Rad Hard Lead Glass Update

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Goal

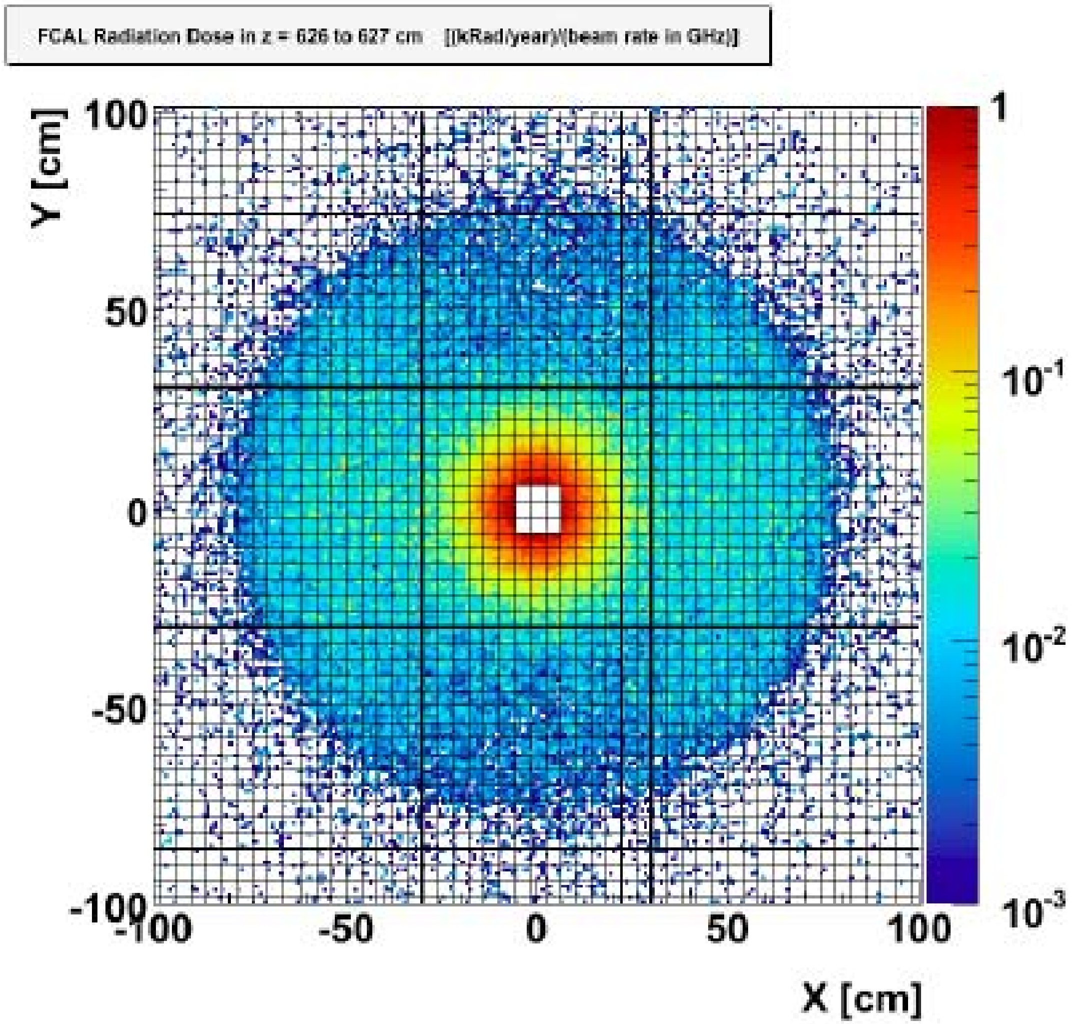
- Need to determine the optimum amount of radiation hard glass (RHG) to insert into the FCAL
  - Need to know how much radiation the FCAL will receive
  - Need to know how radiation damages the lead blocks
  - Need to compare energy resolution of F108(RHG) to F8(regular)
  - Need to know how the radiation damage affects the energy resolution of the FCAL

Calculated Electromagnetic Background

- Ryan Mitchell's simulation of expected dose in FCAL from electromagnetic background
  - Radiation dose in slices of z (along length of bars)
  - Units in kRad per year per beam rate (photons from radiator) in GHz

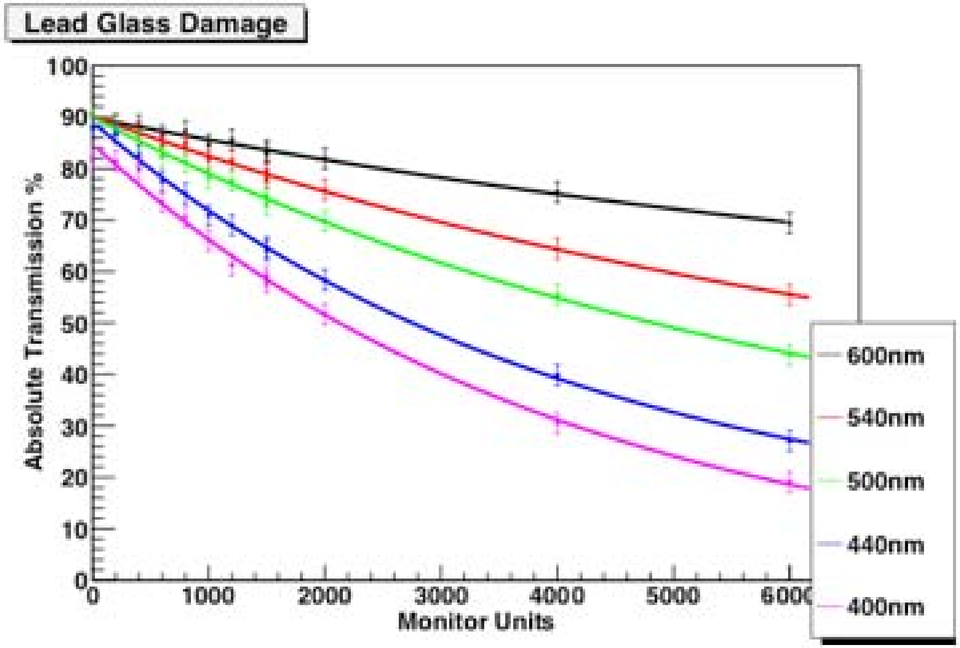
So red is 10kRad per year at 10^8 photons on target per second

(10^7 s running per year)



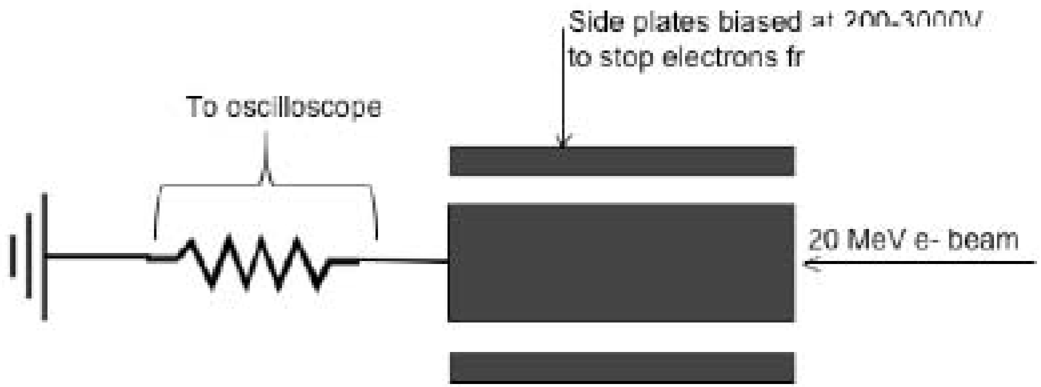
Previous Work

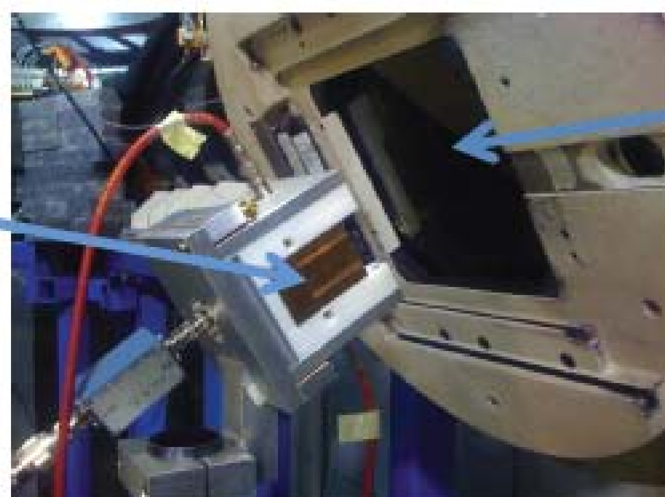
- Radiation damage studies last year were conducted using Monitor Units (output from the medical linac used) as a measure of dosage
- Never really got a good conversion for monitor units to something meaningful
- We needed to redo studies with the beam calibrated



Faraday Cup

- Designed primarily by Patrick McChesney (IUCEEM/ALPHA)
- Goal of absolute current measurement
- 20 MeV electrons used

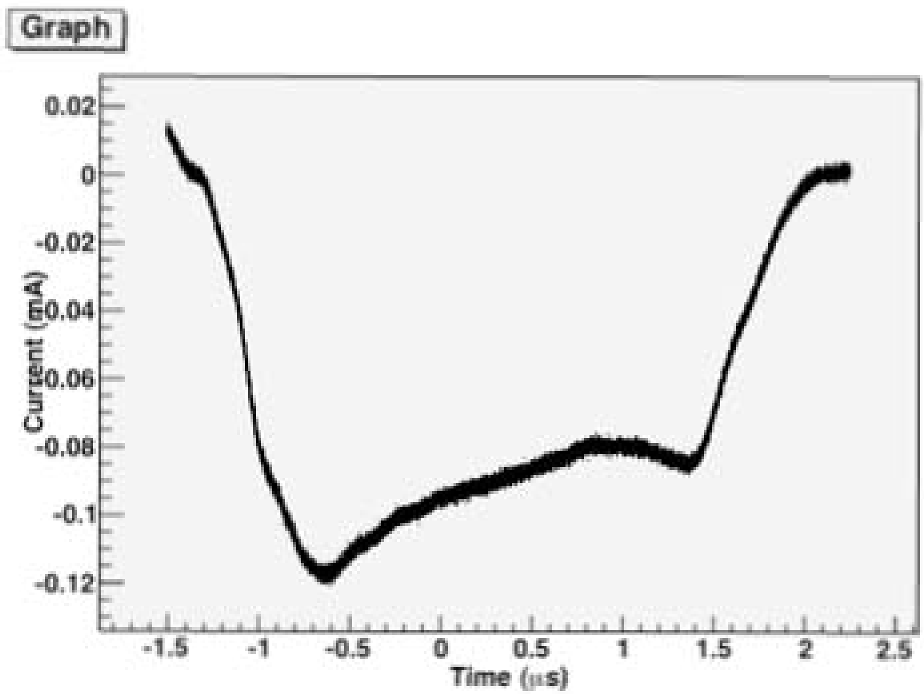




Faraday Cup

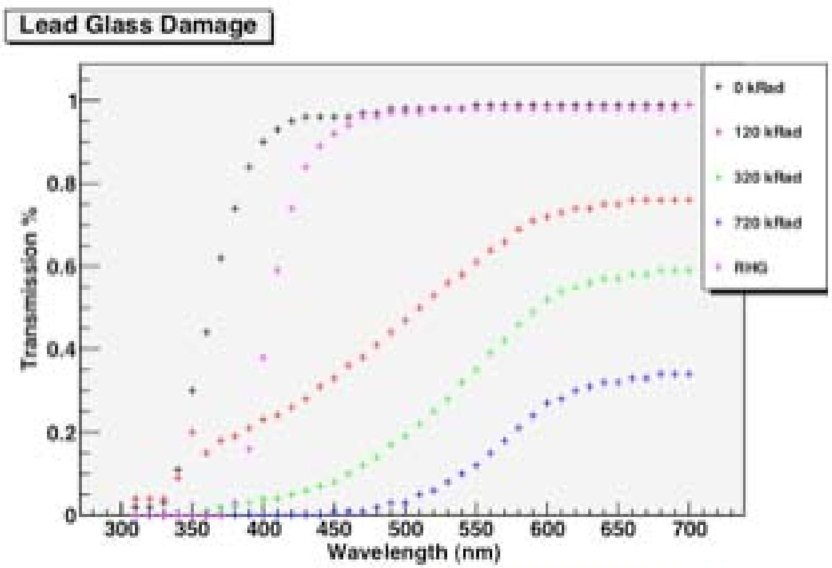
- Linac uses pulses of electrons to dose the target
- From output of oscilloscope connected to the Faraday Cup we can get a measure of the charge per pulse
- Using a counting circuit we can determine the number of pulses per dosage
- Could not determine the optimum bias voltage so no bias voltage was used
  - Gives a lower limit for the current measured

One Pulse from the linac



Damaged Blocks

- Damaged blocks in number of pulses instead of monitor units
  - Also dosed one F108 (RHG) block
- From number of pulses per dose we can convert to number of electrons per dose
- Using GEANT4 simulations of energy deposition in a 2.4 cm by 2.5 cm by 4 cm block dosed with 10,000 electrons with energy of 20 MeV we can convert the number of electrons per dose to radiation dosage in kRad (consistent with Ryan's simulations)

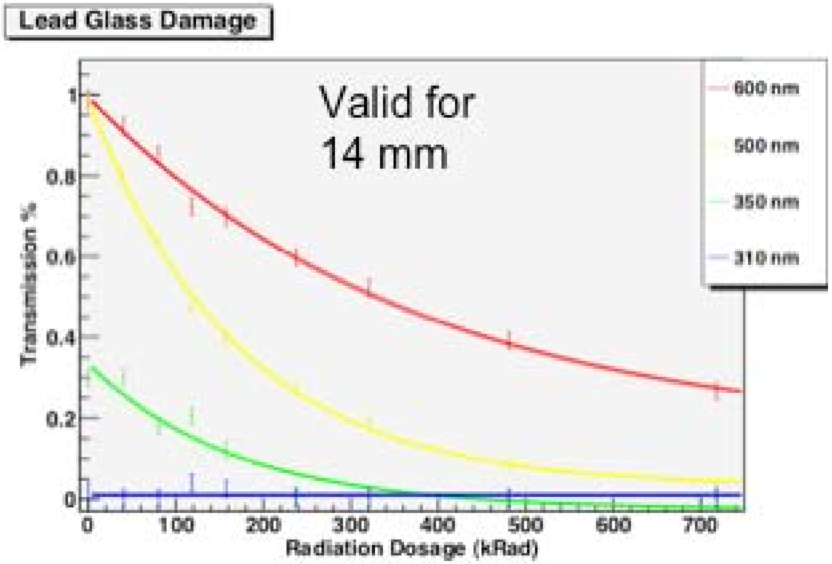


Spectrophotometer measures transmission as a function of wavelength from 700 nm to 300 nm in 10 nm increments

Figure shows spectrophotometer data for various dosages as well as data for undamaged radiation hard glass

Beam Direction

Modeling the Damage

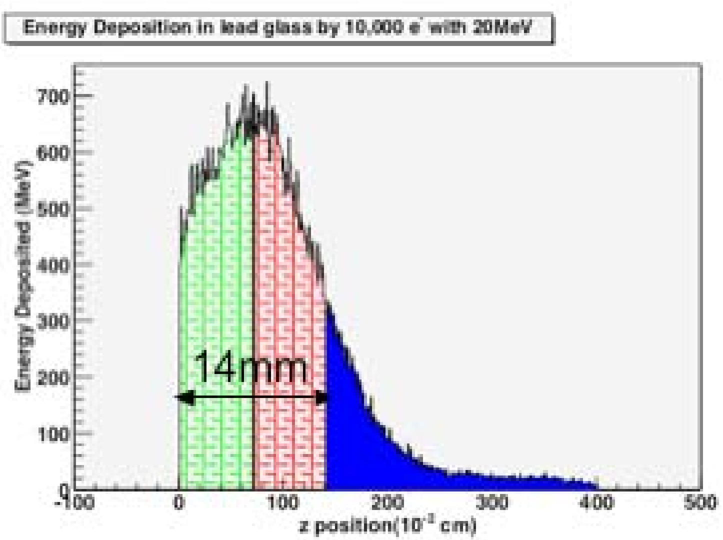


Plots of transmission as a function of dosage

Fit to:

$$A \cdot exp(B \cdot Dose(kRad)) + C$$

Where A, B, and C differ for different wavelengths



All the energy and therefore damage is in the first 14 mm

The first 7 mm contains equal dosage to the second 7 mm

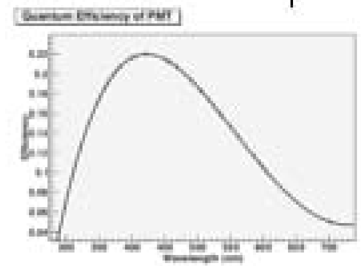
$$T_1 = \sqrt{A \cdot exp(B \cdot Dose(kRad)) + C}$$

So T_1 is valid over 7mm

Inserting Model into HDGEANT

So if we take $F = \frac{T_{\rm eff}}{T_0}$

PMT efficiency



Where

$$T_{\rm eff}(z_0, R, t) = \sum_\lambda \prod_{z=z_0}^{z_f} T_\lambda(z, Dosage(R,t))\epsilon(\lambda)n(\lambda)$$

$$T_0(z_0, R, t=0) = \sum_\lambda \prod_{z=z_0}^{z_f} T_\lambda(z, Dosage(R, t=0)\epsilon(\lambda)n(\lambda)$$

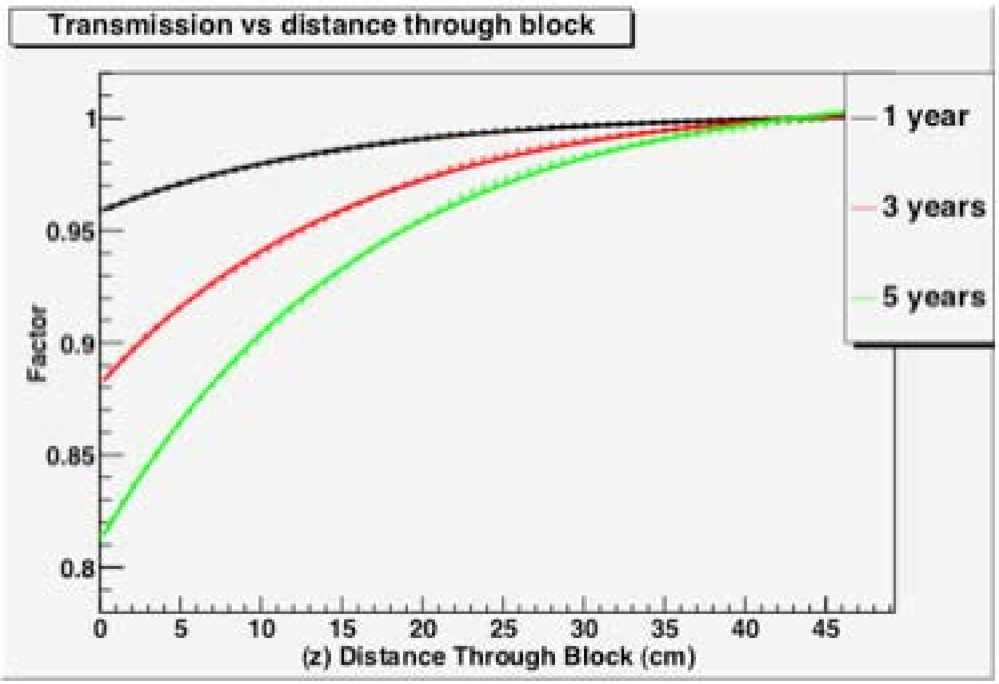
F is the fractional energy loss at radius R after time T with a distance to the end of the block z_0

HDGEANT currently uses $E_{final} = E_{initial} \cdot e^{-z/\lambda}$

to account for optical photons produced by particles that enter the FCAL. In the equation z is the length from the end of the block (z_0) and lambda is the attenuation length

We can take our F for a particular time and radius and multiply it by this exponential to calculate the effect of damage on the energy resolution of the FCAL

Calculating F

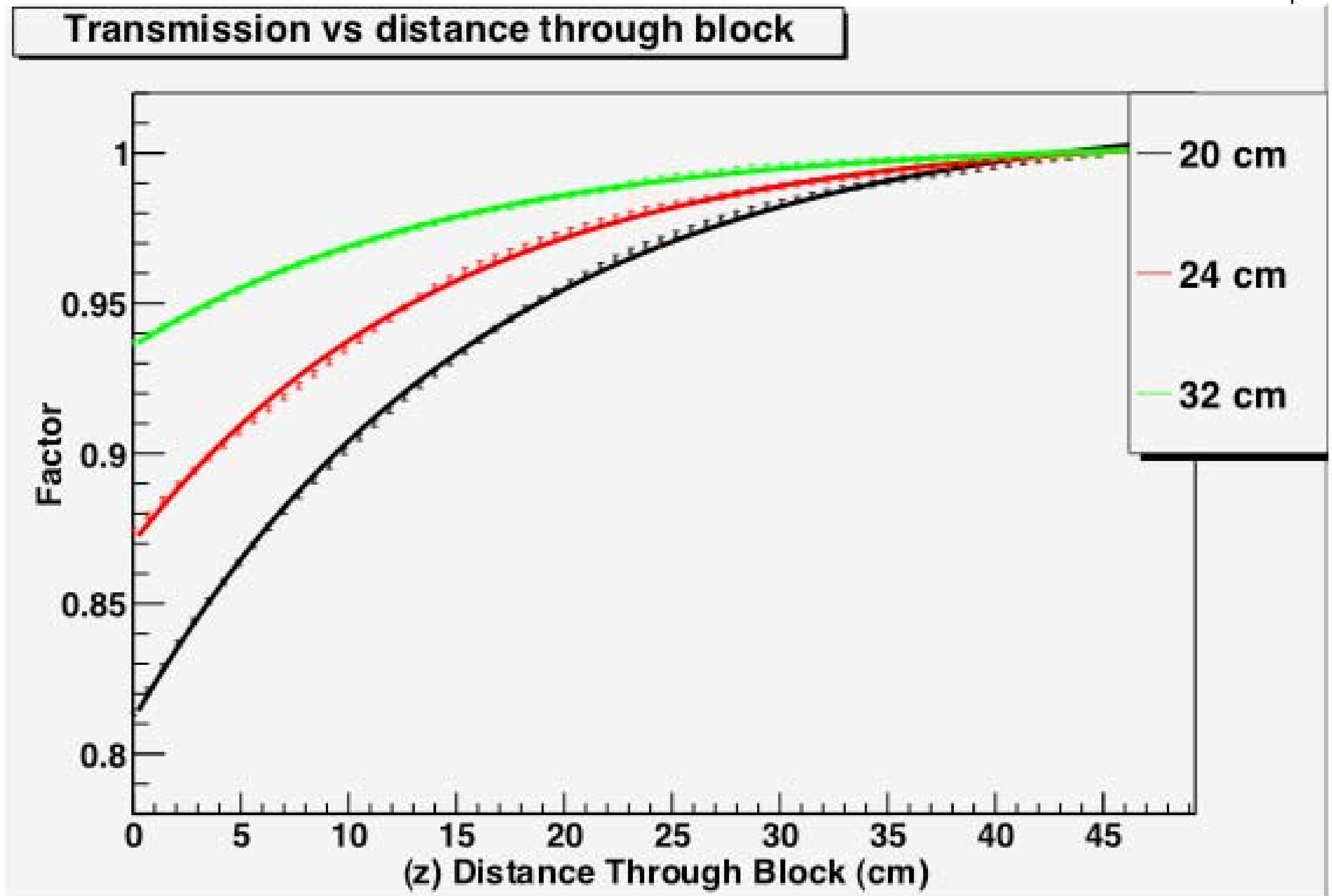


$$F = \frac{T_{\text{eff}}}{T_0}$$

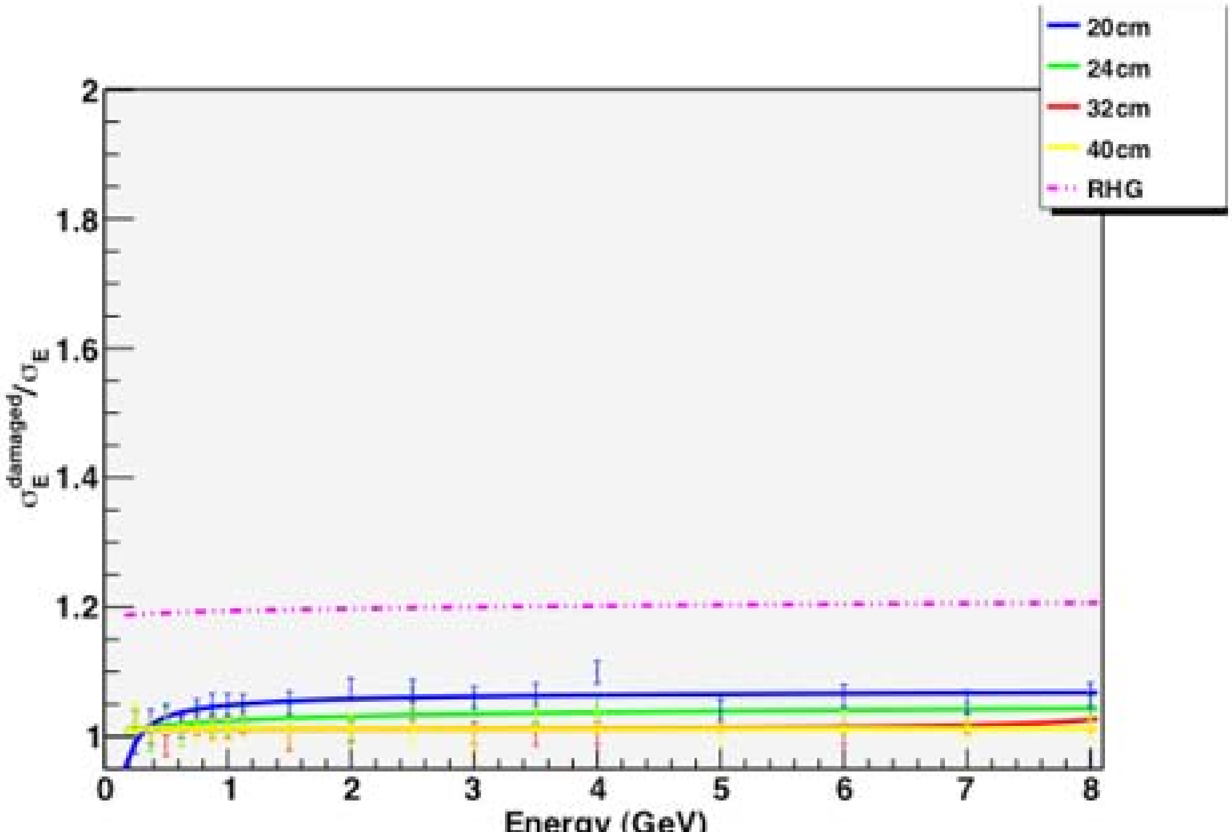
$$T_{\text{eff}}(z_0, R) = \sum_{\lambda} \prod_{z=z_0}^{z_f} T_\lambda(z, Dosage(R))\epsilon(\lambda)n(\lambda)$$

F versus z_0 for FCAL radius of 20 cm

F after 5 Years for Various Radii



FCAL after 1 Year of Running



20 cm = 60 blocks

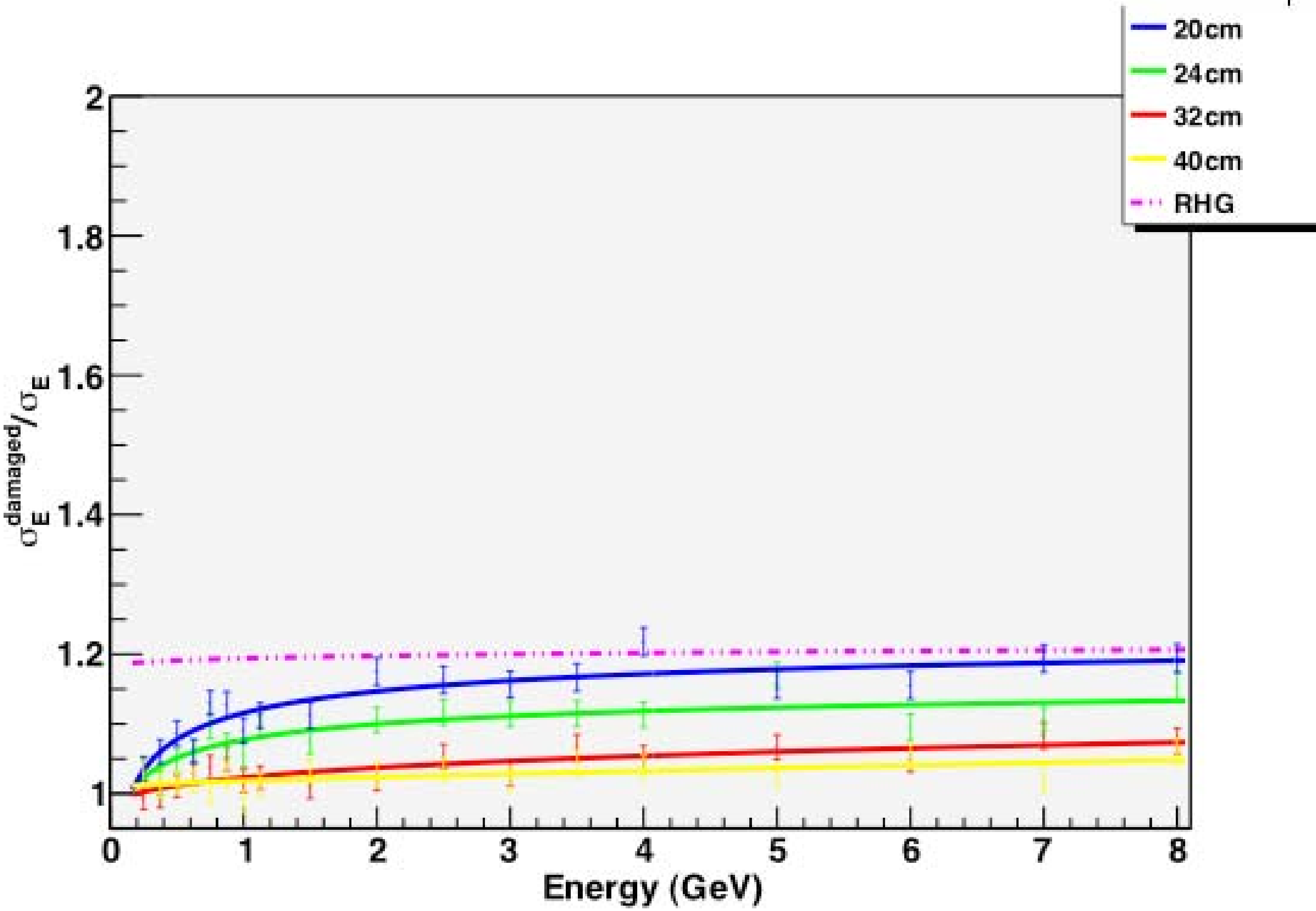
24cm = 100 blocks

32 cm = 184 blocks

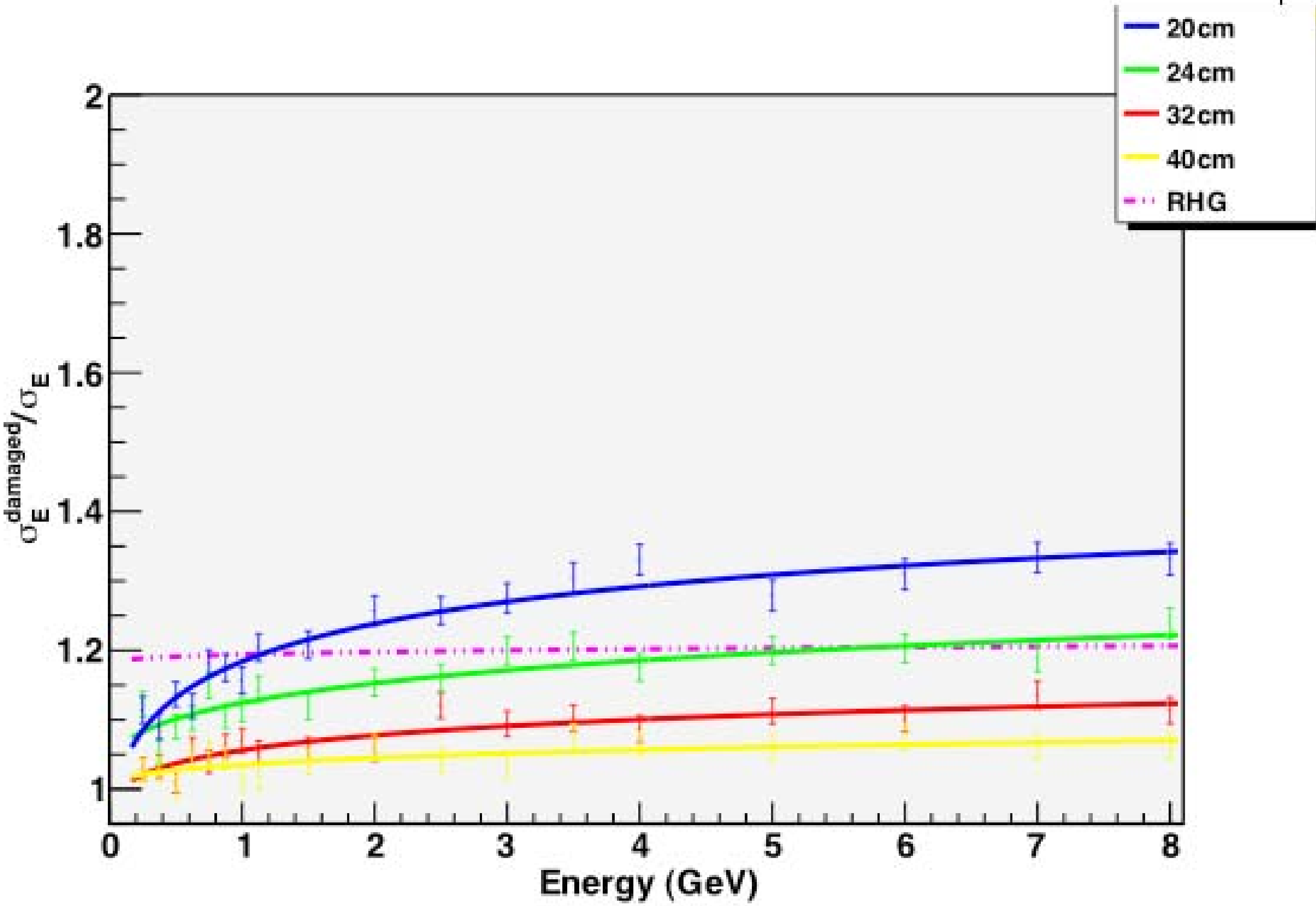
RHG curve: uses complete GEANT 4 analysis which compares F8 to F108

Each Data point is the energy resolution of damaged F8 divided by undamaged F8 for a particular energy

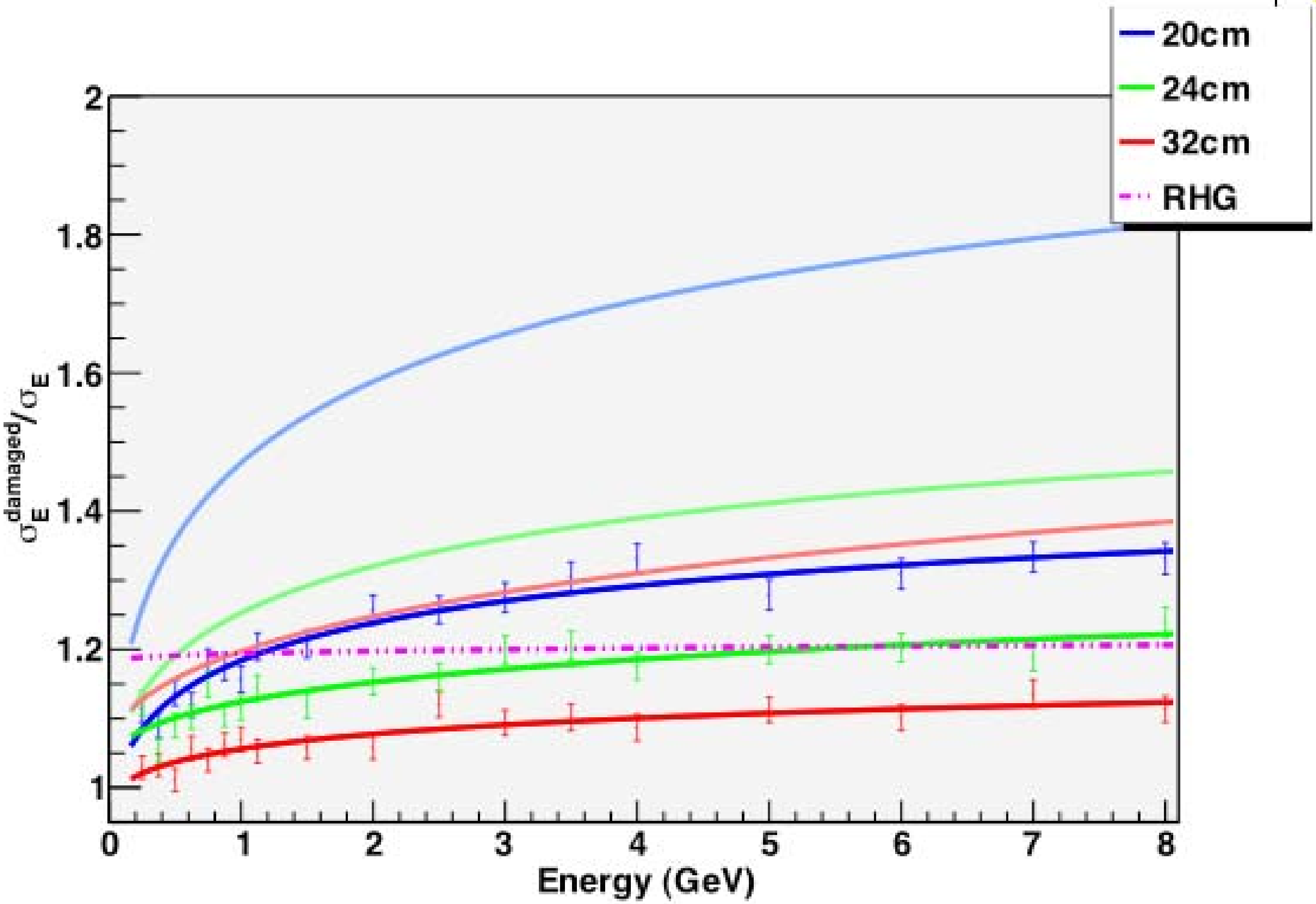
FCAL after 3 years of running



FCAL after 5 years of running



FCAL After 5 Years of Running with Uncertainty in the Transmission

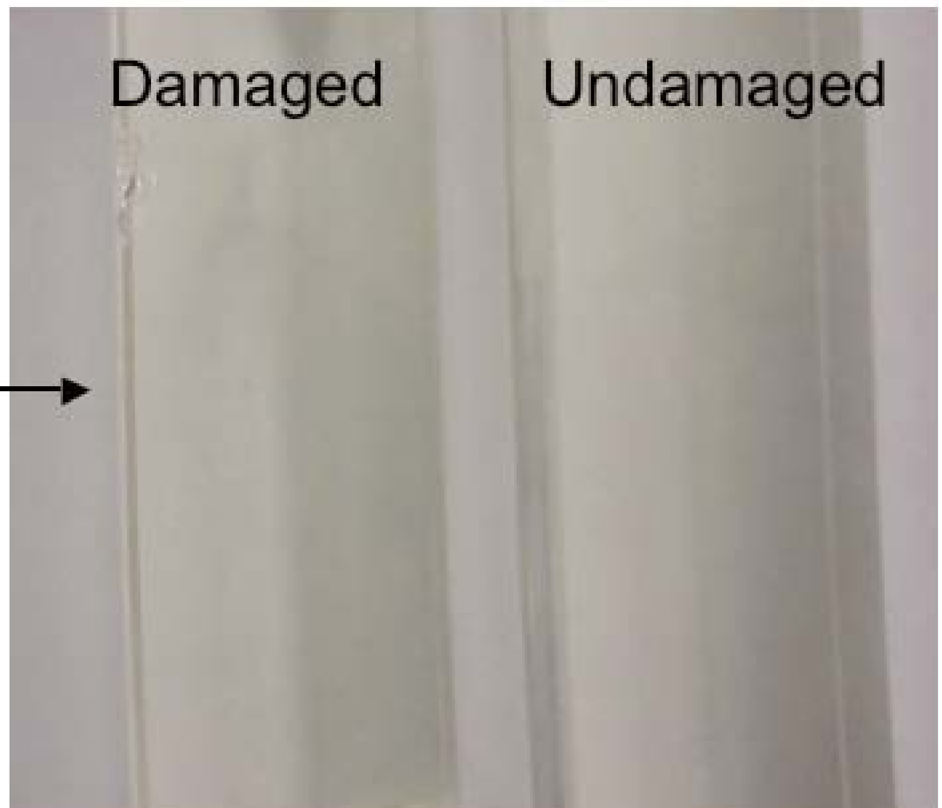


This Analysis Required the Assumptions:

- 10^8Hz beamrate for photons on target
- 10^7s runtime in a year
- No natural or artificial curing of blocks
- Faraday Cup collected all electrons (lower limit on current)
- All of the energy is deposited in first 14mm (really 81%)
- First 7 mm same as second 7 mm (6% relative difference)
- RHG energy resolution is unaffected by radiation dosage (see next slide)
- EM Background Simulation is accurate

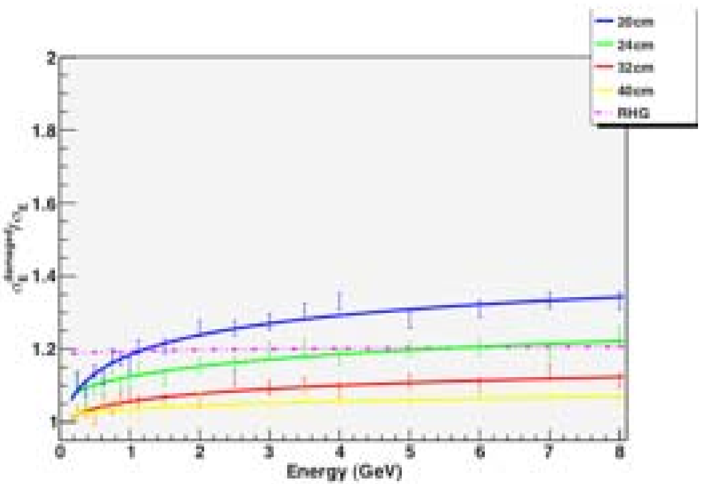
Measuring the radiation hardness of F108

- Dosed F108 for ~700kRad (~70 years of running)
- Damaged F108 produced ~12% worse transmission for 400 nm compared to undamaged F108
- F8 for the same amount of dosage produced ~100% transmission loss



Conclusion

- A radius of F108 between 24cm (100 blocks, aggressive) and 32 cm (184 blocks, conservative) appears to be a good radius for the radiation hard glass

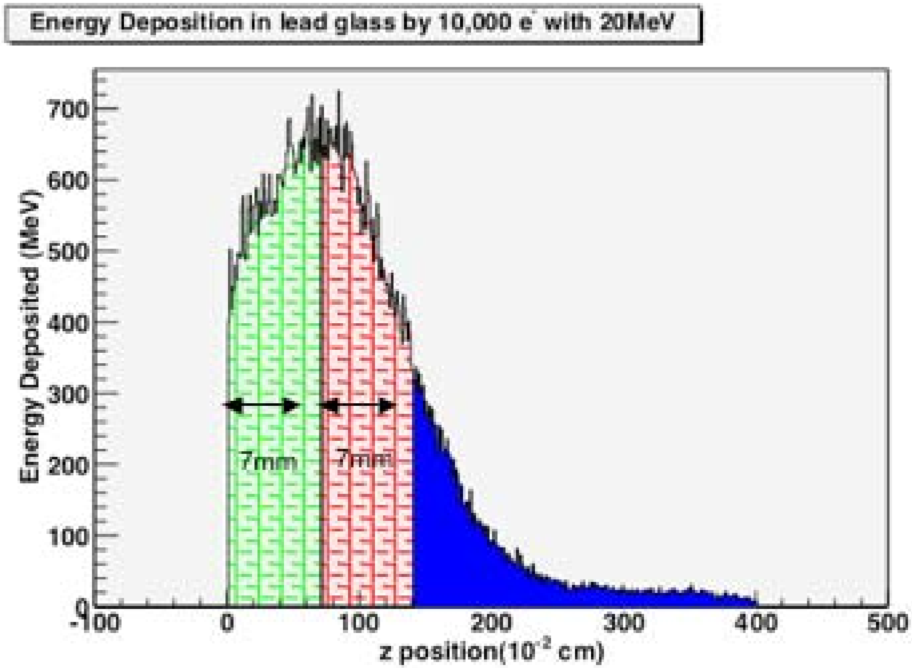


Backup Slides

Aside: Determining the Energy Resolution of F108

- We inserted the undamaged F108 data from the spectrophotometer into a GEANT4 simulation to determine the energy resolution of the RHG
- The detector setup included the lead glass, aluminum foil, cookie, light guide, PMT window and PMT Cathode
- The quantum efficiency of the PMT was included in the simulation.
- The indices of refraction for various wavelengths were inserted.
  - Assuming F108 radiation hard has equivalent indices as its non-hard counterpart F8 (the regular lead glass)
- A 7 block by 7 block array using 1 GeV photons was used to determine the energy resolution

Developing Model of Damage



We assume that all of the transmission loss is due to the energy deposited in the first 14mm

This means the assumed transmission loss is worse than the actual transmission loss for the first 14mm (a worst case)

We also assume the energy deposited in the first 7mm is equal to the energy deposited in the second 7mm

So $T_2 = A \cdot exp(B \cdot Dose(kRad)) + C$

and is valid over 14 mm of lead glass

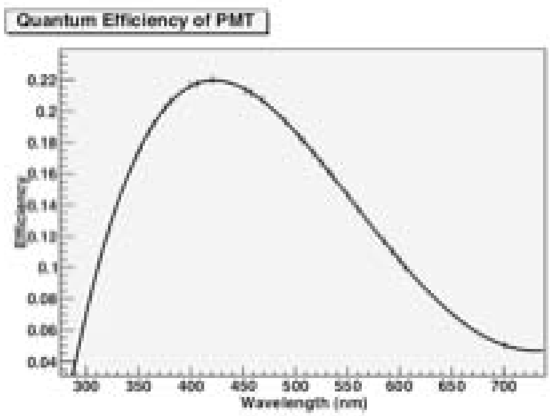
Because of the symmetry in the the first 14 mm we can say

$$T_1 = \sqrt{A \cdot exp(B \cdot Dose(kRad)) + C}$$

Developing Model of Damage

- Now we can calculate the transmission of a particular wavelength through 0.7 mm of lead glass that has been damaged with the equation $T_1 = T_\lambda$ (indexing each function by the wavelength)
- But no single wavelength can properly model the energy resolution of the FCAL
- Other factors need to be accounted for like $1/\lambda^2$ distribution of photons from Cherenkov light and the photo efficiency of the PMT

$$T_1 = \sqrt{A \cdot exp(B \cdot Dose(kRad)) + C}$$



Quantum efficiency of PMTs as a function of wavelength

Can combine all this into one equation

$$T_{\text{eff}}(z_0, R) = \sum_{\lambda} \prod_{z=z_0}^{z_f} T_\lambda(z, Dosage(R))\epsilon(\lambda)n(\lambda)$$

Converting to kRad

- Using GEANT4 simulations of energy deposition in a 2.4 cm by 2.5 cm by 4 cm block dosed with 10,000 electrons with energy of 20 MeV we can convert the number of electrons per dose to radiation dosage in kRad (consistent with Ryan's simulations)
- We dosed the blocks from ~25kRad to ~700kRad
  - The FCAL will receive ~10kRad/year dosage certain sections of the inner blocks
- After dosing, we measured the transmission of light as a function of wavelength through the block using a spectrophotometer
- The end goal is to create a model, to predict the change in energy resolution due to the damage, to implement into HDGEANT