Draft PrimEx Note
Dan Dale
July 22, 1999

Using Electron Compton Scattering as a Luminosity Monitor for PrimEx

This note summarizes my thoughts as of now on using electron Compton scattering with the Hall B tagger and the PrimEx Hybrid Calorimeter (HYCAL). As we know, control of the luminosity to about 1% is crucial in performing our precision measurement of the π^o lifetime. The techniques that we have mentioned are:

Total Absorption Counter (TAC)
- Low intensities
- Just photon flux
- Absolute

X-Ray Absorption on Target
- Just target thickness
- Absolute

$\gamma \to e^+e^-$
- Photon flux $\times$ target thickness
- High and low intensity
- Maybe absolute (either calculate or measure cross section)
- Definitely a good relative monitor

$\gamma \to \mu^+\mu^-$
- Photon flux $\times$ target thickness
- Works only at high intensity
- Maybe absolute

Compton Scattering
- Photon flux $\times$ target thickness
- Maybe absolute

Fission
- Works only at high intensity
- Relative photon luminosity
- Online photon beam profile monitor

In practice, we will most likely use a combination of complementary techniques. Nevertheless, the ideal luminosity monitor will:

(1) Give absolute luminosity,

(2) Work at the high photon intensities of the production data taking,

(3) Monitor both photon flux and target thickness,

(4) Be a nondestructive, online luminosity monitor in place during data taking.

The idea behind using electron Compton scattering comes from the fact that it is a calculable, pure QED process. The cross section is given by the Klein-Nishina formula:

$$\frac{d\sigma}{d\Omega} = r_o^2 \frac{1 + cos^2\theta}{2} \frac{1}{1 + \gamma(1 - cos\theta)^2} [1 + \frac{\gamma^2(1 - cos\theta)^2}{(1 + cos^2\theta)(1 + \gamma(1 - cos\theta))}] \tag{1}$$

This formula for the differential cross section is valid only for collisions in which the energy of the recoiling electron is large compared with its binding energy. I would be quite surprised if this approximation breaks down for our high energies and large kinematical acceptances. However, since intra atomic motion effects are known to be non negligible for Møller polarimeters even in the GeV range, this should be checked.

In any case, I looked at three general experimental configurations to measure the Compton rate:

(1) No sweeping magnetic field, electron and photon detected in HYCAL,

(2) Weak magnetic field ($B \sim 1.3 kgauss$), electron and photon detected in HYCAL, electron dispersed across its face in the horizontal plane,

(3) Strong magnetic field ($B \sim 15 kgauss$), photon detected in HYCAL, electron detected in separate scintillators.

The most "Compton-like" background is pair production followed by bremsstrahlung. Any technique used must provide a clean separation between Compton scattering and this background. In all of the techniques discussed, I will make use of the kinematical correlation between the scattered photon and its energy shown in figure 1.

In the simulations that follow, I have taken the following detector resolutions for the HYCAL:

$PbWO_4$:

$$\frac{\sigma(E)}{E} = \frac{3\%}{\sqrt(E)} \tag{2}$$

$$\sigma(r) = \frac{2.5mm}{\sqrt(E)} \tag{3}$$

and

Lead Glass:

$$\frac{\sigma(E)}{E} = \frac{6\%}{\sqrt(E)} \tag{4}$$

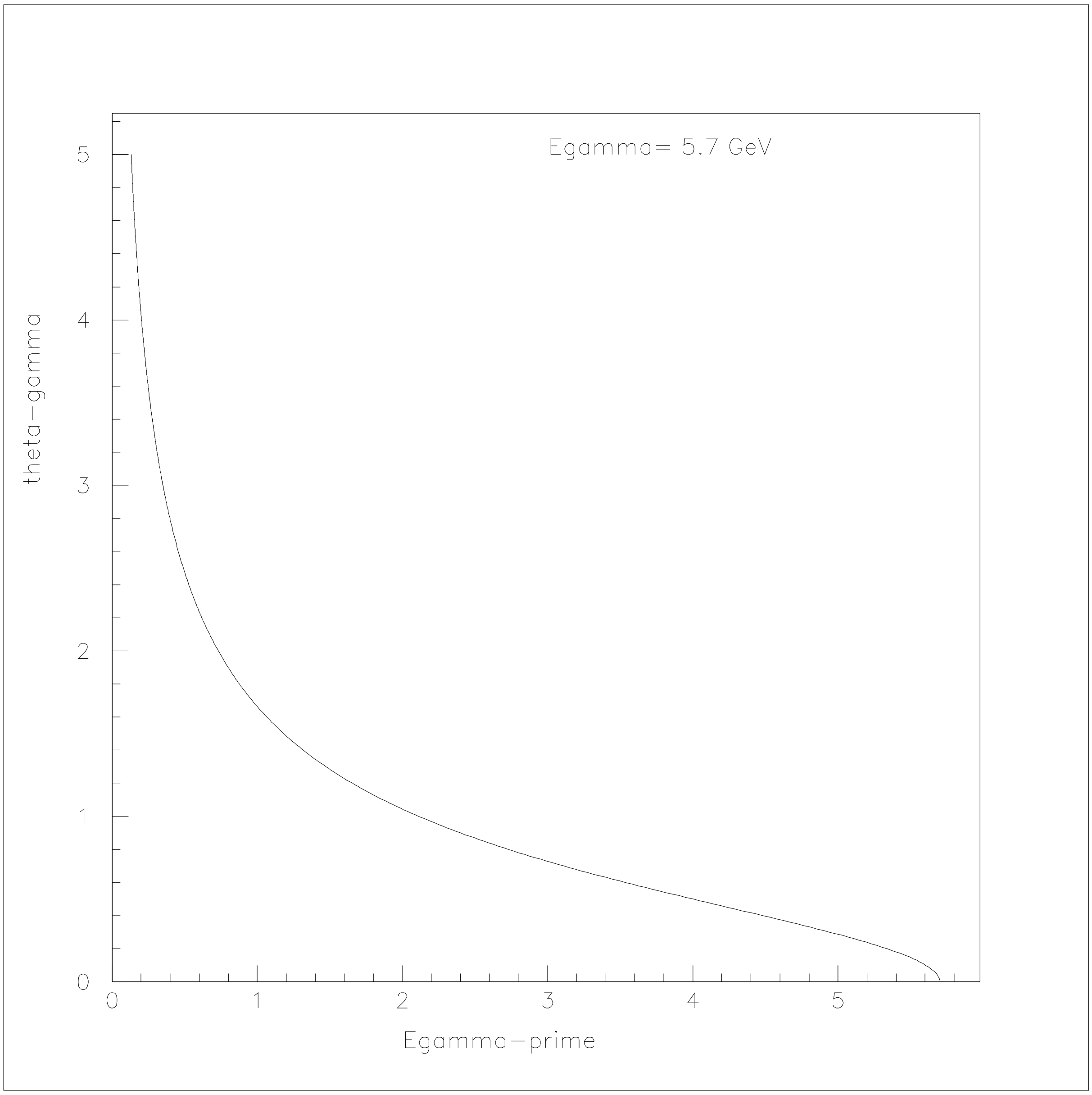

Figure 1: Kinematical correlation between Compton scattered photon energy and scattering angle.

$$\sigma(r) = \frac{5mm}{\sqrt(E)} \tag{5}$$

where E is the energy in GeV. All simulations shown are for a 5% radiation length carbon target.

1 Case 1: No Sweeping Magnetic Field, Electron and Photon Detected in HYCAL

For this configuration, three issues come to mind:

(1) Charged particle rates in the HYCAL due to lack of sweeping field,

(2) Cleanliness of separation between Compton and pair production + bremsstrahlung signals,

(3) Sensitivity to central deadspace size and alignment.

1.1 Case 1: Charged Particle Rates in HYCAL

Probably high. Need to look at this.

1.2 Case 1: Compton Event Identification

A plot of the photon angle *verses* the photon energy when a photon and electron are in coincidence in the HYCAL is shown in figure 2 for an incident photon energy of 6 GeV. As previously mentioned, the dominant background is pair production followed by bremsstrahlung. For our geometry, the minimum distance between a Compton electron and photon on the HYCAL is about 18 cm. When the condition is imposed that the electron and photon must be at least 13 cm apart, we obtain figure 3, which is quite clean. On this basis, I conclude that we can pick out the Compton events very cleanly.

1.3 Systematics Associated with Central Deadspace in HYCAL

Figure 4 shows the relative Compton yield for various sizes of the central hole in the fiducial volume in the center of the HYCAL. The hole is taken to be square. A 1 mm error gives about a 1.5% difference in acceptance, which is pretty large.

If I cut separately on the photon and electron deadspaces, I see that most of the loss in yield to the central hole of HYCAL is due to the electrons. A 1 mm error in the deadspace size for the photons gives just a 0.2% change in the yield as shown in figure 5.

This would argue for the other two techniques in which a magnetic field is used to deflect the Compton electrons away from the deadspace. It also suggests that we might consider putting a precisely machined tungsten collimator in front of the veto scintillator to accurately define the fiducial boundary of the detector in the central region for the photons. I need to simulate this to see if it increases the detector rates, or improves them.

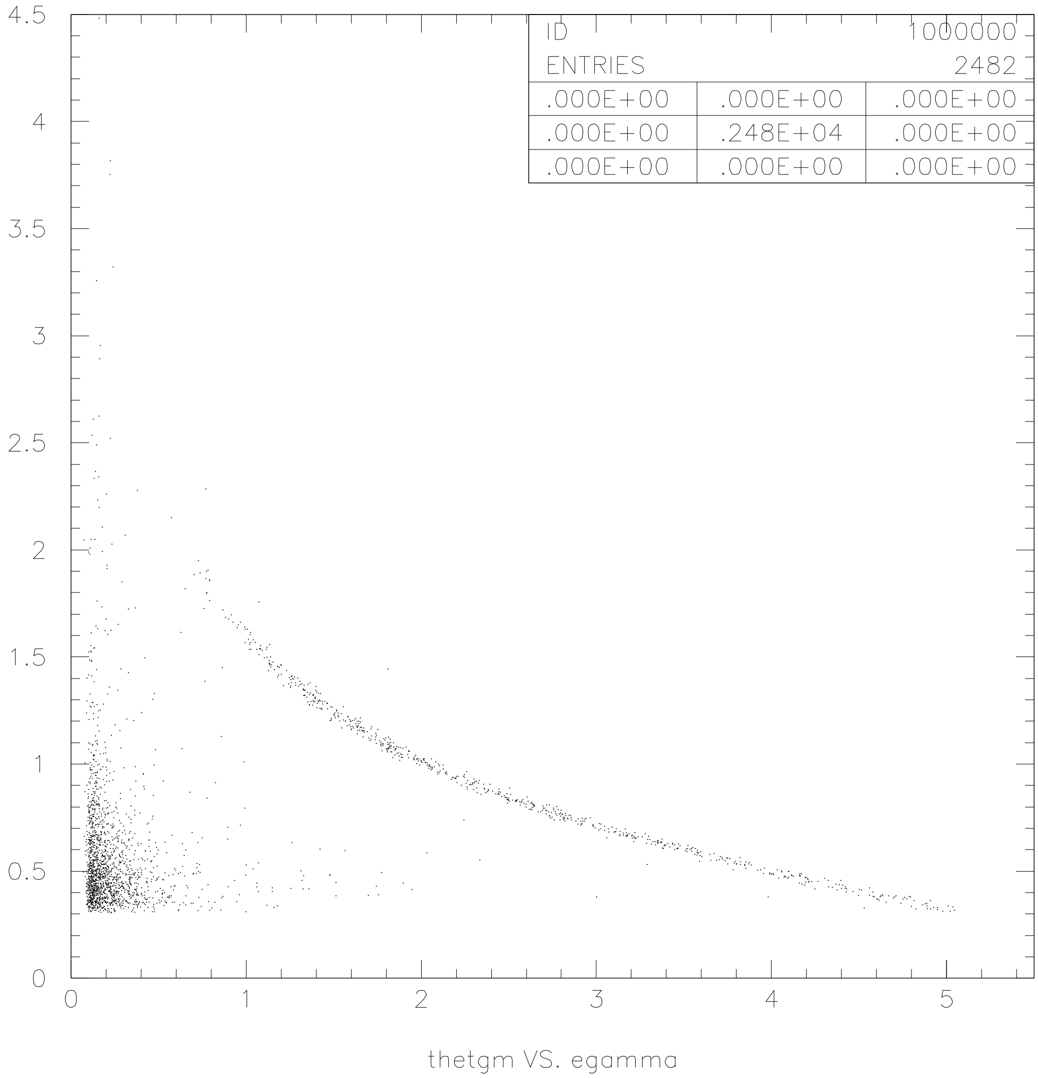

Figure 2: $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 6 GeV incident photon, 8 cm square HYCAL deadspace, B=0 kgauss, no condition on separation of electron and photon hit position on HYCAL. $3 \times 10^7 \gamma$'s sampled.

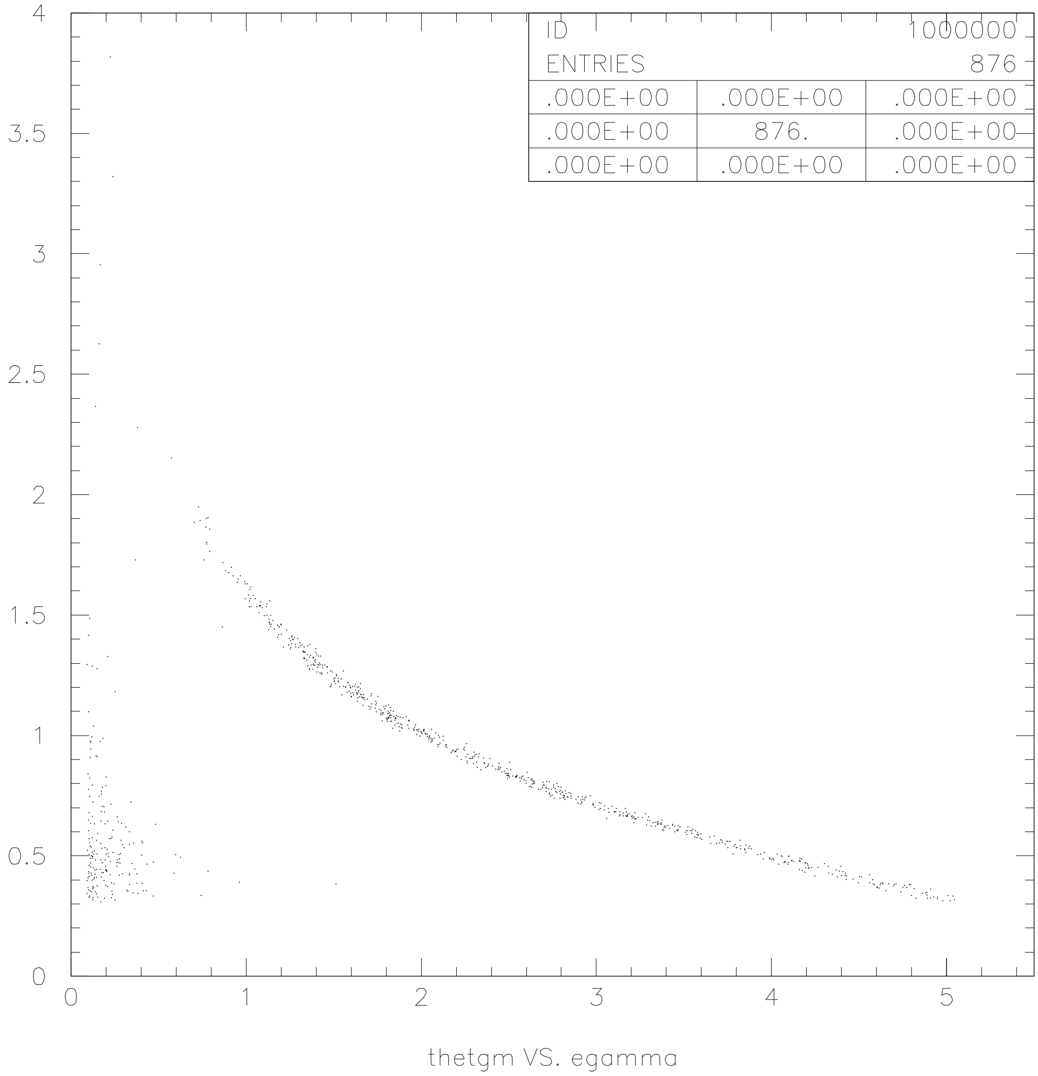

Figure 3: $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 6 GeV incident photon, 8 cm square HYCAL deadspace, B=0 kgauss, electron and photon at least 13 cm apart on HYCAL. $3 \times 10^7 \gamma$'s sampled.

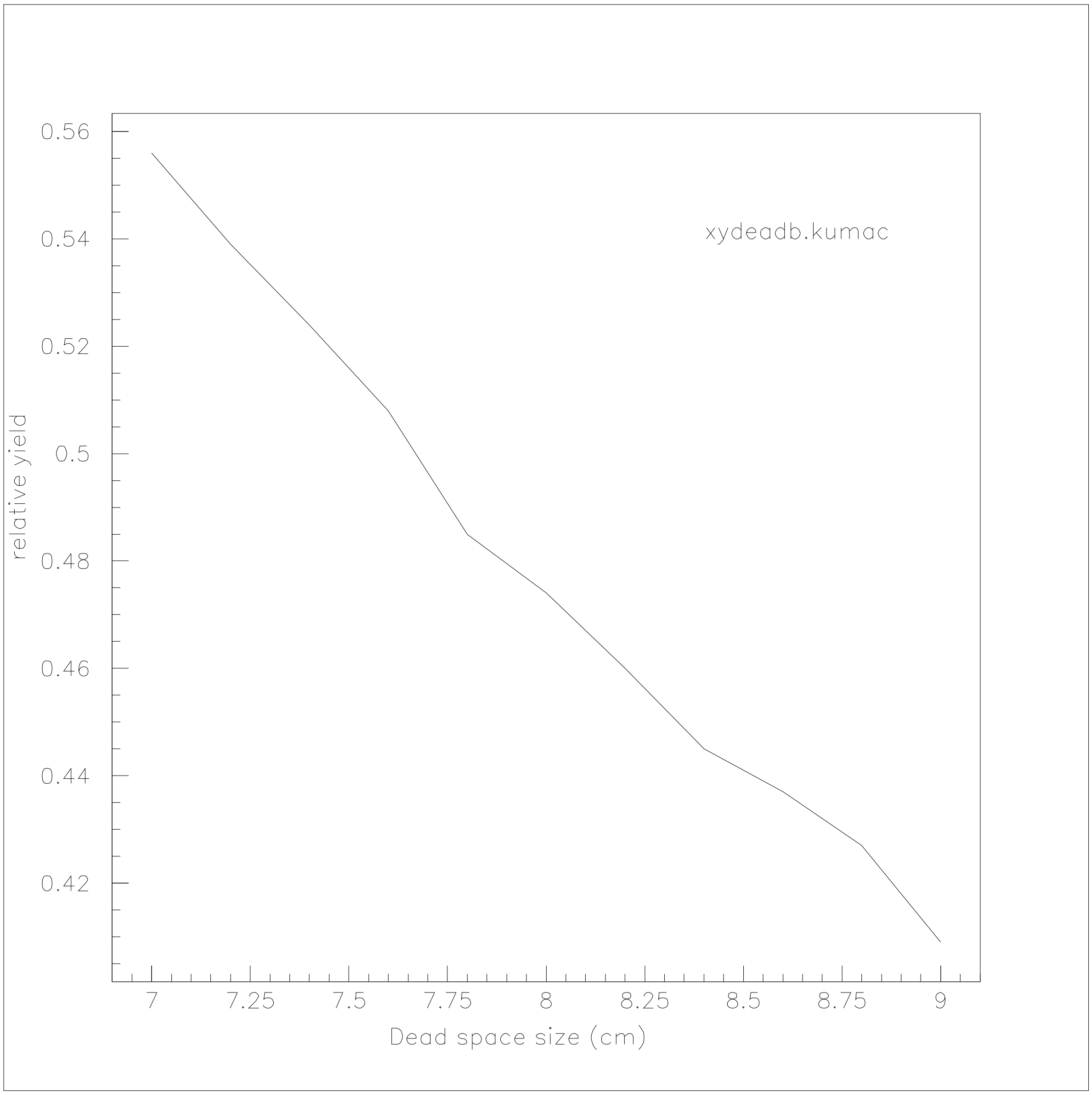

Figure 4: Relative Compton yield as a function of central HYCAL deadspace size for no sweeping field, electron and photon both detected in HYCAL.

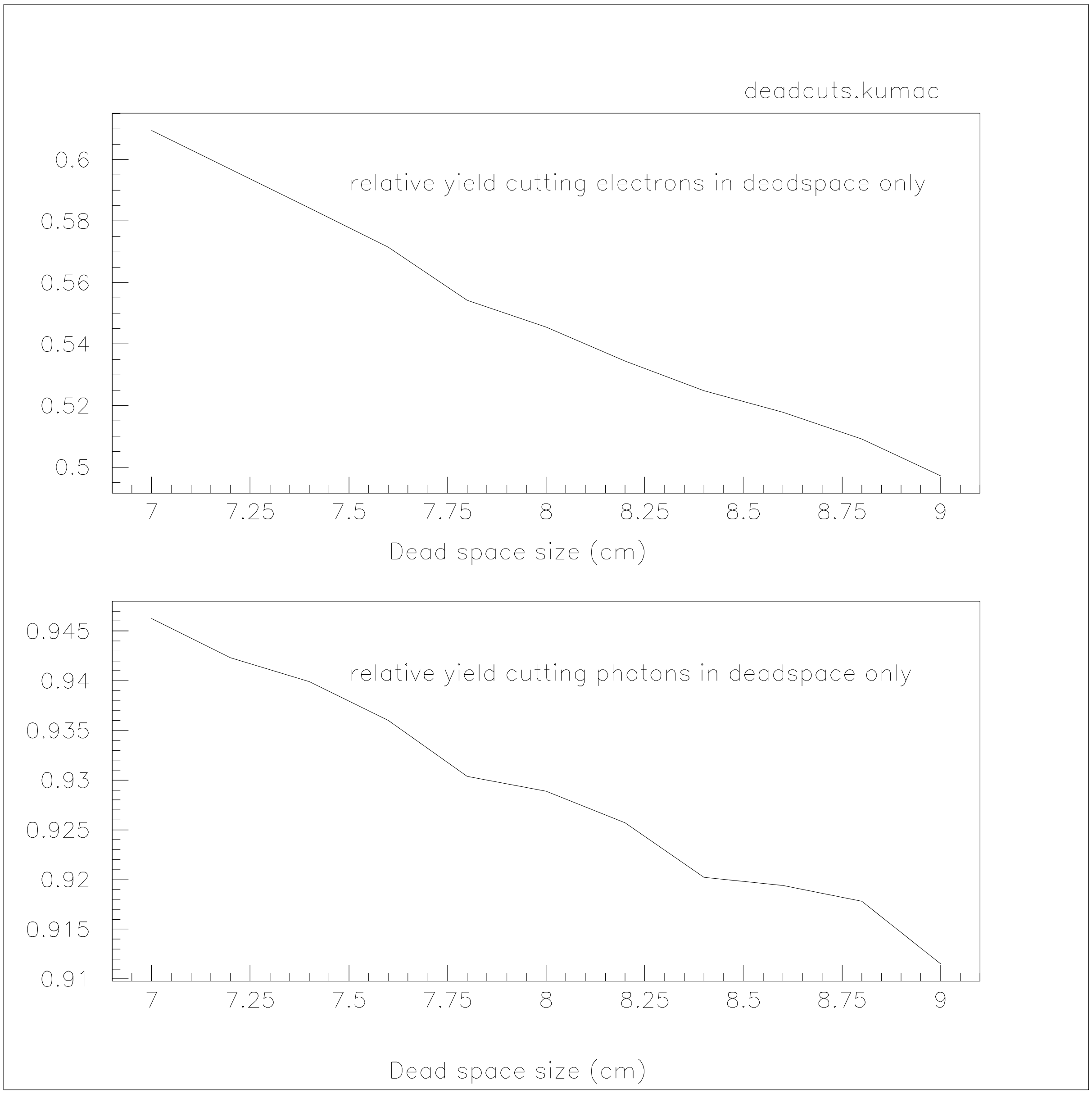

Figure 5: Relative Compton yield as a function of central HYCAL deadspace size. Top: Only electrons cut by deadspace. Bottom: Only photons cut by deadspace.

2 Case 2: Weak Magnetic Field, Electrons Dispersed Across HYCAL

Now, having concluded that we probably don't want to be detecting the Compton electrons near the center of the HYCAL, our two choices are to disperse them across HYCAL with a weak B field in the sweeping magnet, or deflect them totally away from HYCAL and detect them with separate detectors. For either case, the deadspace cut on the electron yield is irrelevant, and I looked at the dependence on the Compton photon yield as a function of the misalignment of the central deadspace. Since this is a single particle acceptance, it is quite insensitive as shown in figure 6.

2.1 Case 2: Charged Particle Rates

For this experimental configuration, the HYCAL obviously suffers from the full charged particle rate from pair production. For a 1.3 kgauss field in the sweeping dipole, the electron energy acceptance goes down to about 0.4 GeV. So, I sampled 0.4 $GeV < E_\gamma <$ 5.7 GeV and got a corresponding charged particle rate of 18.7 MHz on HYCAL distributed as shown in figure 7. (Here, I assumed a 50 MHz rate in the range $0.77E_e < E_\gamma < 0.95E_e$.)

So, if we were to use this setup, the beam current would have to be turned down a lot.

2.2 Case 2: Compton Event Identification

Setting aside rate problems, the Compton events could still be identified pretty cleanly. In figure 8 is the scattered photon angle *verses* its energy under the condition $E_{\gamma'} + E_e >$ 4 GeV with all physics turned on.

3 Case 3: Strong Magnetic Field, Photon Detected in HYCAL, Electron Detected in Separate Scintillators.

To my mind, this is the best configuration.

To see where to put the electron detector, I suppressed the main Compton-like background by turning off pair production. For incident photons 4.62 $GeV < E_\gamma <$ 5.7 GeV, $8cm \times 8cm$ central HYCAL deadspace, $1m \times 1m$ outer HYCAL dimension, I get a $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ plot as shown in figure 9.

This gives a Compton rate of 2.8kHz. I attribute the background to Compton events where the Compton electron emits a bremsstrahlung photon. This must be corrected for.

The spatial hit distribution of the Compton electrons in the plane of the detector, (but outside its boundary, since the electrons were bent away from HYCAL) is shown in figure 10.

A plot of $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ with all physics turned on in the simulation, 4.62 $GeV < E_\gamma <$ 5.7 GeV, $8cm \times 8cm$ central HYCAL deadspace, $1m \times 1m$ outer HYCAL dimension, shows a pretty good separation of the Compton events. See figure 11. In the simulation, the only cut on the electron is its presence at $x_{e^-} > 50cm$, *i.e.* there is no cut on its energy.

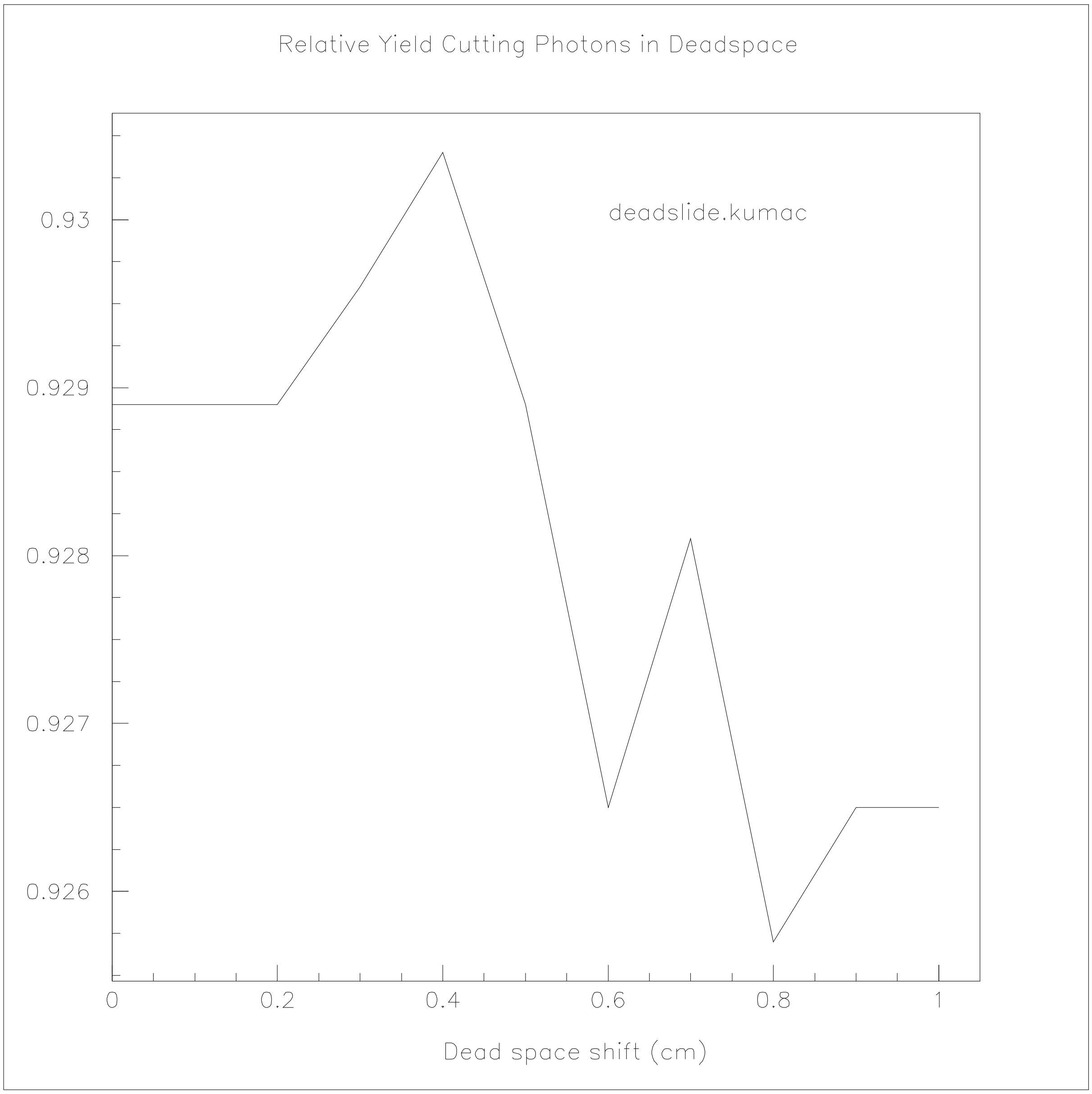

Figure 6: Relative Compton yield as a function of central HYCAL deadspace position. Photons only are cut.

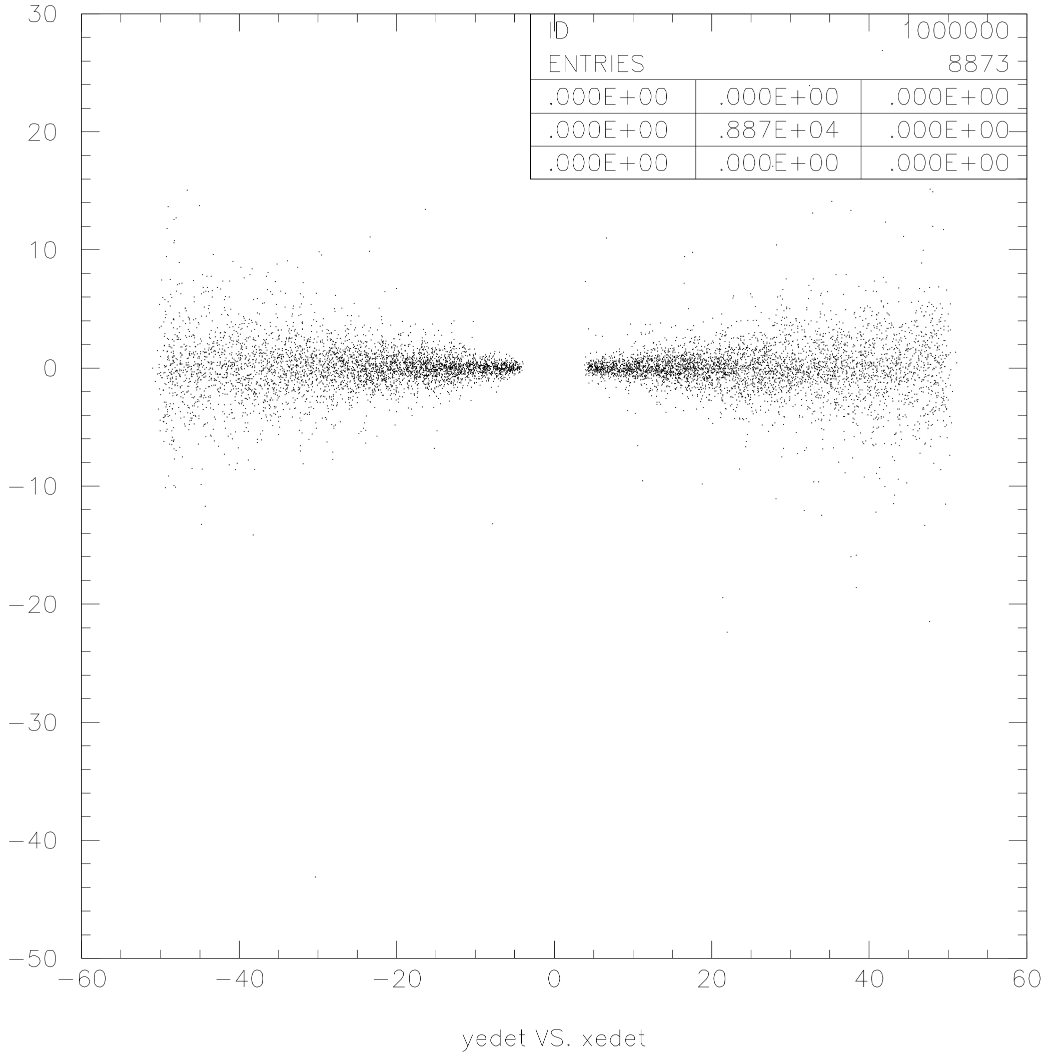

Figure 7: Distribution of charged particles across HYCAL for B=1.3 kgauss. Rate is 18.7 MHz. All physics is on, no photon coincidence condition is imposed.

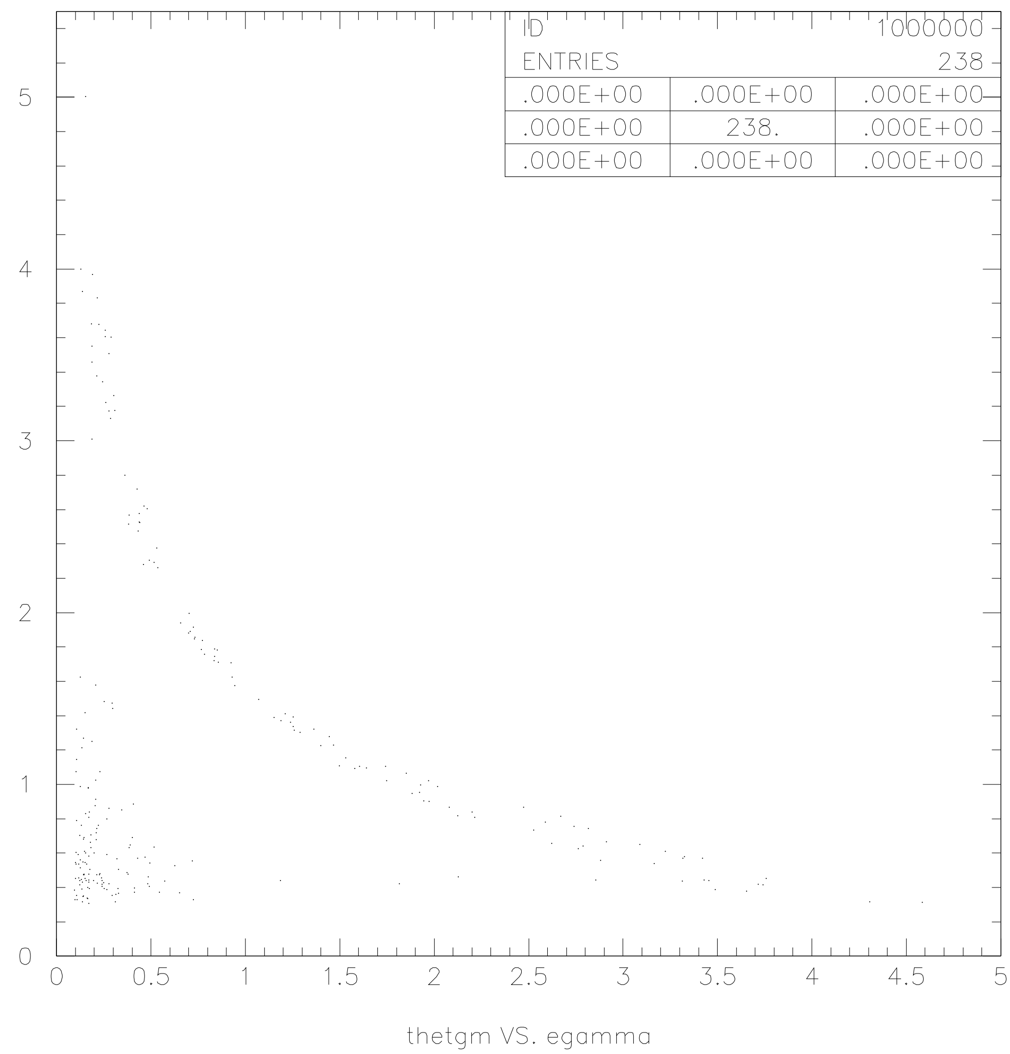

Figure 8: $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=1.3 kgauss, $x_e^{det} > 4.0cm$, all physics on.

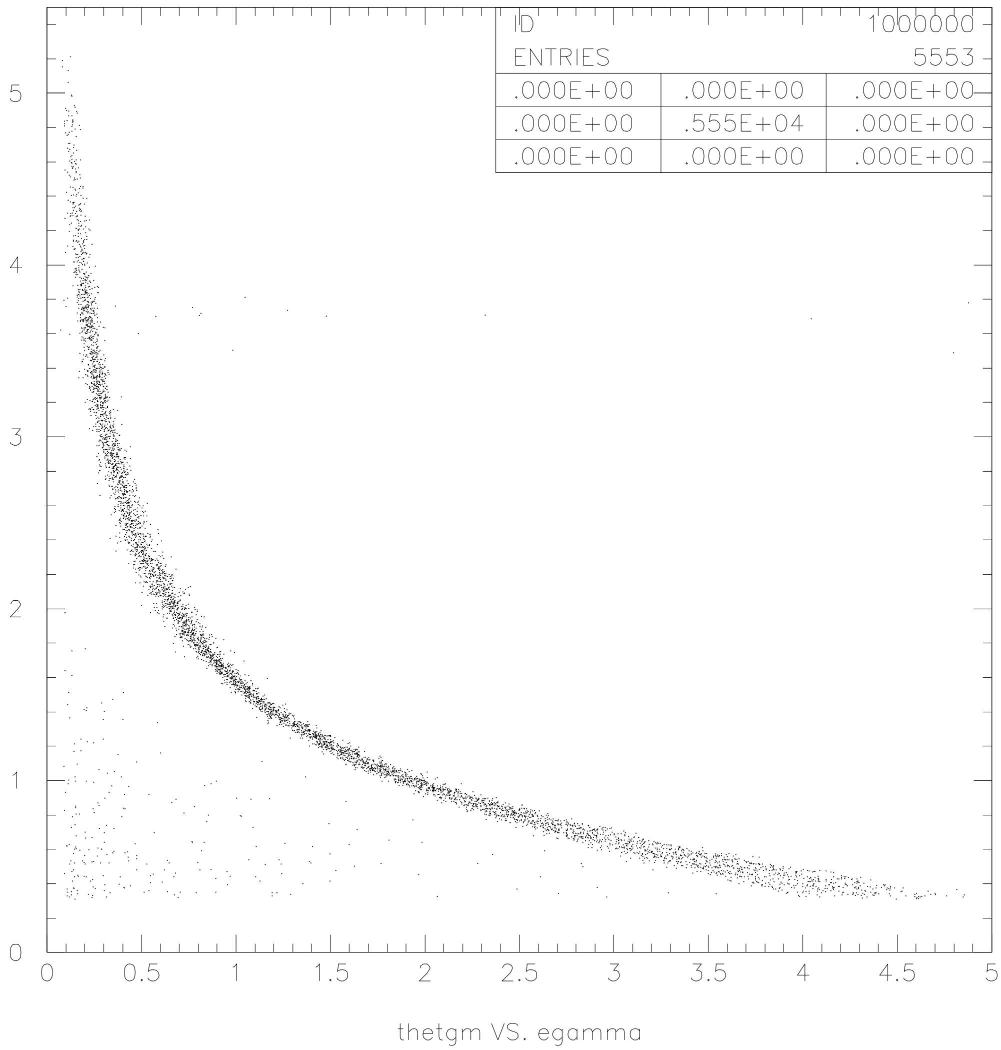

Figure 9: $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=14.3 kgauss, pair production turned off, $4.62 < E_\gamma < 5.7$, electron-photon coincidence. Compton rate is 2.8 kHz.

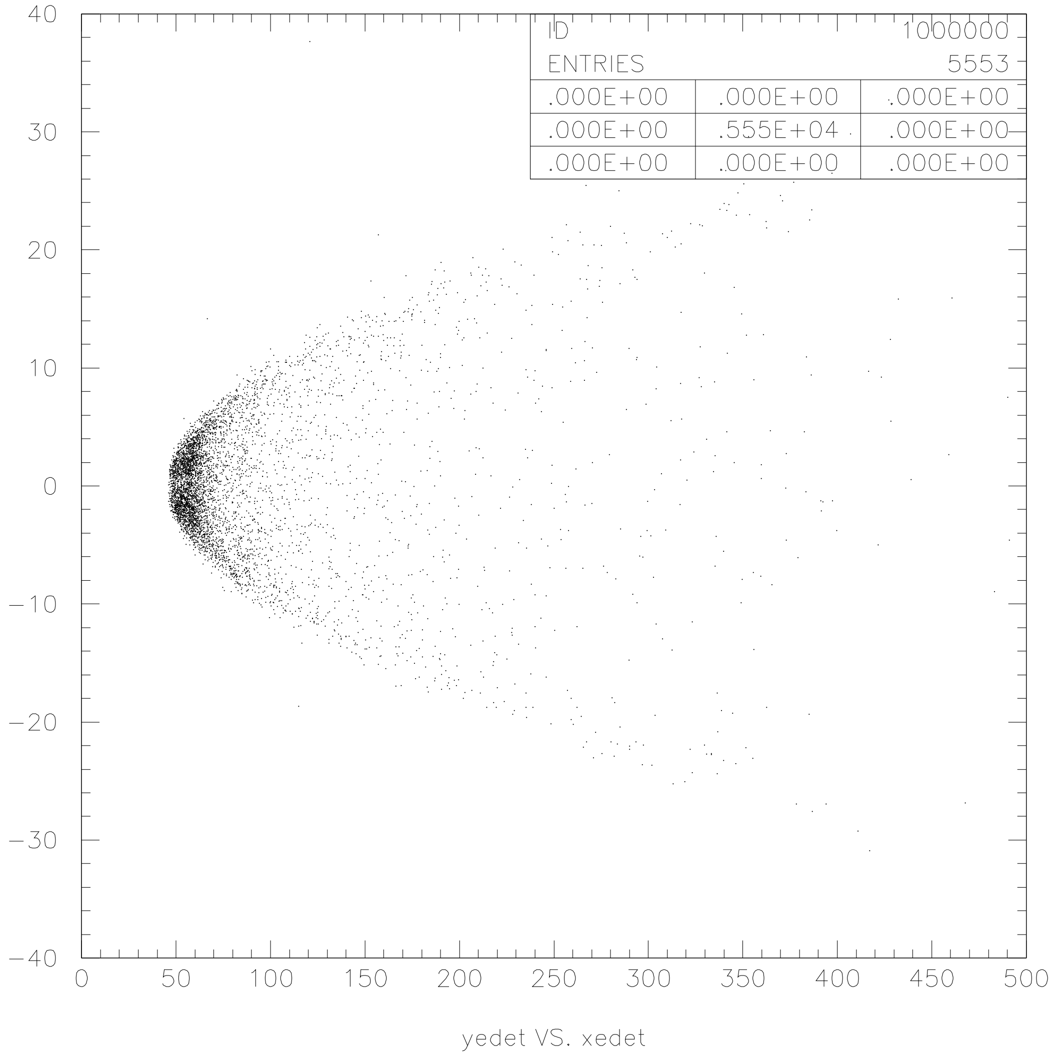

Figure 10: Hit pattern of Compton electrons in the plane of HYCAL (but to the right of it). B=14.3 kgauss, pair production turned off.

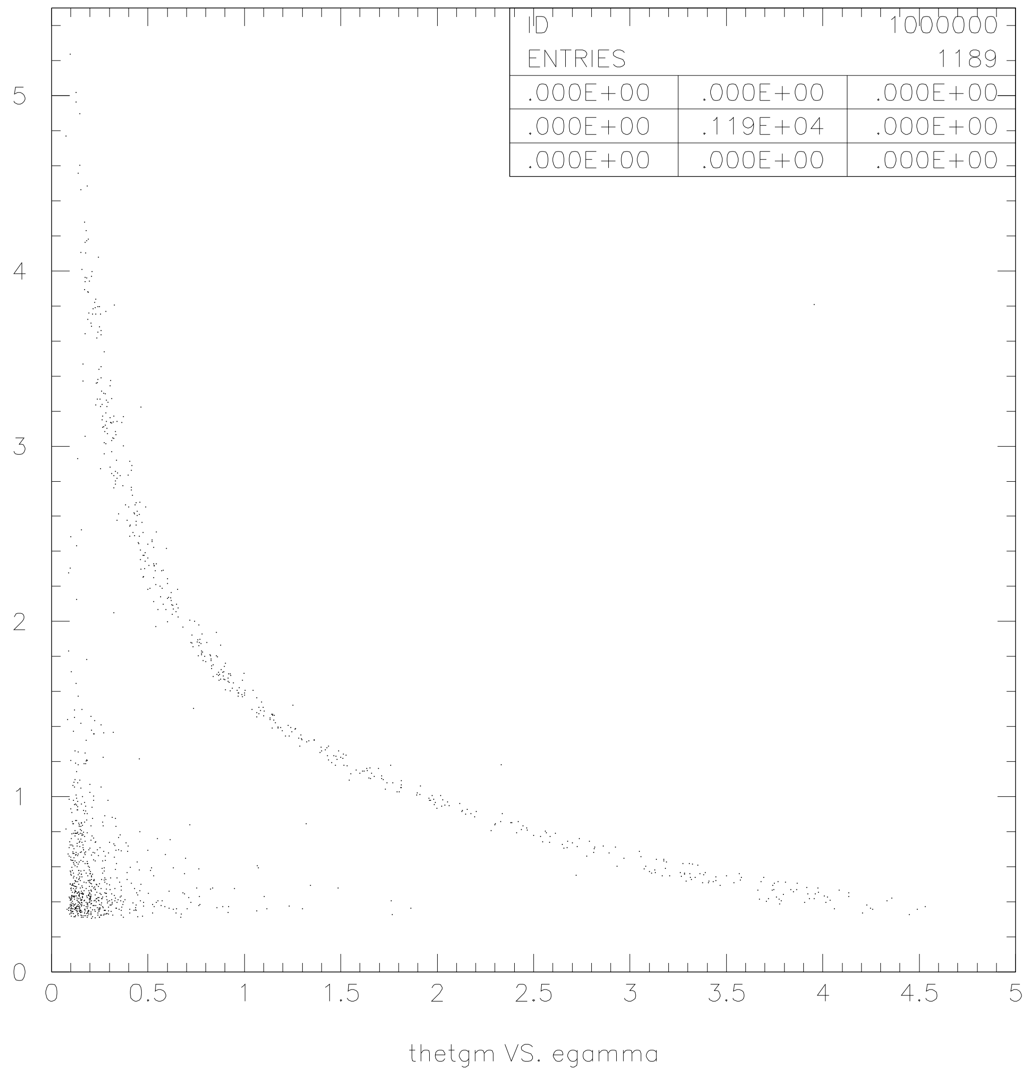

Figure 11: $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=15 kgauss, all physics on, $4.62 < E_\gamma < 5.7$, electron-photon coincidence, electron detected in separate scintillators, $x_{e^-} > 50cm$.

The distribution of charged particles from all processes is shown in figure 12. The rate on one side is about 9.5 MHz, so clearly the electron detector would need to be segmented.

Other Considerations

Rough estimates show that a 10^{-3} photon energy uncertainty will give about a 10^{-3} Compton cross section uncertainty. This should not be a problem.

If we assume overlapping electron counters limited to about 300 kHz each, we would require 60 scintillator channels. Their positioning would not be too critical, as long as they are big enough to let the HYCAL dominate the geometrical acceptance.

To get an idea of what kind of corrections would be employed in measuring the absolute Compton cross section, I did the following simulations, all with the same number of incident photons ($10^7\gamma$'s):

(1) Figure 13. Only Compton scattering. All other physics turned off. This is the rate we ultimately want.

(2) Figure 14. All physics on, *except* Compton scattering. This is the background. In principle, pair production could be suppressed with an anticoincidence.

(3) Figure 15. Only Compton scattering and bremsstrahlung. All other physics turned off. This shows Compton events in which the scattered electron emits a bremsstrahlung photon and the bremsstrahlung photon gets identified with the Compton vertex. 5% of the Compton events are accompanied by bremsstrahlung. (At some level, this is an artifact of the simulation, as it only takes the last generated photon. In reality, one would expect one photon to match the Compton kinematics, and the other (bremsstrahlung photon) not, thus enabling these events to be properly identified as Compton events.)

(4) Figure 16. All physics on, showing background from pair production plus bremsstrahlung. (Same as figure 11). This is responsible for about 50% of the electron-photon events.

Conclusions

At this point, it appears to me that Compton scattering is very promising. It would be an absolute, nondestructive, online, high rate monitor. It could potentially be of general use to anyone interested in photon tagging in Hall B for verifying that the high rate tagging efficiencies are the same as those measured by the total absorption counter at low tagging rates. The main impact is that we would have to provide about 60 scintillator channels and associated electronics.

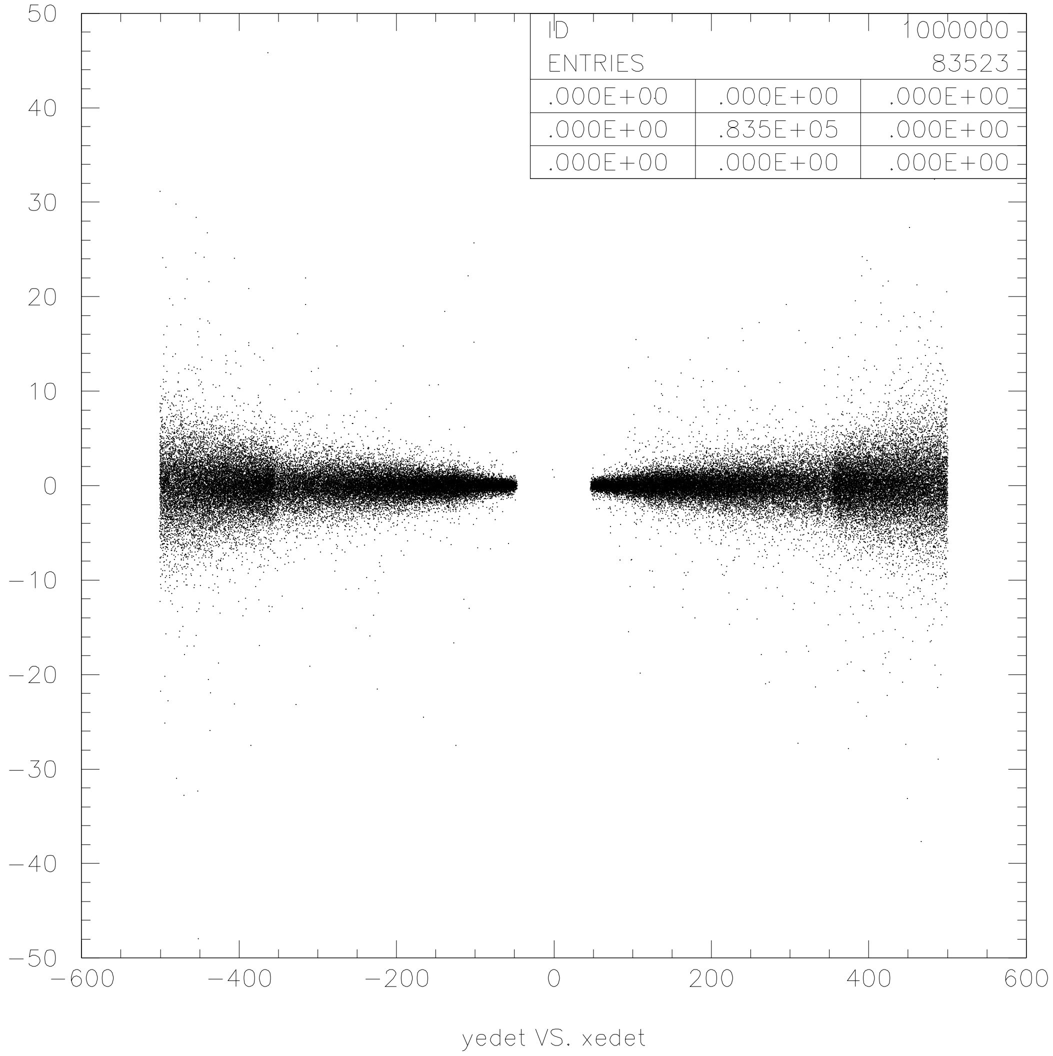

Figure 12: Distribution of charged particle hits, all physics on, B=15 kgauss.

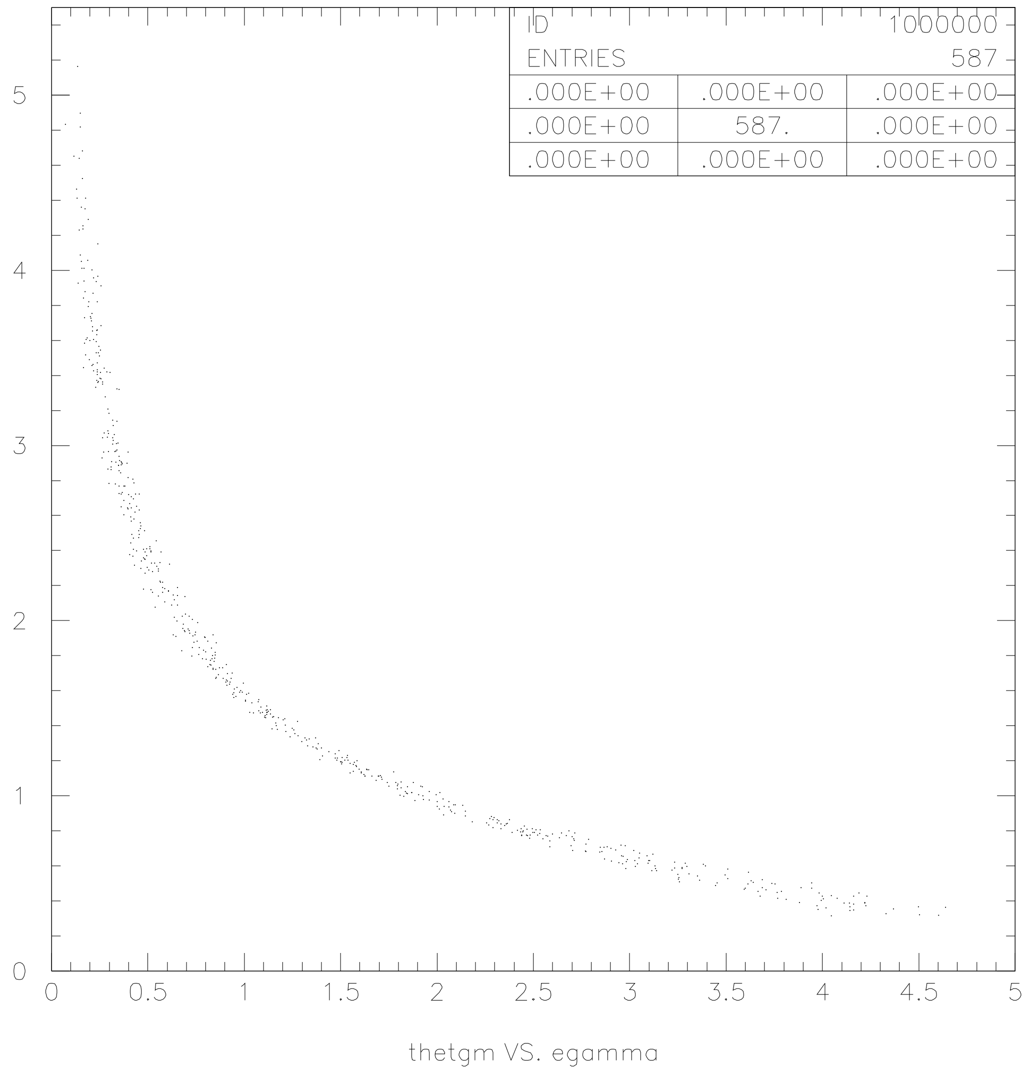

Figure 13: All physics off except Compton scattering. $\theta_{\gamma'}$ $verses E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=15 kgauss, $4.62 < E_\gamma < 5.7$, electron-photon coincidence, electron detected in separate scintillators, $x_{e^-} > 50cm$. Rate is 2.9 kHz.

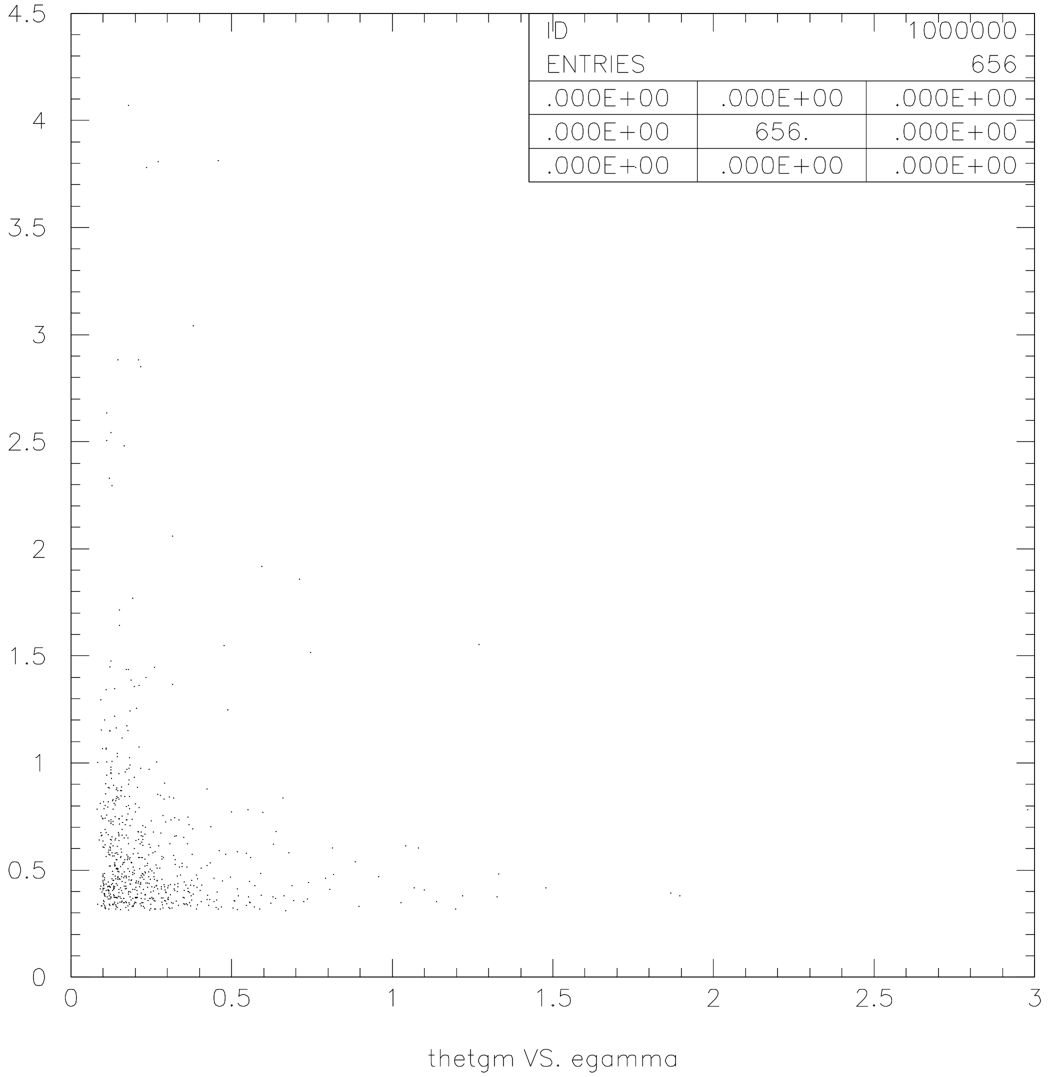

Figure 14: All physics on except Compton scattering. $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=15 kgauss, $4.62 < E_\gamma < 5.7$, electron-photon coincidence, electron detected in separate scintillators, $x_{e^-} > 50cm$.

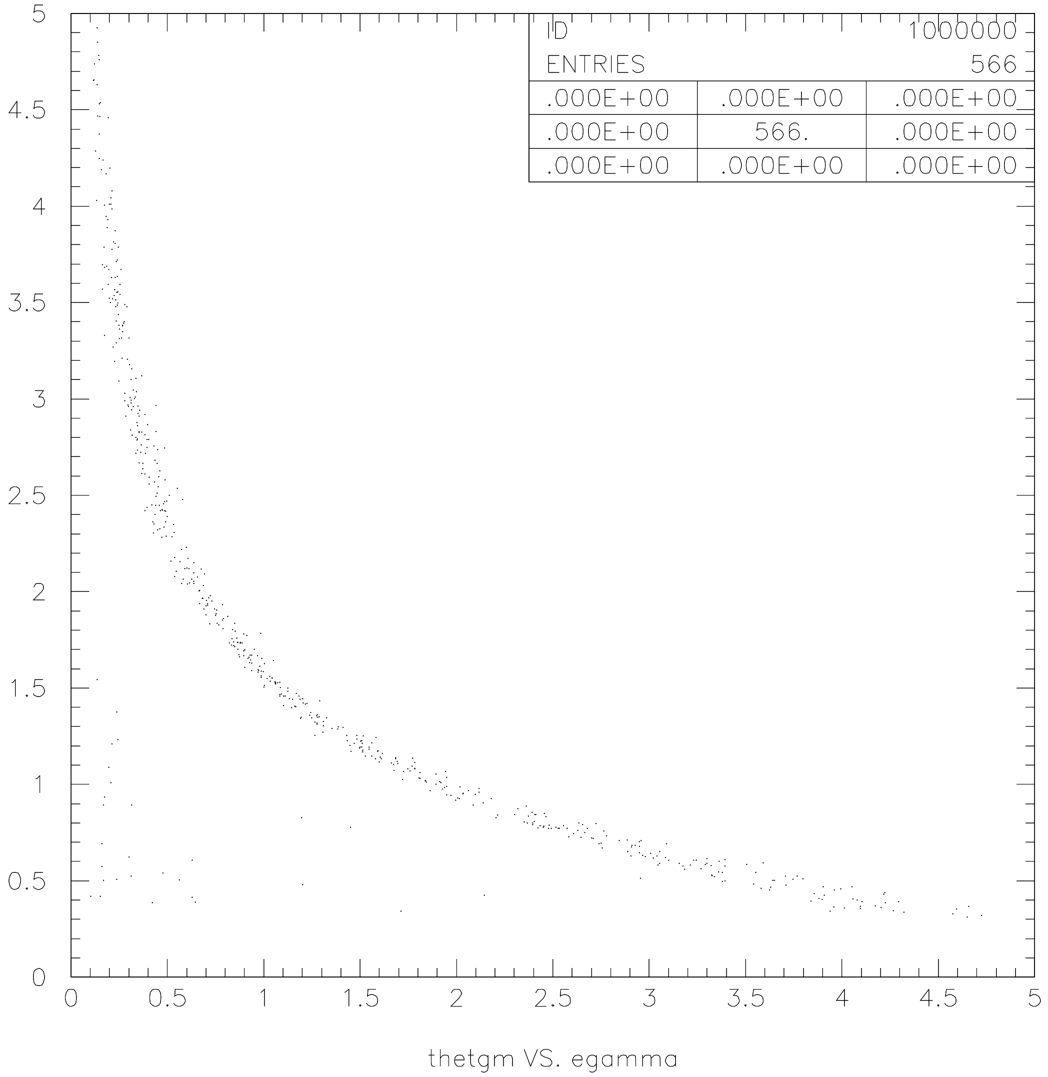

Figure 15: All physics off except Compton scattering and bremsstrahlung. $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=15 kgauss, $4.62 < E_\gamma < 5.7$, electron-photon coincidence, electron detected in separate scintillators, $x_{e^-} > 50cm$.

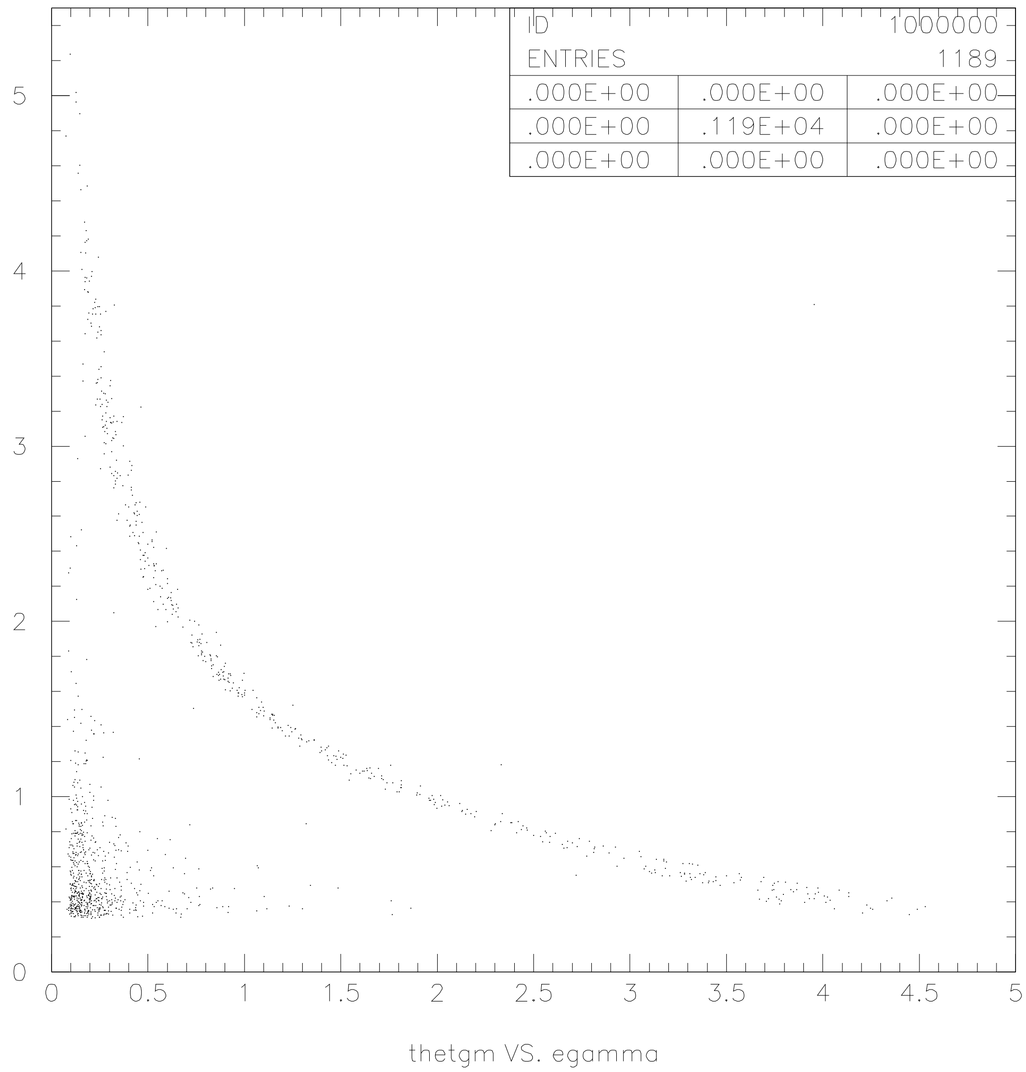

Figure 16: All physics on. $\theta_{\gamma'}$ *verses* $E_{\gamma'}$ for 8 cm square HYCAL deadspace, B=15 kgauss, $4.62 < E_\gamma < 5.7$, electron-photon coincidence, electron detected in separate scintillators, $x_{e^-} > 50cm$.