Atmospheric effects on the production and propagation of secondary particles

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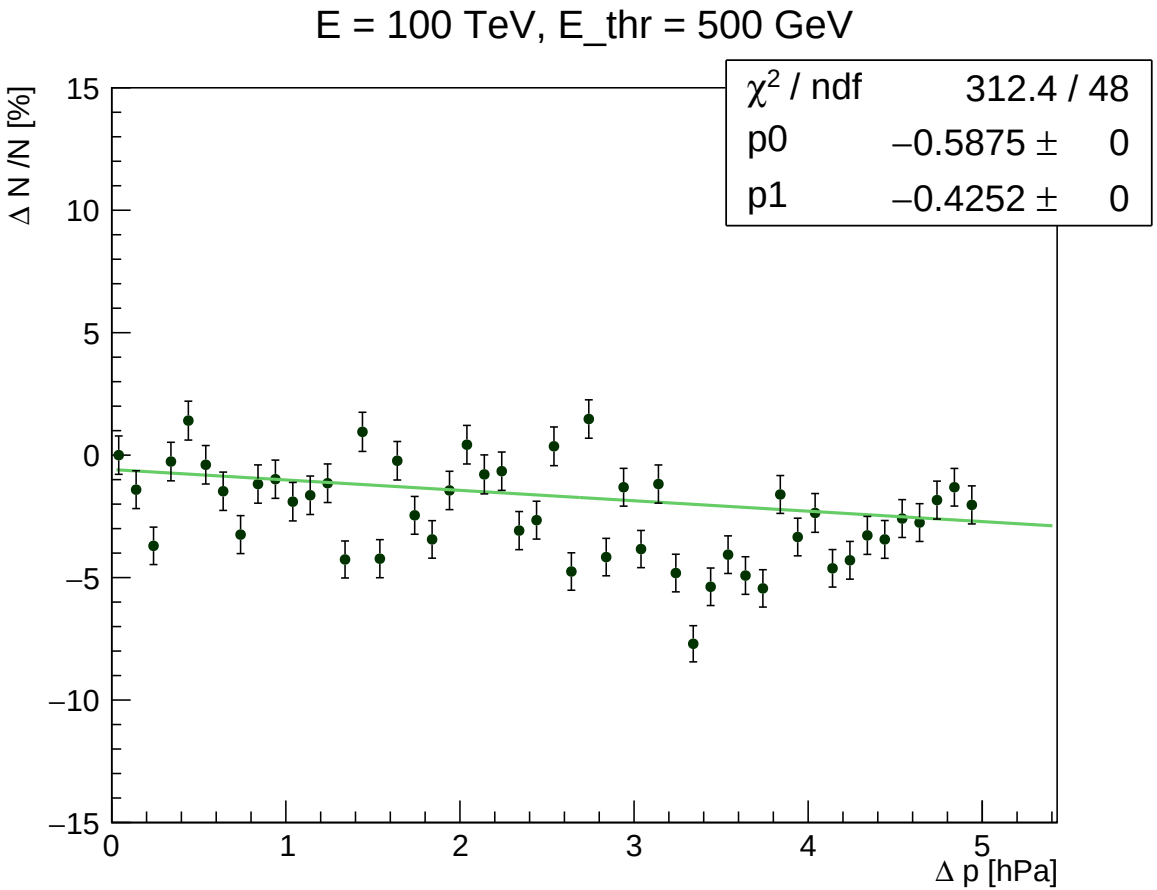
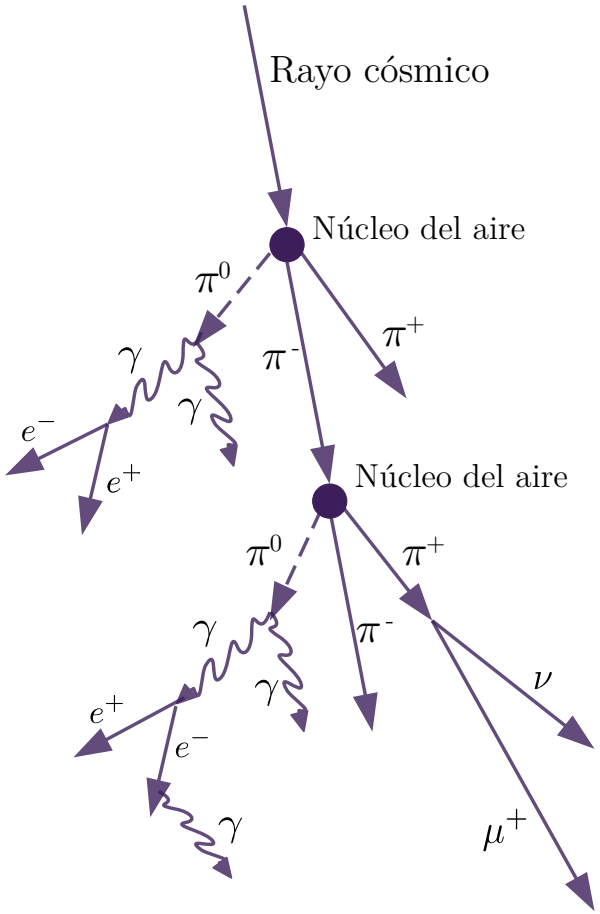
1. Atmospheric effects on air showers
2. Horizontal muons and temperature: data
3. Horizontal muons and temperature: simulations

Our goal

We want to characterize the effects of atmospheric conditions (pressure, temperature, and humidity) on the flux of secondary particles from hadronic air showers that reach the HAWC observatory.



Atmospheric effects on air showers



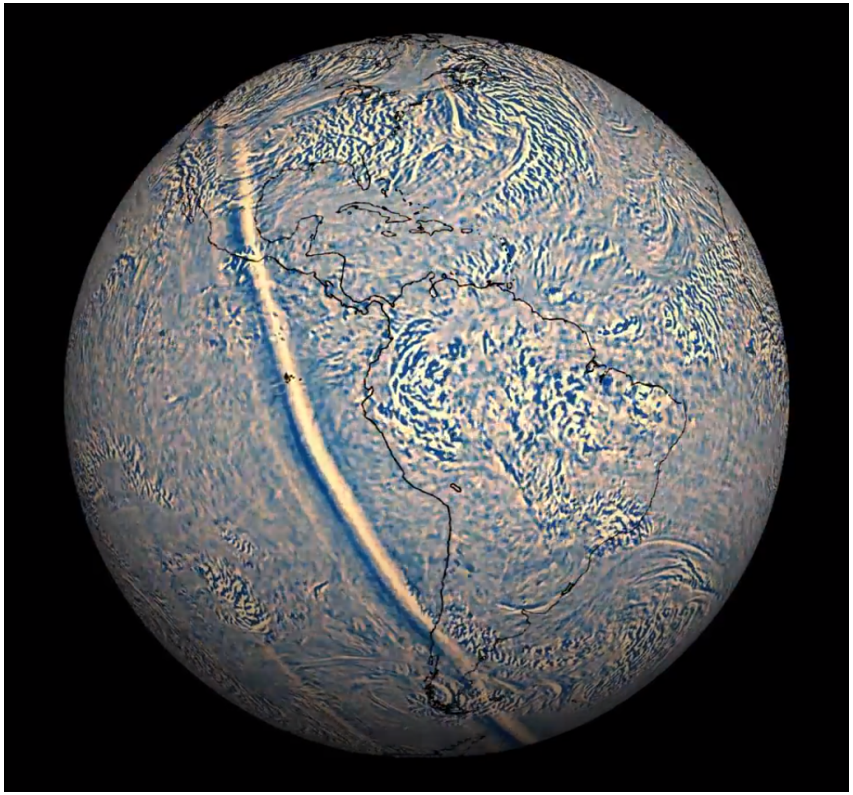
We consider two effects of atmospheric density on the number of secondary particles [1]:

- Positive: $+$ interactions $\longrightarrow$ $+$ particles
- Negative: $+$ absorption $\longrightarrow$ $-$ particles

[1] L. Dorman, vol. 303 (Springer Science & Business Media, 2013)

HAWC observation

Observation of natural events that change atmospheric conditions: **Hunga-Tonga volcano explosion in 2022**[2]



[2] R. Alfaro, C. Alvarez y col., Adv. Sp. Res., 10.1016/j.asr.2023.09.049 (2023), arXiv:2209.15110

HAWC observation

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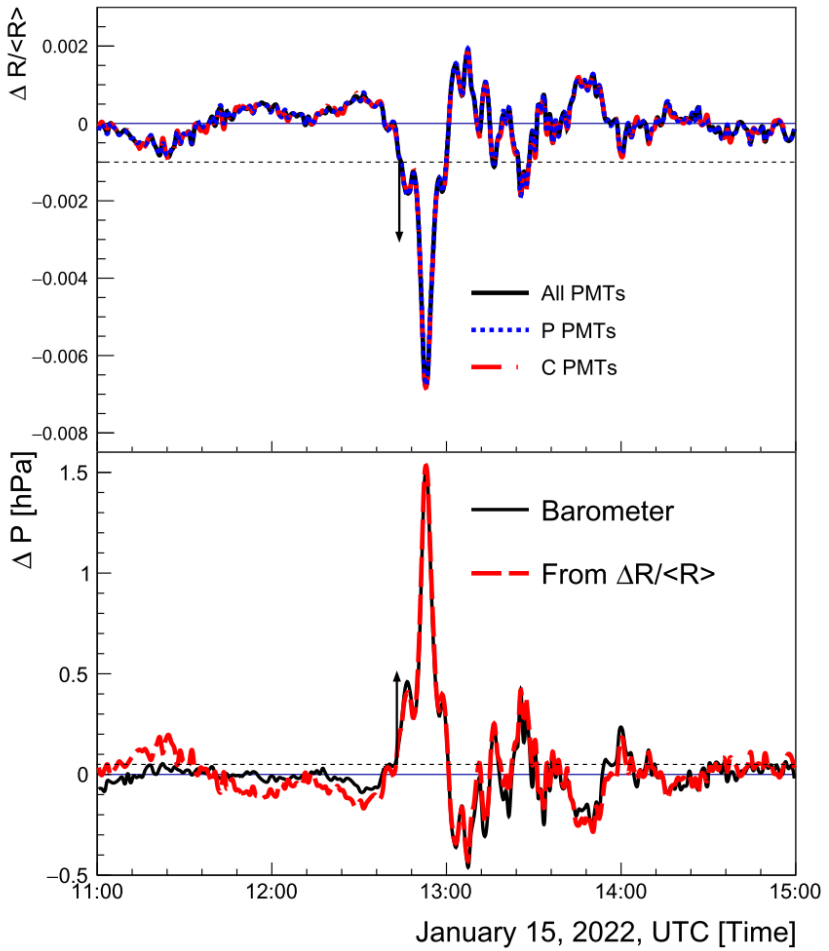

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Projects

- Correlation between the **horizontal muon flux** and the temperature.
- Atmospheric effects on **electromagnetic showers**.
- Effects of **atmospheric electric fields**.

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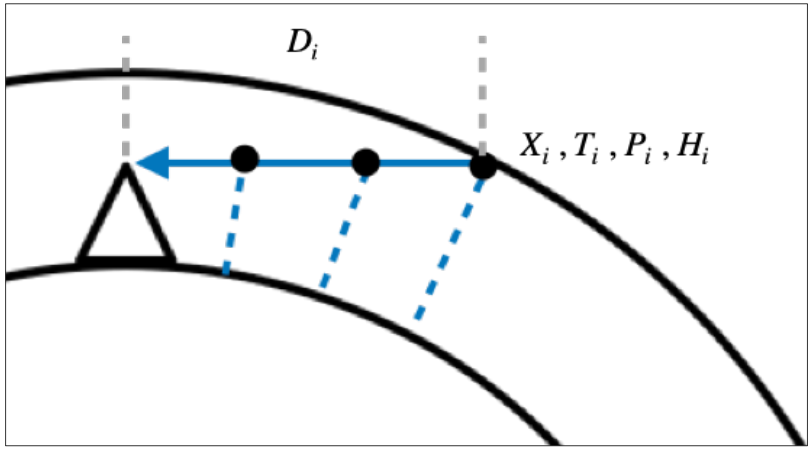
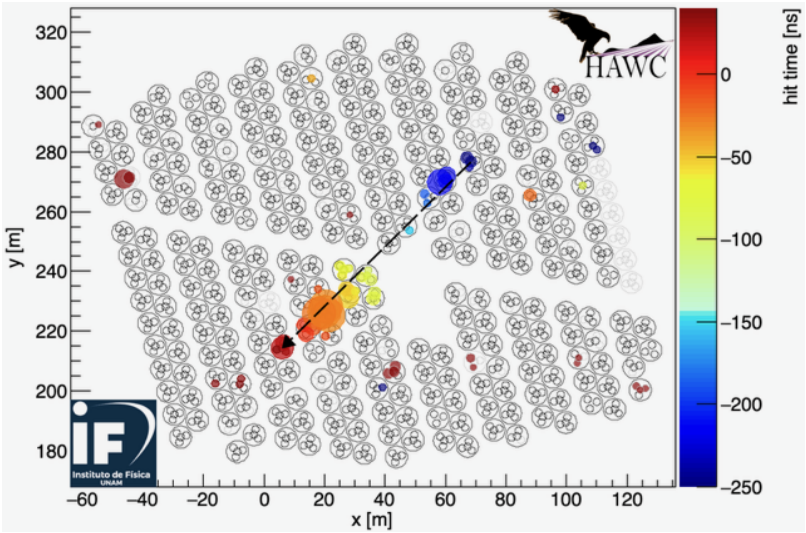
Horizontal propagation

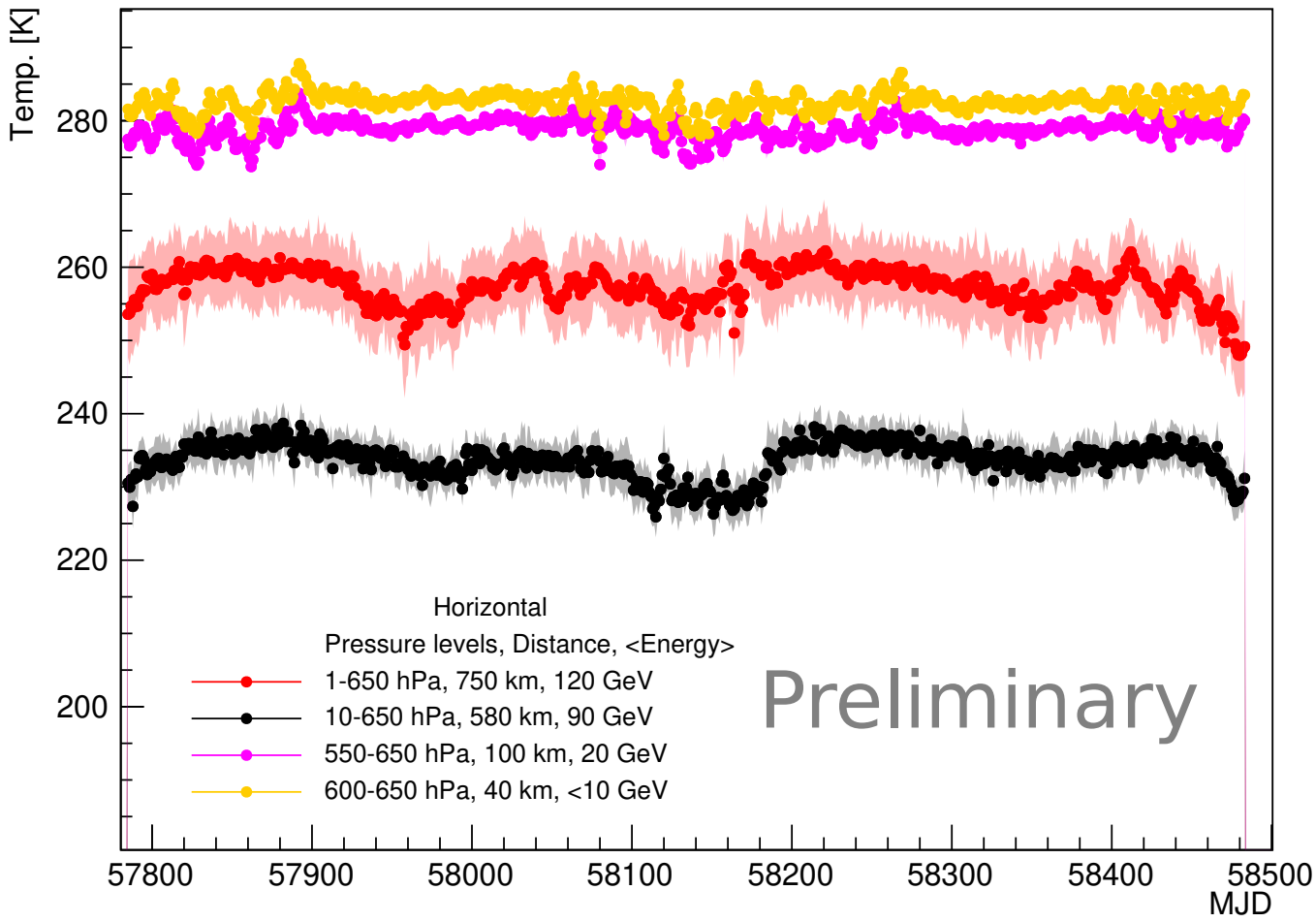




Propagation starting around 750 km from HAWC at (17.8 N, 90.5 W).

Effective temperature

Effective temperatures[3] for different propagation distances.



[3] Atmospheric data from ECMWF, https://www.ecmwf.int/ (visitado 2022)

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Three possible approaches for simulations

- Approach 1: using vertical profiles in CORSIKA (performing tests)
- Approach 2: using horizontal profiles CORSIKA (some results!)
- Approach 3: using cascade equations, CONEX[4] or MCEq[5], instead (or with) Monte Carlo (pending)

[4] T Pierog, M. Alekseeva y col., arXiv preprint astro-ph/0411260 (2004).

[5] A. Fedynitch, R. Engel y col., en EPJ Web of Conferences, vol. 99 (EDP Sciences, 2015), pág. 08001.

Atmospheric model in CORSIKA

CORSIKA models the atmosphere in five layers. In the lower four layers, atmospheric depth X follows an exponential:

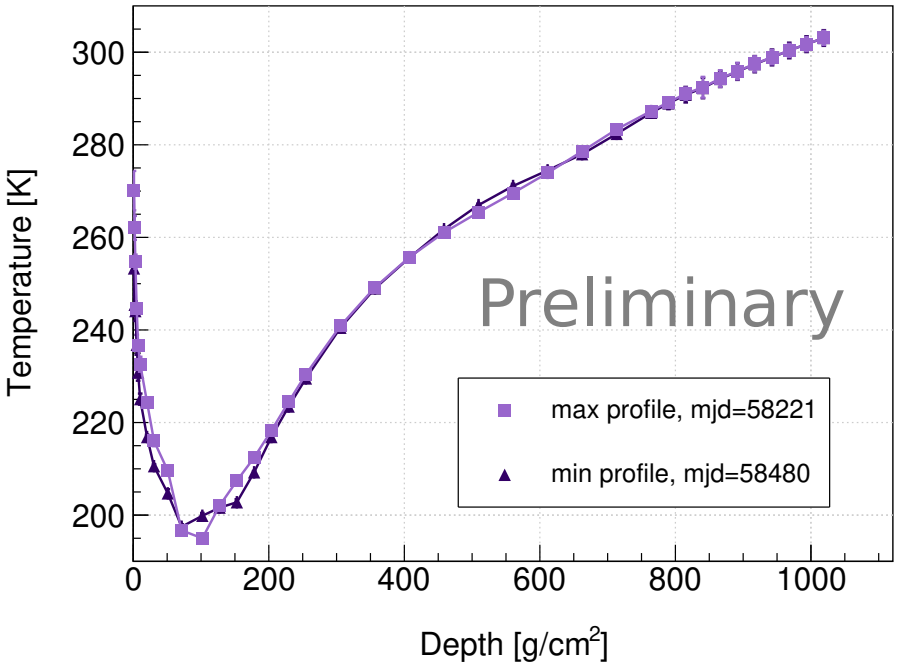
$$X(h) = a_i + b_i e^{-h/c_i}, i = 1, 2, 3, 4, \tag{1}$$

and the highest layer decreases linearly:

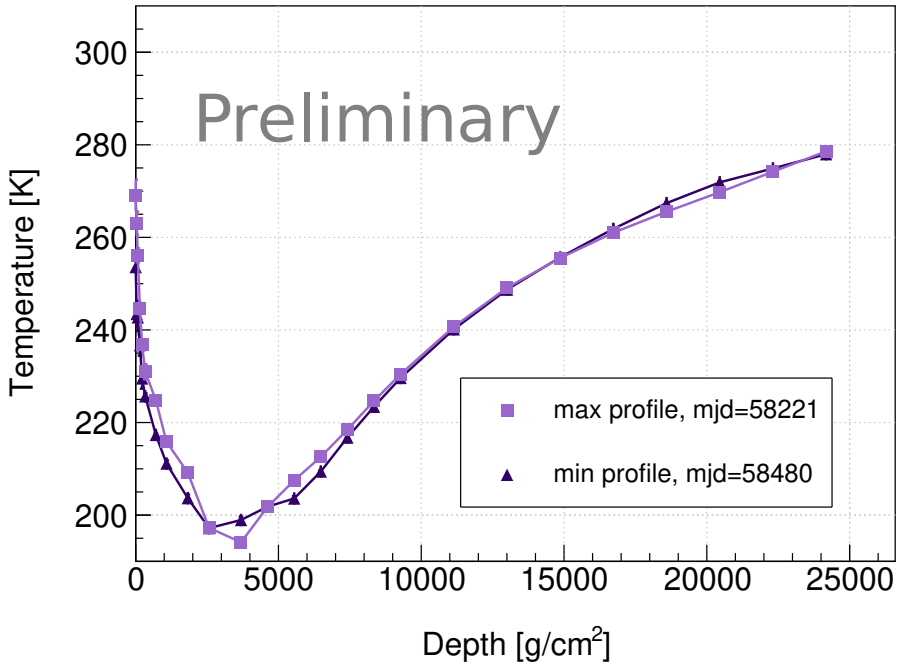
$$X(h) = a_5 - \frac{b_5}{c_5} h.$$

Temperature profiles for simulations

Vertical profile

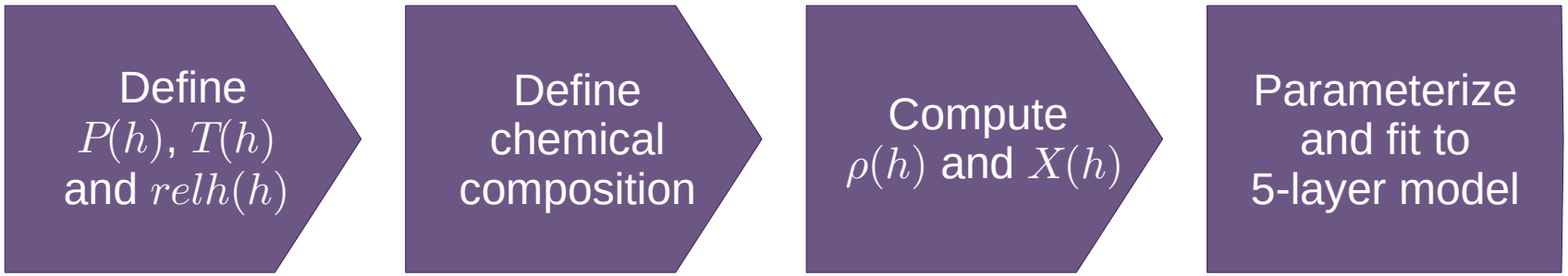


Horizontal profile



Our atmospheric profiles to CORSIKA

Program for modelling the atmosphere for the simulations. Based on the *gdastool* script implemented in CORSIKA.

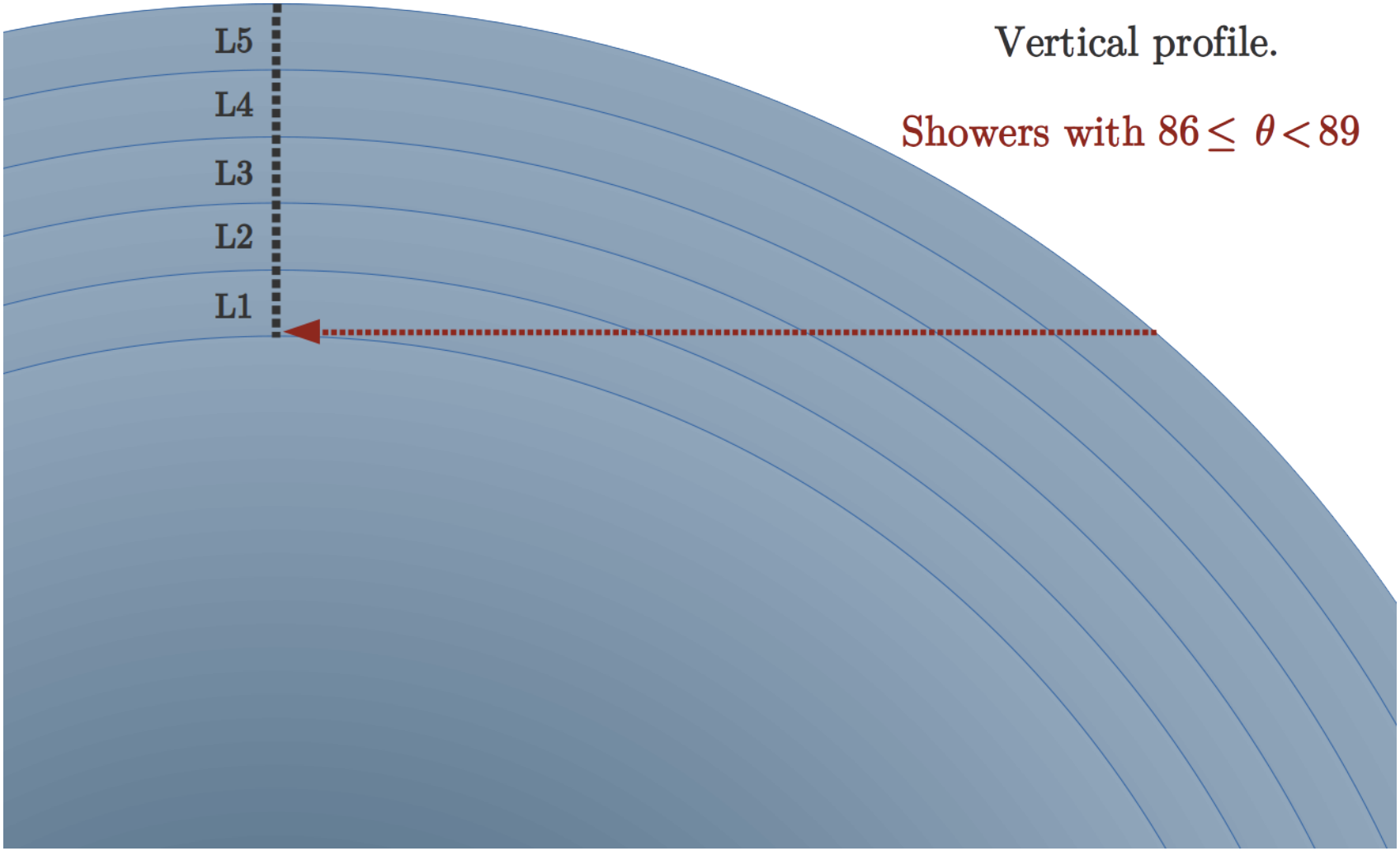


Profile readable by CORSIKA

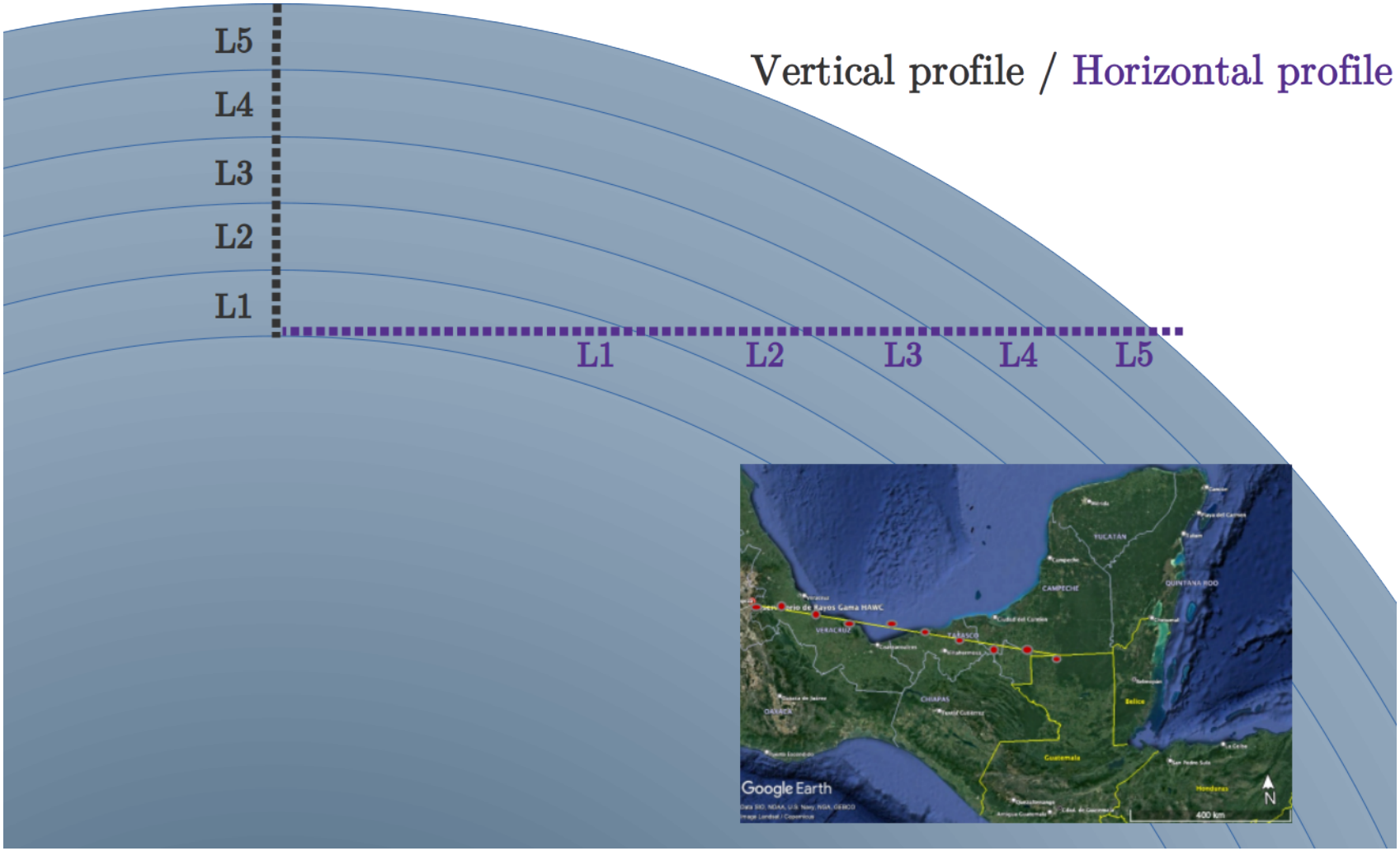
Output of our program in the format of *gdastool* so it can be read by CORSIKA.

	L1	L2	L3	L4	L5
	# atmospheric parameters ATMLAY [cm], A, B, C respectively				
	0.00000000E+00	1.44468000E+06	2.58414000E+06	3.23927000E+06	1.00000000E+07
a_i	-1.21892119E+02	-1.65502001E+00	1.92319851E+00	1.00039341E+00	1.12829200E-02
b_i	1.09279570E+03	2.90206090E+03	1.51999325E+05	3.94641551E+01	1.00000000E+00
c_i	9.25480638E+05	4.40412495E+05	2.48518116E+05	9.39344594E+05	1.00000000E+09

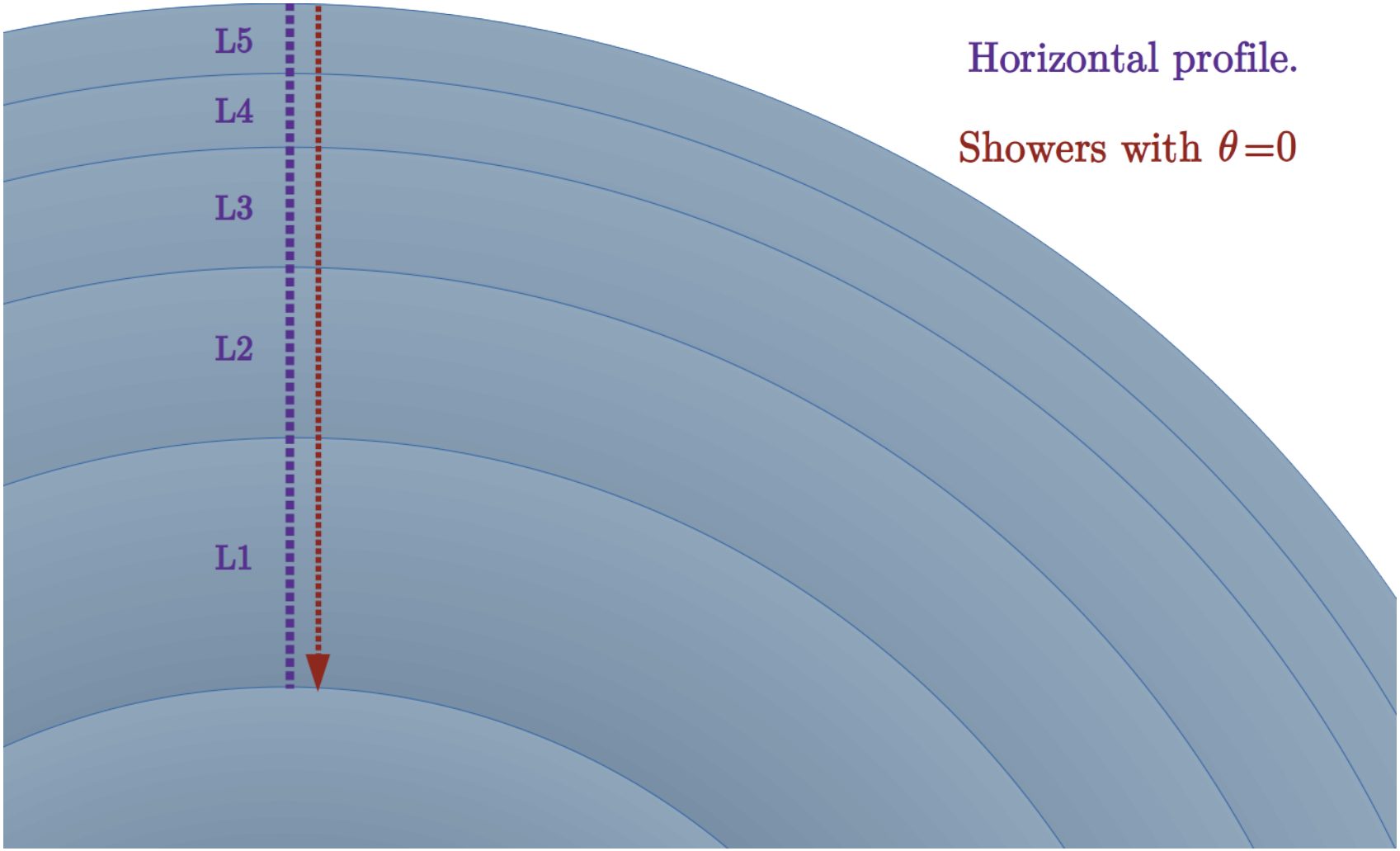
Approach 1: vertical profiles



Approach 2: horizontal profiles

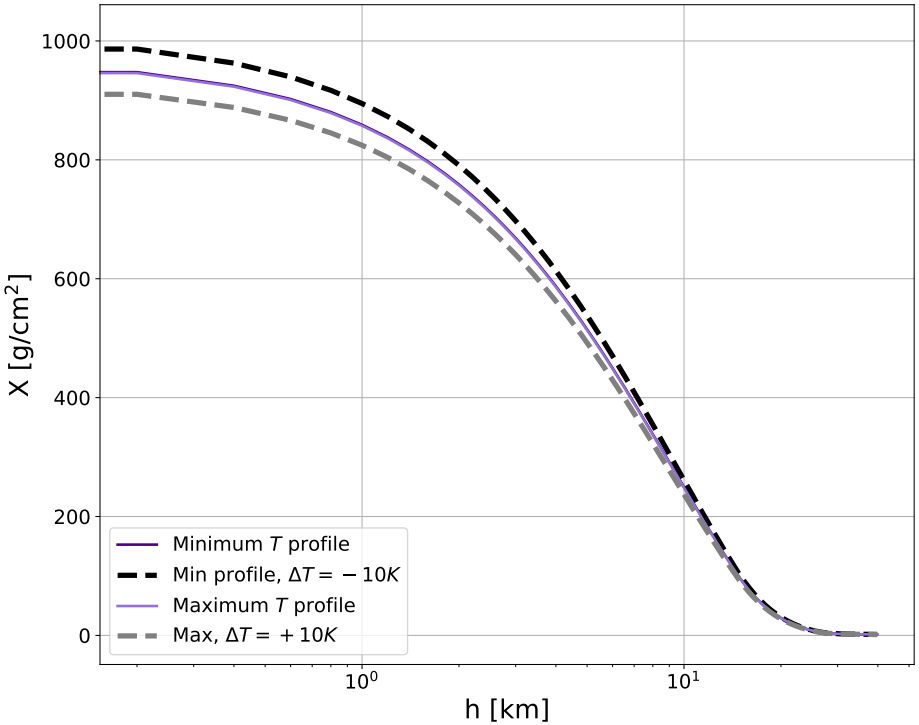


Approach 2: horizontal profiles

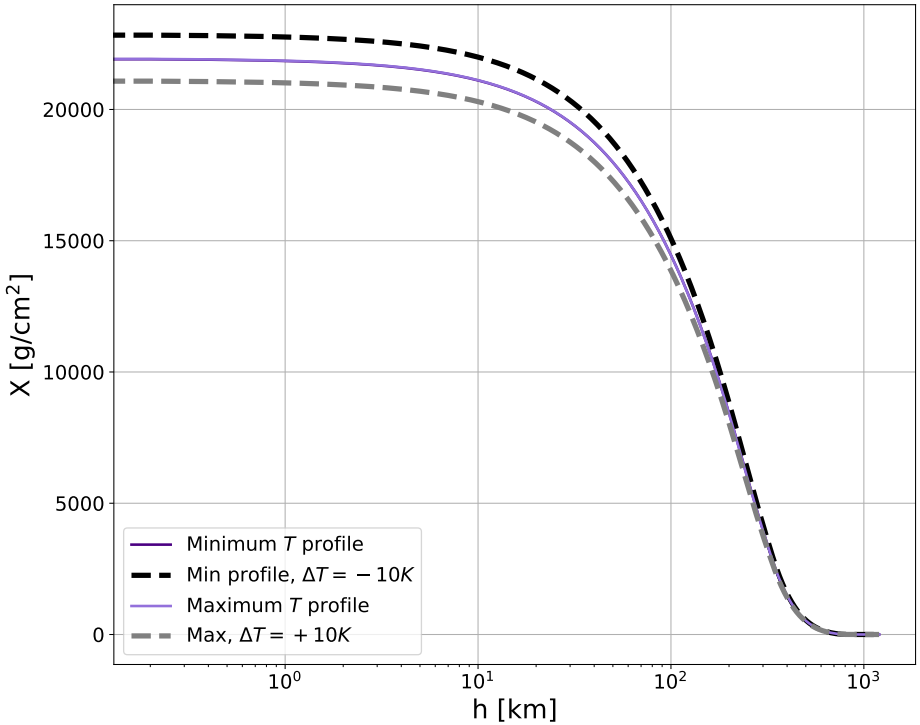


Atmospheric profiles

Vertical profile



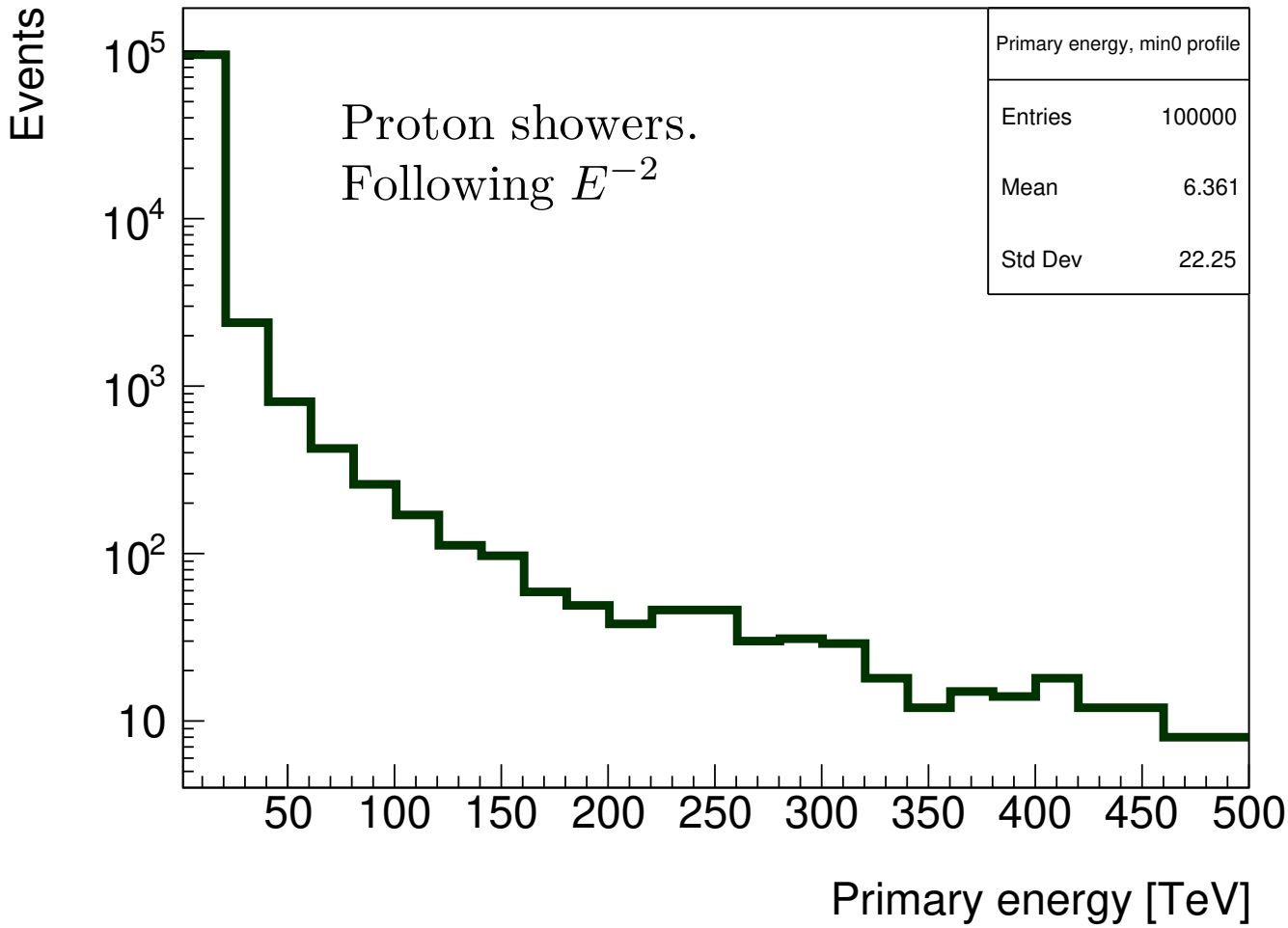
Horizontal profile



Fitted for CORSIKA 5-layer model.

Primary energy

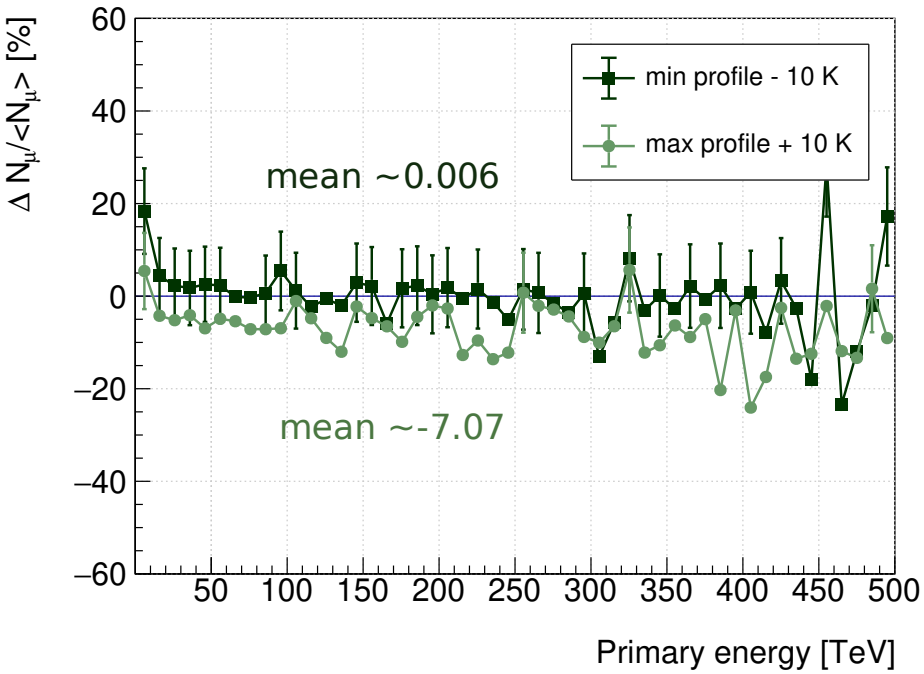
A million events simulated (so far) for each temperature profile.



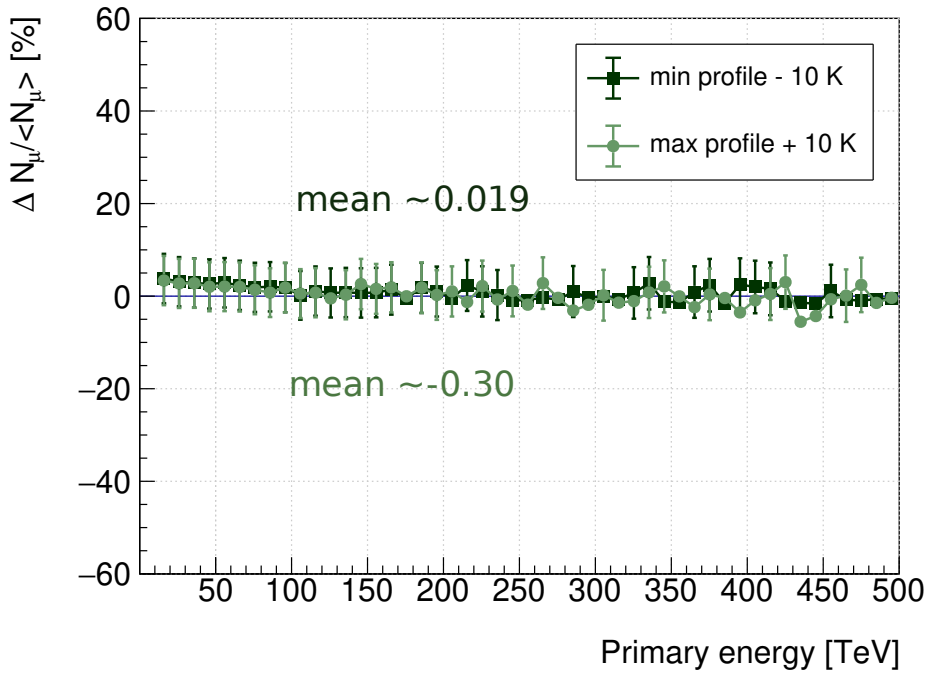
Some preliminary results

Results from approach 2 so far:

Vertical showers



Horizontal showers



To-do

- Choose the better approach. Perhaps validate the second approach with the others
- Longitudinal development of the muon component
- Direct comparison with HAWC data?

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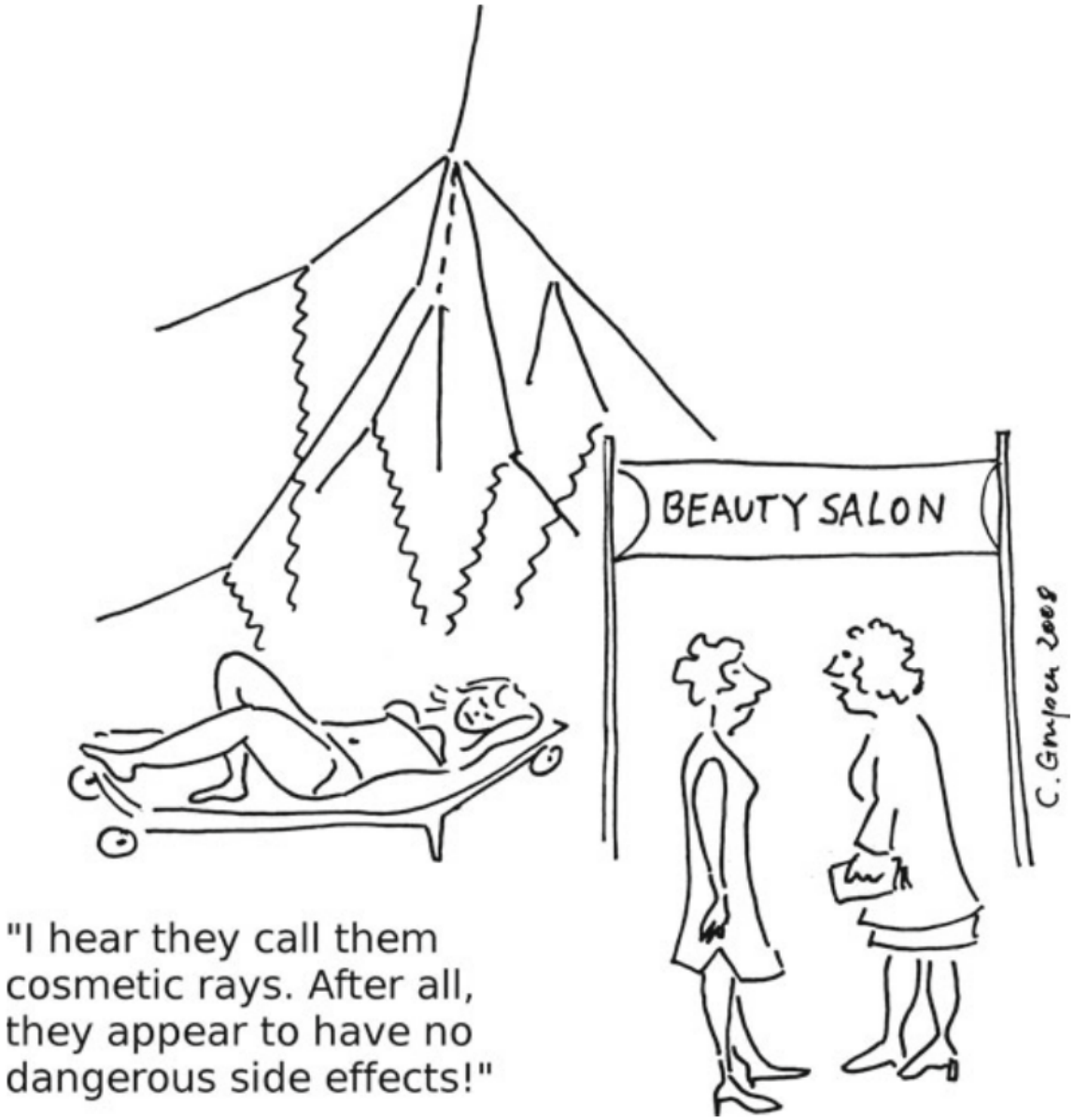

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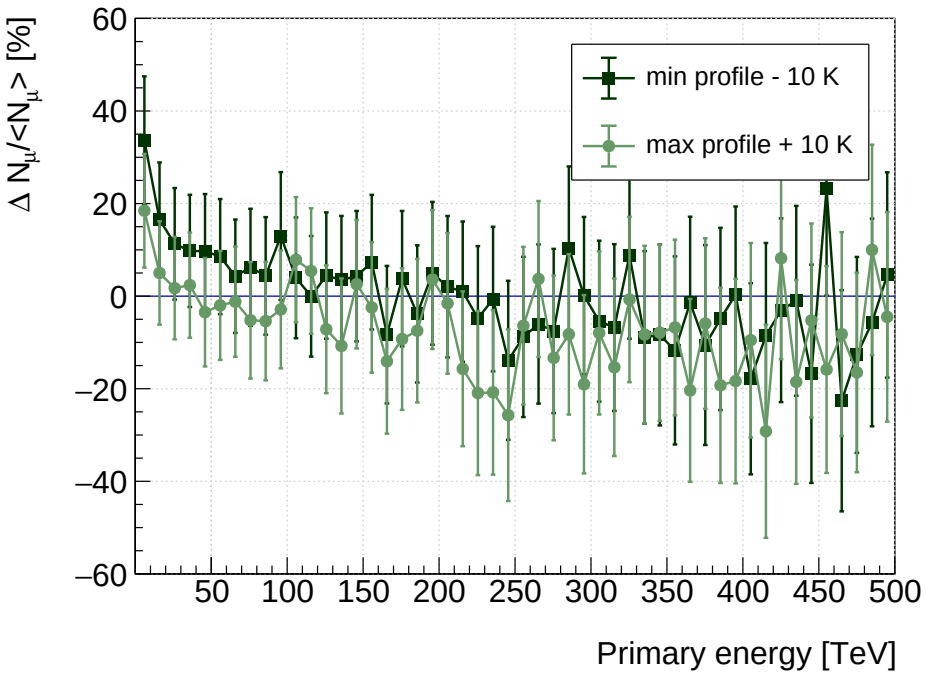
Backup

Some preliminary results

Cut on muon energy of 2 GeVs

Vertical showers



Horizontal showers