Macroscopic Geo-Magnetic Radiation Model (MGMR)

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O. Scholten, K. Werner, F. Rusydi, Astropart.Phys. 29, 94 (2008).

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Astropart. Phys. 29, 393 (2008),
arXiv:0712.2517 [astro-ph]

Outline

Introduction:

- Shower characteristics
- Short reminder MGMR

Current work:

- Askaryan effect in air showers.
- Interference behaviour, observer angle dependent LDF.

Conclusions/Future:

- Full shower description
- Include Cherenkov radiation into MGMR

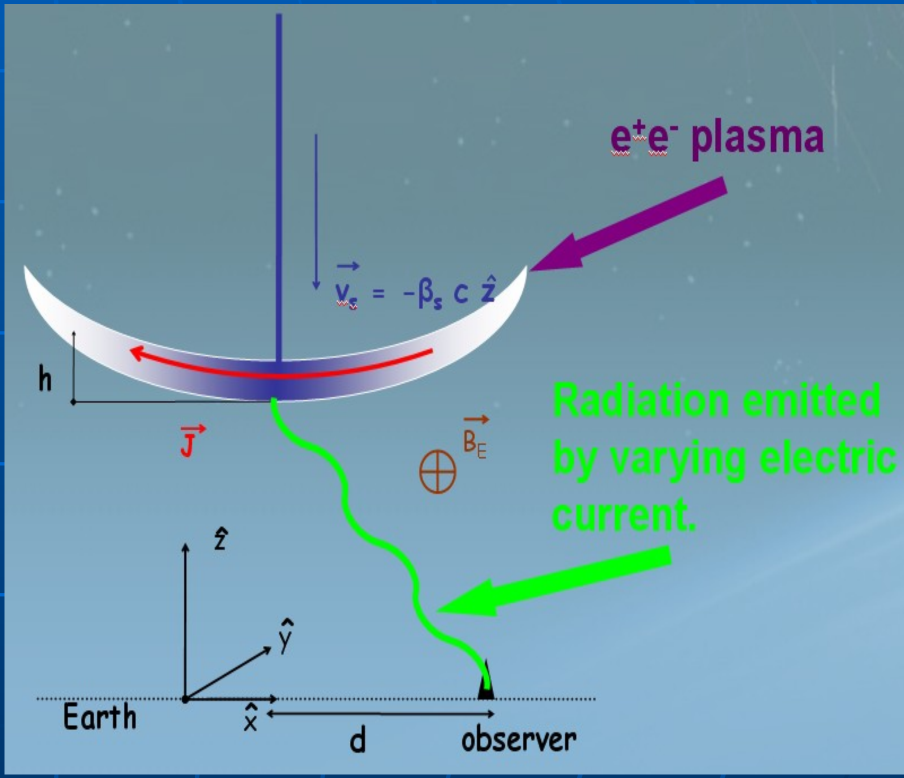
Shower Characteristics

- Three macroscopic functions describe the shower:

1. The total number of particles over time: $N_e(t_r)$.
2. The longitudinal distribution over the 'pancake': $\rho(h)$.
3. The lateral distribution of particles over the 'pancake': In progress.

MGMR

- Deflection of e+ and e- in the Earth magnetic field gives rise to a net macroscopic current.
- Total number of electrons, and thus the current changes over time.
- Due to the variation of this current a signal is emitted within the radio frequency range



Charge excess radiation/the Askaryan effect.

- Charge Excess contribution due to the Askaryan effect:

  Net negative charge in the shower front due to knock out from ambient air molecules ~30%

- Similar result as originally found by Frank and Tamm.

  (G.N. Afanasiev et. al. 1999 J. Phys. D.: Appl.

  Phys. 32 1999)

1.) Macroscopic vector potential for charge excess.

- Lienard-Wiechert Potentials:

$$A^{\cdot}(\vec{x},t)=C_x\frac{N_e(t_r)}{D}-\int dt_r\frac{dN_e(t_r)}{dt_r}\frac{1}{R}$$

$$A^z(\vec{x},t)=C_x\frac{-\beta N_e(t_r)}{D}$$

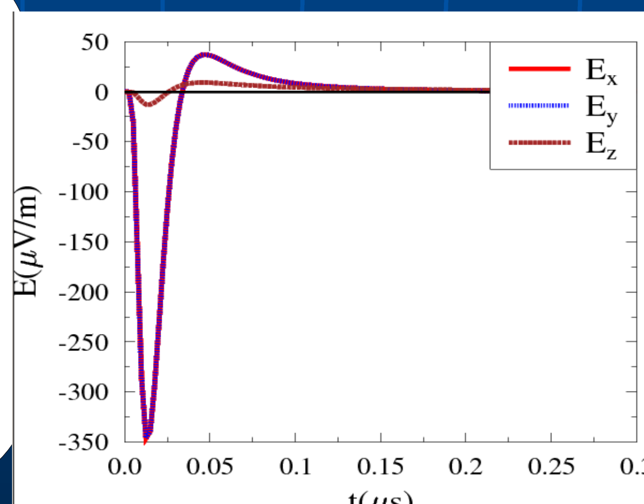
$$\vec{E}(\vec{x},t)=-\frac{d}{dt}\vec{A}(\vec{x},t)-\frac{d}{d\vec{x}}A^0(\vec{x},t)$$

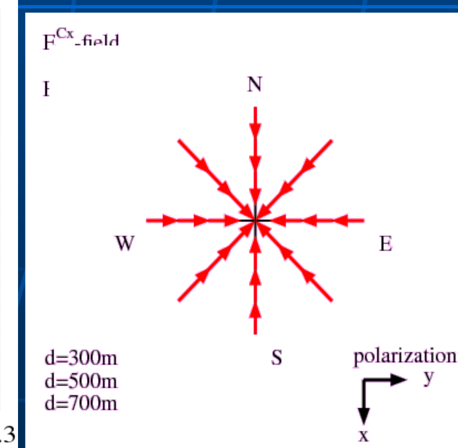
Harm Schoorlemmer

$$E^x_{Cx}(\vec{x},t)=C_x\frac{dN_e(t_r)}{dt_r}\frac{x}{D^2}\frac{z}{R}$$

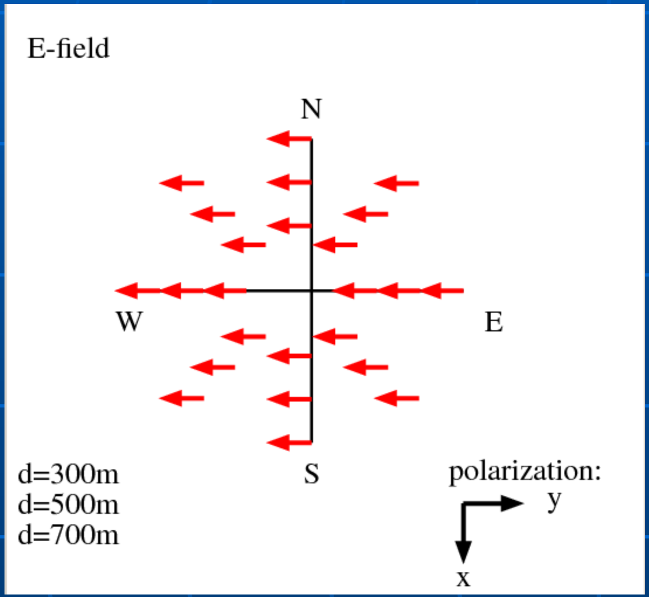
$$E^y_{Cx}(\vec{x},t)=C_x\frac{dN_e(t_r)}{dt_r}\frac{y}{D^2}\frac{z}{R}$$

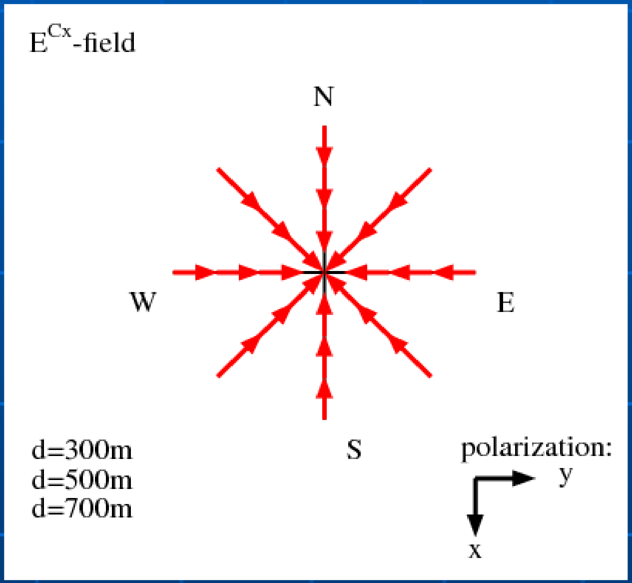
$$E^z_{Cx}(\vec{x},t)=C_x\frac{dN_e(t_r)}{dt_r}\frac{d}{D^2}\frac{d}{R}$$





Polarizations at different observer positions





Geomagnetic polarization ~

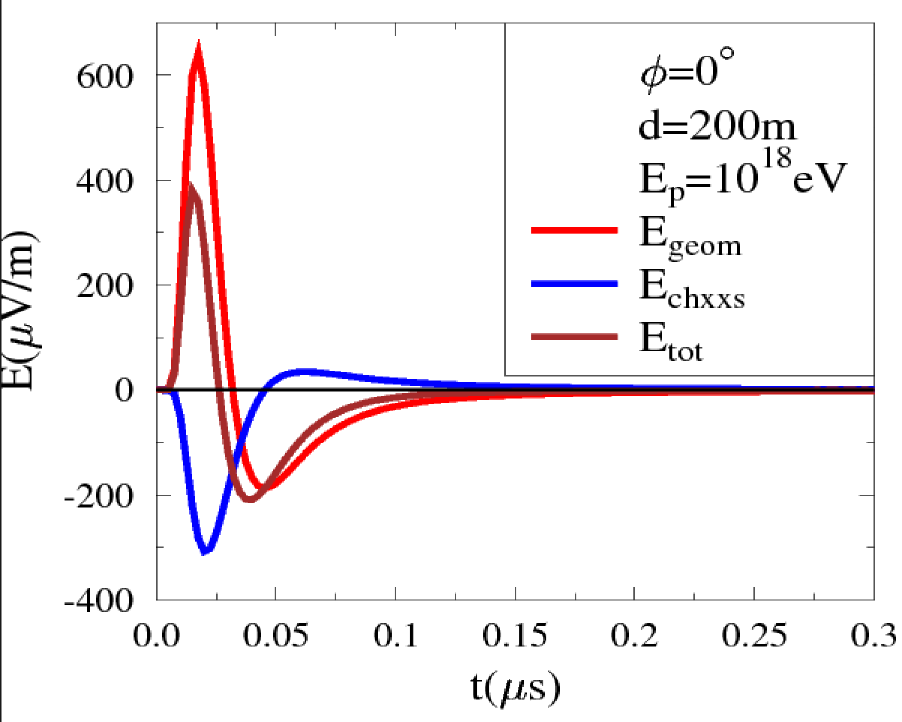
$\vec{\beta} \times \vec{B}$

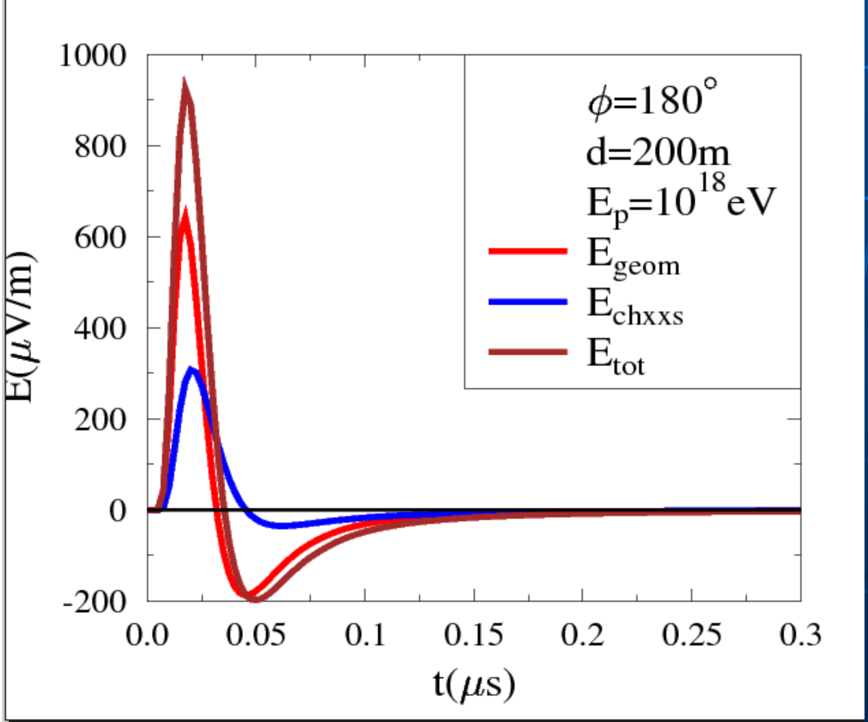
Charge excess polarization:

Depending on observer position.

Interference

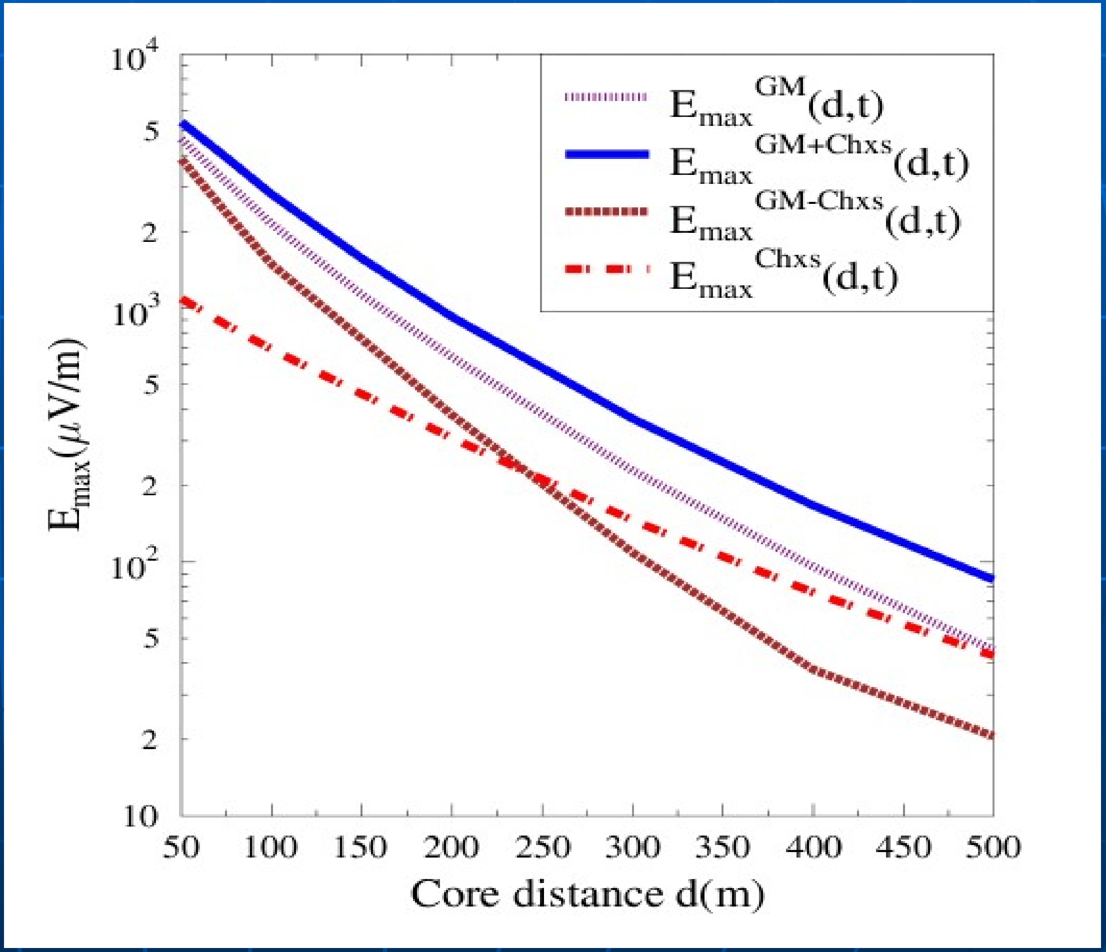
- At different observer angles, different interference between Geo-magnetic and charge excess contribution. → Different LDF for different observer angles.



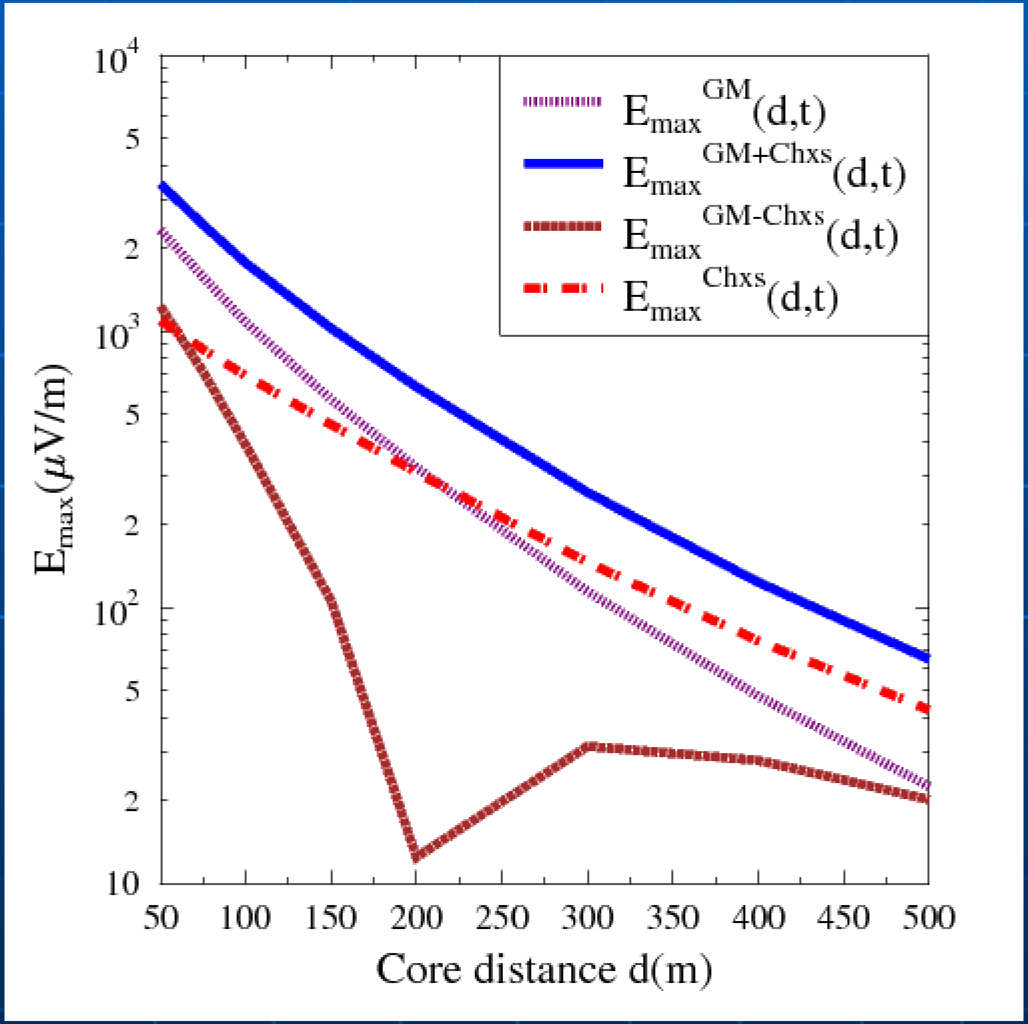


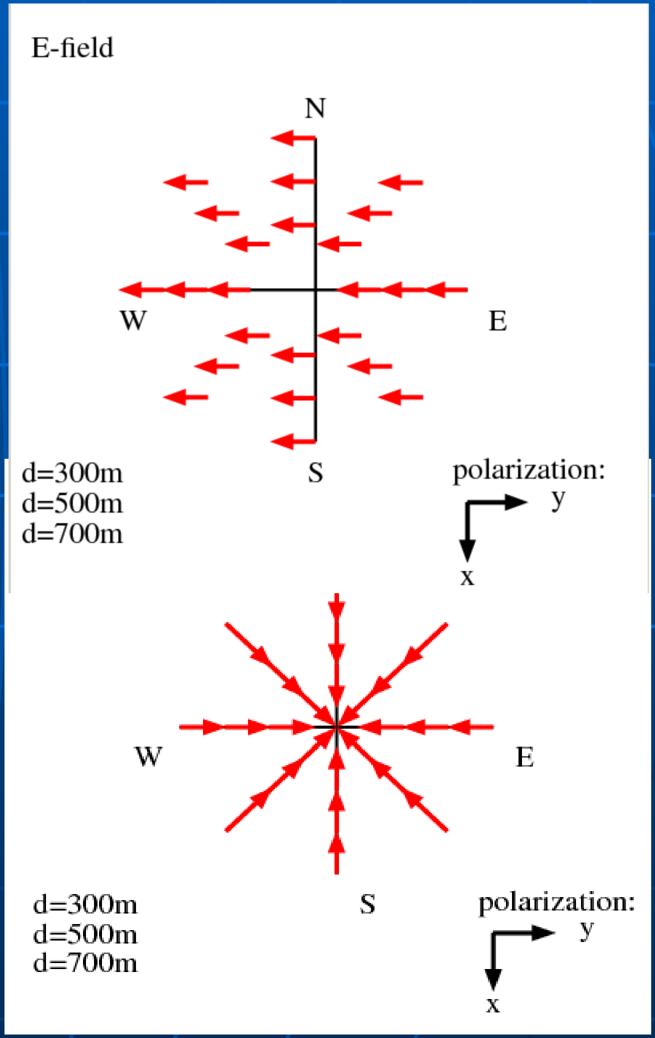
LDF

- Geomagnetic field scales with sin(α).
- One should take into account the observer angle in determining an LDF!



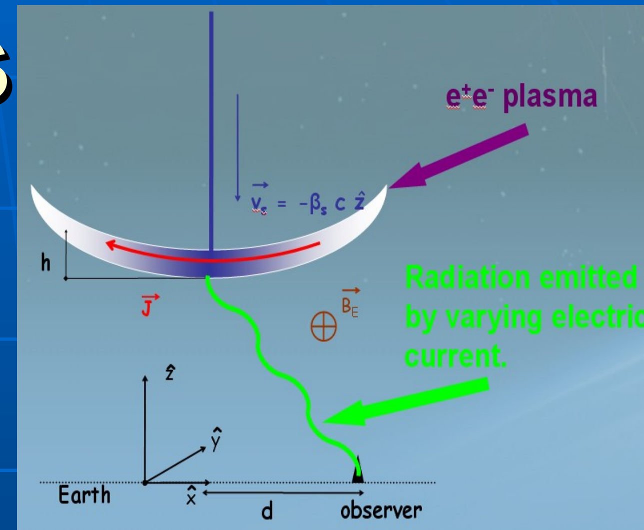
LDF(2) Exteme case

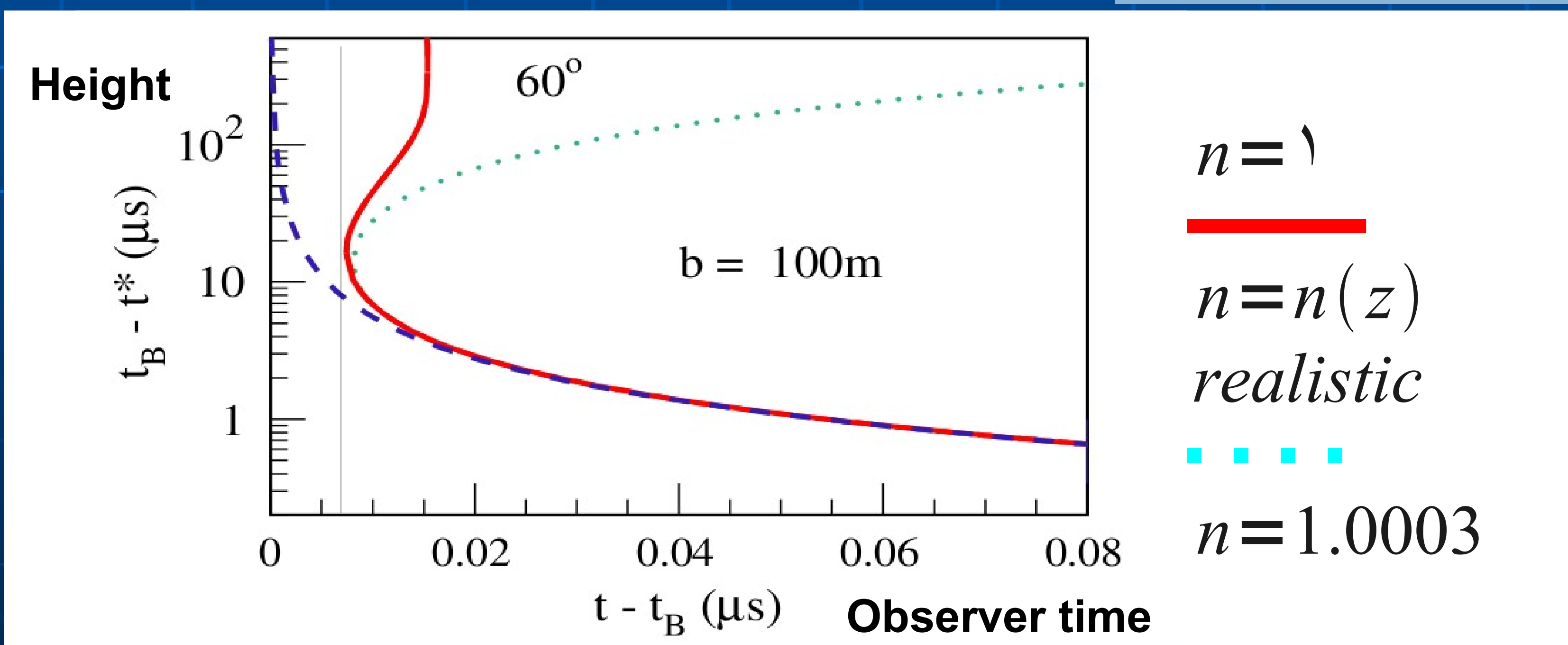




Cherenkov Radiation in Air Showers

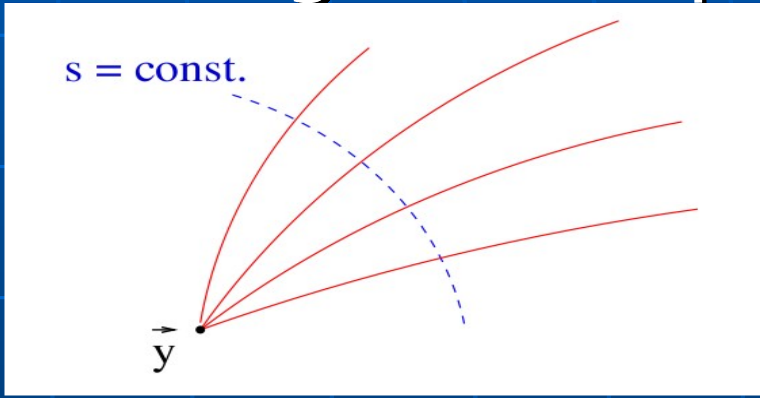
- Lienard-Wiechert potential given by:





Cherenkov radiation in MGMR

- Model realistic index of refraction as function of particle position.
- Use optical path length from particle to observer.



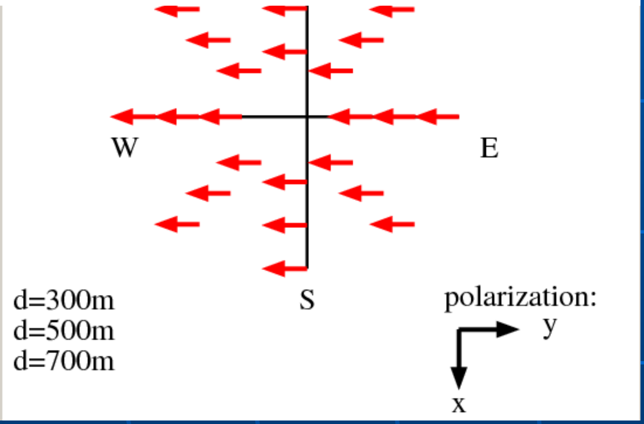
- Include lateral extend of the shower front.
- Include all terms into calculation.
- Calculation and full simulation in progress.

Conclusions and Outlook

- Different polarization patterns for Charge excess radiation due to the Askaryan effect give rise to an observer dependent LDF.
- The shape of the LDF differs for different shower geometries.
- A realistic index of refraction in air, although close to unity gives rise to Cherenkov emission.
- Future: Include Cherenkov and full MC shower extension into MGMR.

Back up: Polarizations at different observer positions

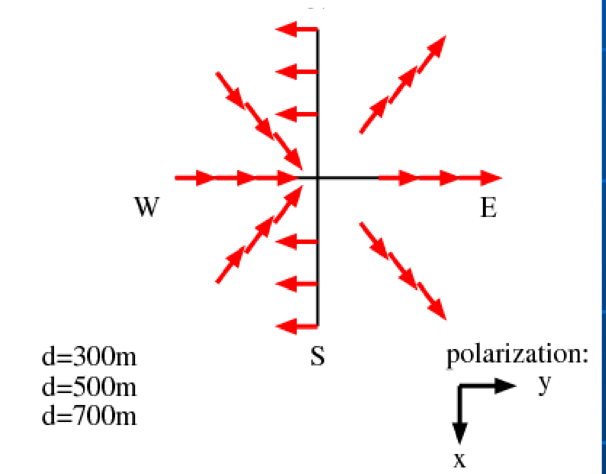
Leading Geomagnetic



Geomagnetic polarization ~

$\vec{\beta} \times \vec{B}$

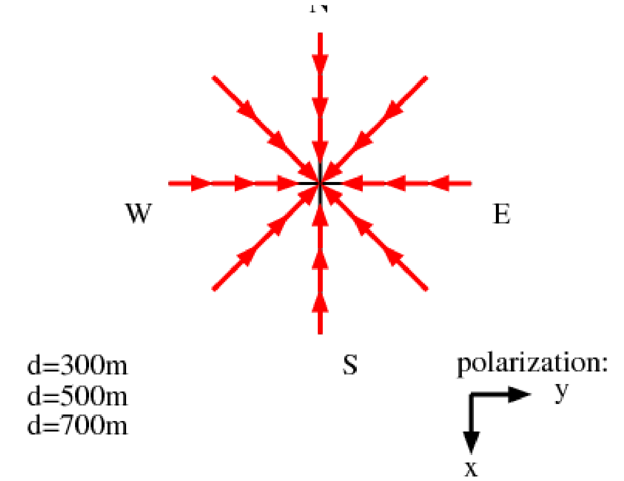
Secondary



Moving dipole polarization:

Depending on observer position.

Askaryan



Charge excess (Askaryan) polarization: Depending on observer position.

2.) Calculation

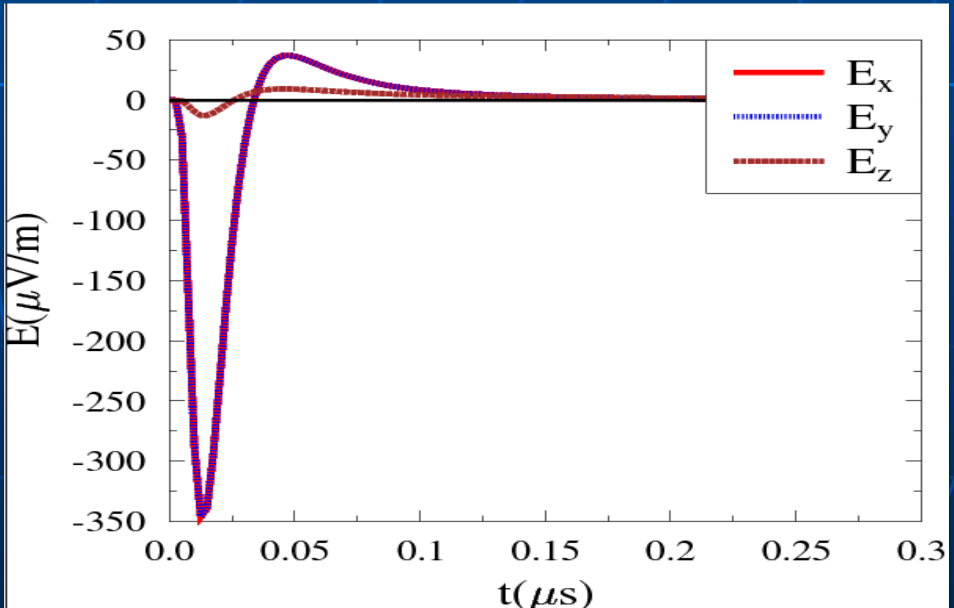
- Bremsstrahlung field in the far-field Fraunhofer regime can be calculated as:

$$\vec{E}^{e}(\vec{x},t)=\frac{\pm\vec{\beta}_{\perp}}{D}\delta(T)$$

$$\vec{E}^{sh}(\vec{x},t)=\int dt\left(\frac{R}{D}\right)\vec{E}^{e}(\vec{x},t)\frac{dN_e(t_0)}{dt_0}$$

$$=\vec{\beta}_{\perp}\frac{R}{D^2}\frac{dN_e(t_0)}{dt_0}\Big|_{t_0=t_r}$$

- E-field:



Approximations

- Fraunhofer:

$$R = |x - \xi|$$
$$\approx R - \vec{e}_R . \vec{\xi}$$
$$= R_0 - \beta z' \cos(\theta)$$

- First order terms used:

$$R_1 \propto z'(1 - \beta \cos\theta)$$

- Vanishes at the cherenkov angle, so expansion up to 2nd order necessary.

- MGMR:

$$\frac{dD}{d\vec{x}} = (1 - \beta^2)\frac{\vec{x}}{D^2} \approx 0$$

- At the cherenkov angle:

$$D = R(1 - \beta \cos\theta_c) = 0$$

The term above has a bad divergence and cannot be neglected.

$$\frac{D}{R} = (1 - \beta \cos\theta) = 0 \Big|_{\theta=\theta_c}$$