Astroparticle physics with the ARGO-YBJ experiment

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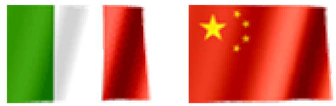
The ARGO-YBJ experiment

Collaboration between:



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

Site: YangBaJing Cosmic Ray Laboratory (Tibet, P.R. of China), 4300 m a.s.l.

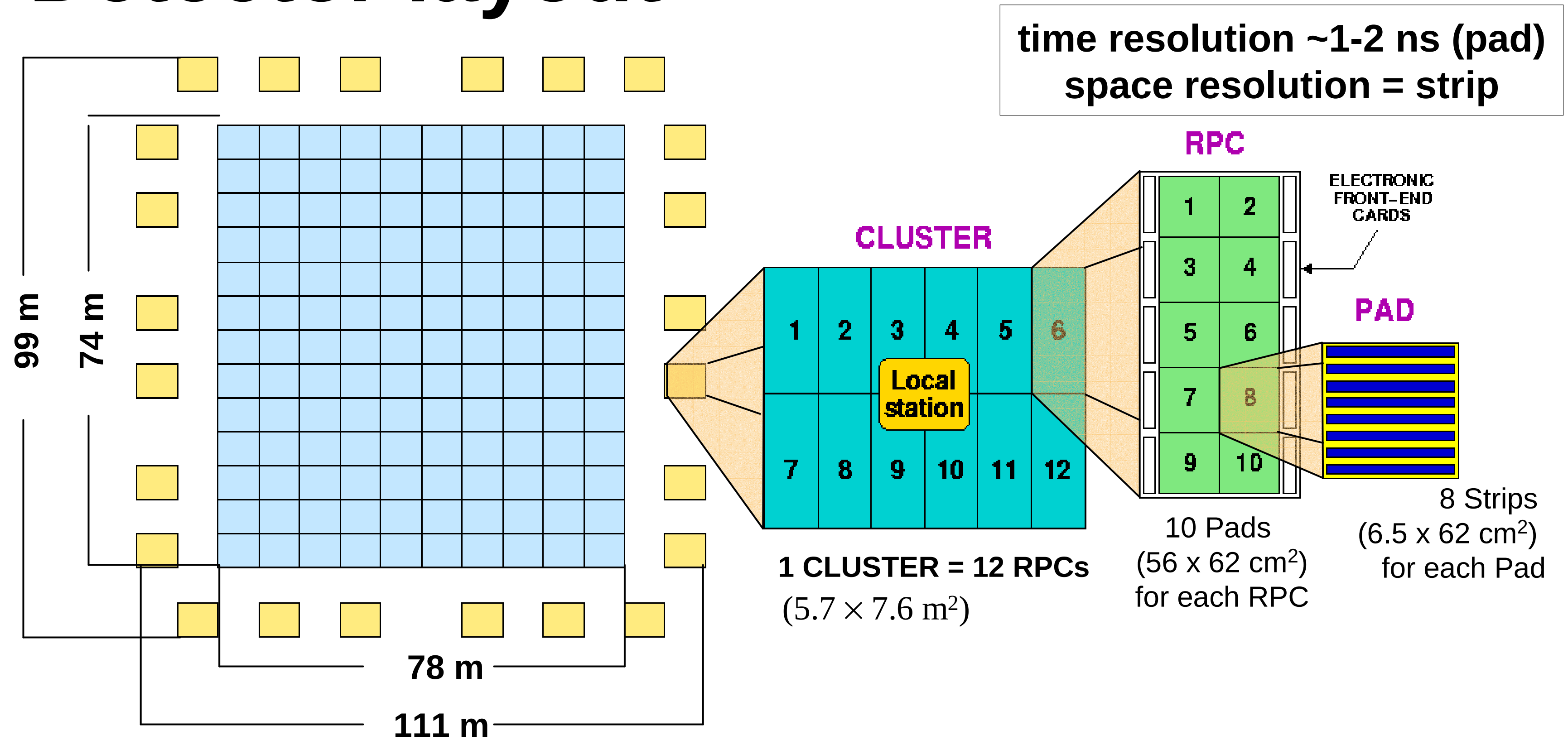
Site Coordinates: longitude 90°31' 50" E, latitude 30°06' 38" N

Physics Goals

- **γ-ray Astronomy**: search for Galactic and extragalactic point sources with a large field of view (~2 sr) and a duty cycle ~100%, at an energy threshold of a few hundreds of GeV
- **Diffuse γ-Rays** from the Galactic plane and SuperNova Remnants
- **Gamma Ray Burst (GRB) physics** in the full GeV – TeV energy range
- **Cosmic Ray physics**:
  - spectrum and composition up to ≈ 10^3 TeV
  - anti-p / p ratio at energy ≈ TeV
- **Sun and Heliosphere physics** with an energy threshold ≈ 10 GeV

through **the observation of *Extensive Air Showers (EASs)* produced in the atmosphere by γ-rays and primary nuclei**

Detector layout

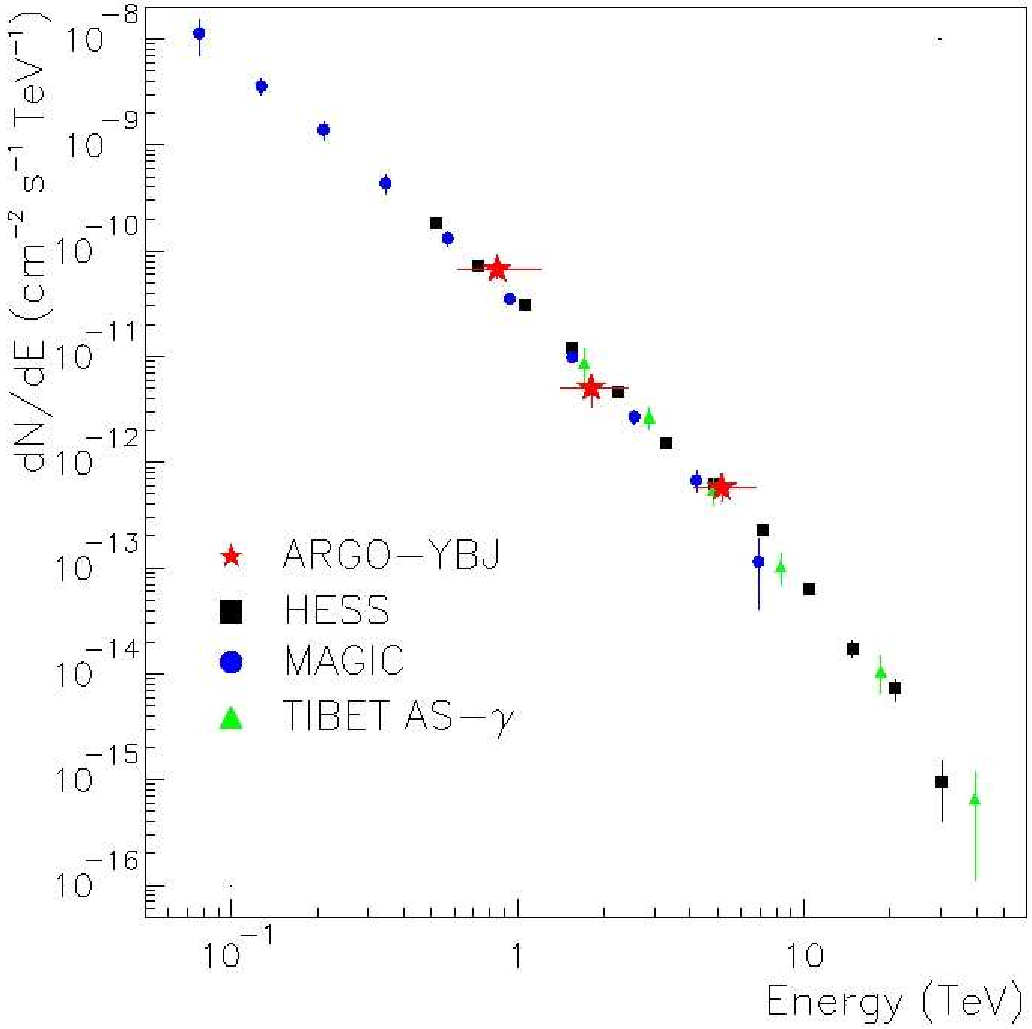


Single layer of Resistive Plate Chambers (RPCs)
with a full coverage (92% active surface) of a large area (5600 m^2)
+ sampling guard ring (6700 m^2 in total)

⇒ detection of small showers (low energy threshold)


Experiment Hall
CLUSTER
RPC

Crab energy spectrum

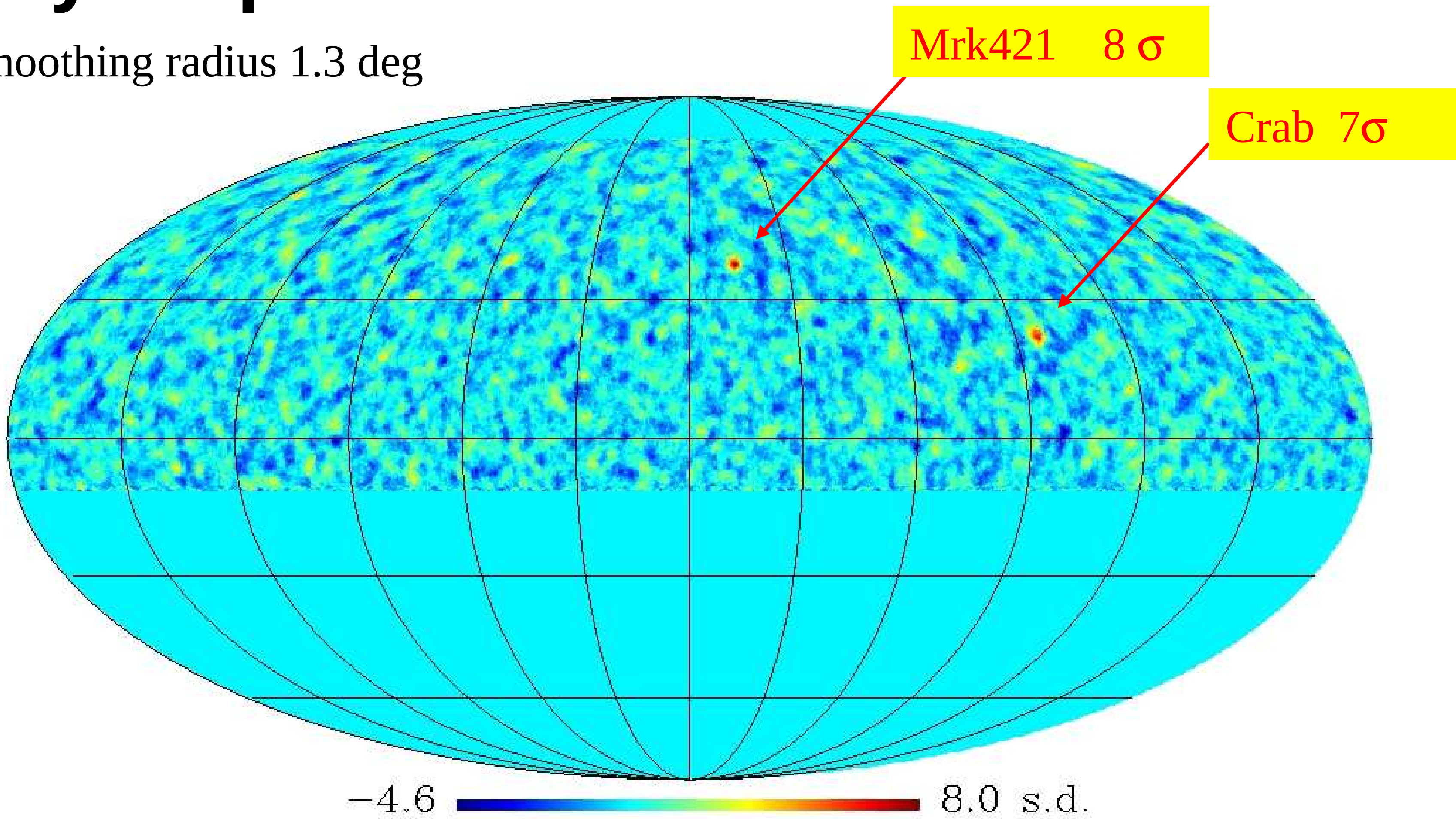


N $_{PAD}$	Events /day	E_{med} (TeV)
40 – 100	128 ± 24	0.85
100 – 300	17.9 ± 6.3	1.8
> 300	9.2 ± 2.3	5.2

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

Sky map

Smoothing radius 1.3 deg



$N_{PAD} > 40$

Gamma median energy ≈ 0.6-2 TeV

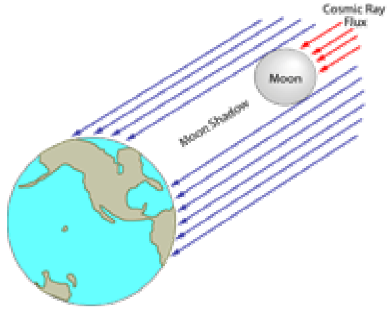
from 2007 day 311 to 2009 day 89

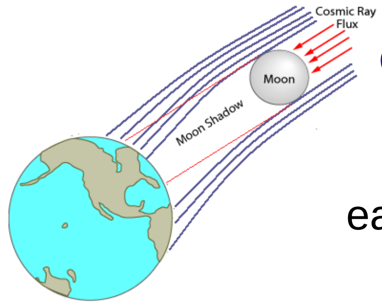
(424 equivalent days)

The Moon Shadow

The cosmic rays are hampered by the Moon

Deficit of cosmic rays in the direction of the Moon

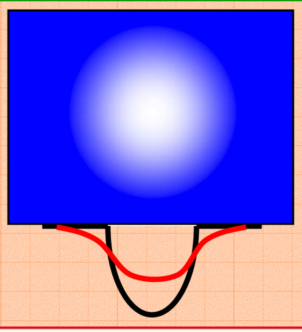




Geomagnetic Field: positively charged particles deflected eastward and negative ones westward.

Size of the deficit:

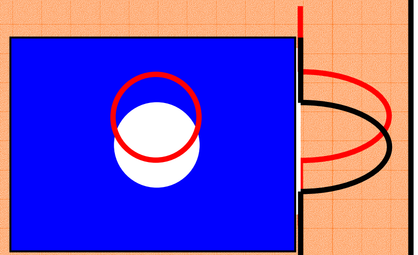
Angular Resolution



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

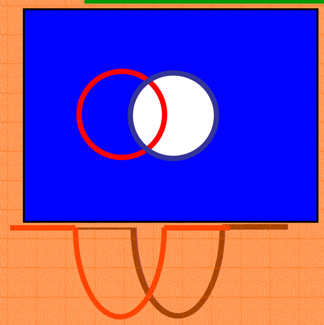
Position of the deficit:

Pointing Error



Displacement of the deficit:

Energy Calibration

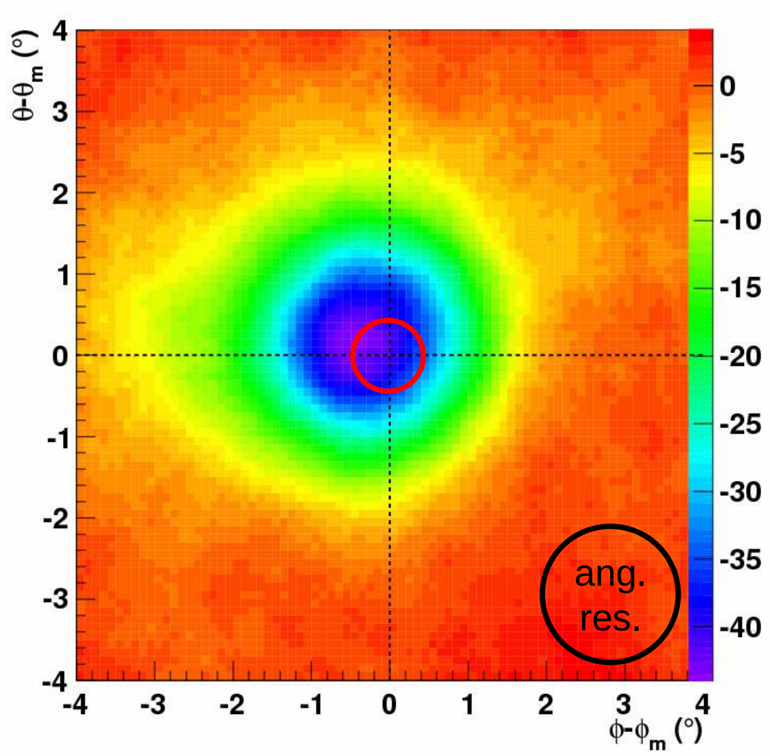


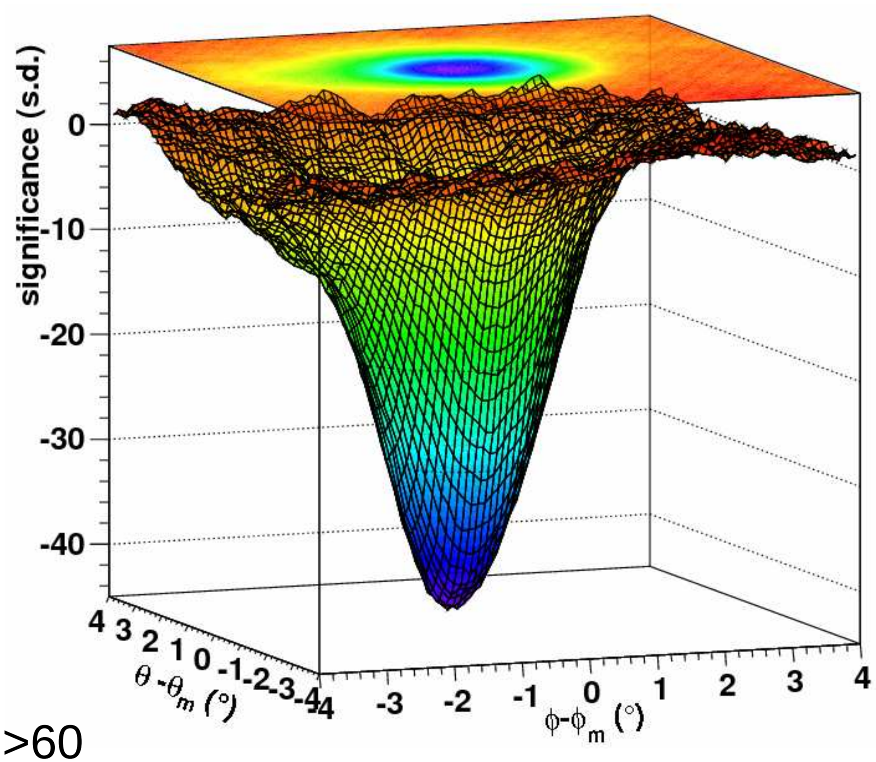
$$\Delta\vartheta \approx \frac{Z\,1.6^0}{E(TeV)}$$

ion spectrometer

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

All data: 2006 - 2008





N>60

The 3-dimensional surface is the convolution of the **P**oint **S**pread **F**unction of the detector and the widespread Moon disc.

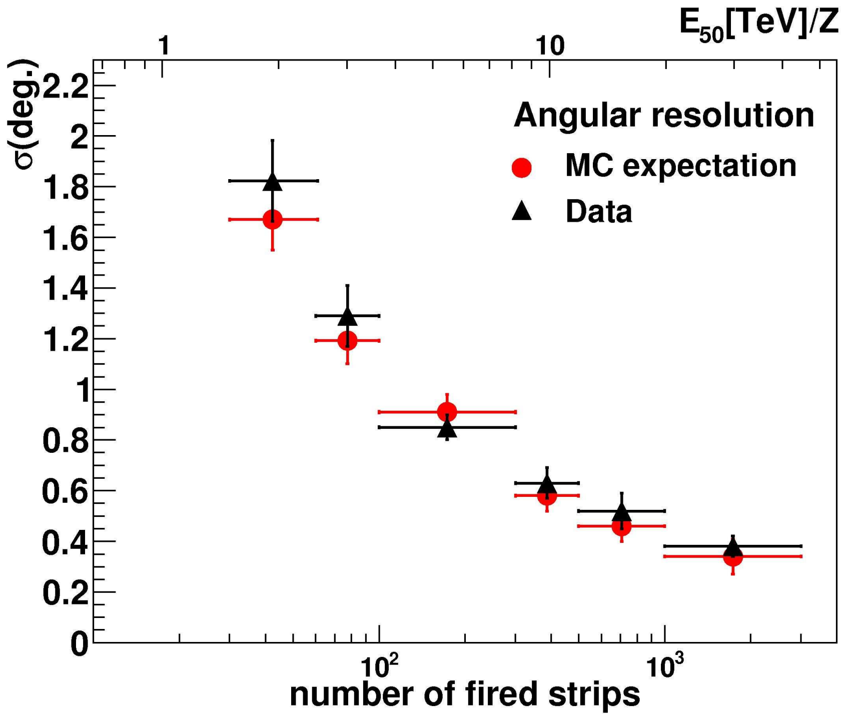
The period until autumn 2007 has been mainly devoted to installation and debugging operations, the duty-cycle being lower in that period.
STABLE DATA TAKING period: since December 2007

Data analysis: general features

Data acquisition time:	***13/12/2007 – 31/12/2008***
Trigger multiplicity threshold	***20*** ***~1 particle per 300 m^2***
Trigger rate	***~4 kHz*** ***1.3×10^{11} events analyzed***
Observation time (θ<50°) :	***1350 hrs***
Source visibility time (θ <50°):	***1500 hrs***
On-source duty-cycle:	***90%***
Reached significance (N>60):	***32 s.d.***

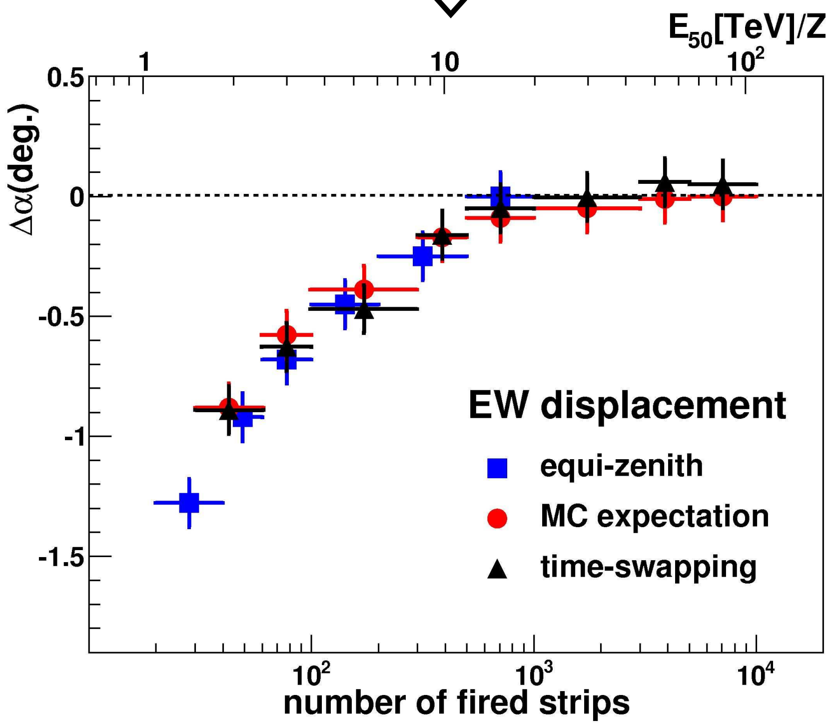
$$S \approx 0.88\sqrt{t[hrs]}$$

Moon Shadow analysis

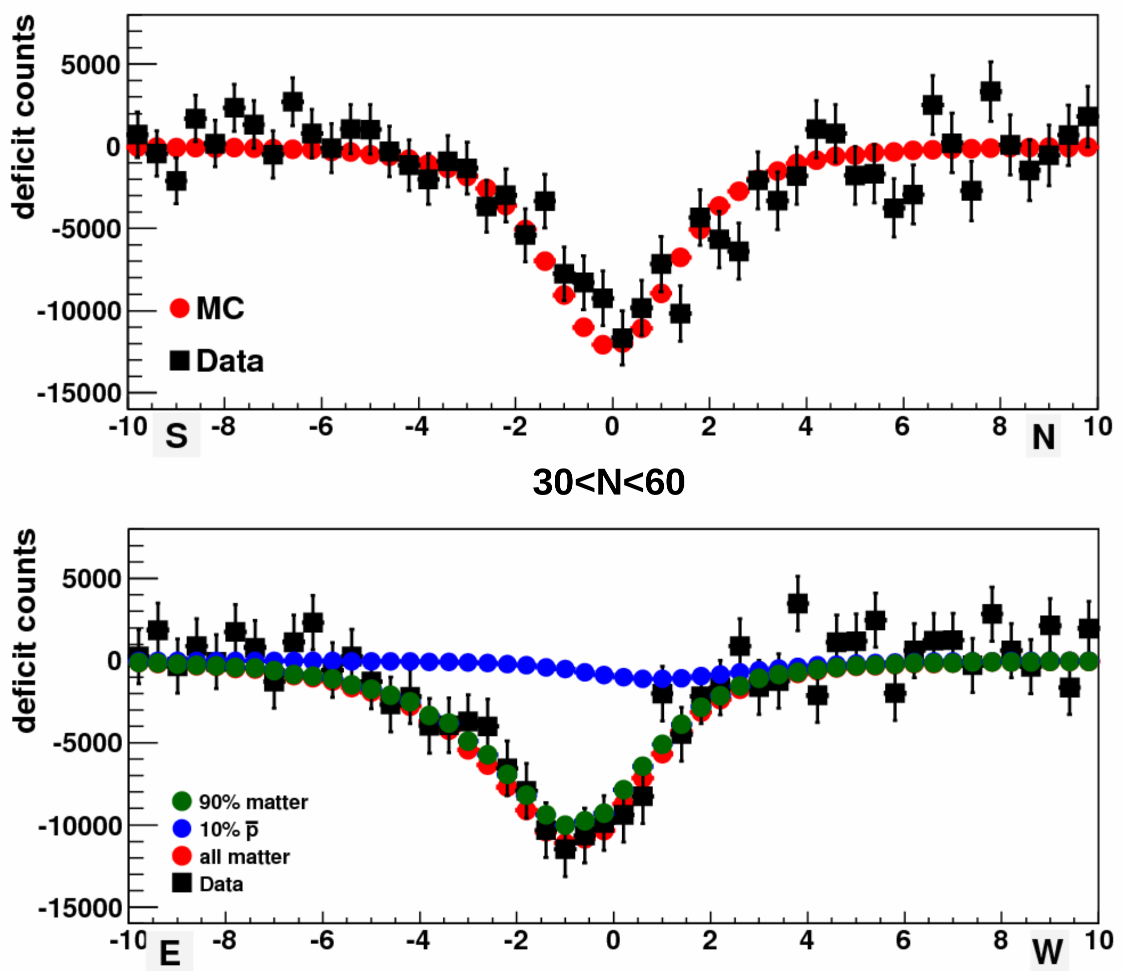


The angolar resolution is well reproduced by the MC simulation. The Moon Shadow is ***the easiest way to measure*** the PSF of the detector.

The shift toward west is well reproduced by the MC simulation: it allows to calibrate the relation size-energy



Data analysis:
the method to estimate the antiproton flux



Concerning the east-west displacement the agreement between the MC simulations and the data is very good. It points out the good choice of cthe composition (p=72%, rest 28% rescaled from WS-compilation) and the ***high reliability of the TIGRF magnetic model***.

They can be used to obtain a simulation of the antiproton contribution.

Data analysis: the *likelihood* method for the estimate of the upper limit 1/2

A fraction ***r*** of the simulated events is assumed to be antiprotons. In such a way, the number of events hampered by the Moon in a certain time remains unchanged.

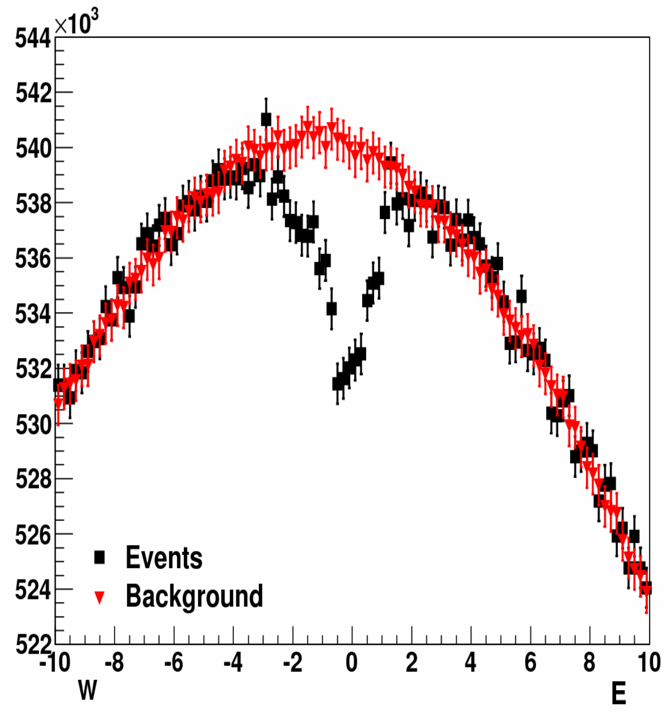
New MC signal:

$$\Phi(matter) \rightarrow r\,\Phi(\bar{p}) + (1-r)\Phi(matter)$$

Likelihood function:

$$\log L(r) = \sum_{i=1}^{B} N_i \ln[E_i(r)] - E_i(r) - \ln(N_i!)$$

The N_i measured events are represented in black. The expected events E_i are calculated by subtracting the new simulated signal from the background (red points).



30<N<60

Data analysis: the *likelihood* method for the estimate of the upper limit 2/2

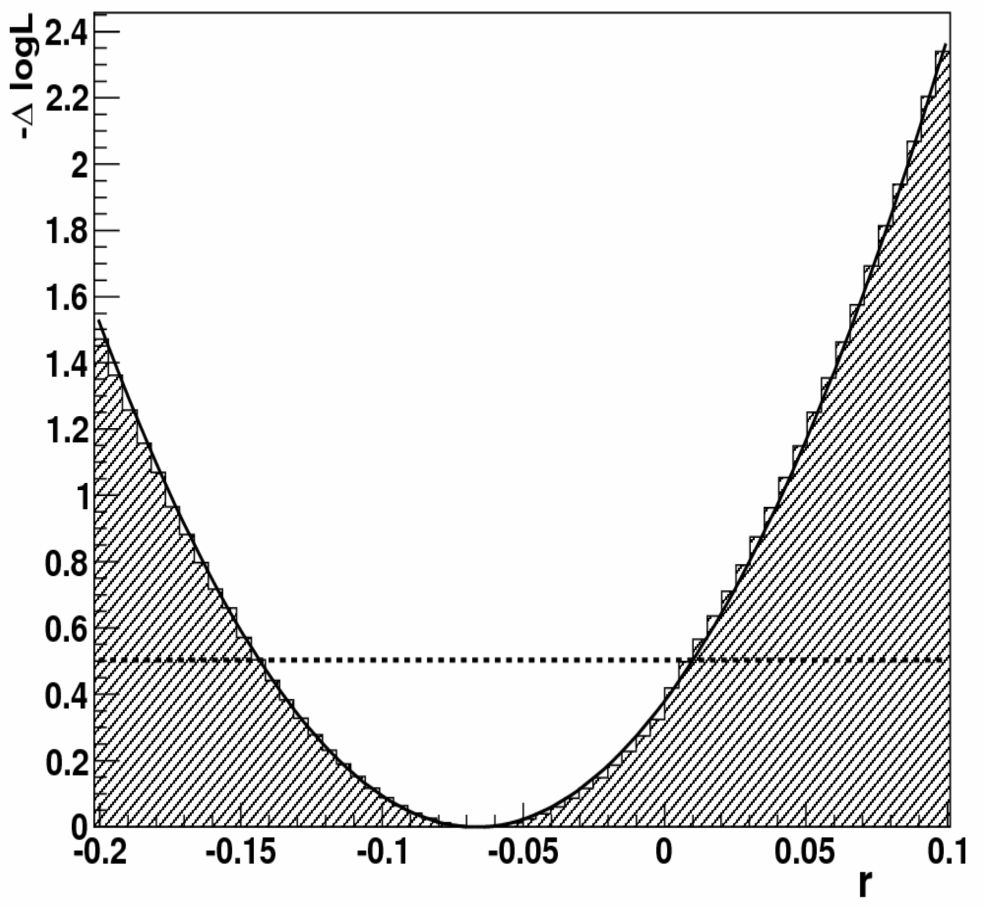
The r-value which maximizes the *likelihood* is:

$$r_{\min} = -0.065 \pm 0.078$$

This value is compatible with 0. The corresponding upper limit according to the Feldman & Cousins approach is:

$$r_{up} = 0.074 \qquad 90\%\ c.l.$$

$$r_{up} = 0.029 \qquad 68\%\ c.l.$$



Ratio upper limits

For 30<N<60, the proton contribution is 72%, with median energy 1.4 (+0.8, -0.7) TeV. *Since the anti-shadow was assumed to be the mirror image of the proton-shadow, we assume for the antiprotons the same median energy.*

$$\frac{\Phi(\overline{p})}{\Phi(p)} = \frac{1}{0.72}\frac{\Phi(\overline{p})}{\Phi(matter)} < 0.105$$

As a consequence we quote the ratios:

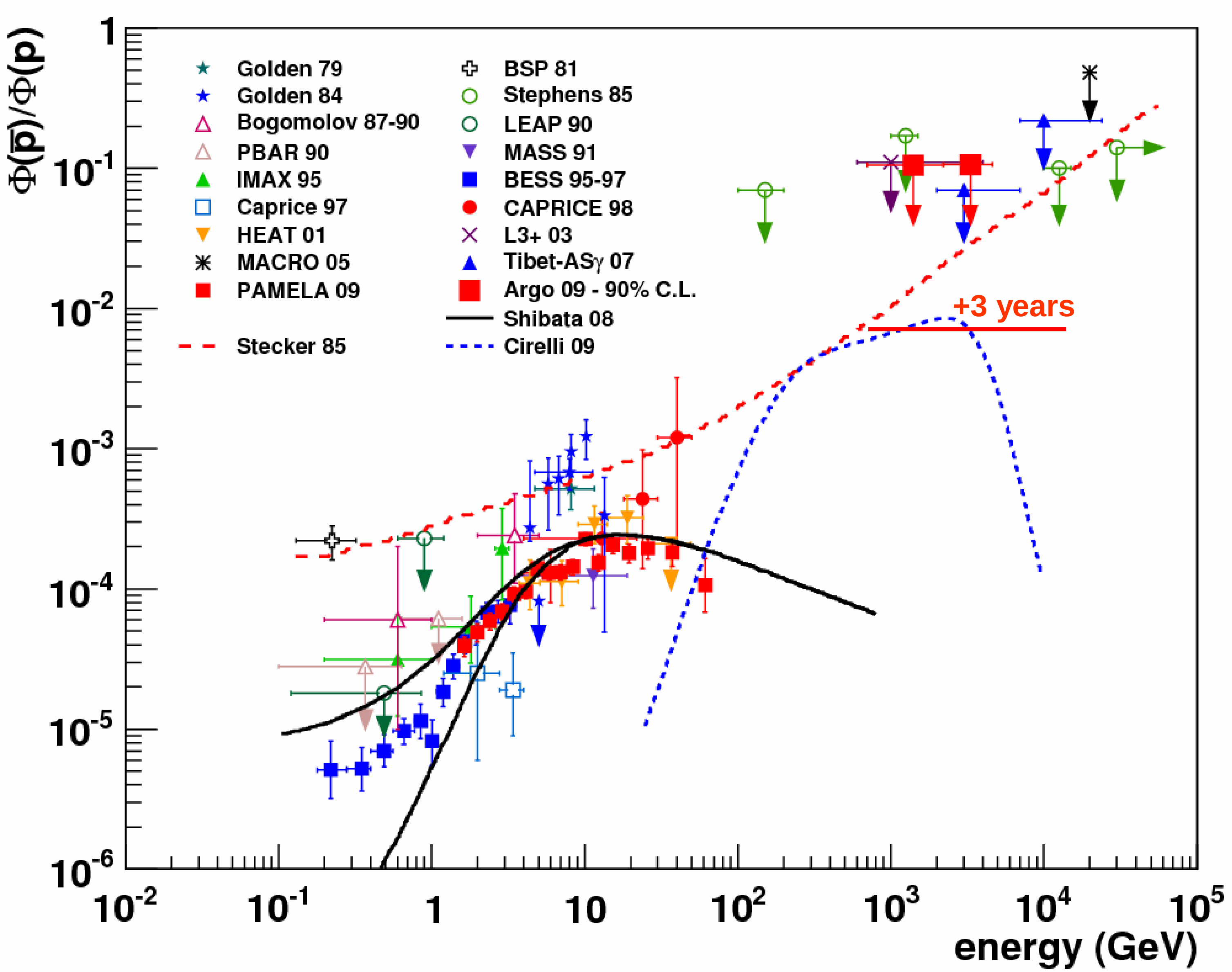
$$\frac{\Phi(\overline{p})}{\Phi(p)} < 10\% \qquad \text{at } 1.4^{+0.8}_{-0.7}\ \text{TeV} \quad 90\%\ c.l.$$

$$4\% \qquad 68.3\%\ c.l.$$

Following the same procedure for higher multiplicities:

$$\frac{\Phi(\overline{p})}{\Phi(p)} < 11\% \qquad \text{at } 3.3^{+1.3}_{-1.1}\ \text{TeV} \quad 90\%\ c.l.$$

$$5\% \qquad 68.3\%\ c.l.$$


Φ(p̄)/Φ(p)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-2
10^-1
1
10
10^2
10^3
10^4
10^5
energy (GeV)
Golden 79
Golden 84
Bogomolov 87-90
PBAR 90
IMAX 95
Caprice 97
HEAT 01
MACRO 05
PAMELA 09
Stecker 85
BSP 81
Stephens 85
LEAP 90
MASS 91
BESS 95-97
CAPRICE 98
L3+ 03
Tibet-ASγ 07
Argo 09 - 90% C.L.
Shibata 08
Cirelli 09
+3 years

Conclusions

- The data collected by the ARGO-YBJ experiment throughout 2008 have been analyzed (1.3×10^{11} events).
  - The measured angular resolution is in good agreement with MC.
  - The systematic sighting inaccuracy is much less than the angular resolution.
    - The size-energy relation has been well calibrated.
      - Many results on gamma-ray astrophysics.

The upper limits for the antiproton/proton ratio have been estimated as:

$$\frac{\Phi(\bar{p})}{\Phi(p)} < 10\% \quad \text{at } 1.4^{+0.8}_{-0.7}\ \text{TeV} \quad 90\%\, c.l.$$

$$4\% \quad 68.3\%\, c.l.$$

$$\frac{\Phi(\bar{p})}{\Phi(p)} < 11\% \quad \text{at } 3.3^{+1.3}_{-1.1}\ \text{TeV} \quad 90\%\, c.l.$$

$$5\% \quad 68.3\%\, c.l.$$

End of slideshow.