ECAL for GEp5

B. Wojtsekhowski

Electron Calorimeter For GEp5

Performance Requirements

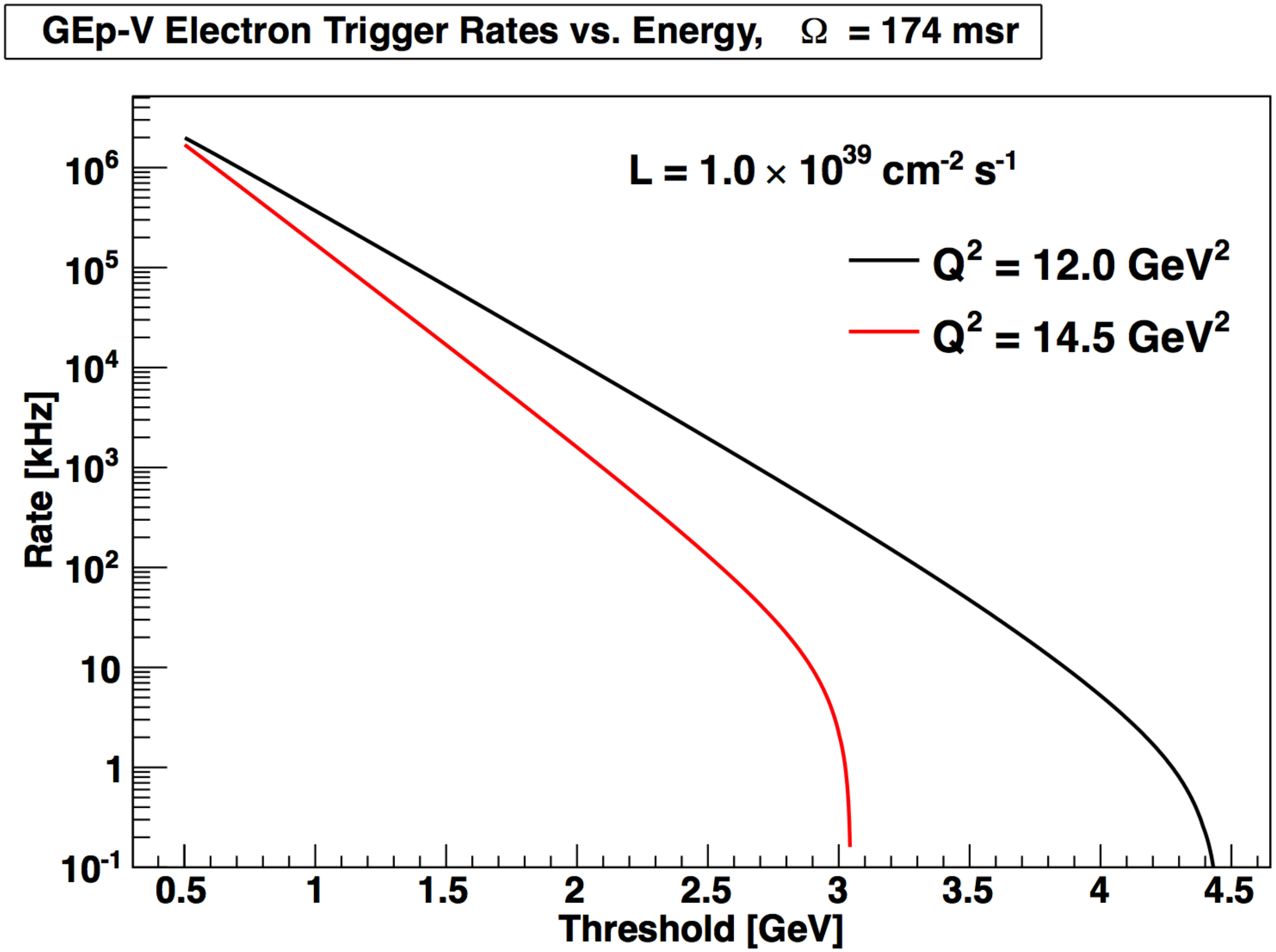
- Function: Detect 4 to 5 GeV Electrons
- Energy resolution: σ/E ~10% for 3.5 GeV electrons
- Spatial resolution: 6-8 mm
  (2 mm with upstream coordinate detector)
- Full luminosity: 8 10^{38} Hz/cm^2
- Trigger: 20 cm thick AL reduces background
  Signal summing capabilities
  Trigger at 75% of elastic peak

Several slides are from G.Franklin's report

E ... 5

Perfor

- Fun
- Ener
- Spat ... ate detector)
- Full

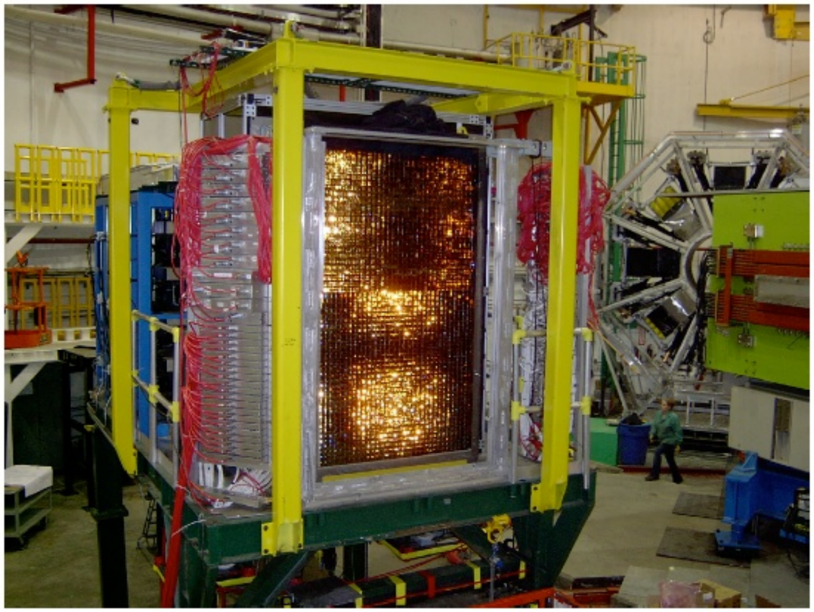


- Trigger: 20 cm thick AL reduces background
  Signal summing capabilities
  Trigger at 75% of elastic peak

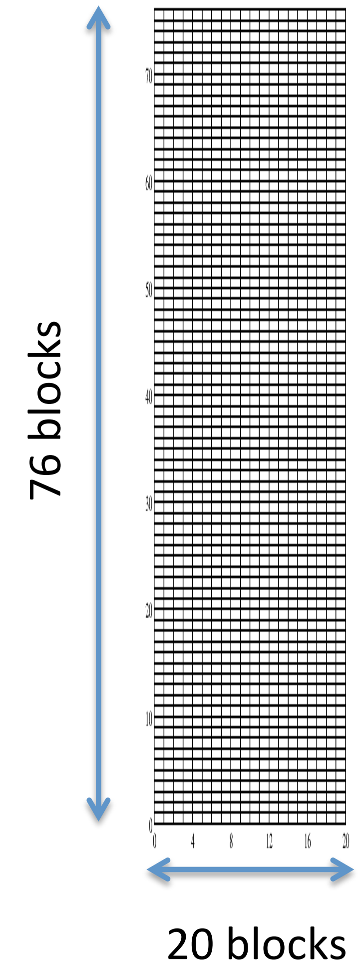
Several slides are from G.Franklin's report

BigCal for GEp experiment

Used in Hall C GEp3



Reconfigure



- Existing lead-glass calorimeter
- Reconfigure: 1520 blocks ?
- Block size : 4x4x40cm^3 and 3.8x3.8x45 cm^3
- Area: 0.80 m x 3.04 m = 2.4 m^2

Several slides are from G.Franklin's report

eCal Development

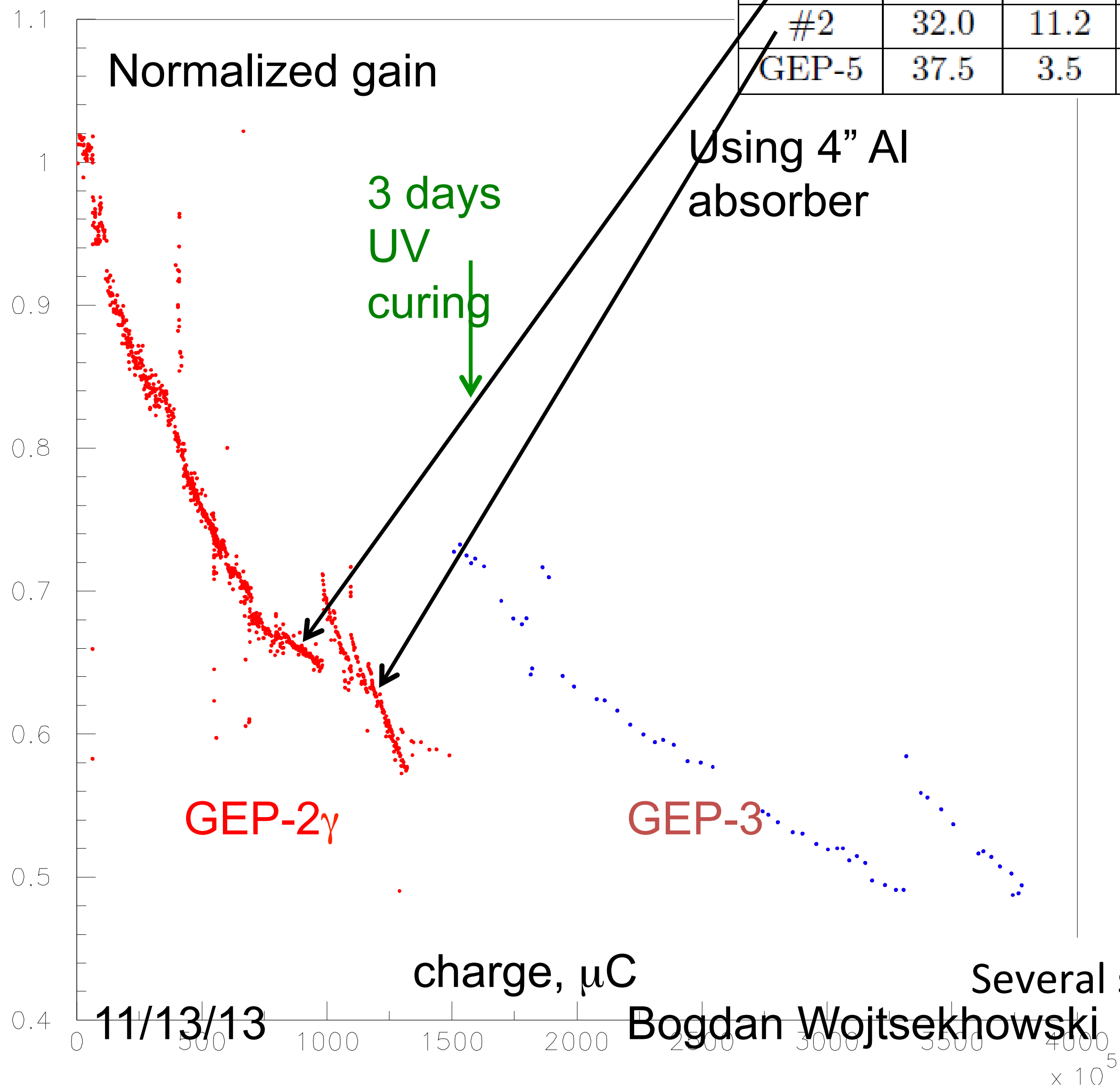
Per Review panel comment: "The lead glass radiation damage and cure rates should be tested with prototype setups under realistic conditions."

- Plan is: UV recovery (needs 5x UV power density rel. GEp3)
  - Test irradiations at Idaho State University
  - Existing experience from GEp3
- New idea: Continual bake-out scheme
  - Heat front of crystals to 300 C, back at 250 C
  - Thermal radiation appears acceptable for PMT
  - Tests are under preparation
- Alternative to BigCal:
  - LAC calorimeter (Pb-scint. bars) from CLAS6
  - Used calorimeter from DESY

Several slides are from G.Franklin's report

BigCal Radiation damage and UV curing

kin.	angle deg.	Dist. m	Target cm	E GeV	Gain loss rate b	soft photon flux J/cm^2/C
#1	44.9	12	20	2.839	0.14%/C	0.0039
#2	32.0	11.2	20	3.539	0.53%/C	0.013
GEP-5	37.5	3.5	40	3.539	~6.7%/C	0.17



Data Geant3 simulations estimation

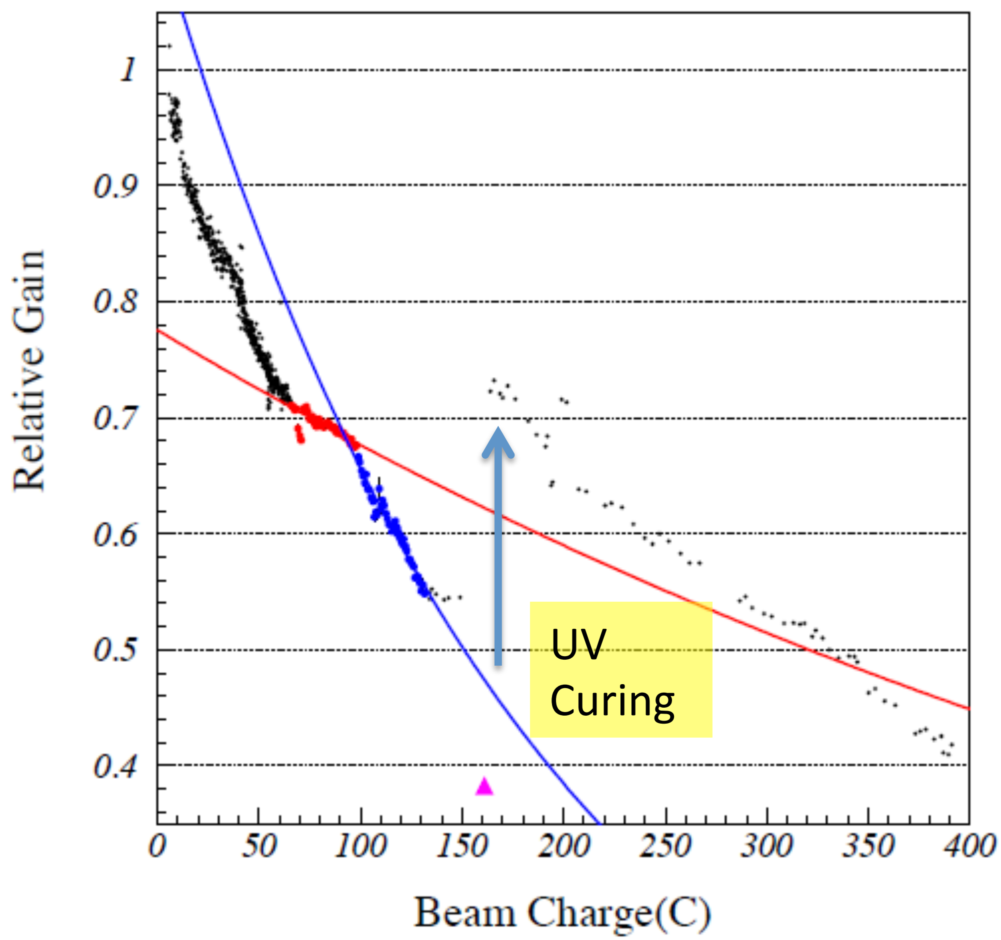
Several slides are from G.Franklin's report

ECAL version #1 is based on lead glass annealing

1. UV-induced annealing

2. Thermal annealing

UV Curing



Hall C Experience:

- UV cured the BigCal for 3 days on each ¼ of the detector.
- Improved the gain from 39% to 74%
- Rate of improvement is 1.24%/hr

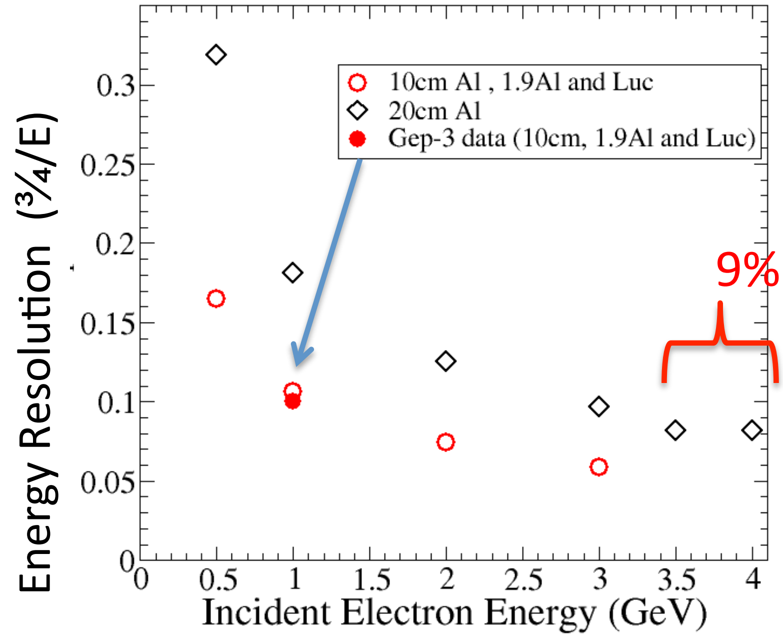
GEp5:

- Need to be cured 6% /hr
- Will increase UV intensity by x5
- UV cure for 1hr after 7 hours of running. (Need to have HV off)

BigCal Performance

Energy Resolution

Simulation shows 10% energy resolution maintained even after increasing absorber thickness

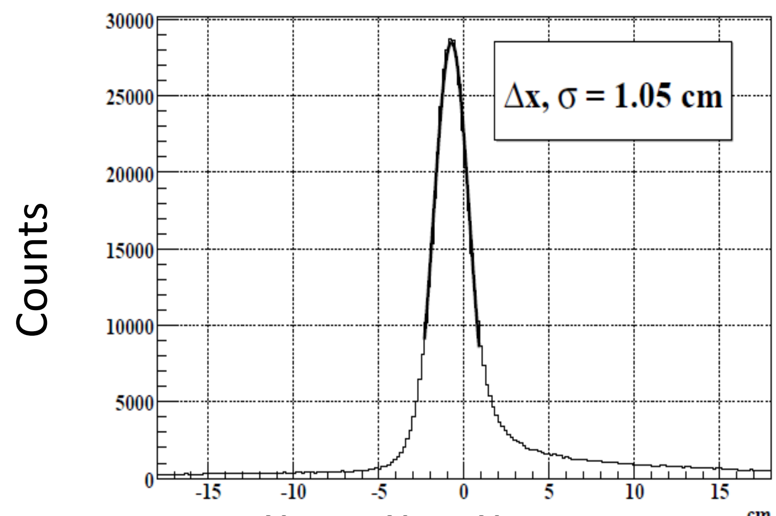


Spatial Resolution

Measured in GEp3

Subtract contributions of HMS, add additional absorber

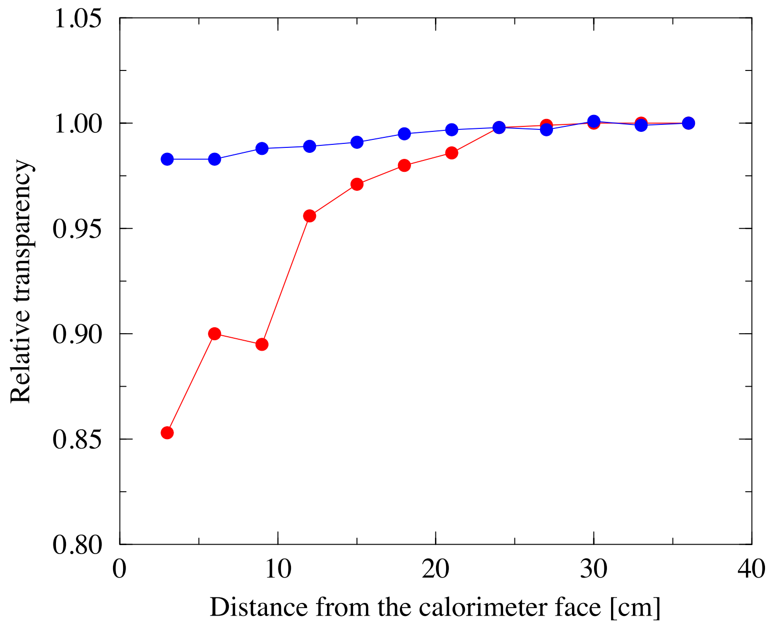
=> Achieve σ ~ 6 mm



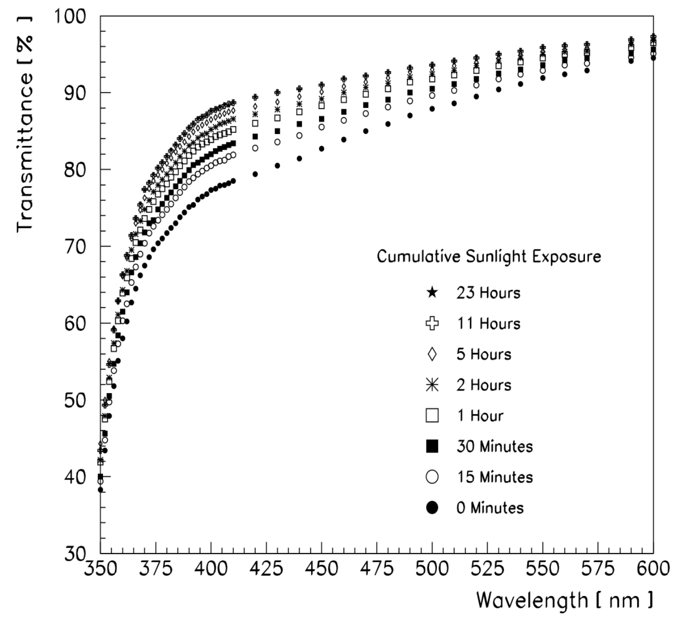
$x_{diff} = x_{cal} - x_{HMS}$

Radiation damage

RCS calorimeter study



from E790 thesis



Variation of optical band gap with radiation dose in $PbO–B_2O_3$ glasses

S. Baccaro [a,*], Monika [b], G. Sharma [a,c,*], K.S. Thind [b], D.P. Singh [b]

[a] *ENEA/FIM, Casaccia RC, Via Anguillarese 301, S. Maria di Galeria, Rome 00123, Italy*
[b] *Department of Physics, Guru Nanak Dev University, Amritsar 143005, India*
[c] *Department of Physics, Kanya Maha Vidyalaya, Jalandhar, India*

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Radiation damage

Radiation Damage of F8 Lead Glass with 20 MeV Electrons

B. D. Schaefer[a], R. E. Mitchell[a], P. McChesney[b], M. R. Shepherd[a,*], J. M. Frye[a]

[a] *Indiana University, Bloomington, Indiana 47405, USA*
[b] *Center for the Exploration of Energy and Matter, Indiana University, Bloomington, IN 47408, USA*

400 kRad from 10^{14} electrons

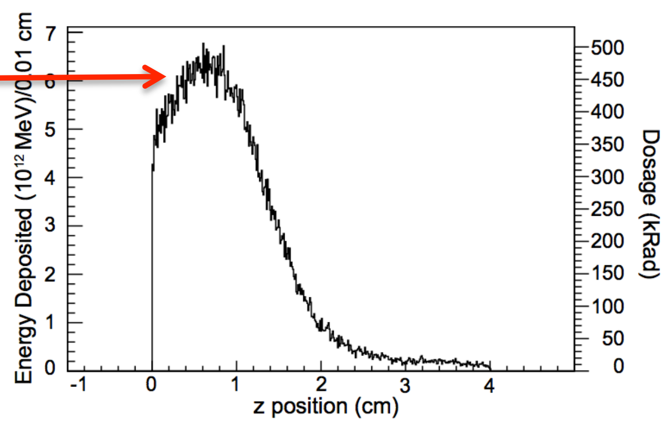
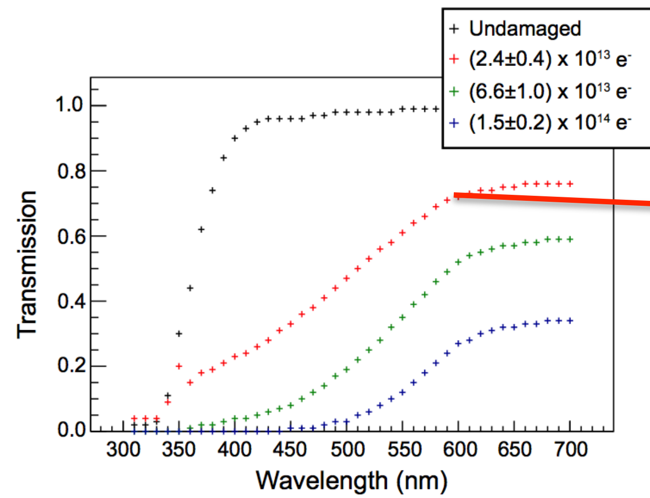


Figure 4: GEANT4 simulation of energy deposition of 10^{14} 20 MeV electrons as a function of depth in a 2.4 cm × 2.5 cm × 4 cm volume of lead glass. The dosage scale assumes a volume element of 2.4 cm × 2.5 cm × 0.01 cm.



80 kRad

Figure 5: Transmission coefficient of 4 cm of lead glass as a function of wavelength for various amounts of radiation. Estimated errors are 2% (10%) for wavelengths above (below) 380 nm.

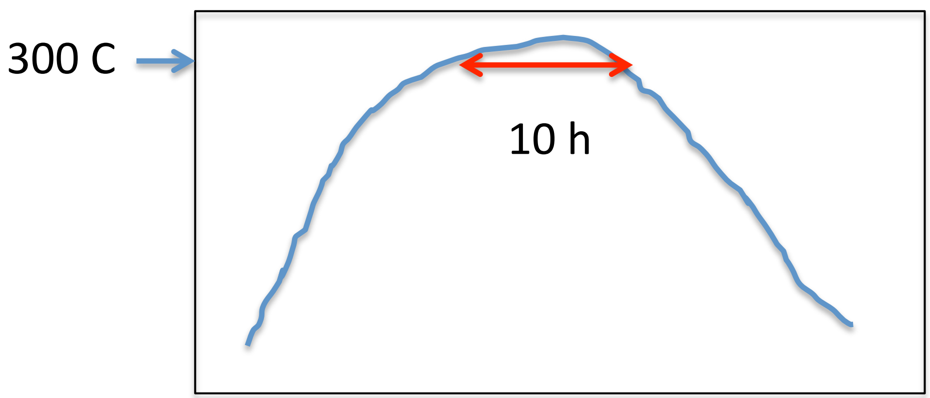
ECAL with Thermal annealing of lead glass **<u>in situ</u>**

1. Experimental data on thermal annealing
2. Annealing speed and Electrical conductivity vs. temperature
3. PMT dark current induced thermal radiation
    a) Emissivity of glass and a heater
    b) Test result
4. Temperature distribution and stresses
5. Power of heating
    a) Heat conductivity of glass, glass wool
    b) First test with front heater

ECAL with Thermal annealing of lead glass **in situ**

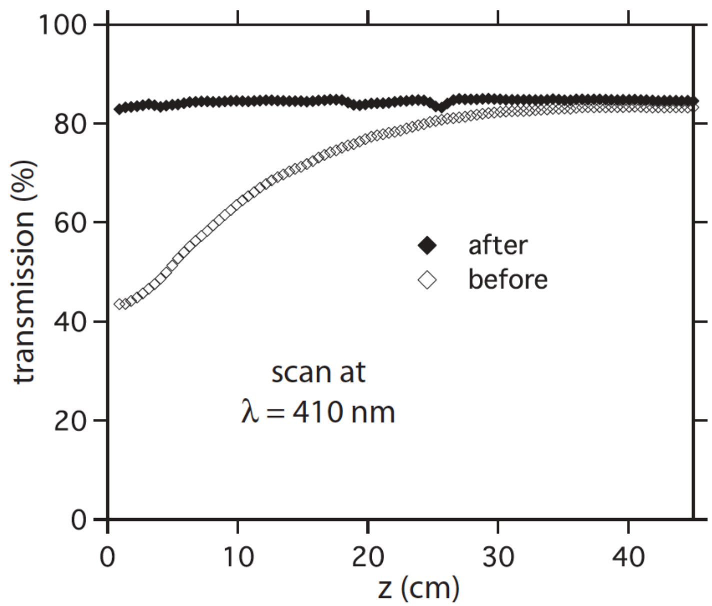
Experimental data on thermal annealing

a) 200 HRS shower blocks
b) Few RCS blocks
c) 600 Hall D blocks



ECAL with Thermal annealing of lead glass **in situ**

Figure 4.4 shows the transmission of light, at $\lambda = 410$ nm, through 4 cm of lead glass as a function of distance along the bar for a radiation-damaged bar before and after heat curing at 260 °C. The $z = 0$ position corresponds to the upstream end of the bar during data taking, *i.e.* the end of the bar closest to the source of the photon beam.



12 hours at 260 C household oven

Figure 4.4: Transmission of light, at $\lambda = 410$ nm, through 4 cm of lead glass as a function of distance along the bar for a radiation-damaged bar before and after heat curing at 260 °C.

Electrical conductivity of glass

	Property	Value	Conditions	
Material: Glass (SiO2), bulk. MEMS and Nanotechnology Clearinghouse.	Electrical resistivity	1e+09 … 3.98e+11 Ω*m	Glass,at temp=250 C	790 Ωm to 3.98×10^{11} Ωm
	Electrical resistivity	3.16e+06 … 6.3e+08 Ω*m	Glass,at temp=400 C	
	Electrical resistivity	630000 Ω*m	Glass,at temp=500 C	
	Electrical resistivity	4600 Ω*m	Glass,at temp=1000 C	
	Electrical resistivity	790 Ω*m	Glass,at temp=1500 C	

At ~400 C change by a factor of 1000 per 100 degrees

Measurement for the lead glass is needed!

Electrical conductivity of glass

$$\Omega = C \times 10^{(4500/T)}$$

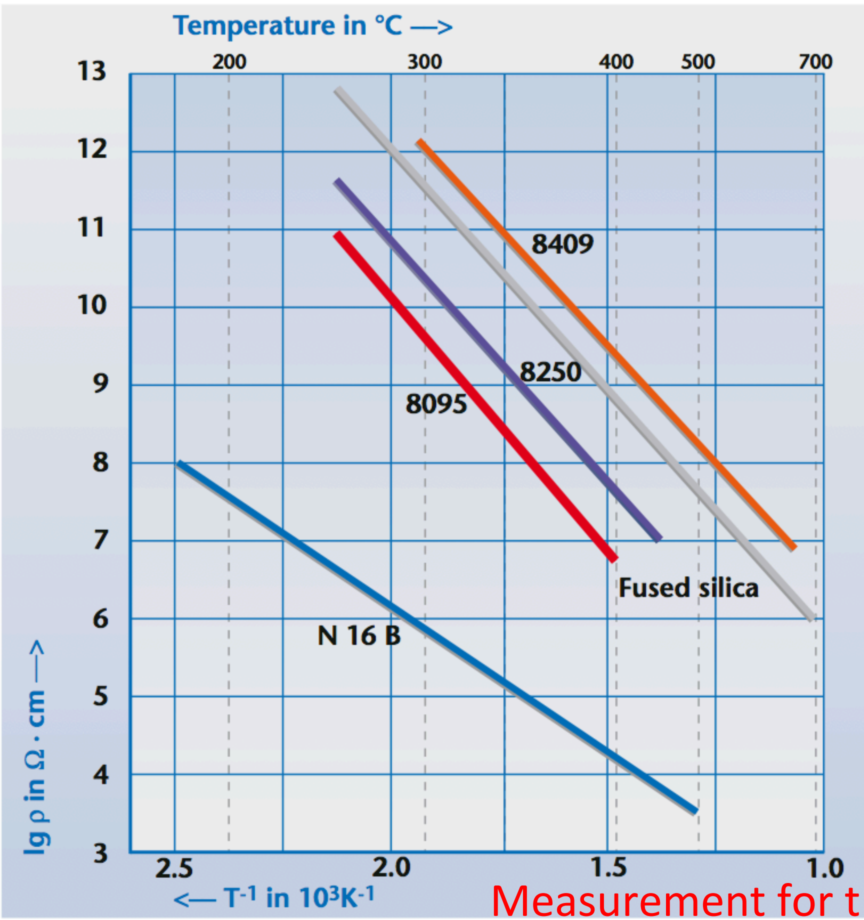


Fig. 21. *Electrical volume resistivity of various technical glasses and fused silica related to the reciprocal of absolute temperature*

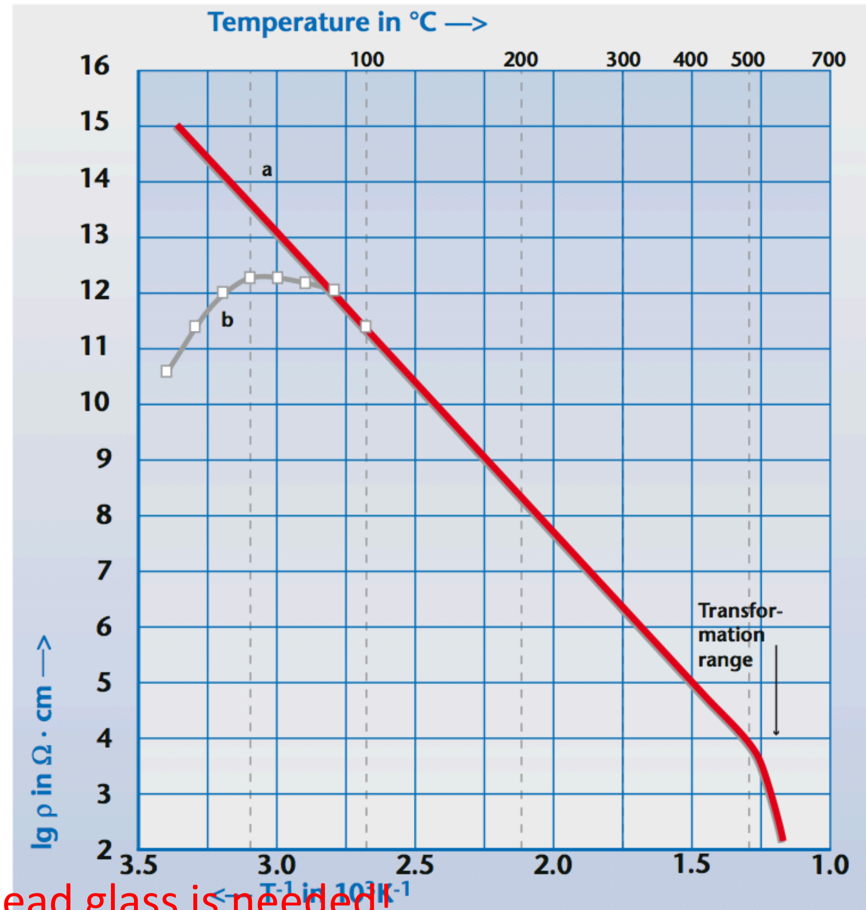


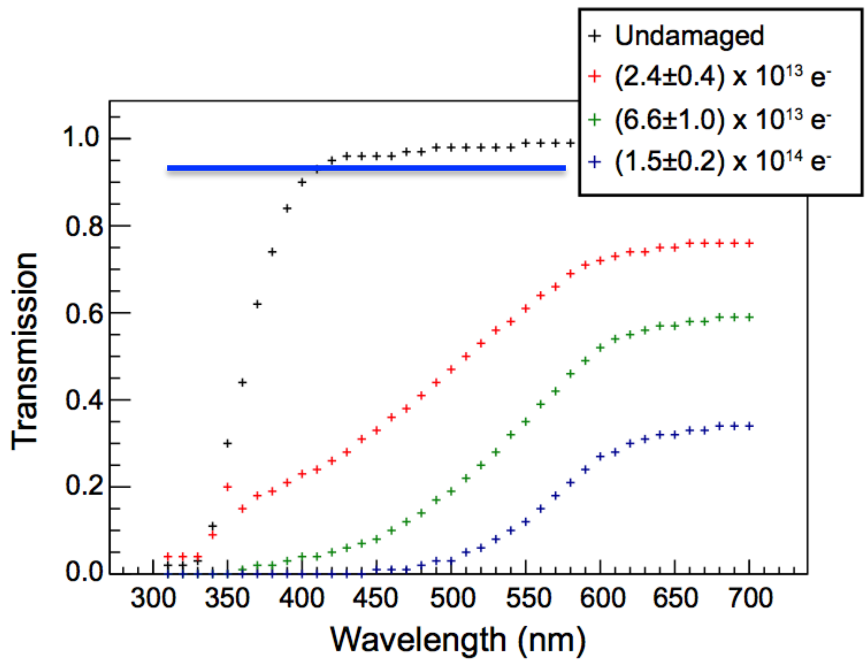
Fig. 22. *Electrical resistance ρ of a soda-lime glass related to temperature (a) without, and (b) with hydrated layer*

Measurement for the lead glass is needed!

PMT dark current induced TR

a) Emissivity of glass and a heater

100% = Emissivity + Transmissivity + Reflectivity



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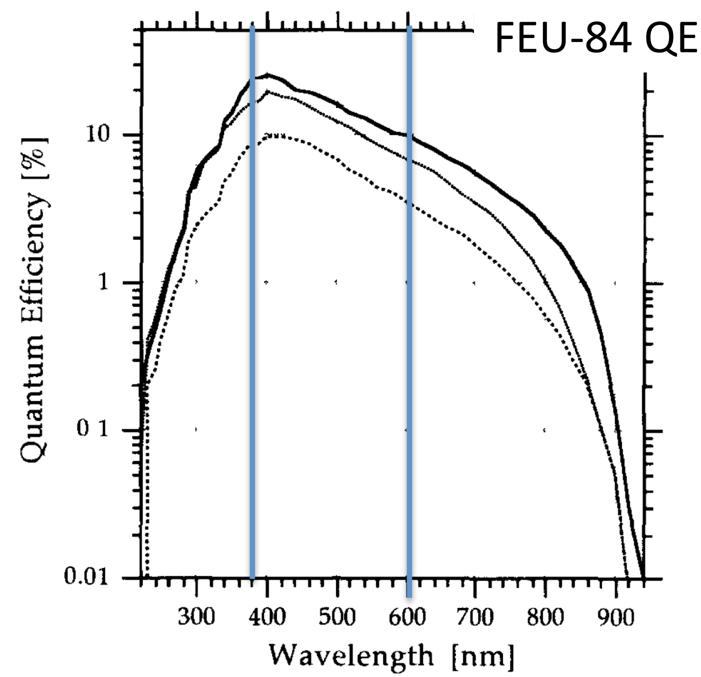


Fig. 4. The absolute quantum efficiency of three FEU-84-3 phototubes as measured by Hamamatsu Inc. using a calibrated source. Three tubes were selected, using the method described in the text, as having relatively high, medium and low relative quantum efficiencies.

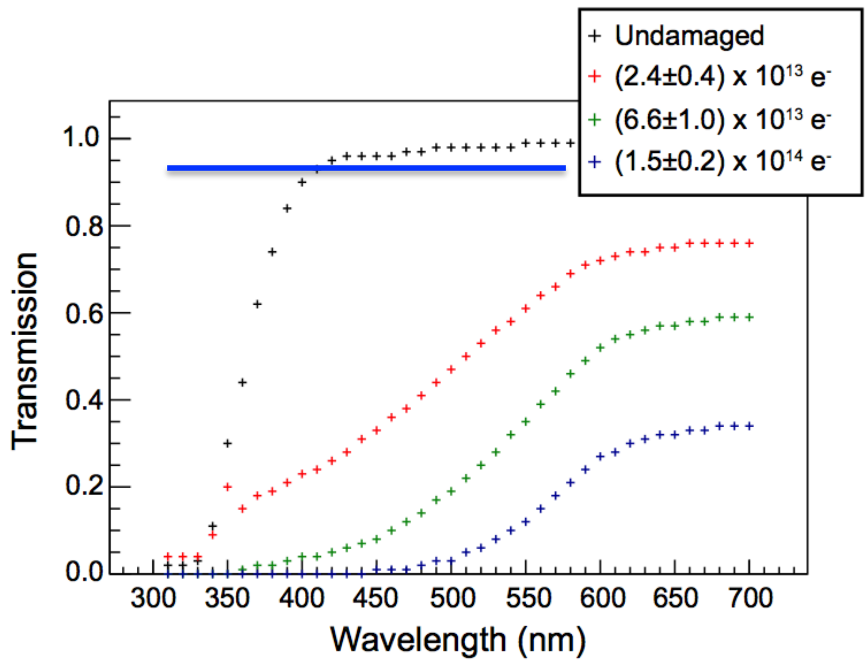
PMT dark current induced TR

a) Emissivity of glass and a heater

$$J_{ph} \propto \exp\left(-h\omega/kT\right)$$

100% = Emissivity + Transmissivity + Reflectivity

$$kT \sim 1/20\,eV;\, h\omega \sim 3\,eV$$



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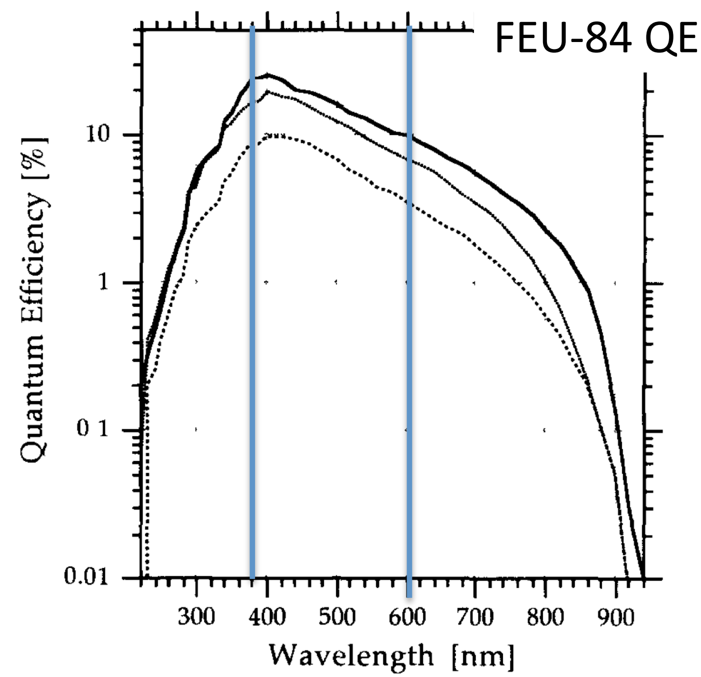

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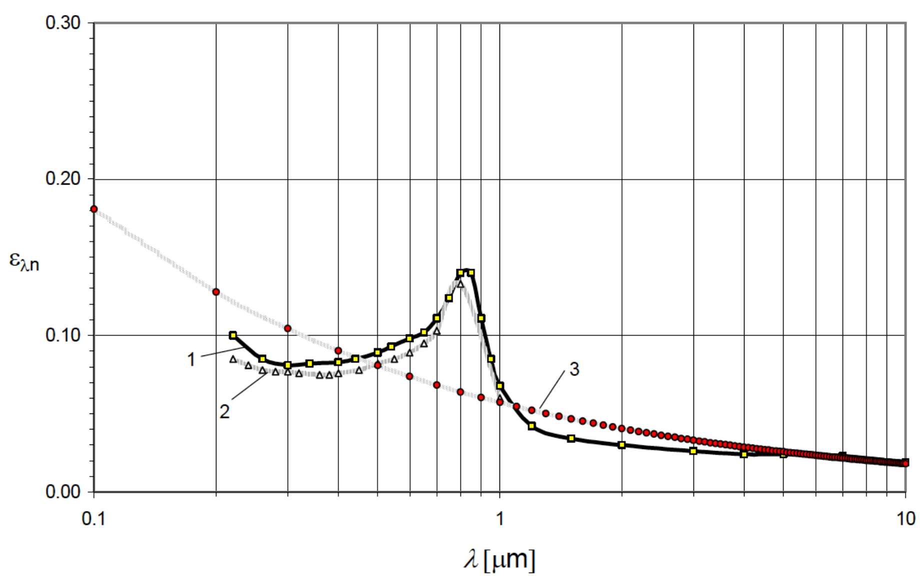
PMT dark current induced TR

a) Emissivity of glass and a heater

100% = Emissivity + Transmissivity + Reflectivity
A polished aluminum surface with emissivity = 0.12 has reflectivity = 0.88.



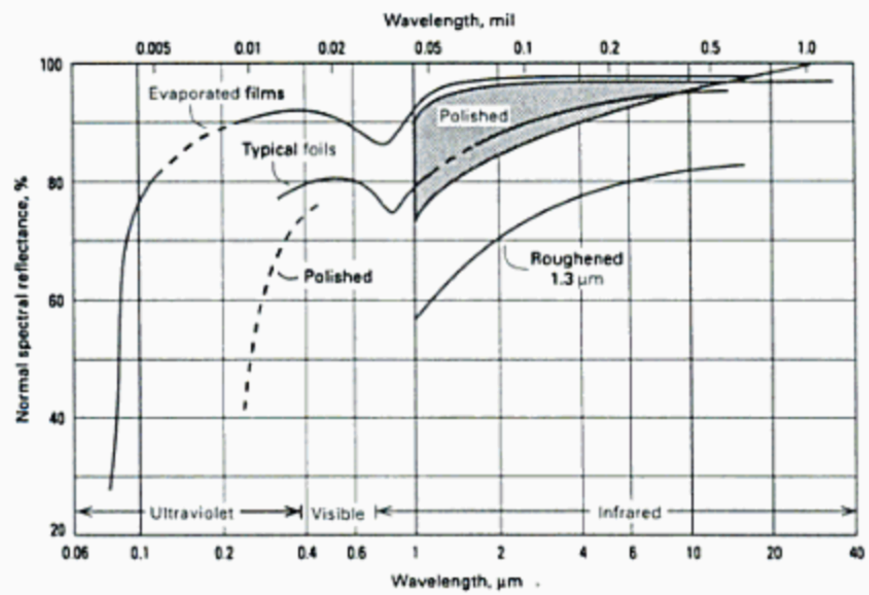


Fig. 4 Spectral reflectance of aluminum. Source: Ref 33

PMT dark current induced TR

a) Emissivity of glass and a heater

- Mechanics
- Miscellaneous
- Physiology
- Piping Systems
- Process Control
- Pumps
- Standards Organizations
- Steam and Condensate
- Thermodynamics
- Water Systems

Convert Units

Temperature

0.0

°C

°F

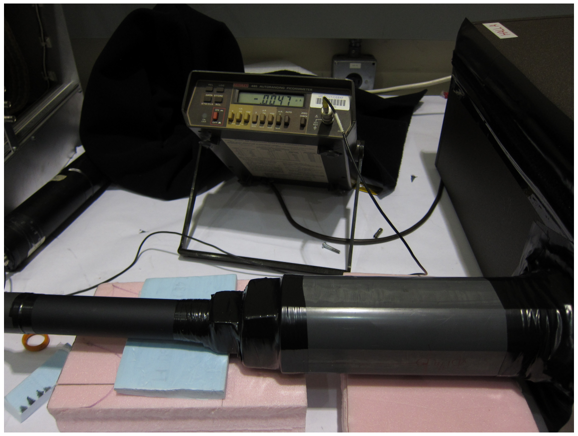
Convert!

Length

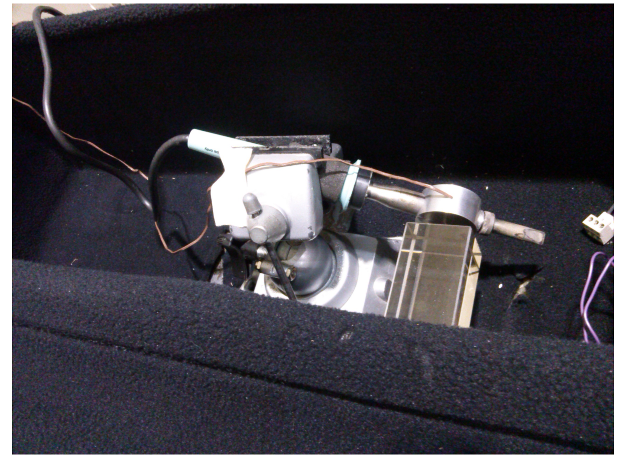
1.0

Surface Material	Emissivity Coefficient - ε -
Alloy 24ST Polished	0.09
Alumina, Flame sprayed	0.8
Aluminum Commercial sheet	0.09
Aluminum Foil	0.04
Aluminum Commercial Sheet	0.09
Aluminum Heavily Oxidized	0.2 - 0.31
Aluminum Highly Polished	0.039 - 0.057
Aluminum Anodized	0.77
Aluminum Rough	0.07
Aluminum paint	0.27 - 0.67
Antimony, polished	0.28 - 0.31
Asbestos board	0.96
Asbestos paper	0.93 - 0.945
Asphalt	0.93
Basalt	0.72
Beryllium	0.18
Beryllium, Anodized	0.9
Bismuth, bright	0.34
Black Body Matt	1.00
Black lacquer on iron	0.875

PMT dark current induced TR



a) Emissivity of glass and a heater
b) Test result



With 300 C on Al (not polished) heater the anode current was measured in the PMT attached to the lead glass module (at room T). Projected to the actual gain in GEp5 experiment the current is of 170 nA Such a current will shift the pedestal by 1.7 MeV. Further reduction by a factor of 5 is due to low emissivity of polished Al

Thermal stress

Example 2.8 When a beam of a rectangular cross section $b \times h$ is subjected to a temperature change $T(y, z) = C_0 + C_1 y + C_2 z$, what thermal stress is produced in the beam?

Solution The substitution of the temperature change $T(y, z) = C_0 + C_1 y + C_2 z$ into ...tion 2.5.1 gives

Longitudinal gradient

$$\int_A \alpha E T(y,z)\, dA$$

$$\int_{-b/2}^{b/2} \int_{-h/2}^{h/2} \alpha E (C_0 + C_1 y + C_2 z)\, dy\, dz = \alpha E b h C_0$$

$$\int_A \alpha E T(y,z) z\, dA$$

$$\int_{-b/2}^{b/2} \int_{-h/2}^{h/2} \alpha E \left(C_0 z + C_1 y z + C_2 z^2\right) dy\, dz = \frac{1}{12} \alpha E b^3 h C_2$$

Heat leak to the sides is the only concern: It creates the stress

$$\int_A \alpha E T(y,z) y\, dA$$

$$\int_{-b/2}^{b/2} \int_{-h/2}^{h/2} \alpha E \left(C_0 y + C_1 y^2 + C_2 y z\right) dy\, dz = \frac{1}{12} \alpha E b h^3 C_1$$

250		250
	300	
250		250

$$= bh, \qquad I_z = \frac{1}{12} b h^3, \qquad I_y = \frac{1}{12} b^3 h, \qquad I_{yz} = 0$$

...rmal stress (2.37) reduces to

$$\sigma_x = -\alpha E (C_0 + C_1 y + C_2 z) + \frac{\alpha E b h C_0}{bh} + \frac{\alpha E b h^3 C_1/12}{b h^3/12} y + \frac{\alpha E b^3 h C_2/12}{b^3 h/12} z = 0$$

The parameters of glass

Main properties of soda lime silicate glass

Volumic mass ρ at 18°C	2,500 kg/m³
Young's modulus (E)	70,000 N/mm²
Modulus of rigidity (G)	29,166 N/mm²
Poisson's ratio (ν)	0.2
Mohs' hardness	6
Melting temperature	≈ 1,500°C
Softening point	≈ 600°C
Linear expansion coefficient (α)	9.10^{-6} m/(m.K)
Thermal conductivity (λ)	1 W/(m.K)
Specific heat capacity (c)	720 J/(kg.K)
Characteristic bending strength:	
annealed glass *	45 N/mm²
heat-strengthened glass *	70 N/mm²
thermally toughened glass *	120 N/mm²
Compression resistance	1000 N/mm²
Thermal transmittance (single glazing 4 mm)	5.8 W/(m².K)
Refraction index (n) compared to air	1.5
Light transmission (single glazing 4 mm)	0.90
Solar factor (single glazing 4 mm)	0.87
Normal emissivity of non-coated glass or coated glass with no impact on emissivity	0.89

Acceptable temperature "gradient" is of 50 C/cm

Heating power in situ

Thermal Conductivity - *k* -(W/m.K)			
Material	Temperature (^oC)		
	25	125	225
Acetone	0.16		
Acrylic	0.2		
Air	0.024		
Aluminum	250	255	250
Ammonia	0.022		
Antimony	18.5		
Argon	0.016		
Asphalt	1.26		
Balsa	0.048		
Bitumen	0.17		
Benzene	0.16		
Beryllium	218		
Brass	109		
Brick dense	1.6		
Brick work	0.5		
Cadmium	92		
Carbon	1.7		
Cement	1.01		
Cobalt	69		
Concrete	1.05		
Constantan	22		
Copper	401	400	398
Carbon Steel	54	51	47
Cotton Wool insulation	0.029		
Ether	0.14		
Epoxy	0.35		
Felt insulation	0.04		
Glass	1.05		
Glass Wool insulation	0.04		
Glycerol	0.28		
Gold	310	312	310

a) Heat conductivity of glass, glass wool

b) First test with front heater: 30 C/cm

For 40-cm long block at T1=300 C and T2=50 C
the power is 1 Watt/block => total for system of 2000 blocks is of 2 kW

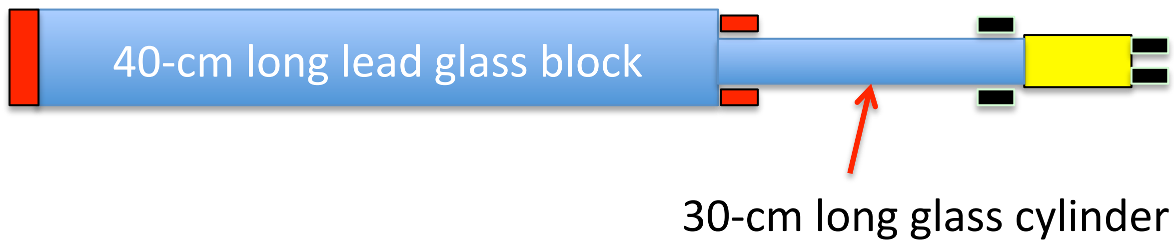
Glass wool layer around: t = 27 cm, area ~ 10 m^2 => 0.4 kW

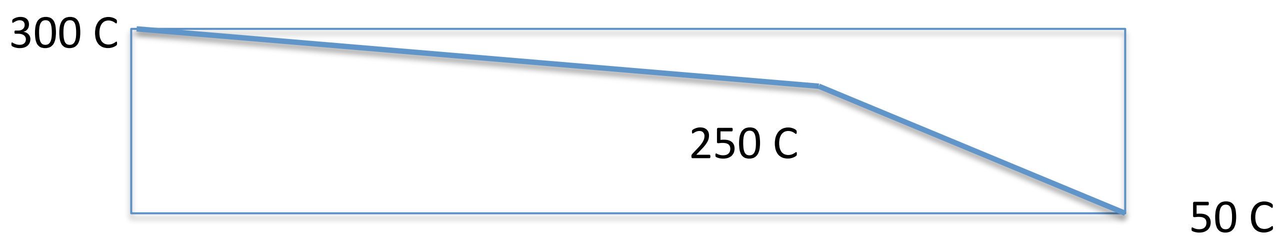
Maybe need to add a distributed heater on the periphery of the calorimeter

1.05 Watt/m/C

0.04 Watt/m/C

The scheme under investigation





Temperature profile

0.008x7x200/30 = 0.4 W heat through light guide

The items to do for ECAL

1. Inventory of the available equipment

i) Lead glass blocks
ii) PMTs
iii) HV bases
iv) Front-end electronics
v) Cables (signal and HV)
vi) HV supplies
vii) NIM electronics

2. Investigation of the Thermal annealing

i) Measure DC for full proposed configuration
ii) Design of 5x5 module
iii) Irradiate 10 blocks and test TA in oven
iv) Measure electrical conductivity vs. T
v) Develop the budget of the 5x5 module
vi) Construct 5x5 module
vii) Full test at Idaho State University

3. Preparation of the required equipment

i) PMTs – test gain, QE
ii) HV bases – test, repair
iii) ....