Importance of Sensitivity Analysis in Intensity Modulated Radiation Therapy (IMRT)

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Outline

- Motivation behind the project
  - Radiotherapy in cancer treatment
  - Conformal vs IMRT
  - Sensitivity Analysis
- Treatment Plan Process
- Optimization Model
- Case Study: Head & Neck Tumor Case
- Results
- Conclusions

Motivation- Radiotherapy in Cancer Treatment

- Used to fight many types of cancer in almost every part of the body
- Approximately 40% of patients with cancer needs radiation therapy sometime during the course of their disease
- Over half of those patients who receive radiotherapy are treated with an aim to cure the patient, i.e. to treat malignancies, and the rest of those patients are treated with an aim to shrink the tumor or to provide temporary relief of symptoms
- In the use of radiation, organ and function preservations are important aims

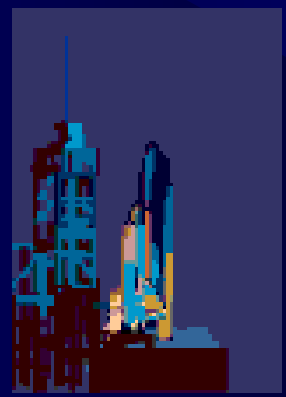
Motivation- IMRT

Conformal Radiotherapy

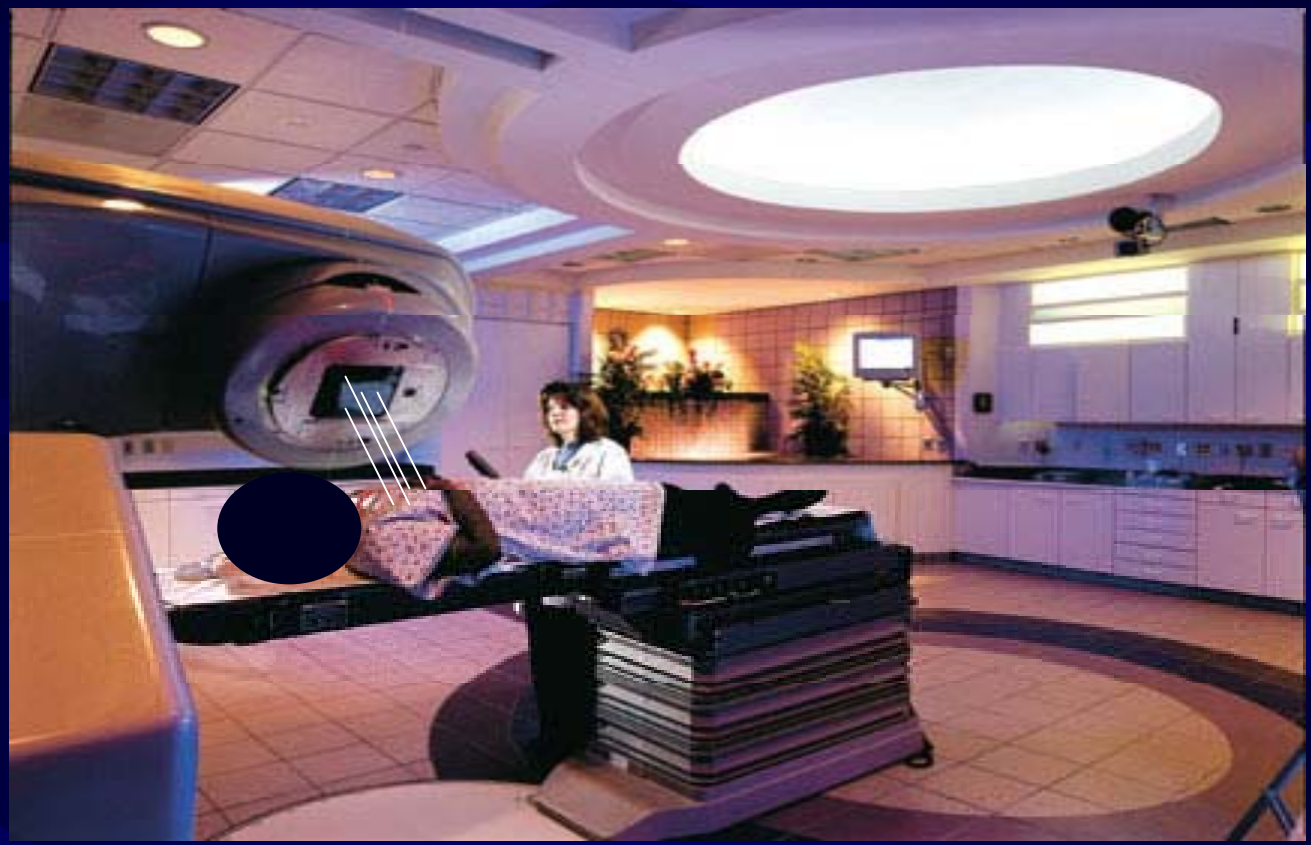
- Utilizes uniform beams of radiation, which ensures the target is adequately covered, however does nothing to avoid critical structure except usage of some blocks.

IMRT

- IMRT provides a non-uniform profile of beams by using pencil beamlets, through which the dose distribution can be shaped to avoid unsustainable damage to the surrounding structures.

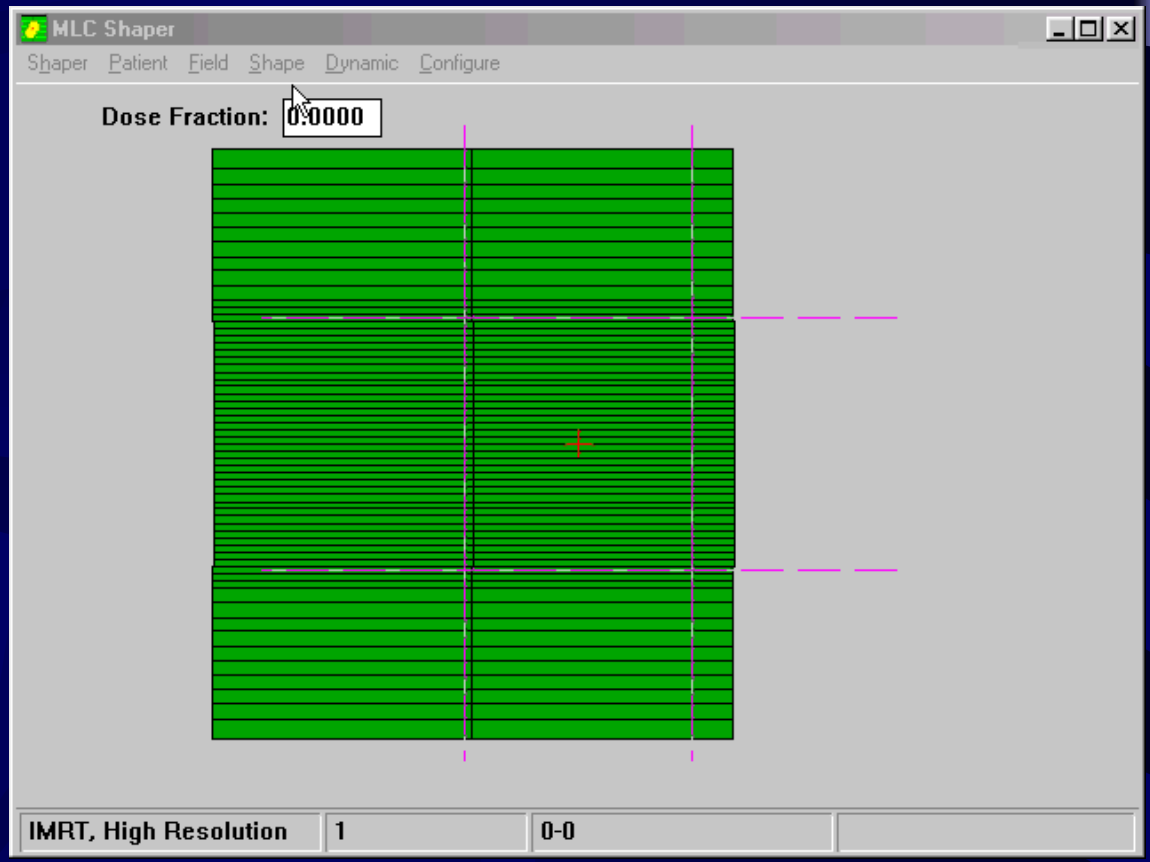


Delivery of Radiation



Motivation- IMRT

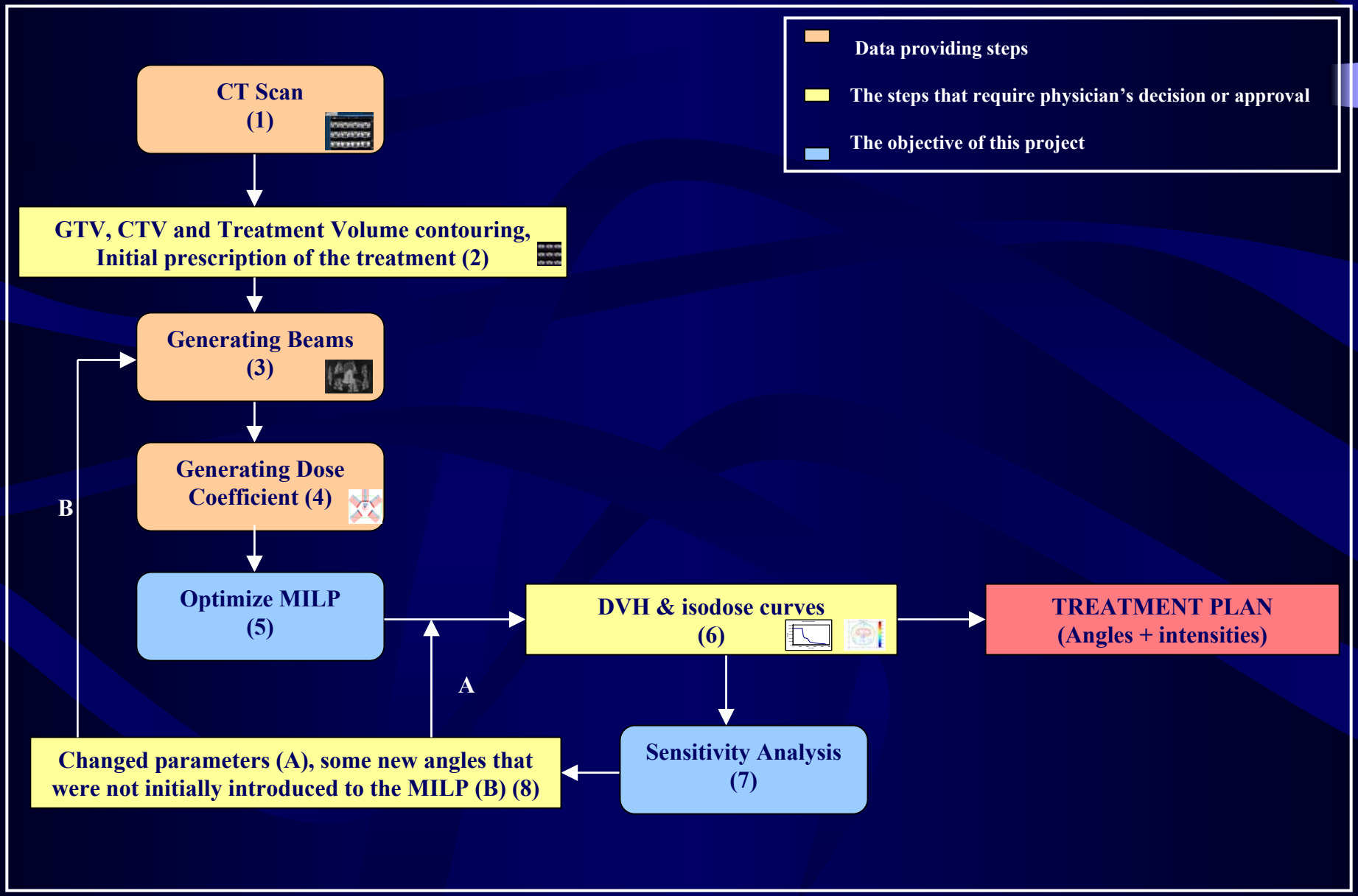
- IMRT can be obtained using a Multi-Leaf Collimator (MLC), which is a specialized, computer-controlled device with many tungsten fingers, or leaves, inside the linear accelerator
- Through a sequence of leaf movements intensity maps are obtained.



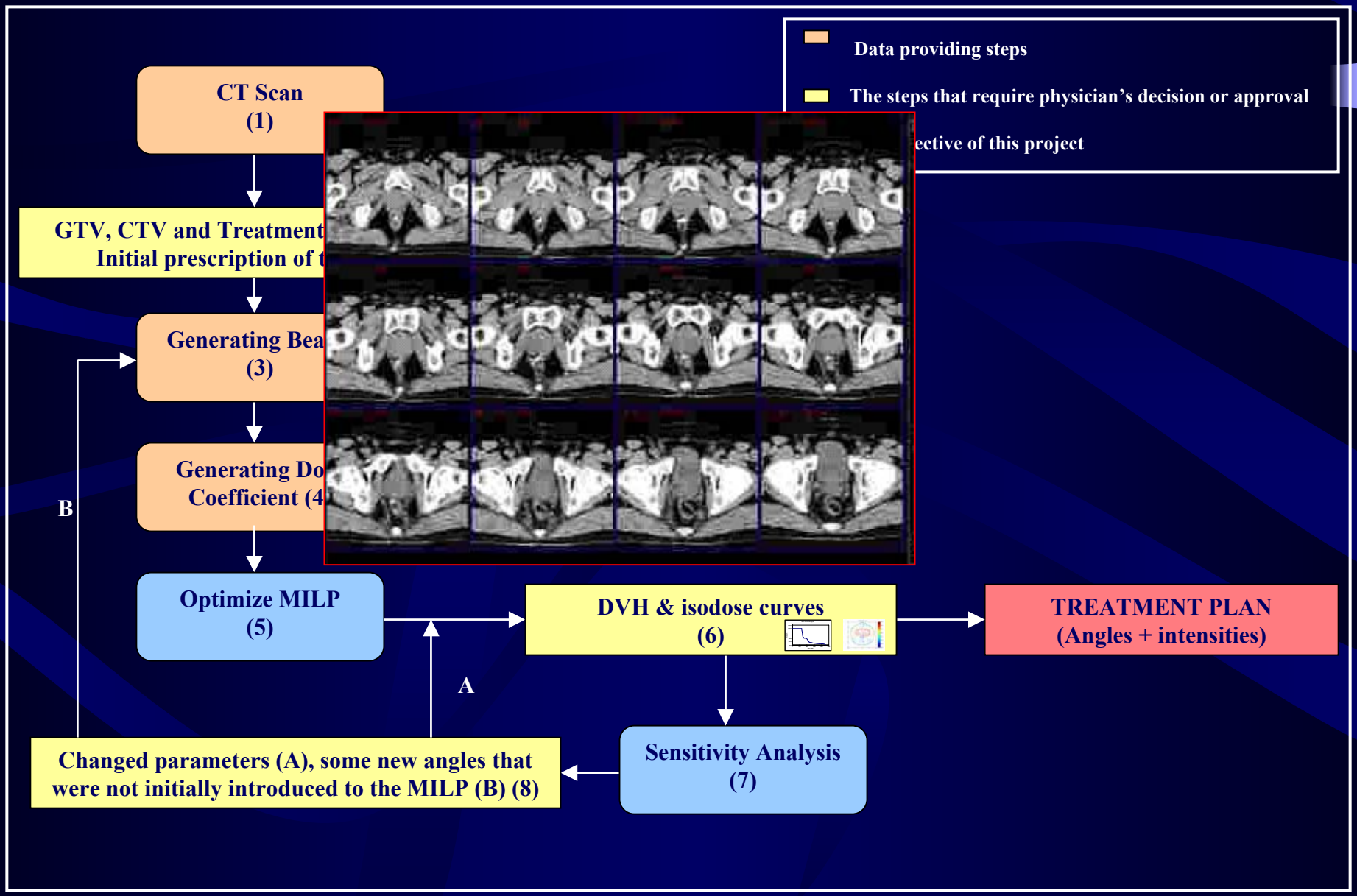
Motivation - Sensitivity Analysis

- Although IMRT is “State-of-the-Art” technology, medical practice needs to adapt to this technology
- Main issue in IMRT is to well define the problem!
  - Contouring of the tissues
  - Prescription
  - Planning
  - Delivery
- Physicians wants to be involved in the optimization procedure

Treatment Plan Diagram



Treatment Plan Diagram



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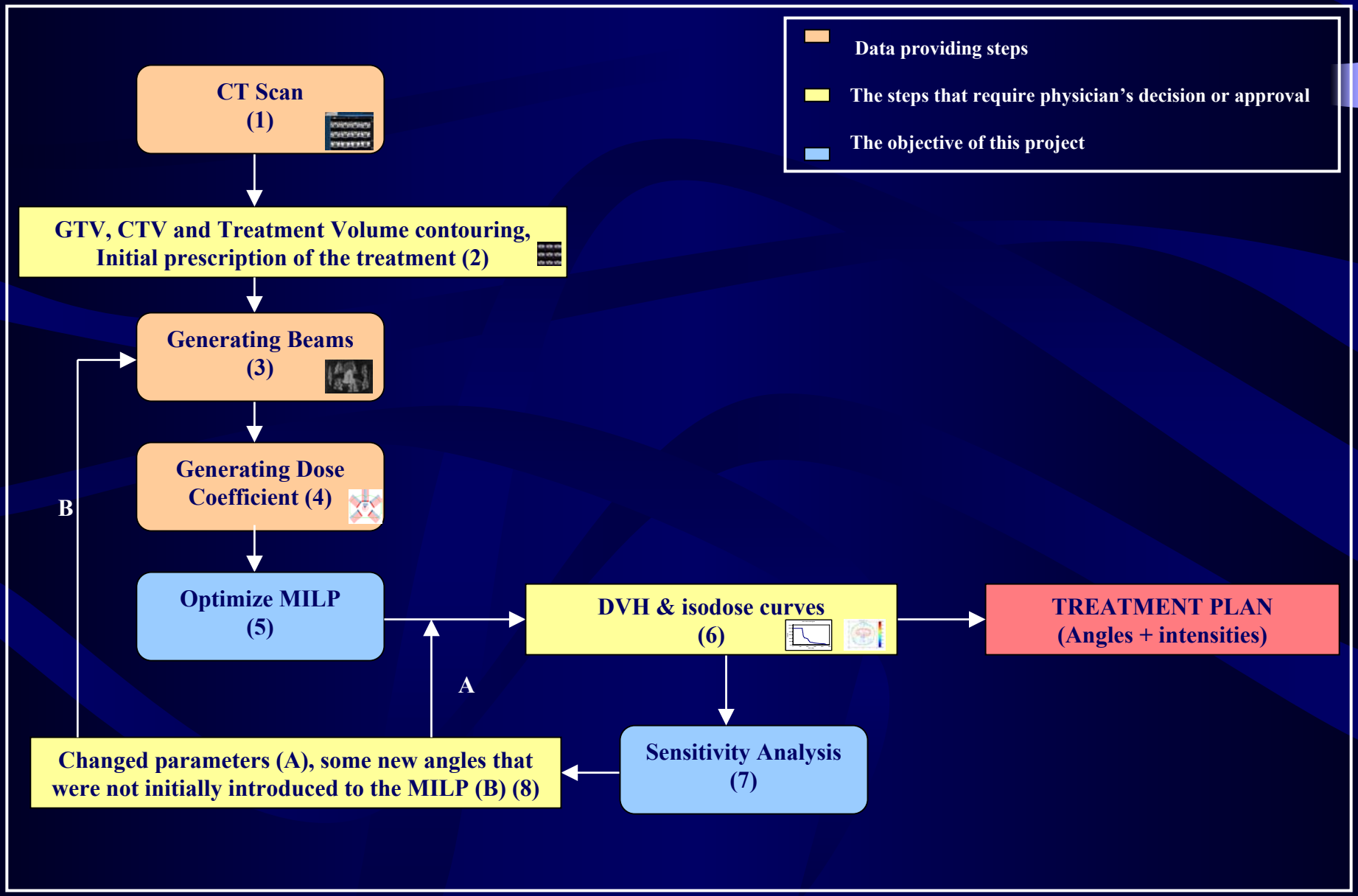

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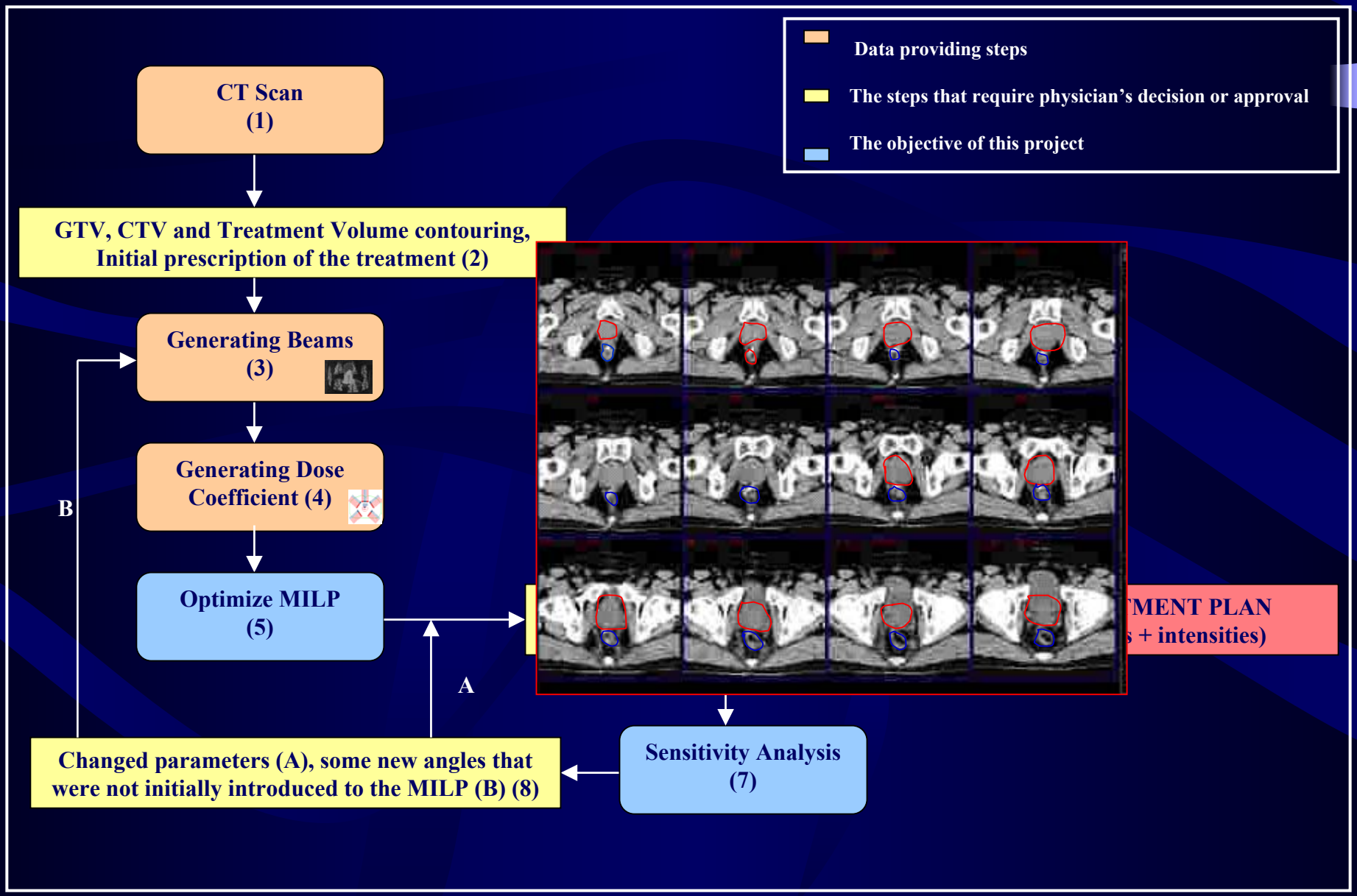

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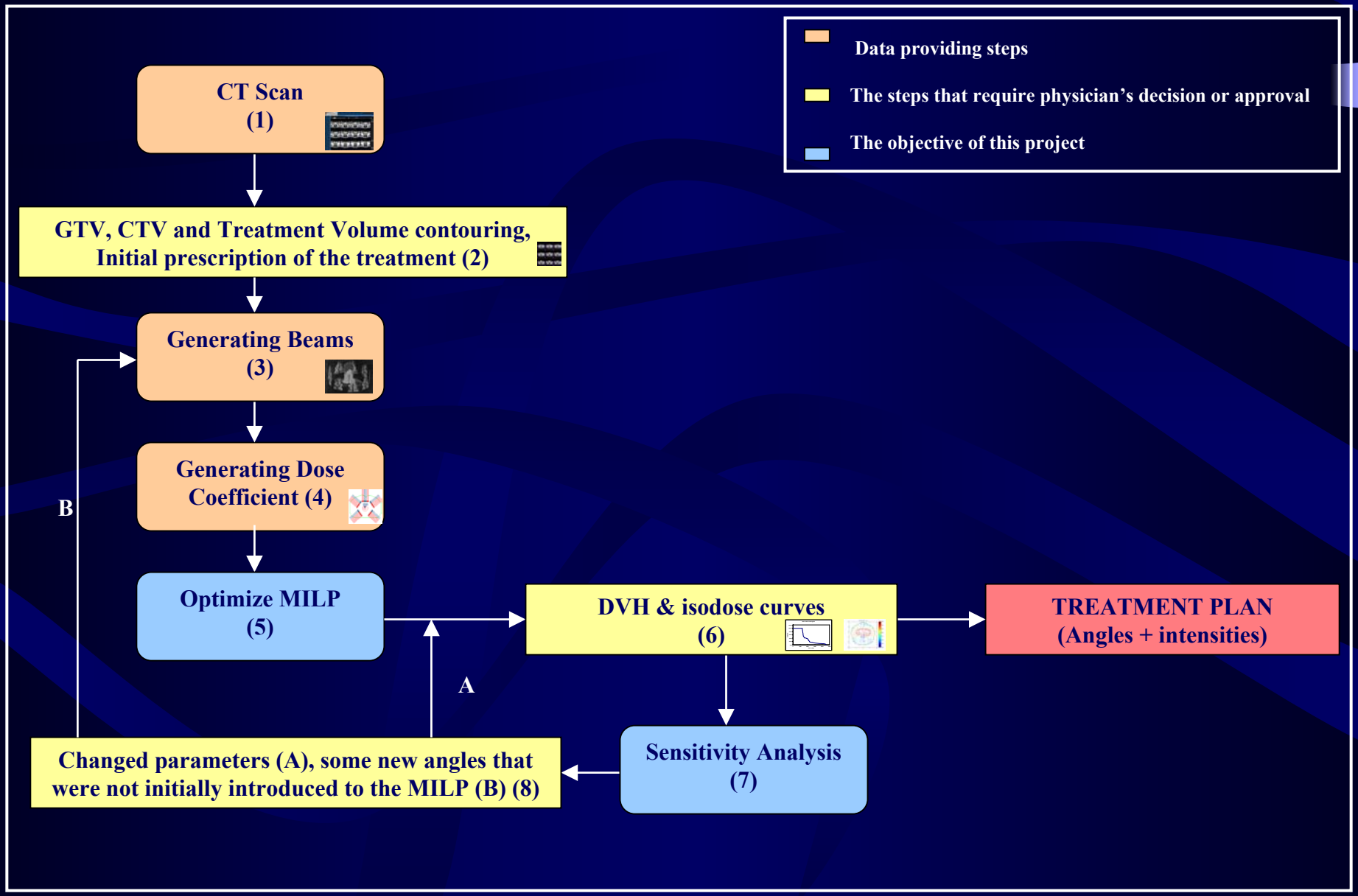
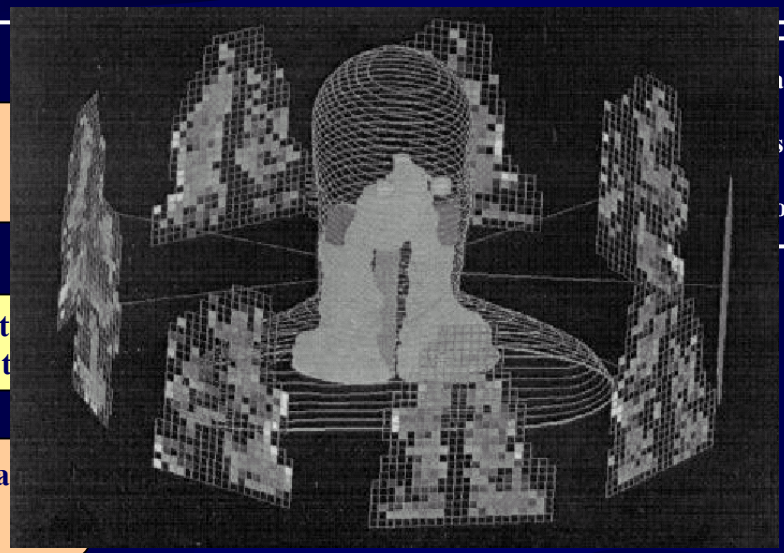


Treatment Plan Diagram

providing steps

steps that require physician's decision or approval

objective of this project



CT Scan (1)

GTV, CTV and Treatment
Initial prescription of t

Generating Bea
(3)

Generating Dose Coefficient (4)

B

Optimize MILP (5)

DVH & isodose curves (6)

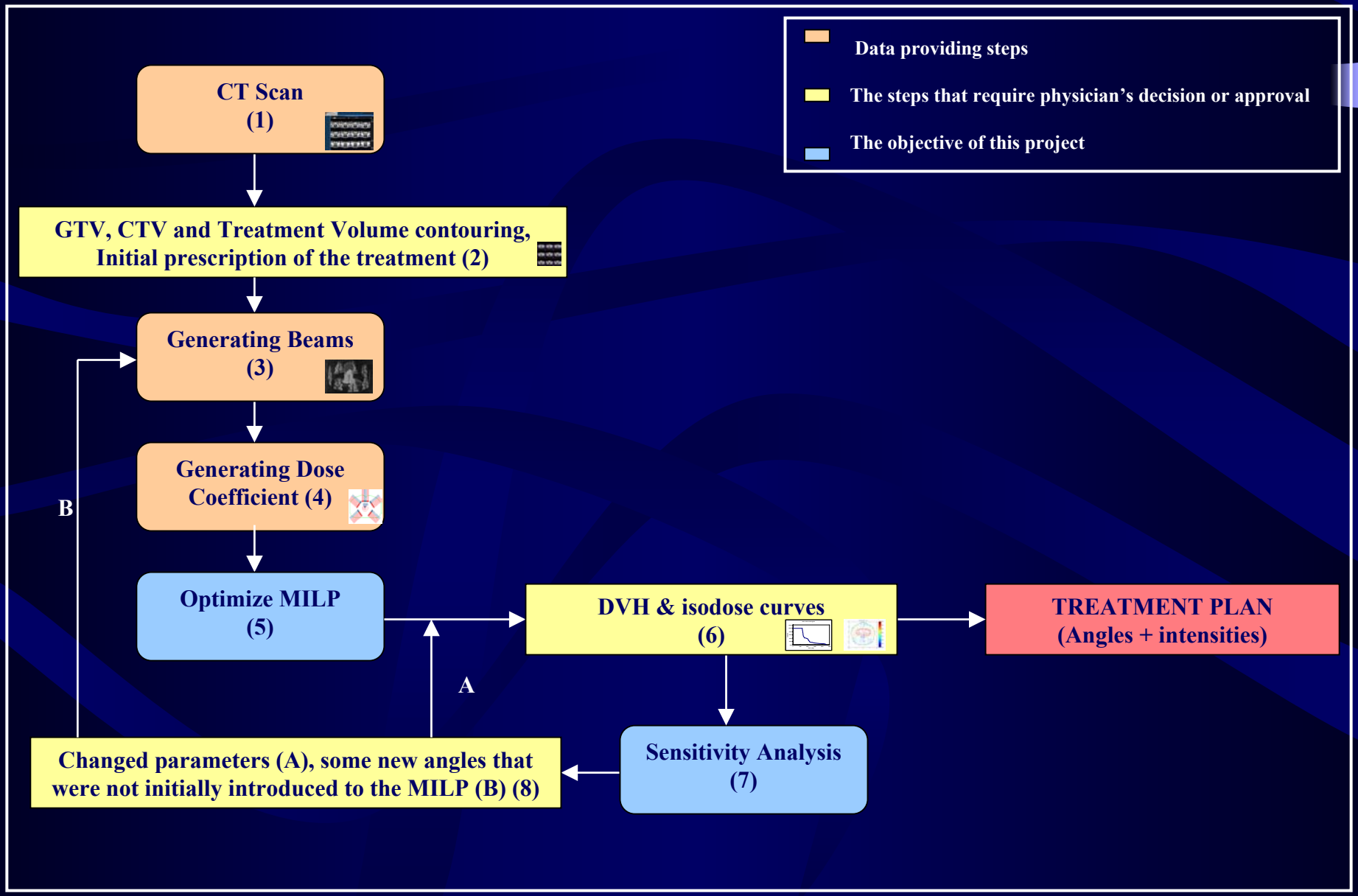
TREATMENT PLAN (Angles + intensities)

A

Sensitivity Analysis (7)

Changed parameters (A), some new angles that were not initially introduced to the MILP (B) (8)

Treatment Plan Diagram



Treatment Plan Diagram

Data providing steps

The steps that require physician's decision or approval

The objective of this project

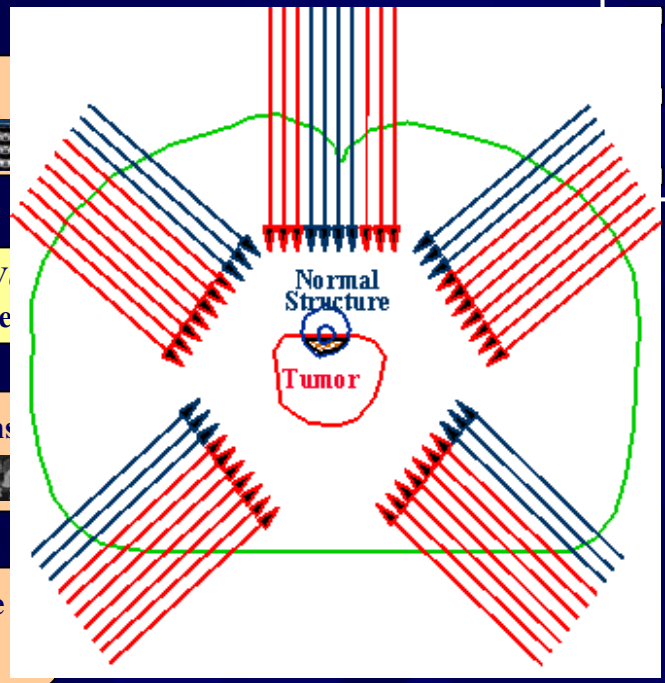
CT Scan (1)

GTV, CTV and Treatment V
Initial prescription of the

Generating Beams (3)

Generating Dose Coefficient (4)

Optimize MILP (5)



DVH & isodose curves (6)

TREATMENT PLAN (Angles + intensities)

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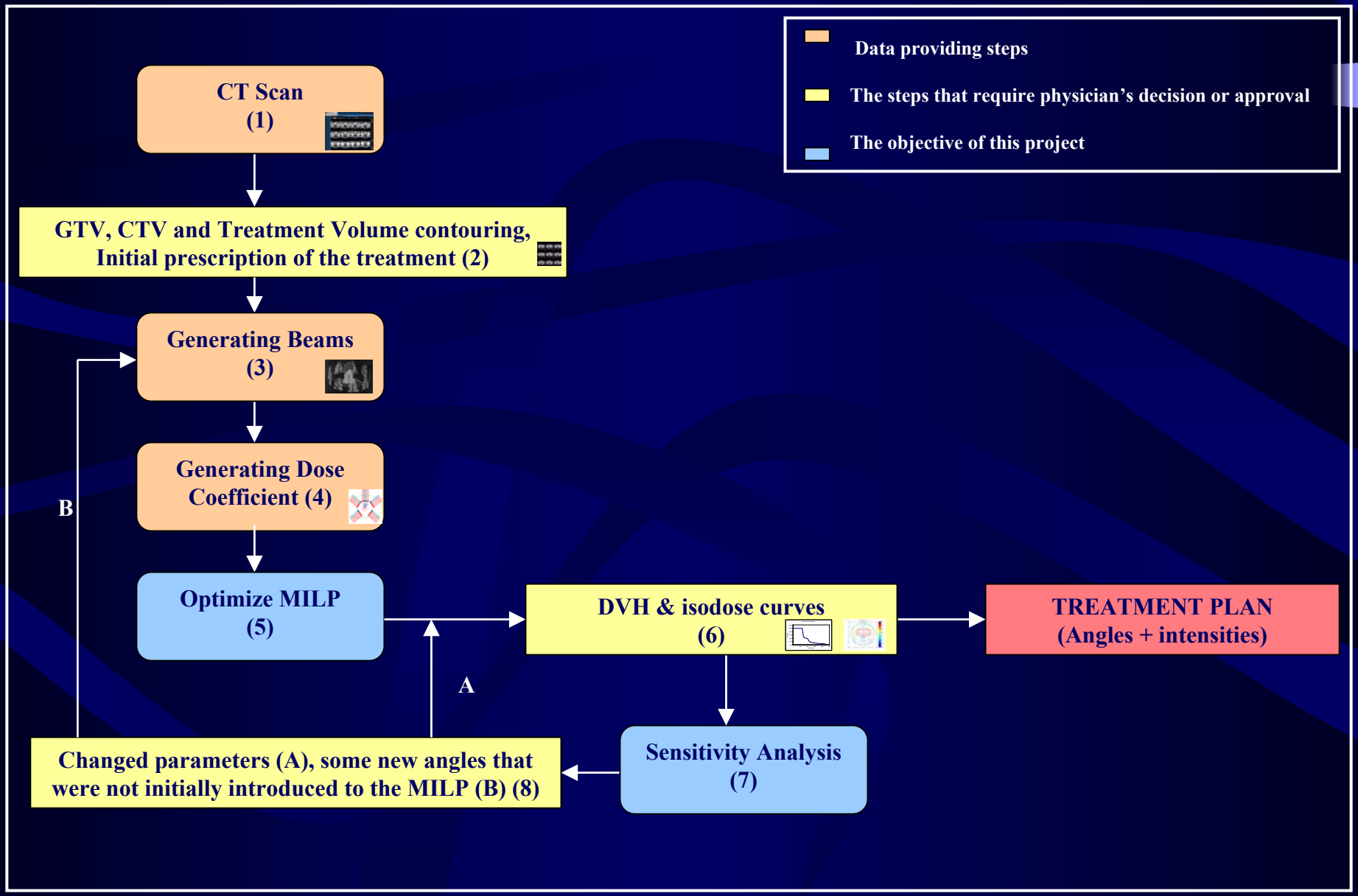
A

B

Treatment Plan Diagram



Treatment Plan Diagram

Data providing steps

The steps that require physician's decision or approval

The objective of this project

CT Scan (1)

GTV, CTV and Treatment Volume contouring, Initial prescription of the treatment (2)

Generating (3)

Generati Coefficie

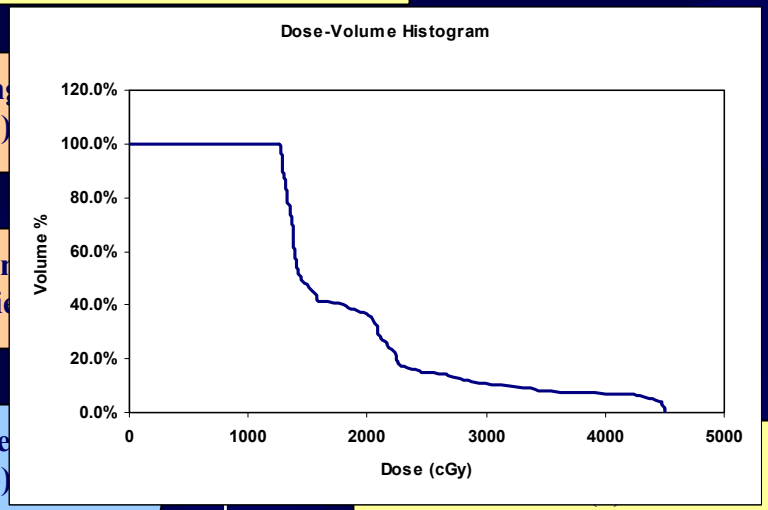
Optimize (5)

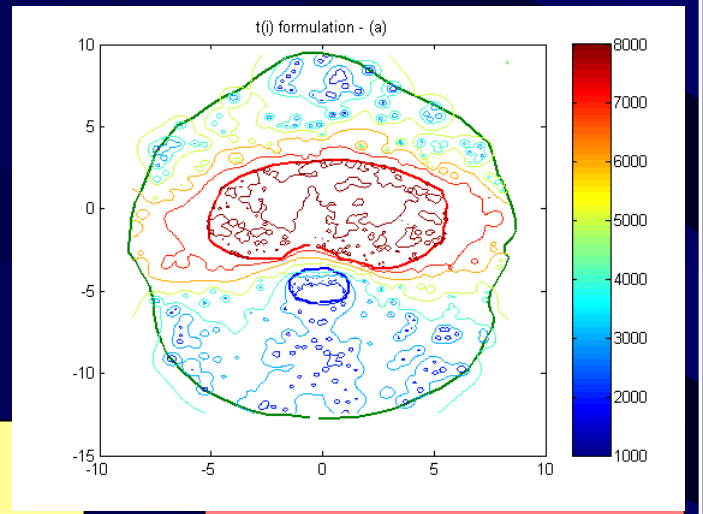
B

A

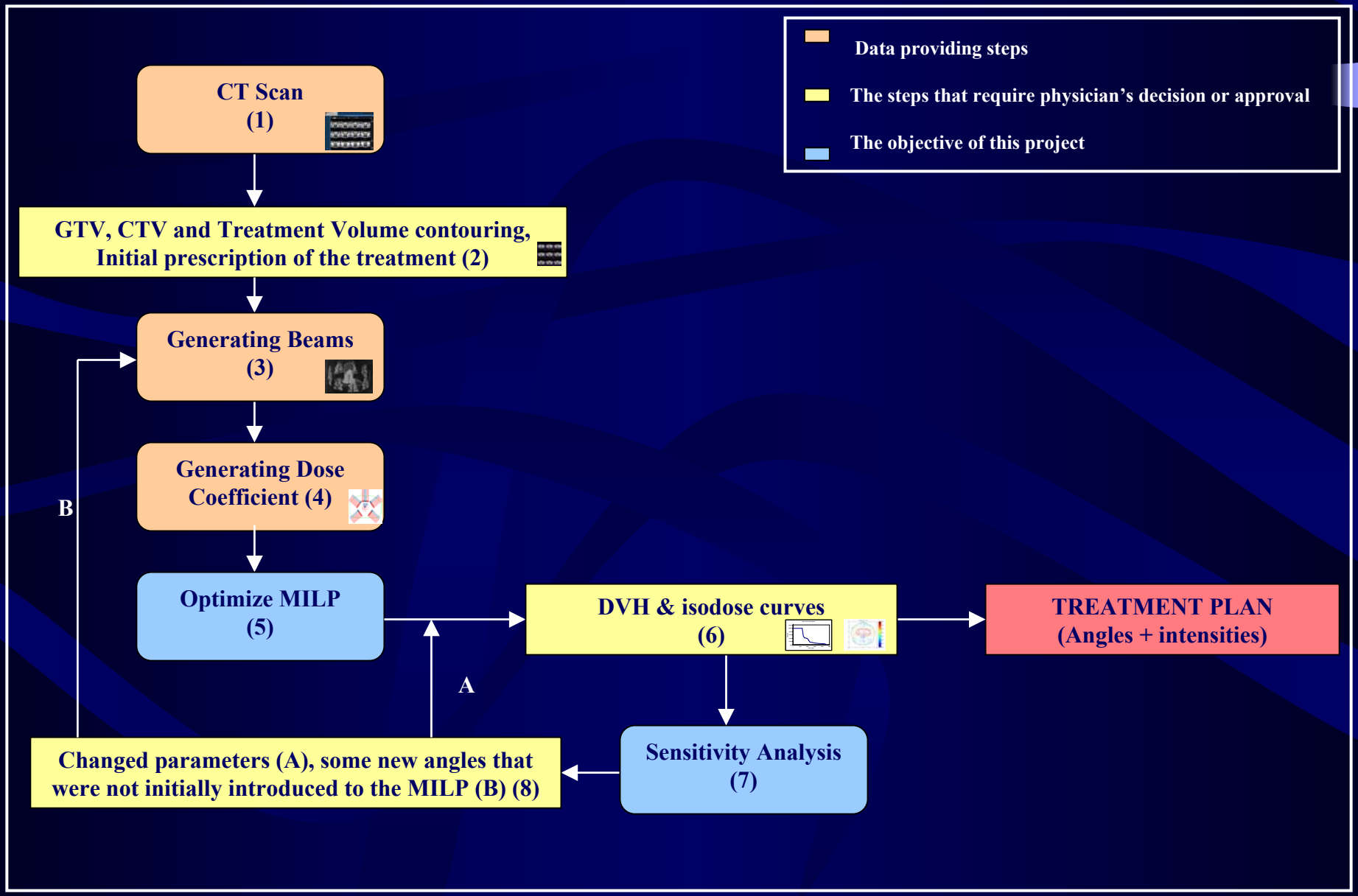
Changed parameters (A), some new angles that were not initially introduced to the MILP (B) (8)

Sensitivity Analysis (7)





Treatment Plan Diagram



Optimization Model

- Maximize the minimum tumor dose

$$\text{Maximize} \quad t_{min}$$

- Healthy tissue dose at any point can not exceed the prescribed upper bound:

$$\sum_{g \in G} \sum_{j \in J^g} a_{ij} x_{jg} \leq b_k \qquad \text{for all } i,\ k$$

where x_{jg} the intensity of beamlet j of angle g

Optimization Model

- The ratio between the minimum and maximum tumor dose should not exceed the homogeneity limit

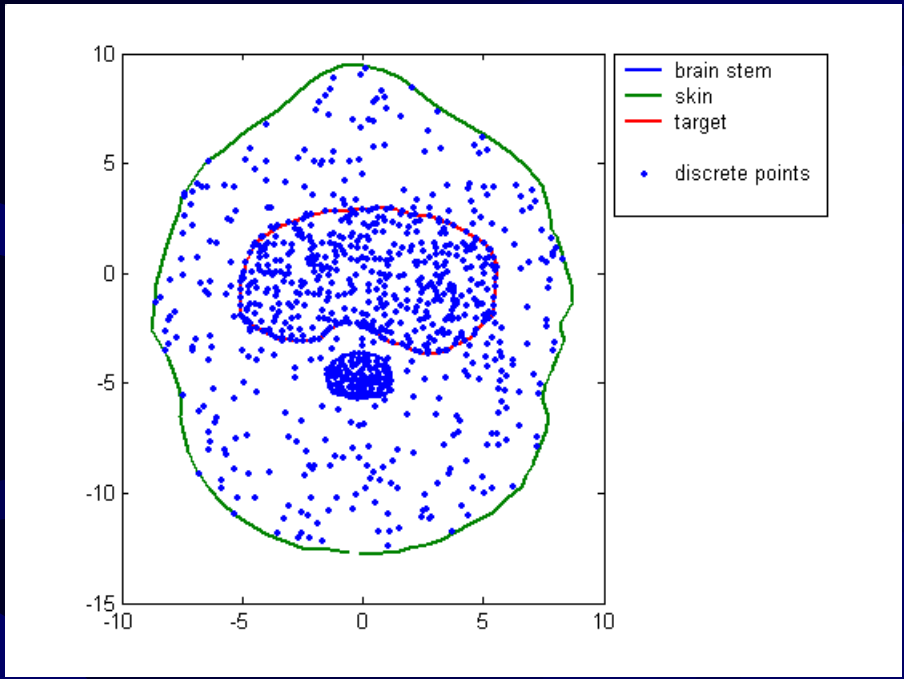
$$t_{\min} \geq \alpha \; t_{\max}$$

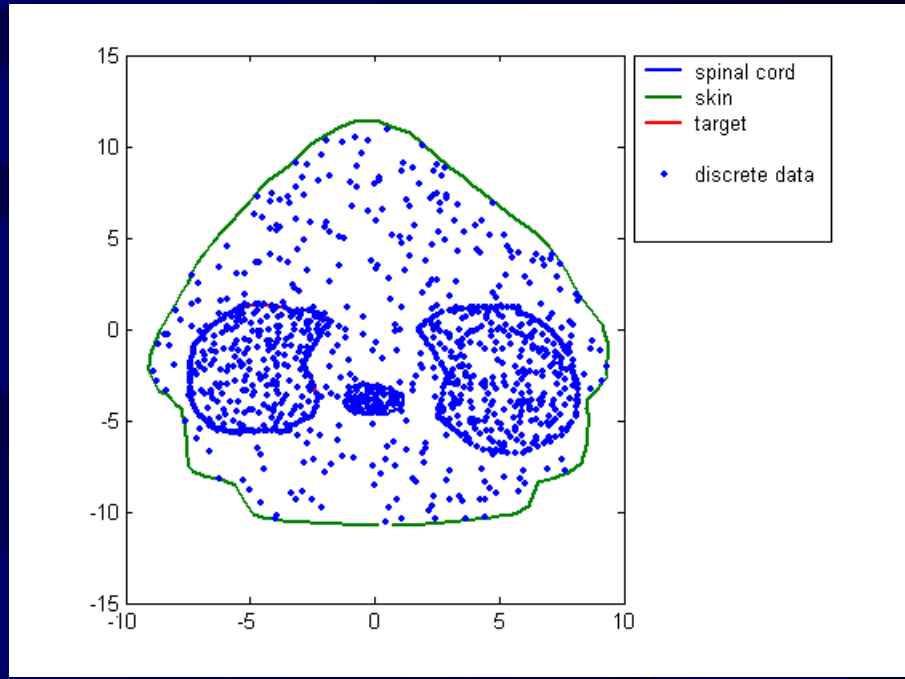
- Total number of fields used in the treatment is limited

$$\sum_{g \in G} z_g \leq n$$

where z_g is 1 if angle g is chosen to be in the treatment plan,
0 otherwise.

Head & Neck Case





- Reference: Hunt M. A., Zelefsky M. J., *et al*. Treatment planning and delivery of intensity-modulated radiation therapy for primary nasopharynx cancer, *Int. J. Radiation Oncology Biol. Phys.* 2001; 49:623-632.

Head & Neck Case Prescription

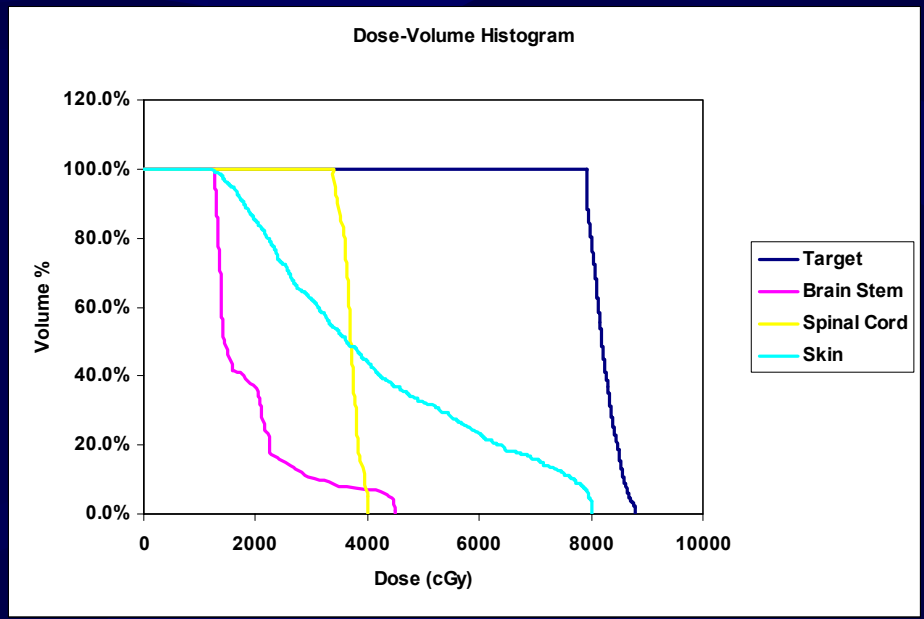
Site	Target Vol Definition	>/<	Dose Objective (cGy)	Volume
Tumor	GTV	>=	8000	100%

Site	>/<	Dose Objective (cGy)	Volume
Brain Stem	<=	4500	100%
Spinal Cord	<=	4000	100%
Skin (External)	<=	8000	100%

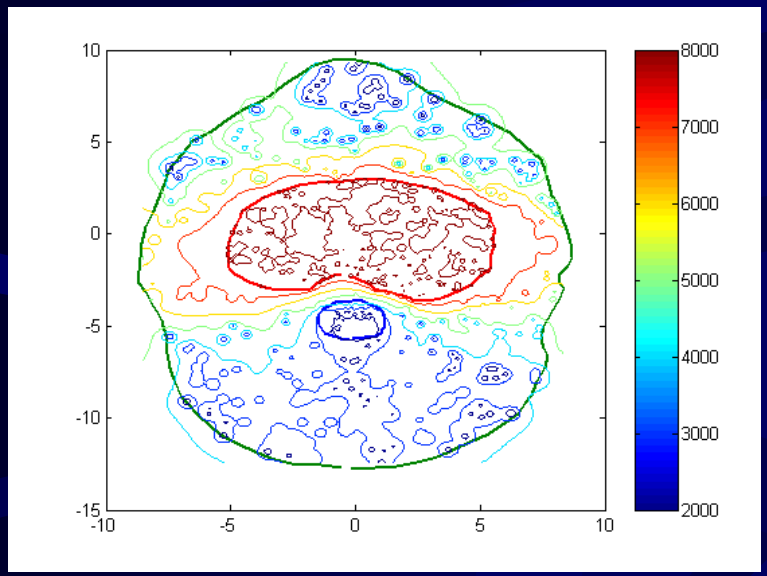
- 90% homogeneity limit defined as the ratio between the minimum and maximum tumor doses.
- Maximum number of angles to be used in the treatment is 9.

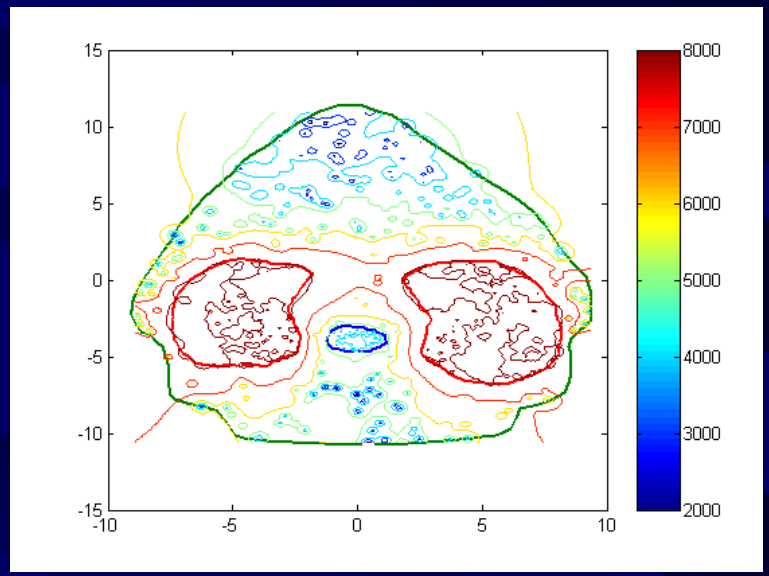
Results

Structure	Statistics	Dose
PTV	Max Dose (D_{05})	86.7 Gy
	Min Dose (D_{95})	79.2 Gy
	Mean Dose	82.3 Gy
Brain Stem	Max Dose (D_{05})	43.7 Gy
Spinal Cord	Max Dose (D_{05})	40.0 Gy
Skin	Max Dose (D_{05})	79.7 Gy



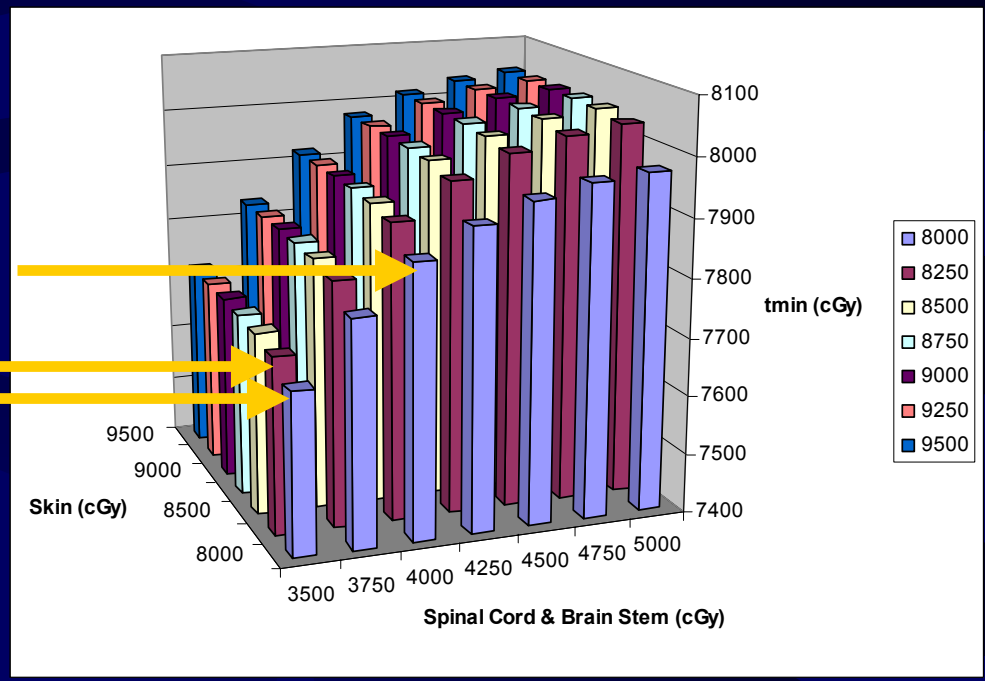
Isodose Curves



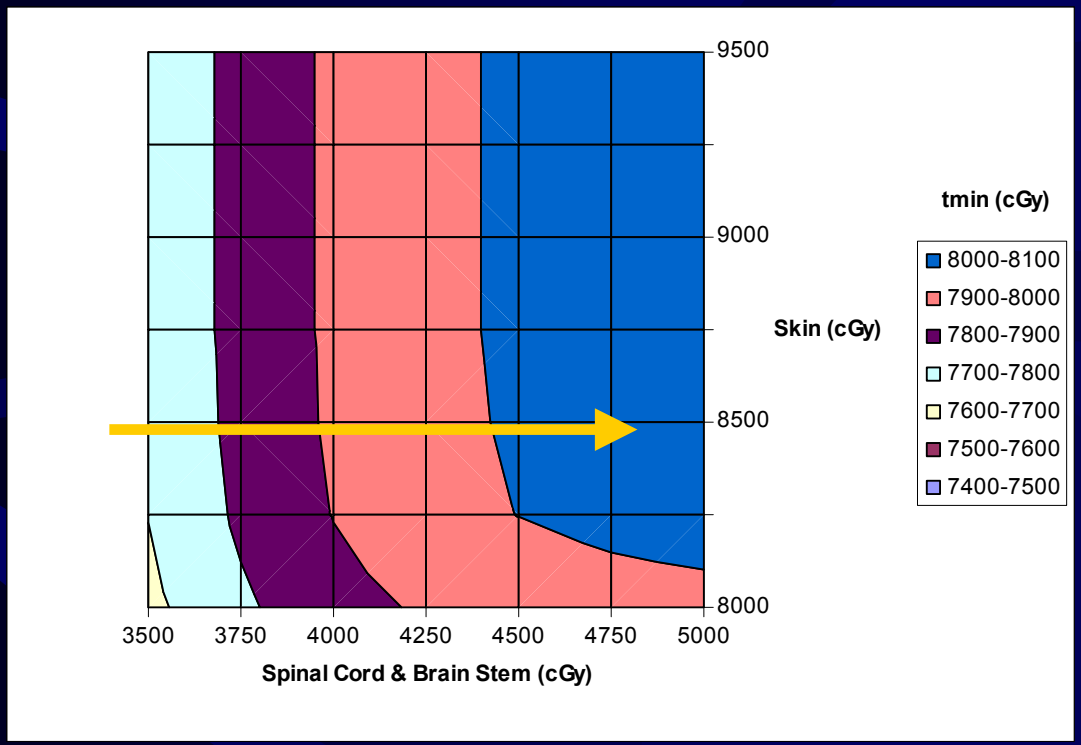


Sensitivity Analysis on the Limits of Healthy Tissues

- An increase in the limit of the cord and b.stem of 500 cGy allows an increase in the minimum tumor dose of around 200 cGy.
- If the skin limit is increased from 8000 cGy to 8250 cGy at any upper bound, tmin would increase by ~50 cGy.



Sensitivity Analysis on the Limits of Healthy Tissues

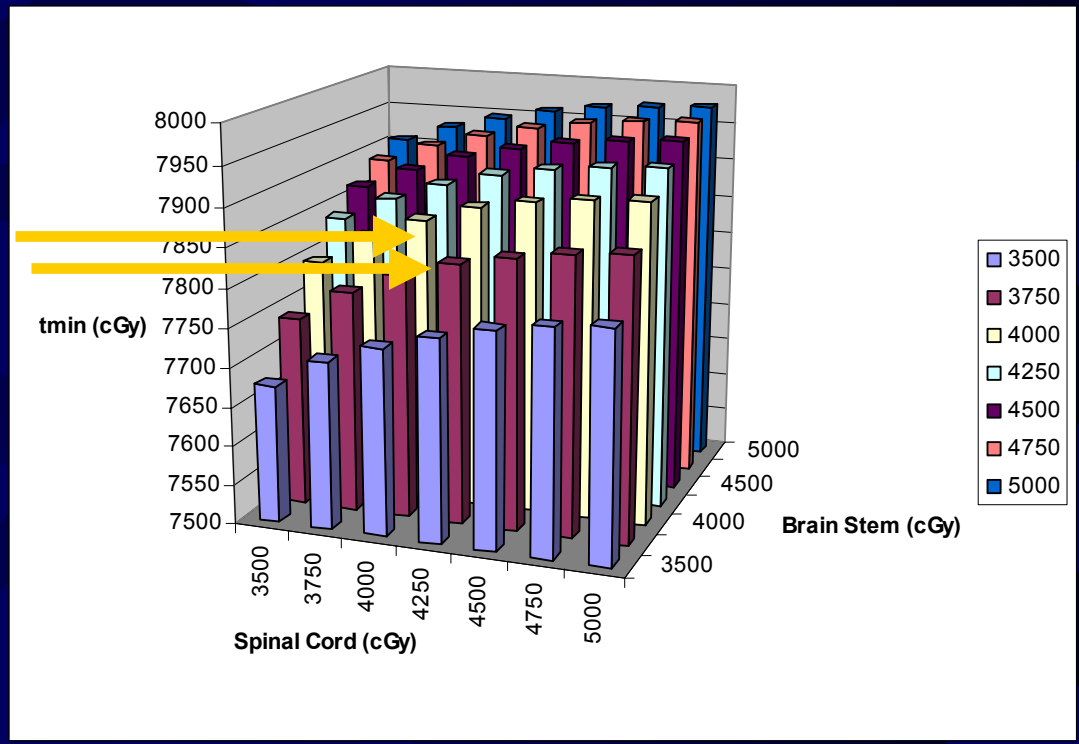


At 85 Gy of skin limit

- Unless the limit is increased above ~39.5 Gy, the maximum reachable t_{min} is 79 Gy.
- No matter how much the limit on spinal cord and brain stem are increased above 4450 cGy, t_{min} won't exceed 81 Gy.

Importance (Penalty) Factors

- The importance ratio of cord and b. stem are considered to be 1:1
- However, a 250 cGy drop in the brainstem dose requires more than a 250 cGy increase in spinal cord to maintain the same t_{min}, i.e. the penalty factor should be more than 1:1 in favor of the brain stem.



Conclusions

Sensitivity analysis:

- Guide the physicians in deciding on the prescription
  - Show if an increase in the tumor dose is possible by a small change in the healthy tissue limit
  - Help to avoid to identify any unnecessary exposure to the healthy tissues
- Show the uncertainty in selecting the penalty factors
- May contribute to the modification of old protocols that are developed based on conformal radiotherapy

Thank you!

- Van Thai - Indiana University
- Felisa Preciado -Walters, Purdue University