General Treatment Planning

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Canceropôle, Rococo, France Hadron
IBA, Varian, Dosisoft, Areva

PTCOG52 Essen 2013

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Menu of today

- The process of planning
- Some differences with protons
- Calculating models
- Compensators : “smearing”
- Limitations of protons
- Basics of planning
- (If time :
    - TPS validation & QA,
    - Management of organ movement)

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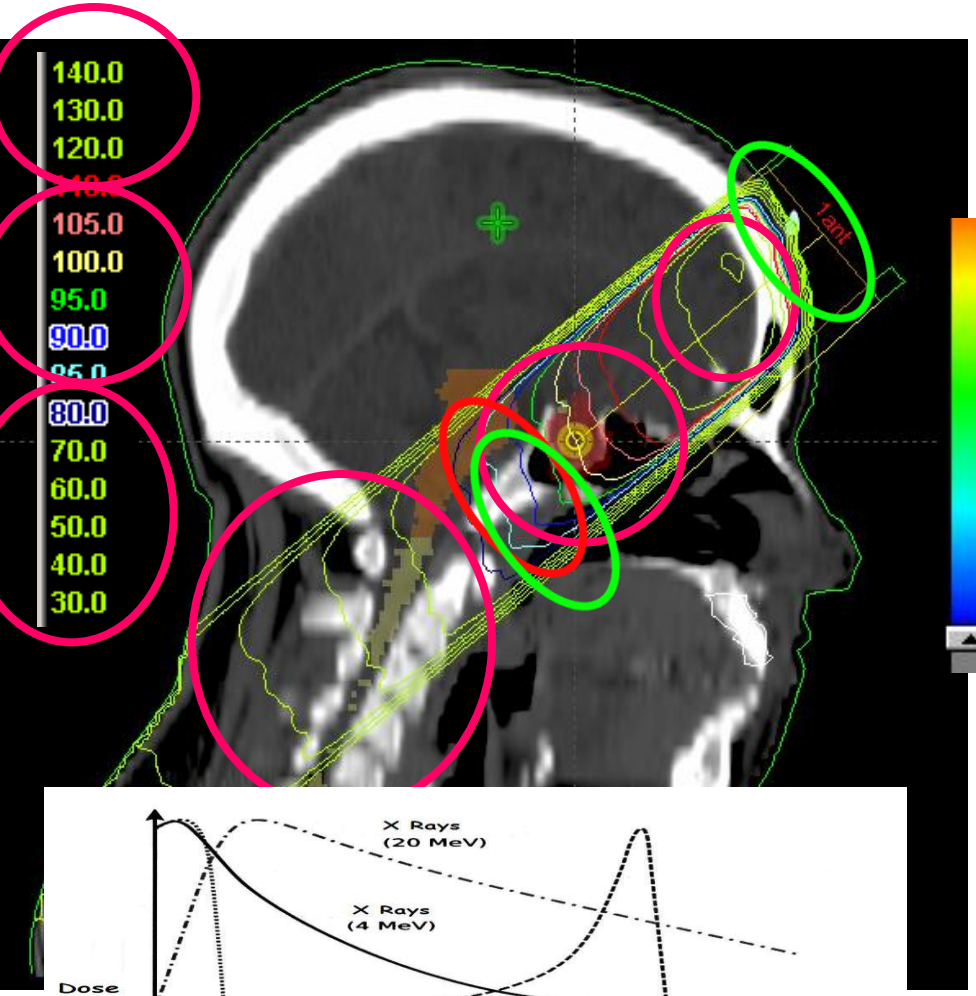
What can we see when we are used to plan with photons
… and move to protons? (1 beam, concepts ~ valid for passive and active techniques…)



(Sub)liminal message

BUT PLANNING

IS NOT ONLY

ISODOSES and HISTOGRAMS

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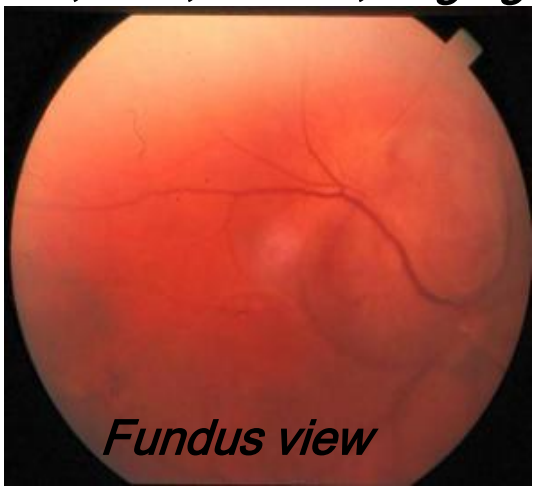
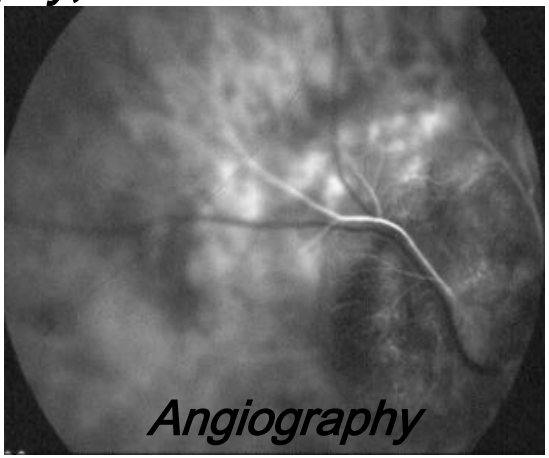
The planning process :
« First simple case » : Ophthalmologic tumors

Imaging

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

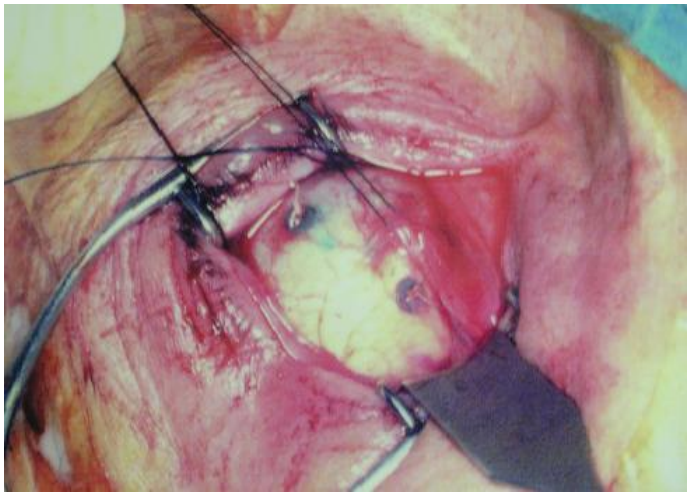




Immobilisation & reference coordinates :

masks, frames,…
and/or…

Use of implanted fiducials



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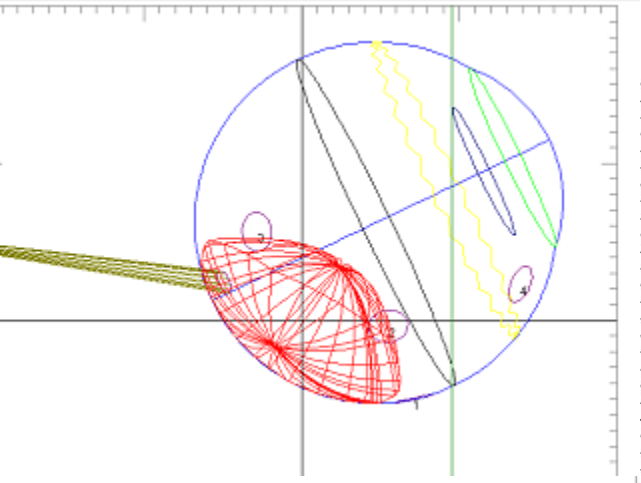
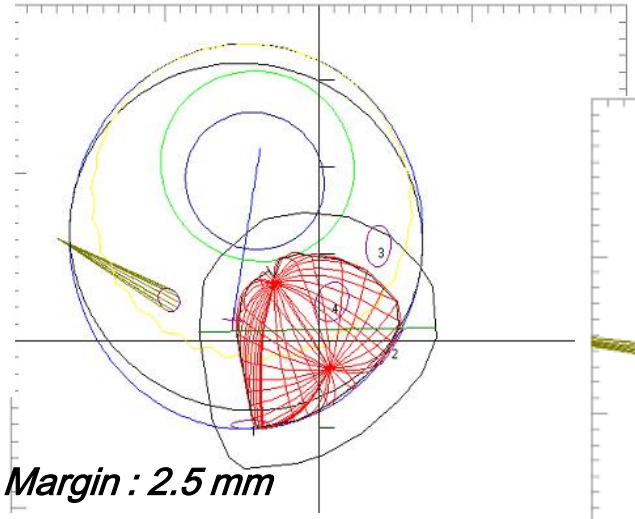
Delineate target, planning aims and beam design

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



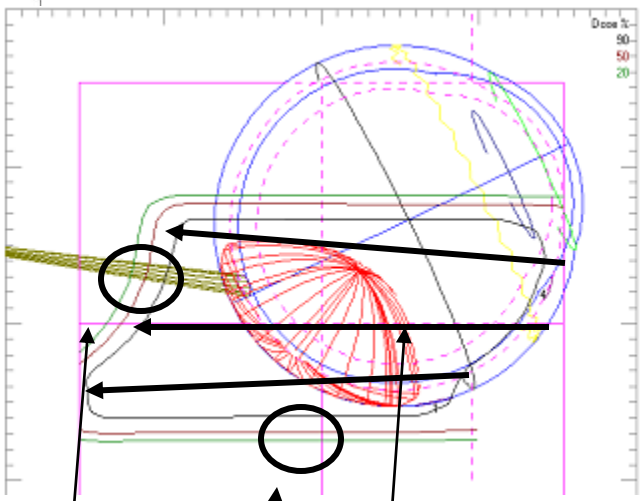
M.Goitein et al

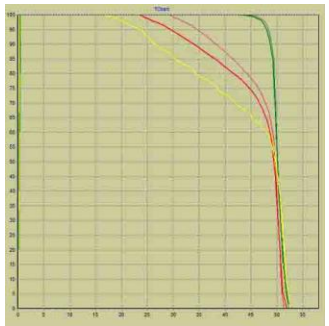
In the beam's eye view:
Design a collimator

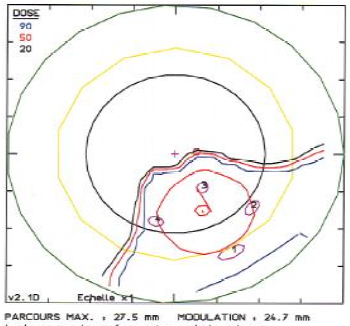


Margin : 2.5 mm

Calculate dose distribution





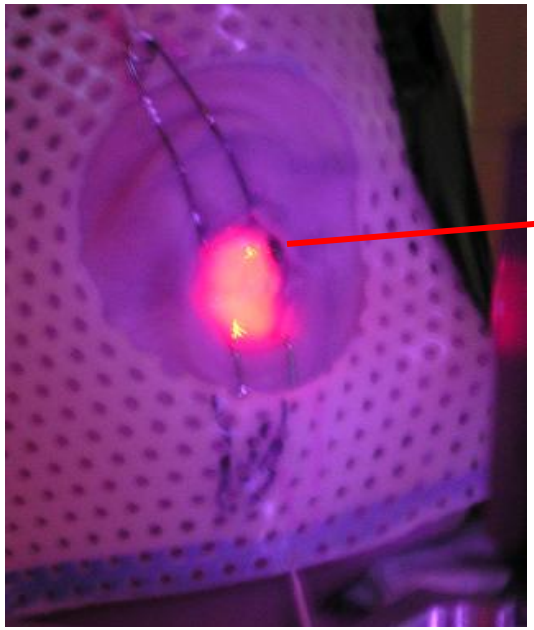


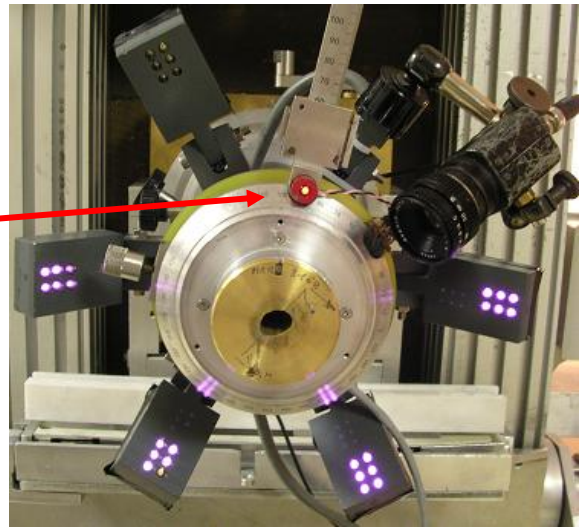
Ray tracing

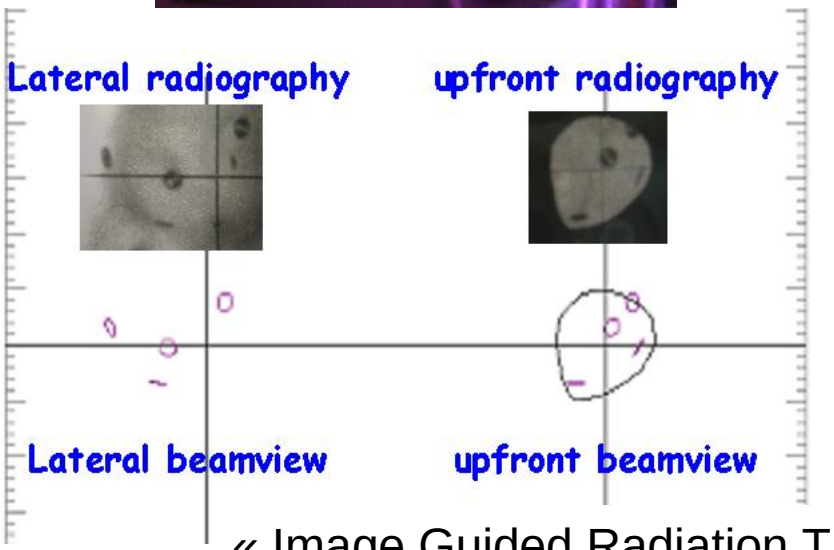
Penumbra

Distal fall off
Eg 30%/mm

Daily set-up control







« Image Guided Radiation Therapy IGRT» with gating

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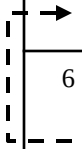
The planning process in general

(adapted from M.Goitein)

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



Steps are common
for any approach in RT…

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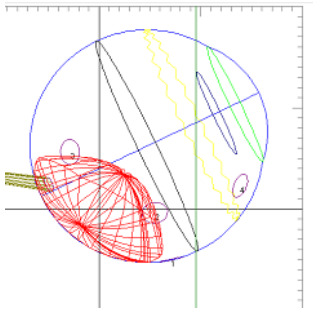
The planning process in general – and the differences between protons and x-rays

(M.Goitein)



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

- Large targets
- Complex geometry

- Meaning of PTV may be different

(Range uncertainties)

- Dose algorithm (depth-dose, lateral profile, field-size dependence, inhomogeneities, MU)

  Set up the configuration data for the dose calculation algorithm
- The effects of inhomogeneities
- Compensation for inhomogeneities
- Beam delivery techniques
- The planning target volume (PTV)
- Design of single beams:
- Design of plans
- Immobilization, localization and verification
- Uncertainty analysis

- 3D dose measurement capability needed

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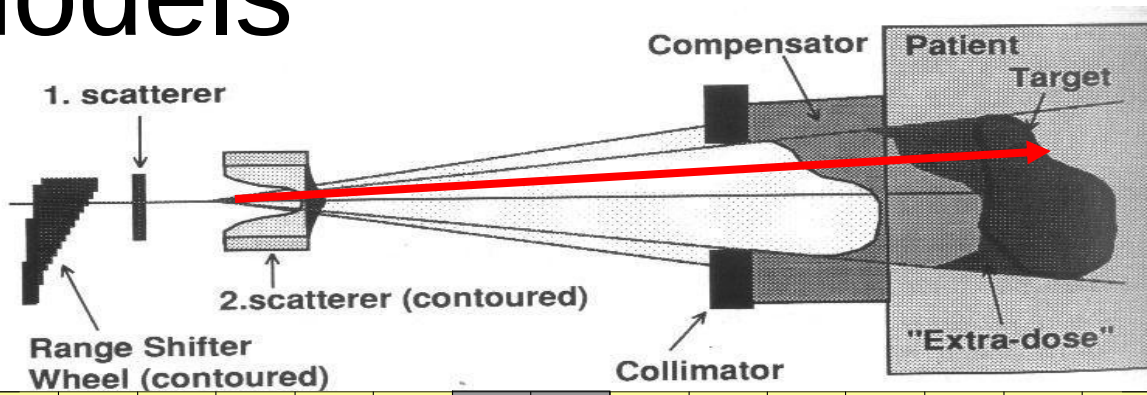
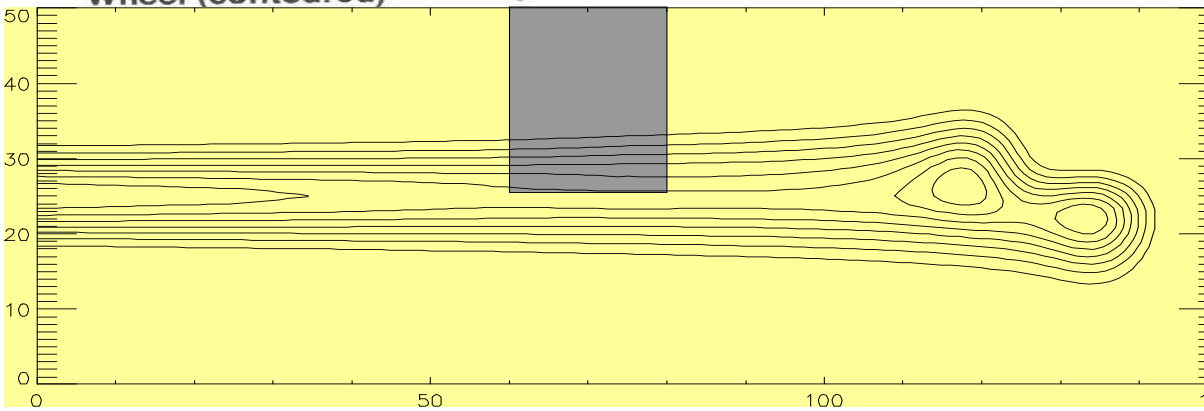
TPS : beam models

3 Families

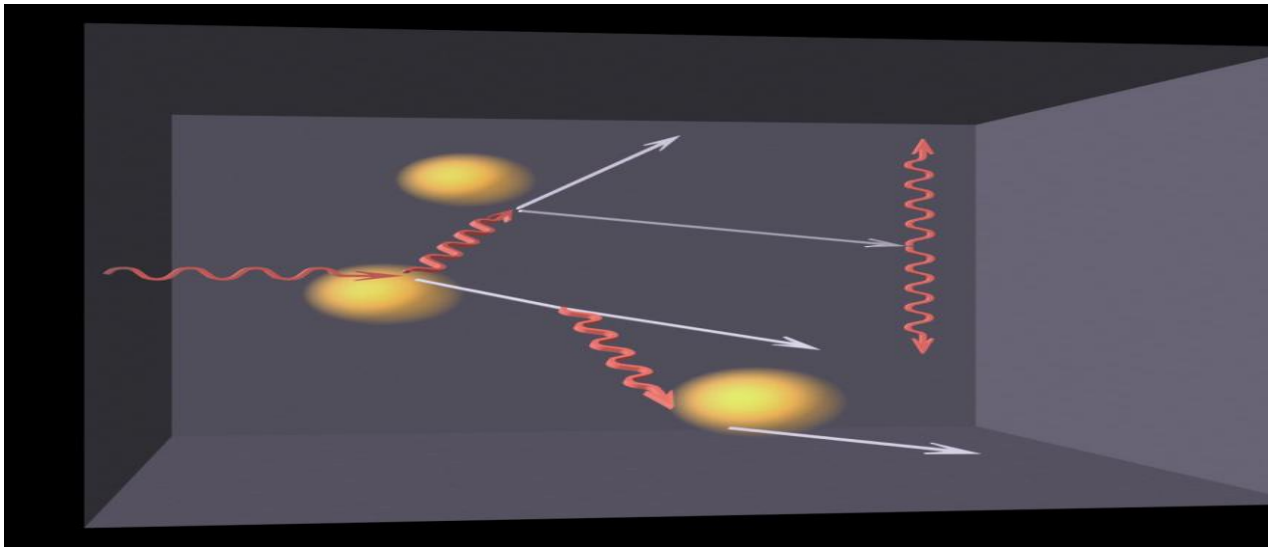
1) Ray Tracing



2) Pencil Beam

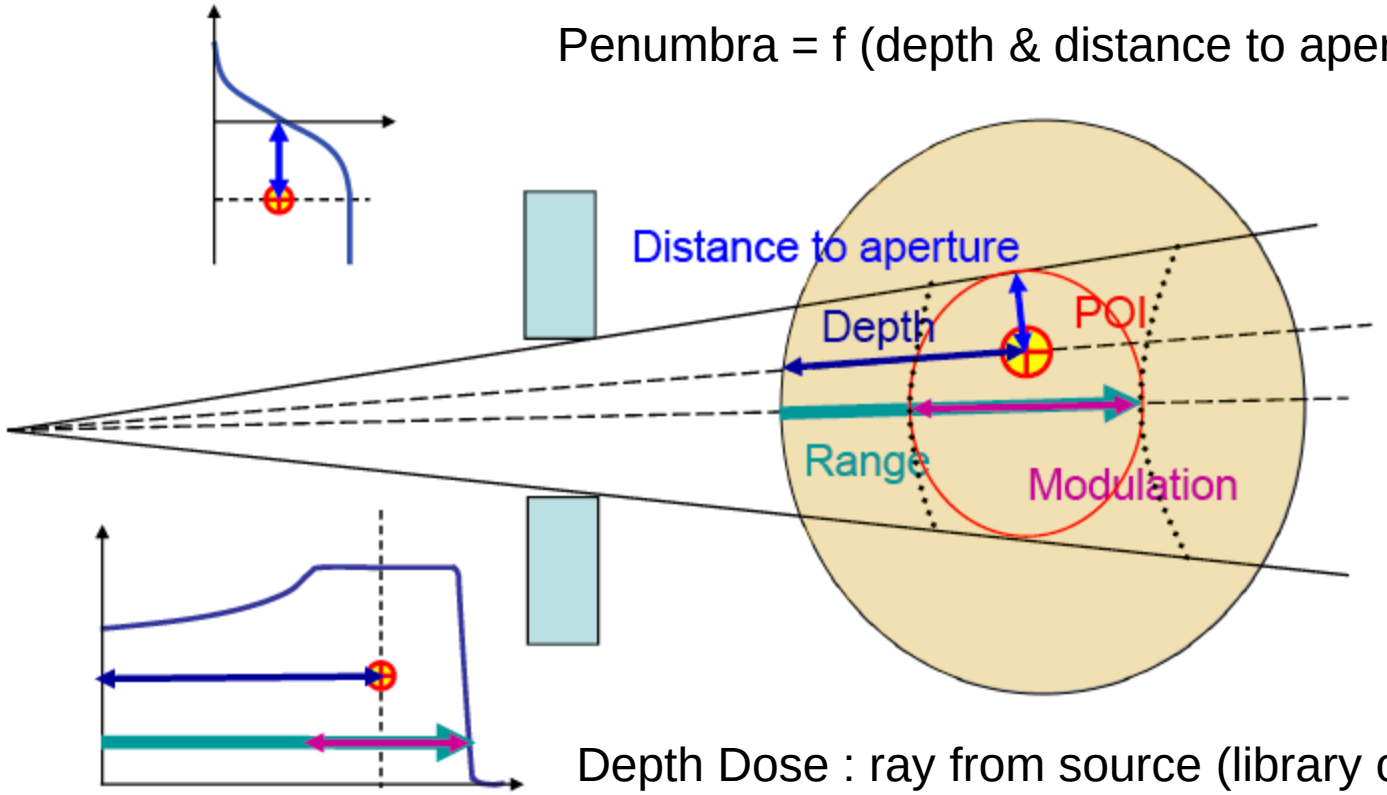


3) MonteCarlo



1) Ray tracing :

Broad beam algorithm - Concept



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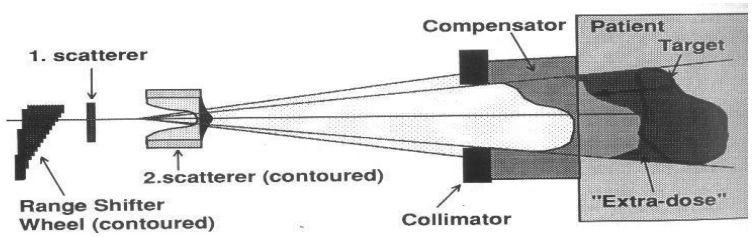
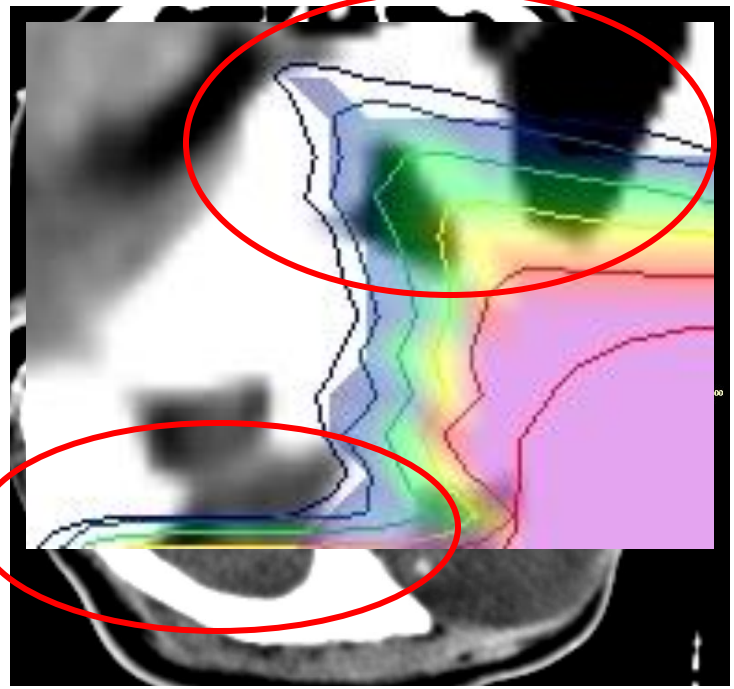
Ray tracing :

- straight protons (no scattering), coming from a ponctual source



- latéral pénumbra model => takes into account scattering due to :
  - initial beam line
  - compensator + air-gap
  - patient



⇒ Limitations in inhomogeneous areas and for compensator gradients

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

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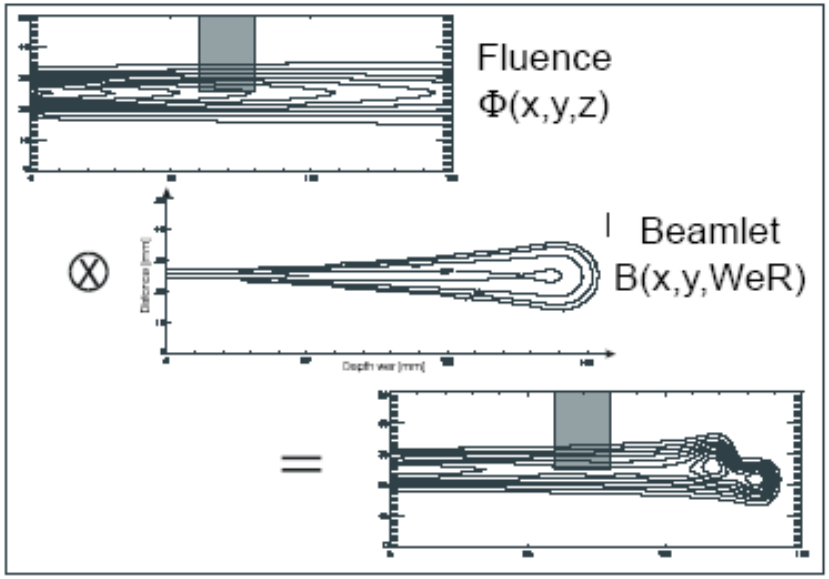
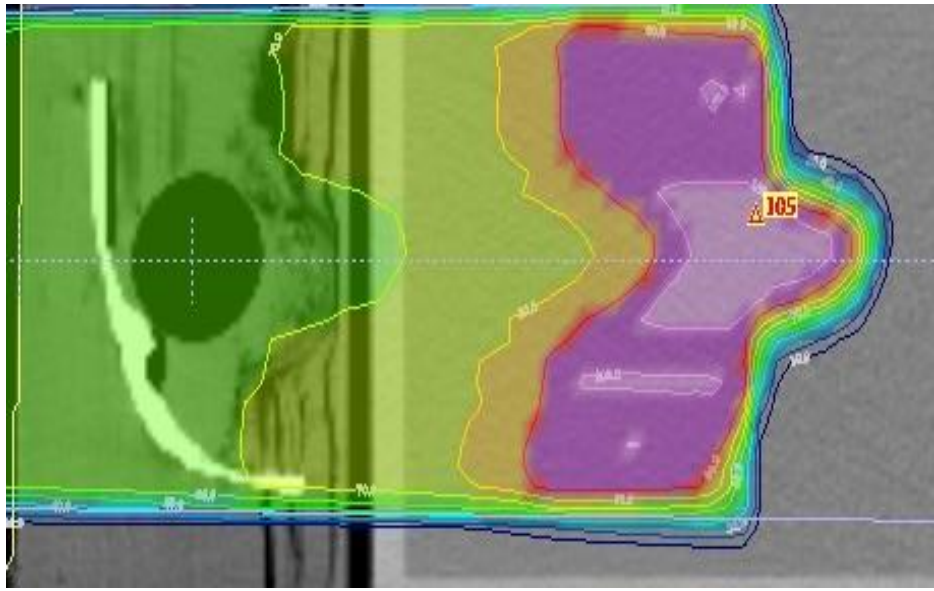
Eclipse pencil beam algorithm - Concept



- 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 (⇔ increase of the σ as a function of depth & upstream parameters)



• Good compromise speed-precision:

- well-suited for compensator
- « smoothes » isodose curves

The most used at present

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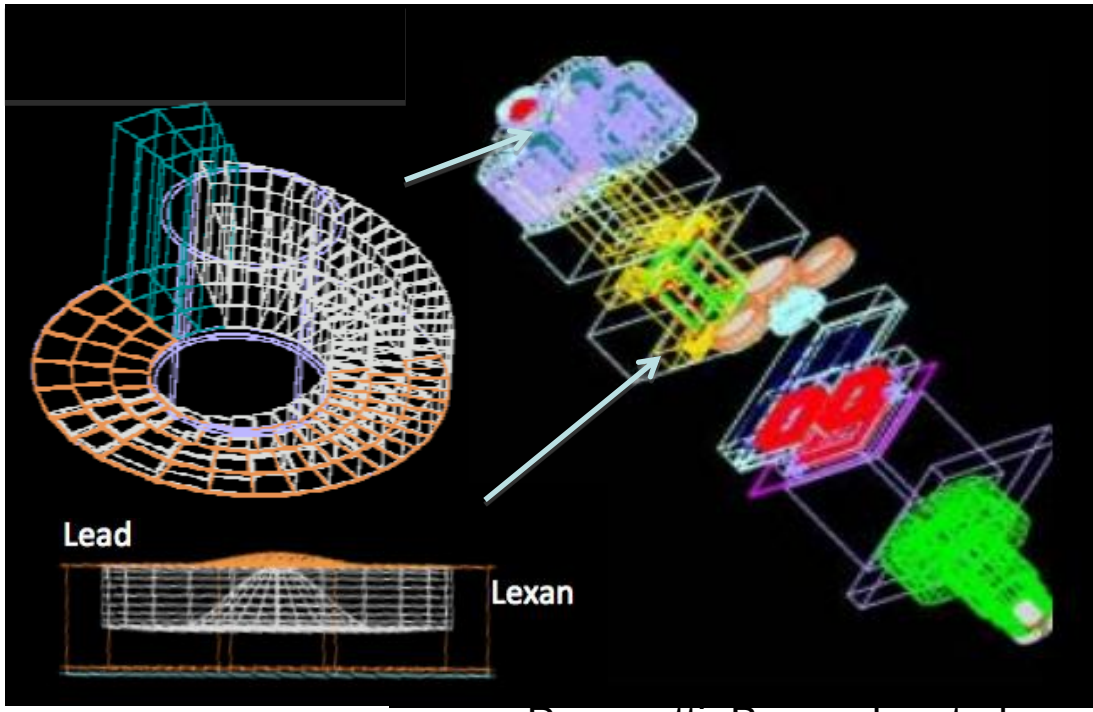
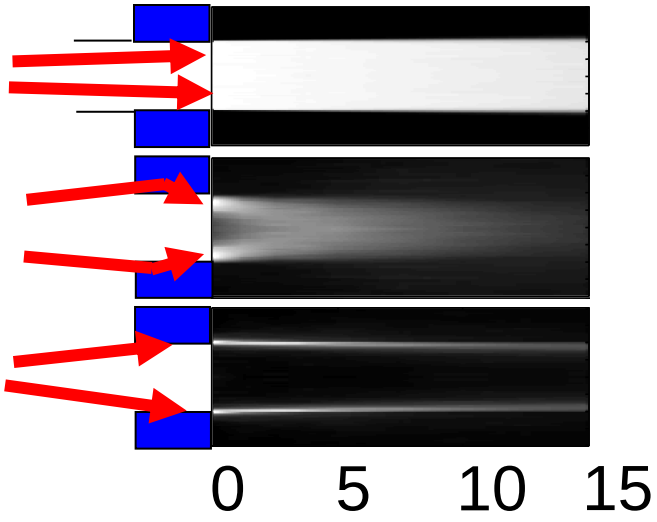
TPS beam models : Monte Carlo

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

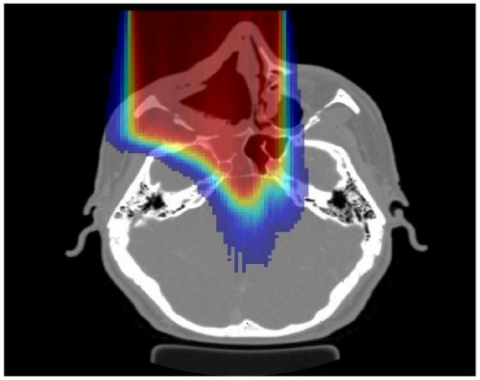
- Beam at the entrance (E,dE,…)
- Treatment Head/nozzle
- 4D if movements
- Patient CT:
  HU → groups of tissues

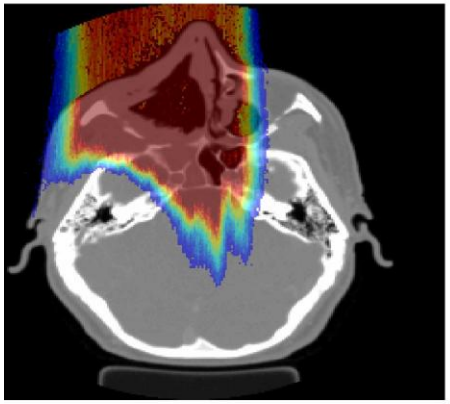


Paganetti, Bernardz, et al



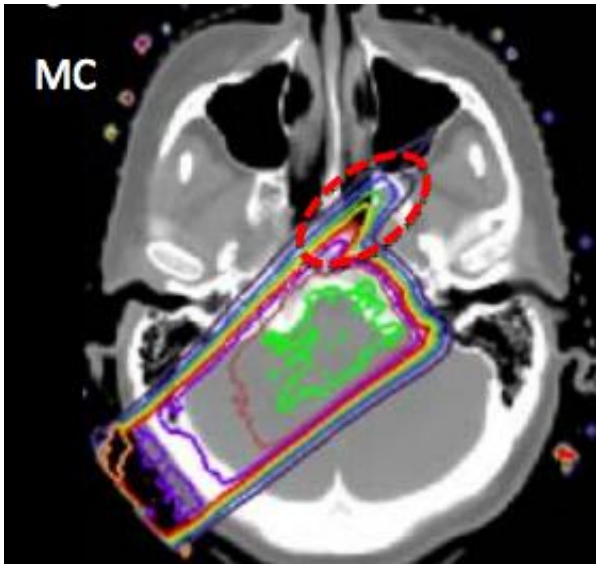
(van Lujik et al)



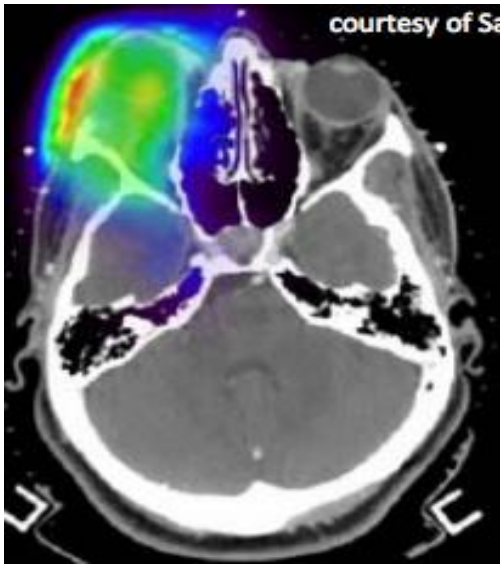


Comparison PB-MC (Paganetti, Trofimov, et al)

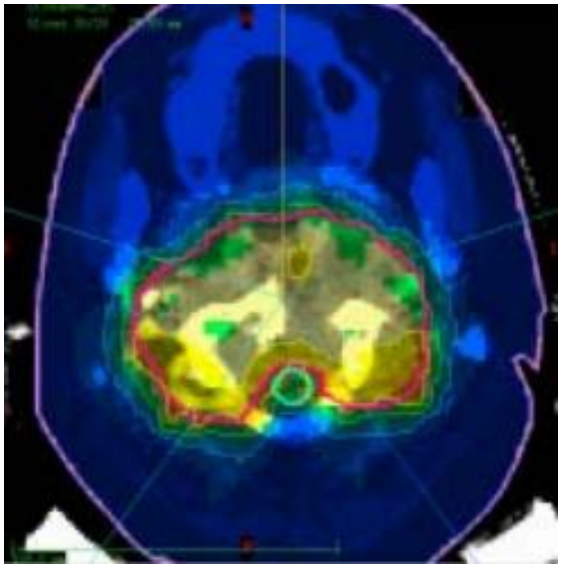
Applications of Monte Carlo :



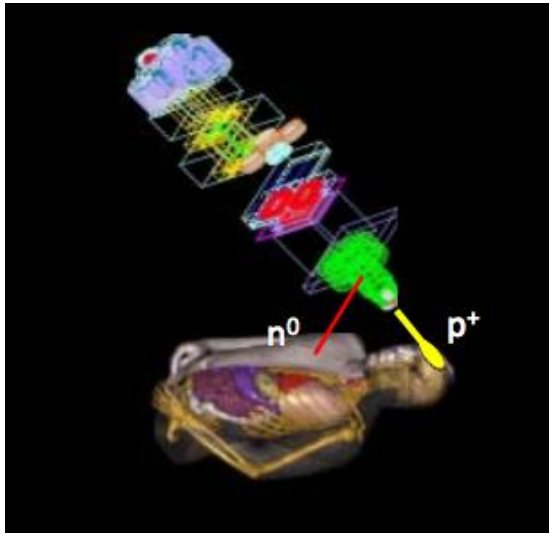
Precise dose calcs with inhomog



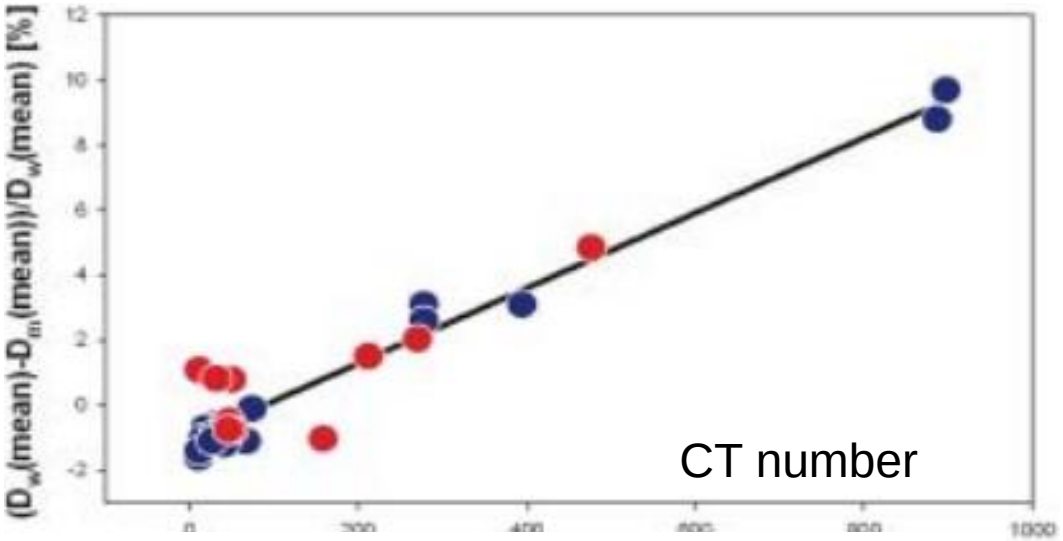
Tissue activation for PET QA



Calculation of LET → RBE



Calculation of neutrons



Conversion from water to tissue dose

Bednardz, PTCOG49 / (Data from Paganetti, Shin, Espana, Oelfke, Athar, Xu and Bolch)

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

(from M.Goitein)

step		*•protons vs. photons*
1	**Evaluate the patient**	~same
2	**Register Images in tt position**	Same
3	**Delineate target and critical organs**	~same
4	**Establish the planning aims**	same
5	**Design beams**	different
6	**Evaluate, replan**	same
7	**Finalize the prescription**	same
8	**Simulate, QA**	same
9	**Deliver, record, verify**	~same, but QA harder.
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12	**Review during follow-up**	same

- Large targets
- Complex geometry

- Meaning of PTV may be different

- Dose algorithm (depth-dose, lateral profile, field-size dependence, inhomogeneities, MU)

  Set up the configuration data for the dose calculation algorithm

- The effects of inhomogeneities
- Compensation for inhomogeneities
- Beam delivery techniques
- The planning target volume (PTV)
- Design of single beams:
- Design of plans
- Immobilization, localization and verification
- Uncertainty analysis

- 3D dose measurement capability needed

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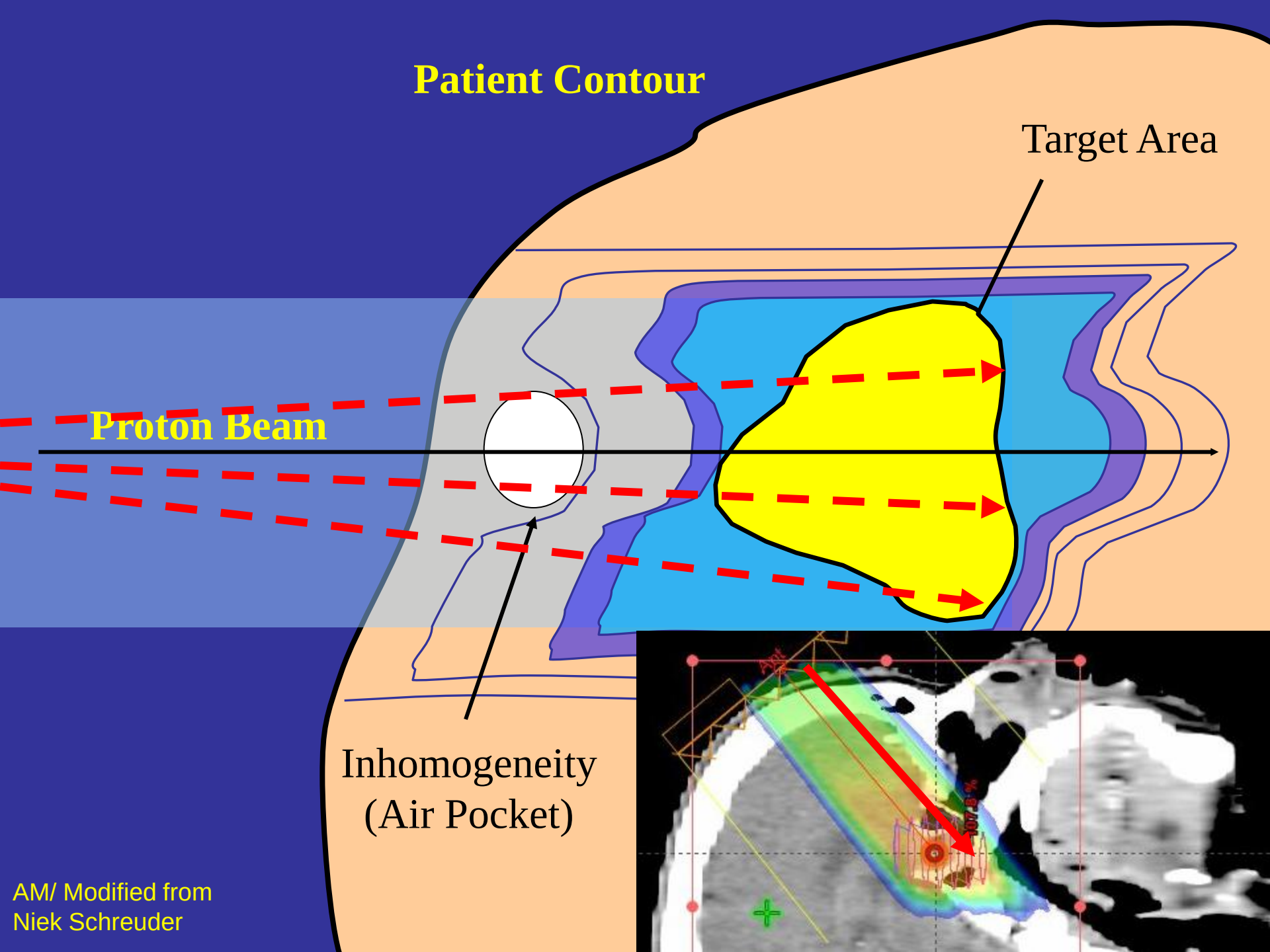
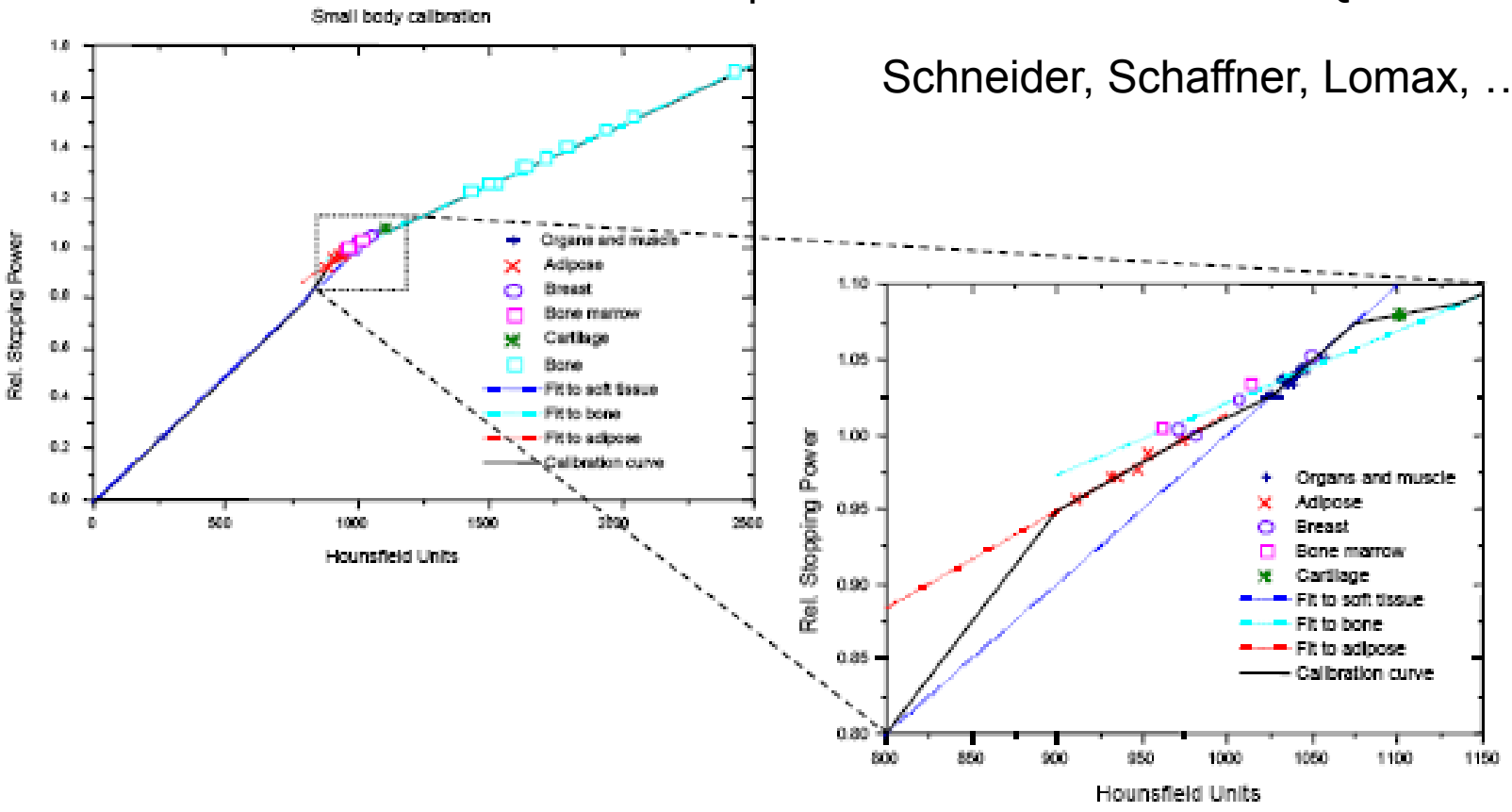


AM/ Modified from
Niek Schreuder

Plot of calculated (HU_{sc},SP_{rel}) pairs and linear fits

Importance of CT calibration & QA = RANGE

Schneider, Schaffner, Lomax, …



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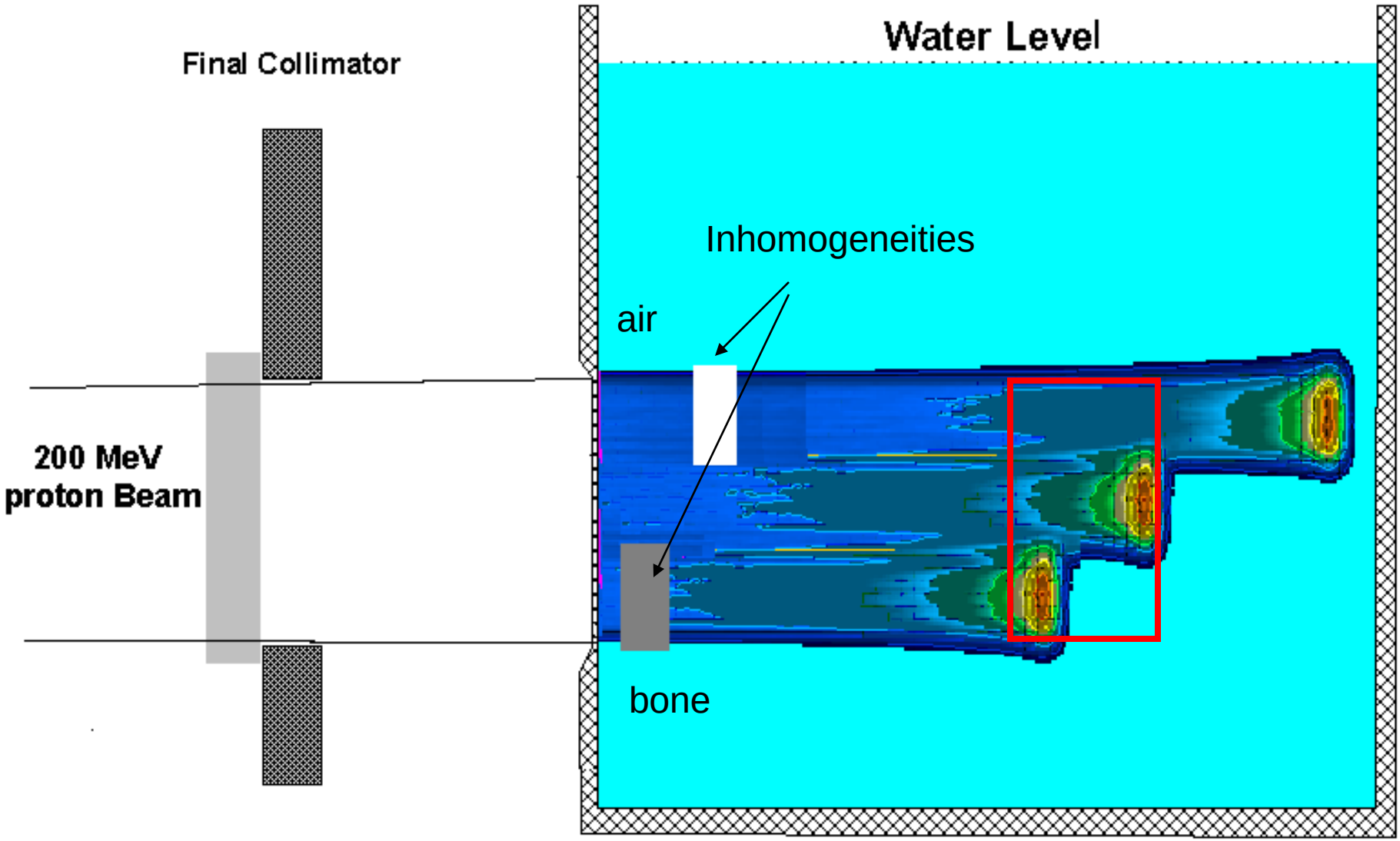
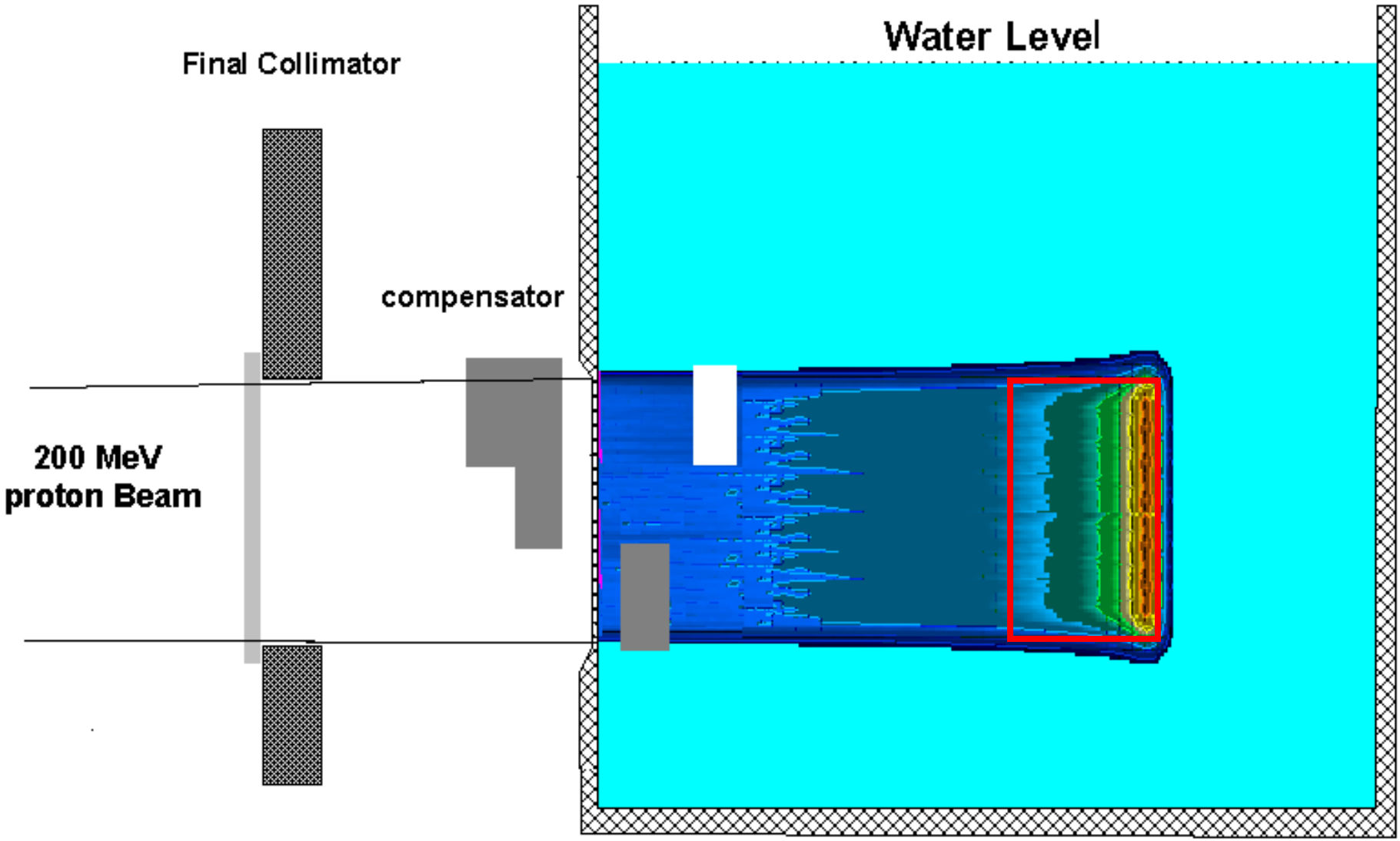
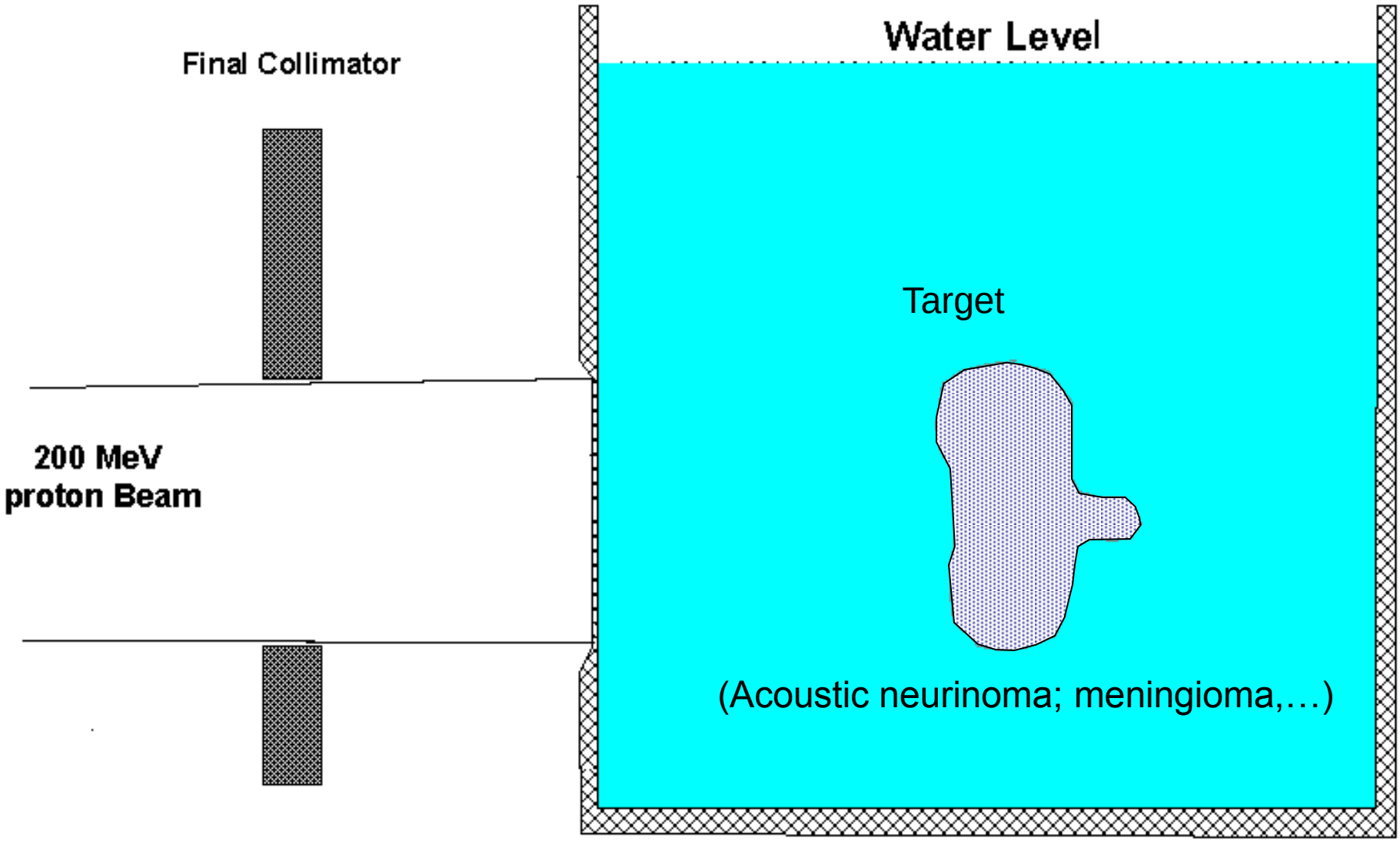
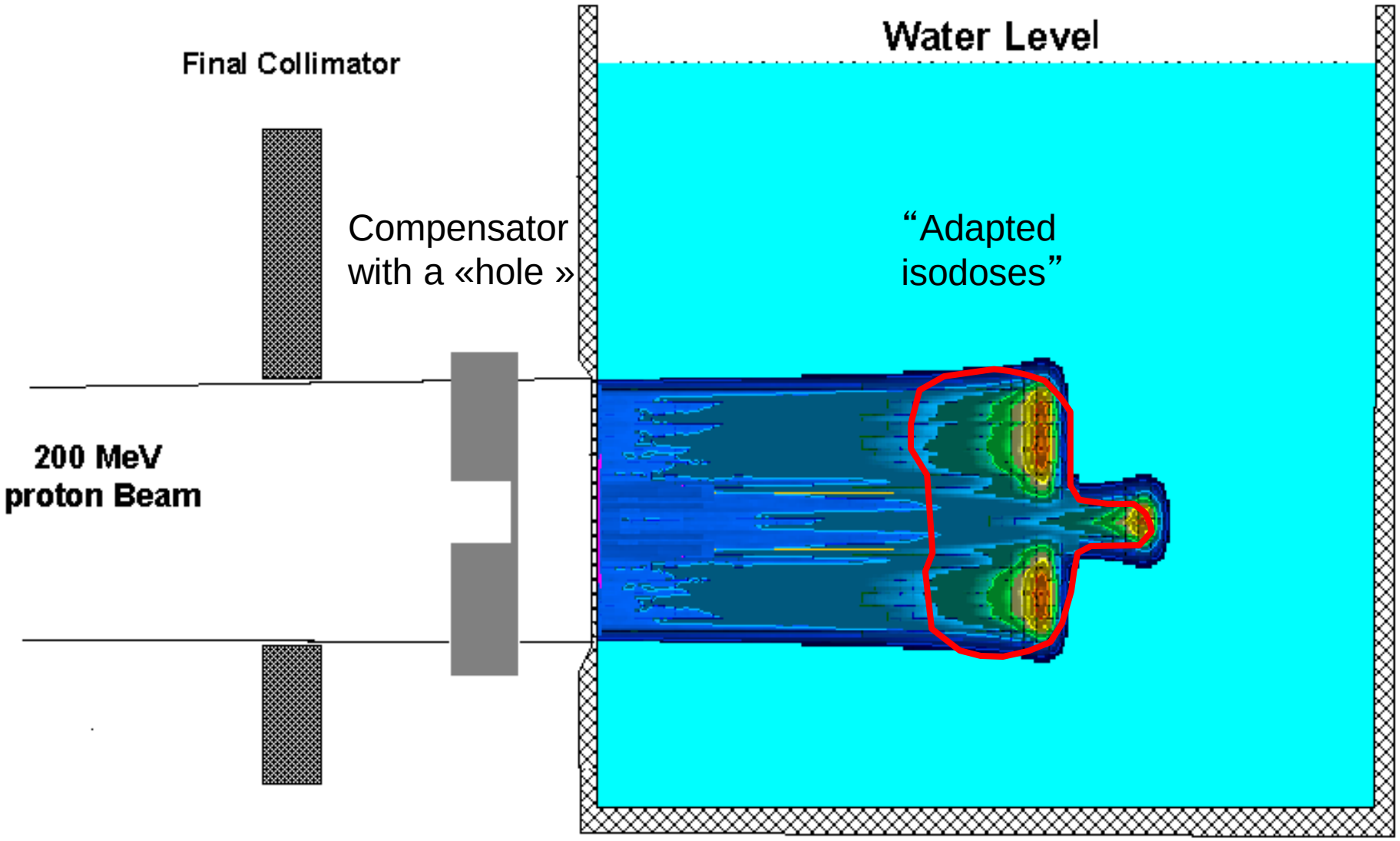
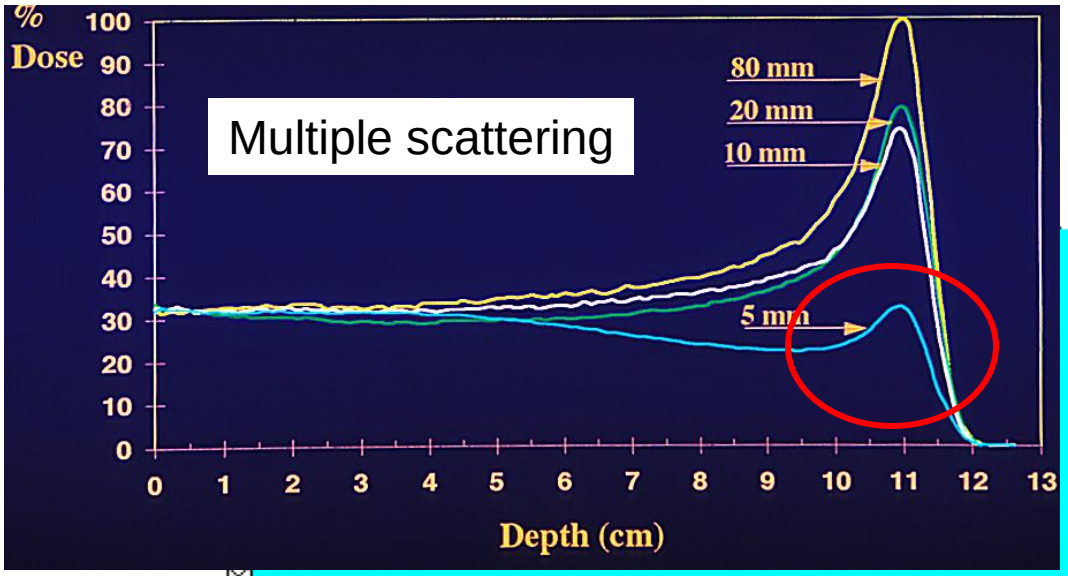

Water Level
Final Collimator
Inhomogeneities
air
200 MeV
proton Beam
bone


Water Level
Final Collimator
compensator
200 MeV
proton Beam


Water Level
Final Collimator
Target
200 MeV
proton Beam
(Acoustic neurinoma; meningioma,…)


Water Level
Final Collimator
Compensator
with a «hole »
“Adapted
isodoses”
200 MeV
proton Beam

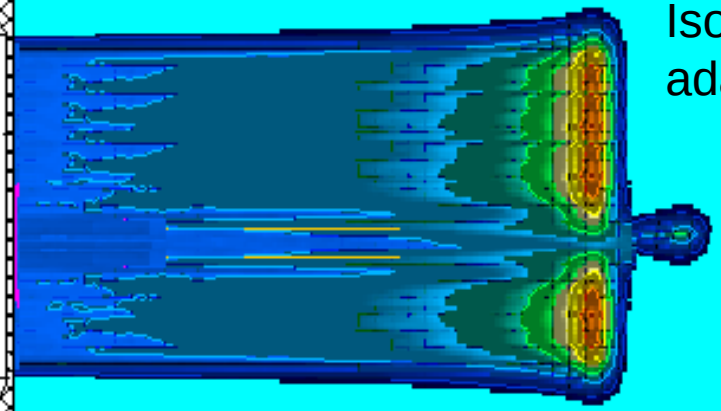


Multiple scattering

Final Collimator

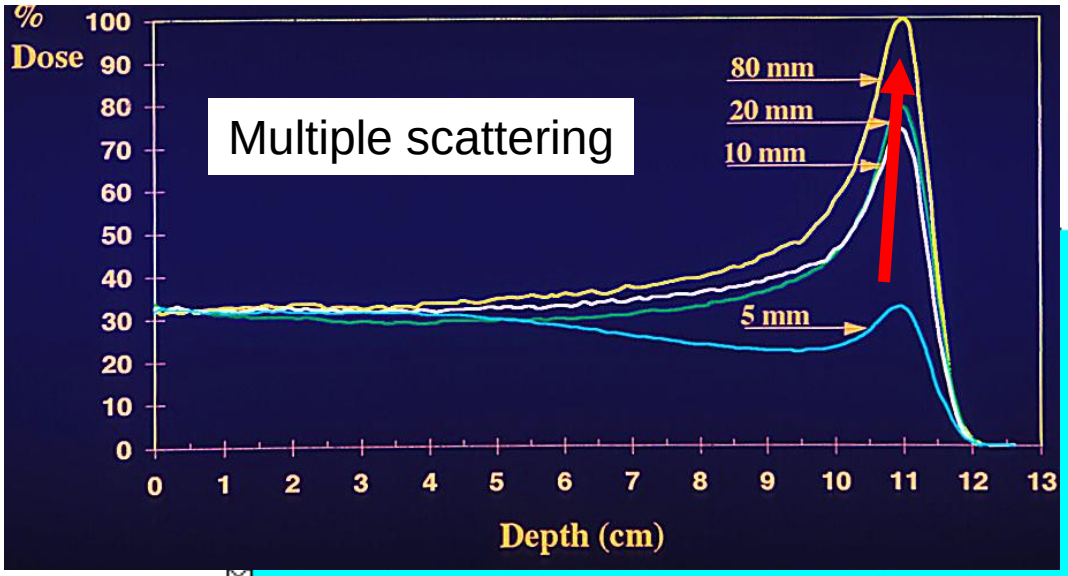
200 MeV
proton Beam

But what if Drilling a too tiny hole?



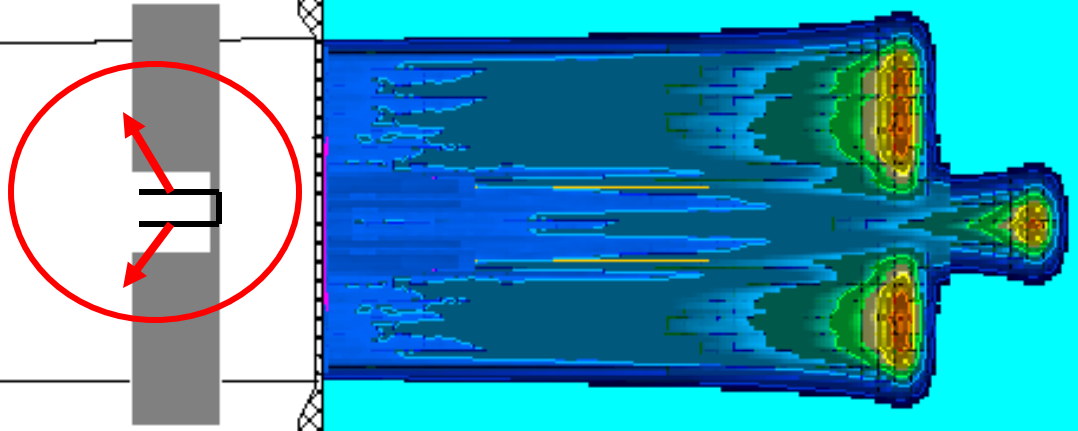
Isodoses not adapted

Getting a too small beam



Final Collimator

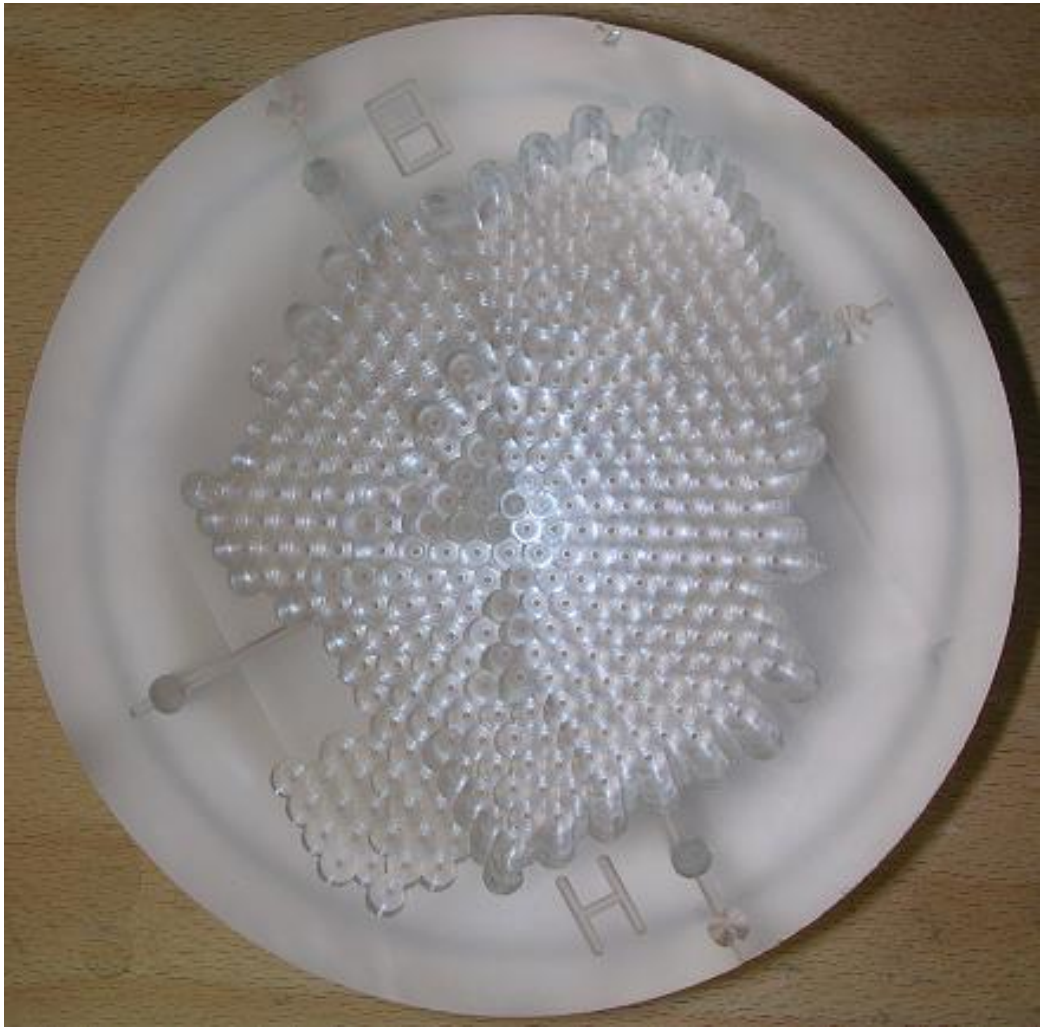
200 MeV
proton Beam

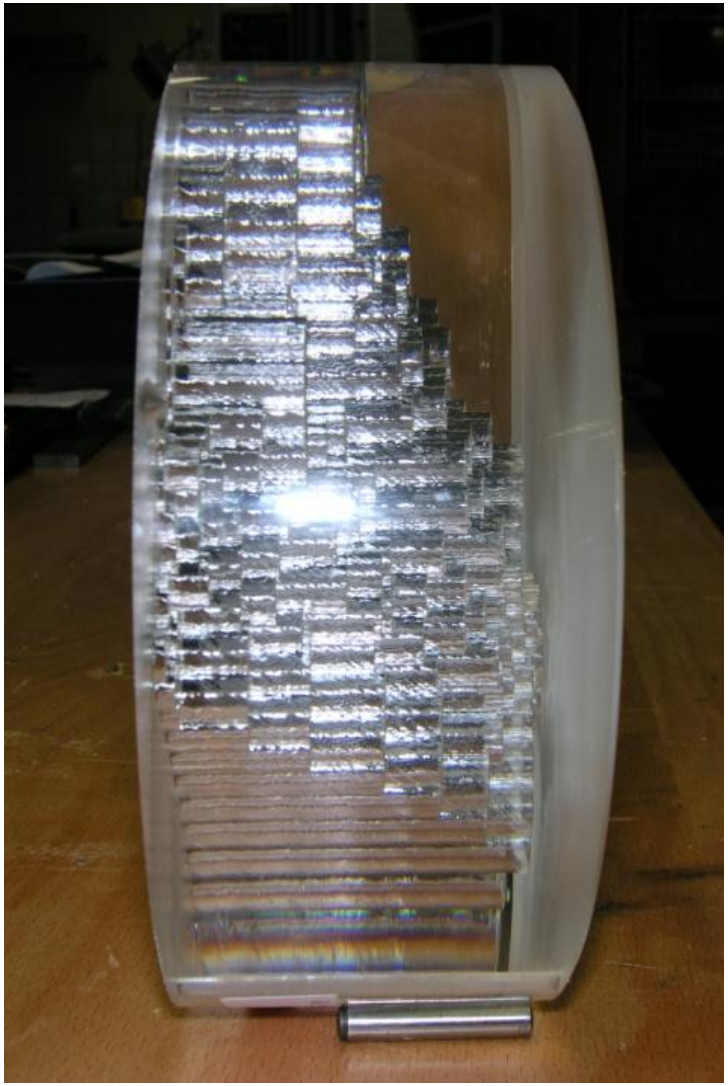


« Smearing the compensator »

Need to work out the compensator in order to get the desired deep peak effect

Ex of a compensator





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

→ See at the end, or other presentations in this course

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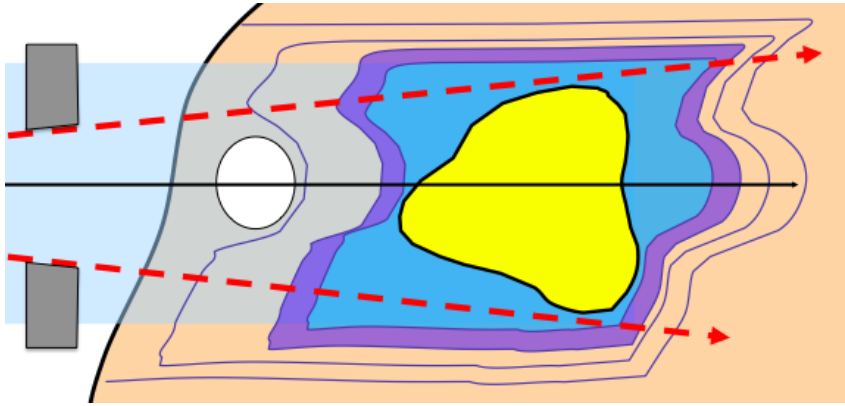
TPS : Compensator design

1. Geometrical ray-tracing
   (taking inhomogénities into account)

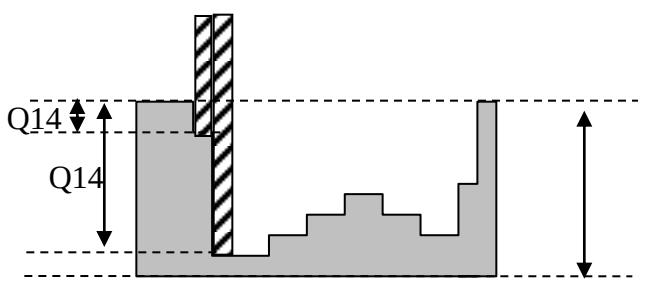


2. Smearing (2-> 6 mm) :
   compensates for uncertainties, scattering, movements

Borders

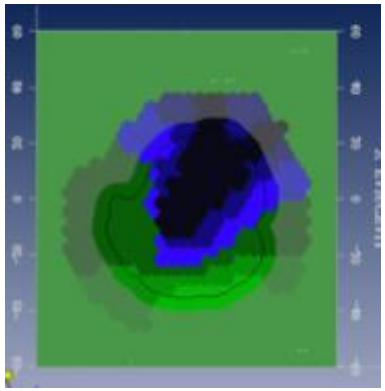
3. Dealing with borders (no target)

4. Tool simulation (⇔2nd smearing)



Tool simulation

5. Milling file generation



QA

6. QA (mechanical, radiological, measurements…)

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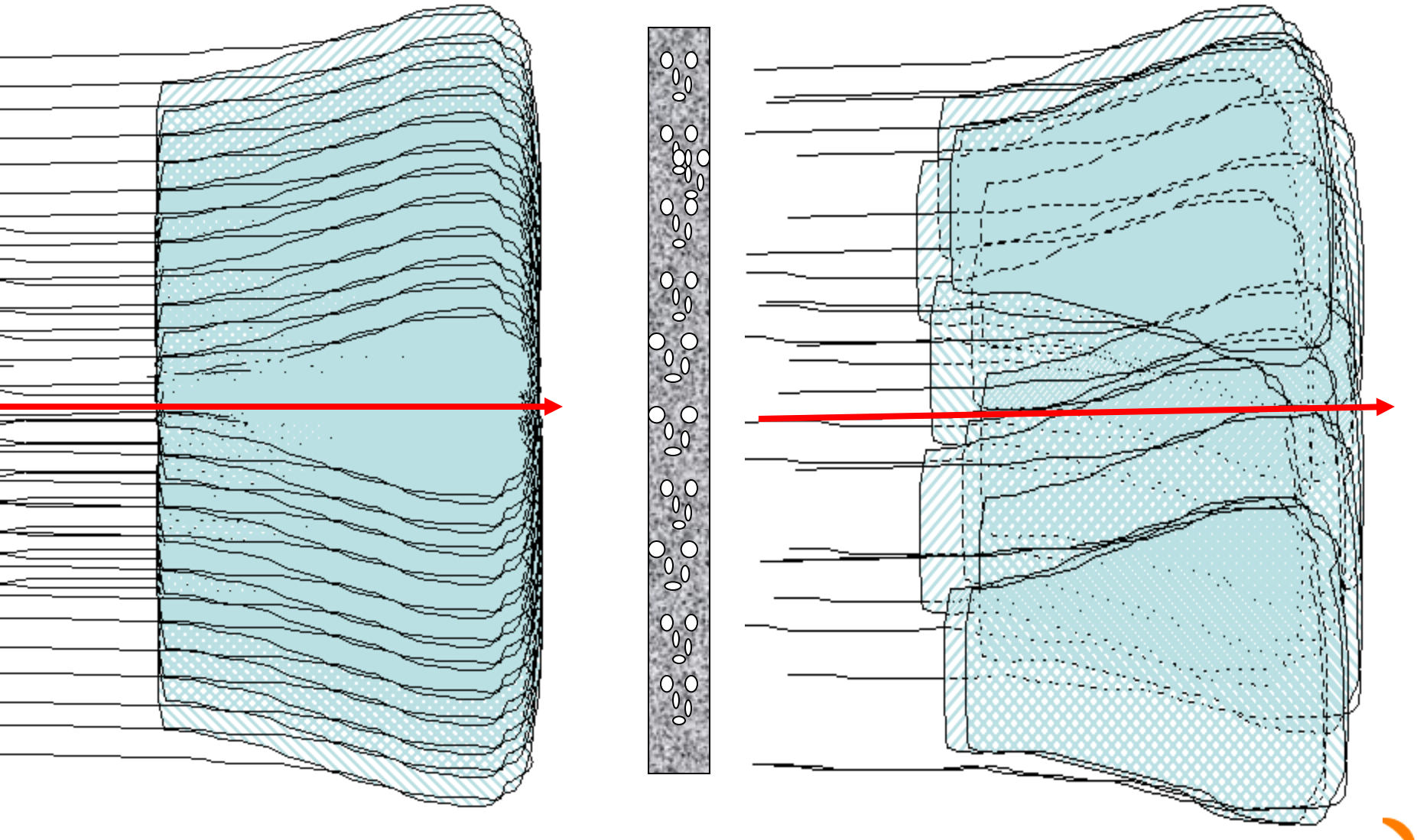
But… if « complex » heterogeneities : not only a « ray tracing approach », also multiple scattering effects :



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

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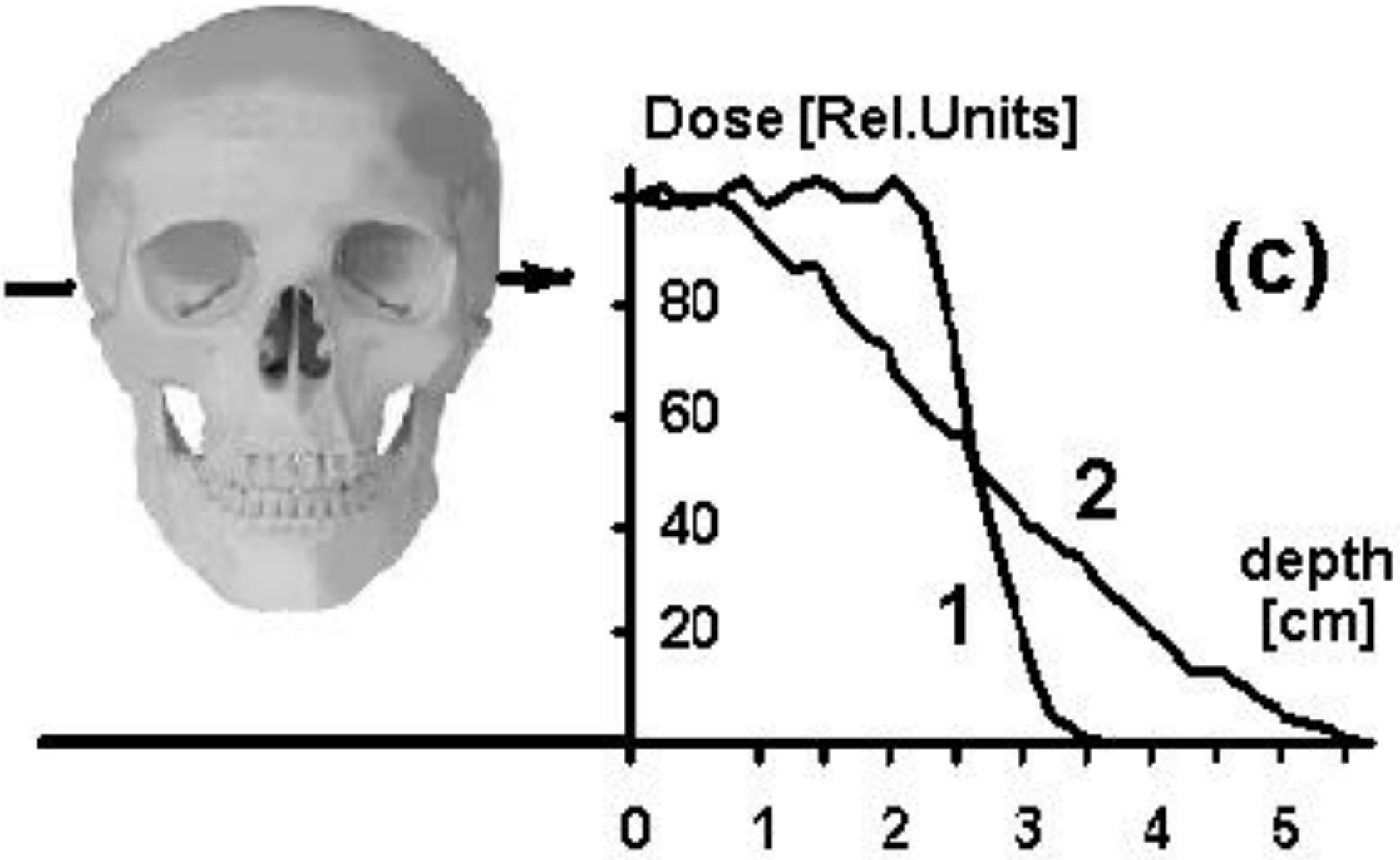


Need to change the range

→ change the incidence !!

Urie et al

Patient Contour

Compensator

Air

Target

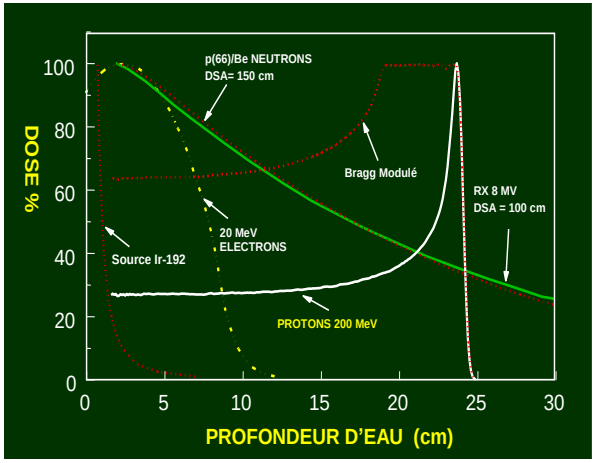
Range

Aperture

Modulation

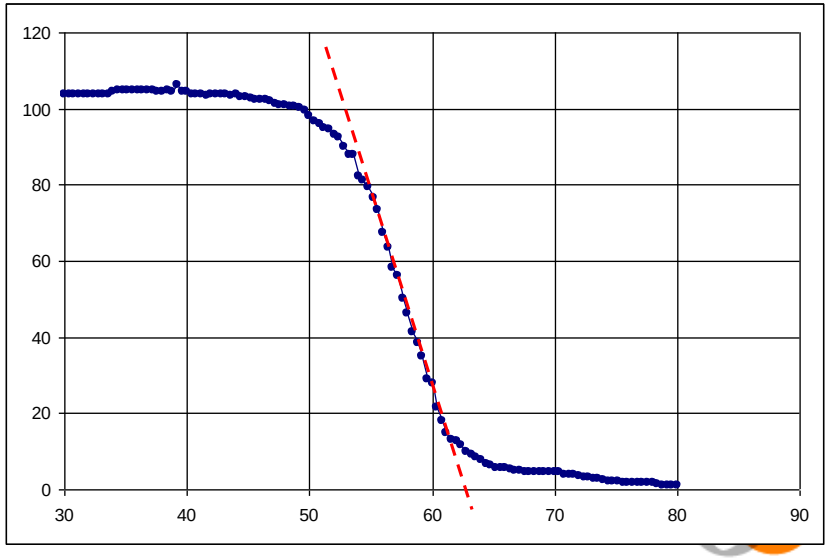
Properties of planning with passive beams

- Good lateral penumbra (~10-15 %/mm) shaped by aperture



- « 2,5 D » tumor shaping (lateral and distal shaping, not proximal)

- Lateral penumbra sensitive to air gap (between aperture and patient)



With this approach:

⇒ **Get profit of proton characteristics**

⇒ **Minimize risks and drawbacks**

⇒ **Not using the full « potential » of protons**

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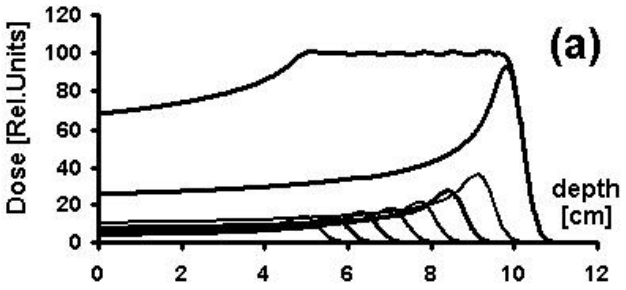
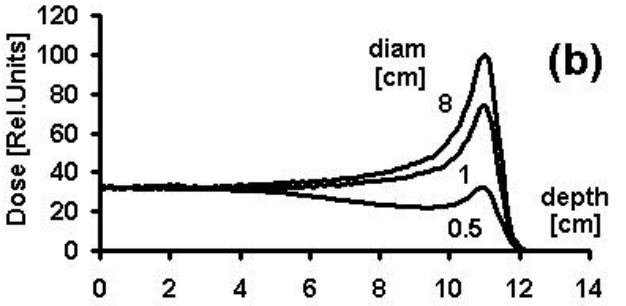
Limits: Degradation of balistic properties

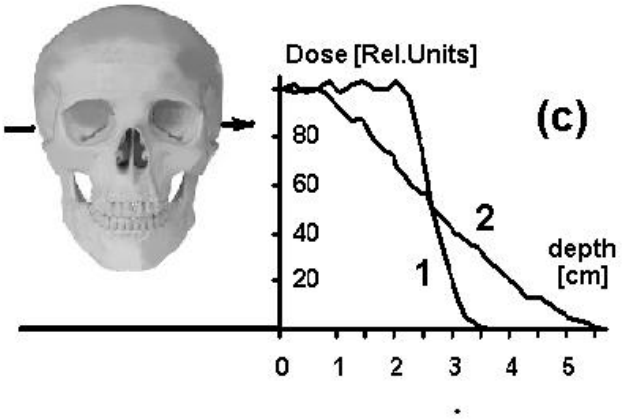
Entrance dose
(& small buildup)



Small field size
< peak/entrance



Degradation
After complex
Inhomogeneities
(and problem of
CT artifacts)



⇒ Check that TPS
takes
all this into account

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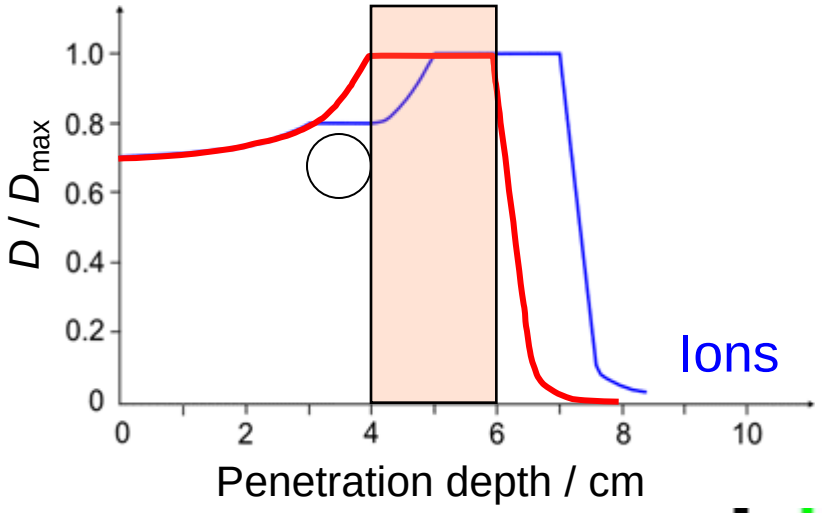
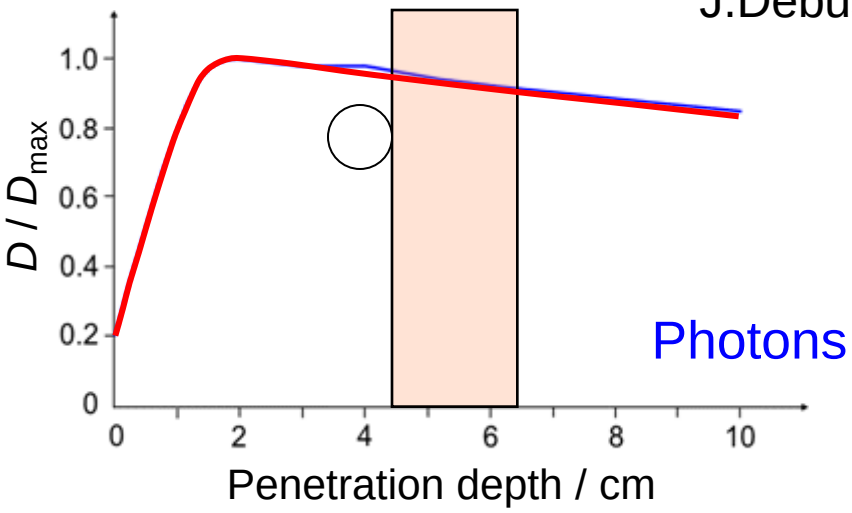
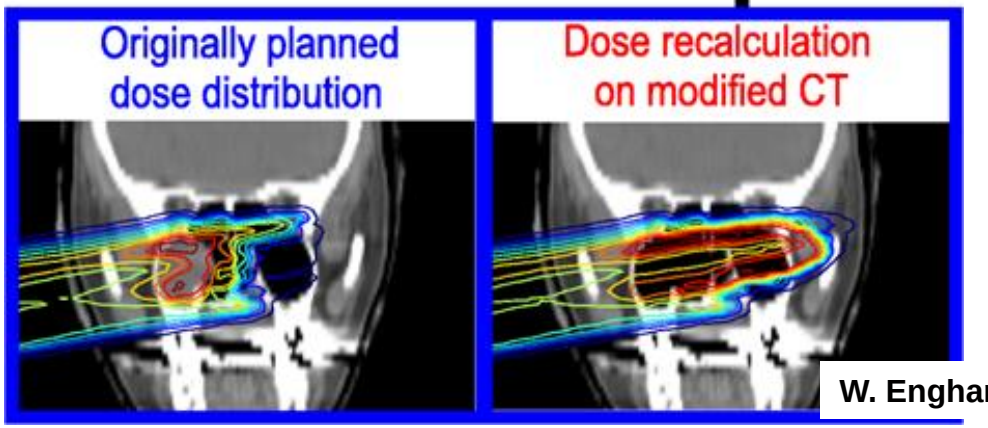
Effect of density changes (eg : in the target volume or in the beam path)

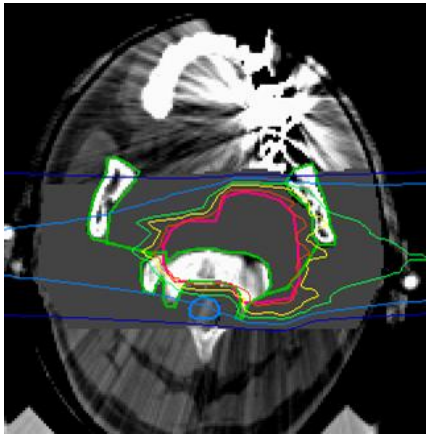


J.Debus





W. Enghardt et al.



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

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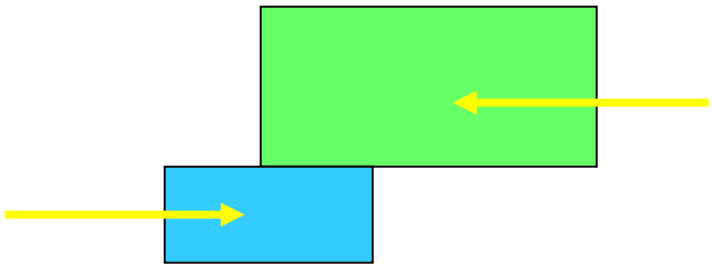
Planning basics

Abbuting fields

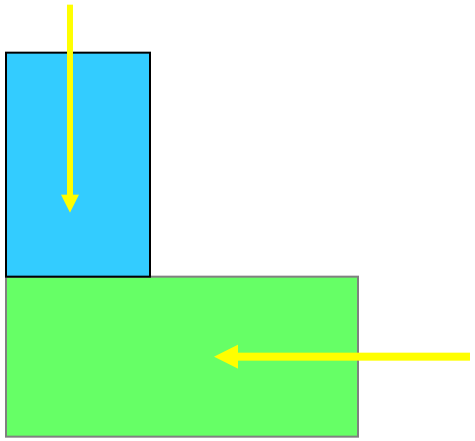


Lateral penumbra

+

Lateral penumbra

Patch fields



Distal penumbra

+

Lateral/distal penumbra

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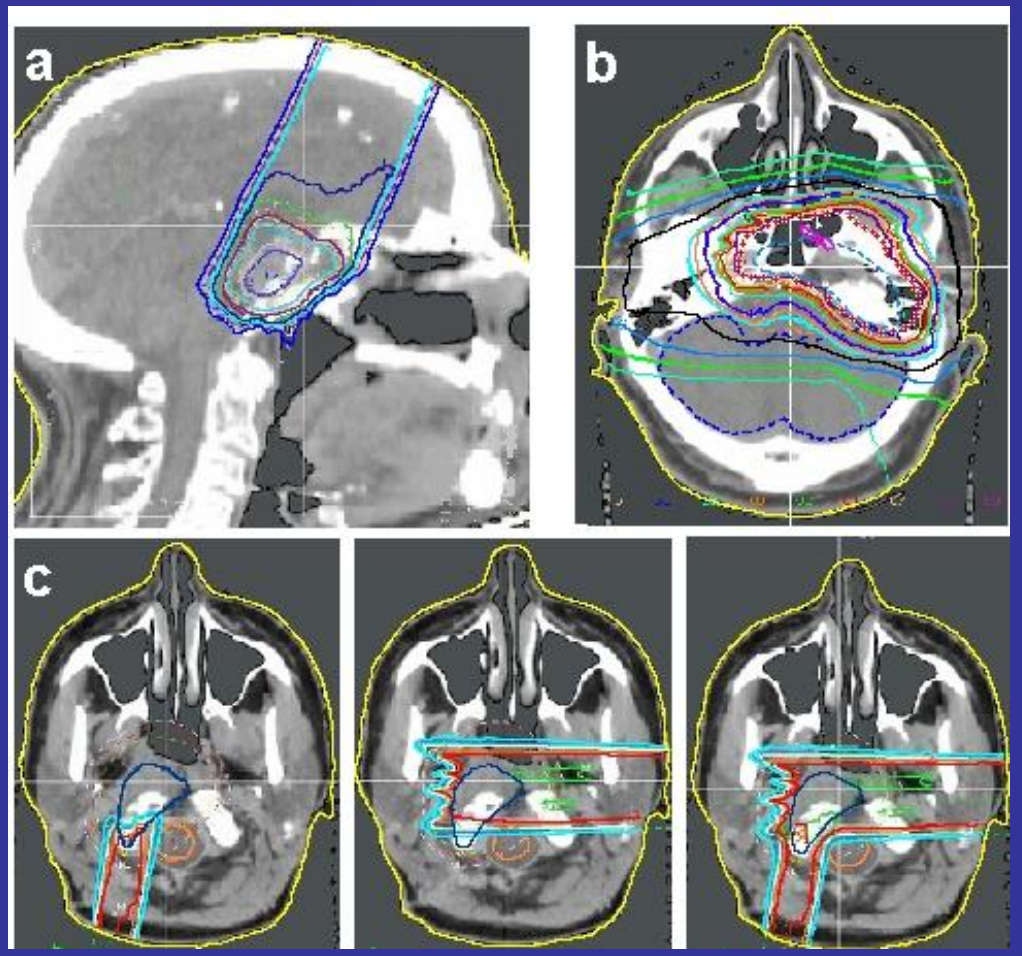
Clinical applications:
Eg: Base of the skull tumors

Non coplanar beams

Photons-protons

Junctions, patching



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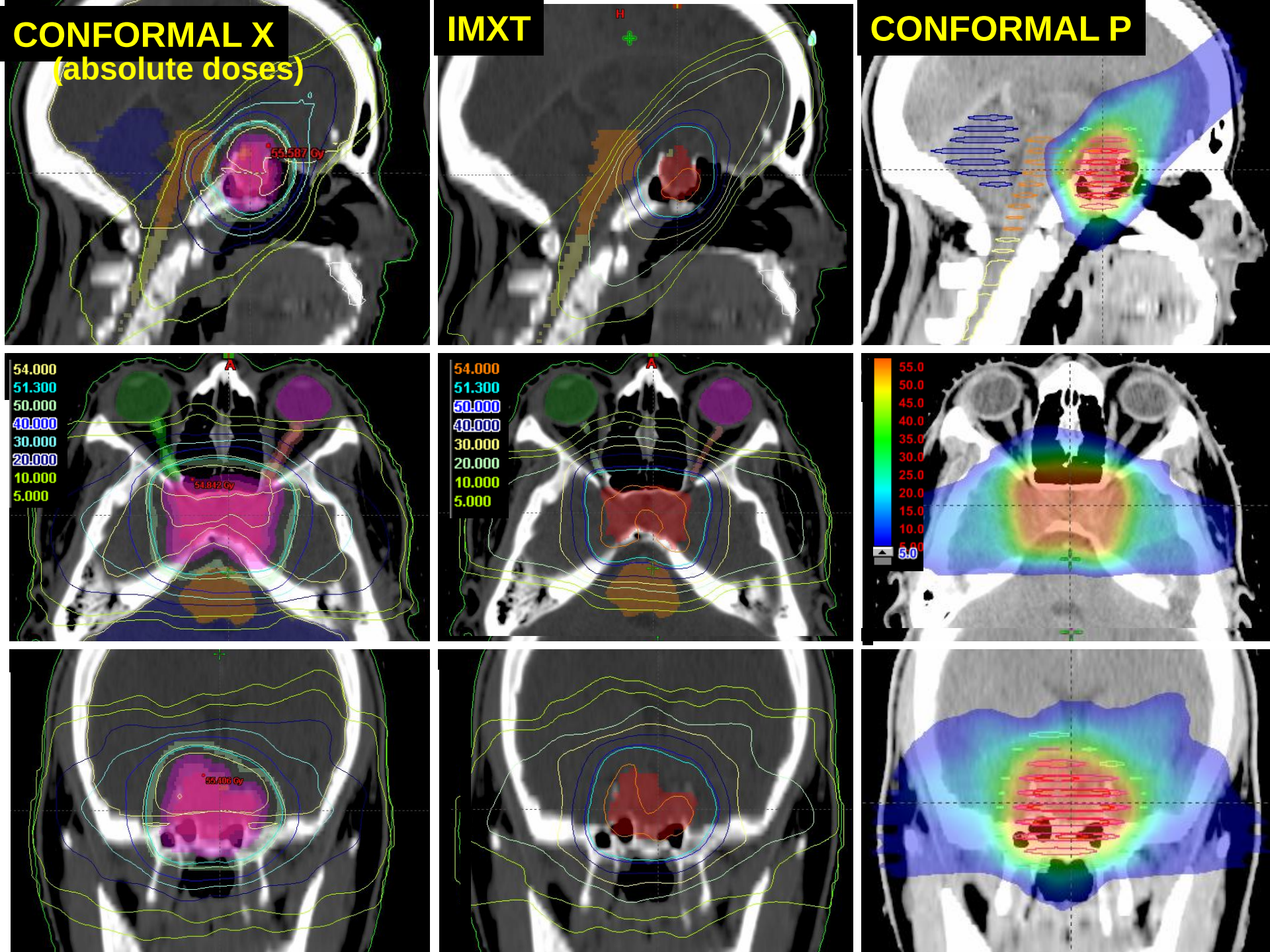

CONFORMAL X
(absolute doses)
IMXT
CONFORMAL P
55.587 Gy
54.000
51.300
50.000
40.000
30.000
20.000
10.000
5.000
54.842 Gy
54.000
51.300
50.000
40.000
30.000
20.000
10.000
5.000
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
55.406 Gy

General planning tricks and some useful rules

- Entrance dose (++) =>

- multiply the ports, combine with photons

- Patch fields risky (hot & cold spots) =>

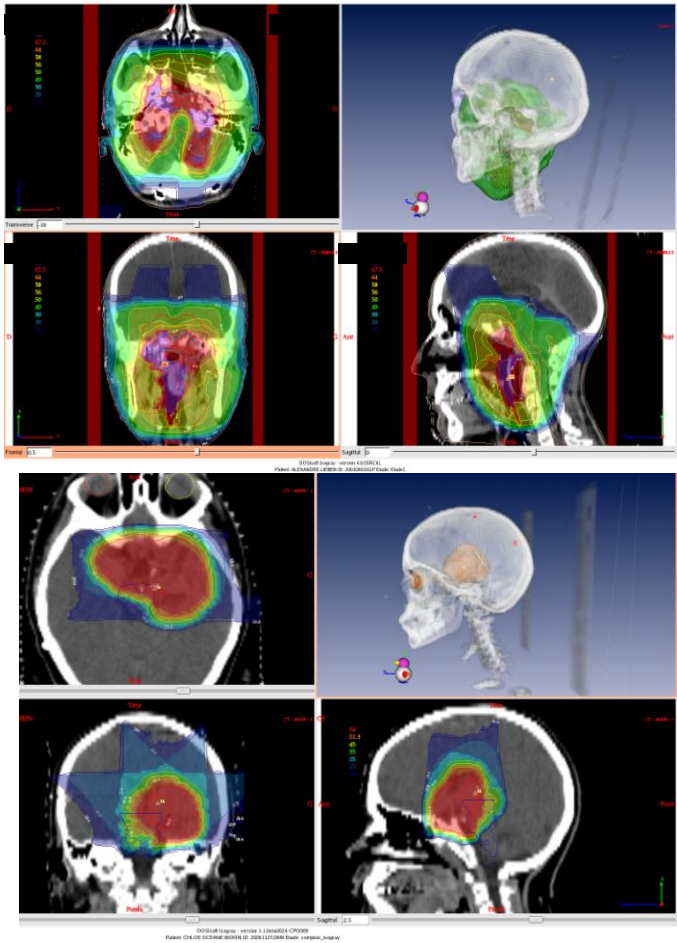
- limit the dose/patch (eg < 8 CGE)

- design several patch fields

- Uncertainties on distal edge position (mask, inhomogeneities) + RBE =>

don’t stop beams with high dose in front of OAR (if possible…)

- avoid « risky » ports (through nose, tongue, …)



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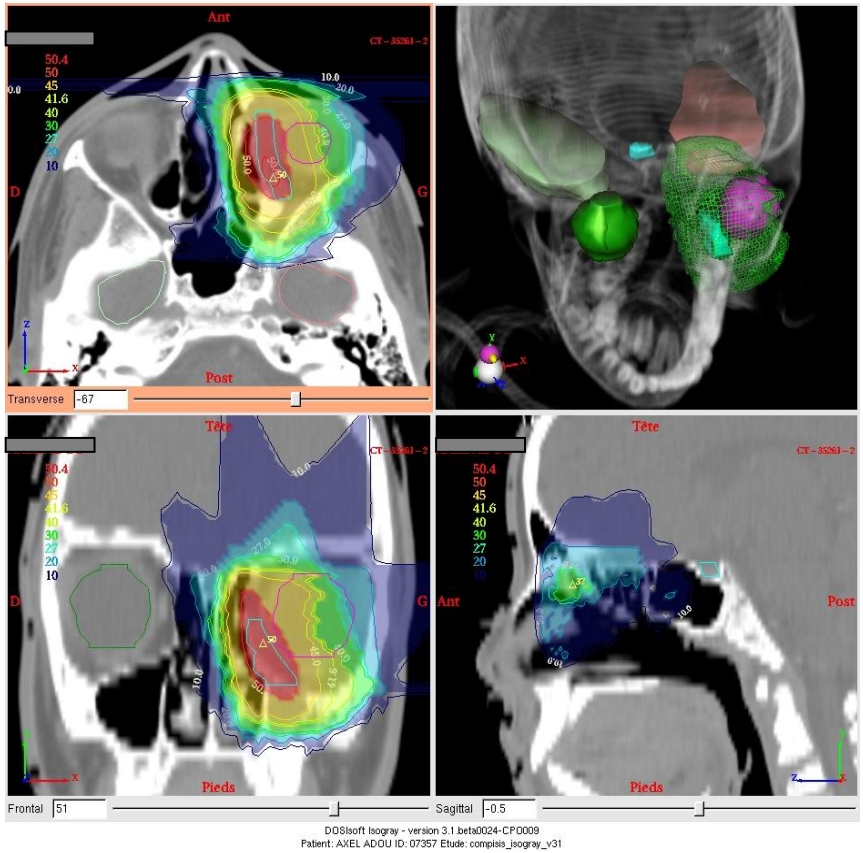
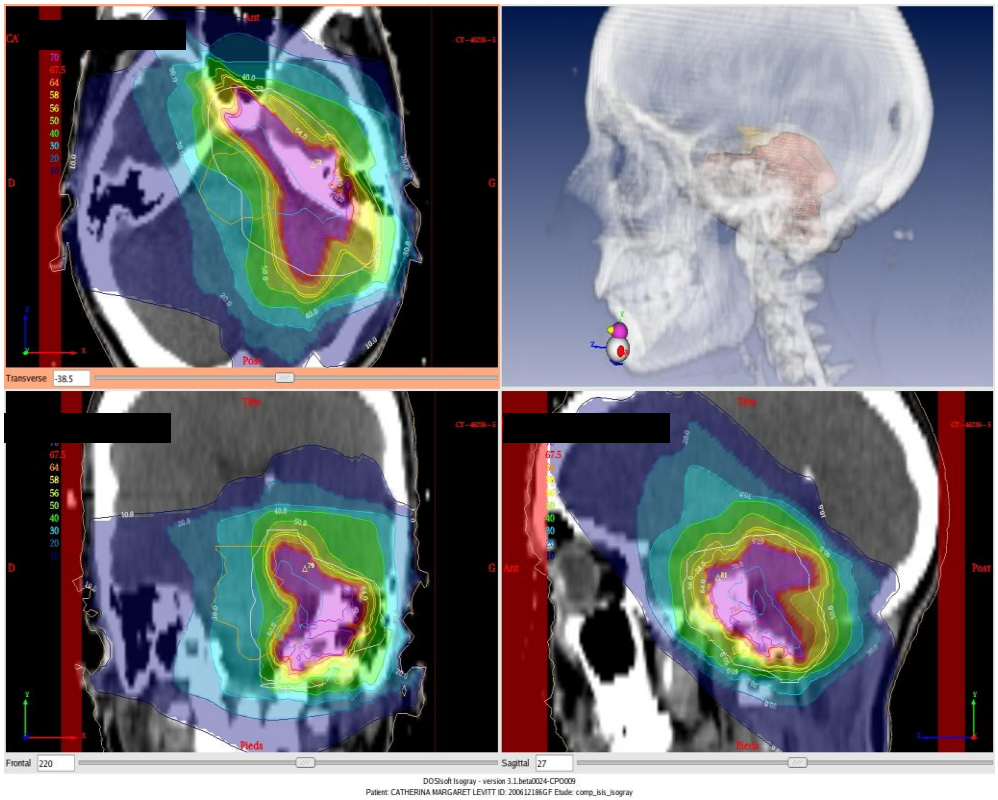
Practical examples (CPO)



Rhabdomyosarcoma



Chondrosarcoma (X + p)

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Combination protons – Tomotherapy
N. Fournier-Bidoz, C.Nauraye et al, PTCOG 2013

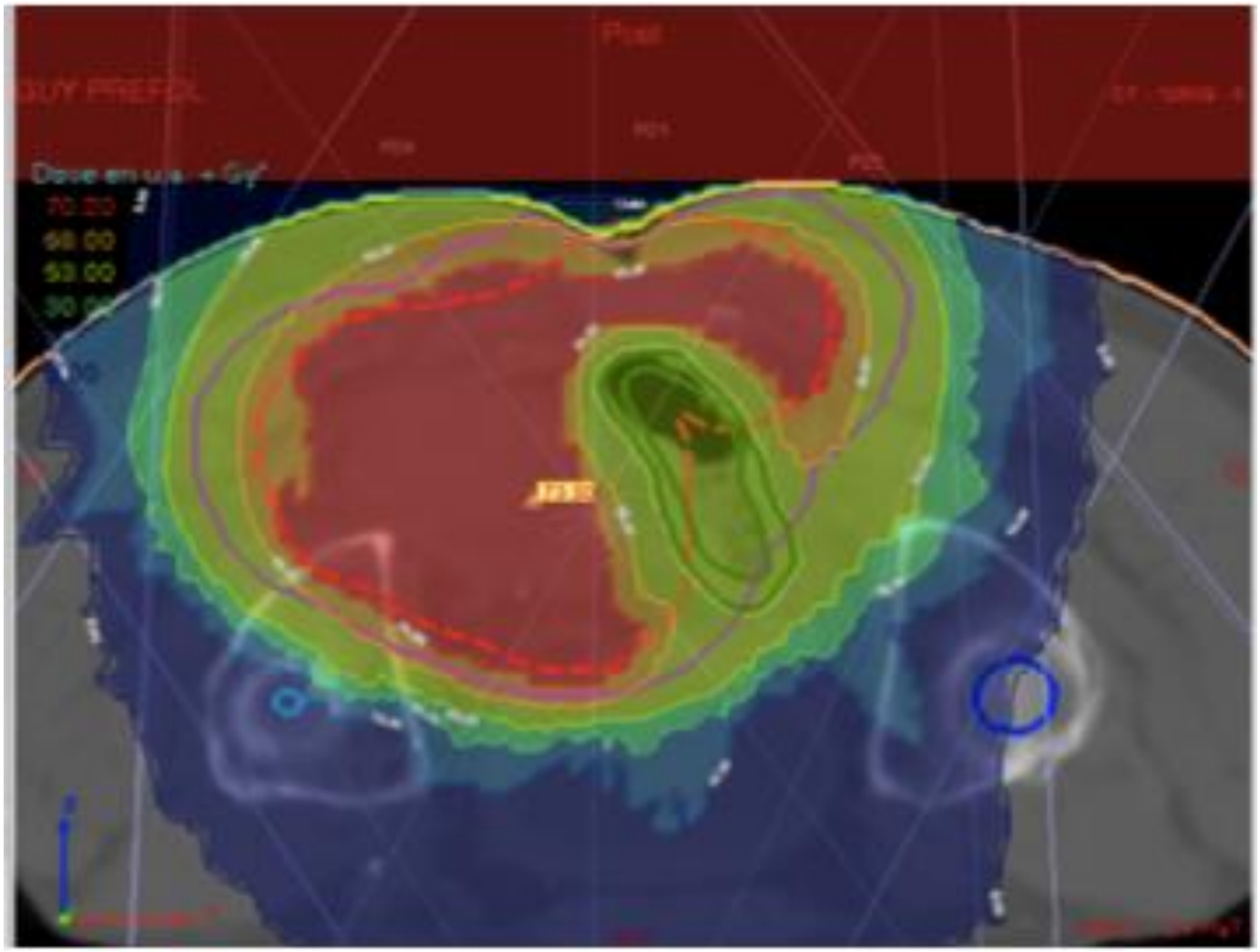

Fig.3: Dose distribution combining 55.8 GyE protons with 18 Gy tomotherapy (rectal wall in green, PTV_55.8Gy in purple, PTV_73.8Gy in dotted-red)

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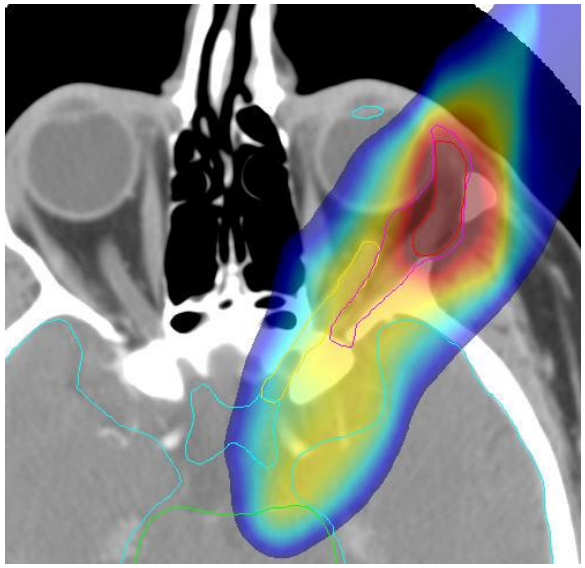
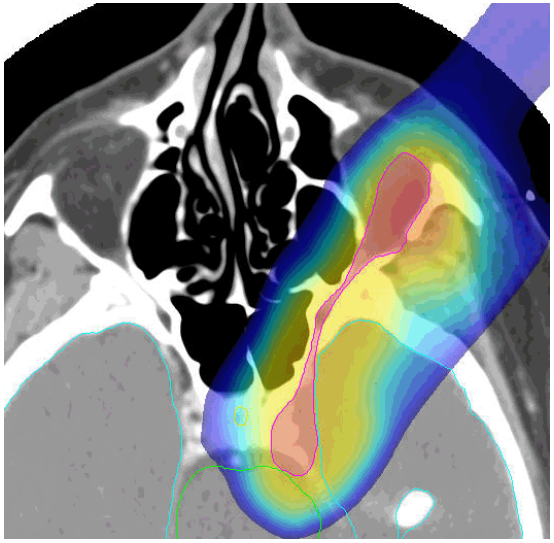
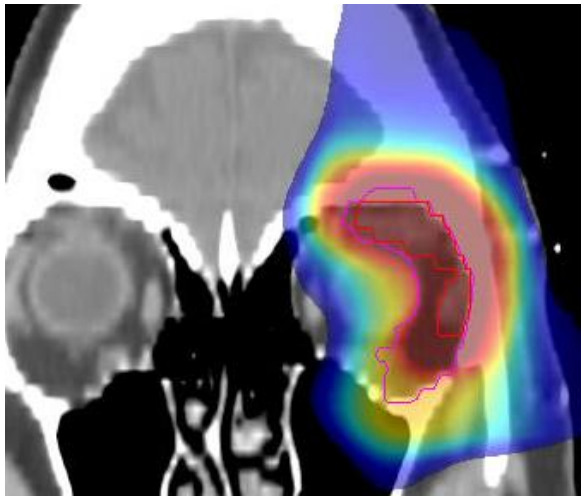
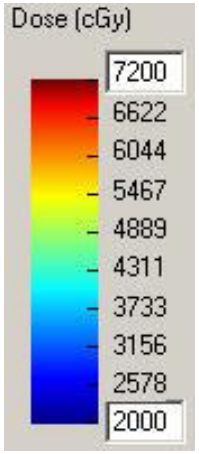
Practical example (MGH)









Judy Adams et al,
Skin sparing
Lacrimal gland

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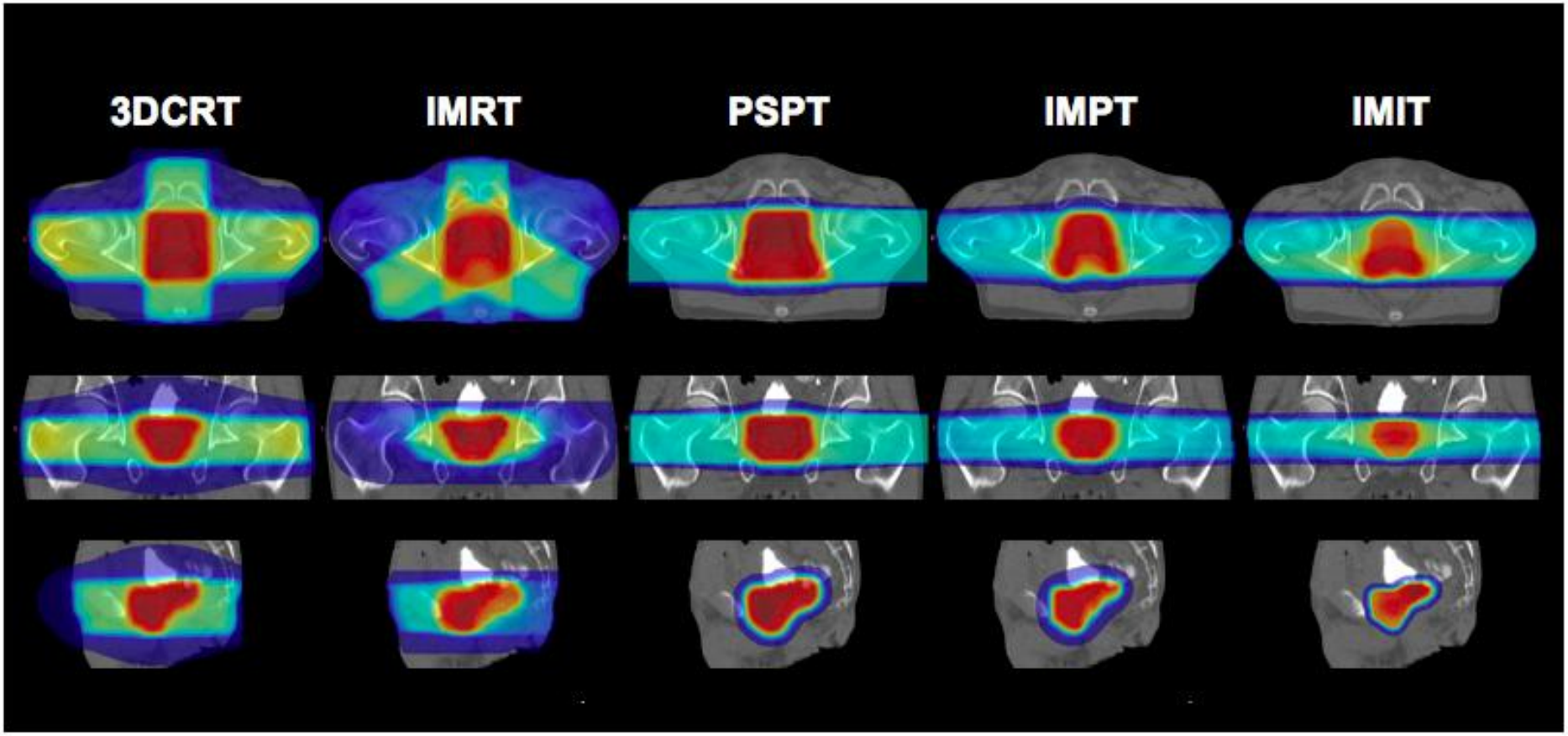
ROCOCO (Maastro & > 15 institutions involved)



Erik Roelofs et al, ROCOCO Trial, PTCOG 51, 2011

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Conclusions (I) : see in the clinical presentations for each location that

- Planning with (passive) protons is “easy“ as :
  - ***no dose behind the target***
  - easy to conform lateraly (as photons)
  - no max dose at entrance
  - homogeneous dose to target
  - simple, not optimized but rather robust

- But be aware of the limitations and take care with:
  - ***Uncertainties in range***
  - Deformation of shape if complex heterogeneities
  - High entrance dose mainly for superficial tumors
  - Care with small beams of complex shapes with small areas
  - Sensitivity to anatomical changes

  - Sensitivity to movements → for passive beams,
    and even more for dynamic beams (see later)

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Conclusions (II)

- Importance of TPS validation, QA and users‘ experience
  - for each plan,
  - for the Treatment Planning System,
  - for the full process

- Synergy & shared experience with photons, electrons, (IMXT, …)

- Need to be able to provide safe treatments to a large population (social, ethics and business) :
  - optimization of the throughput & combined treatments

- Comparative results in general are :
  - Passive protons >> conventional photons
  - Passive protons ~ > IMXT
  - Intensity Mod PT > IMXT

- Need Gantries to plan all incidences as with photons

- Evolution to MonteCarlo, biological modelling … and IMPT

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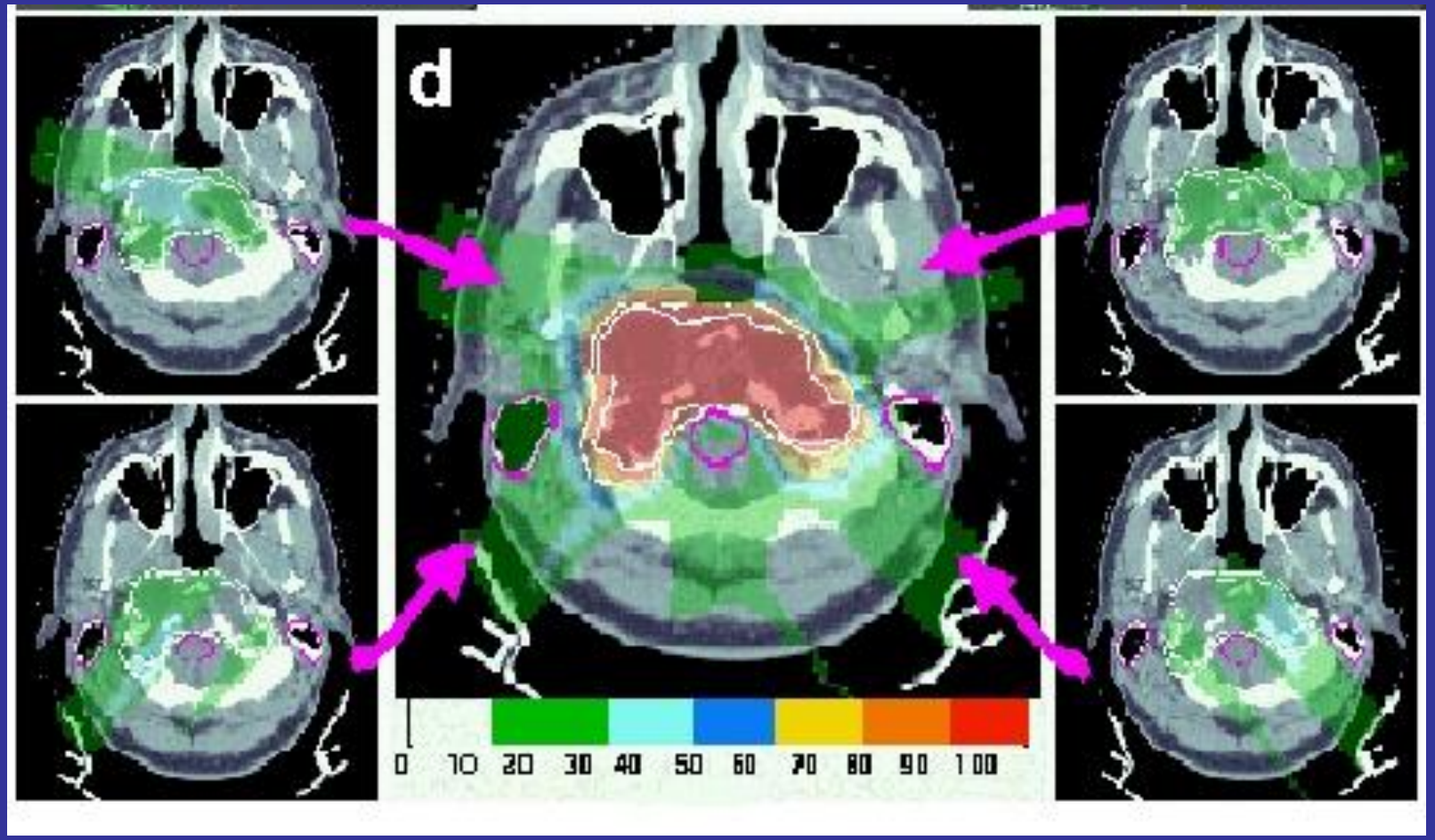
Intensity Modulated IMPT-IMZT



Trofimov, Kooy, Bortfeld, Lomax, …

Next talk T. Lomax

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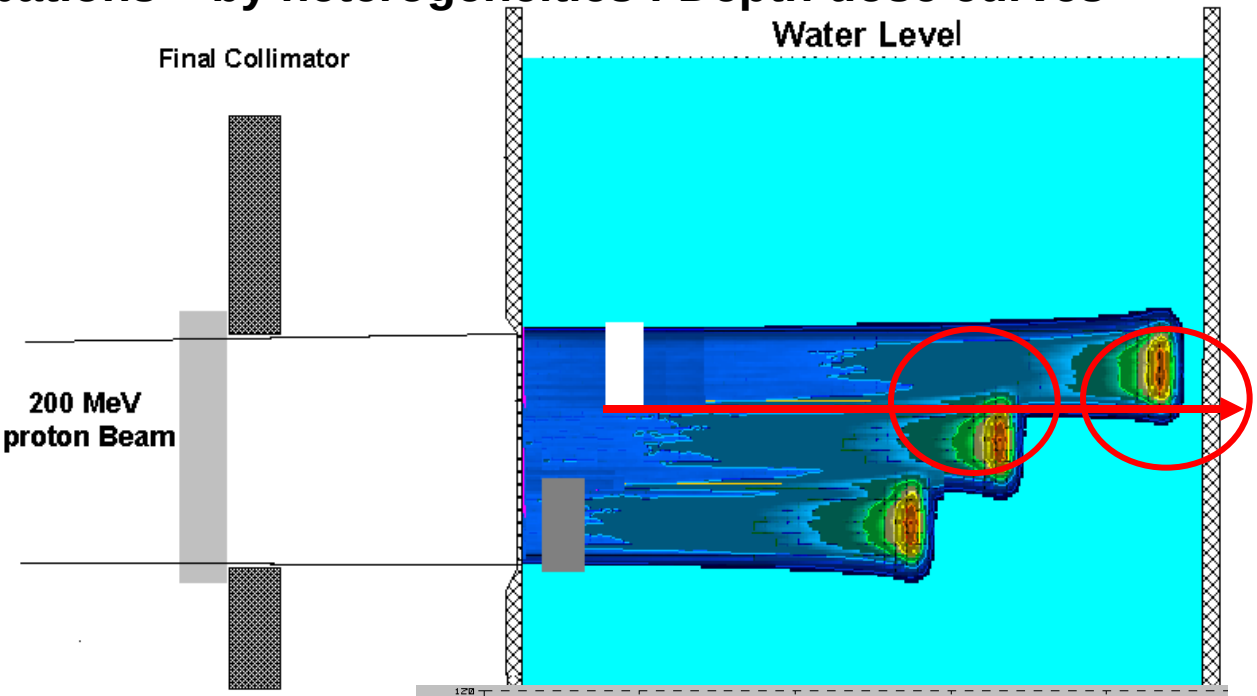
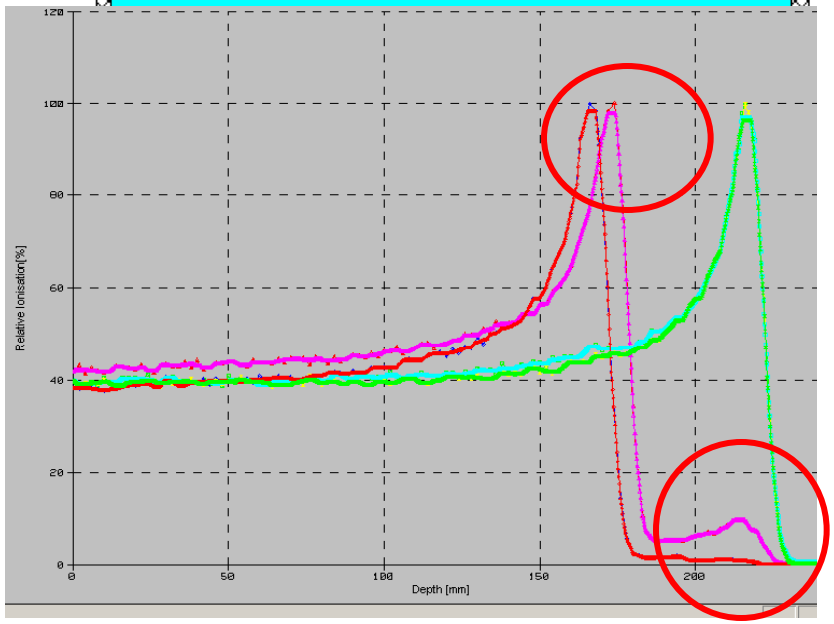
1) TPS validation & QA :

« Perturbations » by heterogeneities : Depth dose curves





A.Mazal, Wanjie, China

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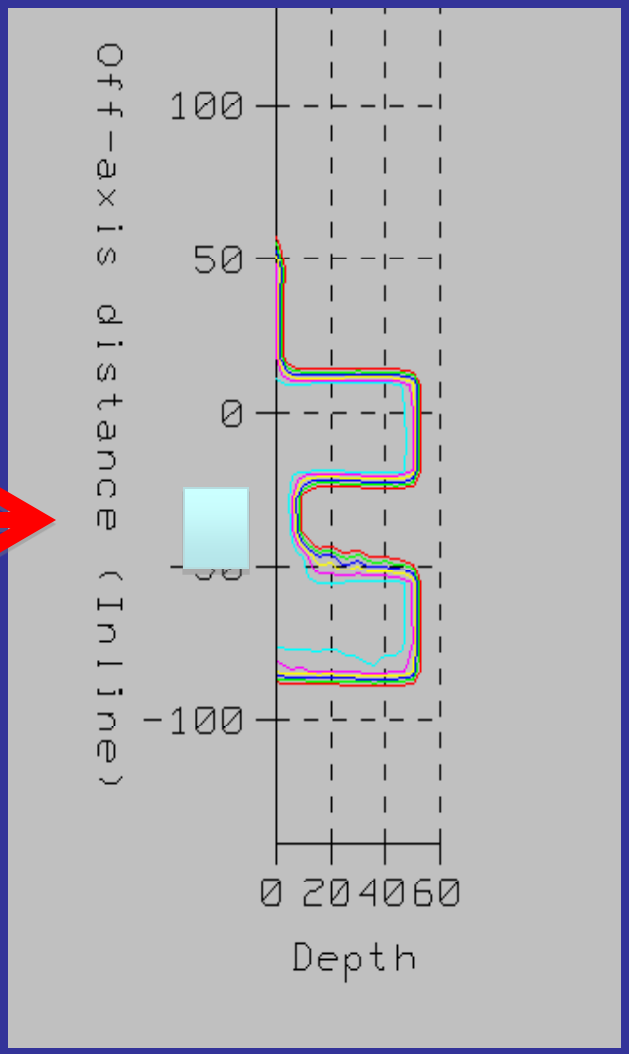
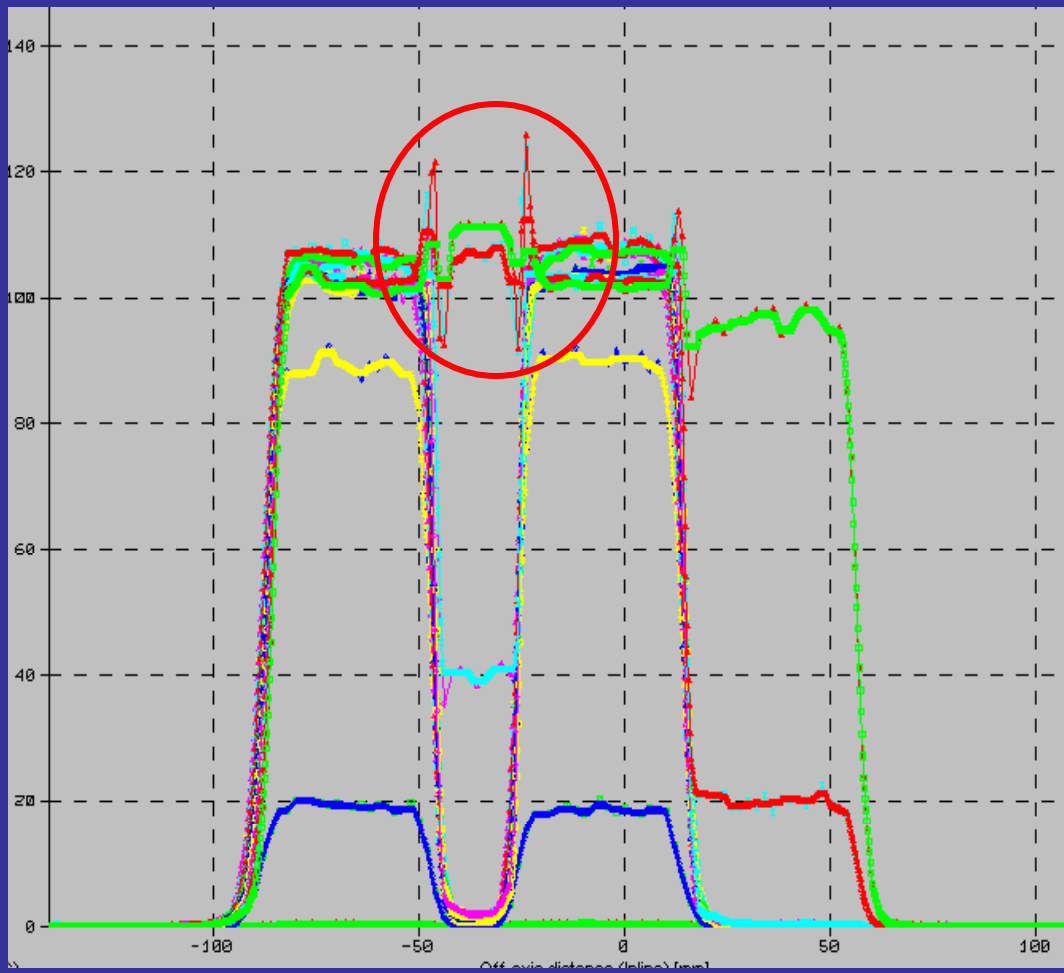
1) TPS validation & QA :

Profiles in depth, modulated beam, low energy
Measurements in Wanjie, China





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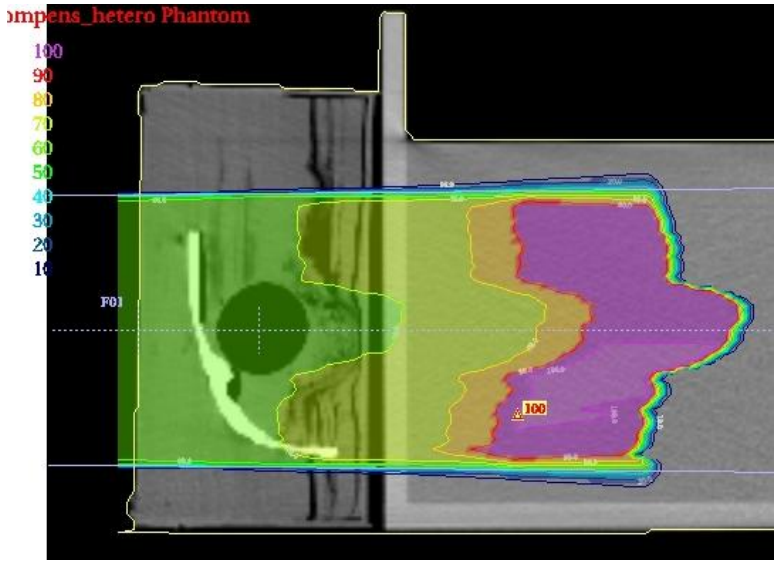
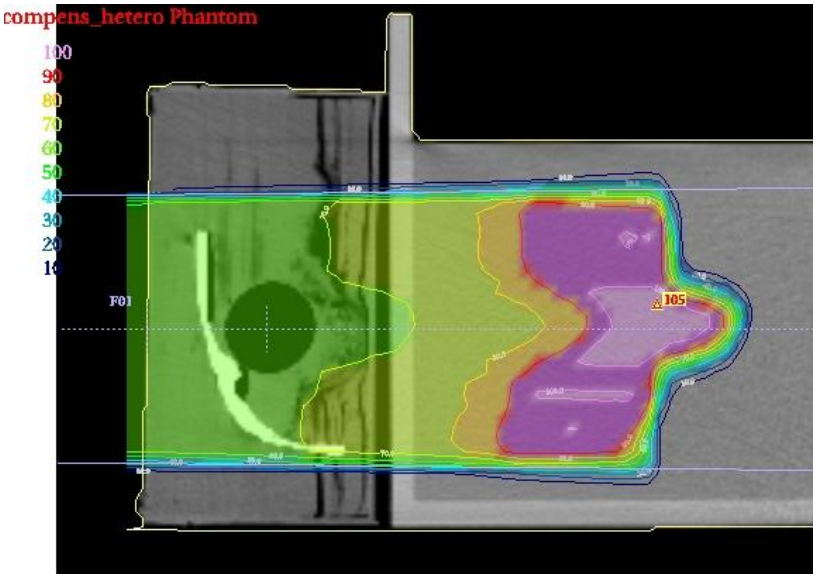
1) TPS validation & QA :



Ray tracing



Pencil beam

- antropomorphic phantom (skull + fat + air)
- shoot through beam
- Absolute comparison : isodoses in water fantom + TPS isodoses
- → gamma function (eg 2%, 2mm, or 3%,3 mm…)

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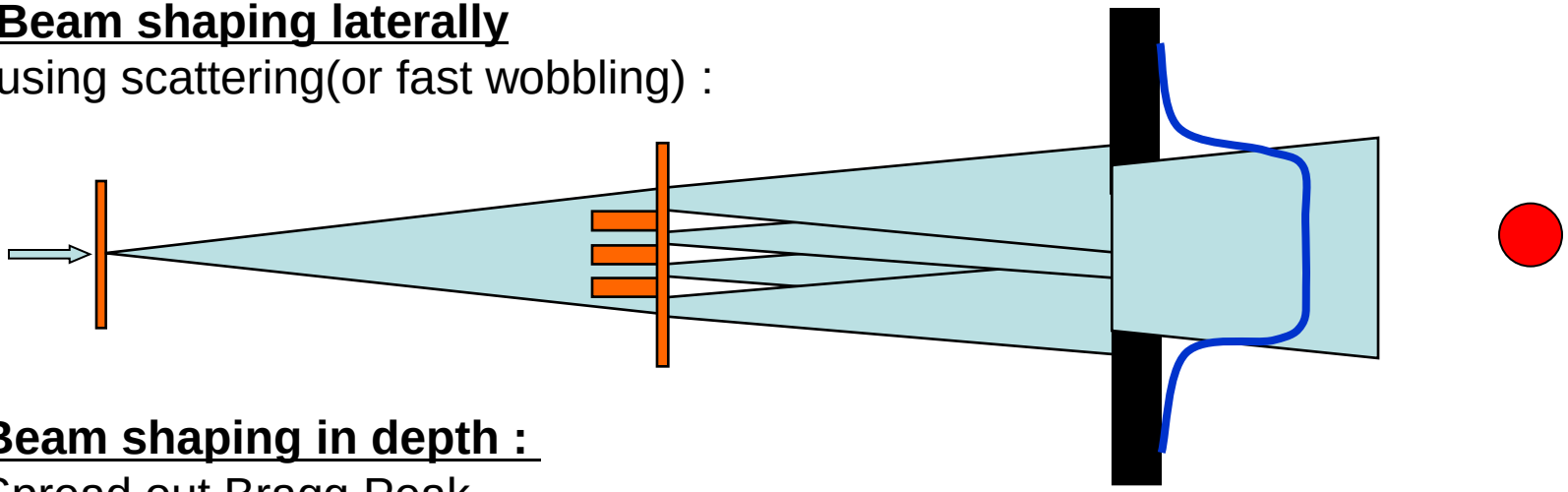
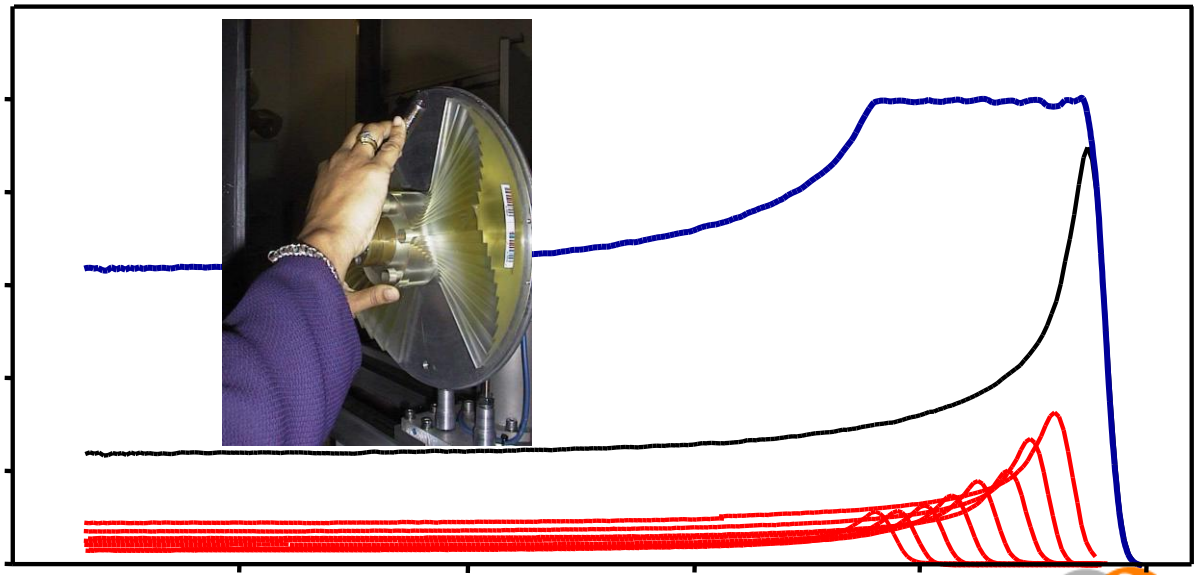
(R.Ferrand, L.DeMarzi et al)

2) 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 »)

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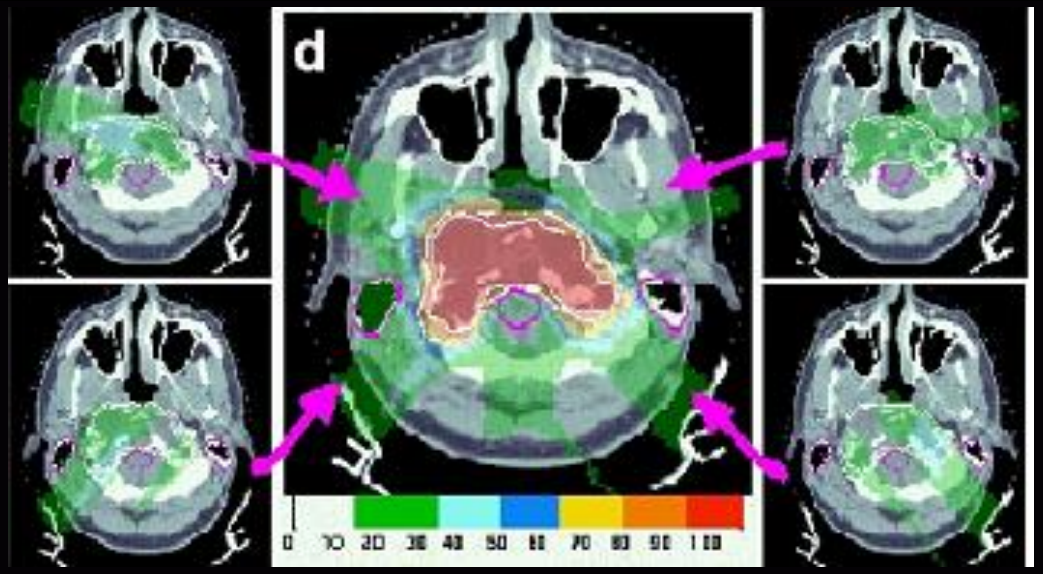
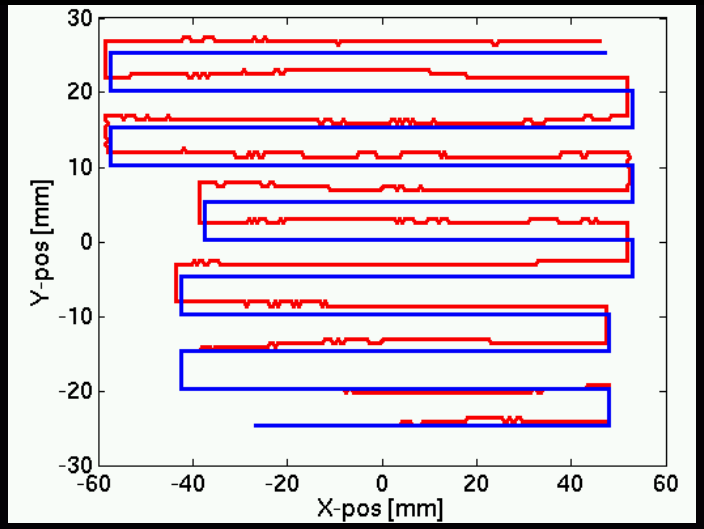
Towards dynamic delivery systems while being able to treat moving organs: « interplay » & « repainting » concepts

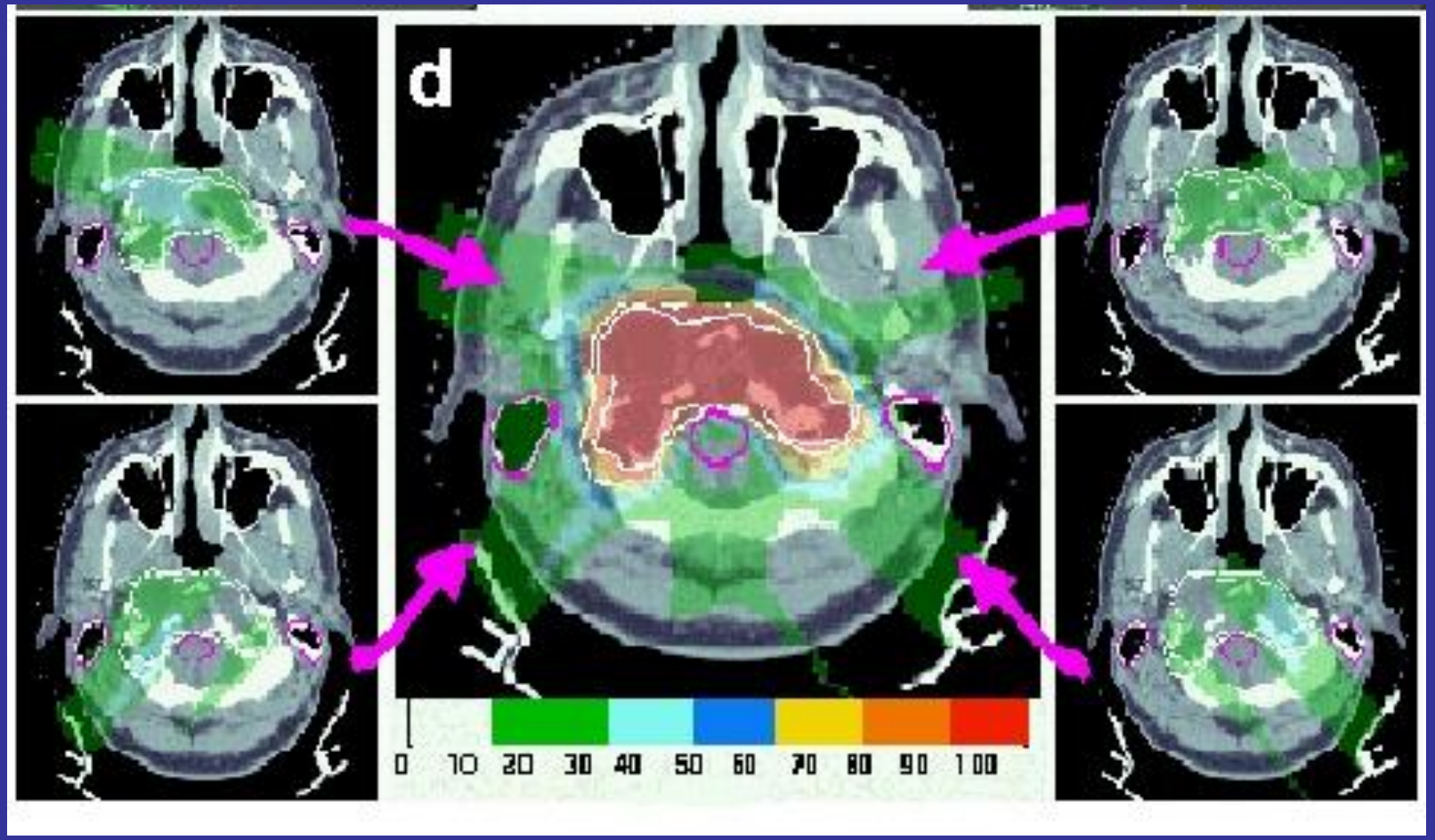




Rietzel,, Bortfeld, Lomax,Trofimov,…

Mitigation techniques :
- Breath holding
- Compression
- Beam Gating
- Beam Tracking
- Repainting
- …

Intensity Modulated IMPT-IMZT



Trofimov, Kooy, Bortfeld, Lomax, …

Next talk T. Lomax

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