EFFECT OF ATMOSPHERIC REFRACTION FOR VERY INCLINED AIR SHOWER GEOMETRIES

COSPA MEETING 19/06/2023

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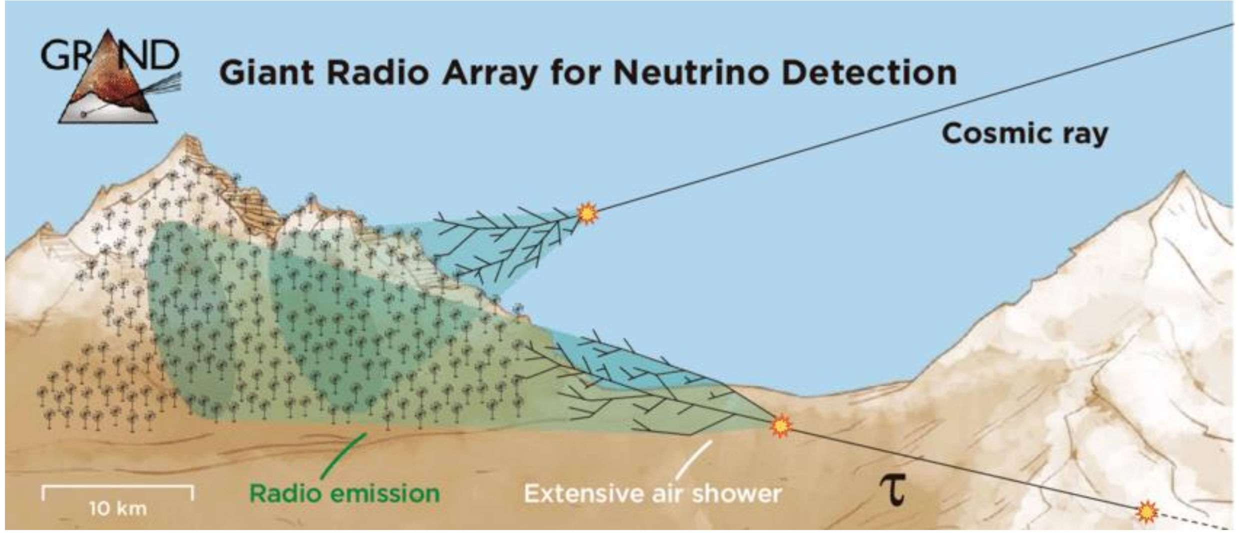
WHY ARE WE LOOKING AT VERY INCLINED SHOWERS?

SOME MOTIVATION…

Very inclined air showers => geometries with large zenith angle (~ 80°)



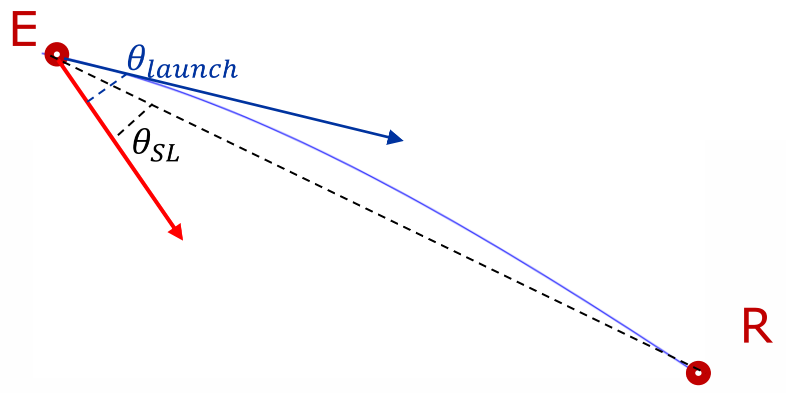
These geometries will be of particular interest for upcoming radio detectors and as such the emisison from them needs to be well understood.

At the same time these geometries require more specific treatment (Earth curvature, atmospheric refraction…).

STRAIGHT LINE VS CURVED PROPAGATION

WHAT DIFFERENCE IS THERE?

Current existing simulation software often assumes straight line propagation for in-air geometries ($\mathrm{n} \approx constant$). This is an approximation which is expected to break down in some regime.



$(\theta_{SL} - \theta_{launch})$ can reach values of even 0.1°

The difference may seem small, but depending on the application this can be important

WHAT IS THE ALTERNATIVE TO STRAIGHT LINE PROPAGATION?

A SUMMARY OF THE RAYTRACING STUDY

Developed a raytracer to investigate the refractive effects of the atmosphere.

In media with $n > 1$: signal emitted over an interval $\Delta t'$ can arrive in a shorter time Δt

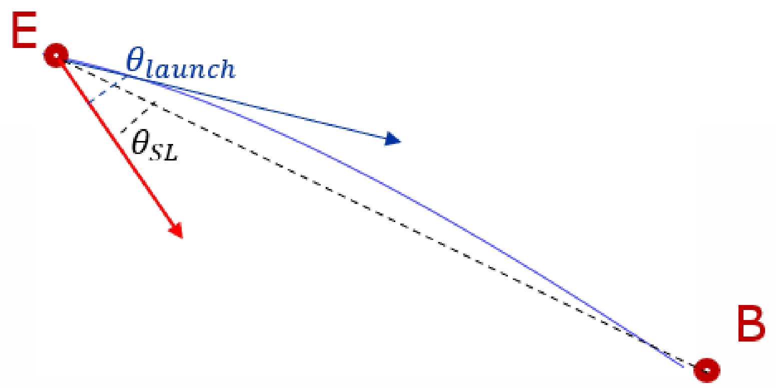
For uniform media:

$$\frac{dt}{dt'} = 1 - n \cdot \beta \cdot \cos(\theta) = Boostfactor^{-1}$$

We found that this relation also holds for non uniform media, provided that:

- The initial launch angle for the ray is used for θ,

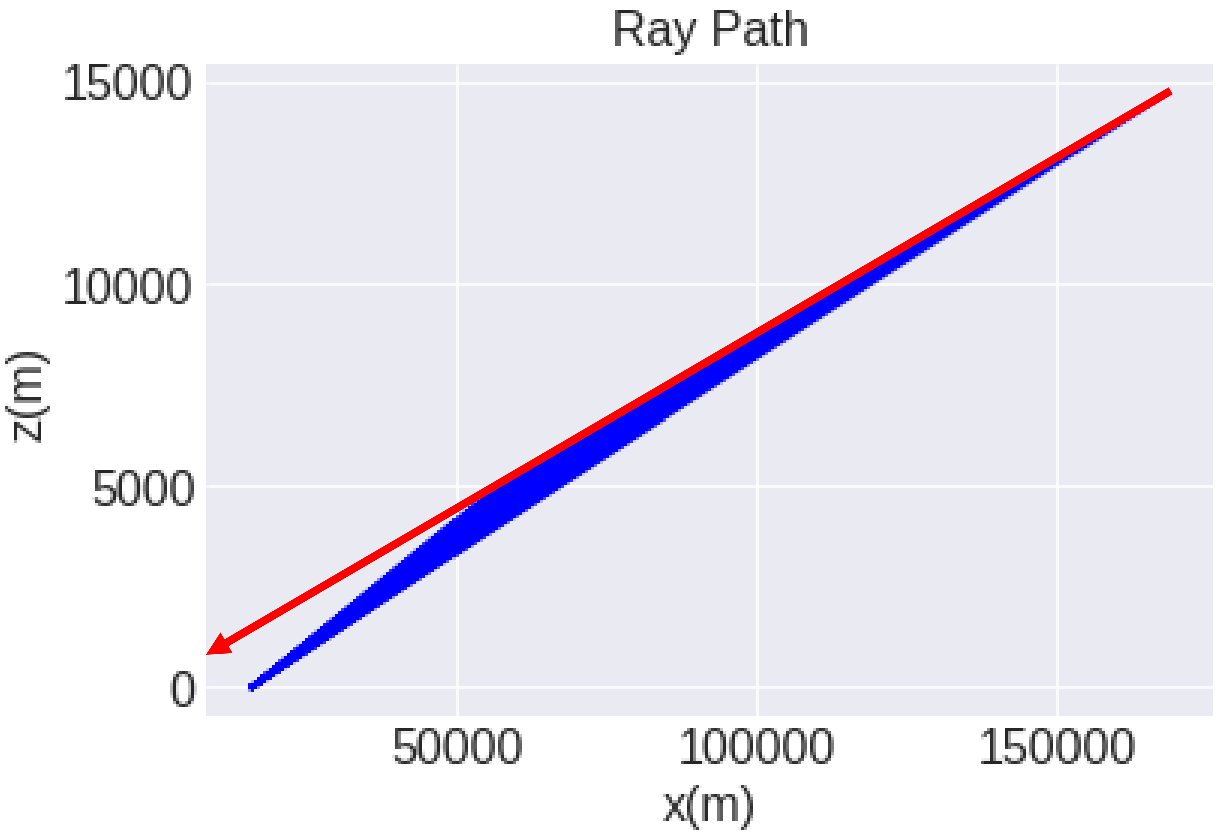
- The index of refraction at the emitter is used for n.

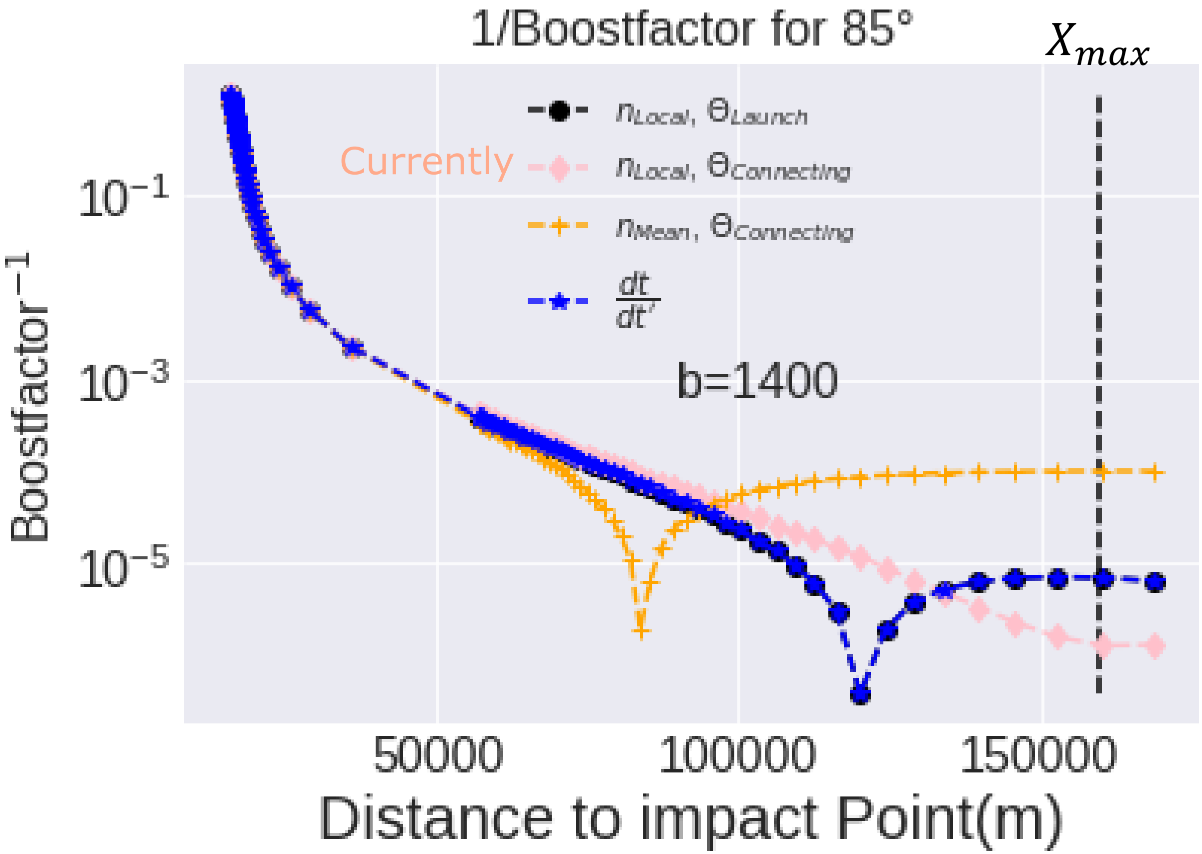


A SHORT SUMMARY OF OUR PREVIOUS STUDY

CORRECT WAY TO CALCULATE THE BOOSTFACTOR?

$$\frac{dt}{dt'} = 1 - n \cdot \beta \cdot \cos(\theta)$$





WHY DOES THIS BOOSTFACTOR MATTER?

WHERE DOES IT SHOW UP?

The end point formalism (arxiv.org/abs/1112.2126), used in CoREAS :

$$\vec{E}_{\pm}(\vec{x},t) = \pm \frac{1}{\Delta t} \frac{q}{c} \left(\frac{\hat{r} \times [\hat{r} \times \vec{\beta}^*]}{\underbrace{(1 - n\vec{\beta}^* \cdot \hat{r})}_{Boostfactor^{-1}} R} \right)$$

Previous studies (A. Timmermans, Ba. Thesis) show that a straight line approximation might not be valid for very inclined geometries in air.

HOW DO WE CHANGE THE CALCULATION OF THE BOOSTFACTOR?

THROUGH TABULATION

No raytracing is done within CoREAS, too much computation -> **Use tabulation.**

Internally the boostfactor is calculated by use of the unit vector along a straight line connecting emitter and receiver.

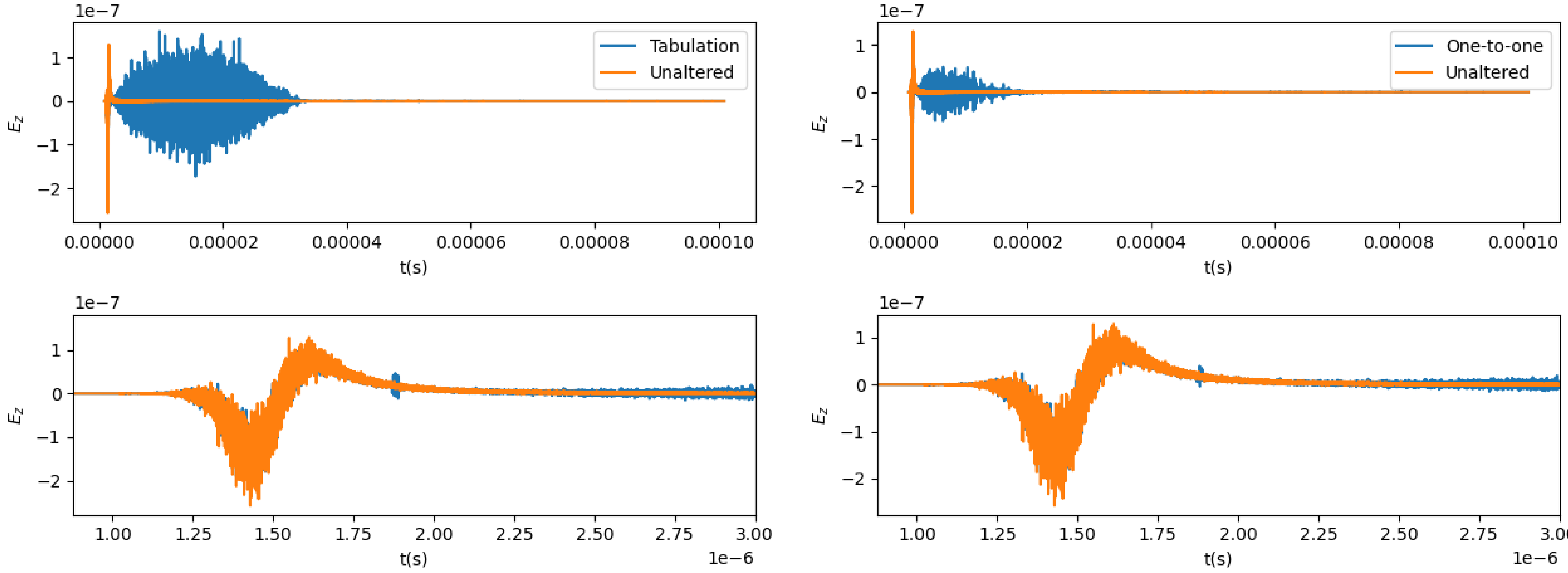
Through tabulation this straight line vector is changed with the more correct launch vector.

$$\vec{E}_{\pm}(\vec{x},t) = \pm \frac{1}{\Delta t}\frac{q}{c}\left(\frac{\hat{r}\times[\hat{r}\times\vec{\beta}^{*}]}{(1-n\vec{\beta}^{*}\cdot\hat{r})R}\right)$$

$$\hat{r}_{SL} \rightarrow \hat{r}_{launch}$$

THE RESULTS UP TO NOW

STILL INVESTIGATING SOME FEATURES



START OF BACK UP SLIDES

SO HOW WELL DOES THIS WORK?

CURRENT RESULTS

We compare traces which are computed with:

1. An unaltered version of coREAS

2. A version which uses a one-to-one table

3. A version which uses a table with data from raytracing

By now comparing these traces we can figure out the effect of the straight line approximation aswell as where it potentially breaks down.

Some assumptions:

- The ray always starts with a negative vertical component (direct rays and no refracted rays)

- In the region of interest, the launch vector does not change significantly when moving a moliere radius in the direction perpendicular to the shower axis.