Methods and tools for transmission muography

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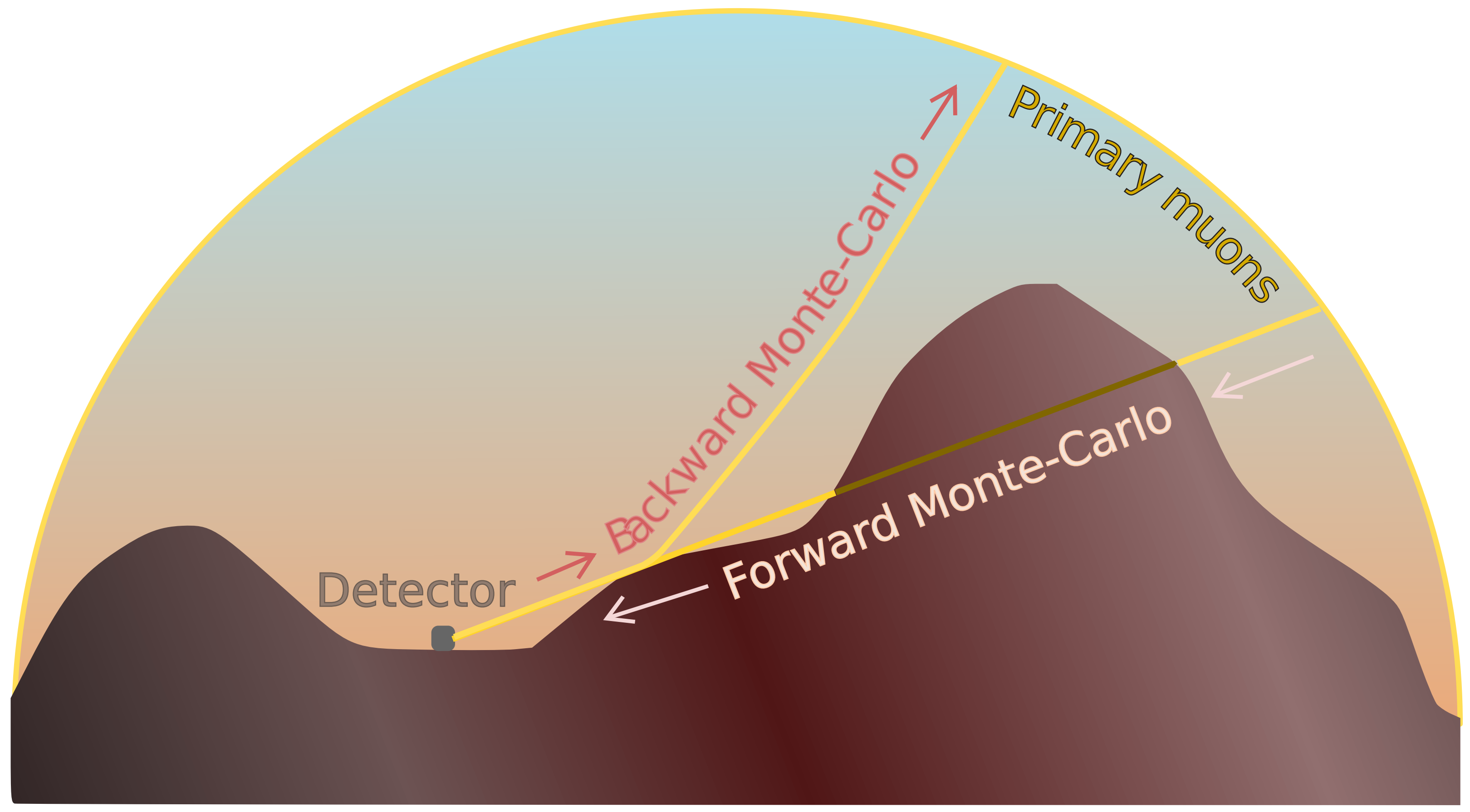


Backward Monte-Carlo

Classical (**forward**) Monte-Carlo is inefficient for simulating the low energy background of scattered particles for muography experiments. This can be understood from pure geometric considerations. The primary source is a skybox of few kilometers while the detector is only a few meters large.

In a **backward** Monte-Carlo the simulation flow is reversed. Muons are backward propagated from a final state of interest in the detector to the primary source. In order to conserve the correct density probablity a jacobian weight factor must be applied at each Monte-Carlo step, as:

$$\omega_{f\to i} = \frac{\partial \mathbf{s}_i}{\partial \mathbf{s}_f}$$

This Monte-Carlo method is an **importance sampling** one. It is analogue to adjoint Monte-Carlo. Note that *one does not reverse the time flow*, e.g. a scattered point source will not be refocused by backward (reverse) sampling.

arXiv.org *Details can be found in arXiv:1705.05636 (Accepted for publication in Comput Phys Commun).*

Implementation : PUMAS

PUMAS is a C99 Monte-Carlo transport engine for relativistic μ. It can run in both **forward** and **backward** mode and has a configurable accuracy on the fly, from fast & straight simulation à la MUM to detailed one à la Geant4. It is shipped with an executable, *pumas-tabulate*, generating muon **energy loss tables in the PDG format**. These tables, or those provided by the PDG, are needed as input for the engine's initialisation.

Available from https://github.com/niess/pumas

Muon fluxes computed with PUMAS

Fig: **muon spectra** computed for the bottom zone (R3) of the **Showa-Shinzan** toy model of Nishiyama, R. *et al.* Geosci. Instrum. Methods Data Sys. **3**, 29-39. A Gaisser primary spectrum was used. Geant4 requires 10^3 CPU x days with a 31×10^3 m^2 detector. *Few hours* needed with PUMAS in backward mode.

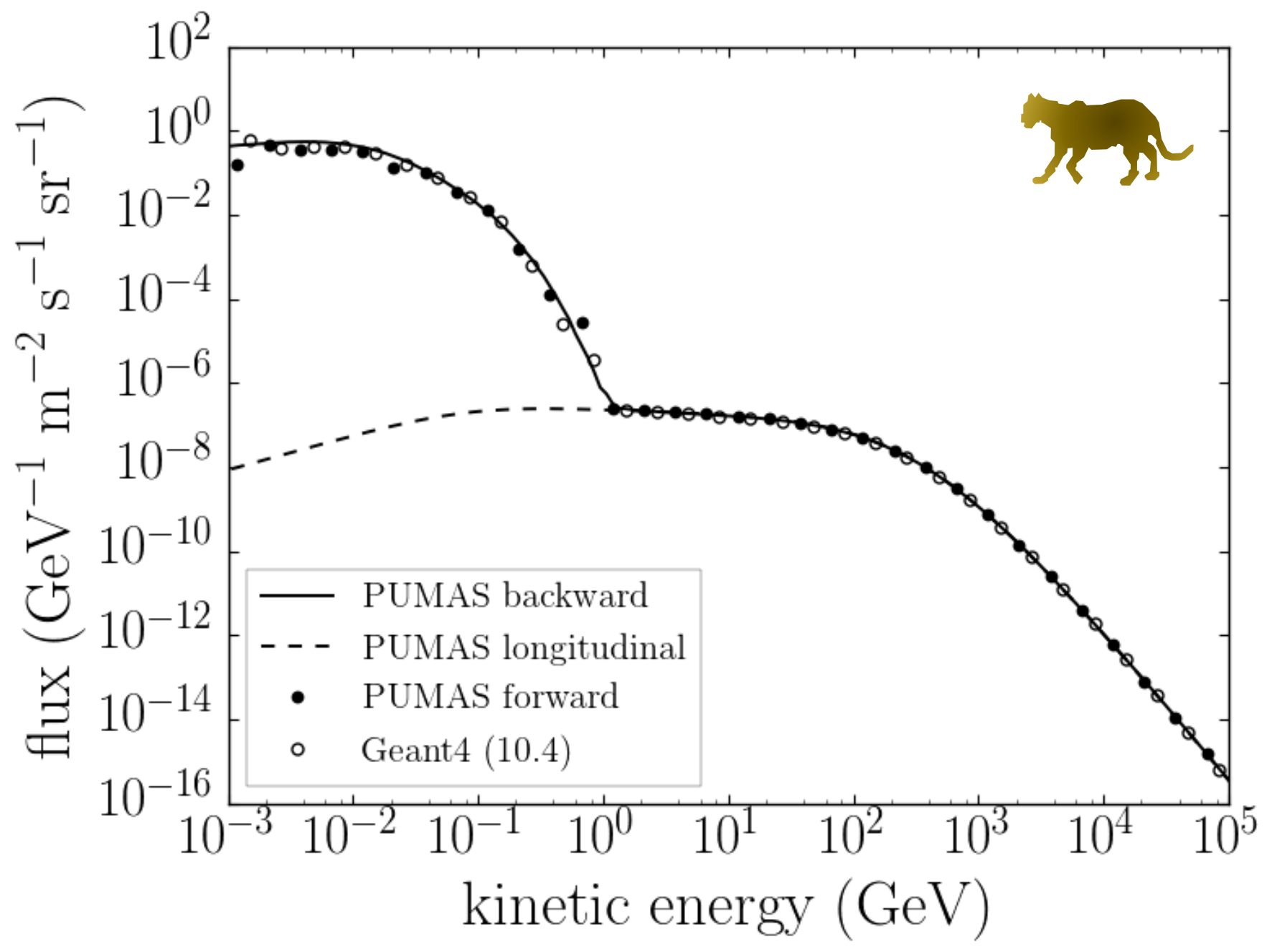
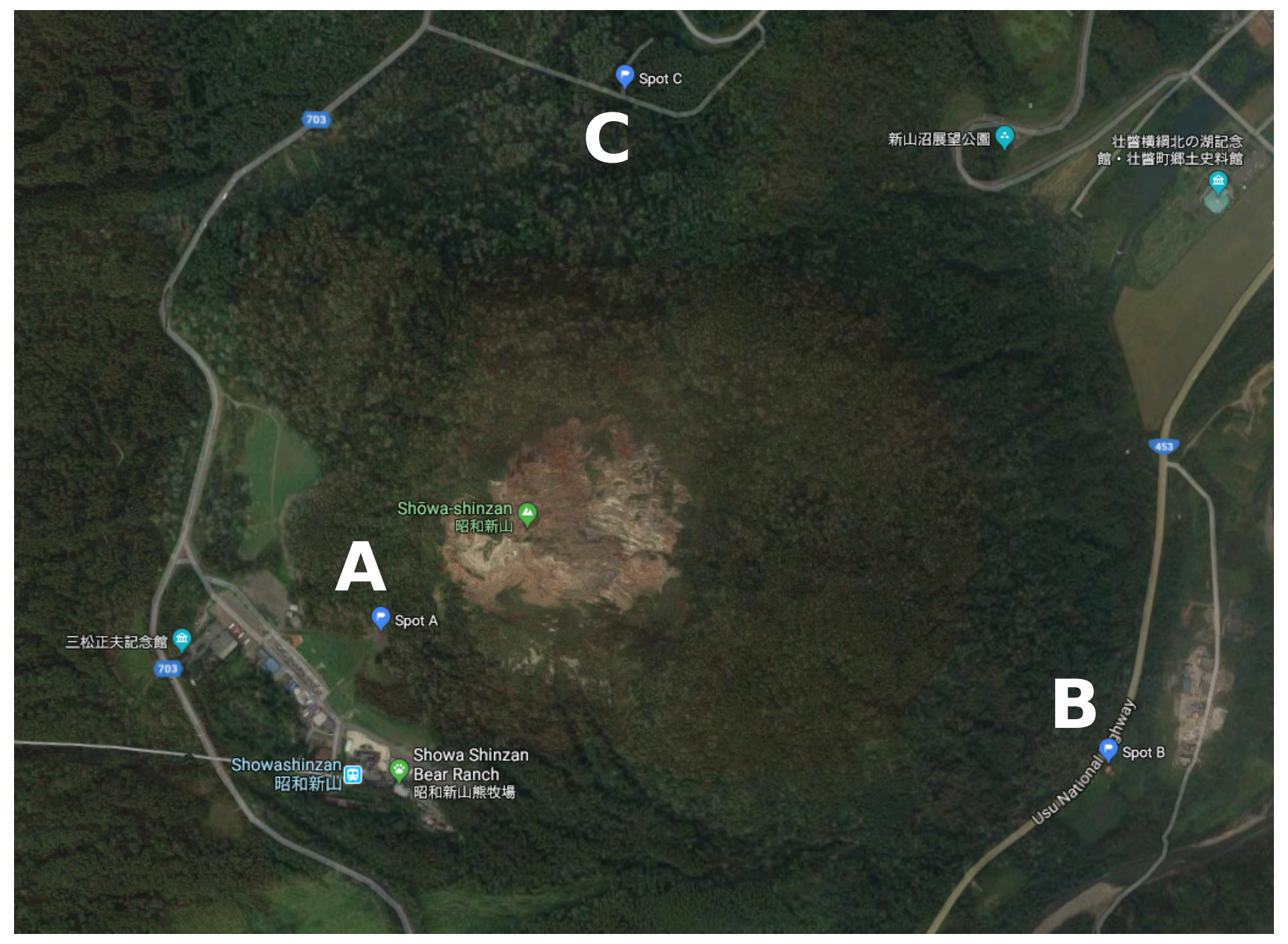
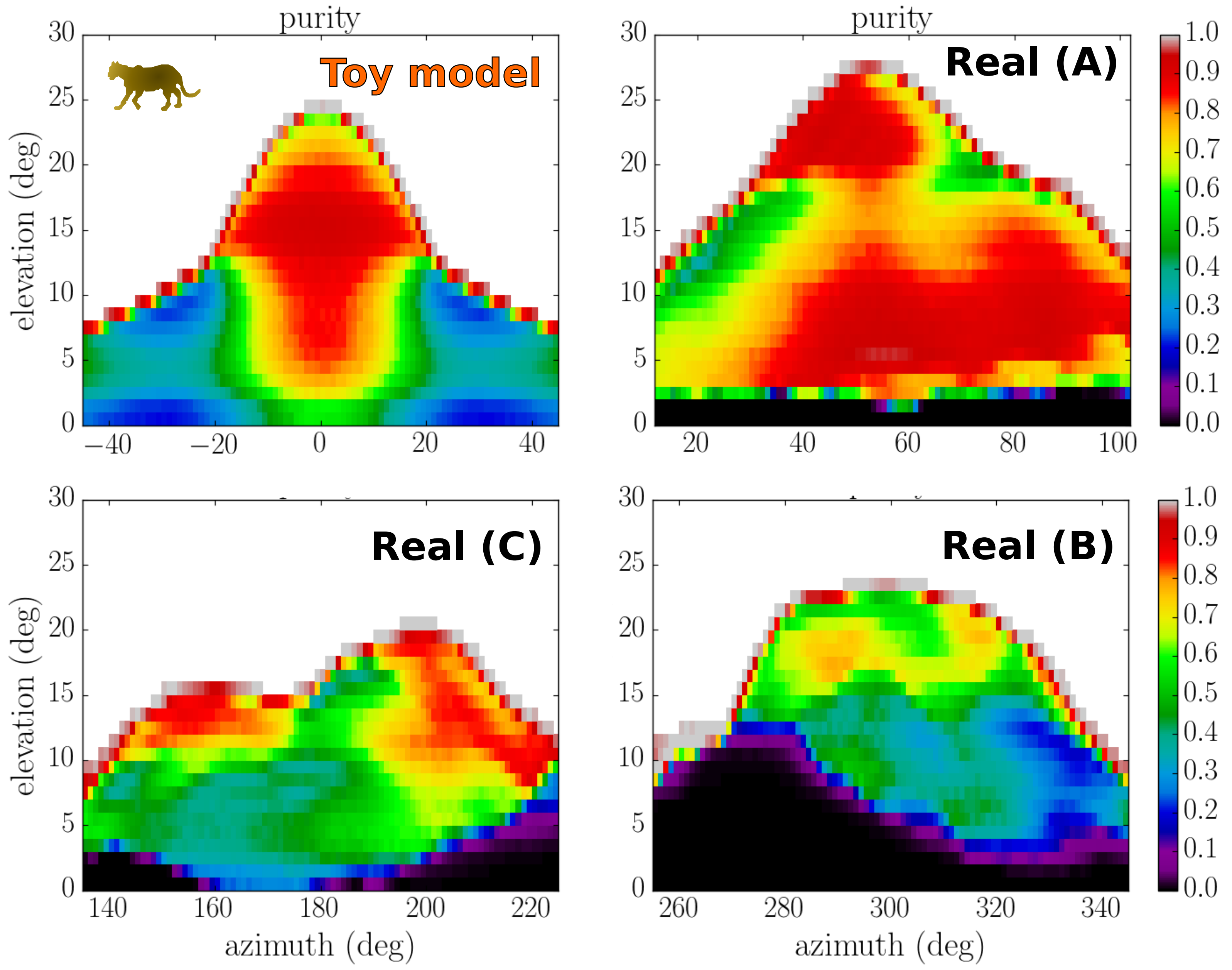


Fig: **purity** of the muon flux computed with PUMAS for various locations around **Showa-Shinzan** and using the previous toy model. The purity is defined as the ratio of the integrated muon fluxes above 100 MeV w/ and w/o scattering. The primary muon flux was computed with CORSIKA.





MuogrAphy Kernel Inversion

In **transmission muography** one counts the number of atmospheric muons (μ) crossing a 1 m^2 detection area over a given time. Large structure(s) surrounding the detector cast a shadow in the μ count, e.g. buildings, mountains. The intensity of this shadow is informative on the shader's shape, density and to a lesser extent on its composition. Extracting any of this information from the μ rate is an inverse problem.

The thicker and denser the shader, the lower the statistics of muons in the shadow area, limiting the quality of the inverted images. **MAKI** is a dedicated kernel based inversion algorithm: it controls statistical fluctuations by varying the resolution (kernel size) over an image depending on the expected muon rate.