Testing a two-component approach to describe radio emission from air showers

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[based on Astroparticle Physics **59**, 29 (2014)]

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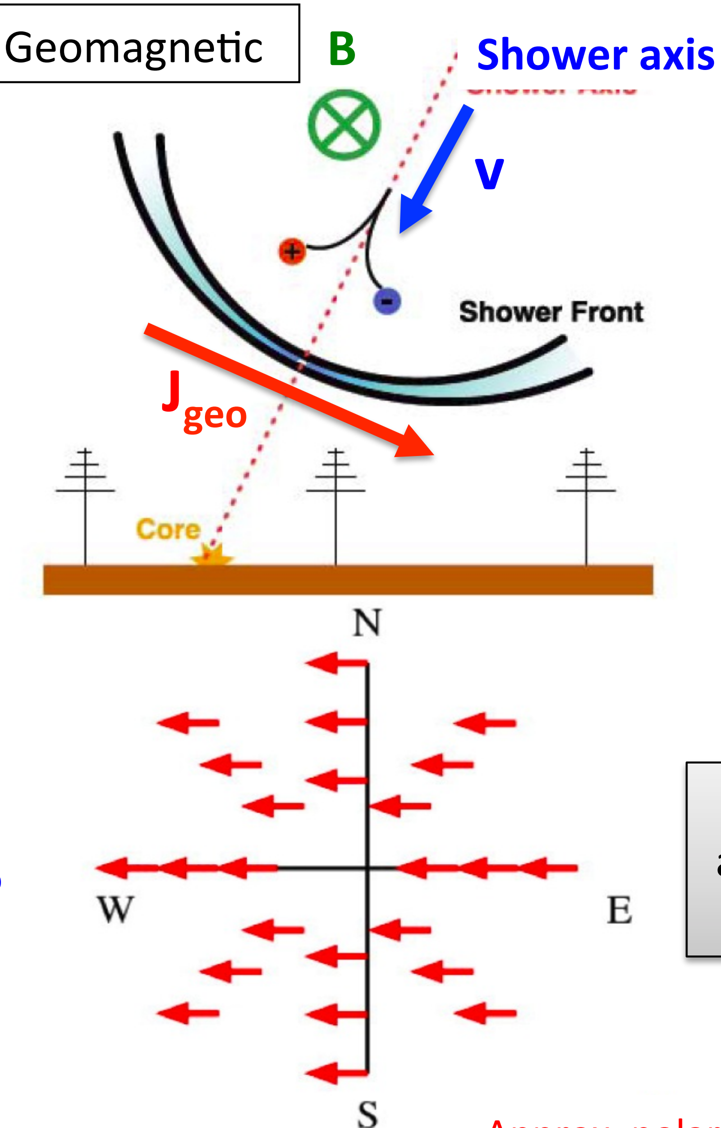
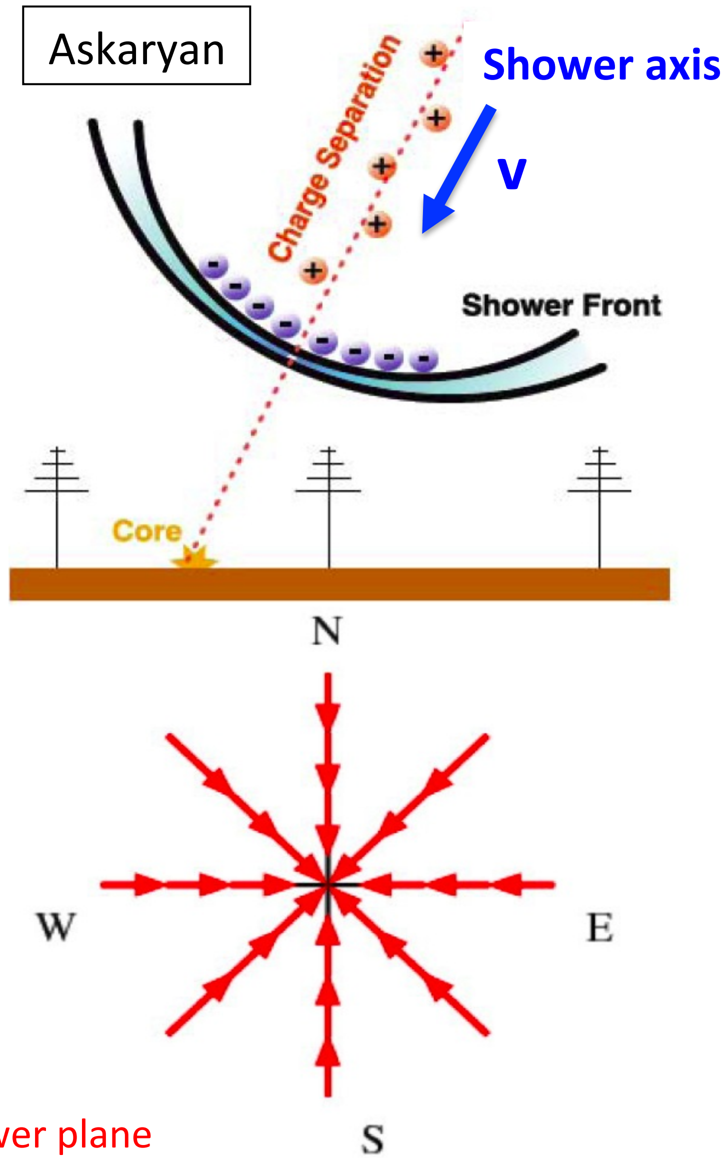
The "two-component" approach



Diagrams H. Schoorlemmer & K. de Vries

Interference between mechanisms determines features of radio emission but…

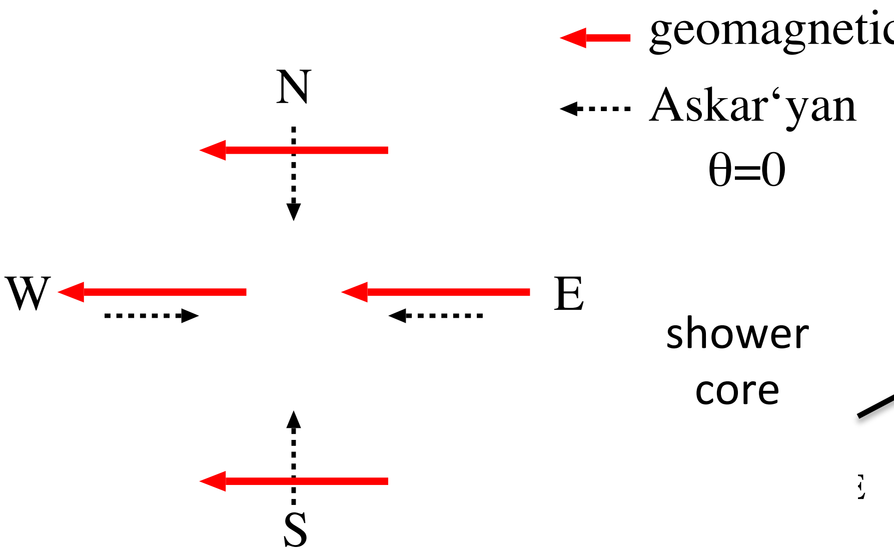
How well is this approach working quantitatively?



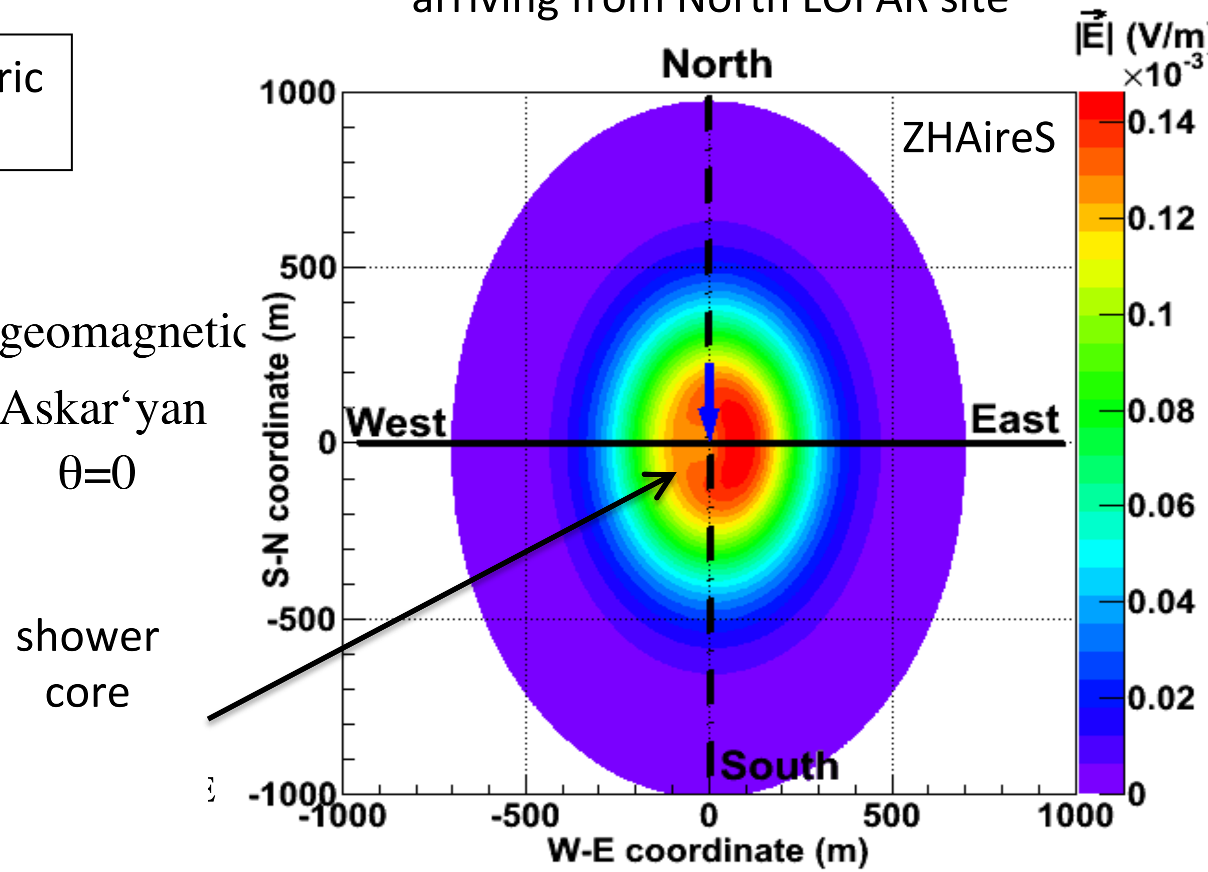
Approx. polarization pattern in shower plane

Recall: total field is not radially symmetric but…

2-dimensional pattern of electric field modulus on ground



Proton, 10^{17} eV, 45°
arriving from North LOFAR site

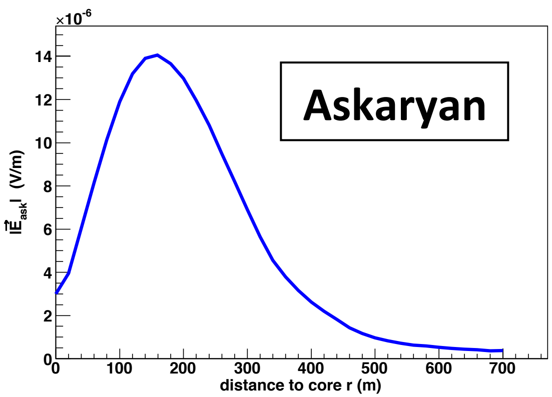


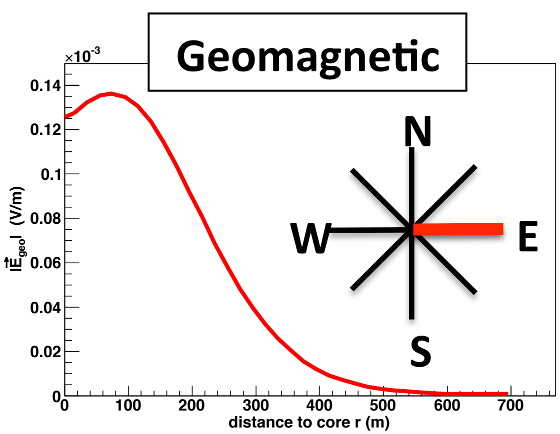
… individual components should be symmetric.

Testing the "two-component"

Inputs

Amplitudes of Askaryan & geomagnetic fields at a **FEW positions**



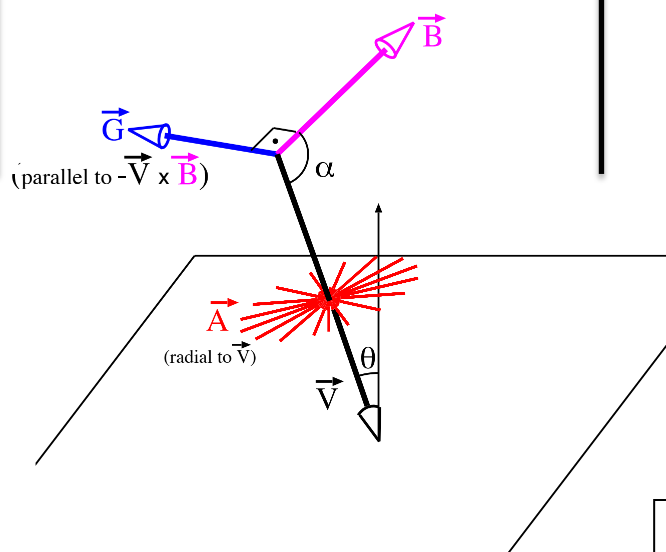


from Monte Carlo sims.

Standard Assumptions

(1) Circular symmetry of amplitudes in plane perpendicular to shower axis (shower plane)

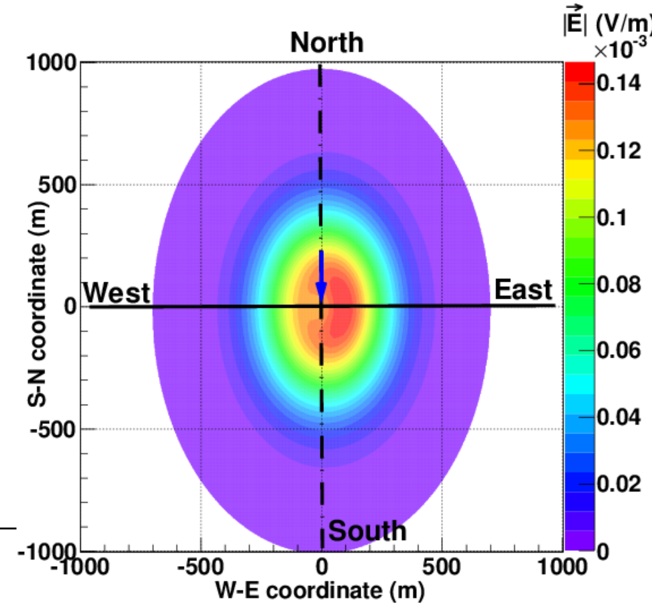
(2) Linear polarization in shower plane:



J. A-M, W.R. Carvalho, H. Schoorlemmer, E.Zas, Astroparticle Physics **59**, 29 (2014)

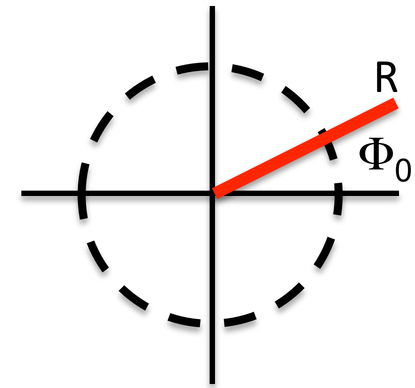
Output

Predited Electric field at **ANY position** on the ground plane



Compare to full Monte Carlo simulations (good agreement)

Methodology:



1. Obtain (MC sims.) **separate amplitudes of Askaryan & geomagnetic fields** along a single line of antennas with coordinates (R, Φ_0)

$$\mathcal{E}_{\mathrm{Ask}}(R,\Phi_0) = |\vec{E}_{\mathrm{Ask}}(R,\Phi_0)| \;=\; |\vec{E}_{B_{\mathrm{off}}}(R,\Phi_0)|$$

Askaryan:
shower with B off

$$\mathcal{E}_{\mathrm{geo}}(R,\Phi_0) = |\vec{E}_{\mathrm{geo}}(R,\Phi_0)| \;=\; |\vec{E}_{B_{\mathrm{on}}}(R,\Phi_0) \;-\; \vec{E}_{B_{\mathrm{off}}}(R,\Phi_0)|$$

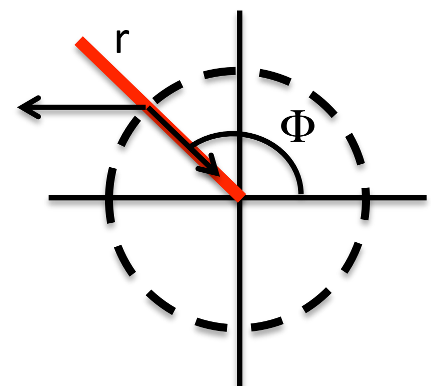
Geomagnetic:
shower B on – B off

2. Assuming **circular symmetry** in shower plane & expected polarization
⟶ obtain field at any other position:

$$\vec{E}(r,\Phi) \;=\; \mathcal{E}_{\mathrm{geo}}(R,\Phi_0)\left[\frac{-\vec{V}\times\vec{B}}{|\vec{V}\times\vec{B}|}\right] \;+\; \mathcal{E}_{\mathrm{Ask}}(R,\Phi_0)\;\hat{r}$$

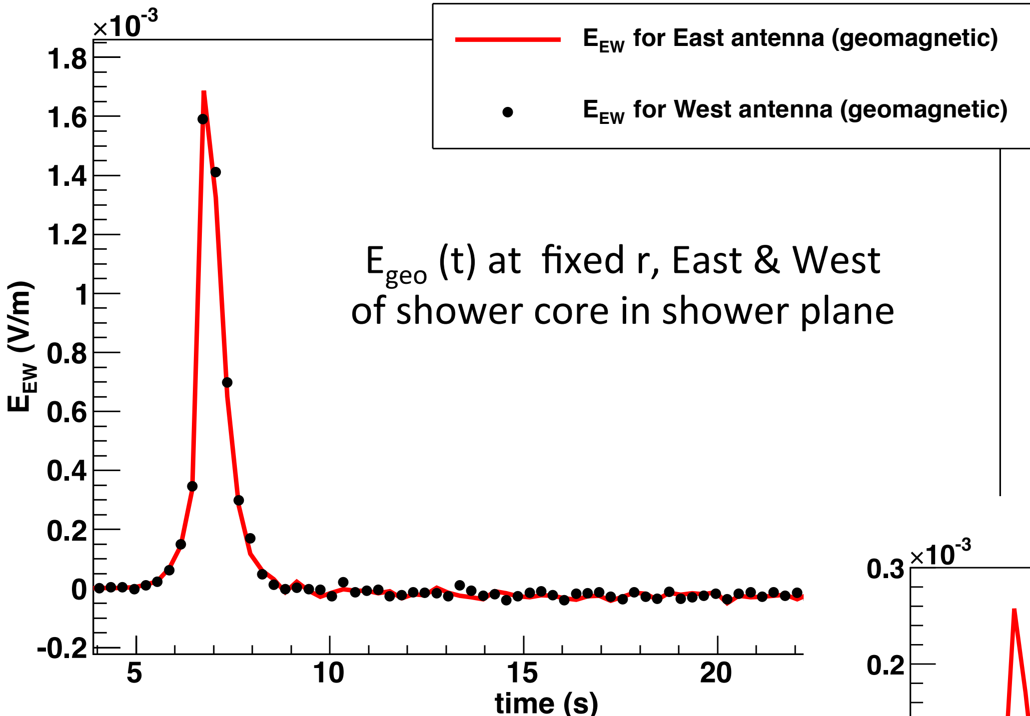
geomagnetic polarization

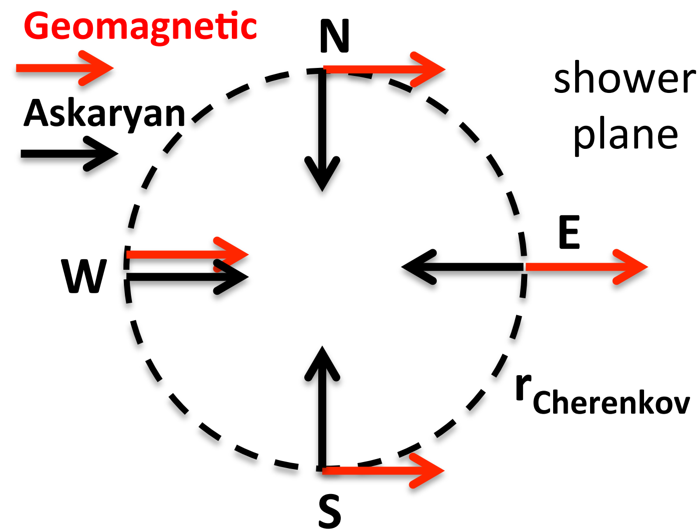
radial polarization

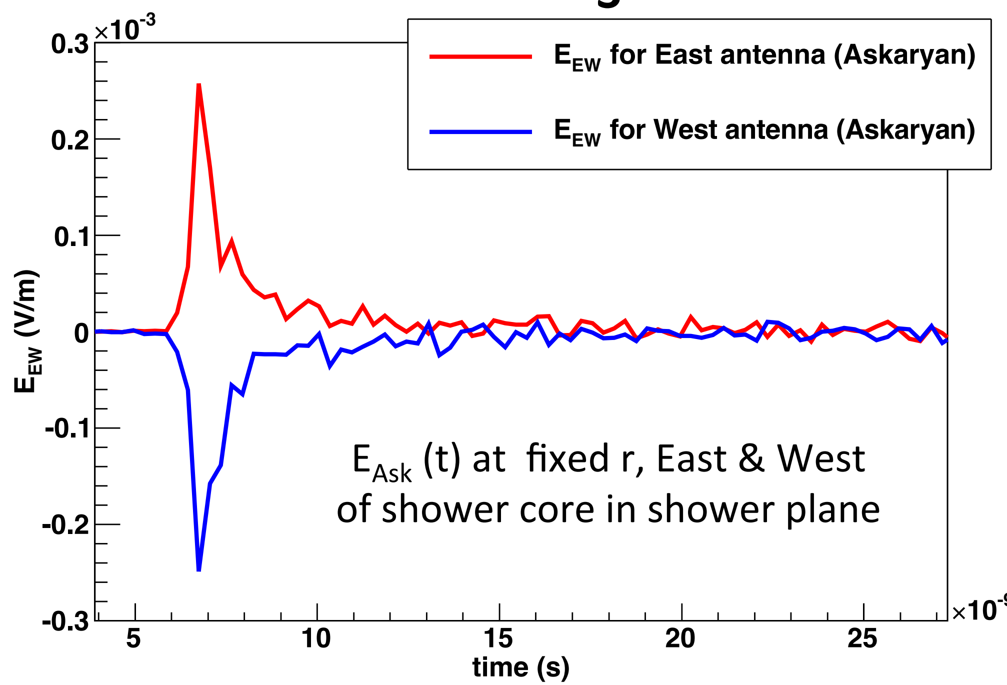


3. Simple geometric projection from (r, Φ) in shower plane onto ground.

Circular symmetry of E_{geo} & E_{Ask}







E_{geo}(t) & E_{Ask} (t) circularly symmetric in shower plane even at the level of time traces

ZHAireS simulations

Results:

Field predicted with the model

Individual components:

- at a few positions only, along fixed ϕ_0
- circularly symmetric

Field at any position (R, ϕ)

$$\vec{E}(r,\Phi) \; = \; \mathcal{E}_{\rm geo}(R,\Phi_0) \; \left[\frac{-\vec{V}\times\vec{B}}{|\vec{V}\times\vec{B}|}\right] \; + \; \mathcal{E}_{\rm Ask}(R,\Phi_0)\; \hat{r}$$

geomagnetic polarization

radial polarization

vs

Field obtained in full MC sims.

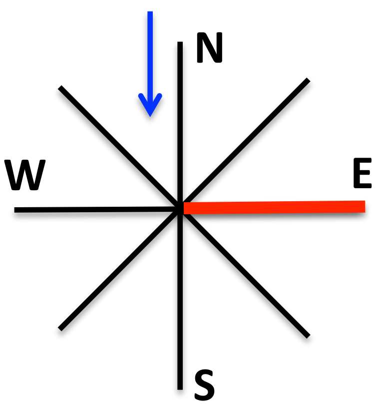
Field predicted by model vs field in full MC sims.

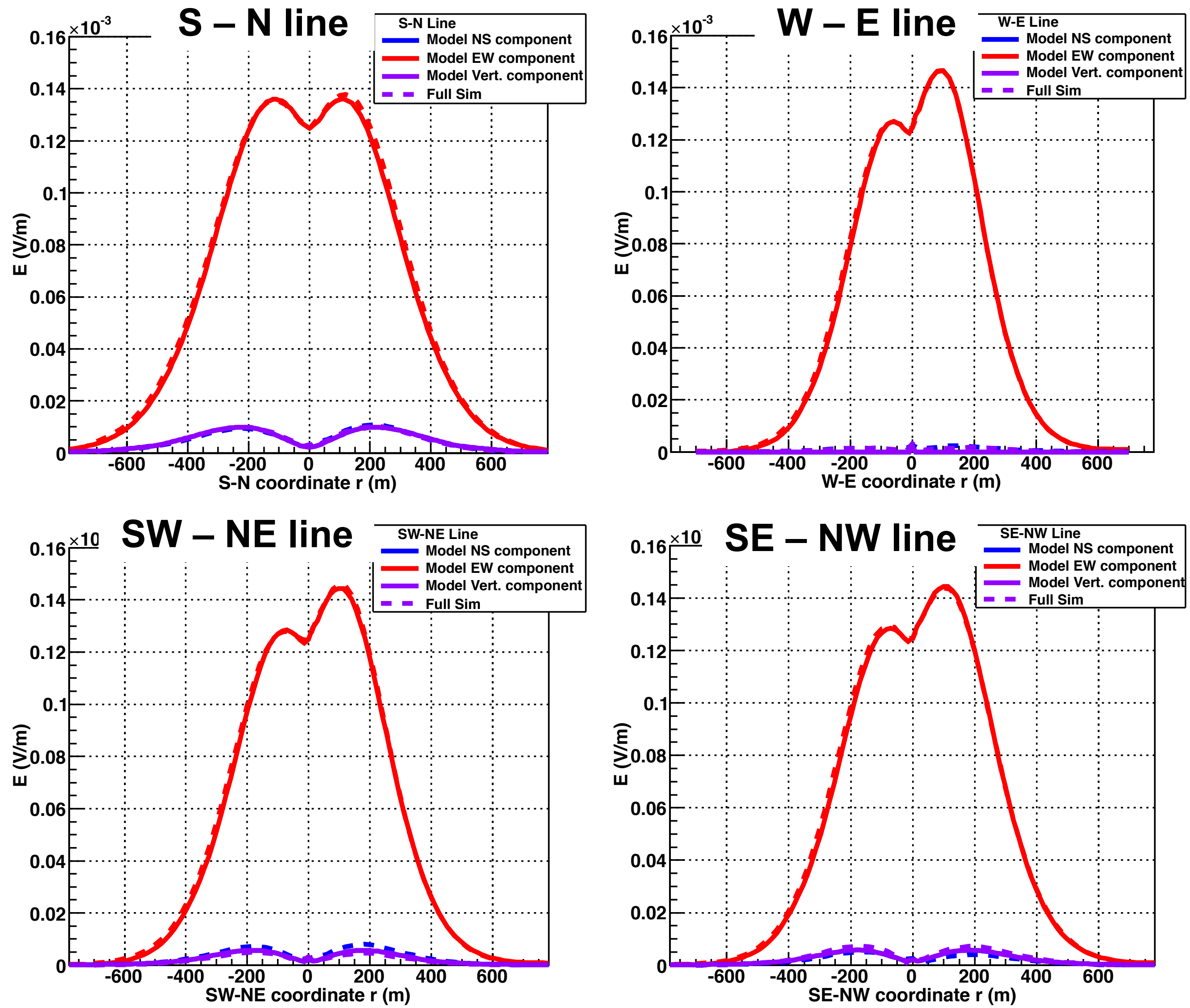
Solid lines ⟶ model
Dashed ⟶ ZHAireS Monte Carlo

E = 10^{17} eV, θ = 45 deg.
Arriving from North
LOFAR site

Input:
$|E_{geo}|$ & $|E_{Ask}|$ at positions along East

Output:
Field components along S-N, W-E, SW-NE, SE-NW



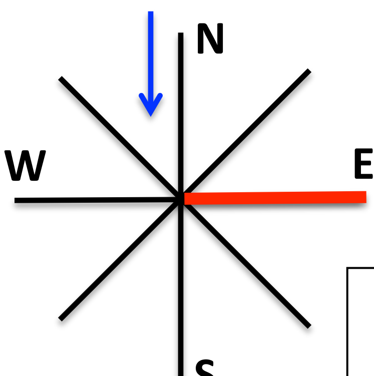


Predicted field vs field in MC sims.

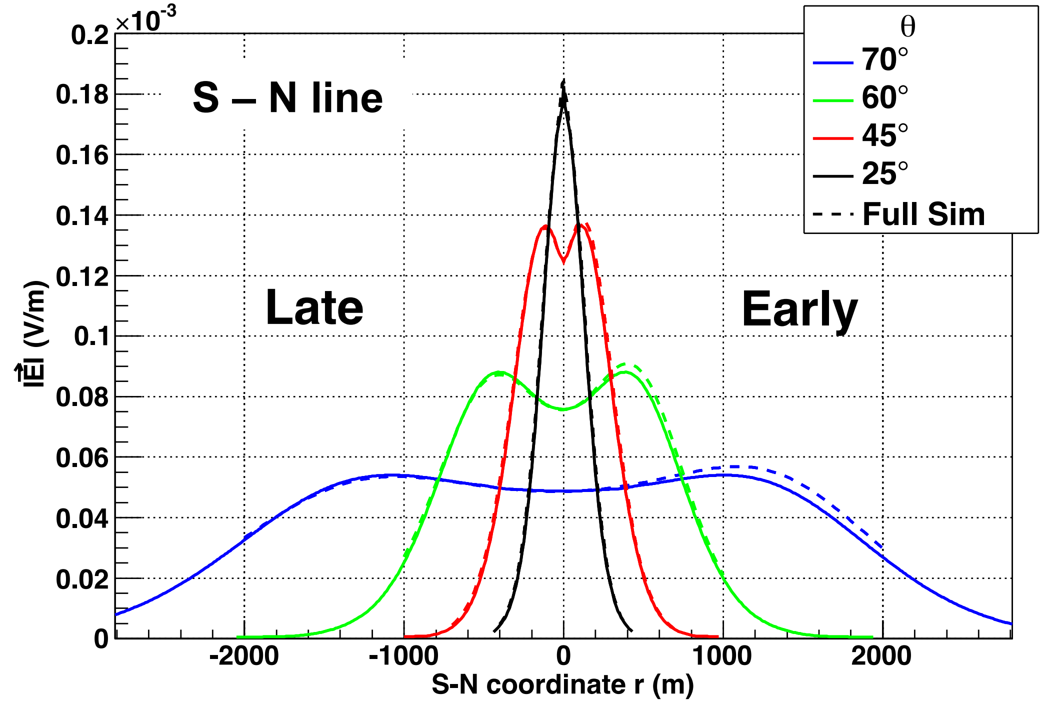
E = 10^{17} eV, Arriving from North
LOFAR site , $\sin\alpha_B$ ~ 0.92

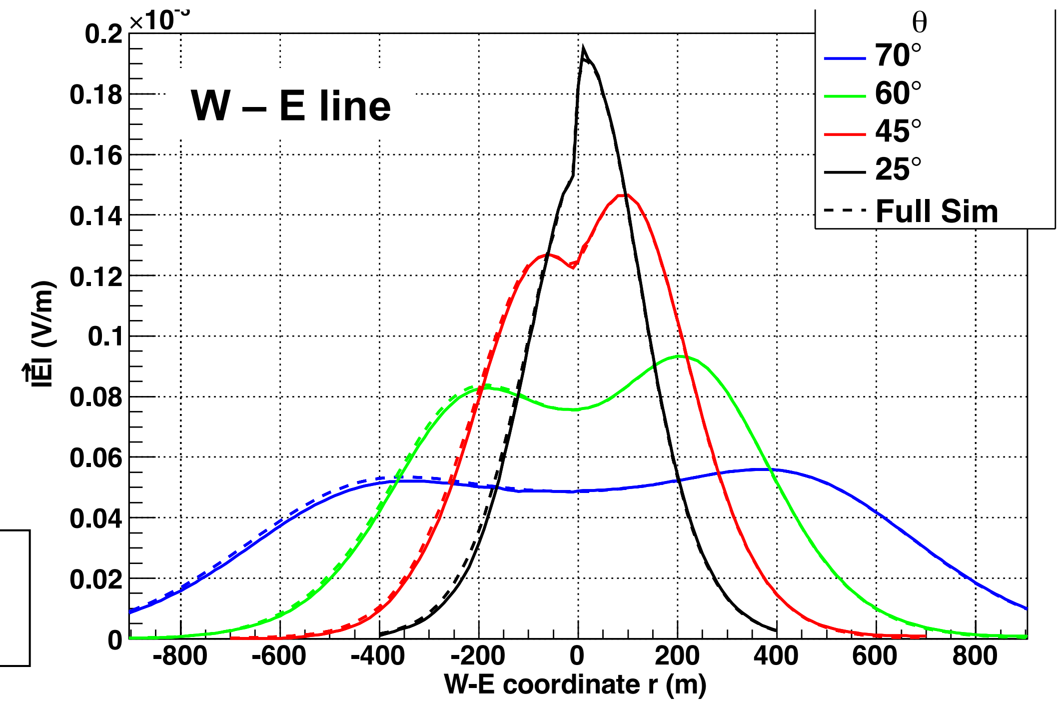
Input:
$|E_{geo}|$ & $|E_{Ask}|$ at
positions along East

Output:
Field components along
S-N, W-E



Solid lines ⟶ model
Dashed ⟶ ZHAireS



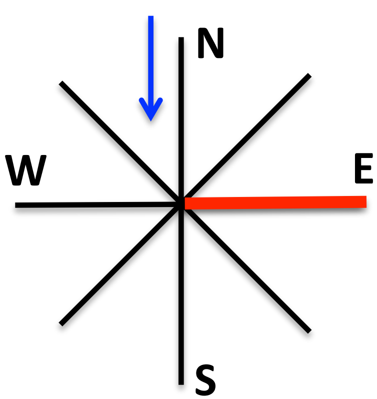


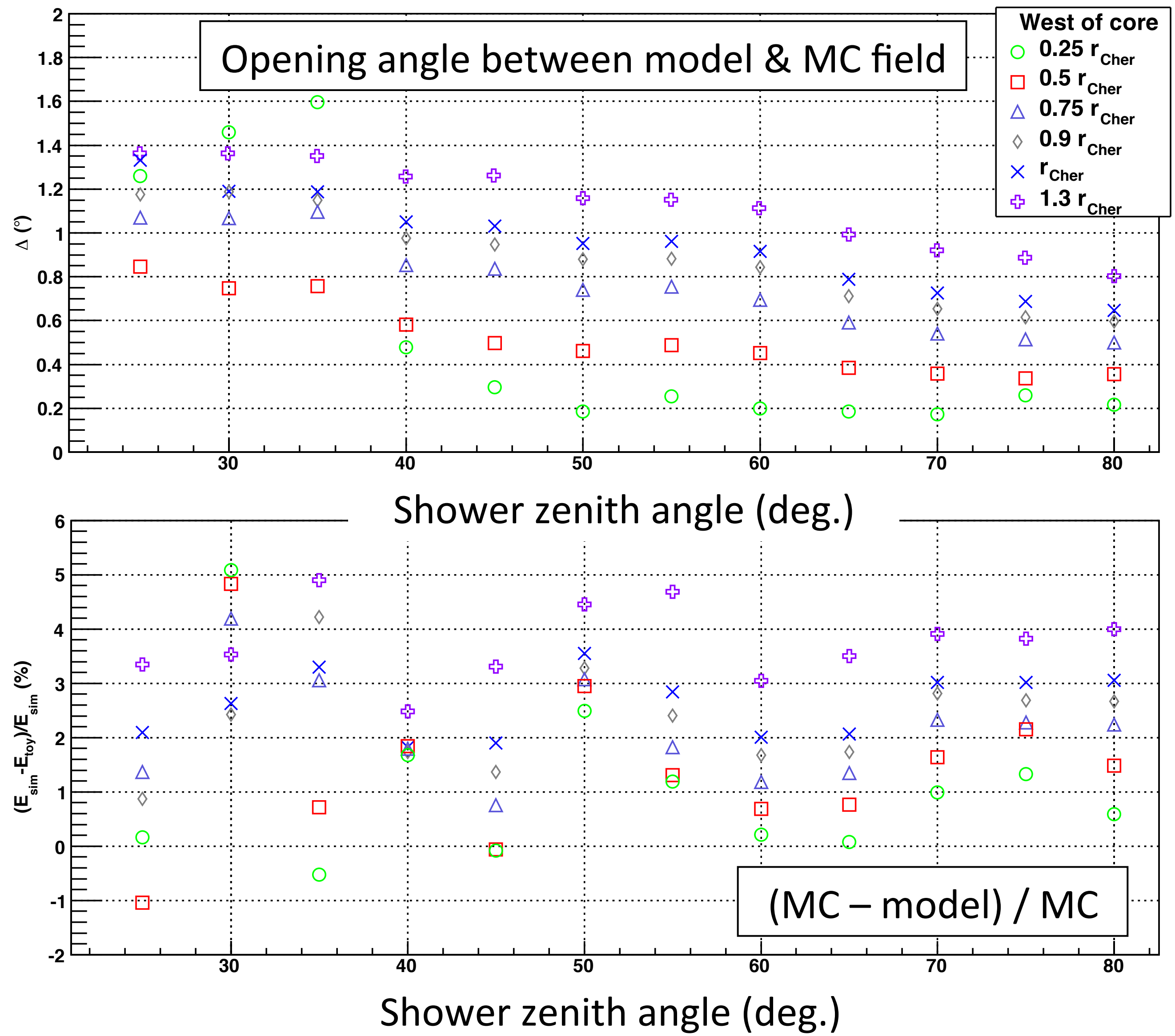
Model predictions vs MC simulations

E = 10^{17} eV,
Arriving from North
LOFAR site

Input:
$|E_{geo}|$ & $|E_{Ask}|$ at
positions along East

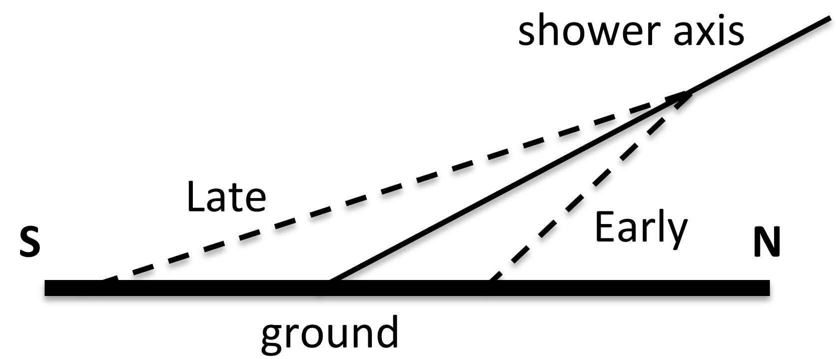
Output:
Field components
along West

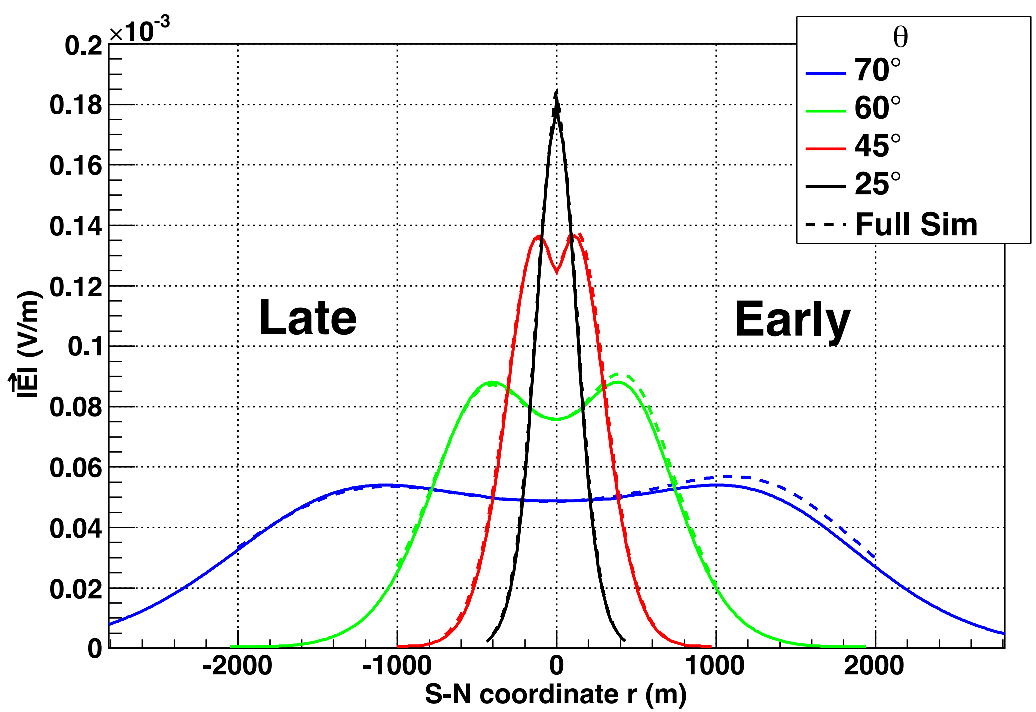




Inaccuracies of model: early-late effect

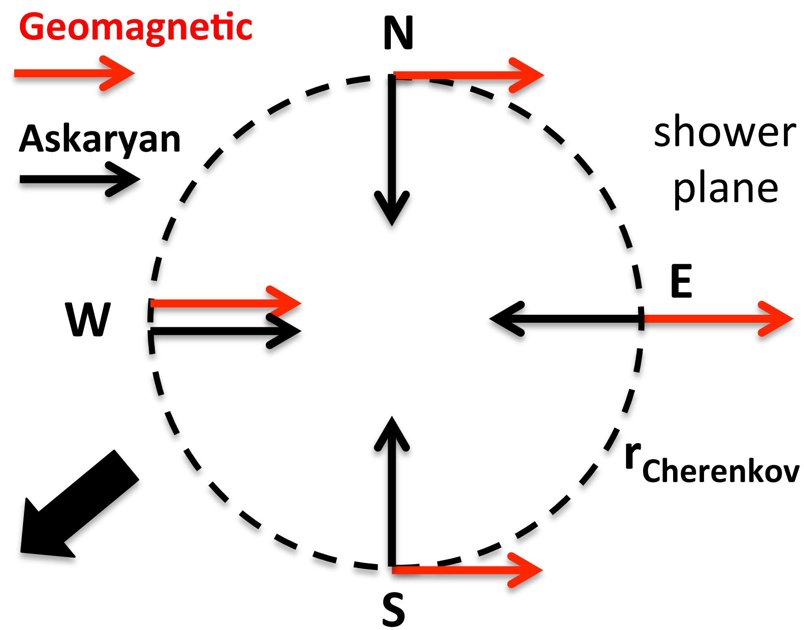
- Model assumes circular symmetry in shower plane
- But… Early-Late effects (not accounted for in model) arise when projecting onto ground:
  - Early part of shower (hitting ground first) is closer to observer than late part
- Model predicts slightly different field than full Monte Carlo simulations
  - ~ 5 % effect at θ = 70 deg.
  - increases with θ



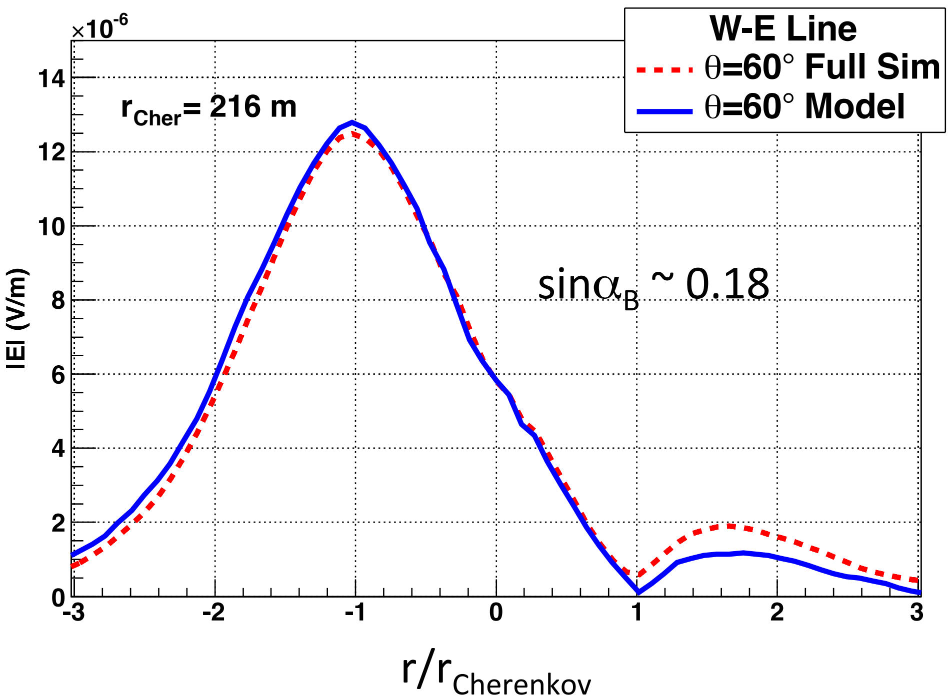


Inaccuracies: cancellation of fields

Model less accurate at observer positions & shower geometries where Askaryan & geomagnetic contributions almost cancel each other.



E = 10^{17} eV, θ = 60 deg. , from North @ Auger site



- Model predicts almost perfect cancellation of $\mathbf{E}_{Ask}$ & $\mathbf{E}_{geo}$ East of core at Cherenkov ring:
  - polarizations are assumed to be perfectly parallel to each other along EW line.
- This is not exactly the case in full MC sims.

Conclusions

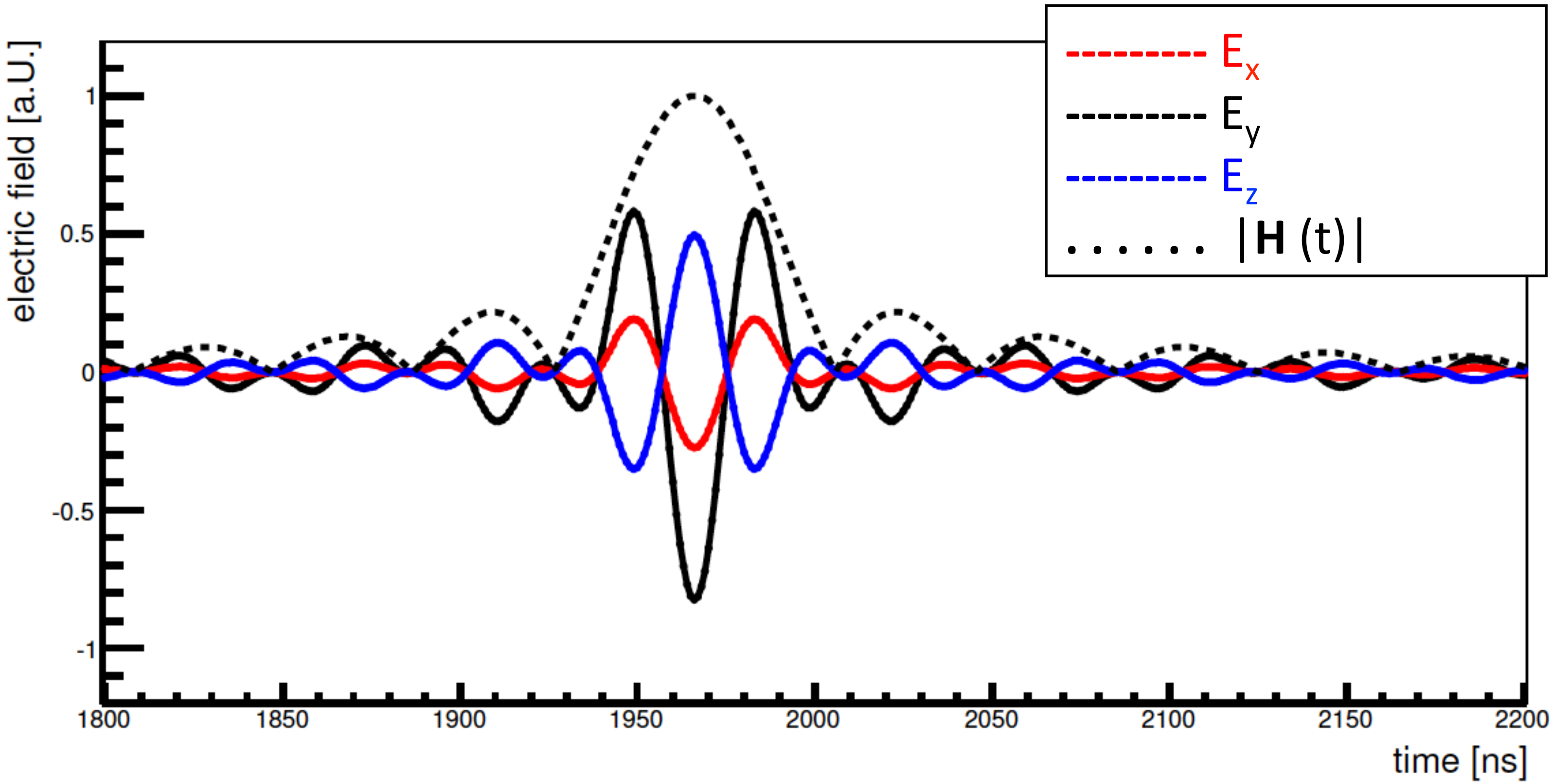
- Quantitatively tested the Askaryan + geomagnetic approach to radio emission in air showers:
  - Methodology:
    - Obtain separate $|E_{Ask}|$ & $|E_{geo}|$ along 1 line of antennas in MC sims.
    - Standard assumptions to predict fields at any position on ground.
  - **Works at few % level for practically all shower geometries & observer positions & on a shower-by-shower basis.**

- Fast & accurate calculation of E-fields with many Applications:
  - Massive production of electric field patterns on ground for studies of:
    - shower-to-shower fluctuations,
    - dependence on mass composition,
    - dependence on hadronic models,…
  - Facilitates the creation of field parameterisations (E, θ, X_{max},…)
  - Alternative to interpolation methods used in reconstrtuctions.
- Limitation: only applicable to observables not dependent on time

Backup slides

Observable: Hilbert envelope

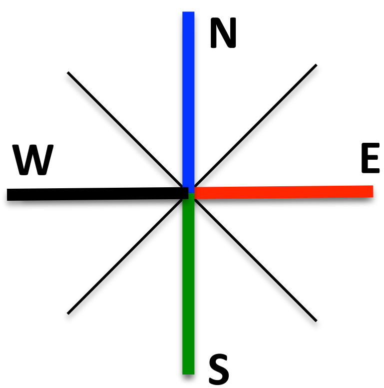
Raw **E**(t) ⟶ Filtered (30 - 80 MHz) **E**(t) ⟶ Hilbert envel. **H**(t) ⟶ |**H**(t)| ⟶ max|**H**(t)|



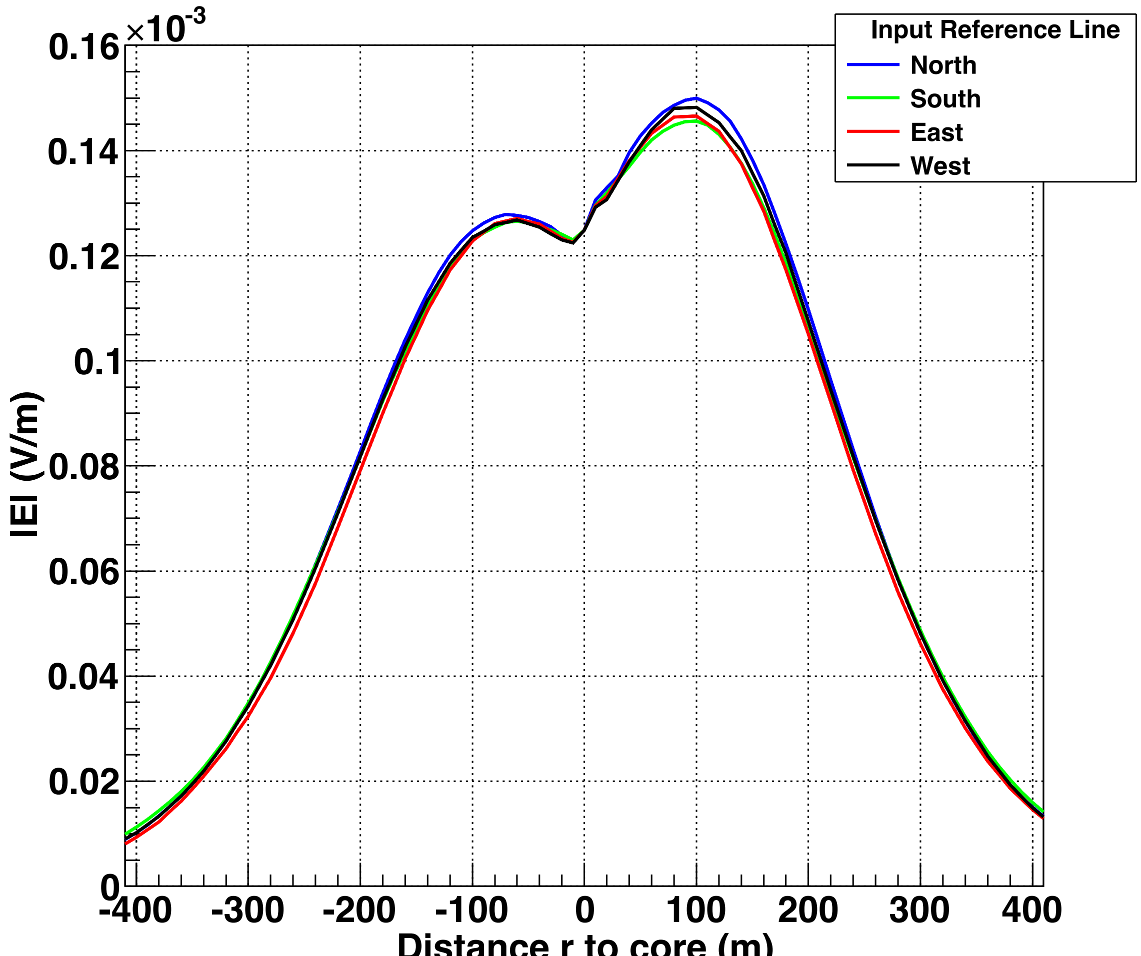
“Robustness” against input line

E = 10^{17} eV, θ = 45 deg.
from North @ LOFAR site

Inputs:
$|E_{geo}|$ & $|E_{Ask}|$ at positions along, North, South, East OR West



Output:
Field components along EW



Small dependence on input line due to early-late shower effects on ground

Example of fastness of model:

36 antennas in input East line (ZHAireS) ⟶ 10 h of CPU

200 thousand antennas in output (model) ⟶ a few minutes

shower core

Proton, 10^{17} eV, 45º
arriving from North
LOFAR site