# ANISOTROPY STUDIES WITH THE PIERRE AUGER OBSERVATORY

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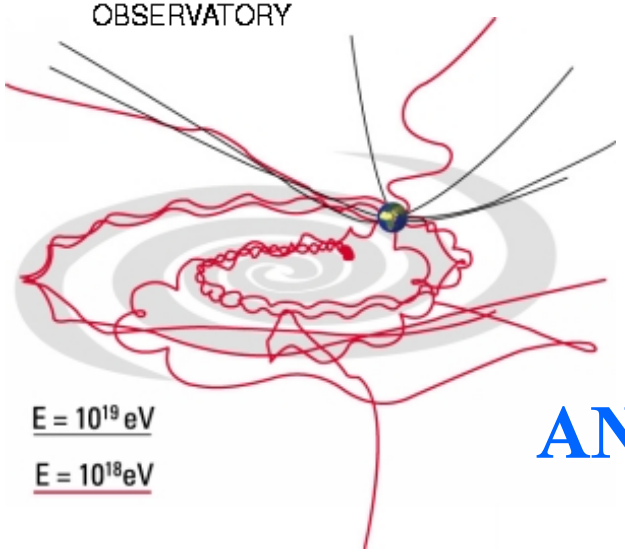
Rencontres de Vietnam – August 7, 2006




## Nature and Origin of UHECRS: ENIGMATIC

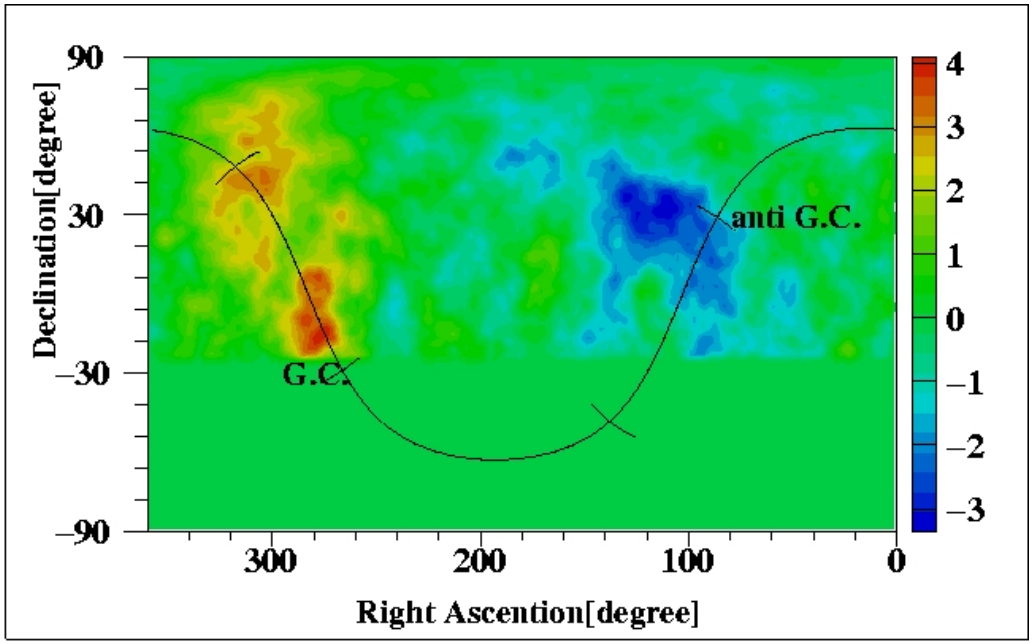
CR ASTRONOMY ←→ MAGNETIC FIELDS

## ANISOTROPIES: CLUES TO ORIGIN ?

**Data reported here ~ 50% annual exposure of complete Observatory**

- Studies of galactic centre region E ~ EeV ($10^{18}$eV) with significant statistics
- Preliminary searches for anisotropies in other targets

# AGASA: Hints of anisotropy



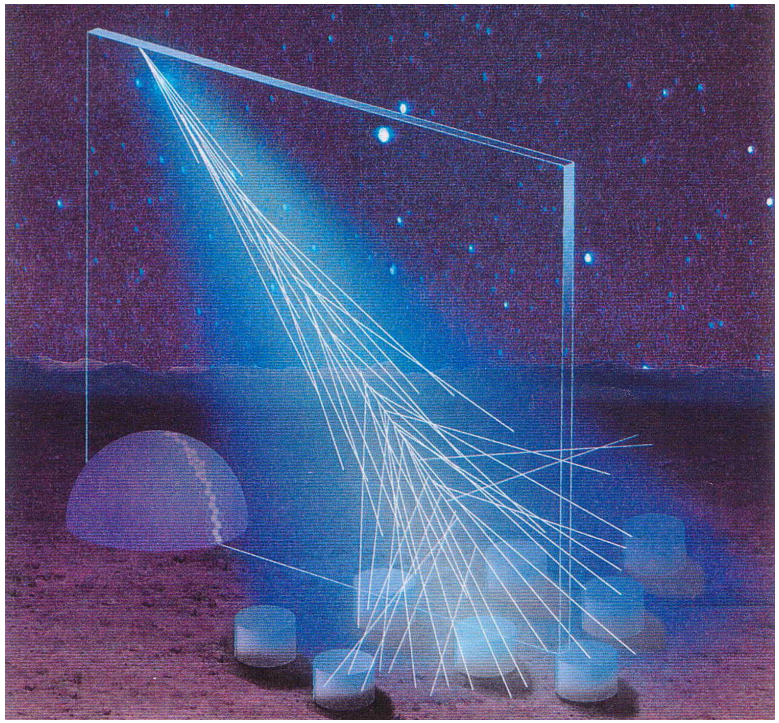

$10^{18}$ eV < E < $10^{18.4}$ eV

AUGER Surface Detector sees GC region 9 hs/day

Statistics already 4 times larger than AGASA in the GC region at these E

# AUGER SOUTHERN OBSERVATORY

**1600 surface detectores spaced 1.5 km over 3000 km$^2$**
**and 24 fluorescence telescopes in 4 “eyes”**



## SPECIAL DESIGN FEATURES

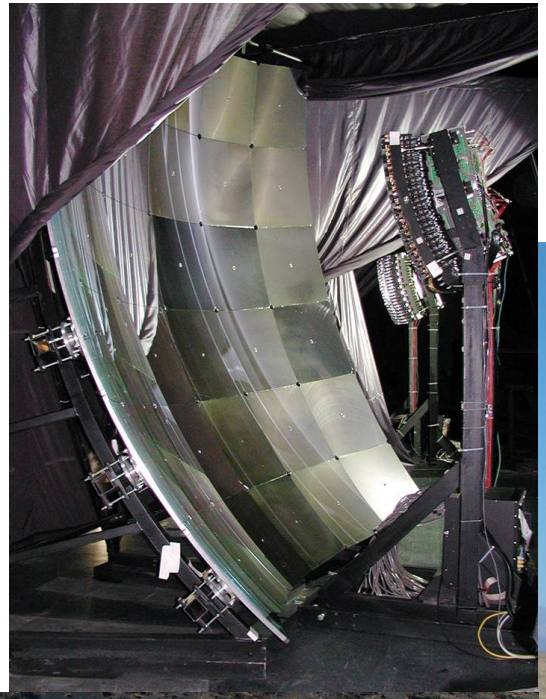
**Surface detectors:** “statistical engine” for showers on the ground

**Fluorescence detectors:** complementary view of shower development

**Hybrid operation:**
**precision energy and angular calibration, consistency checks, etc.**

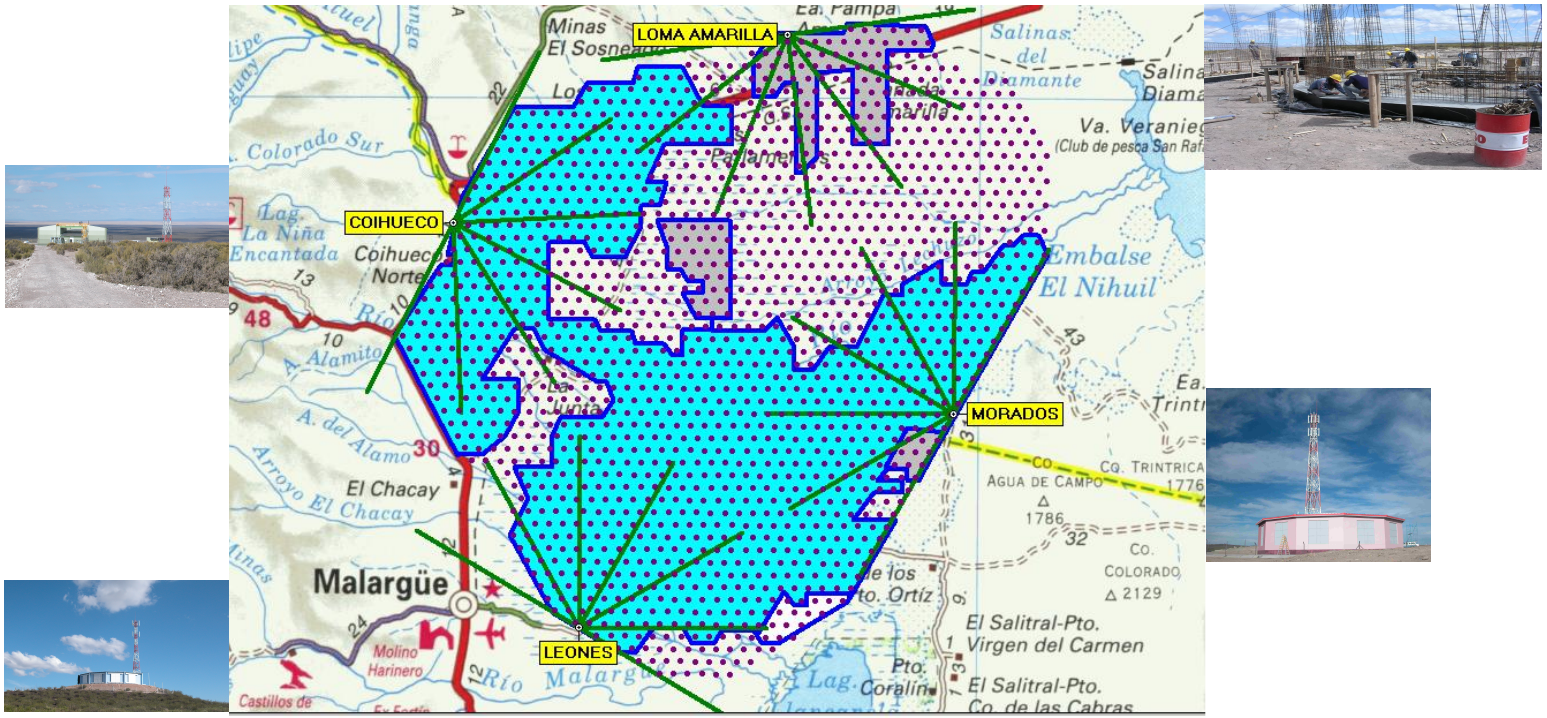
PIERRE AUGER OBSERVATORY

**Fluorescence detectors**



Surface detectors

**Data set reported here: January 1st 2004 → March 30th 2006**
**154 detectors → 930 detectors**




## Events statistics (SD)

Energy (eV) $10^{17.9}$-$10^{18.5}$

# of events: 79265

$\theta_{max} = 60°$ - Level 5 quality trigger

(hexagon of active stations around hottest tank)

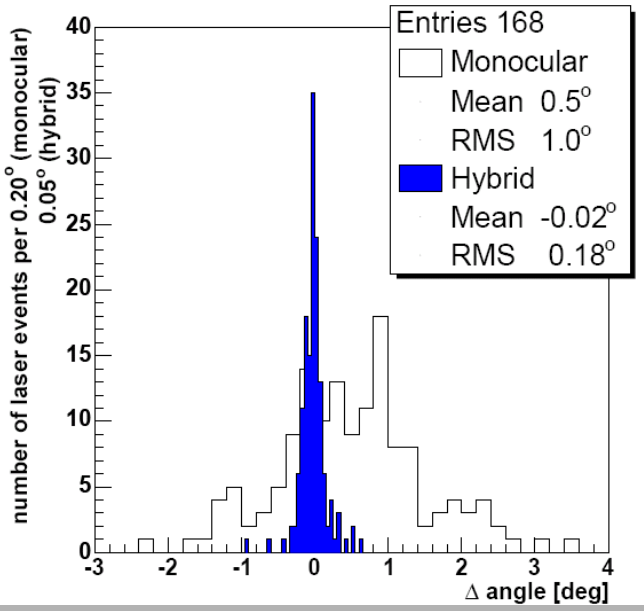
# Angular Resolution

## Surface Detectors

**determined by timing uncertainties (~ 12 ns)**

**< 1°** E > 10EeV

| A.R. (68% CL) | # of tanks | Typical if |
|---|---|---|
| **< 2.2°** | 3 | E < 3 EeV |
| **< 1.7°** | 4 | 3 EeV < E < 8 EeV |
| **< 1.4°** | 5 or more | E > 8 EeV |

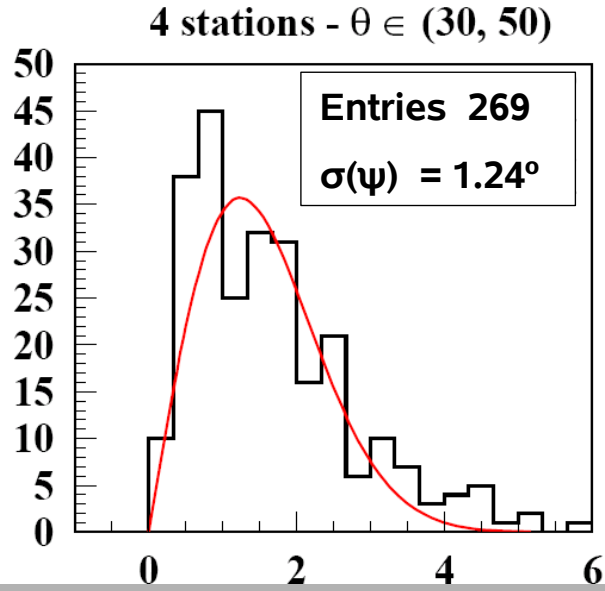



Angle in laser beam /FD detector plane

## Hybrid events

**0.6° (mean)**

**Consistency →**



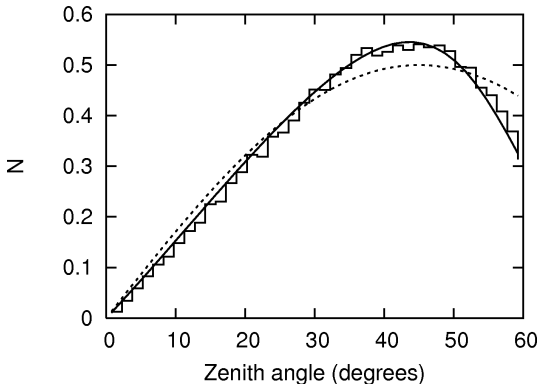

Hybrid-SD only space angle difference

# Relative exposure of the Surface Array

## Two different approaches to estimate isotropic expectations

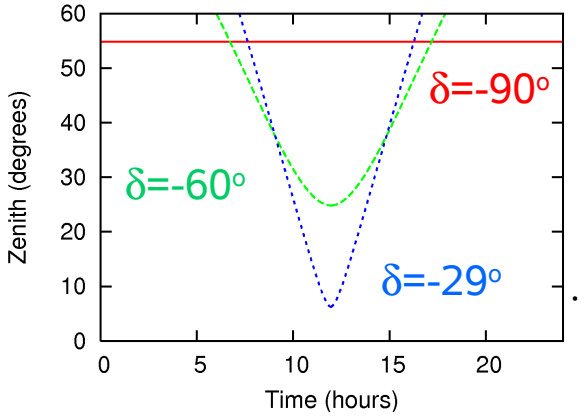
- **Semi-analytic:** coverage almost uniform in azimuth and sidereal time

Declination dependence: from zenith-angle distribution




**dN ~ sinθ cosθ dθ**
**with full acceptance**
**(E > 3 EeV)**

**Fit to data if E < 3 EeV**



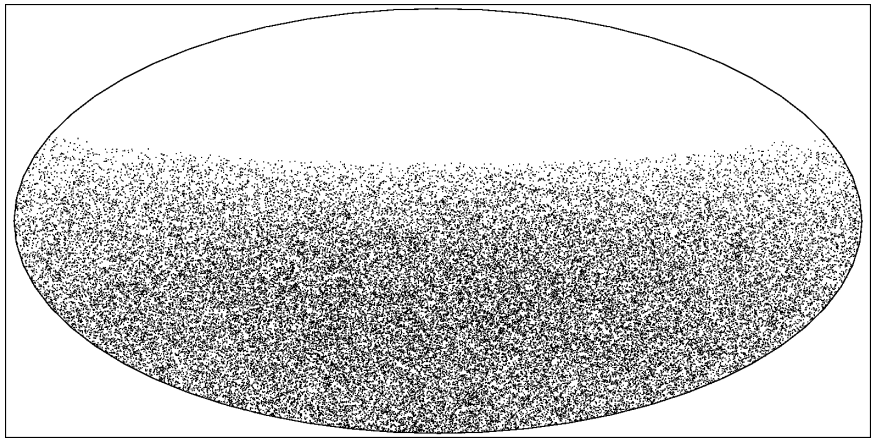

Right ascension modulation: ω(δ,α) due to array growth, dead times

**Evaluated from number of hexagons with active detectors**

- **Shuffling:** Average over many data sets with exchange of arrival times, random azimuths drawn uniformly.

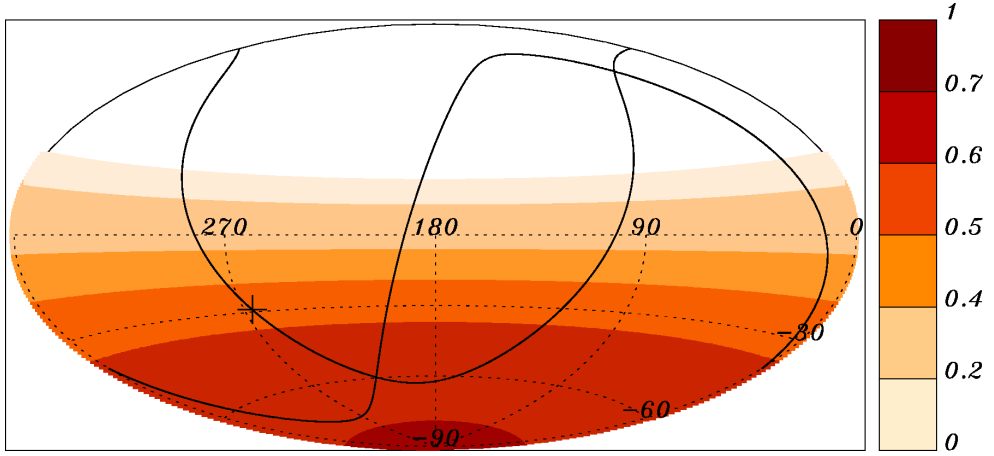
Differences between methods below Poisson fluctuations

Events map

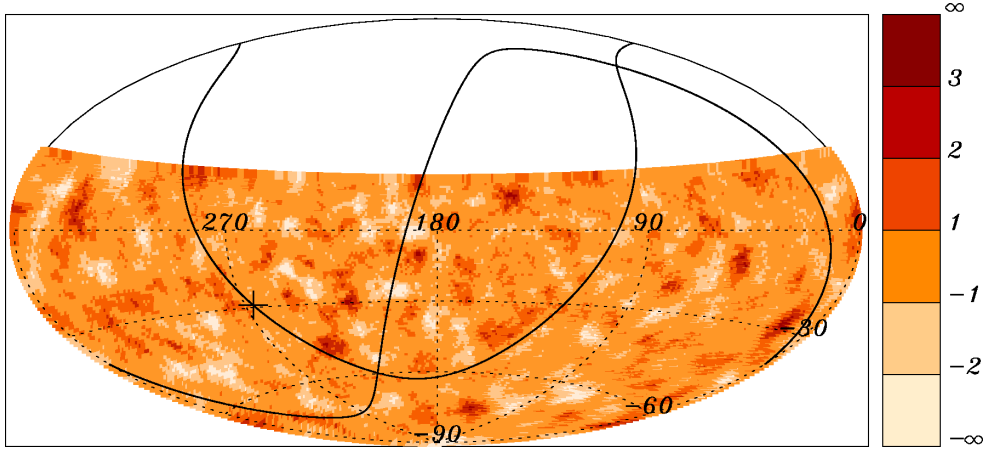


Equatorial coordinates (RA,DEC)

Exposure map
($5^0$ radius windows)



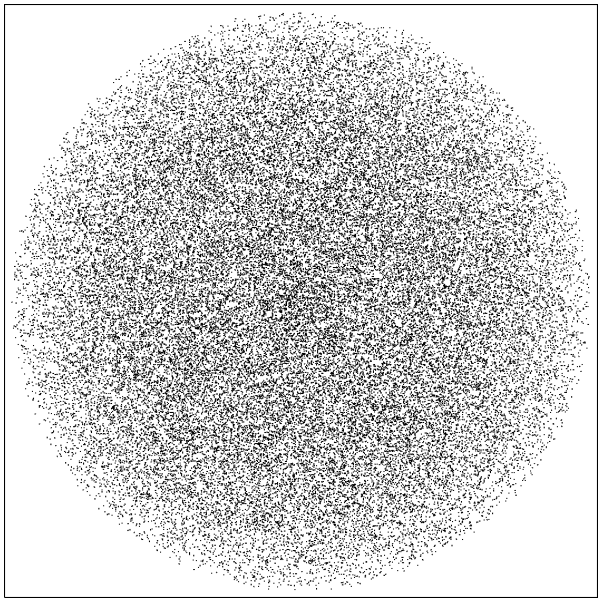

Excesses/defects significance map

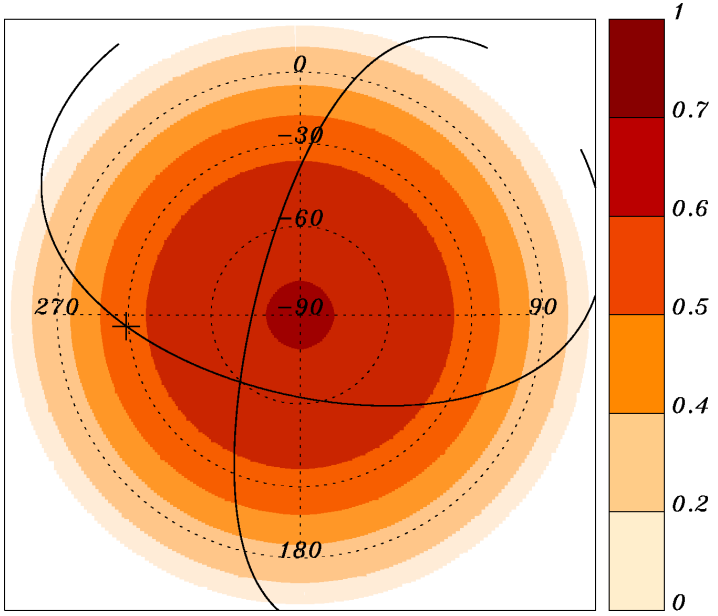



σ

# SOUTHERN PERSPECTIVE

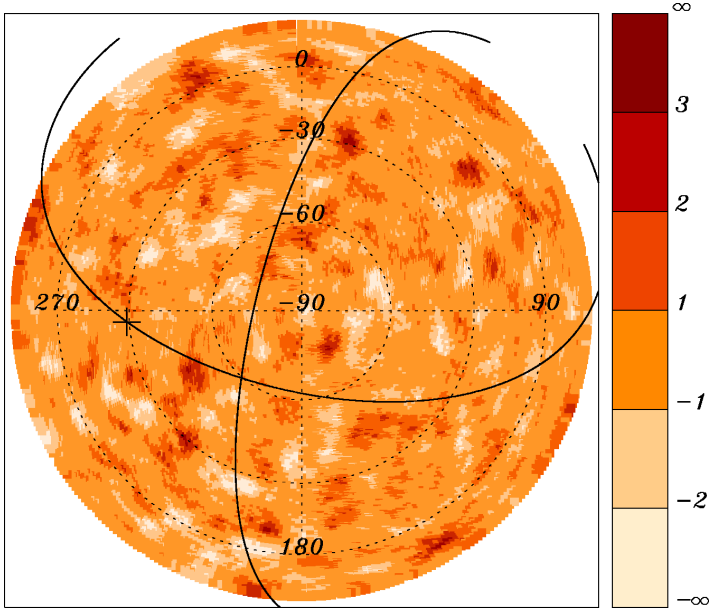
Events map



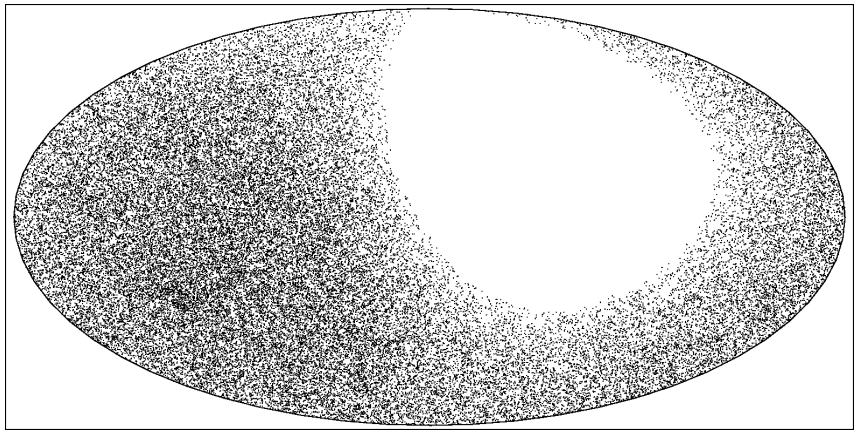



Exposure map

Excesses/defects significance map

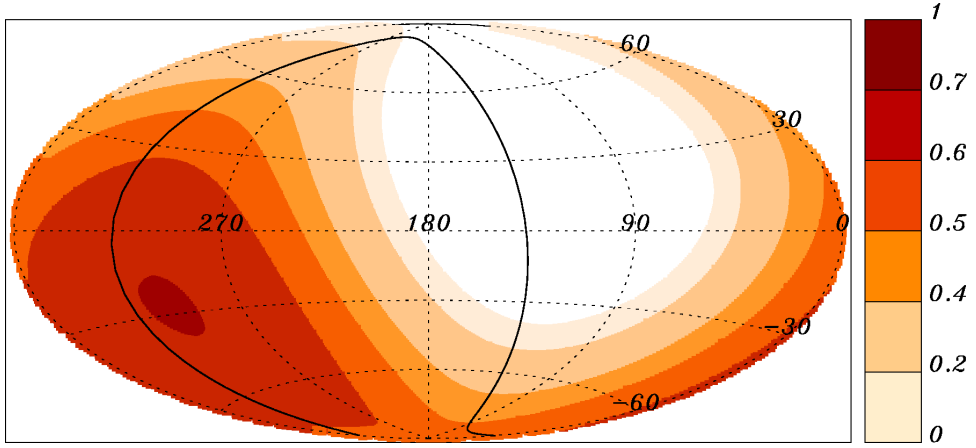


Events map

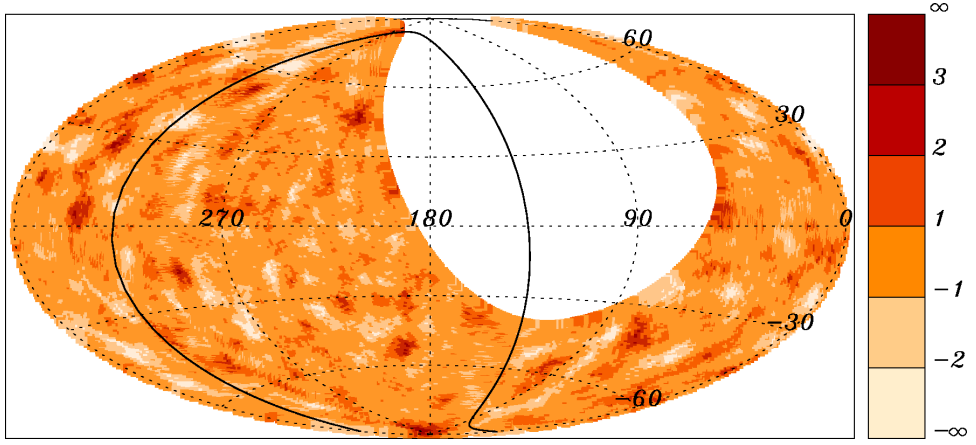


Galactic coordinates (l,b)

Exposure map
($5^0$ radius windows)




Excesses/defects significance map



# PRELIMINARY ANISOTROPY SEARCHES

**1EeV < E < 5 EeV and E > 5 EeV**

## TARGETS:

**All sky, 5° radius top-hat windows**

**GALACTIC PLANE:** band with galactic latitude $|b_G| < 10°$

**SUPERGALACTIC PLANE:** band with $|b_{SG}| < 10°$

**Excesses/defects compatible with isotropic expectations**

# ANISOTROPY STUDIES AROUND THE GALACTIC CENTRE AT EeV ENERGIES

astro-ph/0607382

## Attractive target:

- Galactic component of CRs still dominant at EeV energies?
- Potential accelerators: Massive black hole in Sagittarius A*, expanding SN remnant Sagittarius A East.
- TeV gamma-ray source, region of extended emission in central 200 pc (H.E.S.S.)
- High exposure of Southern Observatory (GC 6$^{o}$ from zenith)
- Previous reports of excesses

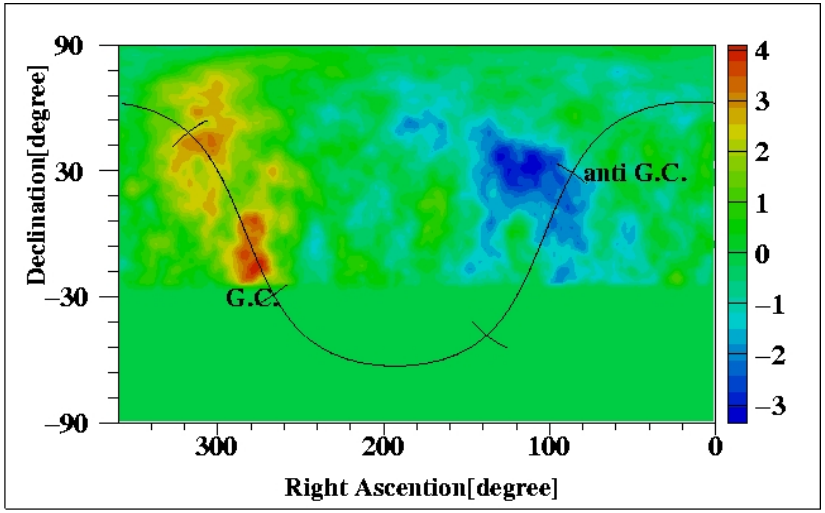
# Testing previous reports of excesses

**AGASA: 506/413.6 ( 22% excess)**

**$10^{18}$ eV < E < $10^{18.4}$ eV**

**20° radius window around (280°,-17°)**

**(Hayashida et al 1999)**

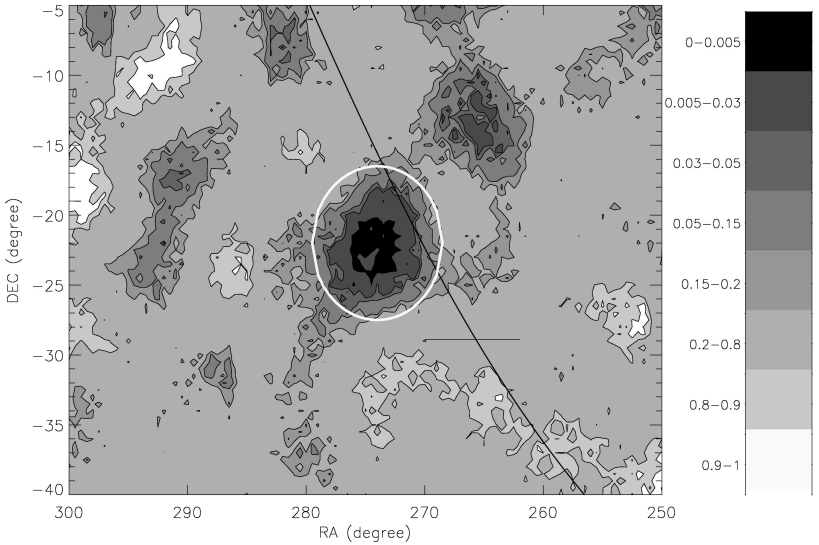



**SUGAR: 21.8/11.8 (85% excess)**

**$10^{17.9}$ eV < E < $10^{18.5}$ EeV**

**5.5° radius window around (274°,-22°)**

**(Bellido et al 2001)**




**AUGER: 2116 / 2159.5**

**= 0.98 ± 0.02**

**AUGER: 286 / 289.7**

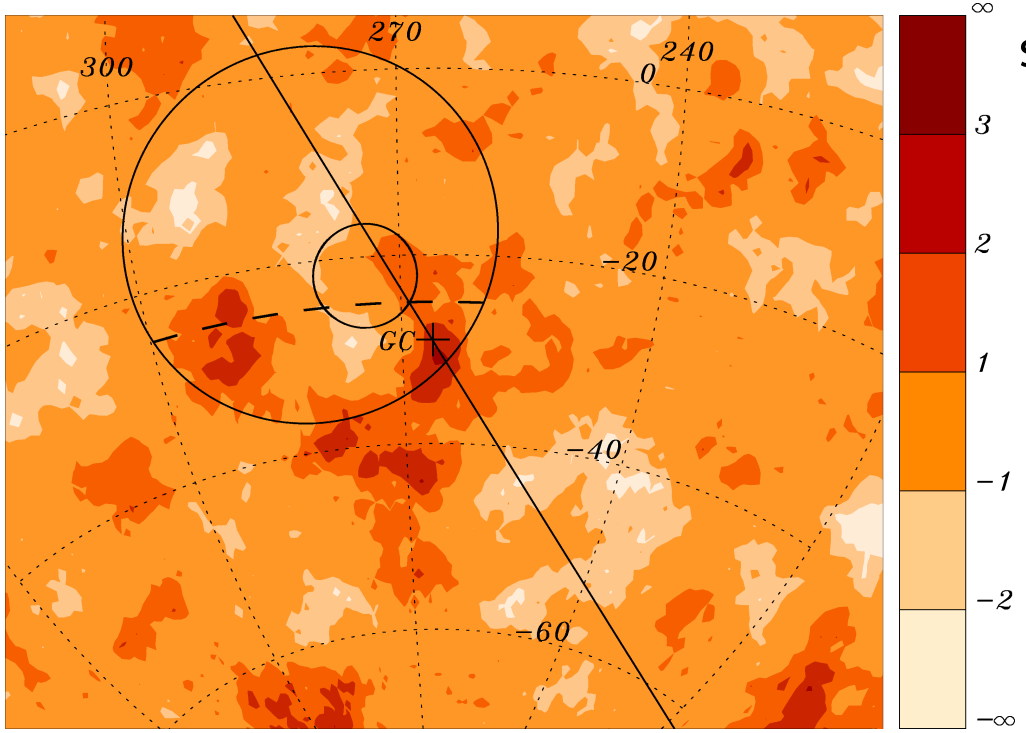
**= 0.98 ± 0.06**

**22% excess would have been 2634 events (10 σ)**

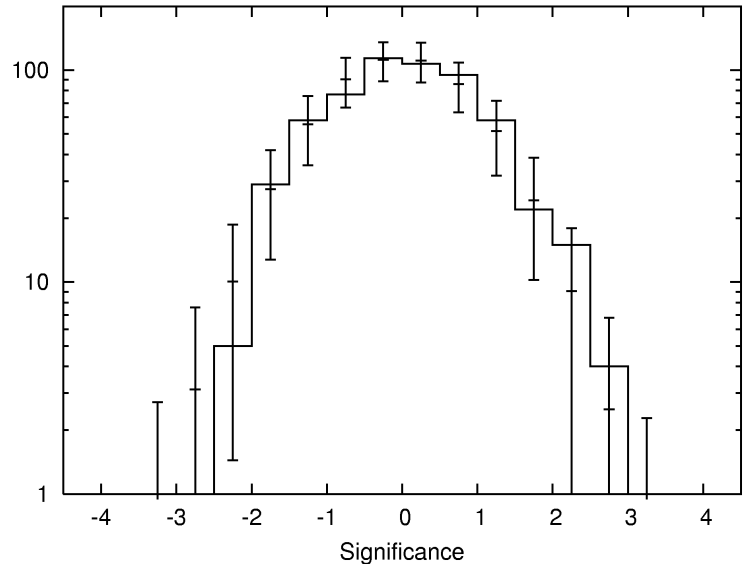
# THE GALACTIC CENTRE REGION

## $10^{17.9}$ eV < E < $10^{18.5}$ eV

PIERRE AUGER OBSERVATORY




Sky map and distribution of significances of overdensities near the GC on 5° radius windows




| $E_{min}$[eV] | $E_{max}$[eV] | $n_{obs} / n_{exp}$ |
|---|---|---|
| $10^{17.9}$ | $10^{18.3}$ | $3179 / 3153.5 = 1.01 \pm 0.02(stat) \pm 0.01(syst)$ |
| $10^{18}$ | $10^{18.4}$ | $2116 / 2159.5 = 0.98 \pm 0.02(stat) \pm 0.01(syst)$ |
| $10^{18.1}$ | $10^{18.5}$ | $1375 / 1394.5 = 0.99 \pm 0.03(stat) \pm 0.01(syst)$ |

Events in 20° radius AGASA region

- Energy: calibrated with clean fluorescence data
  Less than 35% dispersion SD/FD in this energy range

- Energy shifts: to account for potential systematic difference in calibration between experiments.

- Acceptance effects: different for source than background?
  Acceptance to p 30% smaller than to Fe in this energy range.
  22% excess with full acceptance → 15% excess

**OUR RESULTS DO NOT SUPPORT PREVIOUS FINDINGS OF LOCALIZED EXCESSES IN GC REGION**

Anisotropies on large scales (dipole): future work
Require control of potential weather effects
Possible weather-induced modulations ~1% (preliminary)

# Bounds on a point-like neutron source at the GC

$10^{17.9}$ eV < E < $10^{18.5}$ eV (79265 SD events)

Note that $\gamma c\tau_n \sim 9$kpc E/EeV (and GC is 8.5 kpc away)

- Gaussian filter: $\exp(-\beta^2/2\sigma^2)$ $\beta$: angle to Sgr A* $\sigma=1.5^o$ (angular resolution 2.2°)

**$n_{obs}$ / $n_{exp}$ = 53.8 / 45.8 → $n^{95}_{source}$ < 18.5 (95% CL)**

Assume $\Phi_{source}(E) \sim \Phi_{CR}(E)$ and same acceptance to source and bulk

with $\Phi_{CR}(E) = \xi\ 30\ (EeV/E)^3 (EeV\ km^2\ yr\ sr)^{-1}$ ( $\xi \sim 1$ )

**→ $\Phi^{95}_{source} < \xi\ 0.08\ km^{-2}\ yr^{-1}$ (95% CL)**

# Bounds on a point-like neutron source at the GC

$\Phi^{95}_{source} < \xi\ 0.08\ km^{-2}\ yr^{-1}$

$10^{17.9}$ eV < E < $10^{18.5}$ eV

- Acceptance effects: bound 1.3 times weaker if background is Fe

- Same bound holds for **E > $10^{17.9}$ eV**

- $\Phi^{95}_{source} < \xi\ 0.04\ km^{-2}\ yr^{-1}$ for **E > $10^{18}$ eV**

# Bounds on a point-like neutron source at the GC

**Hybrid Results** $10^{17.9}$ eV < E < $10^{18.5}$ eV

- 3439 well reconstructed hybrid events (detected by FD and at least 1 SD)

- Better pointing accuracy: 0.7° angular resolution

- Isotropic expectations: shuffling in different epochs

- Optimal top-hat window 0.75° radius centred in Sgr A*:

$$n_{obs} / n_{exp} = 0 / 0.3 \rightarrow \Phi^{95}_{source} < \xi\ 0.15\ km^{-2}\ yr^{-1}$$

- Acceptance effects: conservative bound if background are heavy nuclei

# Bounds on a point-like neutron source at the GC

$$\Phi^{95}_{source} < \xi\ 0.08\ km^{-2}\,yr^{-1}$$

- Rules out several theoretical predictions for neutrons from GC:

*AGASA excess from n → p diffused by galactic B requires $\Phi_n = 6\ km^{-2}\,yr^{-1}$

(M. Tanco, Watson; Bossa, Mollerach, Roulet - 2003)

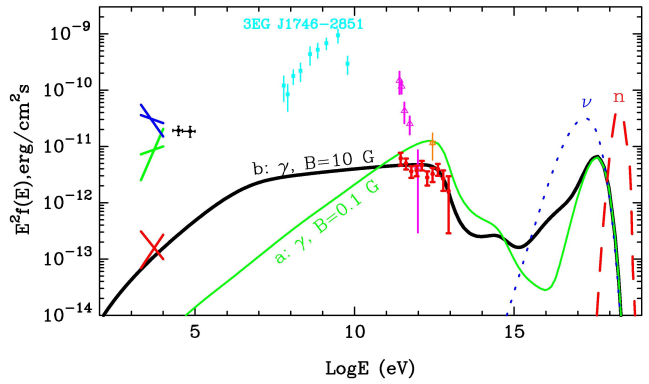
*TeV γ's from Sgr A* from photo-meson interactions predict $\Phi_n = 30\ km^{-2}\,yr^{-1}$

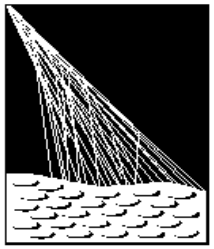
(Aharonian, Neronov - 2004)

- TeV γ's from Sgr A East predict flux of n from uhecr-photodisintegration at the level of present bound (Grasso, Maccione - 2005)
- Bound does not apply straightforwardly to photons

**H.E.S.S. measurement at TeV:**
**$F(E)=0.06\ (E/EeV)^{-2.2}\ km^{-2}\ yr^{-1}\ EeV^{-1}$**

**Naive extrapolation: $\Phi\gamma \sim 0.04\ km^{-2}\,yr^{-1}$**






# CONCLUSIONS

**Observatory still under construction**
**Data reported here ~ 50% annual exposure with complete Observatory**

- No significant localized excesses detected in ranges 1 EeV < E < 5 EeV and E > 5 EeV with present statistics. Arrival directions compatible with isotropy.

- Our results do not support previous findings of localized excesses in Galactic Centre region at E ~ $10^{18}$ eV

- Significant bound on flux of neutron point-source in Galactic Centre

$$\Phi^{95}_{source} < \xi\ 0.08\ \mathrm{km^{-2}\,yr^{-1}} \quad 10^{17.9}\ \mathrm{eV} < E < 10^{18.5}\ \mathrm{eV}$$

# PERSPECTIVES

**Significant increase in statistics**

**Searches in other energy ranges/angular windows**

**Searches for large scale anisotropies**

**Searches for autocorrelation and correlation with astronomical objects**