Development Electron Tracking Compton Camera (ETCC) for multipurpose medical imaging

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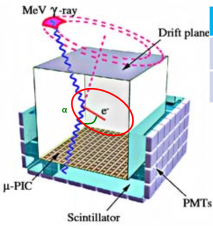
Abstract: PET and SPECT achieved great successes in medical imaging. These detectors, however, have energy limitations, which is a problem in designing new-molecular imaging reagents. We have developed an Electron-Tracking Compton Camera (ETCC) to give the wide energy range (200-1500keV), wide field of view (4str) and abilities of background rejection and clear imaging using the tracking of recoil electrons. Thus ETCC has a potential of the development of new reagents. Until now we carried out several imaging reagent studies of double clinical tracer imaging with FDG and I-131-MIBG, and imaging of Zn-65, Mn-54 and Fe-59 in mice. Also, ETCC images continuum gamma-rays by removing backgrounds using dE/dx of the track, which enables to monitor the Bragg peak location by detecting prompt gammas. We successfully obtained the on-time images of 511keV and continuum gammas rays from the water irradiated by 140MeV proton. In 2013 we have improved all readout system of ETCC, by which its tracking efficiency and data transfer rate ere improved with 10 times, and 50 times. Now ETCC obtain clear images with the use of 50MBq FGD, and starts the test of tomographic image using two ETCCs. We will present its imaging performance including the proton beam test with similar intensity in proton therapy.

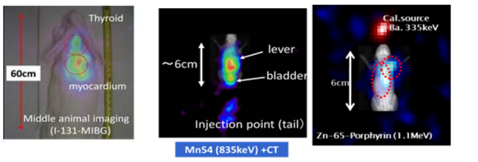
Feature and Expectation for Medical Application of Electron Tracking Compton Camera (ETCC)[1][2][3]

View of ETCC



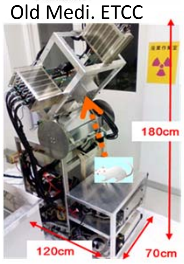
Variety of RI Application (using previous algorithm)

	Ce-139	Cr-51	Ba133	I-131	Au198	Na22	F18	Cu-64	Cs137	Mn54	Fe59	Zn65	Co-60
Energy	167keV	320	354	364	410	511, 1275	511	511	662	835	1095, 1292	1116	1173, 1333
Life	137.6 day	27.7 day	10.52 year	8.01 day	2.6 day	2.609 Year	110 min	12.70 hour	30.04 year	312.1 day	44.5 day	244 day	5.271 year



Features of ETCC	Expectation for Medical Application
Wide Energy Range of Gamma-Ray	Multiple nuclear medicine imaging Monitoring of radiation therapy
Wide Field of View	Save space for an operator (3D imaging by lower number of detectors)
Decision of gamma-ray direction specifically	Improvement in position resolution
Good noise reduction by kinematical cut	Improvement in highly sensitivity = low dose

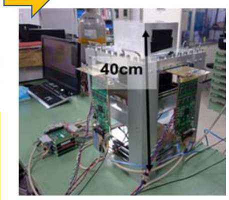
Old Medi. ETCC



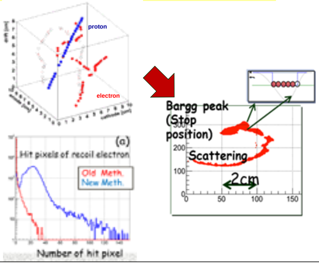
Obs. Time: 3 hours
Pos. Res.: 8mm(FWHM)
(8° at 662keV GSO)
Energy: 150keV-2MeV
FoV: 2 0x20cm
Trigger rate <30Hz

Due to ~10% efficiency & slow DAQ

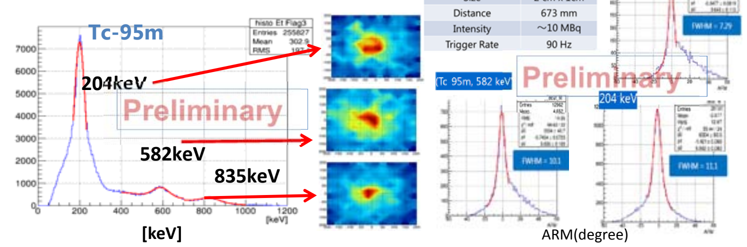
Updated Medical ETCC
(10cm cubic)



- Tacking. Eff. 10% to-100% i
- Fast electronics x 100 and more
- Good Angular resolution ->5°
- Obs, Time ~30min for mouse

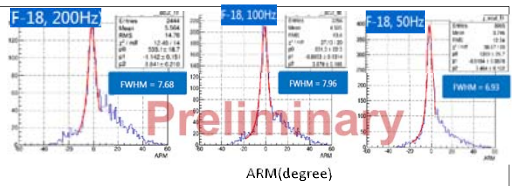


^{95m}Tc (10MBq) by updated ETCC [4]

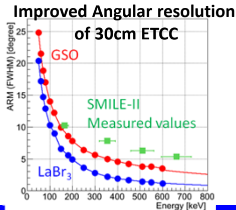


FDG High Counting

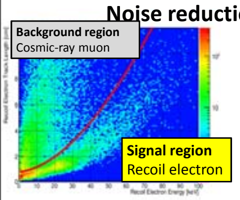
F-18 data table	
Size	Φ1.2mm, 2.35mm Volume 2μL
Distance	587 mm
Intensity	67.6 MBq



Improved Angular resolution of 30cm ETCC



Noise reduction by dE/dx of tracks



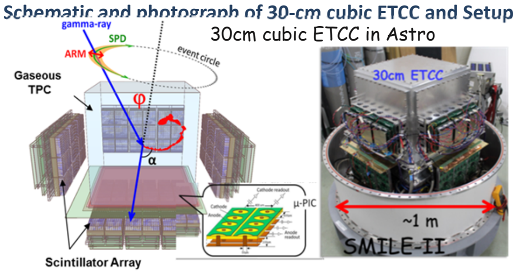
Because of improved recoil electron tracking algorithm, We can divide signal with background event clearly.
→ Sensitivity improved more than 10 times

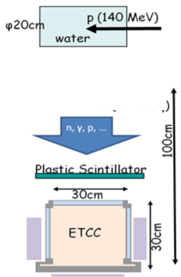
Next Step of Medical ETCC in 2015
- Use of 2 radiation length GSO +. CF4 gas pressure 2 atm
- Network DAQ 500Hz -> several KHz
- Efficiency : 6x10^{-5} -> ~3×10^{-4} @511keV (5 times) 10min for mouse
- Multi modularization → It takes about 10 minutes to take human body image.

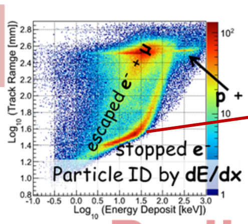
Imaging nuclear spectroscopy with ETCC [5],[6],[7] Details of SMILE-II will be presented at 12:05 on 29th in Astro session

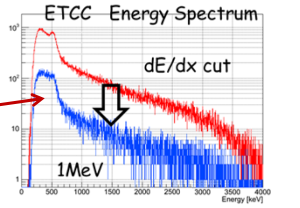
We checked the imaging performance of SMILE-II 30-cm cubic ETCC (originally for ASTRO) for proton therapy by measuring the continuum gamma rays from the water target irradiated by140 MeV proton beam in RCNP Ring Cyclotron in Osaka Univ.

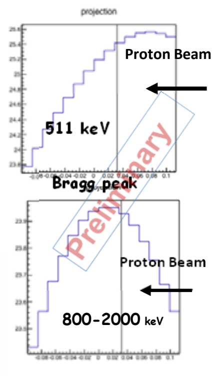
Schematic and photograph of 30-cm cubic ETCC and Setup

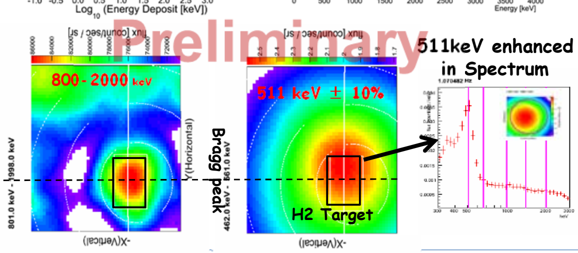










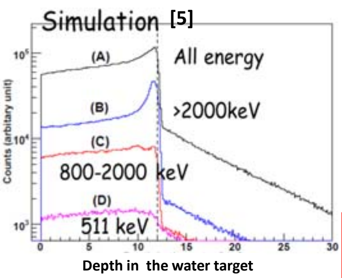


TPC in ETCC	Ar 90%+C_2H_6+CF_4 1atm
# of GSO Pixel Scinti, Arrays (PSAs) (A PSA has 8x8 GSO pixels. 6x6x13 mm^3)	1 radiation length 36(bottom) + 8x4 (side) PSAs
Resolution of ARM, SPD (c.f. figure 1a)	5.3° , 180°@ 662 keV
effective area	1 cm^2 @ 300 keV
Maximum Count rate	up to 2KHz
Energy resolution	~11%@662keV(FWHM)

Proton beam intensit	1/3-5 of proton therapy
Measurement time	~ 30 minutes with 50% dead time-> Live time 14min.
# of obtained gamma rays	~ 2x10^4 for all gamma, 8 gammas /s >1MeV

Result: Peak position of the higher energy gamma ray image clearly shifts upper position of the beam line. → It is consistent to the simulation result.
Goal in a few years, Use of 2atm CF_4 with 3r.l. PSAs will increase to ~10^2 gamma >1MeV, which provides 1mm resolution of Bragg peak every second.

Simulation [5]



Simulation shows that the peak of 511keV γ appears in front of Bragg peak , and the peak of γ above 1MeV appears at the Bragg peak

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References: [1] T.Tanimori et al. [2] S. Kabuki et al., NIM A, 580 (2007) pp. 1031, [3] S. Kabuki et al., NIM A, 623 (2010) , 606, [4] Y.Hatsukawa et al. J. of Radional. & Nucl. Chem. 303 ,2 , 1283 (2015) [5] S.Kurosawa et al. Cuurent Appl. Phys, 12, 364, (2012) [6]Y.Mizumura et al., JINST, 9, C05045 (2014), [7] Y.Matsuoka et al., JINST, 10, C01053 (2015)