

# Gamma ray sources observation with ARGO-YBJ

Silvia Vernetto

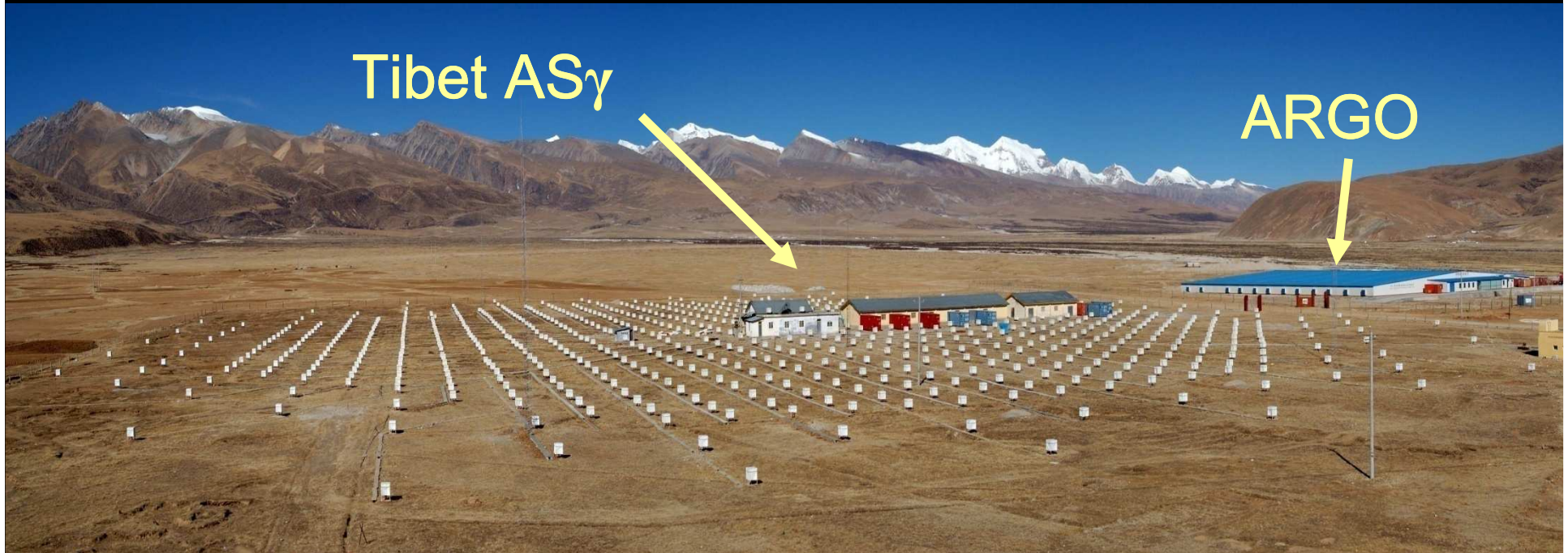
IFSI-INAF Torino, ITALY

On behalf of the ARGO-YBJ collaboration



SciNeGHE Lecce - May 25-27, 2012

# The Yangbajing Cosmic Ray Laboratory



Tibet AS $\gamma$

ARGO

4300 m a.s.l.

Longitude 90° 31' 50" East  
Latitude 30° 06' 38" North



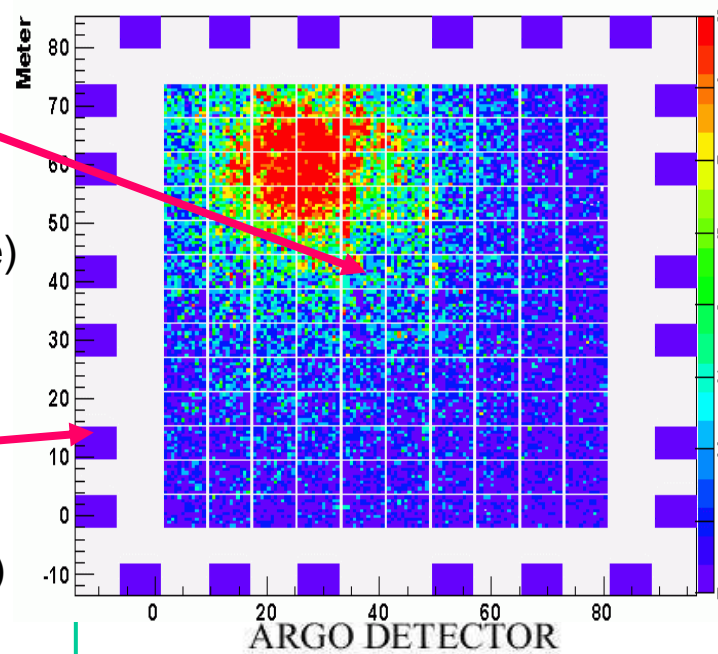


Resistive Plate Chambers carpet

# The ARGO-YBJ detector

Single layer of  
RPCs detectors

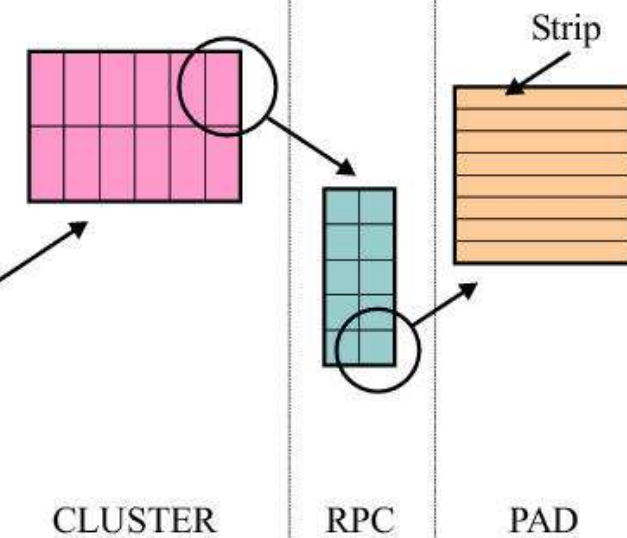
- **Central carpet**  
78 x 75 m<sup>2</sup>  
(95 % of active surface)
- **Sampling ring**  
111 x 99 m<sup>2</sup>  
(20 % of active surface)



The PAD (56 × 62 cm<sup>2</sup>)  
is the space-time “pixel”

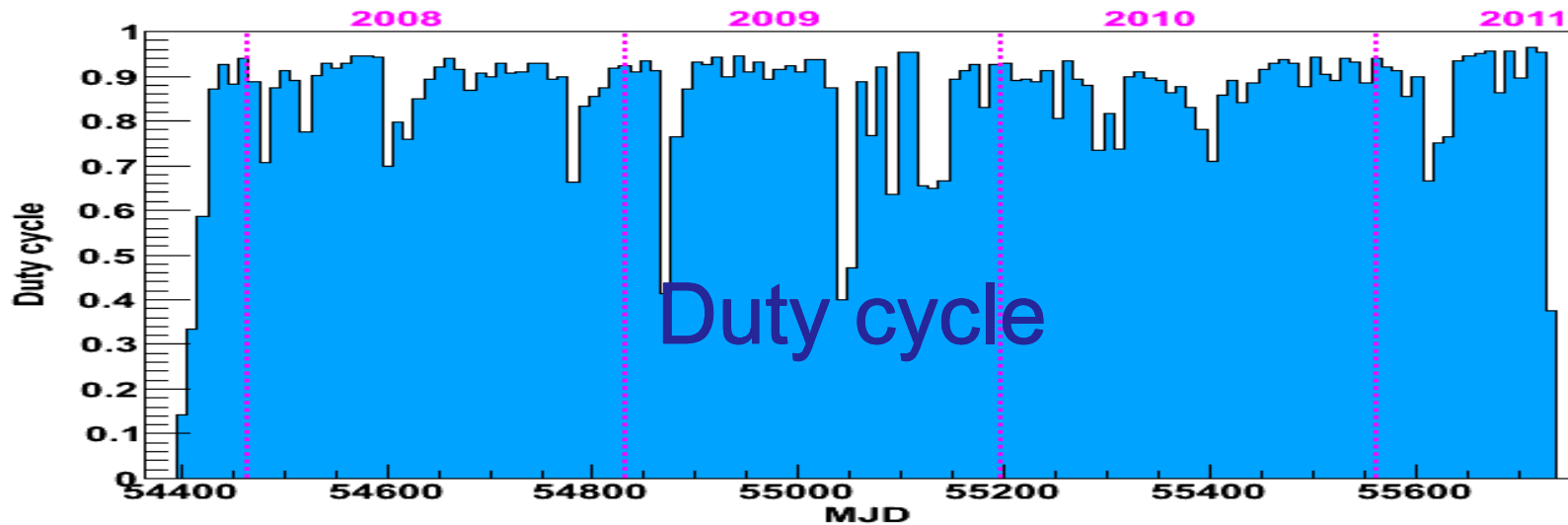
Time resolution ≈ 1 ns

ARGO has 18480 PADs



Trigger : 20 particles →  $E_{th} = \text{few hundreds GeV}$

- First data in July 2006
- Full detector in stable data taking since November 2007
- Rate  $\sim 3.5$  kHz - Dead time 4%
- 220 GB/day transferred to IHEP/CNAF data centers
- Duty cycle  $\sim 86\%$

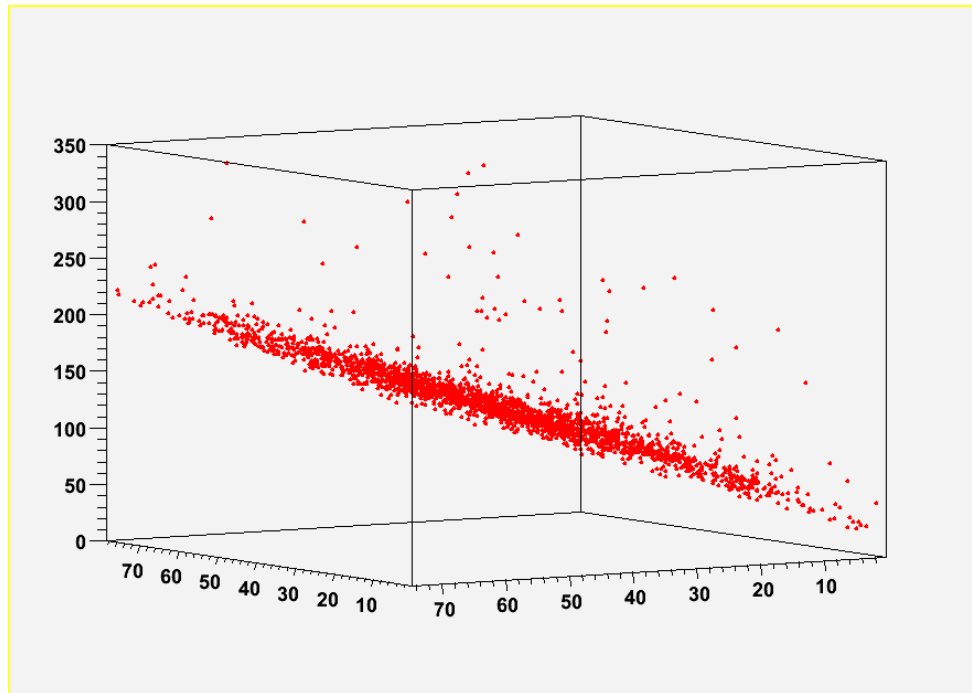


# EAS data

- Shower core reconstruction

Maximum Likelihood Method applied to the lateral density profile of the shower

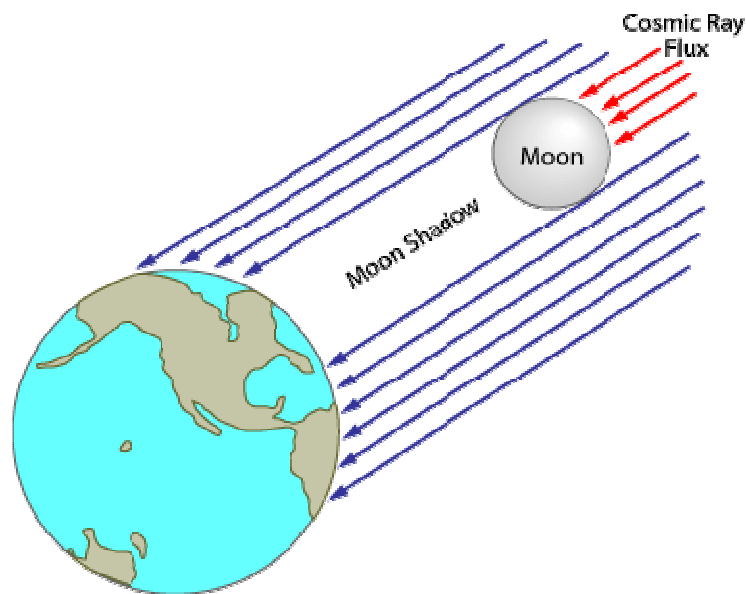
- Fit of the shower front  Primary direction



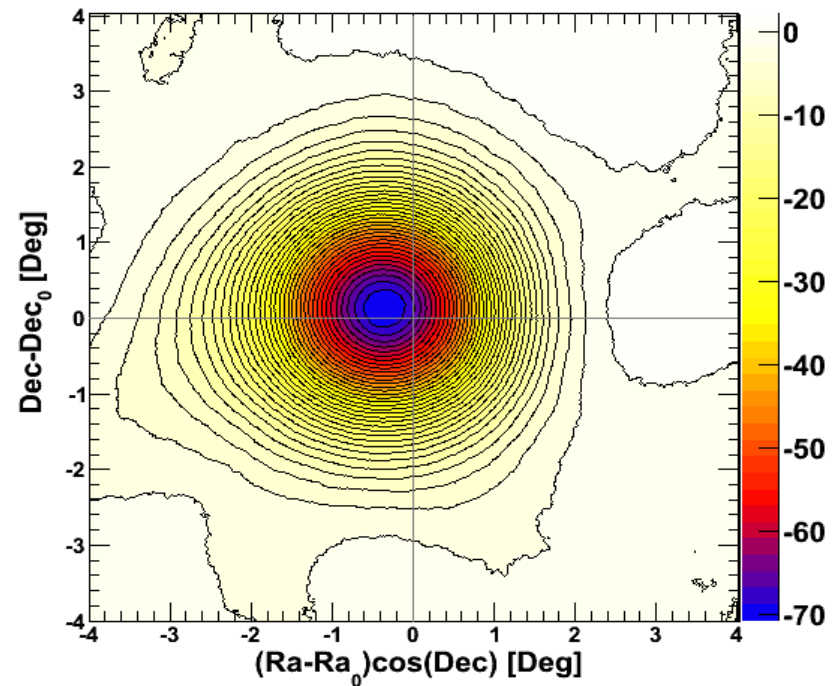
Space and time  
coordinates of the  
fired PADs

# The Moon shadow

An important tool to check the detector performances



**Physics:** antiproton / proton ratio in cosmic rays



**Deficit: > 70 standard deviations**

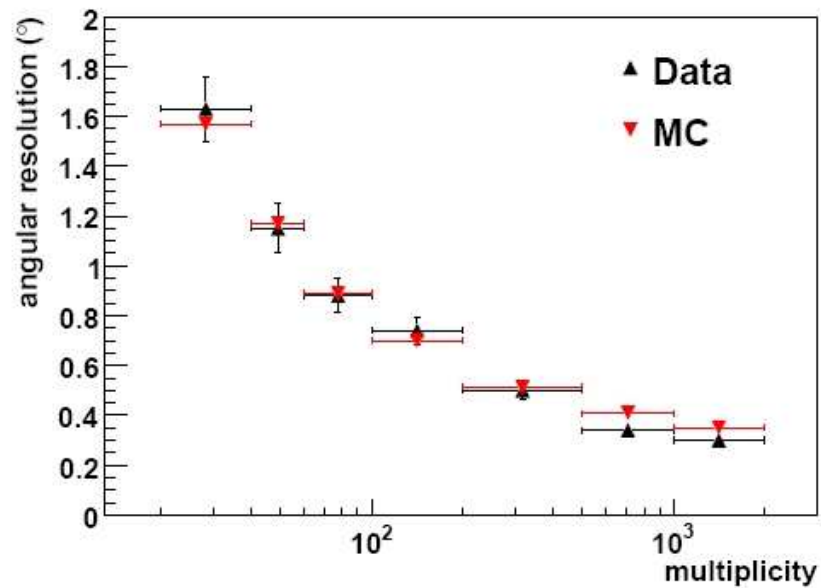
$\approx 9$  standard deviations /month

Bartoli et al., Phys.Rev. D 84 (2011) 022003  
Bartoli et al., Phys.Rev. D 85 (2012) 022002



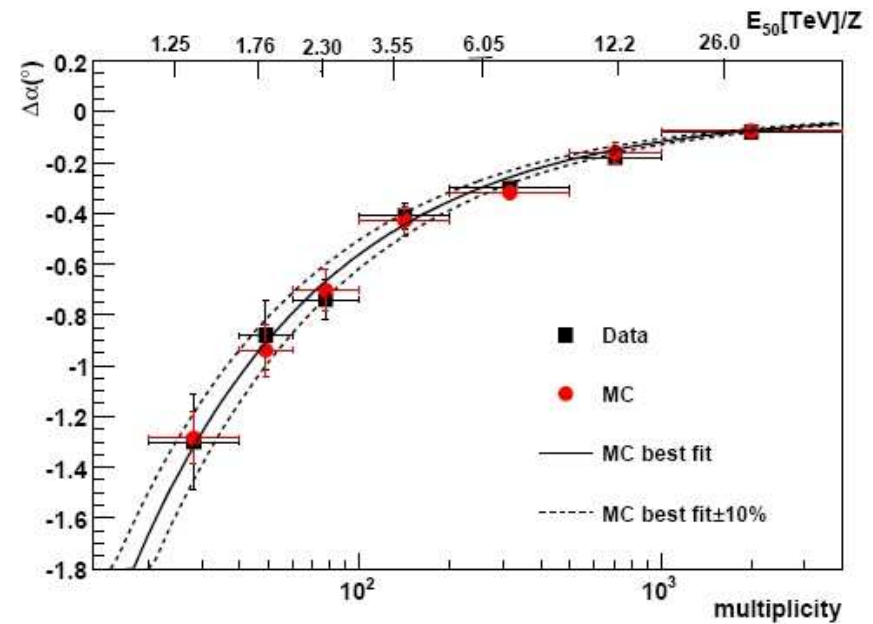
# The Moon shadow

## Angular resolution for cosmic ray showers



## Energy calibration

West displacement of the shadow caused by the Geomagnetic field



Error in energy scale 13%



# Cosmic ray physics with ARGO

- Anisotropy
- Spectrum
- Proton-air cross section measurement
- Anti-p /p ratio with the Moon shadow
- Sun shadow studies

*talk by M.Iacovacci on June 22*

# Gamma ray astronomy with ARGO

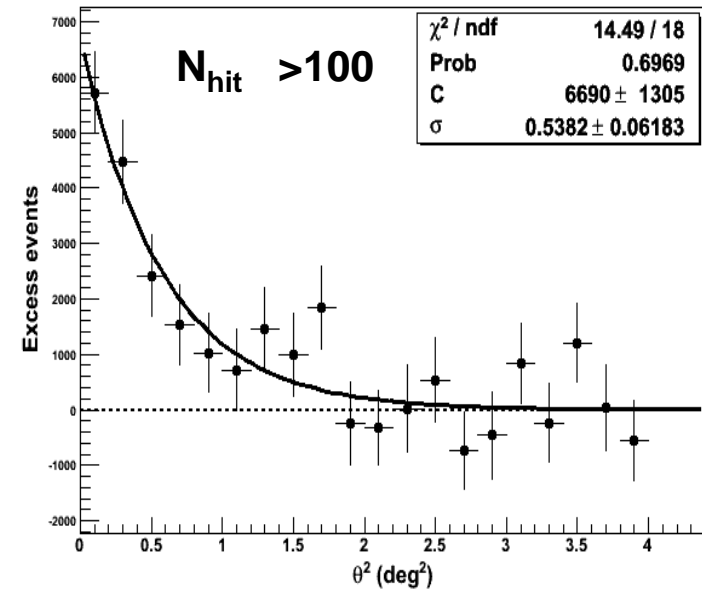
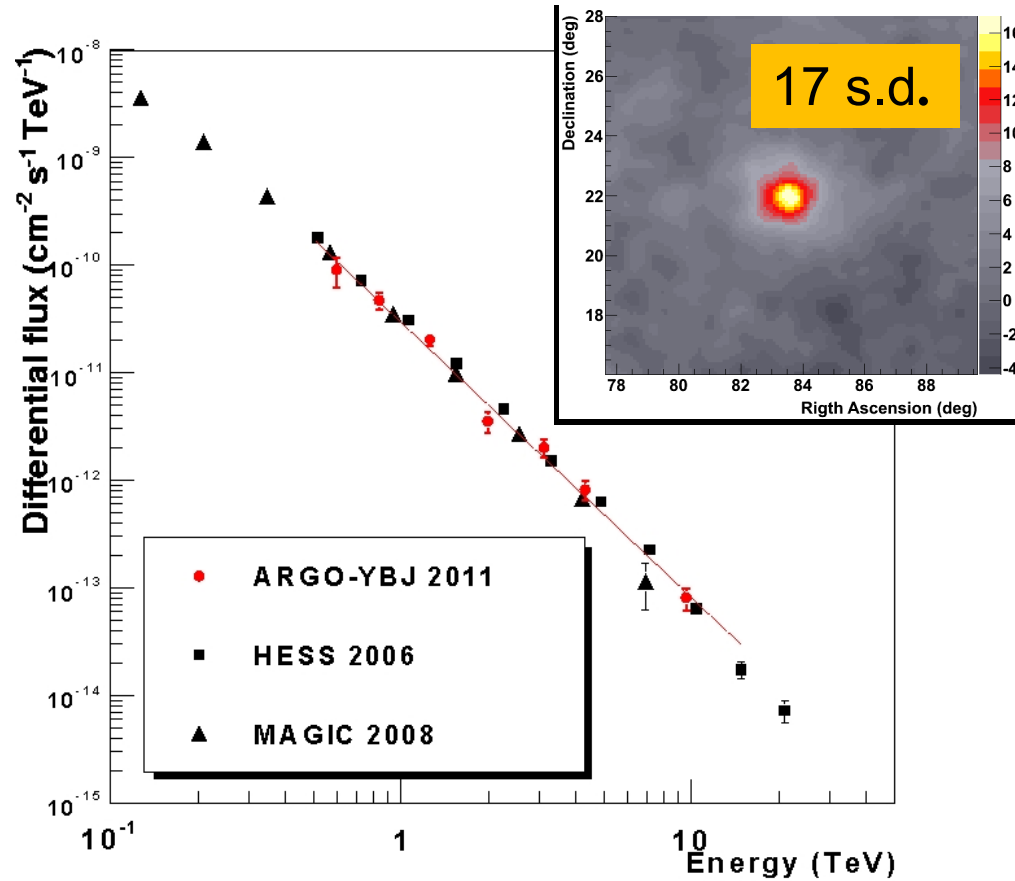
- Energy threshold: few hundreds GeV
- Field of view :  $\sim 2$  sr
- Duty cycle : 86%
- Integrated sensitivity: 0.29 Crab Units

Sky survey of the Northern sky  
at  $\approx 1$  TeV

# ARGO sources

- Crab Nebula
- MGRO J1908+06
- Cygnus Region
- Mrk 421
- Mrk 501
- ❖ GRBs (1-100 GeV, with scaler data)

# Crab Nebula



PSF in agreement with MC

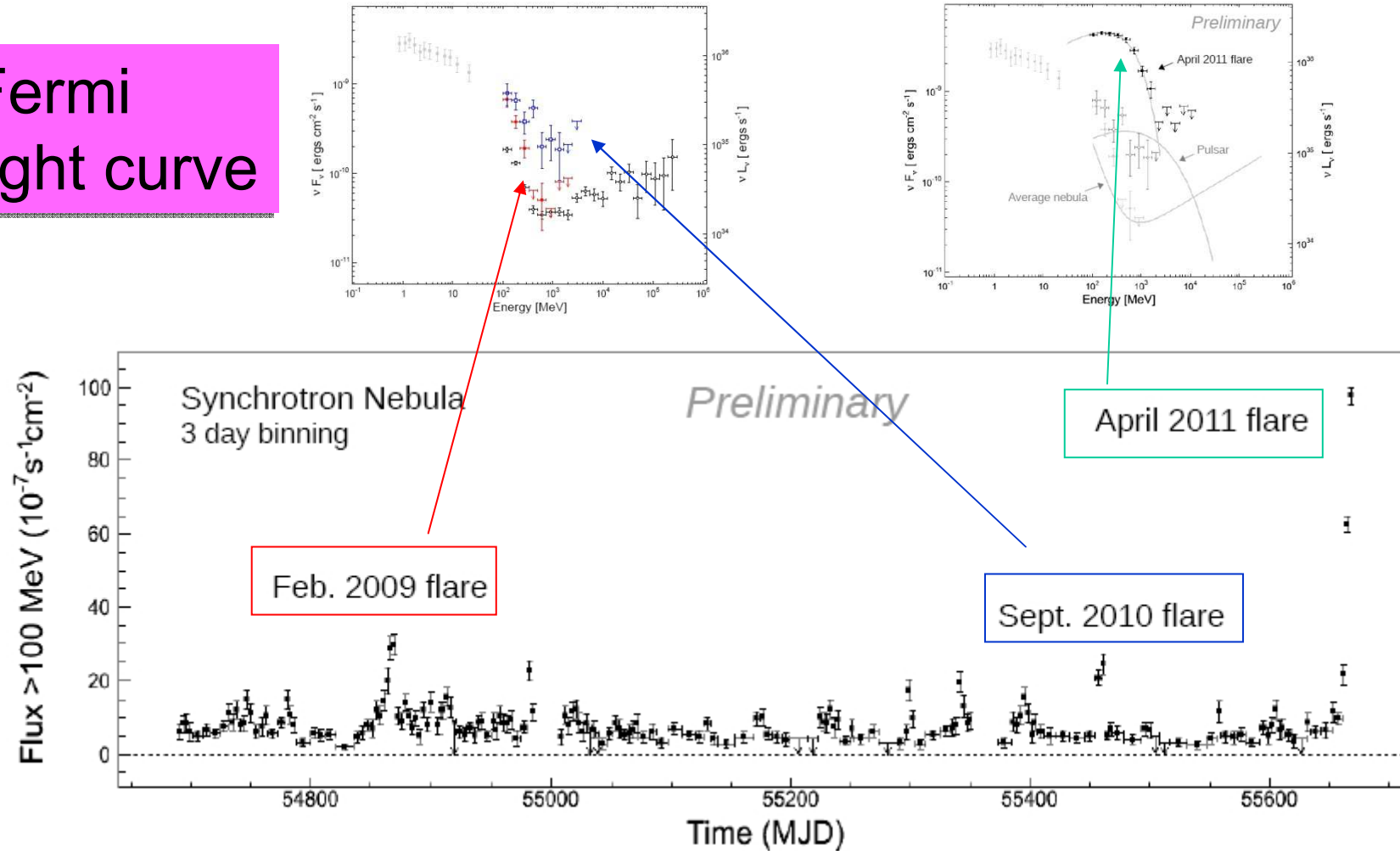
$$\frac{dN}{dE} = (3.0 \pm 0.3_{\text{stat}}) \times 10^{-11} \left( \frac{E}{1 \text{TeV}} \right)^{(-2.59 \pm 0.09_{\text{stat}})} \text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$$

(0.5 – 10) TeV



# Crab Nebula flares at $E > 100$ MeV

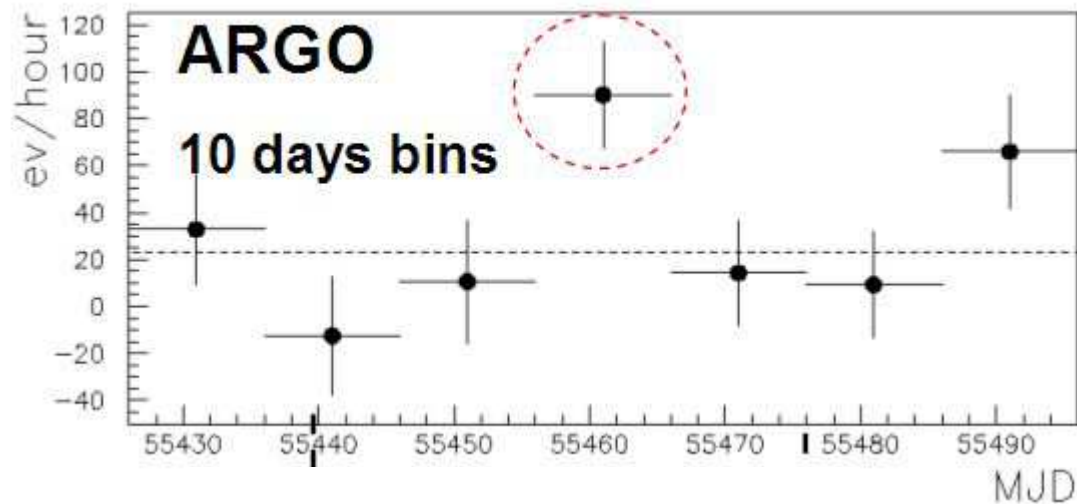
Fermi  
light curve



from Buehler slides – Fermi Symposium 2011

# September 2010 flare

Integrating over 10 days :

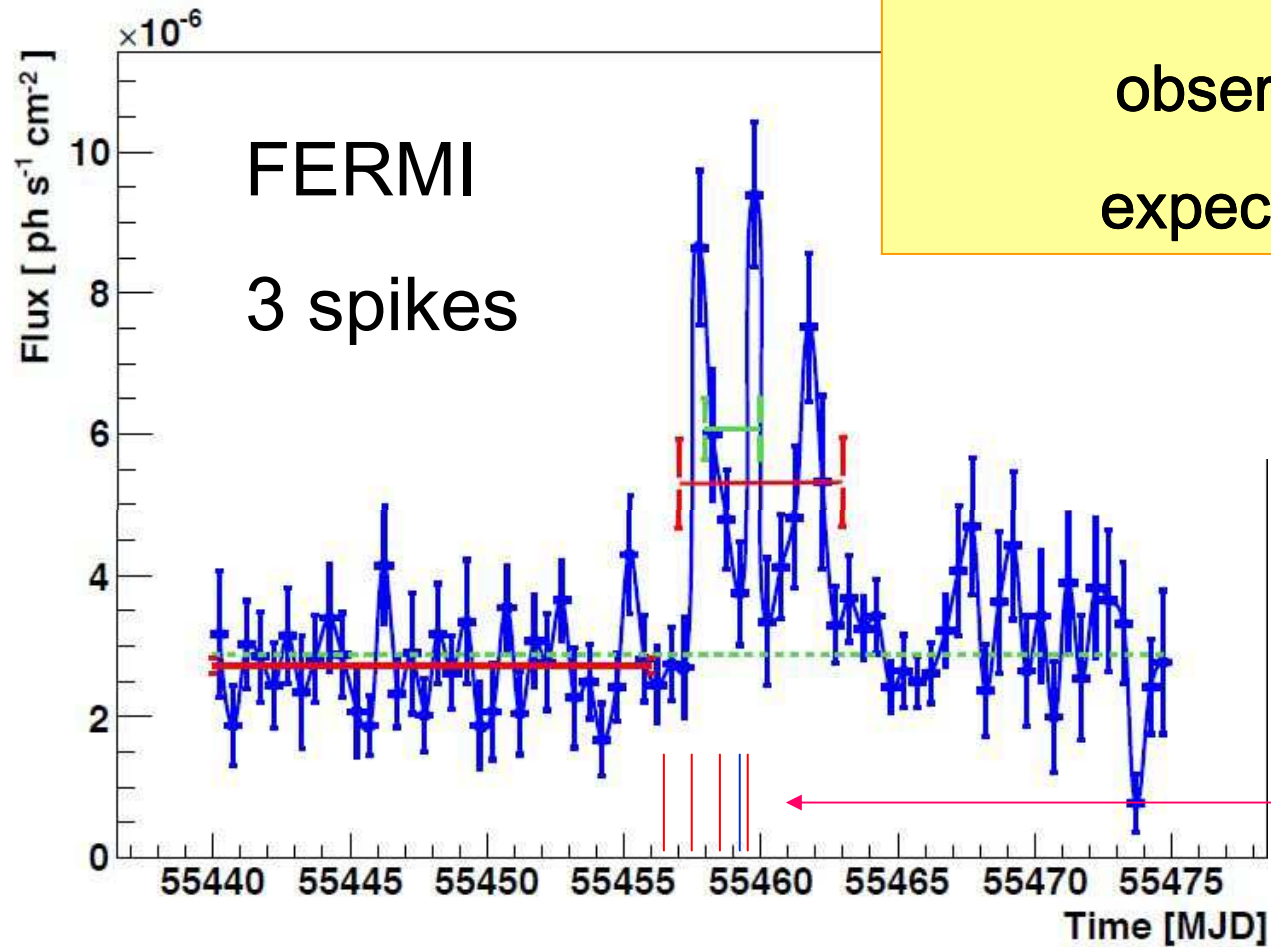


$E \approx 1 \text{ TeV}$

From MJD 55456 to 55465  
observed 4.1 s.d. (pre-trial)  
expected 1.0 s.d

**ATel #2921**

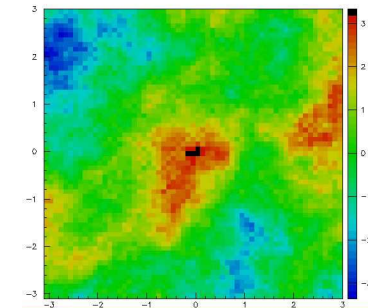
# September 2010 flare



ARGO during the Fermi spikes:

observed 3.1 s.d.

expected 0.55 s.d.



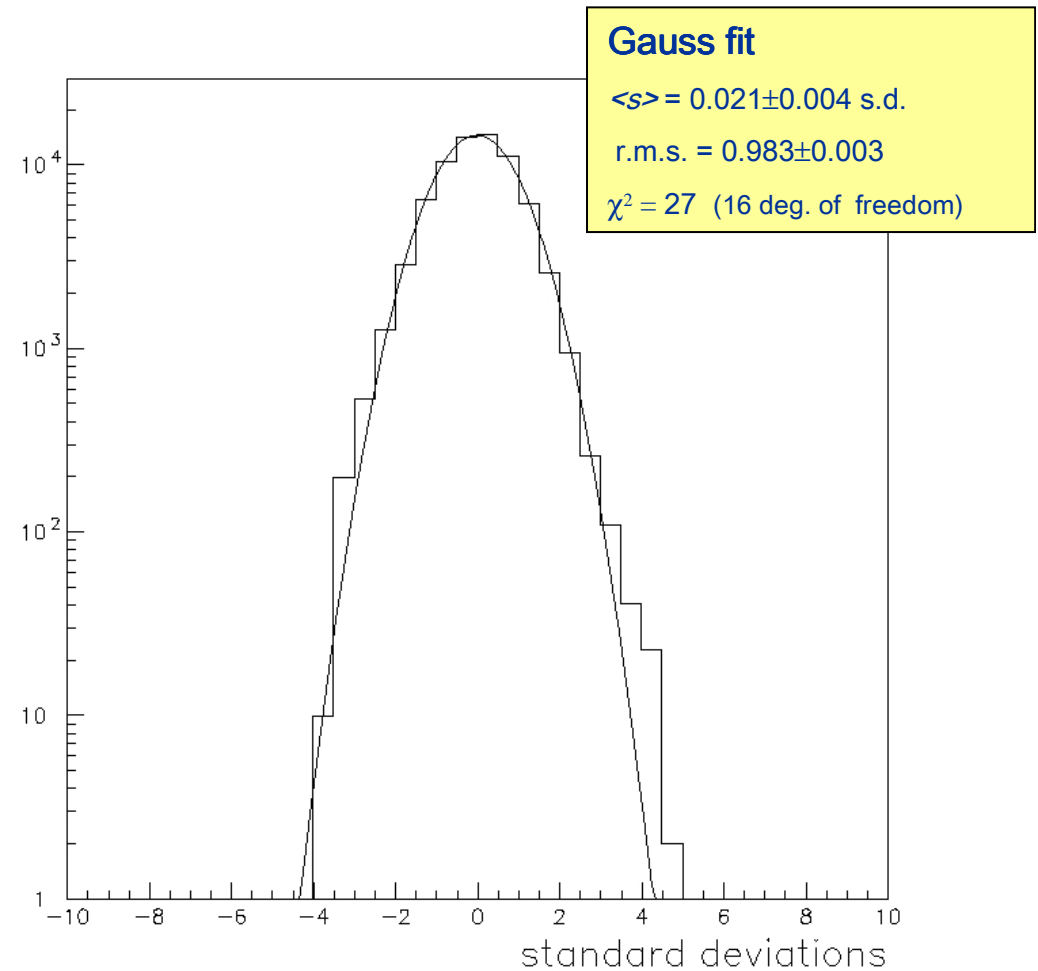
Data by MAGIC  
and VERITAS did  
not show any flux  
increase

# Search for flares of duration 1-20 days from Nov 2007 to Feb 2011

Significances distribution of  
the excesses in all the time  
intervals

after steady flux subtraction  
for events with  
 $N_{\text{hit}} > 40, 100, 500, 1000$

**No significant flare  
found in 72332 trials**

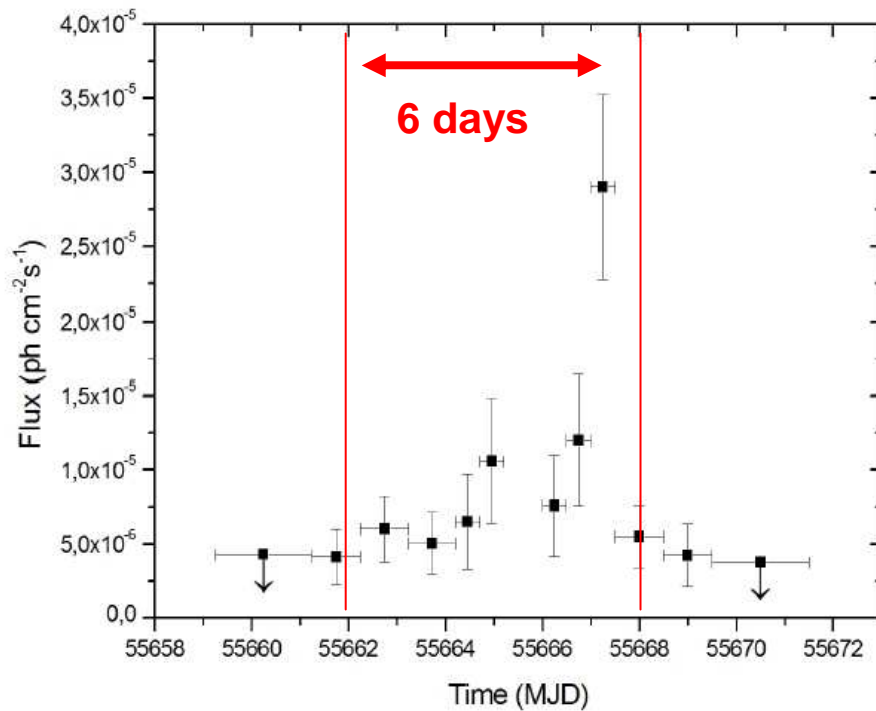




# April 2011 flare

AGILE light curve

$E > 100 \text{ MeV}$

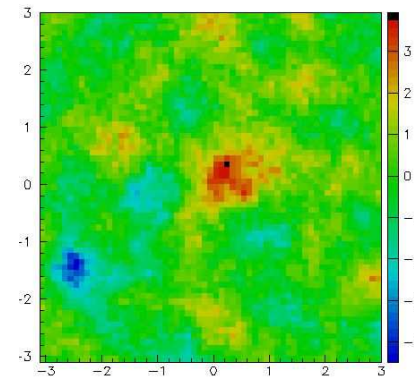


ARGO in 6 days :

observed 4.0 s.d.

expected 0.47 s.d.

> 500 hits ( $E \approx 10 \text{ TeV}$ )



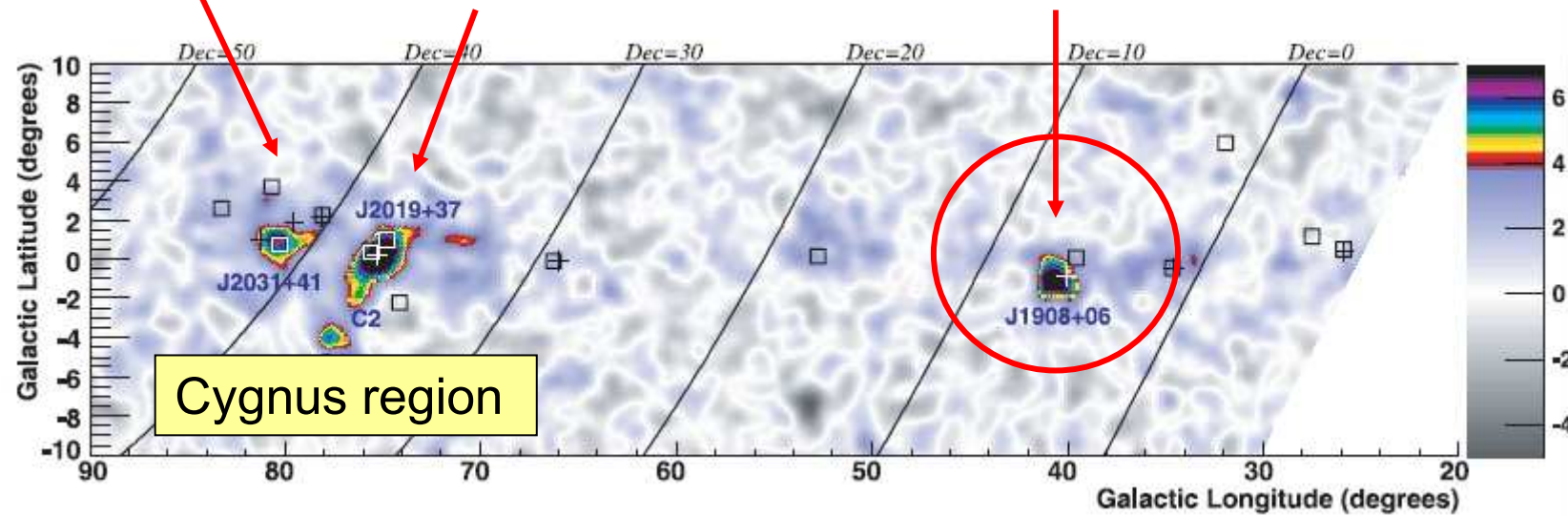
MAGIC in MJD 55663-5 did not detect any increase

# MILAGRO Galactic Plane survey at $\approx 20$ TeV

MGRO J2031+41

MGRO J2019+37

MGRO J1908+06

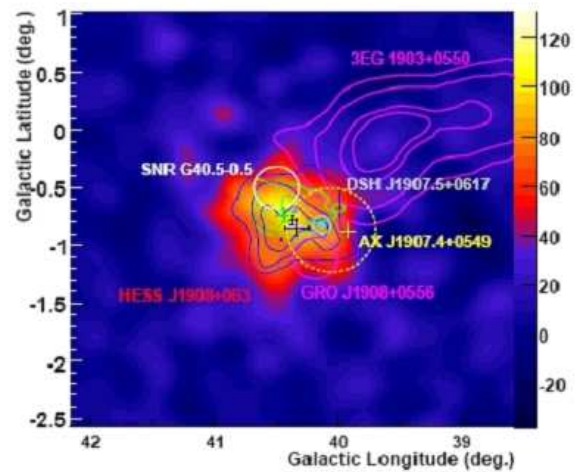


Abdo et al., 2007

3 extended sources  
associated with FERMI pulsars

# MGRO J1908+06

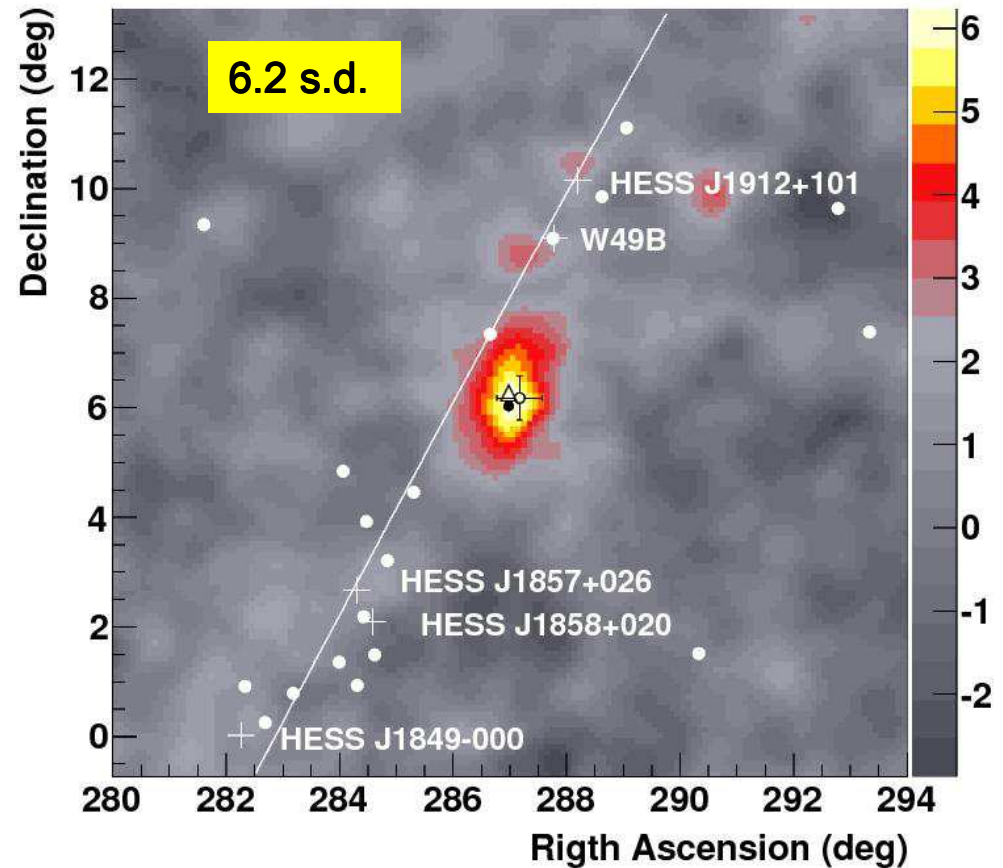
HESS (2009)



Extension  $\sigma = 0.34^\circ \pm 0.04^\circ$

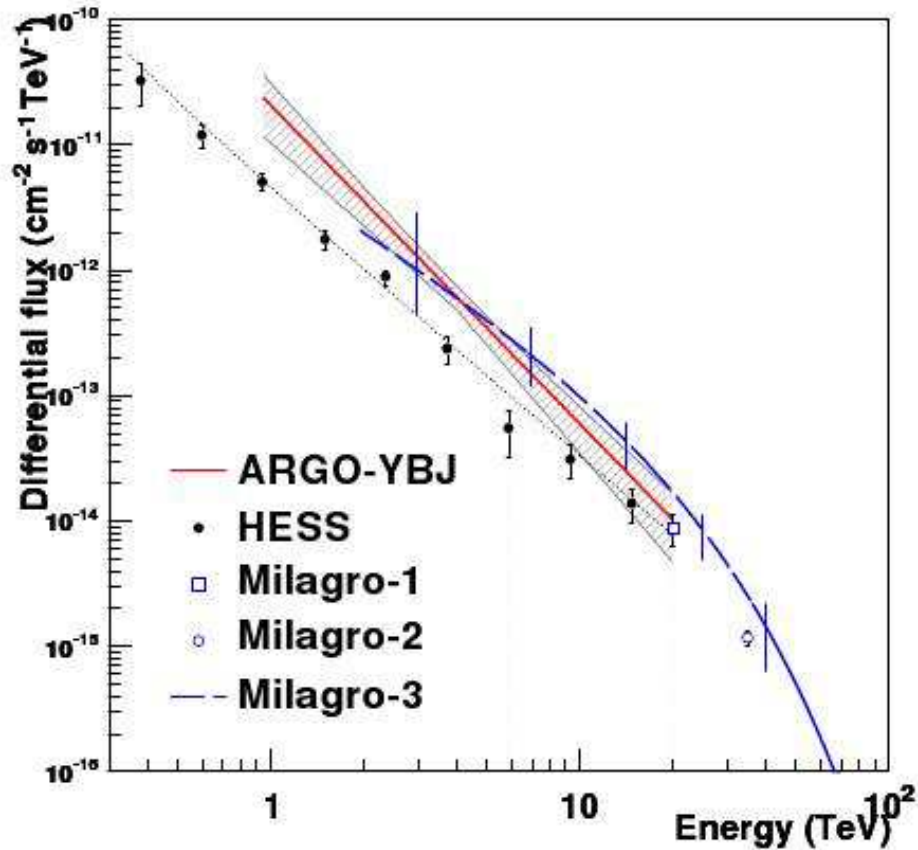
Inside the nebula FERMI detected a pulsar with period 106.6 ms

ARGO



Extension  $\sigma = 0.49^\circ \pm 0.22^\circ$

# MGRO J1908+06 spectrum



$$dN/dE = (6.1 \pm 1.6) 10^{-13} (E/4 \text{ TeV})^{-2.54 \pm 0.36}$$

ph sec<sup>-1</sup> cm<sup>-2</sup> TeV<sup>-1</sup>

F (> 1 TeV) = 69% Crab

Flux in agreement with  
Milagro but higher than  
HESS by a factor 2-3

Contribution from the  
Galactic diffuse gamma  
ray flux < 15%

Systematics < 30%

Paper accepted by ApJ

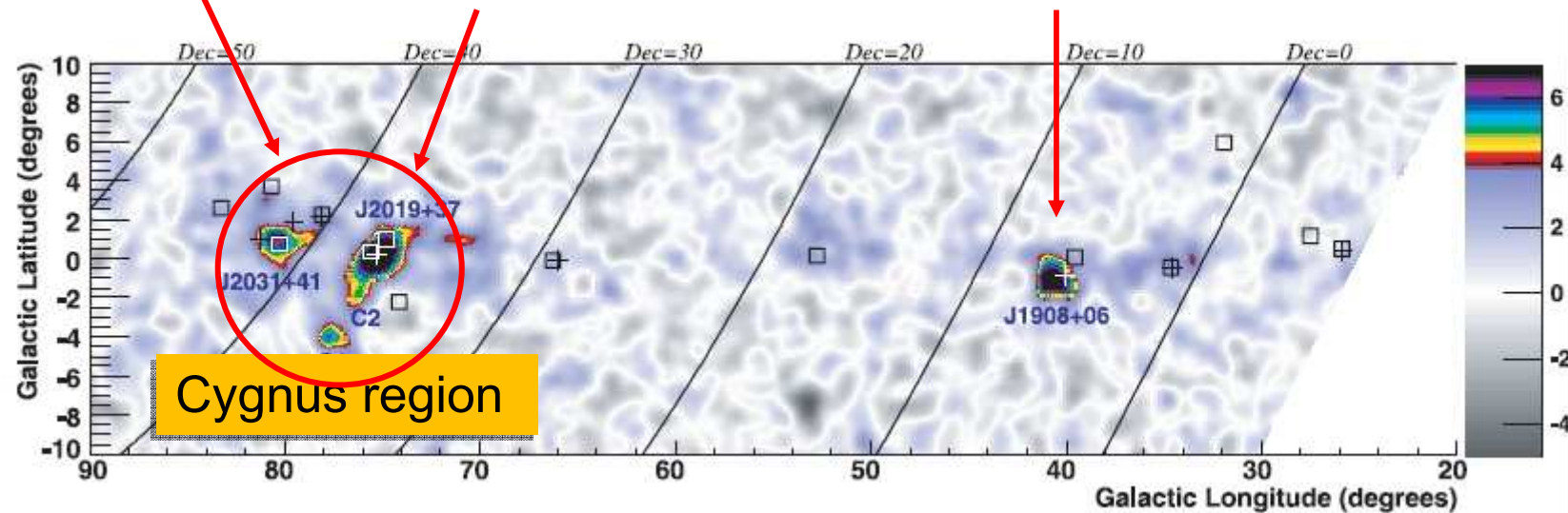


# MILAGRO Galactic Plane survey at $\approx 20$ TeV

MGRO J2031+41

MGRO J2019+37

MGRO J1908+06

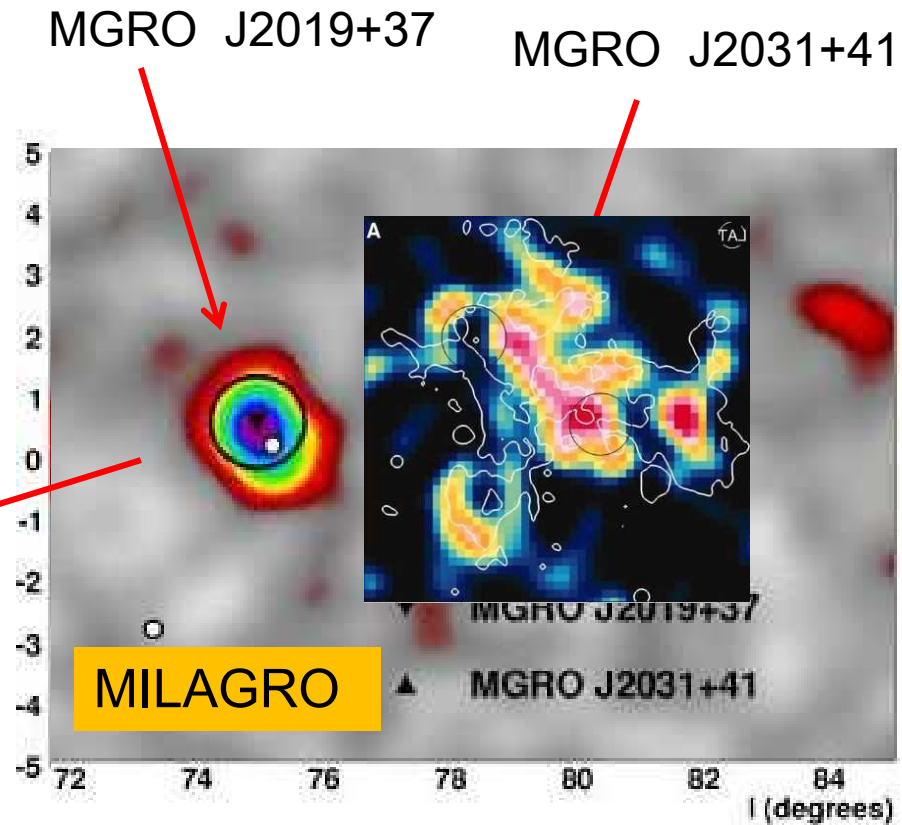
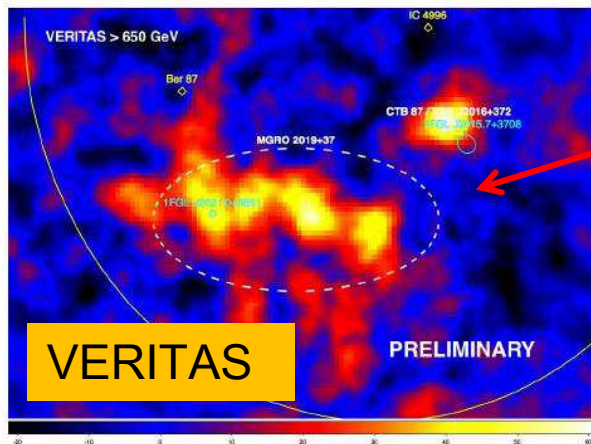


3 extended sources  
associated with FERMI pulsars

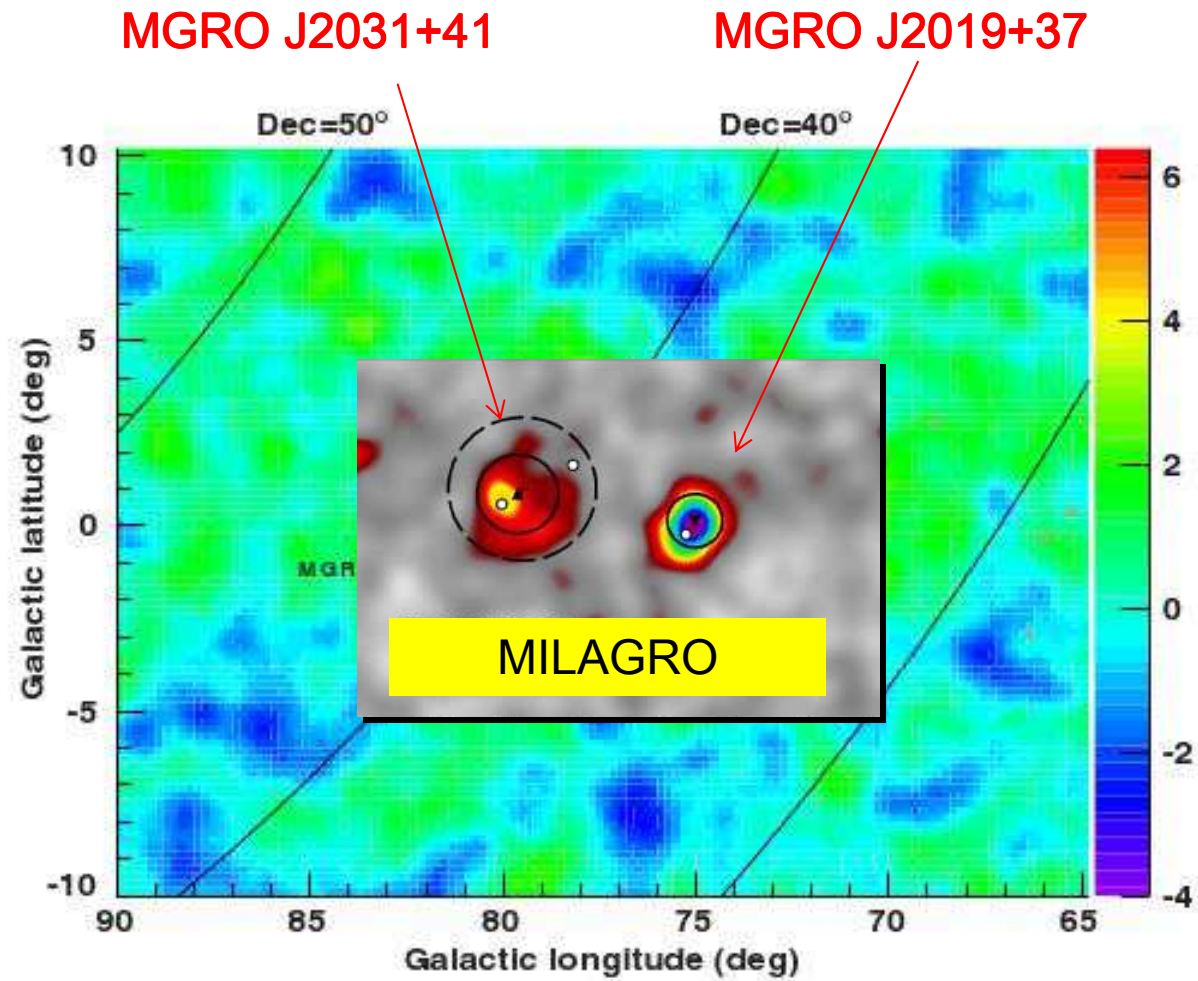
# The Cygnus region

One of the more active region in the Galaxy

- High star formation rate
- OB associations
- Supernova Remnants
- Wolf-Rayet stars
- Ionized Gas
- High diffuse Gamma Ray flux

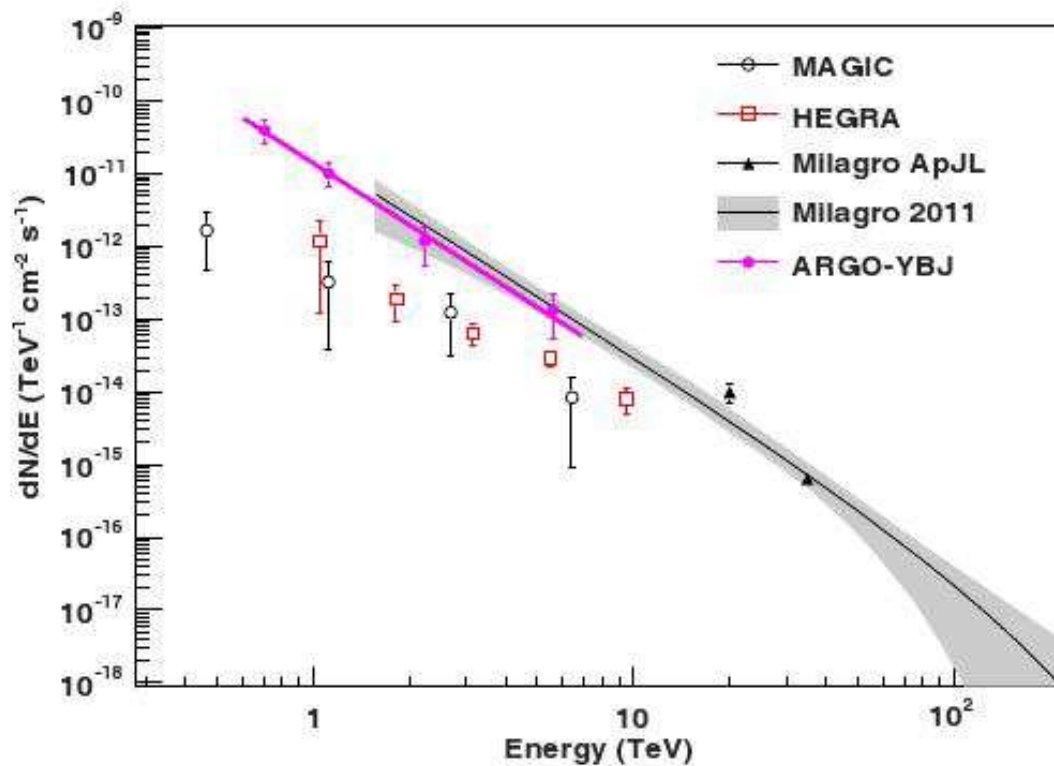


# Cygnus region by ARGO



Bartoli et al., ApJL, 2012

# Cygnus region : MGRO J2031+41 spectrum



$F (> 1 \text{ TeV}) = 31\% \text{ Crab}$

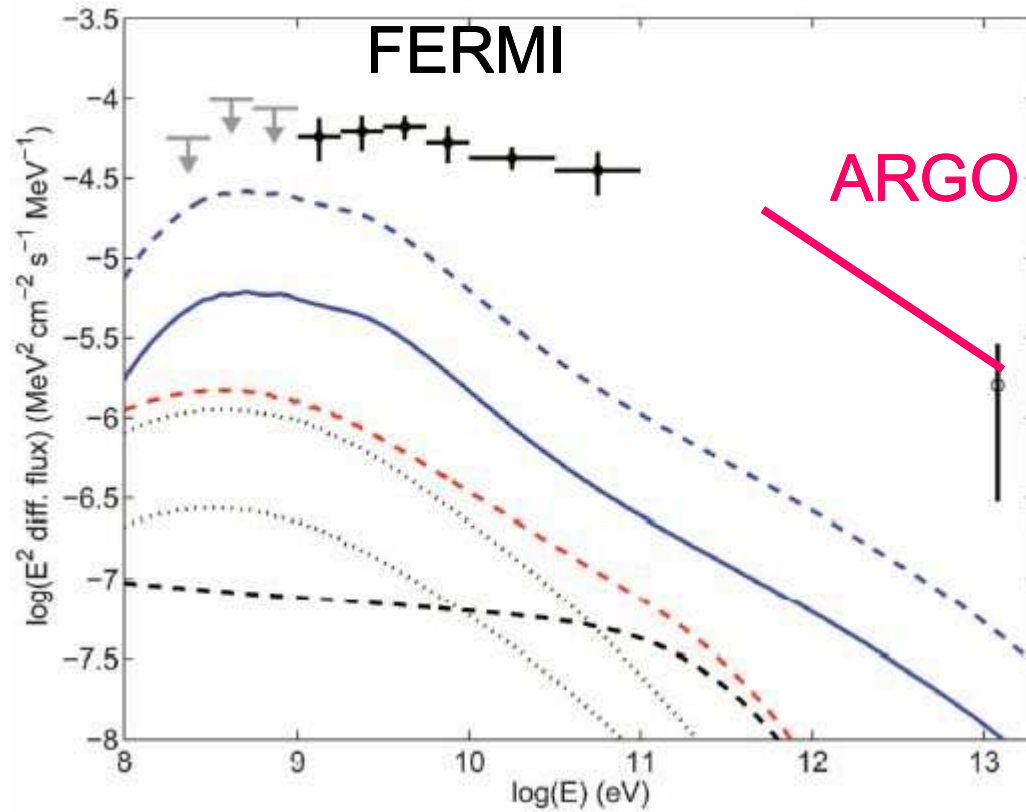
Flux in agreement with Milagro but higher than MAGIC and HEGRA by a factor  $> 10$  !

Contribution from the diffuse Galactic gamma ray flux  $< 10\%$

$$dN/dE = (1.40 \pm 0.34) 10^{-11} (E/1 \text{ TeV})^{-2.83 \pm 0.37}$$

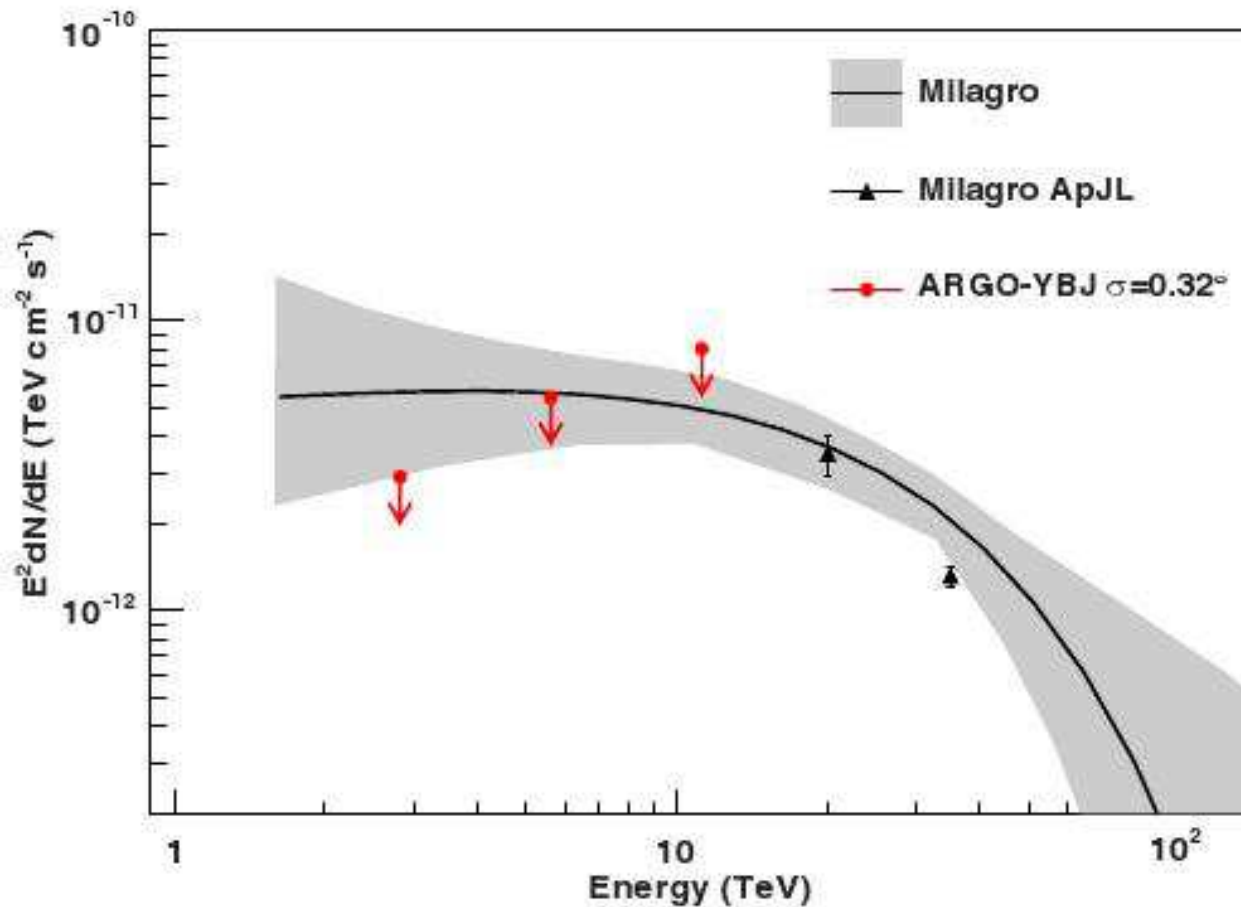
ph  $\text{sec}^{-1} \text{cm}^{-2} \text{TeV}^{-1}$

# Cygnus region : MGRO J2031+41 spectrum



FERMI  
cocoon  
spectrum

# Cygnus region : MGRO J2019+37 upper limits

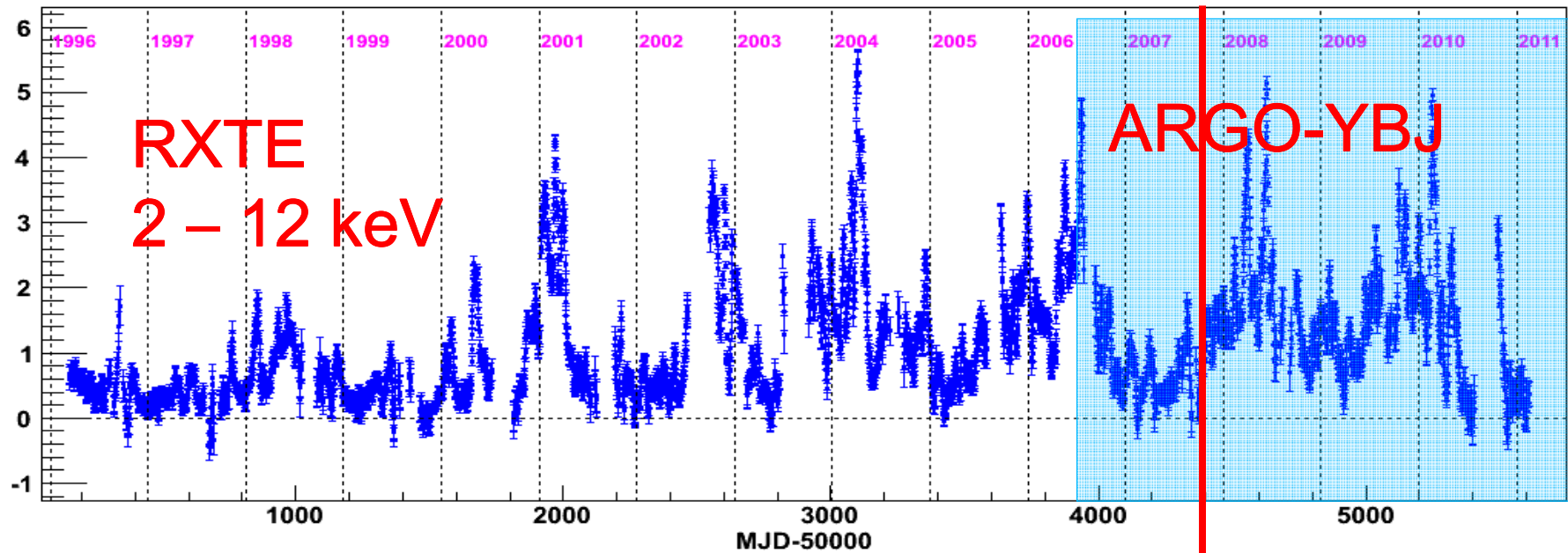


No significant  
signal  
observed by  
ARGO

VERITAS resolved  
some faint sources  
inside the  
MILAGRO  
extended source  
 $F \approx 1\%$  Crab  
(Aliu, 2011)



# Mrk 421 - X ray light curve

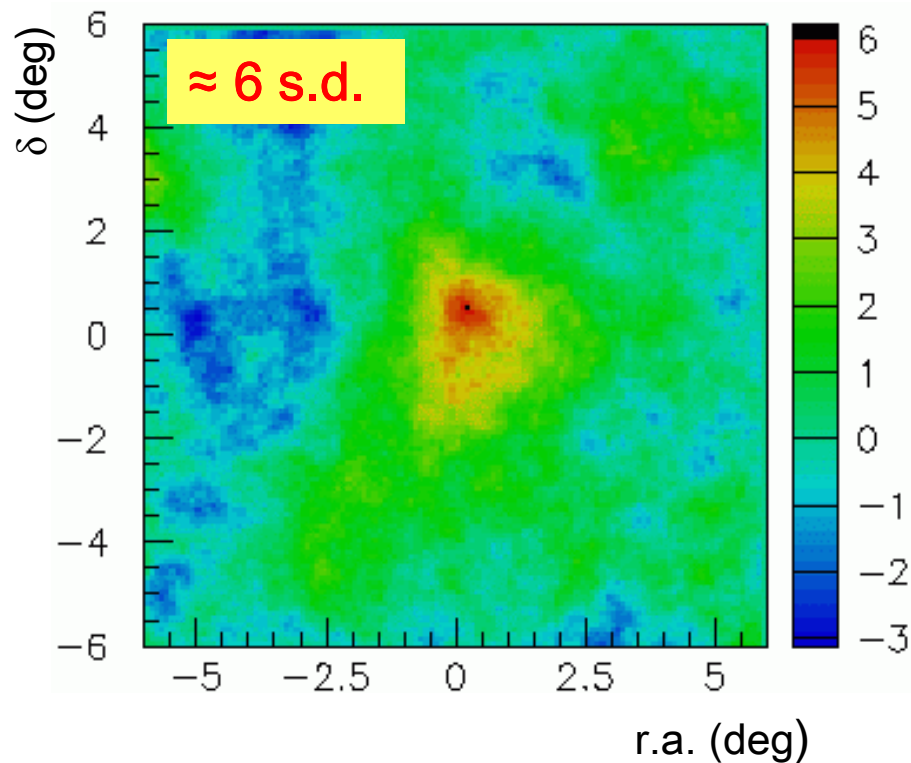


Full ARGO start data taking

November 2007

# Mrk 421 - the first source observed by ARGO

## July 2006 flare



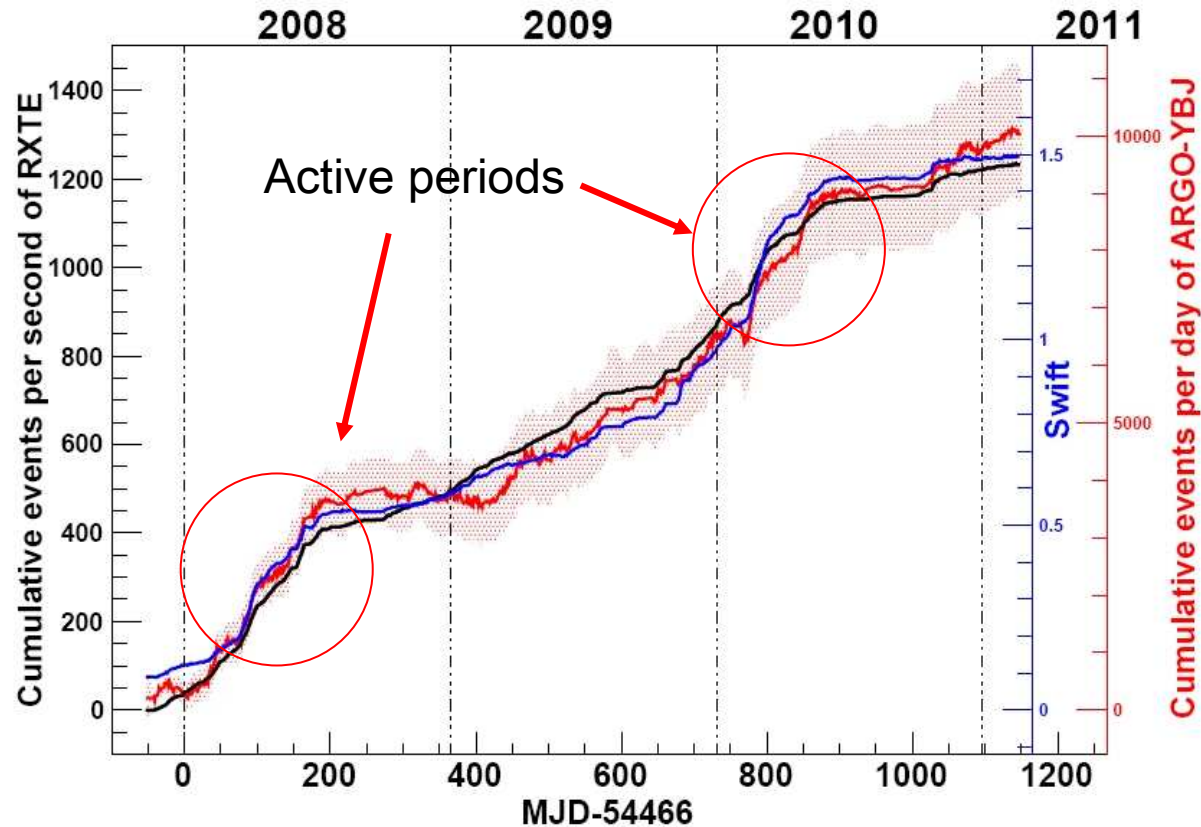
## ARGO Test Data

2006 July 6 – September 2  
(110 hours)

**Flux  $\approx$  3-4 Crab**

No Cerenkov measurements  
available

# Mrk 421 - Correlation with X rays

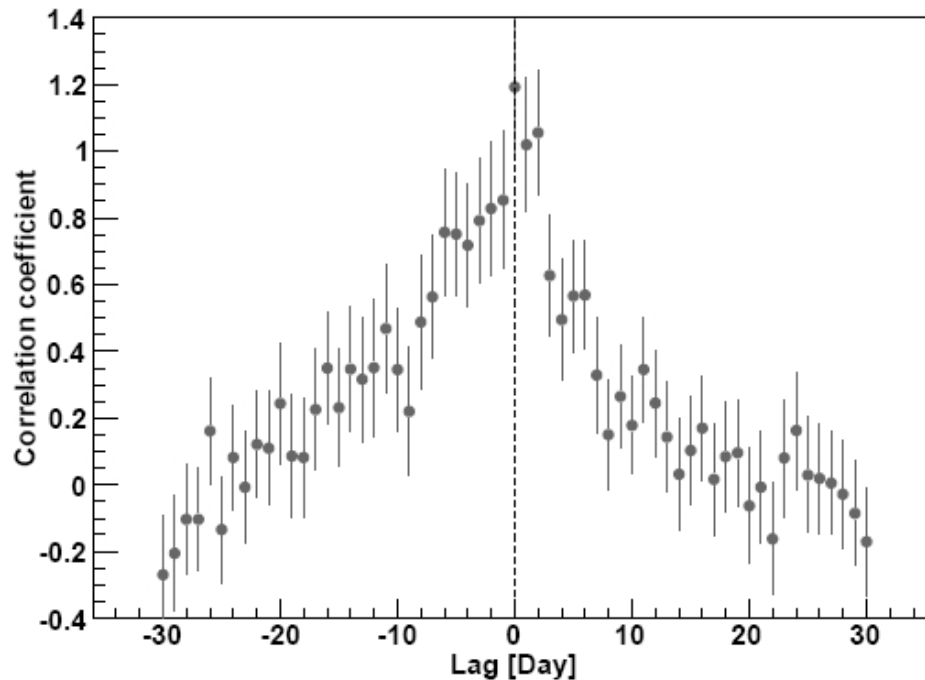


Cumulative  
counting rate

- TeV  $\gamma$  rays ARGO
- X- rays 2-12 KeV RXTE/AMS
- X -rays 15-30 KeV SWIFT/BAT

# Mrk 421 – 3 years correlation between X rays and TeV gamma rays

Correlation coefficient vs. time lag



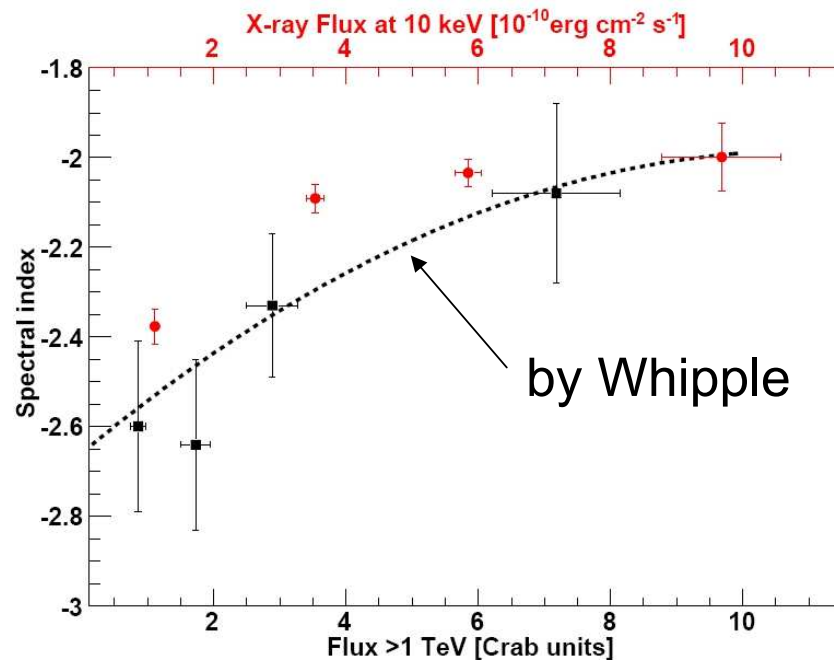
RXTE & ARGO  
Daily counting rates

Time lag consistent  
with zero

# Mrk 421 – 3 years correlation

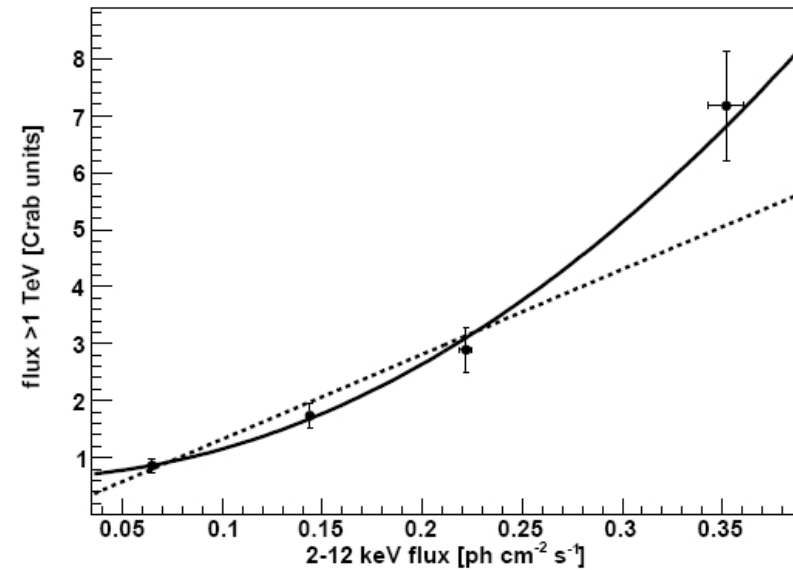
## Spectral features

### Spectral index vs. flux



The X ray and TeV spectra harden increasing the flux

### TeV flux vs. X-ray flux



The relation between TeV and X-ray fluxes is quadratic

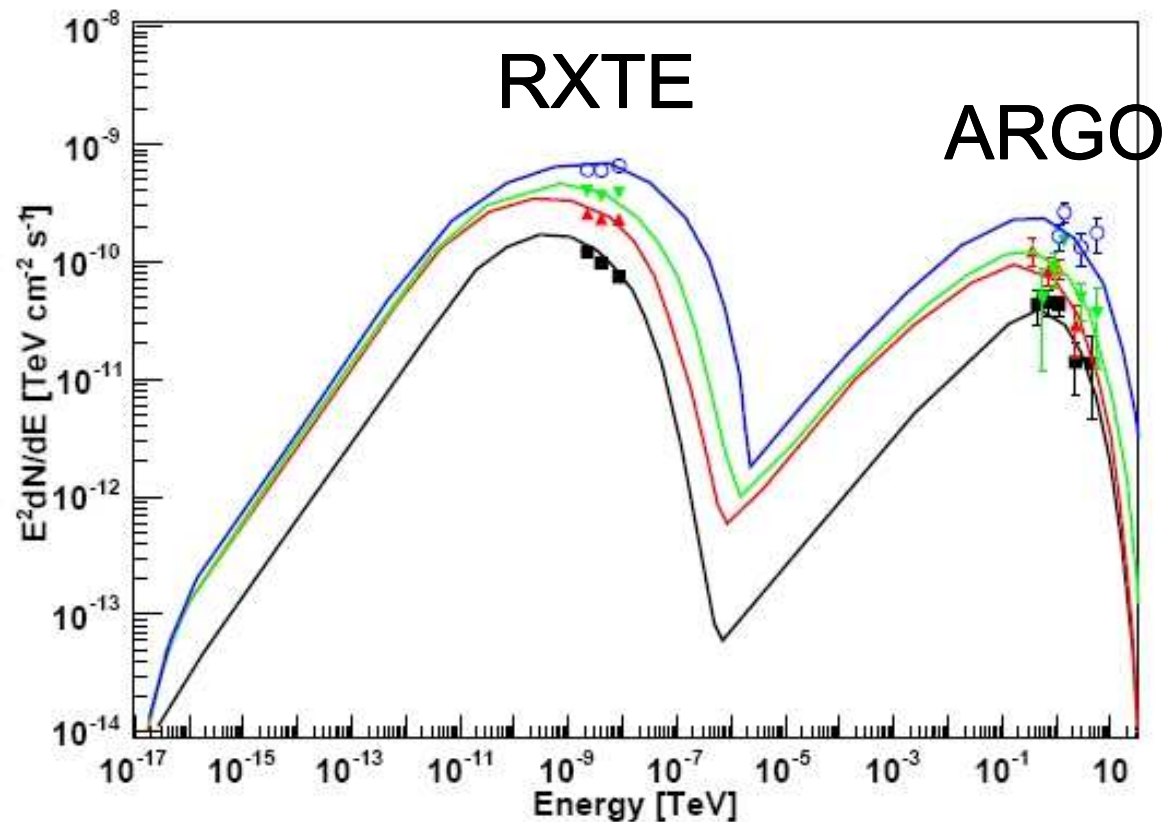
# Mrk 421 – 3 years

## Spectral modeling

### One-zone SSC model

(Mastichiadis & Kirk, 1997, Yang et al., 2008)

flux level	$\gamma_{max}$	$L_e$	B (G)	R (cm)	$\delta$	$\alpha$
1	$2 \times 10^6$	$1.4 \times 10^{-5}$	0.15	$5 \times 10^{16}$	15	1.7
2	$1 \times 10^6$	$1 \times 10^{-5}$	0.15	$5 \times 10^{16}$	15	1.7
3	$7 \times 10^5$	$1 \times 10^{-5}$	0.15	$5 \times 10^{16}$	15	1.7
4	$7 \times 10^5$	$6 \times 10^{-6}$	0.08	$5 \times 10^{16}$	16	1.7





# Mrk 421 - June 2008 flare

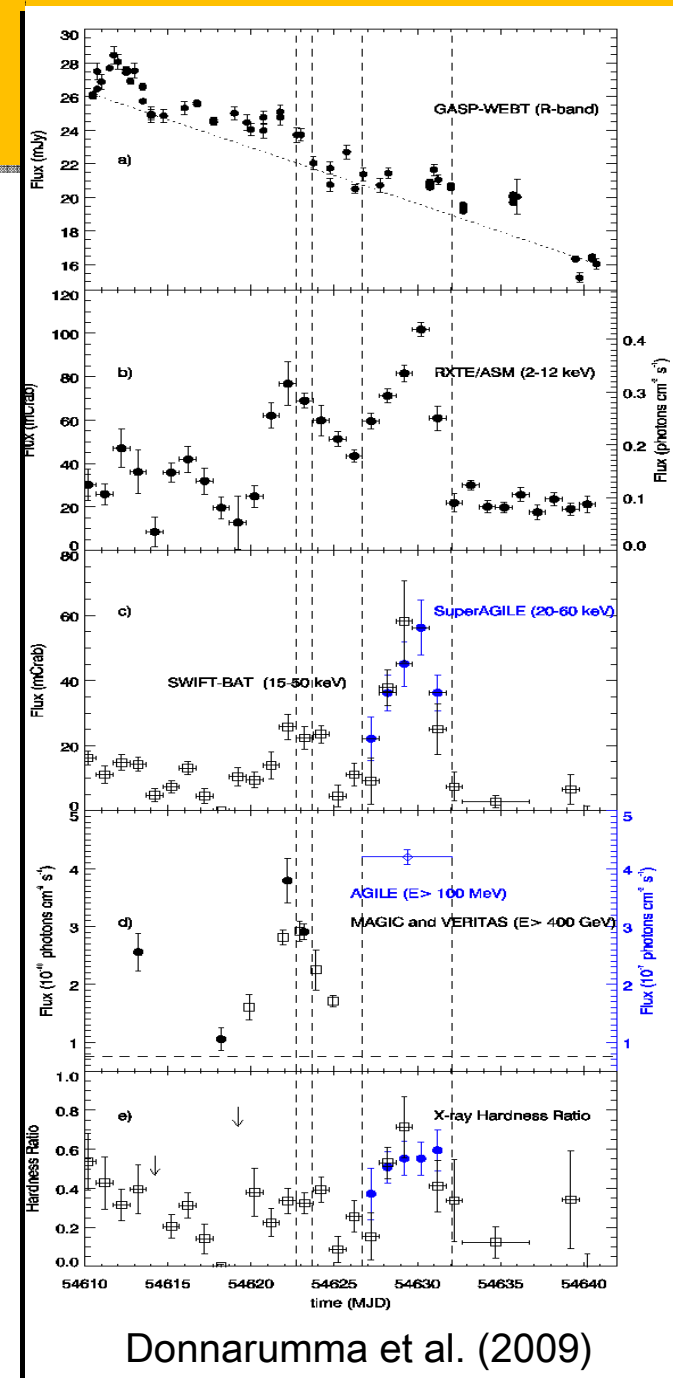
## Multiwavelength observations :

- GASP-WEBT (R-band)
- Rossi RXTE/ASM (2-12 keV)
- Swift/BAT (15-50 keV)
- SWIFT (UVOT & XRT; June 12-13)
- AGILE (E > 100 MeV; June 9-15)
- MAGIC and VERITAS (E > 400 GeV; May 27 - June 8)

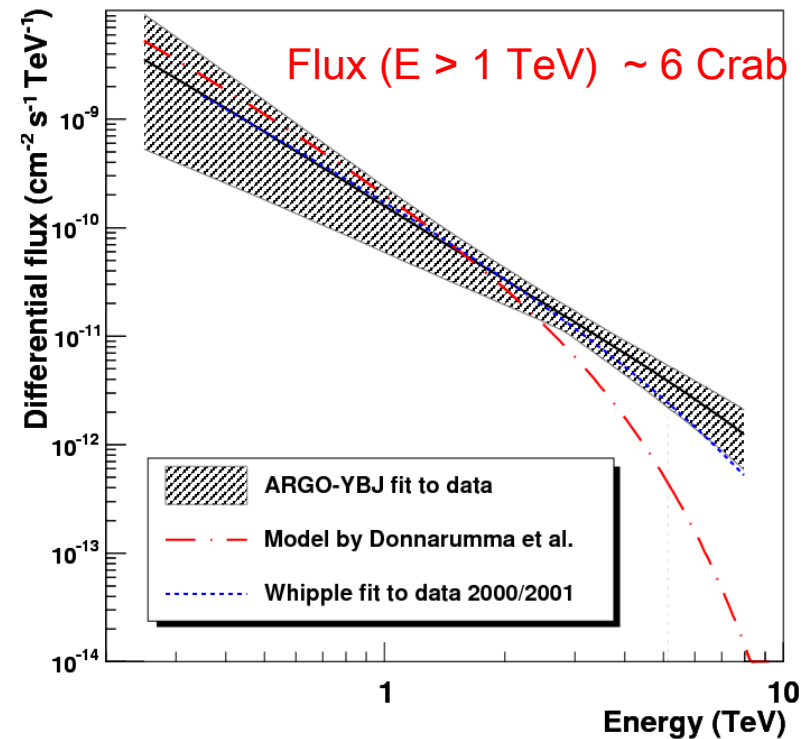
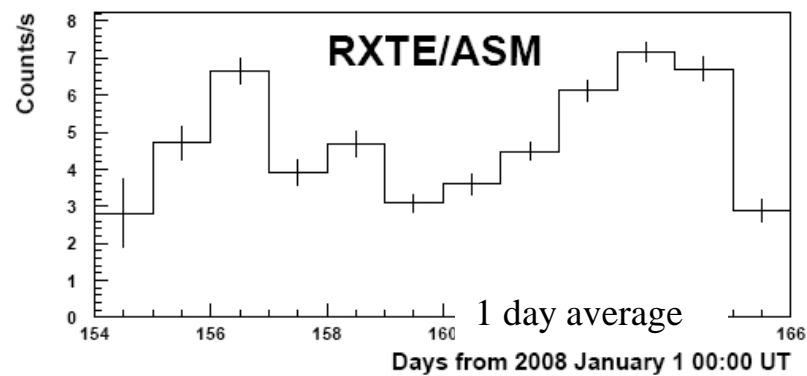
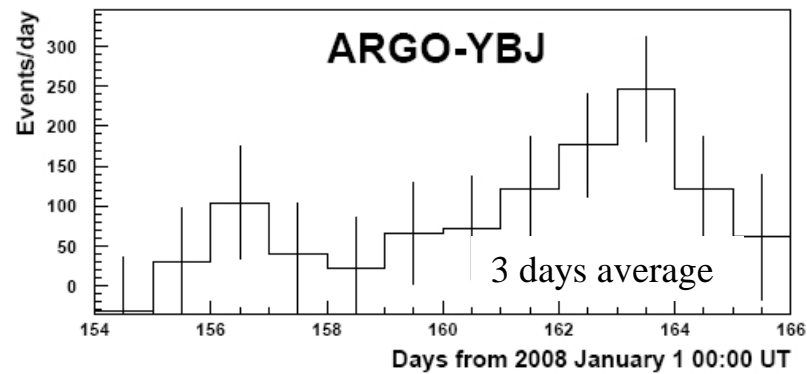
2 flaring episodes:

June 3-8 and June 9-15

No Cherenkov data after June 8



# Mrk 421 - June 2008 flare



G. Aielli et al. – ApJL 714 (2010) L208

Power law spectrum + EBL absorption :

$$dN/dE = (3.2 \pm 1.0) \cdot 10^{-11} \left( E/2.5 \right)^{-2.1 \pm 0.7} e^{-t(E)}$$

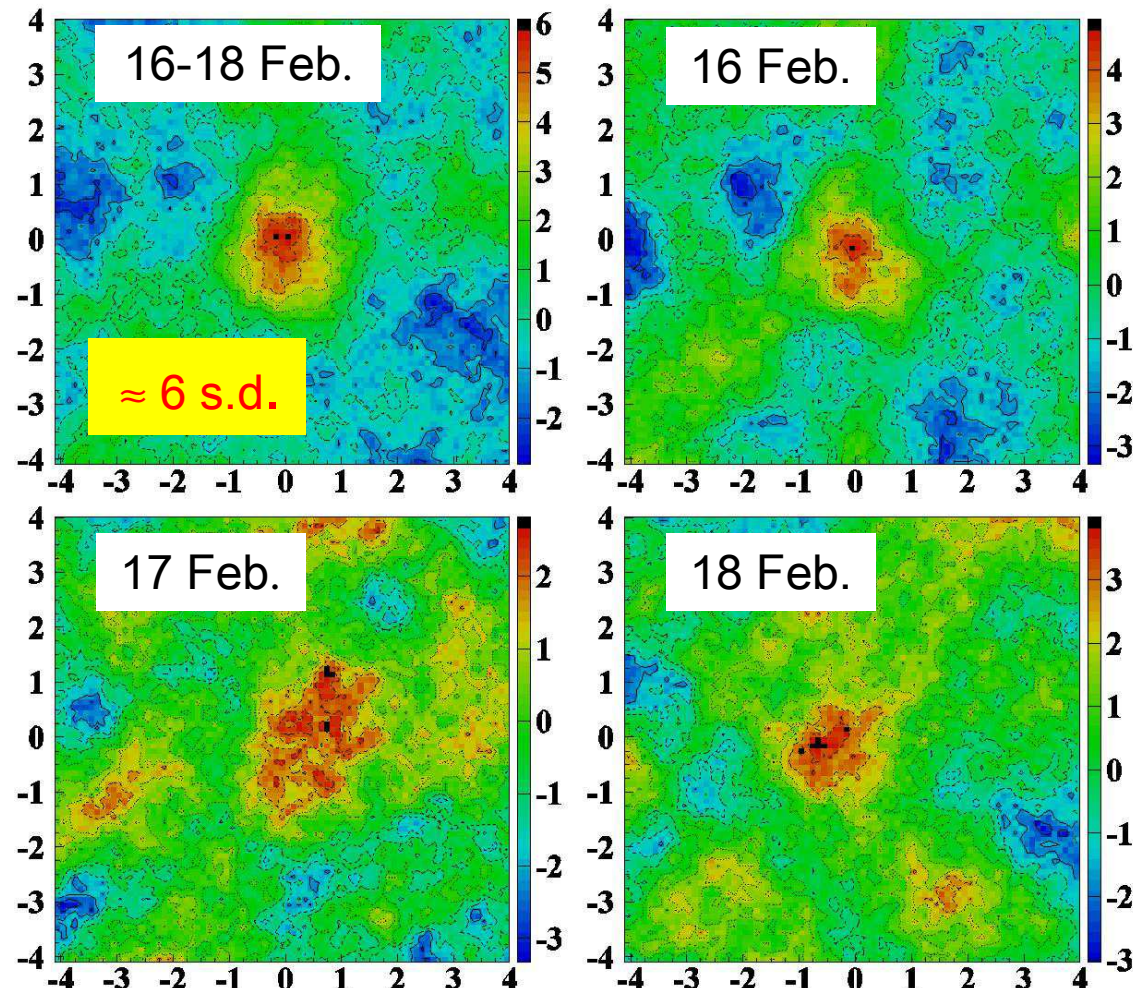
$$\text{ev cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$$

# Mrk 421 - February 2010 flare

- ARGO observed a strong flare on 16-18 Feb. at 6 s.d.
- Flux > 3 Crab

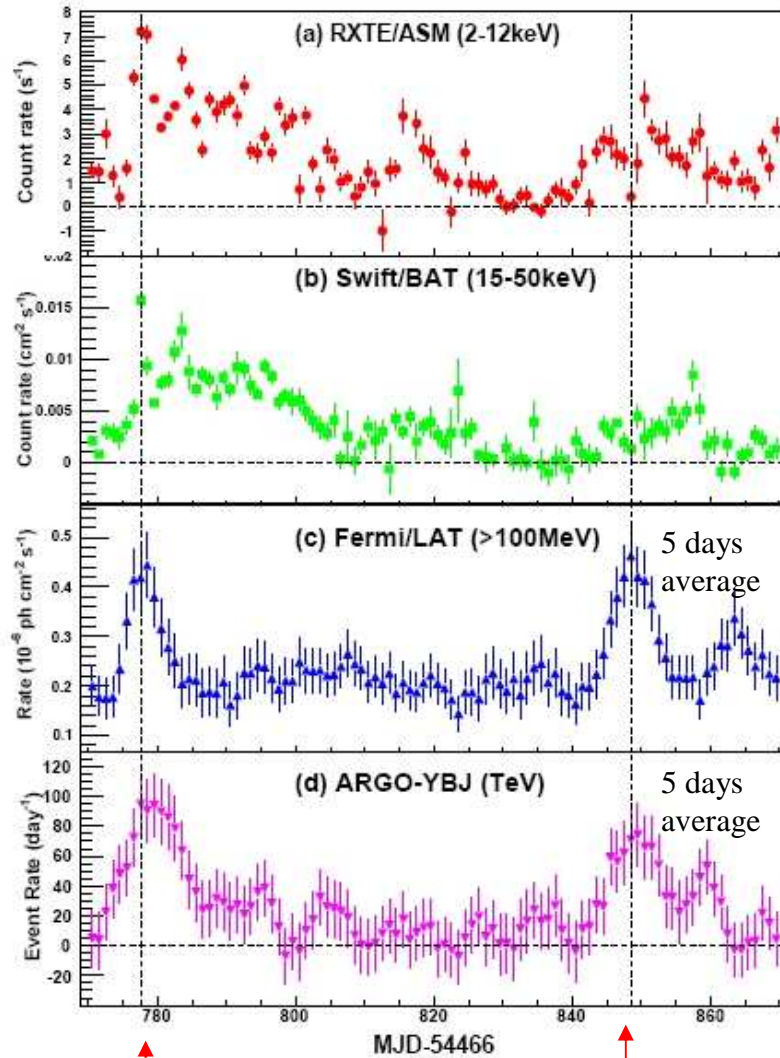
Peak flux (16 Feb) > **10 Crab**

- For the first time an EAS array observed a TeV flare at 4-5 s.d. in one day
- VERITAS reported similar observation in Atel #2443.



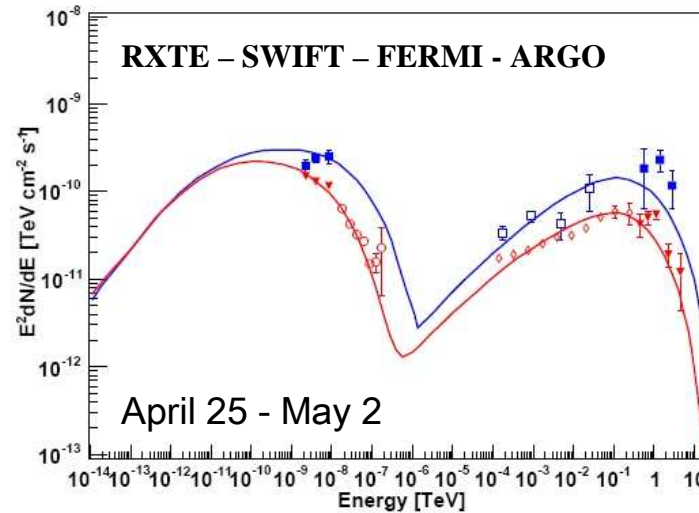
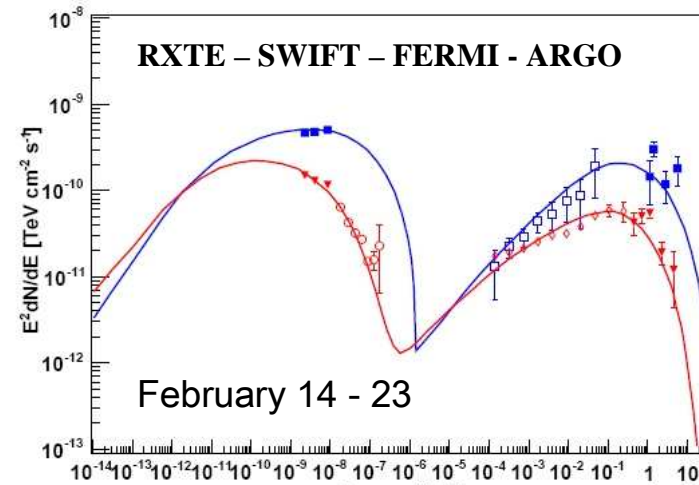
# Mrk 421 - February / May 2010

## multiwavelength observations



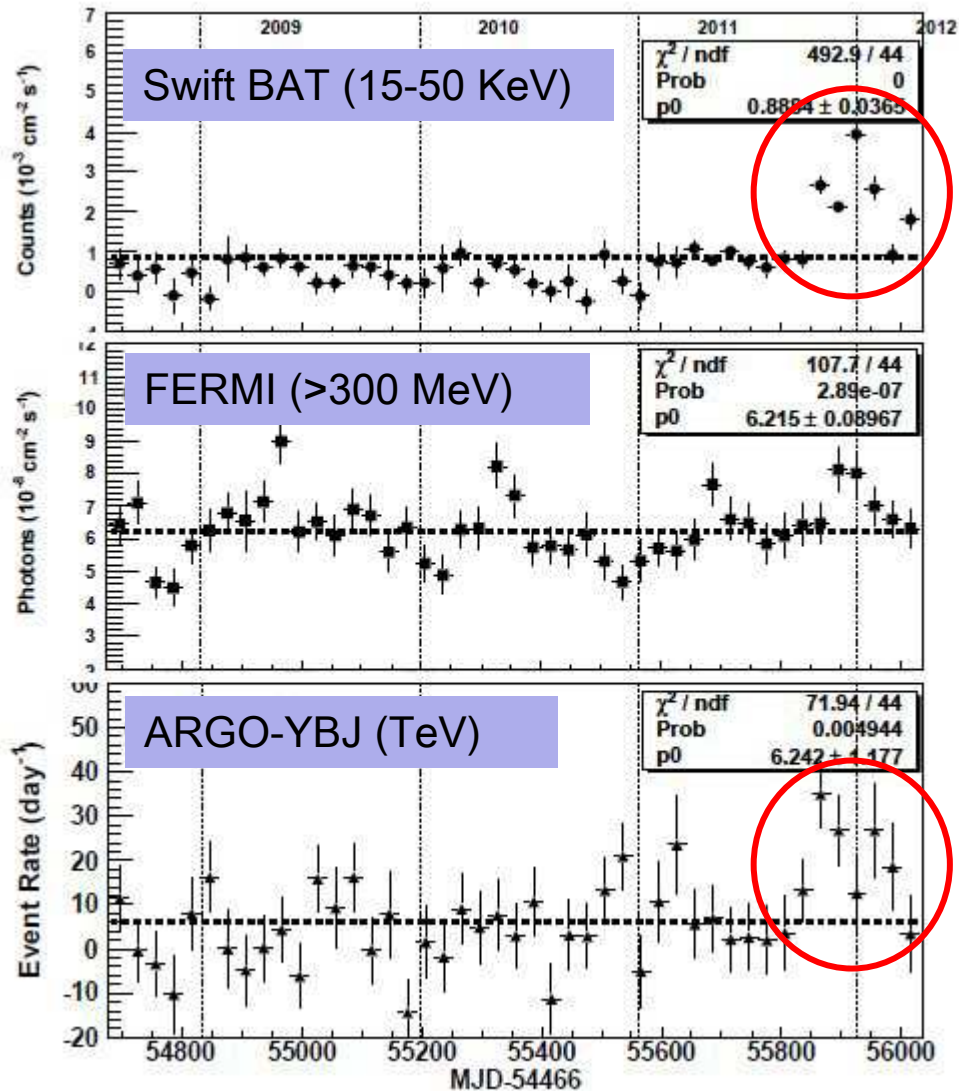
February 16

April 28





# Mrk 501 - October 2011 flare



After 14 years  
a new strong X-ray flare

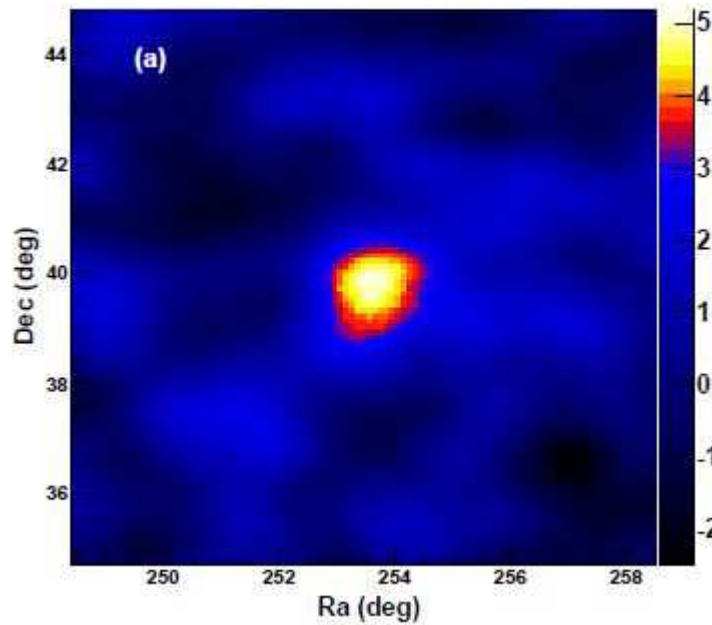
TeV emission  
detected by ARGO-YBJ  
(not observable by  
Cherenkov telescopes)

Paper submitted to ApJ

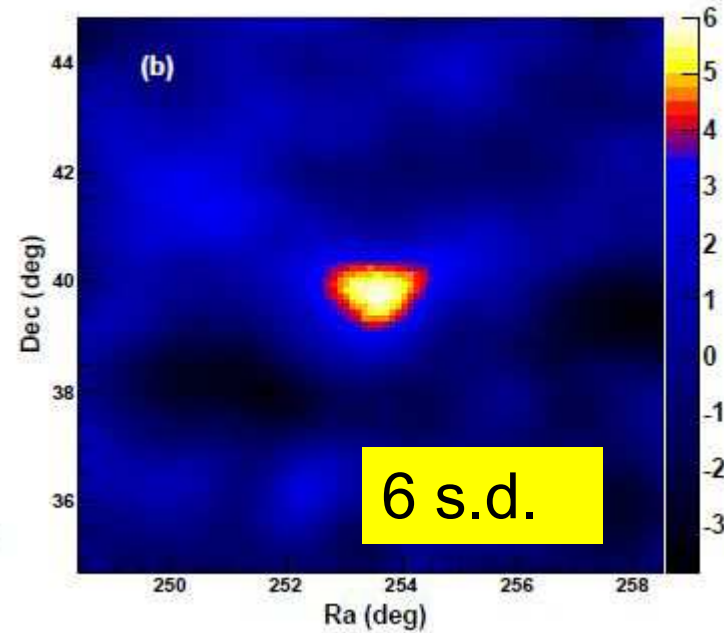
# Mrk 501

Quasi-steady emission  
3.2 years  
August 2008 - October 2011

Flare : 17 Oct – 22 Nov 2001



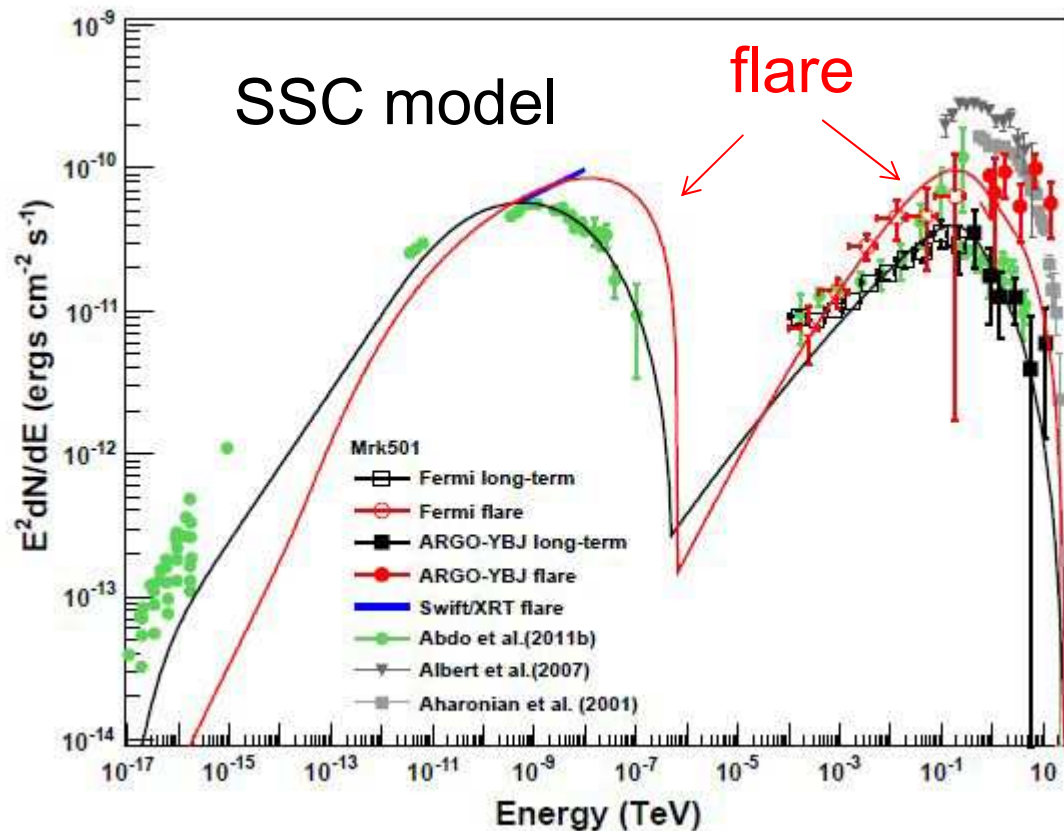
Average flux: 0.3 Crab



Flare flux : 2.1 Crab



# Mrk 501 SED



← ARGO data during flare are **not consistent** with a one-zone SSC model

The long term emission is consistent with a one-zone SSC model

Paper submitted to ApJ

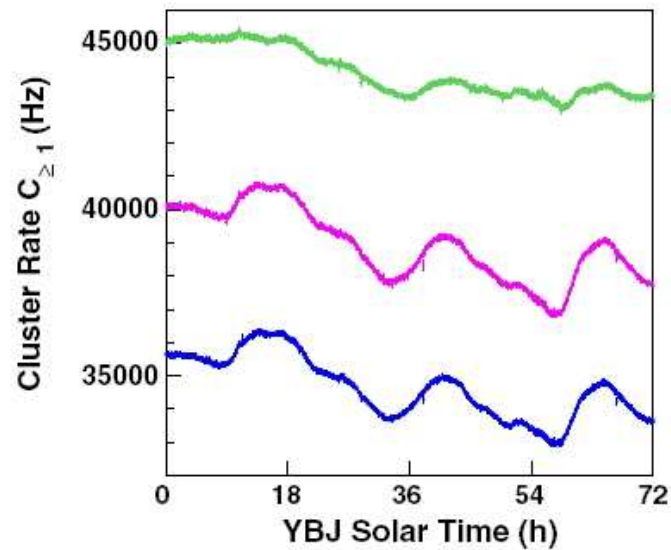
# Scaler data

**DATA** Countings of each cluster recorded every 0.5 s

for 4 levels of coincidence:  $n \geq 1, 2, 3, 4$

NO event reconstruction - **NO primary direction**

## Detector monitoring



**Counting rate modulated by :**

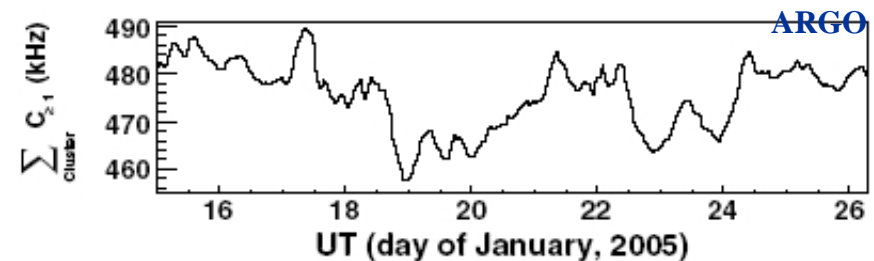
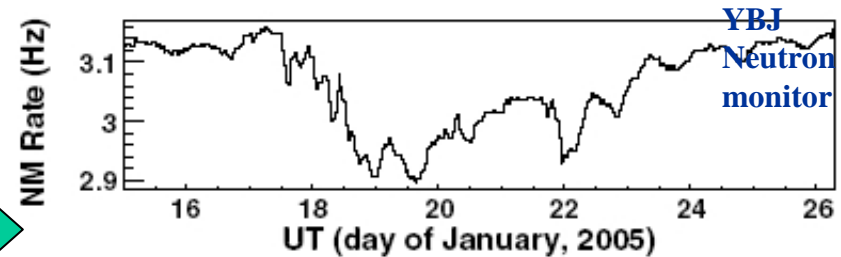
- Pressure
- Temperature
- Radon
- Solar activity

# Physics with scaler data

## Study of transient phenomena

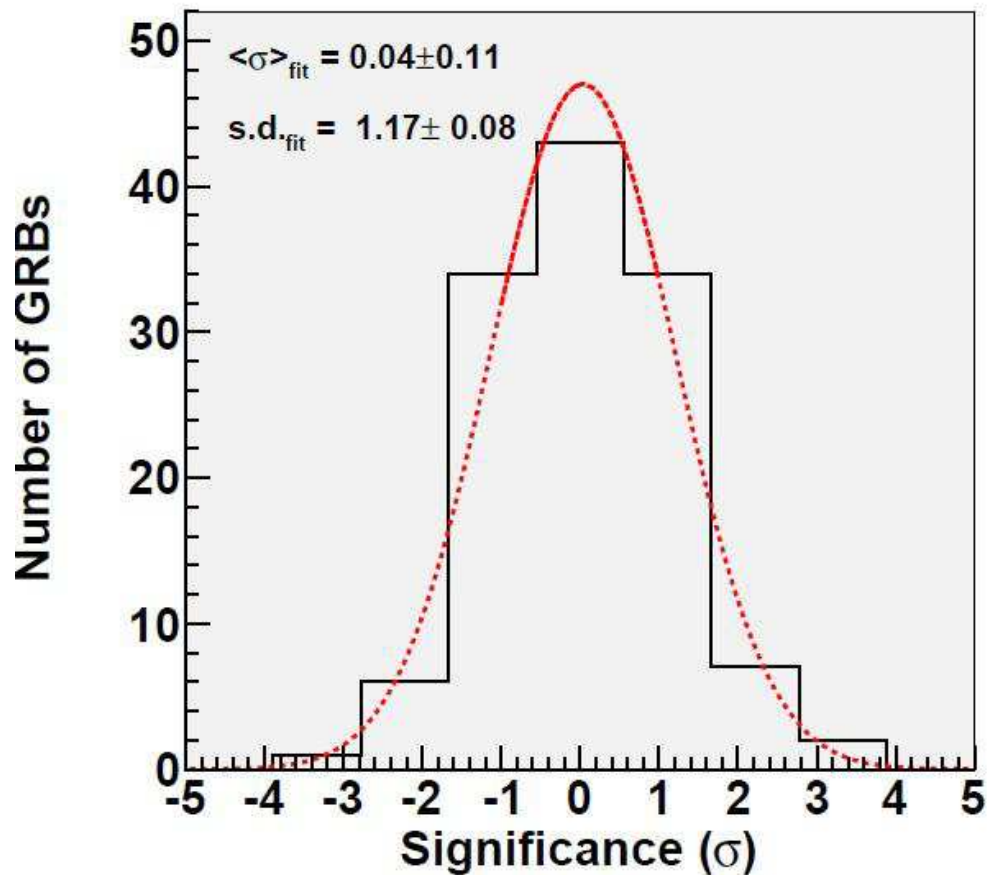
- **Gamma Ray Bursts**  
in the 1-100 GeV energy range
- **Sun and Heliosphere physics**  
Solar flares, GLE
- **Environmental studies**  
Radon monitor

Forbush decrease



# GRBs in scaler mode

## Significance distribution



- 127 GRBs ( $\theta < 45^\circ$ ) from Swift & Fermi
- 20 with known redshift

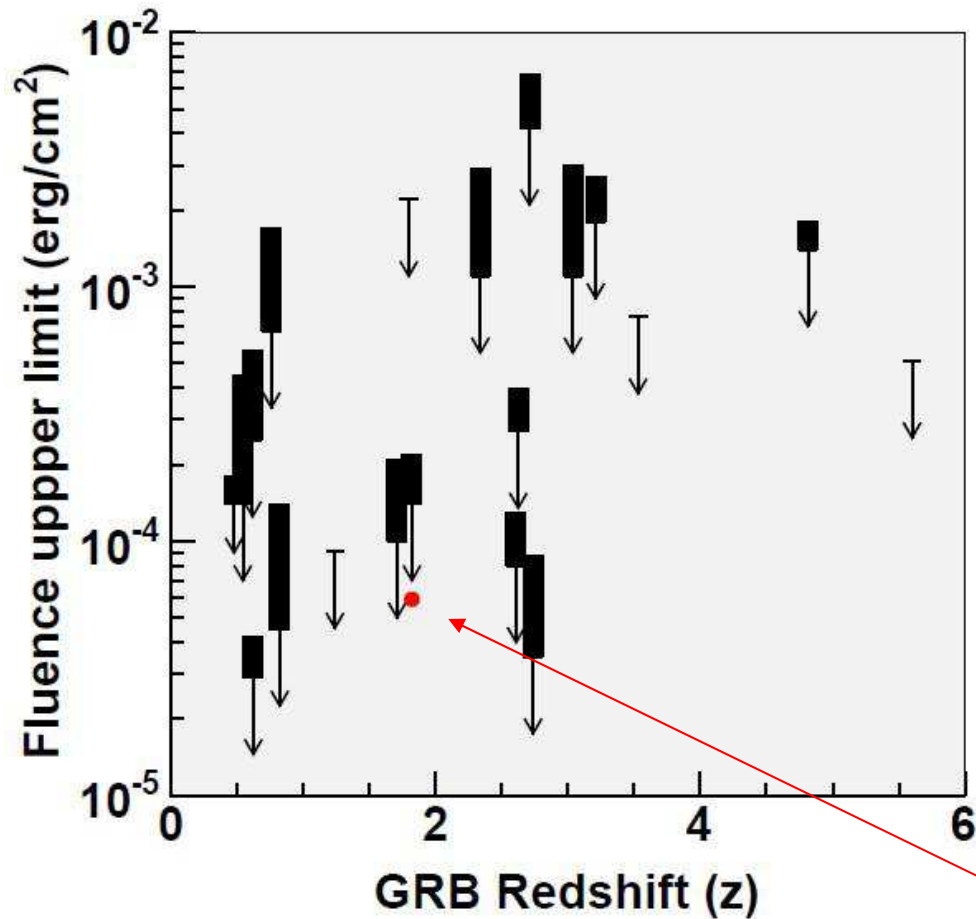
Maximum significance:

**3.52 s.d.**

3.0% chance probability

# GRBs in scaler mode

## Fluence upper limits (1-100 GeV)



- 20 GRBs with known redshift

- EBL according to Kneiske 2004

- spectral index ranging from -2.5 to the value measured by satellite

Fluence measured by Fermi for GRB090902B

# Summary

In 4 years of observation :

- **Crab Nebula** : spectrum in agreement with other experiments  
Some excess in coincidence with GeV flares
- **MGRO J1908+06** : measured extension and spectrum  
observed flux larger than HESS flux
- **MGRO J2031 +41** - observed flux larger than MAGIC & HEGRA flux
- **MGRO J2019 +37** - not observed
- **Mrk421** - continuously monitored
  - VHE flux correlated with X-rays
  - observed flares in 2006, 2008, 2010
  - flare on February 2010 detected in only one day
- **Mrk501** : - new strong flare on 2011, still going on
- **GRBs** – upper limits on 127 GRBs in the 1-100 GeV energy range



# LAWCA project

## Large Area Water Cerenkov

“Low Energy Branch” of LHAASO

Water pool: 205m×110m, 41×22=902 units (5m×5m each) separated by curtains.

Water depth: 4m

LAWCA sensitivity  
similar to HAWC:  
5% Crab flux  
above few TeV

ARGO sensitivity  
would increase  
by a factor  $\approx 3$  at  
1 TeV



A prototype at IHEP (see [Nucl.Instrum.Meth.A644:11-17,2011](#))