GEFÖRDERT VOM

Bundesministerium
für Bildung
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RWTH AACHEN UNIVERSITY

Methods & Observables: Investigation of Cosmic Magnetic Fields using Ultra-High Energy Cosmic Rays

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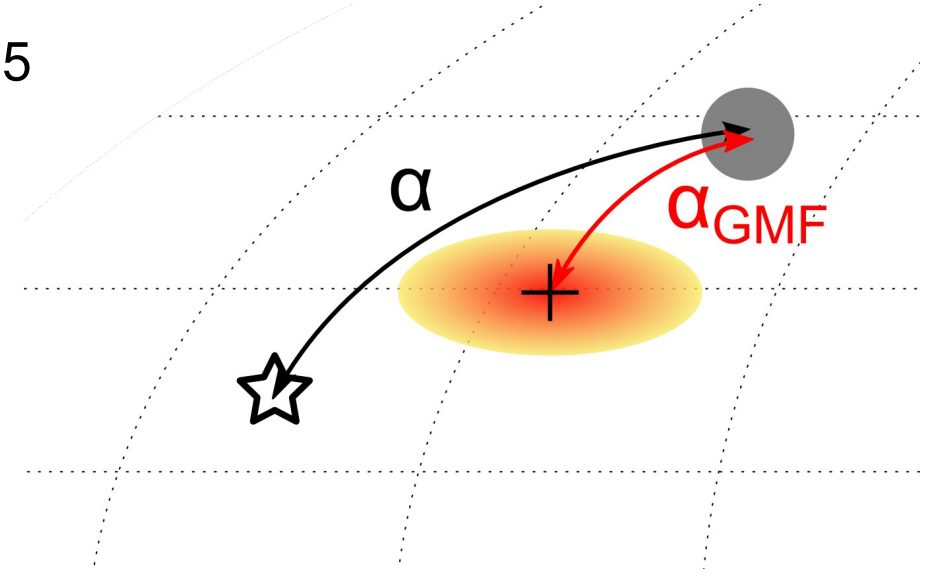
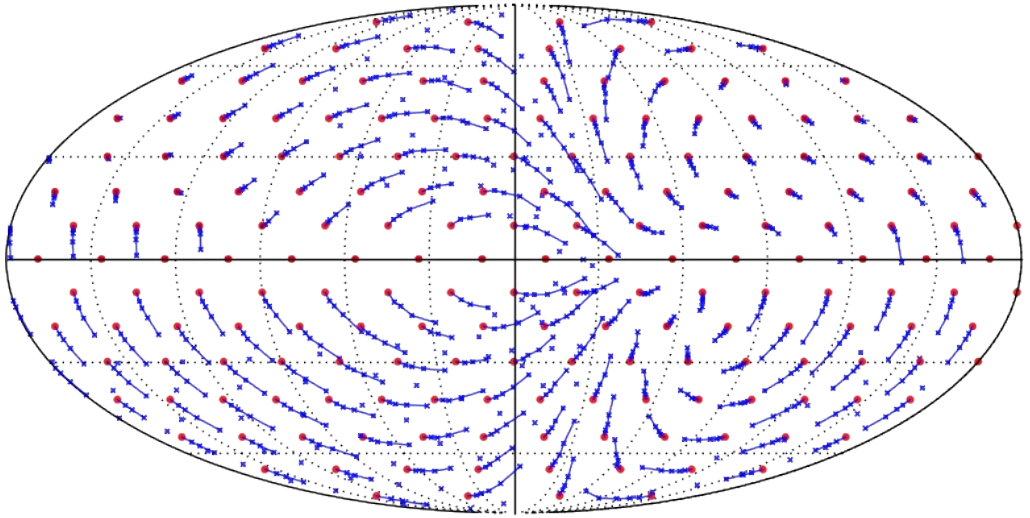
ICRC 2015

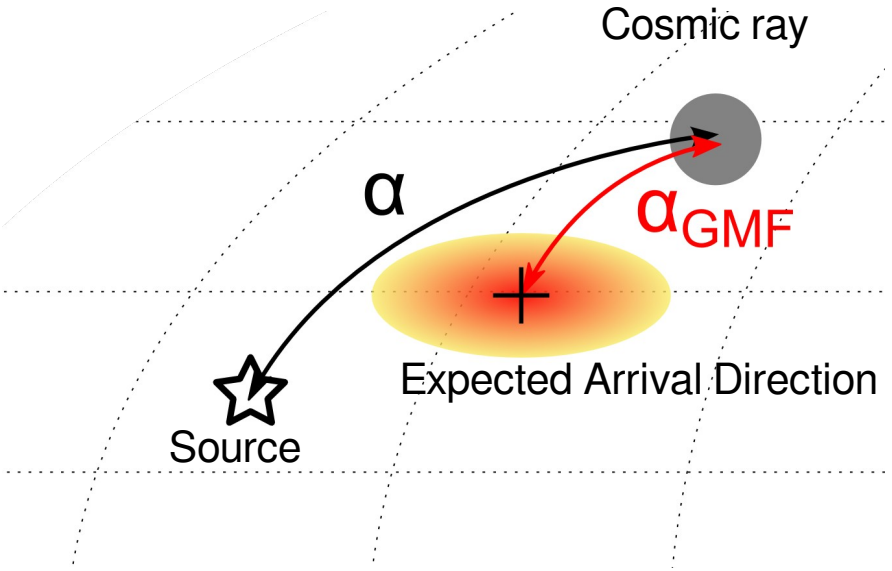


Enhanced Correlation Analysis

- Recent galactic magnetic field parametrizations predict localized deflection
  - → Direction and
  - → Magnitude
- Correlate cosmic rays with expected arrival directions



Farrar et. al

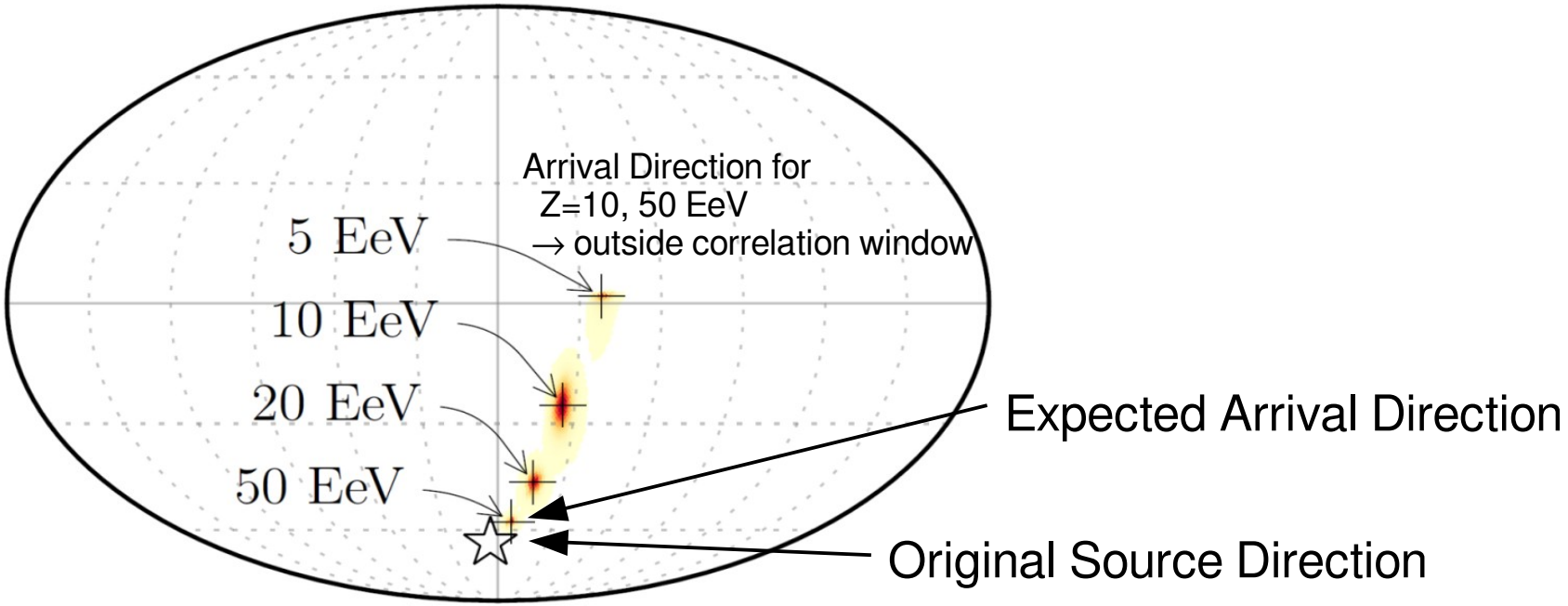


20-200 EeV
Galactic Coordinates
Jansson, Farrar, 2012, ApJ, 757, 14; 2012, ApJ, 761, L11

Expected Arrival Direction

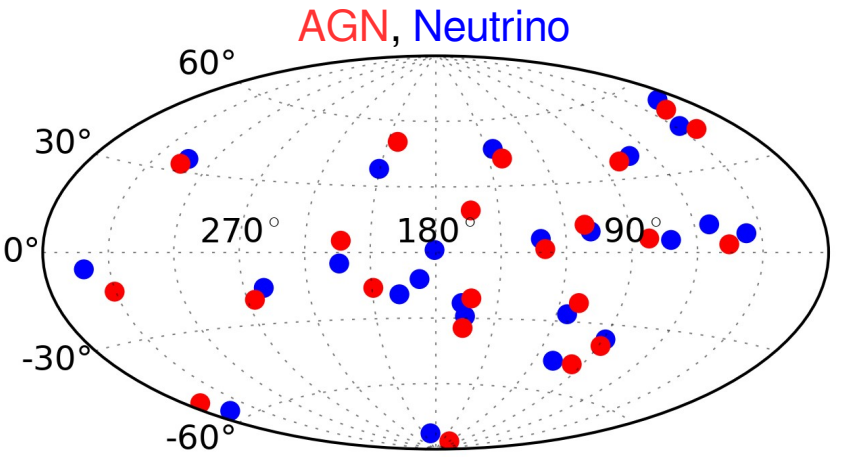
- Cosmic rays with energy E, assume Z=1

1) Source at distance D
2) Extra-galactic propagation: smearing(E, D, B) → probability map
3) Galactic propagation: JF12 regular field (lensing technique)
4) Find expected arrival direction

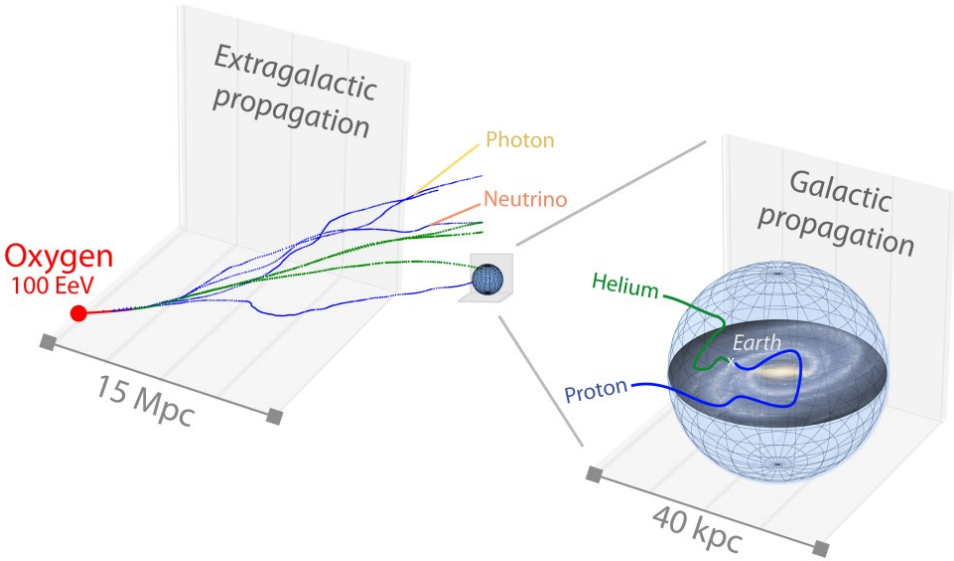


Astrophysical Simulation

- AGNs from VCV catalog closest to selected 24 public IceCube neutrinos



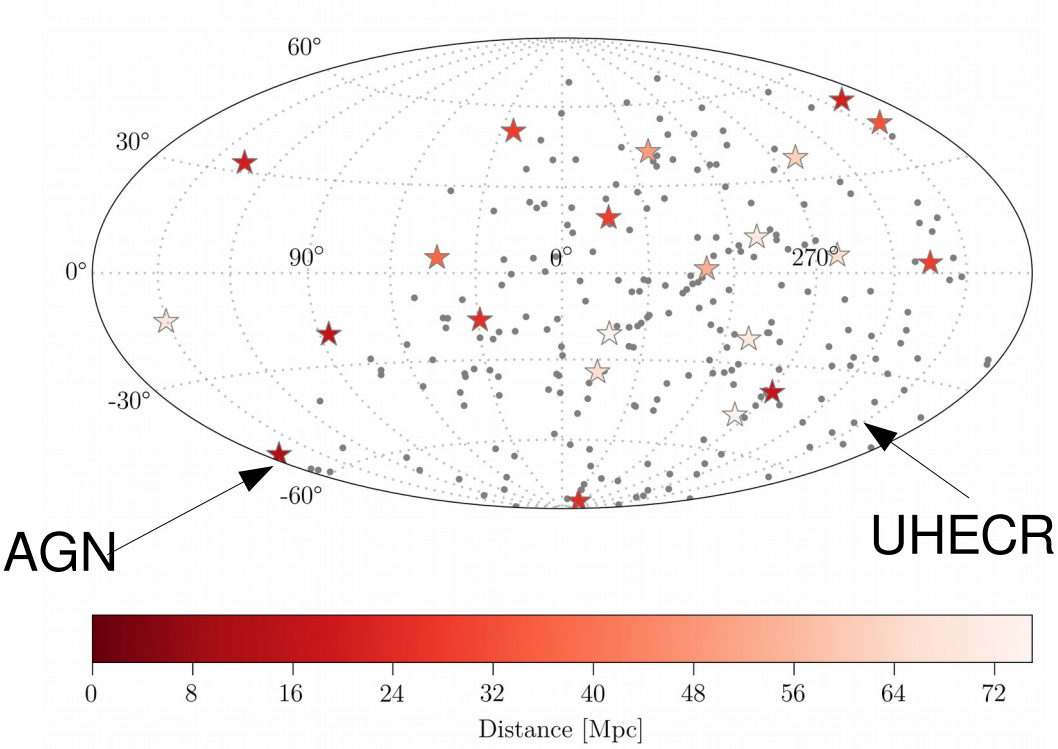
- Propagate 10^7 high energetic nuclei from each source using CRPropa 3:
  - → Structured extra-galactic magnetic field
  - → Interactions
  - → Secondaries
- Propagate detected cosmic rays to Earth using JF12 regular field lens



Simulated Data Set

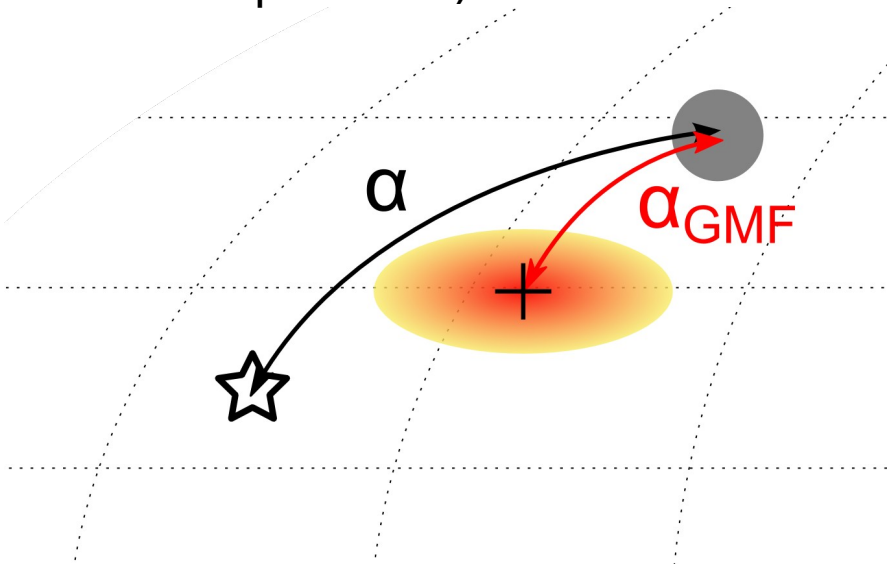
- 231 events

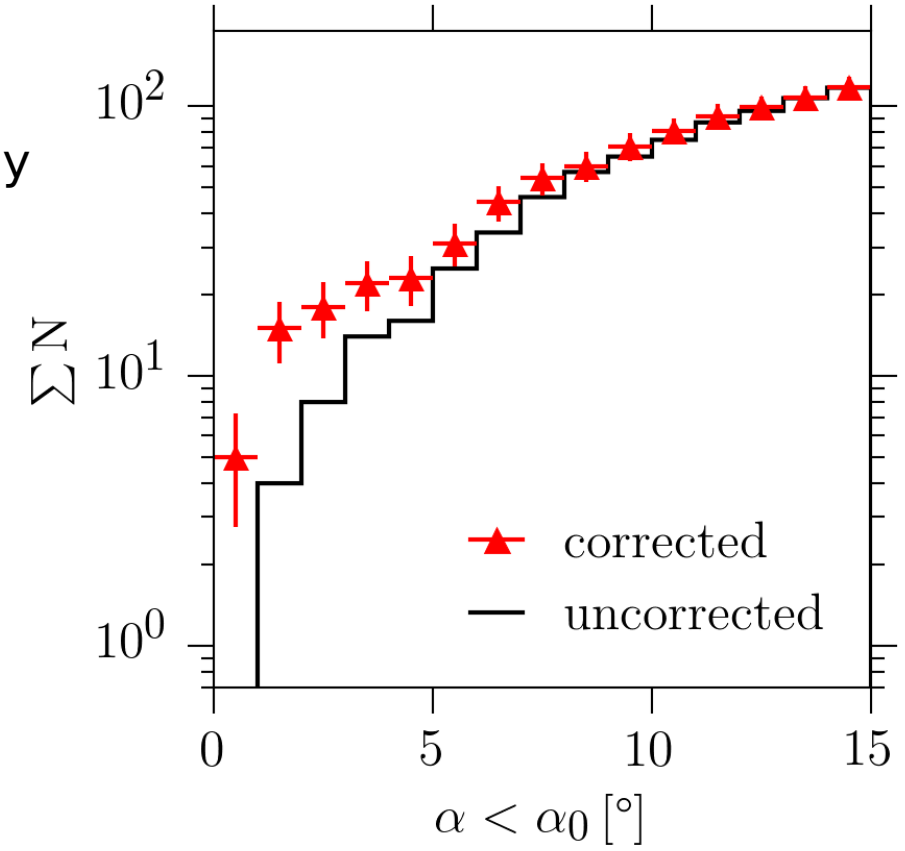
  (see Pierre Auger Observatory publication)
- E > 52 EeV
- Signal: 23 cosmic rays (10%) from astrophysical simulation
  - → 16 protons
- Background: 208 cosmic-rays with isotropic arrival direction
- Pierre Auger Observatory geometric exposure



Angular Distance

- Angular distances between cosmic ray and closest
  - → Source
  - → Expected arrival direction (Energy dependent)

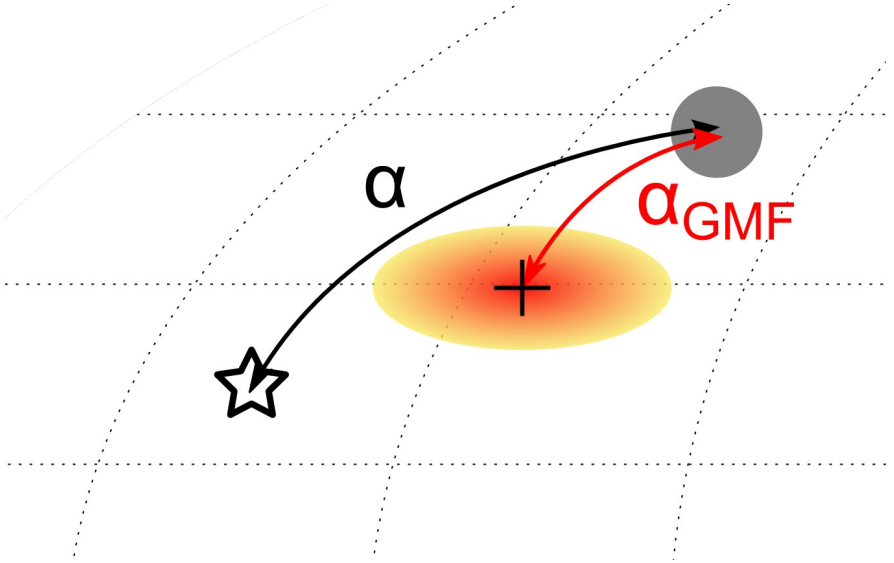


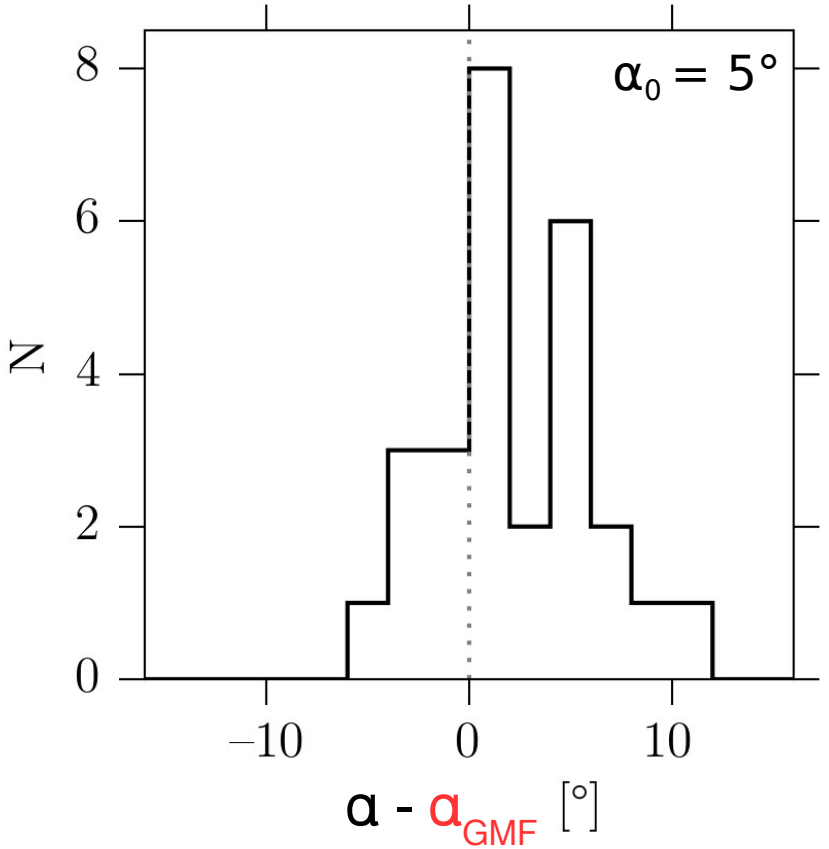


- Preselection:
  - → e.g. α, $\alpha_{GMF} < \alpha_0 = 5°$

Magnetic Field Observable: Angular Asymmetry

- Change in angular distance



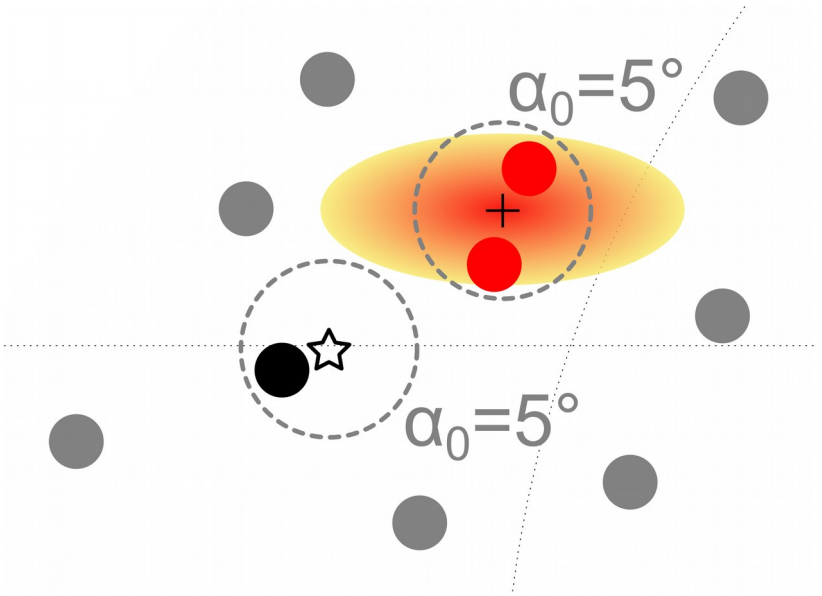


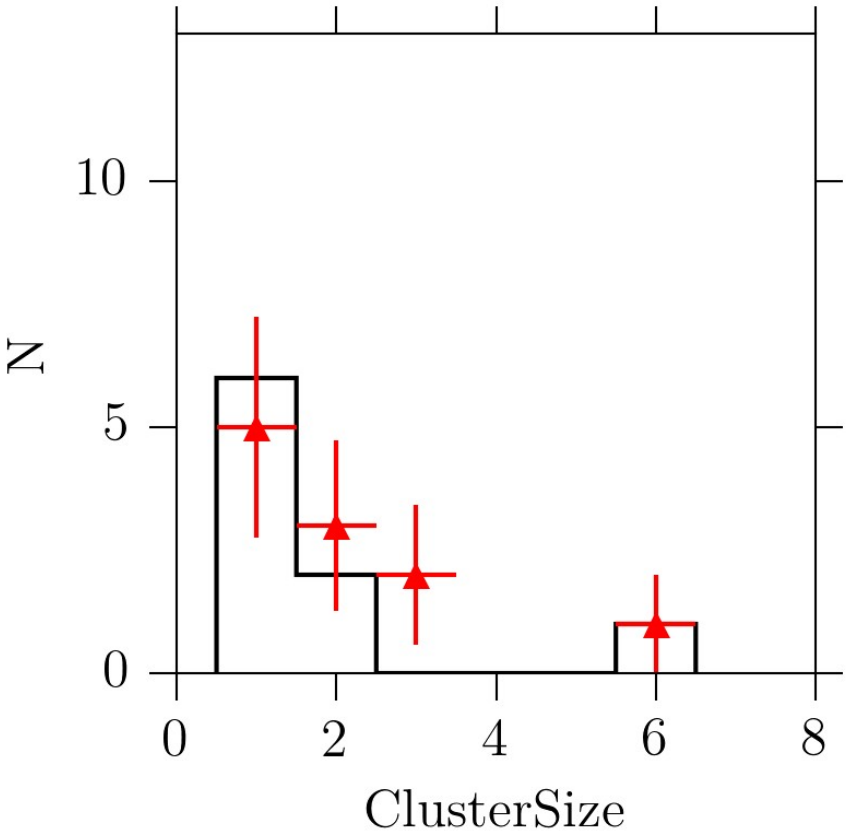
$$A \equiv 2\,\frac{N(\alpha > \alpha_{\mathrm{GMF}}) - N(\alpha < \alpha_{\mathrm{GMF}})}{N(\alpha > \alpha_{\mathrm{GMF}}) + N(\alpha < \alpha_{\mathrm{GMF}})}$$

= 0.962963

Magnetic Field Observable: Clustering

- Number of correlating events per
  - → Source
  - → Expected arrival direction

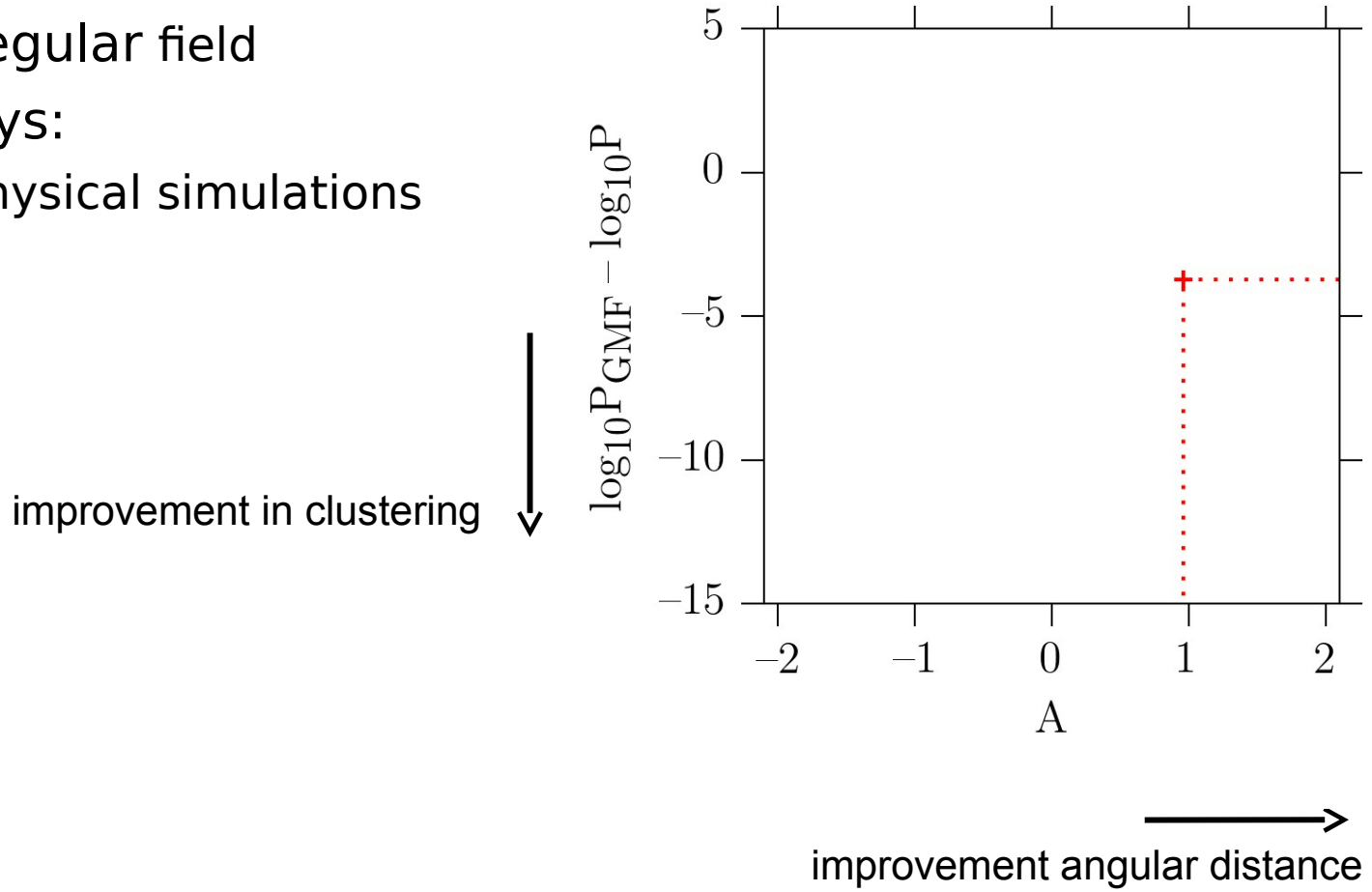




- Cluster distribution probability
  - → P = multinomial distribution
- Observable: $\log(P_{GMF}) - \log(P) \sim 4$

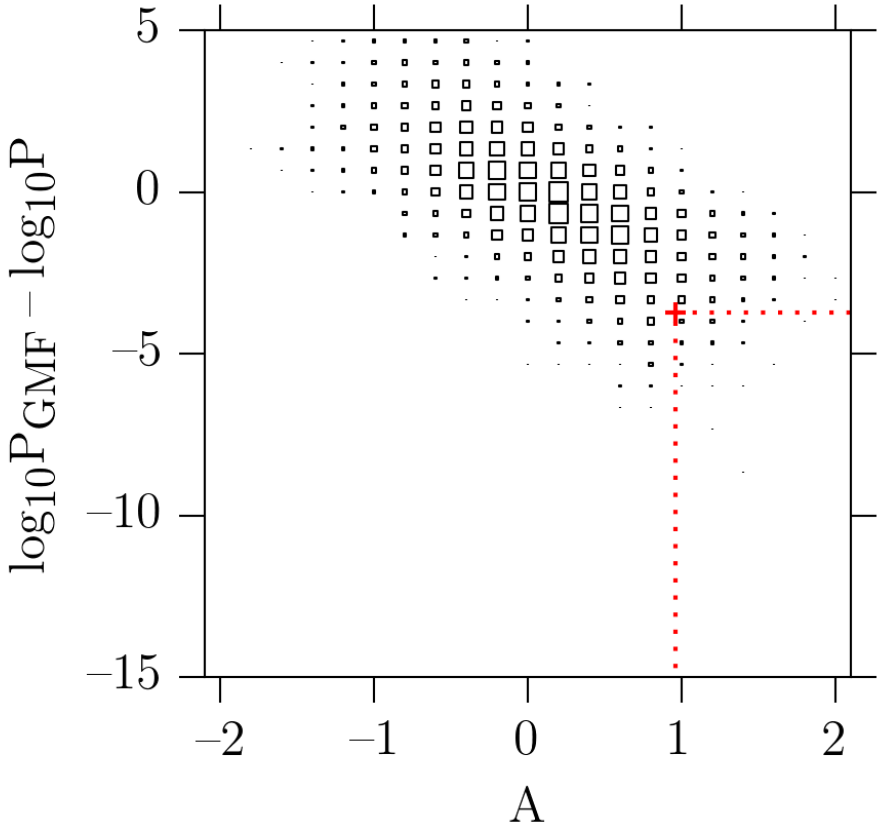
Combine Observables

- Expected Arrival Directions:
  - → AGN sources
  - → JF12 regular field
- Cosmic rays:
  - → Astrophysical simulations



Random Sources

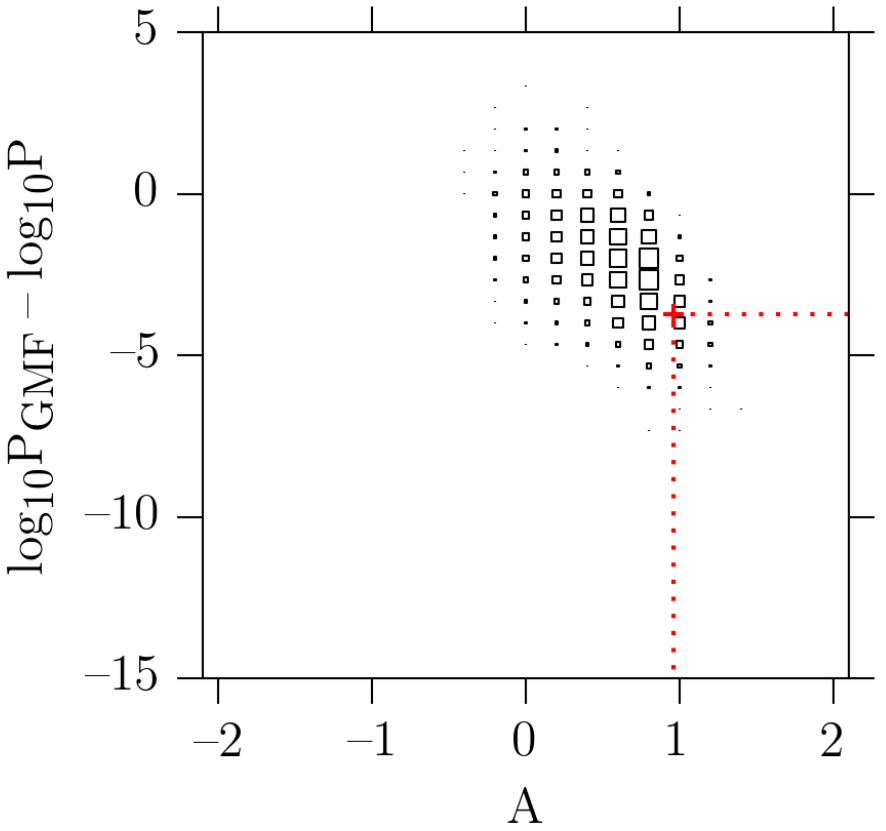
- Expected arrival directions:
  - → AGN sources
  - → JF12 regular field
- Cosmic rays:
  - → Astrophysical simulations
- 10000 variations:
  - → **Random source directions**
  - → 47 show improvement in both observables



Source directions important

Uncertainty in Source Direction

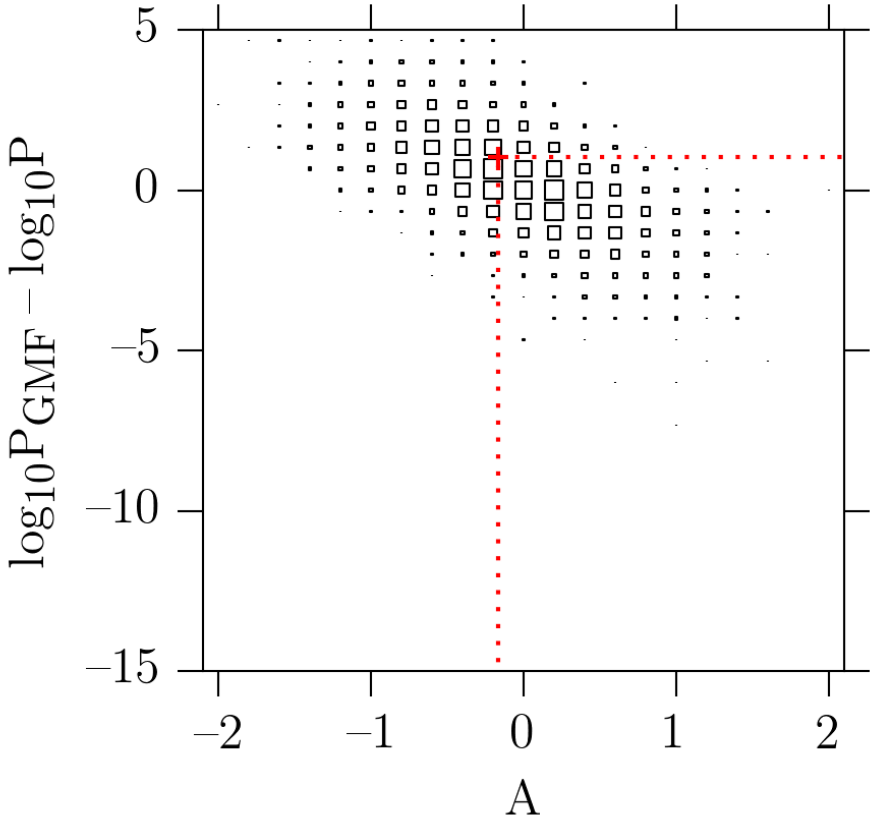
- Expected arrival directions:
  - → AGN sources
  - → JF12 regular field
- Cosmic rays:
  - → Astrophysical simulations
- 10000 Variations:
  - → **AGN sources with 15° directional uncertainty**



Large uncertainties reduce sensitivity

Directional characteristics of galactic magnetic field

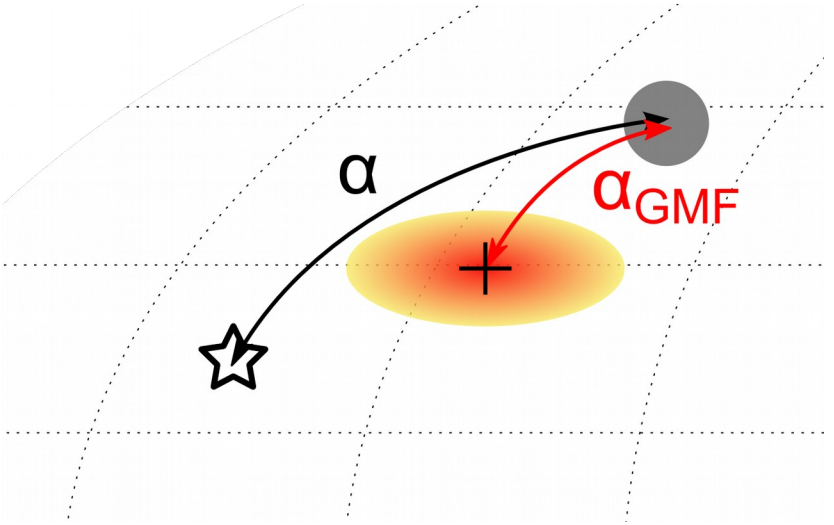
- Expected arrival directions:
  - → AGN sources
  - → **JF12 regular + striated + random, inverted**
- Cosmic rays:
  - → Astrophysical Simulations
- 10000 Variations:
  - → **Isotropic cosmic ray arrival directions**



Correct characteristics of magnetic field is essential to detect signal

Conclusion

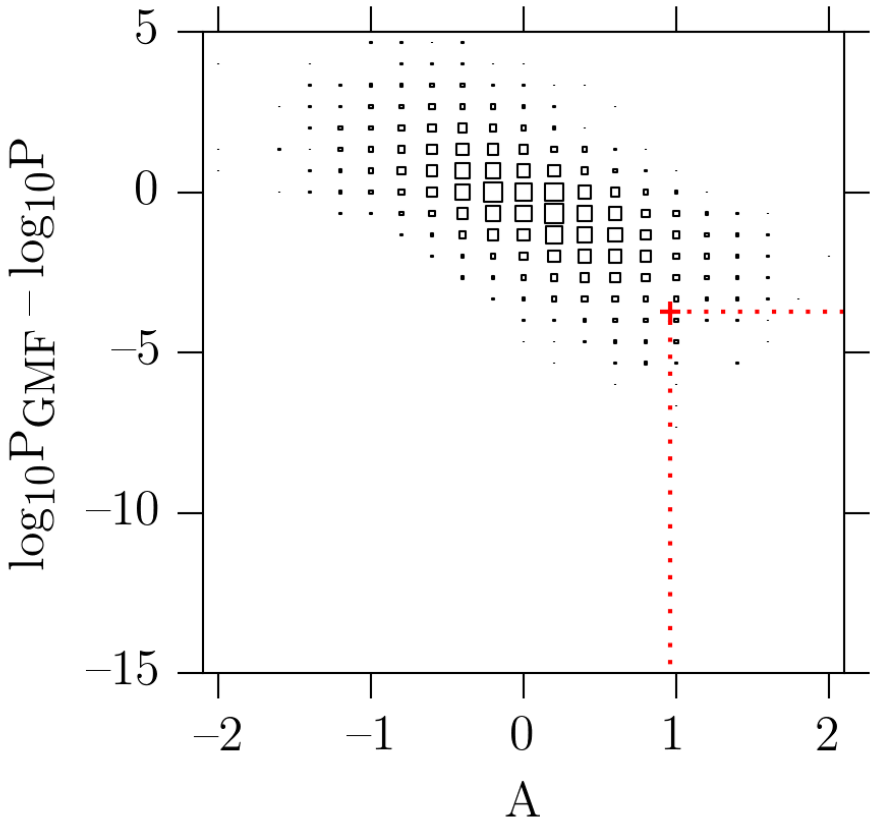
- Enhanced correlation method: expected arrival directions
  - → Include extra-galactic and galactic deflections
  - → Improved correlation count
- Observables for magnetic field investigations
  - → Angular Asymmetry
  - → Clustering
- Analysis method is:
  - → Sensitive to Galactic magnetic field structure
  - → Sensitive to selected source positions



Backup slides

Exceptional Cosmic rays

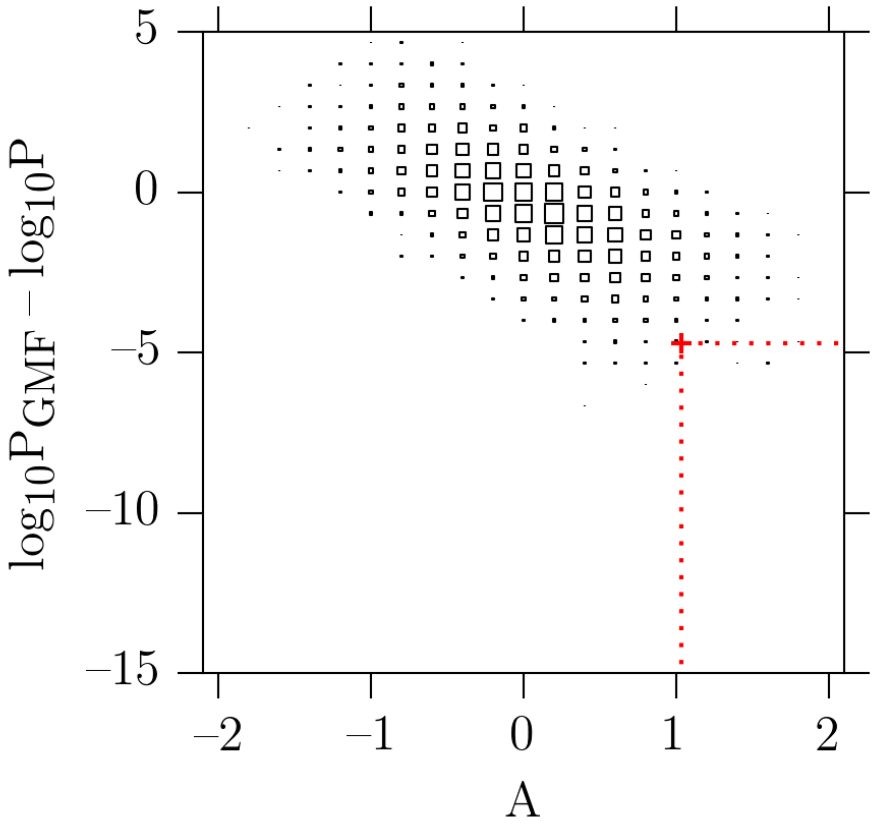
- Expected arrival directions:
  - → AGN sources
  - → JF12 regular field
- Cosmic rays:
  - → Astrophysical Simulations
- 10000 Variations:
  - → **Isotropic cosmic ray arrival directions**
  - → 29 show improvement in both observables



Simulated cosmic rays can be identified

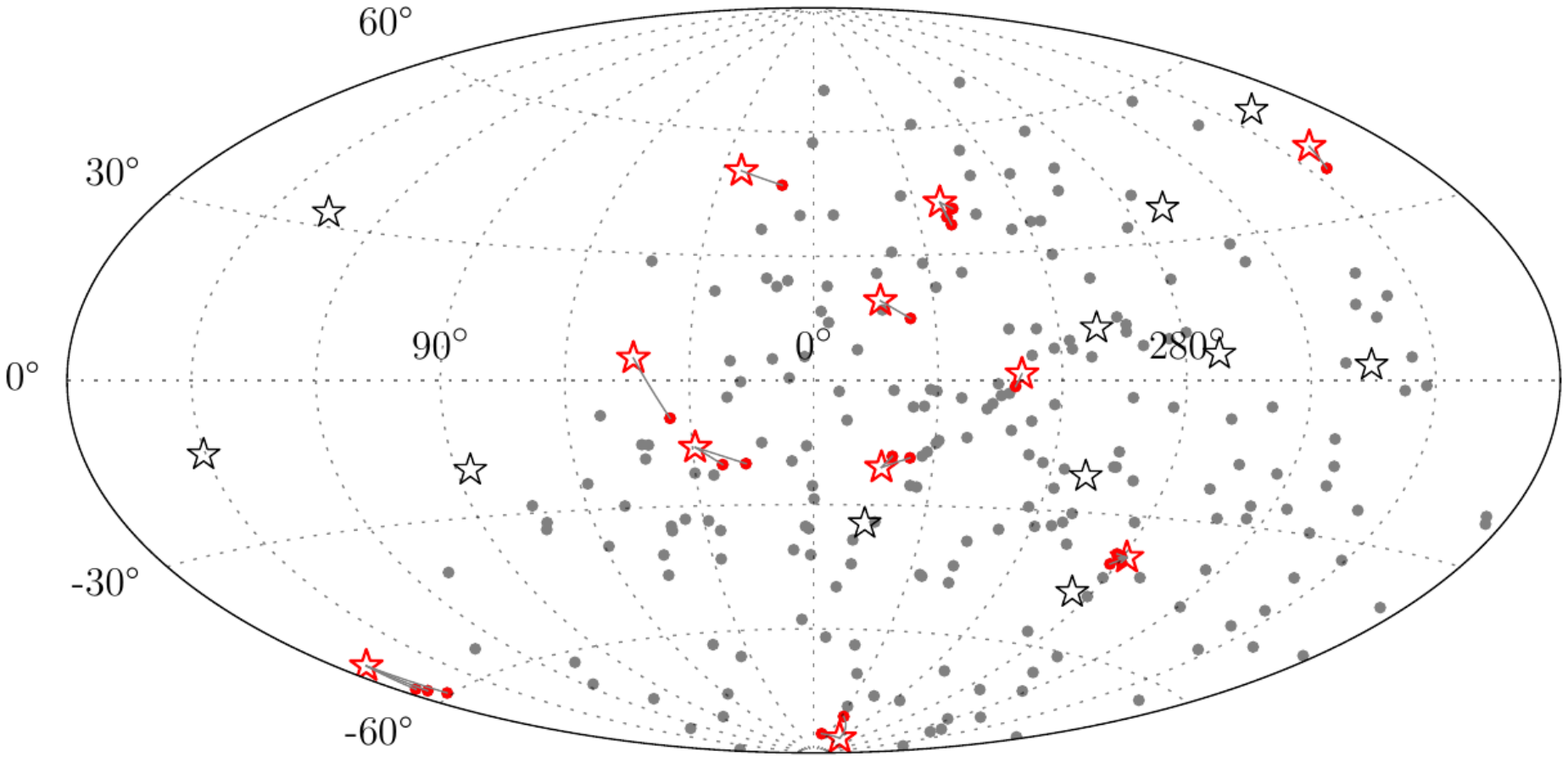
Random component of galactic magnetic field

- Expected arrival directions:
  - → AGN sources
  - → **JF12 regular + striated + random**
- Cosmic rays:
  - → Astrophysical Simulations
- 10000 Variations:
  - → **Isotropic cosmic ray arrival directions**
  - → 10 show improvement in both observables



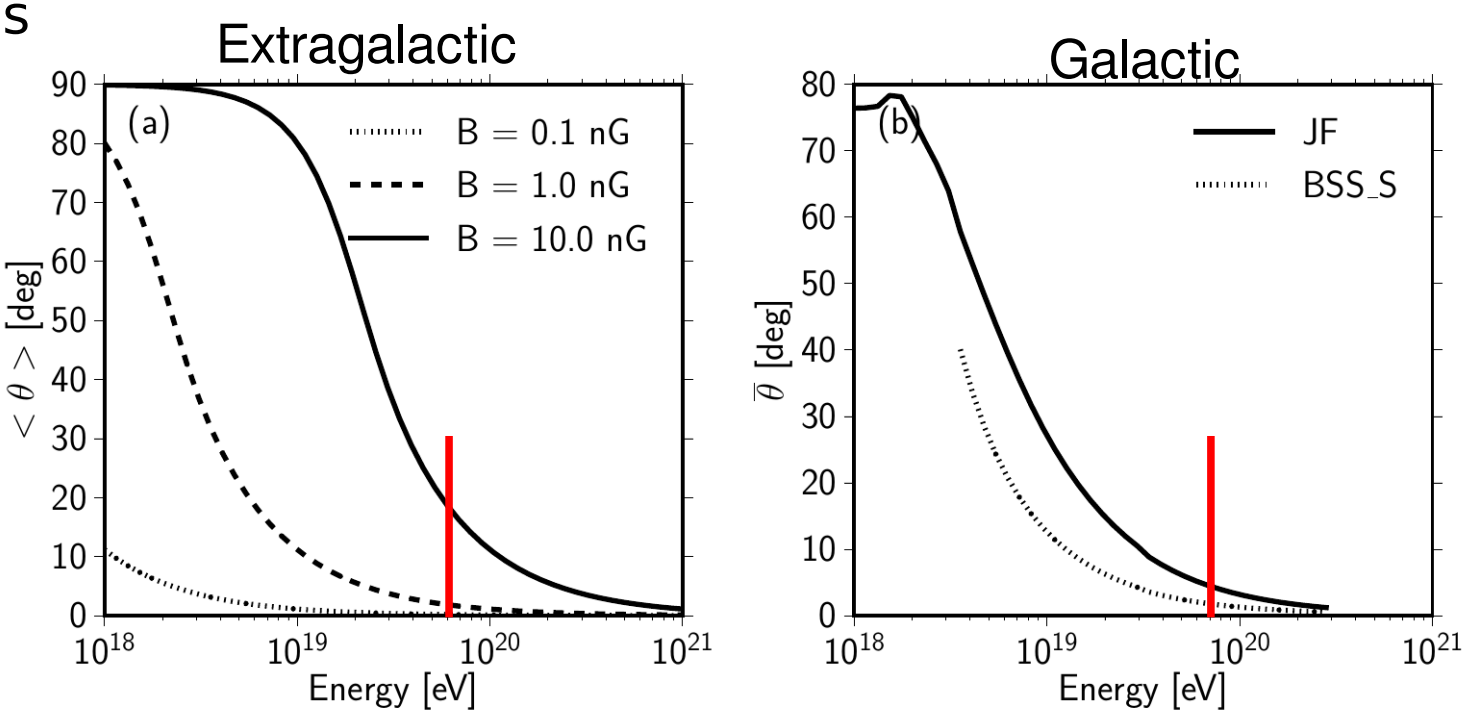
Random component has no effect on analysis

Correlations with transformed position



Motivation

- Mean deflection for E>55 EeV
- 10 Mpc distance
- Protons

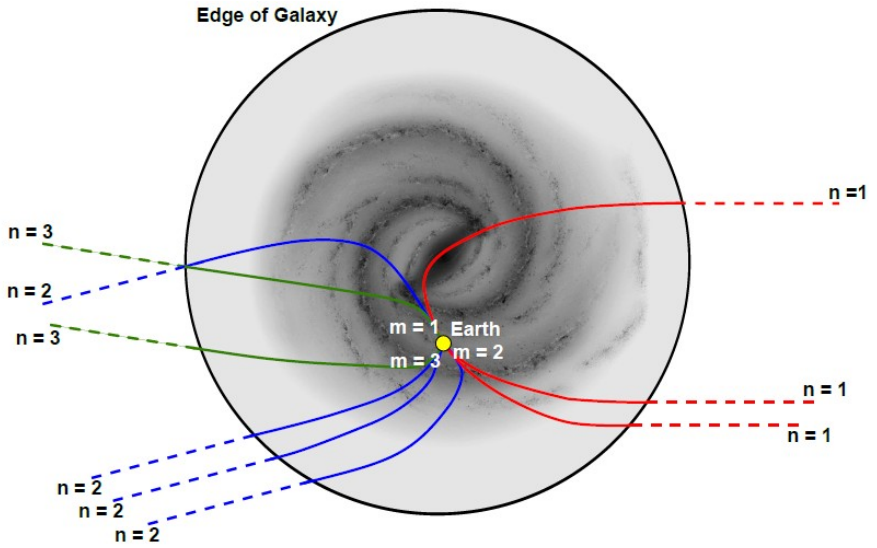


H.-P. Bretz et al., Astropart.Phys. C54 (Feb., 2014) 110–117, 1302.3761.

Galactic magnetic lenses

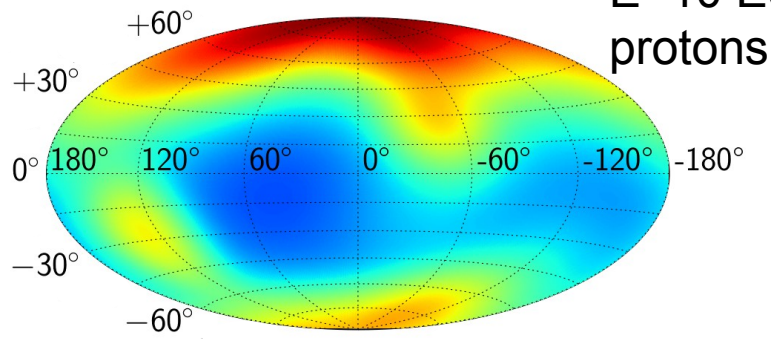
H-P Bretz, M.E., P. Schiffer, D., T. Winchen, AP 54C (2014) 110

Probability of a particle entering galaxy in pixel *n* is observed in direction *m*



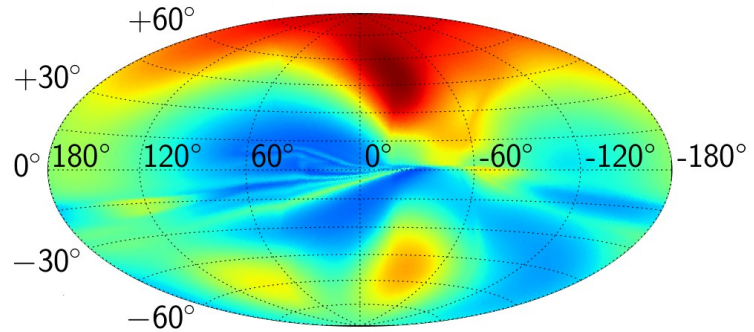
Simulated probability distribution of extragalactic arrival

E=10 EeV protons



Probability distribution projected onto the Earth

Galactic field: Jansson, Farrar 2012



Lenses suited for sources at Mpc distance from the observer

Multinomial probability =probability of cluster configuration

$$P(n_1, ..., n_{24}; N - N_{hit}) = \frac{N!}{n_1!...n_{24}!\,(N - N_{hit})!}\; p_1^{n_1} \;...\; p_{24}^{n_{24}}\; (1 - p_{iso})^{N - N_{hit}}$$

N : total number of cosmic rays

N_{hit} : number of cosmic rays correlating with neutrinos $N_{hit} = Sn_i$

p_{iso} : summed average neutrino hit probability $p_{iso} = Sp_i$

i : neutrino identifier

p_i : neutrino i average hit probability

n_i : number of cosmic rays associated with neutrino i