by

$$\lambda_I \approx 35 \text{ g cm}^{-2} A^{1/3} . \tag{12.13}$$

Longitudinal energy deposition profiles are characterized by a sharp peak near the first interaction point (from the fairly local deposition of EM energy resulting from π^0's produced in the first interaction), followed by a more gradual development with a maximum at

$$x/\lambda_I \equiv t_{\max} \approx 0.2 \ln(E/1 \text{ GeV}) + 0.7 \tag{12.14}$$

as measured from the front of the detector.

The depth required for containment of a fixed fraction of the energy also increases logarithmically with incident particle energy. The thickness of iron required for 95% (99%) containment of cascades induced by single hadrons at 100 GeV is about $7\lambda_I$ $(9\lambda_I)$, as can be seen in Fig. 12.1 [35] in the full *Review.*

The transverse dimensions of hadronic showers also scale as λ_I, although most of the energy is contained in a narrow core.

The energy deposit in a hadronic cascade consists of a prompt EM component due to π^0 production and a slower component mainly due to low-energy hadronic activity. In general, these energy depositions are converted to electrical signals with different efficiencies [36]. The ratio of the conversion efficiencies is usually called the intrinsic e/h ratio. If $e/h = 1.0$ the calorimeter is said to be *compensating.* If it differs from unity by more than 5% or 10%, detector performance is compromised because of fluctuations in the π^0 content of the cascades. Problems include:

a) A skewed signal distribution;
b) A response ratio for electrons and hadrons (the "e/π ratio") which is different from unity and depends upon energy;
c) A nonlinear response to hadrons (the response per GeV is proportional to the reciprocal of e/π);
d) A constant contribution to detector resolution, almost proportional to the degree of noncompensation. The coefficient relating the constant term to $|1 - e/h|$ is 14% according to FLUKA simulations, and 21% according to Wigman's calculations [33].

In most cases e/h is greater than unity, particularly if little hydrogen is present or if the gate time is short. This is because much of the low-energy hadronic energy is "hidden" in nuclear binding energy release, low-energy spallation products, *etc.* Partial correction for these losses occurs in a sampling calorimeter with thick plates, because a disproportionate fraction of electromagnetic energy is deposited in the inactive region. For this reason, it is very unlikely that a fully sensitive detector such as BGO or glass can be made compensating.

Compensation has been demonstrated in calorimeters with 2.5 mm scintillator sheets sandwiched between 3 mm depleted uranium