Anthem
AdvaNced Technologies for Human-centEred Medicine

End of the Year Seminar

UNIVERSITÀ DI PAVIA

Smart BNCT Planning: When Artificial Intelligence Meets Radiobiology

Cristina Pezzi

Università degli Studi di Pavia

17th September 2025

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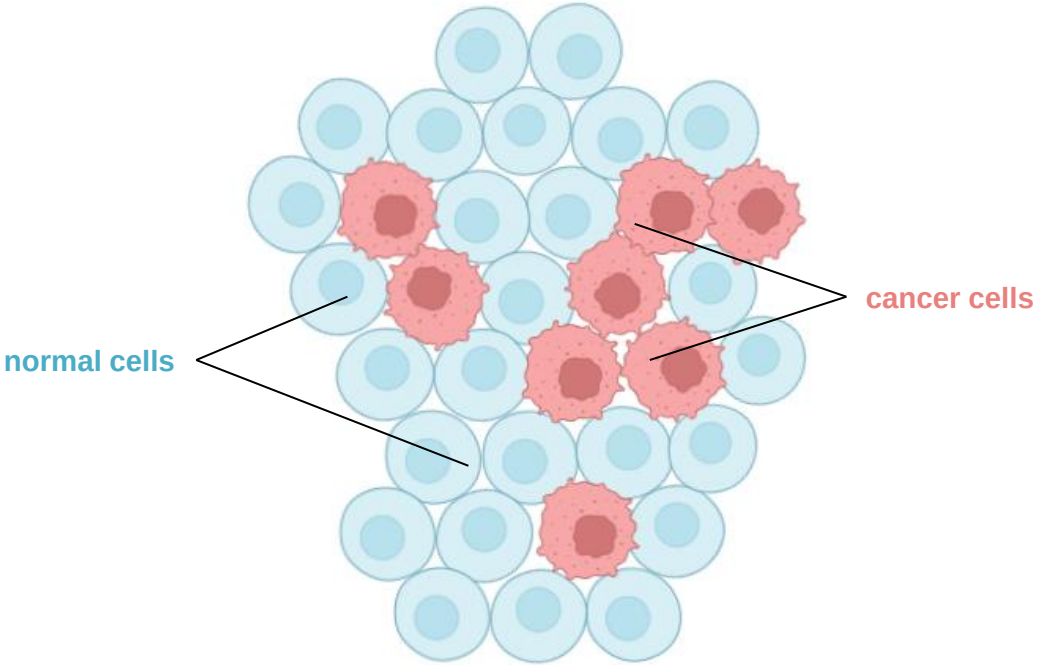
PhD Project by Cristina Pezzi

State of Art : Boron Neutron Capture Therapy (BNCT)



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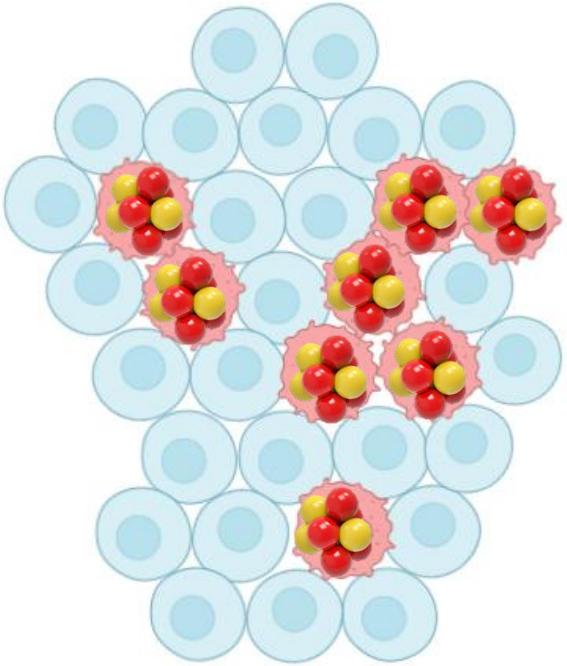
State of Art : Boron Neutron Capture Therapy (BNCT)

- ✓ Boron-10 atoms



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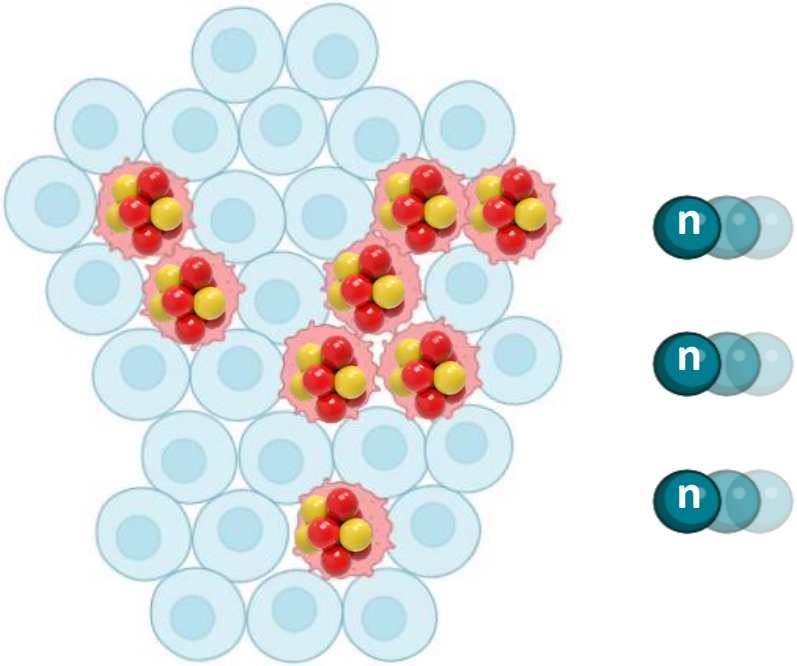
- ✓ Boron-10 atoms
- ✓ Thermal neutron beam



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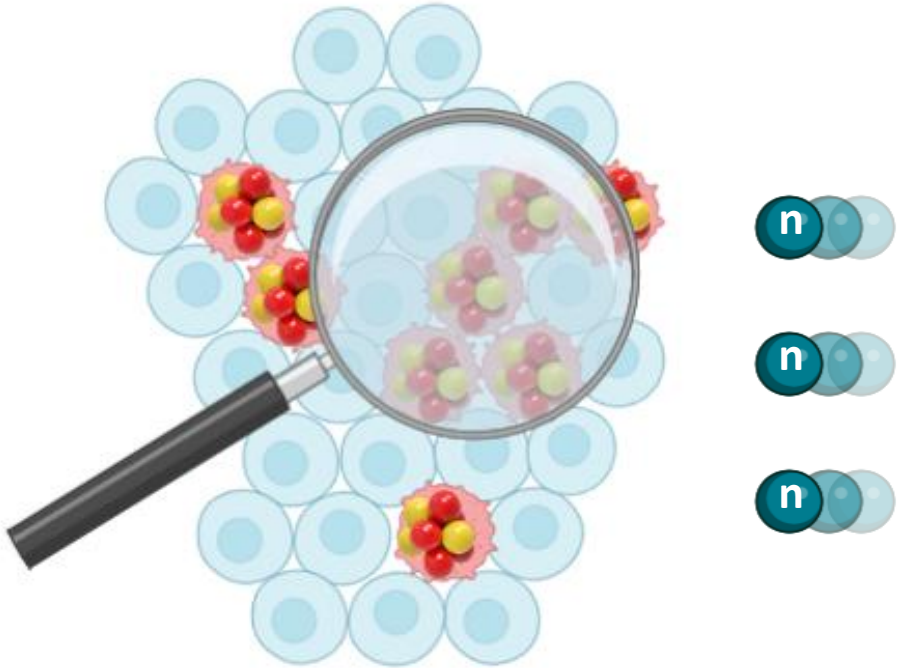

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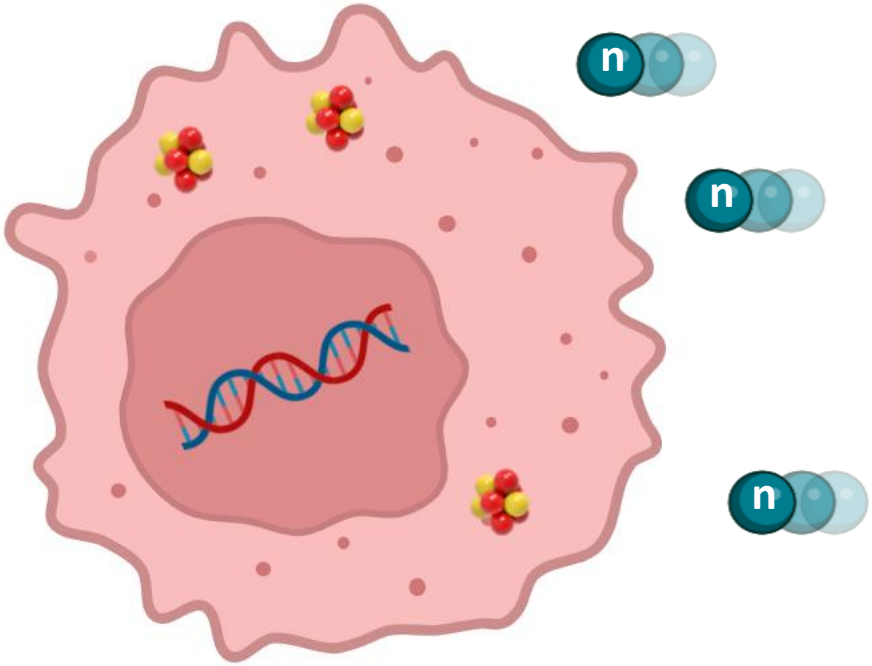

$$^{10}B(n,\alpha)^{7}Li$$

$$^{10}B + n \longrightarrow {}^{11}B \longrightarrow {}^{7}Li^{*} + {}^{4}He + 2.31 \text{ MeV}$$

$$^{7}Li^{*} \longrightarrow {}^{7}Li + \gamma + 0.478 \text{ MeV} \qquad [BR = 93.9\%]$$

$$^{10}B + n \longrightarrow {}^{11}B \longrightarrow {}^{7}Li + {}^{4}He + 2.79 \text{ MeV} \qquad [BR = 6.1\%]$$

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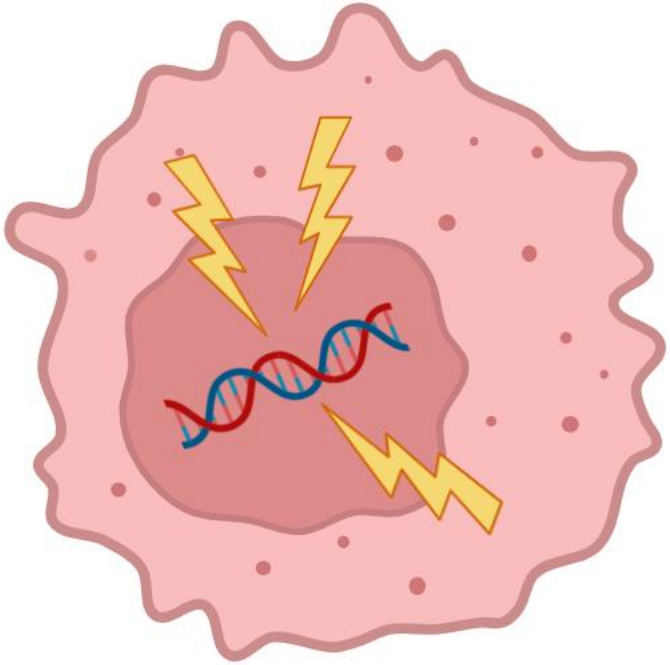

$$^{10}B(n,\alpha)^{7}Li$$

High LET radiations

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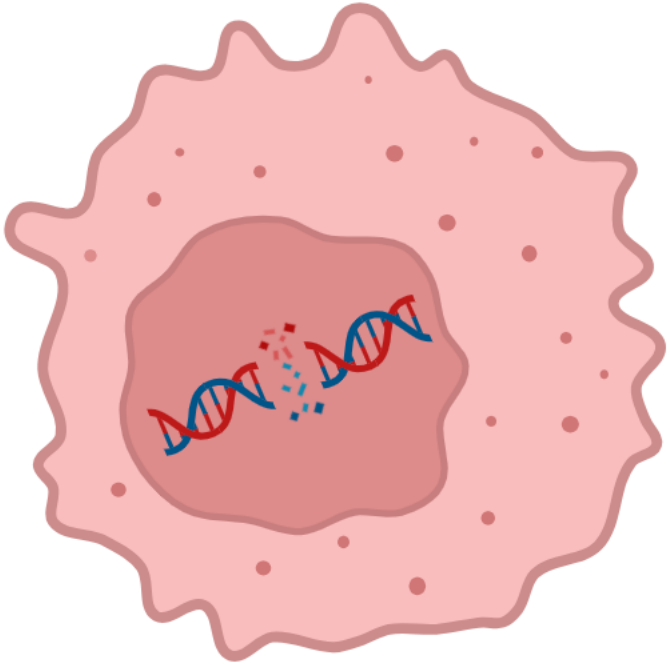

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High LET radiations

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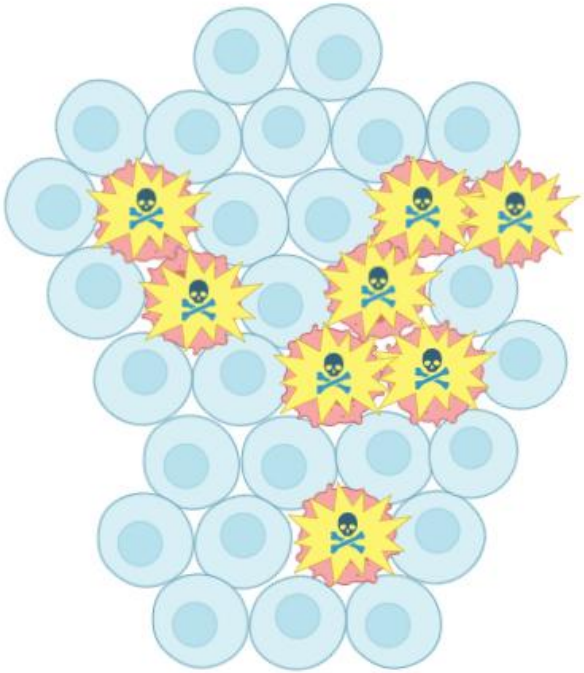

Short range radiations

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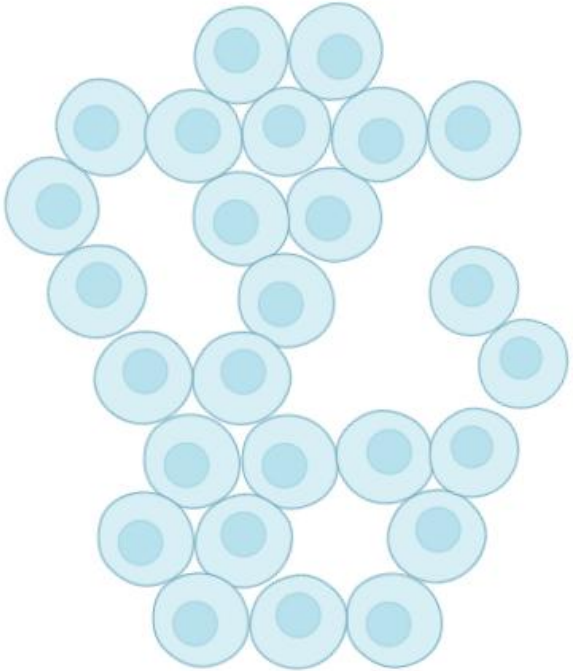

Short range radiations

High Selectivity

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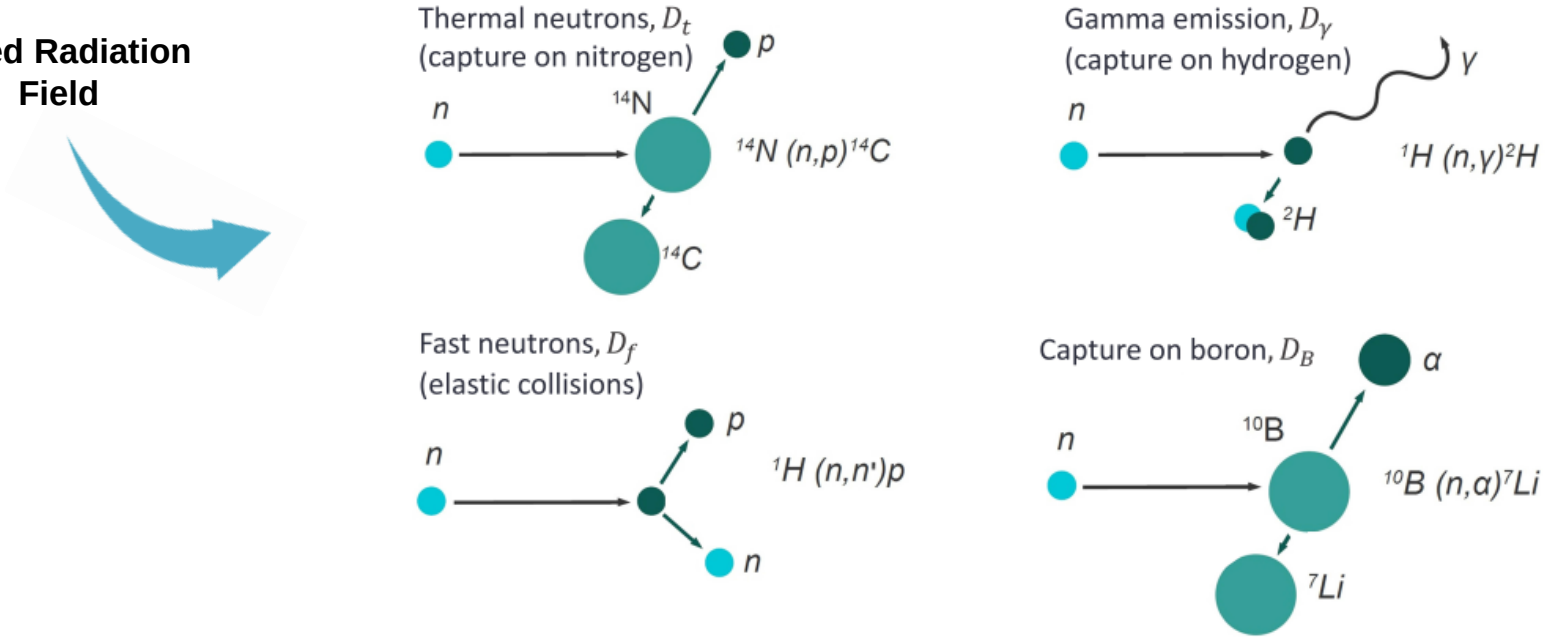
Mixed Radiation Field



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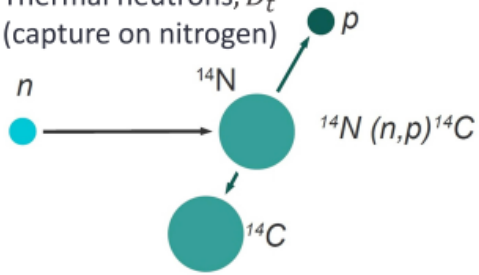
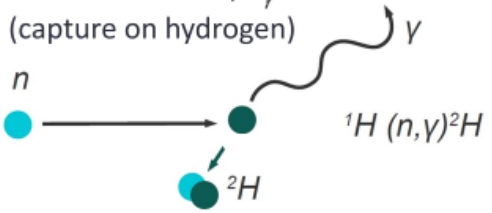
Mixed Radiation Field

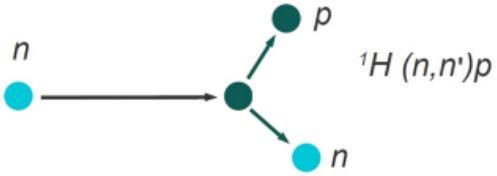
Thermal neutrons, D_t
(capture on nitrogen)



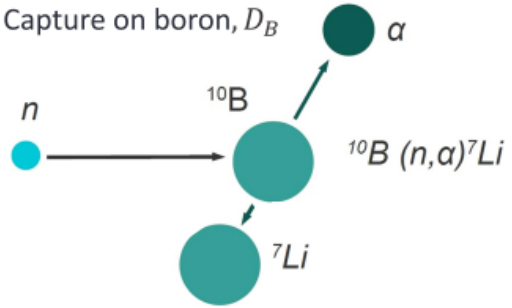
Gamma emission, D_γ
(capture on hydrogen)



Fast neutrons, D_f
(elastic collisions)



Capture on boron, D_B



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Dosimetric Models

✓ ***RBE-weighted Dose Model***

$$D_w = CBE \cdot D_B + RBE_{th} \cdot D_{th} + RBE_f \cdot D_f + RBE_\gamma \cdot D_\gamma \quad \Rightarrow \quad RBE_X = \frac{D_R}{D_X}$$

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Dosimetric Models

✓ ***Photon Isoeffective Dose Model***

$$D_R(D_1,\ldots,D_4)=\frac{1}{2}\frac{\left(\frac{\alpha}{\beta}\right)_R}{G_R}\times\left(\sqrt{1+\frac{4G_R}{\alpha_R\left(\frac{\alpha}{\beta}\right)_R}\left(\sum_{i=1}^{4}\alpha_i D_i+\sum_{i=1}^{4}\sum_{j=1}^{4}G_{ij}(\theta)\sqrt{\beta_i\beta_j}D_iD_j\right)}-1\right)$$

The survival dose-response relationship is described by ***linear quadratic model*** that accounts for dose-rate dependent ***sublesion repair***

Radiation synergism, the survival dose-response is modulated by Lea-Catcheside factors *G* for simultaneous mixed irradiation

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Dosimetric Models

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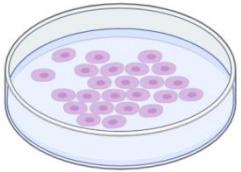
2D CELL CULTURE



How can we apply it in clinic ?

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State of Art : Treatment Planning System (TPS)

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State of Art : Treatment Planning System (TPS)

Image Processing → Region of Interest (ROI) Identification → Patient Modeling → Monte Carlo Simulations → Dosimetric Analysis

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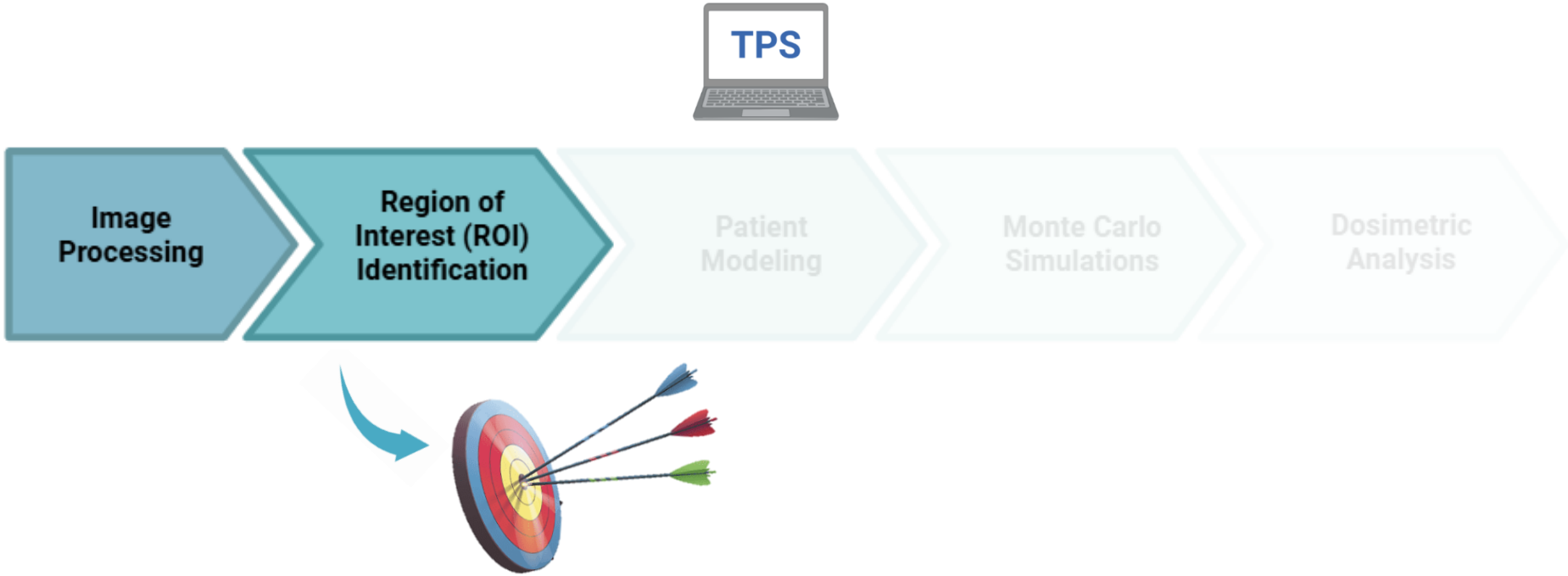

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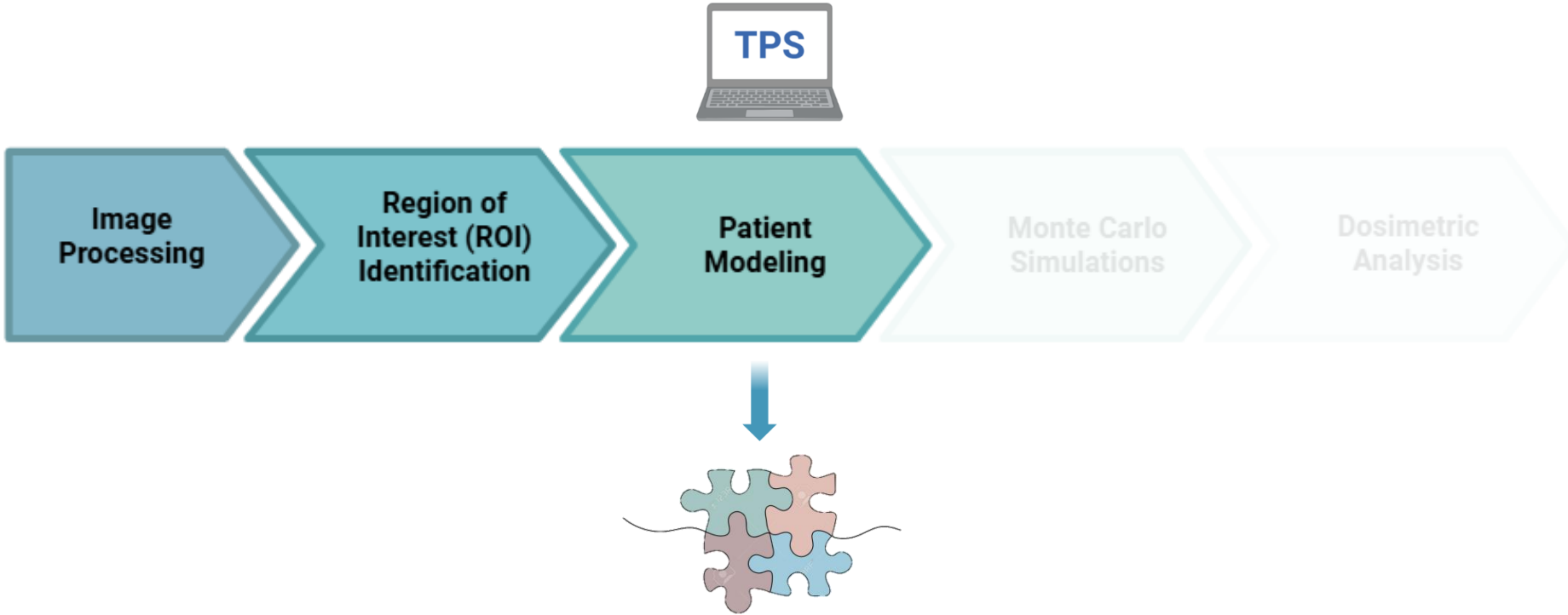

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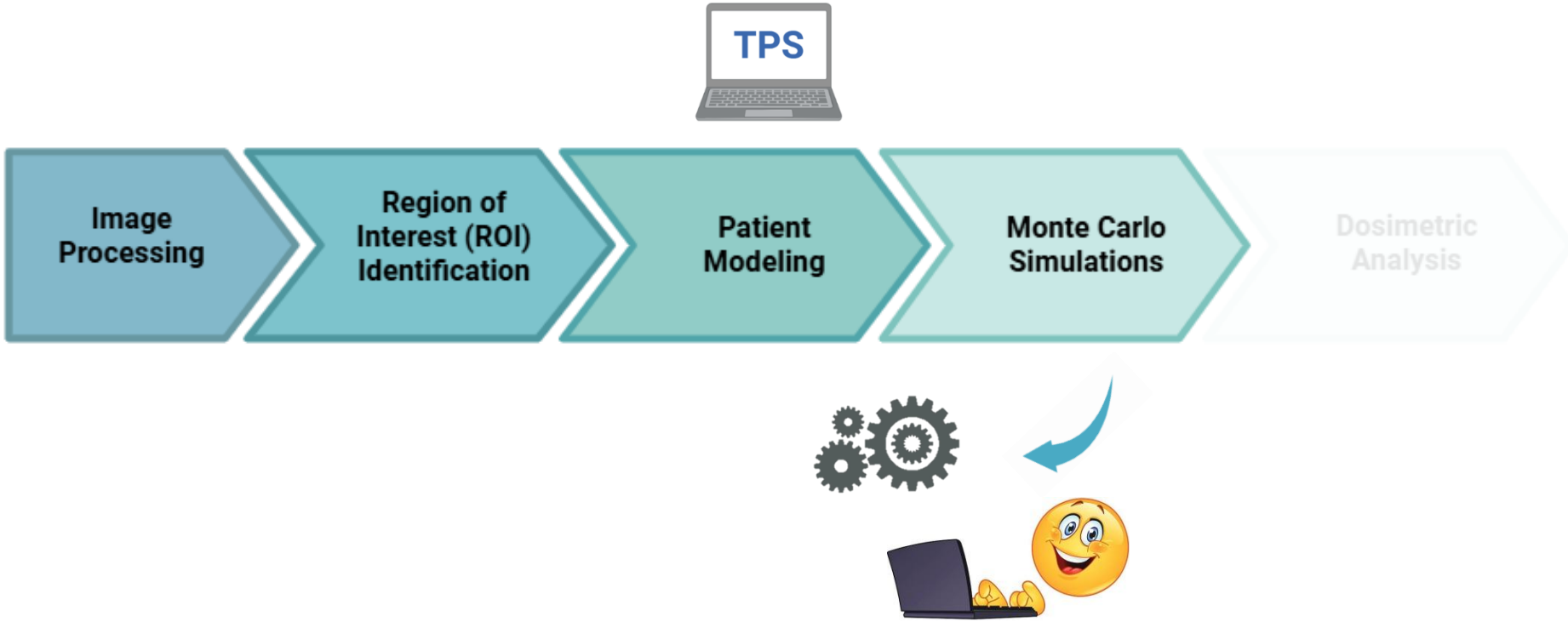

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What is the State of Art of TPS ?

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State of Art : Treatment Planning System (TPS)

MacNCTPlan (1990, MIT – USA)

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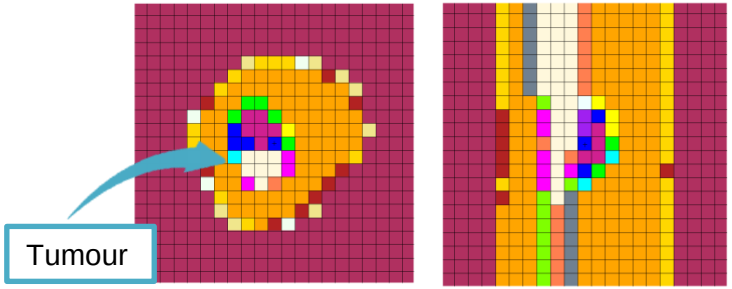

Voxel size = 1 cm^3

56 materials (mixture of air, bone,
normal soft tissue, tumor soft tissue)

MCNP as Monte Carlo simulation code

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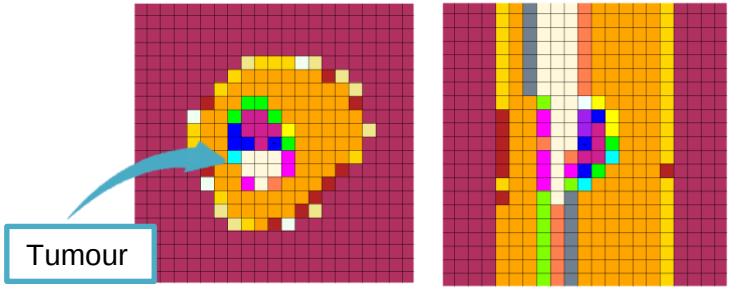

Voxel size = 1 cm^3 → TOO BIG!

56 materials (mixture of air, bone, normal soft tissue, tumor soft tissue) → BIG UNCERTAINTIES (calculation error above 20%)!

MCNP as Monte Carlo simulation code → LONG CALCULATION TIME!

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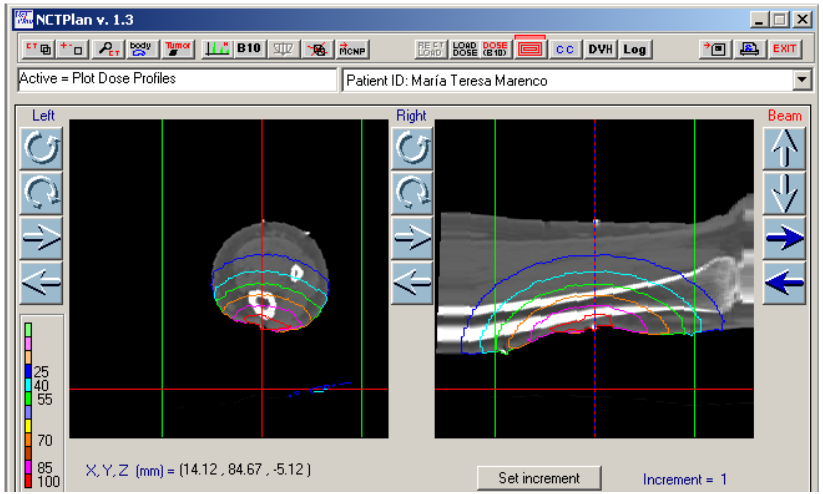
State of Art : Treatment Planning System (TPS)

NCTPlan (2002, Argentina + MIT)

Superimposition of dose contours on CT images → IMPROVEMENT OF DOSE VISUALIZATION



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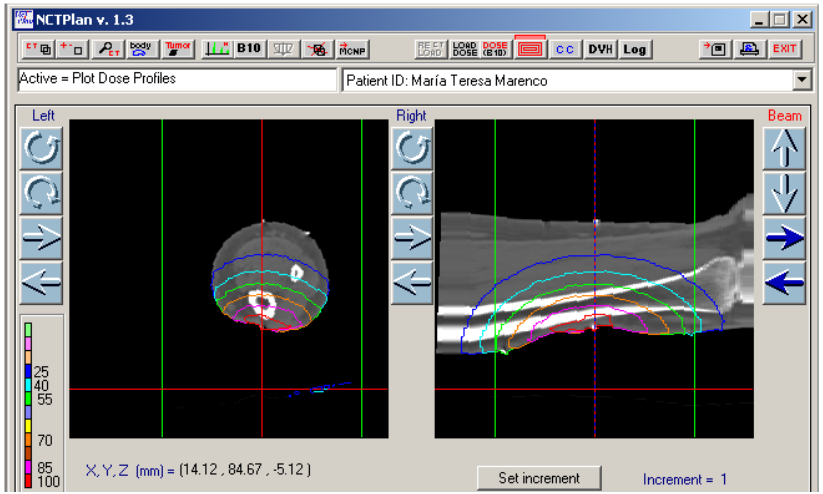

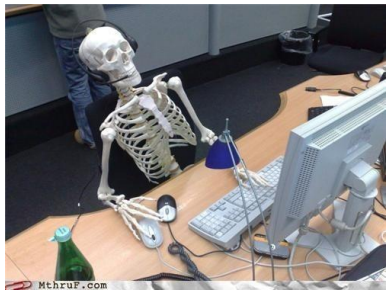

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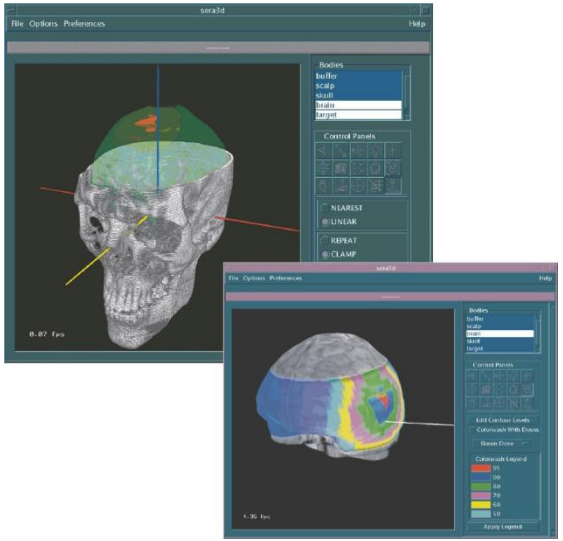
State of Art : Treatment Planning System (TPS)

SERA (1999, Idaho National Engineering and Environmental Laboratory + Montana State University)

Seven modules covering processes

modeling, MC calculation, dose results visualization



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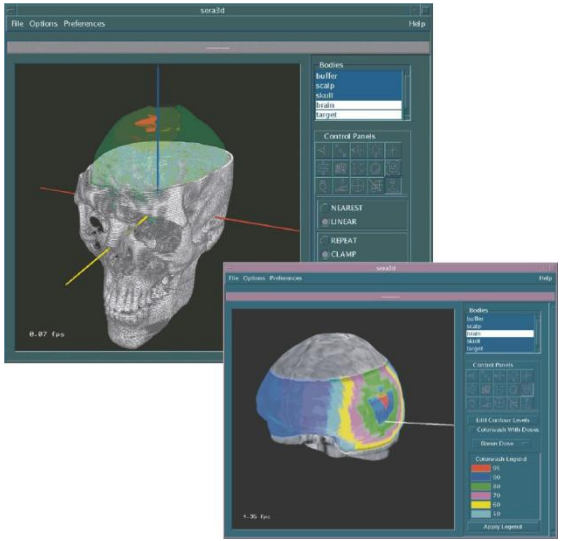

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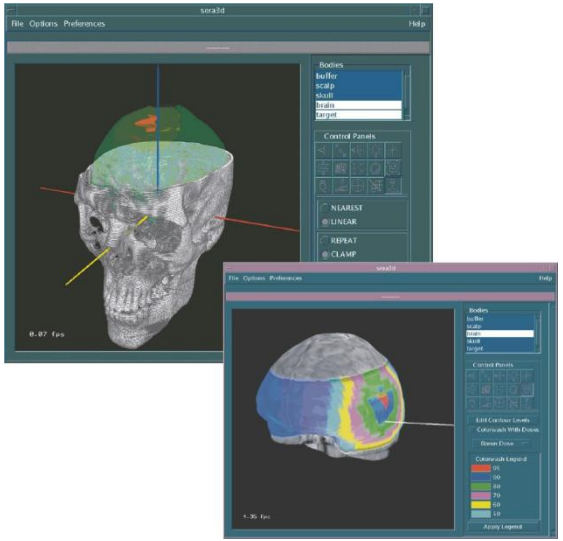
SeraMC



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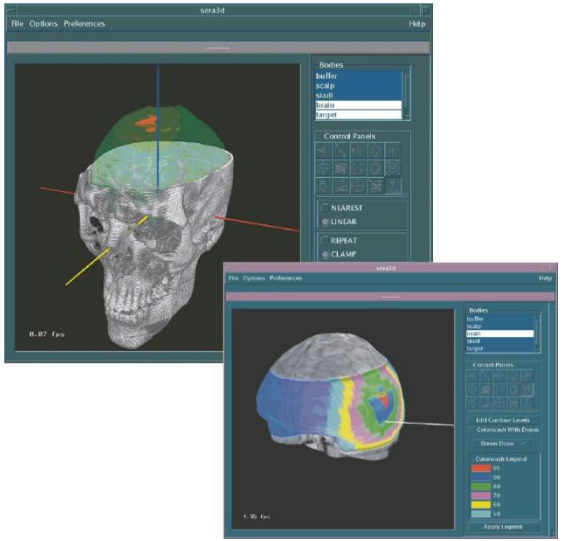
Parallel computing



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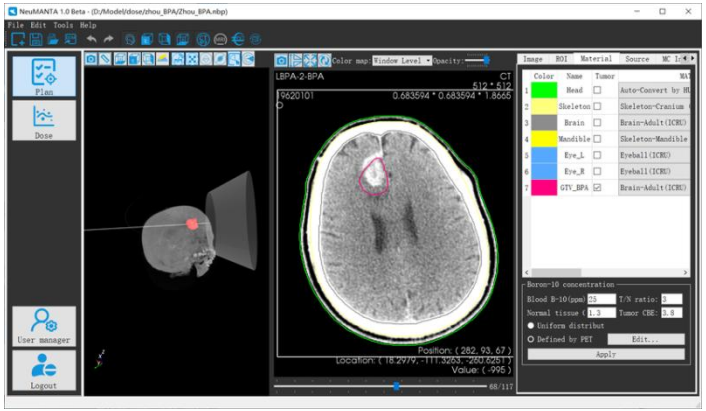
State of Art : Treatment Planning System (TPS)

NeuMANTA (2022, China Neuboron Medical Group)

Three modules: model building, MC calculation, and dose calculation



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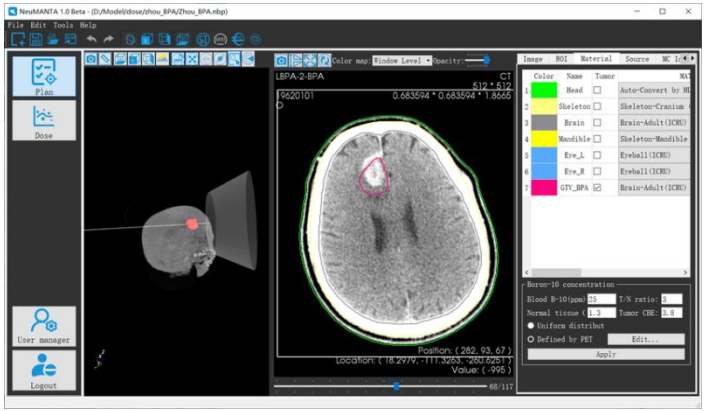
Three modules: model building, MC calculation, and dose calculation

capability to read CT, MRI and PET images (material definition)

heterogeneous boron distribution in patients through PET images



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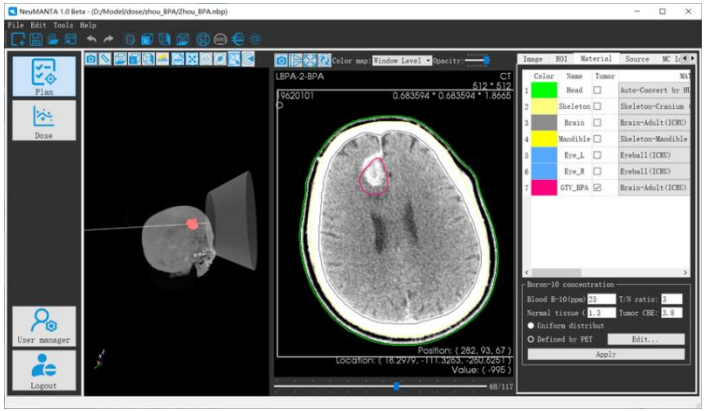
self-developed MC engine COMPASS (high calculation efficiency)



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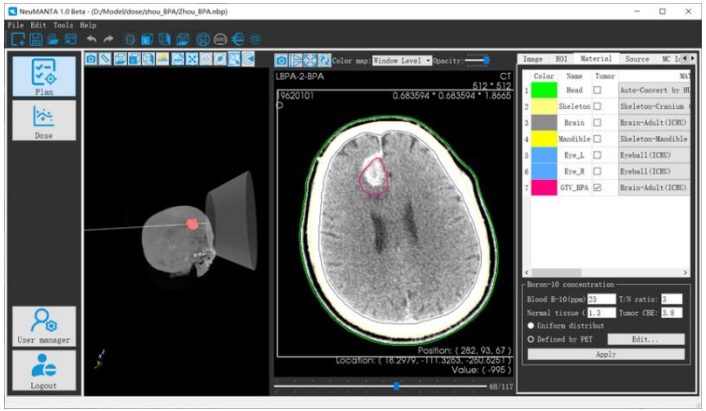
Isodose curves and Dose Volume Histograms (DVH)



What Can We Add Next ?

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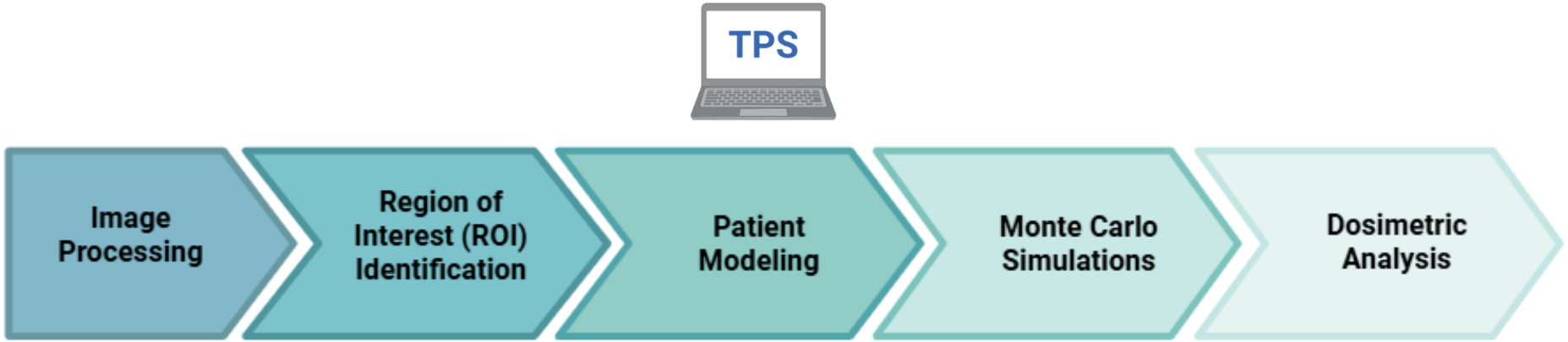

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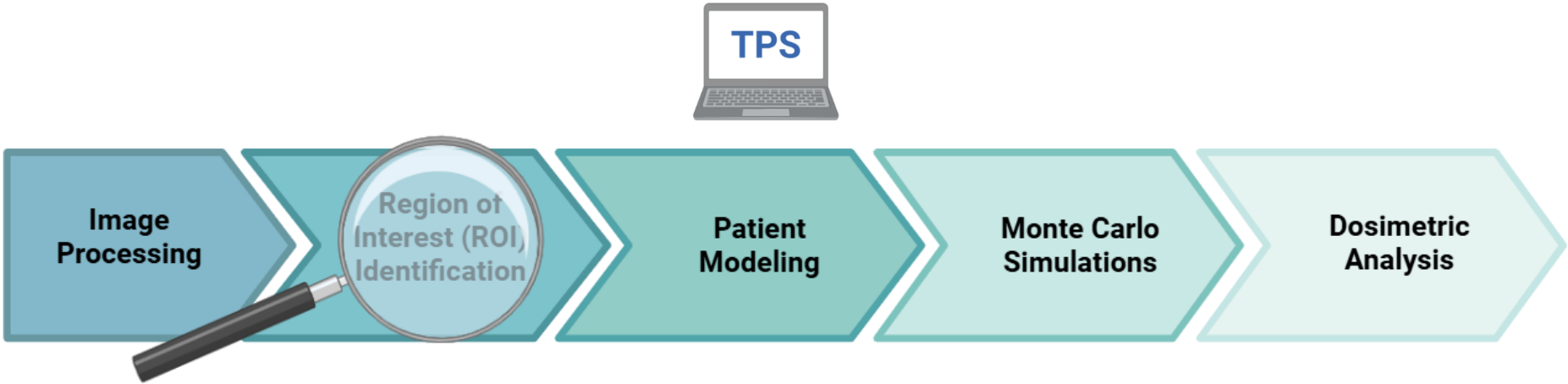

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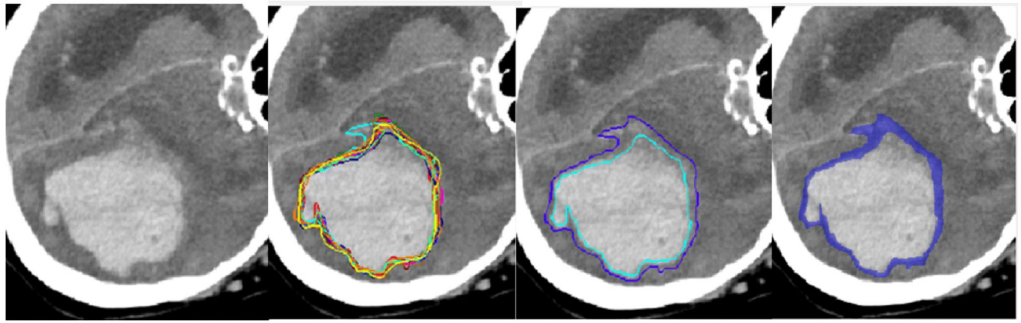
State of Art : ROI Identification

Manual Contouring



Intra-observer variability (differences among contours delineated by a single observer on the same target volume at several different tries)

Time-consuming technique

Inter-observer variability (differences among contours delineated by multiple observers on the same target volume)

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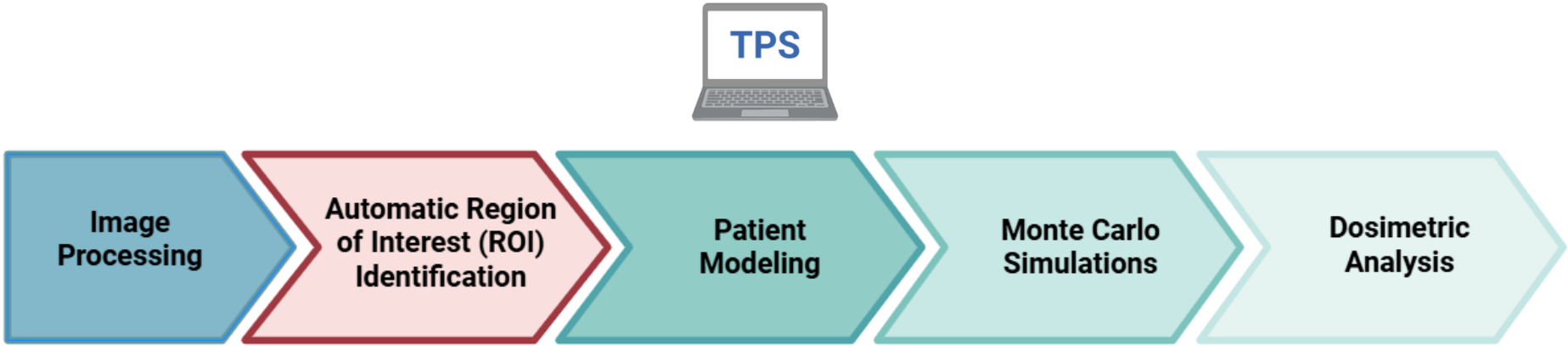
New Goal : Treatment Planning System (TPS)



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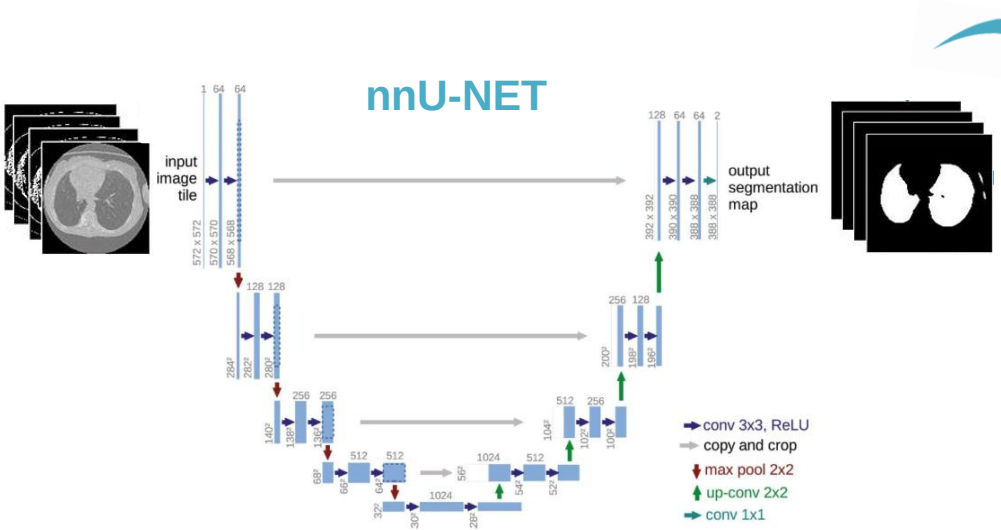
Automatic ROI Segmentation



Contracting Path (*encoder*) feature extraction

Expansive Path (*decoder*) spatially locates the features and generates an output map

GLIOBLASTOMA MULTIFORME

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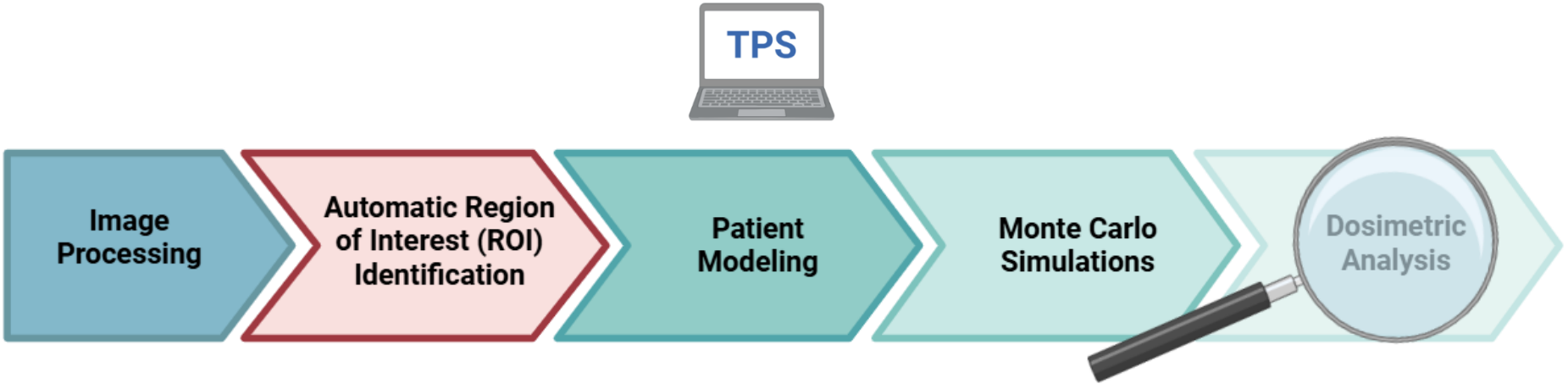

✓ ***RBE-weighted Dose Model***

$$D_w = CBE \cdot D_B + RBE_{th} \cdot D_{th} + RBE_f \cdot D_f + RBE_\gamma \cdot D_\gamma$$

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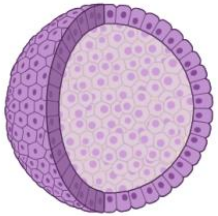
New Radiobiological Models

✓ ***Photon Isoeffective Dose Model***

$$D_R(D_1,\ldots,D_4)=\frac{1}{2}\frac{\left(\frac{\alpha}{\beta}\right)_R}{G_R}\times\left(\sqrt{1+\frac{4G_R}{\alpha_R\left(\frac{\alpha}{\beta}\right)_R}\left(\sum_{i=1}^{4}\alpha_i D_i+\sum_{i=1}^{4}\sum_{j=1}^{4}G_{ij}(\theta)\sqrt{\beta_i\beta_j}D_iD_j\right)}-1\right)$$

3D SPHEROIDS



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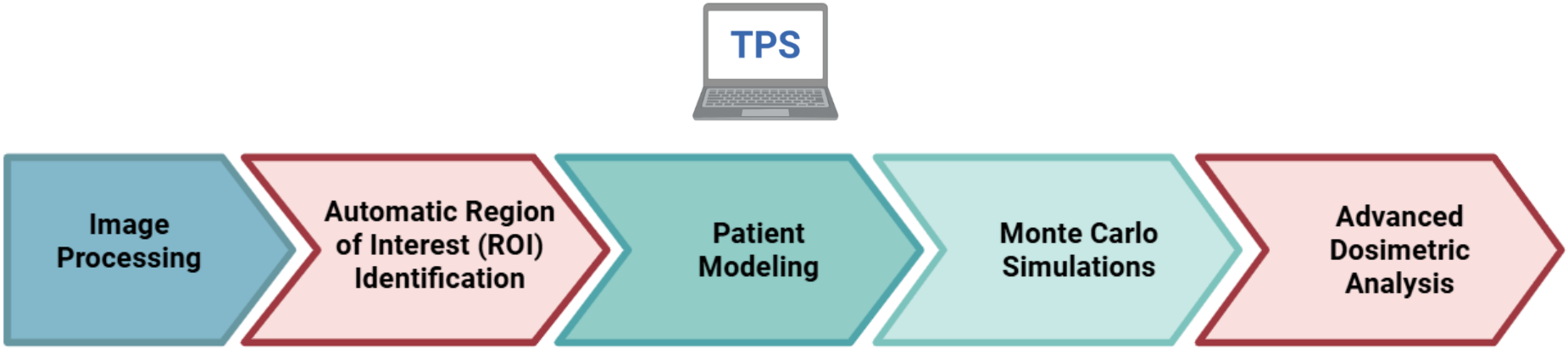

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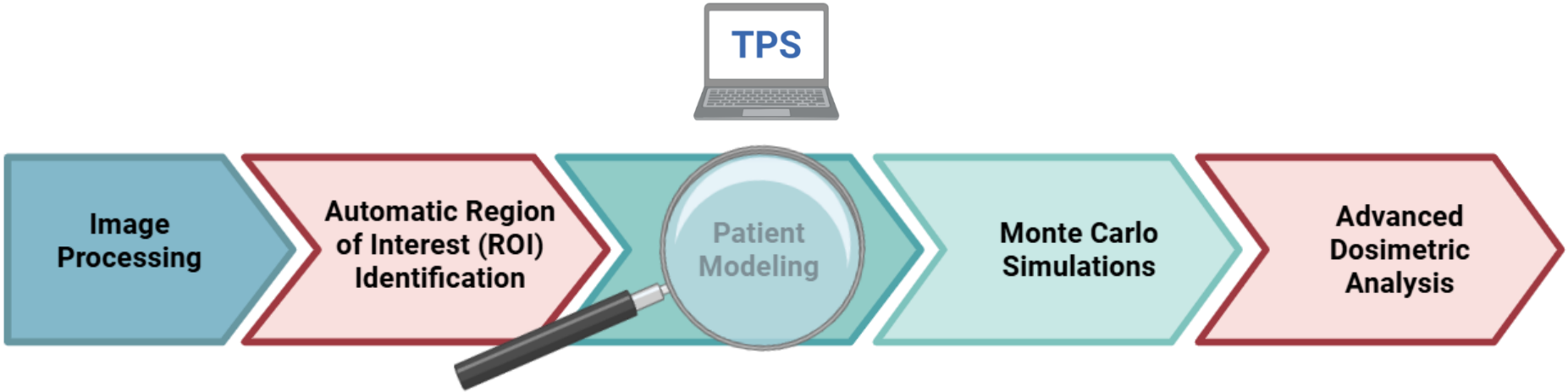

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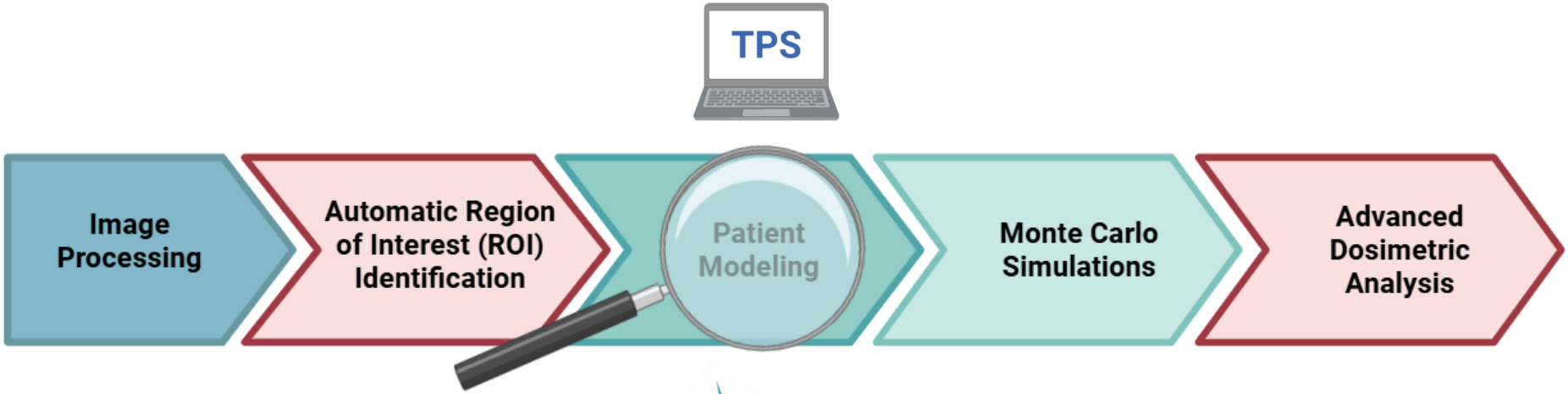

✓ ***Patient Positioning***

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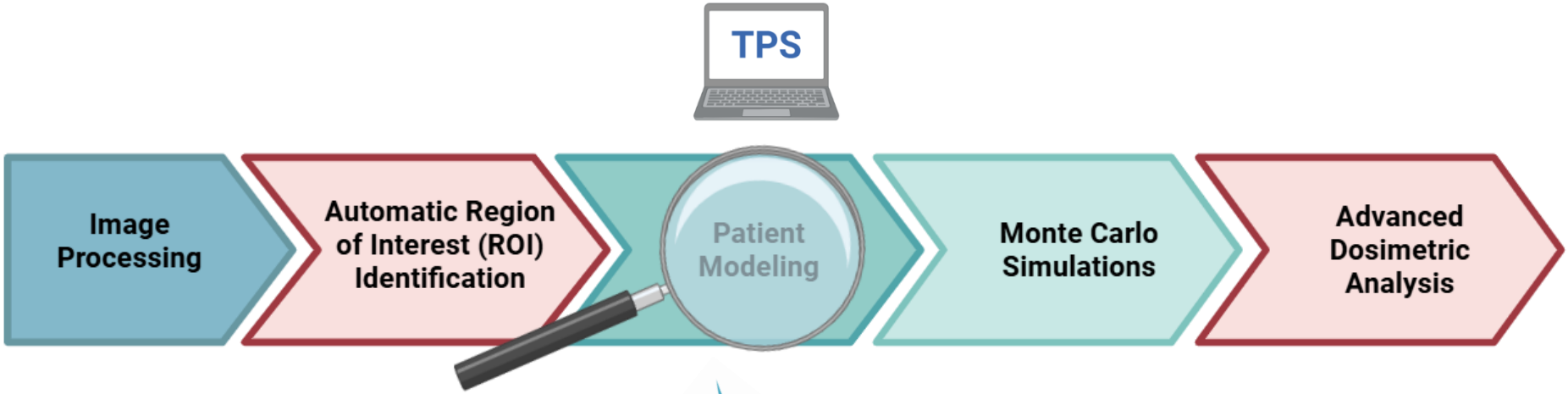

✓ ***Automatic*** ***Patient Positioning***

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Feseability

Experimental Activities → Neutron irradiation facility @TRIGA Mark II reactor and fully equipped biology laboratories

Collaborations → INFN projects (AI_MIGHT and IT_STARTS) and international collaborations (Argentina, China, Taiwan, France, Finland, Spain groups)

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Impact

Anthem
AdvaNced Technologies for Human-centEred Medicine

Thanks for the Attention

Cristina Pezzi

Università degli Studi di Pavia

17th September 2025