Recent upgrades of the simulation, geometry and reconstruction modules of the ANTS2 toolkit

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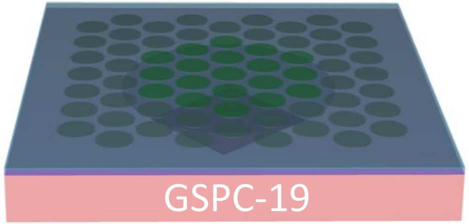
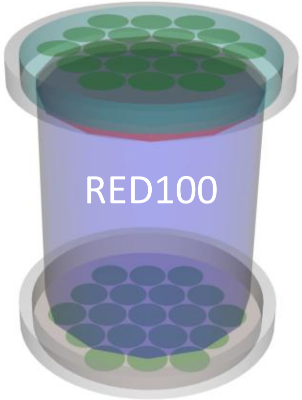
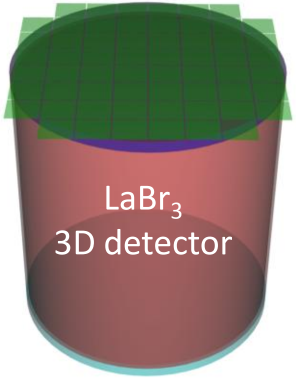
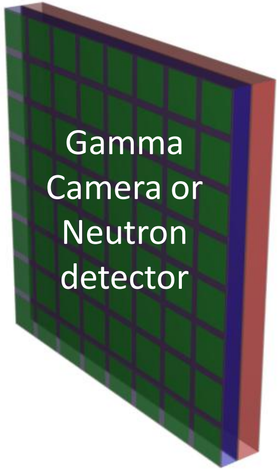
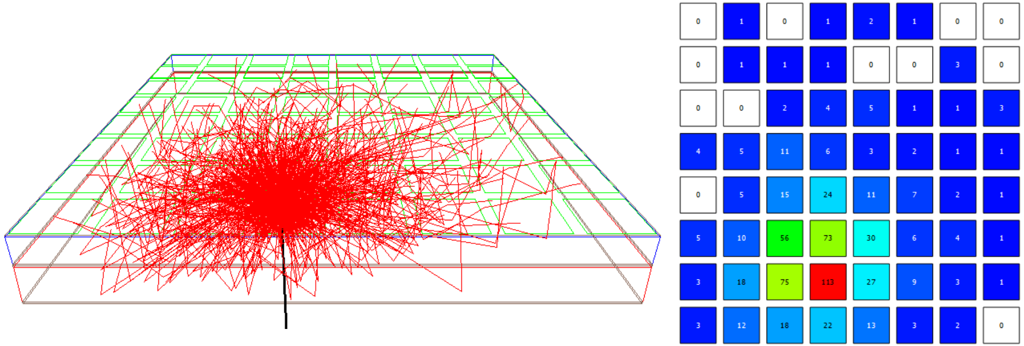
Position Sensitive Scintillation Detectors











Emitted photons and sensor hits following a gamma ray event

ANTS2 highlights

ANTS2 toolkit was created to assist at all stages of PSSD detector development, including:

- conceptual design
- detector optimization
- development of event processing algorithms
- detector calibration
- processing of experimental data (real-time capability)

ANTS2 highlights

Scintillation event reconstruction (position + energy)

- Center of gravity
- Statistical algorithms
  - C++ (fast) and script (highly customizable) based implementations
  - Contracting grids on GPUs (up to ~10^6 events/s)
- Artificial neural networks
- kNN-based reconstruction

Detector response reconstruction

- B-spline and analytic parameterization of sensor response
- Grouping of the sensor to take advantage of the array symmetry
- Iterative reconstruction of the detector response
- A set of tools for calculation of relative sensor response

ANTS2 highlights

Simulations

- 3D, custom detector geometry
- Generation and tracking of gamma rays, neutrons and positive ions
- Primary and secondary scintillation
- Time- and wavelength-resolved tracking of optical photons
- Photon scattering, wavelength shifters
- Signal formation for PMTs and SiPMs

Experimental data processing

- Import and preprocessing of experimental data
- Event discrimination tools (noise and multiple event rejection)

Large collection of tools for characterization of PSSD performance

Detector response reconstruction

Light Response Functions (LRF) are used to describe the response of PSSD to the scintillation light.

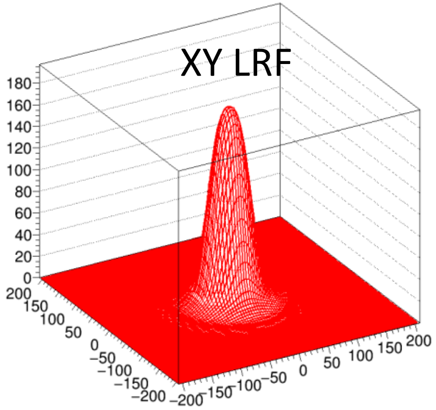
LRF gives the average signal of a sensor *vs* the light source position.

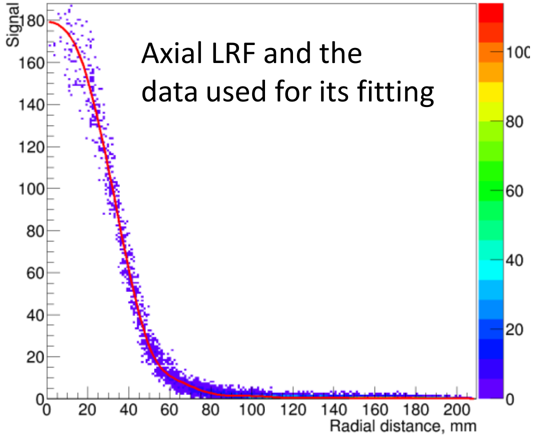
LRF parameterization schemes in ANTS2:

- Cubic B-splines:
  1D (axial symmetry), 2D (XY or axial+Z), and 3D (XYZ or sets of XY LRFs)
- Analytic functions (defined using scripts)
- Custom C++ code through plug-in interface
- Composite LRFs (LRF is a sum of several components)

It is possible to group light sensors and use a common LRF profile for several sensors to benefit from the symmetry of the sensor array.

New features in the B-spline library: constraints on the LRF profile during fitting, e.g., non-increasing function, always positive, and flat-top.

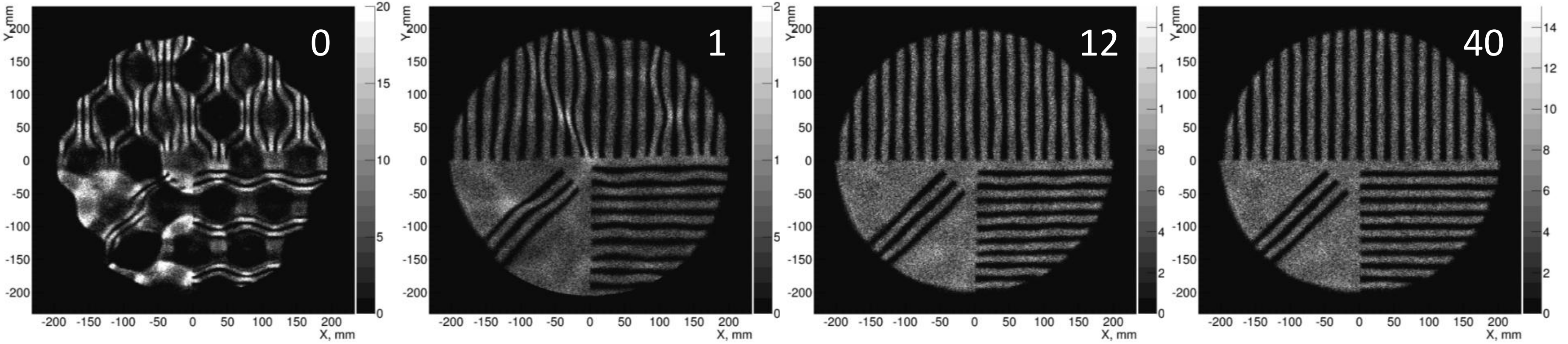




Iterative response reconstruction

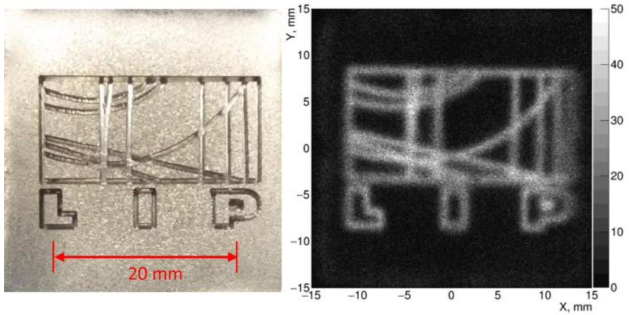
ANTS2 offers tools for *iterative response reconstruction:* LRFs can be reconstructed from flood field calibration data without known true event positions!

Reconstruction tests after 0, 1, 12 and 40 iterations



Feasibility demonstrated for:

- compact camera: Phys. Med. Biol. 62 (2017) 3619
- medical gamma camera: Phys. Med. Biol. 60 (2015) 4169
- GSPC neutron detector: 2012 IEEE NSS/MIC N21-6
- dual phase Xe scintillation detectors: IEEE Trans. Nucl. Sci. 59 (2012) 3286

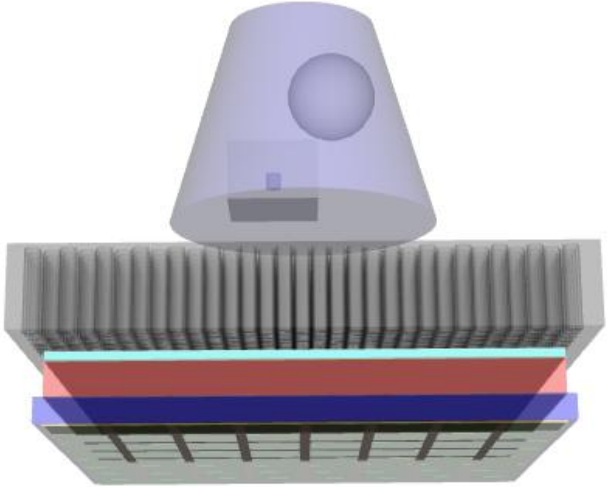


The mask and it's image for the compact gamma camera.

Simulations: Geometry and 3D navigation

TGeoManager from CERN ROOT stores the detector geometry and is used for tracking

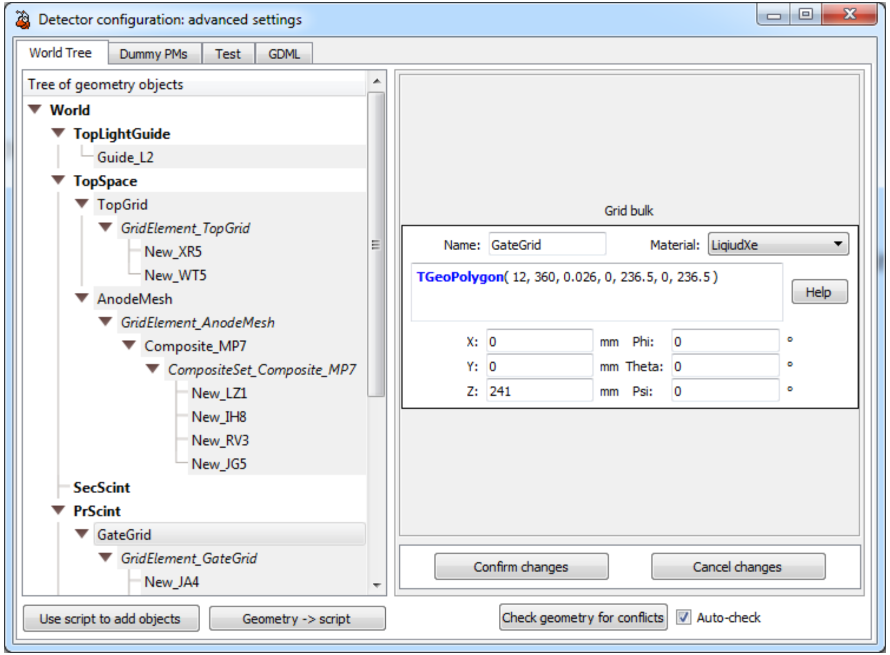
- Tens of elementary shapes + composite volumes
- 3D navigator with multithreading
- Access to a large collection of visualization tools
- Geometry can be exchanged with Geant4 using GDML files

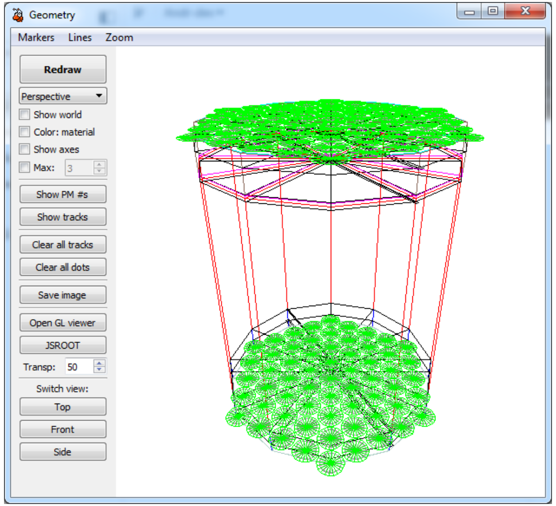


ANTS2 model for simulation of SPECT

Detector geometry

- Detector geometry is defined in a tree-like structure
- Stored in JSON configuration file
- Can be created and modified through
  - Interactive GUI
  - Script (Python, JavaScript)



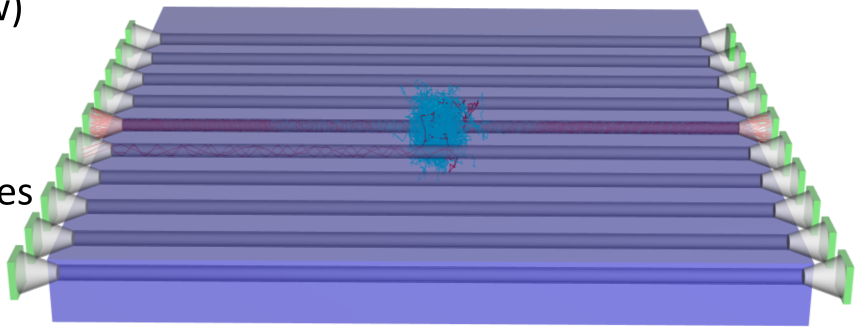


Tools are provided for simple handling of:

- Arrays of objects
- Stacks of objects
- Compound lightguides
- Grids/meshes of wires

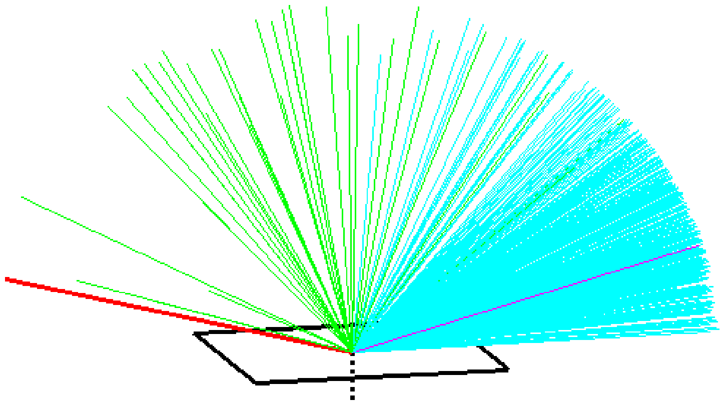
Photon tracing

- Reflection / refraction (Fresnel equations, Snell's law)
- Absorption (+ reemission with wavelength shifting)
- Rayleigh scattering
- Custom rules at the boundaries of geometry volumes


Photon tracing with wavelength shifting fibers

The custom rules:

- defined for a pair of materials (*from* and *to*)
- in the simplest case include the probabilities of absorption, specular reflection and Lambertian scattering (can be wavelength-resolved)
- advanced models describe light scattering on rough surfaces, dielectric-metal interface and wavelength shifters
- custom models can now be defined with a script!


Photon scattering on rough surface: special rule defined in ANTS2

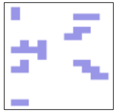
Sensor signal generation

Signal generation for PMTs and SiPMs taking into account:

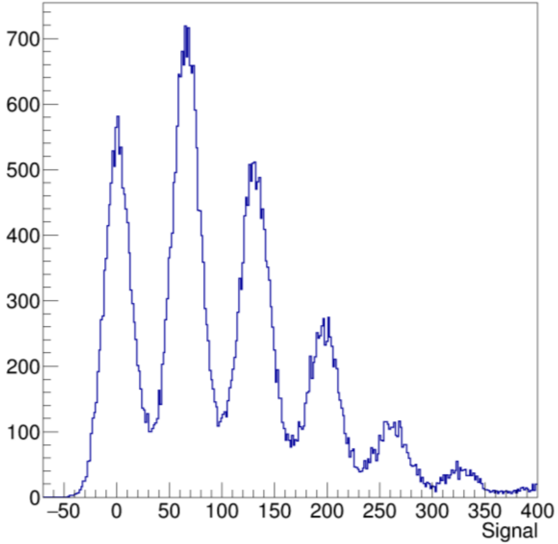
- Photon detection efficiency
  - optionally *vs* wavelength, angle of incidence, and position
- the number of SiPM microcells and the dark count rate
- Signal readout properties
  - single photoelectron spectrum
  - electronic noise
  - signal digitalization properties

Two models were added for simulation of SiPM optical crosstalk:

- Statistical model
- Four-neighbor pixel model →



The computation algorithm for the contribution of the dark counts to the signal was improved by taking into account timing properties.

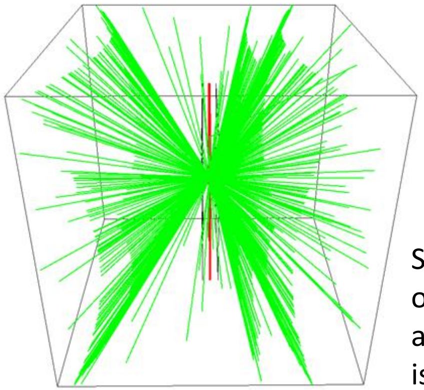


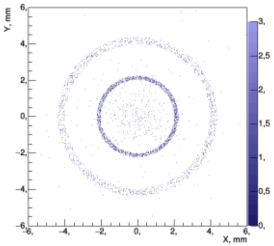
ANTS2 simulation: distribution of signals from a SiPM sensor, showing the contributions from 0 to 5 photoelectrons.

Neutrons

Targeting thermal neutron detectors:

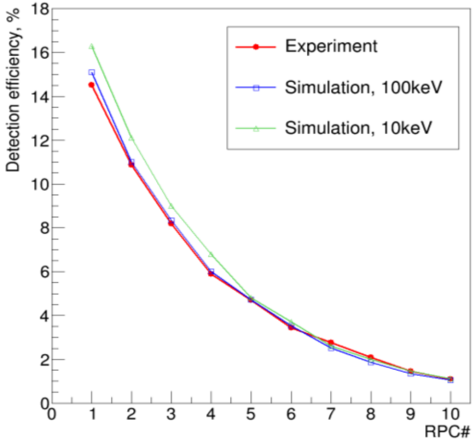
- New material system with configurable isotope composition was implemented
- ANTS2 can now simulate neutron interactions:
  - absorption (including capture + emission of fission fragments)
  - elastic scattering
    - Gas model
    - Coherent elastic scattering on polycrystalline materials using NCrystal library





Simulation of scattering of thermal neutrons on an Al plate. Direct beam is suppressed.

Basic validation study shows good match of the simulated and experimental detection efficiencies.



Experiment vs simulation (two thresholds)

Semi-automatic optimization

A multi-parameter optimization is often required during detector development.

The brute-force approach (can be very time-consuming!)

- Define a grid of parameter values
- Perform simulation + analysis for each grid node
- Find the best node

ANTS2 offers a more efficient alternative:

In script, define a minimization function. This function will be called by the minimizer, running, e.g. Simplex algorithm. On each call from the minimizer the function:

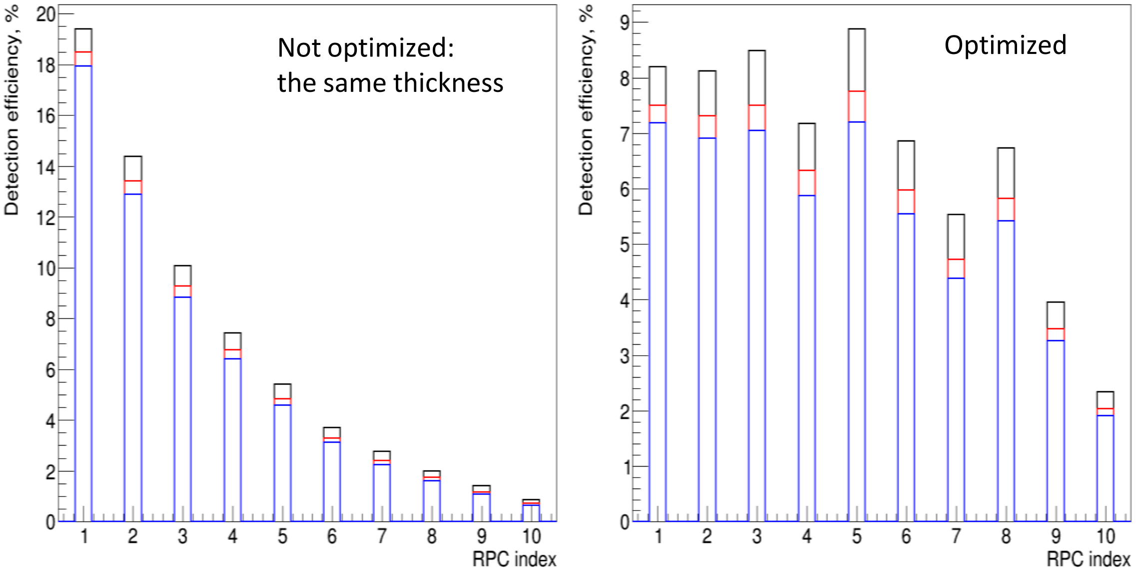
- modifies the detector geometry
- runs a simulation providing a set of events
- reconstructs the events
- performs analysis and returns the goodness value to the minimizer.

Semi-automatic optimization

^{10}B-RPC thermal neutron detector with 10 RPCs:

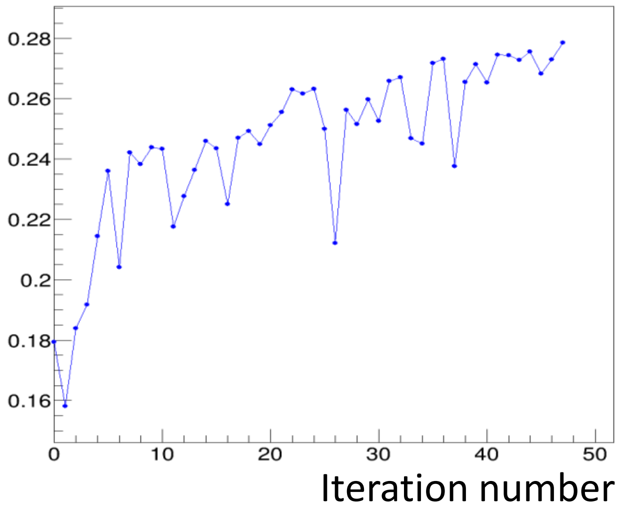
Optimize 5 neutron converter thicknesses to

- equalize as much as possible the count rate of all RPCs
- keep the total detection efficiency as high as possible



Detection efficiency vs RPC index in ^{10}B-RPC neutron detector

Goodness parameter



Scripting

ANTS2 offers scripting in two programming languages:

- **JavaScript**
  - multithread script evaluation is supported
- **Python**
  - uses the system Python interpreter, so all Python modules installed on the system are accessible in ANTS2 via import directive.

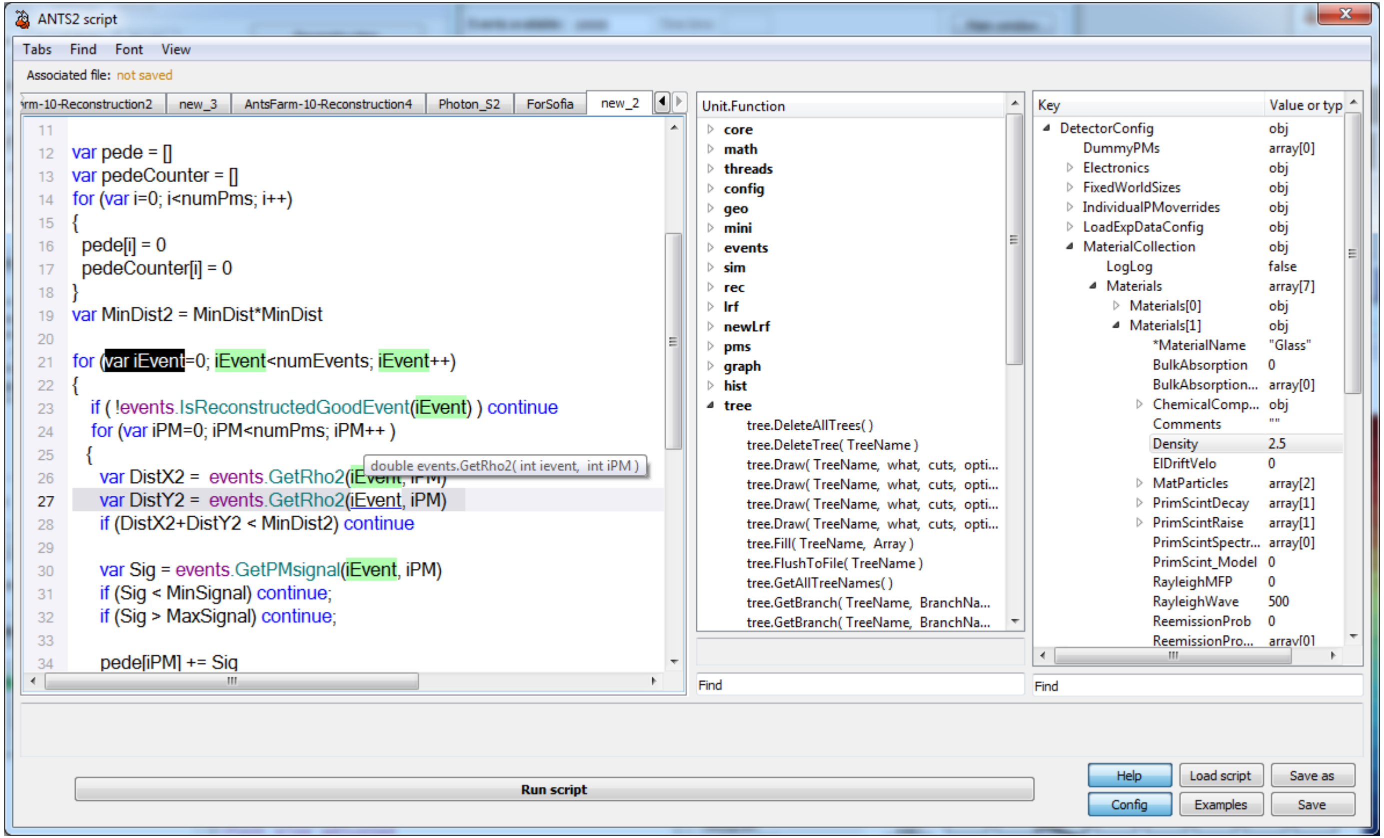
Among many other tasks, scripts can:

- read and modify the detector configuration
- run simulation and reconstruction
- read, modify and filter event data
- write and read ROOT trees,
- create and draw histograms and graphs
- provide interactivity through access to the GUI

Scripts can be executed

- from the GUI (next slide)
- in batch mode
- through the WebSocket interface of the ANTS2 server

Scripting

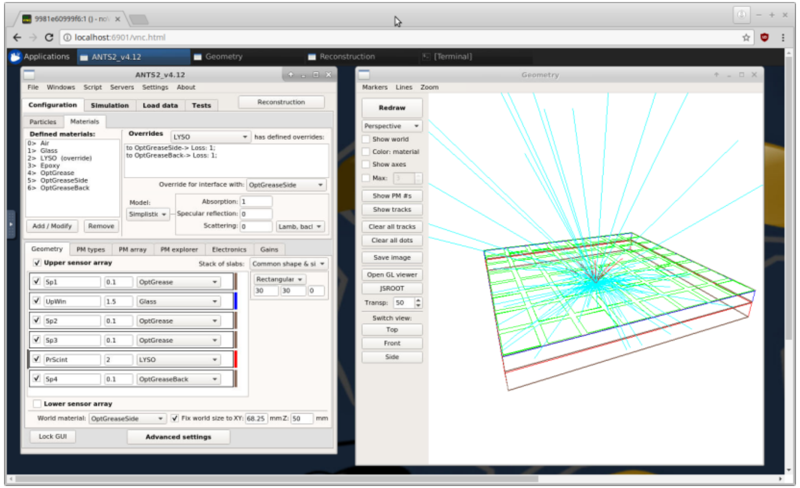


Script window of ANTS2 showing the script text, method help and configuration explorer fields

ANTS2 Docker

ANTS2 Docker container is available
(Linux OS + ANTS2 + all required libraries)

- Runs on Windows, Linux and Mac hosts
- Nearly native code performance
- Safety (strong isolation)
- User-friendly: The already built container can be downloaded from the Docker Hub



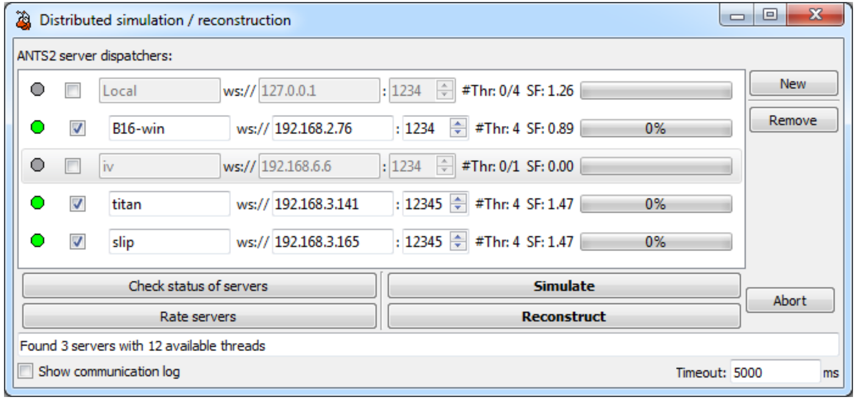
ANTS2 docker with the desktop opened in the Chrome browser

Desktop:
- Docker container: ANTS2 + XFCE desktop + VNC server
- Browser with HTML5 support: noVNC client

Networked/Distributed ANTS2

Server mode was implemented in which, over WebSocket protocol, ANTS2 can:

- Receive binary and text data (including the detector configuration)
- Receive and execute scripts
- Return the results



ANTS2 GUI for distributed simulation /reconstruction

Distributed ANTS2:

- A dispatcher application, on a request from the master, starts a single-use ANTS2 server and gives the master contact info
- The master keeps the list of available servers and distributes the workload between them
- The results are returned to the master
- Docker container with a lightweight ANTS2 server and a very small footprint dispatcher is available

Implementation

ANTS2 is written in C++, uses **Qt** framework and requires **ROOT** 5 or 6

Optional libraries:

EIGEN3:	fast LRF fitting
PythonQt + **Python** 2 or 3:	Python scripting
CUDA toolkit:	GPU-based statistical reconstruction
NCrystal:	elastic neutron scattering simulation
FANN:	ANN reconstruction
FLANN:	kNN reconstruction and event rejection

Open source and more information can be found at:

https://github.com/andrmor/ANTS2

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