Scintillating Plate, Block Bar, and CCD Camera as a Tool of QC Verification System in Proton Therapy at PMRC

Kiyoshi Yasuoka

Proton Medical Research Center (PMRC)
University of Tsukuba, Japan
e-mail: kiyoshi@pmrc.tsukuba.ac.jp

Introduction

- World Wide Spread of Particle Therapy Facilities using Rotational Gantries
- Importance of Quality Control (QC) for Any Equipments Relevant to Particle Therapy
- Importance of Isocenter (IC) Verification

Isocenter (IC)

Definition from the Following Points of View:

1. Geometrical Position – Mechanical View
2. Patient Position – X-ray View
3. Exposure Position – Particle Beam View

Relevant to Lateral Position.

Importance of Isocenter (IC) Verification

1. Consistency in Center Positions of X-Ray Field and Particle Field
2. Consistency in Centers of Particle Fields determined with Treatment Planning and Measurements
3. Effects of Different Exposure Angle from Patient Positioning Angle

Review of IC Verification System

1. **MGH Method**
   - **Three Dial Gauges contact with Reference Stainless Ball**
     - **Accuracy： ±0.1～±0.2 mm**
     - **Time to measure： 1.5 days (twice a year)**
     - **Verified Objects： Geometrical Center of Rotational Gantry**
     - **Reference： A stainless ball required**

   Detector directly contact with the reference ball

2. **PMRC Method-1**
   - **Imaging Plates (IP) contactless with Reference Stainless Ball**
     - **Accuracy ： ±0.1～±0.2 mm**
     - **Time to measure ： 2 hours （irregular time when it is required for QC）**
     - **Verified Objects ： Center of Particle Irradiation Field, Center of X-ray Irradiation Field, Laser Marker**
     - **Reference： A stainless ball required**

   Detectors replaced every gantry angle out of touching with the reference ball

PMRC Method-2

Irradiation Field Images produced on a Scintillating Plate (SciP) and viewed by a CCD Camera

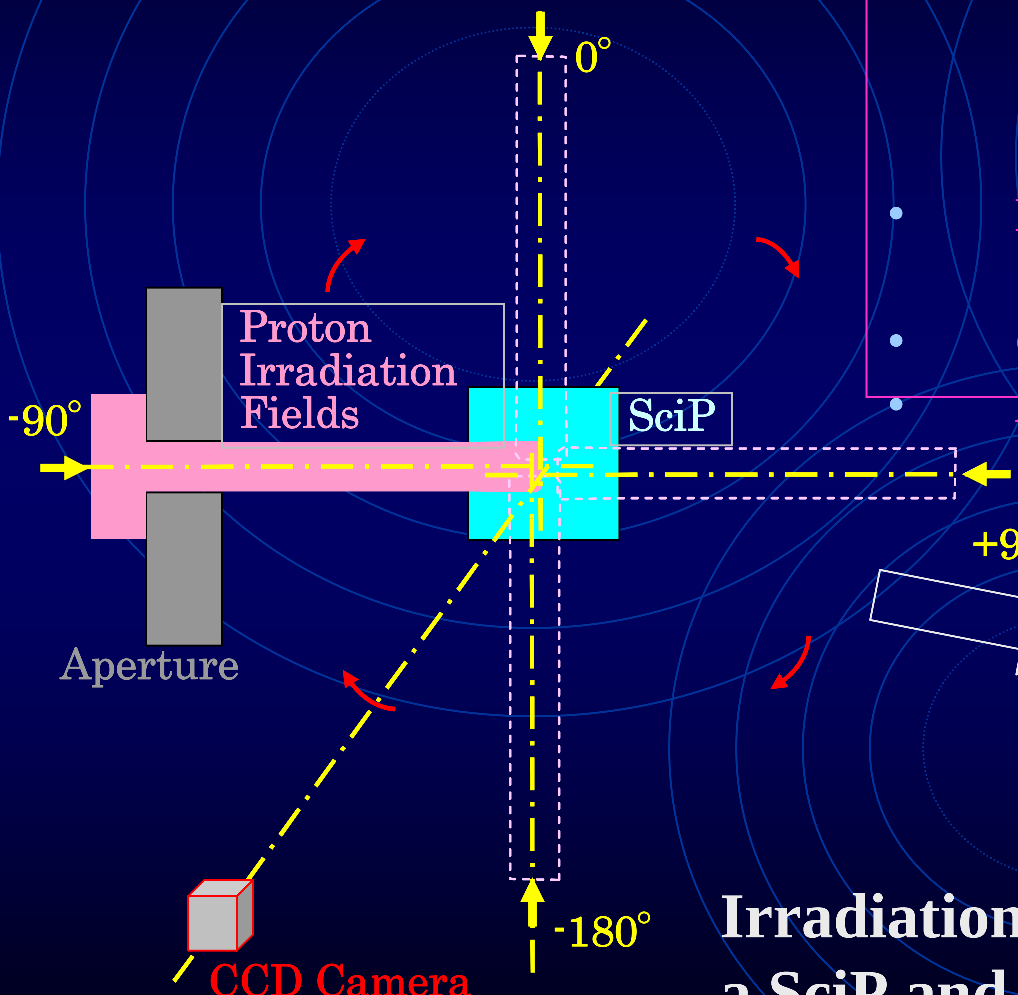
- Verified Objects : Center of Particle Irradiation Field, Center of X-ray Irradiation Field, Laser Marker
- No Reference Ball Required
- No Contacts with Detectors
- Time to measure : Half an hour

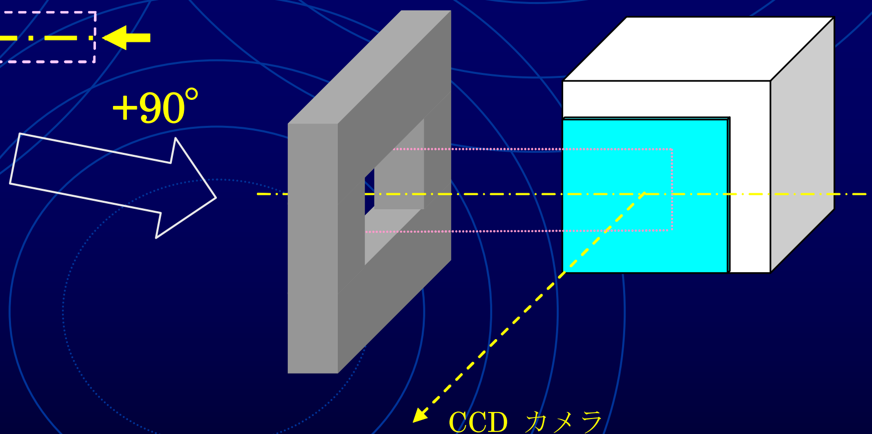
Verification Method

- **Trigger** : Beam Extraction Gate received from Acc.

  （0.5Hz,TTL,400msWidth）
- **Beam** : Proton

  300 ms width at max
- **Gantry** : ±90, 0, -180, +45 degrees
- **Aperture** : 100 x 100 mm^2





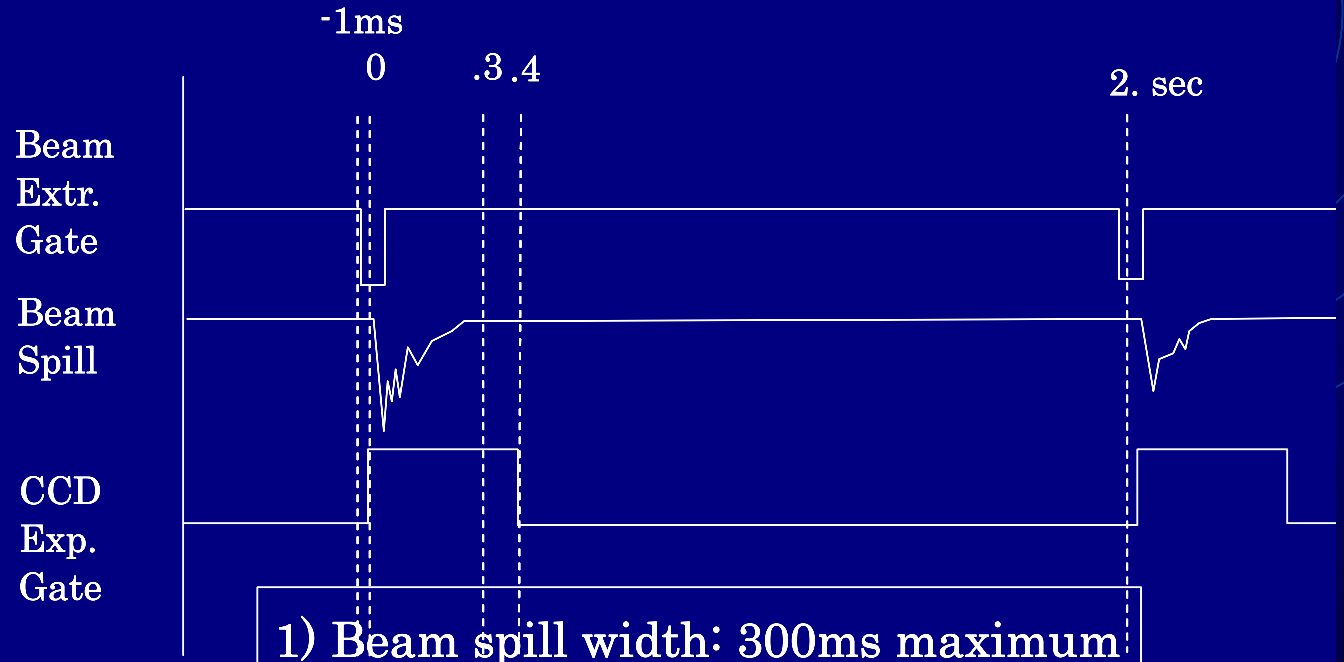
Irradiation Field Images produced on a SciP and viewed by a CCD Camera, which is setup 5-m far from IC.

Equipment

- **Plastic Scintillating Plate (SciP)**
  - **NE102A**
  - **200 mm x 200 mm x 1 mm^{t}**

- **CCD Camera**
  - **Hamamatsu ORCA-ER-1394**
  - **Nikkon 105mm zoom lens**
  - **Hamamatsu CCD Camera Controller**

Timing Chart

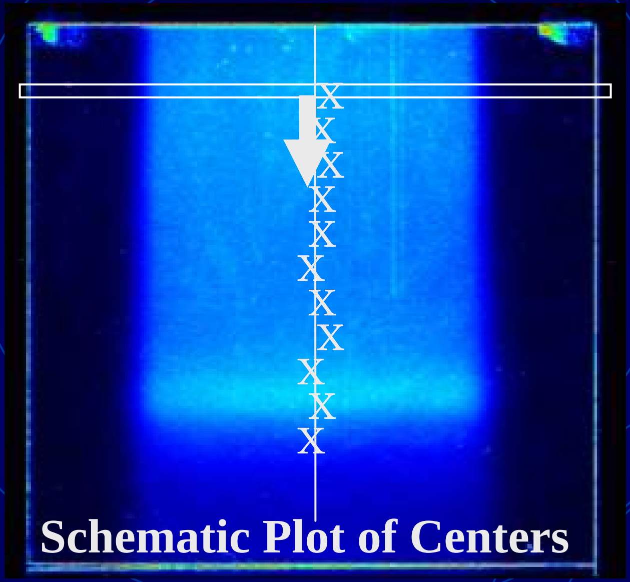


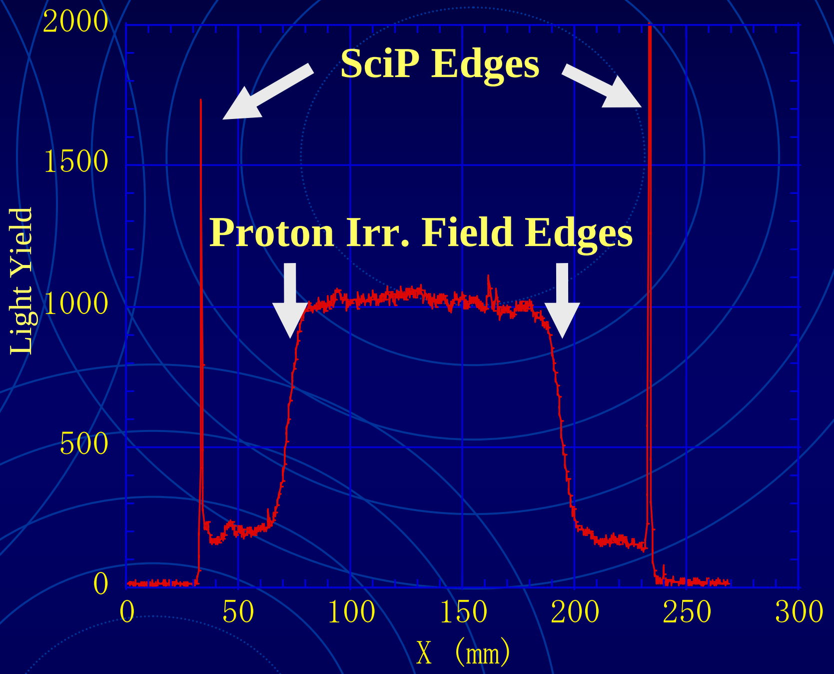
1) Beam spill width: 300ms maximum

2) CCD exposure-time Gate: 400ms

Analysis

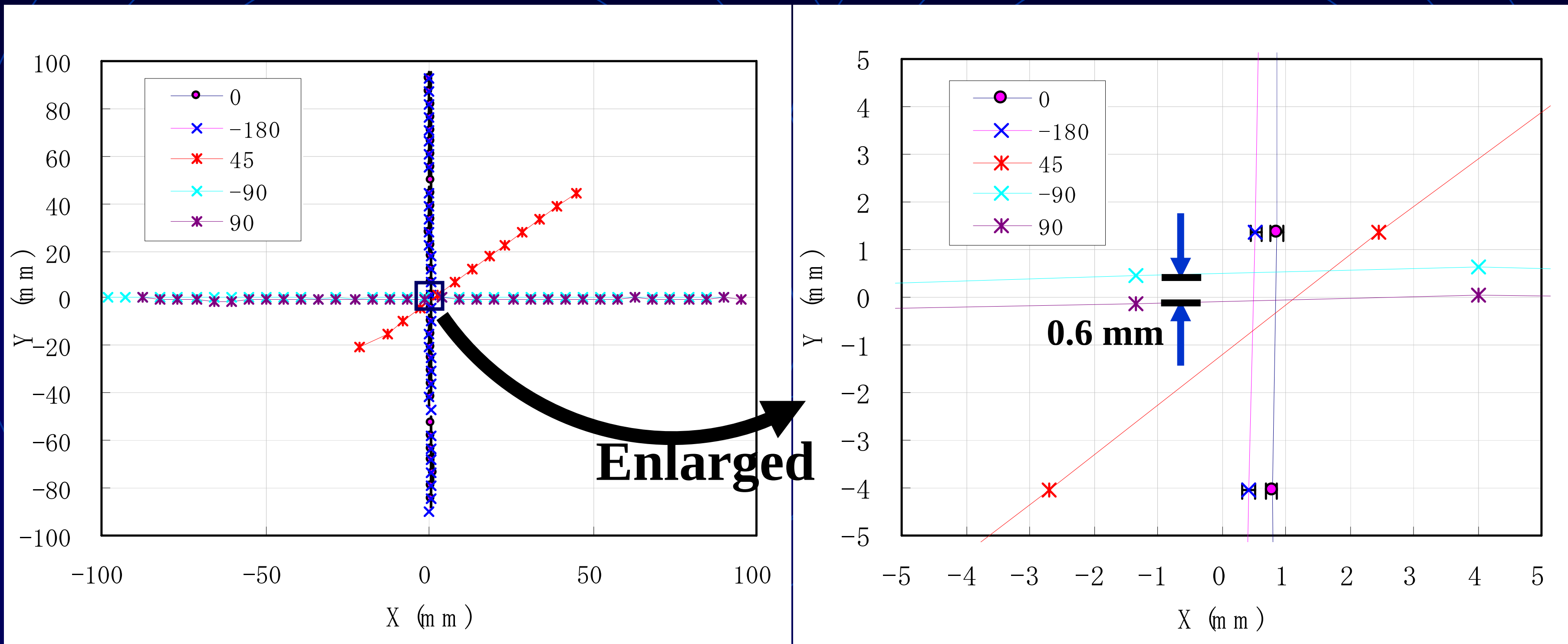
Proton Irradiation Fields Detected with SciP and CCD Camera





1. Setting up Region of Interest (ROI)
   - 1000 pixel x 20 pixel
   - (250 mm x 5 mm)
2. An error function fitting the edges of penumbra in each ROI. The edges X1 and X2 provide each center: $X_C = (X1+X2)/2$.
3. Scanning ROI along a beam direction every step by 20 pixels

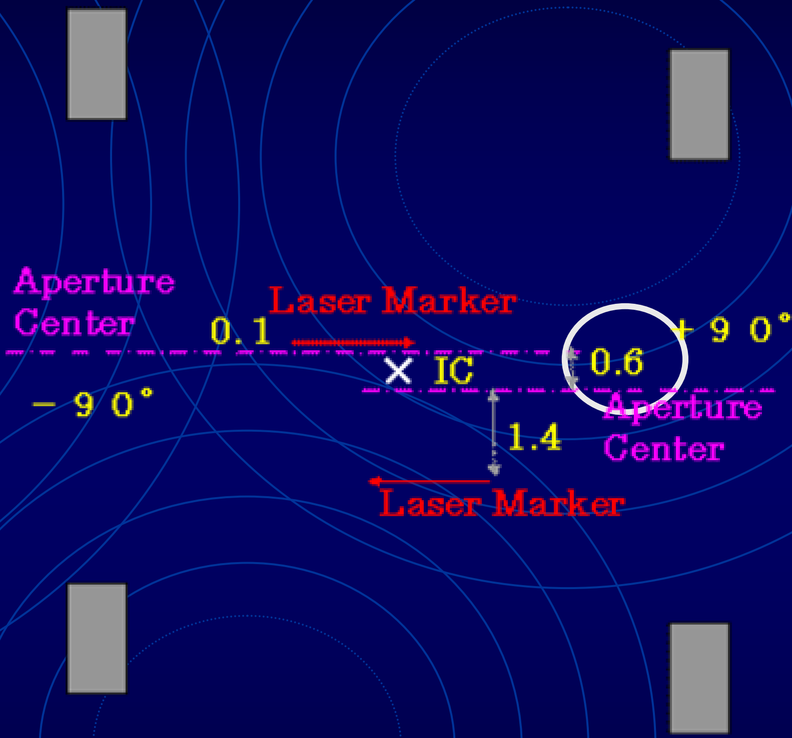
Results



1. A center line of proton irradiation fields is provided by a straight line fitting centers of penumbra edges obtained along beam direction at each gantry angle.
2. Accuracy in measurement of the IC position is ±0.1 mm , which is estimated from the fitting errors for the central line of the proton irradiation fields. The accuracy at +45 degrees is ± 1.8 mm.

Comparison with Other Methods

PMRC Method 1



- In comparison with the center line of proton irradiation field at -90° , the center line at +90° shifts downward by 0.6 mm. This result is consistent with those obtained from PMRC Method 1 and MGH Method.

Importance of Range Verification

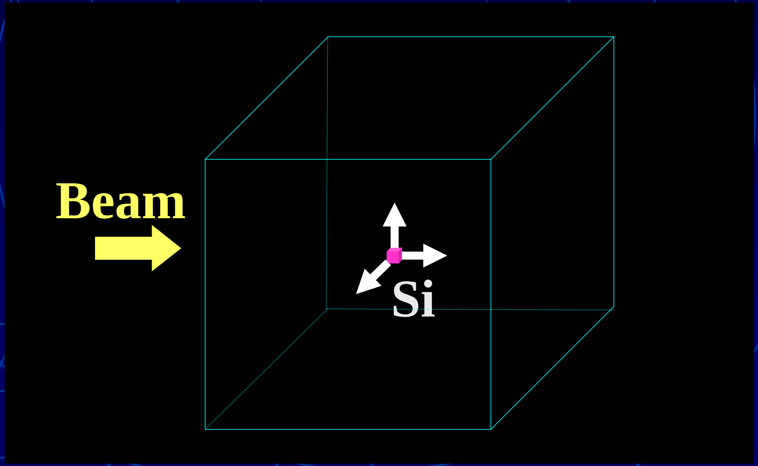
1. Compensators provide various shape of proton irradiation fields: small target volume and/or complicated target volume.
2. Those make it difficult to evaluate precise dose distribution in treatment planning programs even if they use a pencil beam algorithm including no scattering effects produced at steep edges of apertures and compensators.

$$R = \int_{E_0}^{0} \frac{dE}{\left(\frac{dE}{dx}\right)}$$

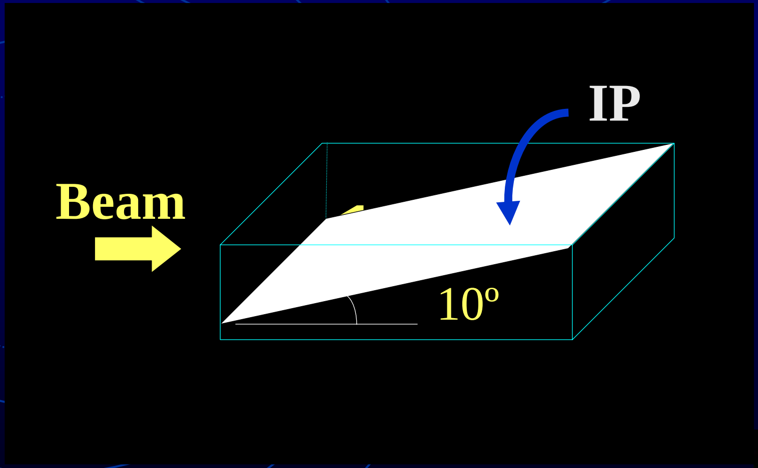
Relevant to Longitudinal (Depth) Position

Review of Range Verification System

- Si detector scanned three-dimensionally in a water phantom

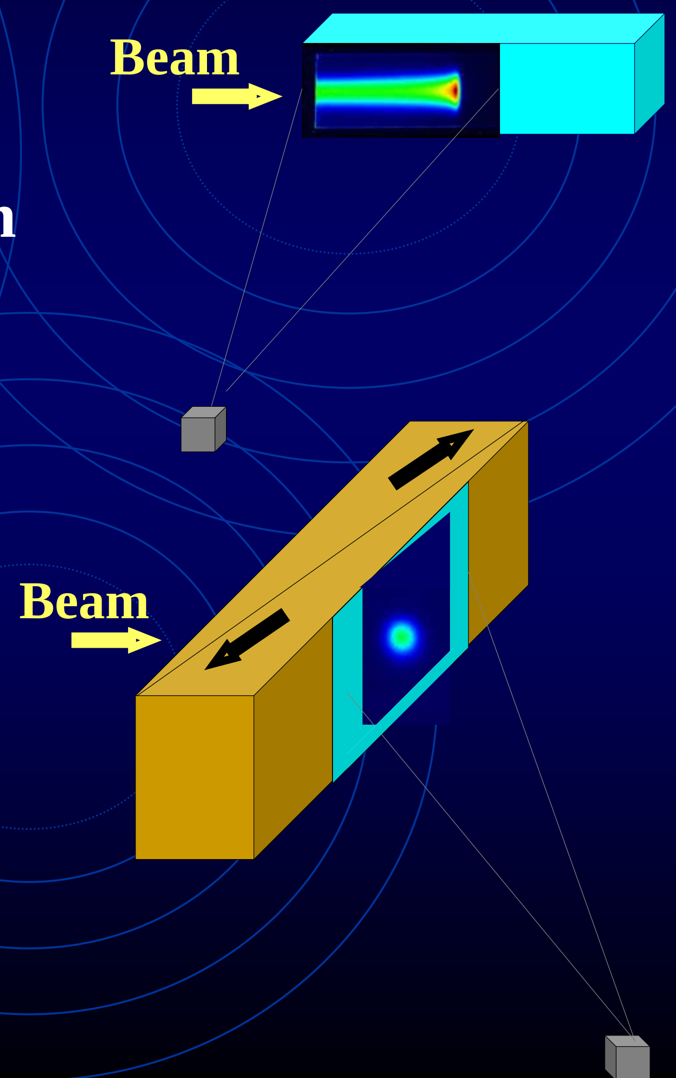


- 10 degrees-inclined imaging plate (IP) sandwiched between two triangle-shaped acrylic blocks



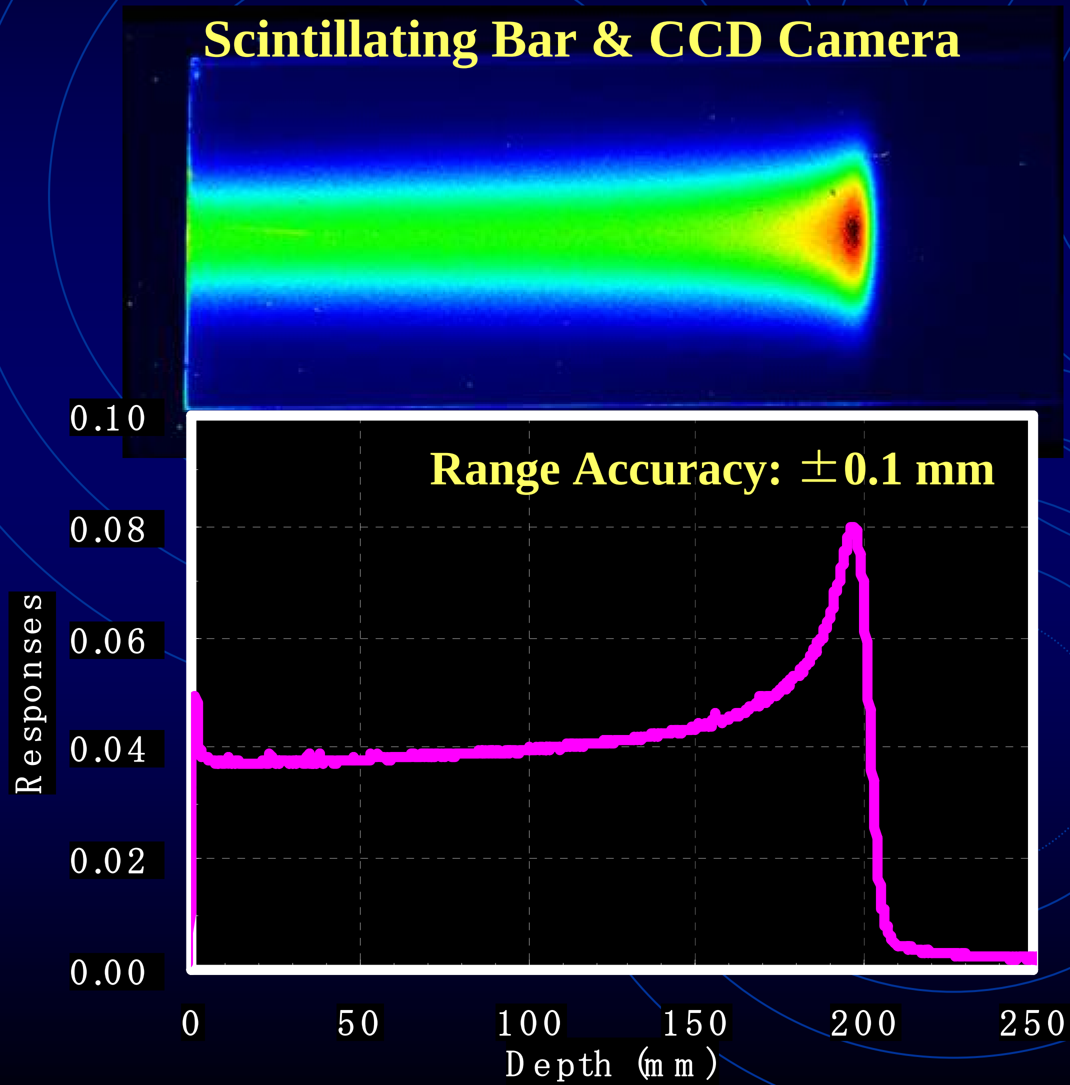
Range Verification using SciBar and SciP

1. **SciBar&CCD Camera**
   - 3D-Dose Distribution in a Scintillating Block Bar → 2D Projection along Depth Direction → 1D Longitudinal Profile → Range
2. **SciP&CCD Camera**
   - 2D-Lateral x 1D-Depth Scanning → 1D Longitudinal Profile → Range



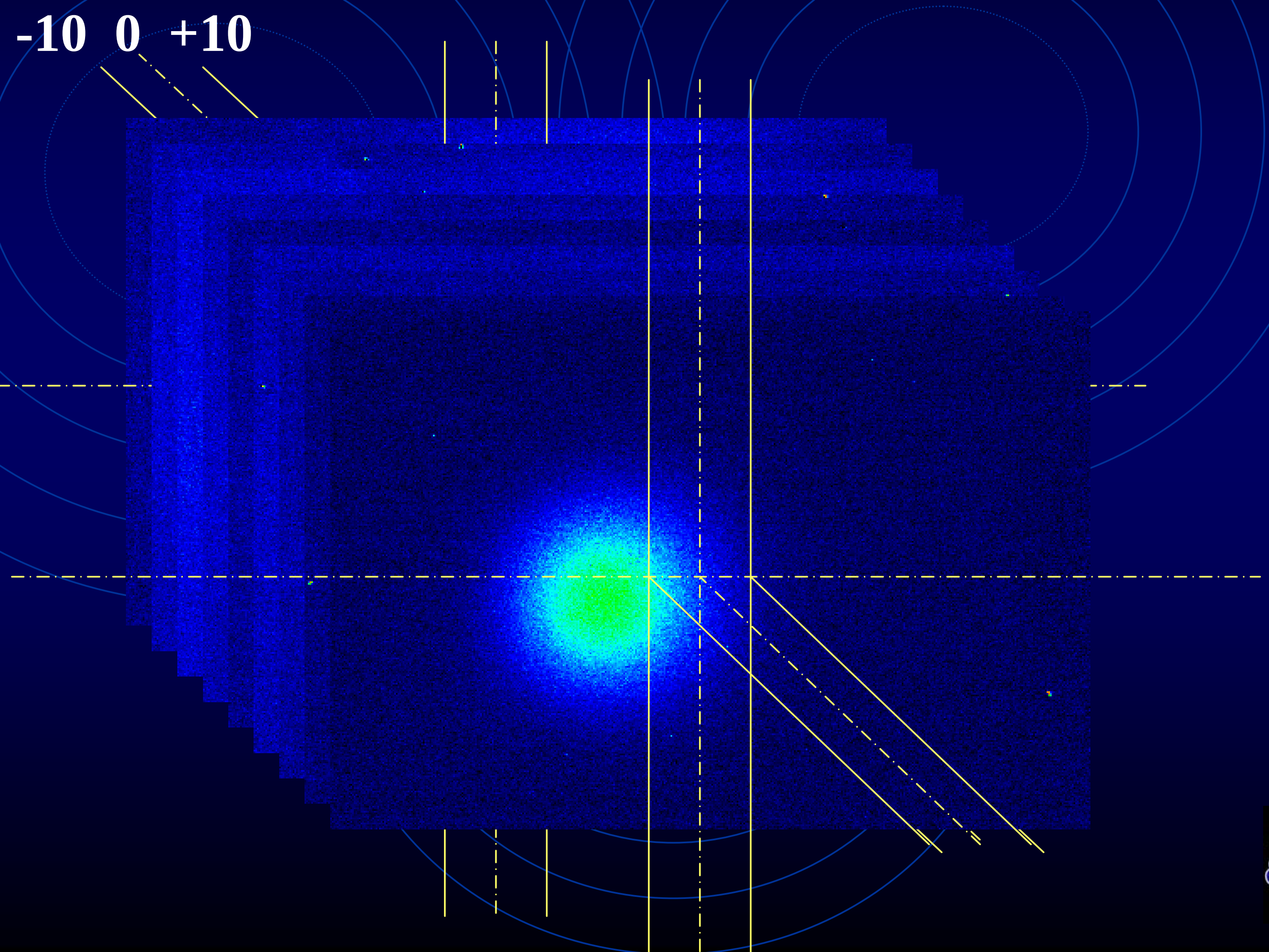
Range

200 MeV
No Range Shifts
No SOBP Filter



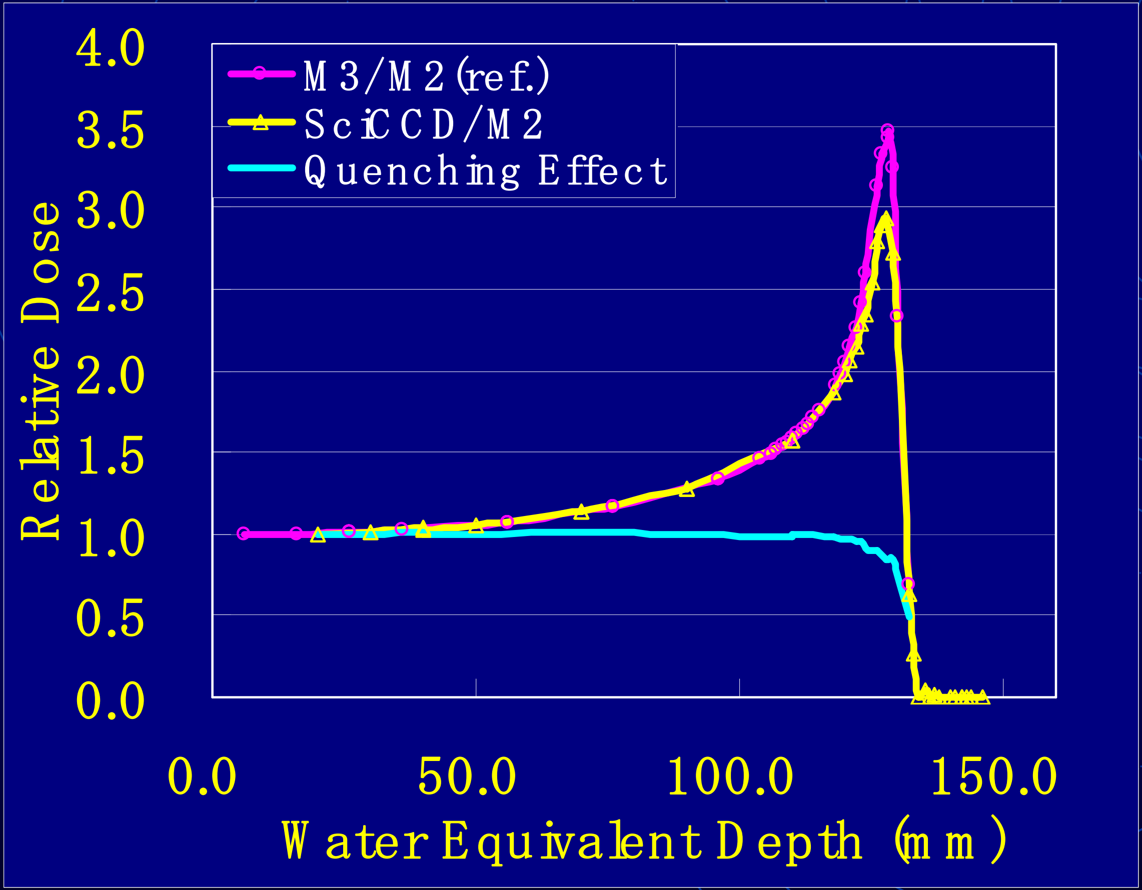
2-D Images x 10 Slices

Scintillating Plate & CCD Camera



Range

Scintillating Plate & CCD Camera



155 MeV
No Range Shifts
No SOBP Filter

Quenching effects on scintillating responses provide <u>no modification on ranges</u>.

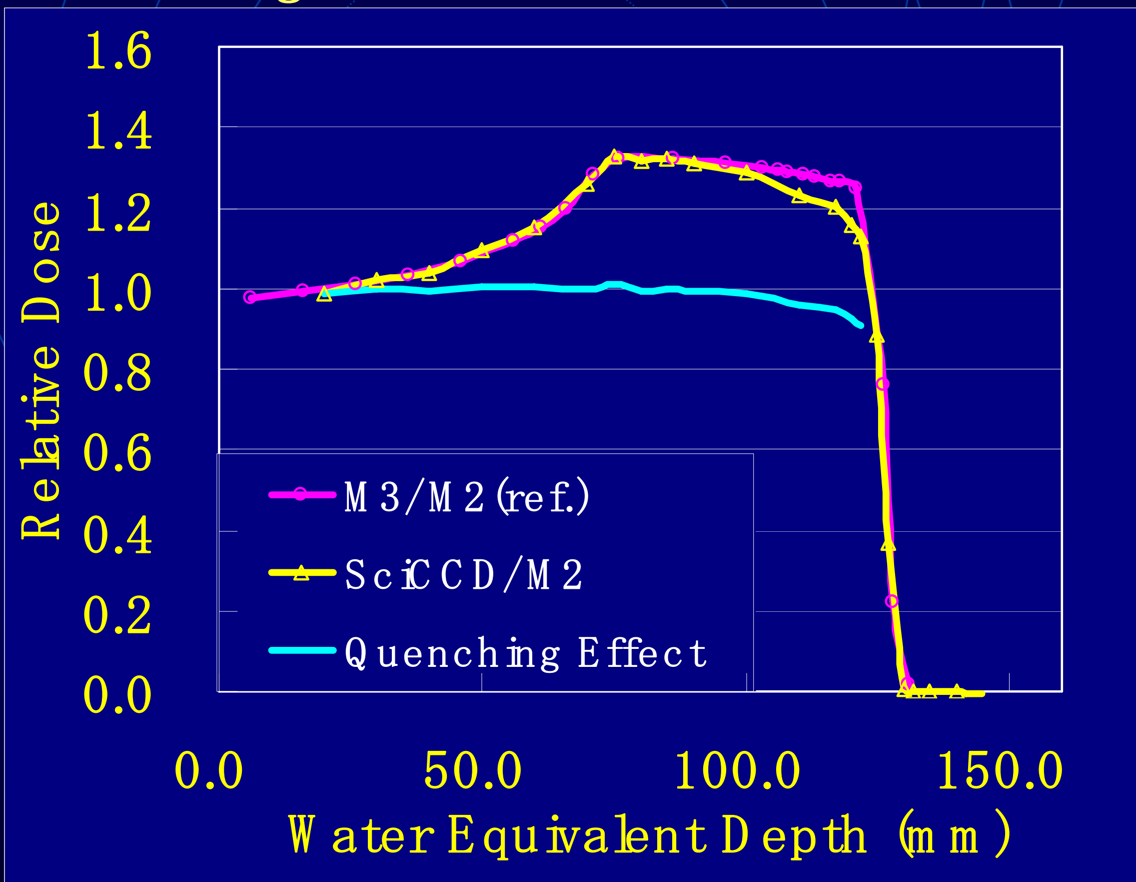
M2: Beam Monitor
M3: Thimble Ionization Chamber

Quenching Effects at Higher LET Regions

- **Light emission from plastic scintillating plates is reduced at higher LET regions**
- **Light yield reduction is <u>15%</u> at Bragg peak**

Range

Scintillating Plate & CCD Camera



155 MeV
No Range Shifts
<u>50-mm SOBP Filter</u>

Quenching effects on scintillating responses provide <u>modification on shapes.</u>

M2: Beam Monitor
M3: Thimble Ionization Chamber

Summary

- **<u>In PMRC Method 2</u>, the accuracy in measurement of the center of proton irradiation fields is the same level as MGH Method and PMRC Method 1: <u>±0.1 mm</u>.**

- **No reference ball and no contacts to detectors are required <u>in PMRC Method 2</u>. It is feasible to measure the center of irradiation fields for both protons and x-rays with the same detector setup and a practical short time.**

- **A system of scintillating plate, block bar, and CCD camera is very useful in verification of IC and ranges.**