

# First demonstration of real-time gamma imaging by using a handheld Compton camera for particle therapy

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# Outline

## ■ Background

- Particle therapy
- Compton camera

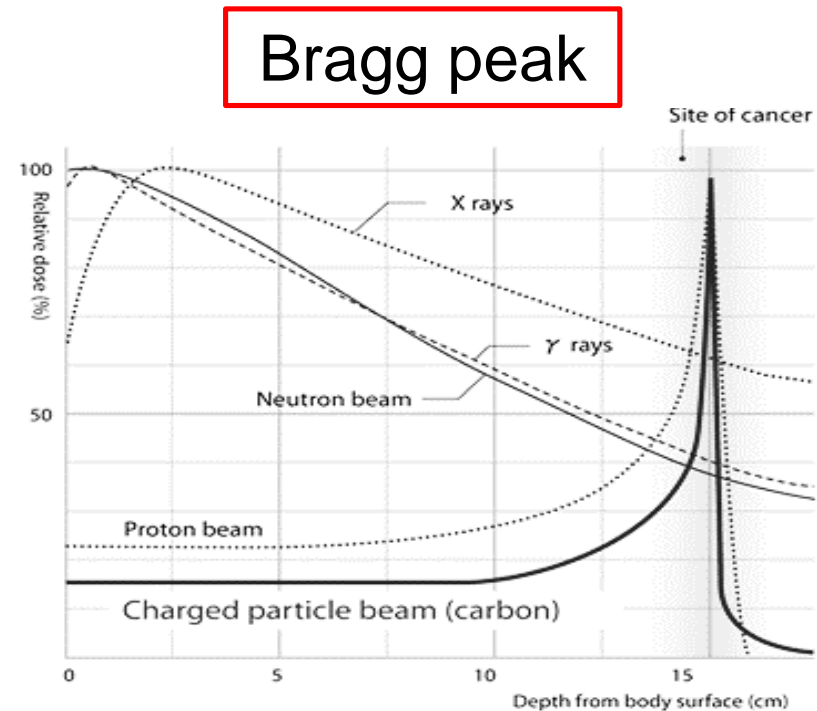
## ■ Proton beam irradiation test

- Irradiation condition
- Measurement of energy spectra of gamma rays
- Online monitoring by using a Compton camera

## ■ Summary

# Particle Therapy

- Particle beams **can damage a cancer efficiently** due to its **Bragg peak**, while normal cells are safe.
- Verification of the energy deposit only on the cancer is very important to prevent **unwanted exposure**.
- ➔ imaging of gamma rays  
emitted by nuclear interactions



<http://www.nirs.go.jp/ENG/core/cpt/cpt01.shtml>

# Particle Therapy

## ■ Gamma rays emitted during irradiation

### Annihilation gamma rays

- 511keV
- Derived from **positron emitter**
- **PET**(**offline image**)
- Don't trace the Bragg peak well  
(in case of proton)

### Prompt gamma rays

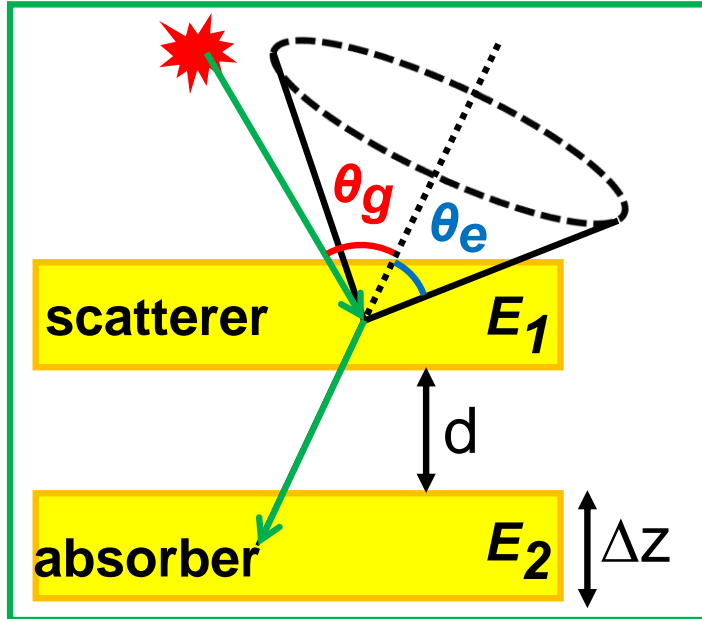
- ~a few MeV
- Derived from **elastic / inelastic scattering de-excitation**
- **Gamma camera** (**online image**)
- Trace the Bragg peak well

*Kurosawa et al.  
2012, Curr. Appl. Phys.*

## **Purpose**

**First demonstration of online gamma imaging**

# Compton camera (CC)



## ■ Compton Kinematics :

$$\cos \theta_e = 1 - \frac{m_e c^2}{E_2} + \frac{m_e c^2}{E_1 + E_2}$$

$$\text{ARM} = \theta_e - \theta_g$$

### Good angular resolution

- Large distance ( $d$ )
- Thin detectors ( $\Delta z$ )
- Good energy resolution ( $\Delta E$ )

## ■ Based on scintillation detectors

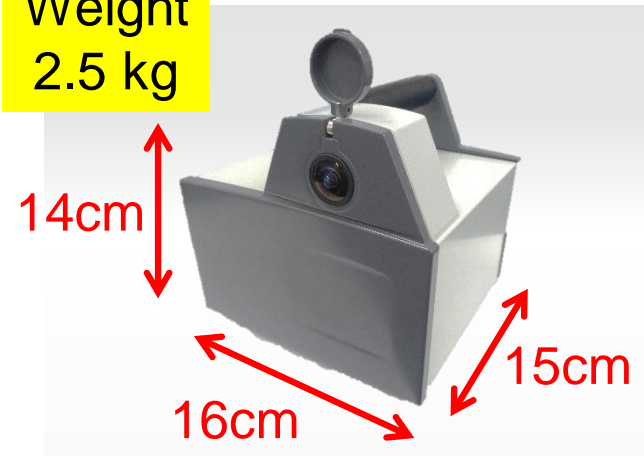
- $8 \times 8$  MPPC array
- GAGG ( $\text{Gd}_3\text{Al}_2\text{Ga}_3\text{O}_{12}$ ) scintillator

## ■ Angular resolution

- **~8 degree** (FWHM) @ 662keV ( $^{137}\text{Cs}$ )

*Kataoka et al. 2014, NIM-A*

Weight  
2.5 kg



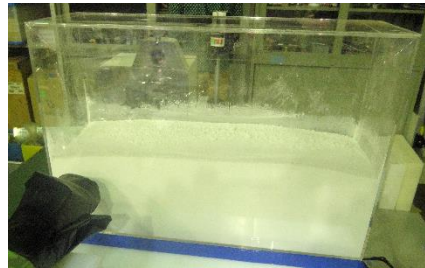
# Proton Beam Test

## ■ Irradiation Condition

- proton energy : 70MeV
- intensity : 3pA
- time : 10min / 20min
- phantom

H<sub>2</sub>O : 10×10×30 cm<sup>3</sup>

Ca(OH)<sub>2</sub> : 10×10×30 cm<sup>3</sup>



Approximately the half depth  
of the phantom case

Phantom case  
(PMMA)

thickness

3mm

10cm

20cm

30cm

PMMA : 3× 3×10 cm<sup>3</sup>  
(Polymethyl metacrylate)



PMMA block

# Proton Beam Test

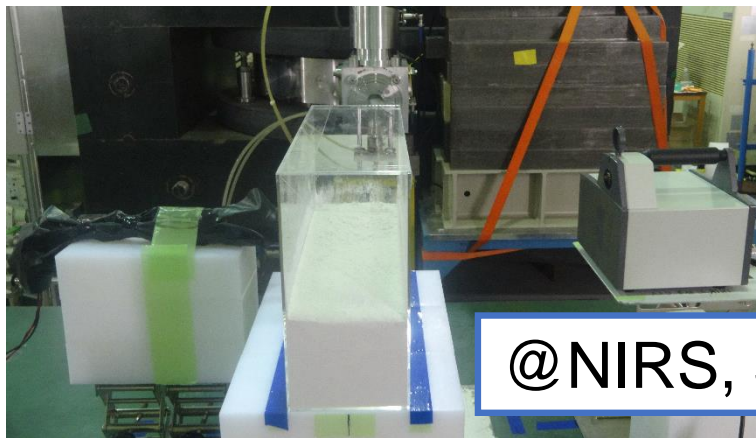
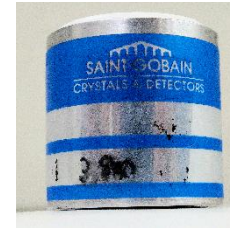
## ■ Experiment

- energy spectra of gamma rays

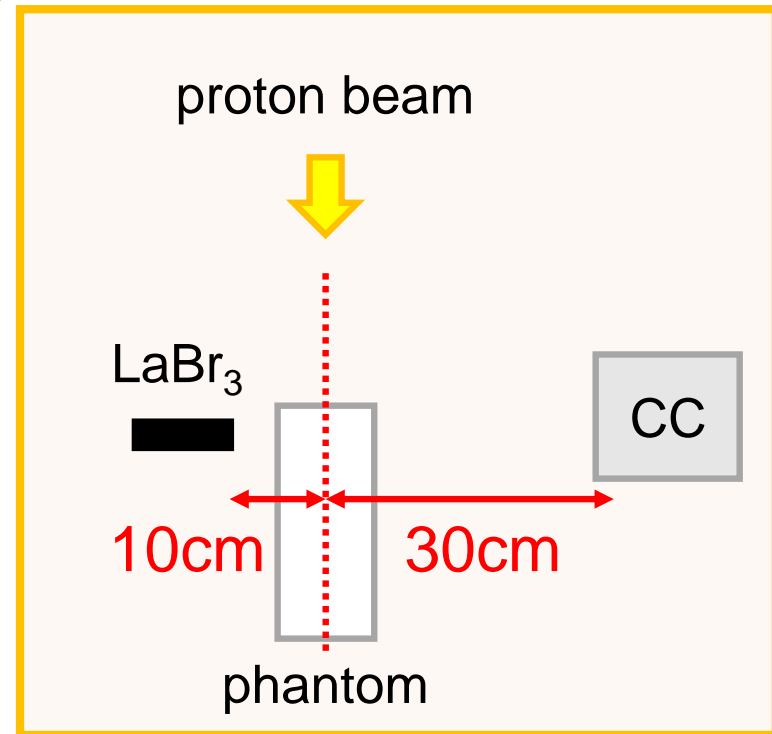
**LaBr<sub>3</sub>(Ce)** ( $\phi$  0.5", height 0.5")

**+PMT**(HAMAMATSU R3998-100-02)

- Online monitoring by using  
**the Compton camera**

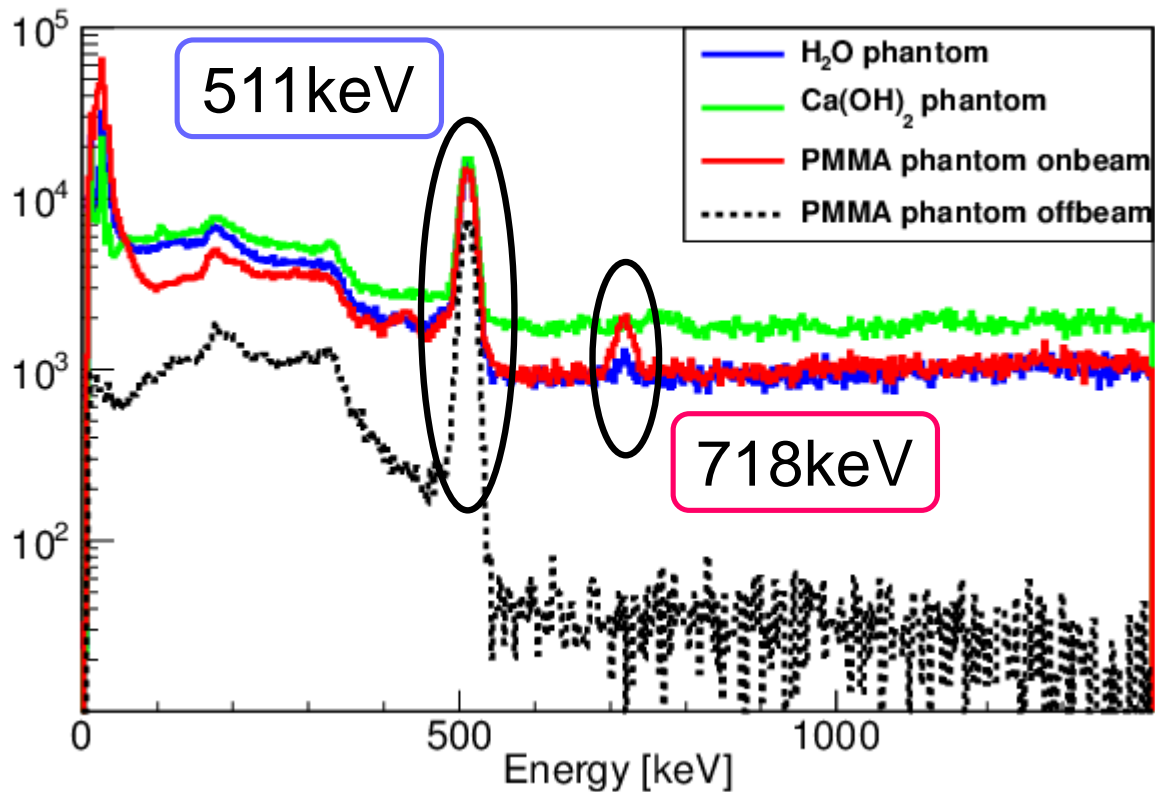


@NIRS, JPN



Experimental Setup

# Results of Energy Spectra



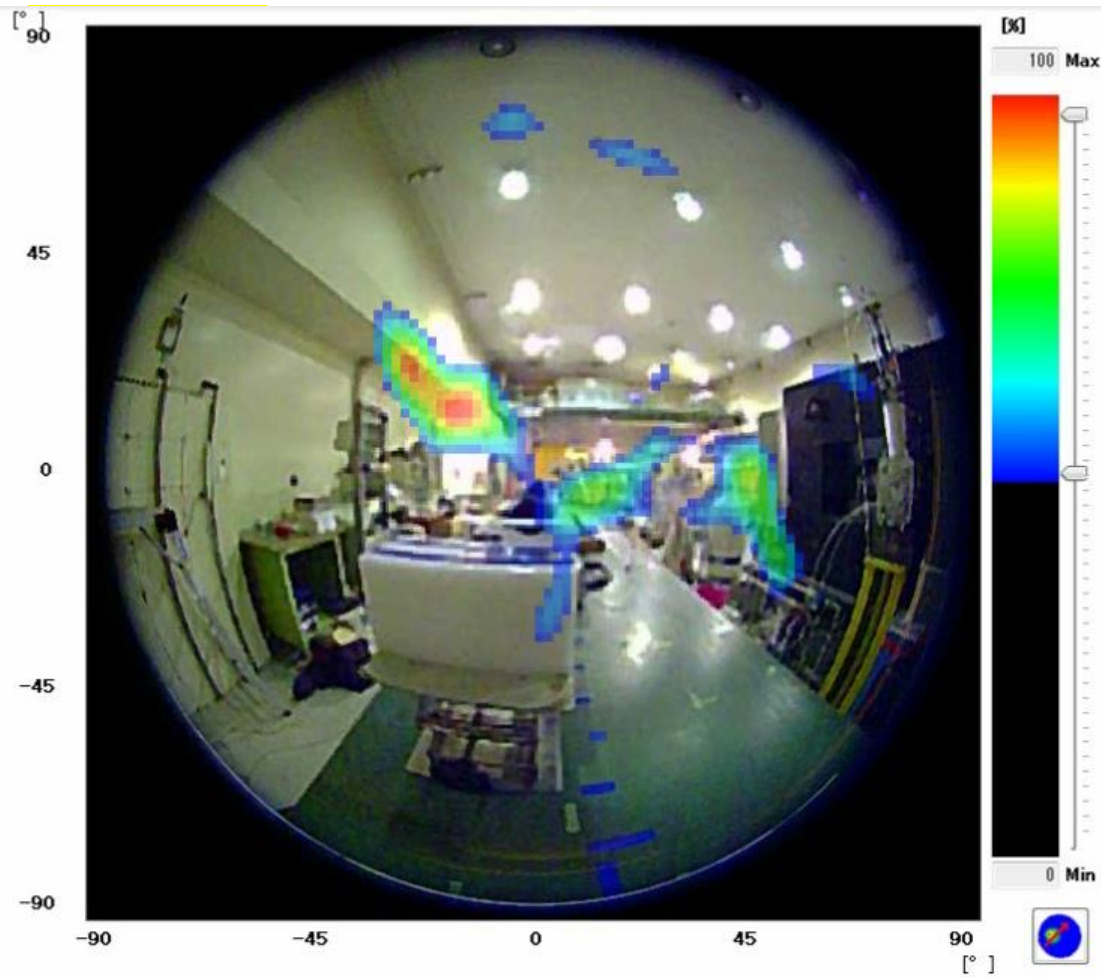
## ■ Obvious peak

- 511keV (annihilation gamma rays) ➔ all phantom
- 718keV (derived from the de-excitation of <sup>10</sup>C) ➔ PMMA



# Online Monitoring

**PMMA phantom**  
energy range **511keV**



measuring time (s)

108

number of events (cps)

340

# CC Image

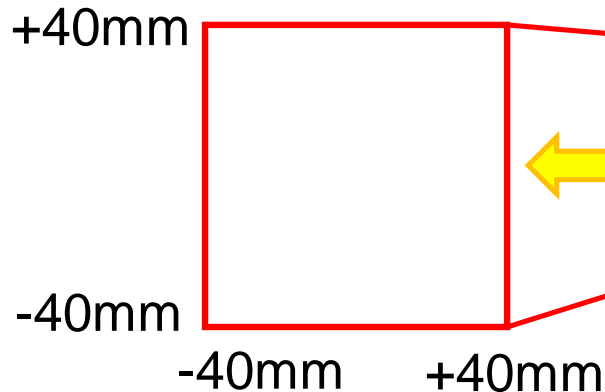
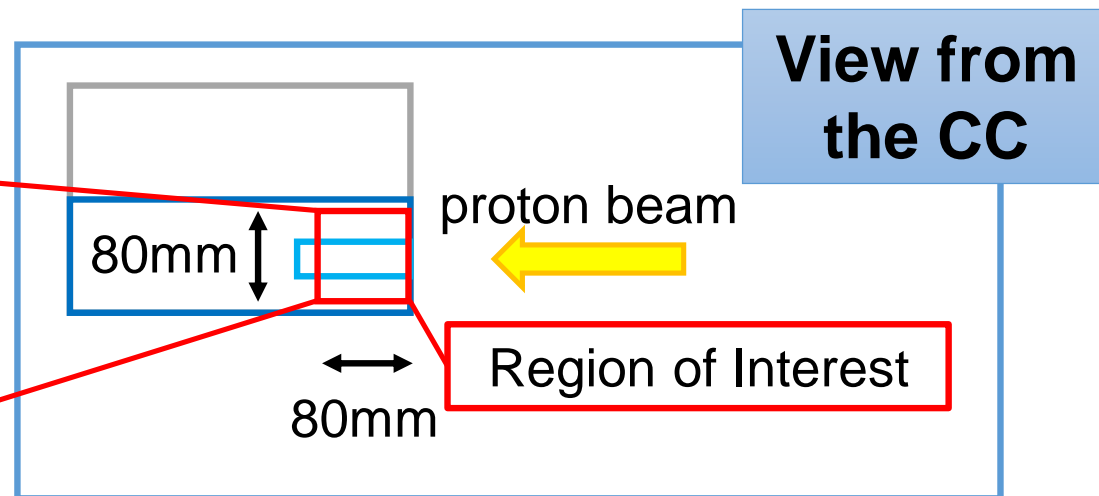
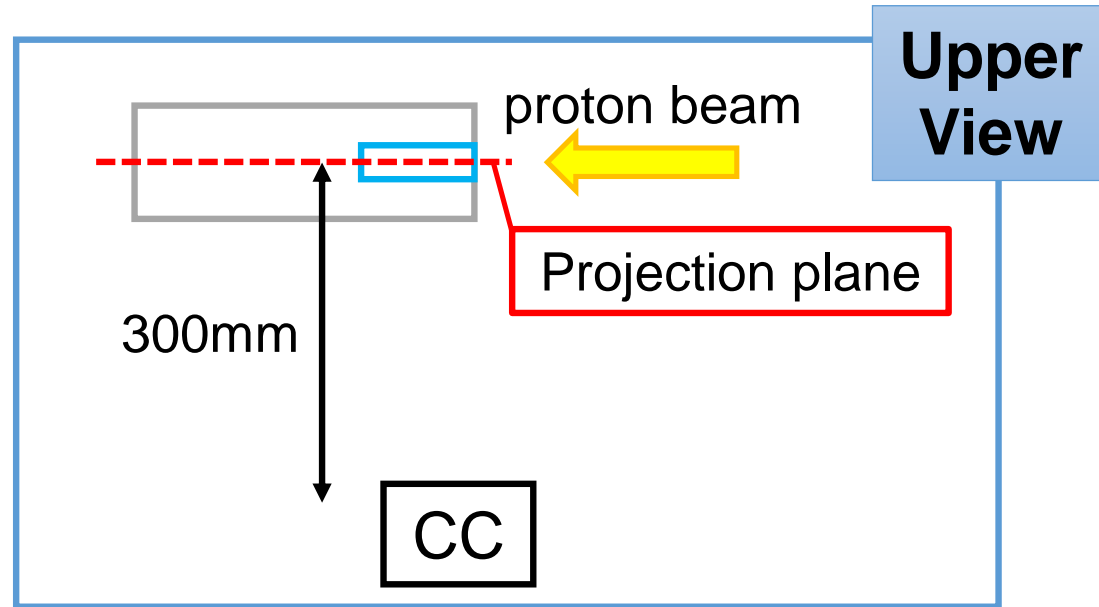
## ■ Image

### Reconstruction

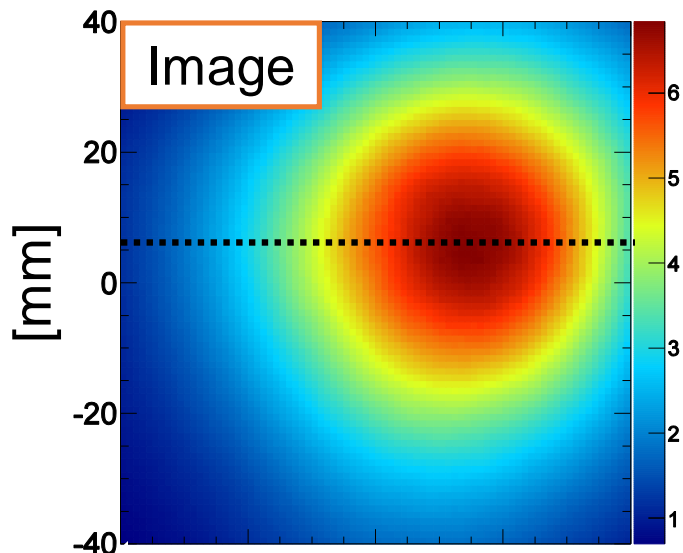
- plane projection

## ■ Energy Range

- 511keV
  - ➡ 451~571keV
- 718keV
  - ➡ 648~788keV



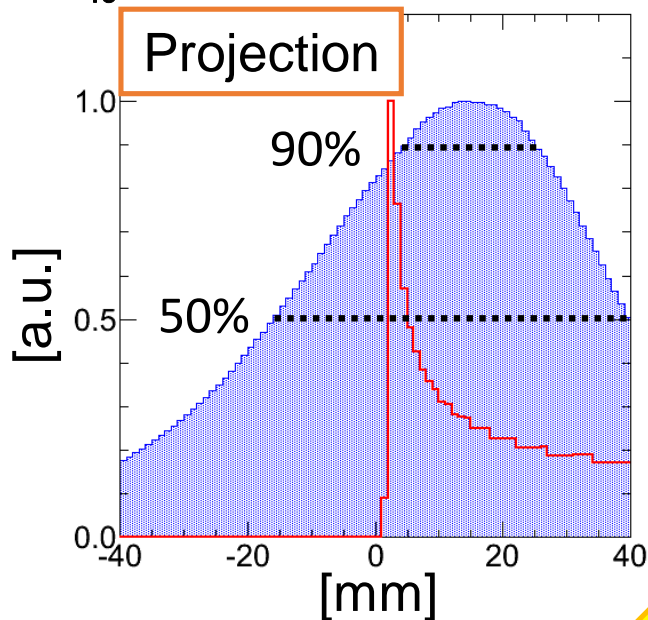
# Results of Images



■ H<sub>2</sub>O 511keV range

6414 events

Bragg peak position  
(calculated by Geant4) : 38 mm

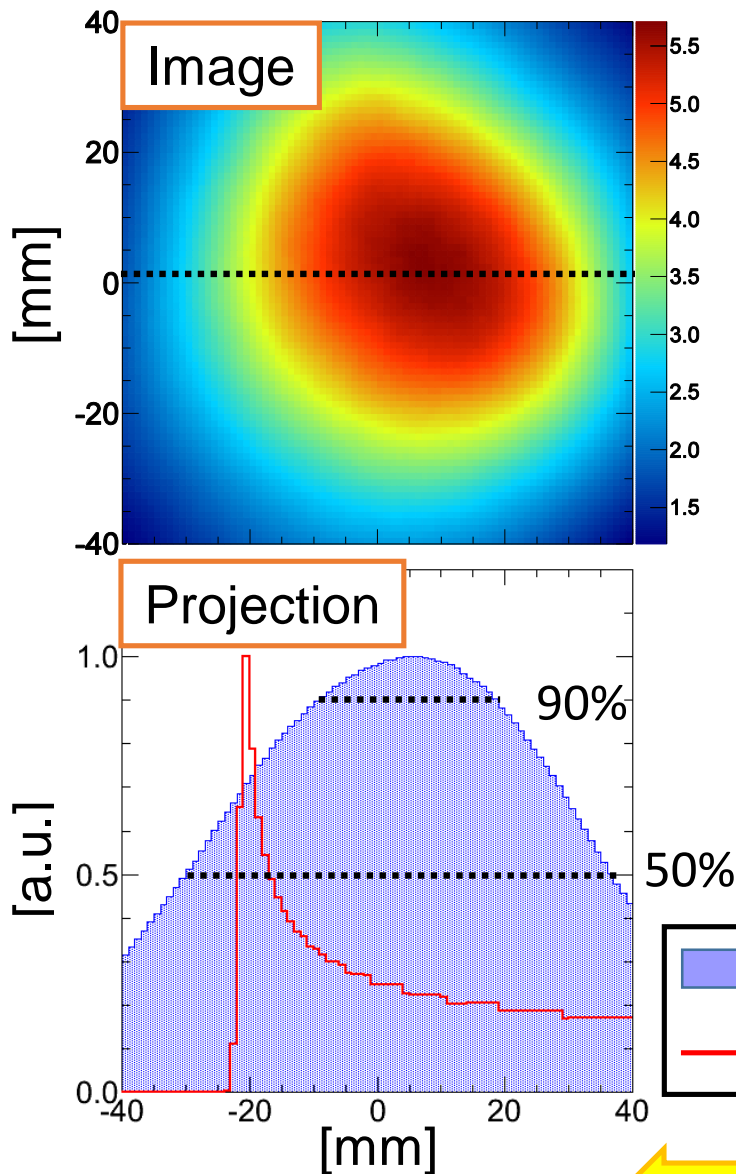


Peak position : 26±2.4 mm

Range of the  
90% peak position : 15~35 mm

← Beam direction

# Results of Images



■  $\text{Ca(OH)}_2$  511keV range

7118 events

Bragg peak position  
(calculated by Geant4) : 61 mm

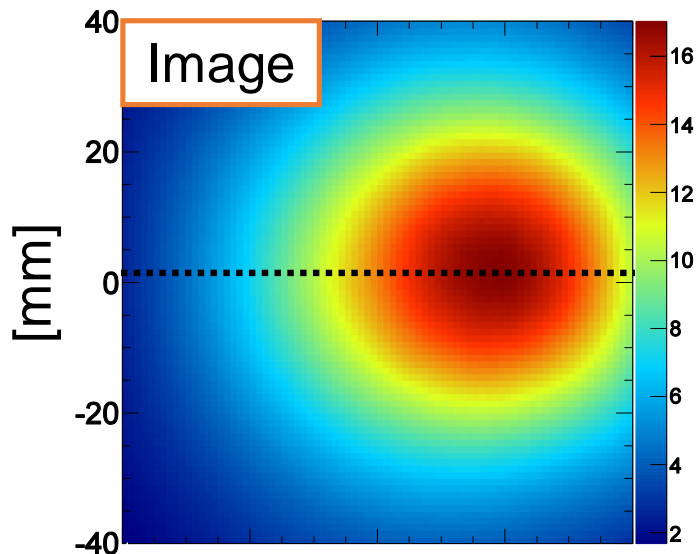
Peak position :  $33 \pm 3.3$  mm

Range of the  
90% peak position : 21~50 mm

■ : projection  
— : Bragg peak

← Beam direction

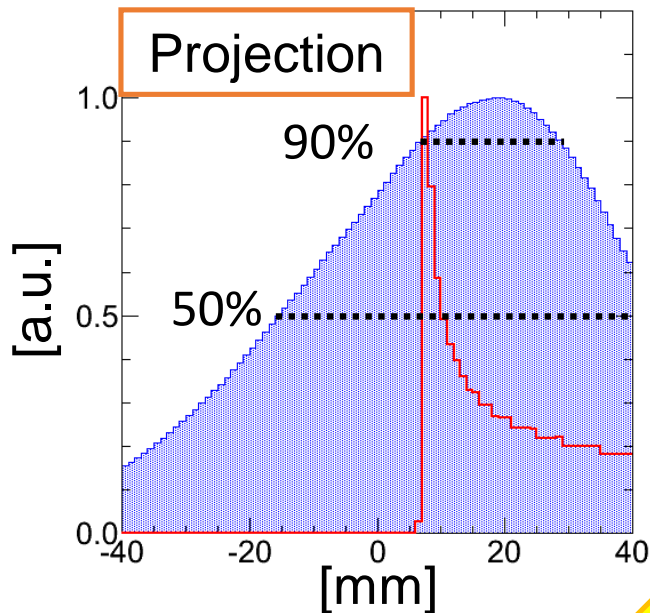
# Results of Images



■ **PMMA 511keV** range

**15184 events** (20min)

Bragg peak position  
(calculated by Geant4) : **33 mm**



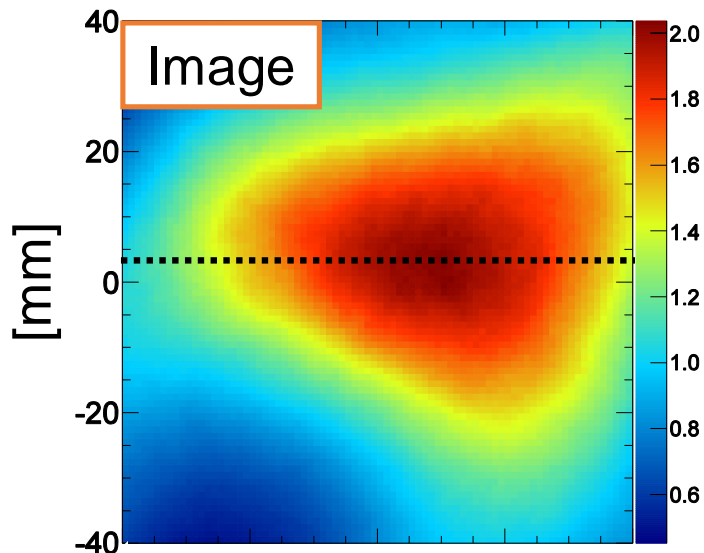
Peak position : **23±1.8 mm**

Range of the  
90% peak position : **11~34 mm**

■ : projection  
— : Bragg peak

← Beam direction

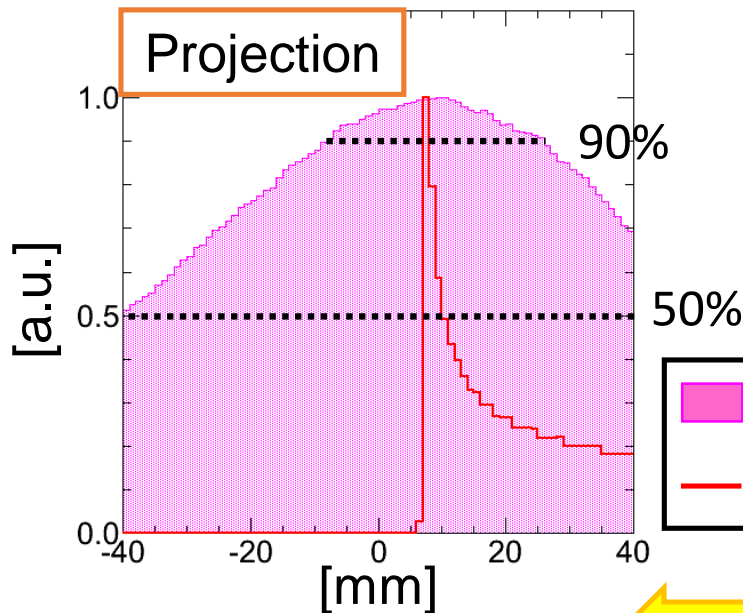
# Results of Images



■ PMMA 718keV range

2853 events (20min)

Bragg peak position  
(calculated by Geant4) : 33 mm



Peak position :  $30 \pm 8.1$  mm

Range of the  
90% peak position : 14~48 mm

← Beam direction

# Summary

- We were able to **acquire online gamma images** in both of the energy ranges (511 / 718 keV).
- We have not arrived at a clear conclusion that prompt gamma rays trace the Bragg peak well.
  - ➡ because of the uncertainty by the spatial resolution of the CC (~60mm(FWHM) @ 511keV)
- Future work ...
  - experiment using 200MeV proton beams (@RCNP, Osaka Univ.)
    - ➡ long proton range
  - development of a high-resolution CC
    - ➡ change of the geometry