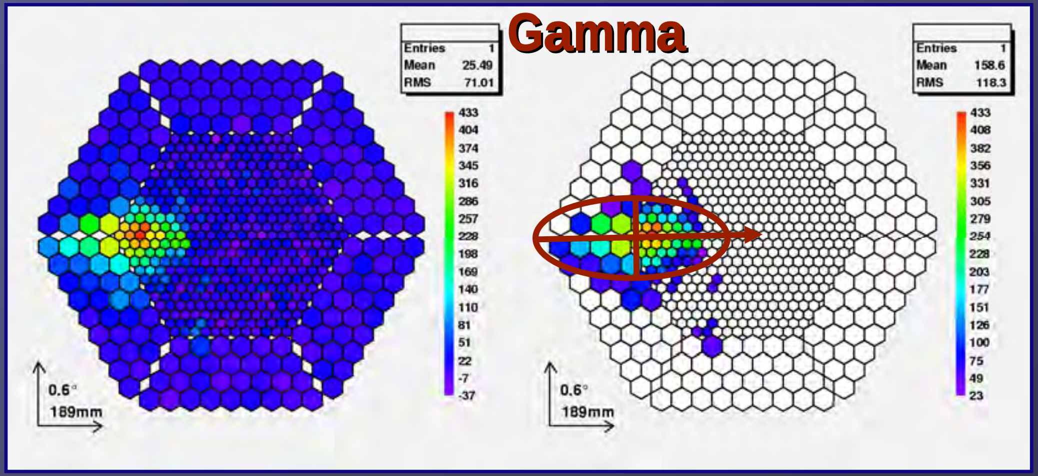
Effective area ~ 10^5m^2

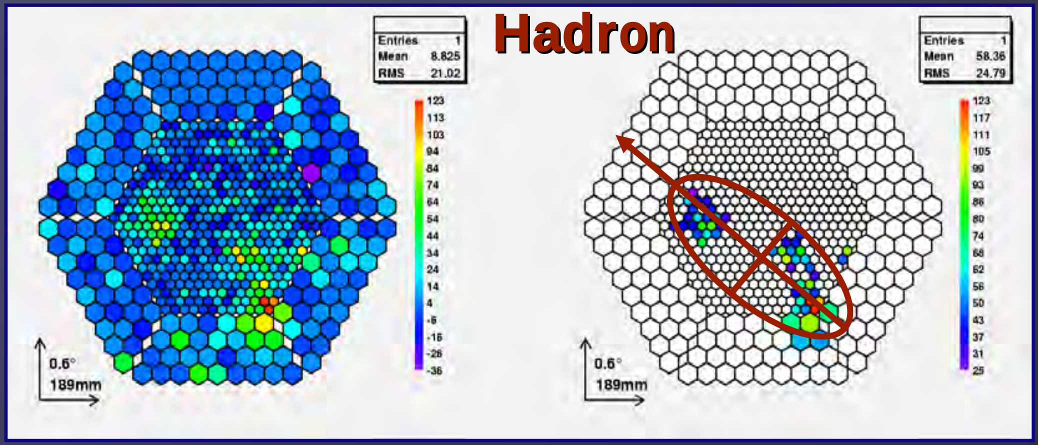


Gamma/Hadron separation



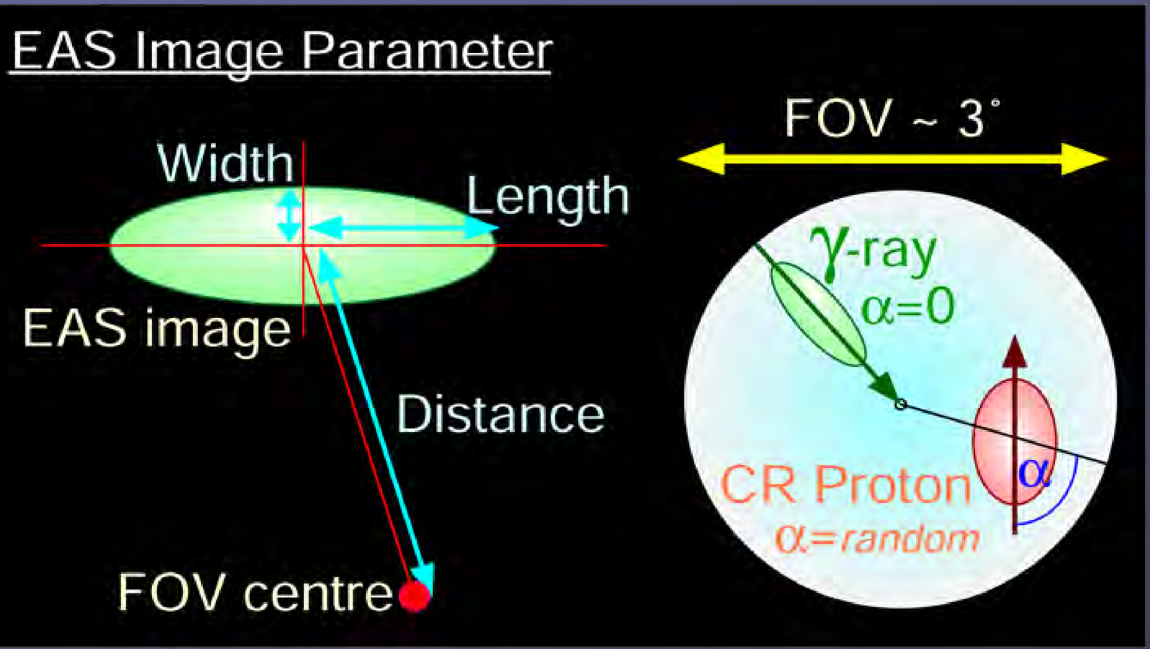
Hadron Rejection by Image ~99%

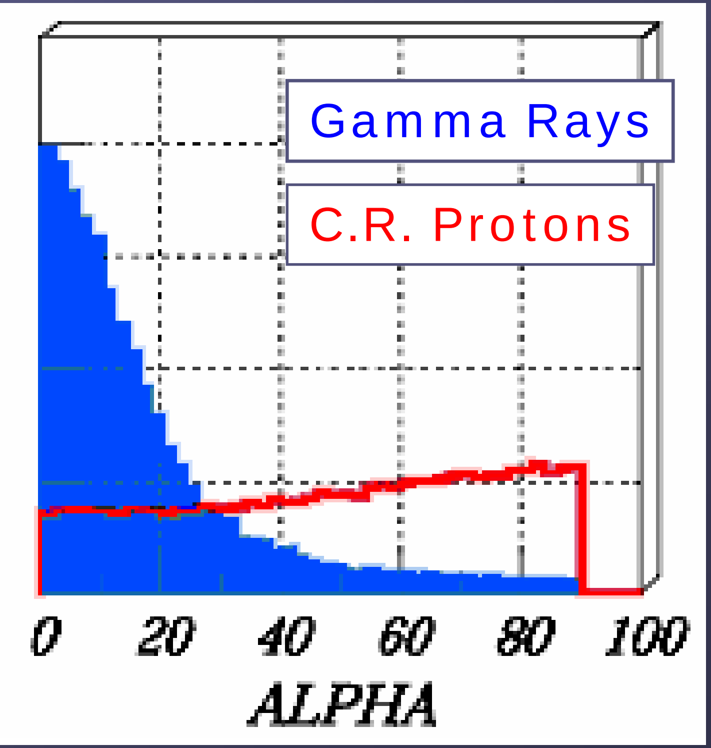




Alpha (Orientation angle) distribution

Hadron rejection by orientation α~90%

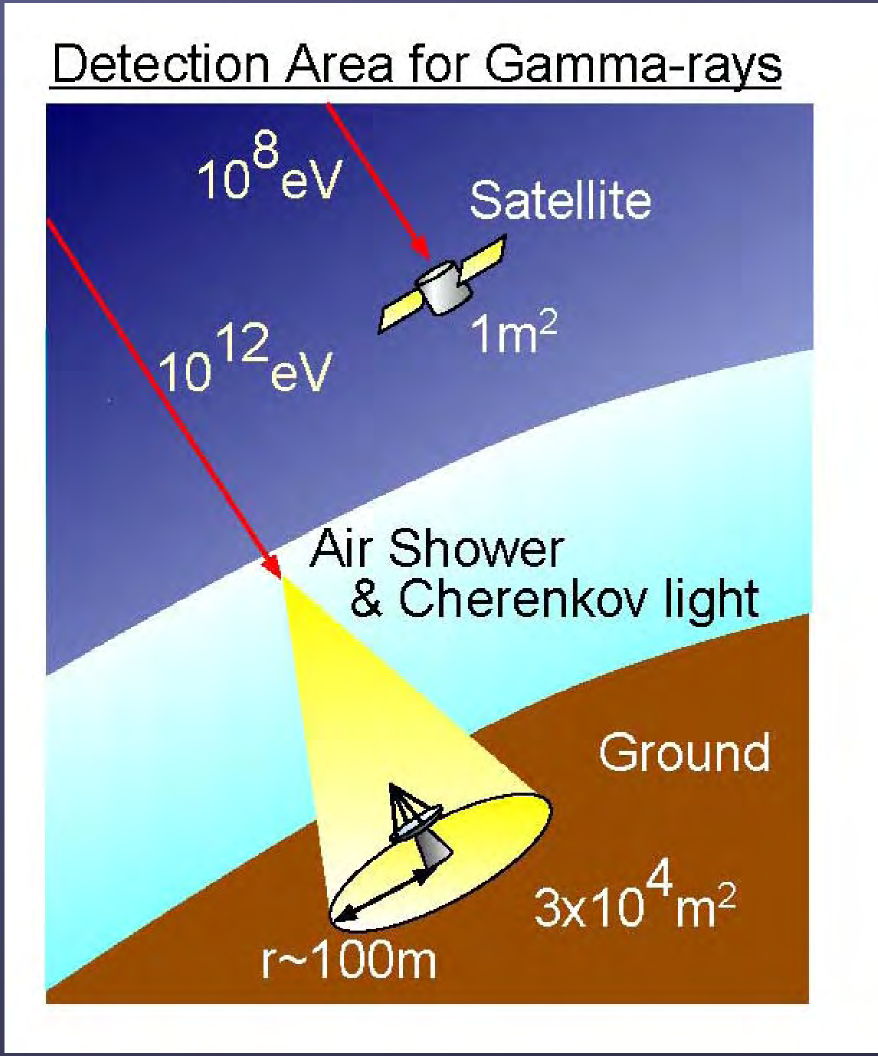




Before Image & Orientation cut N_S/N_B ~1/1000
After Image & Orientation cut N_S/N_B ~1/1

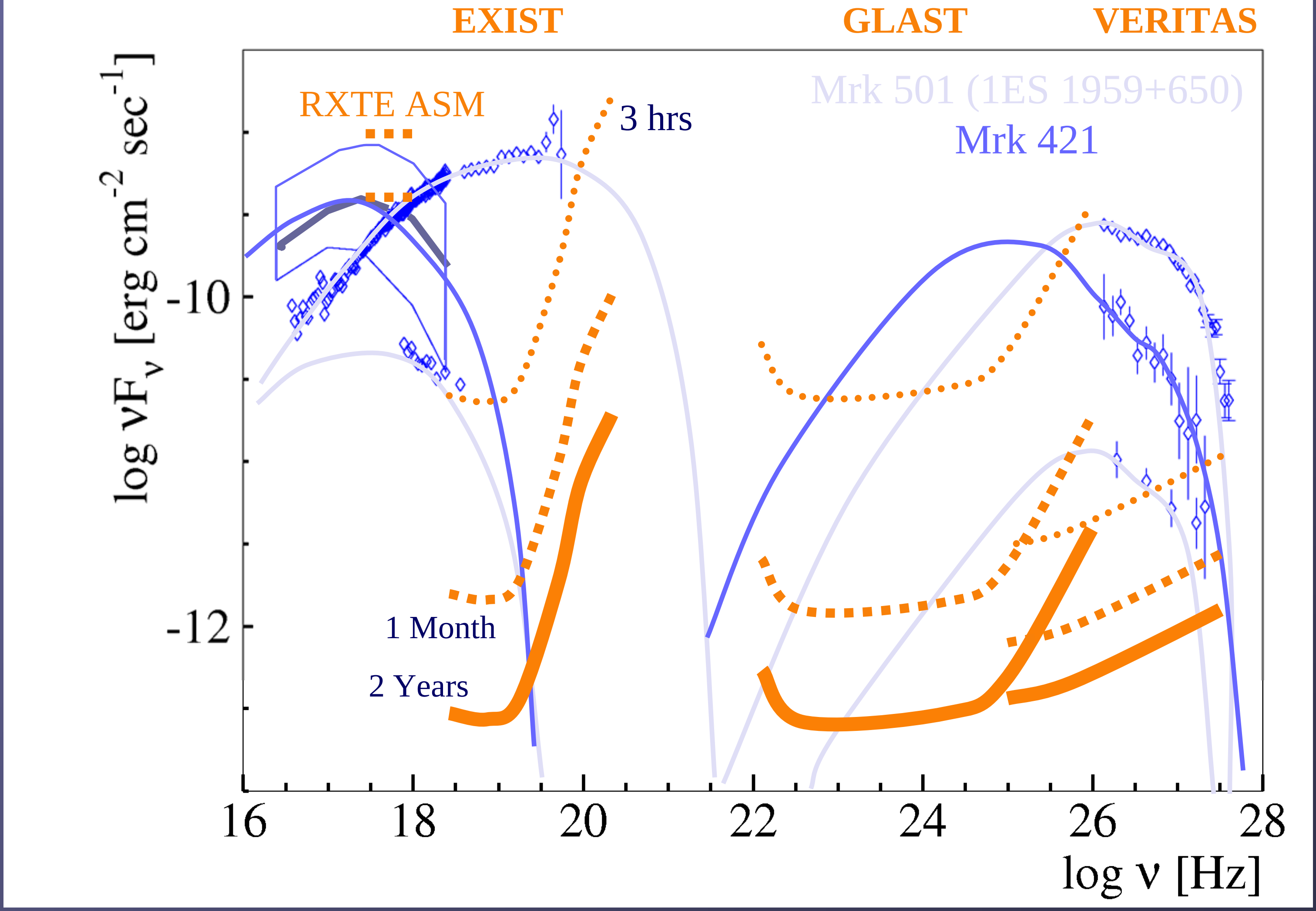
IACT vs. Satellite Complimentary

	Satellite GLAST	Ground MAGIC
Gamma-ray detection	Direct (pair creation)	Indirect (atmospheric Cherenkov)
Energy	Up to 100GeV	From 40GeV
Positive aspects	High S/N Large FOV	Large area Good $\Delta\theta$
Negative aspects	Small area High cost	Large Background Small FOV Only moonless night



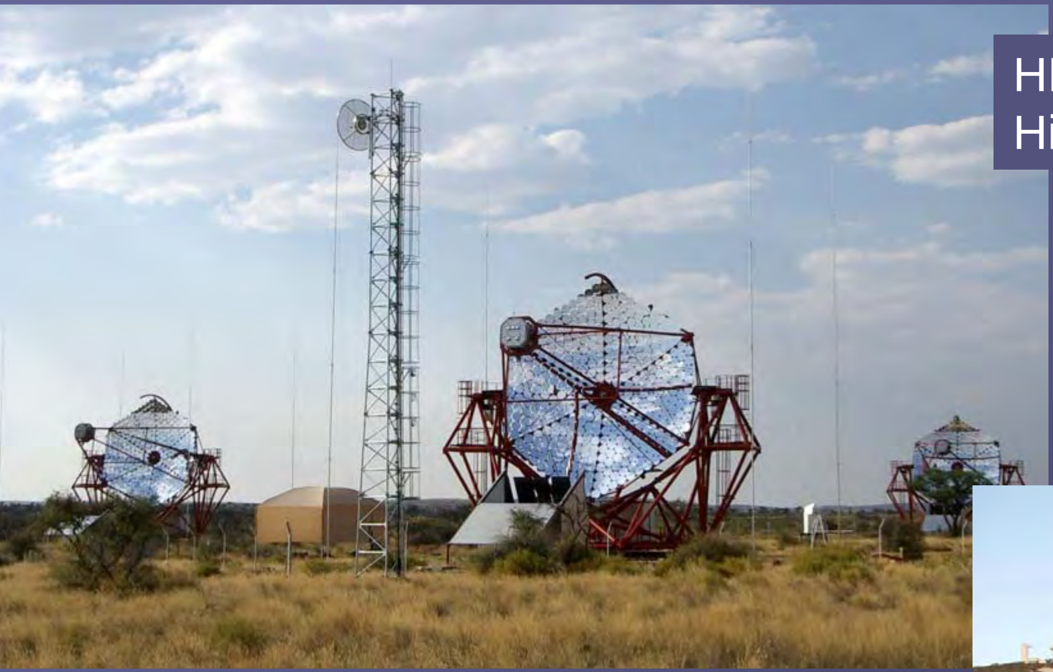
Detector Sensitivities For TeV Blazars

by P.Copi

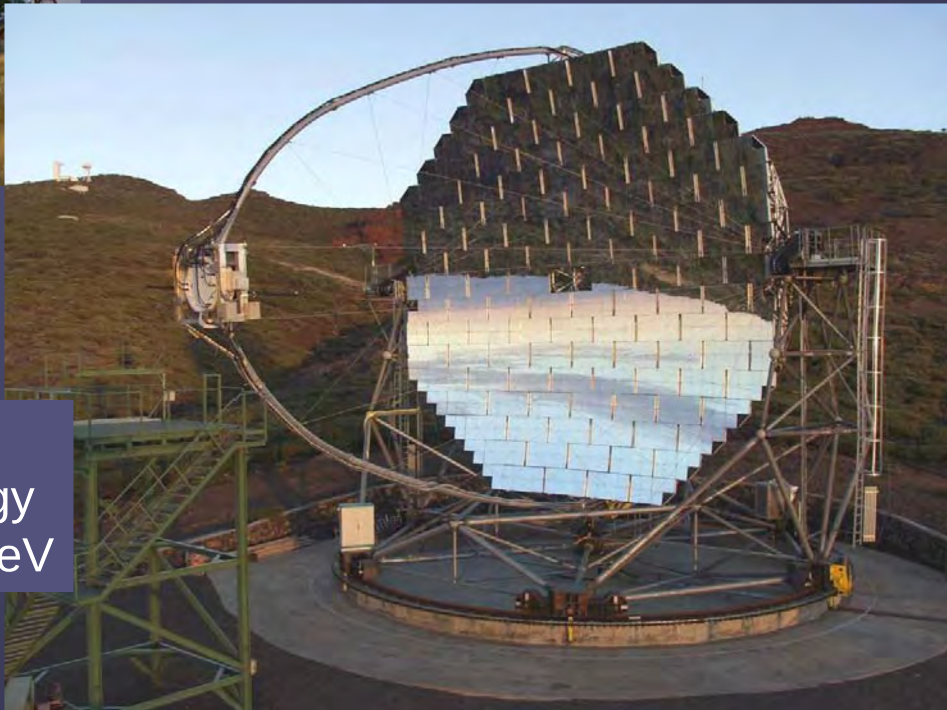


- EXIST: Synchrotron Emission from “Blue” TeV Blazars

Array System or Single Big Telescope



HESS, VERITAS, CANGAROO Concepts
High Precision measurement



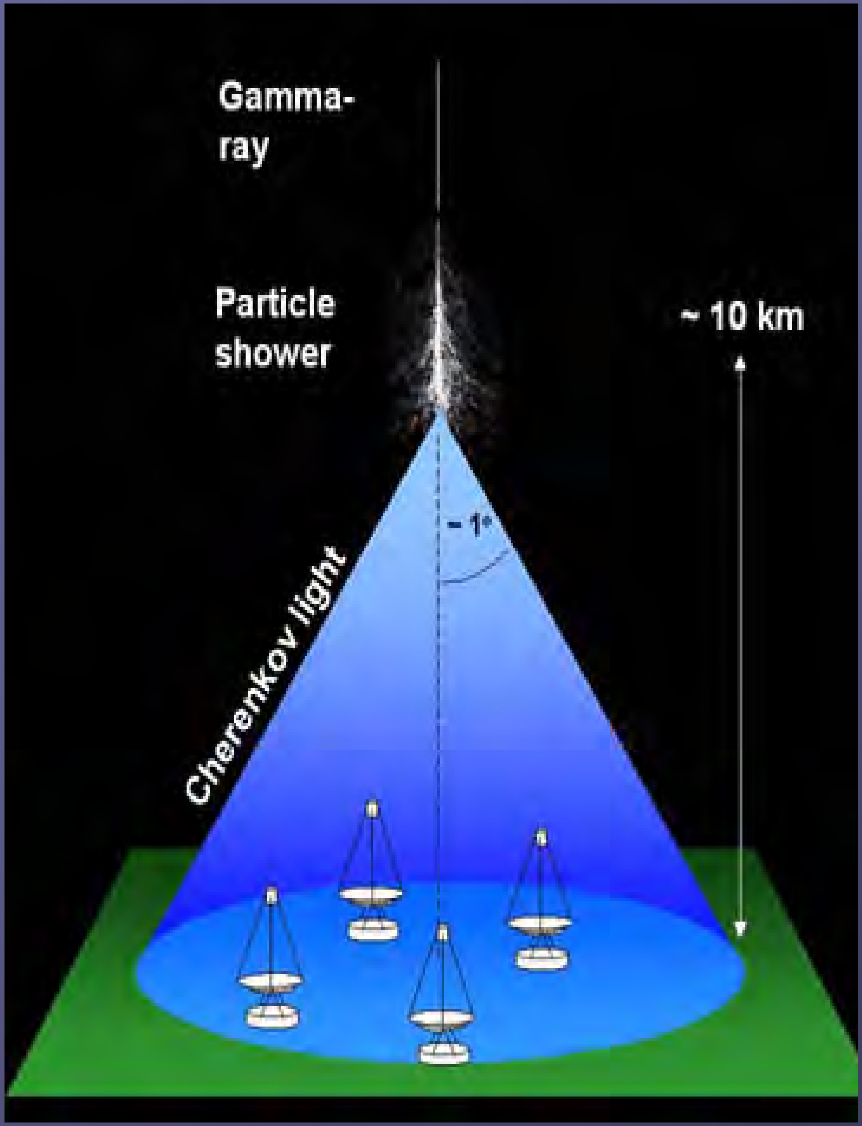
MAGIC Concepts
Low Threshold Energy
Eth > 50GeV → 30GeV

Extension of HESS, MAGIC
No rule in competition

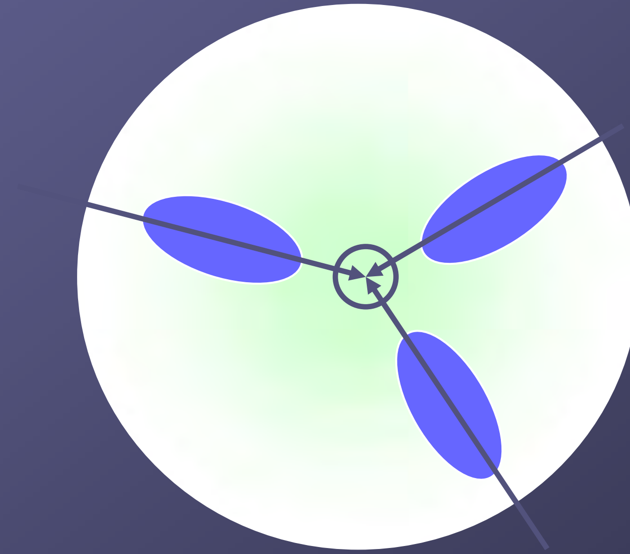
HESS-II
28m diameter telescope
Lower threshold energy

MAGIC-II
2x17m, High Q.E. detectors
Lower threshold energy
High Precision

Stereo system



Cherenkov Images



Multiple Telescopes:

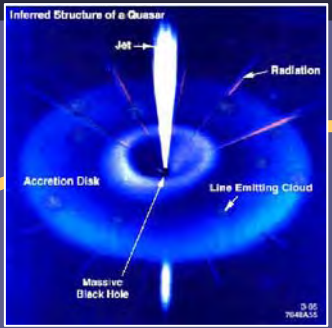
improve angular resolution
reduce background

But n-times expensive

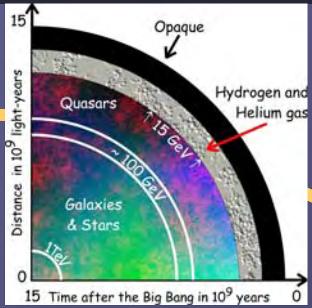

MAGIC

MAGIC Physics Objectives

Pulsars



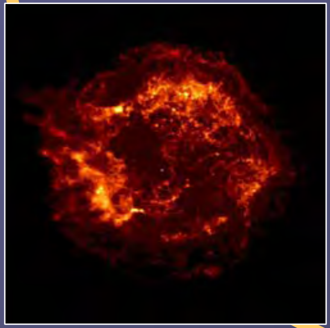
AGNs



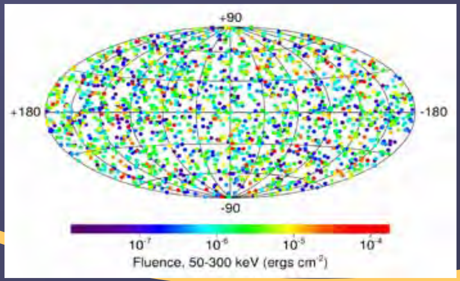
Cosmological
γ-Ray Horizon

Quantum Gravity

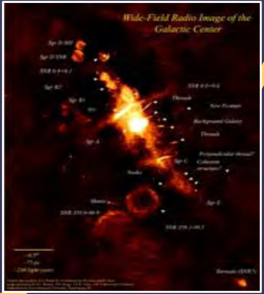
Origin of
Cosmic Rays



SNRs



GRBs

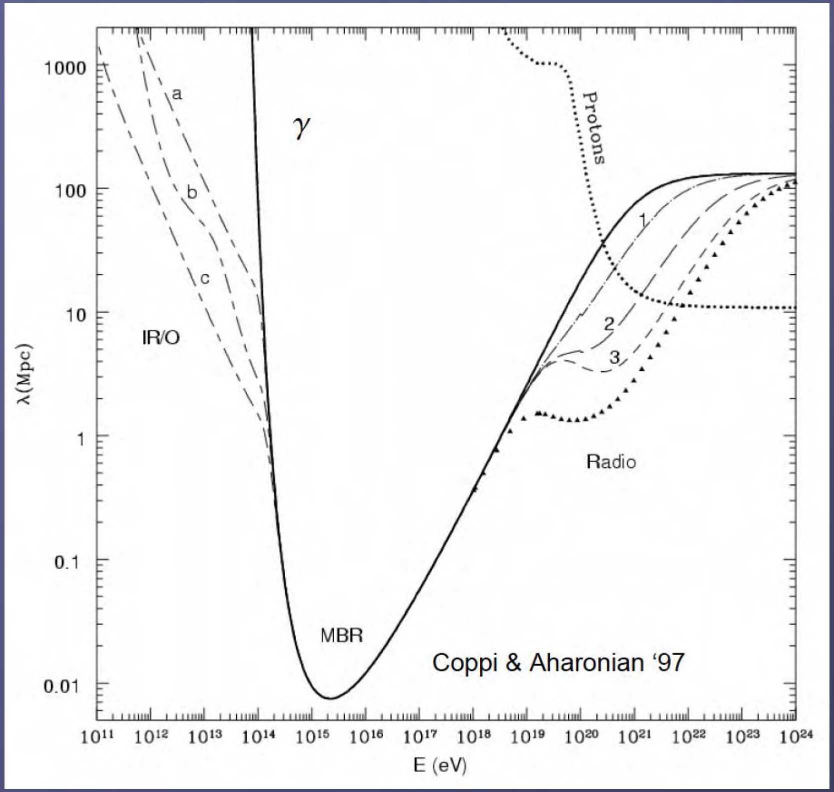


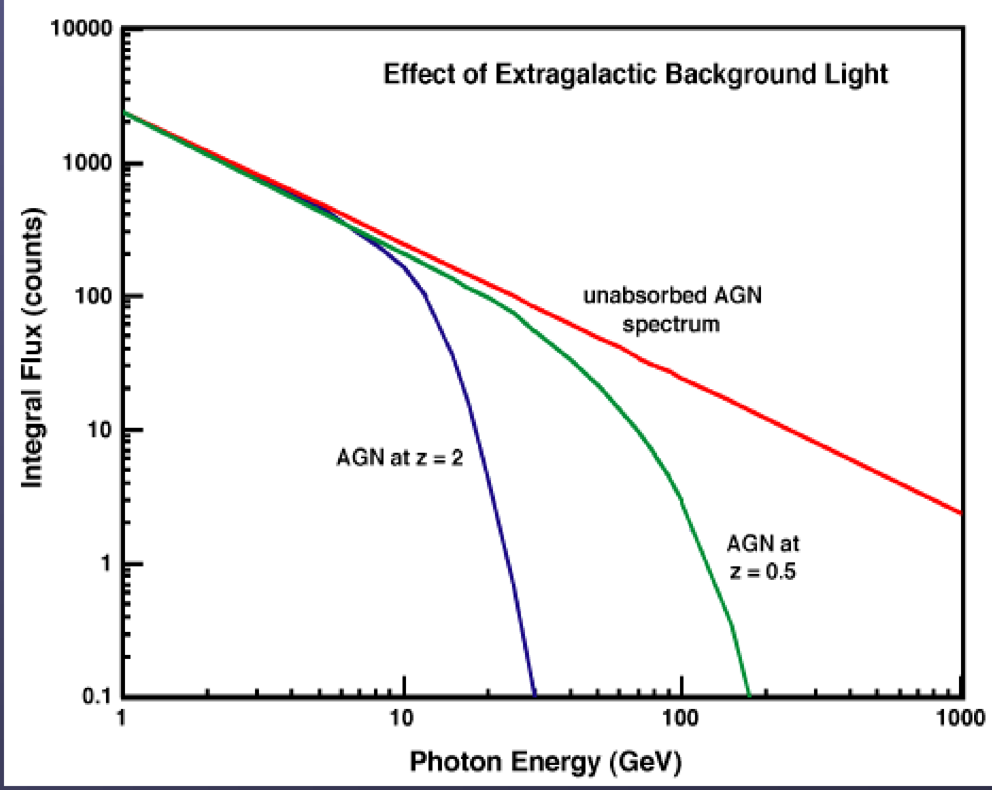
Cold Dark Matter

Why do we want to move lower energy range?

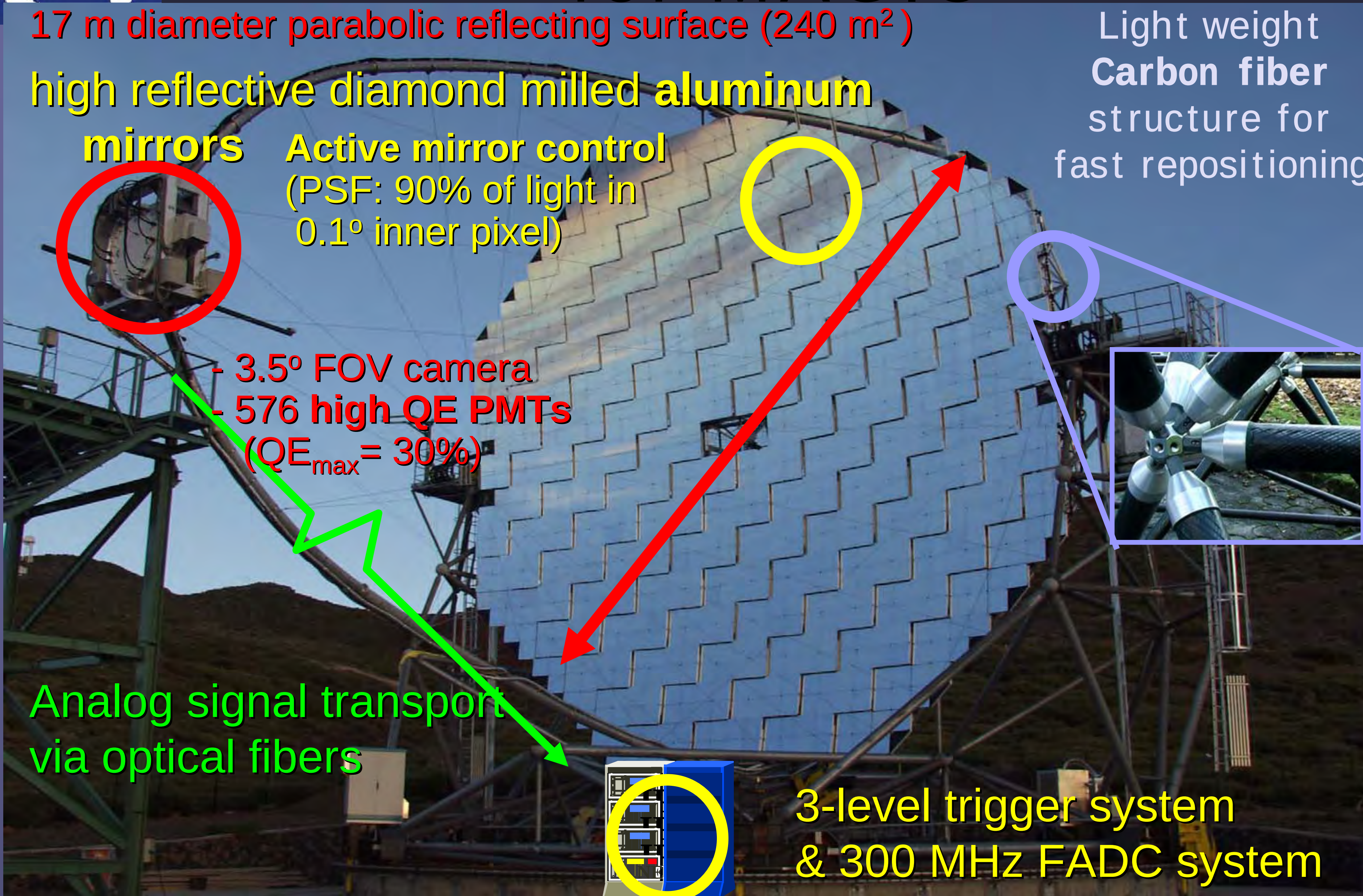
Cosmological Gamma ray absorption

Pair Creation; $\gamma + \gamma \rightarrow e^+ + e^-$





Key technological elements for MAGIC



Signal to Noise ratio

- Data quality depends on two conditions
  - Background night sky background
    - ~2000 photons / nsec sr m^2 in 300nm-600nm
  - Signal to Noise; $S/\sqrt{B} \propto A^{1/2}\ \varepsilon^{1/2}\ \Delta T^{-1/2}\ \Delta\Omega^{-1/2}$
    - A – Mirror Area – 17mΦ
    - ε – photon collection efficiency – high Q.E. devices
    - ΔT – Integration time – ultra FAST readout system
    - $\Delta\Omega$ – solid angle – finer pixelization of 0.1 degrees
  - Image quality ; $S = \rho A \varepsilon \geq 50{\sim}100$
    - In order to get a reasonable quality for the image
- In reality, the threshold energy of cherenkov telescope was so far proportional to mirror area.

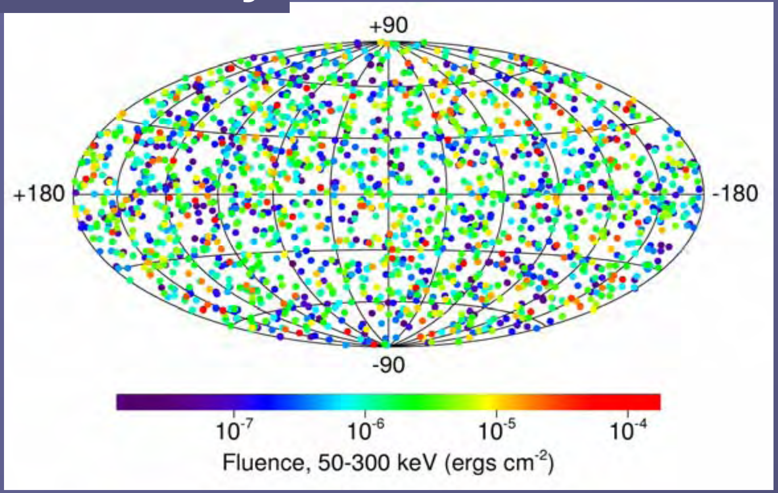
The MAGIC Telescope

(Major Atmospheric Gamma Imaging Cherenkov Telescope)

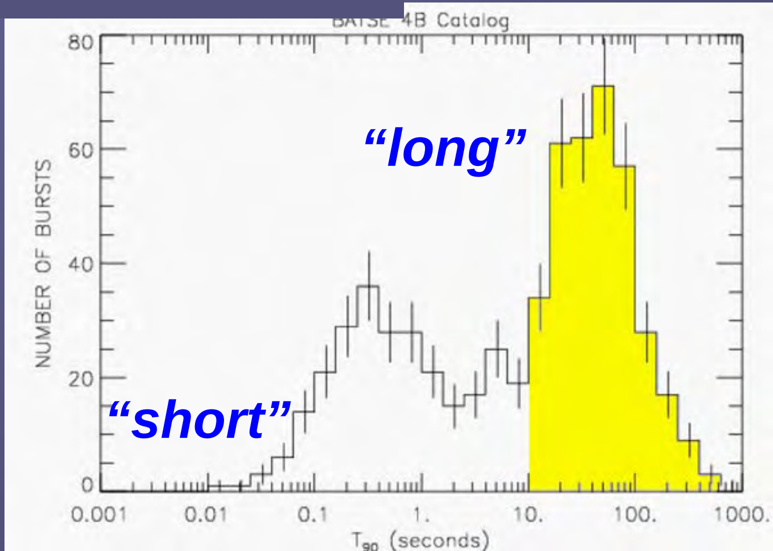
- Many new technologies
  - Lower threshold energy (AGN, GRB, distant sources)
    - *A* ➔ Large mirror area 17m Φ
    - ε ➔ Improved Q.E. Hemispherical PMTs
    - ΔT ➔ Palabolic mirror – minimize time dispersion of photons
    - ΔT ➔ Analog signal transmission by optical fibers
    - ΔT ➔ 300 MHz FADC → upgrade to 2GHz FADC
    - $\Delta \Omega$ ➔ 0.1 degree fine pixel camera
    - 3 Level triggers
  - Fast rotation(<20sec); for GRB observation
    - Low weight Carbon Fiber Space Frame construction, 5tons
    - Light weight All Alminum Mirrors
    - Active mirror control – compensate small frame distortion (~0.1 deg)

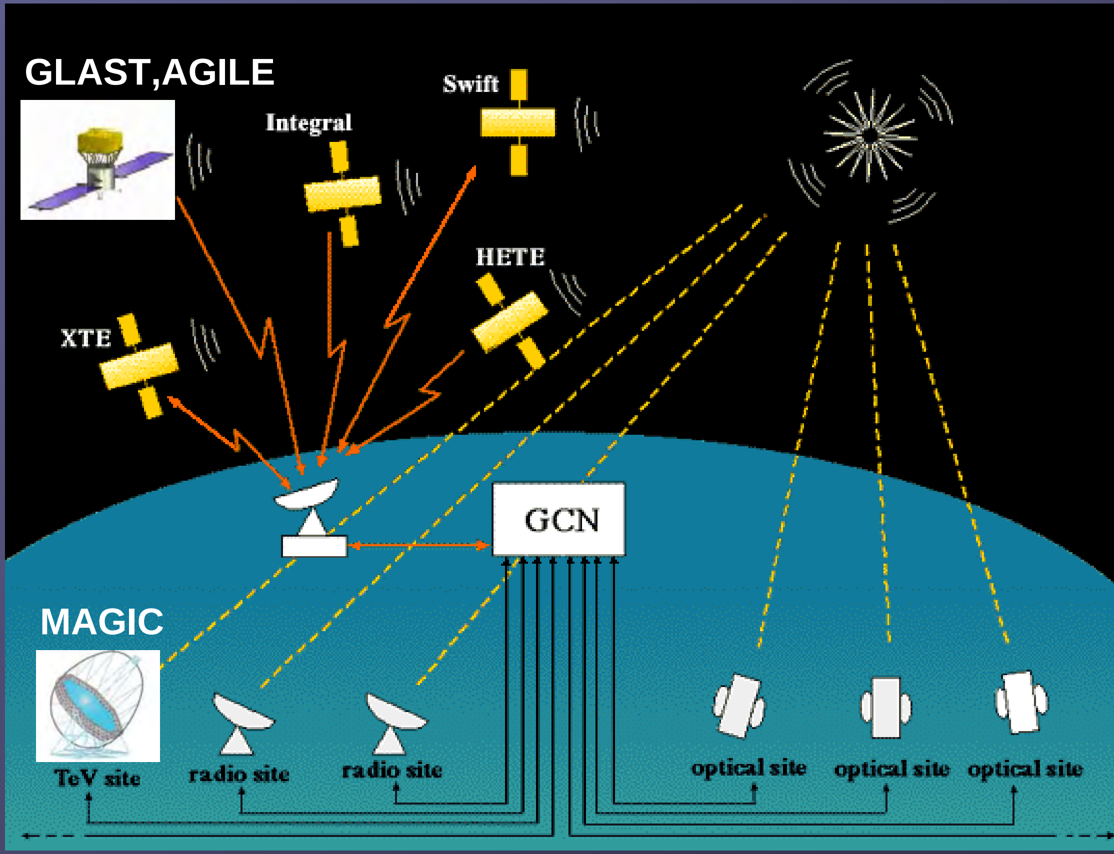
GRB observation by MAGIC

Uniformity



Pulse Duration





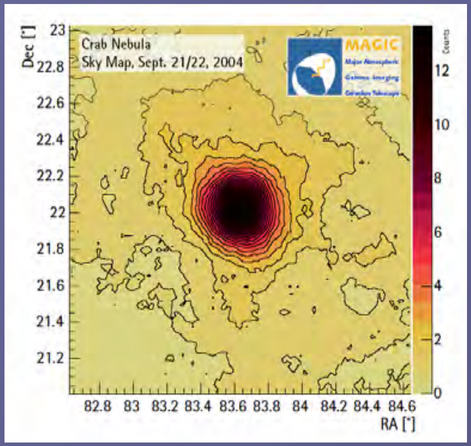
10~20sec GRB trigger Satellite to MAGIC
<30sec MAGIC slewing time

GRB050713A ➔ 40sec after the burst
GRB050904 ➔ 80 sec after the burst

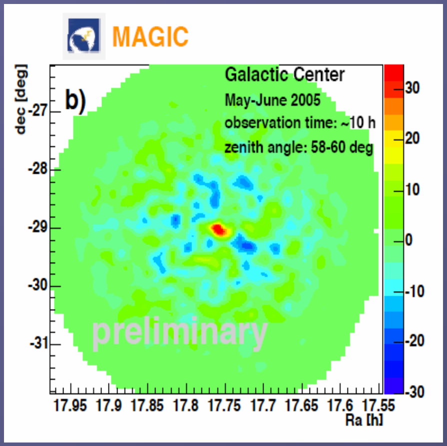
Current Status of MAGIC

- The first telescope is now in regular scientific operation
  - We have understood well our telescope
    - M.C. explains real data well
    - The trigger threshold energy is now ~50GeV
    - Tight cut >100GeV ➔ sure results on several sources
  - GRB fast follow-up observation function was partially implemented (~50% speed)
    - It will be upgraded to full performance (full speed)
    - GRB050713A was successfully observed 40 seconds after the beginning of burst

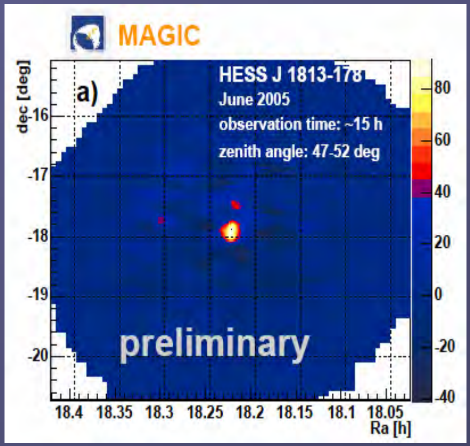
Highlights of MAGIC observations this one year



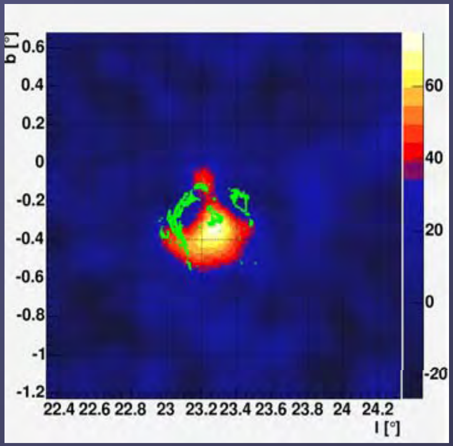
Crab Nebular
SZA & LZA



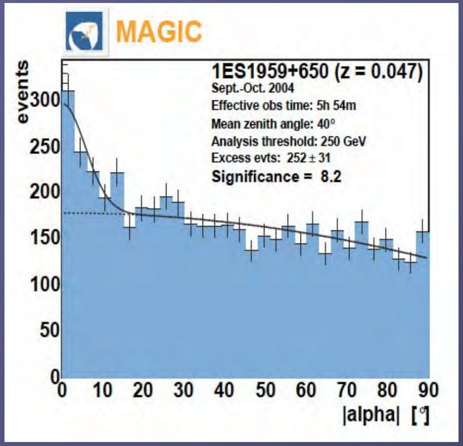
Galactic Center



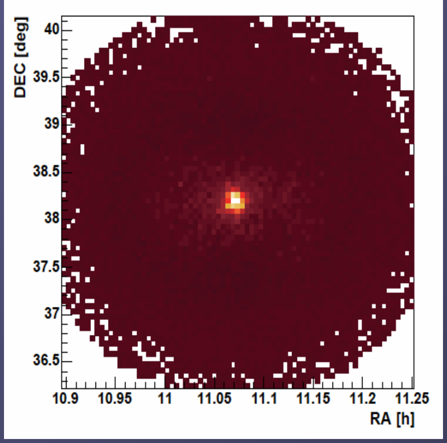
HESS J1813



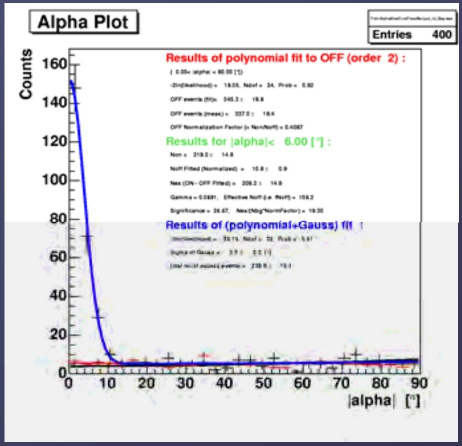
HESS J1834



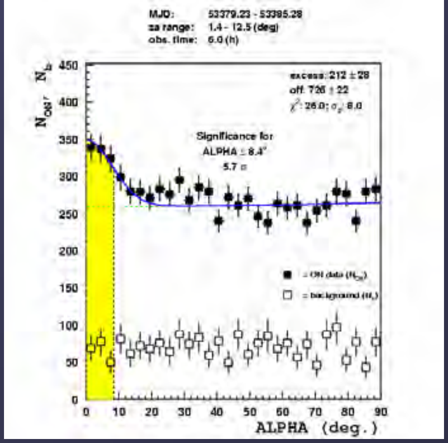
1ES1959+650



Mrk421
Campaign with HESS

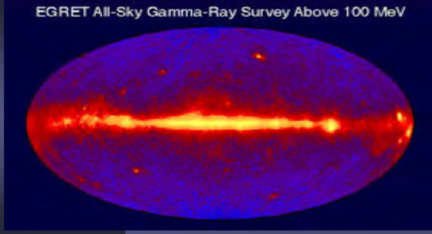


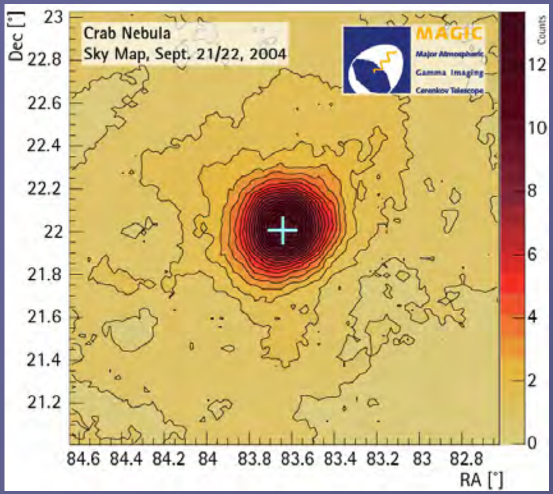
Mrk501
IAU Circular #8562

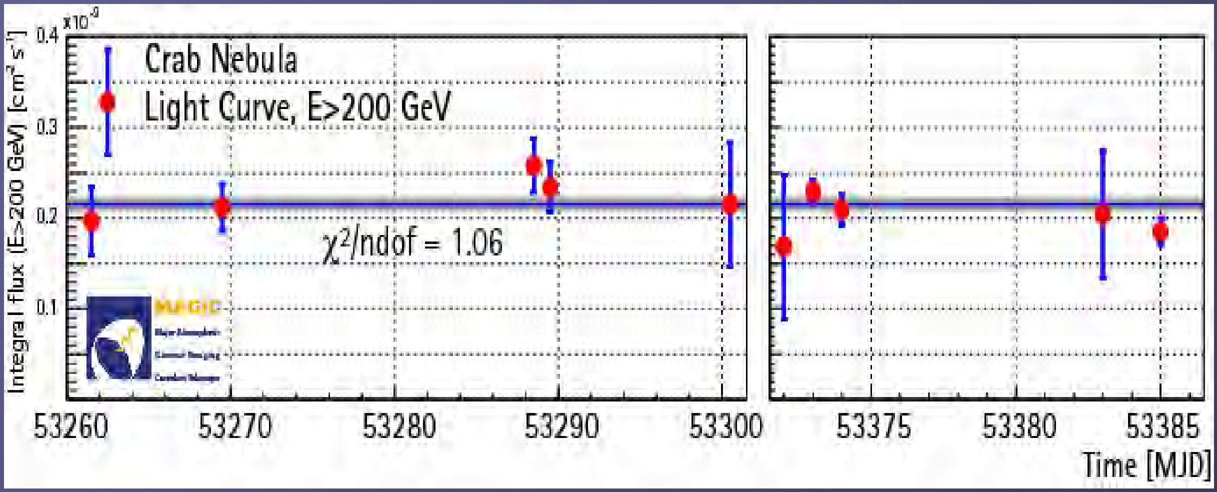


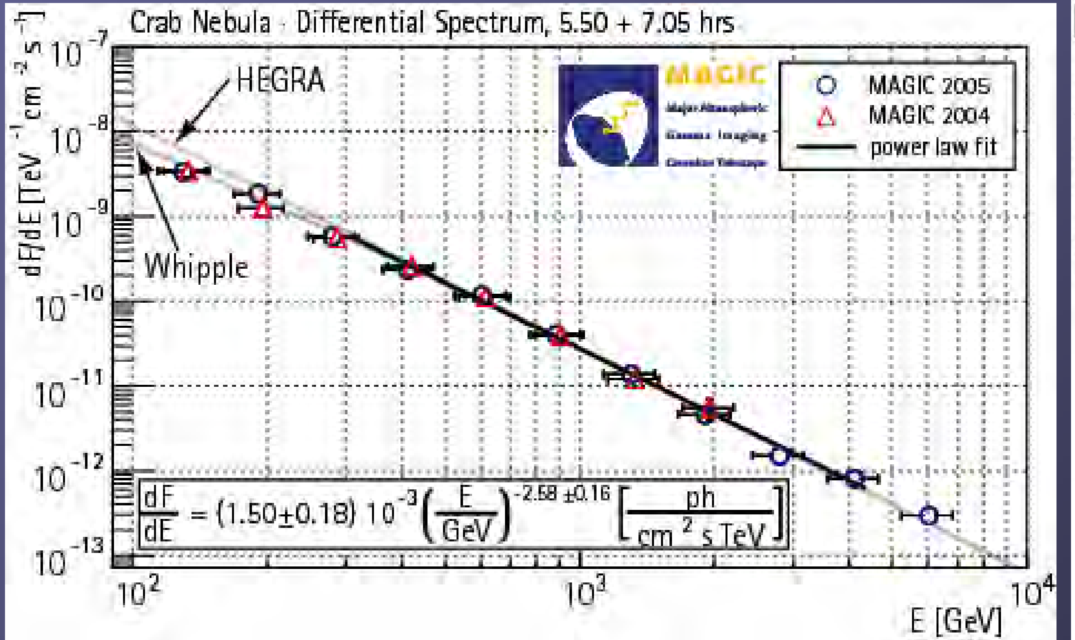
New source
1ES1218 (z=0.18)

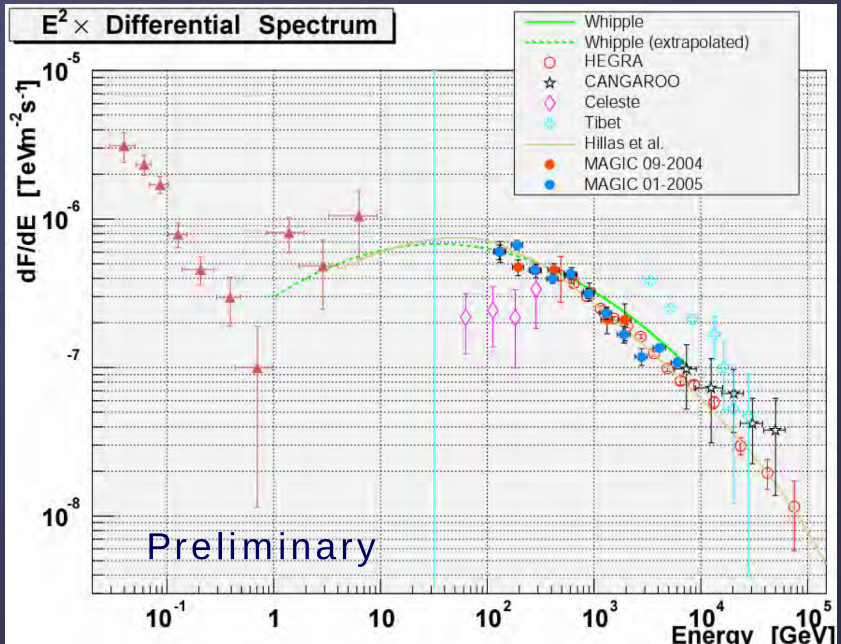
Crab Nebula


EGRET All-Sky Gamma-Ray Survey Above 100 MeV

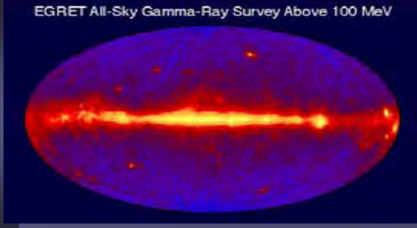

Crab Nebula
Sky Map, Sept. 21/22, 2004
MAGIC
Dec [°]
RA [°]
Counts

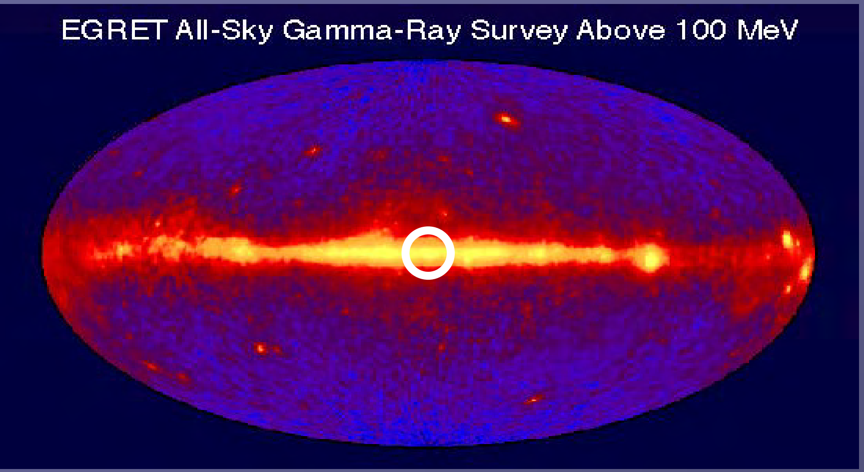

Crab Nebula
Light Curve, E>200 GeV
χ²/ndof = 1.06
Integral flux (E>200 GeV) [cm⁻² s⁻¹]
Time [MJD]
MAGIC

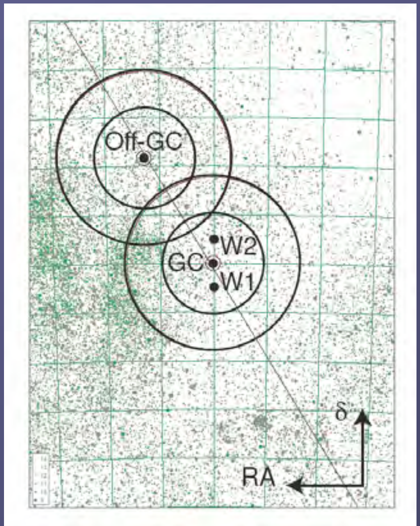

Crab Nebula - Differential Spectrum, 5.50 + 7.05 hrs
HEGRA
Whipple
MAGIC 2005
MAGIC 2004
power law fit
dF/dE = (1.50±0.18) 10⁻³ (E/GeV)^(-2.58 ±0.16) [ph / cm² s TeV]
dF/dE [TeV⁻¹ cm⁻² s⁻¹]
E [GeV]
MAGIC

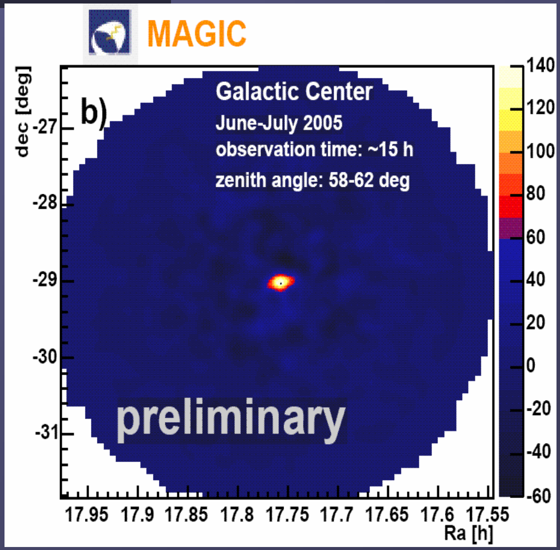

E² × Differential Spectrum
Whipple
Whipple (extrapolated)
HEGRA
CANGAROO
Celeste
Tibet
Hillas et al.
MAGIC 09-2004
MAGIC 01-2005
dF/dE [TeVm⁻²s⁻¹]
Preliminary
Energy [GeV]

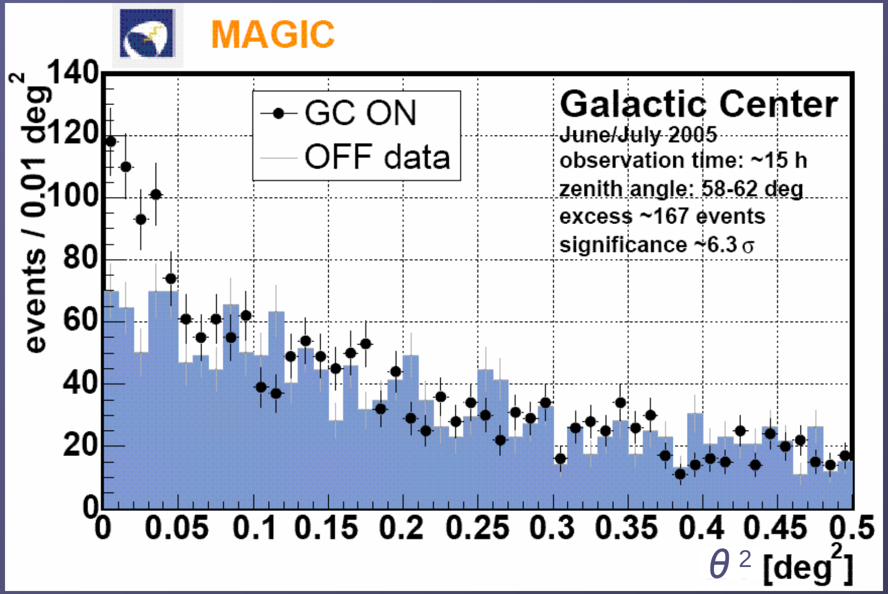
Galactic Center

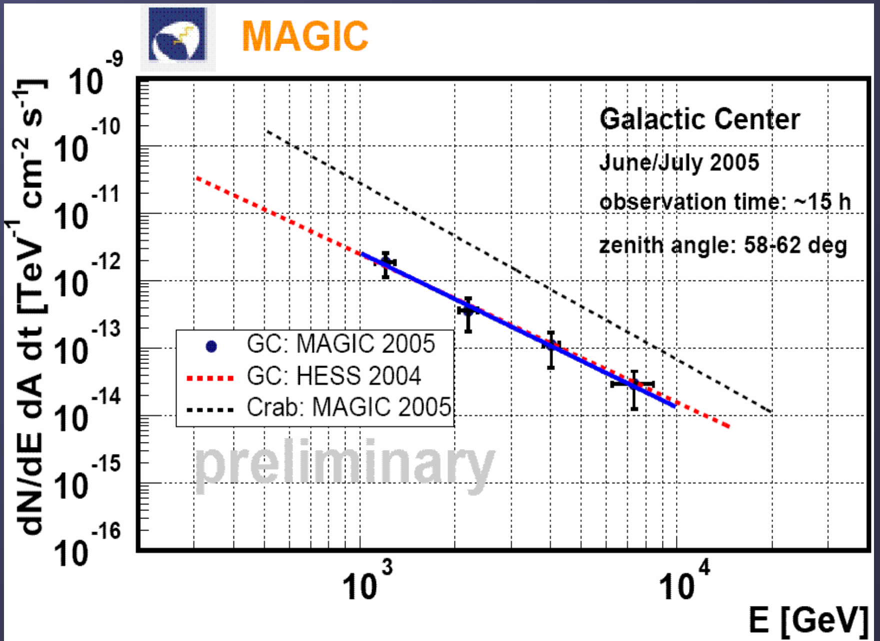






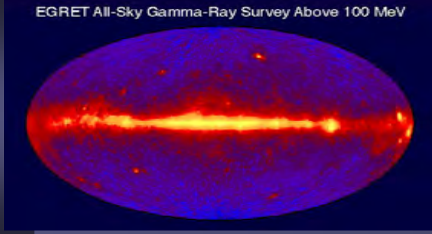


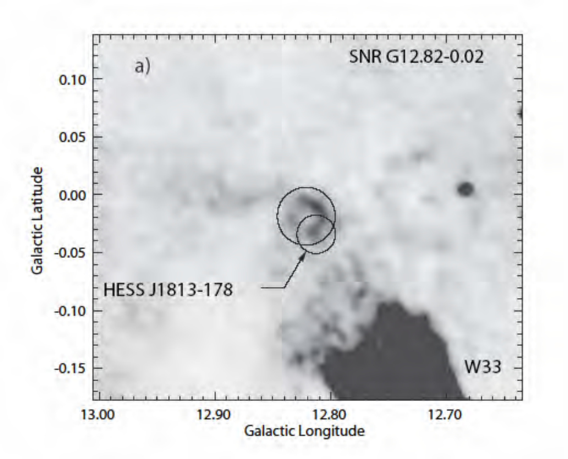


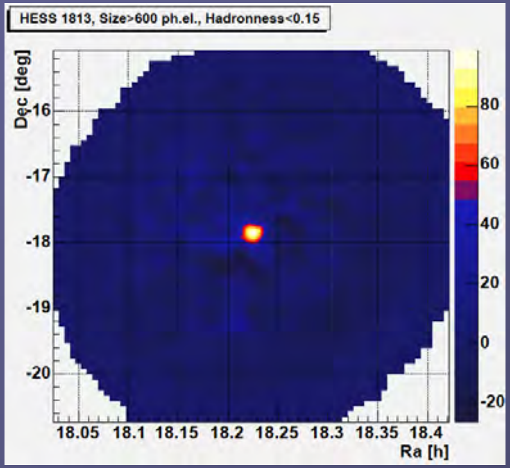


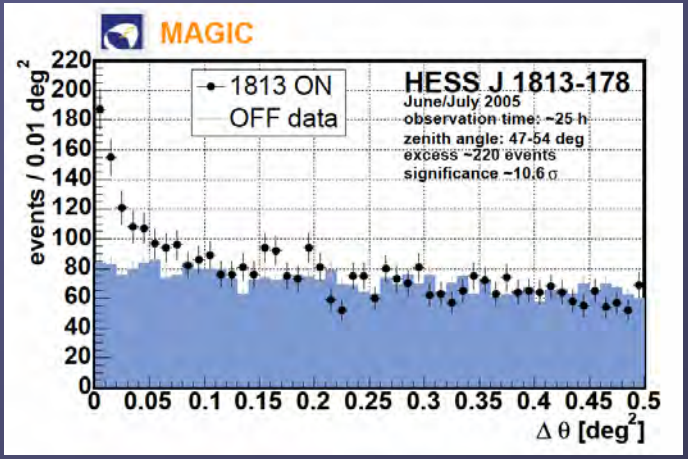
HESS J1813-178

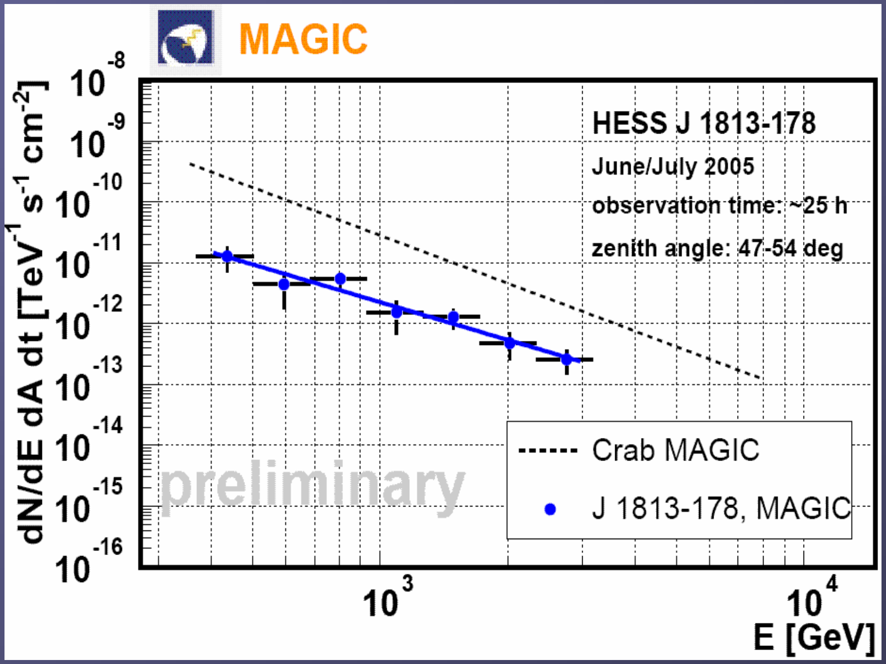
Dark Particle Accelerator -- SNR

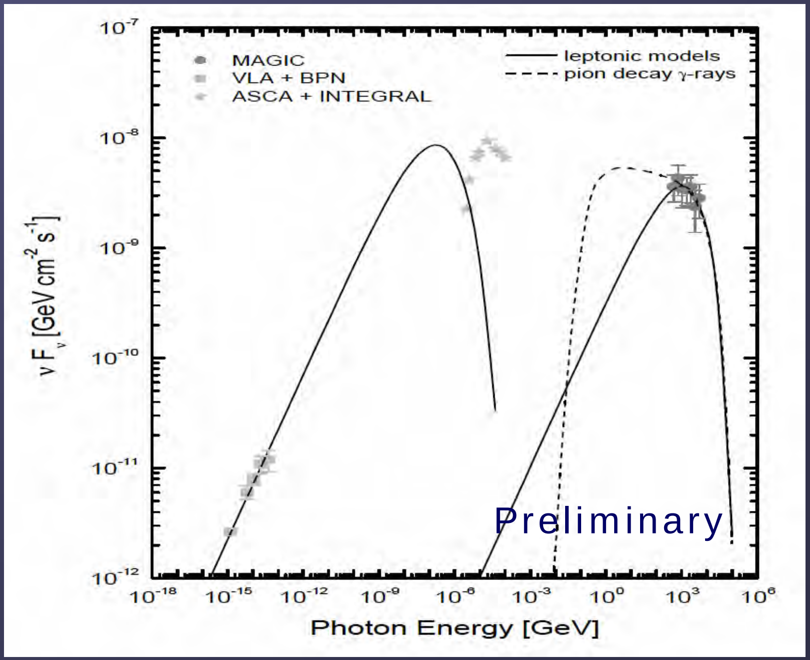




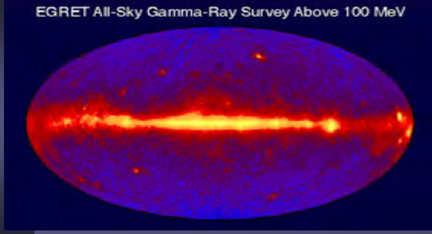


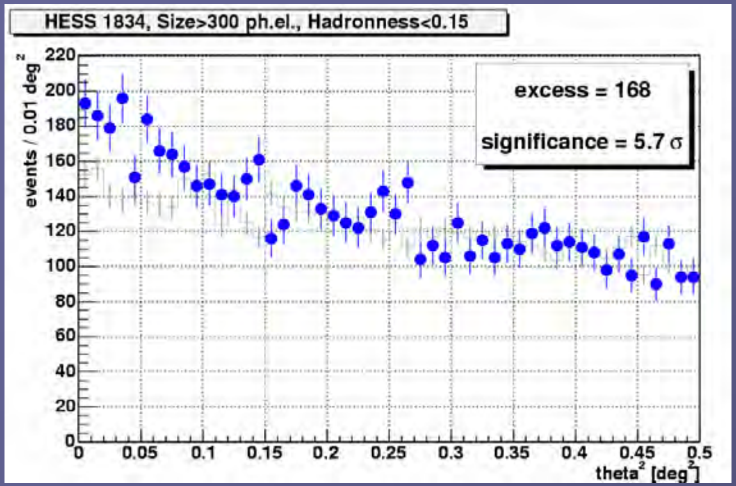




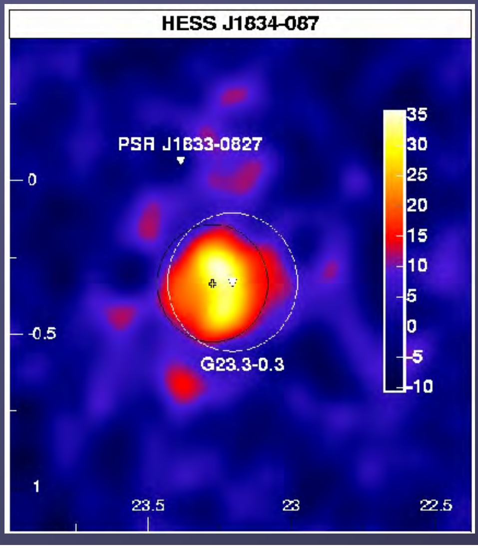


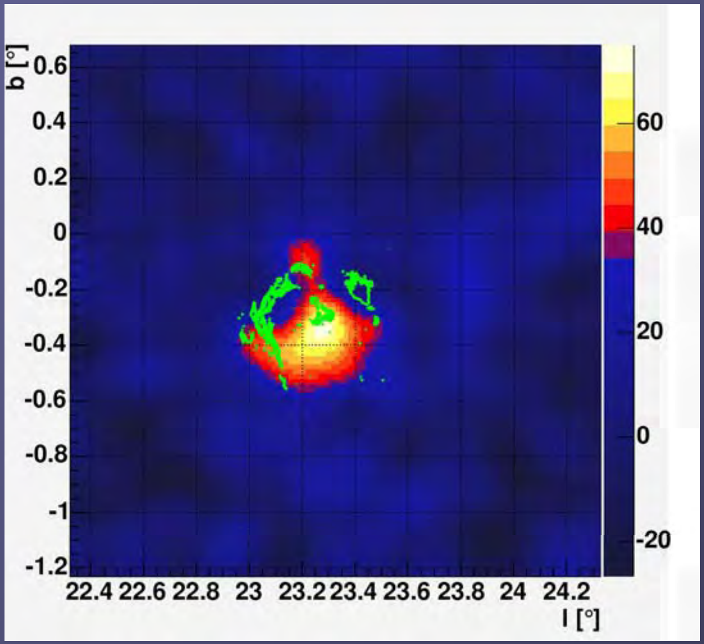
HESS J1834

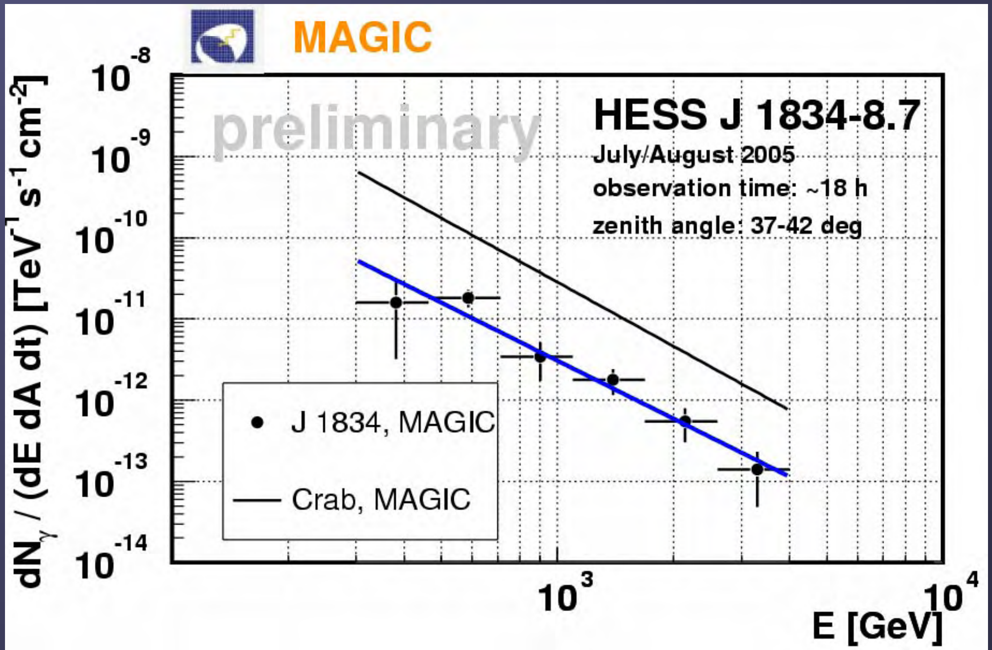




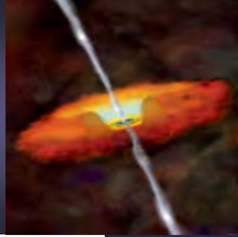
HESS Observation

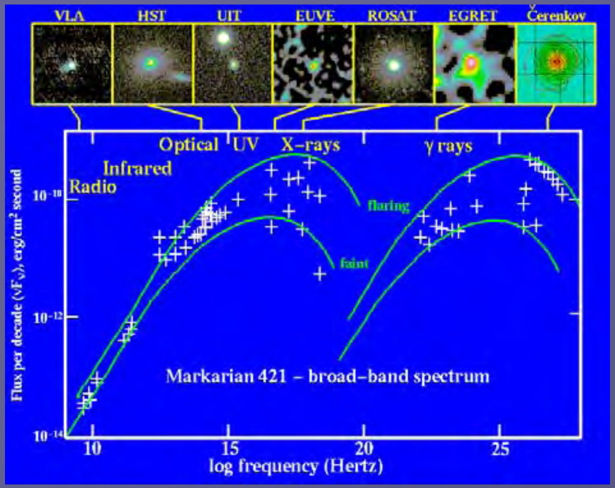


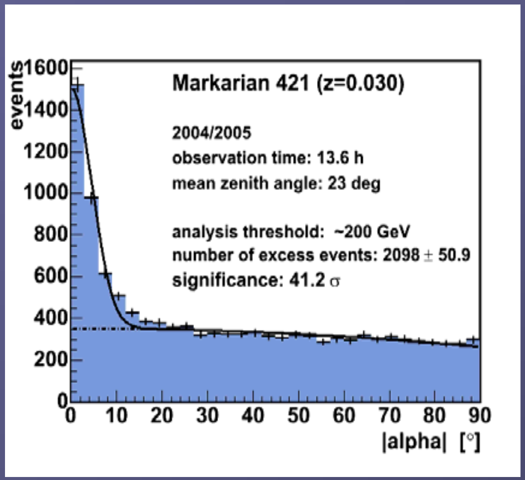


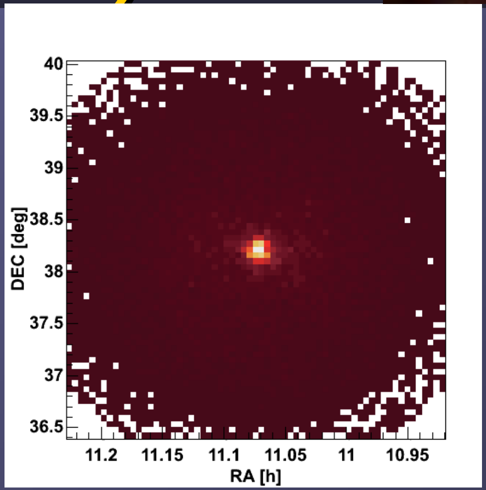


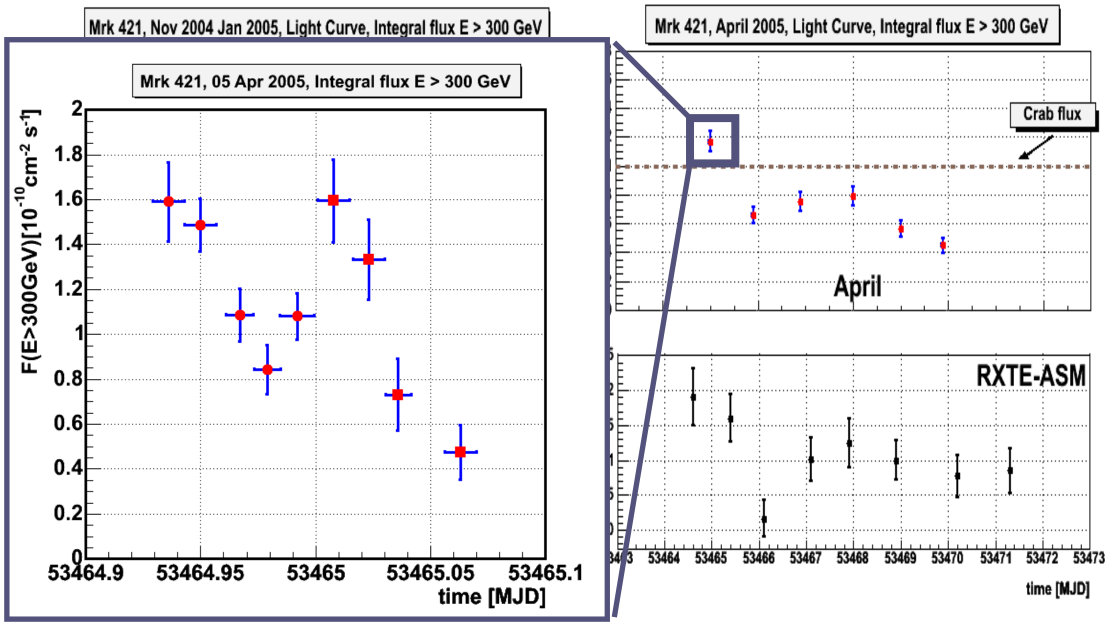
Mrk421 (z=0.03) AGN (Blazar)

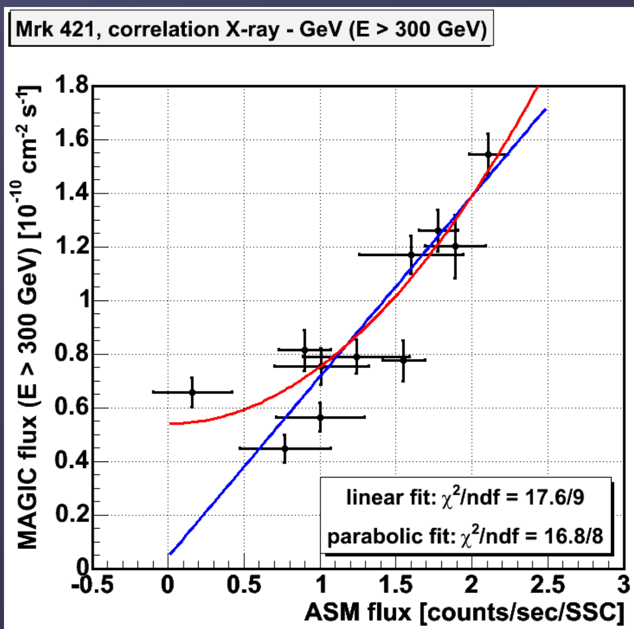








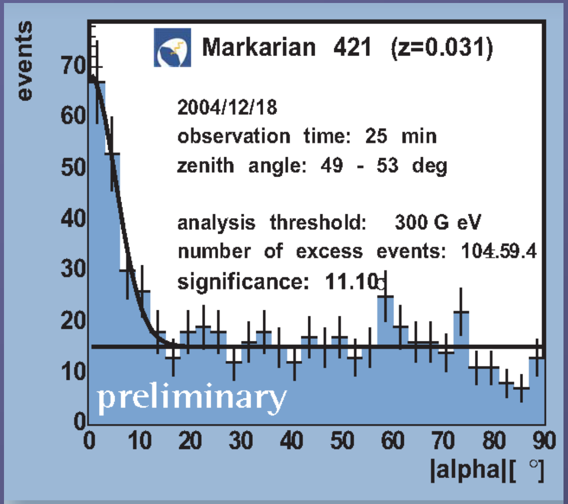




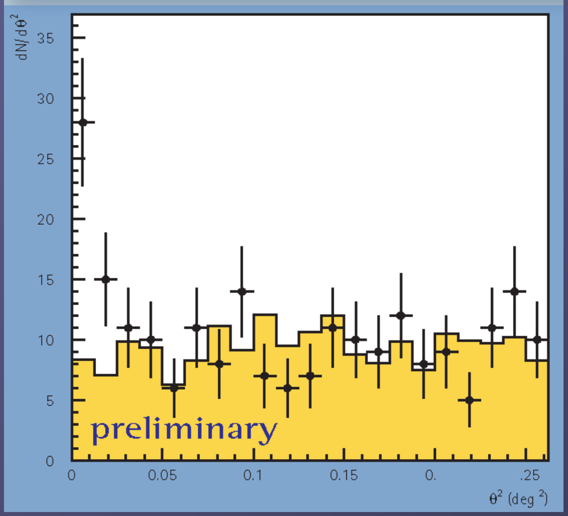
Mrk421 Simultaneous observation MAGIC + HESS

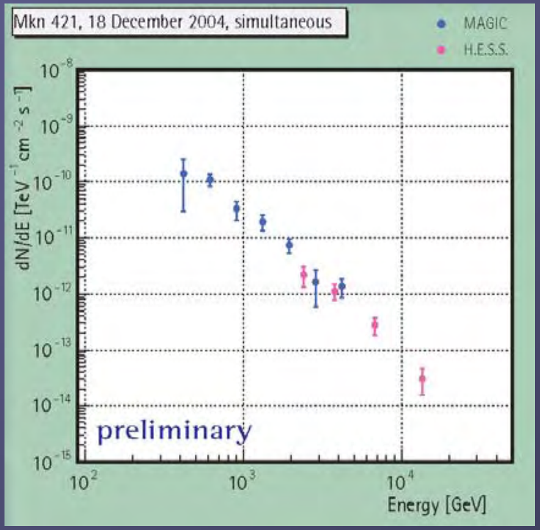
2004/12/18 25mins MAGIC+HESS

MAGIC

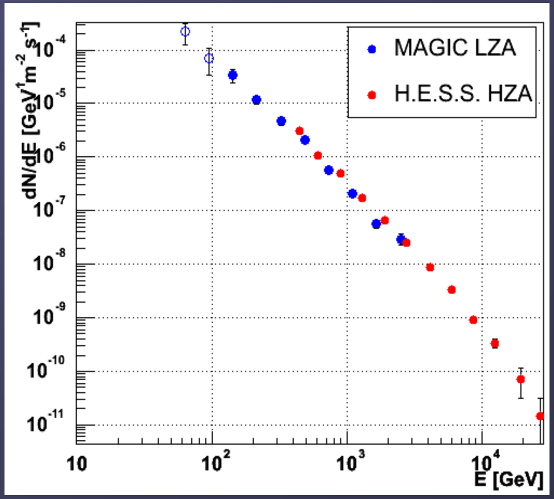


HESS



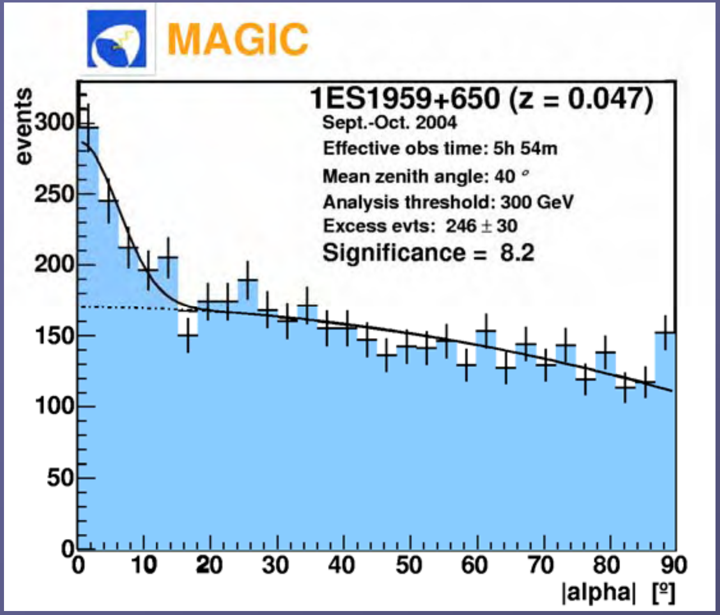


1.5 decades in 25 min

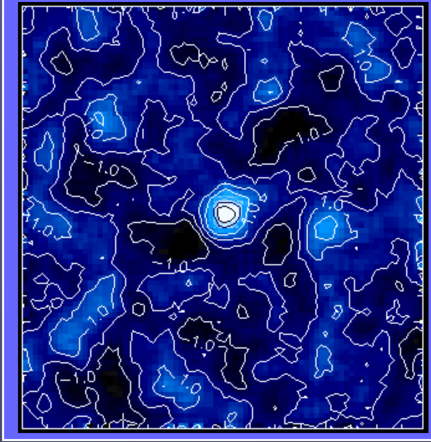


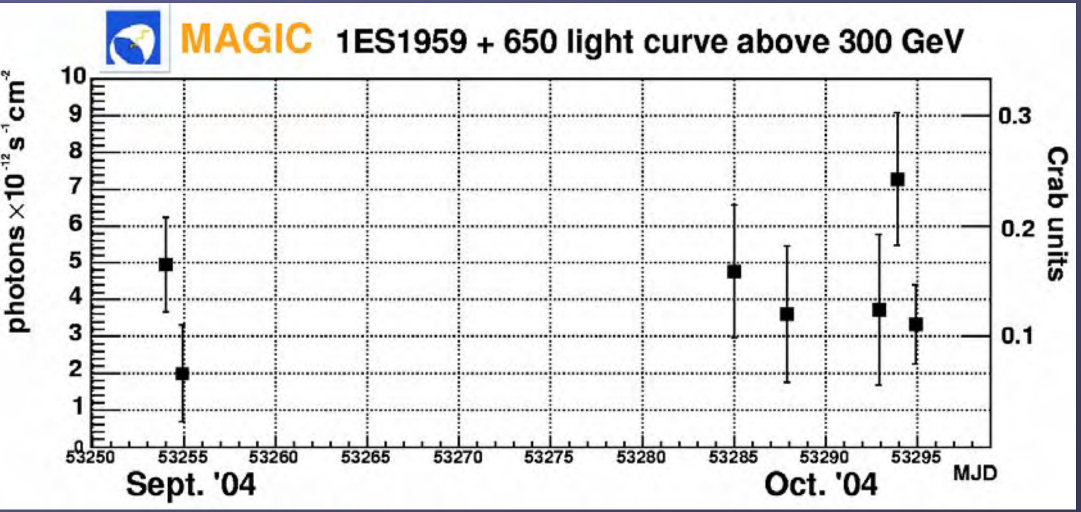
Crab
~3 decades

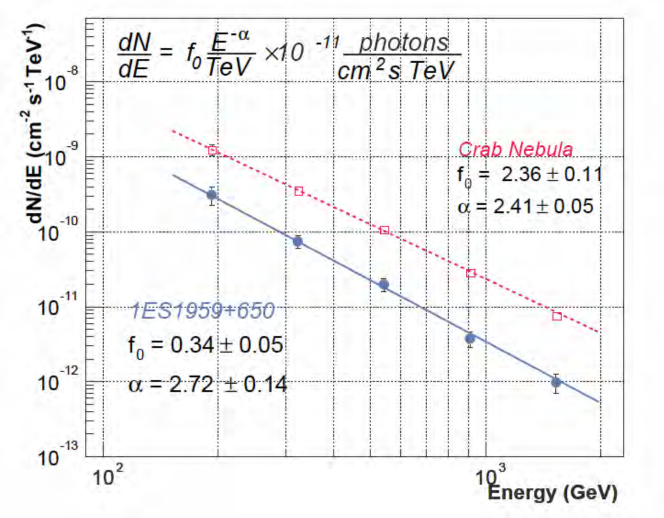
1ES1959+650 (Z=0.047) AGN (Blazar)



First detection
by Utah 7 T.A.
5 sigma







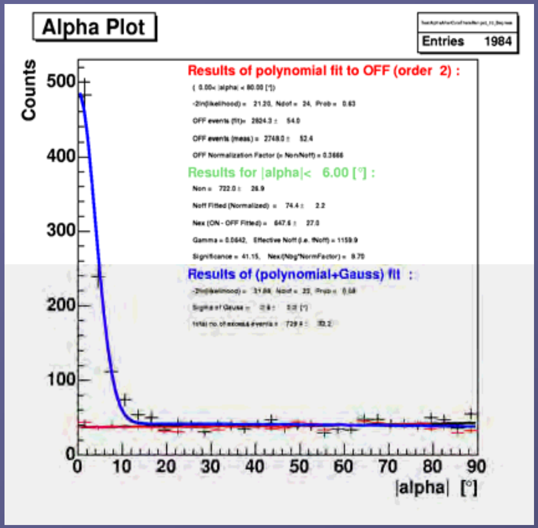
Mrk501 Giant flare

2005 July 01, IAU Circular #8562

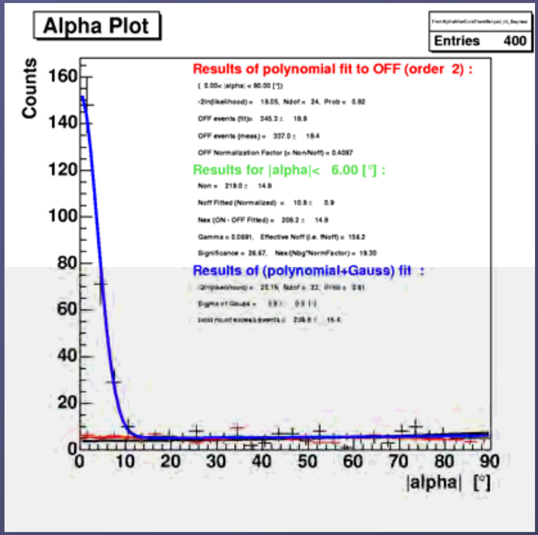
Intensity variation in very short time scale!!

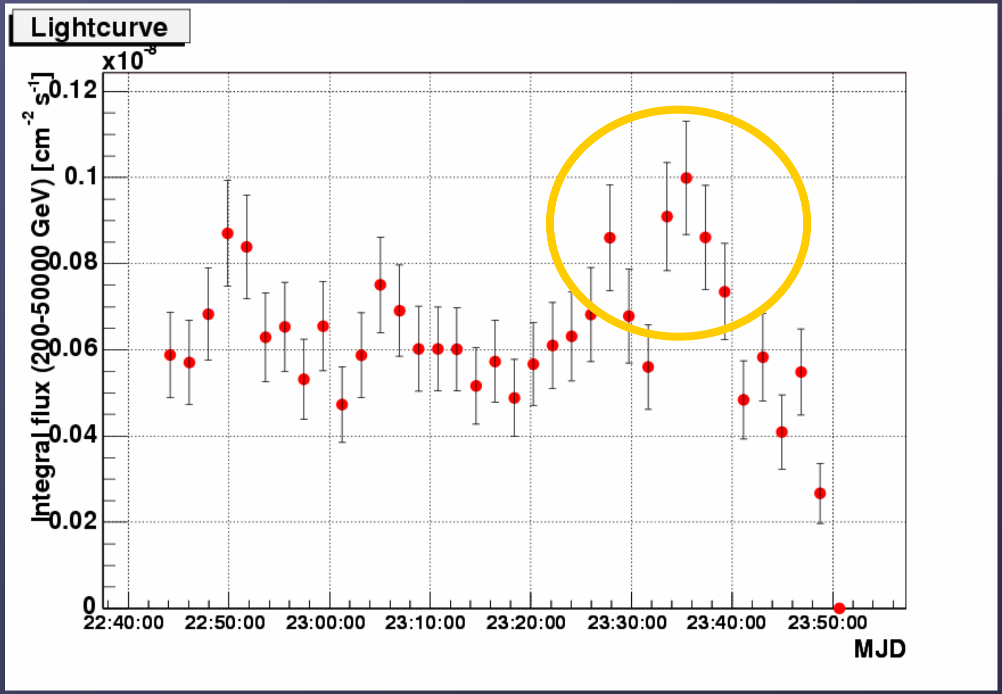
~10 minutes

Standard Cut

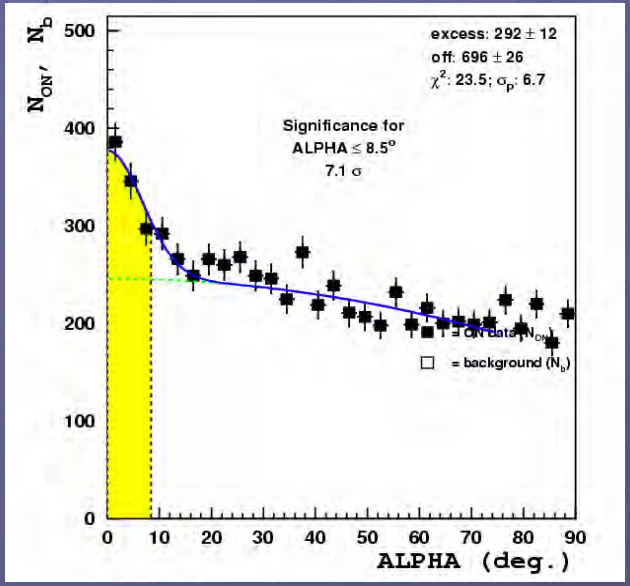


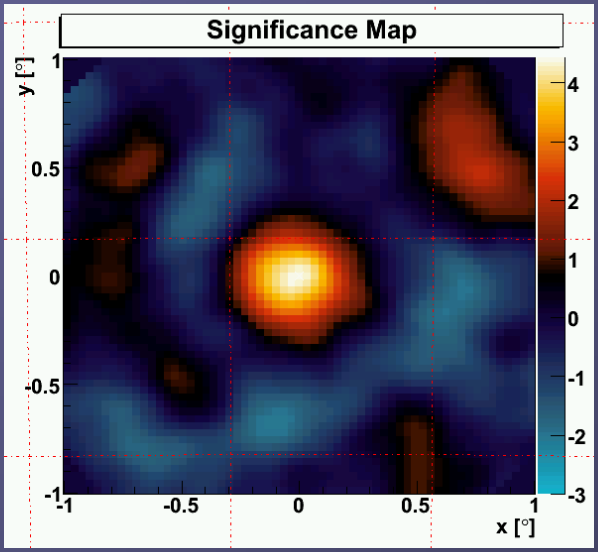
Tight Cut



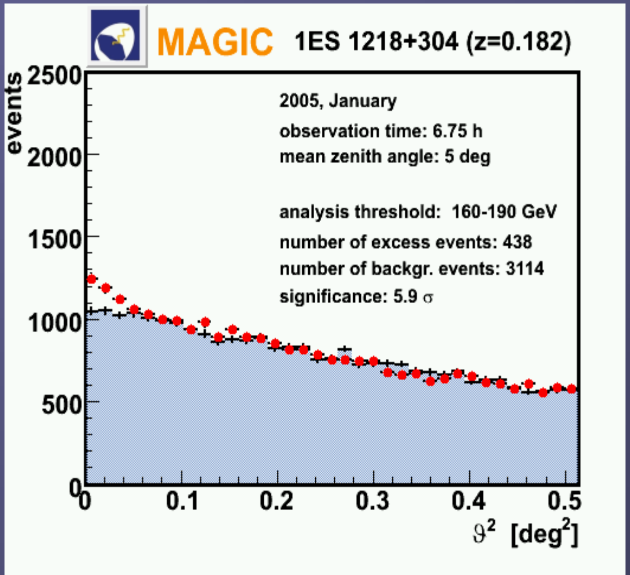


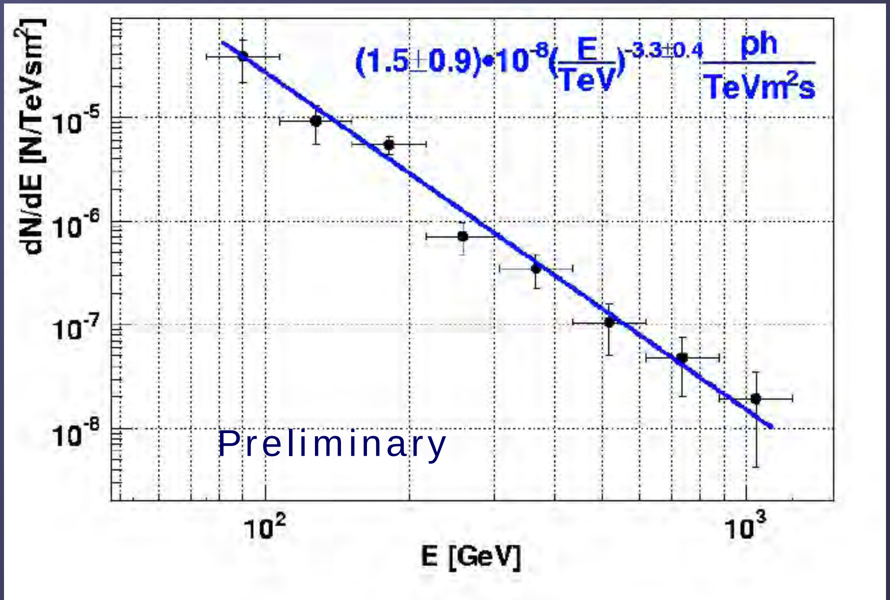
1ES1218+304 (z=0.182)



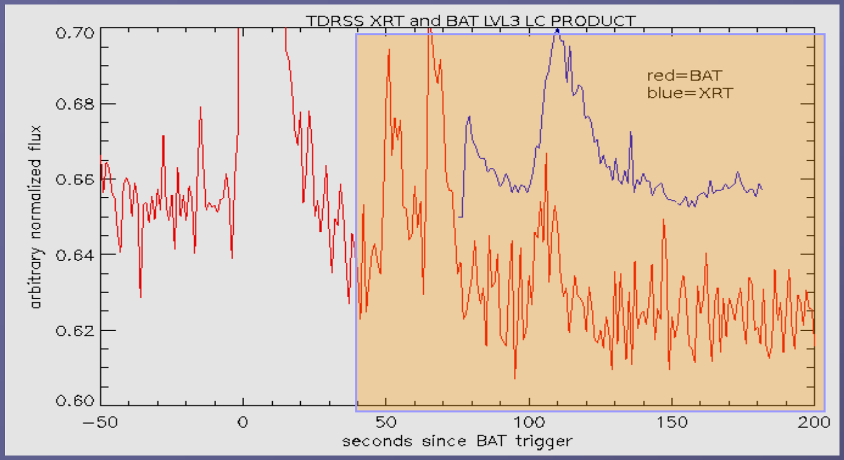


MAGIC [Meyer]:
2005 data:
~7 hrs, 6~7σ
no spectrum yet.

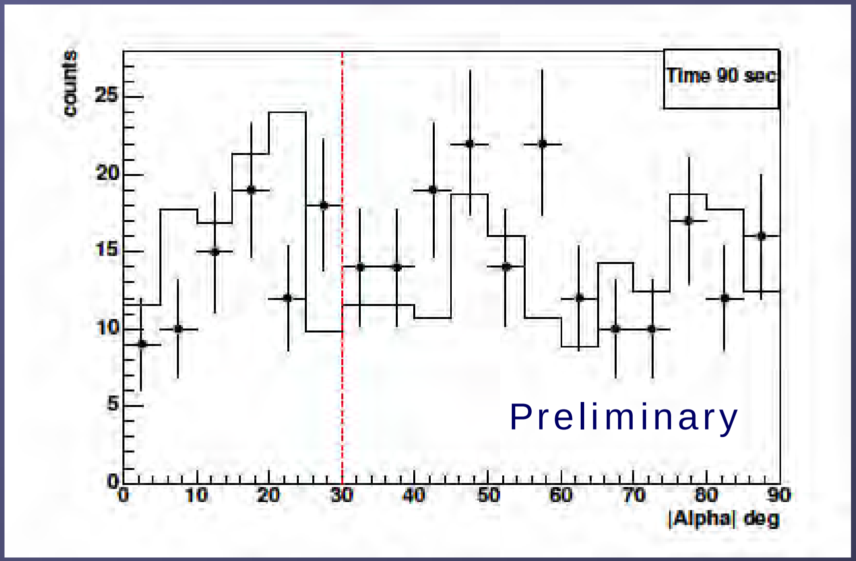


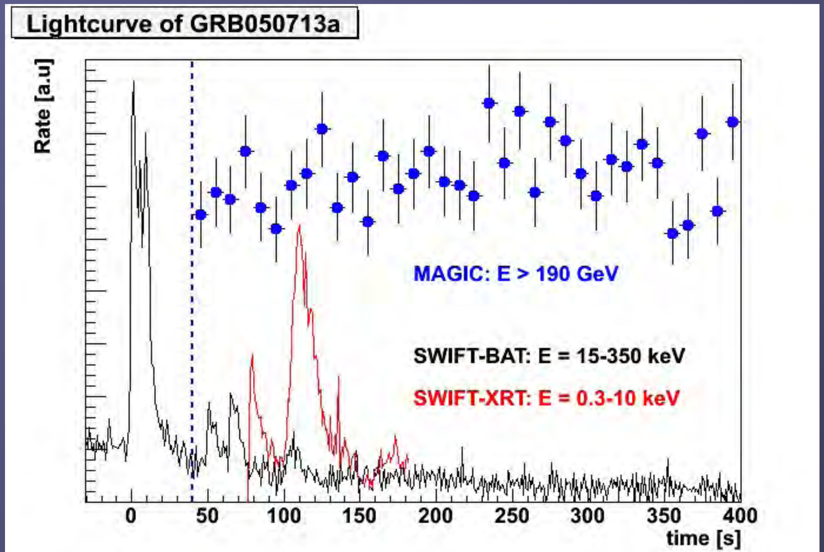


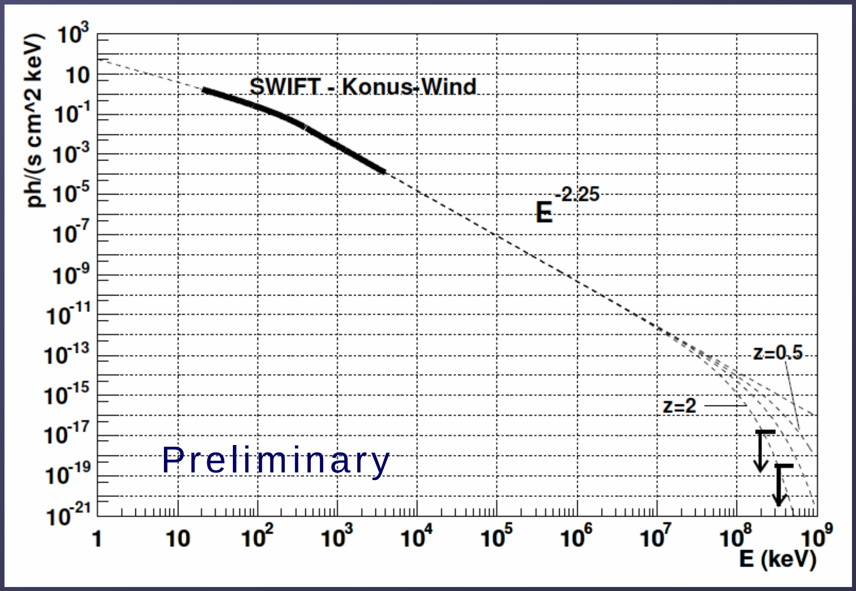
GRB050713a



GRB050713a
Observation 40s after GRB







Extension to MAGIC-II

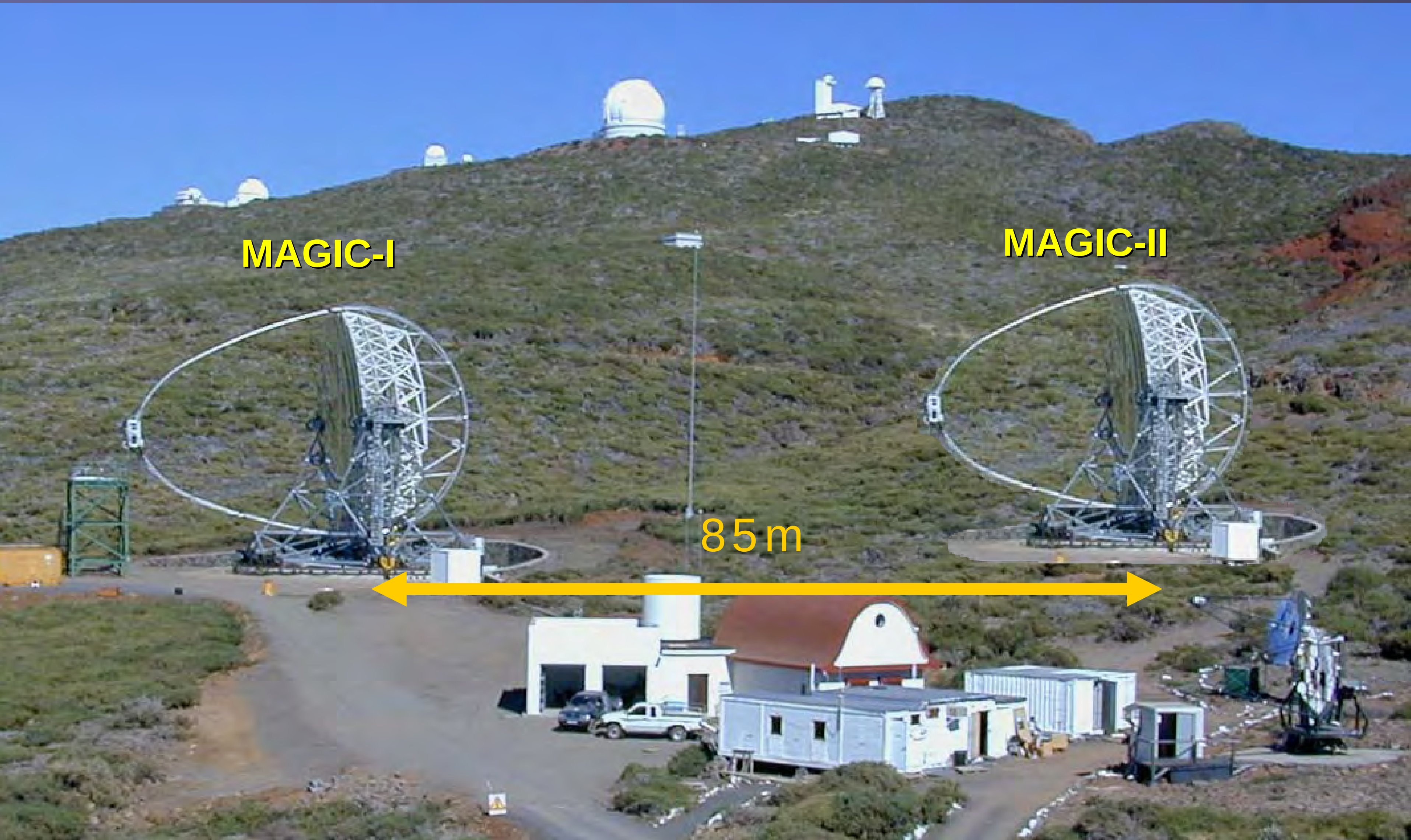
What is the next step

- Now the MAGIC is in good shape

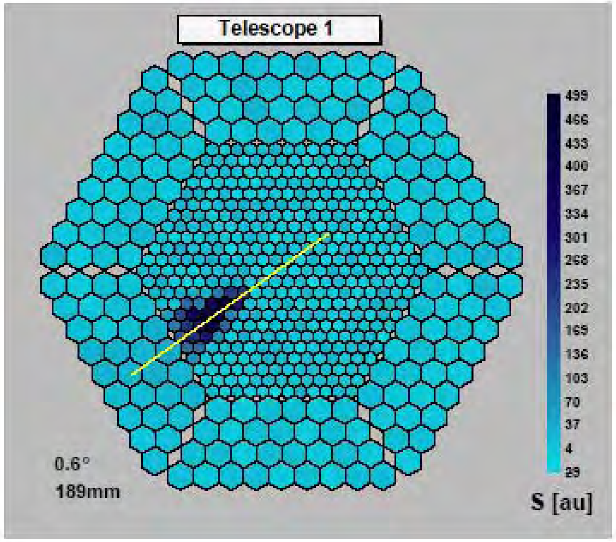
- What is the next step
  - Lower the energy threshold further
  - Improve the sensitivity especially below 100GeV

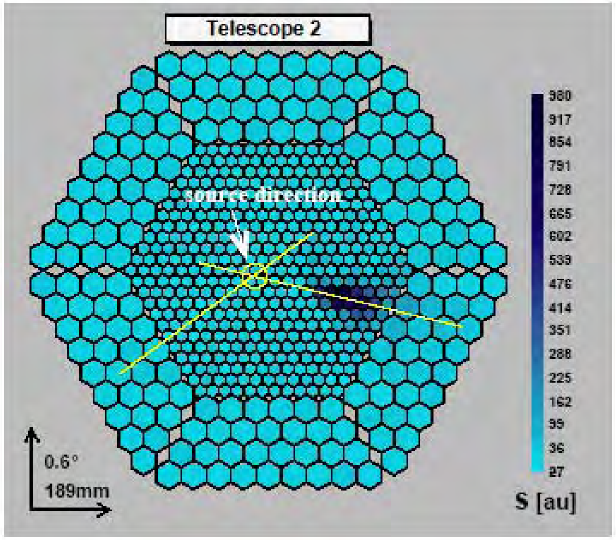
- Our solution – MAGIC-II
  - Second telescope, completion in 2007
    - Stereo ➔ high purity gamma samples ➔ better physics
  - High Q.E. photodetectors, HPD ~50%Q.E.
    - Increase photon collection efficiency
  - Ultra-fast FADCs 2.5 Gsamples/sec
    - Reduce the effect of the night sky background
    - Increase hadron rejection power with time profile

MAGIC-II (2 x 17m)



Stereo reconstruction





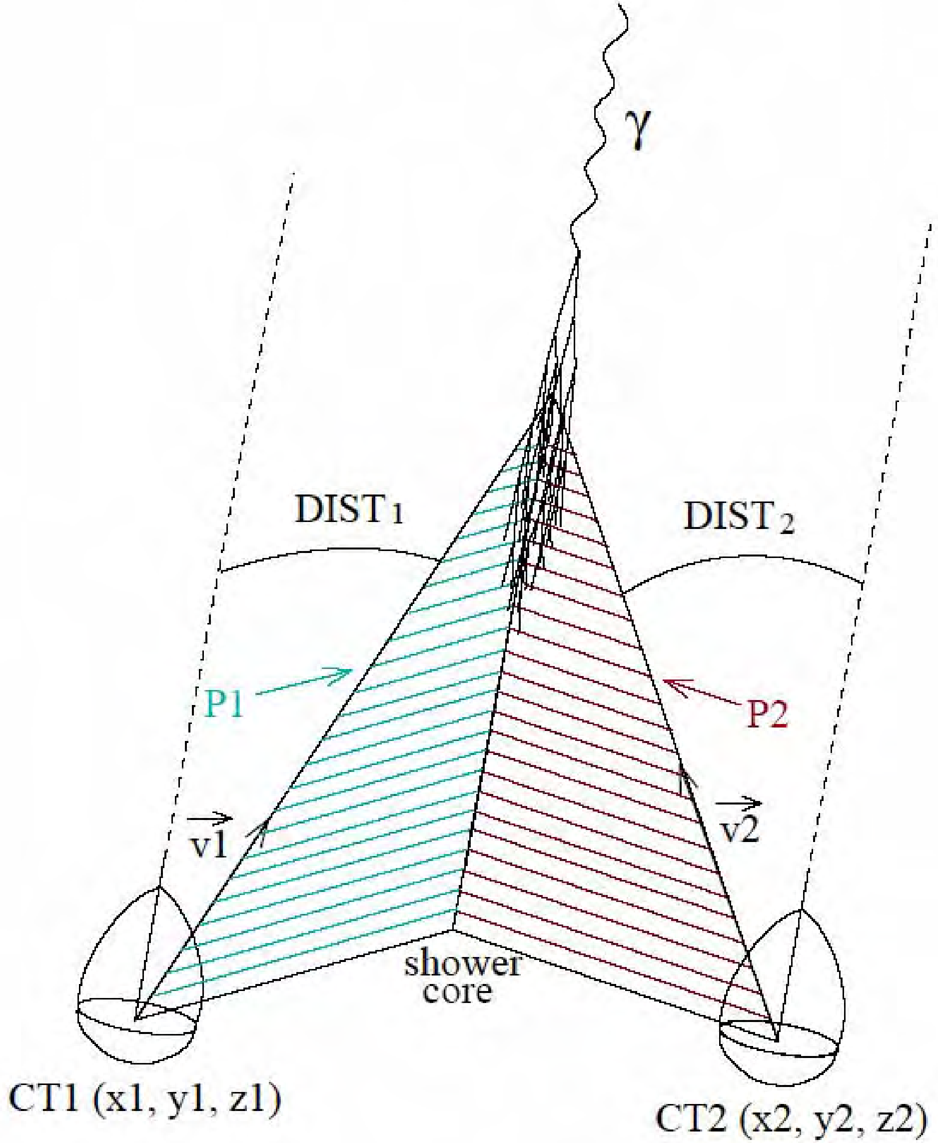
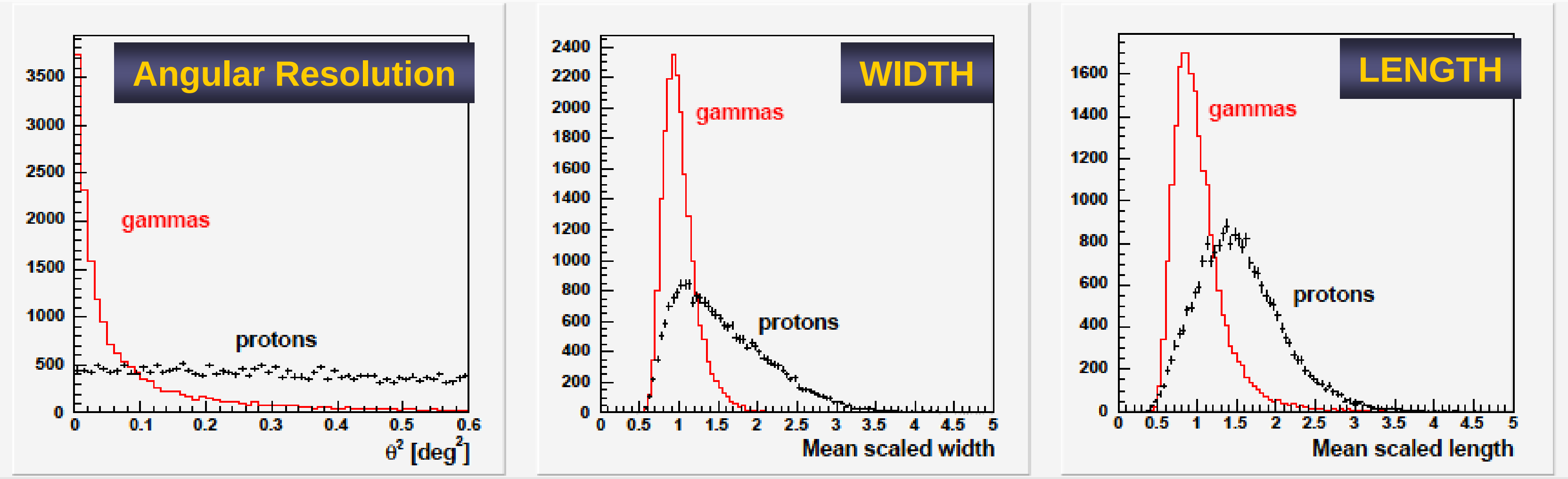
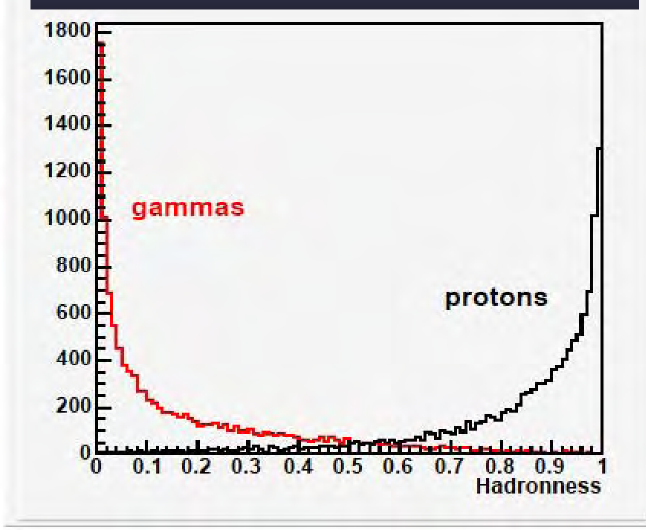


Image parameters

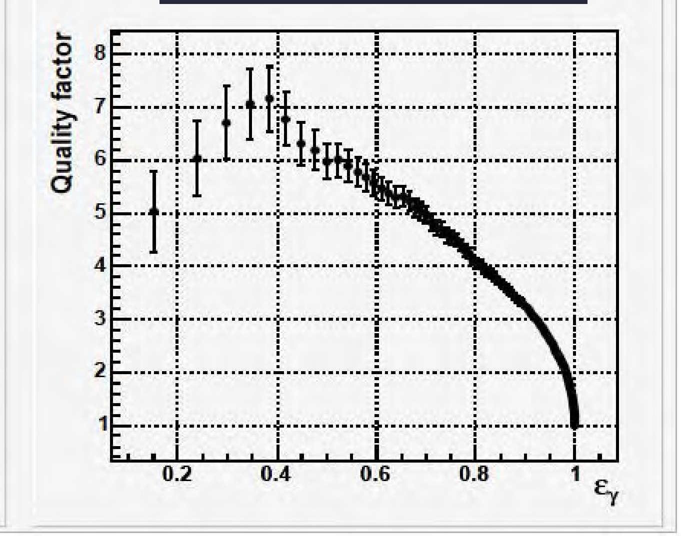
Eγ peak = 40GeV



Gamma / Hadron separation by Random Forest method

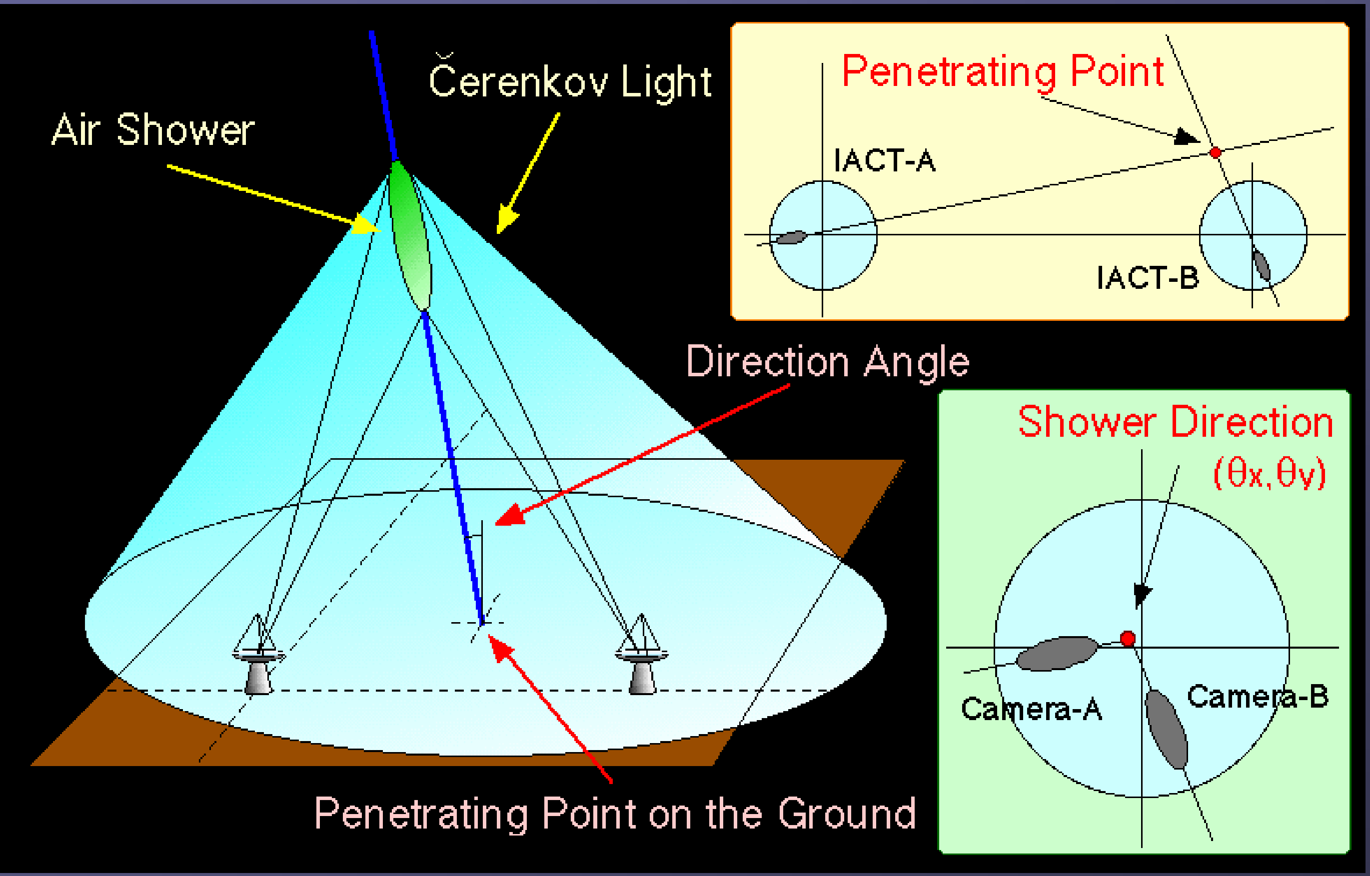


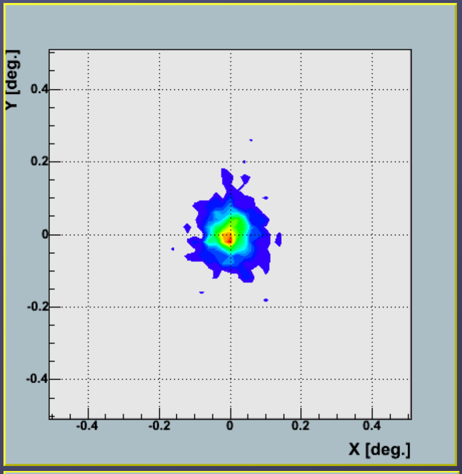
Quality factor of ~7

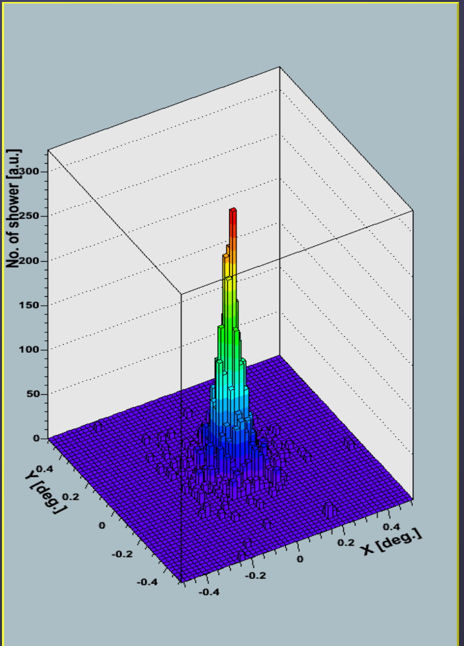


Stereo analysis at high energy in MAGIC II

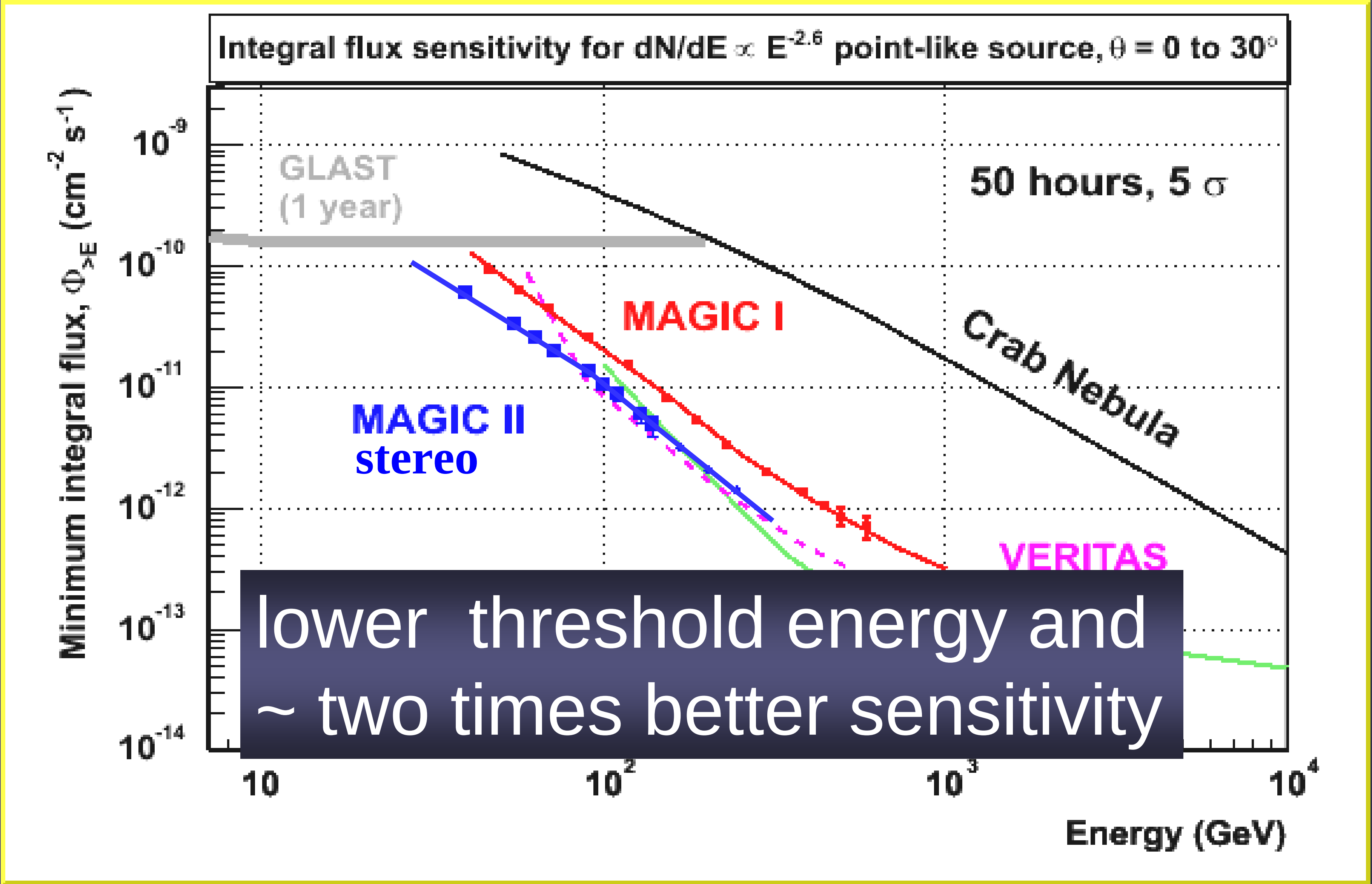
δ θ ~ 3~4 arcmin around 1TeV



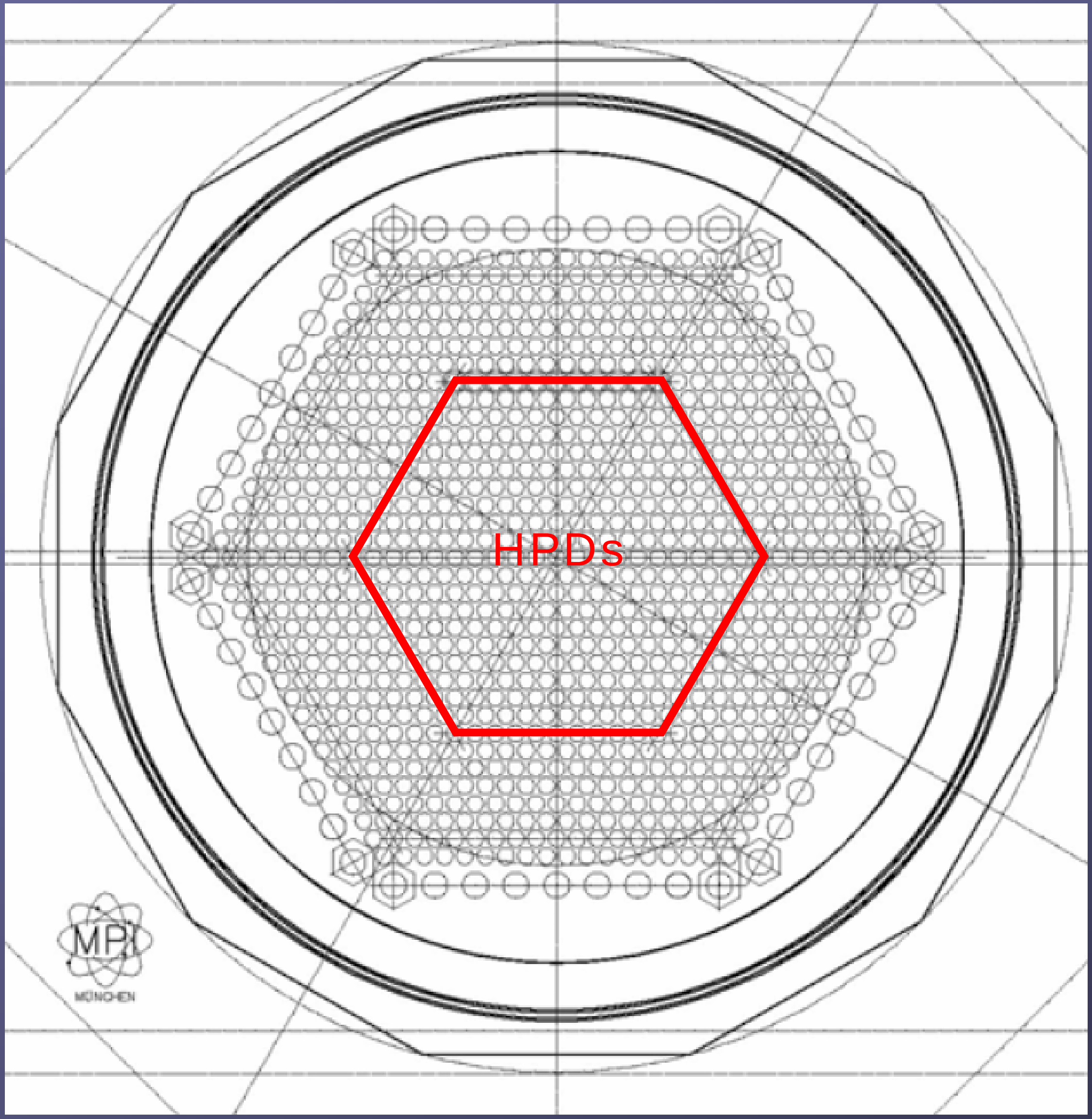




Sensitivity of MAGIC and MAGIC-II



MAGIC-II Camera current plan

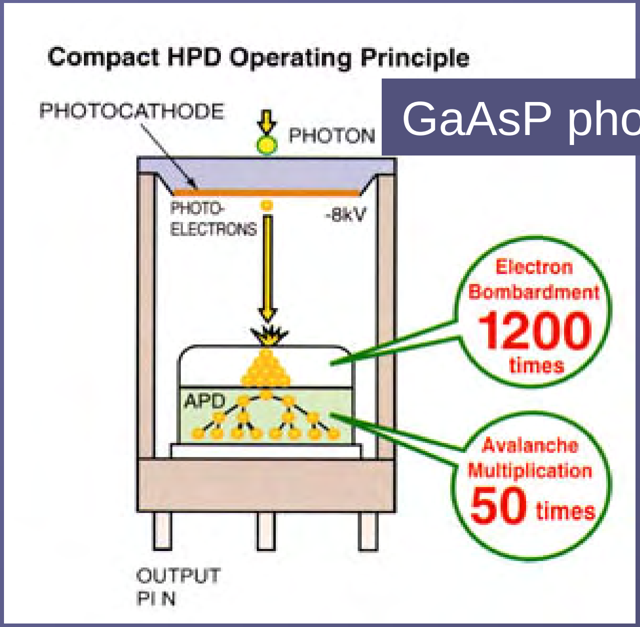


919 fine pixels
54 large pixels

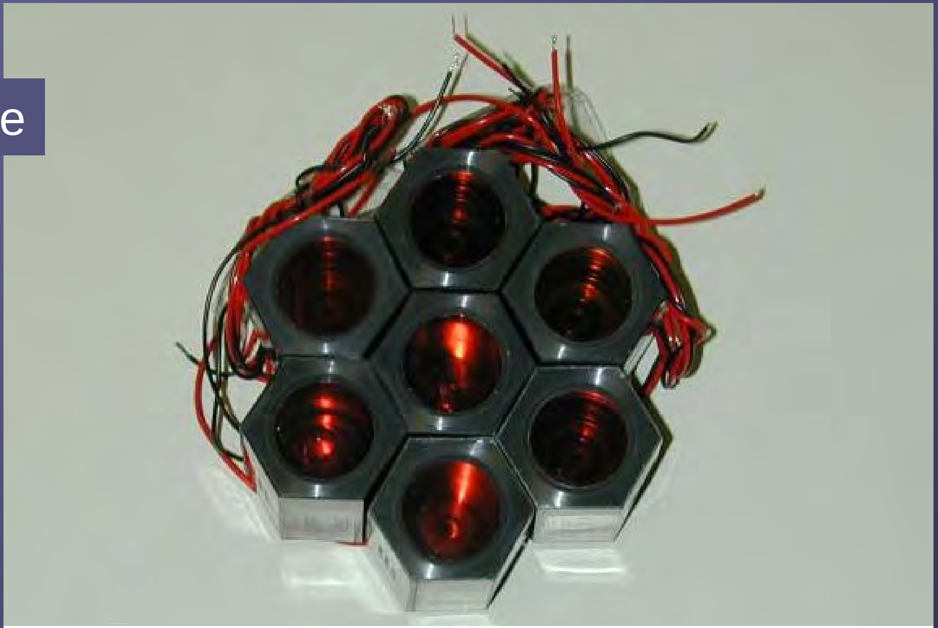
~3.9 degrees

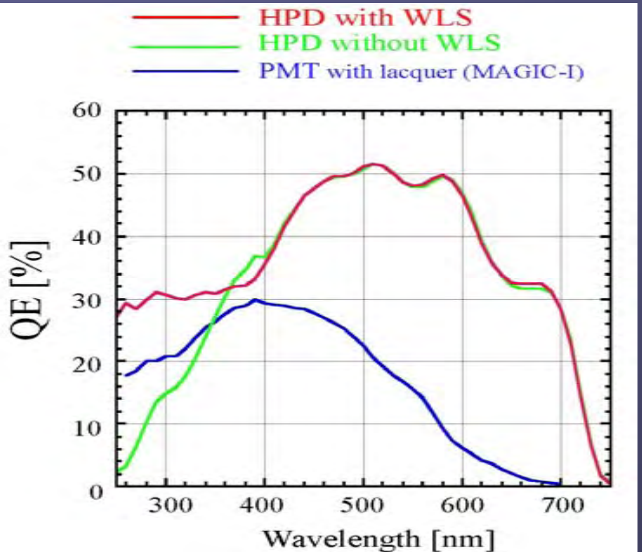
Inner part HPDs
~2.0 degrees

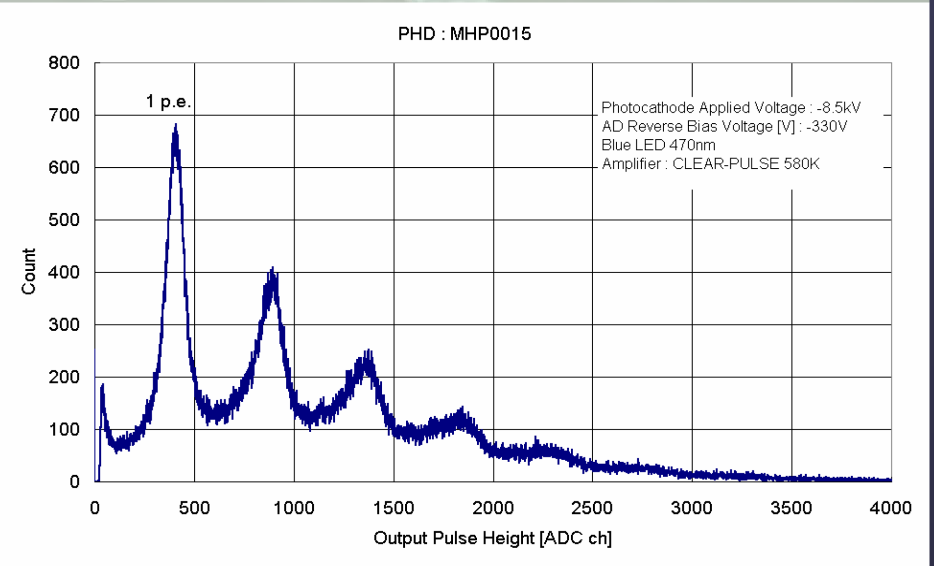
R9792U-40
18mm GaAsP HPD by Hamamatsu



GaAsP photocathode

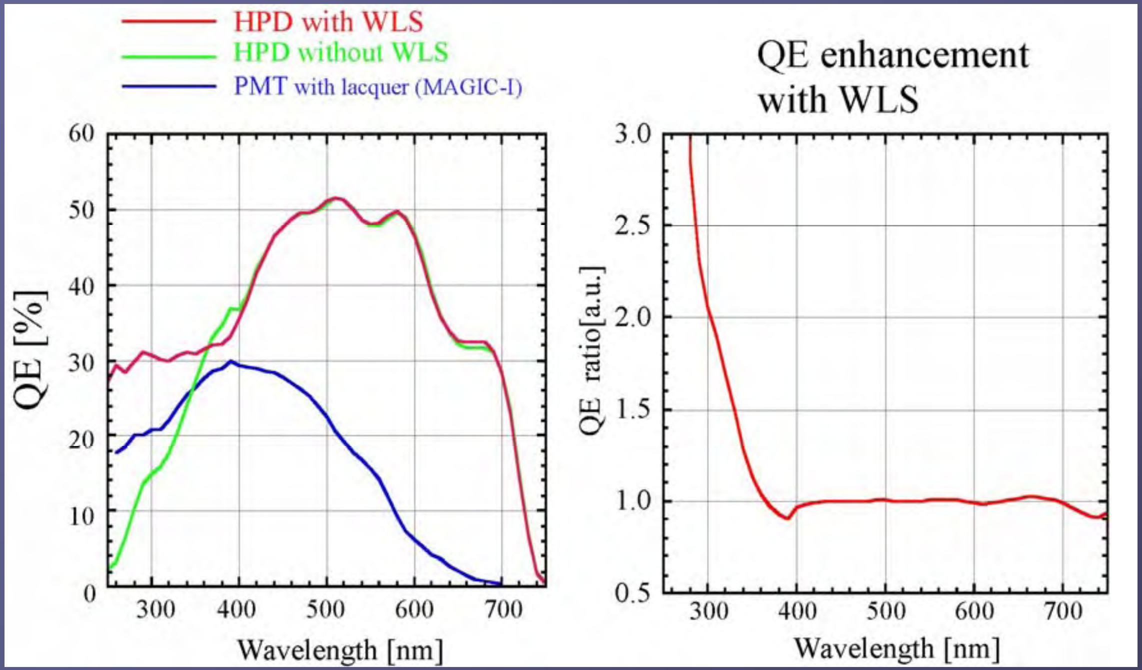


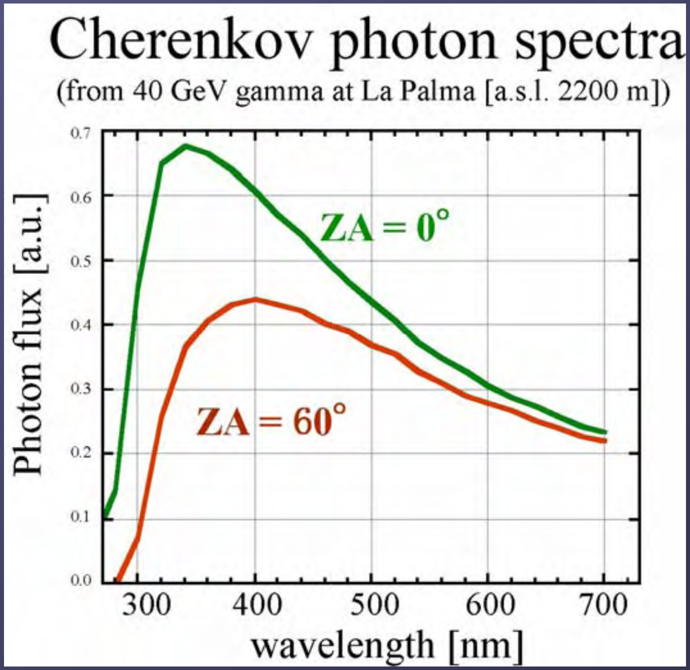




First Test with Wavelength Shifter (WLS)

Equivalent to increase the mirror diameter from 17m to 24m!!



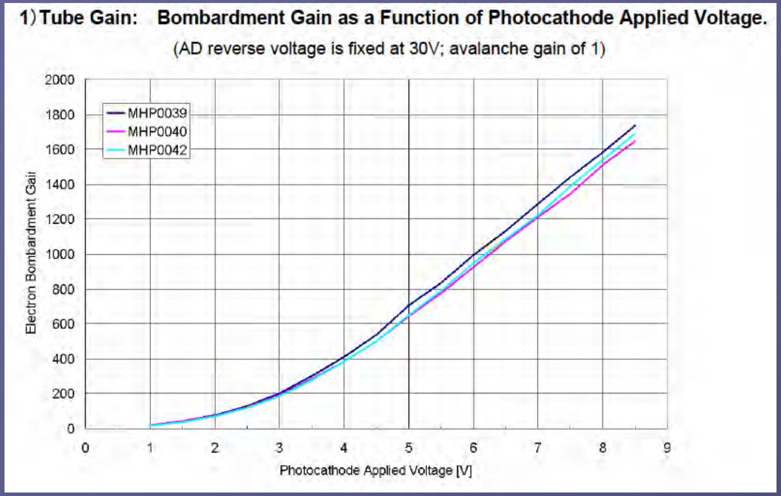


In comparison with the current PMTs With milky coating

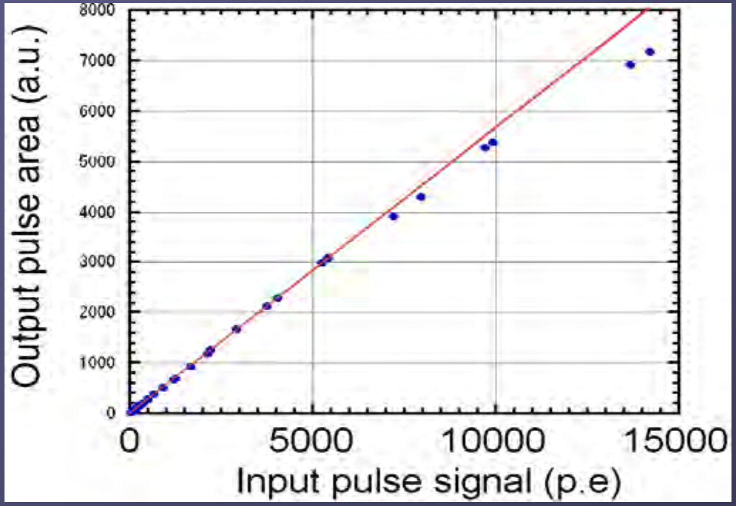
ZA	0°	25°	45°	60°
No WLS	1.90	1.92	2.00	2.14
With WLS	**1.99**	**2.00**	**2.07**	**2.17**

HPD Gains, Dynamic range and time response

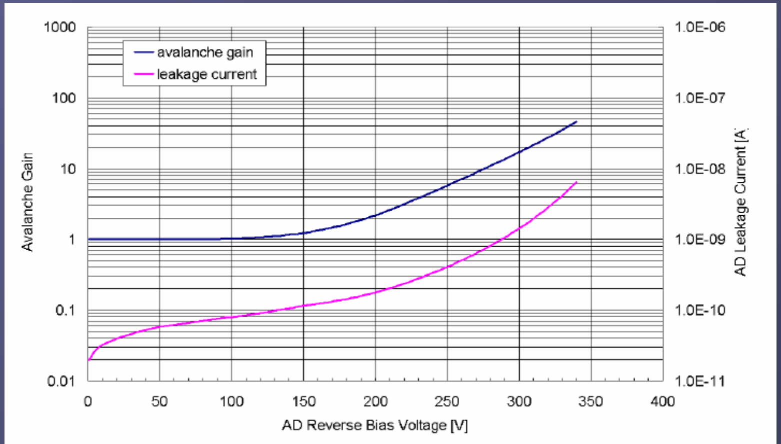
Electron Bombardment Gain



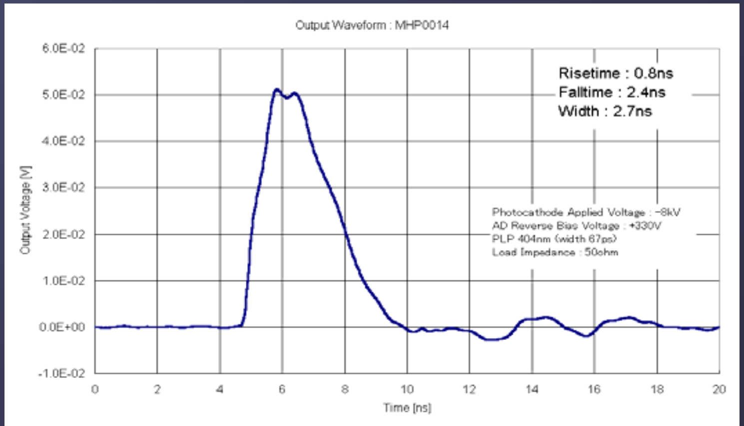
Dynamic range, 1pe ~5000 p.e.



APD Gain and Dark current

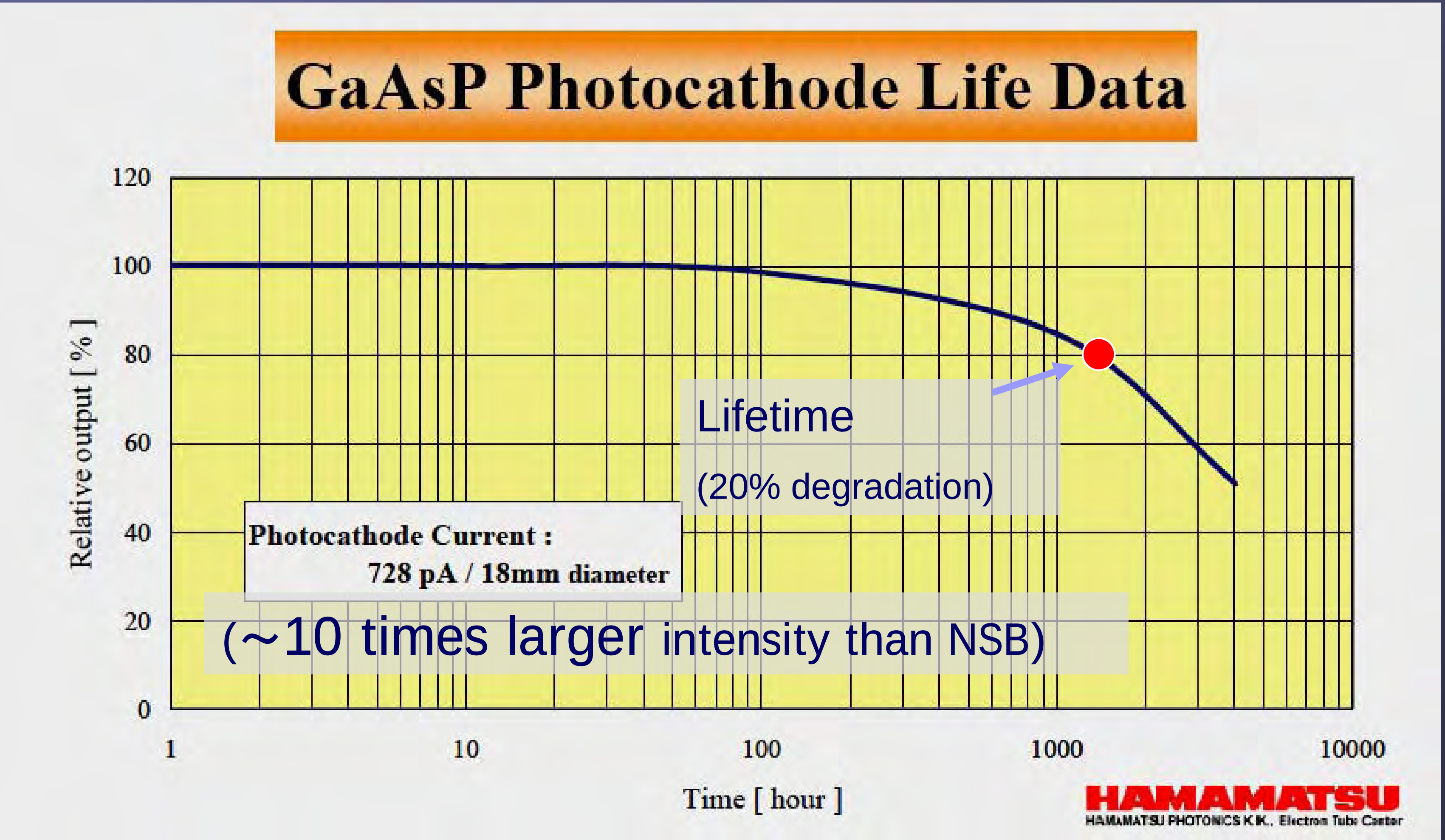


Time response FWHM ~2.7nsec



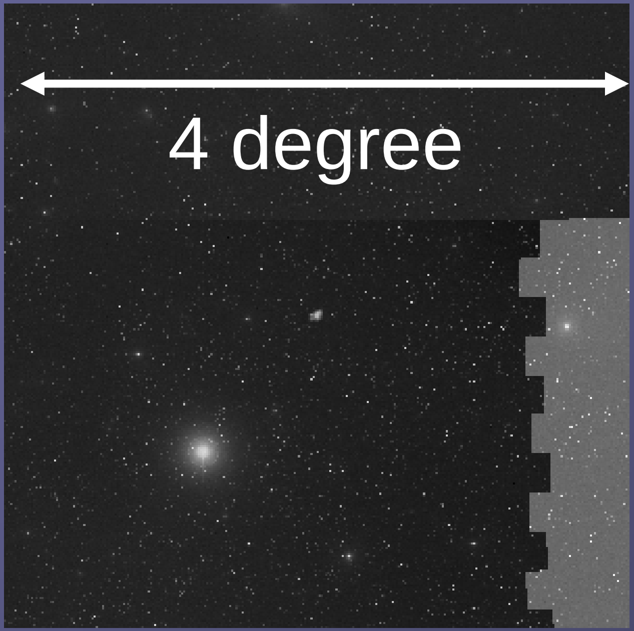
GaAsP HPD life time

- Total charge; 3.5 mC in Photocathode (ca. 100 C in APD output @ gain 30000])



Star Light and NSB Simulation

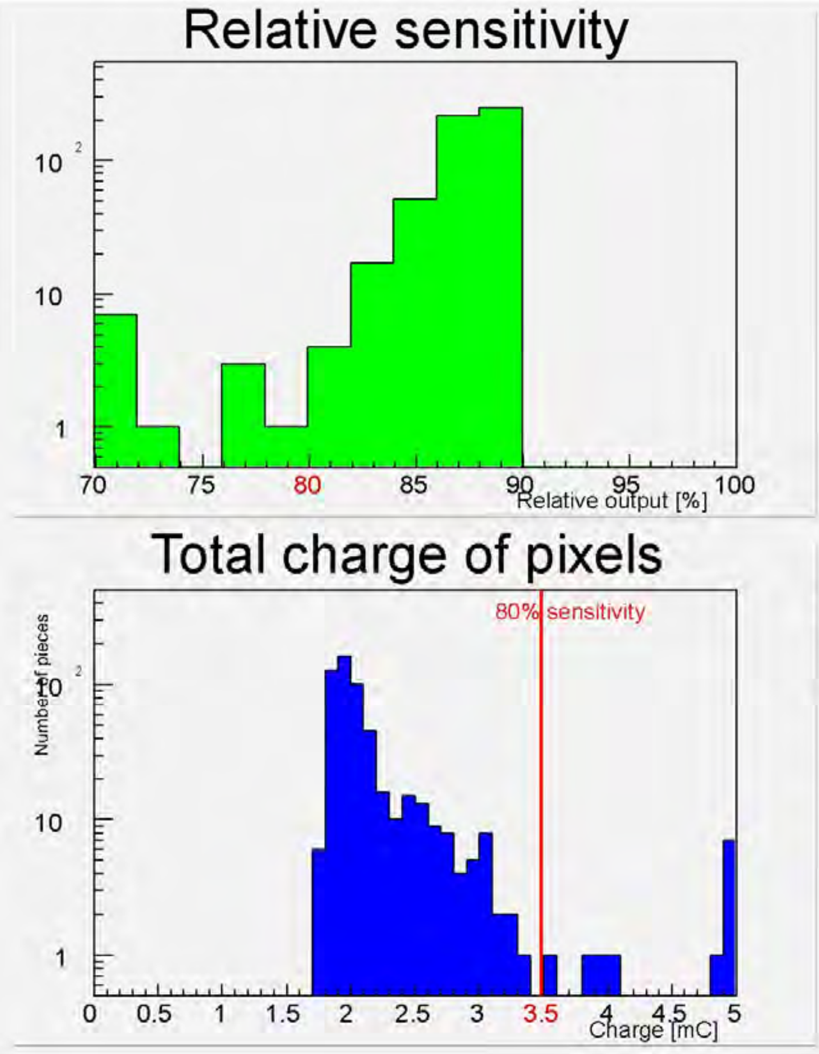
<star field (Crab nebula)>



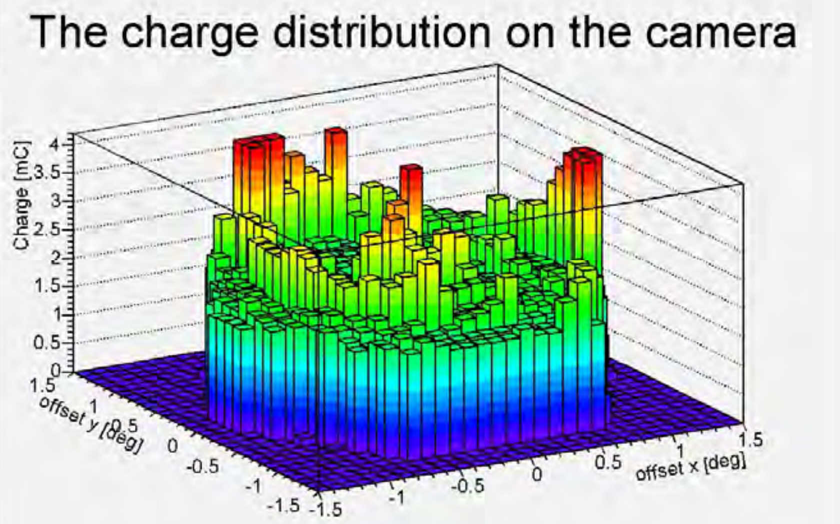
# Objects	# stars <11mag	Brightest star[mag]
10	228	3.02

- 10 typical TeV sources
- Brighter than 11.0 mag stars
- Observation time 100 h/yr for each (Total: **1000h /yr**)
- Star rotation on Camera
- Moon observation is not taken into account

Simulation Results of the Stars and Night Sky



After 10year operation

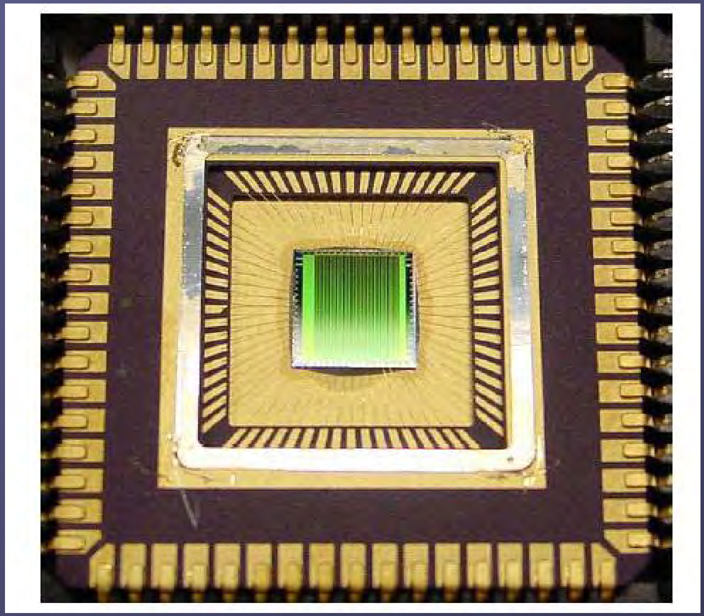


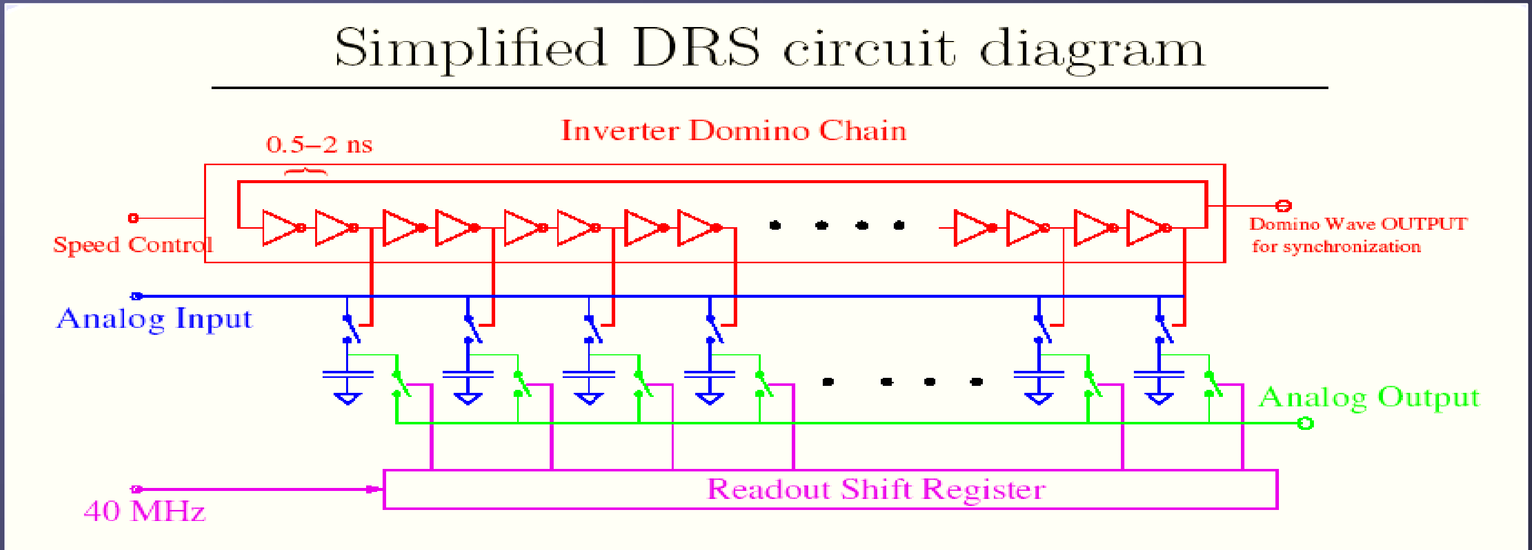
Domino Ring Sampler

Domino Ring Sampler developed by Stefan Ritt in PSI

2.5GSamples/sec with >10bit resolution

DAQ system for MAGIC is in development in U-Siena and U-Pisa





γ Shower Events

(by MC simulation)

HPD

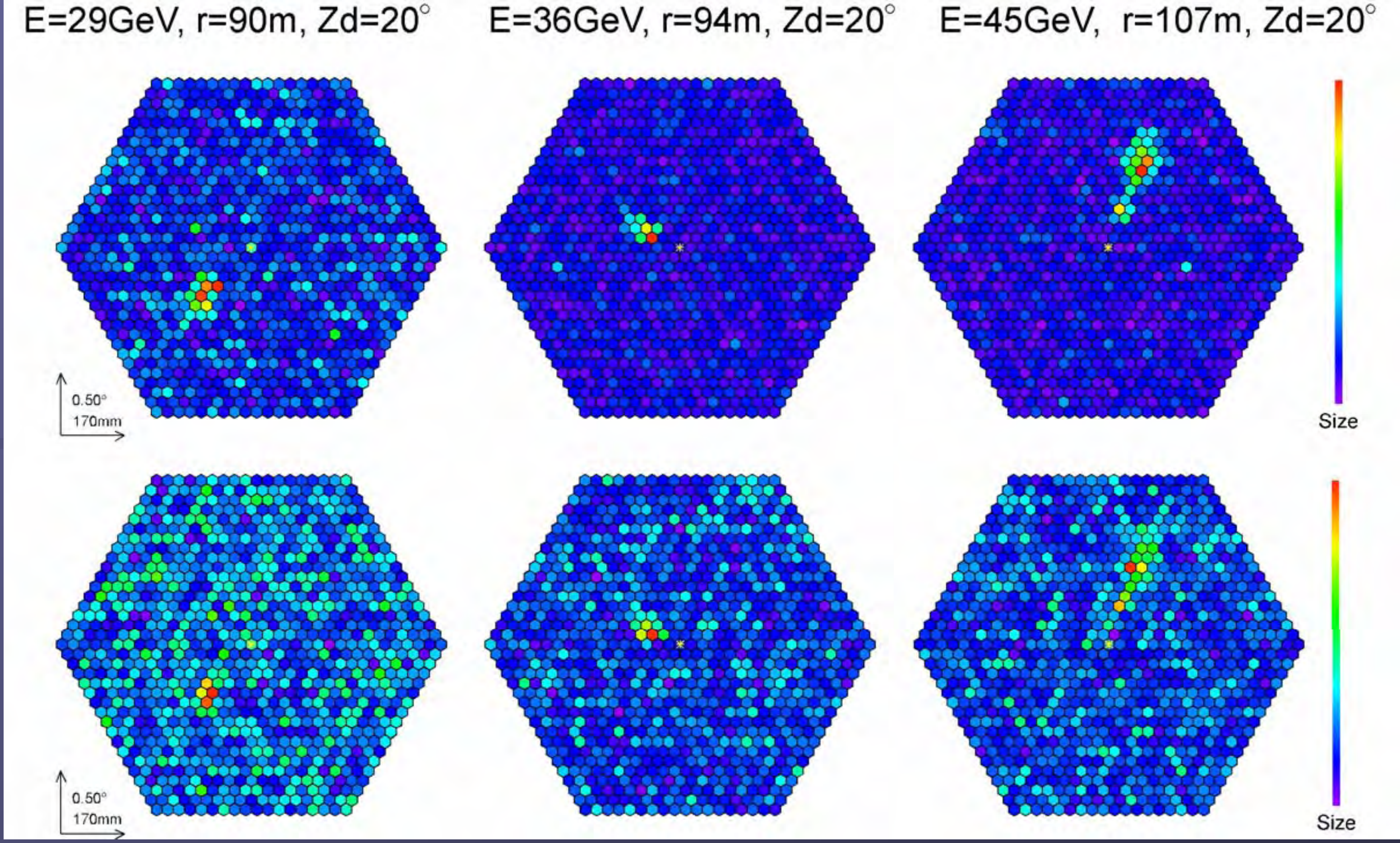
with 10ns gate

(2 Gsample/s FADC)

PMT

with 20ns gate

(300Msample/s FADC)



Advanced Camera for MAGIC-II

- HPDs are ready to use in MAGIC-II camera
  - Life time is estimated to be enough for 10 years
  - Q.E. ~50% at peak
  - Time response (1nsec rise, 3nsec FWHM)
  - Charge response and Dynamic range are satisfactory
- Signal quality
  - Photo collection efficiency is increased x2
    - 17m telescope ➔ 24m telescope
  - Ultra fast FADCs suppress the night sky background x1/2
  - In total, quality factor increase by a factor of 2
- Aiming ~20GeV threshold energy with HPD camera
- SiPM development in the collaboration with MEPhI is also on-going in parallel for further improvement ➔ aiming 60-70% Q.E.

Summary

- New generation telescopes, HESS, MAGIC, VERTITAS and CAGAROO-III are producing science.

- MAGIC (this one year)
  - 3 sources among 8 HESS source above G.C. were confirmed
  - 4 AGNs were observed
  - New TeV source 1ES1218 – z=0.18 was discovered – steep energy spectrum
  - 2 GRBs were observed in bursting phase – under the analysis

- MAGIC will be upgraded to MAGIC-II in 2007
  - Stereo observation → sensitivity x2
  - HPD camera
  - 2.5 GSample/sec Ultra fast FADC
  - Expected threshold energy is ~20GeV
  - Simultaneous observation with GLAST
    - Good science, Cross calibration between 20-100GeV

- Significant contributions from Italian colleagues in MAGIC and MAGIC-II. Padova, Siena, Pisa and Udine