MASSACHUSETTS GENERAL HOSPITAL
CANCER CENTER℠

A potential method for range verification in proton therapy treatment using range-modulated passive scattering fields

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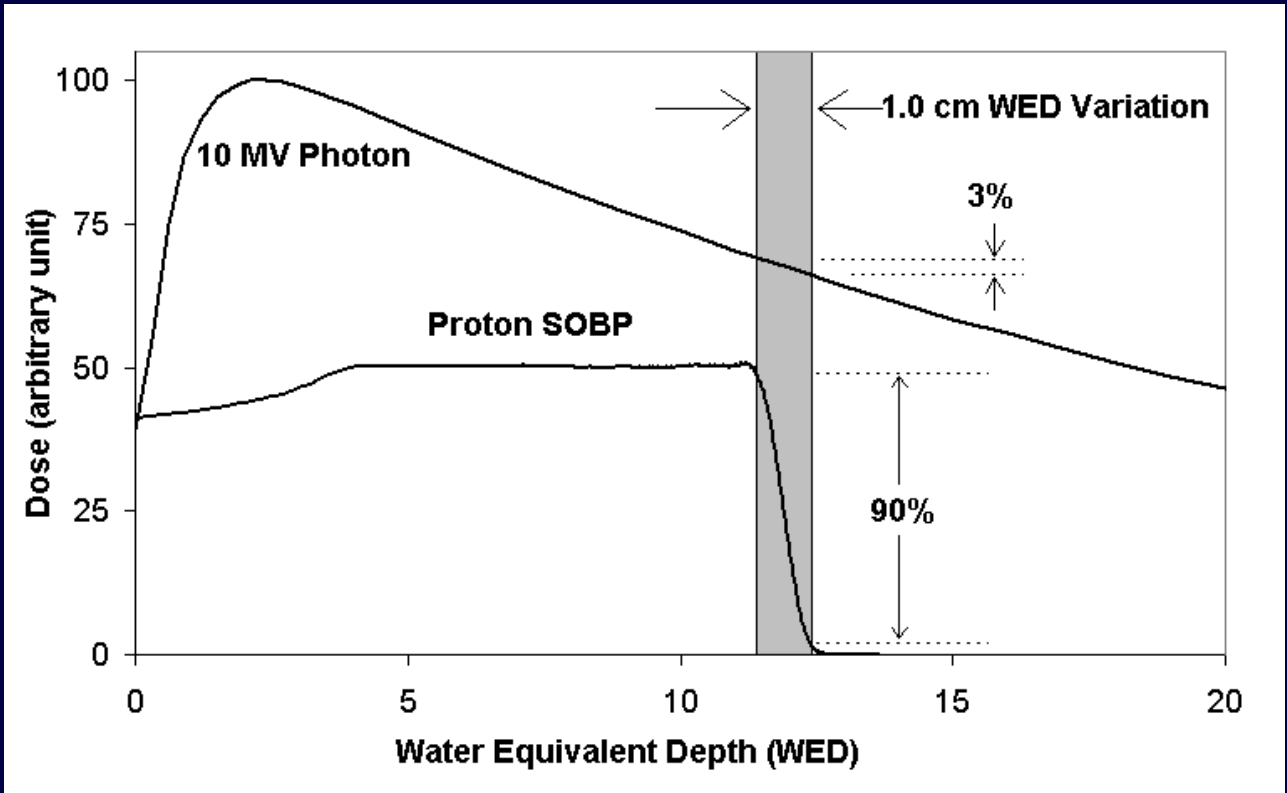
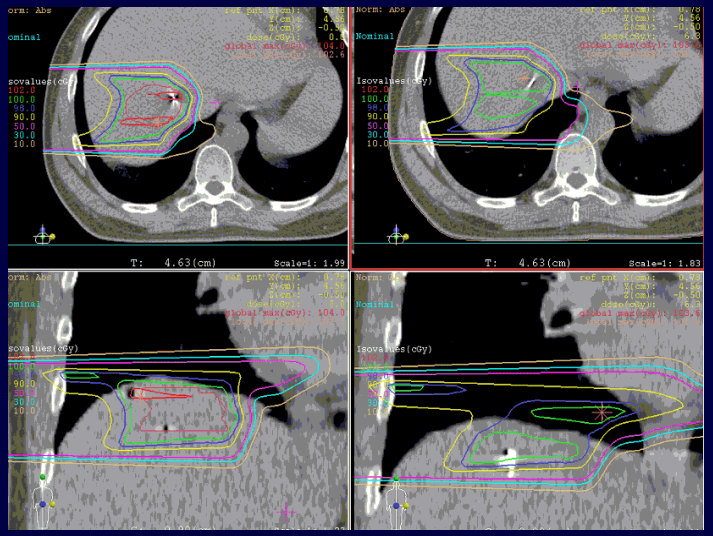
Proton Dose Distribution Extra Sensitive



Uncertainty in water equivalent depth (WED) causes ***overshoot*** or ***undershoot***

Sources of Uncertainty in WED

- Planning CT
  - Conversion to tissue density
  - Artifact due to metallic implants
- Setup errors
  - Compensator-patent misalignment
- Organ motion
  - Lung, liver, etc
  - Respiratory gating
  - No portal imaging

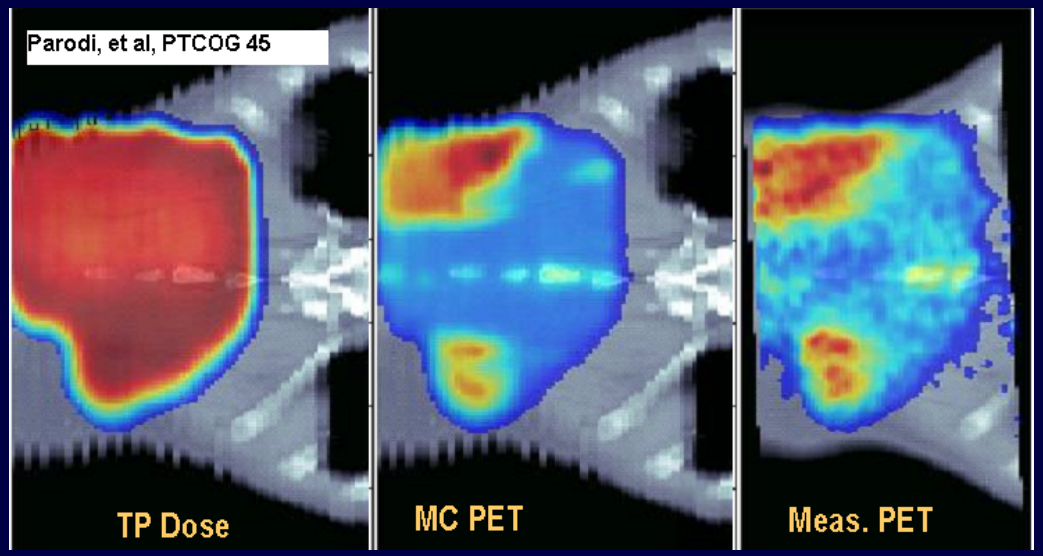


50% phase **0% phase (with field for 50%)**

In vivo dose verification would be great!

Treatment activated PET imaging

In-beam imaging or post-treatment PET/CT



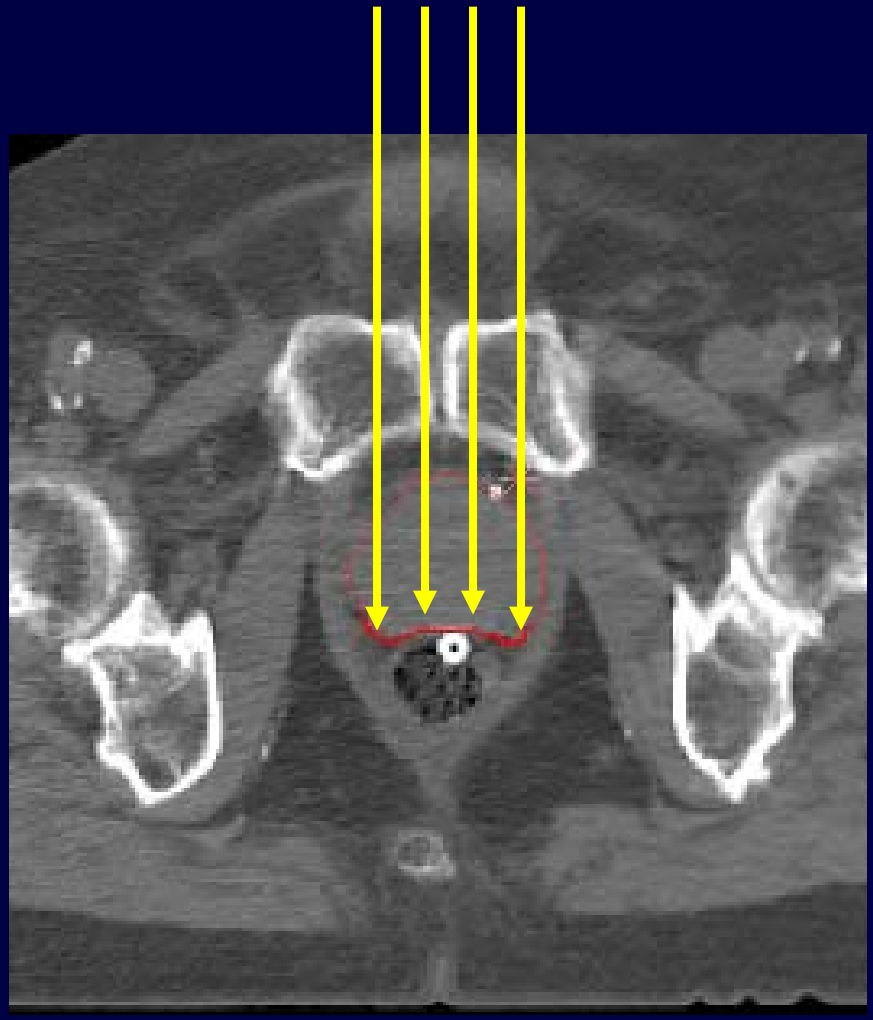
Issues:

- Expensive setup, timing too critical
- Non-interactive due to long computation time (hours)
- More for plan verification than for daily treatment

A Possible Scenario

Use the sharp distal fall-off to spare rectum wall in prostate treatment

Can we try the field first with low dose (<1%), and then adjust the proton energy?

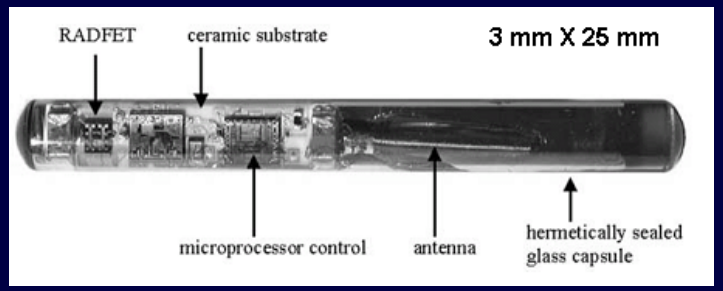


Point Dose Measurement

Detectors: MOSFET, TLD, Diodes

a) Surface use for skin or entrance dose

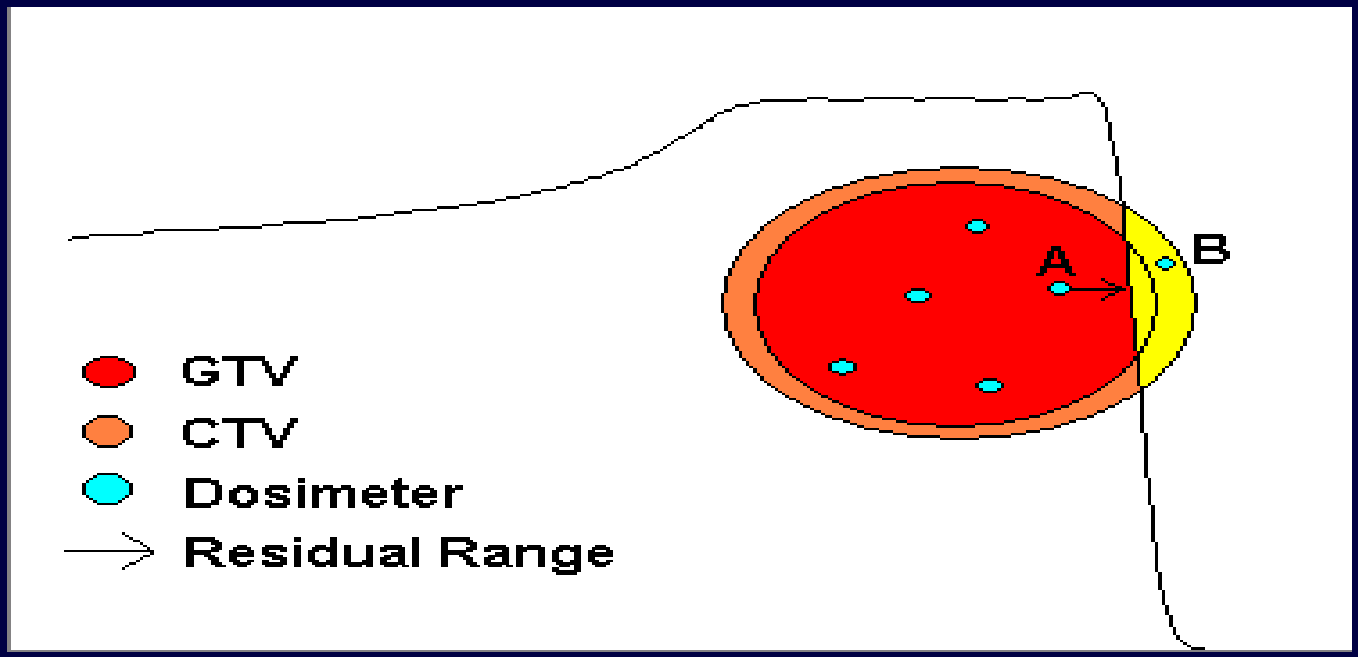
b) Implants with wireless reader



Widely practiced in photon/electron therapy

Not So Easy for Protons

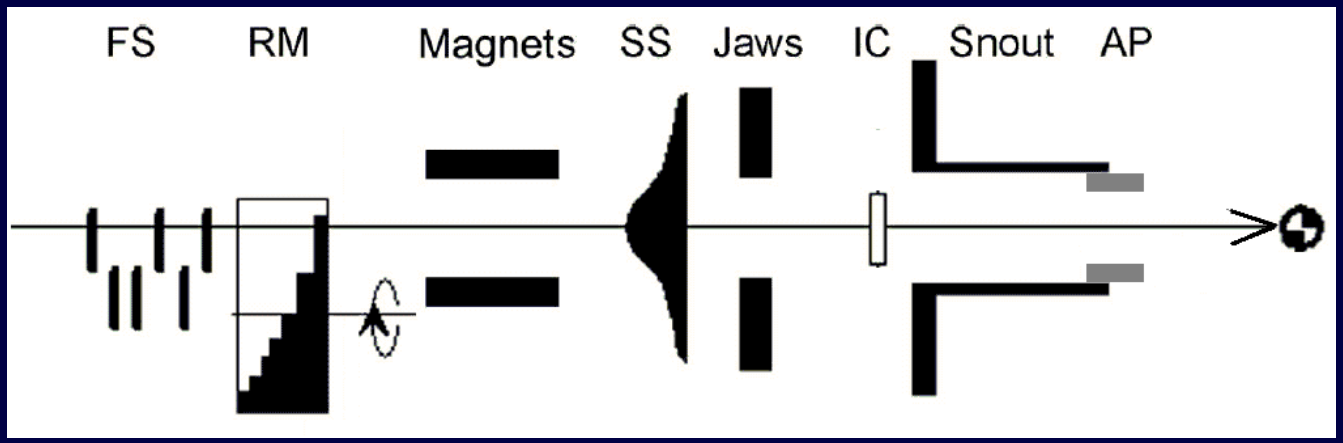
Dose at point A does not verify distal coverage at point B



Also need ***residual proton range*** at point A

Passive Scattering System

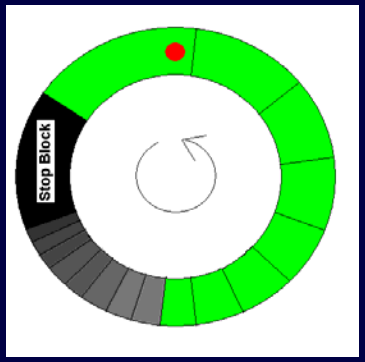
Using range modulator wheels

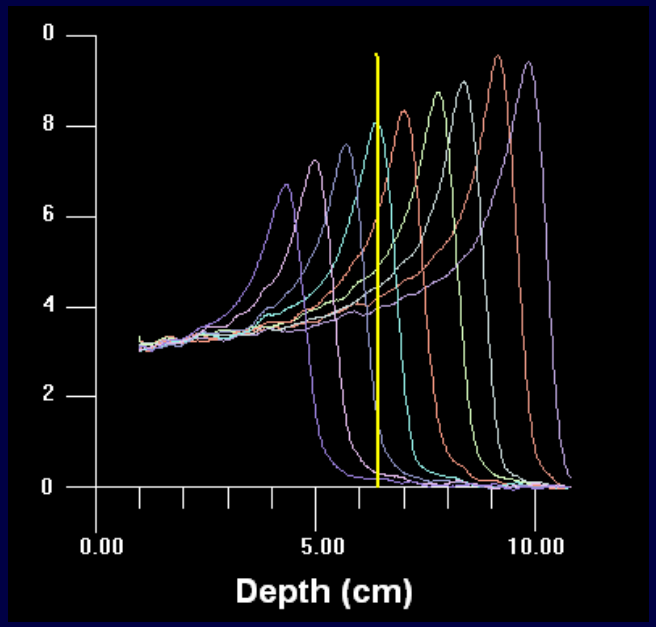


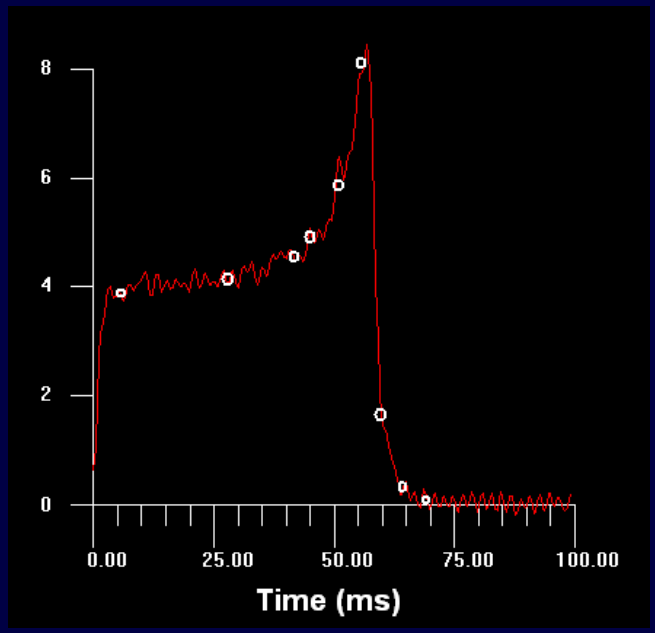
Bragg-peak distribution of the mono-energetic proton beam is pulled back successively as the wheel spins at a constant speed (600 rpm).

Time-Dependent Dose Rate

The dose rate at a fixed depth varies periodically as a function of time.

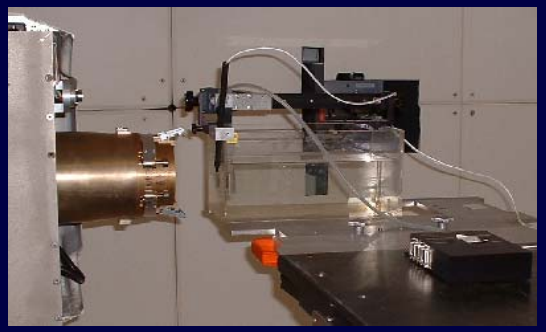


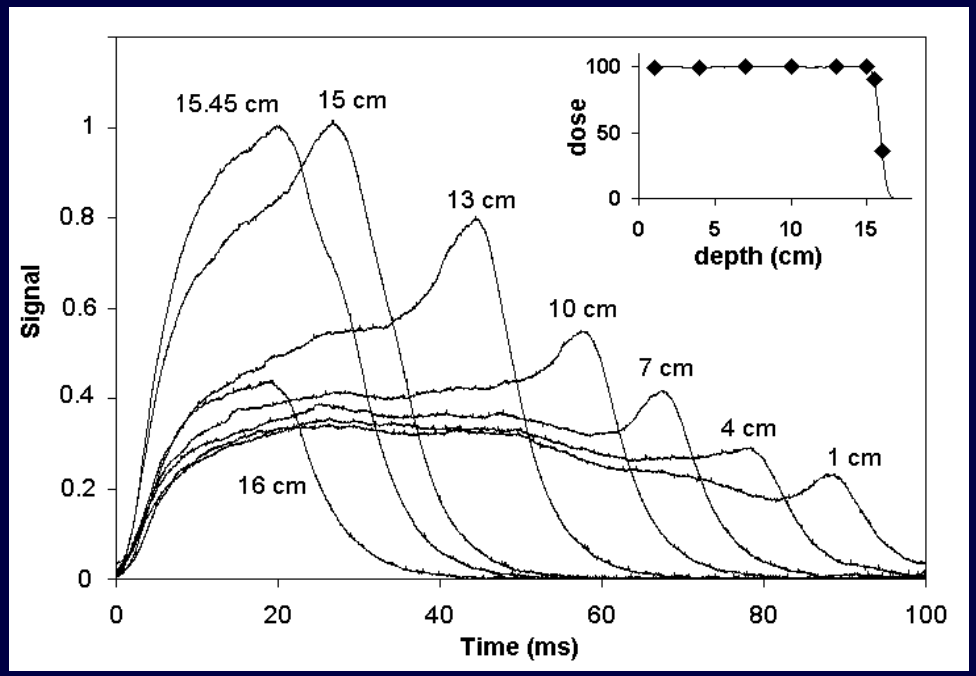




Measure Time-Resolved Depth-Dose

Sample ionization current of chamber as a function of time (30 kHz, Computerized Radiation Scanners, Inc.)





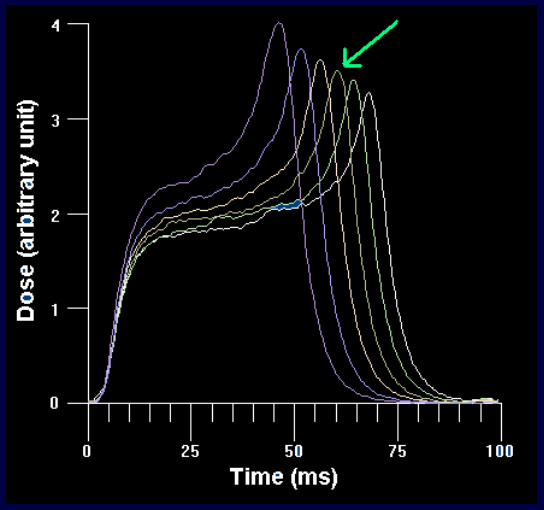
Same total dose but different time-dependence at different depths. ***Time-dependence encodes radiological depth***.

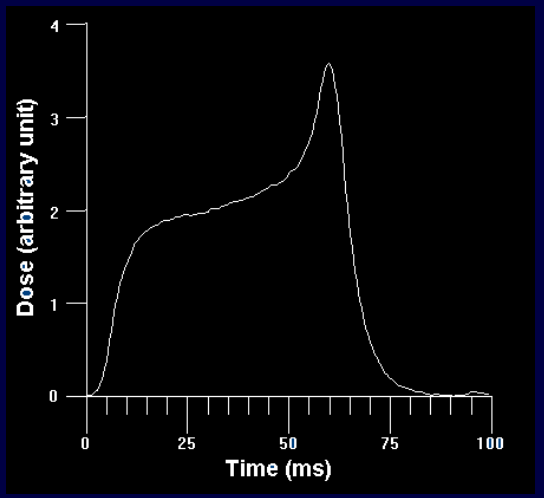
To Obtain Residual Range at Point

Given a specific range/mod for a field

1) Obtain dose-time functions at all depths as a "***ruler***"
   - By phantom measurement
   - Or planning system calc.
   - Or Monte-Carlo simulations

   Each represents a particular depth with a particular residual range
2) Measure dose-time dependence at point in question
3) Match with time-resolved dose functions in "***ruler***"



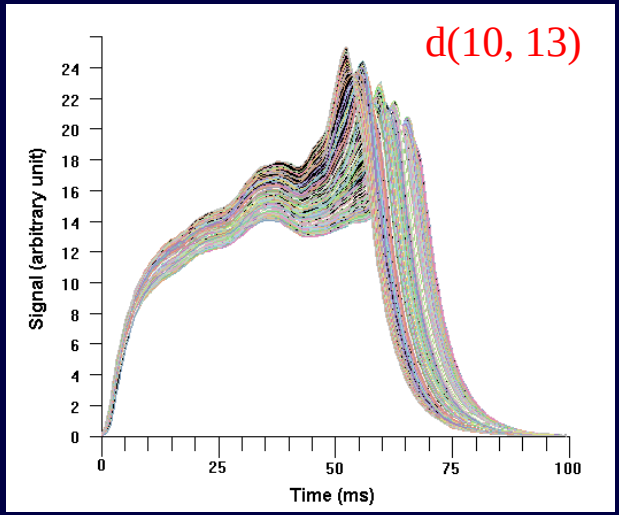


Resolution of the “Ruler”?

How sensitive to depth change?

Factors:

- beam current fluctuations
- Noise from measuring devices
- Matching method:
  - Least square (LS) fit



$$L(f_m, f_d) = \frac{1}{T}\int_0^T dt\left[f_m(t) - \lambda f_d(t-\delta)\right]^2$$

With scale factor λ and time shift δ minimized

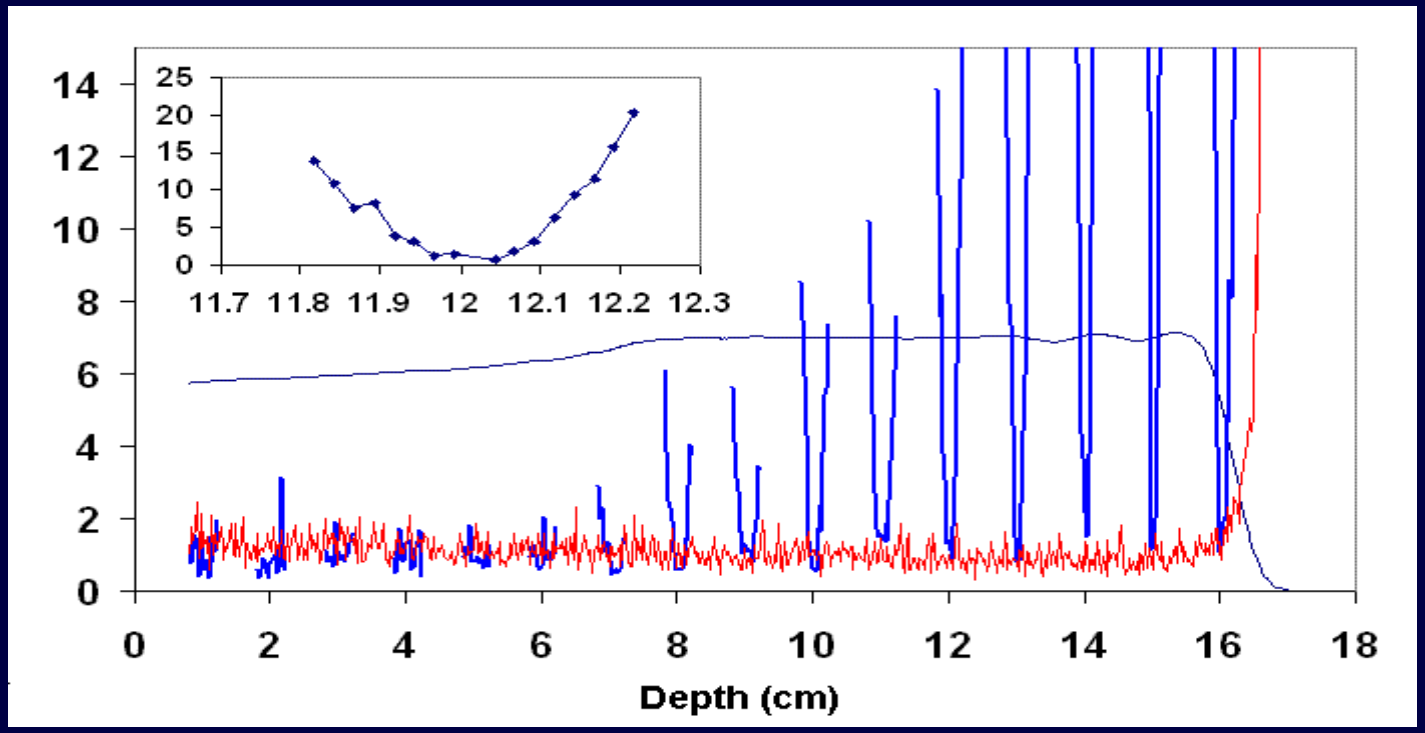
Resolution Test

- Measure function $f_d(t)$ for a given field
  R=16, M=10, 5 periods at every 1/4 mm
- At each depth, calculate the average function
- Calculate LS fit between each period and the average function, and then take the average

- Calculate LS fit between nearest neighbors

Results

Red - deviation, Blue – fit to nearest neighbors (18)

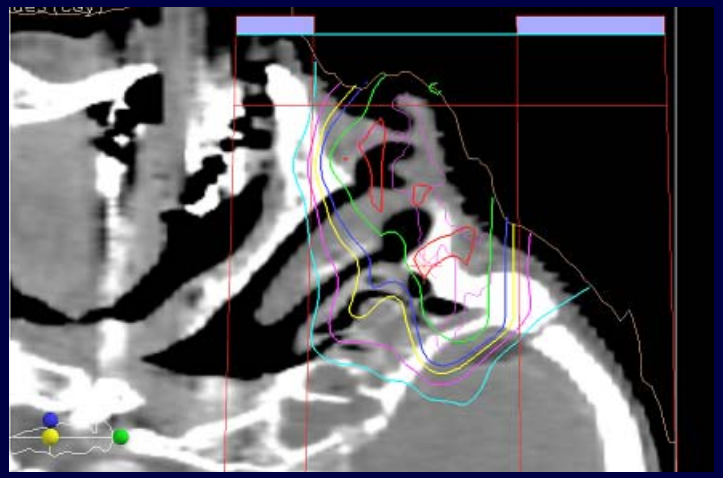


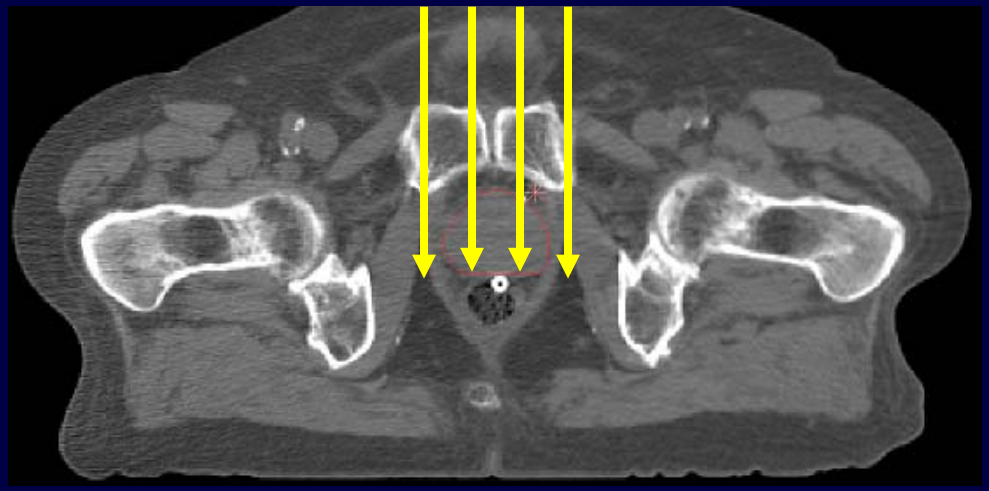
Resolution < 1 mm in dose plateau

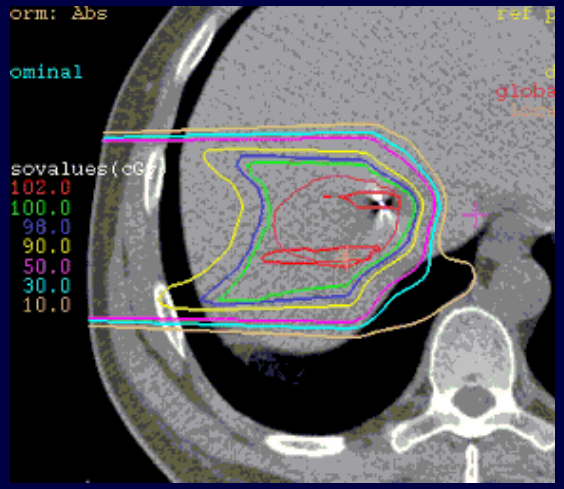
Distal and proximal regions not usable.

Potential Clinical Applications

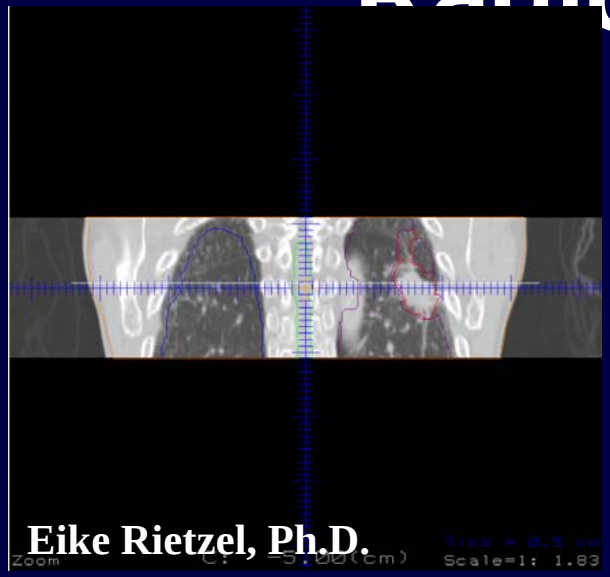
Nasopharynx
Prostate
Beam gating for liver

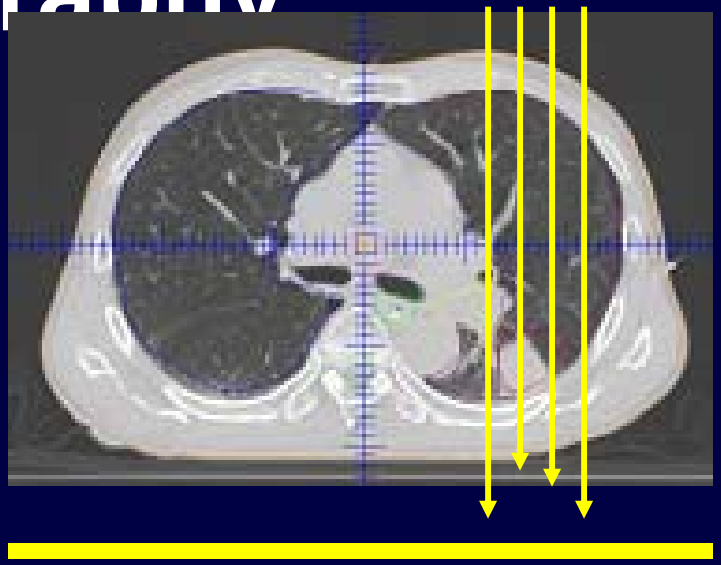






Poor Man's Proton Radiography

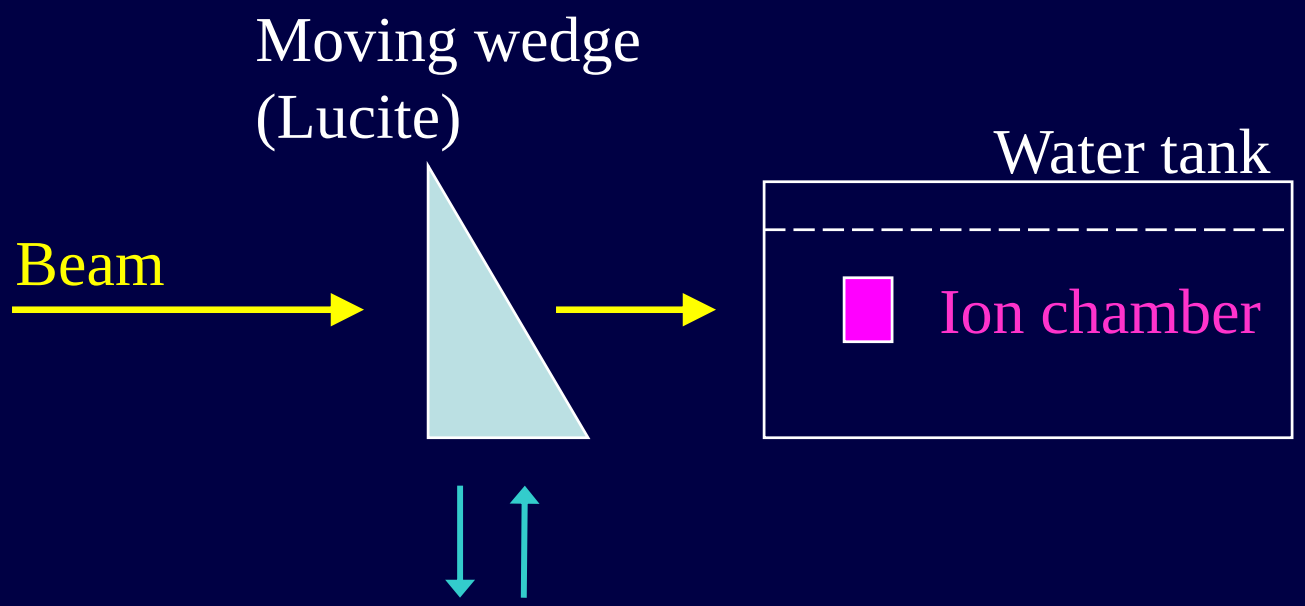




- Measure transmission proton energy, calculate range shift
  Obtain a radiological depth "image"
- Better edge detection for localization of lung tumor
  For treatment, gating, tumor response, etc
- However, measuring proton energy needs expensive systems

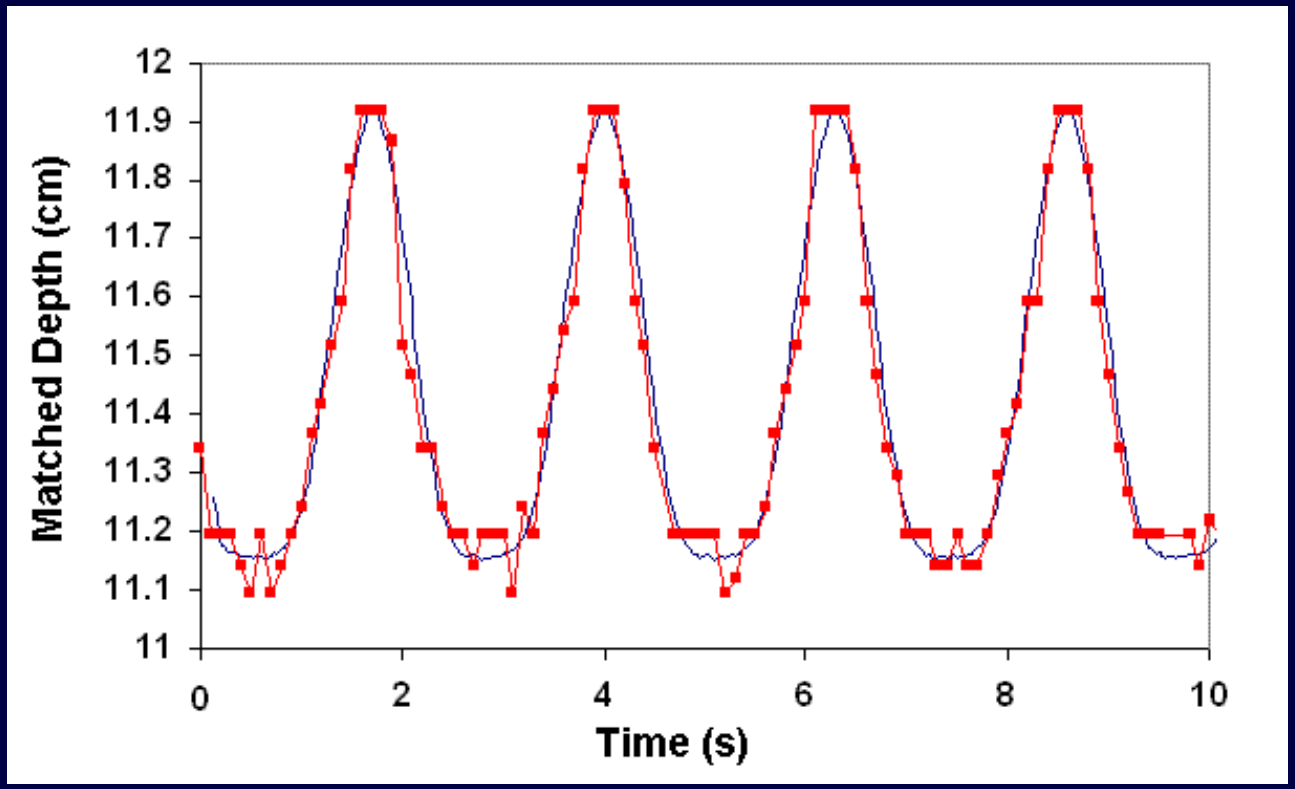
Proof of Principle

Measure proton range perturbation due a Lucite wedge in periodic motion



Results

Red – Measure depth change as function of time
Blue – RPM trace of the motion



Summary

We have explored the possibility of using the unique time dependence of the dose distribution from range-modulated passive scattering field for in-vivo proton range verification and for real-time proton radiography.

Results from the preliminary tests have been encouraging.

Future Works

- Explore characteristics for system with significant tissue inhomogeneity
- Develop solid state detectors for high spatial resolution and low dose rate requirement
- Compute time dependence of dose rate by planning system, or Monte-Carlo simulations