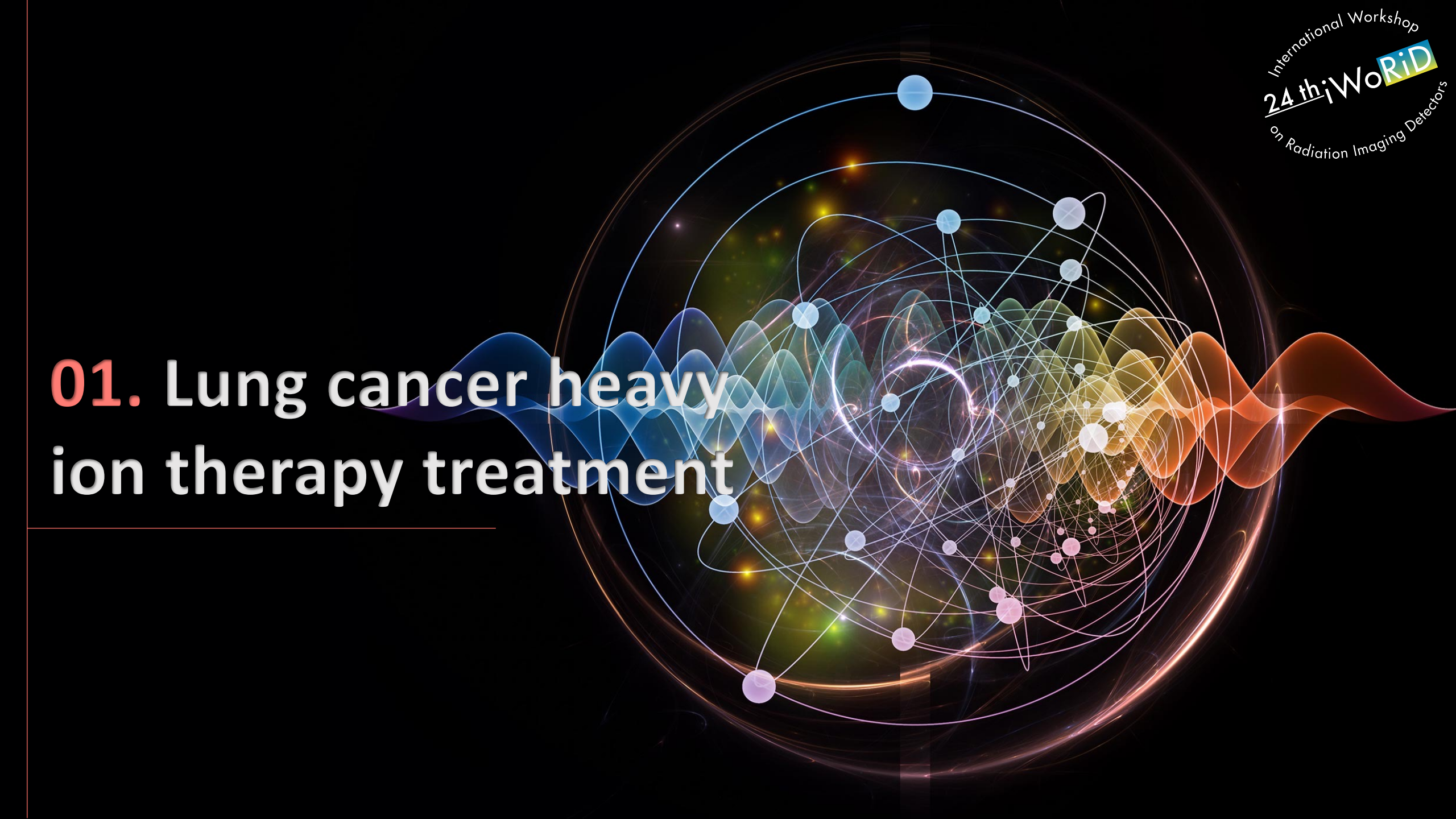
Lung cancer heavy ion therapy CMOS tracking device

iWoRiD presentation – June 2023

Lévana GESSON
PhD student
Under the supervision of
Marie VANSTALLE and Uli WEBER

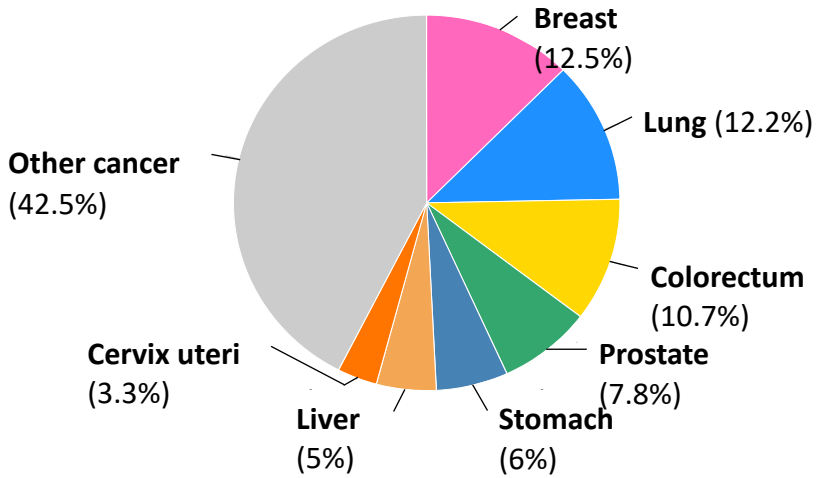


01. Lung cancer heavy ion therapy treatment

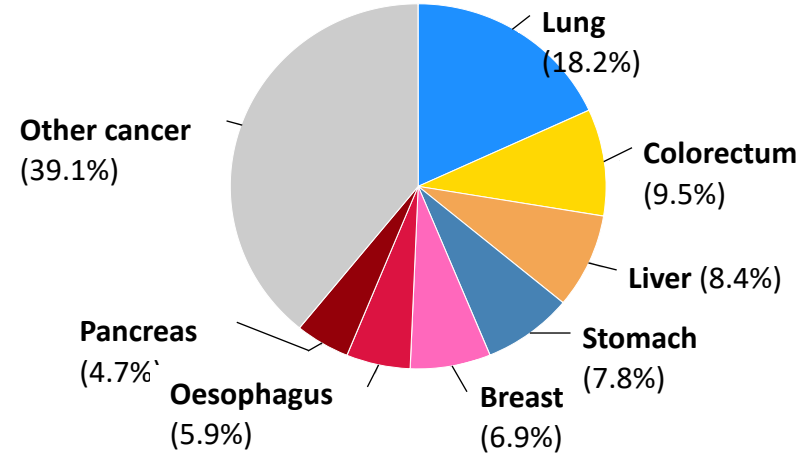
Lung cancer heavy ion therapy treatment

Cancer

Number of new cases in 2020



Number of deaths in 2020



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

International Agency for Research on Cancer
World Health Organization

Lung cancer heavy ion therapy treatment

Cancer

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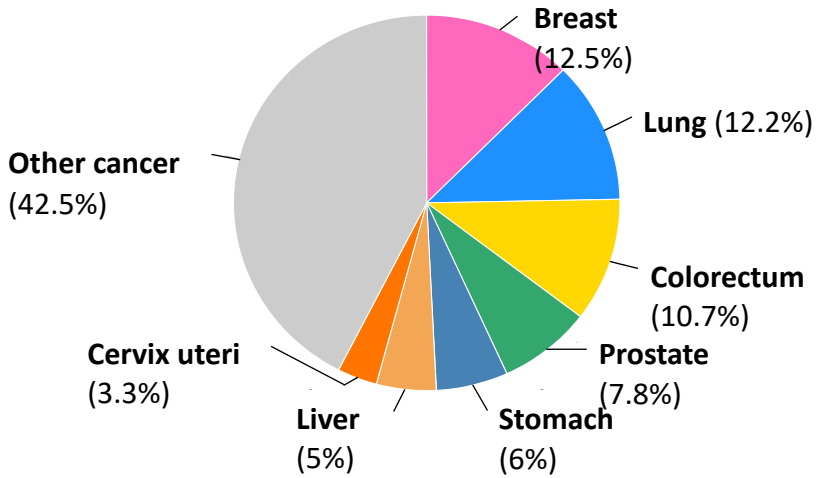

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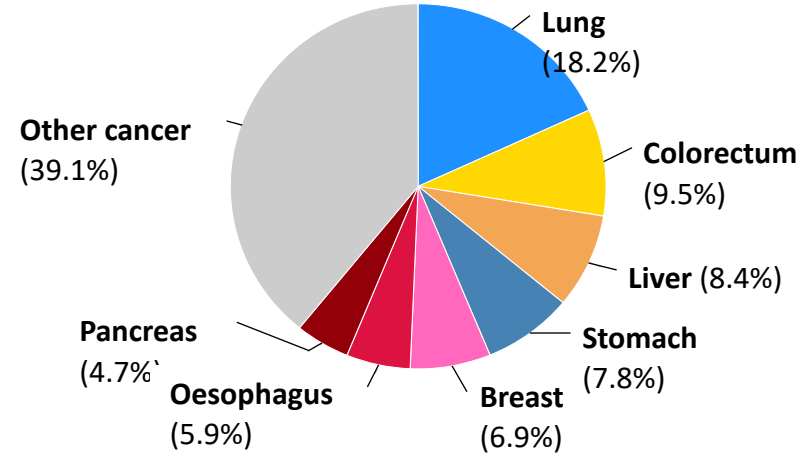

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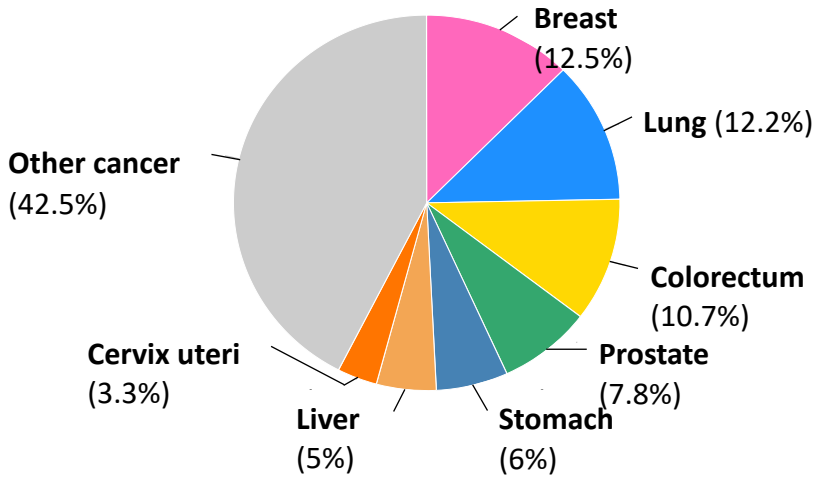

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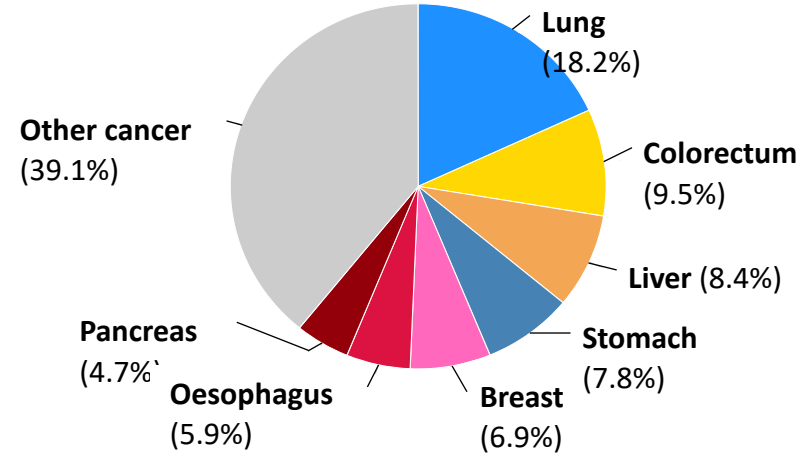

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Lung cancer heavy ion therapy treatment

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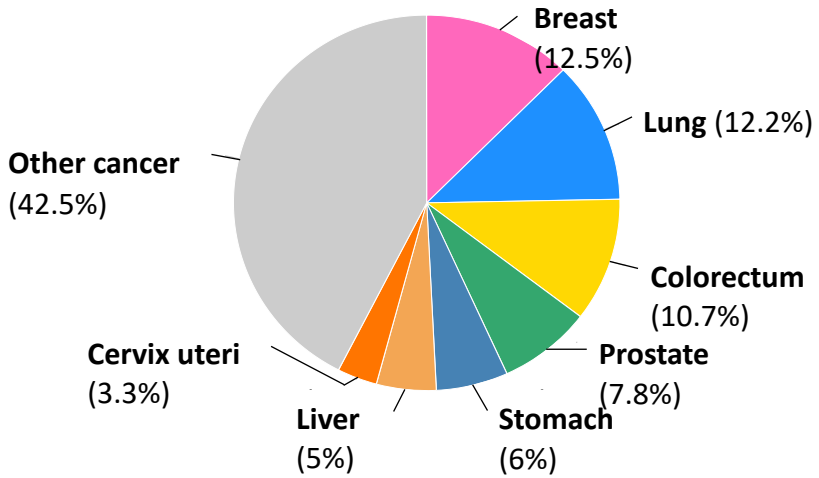

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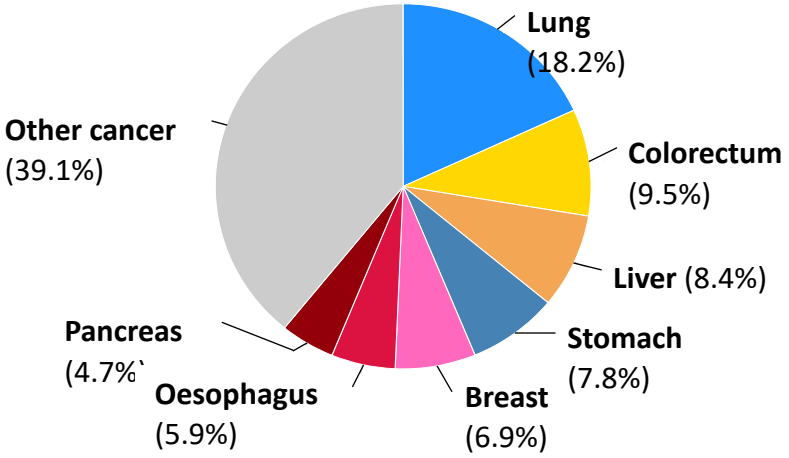

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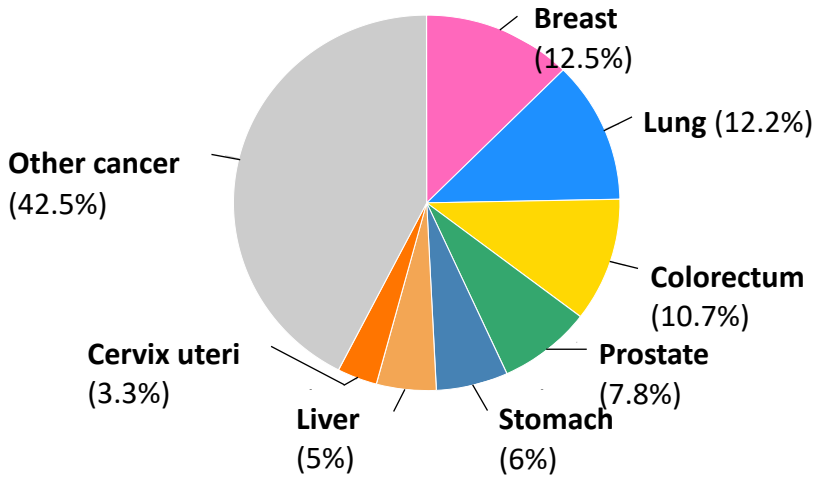

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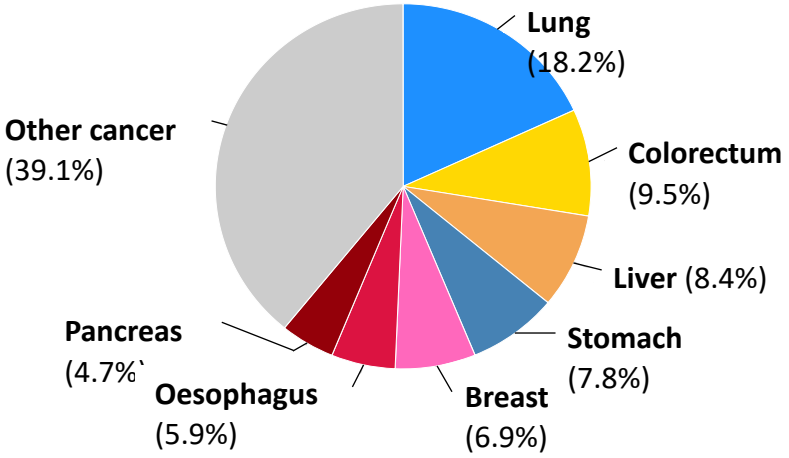

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- X-rays therapy
- Ion beam therapy
  - Carbon
  - Proton

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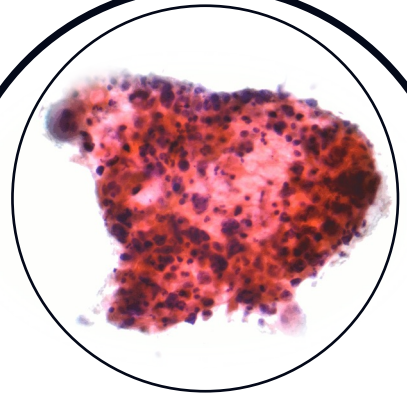
Lung cancer heavy ion therapy treatment

State of art

Lung cancer

- One of most prevalent diagnosed cancer worldwide
- 22% overall mortality rate

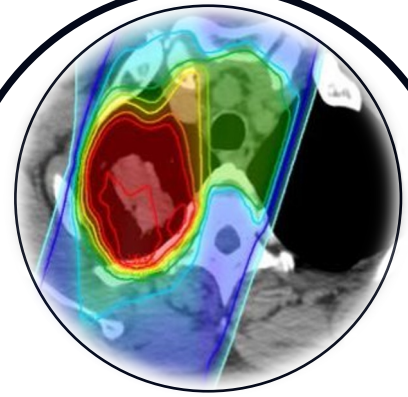


Non-small cell lung cancer

- 80% of lung cancer diagnoses
- 5-year survival rate of 26%
- Stage III and above : tumor size 3-7cm

Treatment

- Photon therapy : 20% 5-year overall survival
- Carbon ion radiation therapy : 42% 5-year survival



Limits of CIRT on NSCLC

- Individual differences
- Respiratory movement
- No adequate sample size to study
- Cost (facility 140 millions ; treatment 50 000)

Lung cancer heavy ion therapy treatment

State of art

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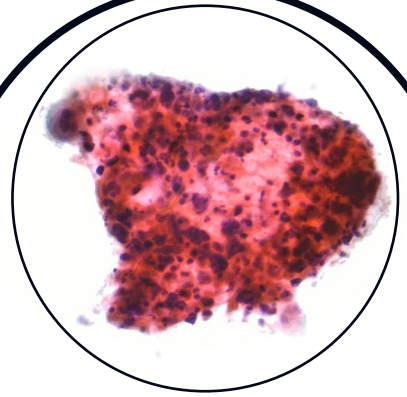

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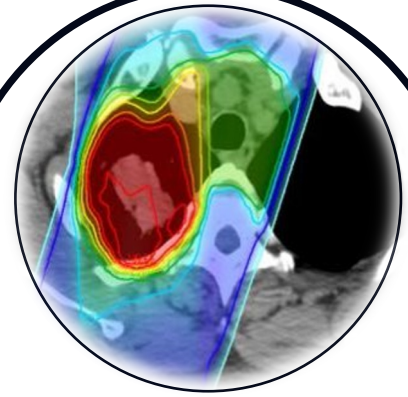

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Lung cancer heavy ion therapy treatment

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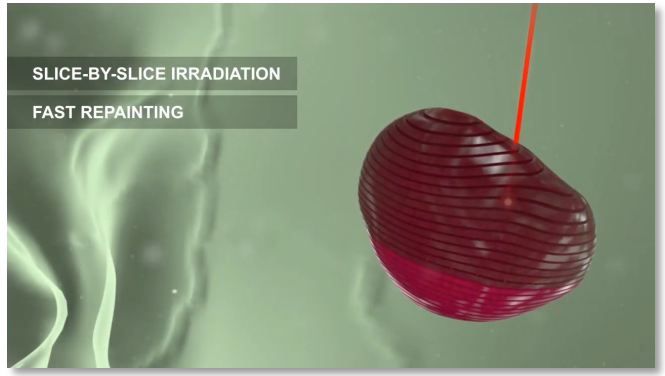
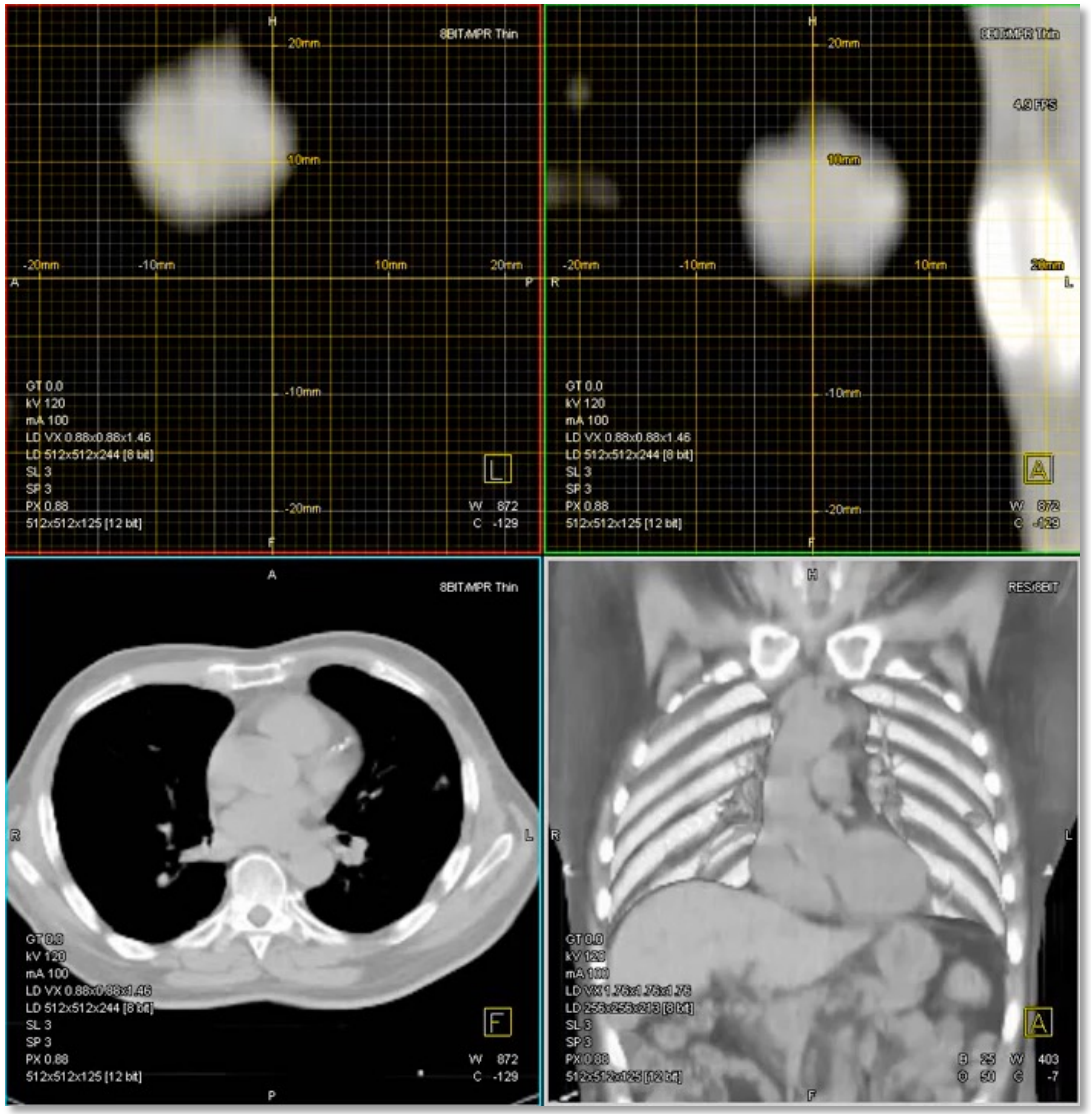


Pencil motion on similar time scale as intra-fractional tumor motion -> interplay effect



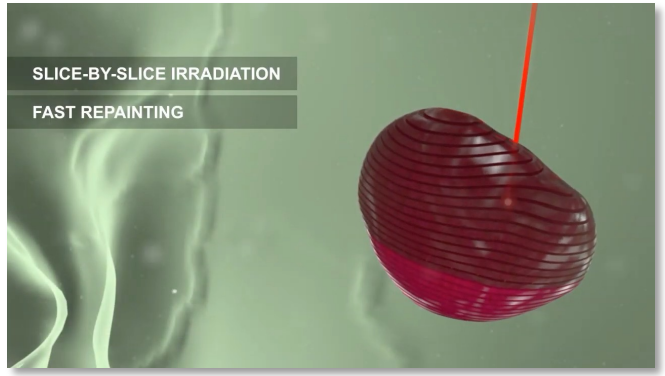
Motion effects

- Dose deterioration
- Delivered dose shift of 10-15% (1-5mm)

[9]

Lung cancer heavy ion therapy treatment

Breathing movement



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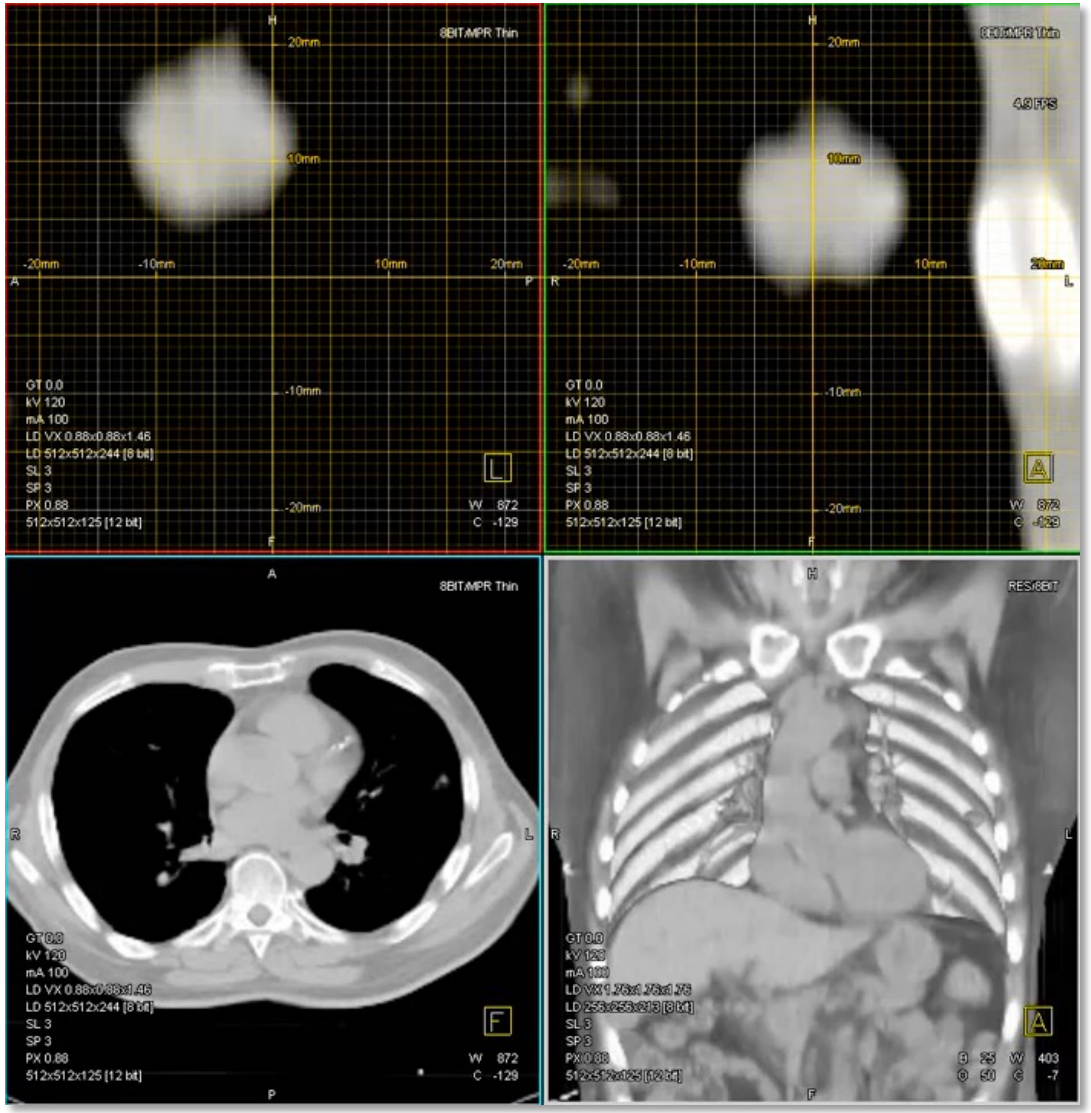

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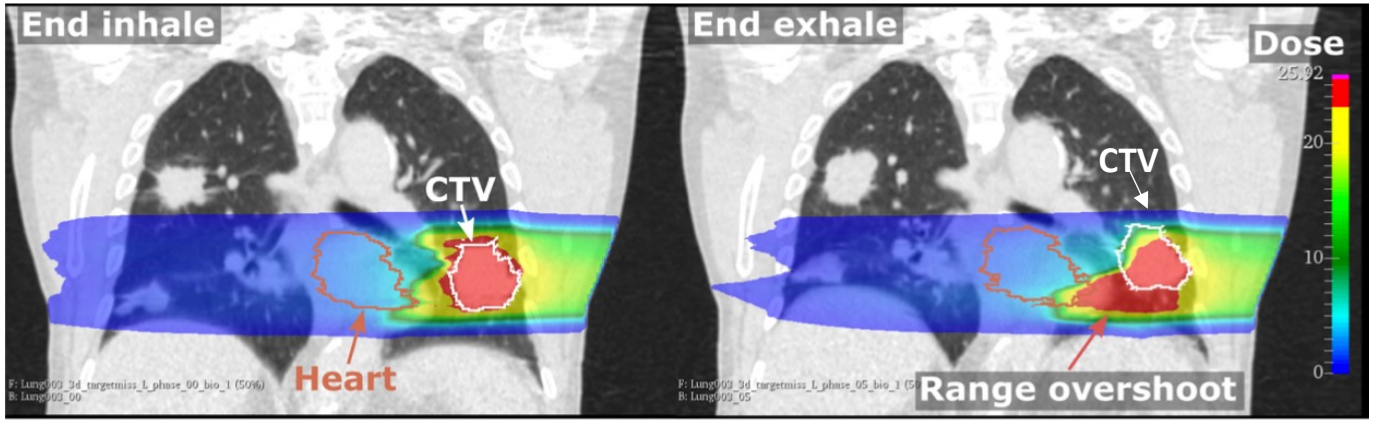
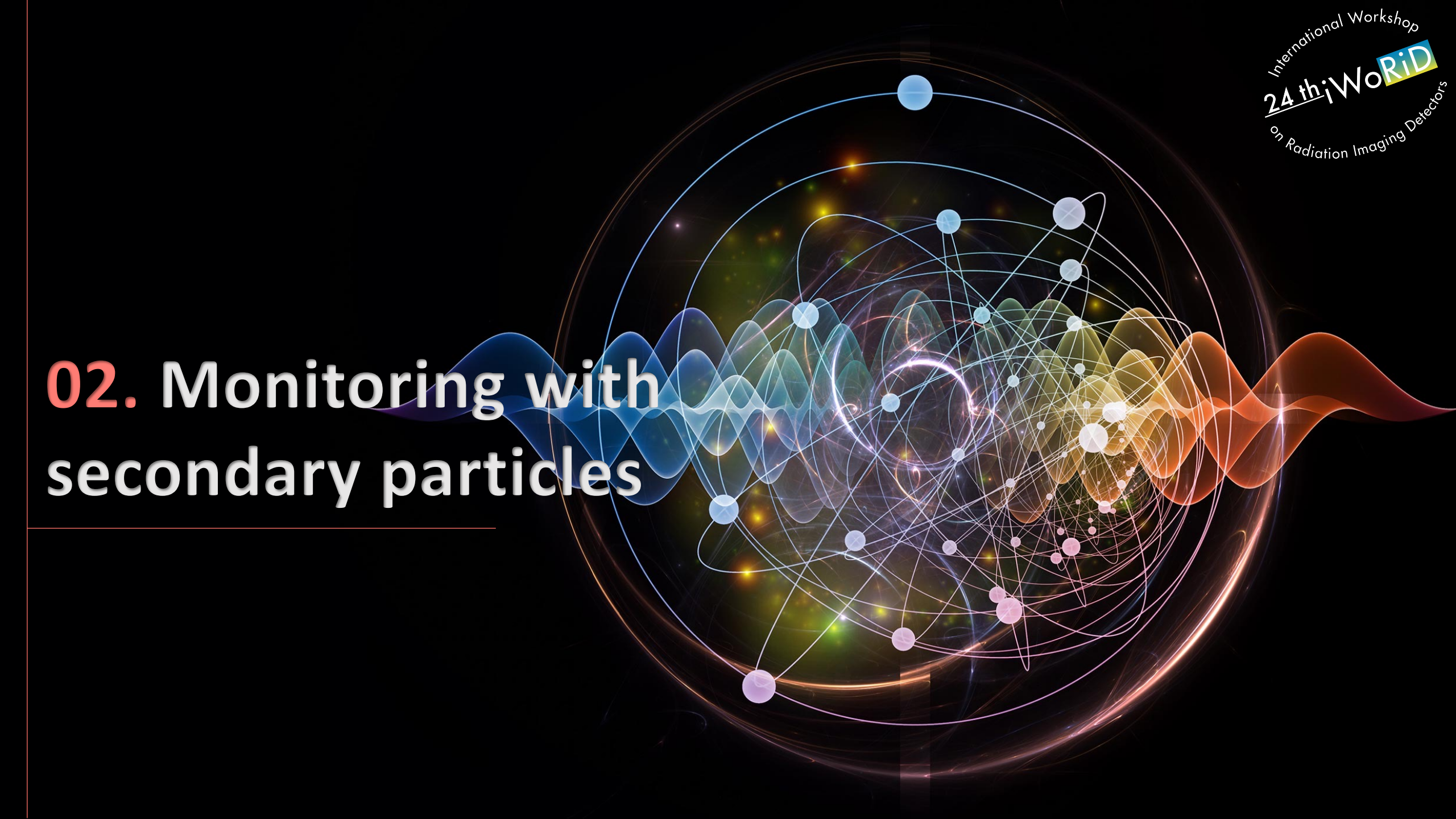


Dose distribution of heavy ions for lung tumor treatment planned at the end of inhale. [8]



02. Monitoring with secondary particles

Monitoring with secondary particles

CMOS protons detection

How can we improve the lung cancer treatment focusing on the breathing movement problematic ?

Collaboration between IPHC / GSI

Monitoring using the secondary protons produced during carbon ion treatment

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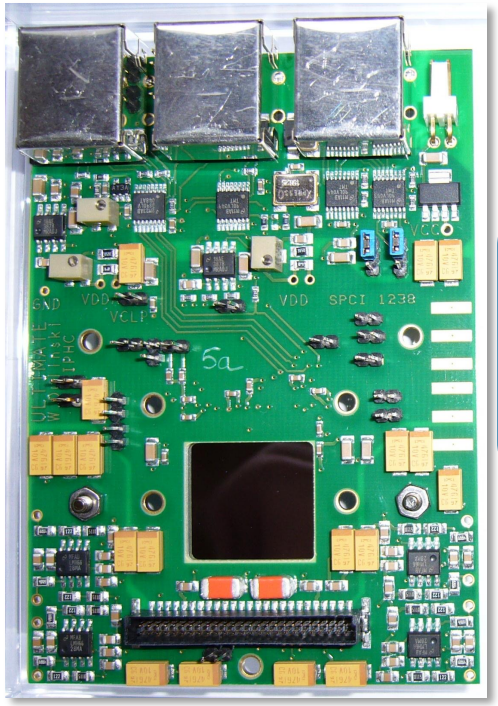
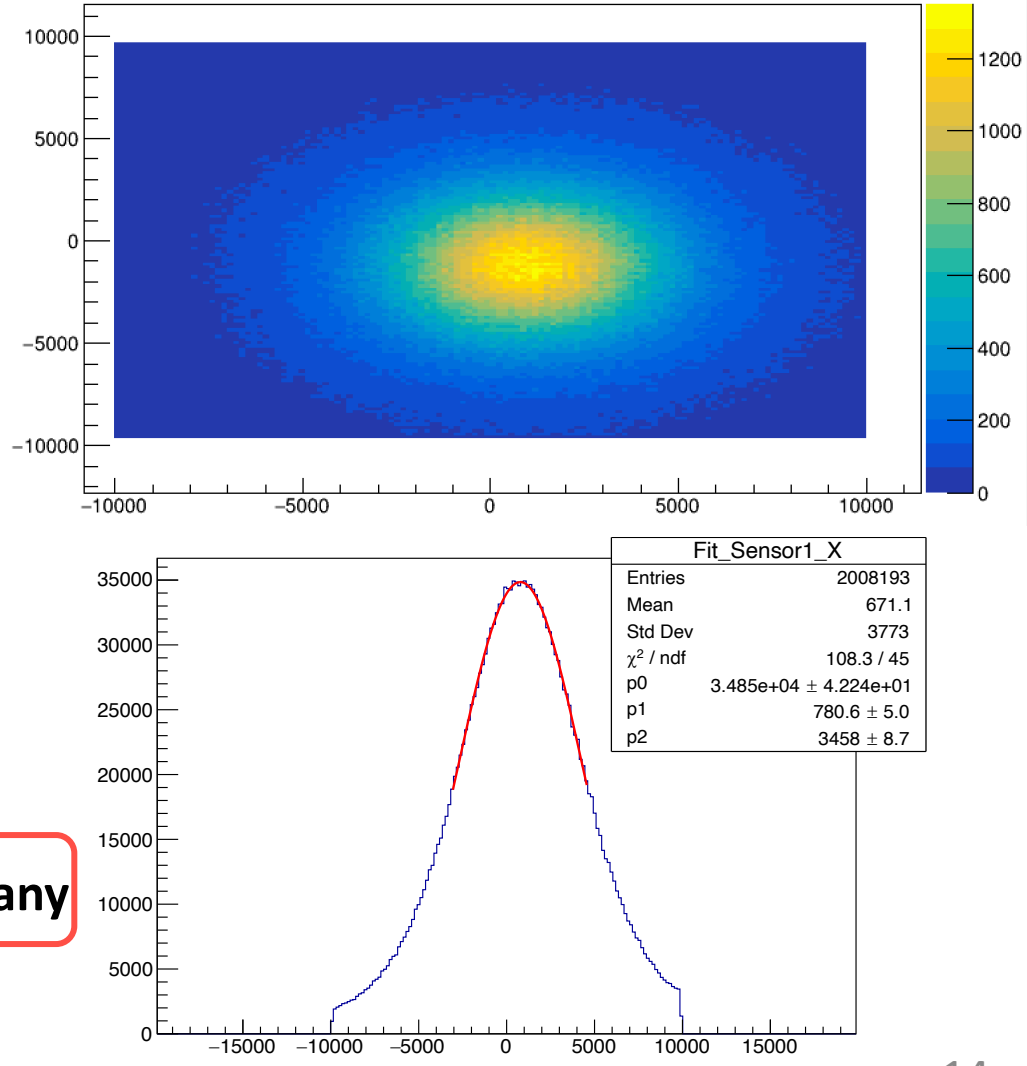


CMOS Mimosa-28 (IPHC)

- 928 rows x 960 columns
- Pixel size 20.7 µm
- 50 µm thickness + 14 µm epitaxial layer
- Readout time 186.5 µs (~ 5 kHz frame rate)
- Spatial resolution 10 µm

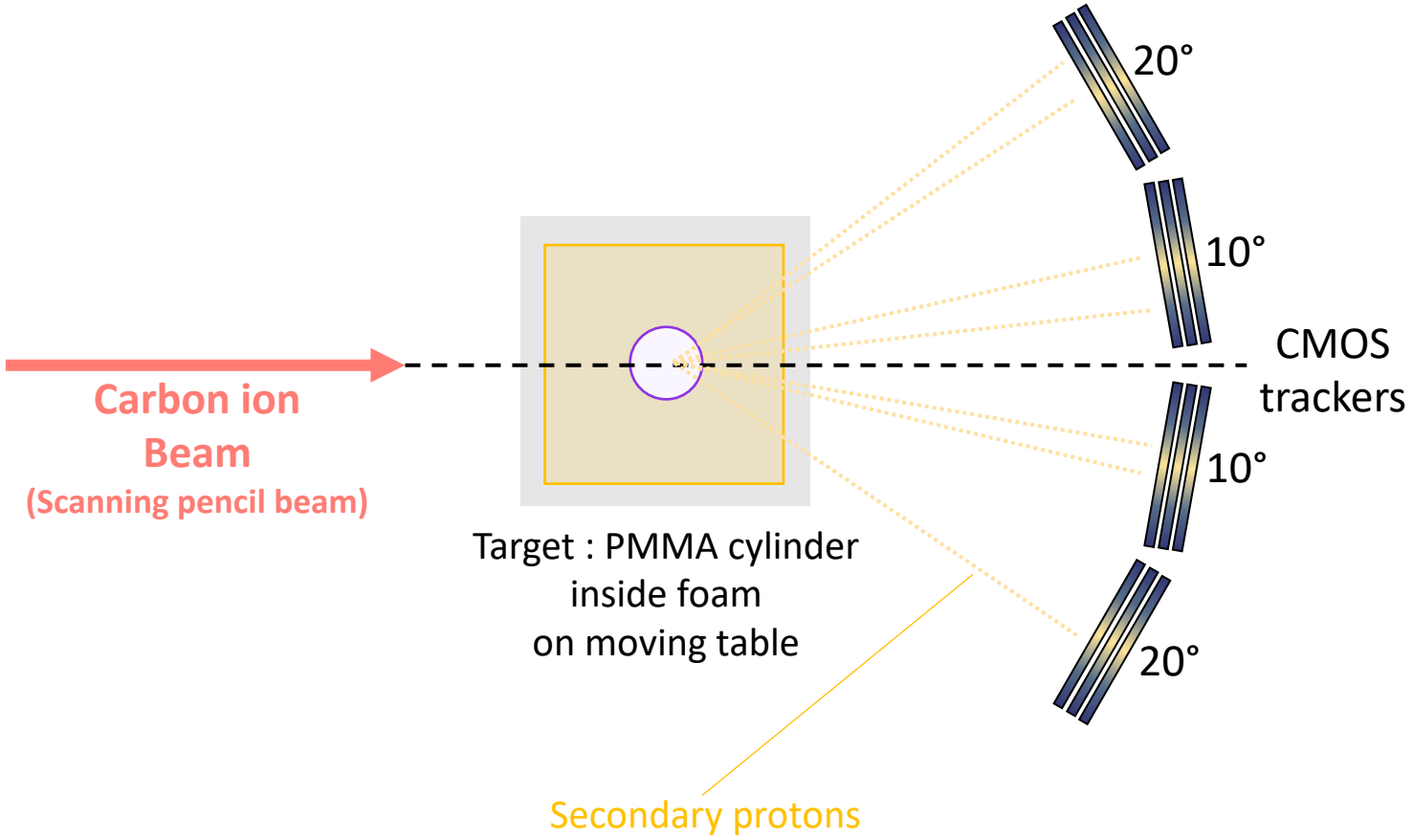
Measurements at MIT clinic, Marburg Germany

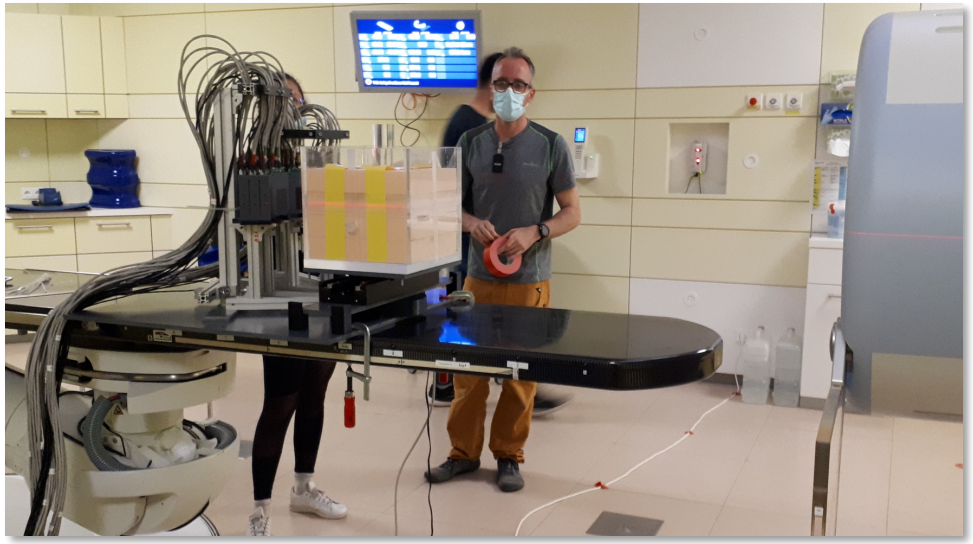
Figure – Cluster map and projection for ^{12}C beam of 326 MeV



Monitoring with secondary particles

MIT experiment





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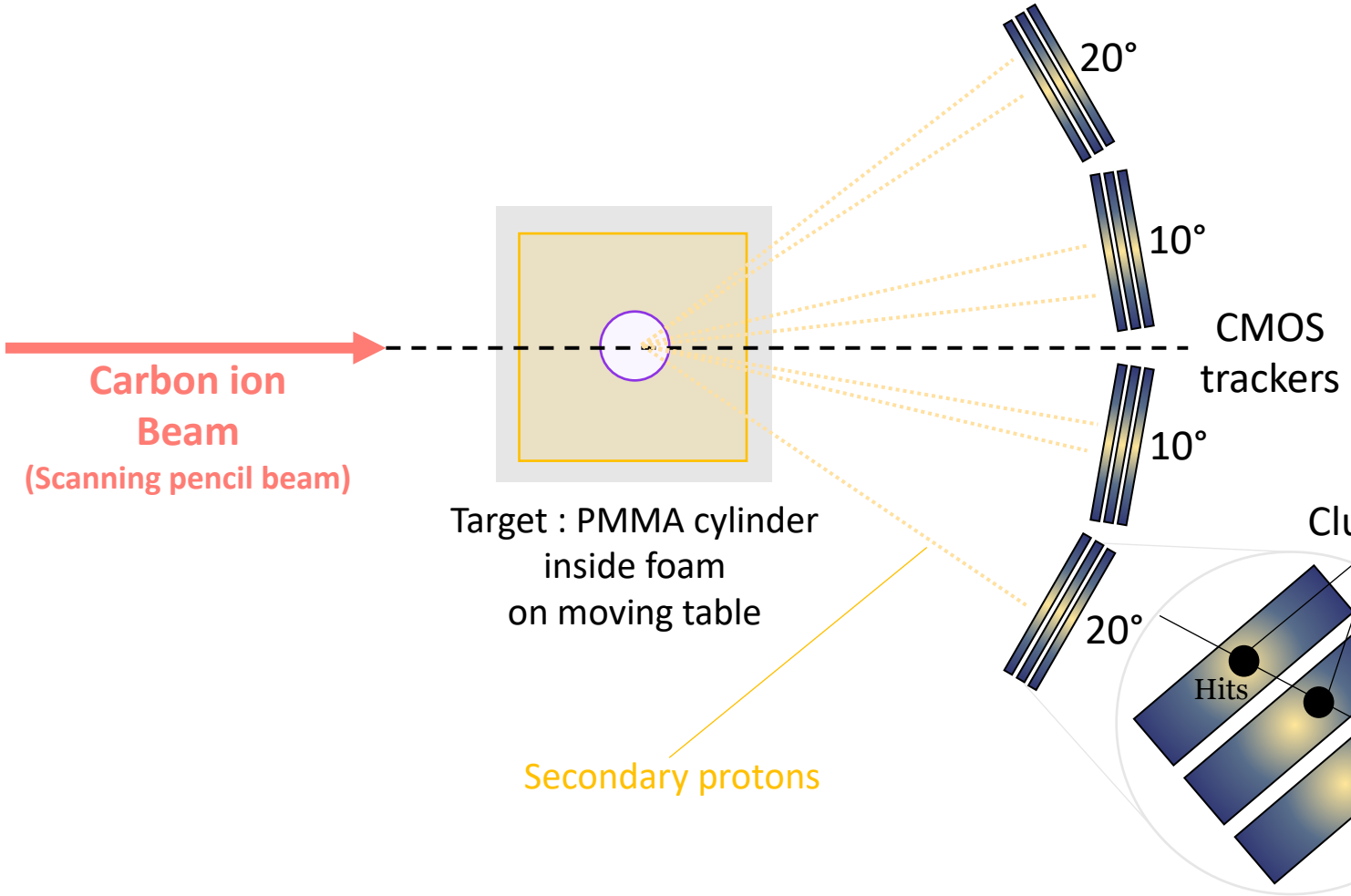

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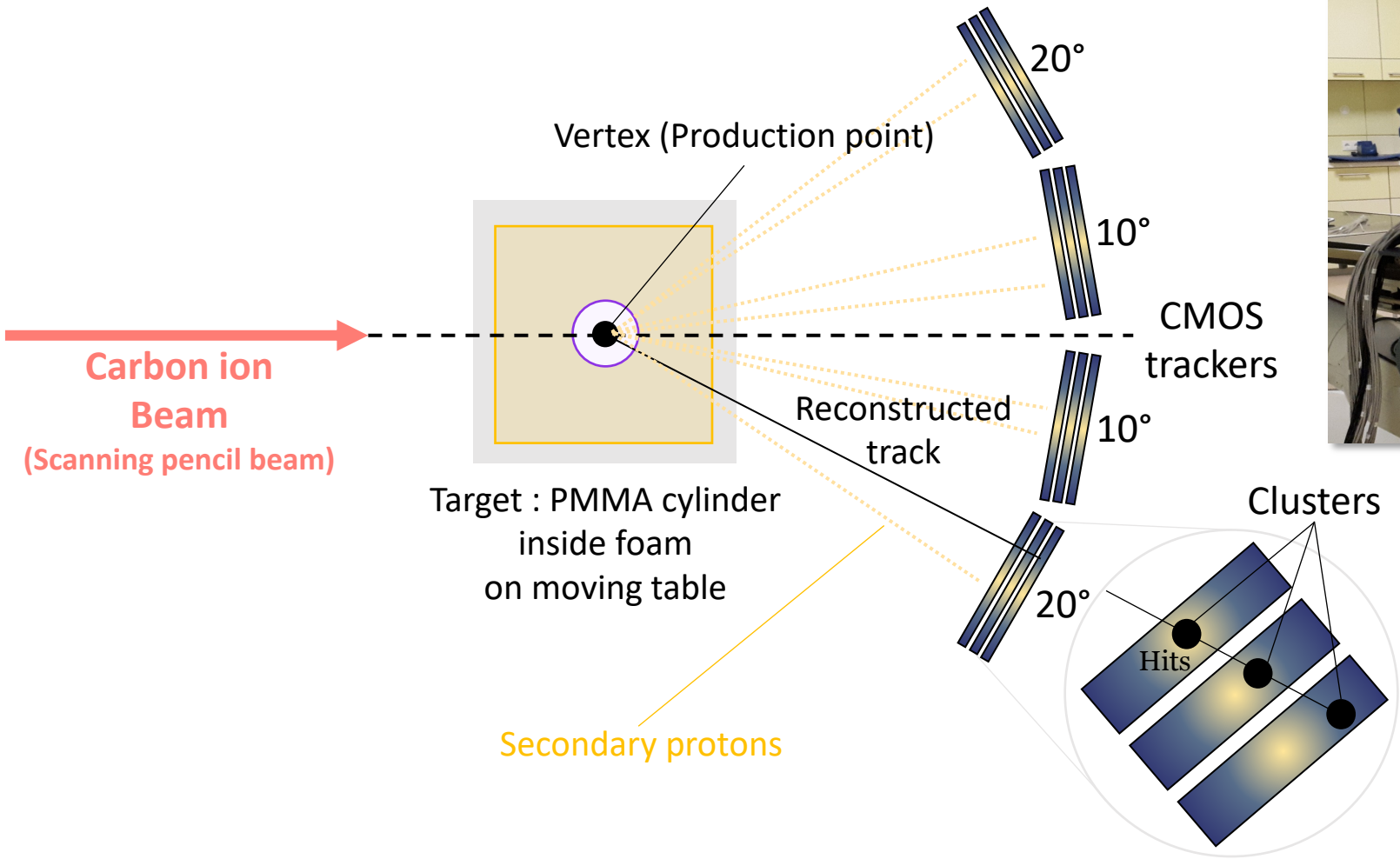
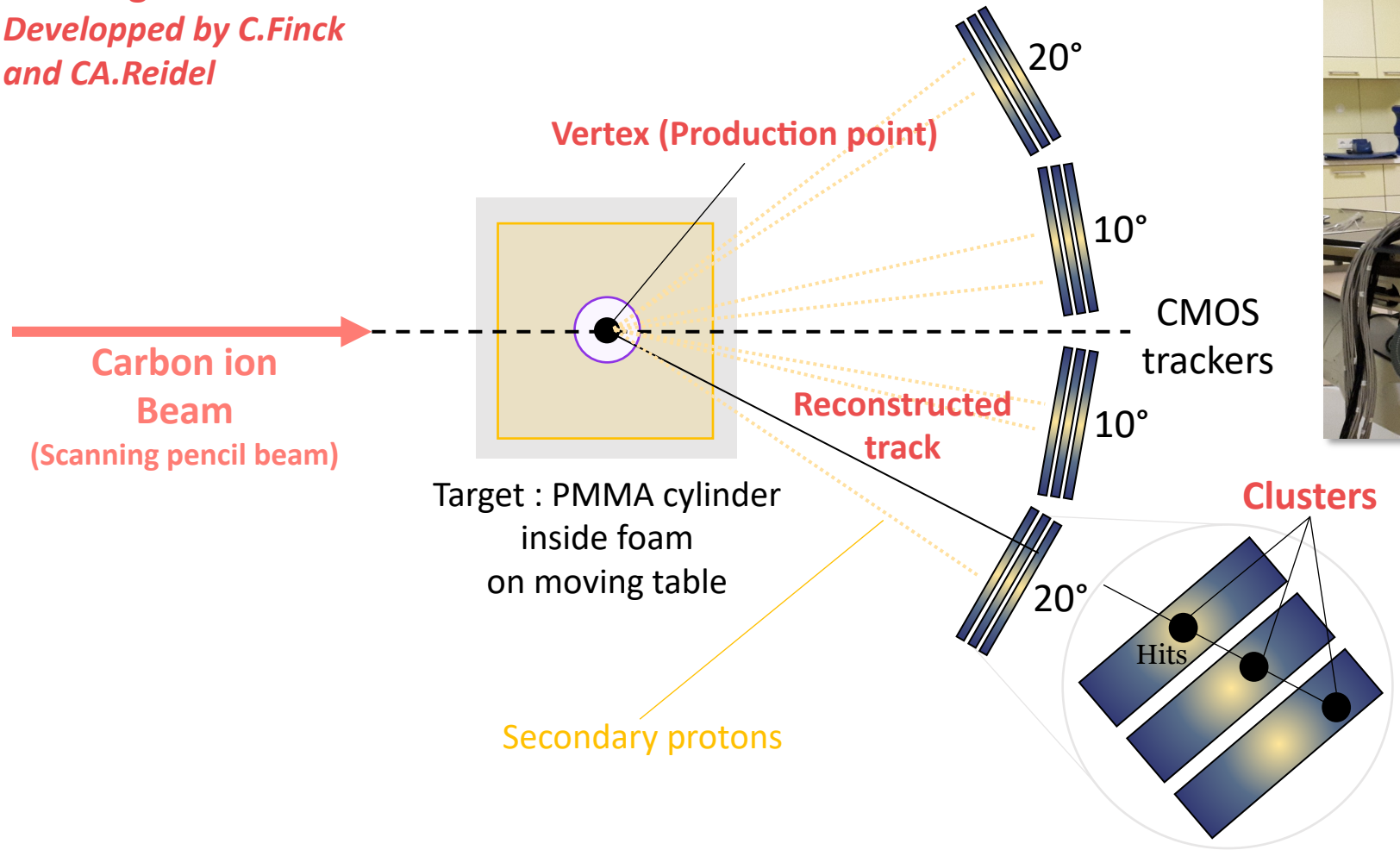


Monitoring with secondary particles

MIT experiment

STIVI algorithm

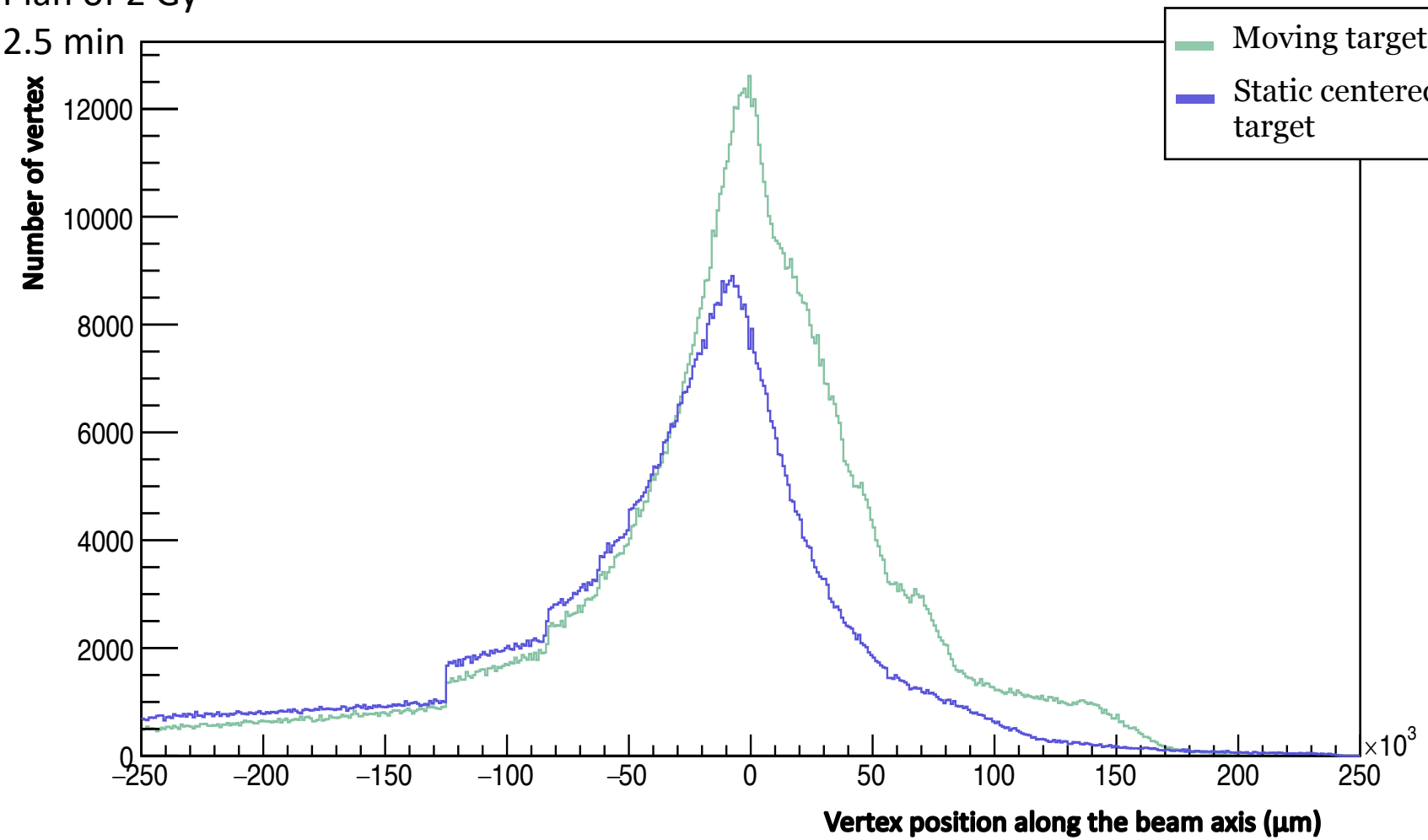
Developped by C.Finck and CA.Reidel

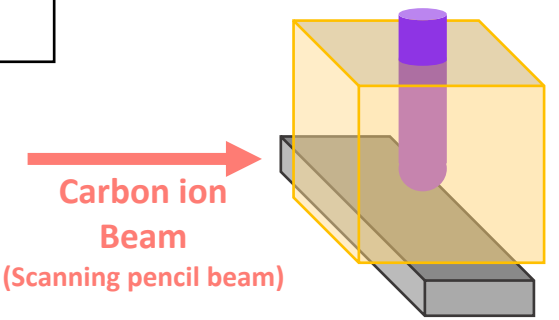


Monitoring with secondary particles

MIT experiment results

- **Full clinical treatment plan**
  - Sphere of 50mm of diameter
  - Plan of 2 Gy
  - 2.5 min





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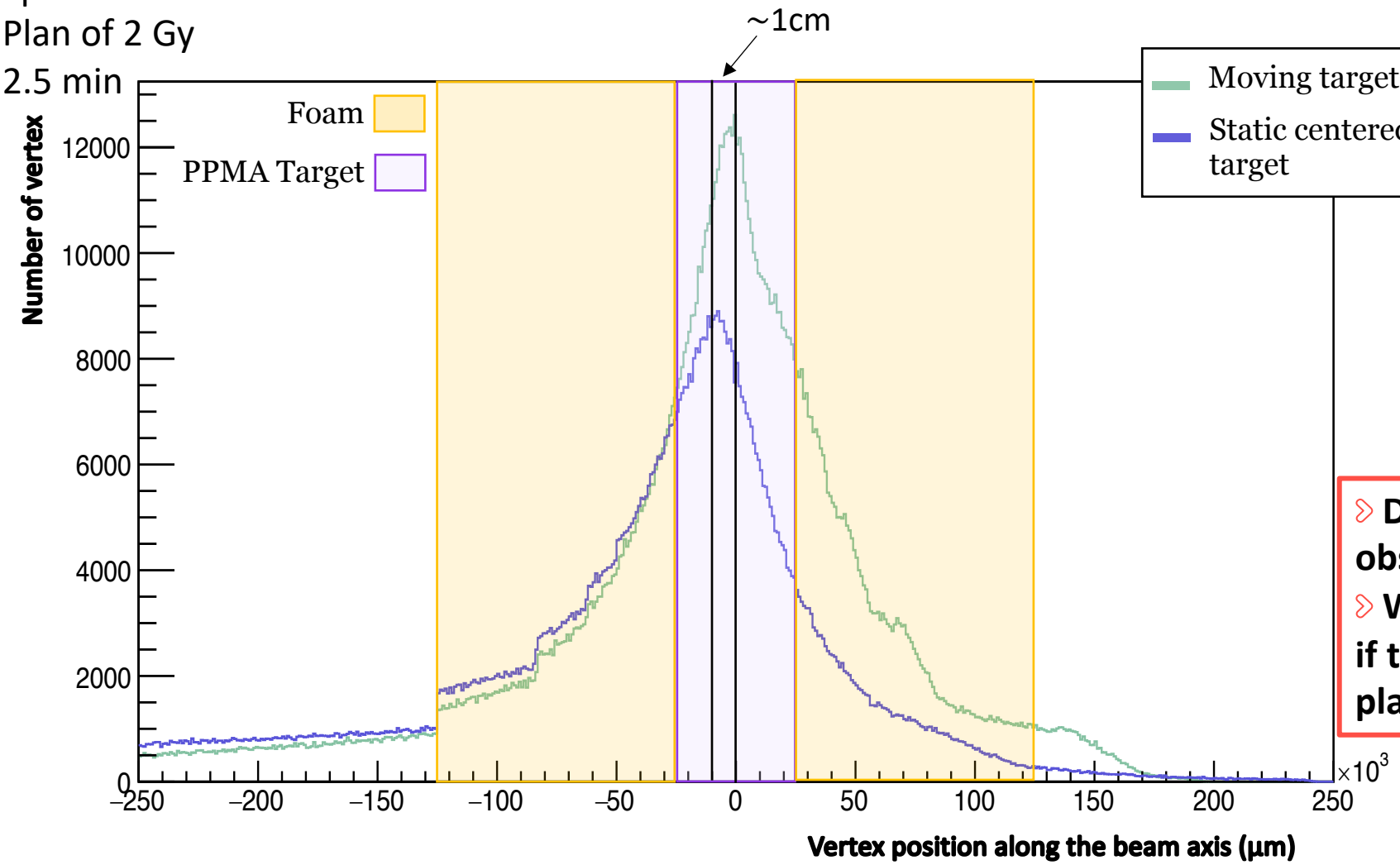

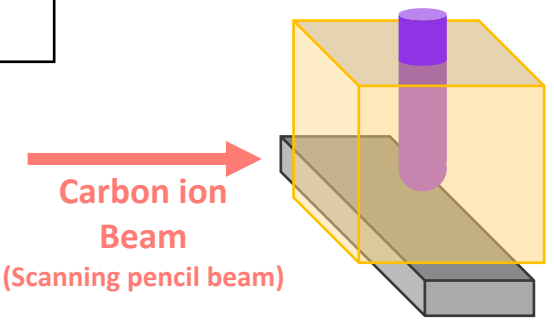

- **Differences in proton distribution observable with the CMOS trackers**
- **We can deduce from distributions if treatment plan delivered as planned**

Monitoring with secondary particles

MIT experiment results

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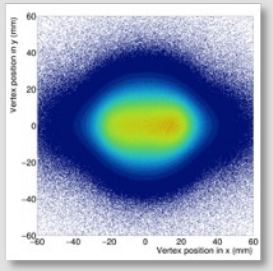
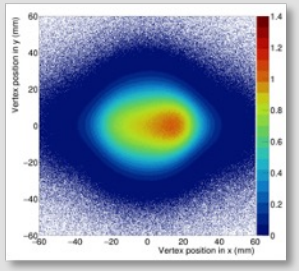
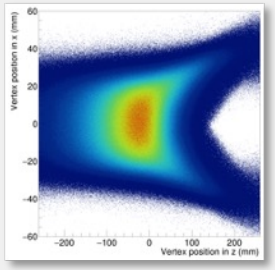
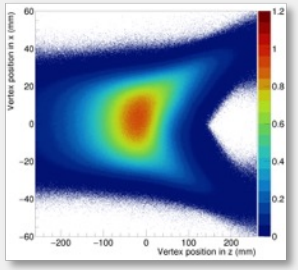
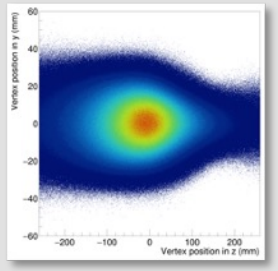
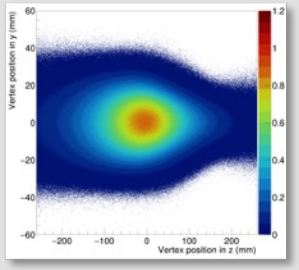
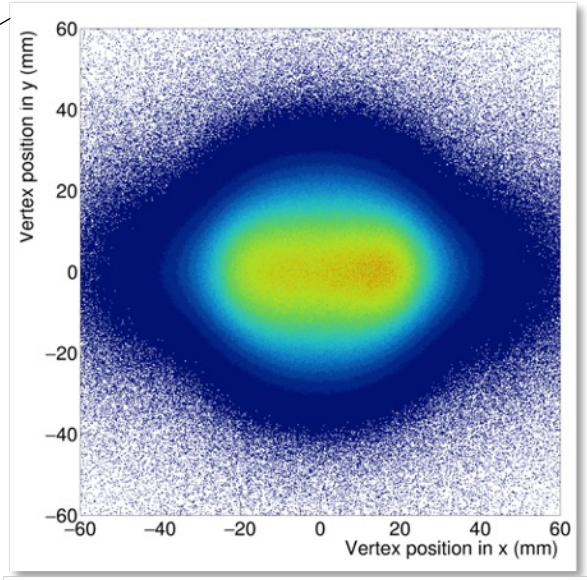
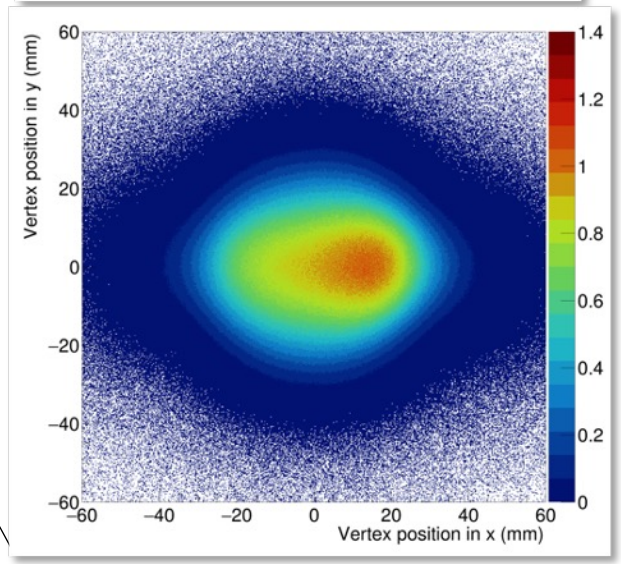
	Static	Moving
Vertex X vs Y		
Vertex X vs Z		
Vertex Y vs Z		





Claire-Anne Reidel preliminary plots

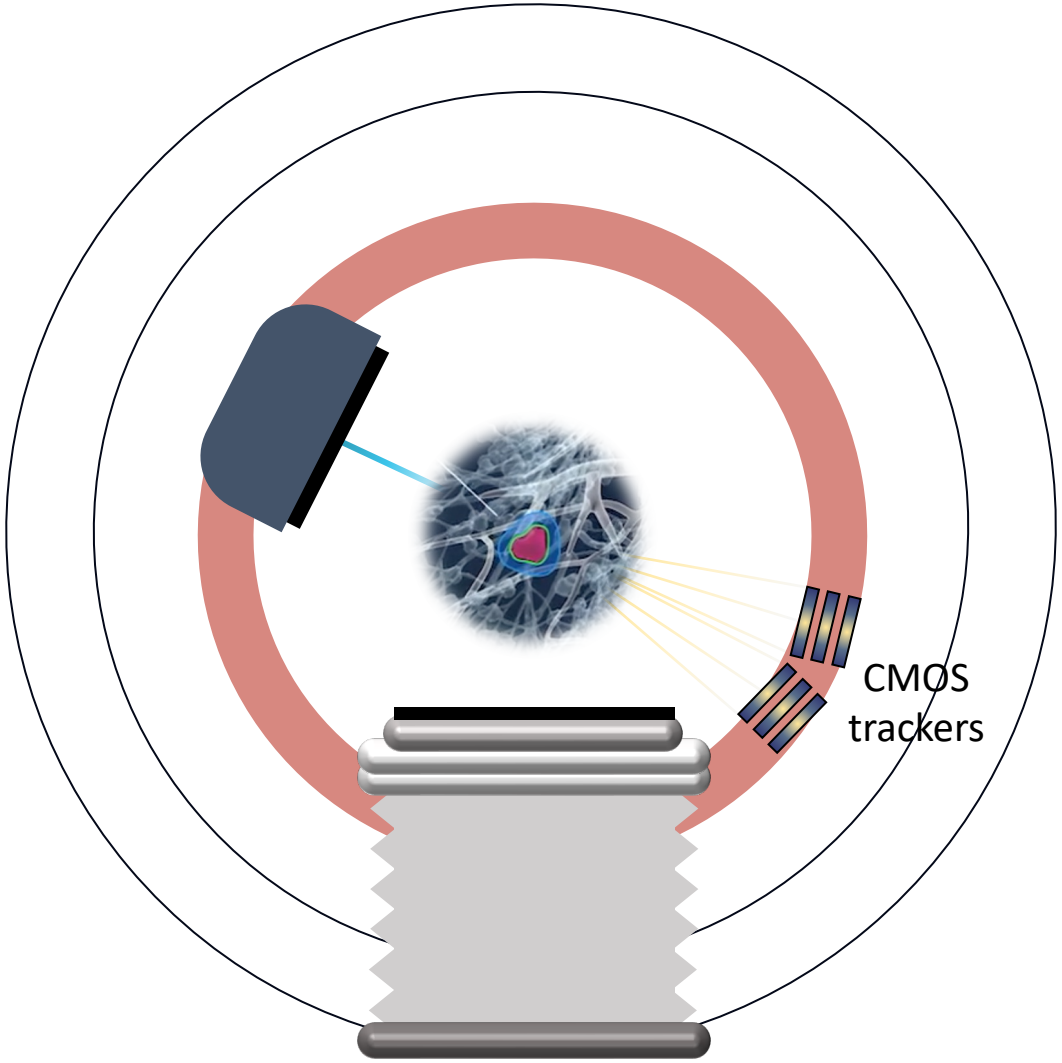
Monitoring with secondary particles

CMOS tracking device

Real time monitoring of :
- Beam position
- Movement of high density-gradients areas

Using these data for better control of the treatment :
- Improve 4D treatment plans and reduce margins

Software and interfaces for the Front-End :
- Real time visualization
- Interfaces for interlock, gating
- Interfaces for beam control



Monitoring with secondary particles
CMOS tracking device

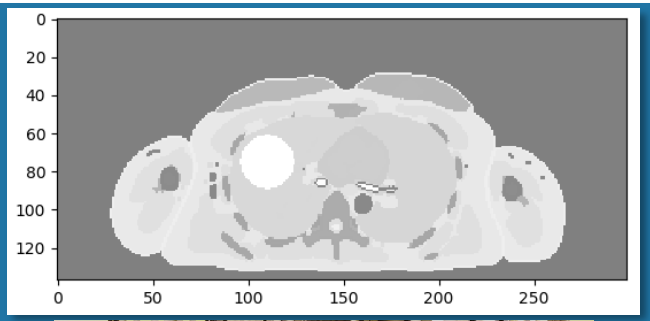
MC simulation on a clinical case with GATE (Geant4 based) on patient 4D-CT

CMOS device optimization :
- dimension, shape, number
- Time of response
- ADC

Digital hardware :
- Data transfer and digital pre-processing on sensor

Algorithms for fast processing of data :
- Deep learning for clustering, tracking
- GPU/FPGA

GATE simulation on a patient 4D-CT



CMOS trackers example of setup

Conclusion

- **Breathing movement induce dose shift and deterioration**

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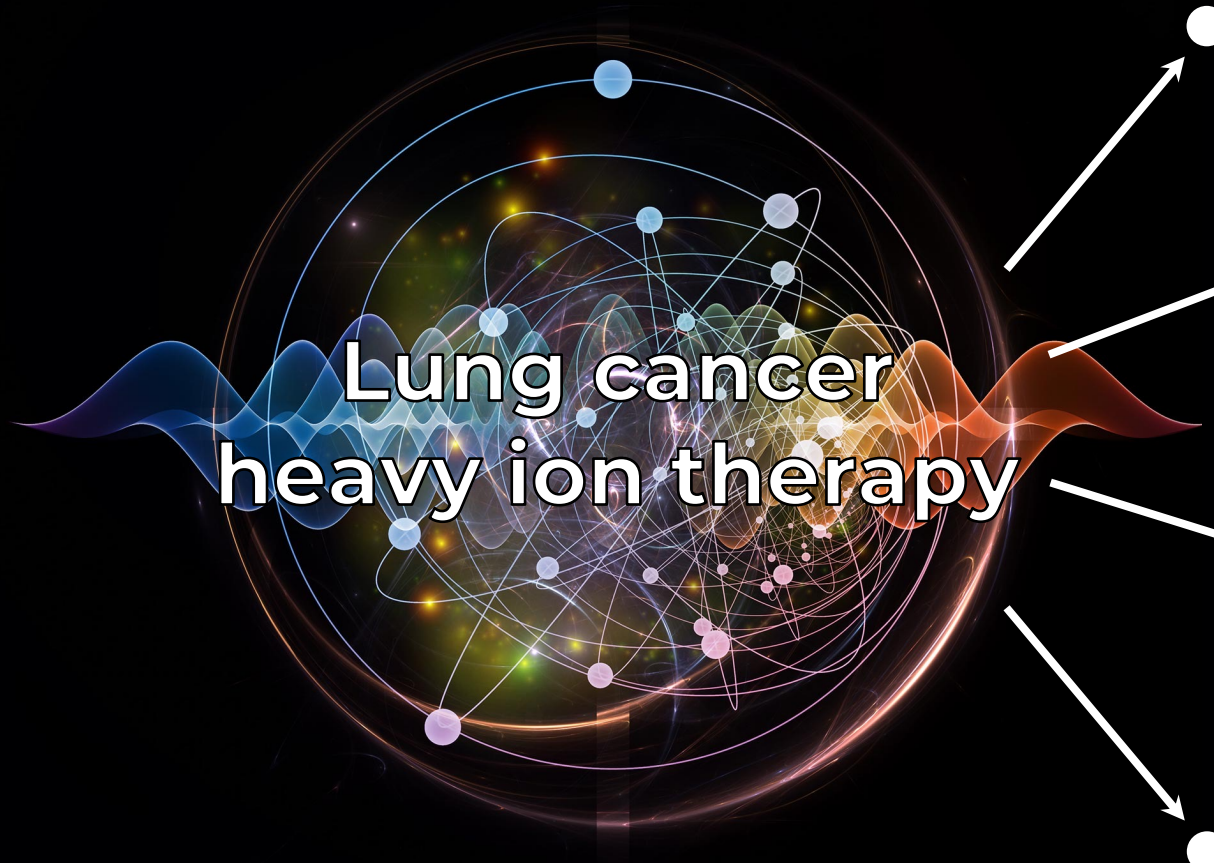
- Monitoring using secondary protons
- CMOS tracking device to reconstruct protons' vertex distribution

Conclusion



- Breathing movement induce dose shift and deterioration
- Monitoring using secondary protons
- CMOS tracking device to reconstruct protons' vertex distribution
- Clinical application concept

References

[1] Nymus 3D animations – part of the Demcon group
[2] Oliver Jäkel, Physical advantages of particles: protons and light ions, Published Online:26 Sep 2019 - https://doi.org/10.1259/bjr.20190428
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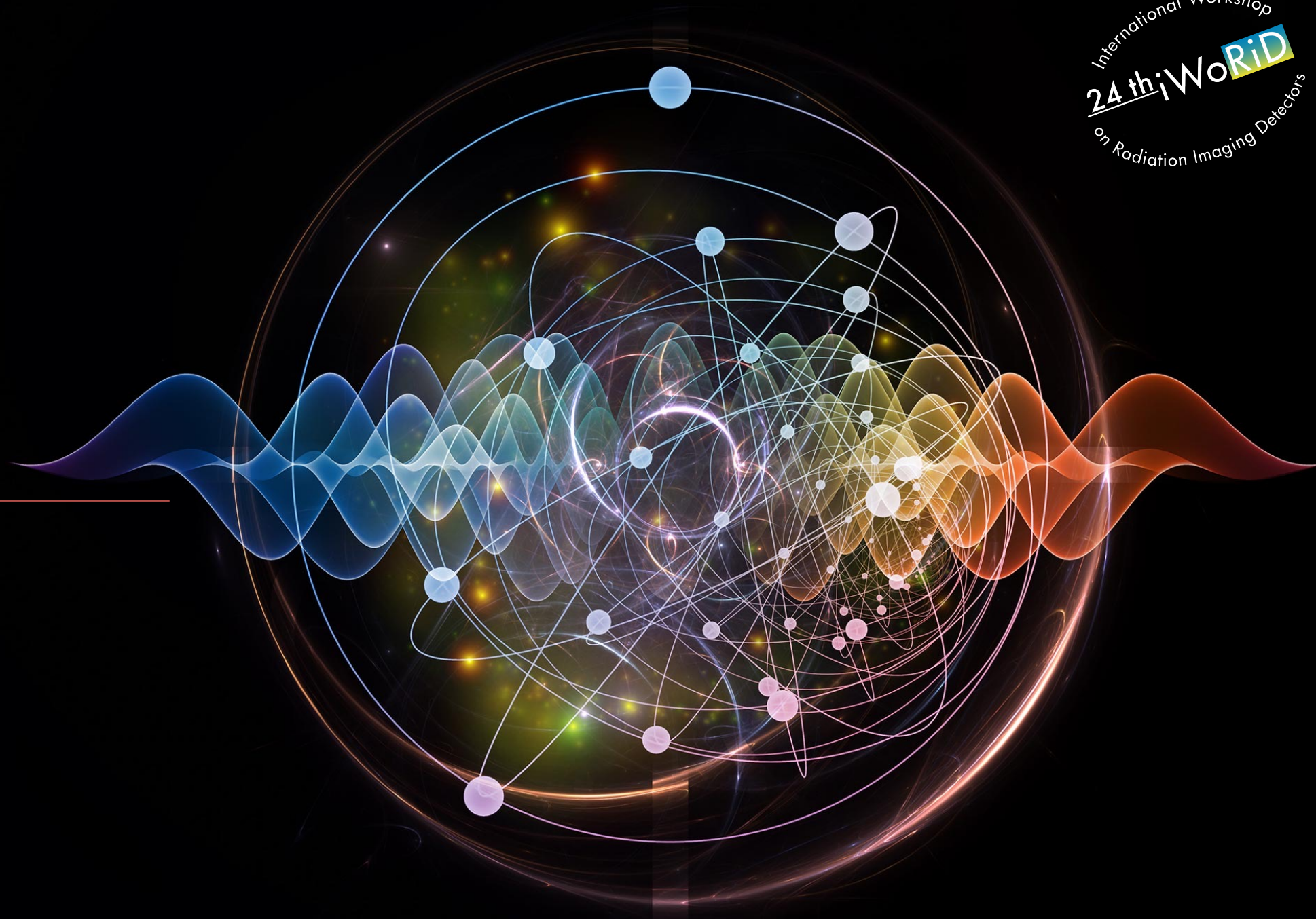
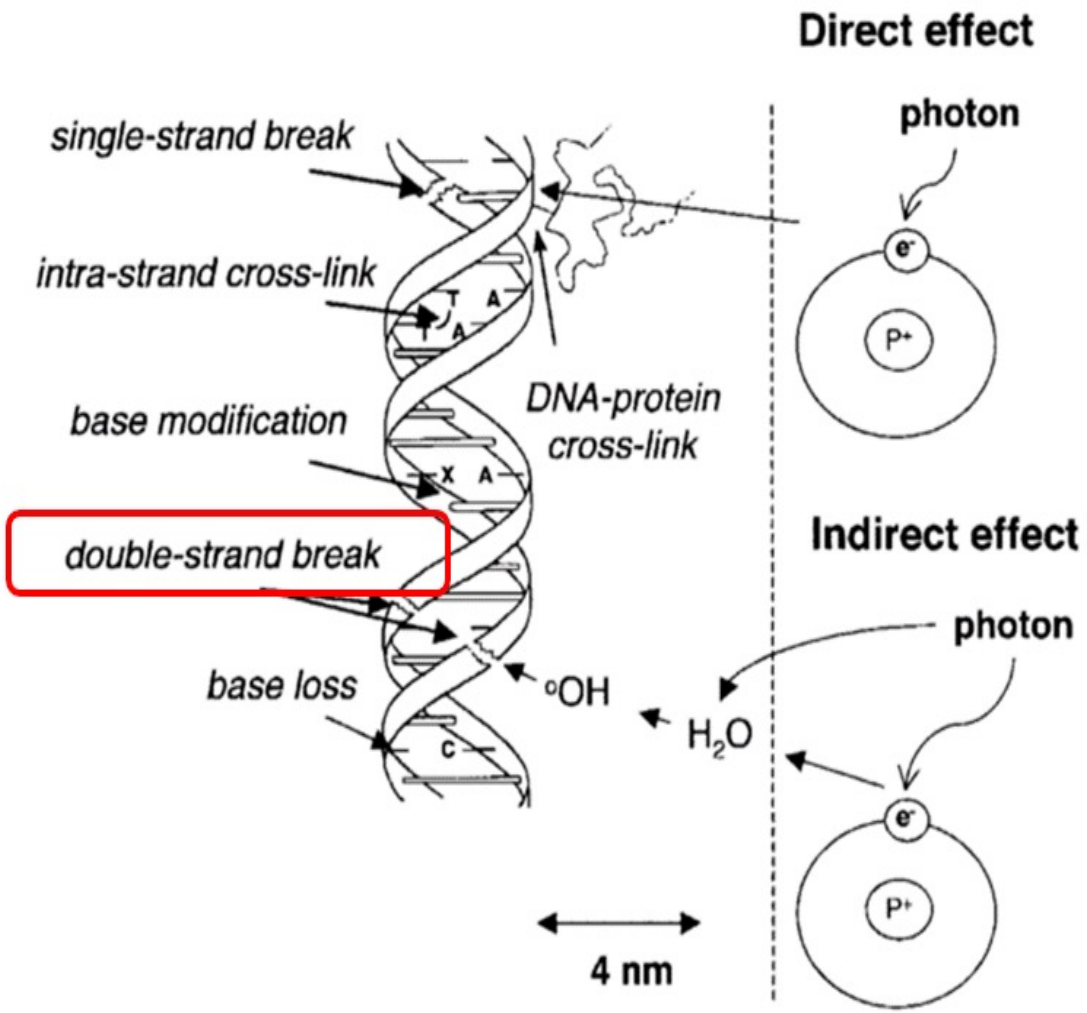
[17] Haettner, Emma & Iwase, Hiroshi & Krämer, M & Kraft, G & Schardt, Dieter. (2013). Experimental study of nuclear fragmentation of 200 and 400 MeV/u C-12 ions in water for applications in particle therapy. Physics in medicine and biology. 58. 8265-8279. 10.1088/0031-9155/58/23/8265.

Back-up

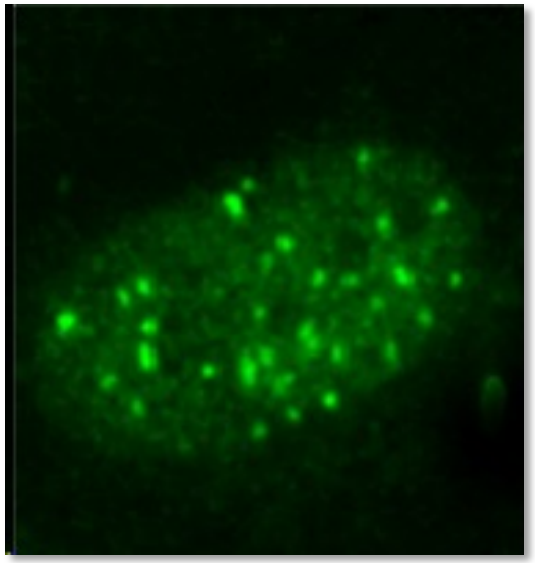


General and scientific context
Biological effects

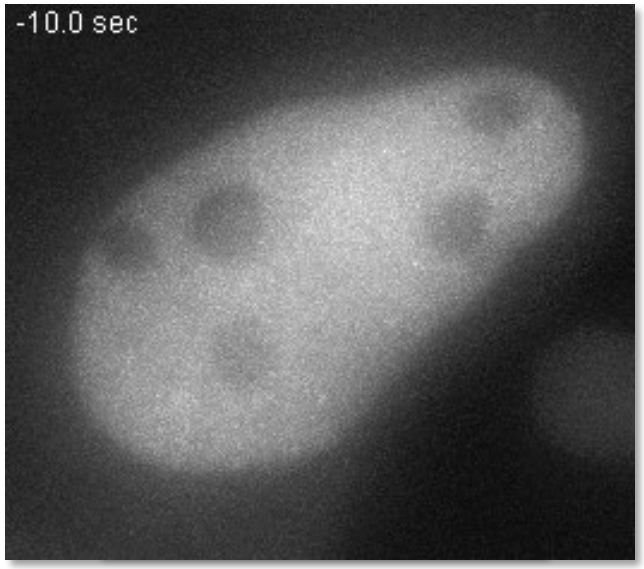


Heavy ions compared to photons

- high LET (linear energy transfer)
- high RBE (relative biological effectiveness)
- low OER (oxygen enhancement ratio)
- high mortality rate of tumor cells
- good activator of antitumor immunity
- more efficient to prevent angiogenesis and metastasis



X-rays



Heavy ion

[4-5]

Lung cancer heavy ion therapy CMOS tracking device

State of art

Combine CIRT with imaging techniques (PET/4D-CT)

Adjuvant chemotherapy drugs

Improvement needed for treatment planning and dose calculation because of lung movement

e CIRT with immunotherapy

Reducing technology / hospitalization / examination cost

General and scientific context

LET 1/3

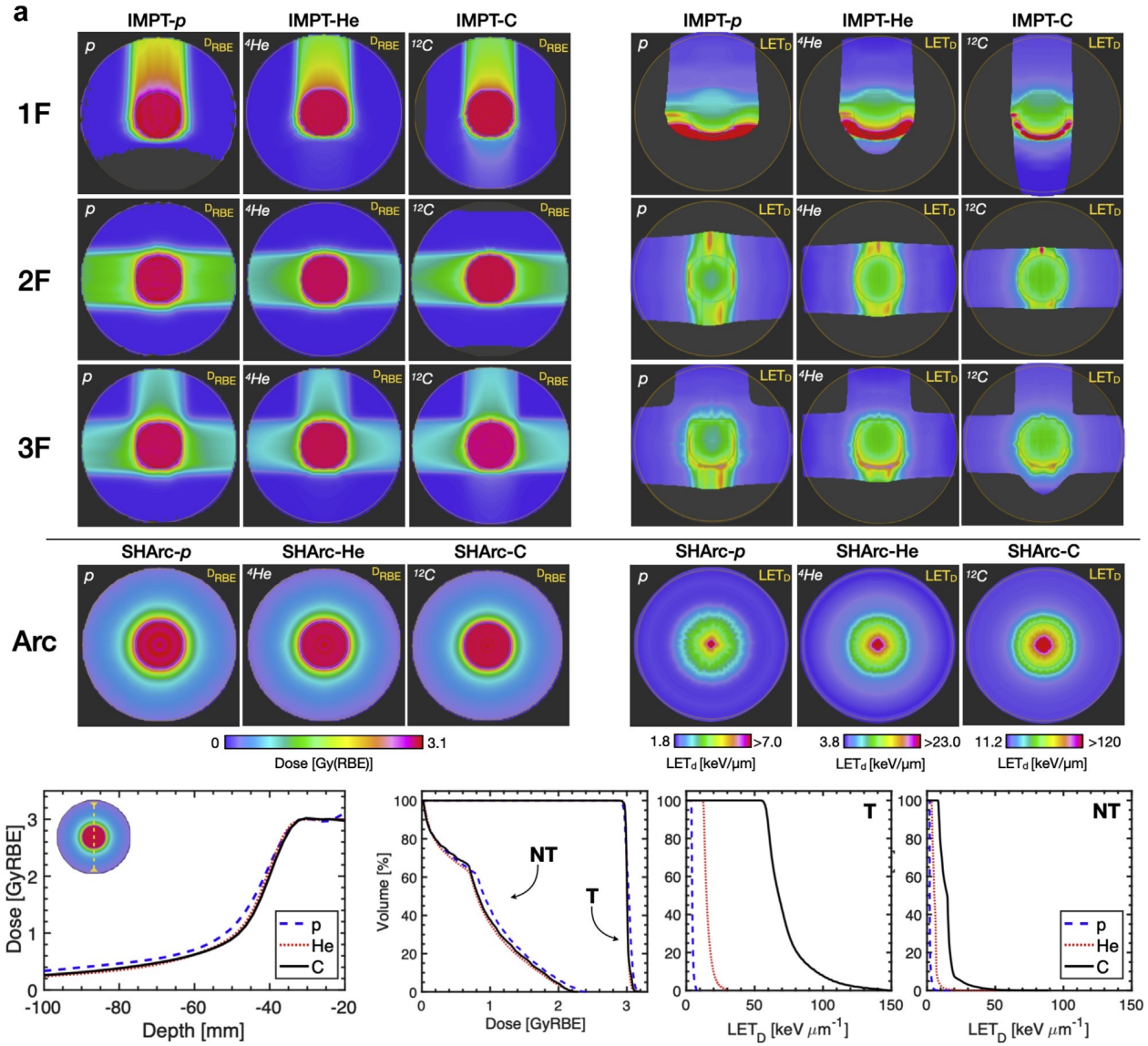


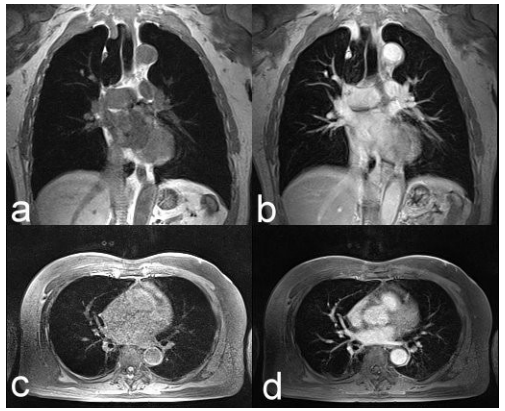
Figure - DRBE and dose-averaged linear energy transfer (LETD) maps for intensity modulated particle therapy (IMPT) versus spot- scanning hadron arc (SHArc). (a) Case A: optimization with target (T) and normal tissue (NT) constraints. (b) Case B: clinical-like scenario with planning target volume (PTV)/organs at risk (OAR) optimization. Both cases were conducted using 3 clinical ion beams (p, 4He, and 12C ions). Line profiles, dose volume histogram (DVH), and dose-averaged linear energy transfer volume histogram (LETDVH) are provided for intercomparison of SHArc plans (bottom panels). (c) Angular-fluence maps for SHArc-p, SHArc-He, and SHArc-C plans in cases A (top) and B (bottom) [16]

Overview

Treatment plan

Imaging

Define tumoral/targeted volume

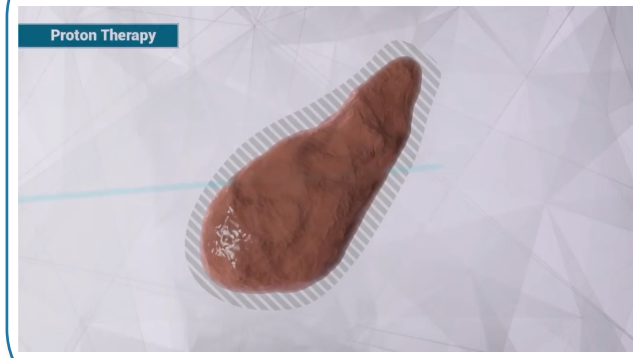


[6]

Treatment planning System (TPS)

[1]

Treatment



[1]

Monitoring with secondary protons

Corrections

Comparison between delivered dose and planned one

Uncertainties

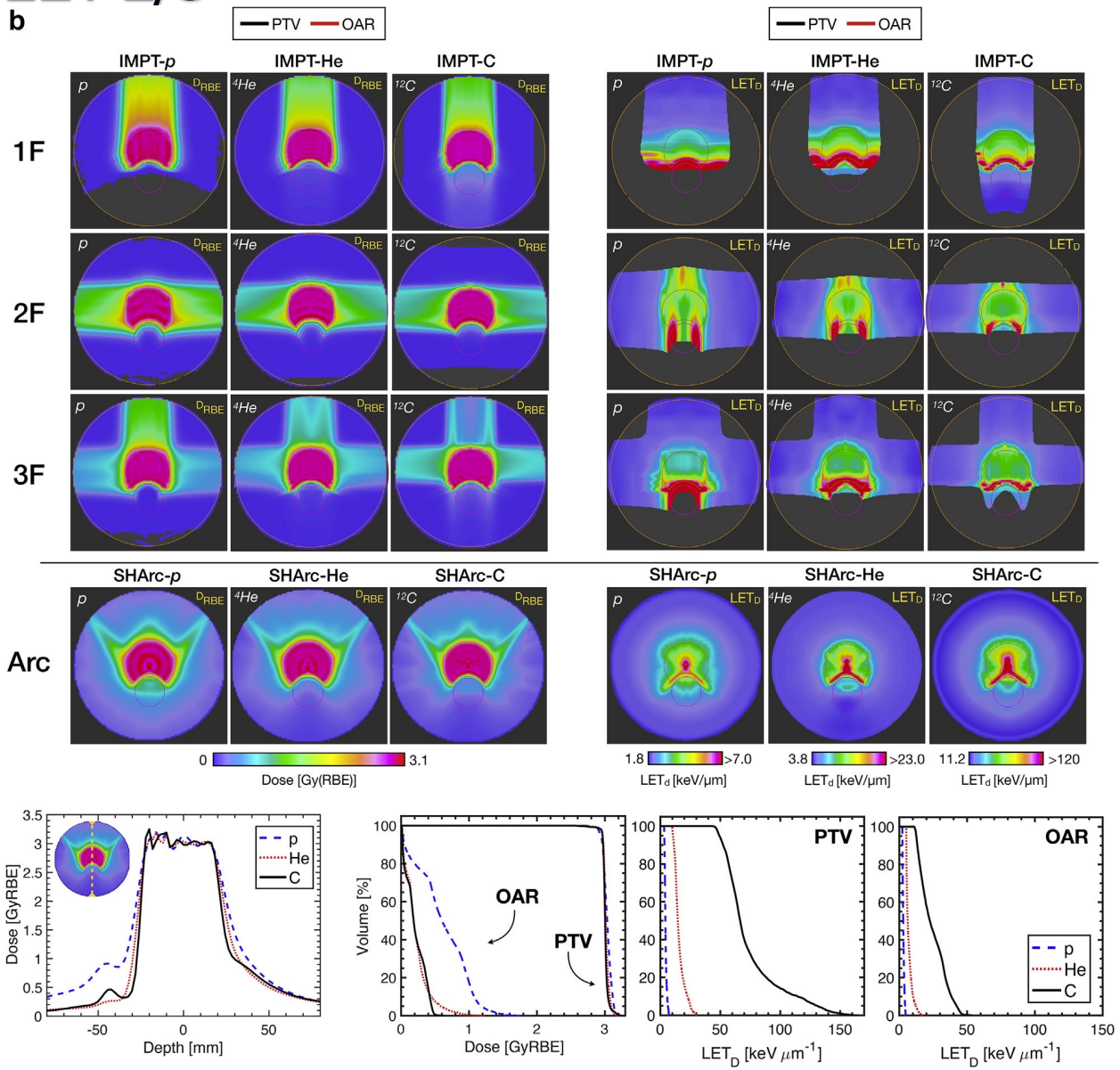
Physical dose calculation

Physical processes ↔ LET ↔ Biological processes

Margins

General and scientific context

LET 2/3



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General and scientific context
LET 3/3

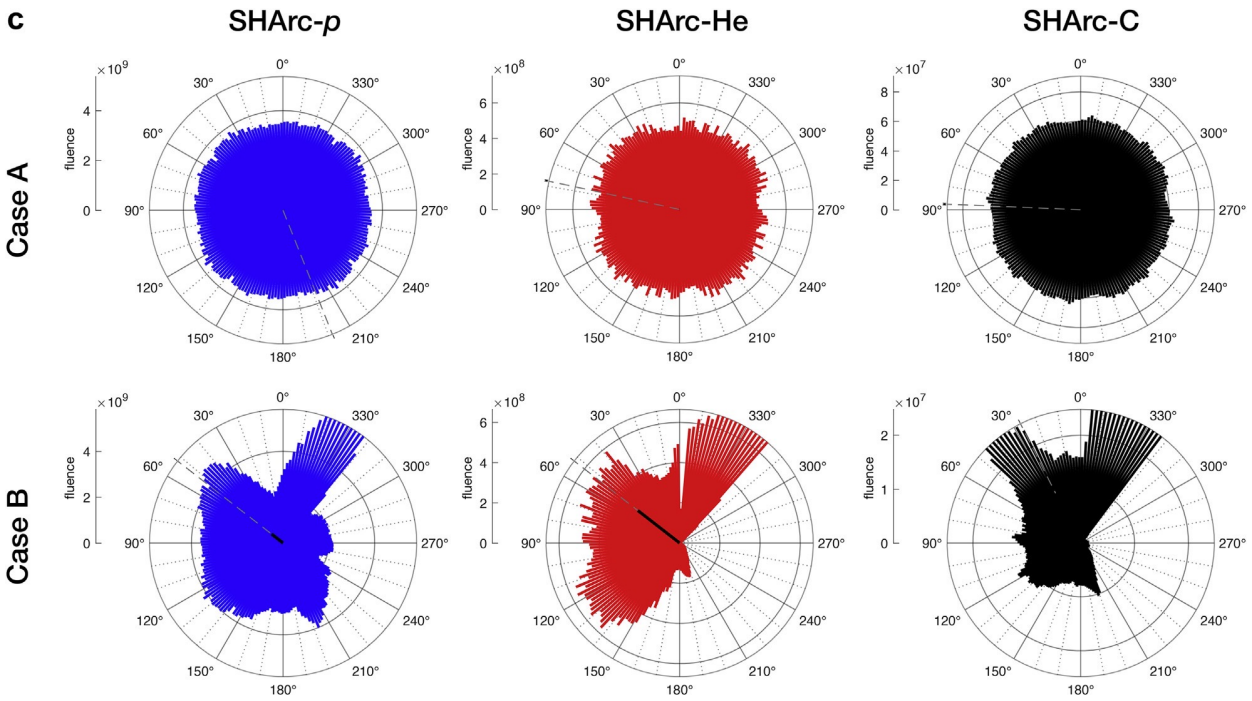
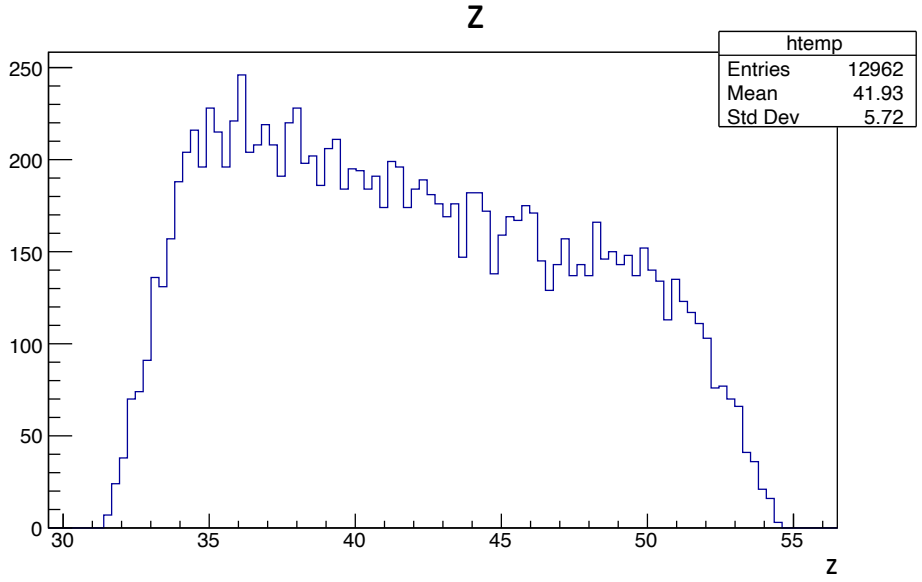
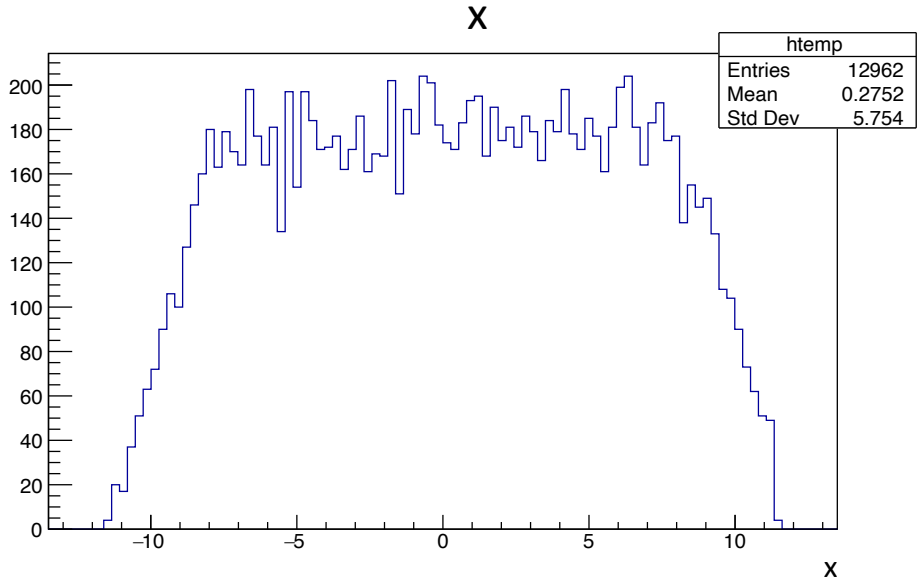


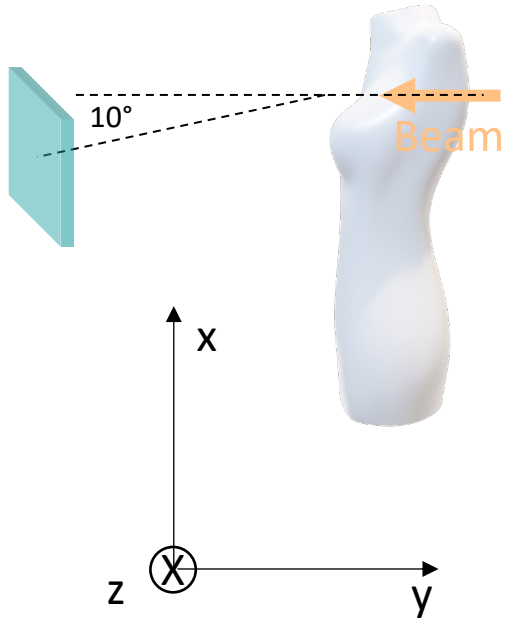
Figure - DRBE and dose-averaged linear energy transfer (LETD) maps for intensity modulated particle therapy (IMPT) versus spot- scanning hadron arc (SHArc). (a) Case A: optimization with target (T) and normal tissue (NT) constraints. (b) Case B: clinical-like scenario with planning target volume (PTV)/organs at risk (OAR) optimization. Both cases were conducted using 3 clinical ion beams (p, 4He, and 12C ions). Line profiles, dose volume histogram (DVH), and dose-averaged linear energy transfer volume histogram (LETDVH) are provided for intercomparison of SHArc plans (bottom panels). (c) Angular-fluence maps for SHArc-p, SHArc-He, and SHArc-C plans in cases A (top) and B (bottom) [16]

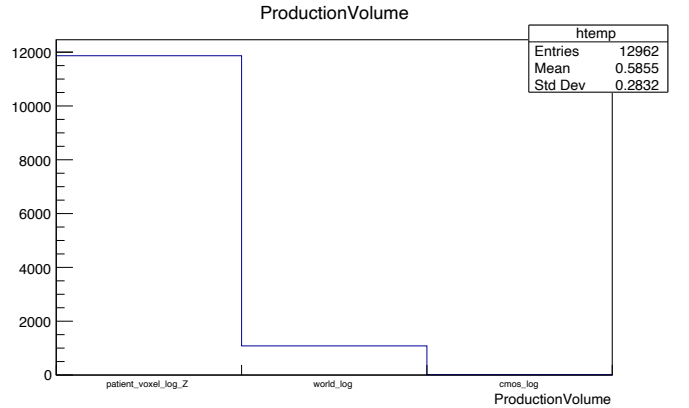
Lung cancer heavy ion therapy CMOS tracking device

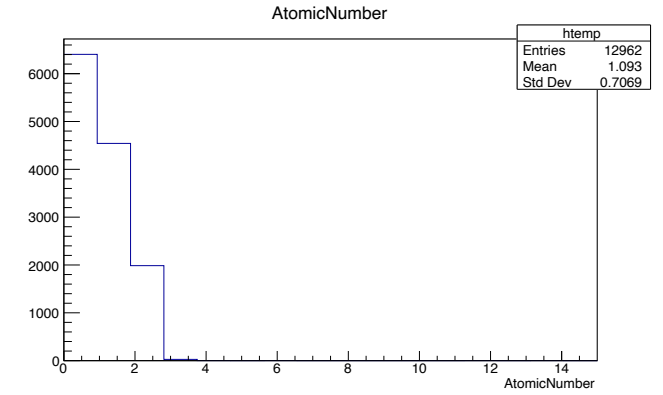
GATE simulation

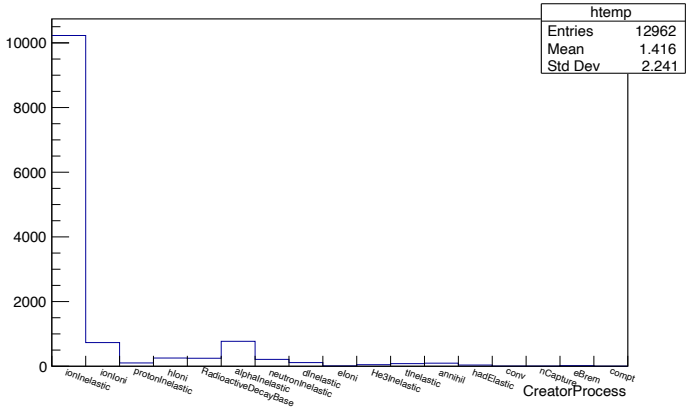






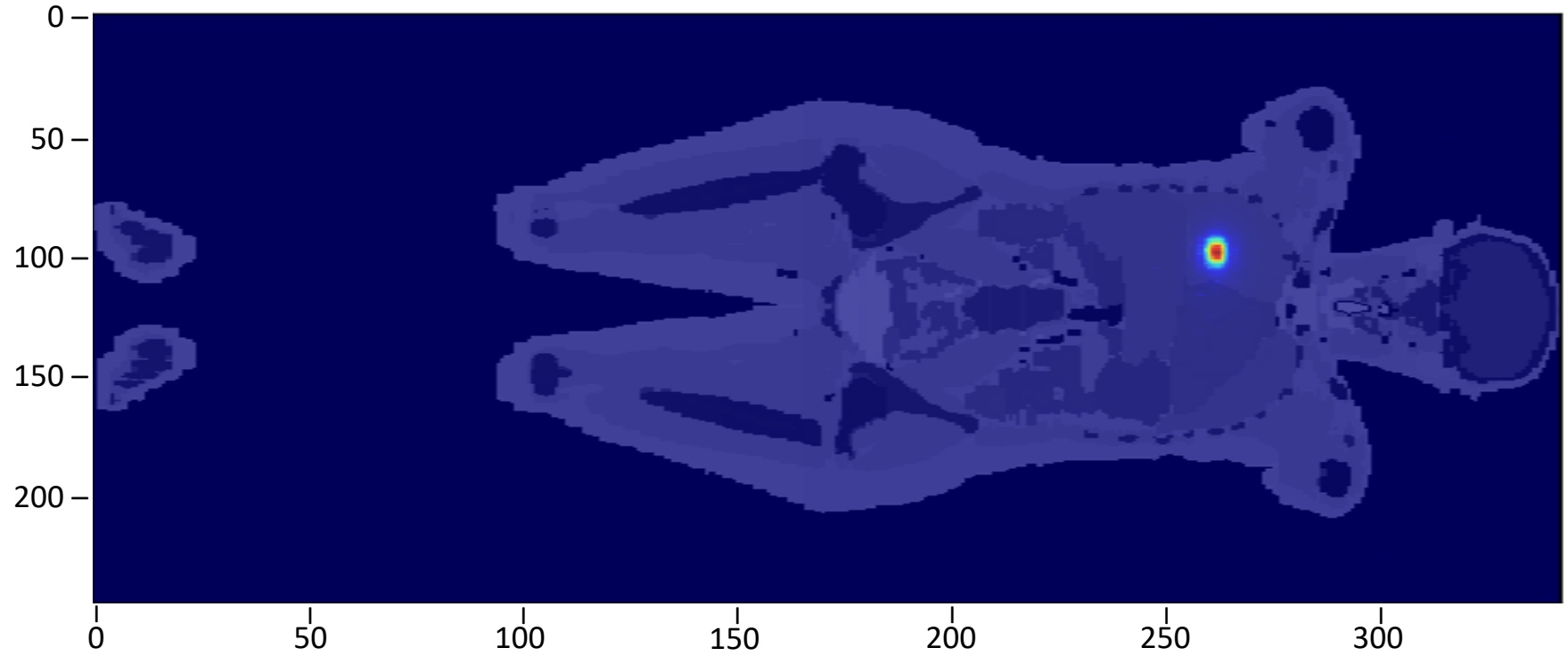


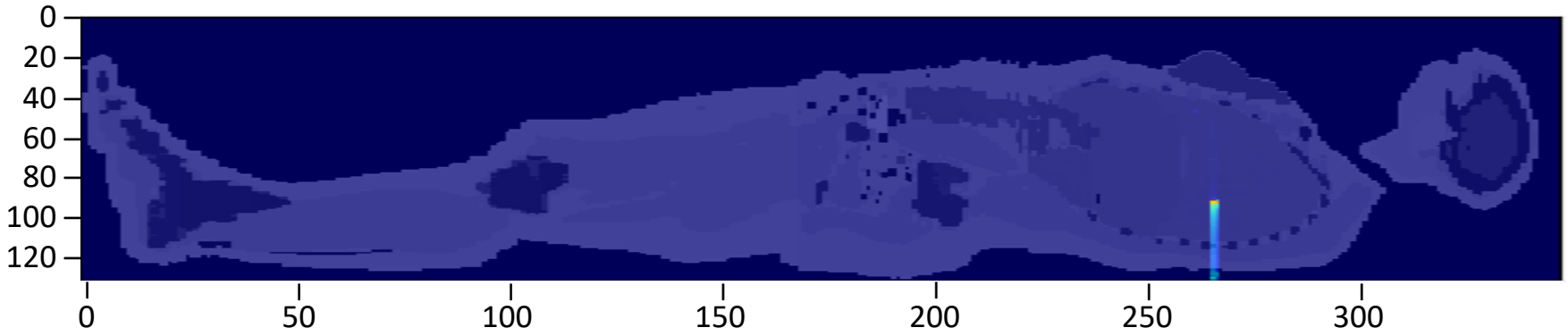


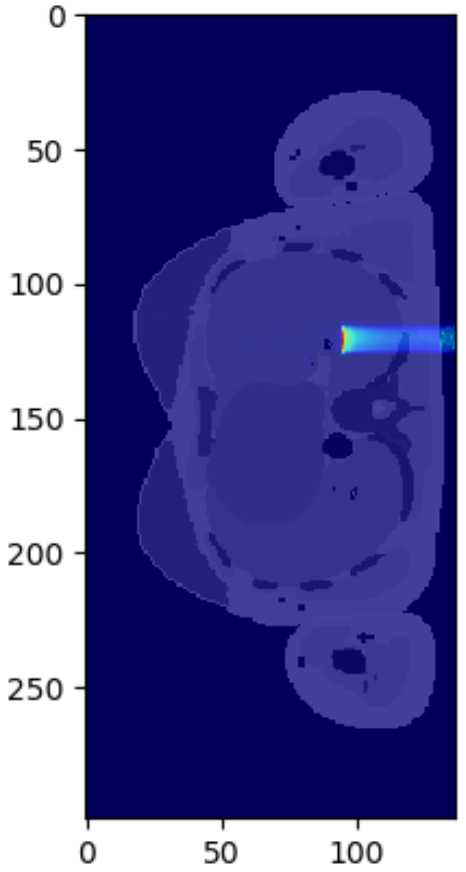


Monitoring with secondary particles

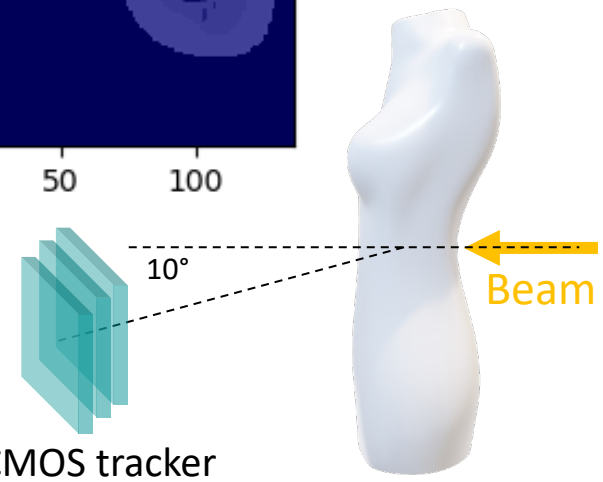
GATE simulation





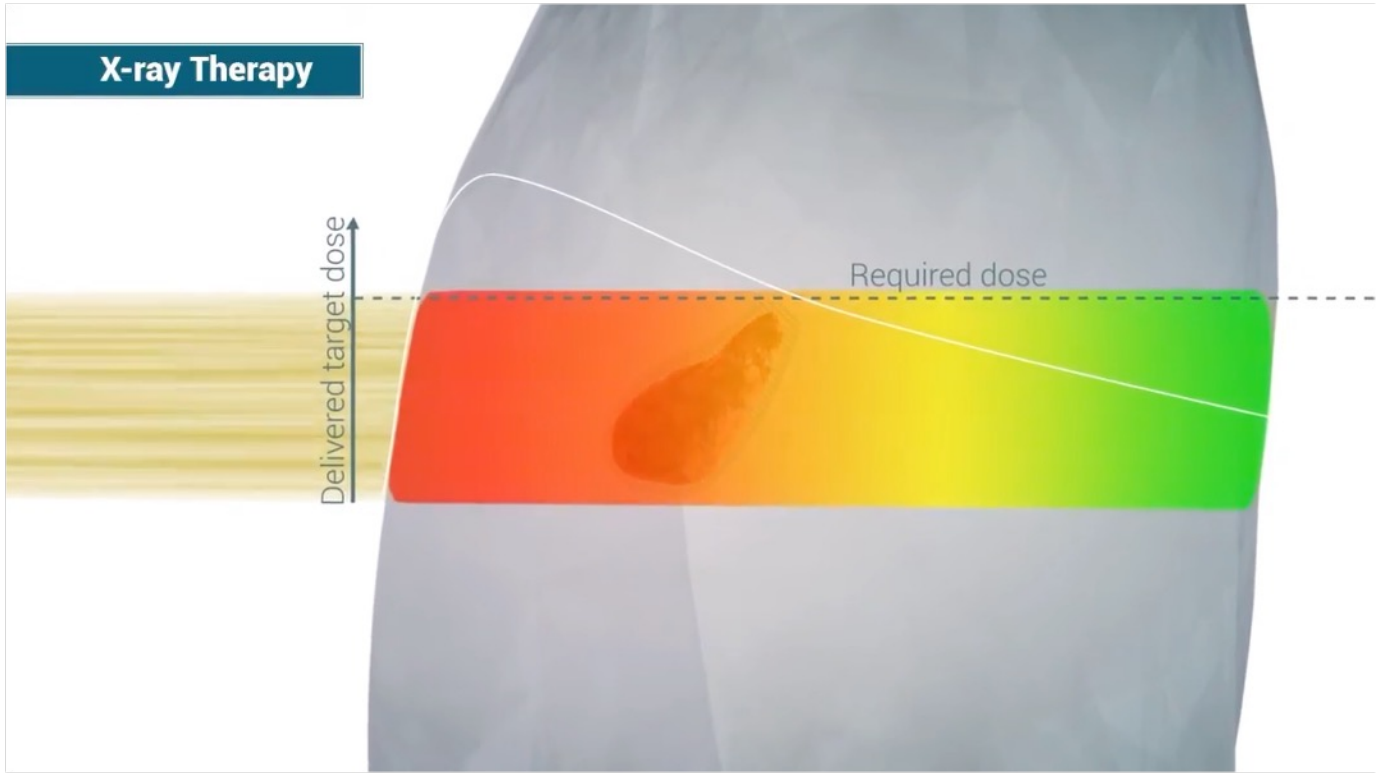


Gate simulation on human phantom with a Carbon ion beam 170 MeV/u



Lung cancer heavy ion therapy treatment

Radiotherapy



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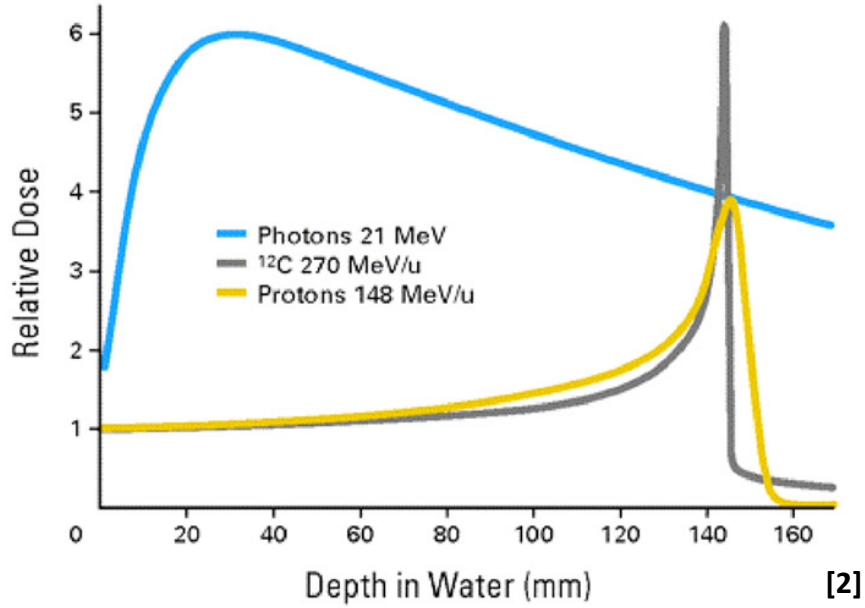
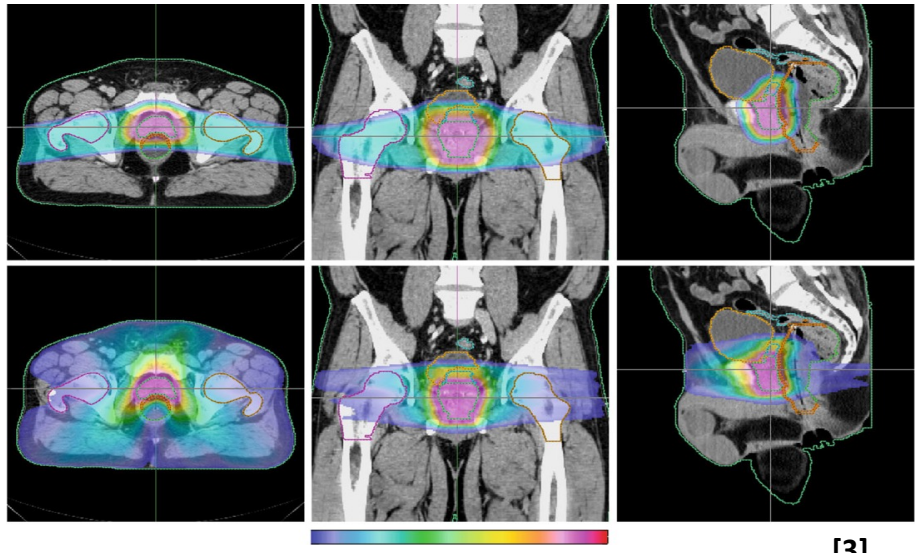


[2]

Carbons

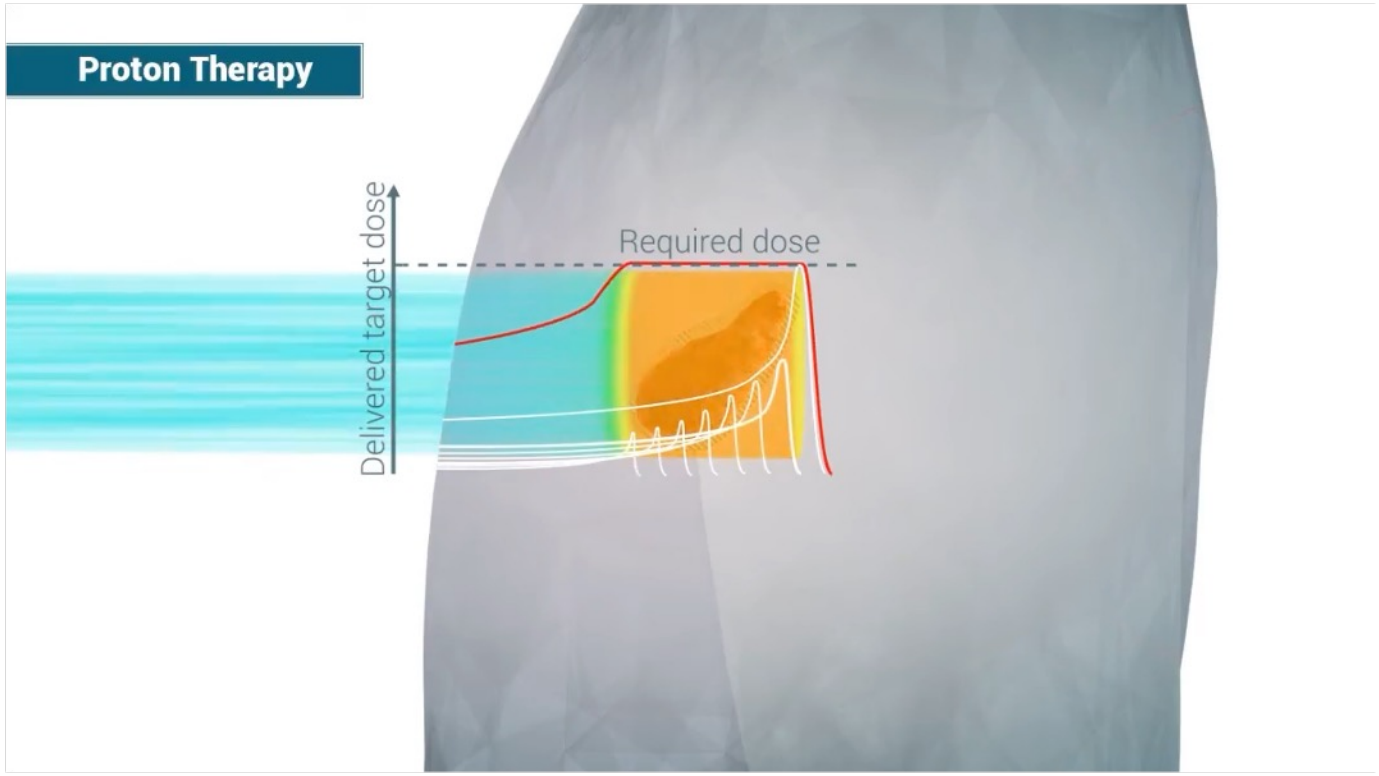
X-rays



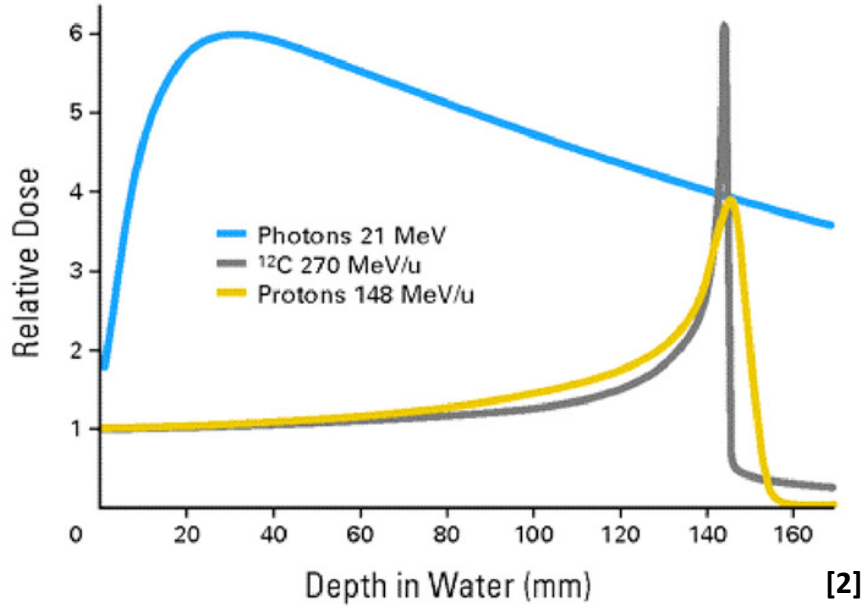
[3]

Lung cancer heavy ion therapy treatment

Radiotherapy



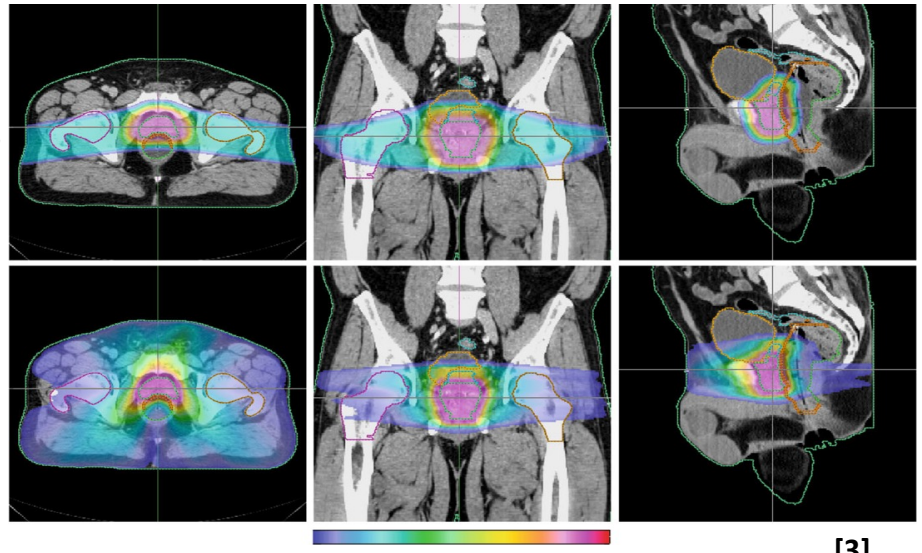
[1]



[2]

Carbons

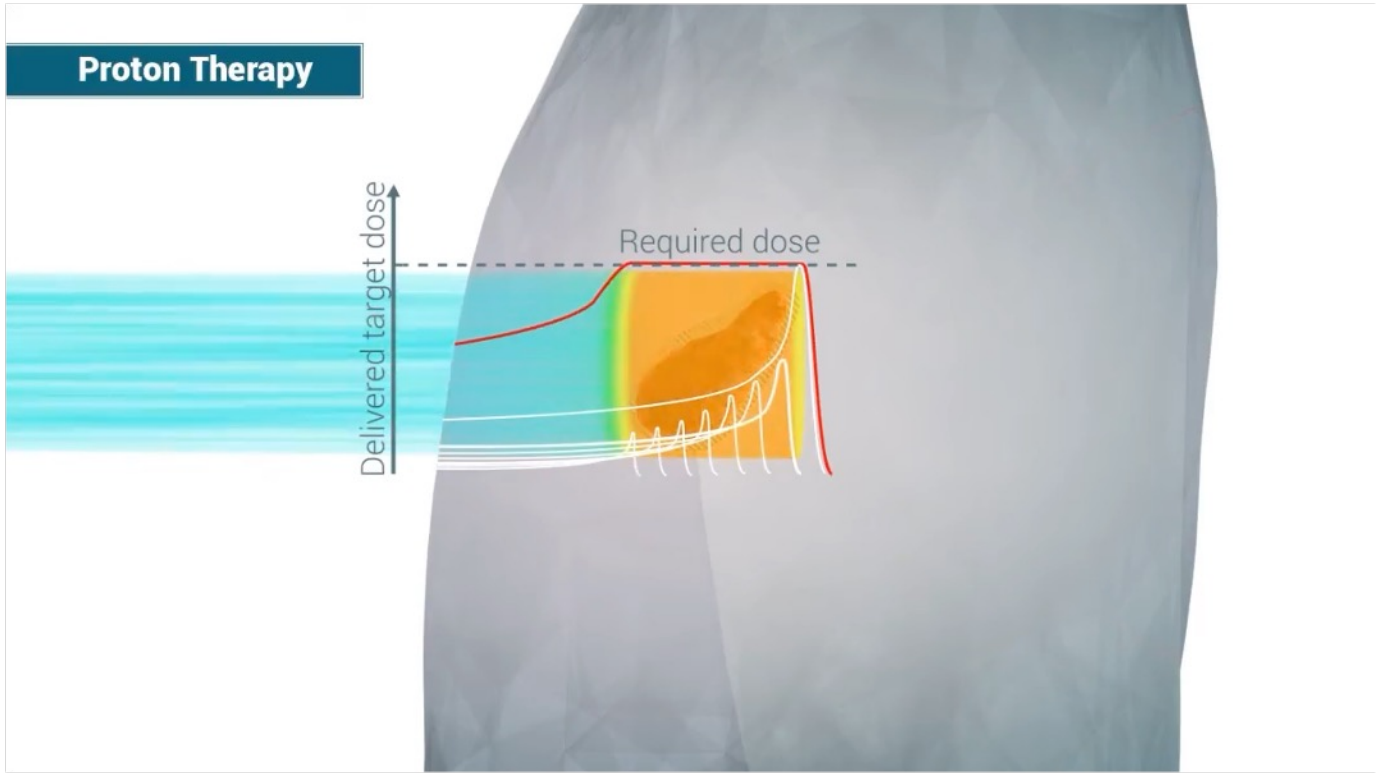
X-rays



[3]

Lung cancer heavy ion therapy treatment

Radiotherapy



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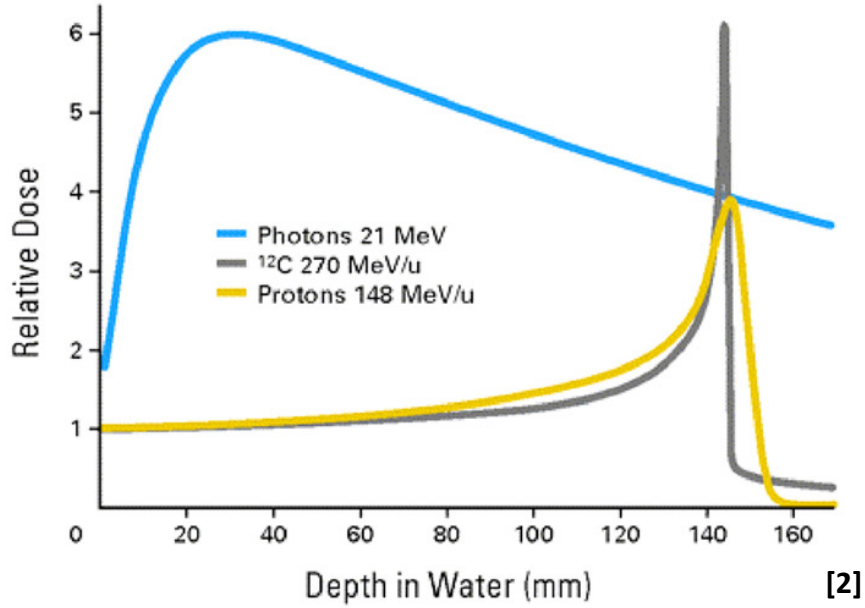

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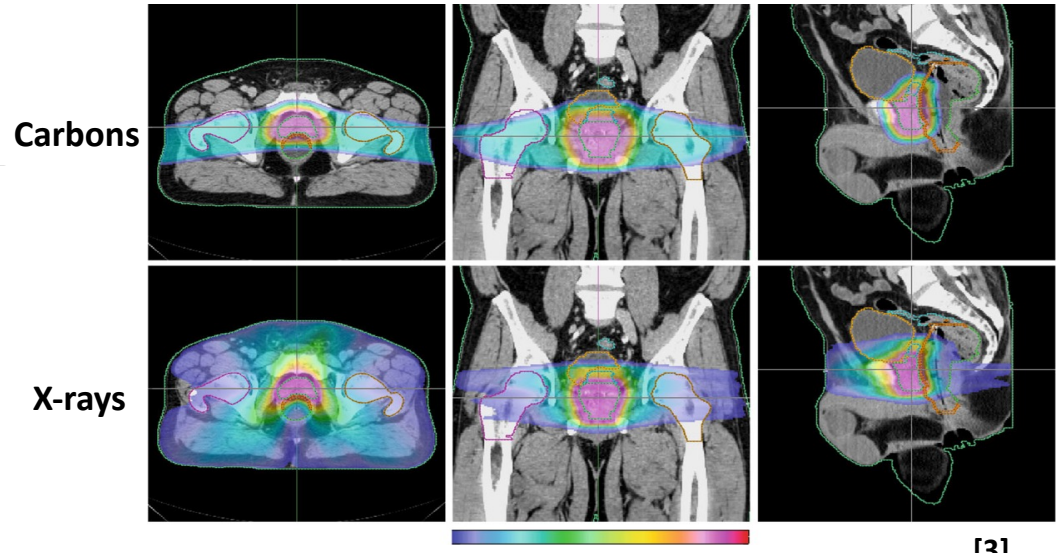

[3]

- **Heavy ion**
  - Less damage to surrounding tissue
  - Lower scattering of the beam
  - Higher biological effect
  - But dose after Bragg peak