diameter d (good for $s \lesssim t$) gives [23]

$$V \lesssim 59 T^{1/2} \left[\frac{t}{\ell} + \frac{s}{\pi \ell} \ln \left(\frac{s}{\pi d} \right) \right] \; , \qquad (12.11)$$

where V is in kV, and T is in grams-weight equivalent.

Proportional and drift chamber potentials The potential distributions and fields in a proportional or drift chamber can usually be calculated with good accuracy from the exact formula for the potential around an array of parallel line charges q (coul/m) along z and located at $y = 0$, $x = 0, \pm s, \pm 2s, \ldots$,

$$V(x,y) = -\frac{q}{4\pi\,\epsilon_0} \ln \left\{ 4 \left[\sin^2 \left(\frac{\pi x}{s} \right) + \sinh^2 \left(\frac{\pi y}{s} \right) \right] \right\} \; . \qquad (12.12)$$

Errors from the presence of cathodes, mechanical defects, TPC-type edge effects, *etc.*, are usually small and are beyond the scope of this review.

12.7. Calorimeters

Electromagnetic calorimeters. The development of electromagnetic showers is discussed in the "Passage of Particles Through Matter" section (Sec. 10 of this *Review*). Formulae are given for the approximate description of average showers, but since the physics of electromagnetic showers is well understood, detailed and reliable Monte Carlo simulation is possible. EGS4 has emerged as the standard [24].

The resolution of sampling calorimeters (hadronic and electromagnetic) is usually dominated by sampling fluctuations, leading to fractional resolution σ/E scaling inversely as the square root of the incident energy. Homogenous calorimeters, such as solid NaI(Tl), will in general not have resolution varying as $1/\sqrt{E}$. At high energies deviations from $1/\sqrt{E}$ occur because of noise, pedestal fluctuations, nonuniformities, calibration errors, and incomplete shower containment. Such effects are usually included by adding a constant term to σ/E, either in quadrature or (incorrectly) directly. In the case of the hadronic cascades discussed below, noncompensation also contributes to the constant term.

Table 12.4 of the full *Review* gives resolution as measured in detectors using typical EM calorimeter technologies. Typically, $\sigma/E \approx 10\%/\sqrt{E}$. In almost all cases installed calorimeters yield worse resolution than test beam prototypes. For a fixed number of radiation lengths, the FWHM in sandwich detectors would be expected to be proportional to $\sqrt{t}$ for t (= plate thickness) ≥ 0.2 radiation lengths [25].

Given sufficient transverse granularity early in the calorimeter, position resolution of the order of a millimeter can be obtained.

Hadronic calorimeters [33,34]. The length scale appropriate for hadronic cascades is the nuclear interaction length, given very roughly