B2G4: Integrating 3D Blender models in Geant4 simulations for synthetic muography data generation

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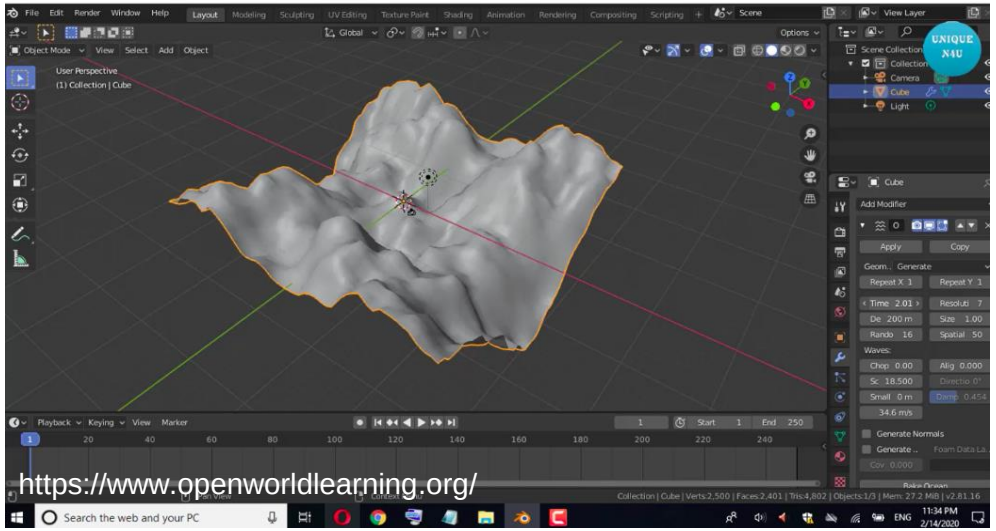
Introduction

- **Data is an essential input** to any machine learning algorithm
- Wide-scale **application of AI** to the field of **muography** therefore **requires a dedicated dataset**
- Experimental data is hard to come by and is often use case specific
- **Simulated data is time consuming to create**, requiring significant manual input
- To alleviate this we propose **the Blender to Geant4 framework**

Blender to Geant4 is a framework which enables the simulation of complex scenes and the production of labeled Geant4 simulation data in a fast, efficient and scalable manner

Blender 3D

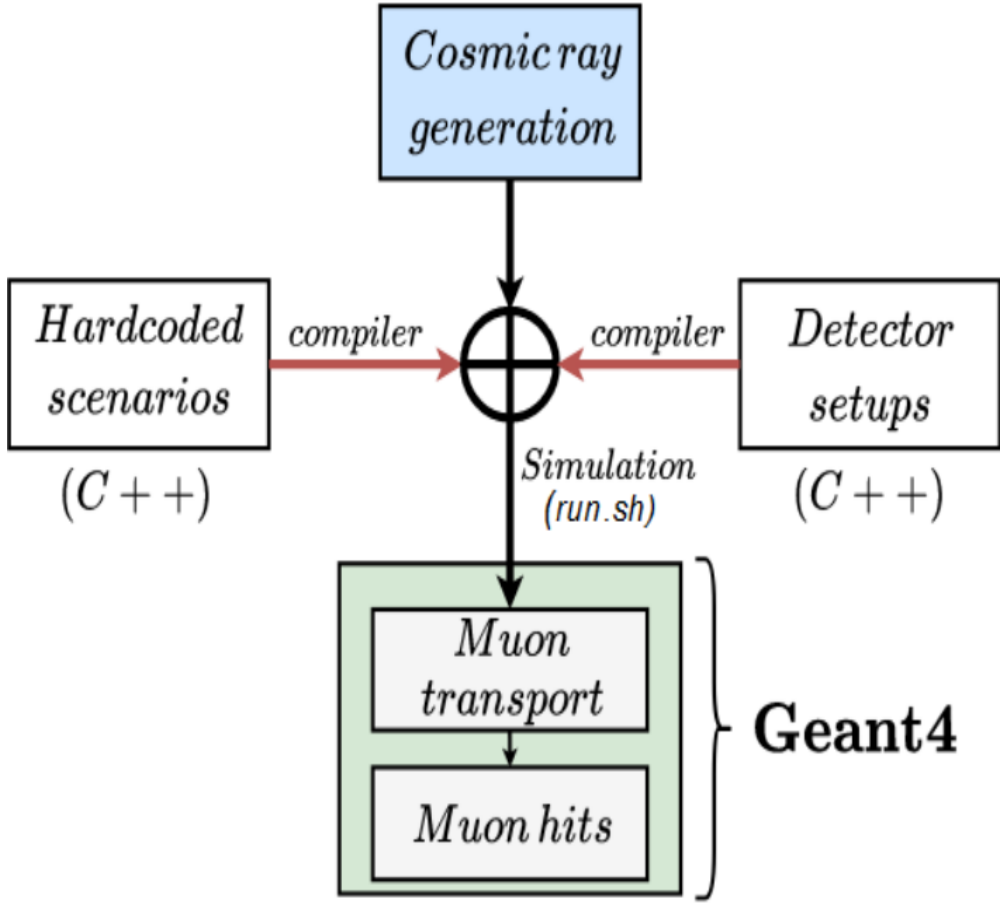
- Blender is a free and open source 3D computer graphics toolkit
- It allows for simple and user friendly creation of complex 3D models and scenes
- Features a python API
- Allows the loading and manipulation of models from many standard formats (e.g. .xml, .ply, .obj)



https://www.blender.org/

3D models in Geant4

- Geant4 currently supports the import of 3D models only in a limited fashion
- CAD model import is possible through the use of dedicated converters (*e.g. GDML, CADMesh*) but these are prone to parsing errors and offer limited visualisation options
- 3D models require special care during design phase to ensure there are no overlaps leading to execution errors in G4
- **Final scene must still be coded manually and compiled, even for minor changes**.

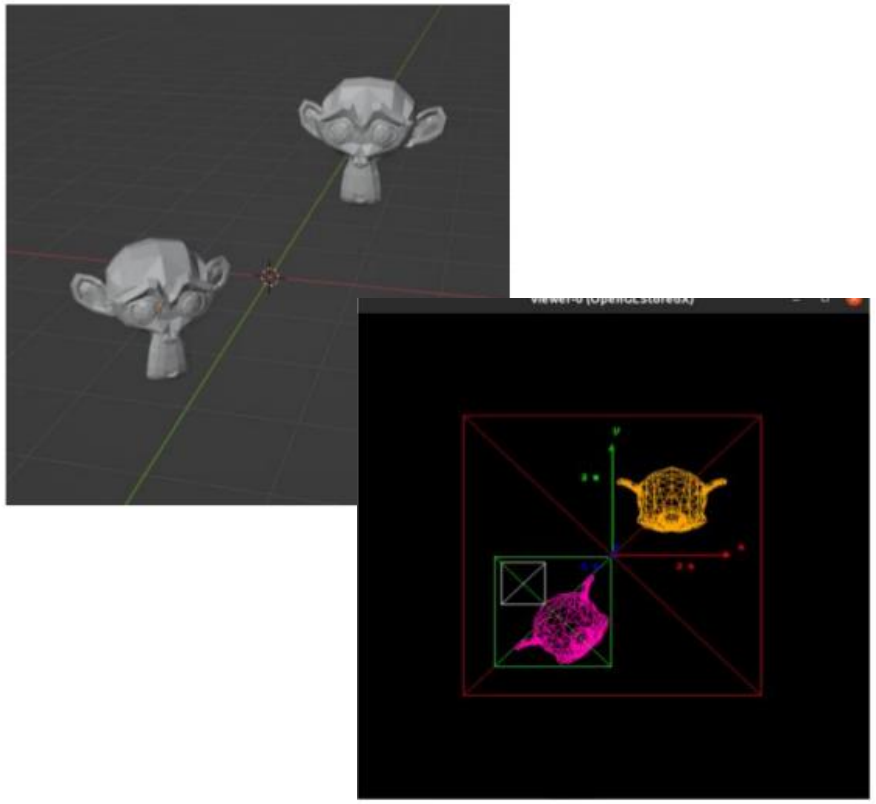


Standard setup for muon tomography simulations with Geant4

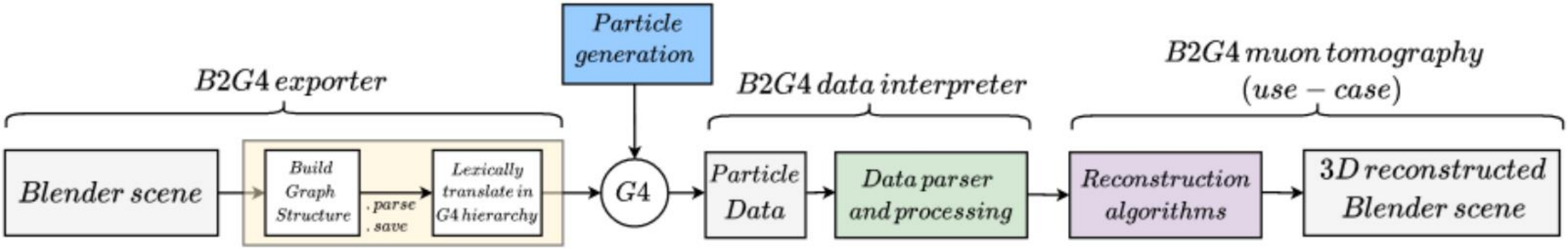
Blender to Geant4 (B2G4)

B2G4 is a novel framework that transplants highly detailed 3D scenes from Blender into Geant4 for a variety of physical applications.

- **B2G4 provides a suite of python scripts for Blender export and a C++ library for Geant4 imports**
- **Scenes are simply created using Blenders** intuitive drag and drop placement, shape variance randomisation and material assignment
- B2G4 **translates** the **scene into a format readable by Geant4**
- New model imports **do not require Geant4 code to be recompiled** allowing for fast and automated dataset creation
- **Particle transport** is simulated **using standard Geant4** tools



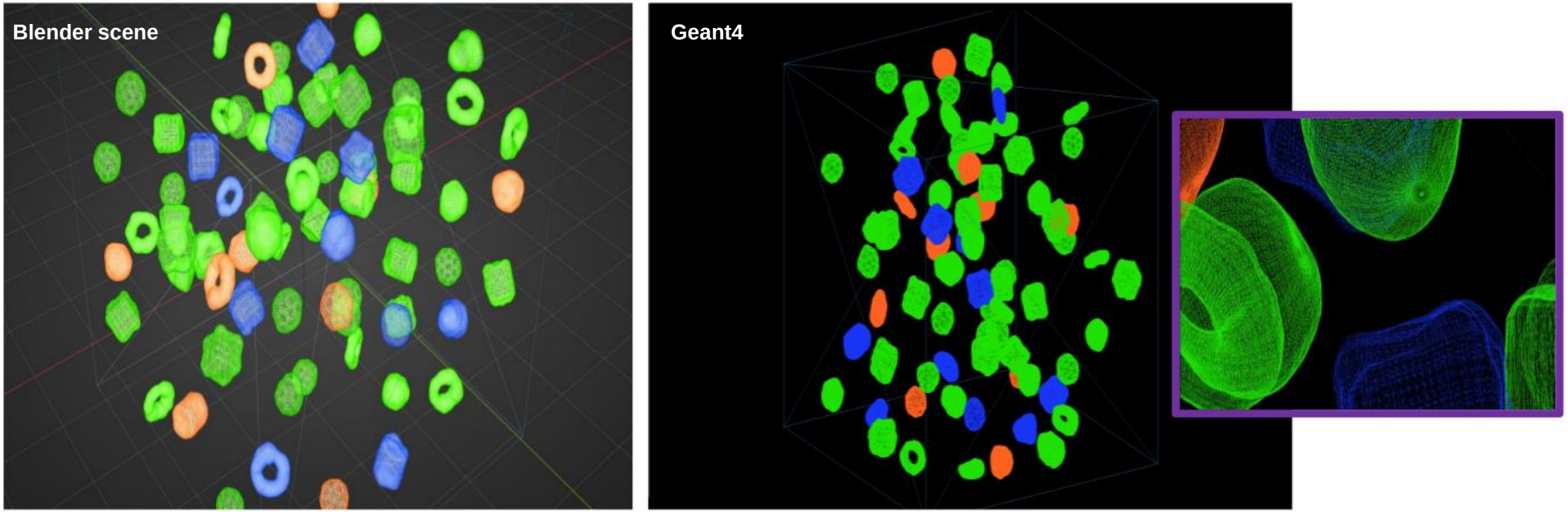
Blender to Geant4 Pipeline (B2G4)



B2G4 end-to-end data pipeline.

- **Scene is created in Blender:** B2G4 defines hierarchies in a way which mirrors the mother-daughter relationship model in Geant4 whilst employing instancing to avoid data duplication
- **Creation of graph data structure:** Physical and logical volume dictionaries representing the respective Geant4 objects are parsed as graphs and saved as a .JSON file. A dedicated parser generates Geant4 scene descriptions from the .JSON file.
- **Data interpreter:** Process and analyse simulation results tailored to the use case.

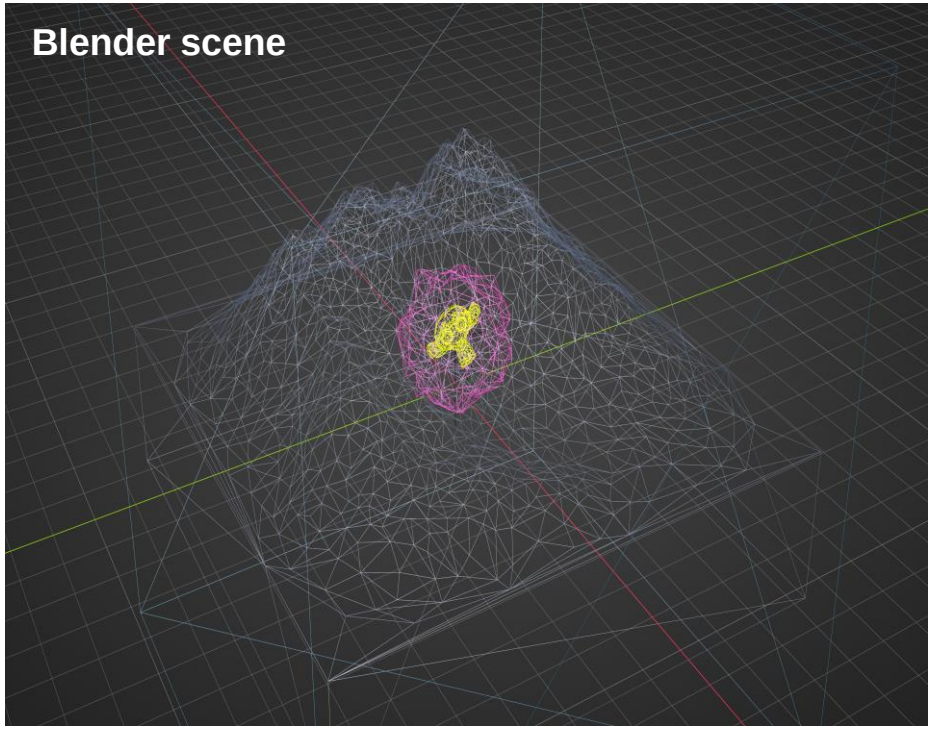
B2G4 Example scenes – randomised items

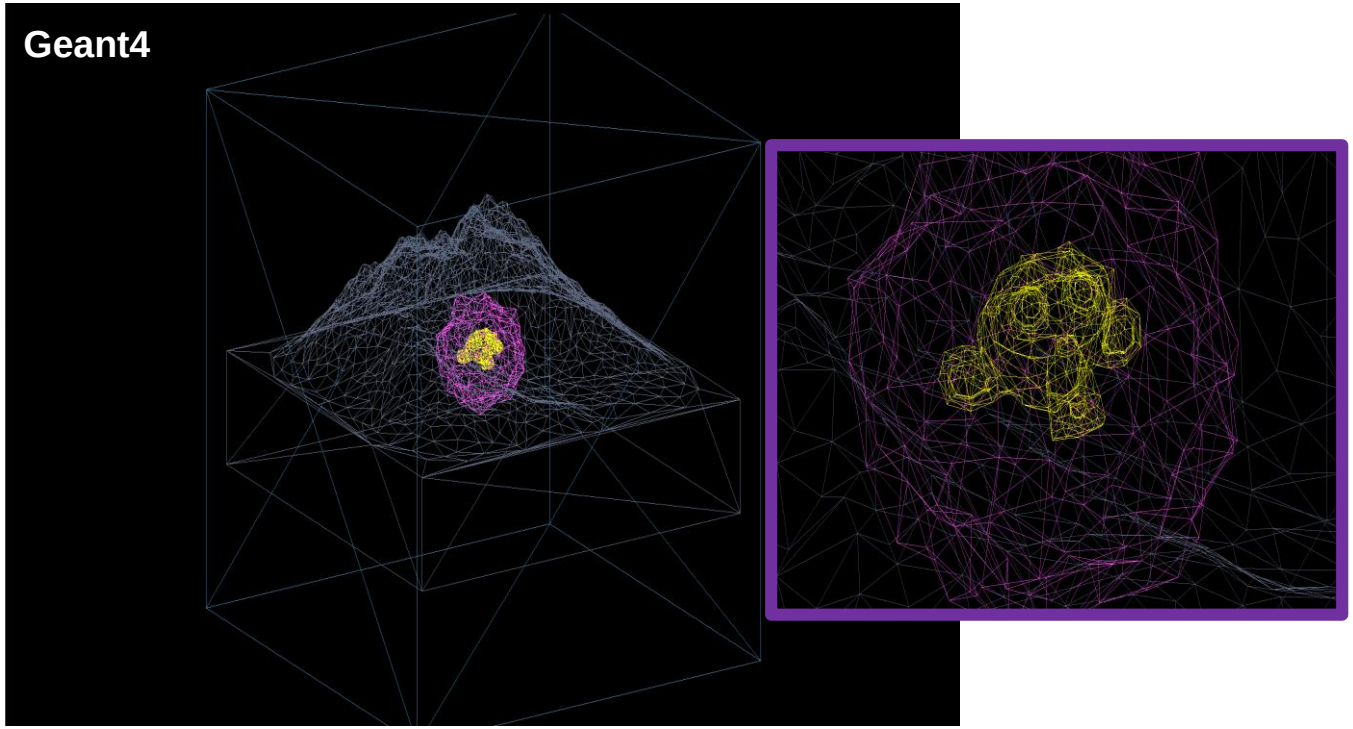


Dataset generation: Random geometry generation in Blender with B2G4 (top). Automatic data labels (green, red and blue colors) can be imported and color-coded in Geant4 (bottom).

Triangles: 669580; exported in **4.8 seconds**.

B2G4 Example scenes – a mountain with golden monkey

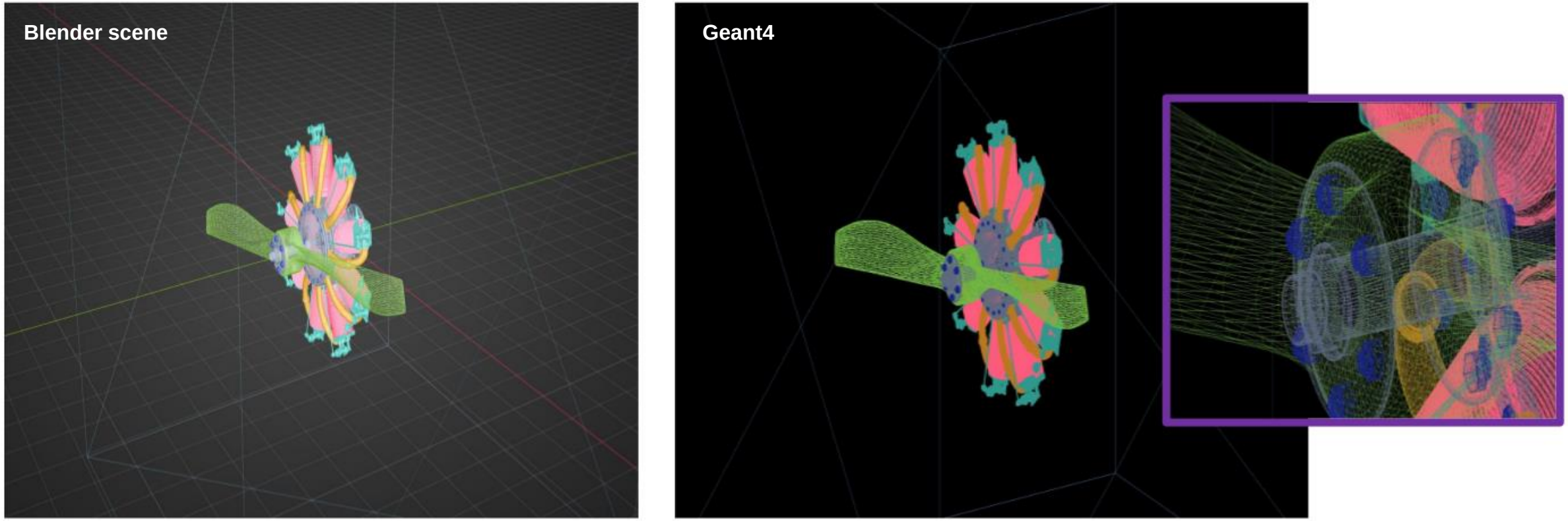




Archeological or geophysical applications: A monkey head made of gold inside an ancient structure buried in a mountain

Triangles: 4487; exported in **0.05 seconds.**

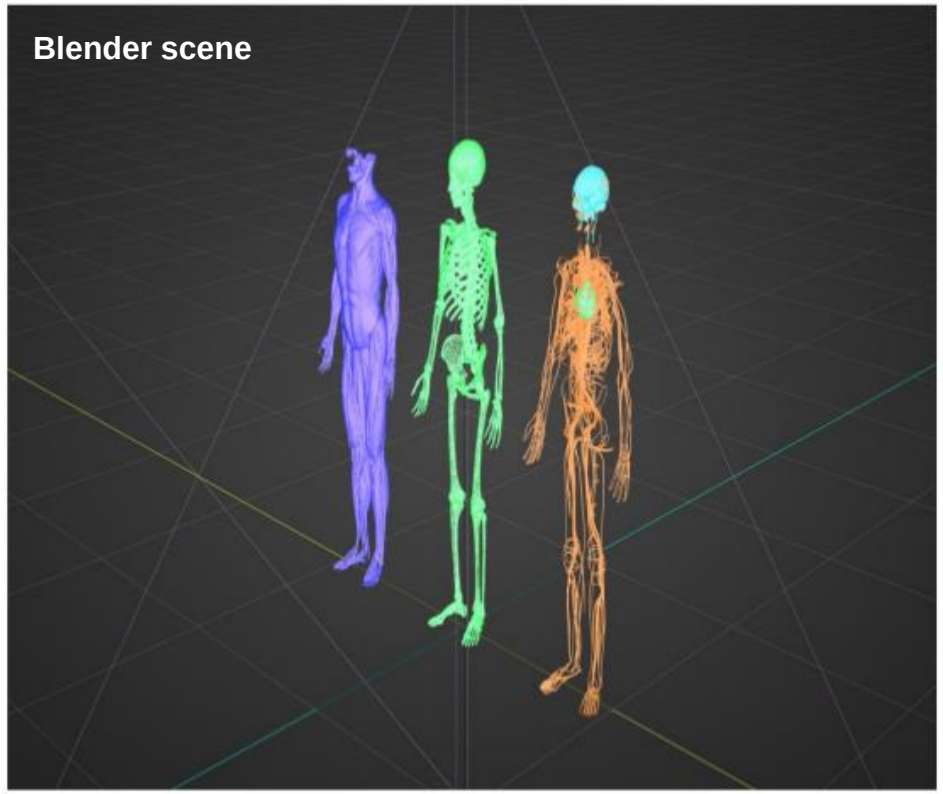
B2G4 Example scenes – rotary aircraft engine

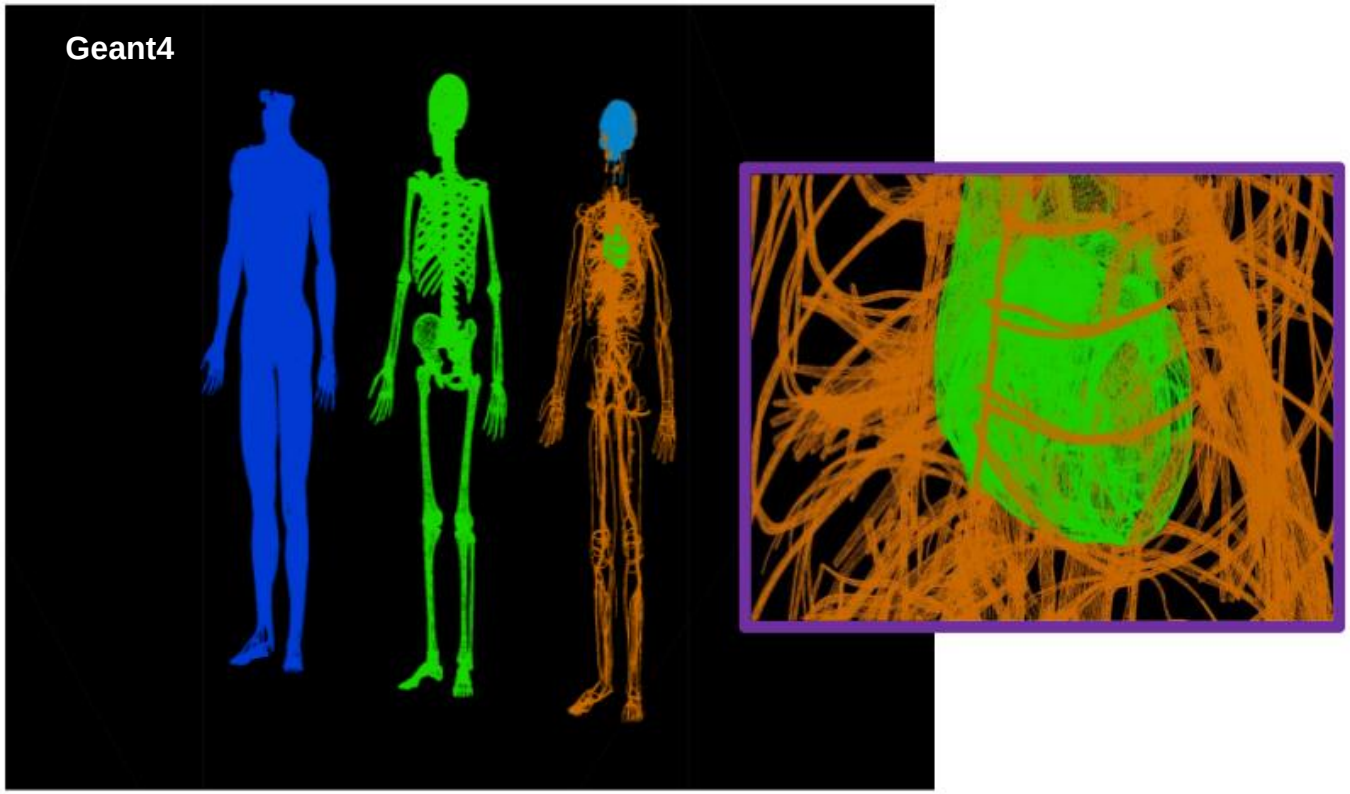


Rotatory aircraft engine. Metal bolts, propellers and cylinders from Blender (top) are faithfully replicated in Geant4 (bottom).

Triangles: 1.5 Million; exported in **15.2 seconds.**

B2G4 Example scenes – human phantoms



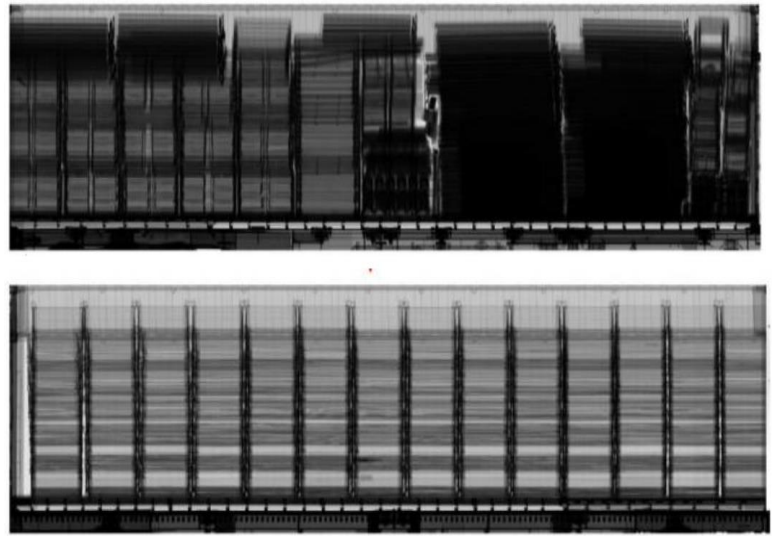


Three highly detailed human phantoms. Body parts can be easily modelled in Blender (top) and parsed into Geant4 (bottom), at full detail.

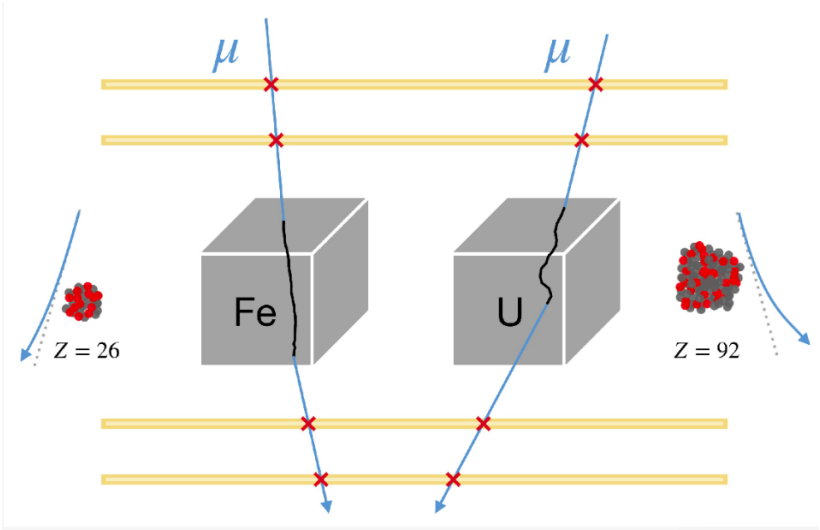
Triangles: 3.0 Million; exported in **30.6 seconds.**

Application to muography – container scanning

- **Cargo screening is typically performed using x-ray and gamma-ray techniques :**
  - Harmful to humans and animals
  - Low throughput (~15mins total scan time)
  - No 3D picture
  - Easily absorbed by shielding materials
  - Labor intensive inspection methods



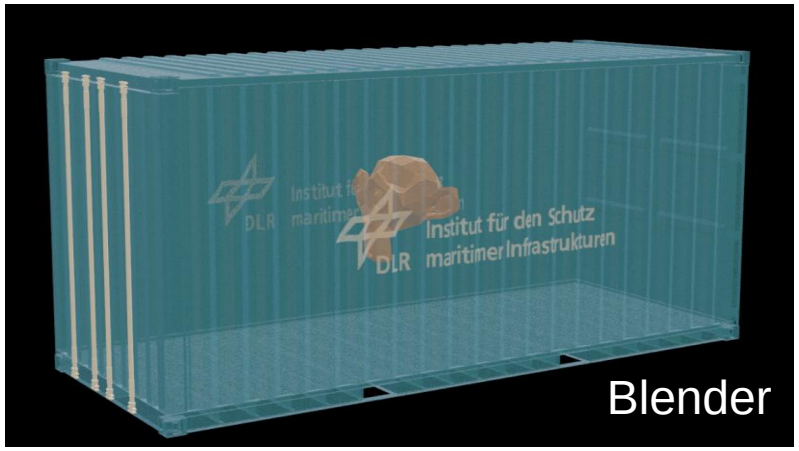
- **Cosmic ray tomography presents a safe alternative using only natural ambient radiation :**
  - Low bureaucratic overhead
  - Faster total scan time (~2-5 mins)
  - 3D picture by default
  - Can easily penetrate shielding materials
  - **Material determination possible using AI methods**

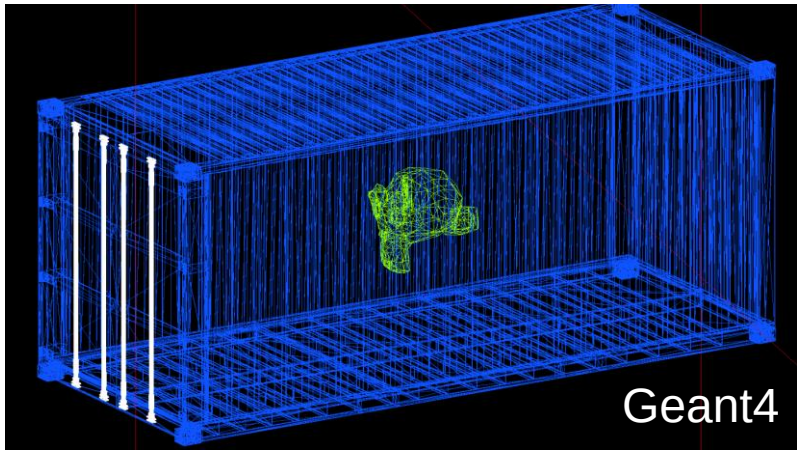


Images : doi.org/10.3390/instruments7010013

Timing and reconstruction comparison

- To validate B2G4 for synthetic data generation, **simple scenes were first created and analysed**
- **Experimental setup:**
  - **4 simple scenes** containing boxes, monkeys and cargo containers were created
    - **Simplified steel container box** model containing: **1 m^3** cube or **1 m^3** monkey head, both made of lead
    - **Maritime container steel** model containing: **1 m^3** cube or **1 m^3** monkey head, both made of lead
    - ***10M muons*** are generated using *CRY* library on *100 CPUs* (*AMD EPYC 7H12*)
  - The **angle statistics reconstruction (ASR)** algorithm with **2 cm resolution** is used for reconstruction
  - **Simulation times and memory consumption are compared for simplified and complex models with similar volumes**





Timing and reconstruction comparison

Simulated Scene	B2G4 total runtime	Memory consumption
Simple container + Block	32 min. 57 s.	4.26 GB
Detailed container + Block	38 min. 17s.	4.30 GB
Simple Container + Monkey	31 min. 19 s.	4.19 GB
Detailed Container + Monkey	38 min.	4.23 GB

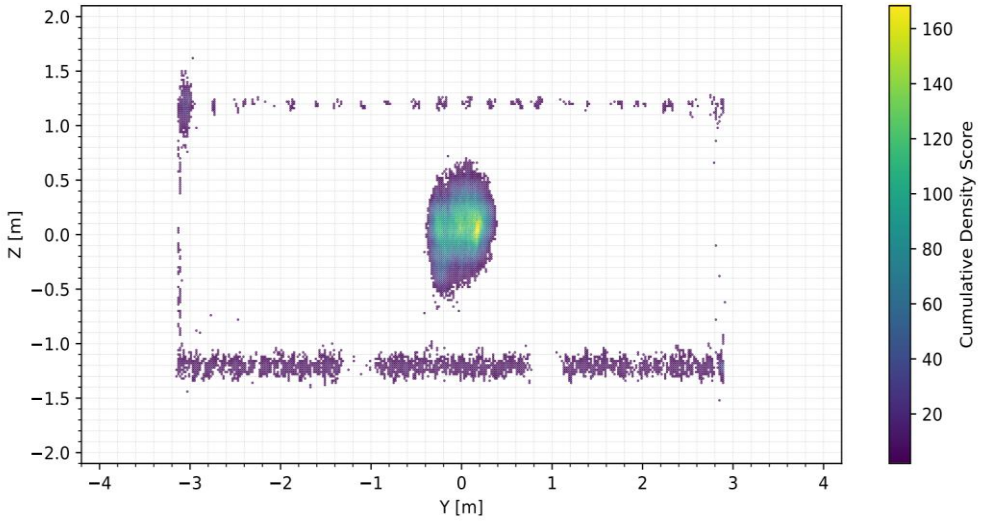
- **Memory consumption and total runtime remain stable through all the simulated scenes.** When detailed models are included**, more hits need to be considered; yet the increments are modest**
- For the **detailed container models with the monkey**; **5 minutes, 3 seconds.** ; whereas the **box container model** is **5 minutes, 40 seconds**
  - Stable runtime allows simulations to scale up to larger scenes without significant performance bottlenecks.
- **The memory consumption marginally increases for detailed scenes:** For a container models with the monkey; **50.6 MB** whereas for the box container model, **40.96 MB**.

Reconstruction tests - Monkey

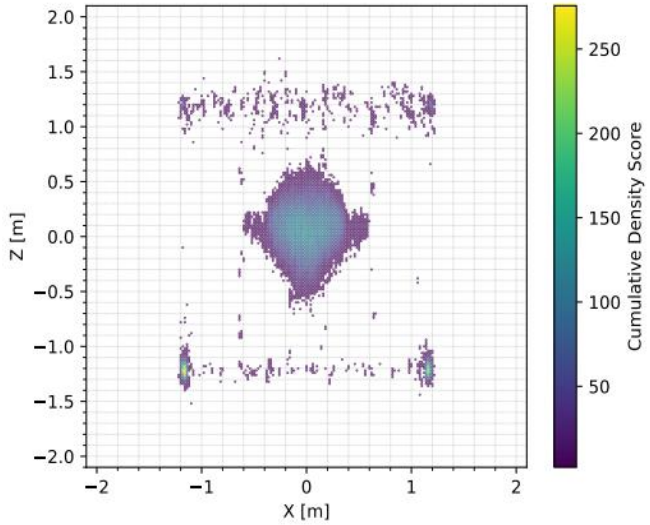
Tomographic ASR reconstructions are depicted in (a), (b), and (c) for the detailed container model

- Notice the details of the container structure (i.e.: the handles) is faithfully recovered
- The monkey head details (ears, skull, and chin) are noticeable in the reconstruction density for all views.

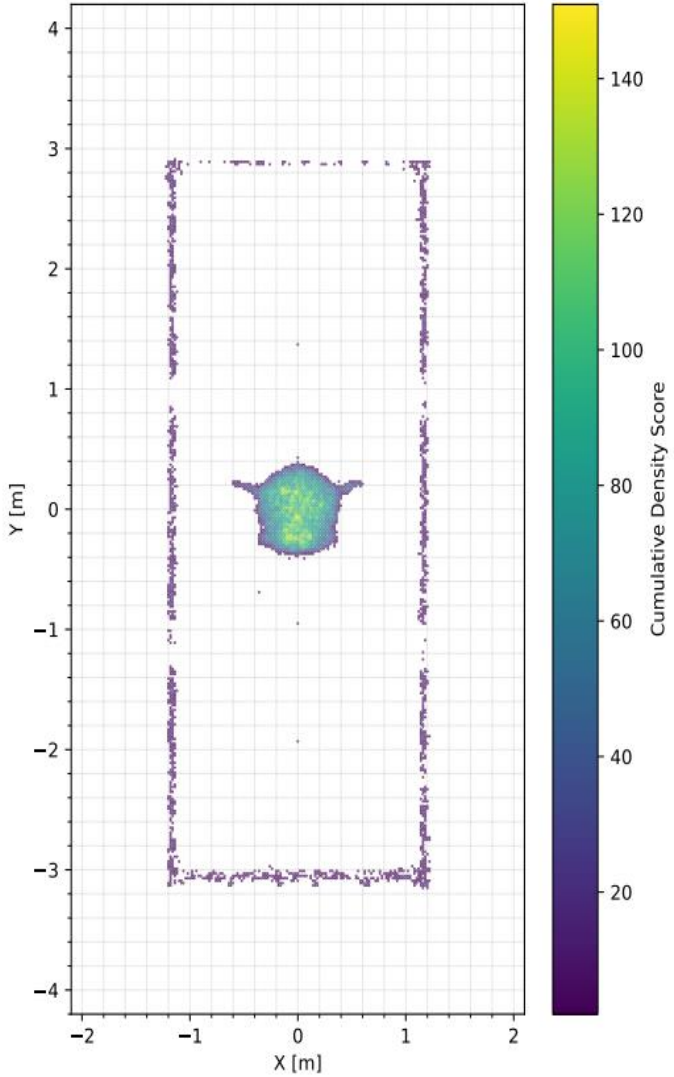
A



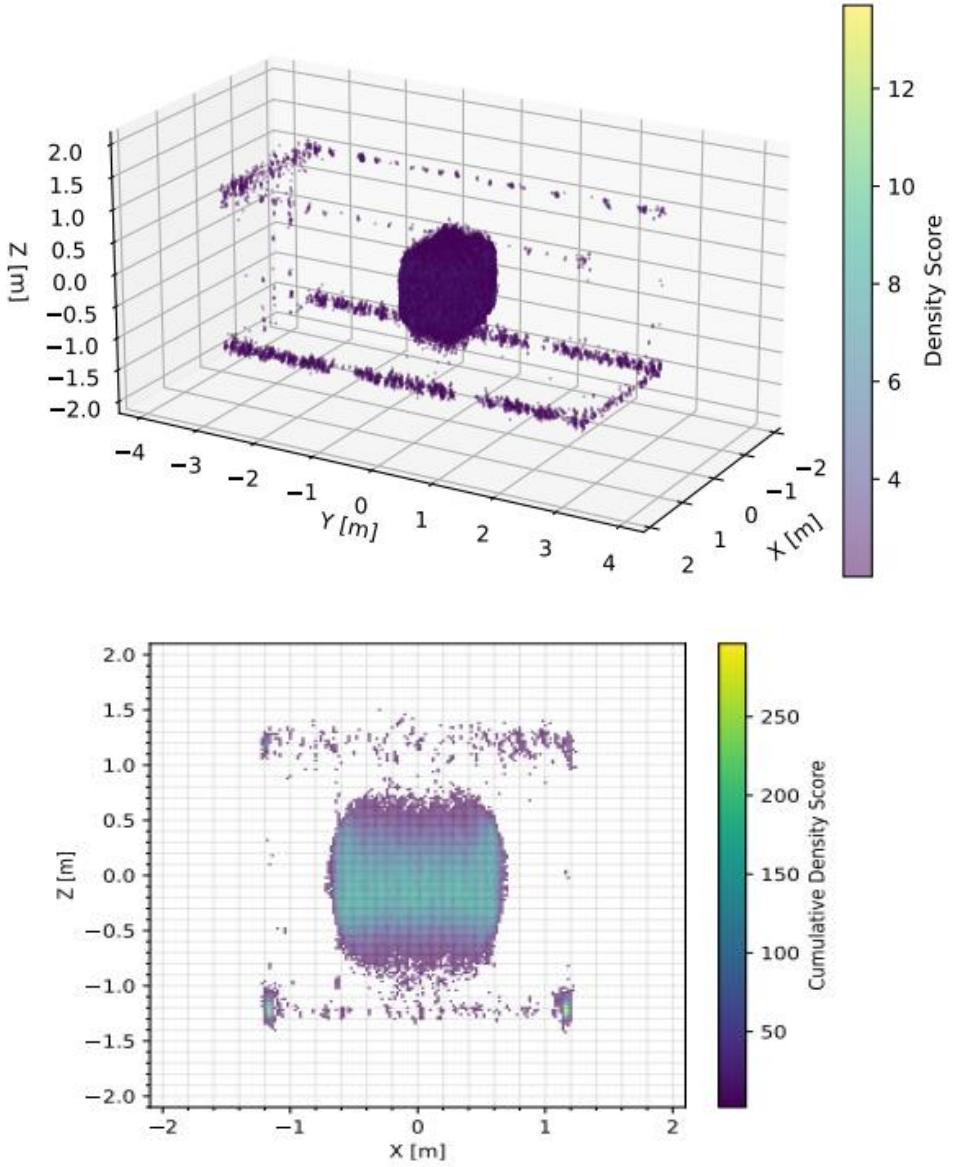
B

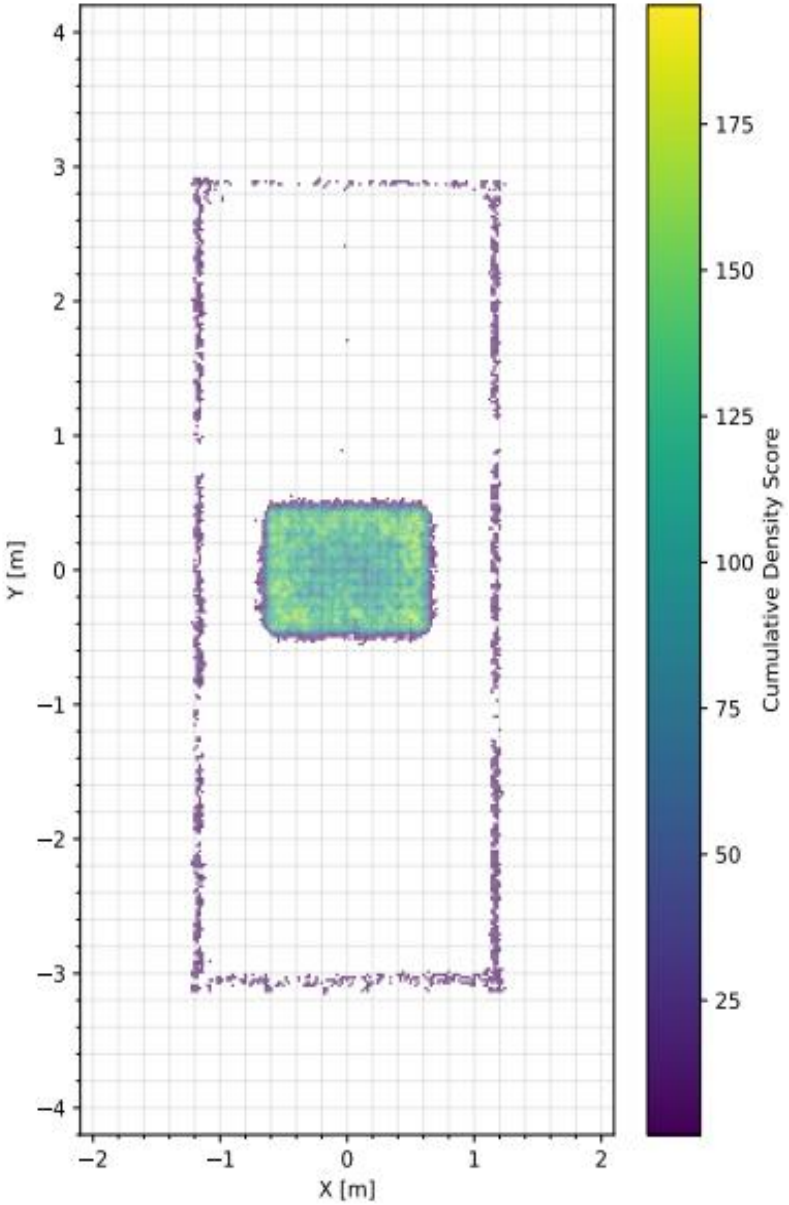


C



Reconstruction tests - Block





Dataset generation with B2G4

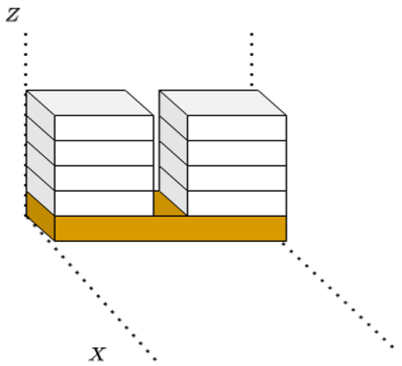
We transplant simple scenes to complex ones to curate a complete dataset for container screening. A new module for random scene generation has been recently incorporated into B2G4

To achieve this**, we need to be able to randomize container contents while keeping detailed spatial information and object material properties**.

From a starting configuration of a maritime container with a box and a wooden pallet;

- we showcase **the randomization capabilities of B2G4 with an example of boxes of random materials and wooden pallets**.

A



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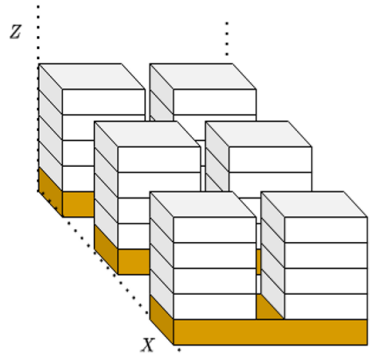
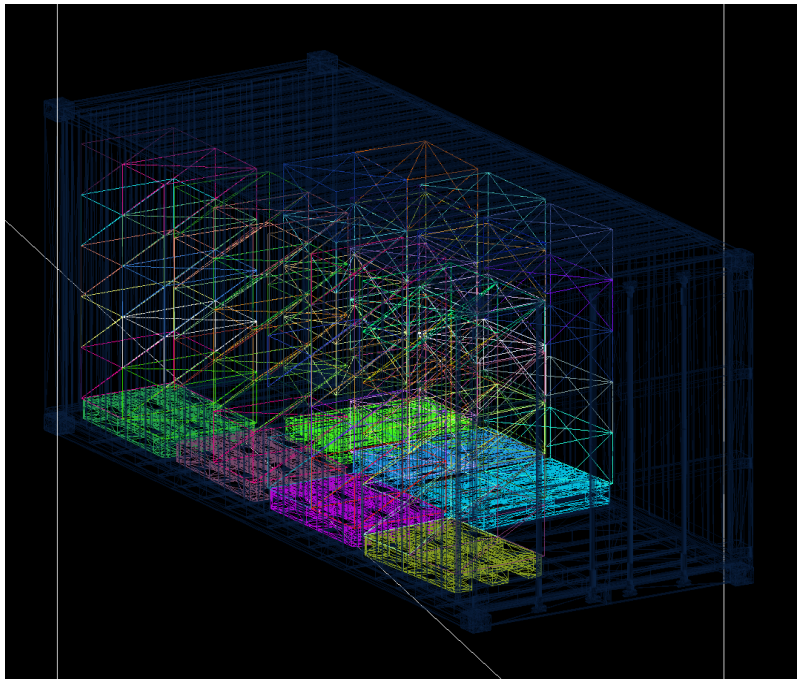
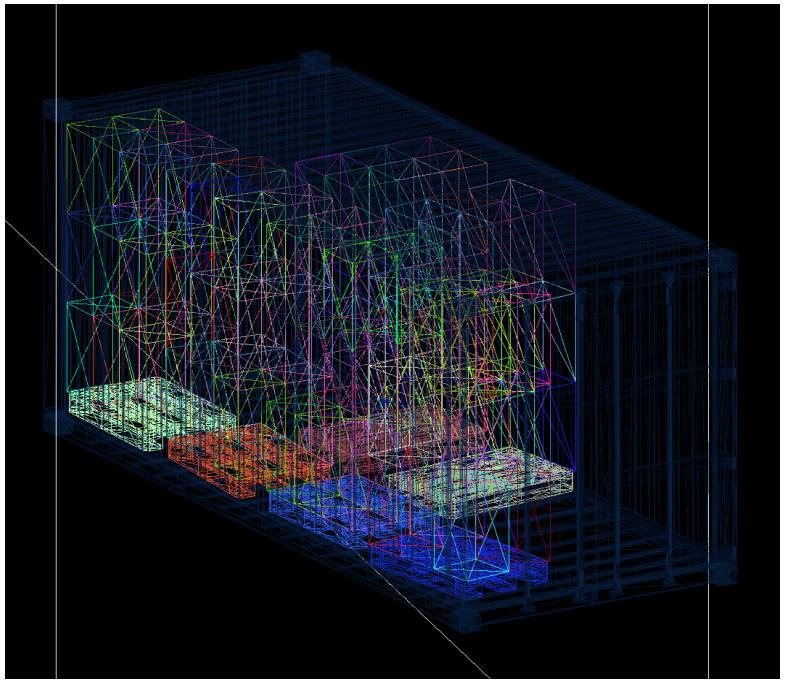
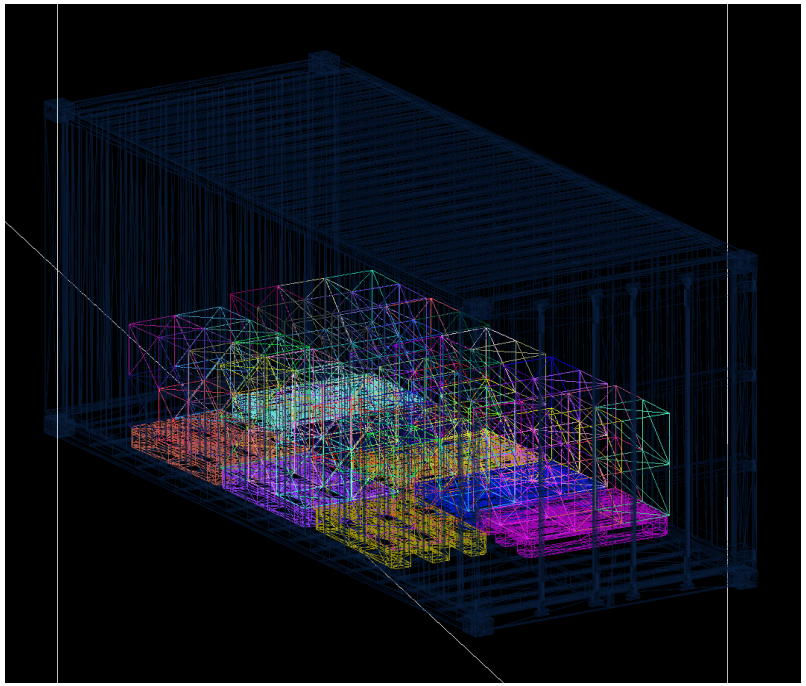


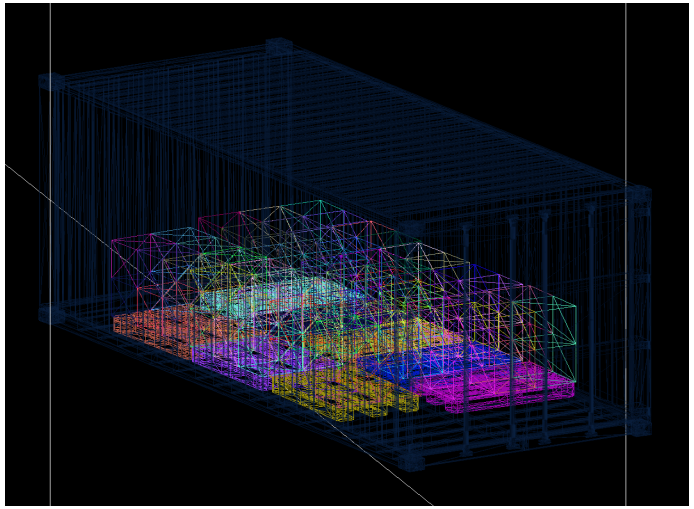
Scene randomisation for container screening

- **Three randomized container loadouts for dataset creation using B2G4:**
  - A random distribution of *boxes* + *wooden pallets* is depicted. Other loadouts are possible.
  - **The randomization feature can be expanded to many other possible scenarios.**
- **WIP: Even if fast, the data interpreter currently ingests one scene at a time;**
  - *Currently working on optimizing the data-interpreter to parallelize data generation*

Summary and Outlook

- **B2G4 synergises** the 3D modelling power of **Blender** with the simulation capabilities of **Geant4**:
- **B2G4** was validated for simple scenes showing **fast end-to-end simulation and reconstruction pipelines.**
- **Scalable synthetic data generation:**
  - B2G4 permits the creation of benchmark datasets for cosmic ray tomography**;** and other physics applications **(WIP)**
- **Highly relevant for the field of muography:**
  - proof-of-concepts and use-cases can be validated prior to hardware deployments
- **Paper and code will soon be released.**
  - **Bueno, A., Sattler, F., Perez Prada, M., Stephan, M., and Barnes, S.:** ***Enhancing Geant4 with Blender for numerical simulations***.
    - ***Shortly on:*** *github.com/DLR-MI/B2G4*



Thanks. Questions?

Contact: angel.bueno@dlr.de

Backup

B2G4 vs CADMESH

CADMesh can only import single meshes. B2G4 import whole scenes

CADMesh does not allow you to build and define detectors and a scene with assigned materials

CADMesh does not use instantiation and has memory leakage. Not scalable as graph-building strcuture is not considered o the mesh.

GDML syntax is complex and lack scalability.

Small changes in CADMesh ad GDML needs to be compiled everytime.

We provide a direct interface from a dedicated OPEN SOURCE FREE 3D Modeling and visualization software to Geant4. Complete with Materials, Hierarchies and Model data.