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CMS ECAL Endcap Geometry Specification

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Abstract

This note describes the geometry of the CMS electromagnetic endcap calorimeter in detail, to provide an unambiguous basis for engineering design and physics simulation.

1 Introduction

The CMS electromagnetic endcap is a complex structure built up from a large number of "supercrystals", which are in turn built up from individual lead tungstate crystals. (*... not complete yet...)*

2 Definition of the crystal shape

The crystal shape is shown in fig 1. The front and rear faces are square. Two of the long sides meet in a right angle; one of these sides will always be the lower surface of the crystal, while the other is vertical. The opposite sides are tapered. The tapering angle is determined by the construction shown in fig 2: in side view, the line connecting the mid-points of the vertical sides is required to cross the plane containing the bottom surface of the crystal at a distance $z^* + \Delta z$ from the front face, where z^* is the distance to the interaction point, and Δz is chosen in order to give a suitable off-pointing angle. In the present endcap design, $z^* = 3250$mm and $\Delta z = 1000$mm. Given that the rear face of the crystal is a square of side 25mm and the crystal is 220mm in length, the taper angle is 0.320°, and the front face is a square of side 23.77mm.

3 Definition of the supercrystal

It is impracticable to assemble the endcaps from individual crystals. Instead, groups of 36 crystals are combined into a larger unit called a "supercrystal"; this forms the basic

Figure 1: The endcap crystal shape.

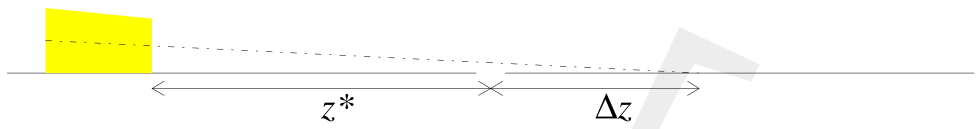

Figure 2: Definition of the crystal taper angle. The symbol $\star$ represents the interaction point.

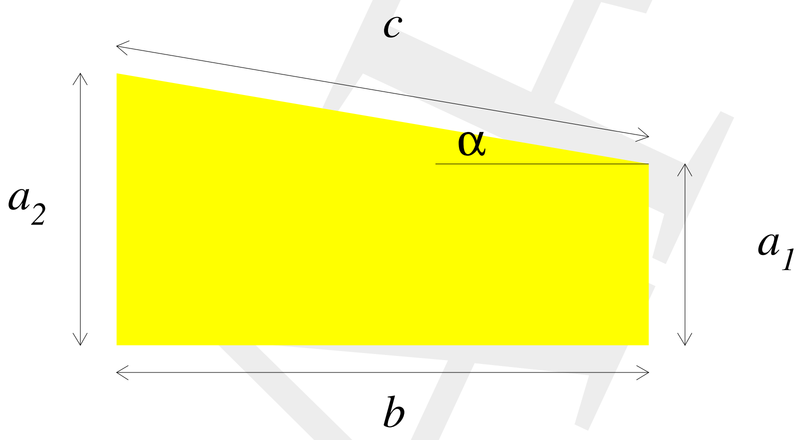

Figure 3: The endcap supercrystal shape.

module for the construction.

3.1 Internal structure of the supercrystal

(*... need something here...*)

3.2 External dimensions of the supercrystal

The supercrystal is a polyhedron of the same form as the single crystal; fig 3 is a schematic drawing of a supercrystal. The total length is defined to be 320mm, allowing space behind the crystals for electronics and other services. With the crystal dimensions given in section 2, and a gap of 0.5mm between crystal faces, the front and rear faces of the supercrystal are squares of side 145.31mm and 156.05mm respectively. The taper angle α is then 1.922°.

Figure 4: Structure of the supercrystal column.

The centre of the supercrystal is defined as the mid-point of the line joining the centres of the front and rear faces.

4 Assembly of supercrystals into endcap

4.1 Stacking of supercrystals into columns

The endcap is assembled conceptually, if not physically, from columns of supercrystals of various heights. All of the real columns are derived from a standard column of twelve supercrystals by truncation at the top or bottom, to achieve an approximately circular profile, as explained in more detail below. The standard column is built on a base supercrystal with its lower face in the horizontal $(X-Z)$ plane. The remaining supercrystals are positioned so that their leading edges line in the plane of front face of the base supercrystal, and the vertical faces are coplanar, as shown in fig 4.

4.1.1 Construction of the standard column

The column is constructed by adding supercrystals incrementally as described in appendix A.

Thus, if supercrystal i slopes at an angle ϑ_i, then the position of the $(i+1)$th supercrystal in a column is derived by:

1. rotation to an angle $\vartheta_{i+1} = \vartheta_i + \alpha + \gamma_i$, where γ_i is the opening angle of the inter-supercrystal gap from (7), and the axis of rotation is the leading edge of the supercrystal, as in fig 7;

2. translation of the rotated crystal in the positive Y direction through a distance t given in (3).

4.1.2 Position of supercrystals in the standard column

In the conceptual design, the base supercrystal has slope angle $\vartheta = 0$, and its lower face is at a distance of 0.25mm from the $X-Z$ plane. The inter-supercrystal gaps are defined so that, in the notation of appendix A $g_1 = 0.5$mm and $g_2 = 1.0$mm. With the supercrystal dimensions given in section 3, these conditions completely specify the standard column.

Table 1 summarises the position of the 11 supercrystals in the standard column. The figures given are the coordinates of the supercrystal centres (defined in section 3) and the slope angles.

S/Crystal	x	$?y$	z	ϑ
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0

Table 1: Position of supercrystals in standard column *(incomplete)*.

Figure 5: Top view of supercrystals in a column.

4.1.3 Definition of the column envelope

A column constructed by stacking supercrystals as just described has a complex non-planar boundary formed by the tapering sides of the individual supercrystals. This is illustrated in fig 5.

To simplify the construction of the endcap, a more regular envelope is defined of the minimal size needed to contain all of the supercrystals of a column. Fig 6 shows the shape of this envelope. Seen from above, the envelope has the same trapezoidal profile as the supercrystals; however, the depth e and the tapering angle β differ from the corresponding supercrystal measurements.

The angle β is determined by the requirement that the envelope must taper enough to contain the topmost supercrystal, sloping at an angle ϑ^{top} (note that for the purposes of this calculation, supercrystals which are cut away to tailor the endcap to a circular profile are treated as whole supercrystals); thus for column j,

$$\tan\beta_j = (a_2 - a_1)\cos\alpha / b\cos({\vartheta^{\mathrm{top}}}_j + \alpha).$$

It should be noted that this angle depends on the height of the column.

The envelope depth is defined by the supercrystal which projects furthest back from the plane containing the leading edges. For the columns used in the endcap, this is always the topmost supercrystal, giving

$$e = b\cos\vartheta^{\mathrm{top}} + a_1\sin\vartheta^{\mathrm{top}}.$$

The remaining distances in fig 6 are now trivially calculated.

$$d_1 = a_1$$

$$d_2 = d_1 + e\tan\beta$$

$$f = e/\cos\beta$$

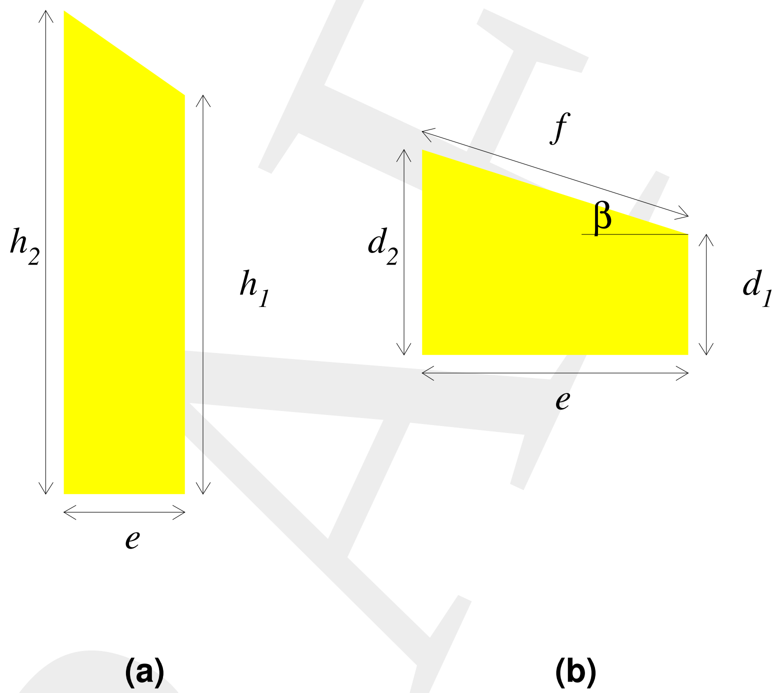

Figure 6: Dimensions of column envelope; (a) side view, (b) top view

Column	Low	High	???	???	???
1	3	11			
2	2	11			
3	1	11			
4	1	11			
5	1	10			
6	1	10			
7	1	9			
8	1	8			
9	1	7			
10	1	6			
11	1	4			

Table 2: Column details *(incomplete)*.

$$h_2 = h_1 + e \tan\left(\vartheta^{\mathrm{top}} + \alpha\right)$$

where the height h_1 of the front of the column is derived from the stacking procedure defined in appendix A.

4.2 Stacking of columns

4.2.1 Construction of a quadrant

The next stage in the endcap construction is to stack columns next to each other to make a quadrant. Table 2 defines the parameters of each of the columns. In most columns, some of the supercrystals will be cut away so that the overall shape of the endcap approximates a circle.

In this process, the boundary of the column is the envelope defined in section 4.1.3. The geometry is again that of appendix A. In this case, the inter-column gap ℓ is assumed to be 0.5mm at the front and the rear, so there is no analogue of the angle γ. Column $(j+1)$ is positioned relative to column j by:

1. rotation to an angle $\varphi_{j+1} = \varphi_j + \beta_j$, where the axis of rotation is the leading edge of the column, and the first column (nearest to the Y axis) has $\varphi_1 = 0$;

2. translation of the rotated column in the positive X direction through a distance u_{j+1} given by
$$u_{j+1} = (d_1 + \ell)/\cos\varphi_{j+1}.$$

4.2.2 Assembly of quadrants into complete endcaps.

Initially, a “dee” is constructed by reflecting a quadrant in the $X-Z$ plane, maintaining a separation of 500μm between supercrystals across the reflecting plane. Two dees are then brought together across the $Y-Z$ plane to form an approximately circular endcap. A gap of 2mm is allowed between supercrystals at the junction of the two dees.

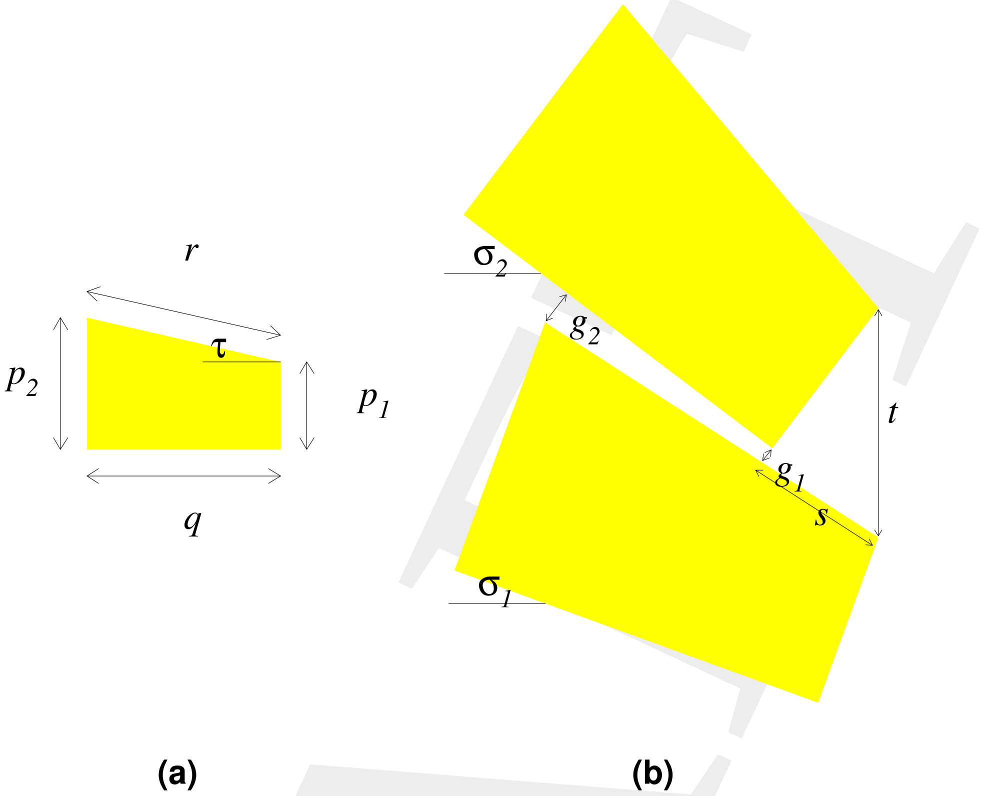

Figure 7: Stacking geometry of trapezia: (a) trapezium dimensions, (b) stacking parameters.

A Geometrical calculations

The geometry of the endcap, and the interior structure of the supercrystals, arise through the stacking of trapezia as illustrated in fig 7. These trapezia have the property that two of the interior angles are right-angles. This appendix sets out the geometry of such stacks in detail.

Consider a trapezium, with the dimensions defined in fig 7(a), sloping at an angle σ_1 with respect to the X axis. A column is to be formed with the leading corners of all members of the column positioned on a line at constant X. The position of the next trapezium in the column may be obtained by rotating the original about the leading corner to angle σ_2 and translating by a distance t in the Y direction, to obtain the position shown in fig 7(b).

The trapezia are separated by a gap of width g_1 at the front of the upper trapezium, and g_2 at the rear of the lower trapezium, with both distances normal to the lower face of the upper trapezium.

A number of geometric relations follow at once from fig 7. Defining the gap angle γ by

$$\sin\gamma = (g_2 - g_1)/(r - s) \equiv \Delta g/(r - s), \tag{1}$$

then

$$\sigma_2 = \sigma_1 + \tau + \gamma, \tag{2}$$

$$t = (p_1 + g_1)\cos\gamma/\cos(\sigma_1 + \tau), \tag{3}$$

$$s = (p_1 + g_1)\sin\sigma_2/\cos(\sigma_1 + \tau). \tag{4}$$

In order to calculate σ_2 and t, γ must be evaluated. Making the approximation that $\cos\gamma = 1$ (which is satisfied to 1 part in 10^6 in the endcap geometry), (4) becomes

$$s = (p_1 + g_1)(\tan(\sigma_1 + \tau) + \sin\gamma). \tag{5}$$

Then, substituting (5) into (1),

$$\sin\gamma = \Delta g/(r' - (p_1 + g_1)\sin\gamma),$$

where

$$r' = r - (p_1 + g_1)\tan(\sigma_1 + \tau).$$

Thus, $\sin\gamma$ is obtained by solving

$$(p_1 + g_1)(\sin\gamma)^2 - r'\sin\gamma + \Delta g = 0 \tag{6}$$

giving

$$\sin\gamma = \frac{r'}{2(p_1 + g_1)}(1 - \sqrt{1 - 4\Delta g(p_1 + g_1)/r'^2})$$

or

$$\sin\gamma = \Delta g/r' \tag{7}$$

provided that $r'^2 \gg 4\Delta g(p_1 + g_1)$. Note that γ is not constant, but rather is a function of σ_1.