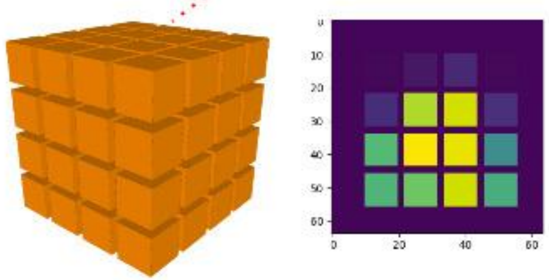
Development of the platform for simulation of spatial distribution for therapeutic dose in Dose-3D phantom

Jakub Hajduga on behalf of Dose-3D-Future Collaboration

About the Dose-3D project.

Dose-3D project entitled “Reconfigurable detector for the measurement of spatial radiation dose distribution for applications in the preparation of individual patient treatment plans” has set itself the following goals:

- build a three-dimensional measurement matrix, filled with a tissue-like substance (scintillator) for measuring the spatial distribution of the deposited dose
- development of software for dose simulation
- testbeam measurement in NIO Kraków



Simulation platform

Challenges:

Flexible detector construction: We are developing a modular, dynamic construction process that can be adapted to accommodate various radiotherapy scenarios, ensuring that the system can handle different geometries and structures.

Complex geometry integration: The platform incorporates STL geometry, enabling accurate spatial representations of patient-specific structures, and ensuring precise dose simulation.

Versatile job definitions: We employ TOML for defining job setups, offering flexibility and user-friendly configuration, with partial support for DICOM-RT integration.

DICOM-CT generation: We enable seamless DICOM-CT conversion and handling, ensuring the exported geometric plans are optimized for accurate radiotherapy treatment.

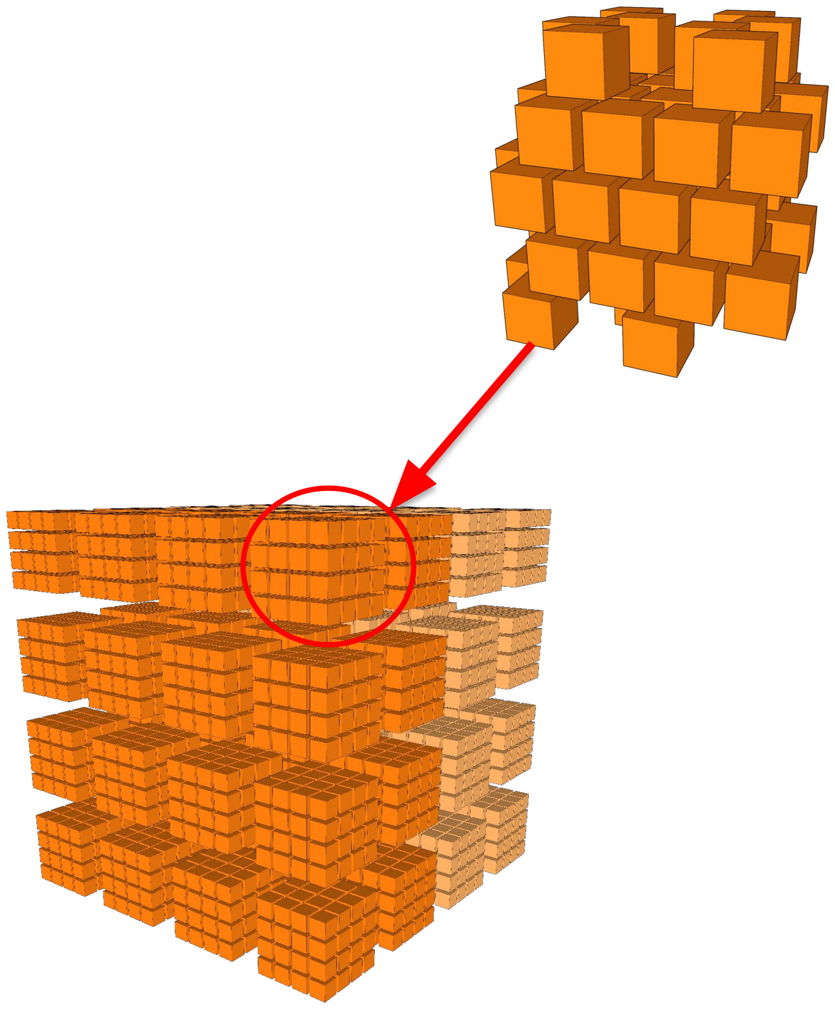
Streamlined workflow: Our platform integrates all components—geometry, job definition, and CT data—into an efficient, workflow for streamlined simulation execution.

Scalable geometry defined by user

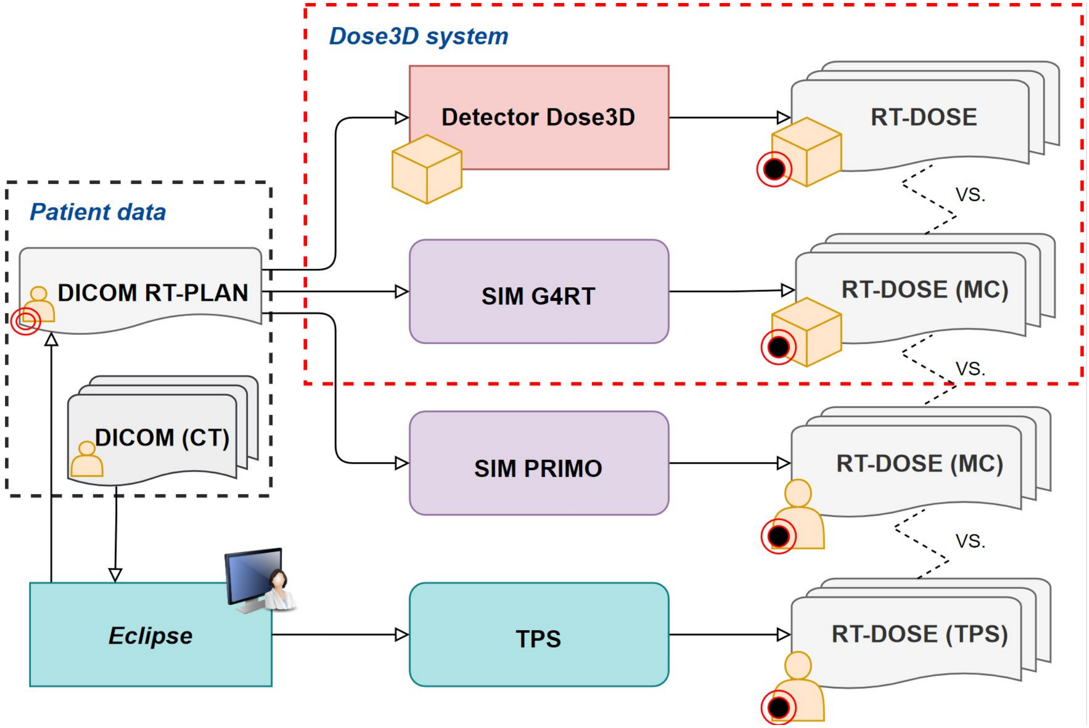
The detector is designed to handle irregular structures that conventional methods like *Geant4GenericRepeter* would find challenging to handle

Our custom-built classes enable the construction of accurate phantoms tailored to *patient-specific* experimental geometries, ensuring precise simulations even for complex structures in the future.

We use the *CADMesh* library to handle complex STL geometries, which allows for the seamless integration of 3D models in the simulation, enhancing the flexibility and accuracy of the simulation environment.

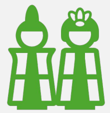


Data Workflow and DICOM as a standard data exchange format



The software stack simulates 3D dose distributions, seamlessly integrating with clinical treatment planning systems (TPS).

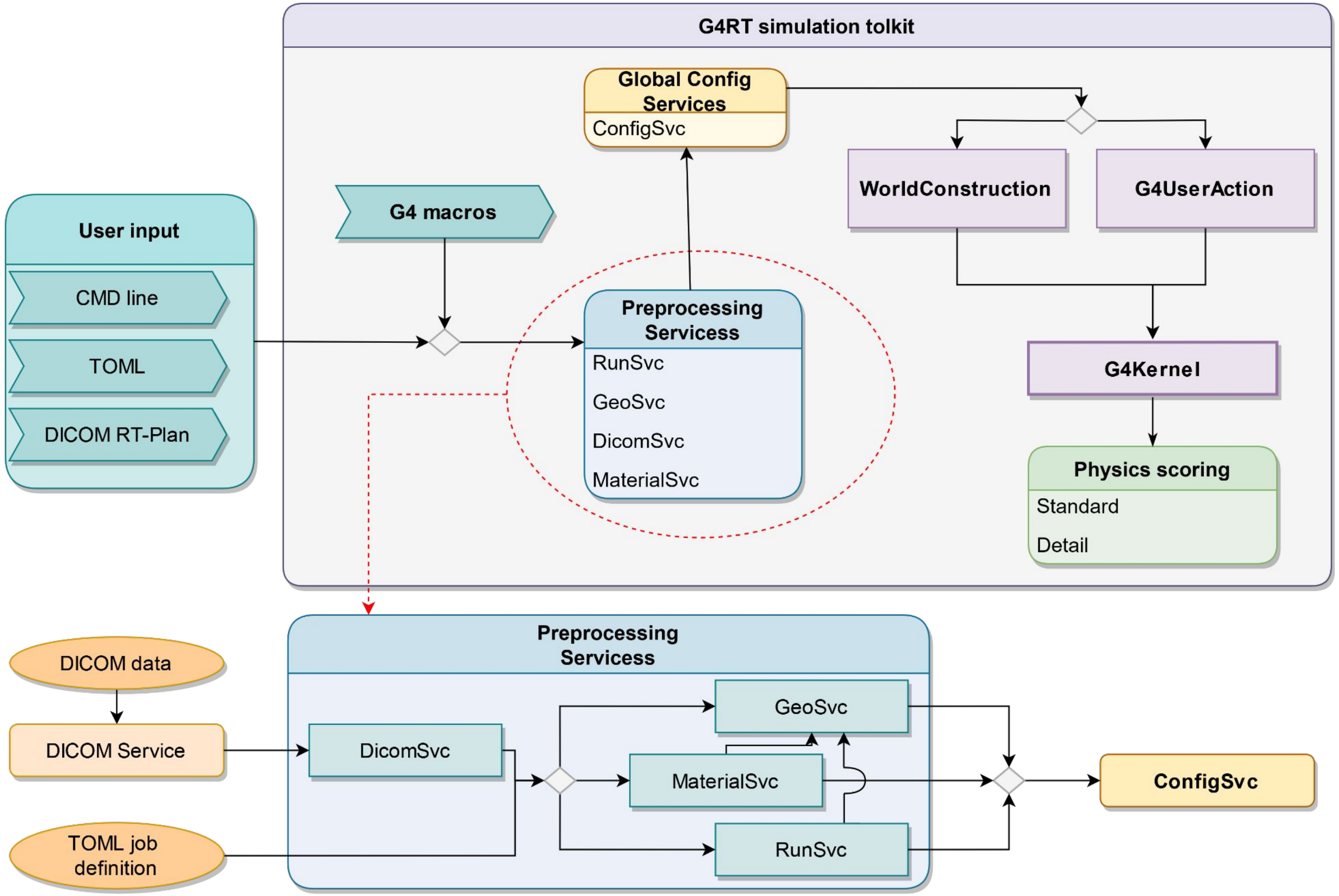
The target format for comparison of results is DICOM RT-DOSE



For future the software is designed to be intuitive to use, enabling medical physicists to easily adopt the platform.

J. Hajduga, et al., Monte Carlo simulation platform and software stack in dose-3D project, Acta Phys. Pol. B Proc. Suppl. 15 (2022) 4–A8, http://dx.doi.org/10.5506/APhysPolBSupp.15.4-A8,

G4RT architecture



G4RT services

ConfigSvc

All system component configurations are stored in a single place, avoiding boilerplate code like writing individual G4Messengers for each component. This makes it easier to maintain and modify the system's parameters.

```
int main() {

    // Instantiate MyDetector (already make it existens in ConfigSvc)
    auto myDetector = MyDetector("Tracker");

    auto configSvc = ConfigSvc::GetInstance(); // access to singleton
    // * can be accessed from any place in the application

    // Retrieve and print values from configuration
    std::cout << "Material : " << configSvc->GetValue<std::string>("Tracker", "Material") << std::endl;
    std::cout << "Resolution  : " << configSvc->GetValue<double>("Tracker", "Resolution") << std::endl;
    std::cout << "# Sensors   : " << configSvc->GetValue<int>("Tracker", "SensorCount") << std::endl;
}
```

G4RT services

ConfigSvc

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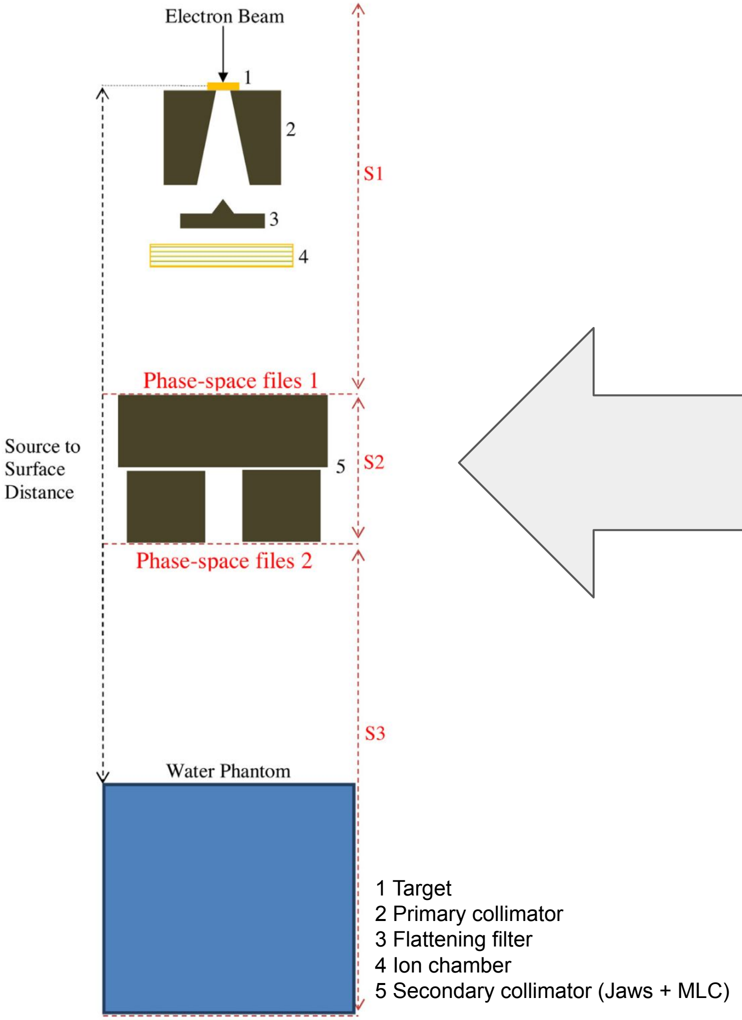
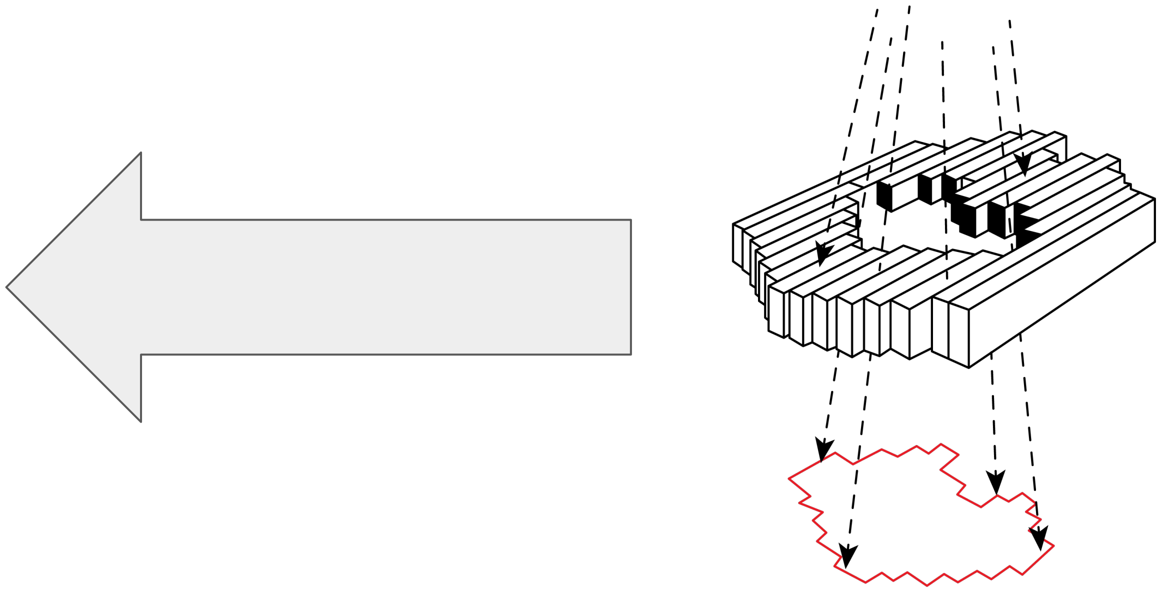
```
#include "ConfigSvc.hh"
class MyDetector : public Configurable {
public:
	MyDetector(const std::string& name) : Configurable(name) {
	Configure(); // Configure on instantiation
	}
	~MyDetector() = default;

	// Override Configure method
	void Configure() override {
		DefineUnit<std::string>("Material");
		DefineUnit<double>("Resolution");
		DefineUnit<int>("SensorCount");

		Configurable::DefaultConfig(); // Setup default values
	}
	void DefaultConfig(const std::string& unit) override {
		if (unit == "Material") m_config->SetValue(unit, std::string("Silicon"));
		if (unit == "Resolution") m_config->SetValue(unit, double(0.01));
		if (unit == "SensorCount") m_config->SetValue(unit, int(128));
	}
};
```

Beam modeling based on DICOM-RT input.



source:
M. Arif Efendi, Amporn Funsian, Thawat Chittrakarn, Tripob Bhongsuwan, Monte Carlo simulation using PRIMO code as a tool for checking the credibility of commissioning and quality assurance of 6 MV TrueBeam STx varian LINAC, Reports of Practical Oncology & Radiotherapy, Volume 25, Issue 1, 2020, Pages 125-132, ISSN 1507-1367, https://doi.org/10.1016/j.rpor.2019.12.021.

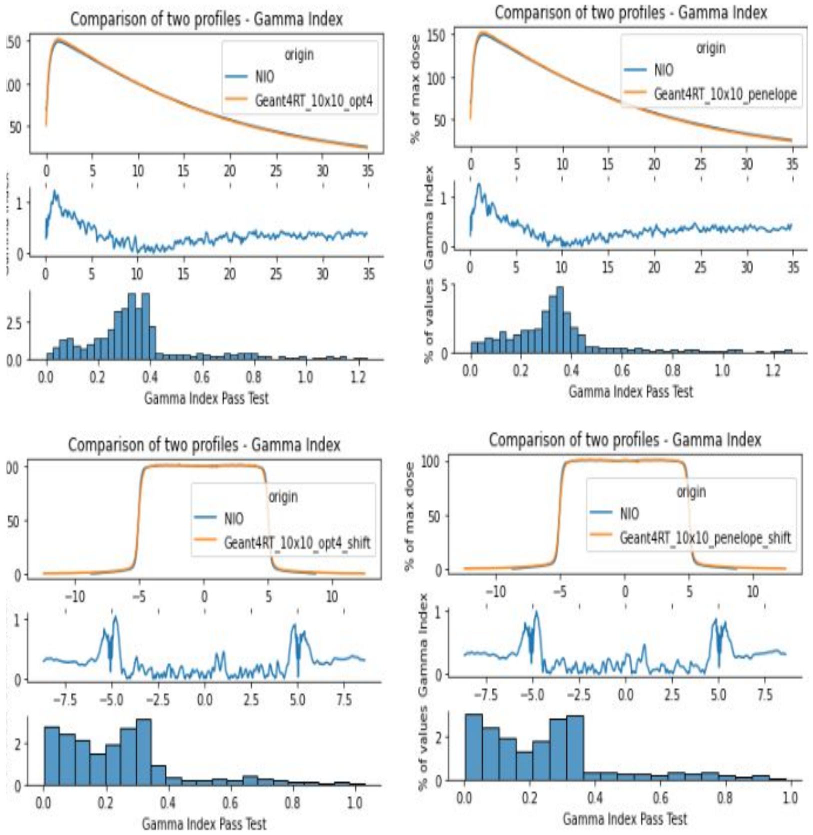


Beam modeling in our platform is based on DICOM-RT inputs, ensuring that each component of the treatment beam—from the target to the collimators and multi-leaf collimators (MLCs)—is accurately represented and simulated.

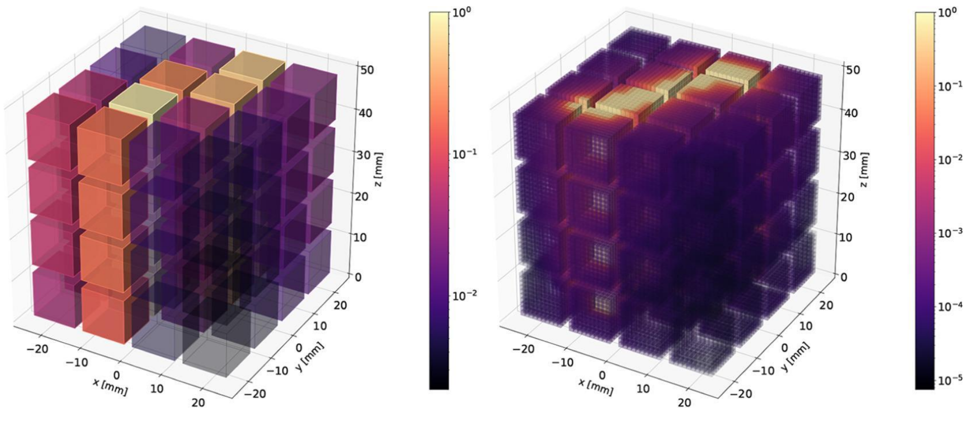
Simulation validation

Validation is critical to ensure that the simulation reflects real-world physics and treatment outcomes. Our beam model is validated through water phantom measurements, ensuring that both the beam and physics models are accurate.

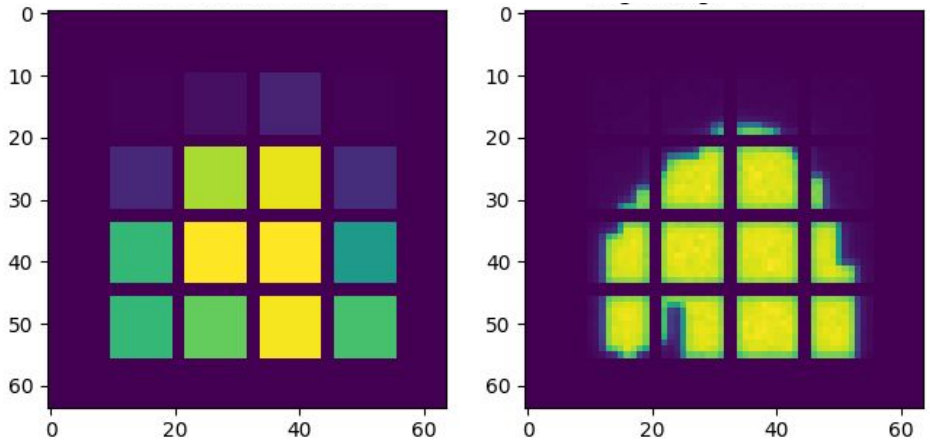
- Dose profiles comparison based on water phantom measurements
- Beam model validated
- Physic model validated



Custom scoring utilized for super-resolution research



(a) (b)



We've implemented custom scoring at both cell-level and voxel-level resolutions, allowing for fine-tuned analysis and comparison of simulation results at different scales.

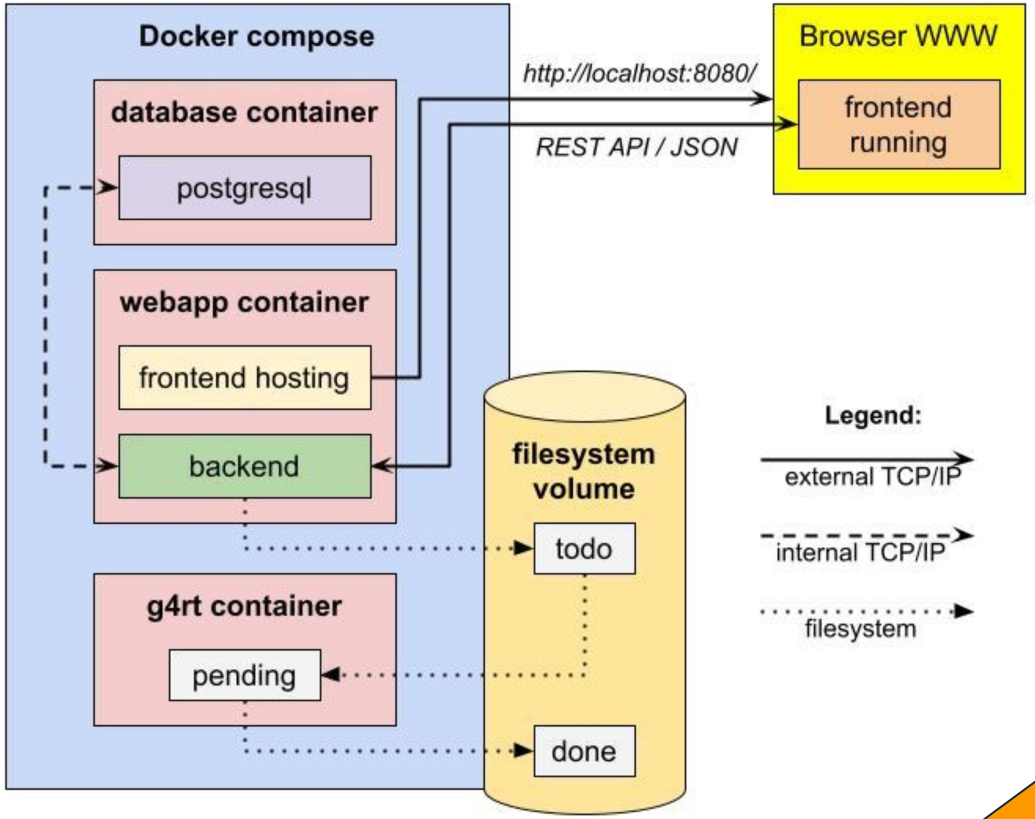
Once the **SensitiveDetector** is assigned at the cell-level, we can voxelise it with user-defined number of voxels in each dimension.

See our ML studies based on data produced with our MC application:
Up-scaling for measuring the spatial distribution of radiation dose for applications in the preparation of individual patient treatment plans,
Poster: chep24/contributions/6016079

Workflow – software environment

Web-based interface

In response to the growing demand for accessible and user-friendly tools in scientific research, we have been developed an innovative web-based interface for our Geant4 application



work in progress

Workflow – software environment

Web-based interface

Local Computer: “G4RT and WebInterface can be installed locally, allowing users to access simulations via a browser on the same machine.”

Local Network: “G4RT can also be installed on a networked computer, enabling users to securely access simulations over the network.”

Server Access: “For remote access, G4RT can be hosted on a server, accessible via the internet, with robust security features including login, password, and SSL encryption.”

work in progress

Summary

The Dose-3D platform is an innovative solution for simulating spatial radiation dose distributions, crucial for personalized radiotherapy planning.

We have developed a **modular and scalable platform** that allows users to define and simulate complex geometries, thanks to the integration of **STL models** and the **CADMesh library**.

Our **workflow** seamlessly integrates DICOM-RT data, ensuring that patient-specific treatment plans are accurately represented within the simulation environment.

By leveraging advanced **beam modeling** and **custom scoring**, we ensure that the platform provides precise and reliable dose distribution results.

The platform supports various deployment models—from **local systems** to **network and server-based configurations**—allowing flexibility in usage and accessibility.

Through rigorous **validation against water phantom measurements**, we have confirmed the accuracy of our simulations, ensuring that the platform is suitable for real-world clinical applications.

Our team

Thank You for attention