The (R)evolution in Radiotherapy

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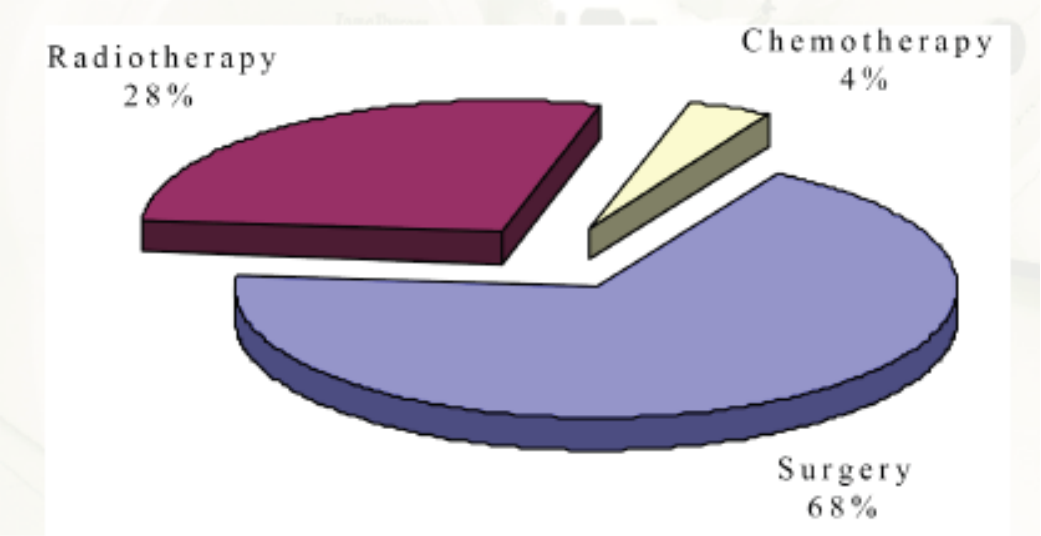
Why Radiotherapy ?

- Cancer is a disease with many facets
- It requires:
  - Individualized treatment strategies
  - Synergy between surgery, radiotherapy and chemotherapy
  - Multi-targeted treatments, ability to adapt, per-treatment monitoring
- For radiotherapy this translates to:
  - Dose sculpting (and dose-painting-by-numbers)
  - Image-guided radiotherapy
  - Developments in radiobiology, functional imaging and adaptive radiotherapy (ART)

Why Radiotherapy?

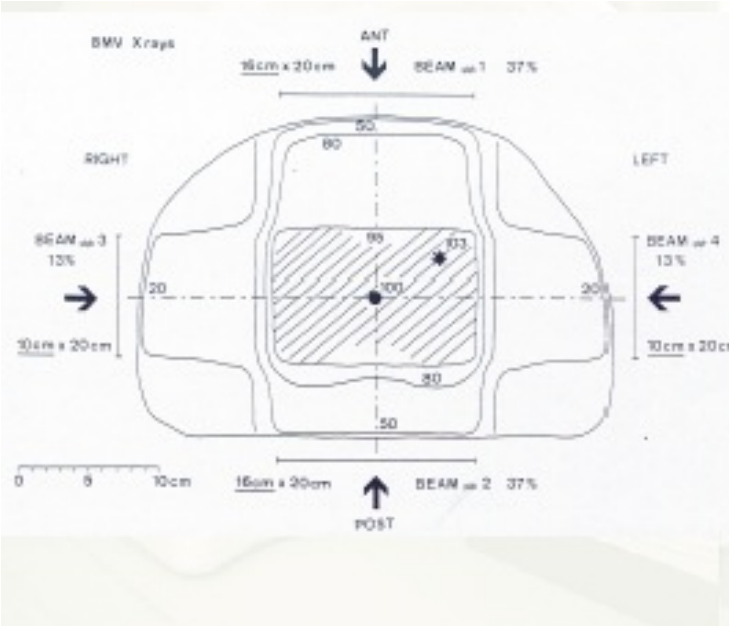
Radiotherapy is the most cost-effective treatment for cancer

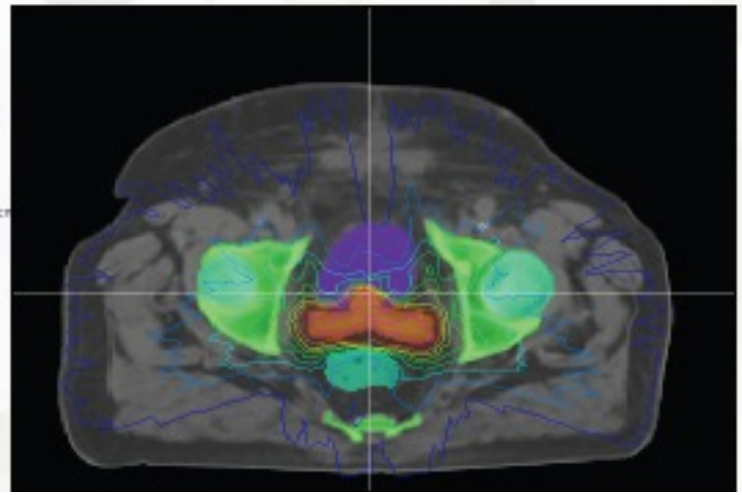


The Cancer Council of Australia

The aim of Radiotherapy

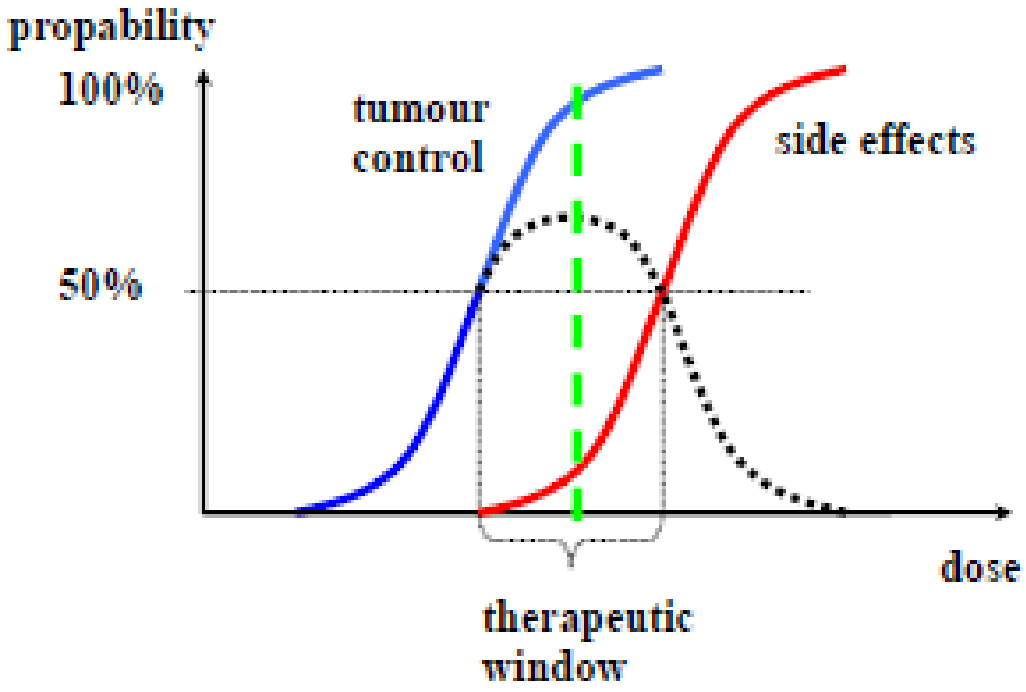
Maximizing outcome – Minimizing complications





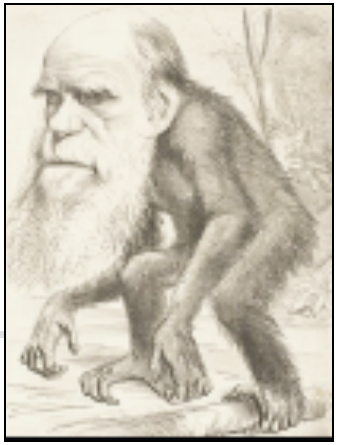
It comes down to "DOSE SCULPTING"

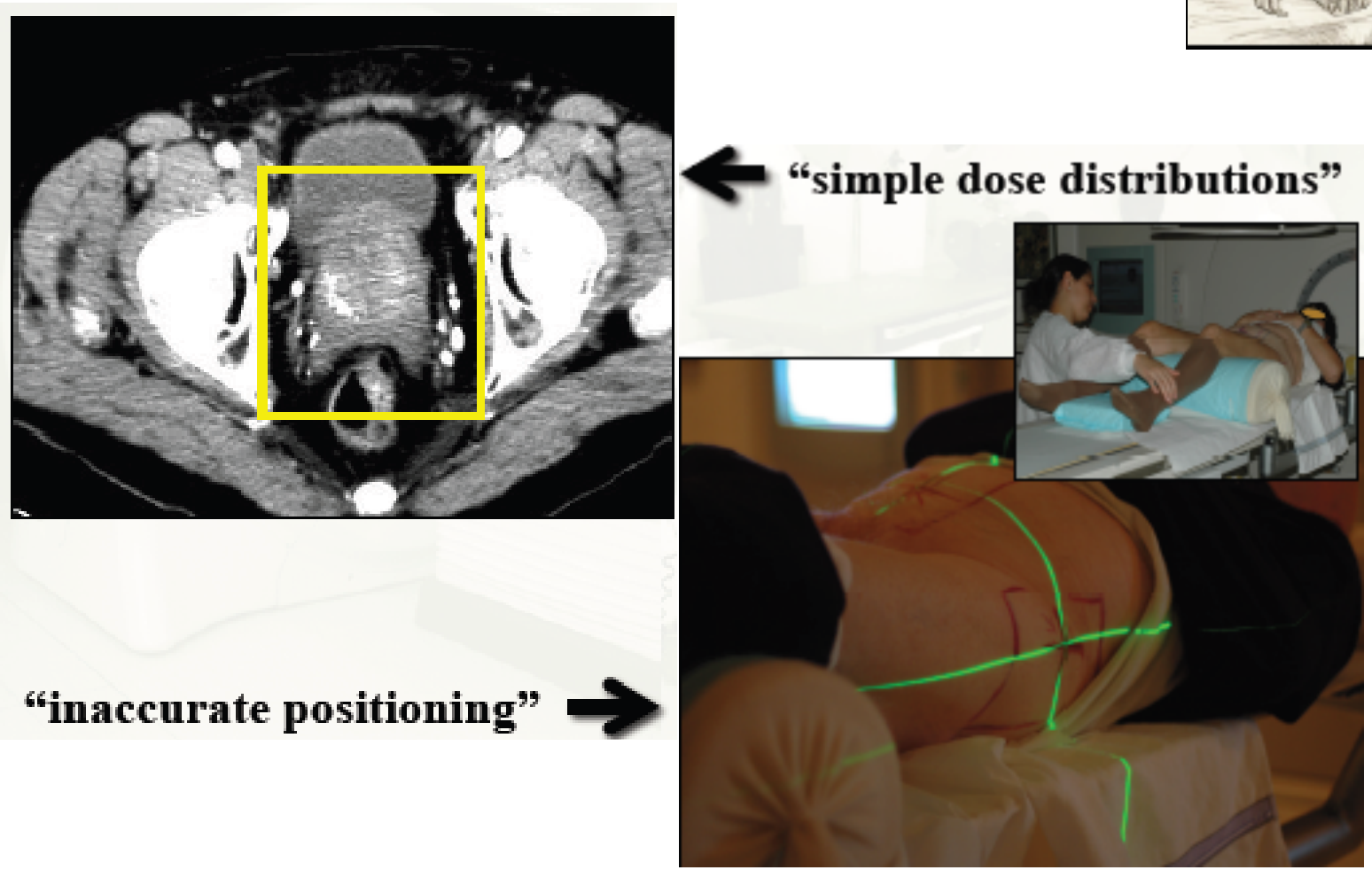
Therapeutic opportunity of Radiotherapy



➔ **Enlargement of the therapeutic window**

The evolution in a nutshell





Conformal radiotherapy (3D - CRT)

- **3D-CRT:** to conform with a high precision the spatial distribution of the prescribed dose to the 3 D target volume,
  - excluding critical structures as far as possible
- **Volume effect:** small volumes of critical structures can tolerate high(er) doses
- Reduced doses to normal tissue allow dose escalation

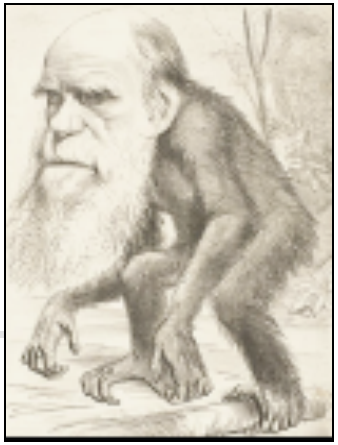
➔ **Possibility to improve local control and outcome**

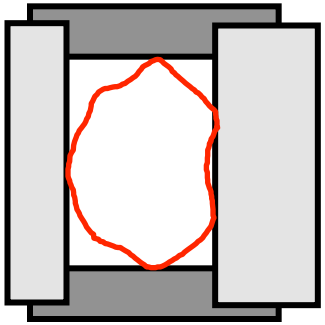
Conformal radiotherapy (3D - CRT)

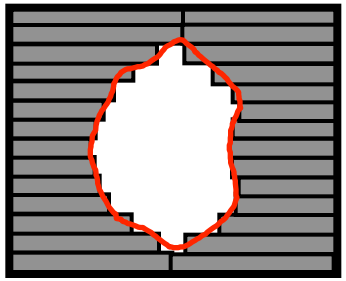
- NOT a new concept
- ONLY **technological improvements** allowed its technical realization
  - better localization modalities (CT / MR / PET imaging)
  - fast computers for full 3 D treatment planning / allowing direct use of other imaging modalities (matching) / more accurate dose calculation
  - new hardware for treatment delivery (customized blocking, MLCs, compensator, ...)

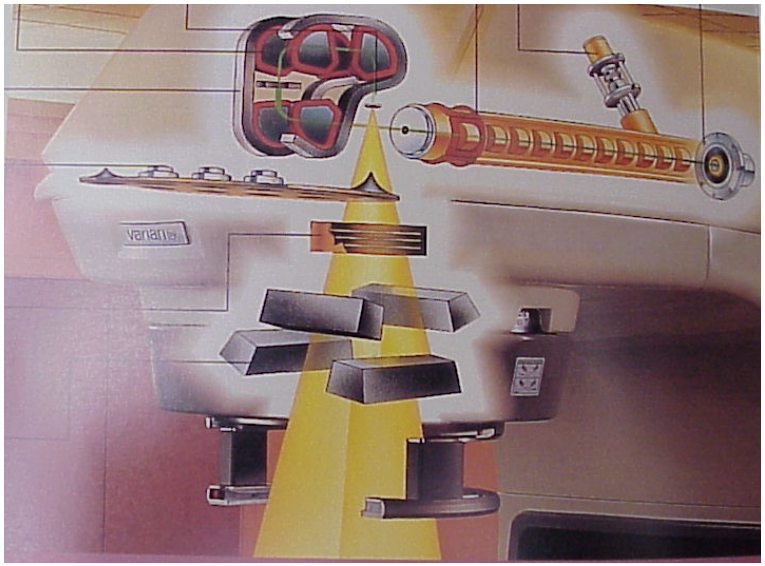
➡ **IN PARALLEL - investigation of new radiation qualities (n, p, ...)**

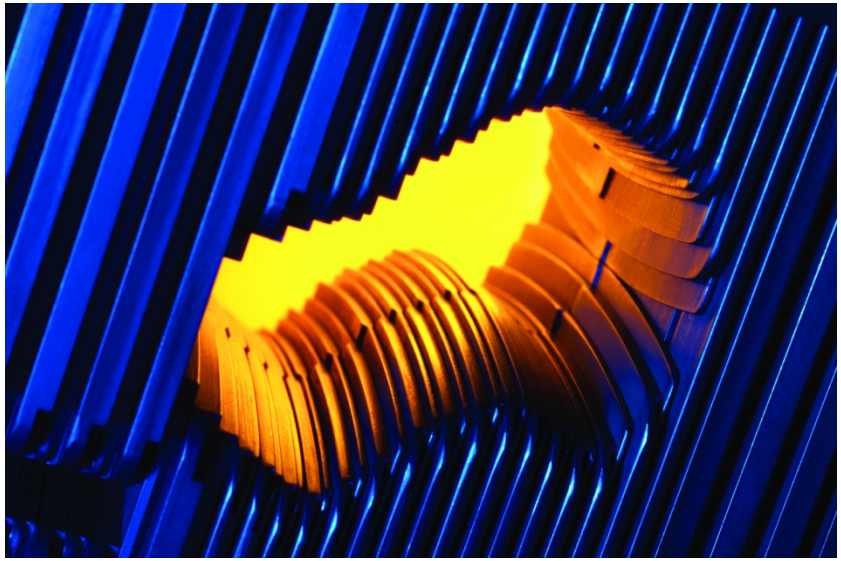
Multi-Leaf Collimator (MLC)







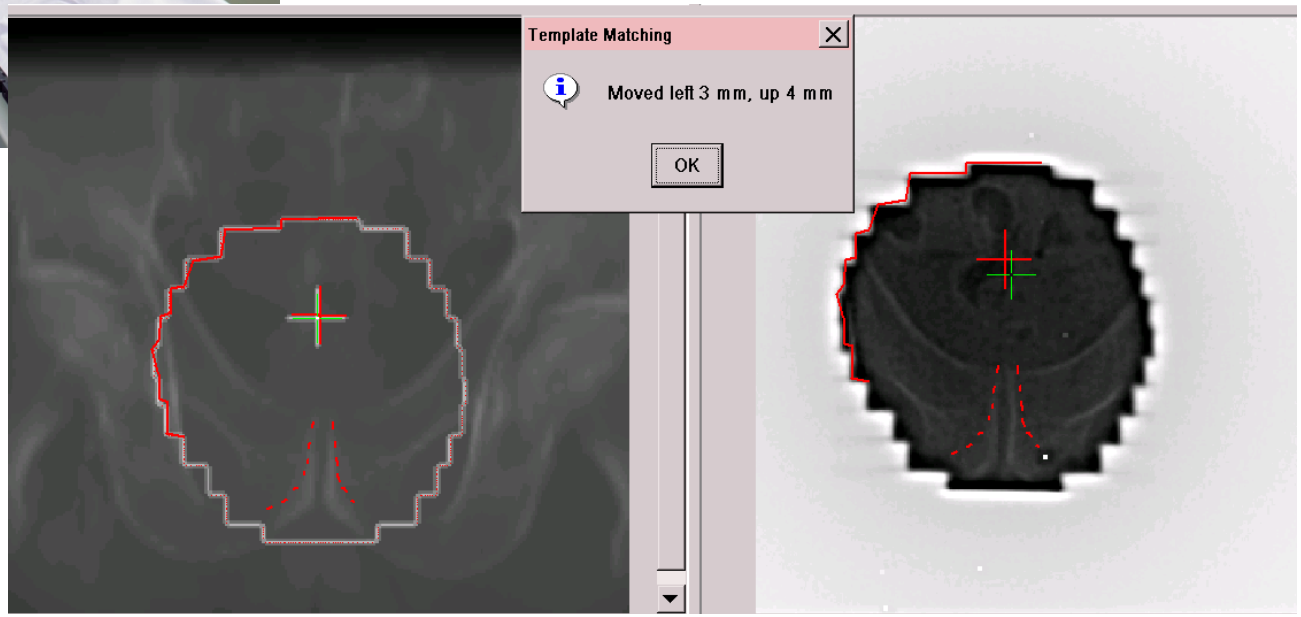




Electronic Portal Imaging (EPID)

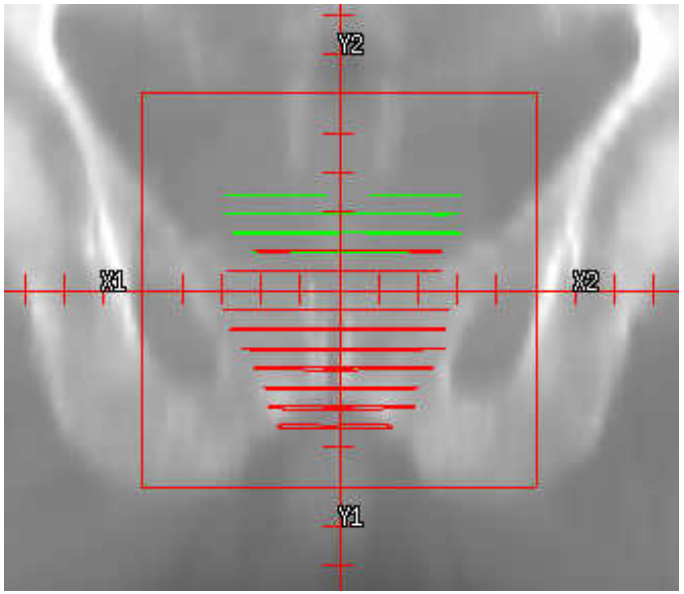
APPLICATION

- verification of patient position (geometrical uncertainties)
- dosimetry purposes (beam characteristics, transit dosimetry**)**

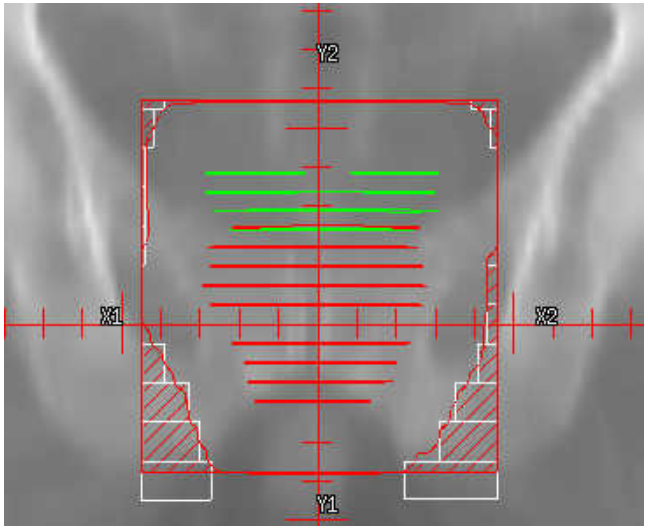


Conventional RT ⇔ Conformal RT

Prostate case



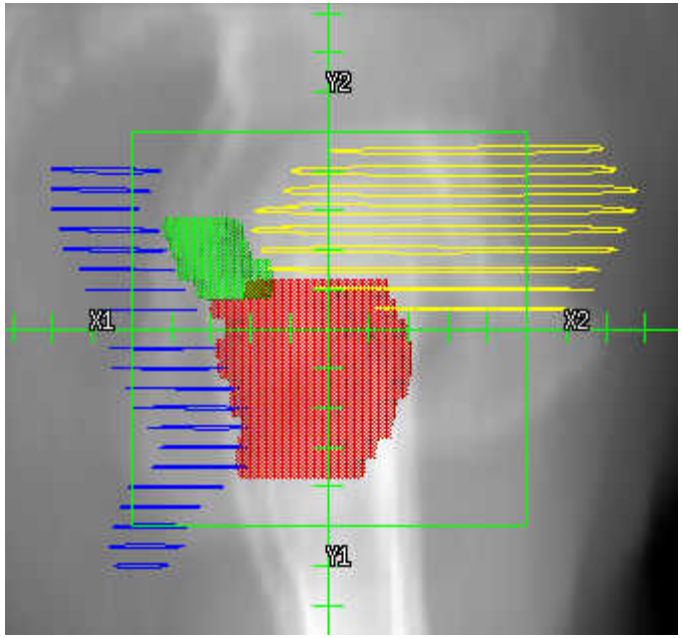
Bony anatomy based



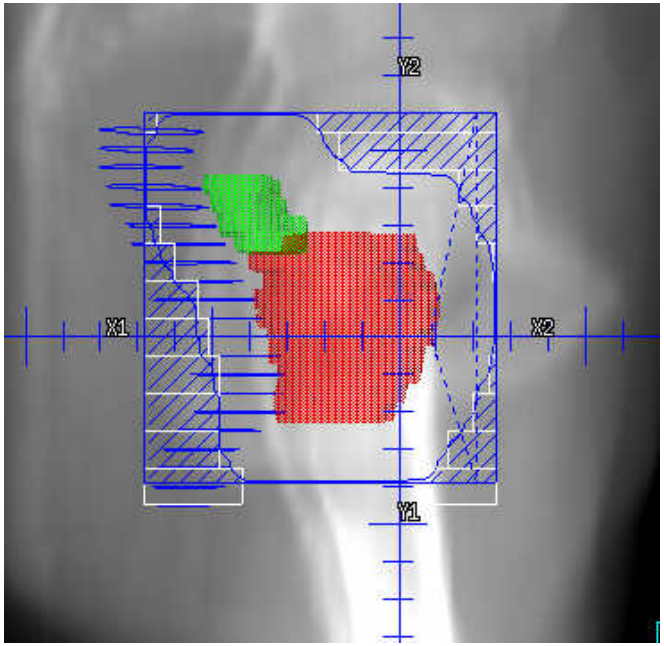
CT data based

Conventional RT ⇔ Conformal RT

Bony anatomy based



CT data based

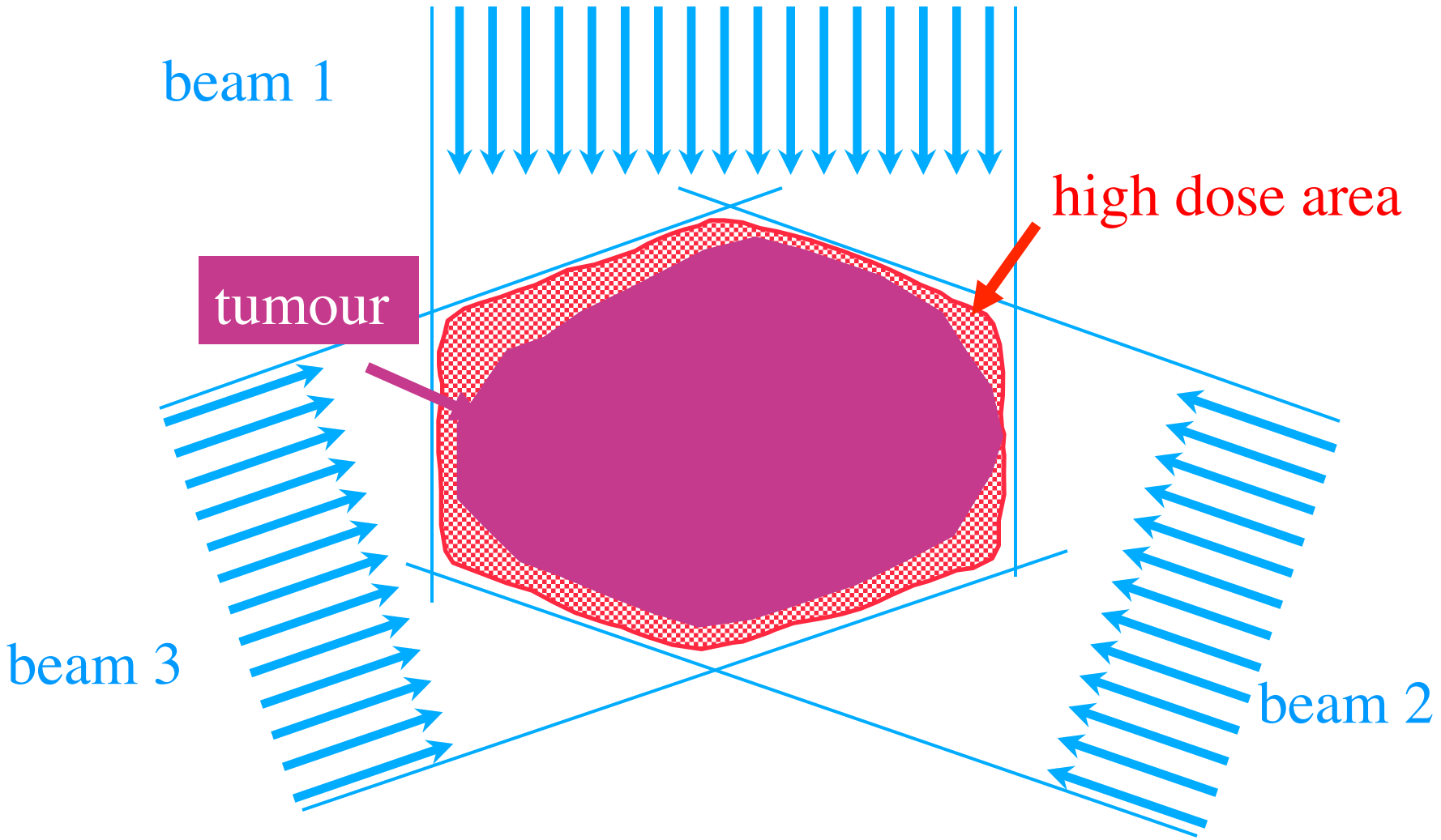


Irradiated Volume

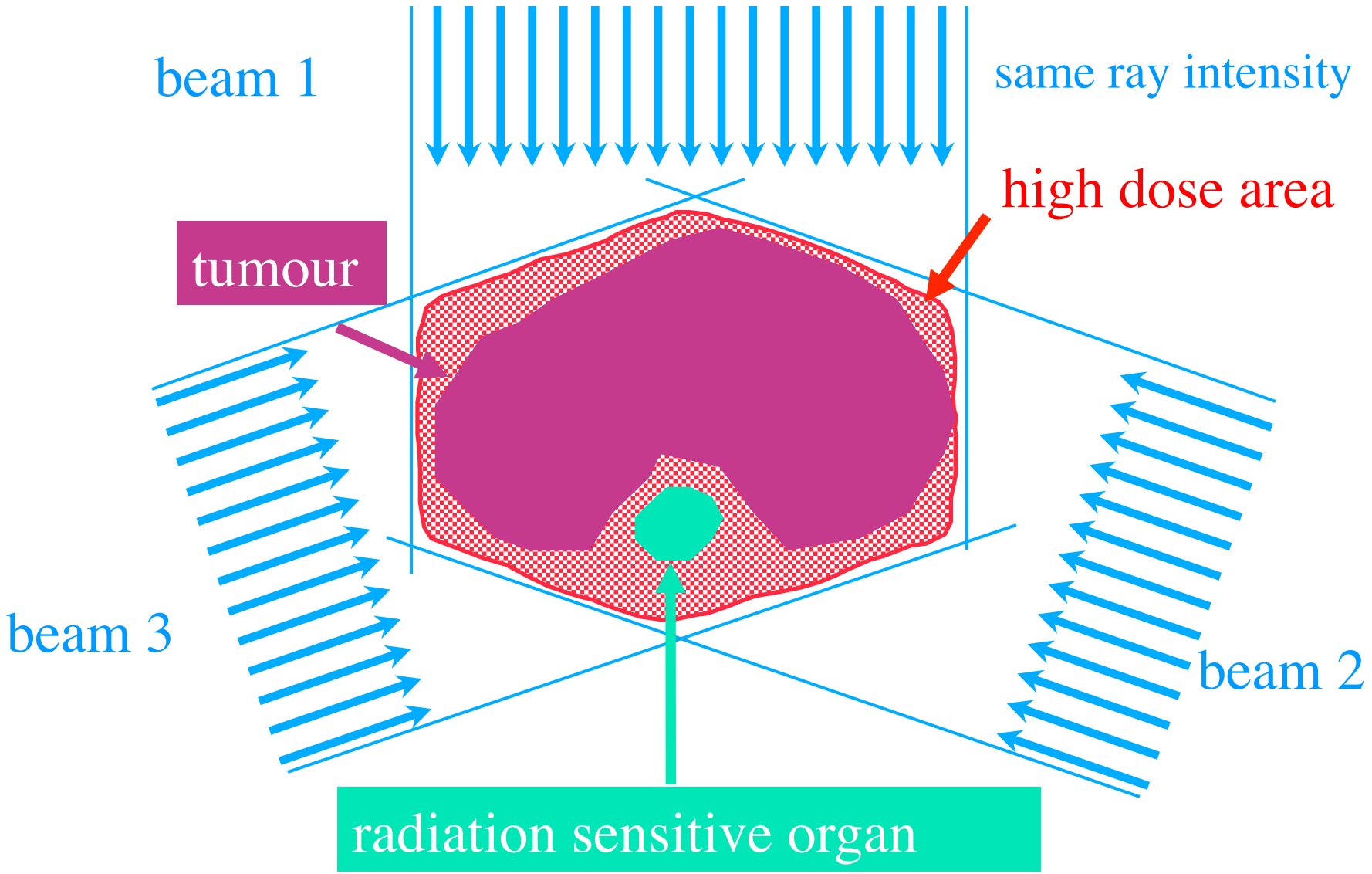
700 cm³

430 cm³

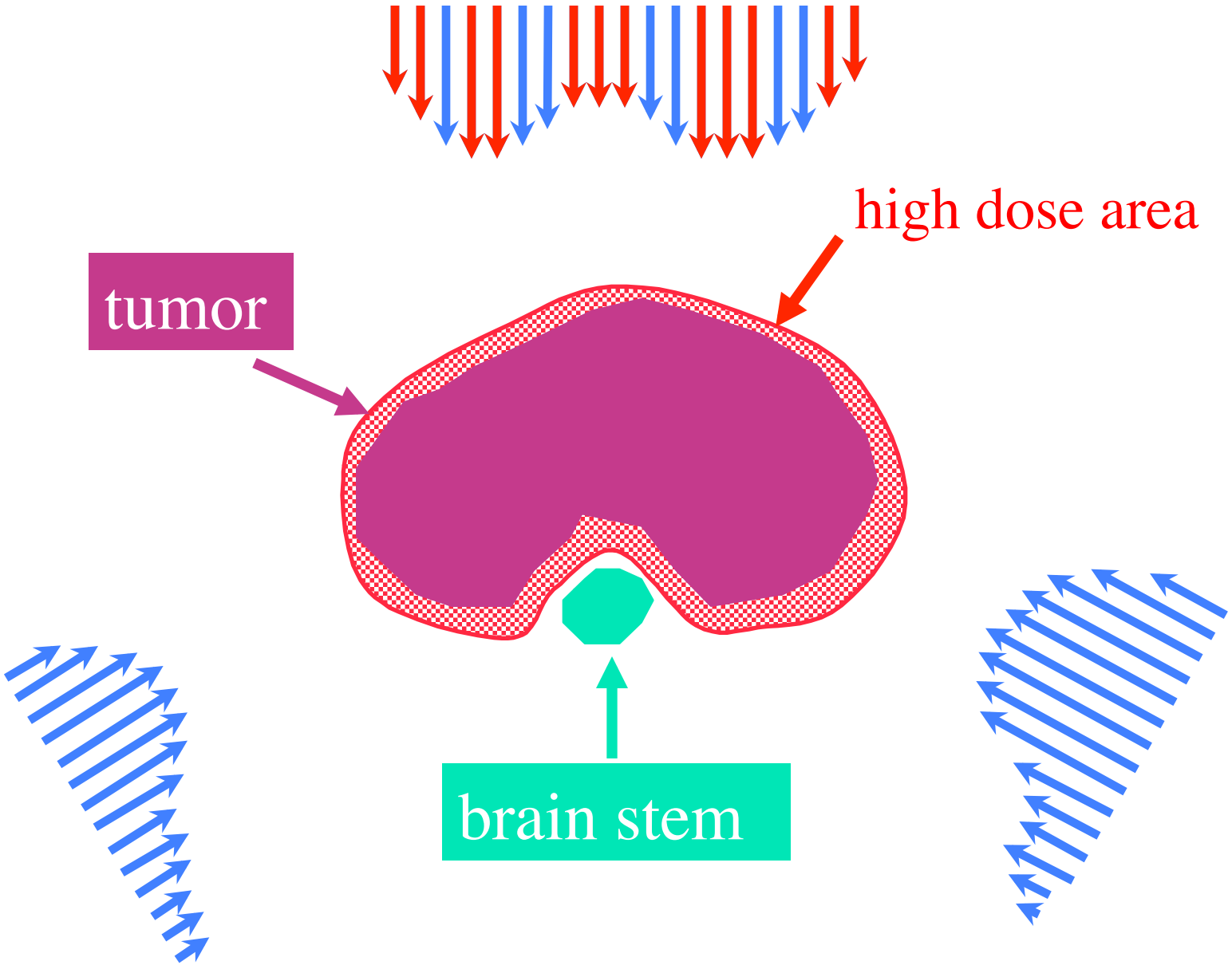
Conformal Radiotherapy



Conformal Radiotherapy

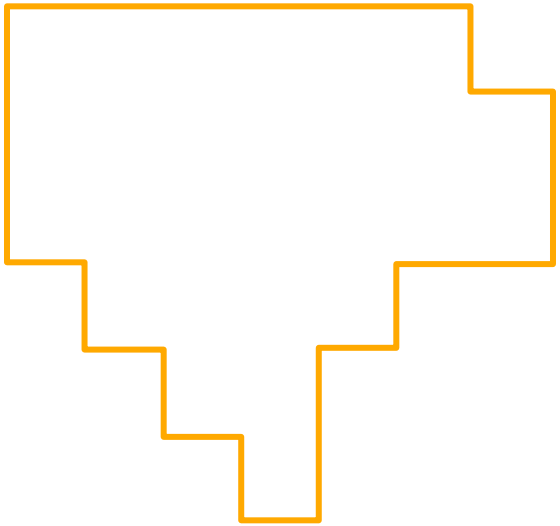


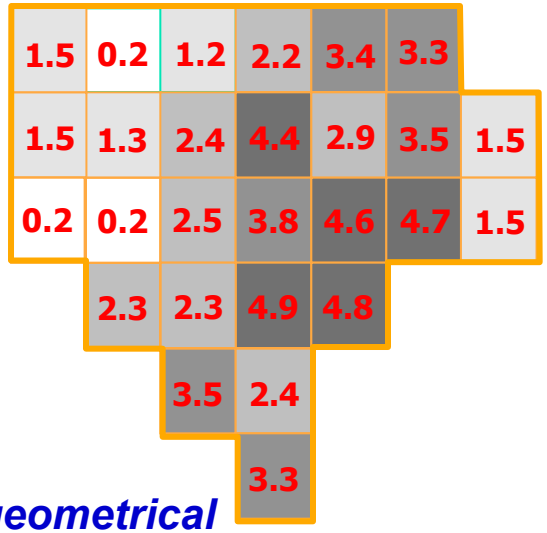
Intensity Modulated Radiotherapy



INTENSITY MODULATION

- Special form of conformal therapy
  - geometric field shaping + intensity variation
  - helps to overcome some limitations of 3D-CRT
- Intensity of the primary photon fluence varies across the target volume
- Each beam may treat only portions of the target

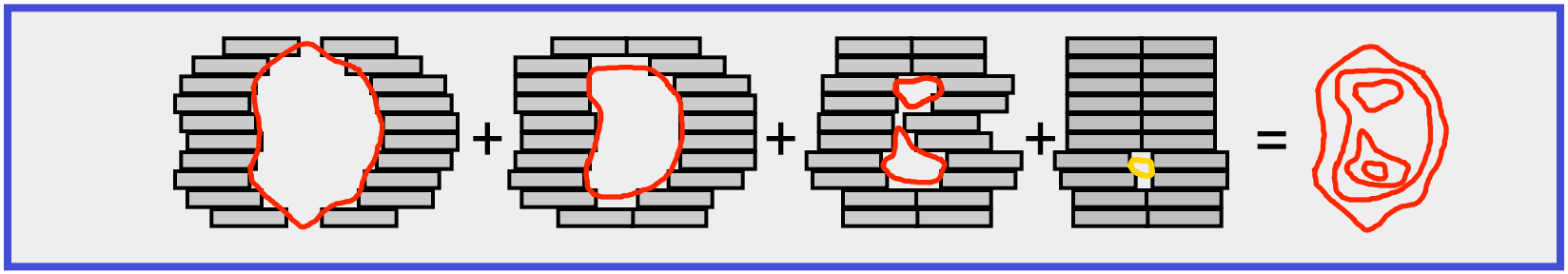




IM and geometrical field shaping

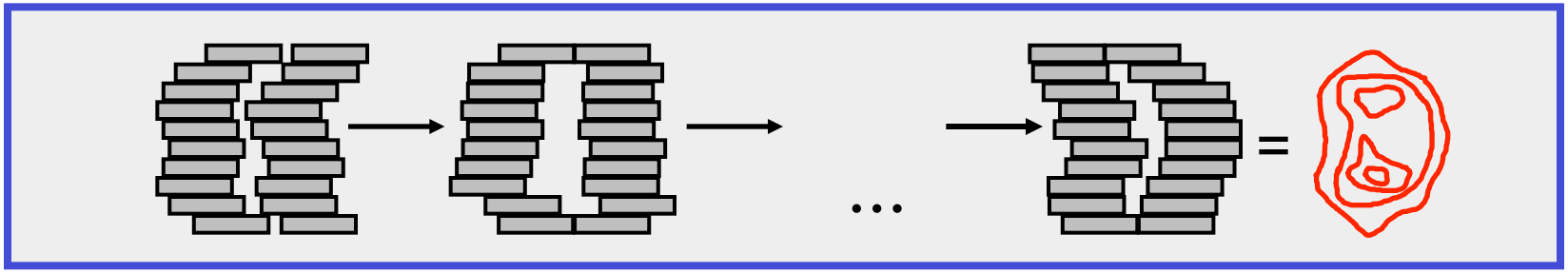
‘MLC’ - IMRT DELIVERY TECHNIQUES

‘STEP AND SHOOT’ - technique



Intensity Modulation by superposition of MLC beam segments

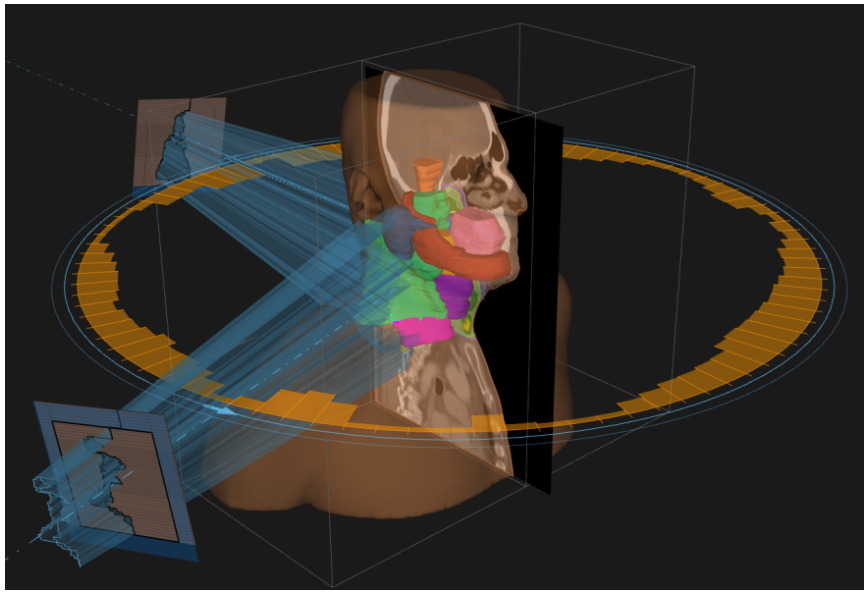
DYNAMIC technique



Intensity Modulation by scanning the beam with an MLC

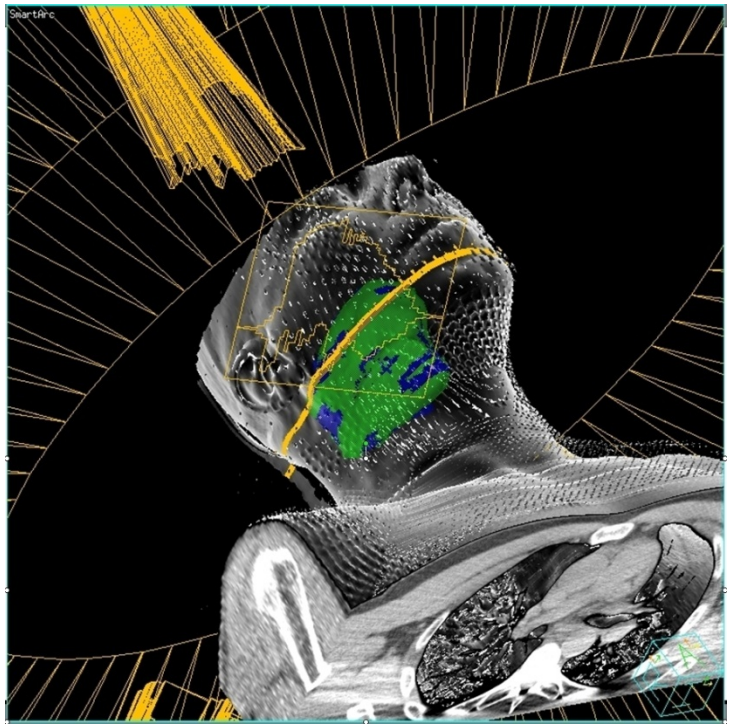
Volumetric Modulated Arc Therapy

- In dynamic rotation therapy the following parameters might vary during dose delivery:
  - MLC aperture
  - Dose Rate
  - Gantry velocity
  - Collimator angle

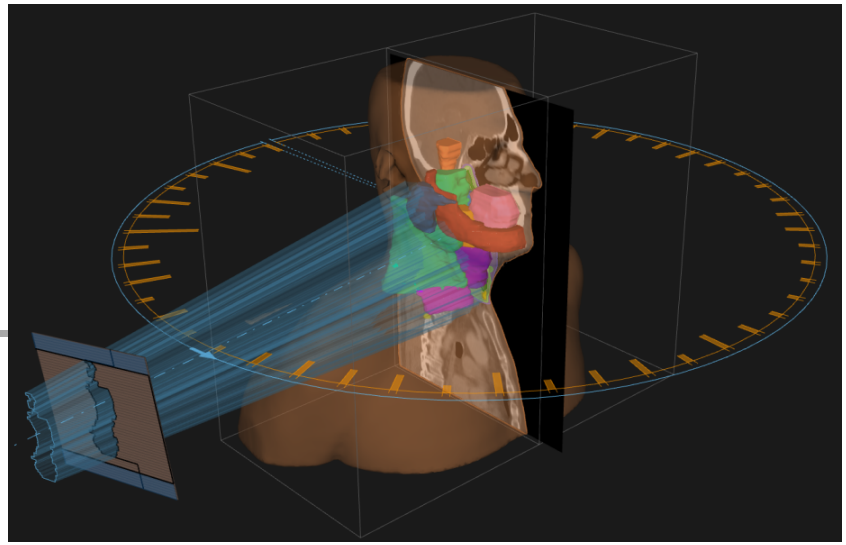


Volumetric Modulated Arc Therapy

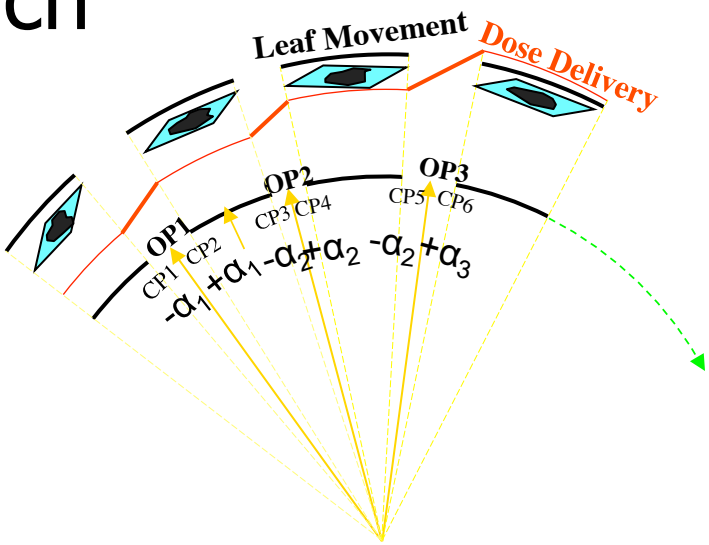
- Different implementations:
  - Tomotherapy
  - Rapid Arc (Varian)
  - VMAT (Elekta)
  - mArc (Siemens)
- ADVANTAGE:
  - Faster delivery
  - Fewer MU



mArc



- (Arc Modulated CBT):
- "Step and shoot" approach
  - CP0 – CP1: MLC adapt.
  - CP1 – CP2: Dose deliv.
  - CP2 – CP3: MLC adapt.
  - CP3 – CP4: Dose deliv.



Planning comparison

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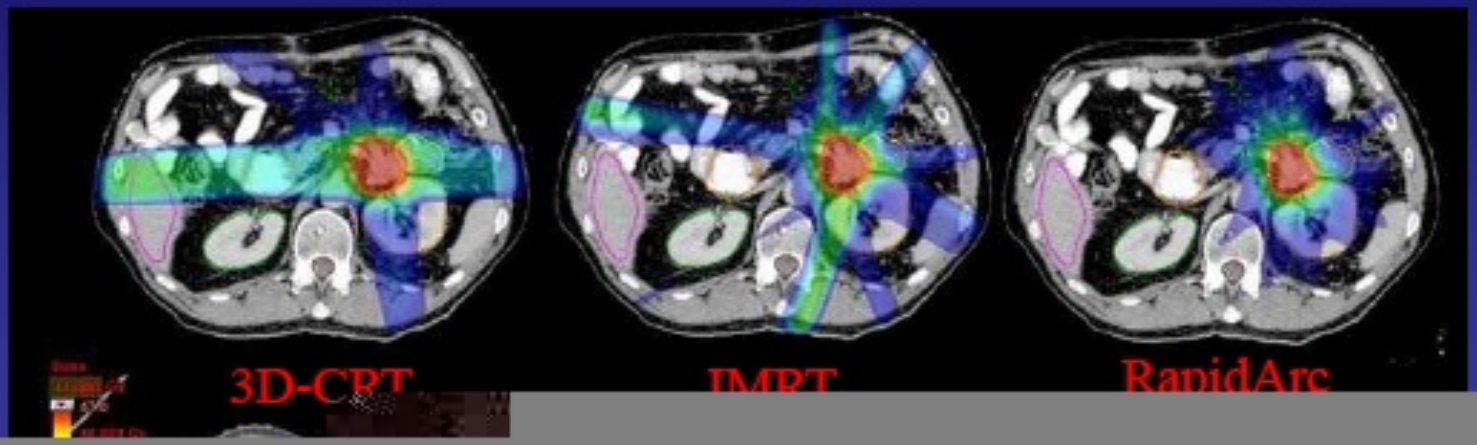
Istituto di Ricovero e Cura a Carattere Scientifico



Planning comparison

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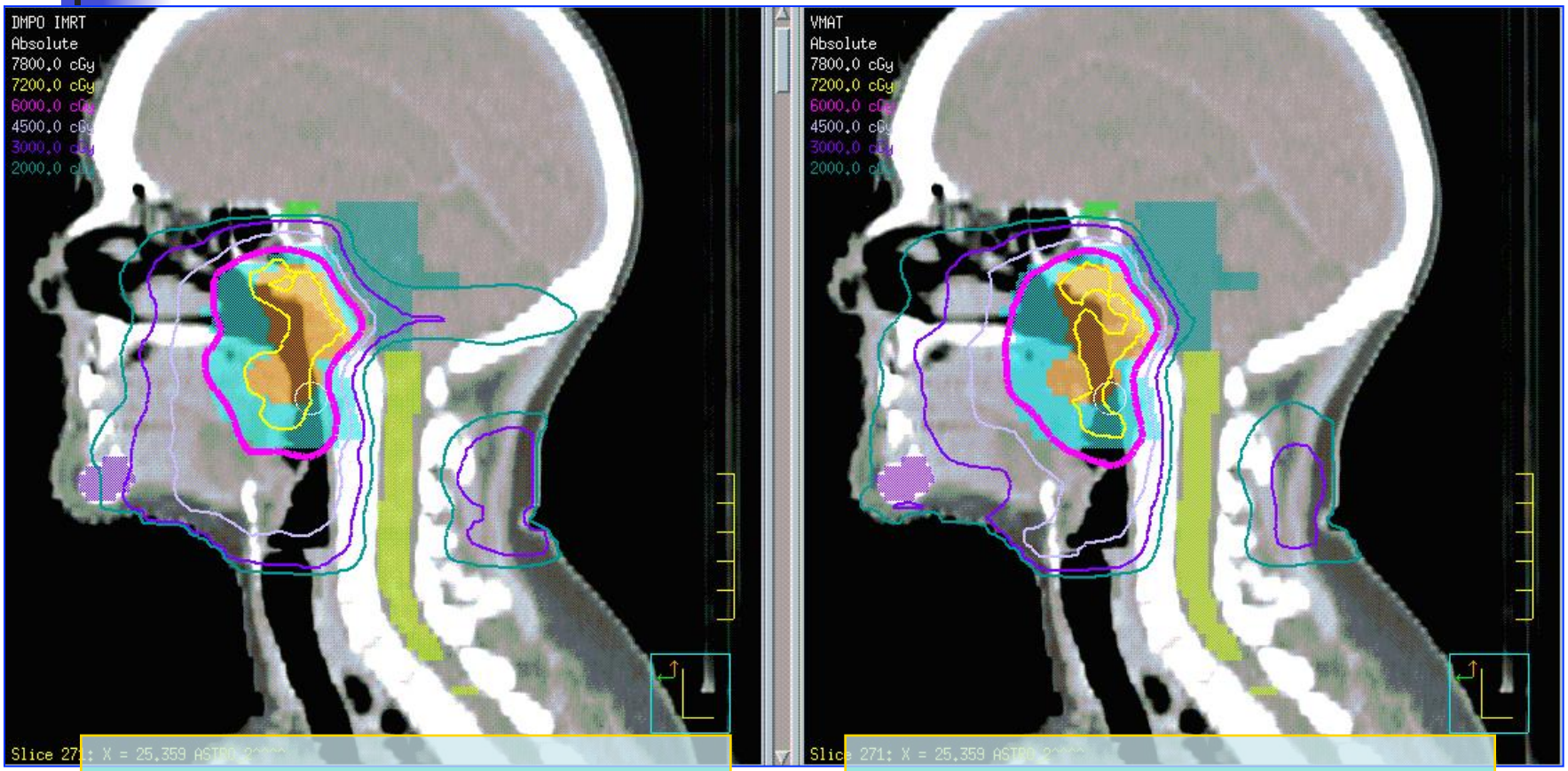
Istituto di Ricovero e Cura a Carattere Scientifico

- RapidArc® improves PTV coverage (V95%):
  - RapidArc®: 90.2±5.2%
  - IMRT: 84.5±8.2%
  - 3D-CRT: 82.5±9.6%
- Most planning objectives for OARs are met by all techniques, excepting for some 3D-CRT plans.
- MU/fraction:
  - RapidArc®: 2186±211
  - IMRT: 2583±699
  - 3D-CRT: 1554±153
- Effective treatment time:
  - RapidArc®: 3.7±0.4 min
  - IMRT: 10.6±1.2 min
  - 3D-CRT: 6.3±0.5 min

* Bignardi M et al. Int. J. Radiat. Oncol. Biol. Phys. 2009

Head and Neck Plan

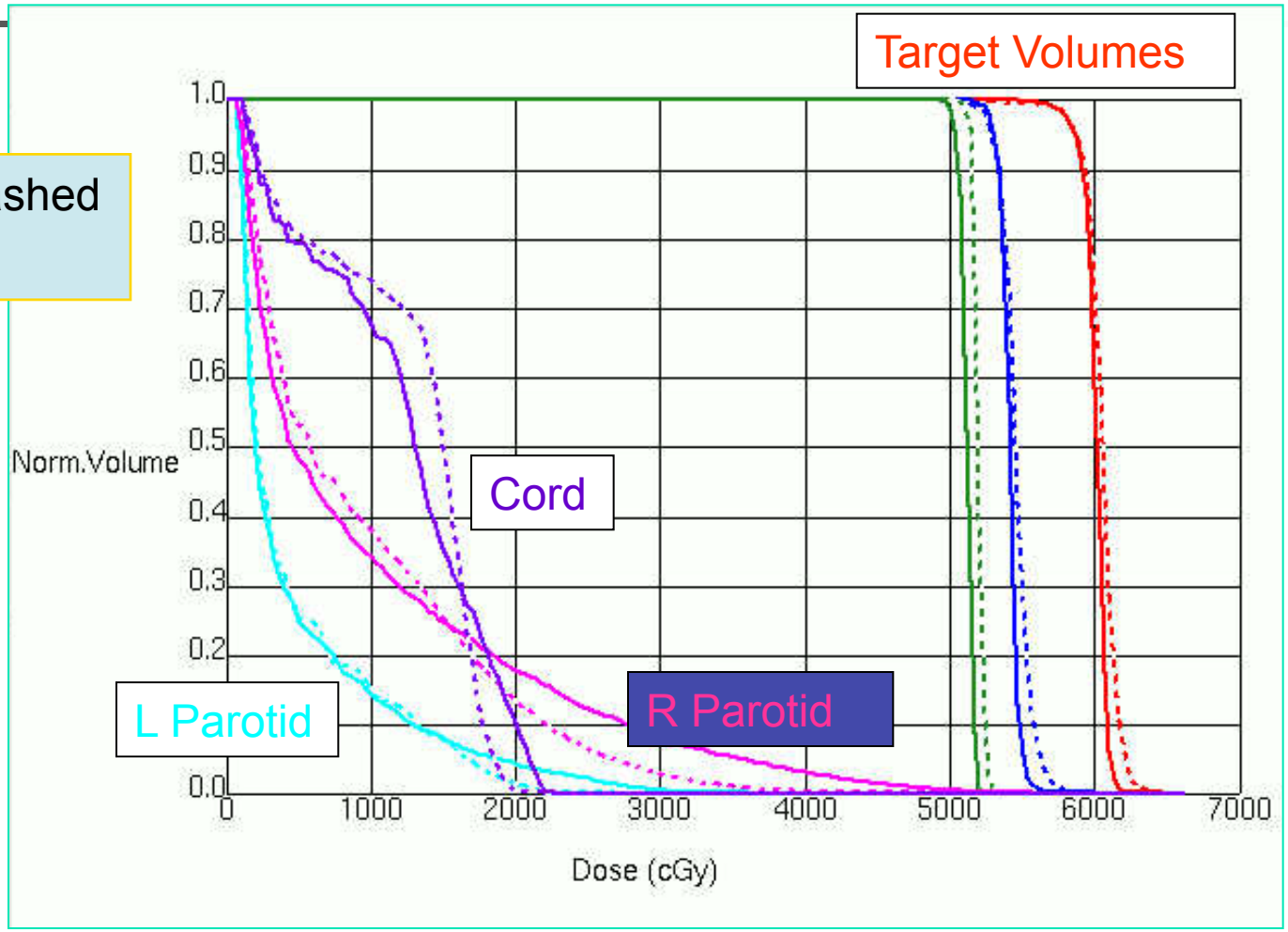


9-beam DMPO

SmartArc

Head and Neck Plan

SmartArc = dashed
DMPO = solid

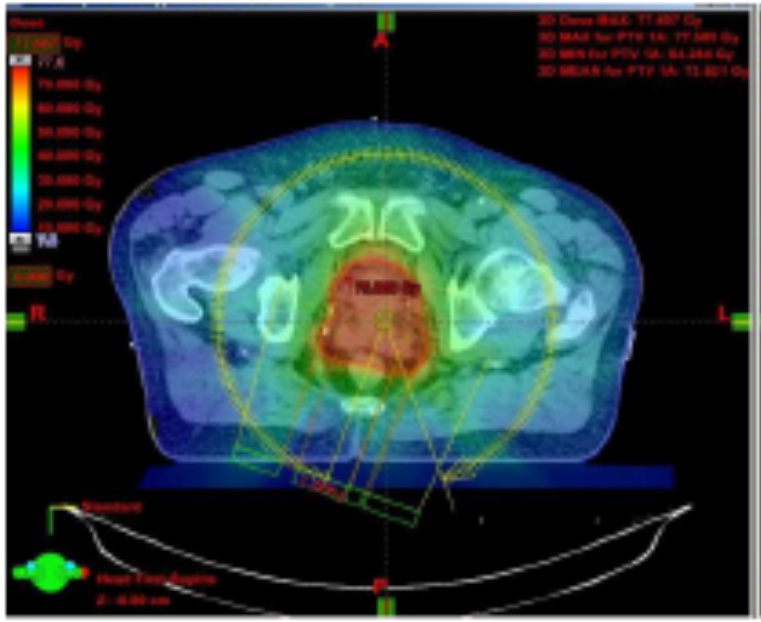


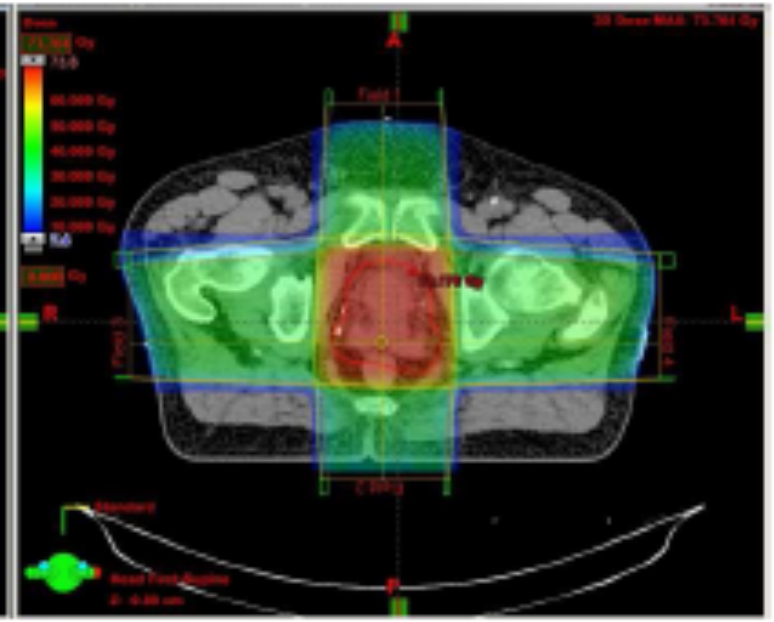
IMRT advantages

⇒ high conformal isodose distribution

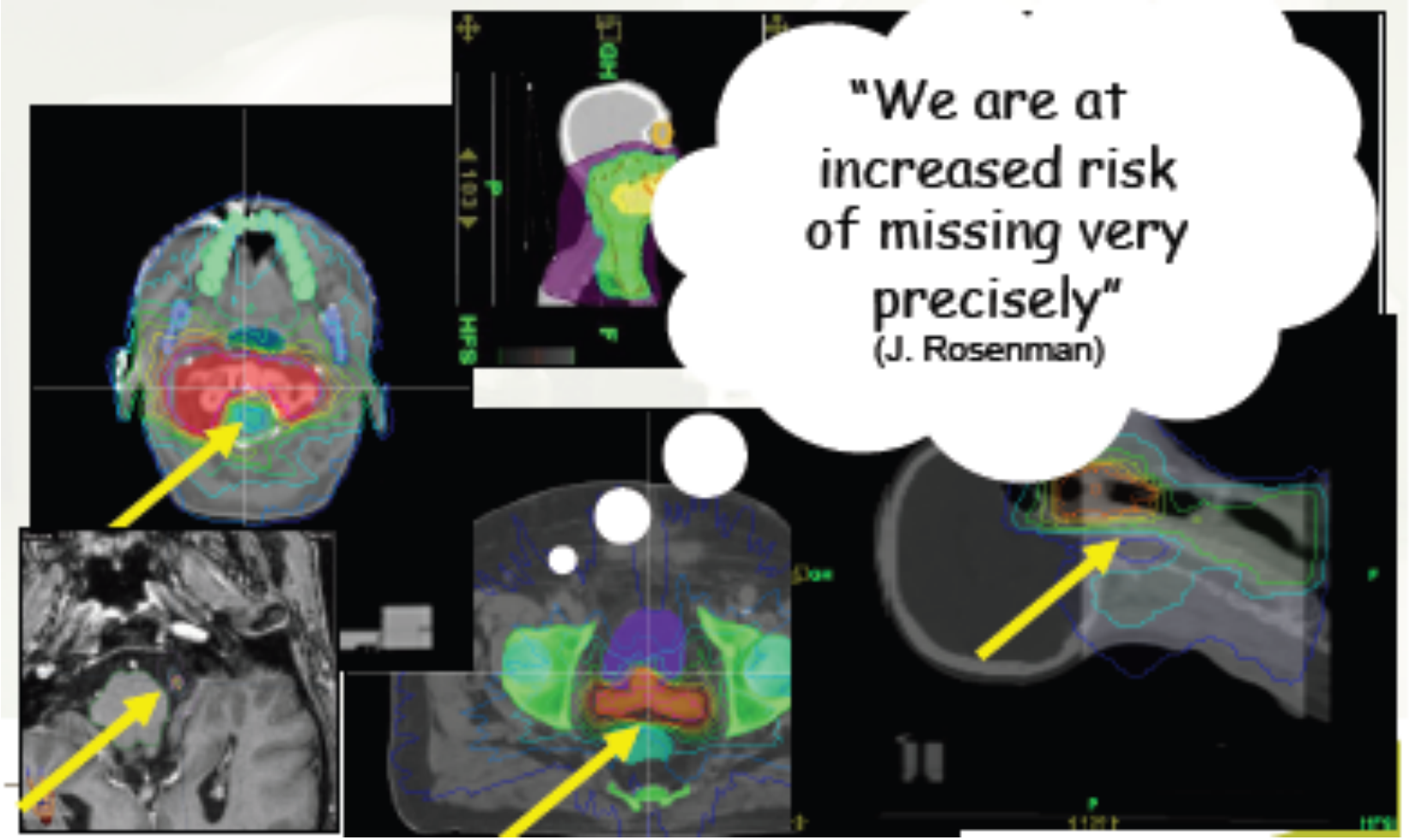
⇒ less irradiation dose to the OAR OR higher dose to the PTV

⇒ NO reduction of the safety margin

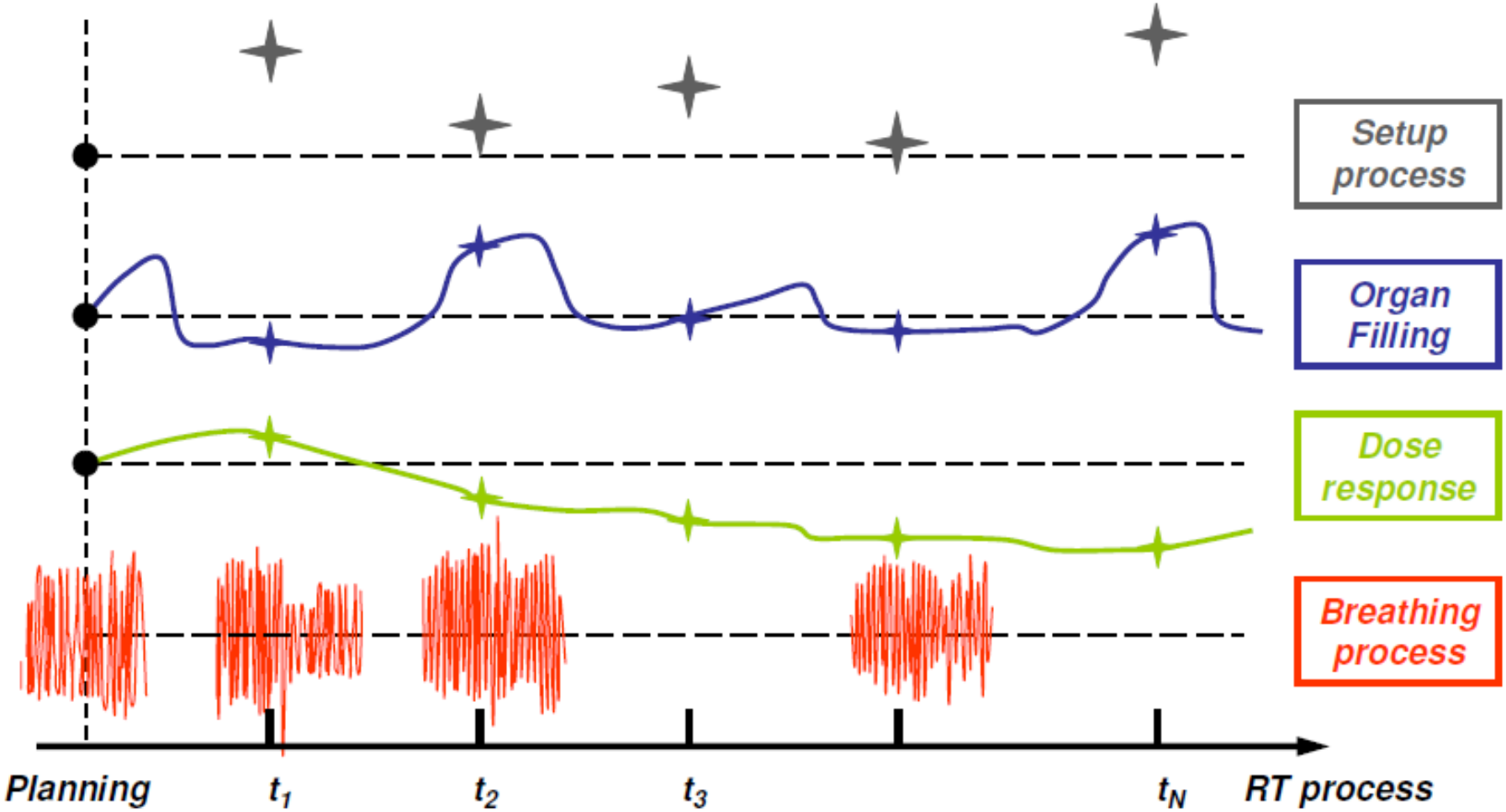




IMRT Drawback

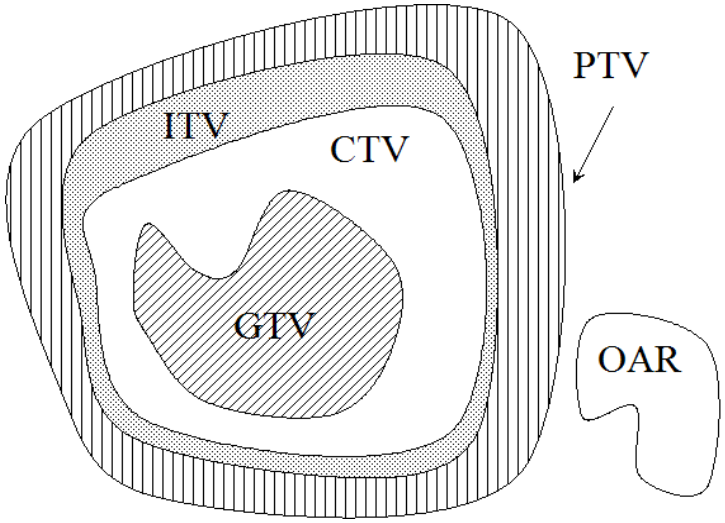


RT is a four dimensional problem



TARGET VOLUME CONCEPTS

Graphical representation of the volumes-of-interest, as defined by the ICRU 50 and 62 reports.



See various ICRU Reports
ICRU 50, 62, 78, ….

Verellen et al

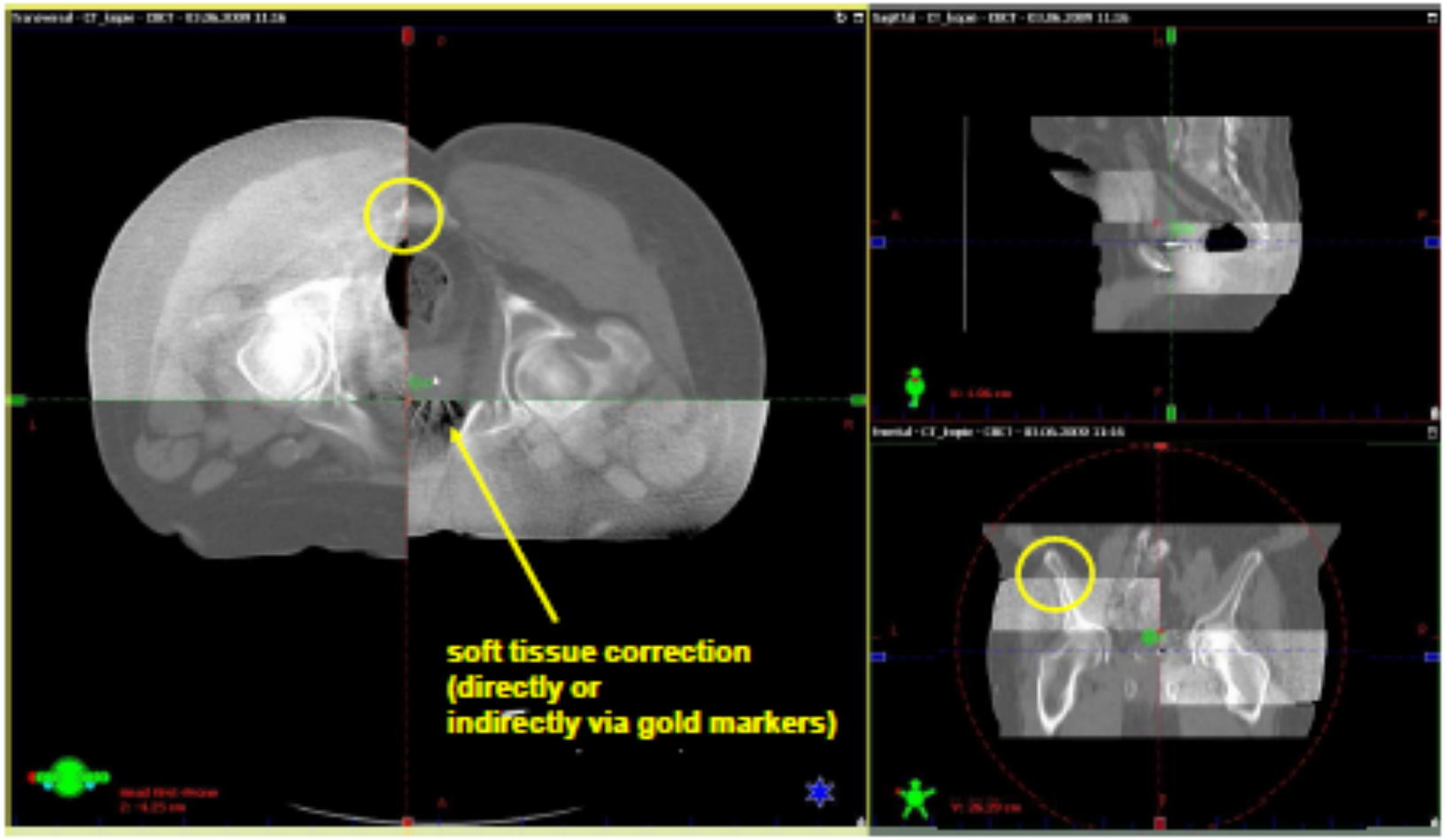
IGRT (Image Guided Radiotherapy)

⇒ correction of
patient positioning errors

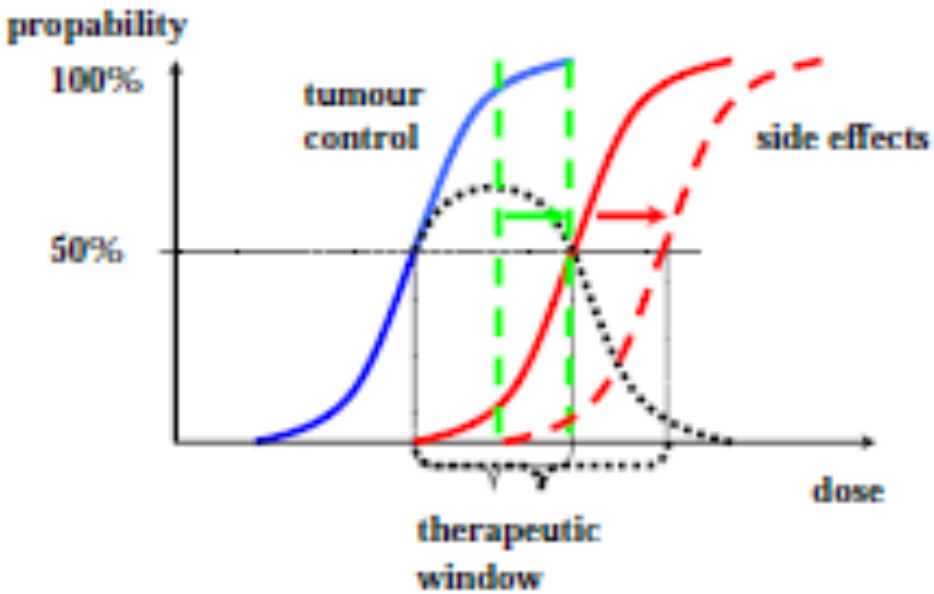
CBCT: anatomy matching

Matching of Cone Beam CT (Linac) with Planning CT

CBCT: soft tissue matching



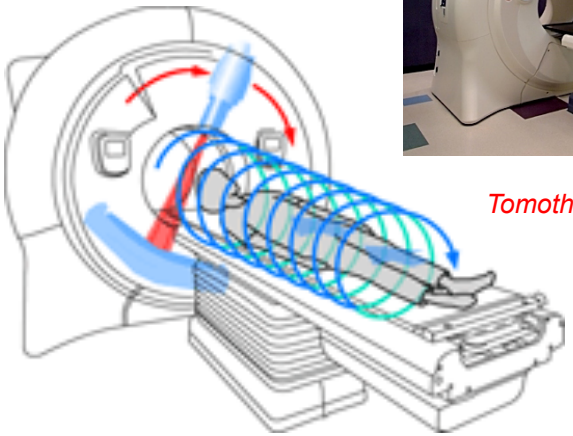
IGRT



➔ **Enlargement of the therapeutic window**

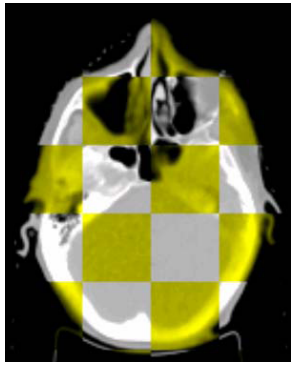
IGRT equipment

Varian

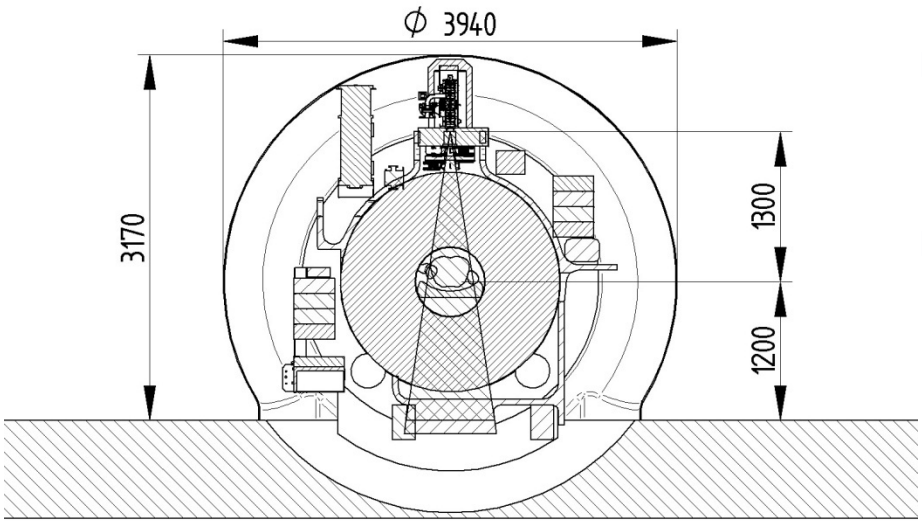


Tomotherapy

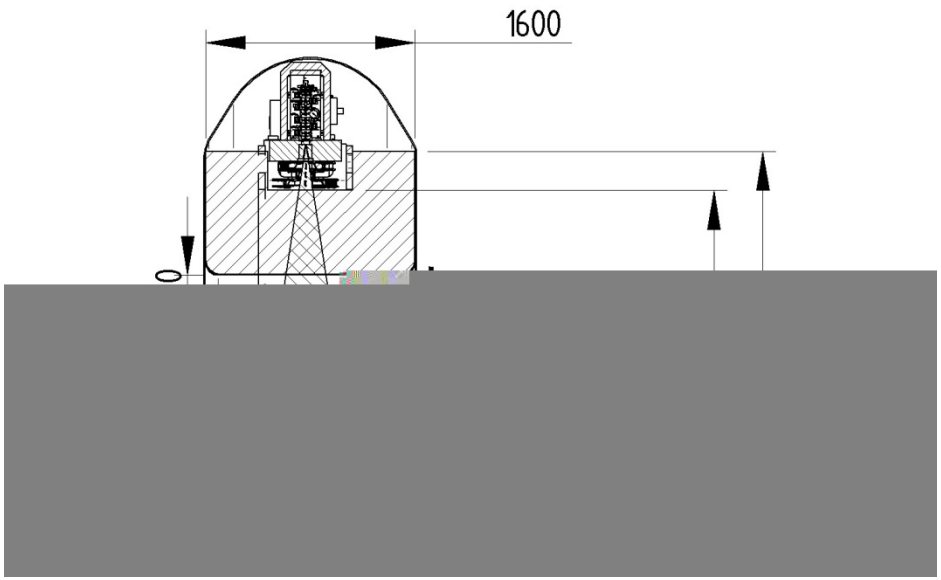
"Image of the day" vs treatment planning information

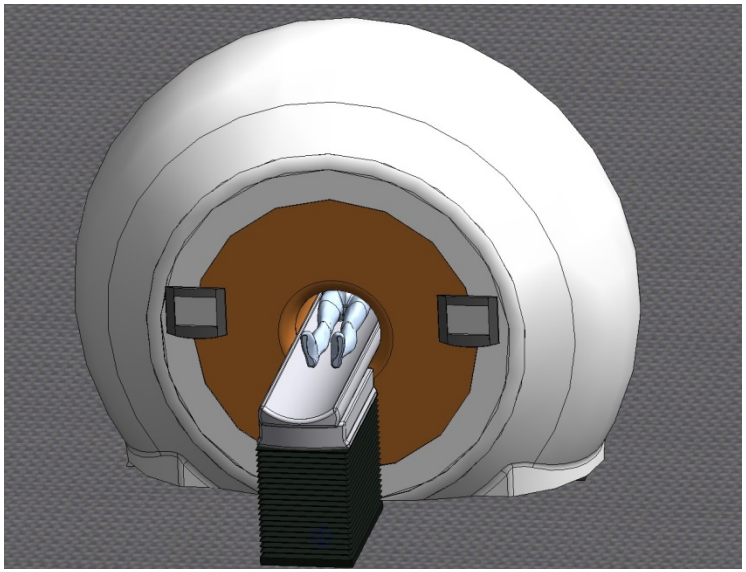


HYBRID MRI linac



- Closed bore high field MRI
- Gantry ring based 6 MV accelerator with MLC
  - accelerator and MRI system have to operate simultaneously and independently





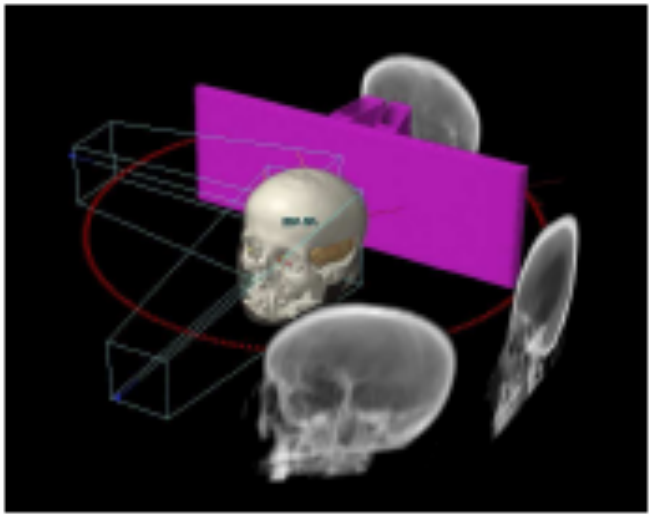
Courtesy J. Lagendijk

IGRT: advantages

⇒ correction of
patient positioning errors

⇒ high propability to hit the tumor

⇒ reduction of safety margin



- IMRT allows
  - Dose reduction to OAR

or

  - Higher dose to the PTV

- IGRT allows
  - Reduction of the safety margin

or

  - Higher probability to hit the target

High Precision RT

- IMRT without IGRT =
  - High Dose gradients + low probability to hit Target => unpredictable dose distribution

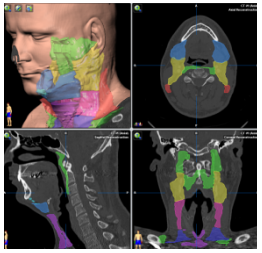
- IMRT + IGRT =
  - Lower probability of side effects

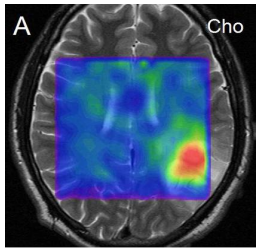
or

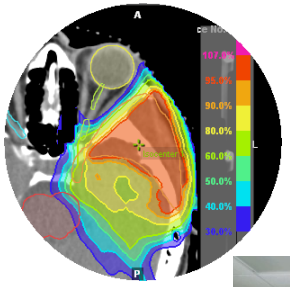
  - Higher dose to tumor

What do we need for high-tech RT ?

- Imaging equipment & software tools
- Treatment planning
- Beam delivery systems
- Patient immobilization
- Dedicated QA procedures
- Dedicated personnel

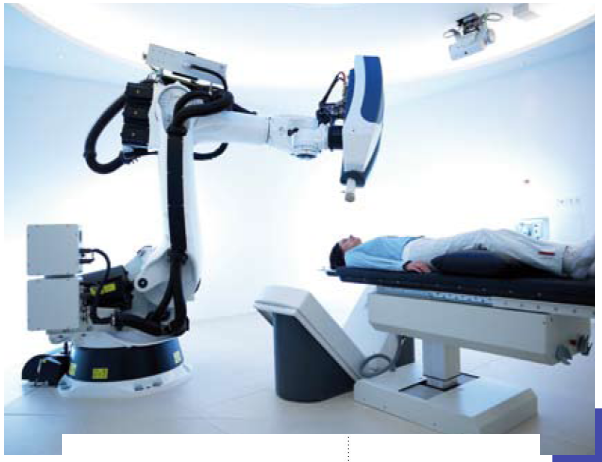


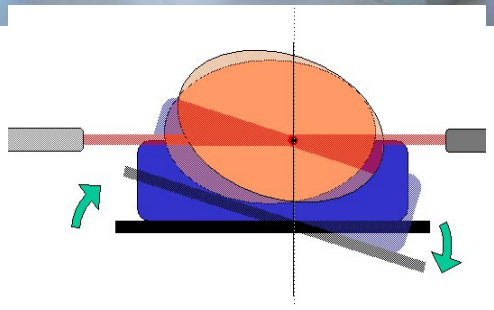


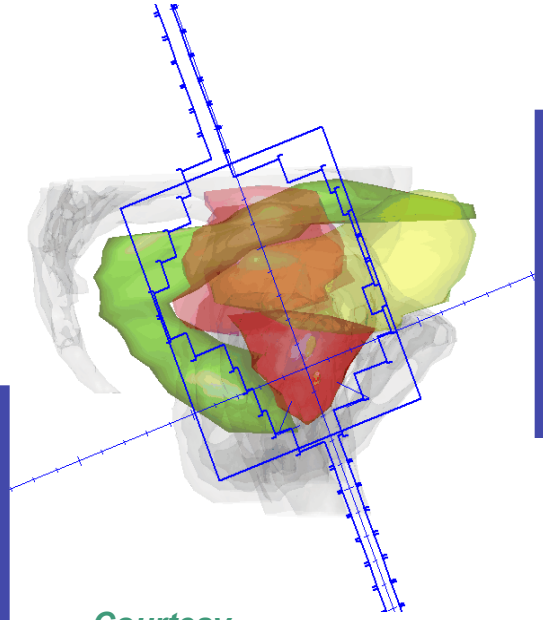


Robotics developments

- To reposition patient or the treatment delivery unit
  - couches with 6 degrees of freedom and tracking MLC
- To position automatically dosimetry and QA tools



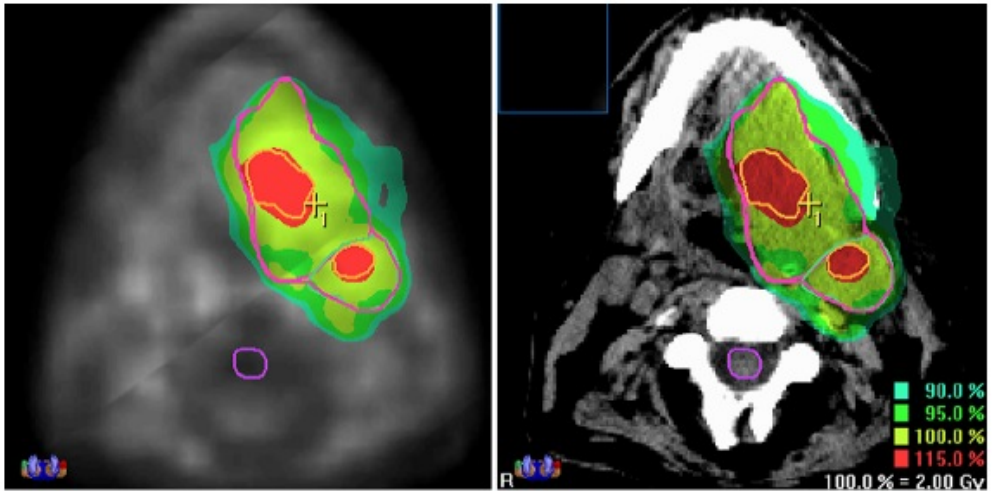




Courtesy H. Deutschmann

Courtesy Siemens

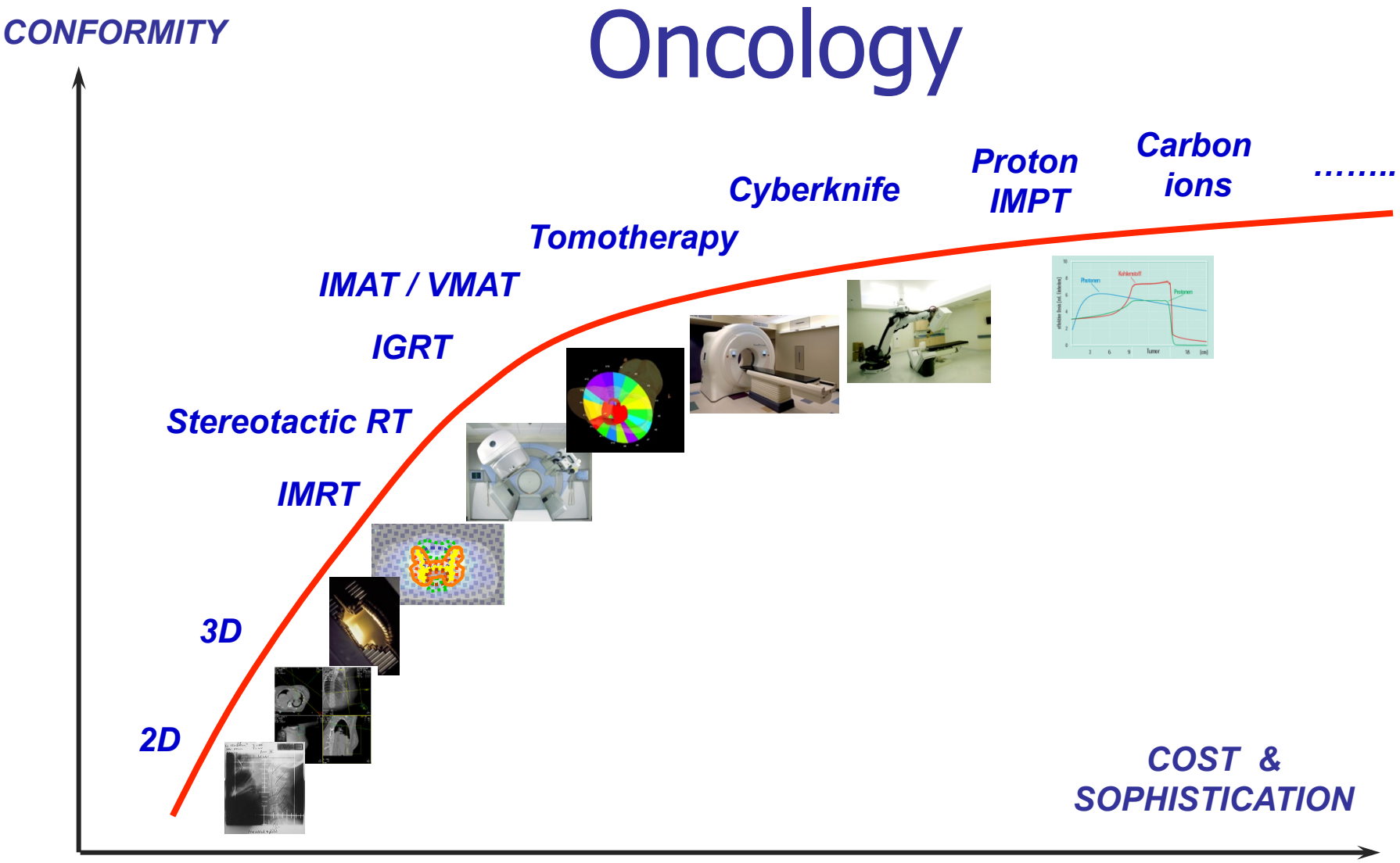
DOSE PAINTING (by numbers)



Grosu et al IJROBP 69, 2007

Fractionation effects !

Maximal conformity at maximal cost ?



General Areas of Responsibility of the Medical Physicist

- Clinical
- Research
- Education
- Regulatory Compliance

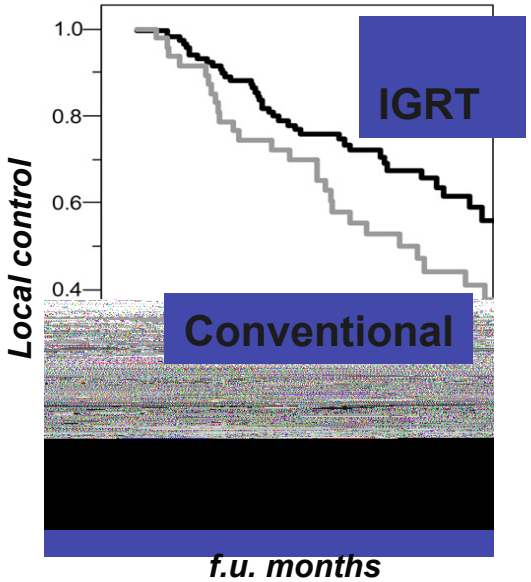
From "Medical Physics as a Career" (AAPM 2005)

Clinical Responsibilities of the Medical Physicist

- Daily clinical support
- Equipment acquisitions
- Equipment calibration and commissioning
- Quality assurance
- Dose calculations
- Liaison between other medical professionals, manufacturers, and regulatory agencies

SUMMARY

- Linacs are the most widely used delivery equipment in RT
  - Important technological developments during last 2 decades, machines designed for VMAT
  - Important clinical achievements
- Geometric accuracy in treatment delivery >> accuracy in target definition & patient immobilization
  - Research focuses on “Image guidance” for target definition and beam delivery
  - Increasing demand for new infrastructure and well trained personnel
  - Photon IGRT also sets standards for particle therapy



"The difference between theory and practice ...

... is larger in practice than in theory !"

John Wilkes

Credits: Dietmar Georg, Dirk Verellen, Hilke Vorwerk