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Development and evaluation of a proton irradiation experimental setup for human cells use.

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1. Background-Aim

The objective of this study is the design, development and evaluation of a proton irradiation experimental setup for human cells and for research purposes. The impetus of this research originated from the high importance of proton therapy that has significantly advanced in recent years, worldwide, since protons, due to their physical characteristics, have proven to be very efficient in radiation therapy[1].

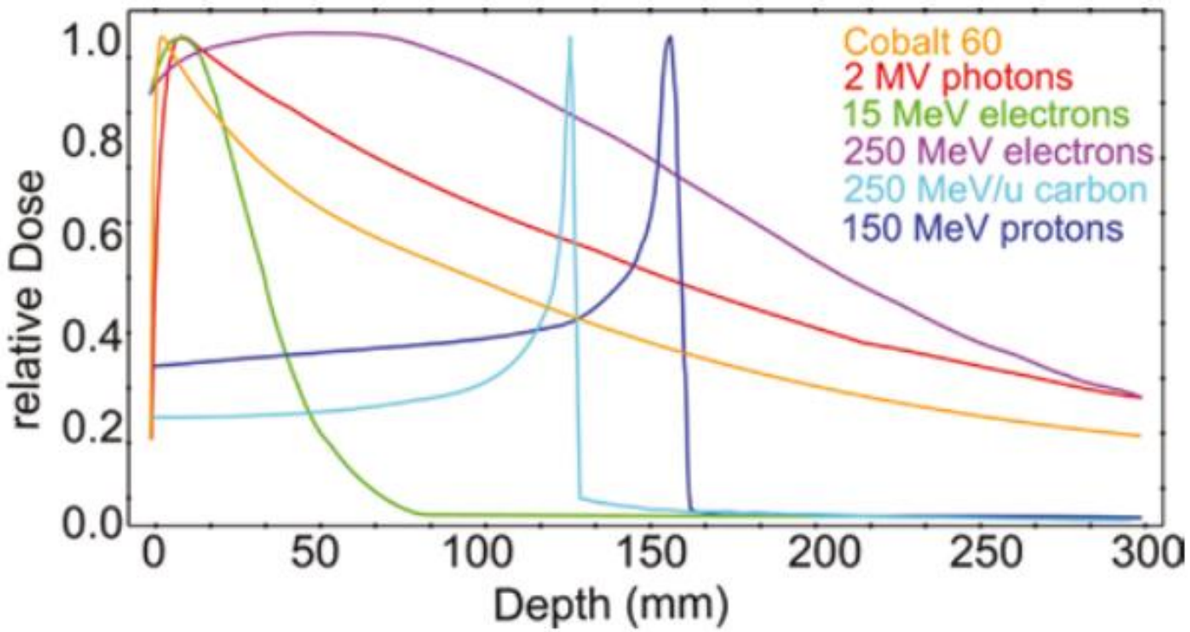
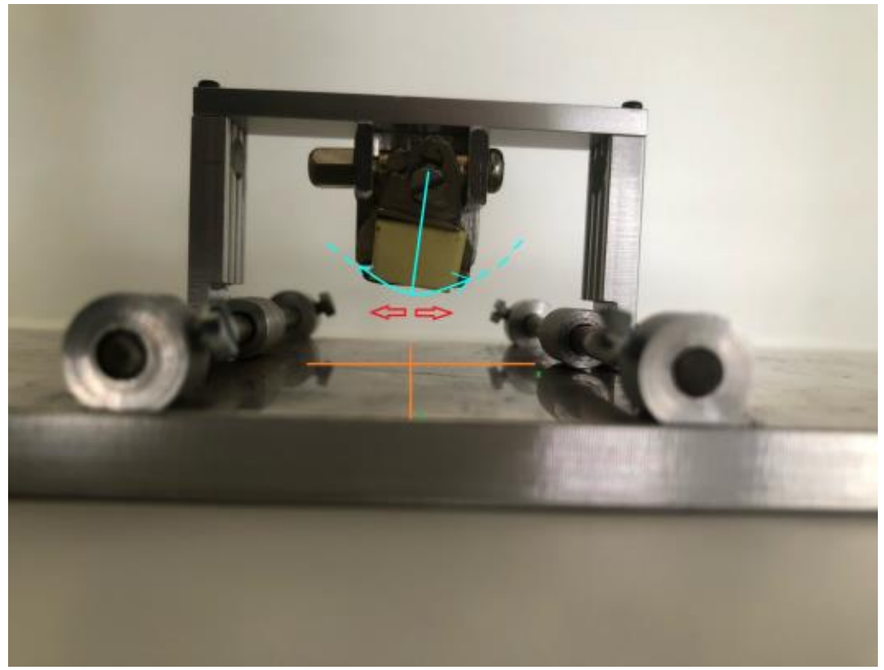
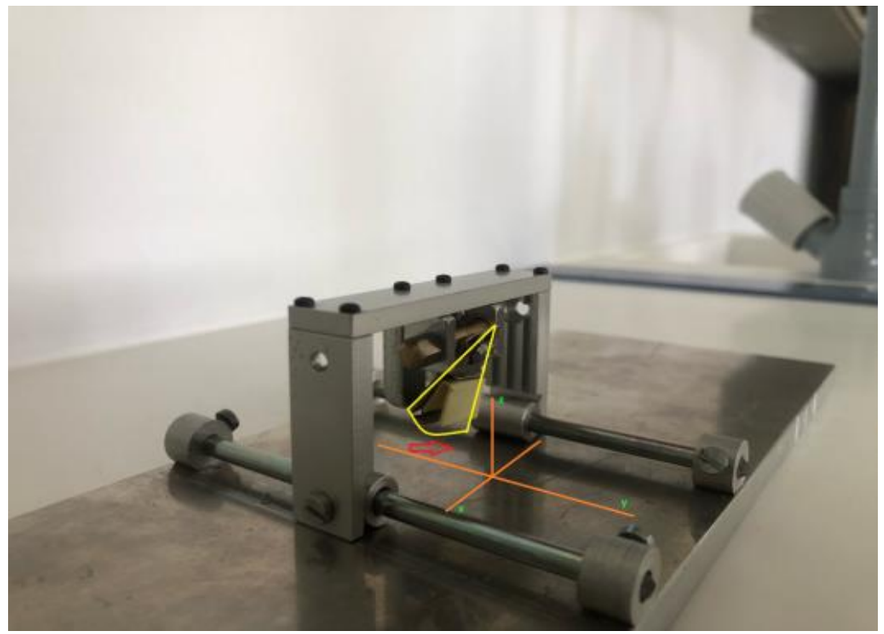


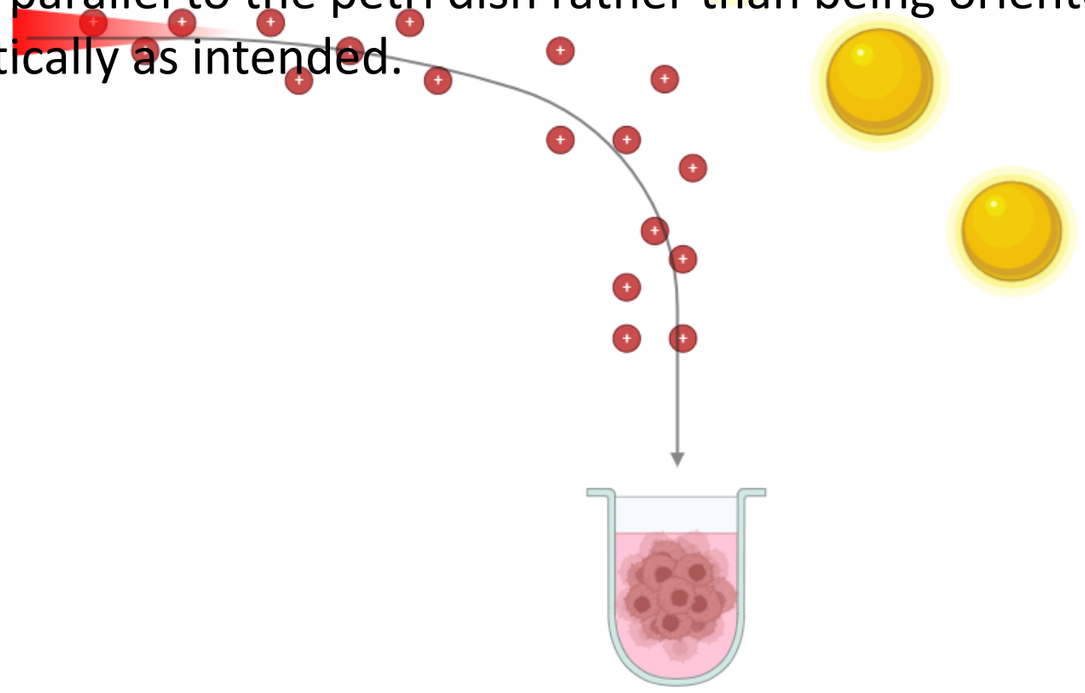
Figure 1:Bragg peaks for different types of radiation

2. Materials & Methods

The proton irradiation setup will be installed and used at the Tandem accelerator, of the Institute of Nuclear and Particle Physics, NCSR “Demokritos”. The proton beam has a mean energy value of 7 MeV and an appropriate holder was constructed to precisely place the cell culture disks and having the maximum degrees of freedom[2]. A gold leaf positioned above the petri dish deflects the beam into the cells through Rutherford scattering, ensuring uniform radiation distribution. This setup is crucial as without it, the beam would run parallel to the petri dish rather than being oriented vertically as intended.







2. Materials & Methods

Following the construction of the holder, the next step prior to the experiment was to perform simulations using MCNP6(Monte Carlo N-Particle), SRIM-TRIM, MCDS[3] and SIMNRA. These simulations provide theoretical values for the accelerator's energy beam spot diameter(as determined by SIMNRA and SRIM-TRIM), and via MCNP6, the construction of the 3D geometry of the set up. The output of these simulations includes the energy values or doses received by the defined cells, which, in this case, are the cells into the petri dish.

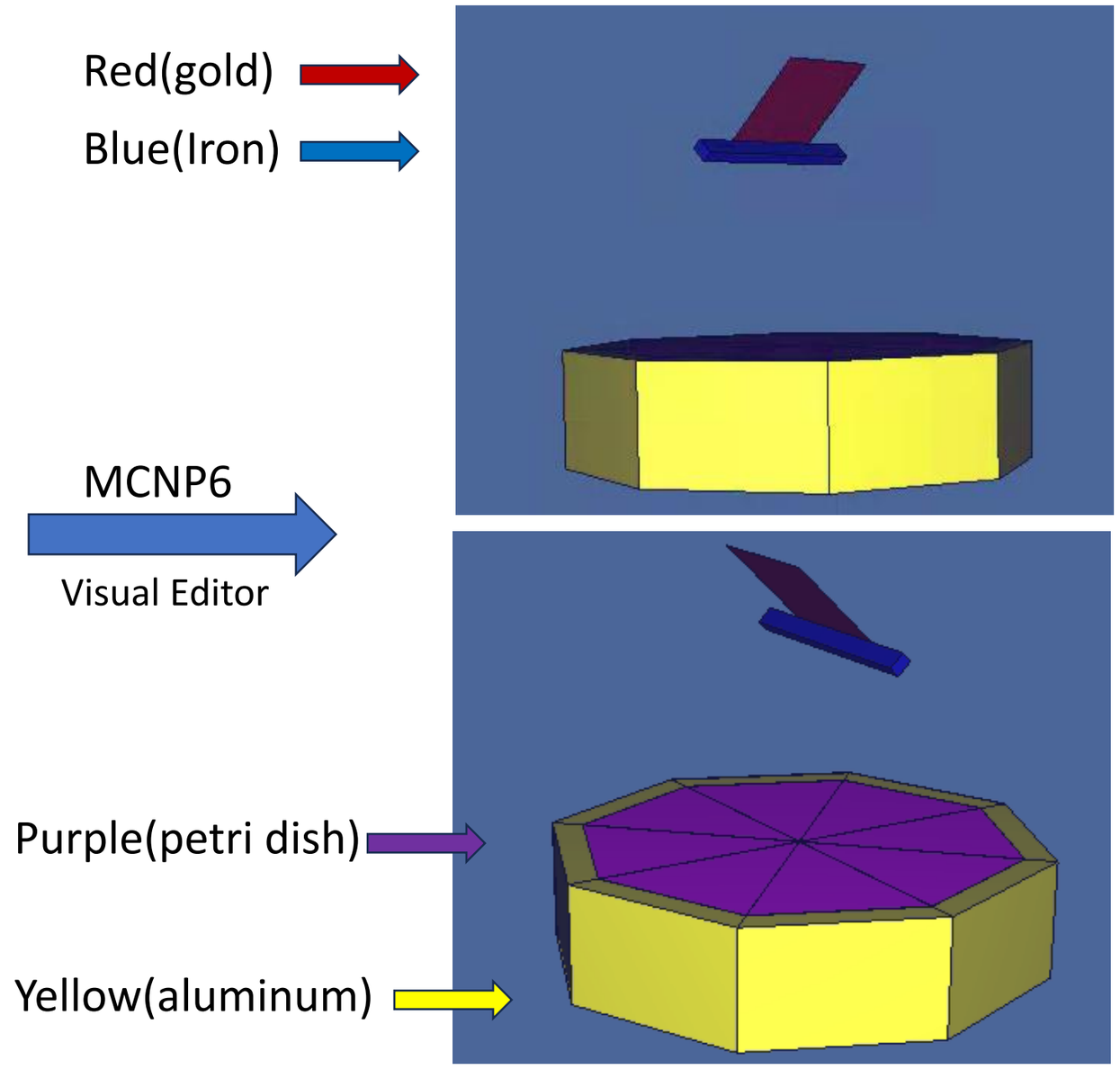
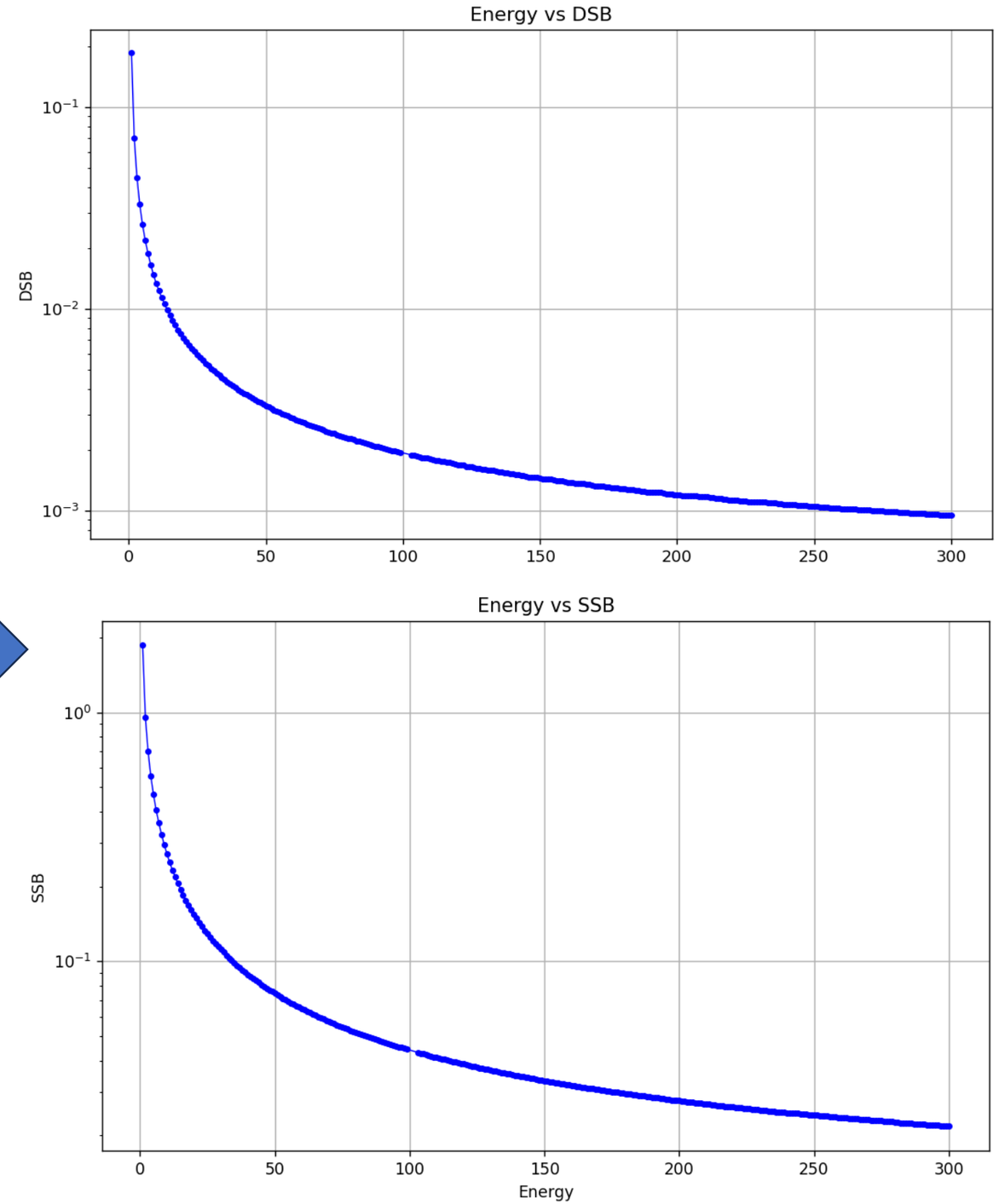


Figure 2&3: 3D Geometry of the holder in Visual Editor.

2. Materials & Methods

After the simulation in MCNP6, the last part was the simulation of the damage of the cells by using MCDS(Monte Carlo fast Damage Simulation) due to protons.

Initially the research was focused on the number of lesions per particle as function of energy(1-300MeV) to understand the biological effect for different values of energy.



3. Results

MCNP6 calculates the average for 1 proton, we use 100 million for better calculation

MCNP6 → **Results for 100 million particles**

Mean Dose per particle
$5.540\text{x}10^{-5}$ MeV/gr

MeV/gram to Gy

$8.875\text{x}10^{-15}$Gy

$$Dose = N \times 8.875\text{x}10^{-15} Gy$$
&
$$N = \dot{N} * t$$

For future experiment if we want to have 1Gy dose we need 30nA(particles*Coulomb/sec) for 10min of irradiation.

3. Results

Protons are accelerated at 7MeV kinetic energy at Tandem

↓

Simulation for DNA damage

↓

MCDS

7MeV →

Number of clusters per cell (DNA=1.000 Gbp, AD=1.000 Gy)							
DSB	SEM	SSB	SEM	OTHER	SEM	CLUSTER	SEM
9.57	0.0115	182	0.0261	390	0.0441	582	0.0460

7MeV →

Number of clusters per cell per track(DNA=1.000 Gbp, ZF=0.00197 Gy)							
DSB	SEM	SSB	SEM	OTHER	SEM	CLUSTER	SEM
0.0189	0.0000227	0.359	0.0000516	0.770	0.0000870	1.15	0.0000906

4. Conclusions

The successful proton irradiation setup we propose, supported by detailed simulations using tools such as MCDS and MCNP6, will significantly:

- enhance the ability of research teams to conduct more precise and comprehensive experiments regarding the radiobiological effects of proton interactions with human cells.
- The integration of these simulation tools not only ensures an accurate representation of particle interactions but also helps to optimize experimental parameters, improving the reliability and reproducibility of the results.
- Through continued research, the combination of experimental studies and advanced simulations will play a pivotal role in advancing the field of proton therapy and radiation biology.

5. References

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ISBN 978-3-031-18810-7 (eBook)
https://doi.org/10.1007/978-3-031-18810-7

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