MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope

The Major Atmospheric Gamma-ray Imaging Cherenkov Telescope

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The MAGIC Telescopes

- A two-telescope stereoscopic Imaging Air Shower Cherenkov telescope system, observing gamma-ray initiated extended air showers, 2 x 17 m diameter
- Located on the Canary Island of La Palma, Spain
- In operation since fall 2004 (1 telescope), summer 2009 (2 telescopes)

- High-sensitivity PMT camera
  28% QE (MAGIC-I) @ 350 nm
  32% QE (MAGIC-II)
- 2 GSampels/s DAQ
- Substantially lower energy threshold than other installations:
  - 55 GeV nominal
  - 25 GeV sum trigger
- Mono sensitivity: 1.6% Crab
- Stereo sensitivity: <1.0% Crab
- Fast repositioning: <17 sec!

- 150 physicists
- 23 institutes

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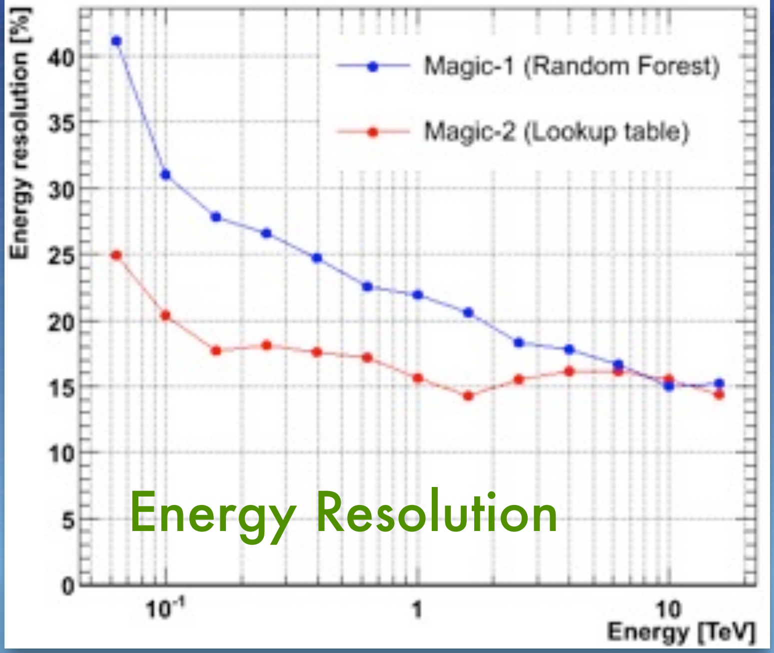
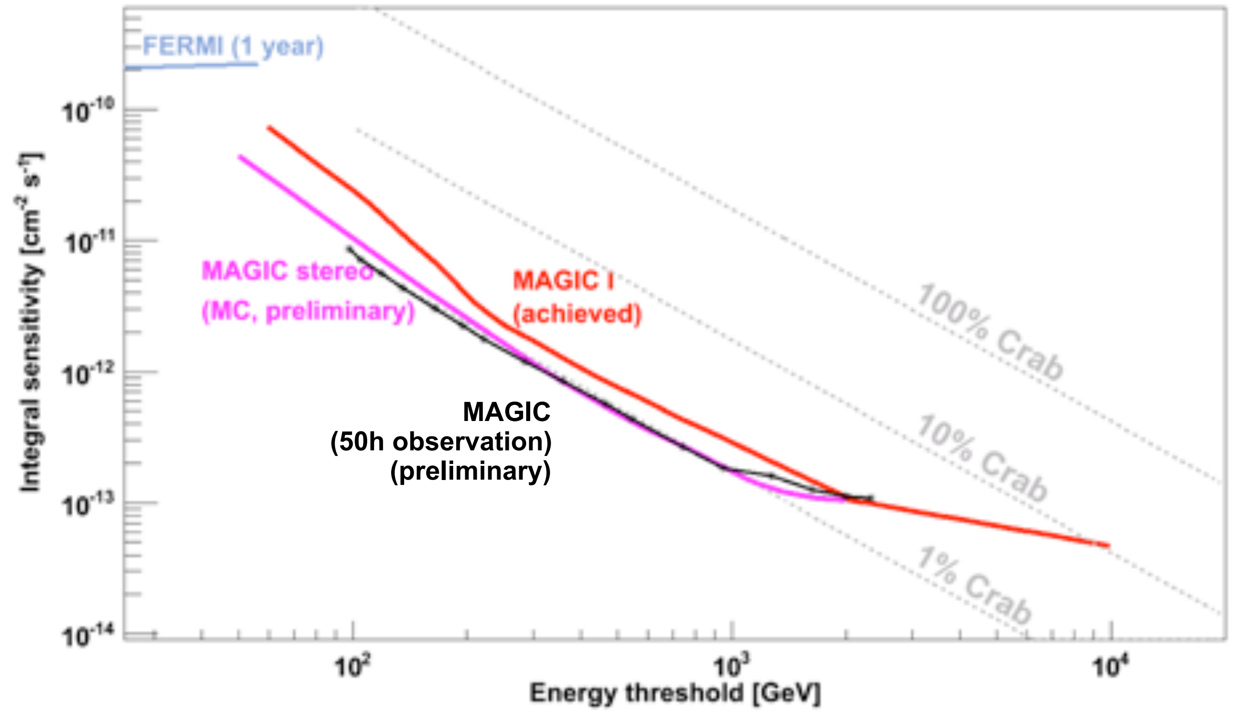
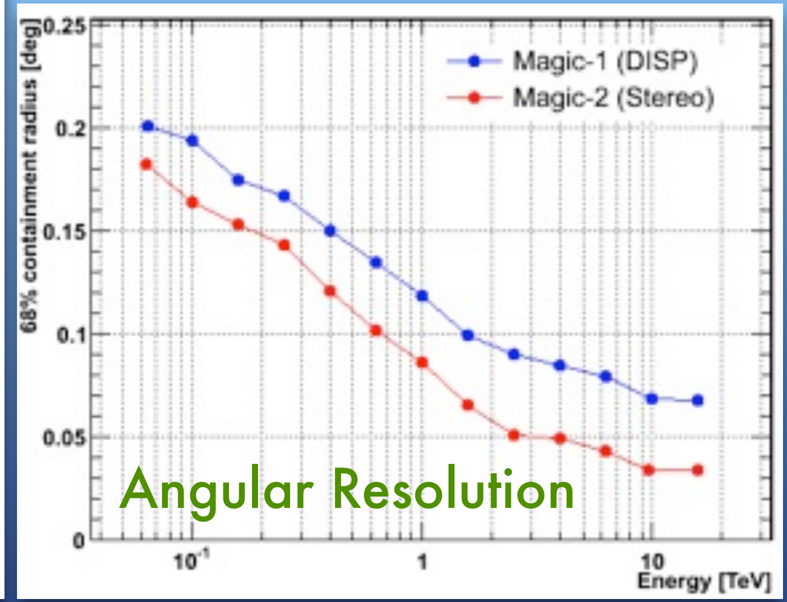
MAGIC Performance

- Energy resolution:
  ~25% (1 telescope) ➙ ~15% (2 telescope)
- Angular resolution:
  Substantial (50%) improvement
- Overall sensitivity improved by a factor of 2–3
- Achieved sensitivity matches well the MC

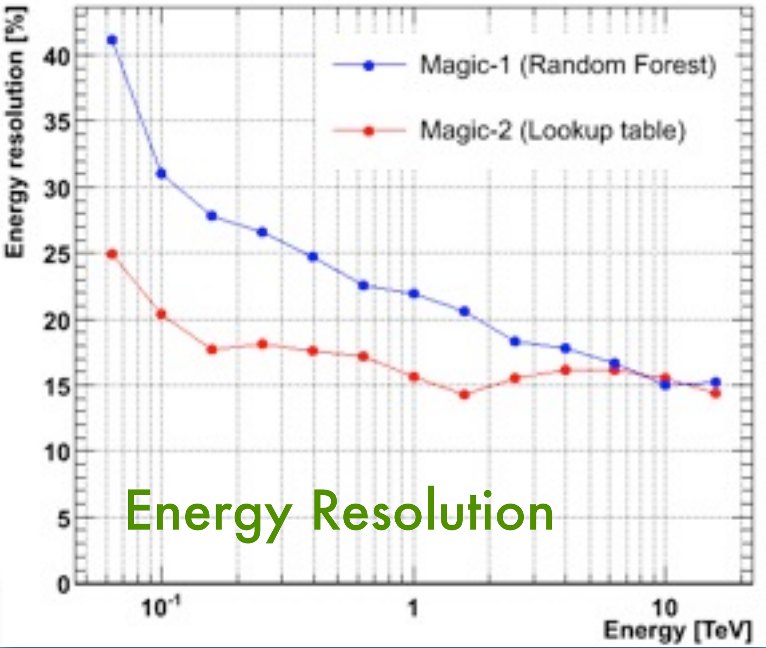


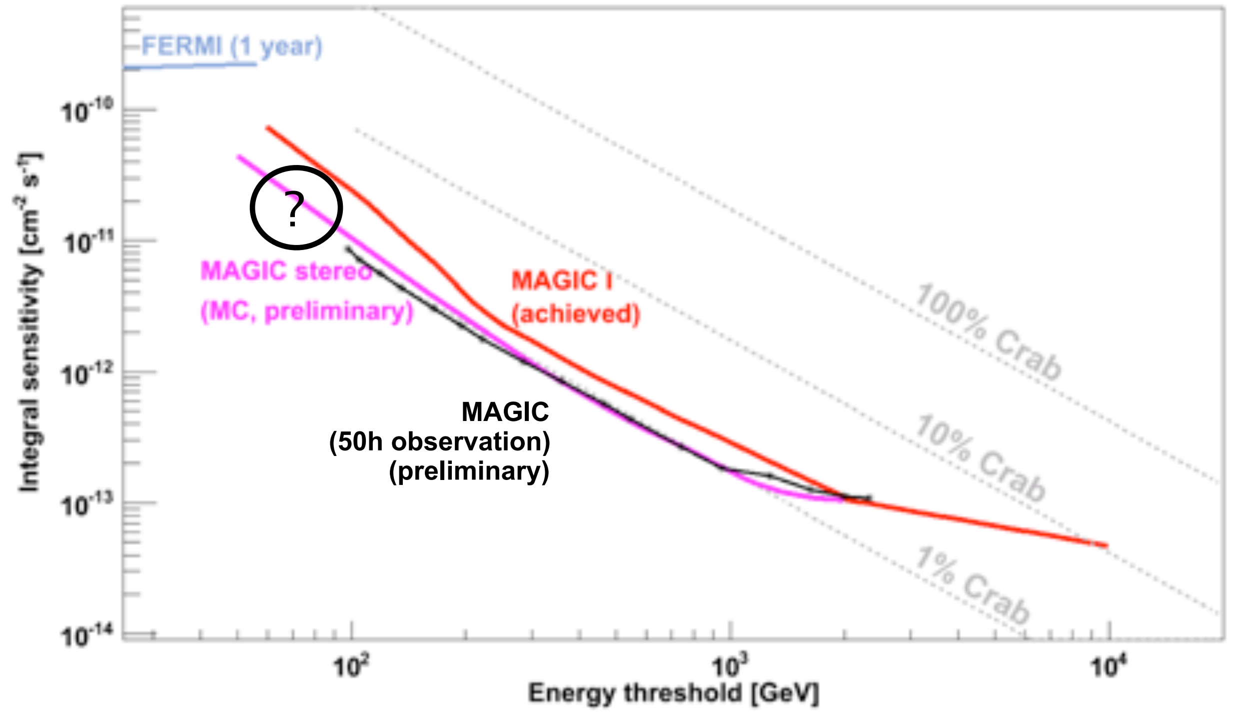


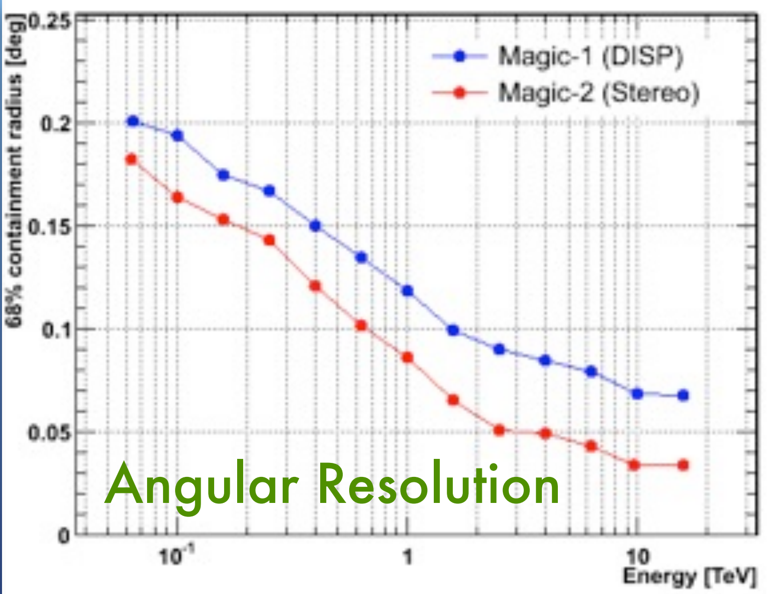


MAGIC Performance

- Energy resolution:
  ~25% (1 telescope) ➙ ~15% (2 telescope)
- Angular resolution:
  Substantial (50%) improvement
- Overall sensitivity improved by a factor of 2-3
- Achieved sensitivity matches well the MC
- Work at low energies ongoing

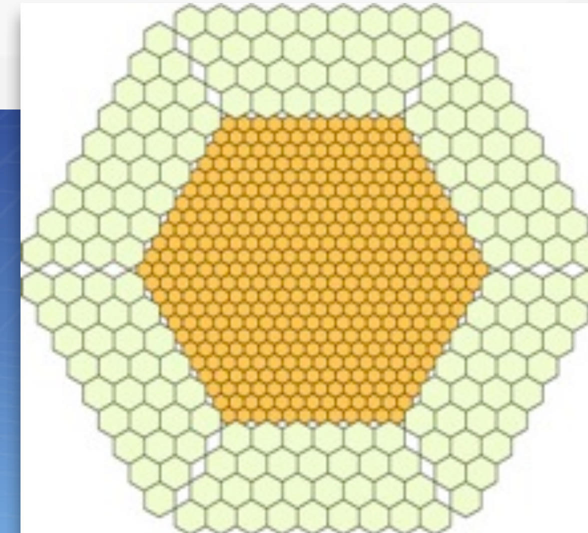




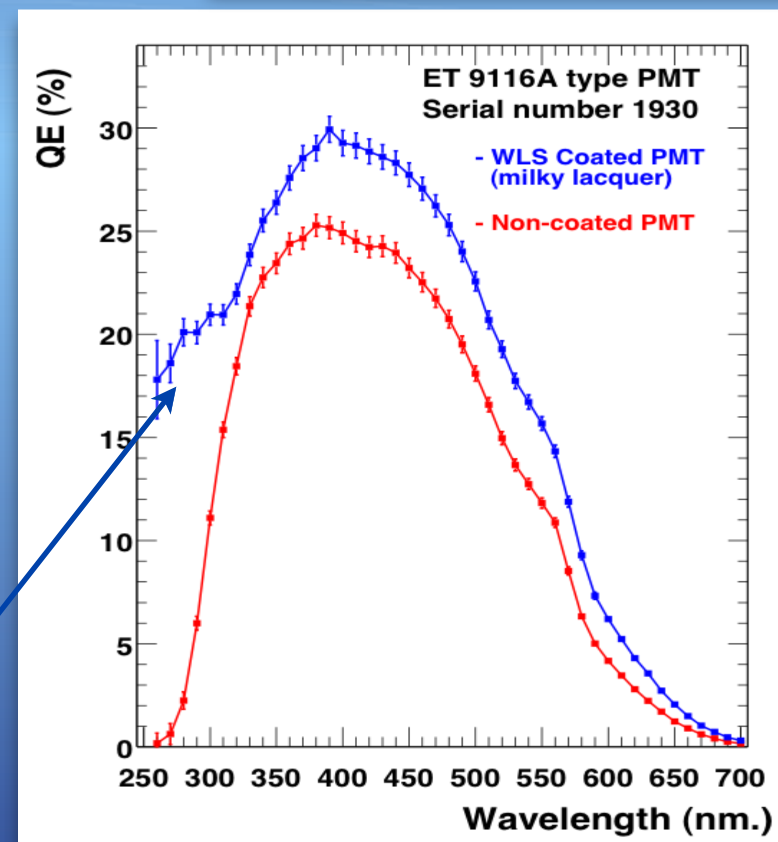


MAGIC-I Camera

- Different types of PMTs:
  396 x 0.1° in the center
  180 x 0.2° in the outer part
- Enhanced QE with special coating (25%)
- 3.5° FoV
- Upgrade in 2011



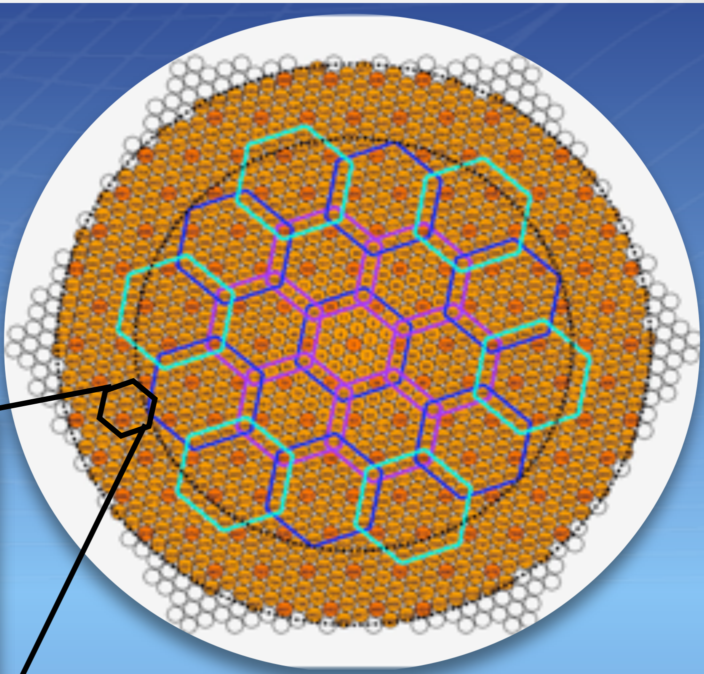
equal to
increasing the reflector
$241 m^2 \rightarrow 286 m^2$

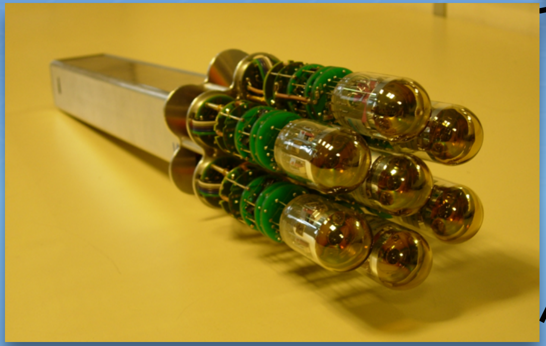


MAGIC-II Camera

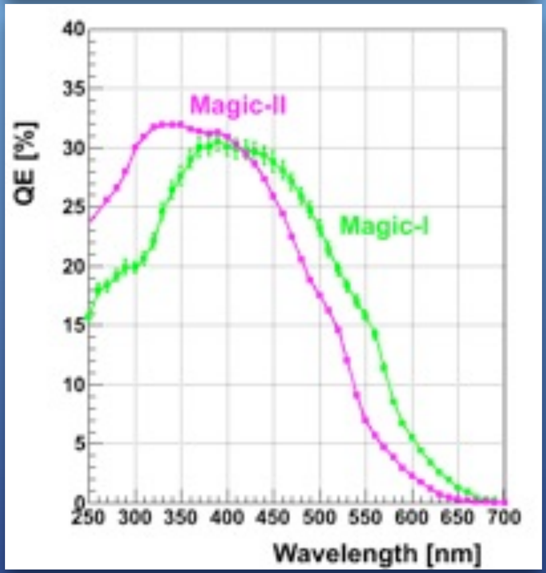
Design criteria:

- 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: HPD, SiPM



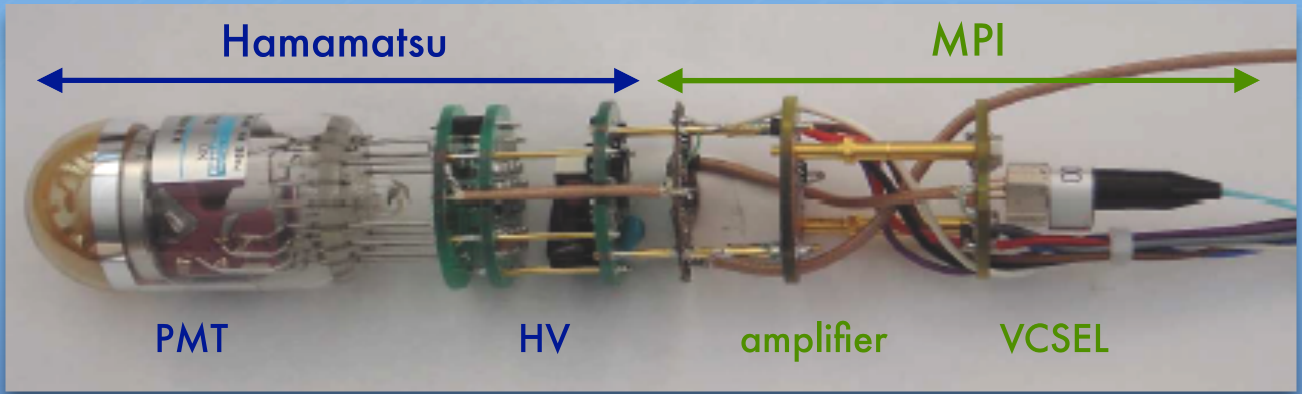


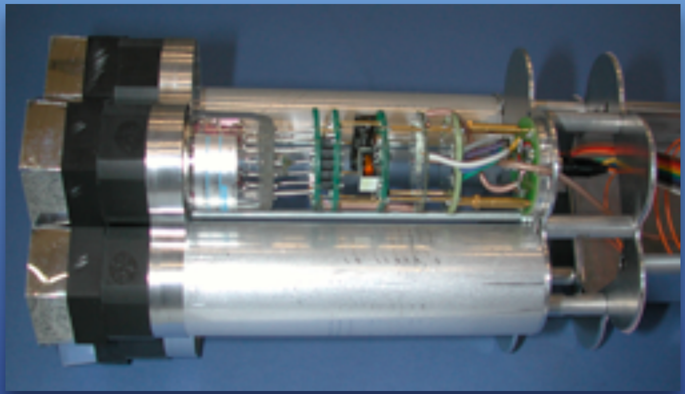
- 1039 identical 0.1° pixels
- Round configuration
- 3.5° FoV (similar to MAGIC-I)

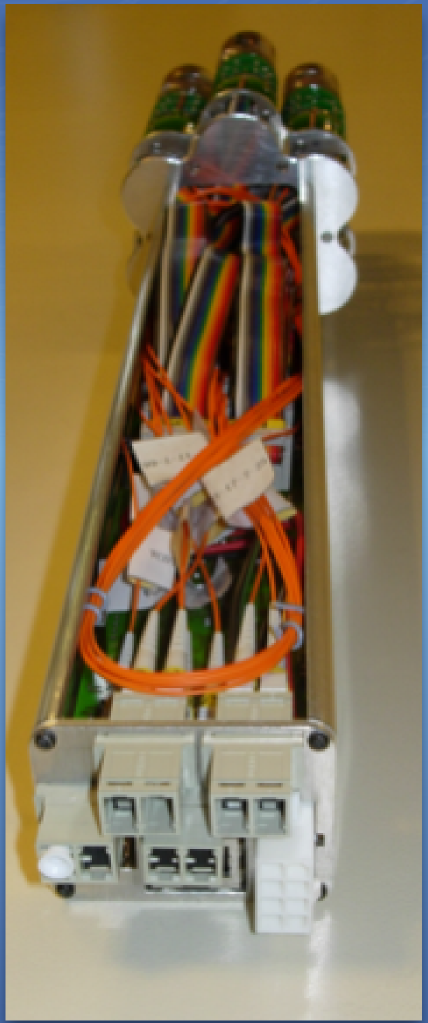


MAGIC-II Camera: PMT Clusters

- Hamamatsu R10408 PMTs
- Peak QE typically 32% (≈15% higher than MAGIC-I)
- FWHM ≈2.3 ns
- Cockroft-Walton HV generator in PMT socket
- Electronics bandwidth: 700 MHz, dynamical range: 800







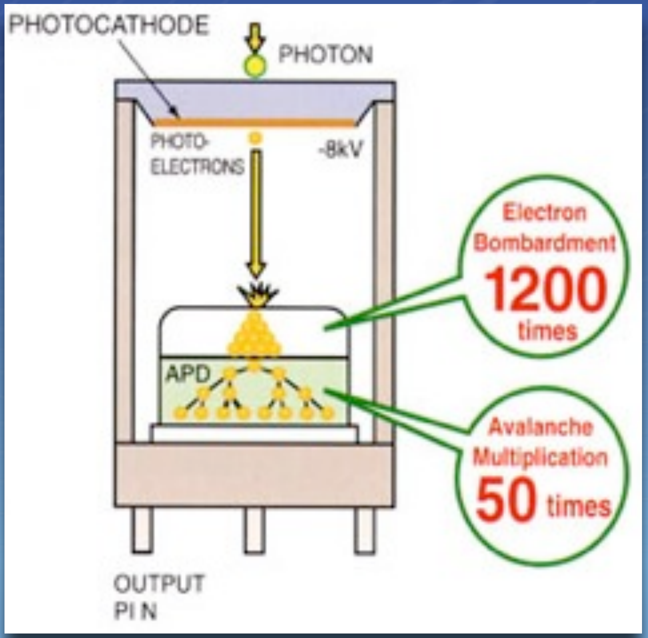
Near Future: Upgrade with HPDs?

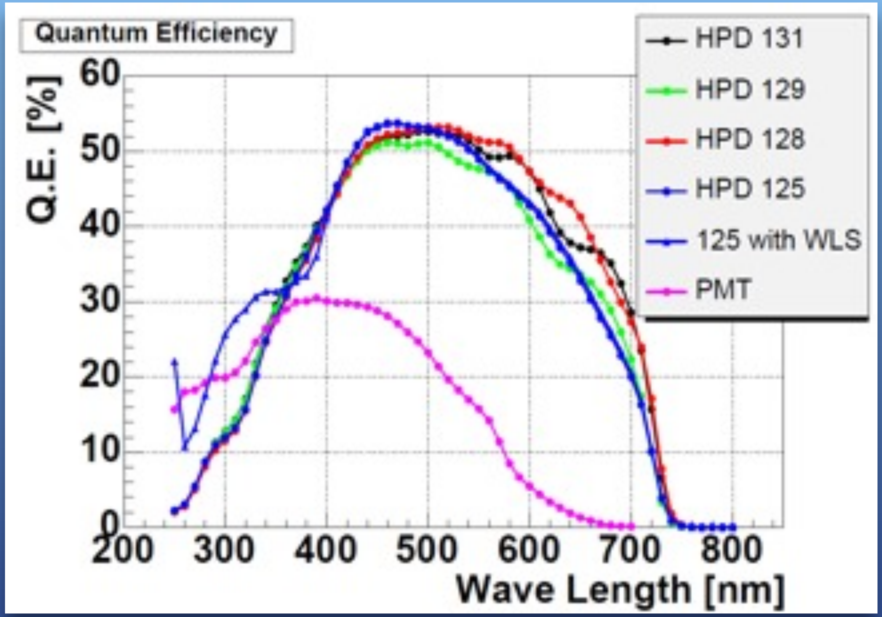
Principle:

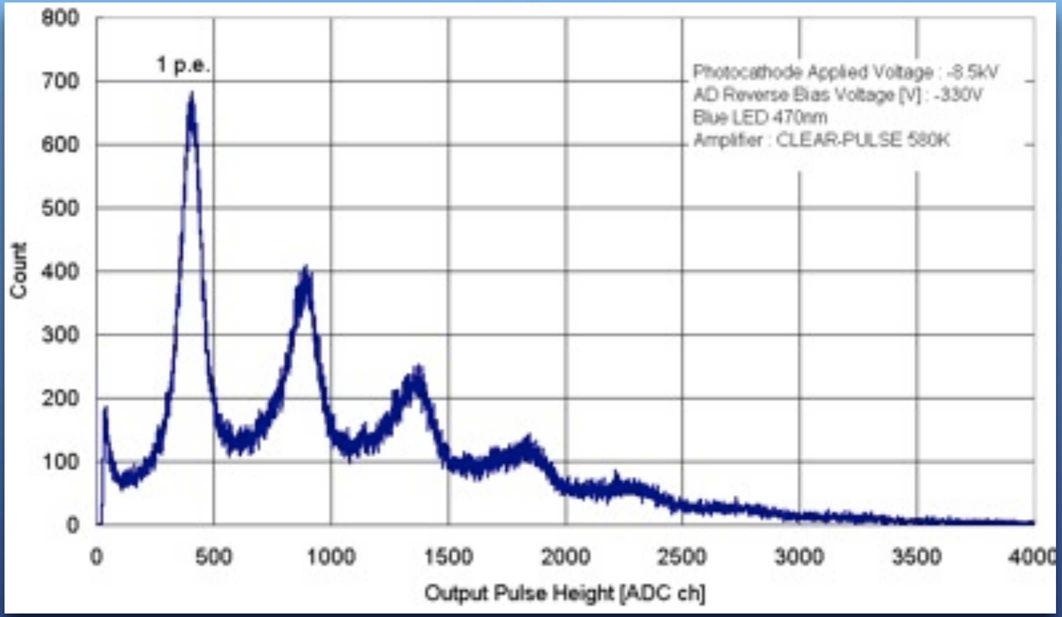
- Vacuum tube operated at 6-8 kV
- Avalanche diode (~300 V)

Advantages:

- Good single photoelectron resolution
- High QE GaAsP Photocathode (QE>50%)
- High photoelectron collection efficiency (~100%)
- Low afterpulse rate (~300 times less than PMTs)

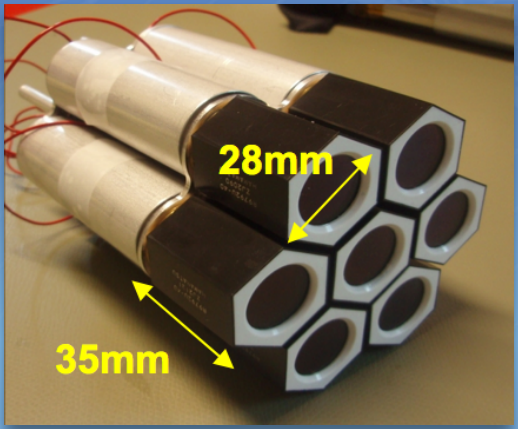


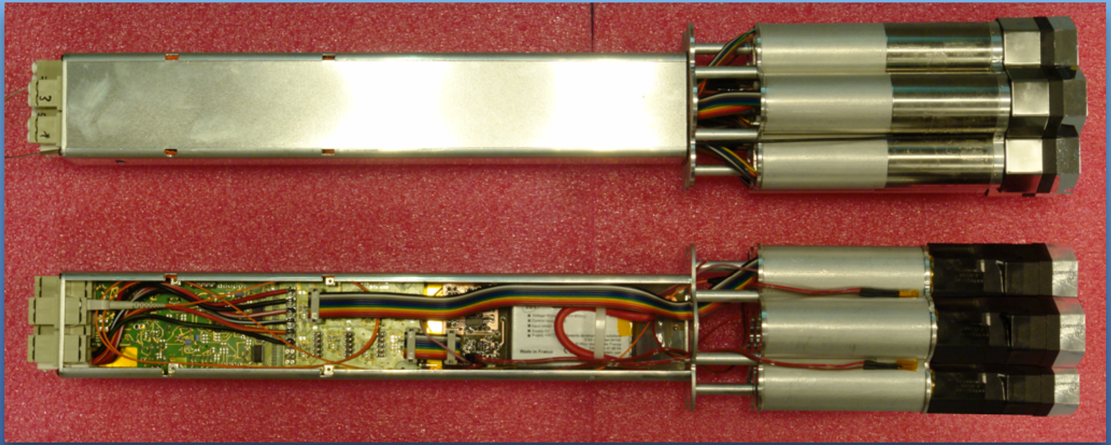




Near Future: Upgrade with HPDs?

- HPD clusters have the same geometrical shape as PMT clusters
  → **easy to replace**
- **Fact:** E_{th} 25GeV → 15GeV using HPDs and analog sum trigger





VCSEL | 8kV power supply | Amplifier and APD HV generator | HPD | Winston Cone

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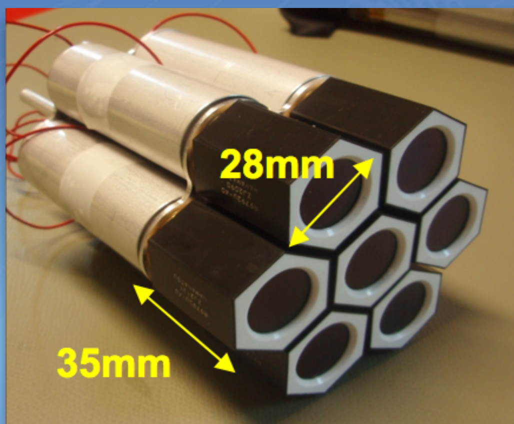
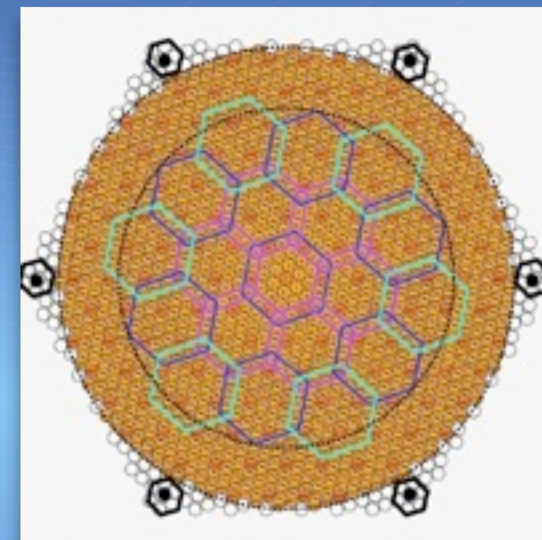
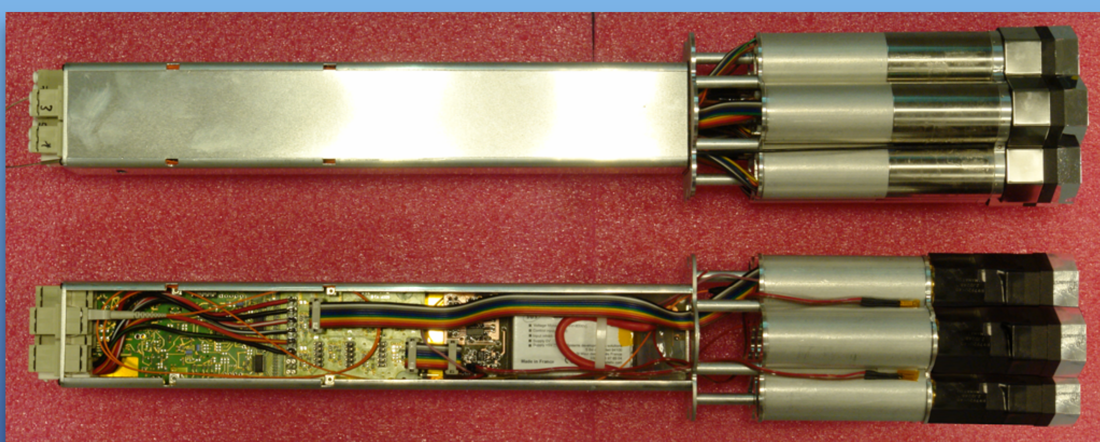


Step 1
Field test 6 clusters (42 HPDs) in MAGIC-II camera (first cluster already installed)





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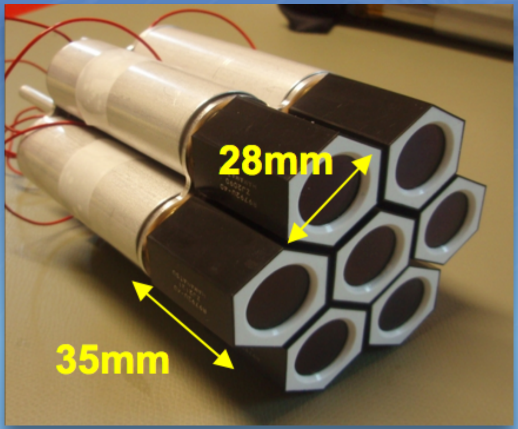

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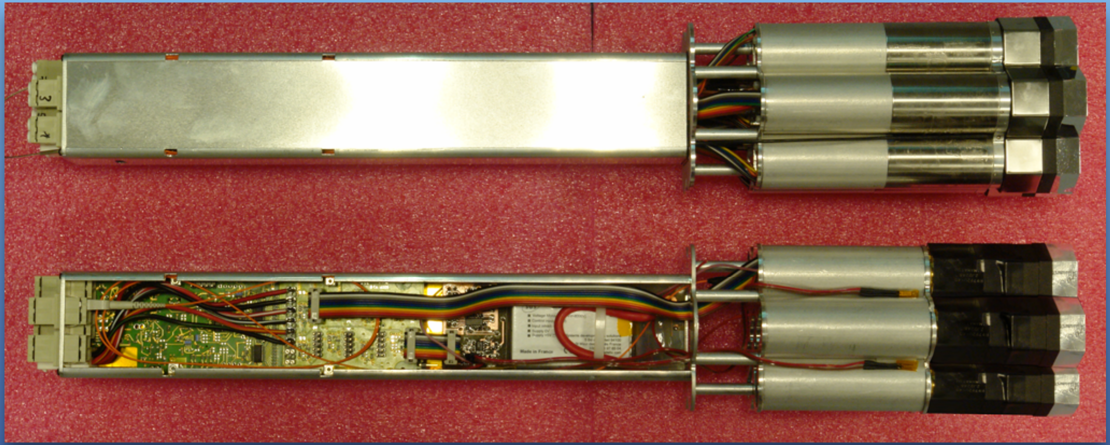
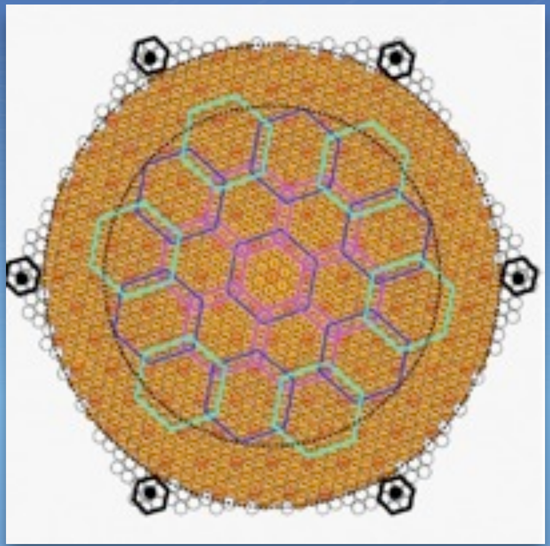
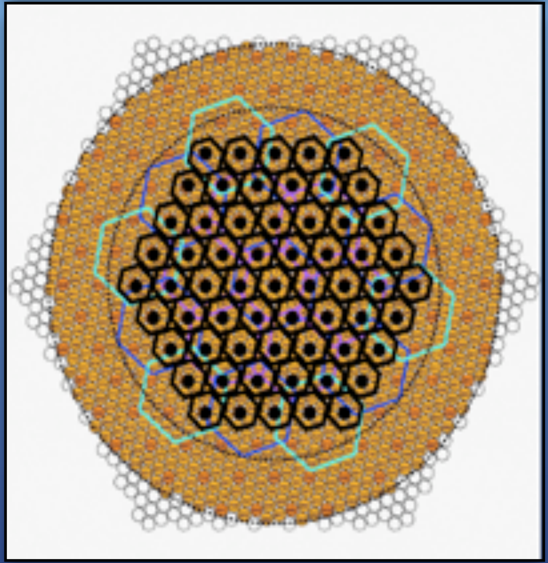
Step 2
427 HPDs in MAGIC-II camera

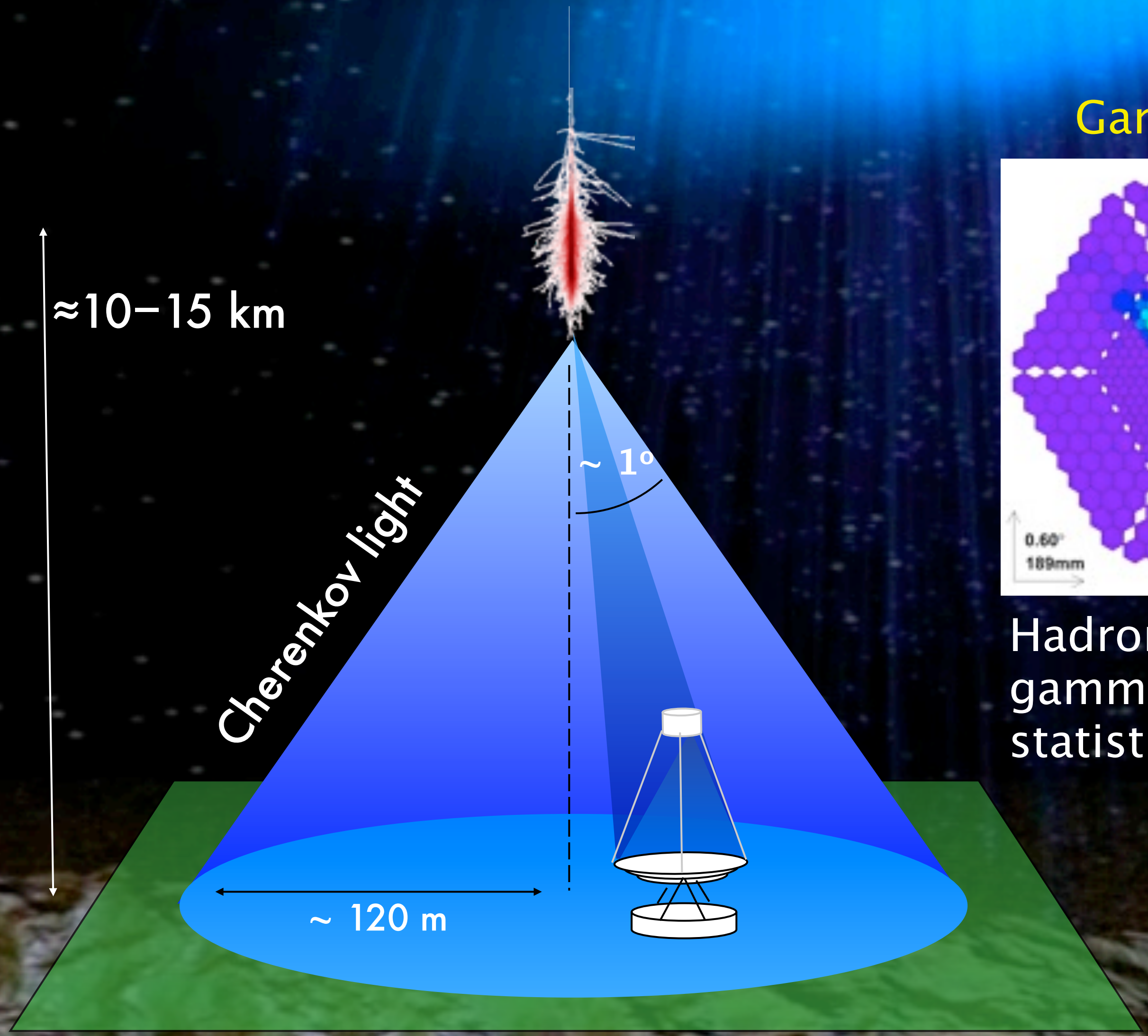


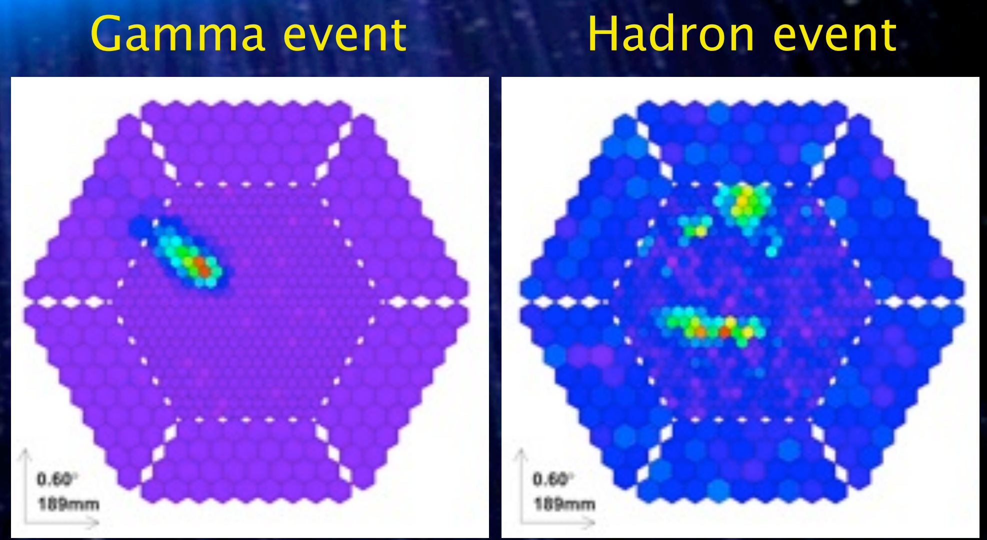




Standard Trigger of MAGIC

- 4-fold logic coincidence of a compact next neighbor group of pixels
- Each pixel has a trigger threshold of 5-6 photoelectrons
- Trigger threshold 50-60 GeV

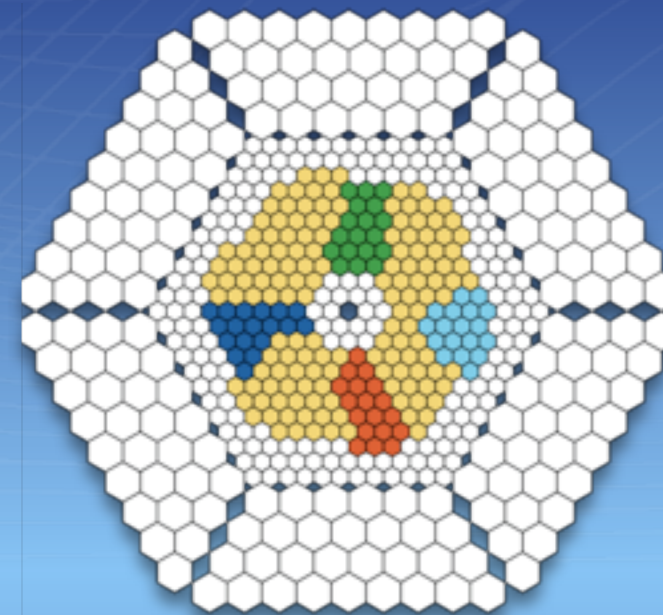


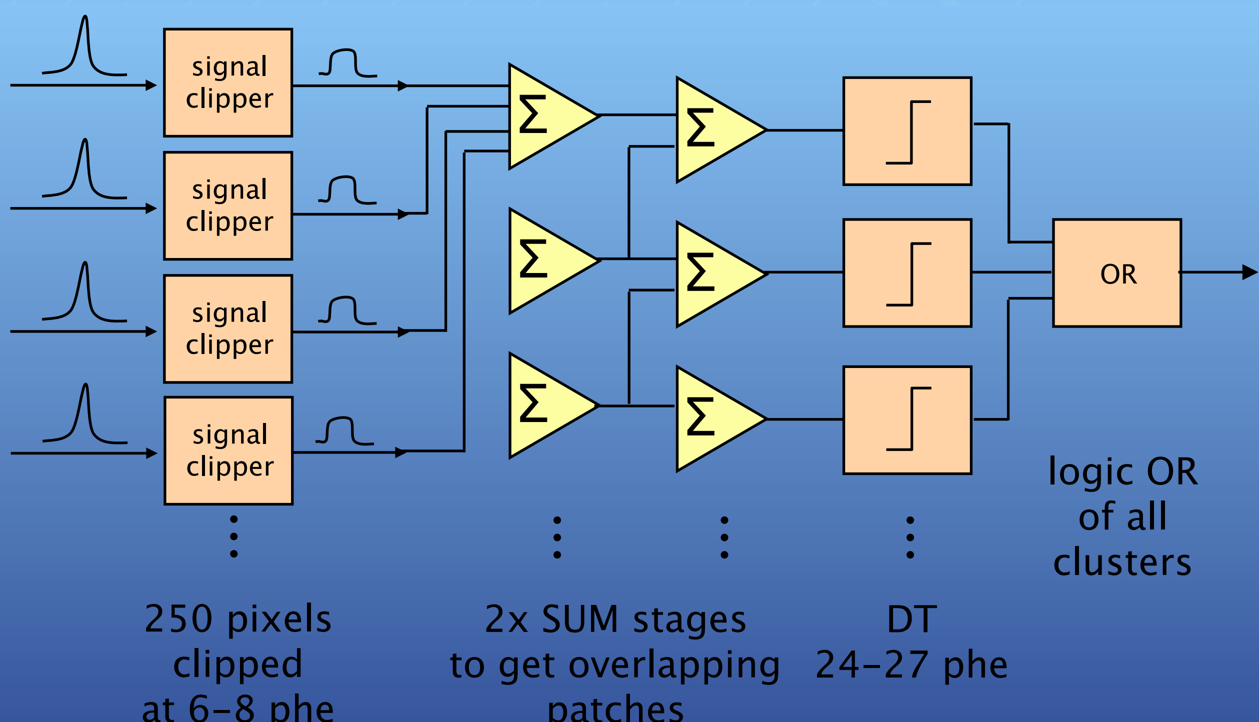


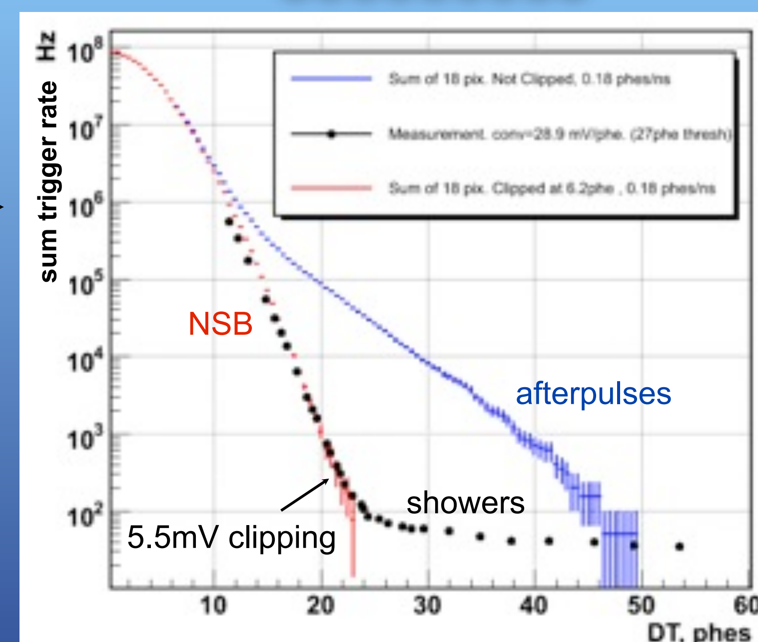
Hadrons (background) dominate over gammas (signal). They must be rejected statistically in the analysis.

Analog sum trigger concept

- Summation of 18 pixel groups in 24 patches in a ring-shape
- Idea: a) Summing up all single photons increases signal to noise ratio
  b) Fluctuations of shower larger than Poissonian fluctuations of NSB background
- PMT afterpulse problem: high noise rate
- Solution: clipping of signal







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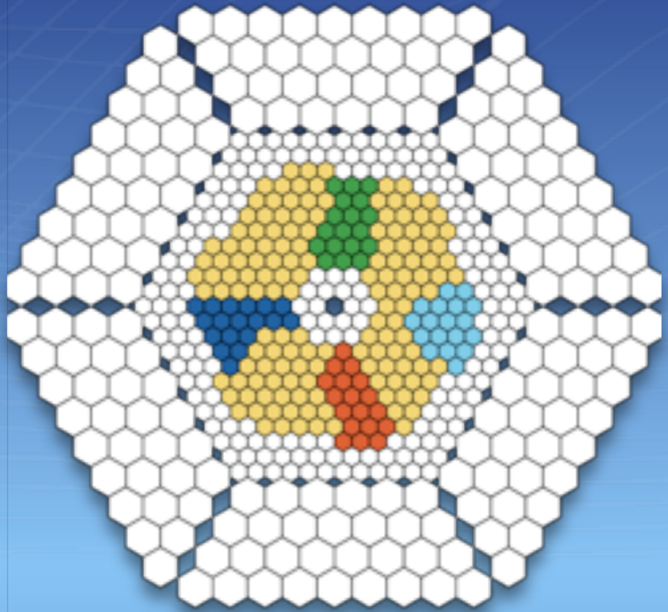
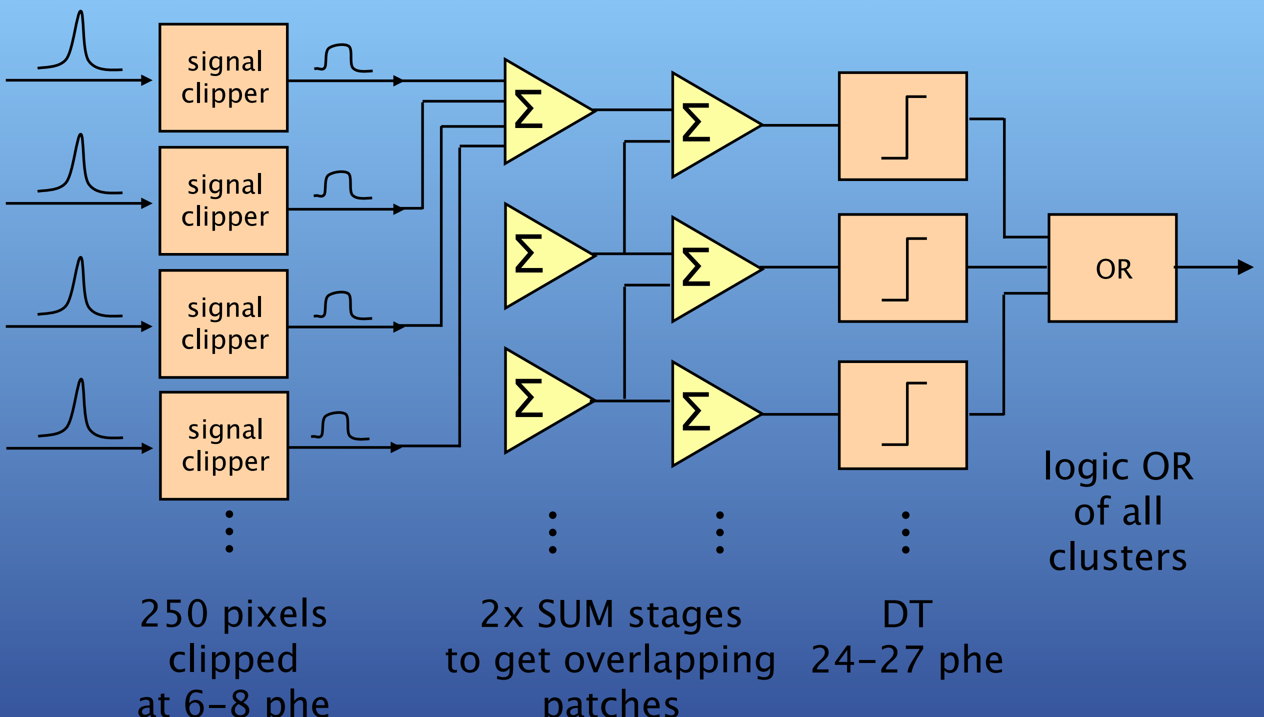
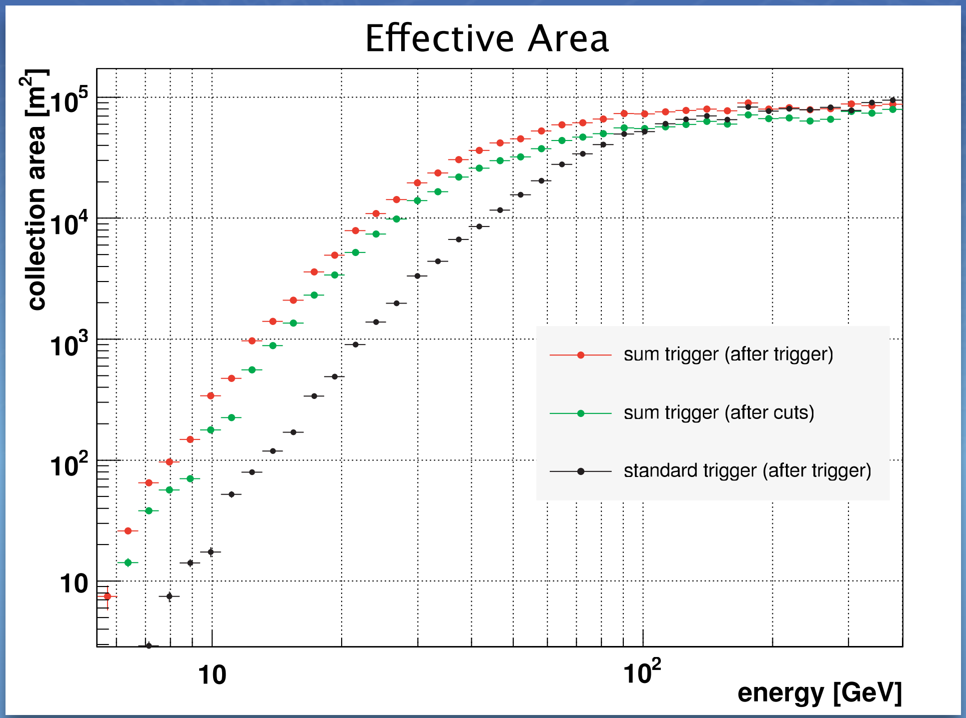
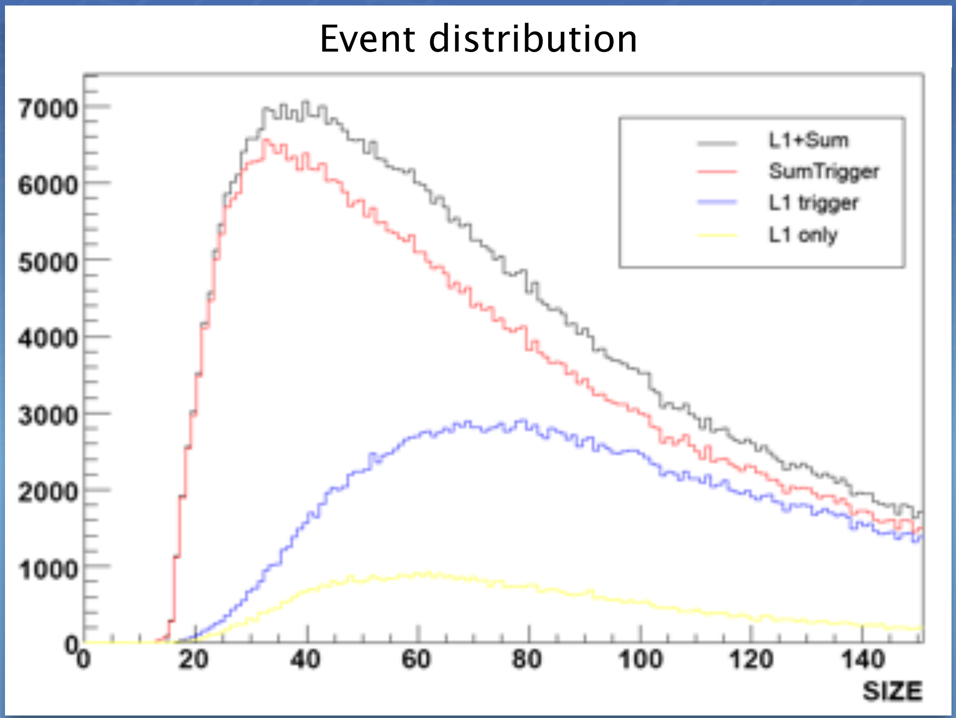




✓ Very simple
✓ Robust
✓ Lower power consumption (100-200 Watt)
✓ Low cost
✓ And in addition lower threshold!

Performance: Standard vs. sum trigger





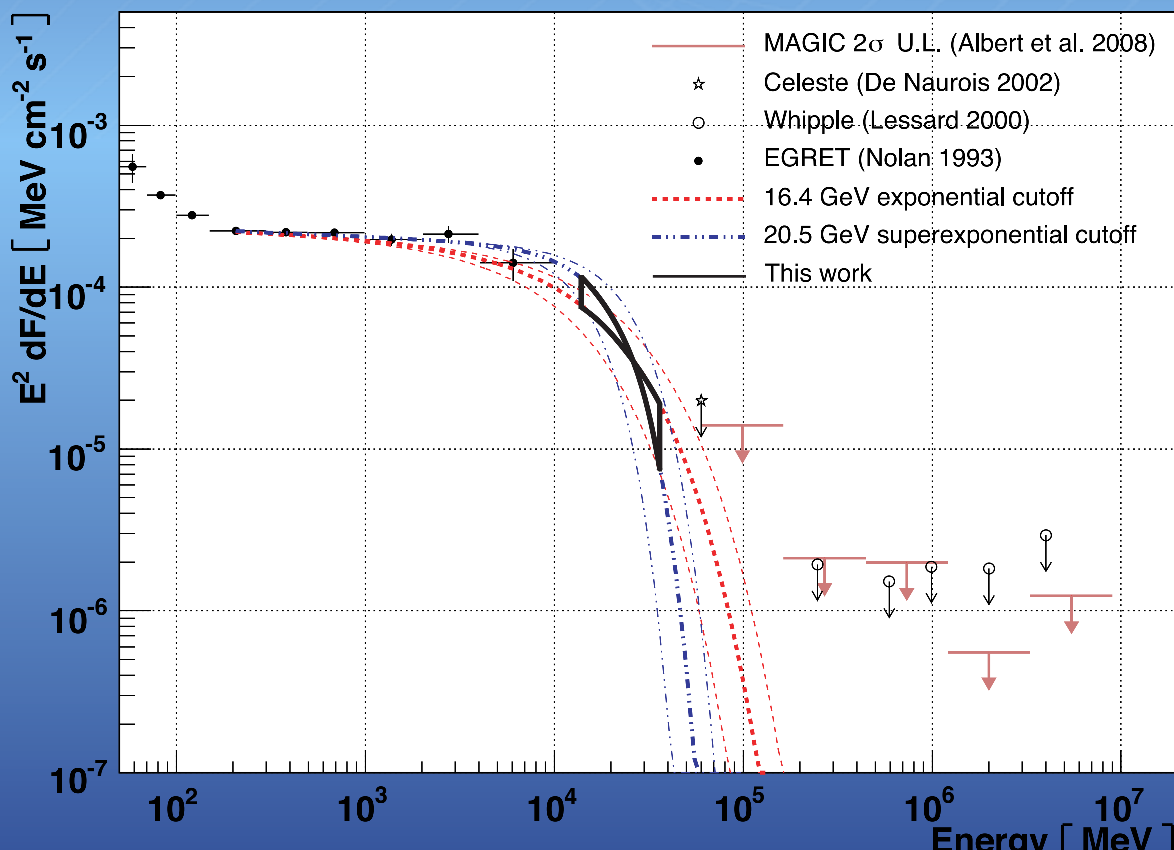
- Pulse width of sum signal: 2.5–3.0 ns (Signal/NSB ratio)
- Topology of trigger region (optimal for 10–20 GeV showers)
- Improvement at 20 GeV by factor 6
- Threshold energy at 30 GeV in respect to 60 GeV with 4NN
- Prototype to prove of principle ...

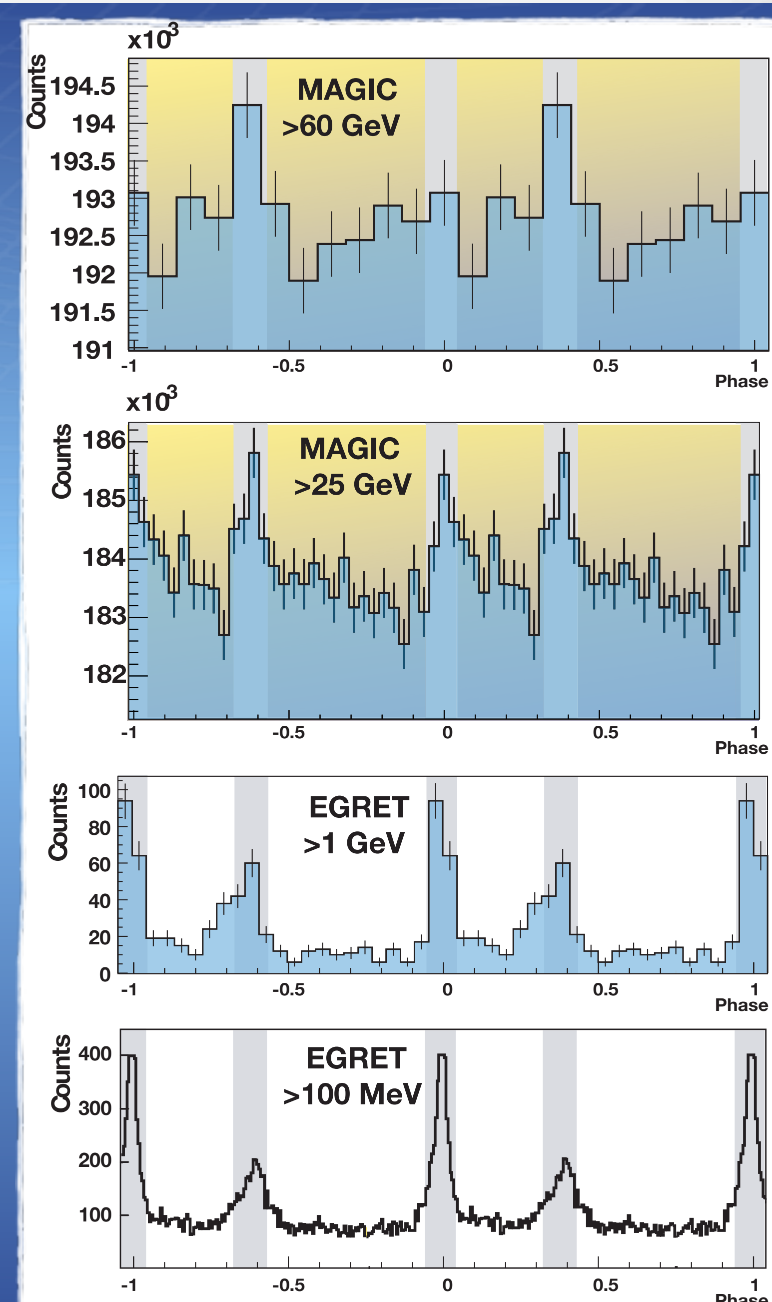
Crab pulsar

MAGIC Collaboration,
Science 322, 1221 (2008)

Observations from October 2007 to February 2008

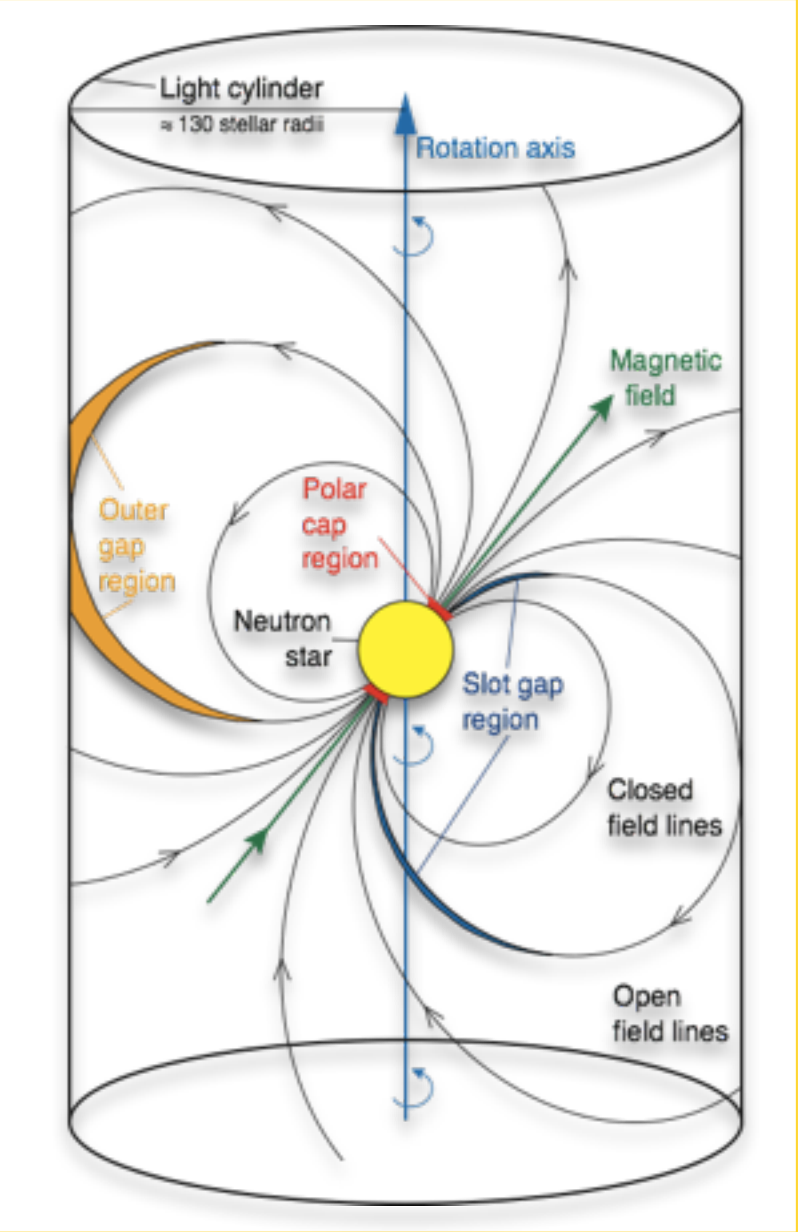
- Novel trigger system:
  threshold from 50–60 GeV down to 25 GeV
- Observed about 8.5k pulsed γ-ray events
- Clear pulsed signal at a 6.4 σ confidence level
- Pulses in phase with EGRET





Mechanism of pulsed GeV radiation?

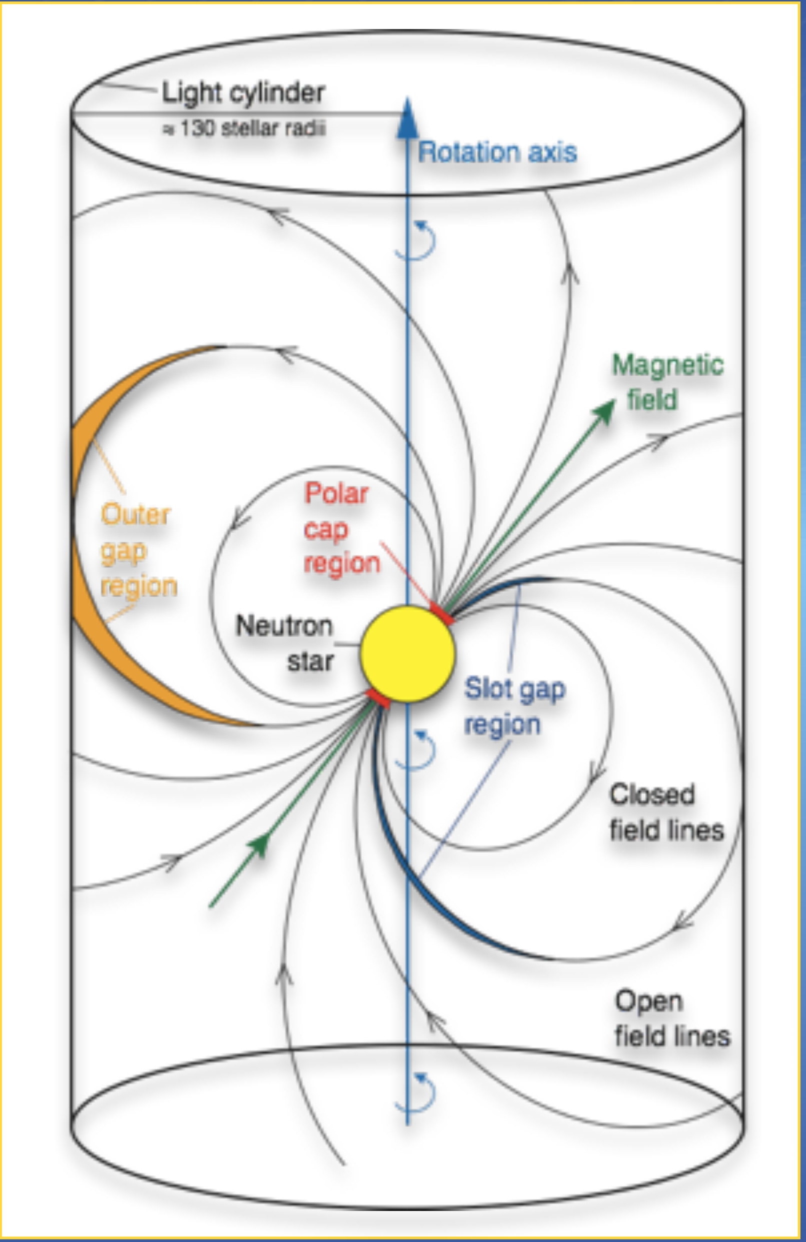
- Huge magnetic field ~10^8–10^9 T
- Exact mechanism of radiation unknown
  - Synchrotron–Curvature radiation & inverse Compton scattering
  - Polar cap model:
    - Formation of vacuum gap close to neutron star surface
    - Vacuum density below Julian–Goldreich density allows acceleration of particles
    - Absorption of γ-rays via magnetic pair production ➙ superexp. cutoff
  - Outer gap model
    - Formation of vacuum gap in outer region
    - Absorption via photon–photon collisions (magnetic field too weak for magnetic pair production) ➙ exp. cutoff
    - Particles escape at light cylinder
  - Slot gap model (from surface to high altitude)



Mechanism of pulsed GeV radiation?

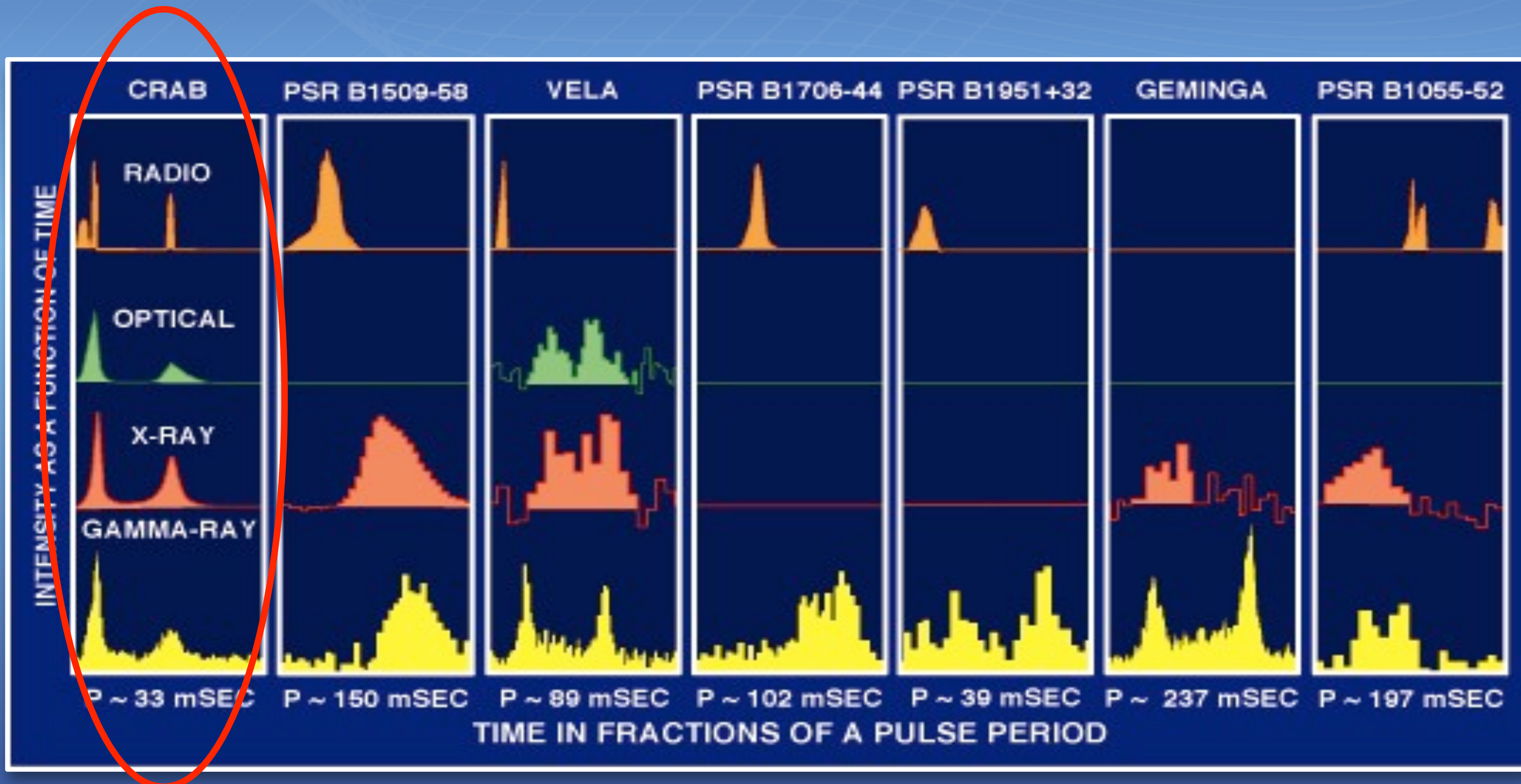
Consequence of MAGIC observation:

- Assuming a magnetic field of 3.8×10^{8} T, can limit to distance to the surface of the neutron star >4 stellar radii
- High cutoff (20 GeV) dismisses polar-cap models

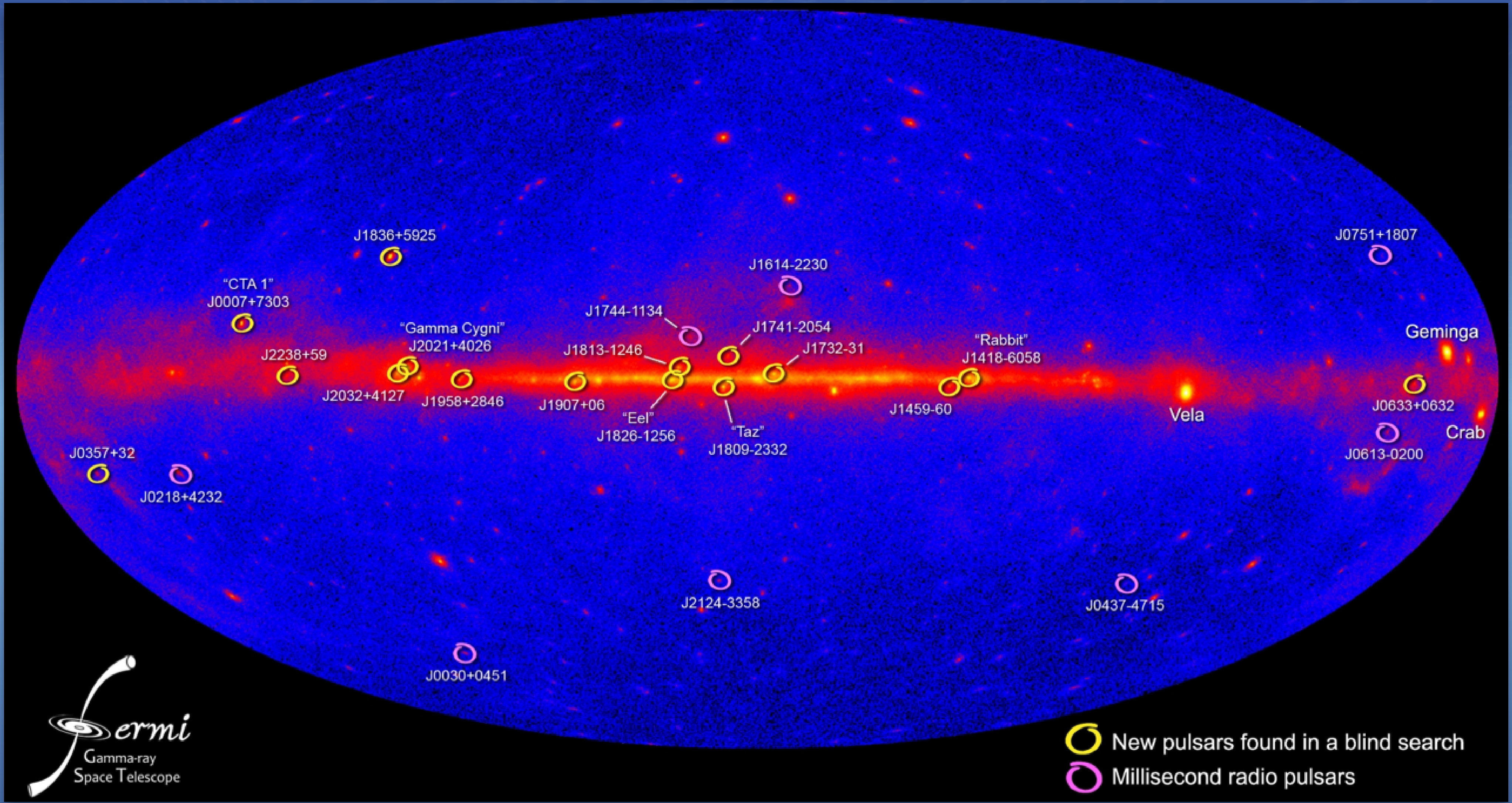


EGRET Gamma-Ray Pulsars

- 2000 pulsars known, but only 7 at γ-rays !
- Typically 2 peaks in pulse profile in gamma-rays energy
- Crab only pulsar for which the phases are the same at all wavelengths



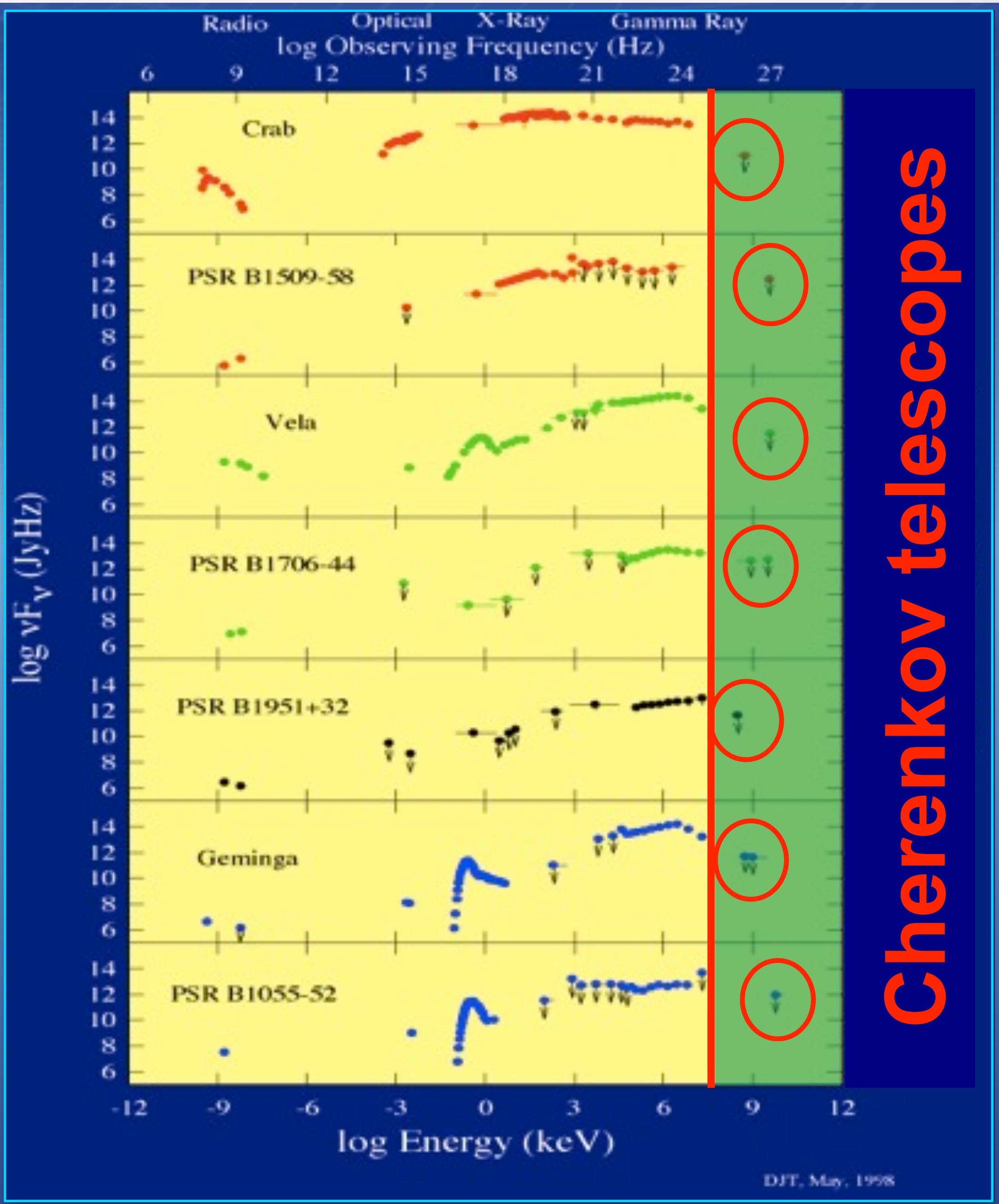
Fermi Gamma-Ray Pulsars



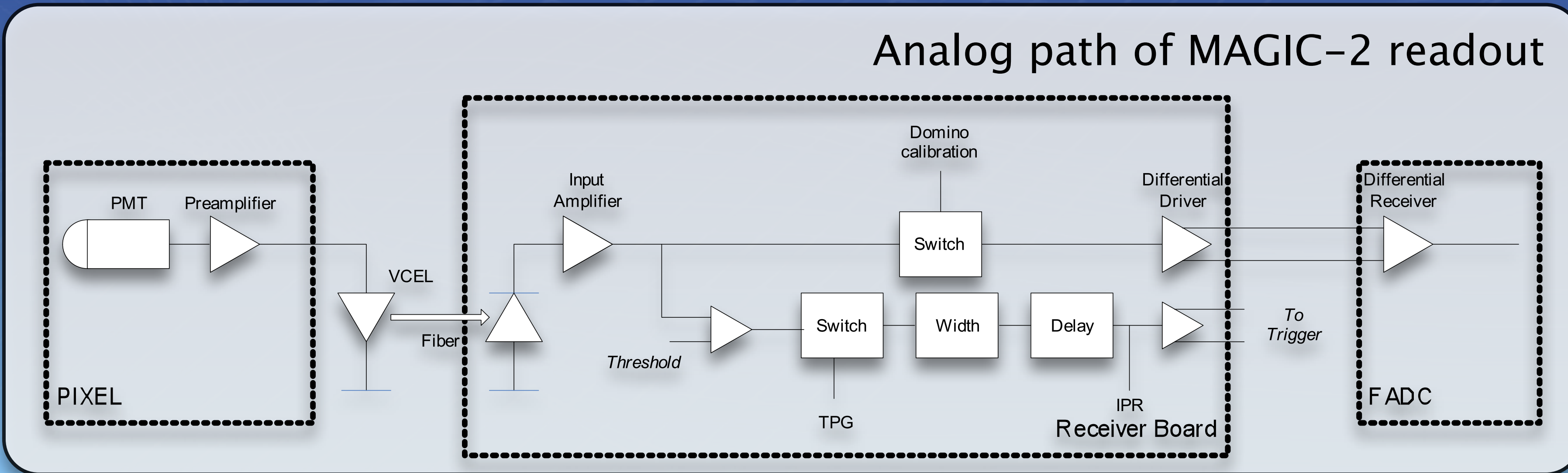
- Some Fermi pulsars emit in GeV range (statistics–limited)
- Energy range right below MAGIC

Sharp cutoff expected at a few GeV

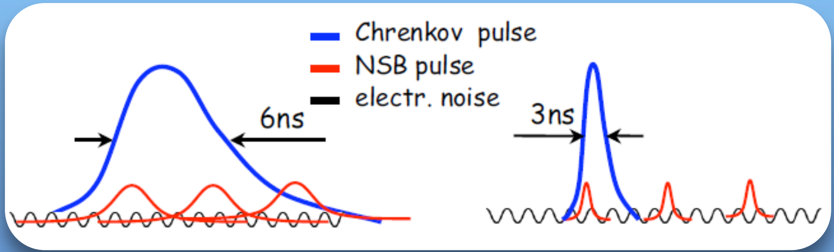
- Observational challenge since three decades
- Cutoff shape and energy contains information about the acceleration and radiation mechanism and the location of radiation
- Instrument with sensitivity well below 50 GeV needed



MAGIC readout system

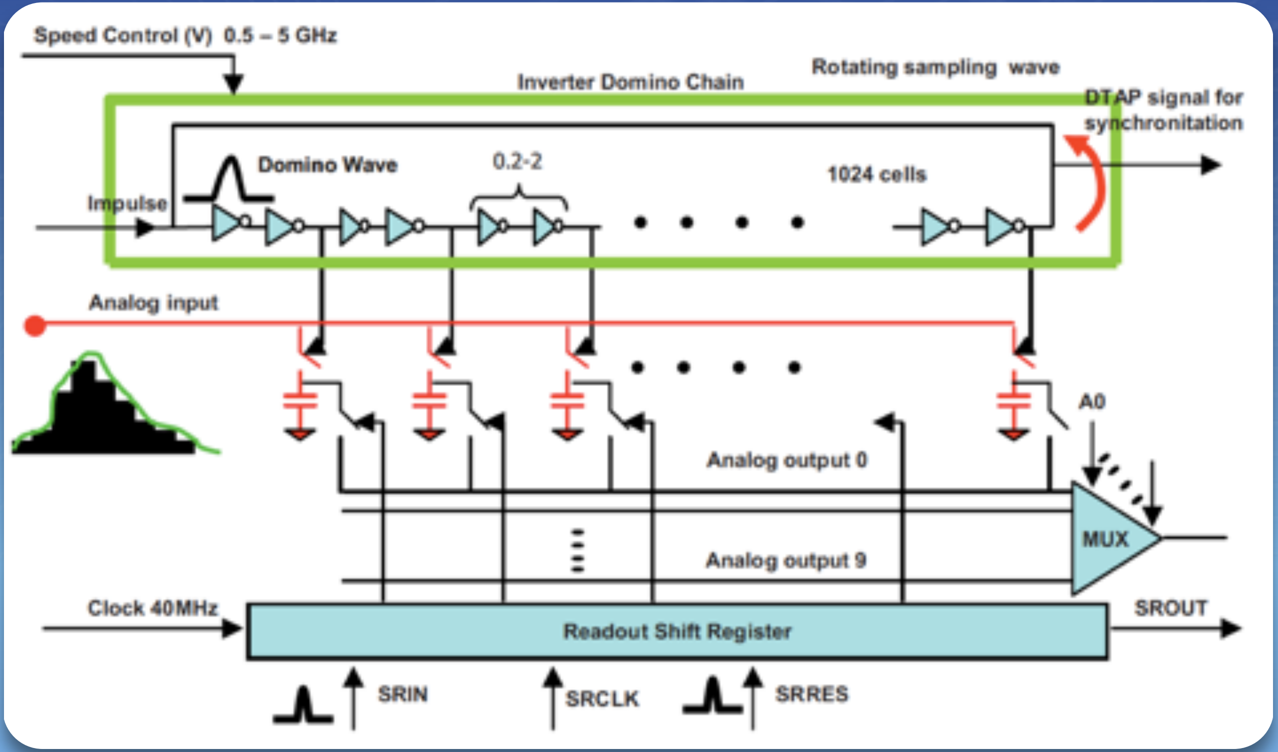


- 2 Gsamples/s ➙ 0.5 ns time slices
  - Shorter pulses ➙ less NSB
  - Better time resolution



- 10 bits FADCs (MAGIC-I) , 12bits DRS2 (MAGIC-II)
  ➙ upgrade to DRS4 for both telescopes next year
- 80 slices window
- Integrated digital modules to record GPS time, trigger pattern, etc.

Domino Ring Sampler



- Analog sampling in a switched capacitor array
- Freely propagating rotating sampling signal
- Signal opens a series of switches and charges the capacitors
- Slow 40 MHz readout of the stored signal and external digitalization

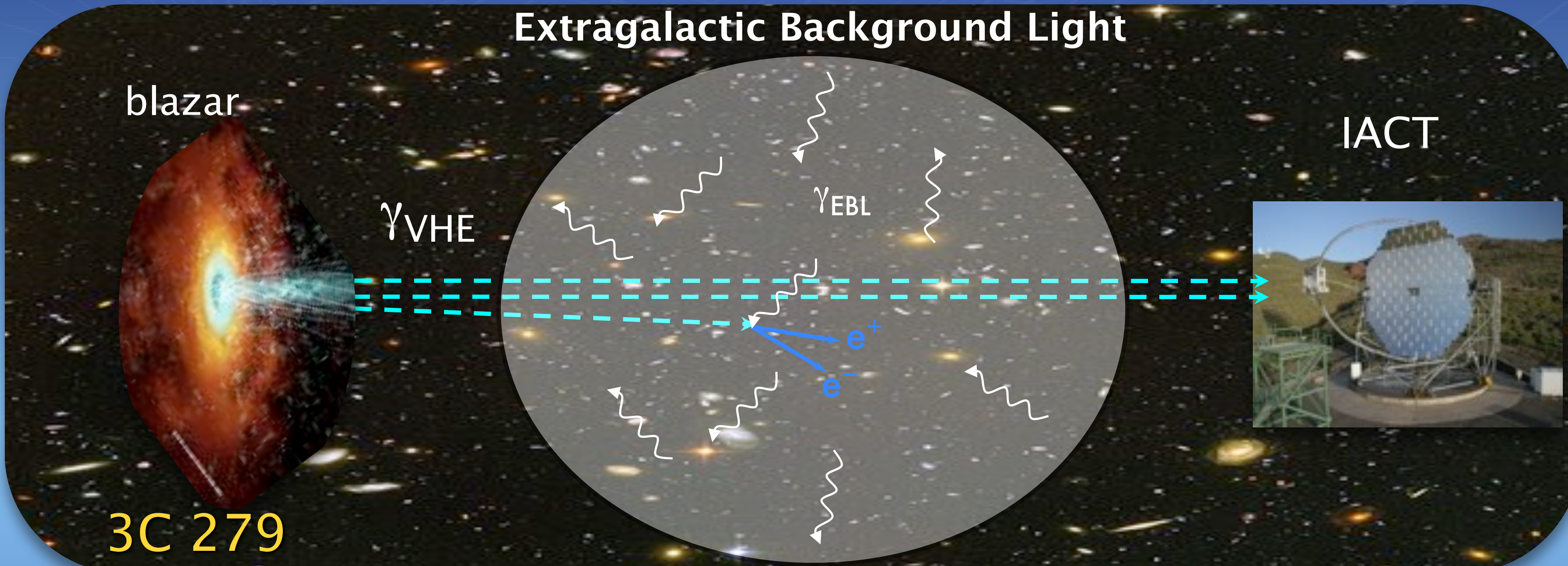
DRS2 pro	DRS2 contra
• Low power consumption @ high #channels • Synchronous sampling of all channels	• residual charge effect, charge leakage • needs frequent calibration • mismatch of transistors, T dependent

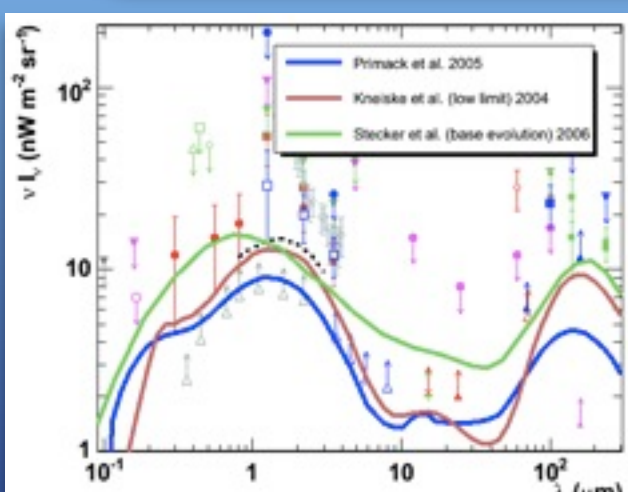
Upgrade to DRS4

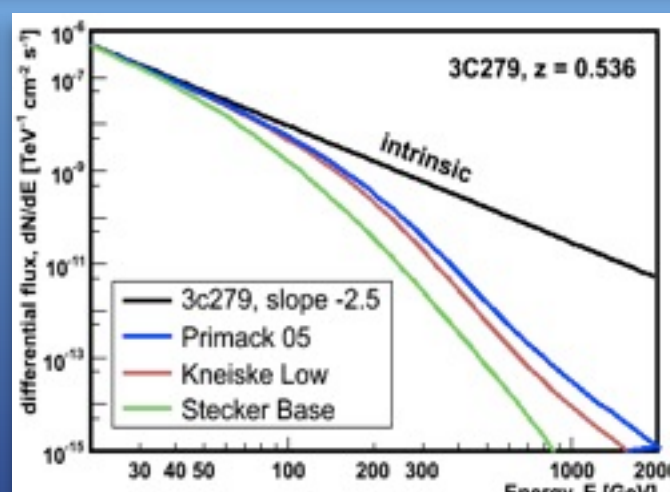
- More bandwidth, linearity etc.
- Lower power consumption

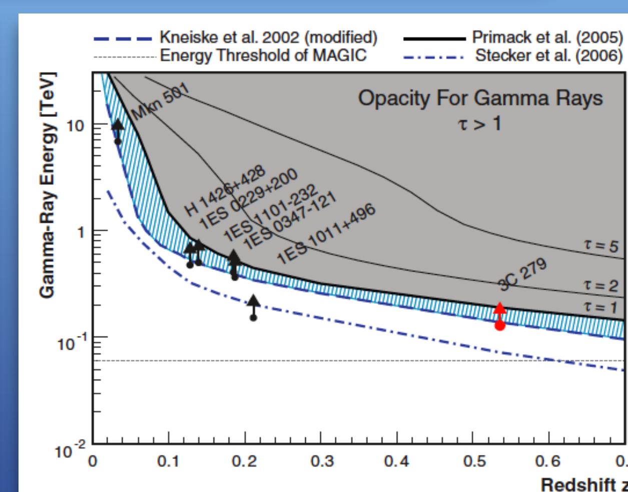
Why Low Energy Threshold? AGN - GRB

MAGIC Collaboration, Science 320 (2008) 1752







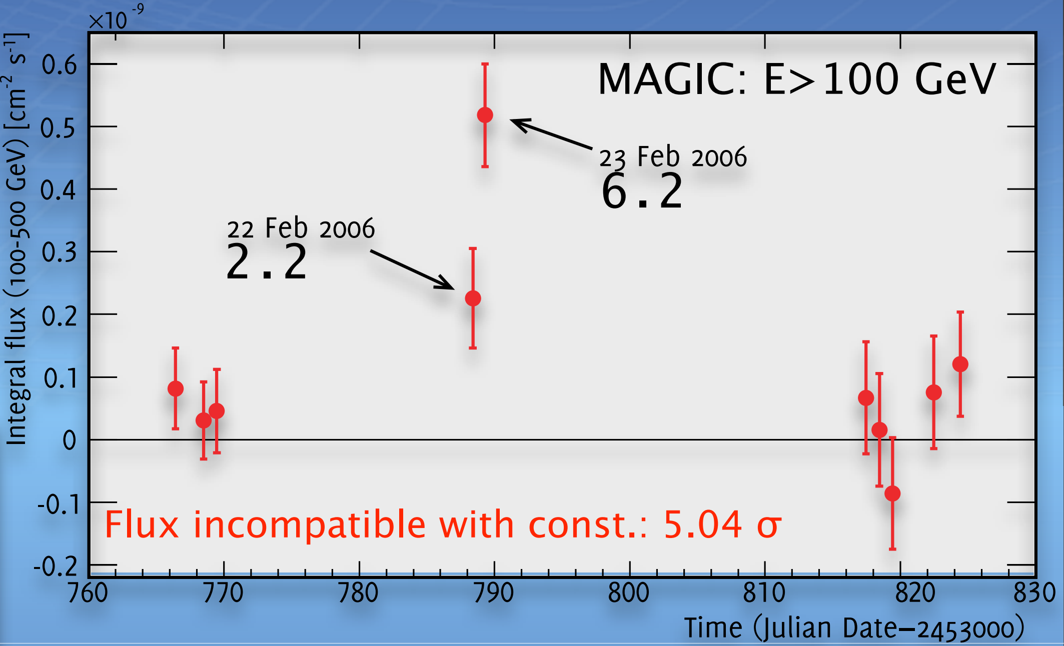


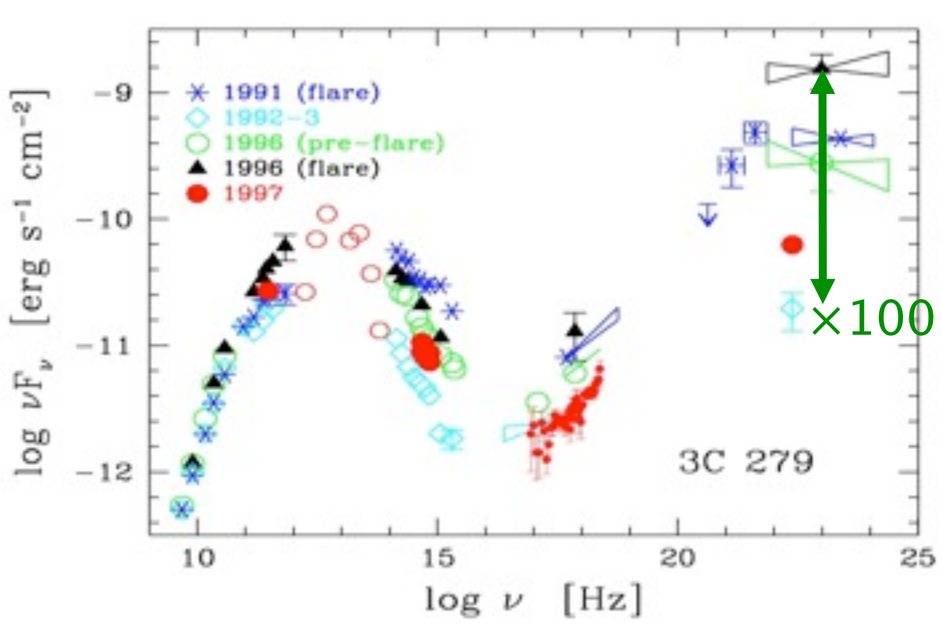
3C 279: A Famous Blazar

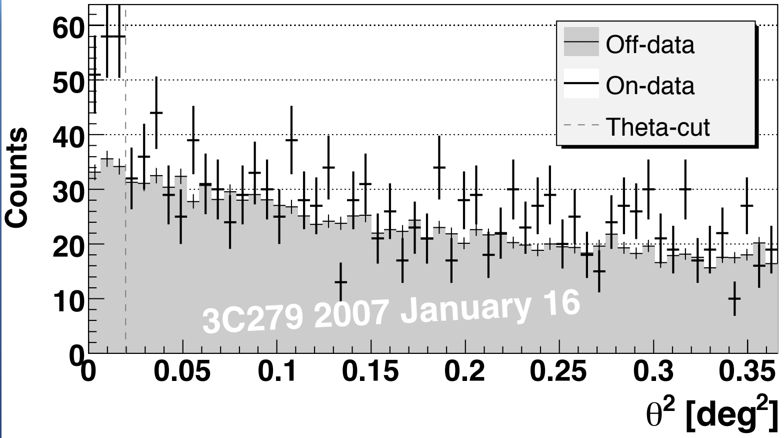
MAGIC Collaboration, Science 320, 1752 (2008)

- Flat Spectrum Radio Quasar at z=0.536
- Apparent luminosity ≈ 10^{48} erg/s
- Brightest EGRET AGN (Wehrle+97,98)
- Gamma-ray flares in 1991 and 1996:
  - High dynamical range in EGRET data
  - Fast time variation: $\Delta T \sim 6$hr in 1996 flare

MAGIC observations: 2006 January–April during WEBT campaign (Böttcher+08)





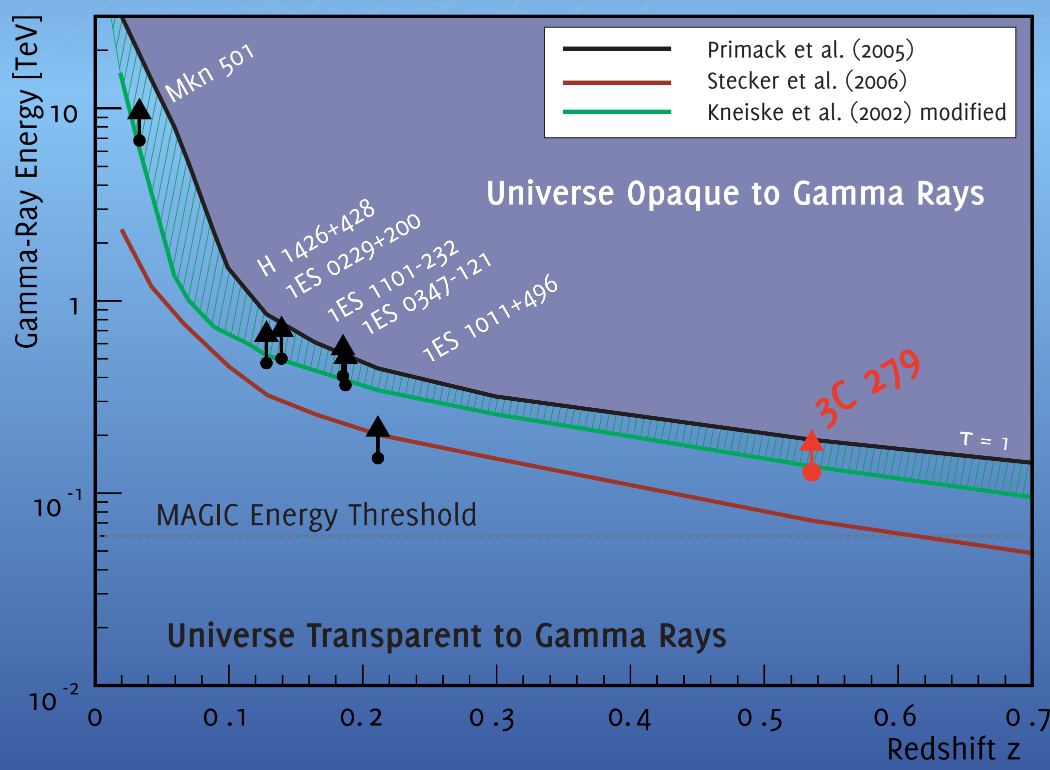


Update: Have seen it again in January 2007!

3C 279: What's the relevance?

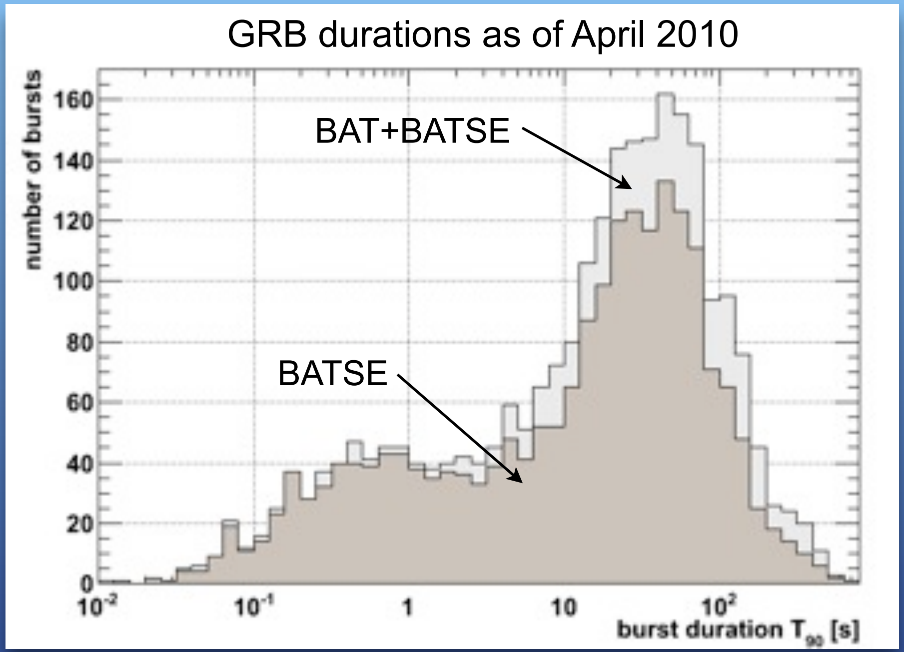
MAGIC Collaboration, Science 320, 1752 (2008)

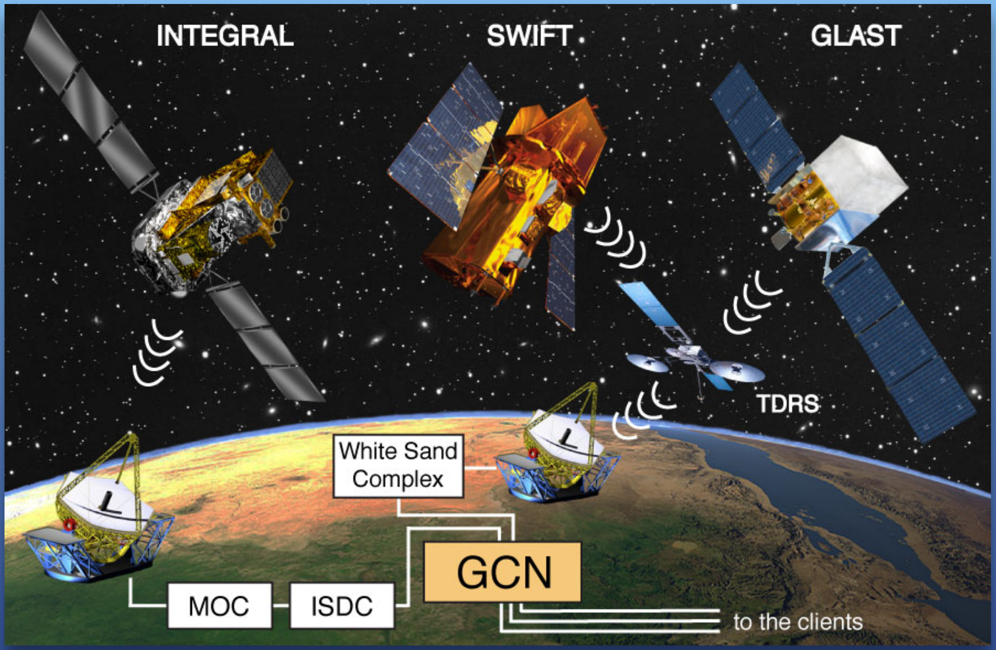
- z=0.536! Major jump in redshift of VHE sources
- First FSRQ in TeV gamma-rays: All source classes of the „blazar sequence" detected in VHE
- Infer gamma-ray horizon
- Probe evolution of EBL
- With enough statistics derive Ω_λ and Ω_m



GRB observations with MAGIC

- Highest priority observations for MAGIC
- Full automatic reaction to GCN alerts
- SWIFT BAT + FERMI GBM triggers accepted
- 13 s delay between T_0 and receipt of the alert
- MAGIC repositioning: 17 s for 180° Az movement
- Full stereo observation + sum trigger in MAGIC-I

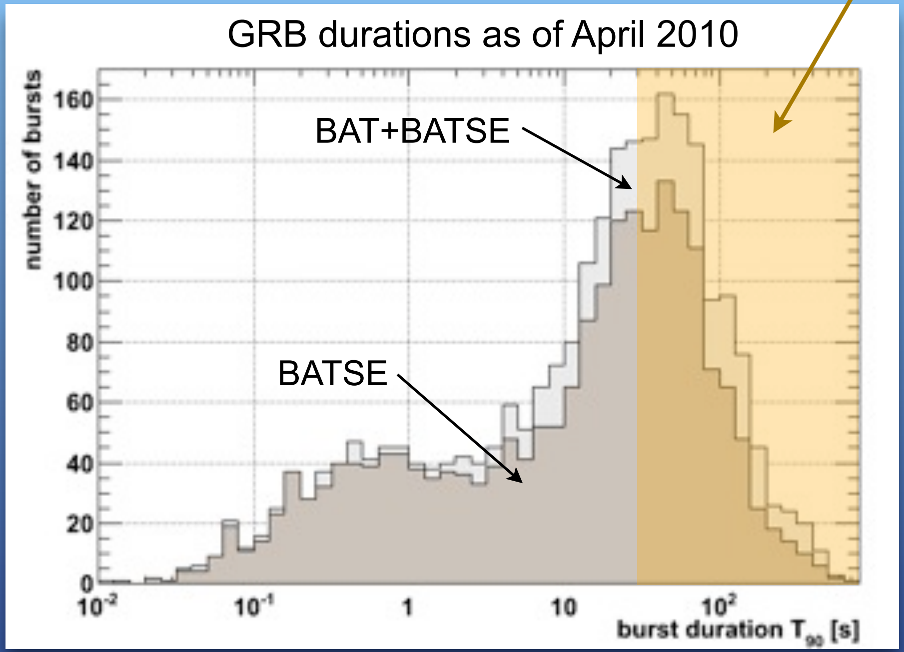


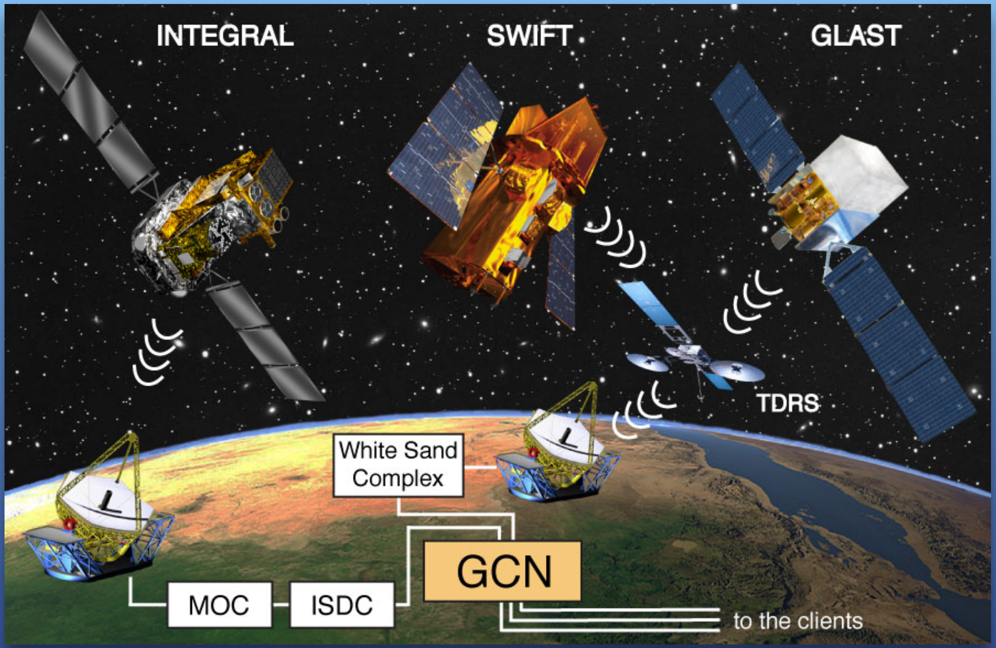


GRB observations with MAGIC

- Highest priority observations for MAGIC
- Full automatic reaction to GCN alerts
- SWIFT BAT + FERMI GBM triggers accepted
- 13 s delay between T_0 and receipt of the alert
- MAGIC repositioning: 17 s for 180° Az movement
- Full stereo observation + sum trigger in MAGIC-I

MAGIC candidates
>55% of SWIFT GRBs

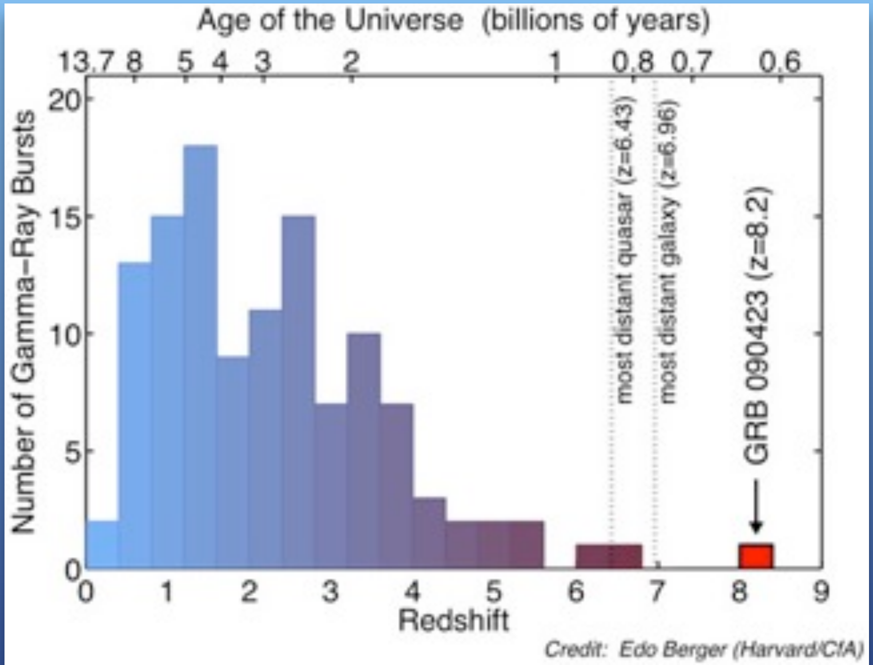


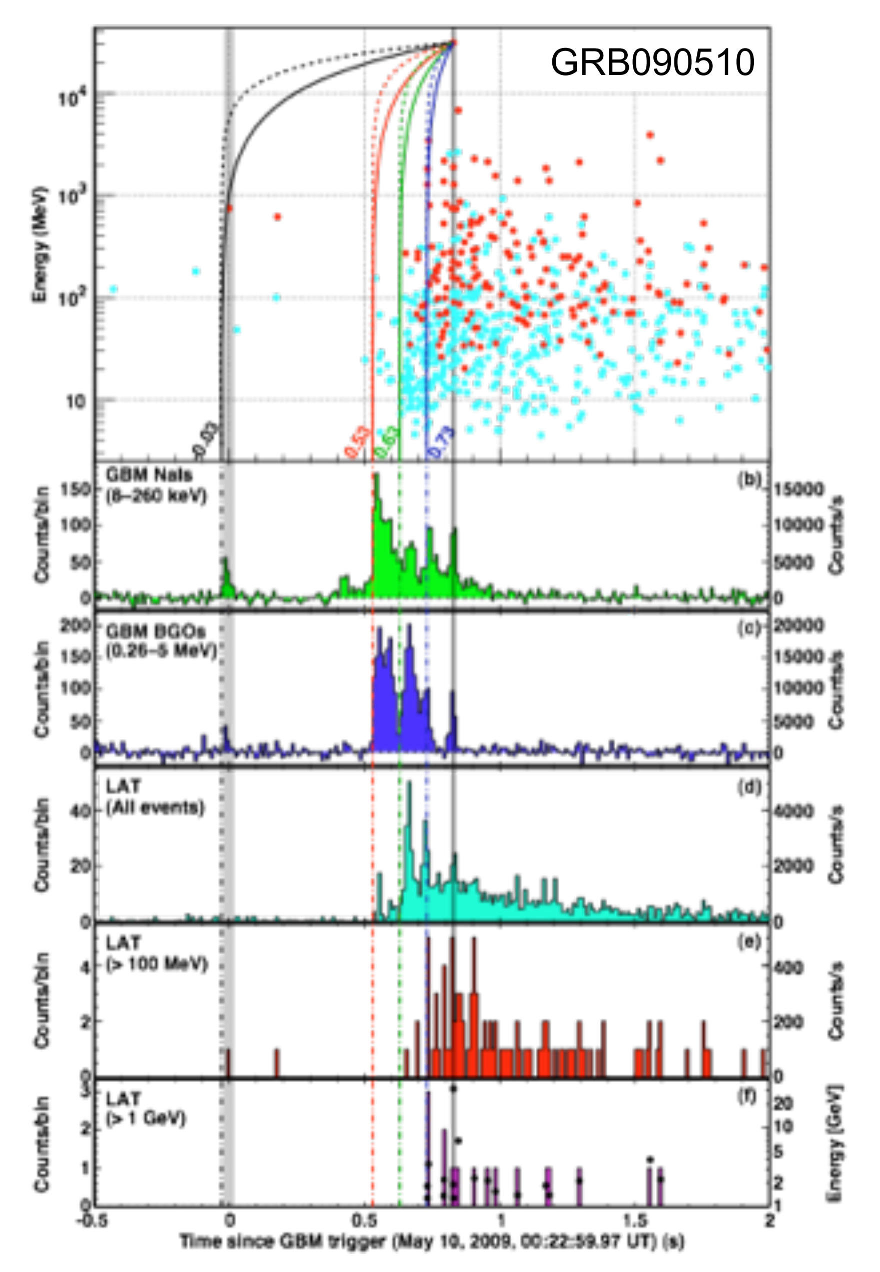


What is our motivation?

- No significant excess in 60 MAGIC GRB follow-up observations up to now
- Many GRBs are dark at VHE (z>2)
- Need to relay on external triggers, 10% duty cycle
+ Large fraction are detected at HE (LAT)
+ MAGIC sensitivity higher by one magnitude than LAT

➡ Just need more luck





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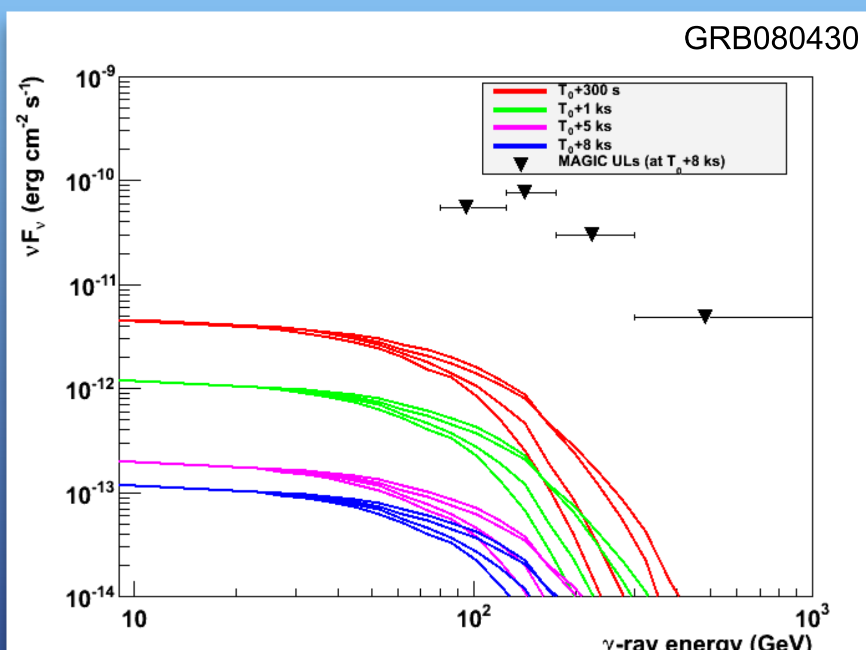

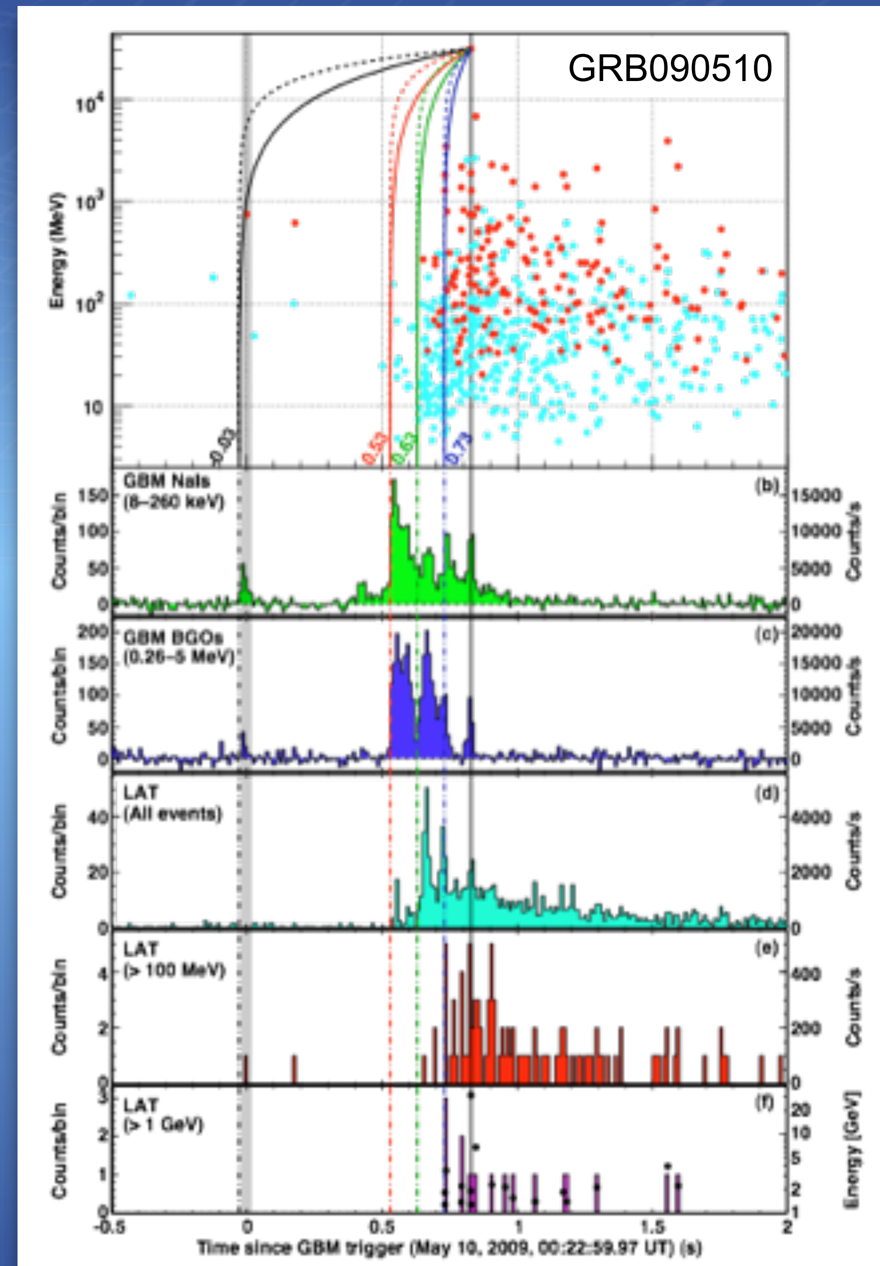

Summary

- **MAGIC is the Cherenkov telescope with the currently lowest energy threshold**
  - ~55 GeV with standard trigger
  - ~25 GeV with analog sum trigger
- Observations below 200 GeV are important particularly for:
  - **Pulsar** physics: acceleration models
  - **Blazars** at cosmological distances: EBL, cosmology
  - Detection of highest-energy emission in **GRBs**
  - Cross-calibration with Fermi-LAT
  - Measuring the complete HE peak with Fermi-LAT
- **Novel technologies** to reach the lower energy threshold:
  - Large (>240 m^2) parabolic reflector, high reflectivity, controlled focussing
  - Fast signal sampling
  - Analog sum trigger
  - Novel photo sensors