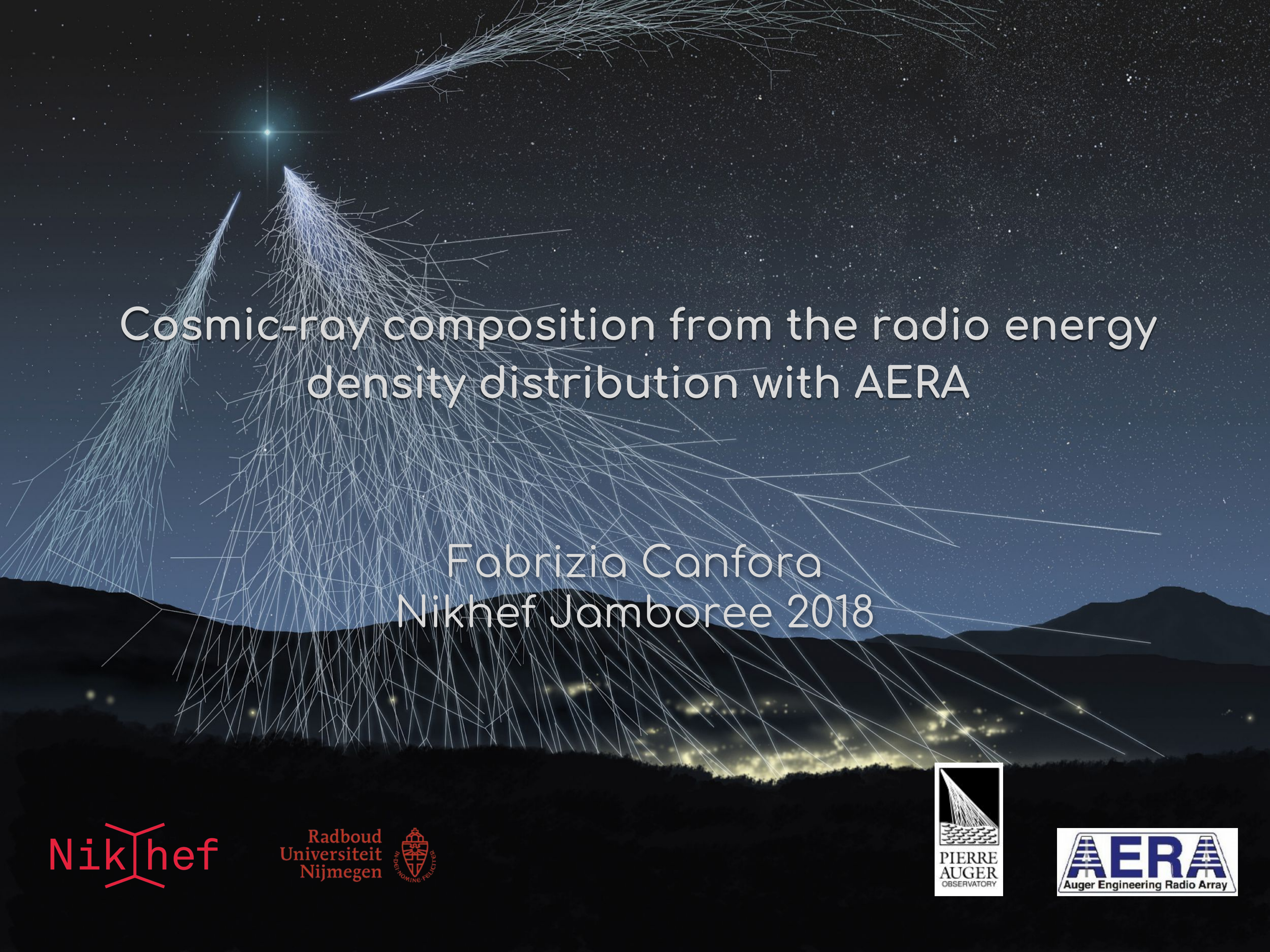
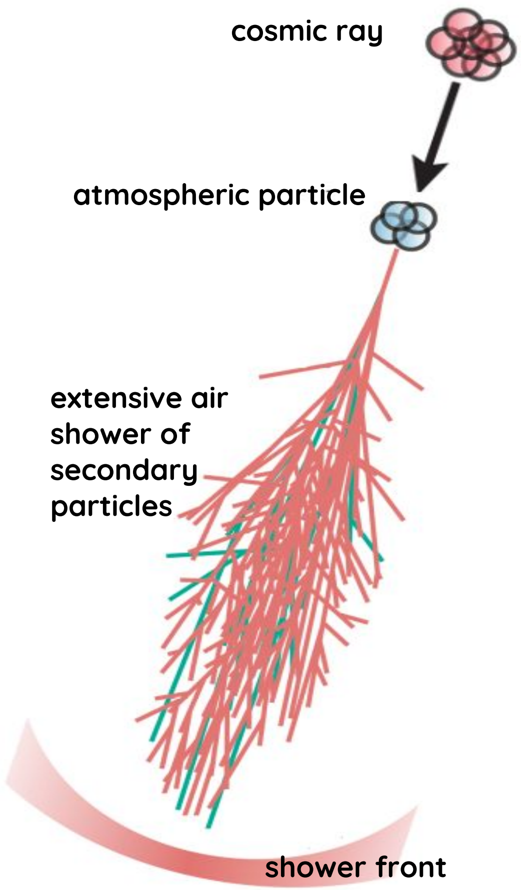


Cosmic-ray composition from the radio energy density distribution with AERA

Fabrizia Canfora
Nikhef Jamboree 2018

Extensive air shower



Primary particle?
Mass?
Charge?
Energy?
Arrival direction?

Fluorescence light

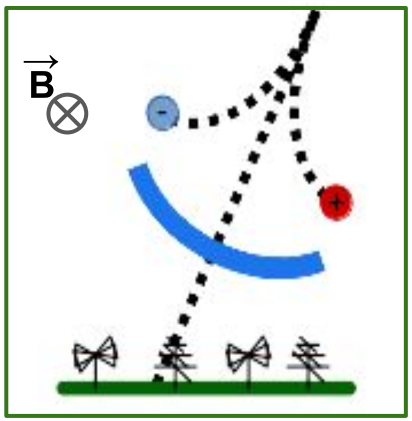
Secondary particles at ground level

Radio signals

Radio emission from extensive air showers

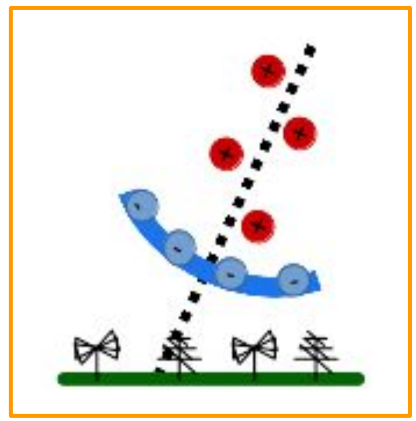
Radio signal primarily composed of two emission mechanisms:

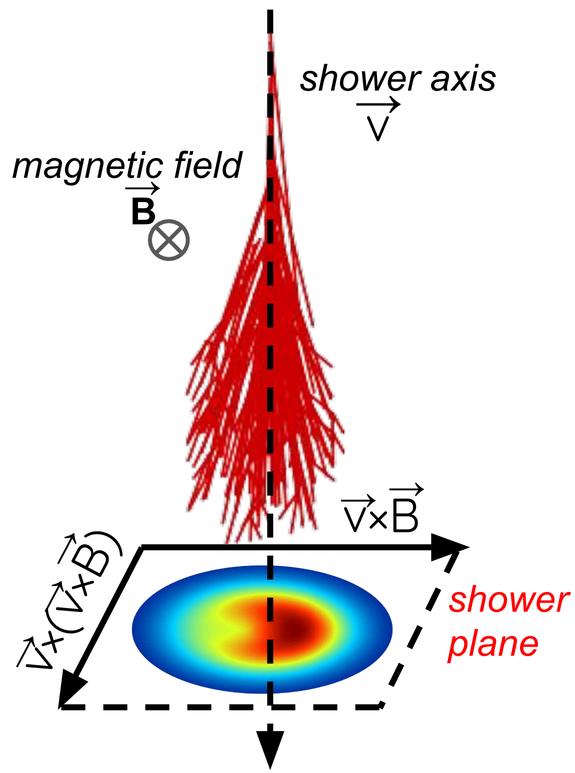
Geomagnetic emission



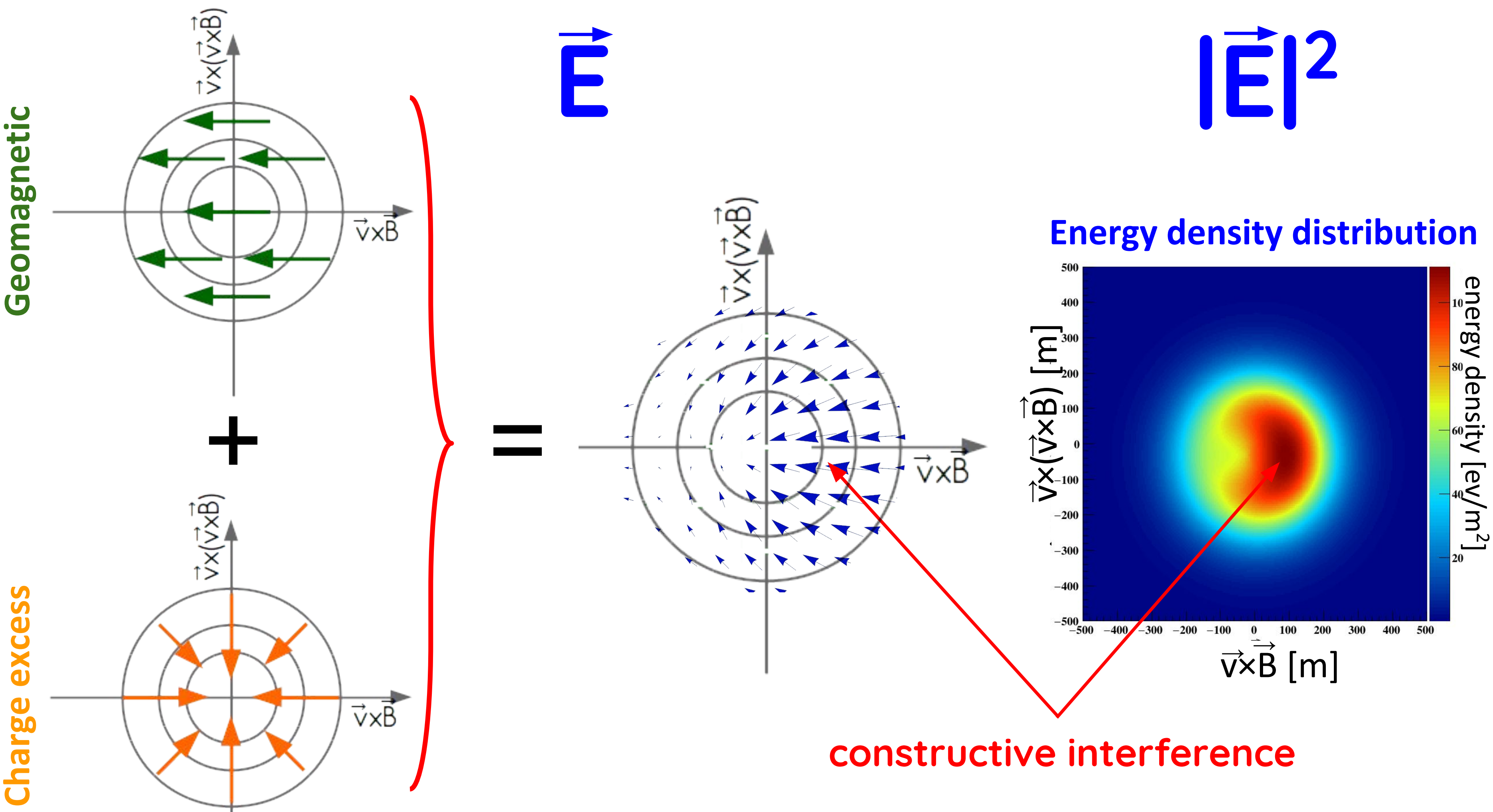
~90% of the total amplitude

Charge excess emission



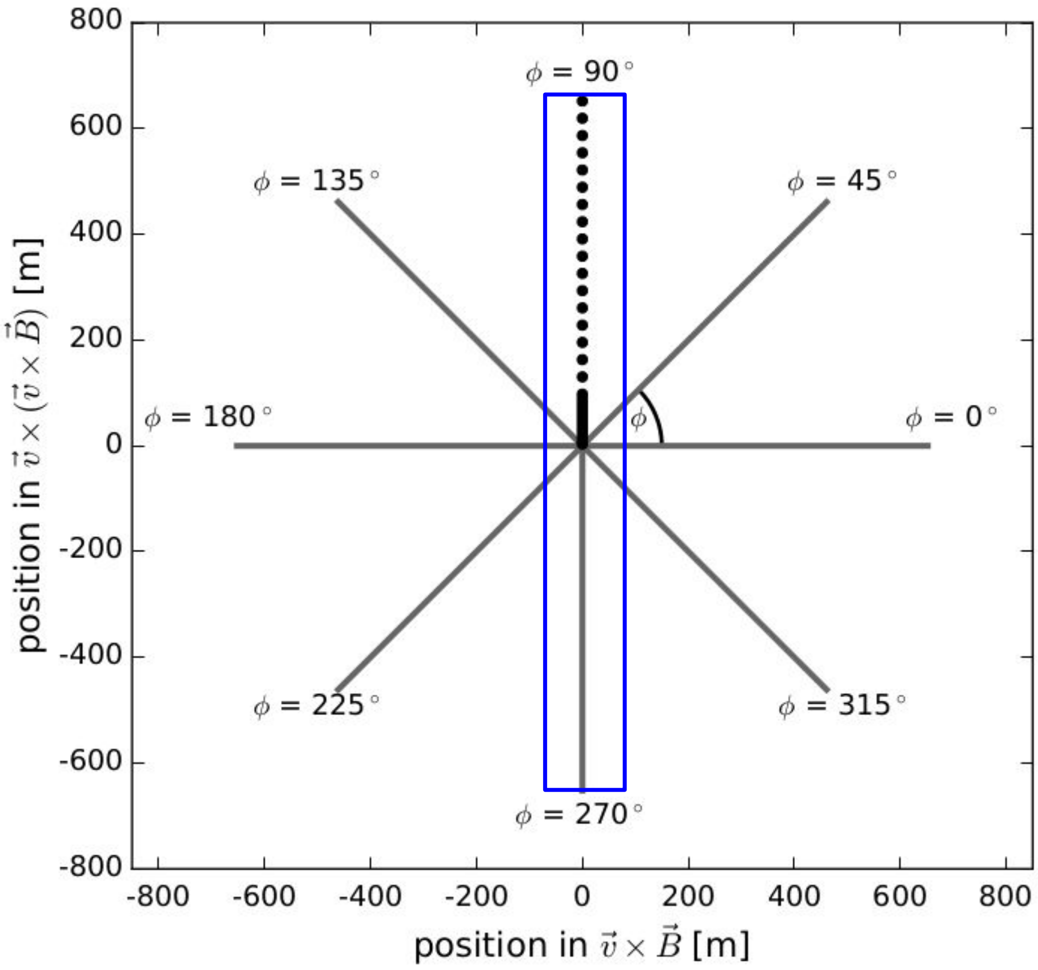


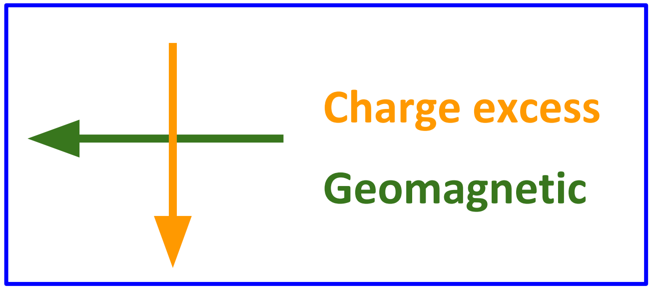
Radio emission from extensive air shower



Ideal case

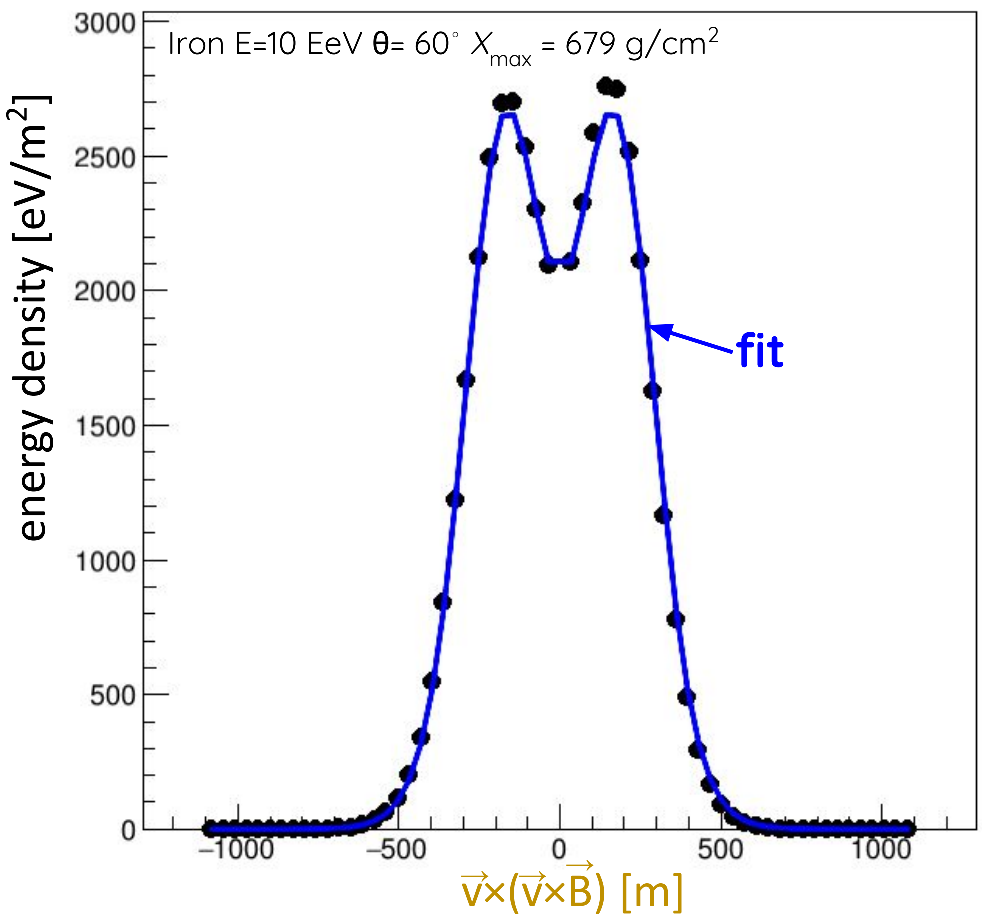
Simulations with ideal antennas in a “star-shaped” grid configuration

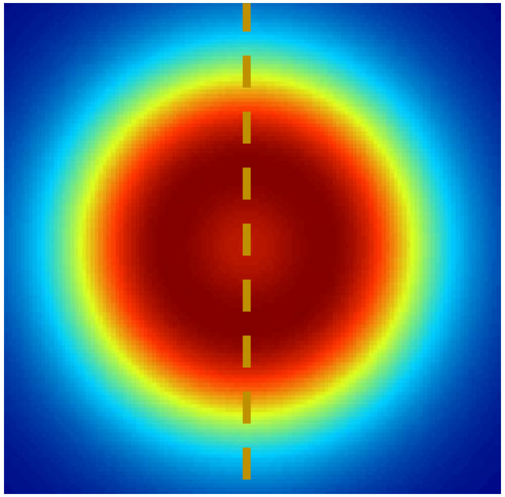




Geomagnetic fit

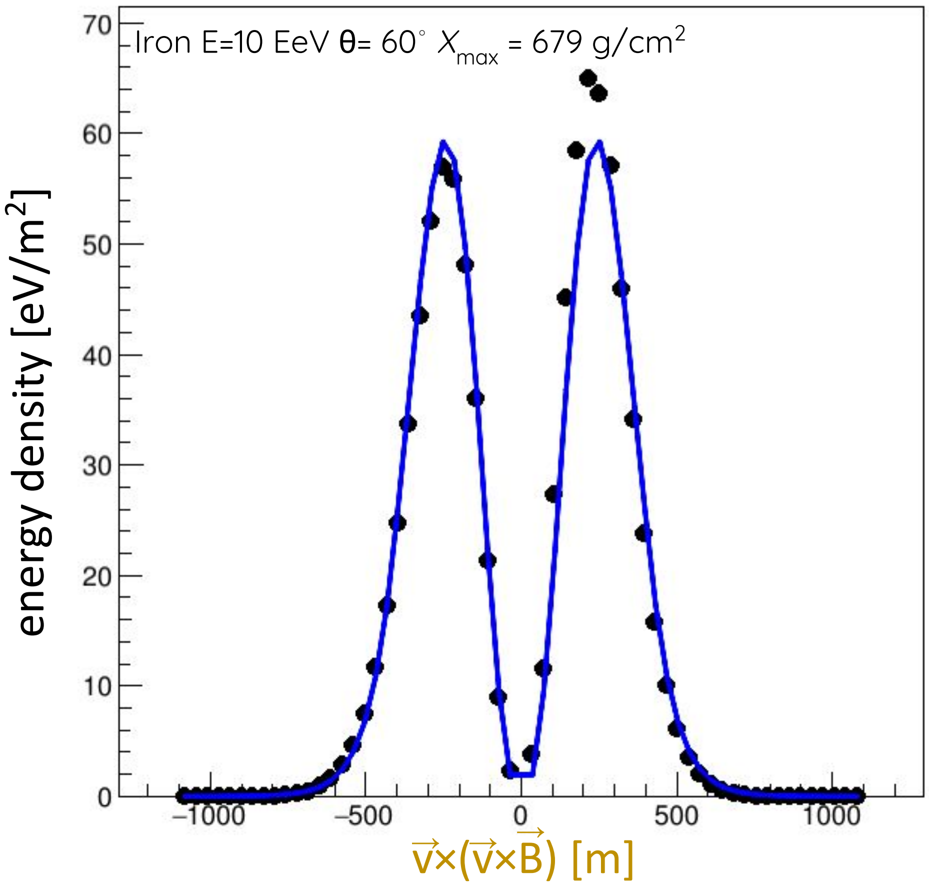
$$f_{\text{geo}} = \frac{1}{N_{R_+}} E'_{\text{geo}} \left[\exp\left(- \left(\frac{r - R_{\text{geo}}}{\sqrt{2}\sigma_{\text{geo}}} \right)^{p(r)} \right) + \exp\left(- \left(\frac{r + R_{\text{geo}}}{\sqrt{2}\sigma_{\text{geo}}} \right)^{p(r)} \right) \right]$$

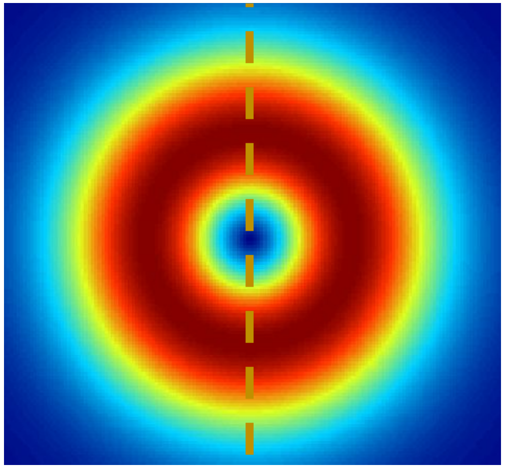




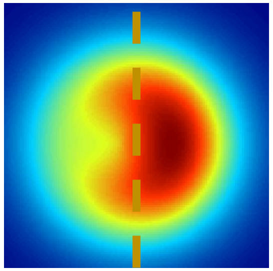
Charge excess fit

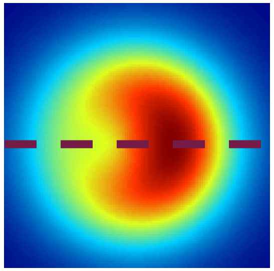
$$f_{\mathrm{ce}}(r) = \frac{1}{N_{\mathrm{ce}}} E'_{\mathrm{ce}}\, r^k \exp\left(\frac{-r^{p(r)}(k+1)}{p(r)\sigma_{\mathrm{ce}}^{p(r)}}\right)$$



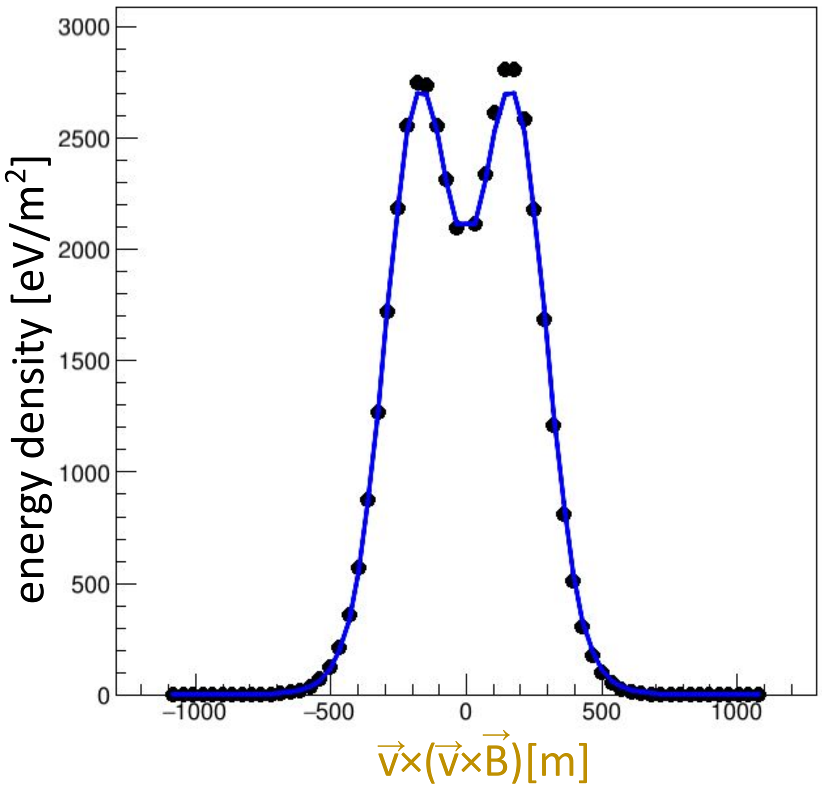


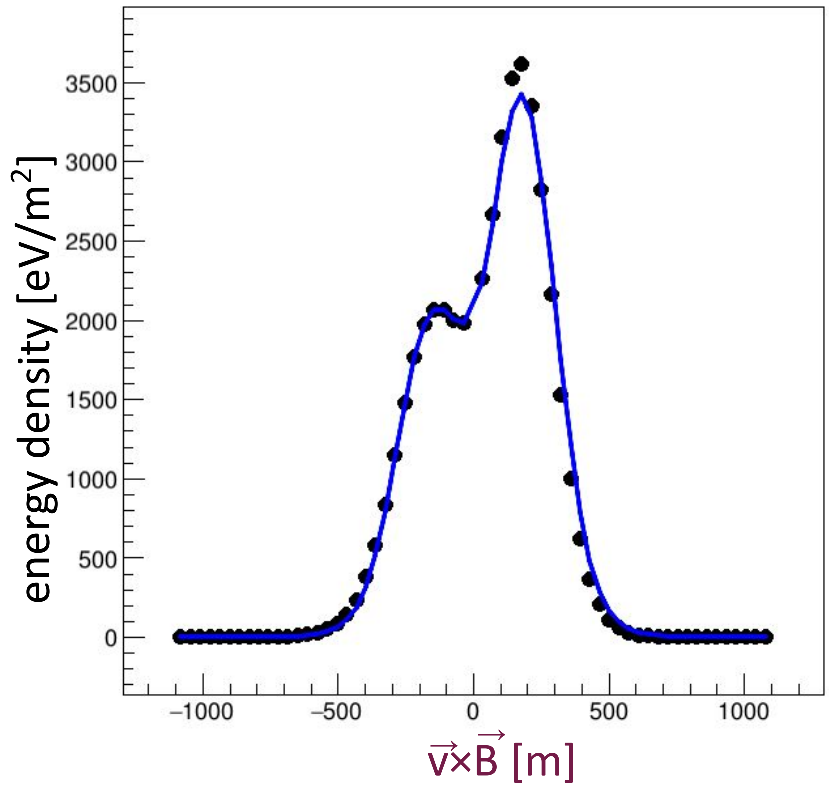
Total energy density fit





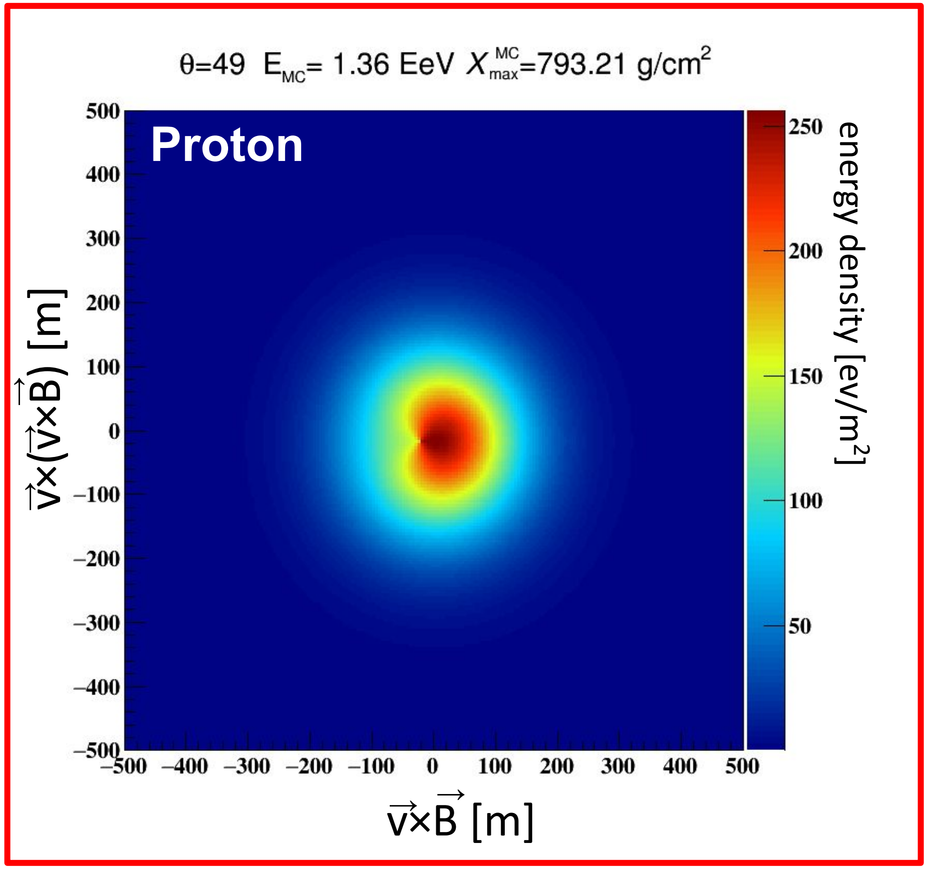
Geomagnetic + Charge excess

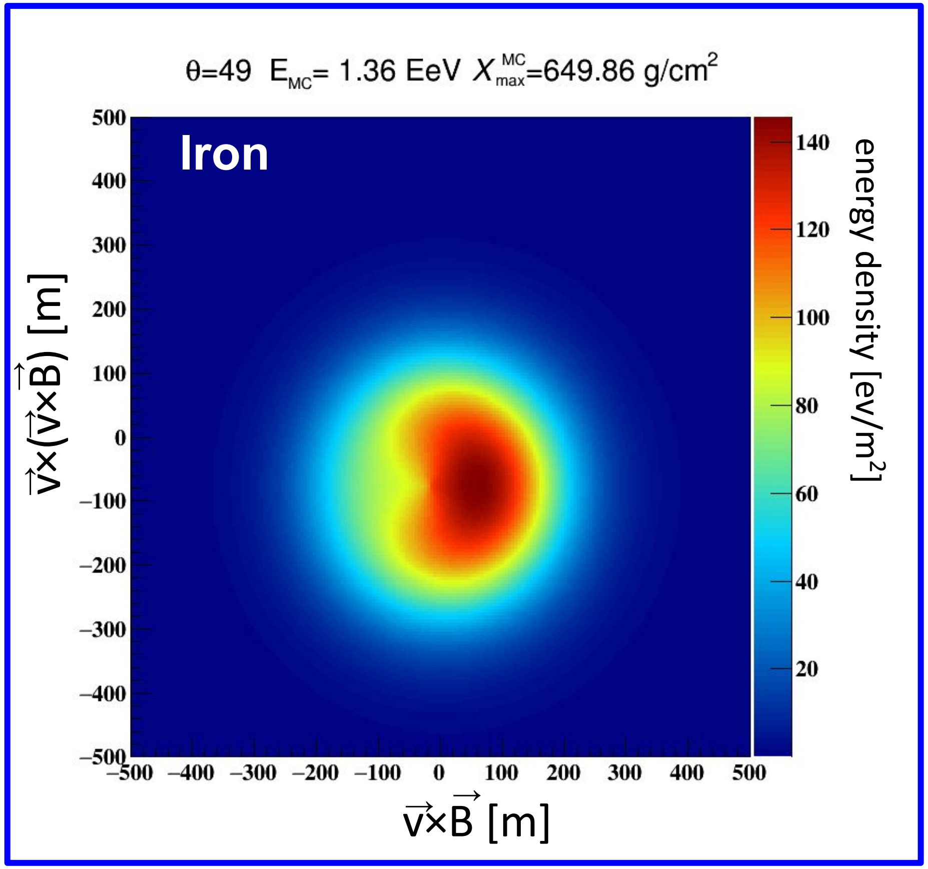




Iron E=10 EeV **θ**= 60° X_{max} = 679 g/cm^2

Mass composition with radio

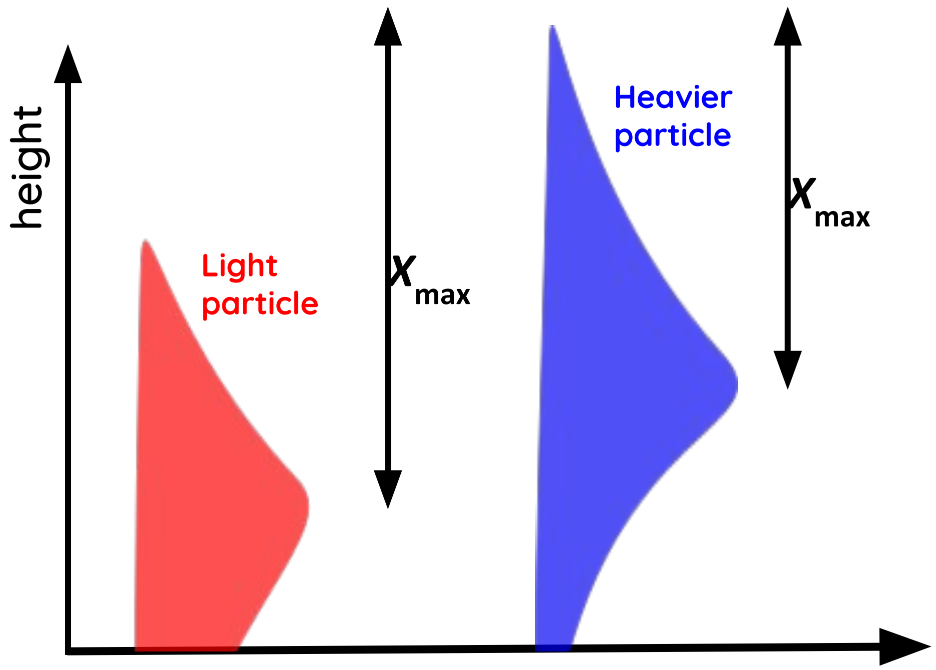




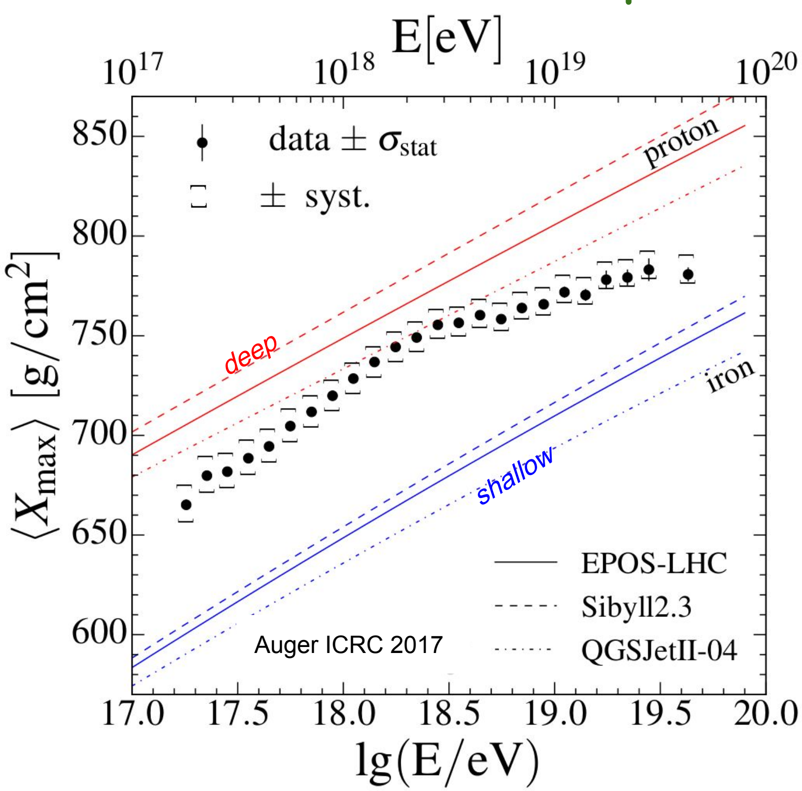
X_{max}

X_{max} atmospheric penetration depth
where the shower reaches **max number of charged particles**

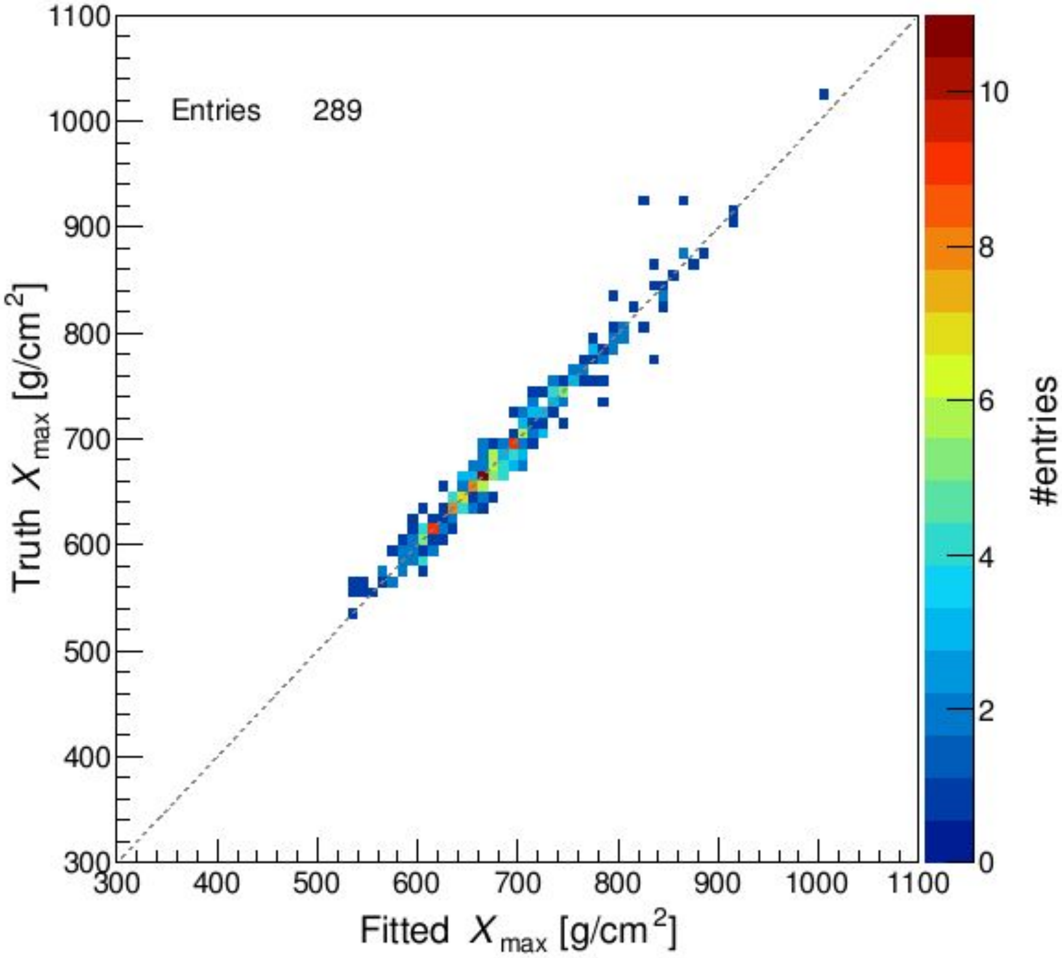
Lighter nuclei interact deeper in the atmosphere



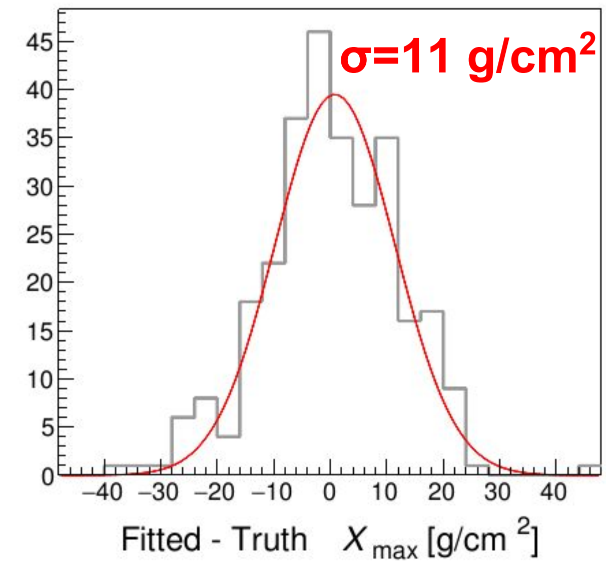
Fluorescence Telescopes



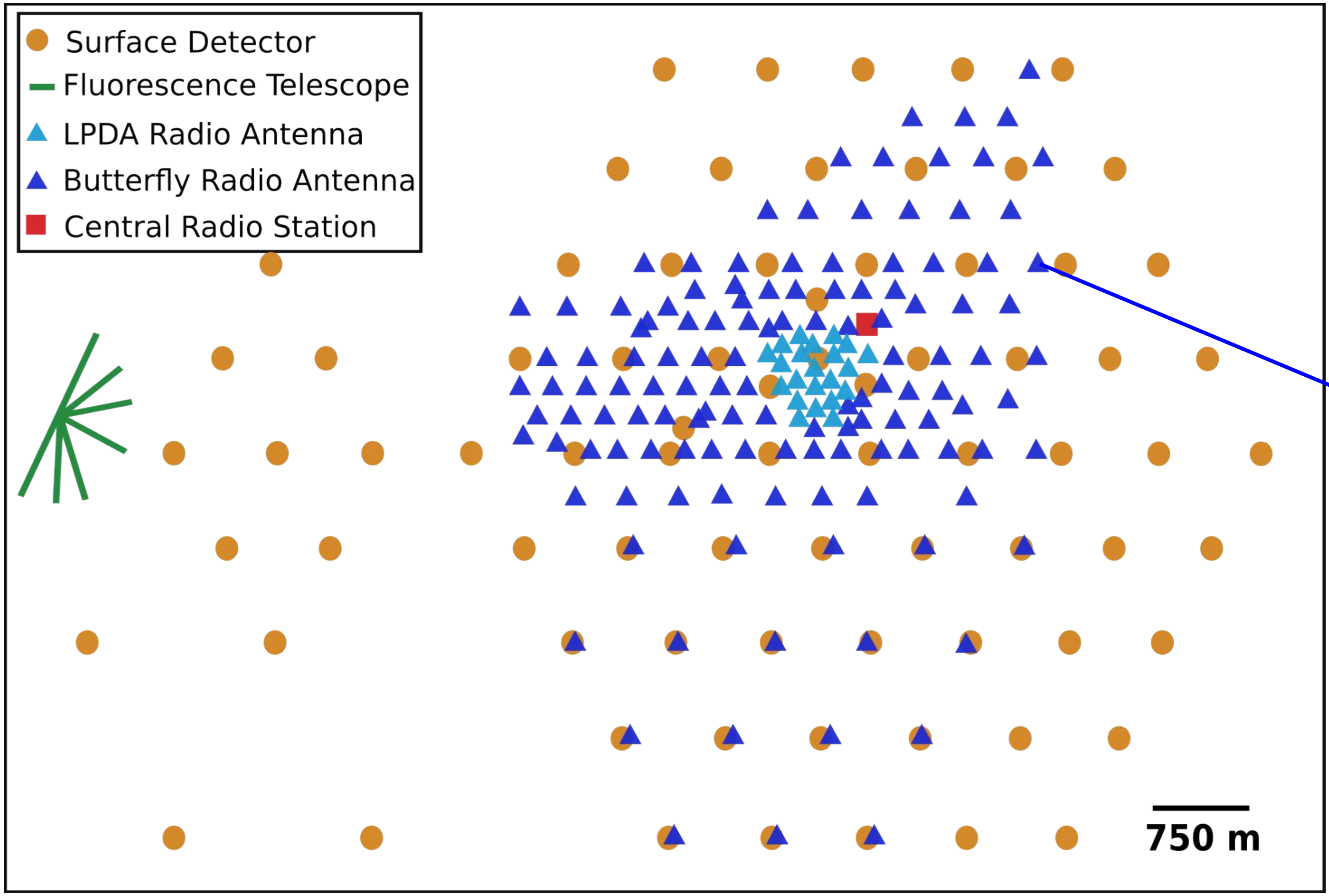
X_{max} from the energy density distribution



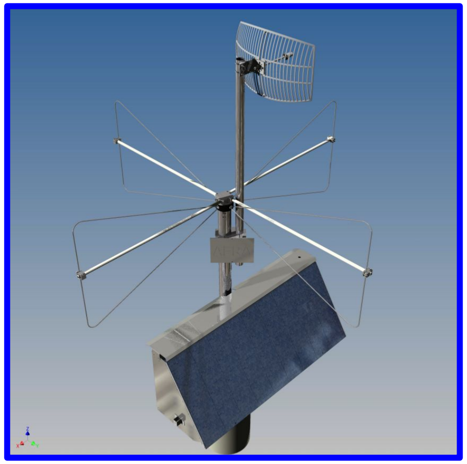
- Ideal detector
- No background noise



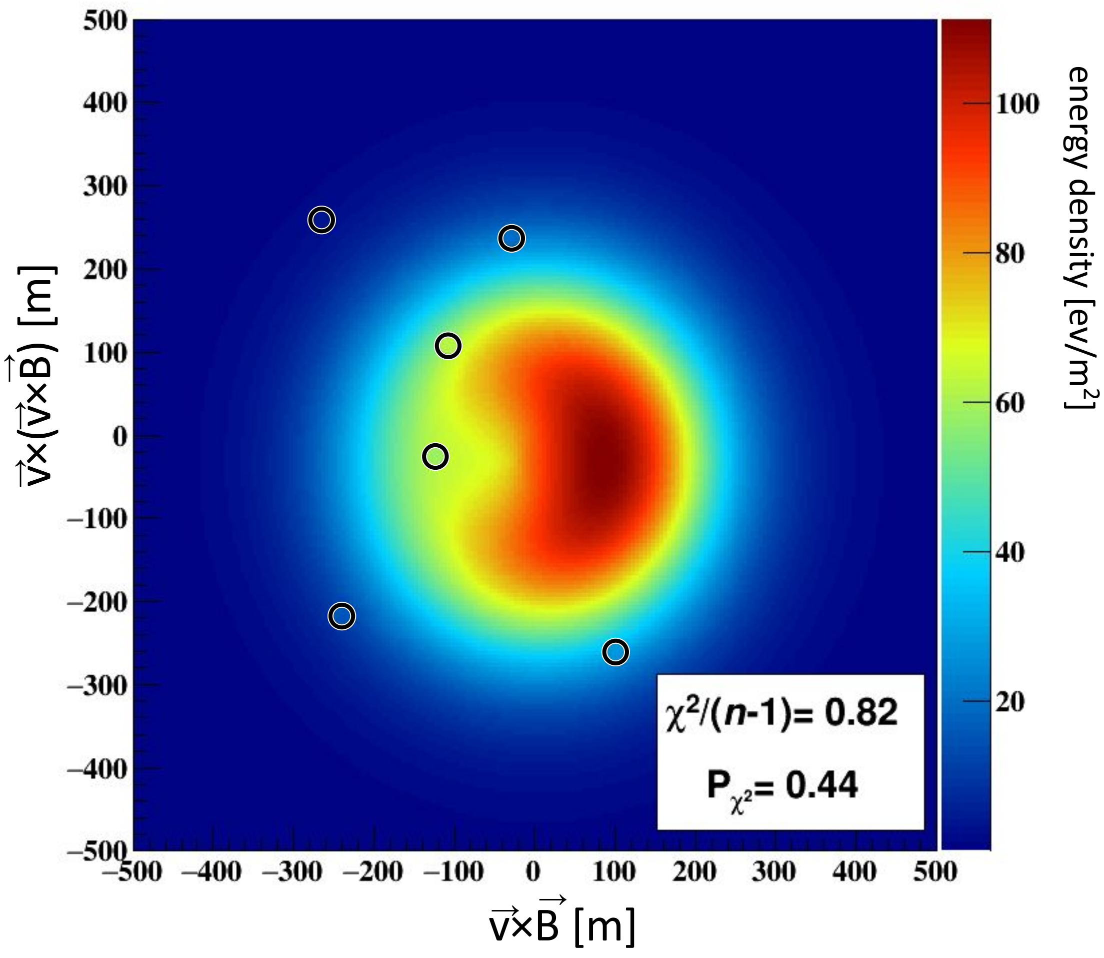
Auger Engineering Radio Array (AERA)



153 radio antennas spread over 17 km^2

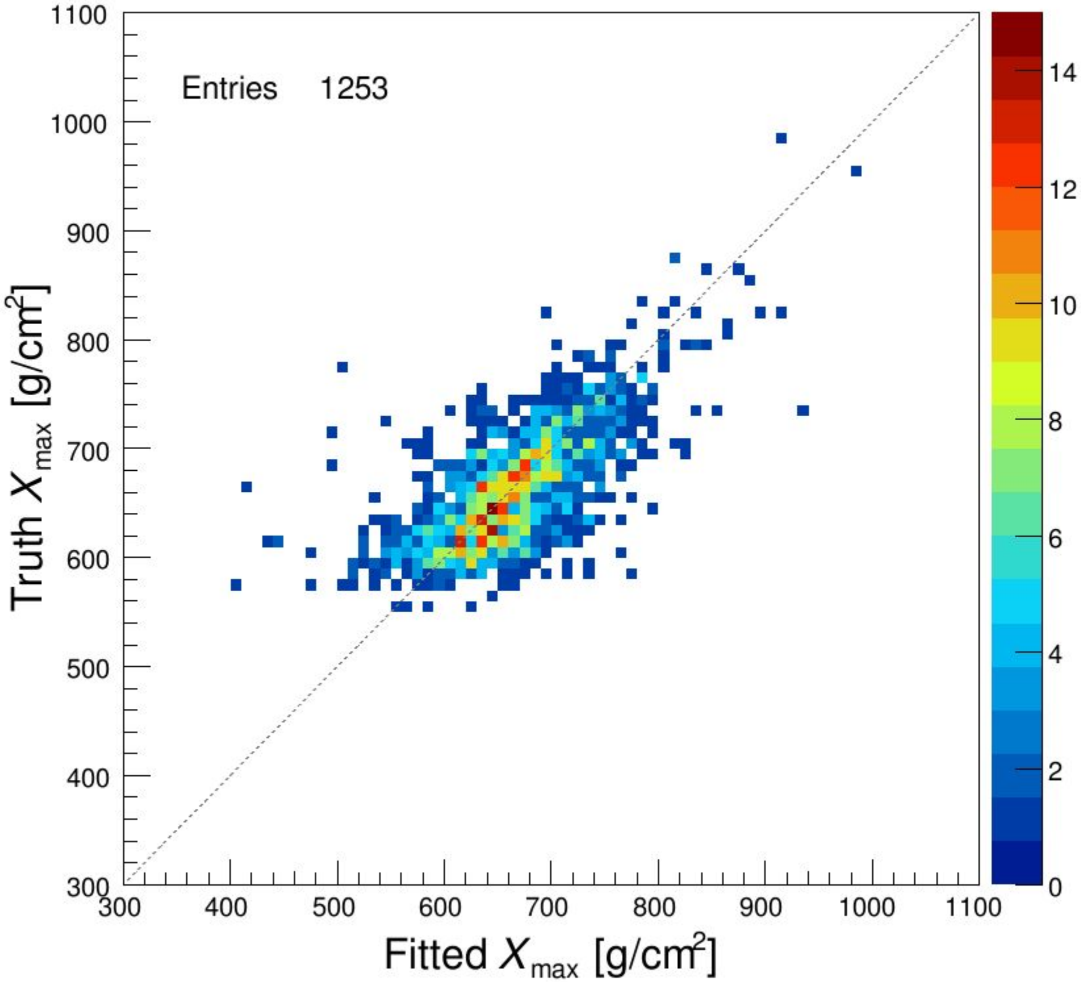


AERA event simulation

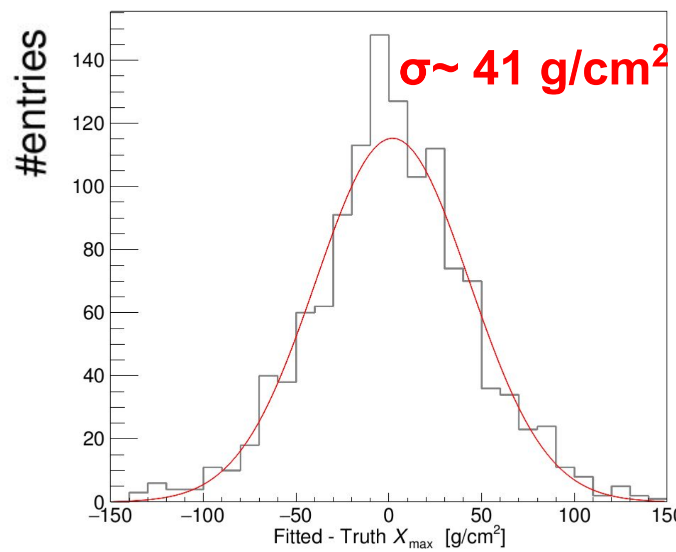


Iron, E= 1.24 EeV, X_{max}=679.03 g/cm^2

X_{max} from the energy density distribution



- Detector simulation
- Real background noise



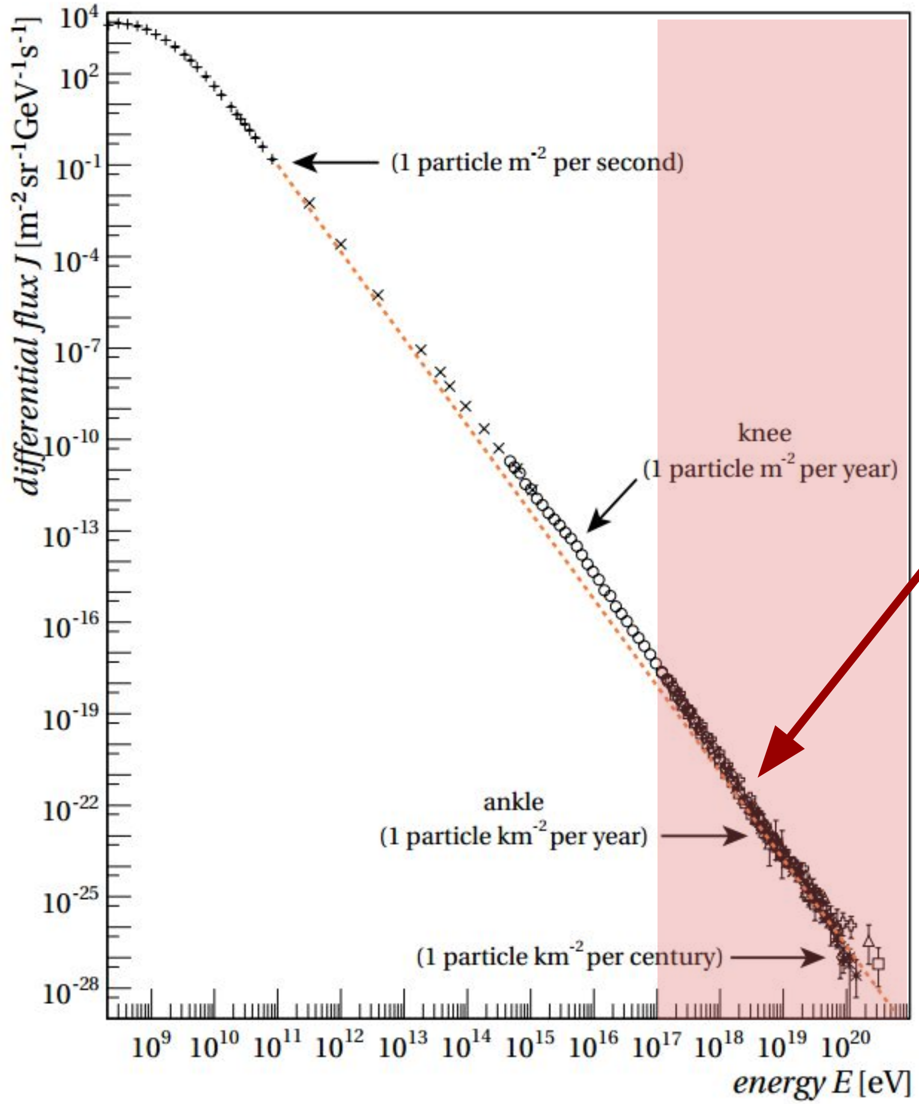
Conclusion and outlook

- New analytic description of the radio signal distribution that models geomagnetic and charge-excess emission separately
  [C. Glaser, S. de Jong, M. Erdmann, J.R. Hörandel, [astro-ph.HE] (2019)] :
  - First X_{max} studies → reconstruction uncertainty ~41 g/cm^2
    - Fluorescence telescopes reconstruction uncertainty ~20 g/cm^2
    - Average iron-proton separation ~100 g/cm^2

- Further improvements can be obtained by combining different strategies:
  - frequency spectrum information
  - arrival time

Backup

Ultra-high-energy cosmic rays



Ultra-high-energy cosmic rays
1 particle km^{-2} per century

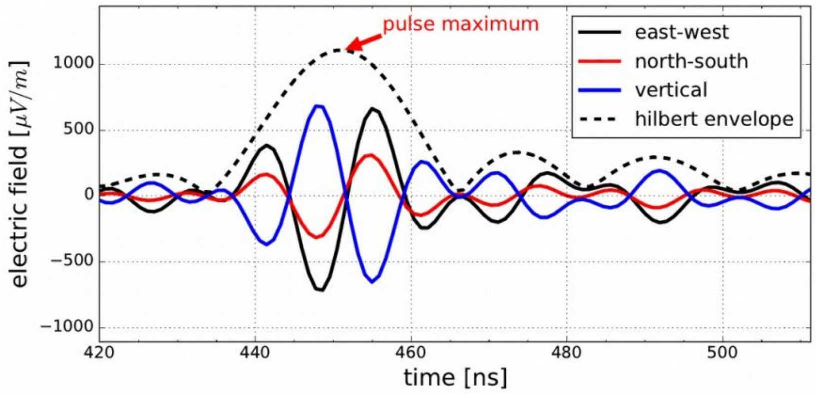
↓

LARGE AREA DETECTOR

↓

Radio antenna:
Cheap detector with ~90% uptime

Energy density



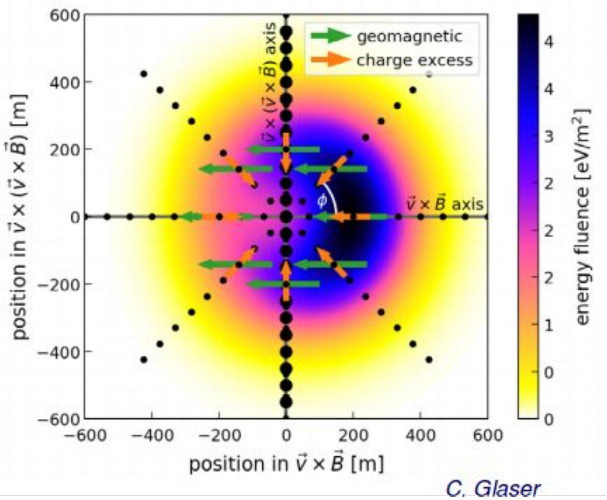
- Window [t_1-t_2] around the maximum of the Hilbert envelope
- Energy density in eV/m²
  - Time integral of Poynting vector
  - Noise expectation subtracted

$$u = \varepsilon_0 c \left(\Delta t \sum_{t_1}^{t_2} |\vec{E}(t_i)|^2 - \Delta t \frac{t_2 - t_1}{t_4 - t_3} \sum_{t_3}^{t_4} |\vec{E}(t_i)|^2 \right)$$

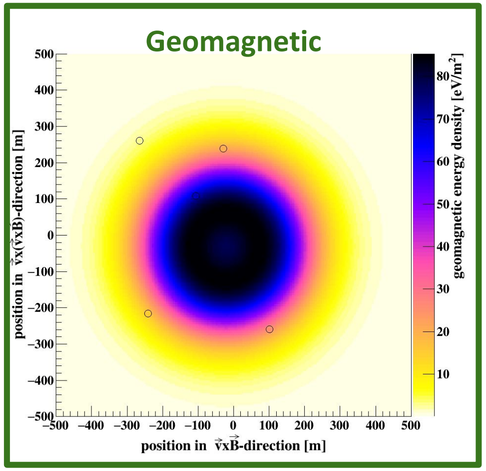
Radio signal distribution

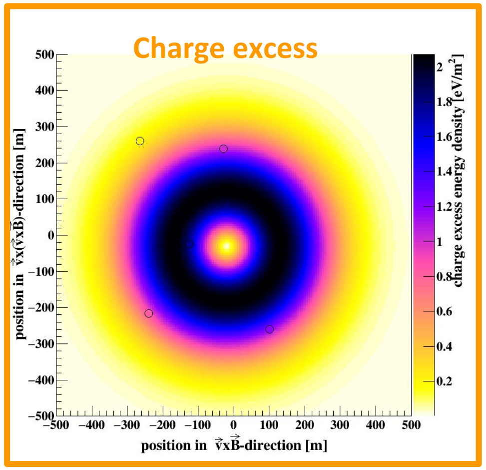
Energy density: $$f = f_{(\vec{v}\times\vec{B})} + f_{\vec{v}\times(\vec{v}\times\vec{B})}$$

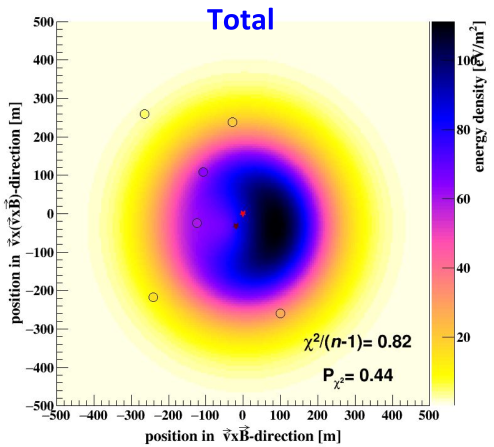
$$\begin{cases} f_{\vec{v}\times\vec{B}} = \left(\sqrt{f_{geo}(r)} + \cos\phi\,\sqrt{f_{ce}(r)}\right)^2 \\ f_{\vec{v}\times(\vec{v}\times\vec{B})} = \sin^2\phi\, f_{ce}(r) \\ \phi = \arctan 2(y, x) \end{cases}$$



Iron
E= 1.24 EeV
X_{max}=679.03 g/cm^2







Dependence of Fit Parameters DX_{max}