Cosmic-ray-induced background in the TAMBO-4 prototype with TAMBOSim

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01 Summary

Objective: **Understanding and characterizing the background in the TAMBO-4 prototype through the study of proton-initiated showers.**

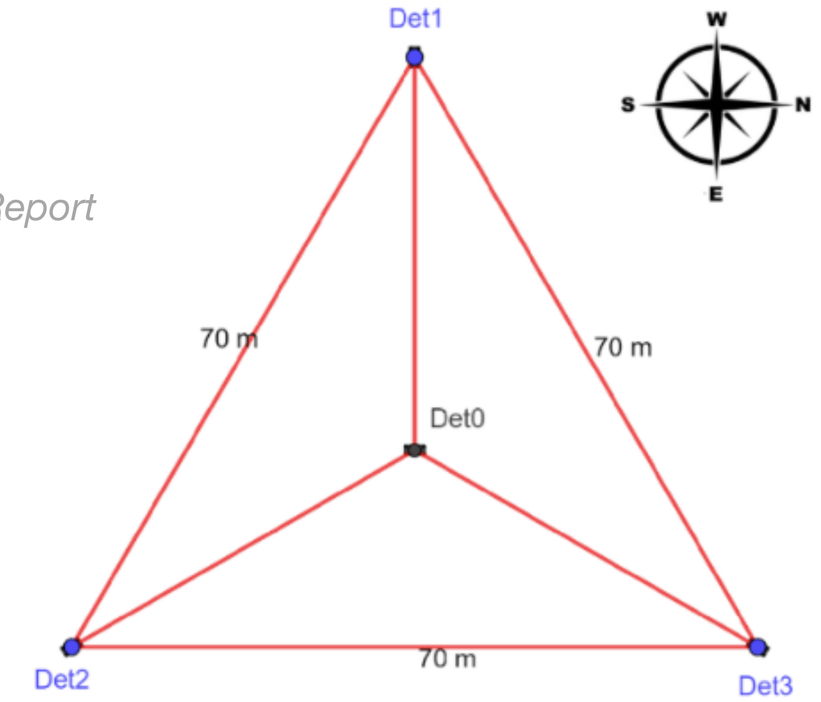
Since the last study, the aim has been to pass from C8 standalone to the TAMBOSim framework. In addition, some strategies were conducted:

- Development of an atmospheric model for Lima, designed to be compatible with TAMBOSim and representative of the typical meteorological conditions of the city.
- Determination of the primary energy range ⇒ 1 - 250 TeV
- A comparative study of different flux models and their integration into the analysis framework ⇒ H3a selection.

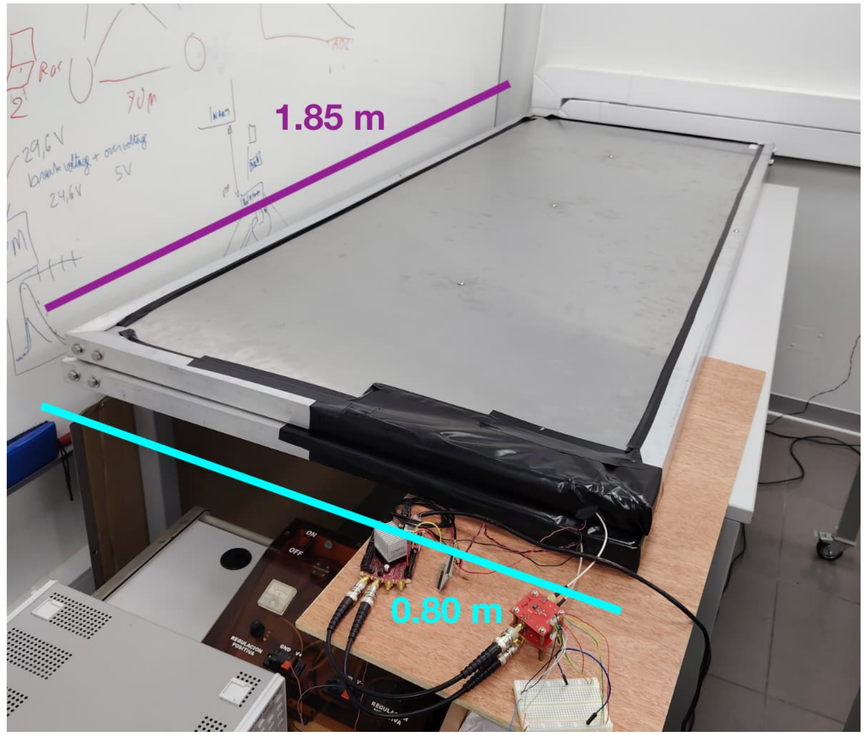
02 TAMBO-4 prototype

- Panel area (m^2): $1.48\,m^2$
- Panel separation (m): $70\,m$ relative to the vertices, and $40\,m$ from the central detector to the vertex detectors.

From: Díaz Arrascue Report



TAMBO-4 detector array



Two panels in coincidence

03 Lima atmosphere

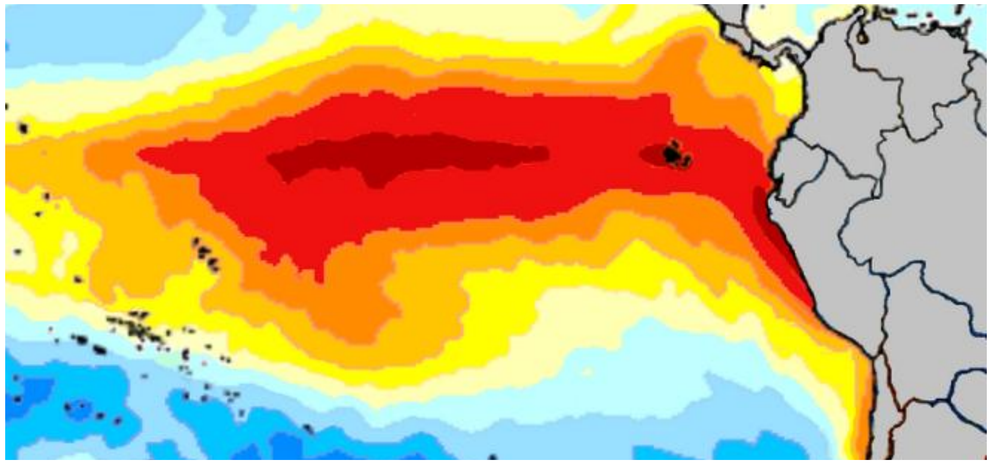
Completely opposite and different climates between Colca and Lima:

Lima: moderate temperatures between 14°C and 28°C without drastic daily changes.

Colca: dry, very sunny during the day, but with extreme cold and temperatures at night (below 0ºC).

For that, we construct an atmosphere for Lima (may-nov), following:

- Data: ERA5*, Garúa season, ENSO filter (removing years with strong signal of El Niño).
- 5-layer parameterization:
  - Layers 1–3 adjusted to ERA5.
  - Layers 4–5 spliced to the default C8 (model 17 Keilhauer).



El Niño phenomenon

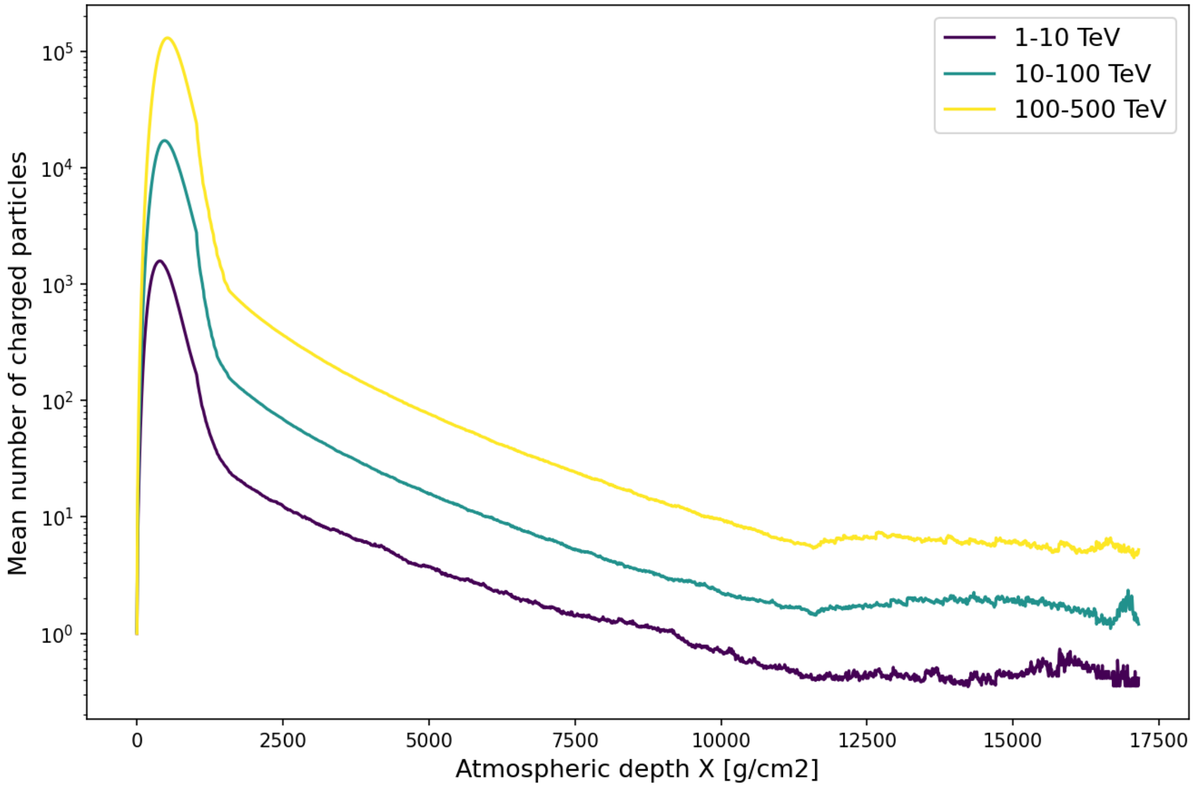
**fifth-generation global climate reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts*

03 Lima atmosphere

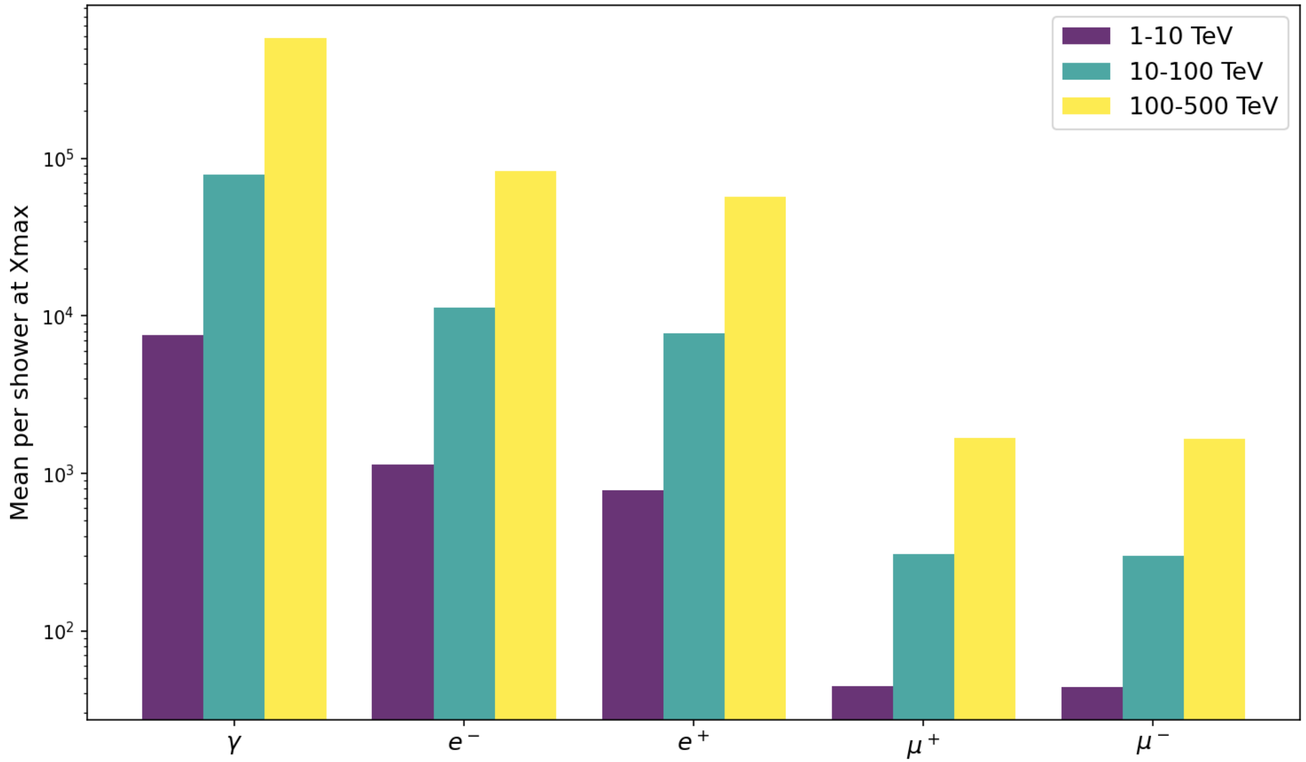
PHYSICAL CONSISTENCY

TAMBO

Mean longitudinal profiles



Composition at shower maximum



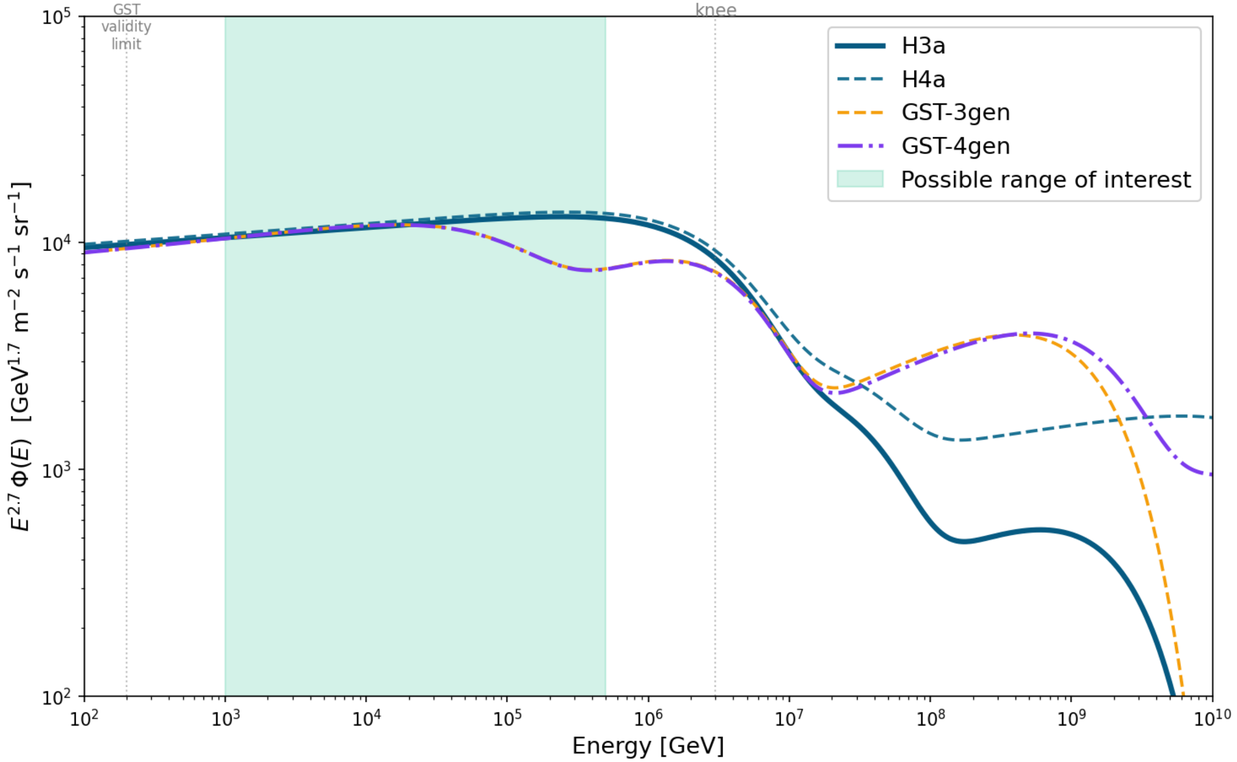
The simulations reproduce the expected behavior of proton showers. The mean longitudinal profile increases consistently with the primary energy, and the composition at the maximum respects the expected electromagnetic hierarchy.

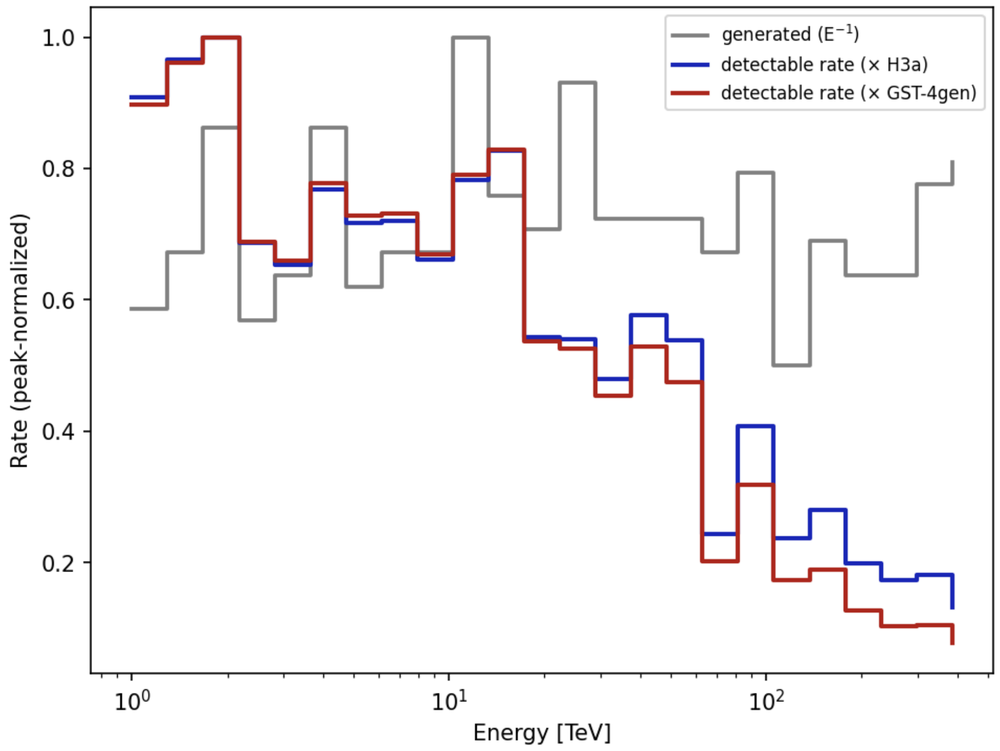
Results considering 1000 proton-initiated showers - [1, 500] TeV

04 Energy range

In our previous simulation, we considered an energy range from 10 to 100 TeV, based on prior studies. However, the appropriate energy range was not explored. To test, we selected 1000 proton-initiated showers in a range of 1 to 500 TeV.

Detectable rate depends on the flux model

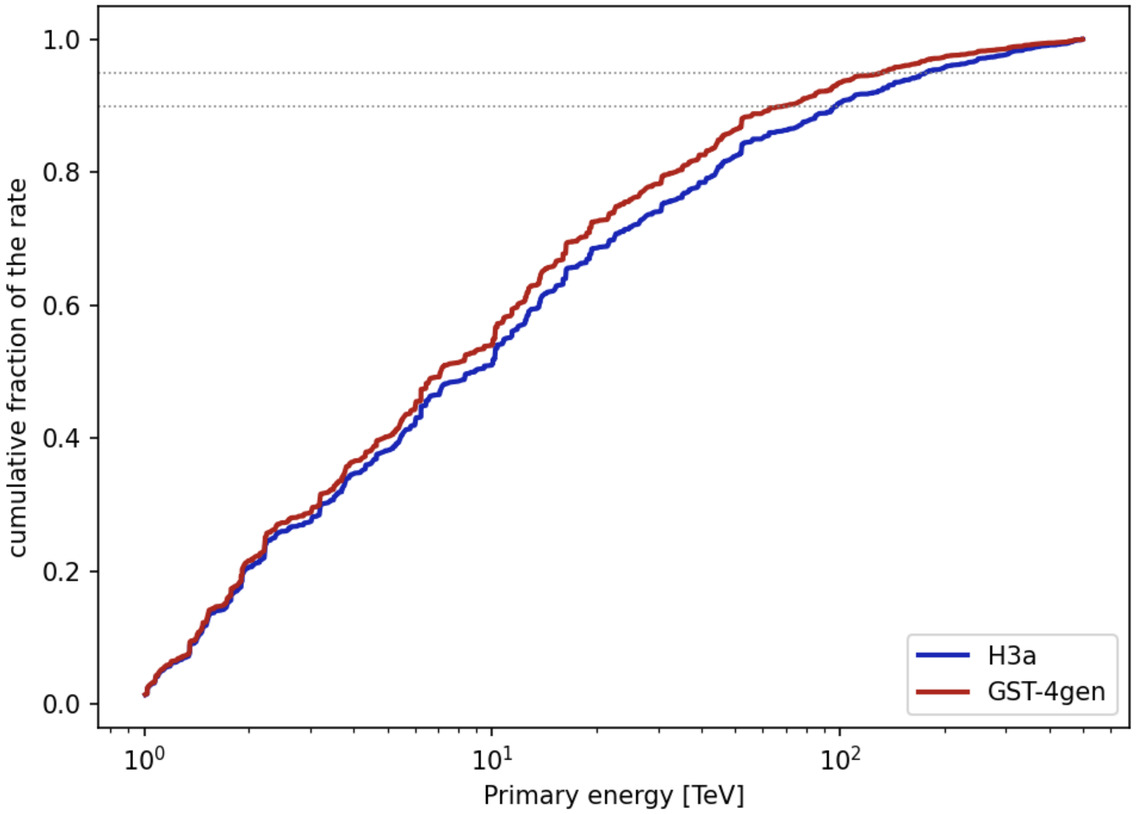


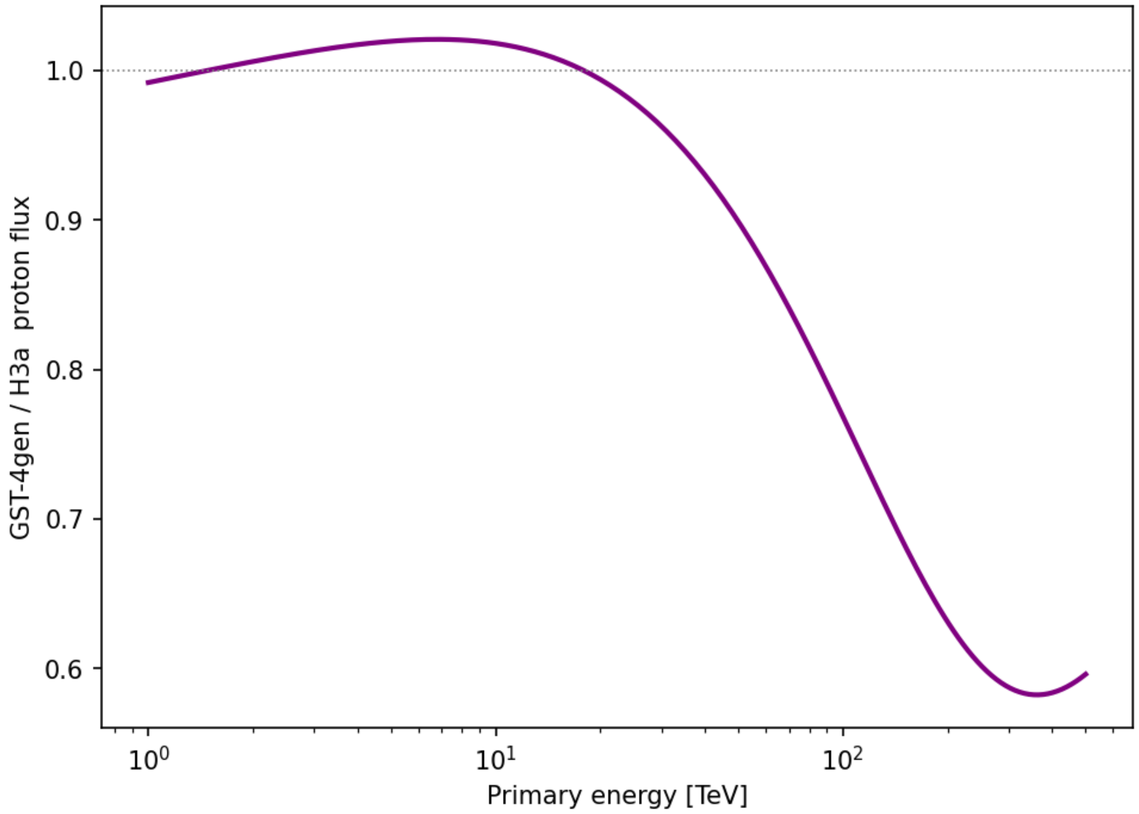


04 Energy range

- Cut depends on the flux model:
  - H3a: 97.1% of the rate is below 250 TeV
  - GST-4gen: 98.2% of the rate is below 250 TeV

Selection of 1 - 250 TeV as the primary energy range





05 TAMBOSim analysis

PROCESS

1) Generate 30k showers: mesh (using TAMBO4.jld2 by Jeff) → primary injection (3_inject.jl) → intercept via ray-casting/BVH (5_run_corsika.jl) → CORSIKA 8 (tambo_shower) simulates the shower → parquet.
2) Apply weight (H3a flux model).
3) Apply detection (criterion of TAMBO-4 array and minimum detectable energy 10 MeV).
4) Report: Scatter 2D plots, kinetic energy per particle type, etc.

Location, magnetic field and parameters

~9.9k proton showers completed (production ongoing) with spectral index $\gamma = -1$ in the energy range from 1-250 TeV.

First location for TAMBO-4 will be Lima, campus PUCP near INRAS

Lima

Lat.:12.07° S

Long.: 77.08° W

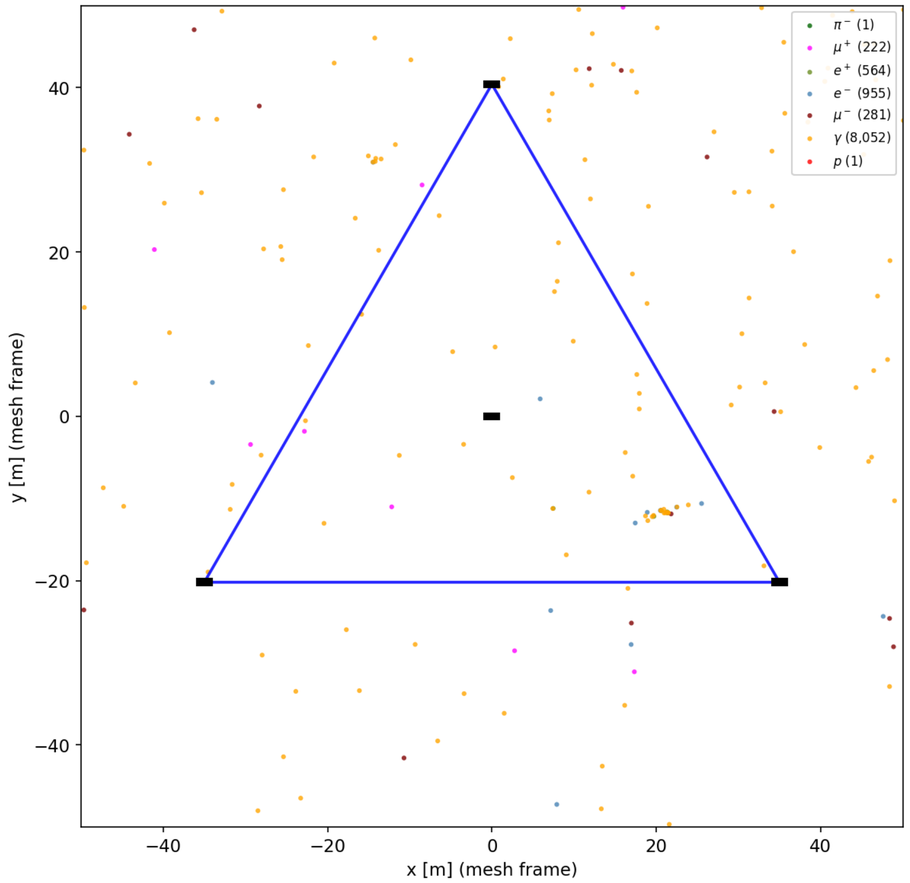
B: $(24.357, -1.525, -0.645)\,\mu\mathrm{T}$

Parameter	Value
`p`	2212 (proton)
`Eslope`	-1
`Energy range`	1 — 250 TeV
`z`	0° — 50°
`a`	0° — 360°
`HE model`	SIBYLL-2.3d
`LE model`	Fluka
`Hadcut, mucut and emcut`	0.3, 0.3, 0.003, 0.003 GeV

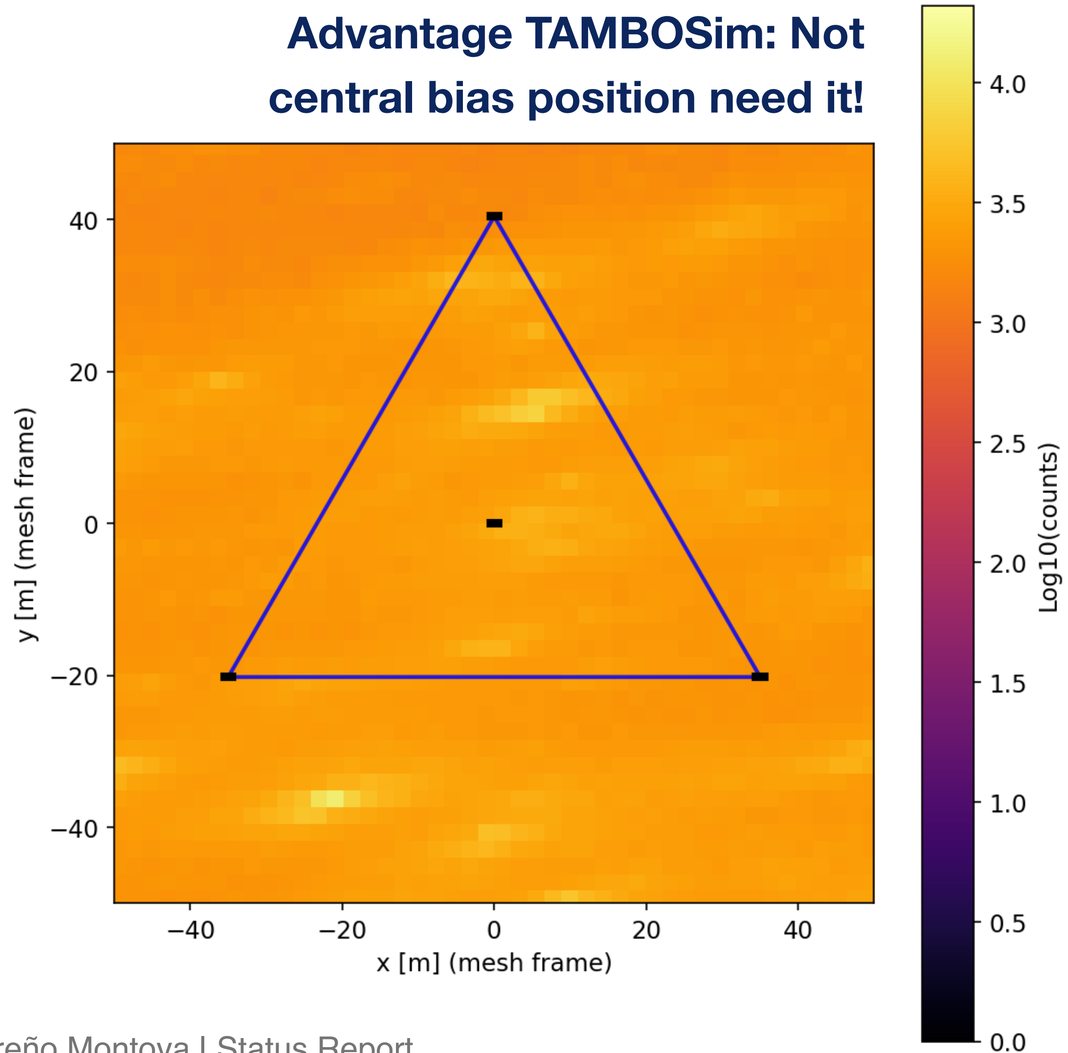
https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfwmm

Results

The 2D histogram of the secondary particle positions shows different “core positions” instead of the Gaussian pattern in the xy plane with only C8.



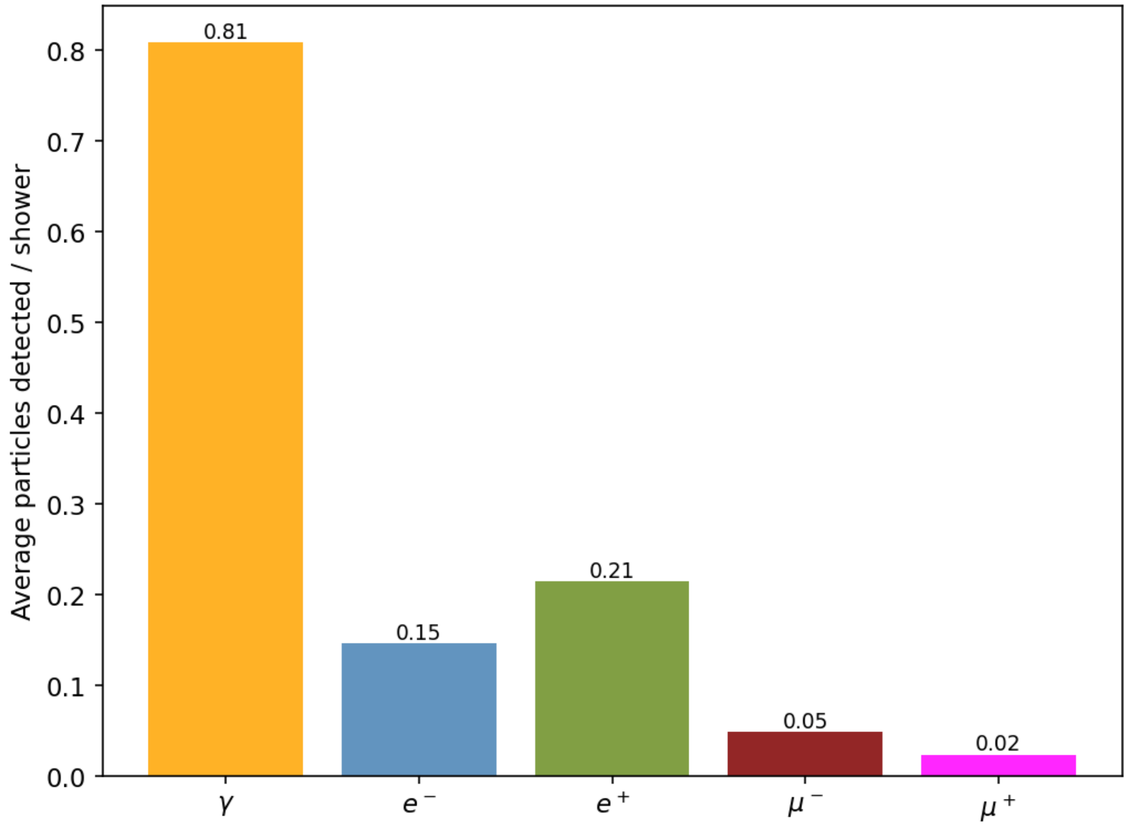
Advantage TAMBOSim: Not central bias position need it!

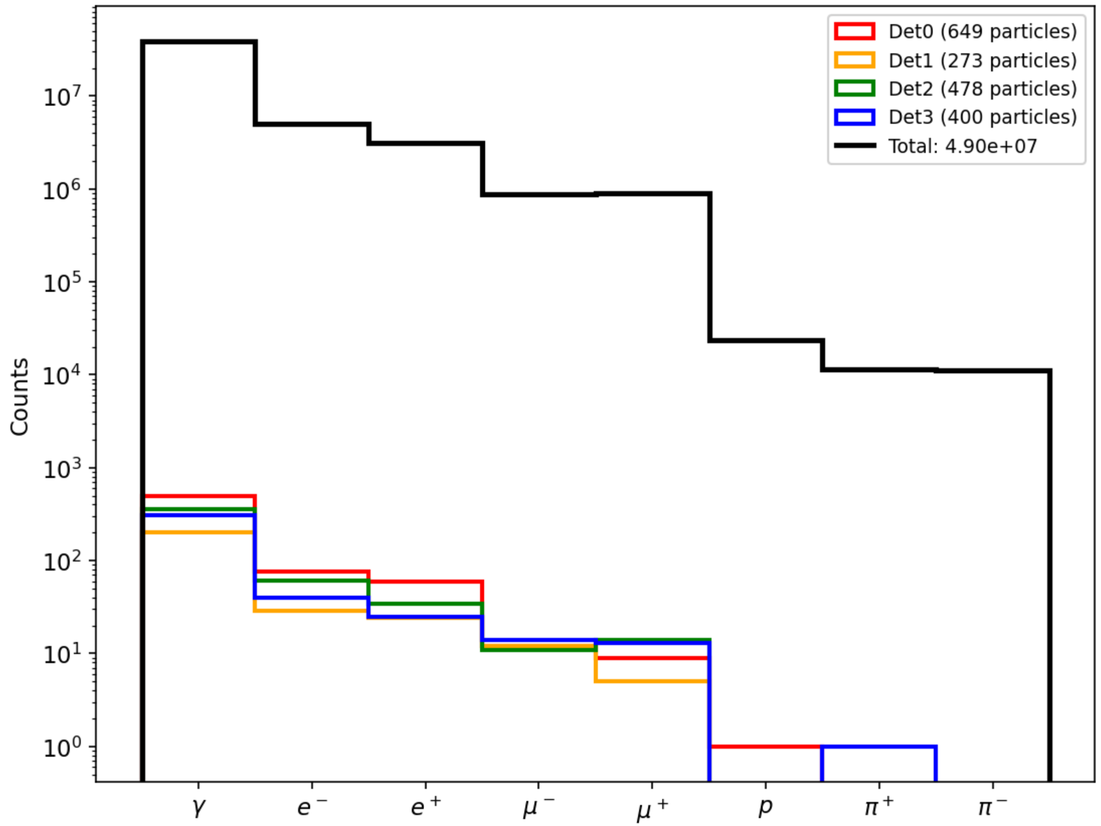


One shower: E (250 TeV), θ_{local} (151°), 10 076 particles

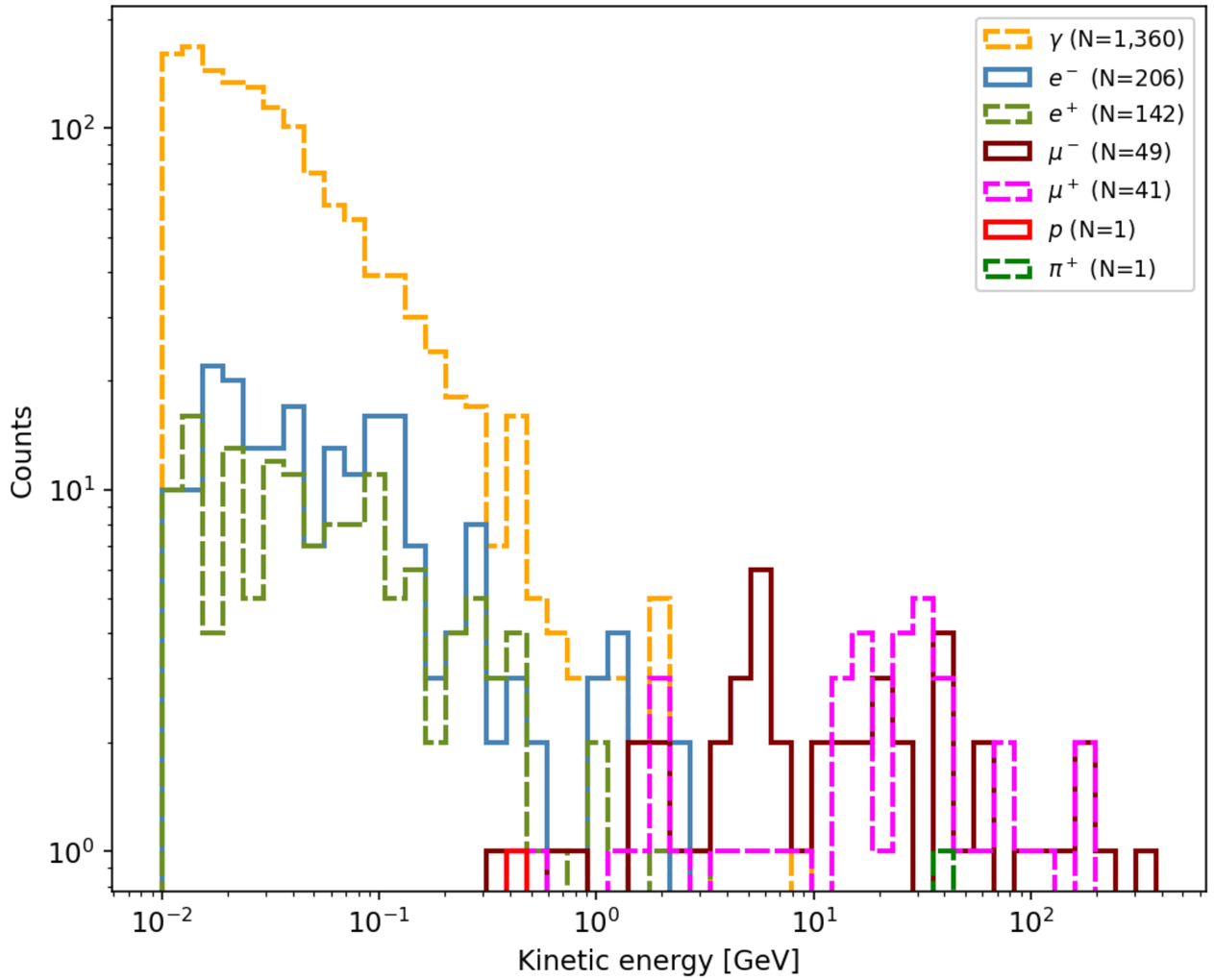
Results

The majority of detected particles are γ, followed by e^- and e^+. The central detector (Det0) receives the highest number of particles. Particles are also detected in the outer panels Det1, Det2, Det3. → Same behavior C8





Results



Photons dominate with an exponentially decreasing spectrum. Electrons and positrons follow with comparable counts, as expected from $\gamma \rightarrow e^{+}e^{-}$ pair production. Muons start to exhibit a characteristic spectrum peaked around 1-30 GeV.

→ Same behavior C8

06 Conclusions

- We demonstrated physical consistency for the Lima atmosphere for May–Nov. Future work should extend it to summer (no garúa), analogous to Pierre Auger's C8 profiles.
- We selected an appropriate energy range of 1 to 250 TeV and further showed how this range relates to the flux models, particularly concerning the high-energy cutoff.
- First validation of TAMBOSim with C8 in terms of CR injection was performed.
- So far, the detected background using TAMBOSim is dominated by the electromagnetic component: photons, followed by e^- and e^+ and muons (μ^-, μ^+). Showing consistency with C8, however, we need to wait to have the complete dataset.

Next: Waiting for the results and analyze them, extend to different ion-showers.

Thank you very much for your attention!

Any questions are welcome :)