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A CsI calorimeter for γ-ray space experiments

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Scientific goals : structures in γ-ray energy distributions, point sources and diffuse radiation

Design aim : • Improve $\frac{\Delta E}{E}$ over existing detectors (e.g. EGRET) by an order of magnitude.
• optimize angular resolution

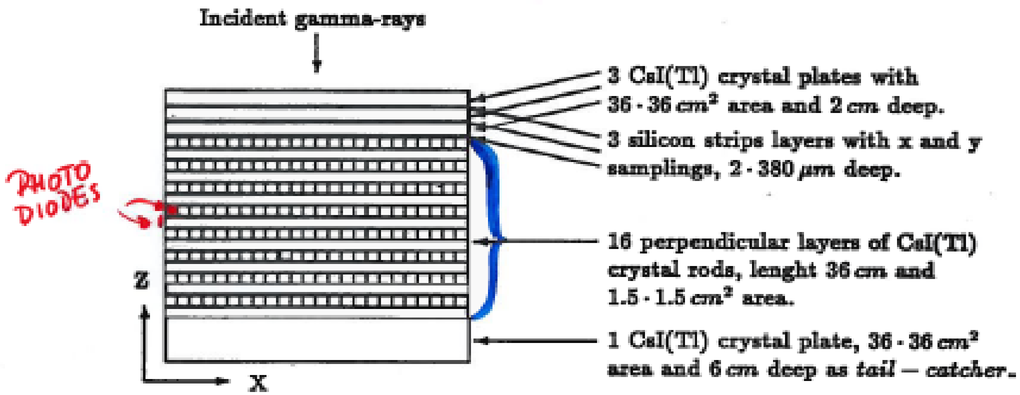


Figure 7.1: Geometrical setup for the final calorimeter prototype.

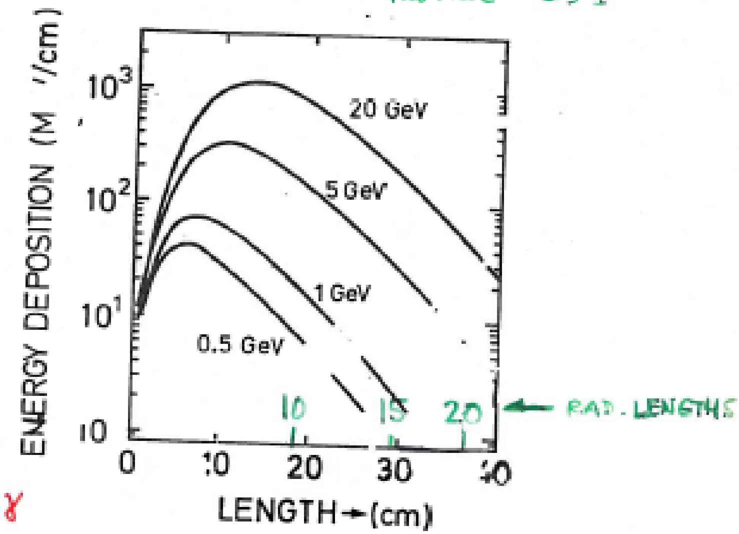
- Total area: 1300 cm^2
- Depth: 36 cm ($19 X_0$)
- Readout: photodiodes

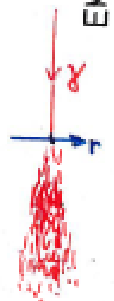
3 plates	2 cm		6 cm
16 layers, 24 rods		1.5 cm	24 cm
1 plate	6 cm		6 cm
Total			36 cm
			(19.5 rad length)

Area $36 \times 36\ cm^2 = 1296\ cm^2$, 211 kg CsI

$50 \times 50\ cm^2 = 2500\ cm^2$, 408 kg CsI

LONGITUDINAL PROFILE CsI





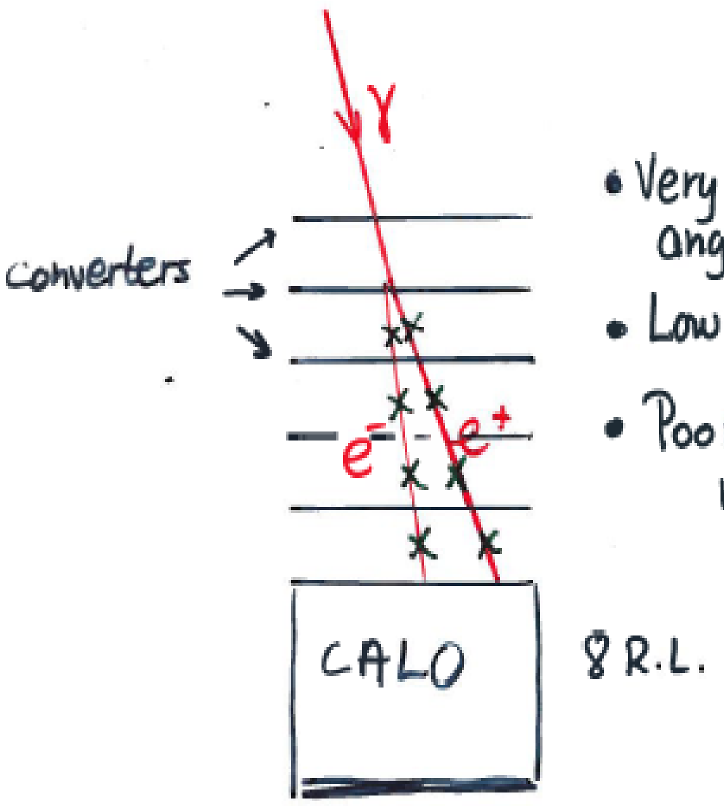
- POSITION OF SHOWER MAX $\propto$ log(E)
- 1 GeV GIVES 3 10^6 PHOTOELECTRONS IN A DIODE – LARGE SIGNAL !!
- LEAKAGE INCREASES WITH E_γ

TRANSVERSE PROFILE :

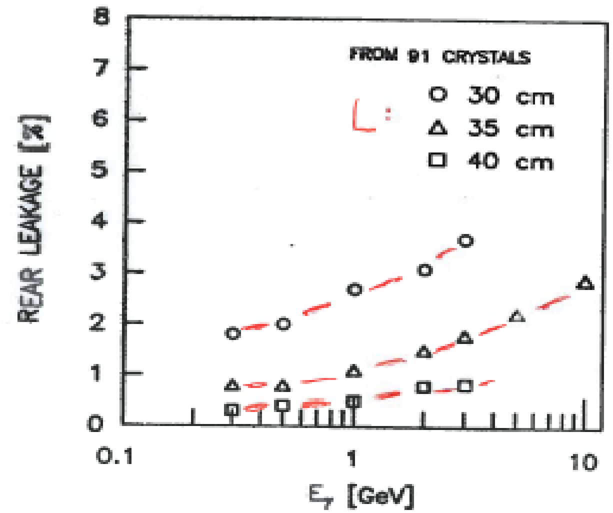
UP TO SHOWER MAX : $r < 1 X_0$ (1.9cm CsI)

AFTER SHOWER MAX : 90% $r < r_M$ (Molière radius) (3.8cm)

Existing γ-ray detectors



- Very good angular resolution
- Low efficiency
- Poor energy-resolution



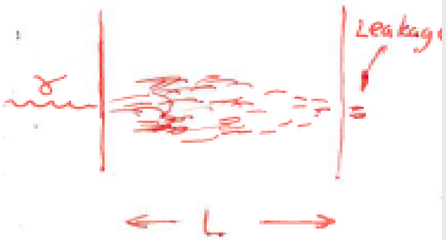
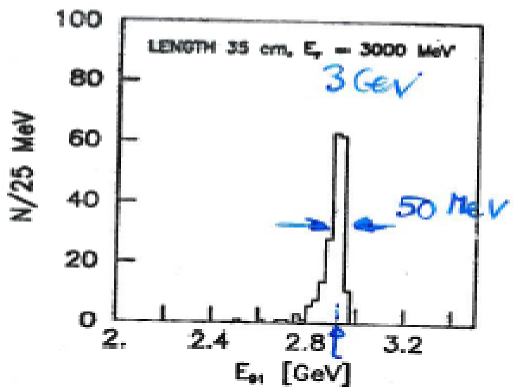


Figure 3. Rear leakage as function of photon energy for different depths of CsI(Tℓ).



ENERGIUPPLÖSNING
(SIMULERINGSRESULTAT)

RMS UPPL. ± 0.7%

Figure 4. Energy deposit in 35 cm CsI(Tℓ) for 3 GeV gamma-ray energy.

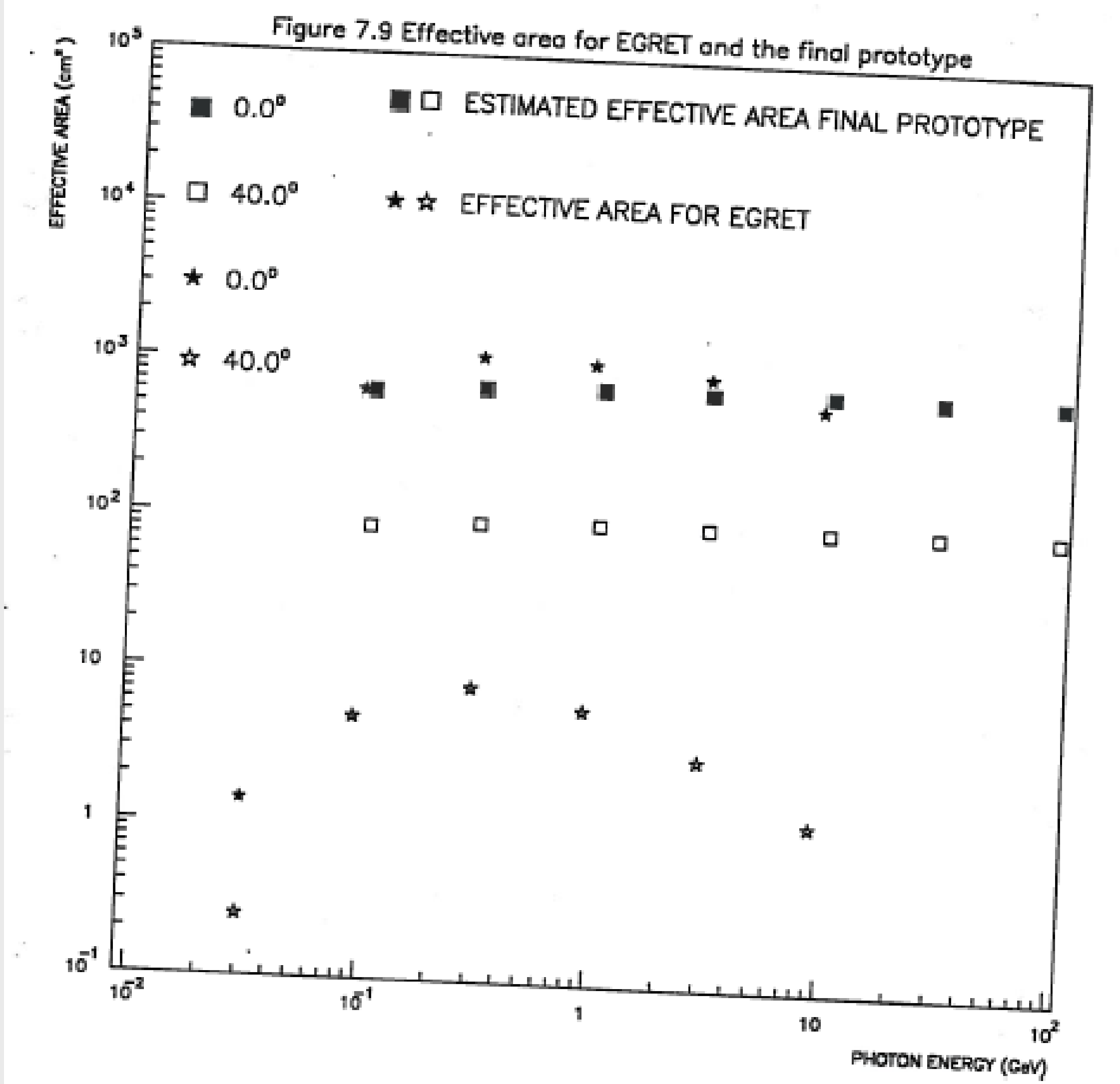


Figure 7.9 Effective area for EGRET and the final prototype
EFFECTIVE AREA (cm²)
0.0°
40.0°
0.0°
40.0°
ESTIMATED EFFECTIVE AREA FINAL PROTOTYPE
EFFECTIVE AREA FOR EGRET
10⁵
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻¹
1
10
10²
PHOTON ENERGY (GeV)

1 GeV Cs I

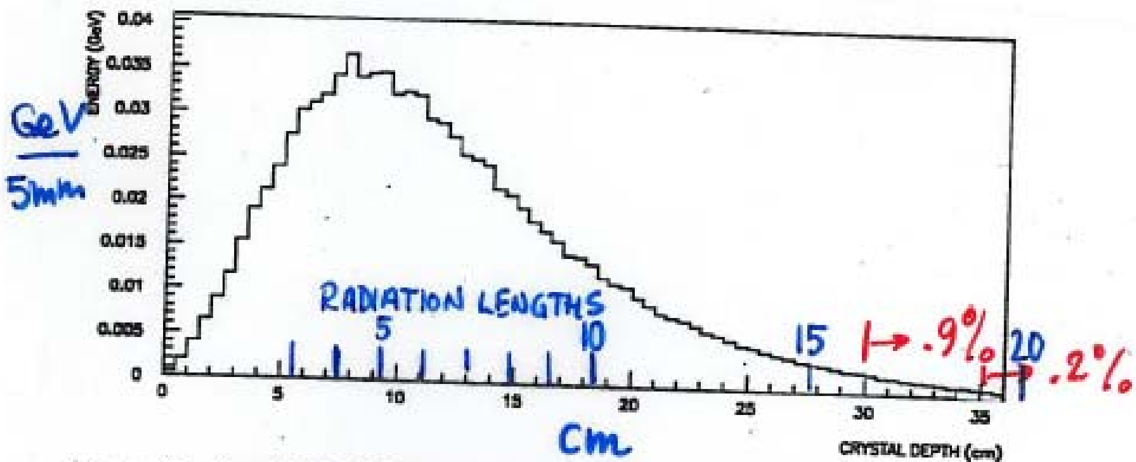


Figure 2.1: *Longitudinal development of an electromagnetic shower with an incident photon energy of $E_0 = 1\,GeV$ in a CsI(Tl) calorimeter from Monte Carlo simulations. Energy deposition per 5 mm CsI(Tl) crystal is shown as a function of crystal depth.*

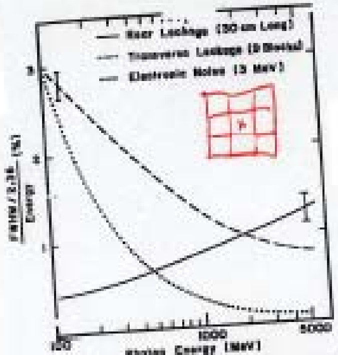


Fig. 3. Contribution to an energy resolution in CsI blocks attributable to the three dominant sources: rear leakage from 30 cm long crystals, transverse leakage from nine square crystals 5 cm on a side, and electronic noise, assumed to be 3 MeV. The error bars show typical uncertainties in the curves.

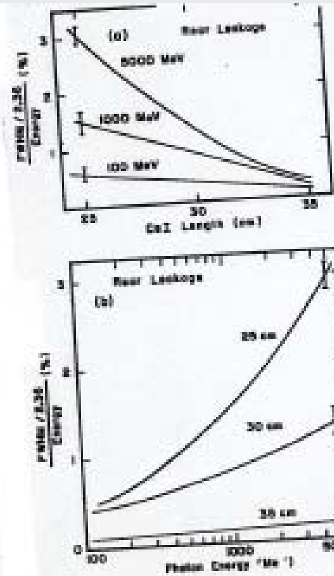


Fig. 4. The EGS prediction for the fluctuation in energy loss from rear leakage in CsI crystals vs (a) length of the crystals, and (b) incident photon energy. The error bars show typical uncertainties in the curves.

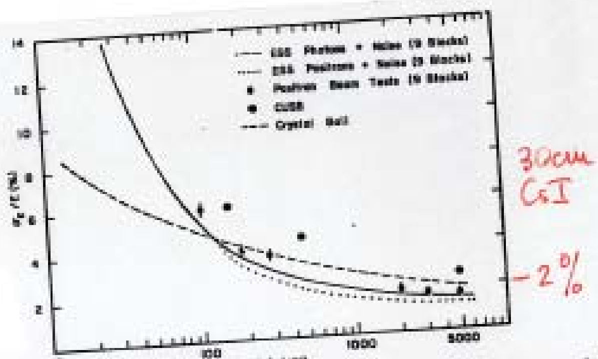
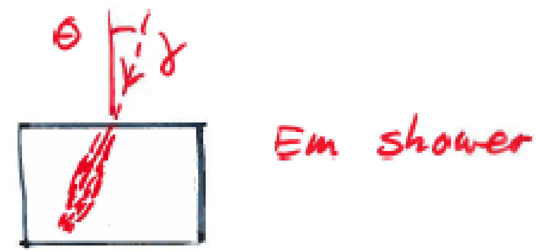


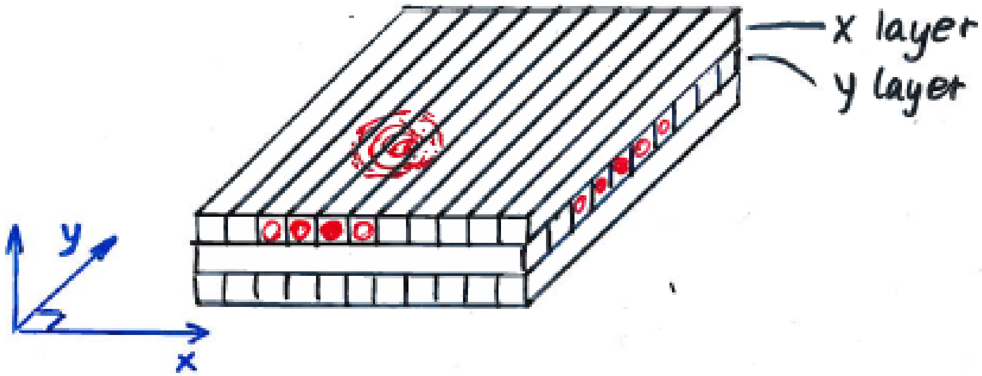
Fig. 5. Energy resolution as a function of energy, showing the EGS prediction for positrons and photons incident on 5 cm by 5 cm by 30 cm CsI crystals from the sum of nine blocks. No effects from nonzero light collection gradients or material between or in front of the crystals are included in the predictions. Also plotted are the positron test beam results on CsI reported here, as well as the Crystal Ball [10] and CUSB [11] resolutions.

SIMULATION STUDY OF AN ELECTROMAGNETIC CALORIMETER OF CsI(Tl)

- CsI well established as E-M calorimeters in particle physics experiments, e.g. CERN, CORNELL
- Energy resolution superb and well known
- Directional properties not studied

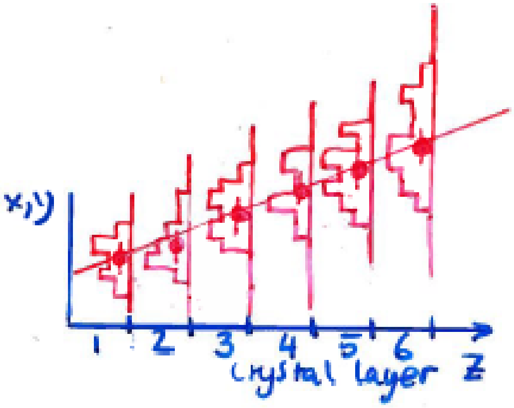


optimize determination of θ !



CsI crystals 1.5 x 1.5 cm^2

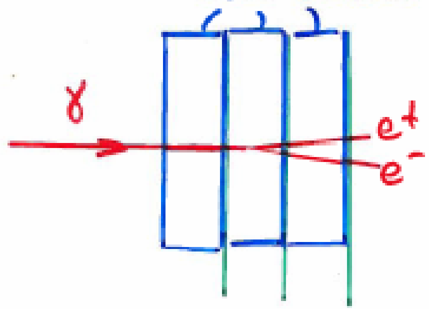
smallest cross-section that we can handle



TO IMPROVE ANGULAR RESOLUTION

MEASURE FIRST e^+e^- PAIR

CsI blocks 2cm ×3



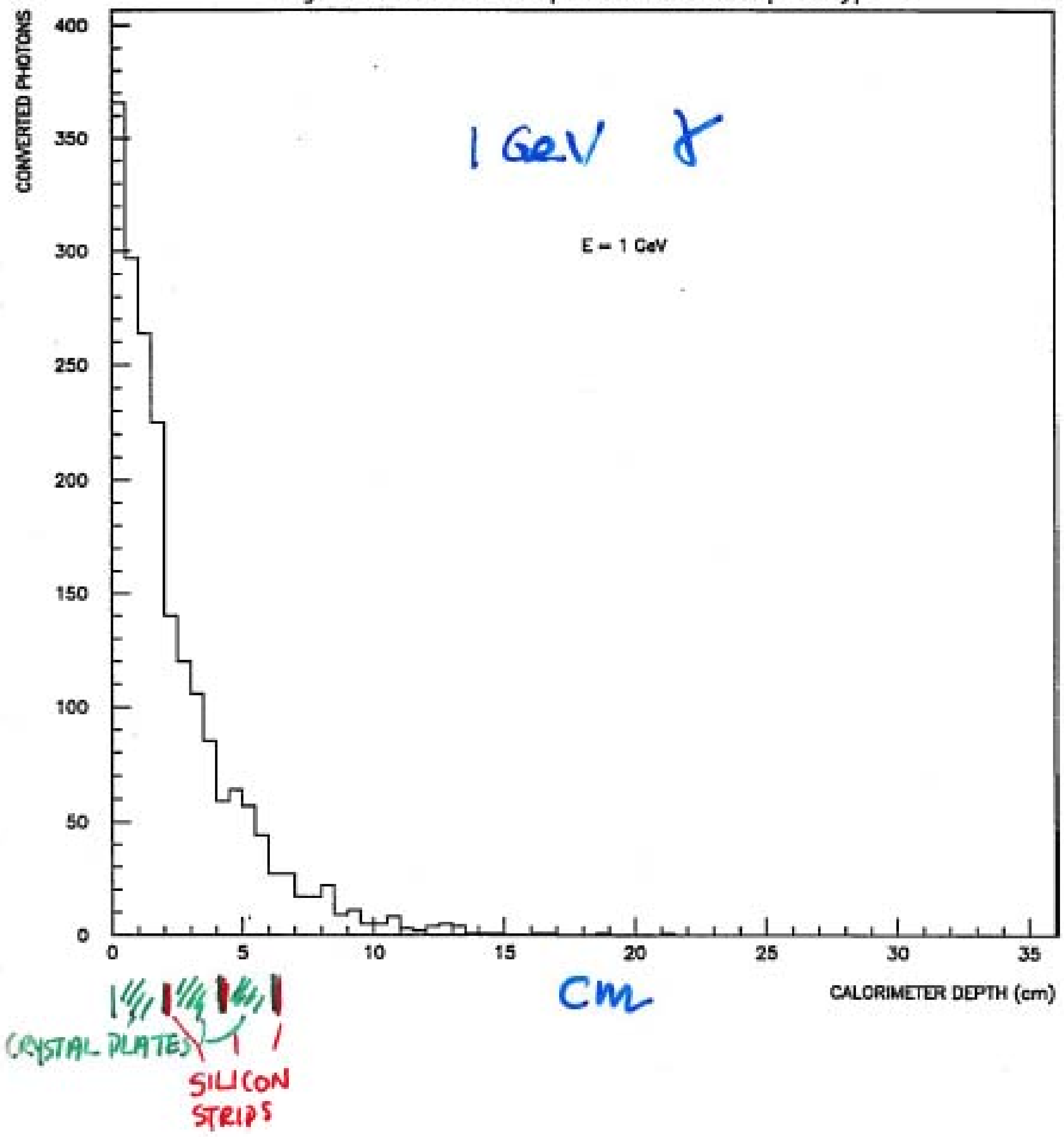
Si strip layers 2× 350μm thick

50% convert in 2cm
80% 4cm
90% 6cm

"Trigger efficiency" 90% 3 Si layers

PHOTON CONVERSION POINT

Figure 7.2 Conversion points in the final prototype



A simulated electromagnetic shower

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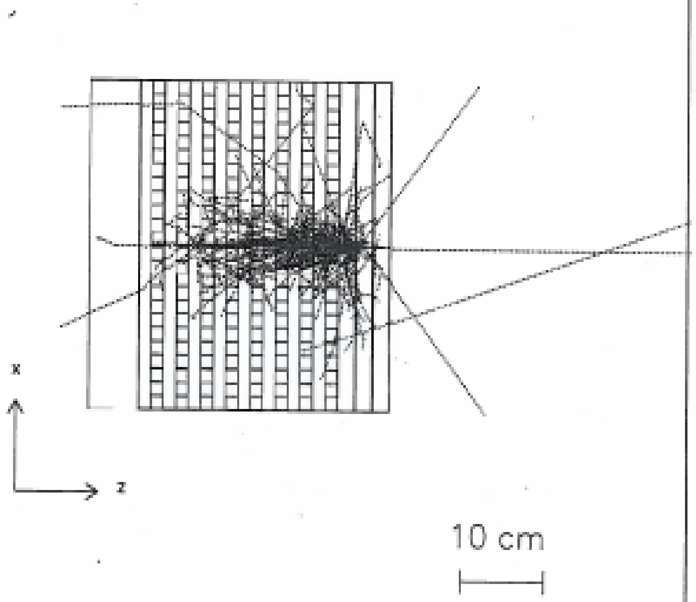

Incident photon energy [GeV]	0.100	0.300	1.000	3.000	10.00	30.00	100.0
Simulated energy resolution [%]	0.47	1.36	1.14	0.96	0.68	0.77	0.90
Material inhomogeneities and calibration errors [%]	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Electronic read — out noise [%]	4.40	1.47	0.44	0.15	0.05	0.02	0.01
Estimated energy resolution [%]	4.54	2.24	1.58	1.40	1.21	1.27	1.35

Table 7.6: ***Estimated contributions to the total energy resolution and the resulting estimated energy resolution versus the incident photon energy for the final calorimeter prototype.***

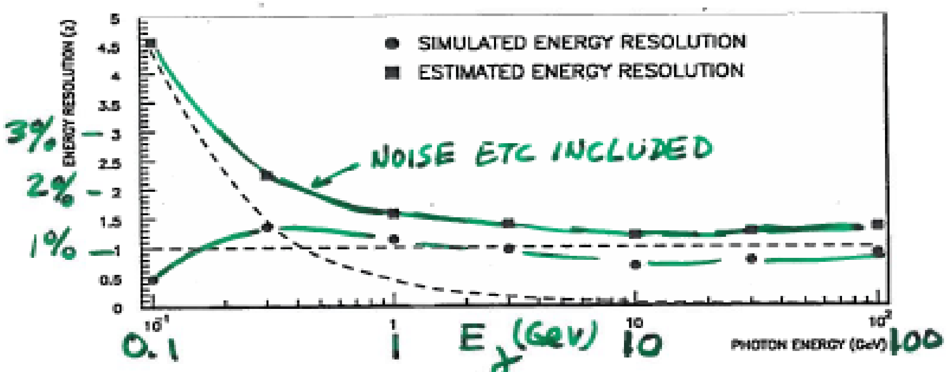

Figure 7.8: ***The simulated energy resolution, the estimated contributions to the total energy resolution as dashed lines, and the resulting energy resolution as functions of the incident photon energy for the final calorimeter prototype.***

7.6 Estimated effective area

The effective area is derived for the calorimeter on the basis of the following expression

$$\text{Effective area} = \text{Efficiency} \cdot \text{Acceptance area } [cm^2] \quad (7.2)$$

where the acceptance area is estimated from the assumtions that along the shower axis, a cylinder with a radius of one Moliere radius (3.8 cm) and a length of about 19 radiation lengths (35.5 cm) should always be available. These assumtions lead to the following expression for the acceptance area

$$\text{Acceptance area} = (28.4 - 35.5 \cdot \sin\alpha) \cdot (28.4 - 35.5 \cdot \sin\beta) \ [\text{cm}^2] \quad (7.3)$$

where α and β are the angles of incidence for each measurement plane. The angle θ between the incident gamma-ray trajectory and the normal to the calorimeter is

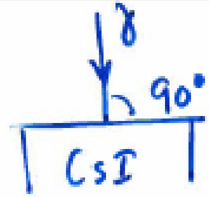

Figure A.10 Distribution of angles for the final prototype