

Performance of the LXeGRIT Compton Telescope During the 2000 Balloon Flight Campaign

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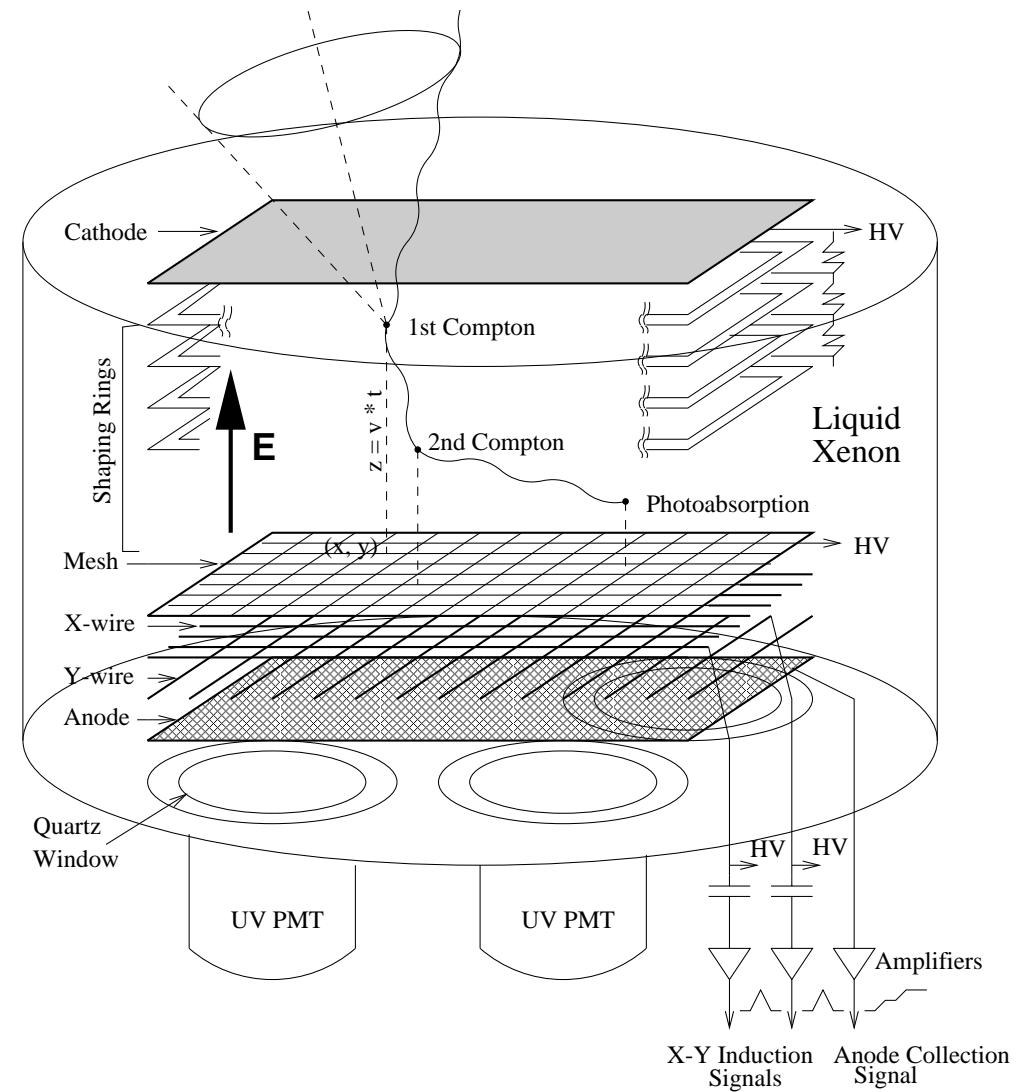
⁴*University of New Hampshire, Durham, NH, USA*

- The Liquid Xenon Time Projection Chamber for Gamma-Ray Imaging
- The LXeGRIT Balloon Payload
- Pre-Flight Calibration
- In Flight Performance

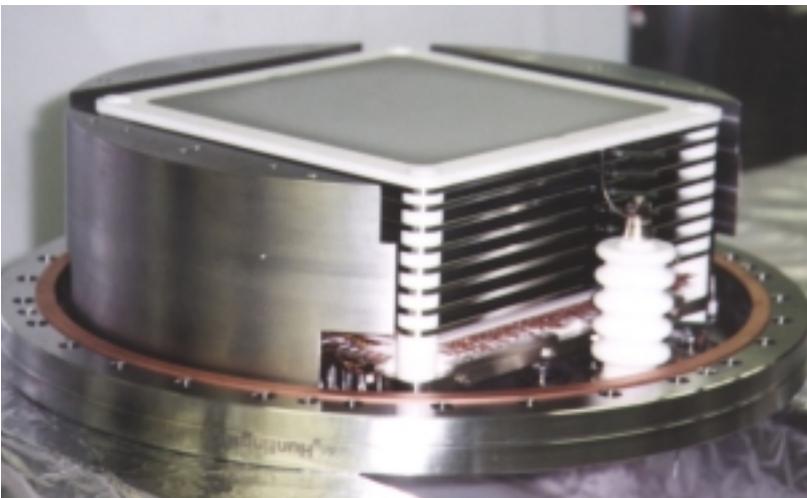
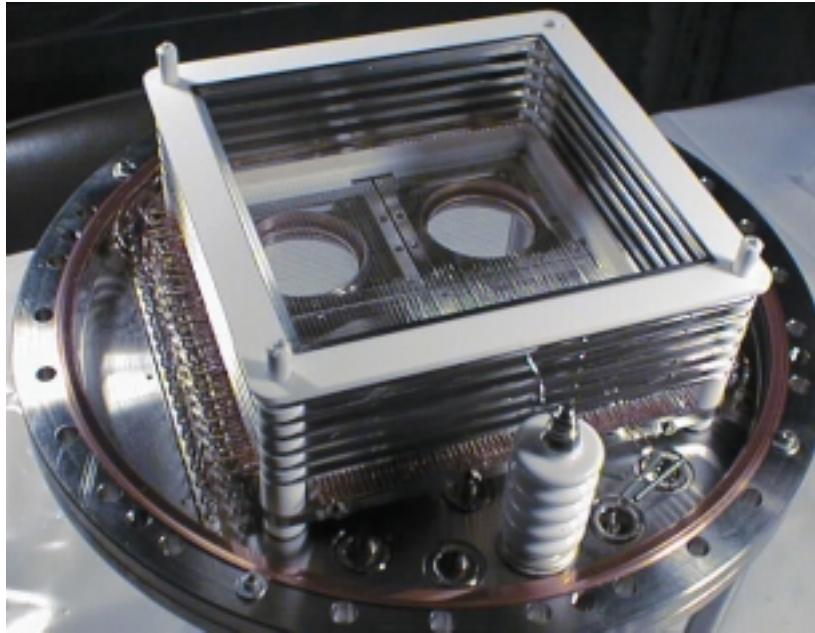


A Liquid Xenon Time Projection Chamber as Compton Telescope

- A homogeneous, self-triggered detector which combines high detection efficiency with calorimetry and 3D event imaging
- Xe ionization and scintillation detected to measure energy and spatial information for each gamma-ray interaction in the sensitive volume
- Events with multiple interactions are identified and used for reconstructing the incoming gamma-ray energy and direction, with Compton kinematics
- Events with a single interaction and high energy charged particles easily recognized and rejected. Background is reduced with 3D event imaging

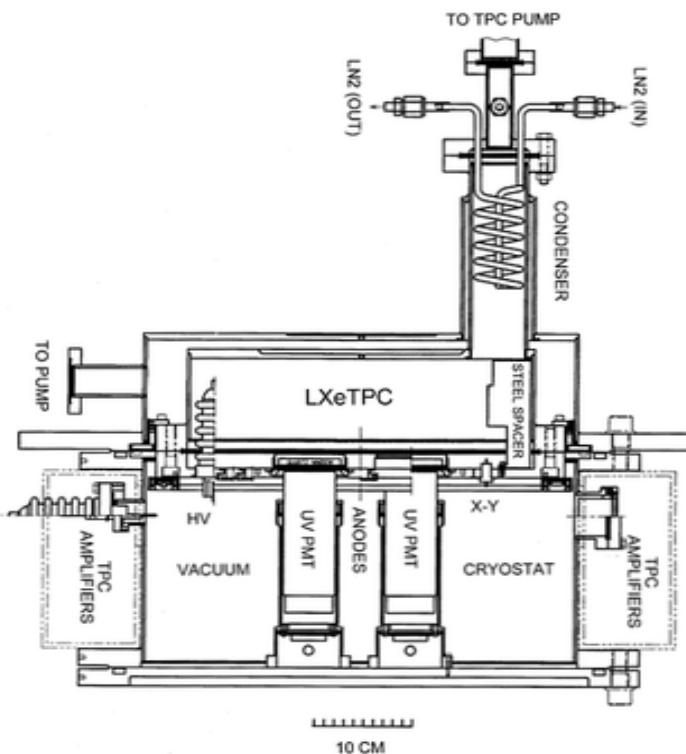
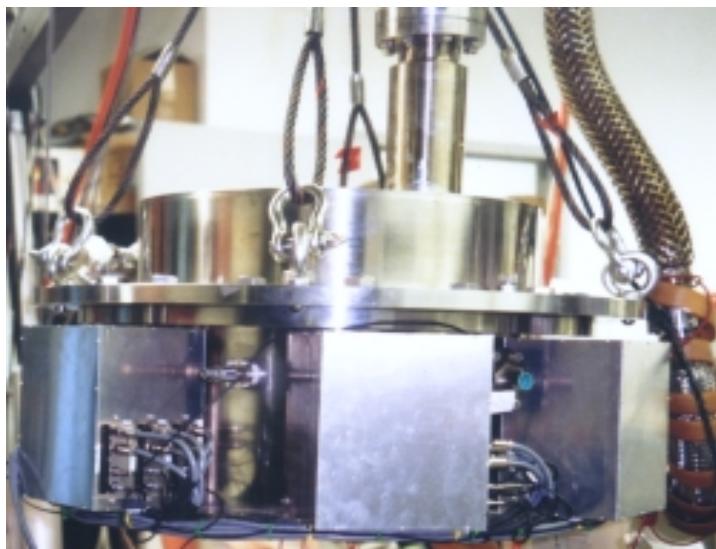
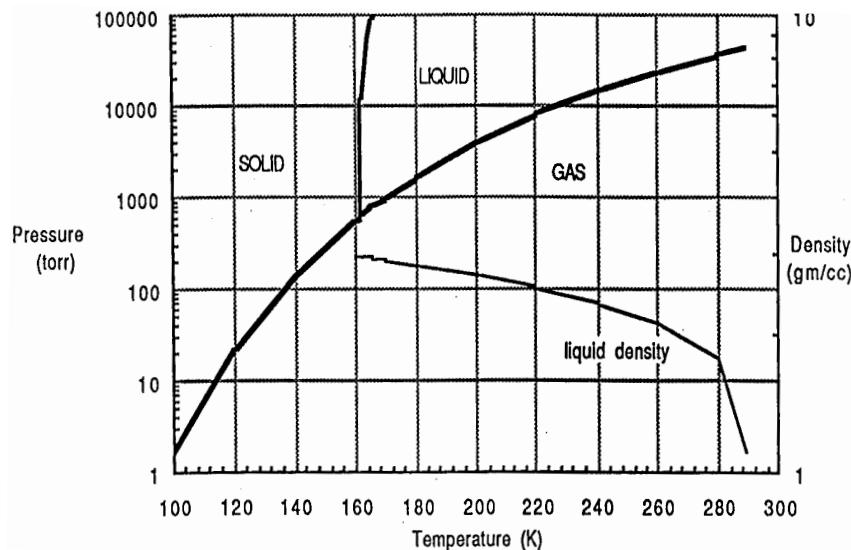


The Liquid Xenon Time Projection Chamber Developed at Columbia



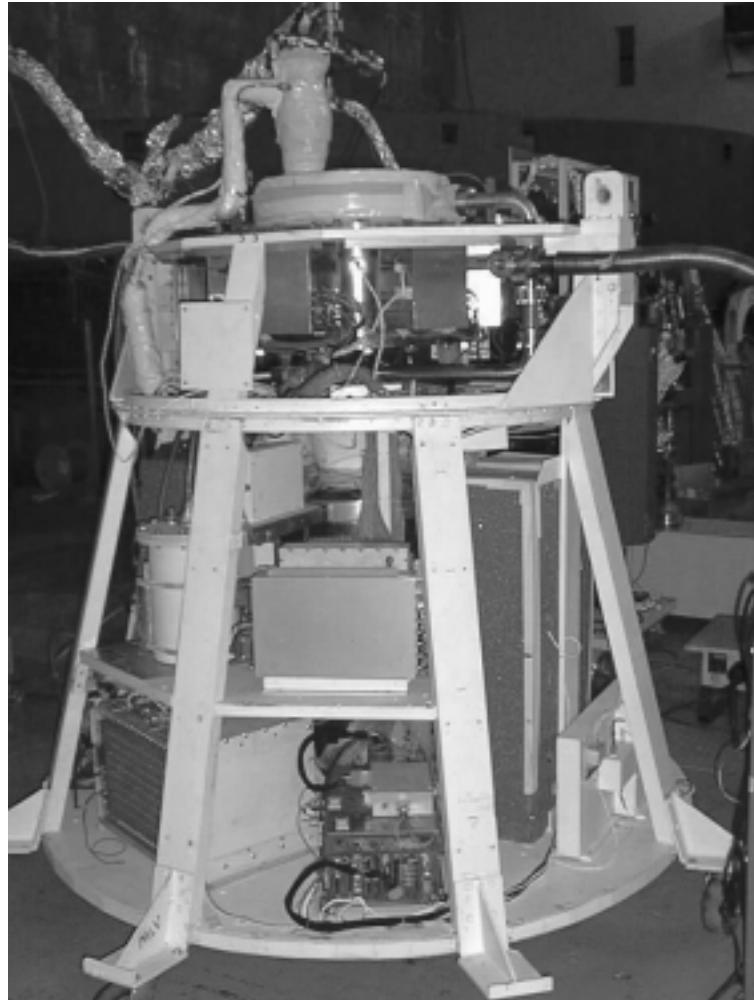
- structure mounted on 41 cm diameter SS flange.
- $20 \times 20 \text{ cm}^2$ sensitive area, 7 cm drift gap (21 g cm^{-2})
- Xe scintillation detected by 4 UV PMTs. Event trigger from the PMTs OR
- charge detected by 62 X-wires + 62 Y-wires + 4 anodes. Each channel digitized at 5MHz
- 1 mm X-Y localization from wire hits. $300 \mu\text{m}$ Z localization from absolute drift time measurements (max=35 μs)
- event energy from sum of each anode amplitude. Electric field is 1 kV/cm
- "Inactive" LXe reduced with SS spacers on three sides. A 3 cm "inactive" LXe layer below anodes unavoidable with this design.
8 l of high purity LXe needed to fill the TPC

The Liquid Xenon Time Projection Chamber Cryostat

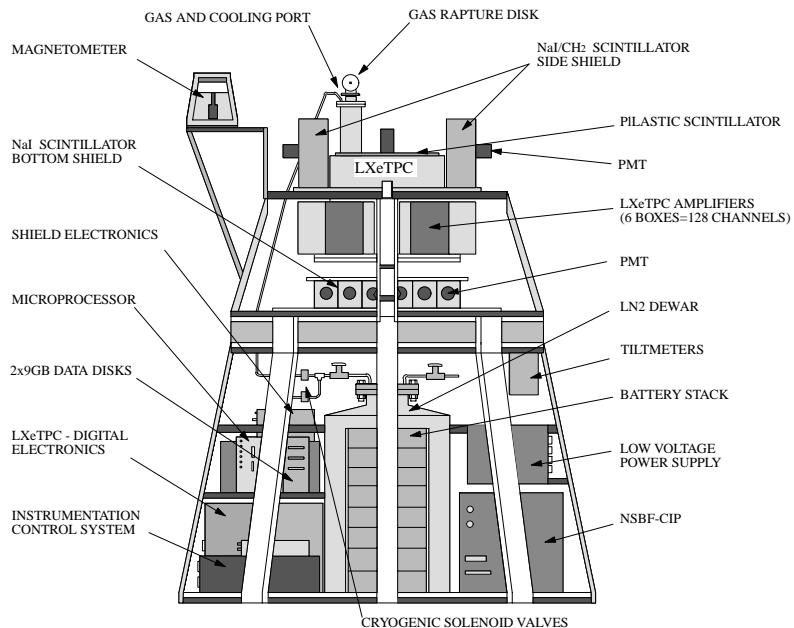


- LXeTPC insulated by a SS **vacuum cryostat** 50 cm diameter and 35 cm high). Total detector mass is **190 kg** including 24 kg Xe
- Cathode HV supply and filter, PMTs and wires **decoupling** inside cryostat.
- Xe gas condensed and kept at desired temperature by a **controlled flow of LN₂** through a copper coil.
- Vapor pressure and thus LXe temperature allowed to vary between 1.5 atm (**-95°**) and 2.4 atm (**-91°**). Flight Dewar (90 l LN₂) hold time is about 40 hours.

The LXeGRIT Instrument in Flight 2000 Configuration

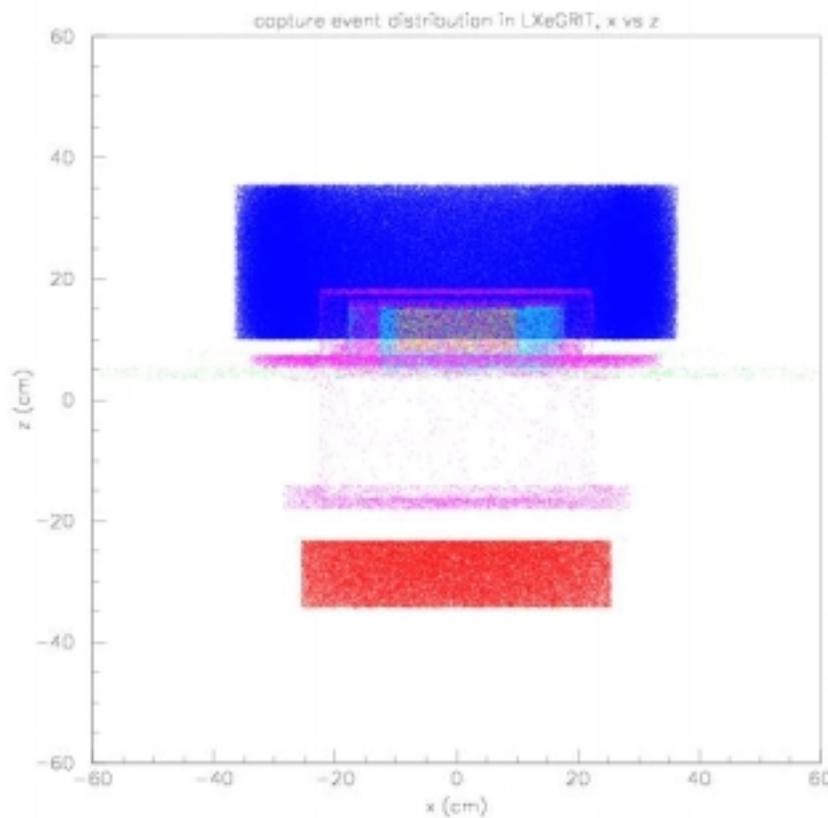


Detector	Liquid Xenon TPC
Active Volume	20 cm × 20 cm × 7 cm
Energy Range	0.1 – 10 MeV
Energy Resolution (<i>FWHM</i>)	$8.8\% \times (1 \text{ MeV}/E)^{1/2}$
Position Resolution (1σ)	1 mm (3 dimensions)
Angular Resolution (1σ)	3° at 1.8 MeV
Field of View (FWHM)	2 sr
Effective Area (Imaging)	20 cm ² @ 1 MeV
Veto Shields	None
LN ₂ Dewar	100 liter
Instrument Mass, Power	2000 lbs, 450 W
Telemetry, Onboard disks	2 × 500 kbps, 2 × 36 GB



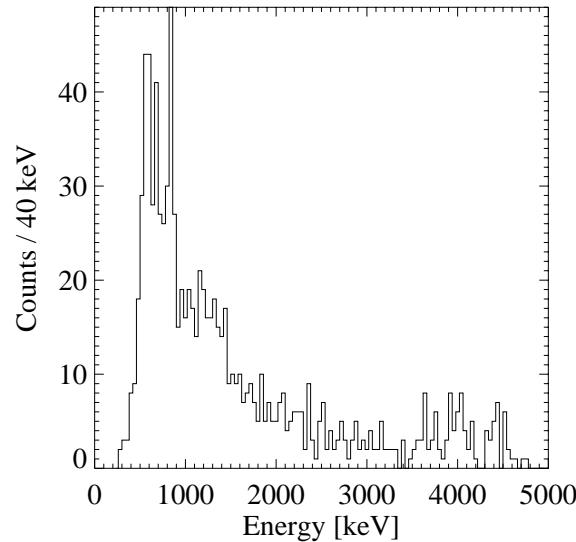
LXeGRIT in flight 1999 configuration

Remove Shields to reduce Neutron induced background

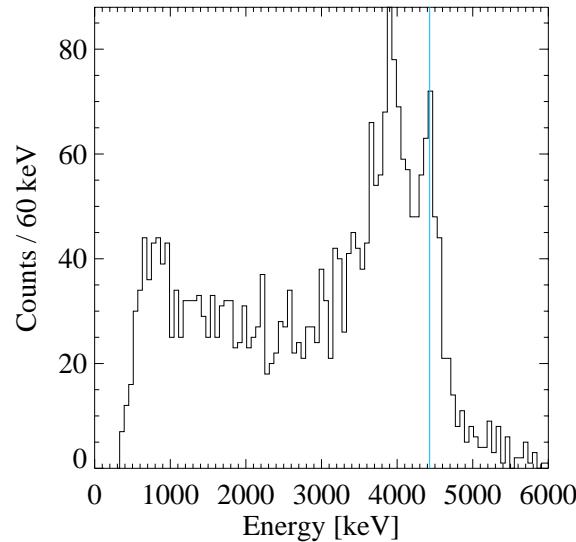


- LXeGRIT "active" shields in 1999: 251 kg of NaI (140 kg side-shield, 111 kg bottom-shields) and 10 kg of CH₂ in side-shields.
 - Use LXeGRIT Mass Model (GEANT) and GCALOR for neutrons transport
 - Use isotropic neutron spectrum $0.97 E^{-1.8}$ (up to 100 MeV) [Klumper, JGR, 78, 1973]
 - Focus on neutron capture reactions in different materials
 - Results: shields account for 93 % of total capture rate (3.4 kHz)
 - Capture Rate in LXe is negligible in comparison: Active Xe (34 Hz), Passive Xe (89 Hz)
 - Studies of these and other neutron reactions on the gamma-ray background in LXeGRIT continue.

Optimize Xe Light Trigger for MeV Energies and Enhance DAQ Speed



Am-Be:trigger as in 1999 flight

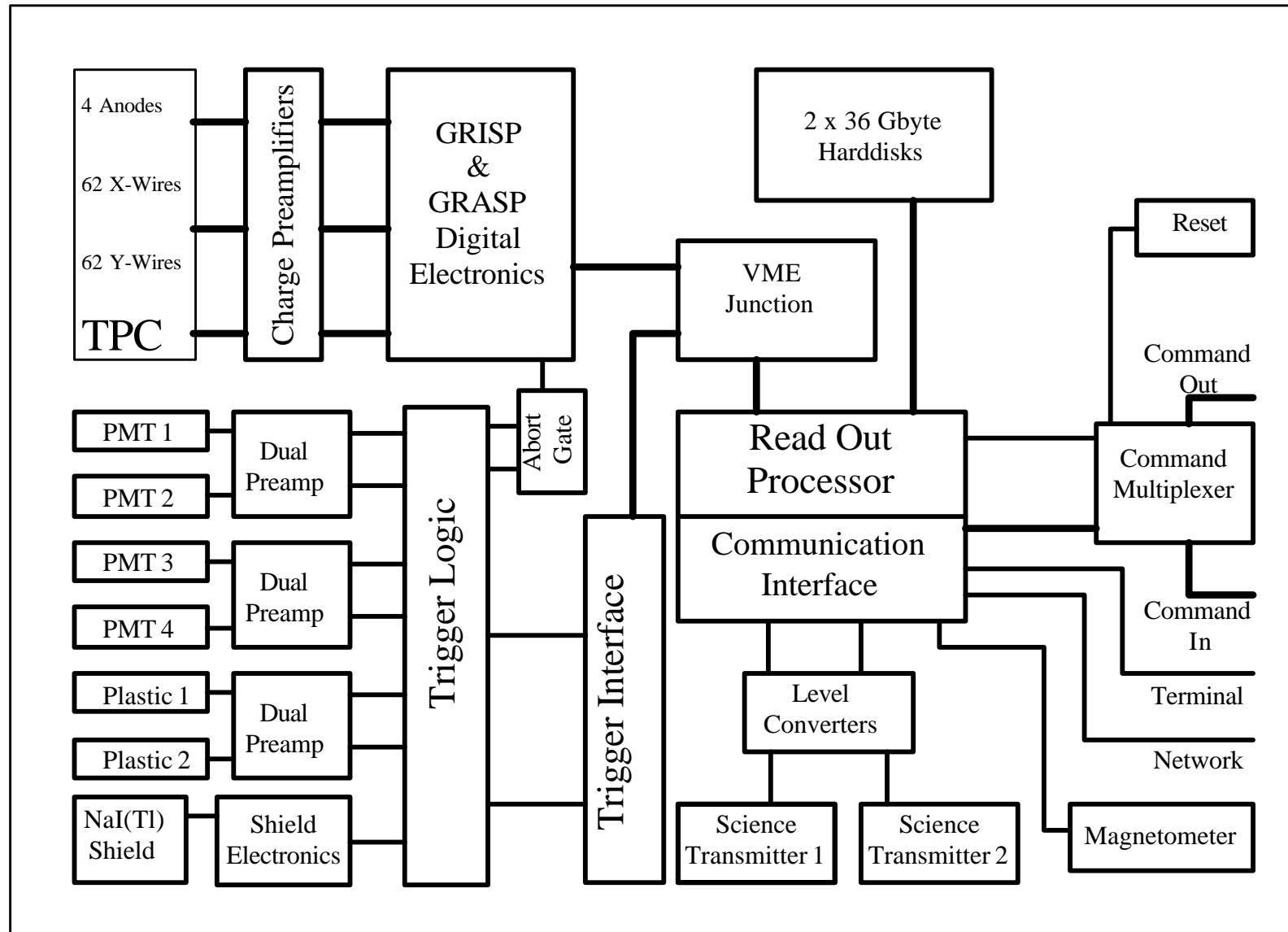


Am-Be:trigger optimized for MeV

For the 1999 flight the trigger conditions favored very low energies, well below the sensitivity of the charge readout of about 150 keV. This, coupled with the enhanced low energy gamma background from neutron capture and the limited event building capability of the DAQ system, resulted in a suppression of MeV gamma-rays. The impact of the trigger is clear from the Am-Be spectra.

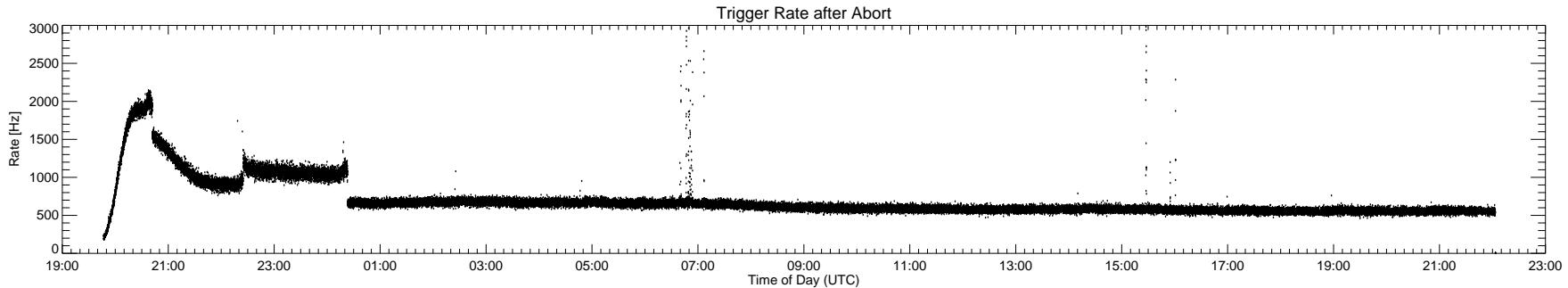
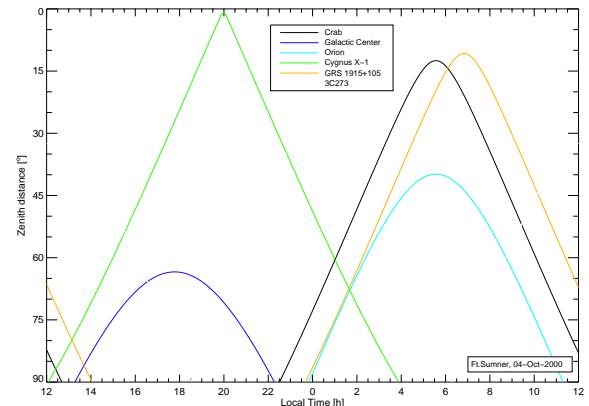
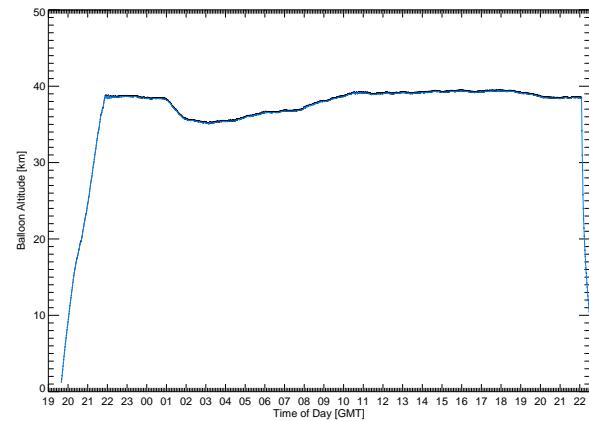
The DAQ system has to cope with the large data throughput from the TPC (30kB in "full imaging mode"). With DMA block transfers, and with software selections, DAQ build rate was increased by factor of 2.5 compared to 1999, reaching 50 events/s in "full imaging mode" and 300 events/s in "standard mode", where event size is reduced to 4.5 - 6.5 kB, by sparse readout and software selections.

Block Diagram of the LXeGRIT Balloon-Flight Electronic System

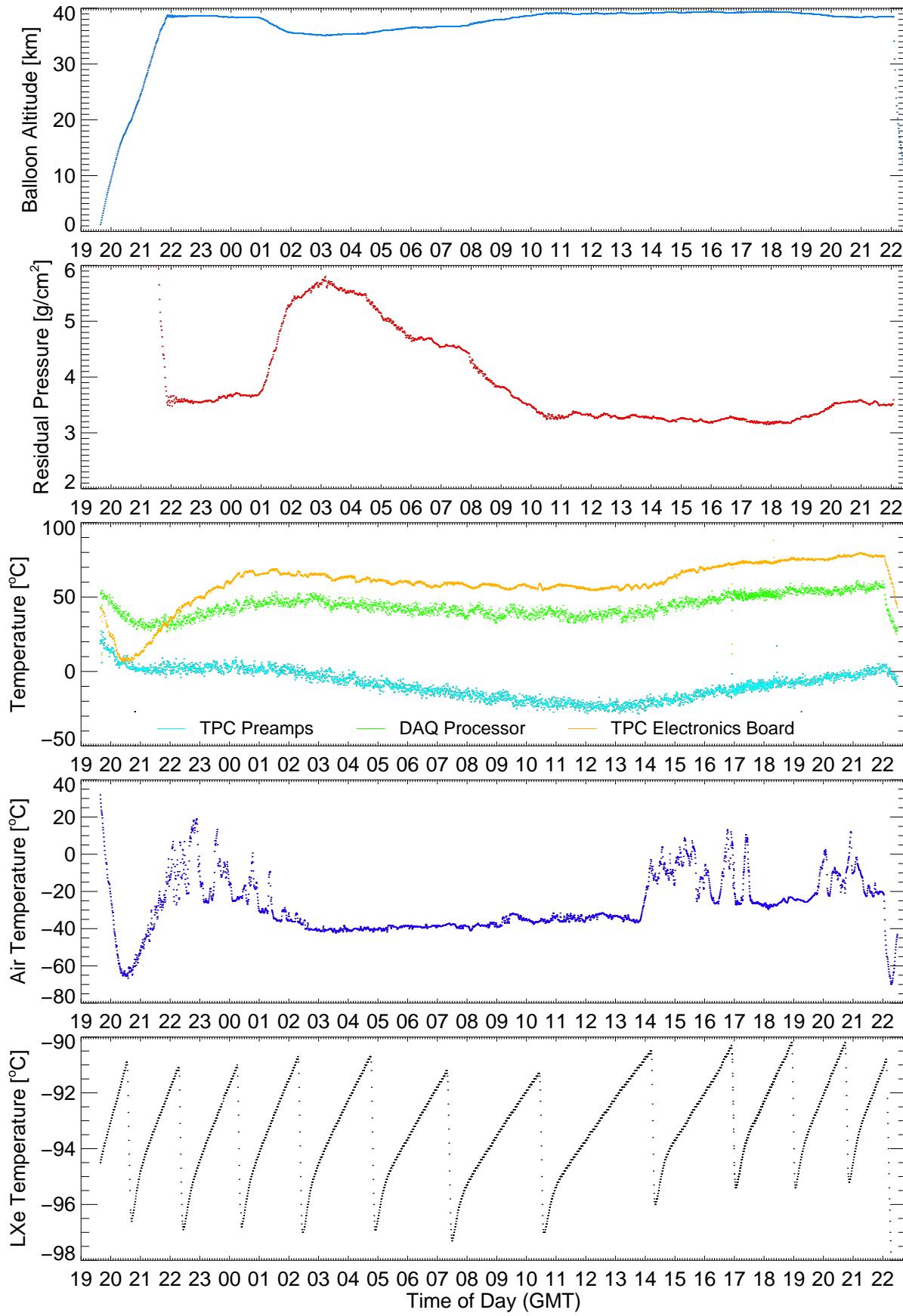


LXeGRIT Flight 491, October 4-5, 2000 Fort Sumner, New Mexico

- launch on Oct 4 at GMT 19:39:48 by 29 Mcft balloon
- termination on Oct 5 at GMT 22:05:269 from Holbrook downrange station
- payload recovered in good condition in Buckeye, Arizona
- all instrument systems worked flawlessly during entire flight of 26 hrs
- 40 GB of data gathered from 2 transmitters (500 kbps) plus on board disks
- data are being analyzed to characterize the instrumental background in the unshielded LXeTPC and to image the Crab nebula at MeV energies with Compton events.
- charged particles, clearly identified and largely rejected in-flight DAQ mode, constitute about 60% of the average rate of 600 Hz at $3\text{g}/\text{cm}^2$ residual atmosphere.



LXeGRIT Balloon Flight on Oct 4–5, 2000



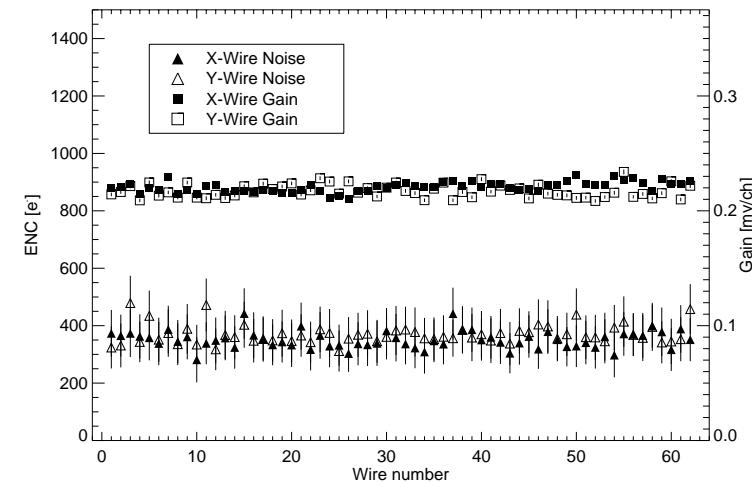
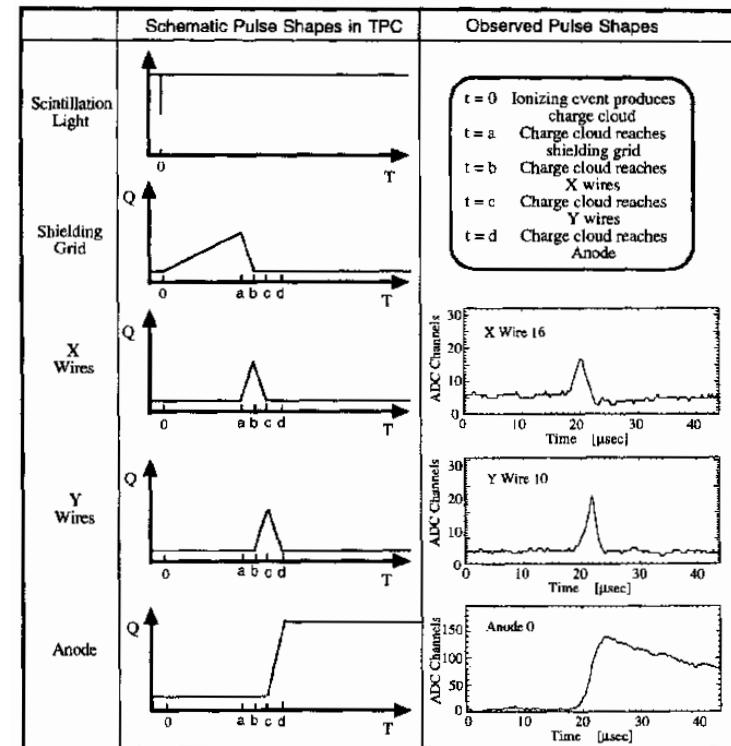
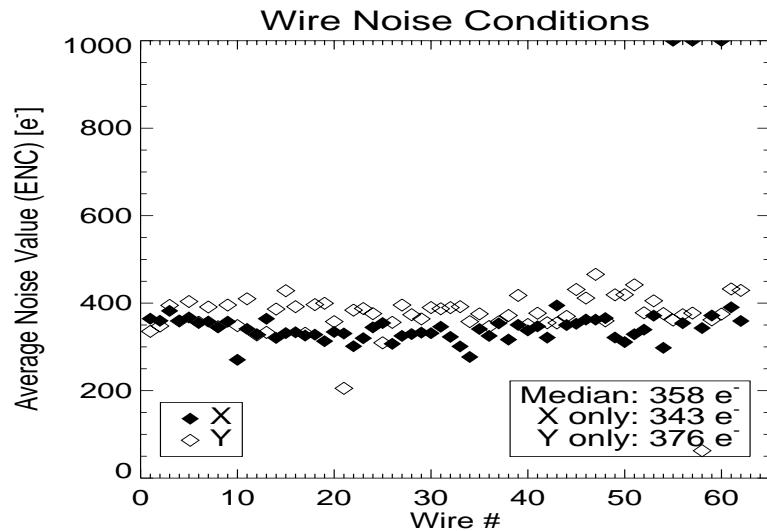
LXeTPC Signal Formation and Read-Out

Charge Signal

- Charge produced in liquid xenon per 100 keV energy deposit:
 $N_e = 100 \text{ keV} / 15.6 \text{ eV} \sim 6,400 \text{ e}^-$
- Electrical field adapted to focus electrons through holes of grid and through the wire spacing
- Induction signal from drifting charge on the wires
- $\sim 75\%$ of the charge is collected on the anodes at a field of 1 kV/cm
- Signals on wires and anodes are digitized by 5 MHz flash ADCs with 8 bit and 10 bit precision, respectively

Electronics Noise:

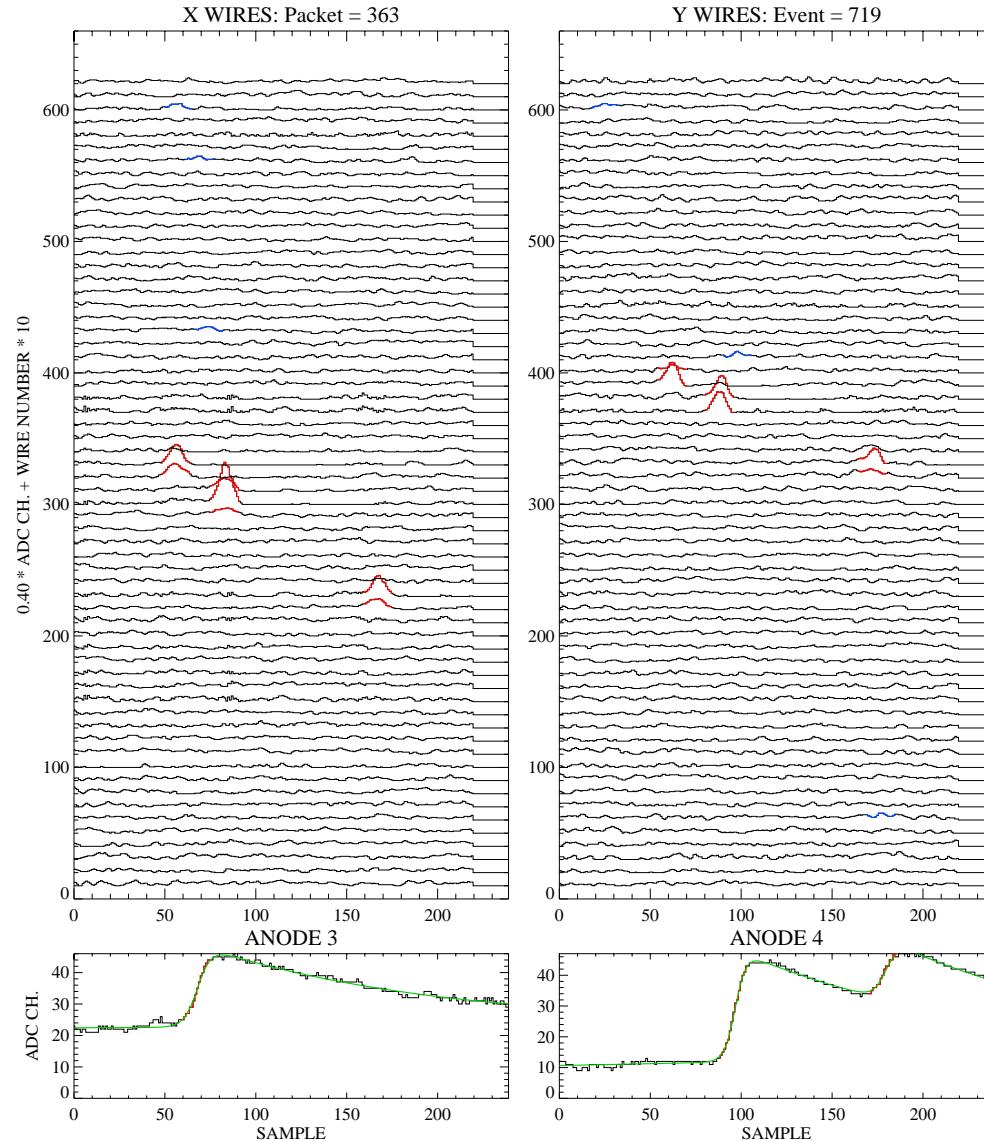
in Oct 1997 (right) and in Oct 2000 (left), after many launches and landings



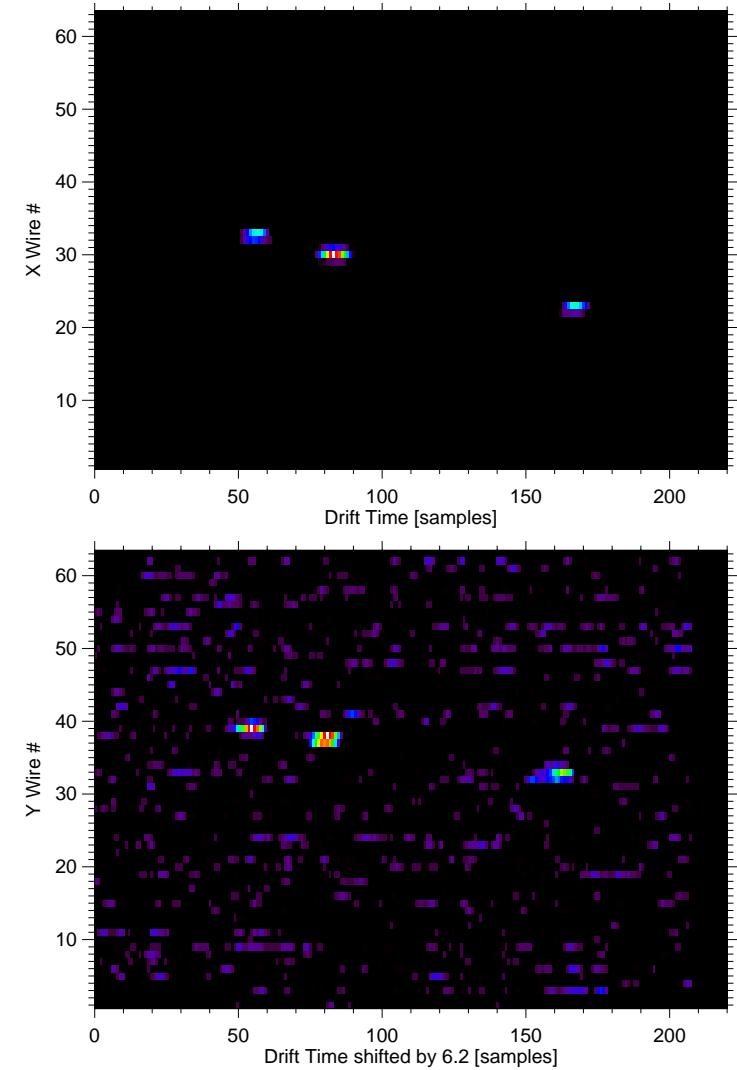
Signal Recognition and Event Reconstruction

X-/Y-Wire and Anode Signals vs. Drifttime

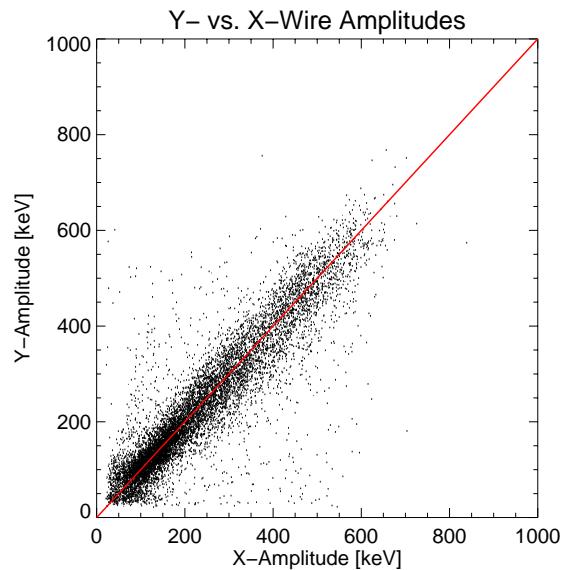
γ -ray with three interactions in the detector.



False Color Display of X-/Y-Wire Signals (same event)

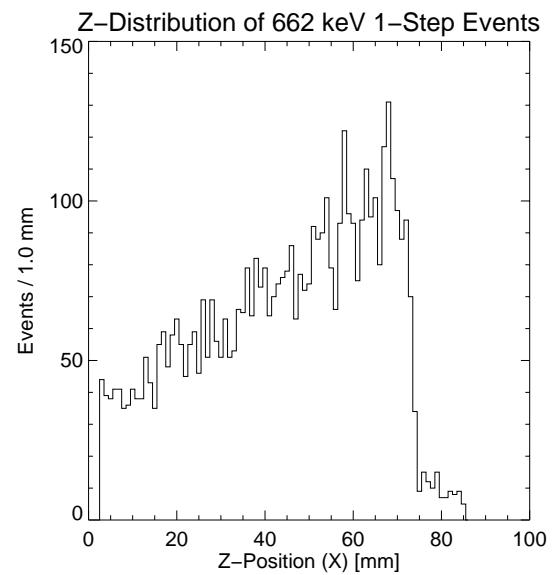
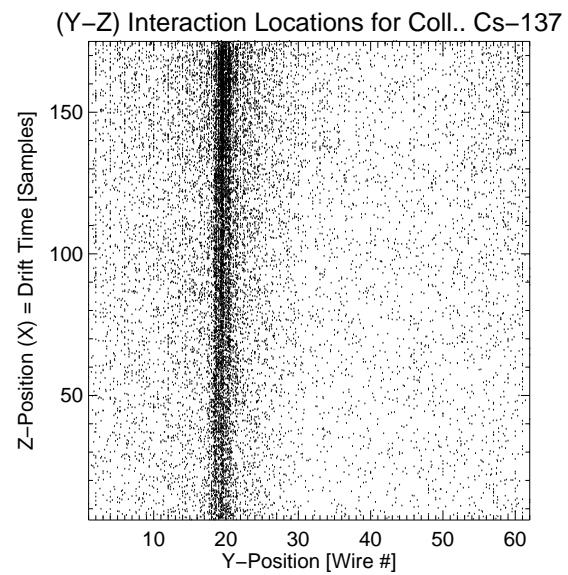
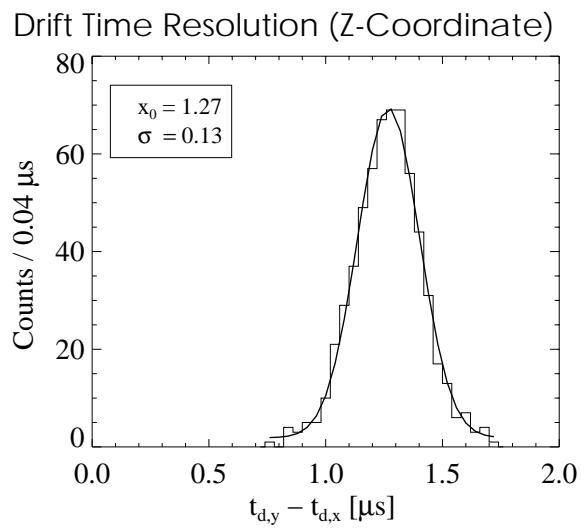
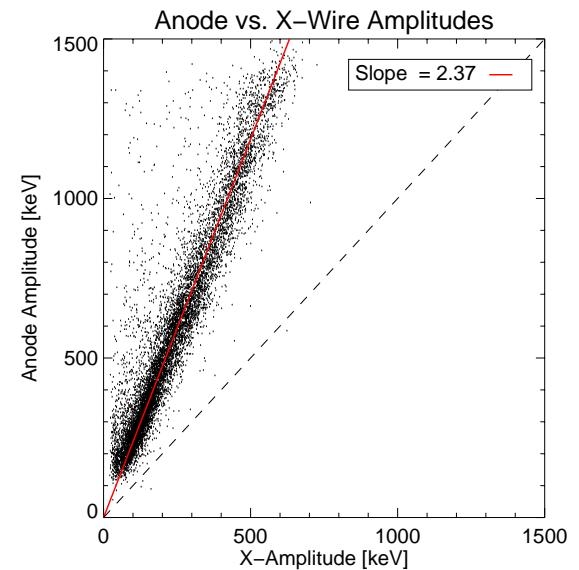


Distributions of Matched X-Wire, Y-Wire, and Anode Signals

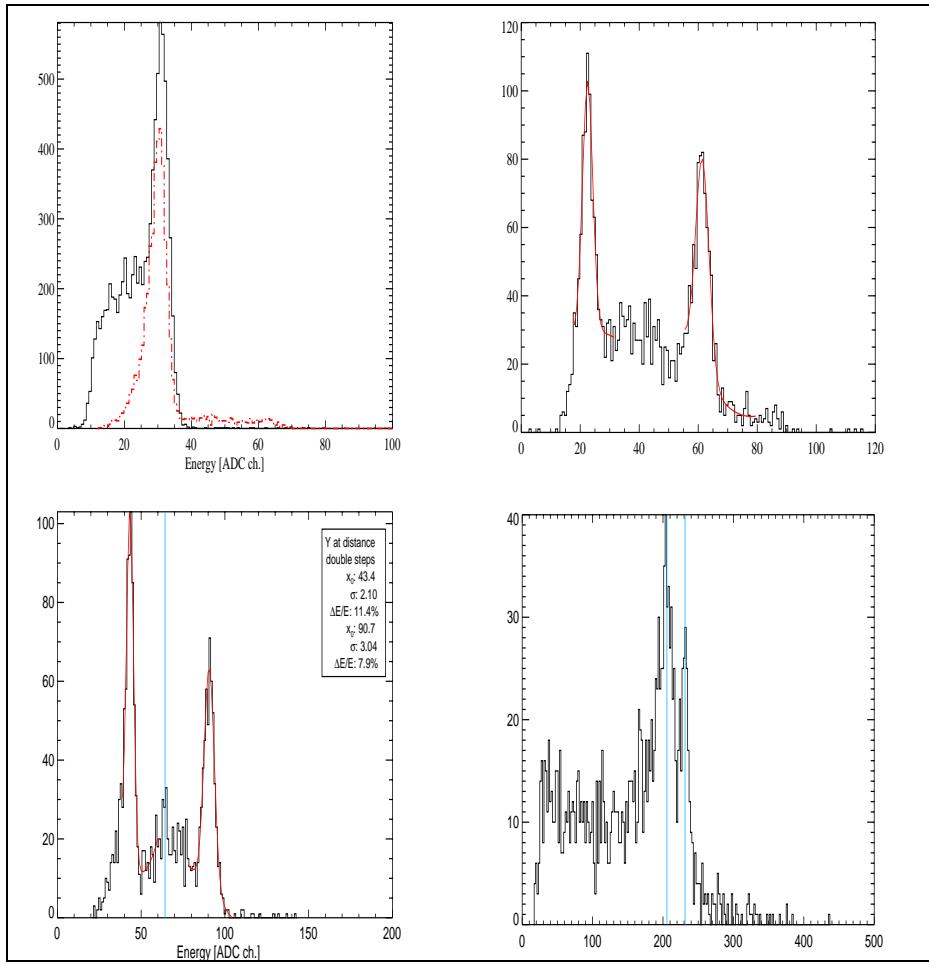


Top row: Close correlation of charge measured on matching X-Y-wire signals and on the corresponding anode confirms successful signal recognition.

Bottom row: Imaging a collimated Cs-137 beam with the LXeTPC.

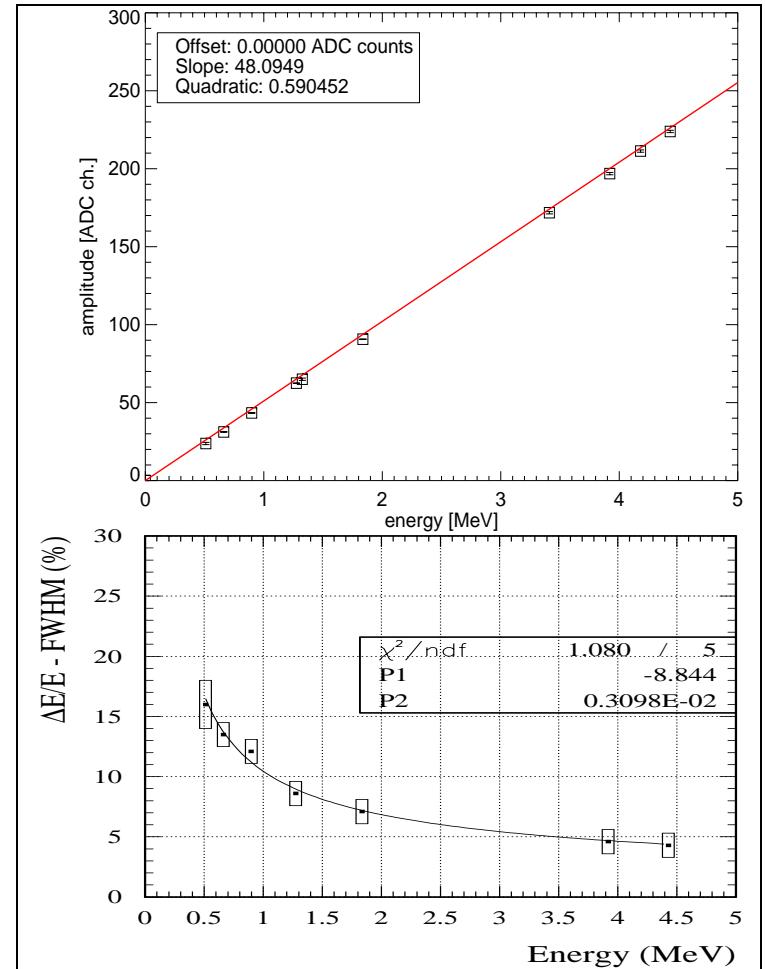


LXeGRIT Energy Calibration and Spectral Performance I



Energy Spectra – From top to bottom, clockwise:

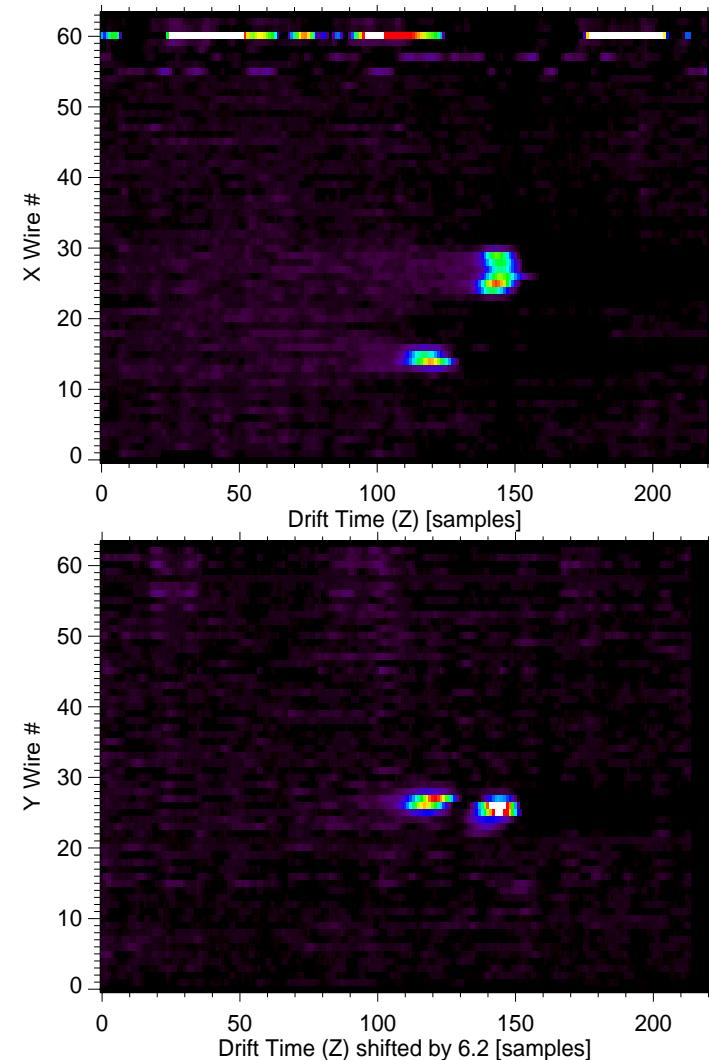
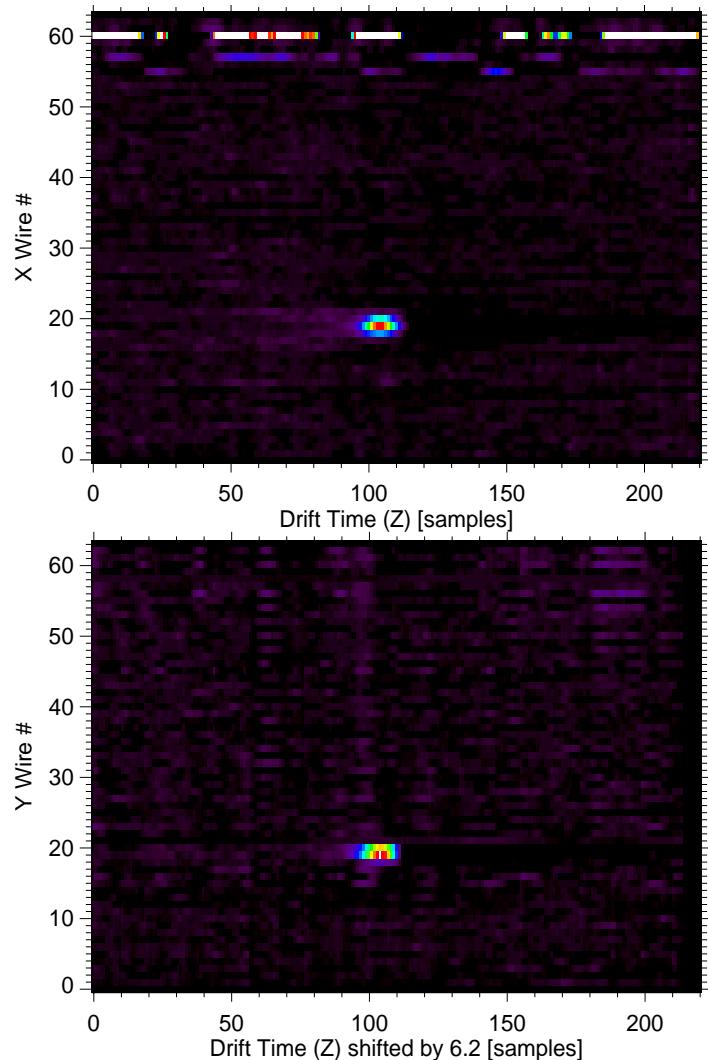
- ^{137}Cs – 0.662 MeV: "1-step" (—) and "2-step" events (---)
- ^{22}Na – 0.511 & 1.275 MeV: "2-step" events
- ^{88}Y – 0.898 & 1.836 MeV: "2-step" events, source ~ 2 m above TPC
- Am-Be:** "2-step" events. The photopeak (**4.43 MeV**) and the single escape peak (**3.92 MeV**) are clearly identified.



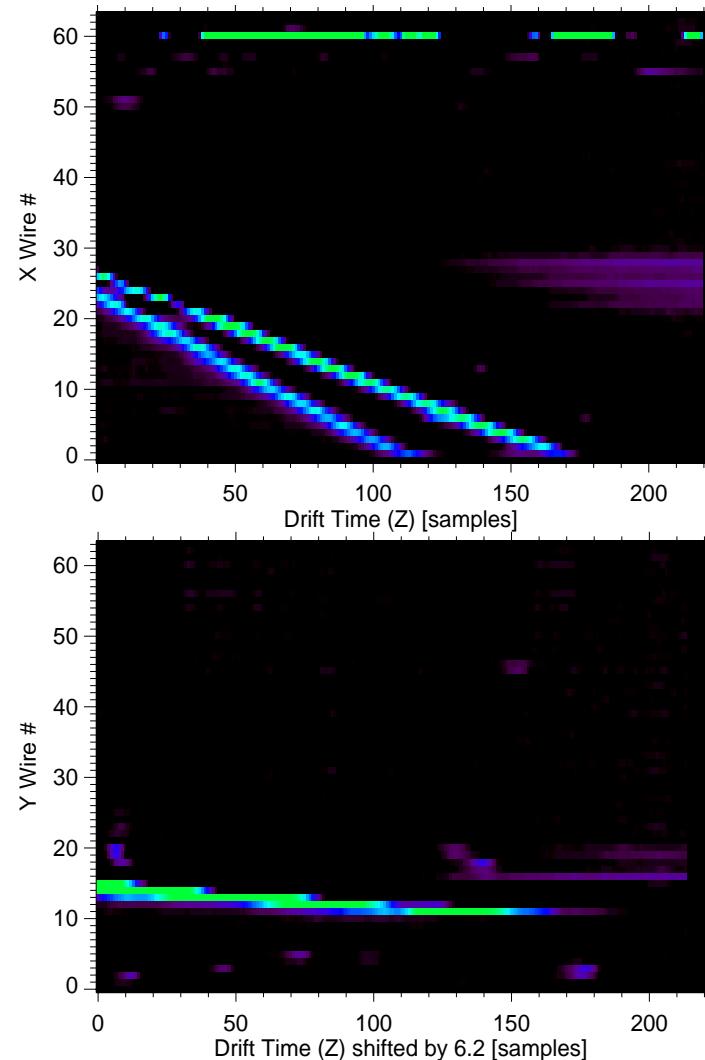
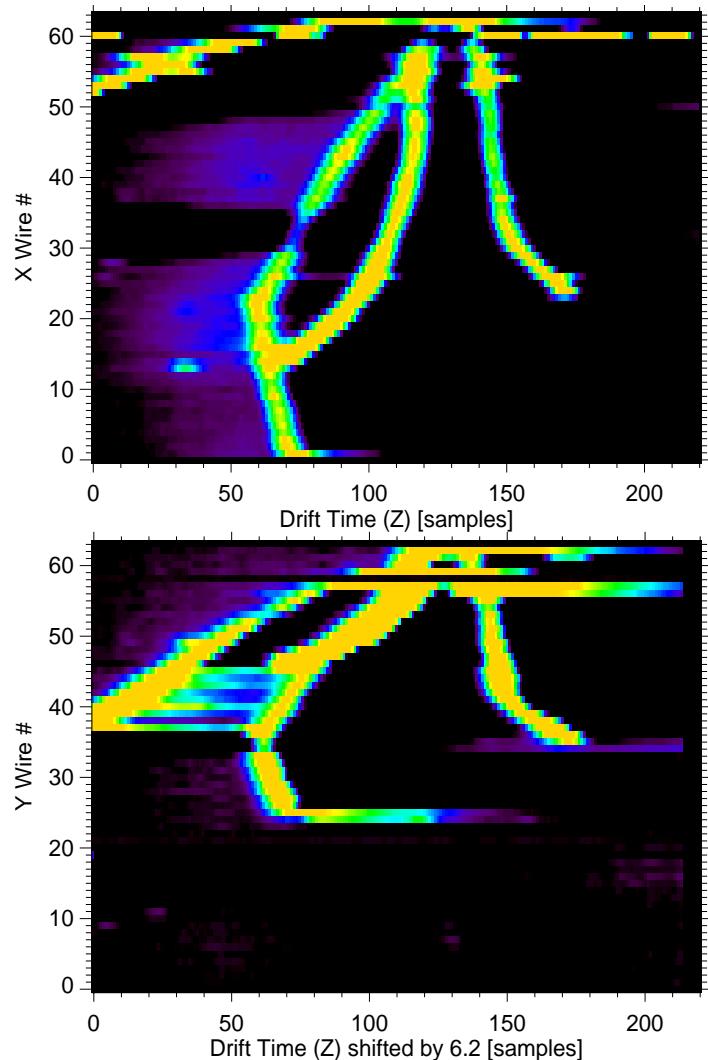
From top to bottom:

- Energy Calibration Curve:** anode amplitude vs. energy
- Energy Resolution vs. Energy:** $\Delta E_{\text{Lxe}}/E = 8.8\% \sqrt{1\text{MeV}/E}$

Event Imaging with LXeTPC: LXeGRIT 2000 – Flight Data – Gamma Rays

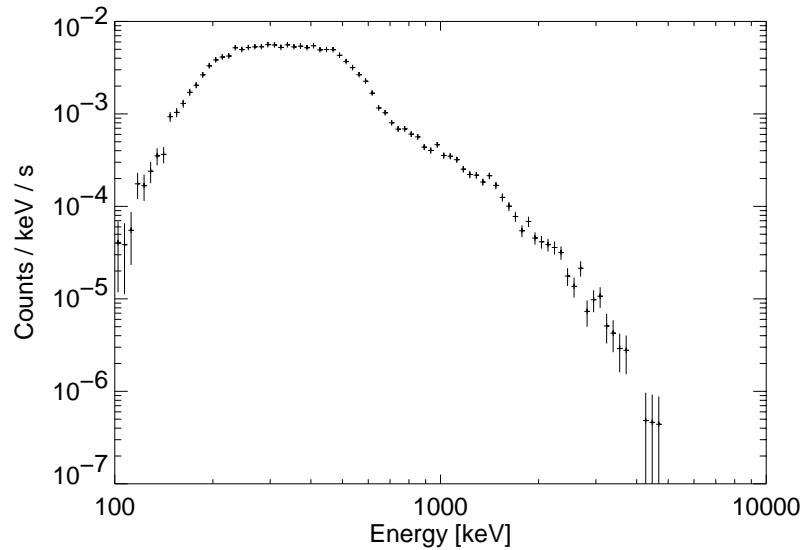


Event Imaging with LXeTPC: LXeGRIT 2000 – Flight Data – Charged Particles

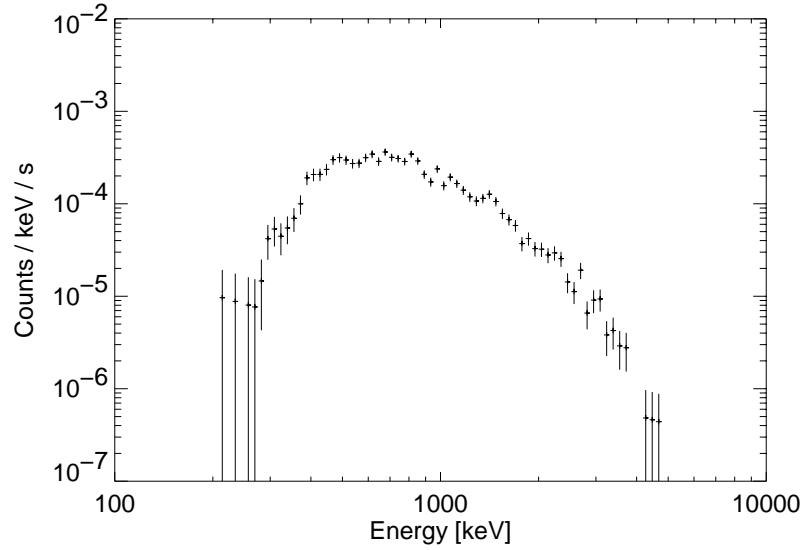


LXeGRIT Energy Response: 2000 vs 1999 Balloon Flight

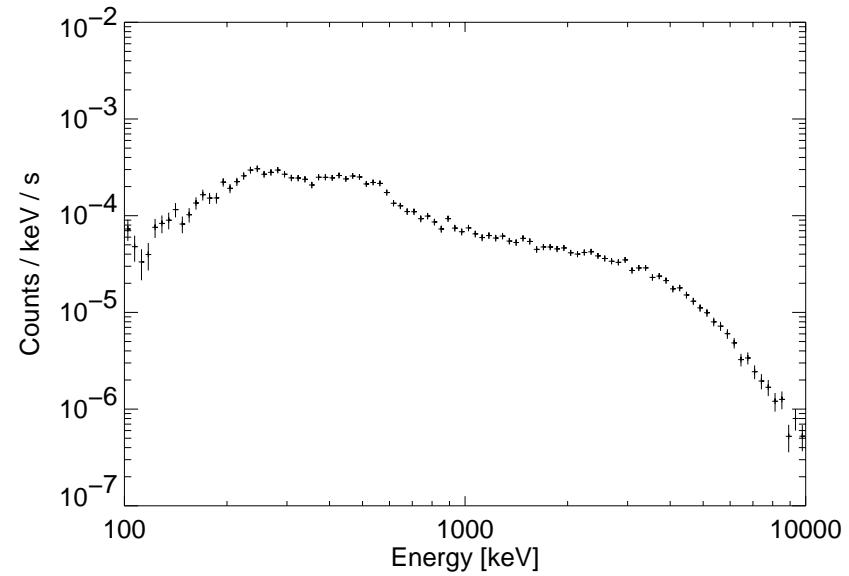
Single Interaction Events- 1999



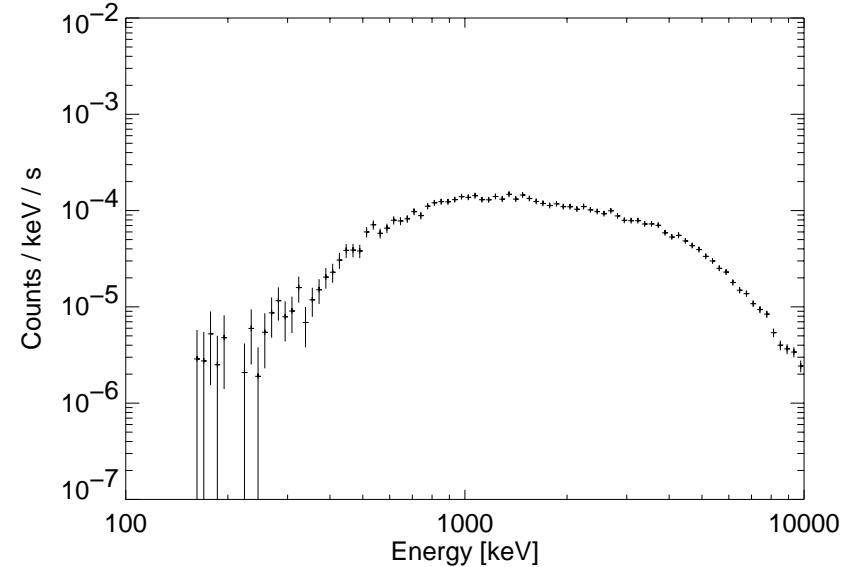
Multiple Interactions Events- 1999



Single Interaction Events- 2000



Multiple Interactions Events- 2000



Study of single Compton scatter events (2-steps) from the 2000 Balloon Flight

Advantage:

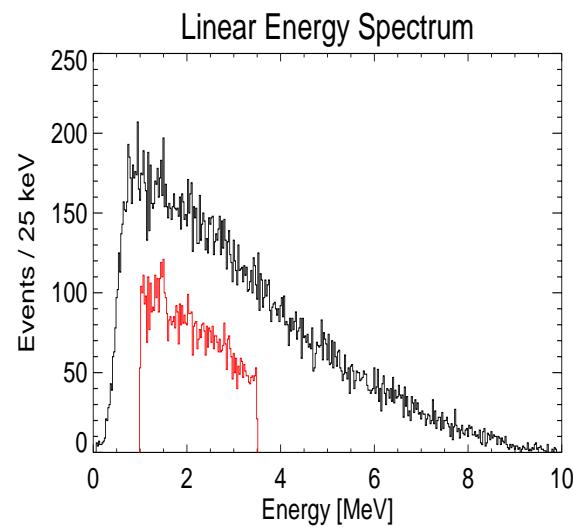
- Simple event topology
- Large statistics

Disadvantage:

- Large scatter angles favored
⇒ broadened imaging response
- Limited background suppression capability

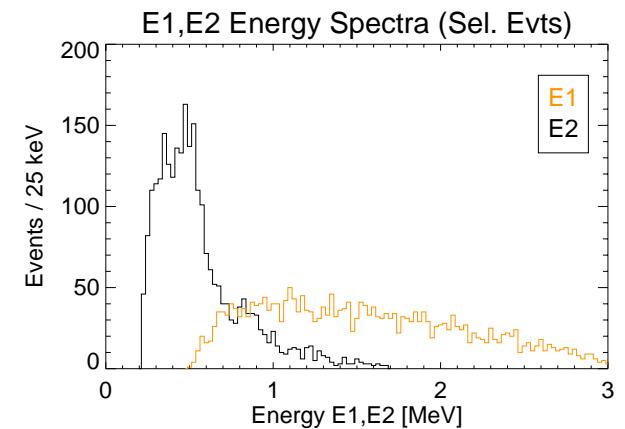
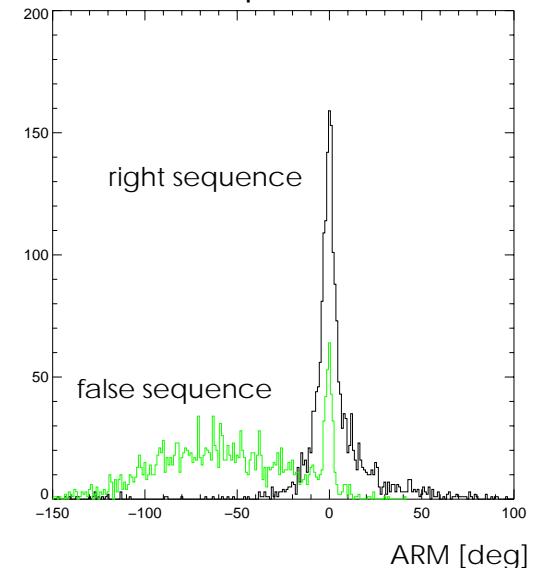
Ordering the sequence:

- Select 2-interactions sequence by amplitude:
Compton effect dominates over photoabsorption above ~ 250 keV.
⇒ Fully contained 2-step events with $E > 1$ MeV usually deposit a large energy first. This ordering works well with Y88 data
- Verification with Monte Carlo: At 1.8 MeV, the sequence "large energy deposit → small energy deposit" is correct in 85% of all contained events (including confusion).
- The E1-E2 distribution of in flight 2-step events in 1-3.5 MeV range is very asymmetric, as expected.



MC Simulation:

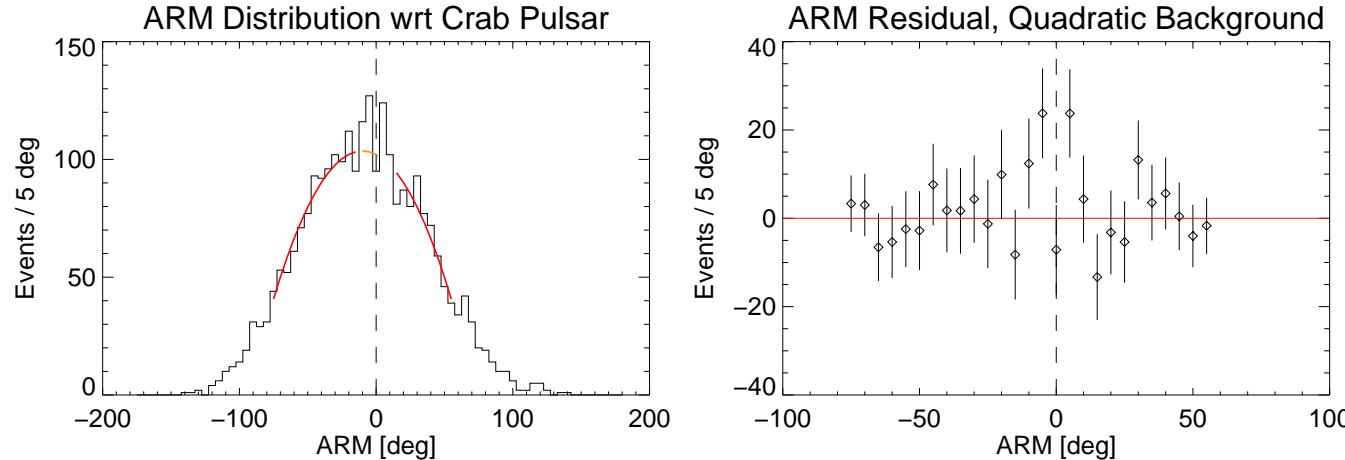
1.836 MeV Photopeak Events



Search for Crab Signal in the 2-Step Events from the 2000 Balloon Flight

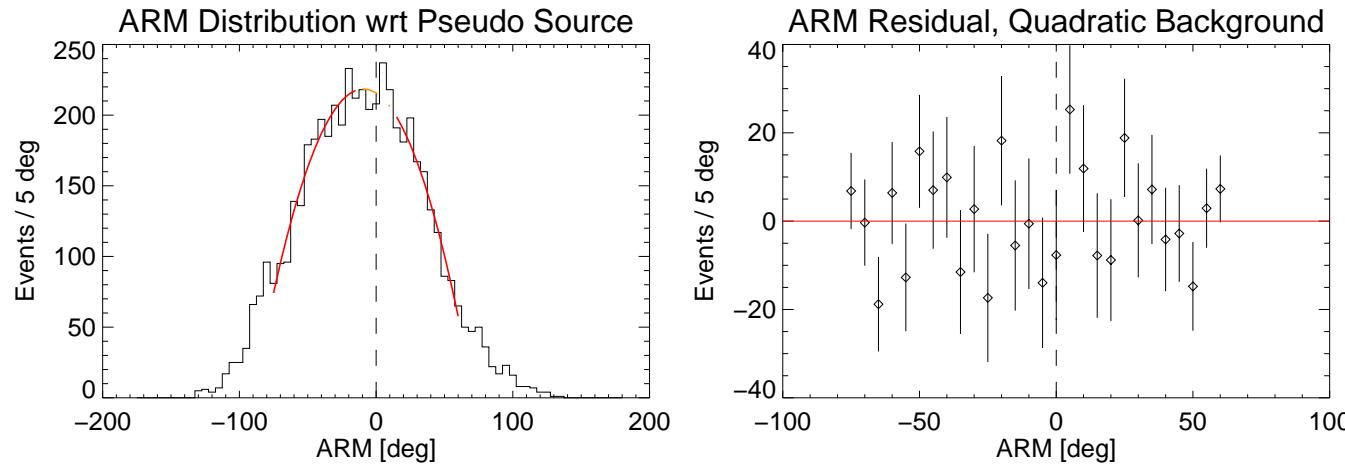
ARM Distribution Crab Observation:

ARM = $\bar{\phi} - \phi_{\text{geo}}$ computed with respect to the Crab position.



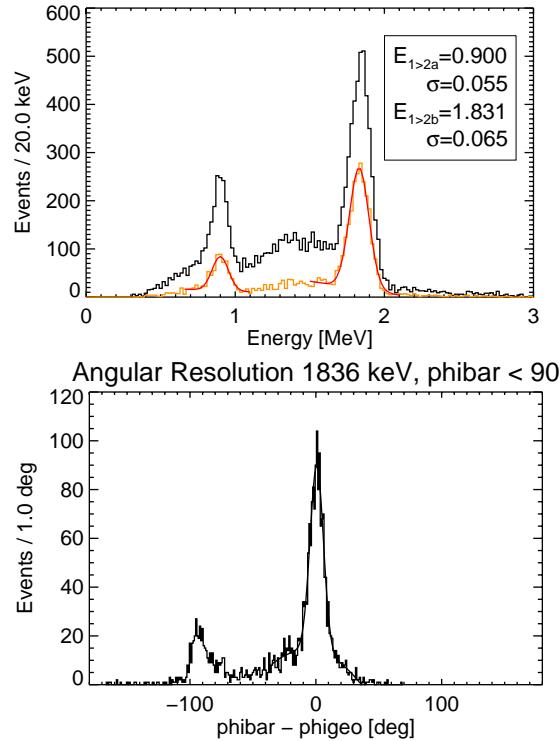
ARM Distribution OFF Observation:

ARM computed with respect to a sky position with similar path through the field of view during the Off observation:

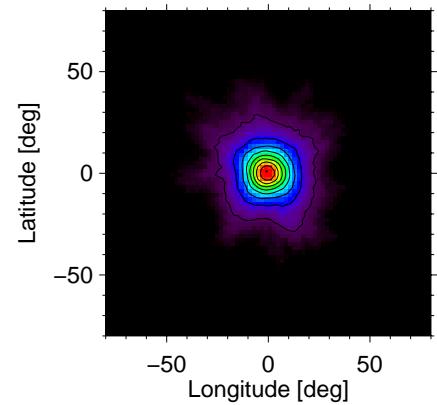


Imaging of an Y-88 Source on Oct. 3, 2000 with LXeGRIT on the Launchpad

2-Step Events: Imaging by "larger step first".

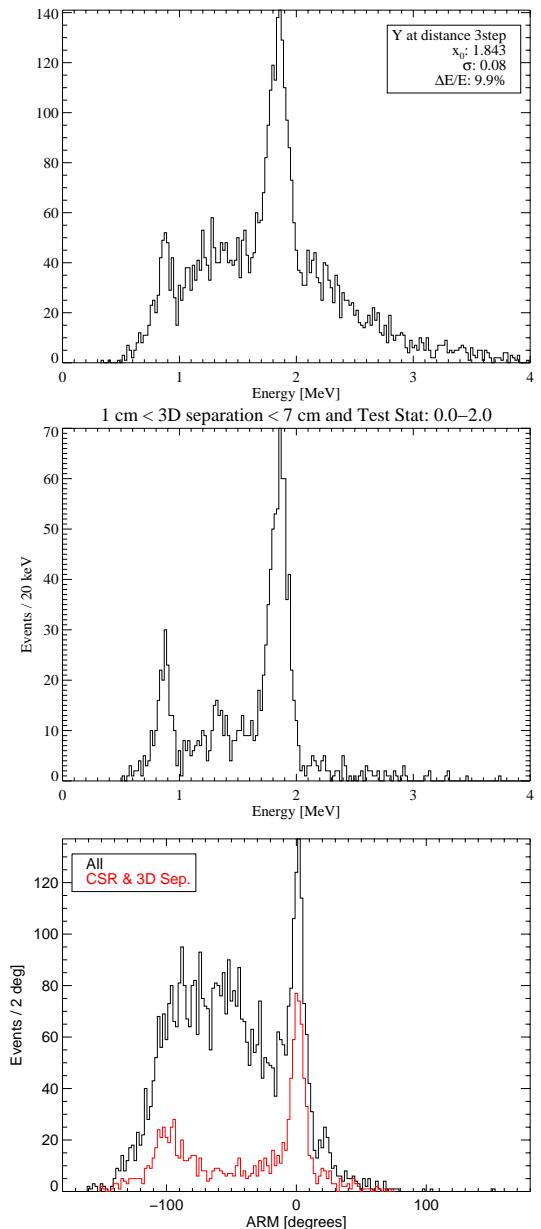
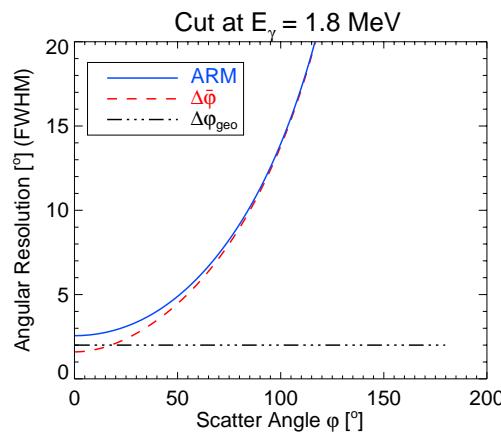


ARM Image:

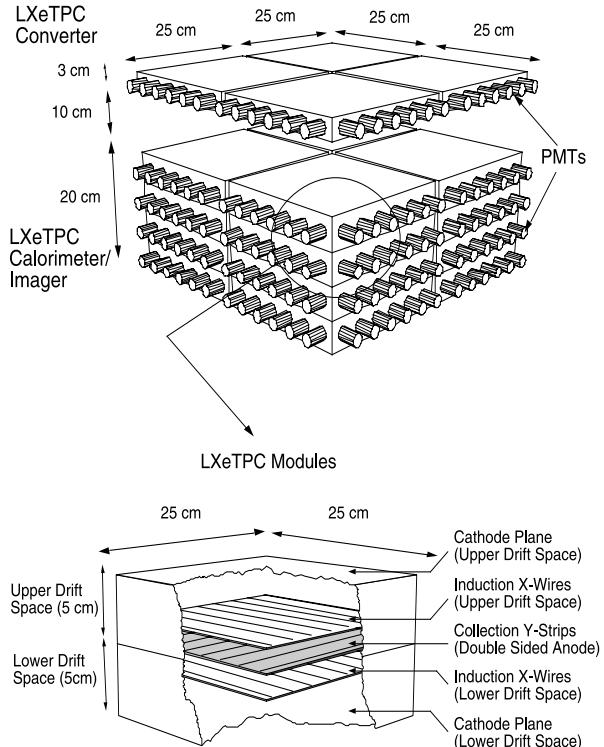


3-Step Events:

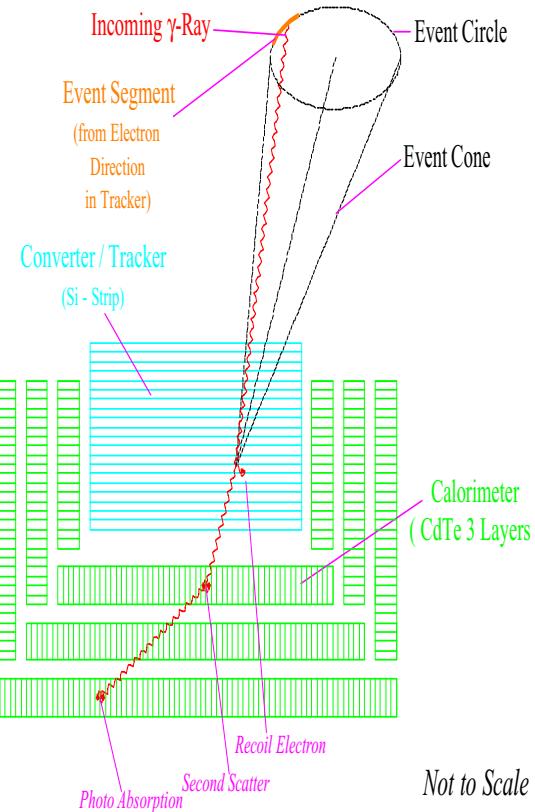
Apply Compton kinematics for sequence reconstruction and background suppression.



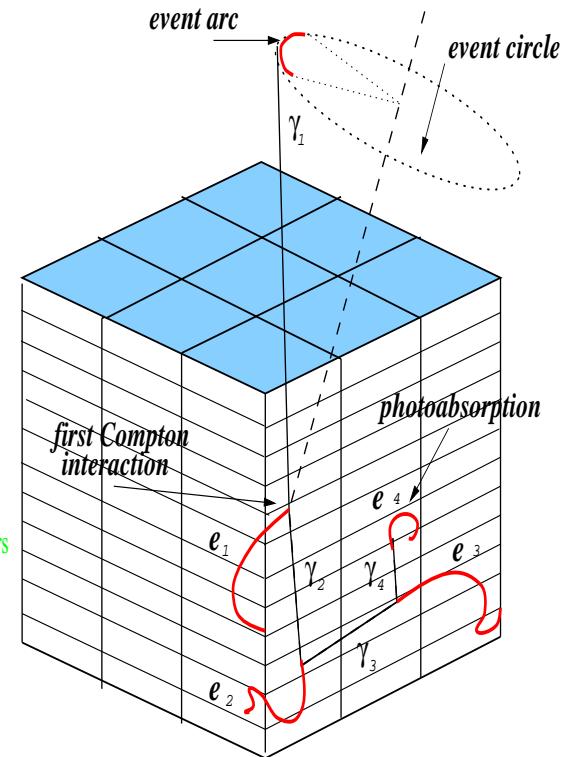
Future Directions for a Compton Telescope at Columbia



LXeTPC Technology Optimized from LXeGRIT Design



Solid-state Technology



Not to Scale Gas TPC Technology