Complex Treatments in Proton Therapy - Selected Topics

Educational Workshop PTCOG 46, May 18-20, Wanjie, China

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Proton Therapy

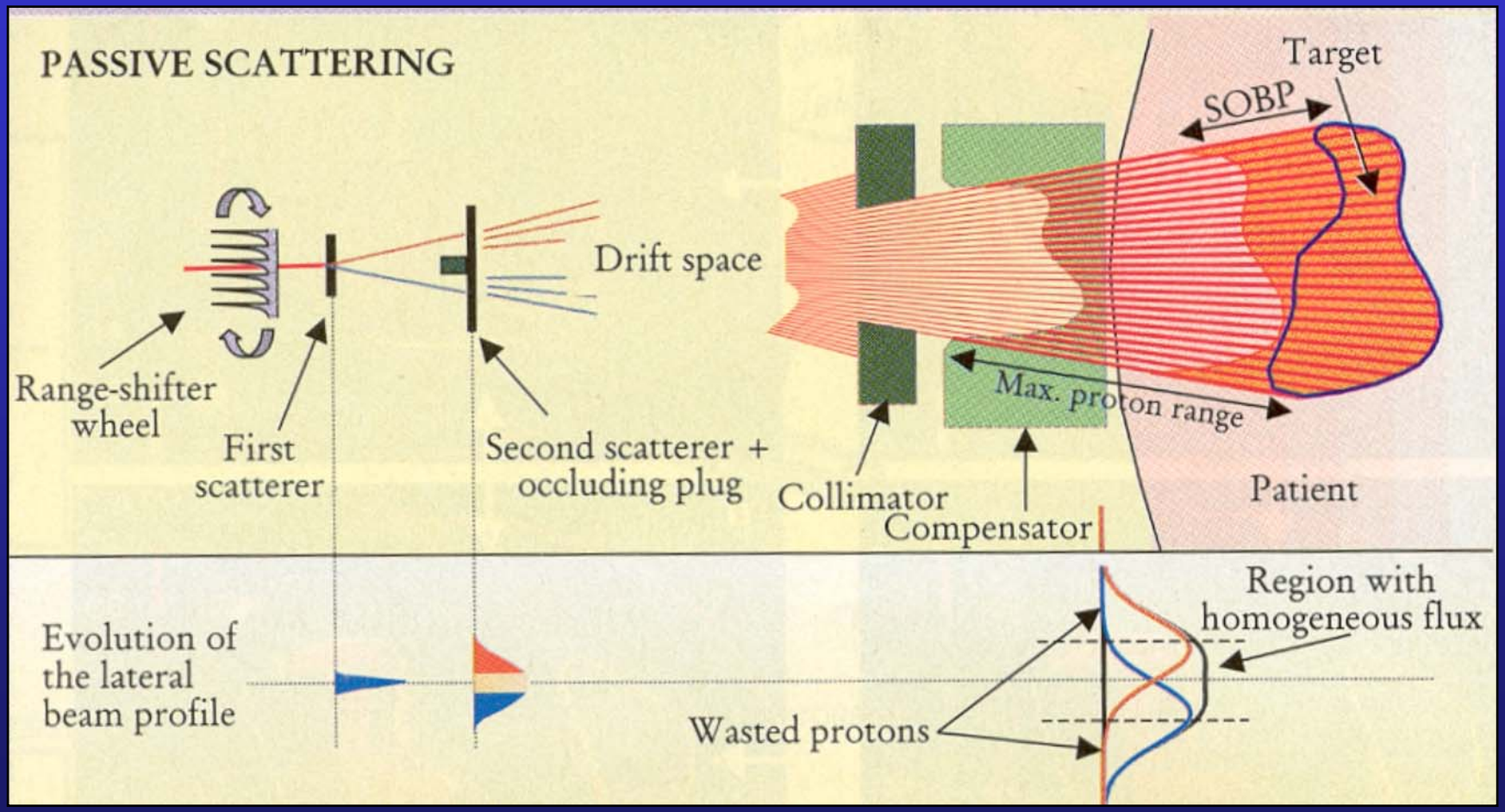
M.D. Anderson Cancer Center

Outline

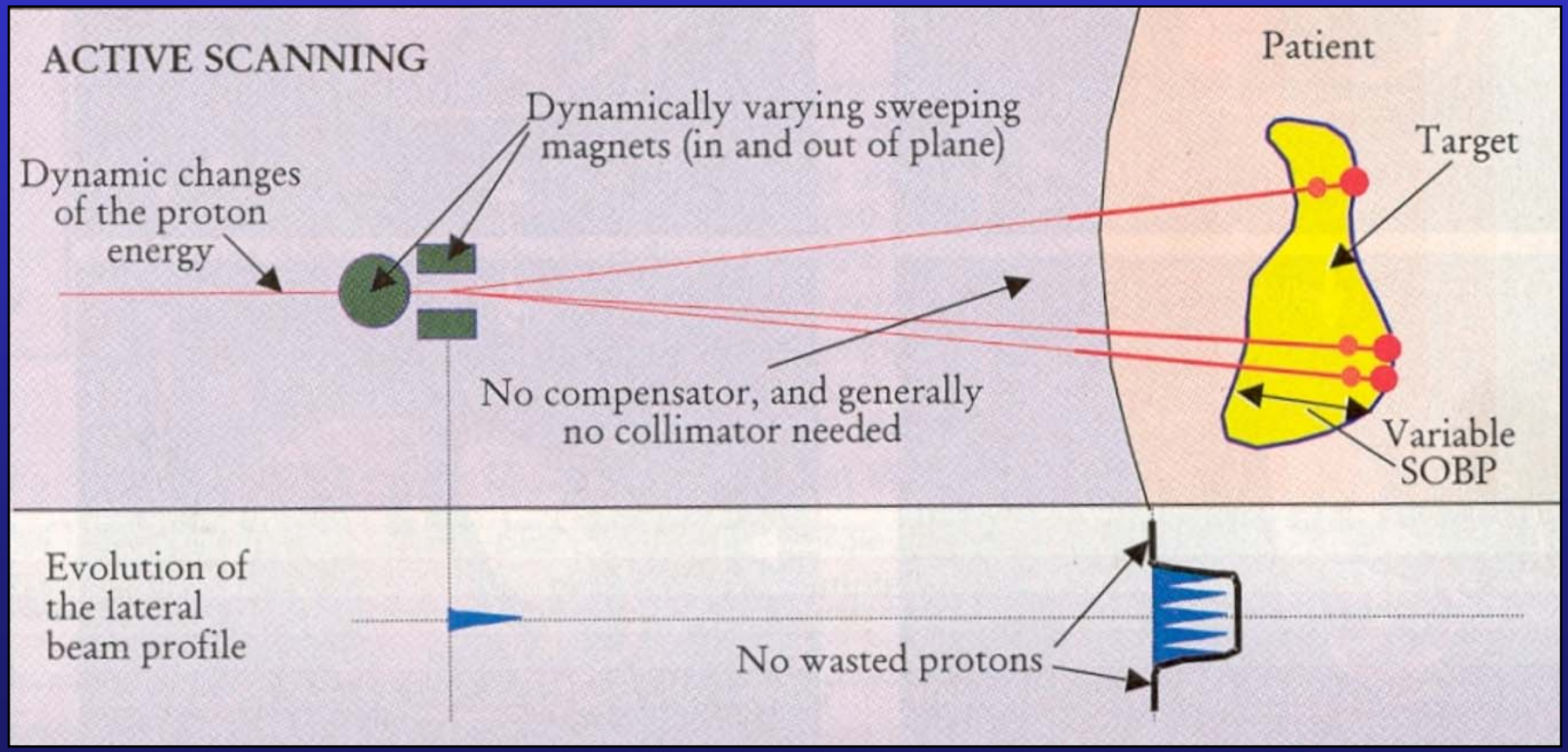
- Topic 1: Proton Beam scanning and Intensity modulated proton therapy (20 min.)
- Topic 2: Introduction to motion management (10 min.)
- Topic 4: Quality assurance of spot scanning treatments (10min.)
- Discussion: (10 min.)

Topic 1: Proton Beam Scanning and Intensity Modulated Proton Therapy

The Passive Scattering Mode of Proton Beam Delivery



The Pencil Beam Scanning Mode of Proton Beam Delivery



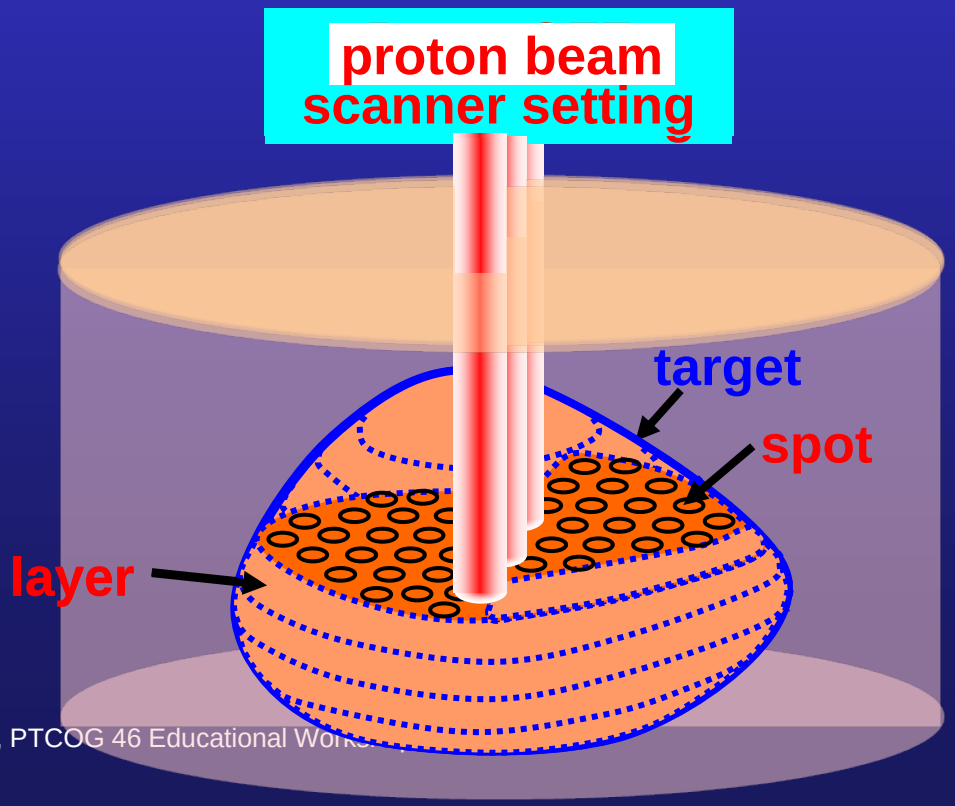
Motivation for Pencil Beam Scanning

- Fewer neutrons
- Sparing of healthy tissues proximal to the target
- Intensity modulated proton therapy (IMPT)

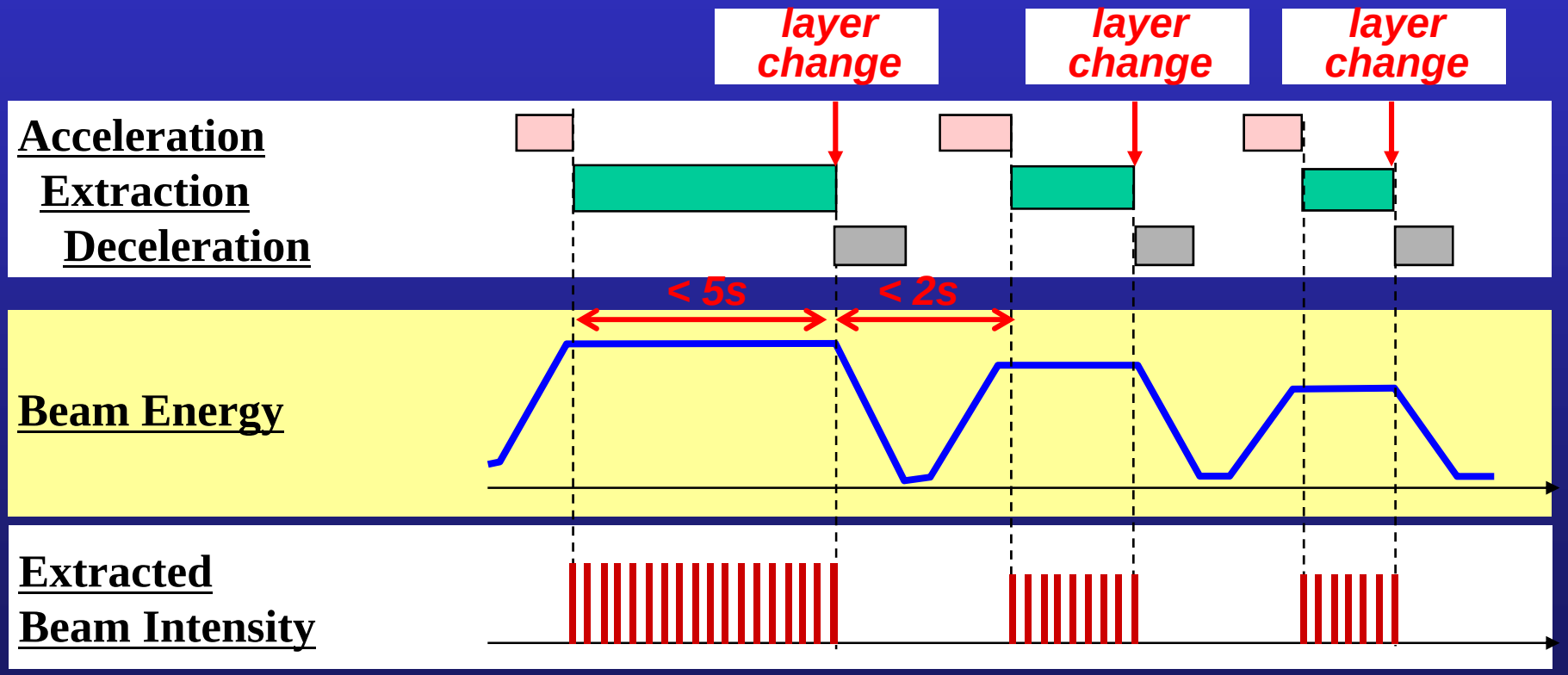
Step and shoot delivery of proton beam scanning

- **Repeating many static irradiations**
- **Speedy beam switching with RF Driven Extraction technique**

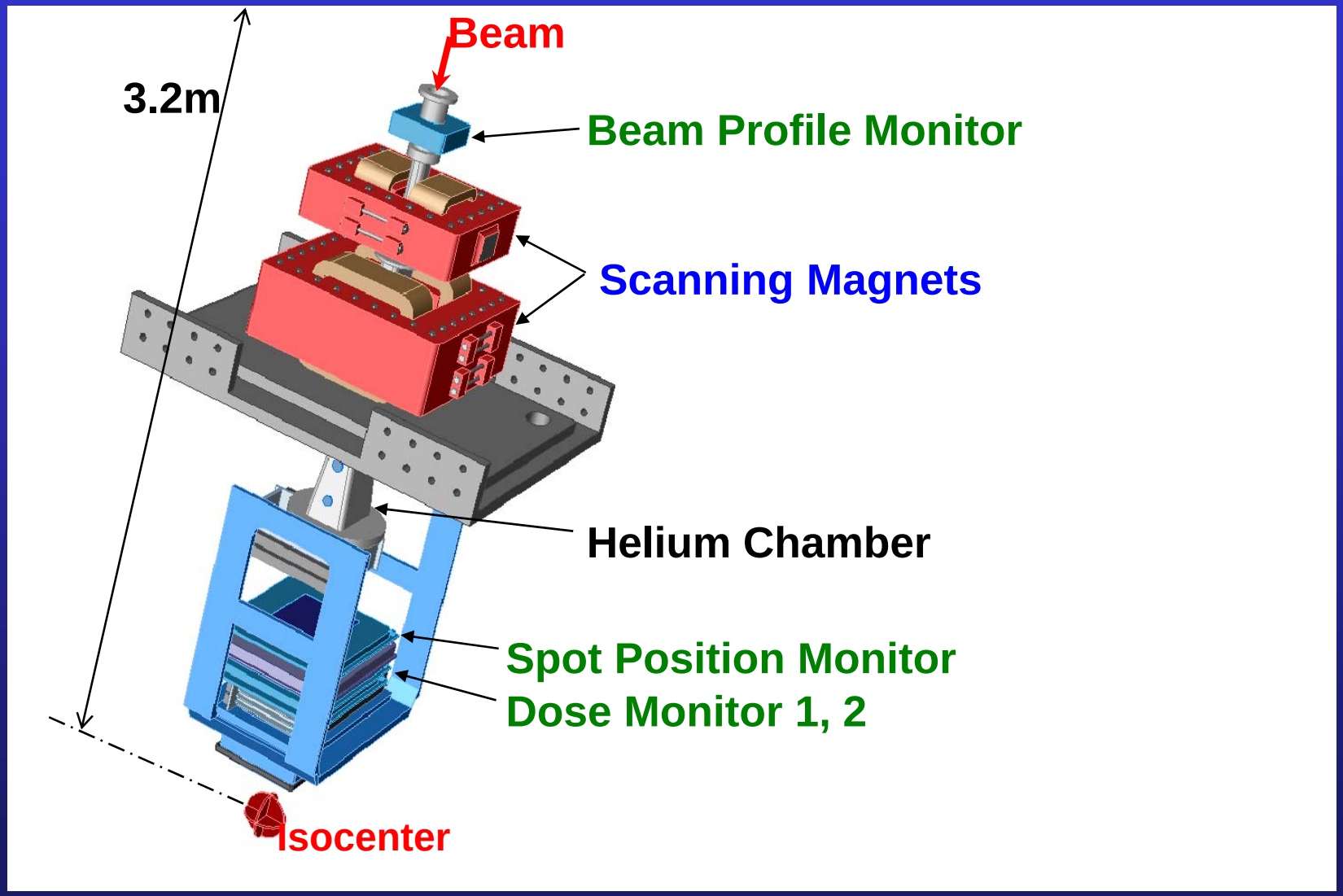
Dynamic scanning is achieved with *discrete spot scanning method*.



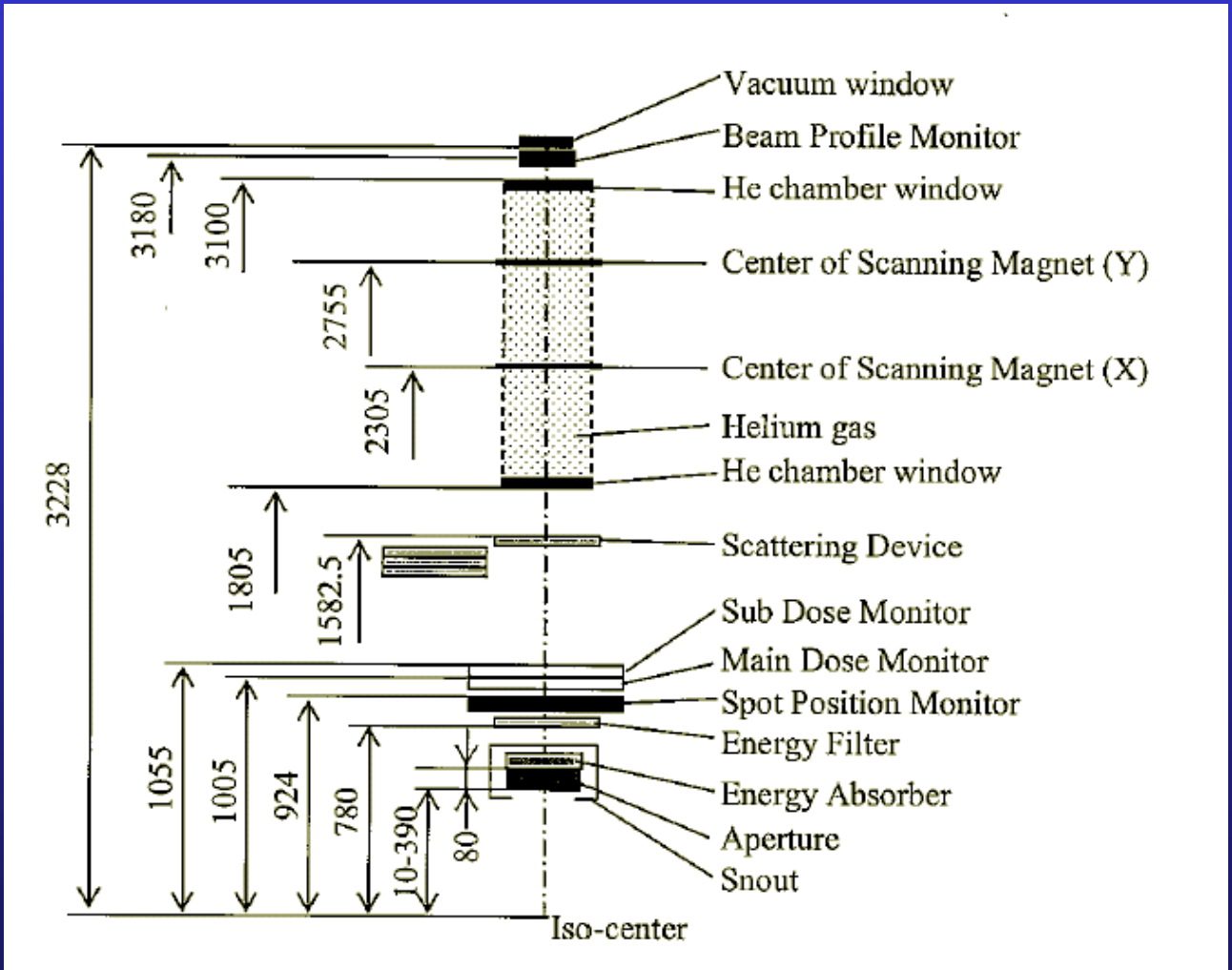
Timing Parameters for PBS with a Synchrotron



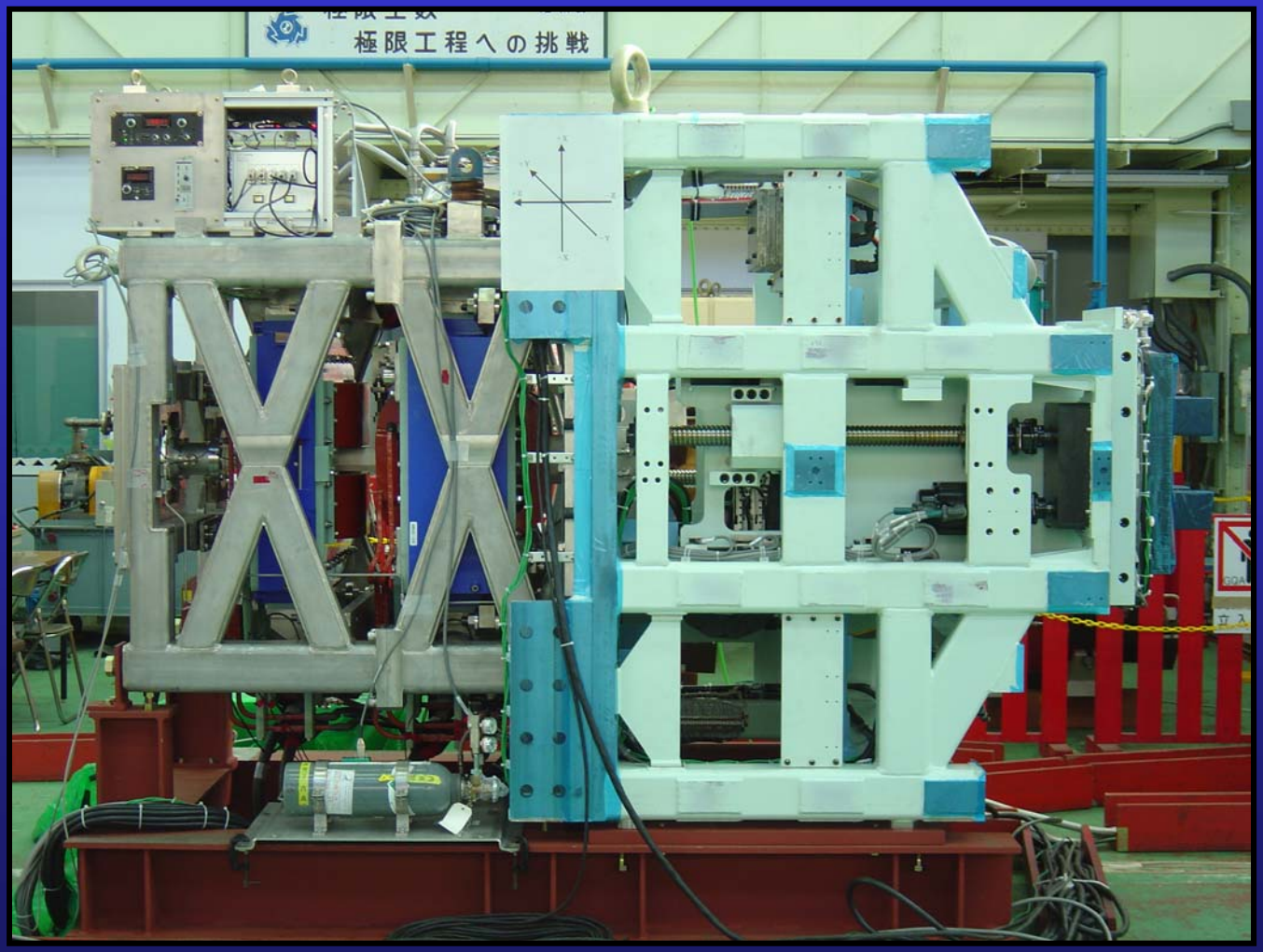
Scanning Nozzle Design



Scanning Nozzle Design (Cont.)



Scanning Nozzle Design (Cont.)



Dose Monitoring Equipment

- Profile monitor
  - Multi-wired ionization chamber
  - Monitors correct incidence and shape of beam at entrance of the nozzle
- Sub dose monitor
  - Independent check for Main dose Monitor
- Main dose monitor
  - Parallel plate ionization chamber
  - Monitors number of protons delivered spot by spot

Dose Monitoring Equipment (Cont.)

- Spot position monitor
  - Multi wired ionization chamber
  - Monitors spot position and spot size
- Spot monitor unit constraints
  - Maximum MU: 0.04 MU
  - Minimum MU: 0.005 MU
  - Resolution: 0.0001 MU = 2 pC monitor chamber charge (= 13 fC proton charge @ 175 MeV)

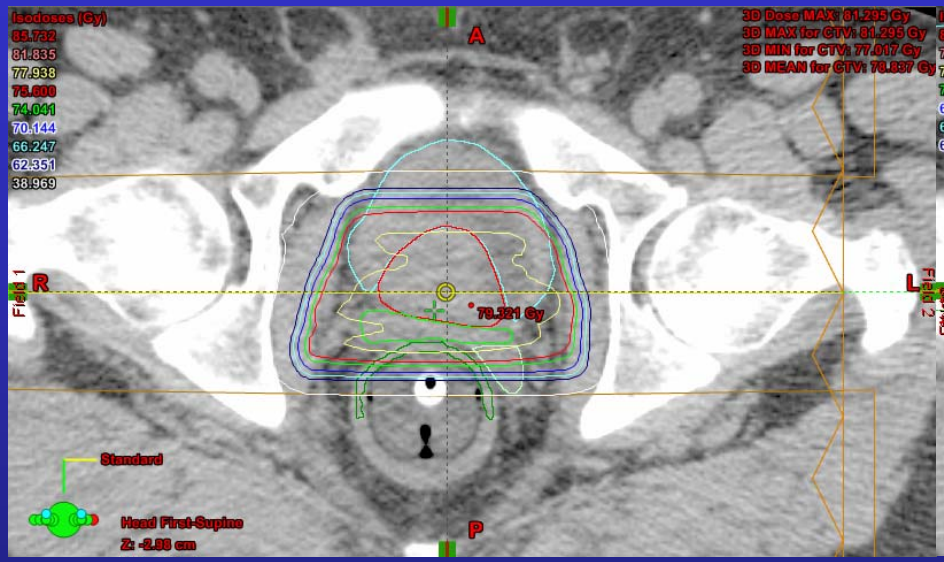
Multipainting

- Locations in the target are visited by pencil beams of the same energy and deflection, **several times**
- Advantages: Reduction of dose error, Compensation for organ motion

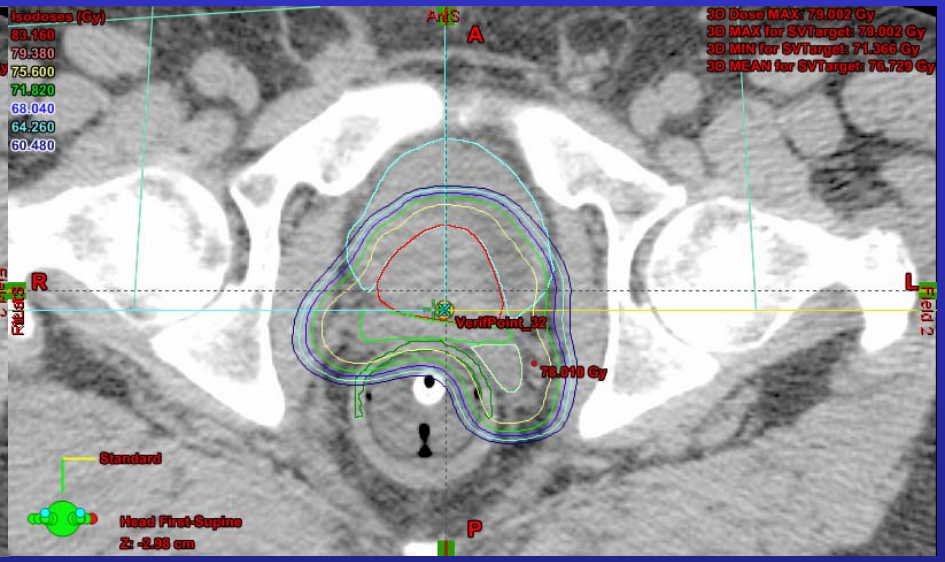
Spot Scanning vs IMPT

- Spot Scanning and IMPT are not the same thing!
- Spot scanning is a proton therapy modality which can be used to deliver homogeneous or in homogeneous dose distributions
- IMPT is the deliberate delivery of inhomogeneous proton fields, which add up to a homogeneous dose distribution,

IMPT Treatment Planning



PS plan



IMPT plan

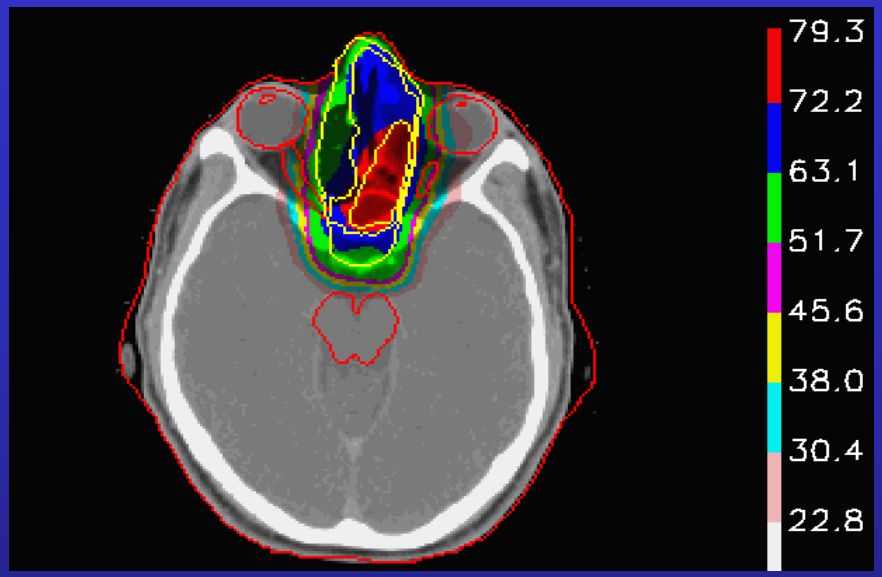
IMPT planning steps: Prostate

- IMPT planning parameters:
  - 75.60 CGE prescribed to 100 % line encompassing the CTV
  - Lateral opposed beams treated with rectal balloon
  - CTV includes entire prostate and, in most cases, proximal seminal vesicles *and distal seminal vesicles*
  - Extended CTV (ECTV), 8mm distal and proximal, 5mm superior and inferior, 8mm anterior, 5mm posterior
  - 5mm isotropic margin surrounding ECTV

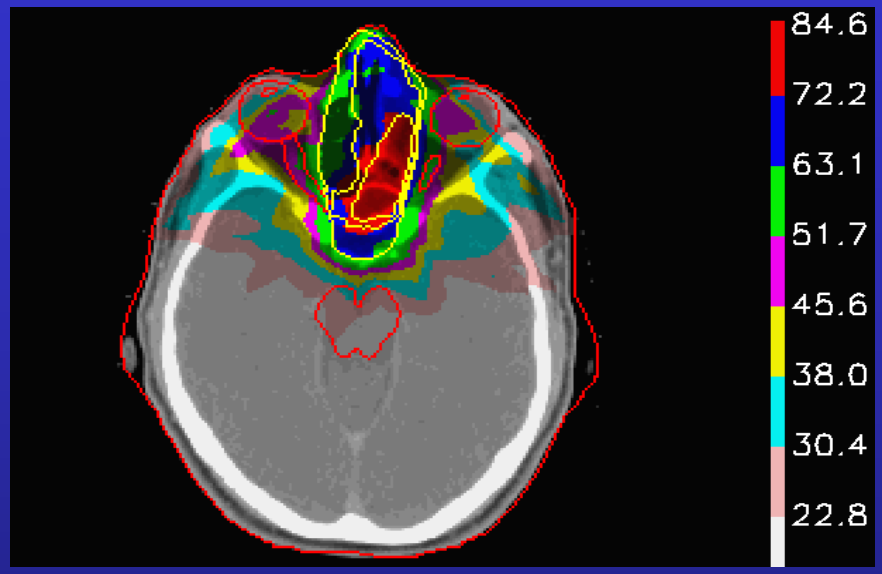
Maxillary Sinus

Lomax, PSI

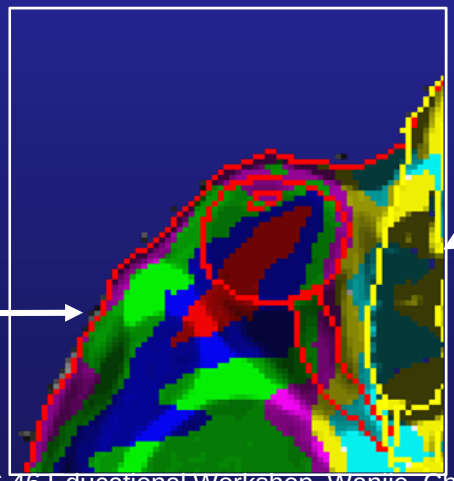
IMPT

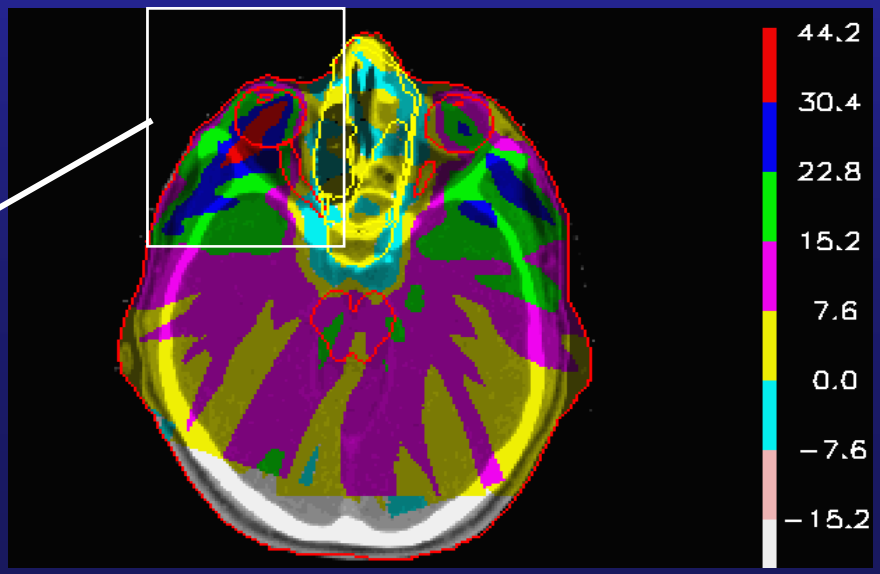


IMXT (6 MV)



Dose Difference (IMXT – IMPT)

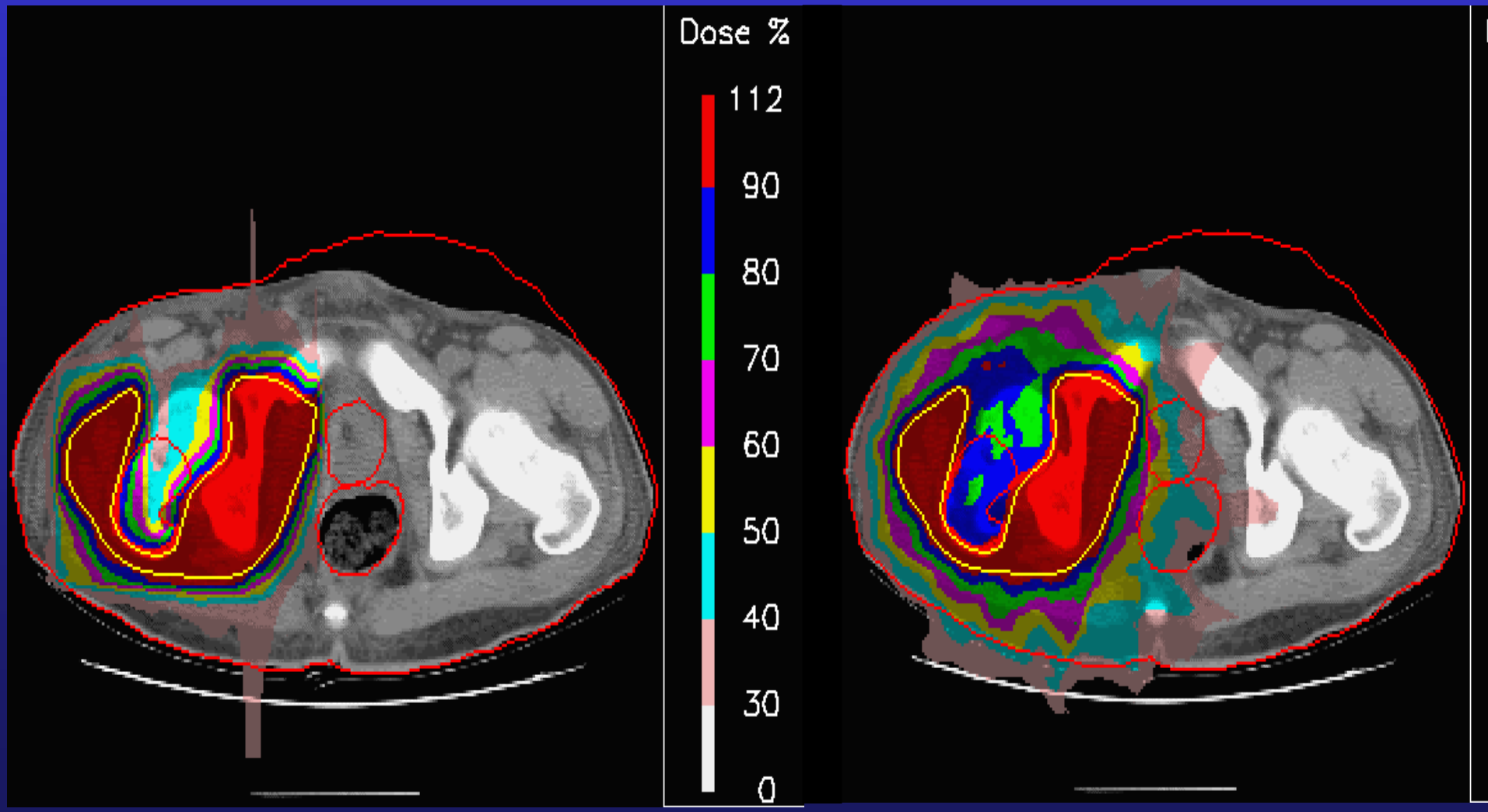




Lomax, PSI

EWING'S SARCOMA

IMPT IMXT



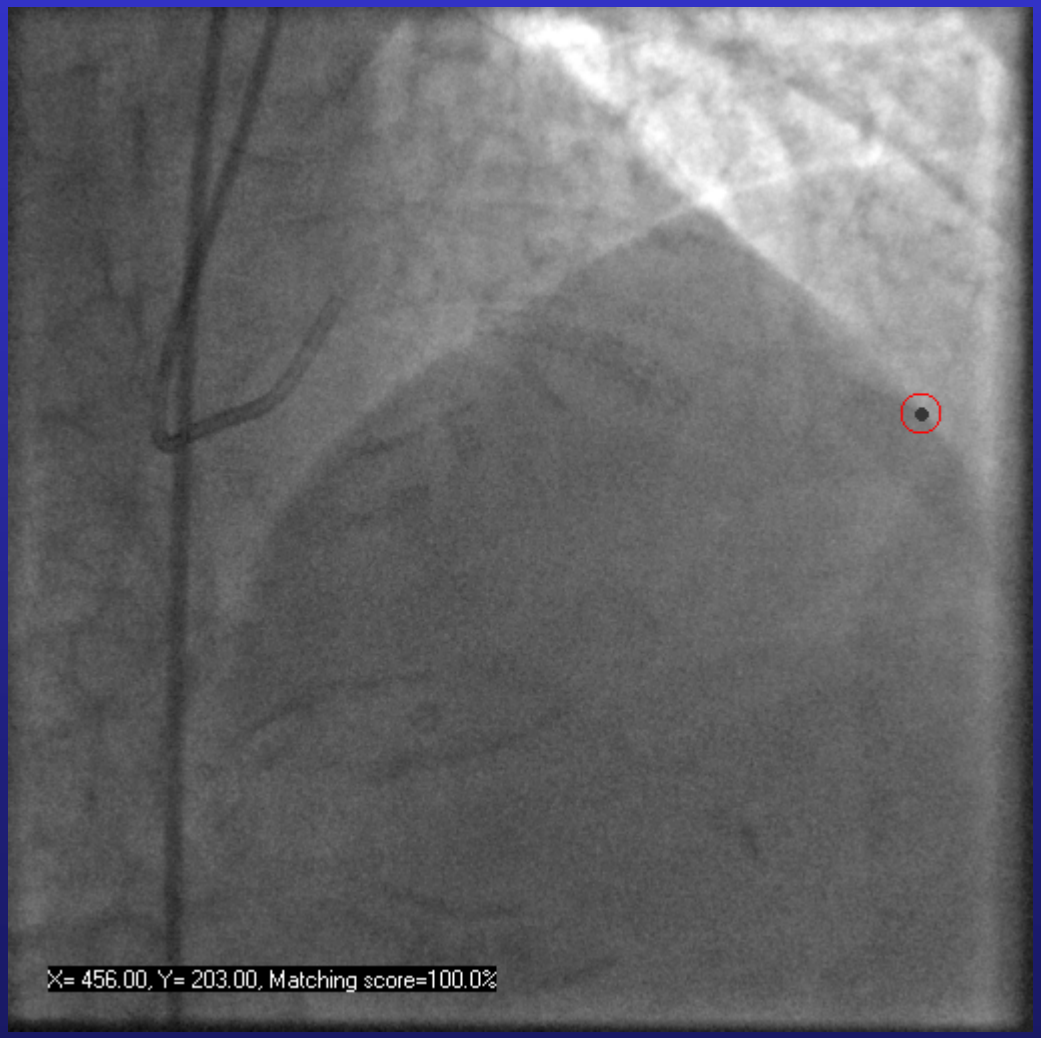
Lomax, PSI

Topic 2: Introduction to Motion Management

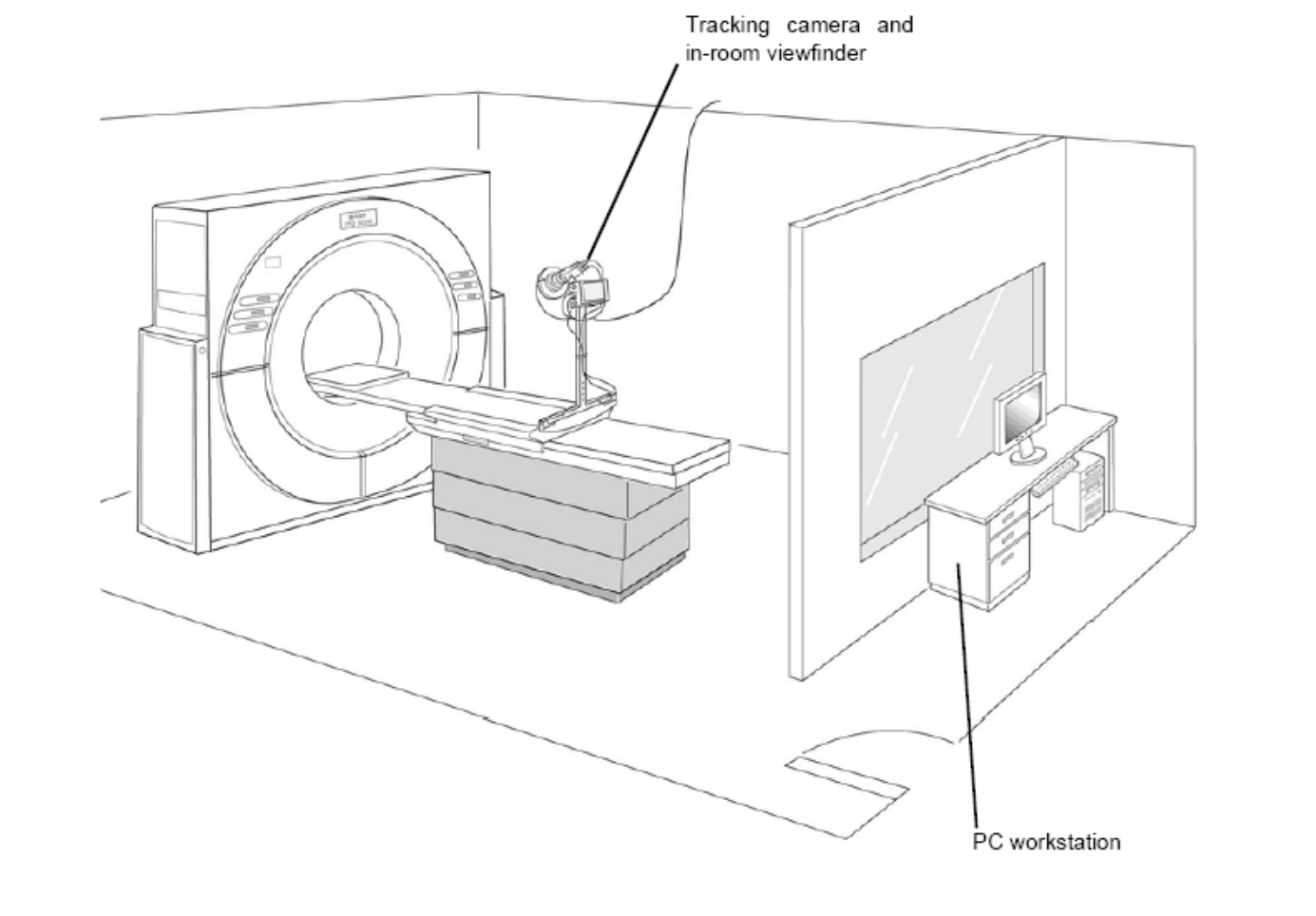
Two Types of Motion

- Interfraction Motion
  - Variations in patient geometry *from fraction to fraction*
    - Imperfect reproducibility of patient setup
    - Internal patient changes (e.g. bladder filling, stomach filling, peristalsis, weight gain/loss)
- <u>Intrafraction Motion</u>
  - Variations in patient geometry *within one fraction*
    - Patient breathing

Motion due to breathing



4D CT image acquisition



4D CT

- 10 3D CT image sets, T_0, …, T_{90}, corresponding to 10 phases in the breathing cycle of the patient
- Average CT, the *voxel by voxel* average over T_0, …, T_{90}.
- Other 3D image sets, e.g. maximum intensity projection.

Two modes of intrafractional motion management

- Passive motion management
  - Fully understand the effects of motion on the dose delivery and plan accordingly
  - Example: 4D-CT based proton planning
- Active motion management
  - Fully understand the effects of motion on dose delivery
  - Modify dose delivery process to minimize these effects
  - Examples: Breath hold, gating, multi-painting, tumor tracking, anesthesia, …

Treatment planning for lung w/o gating for passive scattering at PTC-H

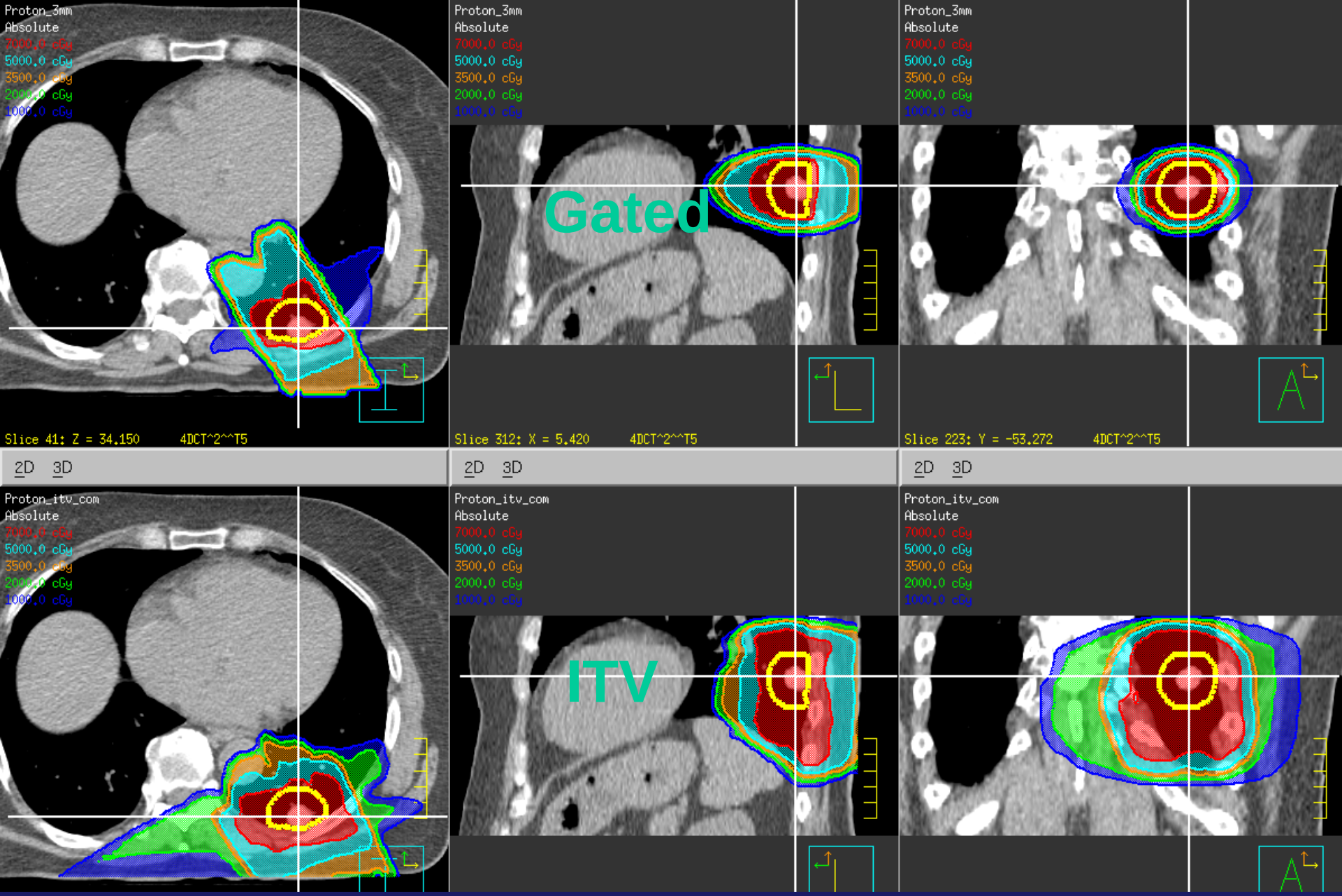
1. Acquires 4D-CT
2. Delineate target on all breathing phases:

$$T_{T_0},\ldots,T_{T_9}$$

3. Form the union of all target, internal gross target volume (IGTV):

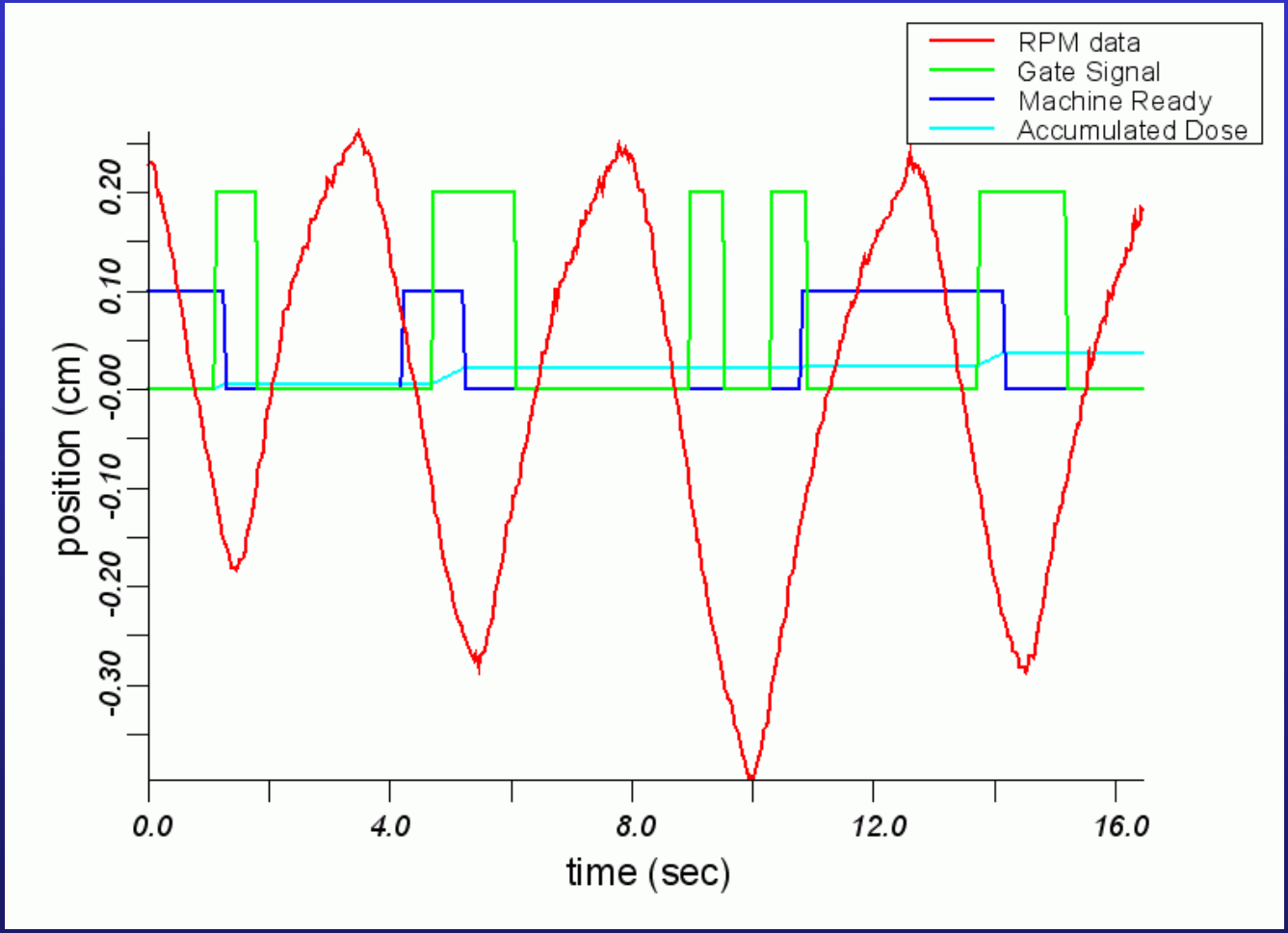
$$IGTV = T_{T_0} \cup \ldots \cup T_{T_9}$$

4. Transfer IGTV contours onto average CT.
5. Plan for IGTV on average CT same as for static target.
6. Verify result of planning process on all/selected breathing phases
7. Repeat process if significant changes in patient anatomy are suspected

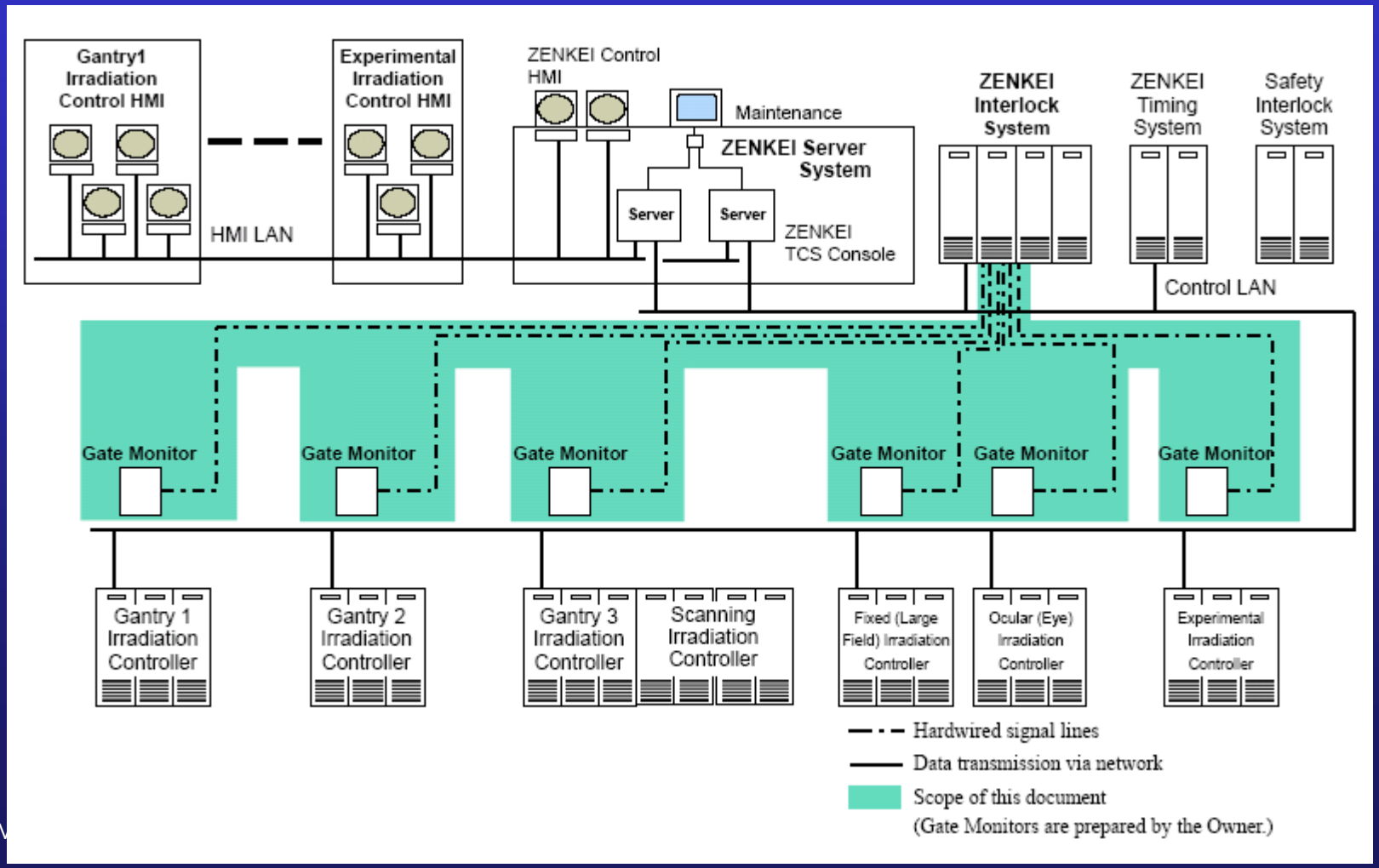


X Zhang, L Dong

Gating Simulation



Gating Hardware on Hitachi PROBEAT System



Topic 4: Quality Assurance

Areas of Quality Assurance

- Hardware QA: Proton Beam delivery machine, CT scanner, …
  - Acceptance test
  - Constancy checks
- Treatment Planning System QA
  - Acceptance test
  - Dose accuracy test
- Patient specific QA
  - Appropriateness of patients specific devices
  - Patient specific proton beam dosimetry

Basic Question of QA for scanning patients

- Are all points in the patient receiving the dose approved by the physician?

Basic Question of QA for scanning patients

- Are all points in the patient receiving the dose approved by the physician?
- Guard against two modes of failure:
  - Treatment planning system (TPS) computes incorrect machine parameters such as spot positions, spot monitor units (see discussion)
  - Hardware fails to deliver what was computed by TPS

Added challenge of scanning vs. passive scattering

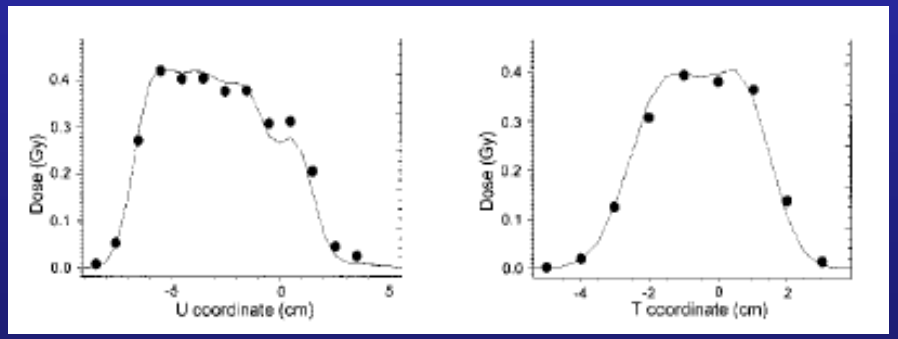
- Scanning has more free parameters, hence more can go wrong
- Scanning dose application varies in space and time
  - Scanning dose at a single point <u>not</u> an indicator of dose elsewhere.
  - Accumulated scanning dose does not scale linearly with time.

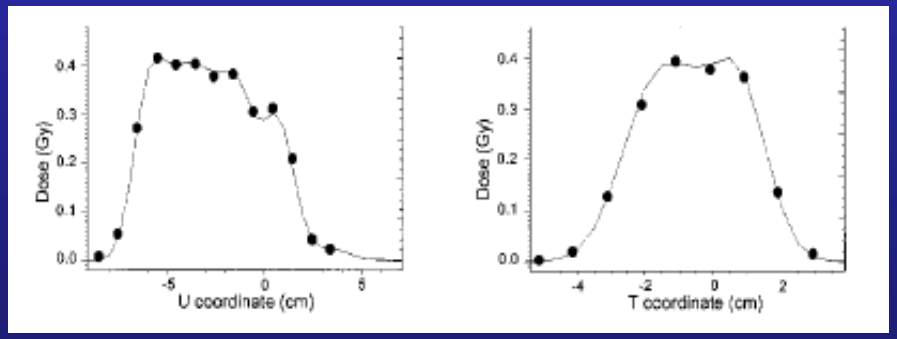
3D approaches

- Ideal solution: Measure dose delivered during entire beam delivery at all points in the patient
  - Impractical? (use positron emission tomography, MGH, GSI)
  - If not in the patient, in a phantom? (scintillator, MGH)

1D approach taken at Paul Scherrer Institute (PSI)

- Array of 2x13 ionization chambers arranged in orthogonal lines perpendicular to beam direction.

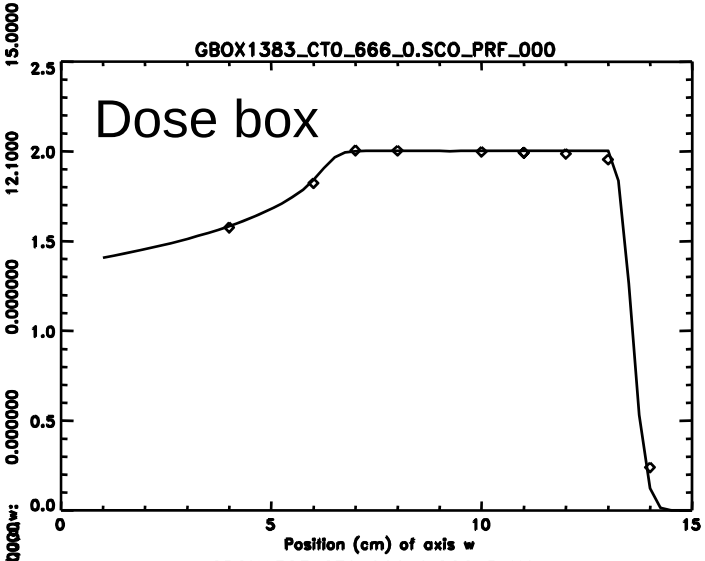


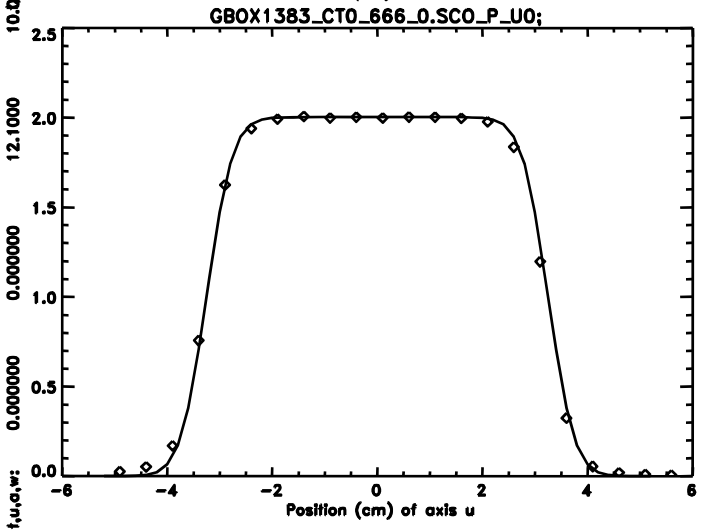


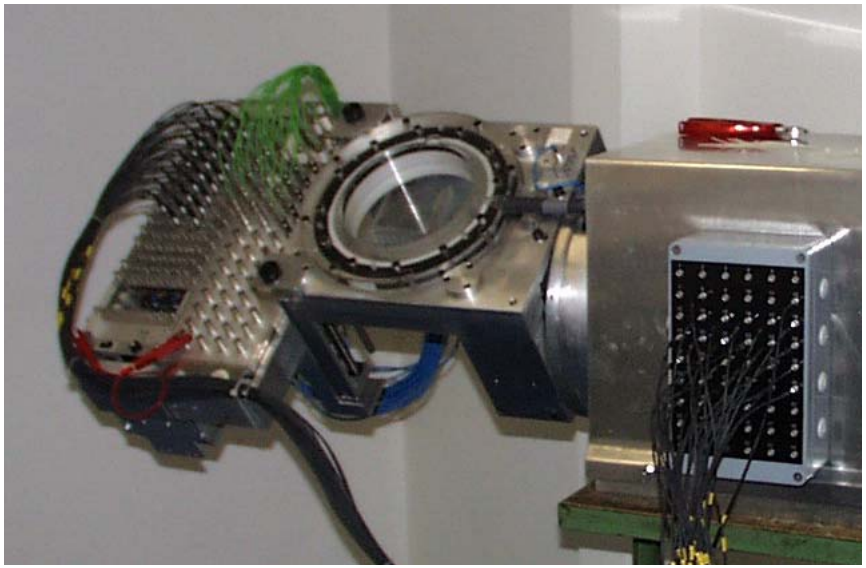
Lomax et al., Med. Phys. 31 (11), 2004

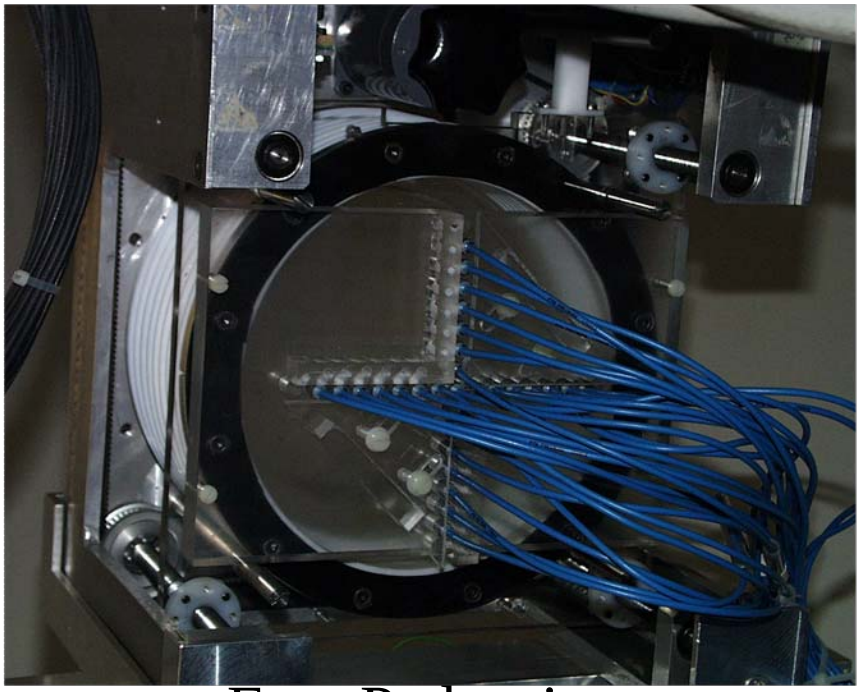
IC array

Water column with 26 small ionization chambers of 0.1 ccm









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2D phantom dosimeter developed at PSI

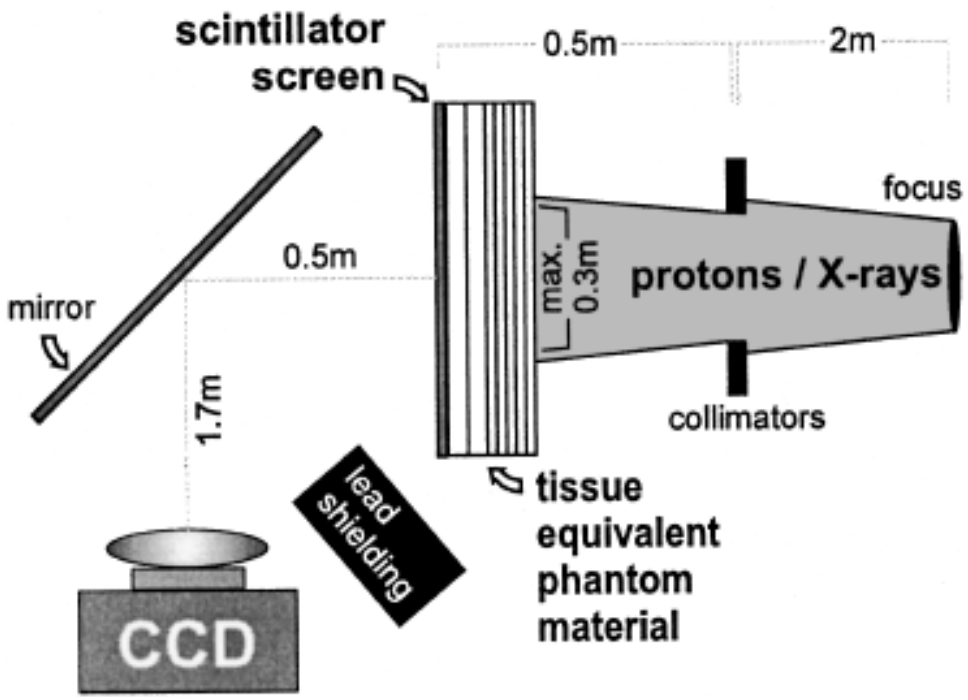
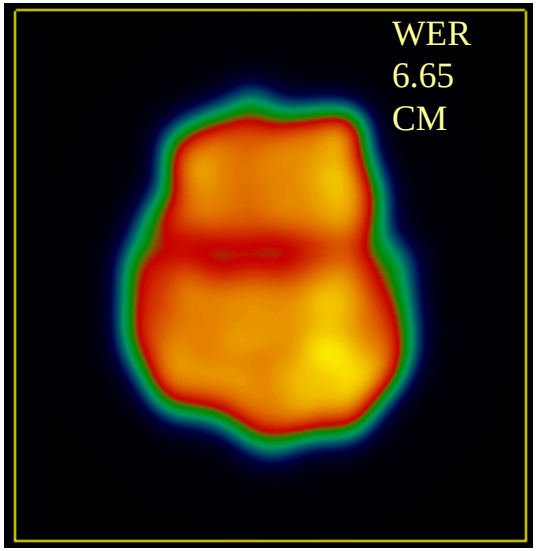


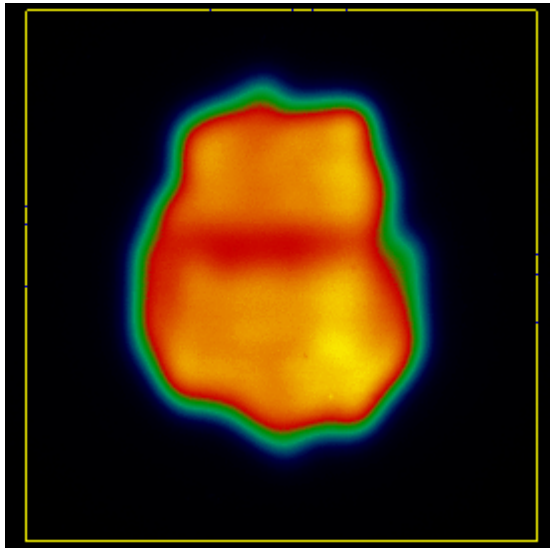
FIG. 1. Diagram of the setup.

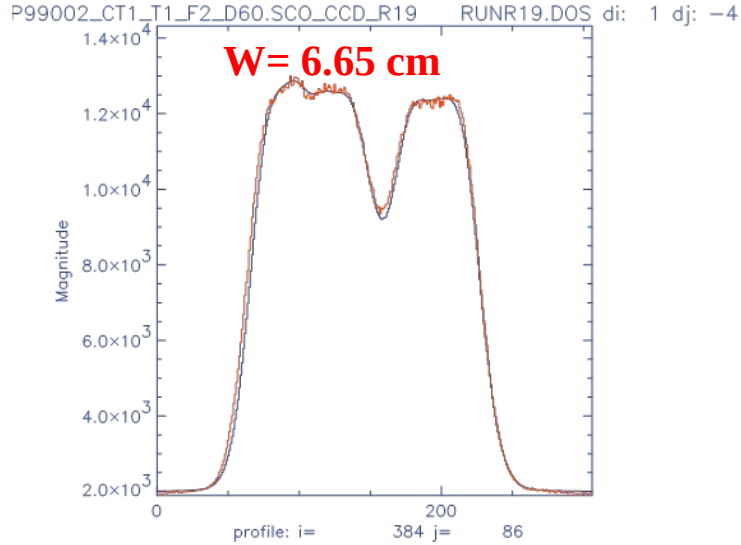
Boon et al., Med. Phys. 27 (10), 2000

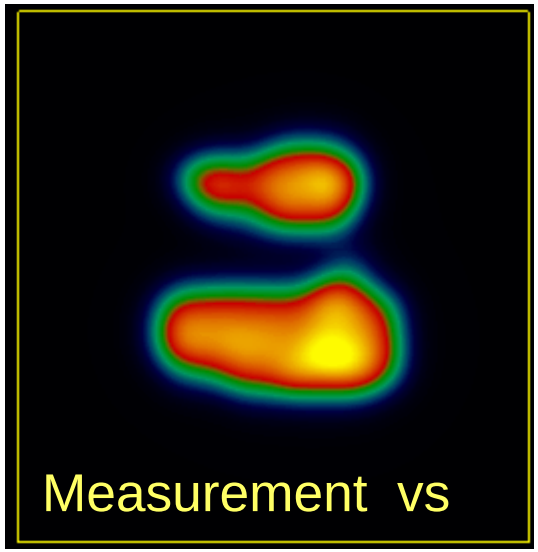
Scintillating screen viewed with a CCD through a 45° mirror

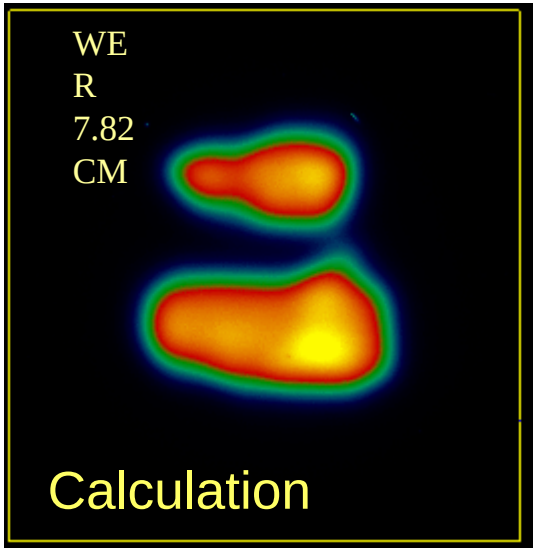
– ideal for non homogeneous dose distributions

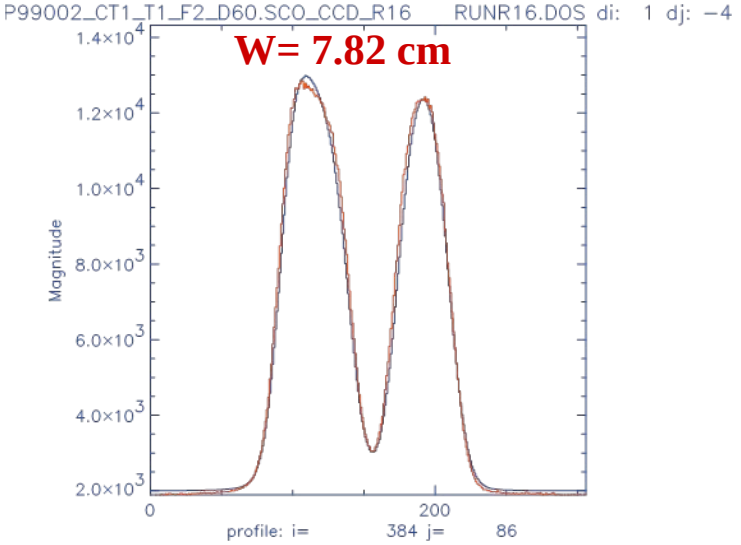












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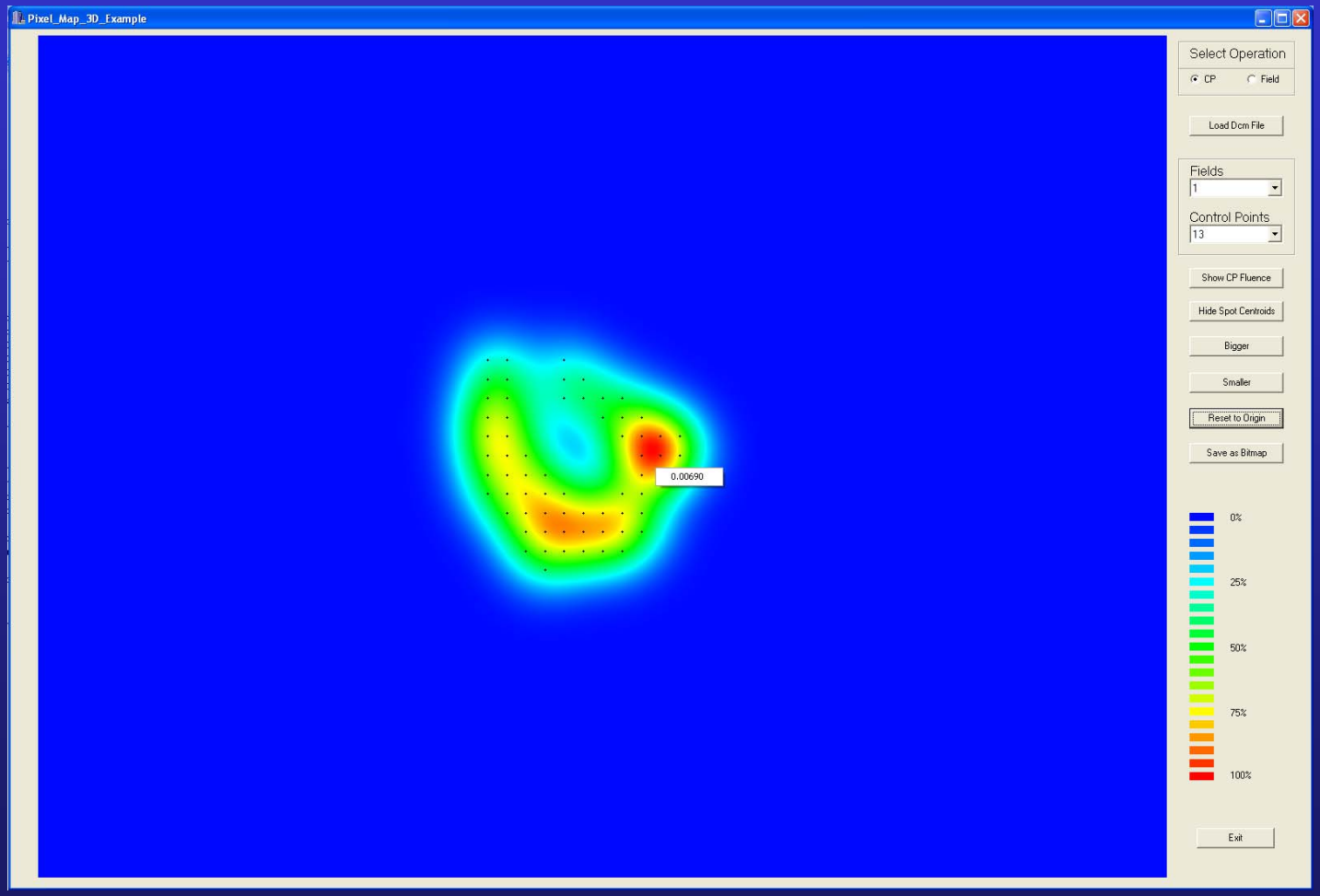
Fluence based proton scanning QA – under development

- Measure proton fluence in air for each energy separately.
- Compare measured fluence to planned fluence.
- Feed measured fluence into dose calculation algorithm (TPS or Monte Carlo) and compute dose on Patient CT and phantom.
- Determine appropriateness of deliverable treatment based on Patient CT calculation.
- Measure dose in phantom.
- Check performance of TPS by comparing predicted and measured water phantom dose.

PTC-H Lanex CCD device

Desired Fluence map for prostate IMPT field



Film dosimetry using EBT Gafchromic film