The CLINM project at CNAO

Centro Nazionale di Adroterapia Oncologica

Chemical impact of ^{12}C ion beam fragmentation on the radiolysis of water

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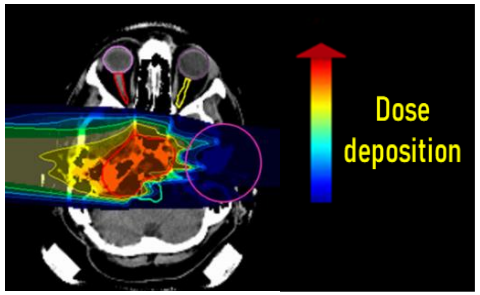
CONTEXT

Hadrontherapy : Treatment of cancer by accelerated ions (~ Gy/min)

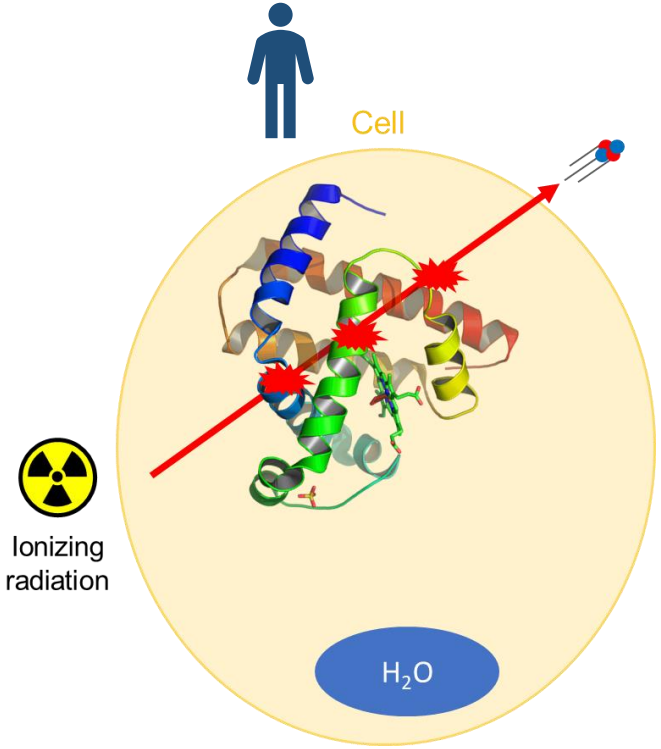
→ Better localized dose deposition in the tumor (Bragg Peak phenomena)

→ High LET → density of energy deposition

Reduced damage to healthy tissue while maintaining a strong impact on tumors



Haettner, E. et al.(2013)



Protein :

- 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

Systematic study

Water radiolysis

Biomolecules radiolysis

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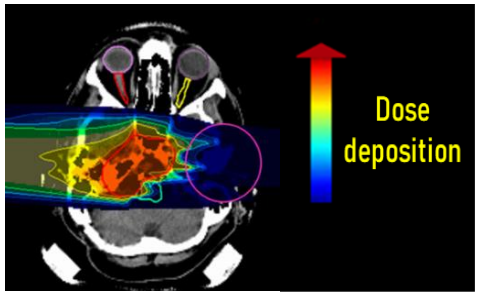

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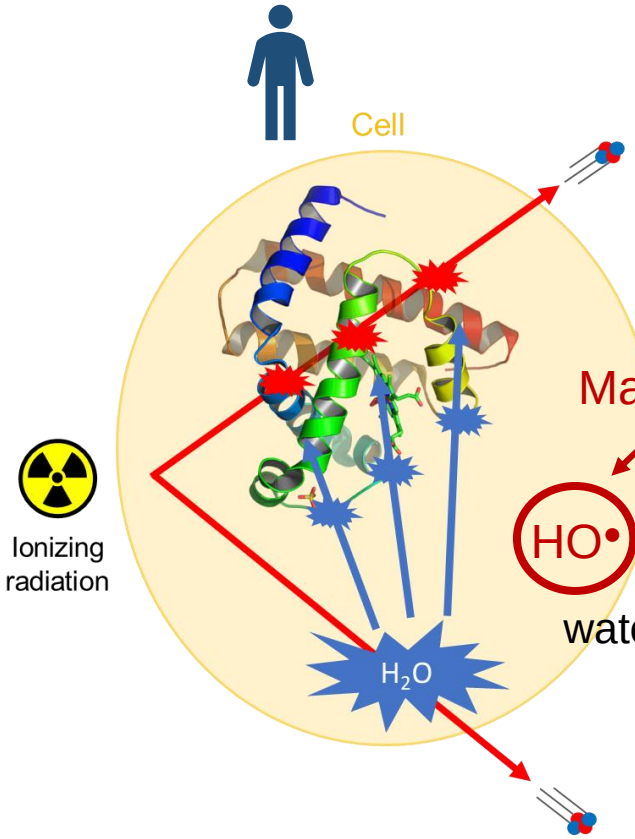

Major source of damage to biomolecules

$HO^{\bullet}$, $H^{\bullet}$, $O_2^{\bullet -}$, e^-_{aq}, H_2O_2

water radiolysis products

Important product of radiolysis

Protein :

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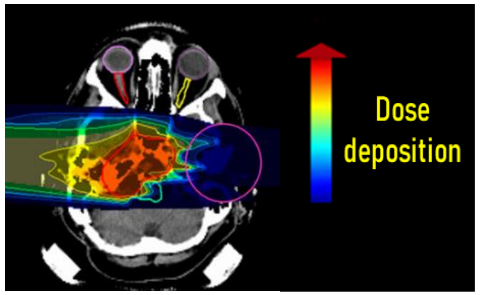

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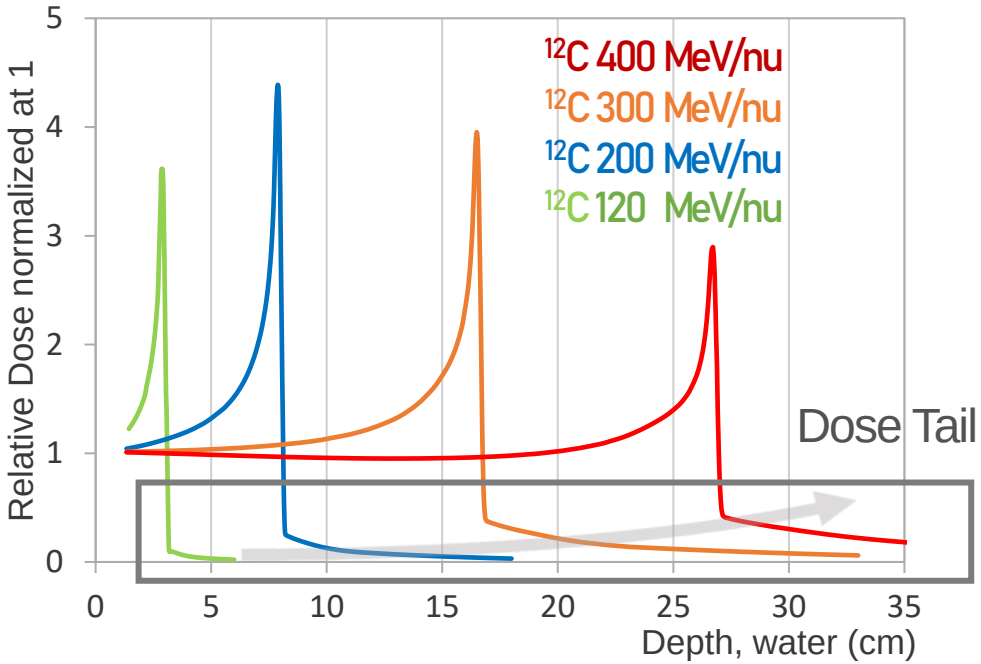

Relative dose as a function of the depth, in water equivalent

Nuclear fragmentation reactions along particle stopping path :

Fragmentation → attenuation of primary beam + build-up fragments

Hadrontherapy → few data at the molecular level on radiolysis

Fragmentation → very few studies at molecular level

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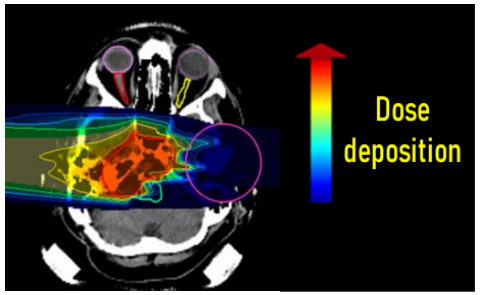

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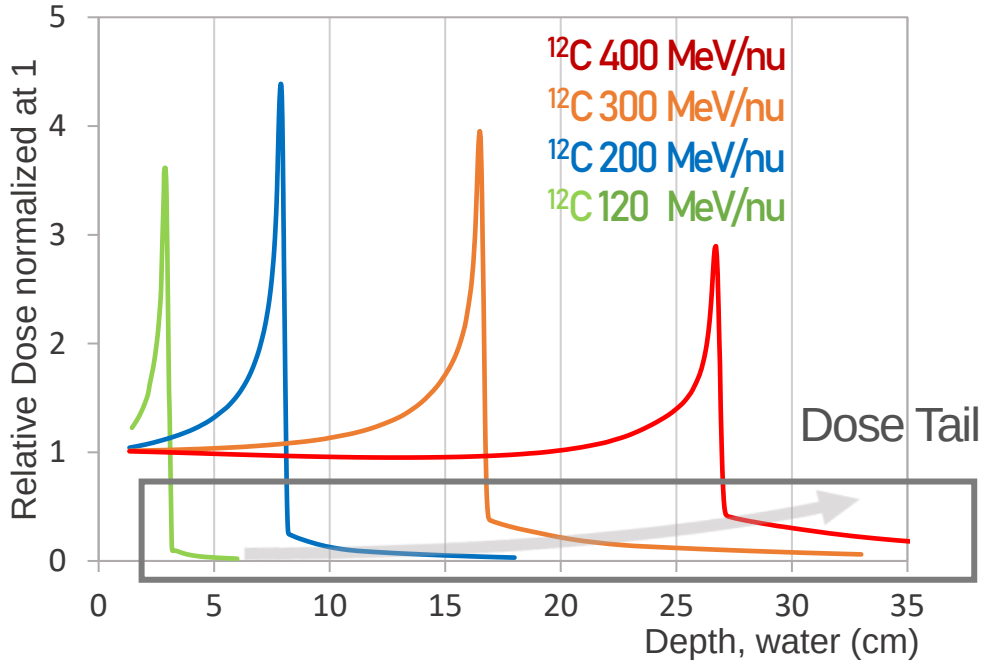

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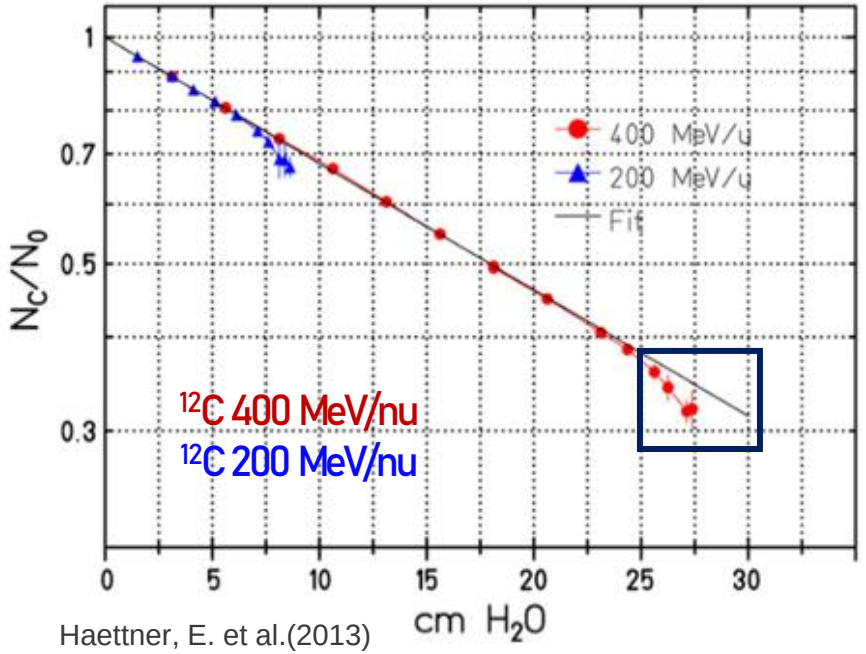


Haettner, E. et al.(2013)

Attenuation of primary ^{12}C ions as a function of the depth in water

Surviving fraction of primary ions
→ 30 % of ^{12}C 400 MeV/nu

Loss of primary ions → higher production of nuclear fragments

Nuclear fragmentation reactions along particle stopping path :

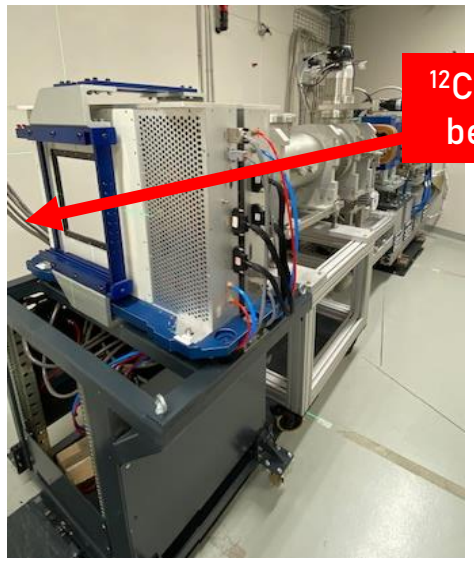
Fragmentation → attenuation of primary beam + build-up fragments

Hadrontherapy → few data at the molecular level on radiolysis

Fragmentation → very few studies at molecular level

Material and method

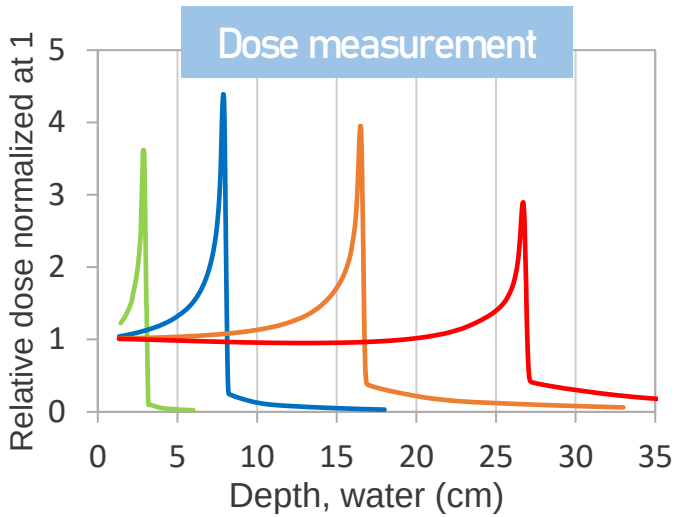
Development of a dedicated experience to study the impact on the radiolysis of an ^{12}C ion beam fragmentation delivered by synchrotron



Experimental Room

4 Energies :
400 MeV/nu
300 MeV/nu
200 MeV/nu
120 MeV/nu

Dose measurement



Ionization Chamber → dose deposition curve for each energy

Chemical measurement

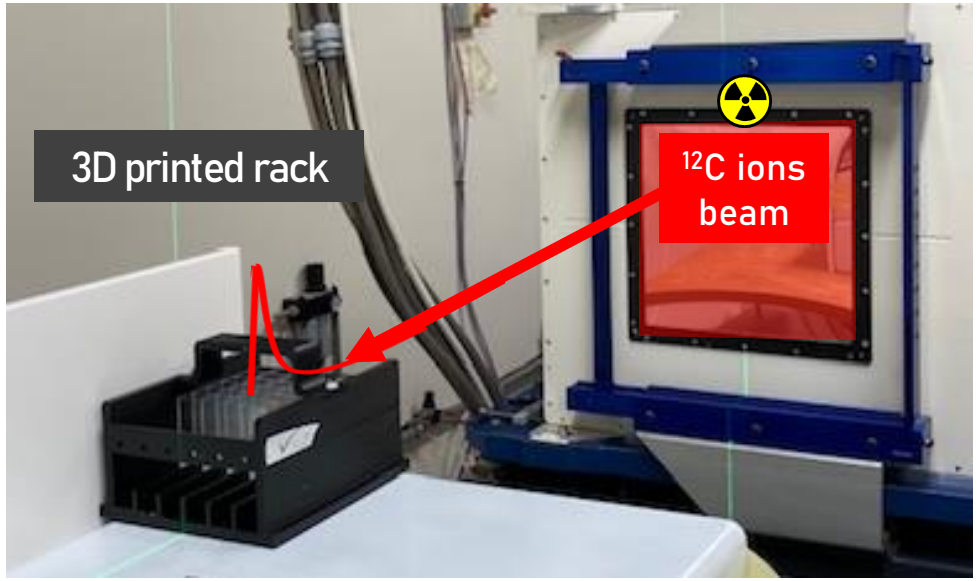
Radiolysis of water

- Measure of hydroxyl radical **$HO^{\bullet}$**
  → Irradiation of KBr, Formate ($HO^{\bullet}$ probes) in aerated solution
- Measure of hydrogen peroxide **H_2O_2** in pure water
  → Irradiation of H_2O in aerated solution

Post irradiation analysis by UV spectroscopy :

- Ghormley reagents (KI et Phthalate)

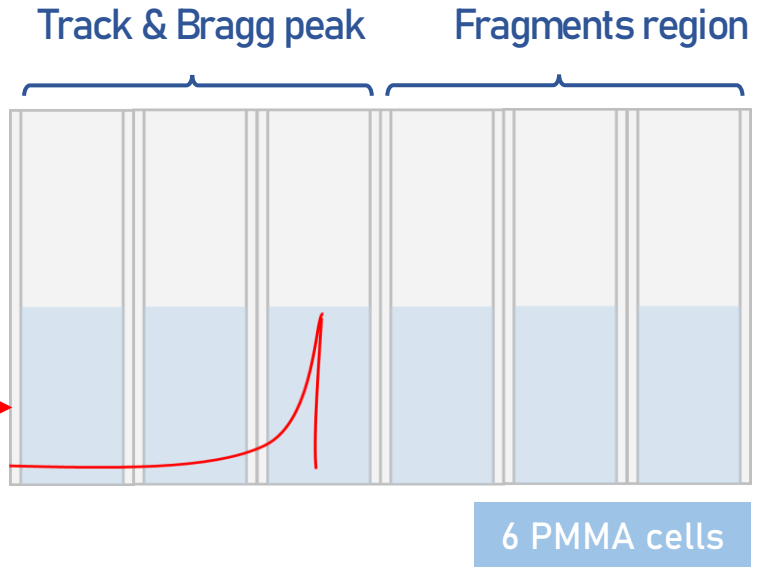
Material and method



Entrance energy :

120 MeV/nu

^{12}C ions beam



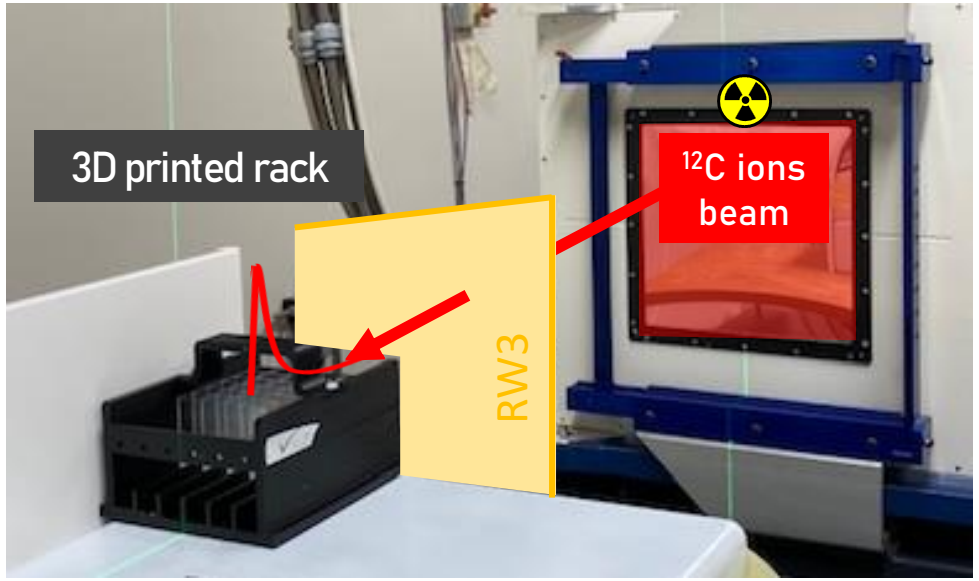
→ Evolution all along the particle path

Development of setup:

PEIGNE *(Portoir Essentiel pour Irradier un Grand Nombre d'Echantillons)*

- 6 rows x 6 PMMA cells aligned with the beam → same time & same conditions
- 6 rows → 6 solutions
- 1,5 mL solution in each cell

Material and method



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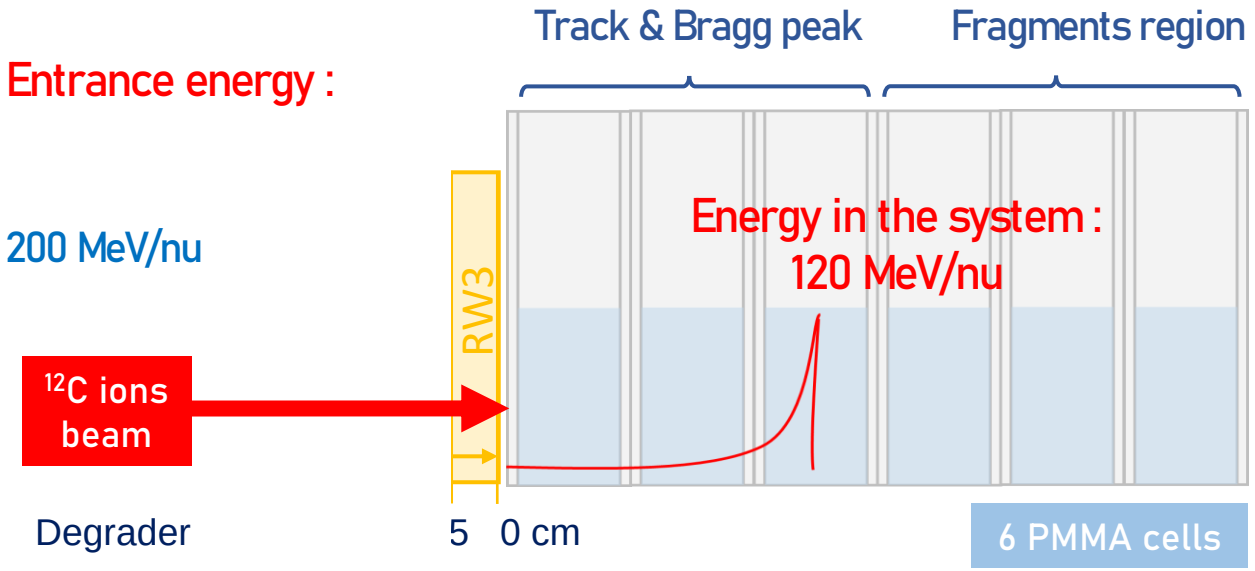
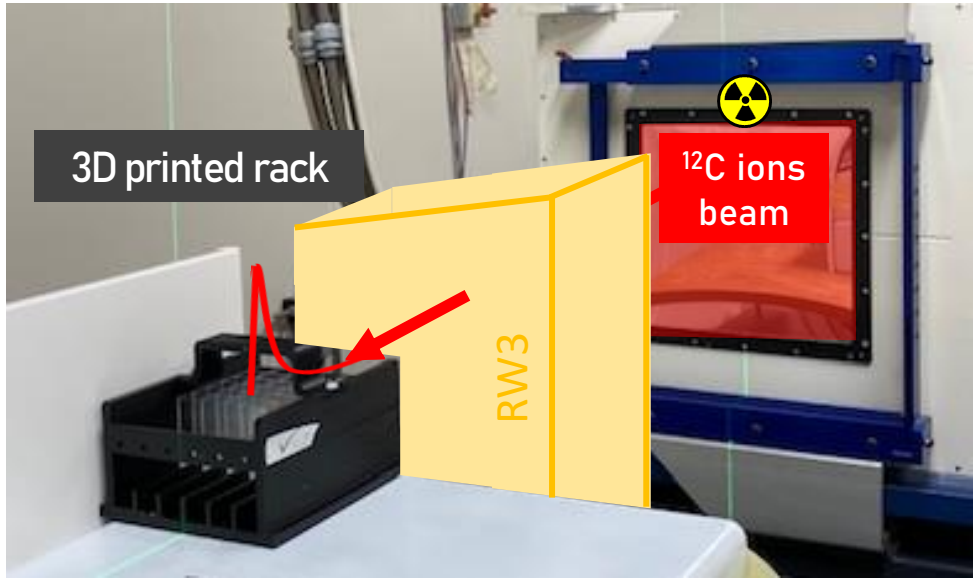
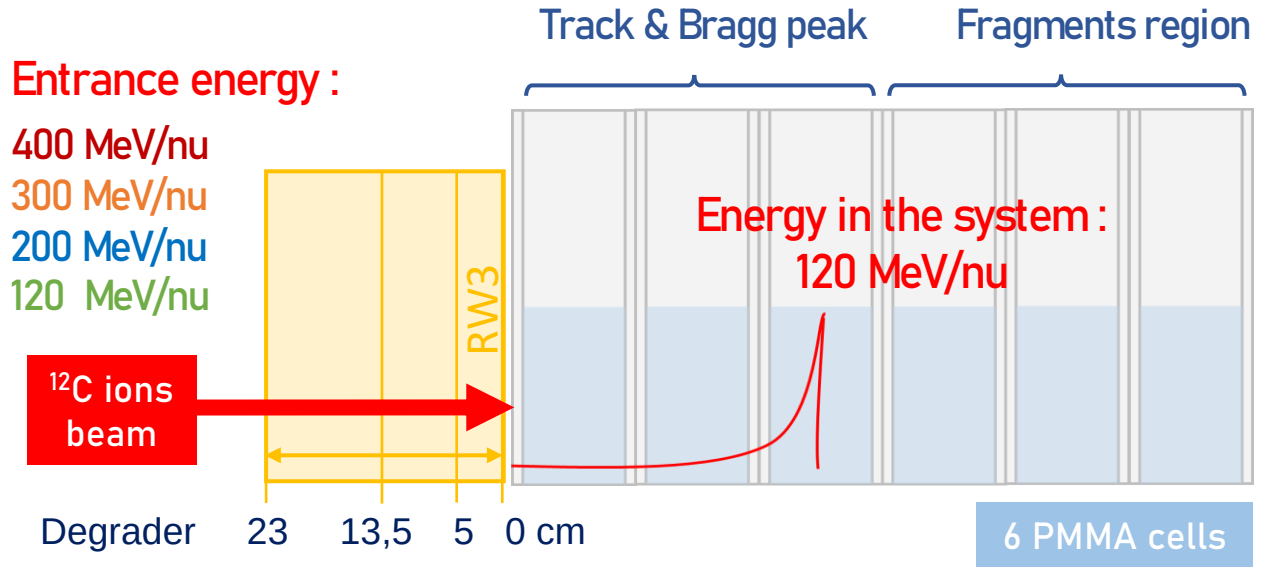


→ Energy **degradation** through the addition of RW3 plates (Polystyrene + TiO_2) as degrader

→ Always **120 MeV/nu** inside the system

Material and method





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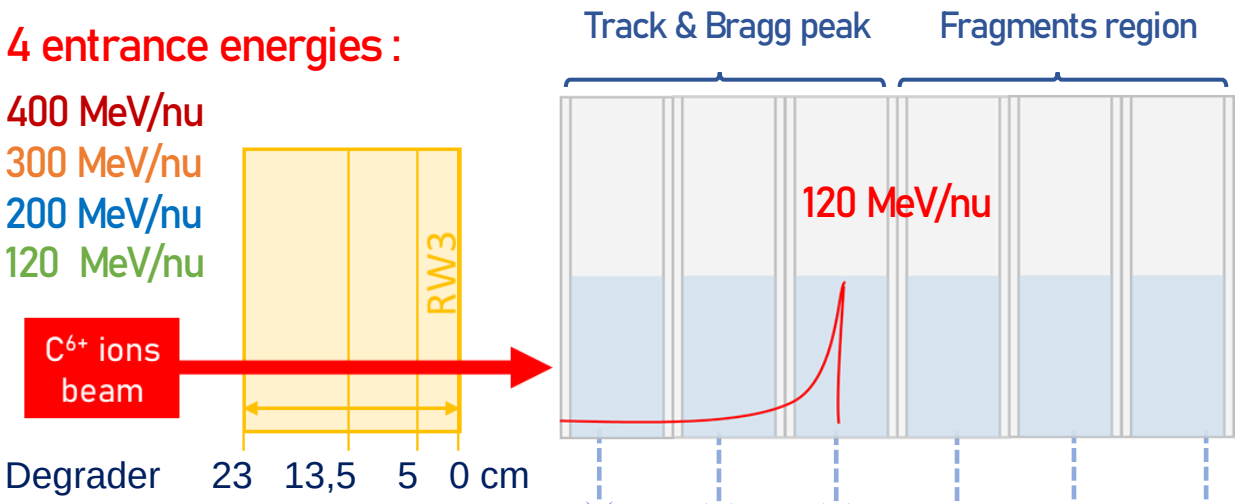
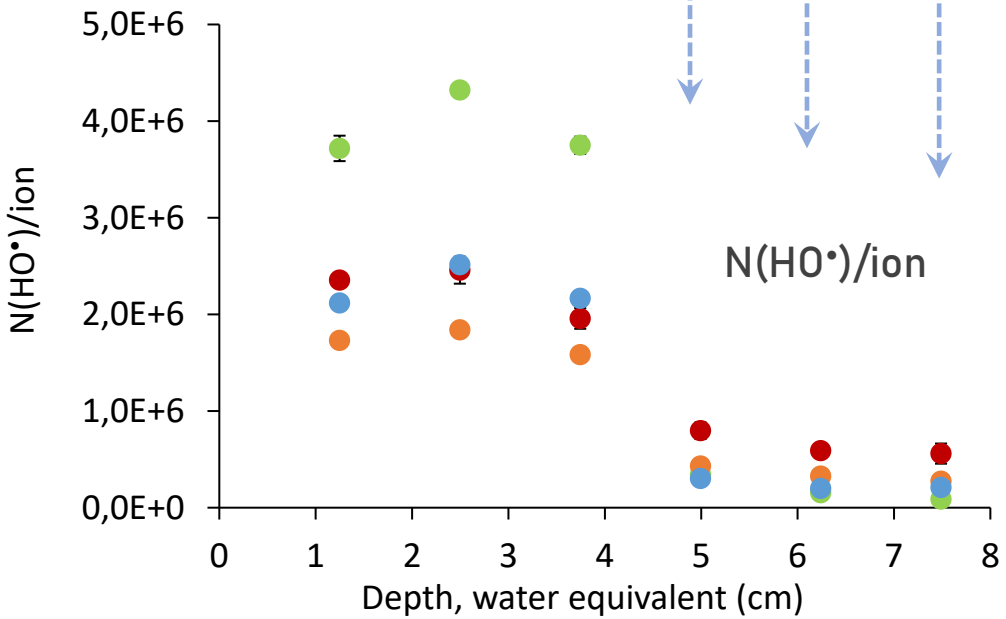
Hydroxyl radical HO•

4 entrance energies :

400 MeV/nu
300 MeV/nu
200 MeV/nu
120 MeV/nu





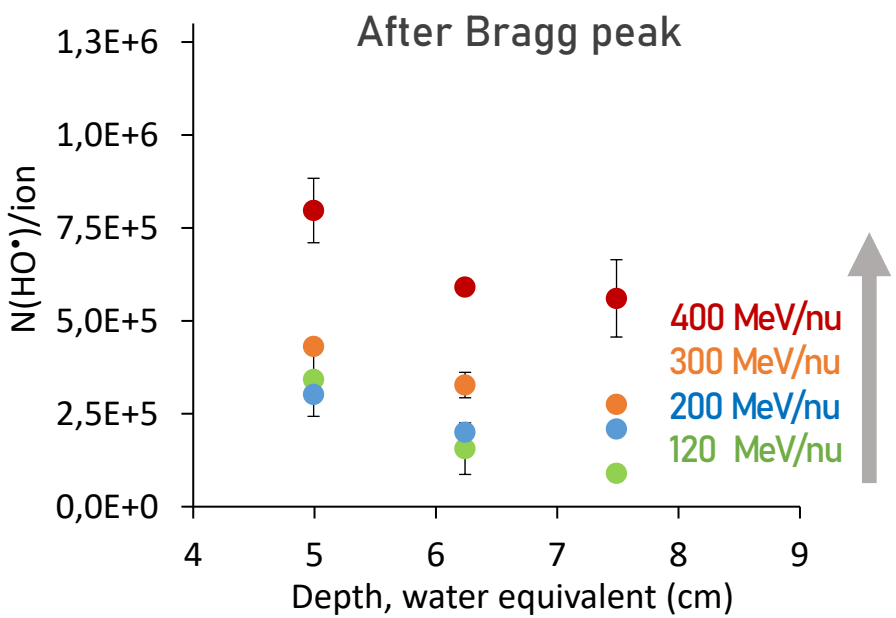
HO•

Radiolysis of water

→ Measuring radical HO• production

Number of HO• formed per ion (N(HO•)/ion) in each cell for each energy

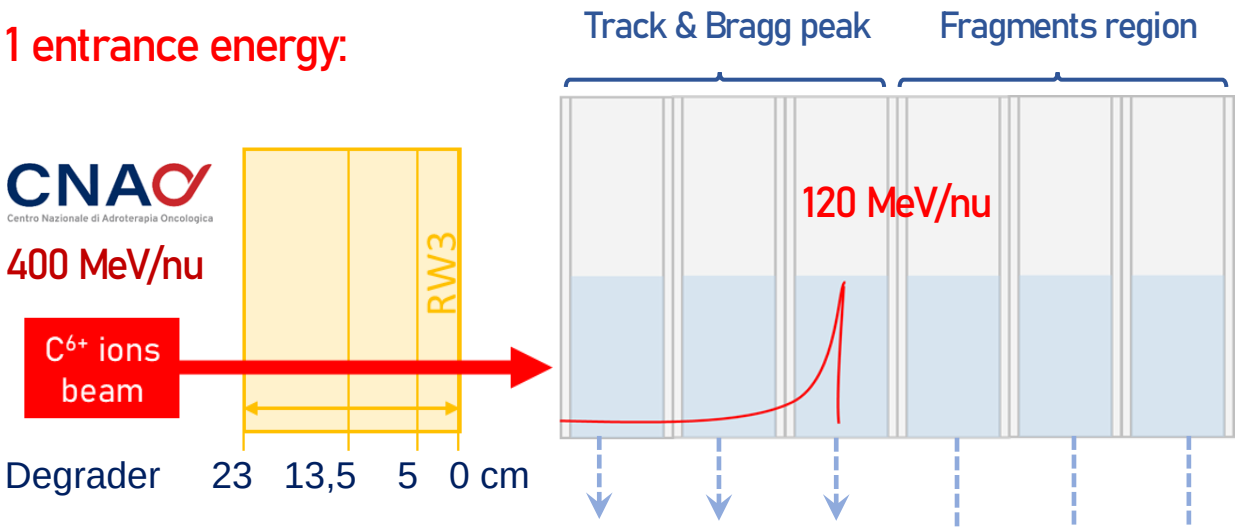
↗ fragmentation → N(HO•)/ion ↗ after Bragg peak

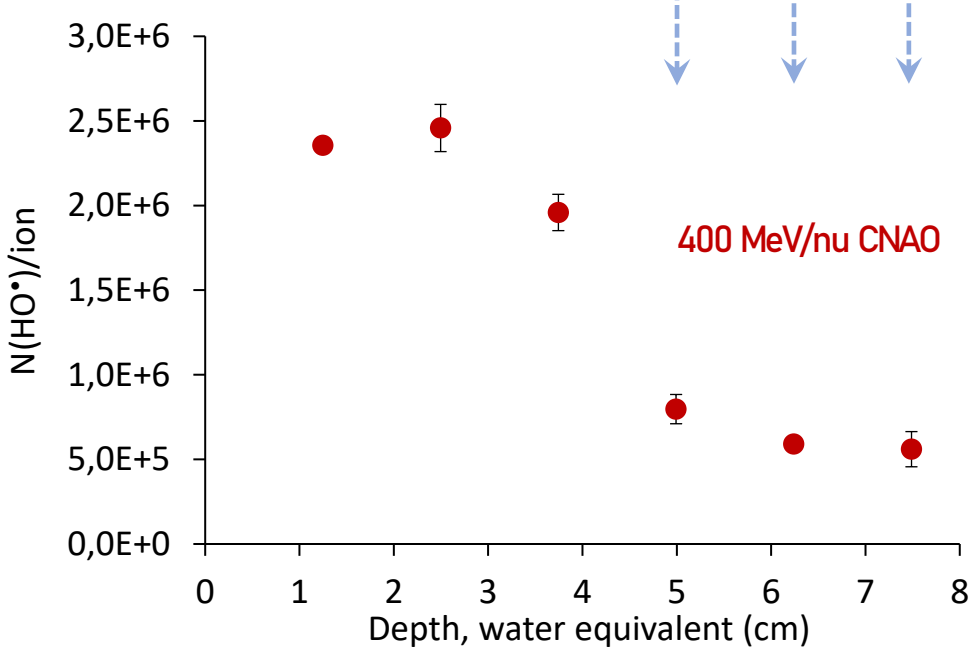


Number of HO• radicals formed per incident ion as a function of the depth in water equivalent

Hydroxyl radical $HO^{\bullet}$

1 entrance energy:





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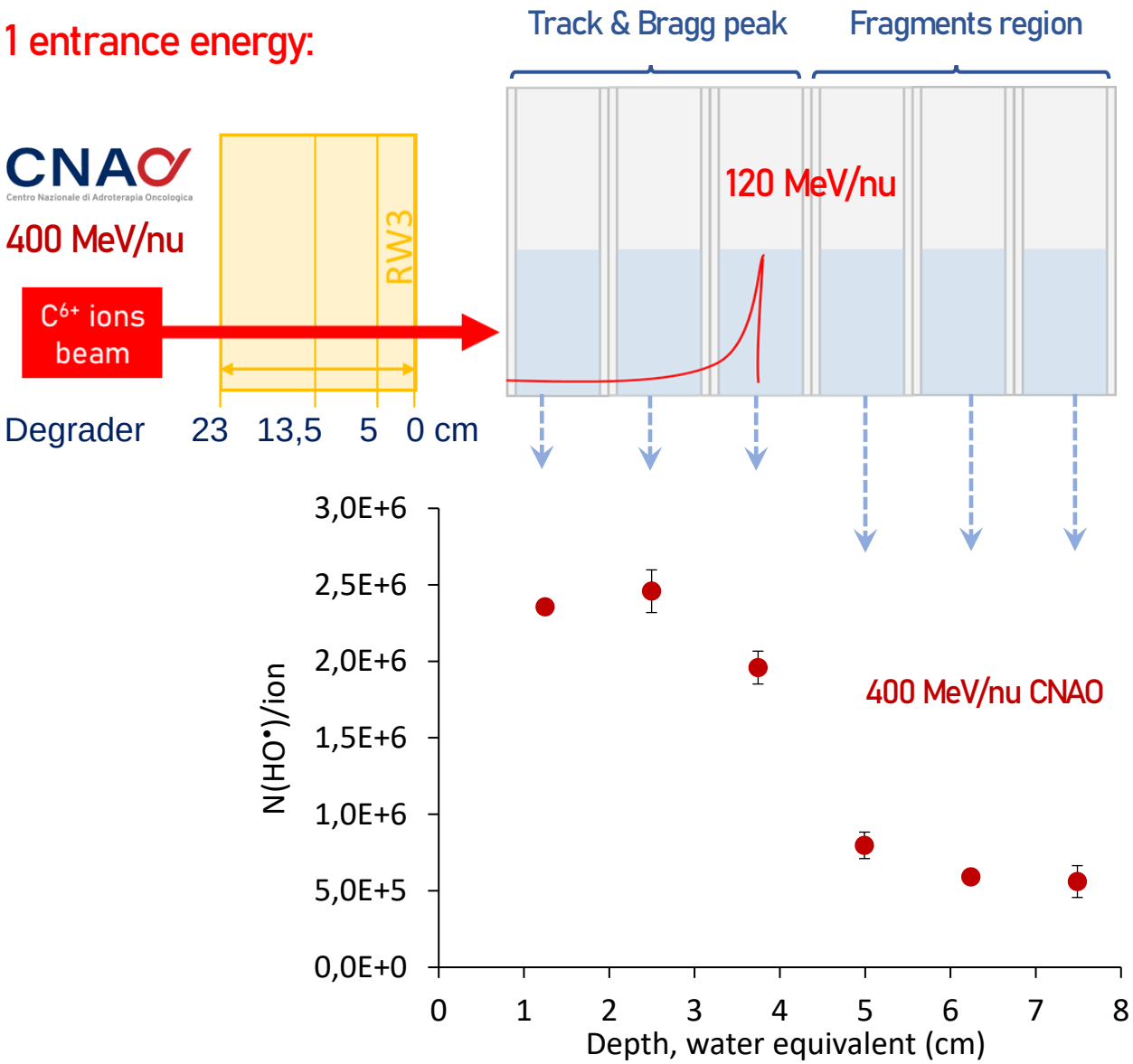
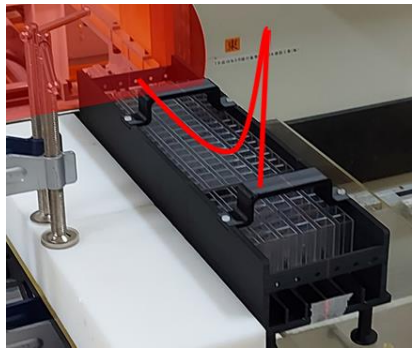


Number of HO• radicals formed per incident ion as a function of the depth in water equivalent

Similar experiment on HIMAC at QST (Japan)

HIMAC *(Heavy Ion Medical Accelerator in Chiba)*



→ ^{12}C 400 MeV/nu

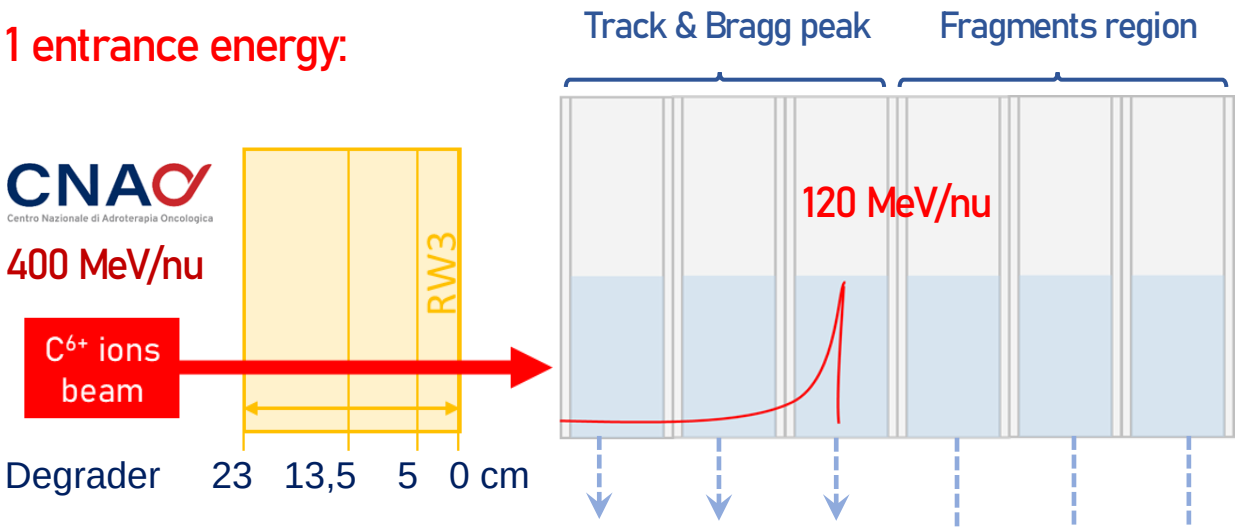
→ Dose measurement→ Ionization Chamber

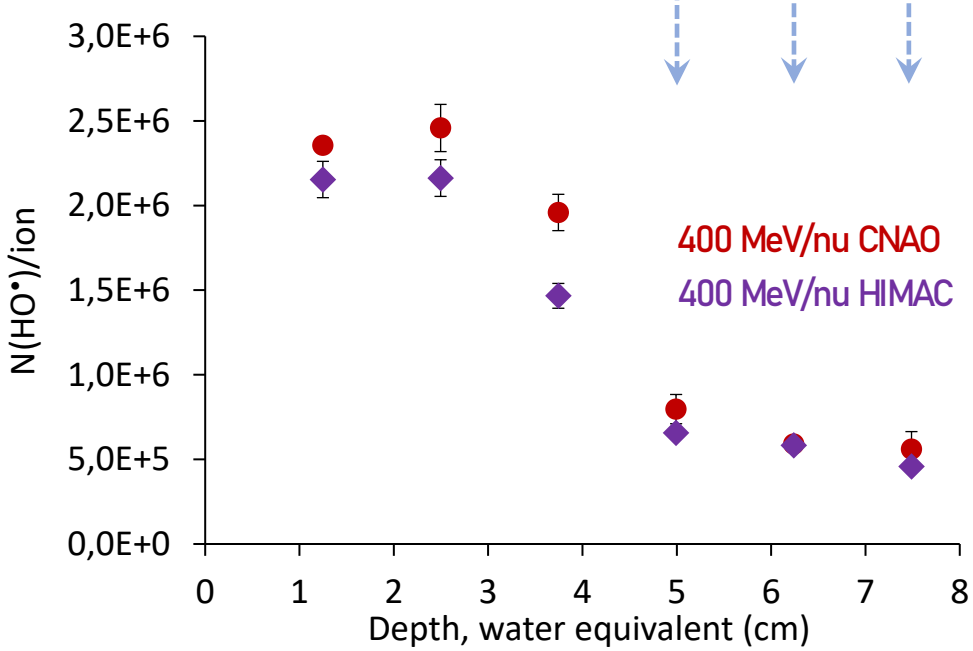
→ Measuring HO• radical production

→ Determine N(HO•) /ion

Hydroxyl radical $HO^{\bullet}$

1 entrance energy:





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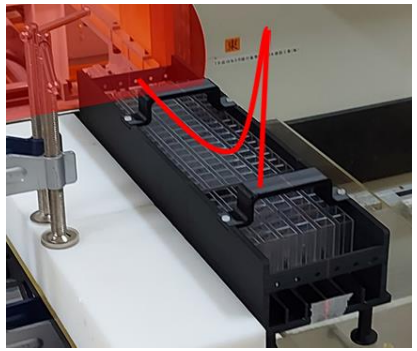


QST

→ ^{12}C 400 MeV/nu

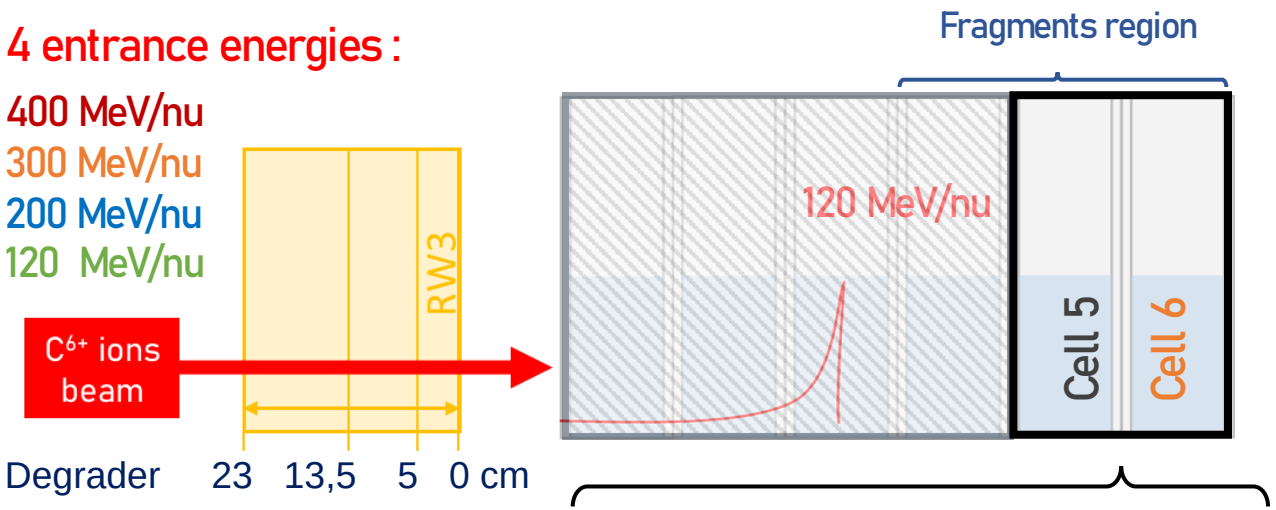
→ Dose measurement→ Ionization Chamber

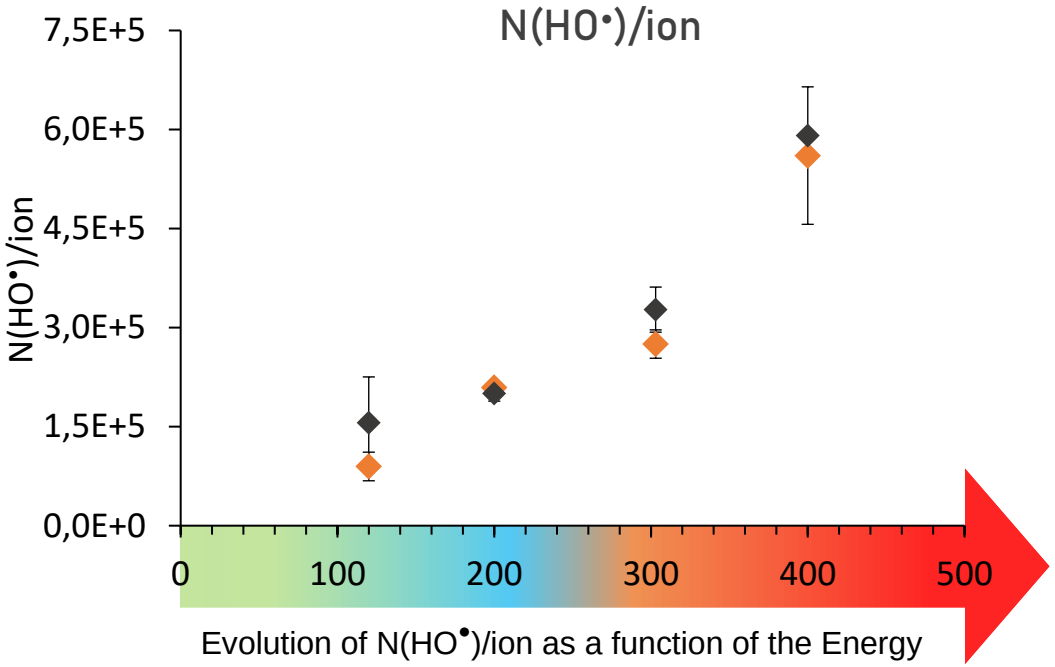
→ Measuring $HO^{\bullet}$ radical production

→ Determine $N(HO^{\bullet})$ /ion

→ Similar evolution between the results obtained at CNAO and QST with ^{12}C 400 MeV/nu

Hydroxyl radical $HO^{\bullet}$





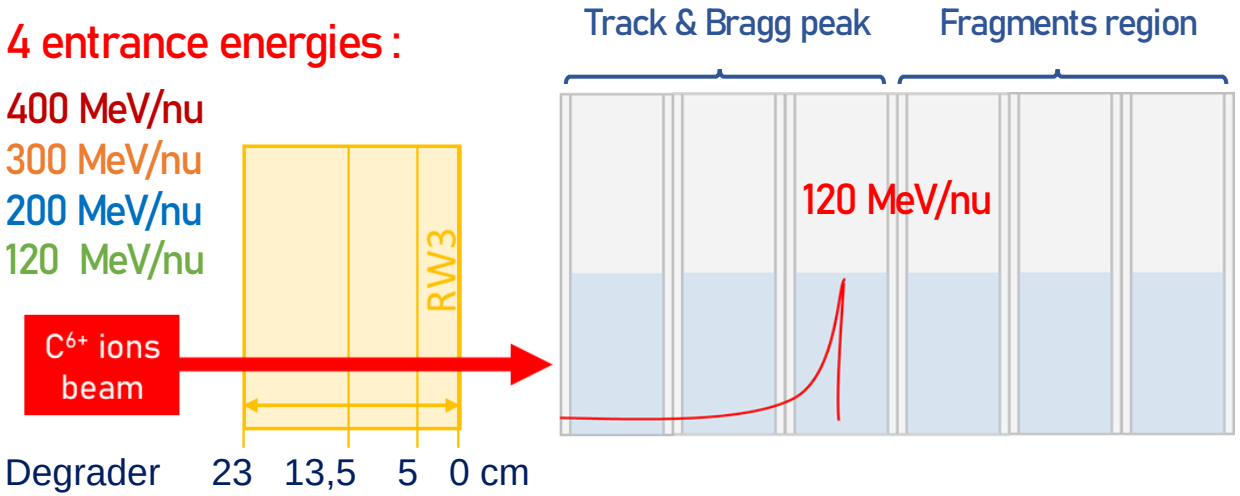
$HO^{\bullet}$

Last cells in the fragment region:

- Similar steady **increase** evolution for both cells
- As energy increase → More **fragmentation**
- **$N(HO^{\bullet})$/ion ↗** even 3 cm after the Bragg peak

  → effect due to **Fragmentation**

Hydrogen peroxide H_2O_2



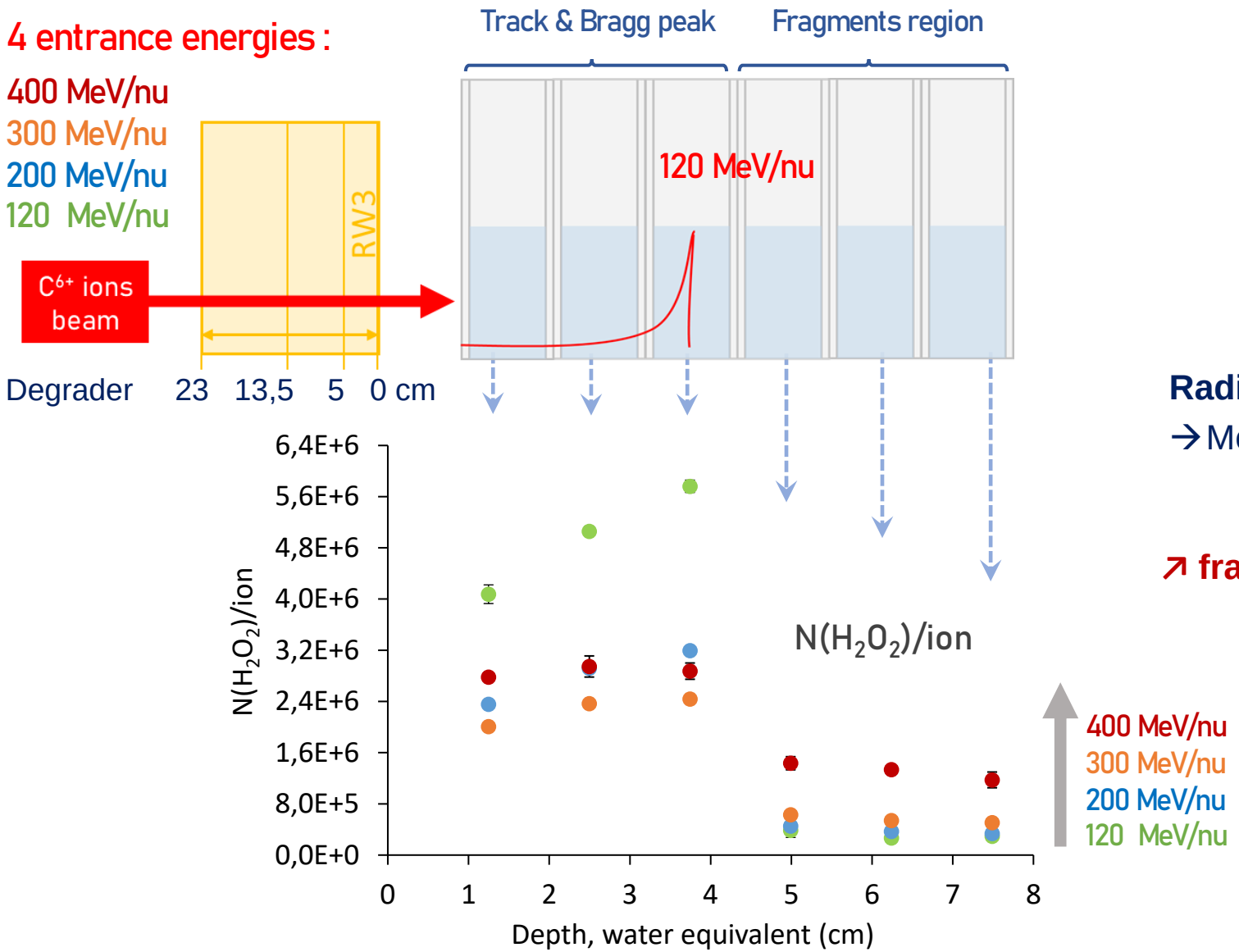
H_2O_2

Radiolysis of water

→Measuring H_2O_2 species production

Number of H_2O_2 formed per ion (N(H_2O_2)/ion)

Hydrogen peroxide H_2O_2



H_2O_2

Radiolysis of water

→ Measuring H_2O_2 species production

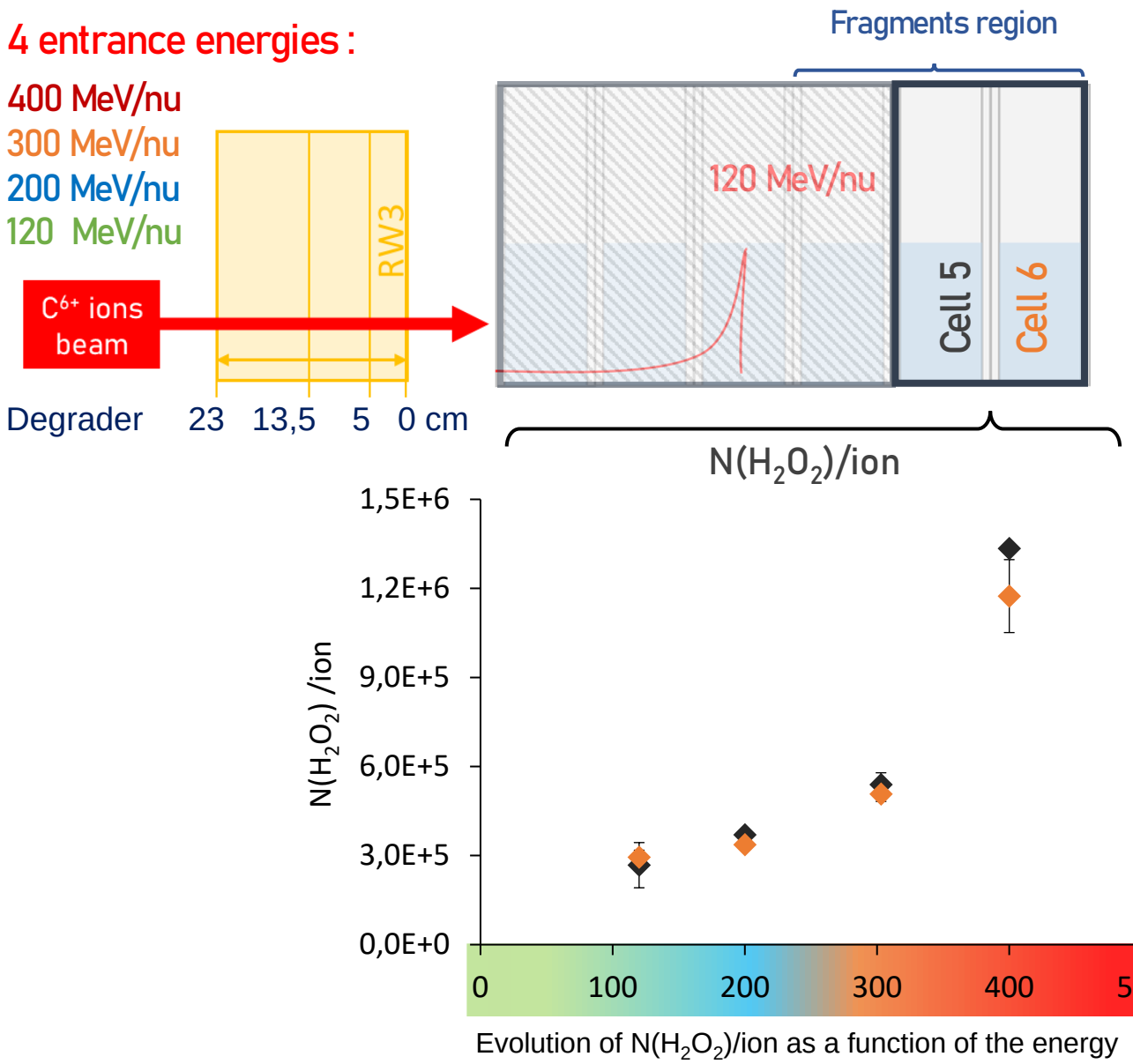
Number of H_2O_2 formed per ion ($N(H_2O_2)$/ion)

↗ fragmentation → $N(H_2O_2)$/ion ↗ after Bragg peak

→ Similar evolution between $N(\mathbf{H_2O_2})$/ion and $N(\mathbf{HO^{\bullet}})$/ion results

Number of H_2O_2 species formed per incident ion as a function of the depth in water equivalent

Hydrogen peroxide H_2O_2



H_2O_2

Last cells in the fragment region:

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- **$N(H_2O_2)$/ion ↗** even 3 cm after the Bragg peak

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Hydrogen peroxide H_2O_2

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400 MeV/nu
300 MeV/nu
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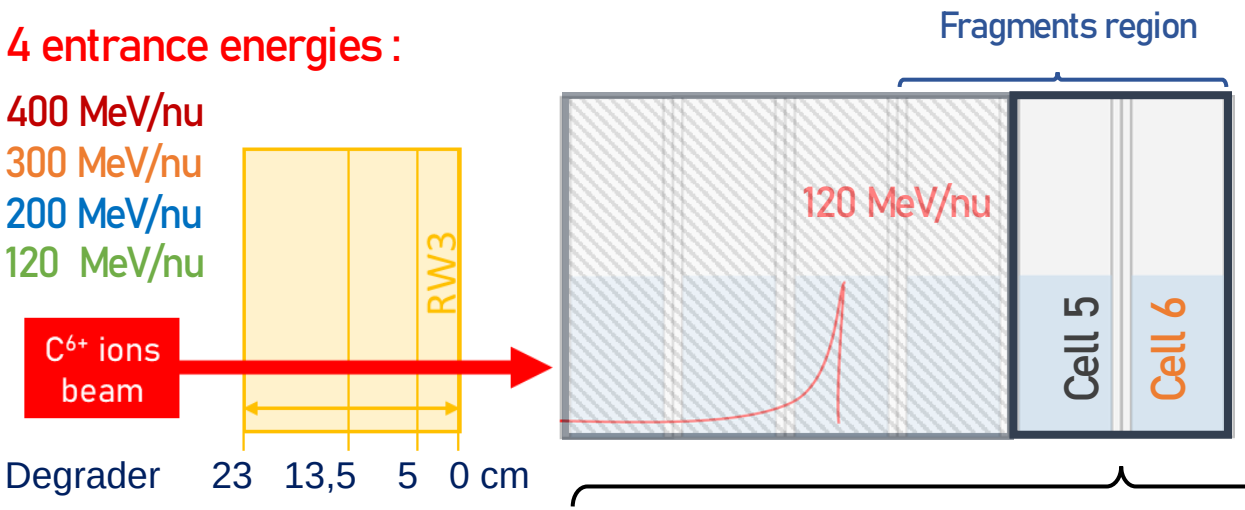
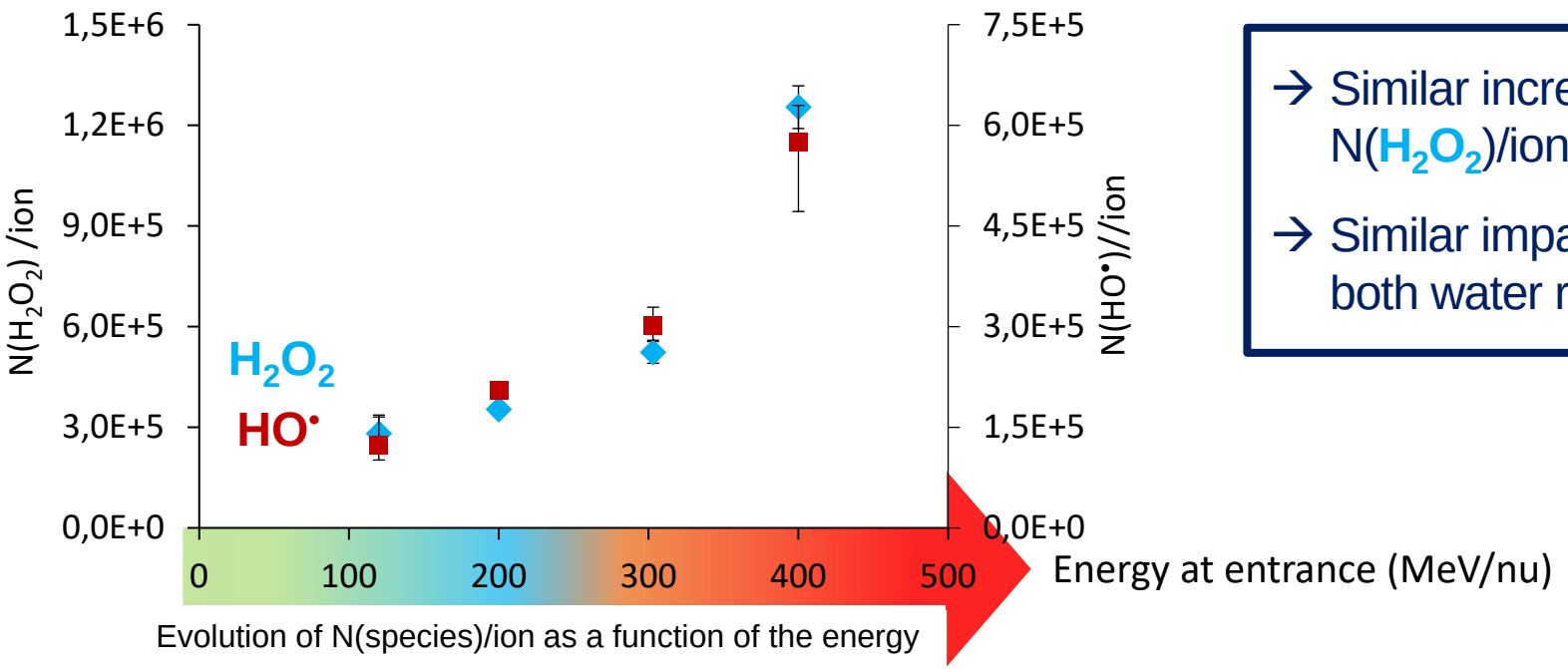




Evolution of N(species)/ion as a function of the energy

Last cells in the fragment region:

→ Similar increase evolution between N(H_2O_2)/ion and N(**HO•**)/ion results

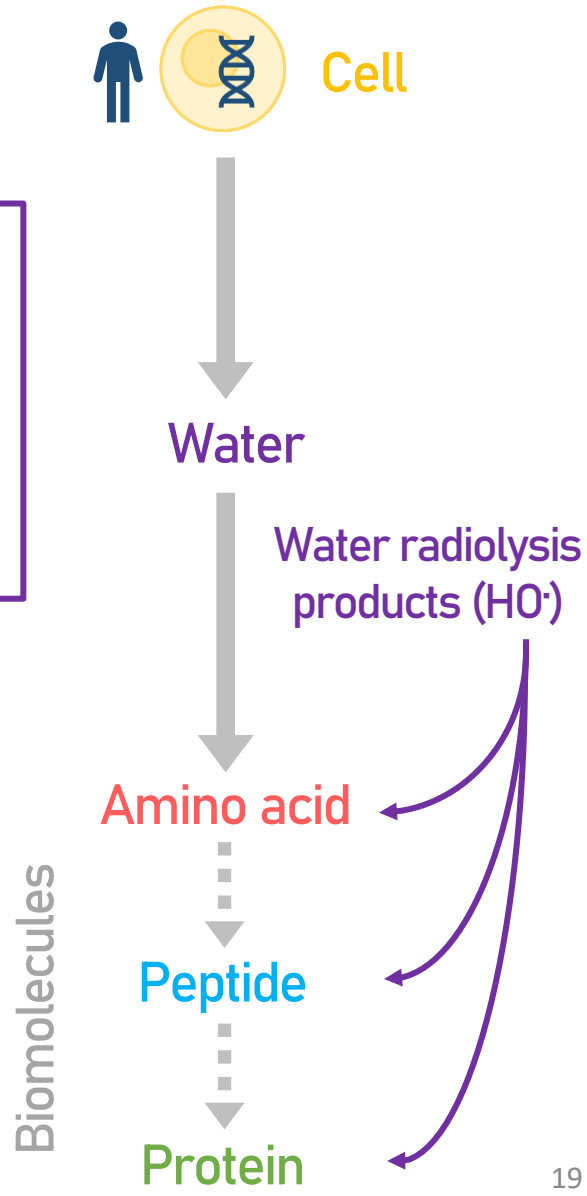
→ Similar impact of **fragmentation** on both water radiolysis species

Conclusion and Perspectives

Chemical impact of ^{12}C ion beam fragmentation on the radiolysis of water

- **Fragmentation** → measurable effect on radiolysis of water ($HO^{\bullet}$ and H_2O_2)
- Steady increase with ions fragmentation for both species

  ↗ fragmentation → N(species)/ion ↗ beyond Bragg peak
- **1st experiments** of this type



- Deepening the study on **fragmentation**

  → Nature of fragments and impact on water radiolysis
- Precise determination of radiolytic yields G
- **Radiolysis of biomolecules**

Thank you for your attention

Acknowledgments

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