Comparing Coherence Effects for GP300 and GRAND@Auger in the 50-100 MHz and 100-200 MHz Frequency Bands

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Outline

1. Air Shower Radio Emission
    a. Coherence
    b. GP300 vs GRAND@Auger
2. Fluence Footprints
3. Comparison Between Frequency Bands
4. Density correction
5. $\vec{v} \times \vec{v} \times \vec{B}$ Significance

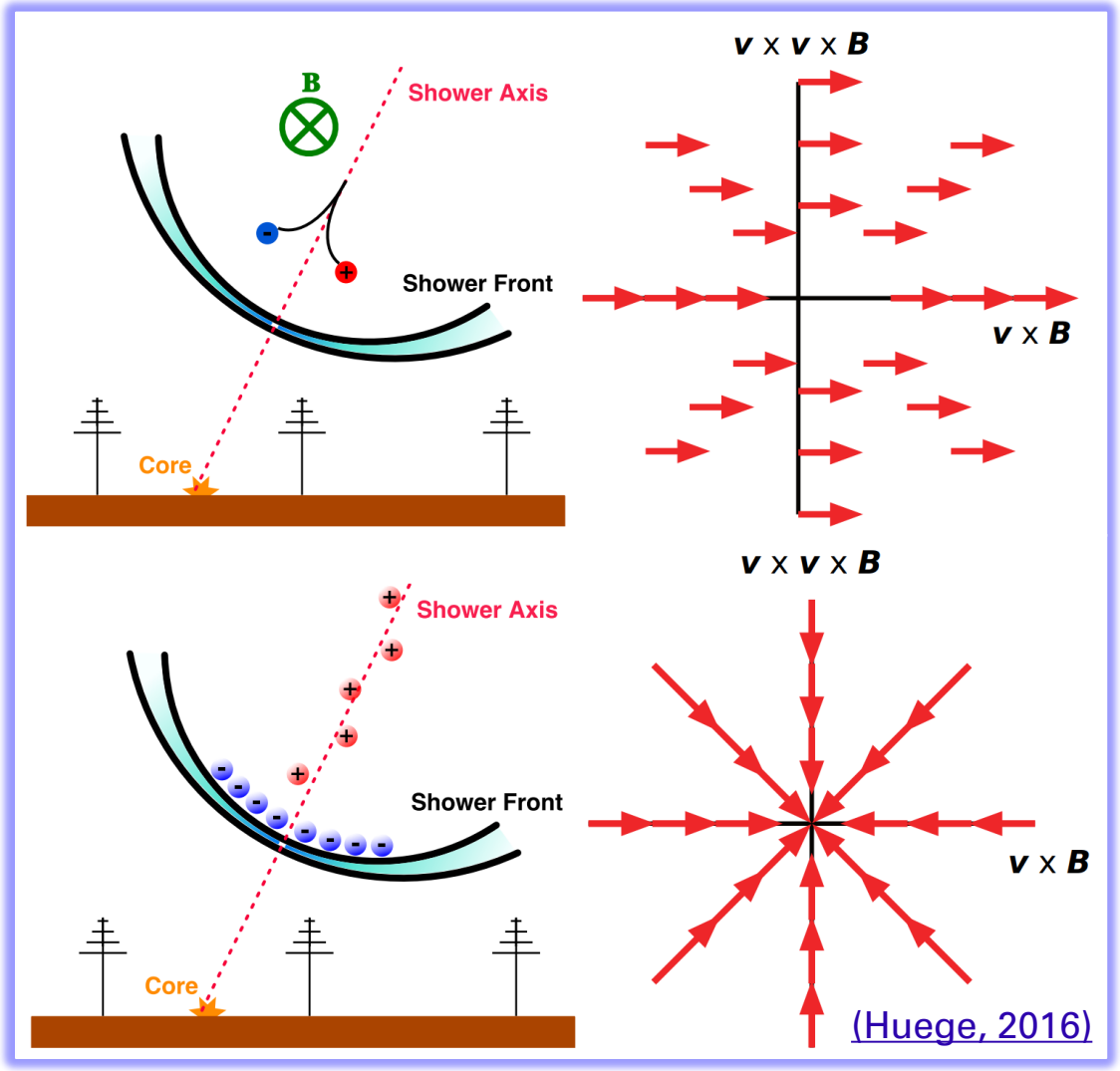
Radio Emission

Geomagnetic Emission:

- Charge separated by magnetic field
- Time-varying transverse currents produce radiation

Charge Excess Emission:

- Electrons swept along by shower, leaving positive charges behind
- Time-varying charge excess produces radiation



Coherence

Frequency

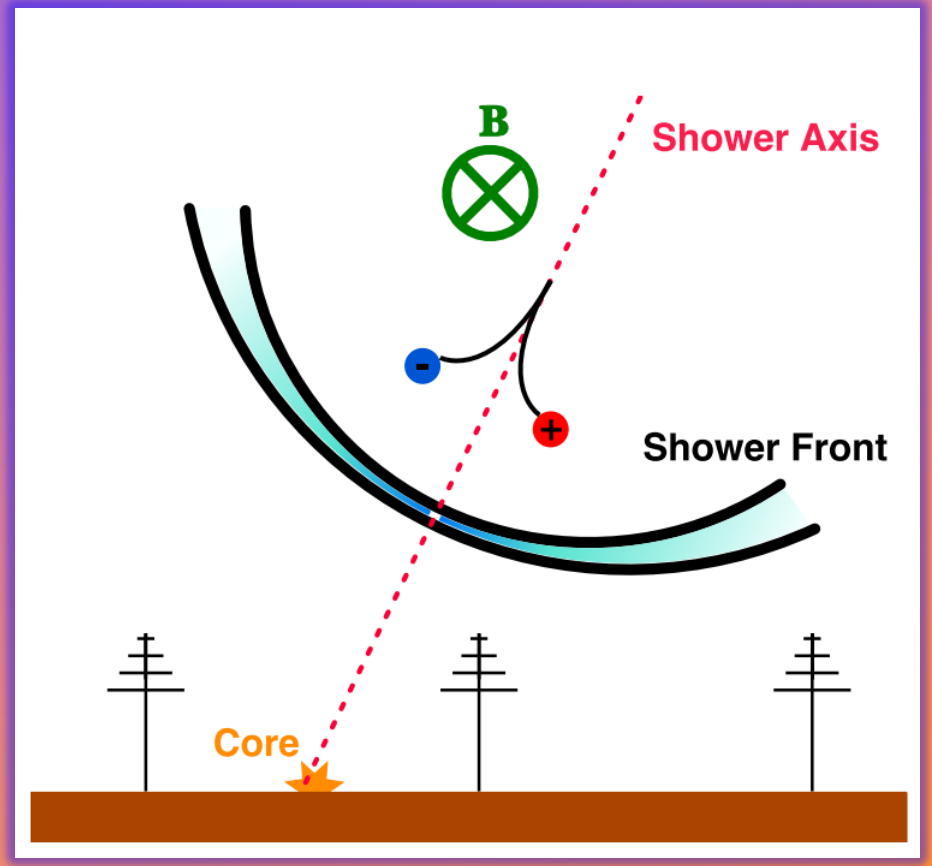
- Smaller wavelengths must be emitted closer to be coherent

Magnetic Field

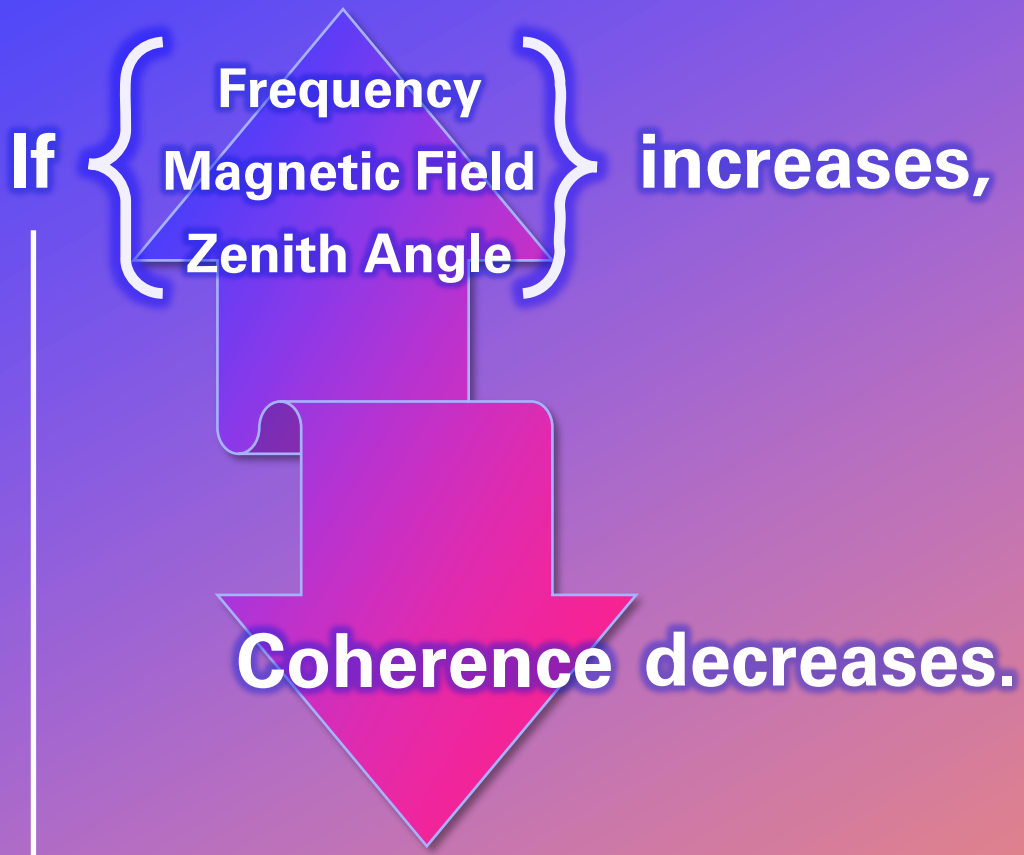
- Particles move farther from each other in stronger B-field

Zenith Angle

- Shower maximum at lower air density lets particles travel farther before colliding with air



Coherence Loss



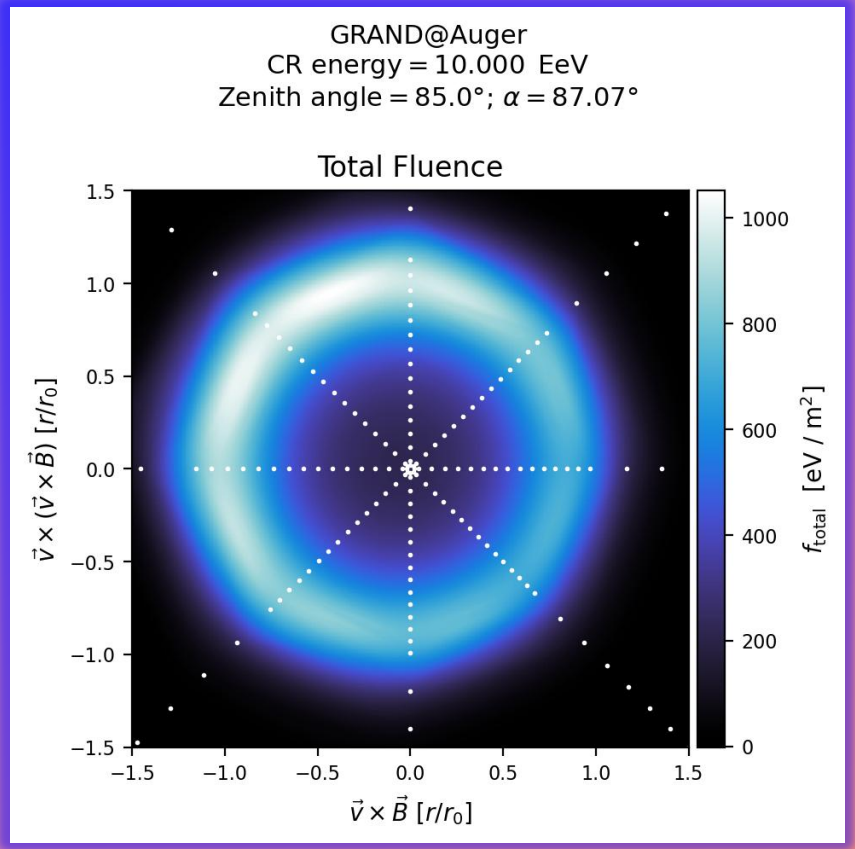
- Coherence loss means there is **less signal intensity**
- **Must be accounted for** when reconstructing energy
- We need to **understand what it looks like** to work backwards

GP300 vs GRAND@Auger

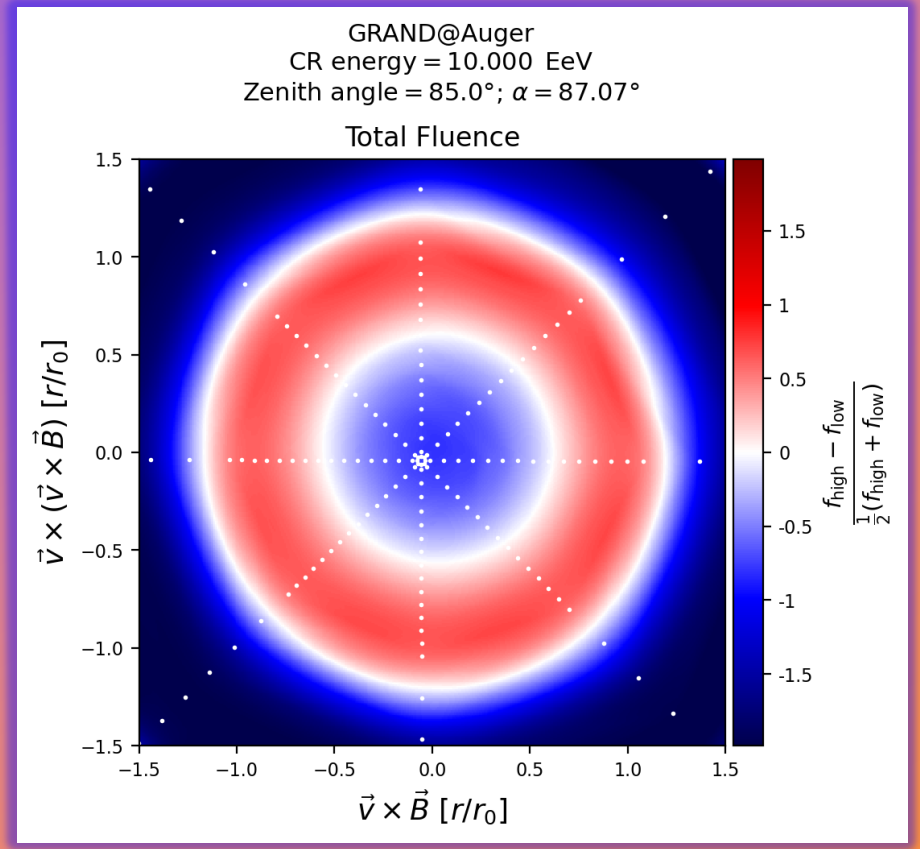
Site	GP300	GRAND@Auger
Magnetic Field Strength	0.5648236565 μG	0.2406346191 μG
Magnetic Field Inclination Angle	61.60505071°	-35.94101765°
Atmosphere Model	China - Dunhuang	Auger (October)
Observation Level	1,142 m	1,400 m
# of Simulations	3677	3443

Fluence Footprints

Fluence in the 50-200 MHz Frequency Band

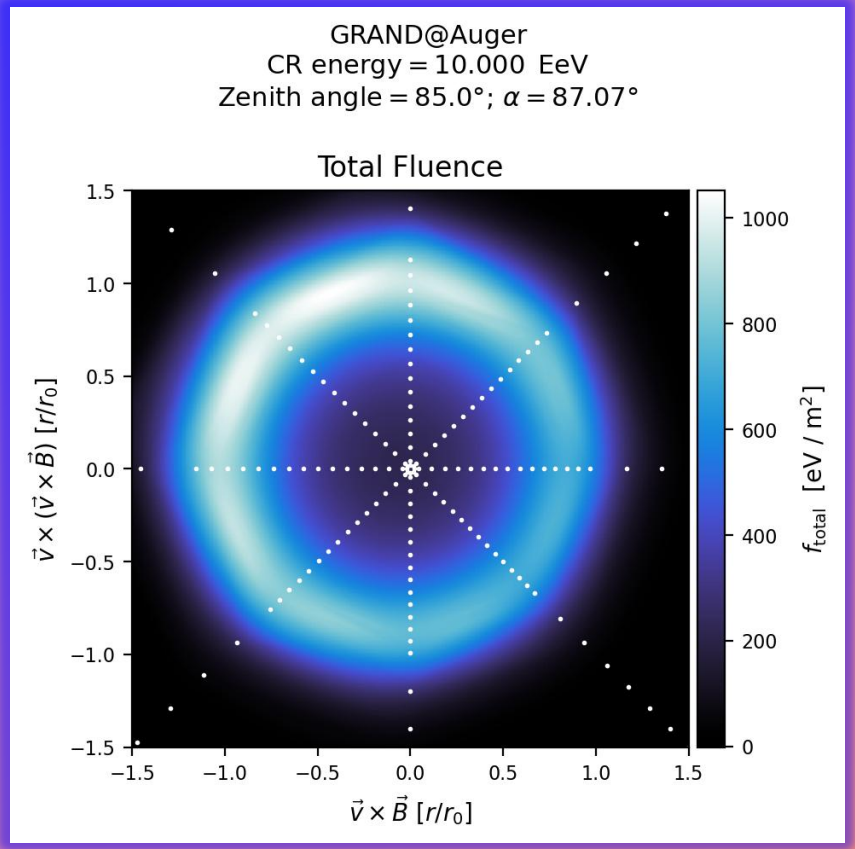


% Difference in Fluence Between the 50-100 MHz and 100-200 MHz Frequency Bands

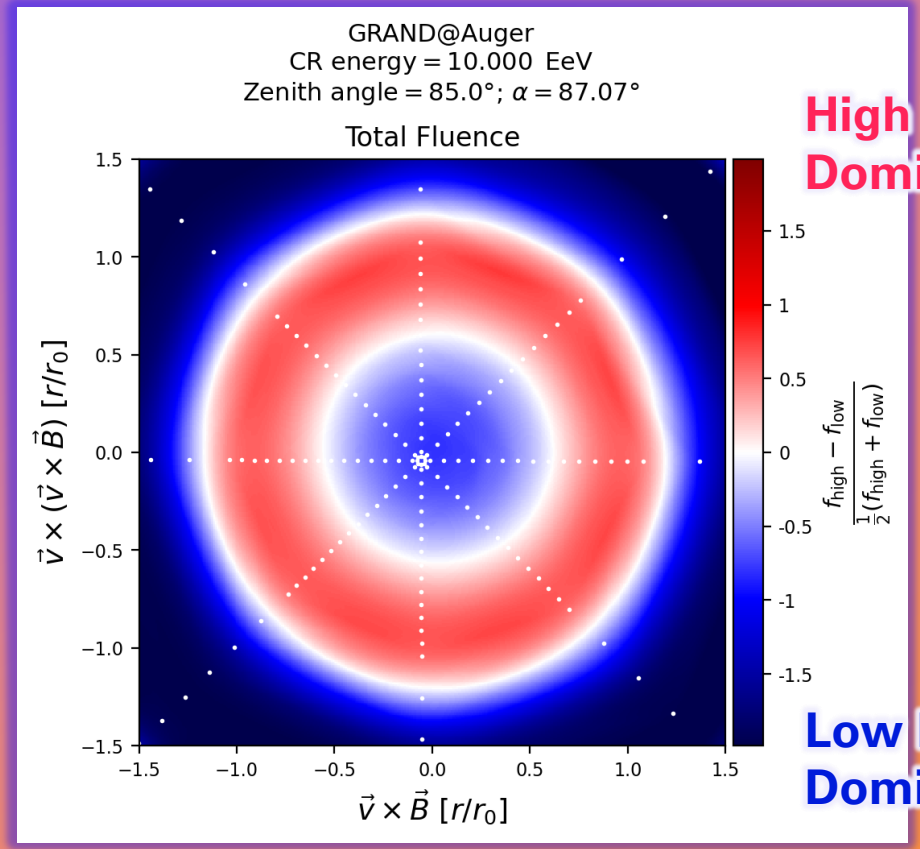


Fluence Footprints

Fluence in the 50-200 MHz Frequency Band



% Difference in Fluence Between the 50-100 MHz and 100-200 MHz Frequency Bands



High Band Dominates

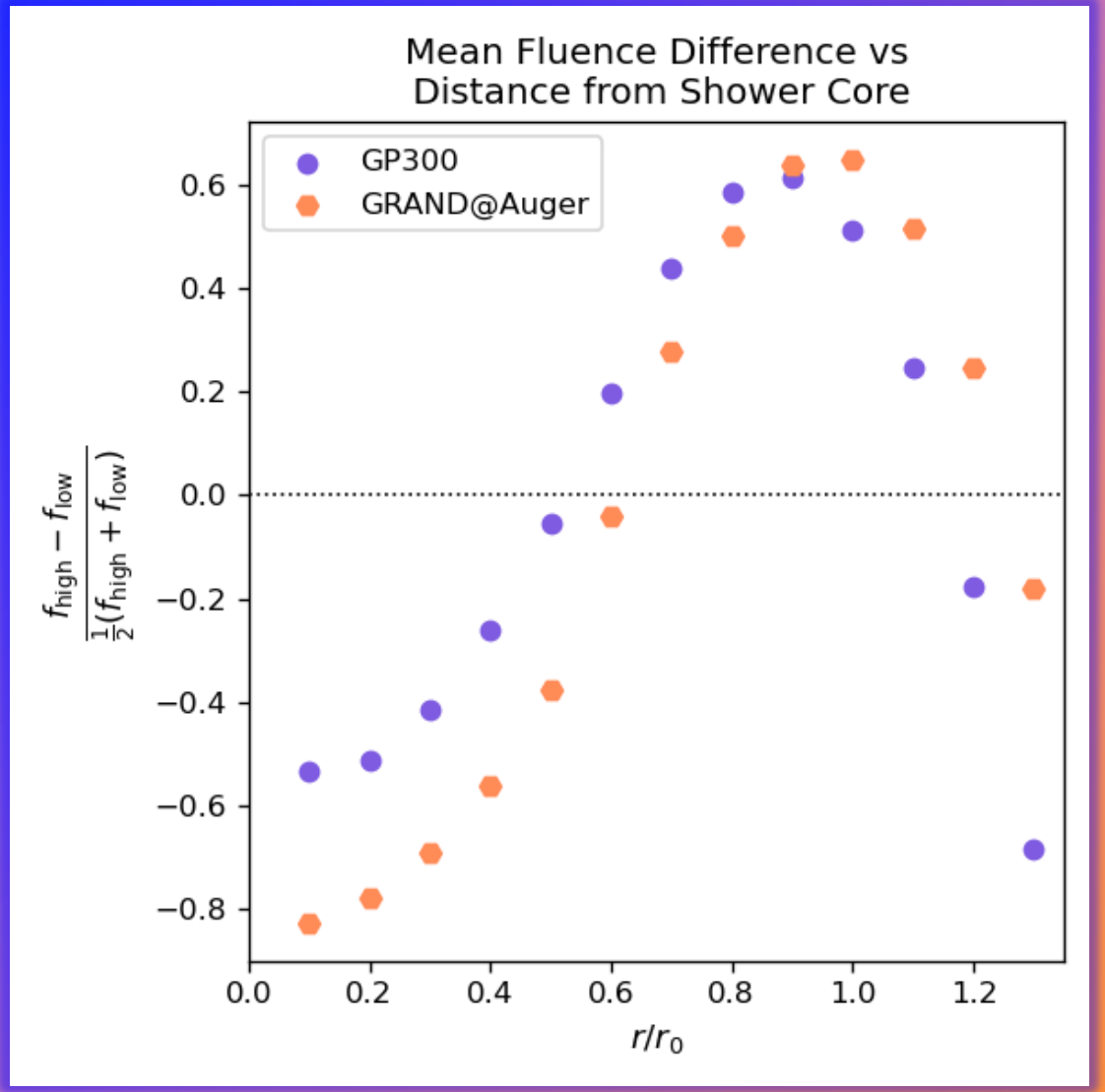
Low Band Dominates

Mean Fluence Difference

Percent difference in fluence between frequency bands at **radial slices**, averaged across every shower in each library.

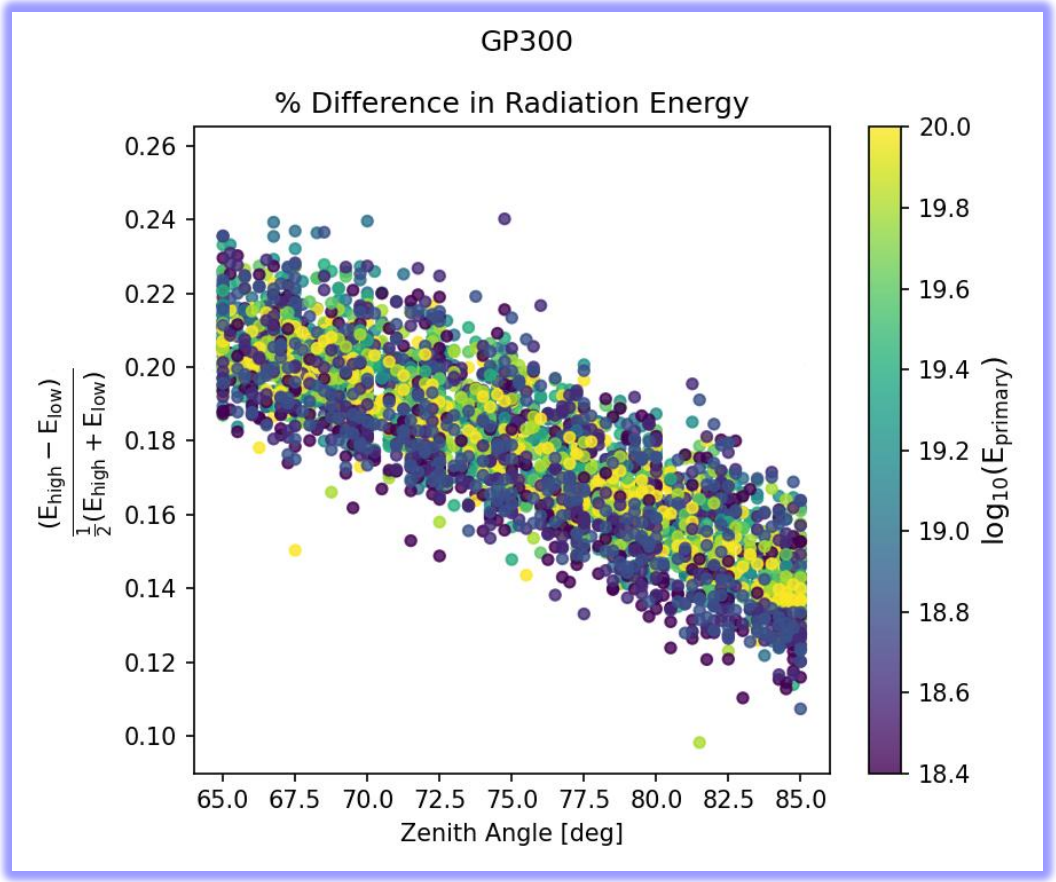
Everywhere aside from the Cherenkov ring is **dominated by the lower band**

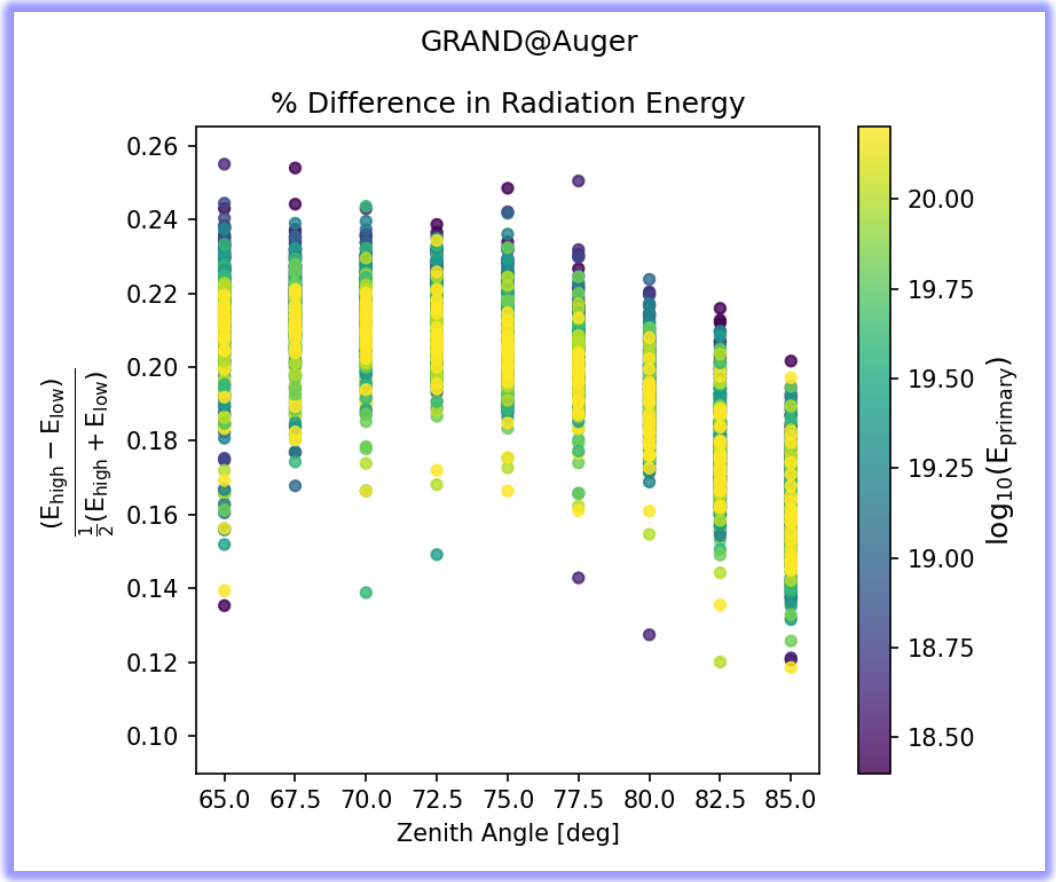
- Higher band covers **twice the frequency range** as the lower band
- **Coherence loss** causes the low-frequency radiation to dominate



Radiation Energy

Zenith-based coherence loss:





High frequency becomes less dominant as zenith angle increases

Density Correction

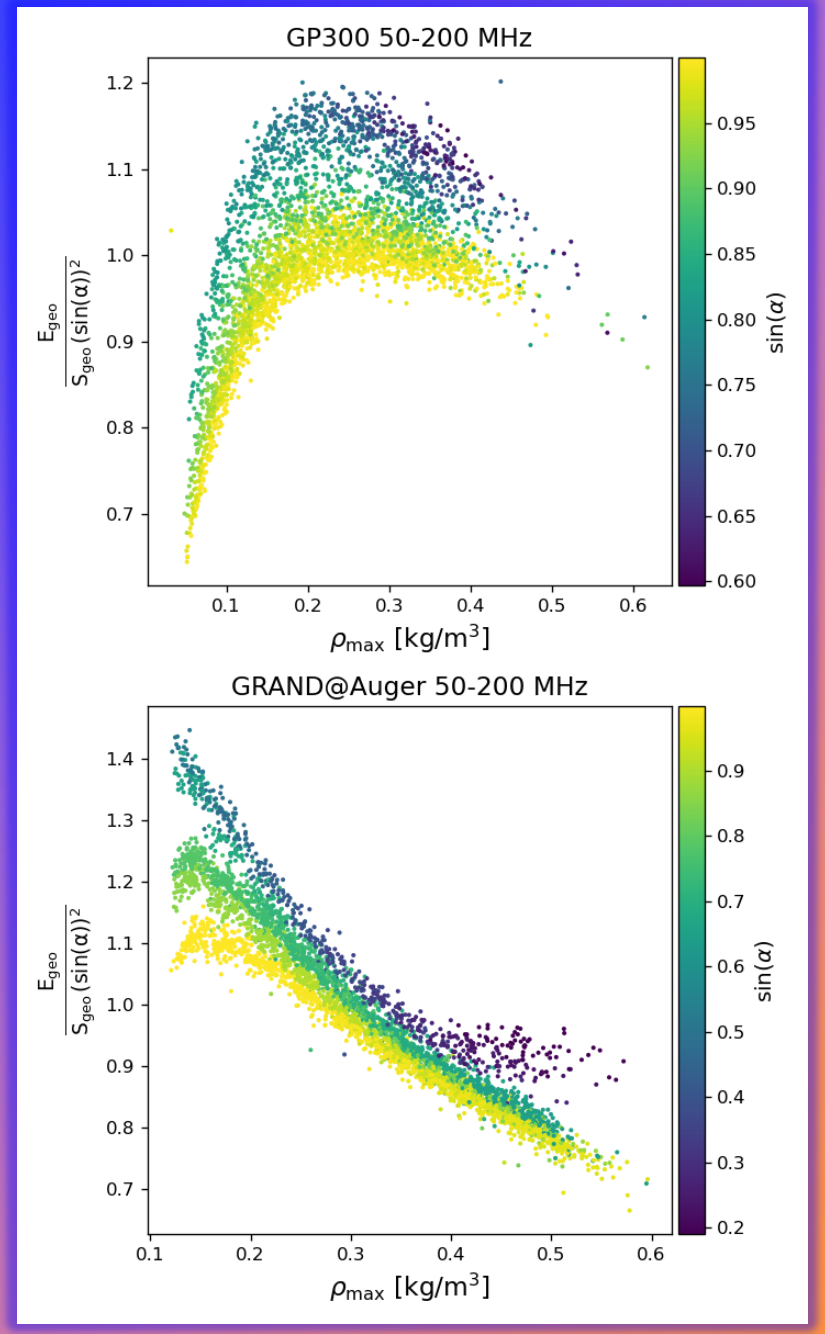
S_{geo} is the corrected radiation energy, independent of zenith and geomagnetic angle.

$$S_{geo} = \frac{E_{geo}}{\sin^{c_\alpha}(\alpha)} \cdot \left(1 + p_0 - p_0\, e^{\,p_1(\rho_{max} - \langle\rho\rangle)}\right)^{-2}$$

Y-Axis:

$$\underbrace{1 + p_0 - p_0\, e^{\,p_1(\rho_{max} - \langle\rho\rangle)}}_{} = \sqrt{\frac{E_{geo}}{S_{geo}\,\sin^2(\alpha)}}$$

This is the **density correction**, which can be fitted via this plot, and used to calculate S_{geo}



Density Correction

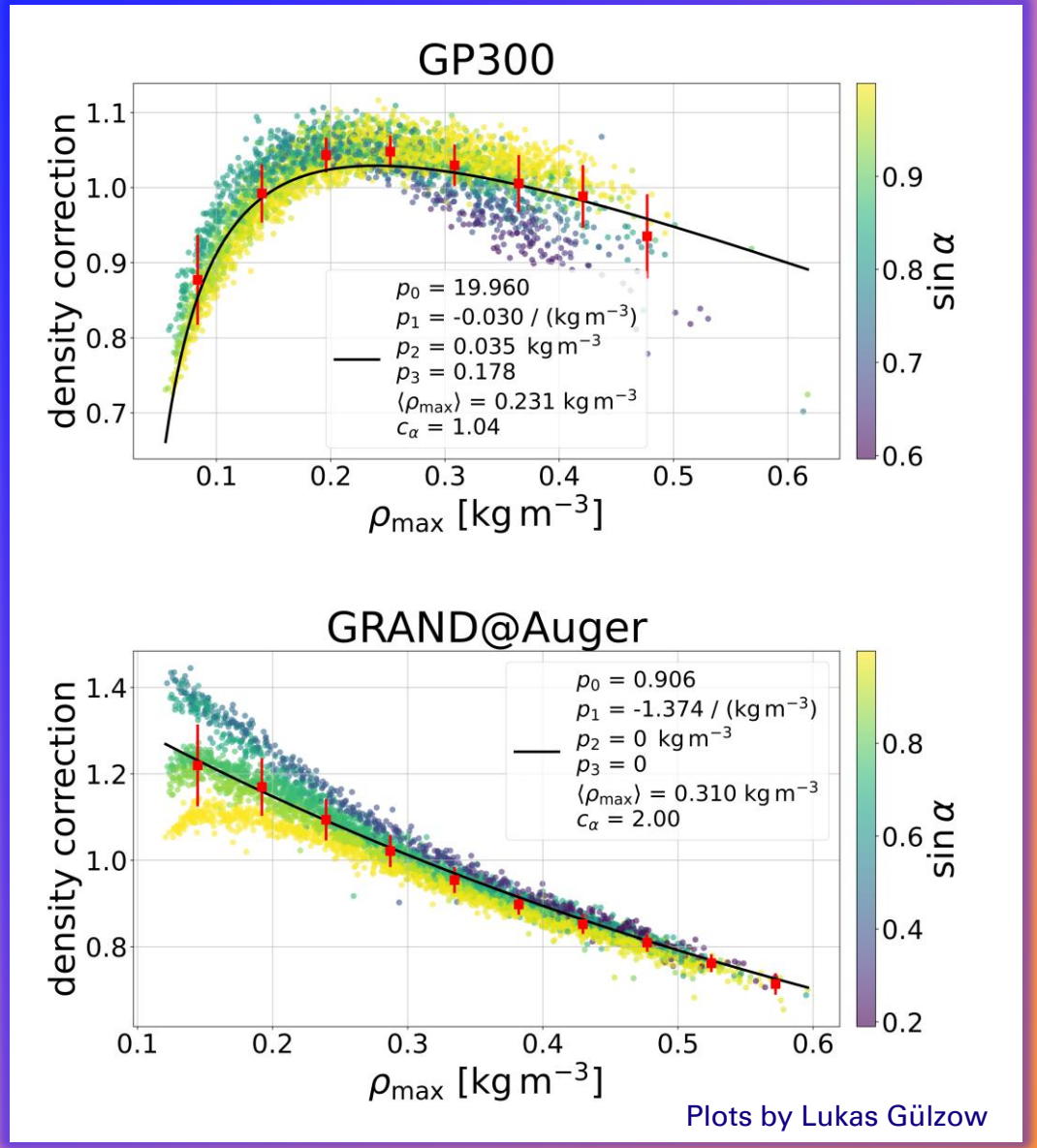
S_{geo} is a radiation quantity, independent of zenith and geomagnetic angle.

$$S_{geo} = \frac{E_{geo}}{\sin^{c_\alpha}(\alpha)} \cdot \left(1 + p_0 - p_0\, e^{\,p_1(\rho_{max} - \langle\rho\rangle)} - \frac{p_2}{\rho_{max}} + p_3\right)^{-2}$$

Y-Axis:

$$\left(1 + p_0 - p_0\, e^{\,p_1(\rho_{max} - \langle\rho\rangle)} - \frac{p_2}{\rho_{max}} + p_3\right)^{2} = \underbrace{\frac{E_{geo}}{S_{geo}\,\sin^{c_\alpha}(\alpha)}}$$

For GP300: $c_\alpha = 1.04$



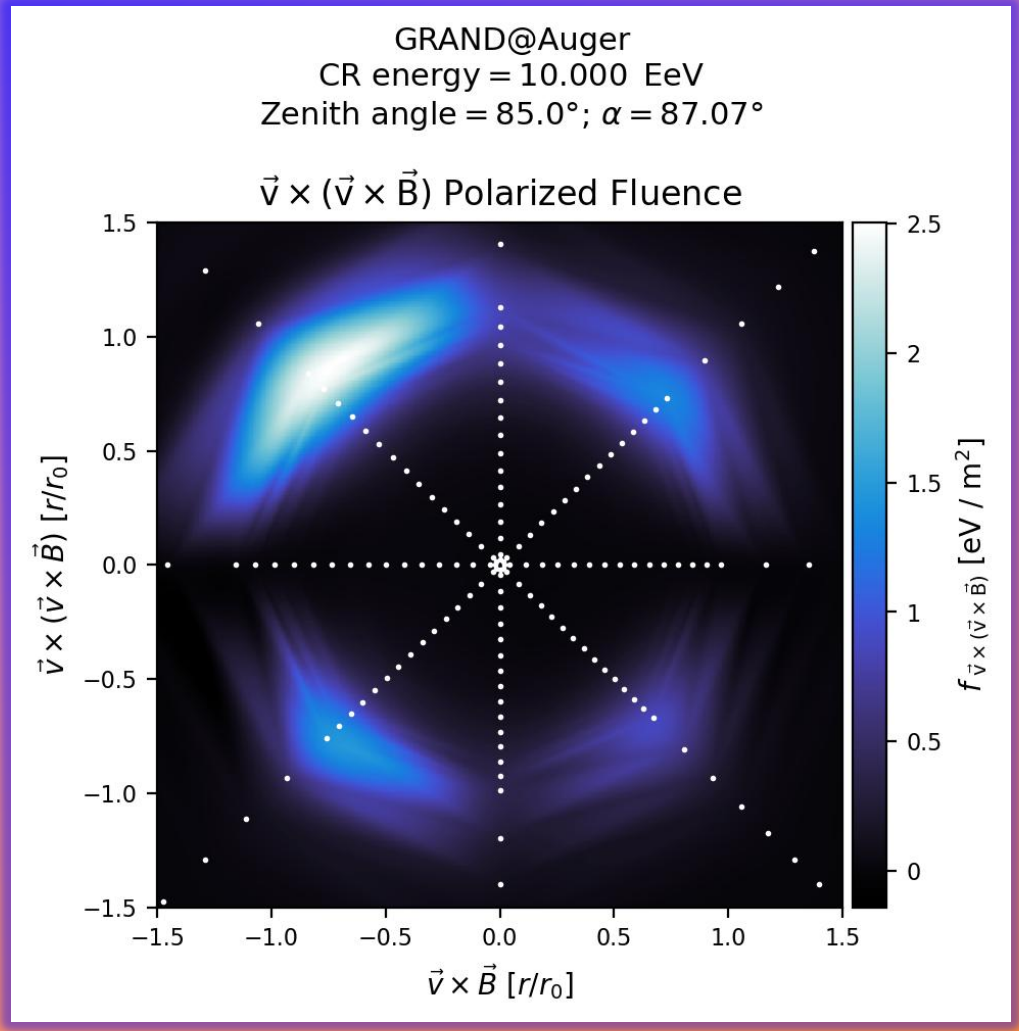
Plots by Lukas Gülzow

$\vec{v} \times \vec{v} \times \vec{B}$ Significance

Geosynchrotron radiation produces "clover-leaf" pattern

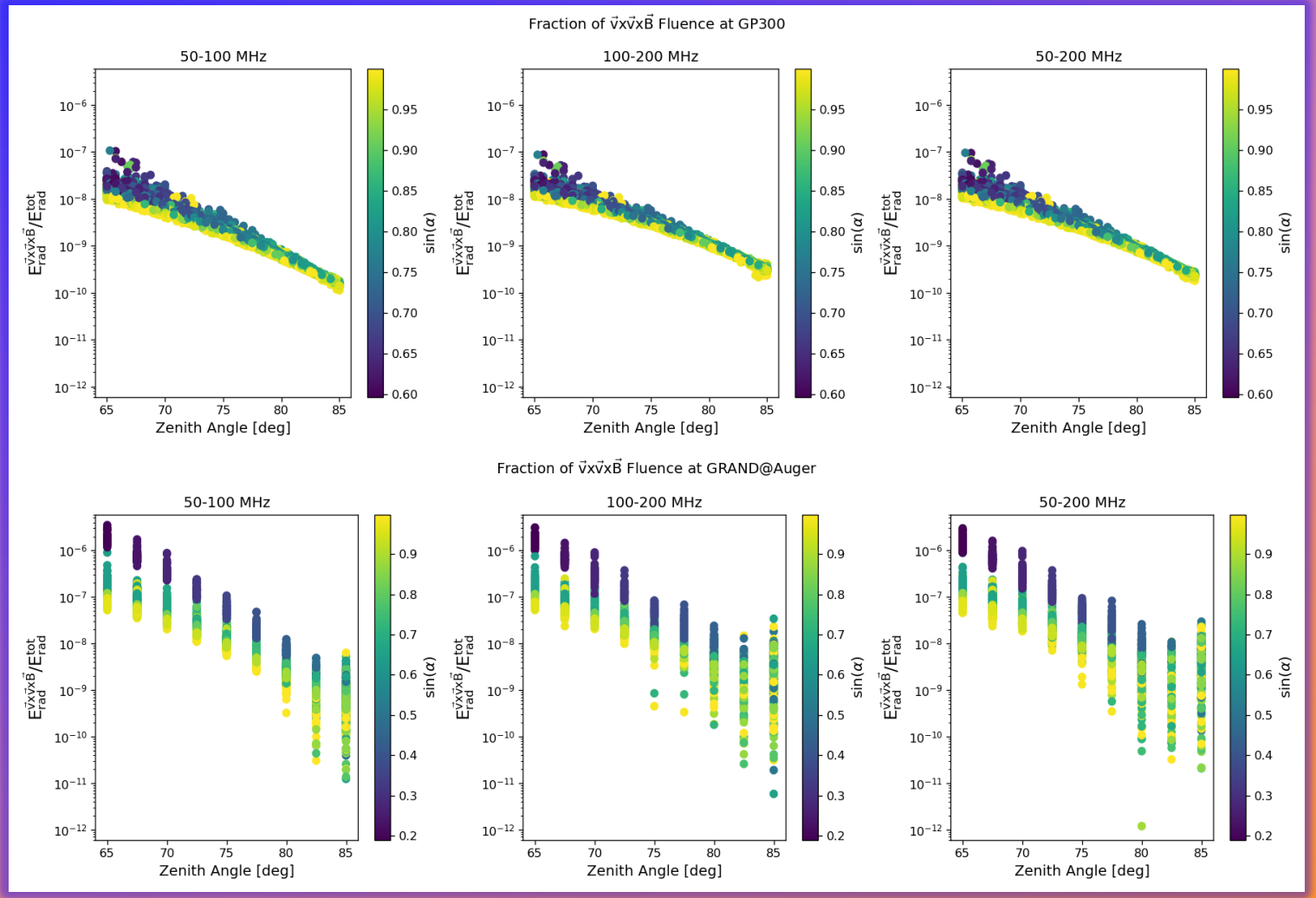
- Polarized in $\vec{v} \times \vec{v} \times \vec{B}$ direction

This effect occurs **due to the same factors as coherence loss**



$\vec{v} \times \vec{v} \times \vec{B}$ Significance

- Geosynchrotron emission is **very weak compared to the total radiation**
- **Shouldn't affect energy reconstruction**



Summary

- Radio emission from cosmic ray air showers **loses coherence at high frequencies, strong magnetic fields, and high zenith angles**
- Fluence is **dominated by low frequency** outside of the Cherenkov ring
- Signal strength of **high frequency** radiation is **lower at high zenith angles**
- **Density correction accounts for coherence loss** and is used to **reconstruct the electromagnetic emission**
- Investigated **“clover-leaf” pattern** from geosynchrotron emission

Acknowledgements

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