Parametrization of the Relative Amplitude of Geomagnetic and Askaryan Radio Emission from Cosmic-Ray Air Showers using CORSIKA/CoREAS Simulations

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ONLINE ICRC 2021

Introduction:

Cosmic rays:
- extremely energetic particles from outer space
- create extensive air showers

Radio emission mechanism in cosmic ray air showers:
1) Geomagnetic emission:
   - Due to deflection of charged air shower particles in the geomagnetic field
   - Linearly polarized in the direction of Lorentz force
   - ∝B sin α
   - Generally dominant emission
2) Askaryan emission:
   - Due to time varying negative charge excess at the shower front
   - Radially polarized about the shower axis

v = velocity of shower along shower axis
B = Earth's magnetic field
α = angle between shower direction and Earth's magnetic field

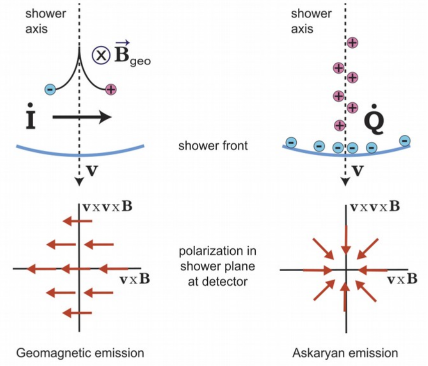

Figure 1: Different radio emission mechanisms [1].

Simulation of Cosmic Ray Air Shower:

CORSIKA simulations with CoREAS extension [2,3]:
- South Pole altitude (2840 m), magnetic field (54.58 μT), atmosphere
- SIBYLL 2.3d, Fluka2011, thinning (1e-6)
- star-shaped layout (Fig 4)
- primary: proton and iron, energy: $10^{17.0}$-$10^{17.1}$ eV

x-axis along **vxB**
y-axis along **vxvxB**
z-axis along **v**

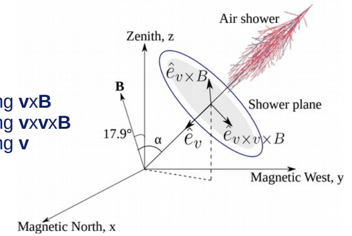

Figure 2: Shower co-ordinate system

At Hilbert peak of signal, x and y Hilbert components were selected

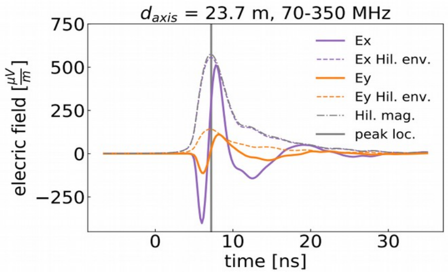

Figure 3: Filtered time traces along vxB and vxvxB.

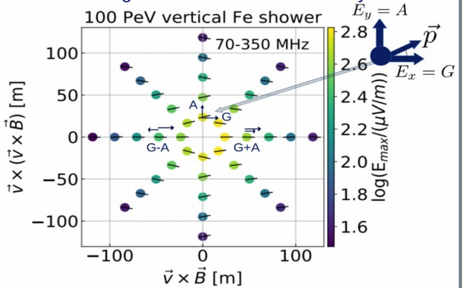

Figure 4: Star-shaped layout showing amplitude and polarization of radio emissions at each locations.

Methods and Results:

$$\frac{A}{A+G} = \frac{|E_y|}{|E_y|+|E_x|} \qquad \frac{G}{A} = \frac{|E_x|}{|E_y|} \qquad SNR = \left(\frac{Signal_{peak}}{Noise_{rms}}\right)^2$$

SNR cut (>10^4) used to remove electric fields with non-coherent signal

Relative Askaryan fraction:
- Decreases with increasing zenith angle
- reaches an asymptotic value with increasing axial distance

A fit can be used to get the plateau value of Relative Askaryan fraction (see Fig. 5)

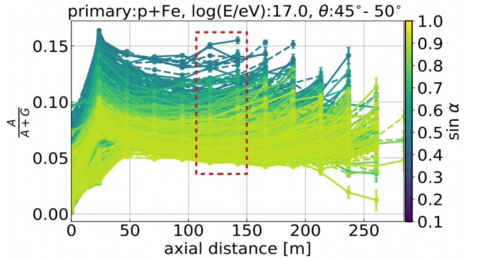

Figure 5: Solid (dotted) line represents antenna locations along positive (negative) y-axis. Red box includes points used for fitting plateau value.

Relative amplitude (G/A):
- depends on sin α
- depends on zenith angle of the shower

Reducing dependence of G on sin α by rescaling:
R= G/(A sin α)

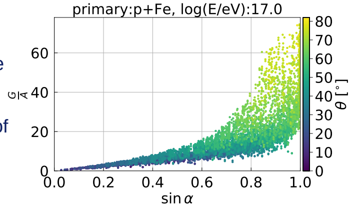

Figure 7: Plateau value of relative amplitude plotted against sin α. Color bar shows zenith angle of shower.

Relative amplitude R:
- depends on distance to shower maximum (dX_{max})
- can be used as handle to get dX_{max} from parametrization

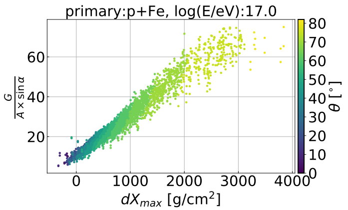

Figure 8: Plateau value of relative amplitude plotted against distance to shower maximum.

Parametrization of dX_{max} for smaller value of relative amplitude, < 75

The fit equation is
$dX_{max}(R)$ =
-474 + 46.7R+2R².

Spread (= standard deviation) around the parametrization shown in the lower panel.

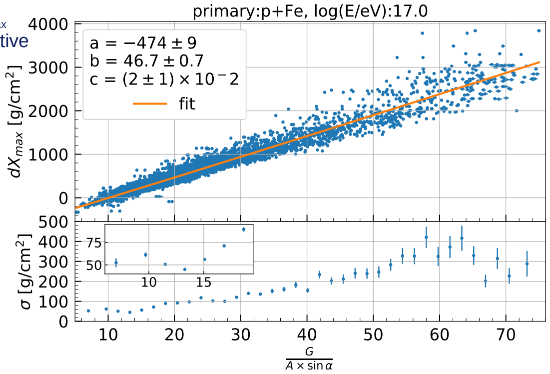

Figure 9: In upper plot, dX_{max} is plotted against relative amplitude of radio emission

Conclusion:

Geomagnetic and Askaryan contribution of the radio emission can be separated.
- The relative amplitude (R) has correlation with distance to shower maximum.
- Parameterization: $dX_{max}(R)$ = -474 + 46.7R+2R²
- The spread is too large for precise reconstruction of X_{max}.

References:

[1] F. G. Schröder, Prog. Part. Nucl. Phys. 93(2017) 1–68.
[2]T. Huege, M. Ludwig, and C. W. James AIP Conf. Proc.1535no. 1, (2013) 128.
[3] D. Heck et al.,Report FZKA 6019, Forschungszentrum Karlsruhe, 1998.