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Title: Time-projection Chamber for Gamma-Ray Energies Between 100 keV to few MeV: April-June 2001 Progress Report on Simulation Studies.

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Time-projection Chamber for Gamma-Ray Energies Between 100 keV to few MeV: April-June 2001 Progress Report on Simulations.

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Gamma imaging based on Compton scattering was first proposed approximately 20 years ago[1,2] as a replacement for mechanically collimated imaging systems[3,4]. The advantages of such methods over mechanically collimated systems are that they provide a wider field of view, higher efficiency (more source photons are used in the image construction), source localization, use in high-background environments, and non-tomographic three-dimensional imaging[5] of near-field sources. One can also image multi-energy photons by selecting events based on the summed energy deposited in multiple detectors. The traditional example of such imaging systems is Compton camera. Until recently, limitations with associated hardware have limited the applications of Compton imaging.

It is obvious that accurate tracking of both the gamma-ray and recoiling electron from a Compton interaction will allow unique determination of the direction of the source gamma-ray. For this method to work effectively one must find detectors such that the scattered electron will deposit enough energy in the detector and yet have enough energy left to escape that detector and deposit a detectable amount of energy in the second detector without much multiple scattering (multiple scattering will distort the knowledge of the initial electron scattering angle). With advent of new detectors such as Micro-Well Detectors (MWD), the tracking of electrons and gamma rays can be done more successfully. The use of MWDs in a time-projection chamber (TPC) may provide true three-dimensional tracking in a Compton telescope. Researchers in Europe and in the United States have shown that MWDs have tremendous potential for application as X-ray imaging/spectroscopy detectors. MWD construction employs advanced Printed Circuit Board (PCB) fabrication techniques to form micro-wells on flexible printed circuit boards. Each micro-well is composed of a well in the insulating PCB substrate with a metal cathode annulus around the well opening and a conducting anode pad at the bottom. The photon interaction volume for the MWD is filled with proportional counter gas and is bounded by a window/drift electrode assembly at the top and by the array of micro-wells on the bottom. Electrons generated by interactions drift toward the micro-well anodes and generate avalanches, with stable charge gains as high as $3x10^4$, in the wells. The micro-wells are arranged in a grid pattern with anodes electrically connected in columns and cathodes connected in rows to form a true two-dimensional X-ray or gamma ray imager.

For simulations we chose the Geant package[6]. Geant is a system of detector description and simulation tools that help physicists design and optimize the detectors, develop and test the reconstruction and analysis programs, and interpret the experimental data. In this report we present Geant simulation of a TPC detector proposed[7] by Phil Deines-Jones and Kevin Black of NASA. The design given to us is shown in Fig. 1. This design uses 10 pairs of back-to-back micro-well detectors to collect the tracks left by electrons generated by a gamma traversing the Xenon-CO_2 mixture at 2.5 atm. A picture of a micro-well detector is shown in Fig. 3 and a cross-sectional view of each micro-well is shown in the Fig. 2. In these detectors primary electrons are focused onto the anodes. The avalanche deposits equal and opposite charges on the anode and cathode. Figure 4 shows the cross-strip read-out schematics, which has been used by Dines-Jones. Here 2D

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[1] D. Herzo et al., Nuclear Instrumentation And Methods,123 (1975) 583.
[2] V. Schonfelder et al., IEEE Trans. Nucl. Sci., NS_31 (1984) 766.
[3] M. Singh, Med. Phys. 10 (1983) 421.
[4] J. B. Martin et al., IEEE Trans. Nucl., Sci. NS-41 (1994) 1221.
[5] King et. Al., Nuclear Instrumentation And Methods, A 353 (1994) 320-323.
[6] "*GEANT:*Detector Description and Simulation Tool", Application Software Group, Computing and Networks Division, CERN, Geneva, Switzerland, CERN Program Library Long Write-up W5013 (1993).
[7] Phil Deines-Jones, "Imaging Well Detectors:a New Gas Electron Tracker for Compton Telescopes?" Talk given at NRL Compton Workshop on May 11, 2000.

positions can be obtained from crossed-strip read-outs shown in this figure. The third co-ordinate is obtained from timing information.

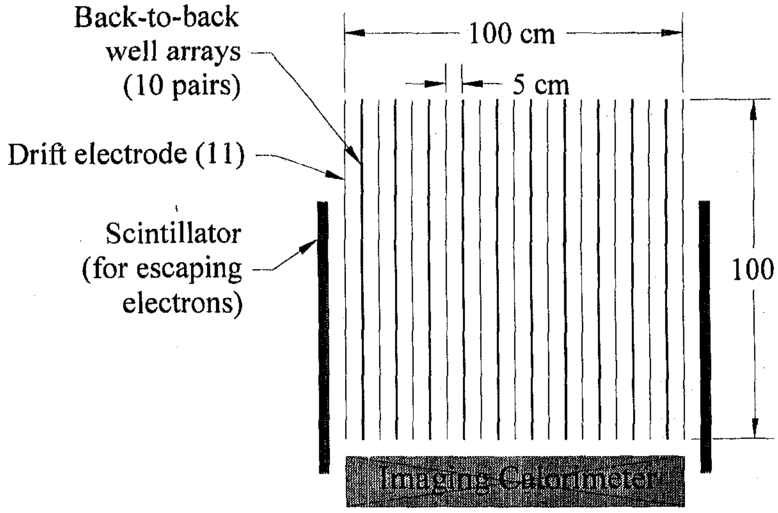

Fig 1: The TPC design[7] as proposed by Deines-Jones and Kevin Black of Goddard

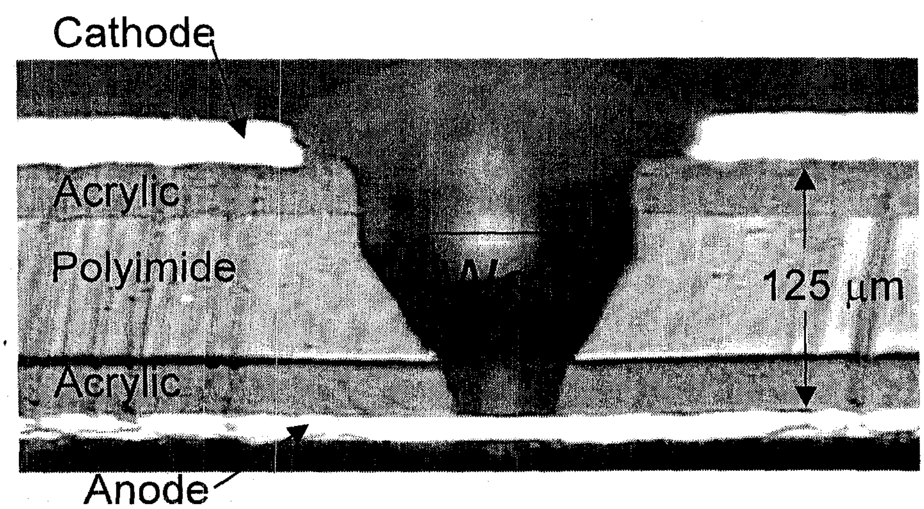

Fig. 2 The Cross-section of the micro-well[7].

Simulation effort

The purpose of our simulation effort is to ultimately provide capability which will help us systematically study the response of the TPC to various gamma sources and background sources. This entire task can then be further broken down into following general steps.

STEP 1: Writing user codes which can be used by major Monte Carlo packages such as Geant or EGS. This will do the throwing of the event. Tracking the primary gamma through the geometry. For each 'event' it will give us coordinates of the interaction points, generation of secondary particles and their transport through the detector. This step will also include writing an event generator.

STEP 2: Propagate the ionization electrons almost to the cathode with a diffusion model.

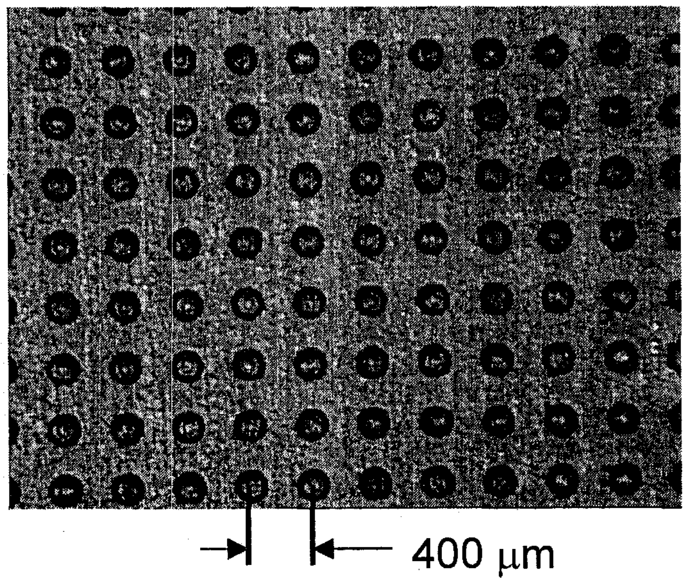

Fig. 3 Picture of a micro-well detector. An array of wells form a micro-well detector[7].

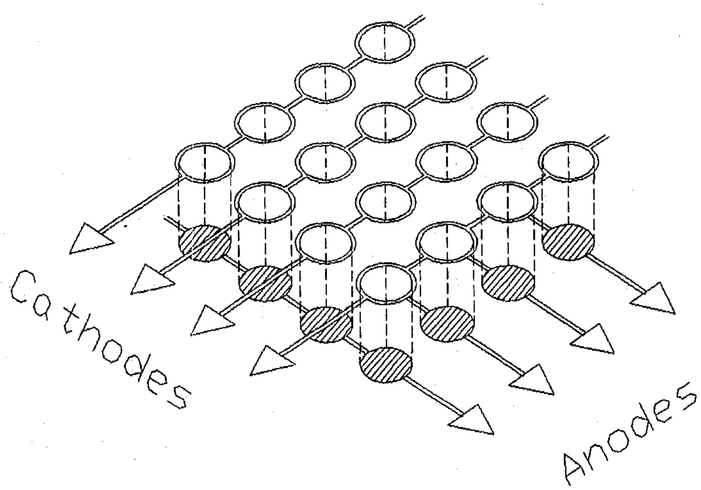

Fig. 4 : 2D read-out of the micro-well detectors. The third co-ordinate is determined using the timing[7].

STEP 3: For these ionization electrons assign 2D coordinates. Phil Dines-Jones suggestion was that it is good enough to just use the electron coordinate "close to" the well to assign a pixel.

STEP 4: Generate pulse heights. This is probably the hardest task, but important, since fluctuations in pulse height degrade position resolution.

STEP 5: Generate a data summary tape or DST which will be equivalent to an experimental data tape if such a detector was built and the data was collected.

STEP 6: Write tracking algorithms to construct the best source image.

STEP 7: Study what parameters (such as geometry, trigger, background, source energy) affect the quality of the constructed source image and quantify the results.

Since last April we have focused our attention on finishing tasks listed in STEP 1. This task is probably the largest task other than the tasks listed in STEP 7.

STEP 1

Since our meeting in April with Dines-Jones et al., at Goddard we have focused our attention on writing the user codes for the Geant Monte Carlo package.

Geometry Set-Up

The geometry set-up included in our Geant Monte Carlo is shown in Fig. 5. It shows an incoming (blue dotted-line) 500 keV gamma ray (from the top of the Fig. 1 in the direction of the negatively axis) Compton scattering in the Al wall. In this event the electron (solid red track) escapes into the gas part of TPC and stops. The scattered gamma ray interacts in the TPC gas via the photoelectric effect, losing all of its energy. The Z-axis in this figure points out from the paper.

The TPC volume is 100 cm X 100 cm X 100 cm and is filled with 2 atm of Xe-CO_2 mixture. Within this TPC volume we have 10 back-to-back MWT detectors. Each simulated MWD detector consists of three planes – a copper anode of thickness 0.0015 cm, followed by kapton of thickness 0.0125 cm, which is followed by Cathode made up of copper 0.0025 cm thickness. We have not simulated the wells of the MWD. In the model the electrodes were made up of a single material of thickness .005 cm. This material was simulated as a mixture of materials with the same net mixture of elements as the real material (aluminized mylar), but the details of the separate aluminum and mylar layers were not included. It was defined as simple mixture after attempts to defining separate layers of thin mylar and aluminum layers caused difficulties related to the rounding errors associated with particles stepping through very thin layers. Although no walls can be seen in Fig. 1, we have added aluminum walls of 400 micron[8] thickness surrounding the gas + MWD + ELECTRODE volume of the TPC.

For scintillators we chose 1″ thick BGO ($Bi_4Ge_3O_{12}$, Density = 7.13 g/cm^3)[9]. Rather than covering sidewalls partially as shown in Fig.1 we chose to cover entire sidewalls with BGO. These scintillators can provide a veto in the trigger for the background photons and for the Compton events taking place inside the TPC they can stop the escaping scattered gamma rays. The imaging gamma calorimeter should be able to provide rough position information and collect the energy of the escaping gamma rays from the bottom and provide a veto for background events. For calorimeter we chose CsI. There are 100 CsI crystals, each of cross-sectional area 10.56 cm X 10.56 cm and thickness of 10 cm cover the entire bottom of the TPC and thickness of BGO walls.

Hits Files

After finishing the geometry set-up we started writing "hits files" resulting from the simulated tracks. In Geant a "hit" contains information about the location of any interaction that results in a measurable signal in the detector. (User defines the measurable signal – in our simulation we have set that to 1 keV.) In the hits files we are currently writing information from the entrance and exit hits for the scintillators and CsI i.e. hits information includes location at which the particle entered and exited these detector volume is stored. Along with these locations we also saved the deposited energy and other miscellaneous diagnostic information such as the location of the interaction (vertex) at which the particle was produced and the

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[8] The number was chosen randomly. No thought was given to if the aluminum wall of this thickness can feasibly hold 2.5 atm of Xenon-CO_2 mixture and such.

[9] "Review of Particle Physics," D. E. Groom et al., The European Physical Journal, C13 (2000) 1

physical processes (e.g. Compton scattering, pair production, photoelectric effect) which produced the particle. The idea is to separate the interaction of the particle with the detector and the actual performance of the detector. In addition, by storing information about the physical processes which occurred in the event, the efficiency of the tracking and reconstruction code which follows can be evaluated. Using information from the hits files, the detector performance is added as an "afterburner". In the TPC, the response depends on the path the particle follows through the detector – just storing the location of the entrance and exit hits is not enough to simulate the TPC response. Therefore, for the TPC additional detail of the path of the particles (including multiple scattering) through the TPC is stored in the hits file. In addition to the above information we need to store the hits information from the hits within the MWD itself. Signals produced in MWD due to the events depositing energy directly into that MWD will be different from the signals produced by the signals generated by electron tracks in the Xe-CO_2 gas.

Along with the hits files we are generating few diagnostic histograms. Before the task of writing hits files we had to make sure that the physics interaction flags and the tracking thresholds were set-up appropriately in Geant. Our results of the study of physics interaction flags is documented[10] elsewhere.

Future Work

Our next step will focus on converting information from the hits files into the signal information on the MWDs. Similarly the hits information from the scintillators and CsI will be converted to the 'real' data. This is straightforward for the hits in the scintillators and CsI, but a little more complex in the TPC volume. All of the real data will be written to a data summary tape (DST). At this point we will continue to record the other diagnostic information for each event. These DST tapes will be used to see if we can recognize the useful Compton tracks from the background created by other processes.

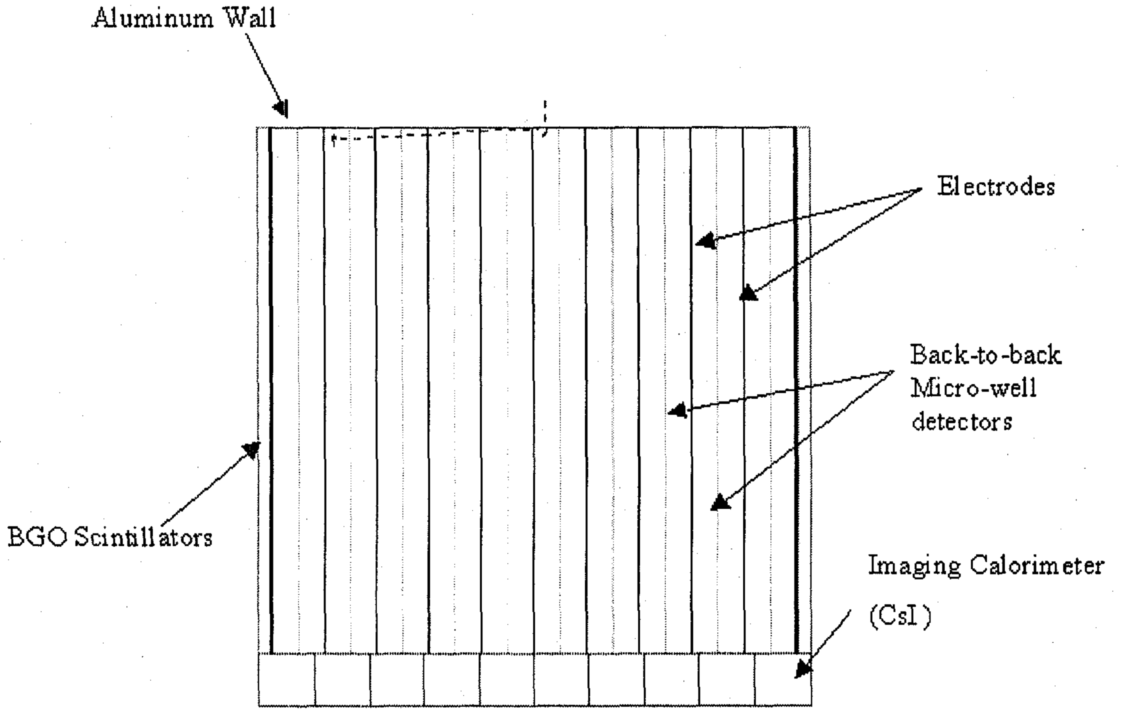

Fig. 5. Cross-sectional view at Z=0 of the TPC detector. This figure is generated using the Geant package itself. The dotted blue lines show the gamma tracks. The red lines indicate the tracks from the generated electrons

[10] Mohini W. Rawool-Sullivan and John P. Sullivan, "Gamma-ray and Electron Physics Processes in Geant." Submitted for the LAUR number.