

# Introduction to Treatment Planning

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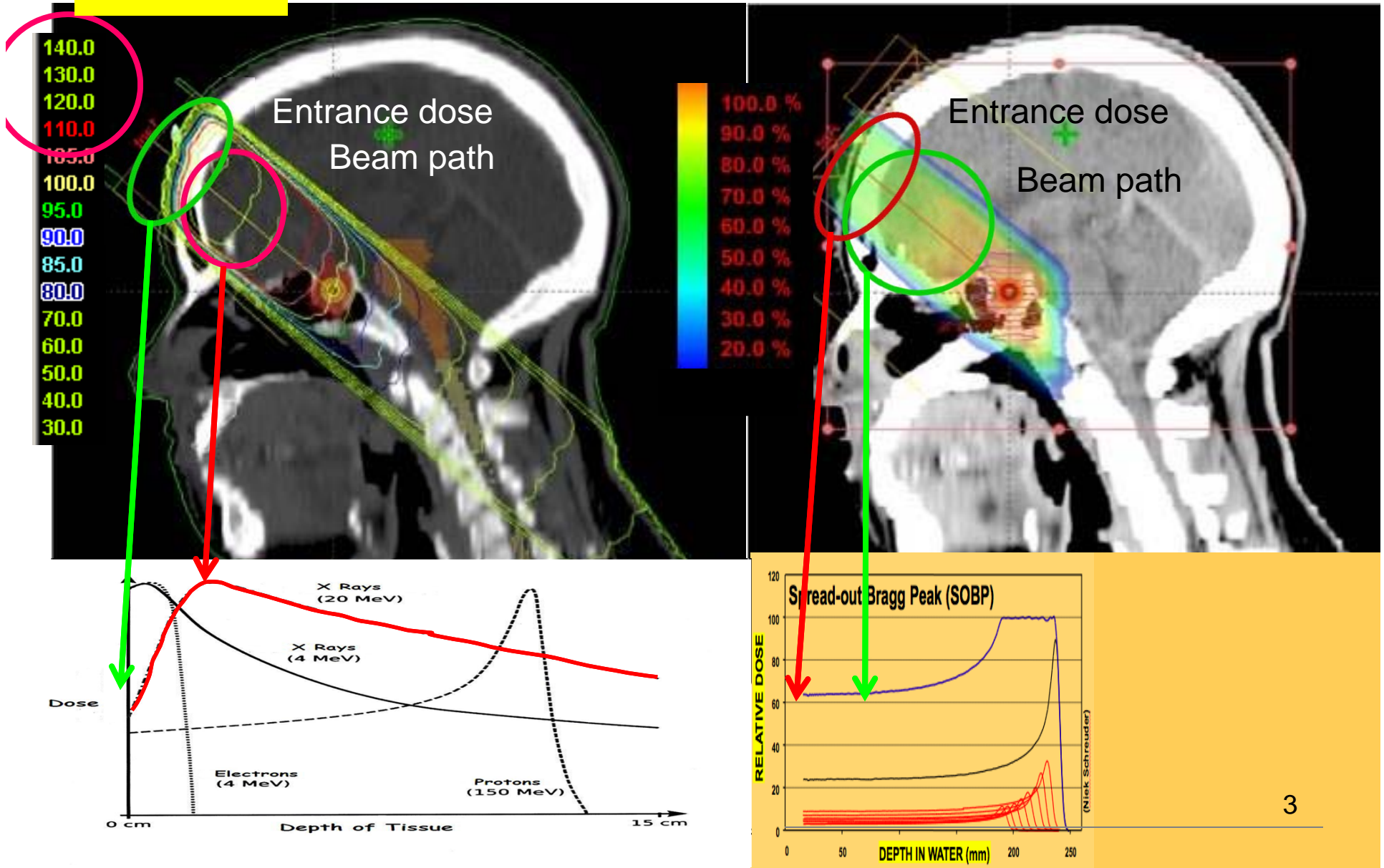
**PTCOG-54 San Diego 2015**

# Menu of today

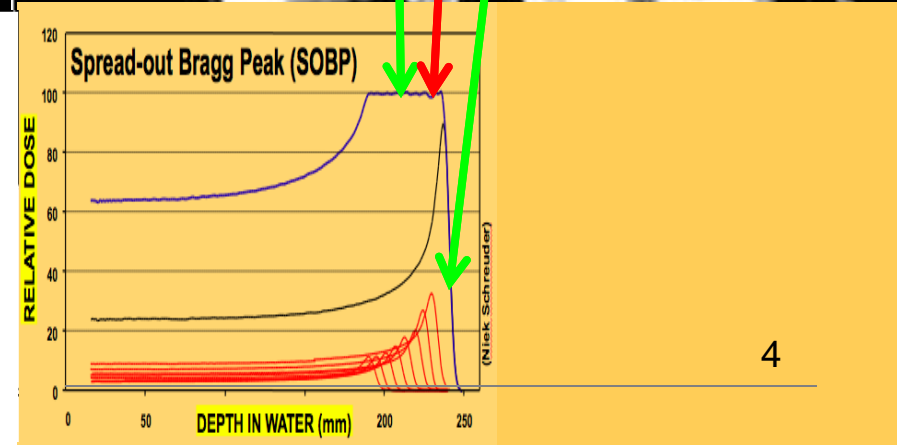
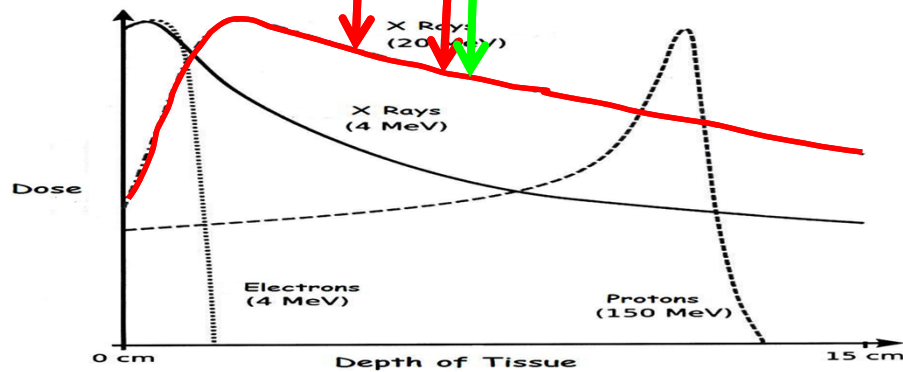
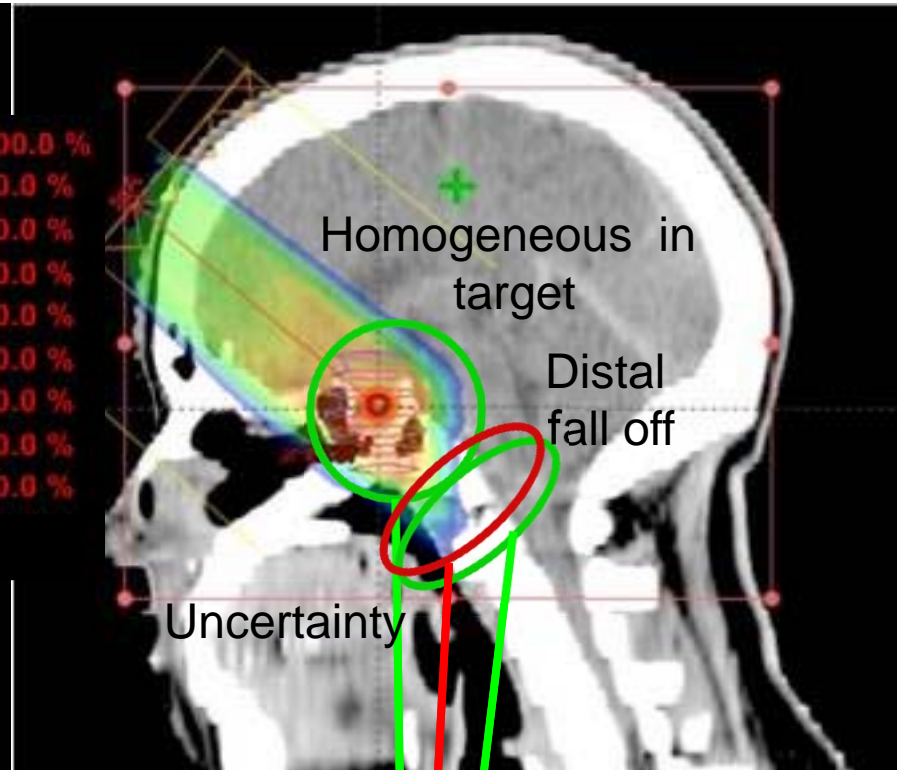
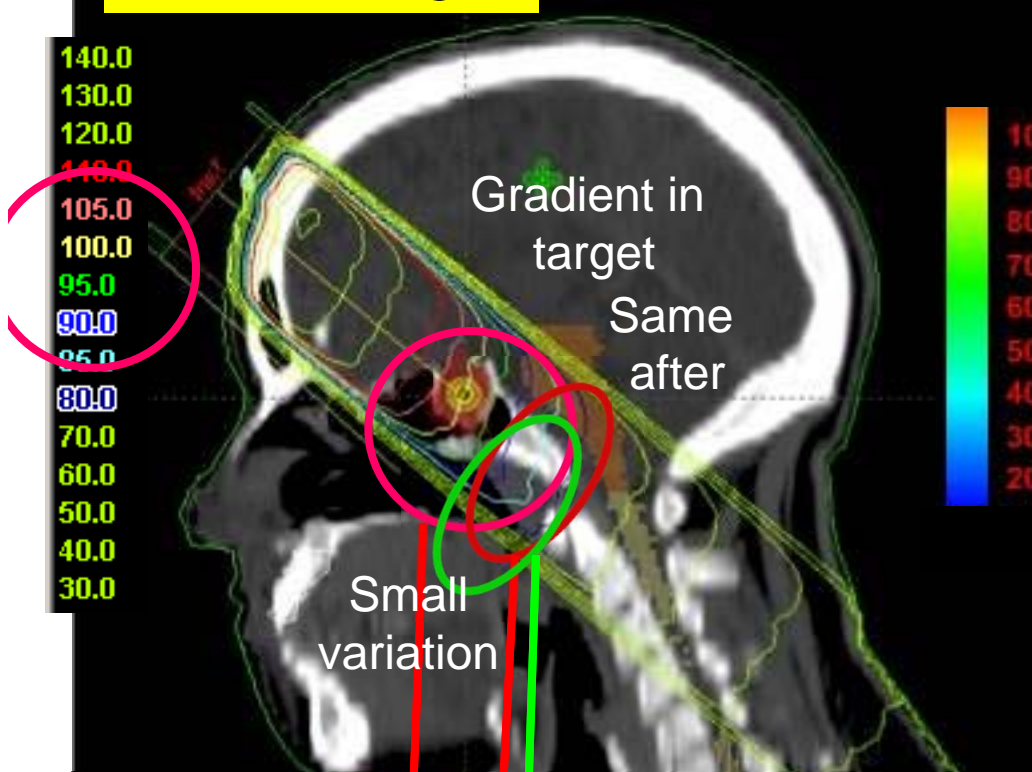
- The **process of planning** with protons
- Calculating **models**
- Planning with **passive beams**:  
Compensators and patching
- Planning with **scanned beams** :  
Uniform beams or intensity modulation
- **Organ movements** and deformations
- Conclusions
- (*ions* → see specific talk later)

Moving from planning with photons to protons? (Isodoses)  
 (concepts for 1 beam ~ valid for passive and active techniques...)

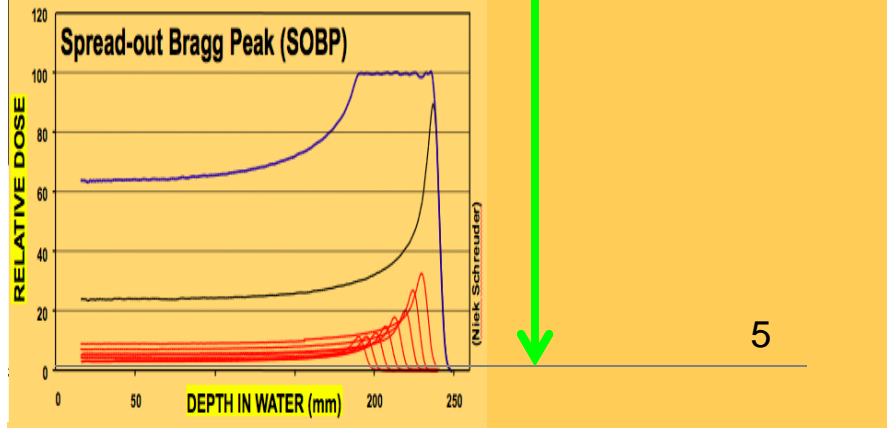
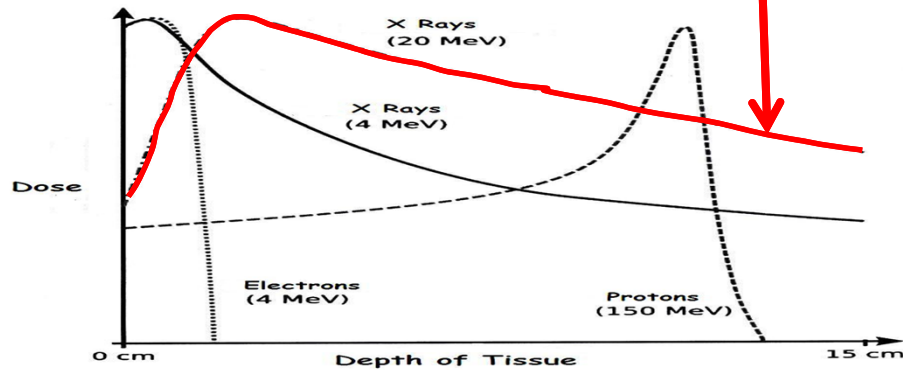
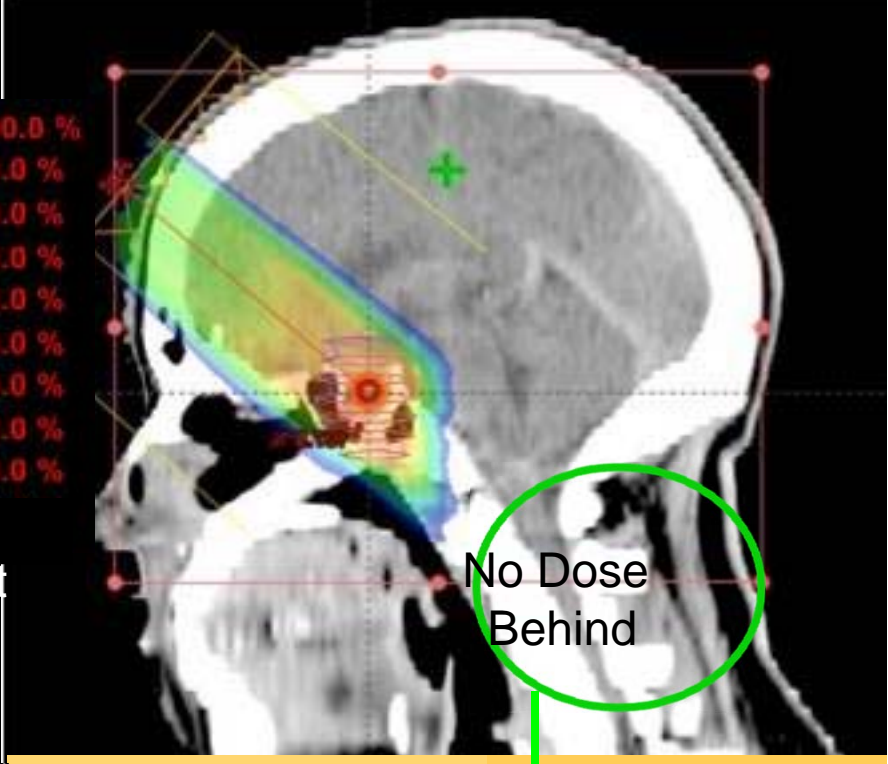
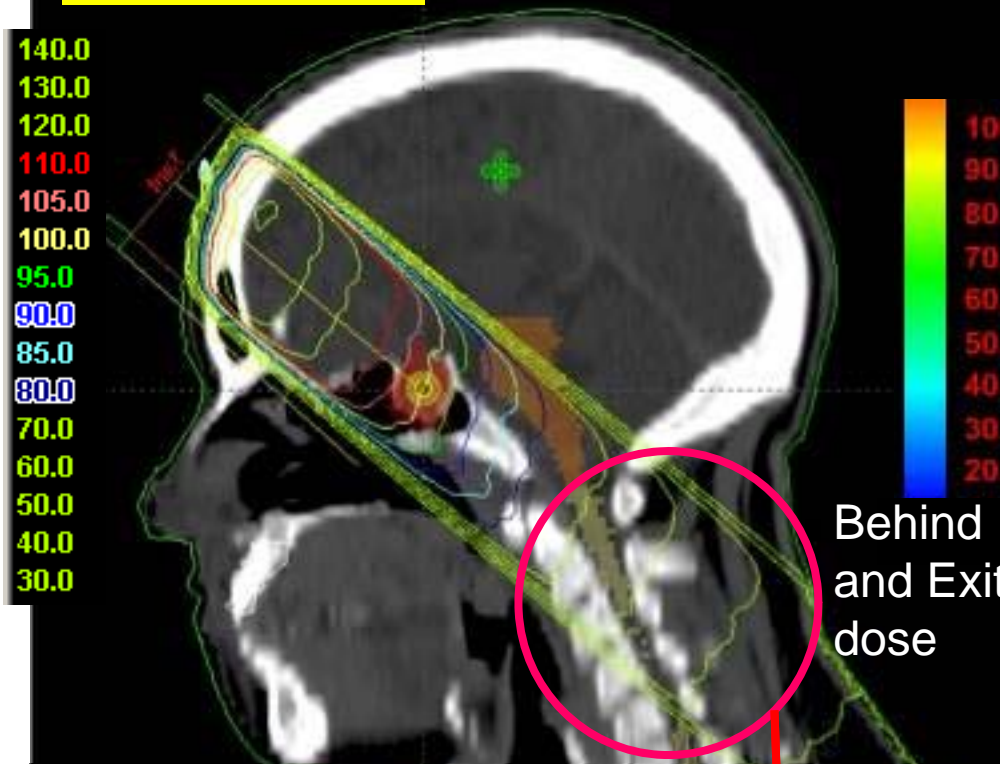
**Entrance**



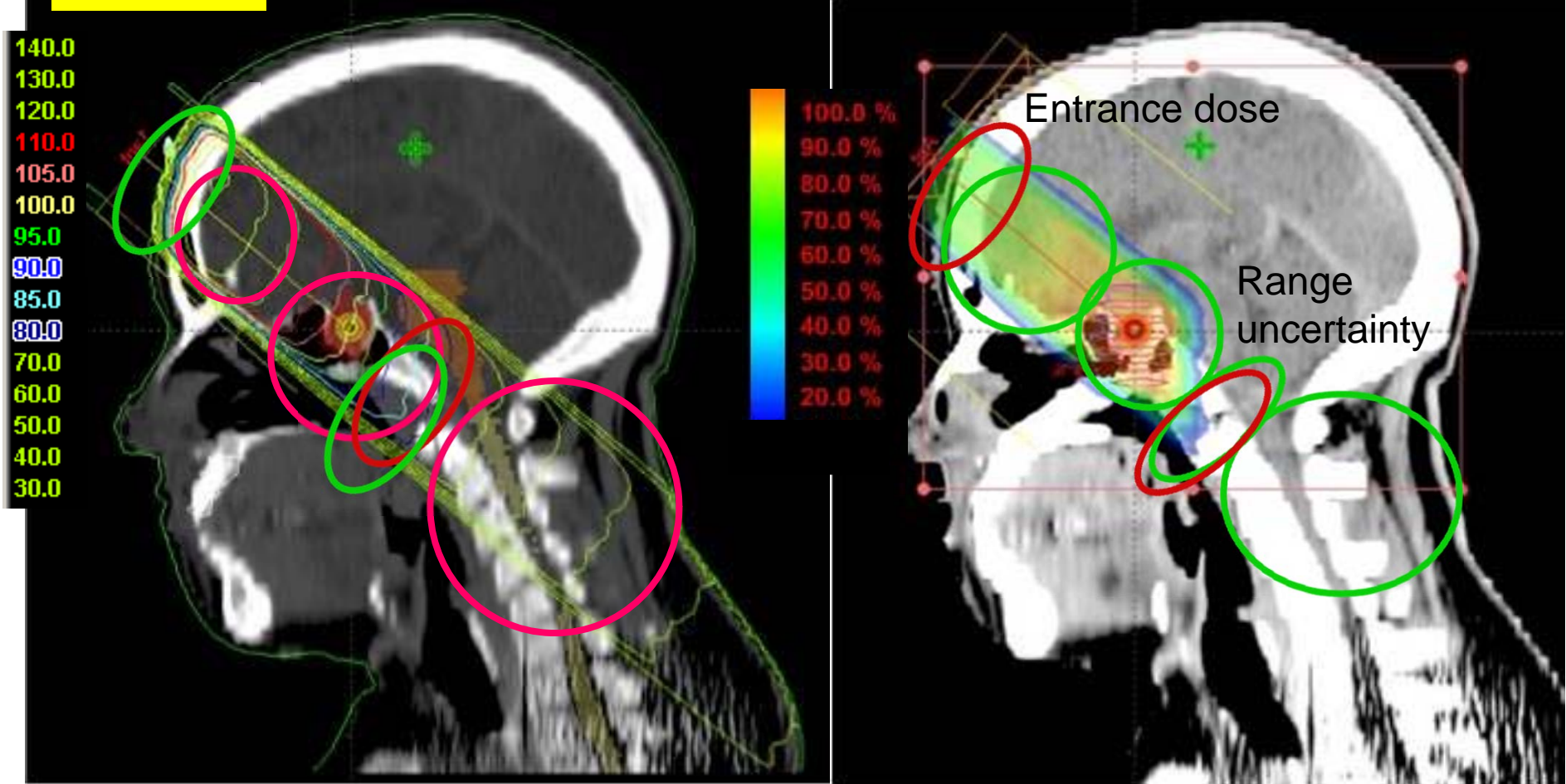
# Around target



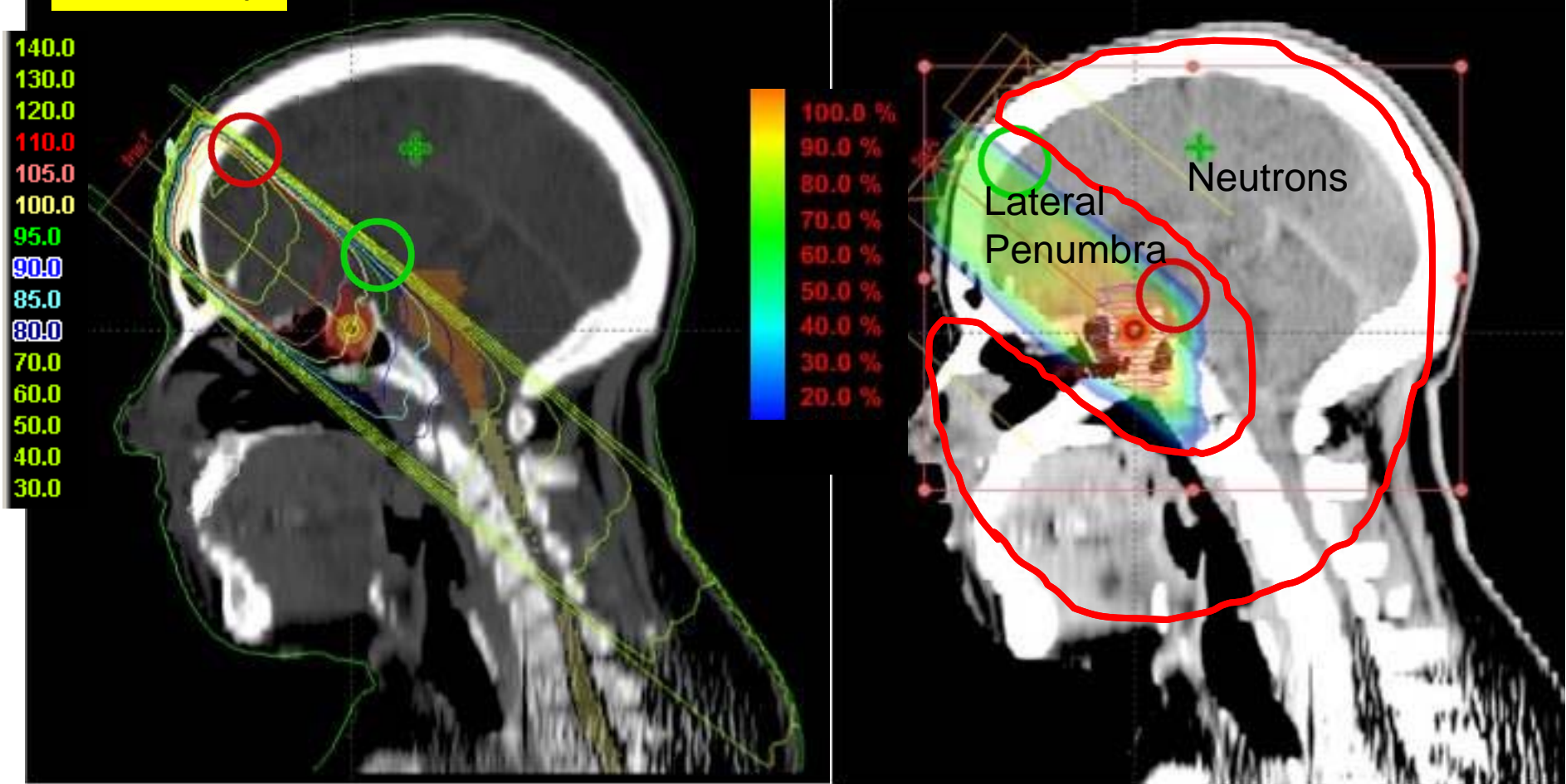
# After target

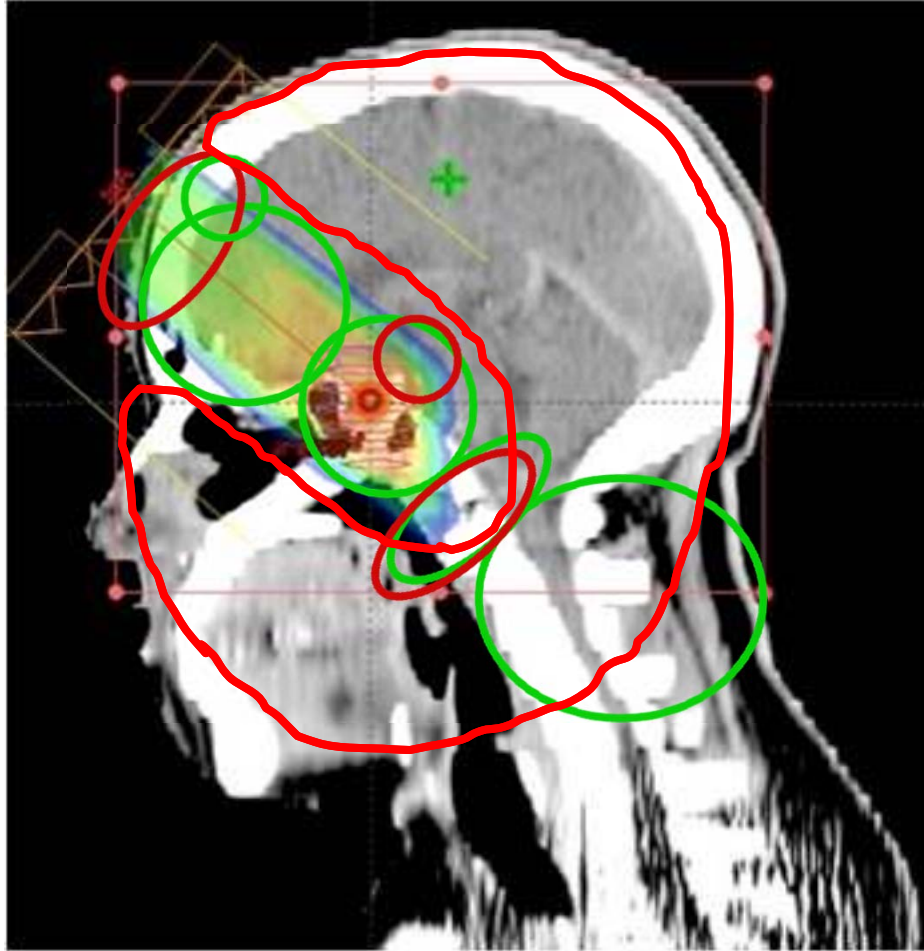


# On axis



# Laterally







(Sub)liminal message

**BUT PLANNING**

**IS NOT ONLY**

**ISODOSES and HISTOGRAMS**

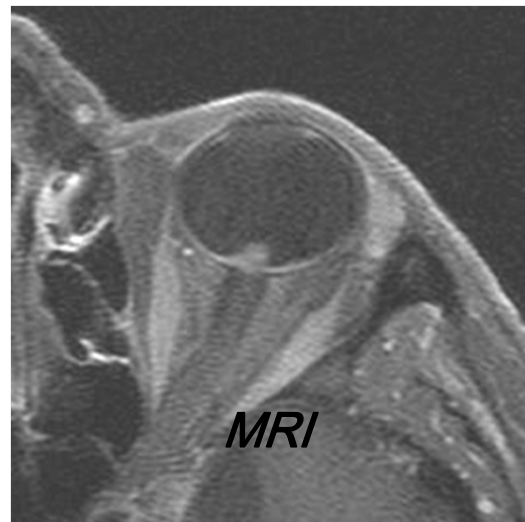
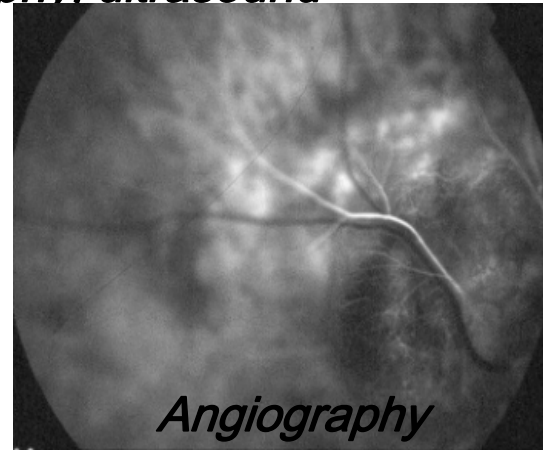
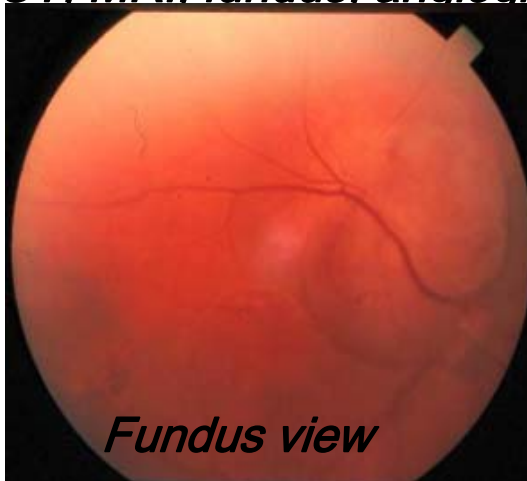
**BUT**

**A PROCESS**

The planning process :  
« First simple case » : Ophthalmologic tumors

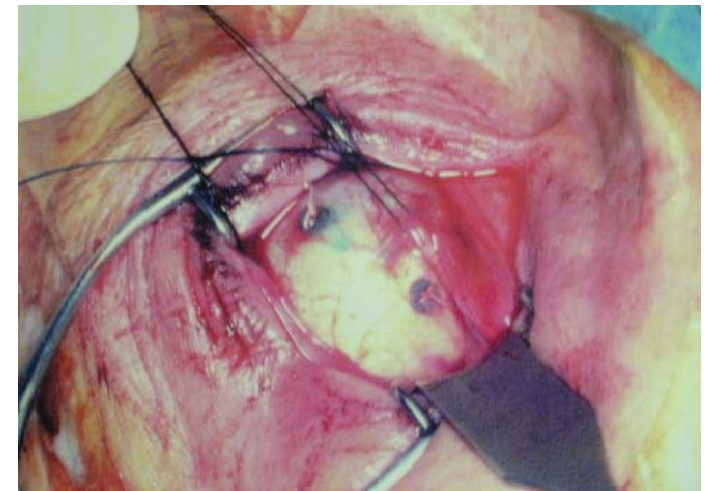
**Imaging**

Obtain and inter-register imaging studies :  
CT, MRI, fundus, angiography, ultrasound



**Immobilisation  
& reference coordinates**

*masks, frames,...*  
*and/or...*  
*use of implanted fiducials*

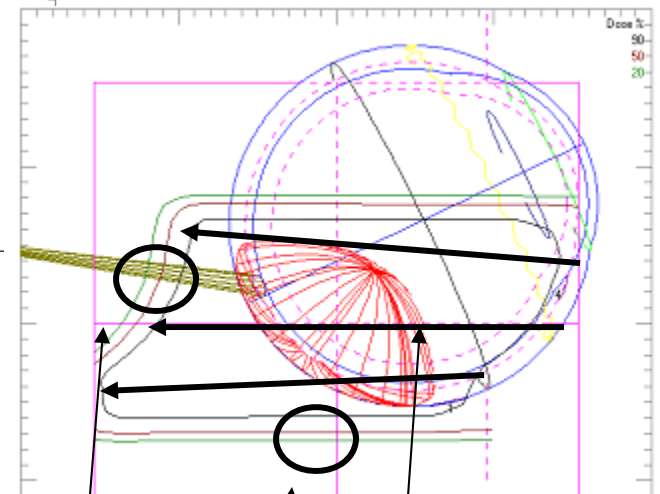
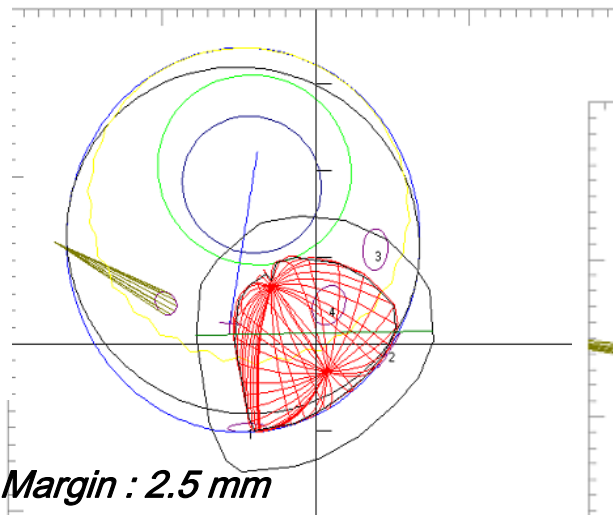
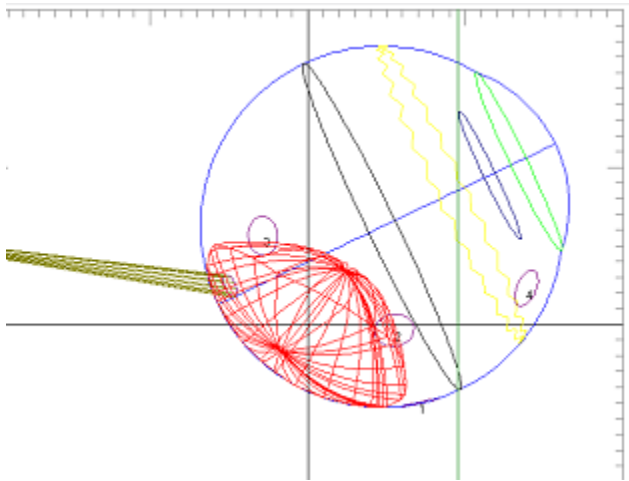


# Delineate target, planning aims and beam design

*Indeed for eyes:  
Choice of the gaze angle  
to avoid critical organs*

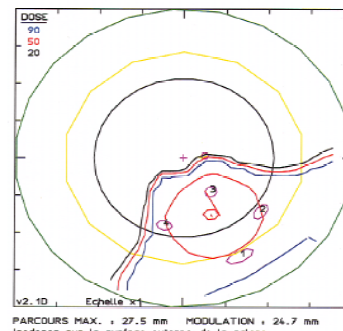
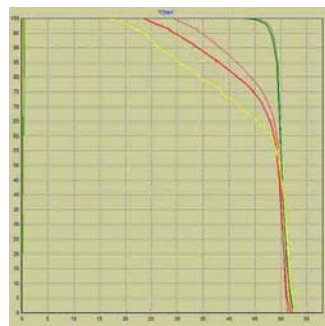
*In the beam's eye view:  
Design a collimator*

*Calculate dose distribution*

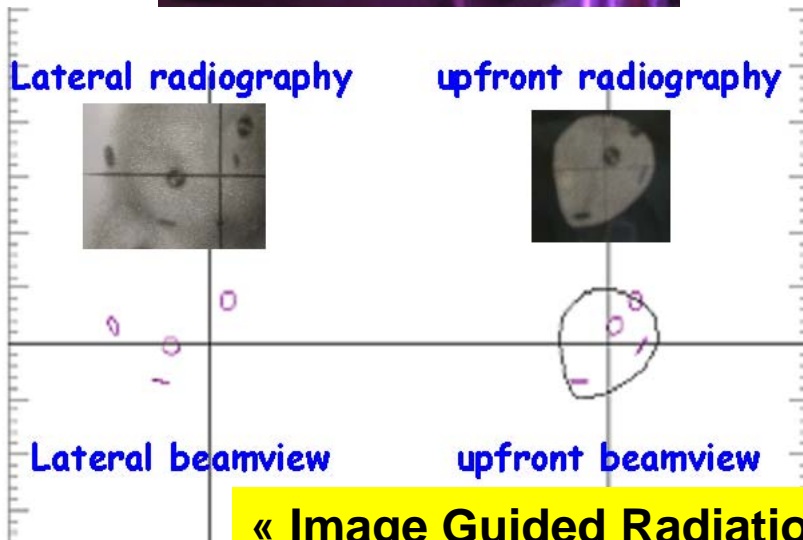
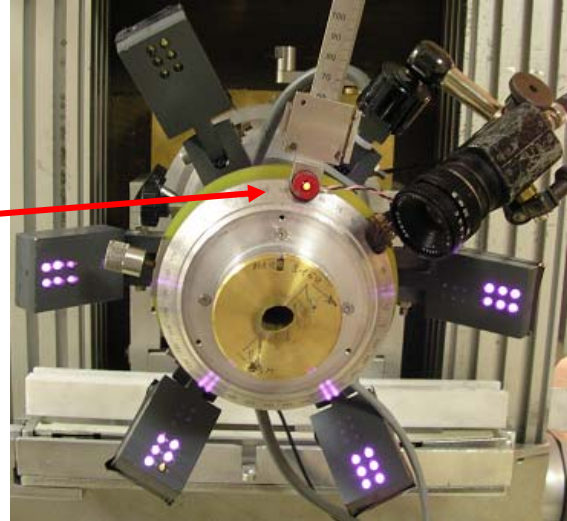


Distal fall off  
Eg 30%/mm

*Show results  
for analysis  
and optimisation*



# Daily set-up control : the Planning System must provide the tools



**« Image Guided Radiation Therapy IGRT »  
with coaching and gating**

*(adapted from M.Goitein)*

## The planning process in general

<i>step</i>	
1	<b>Evaluate the patient</b>
2	<b>Register Images in tt position</b>
3	<b>Delineate target and critical organs</b>
4	<b>Establish the planning aims</b>
5	<b>Design and calculate beams</b>
6	<b>Evaluate, replan</b>
7	<b>Finalize the prescription</b>
8	<b>Simulate, QA</b>
9	<b>Deliver, record, verify</b>
10	<b>Re-evaluate during treatment</b>
11	<b>Document, archive</b>
12	<b>Review during follow-up</b>

Steps are common  
for any approach in RT...

## The planning process in general – and the differences between protons and x-rays

<i>step</i>		<i>•protons vs. photons</i>
1	<b>Evaluate the patient</b>	~same
2	<b>Register Images in tt position</b>	Same
3	<b>Delineate target and critical organs</b>	~same
4	<b>Establish the planning aims</b>	same
5	<b>Design and calculate beams</b>	different
6	<b>Evaluate, replan</b>	same
7	<b>Finalize the prescription</b>	same
8	<b>Simulate, QA</b>	same
9	<b>Deliver, record, verify</b>	~same, harder QA
10	<b>Re-evaluate during treatment</b>	same
11	<b>Document, archive</b>	same
12	<b>Review during follow-up</b>	same

o Meaning of PTV may be different

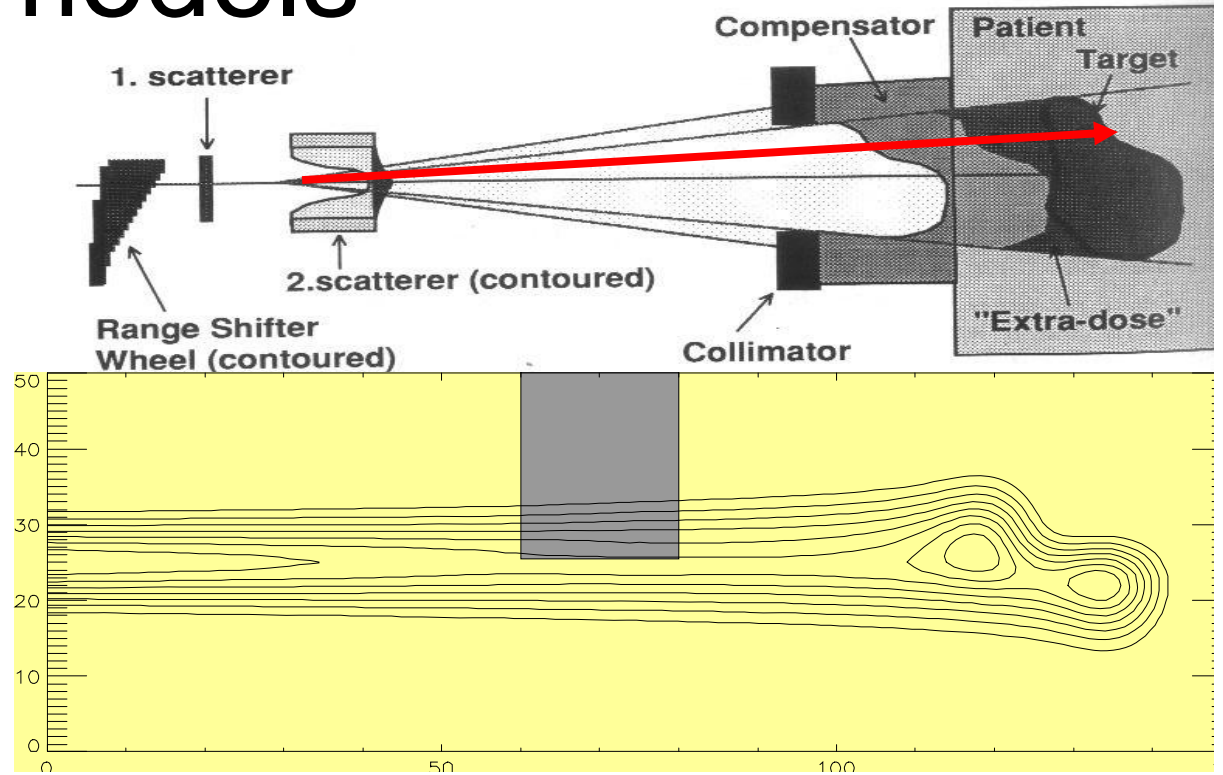
( Range uncertainties)

- o Beam models
- o The effects and compensation of inhomogeneities
- o Beam delivery techniques
- o Design of single beams and plans
- o Immobilization, localization and verification
- o Uncertainty analysis

# TPS : beam models

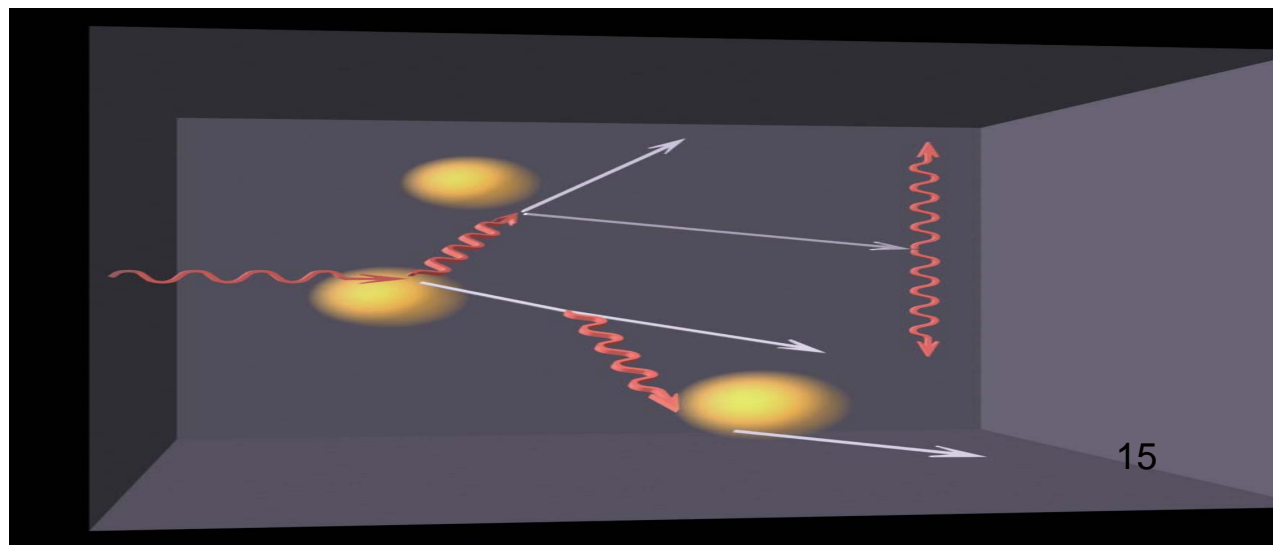
3 Families

1) Ray Tracing



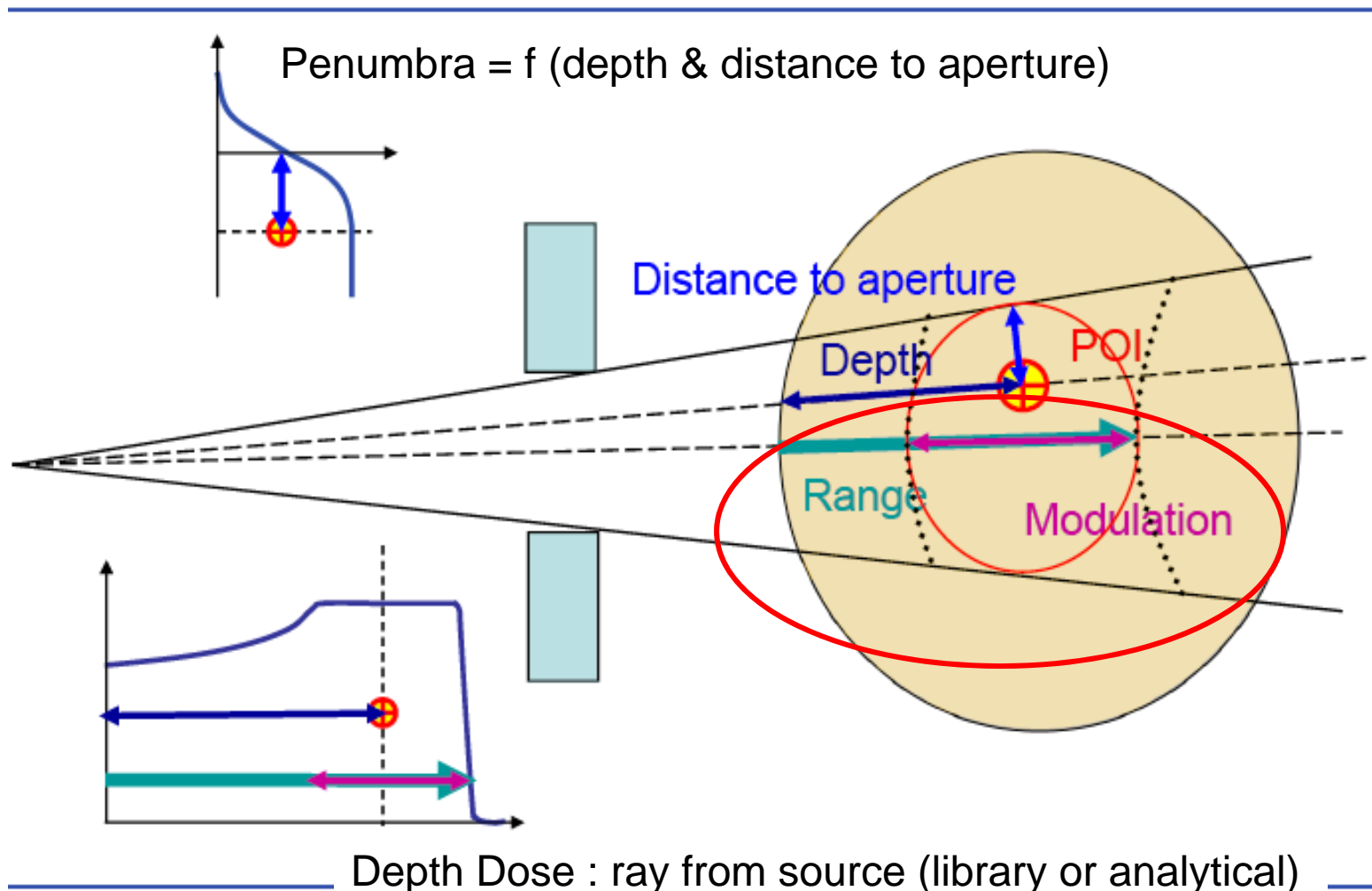
2) Pencil Beam

3) MonteCarlo



# 1) Ray tracing in passive beams :

## Broad beam algorithm - Concept

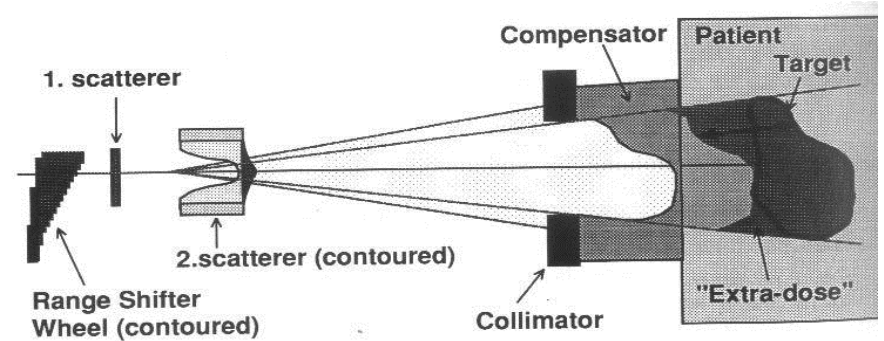


(Barbara Schaffner, Varian)



## Ray tracing :

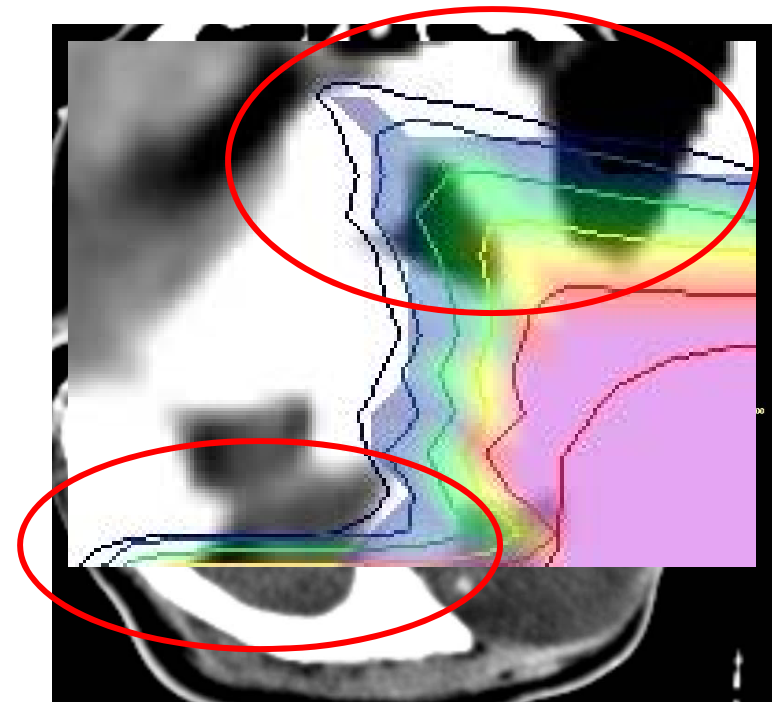
☀ straight protons (no scattering), coming from a (punctual) source



☀ lateral penumbra model => takes into account scattering due to :

- initial beam line
- compensator + air-gap
- patient

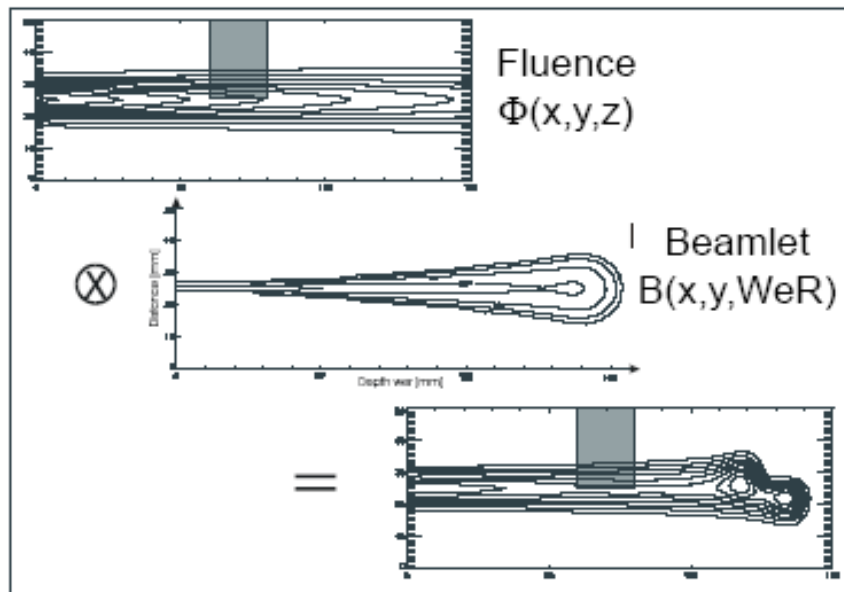
⇒ Limitations in inhomogeneous areas and for high gradients in compensators



⇒ ***Old, simple, fast and relatively efficient***

## 2) Pencil Beam

## algorithm - Concept



- Principle
  - Convolution of 3D undisturbed proton fluence in air with a 'beamlet' in water.
- In practice
  - Superposition of inhomogeneity - corrected beamlets and multiplication with fluence at calculation position.

## Pencil Beam :

- Scattering = broadening of each pencil beam with depth
- Good compromise speed-precision

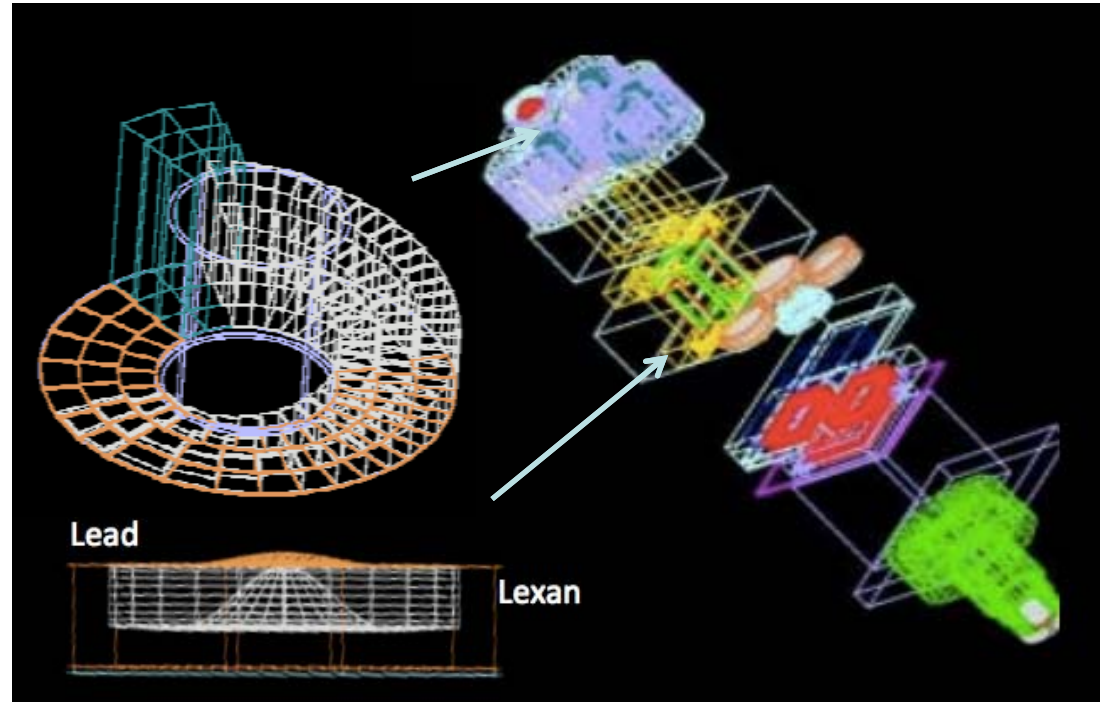


*The most used at present*

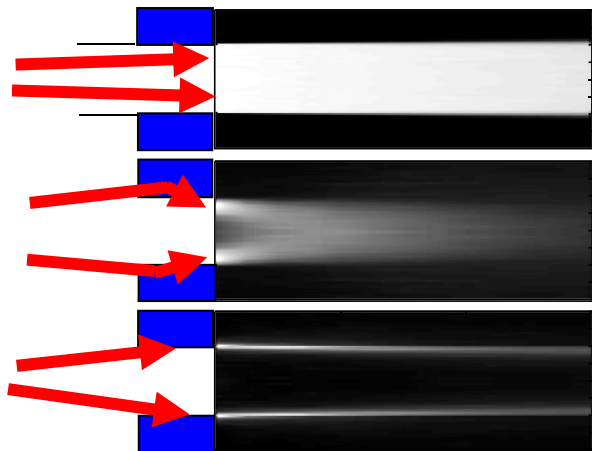
# 3) MonteCarlo

Tracking each particle and all interactions  
(Geant 4, MCNPX,...) :

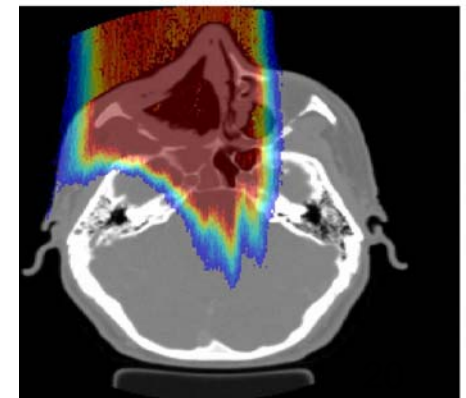
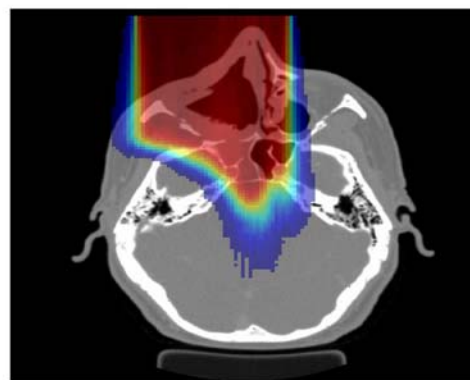
- Beam at the entrance (E,dE,...)
- Treatment Head/nozzle
- 4D if movements
- Patient CT:  
HU → groups of tissues



Paganetti, Bernardz, et al

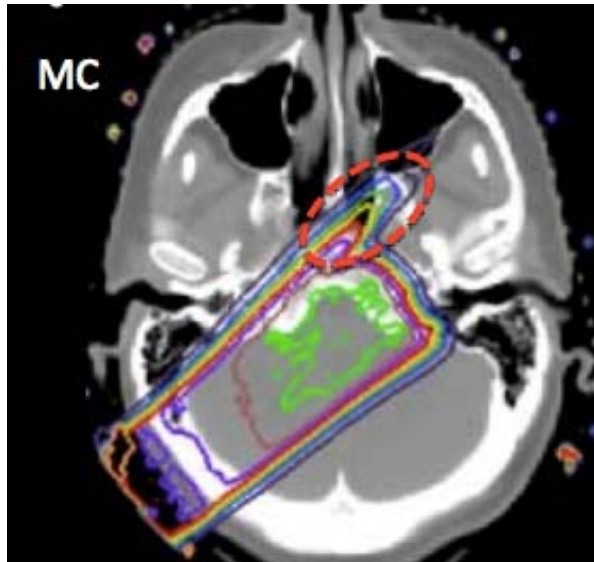


(van Lujik et al ) 5 10 15

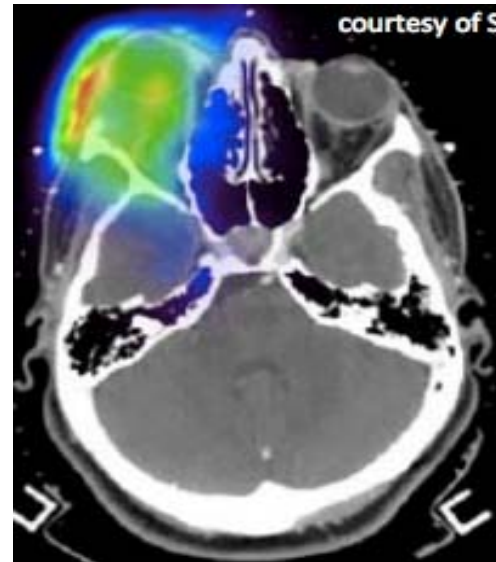


Comparison PB-MC (Paganetti, Trofimov, et al )

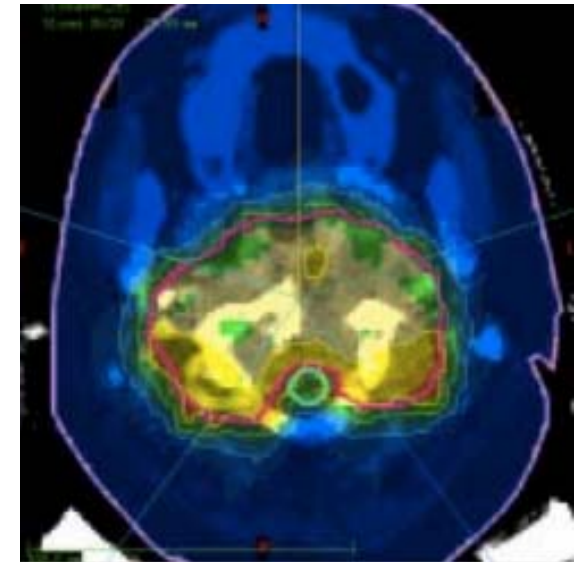
# Applications of Monte Carlo :



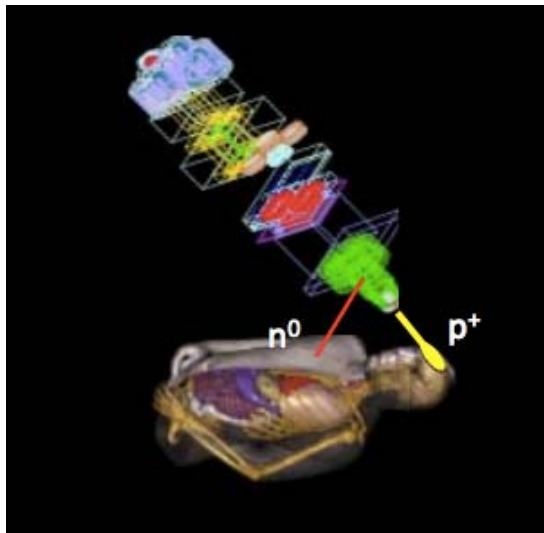
*Precise dose calcs with inhomog*



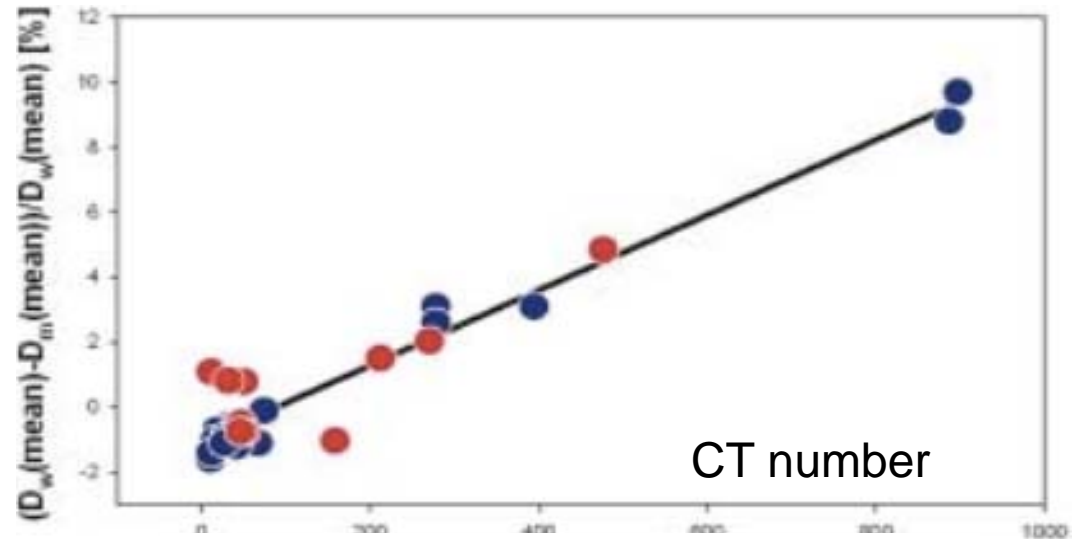
*Tissue activation for PET QA*



*Calculation of LET → RBE*



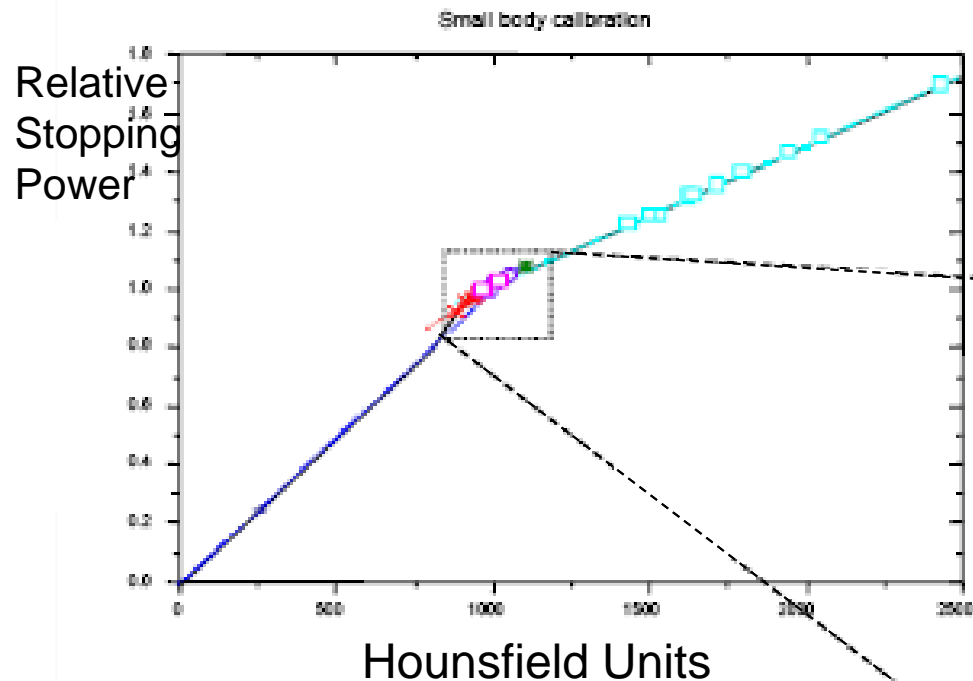
*Calculation of neutrons*



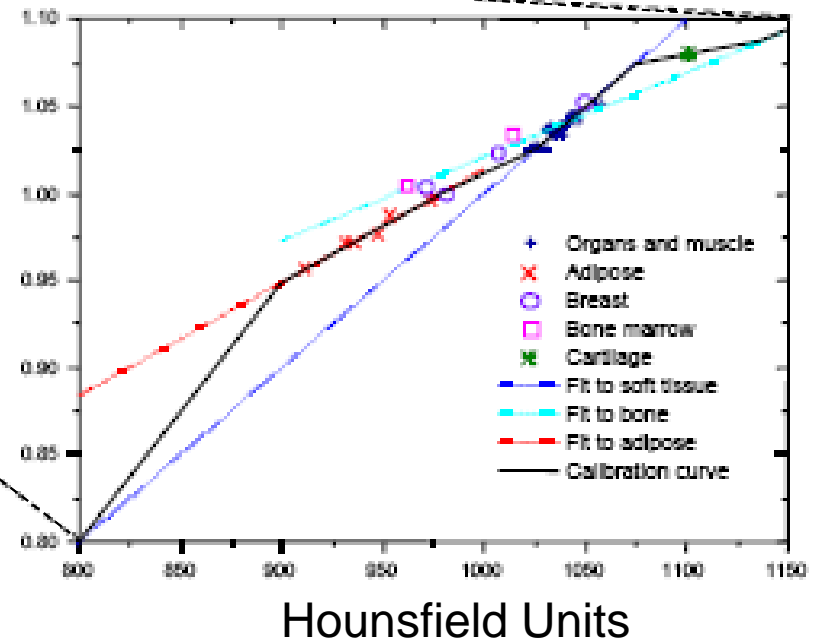
*Conversion from water to tissue dose*

1<sup>st</sup> step:

# Conversion from CT Hounsfield Units to Stopping Power (needed for range and dose calculations)



Importance of calibration  
& continuous Quality Assurance of CT



Stoichiometric method  
Schneider, Schaffner, Lomax, ...

# Range calculation (passive lines)

Patient Cor

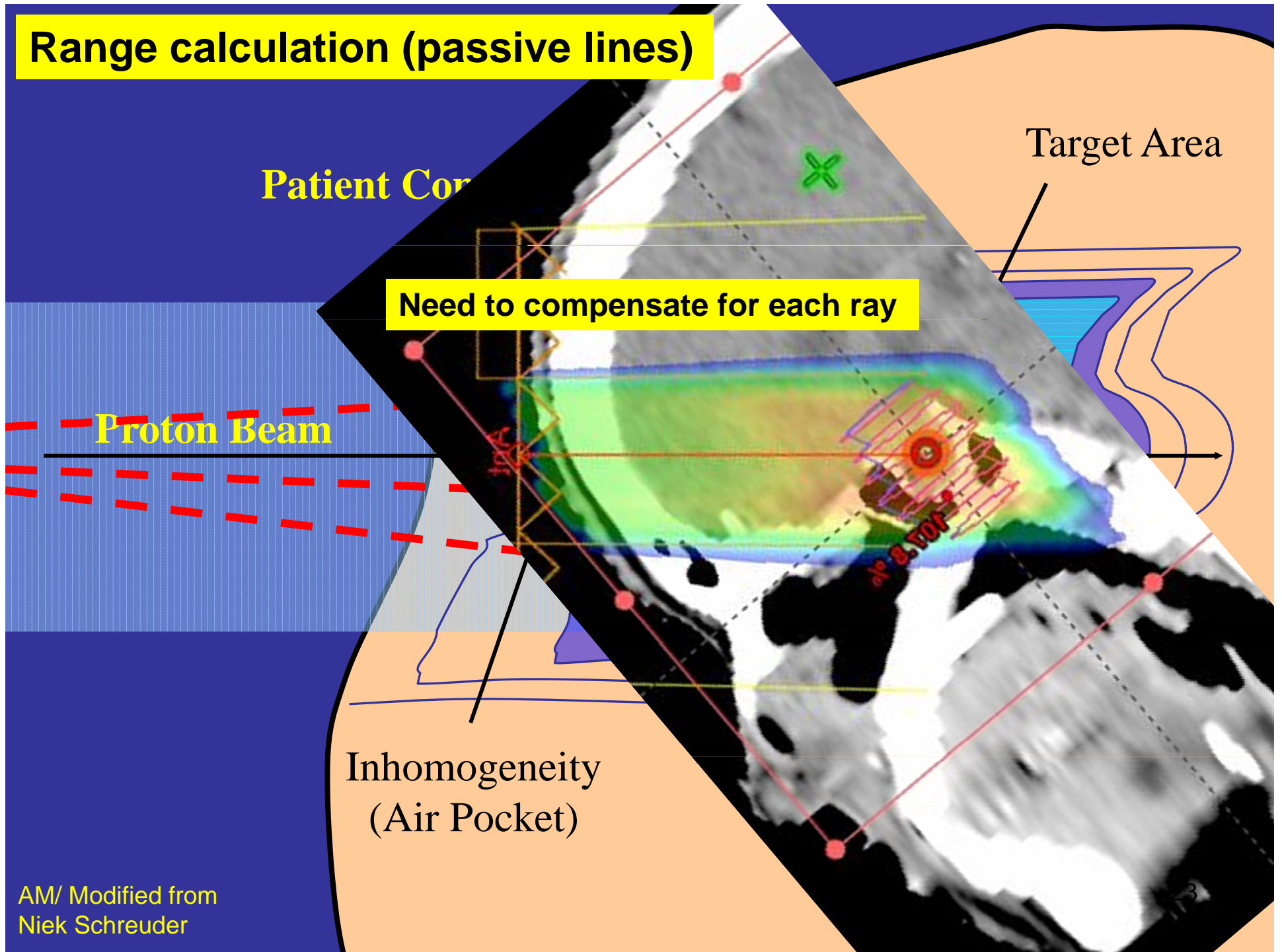
Need to compensate for each ray

Target Area

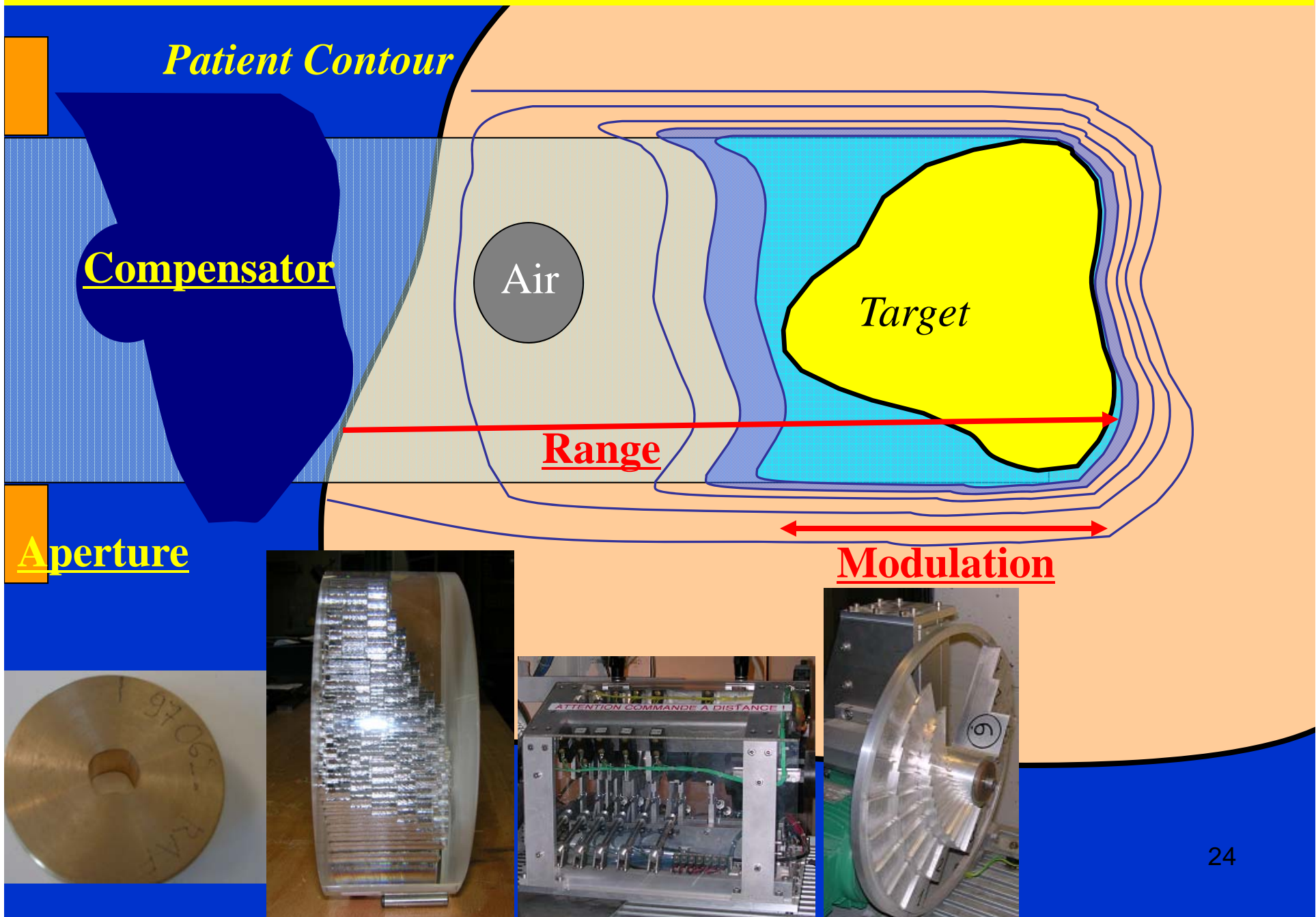
Proton Beam

Inhomogeneity  
(Air Pocket)

AM/ Modified from  
Niek Schreuder

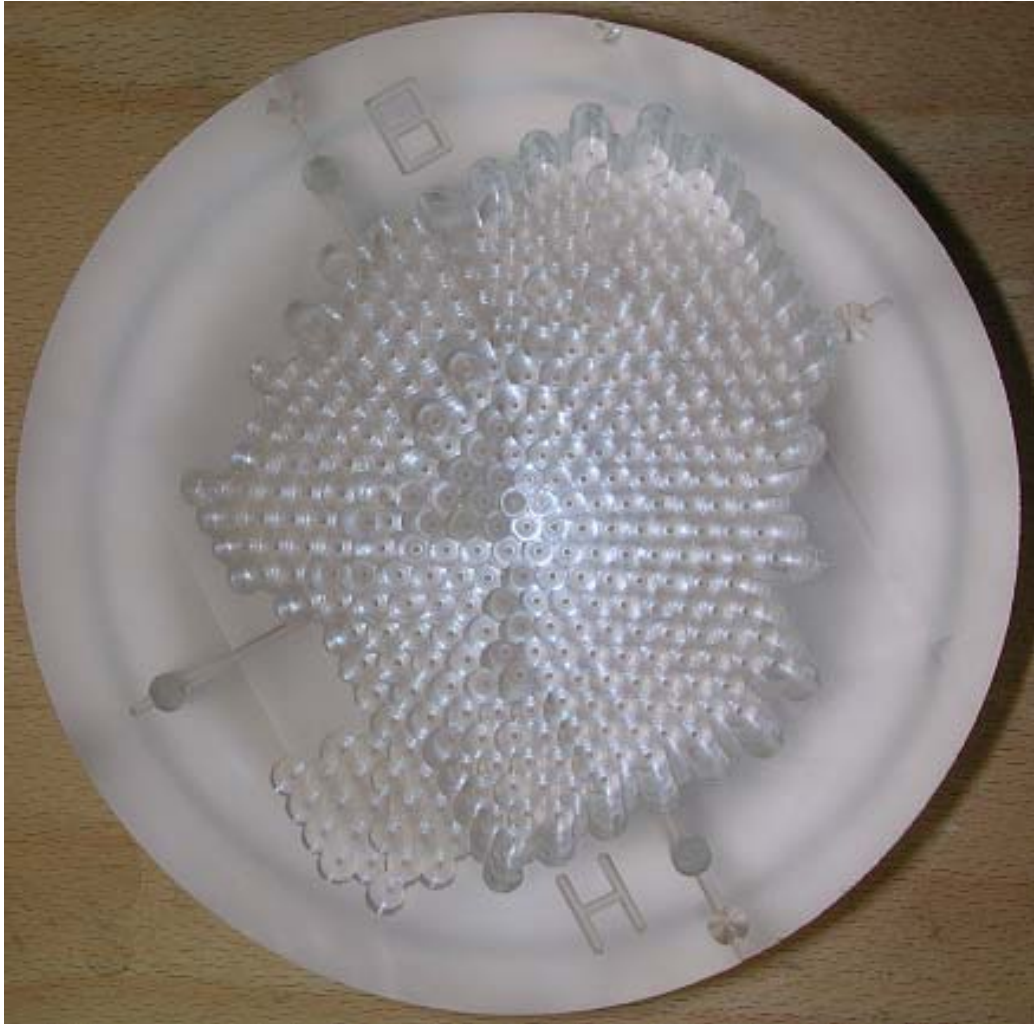


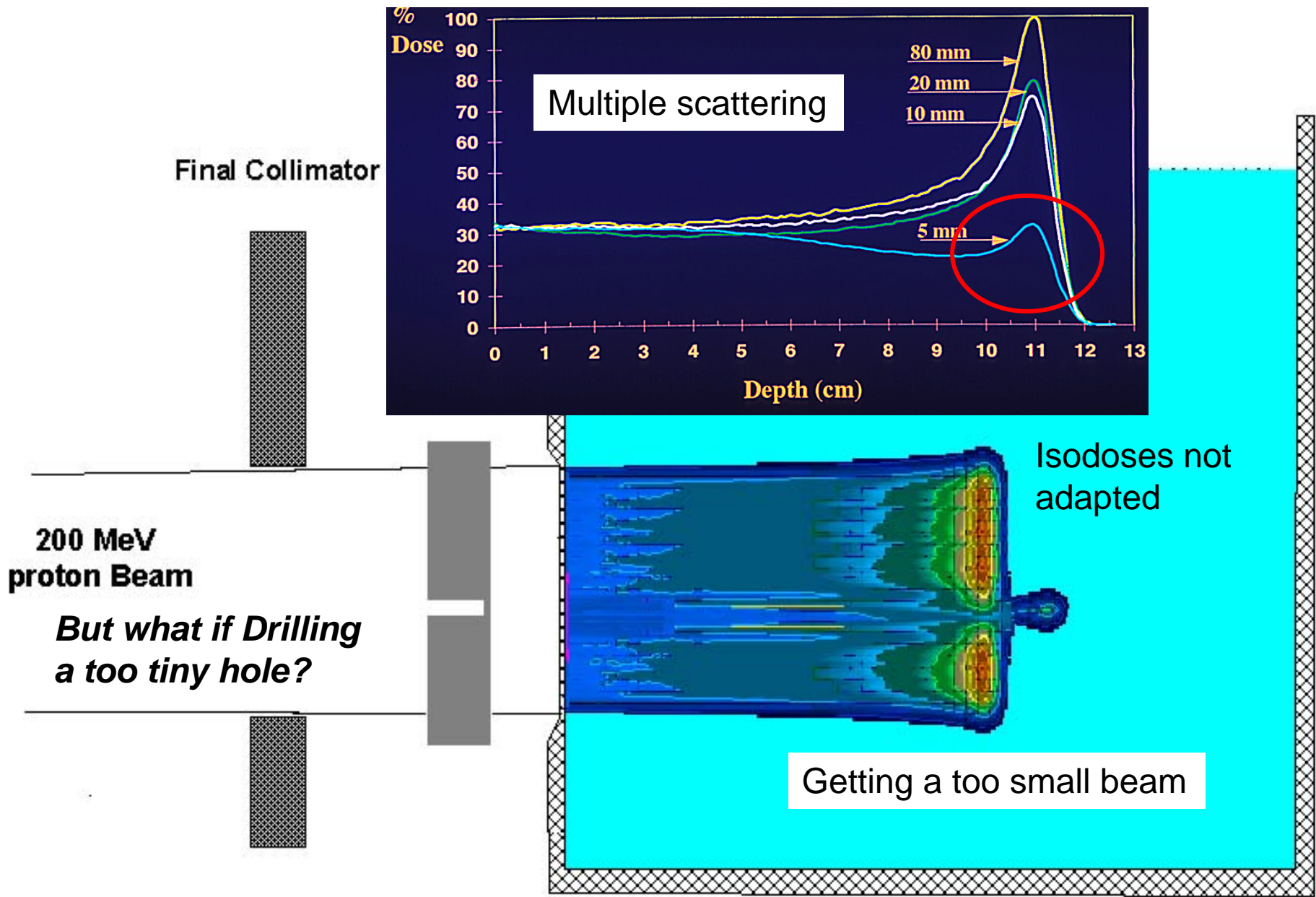
# Passive line elements calculated from the TPS for each beam

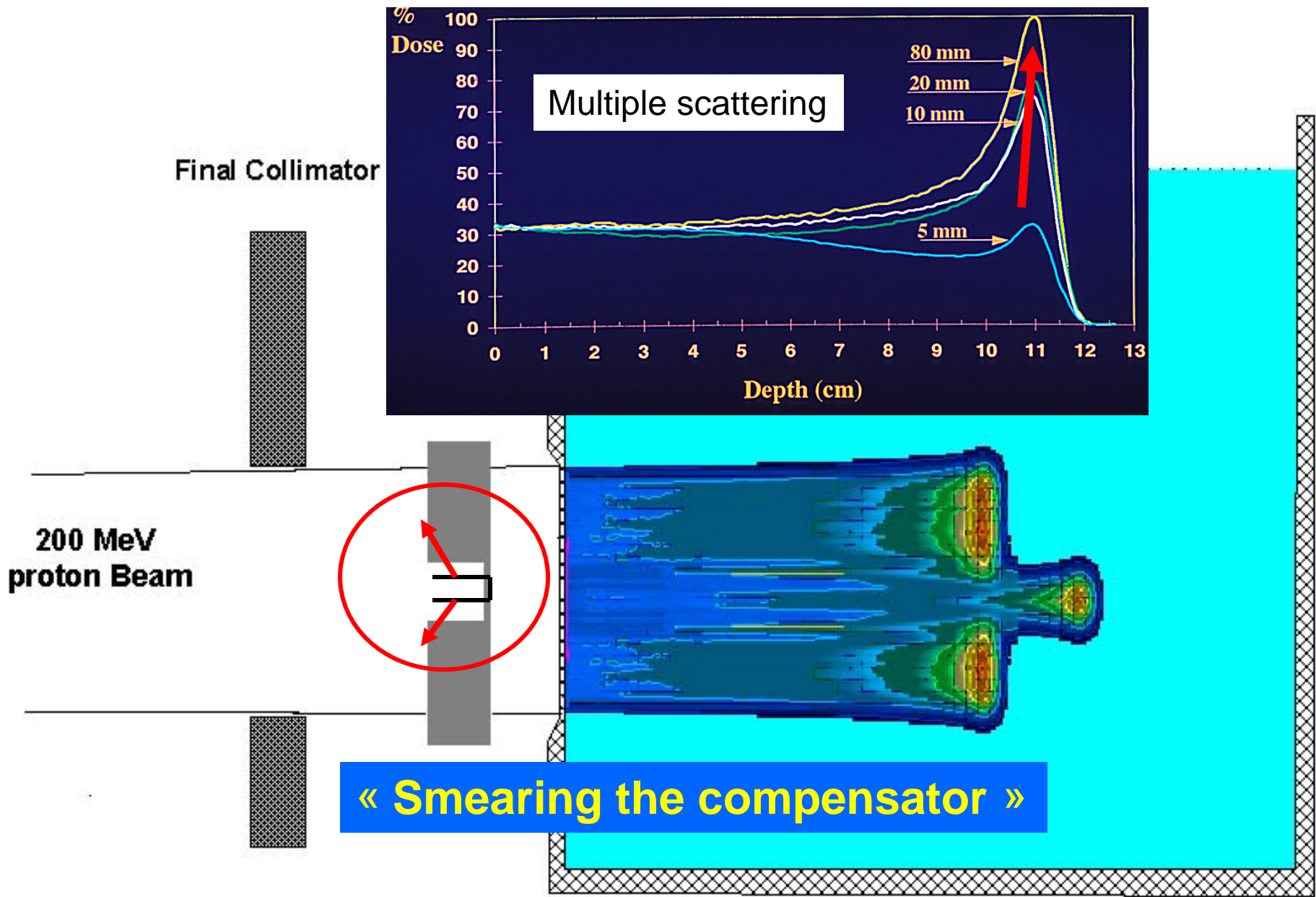




# Example of a compensator



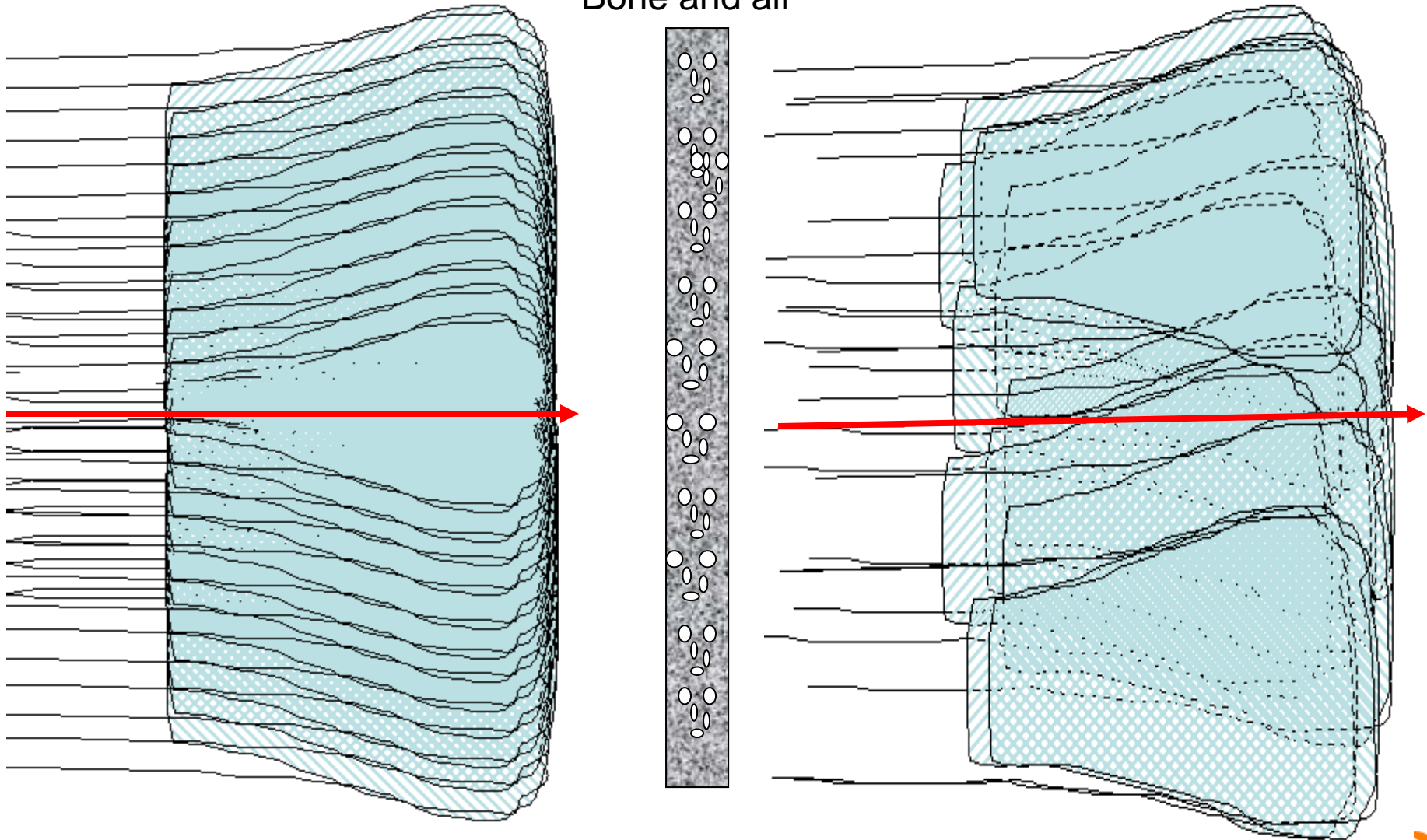




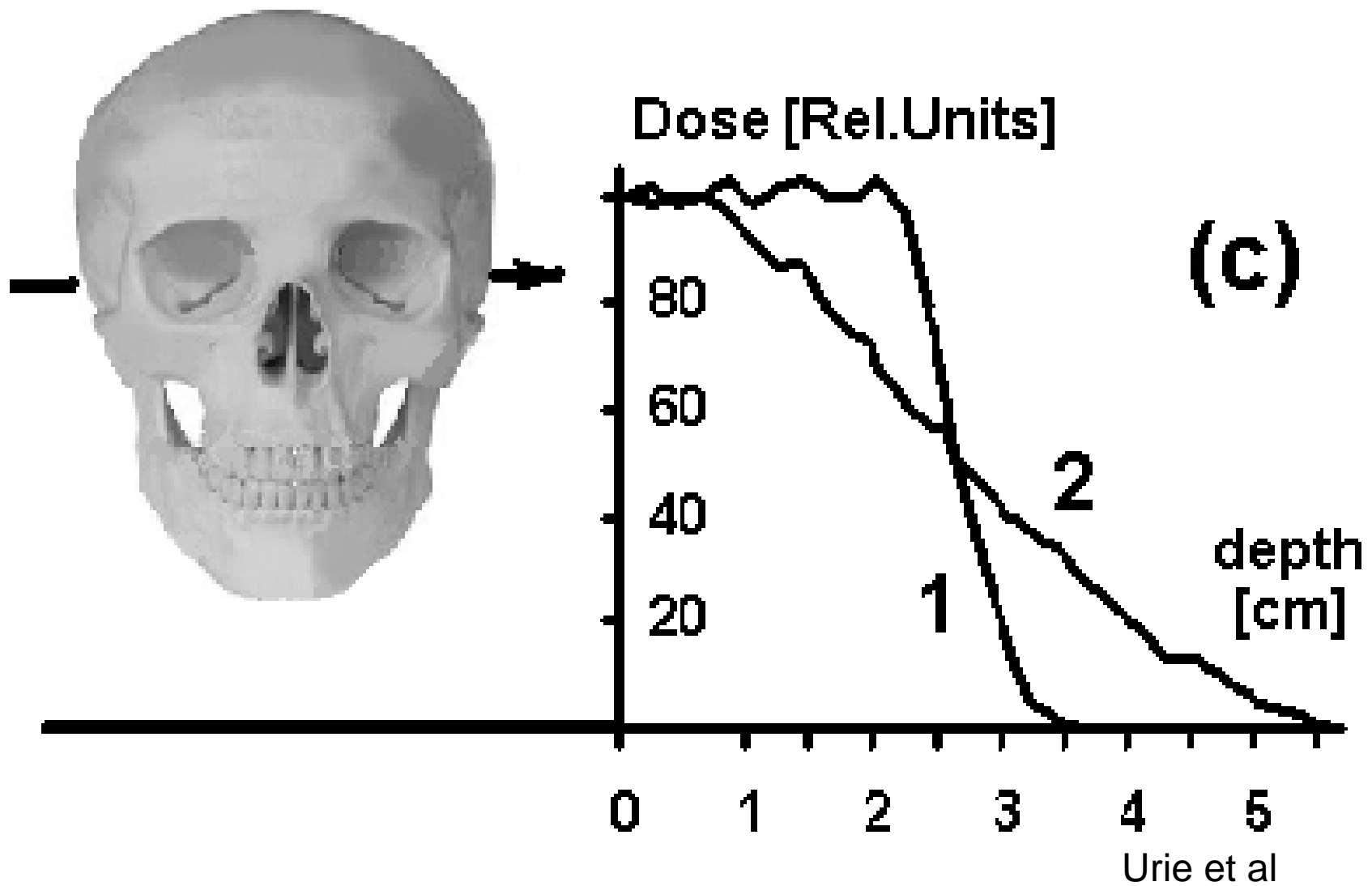
**2nd reason to smear : Mis alignements and/or organ movement**

If « complex » heterogeneities : multiple scattering effects (all delivery systems)

Bone and air

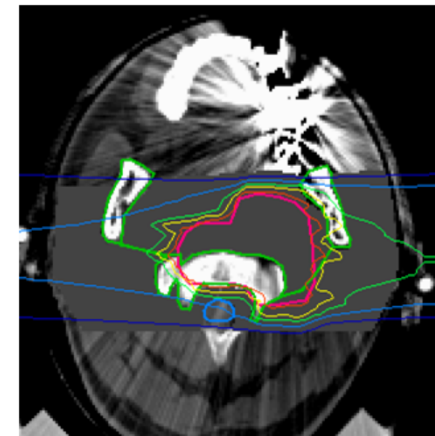
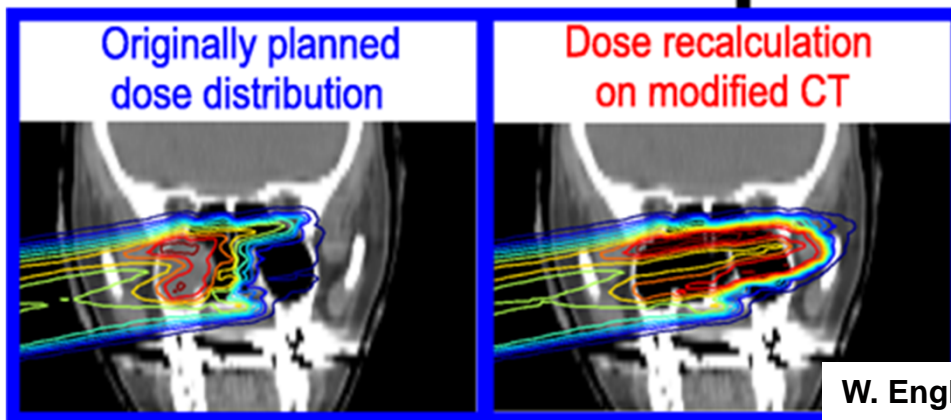
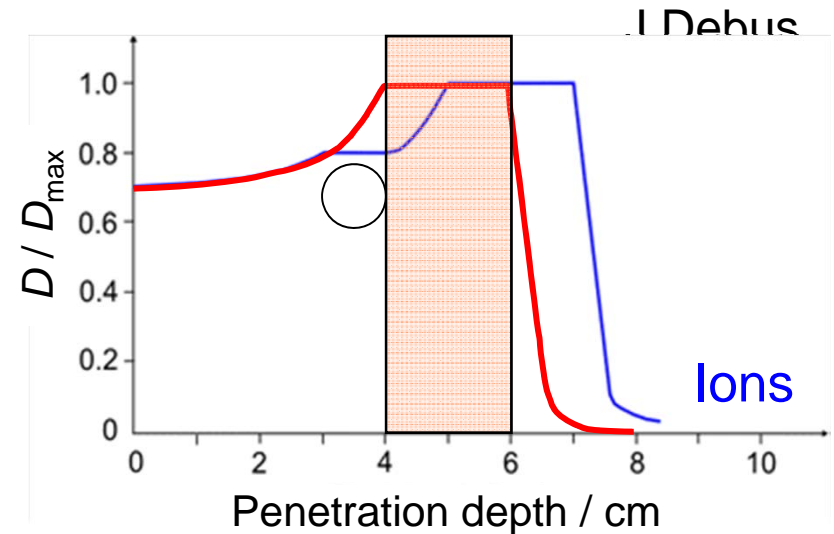
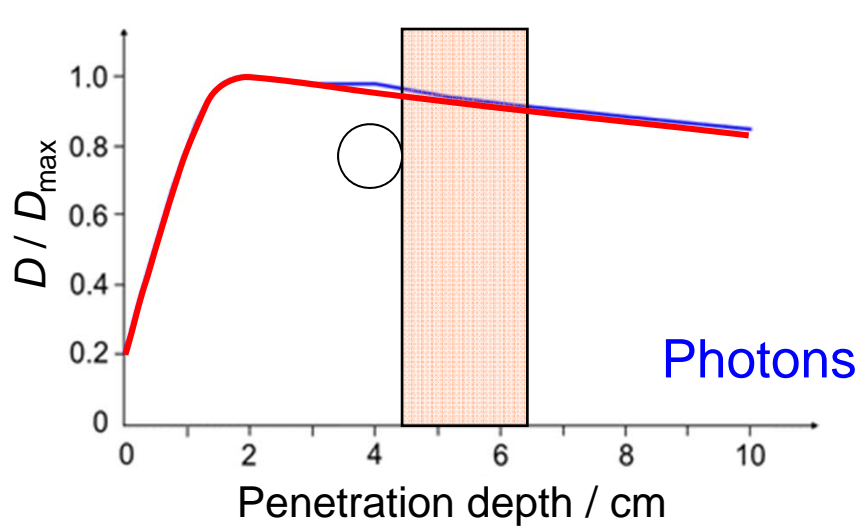


*This effect is even more evident with borders along the beam direction...*



- 1) The TPS must calculate that
- 2) Need to change the beam incidence !!

## Effect of density changes (eg : in the target volume or in the beam path)

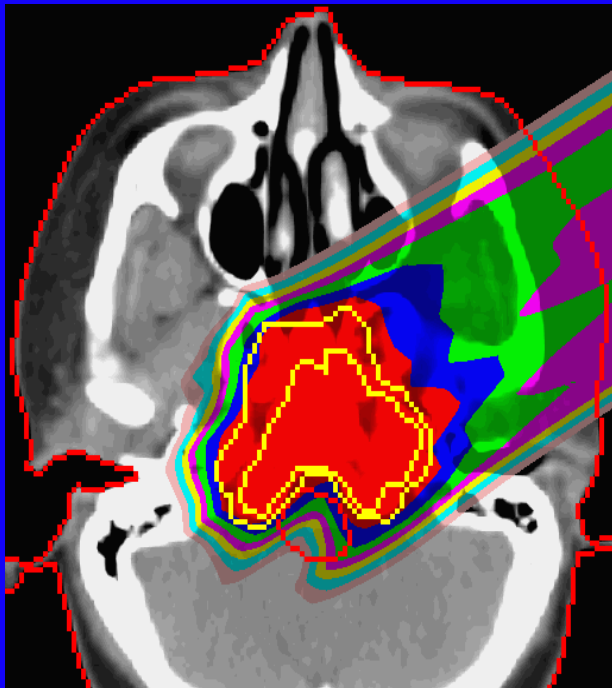


Similar effects for CT artifacts, contrast, mispositioning or organ movement

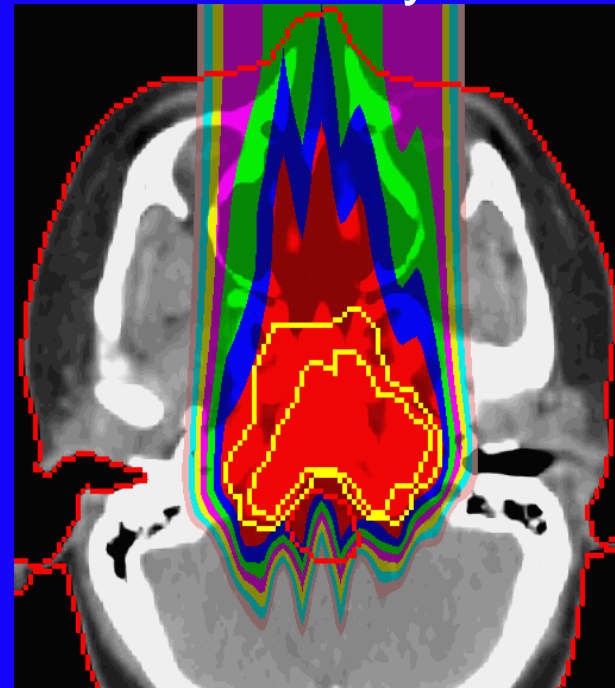
Need to survey the anatomical changes in the path after the planning CT and till the end of the treatment

## Effects on (single field) dose conformity

Example field through relatively homogenous anatomy



Example field through very inhomogenous anatomy

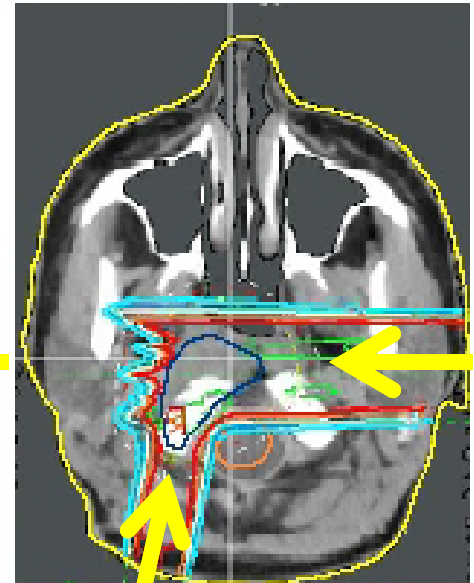
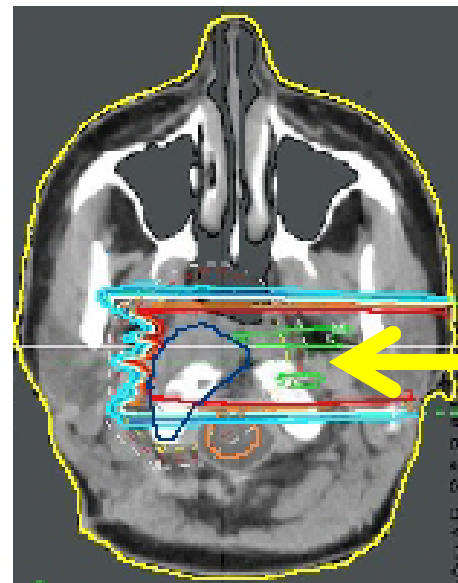
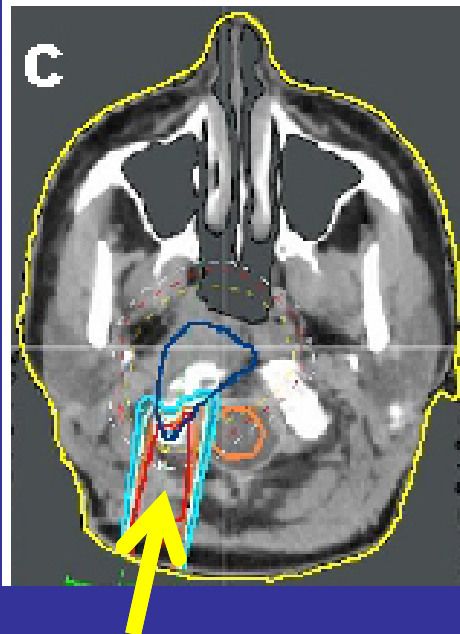
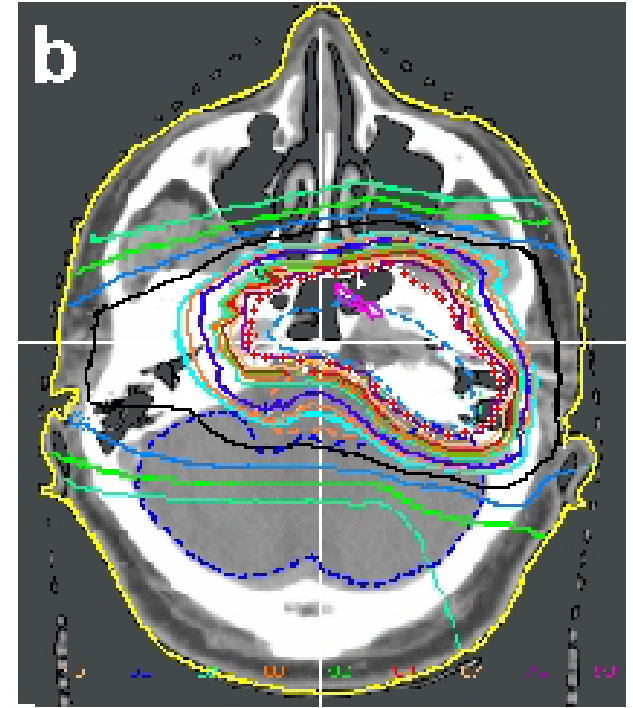
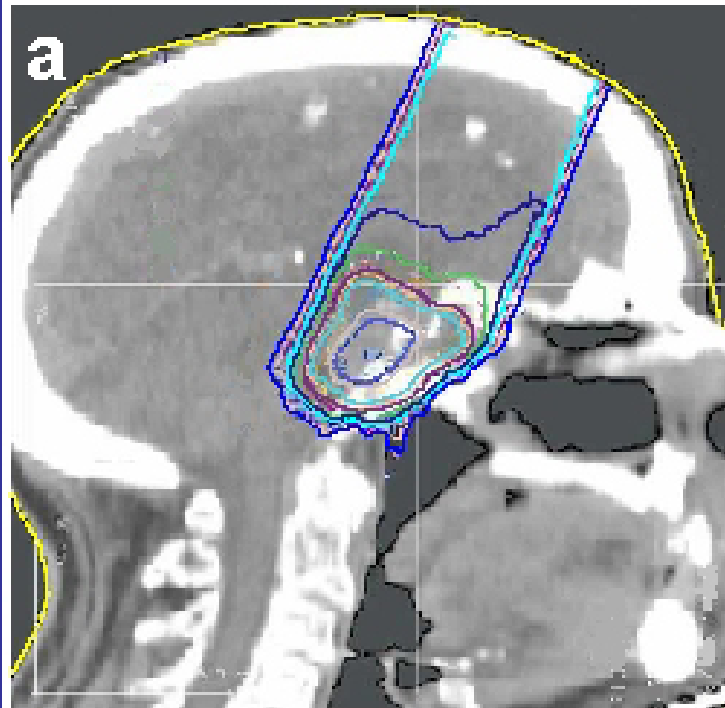


Clinical:

Non coplanar  
beams

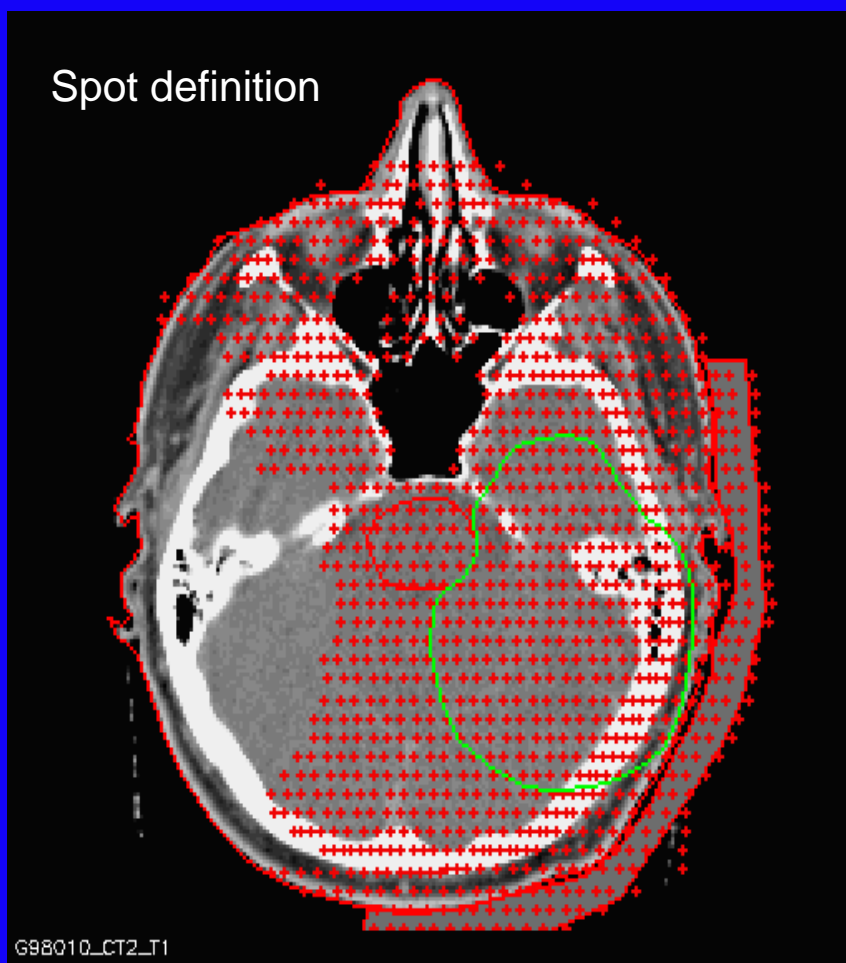
Photons +  
protons

Junctions,  
“patching”





## Spot Scanning



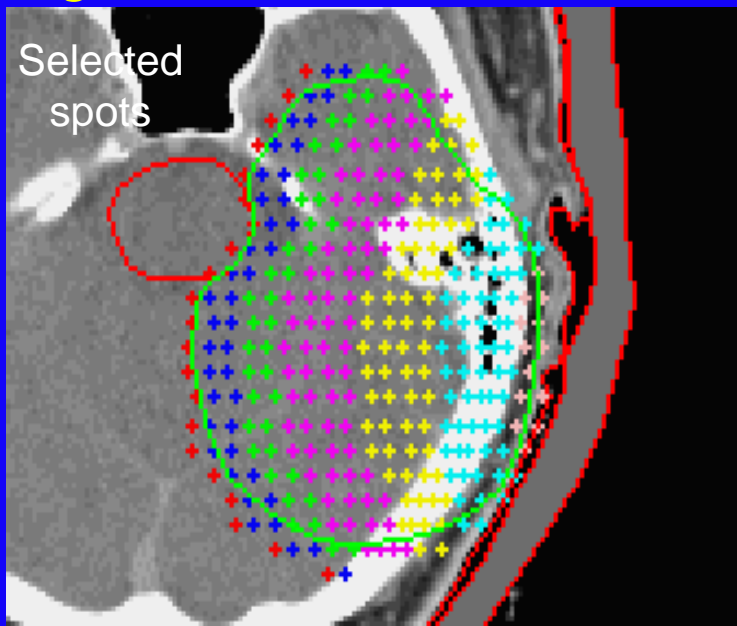
Incident field



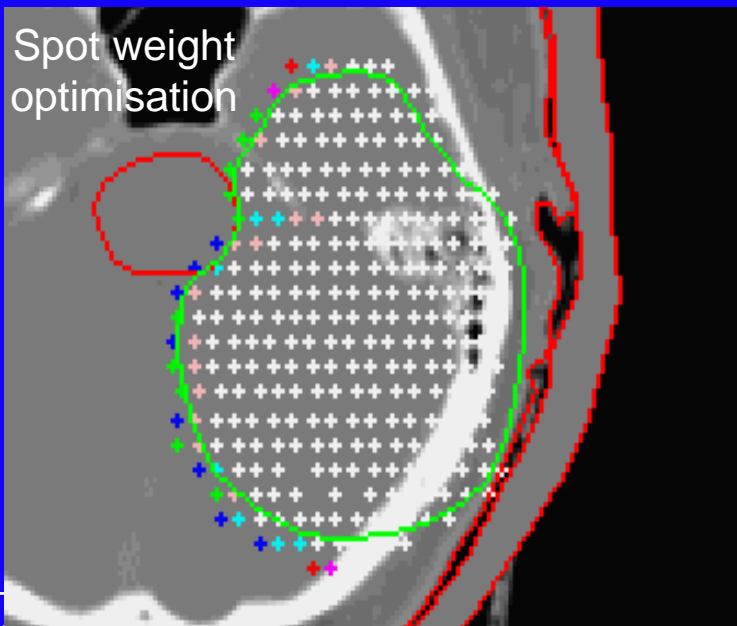
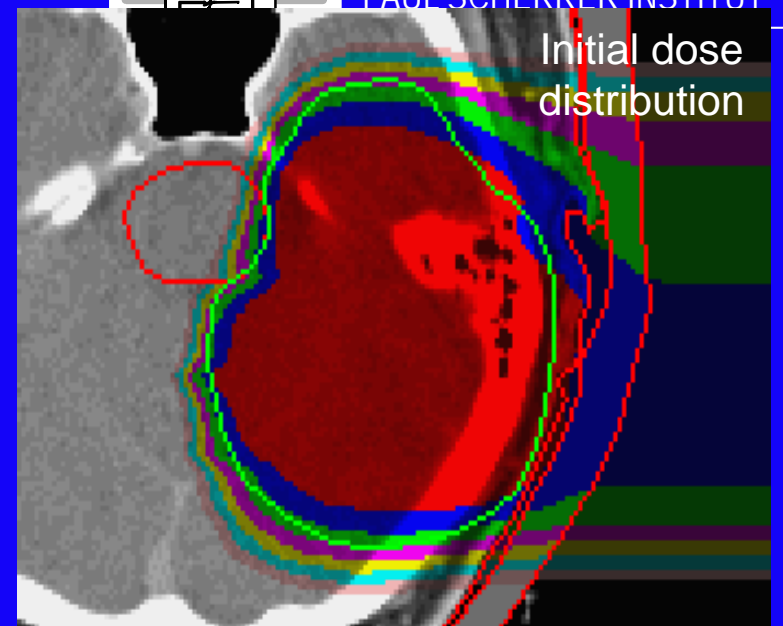
Treatment planning for scanned proton  
beams and IMPT

( from Tony Lomax )

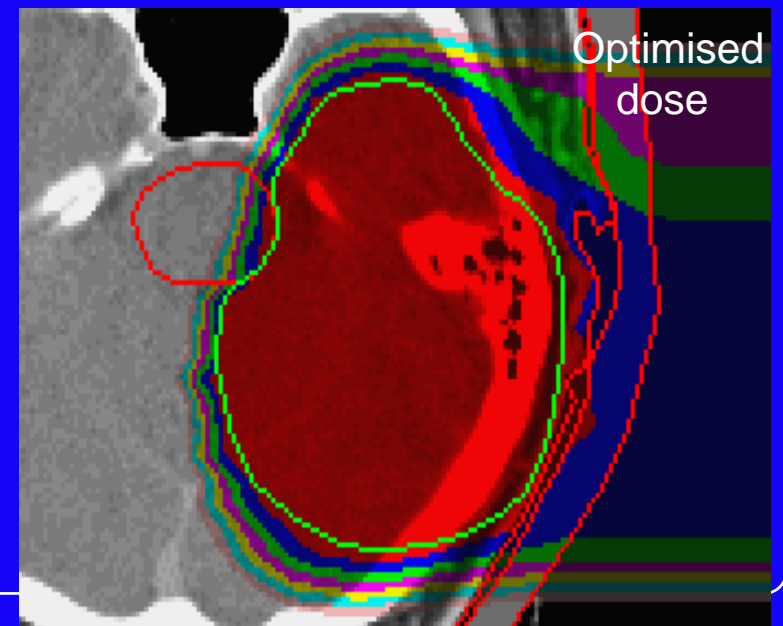
# Single Field



Dose calculation  
➔



Dose Calculation  
➔



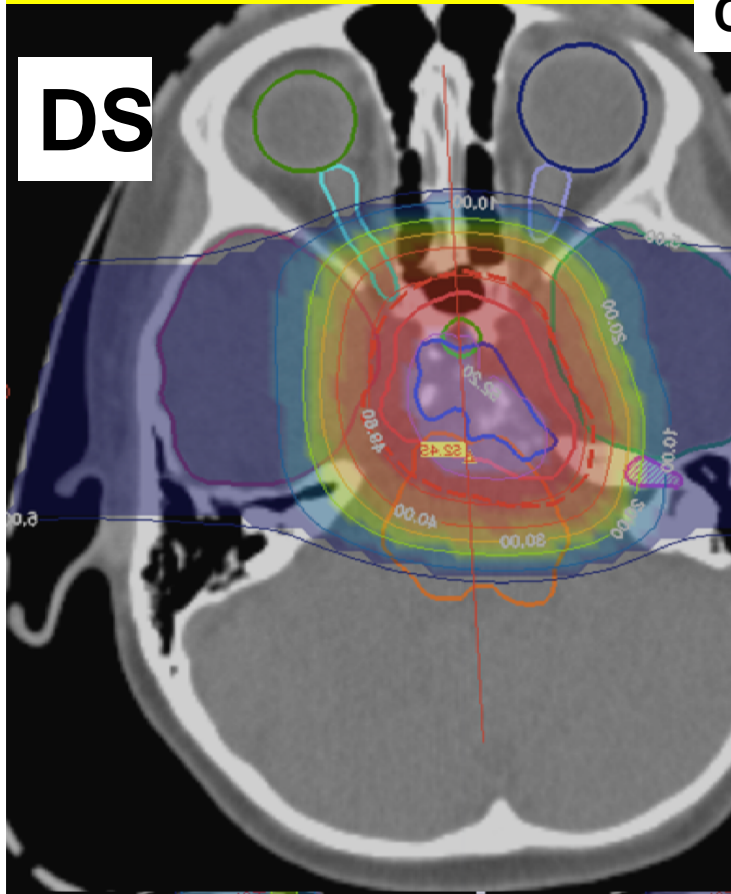
Treatment planning for scanned proton beams and IMPT

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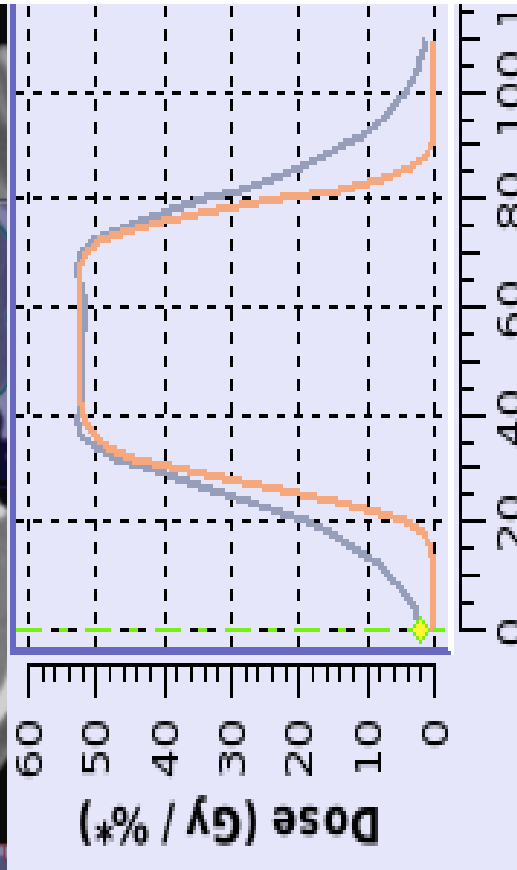
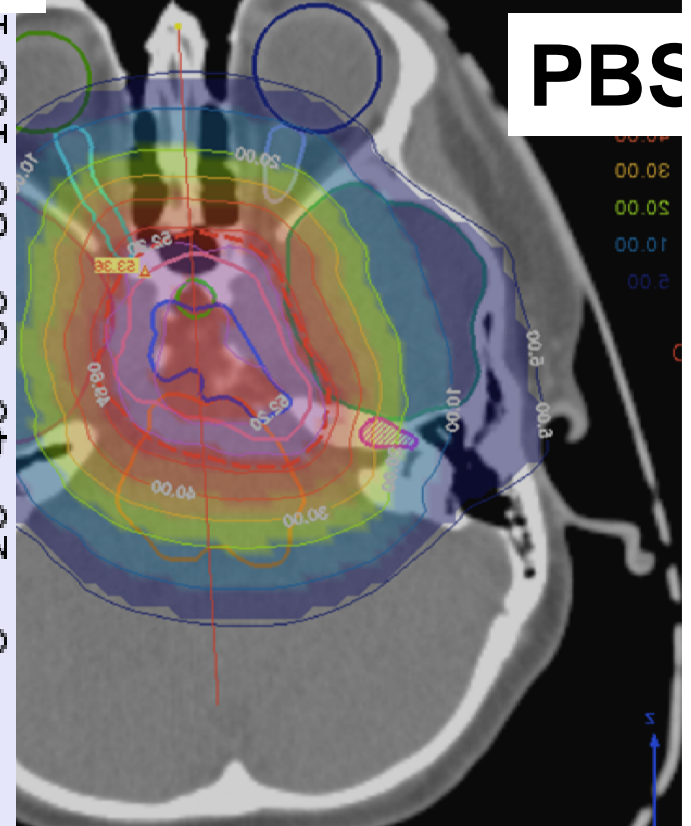
# PENUMBRA ISSUES

## CRANIOPHARYNGIOMA

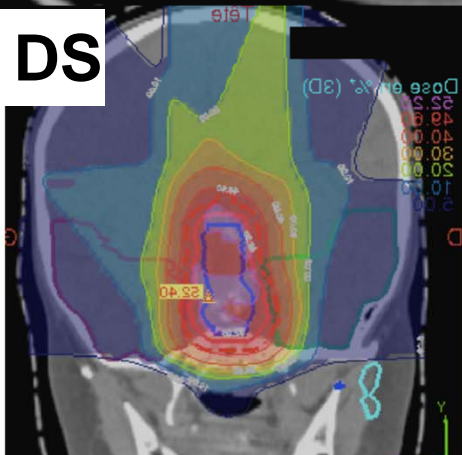
**DS**



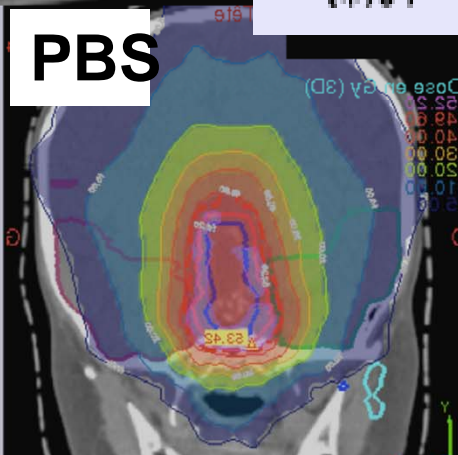
**PBS**



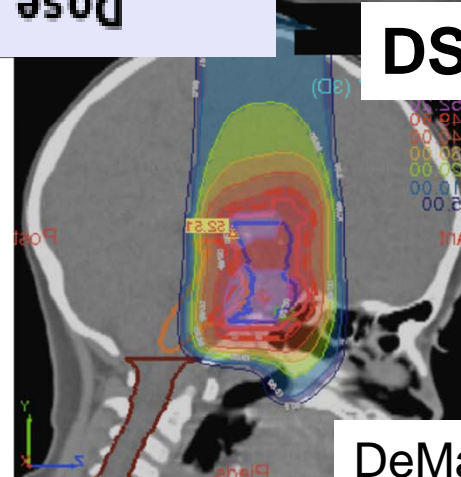
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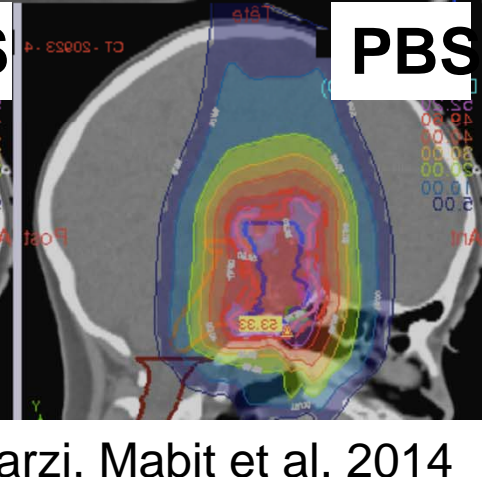
**PBS**



**DS**



**PBS**



# PENUMBRA ISSUES

Ongoing solutions to mitigate :

-Equipment : having **smaller spots** in the target borders

-Software : **optimizing** spots positions and weights

-Users : adding an **aperture** for low energy beams

-...

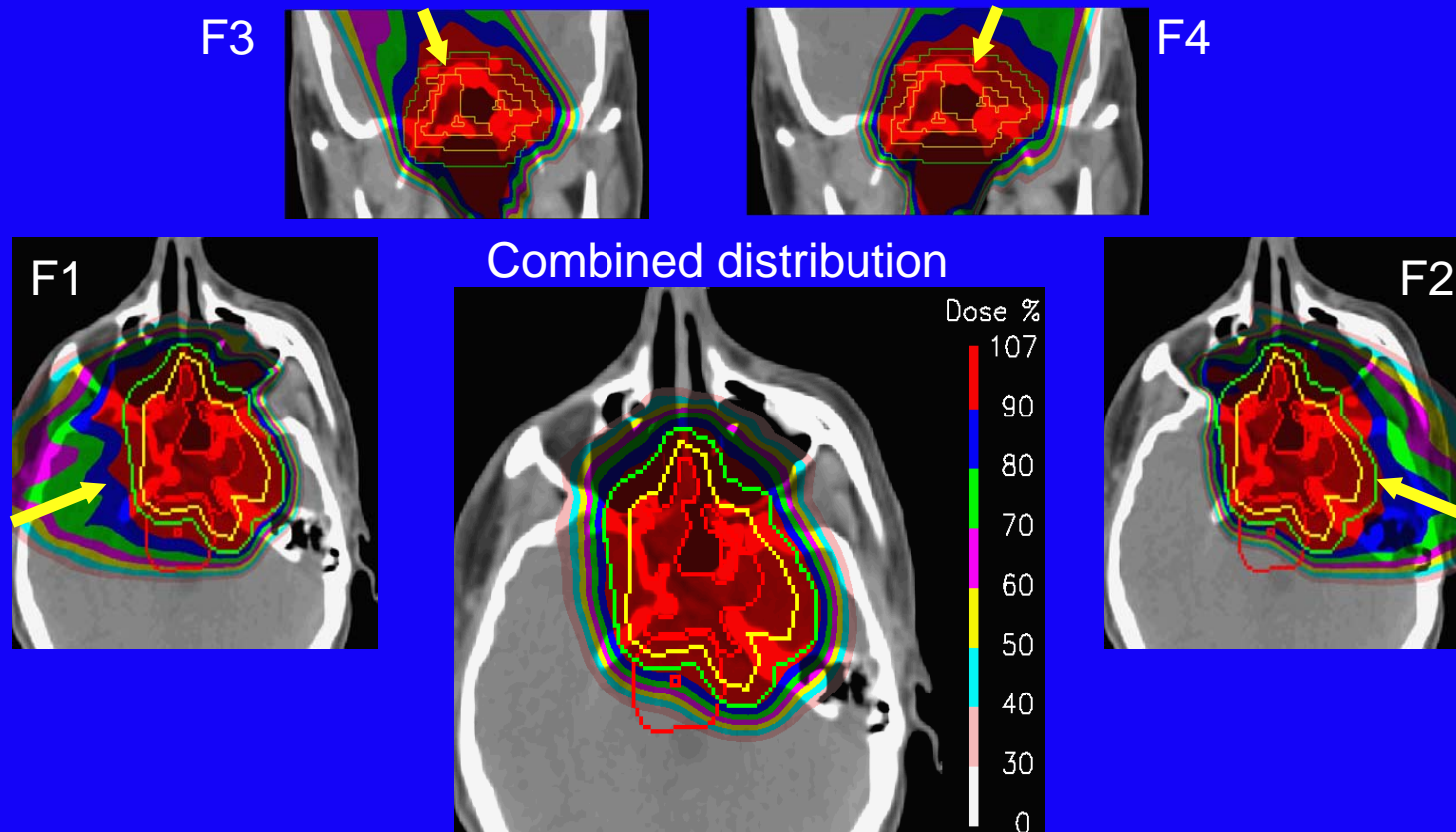
(And have a look to Safai, Bortfeld and Engelsman –  
Phys. Med. Biol. 53 (2008) 1729–1750)

# Single Field Uniform Dose (SFUD)



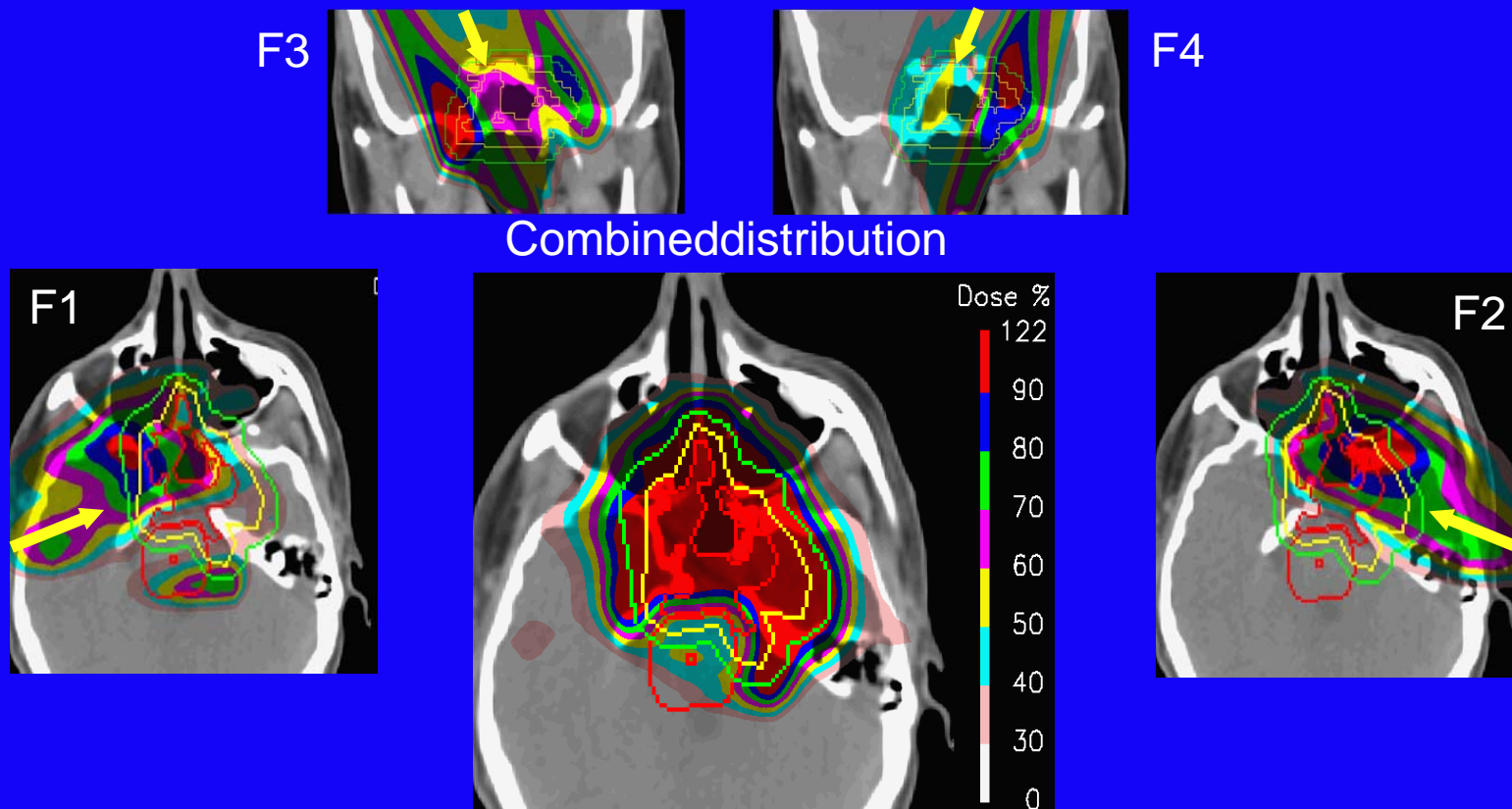
PAUL SCHERRER INSTITUT

A SFUD plan consists of the addition of one or more individually optimised fields.



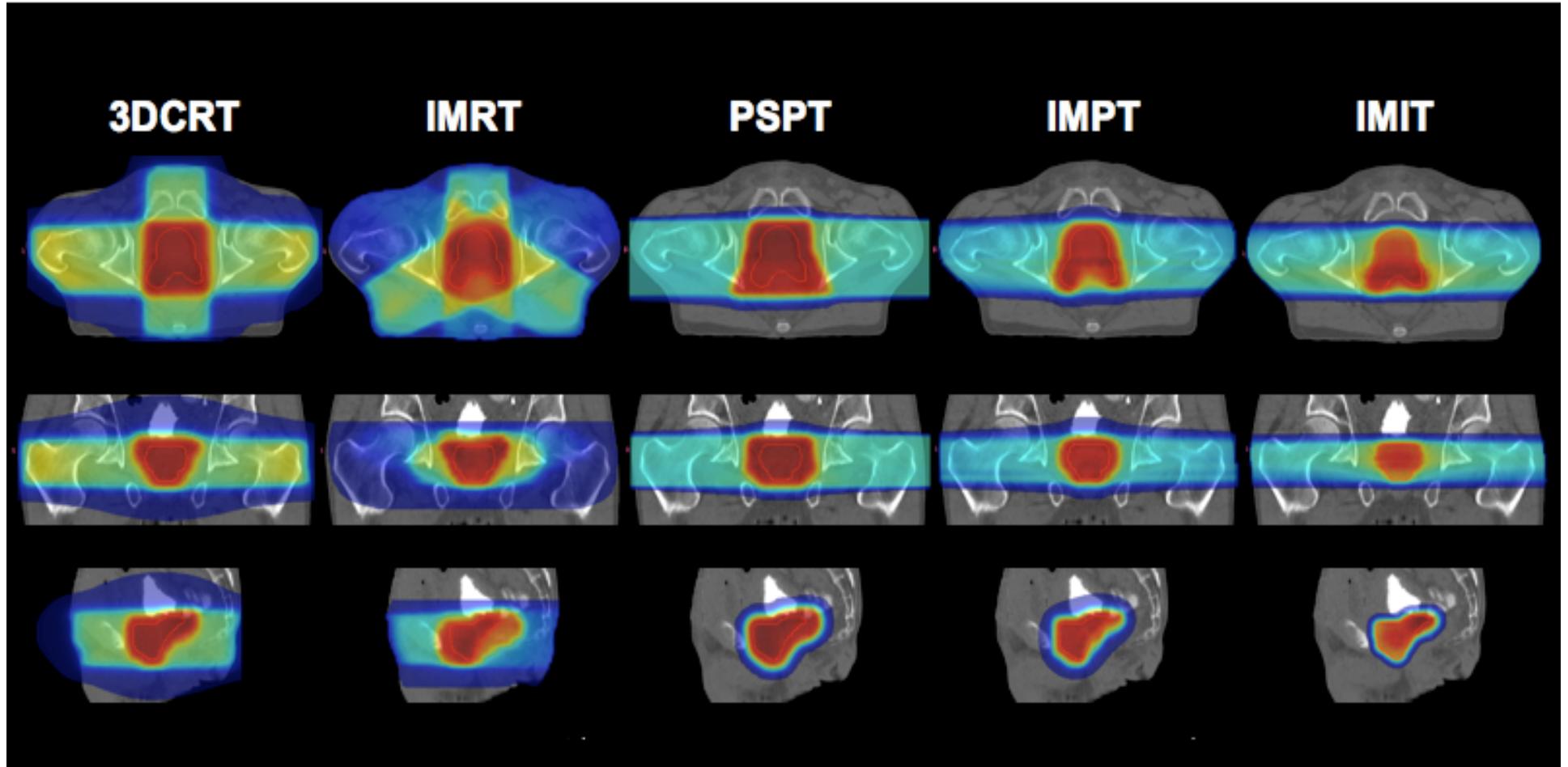
Note, each individual field is **homogenous** across the target volume

# The simultaneous optimisation of all Bragg peaks from all incident beams



Lomax 1999, PMB 44: 185-205

# Comparative planning

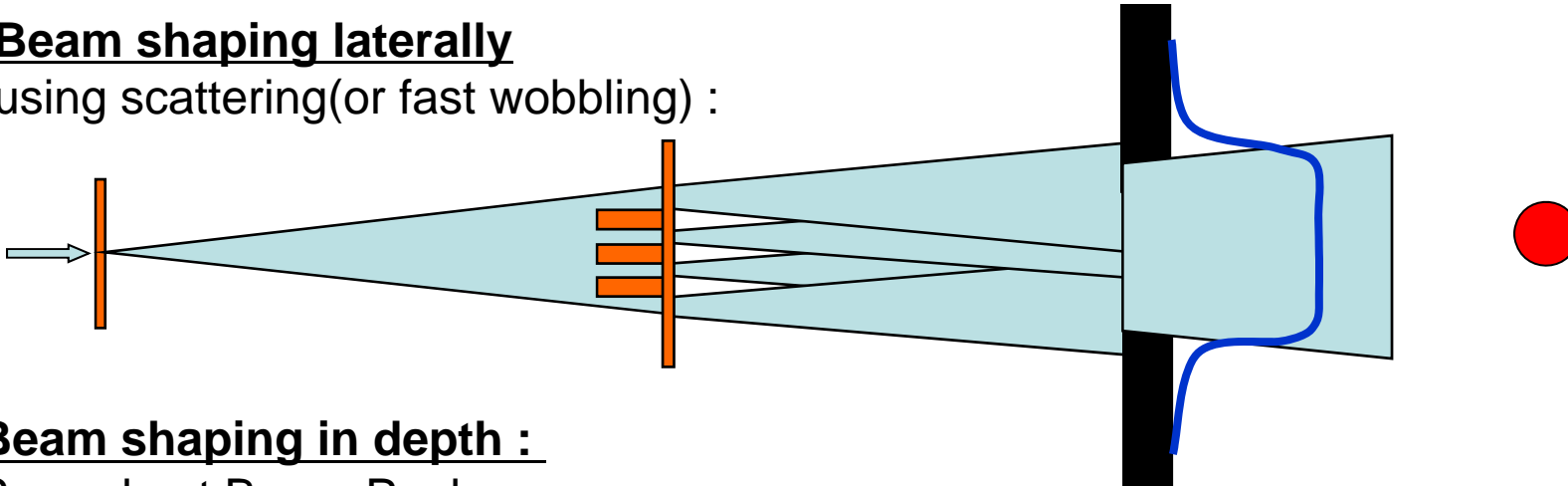


*Erik Roelofs et al, ROCOCO Trial, Maastricht & 15 institutions involved  
PTCOG 51, 2011*

**Practical examples :  
See each of the presentations on clinical cases**

**Limits : Organ movements**  
**Less sensitive with passive lines:**

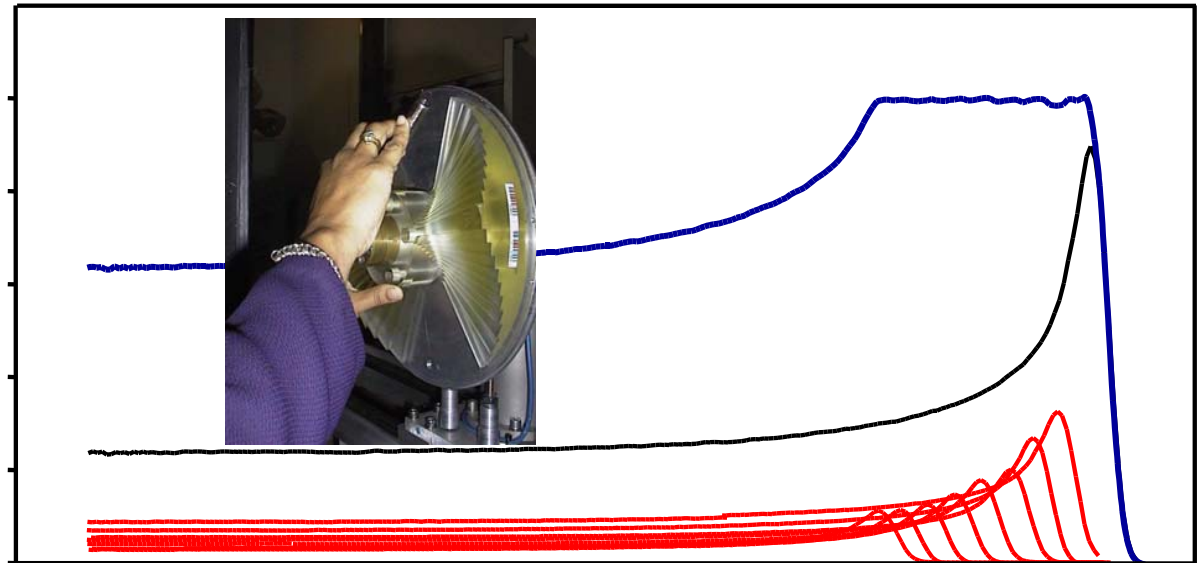
Beam shaping laterally  
using scattering(or fast wobbling) :



Beam shaping in depth :  
Spread out Bragg Peak  
Ridge filters or  
1D scanning

Ex:  
600 rpm  
4 scans/rotation

= 40 scans/sec in depth  
(« fast repainting »)

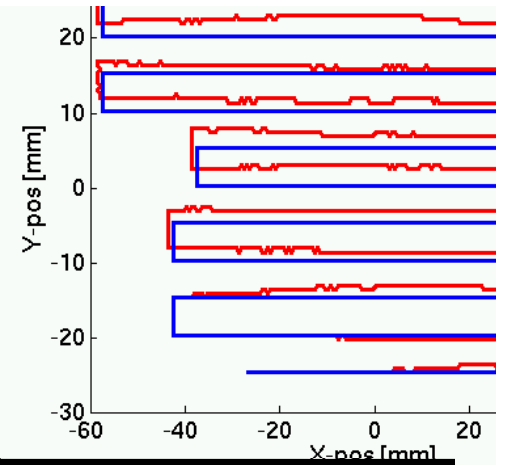
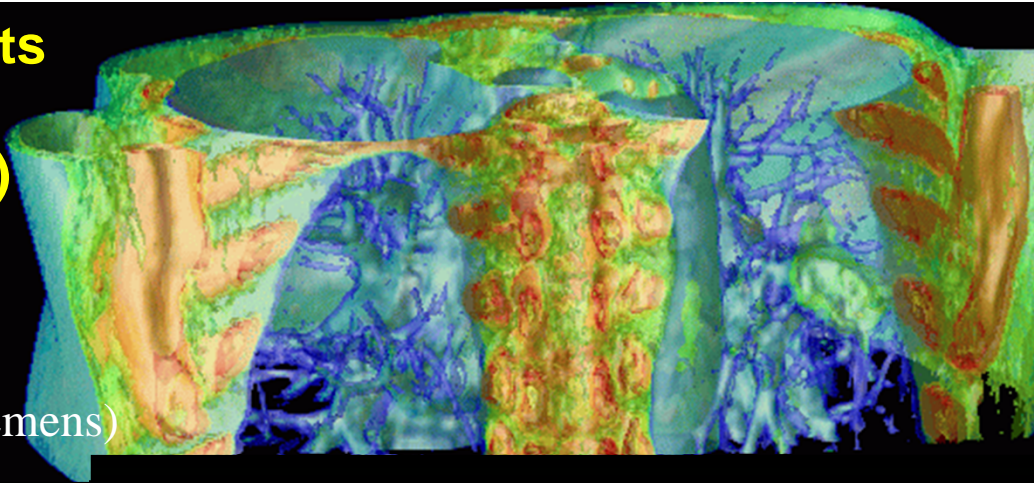


*(Less true with the compensator → need to smear the compensator)*



# Movements and PBS (interplay)

E.Rietzel  
(MGH → Siemens)



Furukawa  
(NIRS)

Fast rescan x20 times

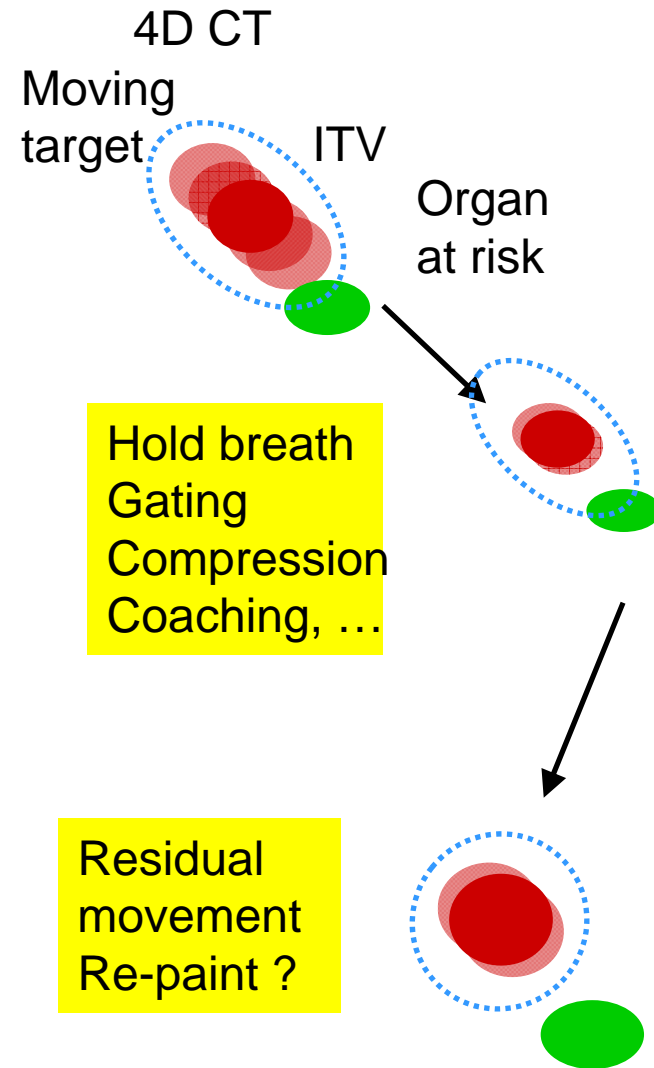
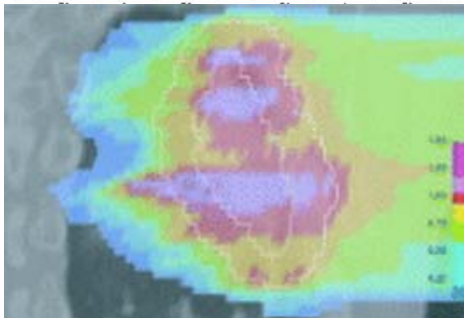
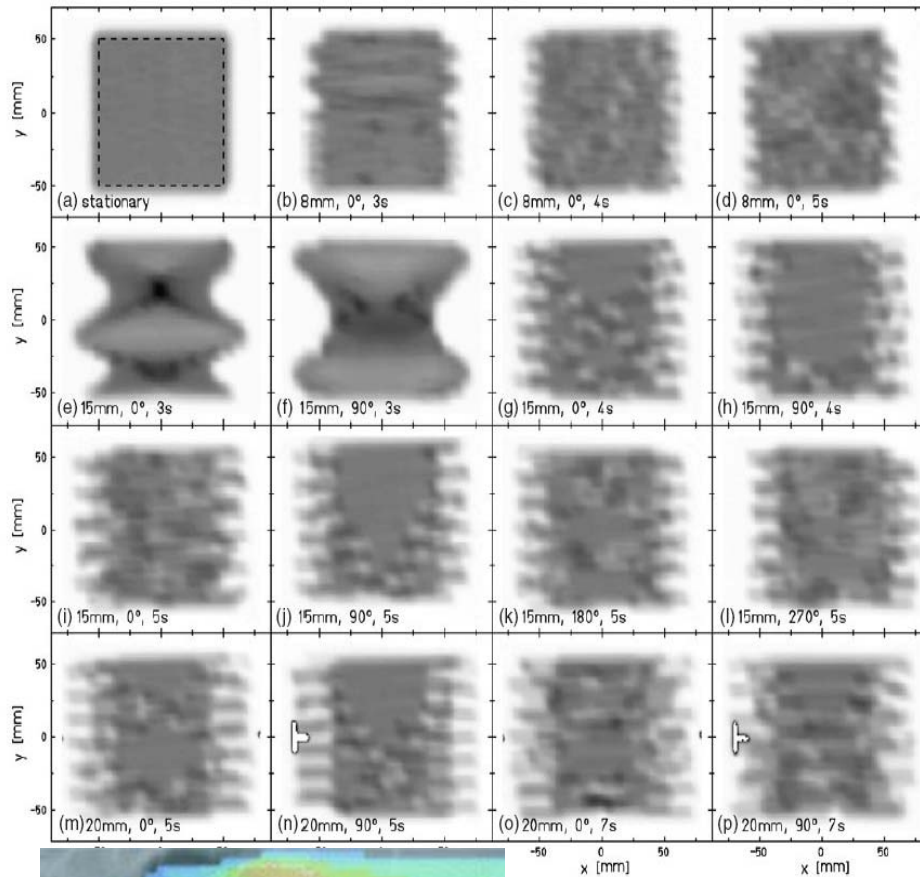
Conventional scan

ax

# PENCIL BEAM SCANNING : very sensitive to Organ Motion

## Quantification of interplay effects of scanned particle beams and moving targets

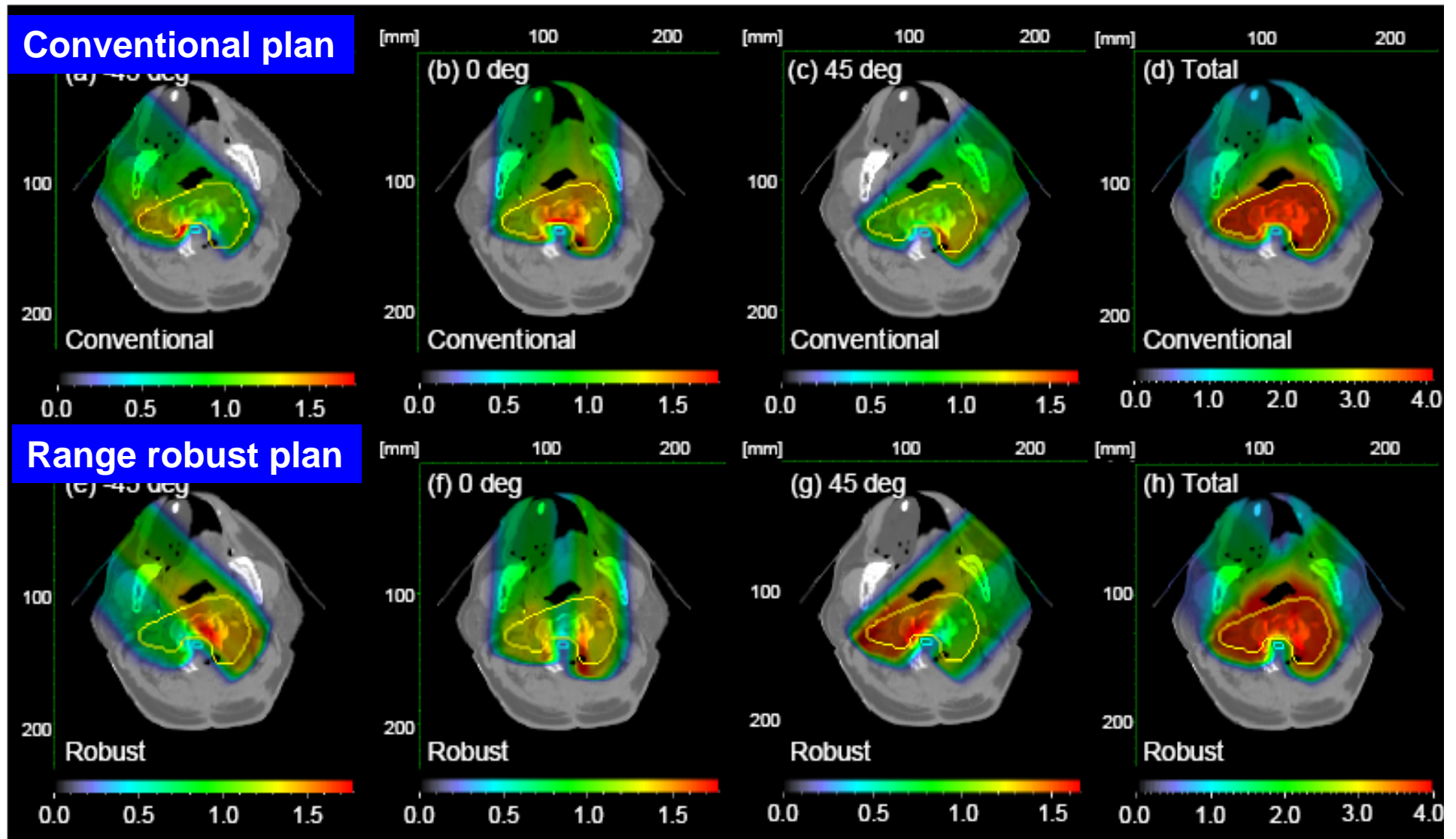
Christoph Bert, Sven O Grözinger and Eike Rietzel, GSI,  
Darmstadt, Phys. Med. Biol. **53 (2008) 2253–2265**



**Part of the planning process !**

# Lower risk from uncertainties using PBS ?

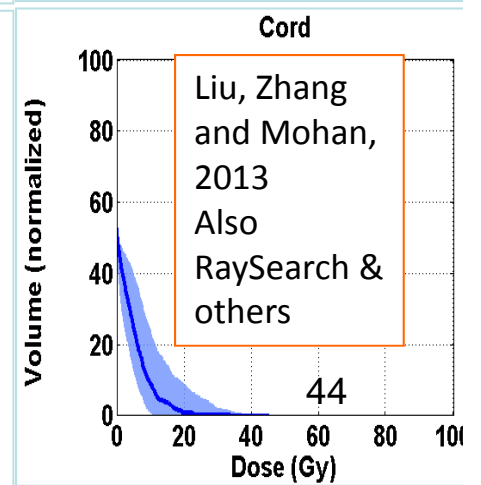
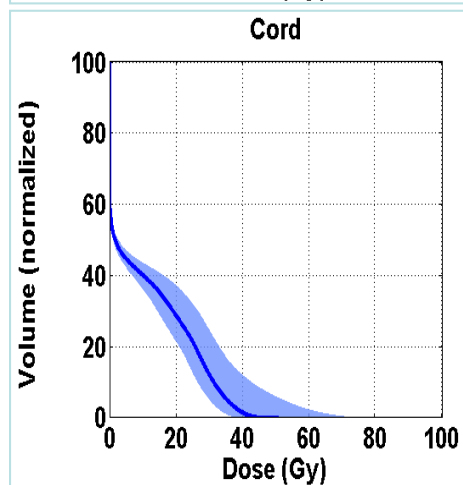
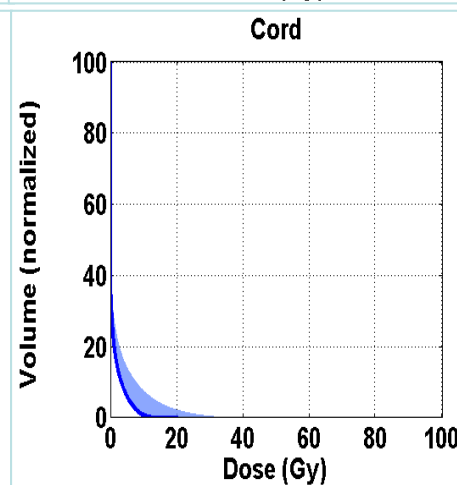
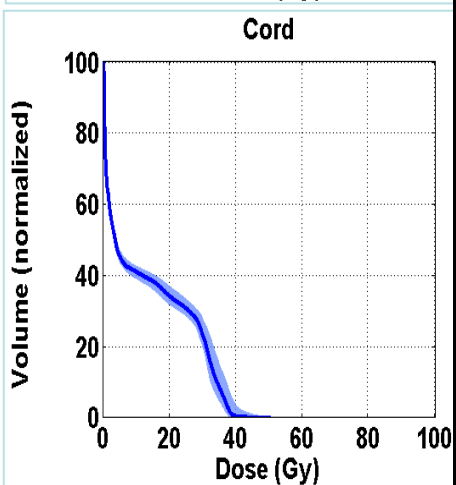
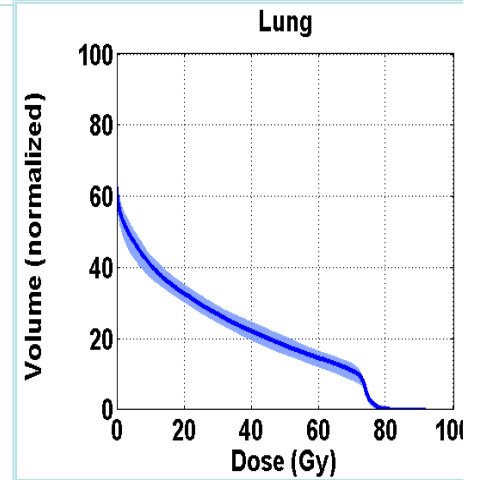
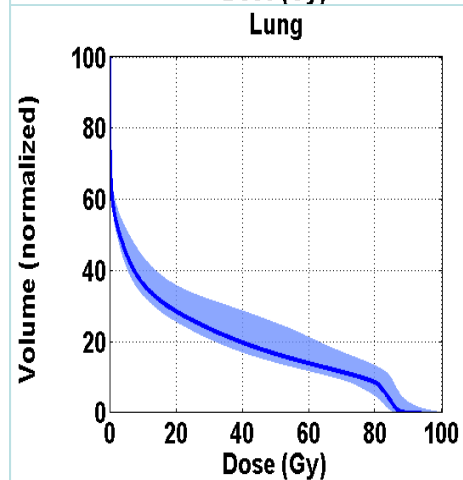
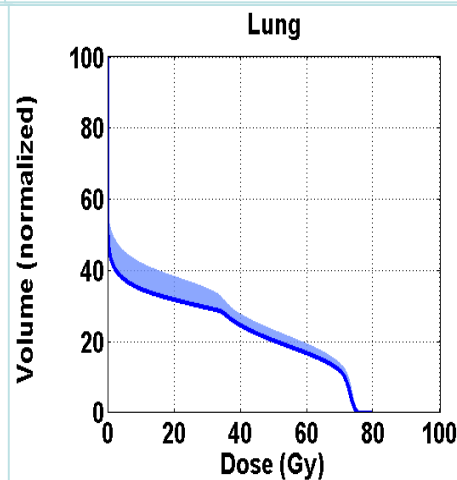
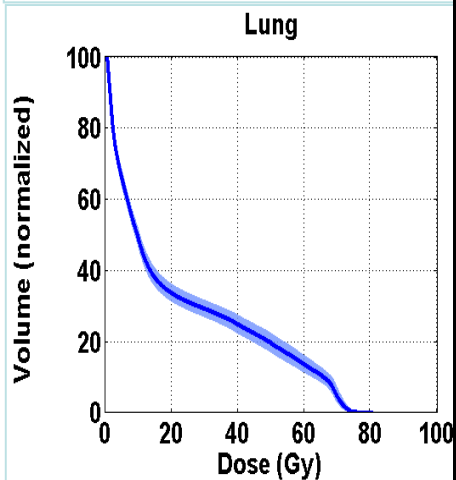
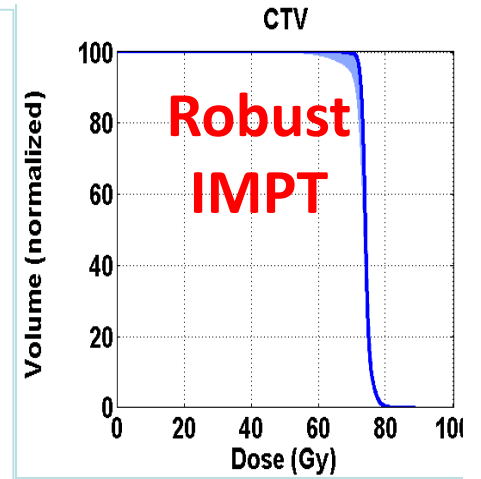
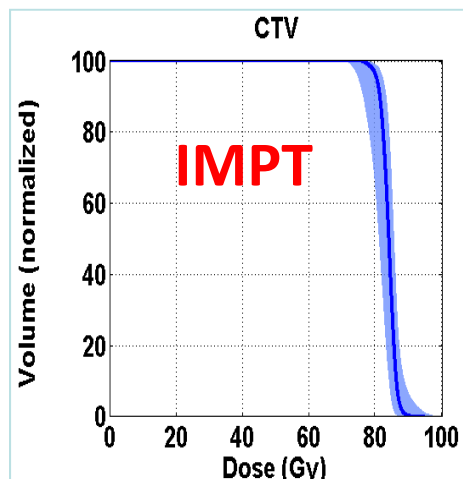
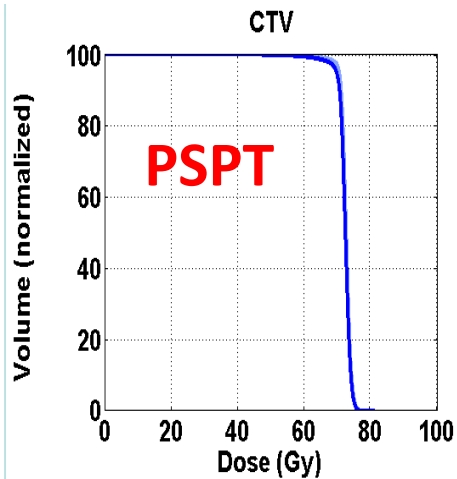
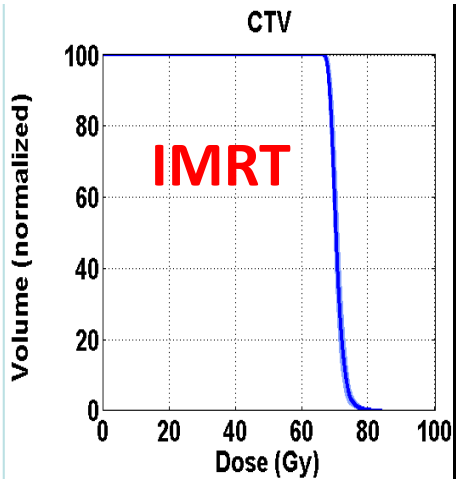
## Range Robust IMCT for Tumor Surrounding Spinal Cord



"These works were performed under research agreement with ELEKTA"

T.Kamada – NIRS - PTCOG


2014



# Conclusions (I)

1. Planning with protons is “easy” :
  - Fast conformation and reduction in integral dose.
2. Different models: Ray tracing, Pencil Beam, Montecarlo,... :
  - Importance of TPS validation, QA and users' experience
3. There are limitations :
  - Entrance dose : multiply beams, combine with photons
  - Uncertainties in range :***
    - avoid risky incidences and distal Organ at risk***
  - Penumbra issues
  - Sensitivity to movements, more with dynamic beams :
    - gating, repainting

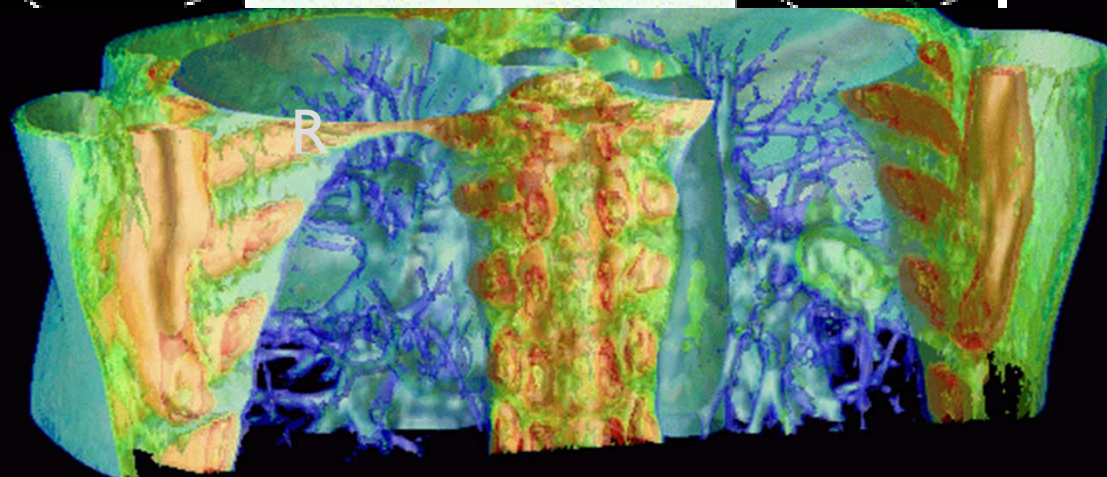
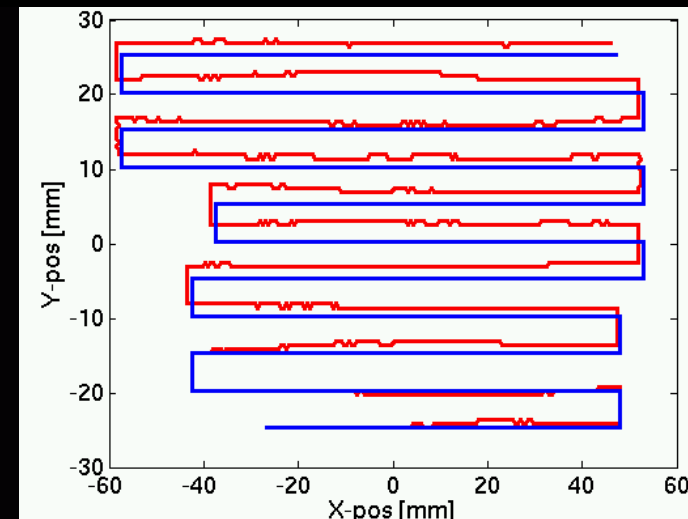
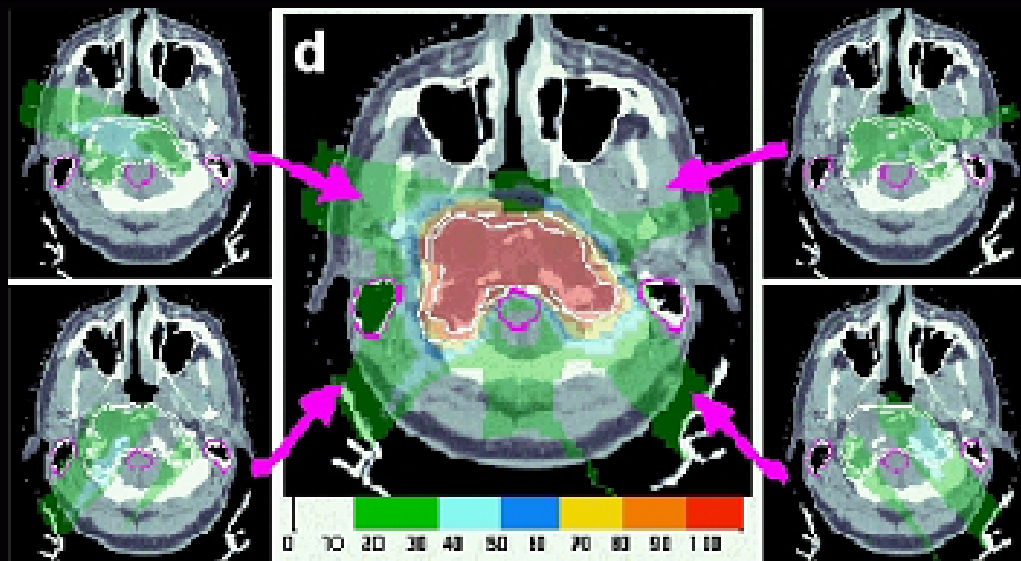
## Conclusions (II)

4. Work in synergy with photons, and optimise throughput :
  - Fast tools and algorithms
  - Need Gantries to plan all incidences as with photons
  
5. Comparative results show in general that :
  - Passive protons  $\sim >$  IMXT (  integral dose)
  - Intensity Mod PT  $>$  IMXT
  
6. TPS evolution towards :
  - MonteCarlo
  - Biological Modeling, mainly for ions
  - Fast and Robust IMPT
  - Adaptive therapy

(need better IGRT & “in vivo” monitoring !)

***Thank You ! Time for Questions ?***

# Moving organs and beam scanning : « interplay » & « repainting » concepts



## Mitigation techniques :

- Breath holding
- Compression
- Beam Gating
- Beam Tracking
- **Repainting**
- ...

Rietzel,, Bortfeld, Lomax, Trofimov,...