Status of the ARGO-YBJ experiment

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The ARGO-YBJ experiment

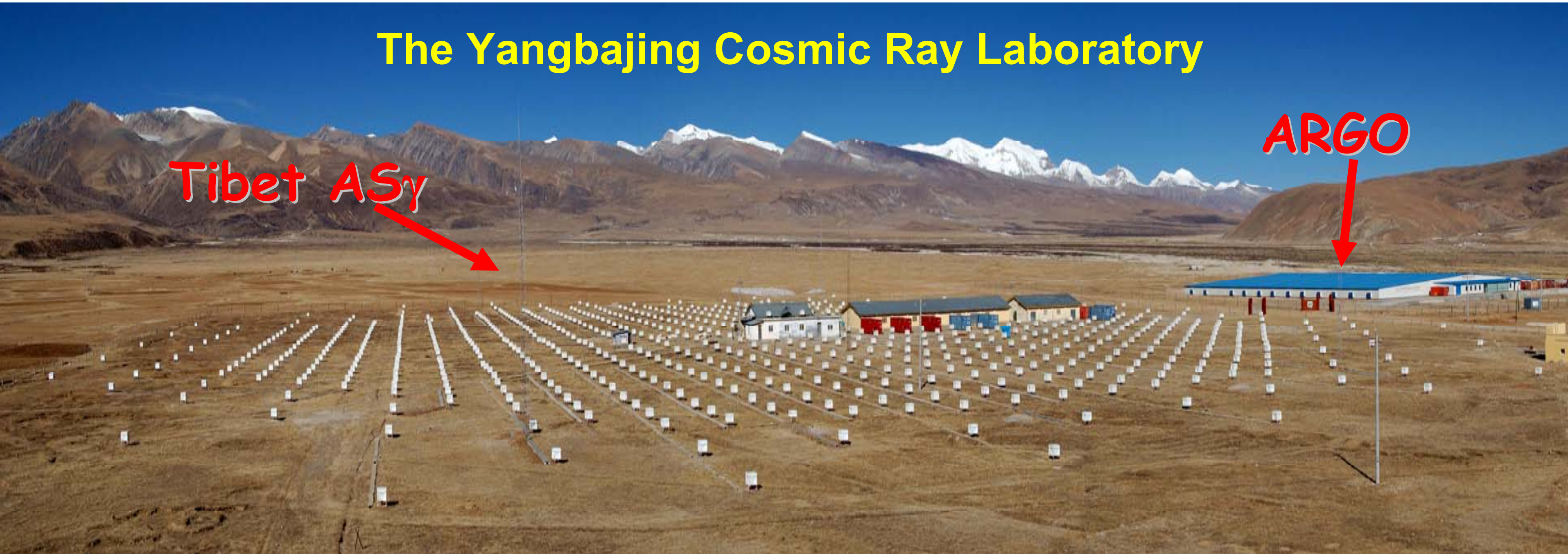
An Extensive Air Shower array exploiting the full coverage approach at very high altitude, with the aim of studying

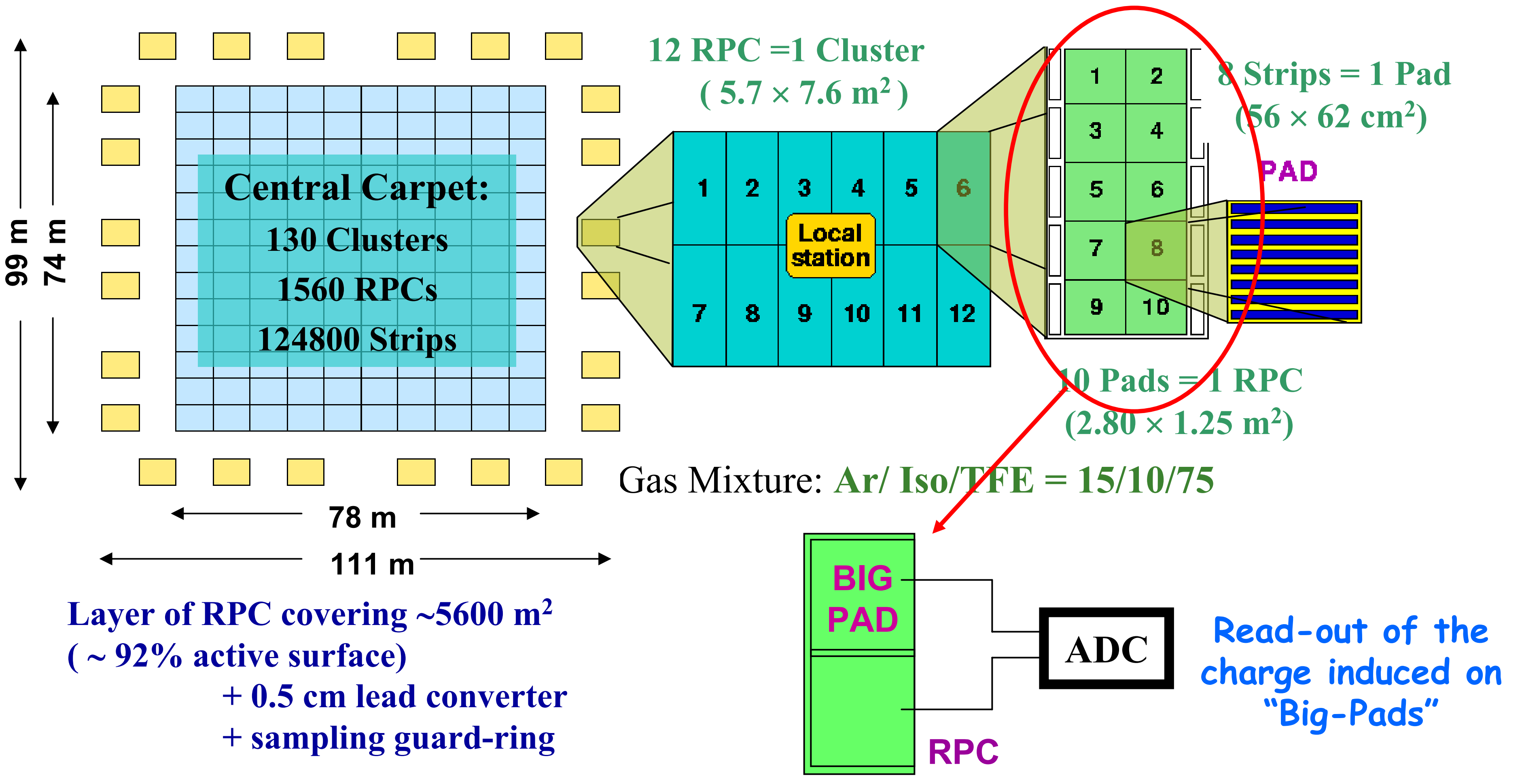
- ✓ VHE γ-Ray Astronomy
- ✓ Gamma Ray Burst Physics
- ✓ Cosmic Ray Physics

Longitude 90° 31’ 50” East
Latitude 30° 06’ 38” North

90 Km North from Lhasa (Tibet)

4300 m above the sea level





99 m
74 m
Central Carpet:
130 Clusters
1560 RPCs
124800 Strips
78 m
111 m
12 RPC =1 Cluster
(5.7 × 7.6 m²)
1
2
3
4
5
6
7
8
9
10
11
12
Local station
8 Strips = 1 Pad
(56 × 62 cm²)
PAD
10 Pads = 1 RPC
(2.80 × 1.25 m²)
Gas Mixture: Ar/ Iso/TFE = 15/10/75
Layer of RPC covering ~5600 m²
(~ 92% active surface)
+ 0.5 cm lead converter
+ sampling guard-ring
BIG PAD
RPC
ADC
Read-out of the charge induced on "Big-Pads"

Operation Modes

Shower Mode:

- Detection of *Extensive Air Showers* (direction, size, core …)
  Trigger : minimum number of fired pads within 420 ns
  ≥ 20 fired pads on the central carpet: rate ~4 kHz

Aims:

- cosmic-ray physics (above ~1 TeV)
- VHE γ-astronomy (above ~300 GeV)

Scaler Mode:

- Recording the counting rates ($N_{hit} \geq 1, \geq 2, \geq 3, \geq 4$) for each cluster at fixed time intervals (every 0.5 s) lower the energy threshold down to ≈1 GeV

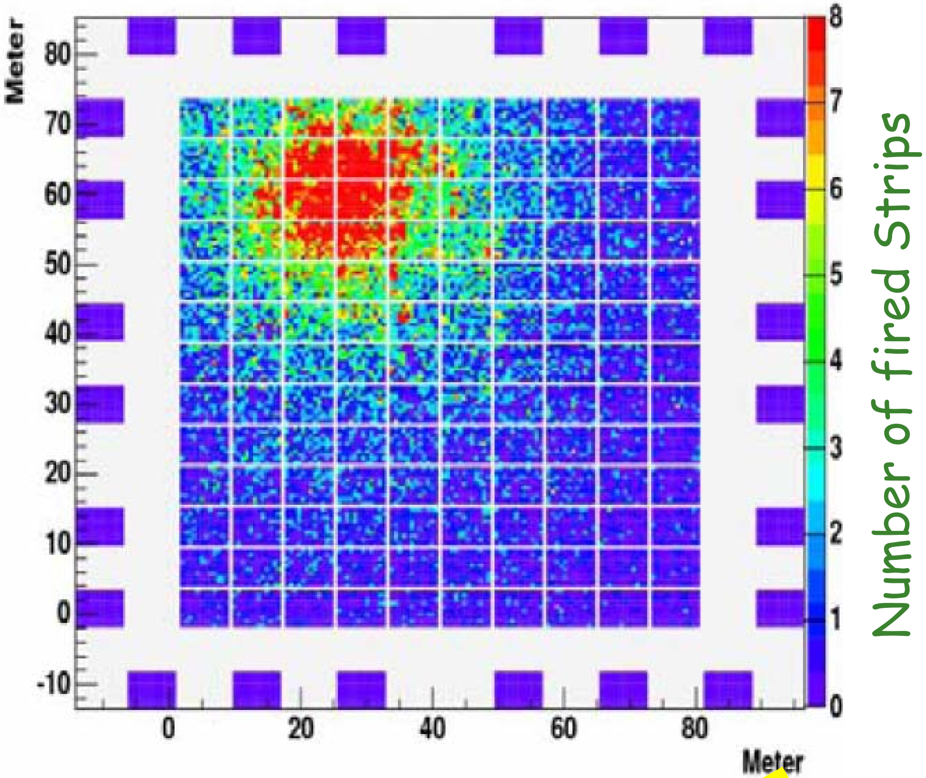
Aims:

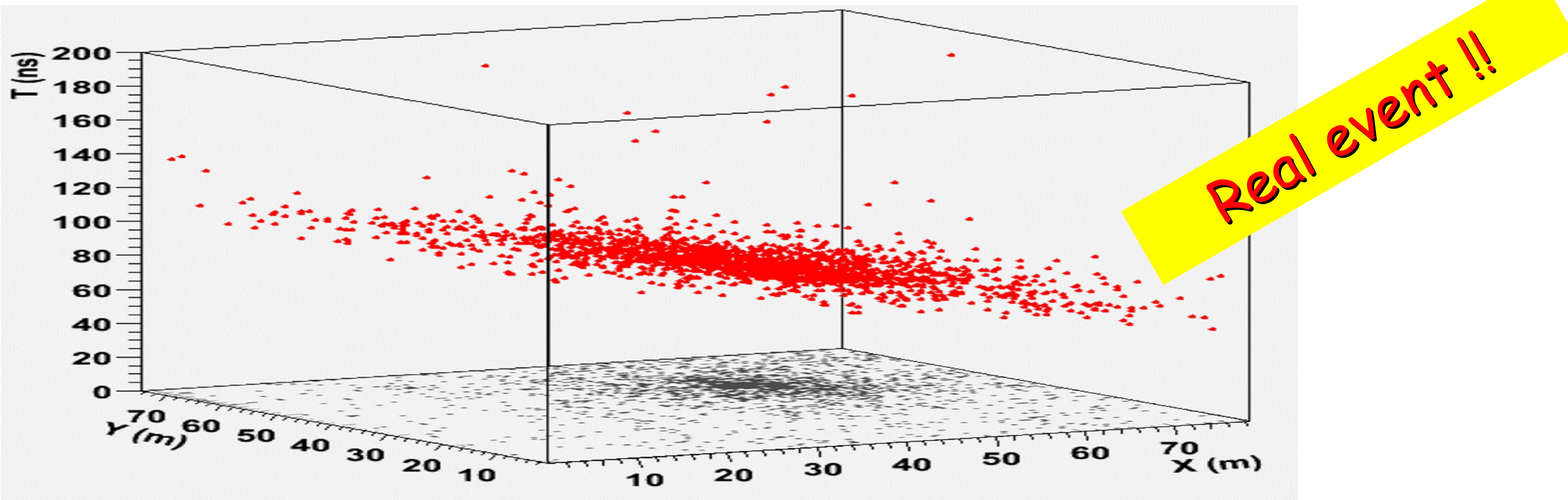
- flaring phenomena (high energy tail of GRBs, solar flares)
- detector and environment monitor

Shower mode:

Space pixel: $7 \times 62\ cm^2$ (1 strip)
Time pixel: $56 \times 62\ cm^2$
(8 ORed strips = 1 Pad)
Time resolution: ≈ 1 ns

The size of pixels, the time resolution and the full coverage of the detector allow to reconstruct the showers with high granularity and unprecedented details





First Results

Present:

- Stable Data Taking since Nov. 2007 (d.c. > 90%) with the full detector Central Carpet (130 Clusters) + Guard Ring

The analyses presented here are based on data collected in the period July 2006-March 2008. These data were mainly used to calibrate and debug the detector and the DAQ.

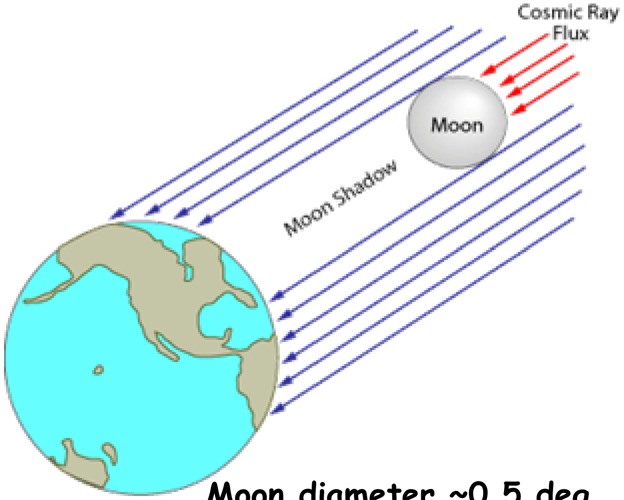
Despite the highly fragmented and preliminary data taking (up to Nov. 2007), some remarkable results are available in different items even with small duty-cycle due to very aggressive cuts applied to select "good" data

- Moon Shadow
- Gamma ray sources
- High Energy GRBs
- p-air cross section
- ……

The Moon Shadow

Cosmic rays are hampered 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



Moon diameter ~0.5 deg

Geomagnetic Field: positively charged particles deflected towards the West and negatively charged particles towards the East.

→ Ion spectrometer

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

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

The Moon Shadow

All triggered events

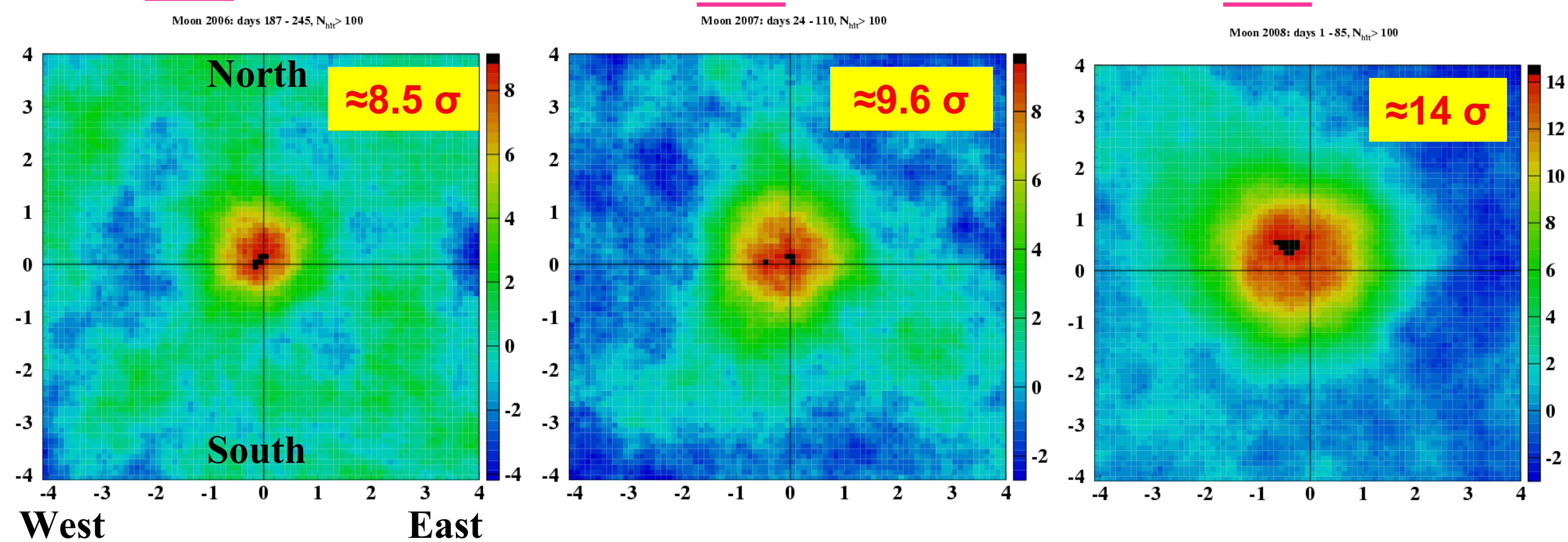
≈100 h/month ≈ 8 σ/month

$N_{hit} > 100$

$\theta < 50°$

$E_{50} \approx 4$ TeV, $E_{mode} \approx 1$ TeV (for protons)

2006: 114 h **2007: 155 h** **2008: 273 h**

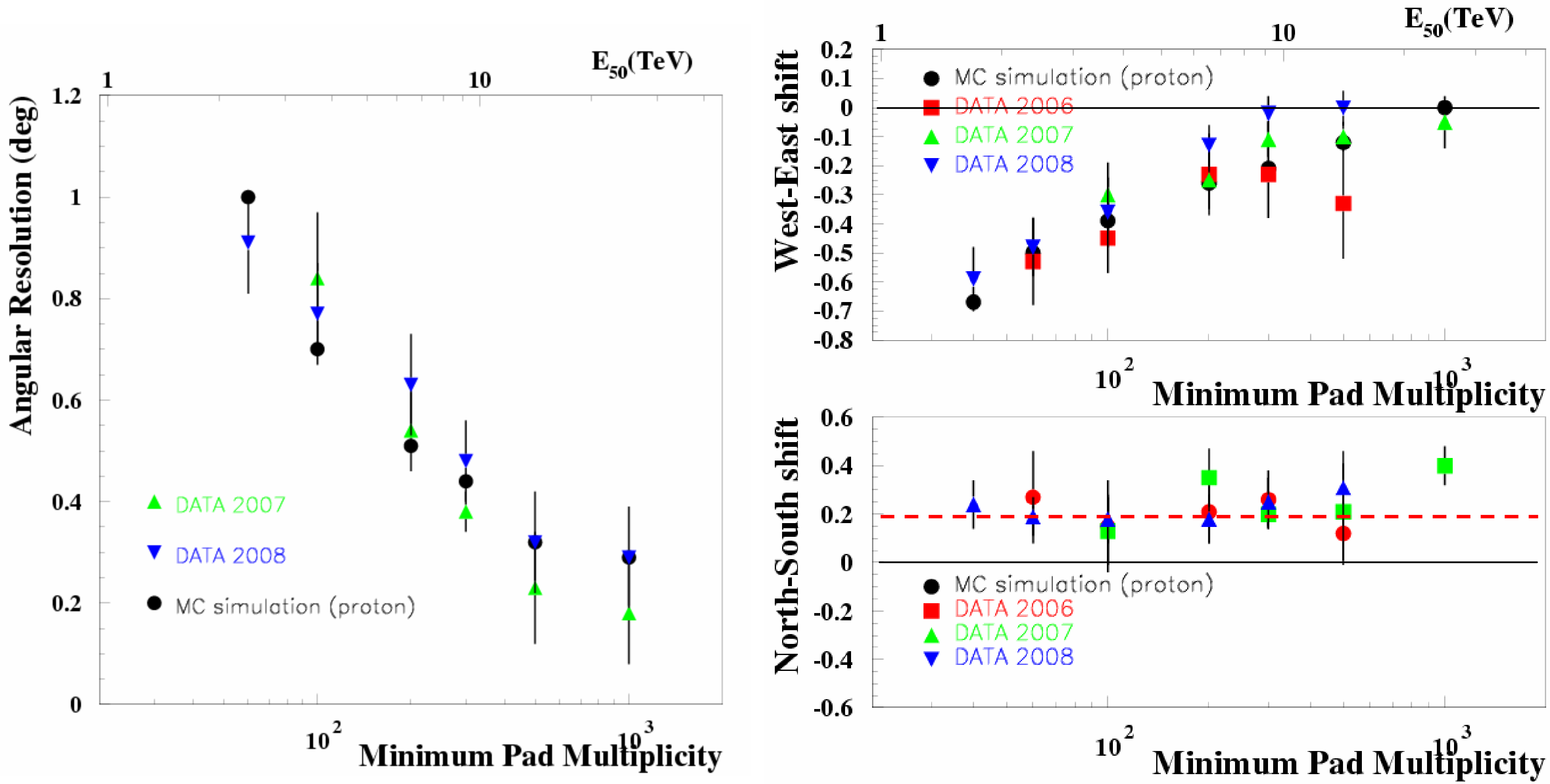


The statistical significance scales with $\sqrt{\text{obs. time}}$

Moon Shadow analysis

Preliminary

The displacement towards West is due to the Earth's Magnetic Field

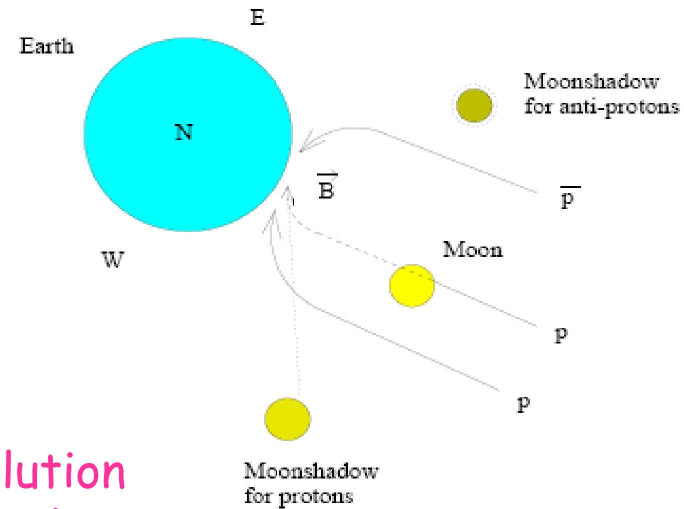


Residual systematic shift towards North of about 0.2 deg

The Earth-Moon system as a spectrometer

The shadow of the Moon can be used to put limits on antiparticle flux.

In fact, if proton are deflected towards West, antiprotons are deflected towards East.



If the displacement is large and the angular resolution small enough we can distinguish between the 2 shadows.

If no event deficit on the antimatter side is observed an upper limit on antiproton content can be calculated.

A preliminary measurement with ARGO...

$$\begin{cases} N_{hit} > 40: \sigma_\theta \approx 1.3° \\ N_{hit} > 100: \sigma_\theta \approx 0.7° \end{cases}$$

Antiproton/proton Ratio

VERY PRELIMINARY !!!

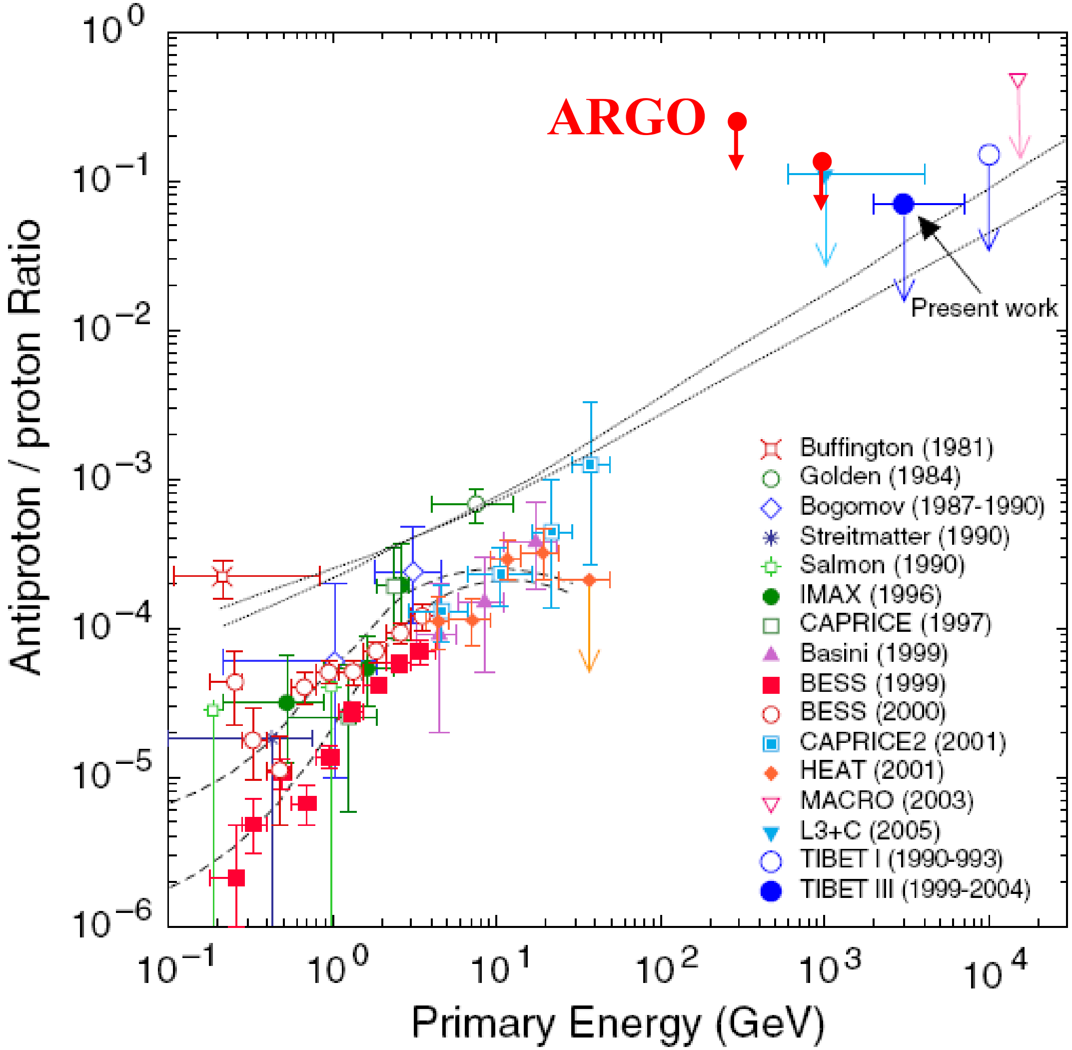
$N_{hit} > 40$: ≈20 σ in 3 months

$N_{hit} > 100$: ≈14 σ in 3 months

antip/p ≈ 25% at ≈300 GeV

antip/p ≈ 15% at ≈1 TeV

(at 90% c.l.)



Goal: ≈ % in the range 300 GeV – few TeV in about 3 years of data taking.

γ-ray astronomy

In this preliminary analysis

1. All events are considered without any internal shower selection
2. No lead converter on the RPC carpet **(with Pb the ang. resol. improves by about 50% at TeV energies)**

The CR background rejection is performed by exploiting

1. the good angular resolution of the detector
2. the fact that at very high altitude the trigger efficiency of TeV γ-rays is about 2 times larger than protons' one at fixed energy

NO additional γ/hadron discrimination algorithms have been yet applied

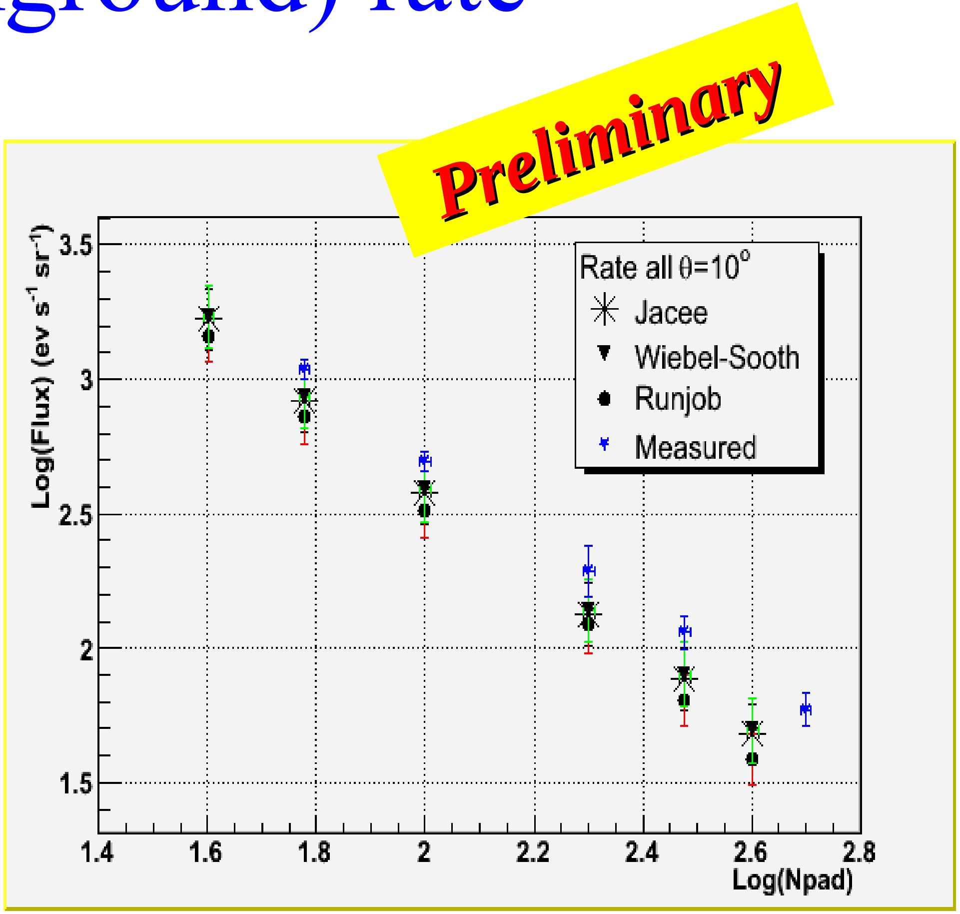
($Q_f \approx 1.5 - 1.8$ with "topological"-based algorithms)

Cosmic Rays (background) rate

In order to evaluate the background rate due to the cosmic rays opening angles of 1° at different θ are considered.

Expected rate

$$R = R_p + R_\alpha + R_{CNO}$$



The observed spectrum shows close agreement with the simulation in terms of both the event rate and the shape.

The 20-25% discrepancy is probably due to the uncertainty in the experimental rates.

Crab Nebula

Preliminary

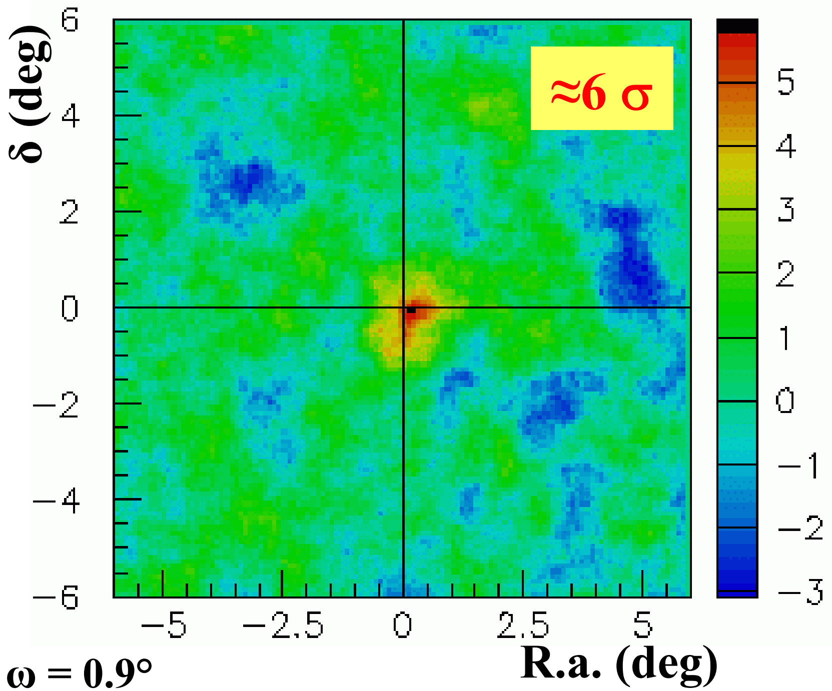
5.8 hours / day

$N_{hit} > 100$

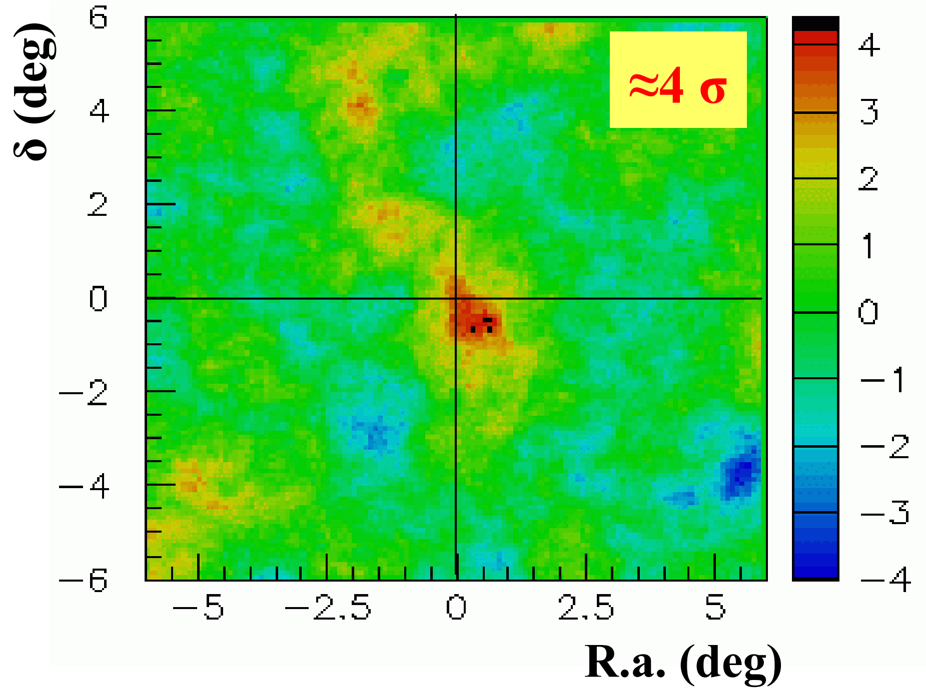
$\theta < 40°$

$E^{\gamma}_{50} \approx 2.4$ TeV, $E^{\gamma}_{mode} \approx 700$ GeV

2007 (days 25 – 110: **241 h**)



2008 (days 01 – 55: **259 h**)



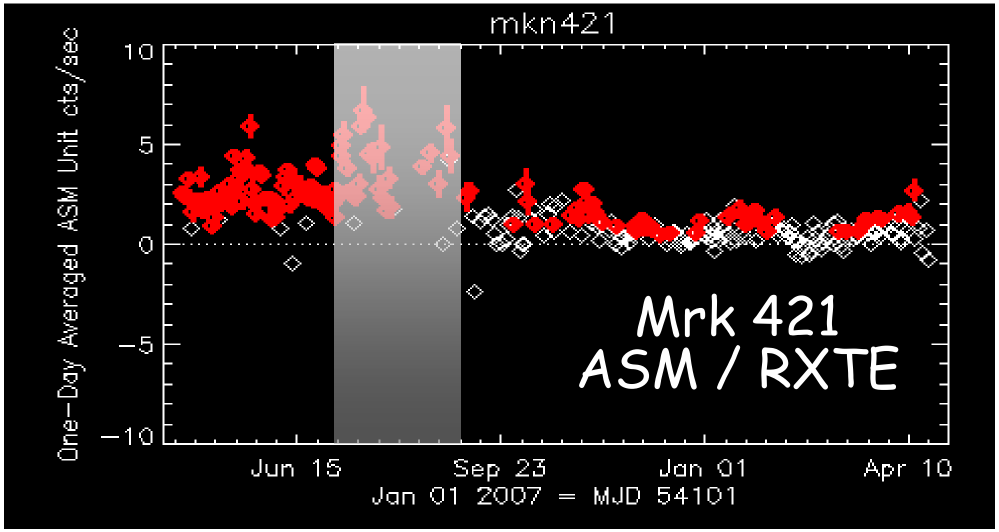
$\omega = 0.9°$

74% ev

ARGO is observing Crab Nebula at > 4 σ in ≈ 50 days

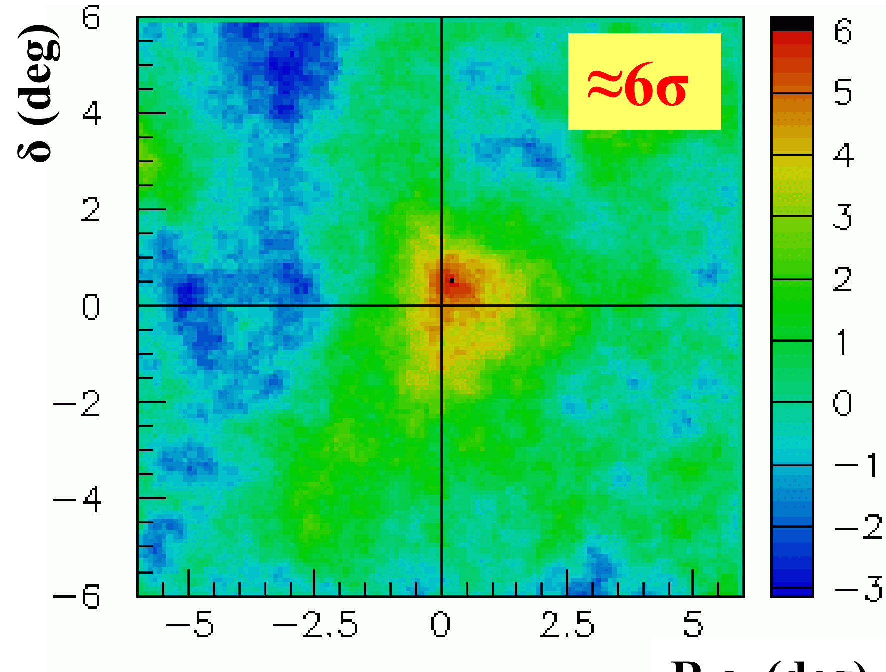
Mrk 421: 2006

ARGO started recording data with the full central carpet during the X-ray flare of Mrk421 in July 2006.



Evidence for TeV emission in coincidence with the X-ray flare

days 187-245 (137 hours)



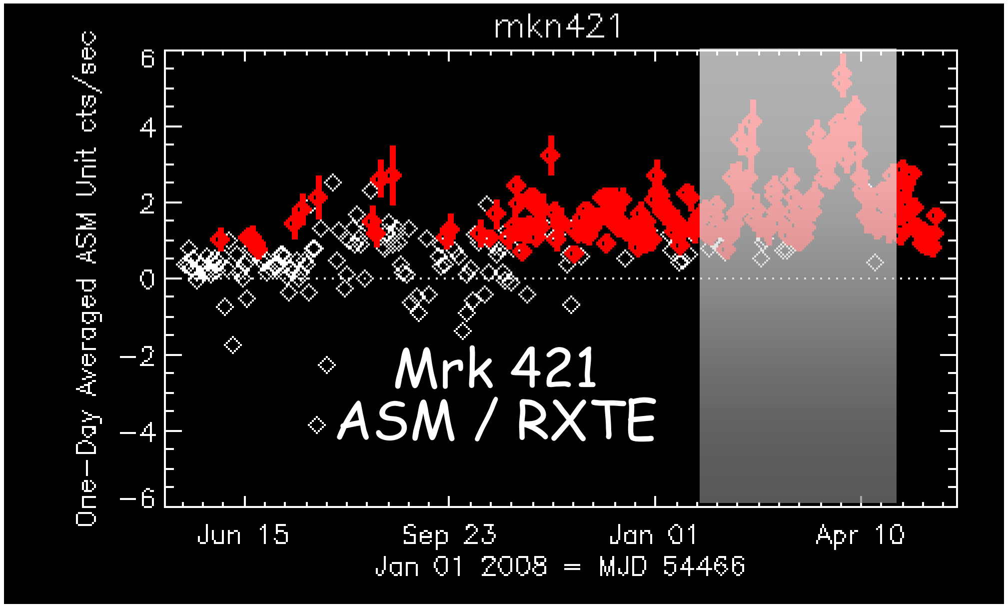
$N_{pad} > 60$

The detector was in its commissioning phase, therefore new analyses are in progress to properly evaluate the statistical significance of the observation.

E^{γ}_{50} ~1.6 TeV, E^{γ}_{mode} ~500 GeV

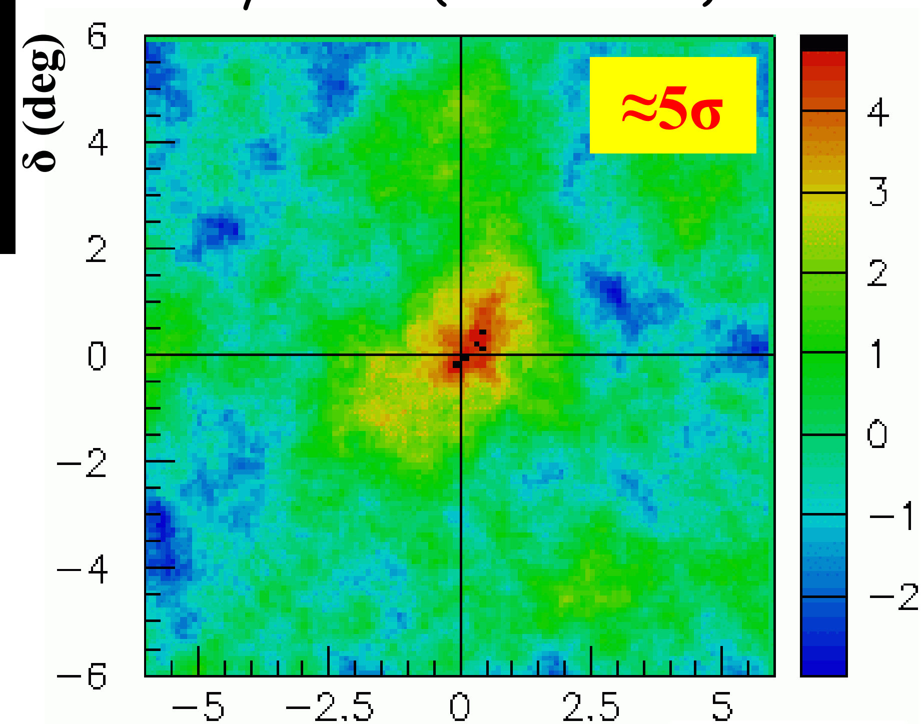
Mrk 421: 2008

Preliminary



Evidence for TeV emission in coincidence with the X-ray flare

days 1-55 (262 hours)



$N_{pad} > 60$ R.a. (deg)

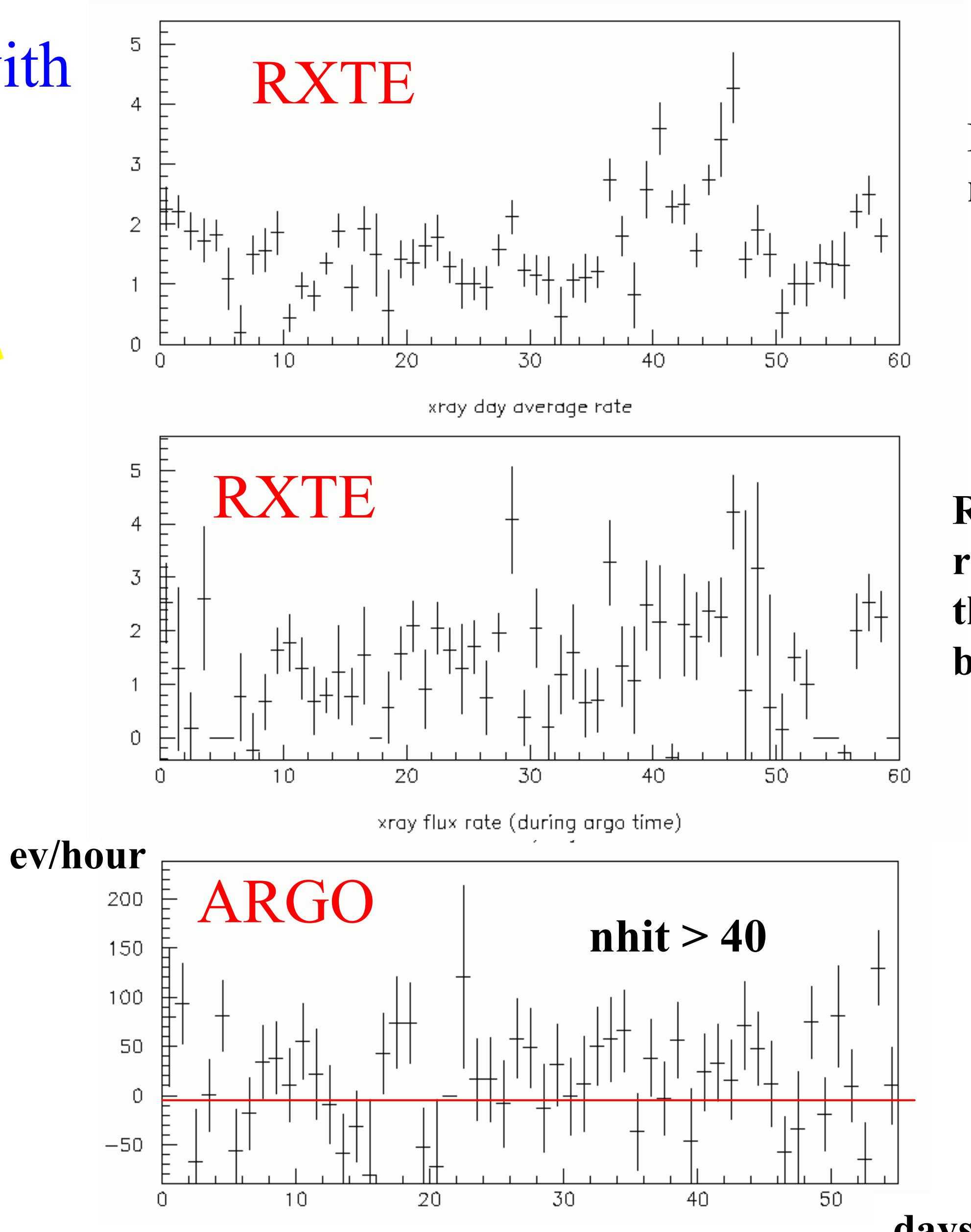
Feb. - April 2008

Deeper analysis and further data integration are in progress

E^{γ}_{50} ~1.6 TeV, E^{γ}_{mode} ~500 GeV

Correlation with X-rays

Preliminary



RXTE counting rate day average

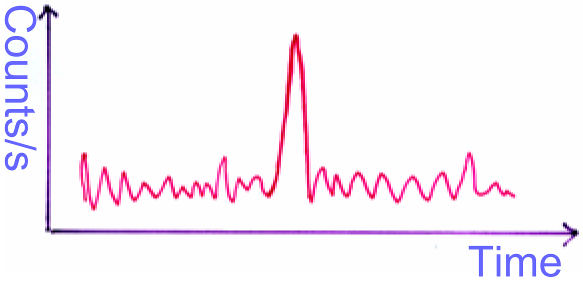
RXTE counting rate averaged when the source is visible by ARGO

days from 1/1/08

No correlation visible

Search for GRBs with Scaler Mode

- **The counting rate of the single particles hitting the detector is recorded at fixed time intervals (every 0.5 s).**
- **No information on the arrival direction and spatial distribution of the detected particles.**
- **An excess is registered if the counting rate is significantly higher than the background.**
- Four channels are implemented selecting PAD multiplicities ≥1, ≥2, ≥3, ≥4 in each cluster. The measured counting rate are respectively ~40KHz, ~2KHz, ~300Hz, ~120Hz.
- With the available sample of **38** GRBs triggered by satellites **no excess was observed** .
- The corresponding **upper limits on the fluence** are of the order of **10^{-6} - 10^{-4} erg/cm^2** in the **1-100 GeV range.**
- **We expect ~1 EGRET-like (with spectrum >200 MeV) GRB to occur in the ARGO f.o.v. (θ < 45°) in 1 year.**



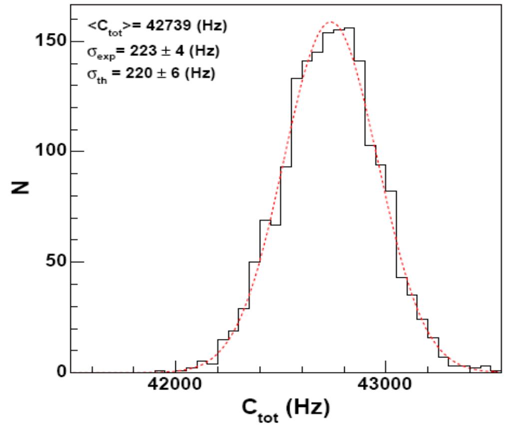


Fig. 3. Experimental distribution of the total number of particles hitting a typical cluster and its Gaussian fit for 30 minutes data accumulation. The standard devi-

Conclusions

Detector setup:

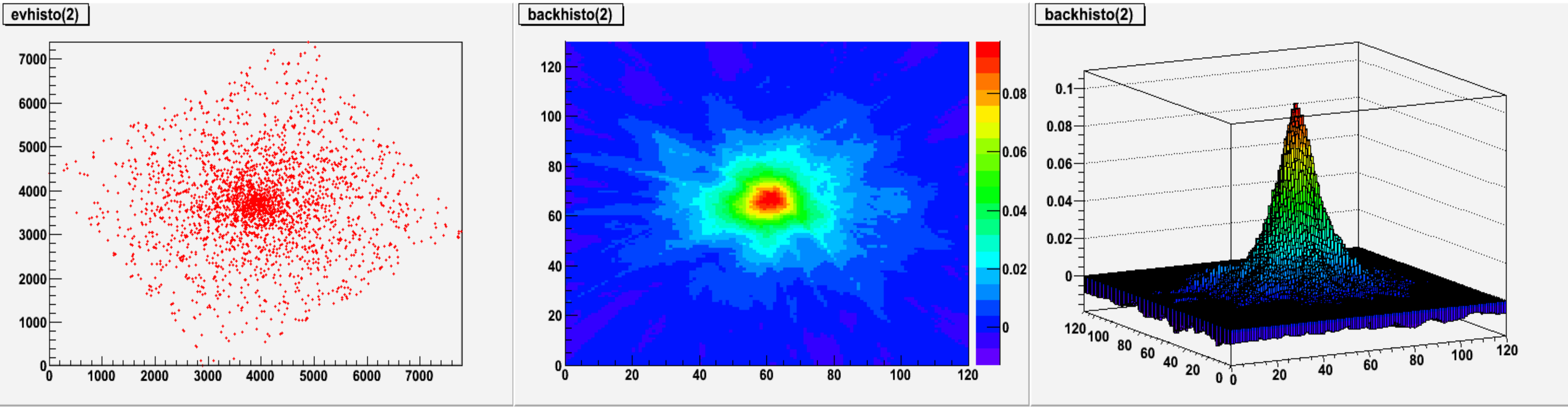
- The ARGO-YBJ detector has been completely installed
- Stable data taking since Nov. 2007 (d.c. > 90%) with the full detector
- Lead plate installation during 2008

Results from preliminary analysis:

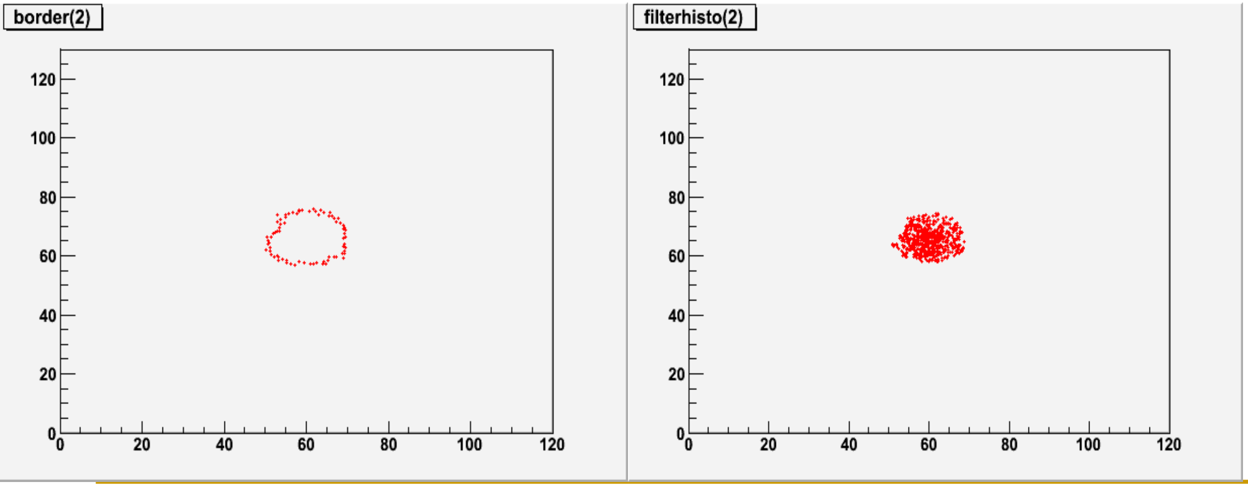
- Moon shadow observed at >8 σ level per month
- Preliminary antiproton/proton ratio measurement at ≈300 GeV and ≈1 TeV
- Mrk421 flares observed in July-August 2006 and Feb-April 2008 at > 5 σ
- Crab Nebula observed in 2007 and 2008 at > 4 σ in ≈ 50 days (no γ/h discrimination yet !!)
- Preliminary "Hot Spots" catalogue (>4σ) in preparation
- Search for high energy tail of GRBs in the 1-100 GeV range
- Inelastic p-air cross section measurements at $\sqrt{s}$ ~ 0.1 TeV

THE END

γ/hadron discrimination

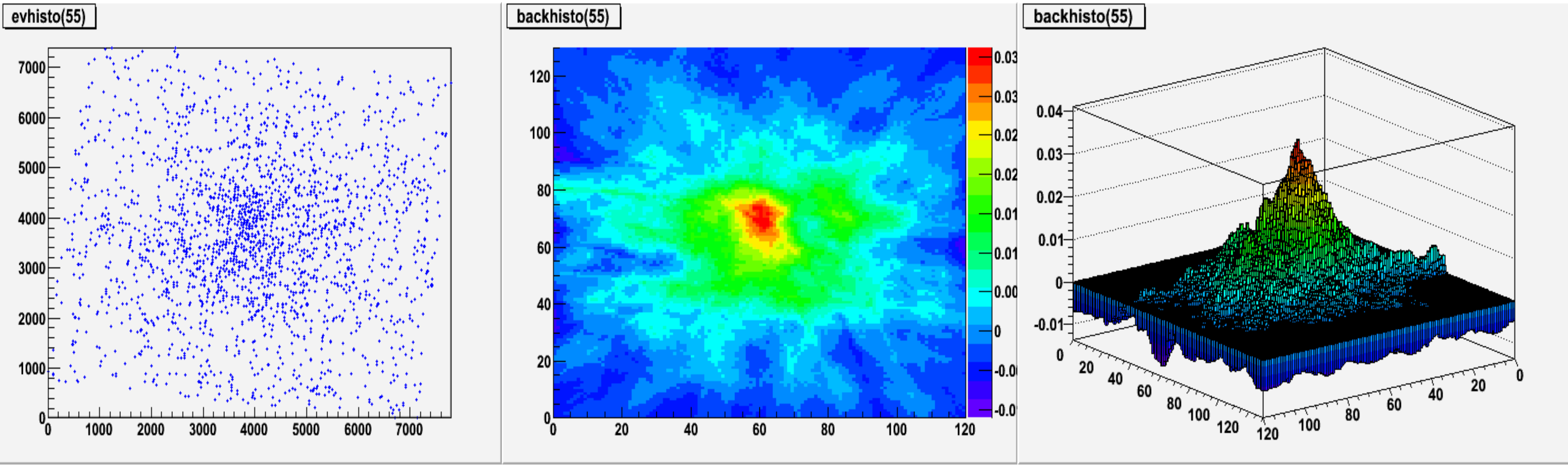


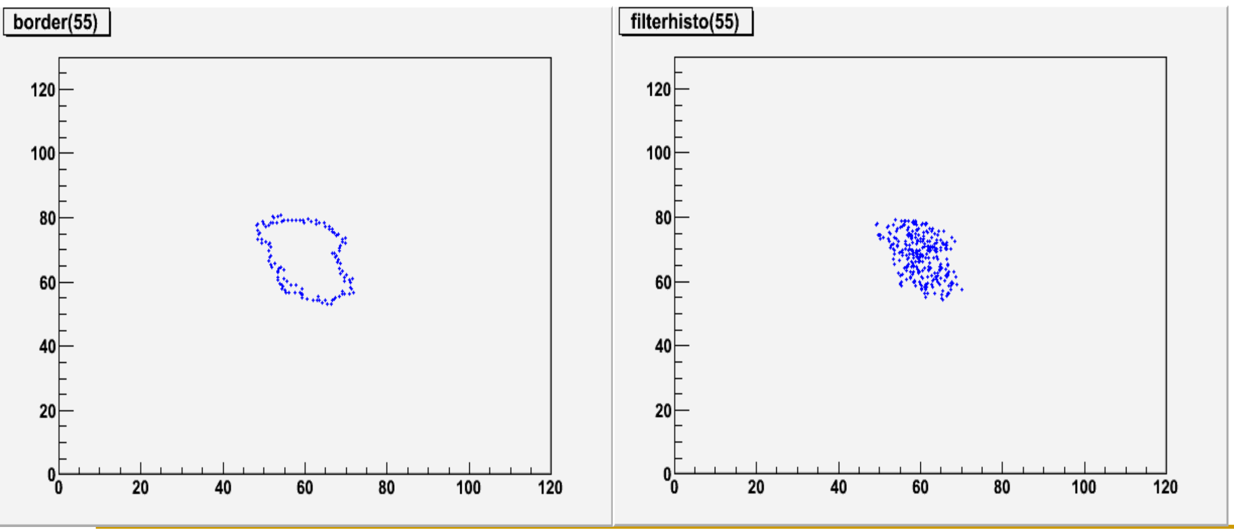
Cut @ 0.5·MaxIntensity



Gamma
2132 hits
E=9.1 TeV

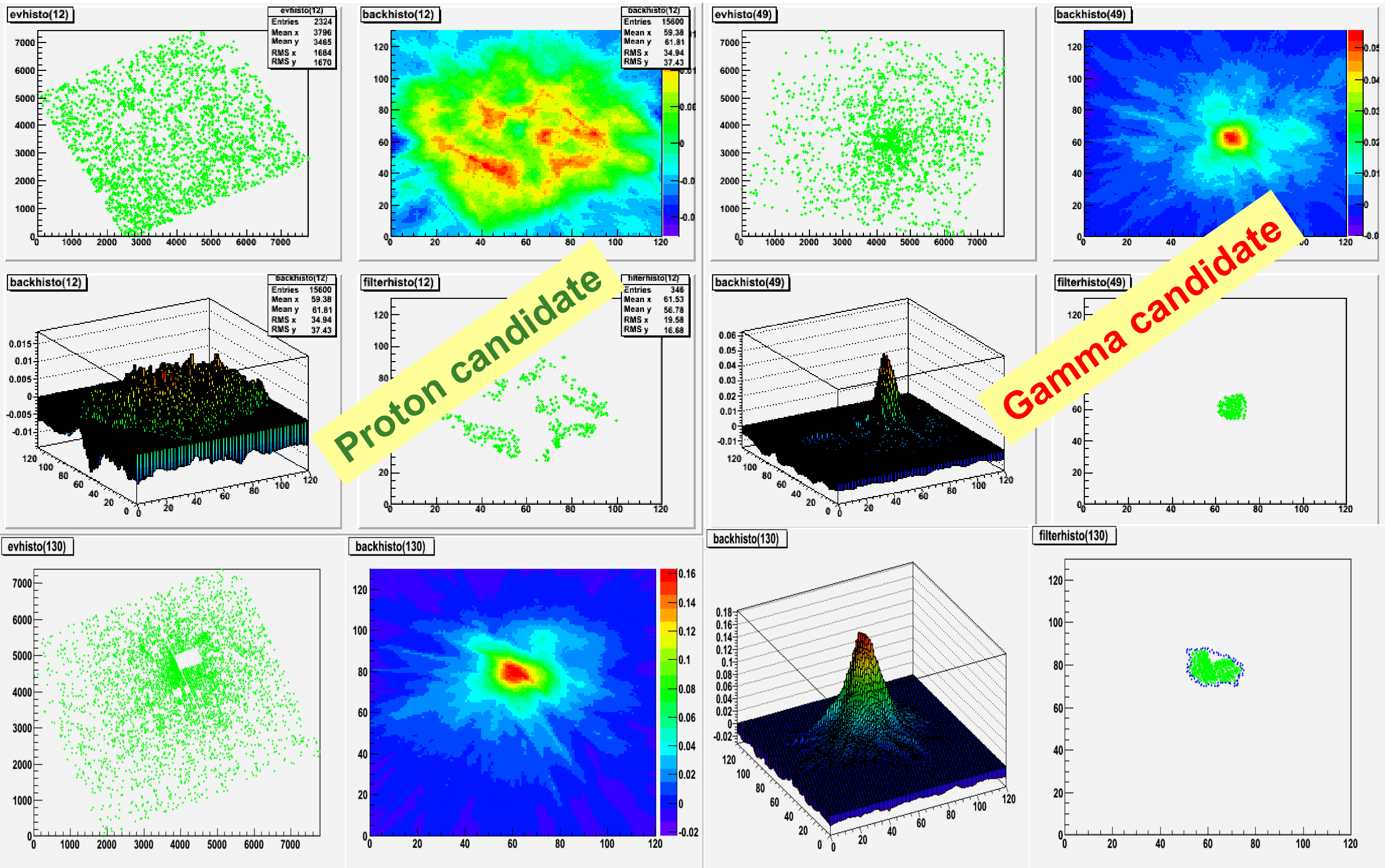
γ/hadron discrimination





Proton
2025 hits
E=19.9 TeV

First check with real events in the Crab region



Analysis procedure

- Source follow up when zenith angle $\theta < 40°$ (Crab: 5.8 hours / day)
- Build the event map ($20° \times 20°$ around the source, $0.1° \times 0.1°$ bins)
- Build the background map with the time-swapping method

  (each event is used 10 times to create the background)

- Map smoothing: all events inside a window of radius ω are summed up
- The background map is subtracted to the event map
- Calculation of the excess significance for each bin:

$$\boxed{N_\sigma = \frac{S - B}{\sqrt{S + 0.1 \cdot B}}}$$

S = number of events in the event map bin

B = number of events in the background map bin

Time Swapping Method

The BKG map is made with the "time swapping method"

Random "background" events are generated for each observed event by associating the event local coordinates (δ, α) with times selected randomly from all event times recorded over a 3 hr period.

New values of celestial coordinates are then calculated for each background event.The new triplet constitues a new, fake, background event.

Because the selection of a new event time amounts to a rotation of the celestial sphere with respect to the Earth, this method changes only the α of an event, but not its δ.

$$\boxed{\begin{aligned}(\delta,\alpha,t)_{event} \to (\delta,\alpha,t'_1)_{BKG}\\ \vdots \qquad\\ (\delta,\alpha,t'_{10})_{BKG}\end{aligned}}$$

To reduce statistical fluctuations 10 fake events are generated for each real events.

Sky maps

1) First map centered on the Moon's position in equatorial coordinates: square bins of 0.1° on a side.

   X axes: $(\alpha_{ev} - \alpha_{lmoon}) \cdot \cos \delta_{ev}$ **(α = right ascension)**

   Y axes: $(\delta_{ev} - \delta_{moon})$ **(δ = declination)**

2) Smoothed map: every bin is a circular window of 1° of radius is made summing square bins of 0.1° on a side. This window is shifted of 0.1° in both X e Y direction. The resulting map is made of not indipendent bins.

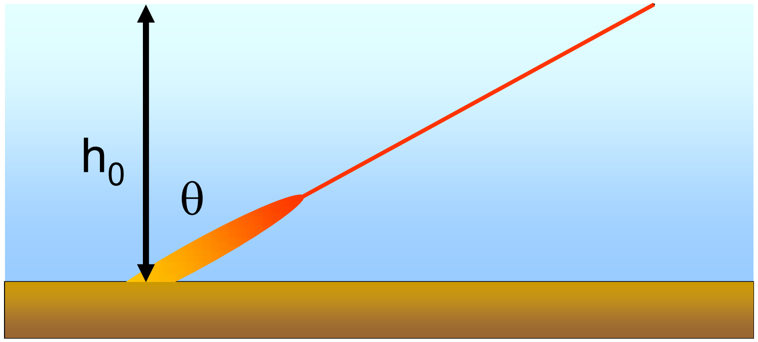
3) BKG maps are made with the same characteristic of events maps.

Measurement of the Flux attenuation

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.



However Λ **= k** λ_{int} mainly because of shower fluctuations.

It is determined by simulations and depends on:

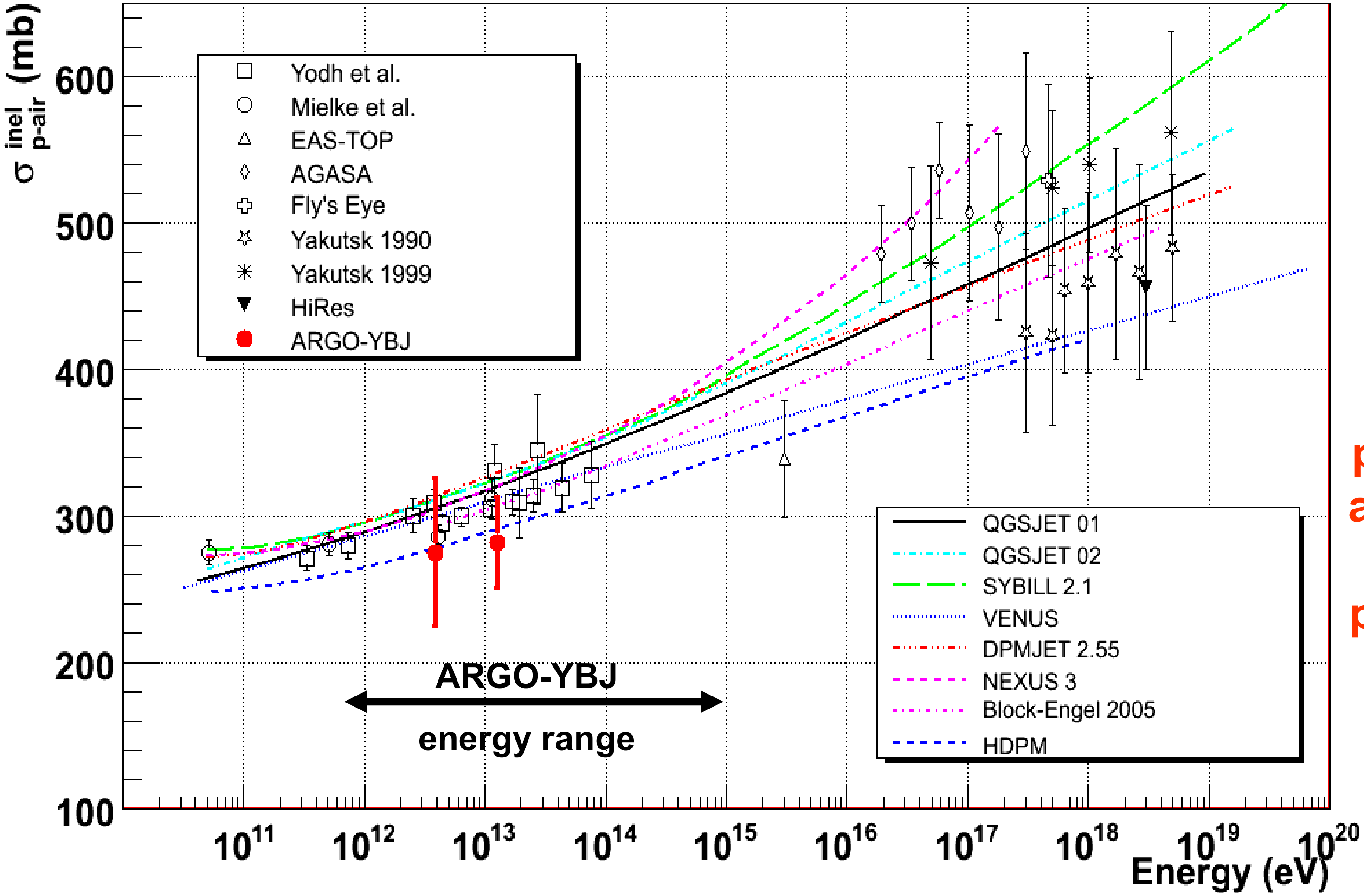
- interaction model
- actual set of experimental observables
- energy
- ……..

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

Warning

Take care of shower fluctuations

- **Constrain** $X_{DO} = X_{det} - X_0$ or better $X_{DM} = X_{det} - X_{max}$
- **Select** deep showers (large X_{max}, i.e. small X_{D0} or X_{DM})
- **Exploit** detector features (space-time pattern) and location (depth).



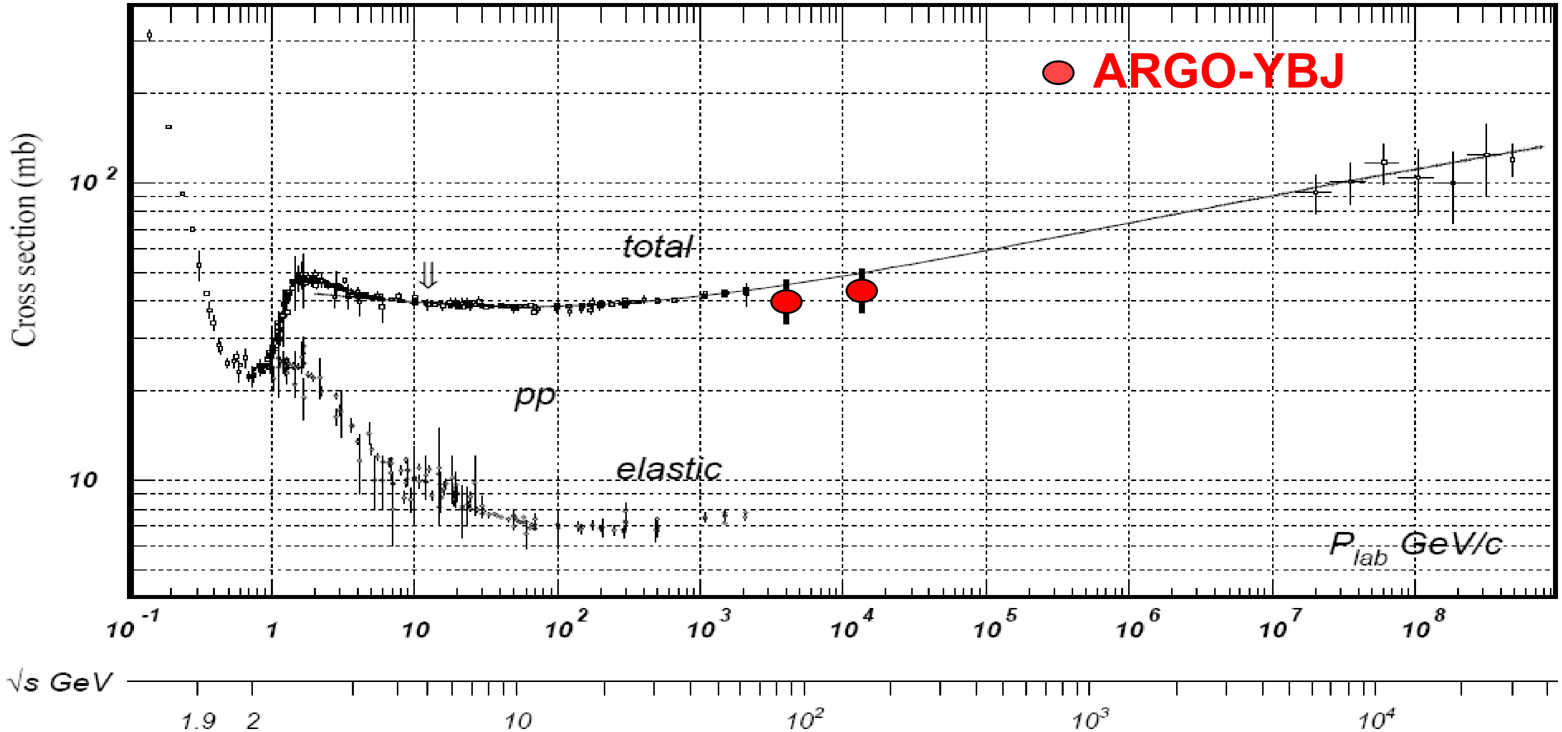
In this plot ARGO-YBJ data points have been already corrected for the effect of primaries heavier than protons.

Nhit	<E>	k	σ_{CR-Air} (mb)	σ_{p-Air} (mb)
300 ÷ 1000	3.9 ± 0.1 TeV	1.6 ± 0.3	**299 ± 55**	**275 ± 51**
> 1000	12.7 ± 0.4 TeV	1.2 ± 0.1	**306 ± 34**	**282 ± 31**

$\sigma^{inel}_{p\text{-}Air} \Rightarrow \sigma^{tot}_{p\text{-}p}$

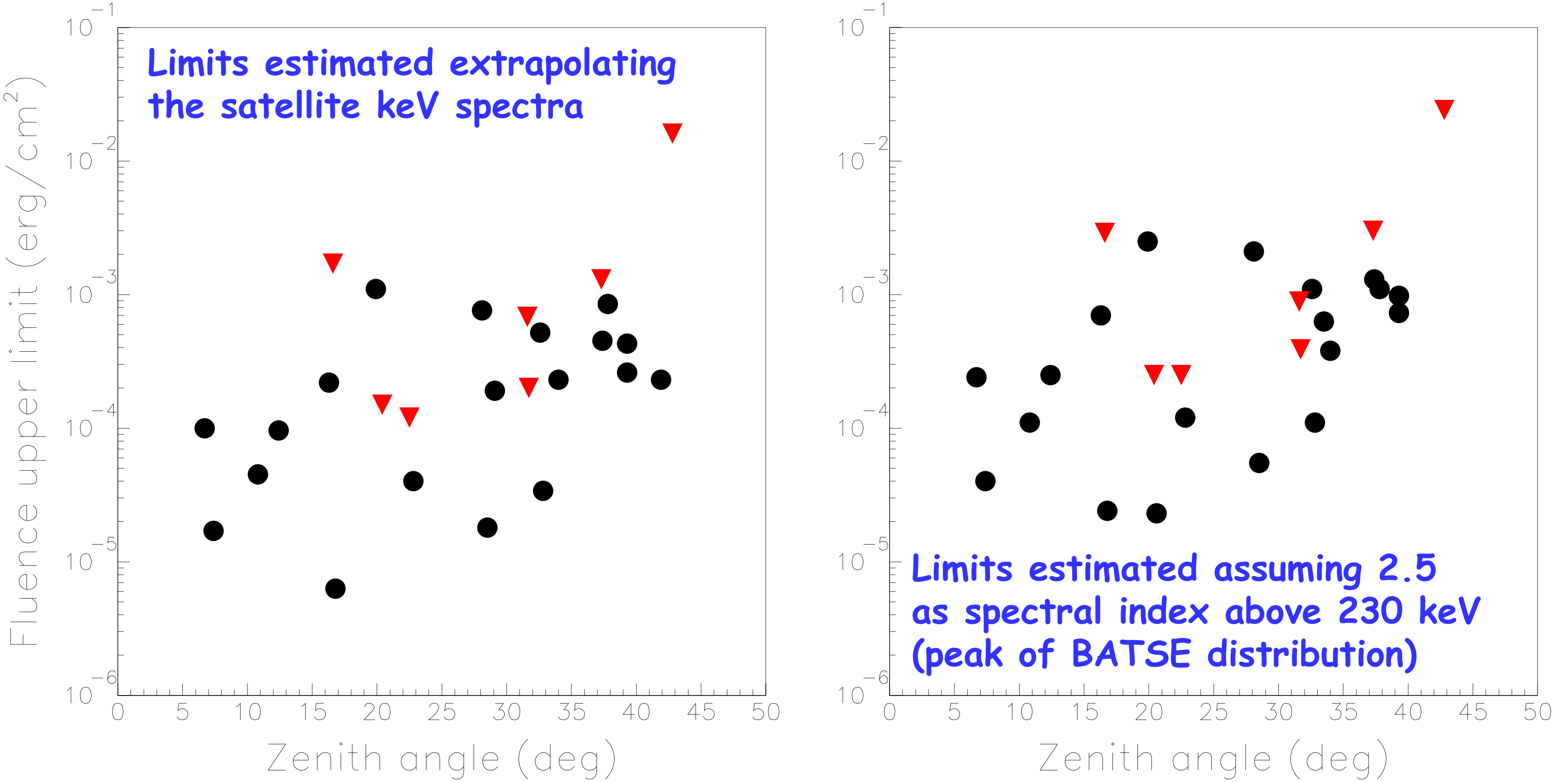
- **Glauber – Matthiae theory**
- **Durand – Pi**
- **Wibig – Sobczynska**
- **….**

Models agree within few % in our energy range



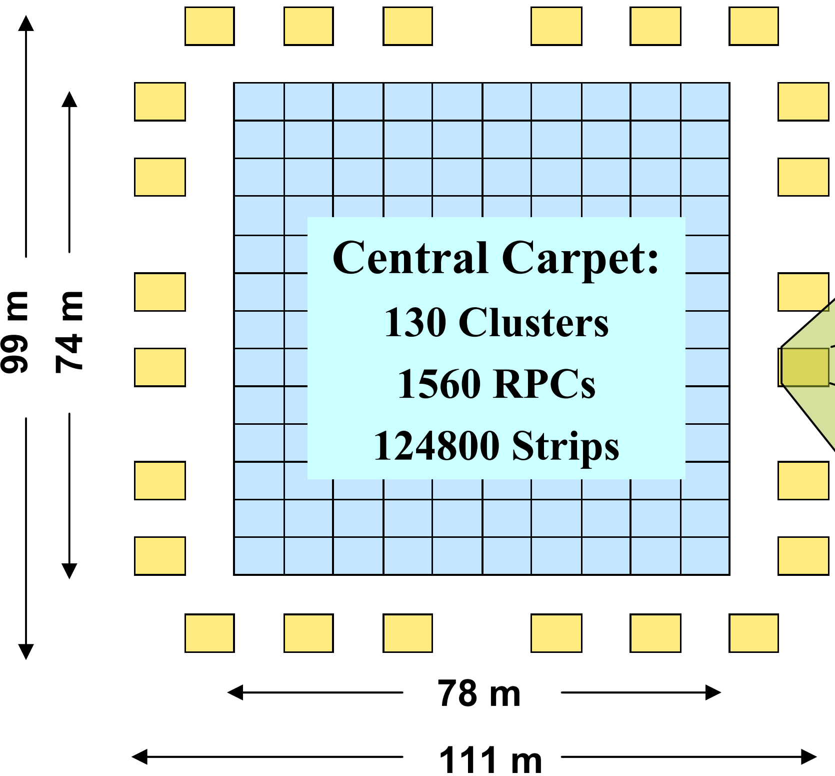
Nhit	<E>	k	$\sigma_{CR\text{-}Air}$ (mb)	$\sigma_{p\text{-}Air}$ (mb)	$\sigma_{p\text{-}p}$ (mbarn)
300 ÷ 1000	3.9 ± 0.1 TeV	1.6 ± 0.3	299 ± 55	275 ± 51	**40 ± 7**
> 1000	12.7 ± 0.4 TeV	1.2 ± 0.1	306 ± 34	282 ± 31	**43 ± 5**

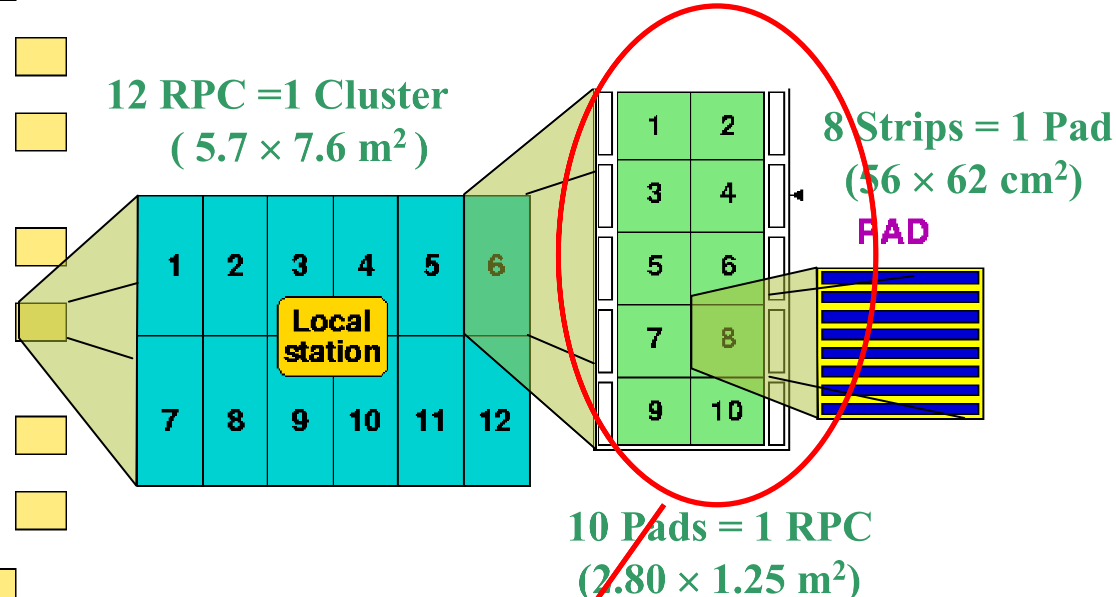
Fluence Upper Limits in the 1–100 GeV range



Extragalactic absorption has been taken into account for GRBs with known redshift (red triangles)

Detector Layout

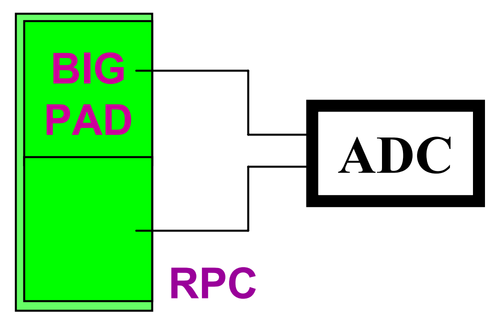




Gas Mixture: Ar/ Iso/TFE = 15/10/75

time resolution ~ 1 ns
space resolution = 6.5 × 62 cm² (1 strip)

Layer of RPC covering ~5600 m²
(~ 92% active surface)
+ 0.5 cm lead converter
+ sampling guard-ring



Read-out of the charge induced on "Big-Pads"