

# INTRODUCTION TO TREATMENT PLANNING

Aafke Kraan

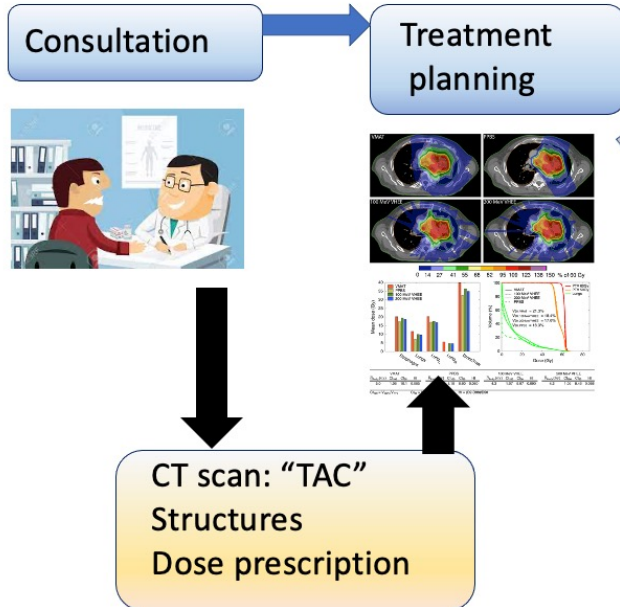
*Slides partly adapted from Aristeidis Mamara*

# INTRODUCTION TO TREATMENT PLANNING

- Questa mattina abbiamo visto che la radiazione puo' essere usato per eliminare cellule cancerose
- La radiazione non danneggia soltanto le cellule cancerose, ma anche quelli sani...
- Il tessuto sano in generale e' piu' capace di ripararsi
- Ma la radiazione deve essere minimo nei tessuti sani...
- Come lo facciamo? Con un piano di trattamento!

# WHAT IS TREATMENT PLANNING?

## Second phase: treatment planning

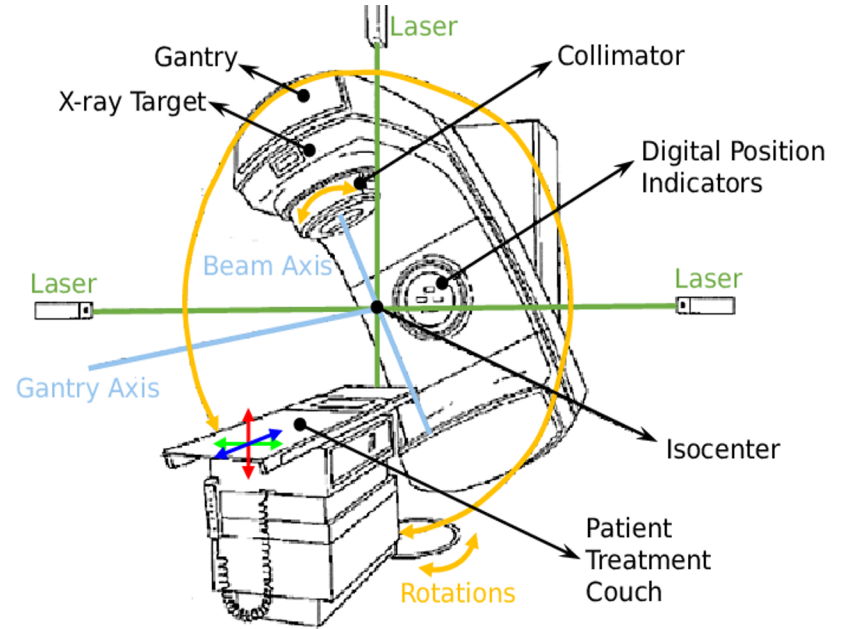
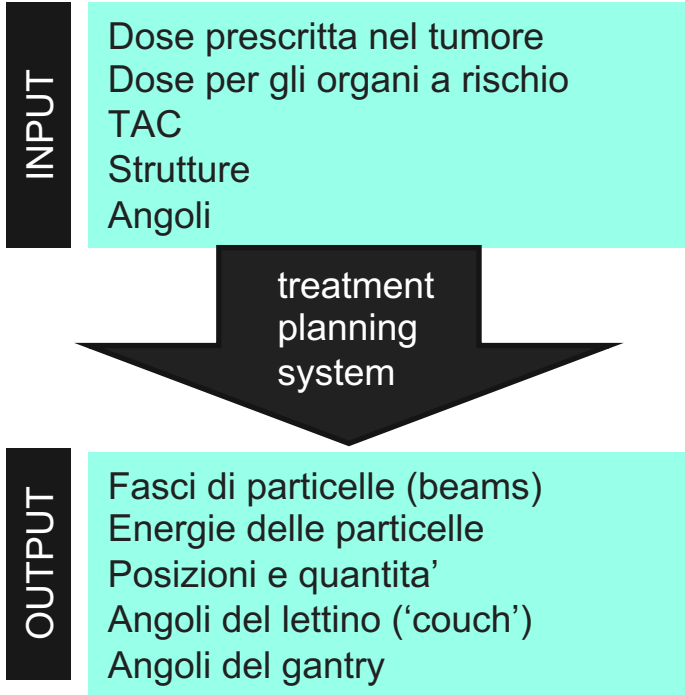


- How can we realize the dose prescription?
- From which direction(s)?
- How can we spare the sensitive organs as well as possible?
- Is the plan not too sensitive?

This is done with help of dedicated software (and highly expertise personnel!): treatment planning system

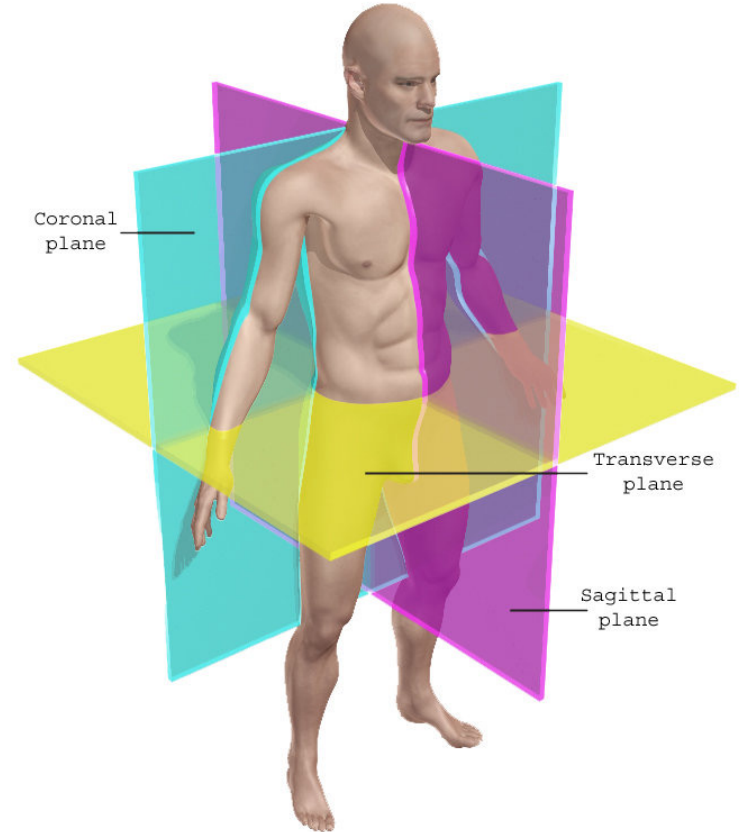
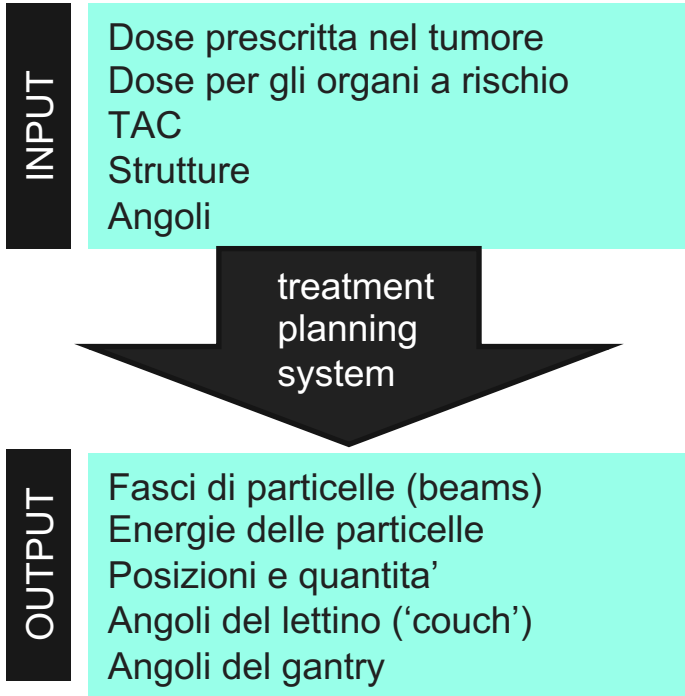
matRad

# WHAT IS A TREATMENT PLANNING?



gantry angles: moves the radiation source around the patient couch: rotates the patient

# WHAT IS A TREATMENT PLANNING?



gantry angles: moves the radiation source around the patient  
patient couch: rotates the patient

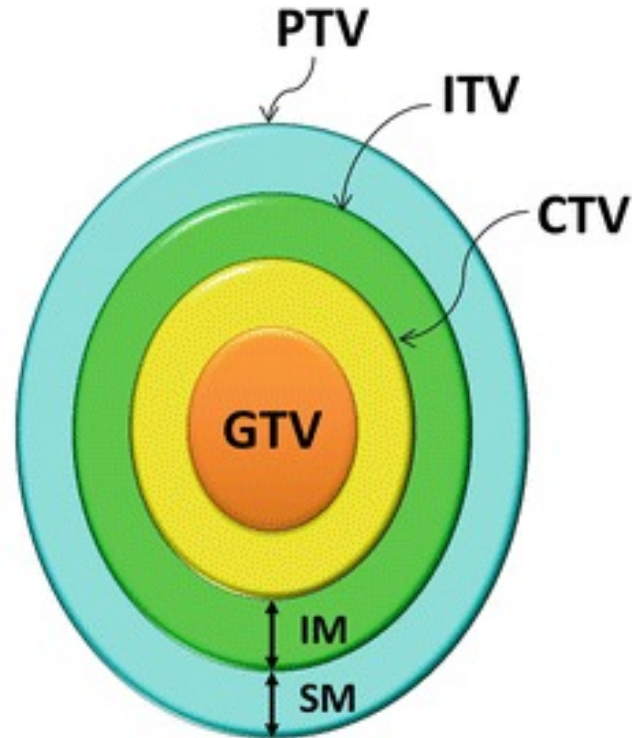
# TUMOR REGION

**GTV:** **gross tumor volume**, defined as visible tumor volume in images

**CTV:** **clinical target volume**, defined as GTV + subclinical/invisible invasion

**ITV:** **internal target volume**, defined as CTV + IM (internal margin for organ motion)

**PTV:** **planning target volume**, defined as ITV + SM (setup margin for setup error)



# WHAT SOFTWARE WILL WE USE?: MATRAD

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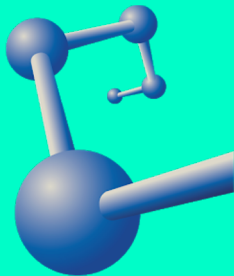
Student of Computational Physics, ATh (Greece)

**Supervised by:**

Ph.D. Yiota Foka

IPPOG's Member

Instituto de  
Ciencias  
Nucleares  
UNAM



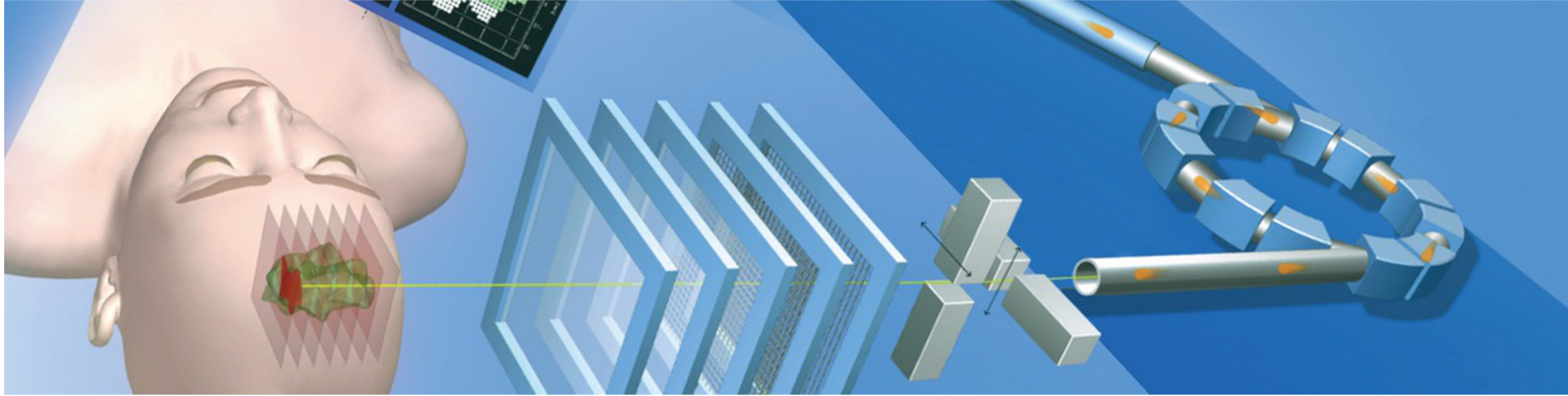
International Particle  
Physics Outreach Group



ARISTOTLE  
UNIVERSITY OF  
THESSALONIKI



# WHAT IS MATRAD?



matRad is a tool kit allowing optimization of treatment planning with photons, protons, ions for educational and research purposes.

matRad

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UNAM



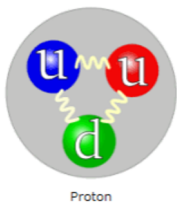
IPG  
International Particle  
Physics Outreach Group



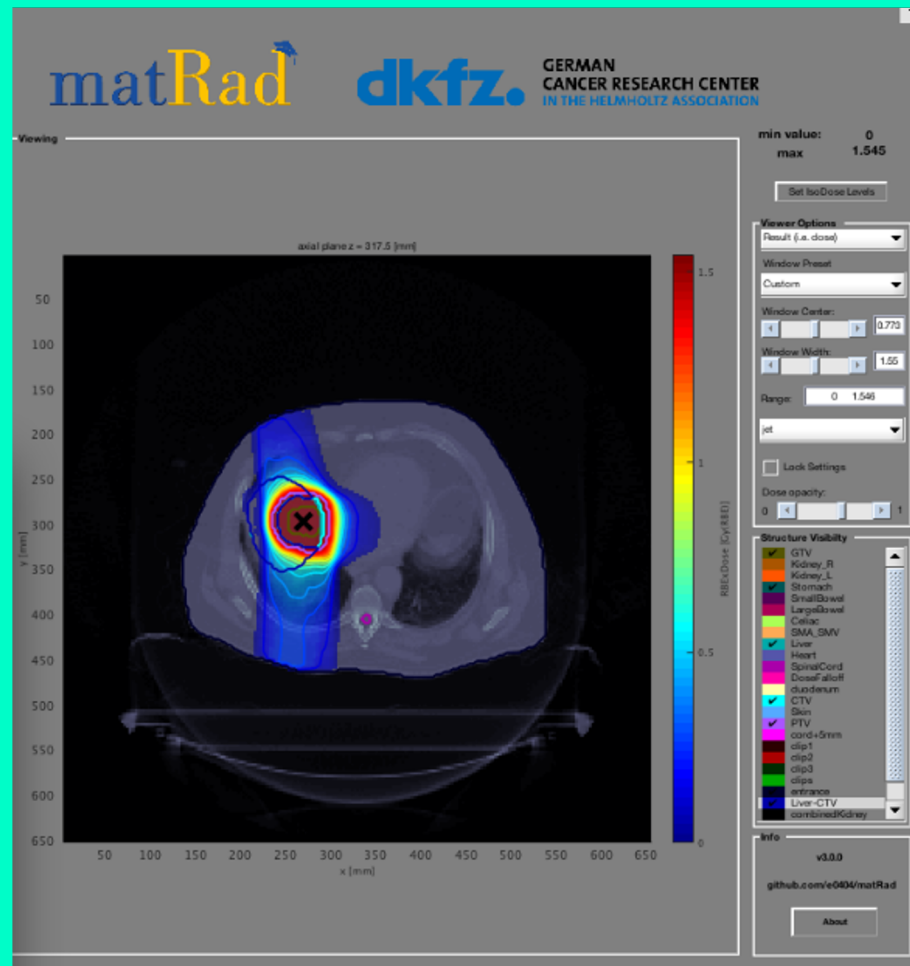
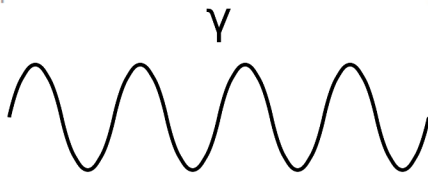


# matRad

THE MATRAD EDUCATIONAL AND RESEARCH SOFTWARE WAS DEVELOPED BY THE GERMAN CANCER RESEARCH CENTER IN ORDER TO HANDLE TREATMENT PLANNING IN AN EASY WAY WITH PROTONS, PHOTONS AND CARBON IONS.



Carbon ion (6+)



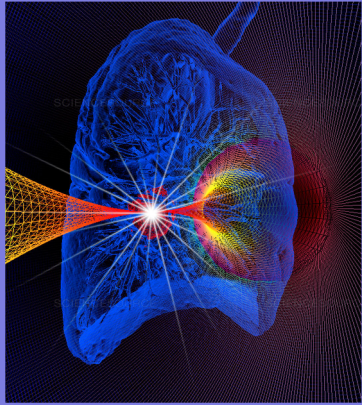
# WHERE IS MATRAD USED TODAY?

# + 30 INSTITUTIONS

CURRENTLY MATRAD IS USED **BY** MORE THAN 30 OFFICIAL INSTITUTIONS, AMONG THEM RESEARCH GROUPS AND A VARIETY OF UNIVERSITIES INTERNATIONALLY RECOGNIZED FOR THEIR HIGH PERFORMANCE AND EXCELLENT RESULTS GLOBALLY.



# HERE YOU CAN SEE SOME OF THE INSTITUTIONS WE ARE TALKING ABOUT



matRad – community



TECHNISCHE  
UNIVERSITÄT  
MÜNCHEN



MEDICAL UNIVERSITY  
OF VIENNA



大阪大学  
OSAKA UNIVERSITY

dkfz.

GERMAN  
CANCER RESEARCH CENTER  
IN THE HELMHOLTZ ASSOCIATION

THE UNIVERSITY OF TEXAS

MD Anderson  
Cancer Center

Proton Therapy



UNIVERSIDAD  
COMPLUTENSE  
MADRID



UNIVERSITY OF  
OXFORD



Universität  
Zürich<sup>UZH</sup>



FOR MORE INFORMATION, YOU CAN CONSULT THE FOLLOWING MAP: [HTTPS://BIT.LY/MATRADUSERS](https://bit.ly/matradusers)

# IN WHAT WAYS CAN THE SOFTWARE BE EXECUTED?

IT CAN BE EXECUTED THROUGH MATLAB OR WITH THE MATRAD APPLICATION FOR WINDOWS:

The image shows the matRad application interface for Windows. The window title is "matRad" and it includes the logos for "dkfz" and "GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION". The interface is divided into several panels:

- Workflow:** Contains buttons for "Refresh", "Load \*.mat data", "Load DICOM", "Import from Binary", "Calc. influence Mx", "Optimize", "Save to GUI", "Recalc", "Export", and "Import Dose". The status indicates "plan is optimized".
- Plan:** Includes fields for "bixel width in [mm]" (5), "IsoCenter in [mm]" (263.3 266.1 124), "Gantry Angle in °" (90.270), "# Fractions" (30), "Couch Angle in °" (0.0), "Radiation Mode" (carbon), and "Machine" (Generic). It also has radio buttons for "use MC (VMC++) dose calculations", "Biological Optimization" (RBE<sub>D</sub>), and "Set Tissue".
- Objectives & constraints:** A table with columns for VOI name, VOI type, priority, obj. / const., penalty, dose, EUD, volume, and robustness. It lists five VOIs: BODY, Bladder, PTV 56, PTV 68, and Rectum.
- Visualization:** Includes "Slice Selection", "Beam Selection", "Offset", "Type of plot" (intensity), "Plane Selection" (axial), "Display option" (RBE<sub>D</sub>Dose), and "Show DVH".
- Viewing:** A central 3D visualization of an axial CT slice at z = 195 [mm]. A color map overlay shows the dose distribution. The axes are labeled "x [mm]" and "y [mm]".
- Colormap Options:** Includes "Result (i.e. dose)", "Window Center", "Window Width", "Range", "jet" colormap, and "Dose spacing".
- Structure Visibility:** A list of structures including BODY, Bladder, Lt femoral head, Lymph Nodes, PTV 56, PTV 68, Penis bulb, Rectum, Rt femoral head, and prostate bed.
- max Dose Value:** 2.3856
- Info:** Version v2.1.2 and a GitHub link.

# WHAT FORM OF EXECUTION IS RECOMMENDED FOR MATRAD?



EDUCATIONAL PURPOSES



- PROCESSING POWER

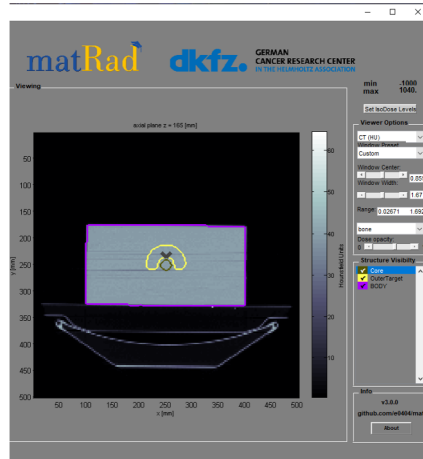
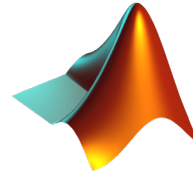


IMAGE OF MATRAD EXECUTED FROM WINDOWS APP



RESEARCH



+ PROCESSING POWER

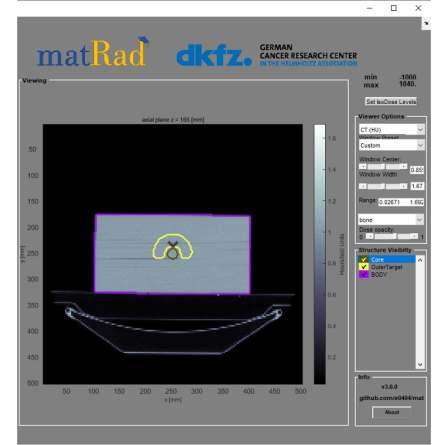


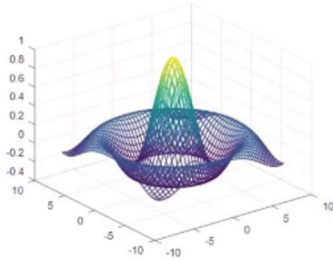
IMAGE OF MATRAD EXECUTED FROM MATLAB

FOR EDUCATIONAL PURPOSES THE USE OF MATRAD AS A WINDOWS APPLICATION IS RECOMMENDED, AS IT TAKES UP LESS STORAGE SPACE AND DOES NOT REQUIRE AN IDE (INTEGRATED DEVELOPMENT ENVIRONMENT) TO USE THE SOFTWARE.

FOR RESEARCH PURPOSES, WHICH INVOLVES TESTING TREATMENTS WITH SPECIFIC PARAMETERS THAT LEAD TO MORE REALISTIC SIMULATIONS, IT IS RECOMMENDED TO USE MATLAB TO PERFORM A MORE DETAILED ANALYSIS. THIS REQUIRES A HIGHER PROCESSING POWER.

# TWO PECULIAR FACTS

- IN CASE ONE NEEDS TO USE MATLAB IDE FOR FURTHER ANALYSIS AND A MATLAB LICENSE IS ABSENT, ONE CAN USE GNU OCTAVE, WHICH IS WRITTEN IN C / C ++ AND IS COMPATIBLE WITH MATLAB SYNTAX.
- THE GRAPHICAL USER INTERFACE (GUI) IS THE SAME WHEN EXECUTING MATRAD FROM ANY OF THE AVAILABLE OPTIONS. HOWEVER... IT IS MORE EFFICIENT TO EXECUTE IT THROUGH THE IDE.

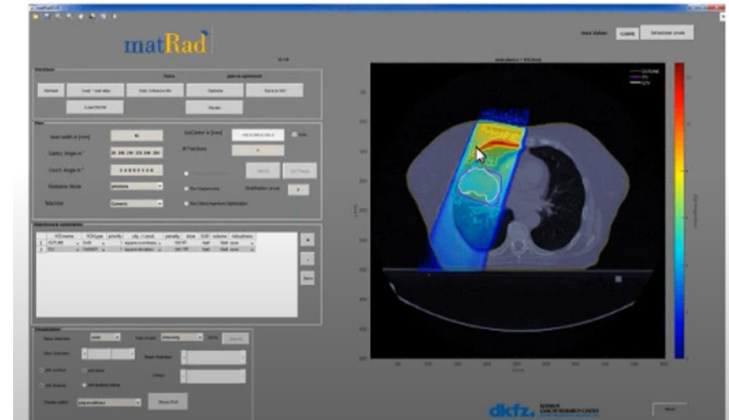


## Scientific Programming Language

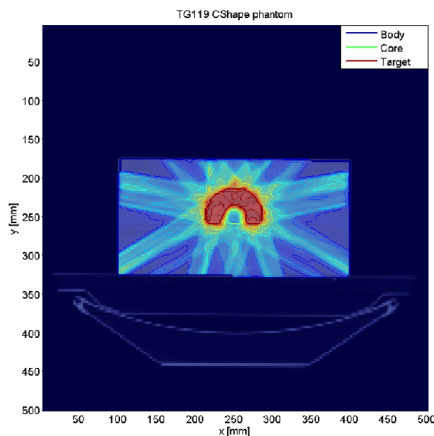
- Powerful mathematics-oriented syntax with built-in plotting and visualization tools
- Free software, runs on GNU/Linux, macOS, BSD, and Windows
- Drop-in compatible with many Matlab scripts

Download

Docs



# WHY IS MATRAD BASED ON MATLAB?



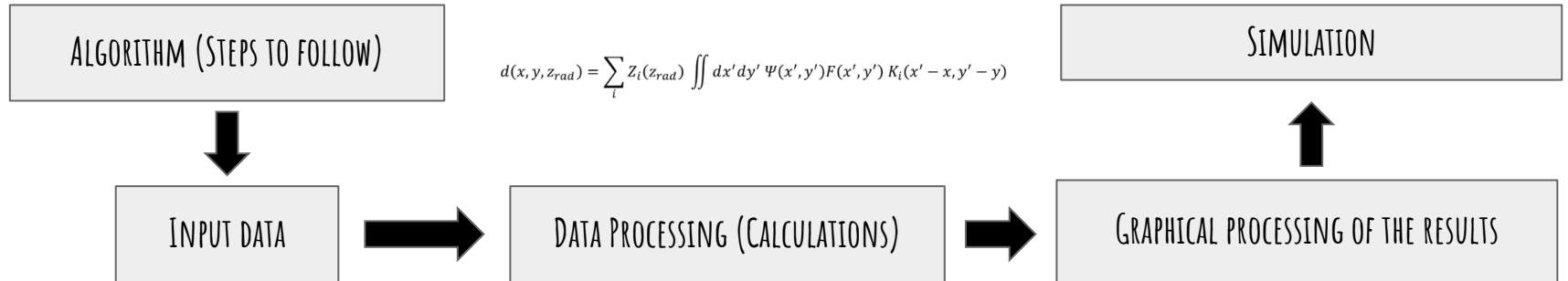
- EASY TO USE DATA VISUALIZATION
- OPTIMIZED DEBUGGING
- ALLOWS FAST DEVELOPMENT OF TREATMENT PROTOTYPES
- WELL KNOWN SOFTWARE IN THE MEDICAL PHYSICS COMMUNITY FOR ITS EFFECTIVENESS.
- SIMPLE SYNTAX COMPARED TO ABSTRACT PROGRAMMING IN LANGUAGES LIKE C ++
- ALLOWS A STANDALONE EXECUTABLE (MATRAD.EXE), WHICH CAN BE USED WITHOUT A LICENSE.



# HOW DOES THIS SOFTWARE WORK?

THE OPERATION OF THIS SOFTWARE IS POSSIBLE THANKS TO THE ALGORITHMS DEVELOPED BY THE PROFESSIONALS FROM INTERDISCIPLINARY AREAS WHO ARE PART OF THIS PROJECT.

THANKS TO THE PROCEDURES PREVIOUSLY PROGRAMMED, THE INPUT DATA IS USED TO PERFORM THE CALCULATIONS AND THUS, DISPLAY THE OPTIMIZED RESULTS OF THE SIMULATIONS ON THE VISUALIZATION PANEL.





# HOW IS DATA PROCESSING CARRIED OUT?

IN THE PREVIOUSLY MENTIONED ALGORITHMS, THE INPUT DATA ARE TAKEN AS VARIABLES, WHICH ALREADY HAVE A CERTAIN MEMORY LOCATION RESERVED. LATER THESE ARE STORED IN DIFFERENT TYPES OF DATA STRUCTURES THROUGH MATRICES, VECTORS, ETC., AND THEN THEY ARE PROCESSED ACCORDING TO THE MATHEMATICAL PROCEDURE THAT EACH OF THEM MUST FOLLOW ACCORDING TO THE ALGORITHM AND ITS PARAMETERS. FINALLY, THE RESULTS ARE STORED IN A RESERVED SPACE.

Fields	gantryAngle	couchAngle	bixelWidth	radiationMode	SAD	isoCenter	numOfRays	ray	sourcePoint_bev	sourcePoint	numOfBixelsPerRay
1	0	30	5	'photons'	1000	[251.3089,23...	302	1x302 struct	[0,-1000,0]	[0,-1000,0]	1x302 double
2	21.1700	47.1400	5	'photons'	1000	[251.3089,23...	309	1x309 struct	[0,-1000,0]	[245.6483,-932...	1x309 double
3	42.3400	64.2800	5	'photons'	1000	[251.3089,23...	300	1x300 struct	[0,-1000,0]	[292.2937,-739...	1x300 double
4	63.5100	81.4200	5	'photons'	1000	[251.3089,23...	248	1x248 struct	[0,-1000,0]	[133.5270,-446...	1x248 double
5	84.6800	98.5600	5	'photons'	1000	[251.3089,23...	180	1x180 struct	[0,-1000,0]	[-148.2039,-92...	1x180 double
6	105.8500	115.7000	5	'photons'	1000	[251.3089,23...	247	1x247 struct	[0,-1000,0]	[-417.1714,273...	1x247 double
7	127.0200	132.8400	5	'photons'	1000	[251.3089,23...	293	1x293 struct	[0,-1000,0]	[-542.8920,602...	1x293 double
8	148.1900	149.9800	5	'photons'	1000	[251.3089,23...	308	1x308 struct	[0,-1000,0]	[-456.3935,849...	1x308 double
9	169.3600	210	5	'photons'	1000	[251.3089,23...	314	1x314 struct	[0,-1000,0]	[-159.9008,982...	1x314 double
10	190.5300	225	5	'photons'	1000	[251.3089,23...	313	1x313 struct	[0,-1000,0]	[129.2240,983.1...	1x313 double
11	211.7000	240	5	'photons'	1000	[251.3089,23...	314	1x314 struct	[0,-1000,0]	[262.7358,850.8...	1x314 double
12	232.8700	255	5	'photons'	1000	[251.3089,23...	286	1x286 struct	[0,-1000,0]	[206.3481,603.6...	1x286 double
13	254.0400	270	5	'photons'	1000	[251.3089,23...	215	1x215 struct	[0,-1000,0]	[0,274.9662,-96...	1x215 double
14	275.2100	285	5	'photons'	1000	[251.3089,23...	202	1x202 struct	[0,-1000,0]	[-257.7498,-90...	1x202 double
15	296.3800	300	5	'photons'	1000	[251.3089,23...	270	1x270 struct	[0,-1000,0]	[-447.9335,-444...	1x270 double
16	317.5500	315	5	'photons'	1000	[251.3089,23...	309	1x309 struct	[0,-1000,0]	[-477.2593,-737...	1x309 double
17	338.7200	330	5	'photons'	1000	[251.3089,23...	307	1x307 struct	[0,-1000,0]	[-314.3031,-931...	1x307 double

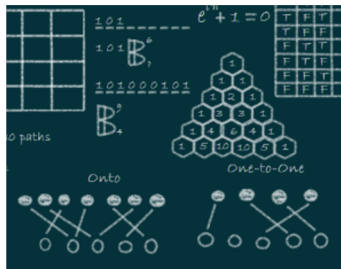
Field	Value	Min	Max
numOfBeams	2	2	2
numOfVoxels	3047040	30...	30...
resolution	1x1 struct		
totalNumOfRaysPerBeam	[303 303]	303	303
totalNumOfRays	606	606	606
totalNumOfBixels	16448	16...	16...
dimensions	[184 184 90]	90	184
numOfScenarios	1	1	1
bixelNum	16448x1 double	1	43
rayNum	16448x1 double	1	303
beamNum	16448x1 double	1	2
physicalDose	1x1 cell		

# 8. HOW IS DATA PROCESSING CARRIED OUT?

INPUT



STORAGE OF VARIABLES THROUGH DATA STRUCTURES



PROCESSING

$$\min f(d(w)), w \in \mathbb{R}^n$$

$$f = \sum_i p_i f_i$$

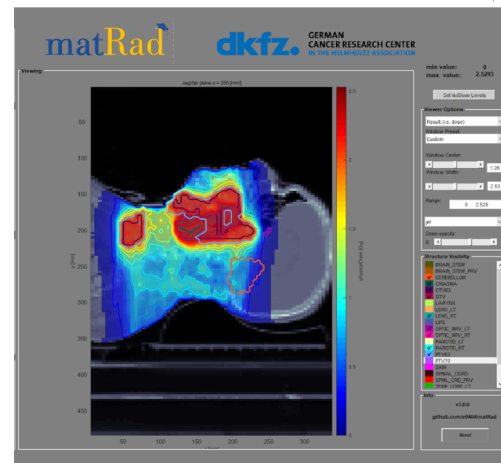
$$\text{s. t.} \quad d = Dw$$

$$c_l \leq c(w) \leq c_u$$

$$w_l \leq w \leq w_u$$

$$f(w): \mathbb{R}^n \rightarrow \mathbb{R}, c(w): \mathbb{R}^n \rightarrow \mathbb{R}^m$$

RESULTS STORAGE AND VISUAL PROCESSING



PROCEDURE

# INPUT

TAC

Angoli del lettino e del gantry

Tipo: p, C, photon

Limiti di dose per zona tumorale e organi a rischio

The screenshot displays the matRad GUI interface. The top left contains workflow buttons: Refresh, Load \*.mat data, Calc, Influence Mix, Optimize, Save to GUI, and Recalc. The status bar indicates 'plan is optimized'. The main input section includes: Dose (5), Gantry Angle (0.180, 225, 270, 315), Couch Angle (0 0 0 0), Machine (photons), IsoCenter (206.8, 296.7, 316.4), # Fractions (30), and Type of optimization (none). The 'Objectives & constraints' table is as follows:

VOI name	VOI type	OP	Function	p	Parameters
Skin	OAR	2	Squared Overdos...	300	$\sigma^{max}$ : 25
PTV	TARG...	1	Squared Deviation	1000	$\sigma^{min}$ : 45
GTV					

The visualization area shows a CT scan of a chest with a dose distribution overlay. The x and y axes are in mm, ranging from 50 to 650. A color scale on the right indicates dose intensity from -1004 to 1886. The right sidebar contains 'Viewer Options' (CT (HU)), 'Structure Visibility' (listing GTV, Kidney, Stomach, etc.), and 'Info' (v3.0.0 - edu, github.com/e040/matRad).

Calculate influence matrix

# DOSE CALCULATION

Optimize all the beams → calculate the plan

The screenshot displays the matRad GUI interface. At the top, the workflow bar includes buttons for Refresh, Load \*.mat data, **Calc. influence Mx**, **Optimize**, and Save to GUI. A red circle highlights the 'Calc. influence Mx' and 'Optimize' buttons, with arrows pointing to the text 'Calculate influence matrix' and 'Optimize all the beams → calculate the plan' respectively. The status bar indicates 'plan is optimized'. The Plan section shows parameters: beam width (5 mm), gantry angle (0.180, 225, 270, 315), couch angle (0, 0, 0, 0), radiation mode (photons), machine (Generic), iso center (206.8, 296.7, 316.4 mm), and 30 fractions. The Objectives & constraints table is as follows:

VOI name	VOI type	OP	Function	p	Parameters
Skin	OAR	2	Squared Overdos...	300	$\sigma^{max}$ : 25
PTV	TARG...	1	Squared Deviation	1000	$\sigma^{rel}$ : 45
GTV					

The Visualization section shows slice selection, beam selection, and offset controls. The plot area displays a cross-sectional dose distribution with a color scale from -1004 to 1886. The plot is labeled 'axial plane z = 355 [mm]'. The Structure Visibility panel on the right lists various organs at risk and target volumes, including GTV, Kidney, Stomach, Small Bowel, Large Bowel, Celiac, SMA, SIV, Liver, Heart, Spinal Cord, Dose/FatOff, Caecum, PTV, and Skin. The info panel at the bottom right shows version v3.0.0 - edu and the GitHub repository github.com/v040/matRad.

# OUTPUT

Workflow

Refresh Load \*.mat data Calc. influence Mix Optimize Save to GUI

Recalc

Status: plan is optimized

box size in [mm] 5

Gantry Angle in ° 0,180,225,270,315

Couch Angle in ° 0 0 0 0

Definition: photons

Machine: Generic

IsoCenter in [mm] 265.8 298.7 916.4

# Fractions: 30

Type of optimization: none

Run Sequencing

Stratification Levels: 7

Auto.

Spot Tissue

±/∓	VOI name	VOI type	OP	Function	p	Parameters
-	Skin	OAR	2	Squared Overdos...	300	$d_{max}^{1.5}$ , 25
-	PTV	TARG...	1	Squared Deviation	1000	$d_{min}^{1.5}$ , 45
-	GTV					

Visualization

Slice Selection: [ ]

Plane Selection: [ ]

Type of plot: intensity

GoTo: [ ]

Open 3D-View

Display option: physicalDose

Show DVH/QI

matRad GUI

matRad dkfz. GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

axial plane z = 317.5 [mm]

axial plane z = 395 [mm]

min value: -1024  
max value: 1886.4

Set IsoDose Levels

Viewer Options

CT (HU)

Window Preset: Custom

Window Center: 431

Window Width: 2.91e4

Range: -1024 1886

bone

Lock Settings

Dose capacity: 1

Structure Viability

- CTV
- Kidney\_R
- Kidney\_L
- Stomach
- SmallBowel
- LargeBowel
- Cervix
- SMN
- Uter
- Heart
- SpinalCord
- DorsalFat/Soft
- duodenum
- CTV\_Skin
- Skin
- PTV
- cont-5mm
- clip1
- clip2
- clip3
- clips
- entrance
- Uter-CTV

Info

v3.0.0 - edu

github.com/e040/matRad

About

TAC slicer

Visualize: what field (direction)

Visualize: sagittal, axial, coronal

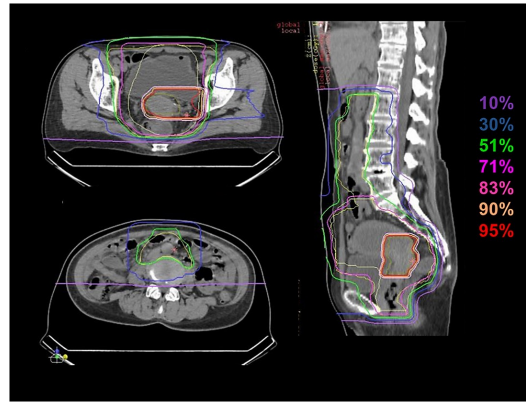
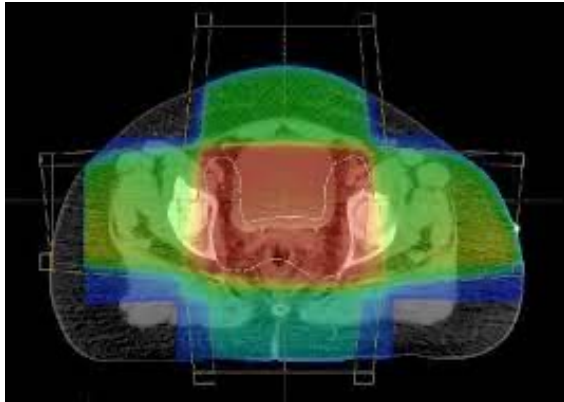
DVH: See next

Dose

Structures

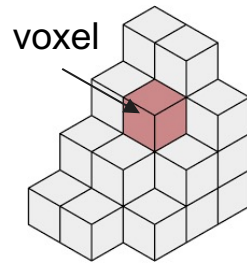
# DOSE

- Per valutare un piano di trattamento, guardare la dose in 3D sulla CT e' il modo piu' diretto per valutare la qualita'

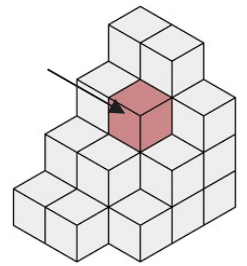


Dimension of dose is Gy [Joule per kg]

- Svantaggio: virtuale, impegnativo guardare tutti gli slices... tipicamente ~100 CT slices, ~500000 voxels...



# DVH



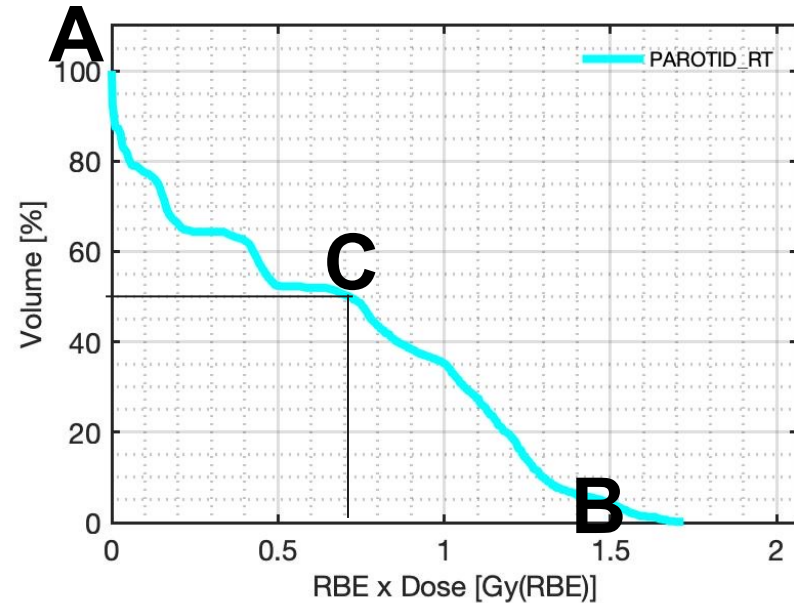
- Dose Volume Histogram: un metodo per valutare velocemente la qualita' della distribuzione di dose
- Tutte le structuree della TAC + informazione sulla dose in poche line!
- In ogni voxel della struttura, valutare la dose --> DHV
- Quindi 1 linea per 1 struttura/organo

## Blue line

- A: 100% of voxels get at least 0 Gy
- B: 0% of voxels receive at least 1.7 Gy
- C: ... % of voxels receive at least ... Gy

## Svantaggi:

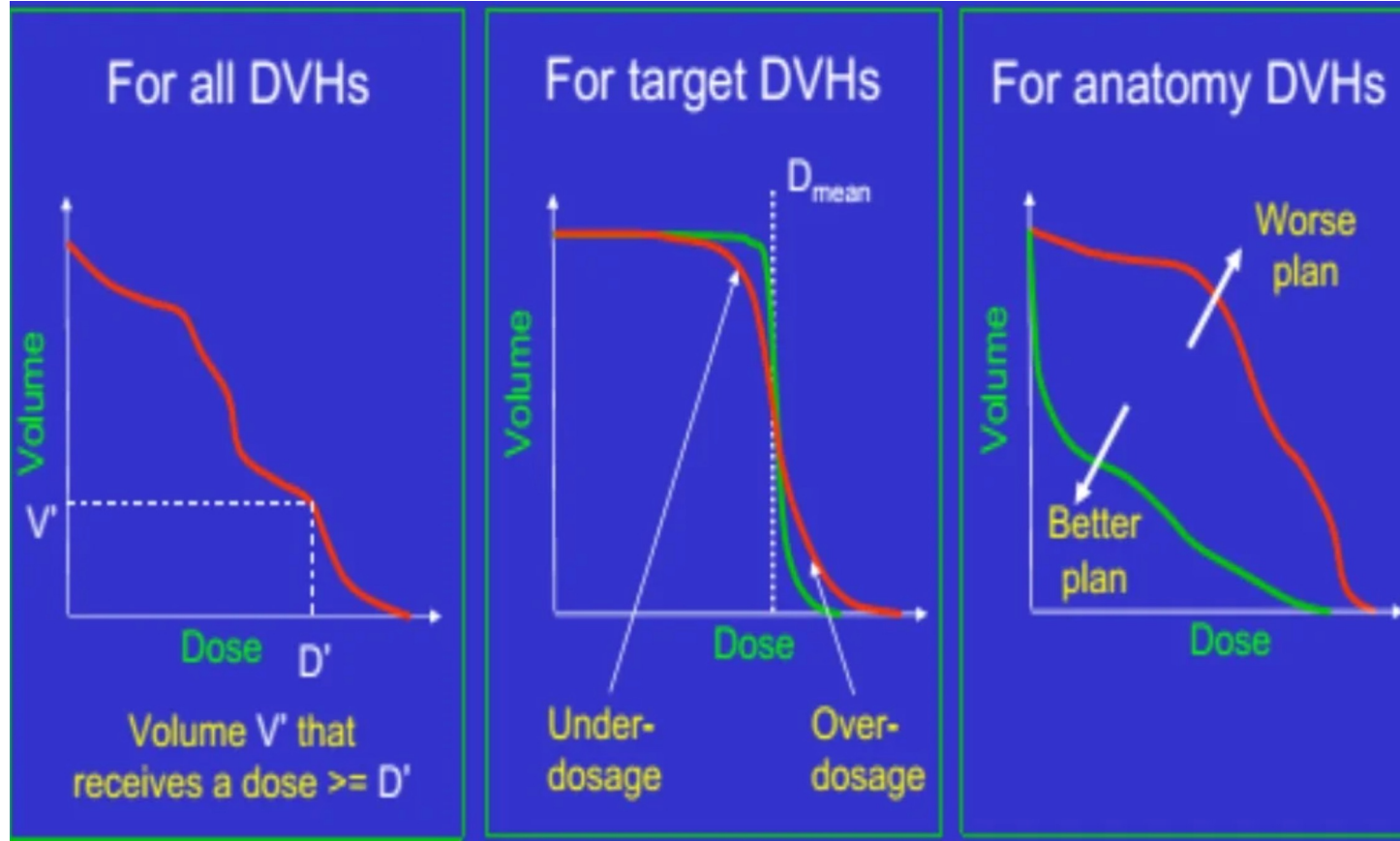
- DVH reduce una distribuzione 3D in una linea
- Un po' di informazioni si perdono...



# VALUTARE E COMPARARE PIANI DI TRATTAMENTO CON DVH

## Scopo:

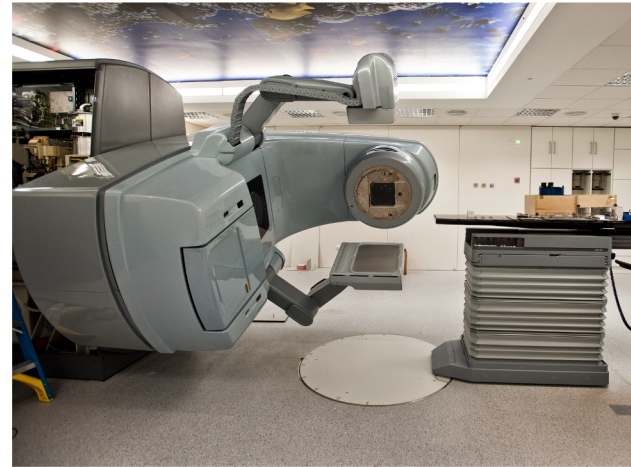
- Se la dose al tumore ('target') prescritta e'  $D_p$ , 100% di quella zona deve ricevere esattamente  $D_p$  → linea verticale
- Organi a rischio: verso le zero





# 9. WHERE DOES ALL THAT REALLY APPLY?

EVERYTHING LEARNED IN THIS MASTERCLASS IS APPLIED PROFESSIONALLY IN HEALTH CENTERS WHERE SPECIALIZED EQUIPMENT IS AVAILABLE TO PERFORM VARIOUS CLINICAL PROCEDURES THROUGH RADIOTHERAPY IN ORDER TO HELP THE TREATMENT OF A WIDE VARIETY OF DISEASES, INSTEAD OF MORE COMPLICATED AND PAINFUL PROCEDURES.



# 10. HOW ARE THE FACILITIES OF A PARTICLE THERAPY CENTER?





TO LEARN MORE ABOUT THE ELEMENTS OF A PARTICLE THERAPY FACILITY, YOU CAN VISIT THE FOLLOWING LINK:

[HTTP://WWW.CERN.NYMUS3D.NL/MAPS](http://www.cern.nymus3d.nl/maps)

WE'RE READY FOR THE  
AFTERNOON SESSION

