Contracting Alignment Patterns of cosmic rays induced in the Galactic Magnetic Field

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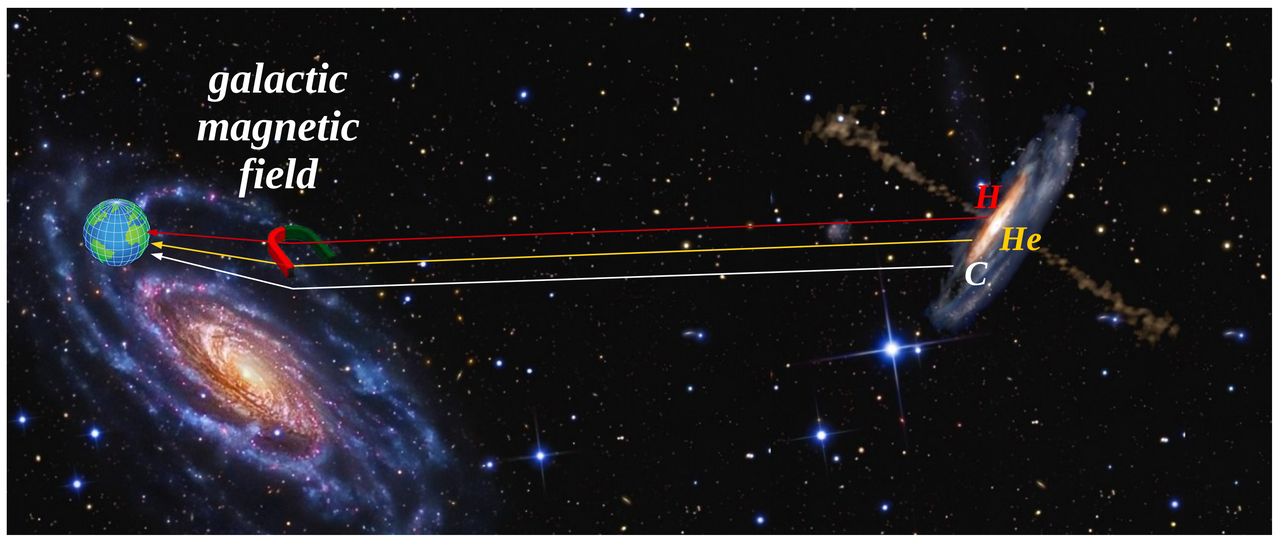
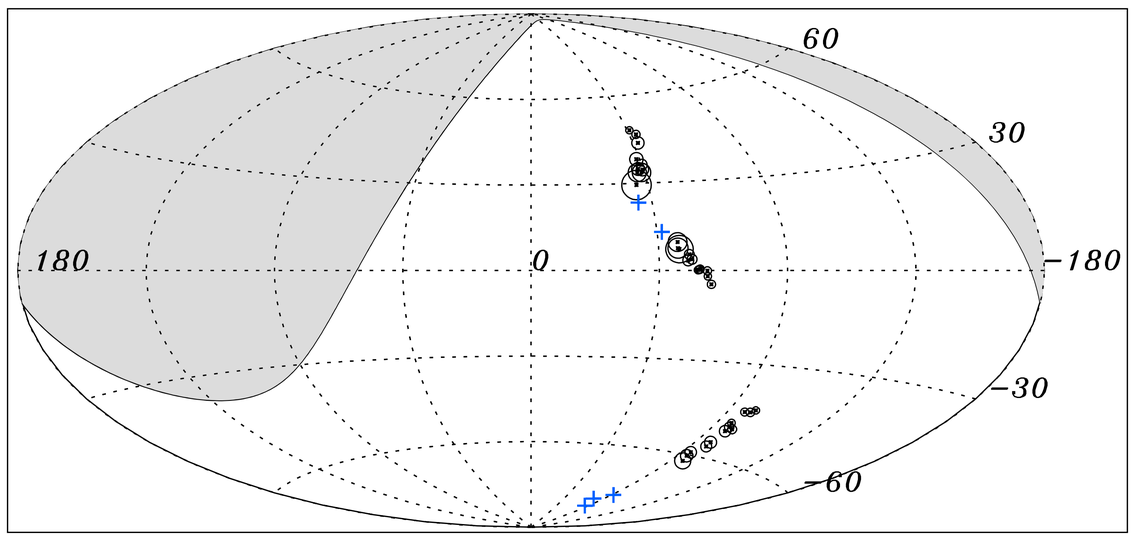
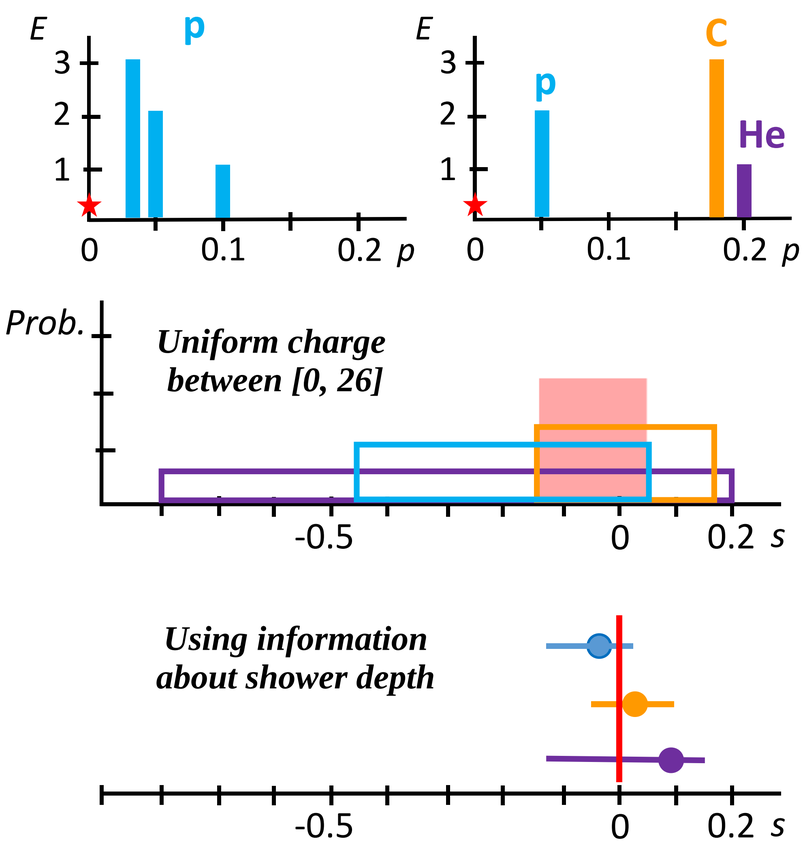
Motivation





- Galactic magnetic field expected to cause specific alignment patterns for charged cosmic rays – depending on energy and elementary charge
- Discovery of significant pattern implies discovery of a point source
- Search for energy alignments in data of the Pierre Auger Observatory yields a 12-plet, with chance probability of 6% to appear in isotropy [2]
- Combinatorics of this analysis explodes when including charges

Contracting alignment patterns – Fit method



Transformation prescription: transforms extragalactic cosmic ray direction s_i, charge Z_i and energy E_i to observed direction p_i – includes a galactic magnetic field model (JF12)

$$\begin{pmatrix} \hat{s}_i \\ \hat{Z}_i \end{pmatrix} \Longrightarrow T\left(\hat{s}_i, \hat{Z}_i, E_i\right) \Longrightarrow \hat{p}_i$$

Loss term: the fit is driven by an objective function that ensures to keep the observed cosmic ray directions, to stay compatible with shower depth measurements and to cluster in as few source directions as possible (representing the source positions)

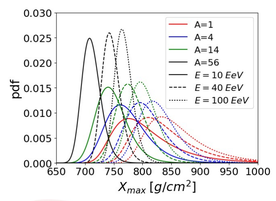
$$J = D + \lambda_Q \cdot Q + \lambda_C \cdot C$$

Distance term: $D = \frac{1}{N} \sum_i \|p_i - \hat{p}_i\|^2$

Keeps observed directions of cosmic rays by penalizing the squared difference

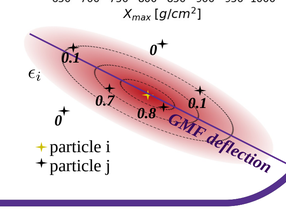
Charge term: $Q = \left[\frac{1}{N} \sum_i \frac{(X_{\max,i} - \mu_i)^2}{\mathrm{Var}(G(\hat{A}_i, E_i))} - 1 \right]^2$

Chi-square for Gumbel distributions close to one

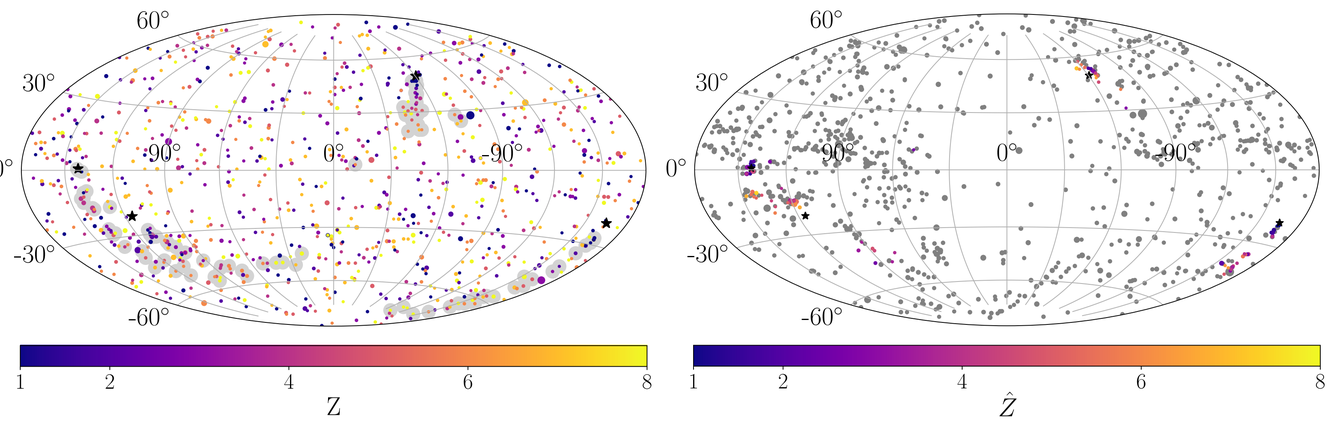


Cluster term: $C = \frac{\sum_{\hat{s}_i} \sum_{\hat{s}_j} \epsilon_{ij} \cdot \|\hat{s}_i - \hat{s}_j\|^2}{\sum_{\hat{s}_i} \sum_{\hat{s}_j} \epsilon_{ij}}$

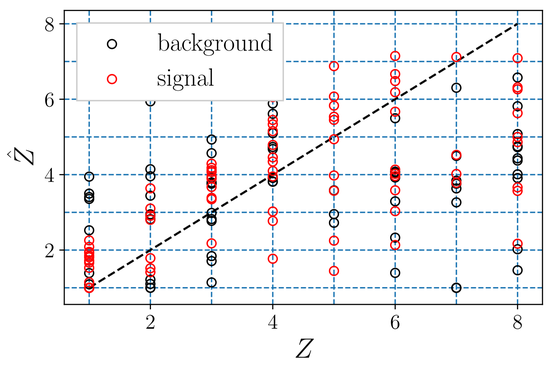
Contracts directions outside the galaxy along magnetic deflections



Exemplary fit

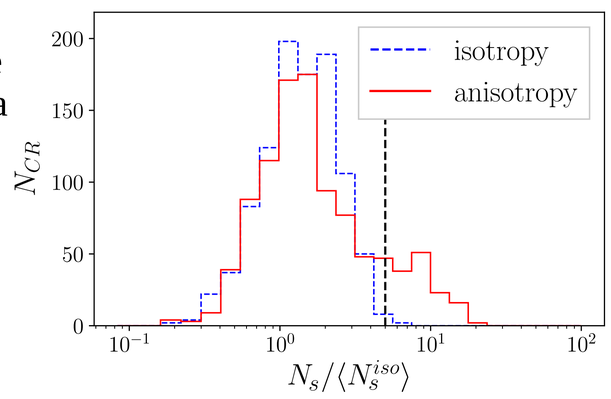


- Construct realistic astrophysical scenario:
  - 4 sources emitting 25 cosmic rays each
  - 900 isotropically distributed cosmic rays
  - Auger-like spectrum above 40 EeV
  - Charges uniformly in Z = 1, …, 8
  - Deflections performed in JF12 field
- Fit contracts most of the signal cosmic rays to their correct origin
- Charges are reasonably fitted

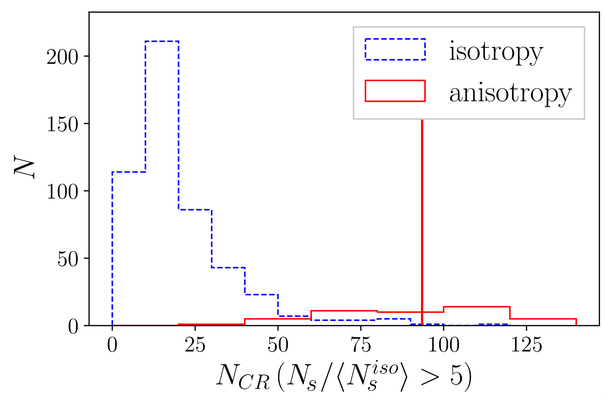


Expected sensitivity

- 5°-tophat count of the fitted directions s_i as a fraction of the mean found in isotropy
- Tail at high tophat in the anisotropic set



- Statistical measure: number of cosmic rays with more than 5x higher densities than in isotropy
- Only 2 / 500 isotropic realizations denser than median signal scenarios



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References

[1] M. Erdmann, L. Geiger, D. Schmidt, M. Urban, M. Wirtz – arXiv: 1807.08734 – accepted for publication in *Astroparticle Physics*

[2] P. Abreu et al. [The Pierre Auger Collaboration], *Astroparticle Physics* 35 (2012), pp 354-361

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