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Advanced Particle Detectors and Data Analysis

Notes for Exercises

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1 Interactions of Particles with Photons

1.1 Bethe-Bloch Equation

The Bethe-Bloch equation describes the mean energy loss per distance traveled while traversing through matter. We generally use the Bethe-Bloch equation when we are dealing with **thick absorbers**, such as the ones in calorimeters. Do note that the Bethe-Bloch equation does not accurately describe the energy loss of **electrons** and **positrons** due to their small mass and the fact that they suffer from much larger energy losses due to bremsstrahlung and pair production. For a particle with charge Z and velocity $\beta = v/c$, the Bethe-Bloch equation is given as:

$$-\left\langle \frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A} \frac{z^2}{\beta^2} \left[\ln \left(\frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} \right) - 2\beta^2 - \delta - 2\frac{C}{Z} \right] , \tag{1}$$

where δ is the **density effect correction** and C is the **shell correction**. The rest is as follows:

$$N_a = 6.022 \times 10^{23}\,\mathrm{mol}^{-1} , \quad r_e = 2.818 \times 10^{-15}\,\mathrm{m} , \quad m_e = 9.11 \times 10^{-31}\,\mathrm{kg} , \quad c = 3 \times 10^{8}\,\mathrm{m/s} ,$$
$$\rho = \text{density of the material} , \quad A = \text{atomic mass of the material} , \quad z = \text{charge of the particle} , \quad \gamma = \frac{1}{\sqrt{1-\beta^2}} ,$$
$$W_{\max} = \text{maximum energy transfer in a single collision} , \quad I = \text{mean excitation energy} . \tag{2}$$

The constant factor in the equation can be written as:

$$2\pi N_a r_e^2 m_e c^2 = 0.1535\,\mathrm{MeV\ cm^2 mol^{-1}} . \tag{3}$$

We can find the mean excitation energy I from the following experimentally determined formula:

$$I = \begin{cases} Z(12 + \frac{7}{Z}) & \text{for } Z < 13 , \\ Z(9.76 + 58.8 Z^{-1.19}) & \text{for } Z \geq 13 . \end{cases} \tag{4}$$

The maximum energy transfer in a single collision $W_{\max}$ can be calculated as:

$$W_{\max} = \frac{2m_e c^2 \beta^2 \gamma^2}{1 + 2\gamma\left({}^{m_e}/_{M}\right) + \left({}^{m_e}/_{M}\right)^2} \approx 2m_e c^2 \beta^2 \gamma^2 . \tag{5}$$

For our purposes we will ignore the density effect correction δ and the shell correction C.