Nuclear data for particle therapy and spatial radioprotection

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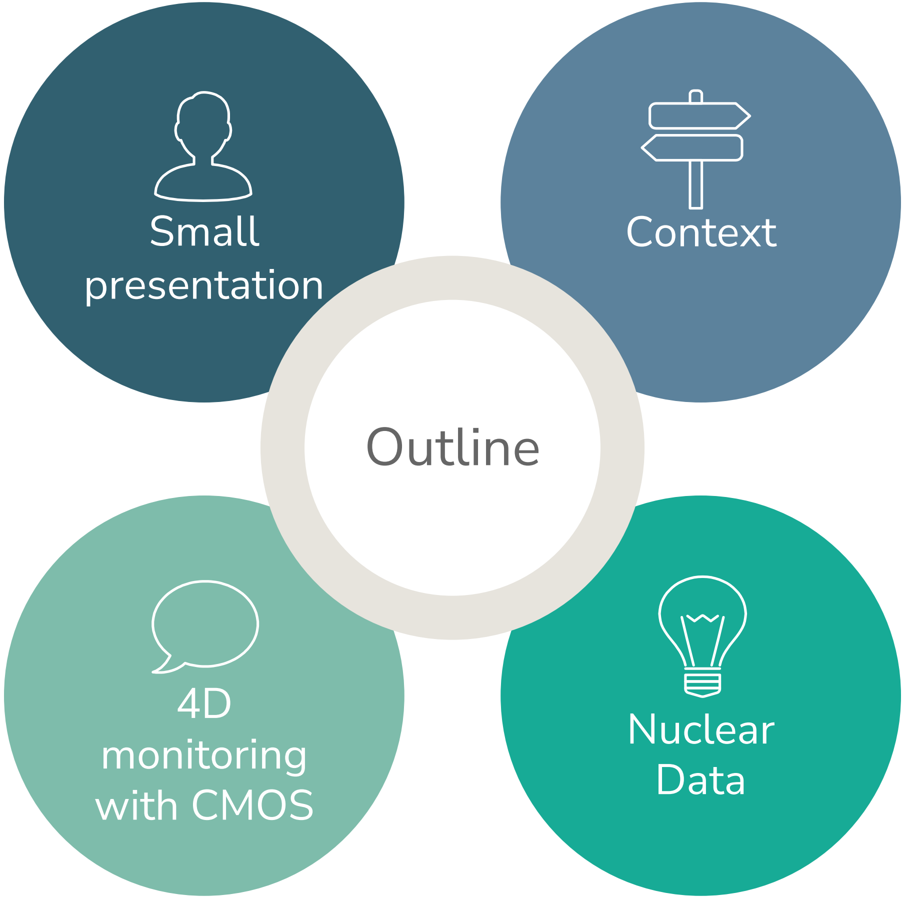
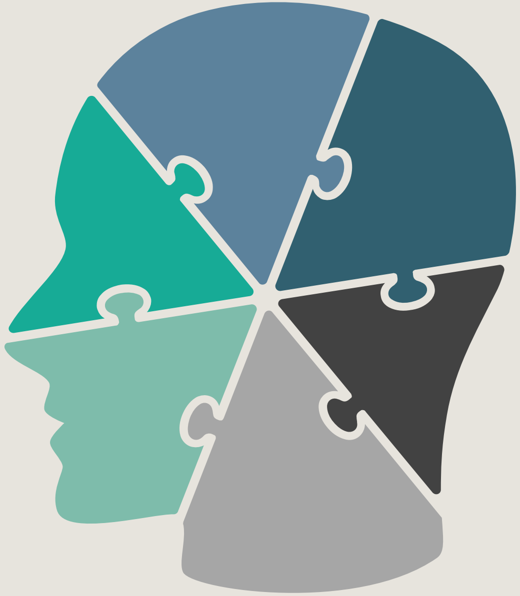

Small presentation
Context
Outline
4D monitoring with CMOS
Nuclear Data

1.

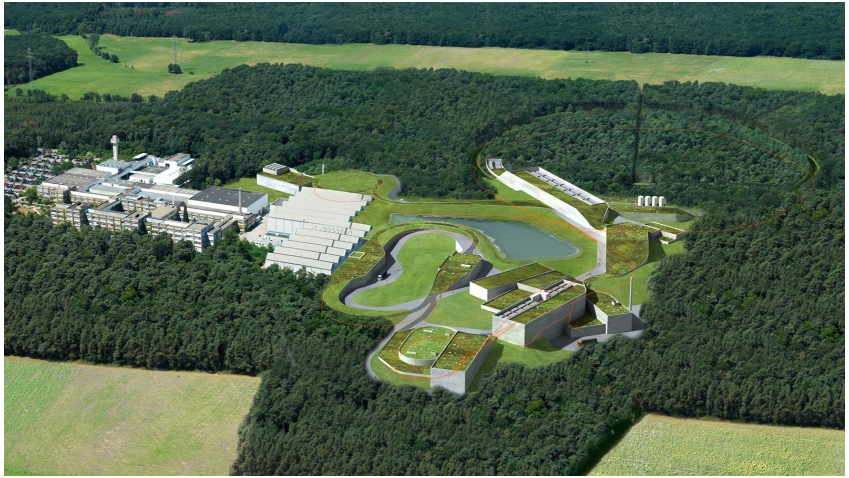
Small presentation



Small presentation

- Second year PhD student in nuclear physics for medical and space radioprotection applications

- Working in collaboration between IPHC in Strasbourg and GSI in Darmstadt in Germany



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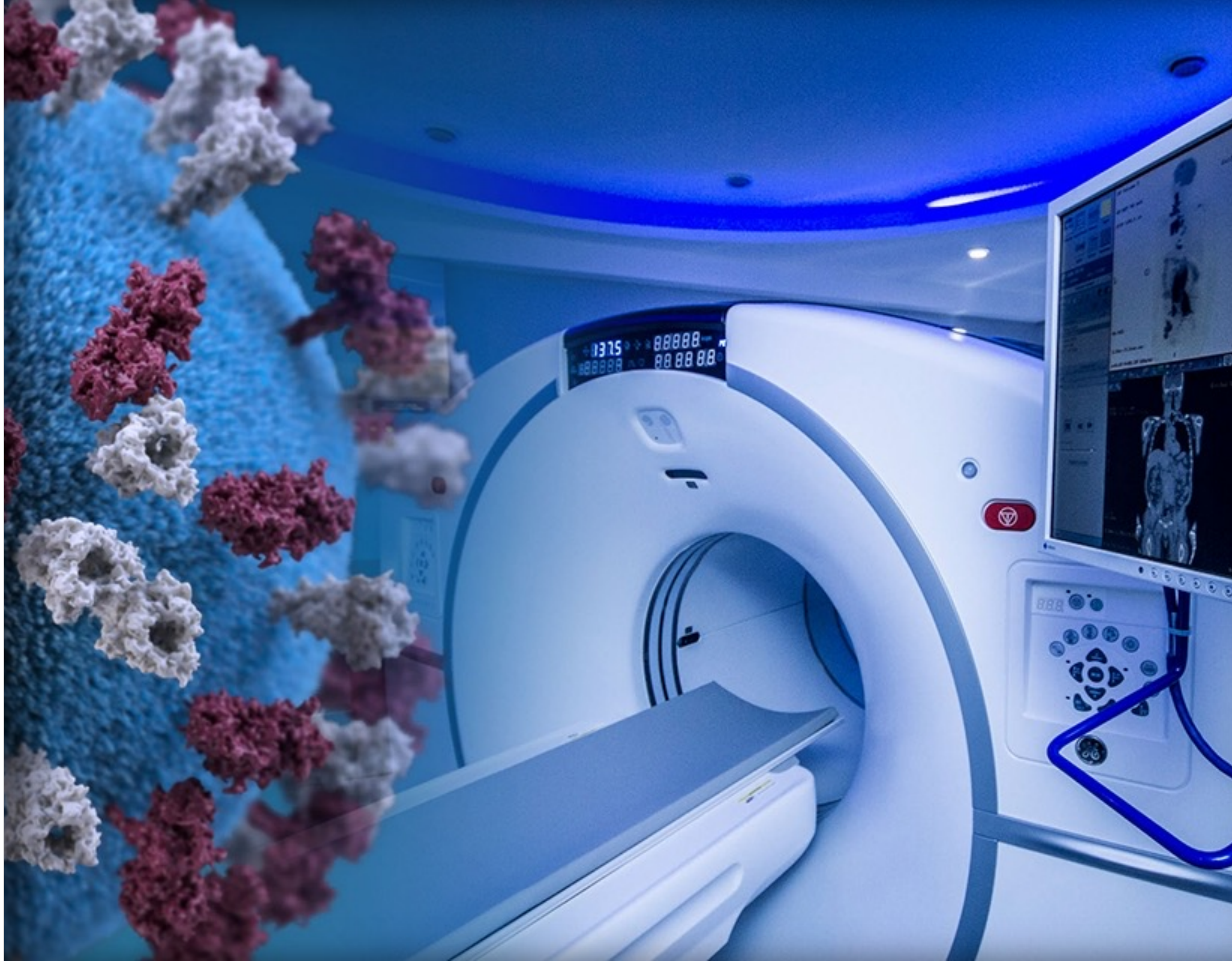
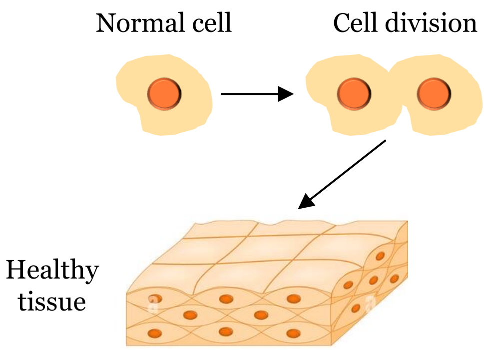
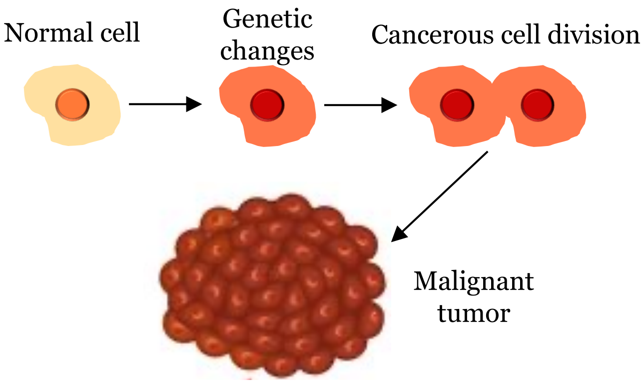
Context :
Cancer and particle therapy



What is cancer ?

- Cancer can start in any cell of the body
- Cancer cells come from genetic mutations
- Cancer exist in many different forms
- Grow out of control or not die when it should
- Cancer cells divide and eventually form a tumor which will grow





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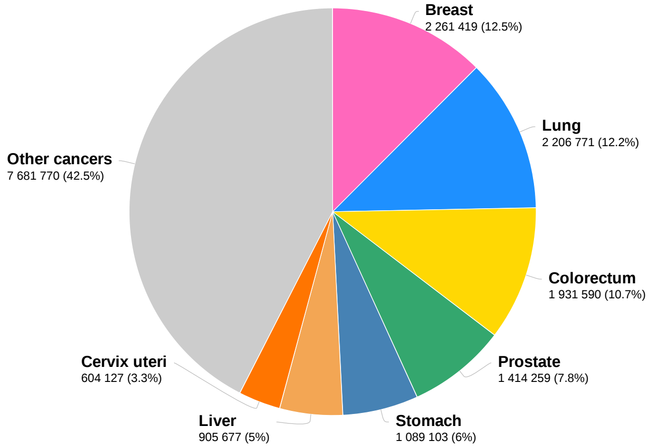
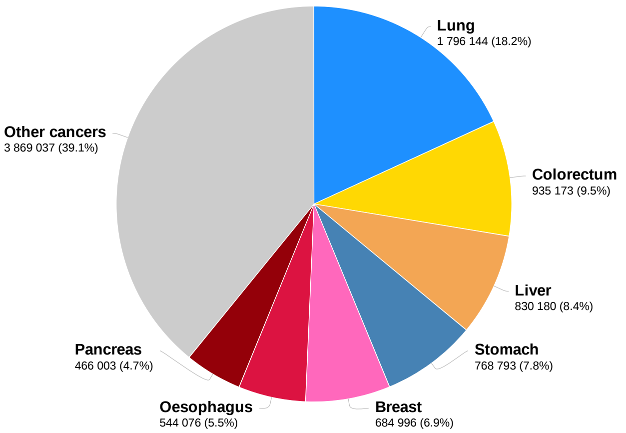
Context

Informations about cancer

First cause of death in Europe and North America





Data source: Globocan 2020
Graph production: Global Cancer Observatory (http://gco.iarc.fr)

International Agency for Research on Cancer
World Health Organization

Most common treatments :

- Surgery
- Chemotherapy
- Radiotherapy → Ion beam therapy

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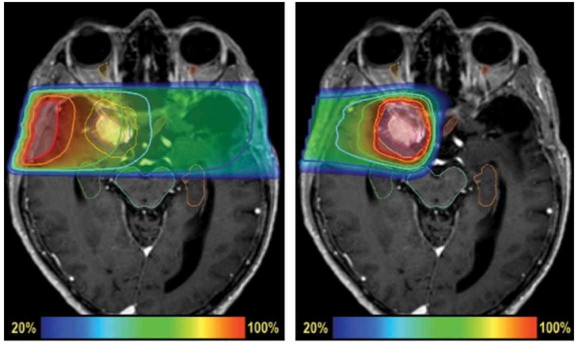
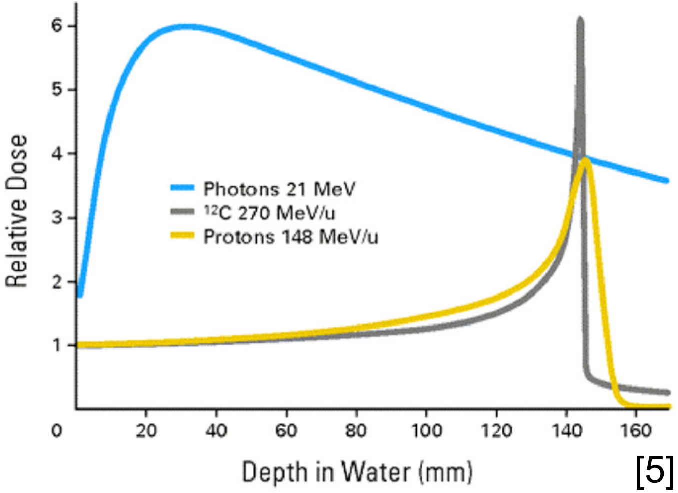
Radiotherapy



X-ray (traditional) radiation beam
Proton radiation beam

Example of dose differences between X-rays therapy and carbon ion-beam therapy



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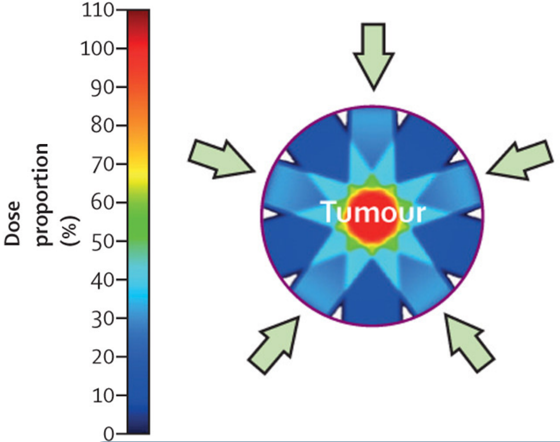
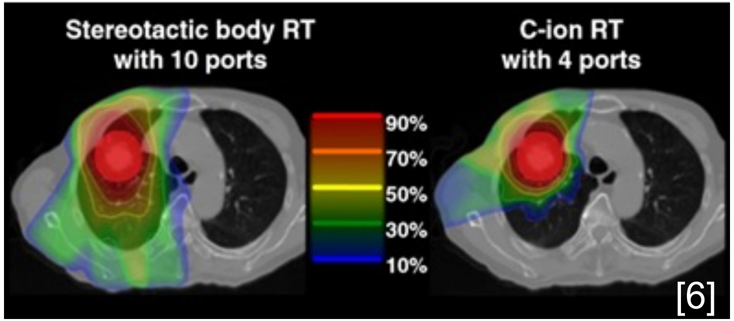


Beam treatment in multiple direction to lessen the dose deposition in healthy tissues



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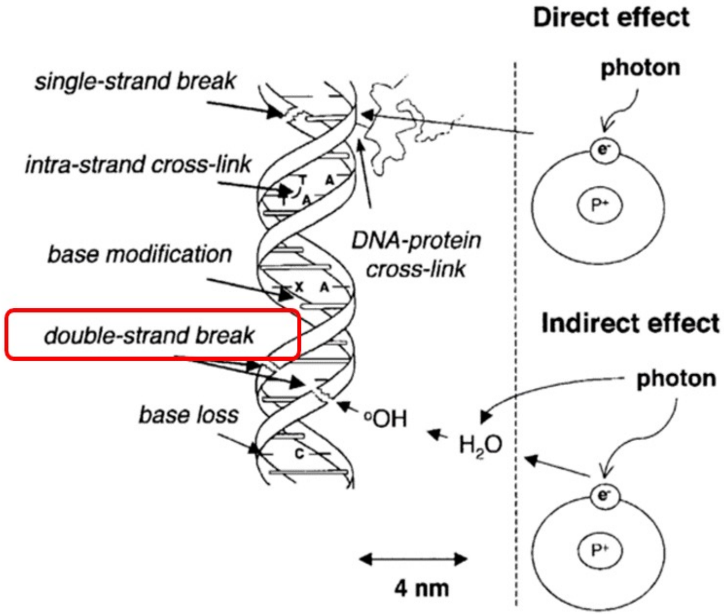
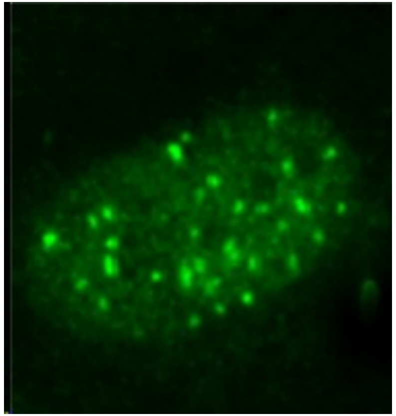
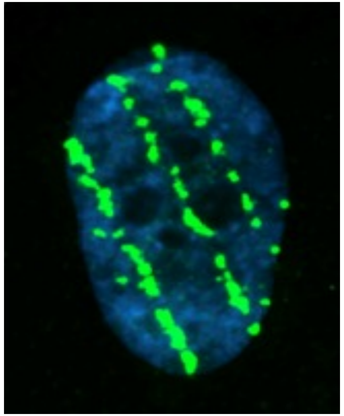
What happens in cells ?



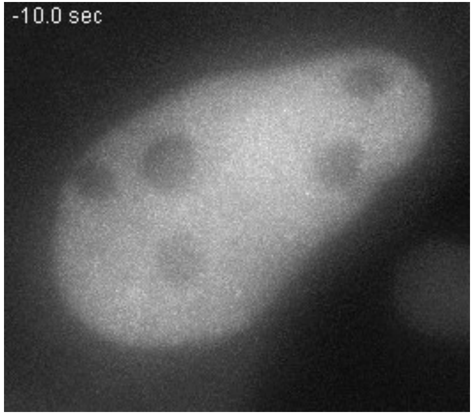


X-rays



Iron

[3]



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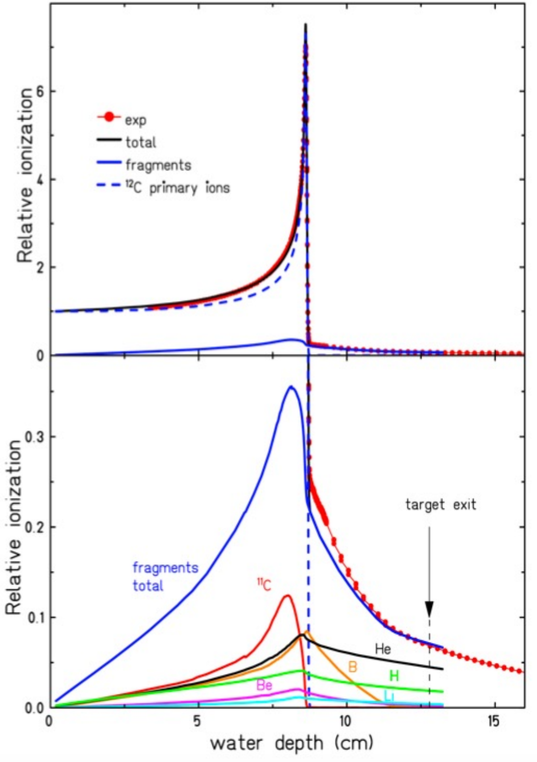
How ions beam interact ?

- Ionisations and Nuclear reactions



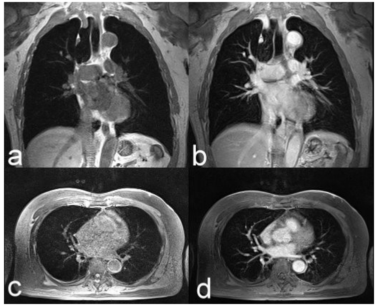
From **Gunzert-Marx et al.**, *"Secondary beam fragments produced by 200 MeV/u 12C ions in water and their dose contributions in carbon ion radiotherapy"*, New J. Phys. (2008).

- Secondary particles used for online control
- Online monitoring : to determine Bragg peak position during irradiation to permit TPS correction if needed
- Most used : Prompt γ and protons

Treatment plan

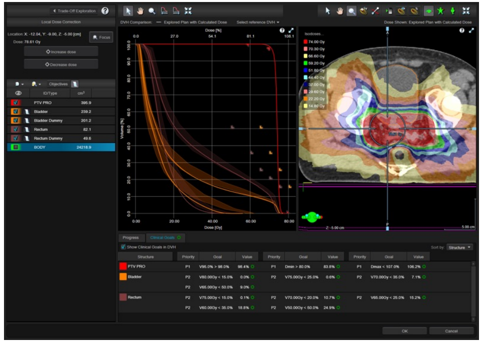
Imaging

Define tumoral/targeted volume



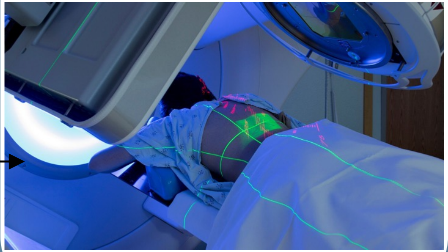
[17]

Treatment planning System (TPS)



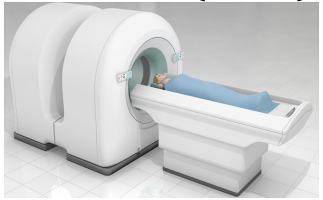
[16]

Treatment



[18]

Irradiation Control (PET)



Corrections

Comparison between delivered dose and planned one

Margins

Uncertainties

Physical dose calculation

Physical processes

Biological processes

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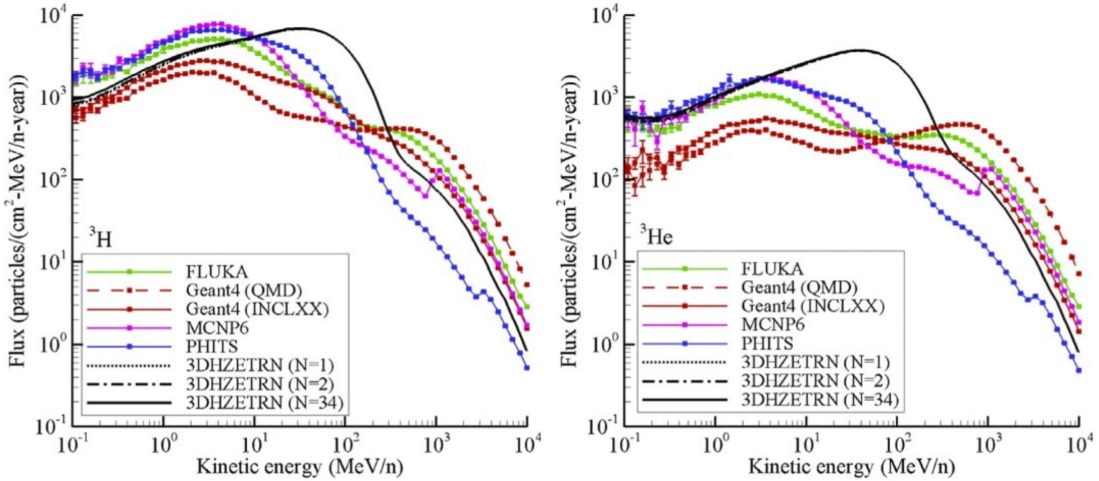
Physics simulation code



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- Simulation codes do not agree together
- Data does not agree with simulations

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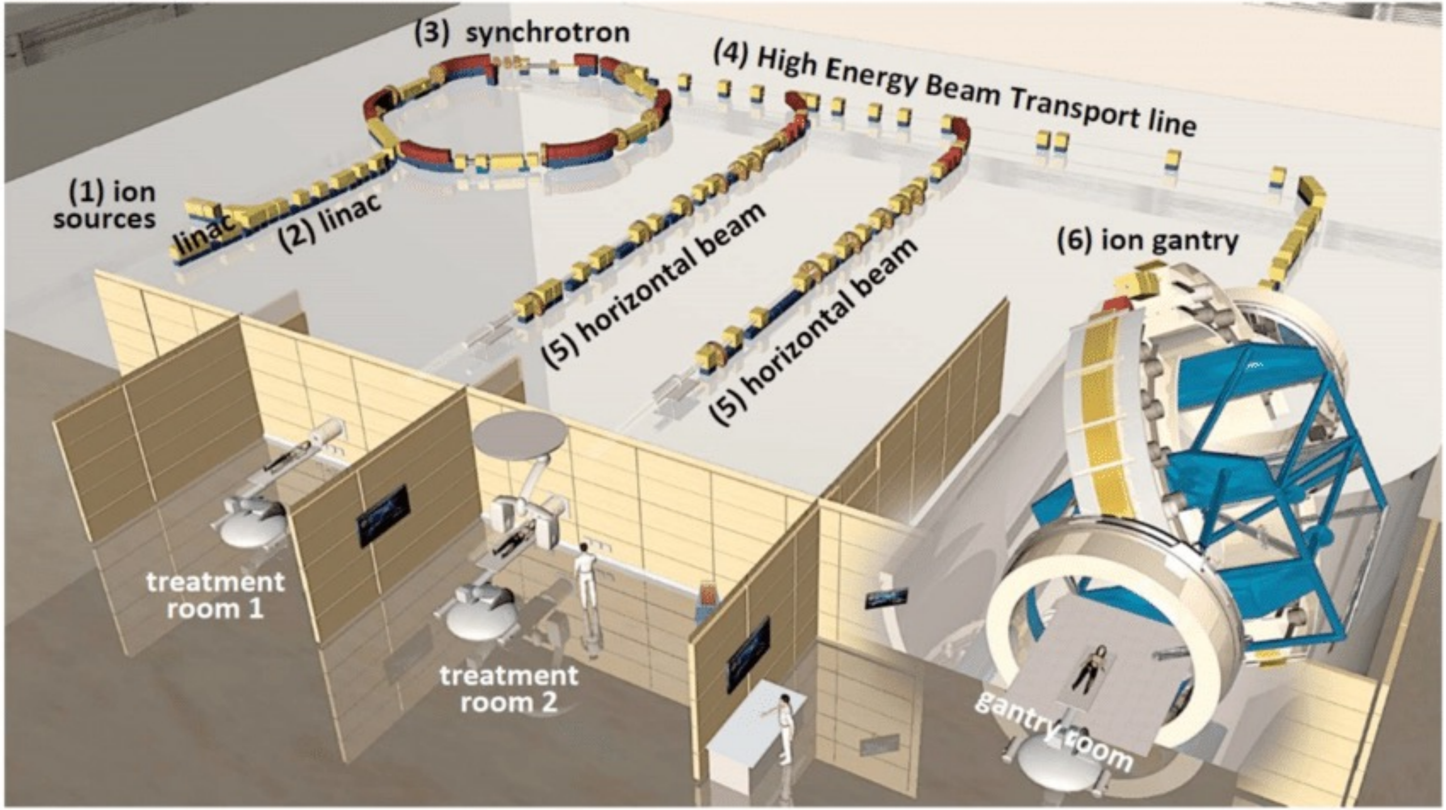
Clinical center (HIT, Heidelberg)



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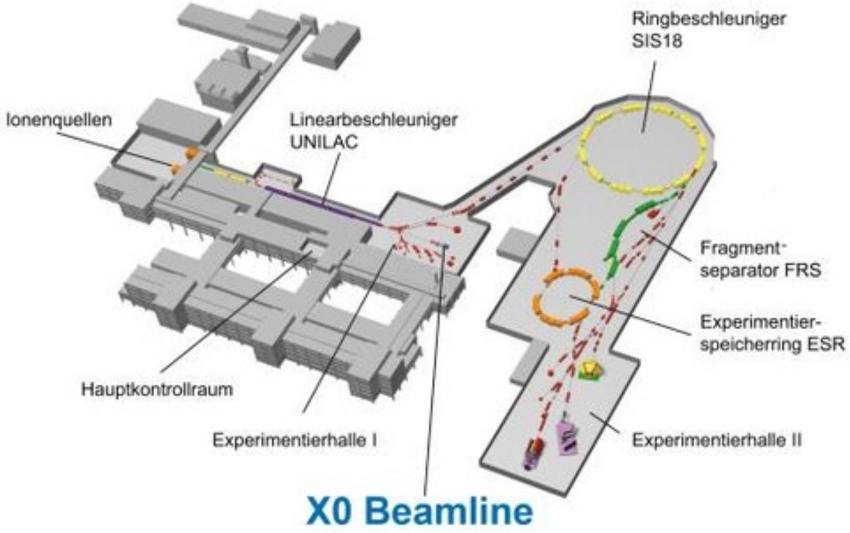
Context

Ion accelerator (GSI, Darmstadt)



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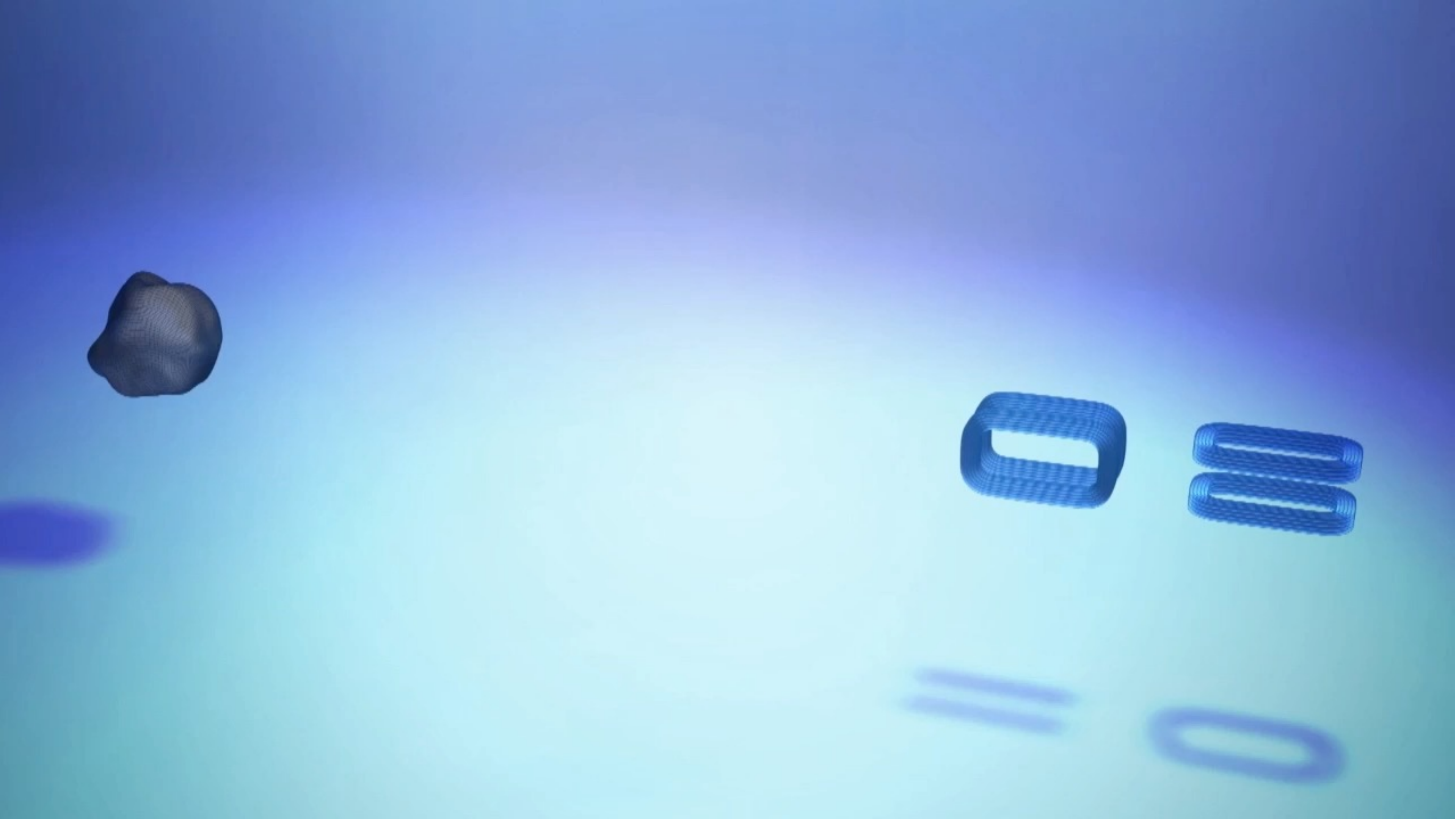
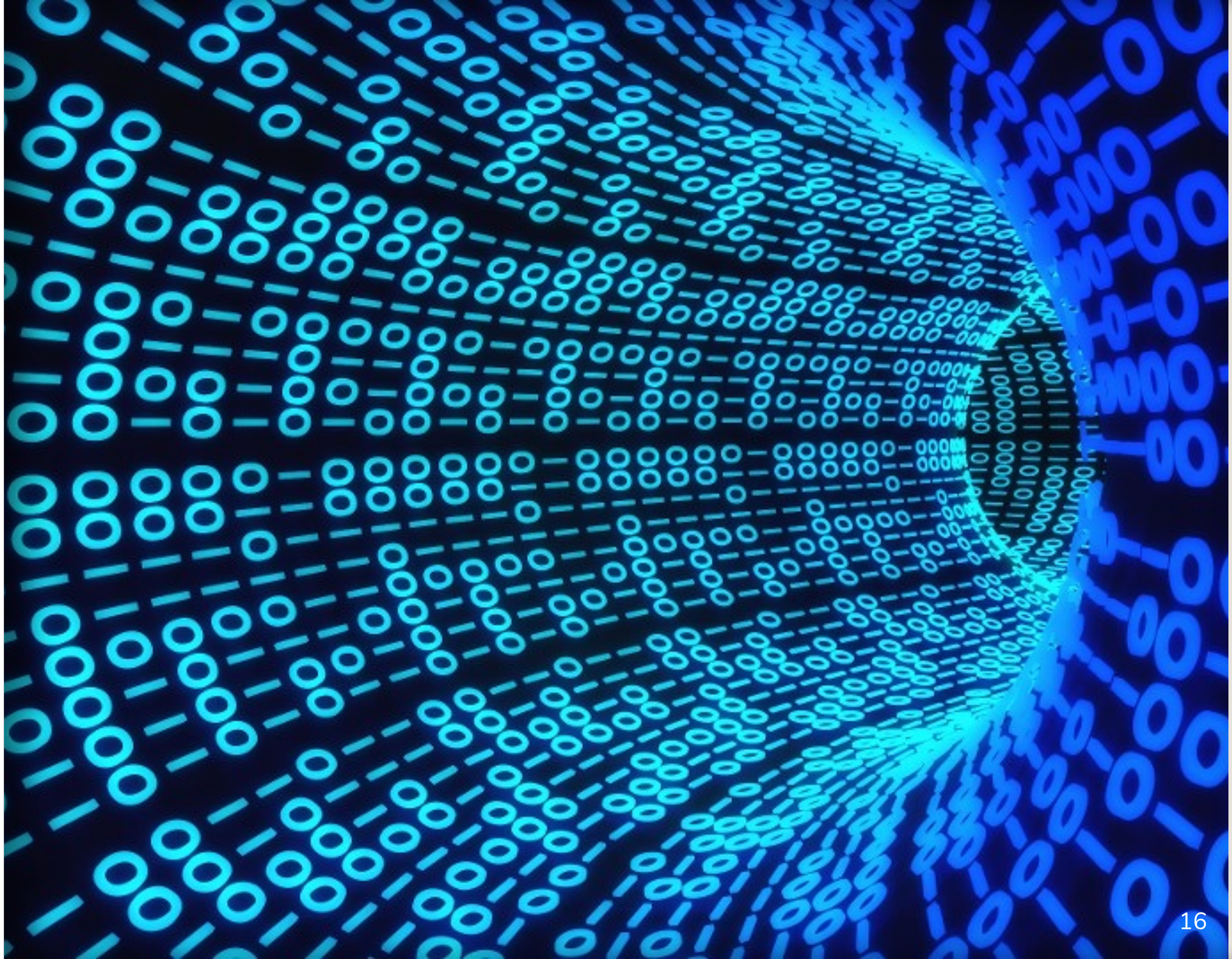


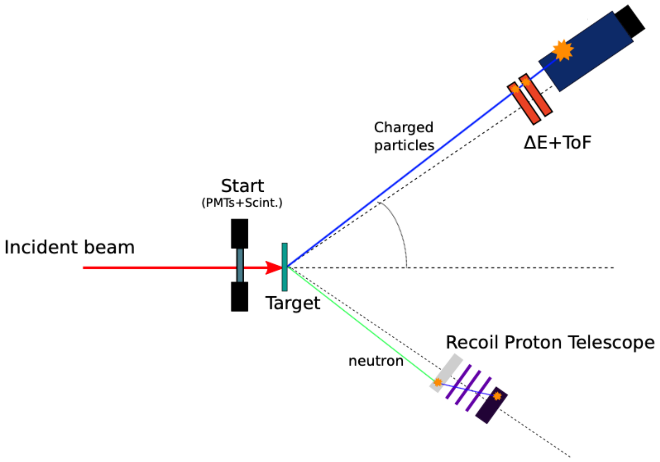
3.

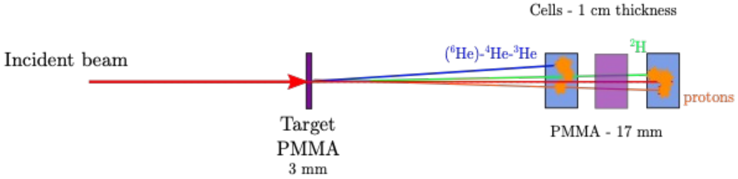
Nuclear Data

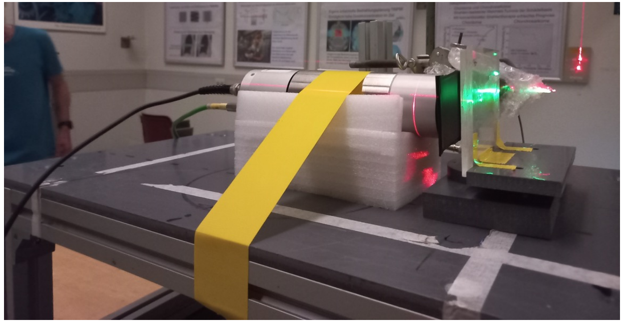


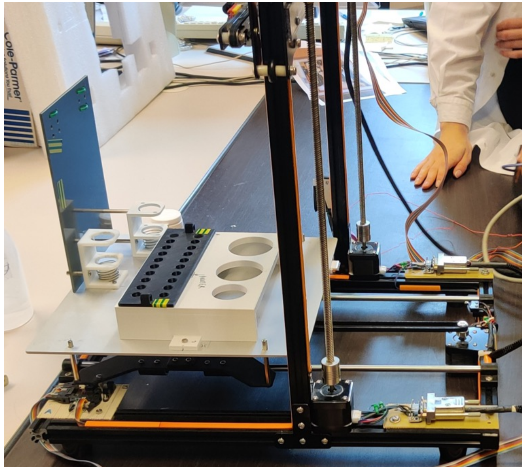
CLINM project

- Combine measurement of secondary particles and radiolyse effectiveness









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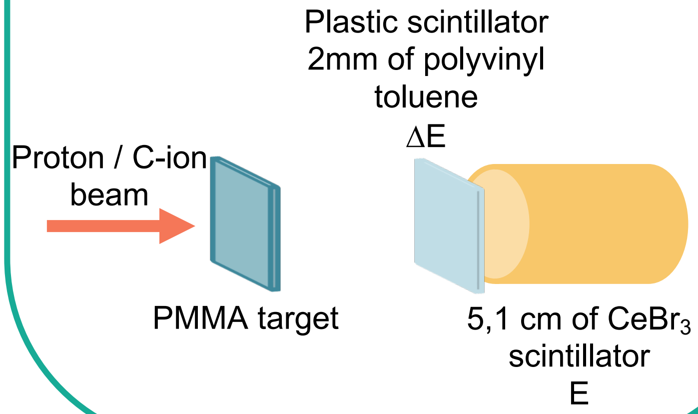
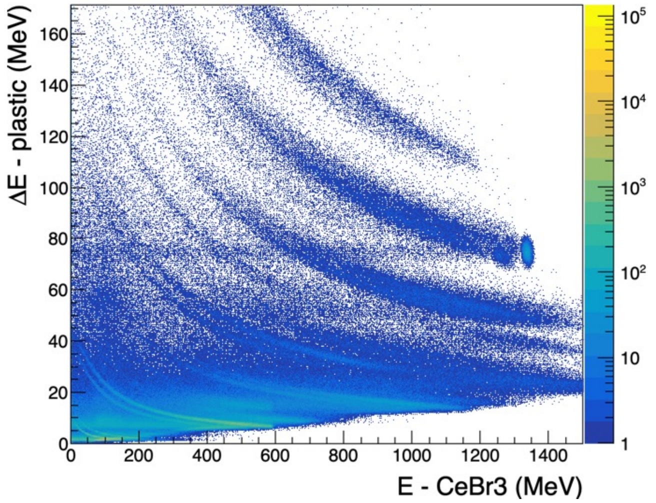
Secondary particle qualitative/quantitative characterization

ΔE-E method :

Secondary particles depose energy in a plastic detector (ΔE), then in a $CeBr_3$ detector where they stop (E).



ΔE-E method :



ΔE-E results from simulation with a carbon-ion beam of 200MeV, the detectors at 5° from the beam axis, and a PMMA target of 4 cm

Work done by M. Vanstalle

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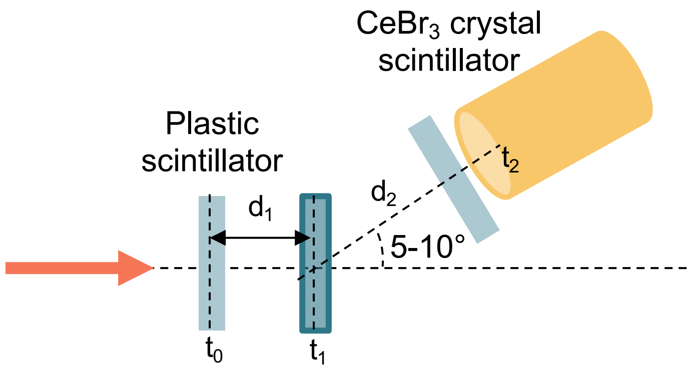
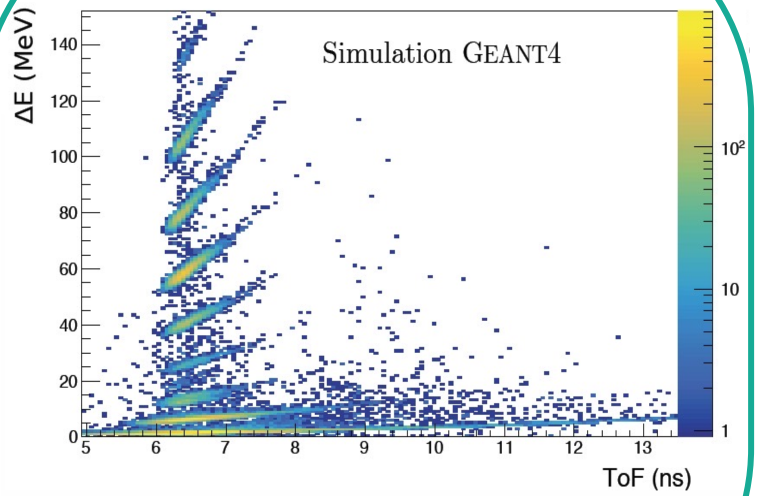
Secondary particle qualitative/quantitative characterization

Time of flight method :

Measurement of the time the secondary particles take to go from the target to the detector



Time of flight method :



TOF results from simulation with a carbon-ion beam of 200MeV, the detectors at 5° from the beam axis, and a PMMA target of 4 cm

Source : A.Secher, PhD thesis

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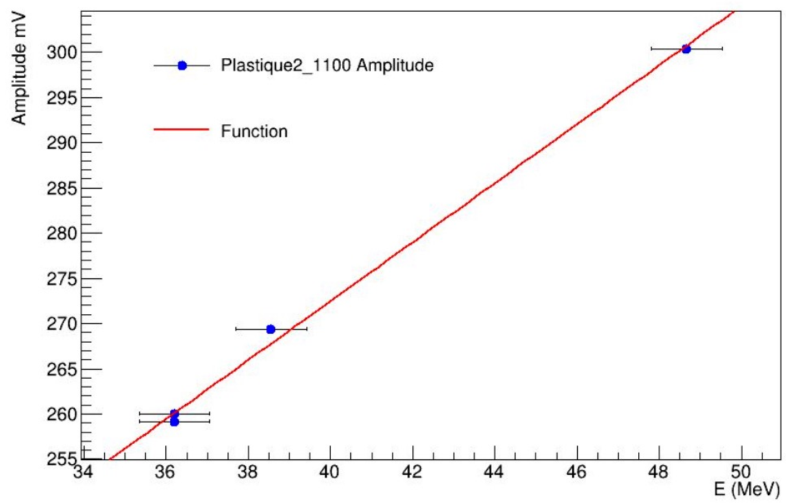
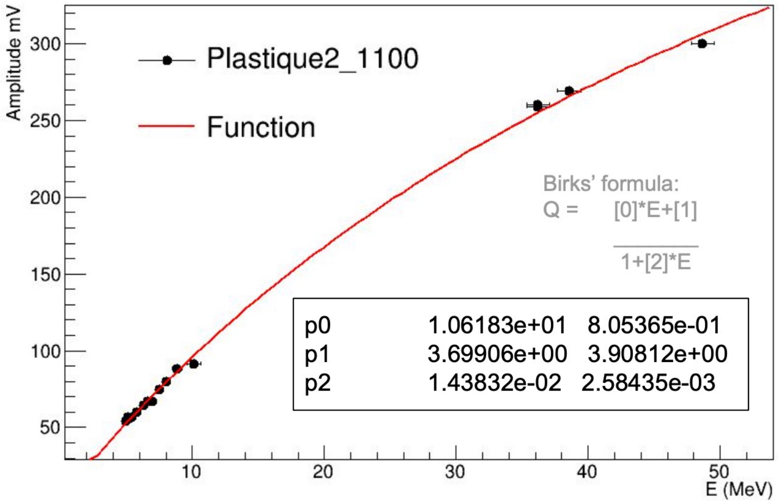
Calibration in amplitude for plastic scintillator

Carbon-ion beam



Carbon-ion + proton beam



Work done with C.Mozzi and J.Gross during their internship

Tension applied : -1100V

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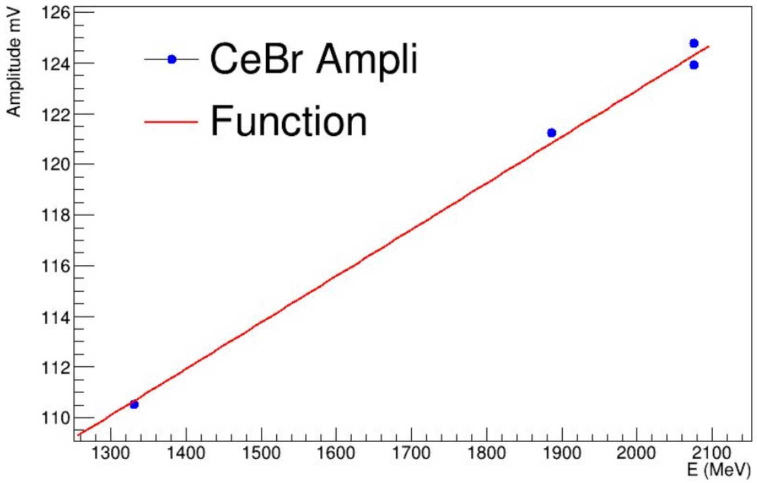
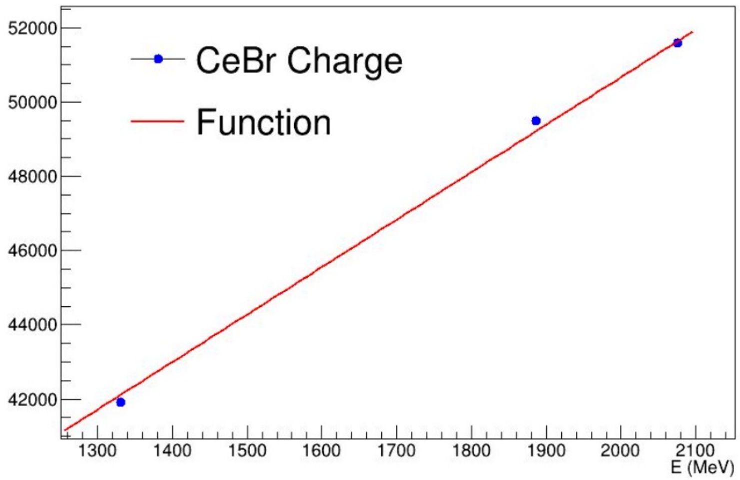
Nuclear data

Calibration $CeBr_3$ scintillator with carbon-ion beam

Amplitude



Charge



Work done with C.Mozzi and J.Gross during their internship

Tension applied : +350V

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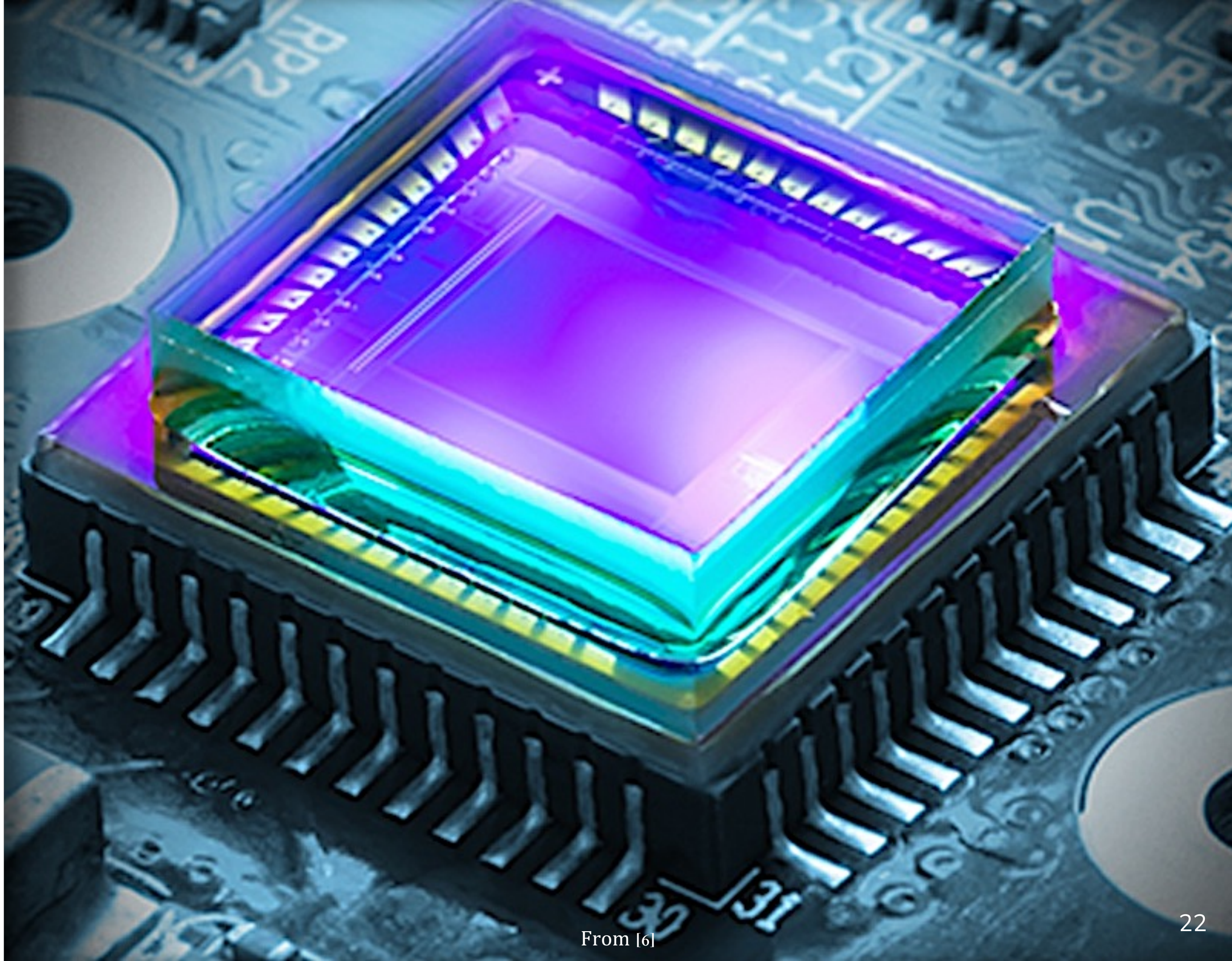
4.

4D monitoring with CMOS



From [6]

4D monitoring with CMOS

Motivations

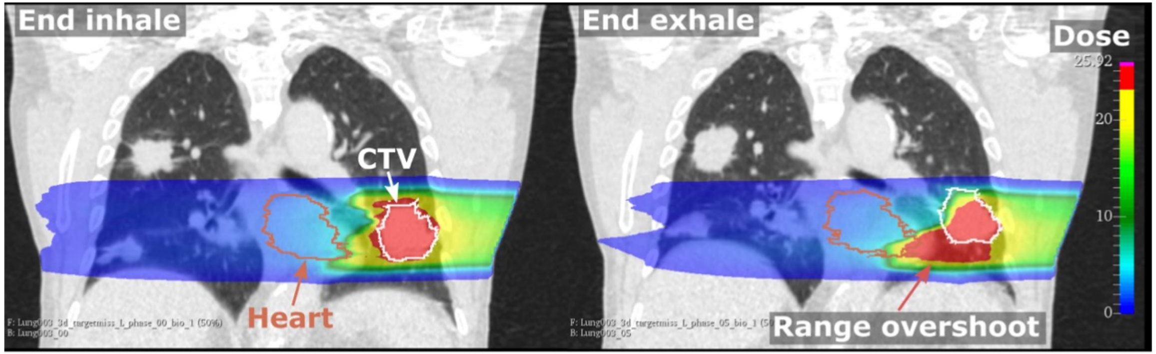
Respiratory motion

Density gradient between tumor, lung tissue and bones

→ Under or overdosage

Increase the dose exposure to the heart

→ **Need to monitor the dose**



[7]

Dose distribution of heavy ions for lung tumor treatment planned at the end of inhale.

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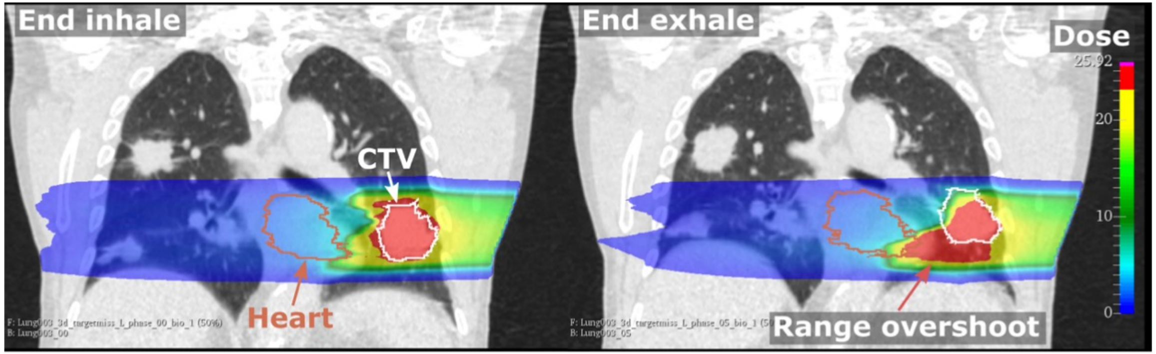
Motivations

Need to monitor the dose → Use of the density gradient between lung and tumor →

- Induce differences in secondary particle production
- More secondary particle if the beam touch the tumor than the lung

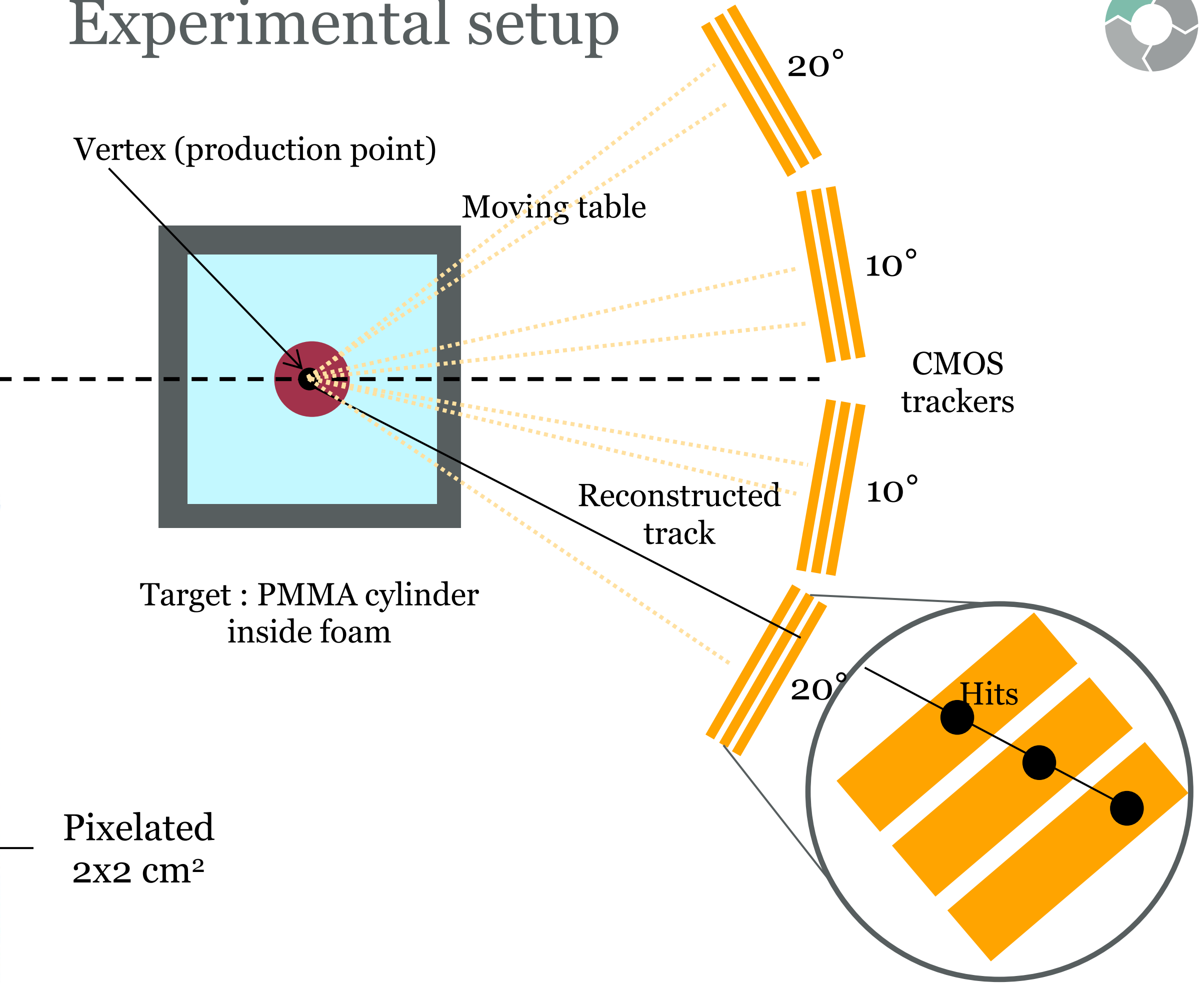


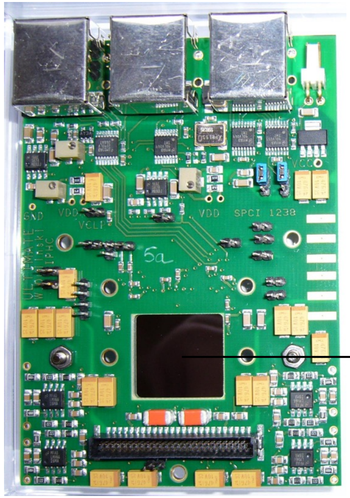
Dose distribution of heavy ions for lung tumor treatment planned at the end of inhale.

[7]

4D monitoring with CMOS

Experimental setup





CMOS Mimosa-28

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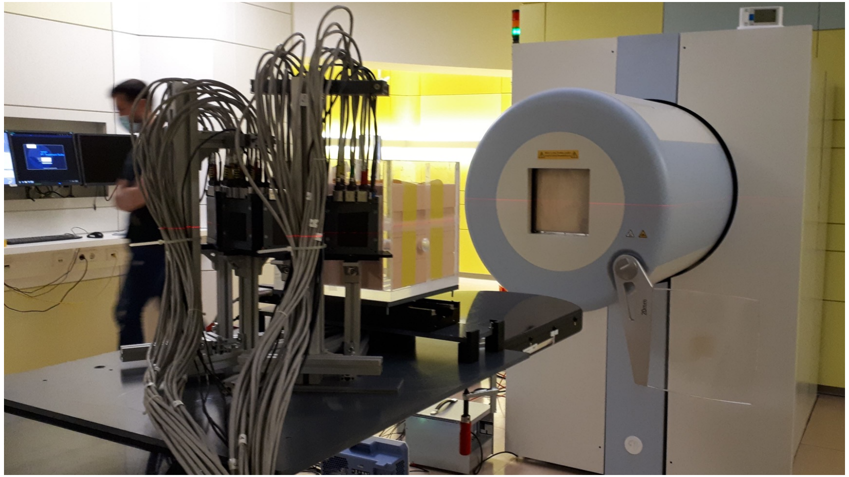
4D monitoring with CMOS

Experiment in MIT



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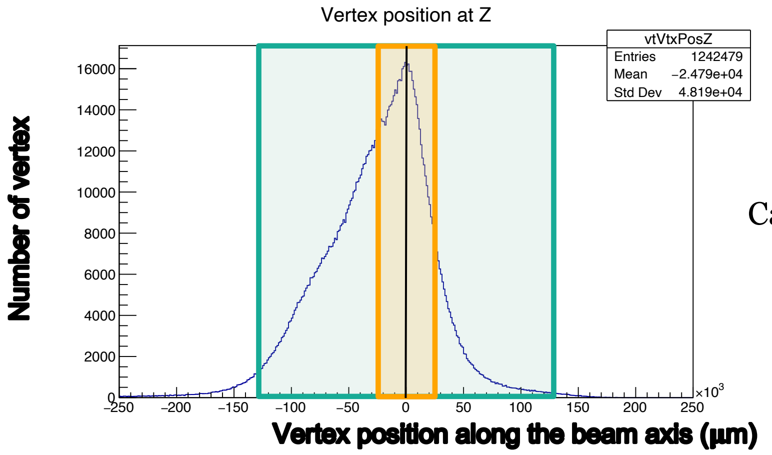
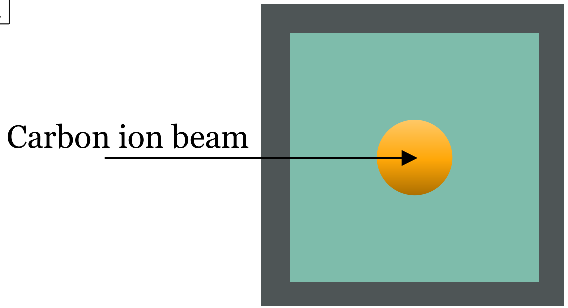
4D monitoring with CMOS

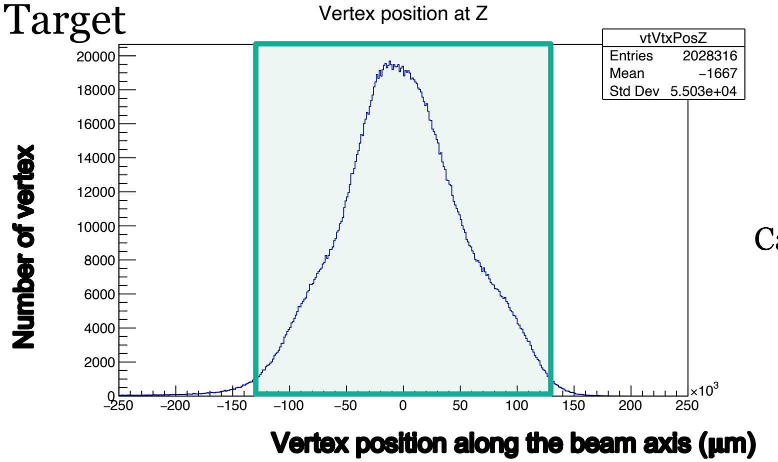
Preliminary results

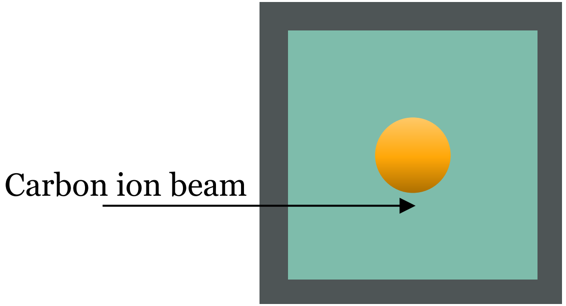




Foam

PPMA Target





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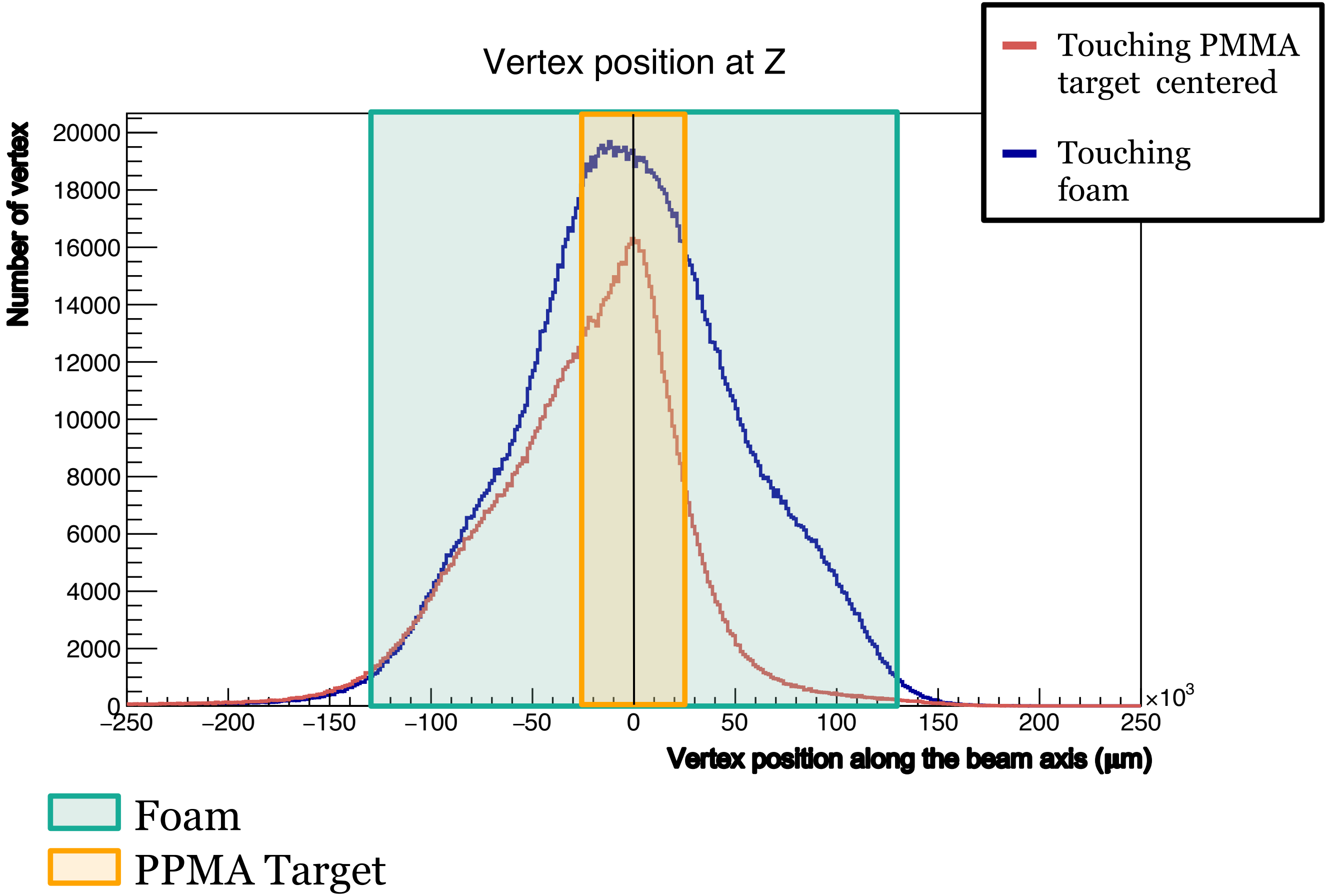
Preliminary results



4D monitoring with CMOS

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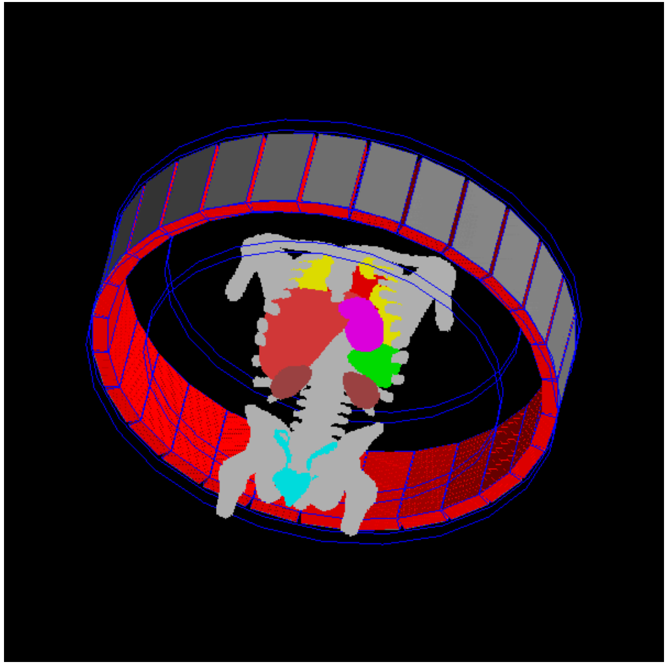
4D monitoring with CMOS

To clinical application

- **GATE** → advanced opensource software for numerical simulations in medical imaging an radiotherapy
  → based on Geant4
- Simulate on a human phantom
- Create a device based on CMOS monitoring usable in clinic



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Conclusion

Particle therapy : Secondy particles produced by the beam fragmentation and the interaction between the beam and the patient

Need to understand dose contribution of those secondary particles

Dev. of a beam time monitoring during lung cancer treatment with CMOS detectors, usable in clinics

Nuclear data with ΔE-E and TOF method to characterize secondary particles production

Thank you for your attention

Uli Weber
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Daria Boscolo
Tim Wagner
Tabea Pfuhl
Marco Durante

Marie Vanstalle
Christian Finck
Nicolas Arbor
Stéphane Higueret
The-Duc Lê

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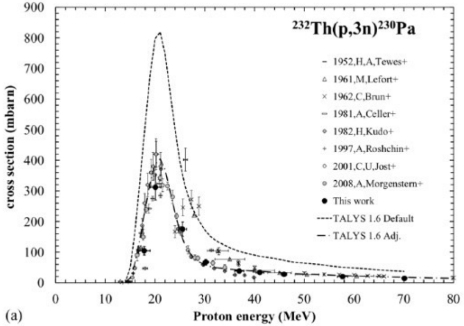
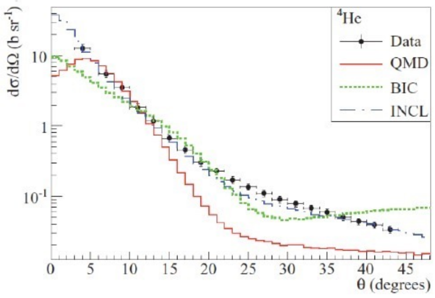
- [16] https://www.wienkav.at/kav/kfj/91033454/physik/eclipse/MCO.html
- [17] https://bmccancer.biomedcentral.com/articles/10.1186/1471-2407-11-242
- [18] https://www.everydayhealth.com/cancer/skin-cancer/how-radiation-therapy-helps-treat-metastatic-cutaneous-squamous-cell-carcinoma/

Back-up

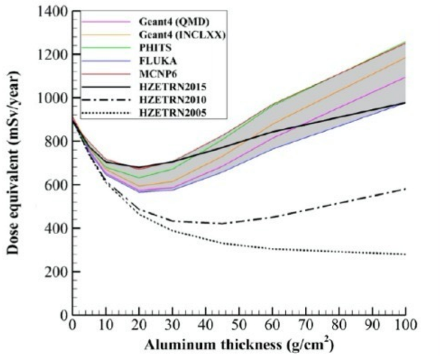


From **Duchemin et al.**, "*Production of medical isotopes from a thorium target irradiated by light charged particles up to 70 MeV*", Phys. Med. Biol. (2015).

Differential angular cross-sections of ^{12}C(^{12}C,^{4}He) reaction @ 95 MeV/n



From **Dudouet et al.**, "*Benchmarking Geant4 nuclear models for hadron therapy with 95 MeV/n carbon ions*", Phys. Rev. C (2014).



From **Norbury et al.**, "*Advances in space radiation physics and transport at NASA*", Life Sciences in Space Research (2019).

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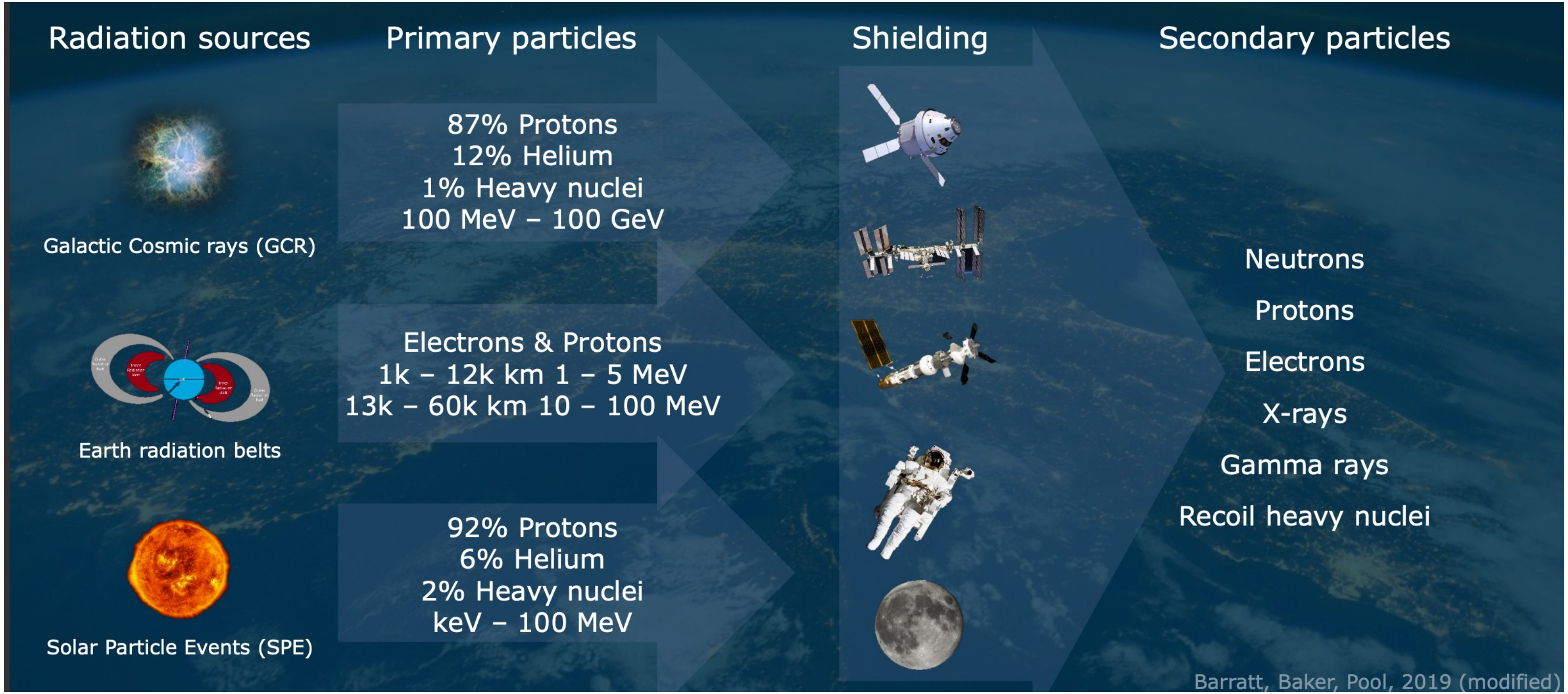
Radiation environment during space travel



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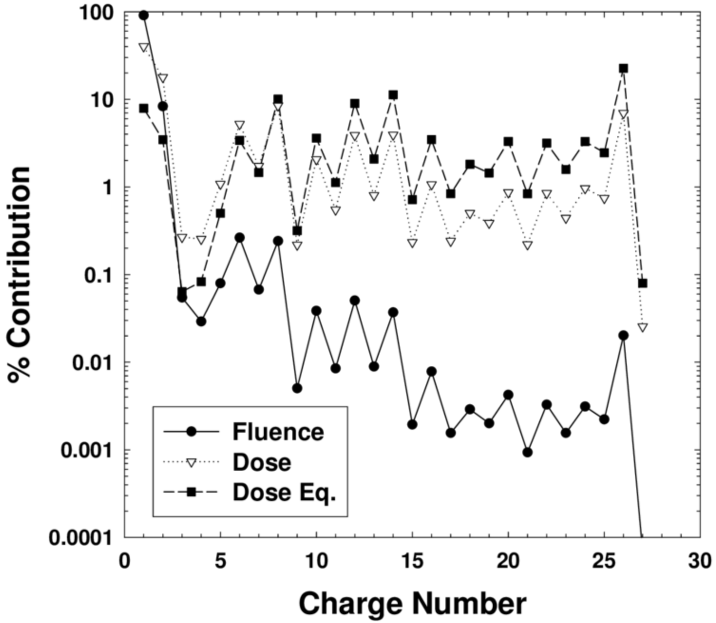
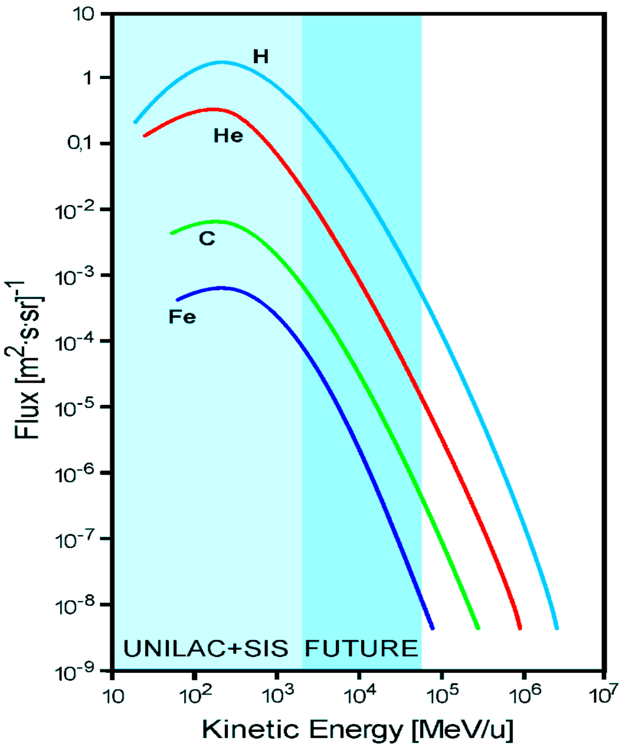
Heavy nuclei distribution in space





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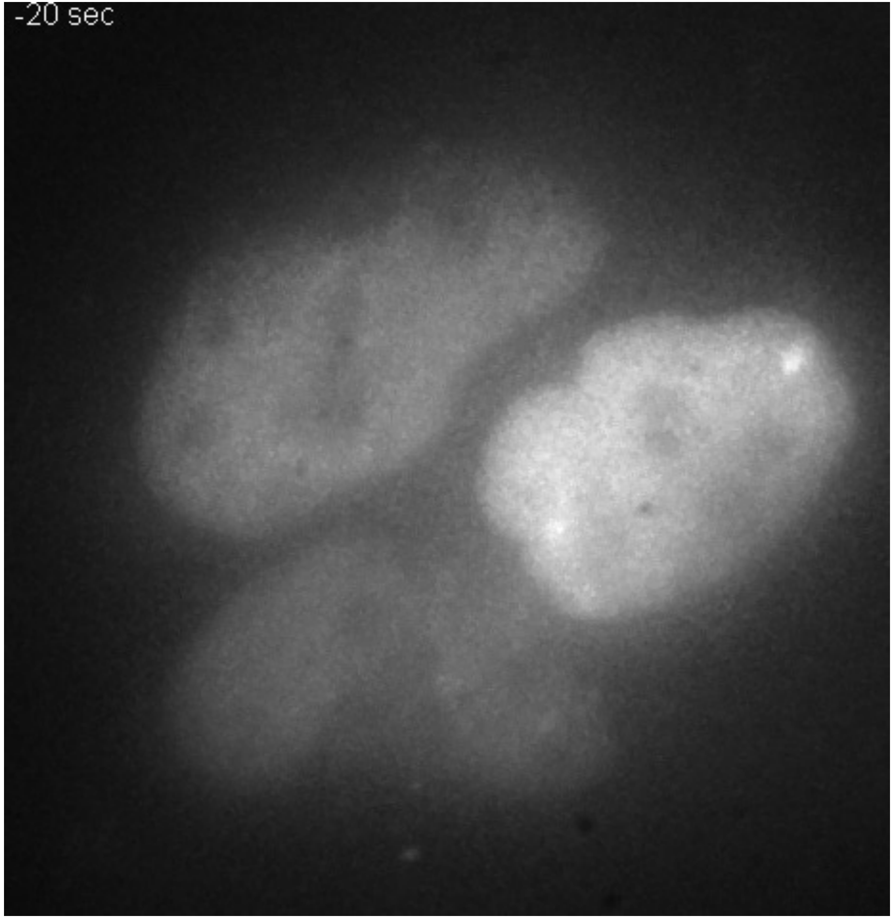
Cell damage



[4]

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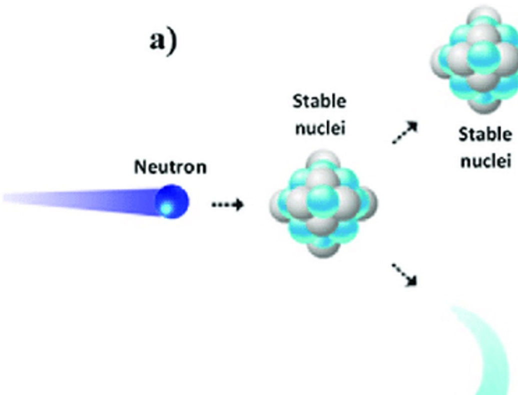
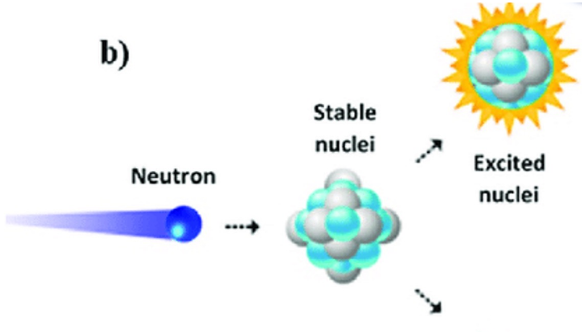
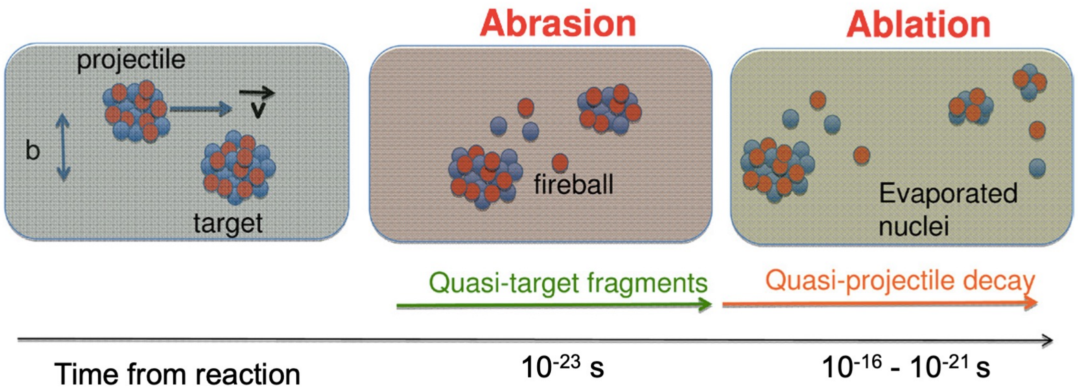
Nuclear interactions





a) Elastic scattering: Recoils nucleus, highest energy loss per collision for low-Z materials.

b) Inelastic scattering: Production of secondary radiation by nuclear de-excitation (n, γ, p, alpha, …), highest for high-Z materials.



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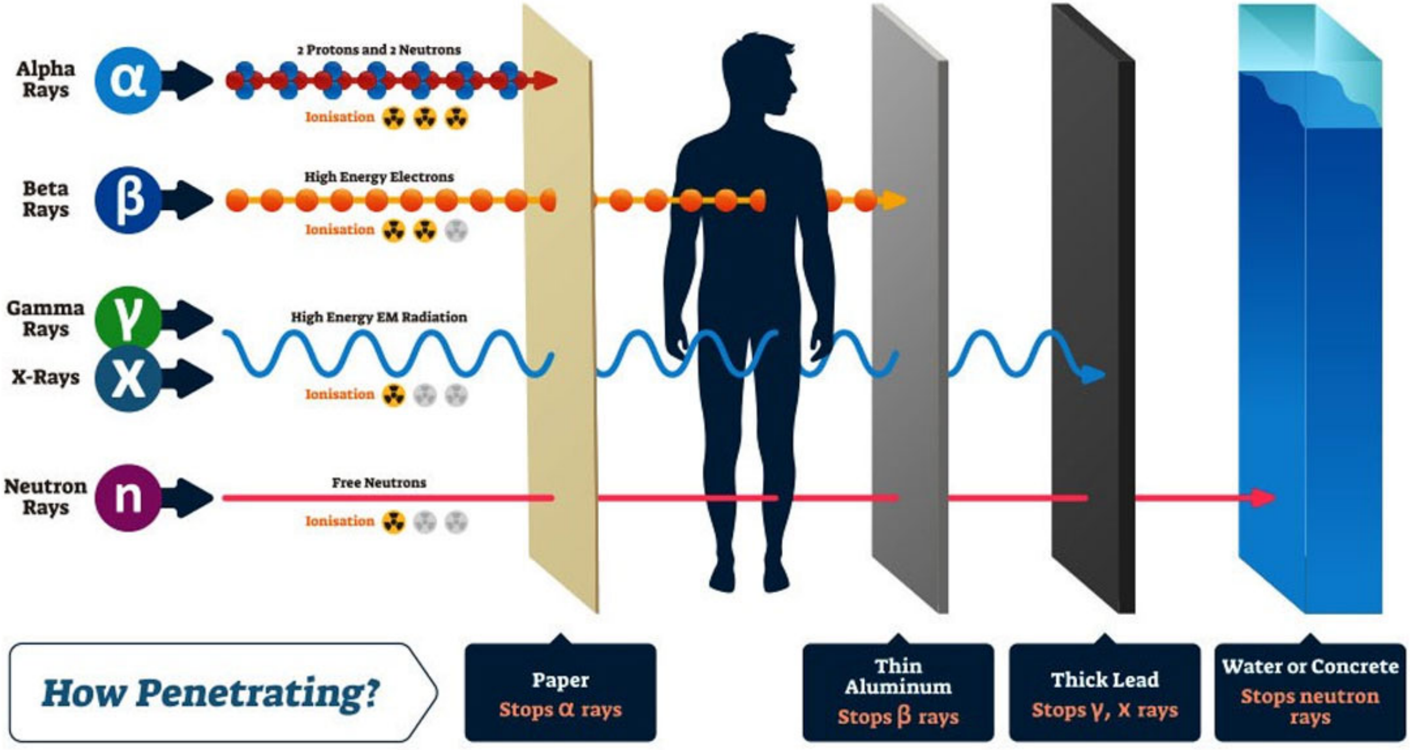
Radiations interactions with matter



[2]

[1]

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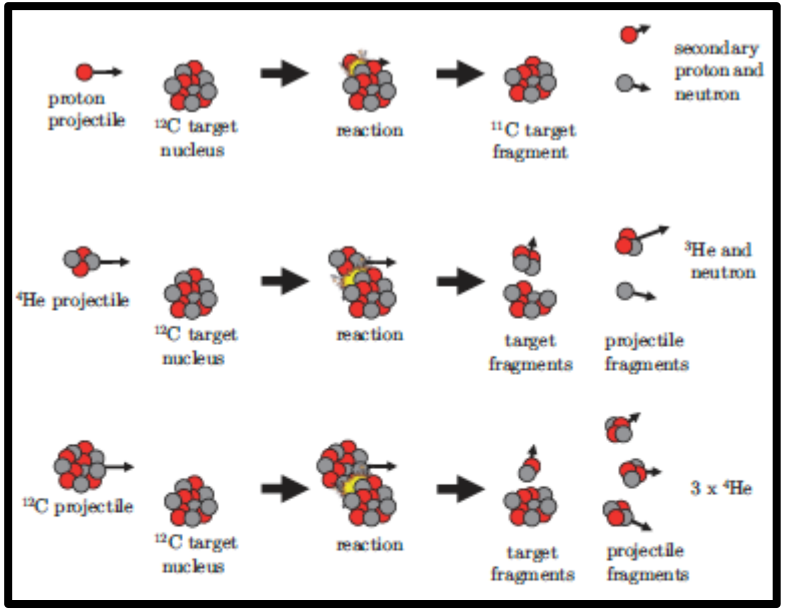
Nuclear interactions

Photons (only EM)
- Photoelectric effect
- Compton scattering
- Pair production

Charged particles (EM and strong*)
- Coulomb elastic or inelastic with e^- and nucleus
- Strong inelastic scattering with nuclei
- Fission/Fusion*

*only for ions

Neutrons (strong)
- Absorption/capture
- Elastic scattering
- Inelastic scattering



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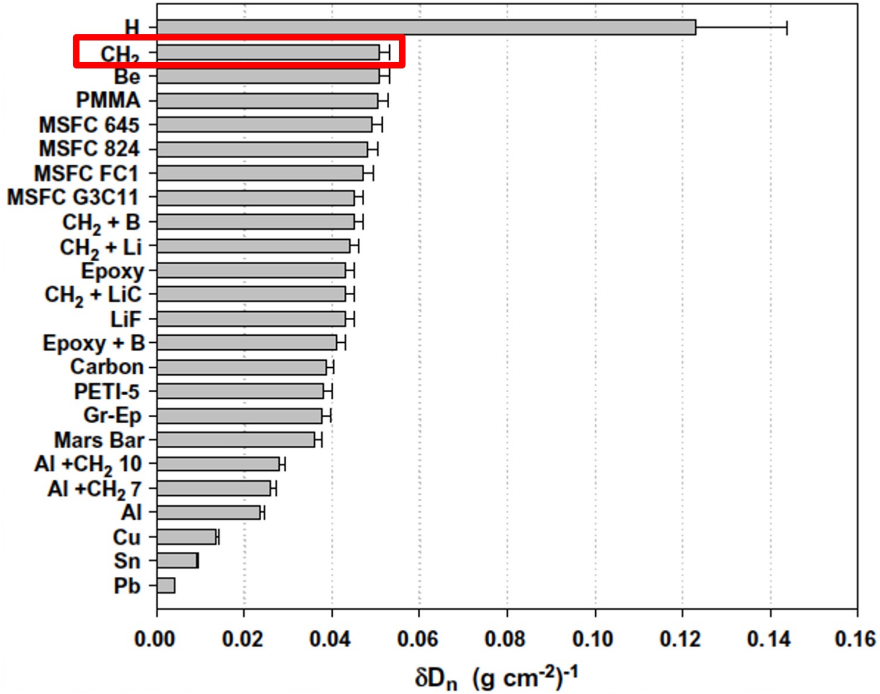
Context

Material effectiveness as shielding (1 GeV/u ^{56}Fe as proxy GCR)



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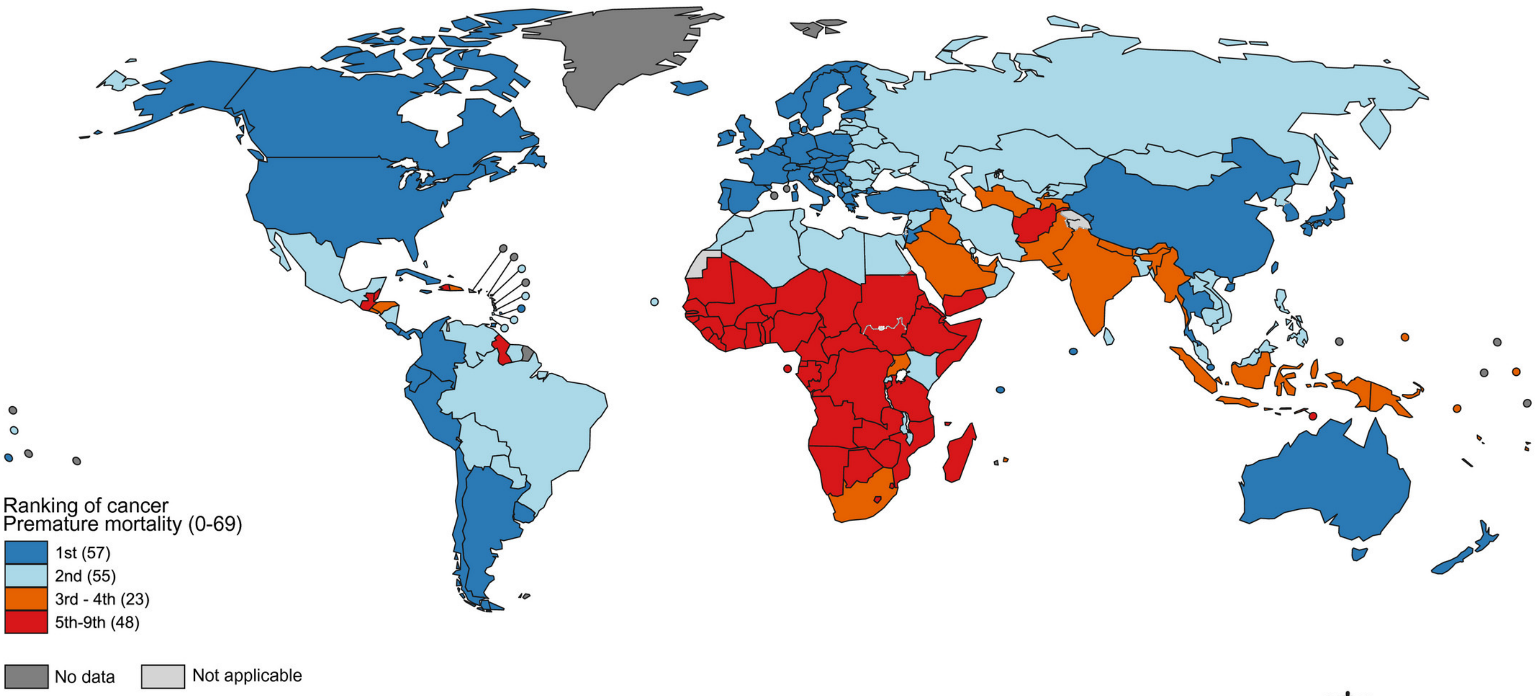
Statistics about cancer



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data source: GHE 2020
Map production: CSU
World Health Organization

World Health Organization

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Radiotherapy

From [8]

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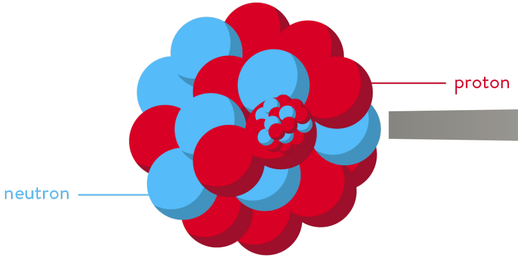
Ion beam therapy

Heavy ion beam

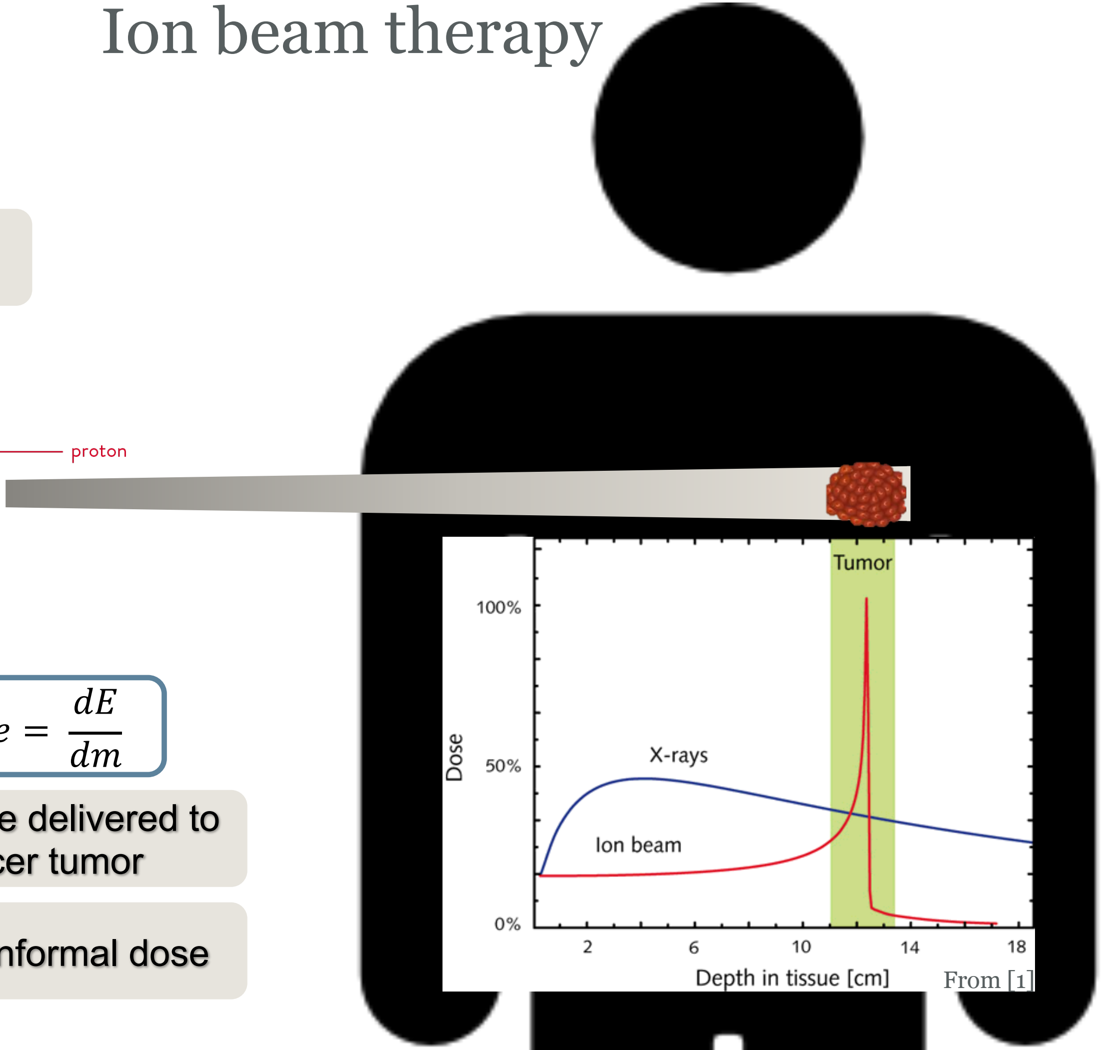
$^{12}C^{6+}$ ions



$$Dose = \frac{dE}{dm}$$

High dose delivered to cancer tumor

More conformal dose



From [1]

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From [3]

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Particle therapy in the world

2017 Nature Reviews | Clinical Oncology

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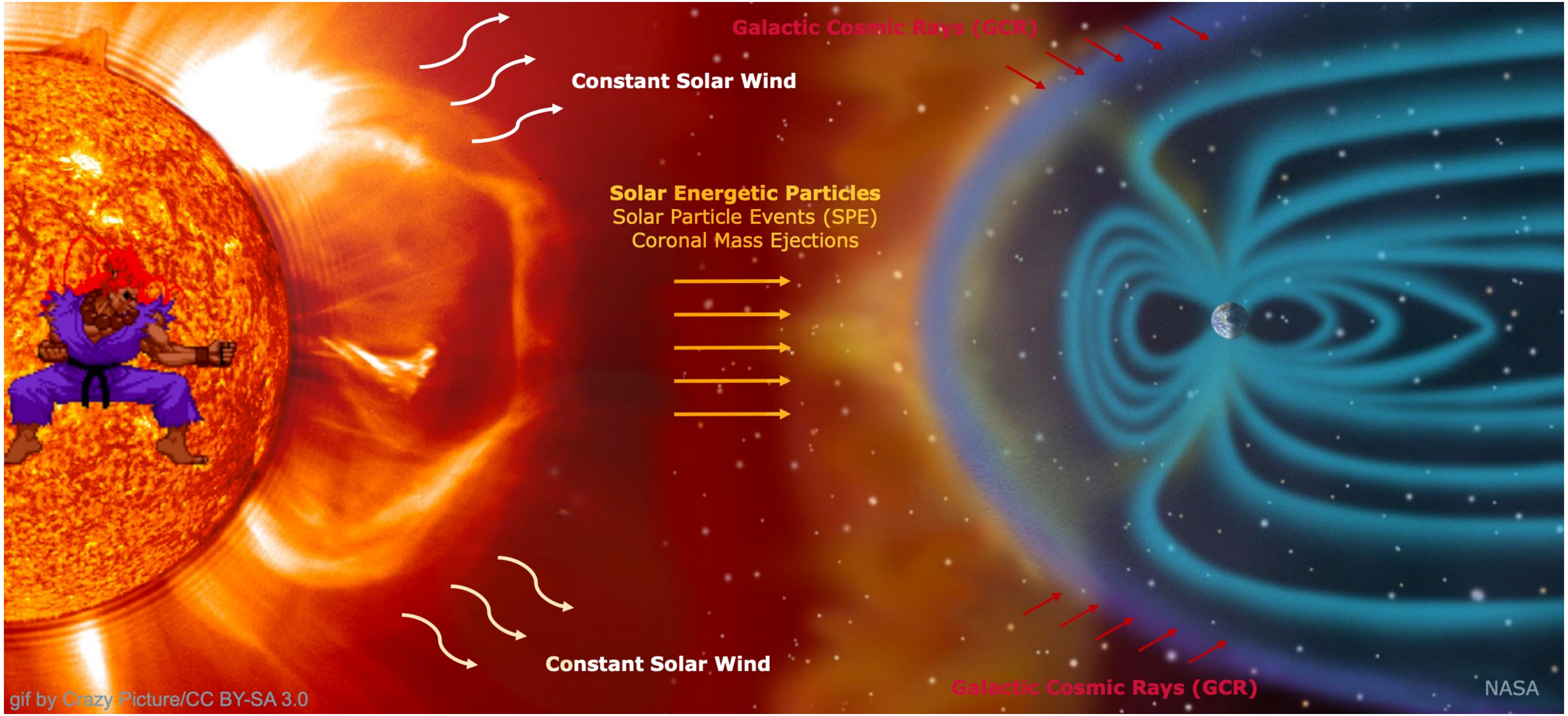
Spatial radiations



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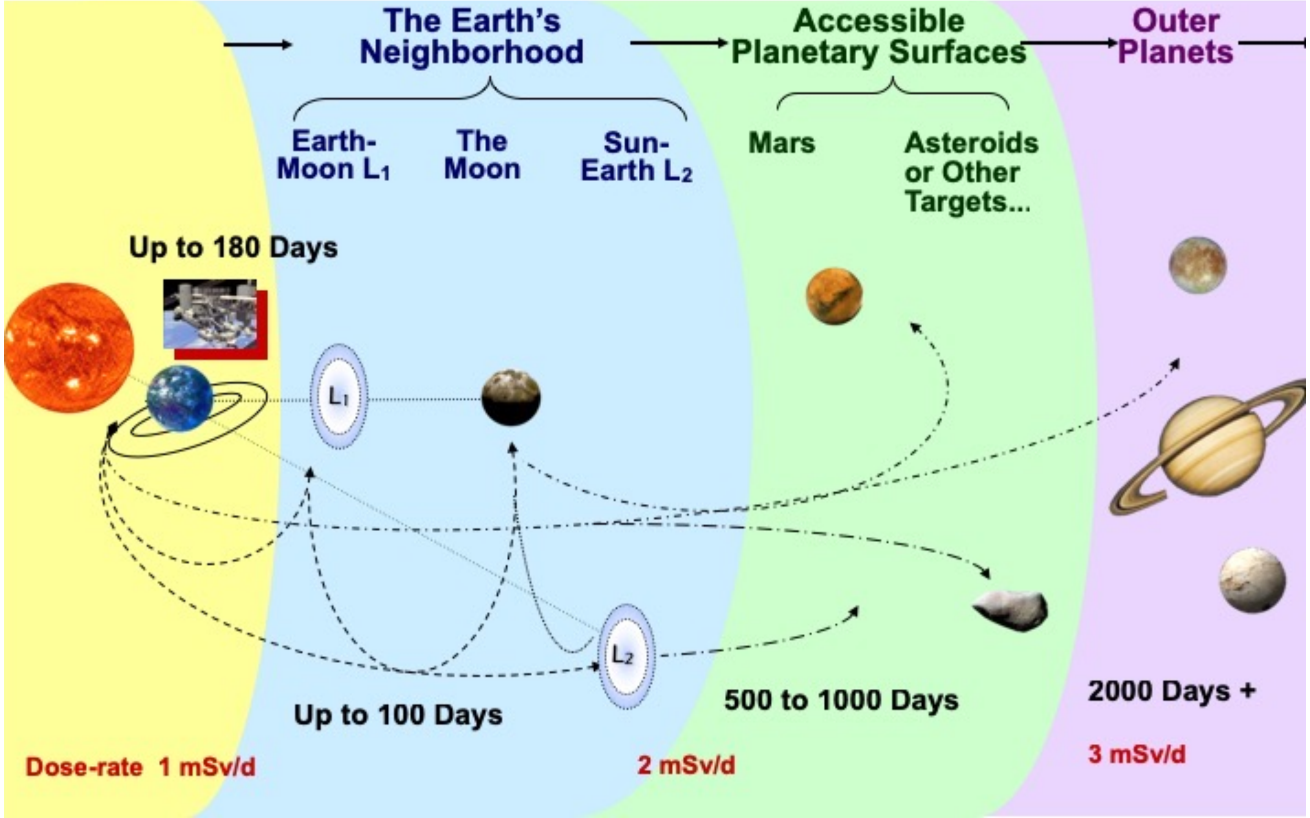
Plan of exploration and colonization



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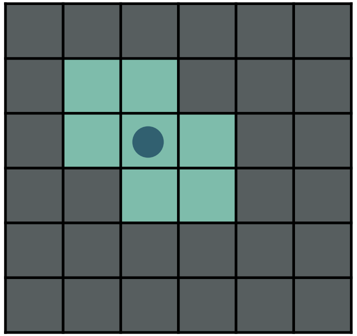
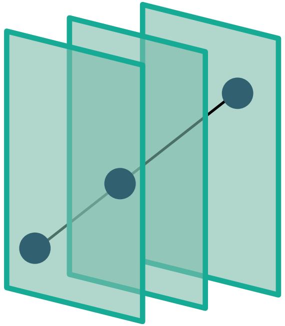
Vertex reconstruction

Clustering



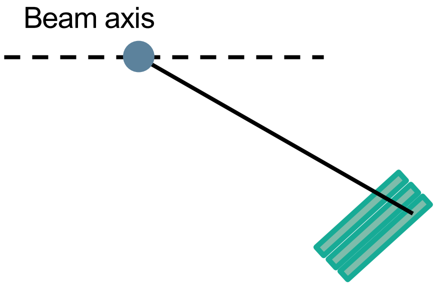
Center of mass

Tracking

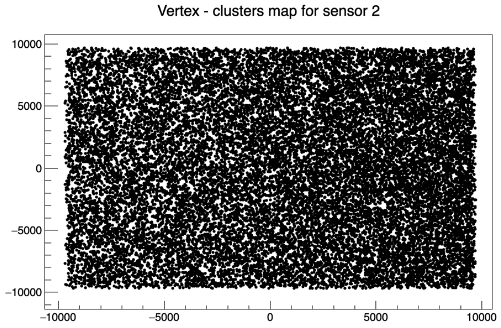


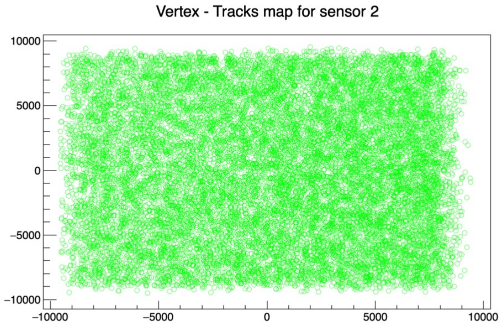
Search of a corresponding line between the 3 CMOS of a tracker

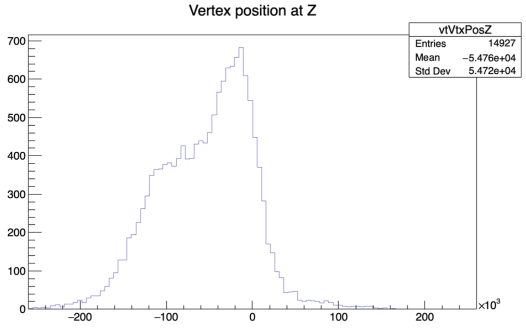
Vertexing



Intersection between the beam axis and the track reconstructed







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