

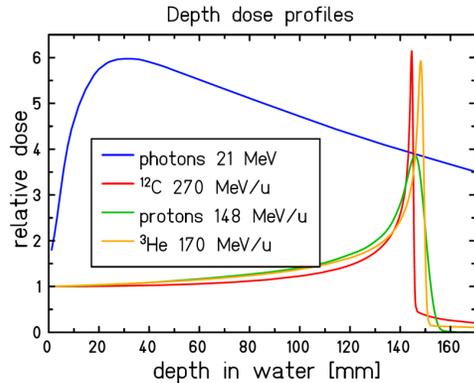
# The CLINM project

Bridging Physics and Biology in Hadrontherapy through Radiolysis

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A. Arnone, S. Chefson, C. Galindo, C. Hoffmann, P. Peupardin, Q. Raffy



# Why nuclear physics for health?

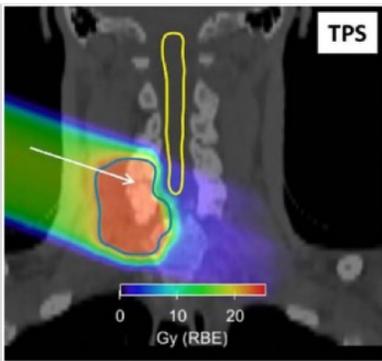


▶ Nuclear reactions of the beam with patient  $\Rightarrow$  additional dose after the Bragg Peak

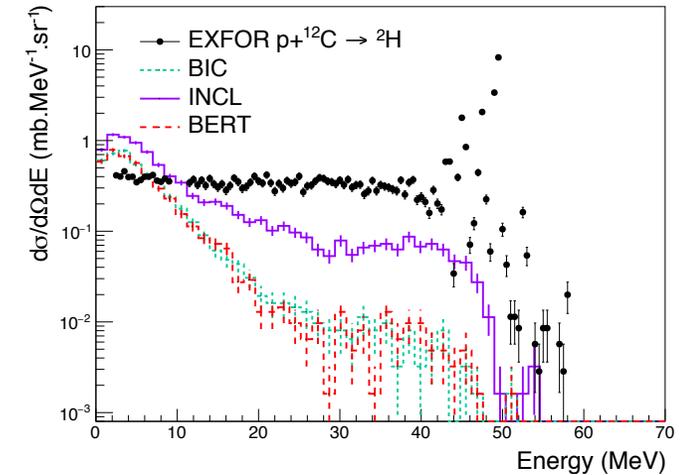
▶ MC simulations unable to correctly reproduce these nuclear reactions

▶ What is the impact of the secondary particles produced by these nuclear reactions?  $\Rightarrow$  not only biology, chemical step needs to be considered

From Kraemer et al., *Helium ions for radiotherapy? Physical and Biological verifications of a novel treatment modality*, Med. Phys. (2016).



Extrait de Battistoni et al., "The FLUKA code: an accurate simulation tool for particle therapy", *Frontiers in Oncology* (2016).

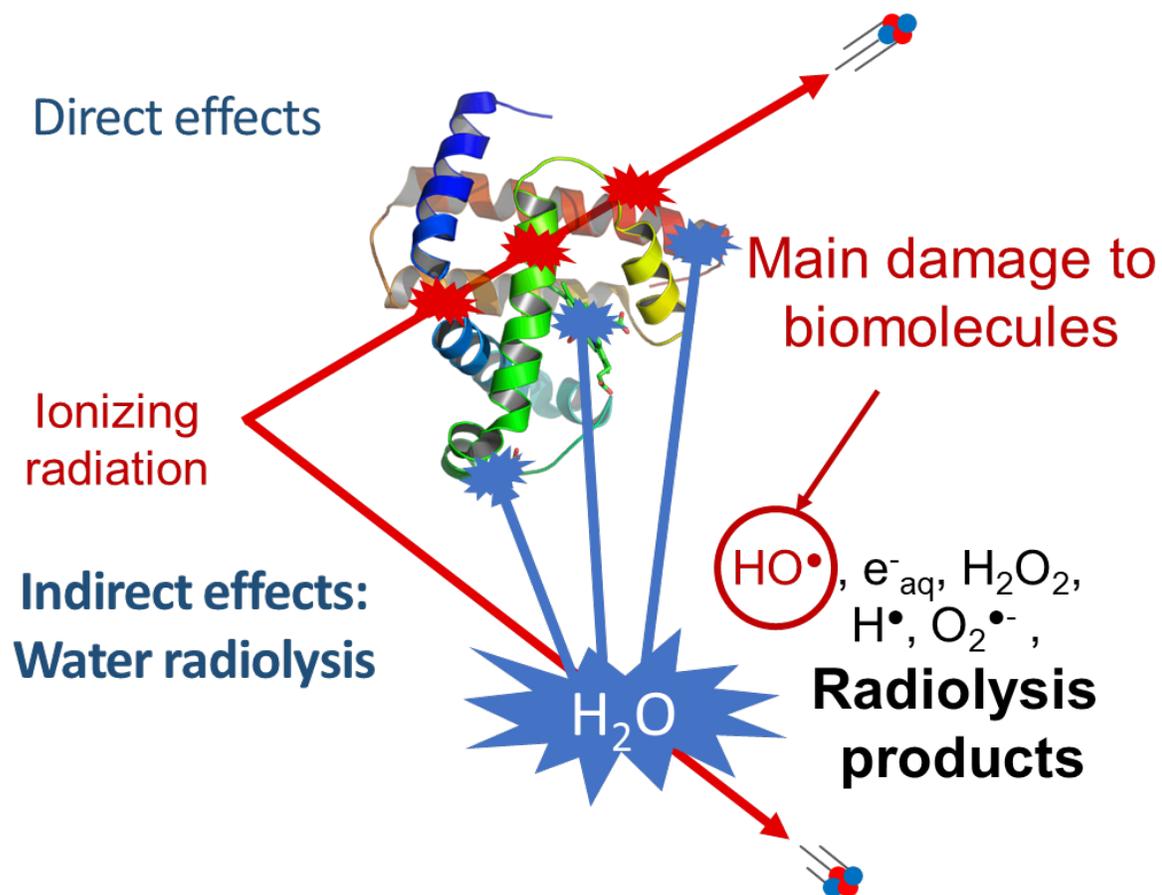


**It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.**

RICHARD FEYNMAN

# Bridging physics and biology through radiolysis

## Radiolysis

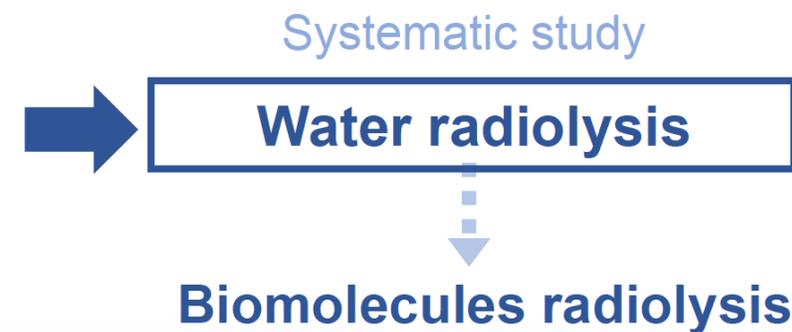


Proteins:

- 20% of the mass of a cell
- Important targets of radiation effects

Water:

- 70% of the mass of a cell
- Great influence on the radiolysis of biomolecules



# The CLINM project



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CLINM

- CLINM (Cross-sections of Light Ion and Neutron Measurements) : secondary particles impact on radiolysis of biomolecules & water, produced from  $^4\text{He}$ ,  $^{12}\text{C}$ ,  $^{16}\text{O}$ , ... ,  $^{56}\text{Fe}$  beam fragmentation
  - ❖  $\Delta E$ -ToF telescope/ $\Delta E$ -E for charged particles identification +  $\gamma$  and n measurement ( $\text{CeBr}_3$ ) of high energy ( $> 50$  MeV)
  - ❖ Development of a neutron counter for low energy neutrons (alphaBEAST  $\Rightarrow$  [D. Betelgueriev talk](#))
  - ❖ Water and biomolecules radiolysis of primary & secondary particles (in collaboration with **Radiochemistry team of IPHC**)

**Final goal:** implementation of physical & chemical data in Geant4-DNA  
([H. Tran talk](#))



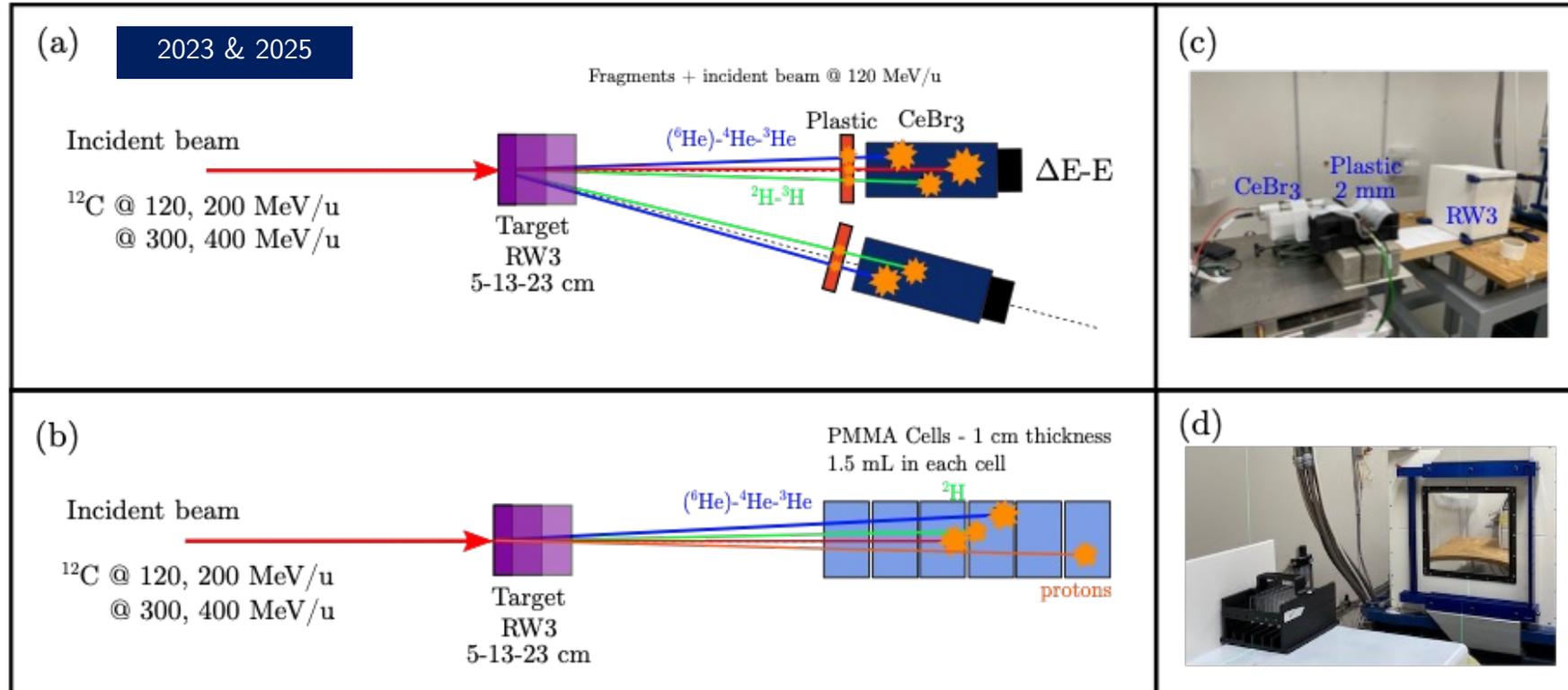
# The CLINM project @ CNAO

**HITRI**  
Heavy Ion Therapy Research Integration



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- Two experimental campaigns funded by HITRI+:
  - ❖ **2023:** first measurements of secondary particles with the CLINM setup from  $^{12}\text{C}$  (120 up to 400 MeV/u) interacting with thick targets of RW3 + associated radiolysis measurements
  - ❖ **2025:** consolidation of 2023 results, additional measurements on thin targets and at higher angles ( $5^\circ$ )



# The CLINM project – on the physical side...

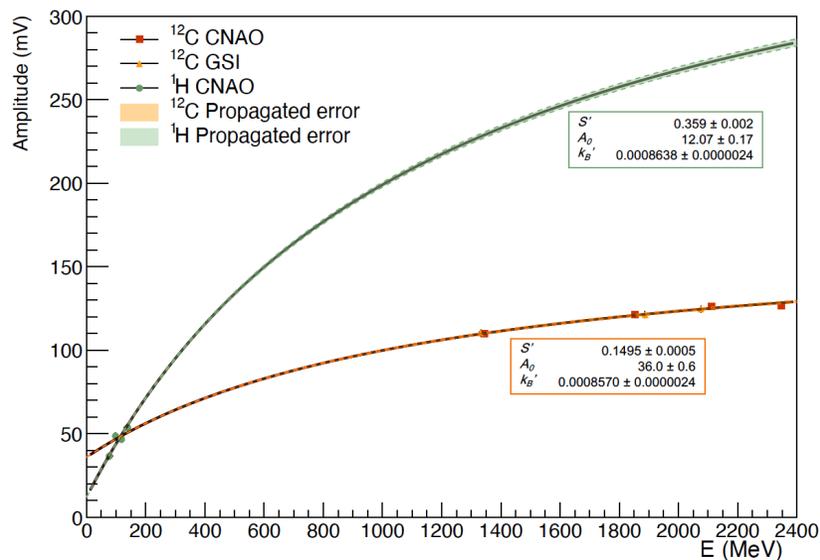


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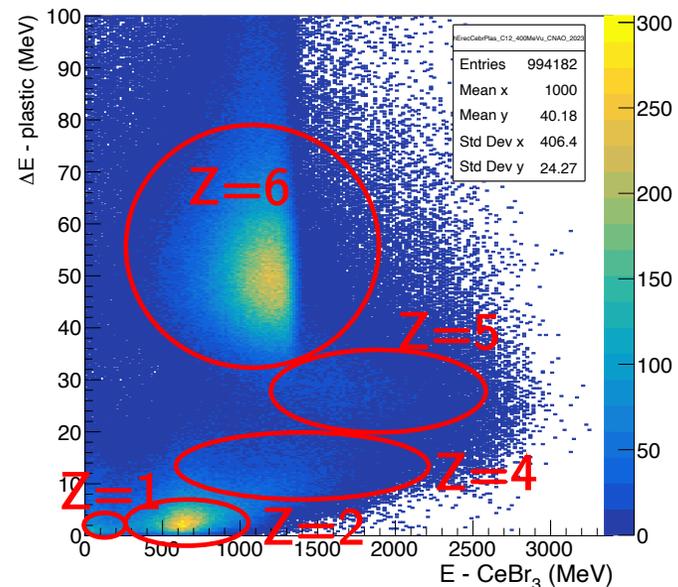
2023  
data

- Calibration of the CLINM setup finalized and published
- First measurements of secondary particles analyzed– publication in writing process

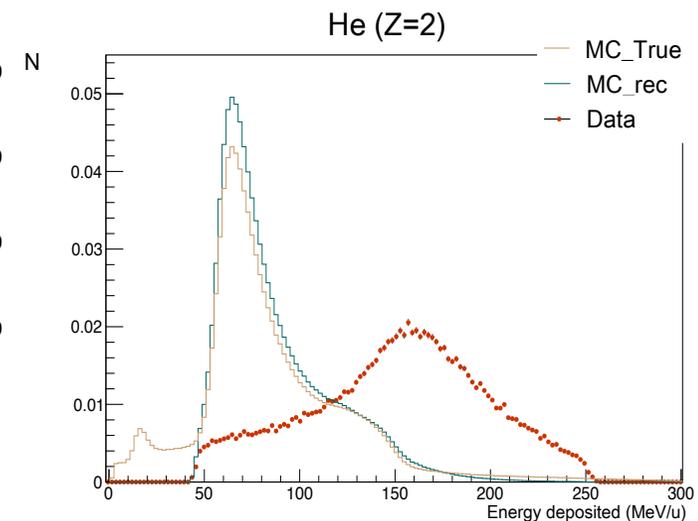
CLINM  
physics



L. Gesson et al., *Calibration of a  $\Delta E$ -E telescope based on CeBr<sub>3</sub> scintillator for secondary charged particles measurements in hadron therapy*, JINST, 2026.



Results extracted from L. Gesson PhD: discrepancy observed between measured and simulated distributions of secondary heliums produced by  $^{12}\text{C}$  of 400 MeV/u on 23 cm-thick RW3 target.



# The CLINM project – on the physical side...

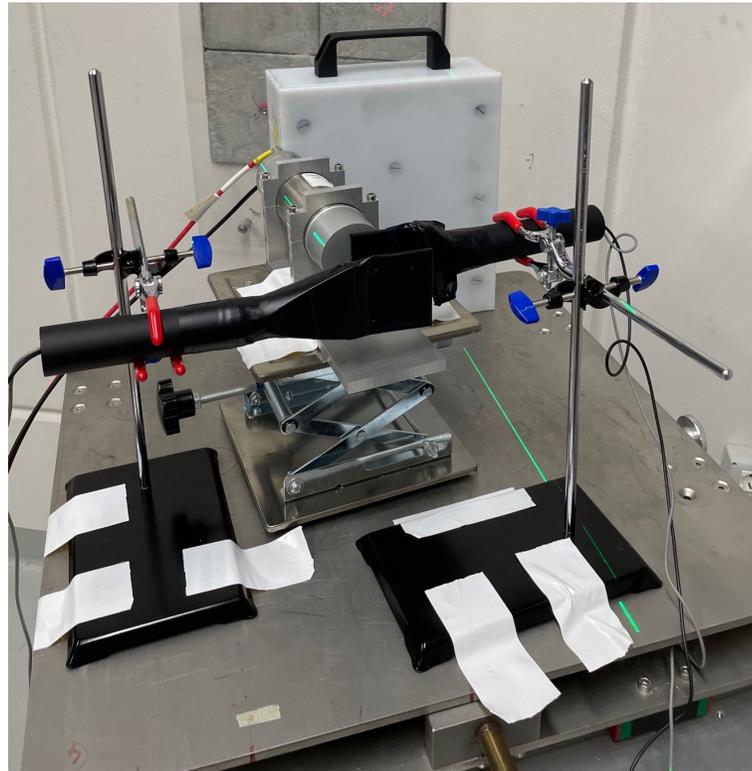


NUCLÉAIRE  
& PARTICULES

2025  
data

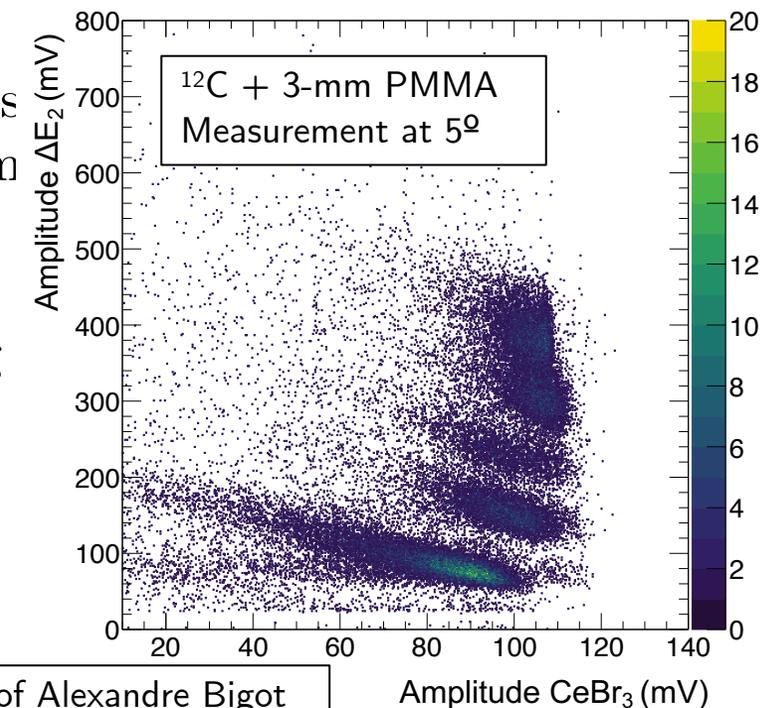
- CLINM setup updated in 2025:  $\Delta E_1$ - $\Delta E_2$ -E telescope with
  - $\Delta E_1$ : 2-mm thick plastic scintillator
  - $\Delta E_2$ : 4-mm thick plastic scintillator
  - E: CeBr<sub>3</sub>

coupled with R7057 PMTs



CLINM  
physics

- Improved resolution on the secondary particles identification
- Experiments with <sup>12</sup>C beam of 120 MeV/u on thin targets of PMMA (3 mm), aluminum (interest for space), PMMA + foam
- Analysis on-going, promising preliminary results

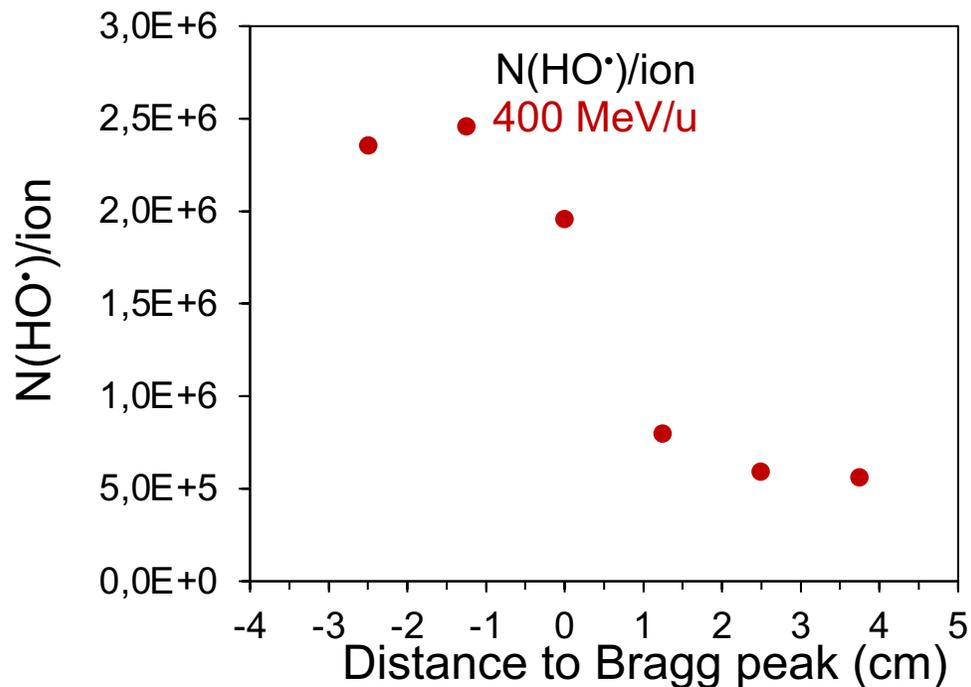
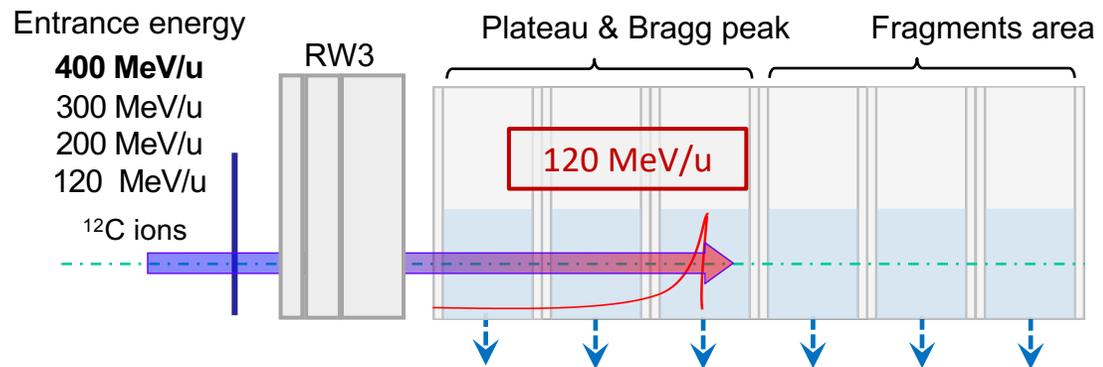


# The CLINM project – on the chemical side...



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& PARTICULES

2023  
data



CLINM  
radiolysis

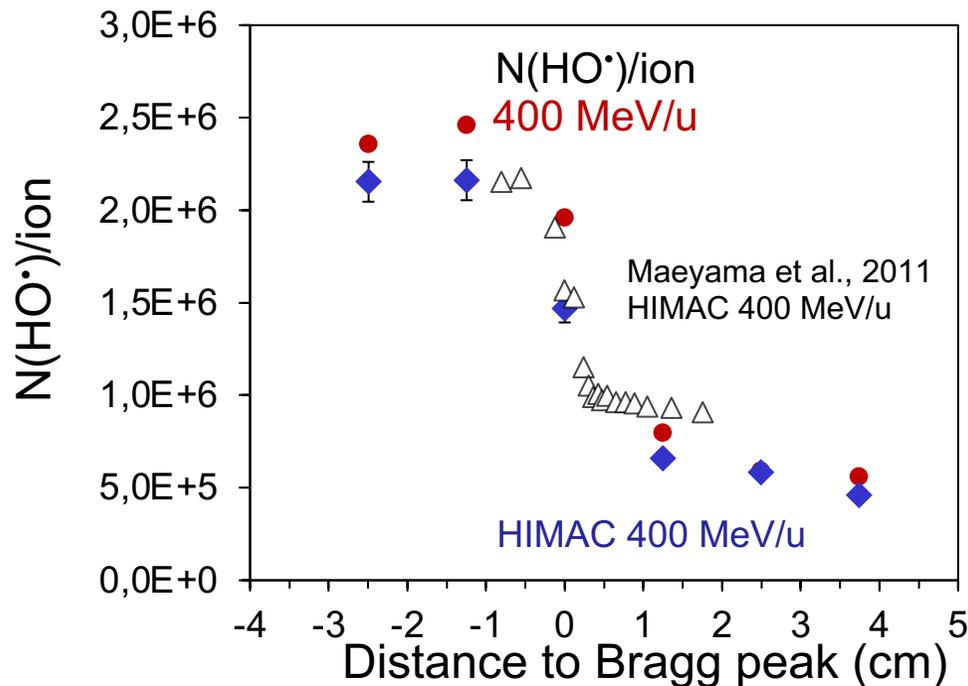
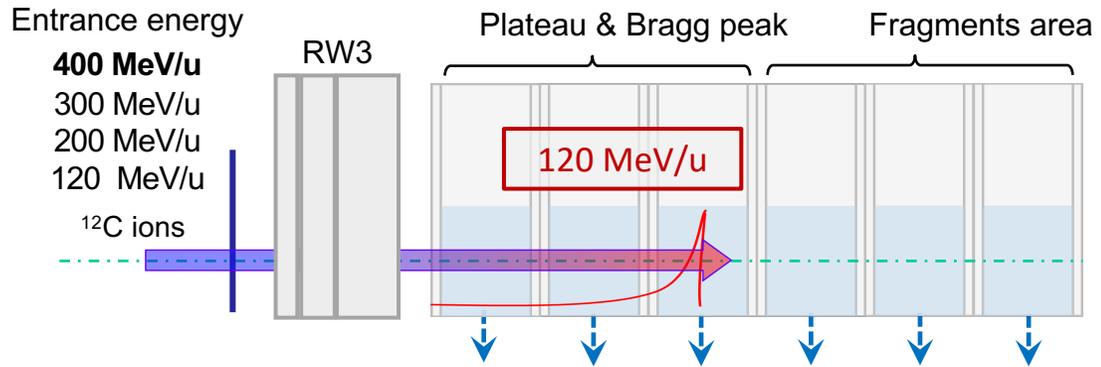
# The CLINM project – on the chemical side...



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2023  
data



- Close to data from *Maeyama et al., 2011* (Himac) and to our data on HIMAC 400 MeV/u

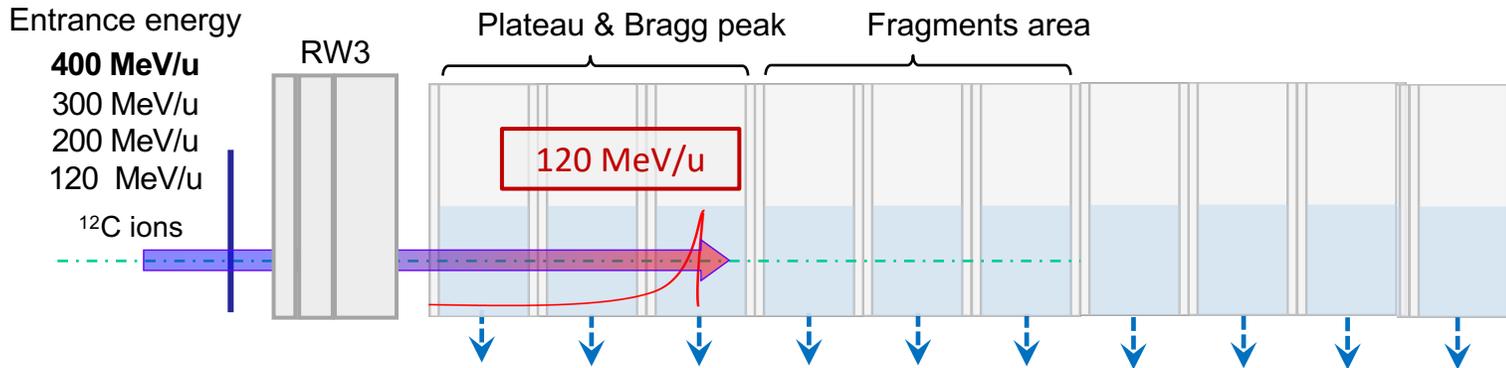
→ Validation

PhD Aurélia Arnone (2022-25)



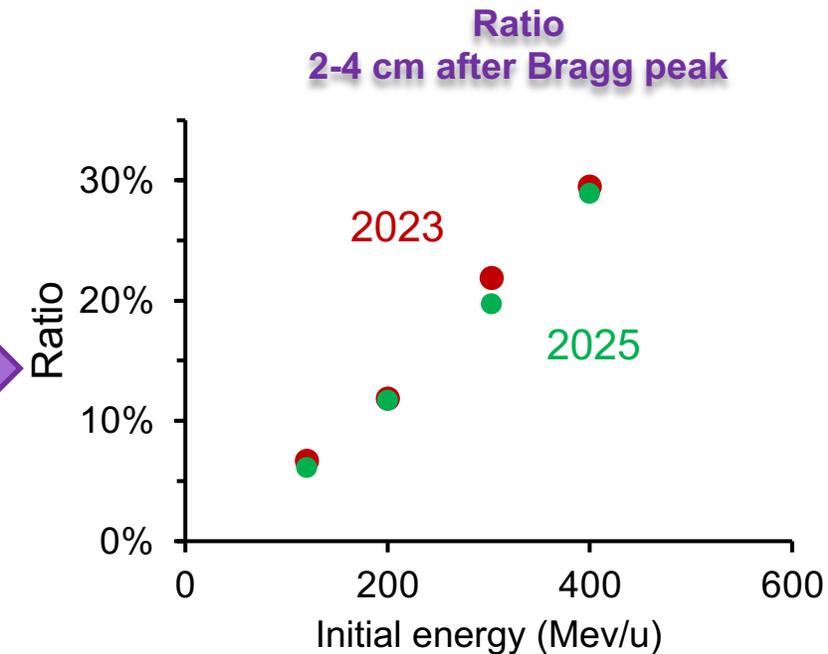
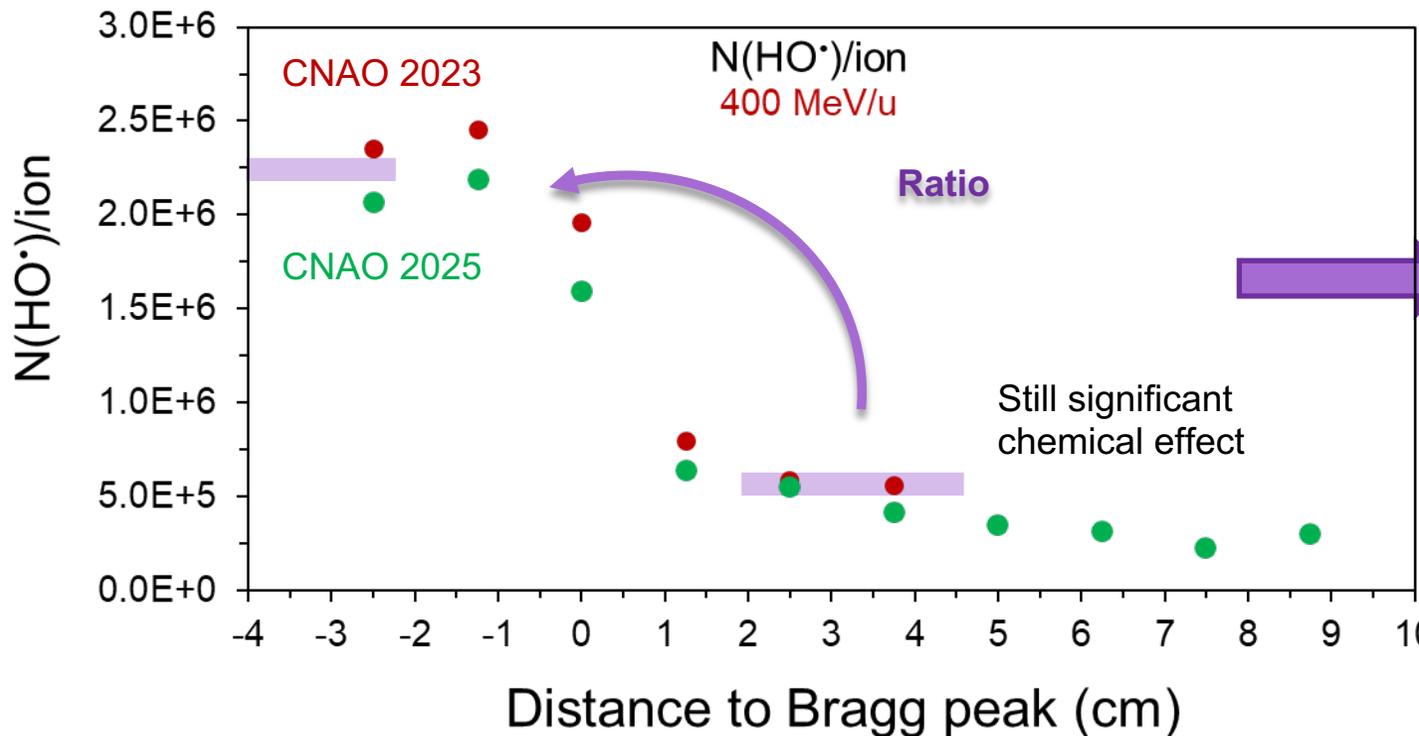


# The CLINM project – on the chemical side...



Expansion fragment area  
 Measurements of  $e^-_{aq}$  and  $H_2O_2$

2025 data



Chemical effect / plateau  
 >25 % 2-4 cm after Bragg peak  
 >10 % ~9 cm after Bragg peak

CLINM radiolysis

# Conclusion



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## Physics

- Measurements planned at CNAO in April 2026: regolith (Mars + Moon) targets for space radiation protection (collaboration with CNES) with  $^{12}\text{C}$  ions
- Time-of-Flight measurements to evaluate high energy neutrons field to complement alphaBeast measurements

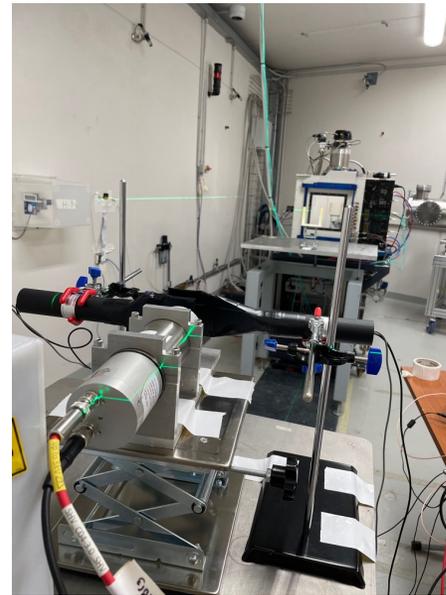
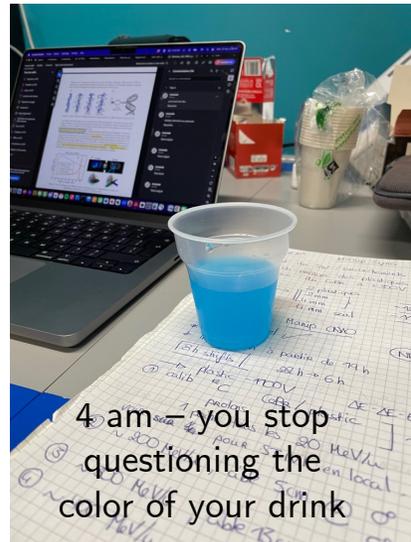
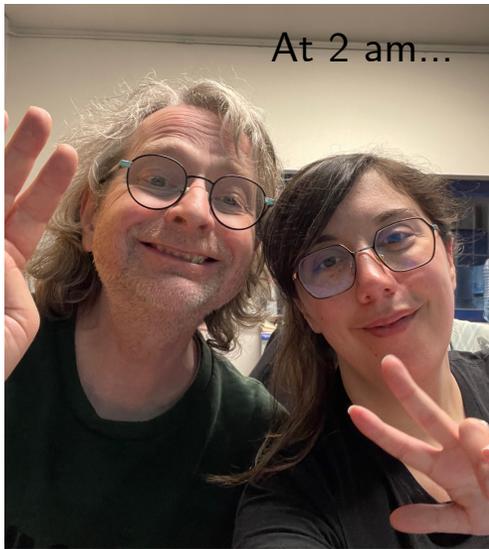
## Radiolysis

- Radiolysis with He ions and fragments
- Radiolysis of biomolecules: amino-acids and peptides
- Chemical effect after fragmentation through regolith targets (space applications)

Conclusion

# Acknowledgements

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