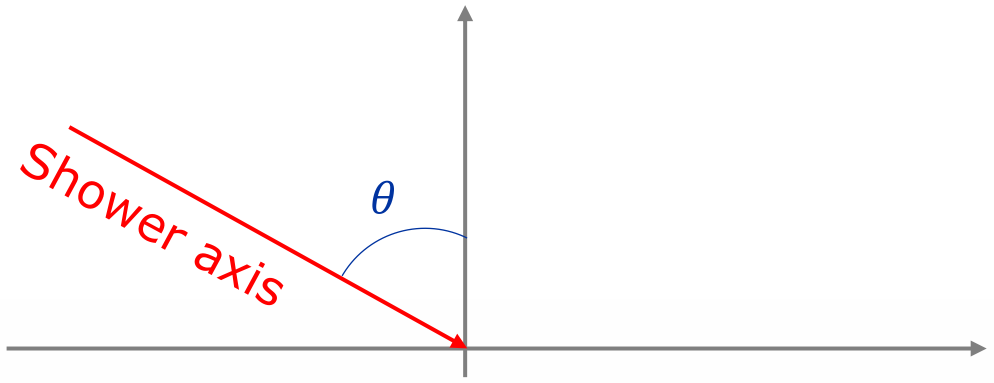
GEOMETRIC BOOSTING IN VERY INCLINED AIR SHOWERS
ARENA MEETING 11/06/2024

Dieder Van den Broeck*
Stijn Buitink
Krijn de Vries
Tim Huege
Uzair Latif

WHAT ARE VERY INCLINED AIR SHOWERS?

Airshowers that propagate nearly horizontally (zenith angle $\theta > 80°$)

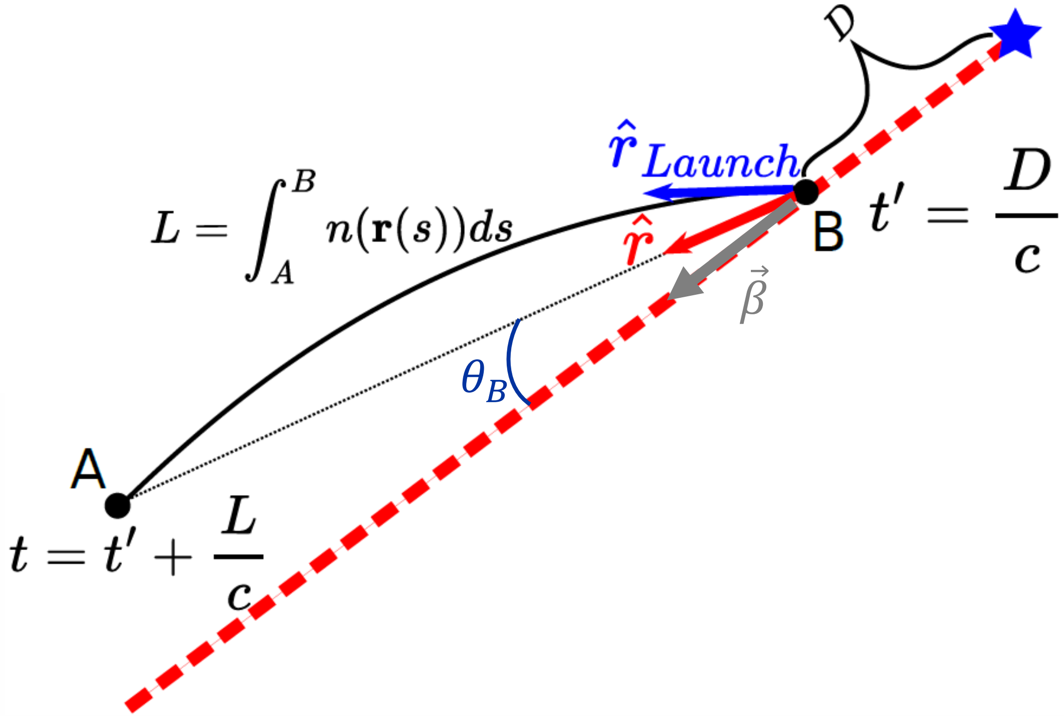


Of particular interest for next generation radio based detectors

Emission from these airshowers could require more careful treatment
=> Do simulations have to take this into account?

HOW TO DESCRIBE THE EFFECTS OF A NON-UNIFORM ATMOSPHERE?

Developed a raytracer based on Fermat's principle, combined with a line model of a cascade



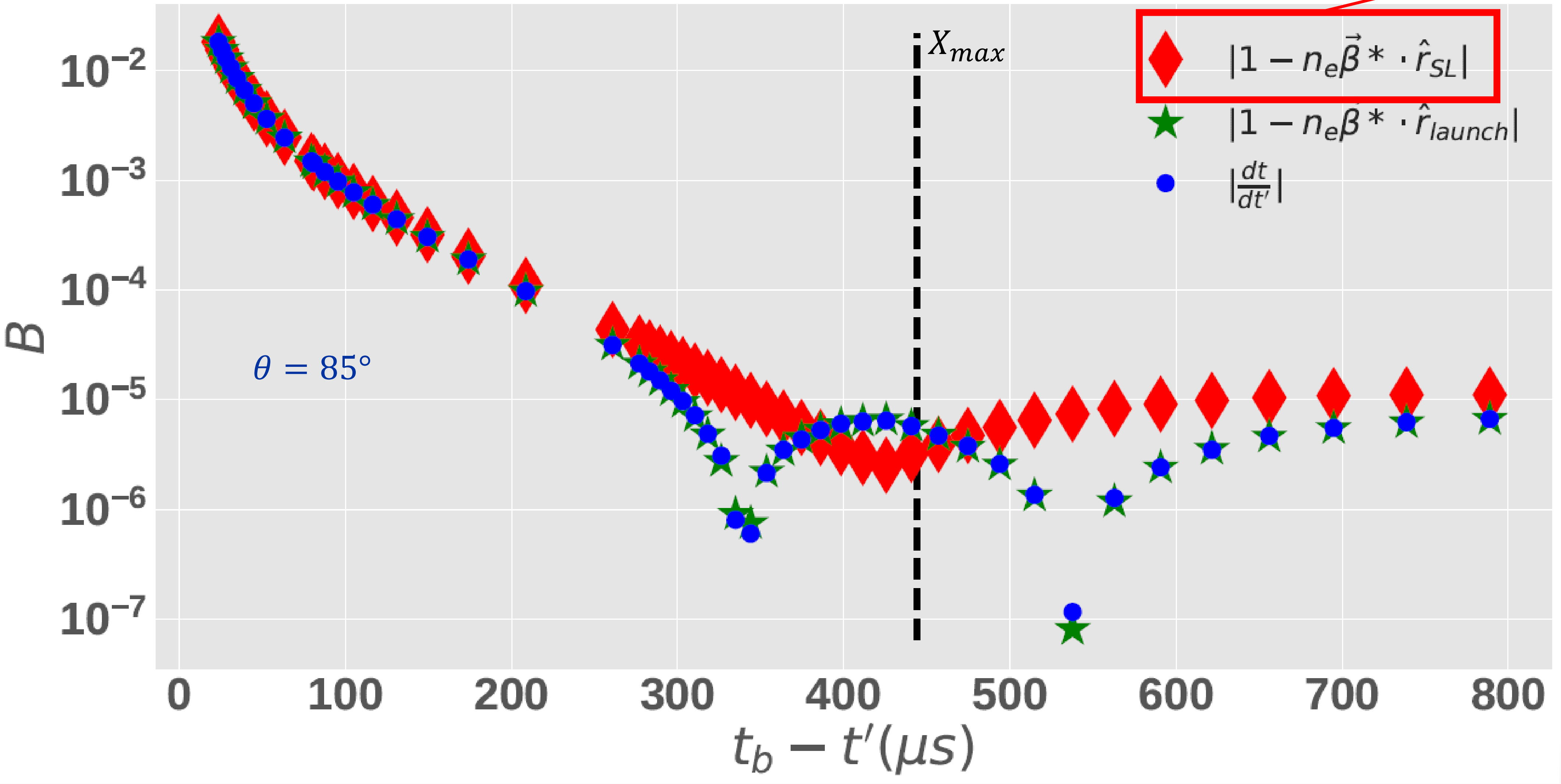
Geometric boosting described by the boostfactor
For **uniform** media:

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

We wish to generalise this to non uniform media

HOW TO DESCRIBE A NON-UNIFORM ATMOSPHERE?

Currently used in CoREAS



WHERE DOES THE BOOSTFACTOR MATTER?

Appears in, for example, the end point formalism which is used in CoREAS

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

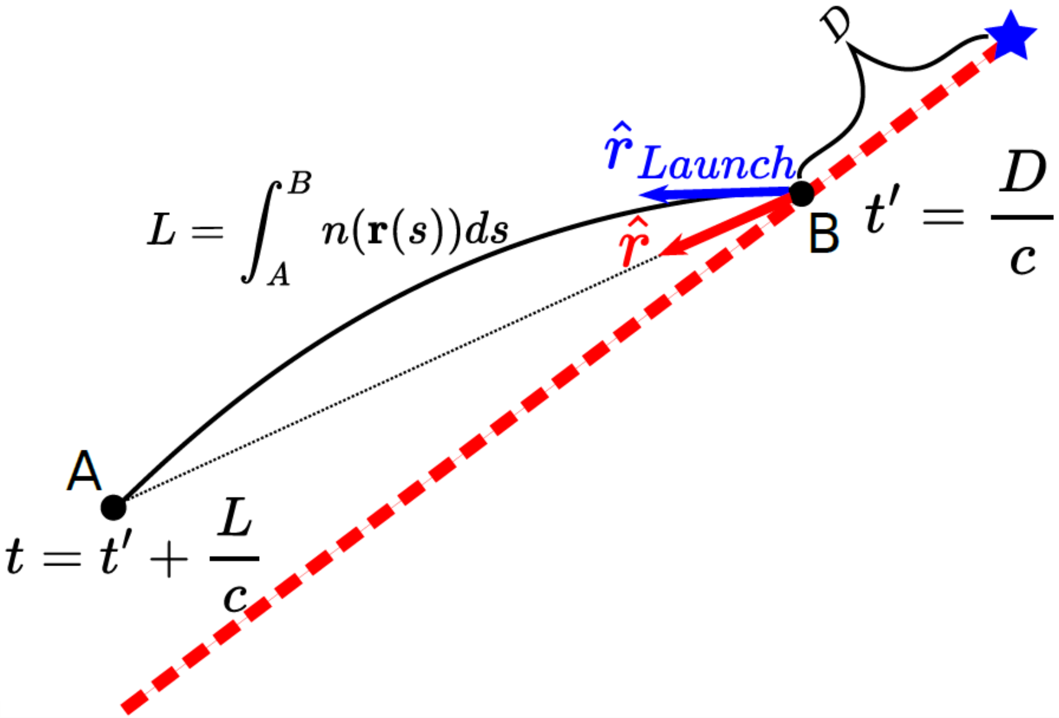
Where for $\hat{r}$ the straight line vector is used

What is the effect of choosing the straight line vector for this boostfactor?

HOW CAN WE ADAPT THE BOOSTFACTOR?

Live raytracing for each emitter is too computationally expensive => Tabulation

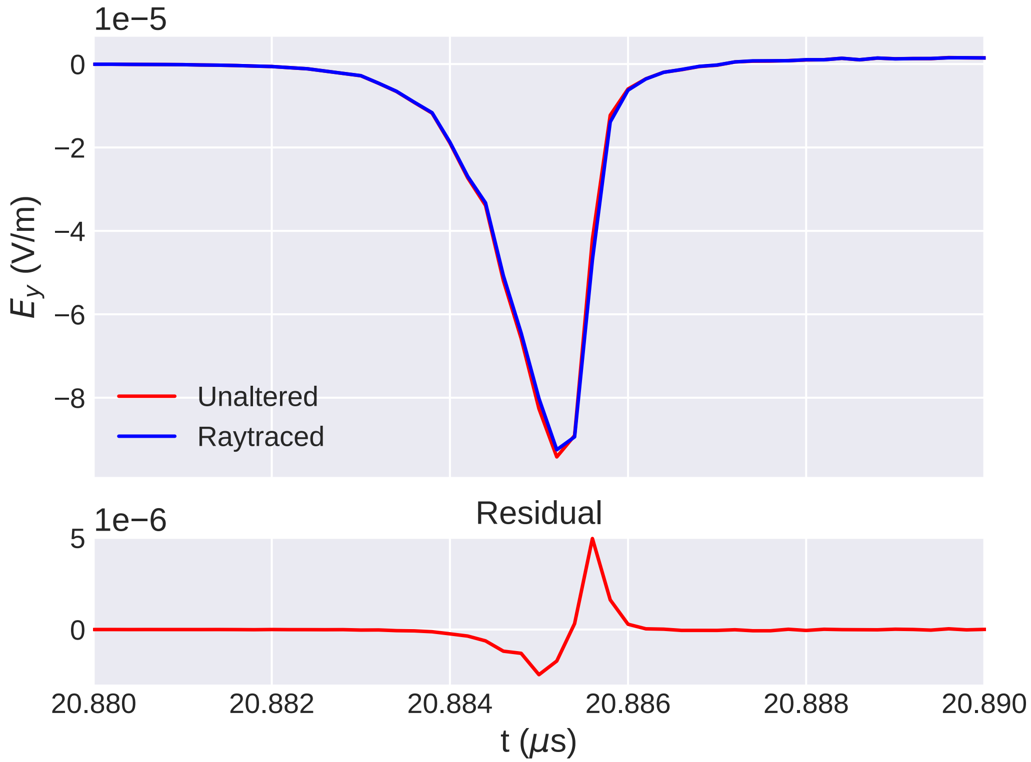
Per observer position: 1 table generated with raytracer that maps $\hat{r} \rightarrow \hat{r}_{Launch}$



Note: for boostfactor calculations, assume the emitter to be on the shower axis when mapping $\hat{r} \rightarrow \hat{r}_{Launch}$

WHAT IS THE EFFECT ON THE COREAS OUTPUT?

CoREAS output are electric field time traces



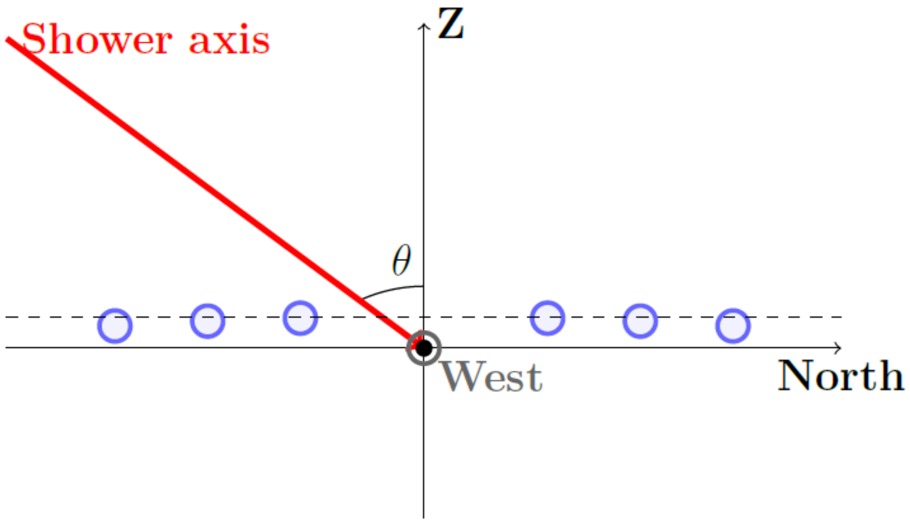
These are limited to single obsever positions and divided into different polarisations
-> hard to get a general picture

HOW CAN WE GET A MORE GENERAL IDEA OF THE EFFECT?

Look at the fluence:

$$f = \epsilon_0 c \Delta t \sum E_i^2$$

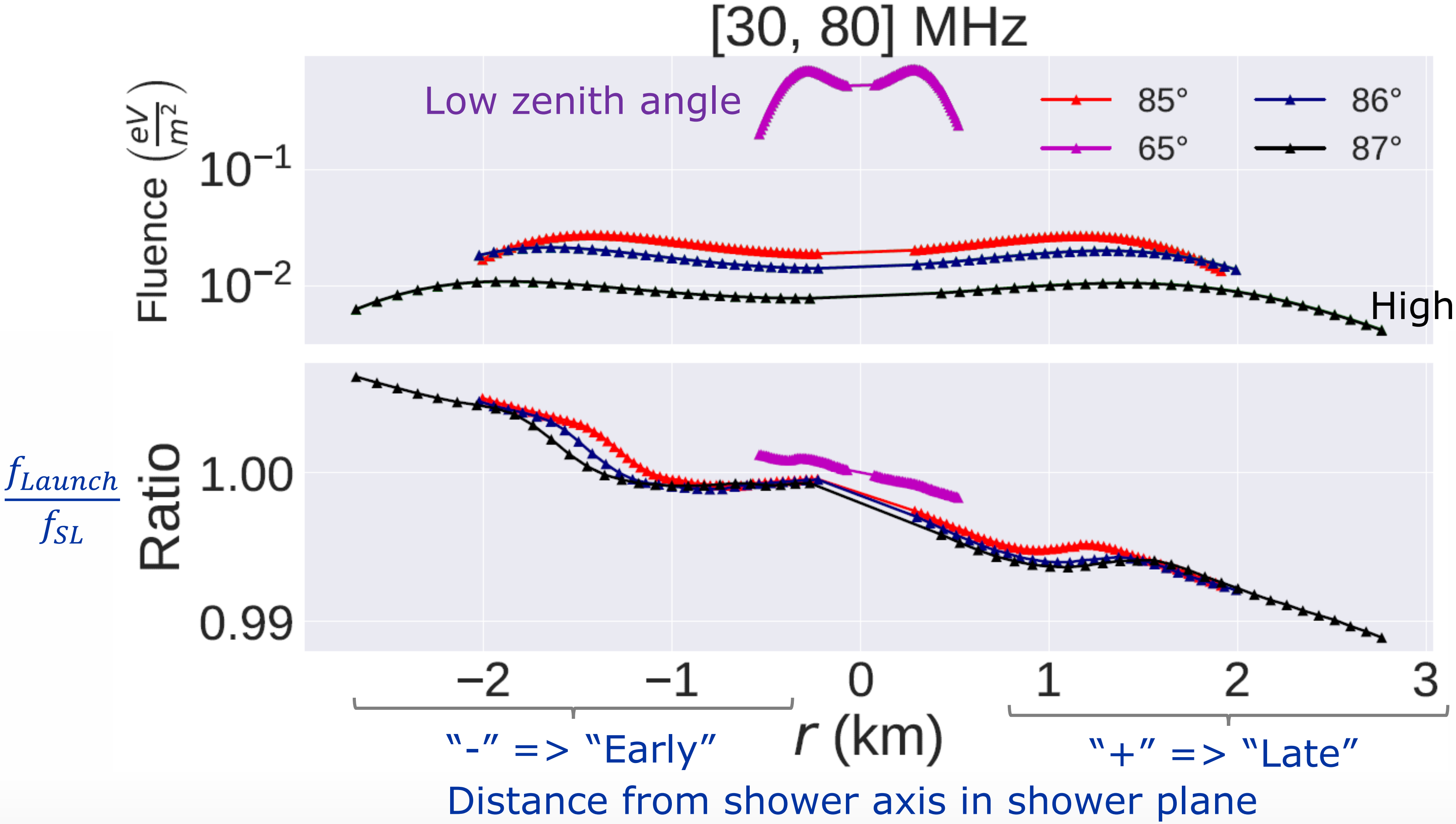
Proton primary
$10^{17} eV$
$\phi = 0°$
$|\vec{B}| = 50\ \mu T$
$\vec{B} = |\vec{B}| \cdot \vec{1}_Z$



Traces for observers in plane with shower axis -> filter traces for desired frequency range -> calculate fluence -> apply early late correction

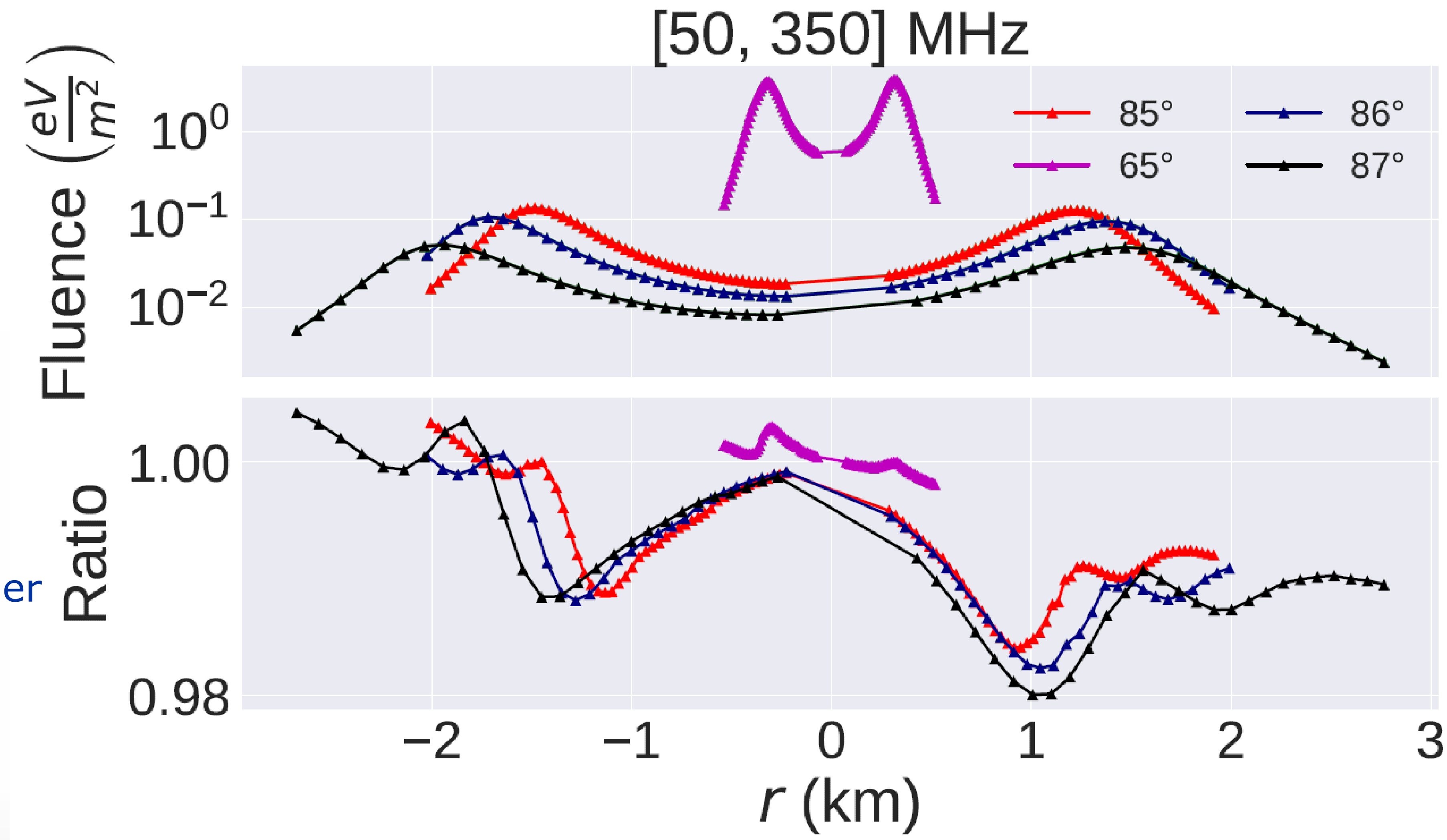
Compare fluence with adapted boostfactor (f_{Launch}) to fluence with standard CoREAS (f_{SL})

WHAT DO WE LEARN FROM LOOKING AT THE FLUENCE?



Up to 1% difference

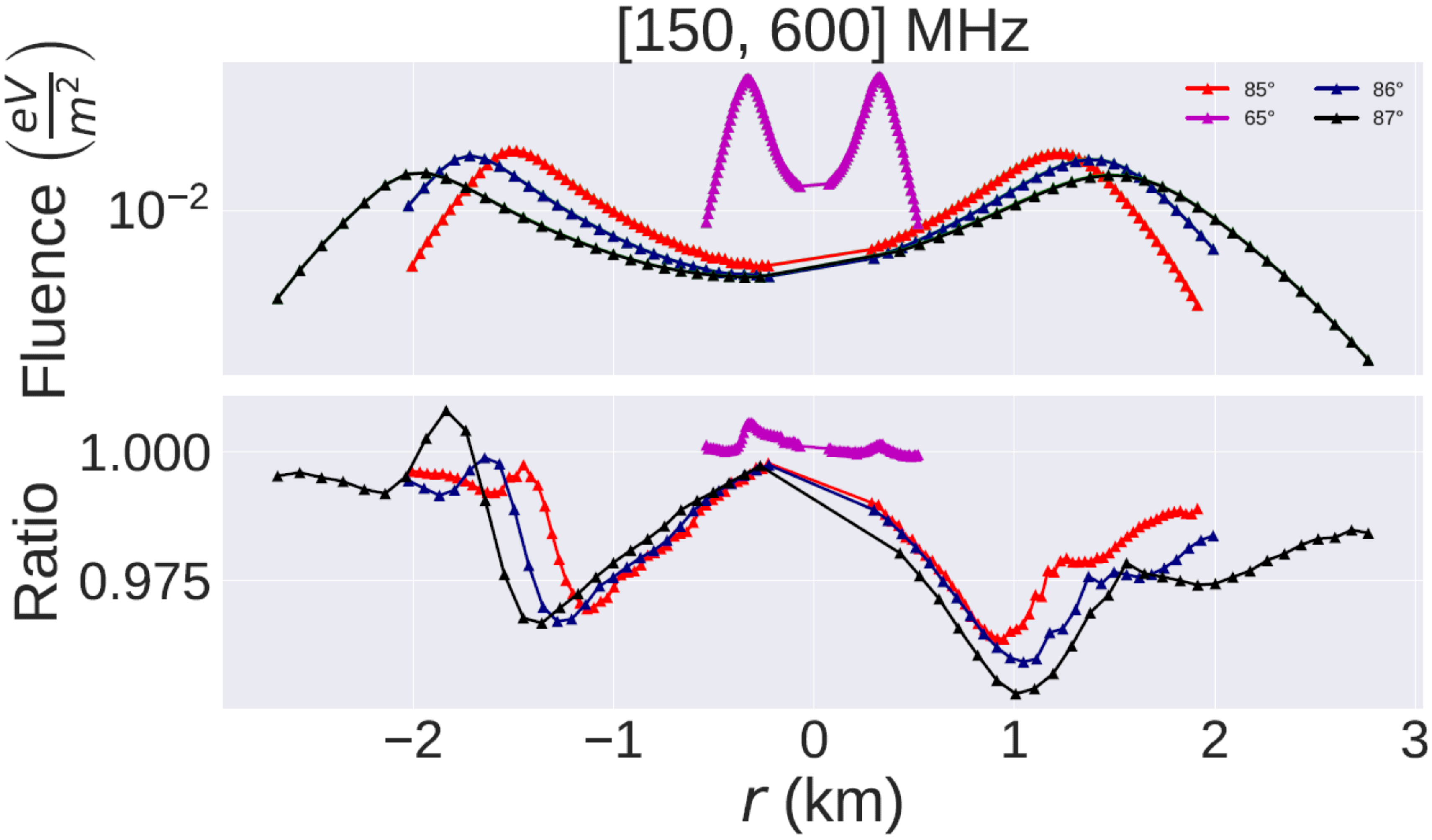
WHAT DO WE LEARN FROM LOOKING AT THE FLUENCE?



Effect more pronounced towards higher θ

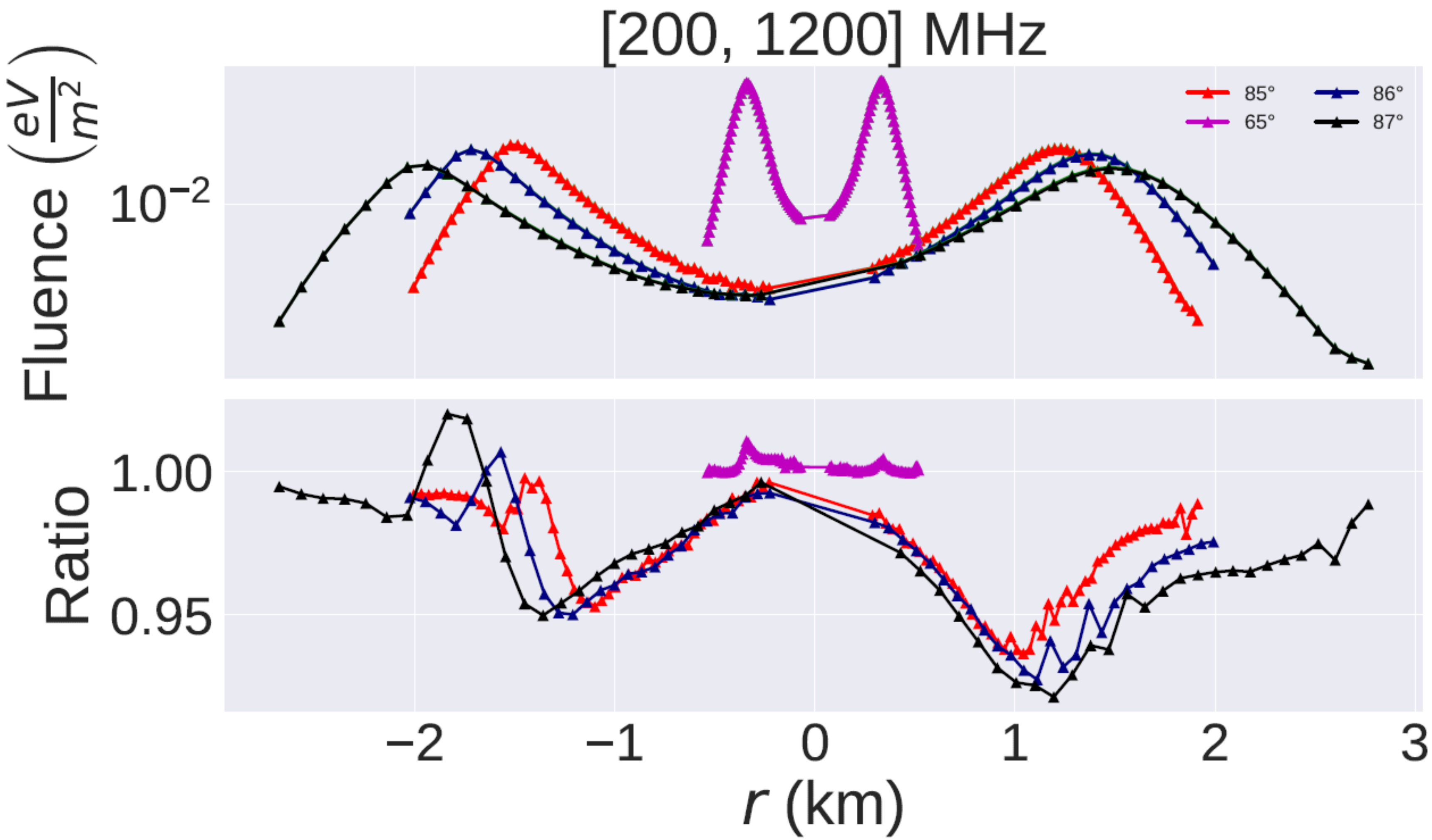
Up to 2% difference

WHAT DO WE LEARN FROM LOOKING AT THE FLUENCE?



Around 2.5% difference

WHAT DO WE LEARN FROM LOOKING AT THE FLUENCE?



Around 4% to 5% difference

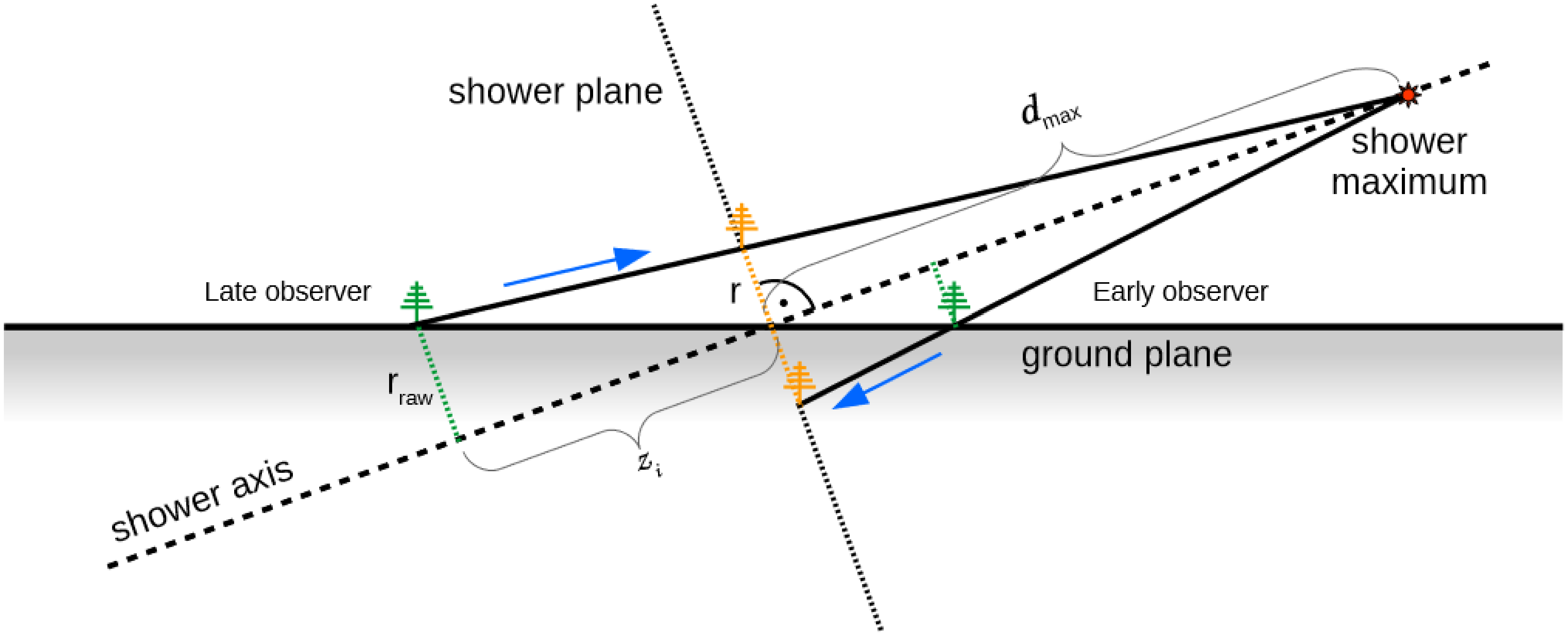
CONCLUSION

- The boostfactor can be correctly calculated by using the index of refraction at the emission point and the original launch direction of the ray

- The effect of changing the boostfactor leads to a few % difference in fluence for zenith angles up to 87°, with the effect more pronounced towards higher frequencies.

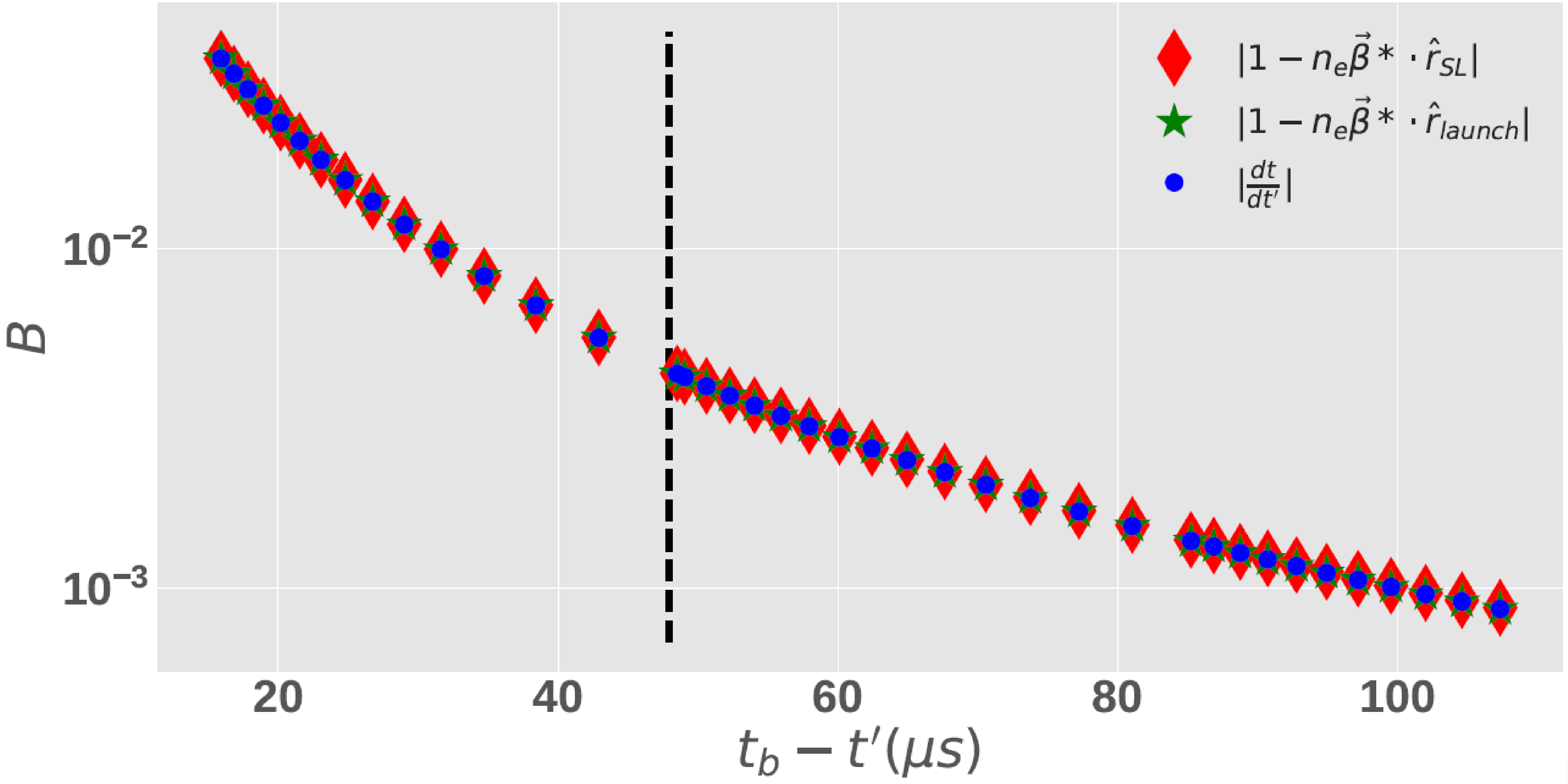
- Coherence between emitters is most important

BACKUP

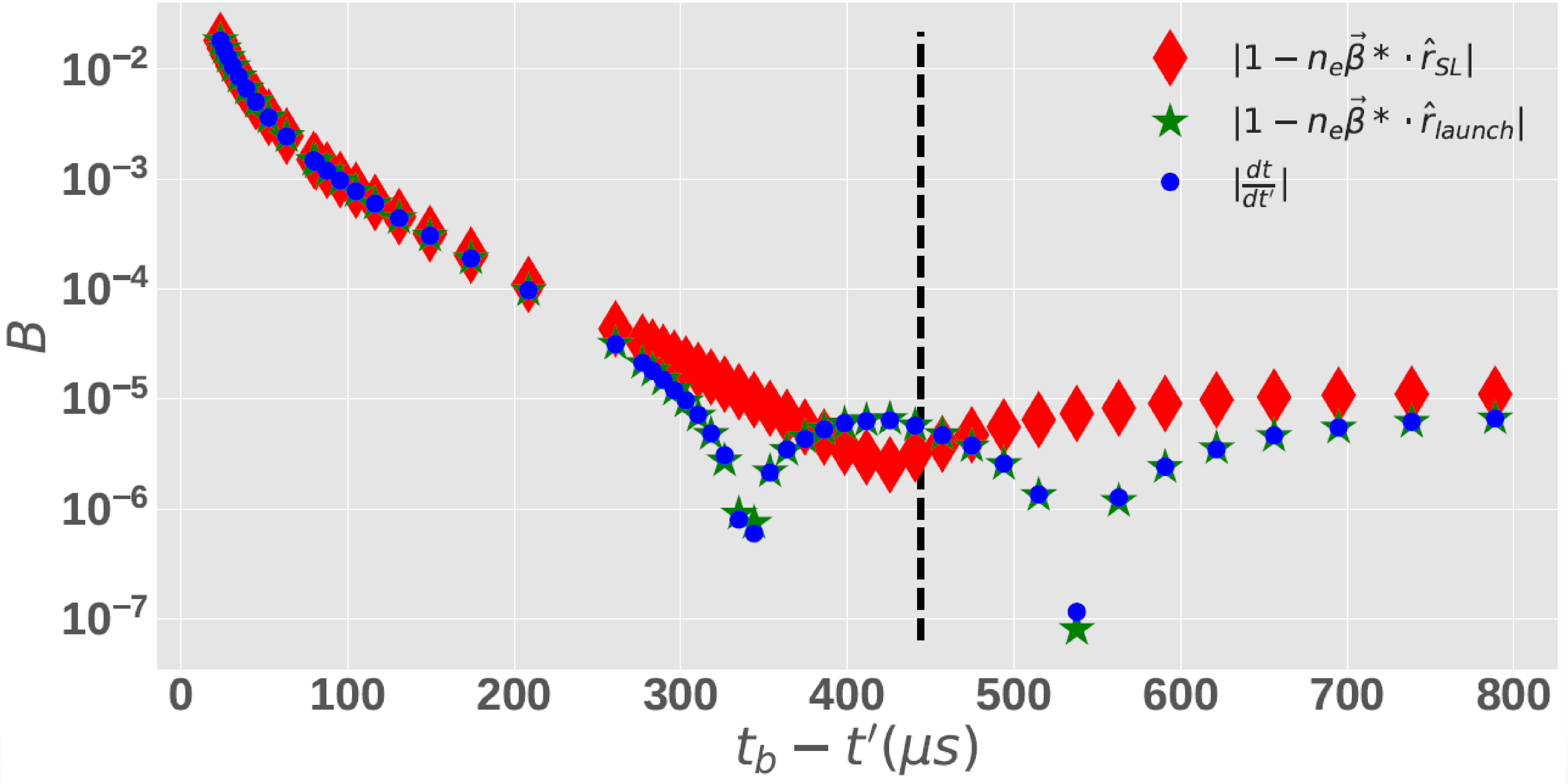


$$c_{\text{el}} \equiv \frac{d_{\text{max}} + \vec{x}_i \cdot \vec{e}_v}{d_{\text{max}}} = 1 + \frac{z_i}{d_{\text{max}}}.$$

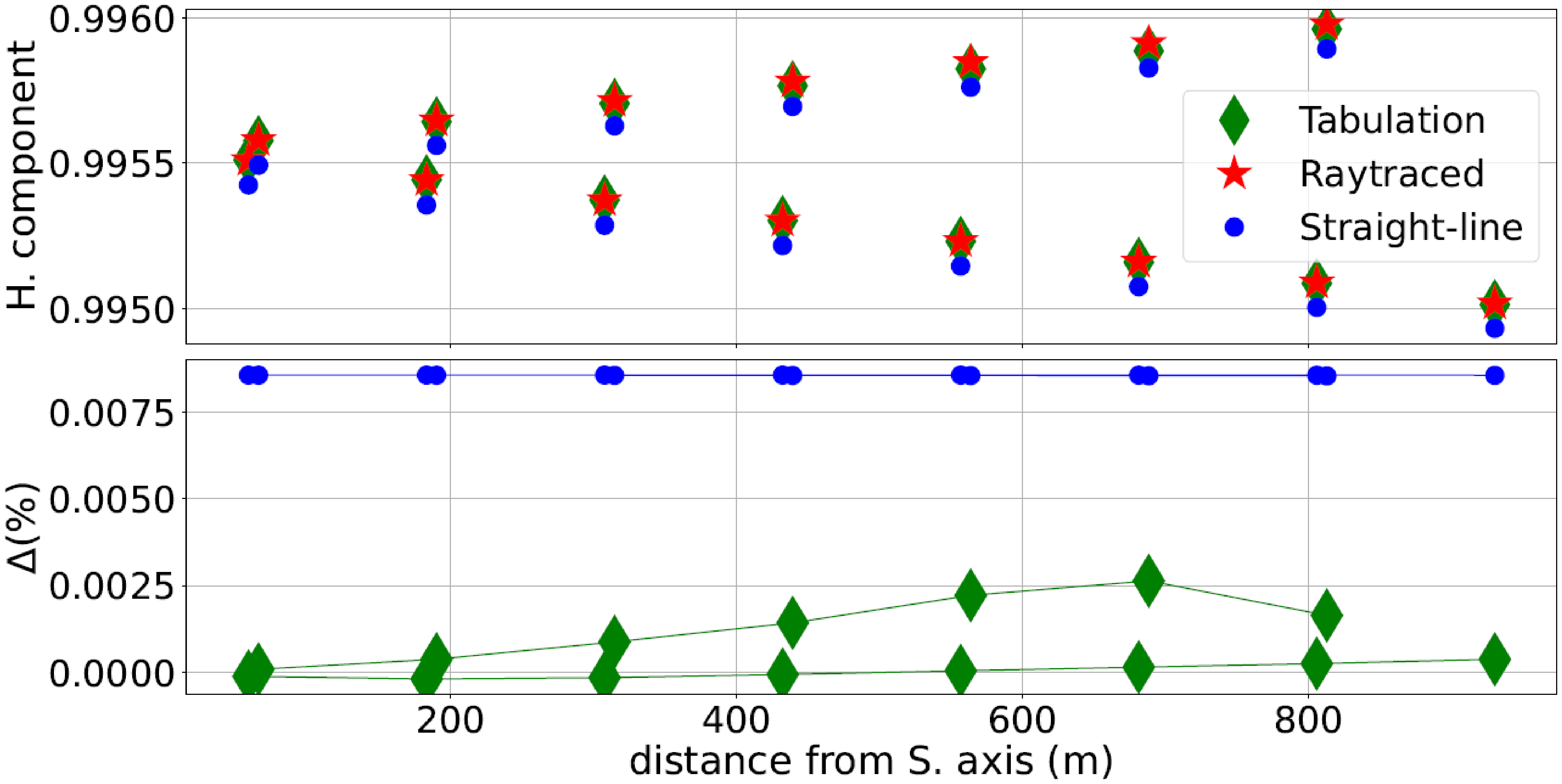
$$f = f_{\text{raw}} \cdot c_{\text{el}}^2, \quad r = \frac{r_{\text{raw}}}{c_{\text{el}}},$$



VRIJE UNIVERSITEIT BRUSSEL



$|1 - n_e\vec{\beta}* \cdot \hat{r}_{SL}|$
$|1 - n_e\vec{\beta}* \cdot \hat{r}_{launch}|$
$|\frac{dt}{dt'}|$
B
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
100
200
300
400
500
600
700
800
$t_b - t'(\mu s)$



0.9960
0.9955
0.9950
H. component
Tabulation
Raytraced
Straight-line
0.0075
0.0050
0.0025
0.0000
Δ(%)
200
400
600
800
distance from S. axis (m)