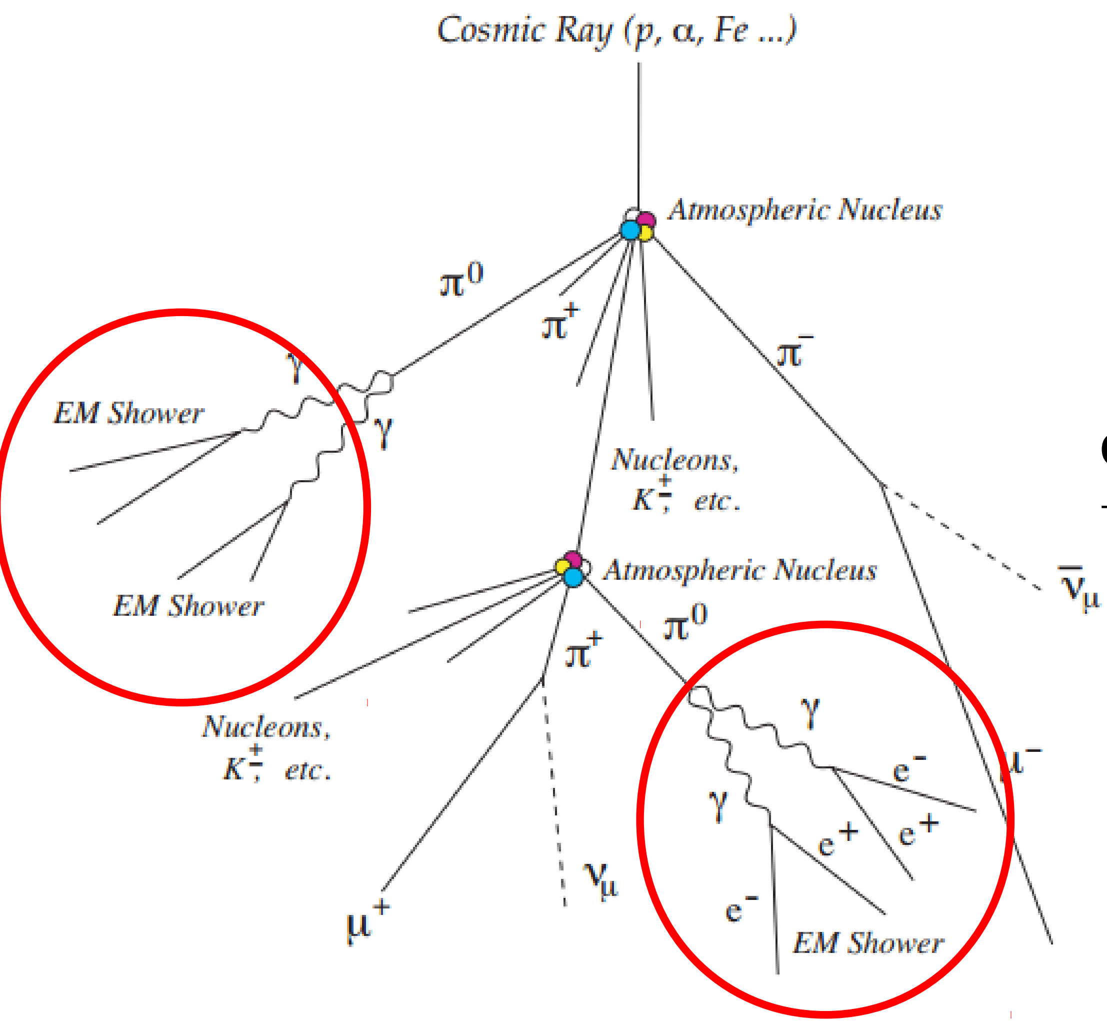
GRAND

~~Big~~ simulations

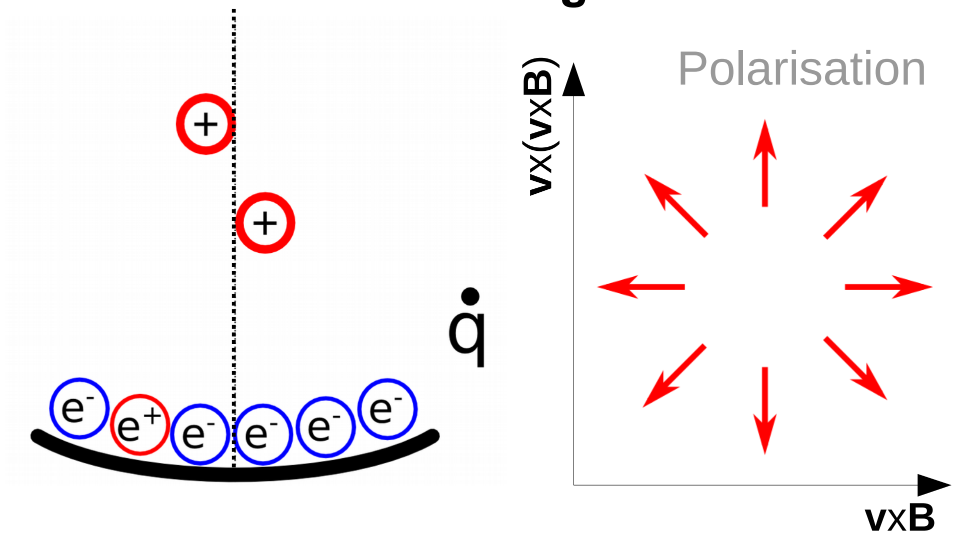
Overview and status:
Radio emission from air showers

Anne Zilles (IAP)

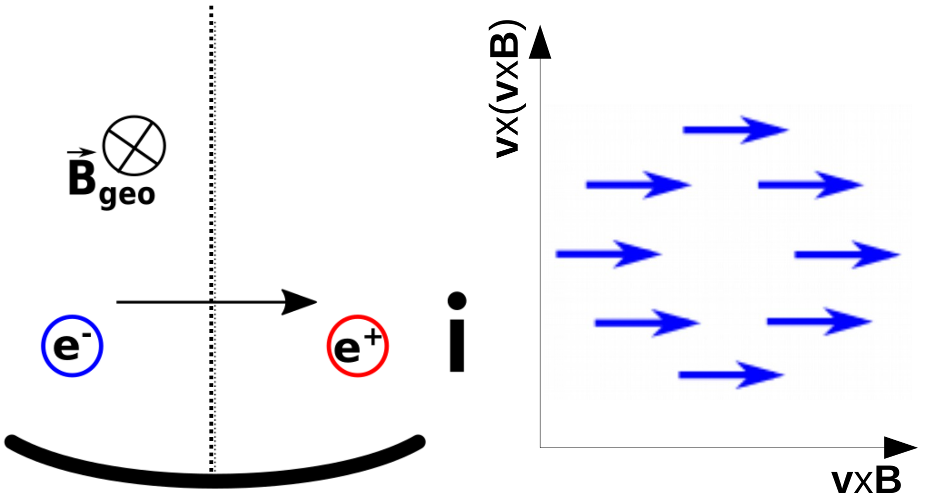
Radio-signal emission from air showers



Askaryan effect
→ time variation of net charge excess



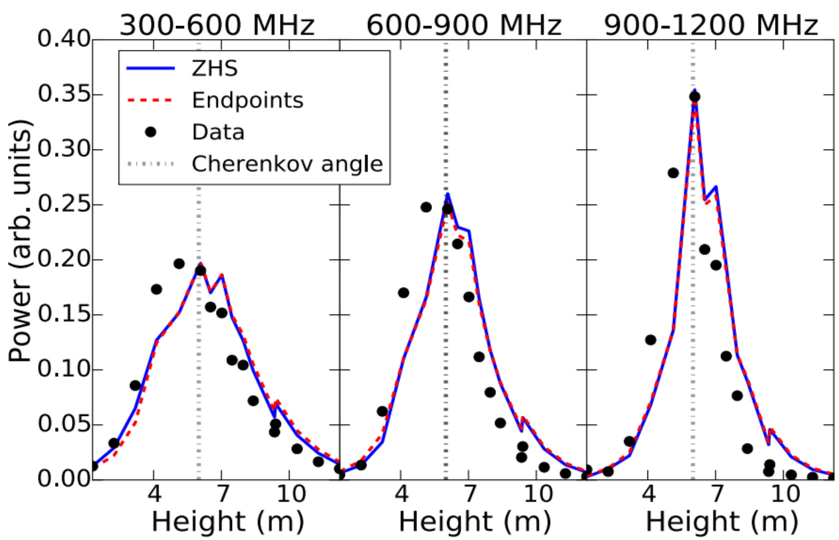
Geomagnetic effect
→ time dependent transverse current



+modification by refractive index

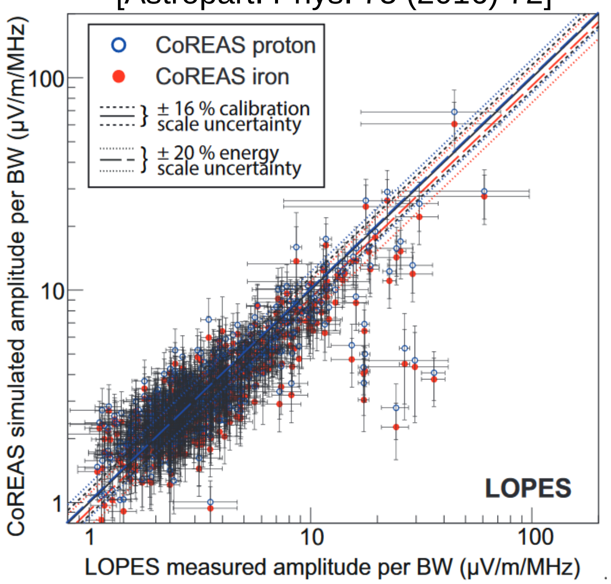
Simulation of radio emission

- Several macroscopic and microscopic simulation programs on the market
- In the last years: results agree with each other
- including all effects on the radio signal e.g. due to refractive index
- simulation codes just differ in their complexity
- Results also agree with radio signal measurements: air shower <20%, lab <35%



[Phys. Rev. Lett. 116 (2016) 141103]

[Astropart. Phys. 75 (2016) 72]



In GRAND, we are using:

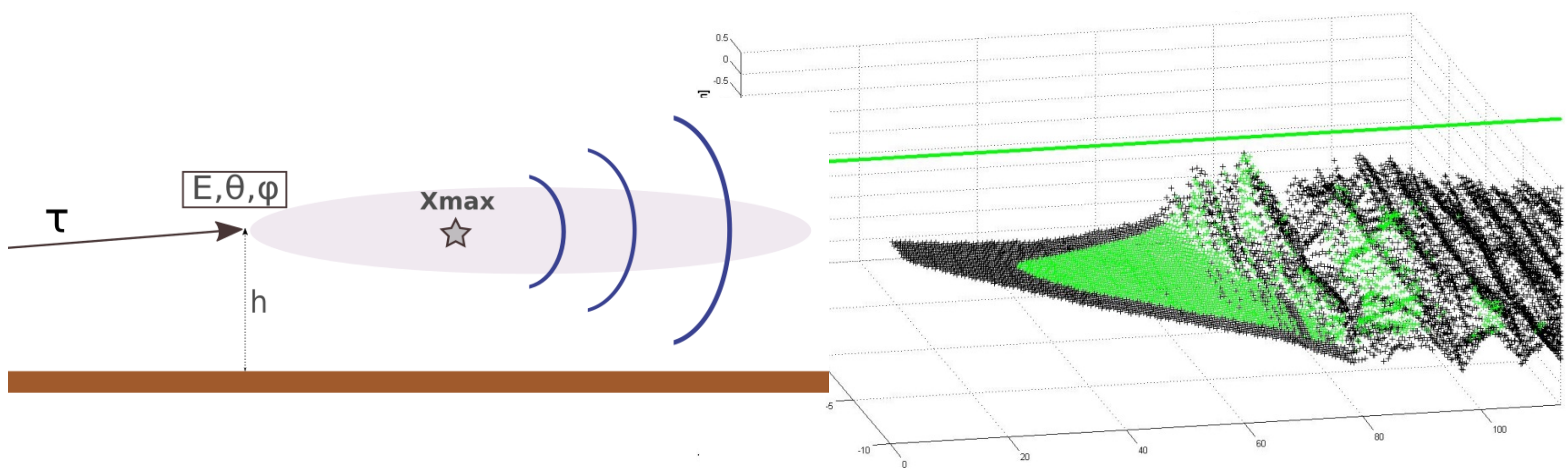
- **ZHAireS**
  (full MC simulations of the radio signal emitted by the individual electrons and positrons in air Showers) [Astropart. Phys. 35 (2012) 325] → more accurate, but **computing intensive**
- cross-checked with **EVA** (macroscopic model) [Astropart.Phys. 37 (2012) 5-16]

Radio morphing

CPU requests too huge (limited resources)

+ non-flat detector → **3D showers simulations if topography!=flat**, not only footprint on ground

=> **parametrization of the shower radio emission**



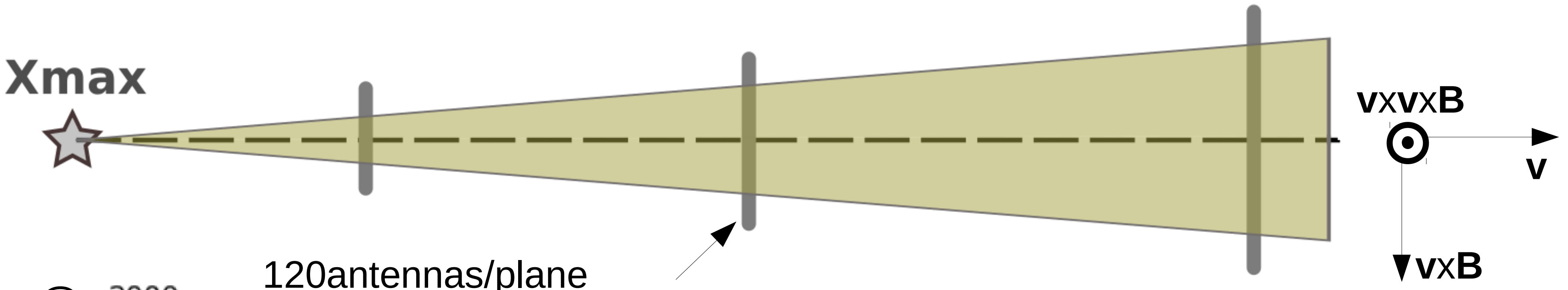
<u>Goal:</u> compute (analytically) the **electric field generated by shower A** at any location within Cerenkov cone **from a generic shower B** simulated with high antenna density (initiated in July 2016):

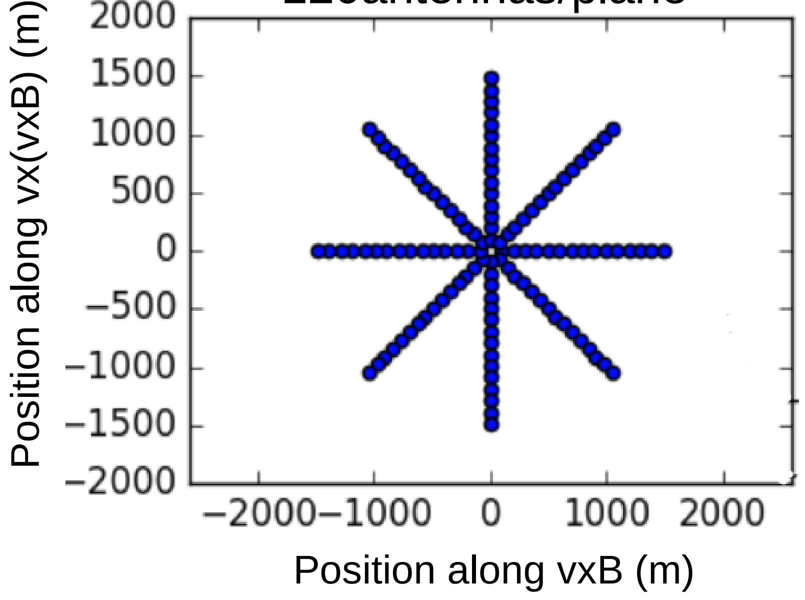
→ Morphing $E_B(t)@x_i$ to $E_A(t)@x$

- **Scaling $E_A(x_i, t) = k_{AB} \cdot E_B(x_i, t)$**
- **interpolation $E_B(x_i, t) \rightarrow E_B(x, t)$**

Scaling study ingredients – radio simulation

Faster shower development when deeper in atmosphere → X_{max} closer to τ decay point
- can be accounted for when using distance from Xmax rather than from τ decay point.





Why do we choose (vxB, vx(vxB))?

- profit from radial distribution of the emission for the interpolation (easier)

- footprint in shower coordinates universal by applying scaling factors?
  → Electric field invariant by azimuthal rotation?

And $E_x, E_y, E_z \rightarrow E_v, E_{vxB}, E_{vx(vxB)}$

Radio morphing – current status

=> **Goal:** determination of expected electric field at any position emitted from any shower derived from generic shower

Work going on since July 2016:
K. De Vries, O.Martineau, C. Medina, M. Tueros, A. Zilles

Current results:

1 - Study showed that at fixed distance from Xmax, **radio emission depends** solely on **E, θ, φ** and **h**

2 - Each parameter dependency can be parametrized by simple scaling factor (eg. $\mathbf{k_E = E_A/E_B}$)

3 - Each parameter is independent from the others => $\mathbf{k_{AB} = k_E * k_\theta * k_\varphi * k_h}$

Radio morphing – current status

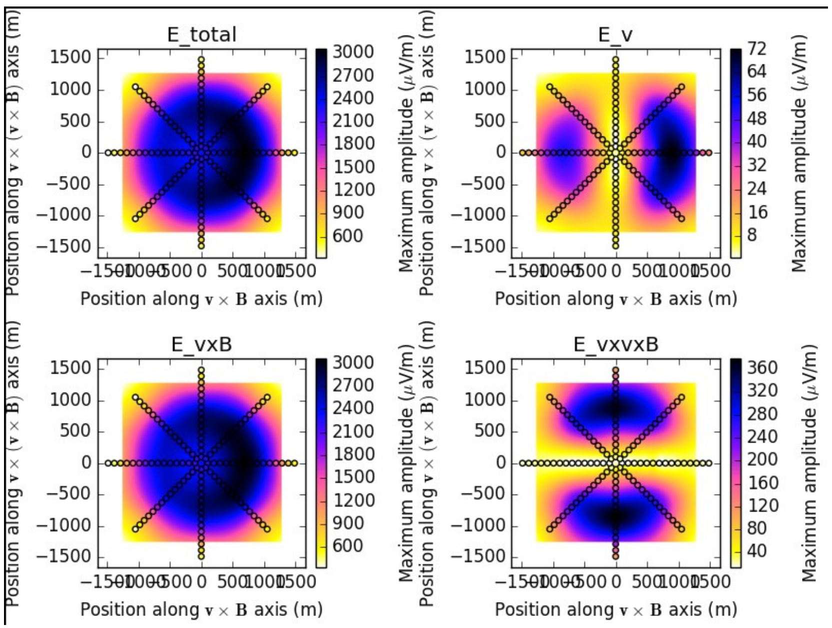
=> **Goal:** determination of expected electric field at any position emitted from any shower derived from generic shower

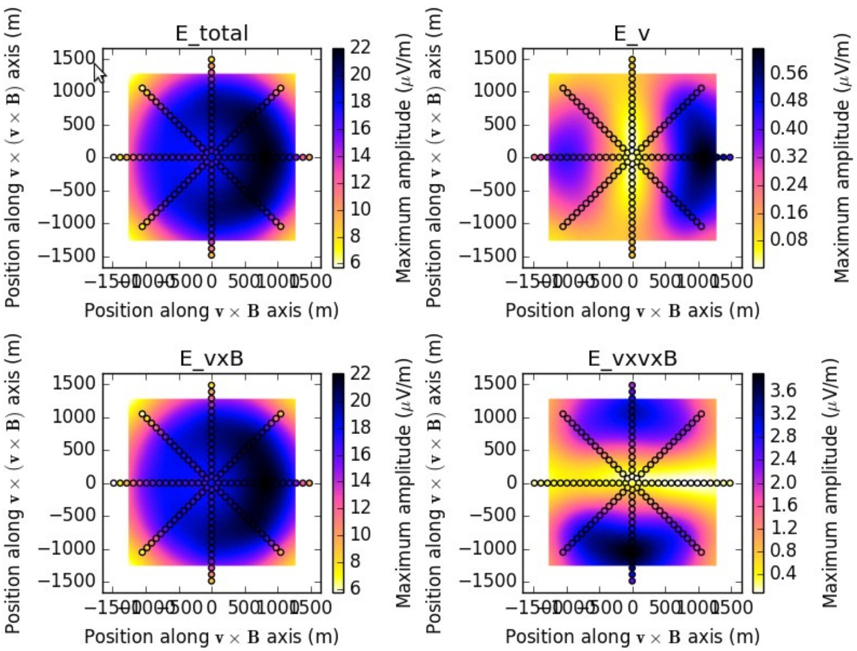
Scaling $\mathbf{E_A(x_i, t)= k_{AB} \cdot E_B(x_i, t)}$ already successfully applied to peak amplitude distrubutions

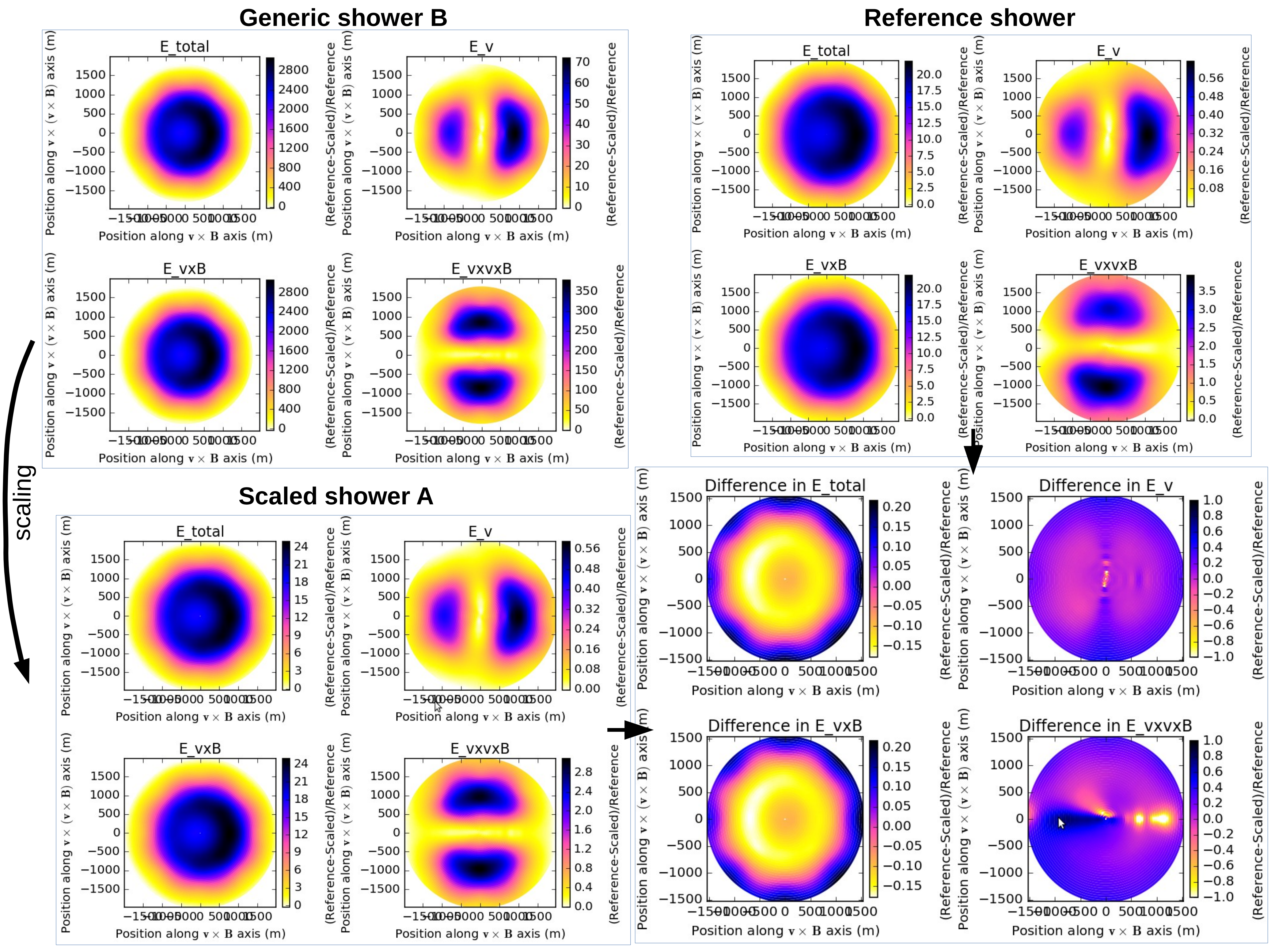
Generic shower B
E=9.6EeV,h=3000m,
zen=1.56rad, az=6.28rad

$\mathbf{E_A(x_i, t)= k_{AB} \cdot E_B(x_i, t)}$ →

Reference shower
E=0.1EeV, h=1000m,
zen=1.55rad, az=3.14rad

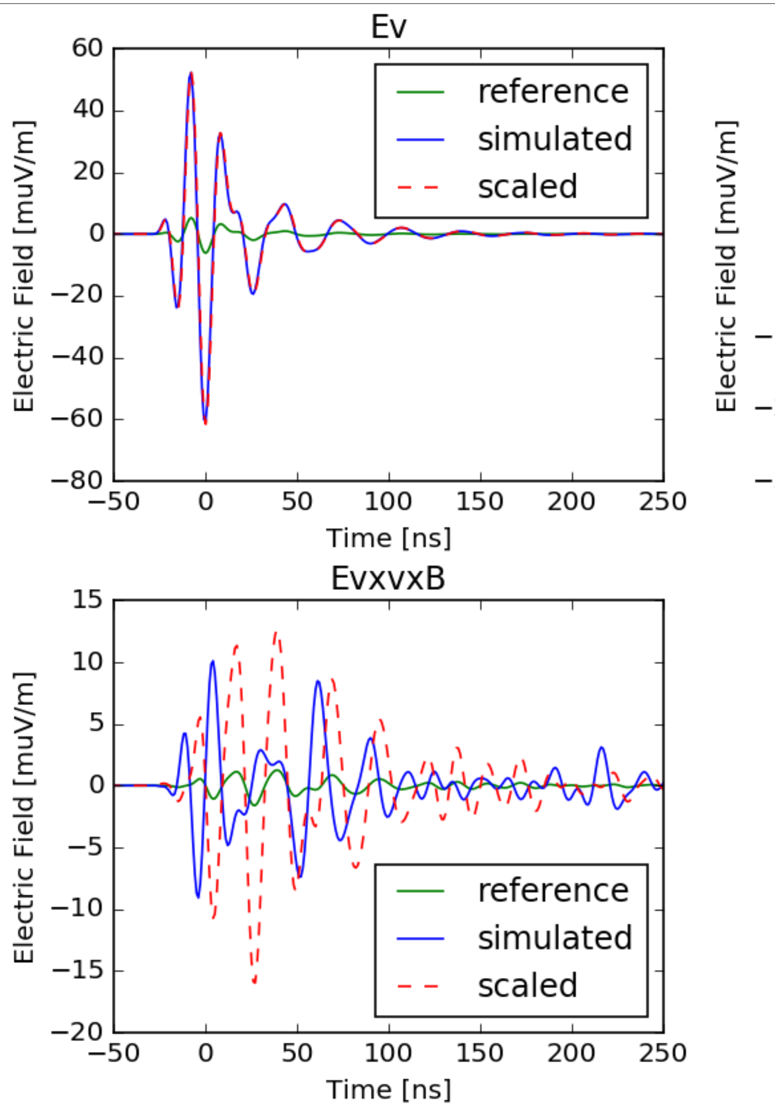
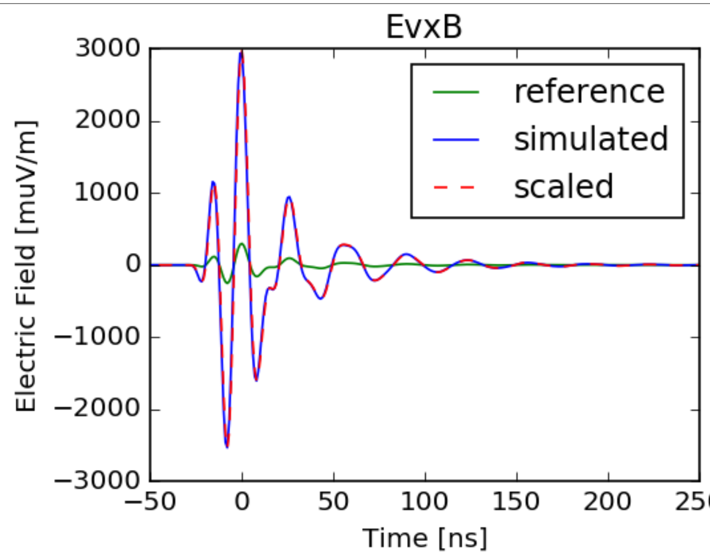






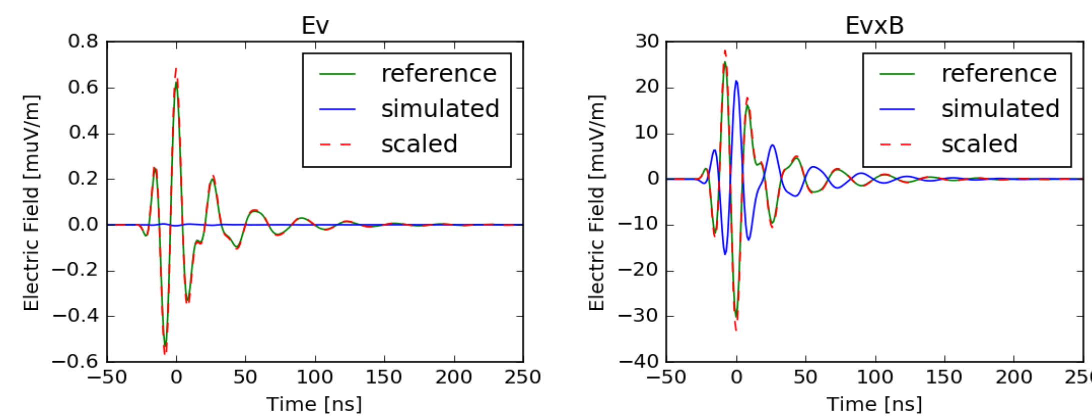
Generic shower B
Reference shower
Scaled shower A
scaling
E_total
E_v
E_vxB
E_vxvxB
Difference in E_total
Difference in E_v
Difference in E_vxB
Difference in E_vxvxB
Position along v × B axis (m)
Position along v × (v × B) axis (m)
(Reference-Scaled)/Reference

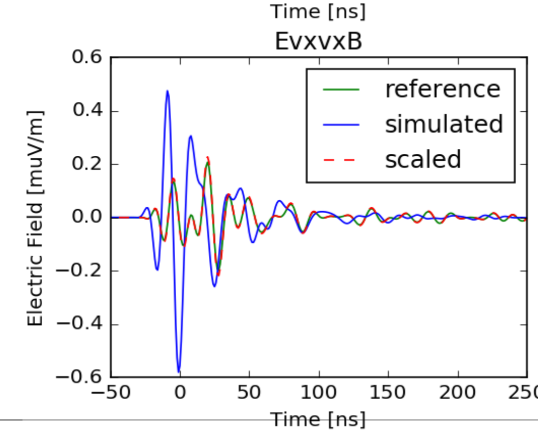
Scaling of pulses

<u>Energy scaling:</u>

E=0.96EeV, d=34km, h=3000m, zen=1.56rad, az=3.14rad
→ **E=9.6EeV**





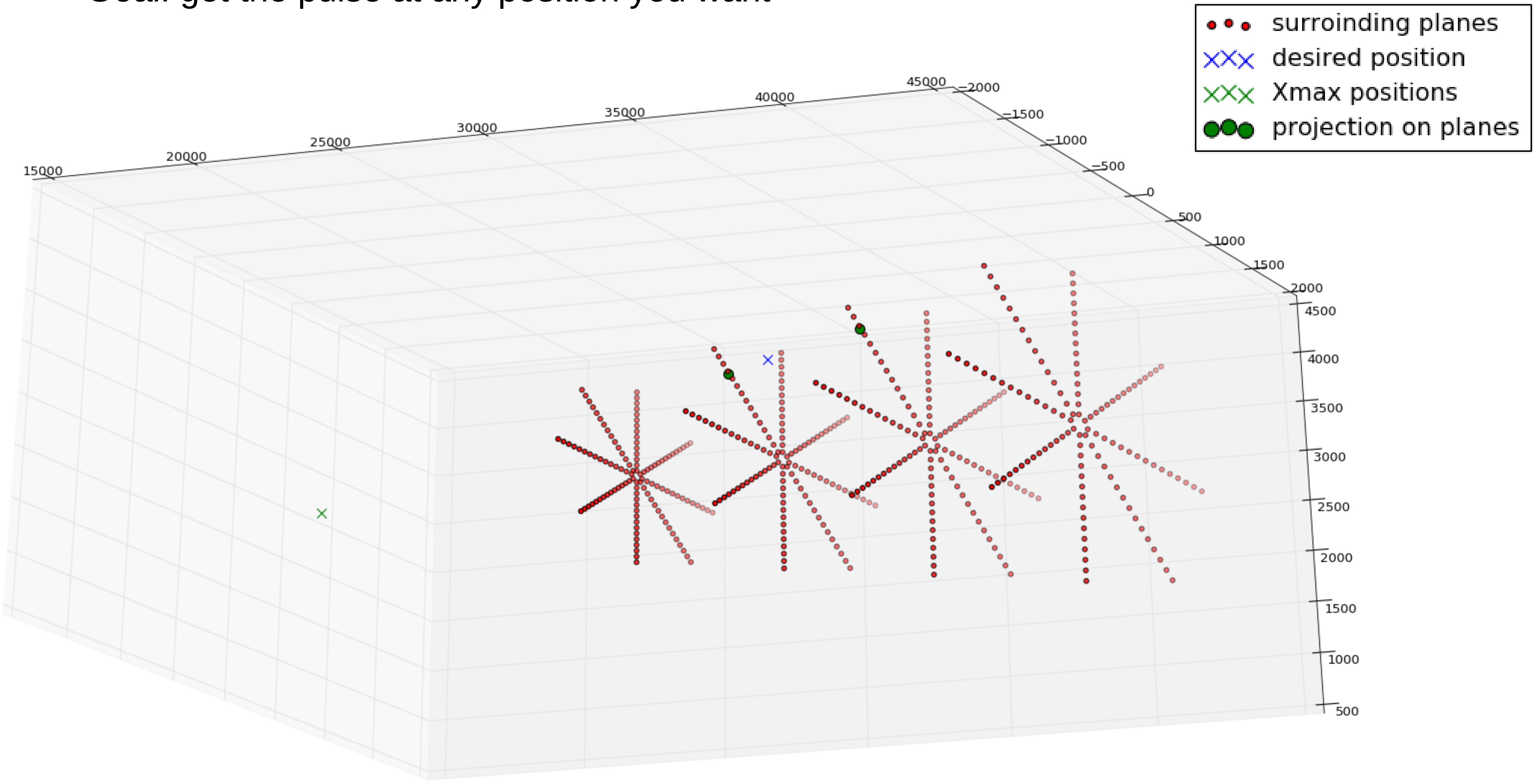
<u>Azimuth scaling:</u>

E=0.096EeV, d=34km, h=3000m, zen=1.56rad, **az=3.14rad**
→ **az=4.19rad**
(flip of EvxB included)

<u>Zenith and height scaling</u>
→ work in progress

3D pulse shape interpolation

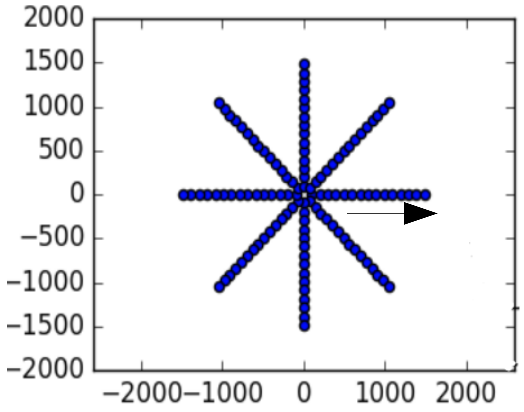
→ Goal: get the pulse at any position you want



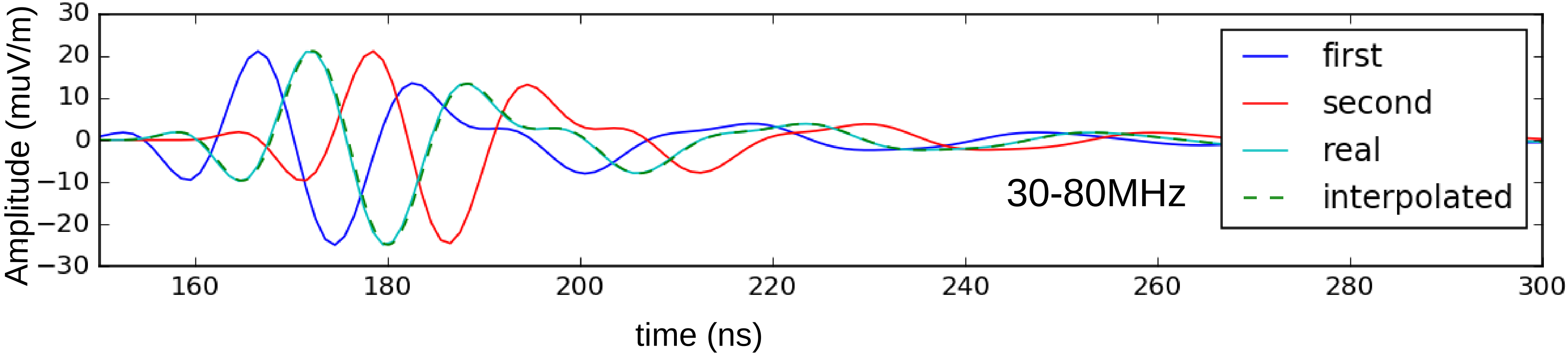
In frequency domain: $f(r,\varphi) = r \cdot e^{i\varphi}$

interpolate amplitude and phase separately

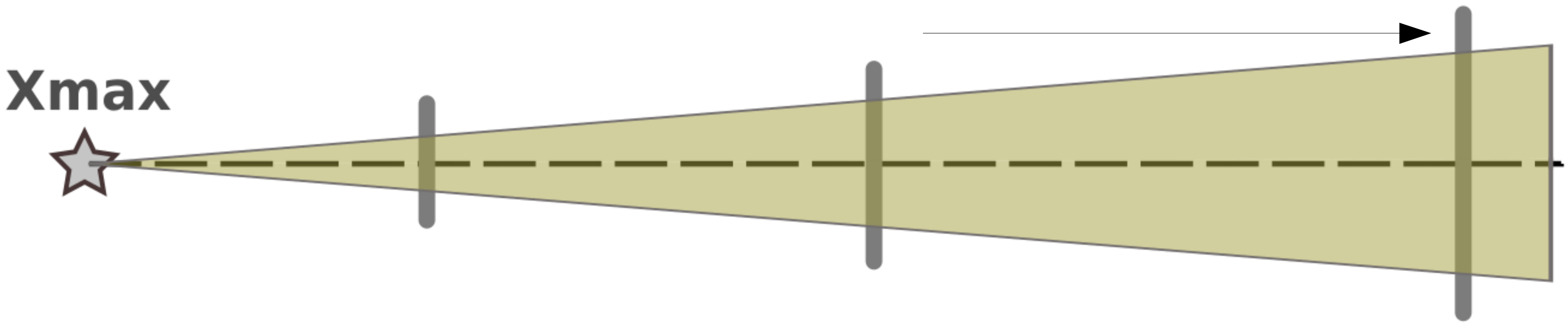
- Method developed for flat ground positions, d <100m, 30-80MHz by **Ewa Holt (diploma thesis 2013, KIT)**



1 - **Pulse shape interpolation along one ray:**
Example: Ey of EnergyScan_2 (49,51,50) with d12<200m



2 - **Pulse shape interpolation in between planes:**
Work in progress: time shift has to be included correctly



Radio morphing - summary

- extremely powerful method:
  → gain a very large amount of time

  in principle only <u>one</u> shower simulation, rest is analytical!

- pulse scaling + 3D interpolation to be completed this summer
  (keep working hard on it!)

- Radio morphing will be tested on the toy model

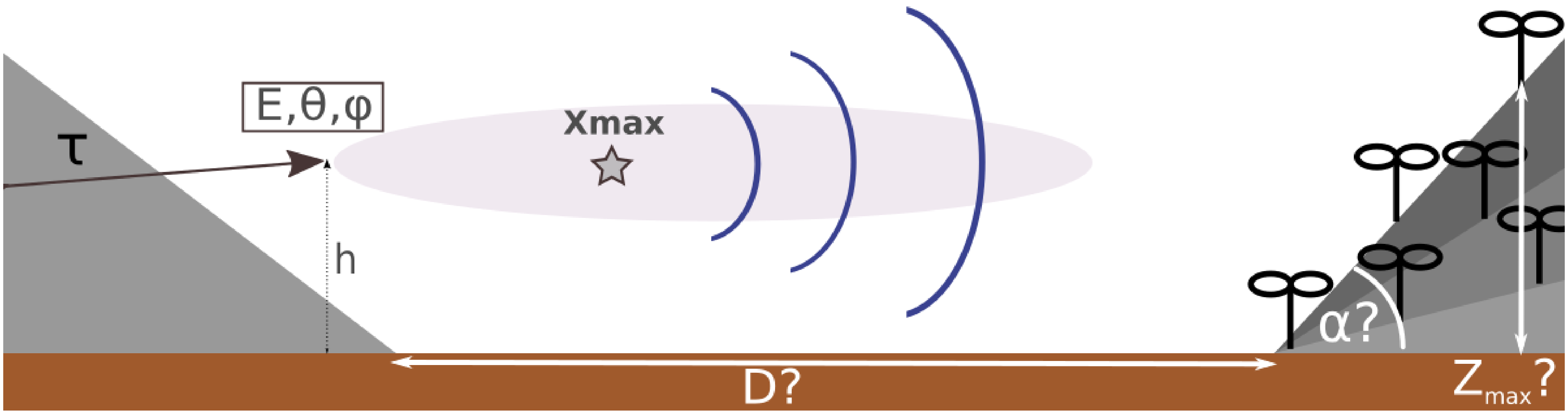
Avoid BIG simulations.
Do GRAND simulations.

The toy model

Performed by C. Medina

→ **test shower parametrisation** by direct comparison of „full“ radio simulation to scaled ones

→ **quantify the role of the antenna array topography on the detection**: Determine optimal topography for detection by changing distance and slope parameters, advantage wrt flat site



+ Test robustness of treatment used for the preliminary GRAND sensitivity determination

Goal: move to simulation over real topography

- first the 60'000km² simulation area used in the preliminary study, then larger area, full Earth?

Simulation chain

→ **Details can be given in the parallel session**

Simulation of noise
(galactic & ground sources)

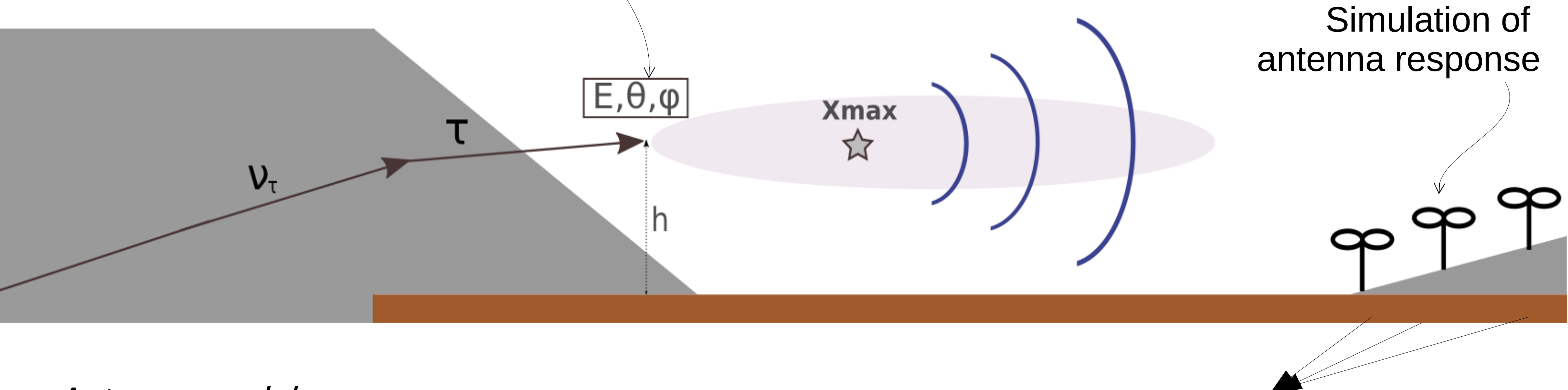
Interface: Handing over
decay products to air shower
simulation program

Toymodel for antenna
array configuration

Interaction of neutrino in Earth
→ DANTON

Simulation of induced air shower
+ calculation of emitted radio signal

Simulation of
antenna response



Antenna model:
Parallel session Wednesday afternoon

Digitalisation
+ trigger based on coincidences