Potential of the Askaryan Fraction of the Radio Emission from Cosmic-Ray Air Shower for X_{max} Reconstruction

June 9, 2022

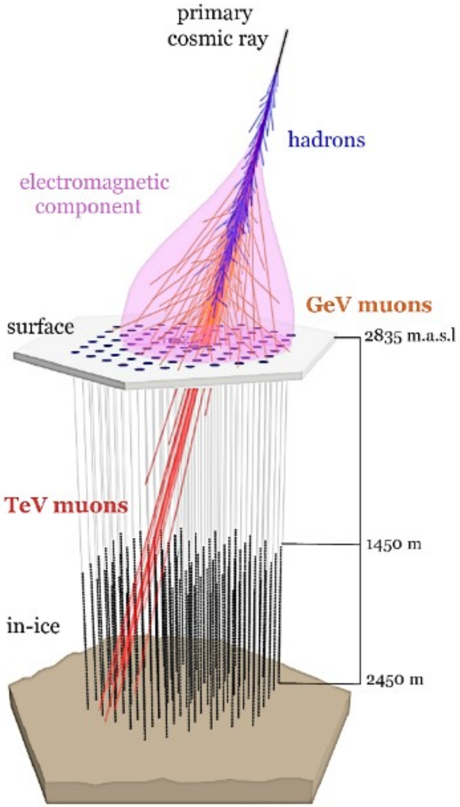
Ek Narayan Paudel, Alan Coleman, Frank Schroeder

UNIVERSITY OF DELAWARE
BARTOL RESEARCH INSTITUTE

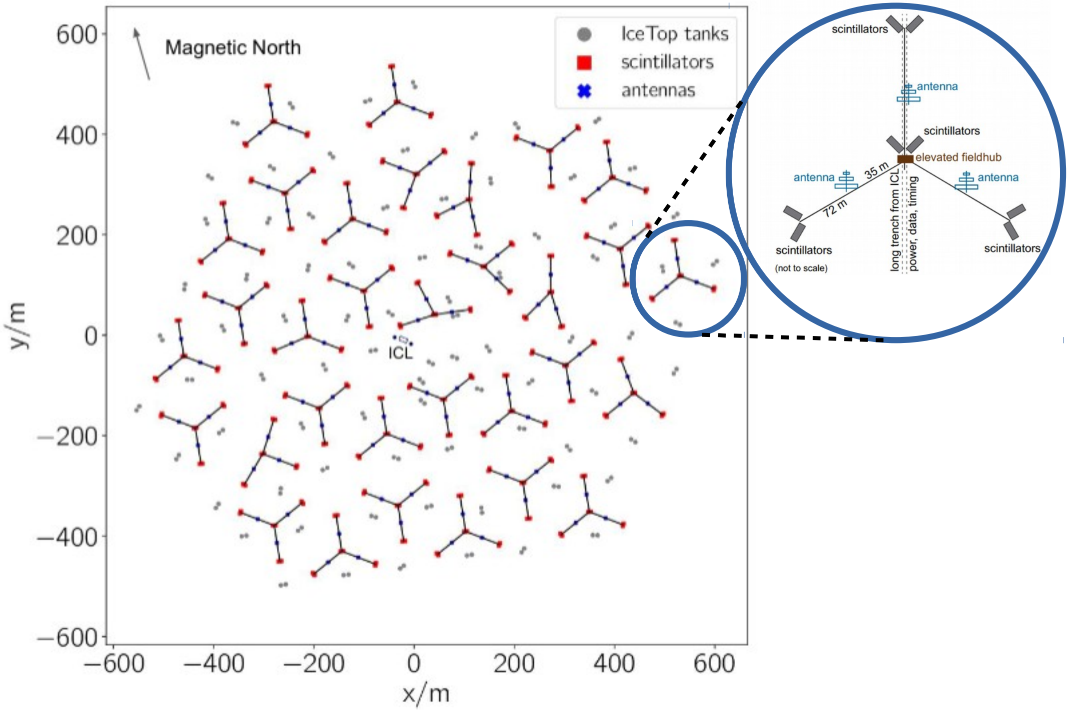
9th International Workshop on Acoustic and Radio EeV Neutrino Detection Activities
ARENA 2022
Santiago de Compostela | June 7-10

Motivation

- Using simulation to understand radio emission at the South Pole



Dennis



IceCube Coll., PoS ICRC2019 (2020) 332 (modified)

Radio antenna at prototype station

Motivation

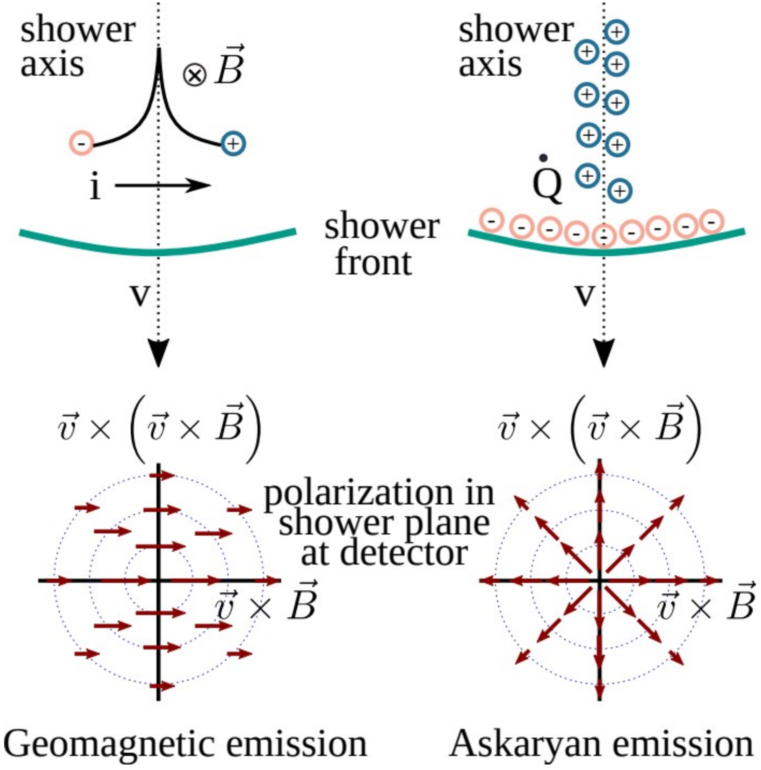
- Using polarization for separating components of CR radio emission

Radio emission from cosmic rays

Geomagnetic emission:
- due to deflection of charged particles in the Earth's magnetic field
- polarized linearly in the direction of geomagnetic Lorentz force (**v**x**B**)

Charge excess/Askaryan emission:
- due to time varying negative charge excess in shower front
- polarized radially about shower axis

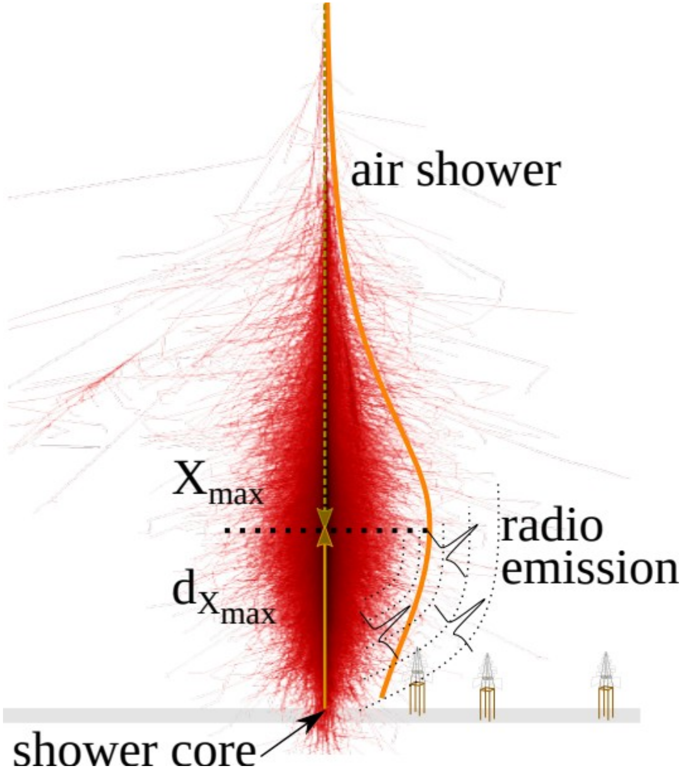
For very inclined shower, geomagnetic emission can be more complex. C. James, Phys.Rev.D 105 (2022) 2

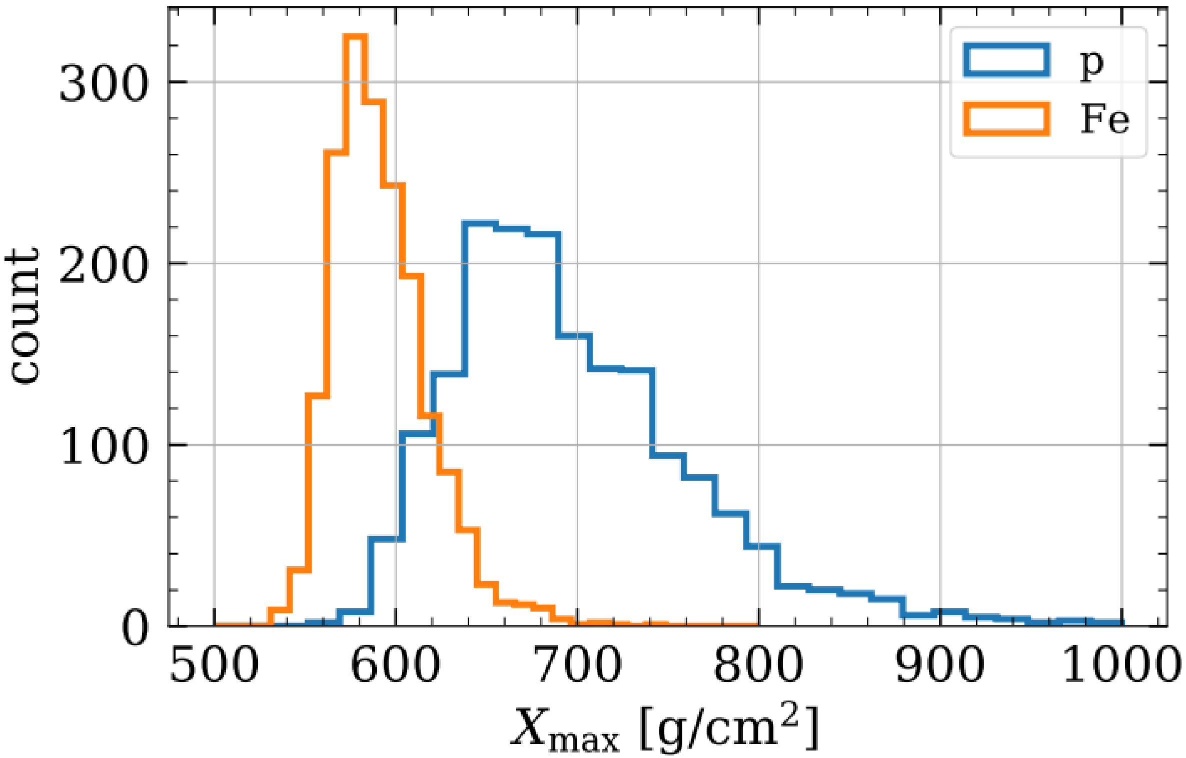


Schroeder, Prog.Part.Nucl.Phys. 93 (2017) 1-68 (modified)

Motivation

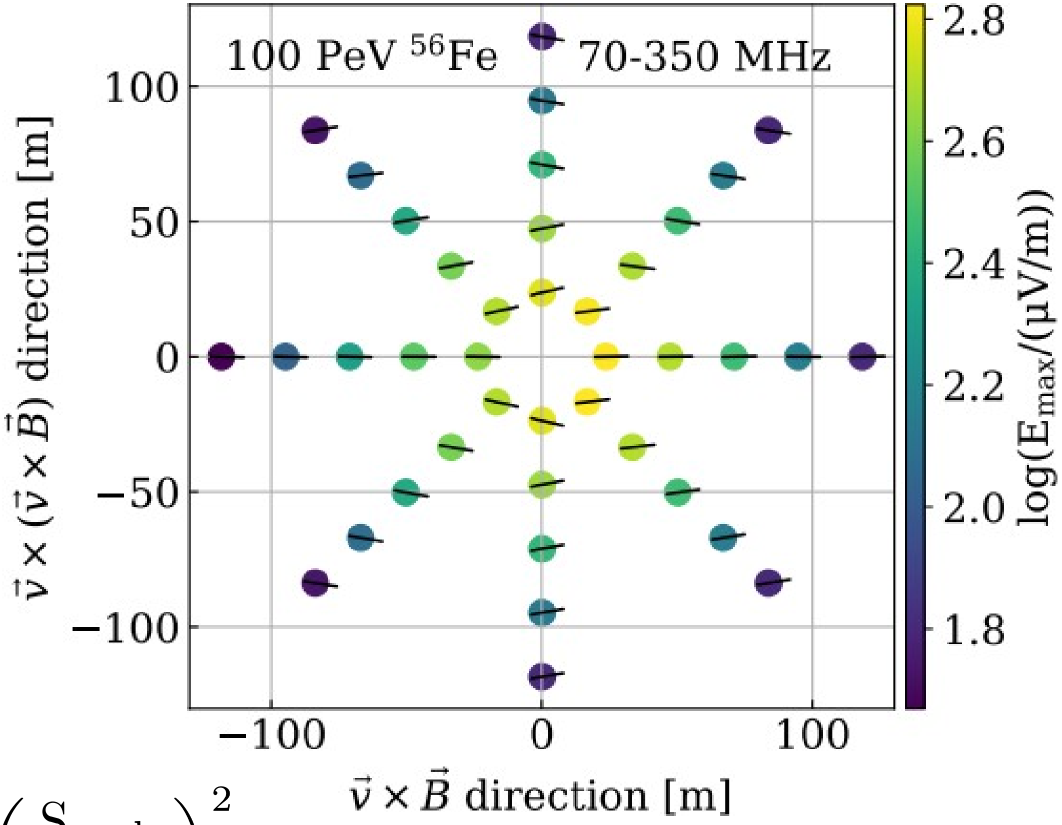
- Study dependence of Askaryan fraction of radio emission with shower parameters
- Study potential use of Askaryan fraction in reconstructing mass sensitive parameter X_{max}





CORSIKA/CoREAS simulations

- 1800 p & Fe showers
- $\theta \leq 71.5°$, $10^{17.0} - 10^{17.1}$ eV
- South pole:
  - 2800 m asl
  - $|\vec{B}|$ = 54.58 μT at 17.87° tilt
  - April South Pole atmosphere
- Hadronic interaction models:
  - Fluka2011, SIBYLL2.3d
- Thinning (10^{-6})
- Star-shaped layout (8 spokes with 20 sampling points)

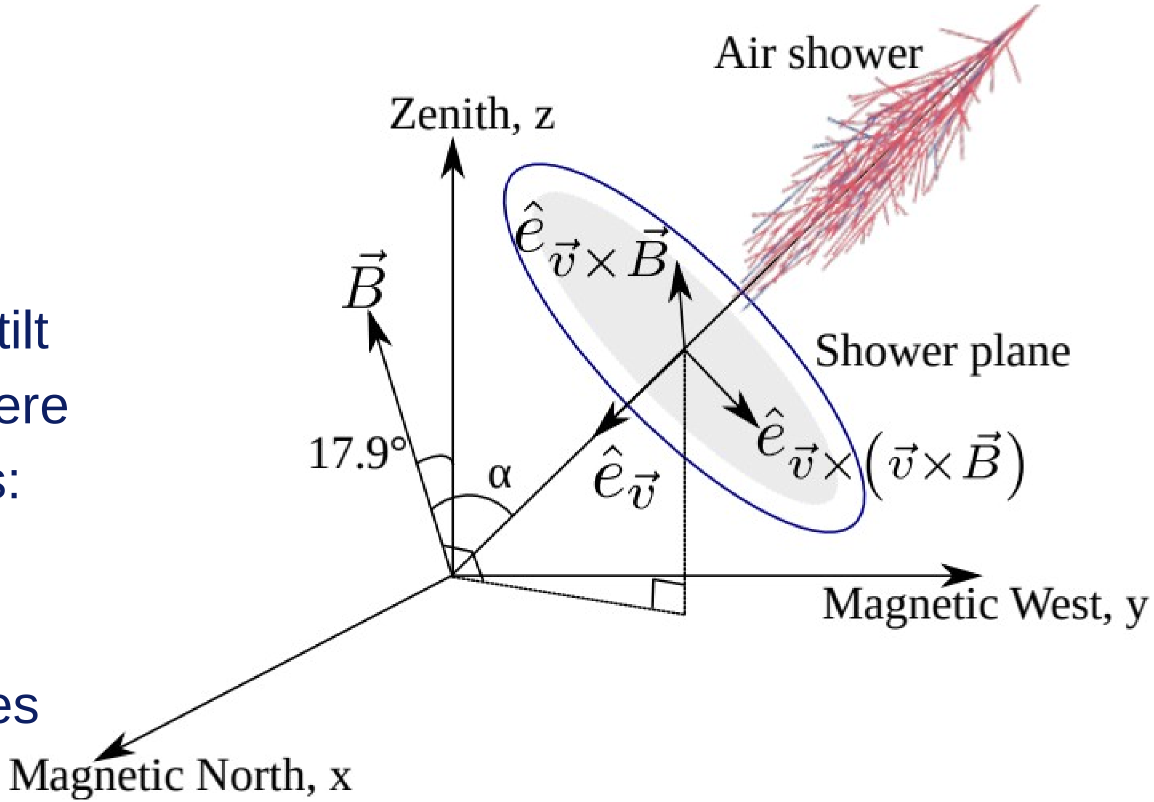


Paudel et al, Phys.Rev.D 105 (2022) 10

SNR > 10^4 $\quad \mathrm{SNR} = \left(\frac{S_{peak}}{N_{RMS}}\right)^2$

CORSIKA/CoREAS simulations

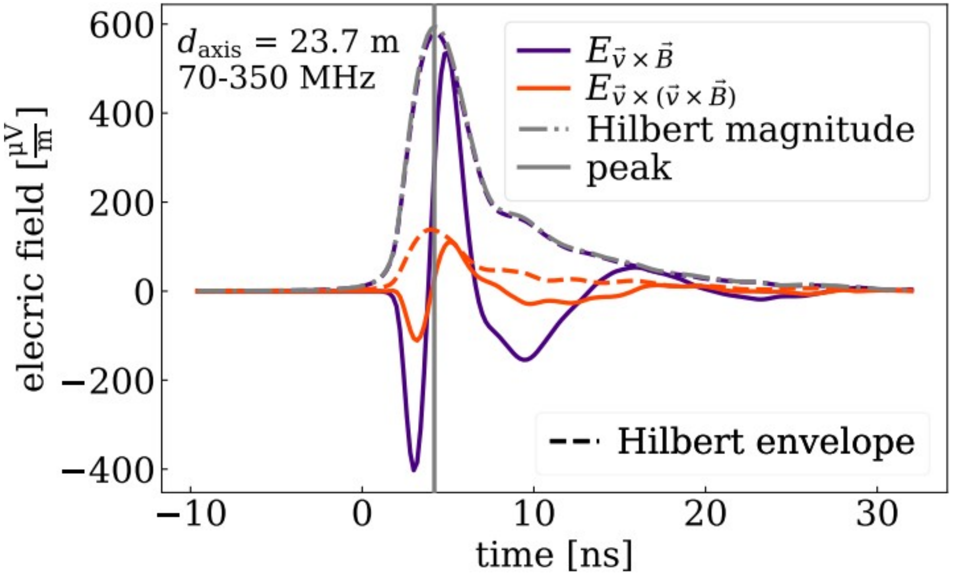
- 1800 p & Fe showers
- $\theta \leq 71.5°$, $10^{17.0} – 10^{17.1}$ eV
- South pole:
  - 2800 m asl
  - $|\vec{B}|$ = 54.58 μT at 17.87° tilt
  - April South Pole atmosphere
- Hadronic interaction models:
  - Fluka2011, SIBYLL2.3d
- Thinning (10^{-6})
- Star-shaped layout (8 spokes with 20 sampling points)

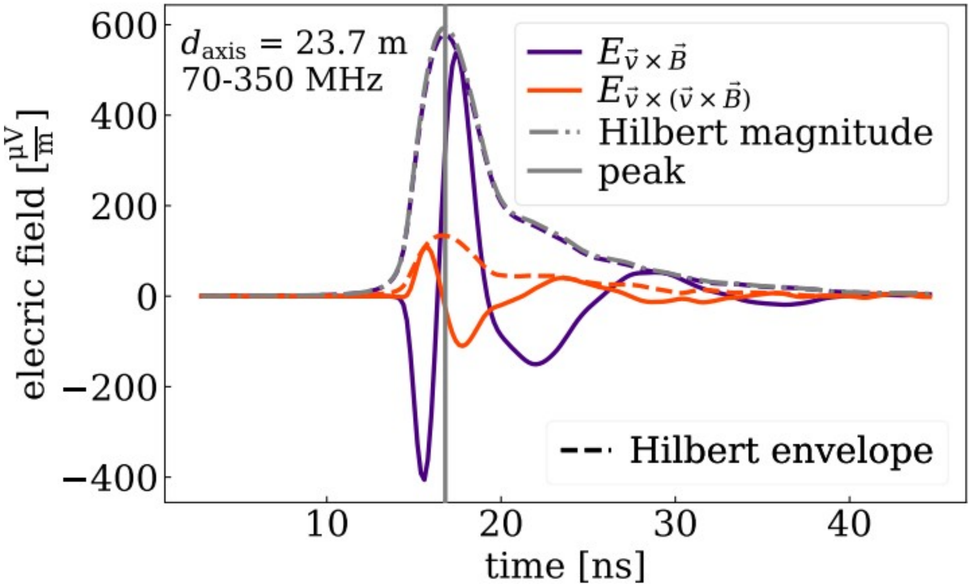


Paudel et al, Phys.Rev.D 105 (2022) 10

SNR > 10^4 $\quad \mathrm{SNR} = \left(\frac{S_{\mathrm{peak}}}{N_{\mathrm{RMS}}}\right)^2$

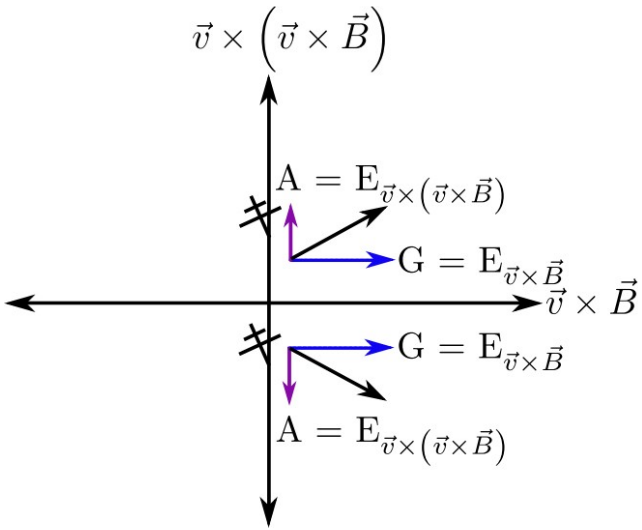
CORSIKA/CoREAS simulations





Paudel et al, Phys.Rev.D 105 (2022) 10

Relative Askaryan fraction



Paudel et al, Phys.Rev.D 105 (2022) 10

$$a_{rel} \equiv \sin\alpha \left(\frac{A}{G}\right)$$

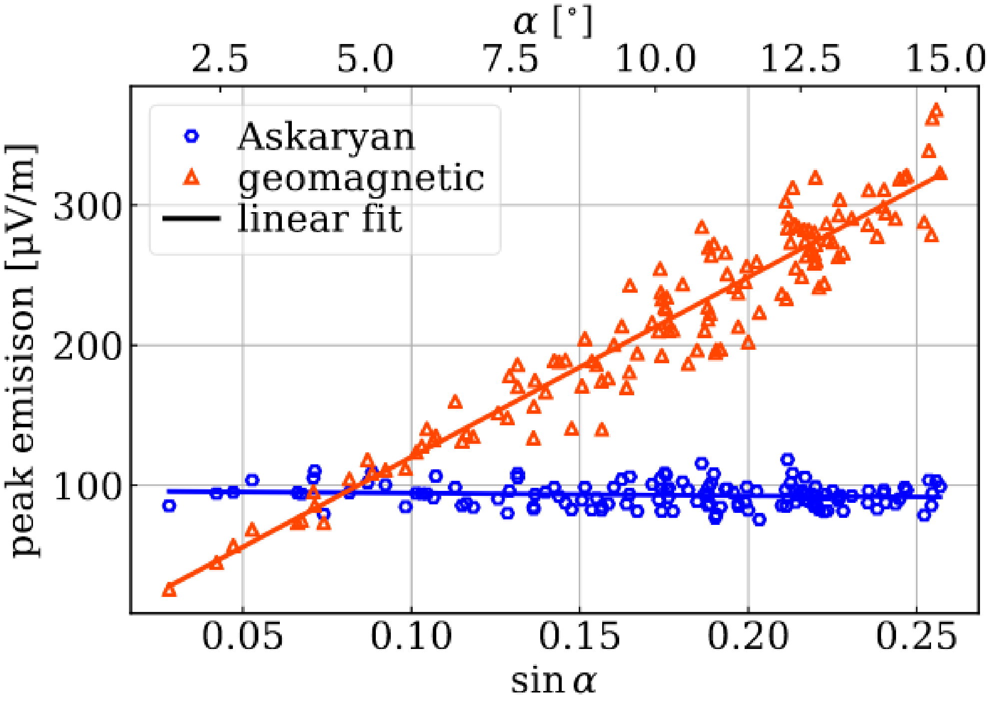
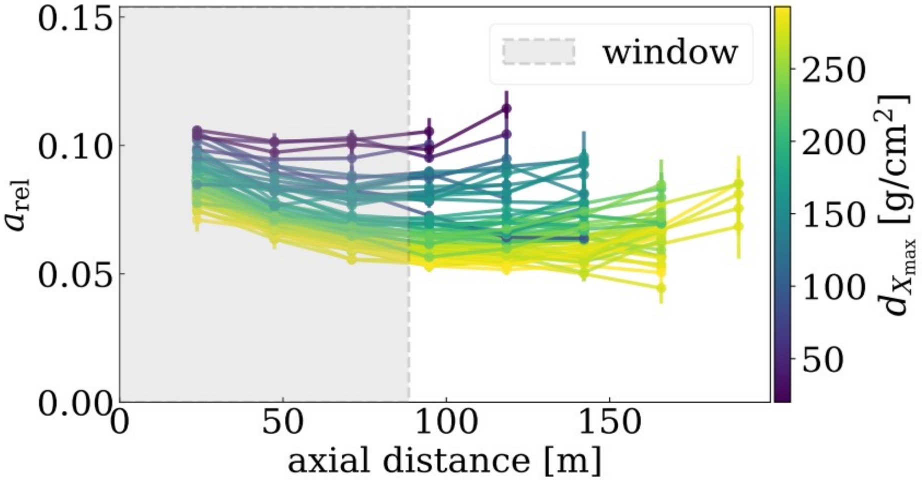


FIG. 5: Amplitudes of the Askaryan and the geomagnetic emission at $\simeq 23$ m from the shower axis in the shower plane for various $\sin\alpha$ simulated for the iron showers of ~100 PeV primary energy.

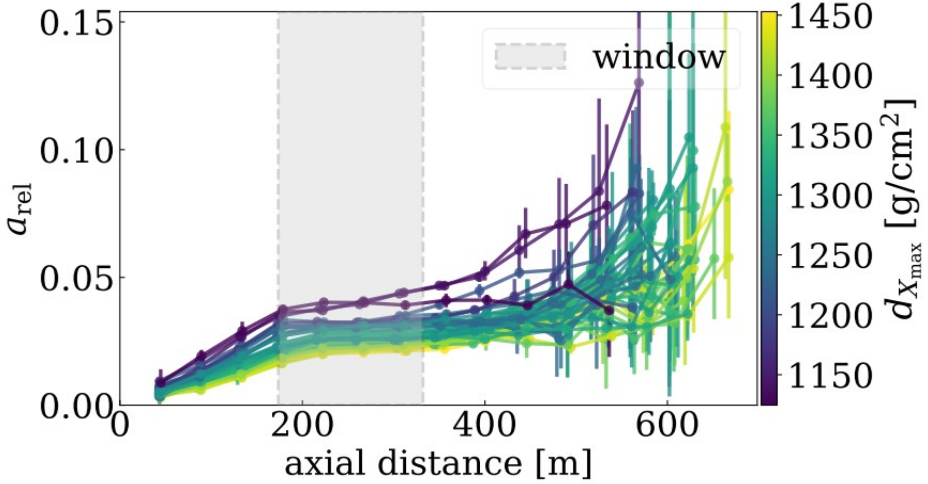
Paudel et al, Phys.Rev.D 105 (2022) 10

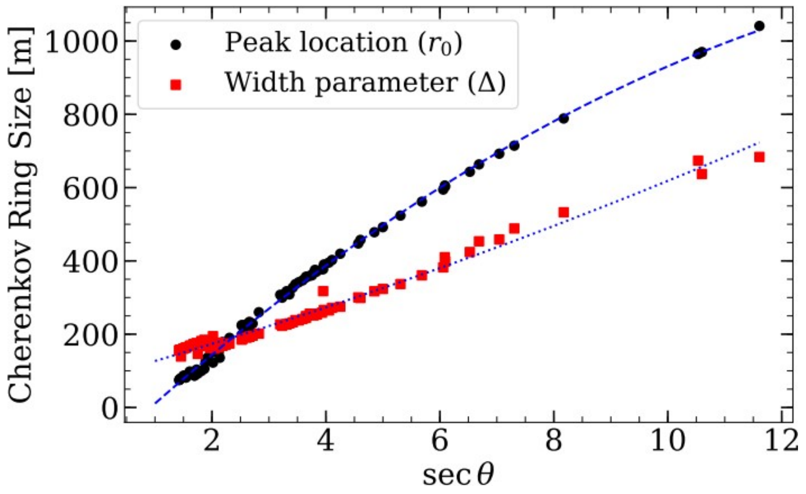
Dependence of a_{rel} with axial distance

θ = 35°-36°



θ = 69°-70°

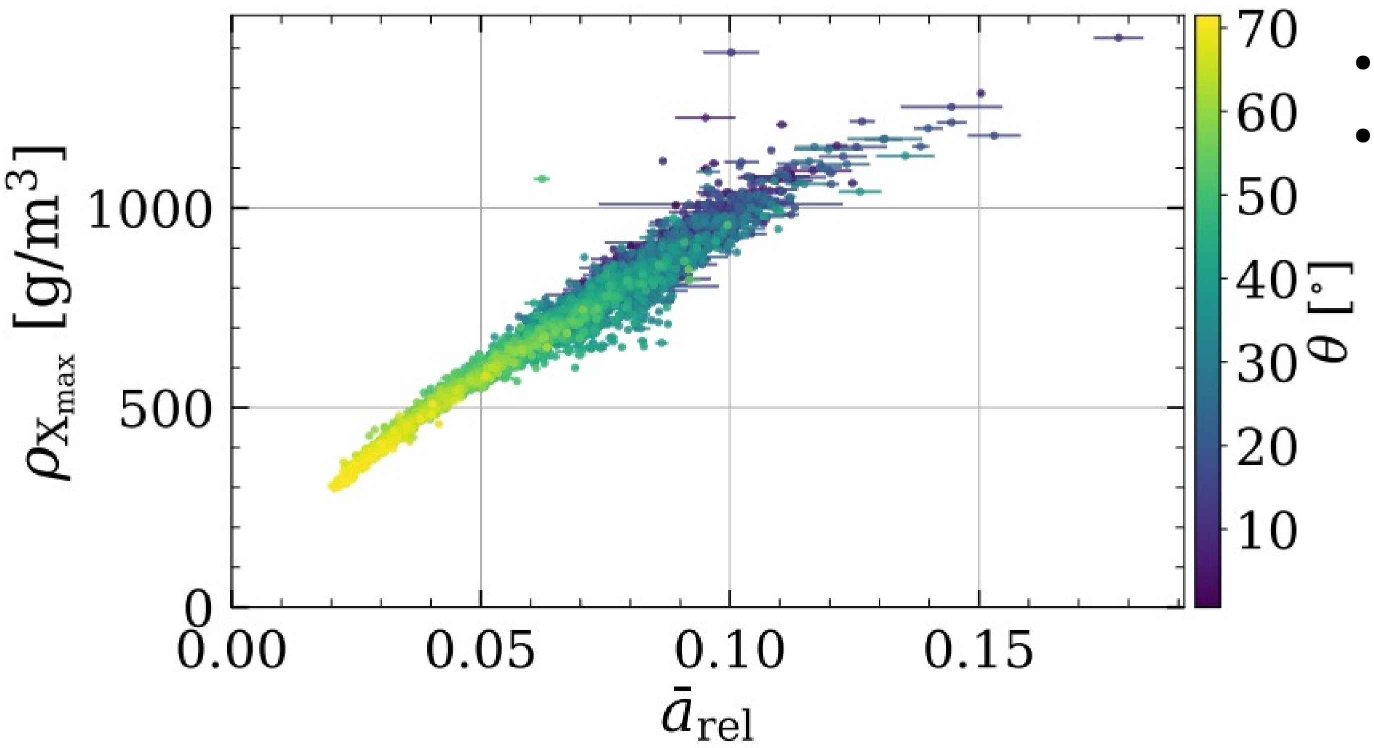




Paudel et al, Phys.Rev.D 105 (2022) 10

$$r_0(\theta) = -3.883\sec^2\theta + 145.0\sec\theta - 130.3$$
$$\Delta(\theta) = 0.9777\sec^2\theta + 43.88\sec\theta + 81.86$$

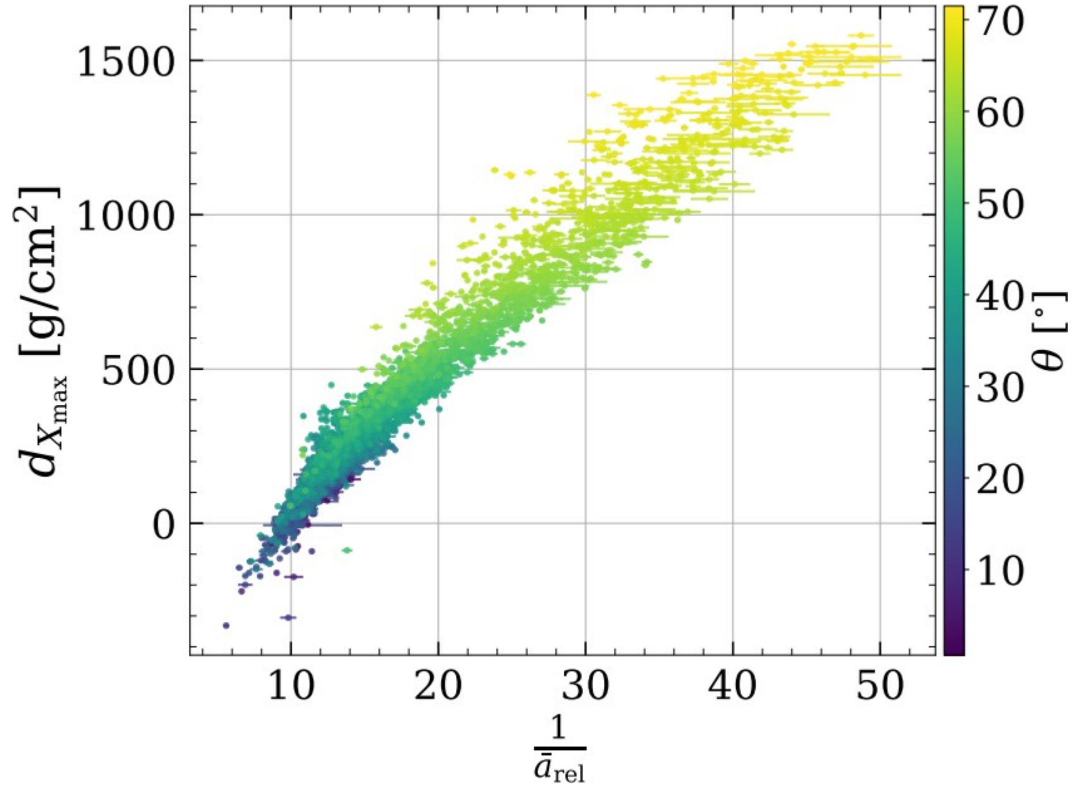
$\rho_{X_{max}}$ as a function of Askaryan fraction and θ



- Higher $\rho_{X_{max}}$ → higher $\bar{a}_{rel}$
- Known from previous study

Glaser et. al., JCAP 09 (2016) 024

$d_{X_{max}}$ as a function of Askaryan fraction and θ



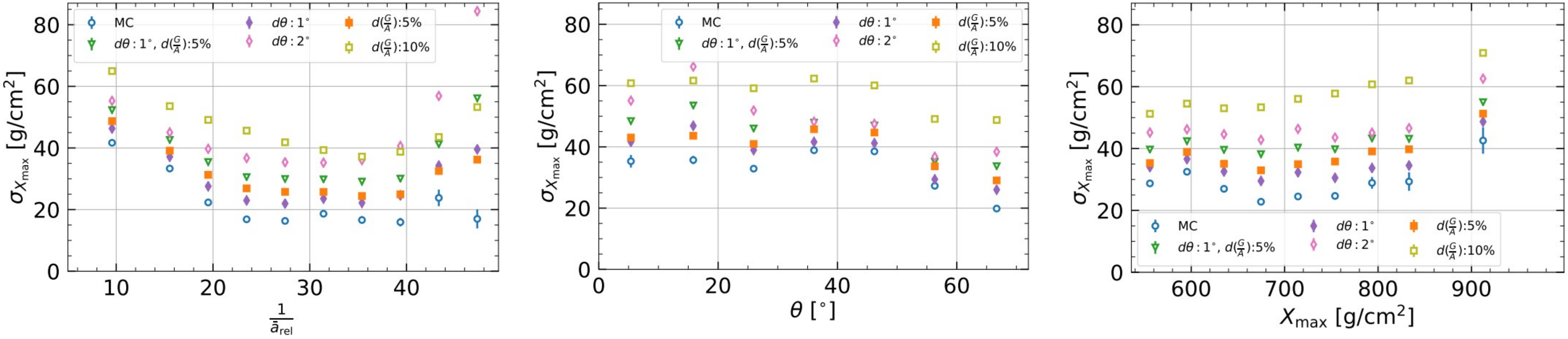
Paudel et al, Phys.Rev.D 105 (2022) 10

$$d_{X_{max}} = \begin{bmatrix} 1 & \frac{1}{\bar{a}_{rel}} & \left(\frac{1}{\bar{a}_{rel}}\right)^2 & \left(\frac{1}{\bar{a}_{rel}}\right)^3 \end{bmatrix} \begin{bmatrix} a & b \\ c & d \\ e & f \\ g & h \end{bmatrix} \begin{bmatrix} 1 \\ \sec\,\theta \end{bmatrix}$$

a	-1050 ± 10
b	220 ± 10
c	131 ± 1
d	-7.6 ± 0.1
e	-5.54 ± 0.03
f	1.11 ± 0.02
g	0.072 ± 0.001
h	-0.0187 ± 0.0003

Resolution of X_{max} reconstruction

Paudel et al, Phys.Rev.D 105 (2022) 10



- X_{max} resolution of 20-40 g/cm^2 with true shower direction and Askaryan fraction
- X_{max} resolution of 30-55 g/cm^2 with angular resolution of 1°, G/A measured within 5 %

Summary and Outlook

- Polarization can be used to calculate Askaryan fraction of radio emission.
- Mean Askaryan fraction is highly correlated with d_{Xmax}.
- X_{max} can be reconstructed using Askaryan fraction and zenith angle of shower for given atmosphere.
- The resolution of X_{max} reconstruction can be similar to other methods.
- Polarization can be considered as additional input for future, multivariate methods for X_{max} reconstruction e.g., by template fitting or machine learning.

Thank you for listening!

Backup

SNR distribution