Patient Specific QA

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Learning Objectives

1. Patient specific quality assurance (QA) for passively scattered beams
2. QA challenges for pencil beam scanning (PBS)
3. In-vivo dose verification techniques

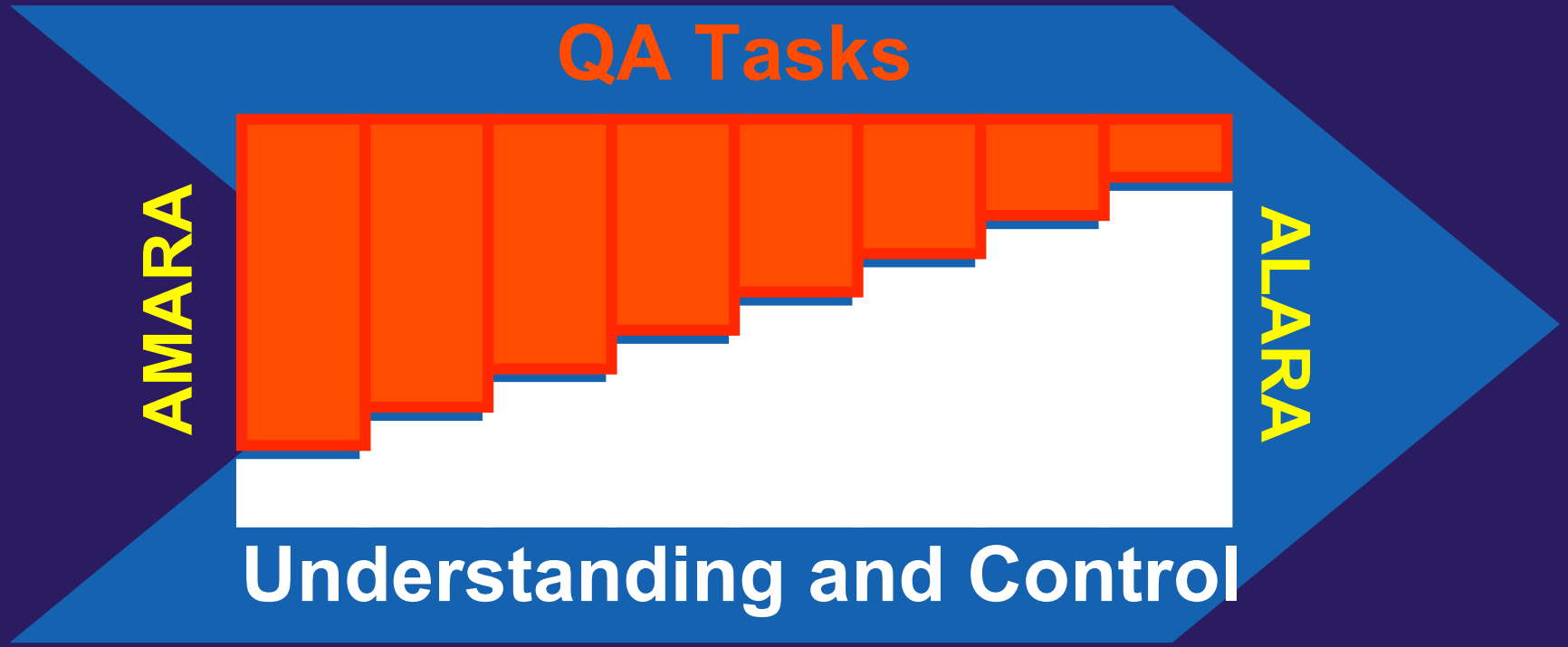
What Needs QA

"AMARA" or "ALARA"

As Much/Little As Reasonably Achievable/Acceptable

Not Exactly Contradicting!

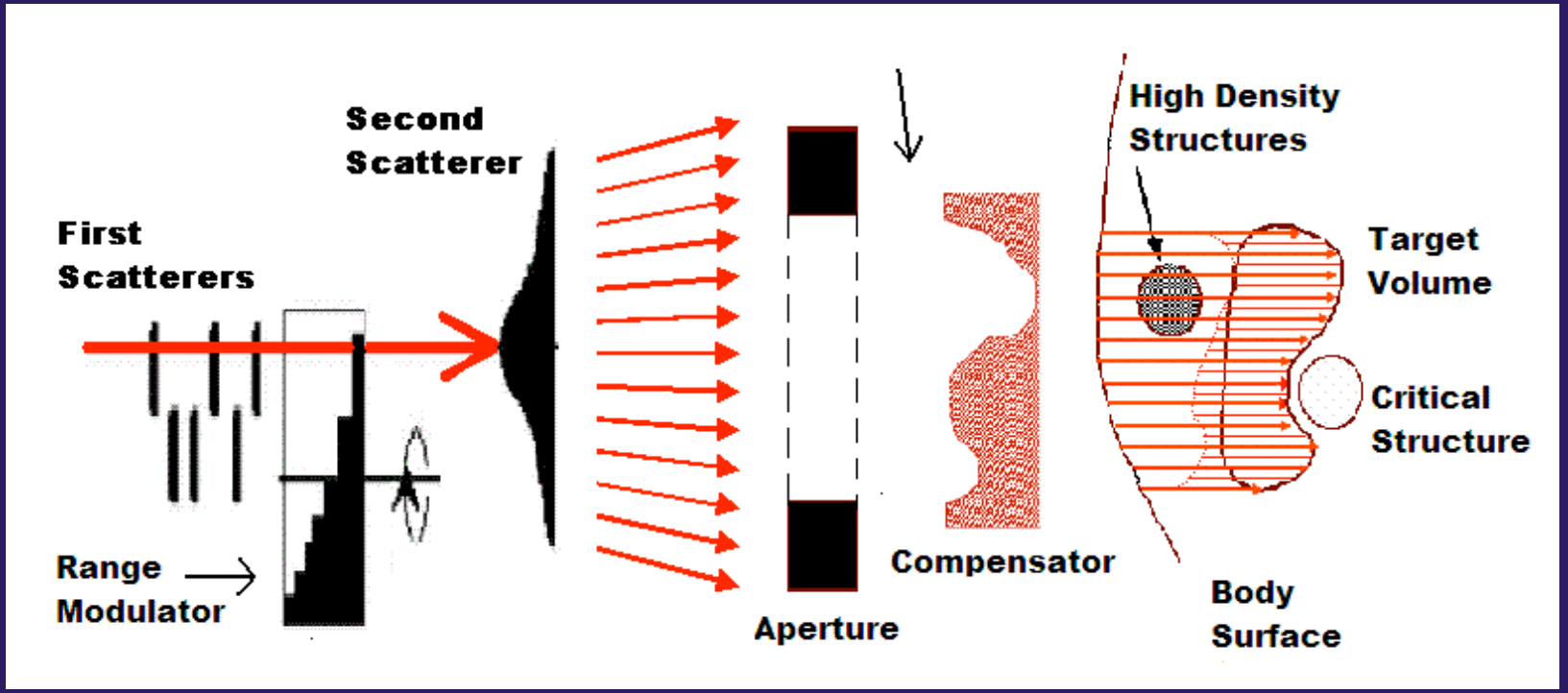
QA Evolution



Patient specific → Systematic

QA for Passive Scattering

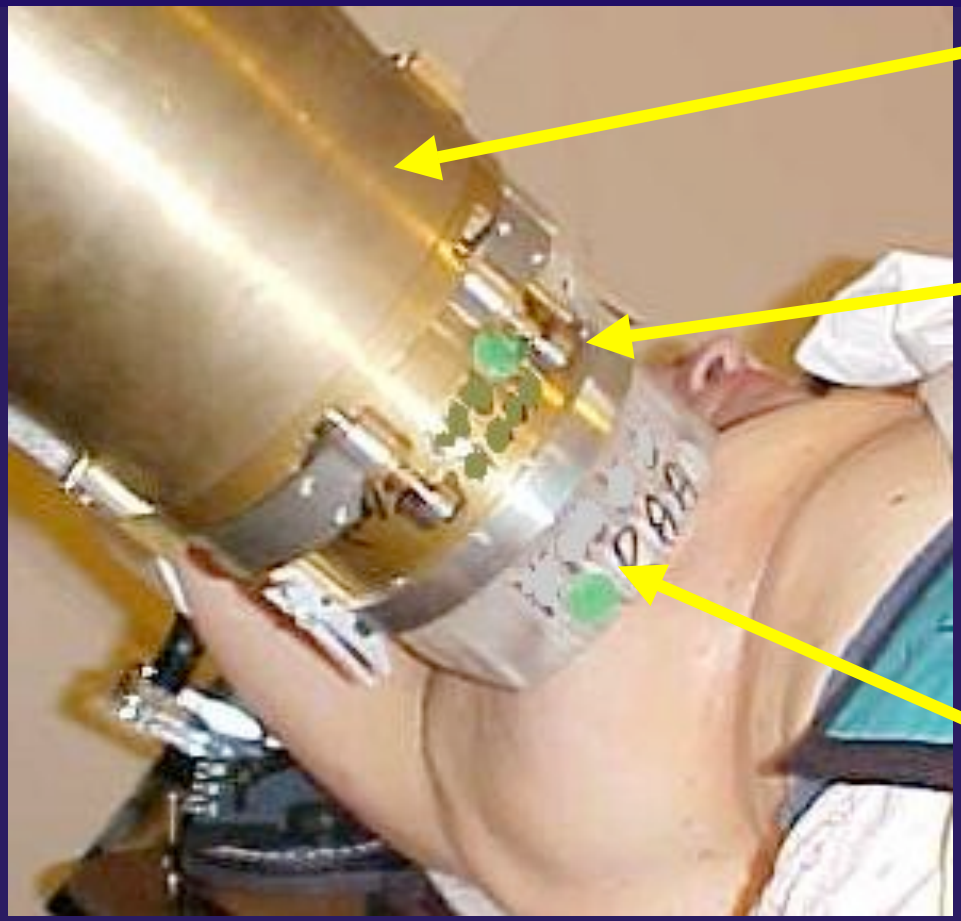
Passive Scattering



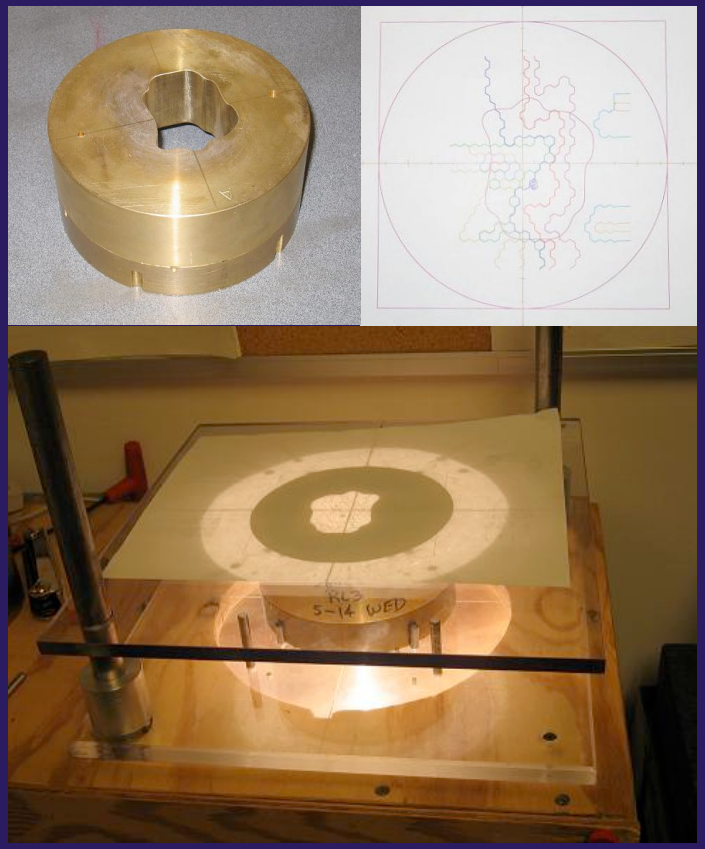
Treatment plan specifies:

Aperture, compensator, range, mod, output factor

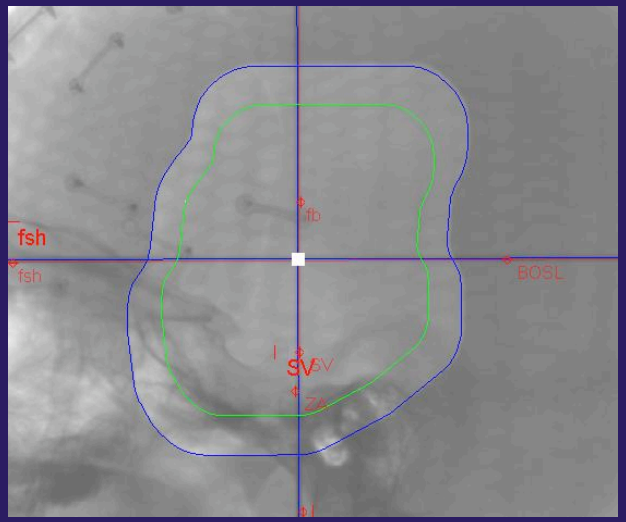
Treatment Configuration



Aperture



- **Physical Verification: Tolerance < 0.5 mm**
- **Imaging Verification: Tolerance < 1 mm**



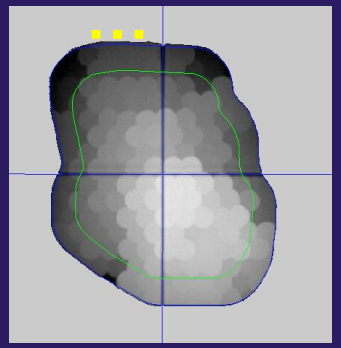
Range Compensator

Range in patient depends on thickness

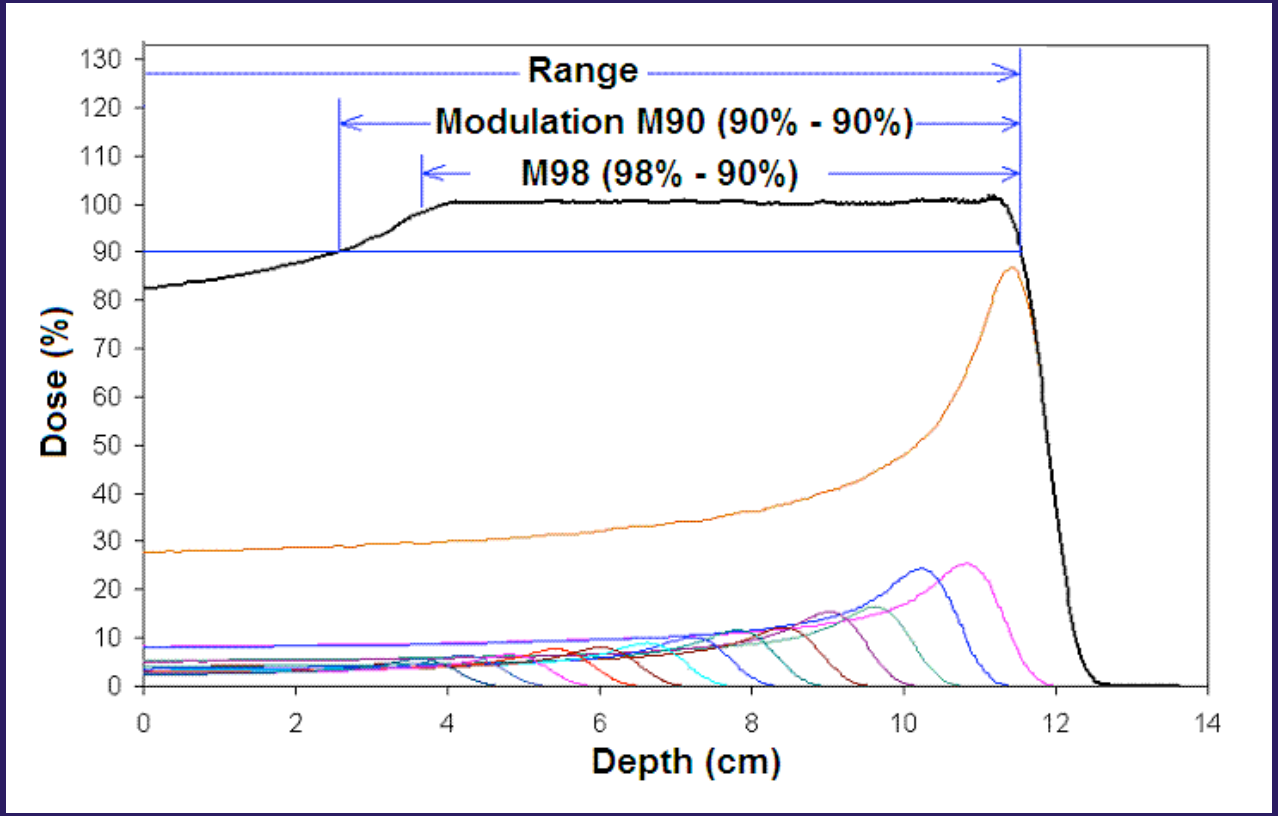
$R_p (x, y) = R_{beam} – T (x, y)$

Check T(x,y) at a selected points

Modern technology?
Laser, ultrasound,
X-ray transmission,



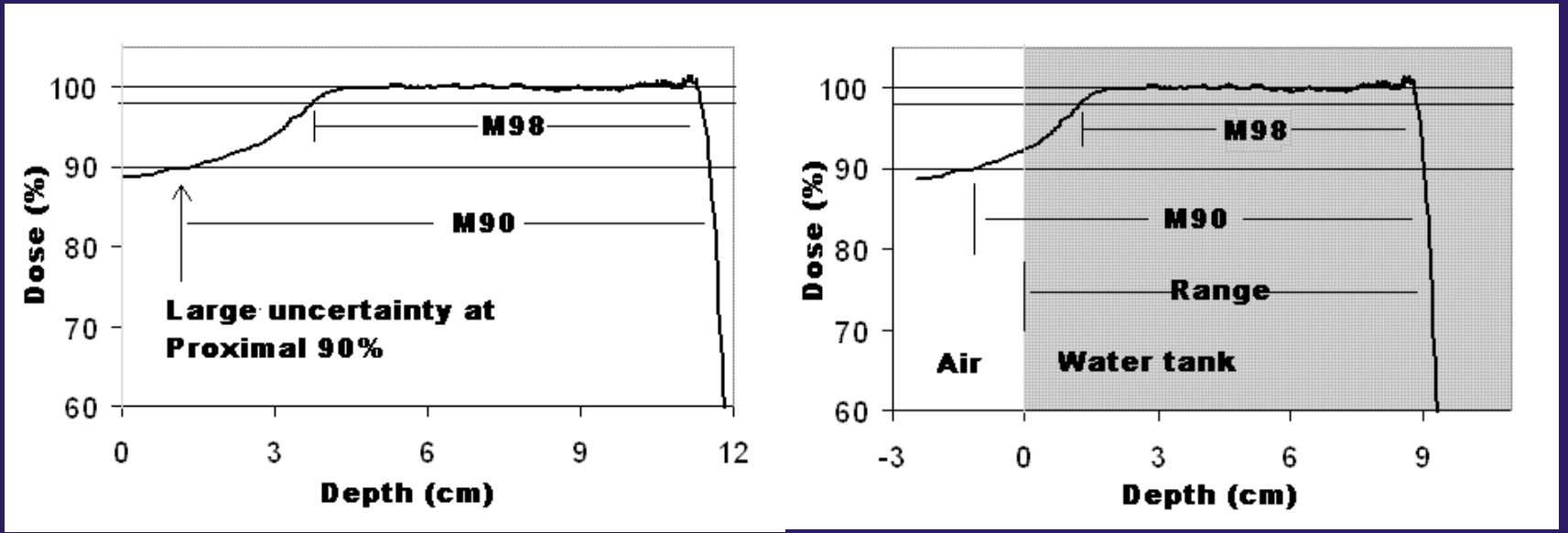
Range and Modulation



Two definitions: M90 (90%-90%) and M98 (98%-90%)

M90 versus M98

- M90 -- historical, M98 -- clinically relevant
- Large uncertainties in M90 for large mod
- M90 value may be larger than range
  → impossible to verify

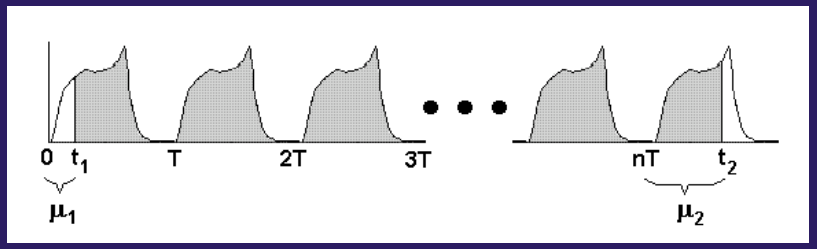


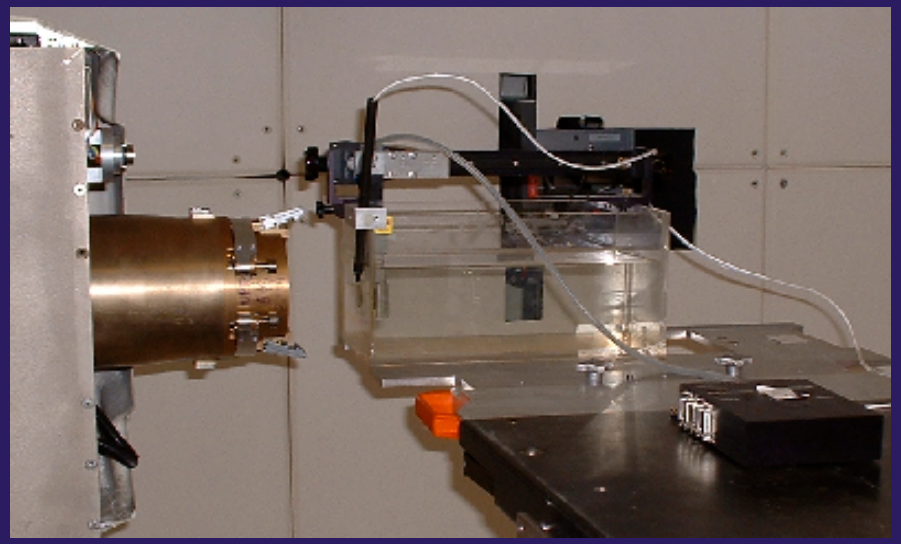
Measuring Depth-Dose

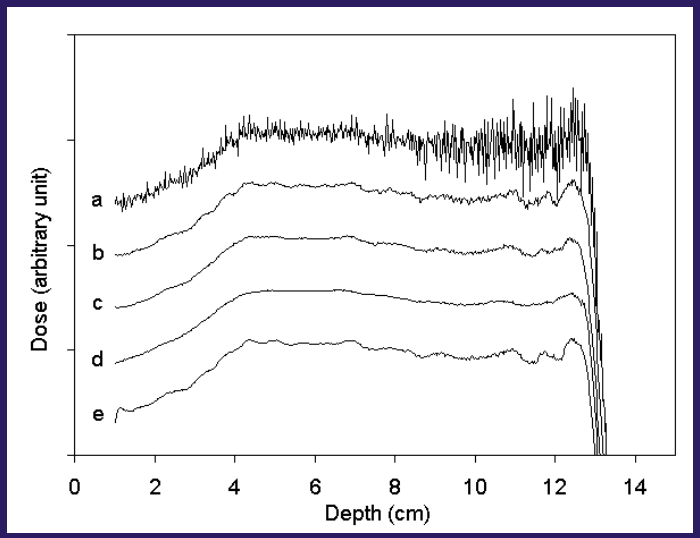
Sampling interval

$t_2 - t_1 = nT$

$N = 2, \delta t < 1$ ms



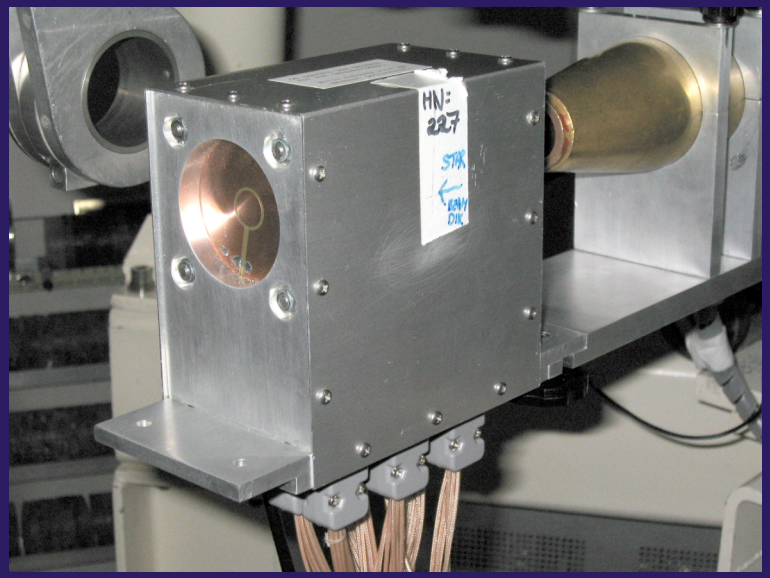


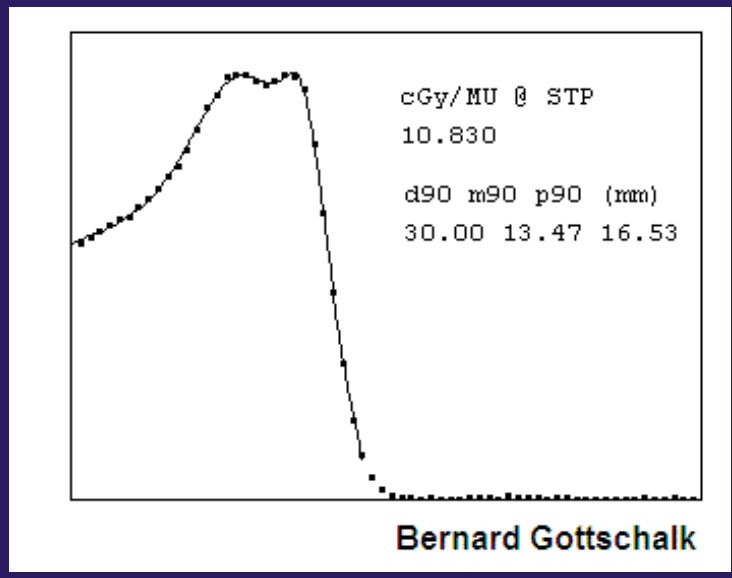


Lu, Med. Phys. 33 (7), 2006

Measuring Depth-Dose

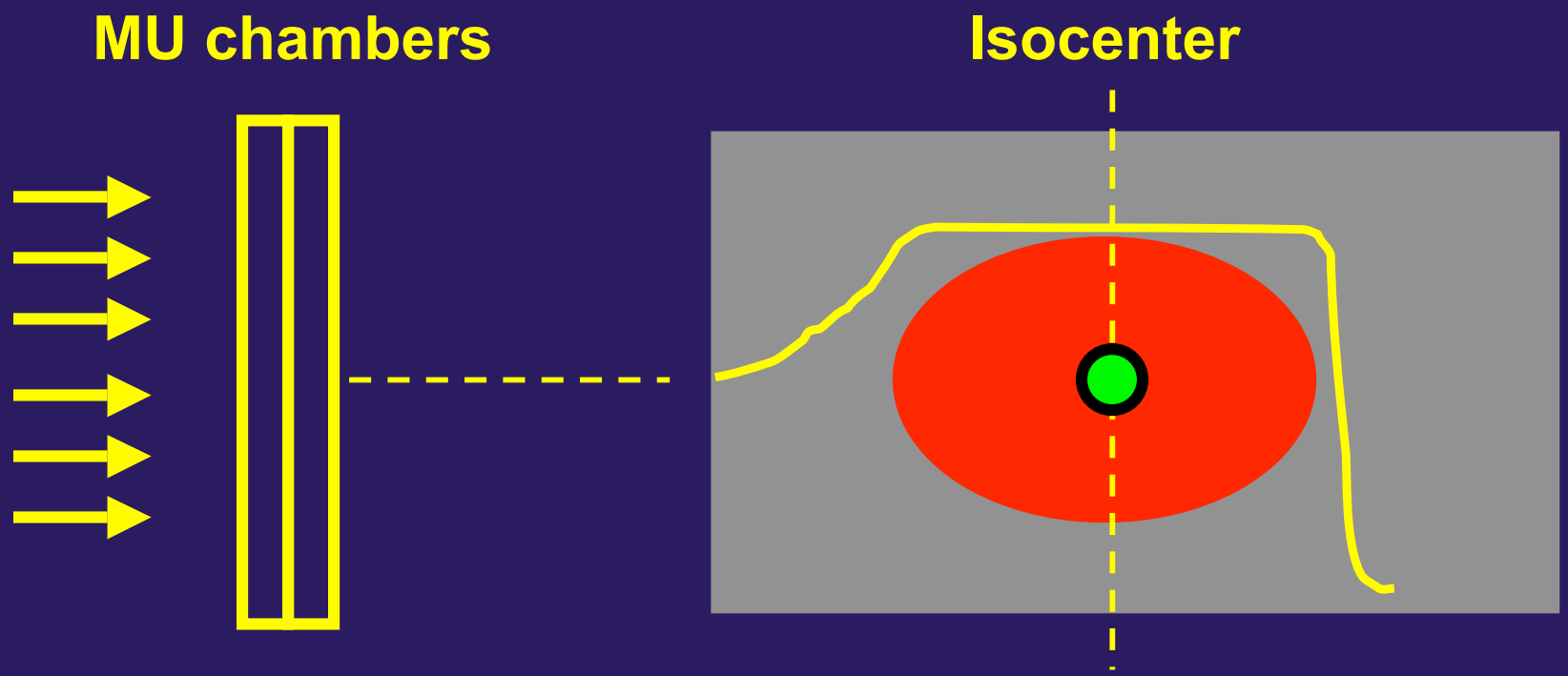
- Multi-Layer Ionization Chamber (MLIC)
- 64 plates with 8 chambers per cm
- Cover 8 cm depth





http://physics.harvard.edu/~gottschalk

Measuring Output Factor



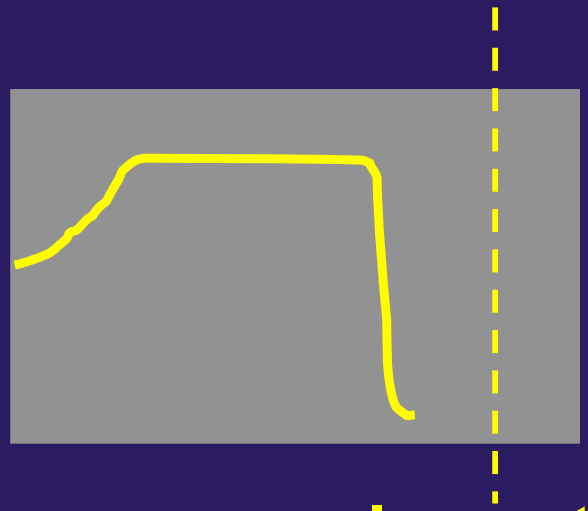
Output factor depends on ratio r = (R-M)/M

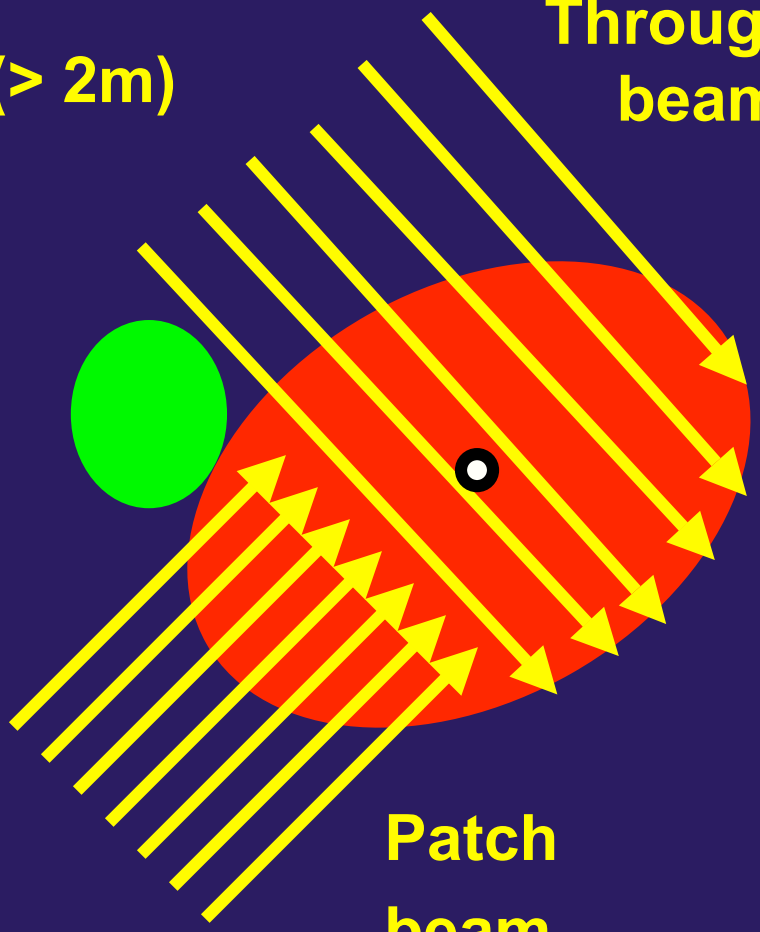
Kooy et al, PMB 48, 2003

Inverse Square Effect

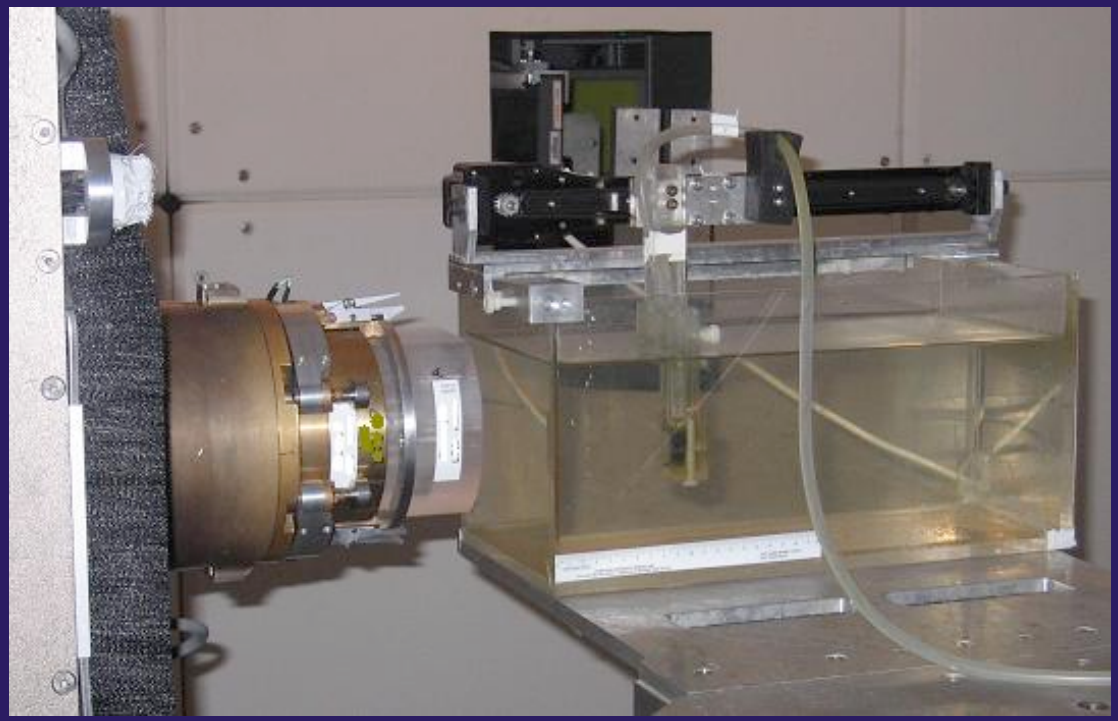
Small due to large SAD (> 2m)

But …





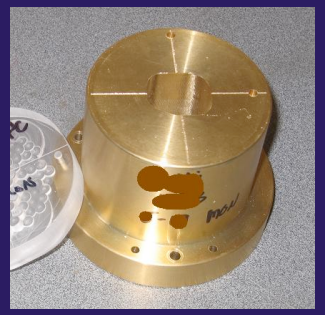
Measuring Output Factor



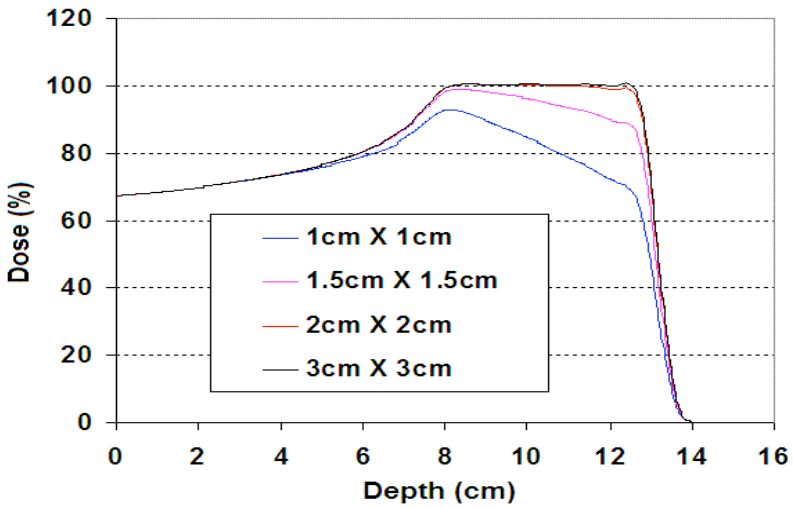
With aperture and compensator?

Field Size Effect

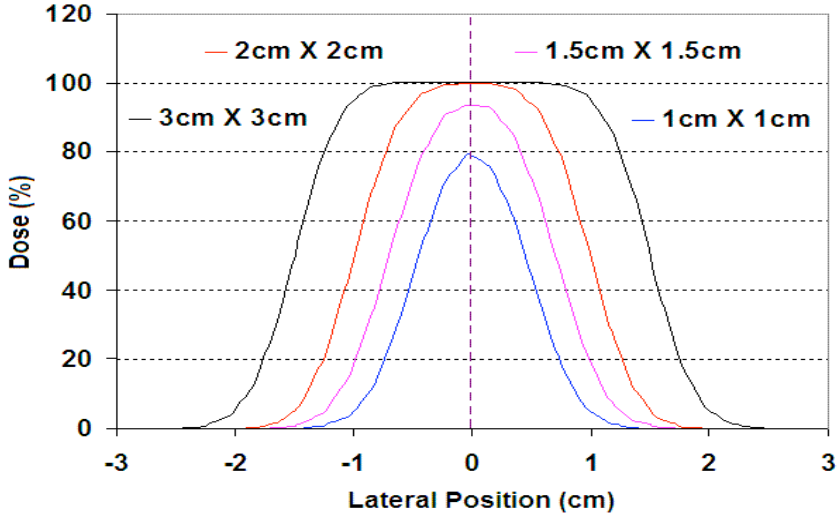
Pencil beam calculation (Xio, CMS, Inc):



Depth Dose

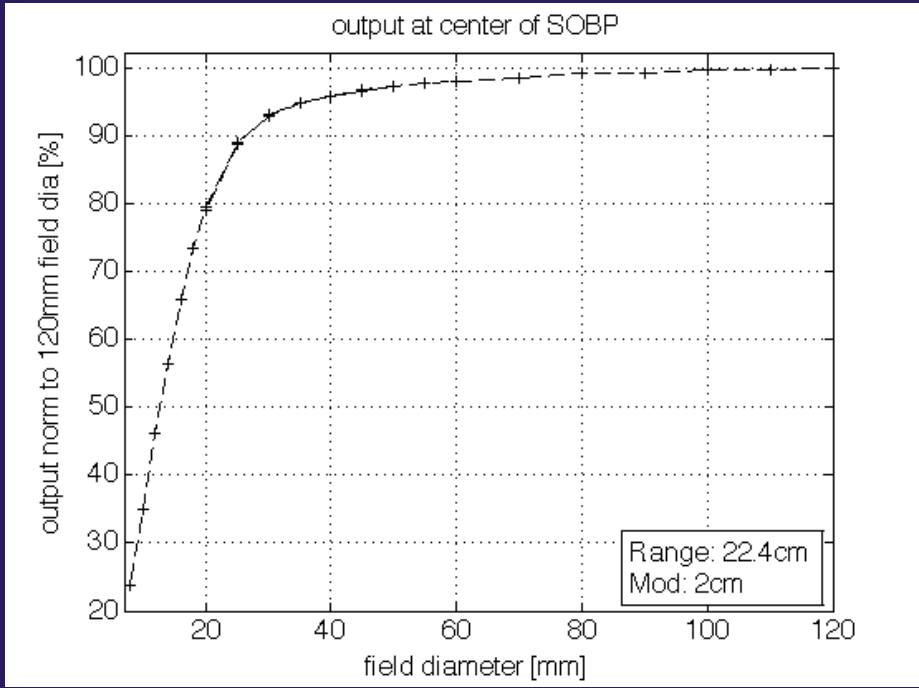


Lateral Profile



Field Size Effect

Measured output change for small field sizes



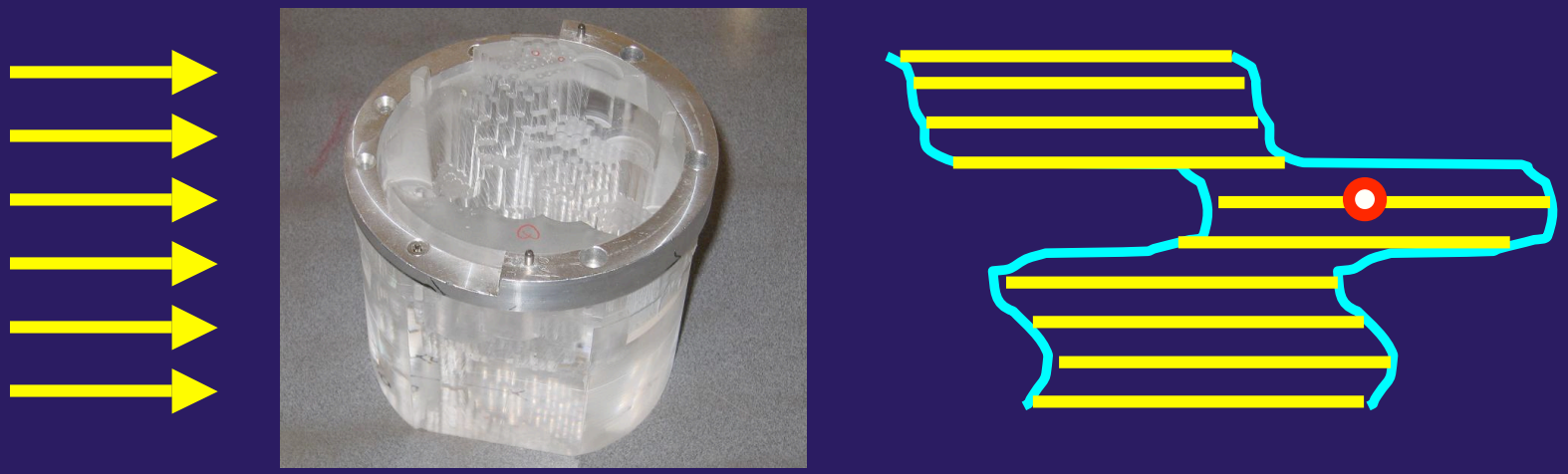
Go to poster:

"Field Size Dependence of the Output Factor in Proton Radiotherapy"

Juliane Daartz, Martijn Engelsman, Marc Bussiere

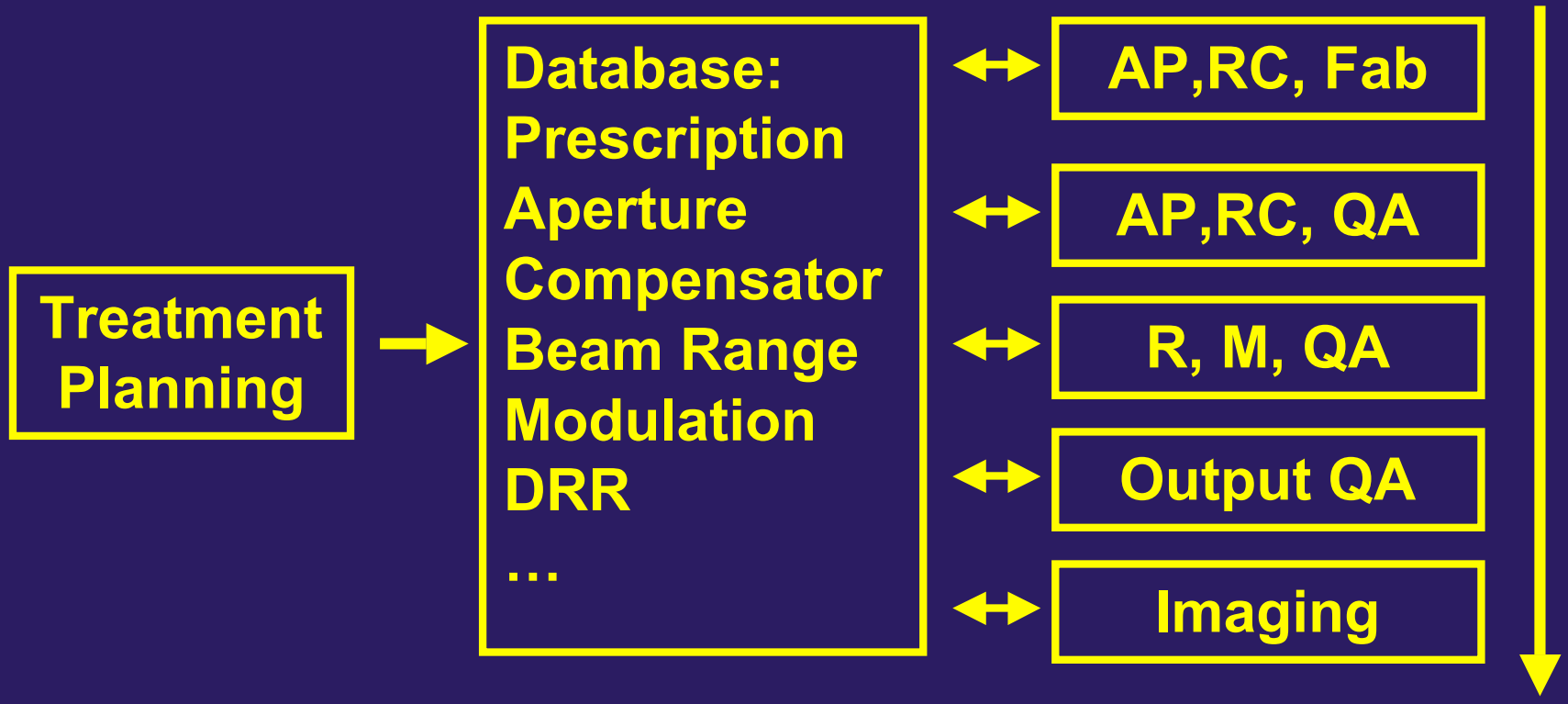
Compensator Effect

deep and narrow



Narrow part equivalent to small field

Information and Work Flow



Statistics leads to confidence!

Understanding → Less QA

- Identify and correct system instabilities
- Establish model for output prediction
- Use M98 for SOBP specification

Full prediction of SOBP distribution

No more evening field cals!

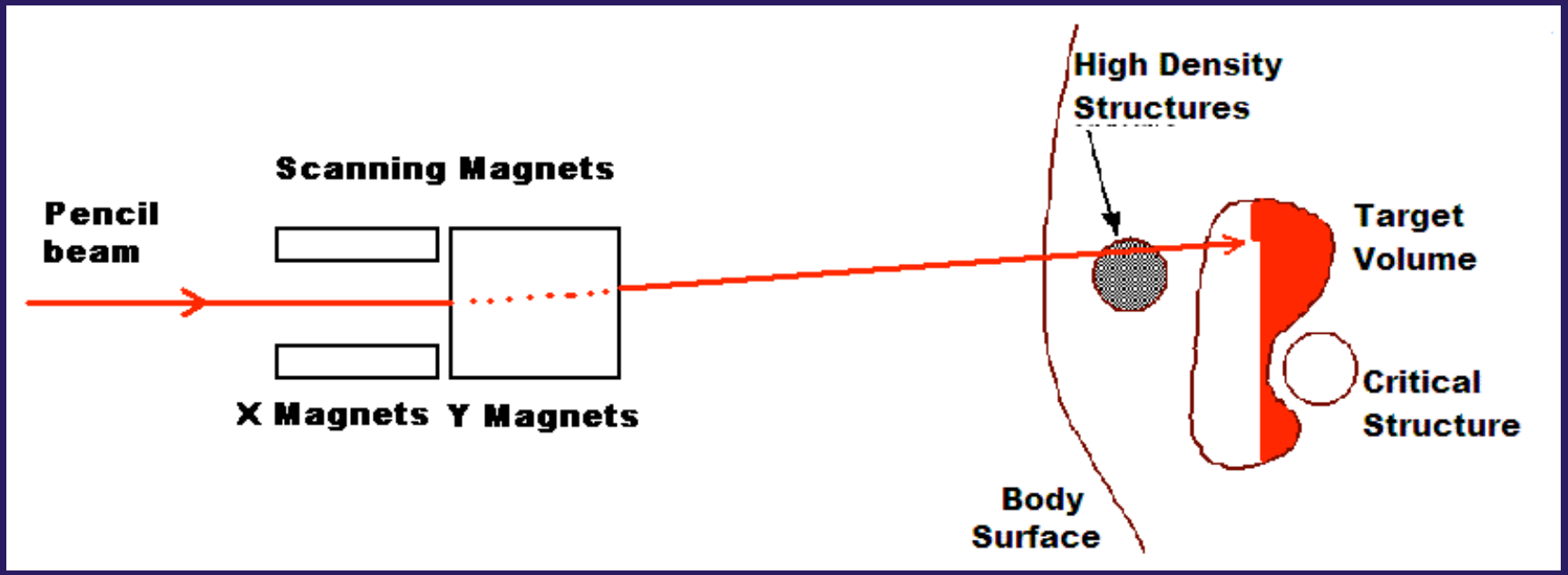
Go to poster:

"A Complete Predictive Model for SOBP Field Delivery"

Martijn Engelsman, Hsiao-Ming Lu, David Herrup, Hanne Kooy

What to do for PBS?

Pencil Beam Scanning



Pencil specification:

Particle energy (E), Particle count (N), Spot size (σ), trajectory (magnet settings)

Delivery Methods

- **Uniform scanning (wobbling)**
  - fixed scan paths, beam current constant over each layer, fixed range shift from layer to layer, use aperture and compensator
- **Spot scanning**
  - treat one spot at a time, beam off between spots, arbitrary range shift between layers
- **Dynamic scanning**
  - Beam non-stop within layer, customized scan paths, customized beam current modulation within layer, repainting

Getting Started

- Understand system capability
- Analyze potential risks
- Develop acceptance standards
- Develop system QA tasks
- Define patient specific QA accordingly
- Measure, analyze, and repeat!

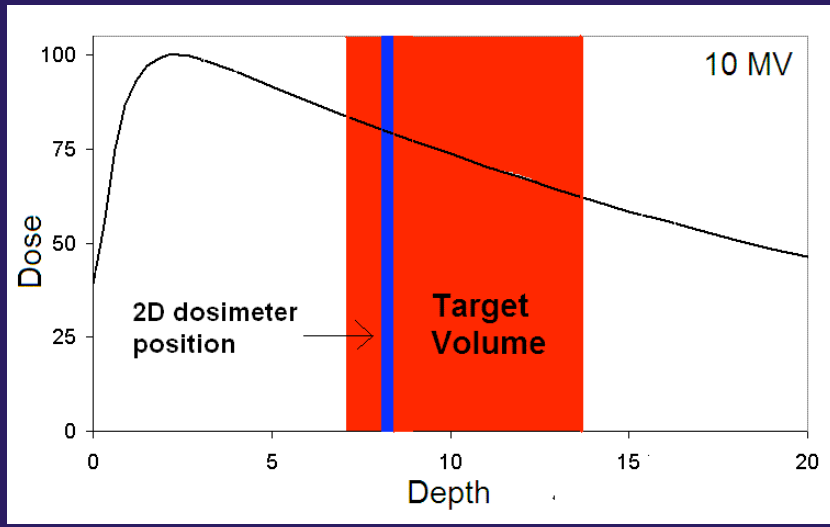
Remember how much you did for IMRT?

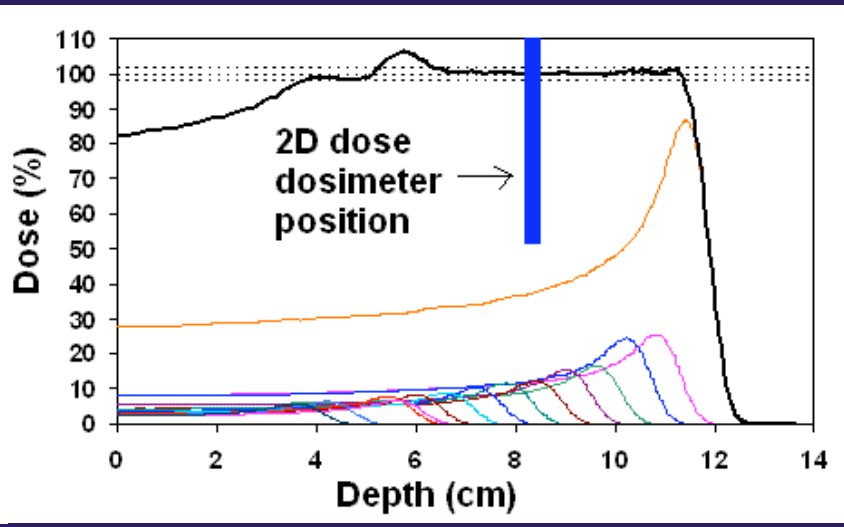
More than IMRT QA

Each layer has own "fluence map"

Standard IMRT QA (output and a 2D distribution)

Not enough!





2D check for IMRT

One layer off by 8 mm

In-Vivo Dose Verification

Sources of Uncertainty

- Planning CT
  - HU conversion to stopping power
  - Artifact due to metallic implants
- Setup errors
  - Variations in position and posture
  - Compensator-patient misalignment
- Organ motion
  - Lung, liver, pancreas, etc.

Point Dose Method

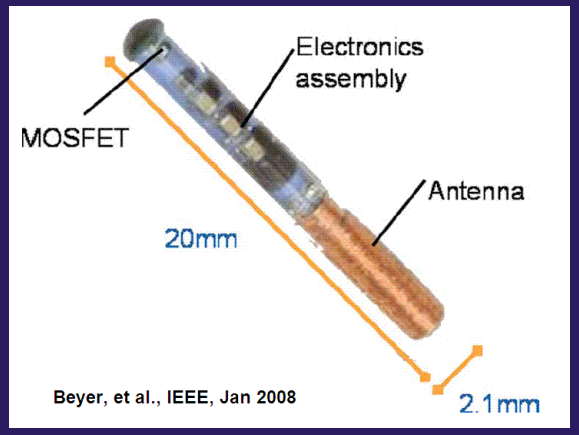
Widely practiced in photon/electron therapy

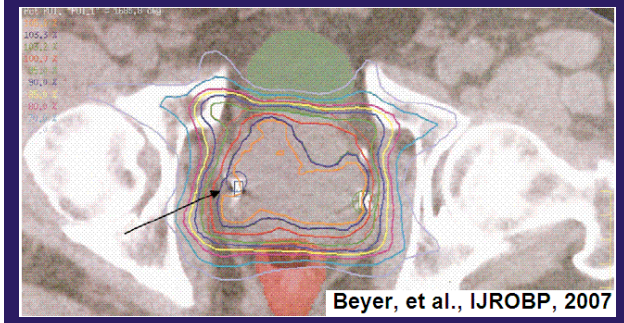
Detectors:

- MOSFET
- TLD
- Diodes

Locations:

- Surface
- Cavity
- Entrance
- Exit

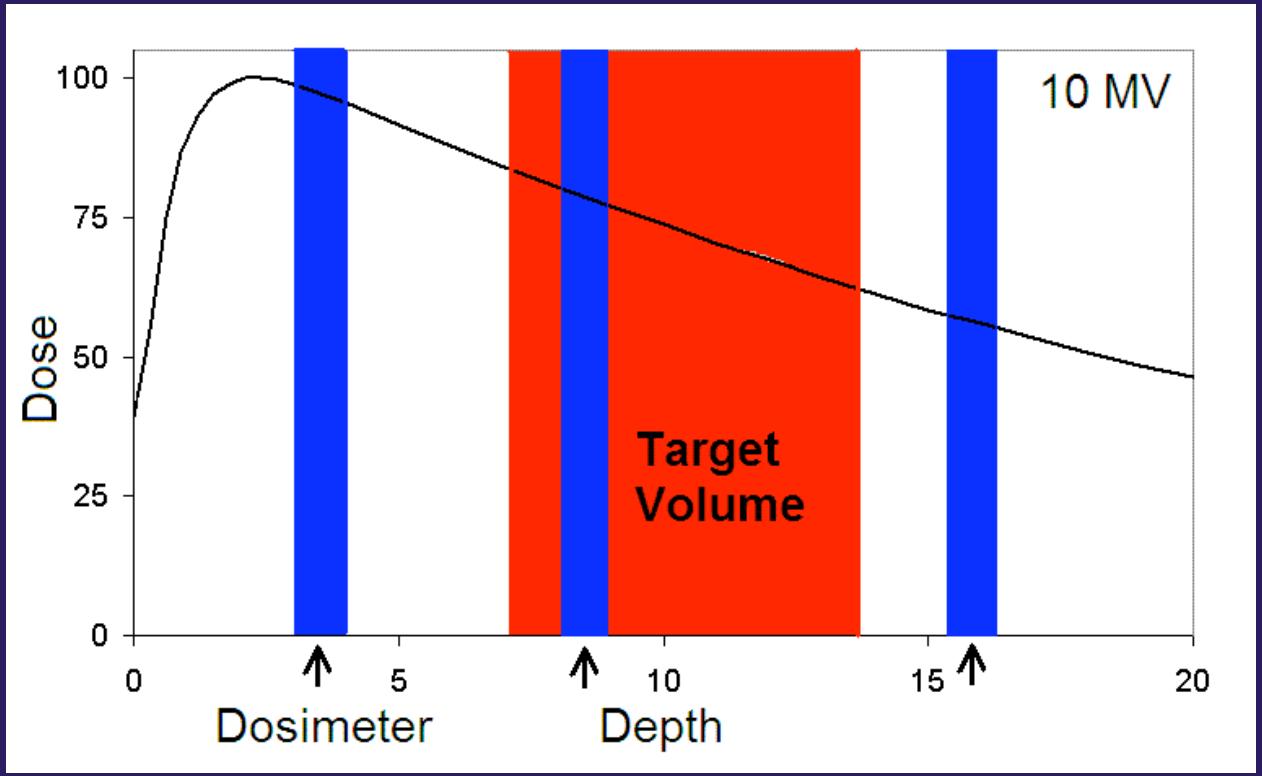




DVS, implants with wireless reading

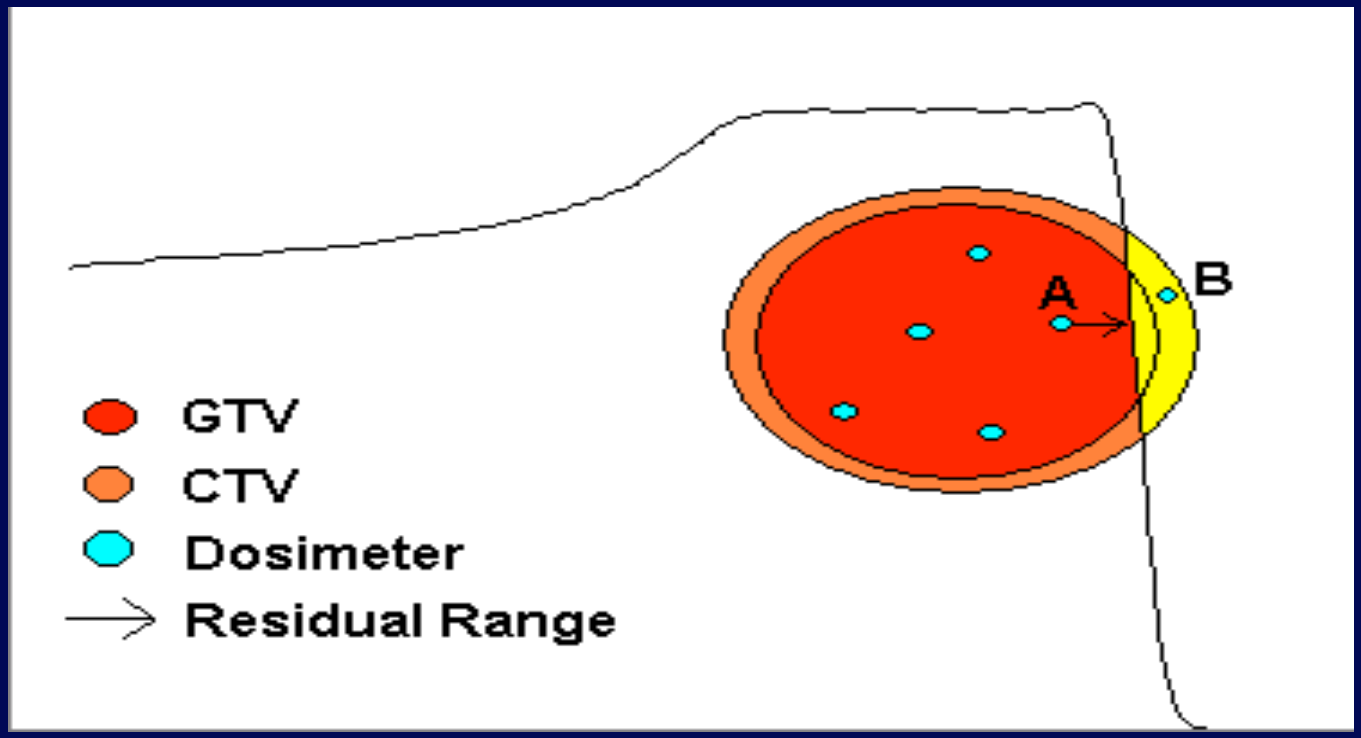
Photon Fields

Measure at one depth, know doses at all depths



For Protons? Not So Fast!

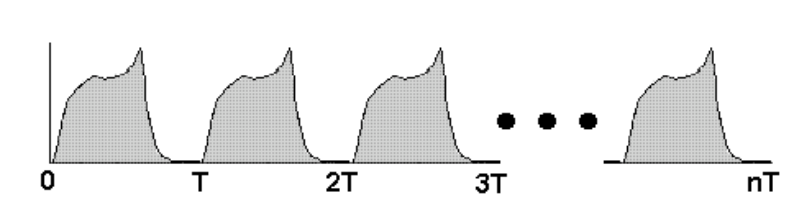
Full dose at point A, but zero dose at point B!



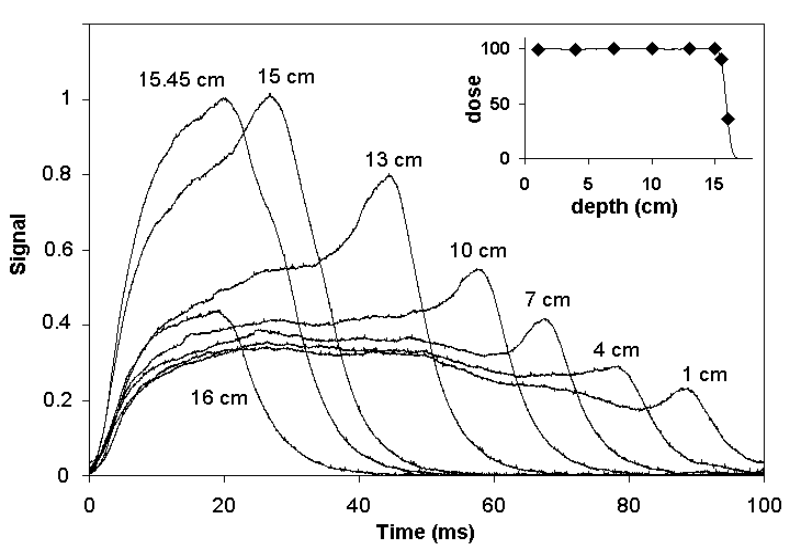
Also need residual proton range at point A

A Potential Method for DS Beam

Periodic Signal



Dose Rate Function d(t)



Unique time-dependence of dose rate at each depth

Time-dependence *encodes* radiological depth

Measure d(t) to get radiological depth to point

PET for Dose Verification

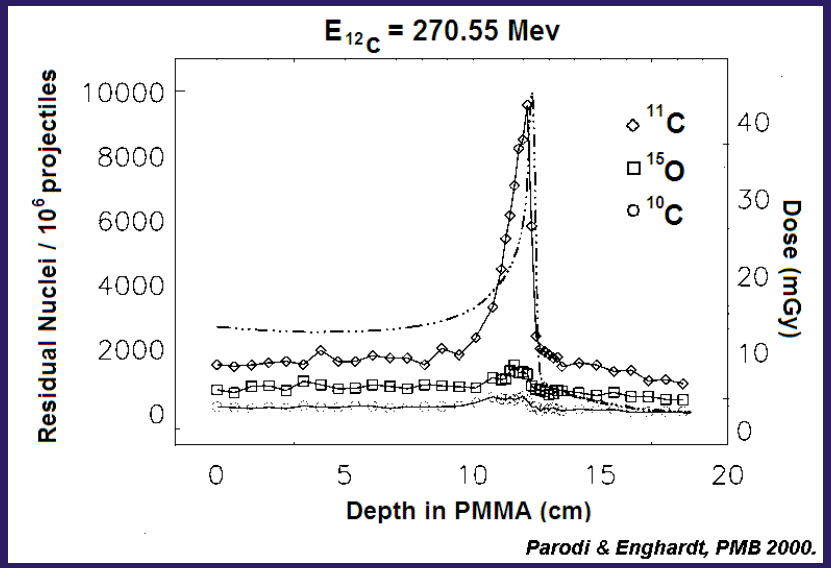
- Proton and heavy ion beams cause nuclear fragmentation reactions
- Products include positron emitters

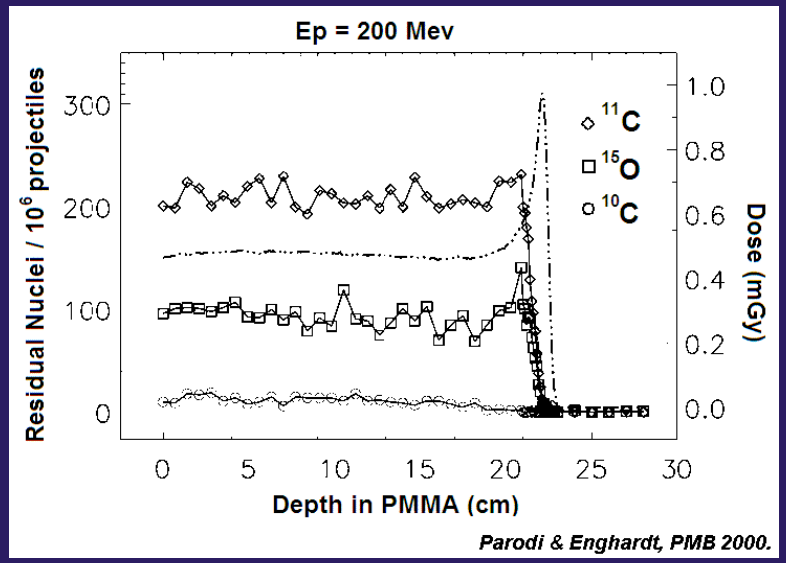
  ^{11}C ($T_{1/2}$=20.3 min), ^{15}O ($T_{1/2}$=122 s)
- Emitters stay at reaction sites
- Activity related to dose distribution

PET image → Dose distribution?

Activity for Bragg Peak

Monte-Carlo simulations (FLUKA) for proton and carbon beam



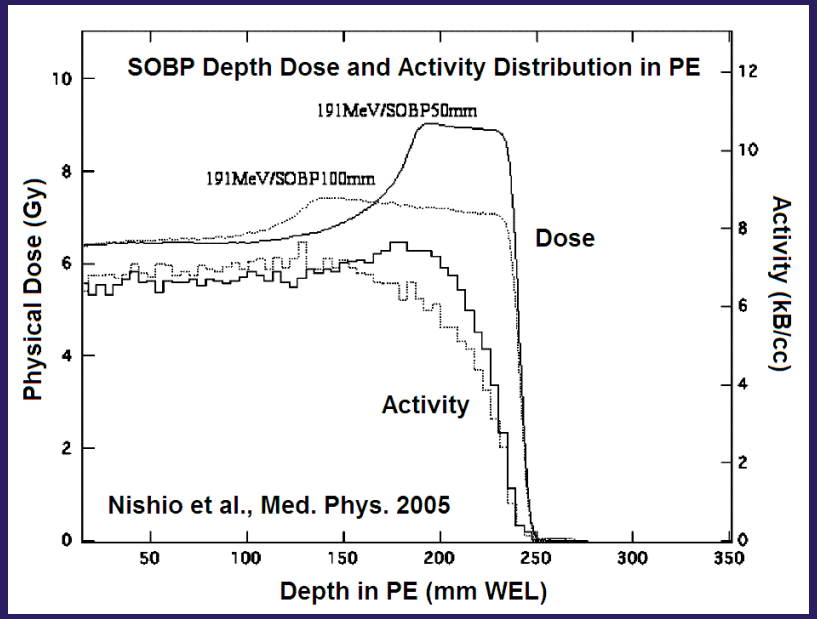


*(Parodi and Enghardt, Phys. Med. Biol. **45,** 2000)*

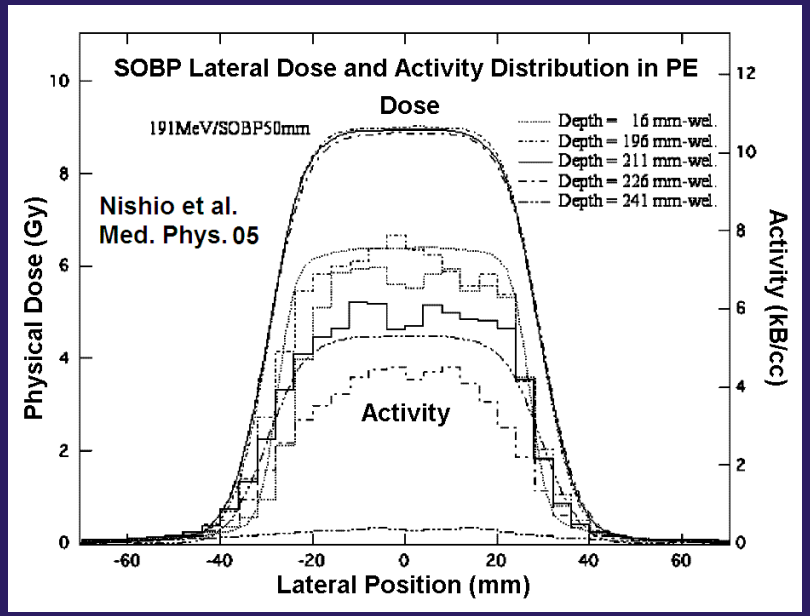
Activity for SOBP

Measured in polyethylene (PE) phantom

Depth Distribution



Lateral Distribution



*(Nishio et al., Med. Phys. **32**, 2005)*

Activity Related to Dose

- But, activity is not equal to dose
- Monte-Carlo (MC) simulations can compute both dose and activity distributions
- Compare simulated and measured activity distribution to confirm beam range, dose

Dose vs MC vs PET

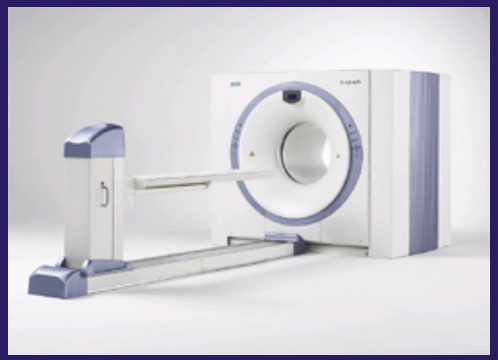
The Process

- **Emitter half lives**

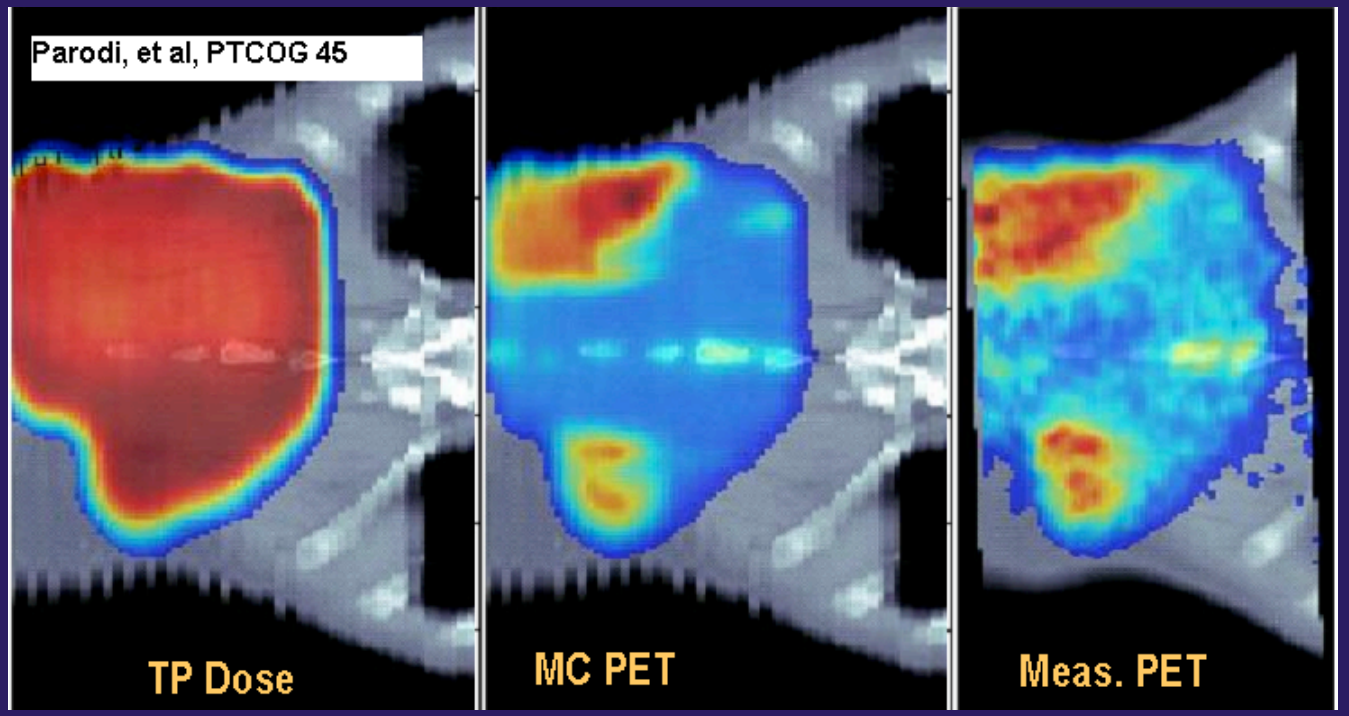
  $T_{1/2}$=20.3 min for ^{11}C

  $T_{1/2}$=122 s for ^{15}O

  ($T_{1/2}$=110 min for ^{18}F)
- **In-beam imaging (GSI)**
- **Post treatment PET/CT within 20 min (MGH)**



The Ultimate Proof



Must go to presentation:

"In-vivo Imaging in Particle Therapy"
Antje Knopf, 4:15PM, Friday, May 23, 2008

Thank You