ASTROPARTICLE PHYSICS WITH ARGO-YBJ EXPERIMENT

G. Marsella
on behalf of ARGO-YBJ collaboration

Dipartimento di Ingegneria dell'Innovazione
Università del Salento and INFN, Lecce, Italy

Outline

- Detector Layout
- The Moon Shadow
- Cosmic Rays
- Gamma Astronomy

ARGO-YBJ experiment

(Astrophysical Radiation Ground-based Observatory)

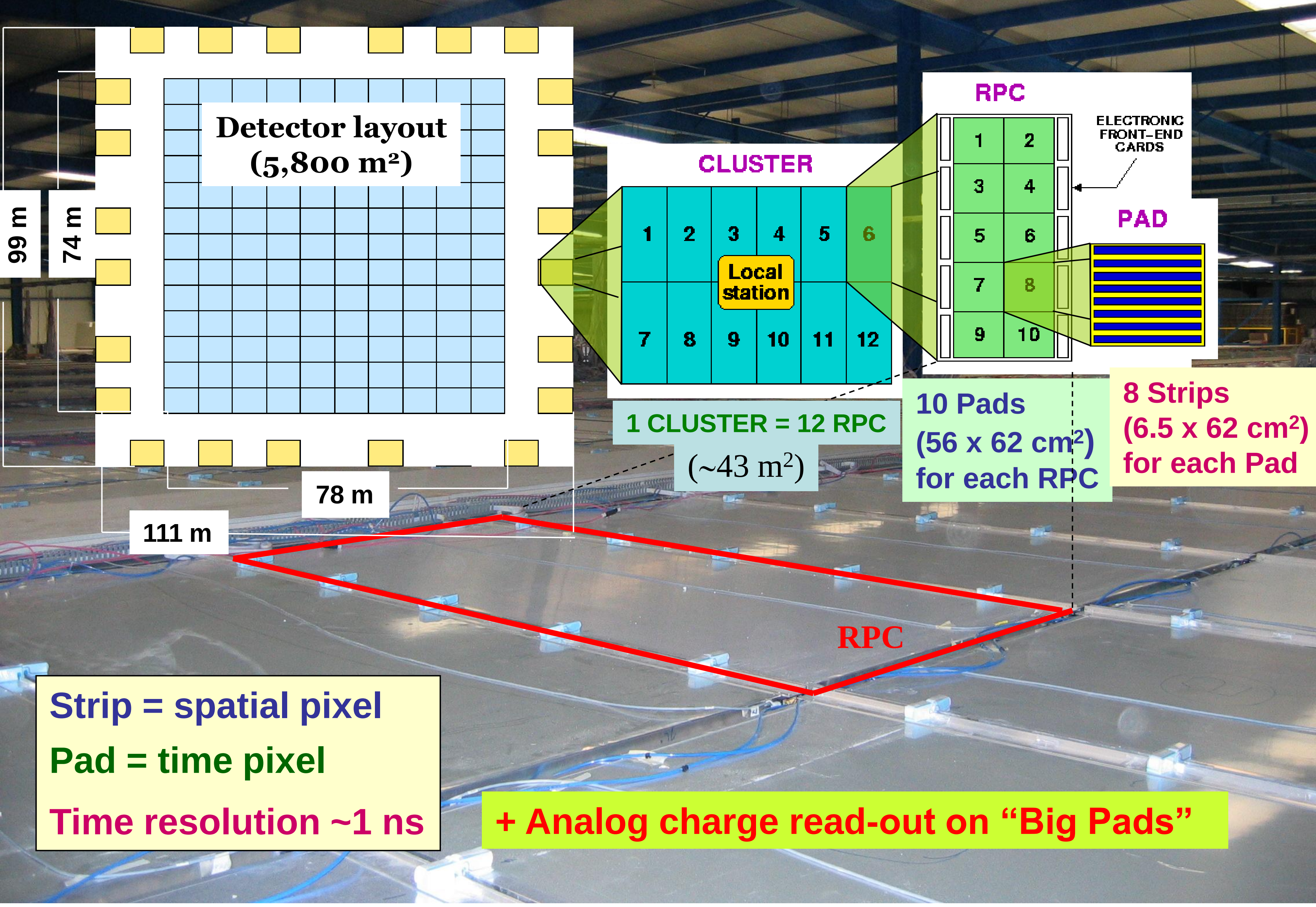
ARGO-YBJ

High Altitude Cosmic Ray Observatory @ YangBaJing

Site altitude: 4,300 m a.s.l., ~ 600 g/cm^2

Coordinates: longitude 90° 31’ 50” E, latitude 30° 06’ 38” N

ARGO-YBJ detector



Detector status

Detector completely installed since 2007
(central carpet + guard-ring, 153 clusters)

Data taking

Since July 2006 with the central carpet
Since November 2007 with the guard-ring

Setup for analog charge readout installed on central carpet (130 cl)

In data taking with lowest gain scale

(Trigger $\geq$ 73 hits/cl)

Experiment operation

Shower mode

Inclusive Trigger: N_{pad}>20 within 420ns on the central carpet

$\Rightarrow$ rate ~ 3.6 kHz (~220 GBytes/day)

Detection of Extensive Air Showers (direction, size, core …)

Aims : cosmic-ray physics (threshold ~ 1 TeV)
VHE γ-astronomy (threshold ~ 300 GeV)
gamma-ray bursts

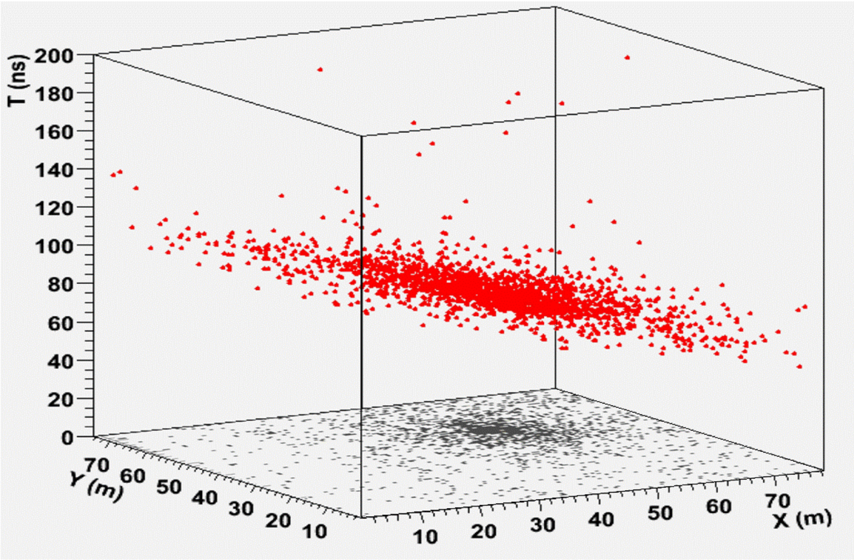
Scaler mode

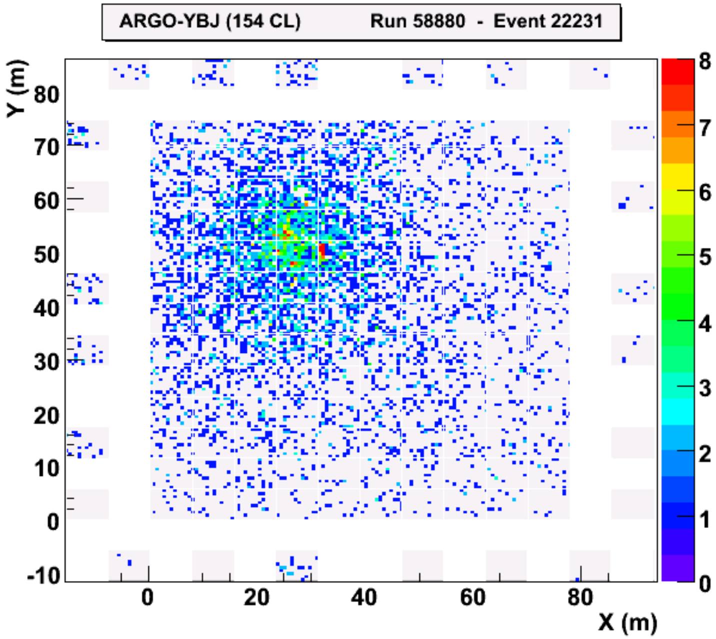
counting rates ($\geq$ 1, $\geq$ 2, $\geq$ 3, $\geq$ 4 coincidences) for each cluster

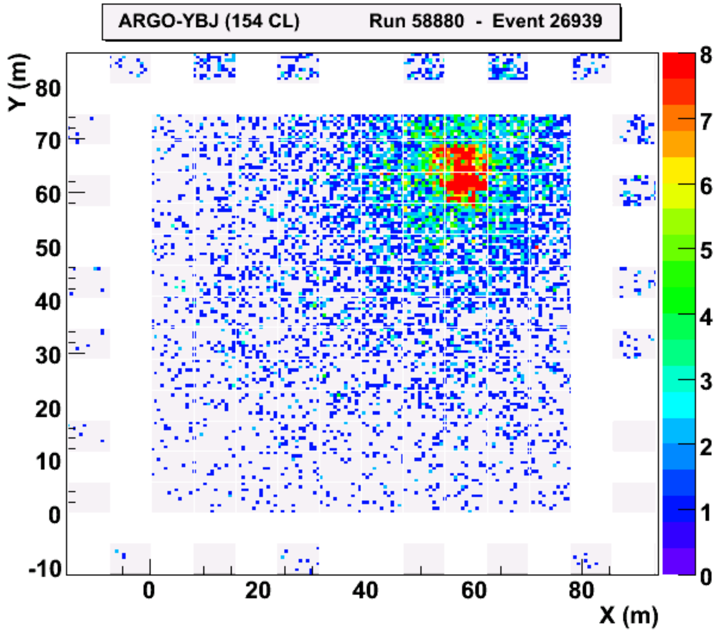
Aims: detector and environment monitor
flaring phenomena (gamma ray bursts, solar flares)
with a threshold of few GeV

Shower events

The number of pixels, the time resolution and the full coverage of the central carpet allow to reconstruct the shower with unprecedented details





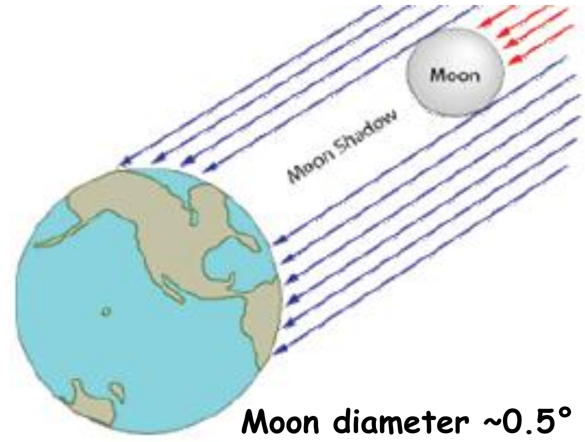



The shadow of the Moon

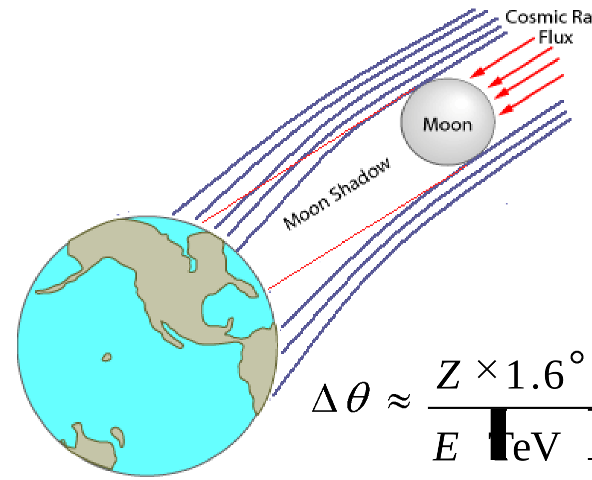
The shadow of the Moon

A deficit in the cosmic ray flux is expected from the Moon direction.

Many items are related:



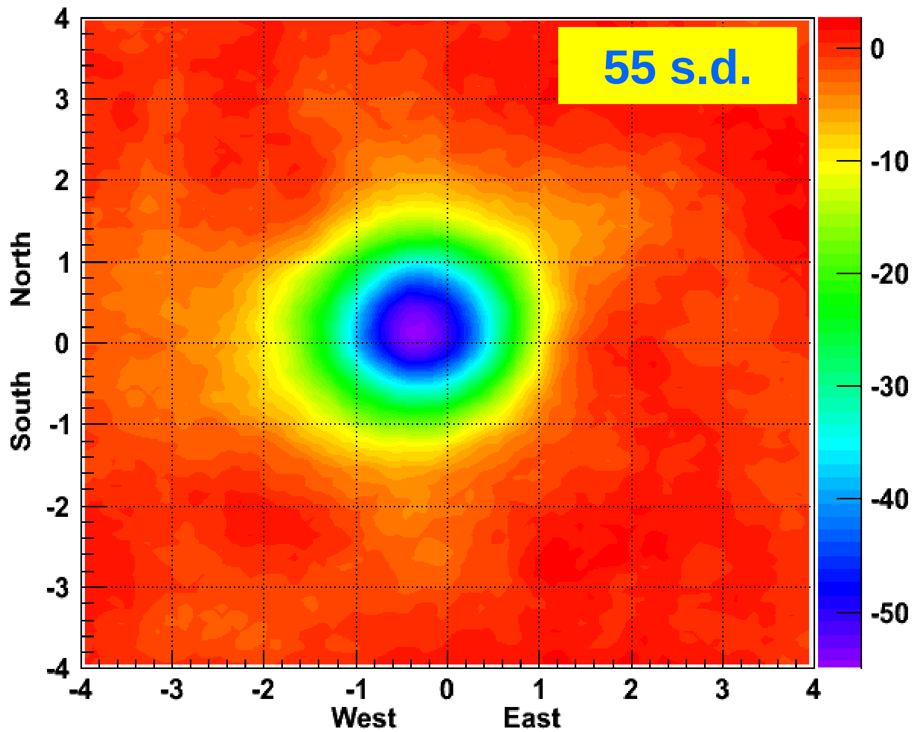
- angular resolution (width of the deficit)
- pointing accuracy (position of the deficit)
- energy calibration (the westward deflection due to the geomagnetic field depends on the energy of cosmic rays)
- proton/antiproton ratio (antiprotons are deflected eastward)

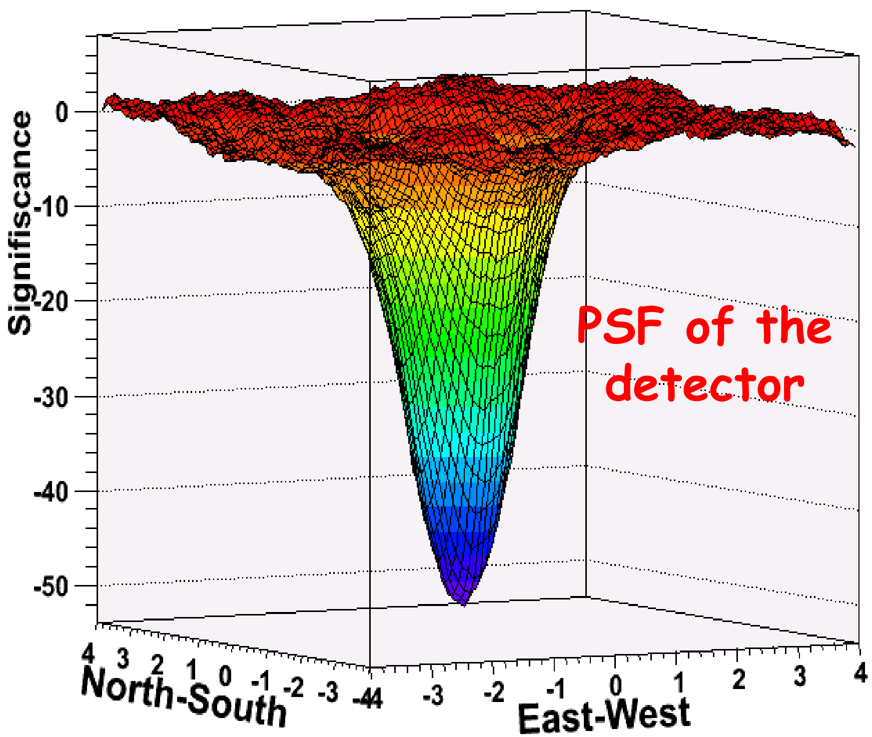


$$\Delta\theta \approx \frac{Z \times 1.6^\circ}{E\,[\mathrm{TeV}]}$$

All data: 2006 → 2009

N > 100 $\theta < 50°$





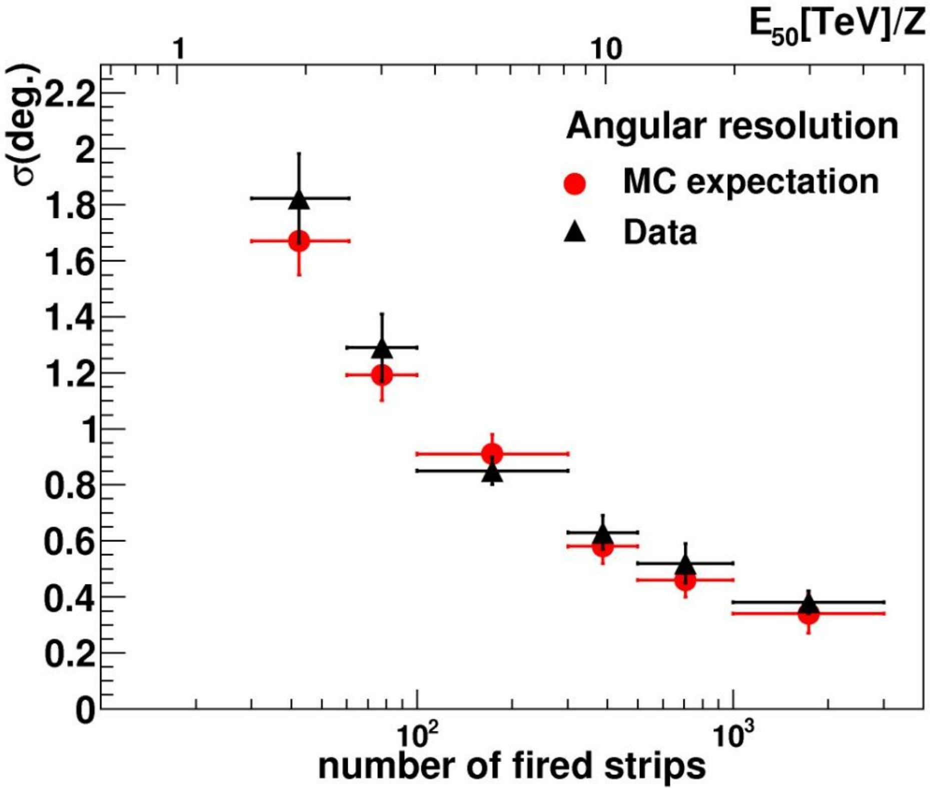
3200 hours on-source

≈ 9 standard deviations / month

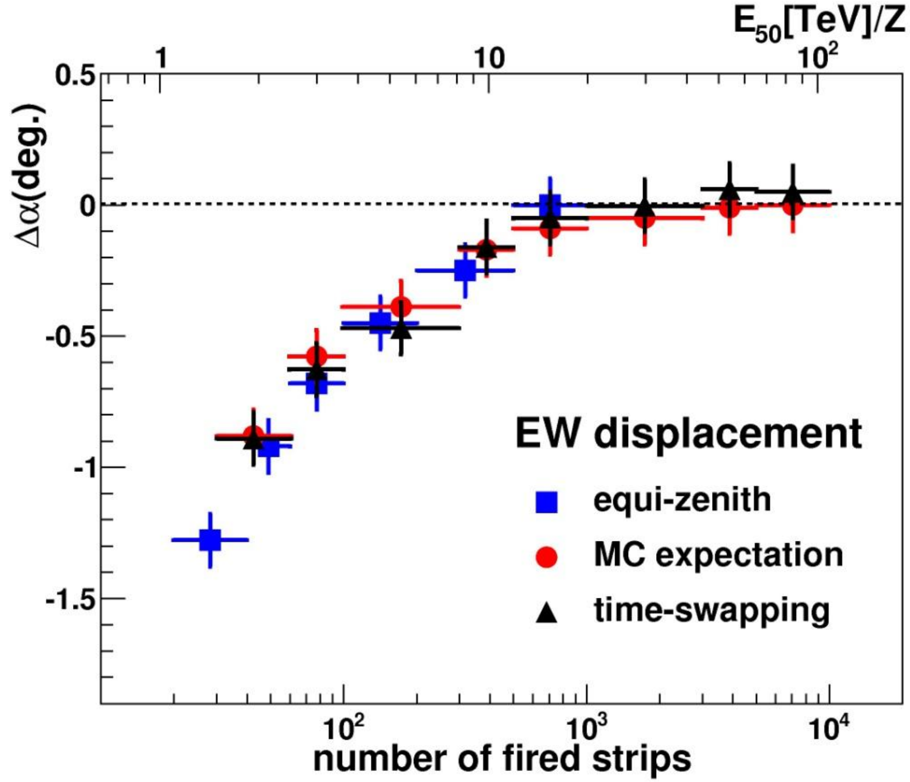
The deficit surface is the convolution of the PSF of the detector and the widespread Moon disc.

$$RMS \simeq \sigma \sqrt{1 + \left(\frac{R}{2\sigma}\right)^2}$$

Moon Shadow analysis



Measured angular resolution



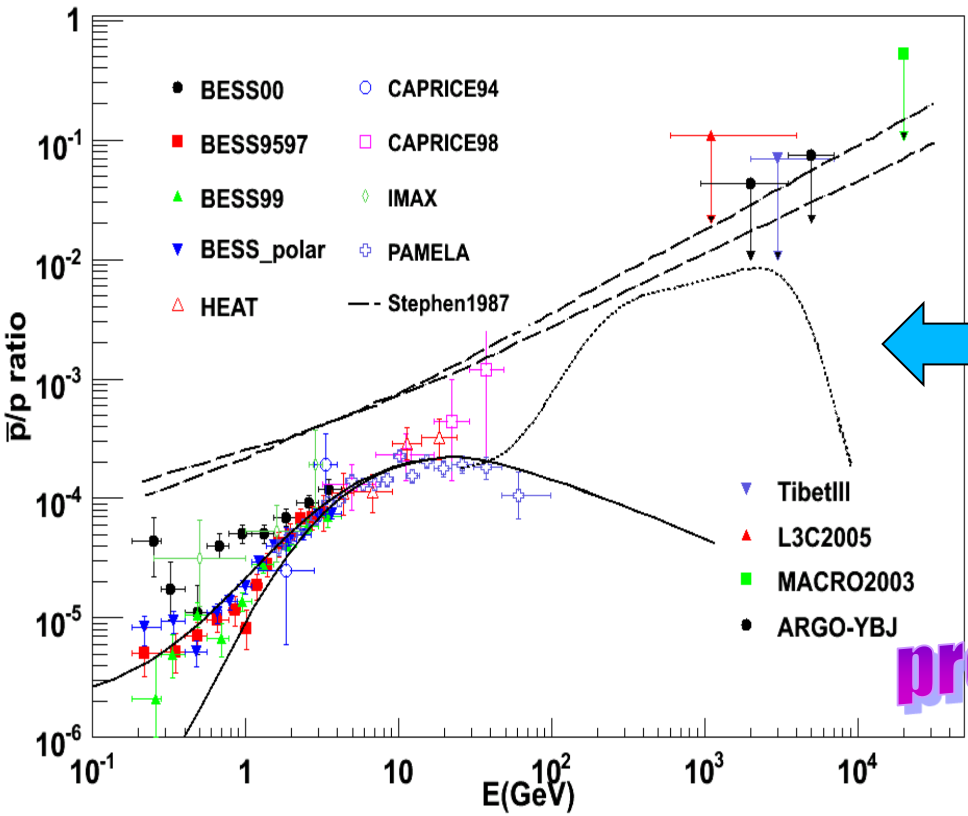
Measured EW displacement

Antiproton/proton ratio

1. From MC,
   the fraction of protons to all cosmic rays. 70.9% for 50000>nHit > 100:
   73.0% for 100>nHit>60:
2. Considering the Boundary condition: b>=0;
   Using Feldman and Cousins statistics:

   60<nHit<100 **(median E ~2 TeV):** 90% C.L. Upper limit **4.2%**

   100<nHit<50000 (**median E ~5 TeV**): 90% C.L. Upper limit **7.4%**



Compute the 90% Upper limit!

1. Dashed lines: antistars models for different rigidity, 0.6, 0.7 respectively
2. Dotted line, the heavy DM particle contribution.

10 Paper being submitted

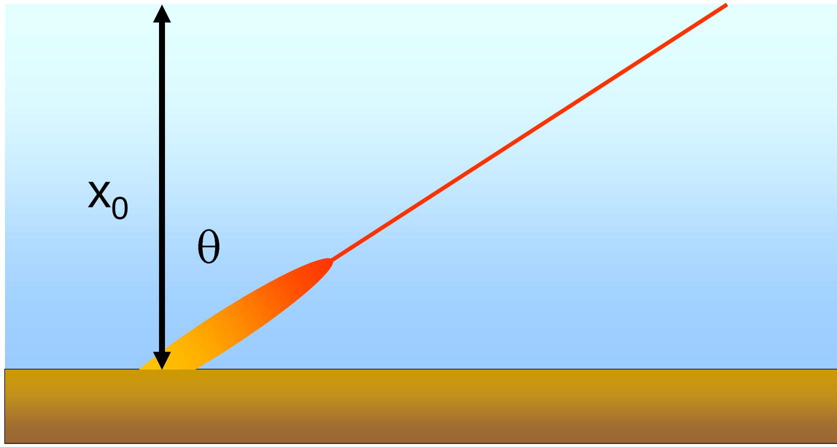

Cosmic rays

Flux attenuation and p-Air cross section

Shower frequency vs *(secθ-1)*:

$$I(\theta) = I(0) \cdot e^{-\frac{x_o}{\Lambda_{abs}}\left(\sec(\theta)-1\right)}$$

$\Downarrow$



Measure the flux attenuation

For <u>fixed energies</u> and shower ages:

$$\Lambda_{abs} = k\,\lambda_{\mathrm{INT}}$$

$$\sigma_{p-Air}[mb] = 2.4\times 10^{4} / \lambda_{\mathrm{INT}}[g/cm^{2}]$$

$\Rightarrow$ $\sigma_{p\text{-}Air}$ $\Rightarrow$ $\sigma_{p\text{-}p}$

- k is determined by MC simulations, selecting energy and age ranges by means of the actual experimental observables (number of fired strips, hit density, lateral profile)

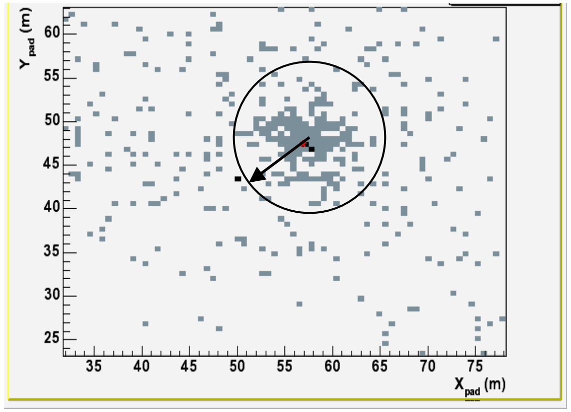
It depends on the interaction model details, but also on the set of experimental observables, energy, ...

Data selection

- **Event selection based on:**
  - **(a) "shower size" on detector, N_{strip} (strip multiplicity)**
  - **(b) core reconstructed in a fiducial area (64 x 64 m^2)**
  - **(c) constraints on Strip density (> 0.2/m^2 within R_{70})**
  - **and shower extension (R_{70} < 30m)**

N_{strip} is used to get defferent E sub-samples

R_{70}: radius of circle including 70% of hits



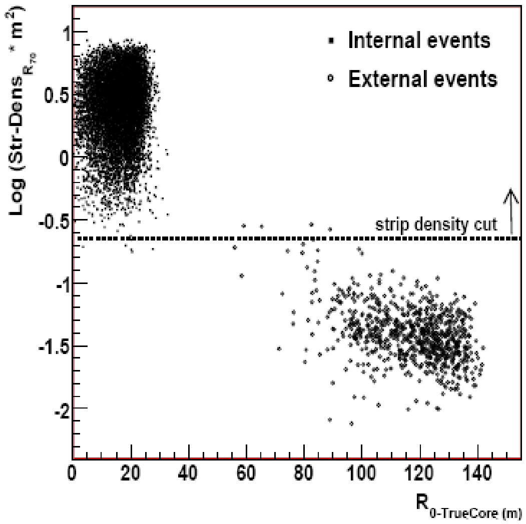
Full Monte Carlo simulation:

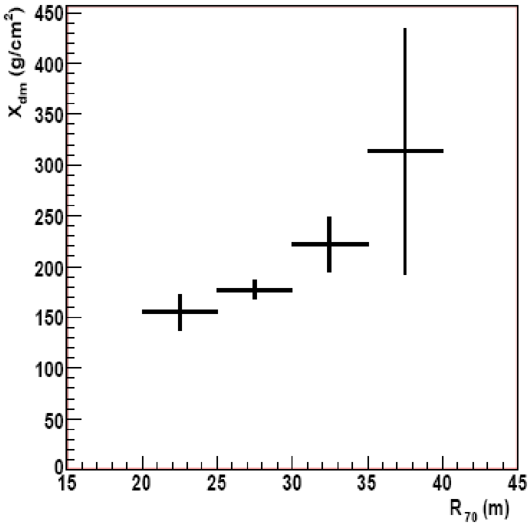
Corsika showers

QGSJET I and II, SYBILL

interaction models

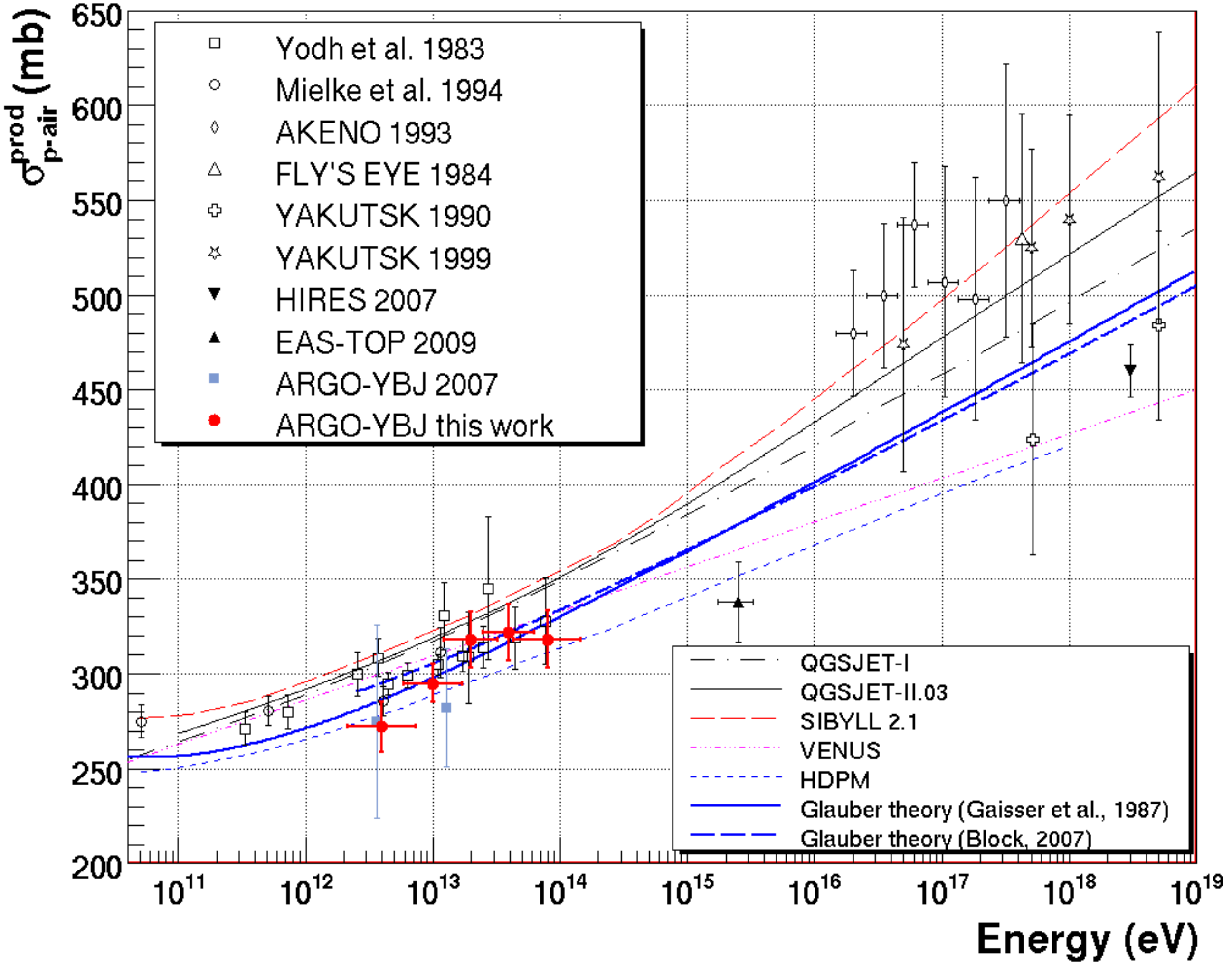
GEANT detector simulation





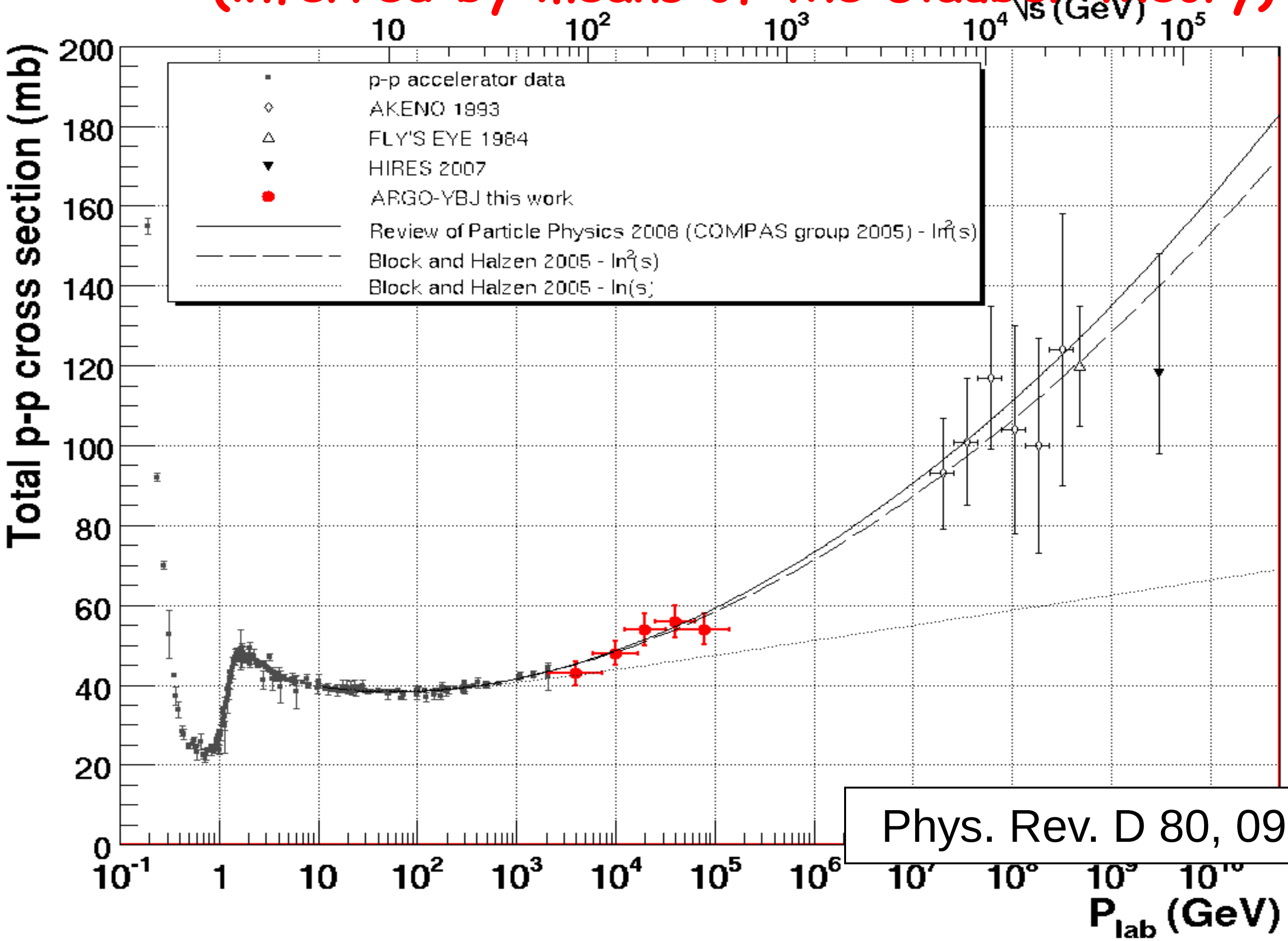
Proton-Air cross section measurement

Phys. Rev. D 80, 092004 (2009)



Total p-p cross section

(inferred by means of the Glauber theory)



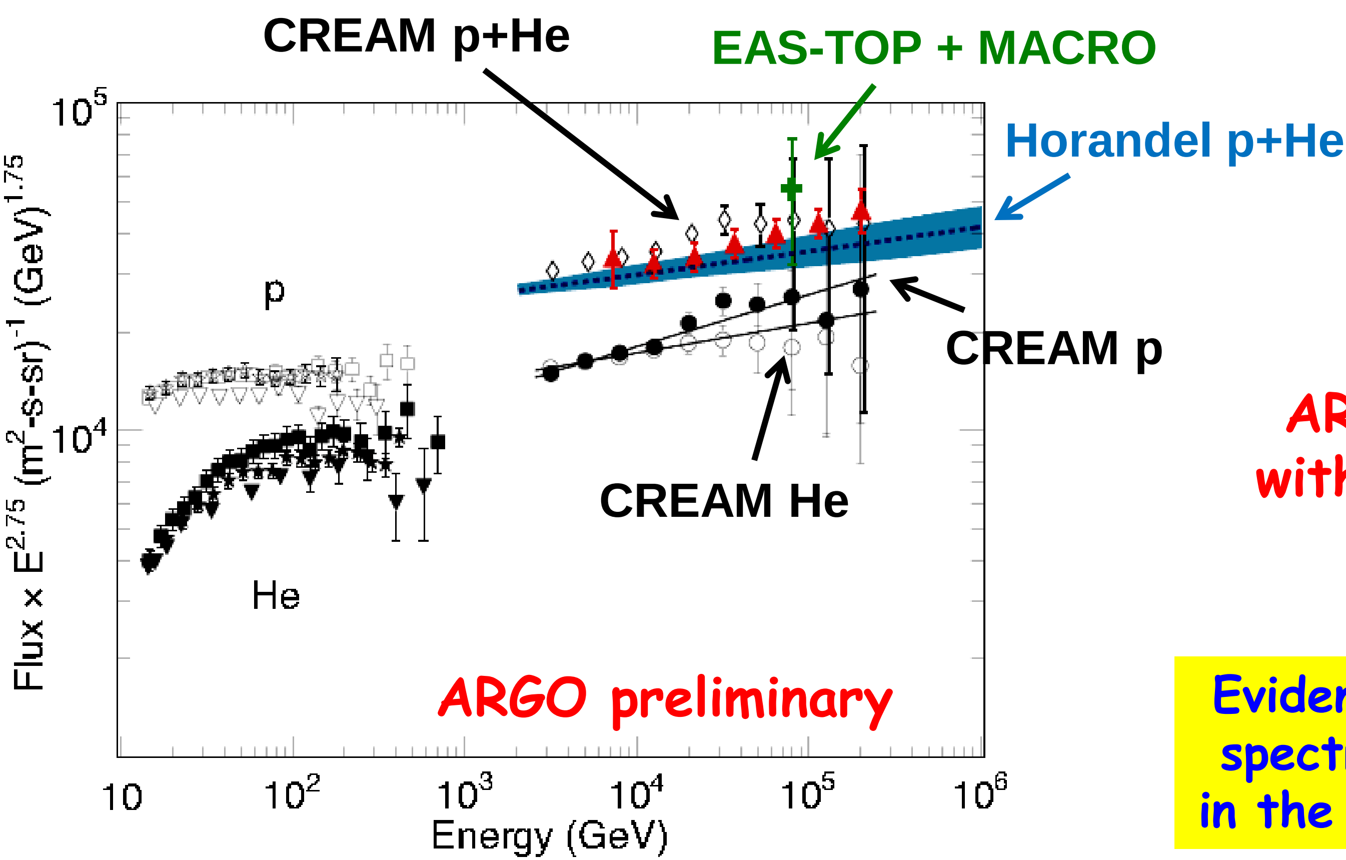
Phys. Rev. D 80, 092004 (2009)

- ✓ No data from accelerators available at these energies
- ✓ The $\log^2(s)$ asymptotic behaviour is favoured

Light-component spectrum of CRs

Measurement of the *light-component* (p+He) spectrum of primary CRs in the energy region (5 – 250) TeV via a Bayesian unfolding procedure

CNO < 2%



ARGO data agree with CREAM results

Evidence that the proton spectrum is flatter than in the lower energy region

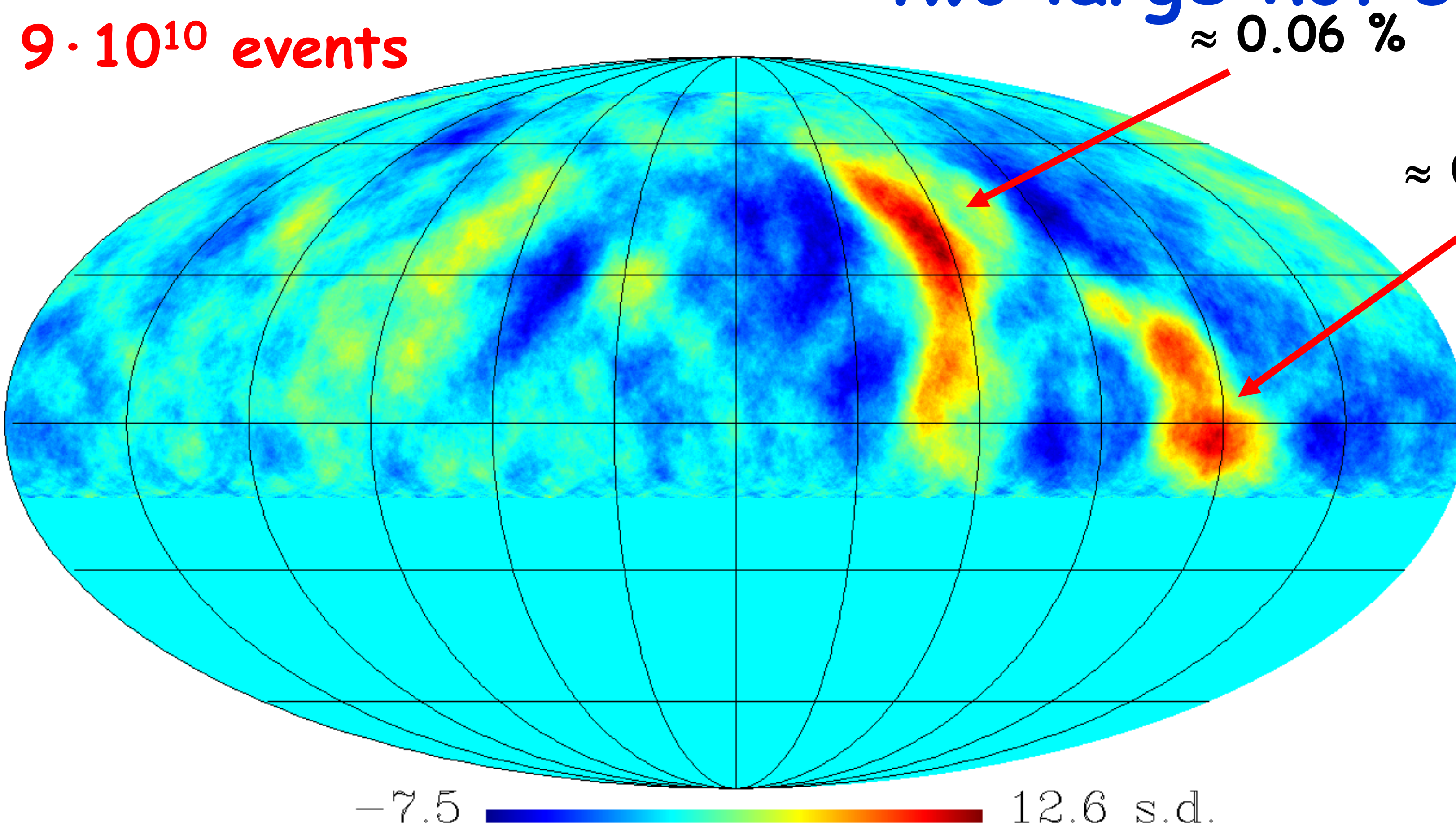
Proton Sky Map: Medium Scale Anisotropy

Smoothing radius = 5

584 days

$9 \cdot 10^{10}$ events

two large hot spots

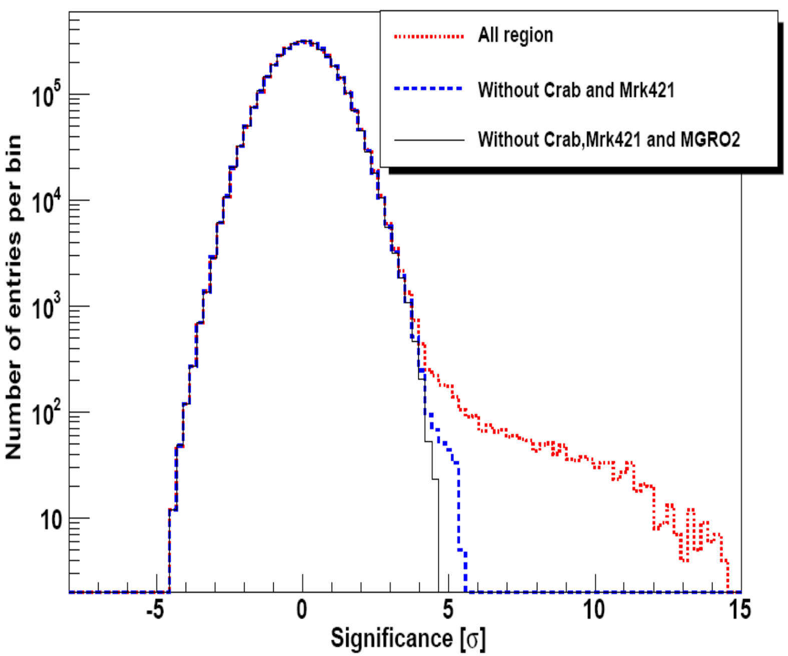


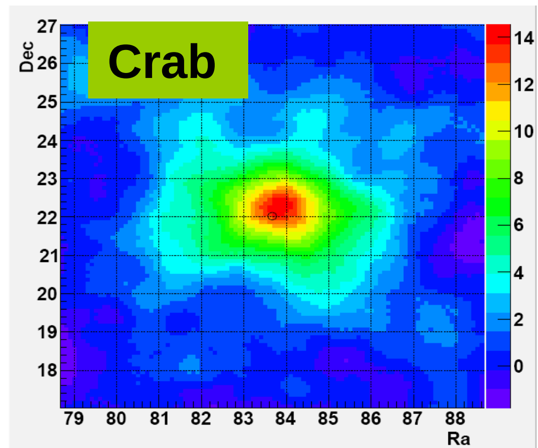
$N_{PAD} > 40$ → Proton median energy ≈ 2 TeV

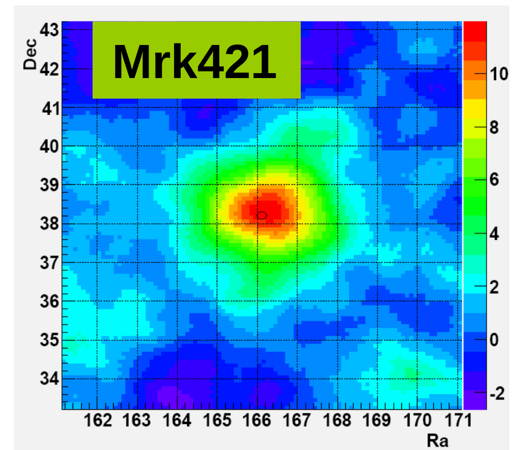
γ-astronomy

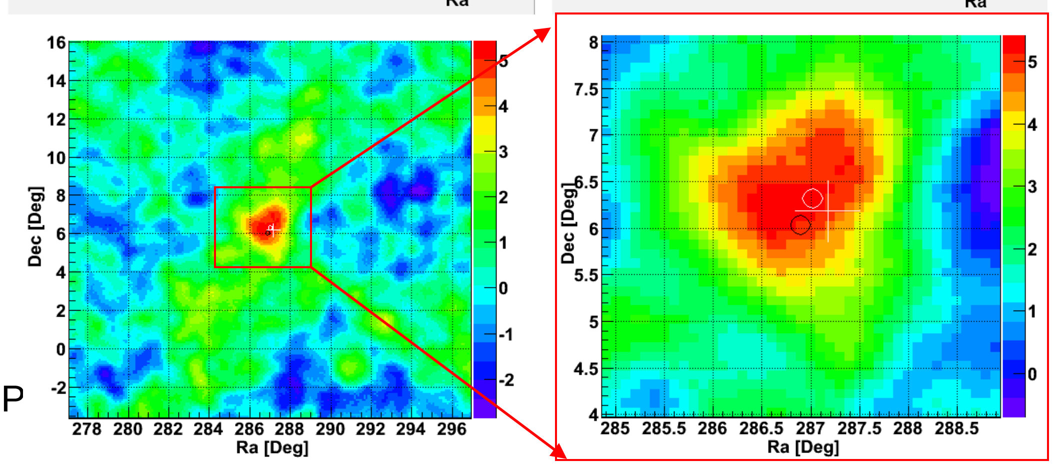
All sky survey result

- Method: Direct Integral method to estimate background.
- 3 sources with significance >5σ
- Crab 14.5 σ,Mrk421 11.9 σ, MGRO1908+06 5.4 σ

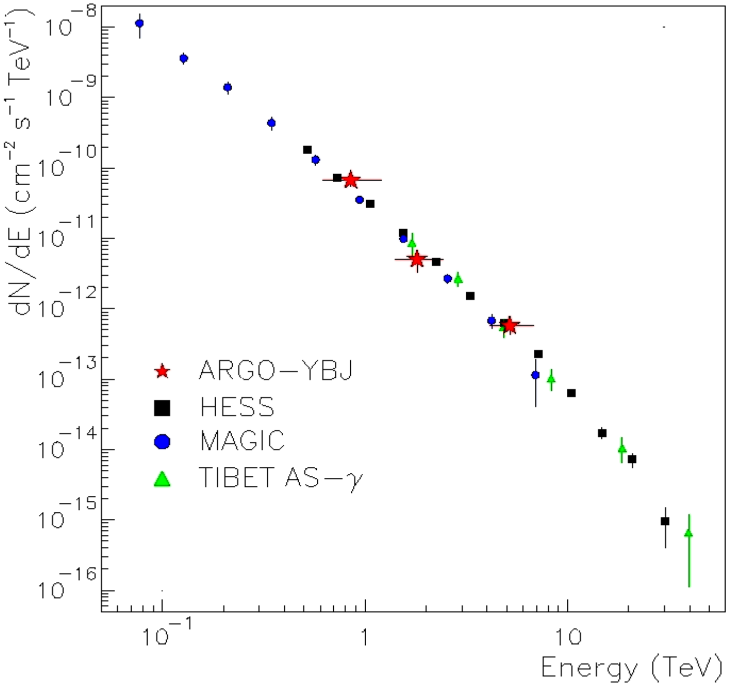


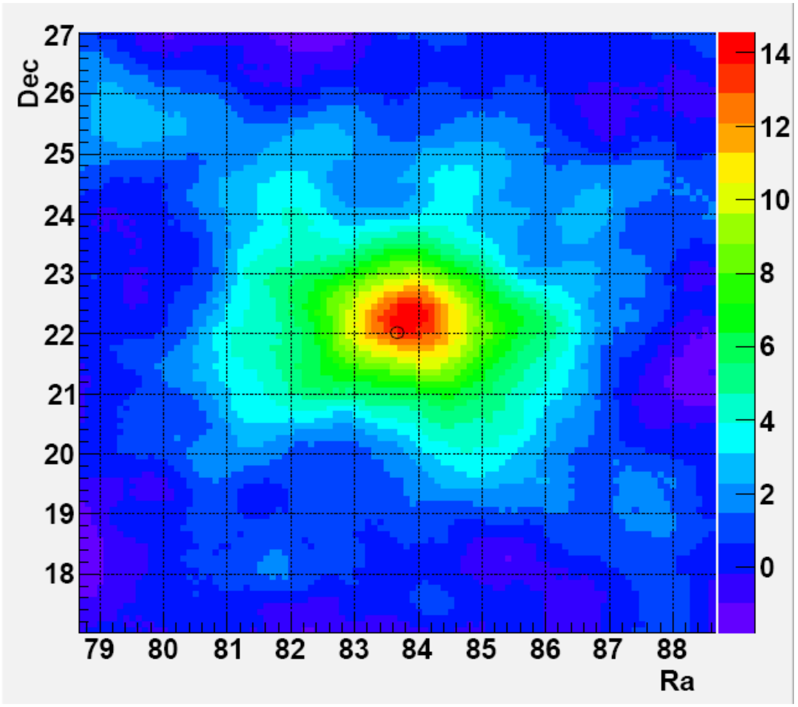






Crab Nebula





N_{PAD}	Events /day	E_{med} (TeV)
40 – 100	128 ± 24	0.85
100 –300	17.9 ± 6.3	1.8
> 300	9.2 ± 2.3	5.2

~14.5 s.d. in ~800 days

NO selection

NO γ/h discrimination

Absolute measurement

~50 % Crab/year

$$dN/dE = (3.73 \pm 0.80) \cdot 10^{-11} \cdot E^{-2.67 \pm 0.25} \text{ ev cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$$

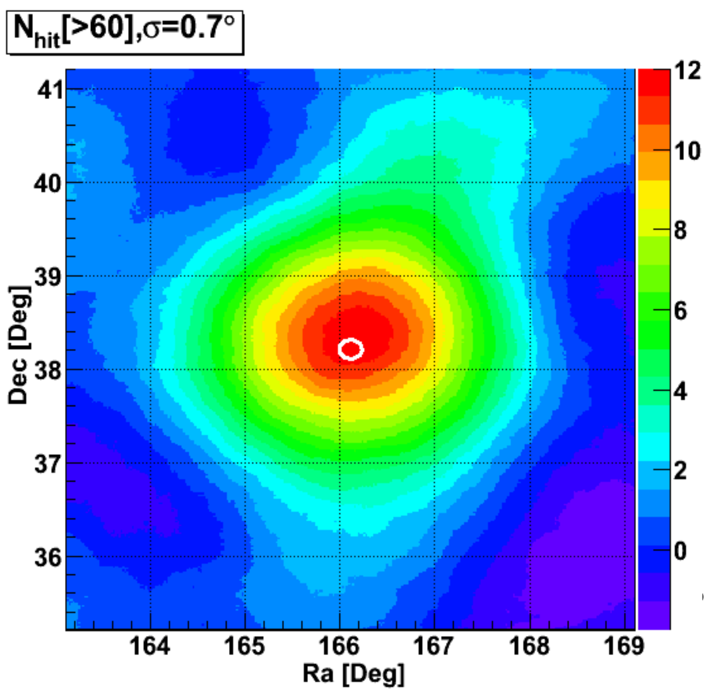
Mrk421

AGN monitored by ARGO-YBJ on a long time scale.

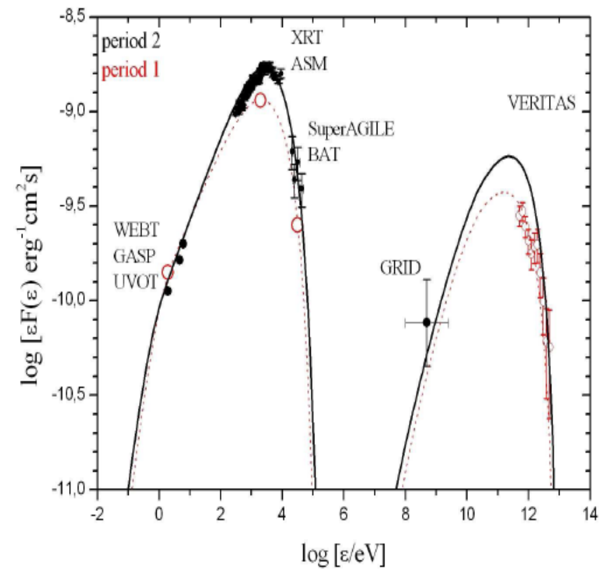
Several big flares have been observed :

1. June 2006
2. Oct. 2006
3. Feb.-Mar 2008
4. June 2008
5. June 2009
6. Feb 2010

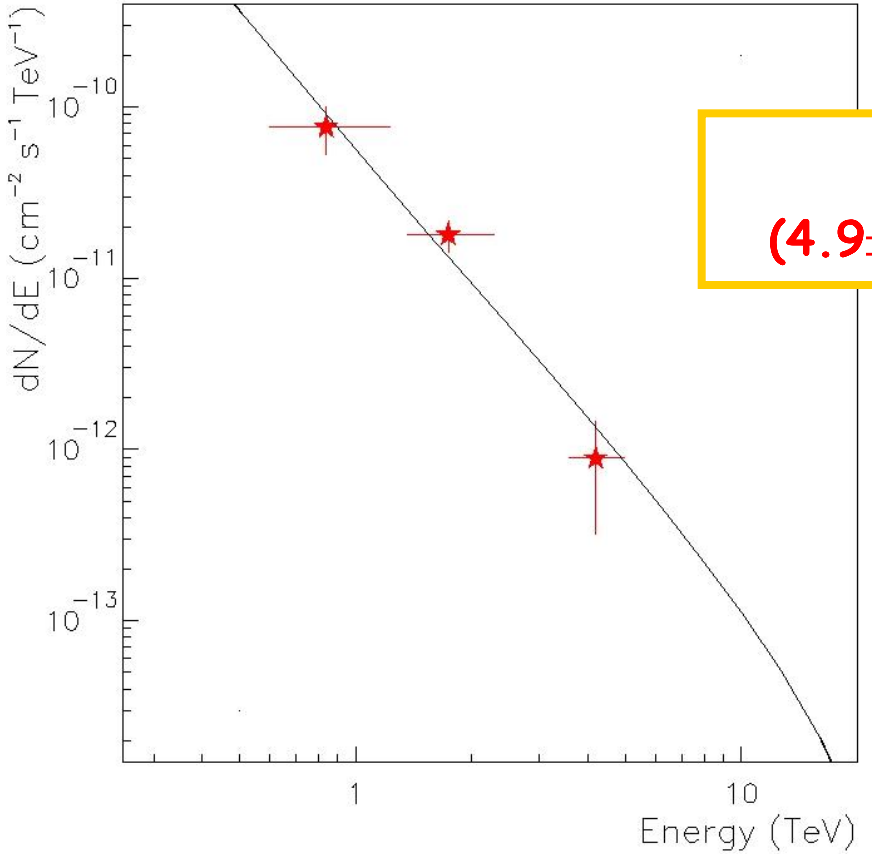
The total significance is 12σ. So, Mrk421 is the best candidate for ARGO-YBJ to study the Blazar emission mechanism.



June 2008 flare



Mrk421 spectrum
days 41 – 180, 2008



Integral flux (E > 1 TeV) :

$(4.9 \pm 2.0) \times 10^{-11}$ cm^{-2} s^{-1} ≈ 2 Crab units

Raue, M. & Mazin, D. 2008, Int. J. Mod. Phys. D 17, 1515

Spectrum + EBL absorption

$$dN/dE = (7.5 \pm 1.7) \times 10^{-11} E^{-2.51 \pm 0.29} e^{-\tau(E)} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$$

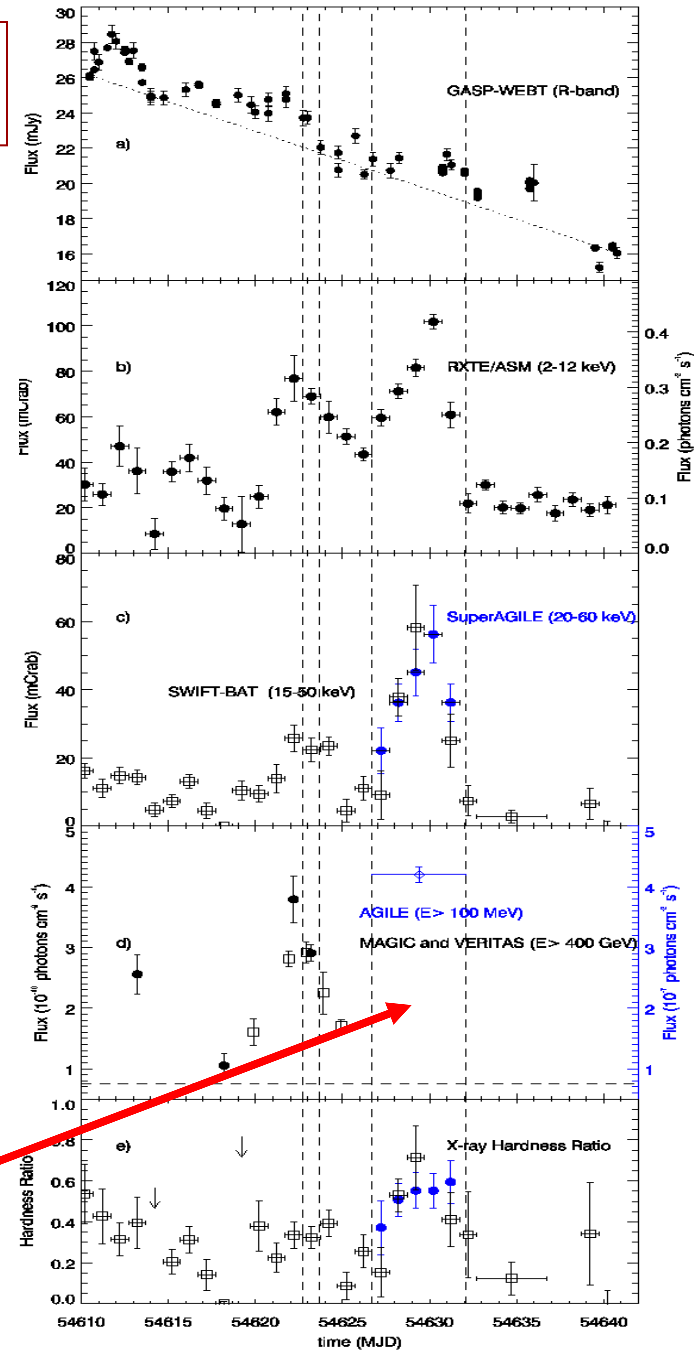
Mrk421: June 2008 flares

Observed from optical to TeV energies

Donnarumma et al. ApJ 691 (2009) L13, data from:

- **GASP-WEBT** (R-band; May 24-June 23)
- **SWIFT** (UVOT & XRT; June 12-13)
- **AGILE** (E > 100 MeV; June 9-15)
- **MAGIC and VERITAS** (E > 400 GeV; May 27-June 8)

complemented by public data by RossiXTE/ASM (2-12 keV) and Swift/BAT (15-50 keV)

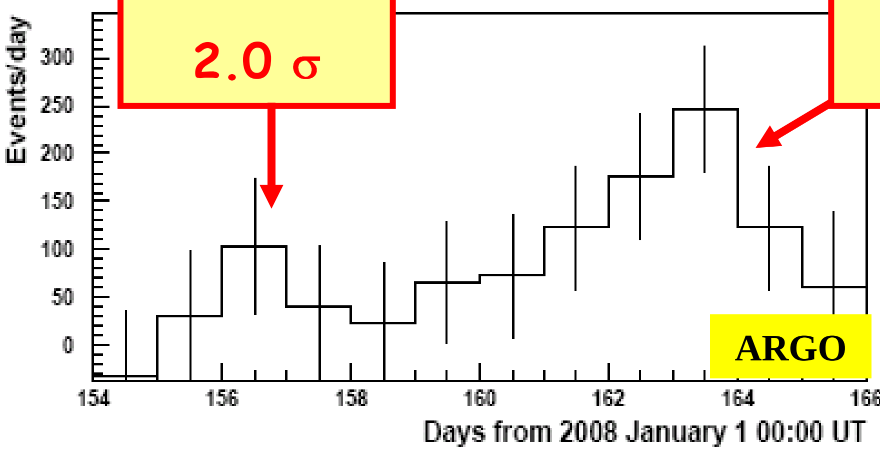


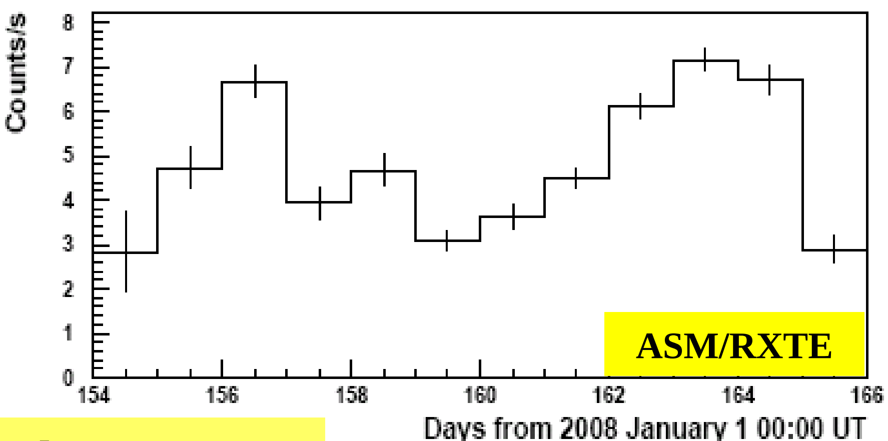
No VHE Cerenkov data after June 8

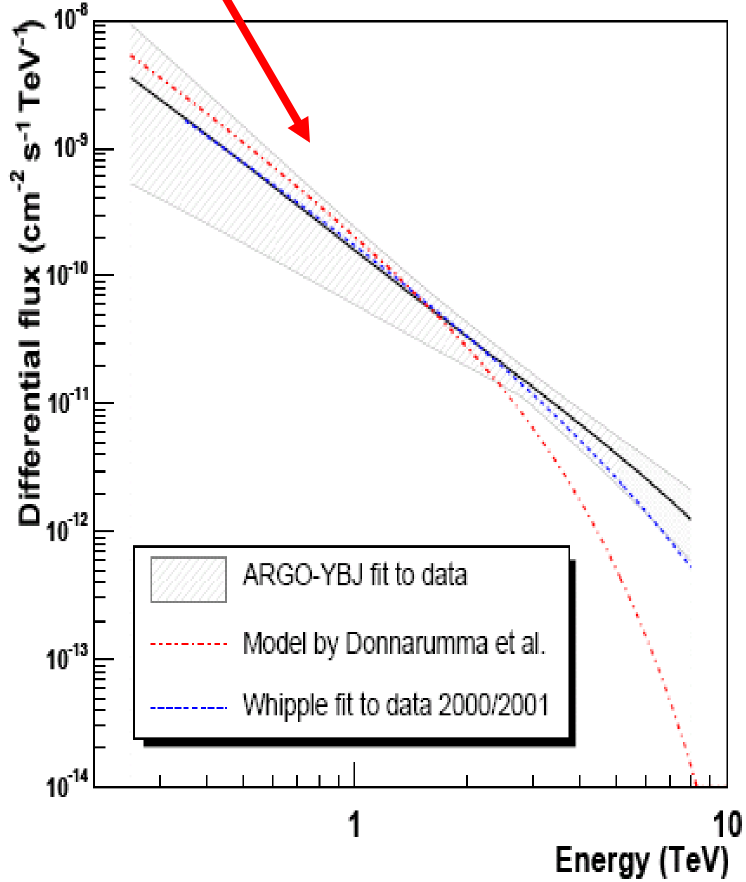
Mrk421: 2008 emission

June 5-7
2.0 σ

June 11-13
3.8 σ







10 days average

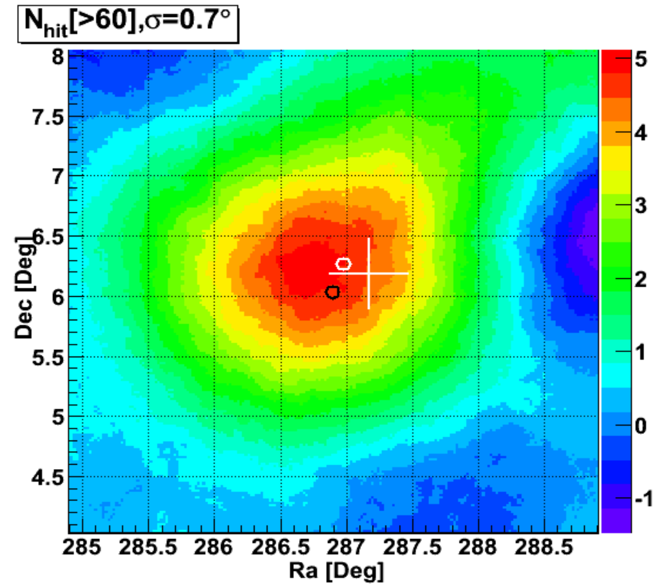
$N_{PAD} > 100$

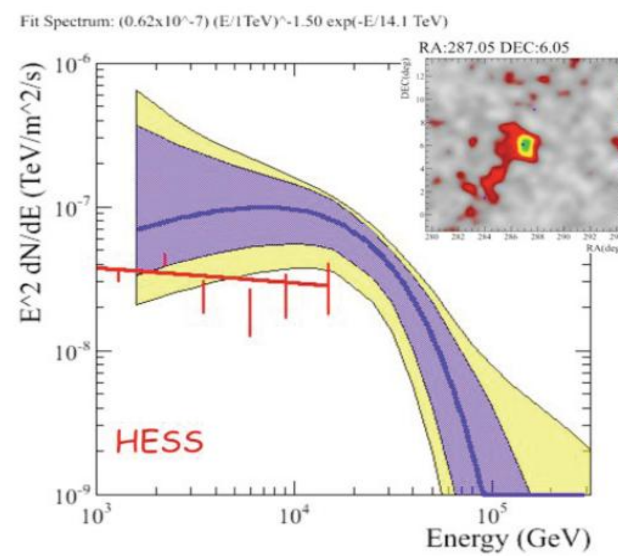
MGRO1908+06

- Discovered by Milagro, confirmed by HESS and VERITAS.
- Associated to the LAT pulsar with nebula PSR J1907.5+0602

- First Milagro result: compatible with point-like and extended source
- HESS result: shows that intrinsic extension is 0.34 deg and its spectral index is -2.1 up to 20TeV without cutoff.
- But, Milagro result shows a spectrum cutoff at about 14 TeV and a flux higher than HESS result.
- ARGO-YBJ measurement about this source very important.
- A detailed systematic analysis aiming better understanding of spectra

  between experiments is undergoing .





Conclusions

- ✓ ARGO-YBJ detector (central carpet + guard ring) is taking data since November 2007 (duty-cycle > 90%, 3.6 kHz rate)

- ✓ First results on Cosmic Rays (p-p cross section, anisotropies, limit on antiproton flux …)

- ✓ First results on γ-astronomy (mainly 2-year data)
  - angular resolution as expected (Moon shadow)
  - Crab Nebula γ-spectrum in agreement with other measurements
  - continuous monitor of Markarian 421, flares observed in 2006, 2008, 2009 and 2010 VHE γ-flux correlated with x-emission
  - MGRO sources survey

- ✓ Studies to increase the sensitivity are in progress (data quality, γ-hadron separation)