

BEAMIDE

INFN
TECHTRANSFER

MRADSIM – MATTER RADIATION INTERACTION SIMULATOR

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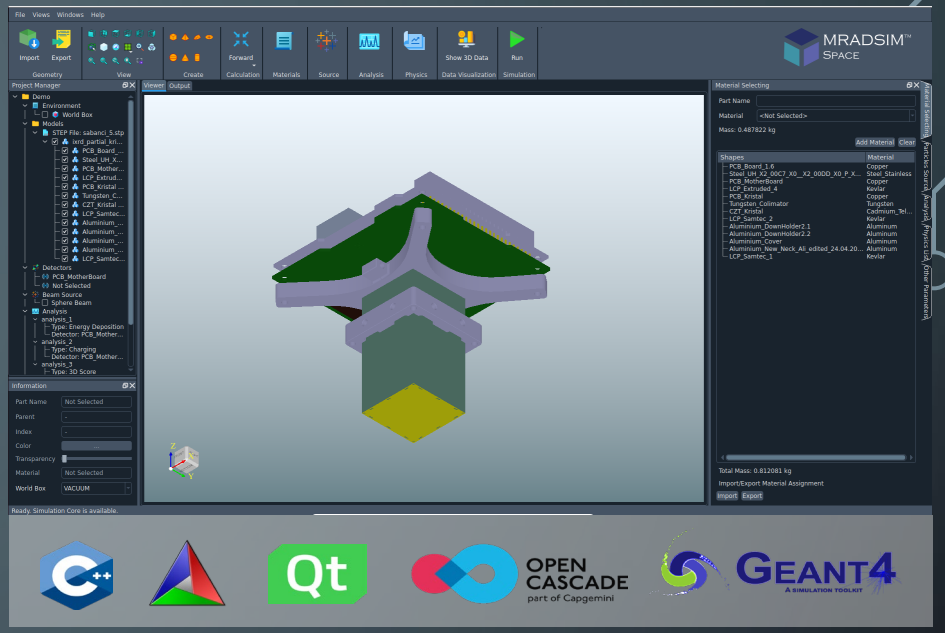
INFN - Sezione di Perugia

Workshop Computing@CSN5 – 14-16 October 2024, Bari

MRADSIM: MATTER-RADIATION SIMULATOR

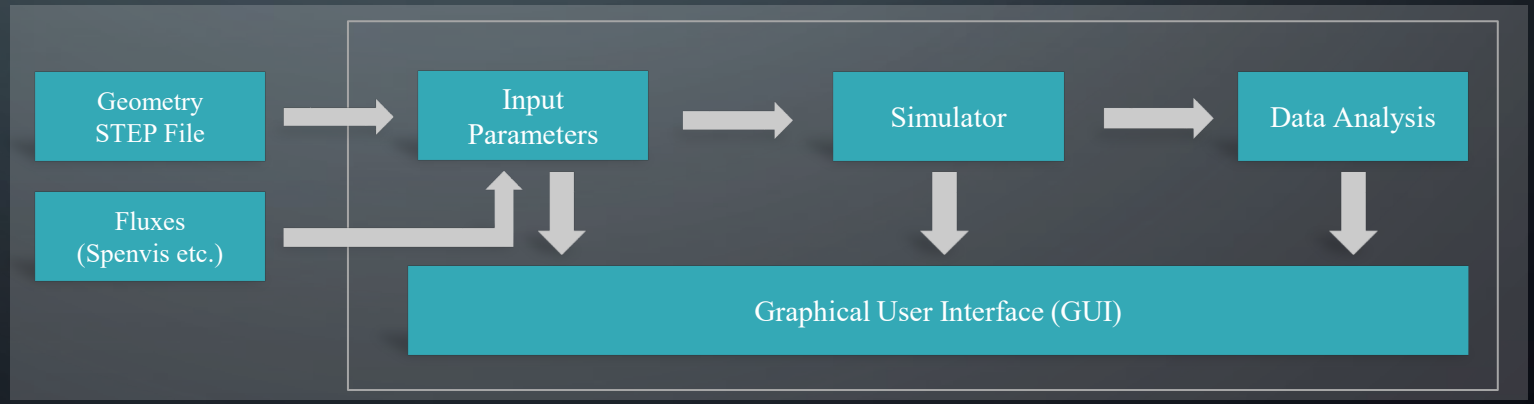


The main project at the foundation of innovative start up of INFN (National Institue for Nuclear Physics), BEAMIDE srl, is the MRADSIM software (www.mradsim.com). The goal is to create a unique tool for studying the effects of radiation and possible mitigation

It is divided in three main components:

- **Conversion tool**: from STEP files (output of CAD software) to GDML (input of the simulation backend)
- **Simulation tool**: based on Geant4, an open-source particle physics software developed at CERN
- **Graphical user interface**: Modern and intuitive, it allows the user to visualize the geometry of the project, easily set the simulation parameters and view the results obtained



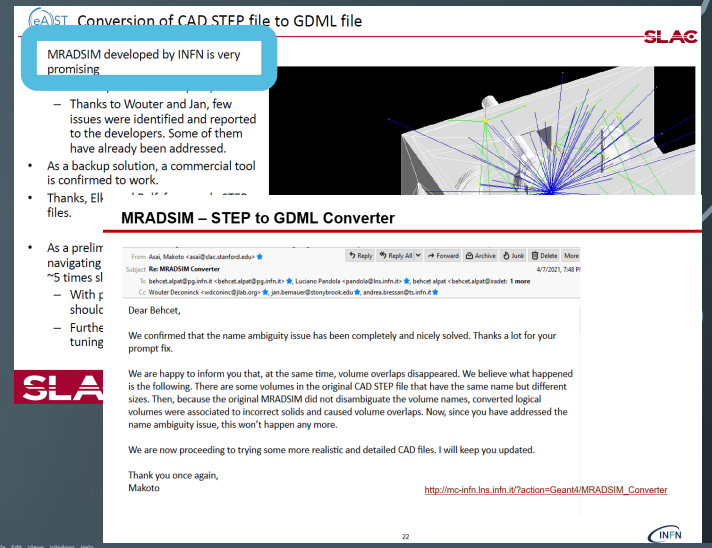


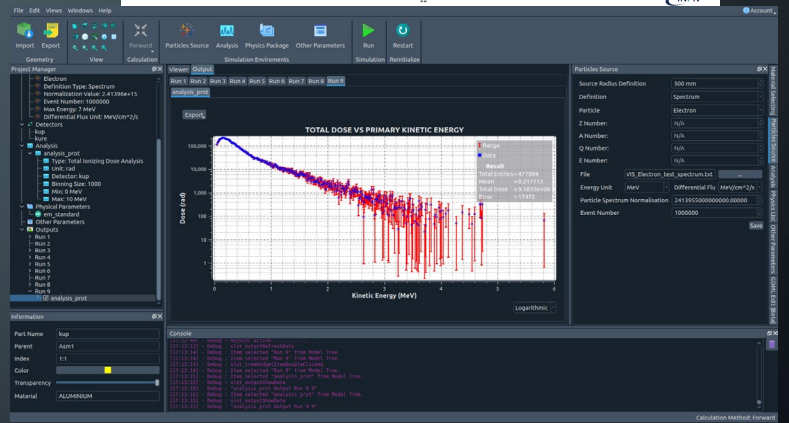
MRADSIM: COMPOSITION

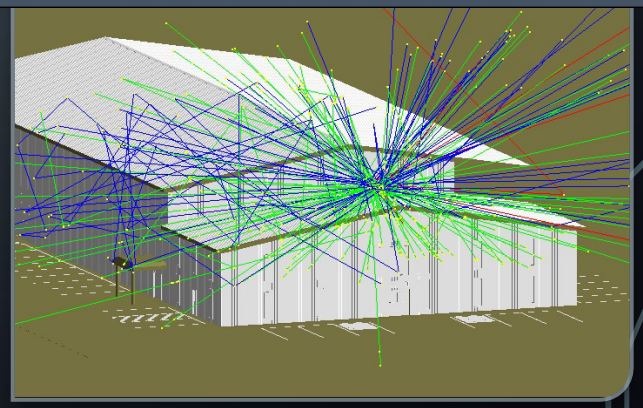
- Source code developed in **C++**
- Compilation tool **CMake**
- GUI developed using **Qt5**
- 3D engine developed using **OpenCascade**
- Monte Carlo based physics simulator developed using **Geant4**
- Graphical results representation developed using **Qt5**

Bilateral agreements with Qt and OpenCascade for licensing & commercialization

MRADSIM: SEVERAL APPLICATIONS



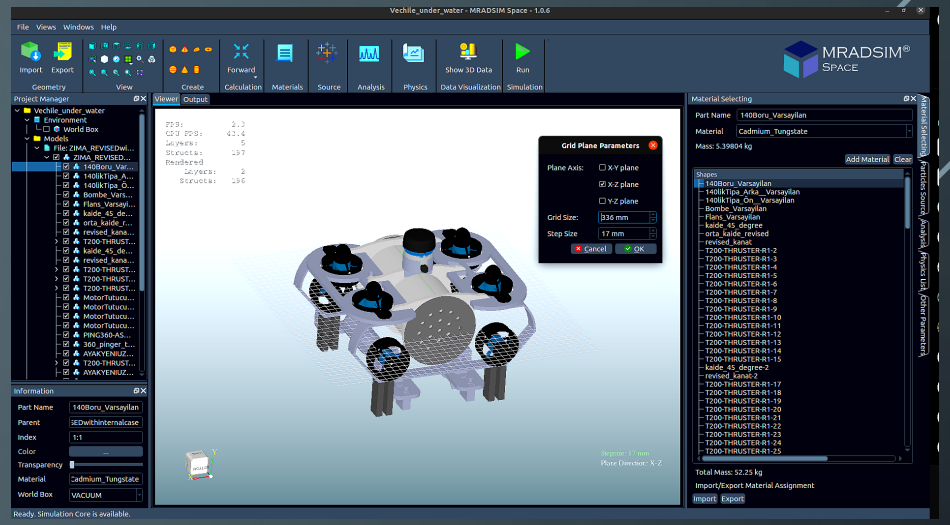




- **CONV-FREE**: developed as free demo to collect initial feedback on the project. It does not contain the physics simulation tool. It has received very positive feedback from many famous institutes (NASA, Stanford University, ESA, CERN, M.I.T. di Boston, etc.). Actually it is used in >150 copies in 26 Countries around the World. . **«MRADSIM-Converter: A new software for STEP to GDML conversion»** Computer Physics Communications, Volume 286, May 2023, 108688.
- **CONV-PRO**: advanced version of the converter, with additional and innovative features compared to the free version. For advanced users who only need the link between the CAD project and their own simulation software.
- **BASIC**: version containing the converter pro with simple simulation and analysis tools.
- **SPACE**: version with more simulation and analysis options, optimized for space applications.
- **EARTH**: version with simulations optimized for terrestrial applications.
- **Modularity**: other than the two optimized versions, we want to provide our clients the possibility to customize his product by starting from the basic version to which additional modules can be added.
- **WEB**: As long-term plan, all the versions will be made available as online service accessible via subscription.

PROBLEMS VS SOLUTIONS

Problems	Solutions
The exponential increase radiation-induced risks on electronics and on living organisms	Simulate effects in advance to take measures of protection, mitigation effects
Lack simulation tools modularly adoptable for Space and Earth apps	MRADSIM is modular for types of applications
Increase performance and reduce simulation time	Multithread & Develop and apply AI/ML algorithms
Large error because of low statistics in big geometries	Use of AI/ML and GPU power
Long STEP conversion times into GDML	MRADSIM converts 260 mb STEP in 2.5 min versus 45 min conversion commercial competitors



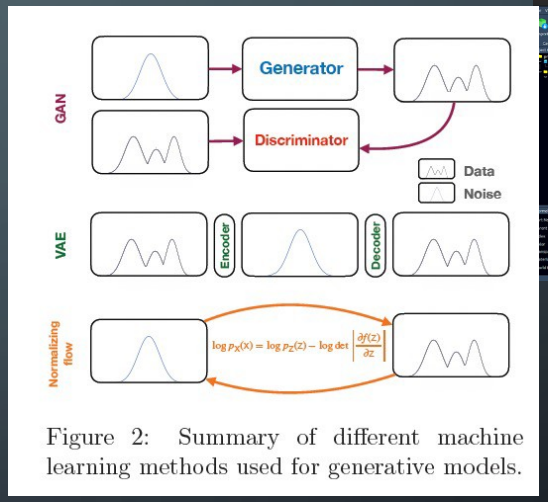
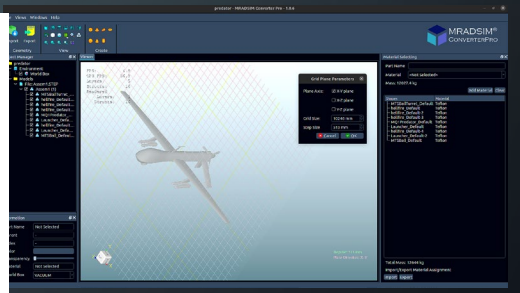


Figure 2: Summary of different machine learning methods used for generative models.



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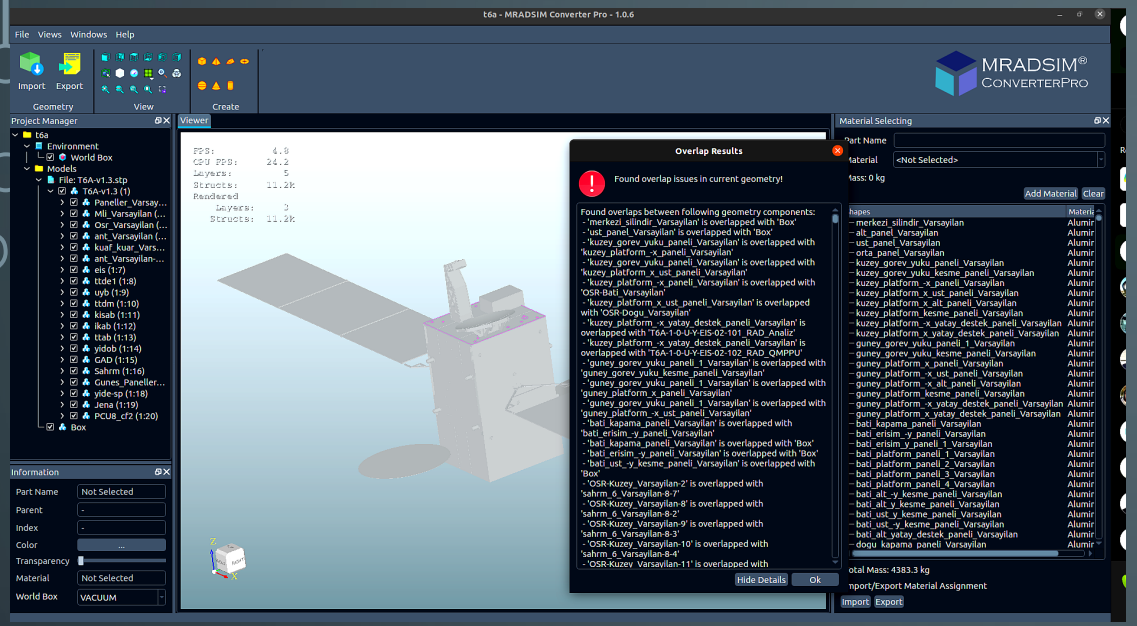
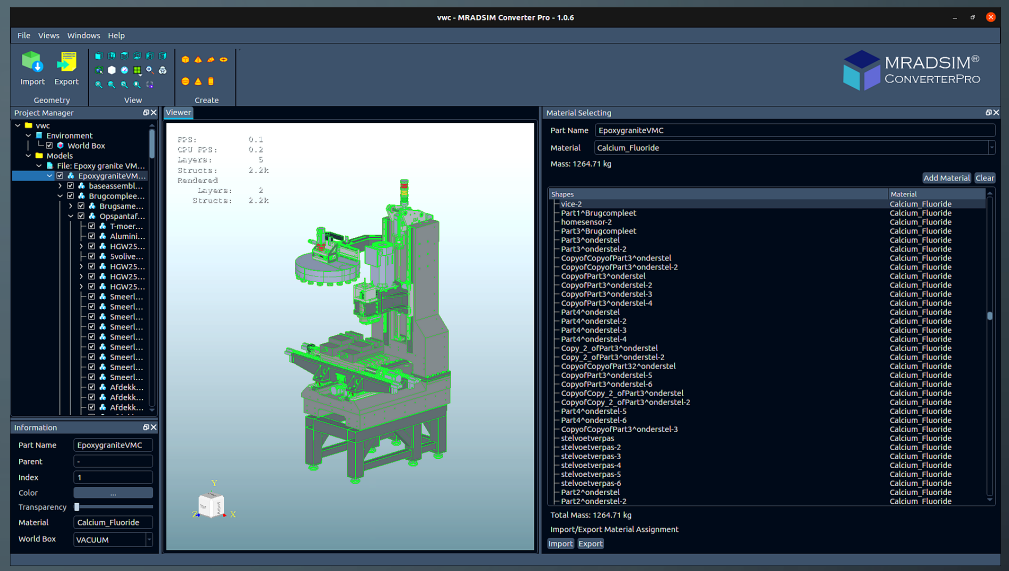
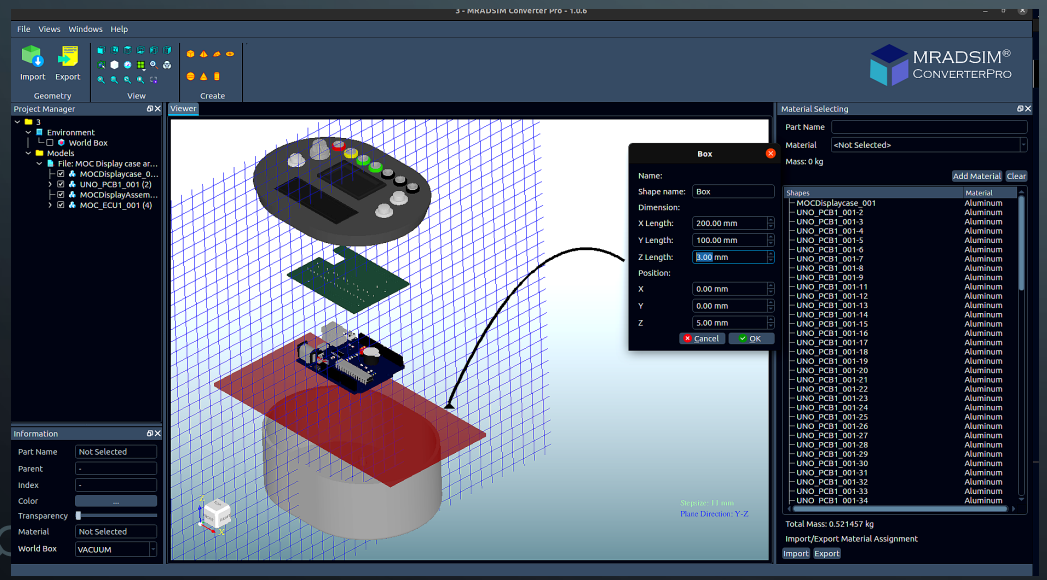
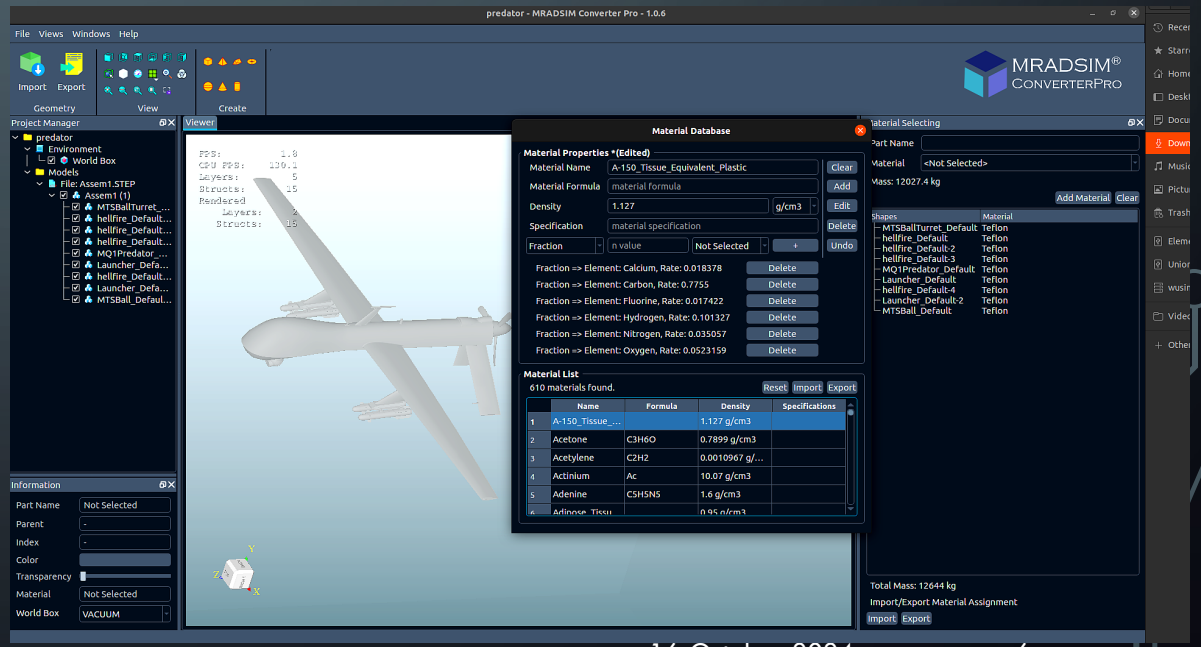
MRADSIM-ConverterPro : FEATURES & EXAMPLES









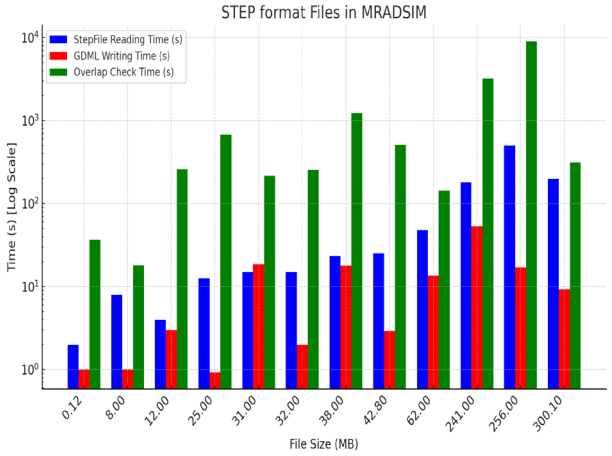
MRADSIM-ConverterPro : FEATURES & PERFORMANCE

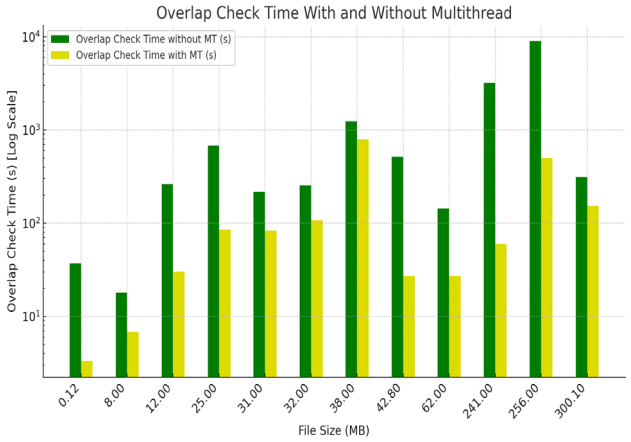
Table 1. Feature list of ConverterFree and ConverterPro.

ConverterFree Features
Interactive geometry view
STEP-to-GDML conversion
Adding new material definitions to the database
Added Features for ConverterPro
≥ x20 faster STEP-to-GDML conversion
Large STEP files (≥ 30 Mb)
STL, IGES, VRML file type support
Improved compatibility with latest STEP file standards
Dedicated GDML viewer
Overlap check feature
Large material database
Material assignment on multiple volumes
Create and combine simple shapes with preview
Add simple shapes to converted STEP file
Single piece, multiple pieces and total mass calculation
Size measurement tool
Search tool for components
Screenshot tool
Multithread support
Multilanguage support (ENG, TR, IT, CN)
Technical Support in 48 hours
Multiple user/seat licensing option

Table 2. The file formats and versions that MRADSIM supports.

File Format	Extension	Version
STEP	.step, .stp	AP203, AP209, AP214, AP214e3, AP214, AP214e1
STL	.stl	ASCII/Binary
IGES	.iges, .igs	IGES 5.3
VRML	.wrl 1	VRML 2.0





- Table 1: Unique Features of MRADSIM-ConverterPro
- Table 2: CAD file formats and versions that MRADSIM-ConverterPro supports
- Upper right: STEP file reading time, GDML file writing time and overlap check performance of MRADSIM for STEP files with various file sizes.
- Lower right: Overlap check performance of MRADSIM with and without multithreading for STEP files with various file sizes.

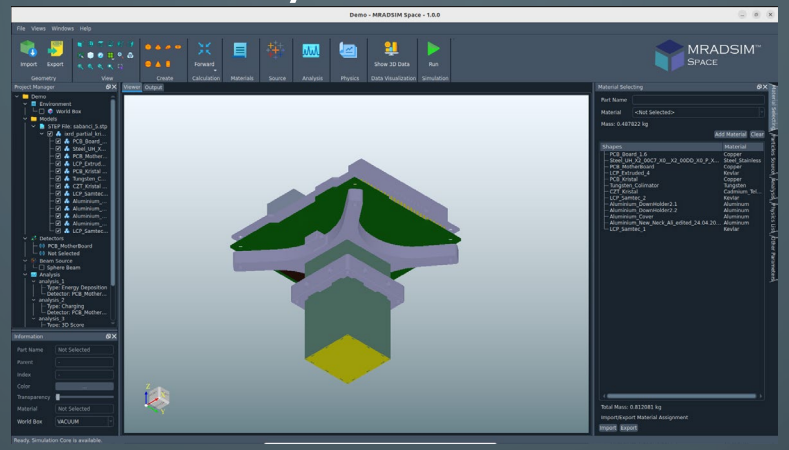
MRADSIM-Space INPUT/OUTPUT

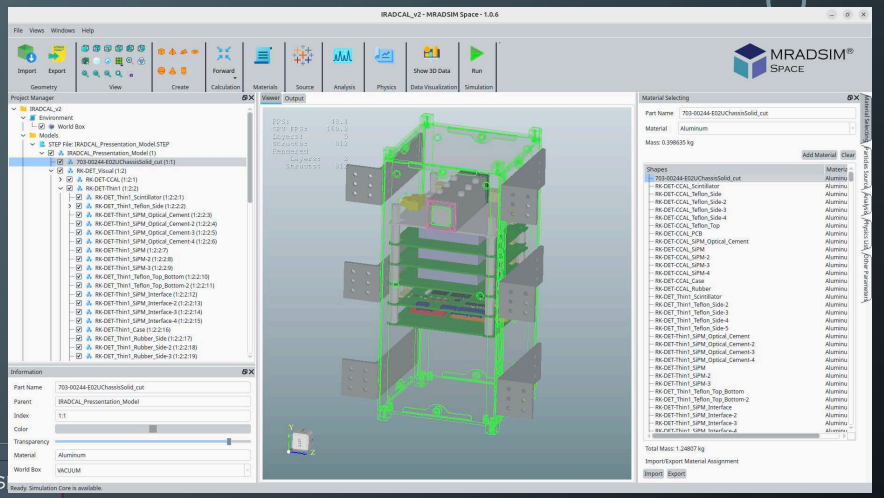
MRADSIM needs five key inputs to perform the analysis:

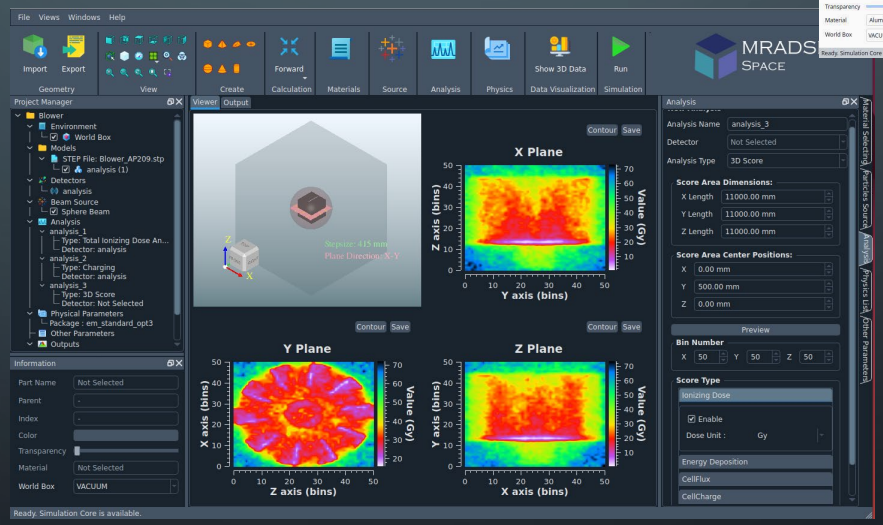
1 GEOMETRY
2 SOURCE PARTICLE
3 ANALYSIS PARAMETERS
4 PHYSICS DEFINITION
5 OTHER

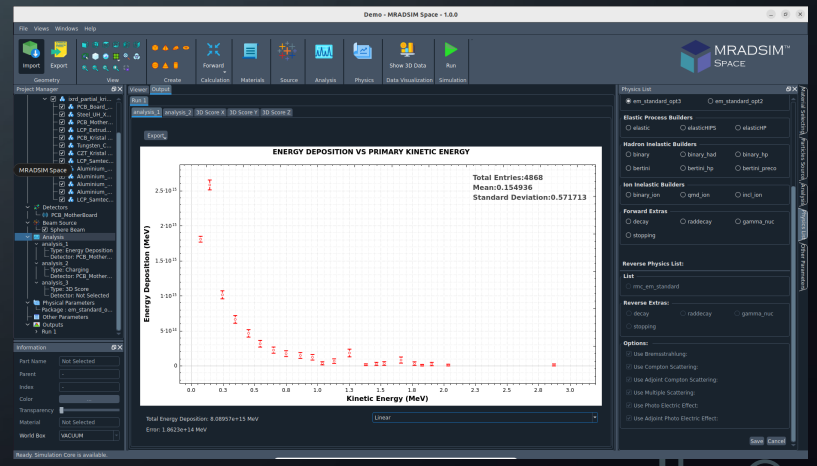
MRADSIM offers various analysis methods for space study purpose:

- **Energy Deposition**
- **3D SCORE – Dose Depth**
- **Total Ionization Dose**
- **Fluence on DUT surface**
- **Path Length Analysis**
- **Linear Energy Transfer**
- **Non Ionising Energy Loss (NIEL)**
- **Charging**





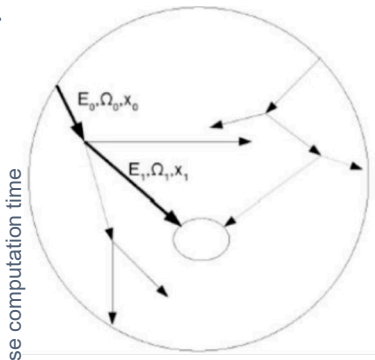




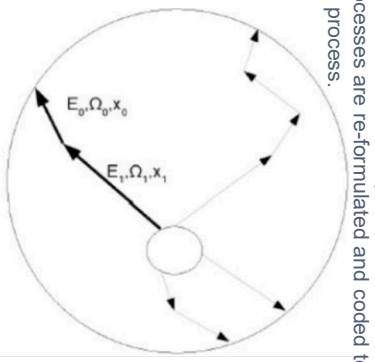
MRADSIM-SPACE SIMULATION TECHNIQUES

- Forward and Reverse montecarlo methods
- Artificial Intelligence (AI) algorithms (RandomForest) to perform
  - 3-D Dose maps,
  - Dose-Depth Curves
  - Total Ionizing Dose (TID) estimations

- A sphere determined by the **Forward** method creates a radiation-matter interaction field in the random inner space from the outer space inwards.
- Particles that do not interact with the respective detector create unnecessary and intense computation time

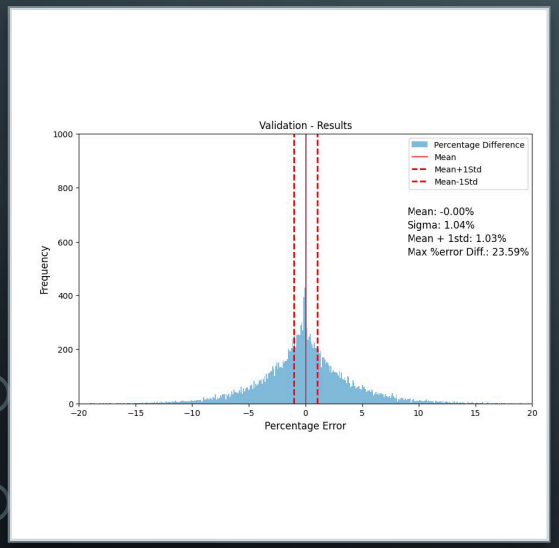


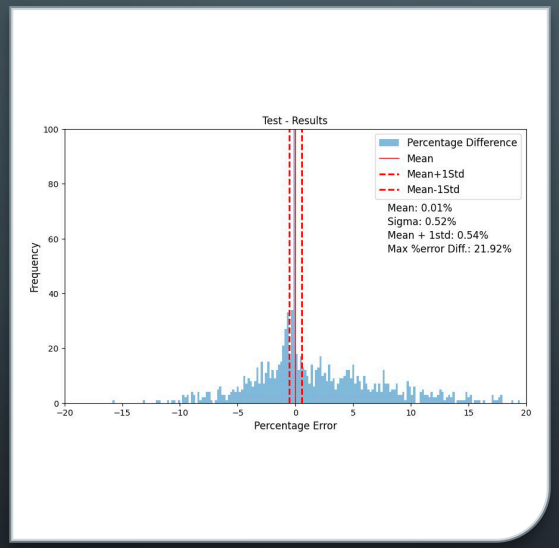
Forward Method

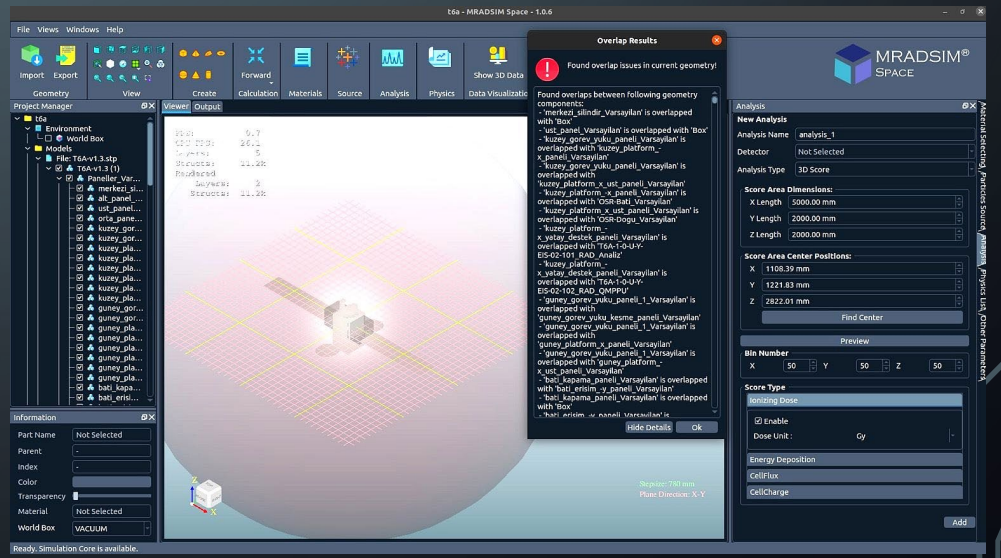


Reverse Method

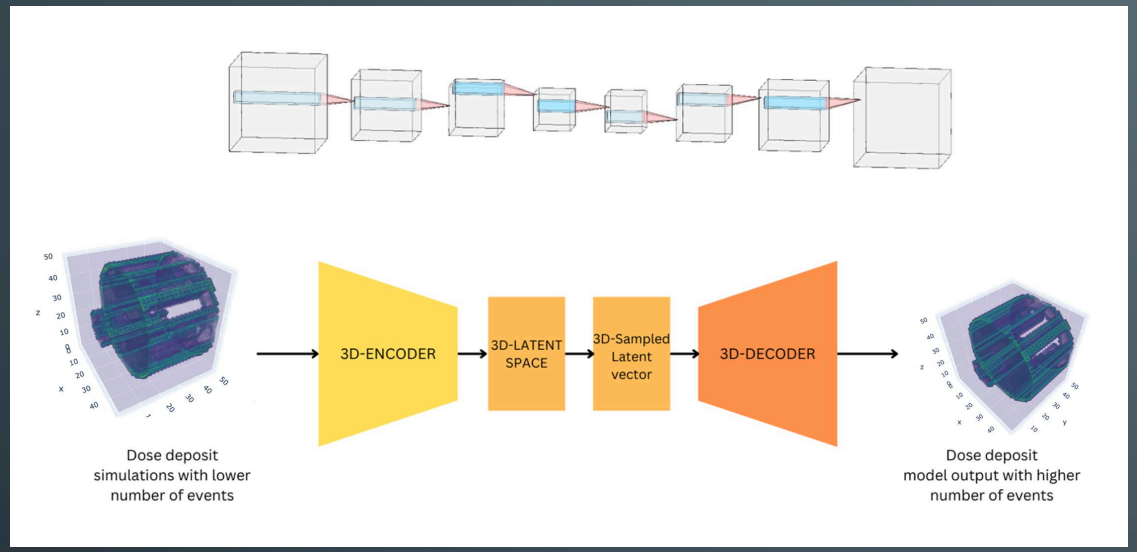
Starting with the Reverse method, the first point where the particle that can come to that point is created is found on a reverse path.
In this way, a very effective calculation time is obtained by eliminating all unrelated interactions.
However, the difficulty here is that all physical processes are re-formulated and coded to reverse the process.

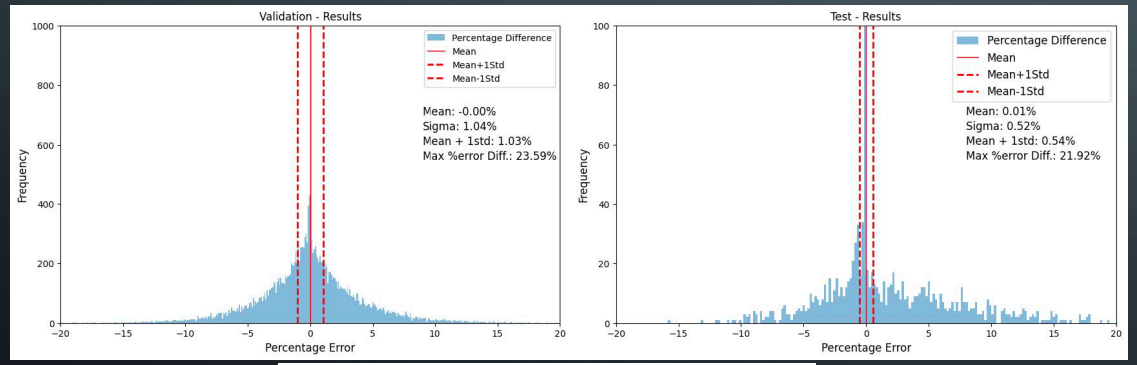






MRADSIM AI – SUPER RESOLUTION FOR 3D DOSE MAPS





$$\text{Percentage Error} = 100 \times \frac{Dose_{\text{predicted}} - Dose_{\text{original}}}{\max(Dose_{\text{original}})}$$

Use ML to artificially increase resolution on 3D dose map distributions

Created model architecture and tested two different models

- 3D-VAE
- Random Forest Regressor

First tests with limited dataset

Results are not yet optimized

Future plans:

- Increase volume and complexity of training dataset
- Test with different optimizers, loss functions, and other models
- Increase the number of events to predict (up to 10^12)

MRADSIM-SPACE BENCHMARKING

MRADSIM-Space Benchmarking with GRAS5 (Forward MC)

$$\#\ \text{of sigma} = (V_m - V_{g4}) / \sqrt{\sigma_m^2 + \sigma_{g4}^2}$$

		TRAPPED PROTONS				
		MRADSIM		GRAS 5		
Units		Value	Error	Value	Error	Delta [sigma]
	# events	4E+08	-	400000000	-	-
s	Total time	56343,5	-	87694,2	-	-
us	Time per event	140,859	-	219,2355	-	-
e	Quartz - Charging	5,53E+09	9,22E+08	5,68E+09	9,34E+08	-0,117041
MeV	Quartz - Edep	1,03E+09	1,86E+08	1,05E+09	1,90E+08	-0,085438
mSv	Quartz - EqDoseQF	147,723	27,243	148,522	26,4851	-0,021029
mSv	Quartz - EqDoseRWF	111,869	20,2141	114,338	20,6702	-0,085399
particles/cm2	Quartz - Fluence - total	7,22E+08	1,20E+08	7,42E+08	1,22E+08	-0,117043
particles/cm2	Quartz - Fluence - electron	0	0	0	0	-
particles/cm2	Quartz - Fluence gamma	0	0	0	0	-
particles/cm2	Quartz - Fluence - proton	7,22E+08	1,20E+08	7,42E+08	1,22E+08	-0,117043
MeV/cm	Quartz - LET	8,07E+19	1,79E+18	8,10E+19	1,76E+18	-0,119525
95MeVmb	Quartz - NIEL	8,73E+11	1,51E+11	8,70E+11	1,48E+11	0,016247
mm	Quartz - Path	1,03E+07	1,86E+06	1,08E+07	2,07E+06	-0,173949
rad	Quartz - TID	0,55934	0,101071	0,571691	0,103351	-0,085419
e	Silicon - Charging	3,53E+09	7,37E+08	3,38E+09	7,20E+08	0,149072
MeV	Silicon - Edep	6,88E+08	1,59E+08	5,79E+08	1,49E+08	0,499295
mSv	Silicon - EqDoseQF	380,207	86,8132	296,294	74,4485	0,733737
mSv	Silicon - EqDoseRWF	277,662	64,0829	233,751	60,2313	0,499297
particles/cm2	Silicon - Fluence - total	3,29E+08	6,87E+07	3,15E+08	6,72E+07	0,149071
particles/cm2	Silicon - Fluence - electron	0	0	0	0	-
particles/cm2	Silicon - Fluence gamma	0	0	0	0	-
particles/cm2	Silicon - Fluence - proton	3,29E+08	6,87E+07	3,15E+08	6,72E+07	0,149071
MeV/cm	Silicon - LET	5,87E+19	2,21E+18	6,34E+19	3,67E+18	-1,110623
95MeVmb	Silicon - NIEL	4,08E+12	1,30E+12	1,28E+12	4,63E+11	2,030266
mm	Silicon - Path	7,62E+06	1,79E+06	7,18E+06	1,89E+06	0,171075
rad	Silicon - TID	1,38831	0,320415	1,168750	0,301157	0,499308

Co60 – Cs137 γs to various target materials
MRADSIM-Space vs pure Geant4

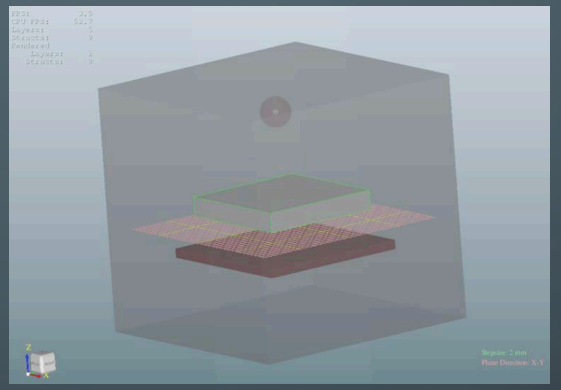
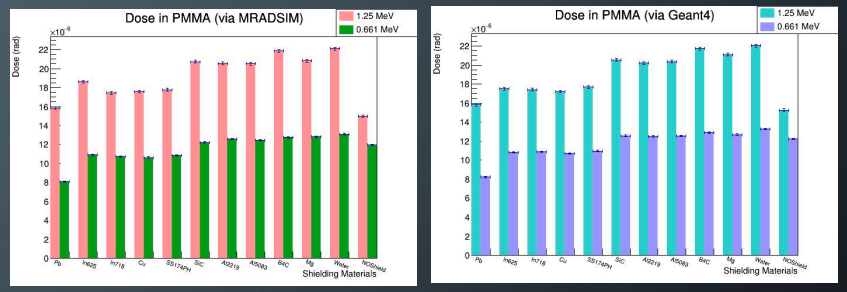
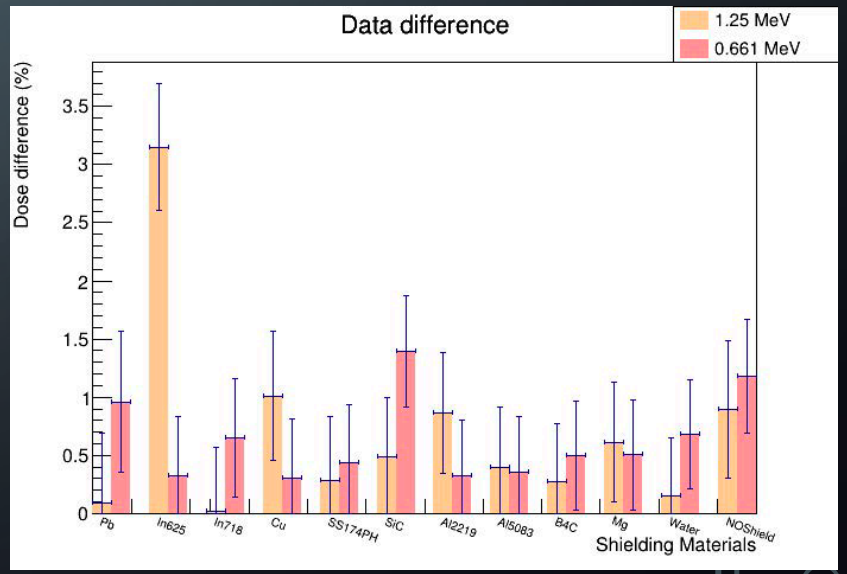


Table 3. The list of materials tested as a shielding material.

Materials	Density (g/cm^3)	Mass (kg)
Pb	11.35	0.115
Cu	8.96	0.091
In625	8.44	0.086
17-4H-SS	7.75	0.079
Al5083	2.65	0.027
Al2219	2.7	0.027
B_4C	2.52	0.026
SiC	3.21	0.033
Mg	1.74	0.018
H_2O	0.998	0.010





MRADSIM NEWS

MRADSIM is now officially available to INFN members

- Already installed: TRIESTE, MILANO-BICOCCA, PADOVA
- In progress: LNGS

CNTT proposed MRADSIM for VQR 2024

A webinar for all interested INFN members will be organized soon

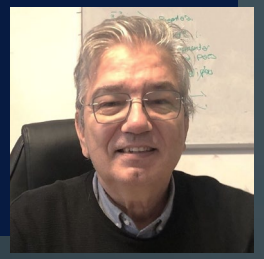


https://web.infn.it/CCR/index.php/it/sito-utenti-del-calcolo/licenze/mradsim/mradsim-descrizione

Recent presentations at:

- **SERESSA2023** "19th International School on the Effects of Radiation on Embedded Systems for Space Applications", 4-7 December 2023, Turin
- **ASI Workshop** "Tecnologie spaziali per le future missioni di ASI", 16-19 April 2024, Rome
- **ESA/ESTEC** RADSHIELD Workshop, 12-13 June 2024, Noordwijk
- **IAC/IAF** 2024, 14-18 October 2024, Milan

OUR TEAM MEMBERS



BEHCET ALPAT
SCIENTIFIC CONSULTANT & FOUNDER

High energy nuclear physics; Particle detector; Scientific simulation; Team manager



GIOVANNI BARTOLINI
R&D MANAGER & CO-FOUNDER

Physics; Distributed computing; Machine Learning ;
Scientific consultant



TALIPJAN OSMANJAN
SOFTWARE DEVELOPER

Simulation; Neural coding; Computing; Parallel computing; GPU cluster; Business research



LAURA MANNI
SALES SURVEJOR & HR

Administration, Sales & Marketing; Public relations, Human resources



LUCIA SALVI
Physics Phd Student

Development
& scientific simulation and Analysis;Radiation Detectors .



NORA CICCARELLA
Graduate Trainee in Physics

AI application integration and advanced algorithm implementation.



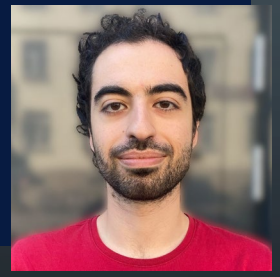
STEFANO GIGLI
IT Graduate Trainee

Software functionality enhancer and technical issues resolver.



HAMED IMAM SHAH
SOFTWARE DEVELOPER & DEBUGGER

Remote contractor for AI algorithm development and testing. Coder in. C++ and debugger



DENIZ DOLEK
EXTERNAL CONSULTANT & DEVELOPER

Master in IT, Expert in Qt, OpenCascade and C++ coding and AI algorithms



HAIDER RAHEEM
SOFTWARE DEVELOPER & DEBUGGER

Remote contractor for AI algorithm development and testing. Coder in. C++ and debugger

STATUS AND PLANS

- A free demo of MRADSIM-Converter largely used by early adopters since 2021
  - Early adopters include NASA, Stanford University, ESA, CERN, NCSS-CAST, M.I.T. of Boston, Brookhaven National Lab-BNL, etc.
- Now released MRADSIM-CONVERTER-PRO and first version of MRADSIM-SPACE
  - In 2024 also the release of MRADSIM-BASIC
- MRADSIM now published on CCR website and available to all interested INFN sections
- MRADSIM is already winner of many projects
  - SMARTUP 2021-POR FESR Umbria 2014-2020 (ended 30 Sept 2023)
  - INVITALIA-SMART&START ITALIA Decreto 30 Agosto 2019 (ends May 2025)
  - EOSC (European Open Science Cloud) pilot project (ended 30 June 2023)
  - **PRIN- PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022, Prot. 2022YEEB9Y. REASE project**
  - **MINISTRY OF DEFENSE, ITALY: Project submitted with THALES-ALENIA-ITALY and BEAMIDE for «simulation of nuclear explosions in space», Approved**



- Recently, BEAMIDE Srl was selected for Premio America Innovazione, the awards ceremony took place on March 14th , 2024 at Italian Parliament

MRADSIM DEMO



MRADSIM_Demo_Video.mp4

THANKS FOR ATTENTION

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