Experimental particle physics

European School of Instrumentation in Particle & Astroparticle Physics

B. particle interactions

Radiation length values

- Three options
  1. Search tabulated value on PDG!
  2. Compute from full formula

$$X_0 = \frac{A}{4\alpha N_A\ Z^2 r_e^2\ \ln\frac{183}{Z^{\frac{1}{3}}}}$$

  3. Compute from approximated formulas…

$$X_0 = 716.4\ \mathrm{g\,cm^{-2}}\ \frac{A}{Z(Z+1)\ln\frac{287}{\sqrt{Z}}}$$

$$X_0 = 1433\ \mathrm{g\,cm^{-2}}\ \frac{A}{Z(Z+1)(11.319-\ln Z)}$$

$$X_0 = \frac{180A}{Z^2}\ \frac{\mathrm{g}}{\mathrm{cm^2}}$$

- What is the X0 of Pb?

Cherenkov counter exercise!

- A threshold Cherenkov detector is used to separate muons from pions in a beam with momentum |p| = 150 MeV.
  - ✓ What values of the refraction index can be used?

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

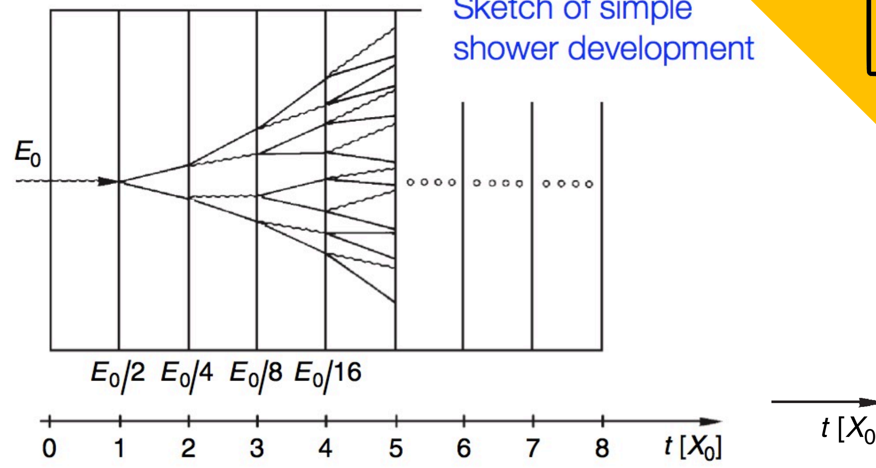
Simple shower model:
[continued]

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



Sketch of simple shower development

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 ...

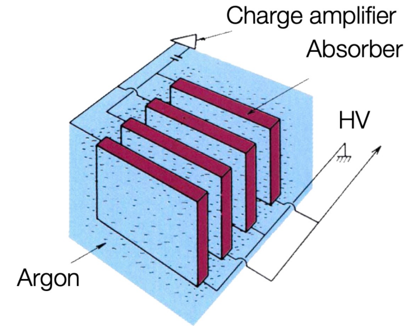
Some numbers: $E_c \approx 10$ MeV, $E_0 = 1$ GeV ➛ $t_{max} = \ln 100 \approx 4.5$; $N_{max} = 100$
$E_0 = 100$ GeV ➛ $t_{max} = \ln 10000 \approx 9.2$; $N_{max} = 10000$

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

A sampling calorimeter…

- The ATLAS electromagnetic calorimeter is made from roughly 2 mm thick layers of lead (Pb), interleaved by 2 mm wide gaps filled with liquid Argon (LAr).
  - ✓ Pb: Z = 82, A = 206,density =11.34 g/cm^3
  - ✓ LAr: Z = 18, A = 40 density = 1.4 g/cm3.
- At $\eta = 0$ the depth of the ATLAS electromagnetic calorimeter is ~22 X_0
- What is the calorimeter depth in cm?
  - ✓ Hint; compute X_0(Pb) and X_0(LAr)
- What would it be is if it was a homogeneous calorimeter (i.e. all made of LAr)?
- And if it was all made of Pb?

A sampling calorimeter…



A sampling electromagnetic calorimeter is composed of series of lead layers about 2 mm thick layers of lead (Pb)[1]. Between the lead layers are 2 mm wide gaps filled with liquid Argon (LAr). 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/cm^3.

1. At $\eta = 0$ 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 all made of LAr? And if it was all made of lead?

2. An electron of 5 GeV generated an electromagnetic shower in the calorimeter. Assuming that the detector was all made of LAr, at what depth would the shower reach its maximum?

3. How much energy does a minimum-ionizing-particle (mip) deposit in 22 X_0 of LAr, assuming:

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

4. How deep in cm is the *real* ATLAS electromagnetic calorimeter at $\eta = 0$, assuming a perfect succession of lead and liquid argon layers of the same thickness?