The Electron tracking Compton Camera (ETCC) has been developed with reconstructing the 3-D tracks of the scattered electron in Compton process for both gamma-ray astronomy and medical imaging. By measuring both the directions and energies of a recoil gamma ray and a scattered electron, the direction of the incident gamma ray is for an individual photon. Furthermore, a residual measured angle between the recoil electron and scattered gamma ray is powerful for the kinematical background-rejection. For the 3 determined -D tracking of the electrons, the Micro Time Projection Chamber (μ-TPC) was developed, which consists of a new type of the micro pattern gas detector, or a Micro Pixel Gas Chamber (μ-PIC). The ETCC consists of this μ-TPC and the GSO crystal pixel arrays below the μ-TPC for detecting the recoil gamma rays. The ETCC provided the gamma ray images of point sources between 120 keV and ~1 MeV with the angular resolution of 6 degree (FWHM) at 511 keV of $^{18}$F ion, respectively. Also the angle of the scattered electron was measured with the resolution of ~80 degree. Two mobile ETCCs with 10 cm-cube TPC for small animal and 30 cm-cube TPC for human body are now being operated for Medical Imaging test. We have studied the imaging performances using both phantoms and small animals (rats and mice) for conventional radioisotopes of $^{131}$I and $^{18}$F-FDG. In particular, new ETCC with LaBr$_3$ pixel scintillator provides good images similar to SPECT for $^{131}$I and human PET for 511 keV, respectively, where a clear concentration to tumors in a mouse is observed. The 30 cm-cube ETCC can get an image for 1m-size length objects in one measurement. Thus, we have carried out several comparisons of our images with those of SPECT and PET. Multi-tracer image using $^{131}$I and FDG for small animal and the image for higher energy gamma ray above 511 keV for plants using $^{54}$Mn have been carried out successfully.

The ETCC has a wide energy dynamic range of 200-1300 keV and a wide field of view. Therefore, ETCC has a potential as a quality assurance tool for proton therapy. An experiment with a 140 MeV proton beam and a water phantom were simulated and conducted. We succeeded in imaging a Bragg peak with prompt gamma rays.
Electron Tracking Compton Camera (ETCC)

1. Determination of the direction of each gamma ray
2. Noise Reduction by Kinematics (γ-angle)
3. Large Field of View (3-4° str)

Developed for MeV γ-Astronomy
Black holes, GRB etc.

Balloon flight 1st Sep. 2006

Features in ETCC

1. Wide Energy Band, 200keV ~ 2000 keV
2. New lots of RI available
   Na, Mg, Cl, Si, Ca, Fe, Cr, Zn, Cu, Br etc.
   New type of Tracers
   Long life time RI for visualizations of immunity and enzyme: higher sensitivity for tumor
   (FDG for visualization of metabolism)
   Higher energy gamma-ray RI for visualization of mineral
3. Multi RI Tracer Image
4. Visualization of beam Therapy, Neutron Therapy, 
   & Therapy using β-emitter biomarker
5. Higher sensitivity imaging
ETCC for Molecular Imaging

Quantitative Analysis & Uniformity

Comparison to Animal MET (FDG-511keV)

Multi Tracer Image using LaBr₃

Double tracer imaging using Clinical drags
Proton Therapy in situ Imaging
Collaboration with Dr. J.Kim group

- Proton (Ion) Therapy
  - Using Bragg peak
  - Next generation beam therapy by spot scanning radiation (Pin-point radiation by changing beam energy)
  - Requirement of 1cm resolution for Bragg peak position in beam-on time.

PET (Positron emission tomography):
Now testing in the world, but imaging only after beam off
⇒ More precise and on-time Imaging method are needed

Problems in PET
1. Imaging mainly for $\text{J}^+$ emitting nuclei (Poor linearity for Bragg peak intensity)
2. Beam off Imaging
3. Restriction from the ring structure

PET Image (color contour)

Gamma rays in Proton therapy
$^{16}\text{O}(p,2p2n)^{15}\text{N}$
$^{16}\text{O}(p,pn)^{15}\text{O}$
$\gamma \rightarrow 511\text{KeV} (=\sim 10\text{MeV }p)$
-Prompt gamma; $\approx$ few MeV $p$

Geant4 Simulation

J. Min et al.
C.H.Min et al.

Summary
1. ETCC has been used for molecular imaging during several years.
2. Imaging quality of ETCC will be soon similar to human PET $\ominus$511 keV.
3. Wide FoV and Noise reduction of ETCC seems useful for less dose imaging.
4. ETCC provides new approaches in medical Imaging: Multi Tracer Imaging, New tracers using long-life time and higher energy nuclides
5. ETCC shows the ability of in situ imaging for proton therapy