

# Measuring x-ray emission from lightning

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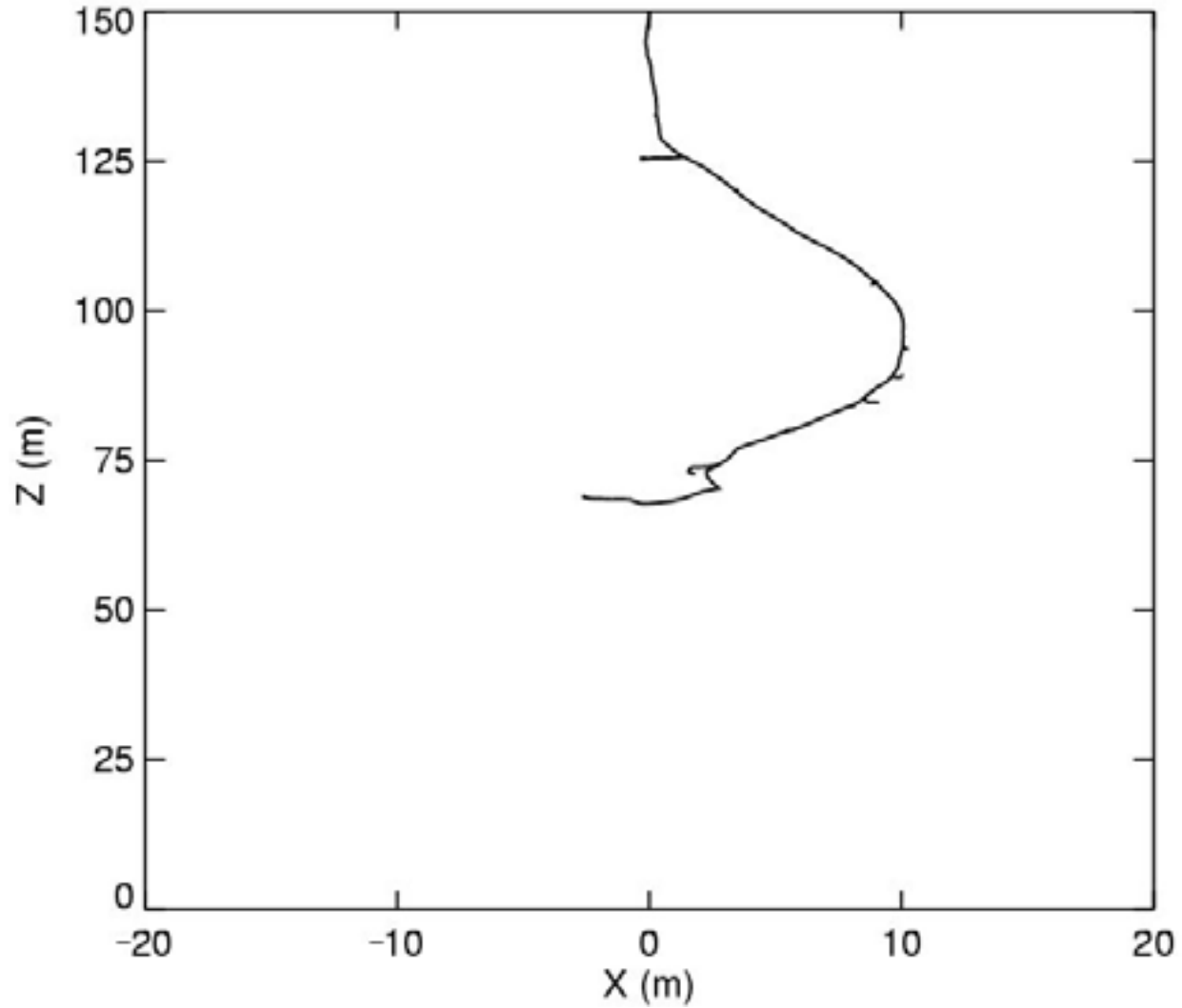
# Despite its familiarity, lightning remains a mystery

- Big question #1: What microphysical processes are responsible for thunderstorm electrification?
- Big question #2: How does lightning get started with the relatively low electric field strengths inside thunderstorms?
- Big question #3: How does lightning travel through tens of kilometers of air?

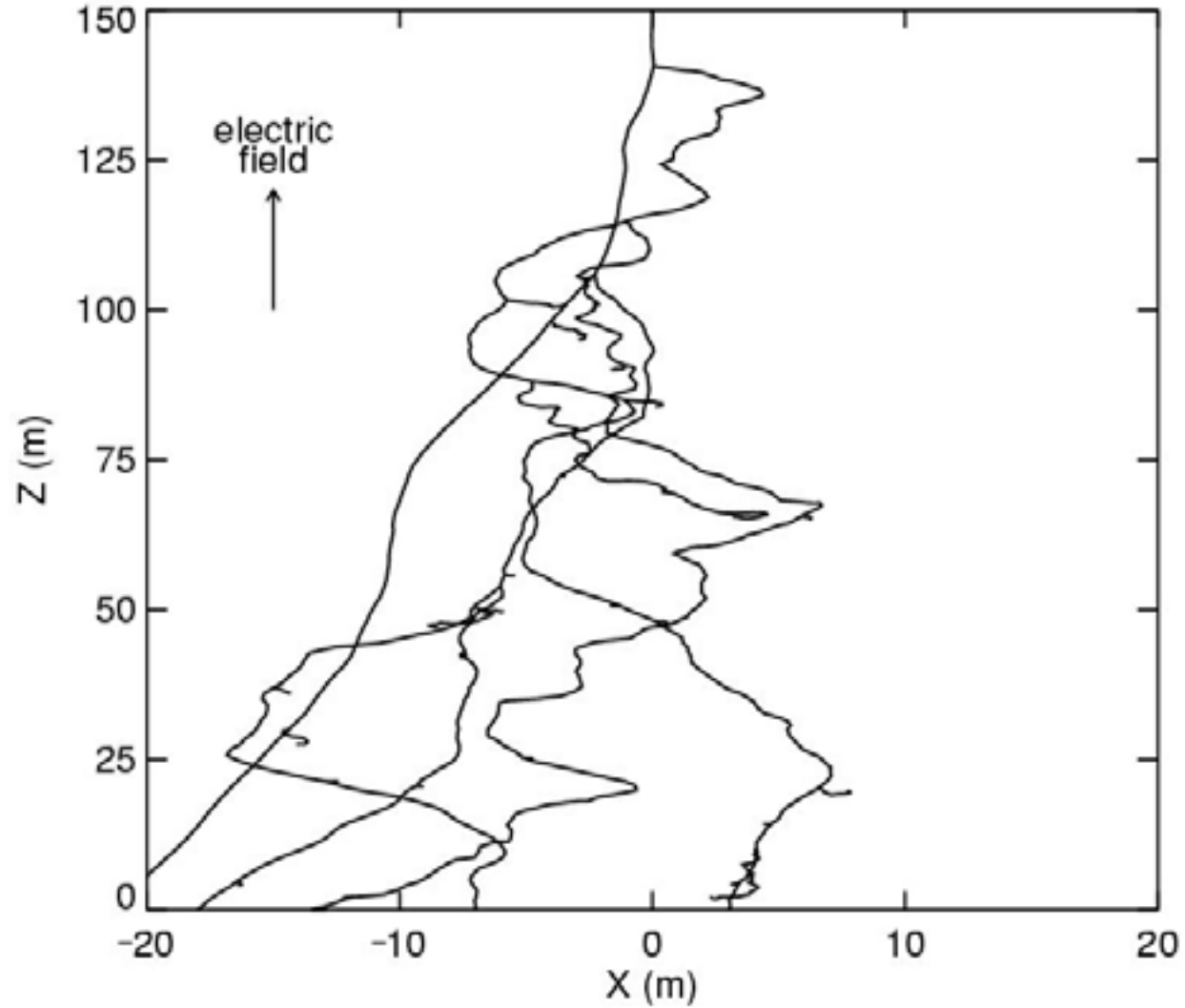
Since we are still struggling to understand how lightning works  
250 years after Franklin's kite experiment, perhaps we are  
missing something important....

# Runaway Electrons

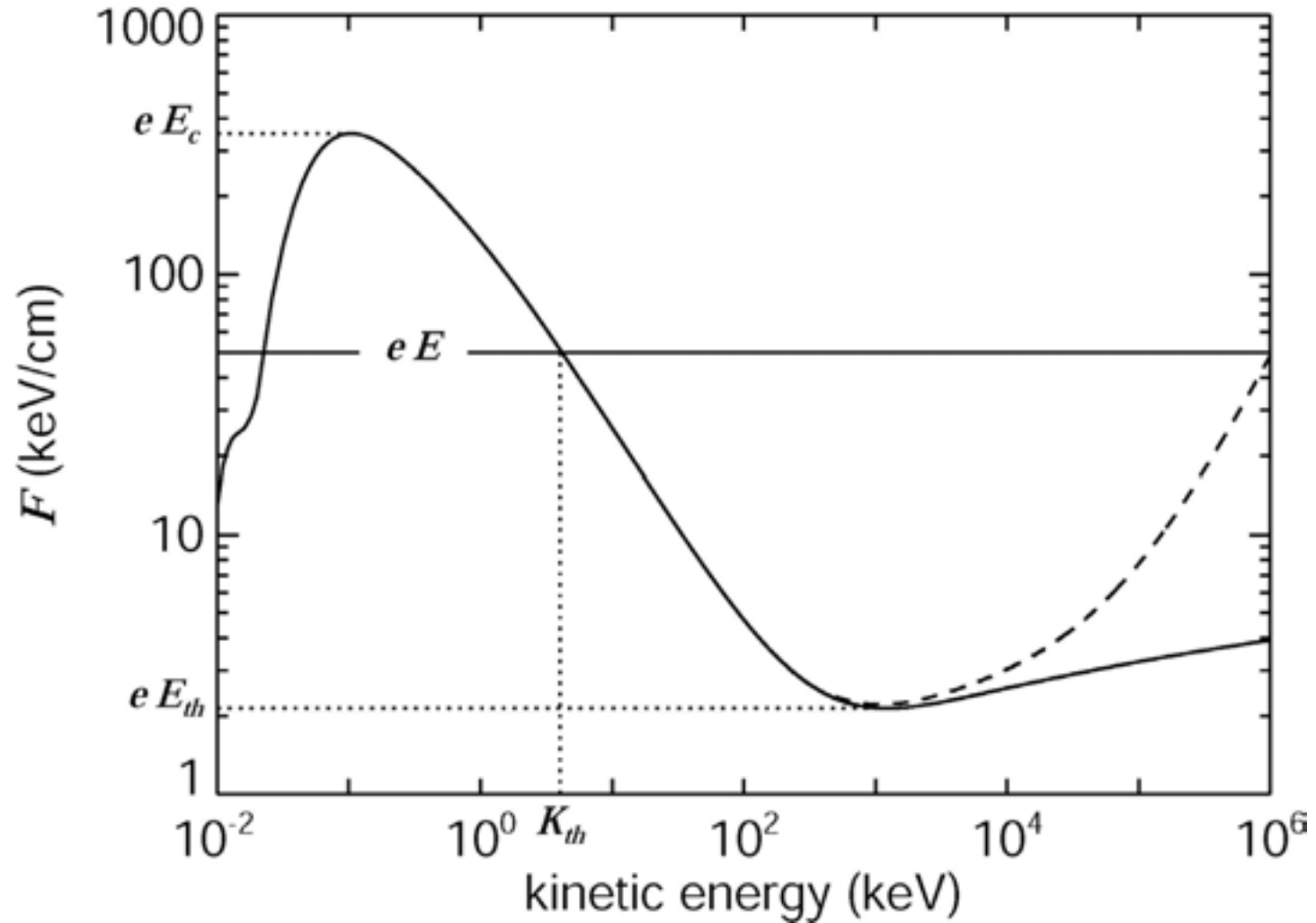
25 MeV electron moving through air at 1 atm



25 MeV electron moving through air at 1 atm  
in a 3 kV/cm electric field

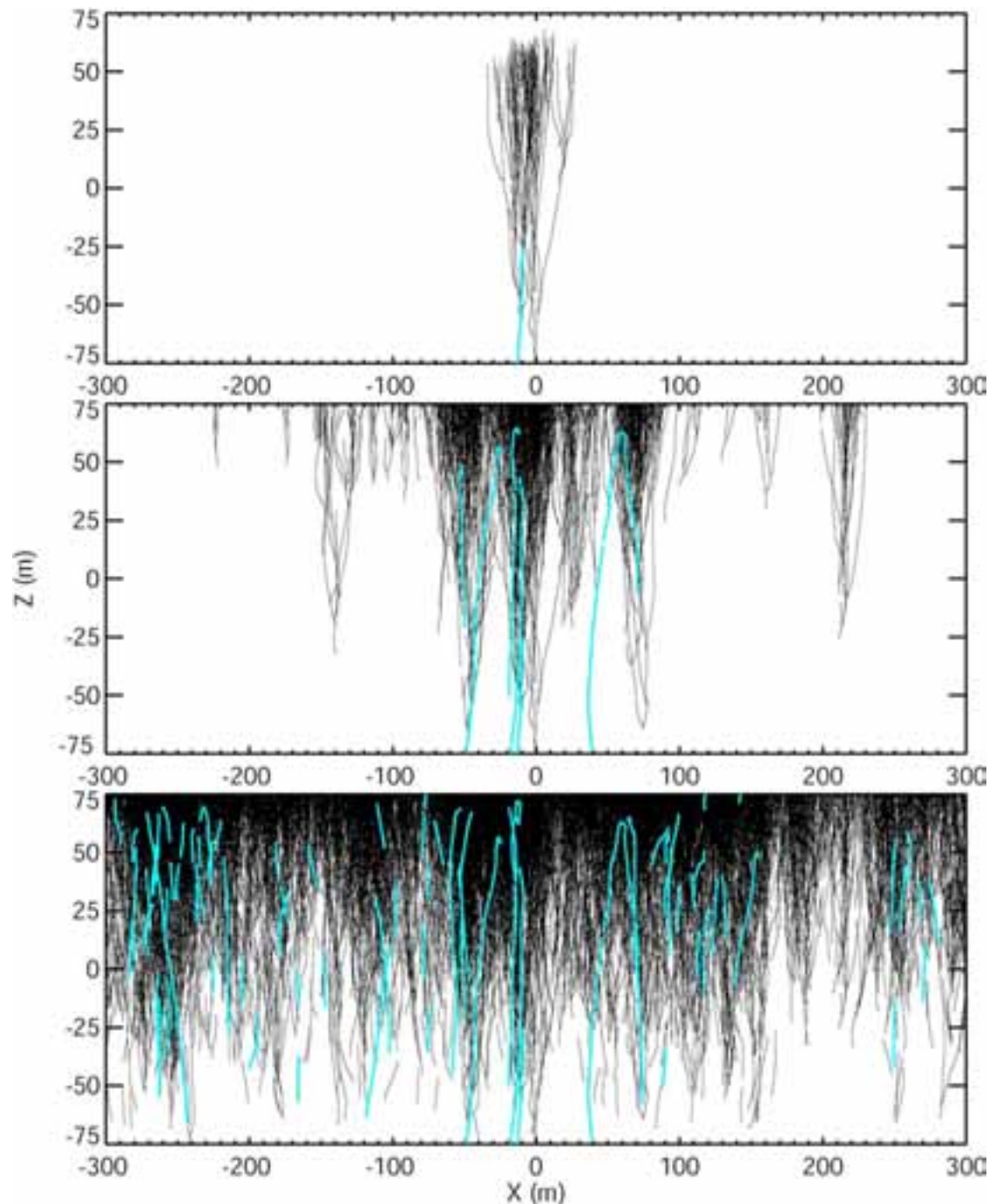


# Energy loss and gain experienced by an electron in air



## Relativistic Breakdown due to x-ray and positron feedback.

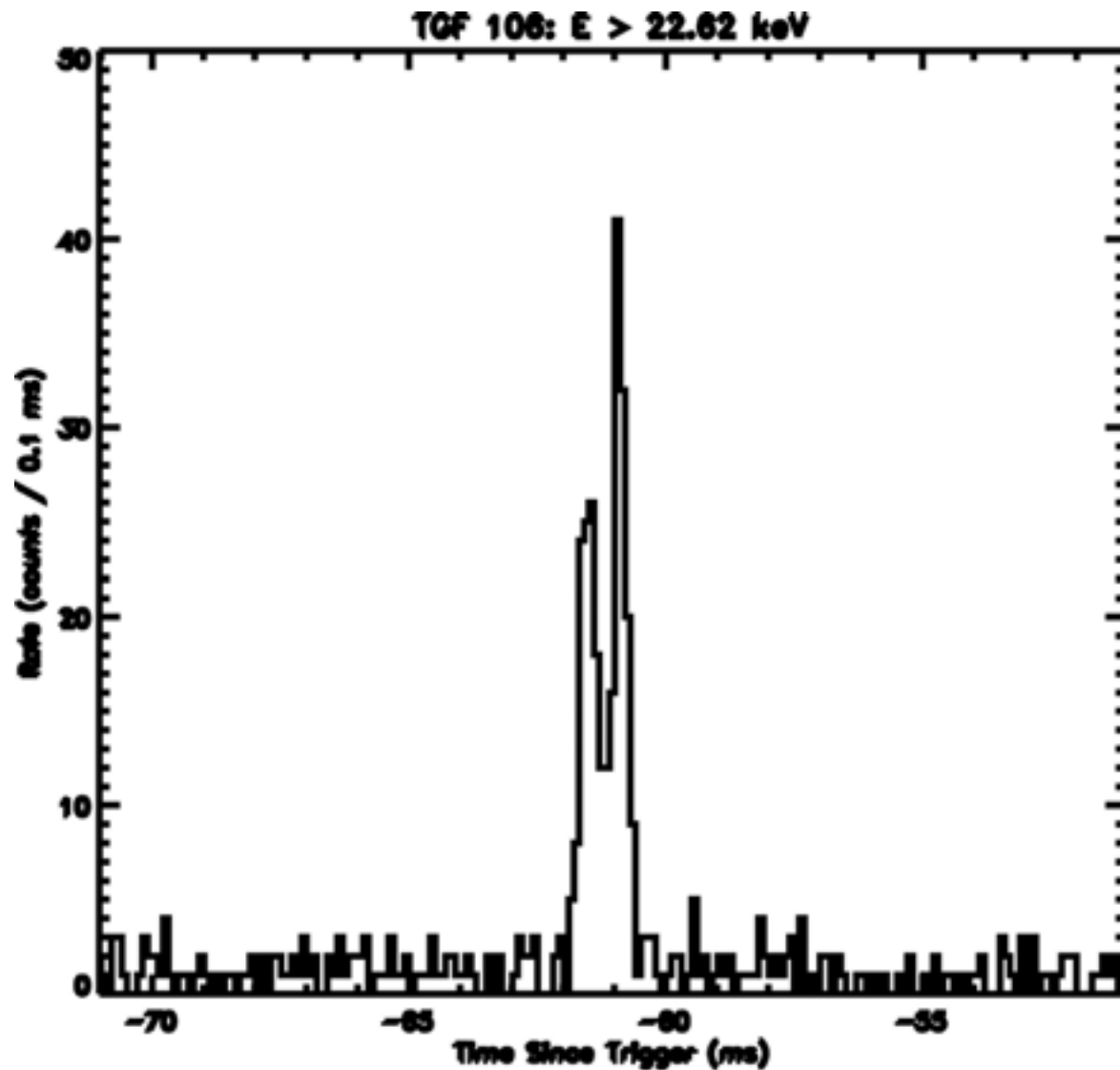
The central avalanche is due to the injection of a single, 1 MeV seed electron. All the other avalanches are produced by x-ray and positron feedback. The top panel is for times,  $t < 0.5 \mu\text{s}$ . The middle panel is for  $t < 2 \mu\text{s}$ , and the bottom panel is for  $t < 10 \mu\text{s}$ .



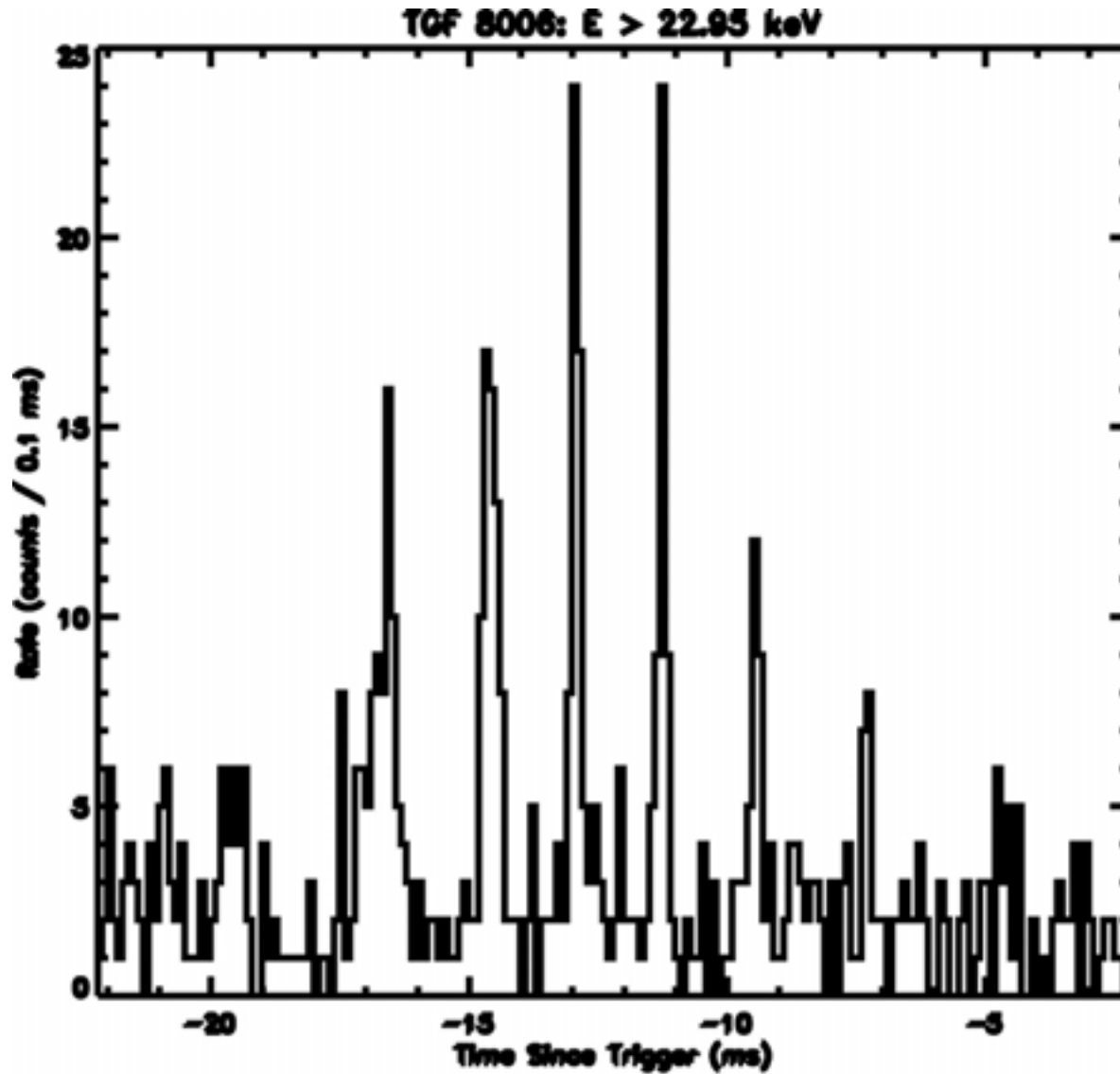


# Gamma-ray bursts seen from space

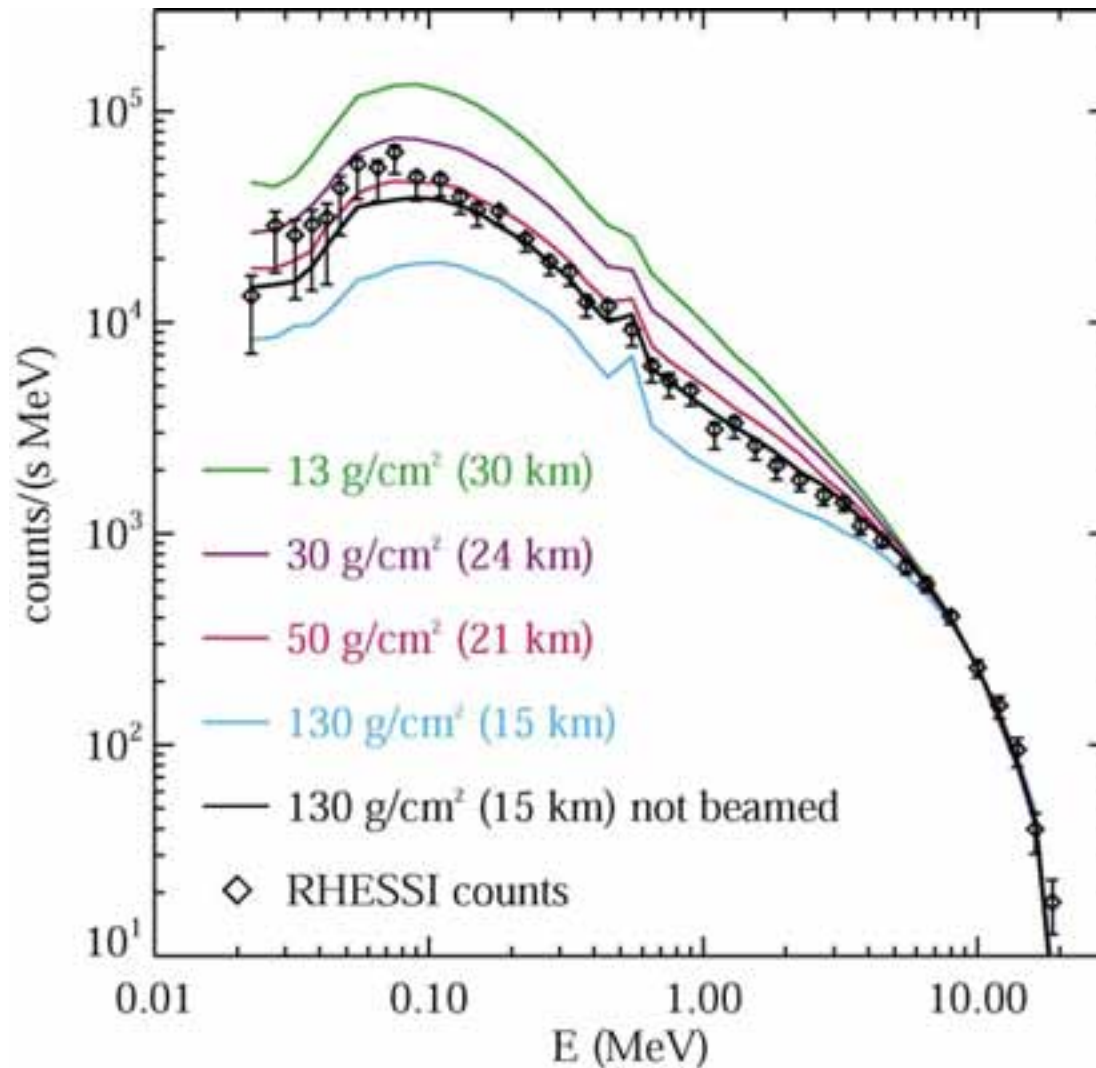
## BATSE Terrestrial Gamma-ray Flash (TGF)



# BATSE Terrestrial Gamma-ray Flash (TGF)



# Terrestrial Gamma-Ray Flash (TGF) spectrum and results of Monte Carlo simulation for different source altitudes



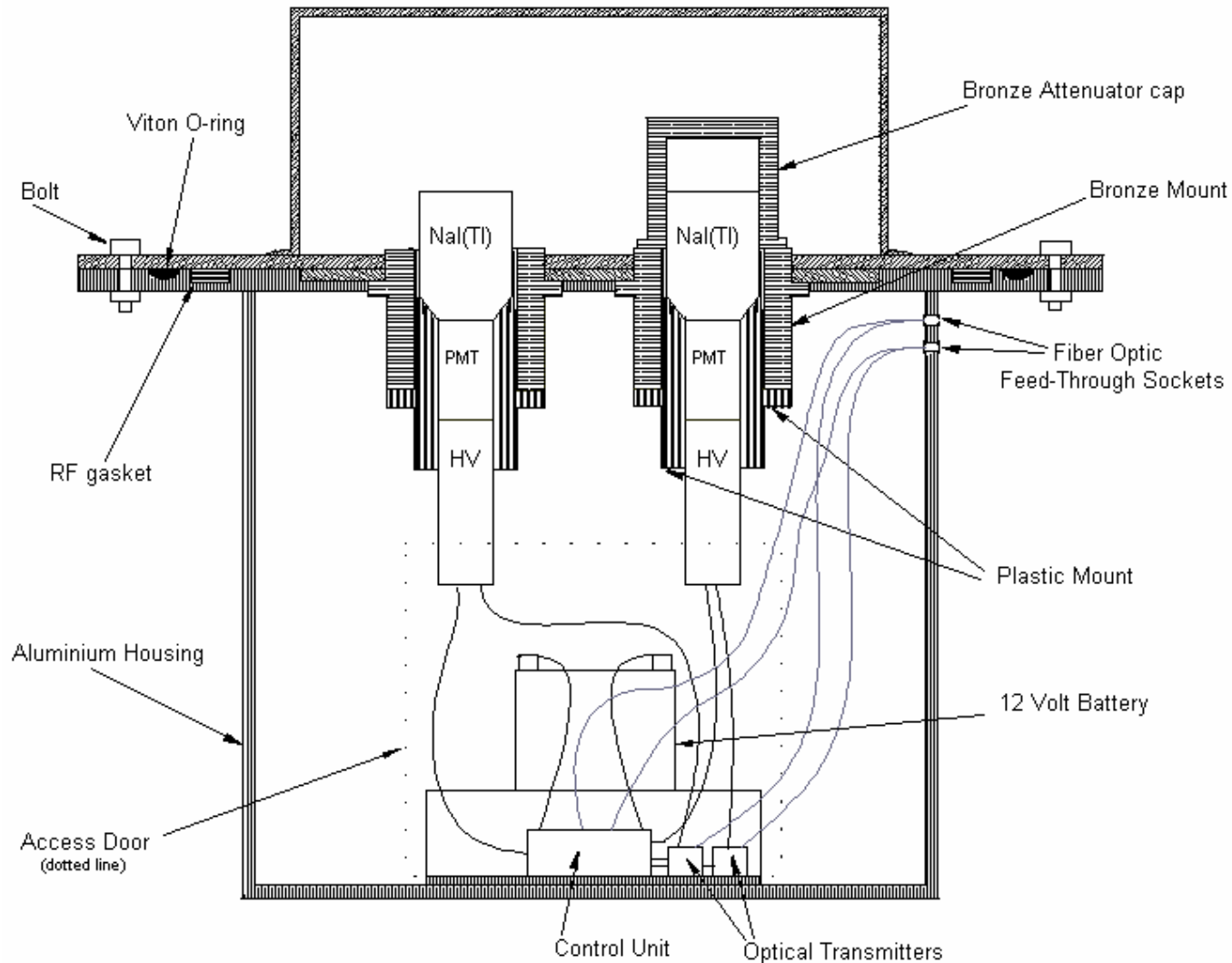
# What about lightning?

Experiment	Location	X-rays in thunderstorms?	X-rays in lightning?
Appleton & Bowen (1933)	ground	No	No
Macky (1934)	balloon	No	No
Clay et al. (1952)	ground	Yes	No
Hill (1963)	300 m tower	No	No
McCarthy & Parks (1985)	aircraft	Yes	No
Fishman <i>et al.</i> (1994)	space	?	No
Moore <i>et al.</i> (2001)	mountain (3288 m)	No	Yes

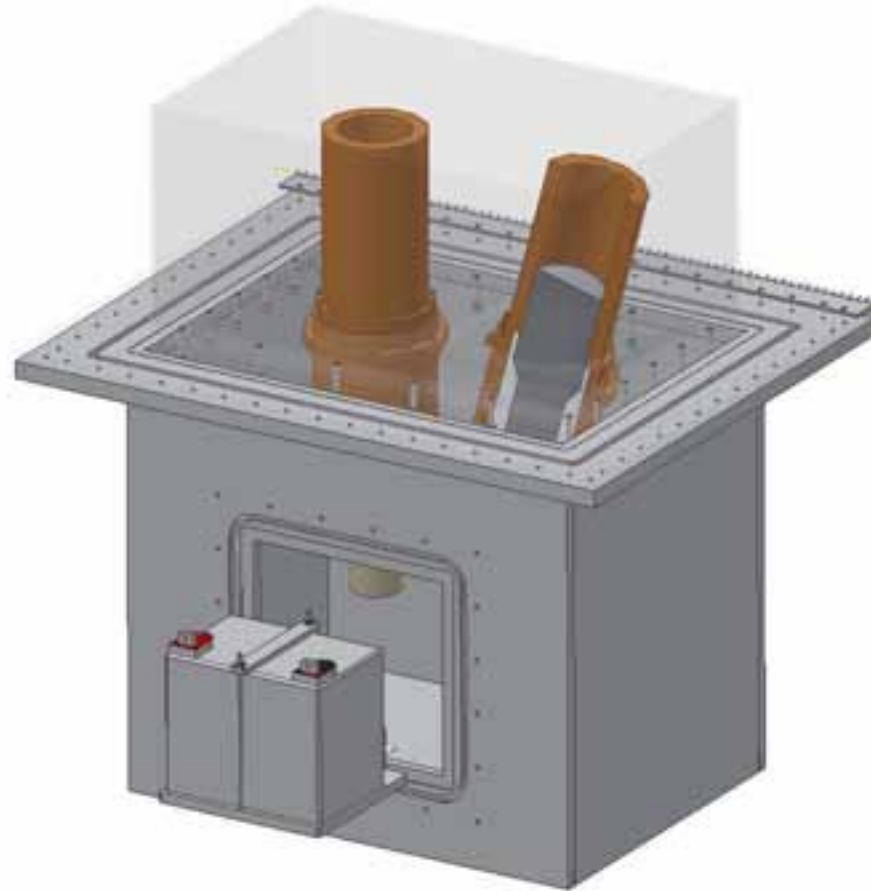
# Rocket-triggered lightning



# Instrument used to measure x-rays from lightning at the UF/Florida Tech International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, FL

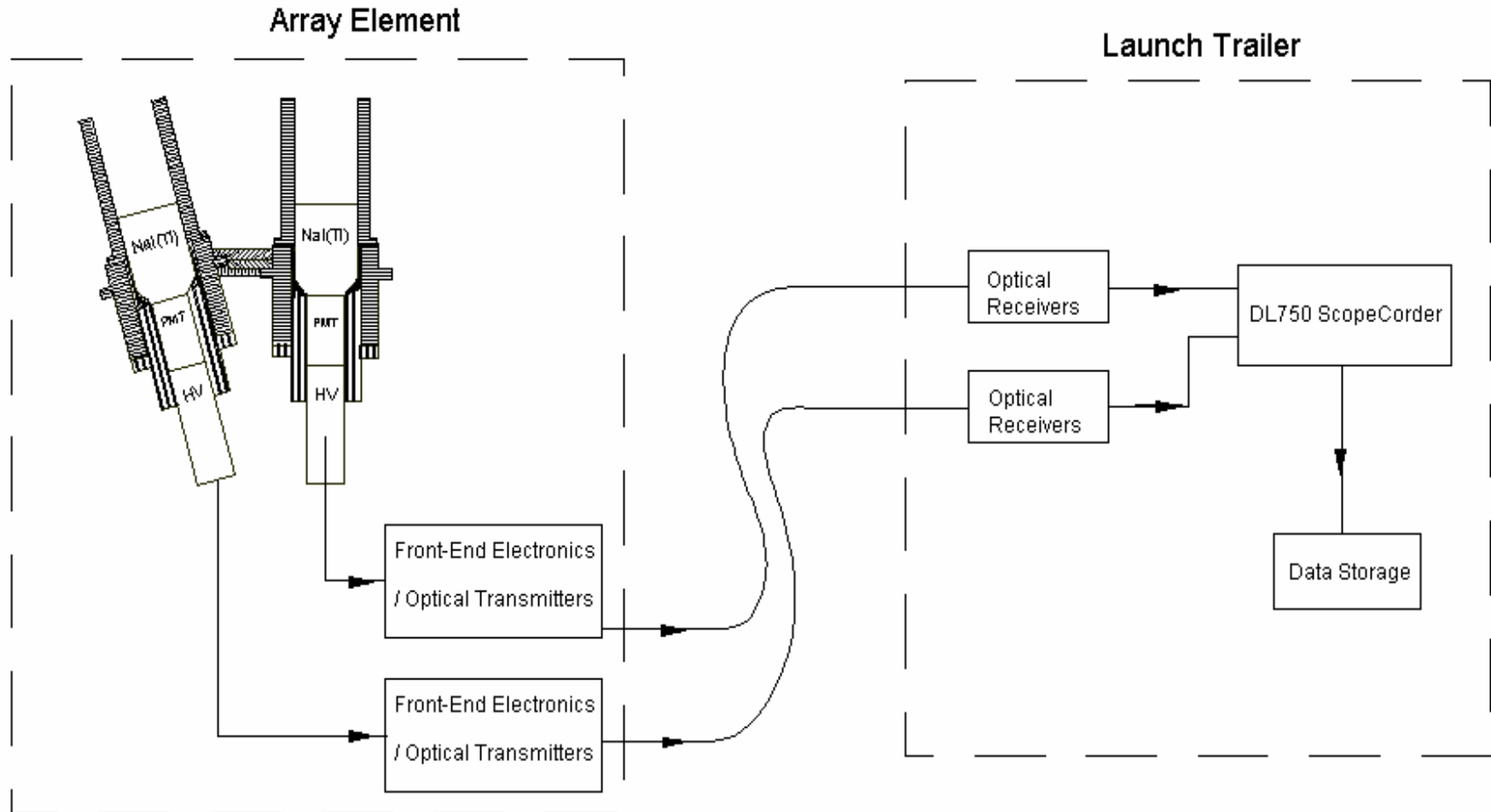


# Instrument configuration with collimators



Data acquisition is triggered using current measurements for triggered lightning and optical measurements for natural lightning.

For each trigger, the signals from the PMT anodes are recorded for 2 seconds (0.5 sec pre-trigger data) with 0.1  $\mu$ sec resolution.





## An x-ray instrument at the ICLRT



X-ray instruments in front of rocket launch tower  
used to trigger lightning



# Rocket-triggered lightning



# Rocket-triggered lightning



PM 3:06  
JUL. 13 2003

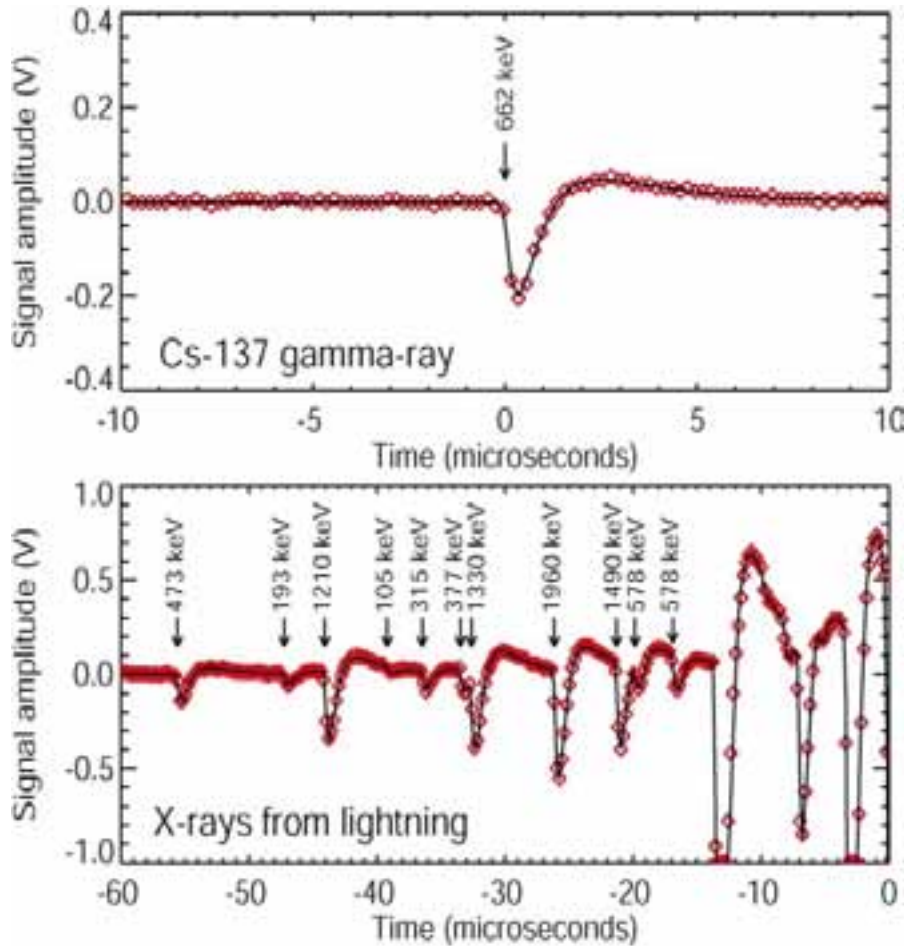
# Rocket-triggered lightning



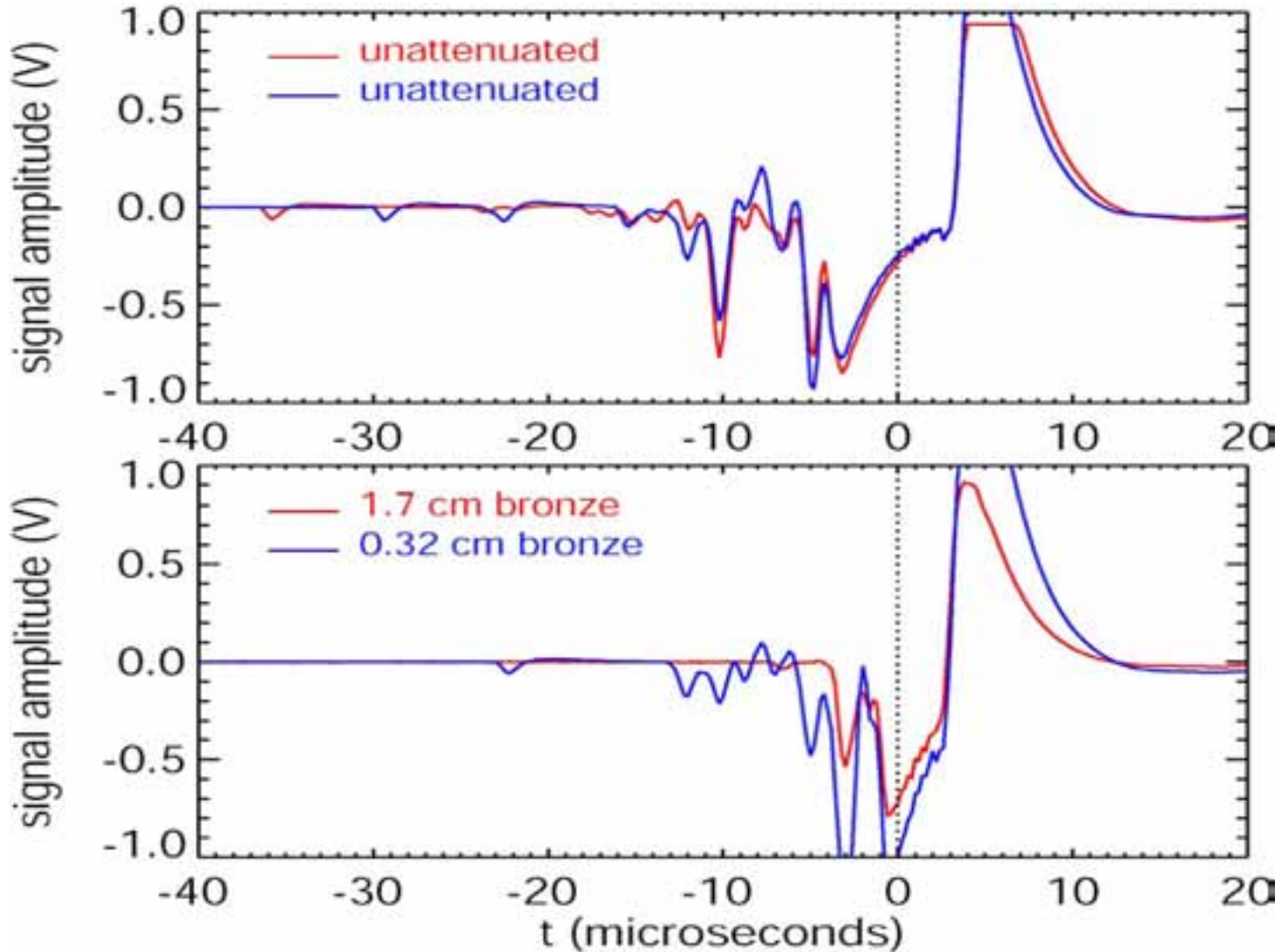
# Triggering lightning Method 2



# X-rays from rocket-triggered lightning dart leaders

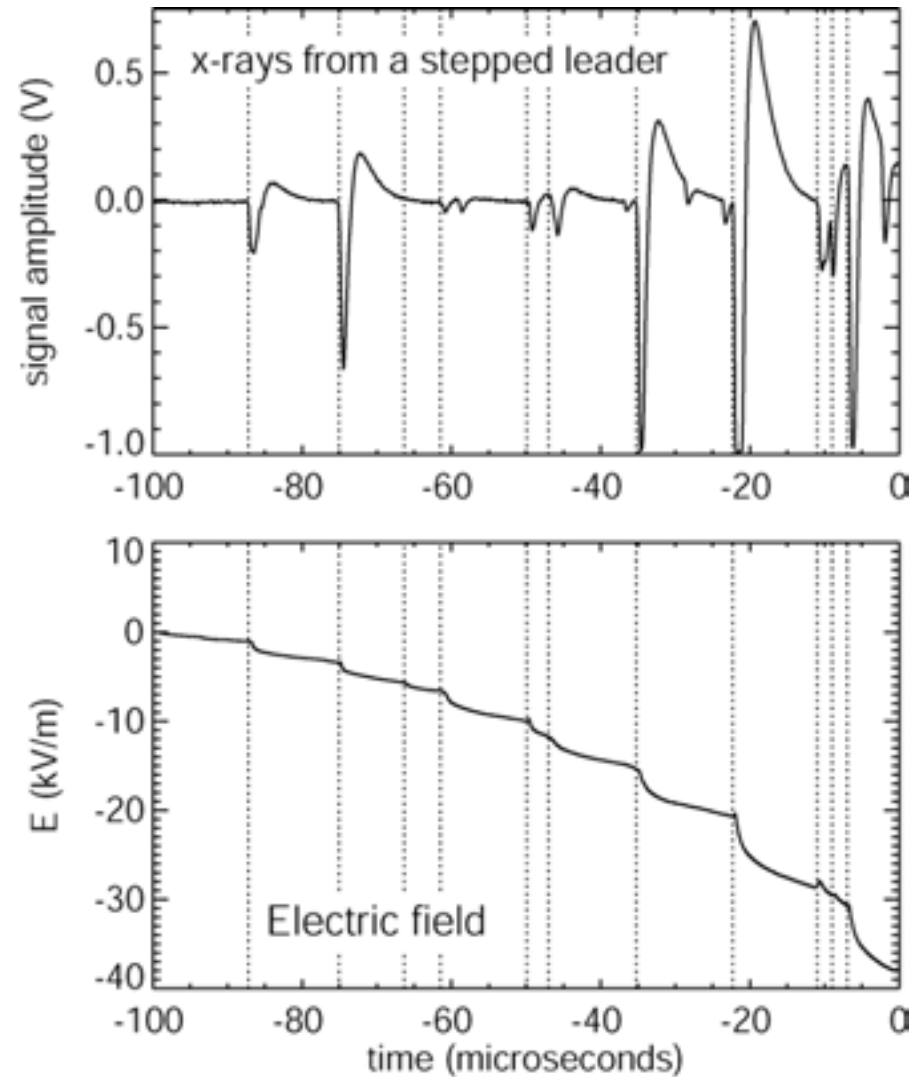


# Energy of x-rays from triggered lightning





# X-rays from natural cloud-to-ground lightning





# Thunderstorm Energetic Radiation Array (TERA)

- With funding from a NSF/MRI grant, we are currently constructing 32 new x-ray instruments, each containing two 3” NaI(Tl)/PMT detectors, covering 1 square km at the ICLRT.
- For the summer of 2006 we had the first twenty elements in place plus four old instruments. The remainder of the array will be added over the next year.
- At the TERA stations we also make electric and magnetic field, fast  $dE/dt$  and optical measurements. In addition, will have current measurements for triggered lightning.
- TERA will make detailed measurements of x-ray emission from natural and triggered lightning and thunderstorms.

# TERA at the UF/Florida Tech International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, FL



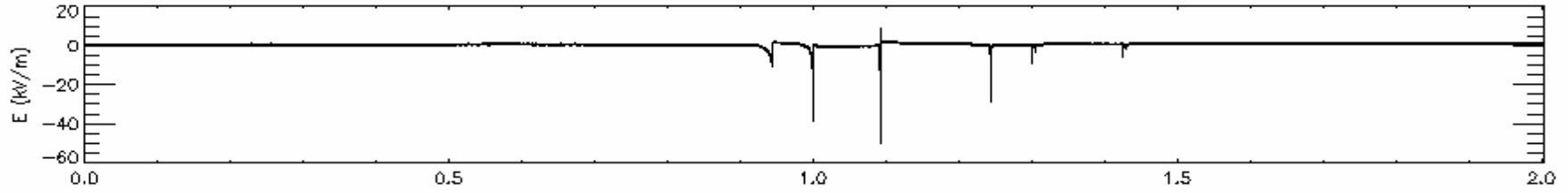
# TERA Instrument Design



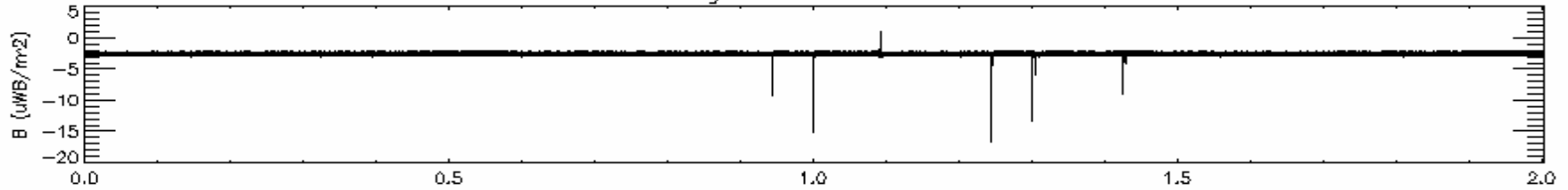
# Natural Lightning Data on 09/28/05

## Negative Cloud-to-Ground

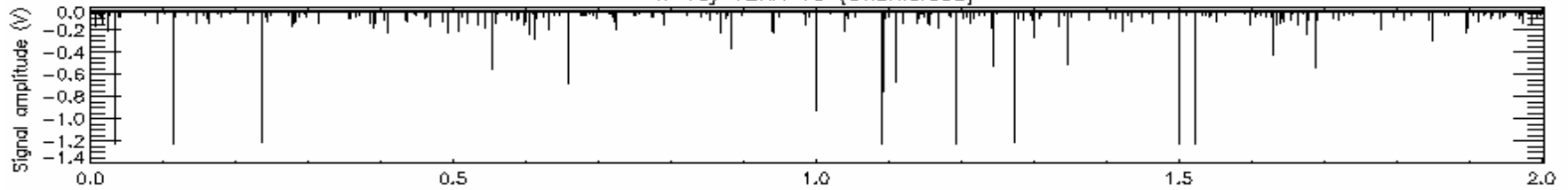
Electric Field Station 9



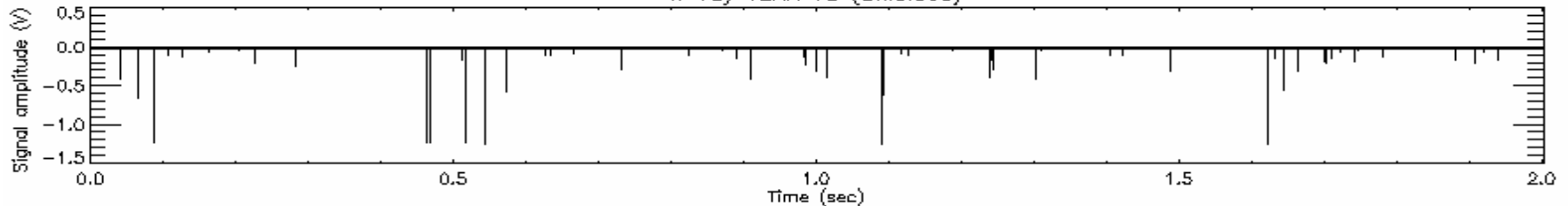
Magnetic Field Station 9



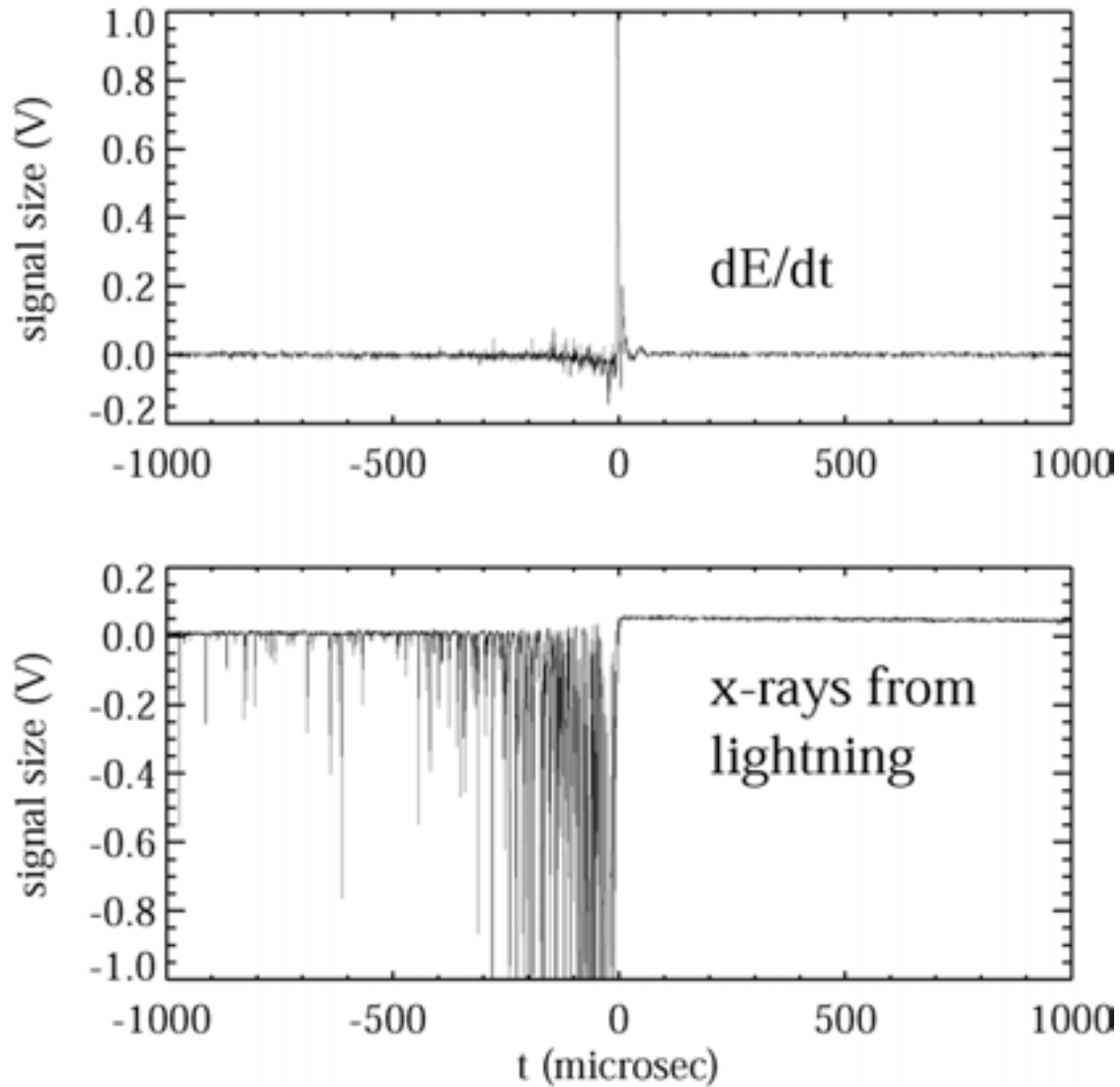
x-ray TERA 10 (Unshielded)



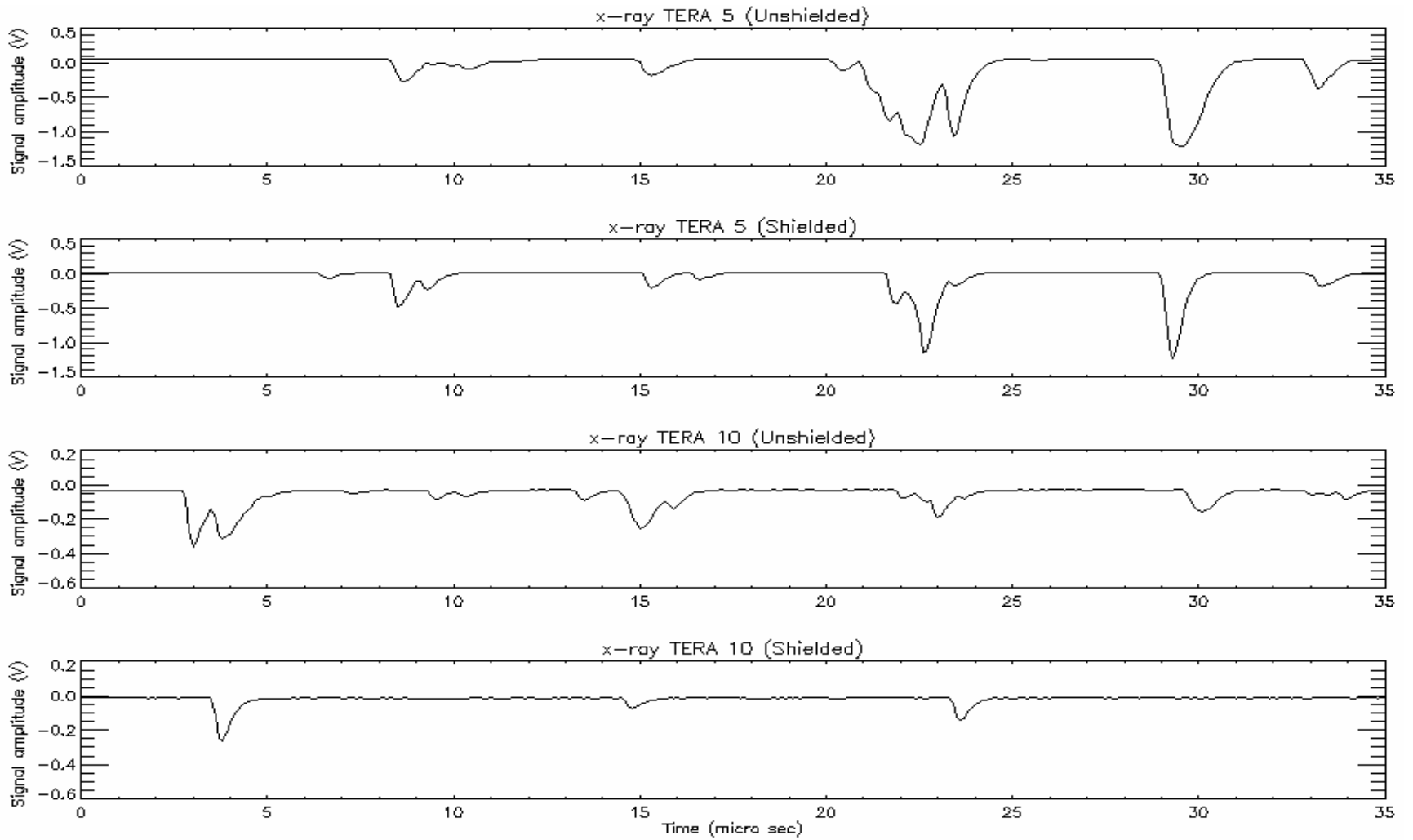
x-ray TERA 10 (Shielded)



# Natural lightning strike as measured by TERA station 1

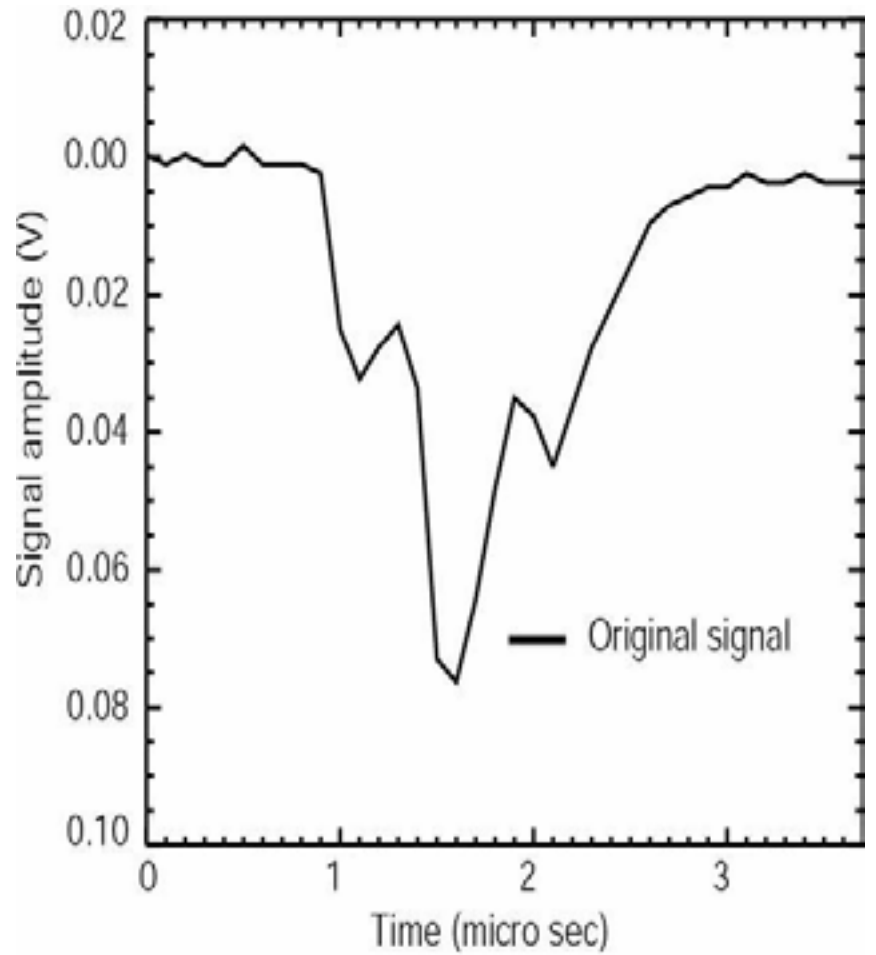
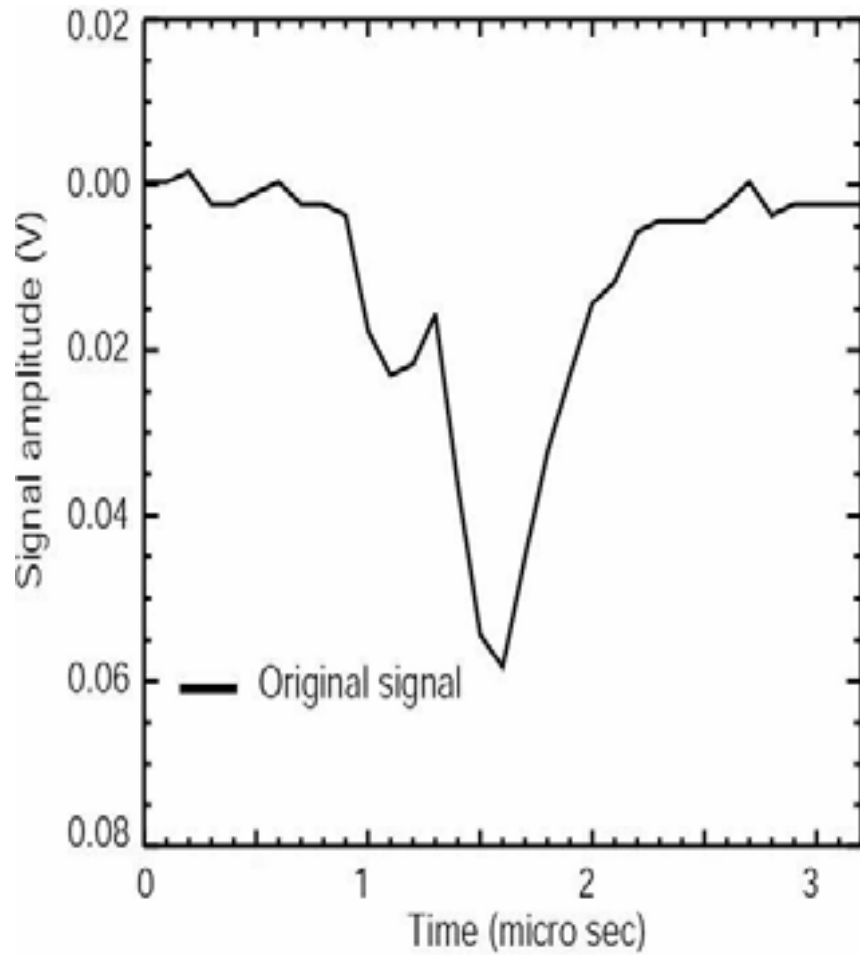


# Close-up view

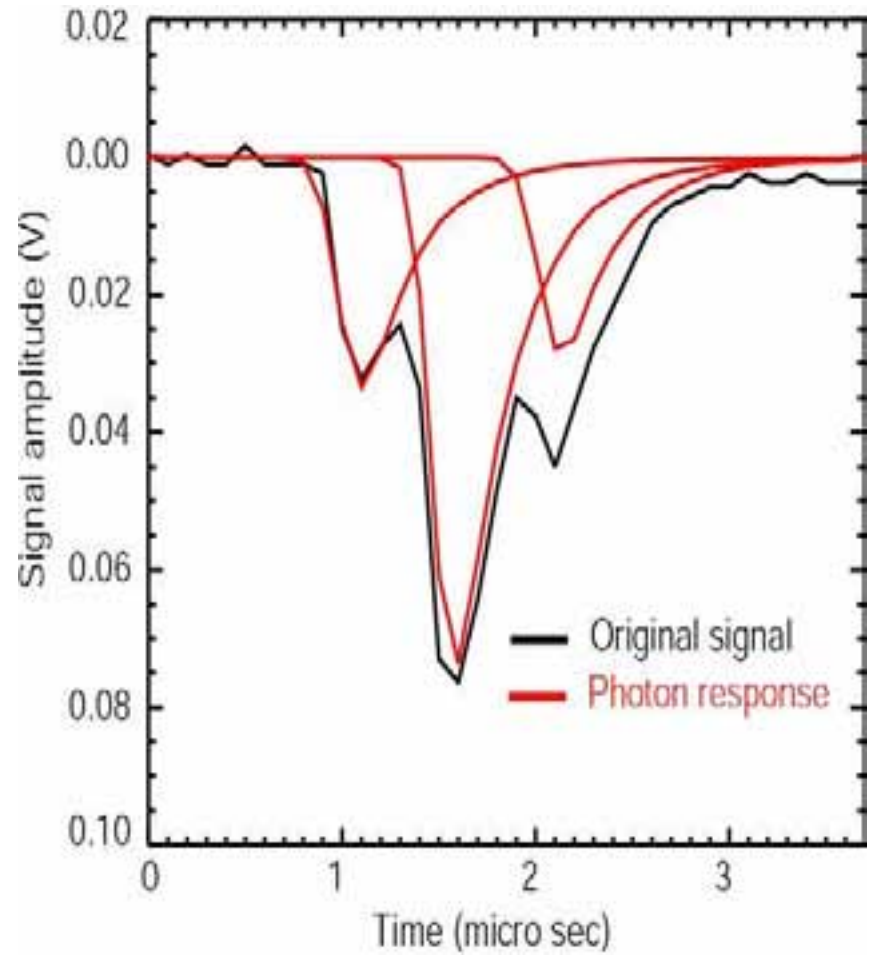
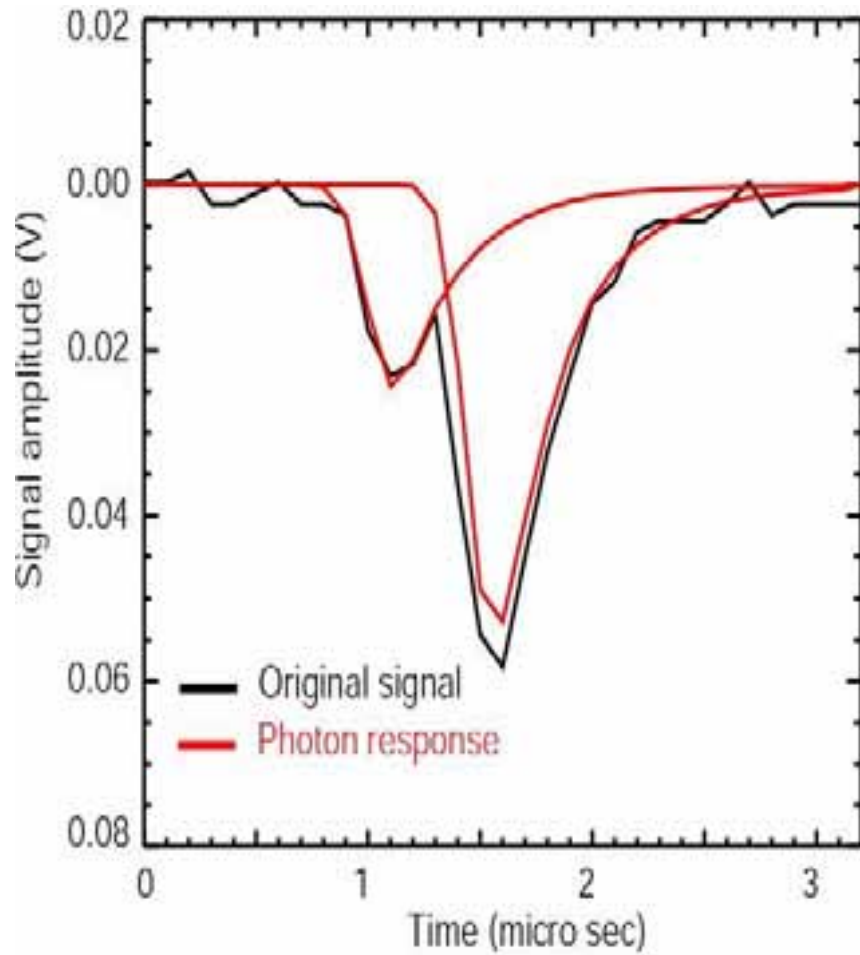




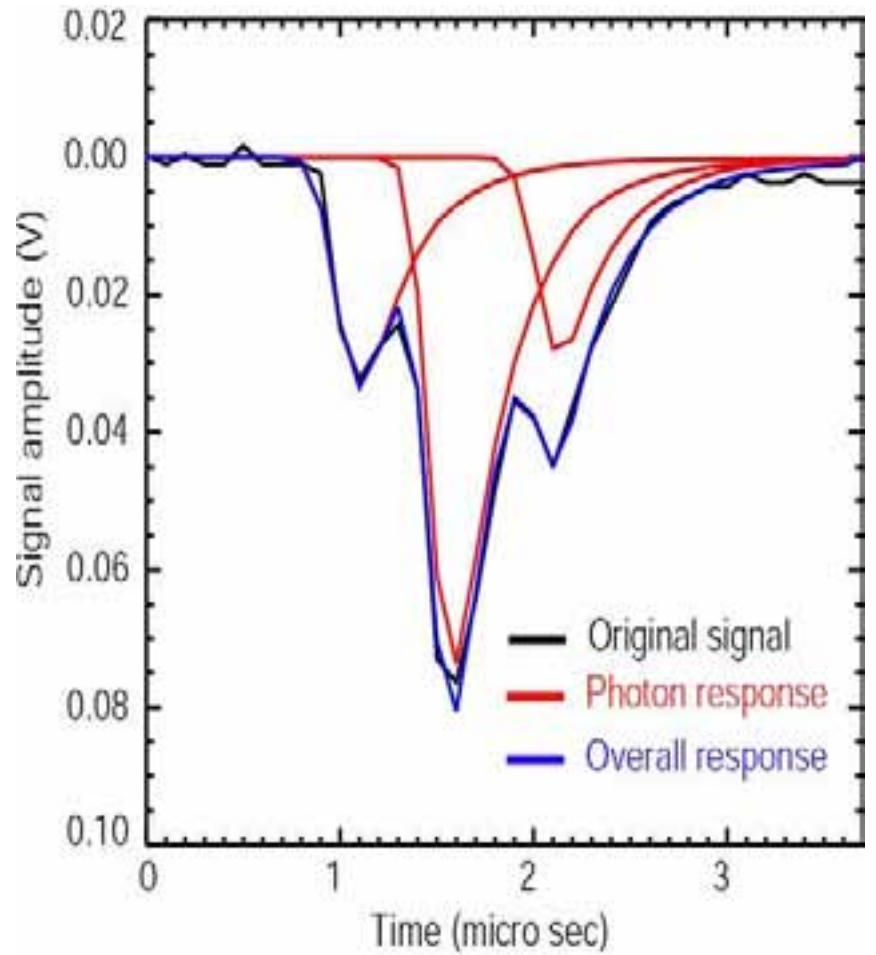
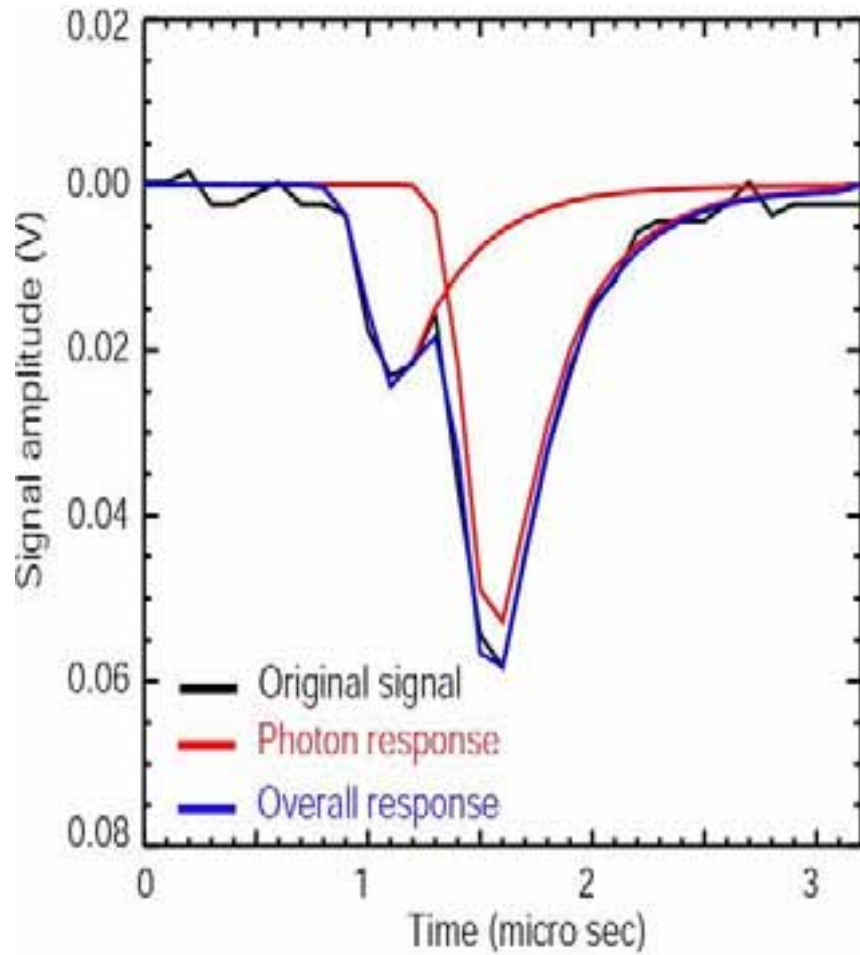
# Response Fit



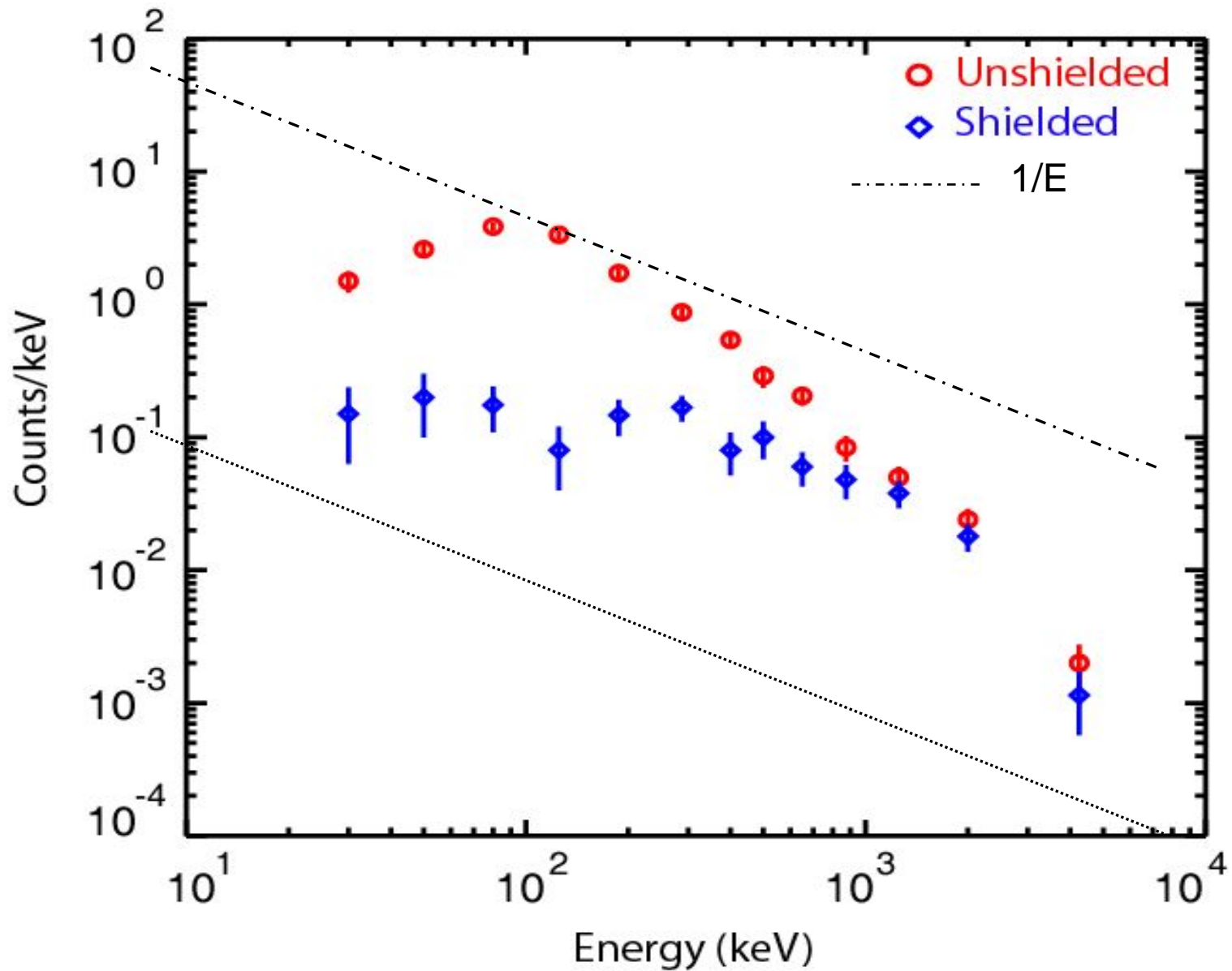
# Response Fit



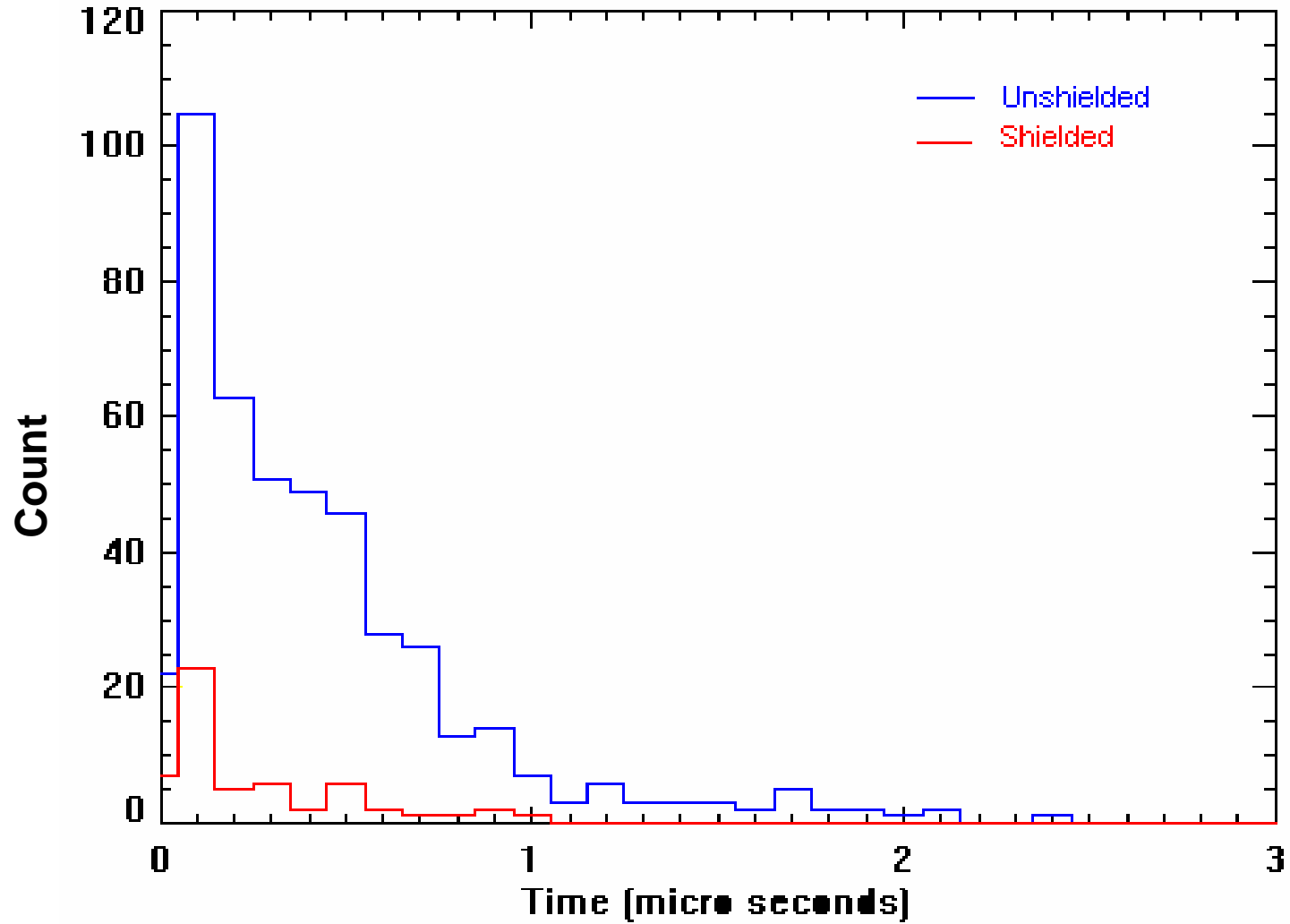
# Response Fit



# First energy spectra of x-rays from lightning



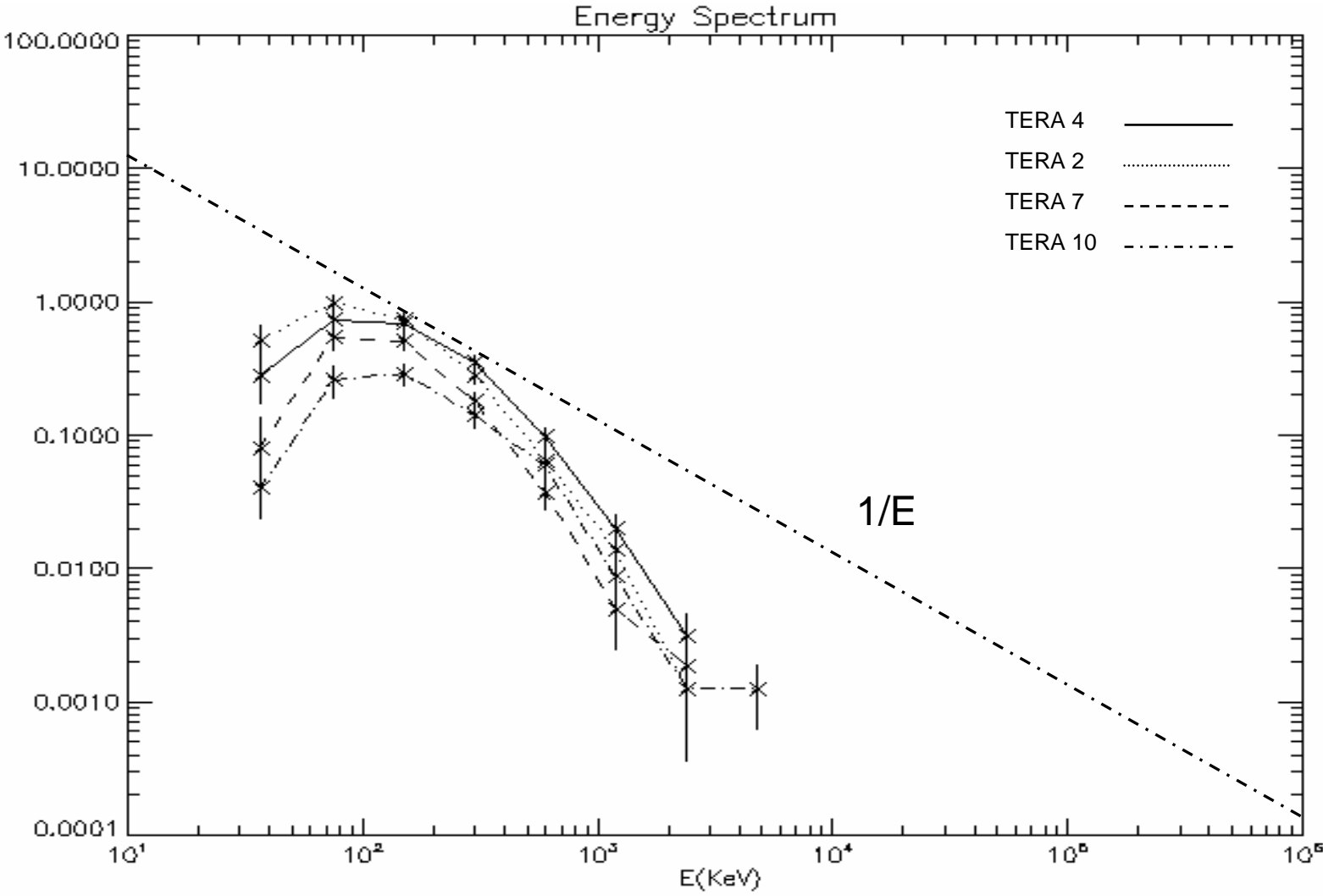
# Pulse Time Distribution



# TERA 2, 4, 7 & 10 for the event 08/28/05



# Individual Energy Spectrum for TERA 2, 4, 7 & 10 for the event 08/28/05



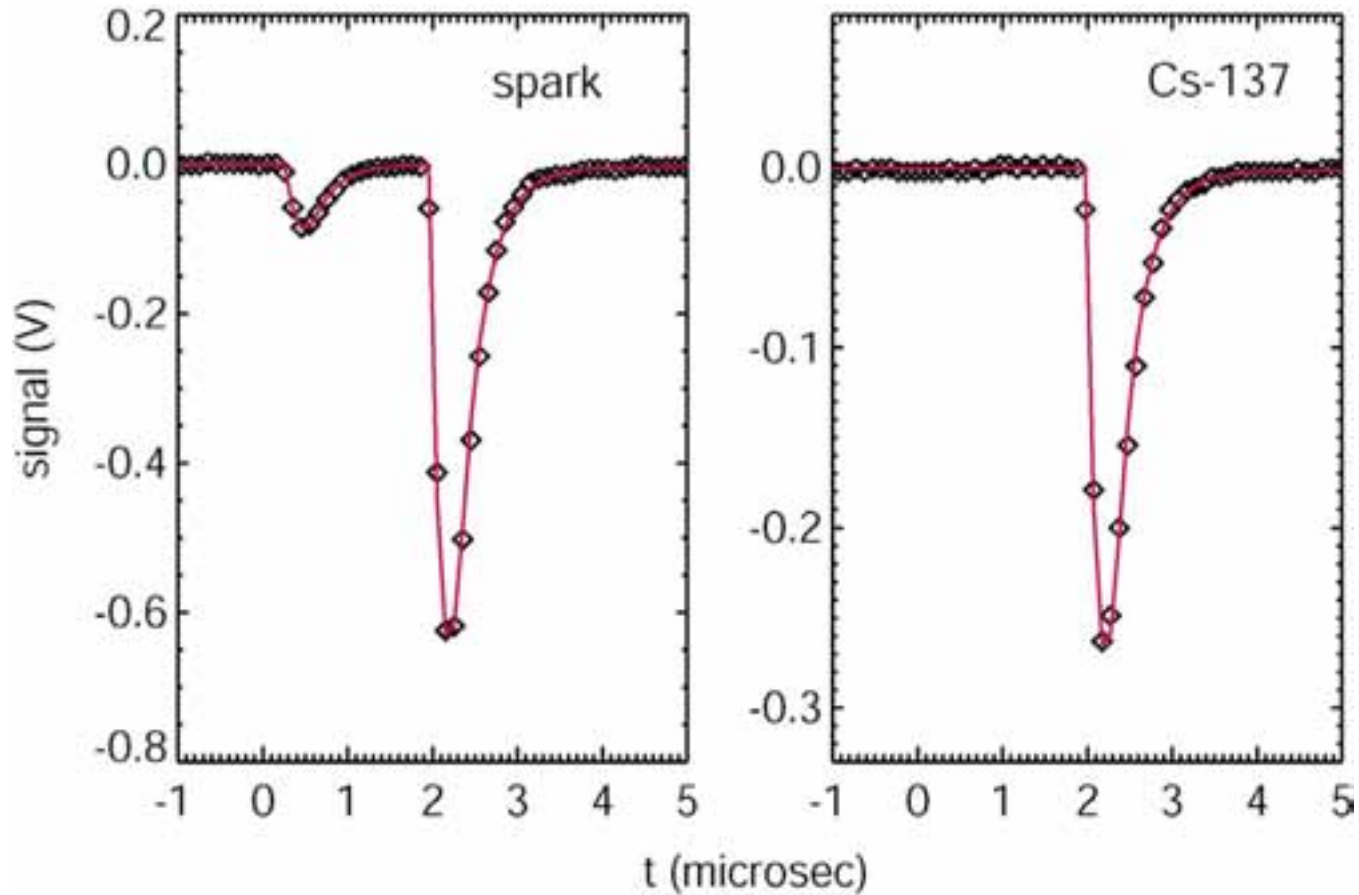
2 m spark produced by a 1.5 MV Marx generator





# X-ray emission from laboratory sparks

X-rays bursts occurred during discharges  
from a 1.5 MV Marx generator



No x-rays were detected from the world's largest air insulated Van de Graaff machine at the Boston Museum of Science



# Conclusions

- Lightning is exotic kind of discharge that involves runaway electrons, which are accelerated to nearly the speed of light and produce large numbers of x-rays.
- Since the standard models of lightning do not include runaway electrons nor do they predict x-ray emission, clearly we need to revisit these models.
- X-rays give us a new tool for studying lightning.
- The Thunderstorm Energetic Radiation Array (TERA) at Camp Blanding, FL is currently giving us a new way of looking at lightning.