Production of Copper-64 via laser-driven proton acceleration exploiting Double-Layer Targets for theragnostic applications

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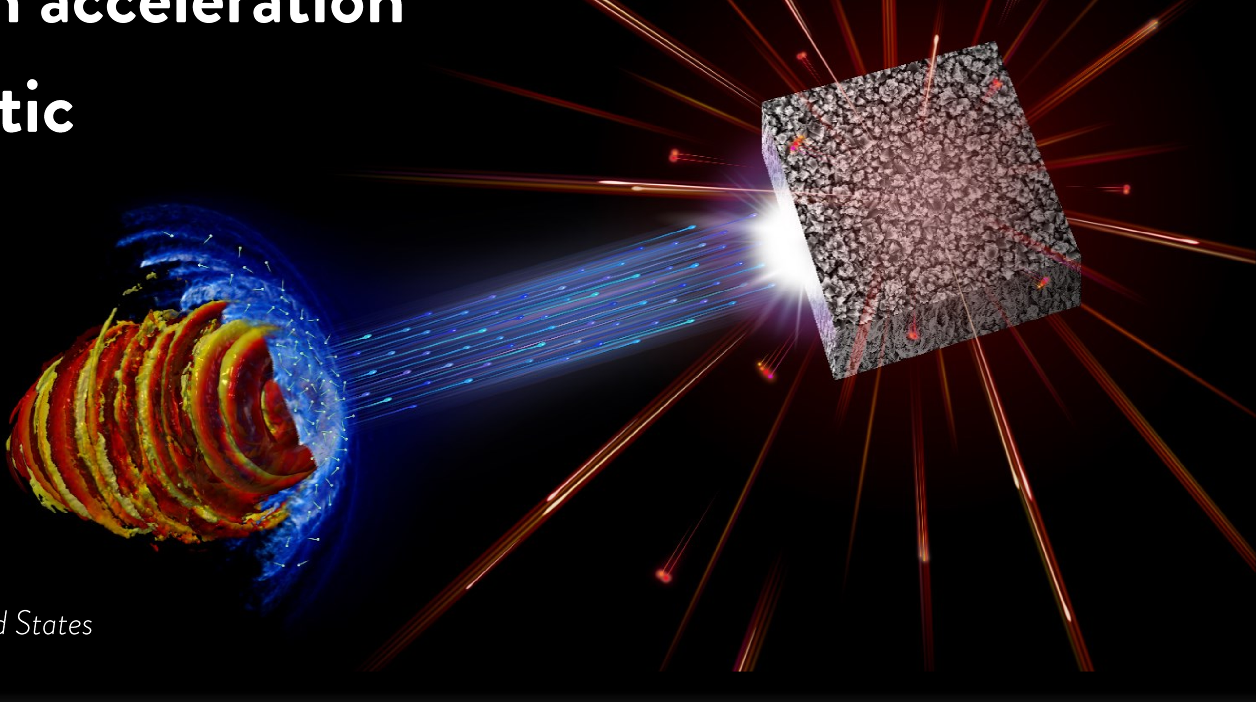
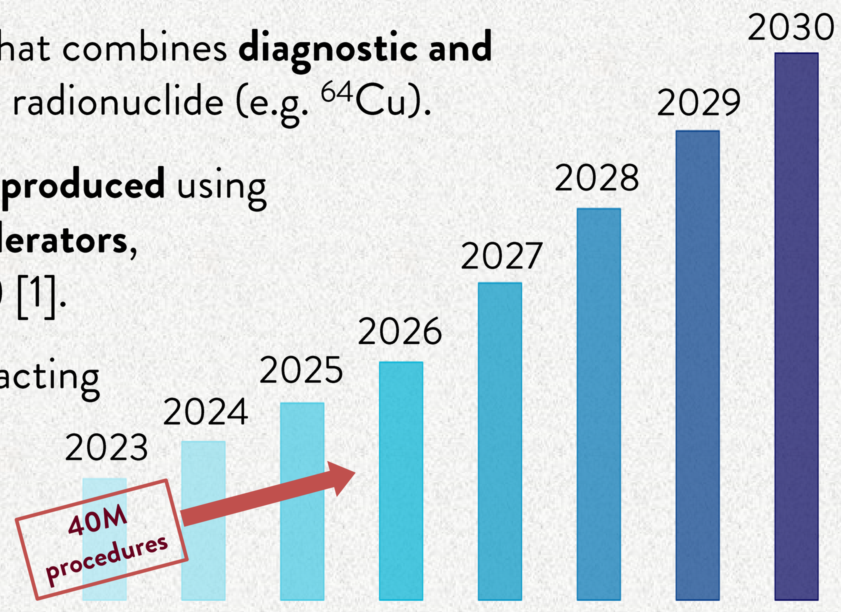


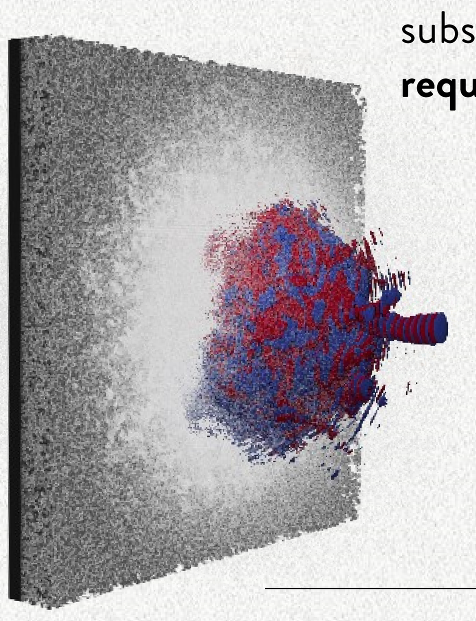
1 BACKGROUND

- **Radioisotopes play a crucial role in nuclear medicine** for both diagnostic and therapeutic purposes [1].
- The **demand** for radioisotopes will **increasing at up to 5% annually** in the next years.
- **Radiotheranostics** is a novel approach that combines **diagnostic and therapeutic** applications using the same radionuclide (e.g. ^{64}Cu).
- Radioisotopes for nuclear medicine are **produced** using nuclear reactors and **conventional accelerators**, mostly cyclotrons (**3–30 MeV, 10s μA**) [1].
- **Laser-driven ion acceleration** [2] is attracting interest as a **promising alternative** for radioisotope production (potentially **compact** & cost **effective**) [3].



MOTIVATIONS & GOALS 2

- **Radioisotopes production** is a **demanding application** in terms of particle fluxes and energies.
- **Exploit advanced Double-Layer Targets** (near-critical carbon foam layer [4] + dense substrate) to **enhance the acceleration** process and **mitigate the laser requirements** for challenging applications [5,6].

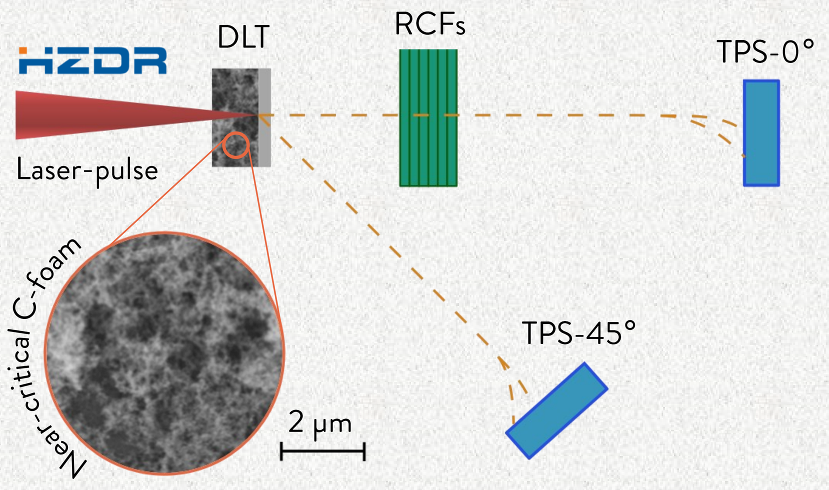


Starting from experimental data [7], **assess the applicability** of laser-driven proton sources **to the production of ^{64}Cu** for pre-clinical and clinical studies [8].

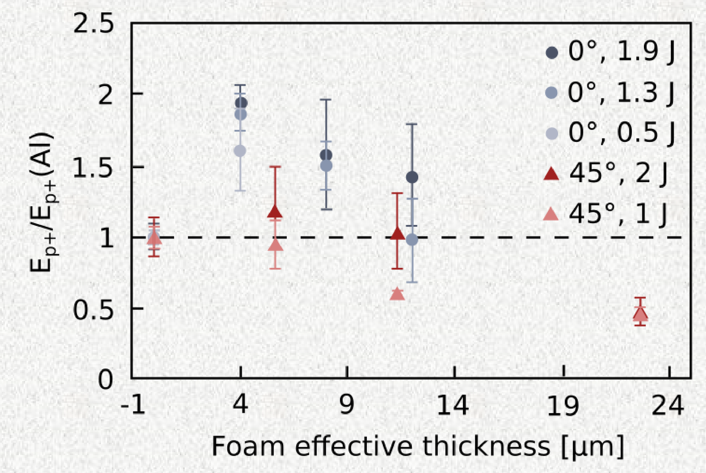
- ≳ **5 MBq** for **pre-clinical** studies with mice.
- ~**100 MBq** for **clinical** studies.

3 LASER-DRIVEN PROTON ACCELERATION: COMPARISON BETWEEN EXPERIMENT & PIC

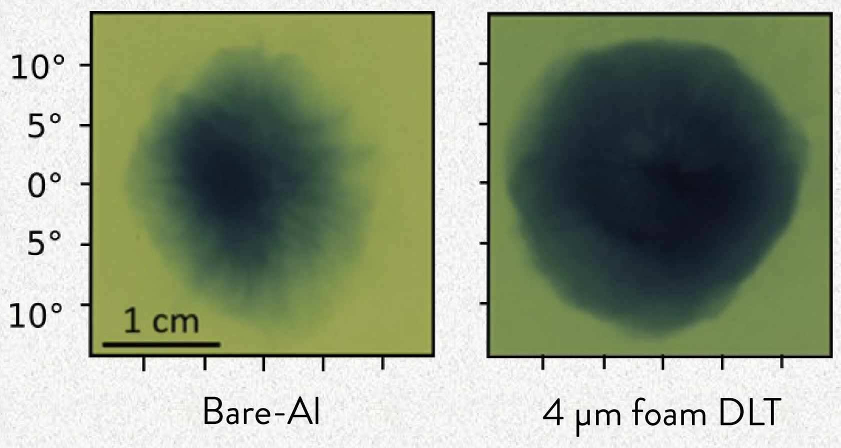
- Experimental scheme [7]*:



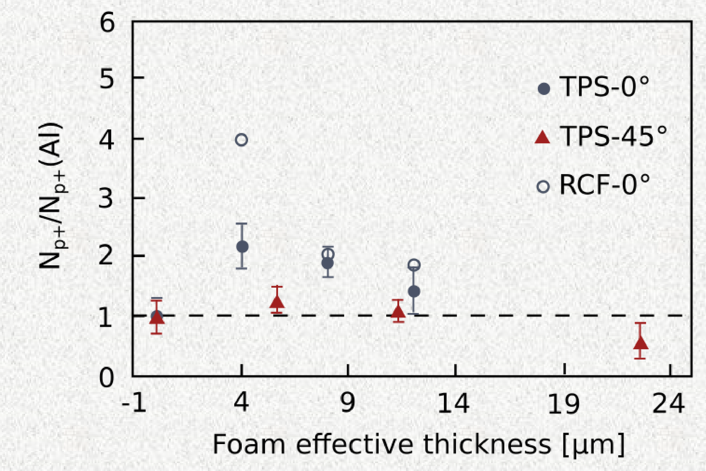
- Maximum **energy enhancement**:



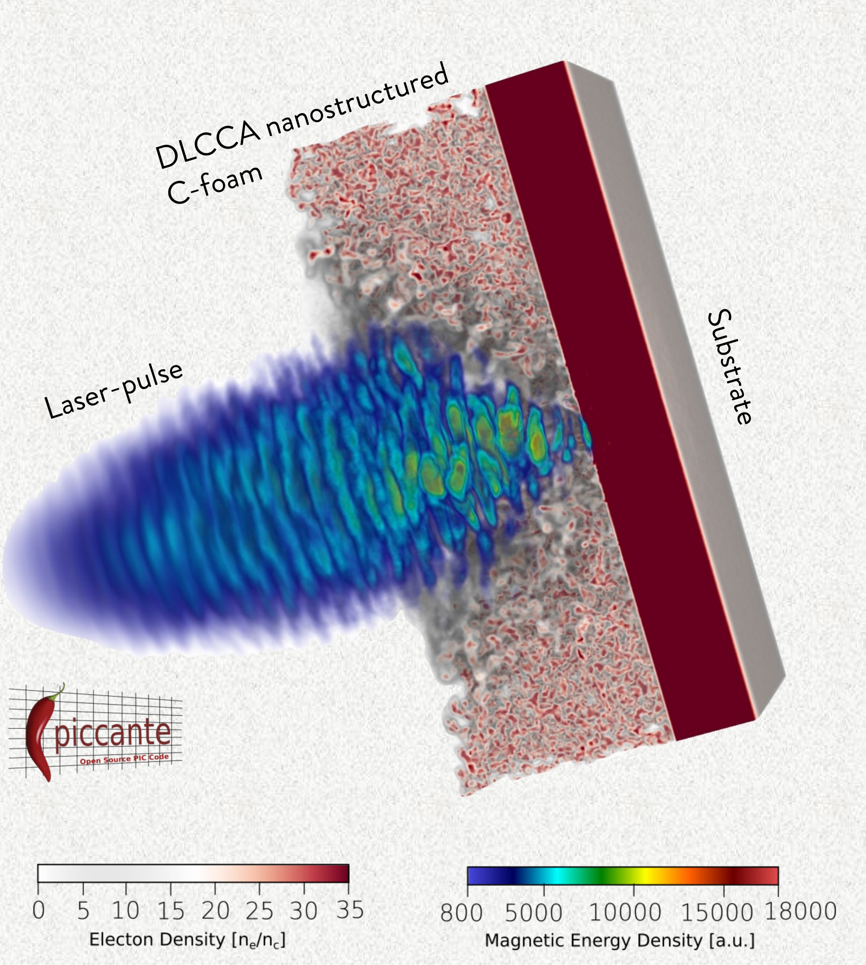
- **Angular divergence** from RCFs:



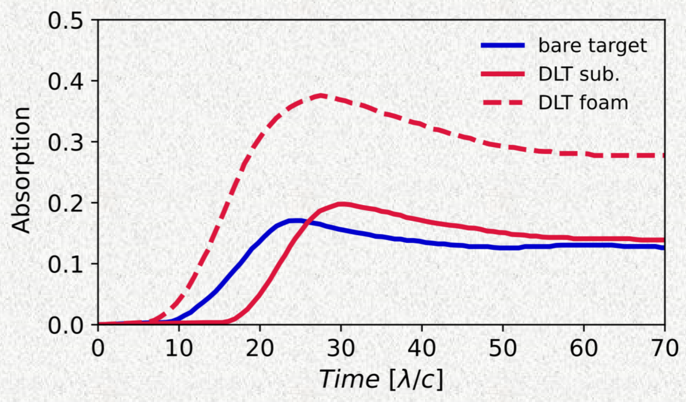
- Proton **number enhancement**:



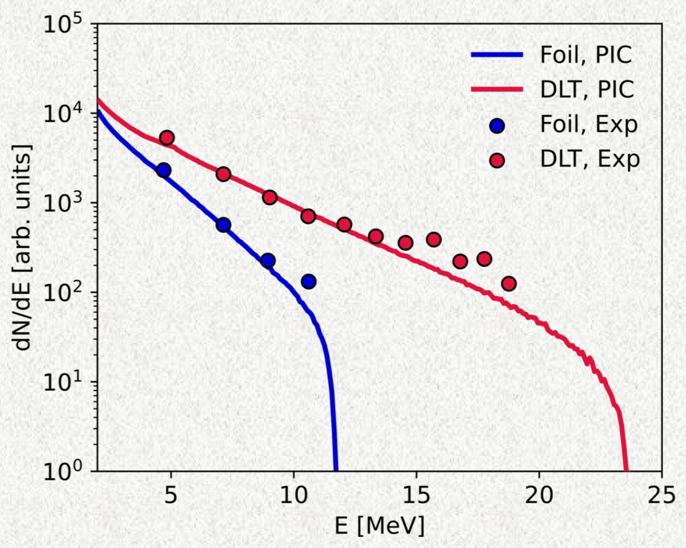
- **3D Particle-In-Cell** snap-shot:



- 3D-PIC laser **energy absorption**:



- **Comparison** between **PIC & RCF**:

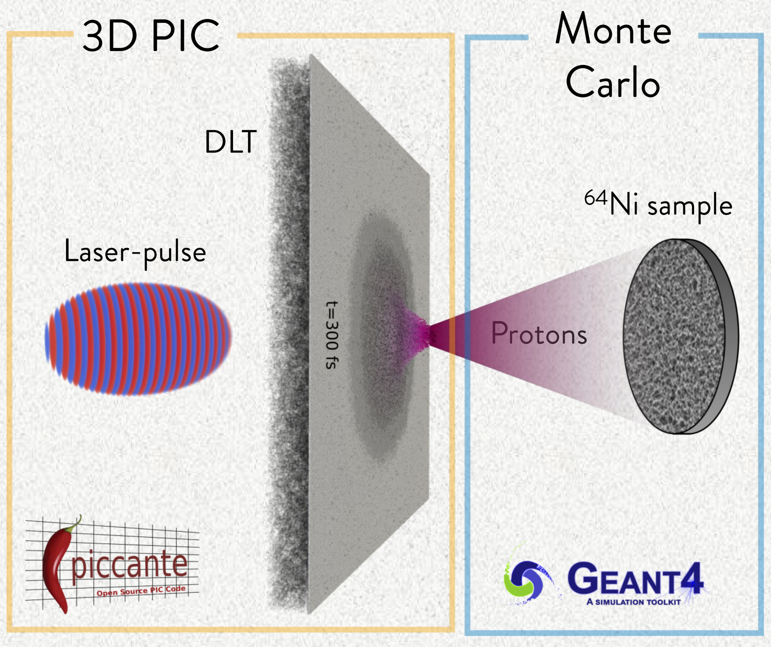


* **Laser parameters**: 150 TW laser power, 30 fs pulse duration, 2.8 μm FWHM focal spot size, 16 normalized laser intensity (a_0), normal incidence to the target surface.
Target parameters: 1 n_c average density C-foam, 1.5 μm Al-substrate thickness.

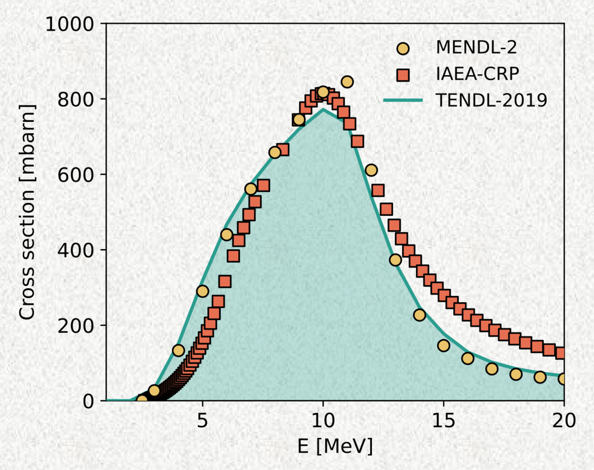
- Energy **enhancement of ~2 for the maximum energy** (11.6 → 23.5 MeV) and 2.2 for the number of accelerated protons.
- **Agreement between experimental and PIC** results. → **Input** for ^{64}Cu **activity estimation.**

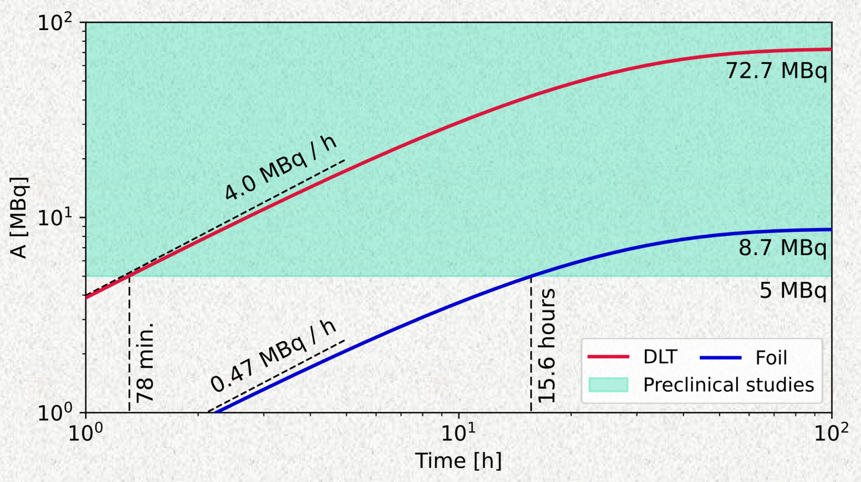
4 ^{64}Cu ACTIVITY WITH A 150 TW LASER

- ^{64}Cu production **scheme**:



- ^{64}Ni(p, n)^{64}Cu **cross section** (σ):





- **Production yield** of ^{64}Cu (Y) **retrieved with Monte Carlo** for both single-layer target and DLT.
- **Activity (A)** during irradiation (t):
  $$A = RR \cdot N_P \cdot Y \cdot (1 - e^{-\lambda t})\ *$$
- **78 min. irradiation required with DLTs** and **150 TW** laser **for pre-clinical studies.**

* Repetition rate RR = 10 Hz, Number of protons per shot N_p = 2.6 × 10^{10}, Decay constant λ = 0.055 h^{-1}

5 ^{64}Cu ACTIVITY ESTIMATION WITH MODEL

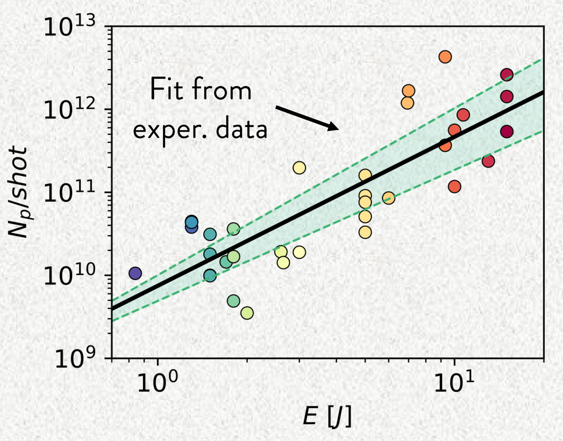
- **Analytical formula for production yield** of ^{64}Cu in a semi-infinite converter:

$$Y = \frac{N_{Cu}}{N_P} = \frac{N_{Av}}{M}\rho \int_0^\infty f(E_P) \int_0^{E_P} \frac{\sigma(E)}{S_P(E)} dE dE_P \approx$$

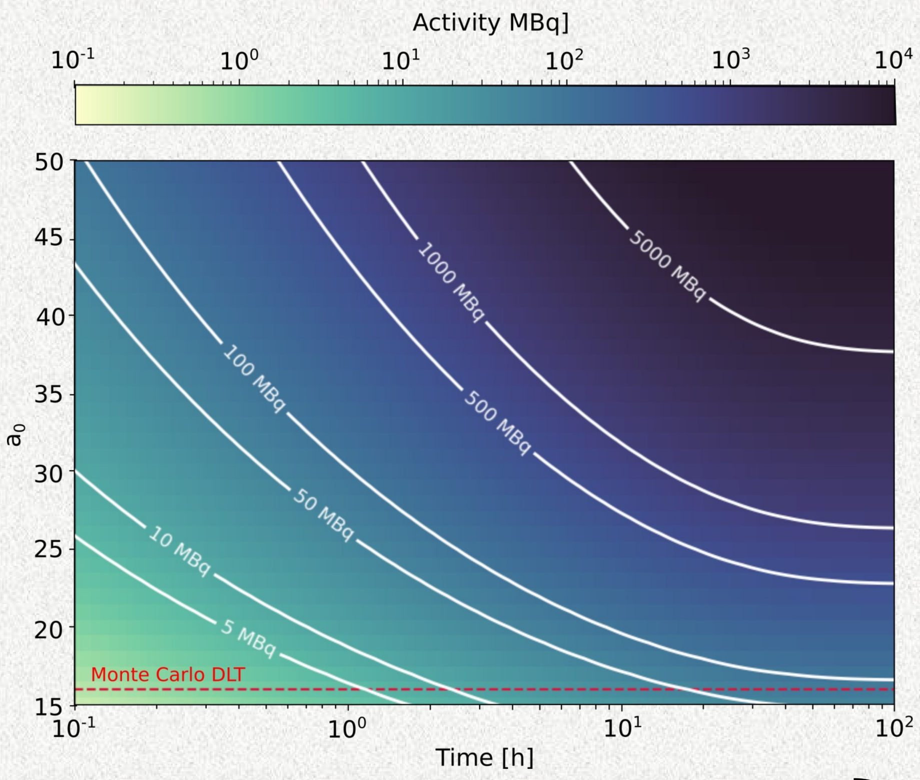
$$\approx Y_{max} \exp\left(\frac{\omega^2 - 4E_0T_e}{T_e^2}\right)$$

* ...with some approx. & model presented in []...

- Number of protons:



- Retrieve **A as a function of** the irradiation **time and a_0** between 15 – 50 (0.7 – 17.5 J).
- For a_0 = 20 – 50:
  - ✓ **pre-clinical studies achievable in minutes** irradiation;
  - ✓ **clinical** studies achievable in **~ 1 hour** irradiation **or more.**
- Rep. rate = 10 Hz kept fixed. → **Advances in targetry required.**



* σ/S ~ Gaussian function, f ~ exponential function of temperature T_P, electron temperature $T_e \sim T_P \rightarrow$ Y_{max} = 2.0×10^{-3}, ω = 4.38 MeV, E_0 = 10.25 MeV

7 REFERENCES

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6 CONCLUSIONS

- **Laser-driven proton sources** can be **adequate to produce ^{64}Cu** isotopes **for pre-clinical studies.**
- To this aim **100s TW – PW** class lasers and **advanced DLTs** are required.
- **Advancing target delivery system** and **laser technology** could unlock their use **for clinical purposes.**

ACKNOWLEDGEMENTS & CONTACTS 8

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To the publication...

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