



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

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### **Position Sensitive Scintillation Detectors**



# 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<sup>6</sup> 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



### 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



NTS2 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)



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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

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 tracing with wavelength shifting fibers



# 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

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





# 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

<sup>10</sup>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



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

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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

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Desktop:

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

ANTS2 docker with the desktop opened in the Chrome browser

# 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

### 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

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VTS2	server	dispatchers:				

ANTS2 GUI for distributed simulation /reconstruction

• 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 JINST 11 (2016) P04022 JINST 11 (2016) P09014

