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Design and characteristics of a novel Single Plane Compton Gamma Camera based on GAGG scintillators readout by SiPMs

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Introduction

- Compton gamma camera (CGC) is a compact gamma-ray detection tool which, in contrast to gamma cameras with mechanical collimation, uses electronic collimation based on the kinematics of the Compton scattering.
- Compton cameras have potential as radiation imagers in environmental remediation, as survey devices for nuclear industrial sites and gamma source detection.
- The evolution of CGC started with semiconductor detectors, which provide excellent spatial resolution, but suffer from complexity, limited efficiency and high costs. Later, it shifted to scintillator detectors, initially with photo-multiplier tubes (PMTs) and more recently with Silicon photomultipliers (SiPMs).
- Scintillator based CGCs have lower, yet still acceptable, energy resolutions compared to the ones based on semiconductors, but higher efficiencies and lower cost.[1]
- Most CGC realizations comprise two separate detector planes, the scatterer and the absorber, with recent attempts to make a single plane Compton gamma camera to enhance compactness and reduce costs. [2]
- We designed and explored a novel concept of a Single Plane CGC based on pixelated GaGG scintillators read out on only one side by SiPMs.

Single plane Compton camera

- In this concept the scatterer (front) layer consists of an 8x8 array of 3 mm x 3 mm x 3 mm GaGG scintillators with a 3.2 mm pitch.
- It is connected to a layer of plexiglass light guides 3 mm x 3 mm x 20 mm using optical cement (EJ-500, Eljen technology) which is coupled to GaGG pixels in another identical 8x8 array - the absorption (back) layer. The crystals and light guides are polished from all sides.
- The latter GaGG layer is coupled to a matching array of 8x8 SiPMs (Hamamatsu, S13361-3050AE-08). Both the scatterer and the absorber pixels in one column are read out by the same SiPM, which keeps the number of readout channels at a minimum.
- We assembled the detector using precision 3D printer for housing (Fig 1 (a)-(c)).
- Enhanced Specular Reflector (ESR, 3M) is used as reflecting material. The ESR was cut precisely using a foil cutter (Silhouette Cameo) according to our requirement, for the inner walls between the crystals in each column and between the rows.

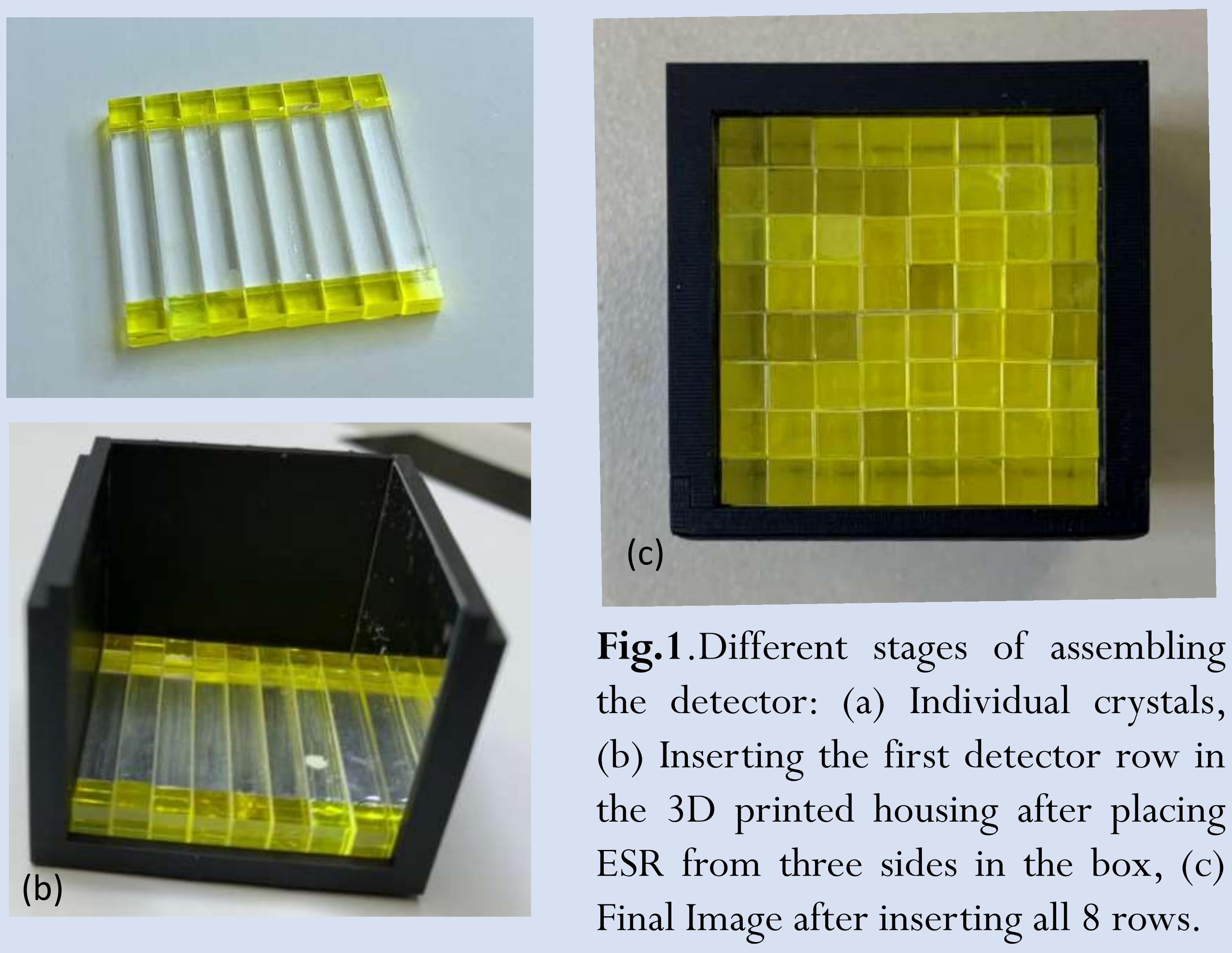

Fig.1.Different stages of assembling the detector: (a) Individual crystals, (b) Inserting the first detector row in the 3D printed housing after placing ESR from three sides in the box, (c) Final Image after inserting all 8 rows.

Detector simulation

- GEANT4 simulations were performed to estimate the angular resolution and intrinsic efficiency of various detector configurations in dependence on the lightguide length.
- The simulation took into account the measured energy resolution of 3x3x3 mm^3 GaGG pixels.
- The image of the point source located at the central axis, 5 cm from the detector is reconstructed using a simple back-projection algorithm.
- The lightguide length of 20 mm is chosen for the final design as the best tradeoff between the efficiency and angular resolution.

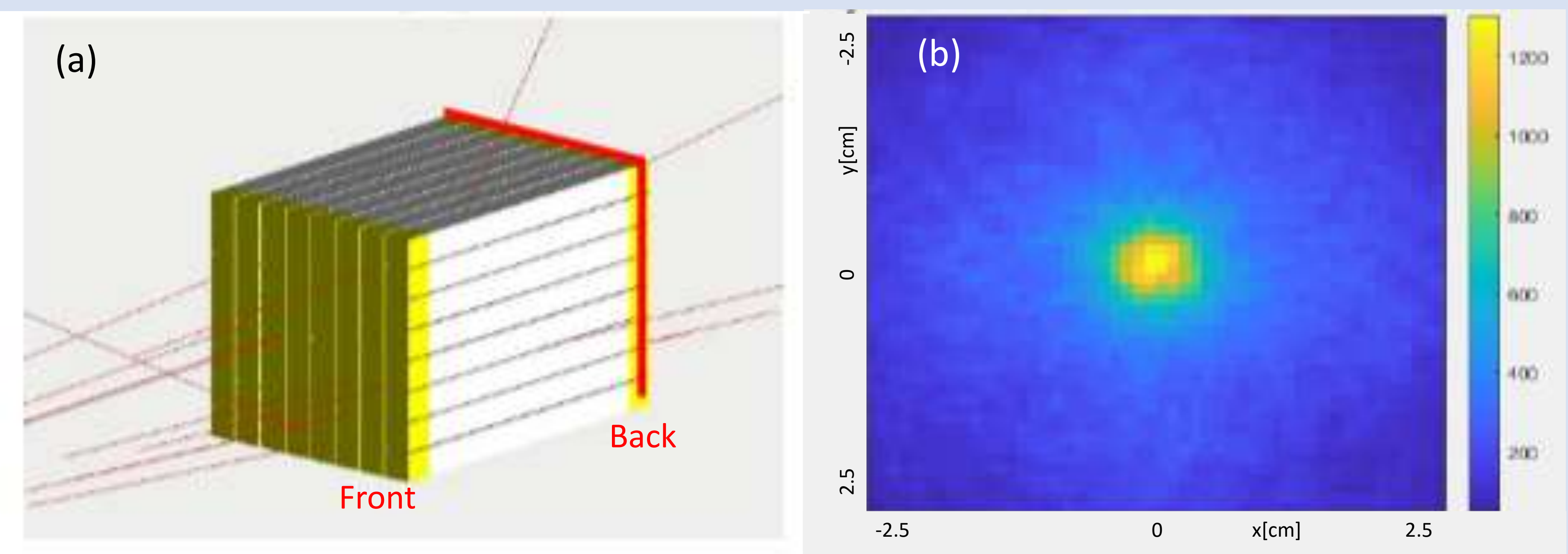

Fig.2. (a) Simulated detector, (b) Reconstructed image from the simulated data

Laboratory characterisation

- ^{137}Cs source, diameter < 3 mm placed 50 mm in front of the detector; the laboratory temperature kept between 18-20 °C.
- The TOFPET2 [3] system was used for SiPM readout and data acquisition in the evaluation measurements.
- The average energy resolution at 662 keV of the front and the back GaGG layer is found to be 8.9% ± 1.9% and 10.8 ± 1.6% respectively, where the uncertainty reflects the standard deviation of pixel resolutions. It is observed that the front layer shows up to 20% higher signals.

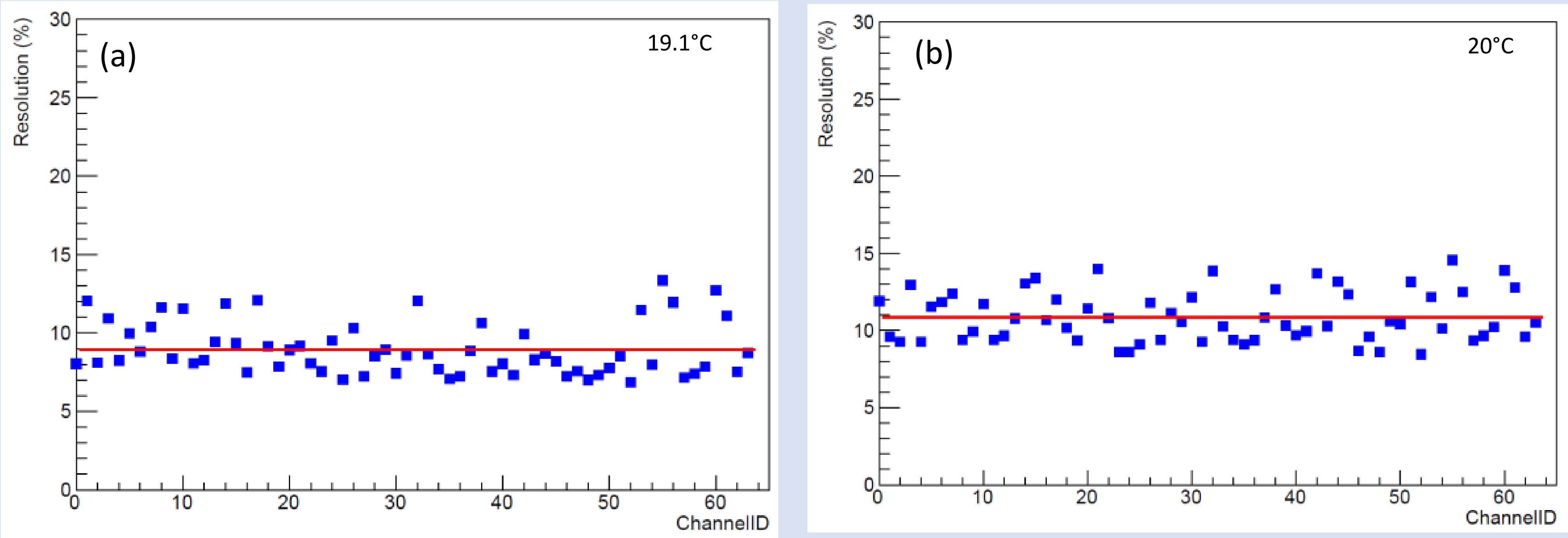

Fig.3. (a) Front layer energy resolution at 662 keV, (b) Back layer energy resolution at 662 keV.

Results

- We recontructed the Compton events requiring: (a) exactly two SiPM pixels fired, E_px > 80 keV to avoid noise contributions; (b) their energy sum is 662 keV$\pm 3\sigma$; (c) the transaxial distance between the pixel centres is d>8 mm and (d) the energy of the front pixel is in the range 80-120 keV.
- The last two conditions kinematically limit the scattering Compton scattering angles to $\theta_{Compton}$ = 25°-35° for the 662 keV gamma photons.
- The pixel 1 (front) and 2 (back) positions and energies (E_{12}, x_{12},y_{12},z_{12}) are fed into a simple back-projection algorithm and the source image is reconstructed (Fig. 4(b)).

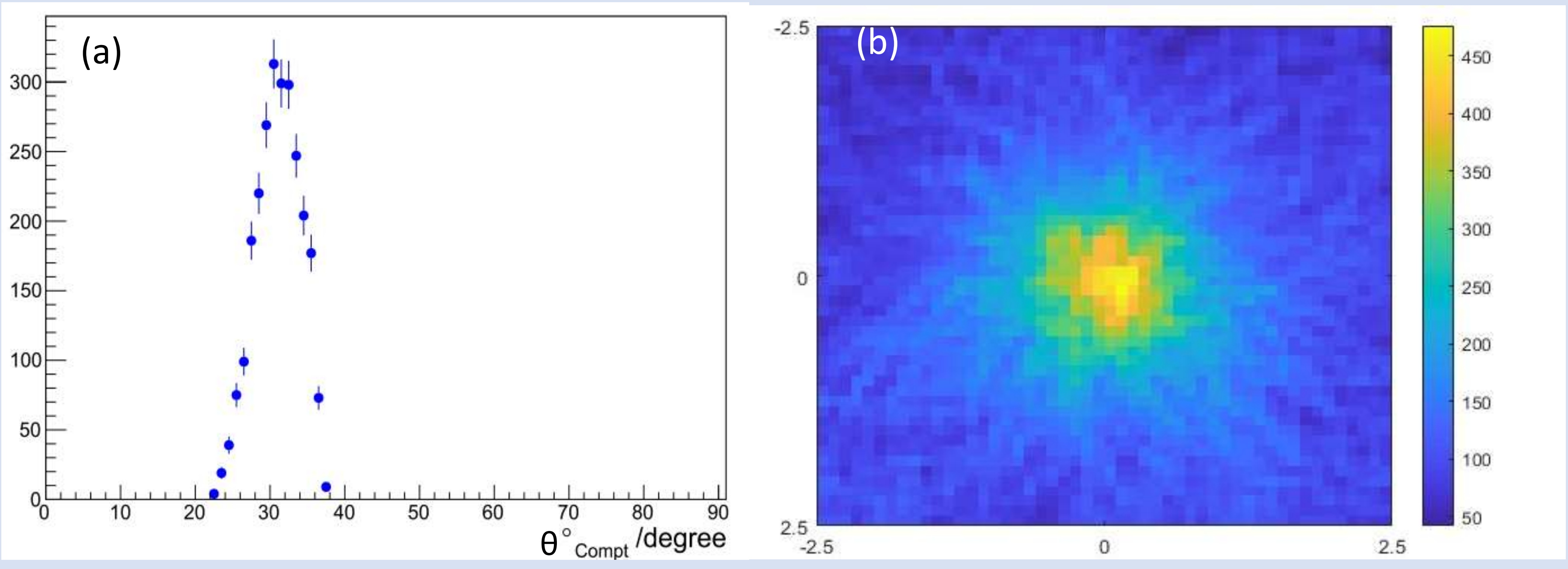

Fig.4. (a) Reconstructed scattering Compton angle, (b) Image reconstructed using simple back-projection algorithm from the measured data

Summary

- The compact single-plane Compton camera was successfully designed, assembled and tested and it performed within expectatation.
- The preliminary results demonstrate the ability to reconstruct the source image

References

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2. J. Kataoka, et al. Nucl. Instr. Meth. A 732 (2013) 403
3. A. Di. Francesco et al. JINST 11 (2016) C03042

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