Gamma-ray astronomy and cosmic-ray physics with the ARGO-YBJ experiment

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The ARGO-YBJ Collaboration

International Collaboration:

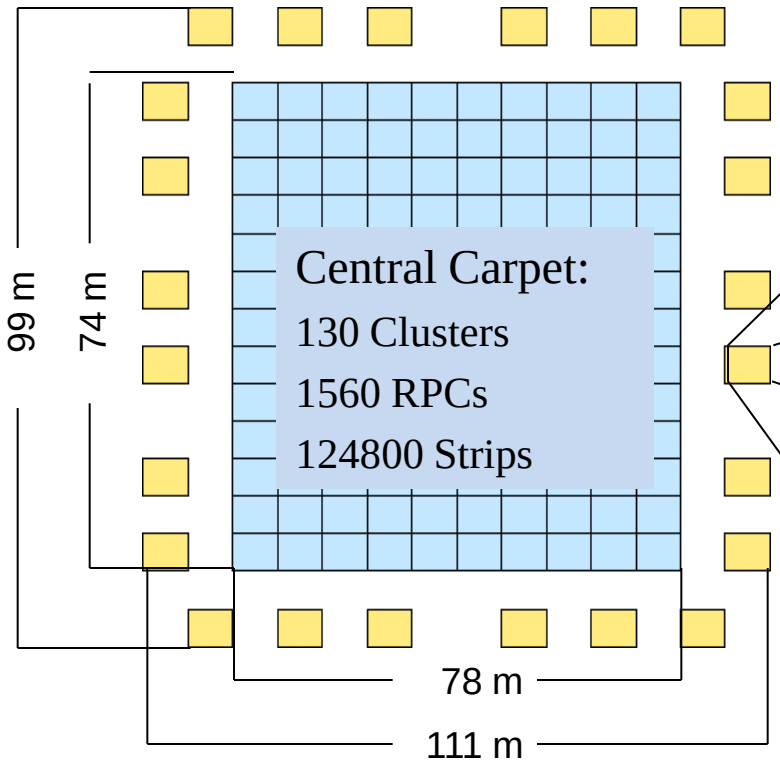
- ✓ **Chinese Academy of Science (CAS)**
- ✓ **Istituto Nazionale di Fisica Nucleare (INFN)**

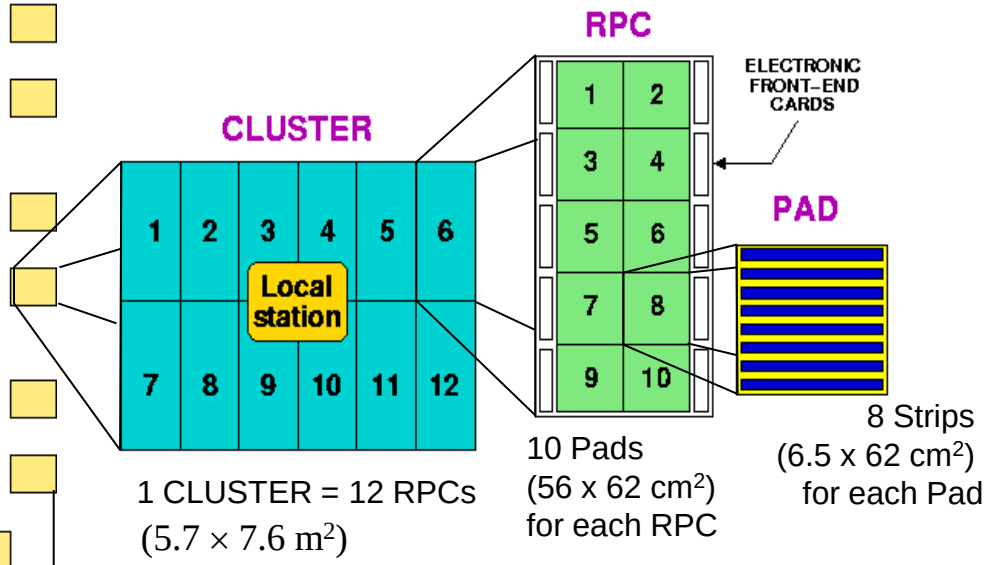
INFN and Dpt. di Fisica Università, Lecce
INFN and Dpt. di Fisica Universita', Napoli
INFN and Dpt. di Fisica Universita', Pavia
INFN and Dpt di Fisica Università "Roma Tre", Roma
INFN and Dpt. di Fisica Univesità "Tor Vergata", Roma
INAF/IFSI and INFN, Torino
INAF/IASF, Palermo and INFN, Catania

IHEP, Beijing
Shandong University, Jinan
South West Jiaotong University, Chengdu
Tibet University, Lhasa
Yunnan University, Kunming
ZhengZhou University, ZhengZhou
Hong Kong University, Hong Kong

Experimental Hall & Detector Layout

time resolution ~1-2 ns (pad)
space resolution = strip





Gas Mixture: Ar/ Iso/TFE = 15/10/75

HV = 7200 V

Single layer of Resistive Plate Chambers (RPCs)
with a full coverage (92% active surface) of a large area (5600 m²)
+ sampling guard ring (6700 m² in total)

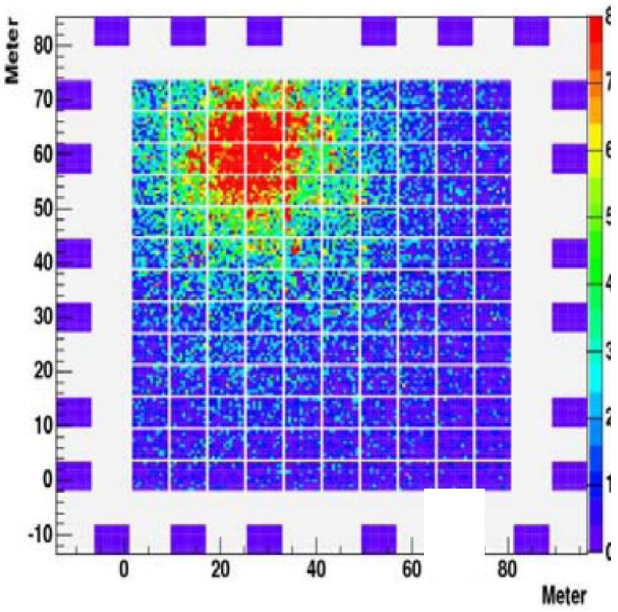
The basic concepts

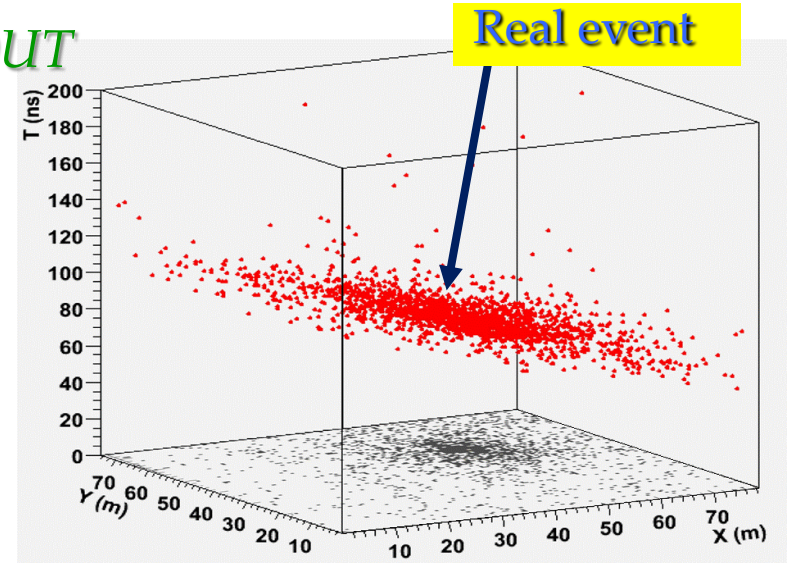
…for an unconventional air shower detector

- *HIGH ALTITUDE SITE*
  (YBJ - Tibet, 4300 m a.s.l, ~ 600 g/cm^2)

- *FULL COVERAGE*
  (RPC technology, 92% covering factor)

- *HIGH SEGMENTATION OF THE READOUT*
  (small space-time pixels)
  Space pixels: 146,880 strips (7×62 cm^2)
  Time pixels: 18,360 pads (56×62 cm^2)





… in order to:

- image the shower front
- get a energy threshold of a few hundreds of GeV

The Moon Shadow technique

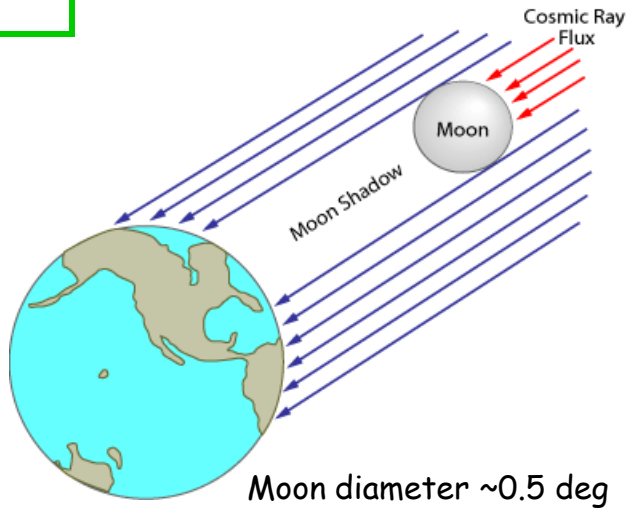
Cosmic rays are blocked by the Moon → Deficit of cosmic rays in the direction of the Moon

- Size of the deficit → Angular Resolution
- Position of the deficit → Pointing Error

Geomagnetic Field: positively charged particles are deflected towards the West.

→ Ion spectrometer

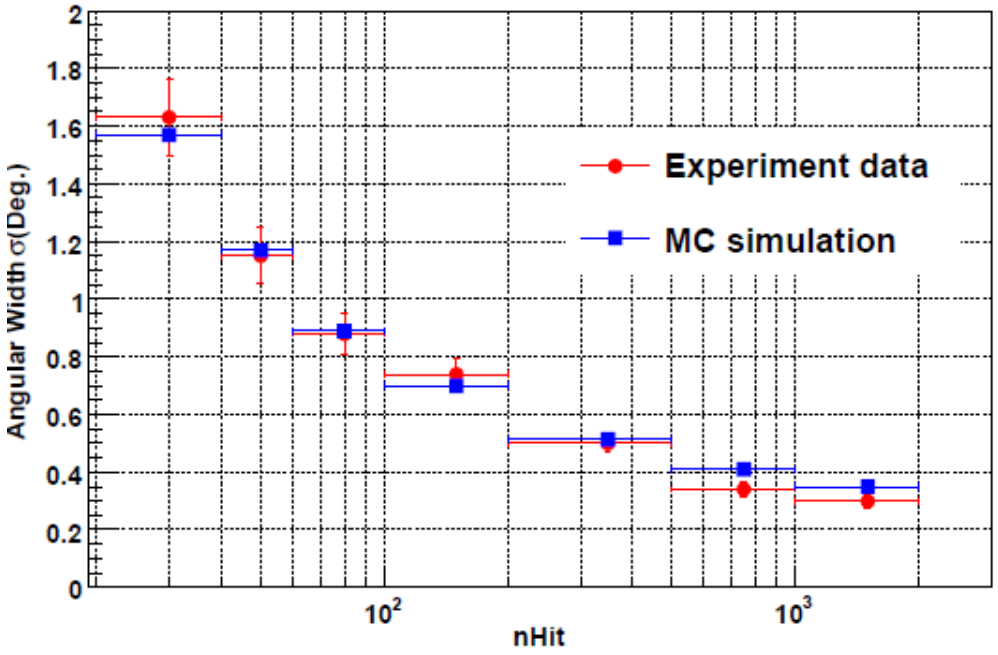
$$\Delta\alpha \approx \frac{1.6^0 \cdot Z}{E(TeV)}$$



The observation of the Moon shadow may provide a direct check of the relation between size and primary energy

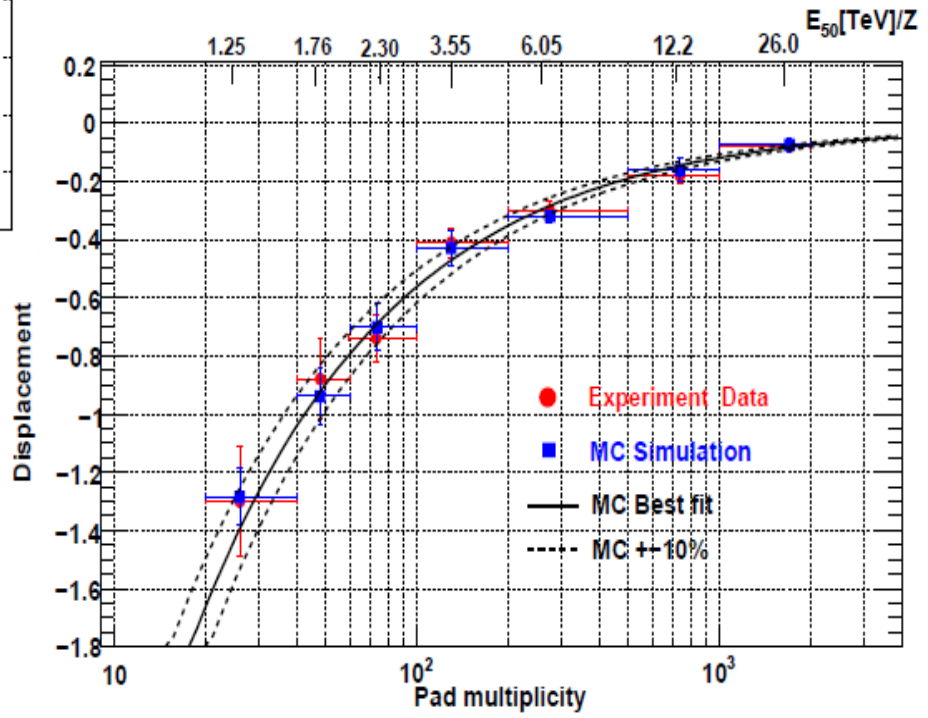
- West displacement → Energy calibration

Moon Shadow analysis



Measured angular resolution

$$\Delta\alpha = -12.58^{o} \cdot N^{-0.68}$$



Measured EW displacement

Relation multiplicity – primary energy

Proton-air cross section measurement

Use the shower frequency vs (secθ -1)

$$I(\theta) = I(0) \cdot e^{-\frac{h_o}{\Lambda}(\sec\theta - 1)}$$

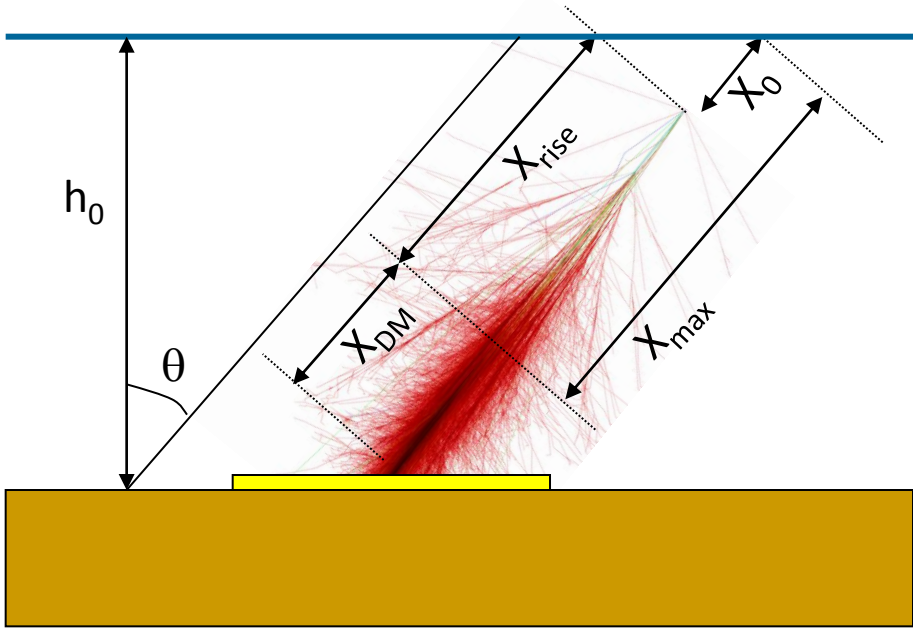
for fixed energy and shower age.

The lenght Λ is not the p interaction lenght mainly because of collision inelasticity, shower fluctuations and detector resolution.

It has been shown that $\Lambda = k\,\lambda_{int}$, where k is determined by simulations and depends on:

- **hadronic interactions**
- **detector features and location (atm. depth)**
- **actual set of experimental observables**
- **analysis cuts**
- **energy, ...**

Then: **$\sigma_{p\text{-}Air}$ (mb) = 2.4 10^4 / λ_{int}(g/cm^2)**



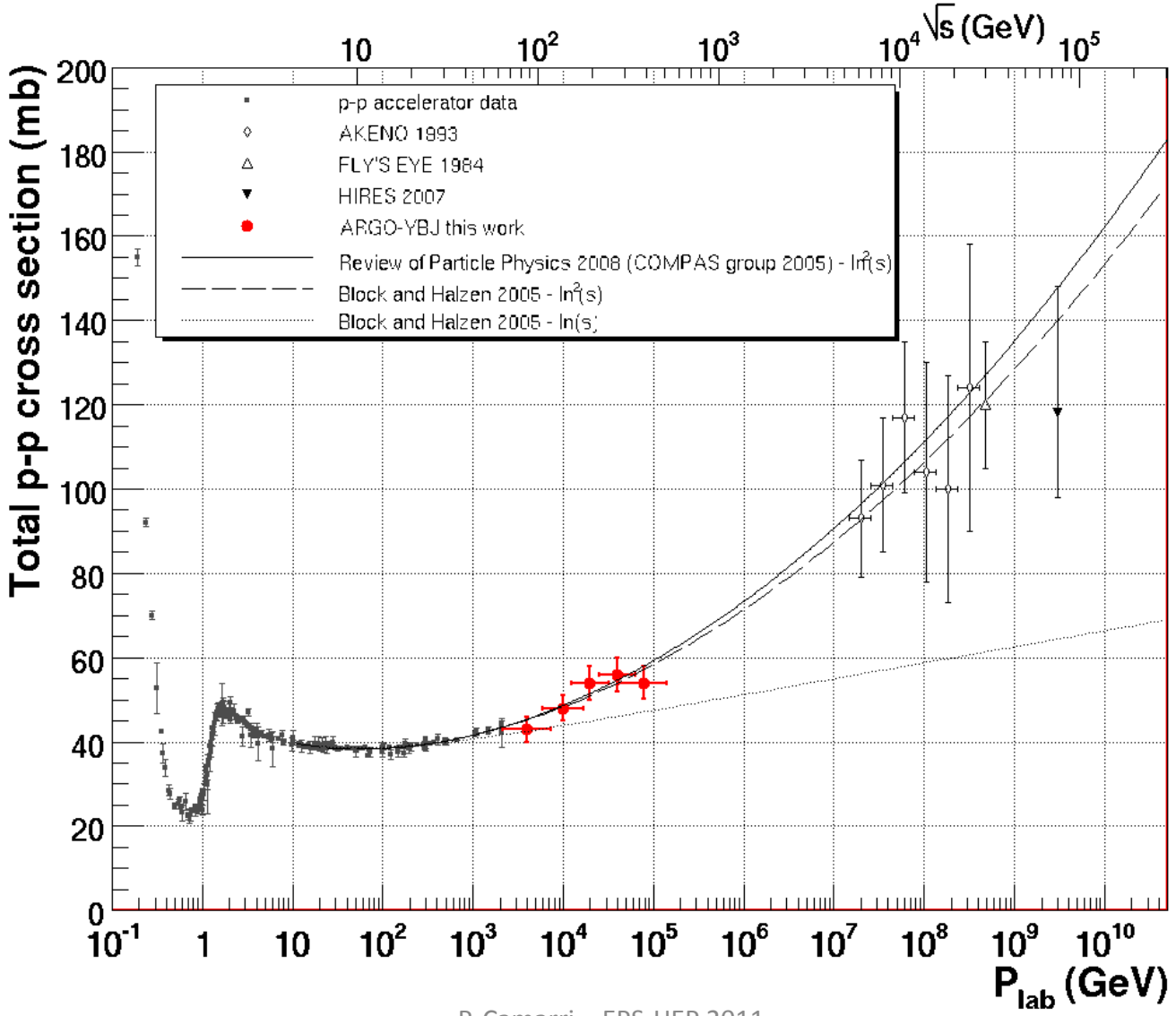
Take care of shower fluctuations

- **Constrain** $X_{DO} = X_{det} - X_0$ or

  $X_{DM} = X_{det} - X_{max}$

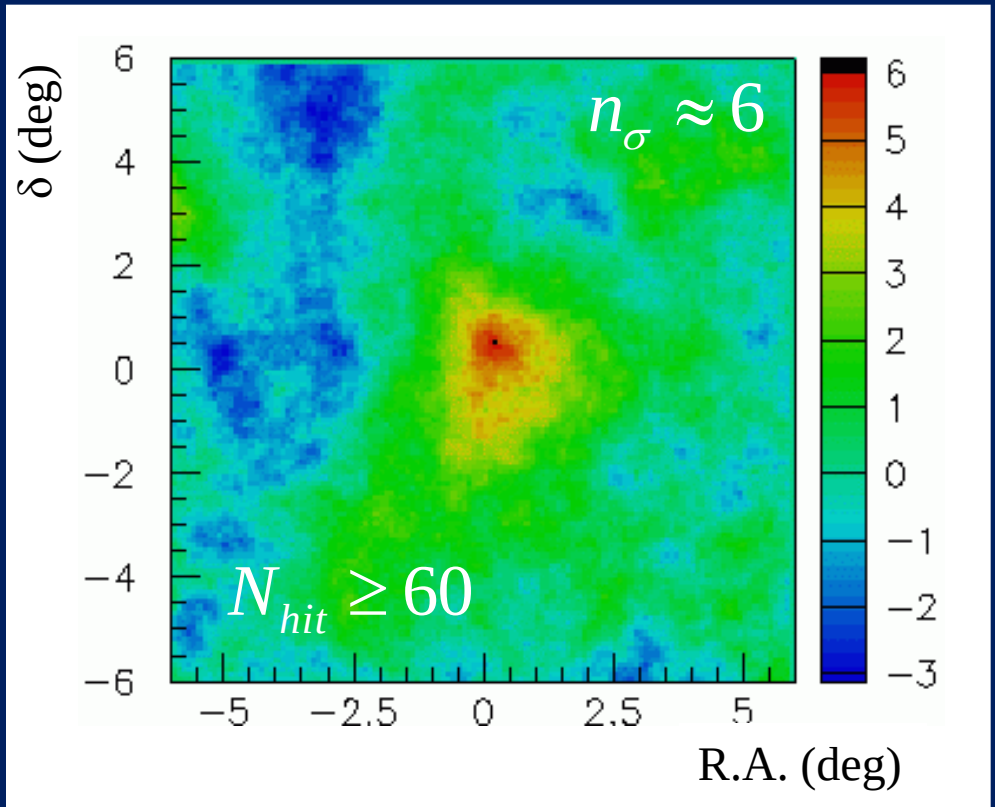
- **Select** deep showers (large X_{max}, i.e. small X_{DM})
- **Exploit** detector features (space-time pattern) and location (depth).

Phys. Rev. D 80, 092004 (2009)



Markarian 421
first source observed by ARGO-YBJ

July-August 2006 flare



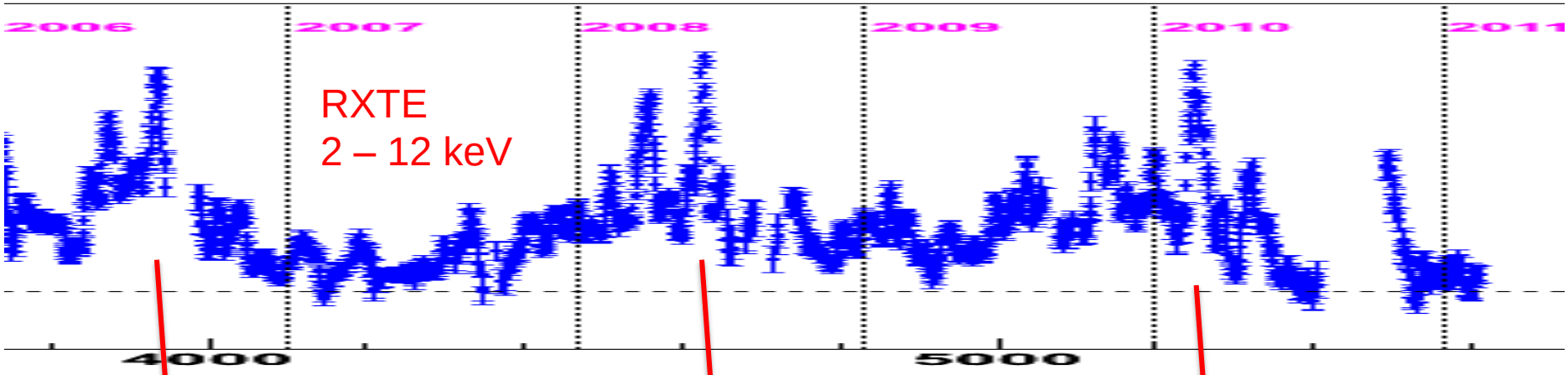
2006, days 187-245
(110 hours)

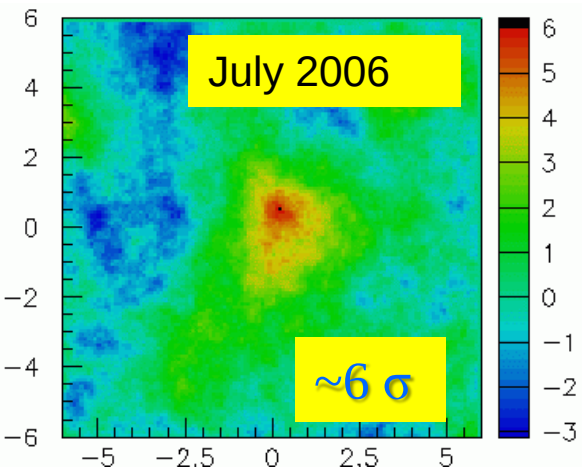
data collected during the commissioning

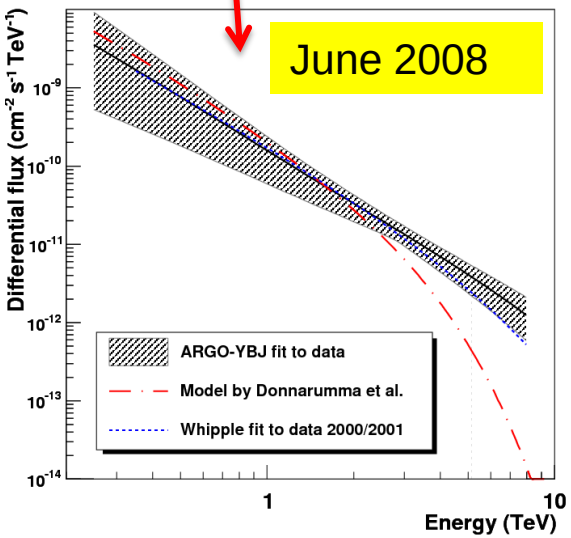
Flux ≈ 4 Crab units

NO Cherenkov measurements available at that time

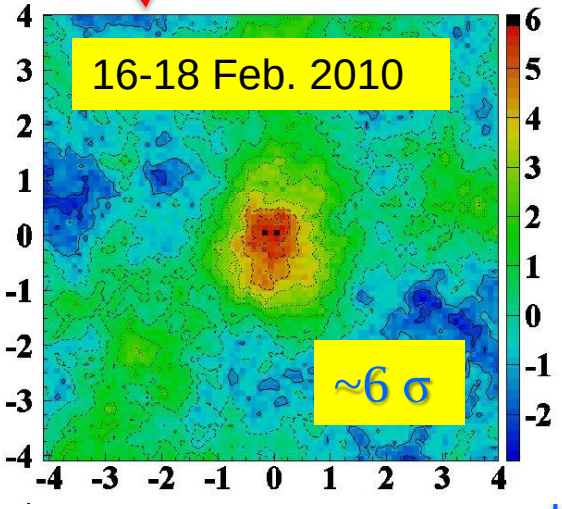
Mrk421: X-ray / TeV flares







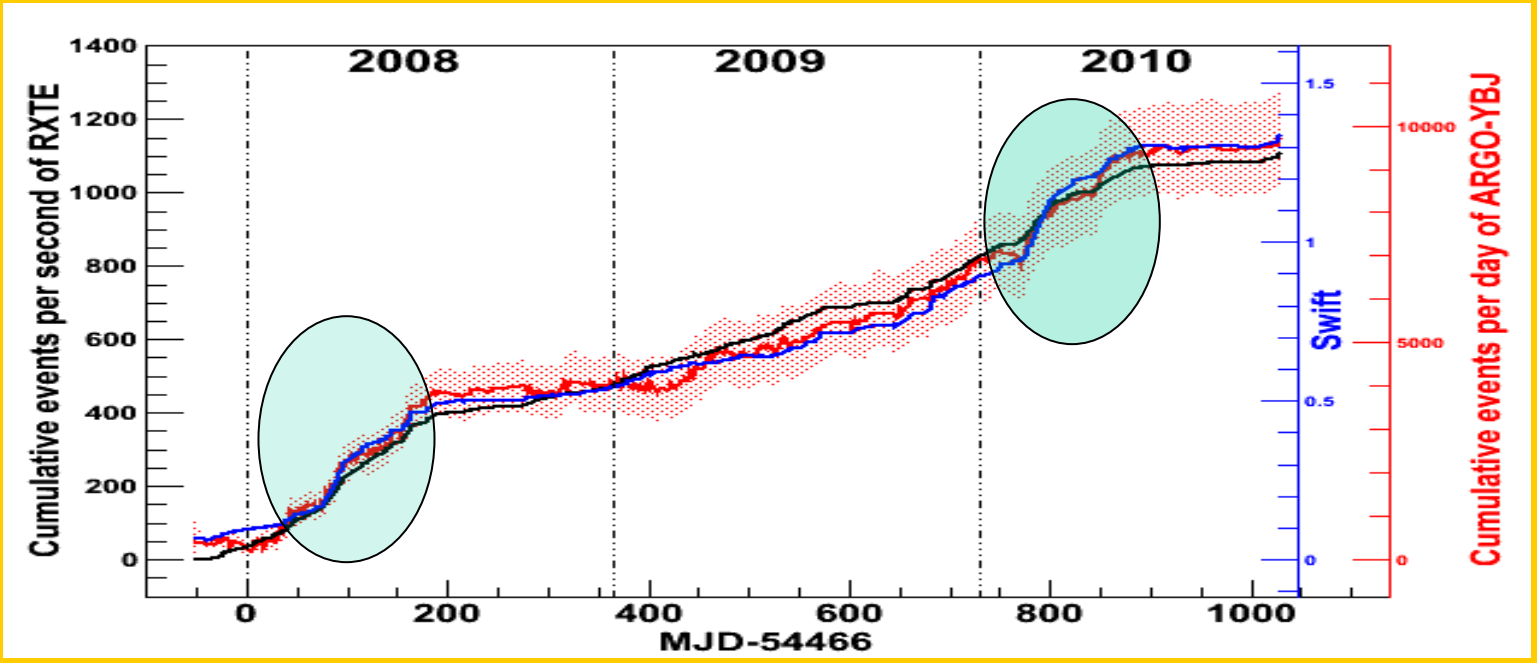
G. Aielli et al, ApJL 714 (2010) L208



Mrk421 long-term monitoring

- ARGO-YBJ cumulative light curve (>TeV) compared with Swift and Rossi/RXTE data.
- Good correlation between TeV/X-ray data.
- Active and quite periods are observed.

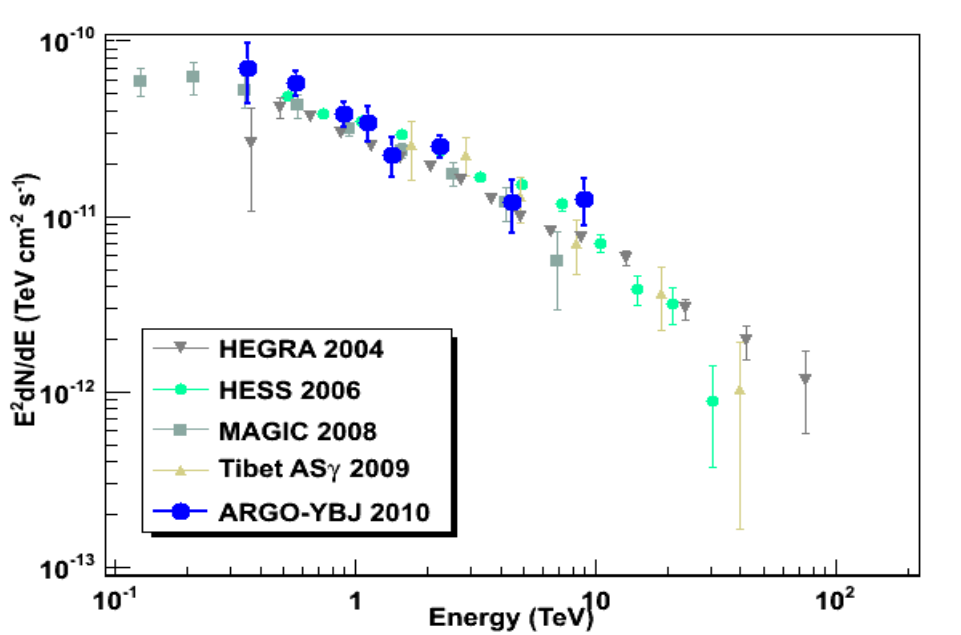
RXTE/ASM 2-12 keV
Swift/BAT 15-50 keV
ARGO-YBJ TeV

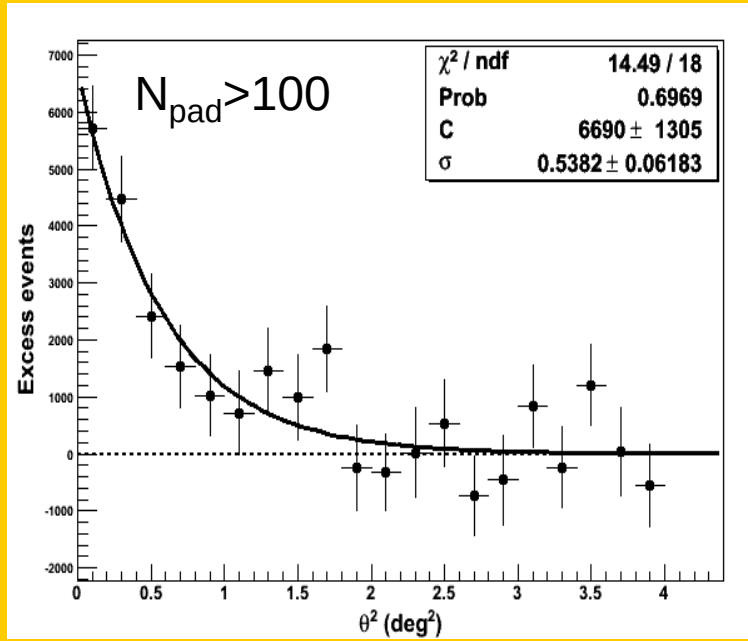


Crab Nebula

- Energy spectrum (0.3 – 10) TeV in agreement with other experiments.
- Measured PSF in agreement with MC.

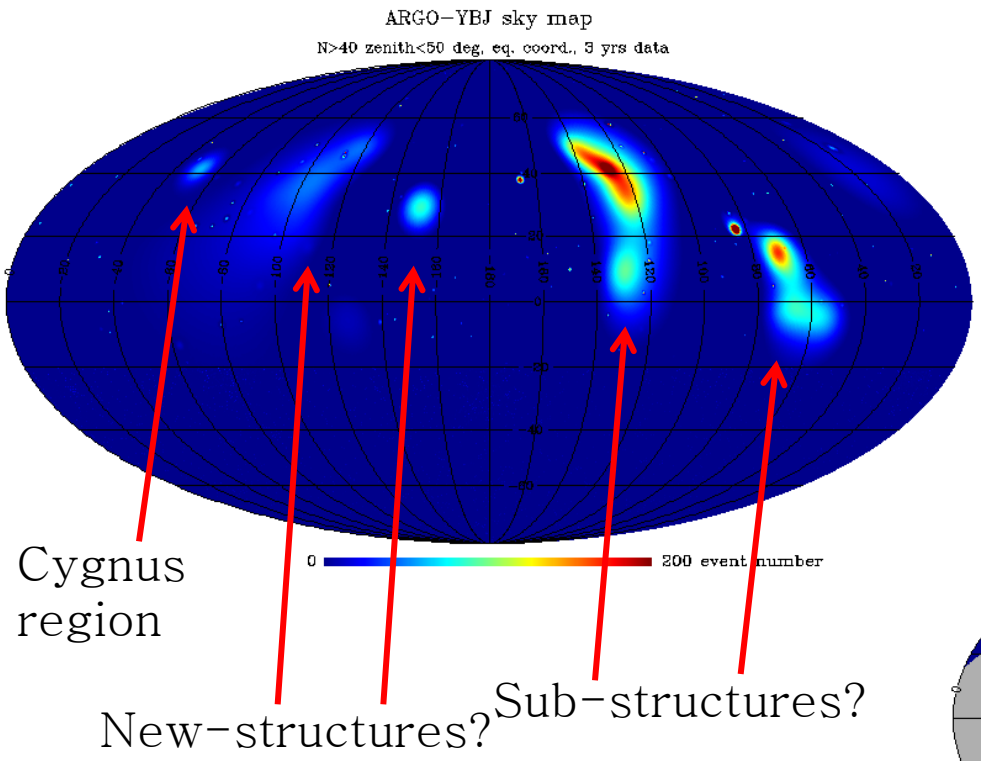
$$\frac{dN}{dE} = (3.67 \pm 0.39_{stat} \pm 0.73_{sys}) \times 10^{-11} \left(\frac{E}{1\,TeV}\right)^{(-2.61 \pm 0.11_{stat} \pm 0.20_{sys})} \; cm^{-2}\, s^{-1}\, TeV^{-1}$$





Intermediate scale CR anisotropies

Focus on >4 s.d. significant regions

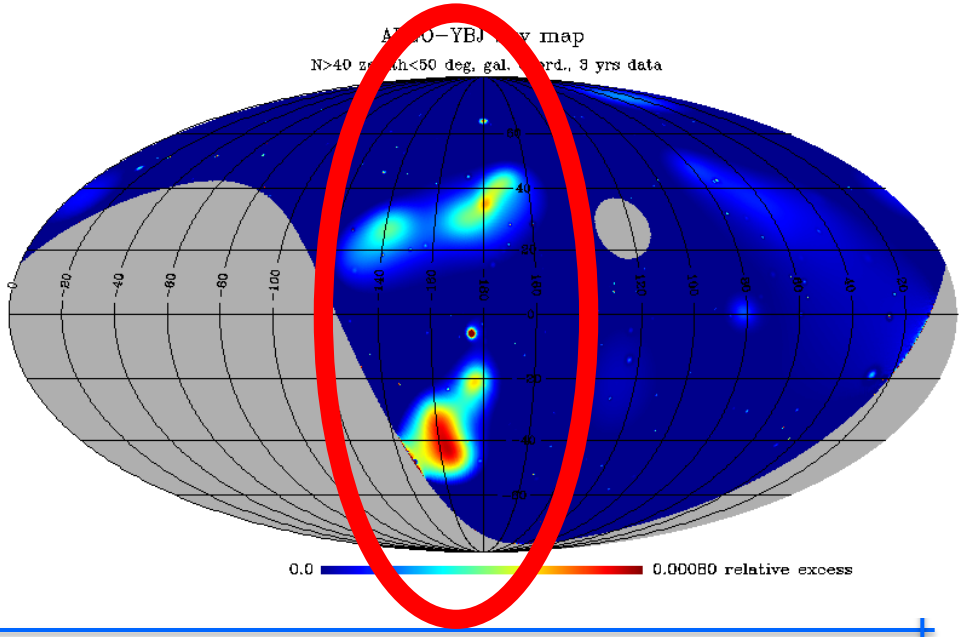


Zenith angle < 50°

3 years data ~2.2 10^{11} events

Median energy 1 TeV

GALACTIC ANTI-CENTER



Background: direct integration method (2 hours intervals)

Equatorial coordinates:
projection of the earth longitude and latitude

Conclusions

- ARGO-YBJ has been running uninterruptedly for over 3 and a half years with its complete layout.
- The results in cosmic-ray physics are going to be the most accurate so far between ~ 1 TeV and ~ 100 TeV, and specifically:
  - Moon shadow and $\bar{p}$-p ratio
  - **p – p cross section at c.m. energies not directly obtained at colliders**
  - **Anisotropy of galactic cosmic rays, with unprecedented and unexpected results**
  - IMF studies
- Gamma-ray astronomy
  - The experiment is monitoring the Northern sky with a sensitivity of ≈ 50 % Crab flux / year.
  - **Measurement of the Crab gamma-ray spectrum down to ~300 GeV, unprecedented results for a ground-based experiment**
  - **Evidence for TeV Crab flaring activity is observed: long-term monitoring under study**
  - A 3-year Mrk421 TeV/X-ray correlation study is in press on ApJ.