GRAND simulations

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Radio-Workshop

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DESY Zeuthen, Brandenburg, Germany

(pdf) (html)

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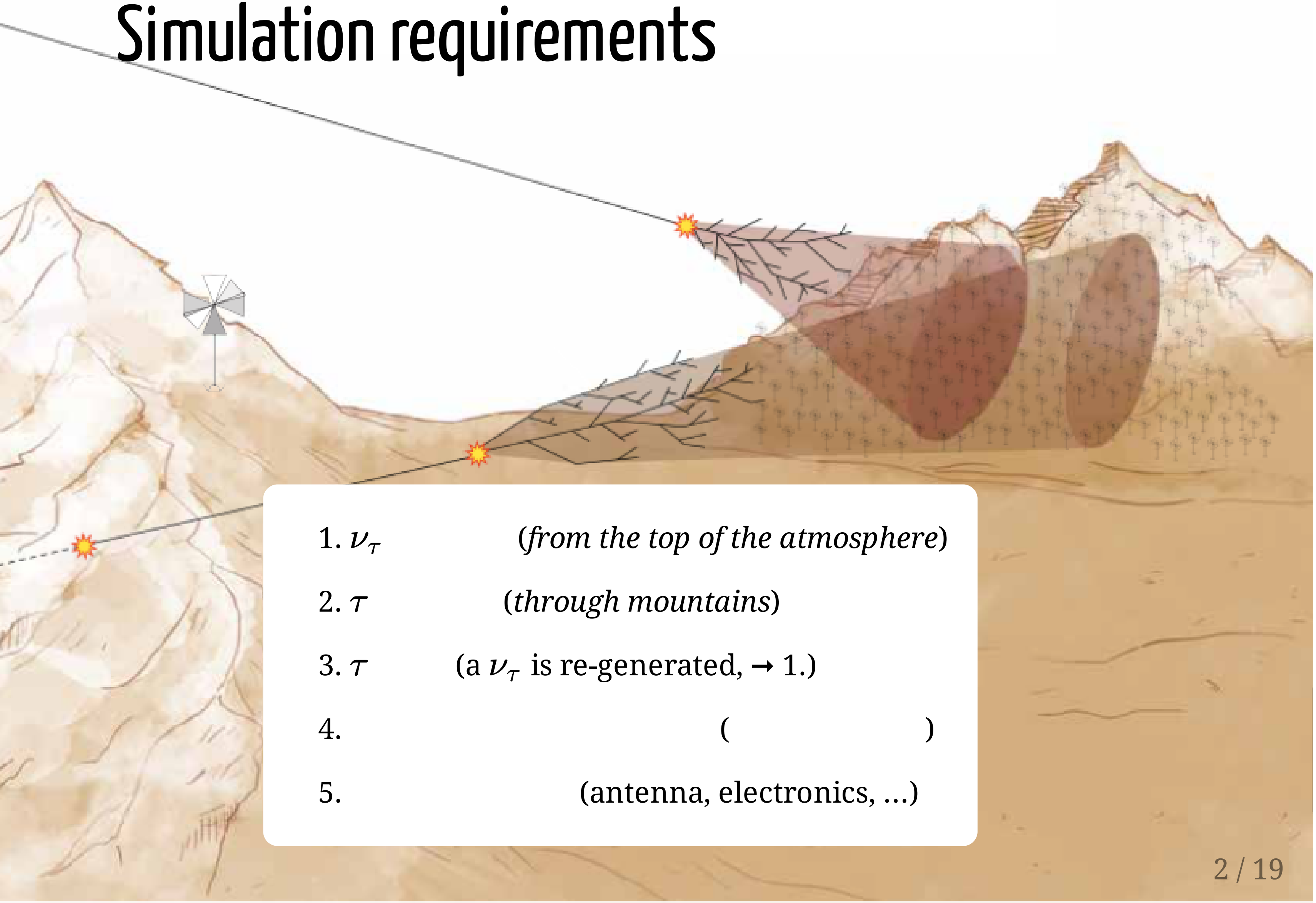
Simulation requirements



1. ν_τ *(from the top of the atmosphere)*
2. τ *(through mountains)*
3. τ (a ν_τ is re-generated, → 1.)
4. ( )
5. (antenna, electronics, …)

Implemented simulation scheme

Original software components have been developped for GRAND.

τ *over the sensitive area* ( ).

τ

> Coupled $\nu_\tau - \tau$ transport with a .
> Includes backward τ decay by wrapping TAUOLA.

1. τ decay with TAUOLA
2. Shower & EM field sampling ZHAires
3. Detector response

in a nutshell

For more details see ArXiv:1811.01750 (accepted in Astropart. Phys.), *or ask Anne Zilles*.

Radio-simulate one *reference* shower, compute any radio signal by:

1. Scaling the electric-field amplitude of the reference shower.
2. Applying an isometry on the simulated positions.
3. Interpolating the radio pulse at the desired position.

The resulting electric field traces are very similar to detailed computation (~10%) while a speed-up by several orders of magnitude is achieved.

Backward Monte-carlo for Physicists

Details can be found in V. Niess *et. al*, CPC 229 (2018).

Let us consider a simple Monte-Carlo (energy loss) process, described as:

$$E_f = F(E_i, u)$$

with u uniform in $[0, 1]$. Then, if F can be inverted w.r.t. to E, the process can be backward sampled as:

$$E_i = F_u^{-1}(E_f, u)$$
$$\omega_i = \omega_f \left| \frac{\partial E_i}{\partial E_f} \right|$$

The Monte-Carlo events must be re-weighted (ω_i) by a Jacobian factor corresponding to the change of sampling variable from E_i to E_f.

If the Monte-Carlo process is difficult to invert, a bias process can be used instead, E.g. the adjoint process, a power law, etc.

The $\nu_\tau - \tau$ simulation : DANTON

(ec yi g aus fr m eutrinos)

Recycling of software components formerly developed for TREND and for muography. Detailed yet fast MC simulation thanks to the backward technique.

Draft preprint:arXiv:1810.01978.

: , : library (API) *and* executable (API)

build passing LGPL

Beta version, *validated*, but the geometry & API will change

DANTON performances

Consistent with NuTauSim within theoretical uncertainties. More efficient in backward mode.

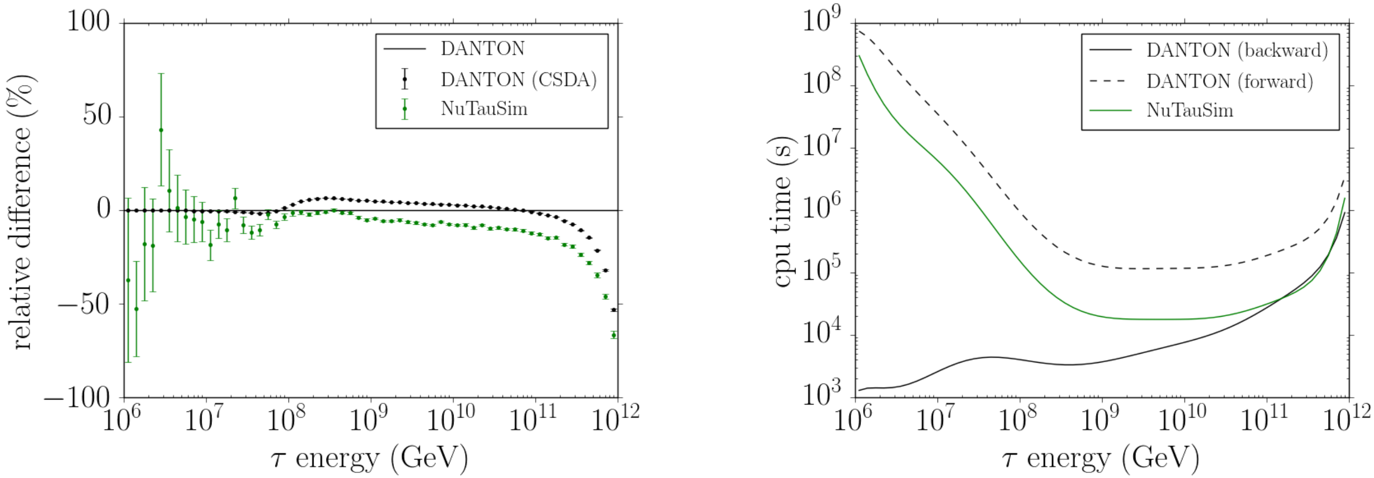


Figure 1: Comparison of NuTauSim and DANTON for the upward τ flux emerging from the Earth with an elevation angle of 1 deg and for a $1/E^2$ primary ν_τ flux. Left: relative difference to DANTON. Right: CPU time needed for reaching a 1 % Monte-Carlo accuracy.

DANTON software components

All components are independent libraries, depending on the standard library, and available from GitHub under LGPLv3 license.

- PUMAS — V. Niess *et. al*, CPC 229 (2018)

  Revertible transport engine initially for μ (muography), extended to τ for GRAND.

  > Pure μ (τ) transport engine. Secondaries are not recorded, nor tracked. Could be added though.

- ENT

  Revertible transport engine for high energy neutrinos. Strongly influenced by PUMAS.

DANTON software components

All components are independent libraries, depending on the standard library, and available from GitHub under LGPLv3 license.

- ALOUETTE

  Thin wrapper for TAUOLA providing backward decays, from ν_τ to τ.

  - Depends on TAUOLA, requiring e.g. .

- TURTLE arXiv:1904.03435, under review

  Wrapper for stepping through topography data. Optimized for and applications.

  - Some topography data formats might require or .

PUMAS

Two files: and (10 kLOC) with no external dependencies. Works (almost) *everywhere*: Linux, OSX, Windows, , , …

Clear namespaces: , , *etc*. Documentation generated with (initially developped for).

Can be operated in or mode. As a fast simulation *a la* MUM, or a detailed one *a la* Geant4. Settings can be changed on the fly, E.g. depending on the particle energy.

PUMAS

Separation of read only shared data (Physics tabulations) and writeable temporaries within isolated simulation contexts.

Predefined DCS for , , ,
and processes. *Could easilly be made modular*.
according to energy loss tables, *per material*, in .

Materials & composites Physical properties are specified in an XML file. The Physics can be dumped & reloaded in binary format for .

No explicit geometry. Instead the navigation uses a generic *callback*. Flexible mechanism. E.g. interface to , , *etc.*

PUMAS

PUMAS forward and backward modes agree at better than 1%. Excelent aggreement with legacy codes as well (Geant4, MUM, MUSIC).

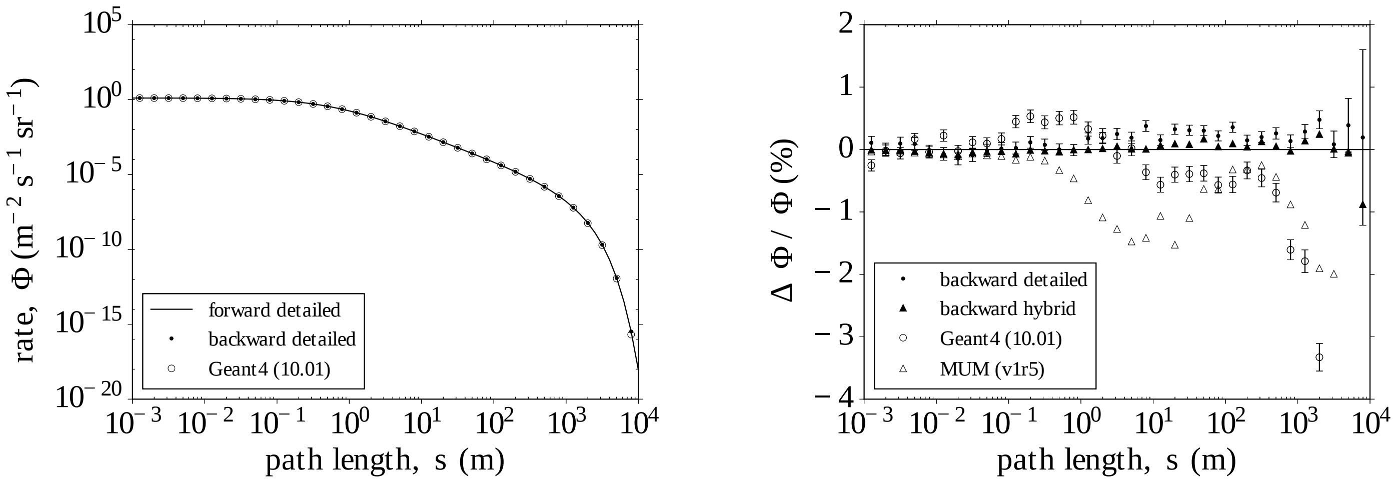
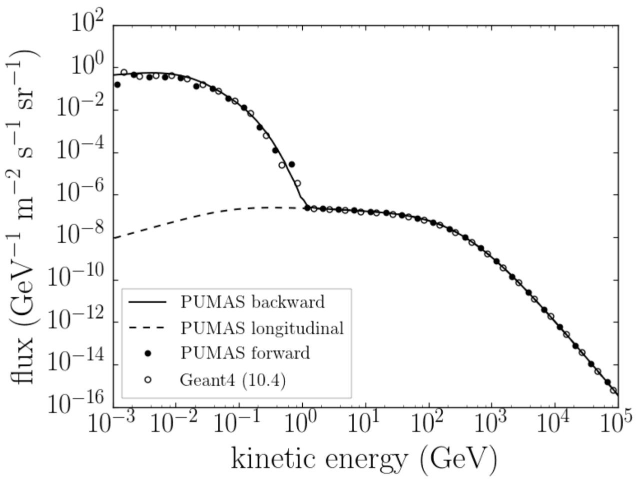


Figure 2: Left: integrated rate of muons transmitted through standard rock for a Gaisser spectrum. Right: relative difference w.r.t. PUMAS in mode.

PUMAS

*Tremendous speed up (**x10^4**) over classical Monte-Carlo for muography applications while delivering same accuracy.*



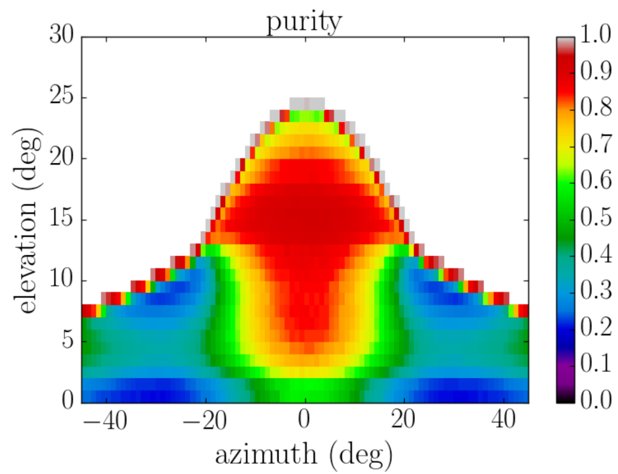


Figure 3: Example of μ spectrum for a toy model of volcano with a cylindrical symmetry. Right: fraction of straight going μ for the same model.

ENT

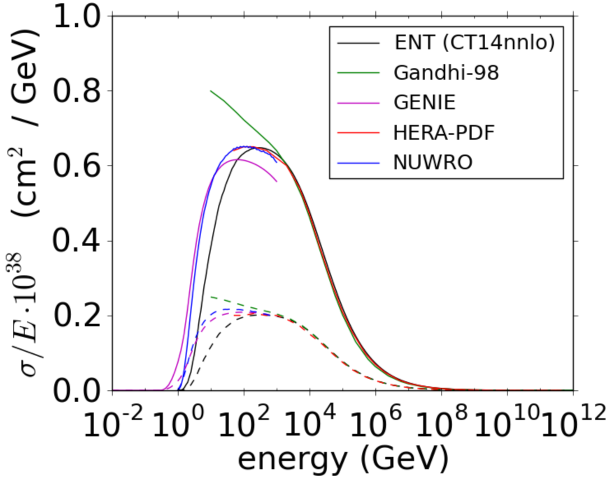
Similar to PUMAS: Plug and play (ent.h and ent.c, 3 kLOC), structured OO API, thread safe and generic geometry navigation allowing for *explicit materials composition*.

See e.g. Gandhi et al. (arXiv:hep-ph/9512364) or J.A. Formaggio and G.P. Zeller (arXiv:1305.7513) for more detailed discussions.

- DIS DCS are computed at NLO from input PDF provided in (*Les Houches Accord*). This is done dynamically, at the Physics initialisation.
- Scattering on atomic electrons is implemented as well, E.g. the Glashow resonant process $\bar{\nu}_e e^- \rightarrow W^-$.

ENT

DIS cross-sections are in good agreement (~10 %) with other recent computations for UHE ν. Discrepancies are observed below TeV w.r.t. dedicated low energy codes.



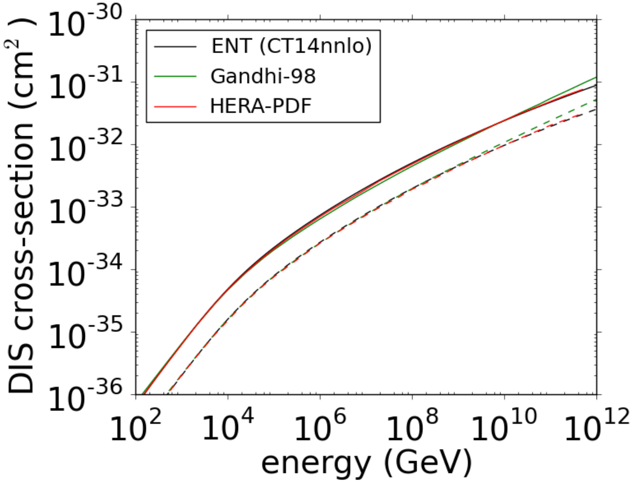


Figure 4 : Comparison of DIS cross-sections for various computations. For ENT the CT14nnlo Parton Distribution Functions have been used. Solid lines stand for CC interactions and dashed lines for NC ones.

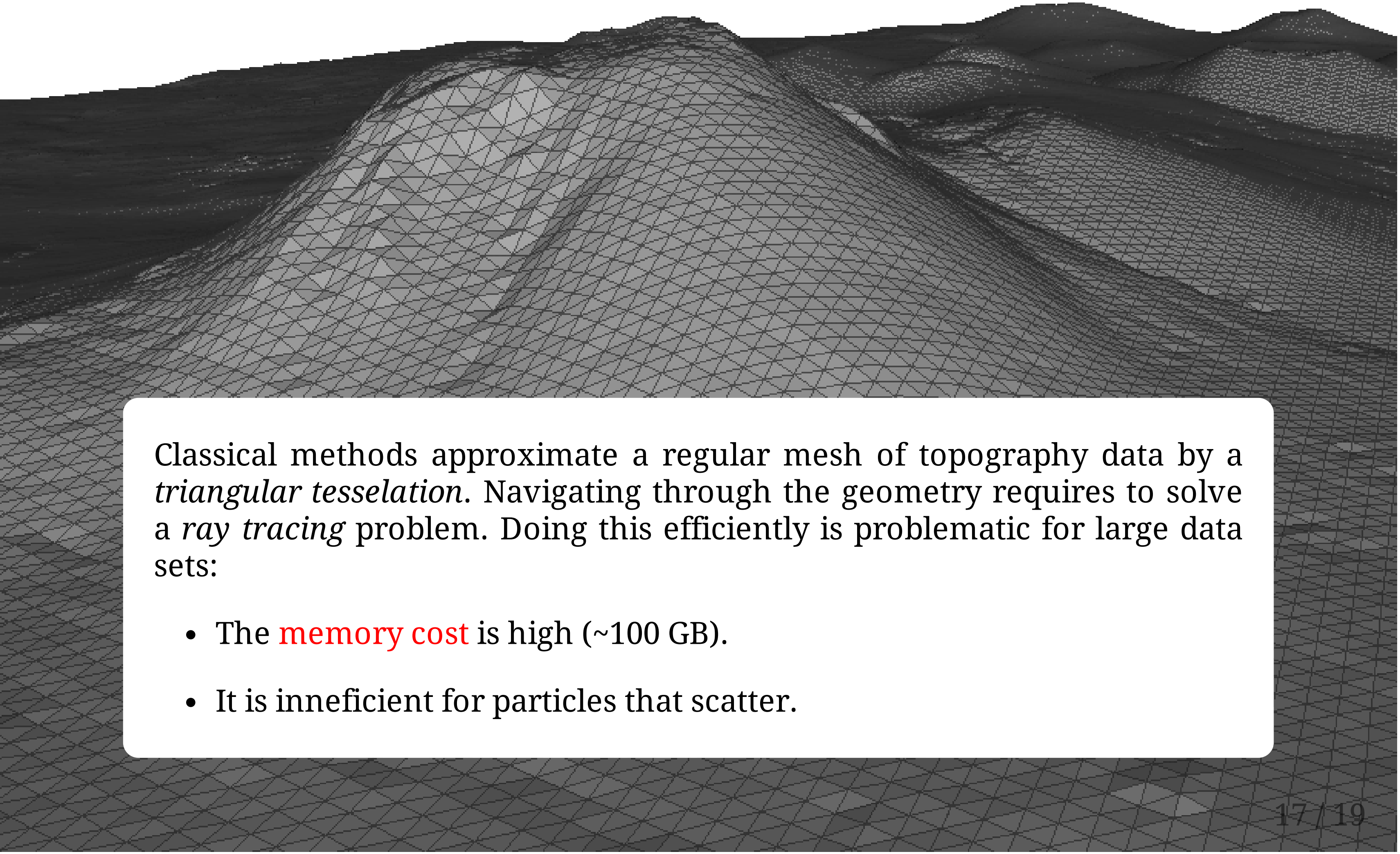
ALOUETTE

Simple wrapper to TAUOLA. The wrapper itself is only two files (alouette.h and alouette.c, 500 LOC), with a structured OO API. TAUOLA v2.9 (FORTRAN) is packaged with the source.

The implementation requires a POSIX system and is not thread safe (TAUOLA isn't neither).

The decay Physics is fully handled by TAUOLA. Backward decays, $\nu_\tau + X \rightarrow \tau$, are generated from a rest frame τ decay provided by TAUOLA.

TURTLE



Classical methods approximate a regular mesh of topography data by a *triangular tesselation*. Navigating through the geometry requires to solve a *ray tracing* problem. Doing this efficiently is problematic for large data sets:

- The memory cost is high (~100 GB).
- It is inneficient for particles that scatter.

TURTLE

Additional details can also be found here.

Optimistic

Proceed by trials and errors. The average approximation error (~8 μm) is well below the topography measurements accuracy (10 cm). In addition, a higher level interpolation can be used, improving the accuracy over a triangular tesselation.

In detailed Monte-Carlo, the slow down due to the topography resolution is only a factor 2 with no exra memory cost.

Turtle allows multiple topography layers to be defined E.g. rocks and ice. *This is not yet included in DANTON though*.

Putting things together

is our current . Various scripts are used:

- To steer the ν_τ simulation and mass produce τ events.
- To produce the corresponding radio signals.
- To model the detector response: antenna, digitization, noise.

Currently we are in a process of updating, standardising and cleaning this glue level. We migrated to and interfaced to .