ESIPAP 2015

Friday 20th of February 2015

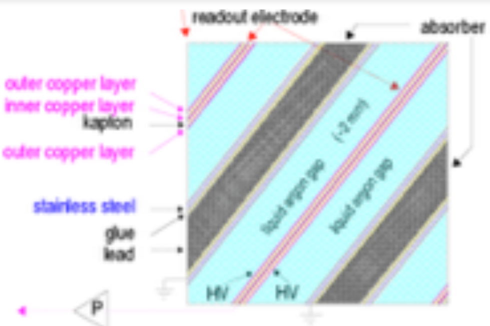
Problem on Calorimetry

The answers to the questions can be written in either French or English.

The slides for the lectures can be found at:
https://indico.cern.ch/event/366272/other-view?view=standard

1) Slide 33 of the first calorimetry lecture shows the cross-sections of various photon interaction processes in matter (the plots shown are for carbon, and for lead). Draw Feynman diagrams for the photoelectric effect, Compton scattering and pair production. Indicate clearly the interaction with material (atomic electrons, or atomic nuclei).

2) The ATLAS electromagnetic calorimeter is made of alternating layers of lead absorber plates and liquid argon (see pages 57 & 64 of the second calorimetry lecture). At $\eta \sim 0$, the lead thickness is t_{Pb}=1.53 mm and the liquid argon one is t_{LAr}=4.2 mm.



Lead - Pb	Liquid argon - LAr
Z=82, A=208	**Z=18, A=40**
X^0_{Pb}=6.3 g/cm^2	**X^0_{LAr}=19.6 g/cm^2**
ρ_{Pb}=11.3 g/cm^3	**ρ_{LAr}=1.4 g/cm^3**
E_c = 7.4 MeV	**E_c = 37 MeV**
t_{Pb}=1.53 mm	**t_{LAr}=2x2.1 mm**

Some properties of lead and liquid argon

2.1 Recall the formulae to compute the radiation length for composite materials.

2.2 Compute the radiation length [g/cm^2] of this composite material, made of sandwichs of Lead + LAr (ignoring the contribution of the electrodes, the stainless steel which covers the Lead).

2.3 Compute the average density of this composite material

2.4 Give the radiation length of the composite material in [cm].

2.5 The calorimeter is ~50 cm thick at η~0; how many radiation lengths does this correspond to ?

N.B. Do not refer to the number obtained during the tutorial session for which a different LAr gap thickness was used.

3) The ATLAS calorimeter is segmented longitudinally in three compartments: 4, 16 and 2 radiation lengths deep for the first, second and third layers respectively. The second layer of this calorimeter is segmented transversally in elementary cells of ~4x4 cm^2 corresponding to $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ (see page 57 of the second calorimetry lecture).

3.1 Estimate the position of the maximum of the shower, t_{max}, in units of X_0 , for an incoming electron with E=45 GeV and for an incoming γ with E=60 GeV, using the formula (page 40 of the first calorimeter lecture - *please note that there was a mistake in the formulae presented during the lecture which has been corrected since*):

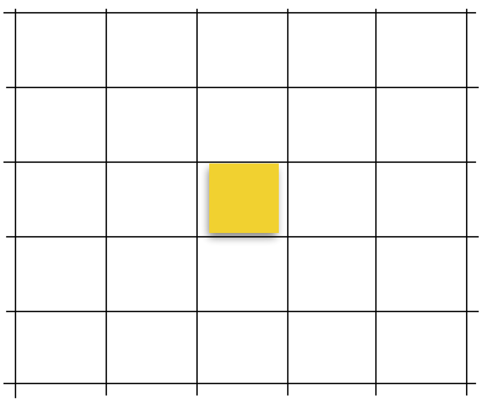
$$t_{max} = \ln E/E_c - t_1$$

with E being the incident particle energy, E_c the critical energy of the material, $t_1 = 1.0$ for an electron induced shower, $t_1=0.5$ for a γ induced shower
The shower develops mainly in the lead sheets; the critical energy for lead is given in the table given in question 2.

3.2 Comment on the position of the shower maximum with respect to the longitudinal segmentation.

3.3 The transverse development of electromagnetic shower can be described using the Moliere Radius, R_M. The Moliere radius, in a simplified model, can be estimated by the formulae given page 43 of the fist calorimetry lecture. Using the estimated radiation length computed in question 2, give an estimate of R_M.

3.4 Draw on the matrix below (sketch of the second layer of the ATLAS electromagnetic calorimeter) a circle which would contain 95% of the shower initiated by an incoming high energy (E>10 GeV) electron or photon.



4) The CMS barrel electromagnetic calorimeter is an homogeneous lead tungstate, $PbWO_4$ scintillating crystal calorimeter. One crystal is 23 cm (see page 45 of the second calorimetry lecture) long.

	Mass	**X^0 [g/cm2]**
Pb	208	6.4
W	184	6.8
O_4	64	34.2

4.1 Calculate its radiation length, and, given that its density is 8.3 g/cm3, express it in cm.

4.2 How many radiation lengths is one crystal ?

4.3 Compare with the ATLAS electromagnetic calorimeter and comment.

Question Bonus

The first layer of the ATLAS electromagnetic calorimeter is 4 radiation lengths deep; it is very thinly segmented along the η direction (along the beam line): $\Delta\eta=0.003$ corresponding to $\Delta z \sim 5$mm.

a) Give at least on motivation for choosing $4X_0$ depth for the first calorimeter layer ?
b) How does the cell width in this first layer compare to the Molière Radius computed in question 3? comment.
c) Give at least one motivation for the narrow lateral segmentation of the first calorimeter layer