Extracting information from the way the highest energy events cluster

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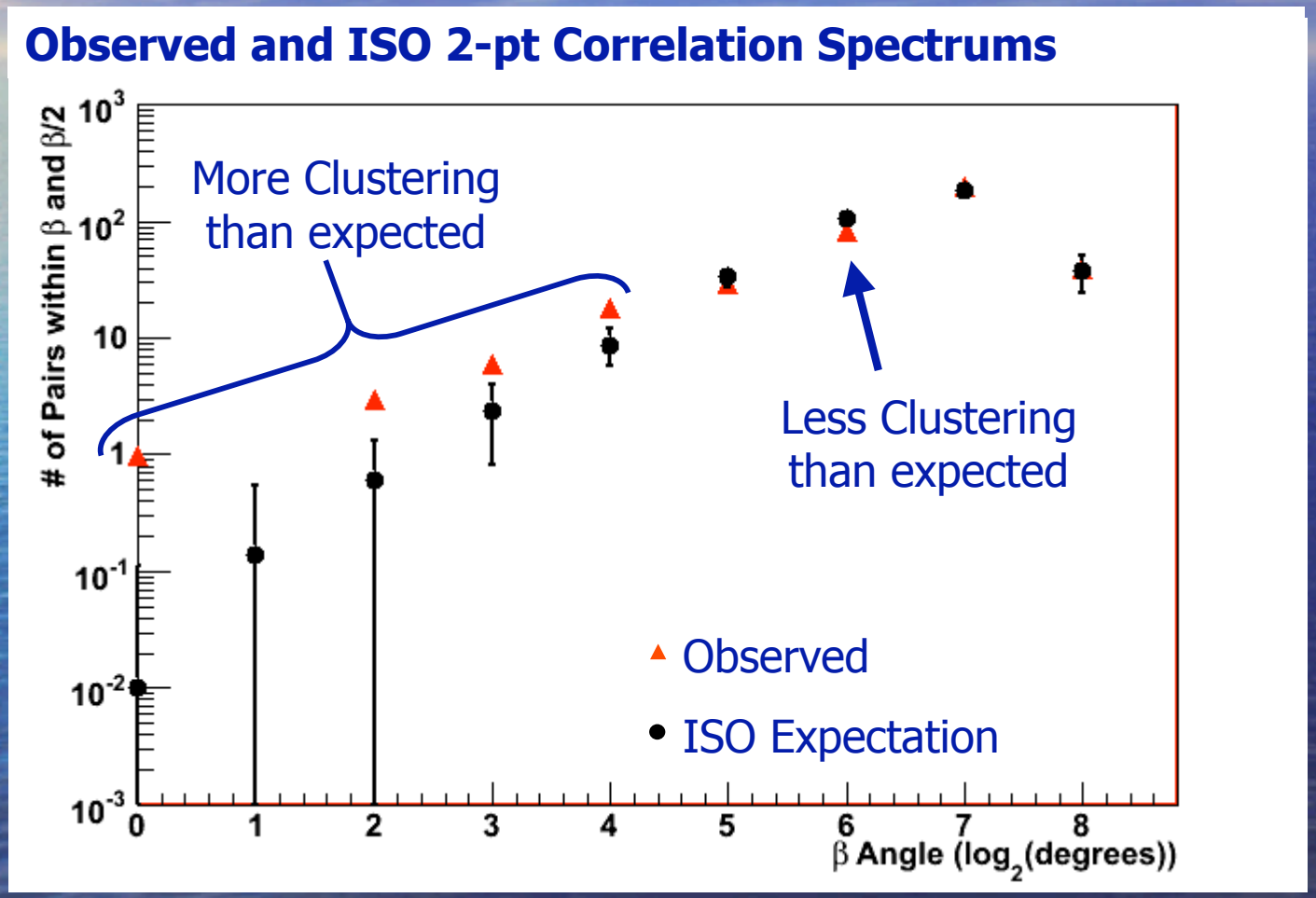
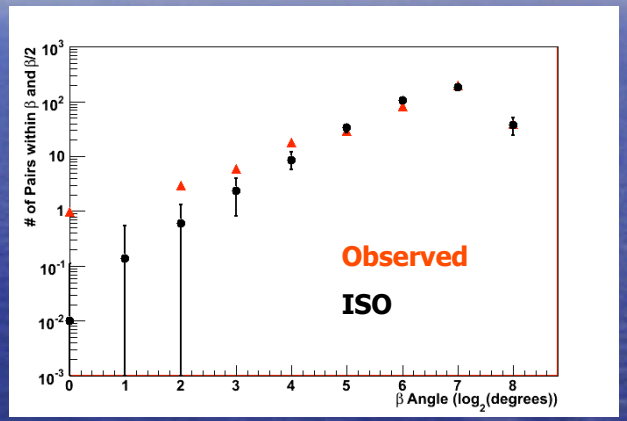
The Auger Cosmic Ray Sky >57 EeV



*Data from Abraham et al., Astroparticle Physics 27 (2007) 244.

What can event clustering tell us?

- The 2-pt correlation spectrum is dependent on:
  - Source Distribution and Number,
  - Particle Charge,
  - Intervening Magnetic Fields.

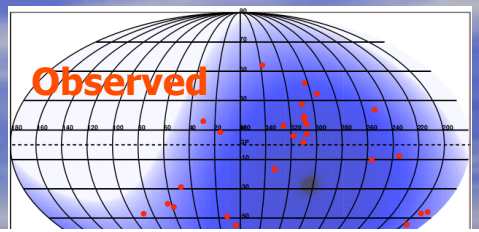


- Important information can be extracted from the observed clustering.

Analysis Approach

- Simulate Different Scenarios (Monte Carlo)
- Simple but realistic assumptions:
  - Flux is either Pure Iron or Pure Protons.
  - The source distribution is a combination of:
    - Few bright sources
    - Many dim sources
  - Galactic field dominates the deflections.
    - We use a reasonable galactic magnetic field model
- Compare simulation results with the observed spectrum.
- What are the indications?

Example: 20 Sources



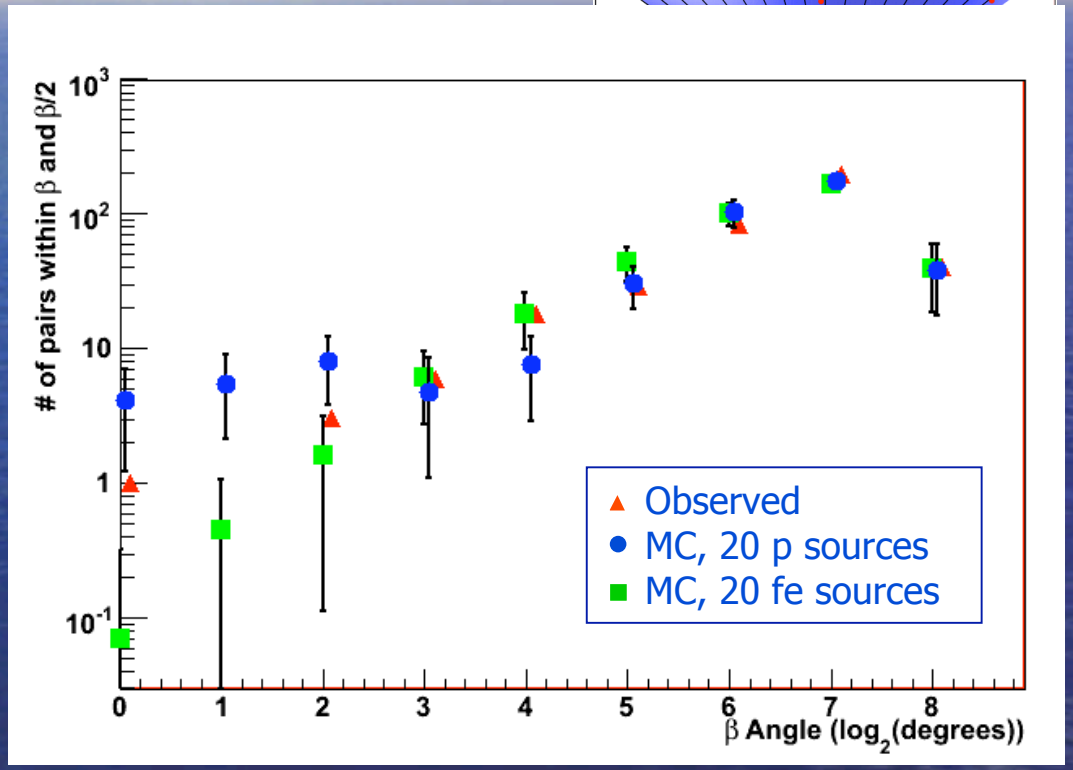
Monte Carlo Details

On average, 75% of flux from 20 "bright" sources, 25% from an ISO background (many dim sources).

Each source has equal apparent luminosity just outside the galactic B-field. E_{cut} = 60 EeV, Spectral Slope = -3.

Every sky location has equal probability of having a source.

Galactic B-field: BSS, dipole, and random, 1 kpc and 4 kpc scale heights, 1.5 μG at sun*.



* The regular field is based on Alverez et al., Astrophys. J. 572 (2003) 185. The random field component is approximated by randomly spreading iron events by 6º.

Some General Results

- Scenarios compatible with current data:
  - Few bright Fe sources (3-30).
  - Many clustered p sources.
  - Fe+p sources which split the difference.
- Disfavored scenarios:
  - Few bright p sources* or many evenly distributed p sources.
  - Many Fe Sources, inclusive of any realistic source clustering.

*Unless the intervening B-fields are much greater than assumed in this study.

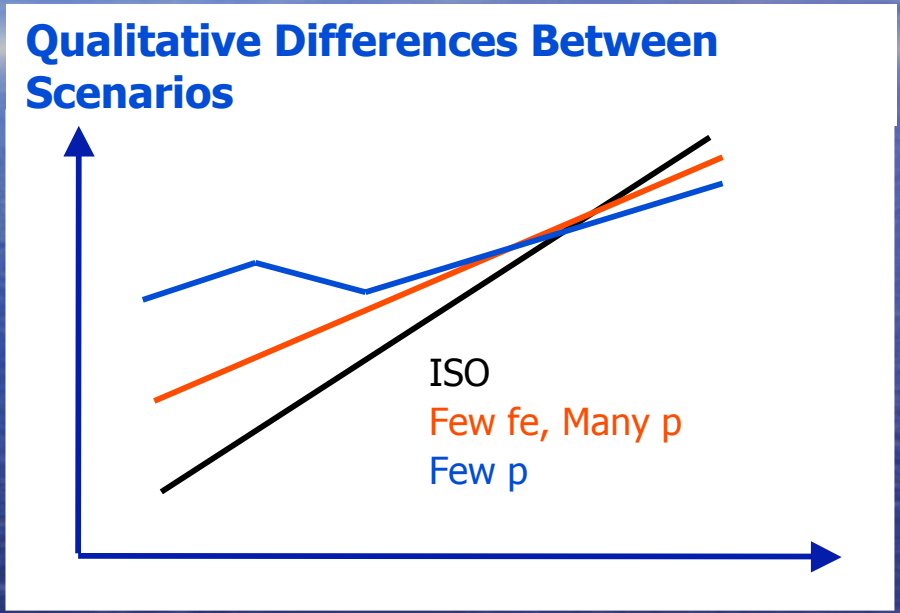
Can we be more definite?

Three Scenarios

- Few p
- Many p
- Few fe

Somewhat Degenerate

- Scenario 1 has a unique signature at small angles.



- We can test against scenarios 2 & 3: Put a limit on the flatness of the spectrum at small angles.

Summary

- Some general properties of the ultra-high energy sources can be determined based on event clustering.
- Specifically, we can test for the existence of a few high luminosity proton sources.
- A few proton sources may be confirmed to exist in the next few years.
  - Are a few sources a signature of AGN?
  - What limits can we put on magnetic fields?
  - Lorentz Invariance Studies?

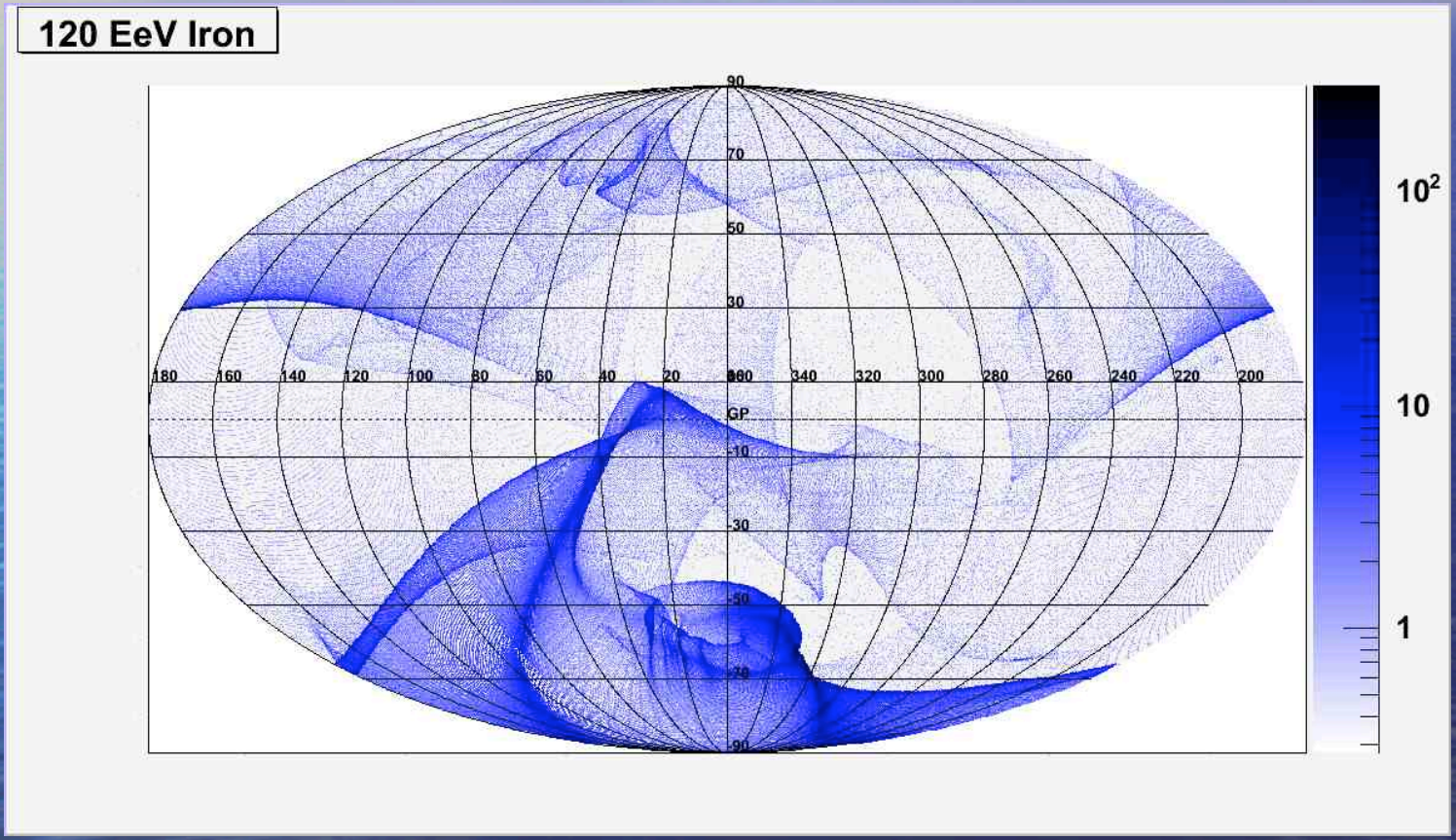
Some extra slides…

Our Current Understanding

- Particle Composition: protons or nuclei (no photons observed[1]).
- Super 10^{19} eV sources are rare (no galactic signature[2]).
- Most of the highest energy particles originate from a relatively few nearby sources because of a GZK-type mechanism (flux suppression[3]).
- The nearby sources are not distributed evenly on the sky (anisotropy[4]).

1. Astroparticle Physics 29 (2008) 243.
2. S. Mollerach, Proceedings of ICRC07
3. Phys. Rev. Lett. 101 (2008).
4. Astroparticle Physics 29 (2008) 188.

If the flux is ISO at earth, where the particles come from:



Monte Carlo Realization: An Expected Event Distribution for the 20fe Scenario