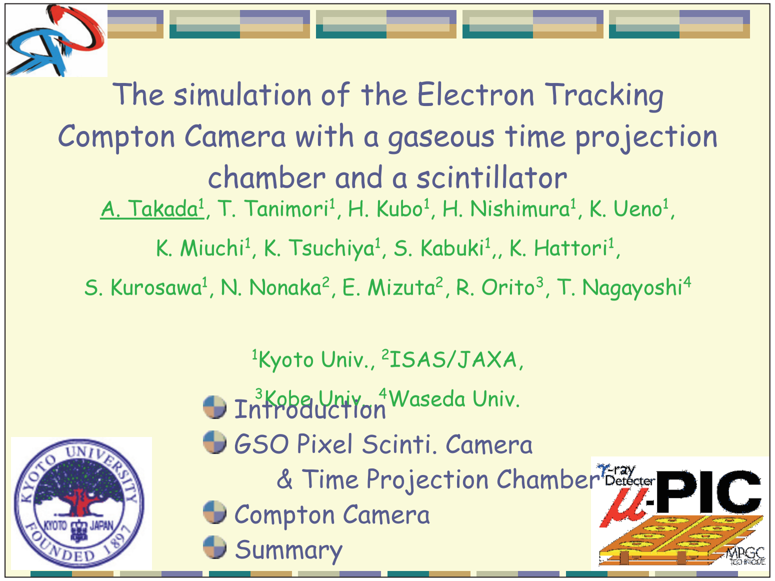
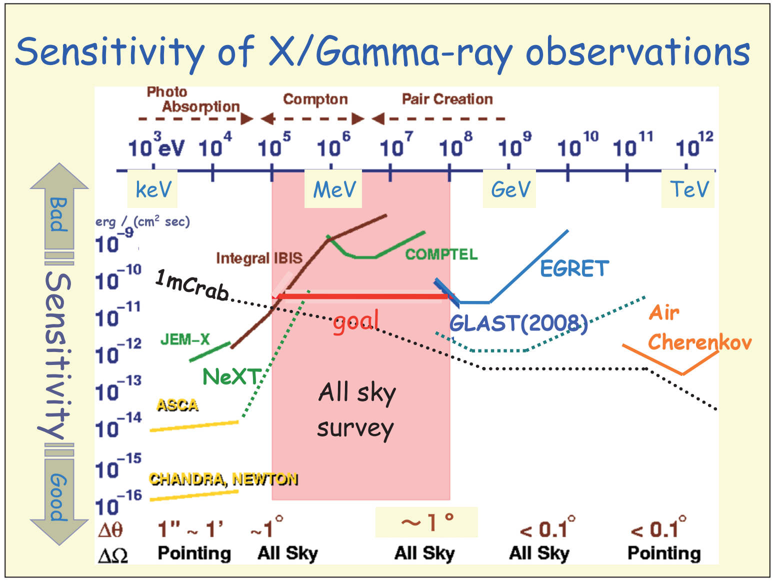
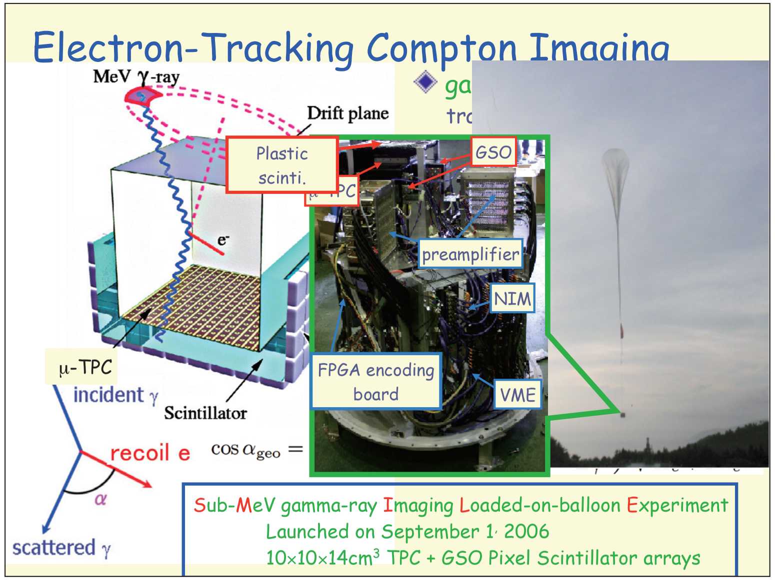
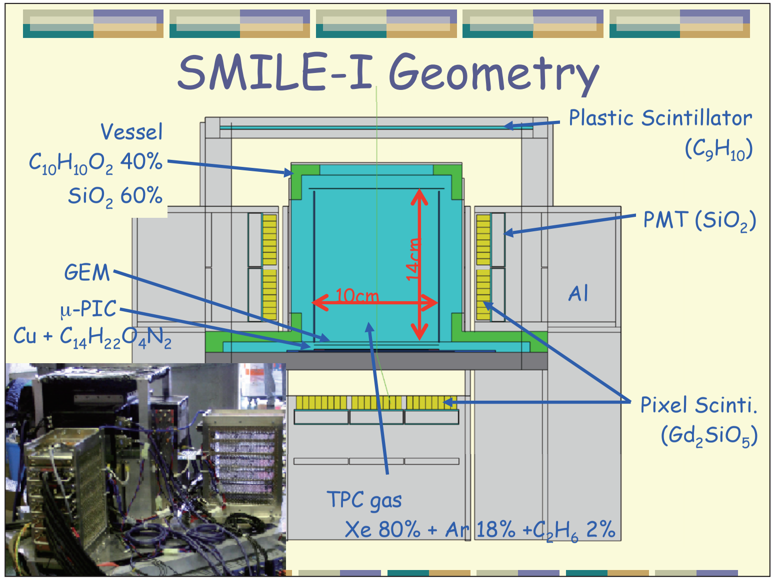

The simulation of the Electron Tracking Compton Camera with a gaseous time projection chamber and a scintillator
A. Takada[1], T. Tanimori[1], H. Kubo[1], H. Nishimura[1], K. Ueno[1],
K. Miuchi[1], K. Tsuchiya[1], S. Kabuki[1],, K. Hattori[1],
S. Kurosawa[1], N. Nonaka[2], E. Mizuta[2], R. Orito[3], T. Nagayoshi[4]
[1]Kyoto Univ., [2]ISAS/JAXA,
[3]Kobe Univ., [4]Waseda Univ.
Introduction
GSO Pixel Scinti. Camera
& Time Projection Chamber
Compton Camera
Summary
γ-ray Detector
μ-PIC
MPGC


Sensitivity of X/Gamma-ray observations
Photo Absorption
Compton
Pair Creation
10^3eV 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12}
keV
MeV
GeV
TeV
Bad
Sensitivity
Good
erg / (cm² sec)
10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} 10^{-16}
1mCrab
Integral IBIS
COMPTEL
EGRET
GLAST(2008)
Air Cherenkov
JEM-X
NeXT
ASCA
goal
All sky survey
CHANDRA, NEWTON
Δθ 1" ~ 1' ~1° ~1° < 0.1° < 0.1°
ΔΩ Pointing All Sky All Sky All Sky Pointing


Electron-Tracking Compton Imaging
MeV γ-ray
Drift plane
Plastic scinti.
GSO
preamplifier
NIM
FPGA encoding board
VME
e⁻
μ-TPC
incident γ
Scintillator
recoil e
$\cos\alpha_{geo} =$
α
scattered γ
Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment
Launched on September 1, 2006
10×10×14cm³ TPC + GSO Pixel Scintillator arrays


SMILE-I Geometry
Vessel
$C_{10}H_{10}O_2$ 40%
SiO_2 60%
Plastic Scintillator
(C_9H_{10})
PMT (SiO_2)
GEM
μ-PIC
Cu + $C_{14}H_{22}O_4N_2$
14cm
10cm
Al
Pixel Scinti.
(Gd_2SiO_5)
TPC gas
Xe 80% + Ar 18% +C_2H_6 2%

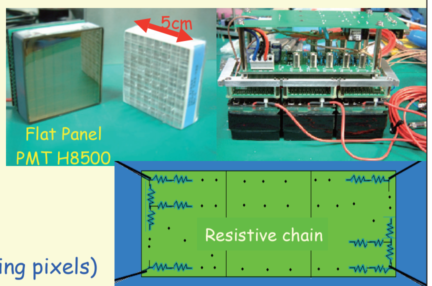
Physics List for SMILE-I

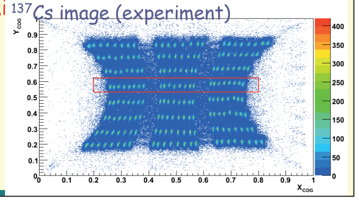
- Gant4.9.0_p01
- Gamma-ray detection ⇒ Electromagnetic Processes
- Background simulation ⇒ Hadronic Processes
- Based on the physics list of 'examples/advanced/underground_physics'
- The several alterations
  - Compton/Rayleigh scattering for gamma
    ⇒ LECSCompton/Rayleigh
    For the Doppler broadening
    (http://public.lanl.gov/mkippen/actsim/g4lecs)
  - For the charged particles
    ⇒ G4StepLimiter in TPC
    Tracing the tracks with the pitch of less than 40 μm

GSO Pixel Scintillator Array

Simulation of Absorber

- Scintillator : GSO(Ce)
- Pixel size : 6×6×13 mm^3
- 8×8 pixels ⇒ 1 array
- 3 PMTs ⇒ 1 unit
- Photo readout : H8500 (HPK)
  gain uniformity is not good
  (Min:Max = 1:2~4)
  light cross-talk at window
  (~40% leaks to surrounding pixels)
- 4 channels readout with resistive chai[n]
  incomplete quantization
  distorted image
- Energy resolution :
  Average 10.9% (662keV, FWHM)
  inside (6×6 pixels) : 10.5%
  outside (28 pixels) : 11.5%



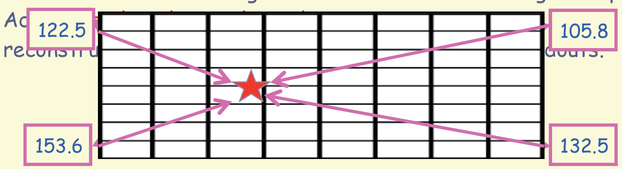


Simulation of Absorber

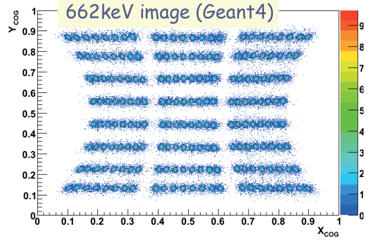
1. Geant4 ⇒ pixel ID, deposit energy E
2. Obtain the light cross-talk rate l_i of each pixel.

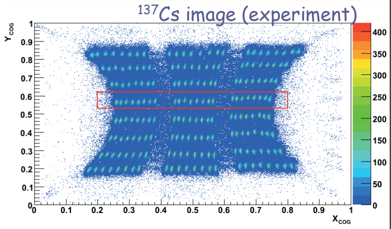
center	1
horizontal	Gauss (mean: 0.153, RMS: 0.0265)
diagonal	Gauss (mean: 0.0323, RMS: 0.00951)

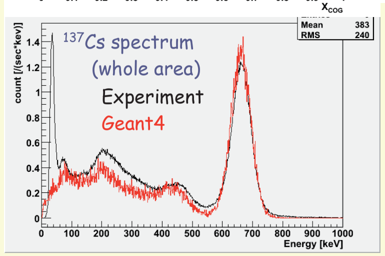
3. Calculate the detected charge of each anode considering with energy resolution.
   Gauss (mean: El_i , RMS: $1.2\times(El_i)^{0.5}$)
4. multiply the gain map of PMT by the detected energy.
5. Divide the obtained charge to 4 channel readouts using a template.
6. Ac...
7. reconstru... ...outs.



Simulation of Absorber







Energy resolution

Geant4

Whole : 11.3%

inside : 10.5%

outside : 12.3%

Experiment

Whole : 10.9%

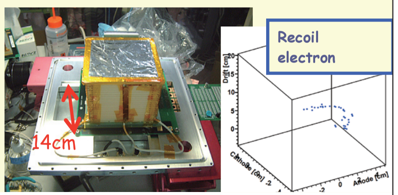
inside : 10.5%

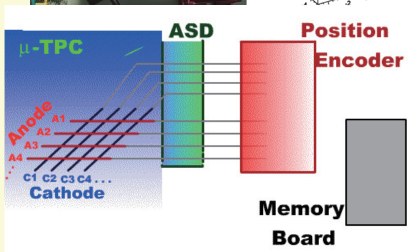
outside : 11.5%

Electron Tracker

Simulation of Tracker

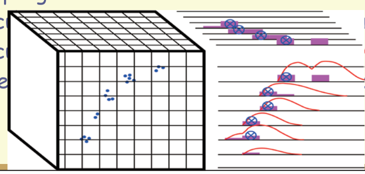
- Gas : Xe 80% + Ar 18% + C_2H_6 2%
  1atm, sealed, 10×10×14 cm^3
- w value : 23 eV
- Diffusion : (Magboltz simulation)
  transverse 0.52mm/√cm
  longitudinal 0.28mm/√cm
- Strip readout (0.40mm pitch)
- Gas Gain : ~30000
- Preamp : τ=16 nsec, C=1pF
- Drift velocity (V_d=400V/cm) :
  measured 2.4 cm/μsec
- calculate the track points
  with 100 MHz
- Energy resolution :
  ~45% (22.2keV, FWHM)
- Position resolution : ~0.5mm



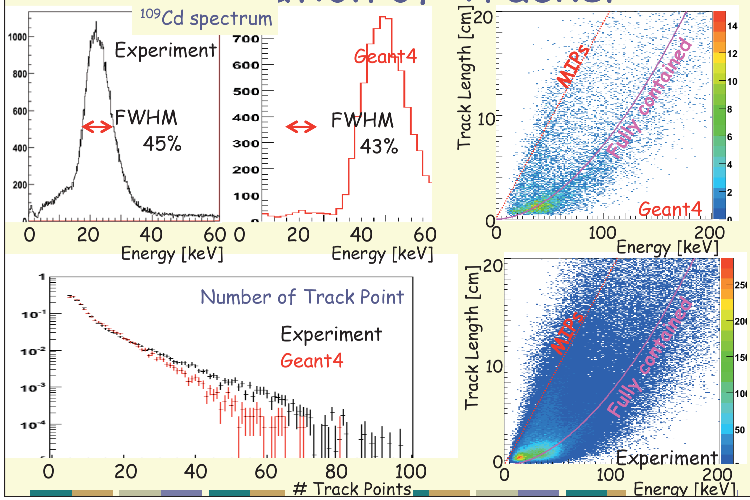


Simulation of Tracker

1. Geant4 ⇒ position x, deposit Energy E (pitch < 40 μm)
2. Obtain the number n of ionized electron at x.
   Poisson (mean: E/w)
3. Calculate the diffusion which is the function of the drift length d.
   transverse Gauss (RMS: 0.52√d mm)
   longitudinal Gauss (RMS: 0.28√d mm)
4. Quantize to the strip readout and sampling clock.
   x/y 0.4 mm pitch ⇐ readout pitch of 400 μm
   z 0.24 mm pitch
   ⇐ drift velocity 2.4 cm/μsec, 100MHz sampling
5. Calc… ng with energy resolution.
6. Calc… nse template of the preamp.
7. take… ce between x and y.

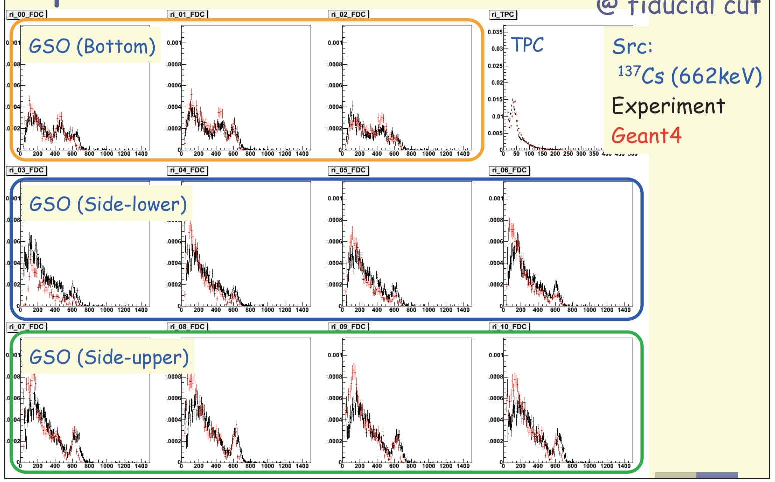


Simulation of Tracker



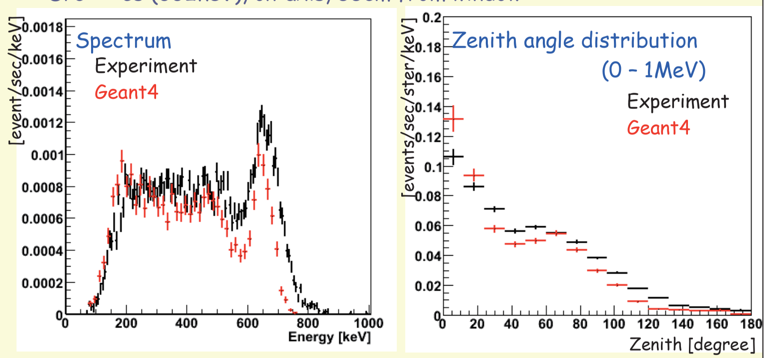
Electron Tracking Compton Camera (ETCC)

Spectra of GSO units/TPC @ fiducial cut



Reconstruction of gamma-ray

Src: ^{137}Cs (662keV), on-axis, 55cm from window

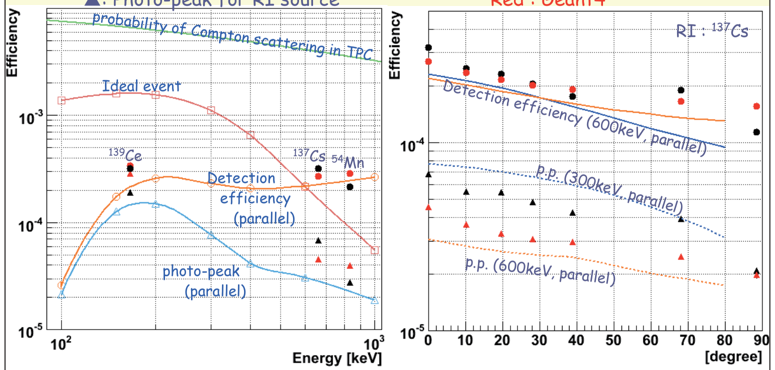


- ▶ We succeeded in the reconstruction of gamma-rays by both experiment and simulation.
- ▶ The simulation are roughly consistent with the experiment.

Detection Efficiency & FOV

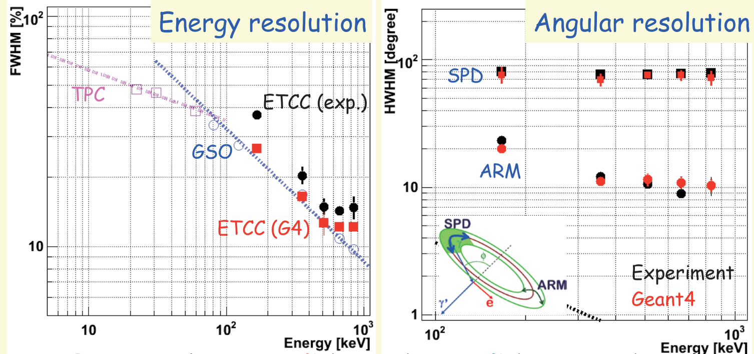
●: Detection Efficiency for RI source
▲: Photo-peak for RI source

Black : Experiment
Red : Geant4



Detection efficiency : ~2.5×10^{-4}
Field Of View : ~4 steradian (FWHM)

Energy/Angular Resolution



Energy resolution : 12.2% (Geant4) ⇔ 14.3% (experiment)
@ 662keV FWHM
Angular resolution : ARM 10.9° (Geant4) ⇔ 8.9° (experiment)
SPD 75.1° (Geant4) ⇔ 77.8° (experiment)
@ 662keV HWHM

Summery & Future Work

- We constructed the simulator for the Electron Tracking Compton Camera (ETCC).
- Absorber :
  Energy resolution, Distorted image ⇒ roughly consistent
- Tracker :
  Energy resolution, Tracking ⇒ roughly consistent
- ETCC :

In more detail...

- ▶ Gas gain distribution for 1 electron
- ▶ Update the response template of preamp
- ▶ Electrical noise
- ▶ etc...

- ・Check the rejection power for p/n
- ・Background simulation at balloon altitude
- ・Study for the analysis
- ・Design for the next balloon experiment

End