

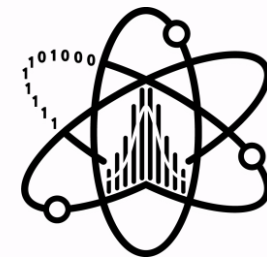
Recent developments on ion transport simulation in Geant4

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**Laboratory
of High Energy Physics
Data Analysis**

Tomsk
State
University

Preliminaries

(Relevance | Purposes | Tasks)

Relevance

In the coming decades, many space missions are planned, including some with human participation and some without. Despite the differences in their goals, each mission faces the challenge of cosmic radiation. This radiation can cause various types of breakdowns, from **single event effects in microcontrollers** to **breaks in the DNA chain**. As we know, developing these missions is costly and time-consuming, so it is essential to assess the risks to both human life and technology in space projects.

Purposes

- I. Create new DNA-model of ionization losses
- II. Validation modeling Geant4 data using ICRU90

Tasks

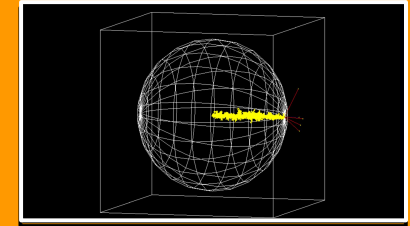
- I. Develop test-ground using Geant4
- II. Develop model of ionization losses based on «*physical*» charge
- III. Test physical configuration: DNA and EM Standard Physics
- IV. Realize python-script for visualization data

Plan

START

Preliminaries

Why the water?
Geant4-application



Part I: EM PHYSICS LIST

What is Geant4?
What is Physics List?
EM Standard 11.3
DNA 11.3
Rudd Ion models 11.3

Part II: PLOTS

What is ICRU90?
Detour factor
Range
Computation time
SKIF Cyberia



END

General conclusion
New plans



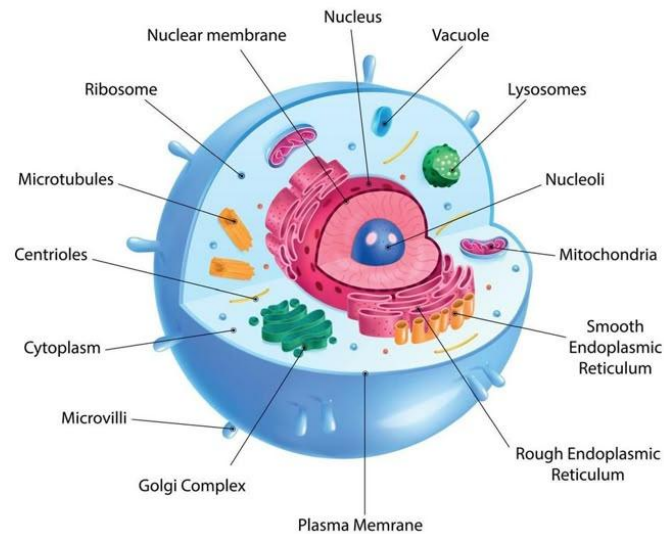
Preliminaries: Why the water?

A cell is composed of approximately
60-80% water

If we can model the interaction between ionizing
radiation and water, we can also effectively simulate
medical procedures & cosmic missions

For example,
effects of **Van Allen radiation belts** or
galactic cosmic radiation on cells

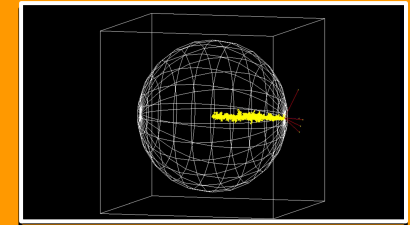
HUMAN CELL ANATOMY



Plan

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Why the water?
Geant4-application

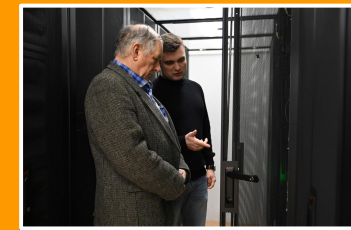


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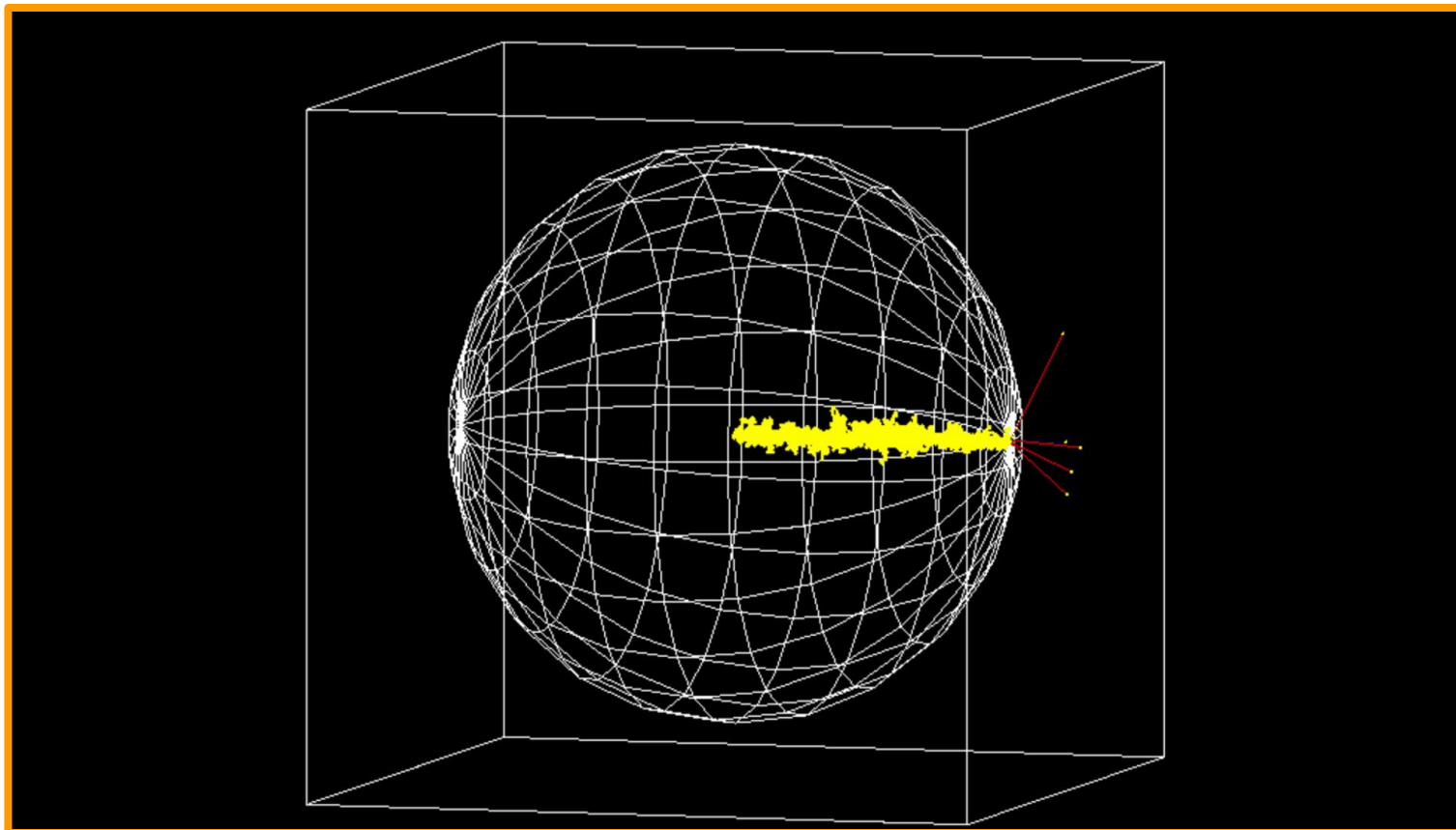


END

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Preliminaries: Geant4-application

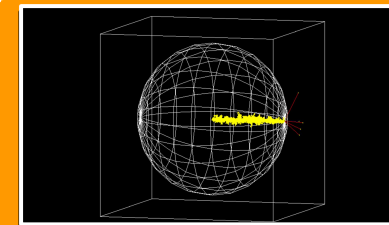


«Test-ground for Ion ranges: The water sphere & Incoming particle»

Plan

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Why the water?
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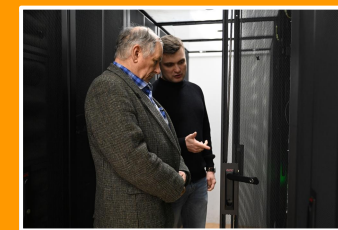


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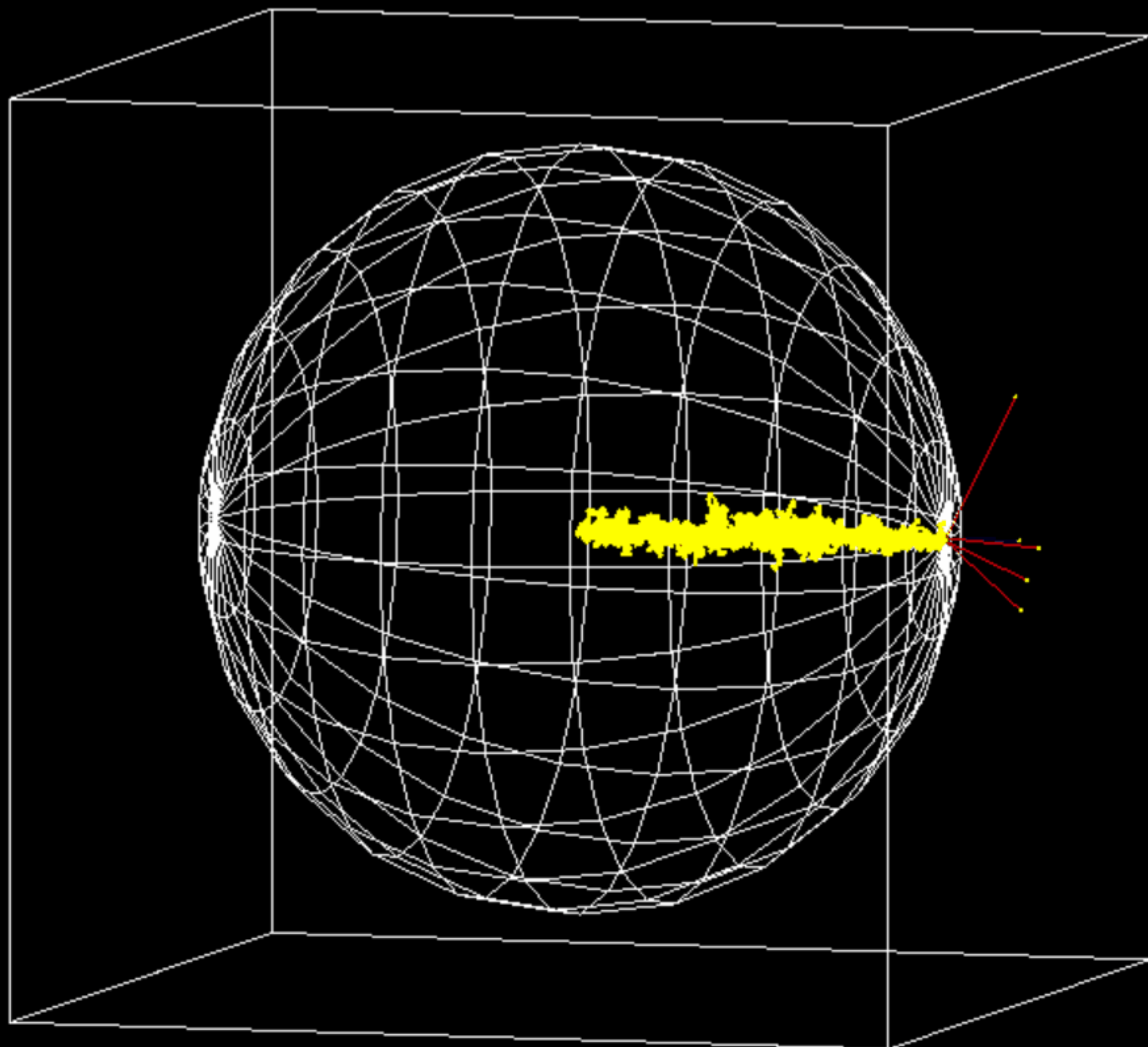
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Part I

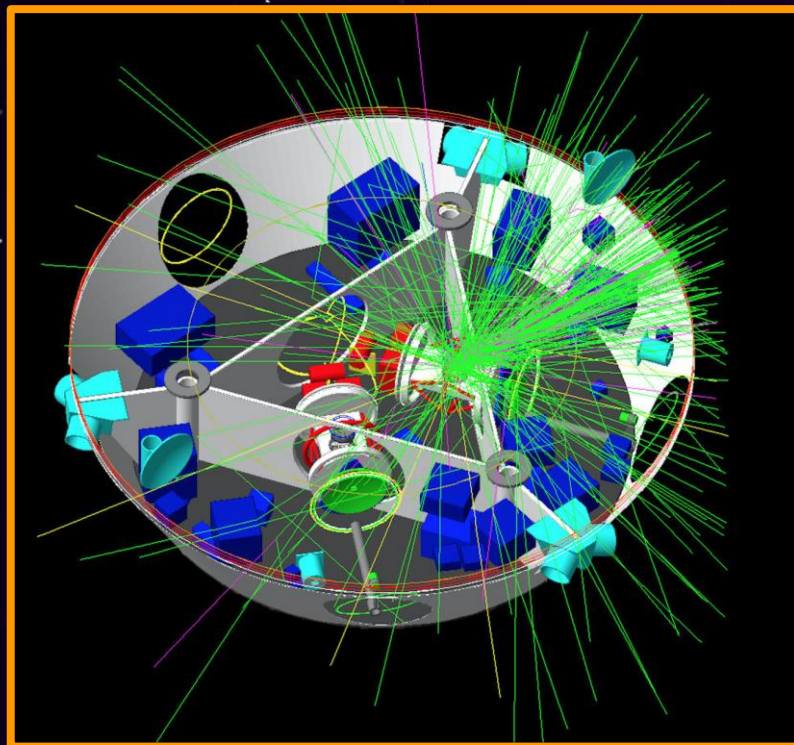
EM PHYSICS LISTS

What is Geant4?

- **Geant4** is Monte-Carlo toolkit for passage of the particles through matter simulation (Last version: 11.3)
- Geant4 provides modeling a both **high energy physics** (astroparticles, accelerated particles) and **low energy physics** (DNA breaks, radiation effects)
- You need answer to three question to create Geant4 application:

What? Where? How?

Particle. Geometry. Models

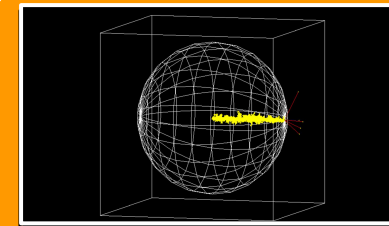


«Example of using Geant4 application»

Plan

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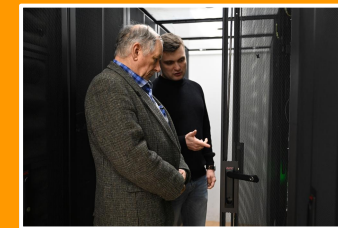


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What is Physics List?

- **Physics List** is a set of particles and physical models which uses to describe processes relate to particles
- **The existing Physical Lists:** transportation; electromagnetic, decay, hadronic(elastic/inelastic) lists etc.
- **Standard EM & DNA** are lists that uses to modeling electromagnetic process but at various *energies* and *geometry scales*
Condensed-history approach \approx *Standard EM*
Detailed-track structure approach = *DNA*
- **Option** is the configuration of the specific Physical List

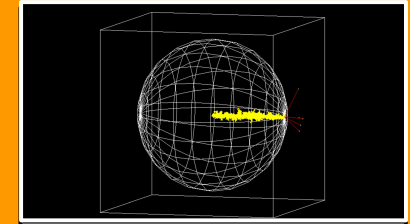
G4EmStandardPhysicsList_option4

"G4" – Geant4

Plan

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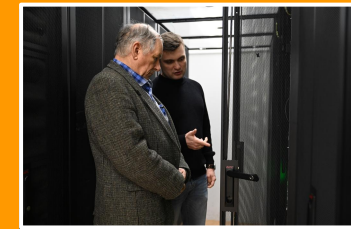


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EM Physics Lists: Standard 11.3

- **G4EmStandardPhysicsList** uses for simulation of high energy particles which participate in electromagnetic interaction
- Standard EM Physics List consist of models:
 - 1) *G4BetheBlochModel*
default high-energy model for heavy particles
 - 2) *G4LindhardSorensenModel*
using for ions $Z > 2$
using: ICRU73 & ICRU90
 - 3) *G4BraggModel*
for protons, backup for all ions,
effective charge for ions
using: ICRU90 & PSTAR
 - 4) *G4BragglonModel*
for alpha-particles
using: ICRU90 & ASTAR
- It's based on *Condensed-History approach*

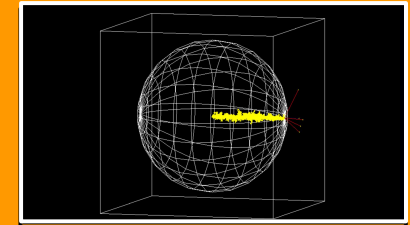
High-energy
MODELS

Low-energy
MODELS

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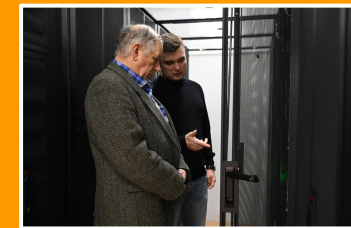


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EM Physics Lists: DNA 11.3

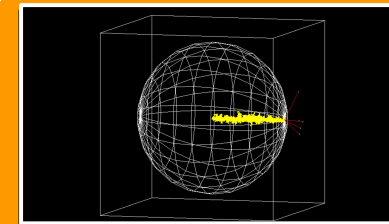
- DNA Physics list uses to modeling low-energy particles based on *Detailed-Track structure approach*
 - Main configurations:
 - option 2 (*precisest*)
 - option 4 (*worst*)
 - option 6 (*CPA100-models*)
 - option 8 (*dynamic charge*)
- It consist from models:
 - 1) *G4DNABornIonisationModel* for protons
 - 2) *G4DNARPWBAIonisationModel* for protons
 - 3) *G4DNARuddIonisationExtendedModel* for ions
 - 4) *G4DNARuddIonisationDynamicModel* for ions

Energy	Particle		
	Protons	Alpha-type	Other Ions
$E < 0.5 \text{ MeV/u}$	<i>Rudd model</i>	<i>Rudd model</i>	
$0.5 < E < 100 \text{ MeV/u}$	<i>Born model</i>		
$100 < E < 300 \text{ MeV/u}$	<i>RPWA model</i>		
$E > 300 \text{ MeV/u}$	<i>Standard models</i>		

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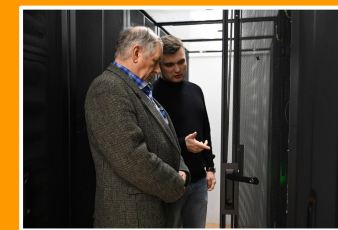


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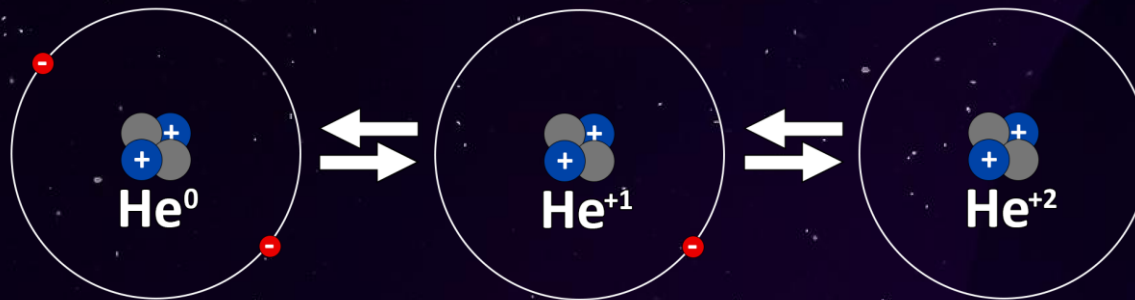
END

General conclusion
New plans



Rudd Ion models 11.3

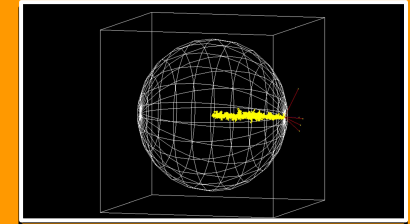
- **Rudd model** (*Nucl. Track Rad. Meas.* 16 (1988) 219) provides sampling of electron emission in proton or electron collision with water molecule
- Three flavors of the model:
 1. G4DNARuddIonisationModel – DNA Option #4
(The effective charge)
 2. G4DNARuddIonisationExtendedModel – DNA Option #2
(The effective charge)
 3. G4DNARuddIonisationDynamicModel – DNA Option #8
(The dynamic charge = charge exchange with the media)



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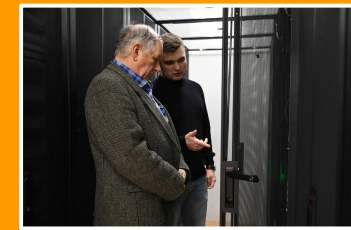


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Part II

PLOTS

Comparison Geant4 VS ICRU90

- ICRU90 - the report of the International Commission on Radiation Units and Measurements (ICRU), published in October 2016

2. Definitions of Basic Quantities and Terms

Although some familiarity with quantities and terms has to be assumed, the full and accurate development of the discussion of key data requires the definition of a number of quantities. These, from ICRU Report No. 100 (1991, 2011), are listed below.

2.1 Fluence

The fluence, Φ , is given by $\Phi = dN/dA$, where dN is the number of particles incident on a sphere of cross-sectional area dA . The energy fluence, Ψ , is given by $\Psi = dE/dA$, where dE is the radiant energy incident on a sphere of cross-sectional area dA . The radiant energy, E , is the energy (including rest energy) of the particles that are emitted, transmitted or received.

The distributions, Φ_0 and Ψ_0 , of the fluence and energy fluence with respect to energy are given by $\Phi_0 = d\Phi/dE$ and $\Psi_0 = d\Psi/dE$, where $d\Phi$ is the fluence of particles of energy between E and $E + dE$, and $d\Psi$ is the energy fluence. The relationship between the two distributions is given by $\Psi_0 = E\Phi_0$.

2.2 Mass Attenuation Coefficient

The mass attenuation coefficient, μ_a , of a material of density ρ for uncharged particles of a given type and energy is given by

$$\mu_a = \frac{1}{\rho} \frac{dN}{dx} = \frac{N_A}{\rho} \sum_i \sigma_i \quad (2.1)$$

where dN/dx is the mean fraction of the particles that experience interactions in traversing the distance dx in the material, N_A the Avogadro constant, M the molar mass of the target material, and σ the total cross section for an interaction, which is the sum of the component cross sections, σ_i . In this Report, the only uncharged particles considered are photons, and the component cross sections are for photoelectric absorption, incoherent scattering, Compton scattering, pair production, and pair and triplet production.

2.3 Mass Energy-Transfer Coefficient

The mass energy-transfer coefficient, μ_{tr} , of a material of density ρ for uncharged particles of a given type and energy is given by

$$\mu_{tr} = \frac{1}{\rho} \frac{dE_{tr}}{dx} = \frac{N_A}{\rho} \sum_i \sigma_i E_{tr,i} \quad (2.2)$$

where dE_{tr}/dx is the mean energy lost by the charged particles in traversing the distance dx in the material, N_A the Avogadro constant, M the molar mass of the target material, and σ_i the total cross section for an interaction, which is the sum of the component cross sections, σ_i . In this Report, the only uncharged particles considered are photons, and the component cross sections are for photoelectric absorption, incoherent scattering, Compton scattering, pair production, and pair and triplet production.

2.4 Mass Energy-Absorption Coefficient

A function μ of the kinetic energy transferred to charged particles is subsequently lost as average inelastic processes (bremsstrahlung, ionization, excitation, and fluorescence radiation) as the charged particles move in the material, and the function μ is specific to the material. The product of μ_{tr} for a material and $(1 - g)$ is called the mass energy-absorption coefficient, μ_{en} , of the material for uncharged particles of a given type and energy is given by

$$\mu_{en} = \mu_{tr}(1 - g) \quad (2.3)$$

The mass stopping power, S , of a material of density ρ for a charged particle of a given type and energy is given by

$$S = \frac{1}{\rho} \frac{dE}{dx} \quad (2.4)$$

where dE/dx is the mean energy lost by the charged particles in traversing the distance dx in the material. The quantity $S - gS$ denotes the linear stopping power for photons, the stopping power minus three components.

Appendix

Table A.1. Electrons in liquid water, $T = 293.15$ K, $\rho = 0.997$ g cm⁻³.

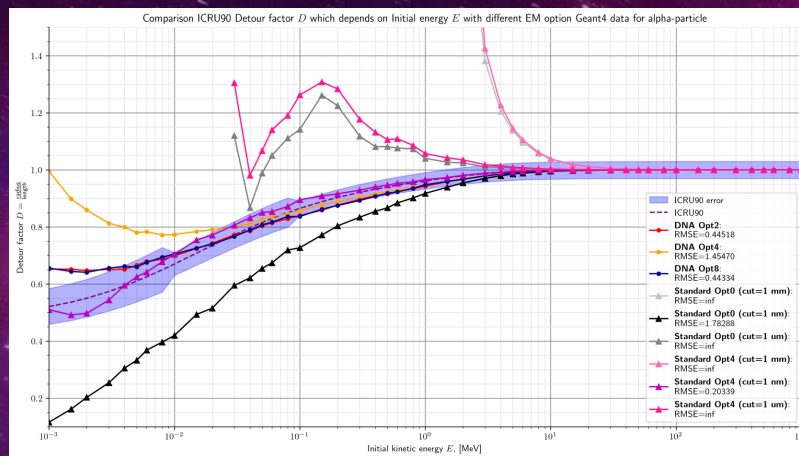
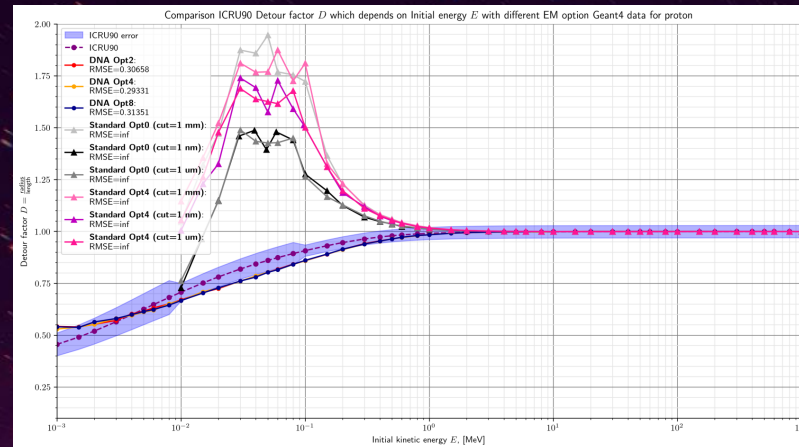
E	$R_{0,0}$	$R_{0,0}/\rho$	$R_{0,0}/\rho$	μ_a	μ_{tr}	μ_{en}	S	$S - gS$
MeV			MeV g ⁻¹					
0.001	1.0010	1.0010	1.0010	0.0000	0.0000	0.0000	0.0000	0.0000
0.002	1.0020	1.0020	1.0020	0.0000	0.0000	0.0000	0.0000	0.0000
0.005	1.0050	1.0050	1.0050	0.0000	0.0000	0.0000	0.0000	0.0000
0.010	1.0100	1.0100	1.0100	0.0000	0.0000	0.0000	0.0000	0.0000
0.020	1.0200	1.0200	1.0200	0.0000	0.0000	0.0000	0.0000	0.0000
0.050	1.0500	1.0500	1.0500	0.0000	0.0000	0.0000	0.0000	0.0000
0.100	1.1000	1.1000	1.1000	0.0000	0.0000	0.0000	0.0000	0.0000
0.200	1.2000	1.2000	1.2000	0.0000	0.0000	0.0000	0.0000	0.0000
0.500	1.5000	1.5000	1.5000	0.0000	0.0000	0.0000	0.0000	0.0000
1.000	1.8000	1.8000	1.8000	0.0000	0.0000	0.0000	0.0000	0.0000
2.000	2.2000	2.2000	2.2000	0.0000	0.0000	0.0000	0.0000	0.0000
5.000	2.8000	2.8000	2.8000	0.0000	0.0000	0.0000	0.0000	0.0000
10.000	3.2000	3.2000	3.2000	0.0000	0.0000	0.0000	0.0000	0.0000
20.000	3.5000	3.5000	3.5000	0.0000	0.0000	0.0000	0.0000	0.0000
50.000	3.8000	3.8000	3.8000	0.0000	0.0000	0.0000	0.0000	0.0000
100.000	4.0000	4.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200.000	4.2000	4.2000	4.2000	0.0000	0.0000	0.0000	0.0000	0.0000
500.000	4.5000	4.5000	4.5000	0.0000	0.0000	0.0000	0.0000	0.0000
1000.000	4.7000	4.7000	4.7000	0.0000	0.0000	0.0000	0.0000	0.0000
2000.000	4.8000	4.8000	4.8000	0.0000	0.0000	0.0000	0.0000	0.0000
5000.000	5.0000	5.0000	5.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10000.000	5.1000	5.1000	5.1000	0.0000	0.0000	0.0000	0.0000	0.0000
20000.000	5.2000	5.2000	5.2000	0.0000	0.0000	0.0000	0.0000	0.0000
50000.000	5.3000	5.3000	5.3000	0.0000	0.0000	0.0000	0.0000	0.0000
100000.000	5.4000	5.4000	5.4000	0.0000	0.0000	0.0000	0.0000	0.0000
200000.000	5.5000	5.5000	5.5000	0.0000	0.0000	0.0000	0.0000	0.0000
500000.000	5.6000	5.6000	5.6000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000.000	5.7000	5.7000	5.7000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000.000	5.8000	5.8000	5.8000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000.000	5.9000	5.9000	5.9000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000.000	6.0000	6.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000.000	6.1000	6.1000	6.1000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000.000	6.2000	6.2000	6.2000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000.000	6.3000	6.3000	6.3000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000.000	6.4000	6.4000	6.4000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000.000	6.5000	6.5000	6.5000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000.000	6.6000	6.6000	6.6000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000.000	6.7000	6.7000	6.7000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000.000	6.8000	6.8000	6.8000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000.000	6.9000	6.9000	6.9000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000.000	7.0000	7.0000	7.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000000.000	7.1000	7.1000	7.1000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000000.000	7.2000	7.2000	7.2000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000000.000	7.3000	7.3000	7.3000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000000.000	7.4000	7.4000	7.4000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000000.000	7.5000	7.5000	7.5000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000.000	7.6000	7.6000	7.6000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000.000	7.7000	7.7000	7.7000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000.000	7.8000	7.8000	7.8000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000000.000	7.9000	7.9000	7.9000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000000000.000	8.0000	8.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000000000.000	8.1000	8.1000	8.1000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000000000.000	8.2000	8.2000	8.2000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000000000.000	8.3000	8.3000	8.3000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000000000.000	8.4000	8.4000	8.4000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000000.000	8.5000	8.5000	8.5000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000000.000	8.6000	8.6000	8.6000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000000.000	8.7000	8.7000	8.7000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000000000.000	8.8000	8.8000	8.8000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000000000000.000	8.9000	8.9000	8.9000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000000000000.000	9.0000	9.0000	9.0000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000000000000.000	9.1000	9.1000	9.1000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000000000000.000	9.2000	9.2000	9.2000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000000000000.000	9.3000	9.3000	9.3000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000000000.000	9.4000	9.4000	9.4000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000000000.000	9.5000	9.5000	9.5000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000000000.000	9.6000	9.6000	9.6000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000000000000.000	9.7000	9.7000	9.7000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000000000000000.000	9.8000	9.8000	9.8000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000000000000000.000	9.9000	9.9000	9.9000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000000000000000.000	10.0000	10.0000	10.0000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000000000000000.000	10.1000	10.1000	10.1000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000000000000000.000	10.2000	10.2000	10.2000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000000000000.000	10.3000	10.3000	10.3000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000000000000.000	10.4000	10.4000	10.4000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000000000000.000	10.5000	10.5000	10.5000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000000000000000.000	10.6000	10.6000	10.6000	0.0000	0.0000	0.0000	0.0000	0.0000
50000000000000000000000.000	10.7000	10.7000	10.7000	0.0000	0.0000	0.0000	0.0000	0.0000
100000000000000000000000.000	10.8000	10.8000	10.8000	0.0000	0.0000	0.0000	0.0000	0.0000
200000000000000000000000.000	10.9000	10.9000	10.9000	0.0000	0.0000	0.0000	0.0000	0.0000
500000000000000000000000.000	11.0000	11.0000	11.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1000000000000000000000000.000	11.1000	11.1000	11.1000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000000000000000.000	11.2000	11.2000	11.2000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000000000000000.000	11.3000	11.3000	11.3000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000000000000000.000	11.4000	11.4000	11.4000	0.0000	0.0000	0.0000	0.0000	0.0000
20000000000000000000000000.000	11.5000	11.5000	11.5000	0.0000	0.0000	0.0000	0.0000	0.0000
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1000000000000000000000000000.000	12.0000	12.0000	12.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2000000000000000000000000000.000	12.1000	12.1000	12.1000	0.0000	0.0000	0.0000	0.0000	0.0000
5000000000000000000000000000.000	12.2000	12.2000	12.2000	0.0000	0.0000	0.0000	0.0000	0.0000
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5000000000000000000000000000000.000	13.1000	13.1000	13.1000	0.0000	0.0000	0.0000	0.0000	0.0000
10000000000000000000000000000000.000	13.2000	13						

Geant4 VS ICRU90: Detour factor

Detour factor is the ratio of the penetration depth to the actual path length

$$\text{Detour factor} = \frac{\text{radius}}{\text{length}}$$

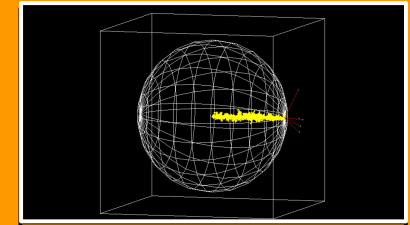
It characterizes the scattering of the particles



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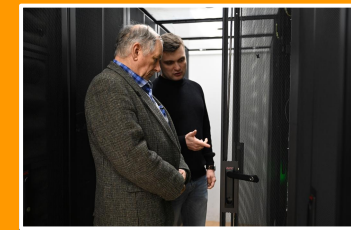


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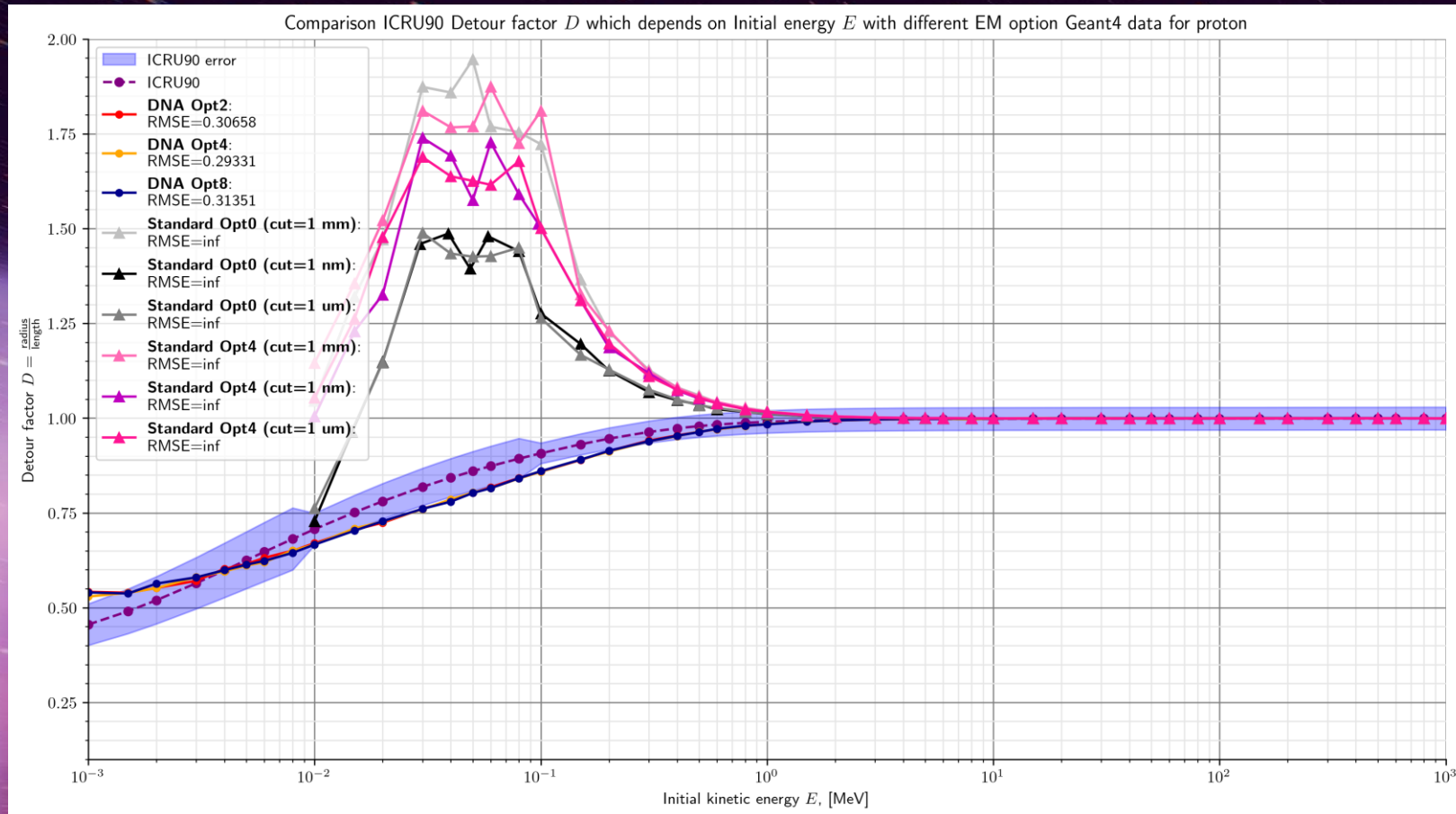


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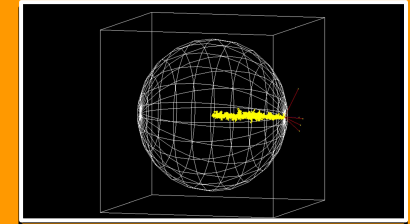
Geant4 VS ICRU90: Detour factor



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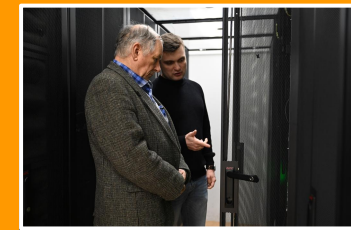


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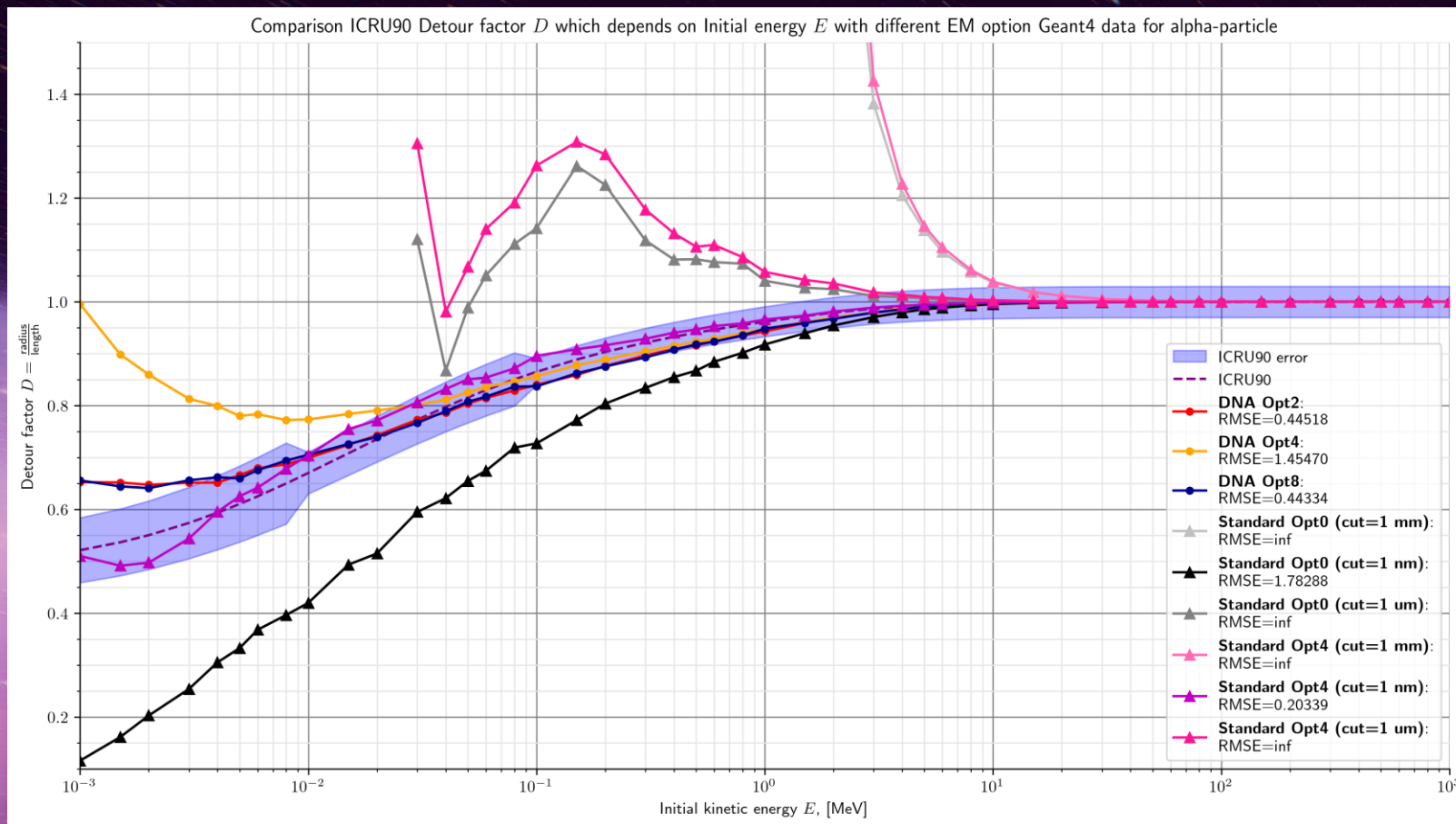


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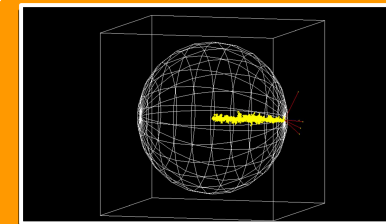
Geant4 VS ICRU90: Detour factor



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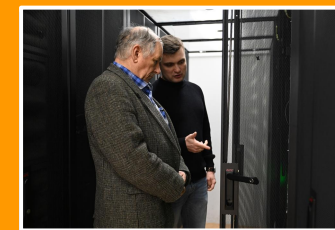


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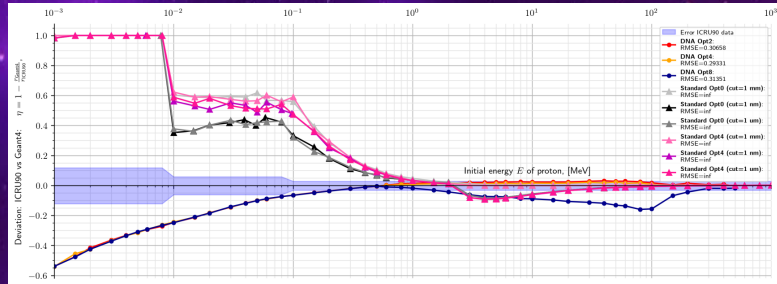
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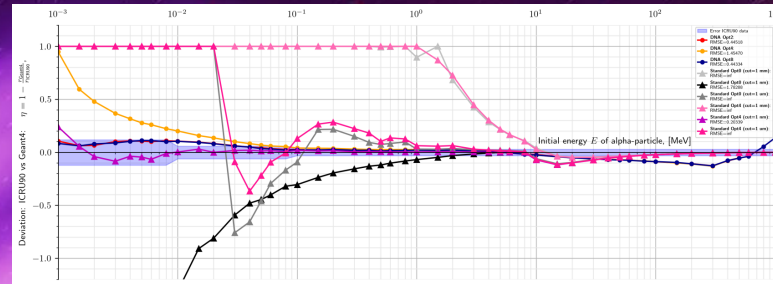
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Geant4 VS ICRU90: Range

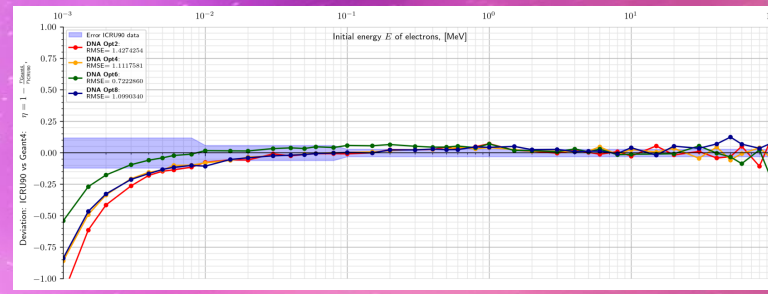
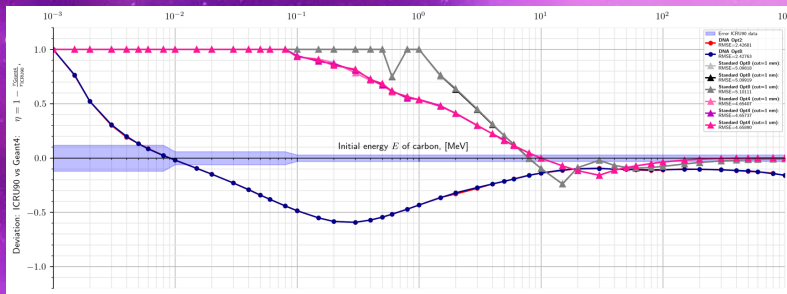


Range is the path length of some particle in some material

Dynamical charge
 $\text{He}^0 \leftrightarrow \text{He}^{+1} \leftrightarrow \text{He}^{+2}$

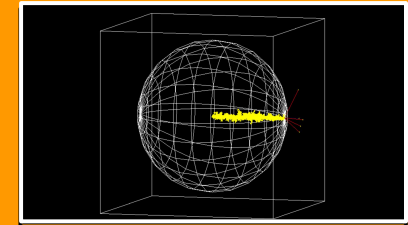


$$\text{Deviation} = 1 - \frac{\text{Range}_{\text{Geant4}}}{\text{Range}_{\text{ICRU90}}}$$



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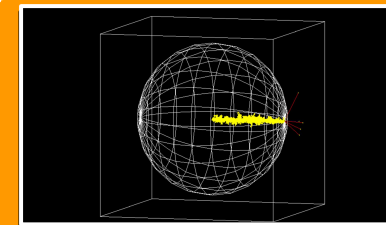


Geant4 VS ICRU90: Range

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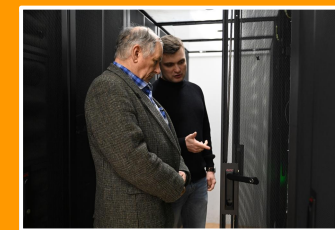


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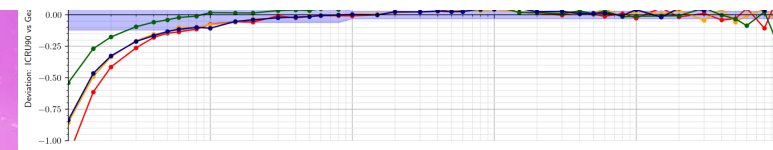
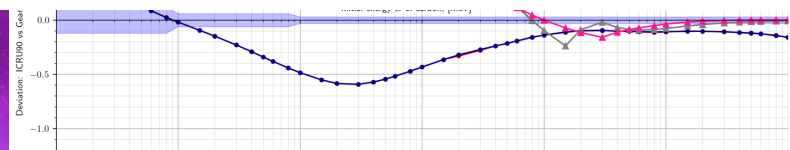
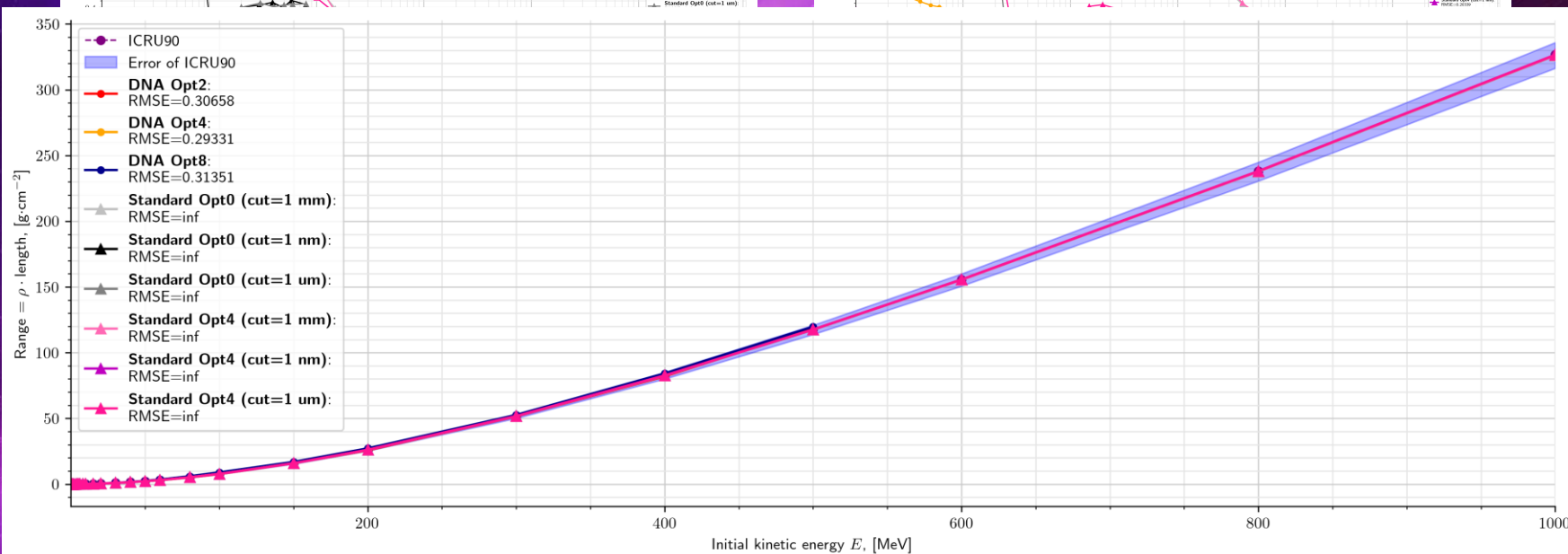
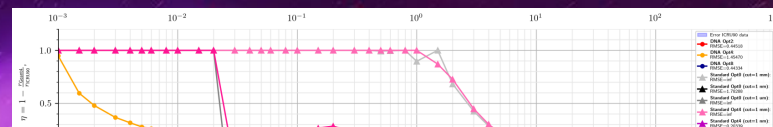
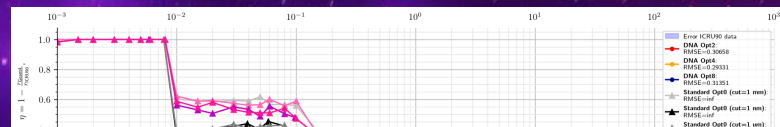
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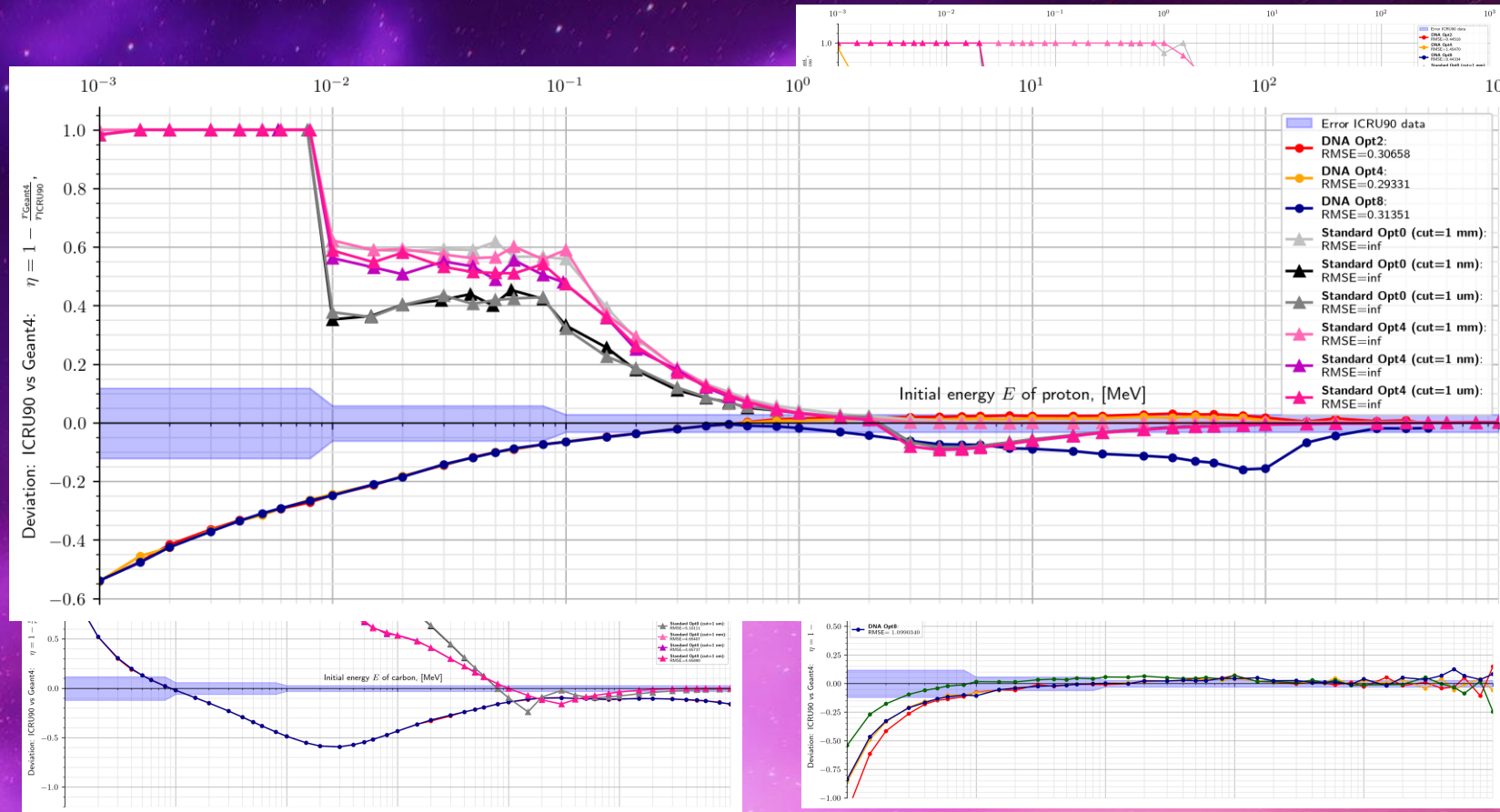
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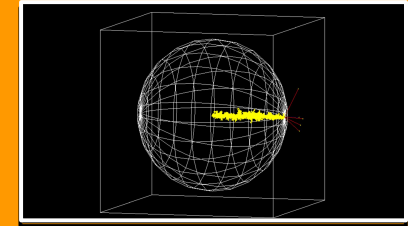
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Geant4 VS ICRU90: Range



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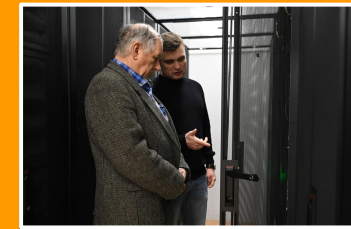


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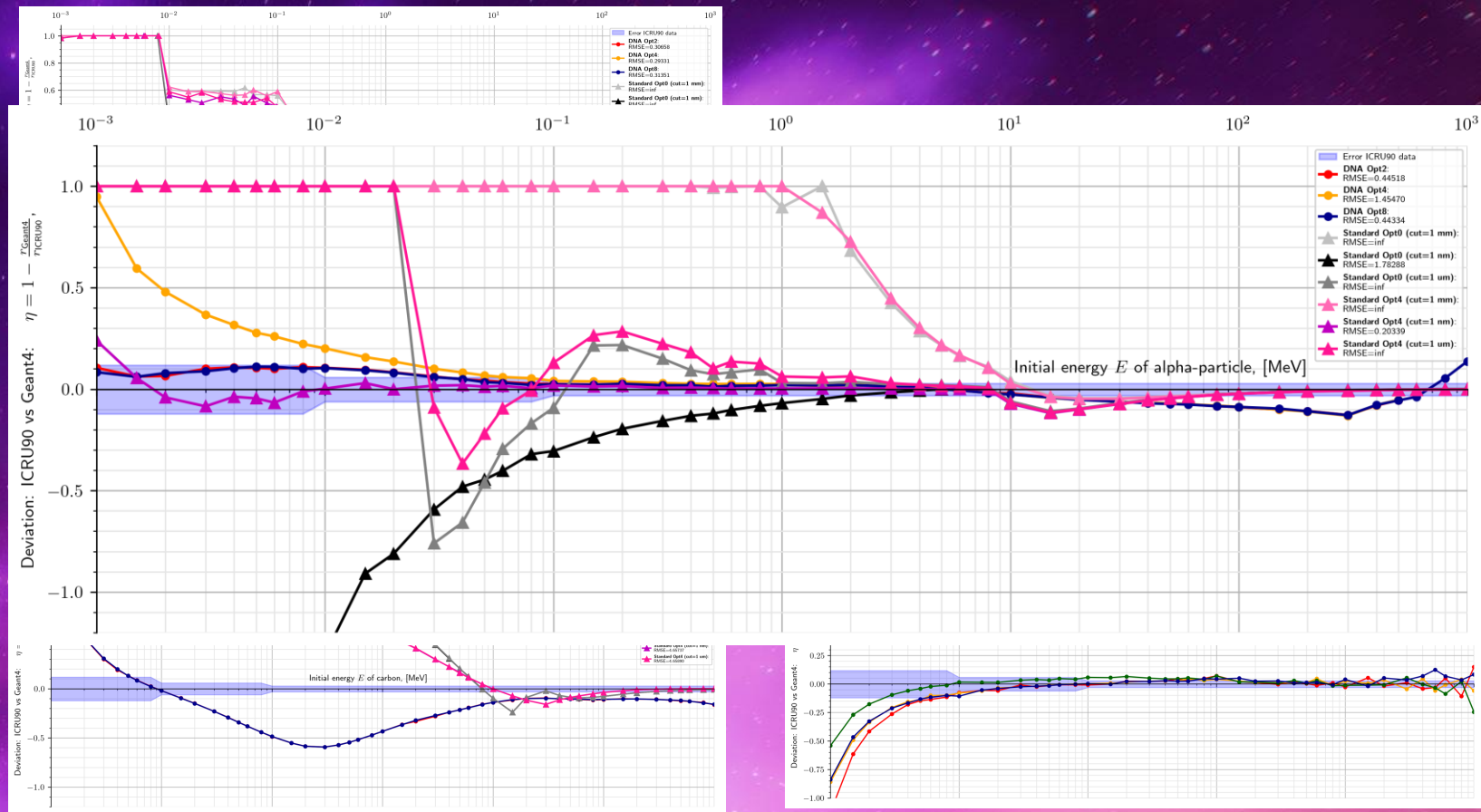


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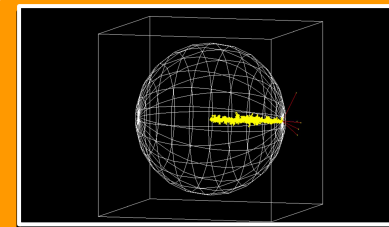
Geant4 VS ICRU90: Range



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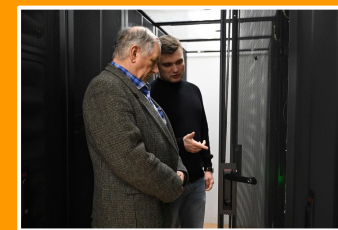


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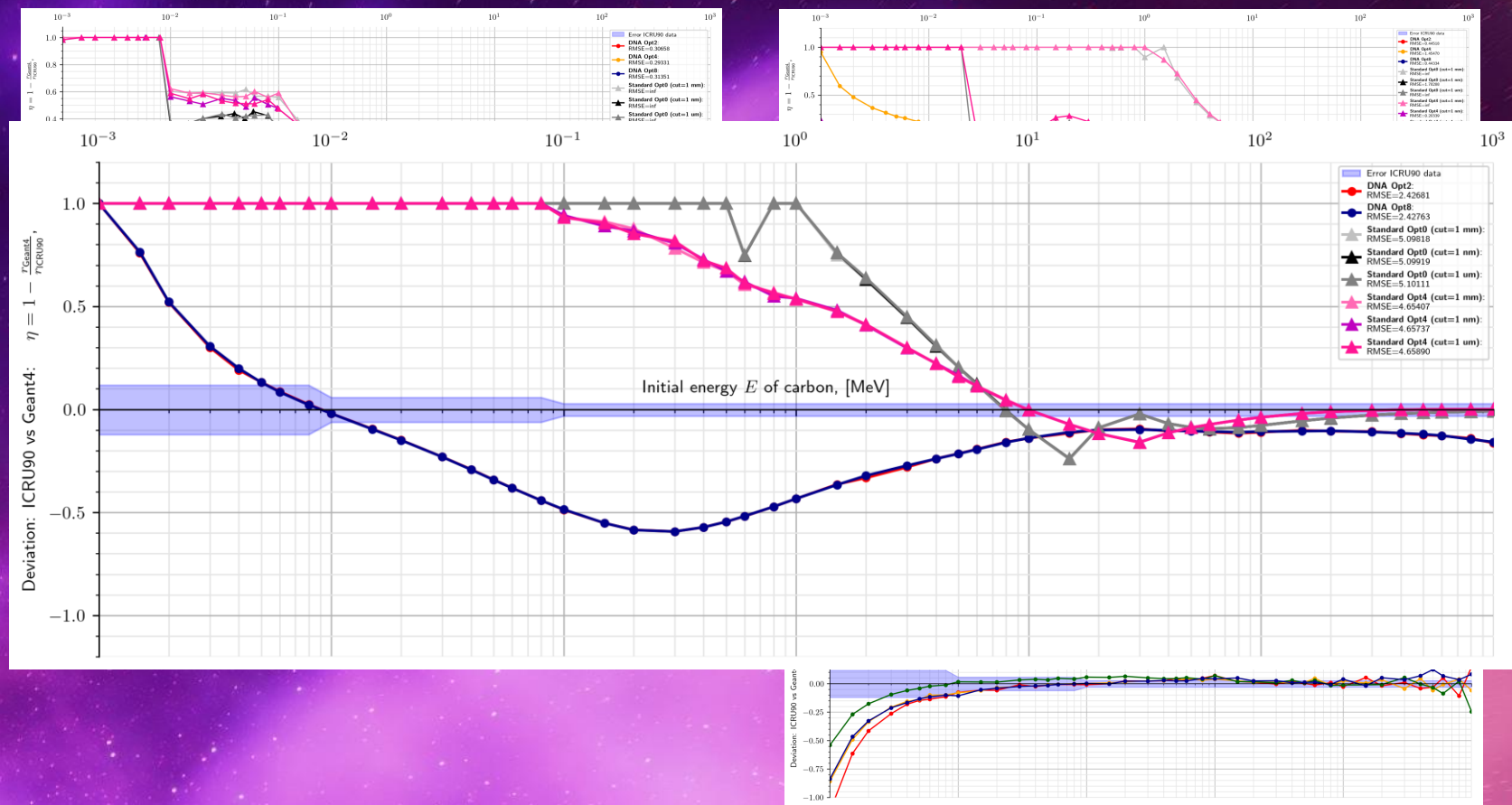


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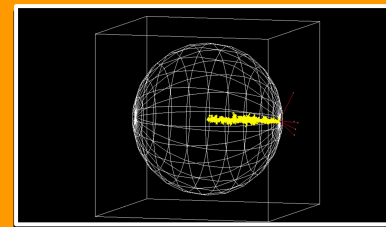
Geant4 VS ICRU90: Range



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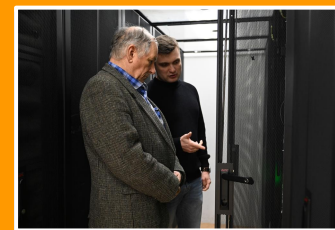


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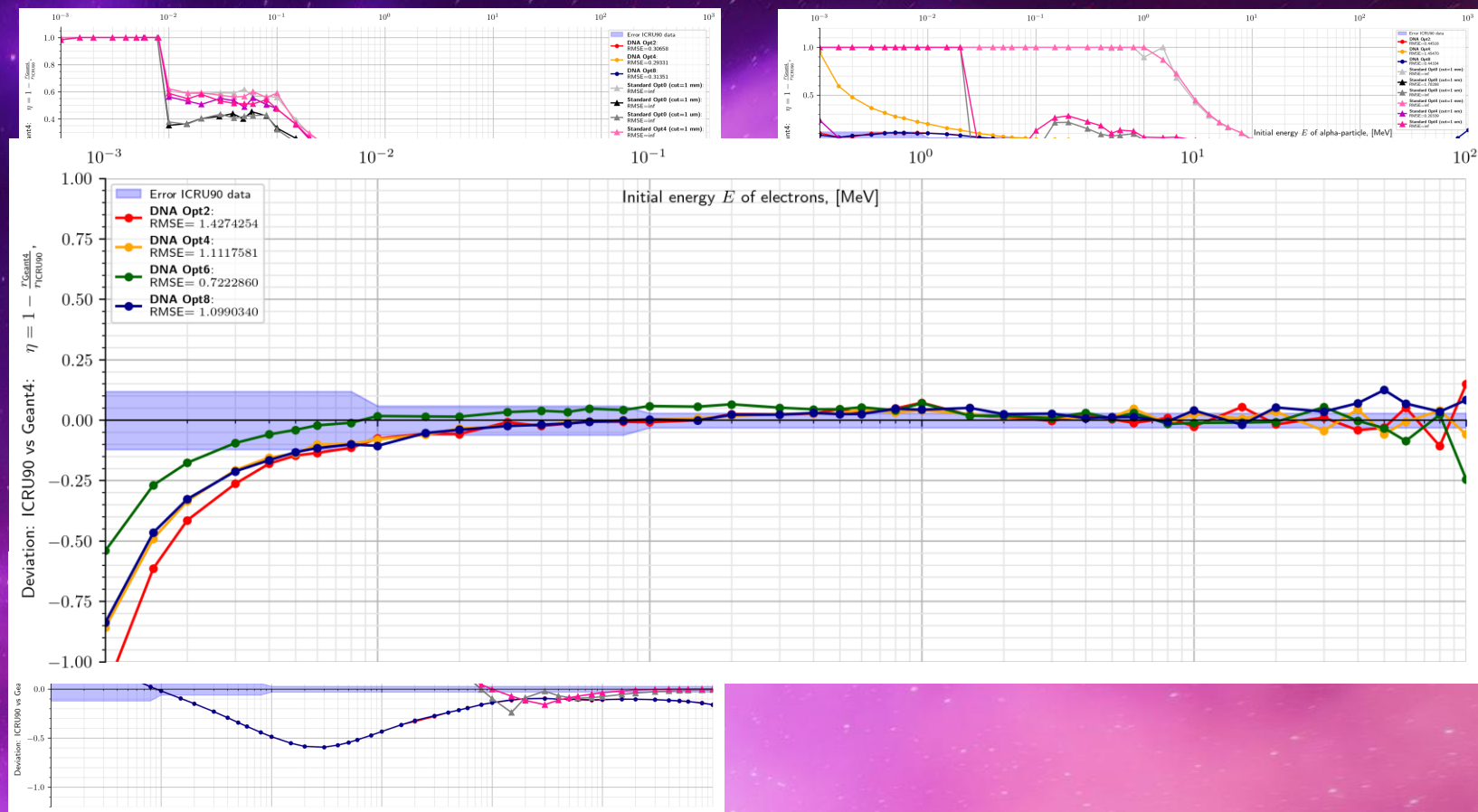


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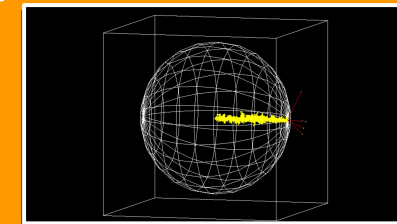
Geant4 VS ICRU90: Range



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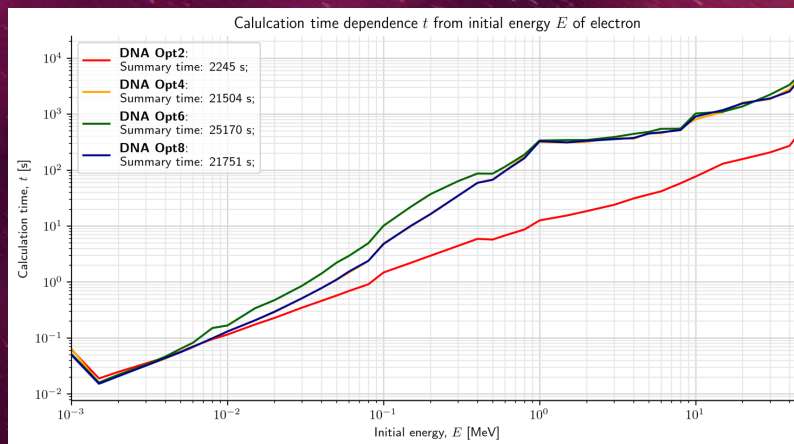
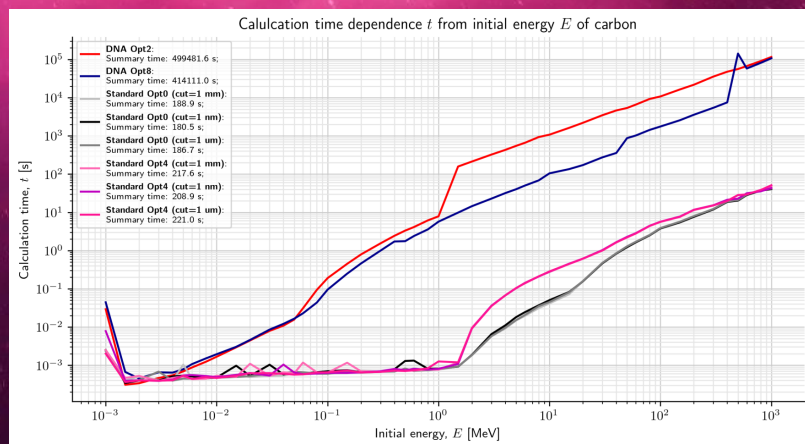
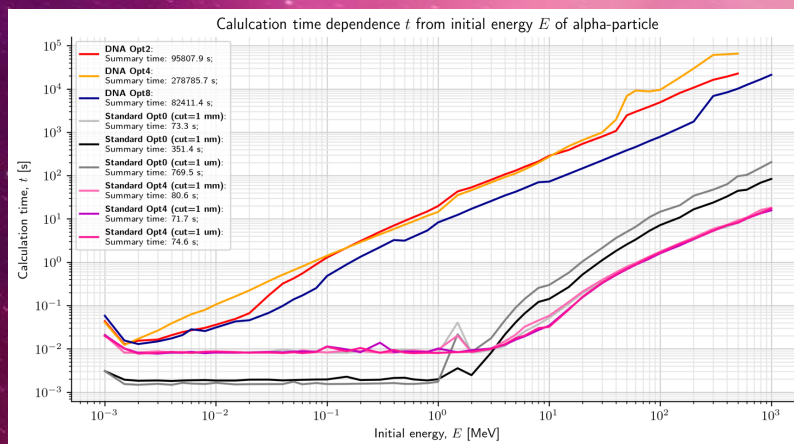
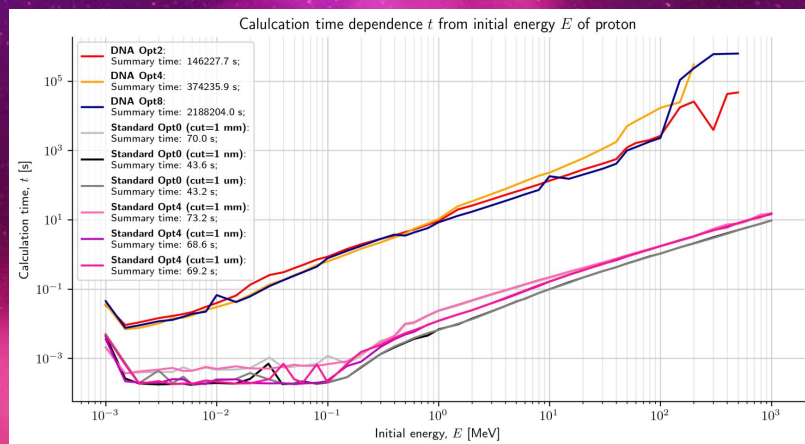
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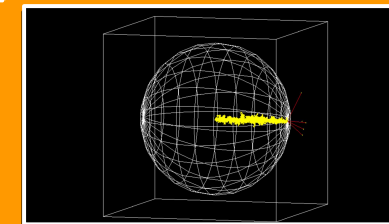
Plan

Geant4 VS ICRU90: Computation time



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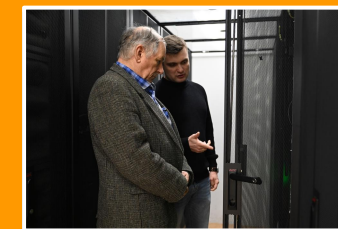


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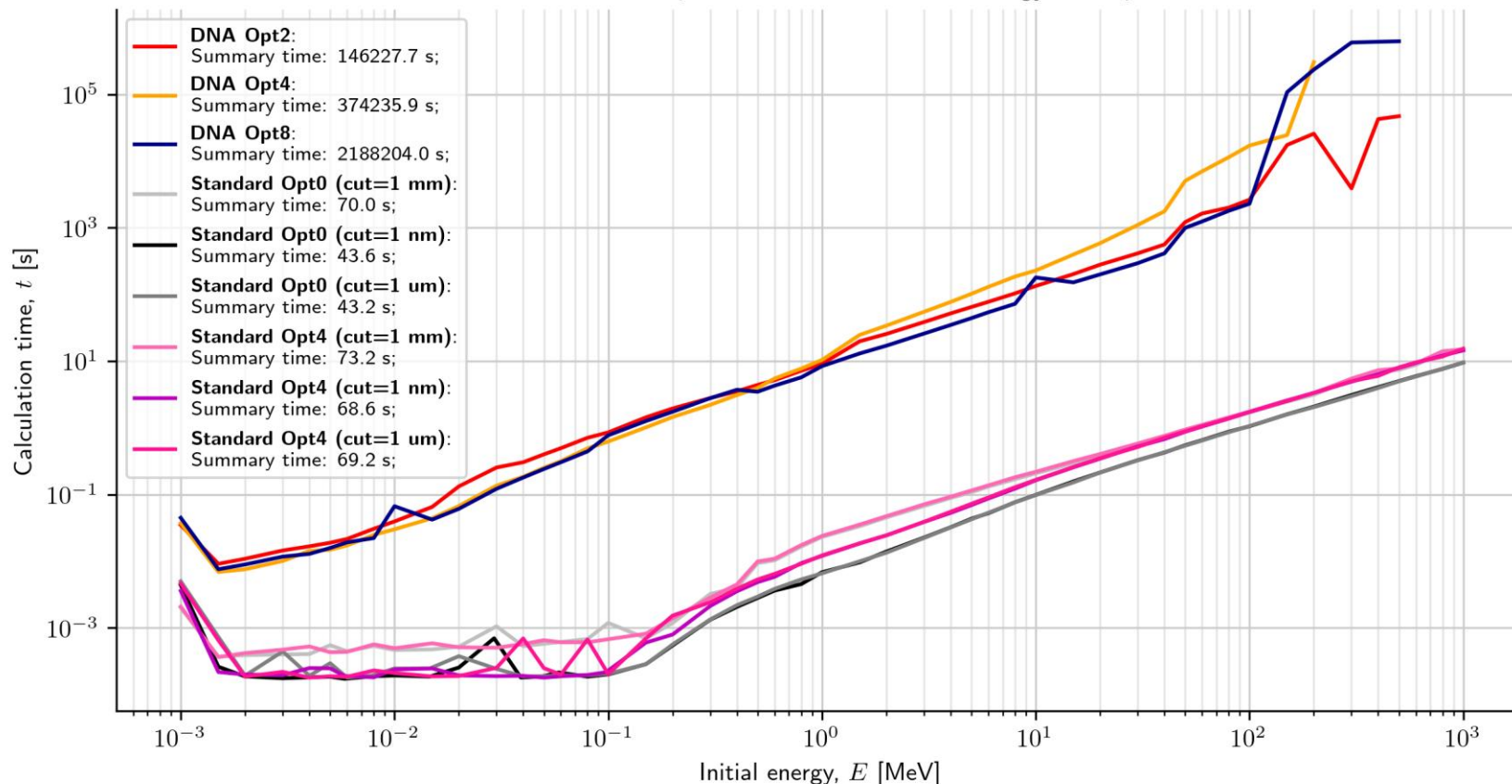
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Geant4 VS ICRU90: Computation time

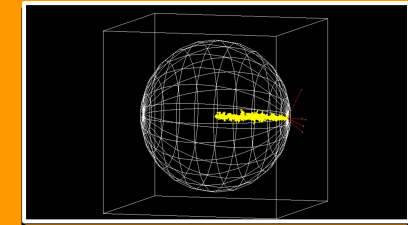
Calculation time dependence t from initial energy E of proton



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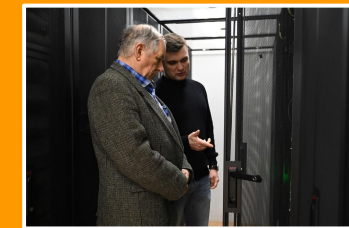


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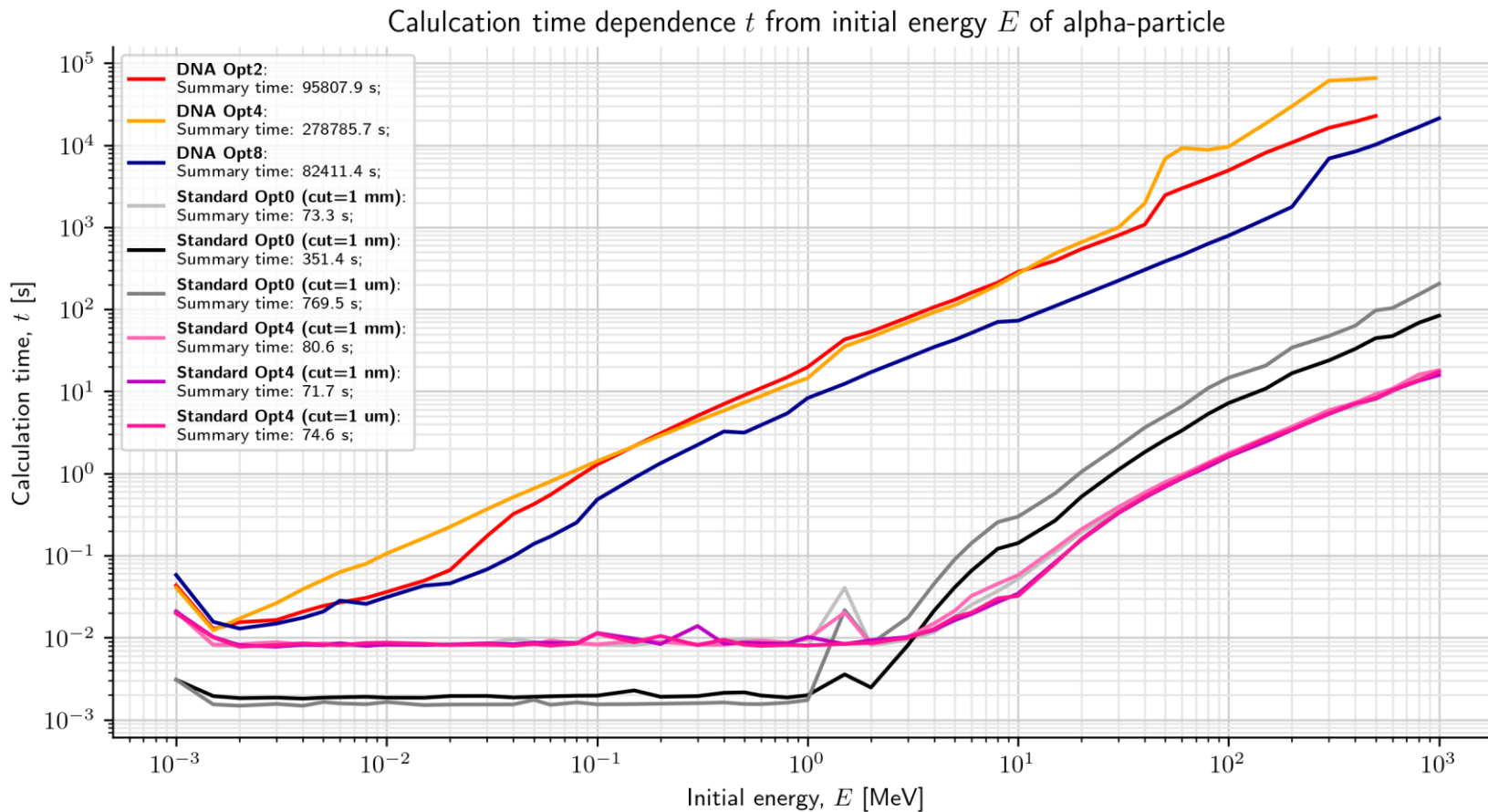
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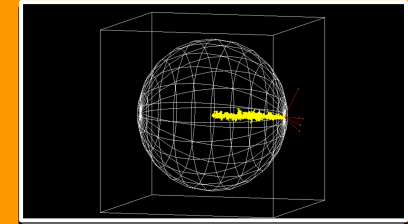
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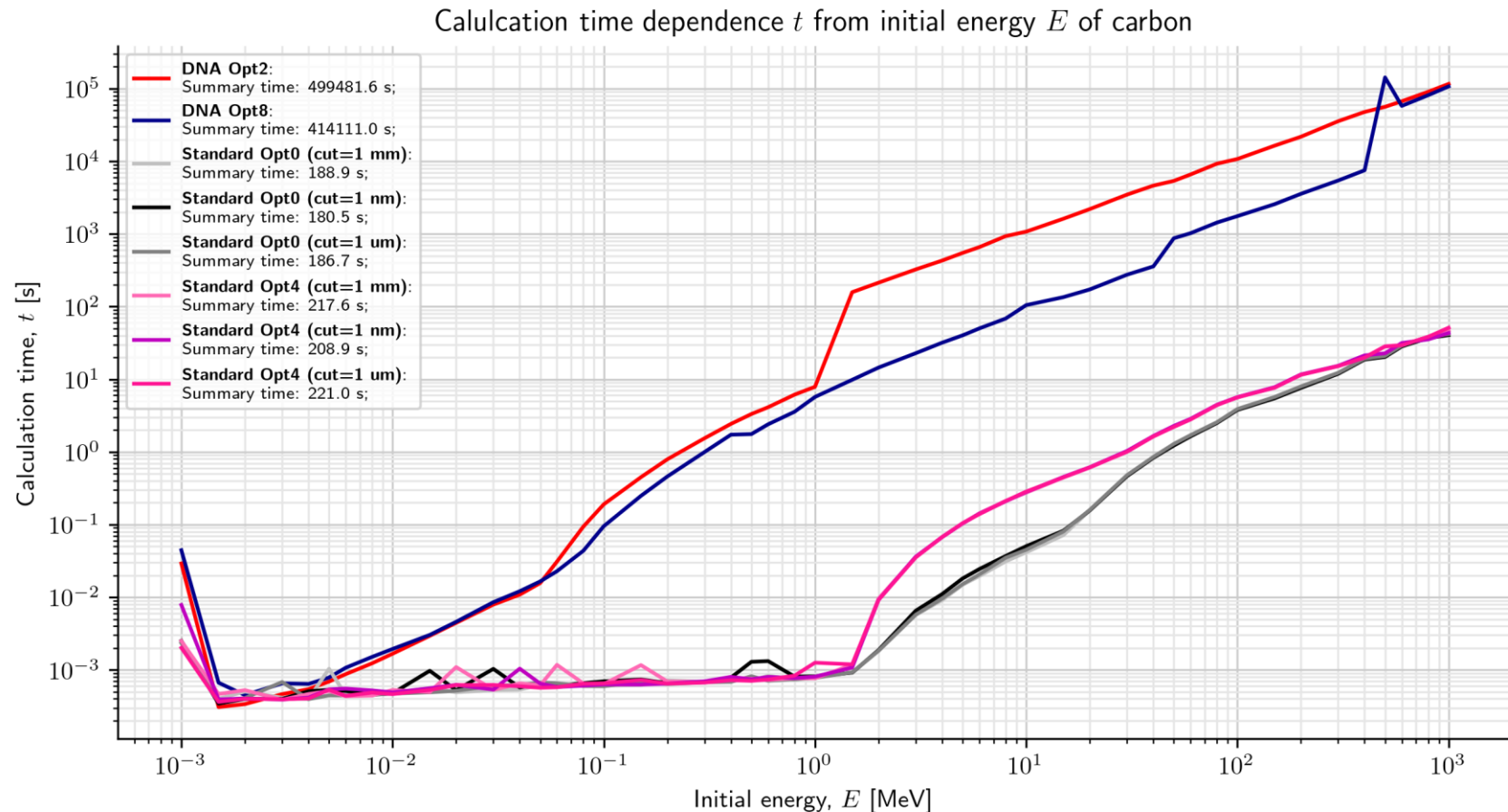
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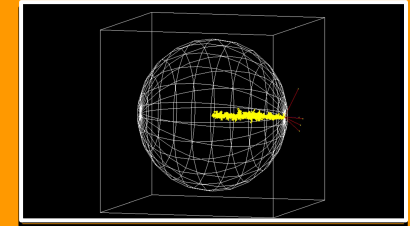
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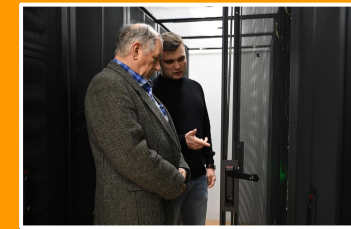


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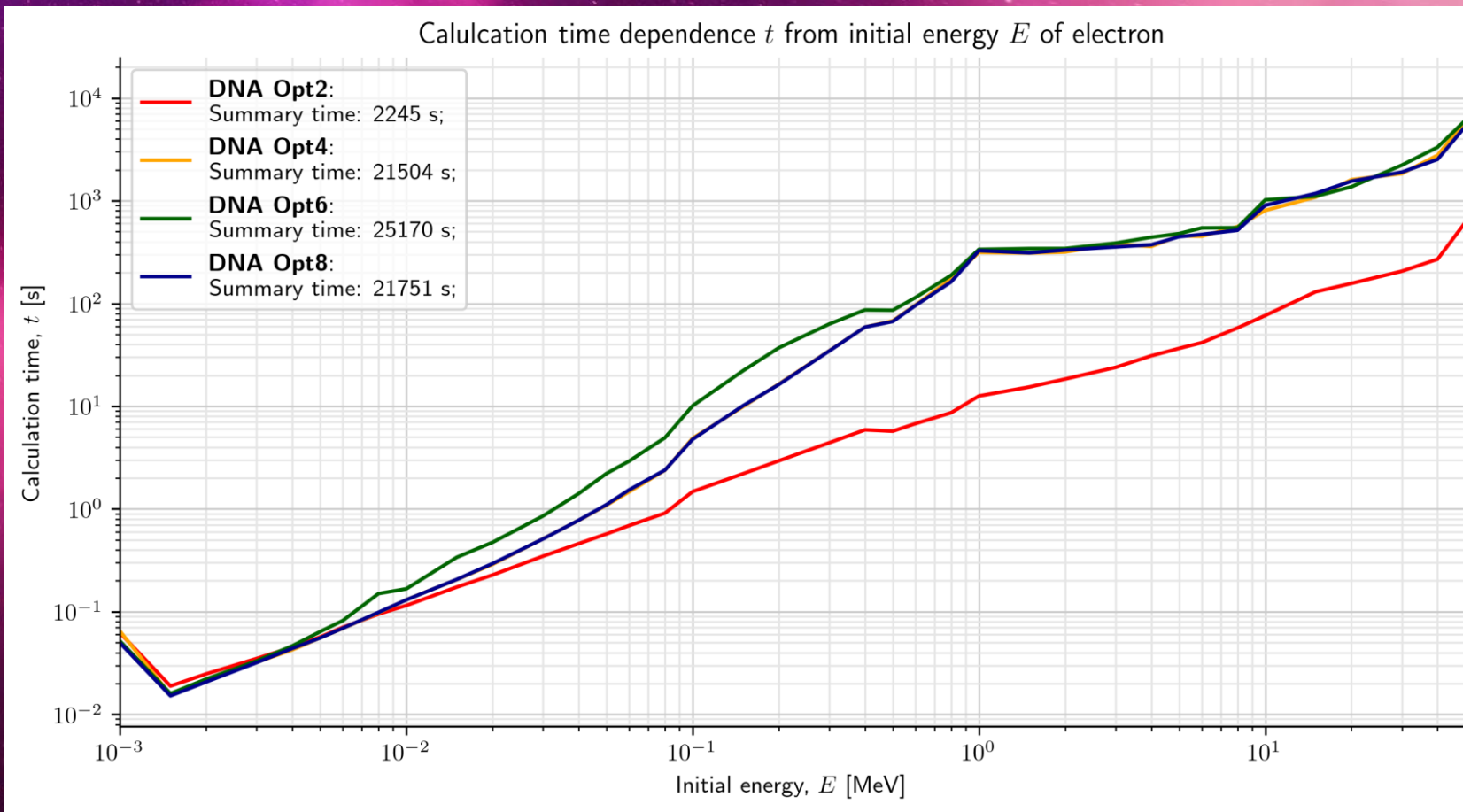


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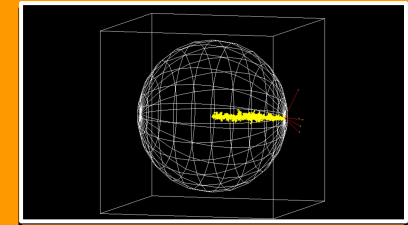
Geant4 VS ICRU90: Computation time



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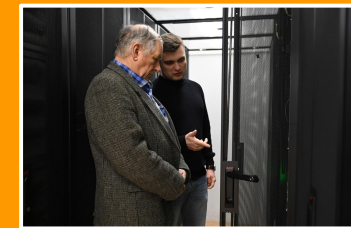


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Geant4 VS ICRU90: SKIF Cyberia



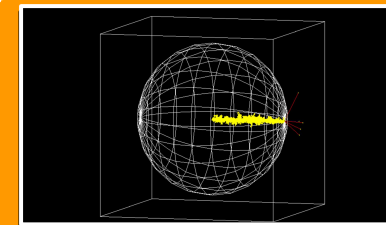
*«Director of the TSU SKIF Cyberia
Supercomputing Center
demonstrates new equipment for
Vladimir Ivanchenko»*

Processor: Intel Xeon Silver 4114T
(40 threads with a maximum PROCESSOR clock speed of 3 GHz)
RAM: 93 GB

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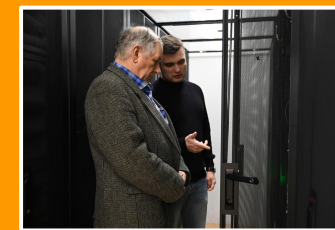


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The END

Conclusion & Plans

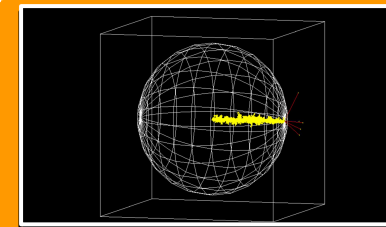
Conclusion

- **New ionization losses model** was developed:
it uses “*dynamic charge*” concept (*G4DNARuddIonisationDynamicModel.cc*)
- Geant4 EM Physics Lists (*Standard & DNA*) **validation** was performed based on the result of ICRU90 review:
 - Proton
 - 1) **Detour factor** isn't described by EM Standard Physics Lists up to 1 MeV
 - 2) **DNA Opt4** is the best for **Range**
 - 3) **DNA Opt2** is the **fastest option**
 - Alpha-particle
 - 1) **Detour factor** isn't described by EM Standard Physics Lists up to 1 MeV
 - 2) **EM Standard Opt4 (cut = 1 nm)** is the best for **Range** among All Physics Lists
 - 3) **DNA Opt2 & DNA Opt8** are the best for **Range** among DNA Physics Lists
 - 4) **DNA Opt8** is the **fastest option** among DNA Physics Lists
 - Carbon
 - 1) **DNA Opt2 & DNA Opt8** are the best for **Range**
 - 2) **DNA Opt8** is the **fastest option** among DNA Physics Lists
 - Electron
 - 1) **DNA Opt6** is the best for **Range**
 - 2) **DNA Opt2** is the **fastest option**

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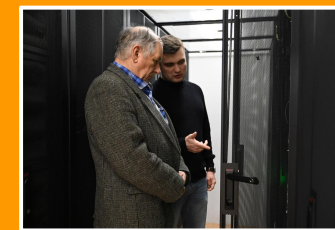


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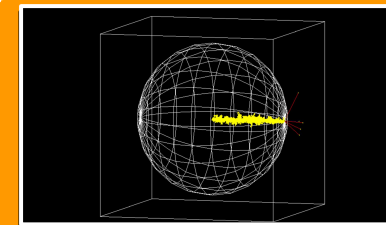
New plans

- Developing new *G4ChargeIncrease.cc* and *G4ChargeDecrease.cc* classes for heavy ions. For example: B10, C12, Fe56 etc.
- Developing new methods to use Chemistry Lists for modeling alpha-particles using EM Standard Option 4 – It provides possibility to modeling **brachytherapy**, **targeted alpha-therapy** much faster than any DNA Physics Lists

Plan

START

Preliminaries
Why the water?
Geant4-application

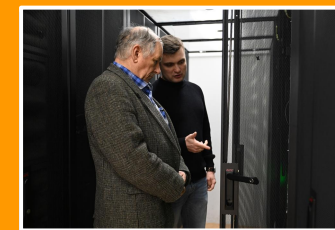


Part I: EM PHYSICS LIST

What is Geant4?
What is Physics List?
EM Standard 11.3
DNA 11.3
Rudd Ion models 11.3

Part II: PLOTS

What is ICRU90?
Detour factor
Range
Computation time
SKIF Cyberia



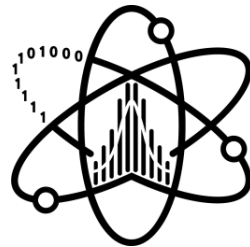
END

General conclusion
New plans



Thank you for your attention!

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