Report WP 5.3: Geant4 simulation of scintillation and photon propagation

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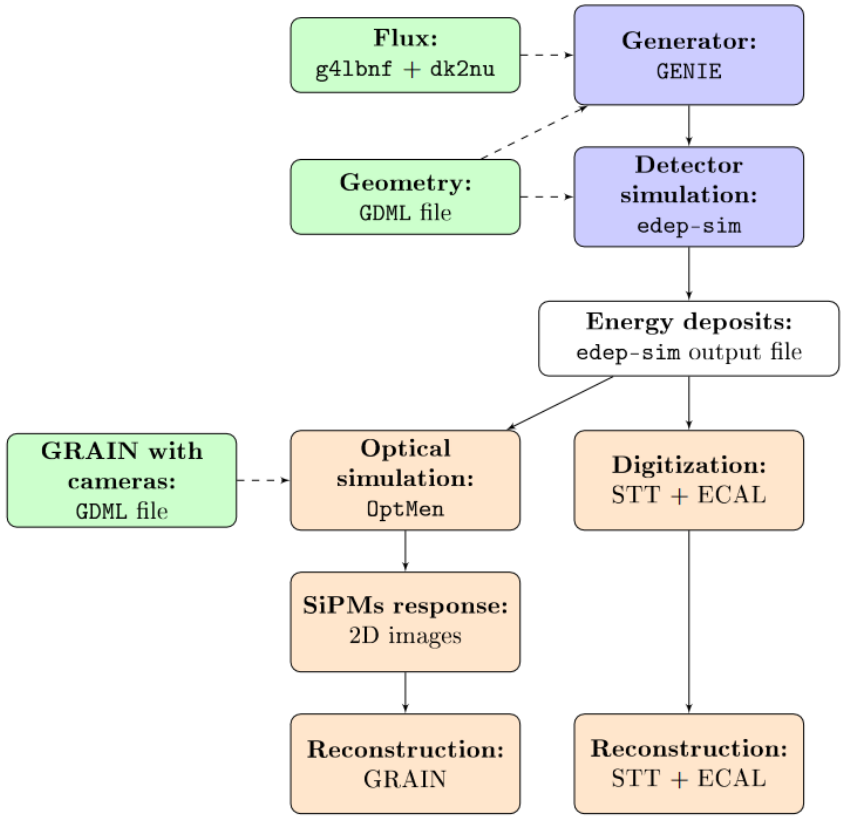
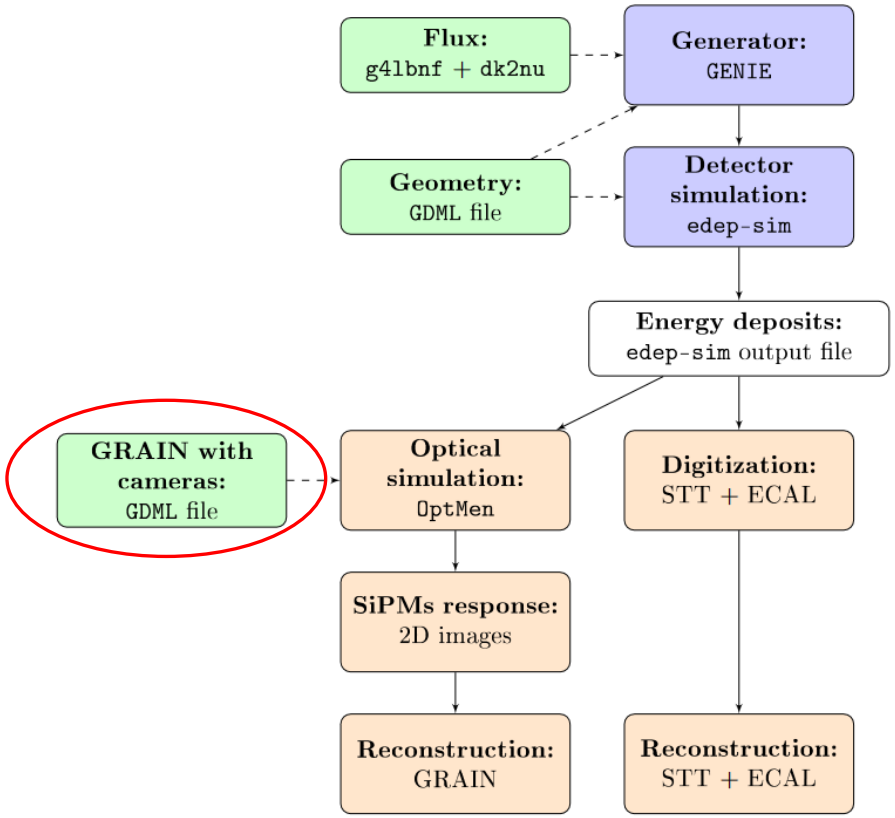
Simulation pipeline

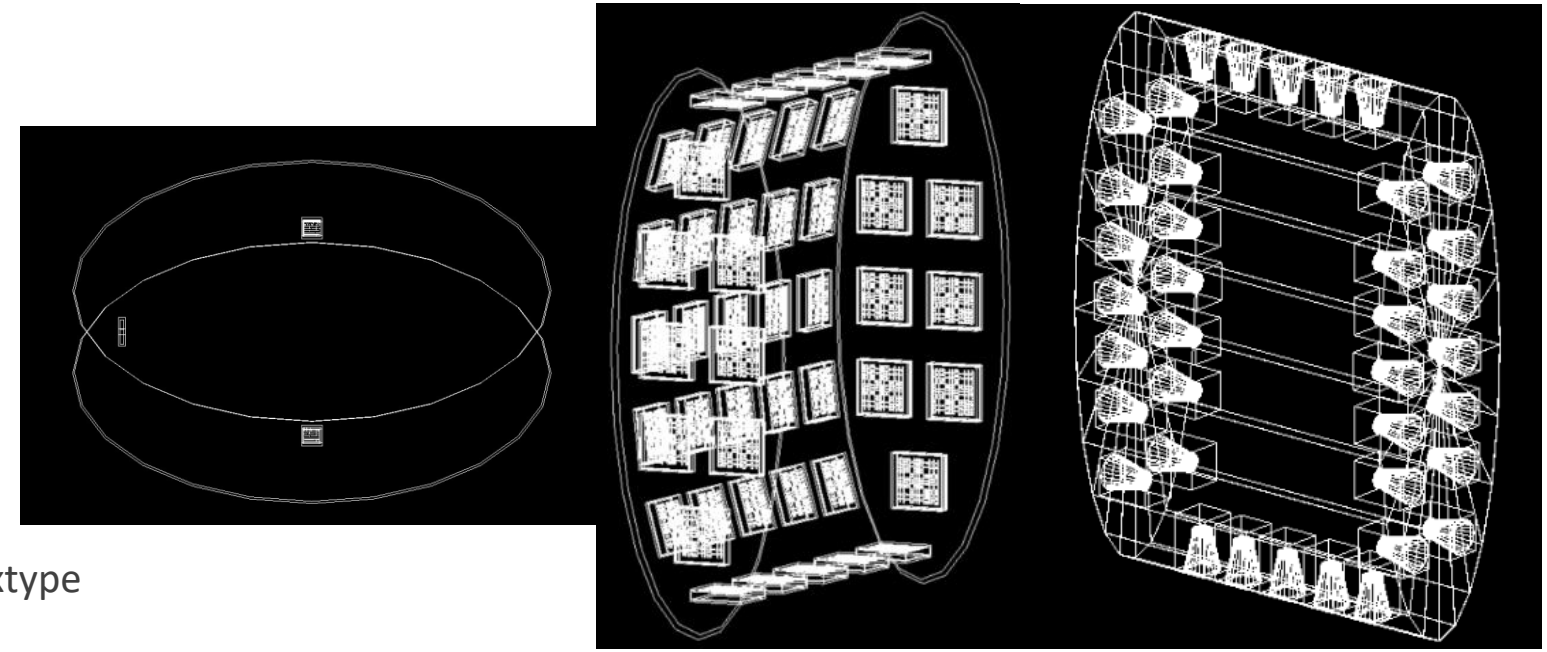


Simulation pipeline



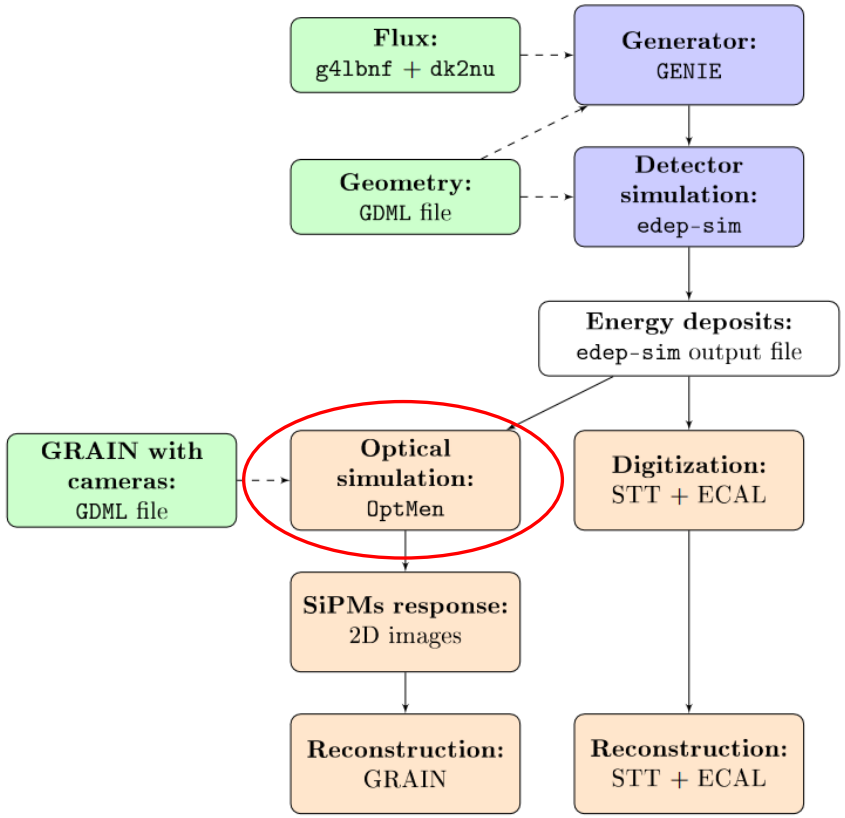
Geometry

- Possibility to simulate different geometries (not only GRAIN).
- Geometry based on gdml file(s)
- Requirements:
  - A lar_volume volume
  - One or more cam_volume
  - One or more volumes with Sensor auxtype



```
<auxiliary auxtype="Sensor" auxvalue="S14160-6050HS">
  <auxiliary auxtype="cellcount" auxvalue="32"/>
  <auxiliary auxtype="cellsize" auxunit="mm" auxvalue="3.000"/>
  <auxiliary auxtype="celledge" auxunit="mm" auxvalue="0.200"/>
</auxiliary>
```

Simulation pipeline



Optical simulation – Photons emission

- Mean number of photons obtained from edepsim step and argon light yield:

$$N_{mean} = E_{step}[\mathrm{MeV}] \times 40k\ [\mathrm{ph/MeV}]$$

  - Number of photons extracted from a Poisson distribution ($N_{mean} < 20$) or from a Gaussian distribution ($N_{mean} > 20$).

- Position and time of each photon is random between start and stop of edepsim step

$$\mathbf{x}_0 = \mathbf{x}_{\mathrm{start}}^{\mathrm{step}} + \mathrm{random}(0,1) \cdot (\mathbf{x}_{\mathrm{stop}}^{\mathrm{step}} - \mathbf{x}_{\mathrm{start}}^{\mathrm{step}})$$

$$t_0 = t_{\mathrm{start}}^{\mathrm{step}} + \mathrm{random}(0,1) \cdot (t_{\mathrm{stop}}^{\mathrm{step}} - t_{\mathrm{start}}^{\mathrm{step}}) + t_{\mathrm{scint}}$$

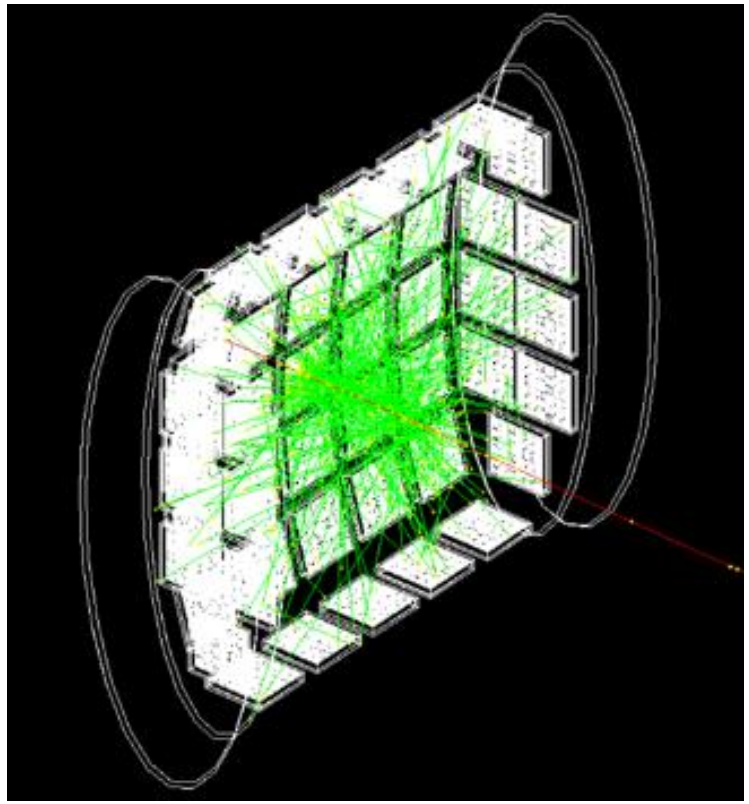
- Fast and slow components selection based on experimental singlet to triplet ratio:

$$fast \sim 25\%\ (\ E \gtrsim 1\ \mathrm{MeV})$$

- Photons energy randomly extracted from the emission spectrum

Optical simulation – Photons propagation

- Refractive index parametrized from recent experimental results
- Light propagation is simulated using standard Geant4 optical processes
  - Rayleigh scattering set to 90 cm (in non-doped Argon)
  - Absorption length set to 5 m (in non-doped Argon)
- Vessel and camera mechanical support reflectivity set to 0%, absorption set to 100%



Optical simulation – Xe doping

- Singlet-to-triplet ratio same as in pure LAr. Fast component assumed unaffected by the dopant.
  - Invisible for lens-based camera due to low transmittance
  - A suppression must be included in the simulation when using mask-based camera
- Slow component almost completely shifted to 174 nm: 10% at 127 nm, 90% at 174 nm. $\tau_{slow} = 160$ nm
- Total light yield increased by 20%. Additional photons assumed to be slow component only.
- Parametrization of refractive index, scattering and absorption length is wavelength dependent
  - Abs length: 1000 m if $\lambda < 151$ nm, 3.8 m if $\lambda > 151$ nm
  - Scattering length: [4, 30000] m for λ in the [119, 1200] nm range

Optical simulation – Inputs

- Three possible input files:
  - Geant4 macro
  - Edep-sim
  - Genie
- Macro based on the Geant4 General Particle Source (GPS).
  - It uses Geant4 scintillation model, not the one described earlier.
  - Useful for debug purposes
- Edep-sim uses an edepsim output file and searches for hits in the GRAIN volume.
  - It uses the scintillation model described earlier.
- Genie can be used to propagate the particles produced in the neutrino interactions skipping the edepsim step
  - It uses Geant4 scintillation model, not the one described earlier.

Optical simulation – Inputs 2

- A configuration file is used to set all the options needed for the simulation
- Mandatory fields:

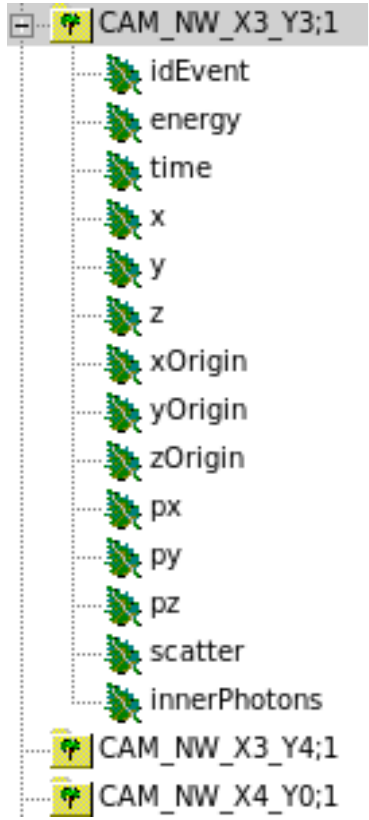
```
inputFile = here_input_path
generatorType = here_generator
eventNumber = here_event_number
geometryFile = here_geometry_path
destinationPath = here_output_path
opticalPhotonsFile = no
sensorsFile = yes
ui = no
```

Optical simulation – Output

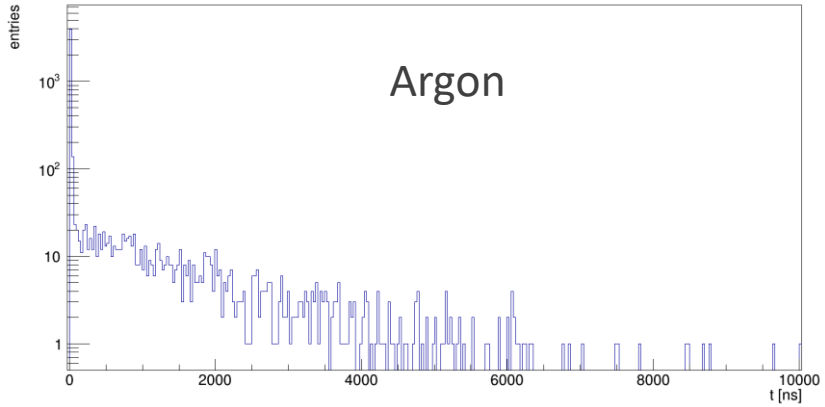
- Up to three output files can be generated:
  - Primaries
    - Used to store information about the primary particles
    - Only working for macro and genie input
  - Optical photons
    - Used to store information about ALL the generated optical photons
    - Useful for debug purposes, it grows in size quickly and it will probably crash everything when used with large productions
  - Sensors
    - Used to store information about the detected photons on all the sensors

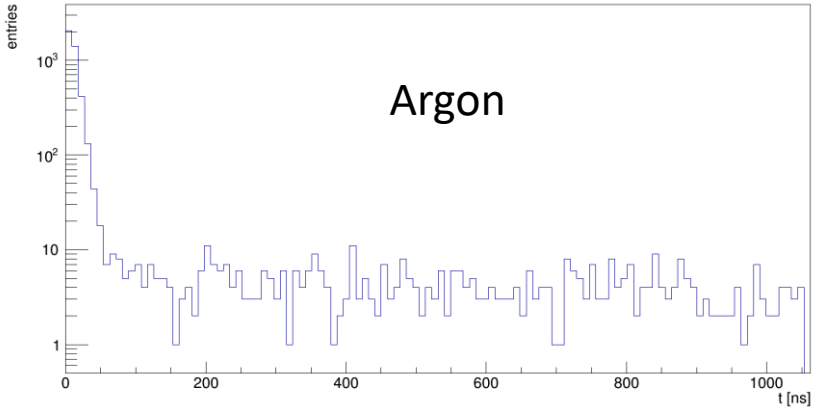
Optical simulation – Output 2

- Sensors
  - Used to store information about the detected photons on all the sensors
  - One tree per sensor in a root file
  - Multiple branches with local coordinates on the sensor, arrival time, energy, direction and more
  - Each entry is an event. One event is what genie and edepsim consider a single entry (neutrino interaction, spill, other?)

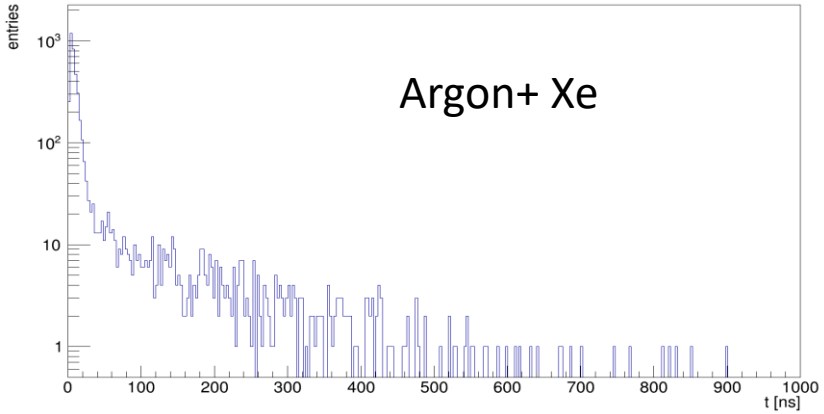


Optical simulation – Output 3



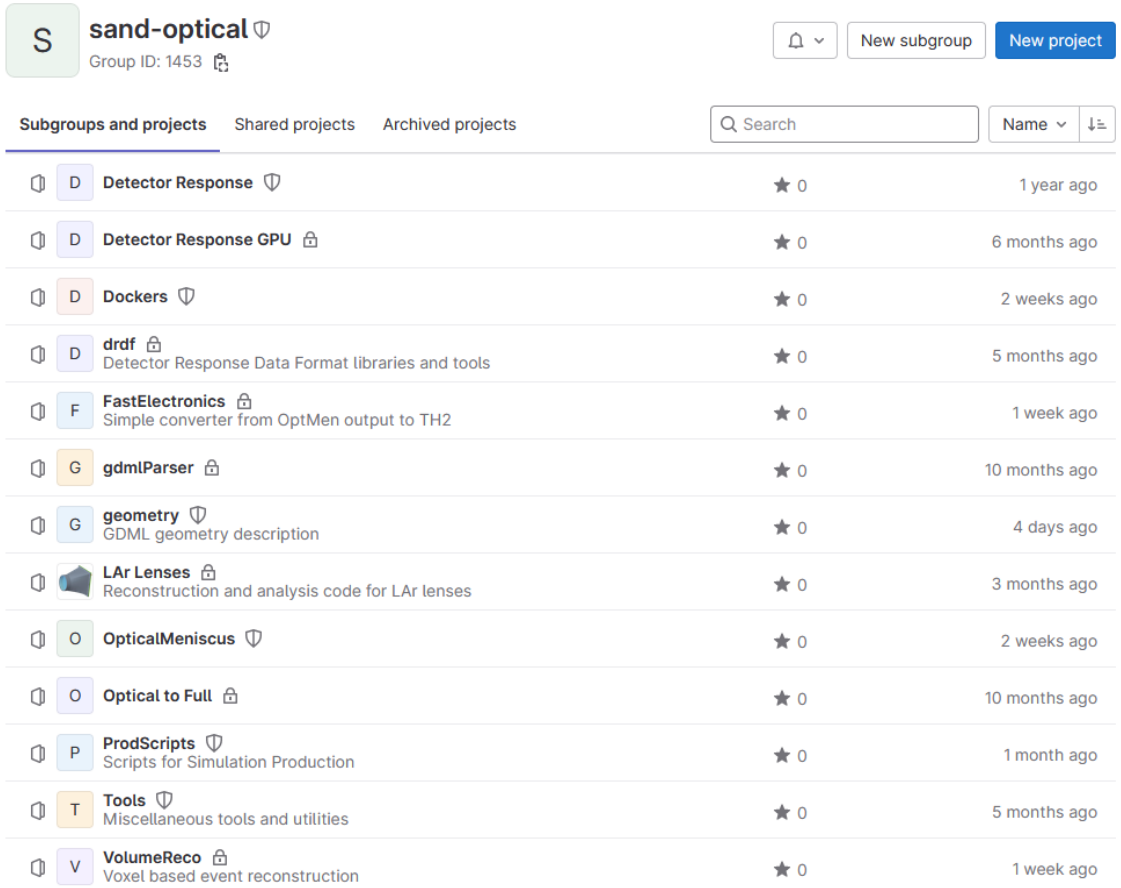


Example of arrival time for all the detected photons on one camera for pure Argon and Xe-doped Argon.



Optical simulation – Tools

- Different tools to process the simulation output:
  - 2D images with and without electronic simulation
  - Mask gdml generator
  - Docker file with geant+root+edepesimIO+optical simulation
  - Time profile of each channel



Next steps and conclusions

- Update the simulation to support more recent geant versions
- More complete Xe doping implementation

- The simulation is working without major bugs
- Flexible input parameters set with a configuration file
- Multiple output files for debugging and physics