Experimental particle physics

esipap...
European School of Instrumentation in Particle & Astroparticle Physics

B. particle interactions and detector response

A simple shower model

Simple shower model:
[from Heitler]

Only two dominant interactions:
Pair production and Bremsstrahlung ...

γ + Nucleus ➛ Nucleus + e^+ + e^-
[Photons absorbed via pair production]

e + Nucleus ➛ Nucleus + e + γ
[Energy loss of electrons via Bremsstrahlung]

Shower development governed by X_0 ...

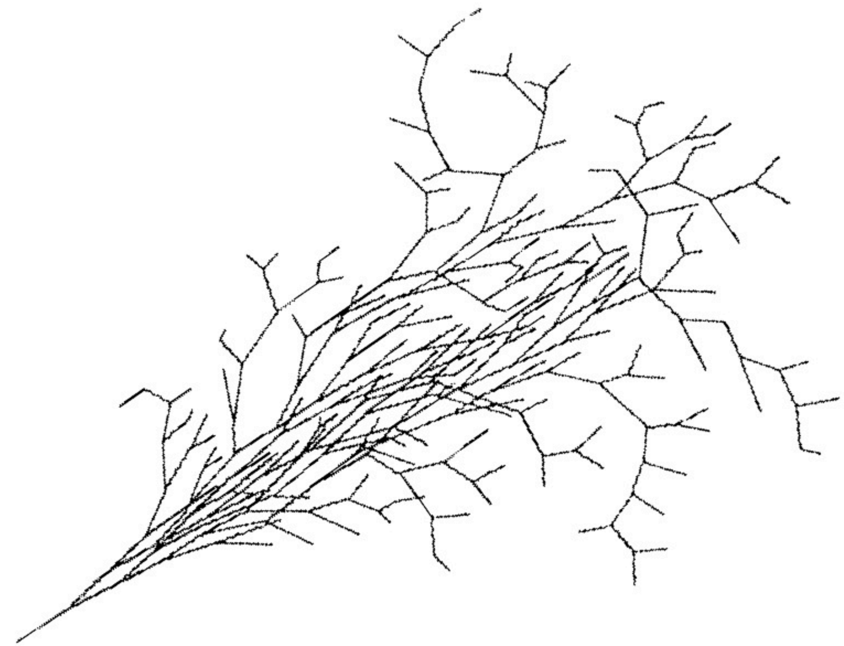
After a distance X_0 electrons remain with only $(1/e)^{th}$ of their primary energy ...

Photon produces e^+e^--pair after $9/7 X_0 \approx X_0$ ...

Assume:

$E > E_c$: no energy loss by ionization/excitation

$E < E_c$: energy loss only via ionization/excitation



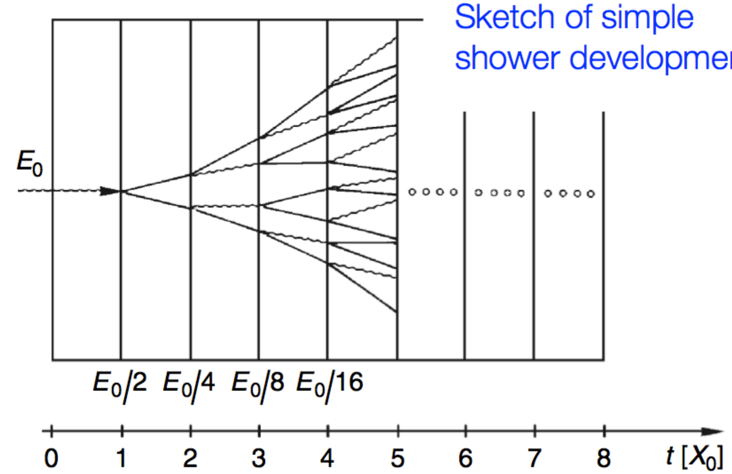
Use
Simplification:

$E_\gamma = E_e \approx E_0/2$
[E_e looses half the energy]

$E_e \approx E_0/2$
[Energy shared by e^+/e^-]

... with initial particle energy E_0

A simple shower model



Simple shower model:
[continued]

Shower characterized by:

- Number of particles in shower
- Location of shower maximum
- Longitudinal shower distribution
- Transverse shower distribution

Longitudinal components; measured in radiation length ...

... use: $t = \dfrac{x}{X_0}$

Number of shower particles after depth t:

$$N(t) = 2^t$$

Energy per particle after depth t:

$$E = \frac{E_0}{N(t)} = E_0 \cdot 2^{-t}$$

$$\rightarrow \quad t = \log_2(E_0/E)$$

Total number of shower particles with energy E_1:

$$N(E_0, E_1) = 2^{t_1} = 2^{\log_2(E_0/E_1)} = \frac{E_0}{E_1}$$

Number of shower particles at shower maximum:

$$N(E_0, E_c) = N_{\max} = 2^{t_{\max}} = \frac{E_0}{E_c} \propto E_0$$

Shower maximum at:

$$t_{\max} \propto \ln(E_0/E_c)$$

A simple shower model

Simple shower model:
[continued]

Longitudinal shower distribution increases only logarithmically with the primary energy of the incident particle ...

Some numbers: $E_c \approx 10$ MeV, $E_0 = 1$ GeV ➛ $t_{max} = \ln 100 \approx 4.5$; $N_{max} = 100$
$E_0 = 100$ GeV ➛ $t_{max} = \ln 10000 \approx 9.2$; $N_{max} = 10000$

$$t_{\max}[X_0] \sim \ln \frac{E_0}{E_c}$$

Particle detection

- The number N of the particles which are created in shower is proportional to the energy E of the original particle. Use this to show that the relative energy resolution is given by

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}}$$

LAr calorimeter exercises

- The electromagnetic calorimeter for the ATLAS detector is made from roughly 2 mm thick layers of lead. Between the lead layers are 2 mm wide gaps filled with liquid Argon. Lead has a Z = 82, A = 206 and a density of 11.34 g/cm^3. Liquid argon has a Z = 18, A = 40 and a density of 1.4 g/cm3.
  - ✓ At η = 0 the depth of the ATLAS electromagnetic calorimeter is (about) 22 radiation lengths X_0. What would be the depth of the detector in cm if it was an homogeneous calorimeter (i.e. all made of liquid argon)? And if it was all made of lead?
  - ✓ An electron of 5 GeV is generating an electromagnetic shower. At what depth would the shower reach its maximum in liquid argon?
  - ✓ Compute the longitudinal depth of lead needed to contain 95% of the energy of a 10 GeV and a 100 GeV photons respectively.
  - ✓ How much energy does a minimum-ionizing-particle (mip) deposit in 22 X_0 of liquid Argon, assuming:

$$\frac{1}{\rho_{\mathrm{LAr}}}\left(\frac{dE}{dx}\right)_{\mathrm{mip}} = 1.52\,\mathrm{MeV}/(\mathrm{g\,cm}^{-2})$$

  - ✓ How deep in cm is the real ATLAS electromagnetic calorimeter at η = 0, assuming a perfect succession of lead and liquid argon layers of the same thickness?

Particle interactions

- Compute the threshold energies an electron and a proton must possess in water to emit Cherenkov radiation
  - ✓ N_{water} = 1.3