Ultra-high Energy nuclei source in Virgo galaxy cluster

Dmitri Semikoz

APC , Paris

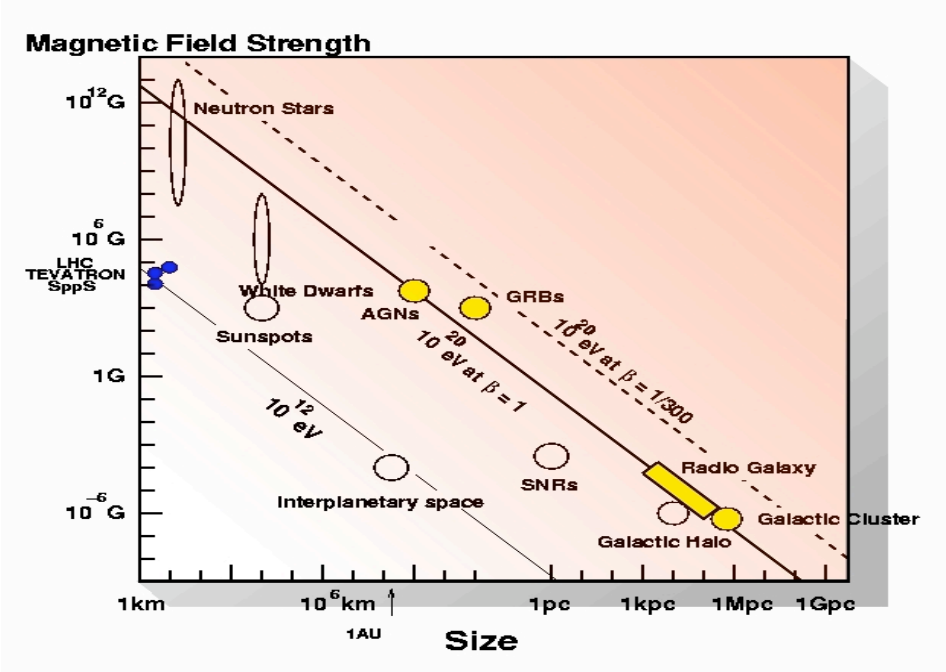
in collaboration with G.Giacinti

arXiv:1011.6333

Overview:

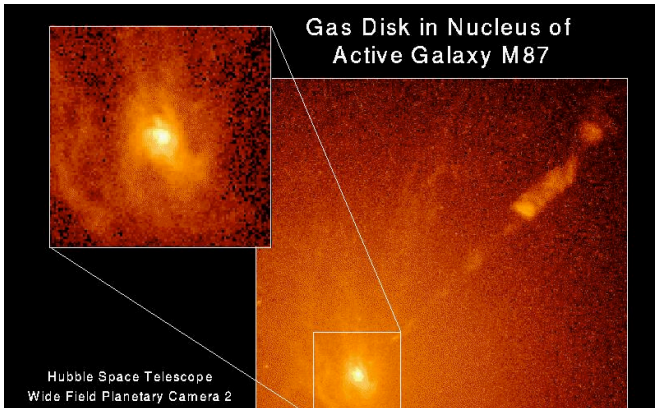
- *UHECR spectrum and composition*
- *Arrival directions and magnetic field*
- *Method for search for UHE nuclei sources*
- *Application to the Auger data*

Acceleration of UHECR

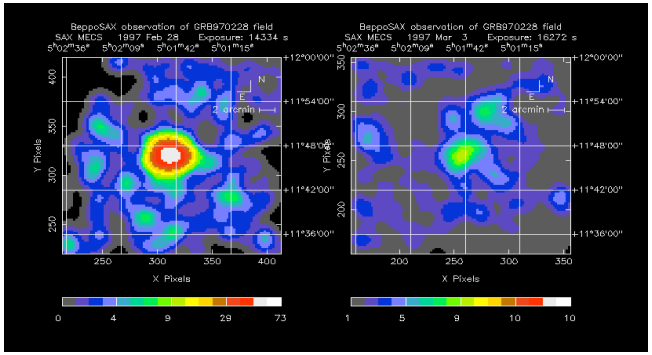


- Shock acceleration $1/E^{\alpha}$ $\alpha>=2$
- Electric field acceleration line at E_{max}
- Converter acceleration can be both

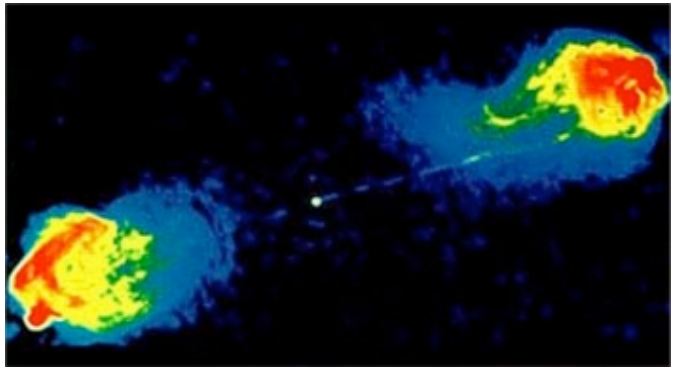
A.G.N.



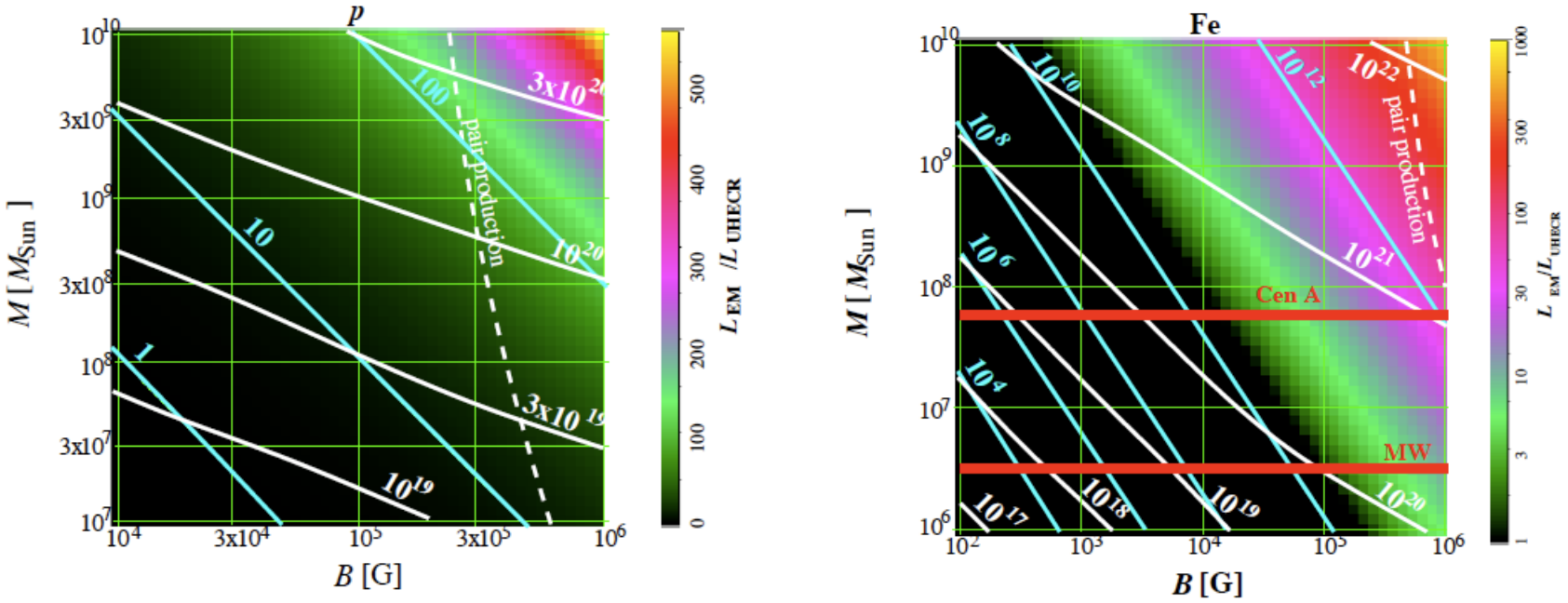
GRB



Radio Galaxy Lobe



Acceleration in polar cap of Black Hole by the electric field

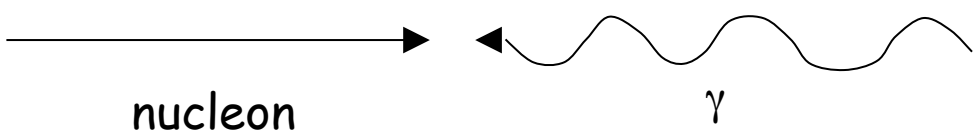


A.Neronov, D.Semikoz and I.Tkachev astro-ph/0712.1737

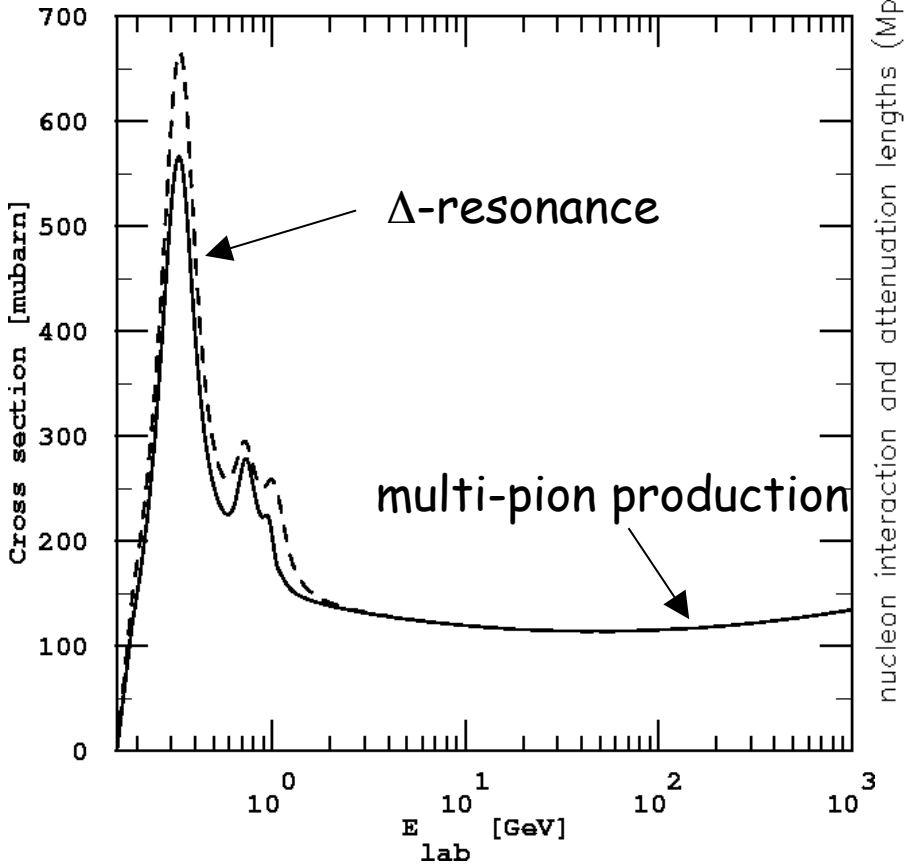
UHECR spectrum and composition

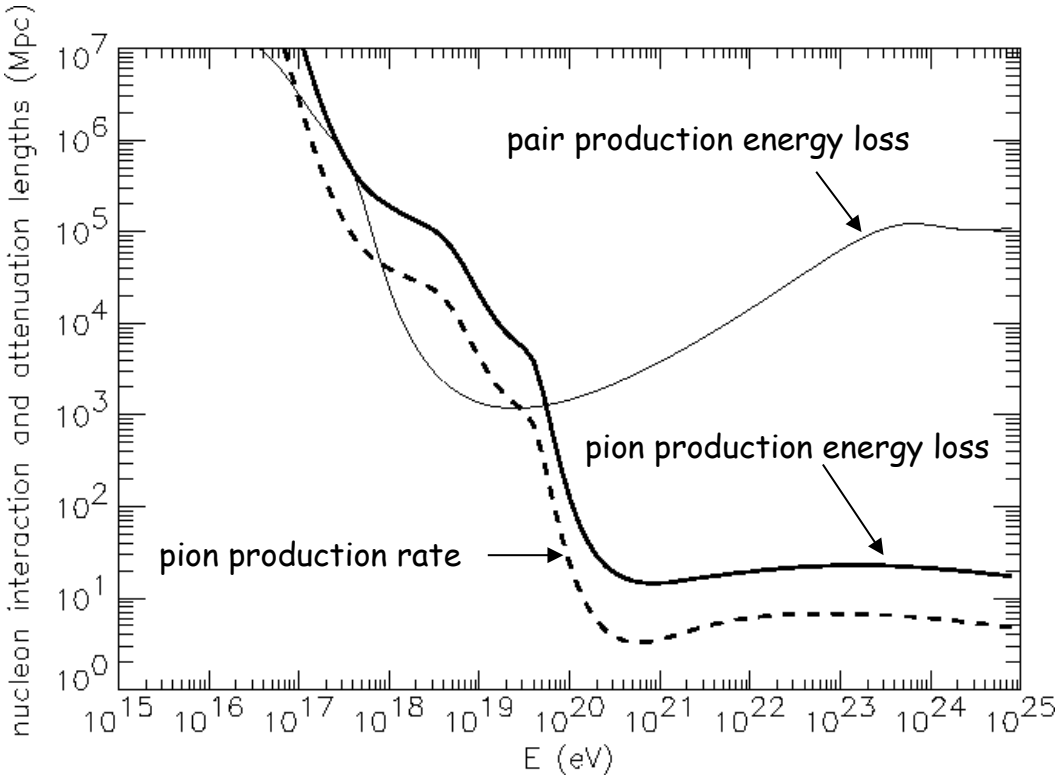
The Greisen-Zatsepin-Kuzmin (GZK) effect

Nucleons can produce pions on the cosmic microwave background



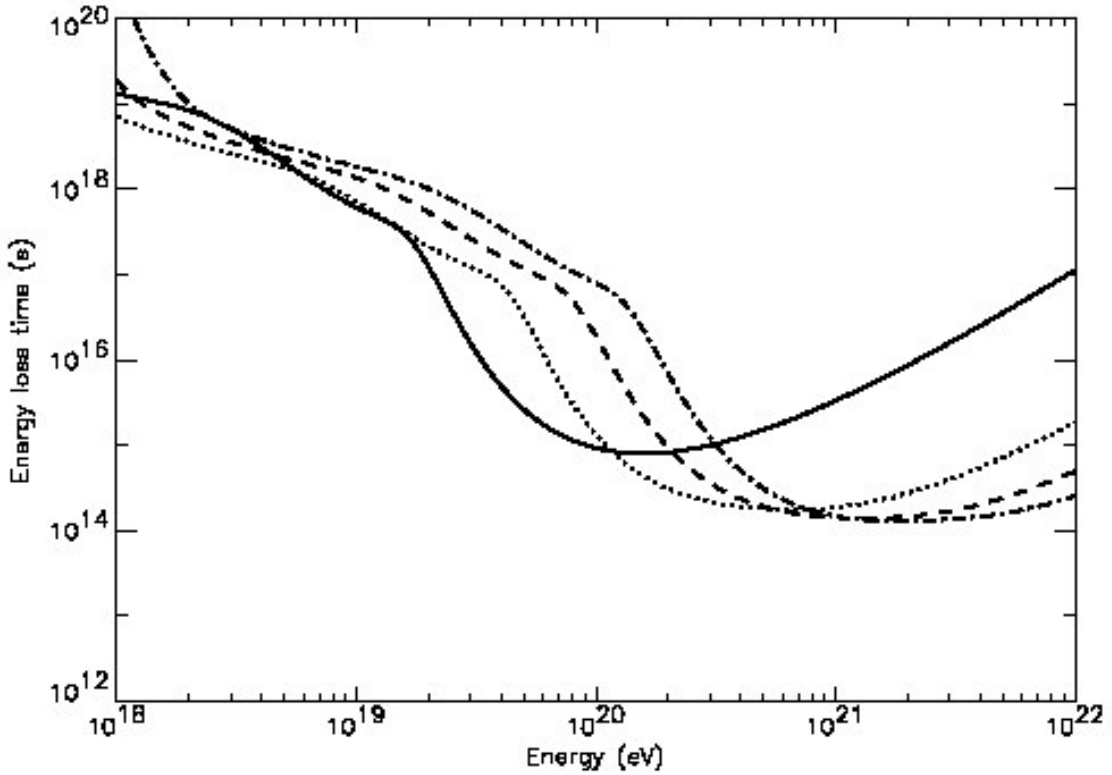
$$E_{th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \approx 4 \cdot 10^{19}\,\mathrm{eV}$$





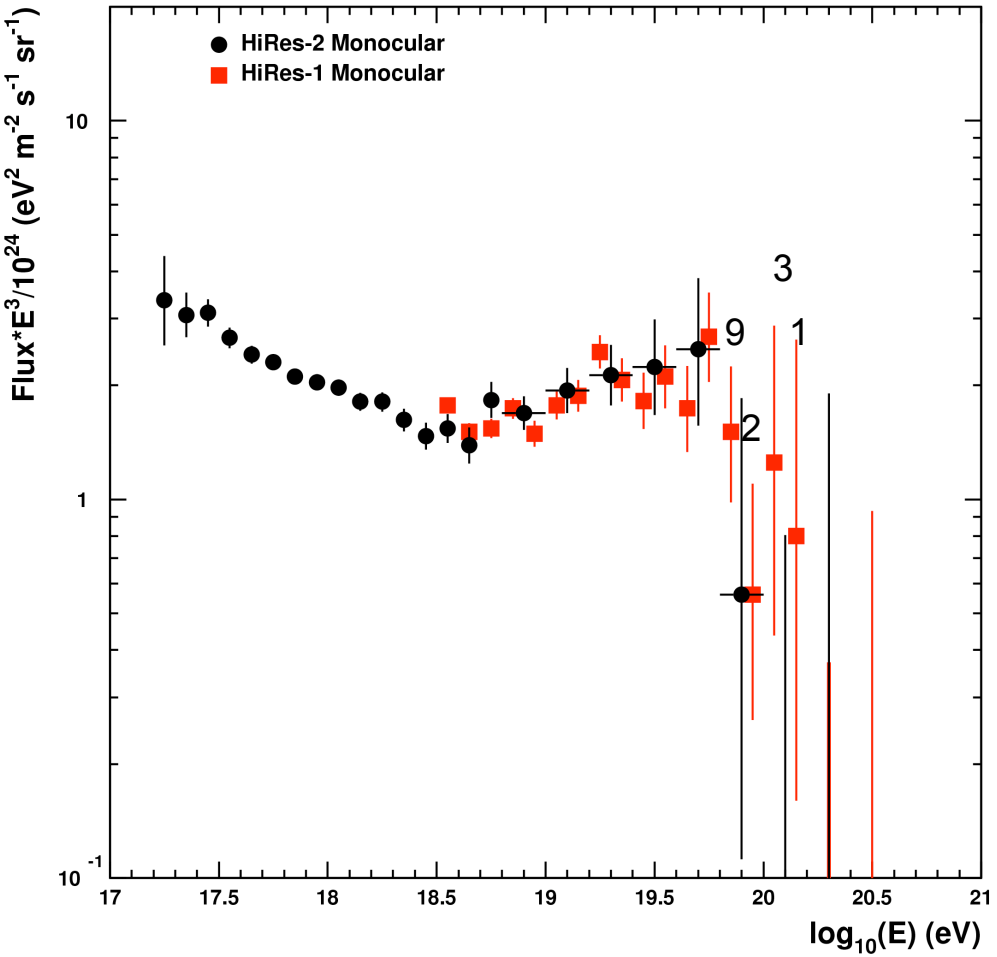
⇒sources must be in cosmological backyard within 50-100 Mpc from Earth
(compare to the Universe size ~ 5000 Mpc)

Same true for heavy nuclei: Fe



Simulation by D.Allard

HiRes: cutoff in the spectrum

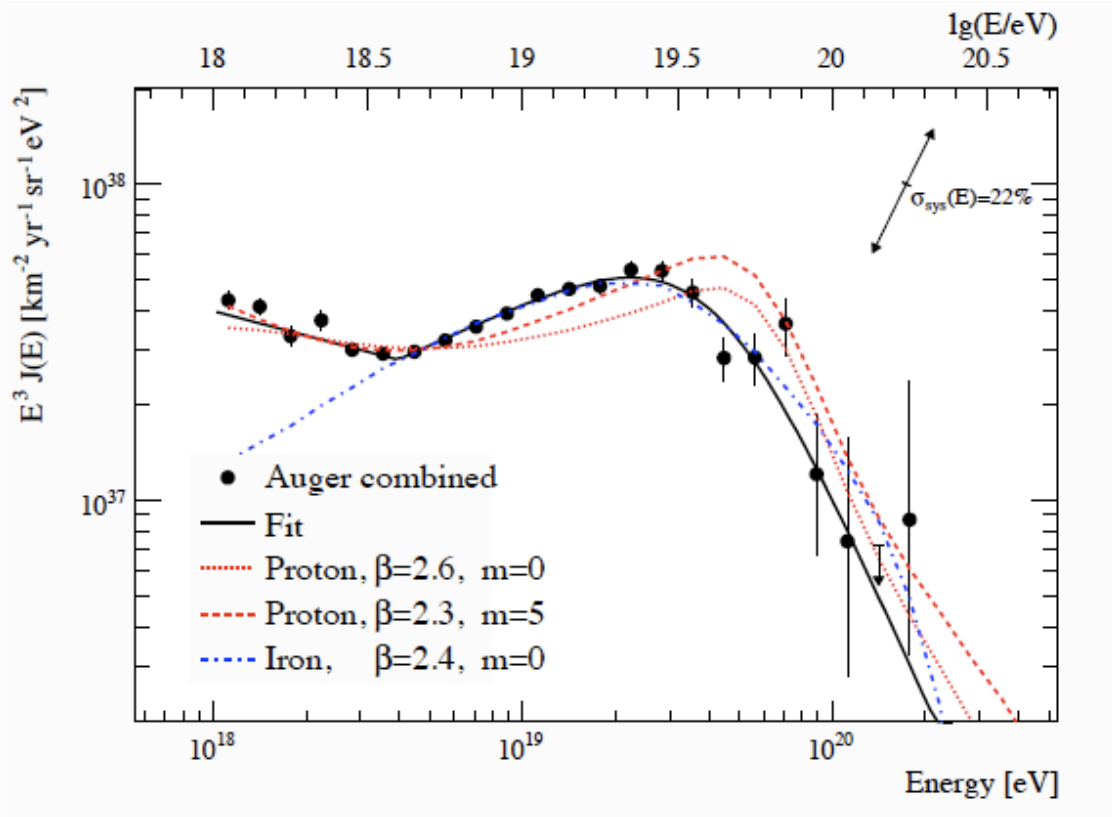


"GZK" Statistics

- Expect 42.8 events
- Observe 15 events
- ~ 5 σ

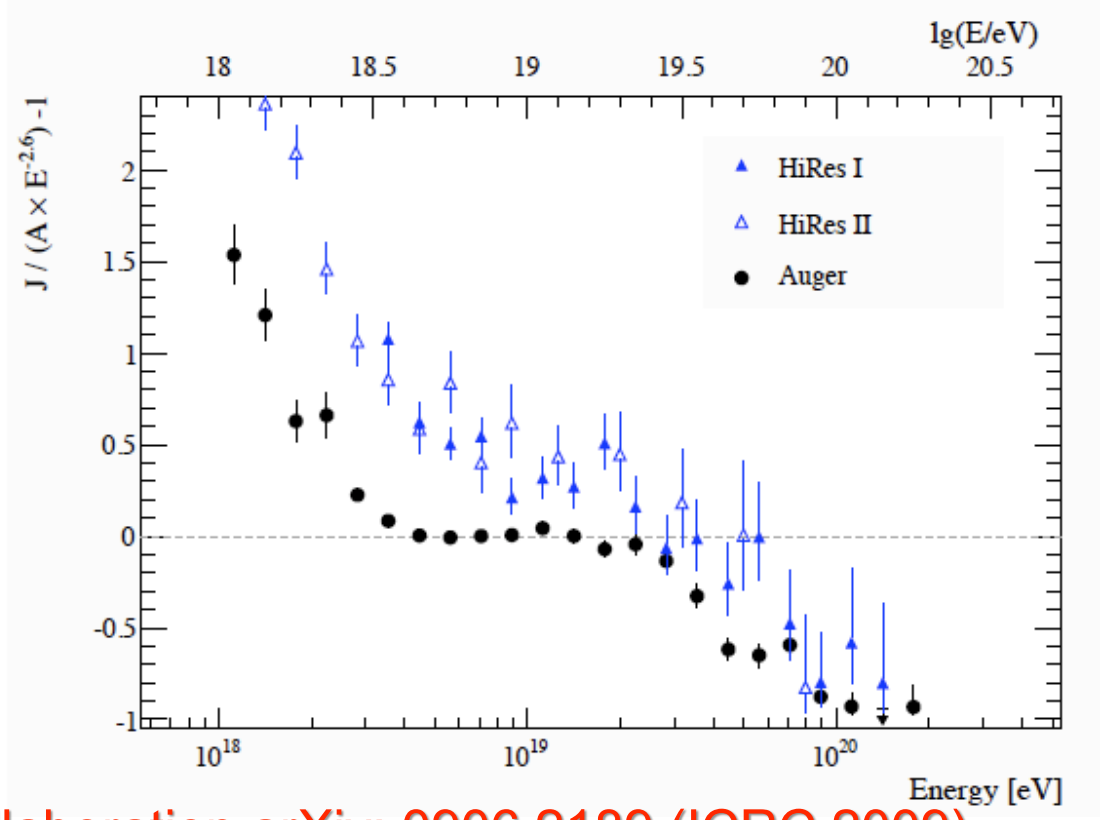
Bergman (ICRC-2005)

Auger Energy Spectrum 2009



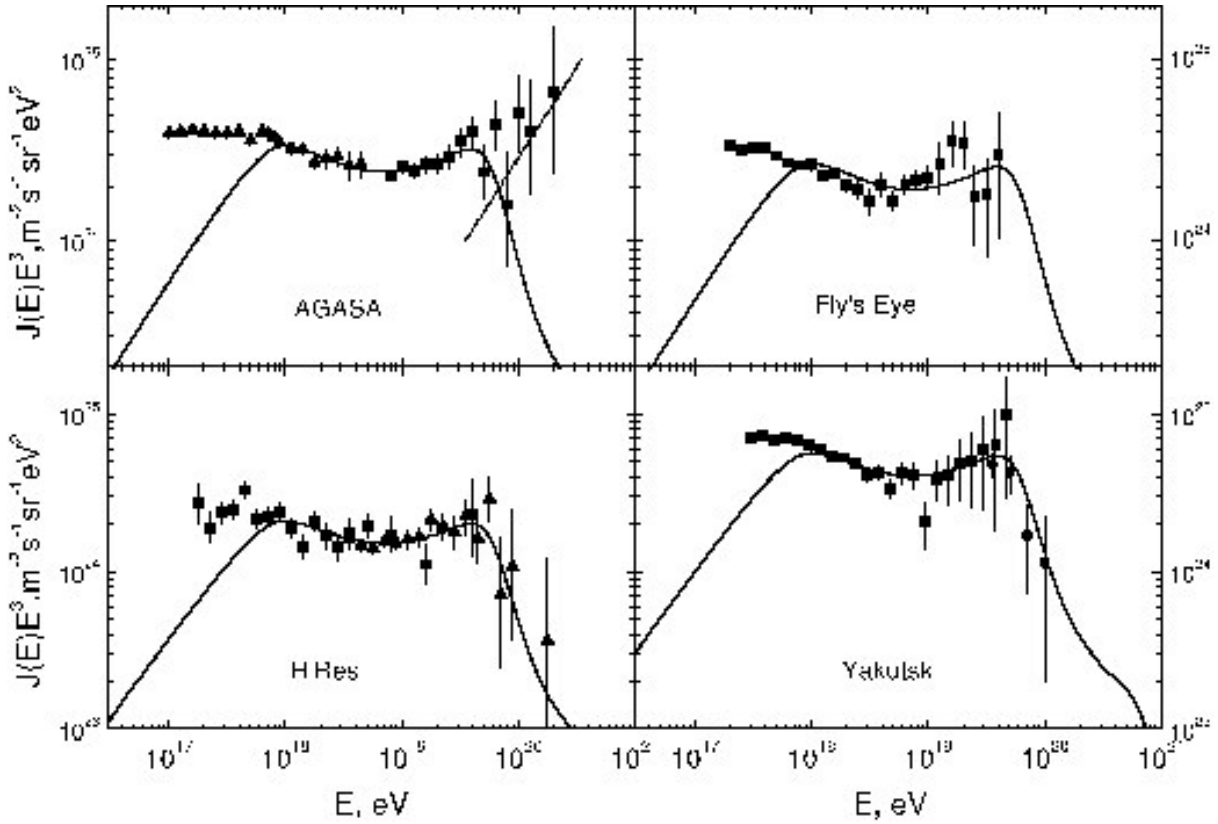
Auger collaboration arXiv: 0906.2189 (ICRC 2009)

Auger Energy Spectrum 2009



Auger collaboration arXiv: 0906.2189 (ICRC 2009)

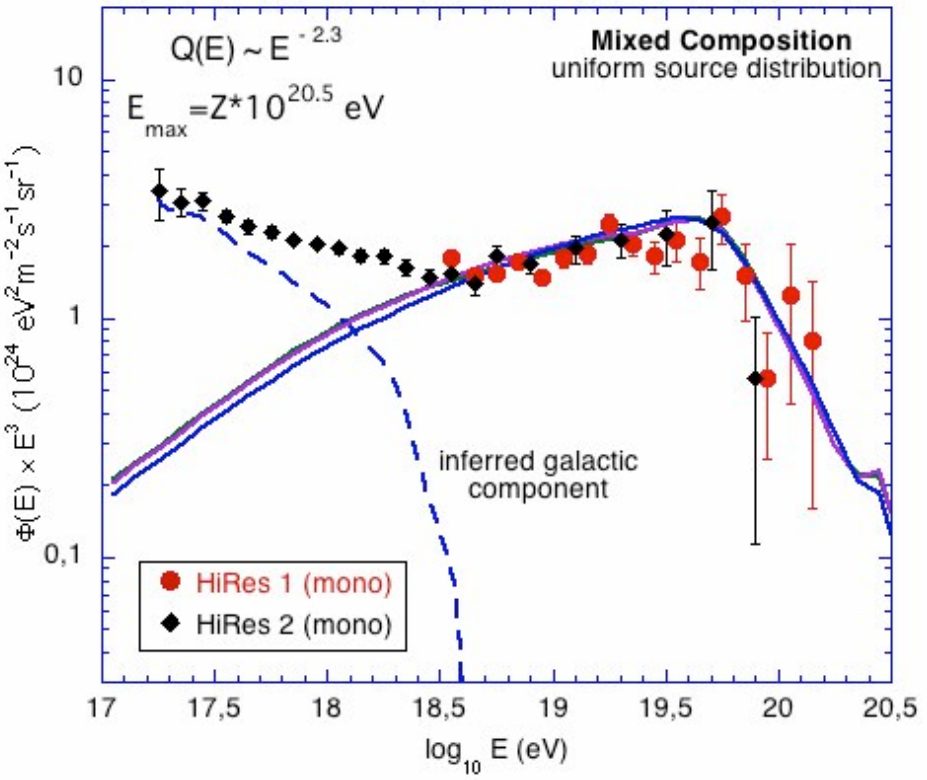
Protons can fit UHECR data



V.Berezinsky , astro-ph/0509069

problem: composition

Mixed composition model

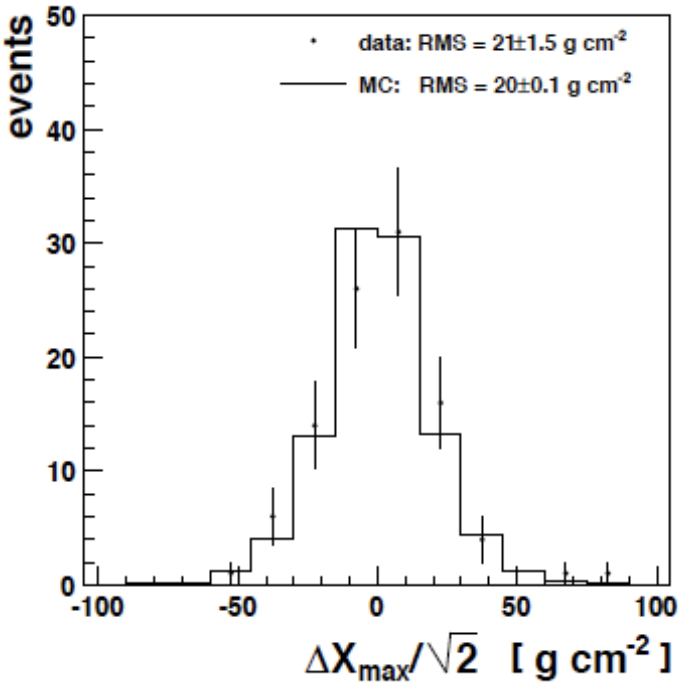


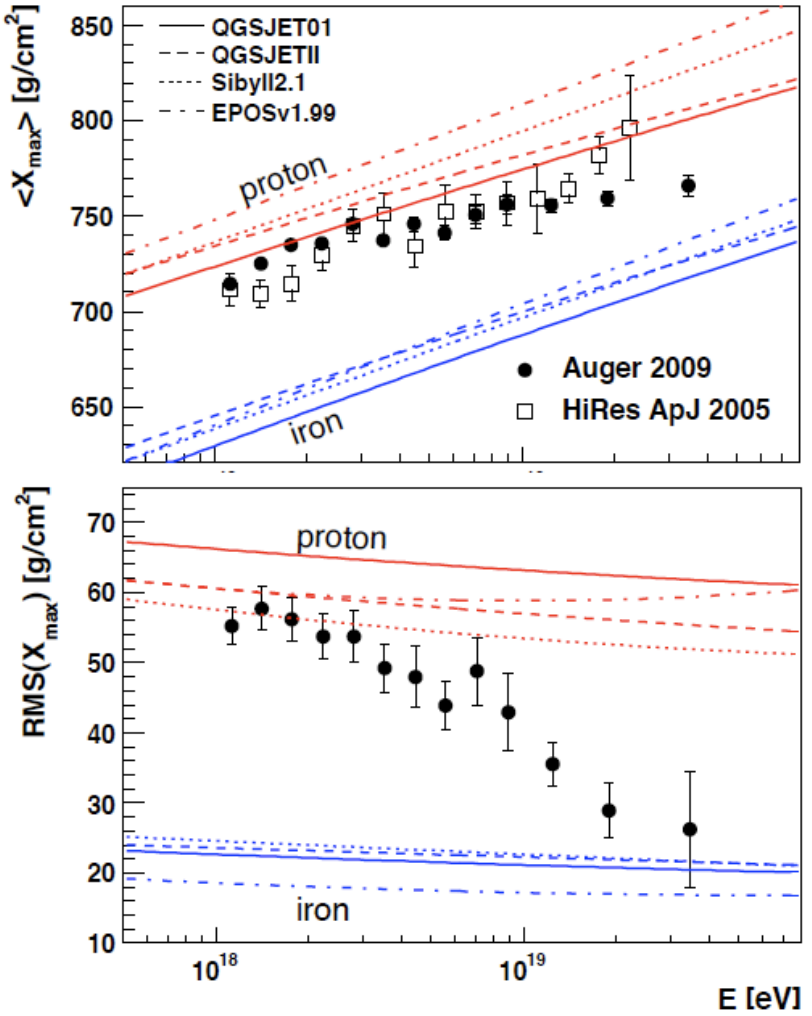
D.Allard, E.Parizot and A.Olinto, astro-ph/0512345

Problems: 1) escape of the nuclei from the source

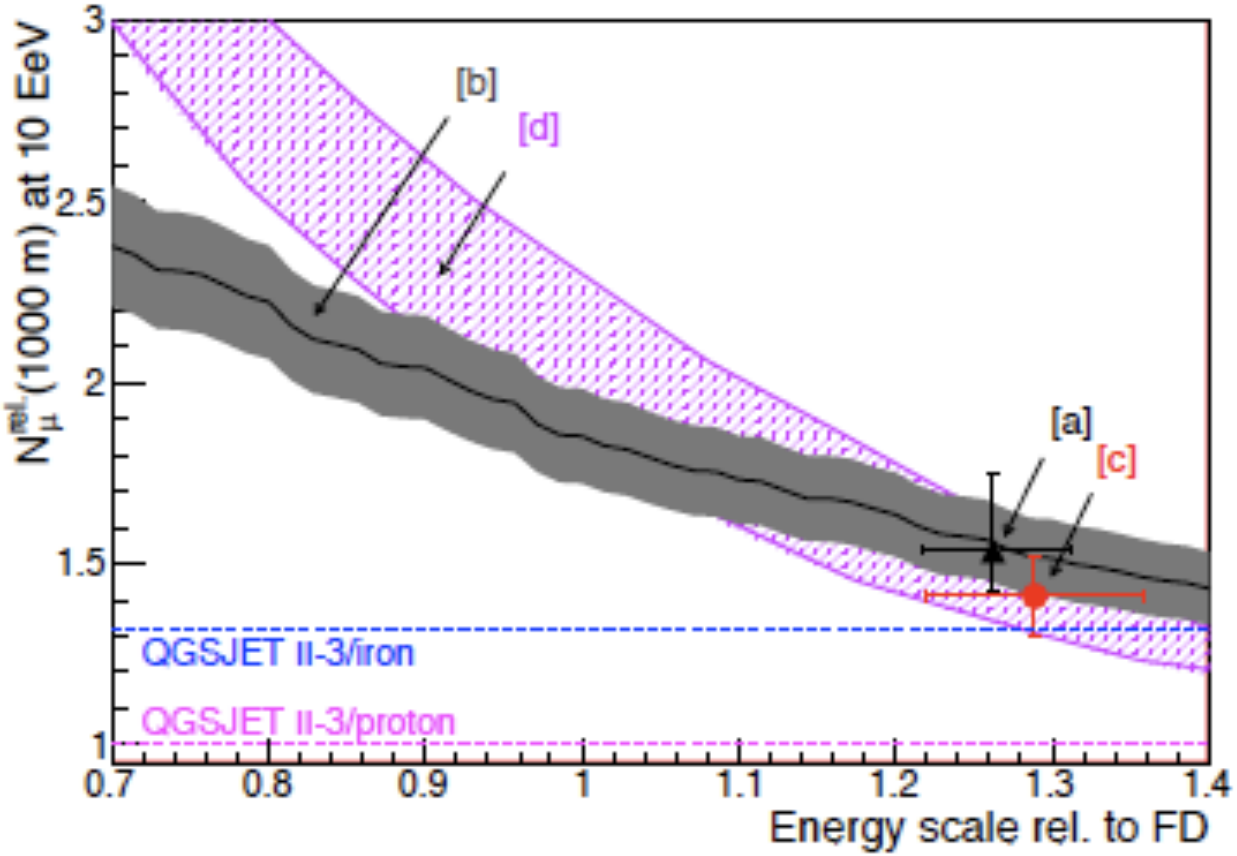
2) How to accelerate Fe in our Galaxy

Auger composition 2009: nuclei!

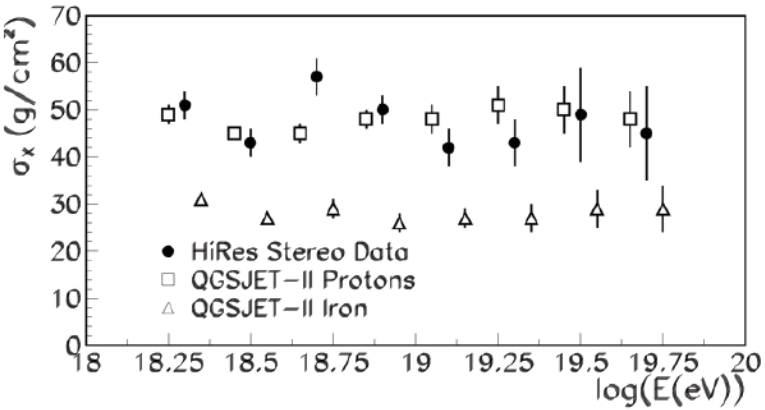


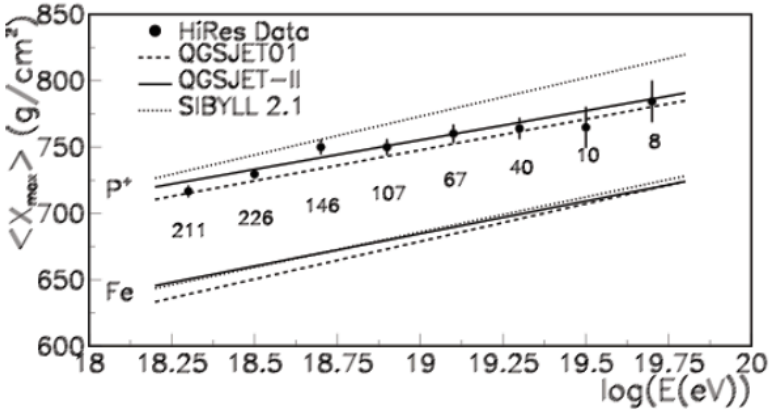


Muon number in Auger



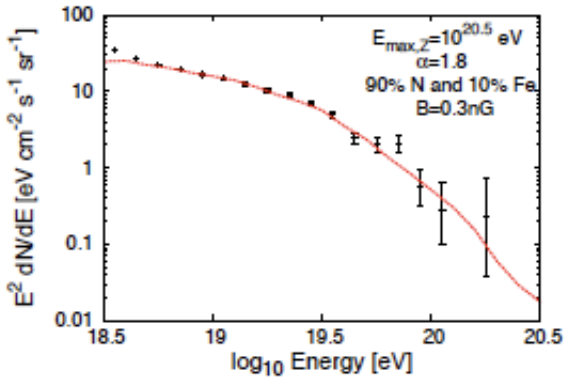
HiRes composition

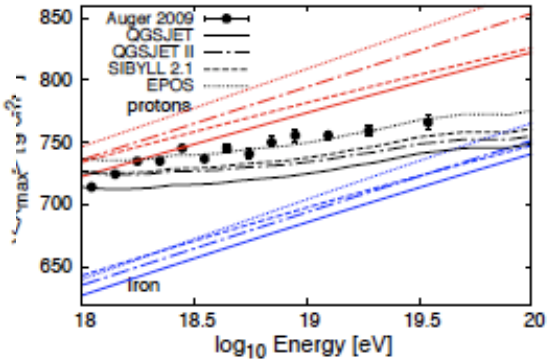


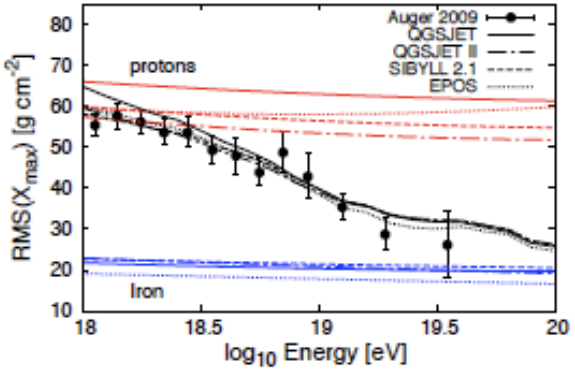


From 1010.2690

Can one explain nuclei + cutoff?





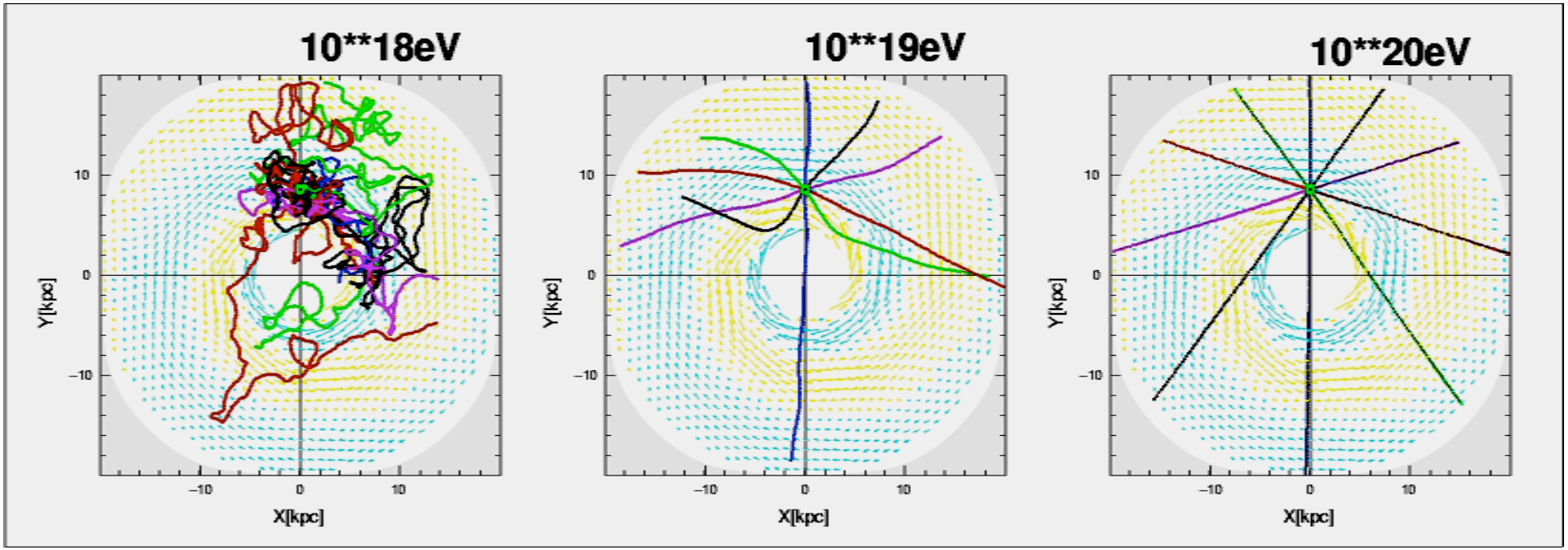


D.Hooper and A.Taylor 0910.1842

Arrival directions of UHECR and magnetic fields.

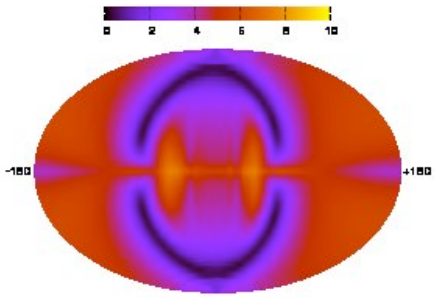
UHECR proton propagation in Milky Way

- Deflection angle ~ 1-2 degrees at 10^{20}eV for protons
  - Astronomy by hadronic particles?

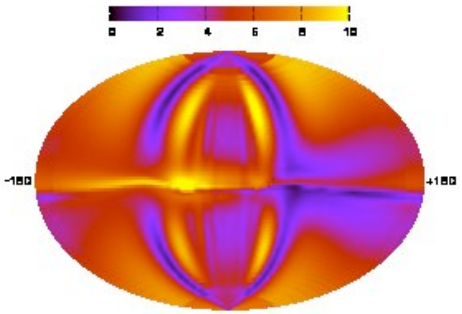


Uncertainty of GMF models

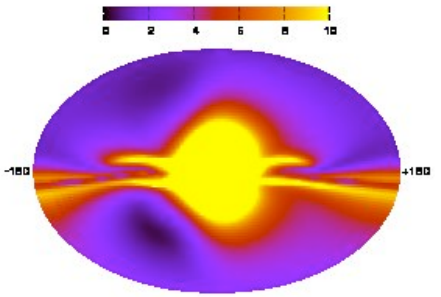
- From M.Kachelriess et al, astro-ph/0510444
- Protons with energy $4*10^{19}$ eV deflection in galactic magnetic field.



TT model

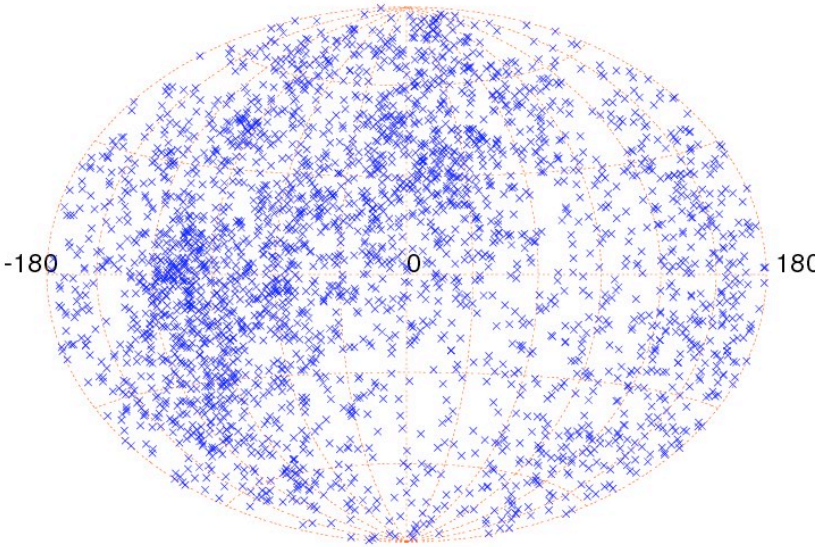


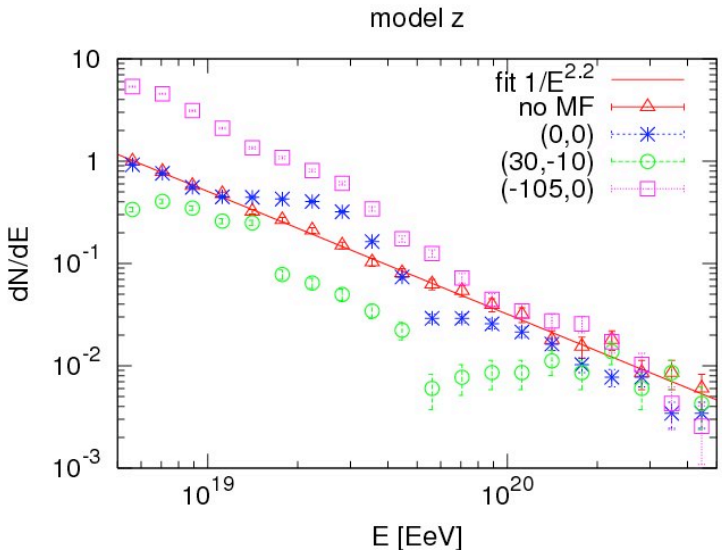
HMR model



PS model

Source in magnetized region





K.Dolag, M.Kachelriess and D.S., **arXiv:0809.5055**

Deflections by EGMF

By K.Dolag, D.Grasso, V.Springel, and I.Tkachev

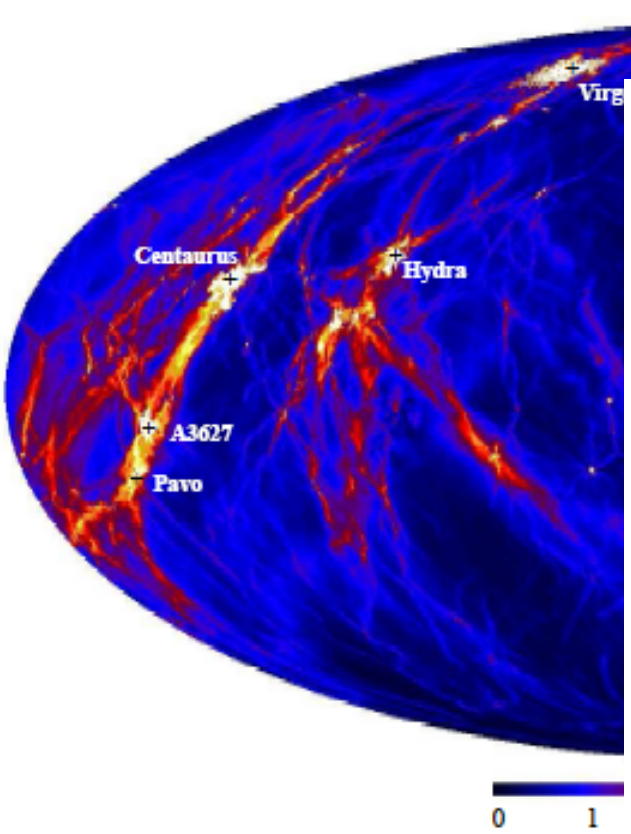


FIG. 1: Full sky map (area preserving projection) of c
scale. All structure within a radius of 107 Mpc aroun
with the galactic anti-center in the middle of the ma
corresponding halos in the simulation.

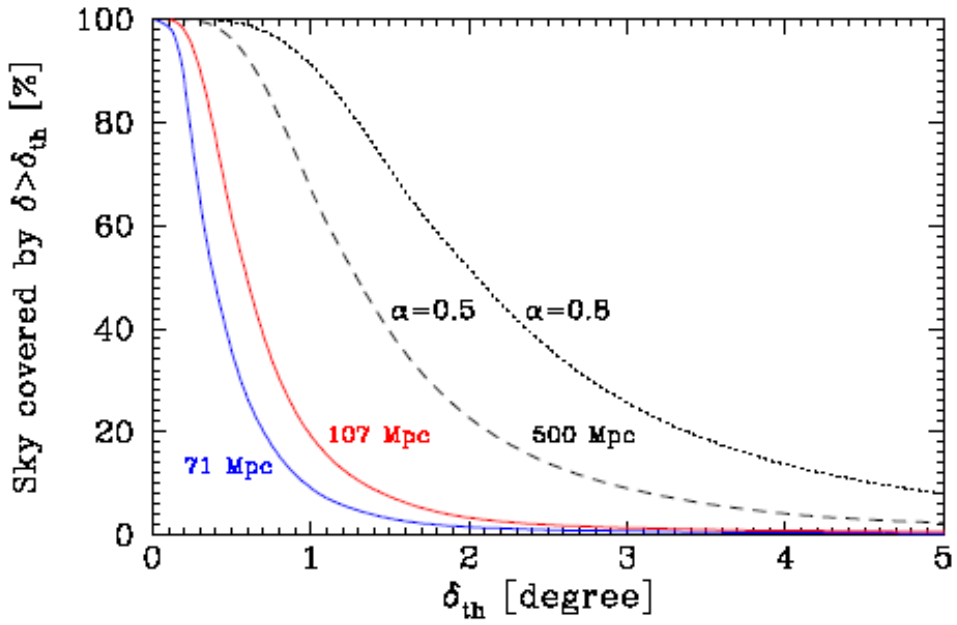
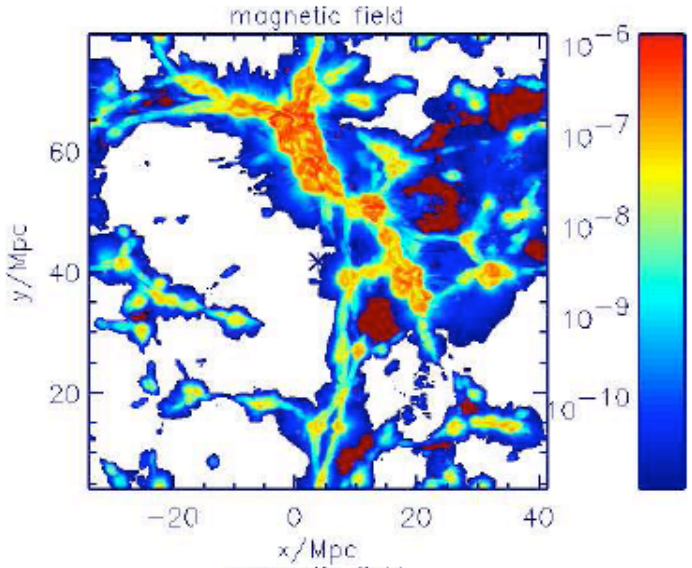
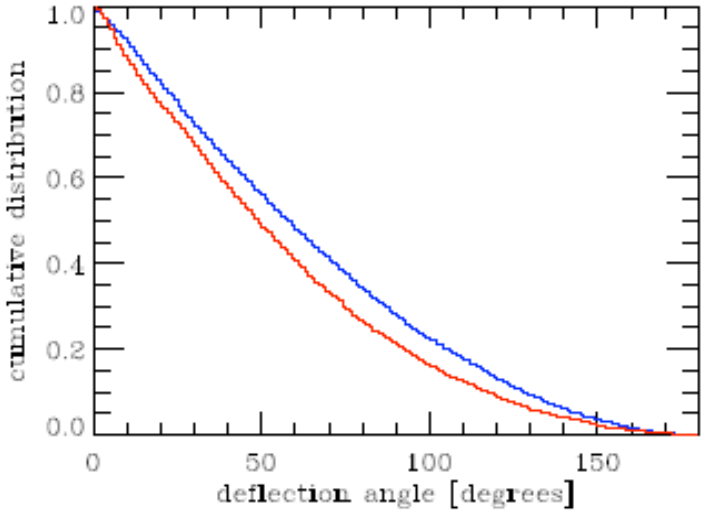
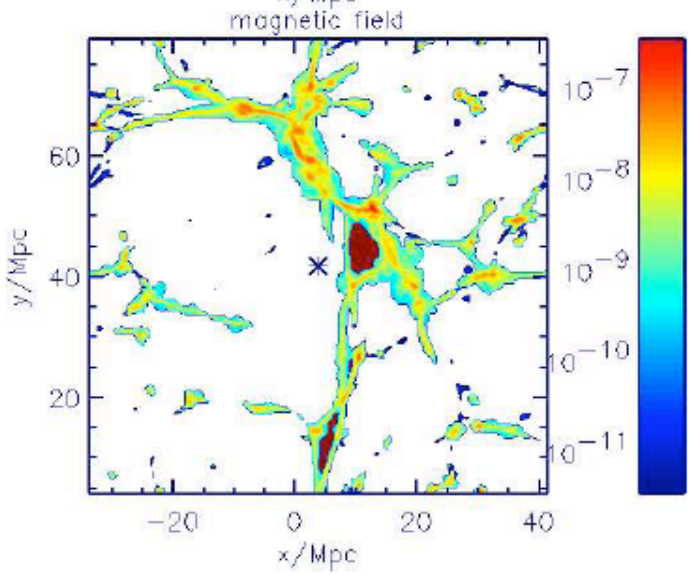


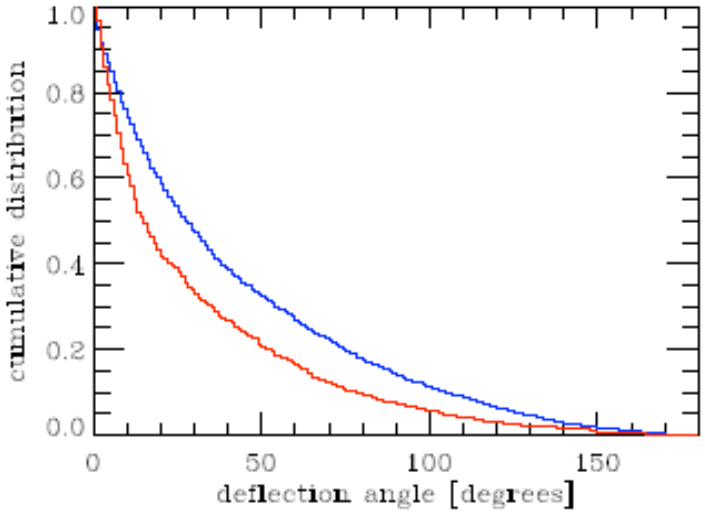
FIG. 2: Cumulative fraction of the sky with deflection angle larger than $\delta_{\rm th}$, for several values of propagation distance (solid lines). We also include an extrapolation to 500 Mpc, assuming self similarity with $\alpha = 0.5$ (dashed line) or $\alpha = 0.8$ (dotted line). The assumed UHECR energy for all lines is 4.0×10^{19} eV.

EGMF by G. Sigl et al. astro-ph/0401084

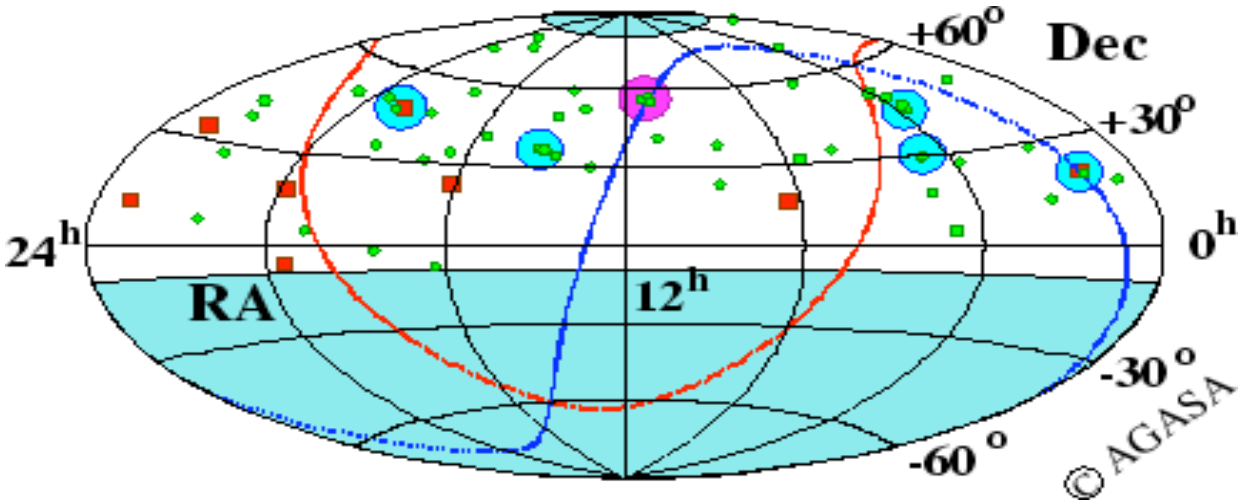






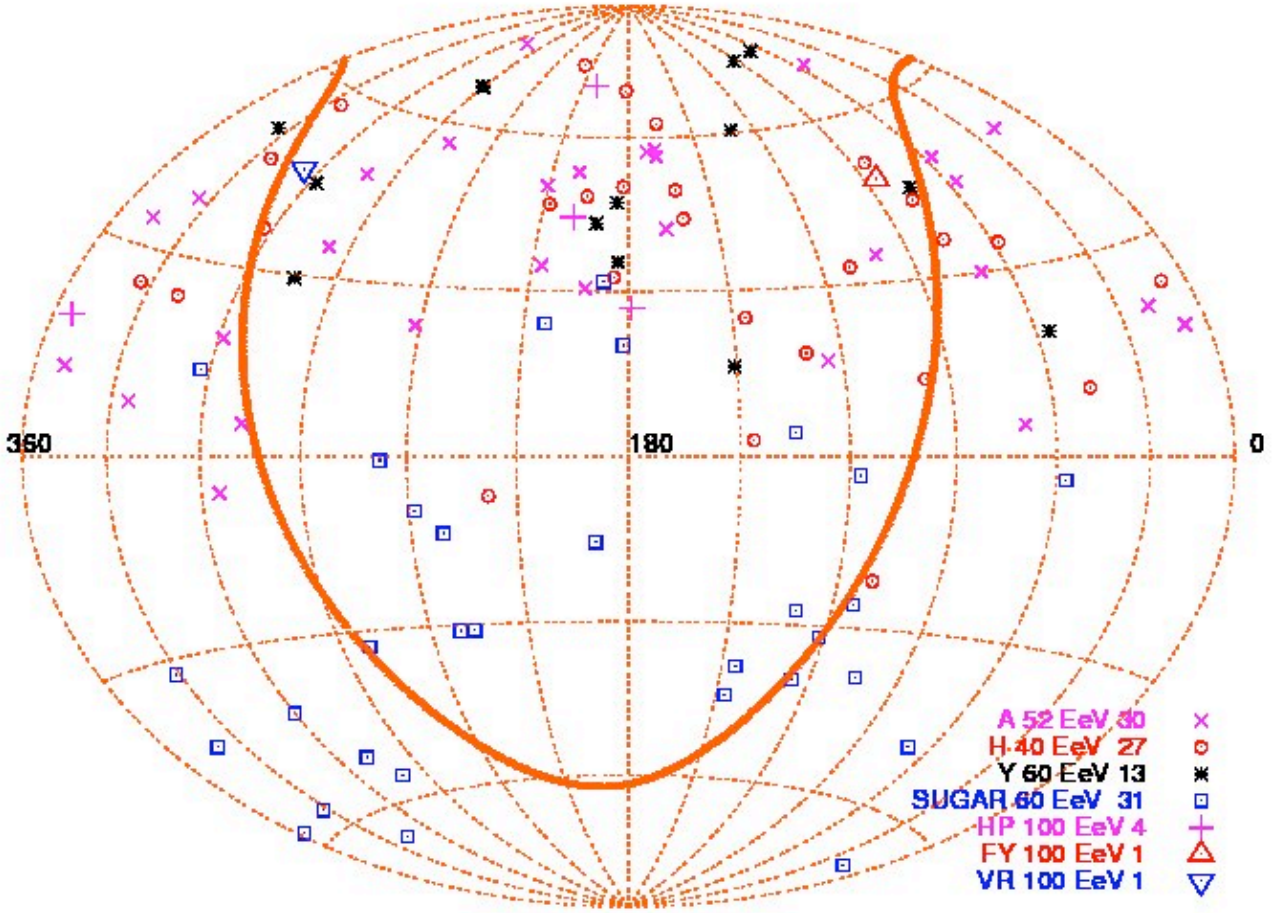


AGASA data $E > 4 \times 10^{19}$ eV ~60 events

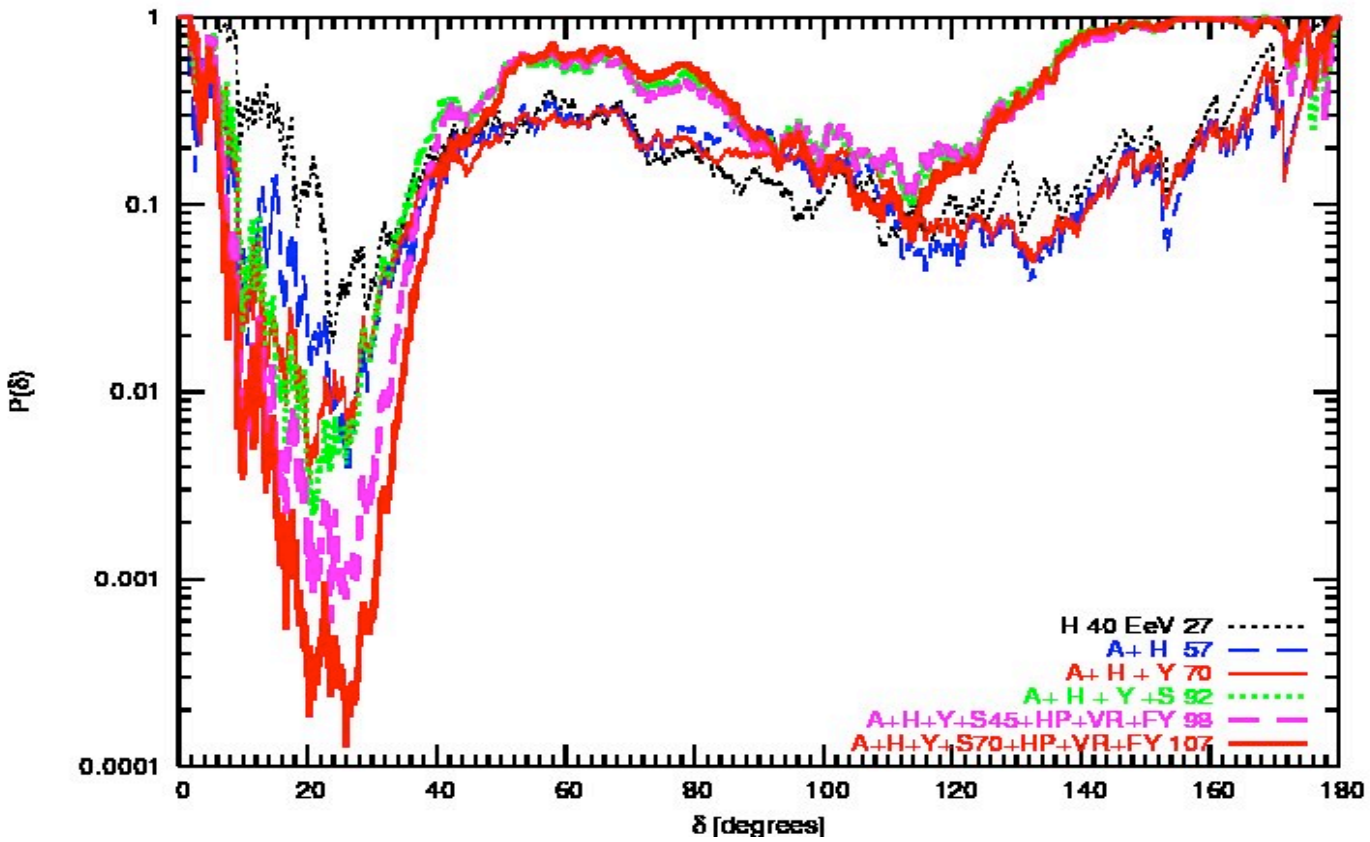


Clusters -- are events which came from the same part of sky within given (usually small) angle from each other. Angle is 2.5 degrees for AGASA.

Arrival directions for E>40 EeV in HiRes (E>52 EeV in AGASA)



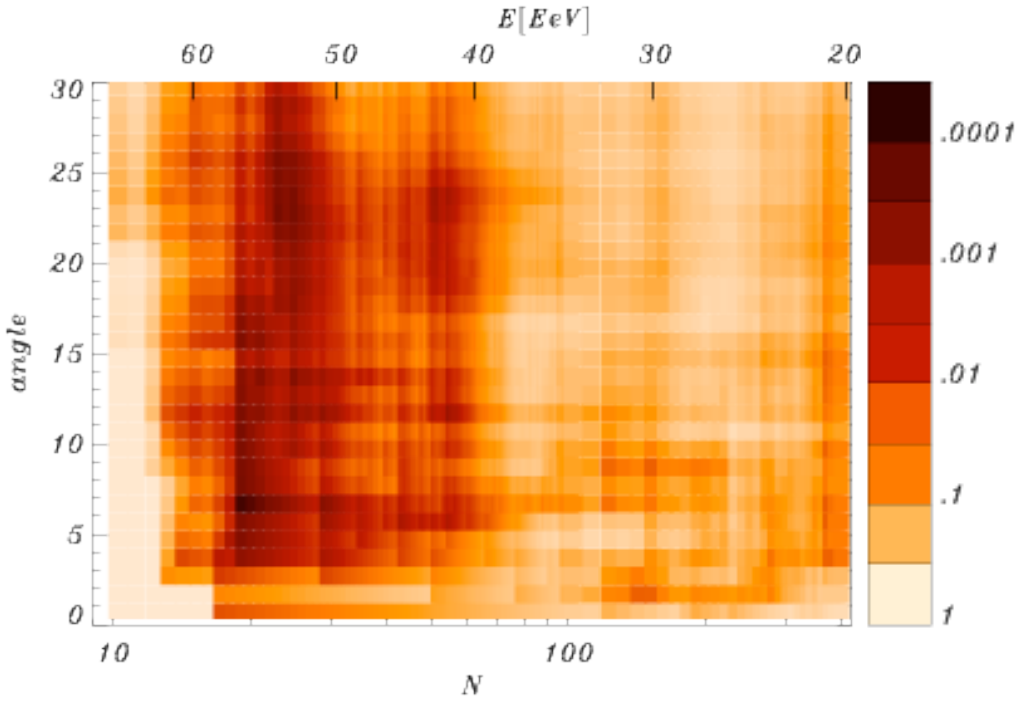
Probability of correlation



3 σ after penalty on angle

M.Kachelriess and D.S. astro-ph/0512498

Clustering signal in AUGER: scan



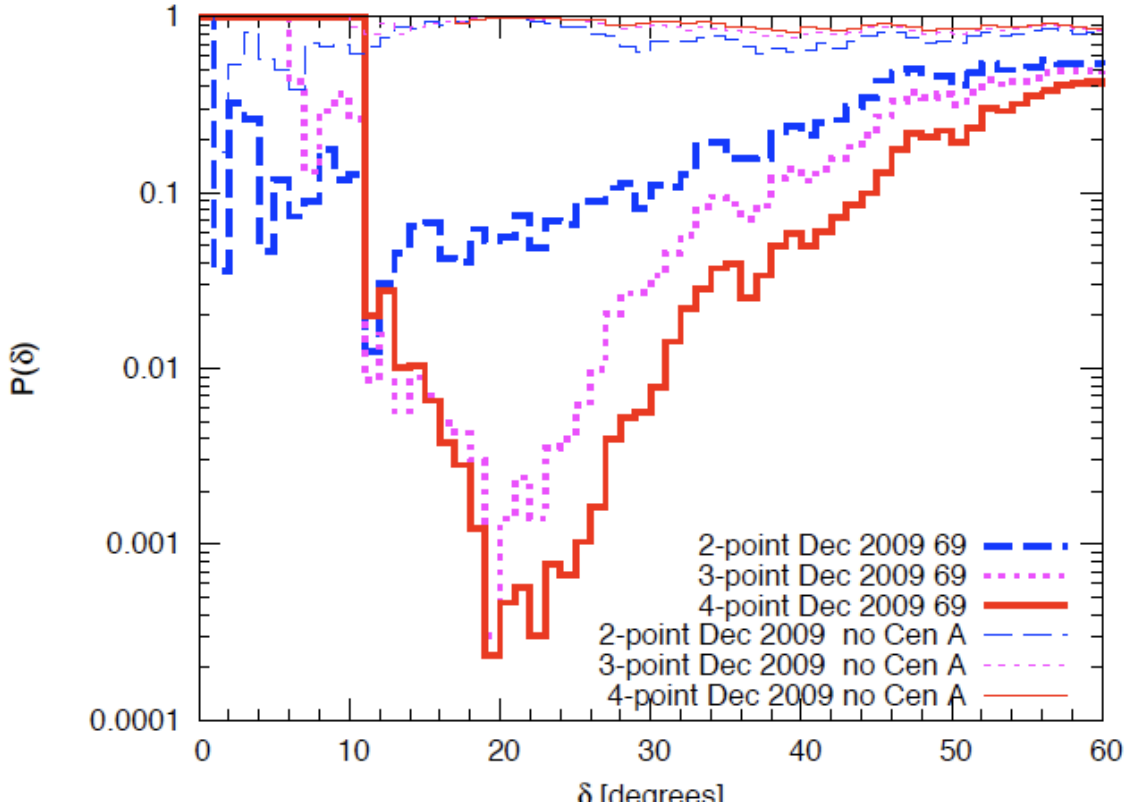
2% after scan and penalty between 7 and 23 degrees

Pierre Auger Collaboration, ICRC 2007

Statistically limited.

If real, connection to LSS and EGMF

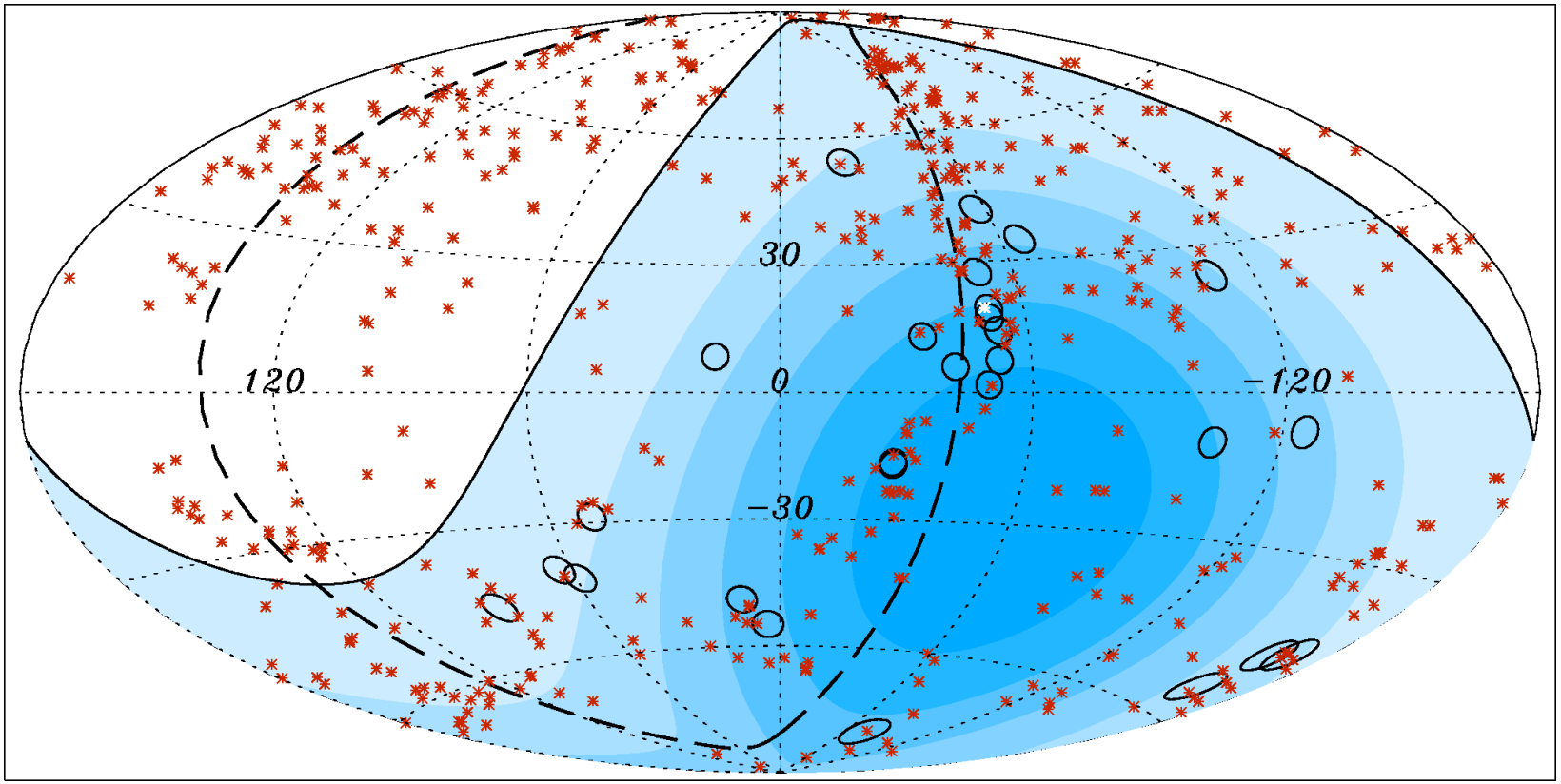
Autocorrelation of 69 Auger events with E>55 EeV



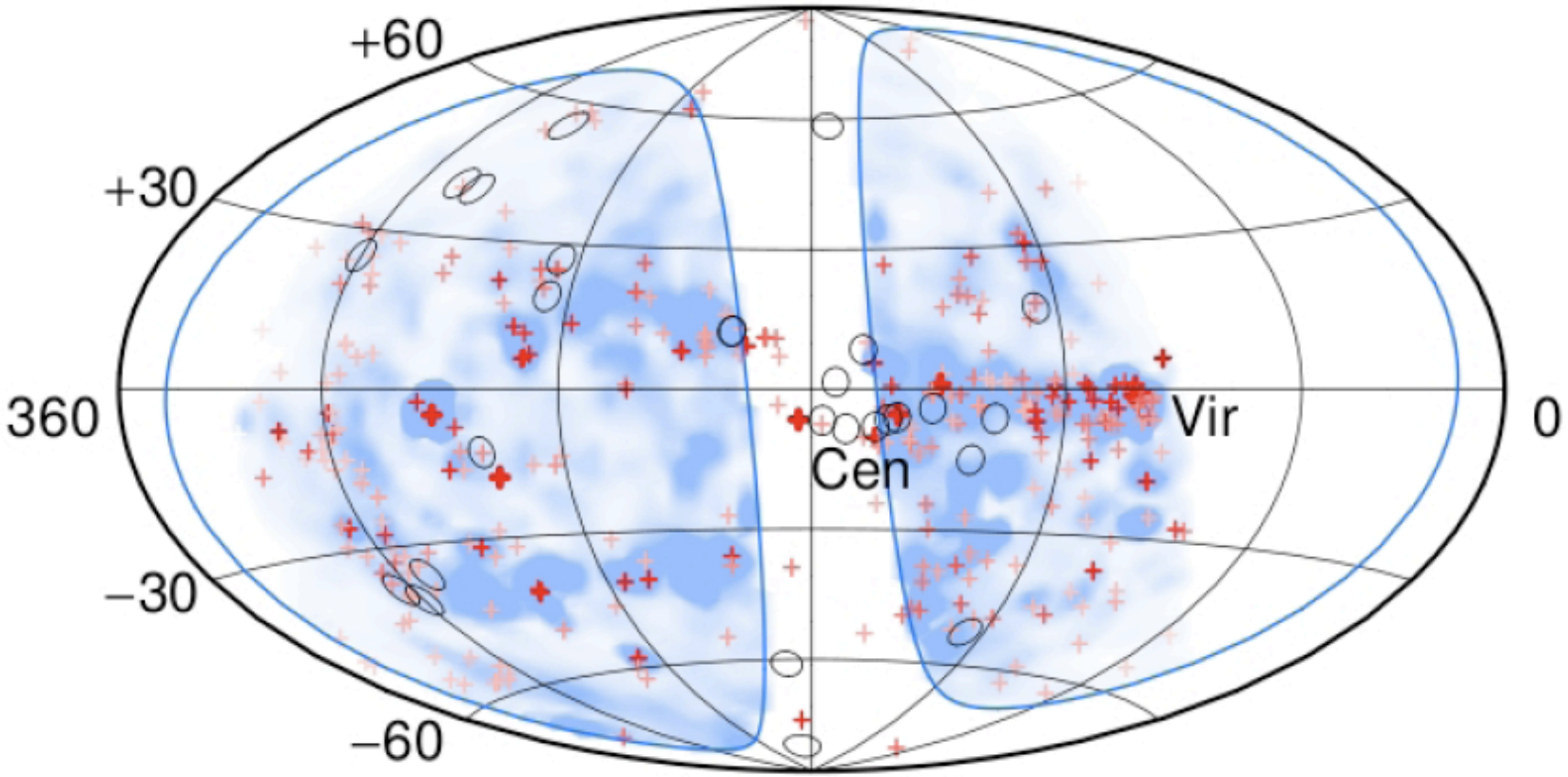
D.S. **arXiv:1009.3879**

Anisotropy of UHECR in Auger

Arrival directions for 27 events with E>56 EeV in Auger

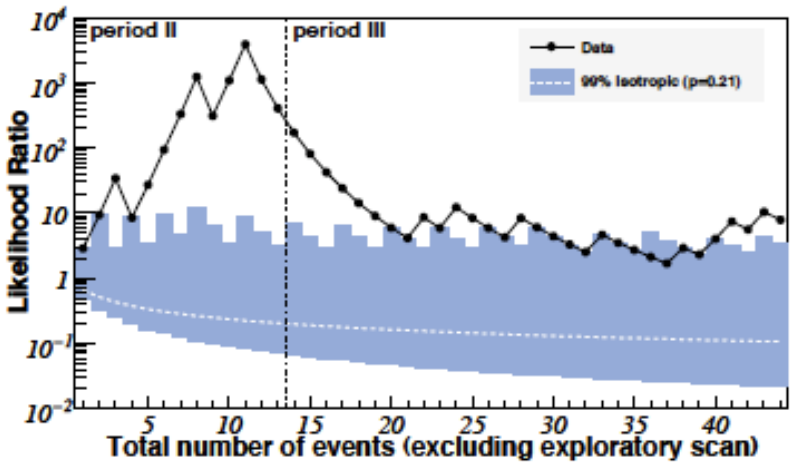


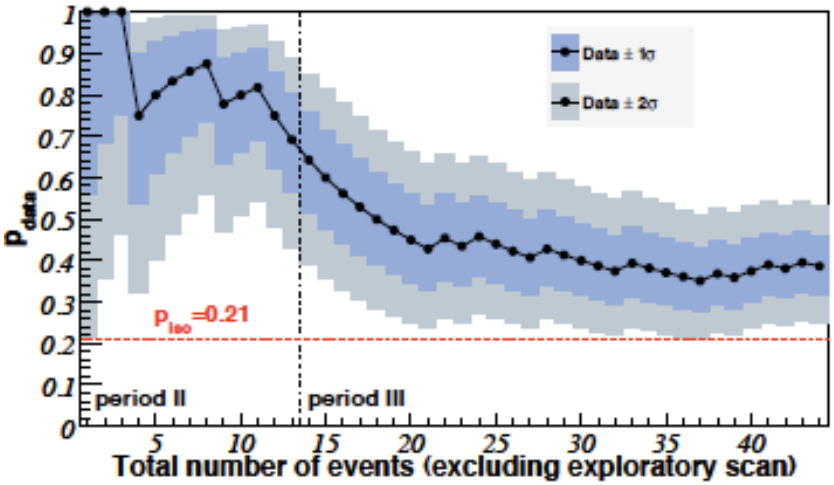
Arrival directions for E>56 EeV protons: 10% from Virgo



D.S. Gorbunov *et al* arXiv:0804.1088

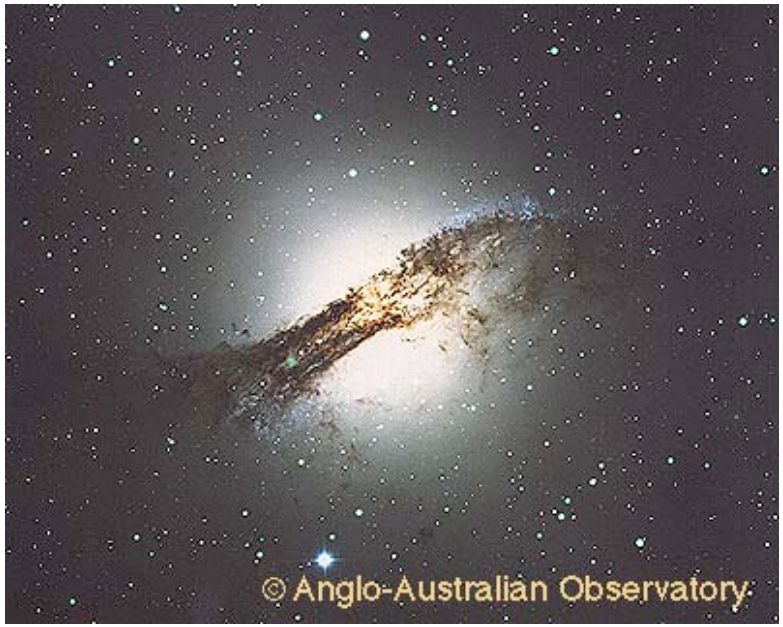
Correlations with AGN's 2009

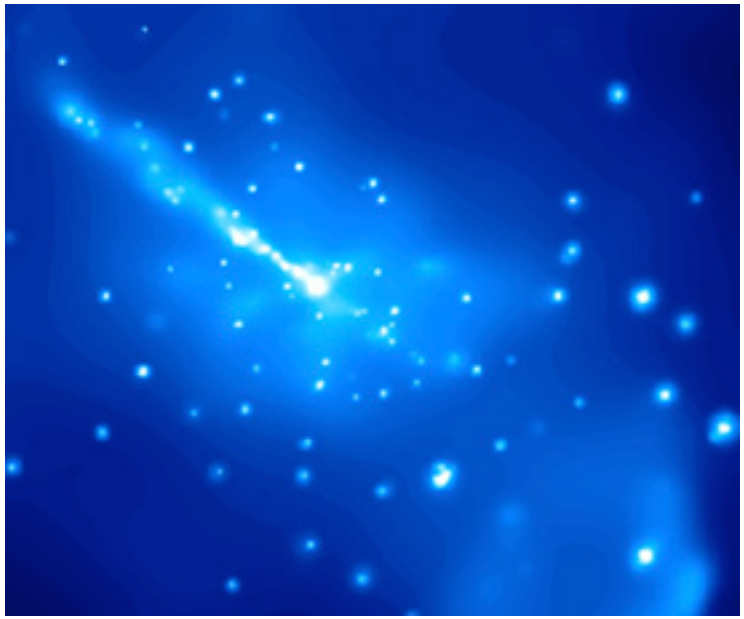




Cen A

- Radio galaxy with AGN located at 4 Mpc from our galaxy: extremely nearby
- Typical distance between radio galaxies is 20-40 Mpc





- Most nearby AGN: typical distance between AGN's is 10 Mpc (if not in clusters)

Cen A: Auger ICRC 2009

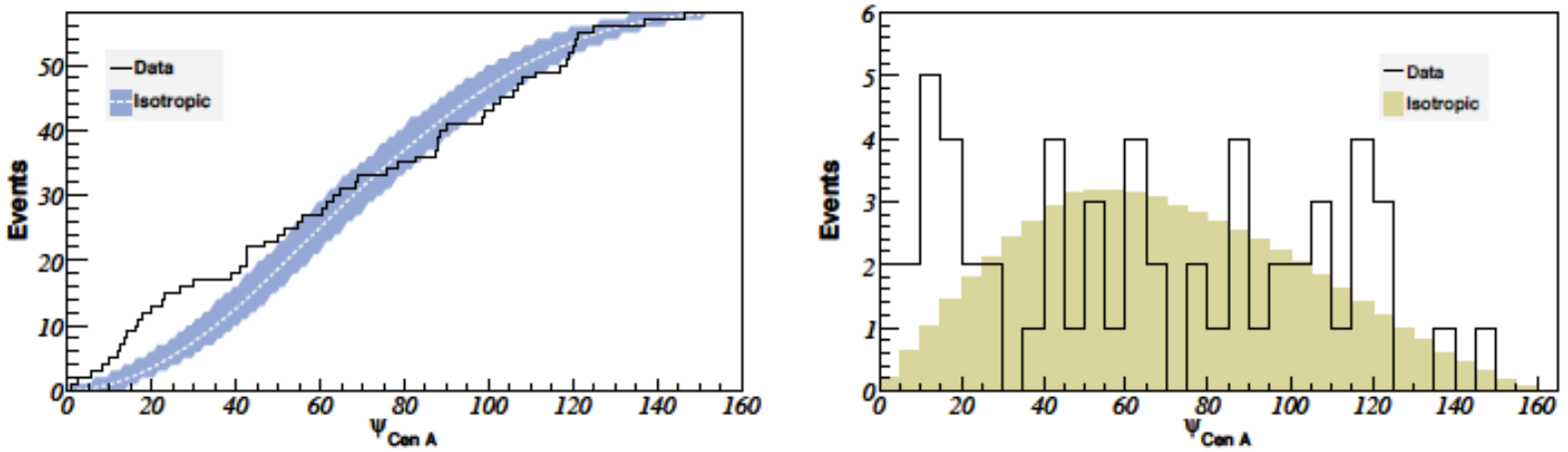
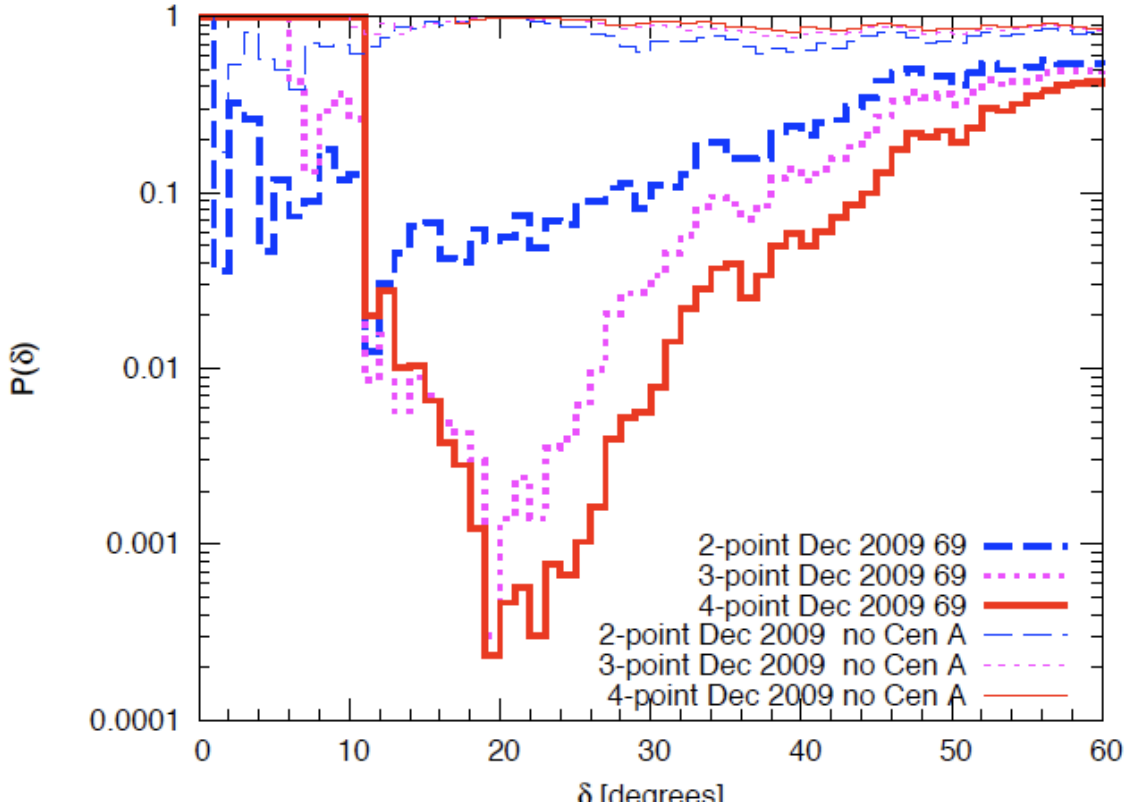


Fig. 3. *Left:* The cumulative number of events with $E \geq 55$ EeV as a function of angular distance from Cen A. The average isotropic expectation with approximate 68% confidence intervals is shaded blue. *Right:* The histogram of events as a function of angular distance from Cen A. The average isotropic expectation is shaded brown.

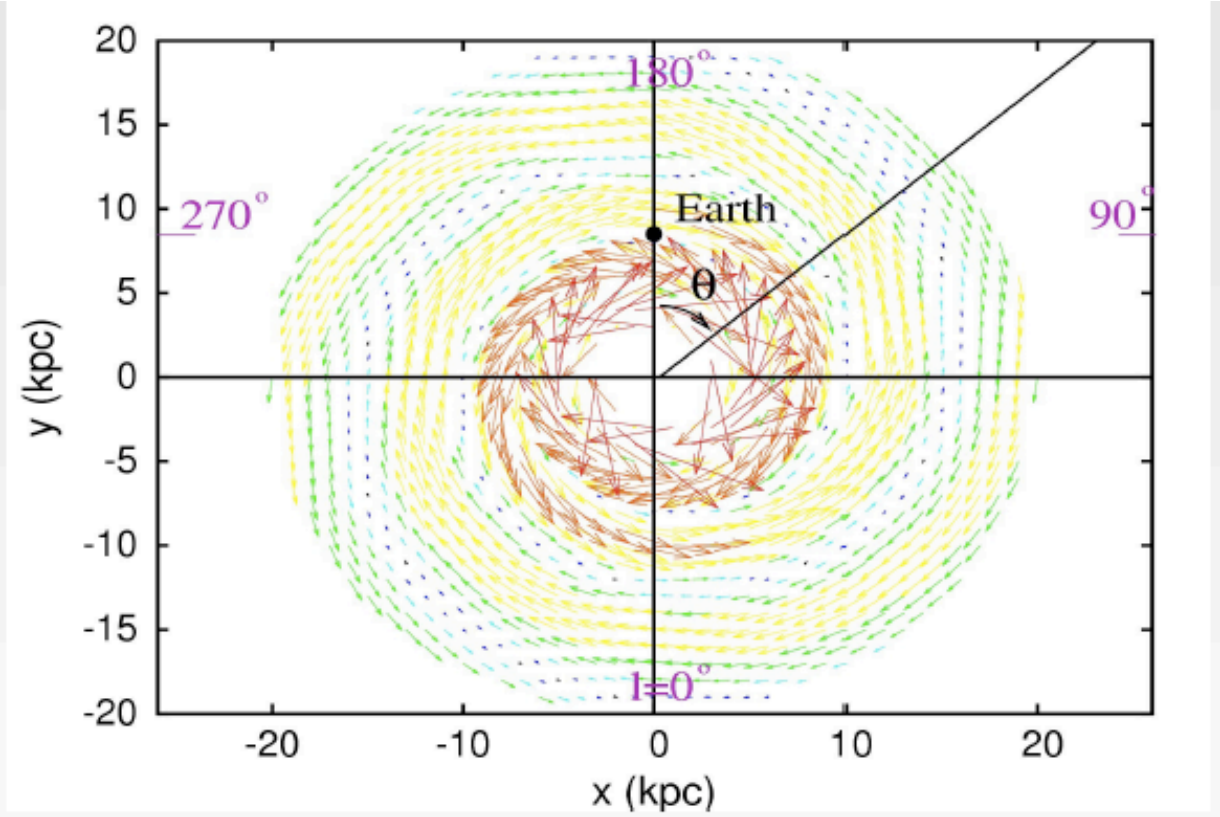
Autocorrelation of 69 Auger events with E>55 EeV



D.S. **arXiv:1009.3879**

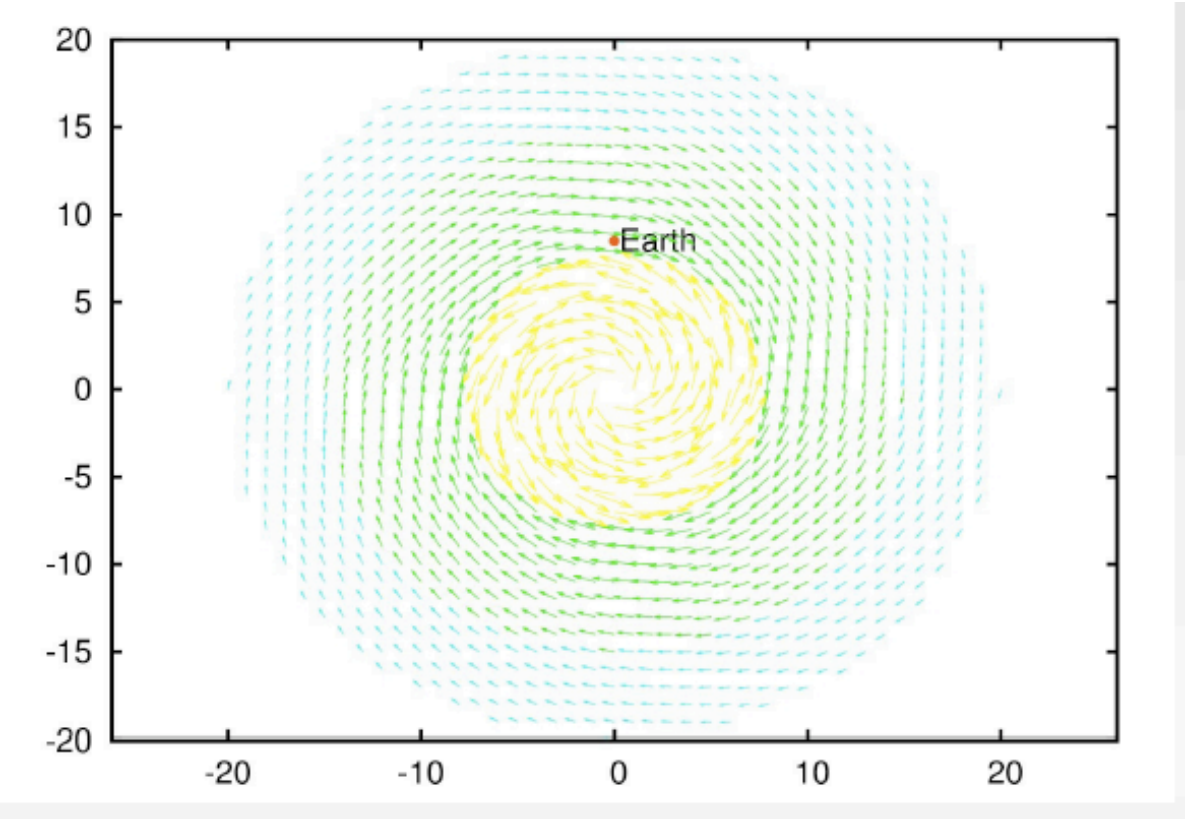
Nuclei sources and Galactic field

Galactic magnetic field: disk



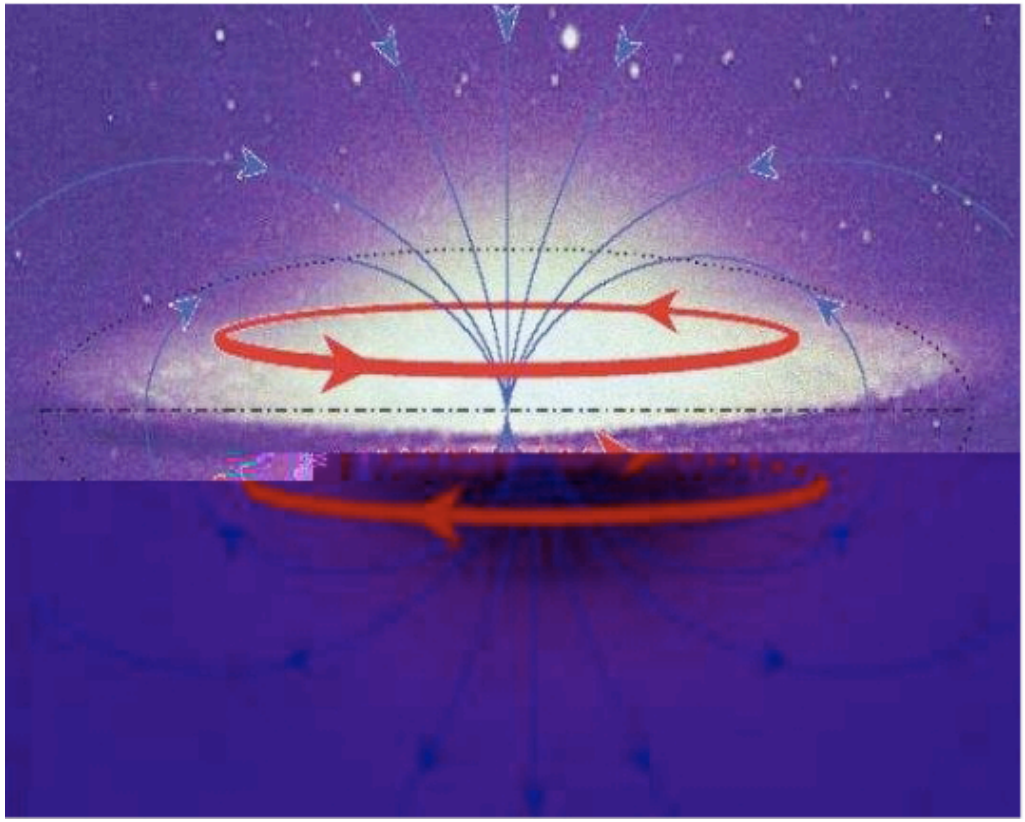
M. Prouza and R. Smida astro-ph/0307165

Galactic magnetic field: disk



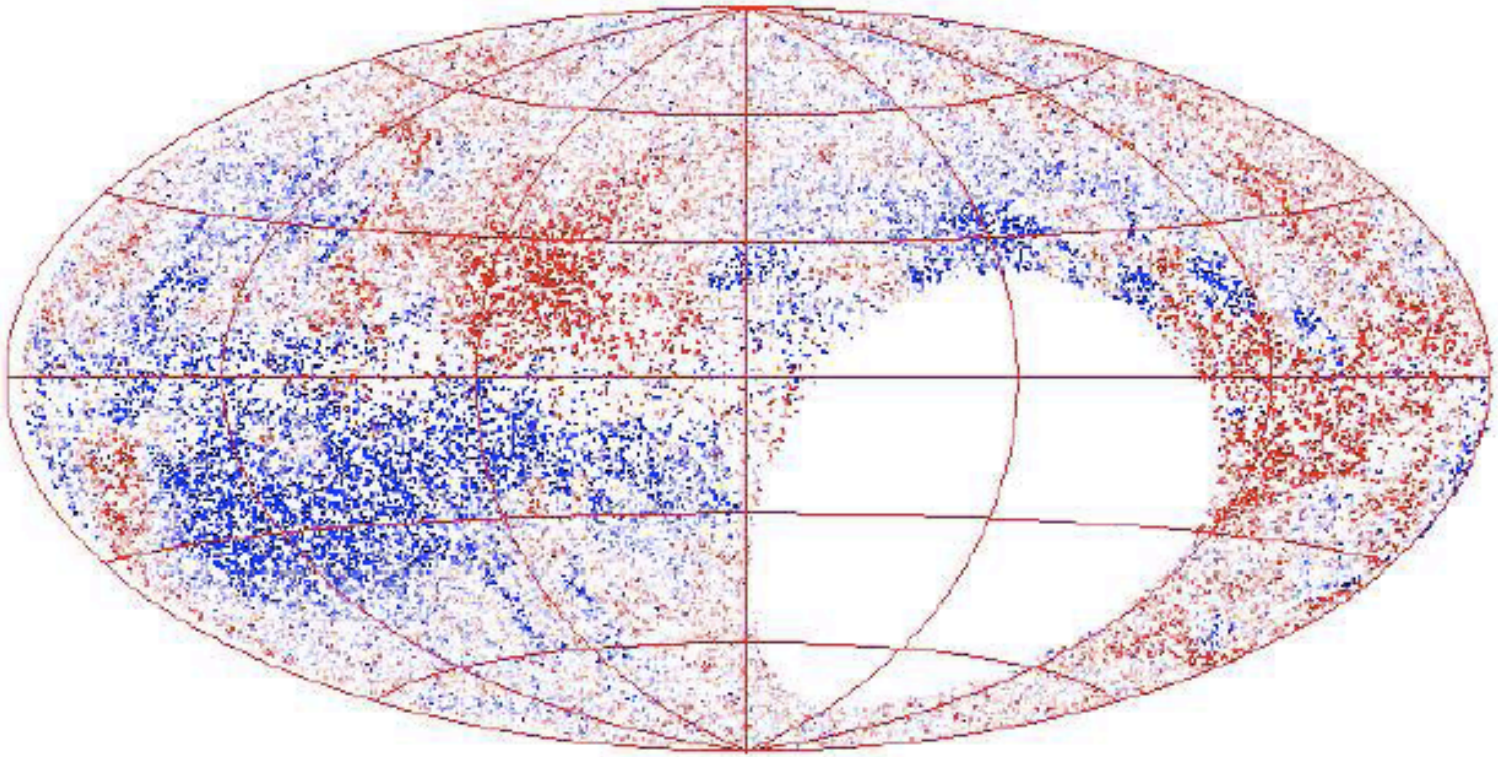
X.H. Sun et al, arXiv:0711.1572

Galactic magnetic field: halo



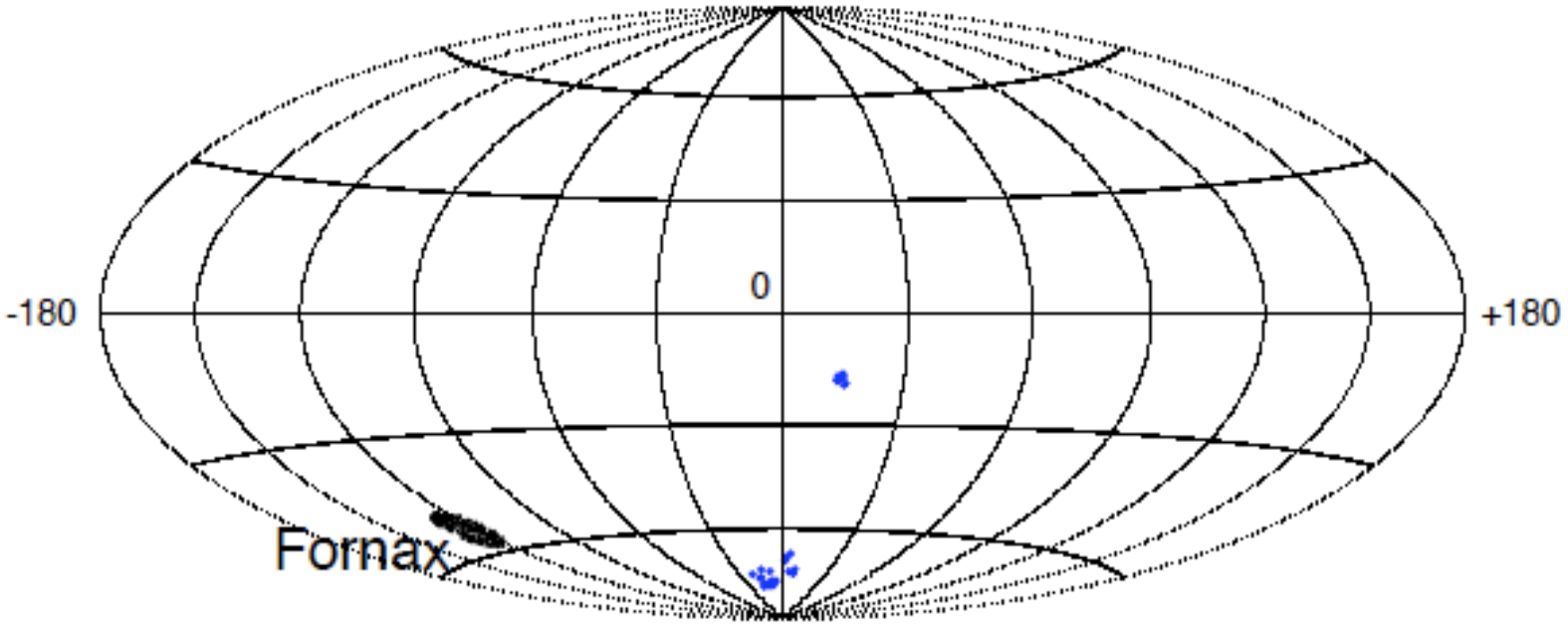
J-L. Han et al, **arXiv:0901.0040**

Galactic magnetic field measurement: RM



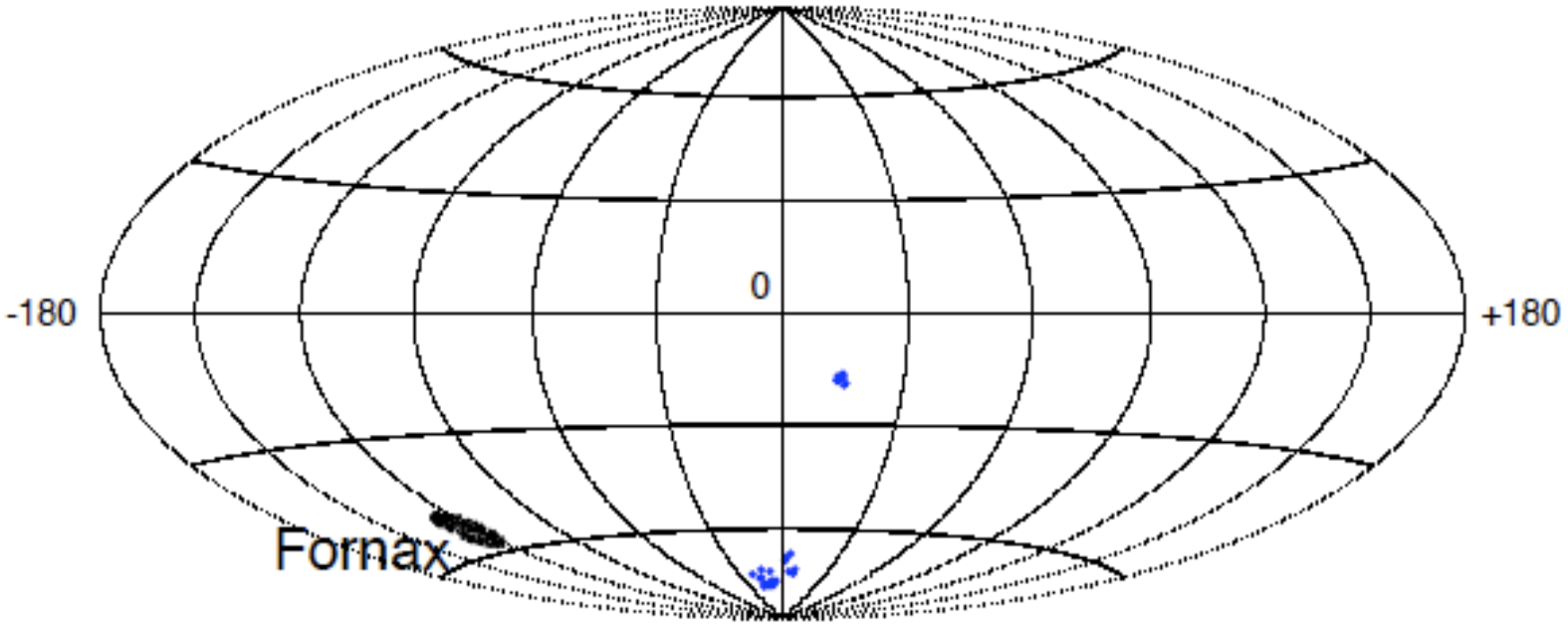
Pshirkov et al, **arXiv:1103.0814**

Galactic magnetic field



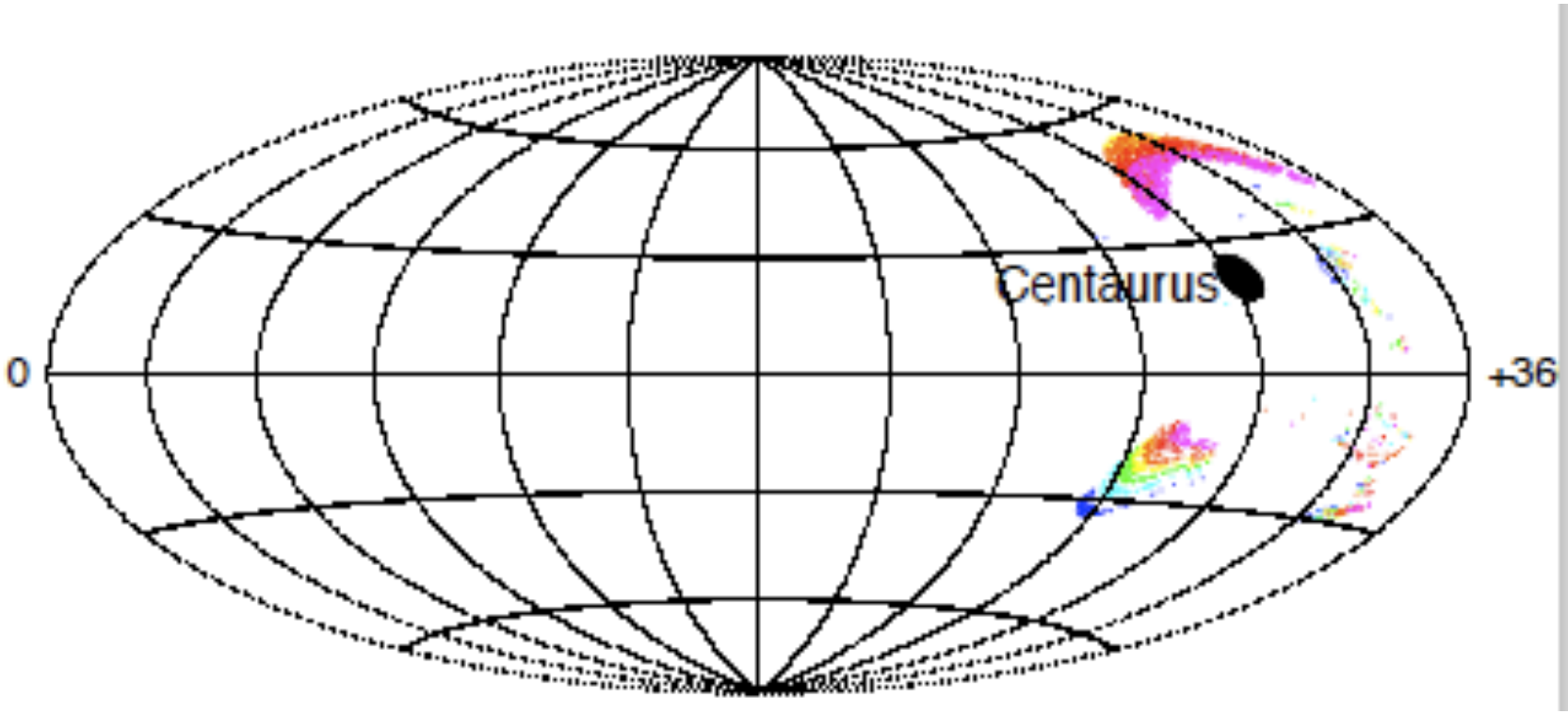
G.Giacinti et al, **arXiv:1104.1141**

Image of galaxy cluster: regular field



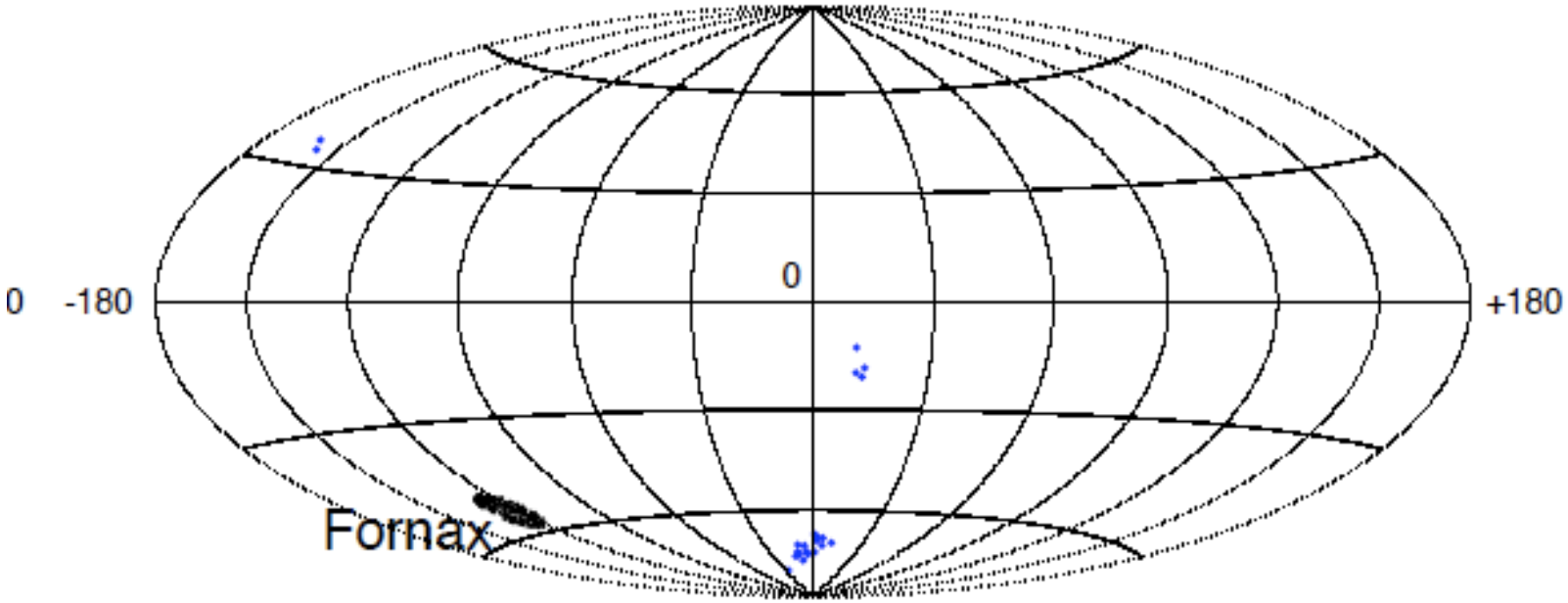
G.Giacinti et al, **arXiv:1104.1141**

Image of galaxy cluster: regular field



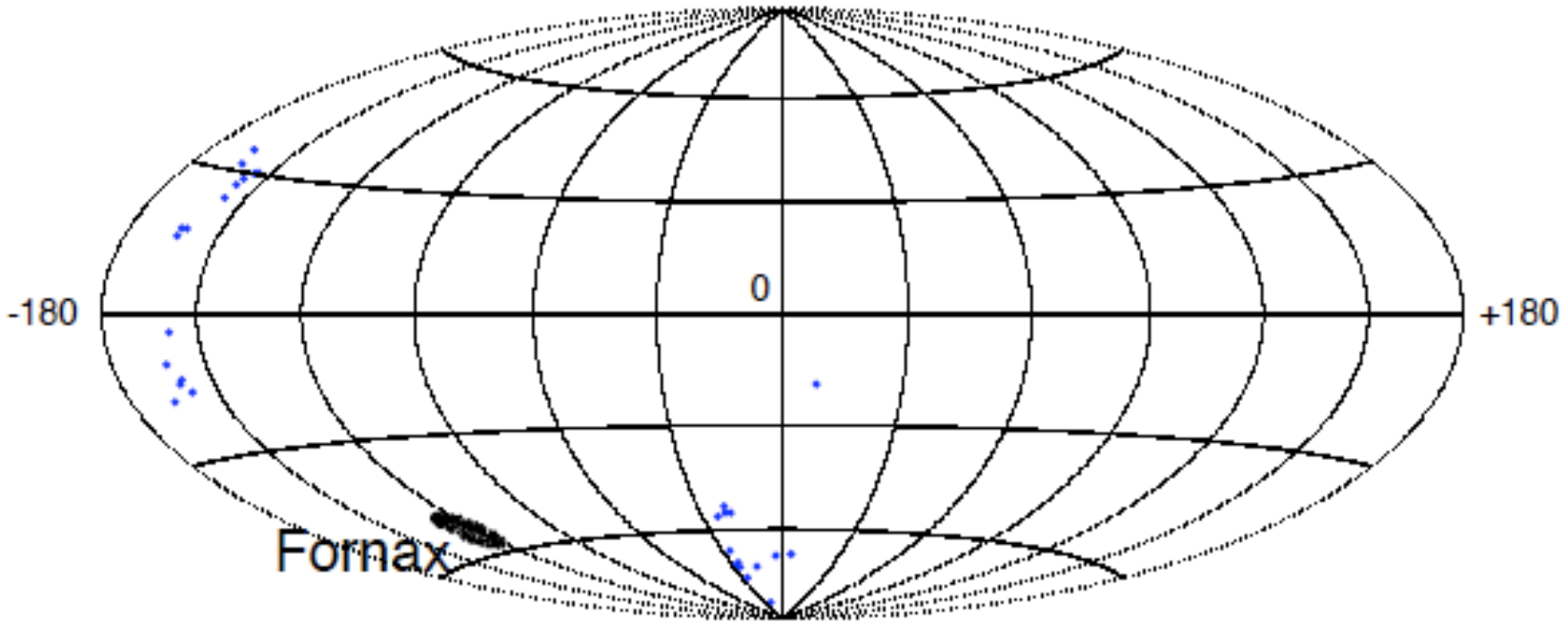
G.Giacinti et al, **arXiv:1006.5416**

Image of galaxy cluster: turbulent field



G.Giacinti et al, **arXiv:1104.1141**

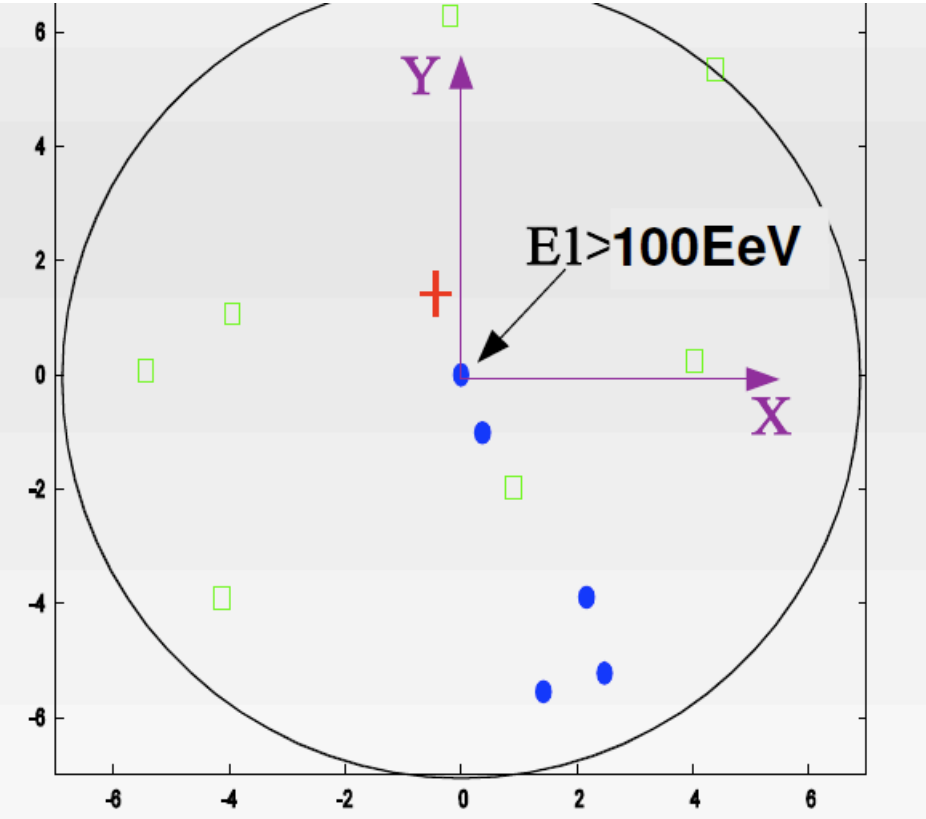
Image of galaxy cluster: turbulent field



G.Giacinti et al, **arXiv:1104.1141**

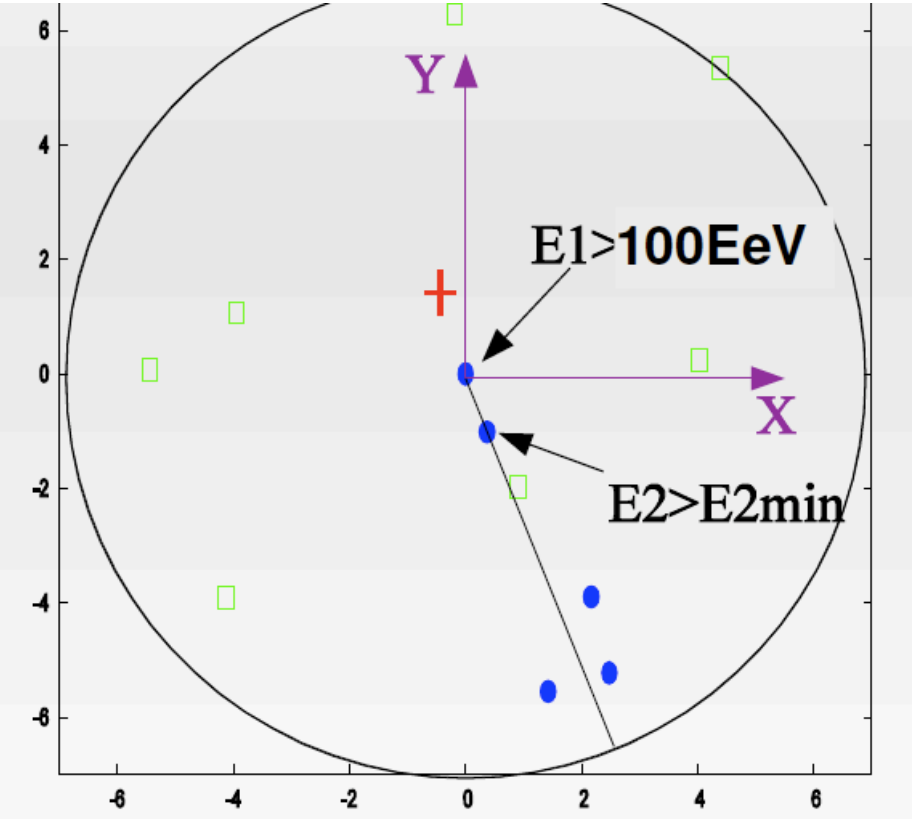
Nuclei sources and Auger data

Method for search of UHE nuclei source



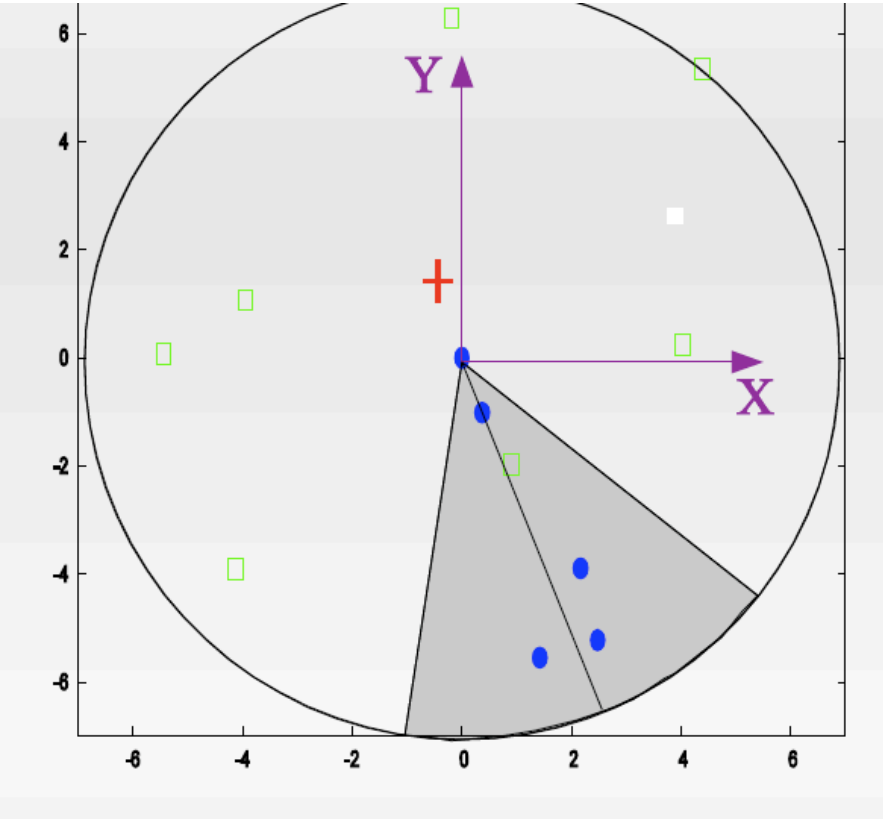
G.Giacinti and D.S., **arXiv:1011.6333**

Method for search of UHE nuclei source



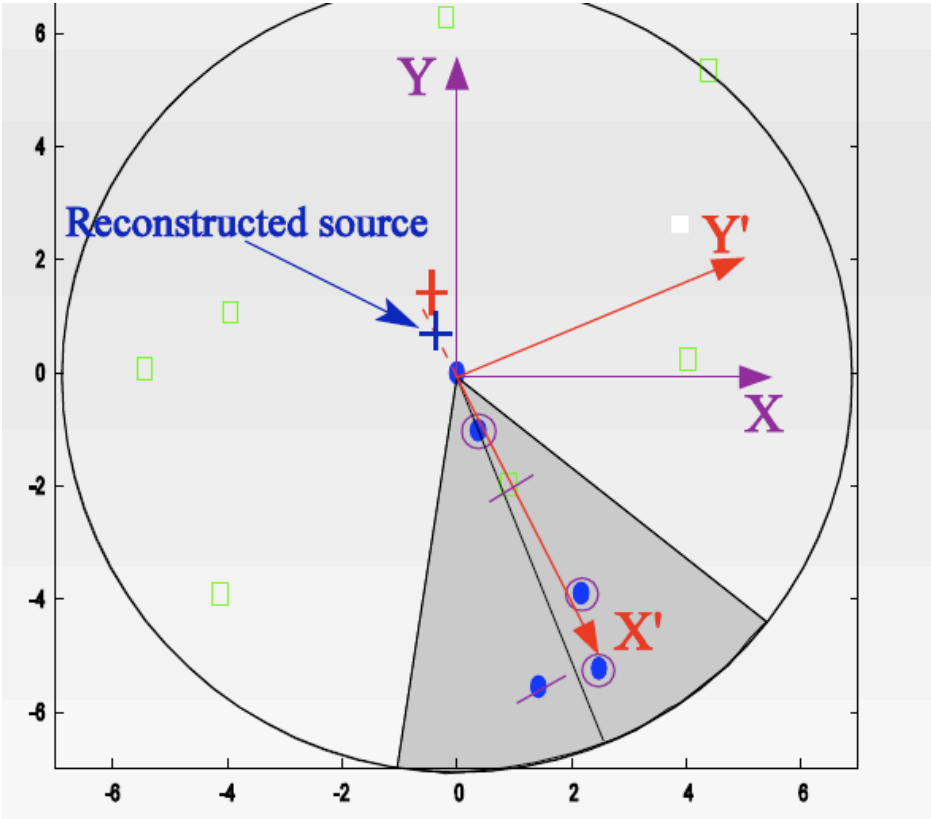
G.Giacinti and D.S., **arXiv:1011.6333**

Method for search of UHE nuclei source



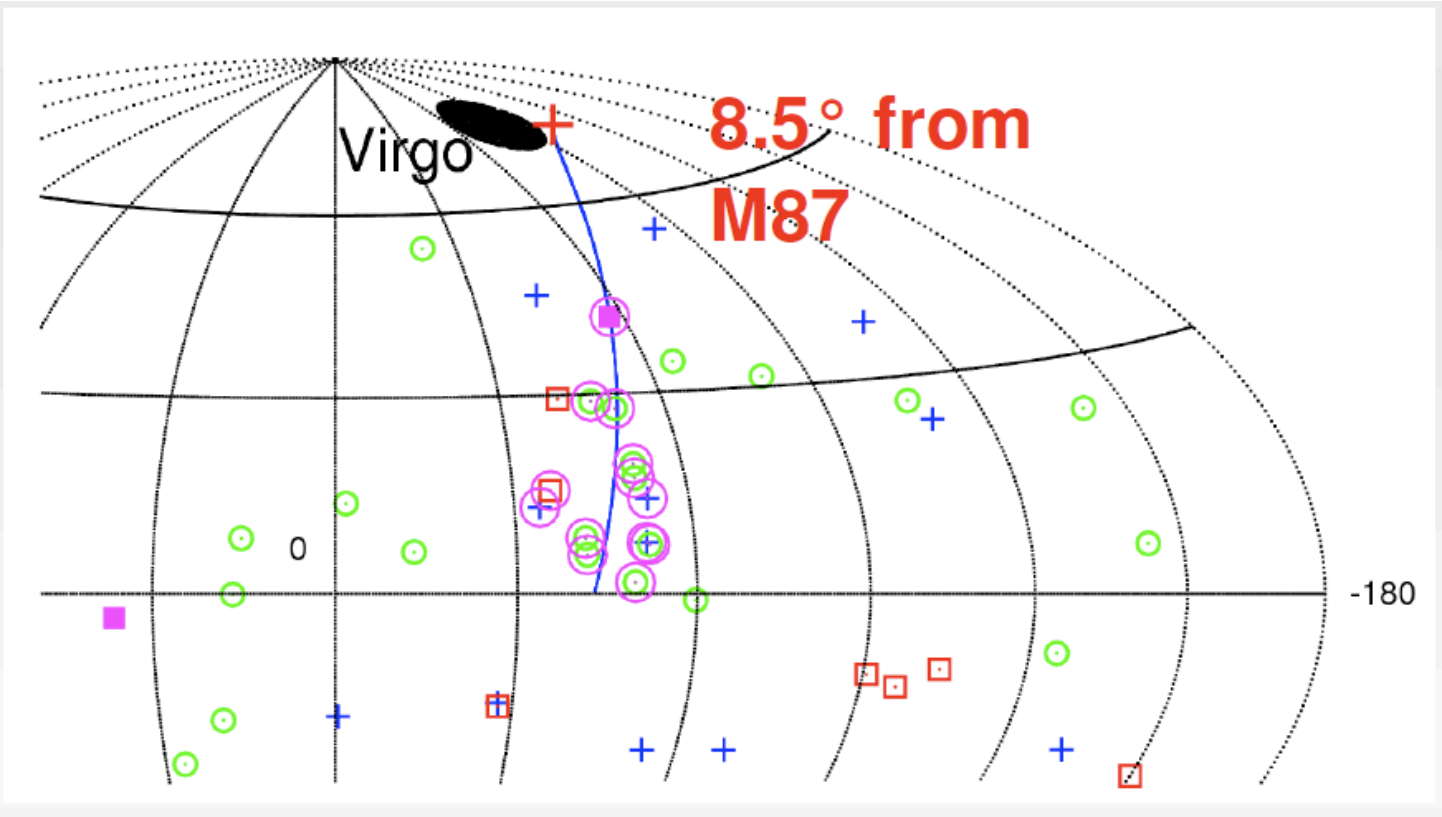
G.Giacinti and D.S., **arXiv:1011.6333**

Method for search of UHE nuclei source



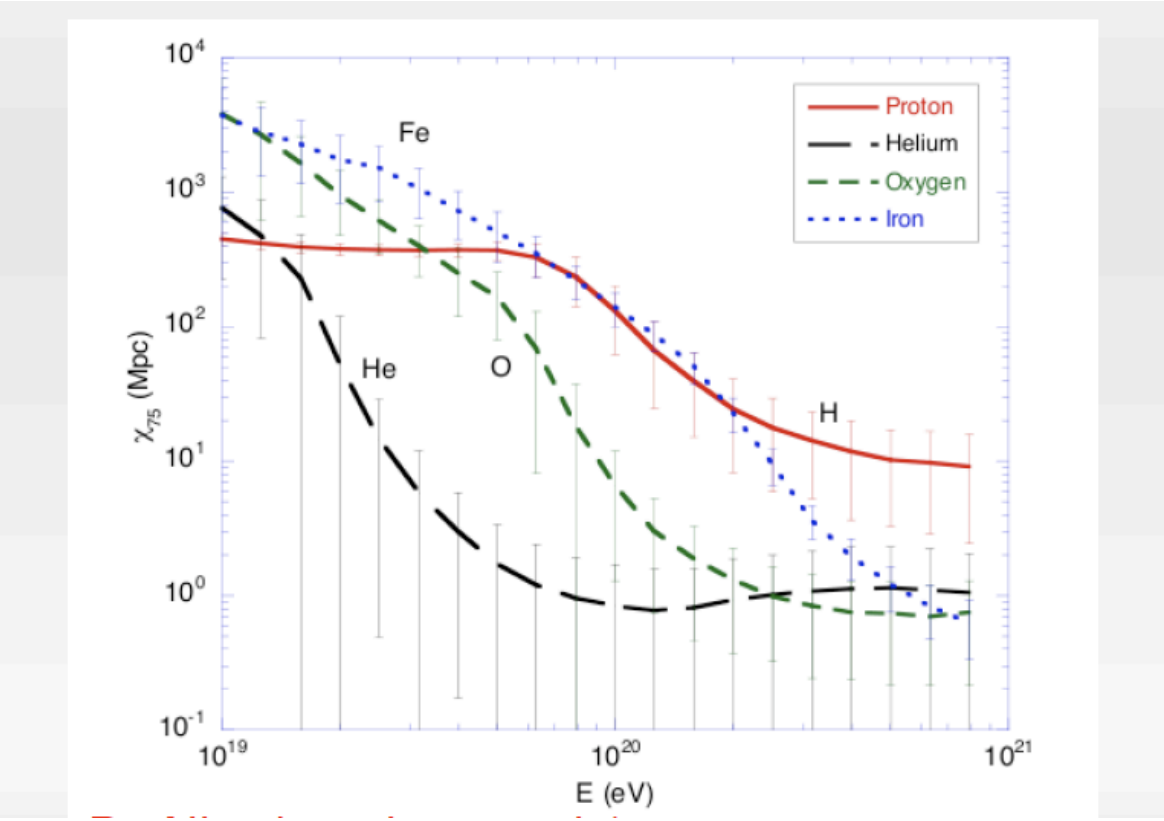
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data



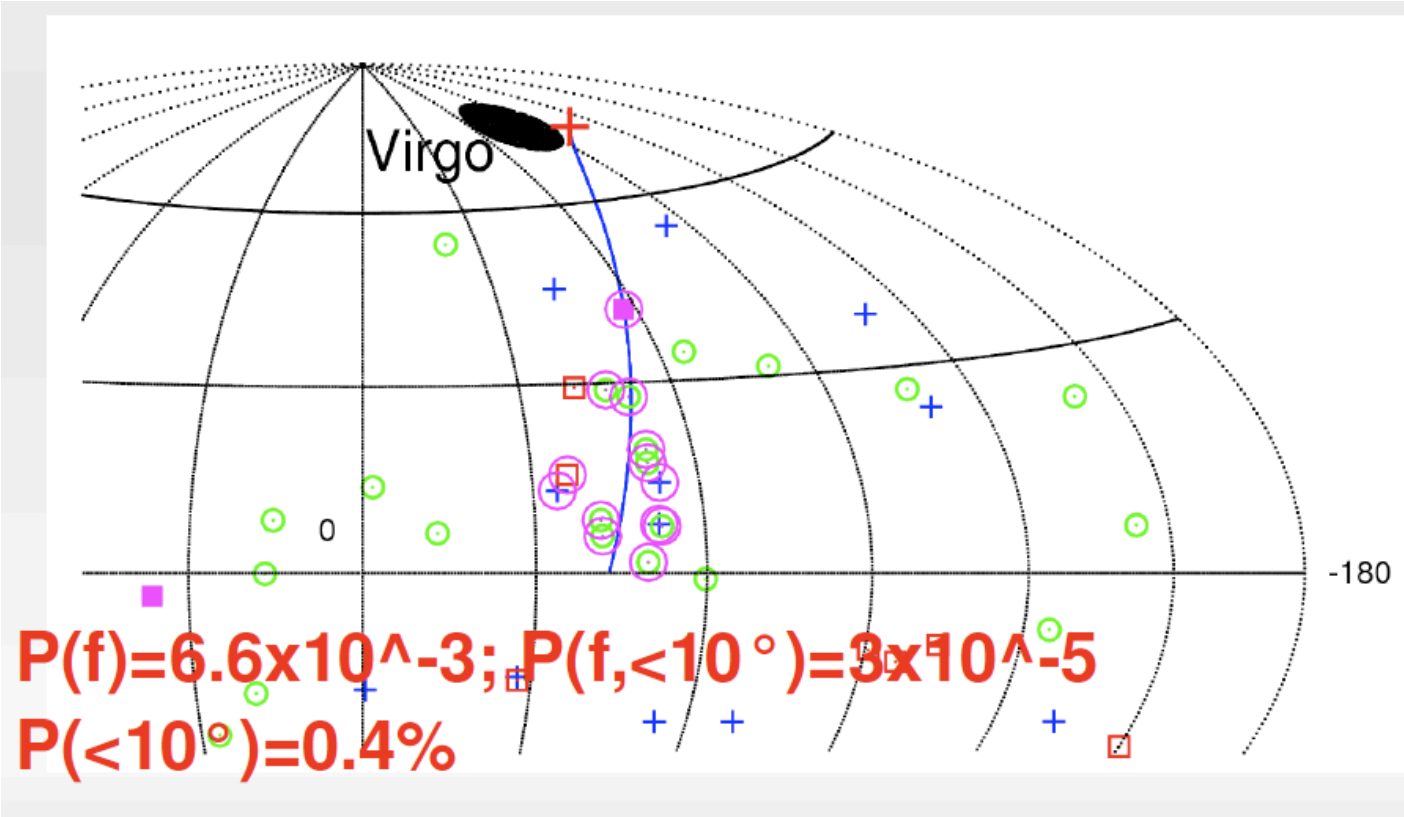
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data



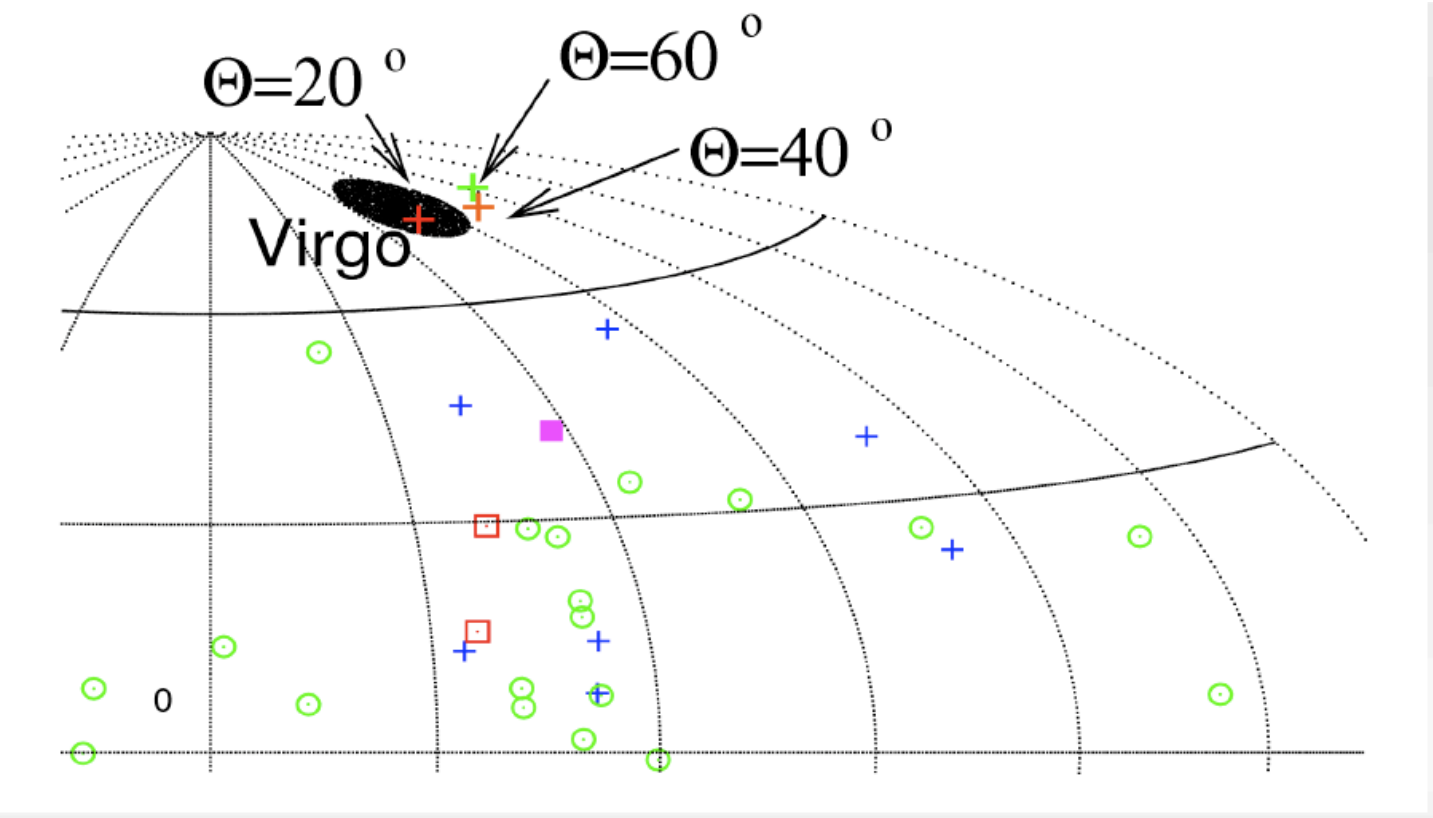
D.Allard et al

Application to Auger data



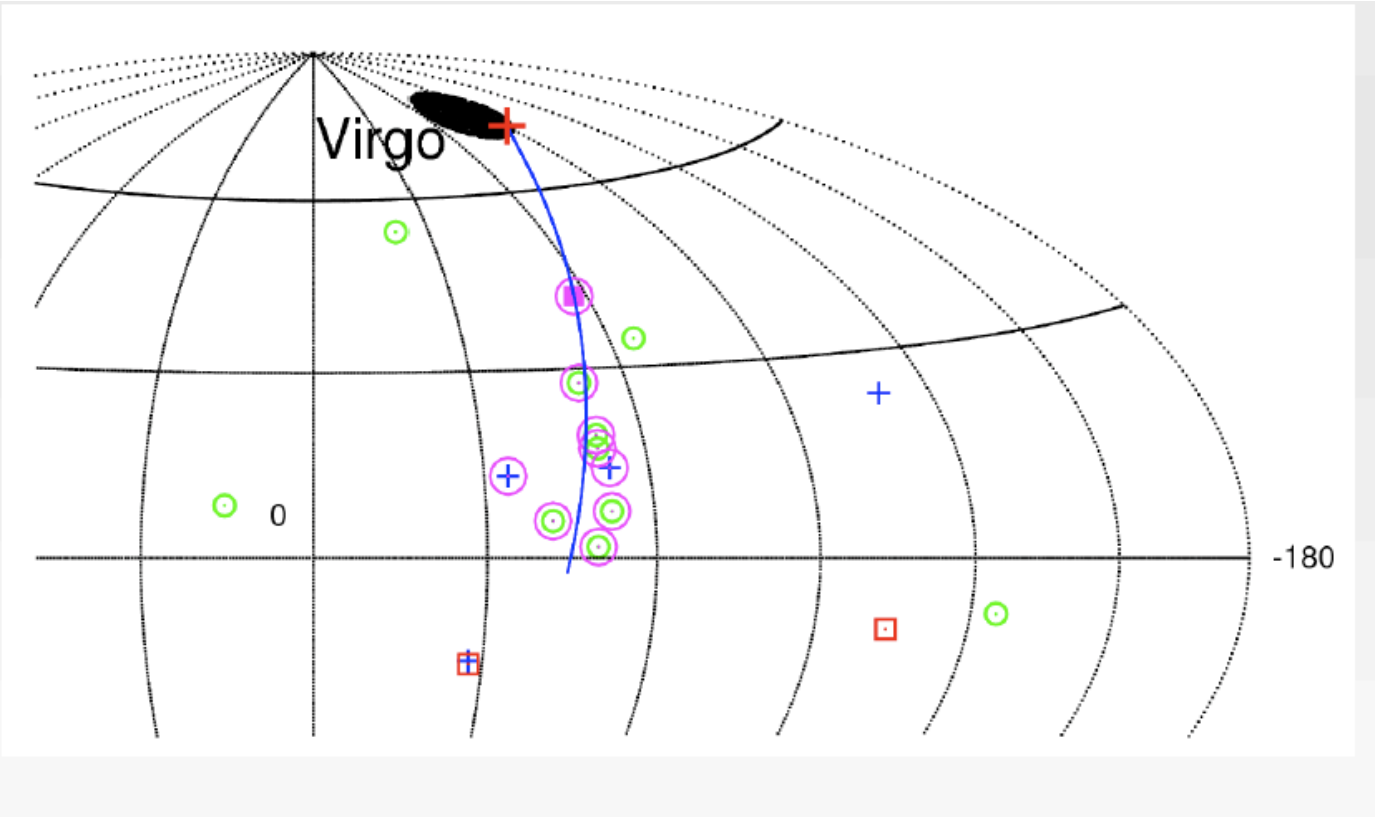
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data



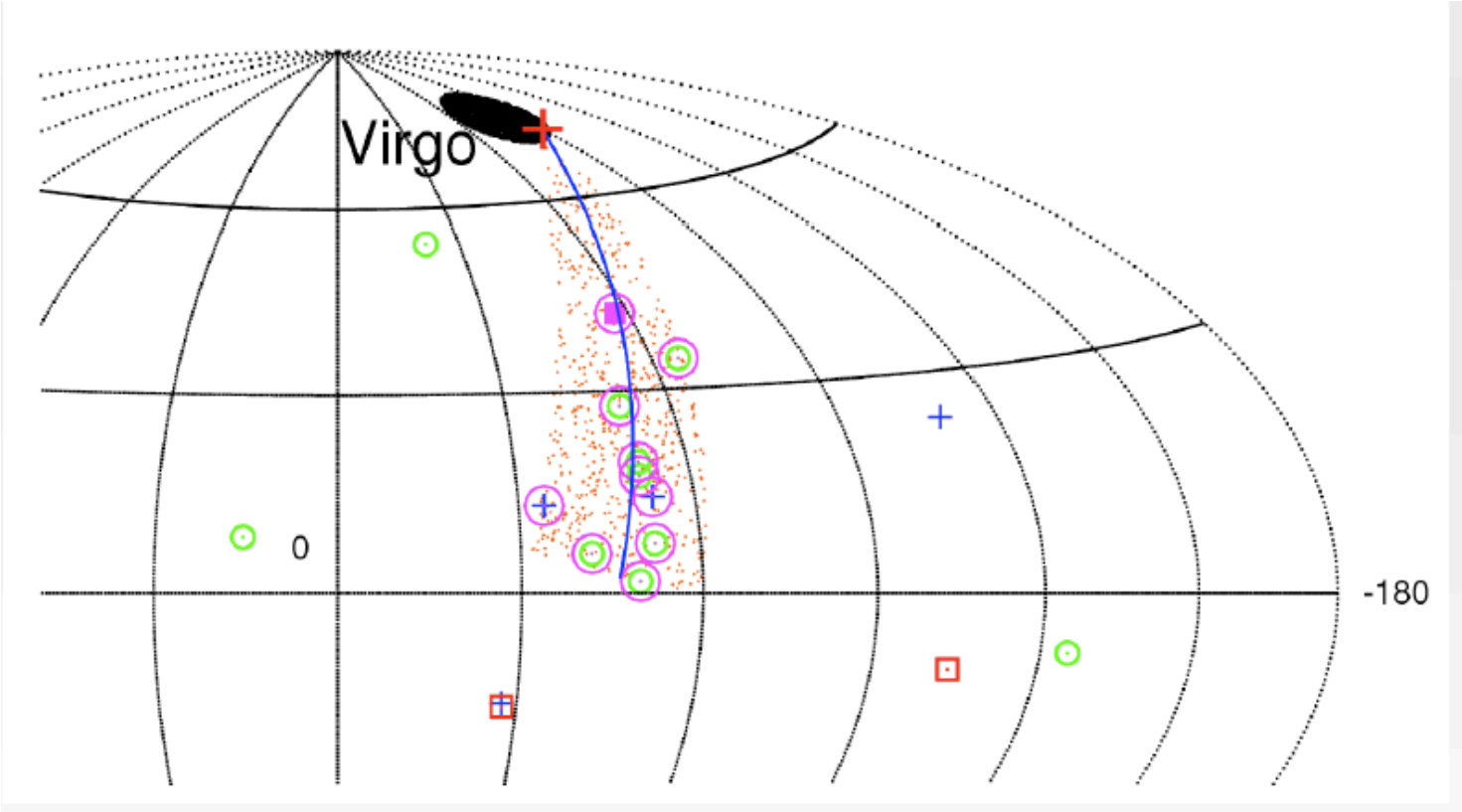
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data: 27 events as first set



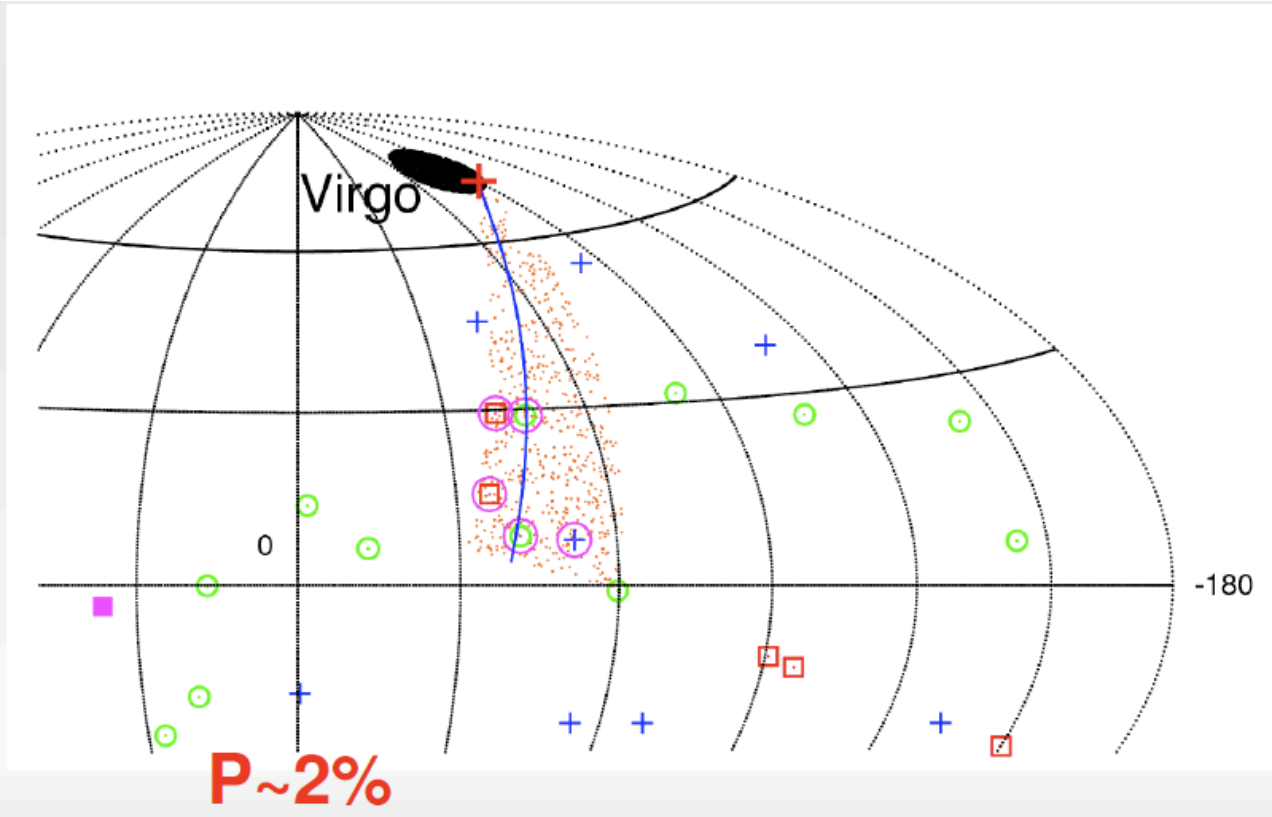
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data: 27 events as first set



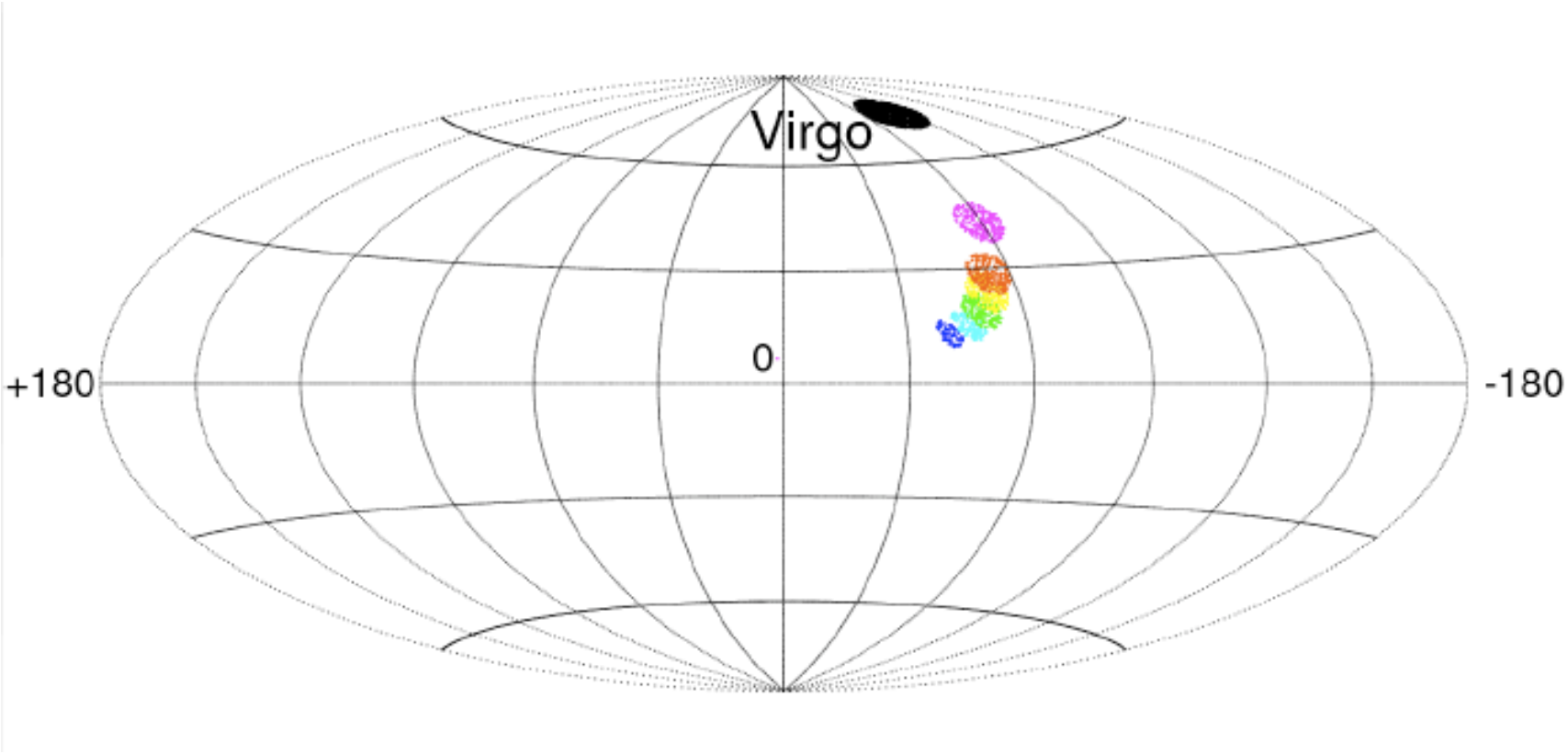
G.Giacinti and D.S., **arXiv:1011.6333**

Application to Auger data: 39 events as second set



G.Giacinti and D.S., **arXiv:1011.6333**

Model simulation of the galactic magnetic field



G.Giacinti and D.S., **arXiv:1011.6333**

Conclusions

- UHECR with E>30 EeV are dominated by heavy nuclei
- Only anisotropy in Auger data is cluster of events 20 degrees around Cen A
- UHECR nuclei are deflected in galactic field by 50-100 degrees even at E>60 EeV
- We developed new method to search for the nuclei sources in UHECR data.
- Application of this method to the Auger data allowed to find that cluster of events near Cen A can be due to nuclei source in Virgo galaxy cluster. Probability that this happened by chance is 0.5-2% in present Auger data.