# Pencil Beam Scanning at PTC-H

## Workshop PTCOG 45, October 7-11, Houston, Texas

## Martin Bues, PhD

# Outline

- Overview pencil beam scanning
- Spot scanning with the Hitachi Probeat system
  - Performance parameters for spot scanning at PTC-H
  - Synchrotron beam extraction for pencil beam scanning
  - Scanning nozzle design
  - Dose monitoring system

# Outline (cont.)

- Beam measurements on the PTC-H scanning nozzle
  - Ion chamber Measurements of single pencil beams
  - Film meaurements
- Development of treatment planning software for the PTC-H scanning nozzle
  - Commissioning of the Varian eclipse treatment planning system for proton spot scanning

# Acknowledgements

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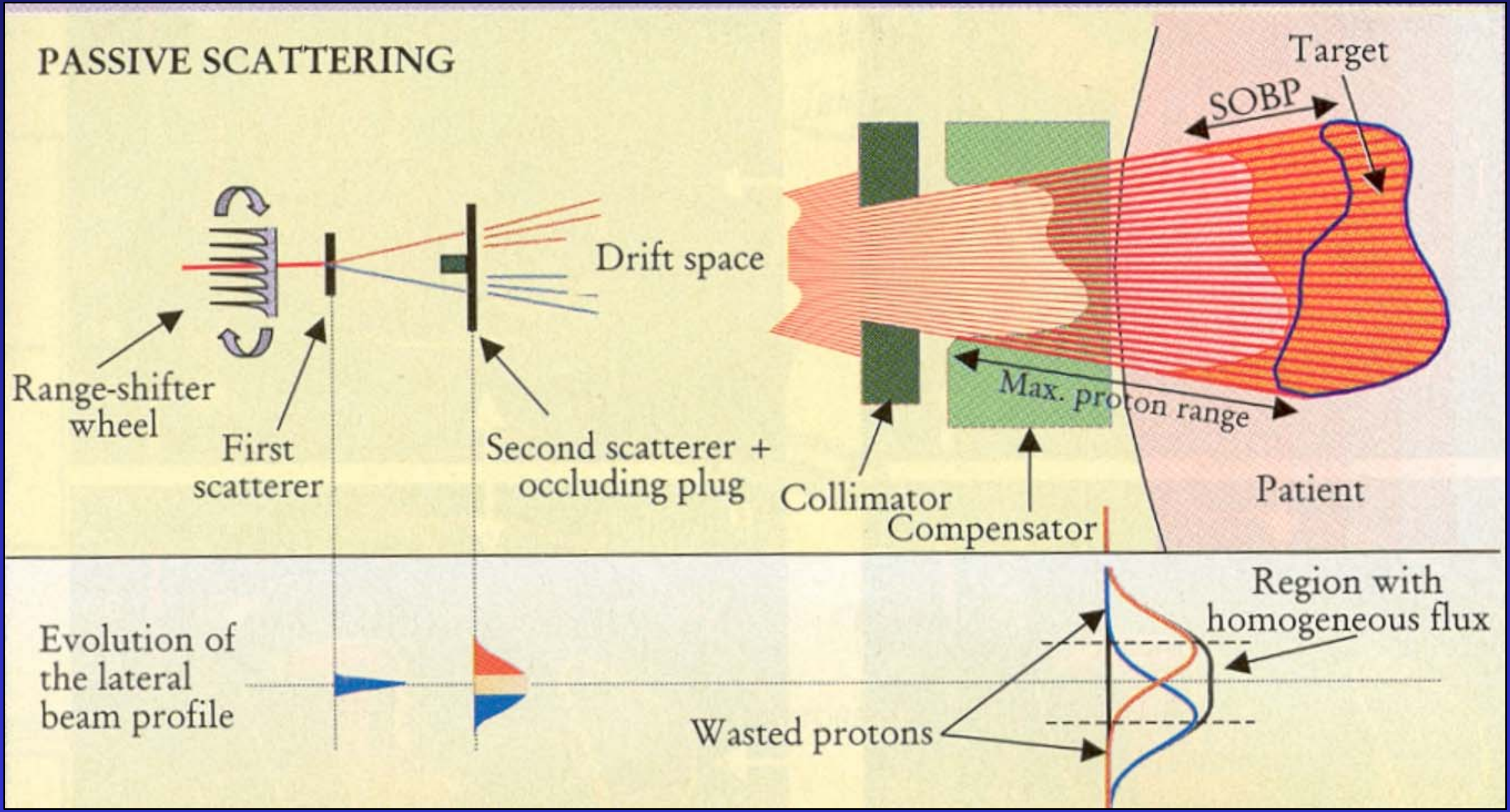
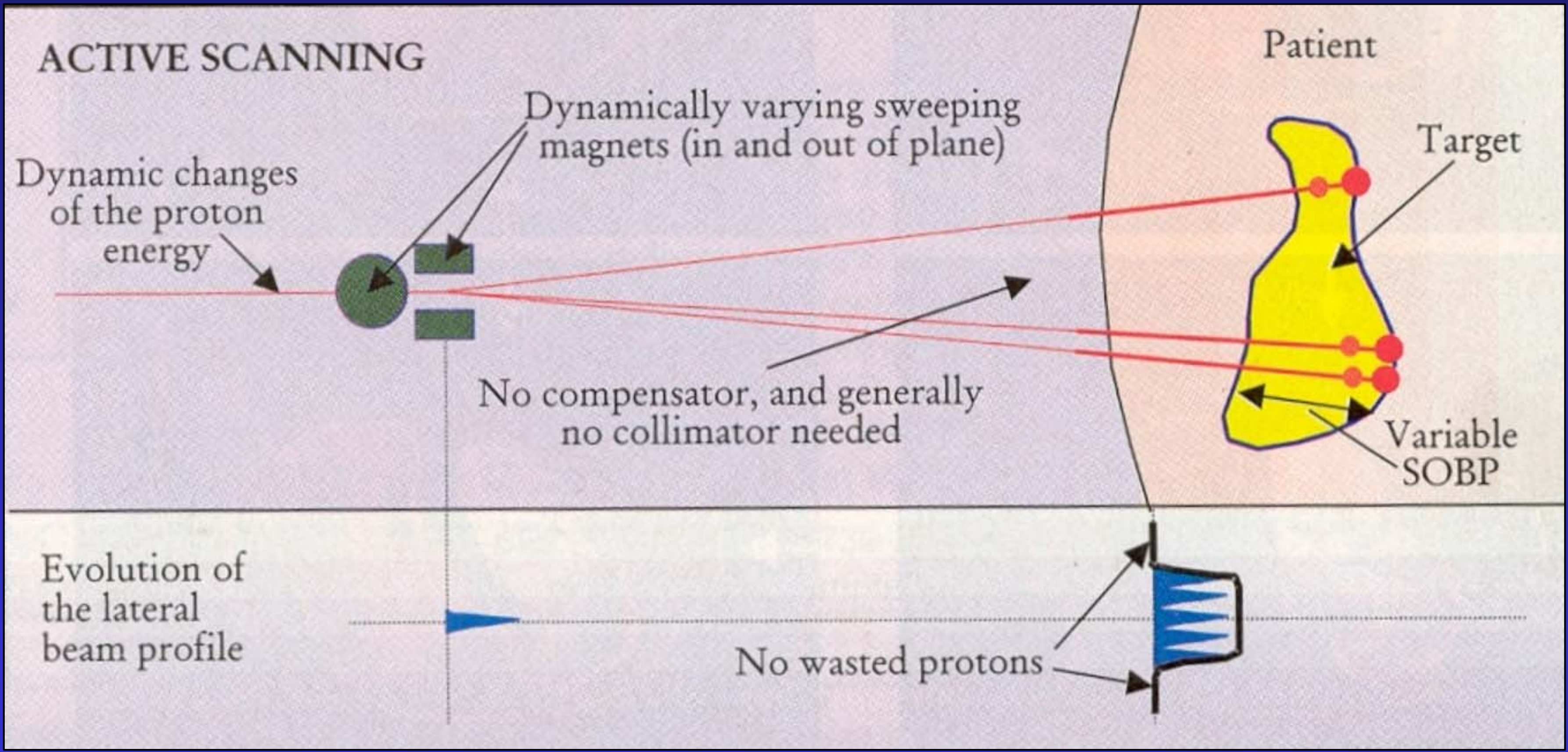
  - Toshie Sasaki
  - Koji Matsuda

# Overview of Pencil Beam Scanning

# Physics of the Passive Scattering Mode of Proton Beam Delivery



# The Pencil Beam Scanning Mode of Proton Beam Delivery

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# Motivation for Pencil Beam Scanning

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

# Drawbacks of Pencil Beam Scanning

- More “complicated” due to large number of parameters required to specify a treatment field
- Possibility of “Interplay Effect” in the presence of organ motion

# Discrete Spot Scanning with the Hitachi ProBeat System

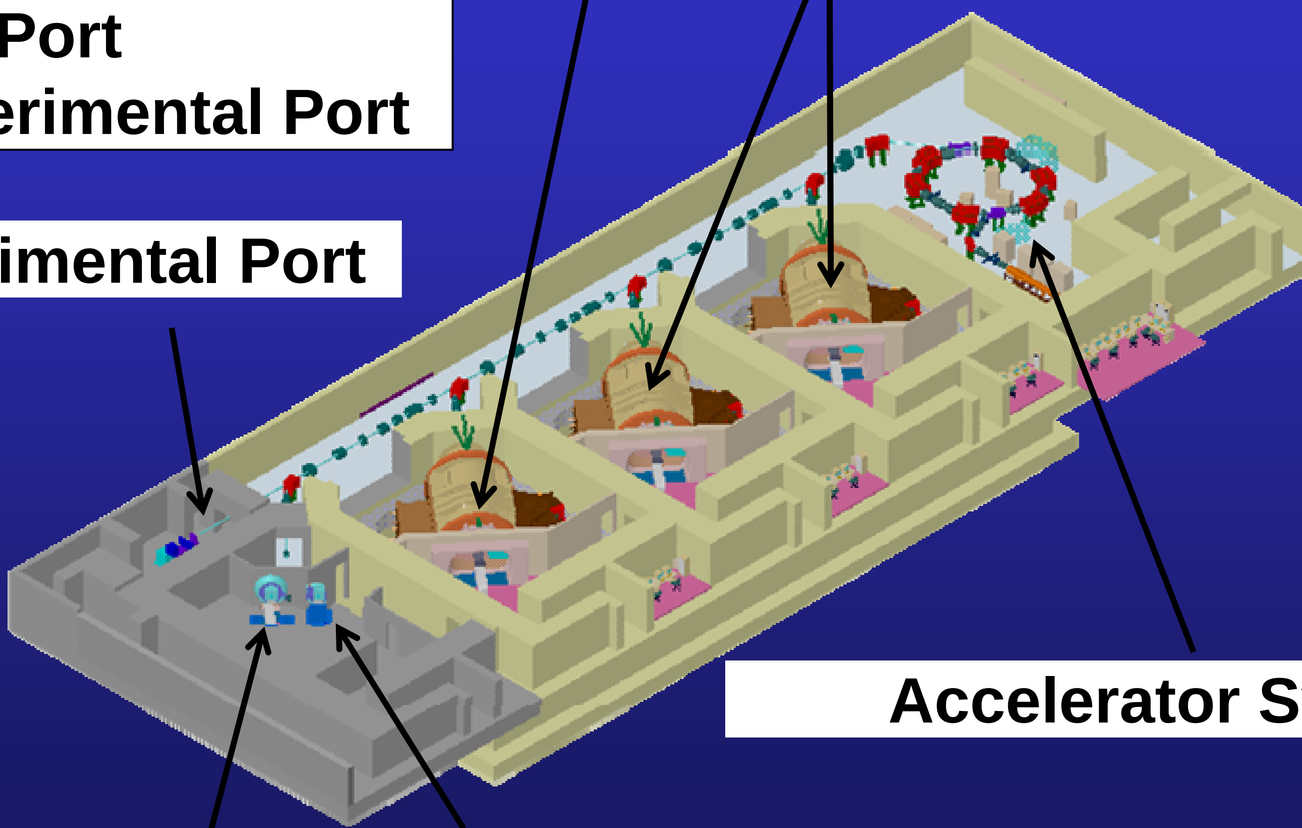
# Proton Therapy Center - Houston

**<u>PTC-H</u>**
**3 Rotating Gantries**
**1 Fixed Port**
**1 Eye Port**
**1 Experimental Port**

**Pencil Beam Scanning Port**

**Passive Scattering Portst**

**Experimental Port**



**Accelerator System**

**Large Field Fixed**

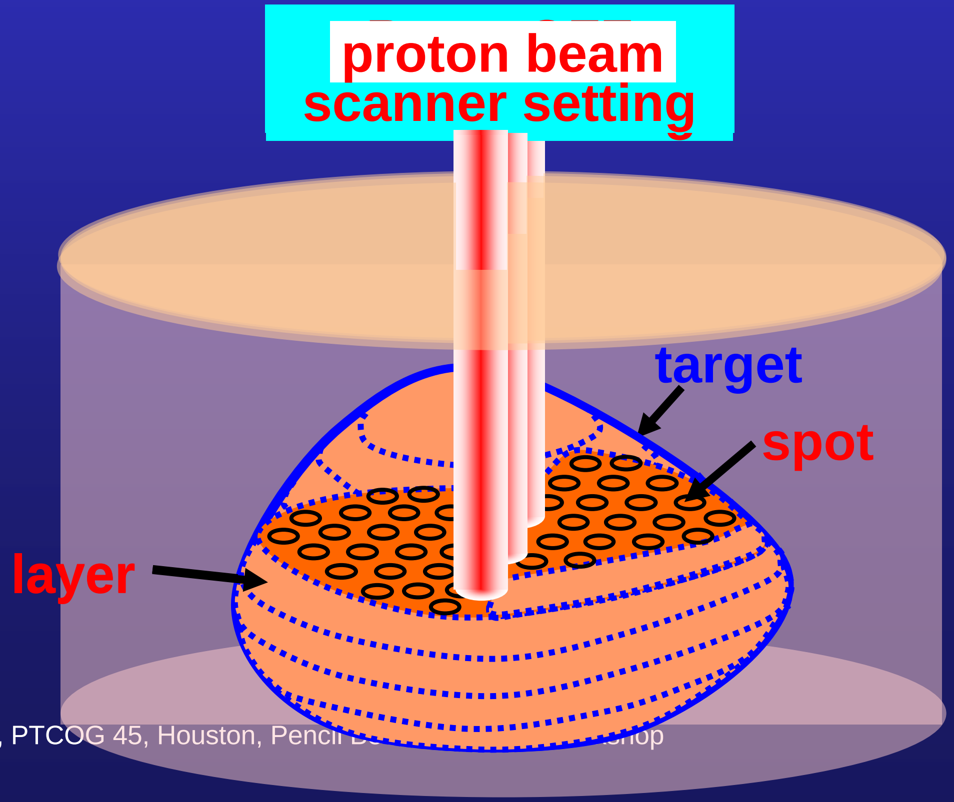
**Eye Port**

Hitachi, Ltd.

# Scanning Scheme

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

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



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# Status of Pencil Beam Scanning at PTC-H

- Contract signed, May 2003
- White paper on pencil beam scanning finalized, November 2004
- Pencil beam scanning (PBS) specifications finalized, February 2006
- First beam in gantry 3, July 2006
- Turnover of PBS nozzle to PTC-H, November 2006
- First PBS patient, summer 2007

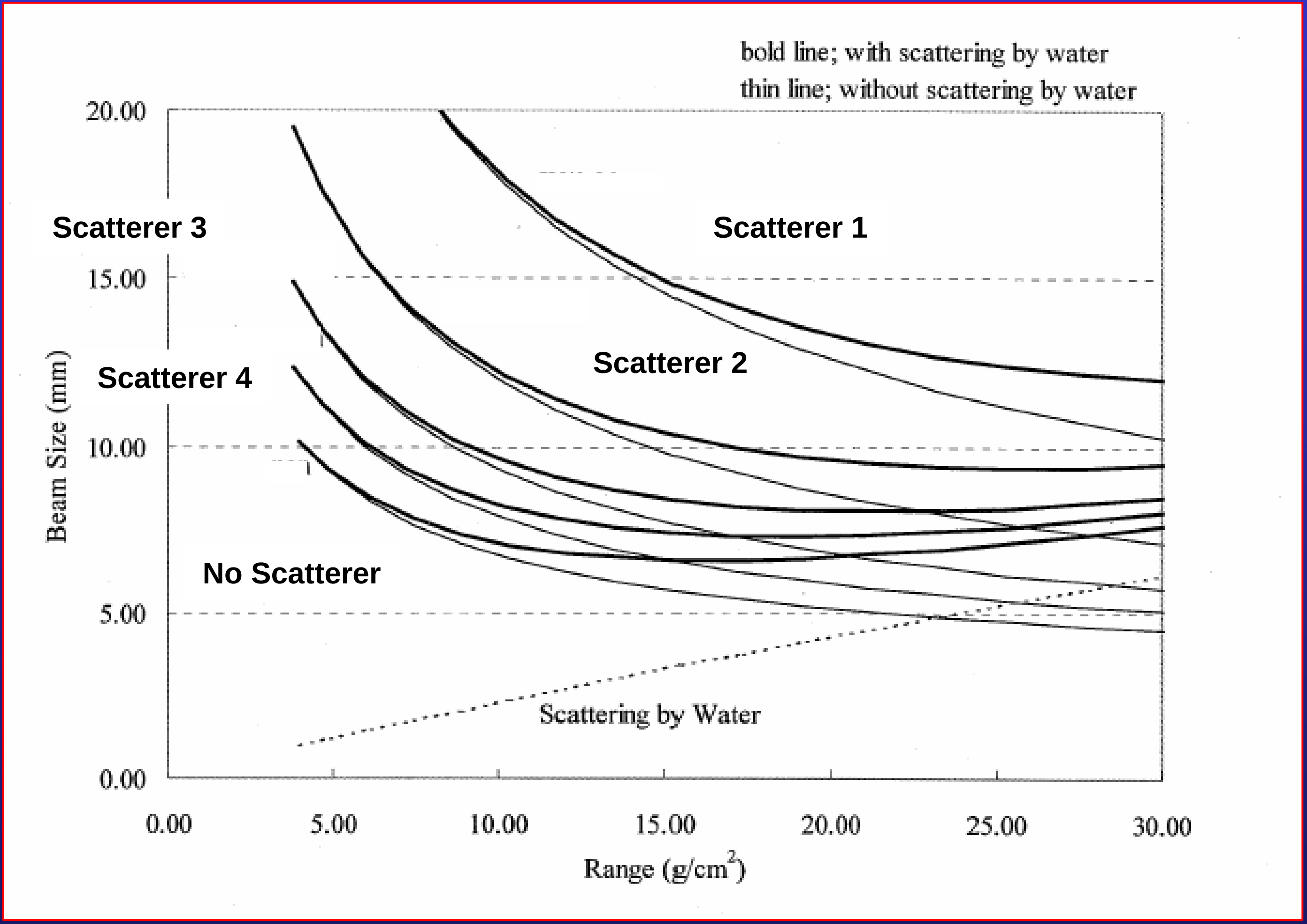
# Basic Design Parameters for PBS at PTC-H

- Triple redundancy against catastrophic failure
- Step and shoot delivery
- Maximum range: 30 cm
- Minimum range: 4 cm
- Field size: 30 x 30 cm
- Source-axis-distance (SAD): 250 cm

# Single Pencil Beam Parameters

- Spots size in air, at isocenter:
  - Range 4 cm: 11 mm
  - Range 10 cm: 6.5 mm
  - Range 20 cm: 5 mm
  - Range 30 cm: 4.5 mm

# Spot Size in Air and Water



# Single Pencil Beam Parameters (cont.)

- Difference of spot size in x an y:
  - Less than 1 mm
- Dependence of spot size on Gantry angle:
  - Less than 1mm
- Skewness:
  - Less than 0.001

# Skewness

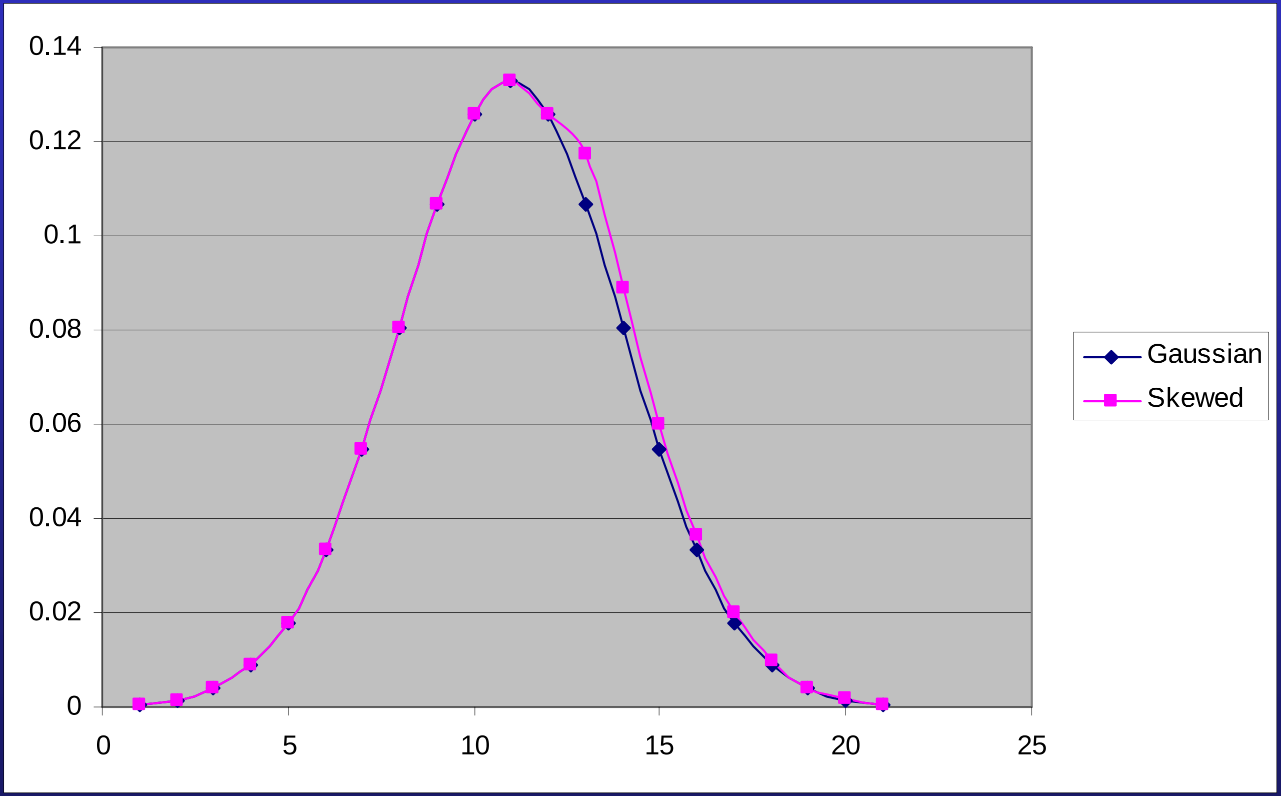
- Measure of deviation of single spot beam from a Gaussian
- Moments of a probability function P(x):

$$\mu_n = \int (x - \mu)^n P(x) dx$$

- Skewness: $$\gamma_1 = \frac{\mu_3}{(\mu_2)^{3/2}}$$

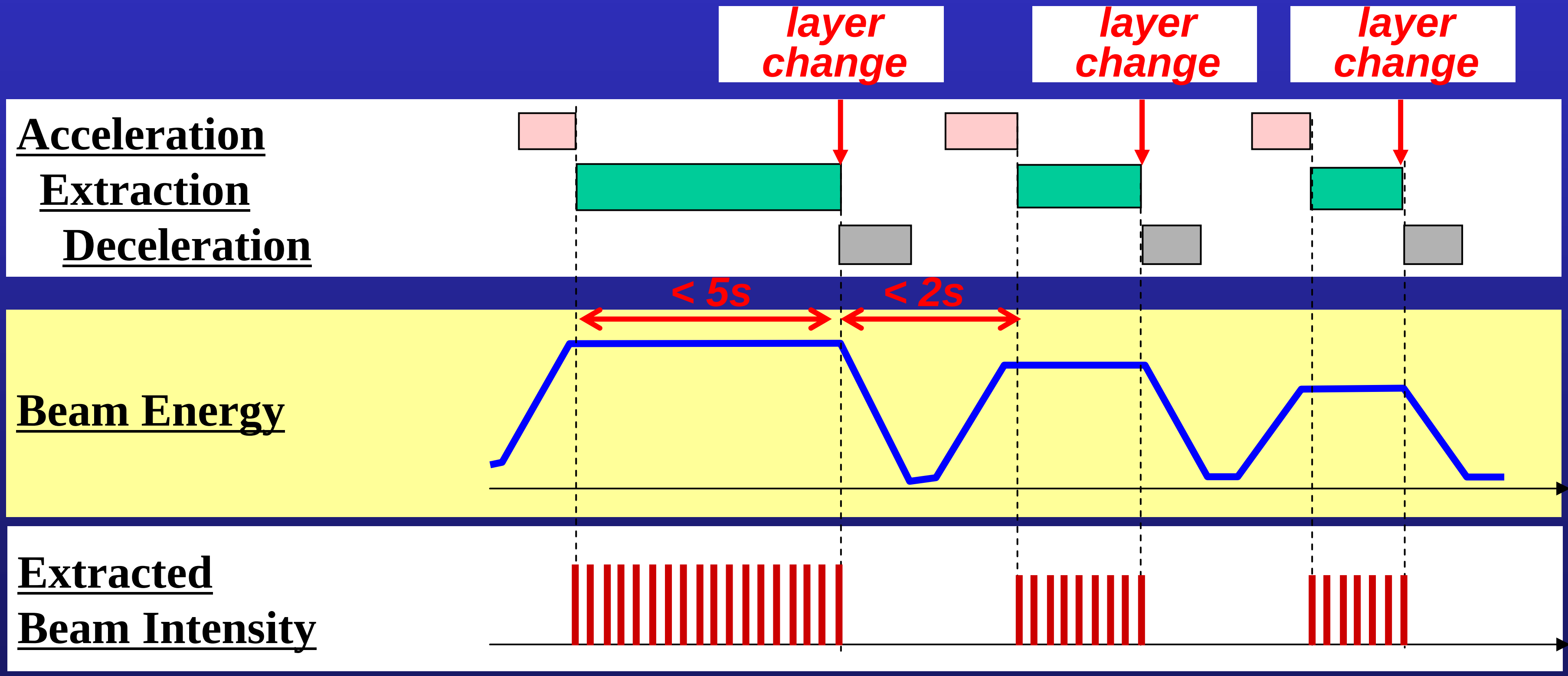
# Example of Skewness

- Skewness = 0.018

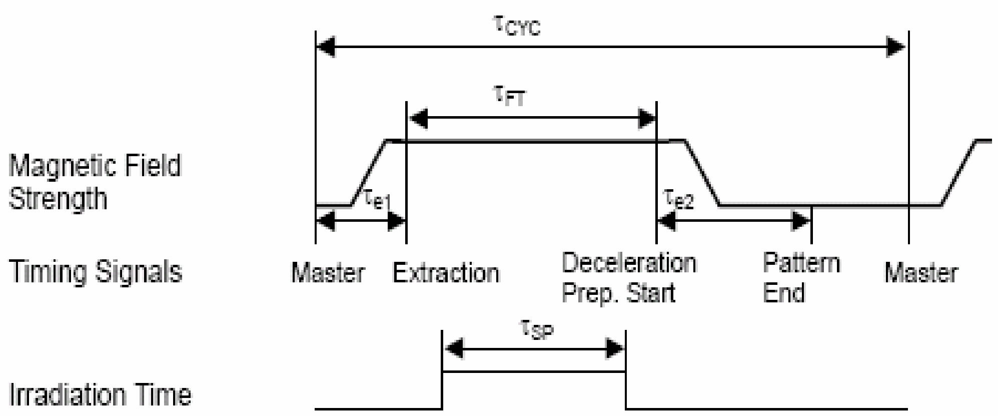


# Synchrotron

# Timing Parameters for PBS



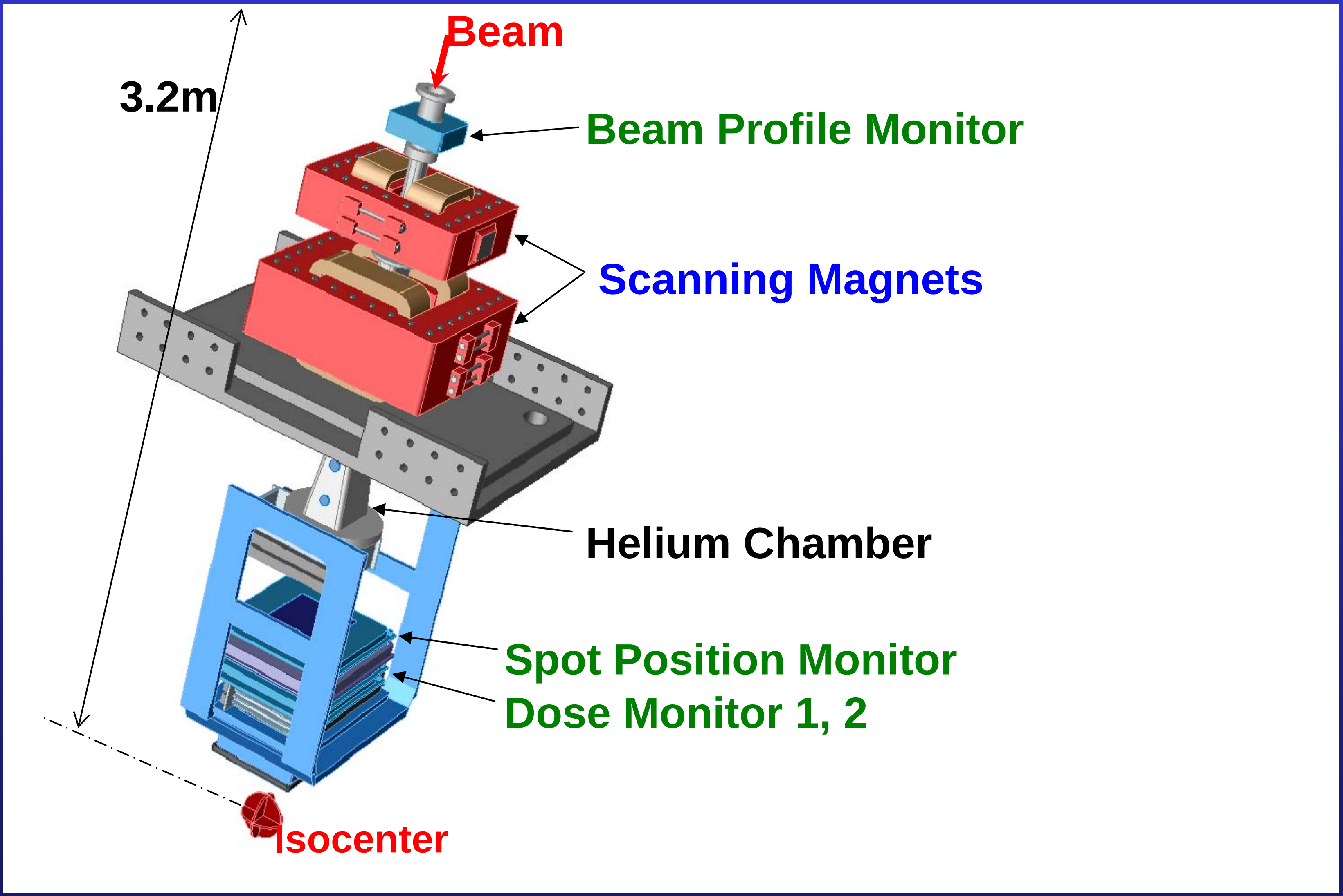
# Variability of Timing Parameters for PBS



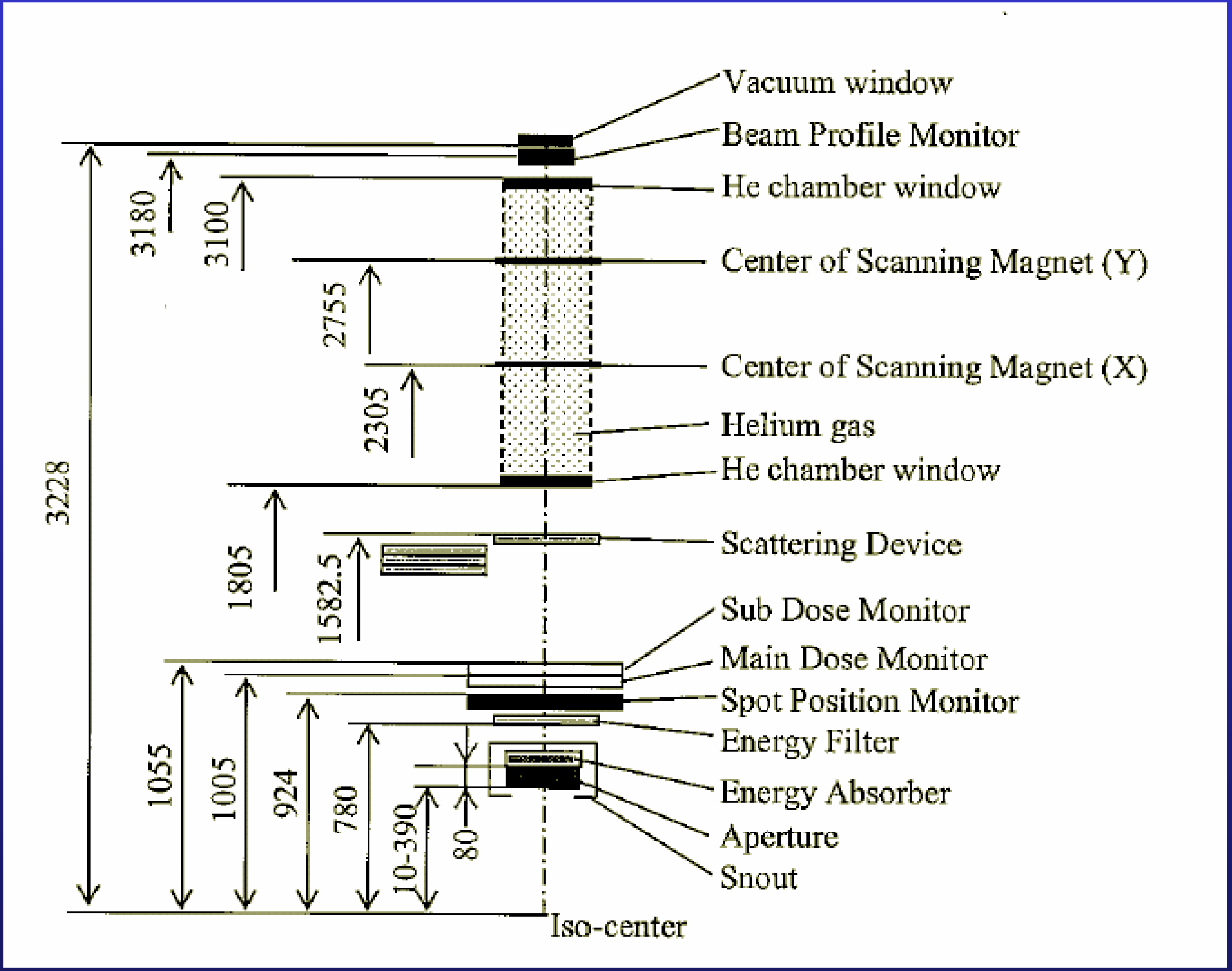

| Parameters | Time Elements | Set Value Variable | Default Settings | User-configurable Settings |
|---|---|---|---|---|
| $\tau_{CYC}$ | Repetition cycle of the magnetic field strength pattern | Yes | $\tau_{CYC} = (\tau_{FT} + \tau_{e1} + \tau_{e1})$ | $(\tau_{FT} + \tau_{e1} + \tau_{e1}) \leq \tau_{CYC}$ |
| $\tau_{FT}$ | Flat top period | Yes | $\tau_{FT} = \tau_{SP}$ | $\tau_{SP} \leq \tau_{FT} \leq$ 5sec. |
| $\tau_{SP}$ | Respiration synchronized Irradiation time | Yes | 0.5sec. | Selectable from five preset patterns.<br>0.5sec. $\leq \tau_{SP} \leq$ 5sec.<br>(Only applicable for the respiration synchronized irradiation) |
| $\tau_{e1}$ | Acceleration time | No | (Determined automatically according to the beam energy) | |
| $\tau_{e2}$ | Deceleration time | No | (Determined automatically according to the beam energy) | |

**Figure 4: Relationship between Magnetic Field Strength Pattern and Irradiation Time**

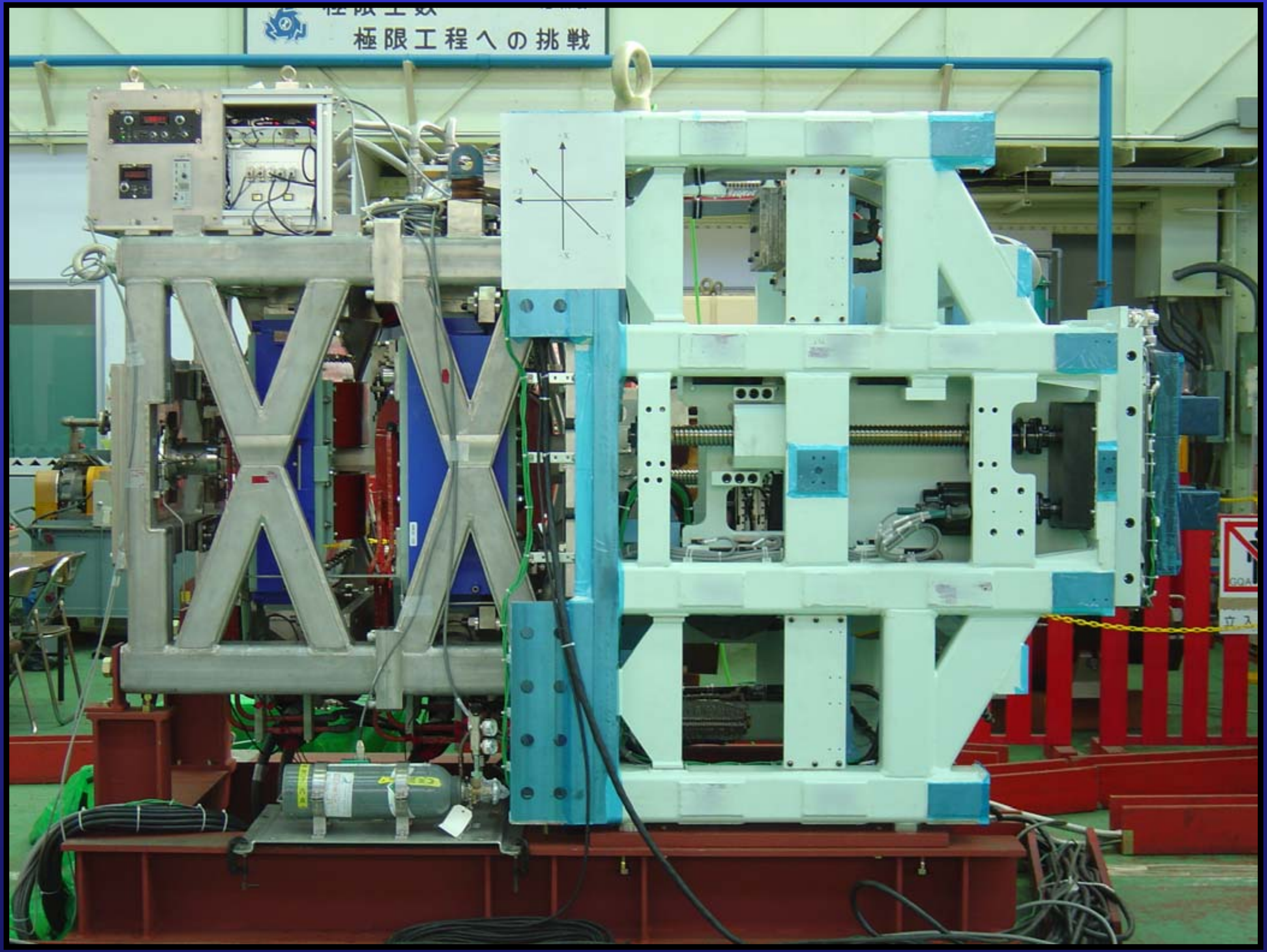
# Scanning Nozzle Design



# Scanning Nozzle Design (Cont.)



# 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

# Example

- Uniform Irradiation of 10x10x10 cm of water, range 20 cm, to 1 Gy
  – Requires 26 Energies: 170 … 120 MeV
  – 3.9 … 0.1 nC proton charge for a total of 13 nC proton charge
  – ~400 spots per  energy layer
  – 10400 spots in total
    - For 170 MeV: 10 pC proton charge per spot
    - i.e. 1.5 nC monitor chamber charge
    - i.e. 0.075 MU per spot
    - 30 MU for first energy layer

# Example (Cont.)

- …
- For 120 MeV: 0.25 pC per spot
- i.e. 50 pC monitor chamber charge
- i.e. 0.0025 MU per spot
- 1 MU for last energy layer

- Irradiation of 10x10x10 cube of water at a depth of 20 cm requires 100 MU

# Multipainting

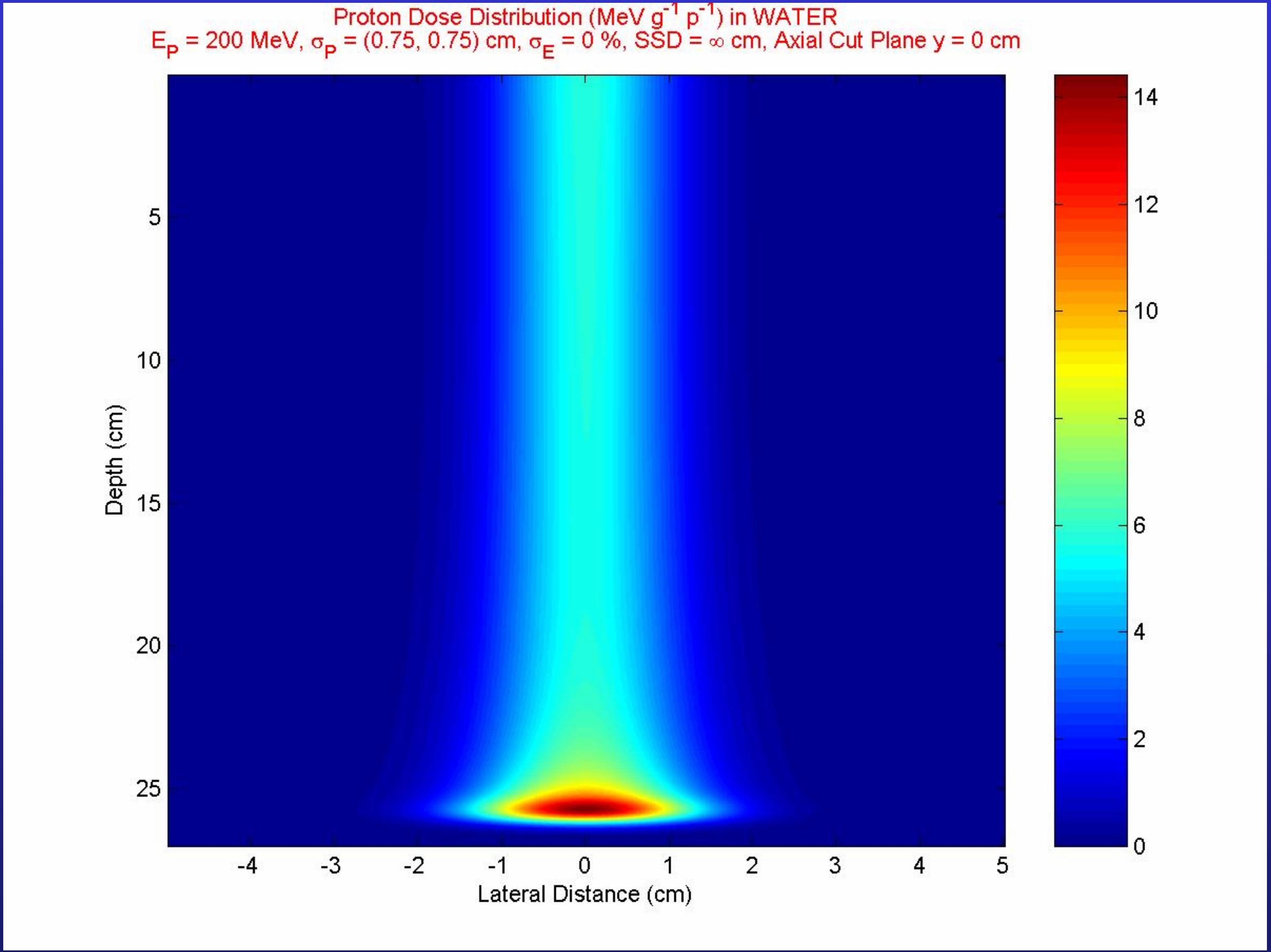
- Assume Multipainting numbers of:

  8, 4, 3, 2, 2, 2, 2, 1, …,1
- 16800 spots

# Beam Measurements

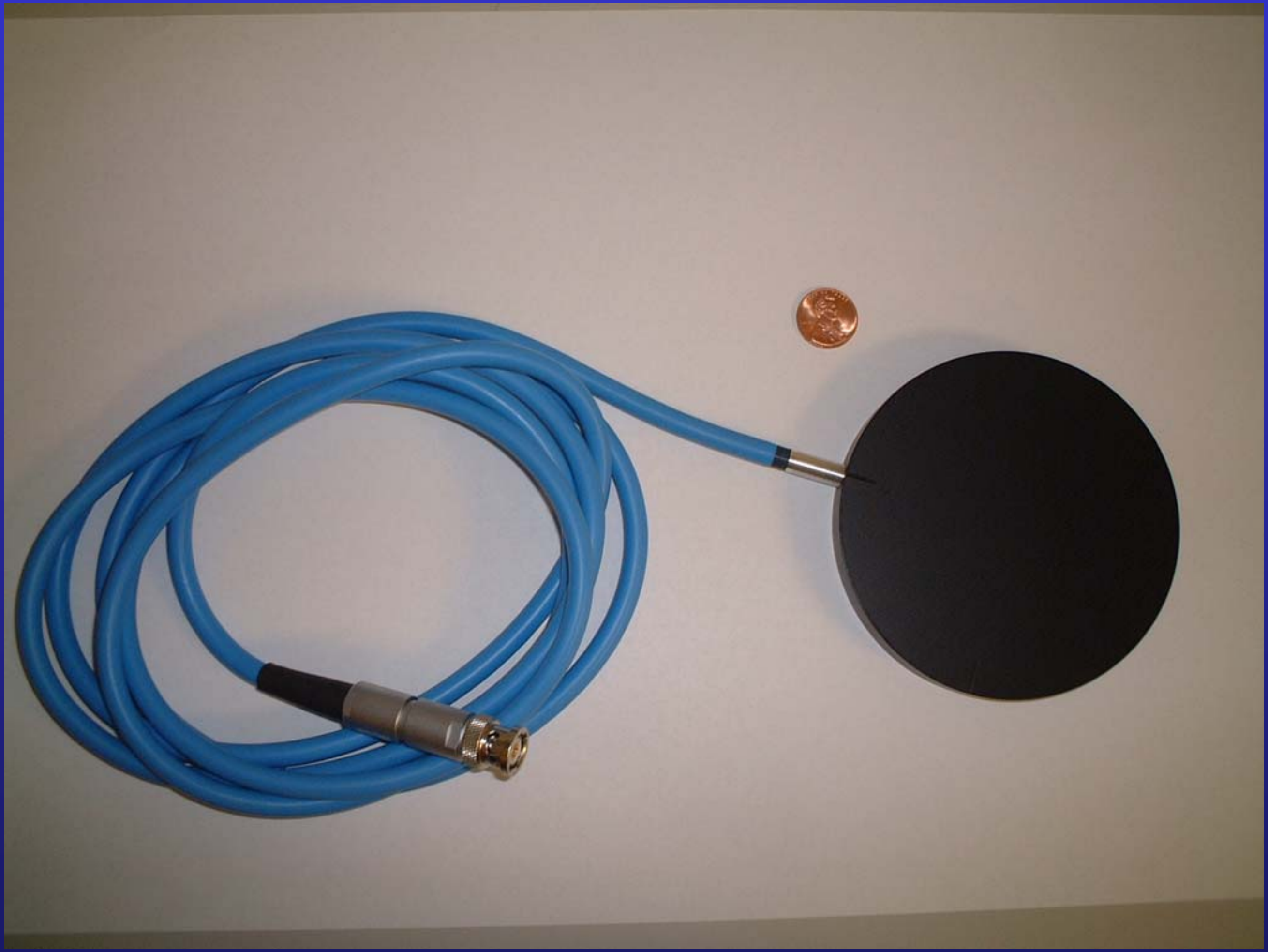
# First Measurements

- Depth dose measurements with PTW Bragg peak chamber
- Depth dose measurements with PTW Advanced Markus chamber
- Film measurements



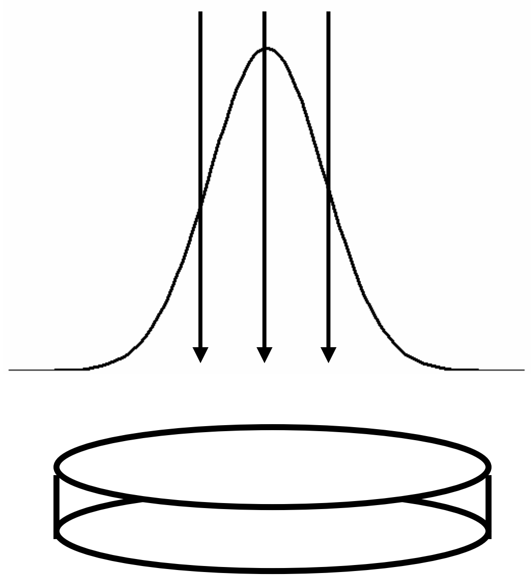

Ciangaru, et al. Med. Phys.

# PTW Bragg Peak Chamber (BPC)

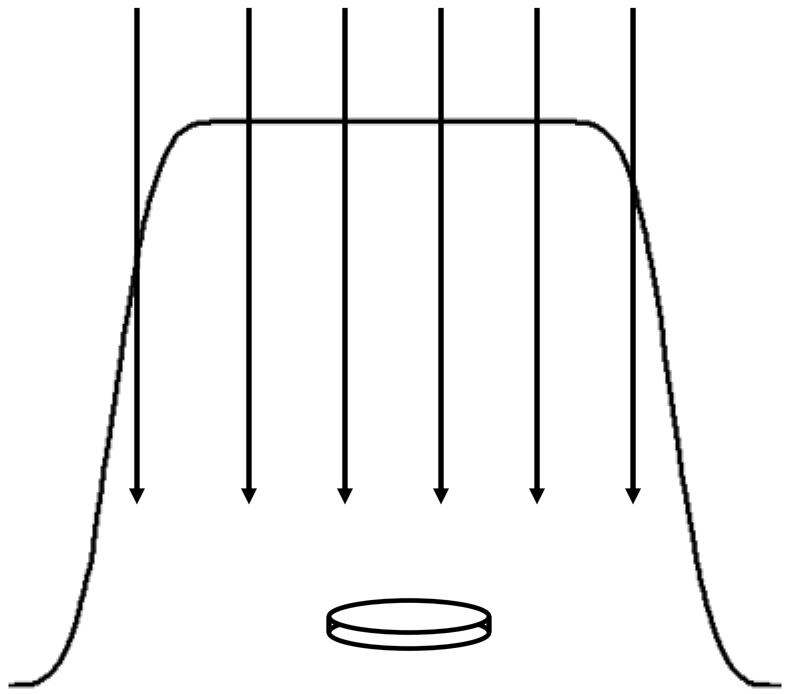


# PTW Advanced Markus Chamber (AMC)

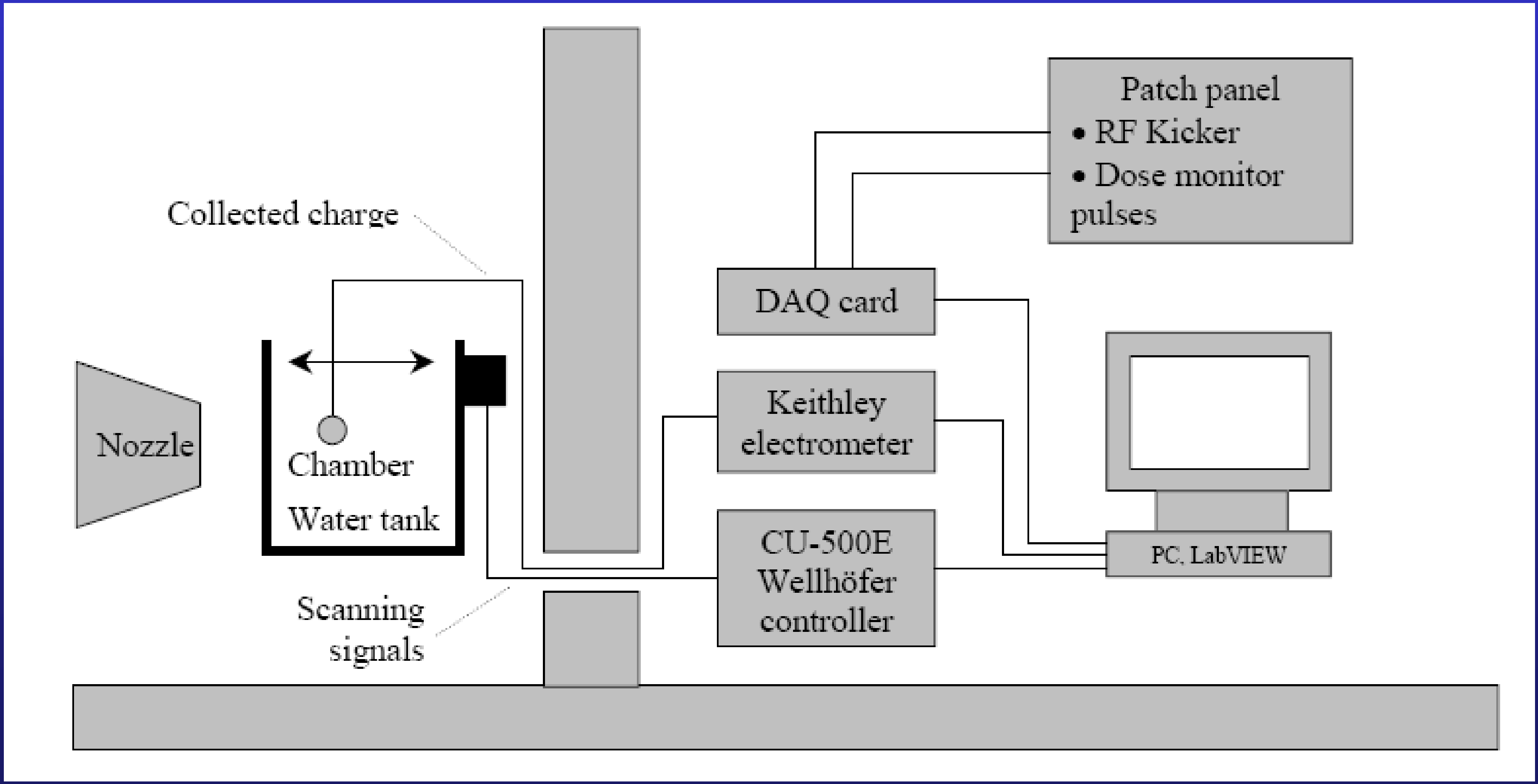
# Bragg Peak Chamber Measurement



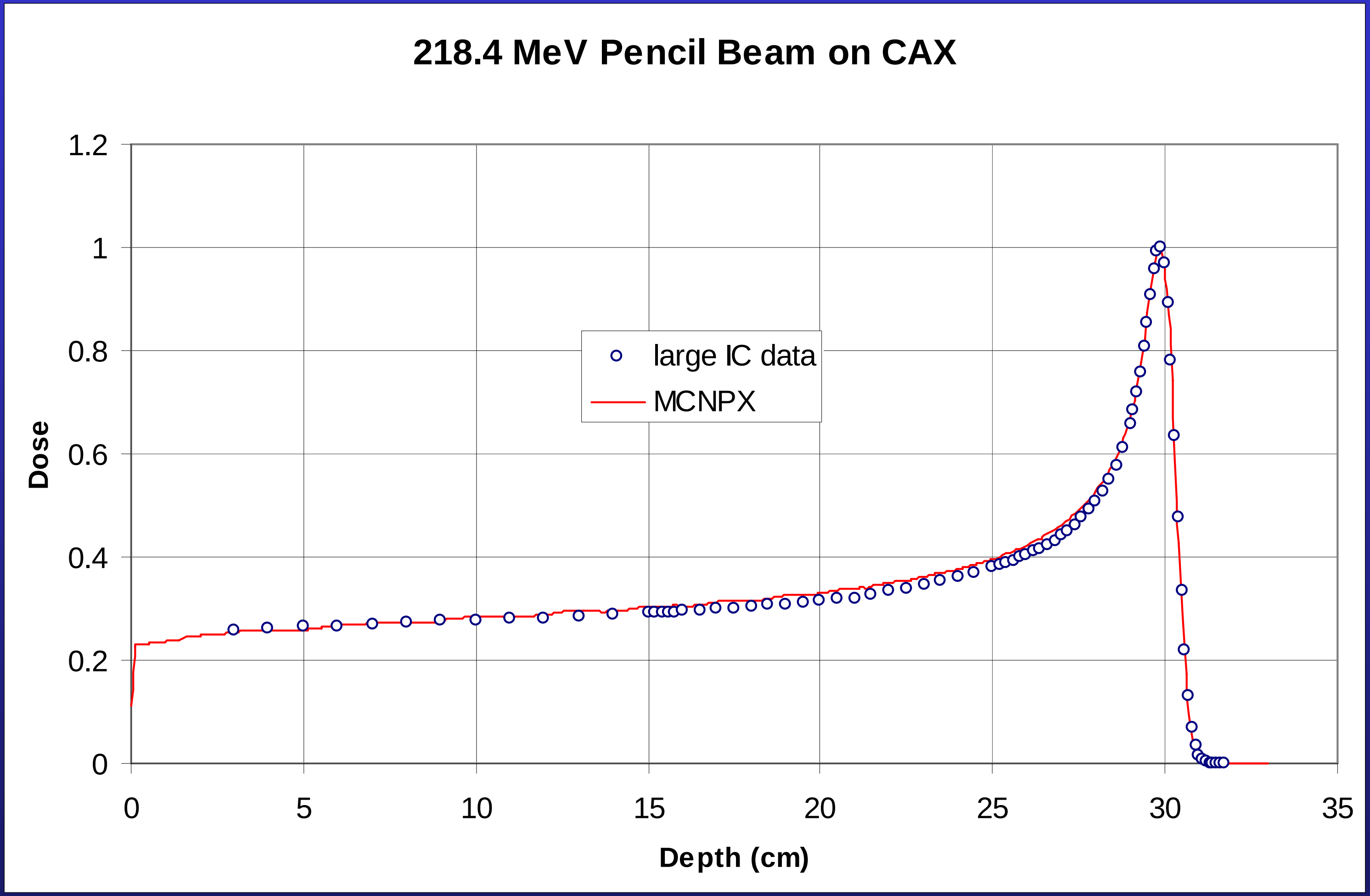
# Markus Chamber Measurement



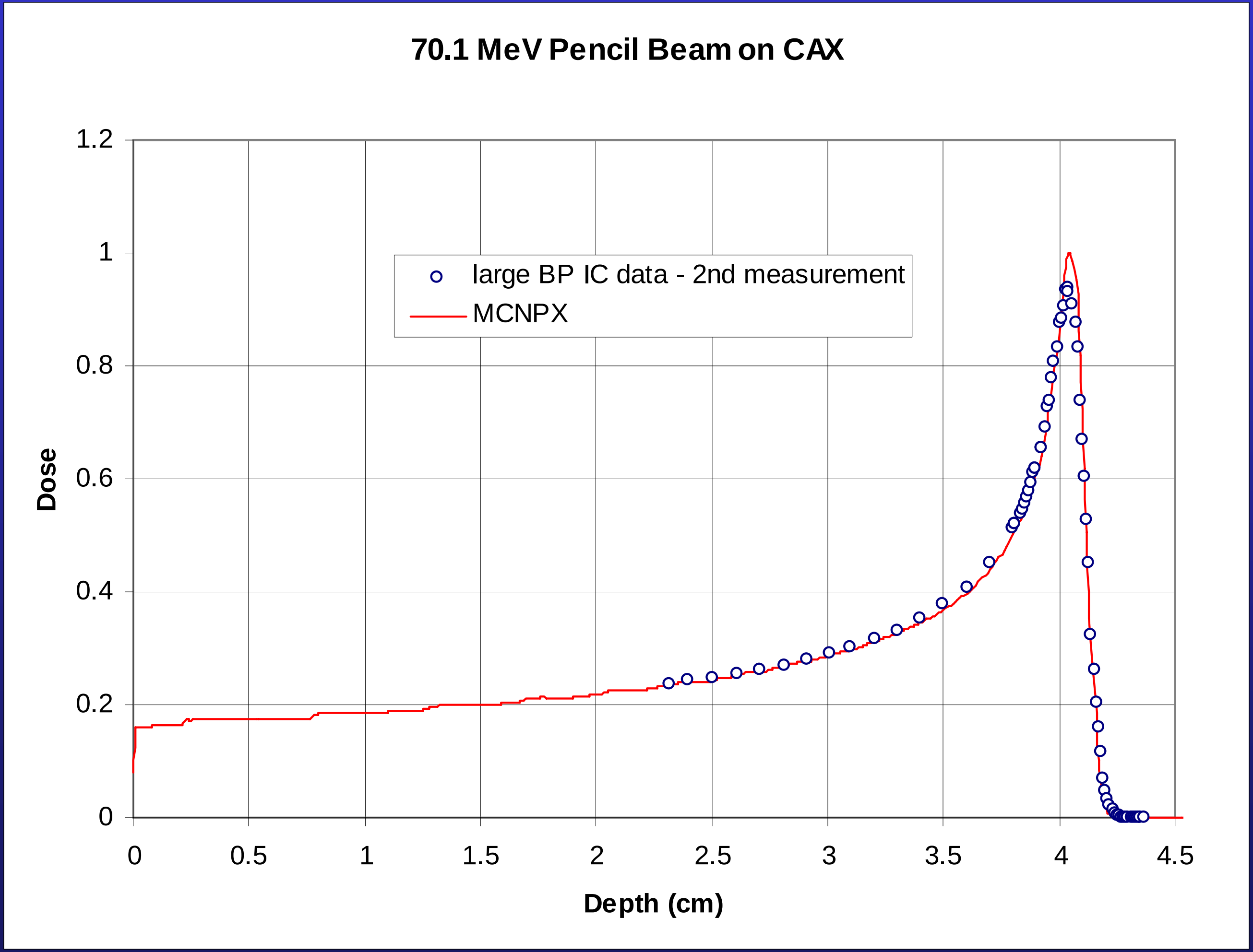
# Measurement Setup



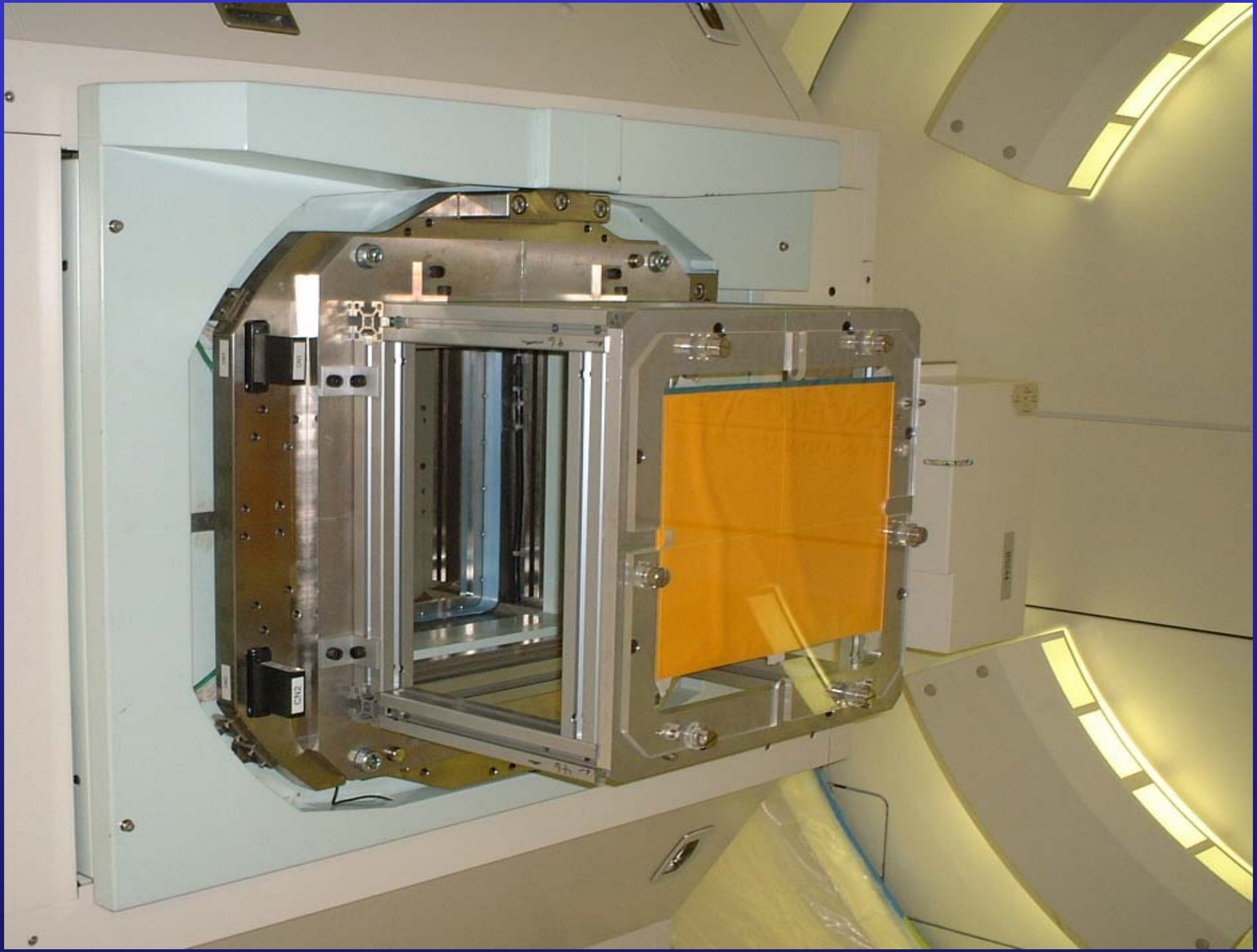
# BPC Measurement vs. MCNPX



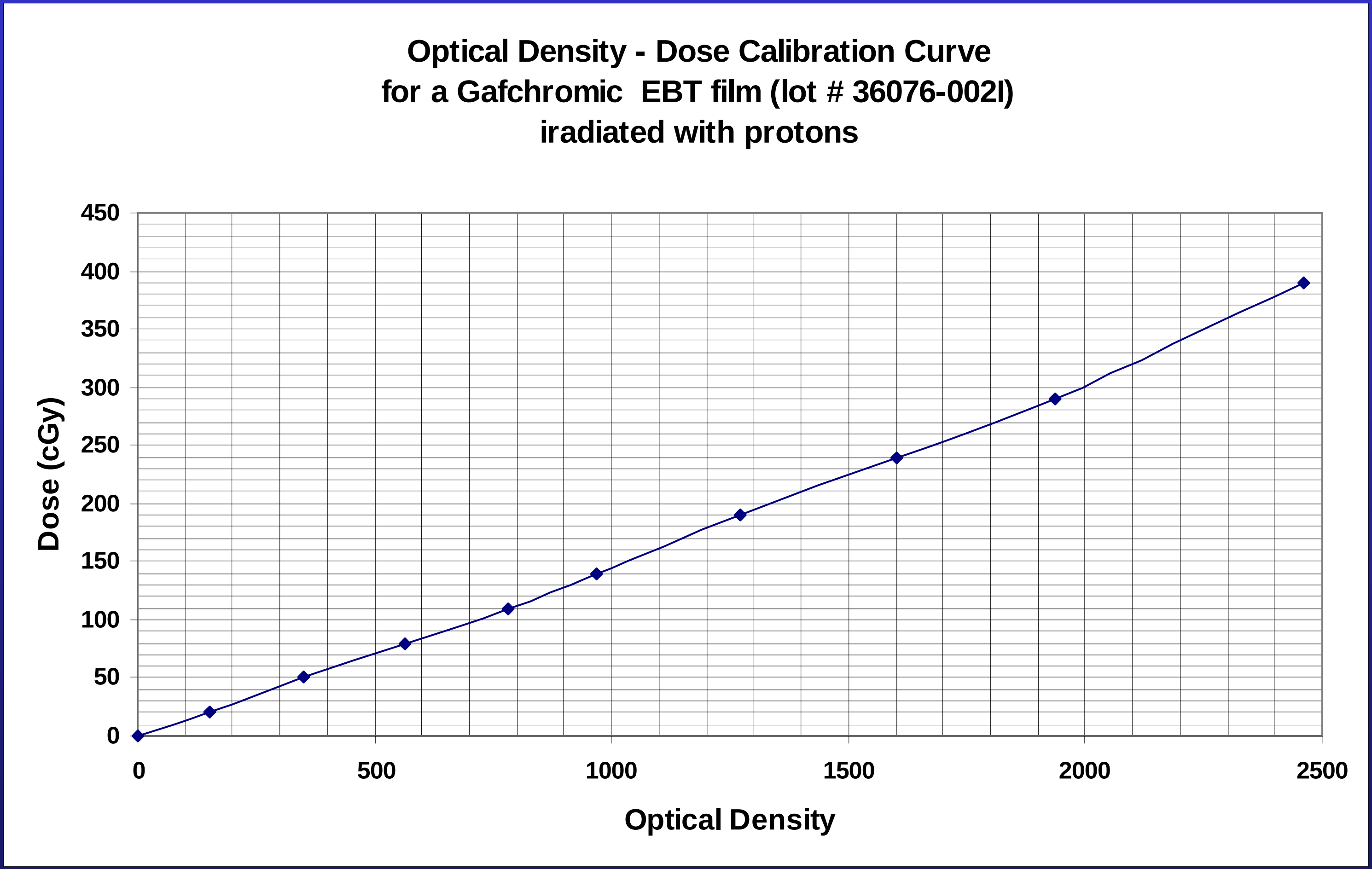
# BPC Measurement vs. MCNPX (Cont.)



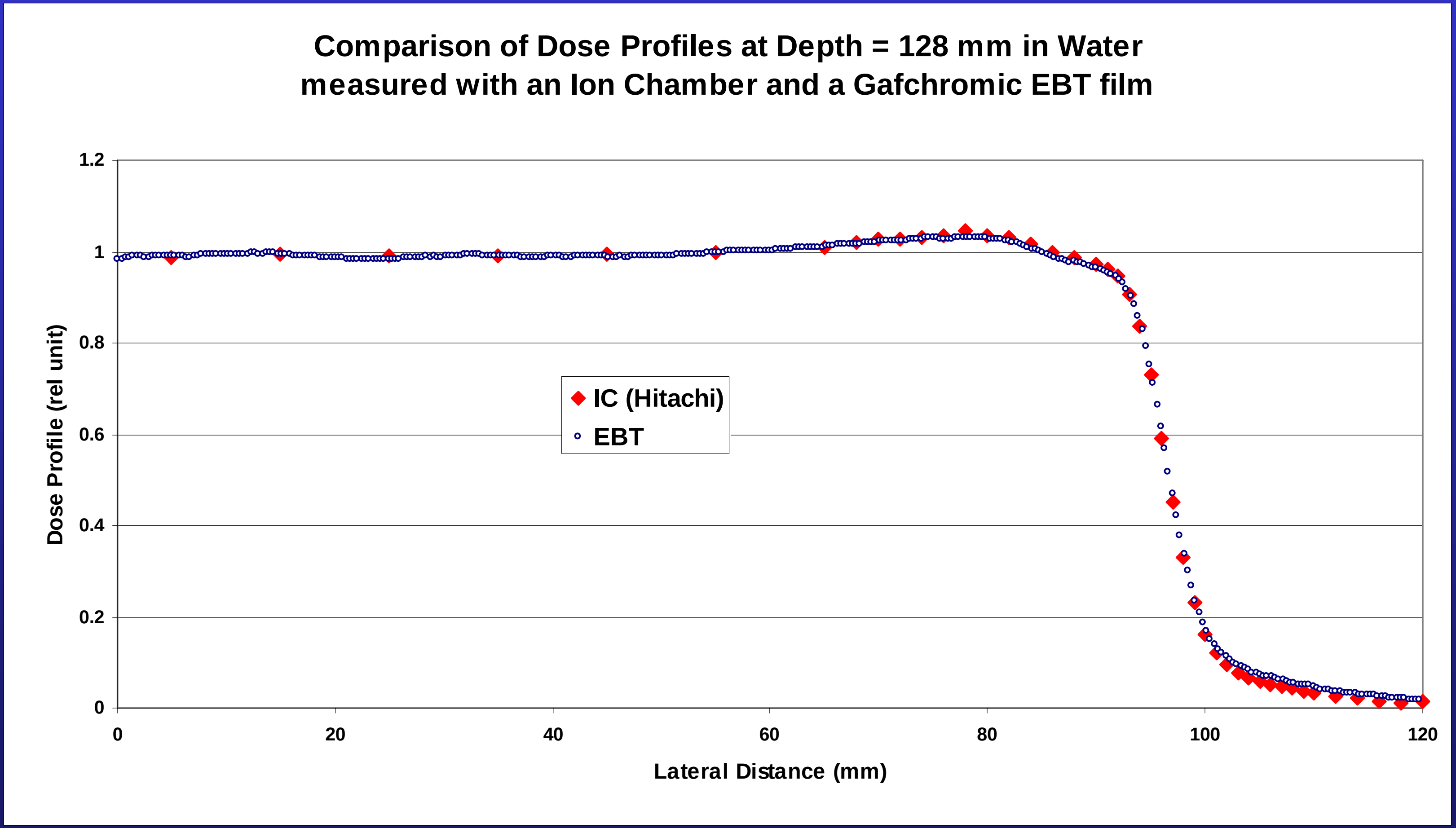
# Film holder



# EBT Gafchromic Film Calibration



# Dose profile perpendicular to beam

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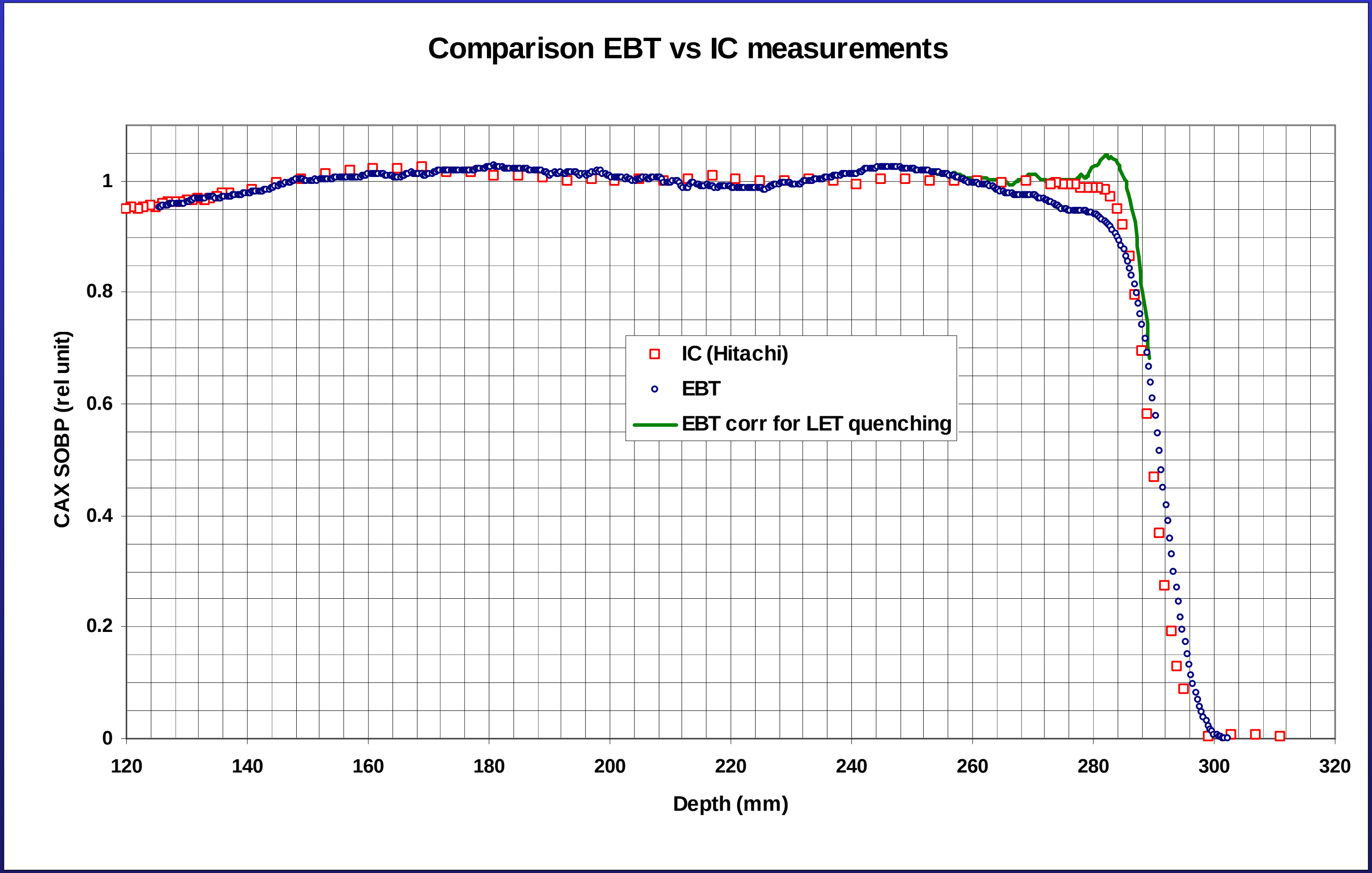
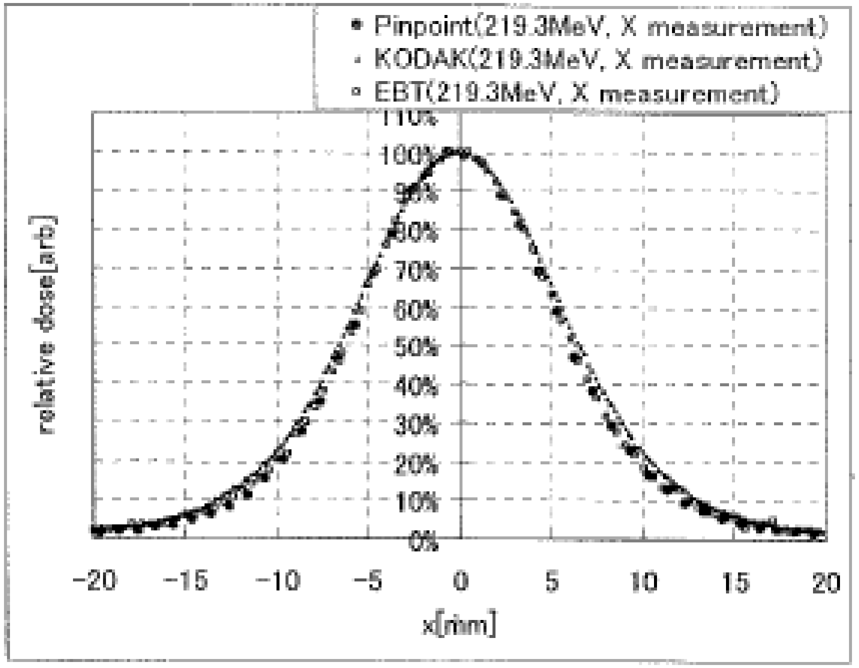
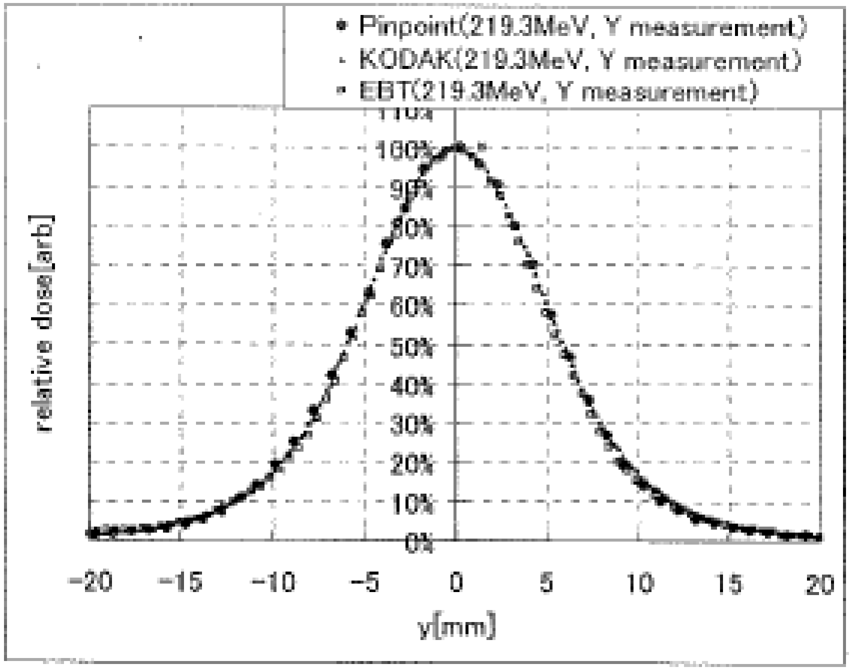
# Dose profile parallel to beam (work in progress)



# Film vs. Pin Point Chamber



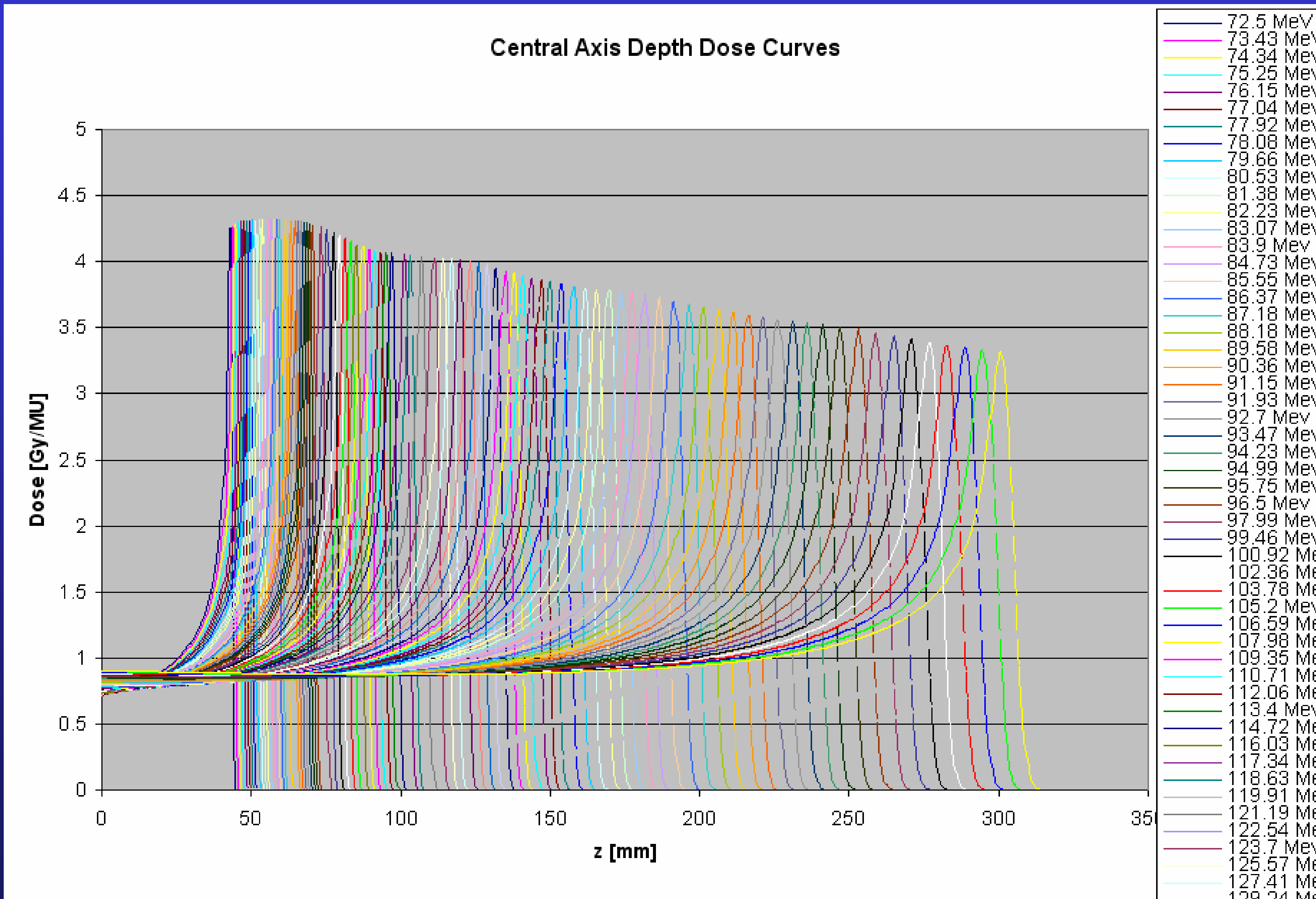



# Mock Commissioning of Varian Eclipse Treatment Planning System (TPS)

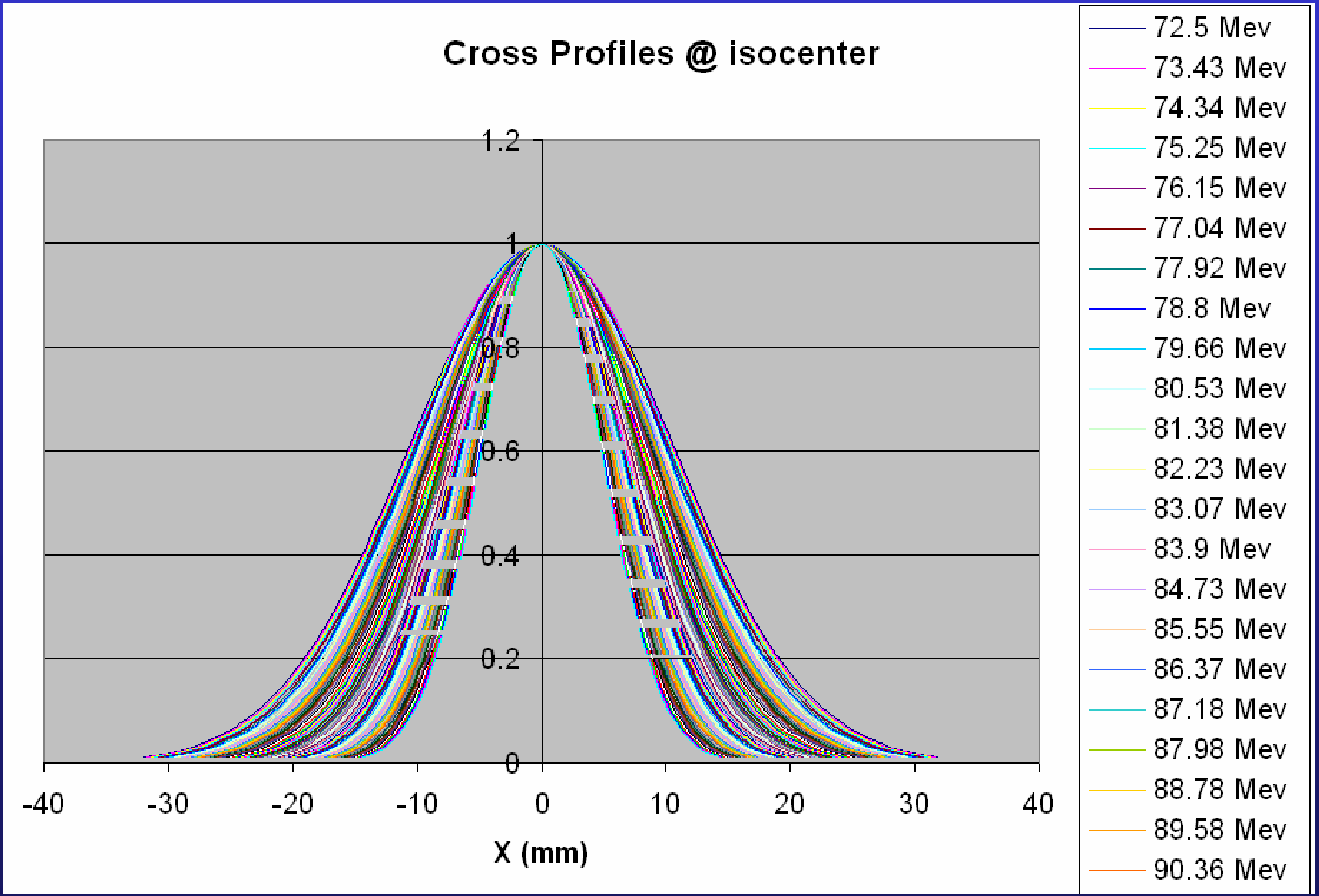
# Minimal TPS commissioning data requirements

- 93 CAX depth dose curves, in water for 93 energies ranging in penetration from 30 cm to 4 cm
- 2 x 5 x 93 lateral scans through CAX pencil beams in air, corresponding to 2 orthogonal scans at 5 distances from the isocenter plane

# CAX depth dose curves



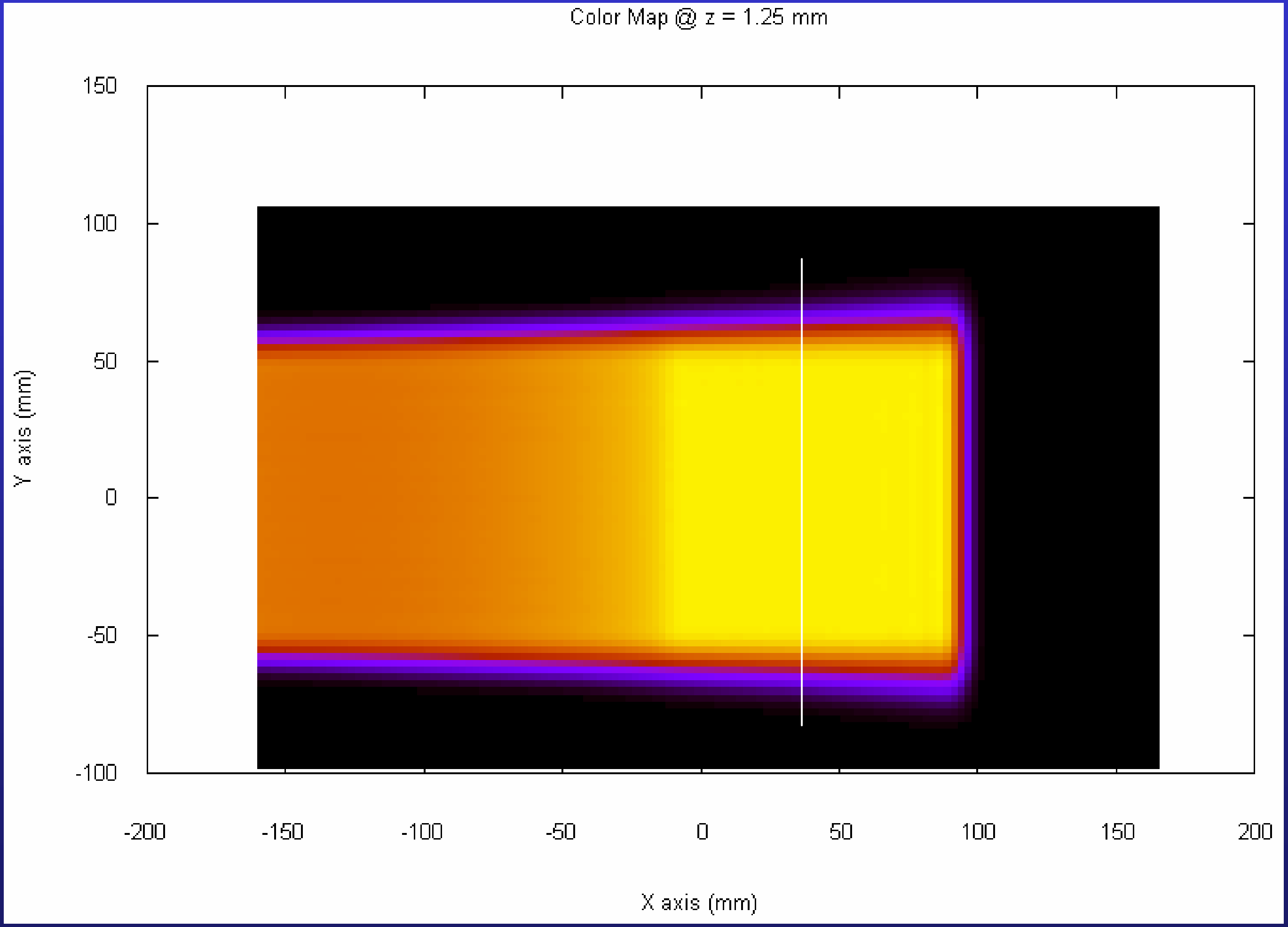
# Cross Profiles



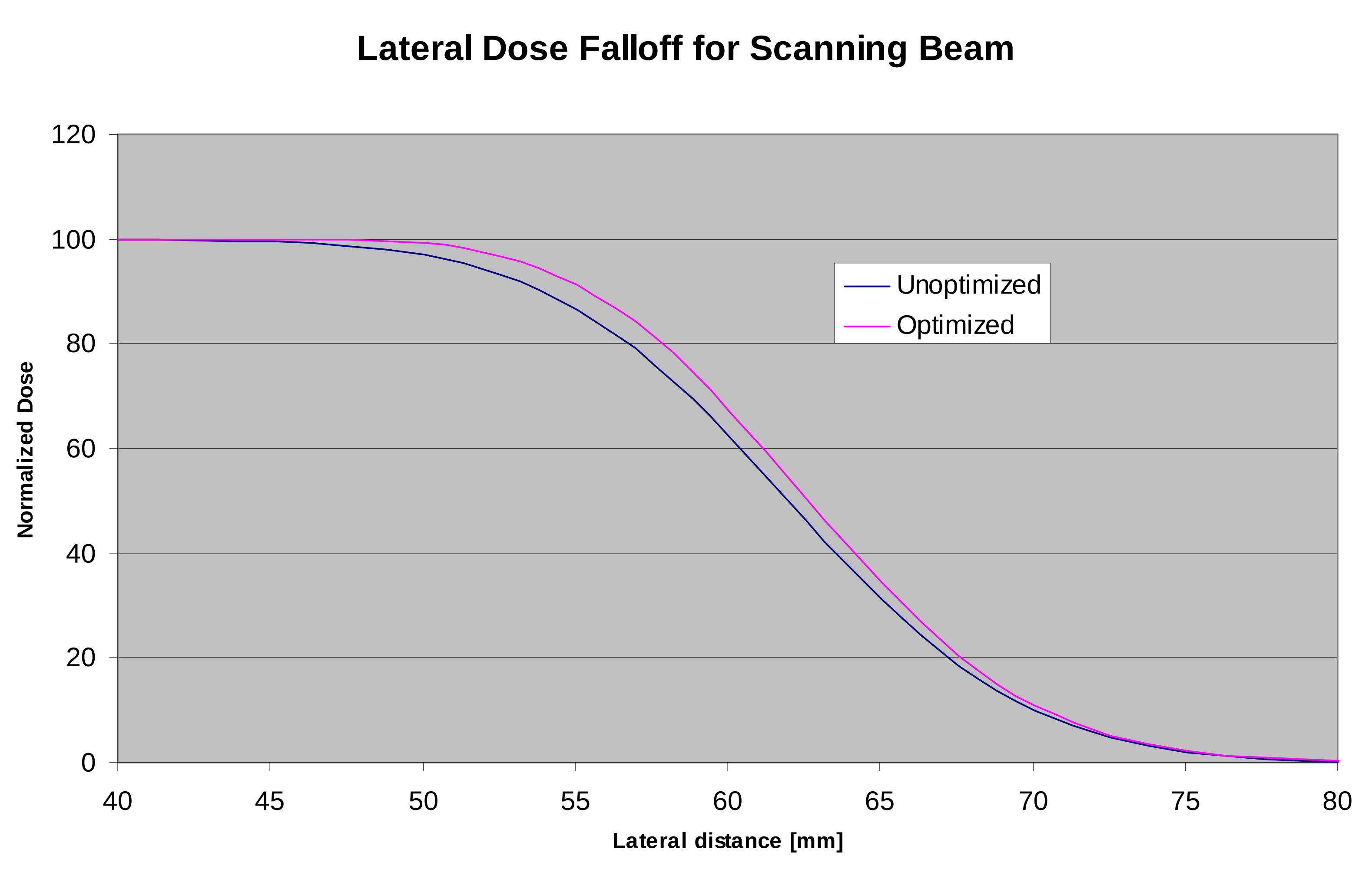
# Simple Treatment Planning Exercise

- Simple geometric TP scenarios 10x10x10 cm target volumes in a water phantom
- Spot placement distance of 6.5 mm
- “Optimized” and “un-optimized” treatment plans

# Scanned beam



# Un-optimized vs. optimized



# Penumbra Comparison for Varian Eclipse Plans

- Penumbra for un-optimized scanning:
  11 mm
- Penumbra for optimized scanning:
  10 mm

For reference:

- Penumbra for passive scattering:
- 10 mm

# Limit for PBS penumbra

- Spot Sigma in water x 1.3
- At center of SOBP energy of ~ 150 MeV
- Spot Sigma = 6.5 mm
- 9 mm Penumbra may be achievable