Therapeutic Imaging and Imaging Application
-Electron Tracking Compton Camera-

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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.

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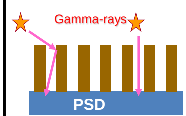
Gamma-Ray Imaging

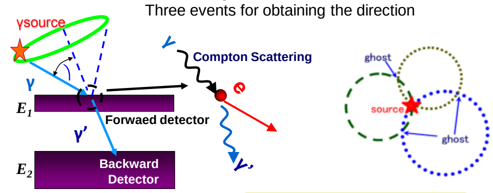


1：Collimator + Position Detect（SPECT)

Narrow Field of View (FoV)
Energy < ～300keV

2.：Compton-Camera

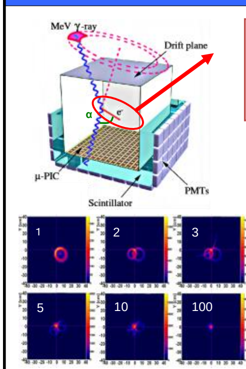
Three events for obtaining the direction



$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2}\right)$$

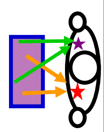
$\Delta\phi$ $\Delta E/E$ $(E=E_1+E_2)$

Electron Tracking Compton Camera(ETCC)

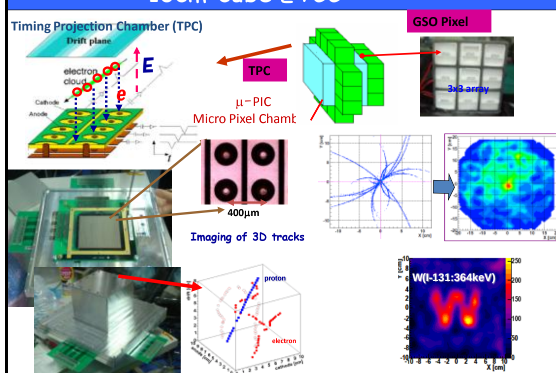


1. Determination of the direction of each gamma ray
2. Noise Reduction by Kinematics (α-angle
3. Large Field of View (3-4 str)

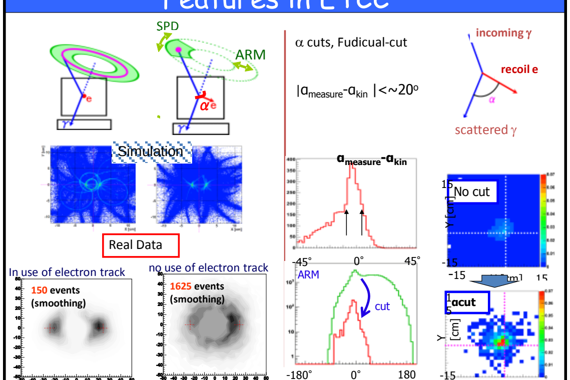
Developed for MeV g-Astronomy



10cm-cube ETCC

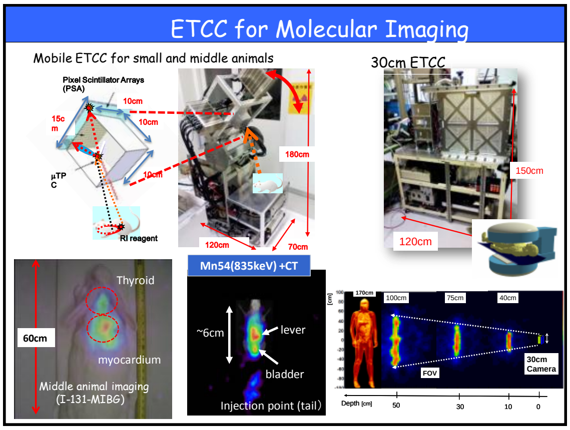


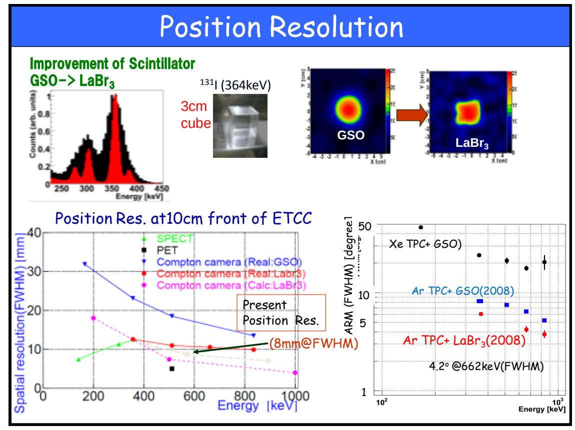
Features in ETCC

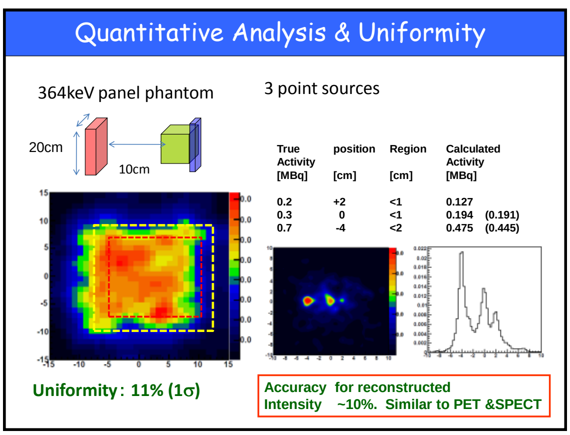


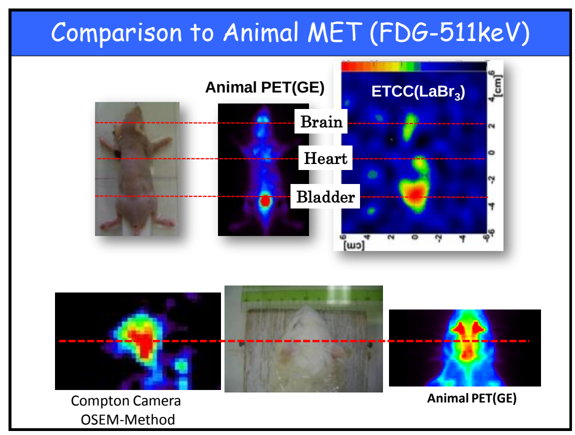
Features of ETCC to Molecular Imaging & Nuclear Medicine

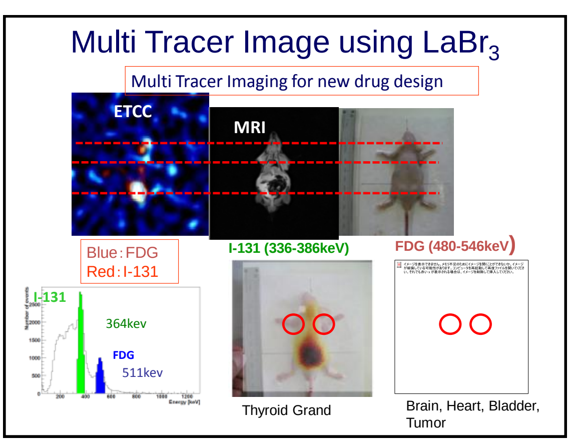
1. Wide Energy Band、 200keV ~ 2000 keV
2. New lots of RI available
   Na, Mg, Cl, Si, Ca, Fe, Cr, Zn, Cu, Br etc.
   New type of Tracers
   Long life time RI for visualizations of immunity and enzyme : higher sensitivity for tumor
   (FDG for visualization of metabolism)
   Higher energy gamma-ray RI 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**

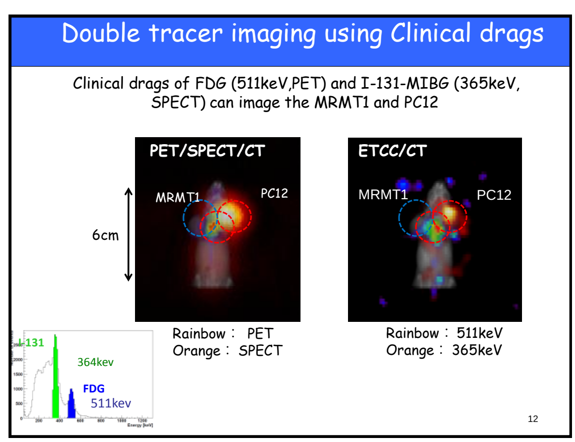

ETCC for Molecular Imaging
Mobile ETCC for small and middle animals
Pixel Scintillator Arrays (PSA)
10cm
15cm
10cm
μTPC
10cm
RI reagent
180cm
120cm
70cm
30cm ETCC
150cm
120cm
Thyroid
60cm
myocardium
Middle animal imaging (I-131-MIBG)
Mn54(835keV) +CT
~6cm
lever
bladder
Injection point (tail)
170cm
100cm
75cm
40cm
30cm Camera
FOV
Depth [cm]


Position Resolution
Improvement of Scintillator
GSO-> LaBr3
131I (364keV)
3cm cube
GSO
LaBr3
Energy [keV]
Position Res. at10cm front of ETCC
SPECT
PET
Compton camera (Real:GSO)
Compton camera (Real:LaBr3)
Compton camera (Calc:LaBr3)
Present Position Res.
(8mm@FWHM)
Spatial resolution(FWHM) [mm]
Energy [keV]
ARM (FWHM) [degree]
Xe TPC+ GSO)
Ar TPC+ GSO(2008)
Ar TPC+ LaBr3(2008)
4.2° @662keV(FWHM)
Energy [keV]


Quantitative Analysis & Uniformity
364keV panel phantom
20cm
10cm
3 point sources
True Activity [MBq] | position [cm] | Region [cm] | Calculated Activity [MBq]
0.2 | +2 | <1 | 0.127
0.3 | 0 | <1 | 0.194 (0.191)
0.7 | -4 | <2 | 0.475 (0.445)
Uniformity: 11% (1σ)
Accuracy for reconstructed Intensity ~10%. Similar to PET &SPECT

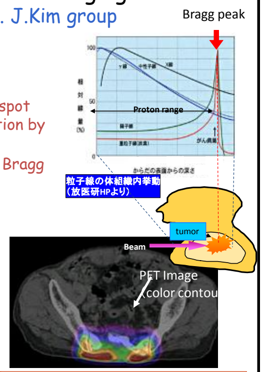

Comparison to Animal MET (FDG-511keV)
Animal PET(GE)
ETCC(LaBr3)
Brain
Heart
Bladder
[cm]
Compton Camera
OSEM-Method
Animal PET(GE)


Multi Tracer Image using LaBr3
Multi Tracer Imaging for new drug design
ETCC
MRI
Blue: FDG
Red: I-131
I-131 (336-386keV)
FDG (480-546keV)
I-131
364kev
FDG
511kev
Energy [keV]
Thyroid Grand
Brain, Heart, Bladder, Tumor


Double tracer imaging using Clinical drags
Clinical drags of FDG (511keV,PET) and I-131-MIBG (365keV, SPECT) can image the MRMT1 and PC12
PET/SPECT/CT
MRMT1
PC12
6cm
Rainbow : PET
Orange : SPECT
ETCC/CT
MRMT1
PC12
Rainbow : 511keV
Orange : 365keV
I-131
364kev
FDG
511kev
12

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

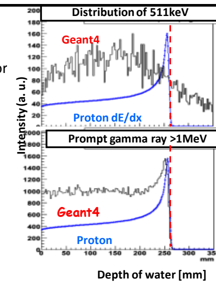
⇒More precise and on-time Imaging method are needed

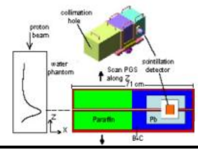
://www.ncc.go.jp/jp/ncce/rcio/ptd/ptd_01.html

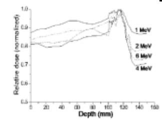
Problems in PET

1. Imaging mainly for β+ emitting nuclei (Poor linearity for Bragg peak intensity)
2. Beam off Imaging
3. Restriction from the ring structure

Gamma rays in Proton therapy
- $^{16}O(p,2p2n)^{13}N$ $^{16}O(p,pn)^{15}O$
  →β⁺ → 511keV (>~10MeV p)
- Prompt gamma(<a few MeV p)







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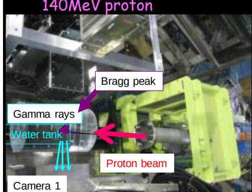
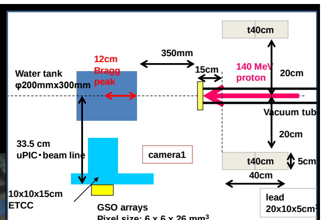
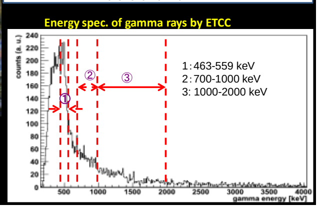
Set Up in RCNP (Osaka Univ.)

140MeV proton







1. Neutron & charged particle rejection
2. Continuum g-ray Imaging

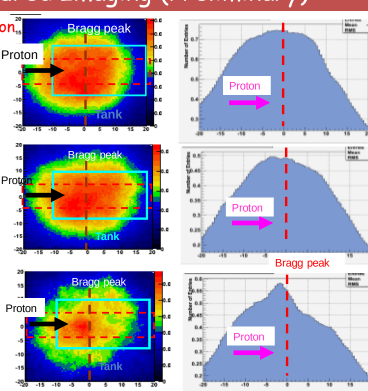
Measured Imaging (Preliminary)

Acceptance Correction

1:463-559 keV
Event#:3358

2:700-1000 keV
Event#:4252

3:1000-2000 keV
Event#:4252



Summary

1. ETCC has been used for molecular imaging during several years.
2. Imaging quality of ETCC will be soon similar to human PET @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