Monday 10th of February 2014

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/294651/other-view?view=standard

1) List the three types of particles which interact dominantly via electromagnetic interaction when traversing a block of matter. Among these three types, two would be stopped by a block of Lead of ~15 cm. Describe the processes involved in the interaction with matter, in that case (cf lecture 1).

2) The approximation for X_0 given in a recent edition of the Particle Data Group "Review of Particle Physics" is $X_0 = 716.4A/(Z(Z+1)\ln(287/\sqrt{Z}))$ g cm^{-2} (Z and A are the atomic number and atomic weight). Take a range of elements (say: C, Al, liquid Ar, Fe, Cu, Ge, liquid Kr, W, Pb, U) and calculate the radiation length given by a) this approximation, b) the approximation given on Slide 26 of the first calorimeter lecture. Express the answers in cm (not g/cm^{-2}) and put them in a table together with the true/measured values of X_0. Table 1 of this document gives a list of properties of current materials.

3) On page 40 of the same lecture (first calorimeter lecture) a formulae describing the position of the maximum of the shower is given in units of X_0. Give an estimate of the position of the maximum of a shower initiated by a high energy photon (E=1000 GeV) in the atmosphere, at a height of 10 km. (use the approximation that the atmosphere is at atmospheric pressure independently of the height). As a comparison, what would be the position of the shower maximum is Liquid Krypton calorimeter.

$$X_{max} = X_0 \ln (E/E_c + t_0)$$

where X_0 is the radiation length in unit length,
E is the incident energy of the particle, Ec is the critical energy of the material (both in the same energy unit) and
t_0=-0.5 for electrons and +0.5 for photons.

4) The CMS barrel Electromagnetic calorimeter is a homogeneous lead tungstate scintillating crystal calorimeter using avalanche photo-diodes to detect the scintillation light. Nine supermodules have been measured in a test beam at CERN. The energy resolution has been fitted by the function: $\sigma/E = 2.8\%/\sqrt{(E/GeV)} \oplus 125MeV/E \oplus 0.3\%$ (slide 31 of the second lecture). What is the resolution at 120 GeV? (The symbol $\oplus$ means that the sum is quadratic.)

5) The ATLAS barrel electromagnetic calorimeter is a sampling Lead and liquid argon calorimeter. Three out of the 32 modules were tested in test beam at CERN. The energy resolution has been measured to be

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b, \text{ with } a = 10.1 \pm 0.1\% \cdot \sqrt{\text{GeV}} \text{ and } b = 0.17 \pm 0.04\%. \quad (8)$$

The symbol $\oplus$ indicates that the two terms are added in quadrature. The What is the resolution at 120 GeV. How does it compare to the noise term which is equivalent to a spread of 250 MeV.

Question Bonus

6) What factors might limit the resolution of the calorimeter in ATLAS and CMS so that the resolution obtained is worse than this resolution measured in a test beam? a) for photons, b) for electrons.

Material	Z	Density [g cm^{-3}]	E_c [MeV]	X_0 [mm]	ρ_M [mm]	λ_{int} [mm]	$(dE/dx)_{mip}$ [MeV cm^{-1}]
C	6	2.27	83	188	48	381	3.95
Al	13	2.70	43	89	44	390	4.36
Fe	26	7.87	22	17.6	16.9	168	11.4
Cu	29	8.96	20	14.3	15.2	151	12.6
Sn	50	7.31	12	12.1	21.6	223	9.24
W	74	19.3	8.0	3.5	9.3	96	22.1
Pb	82	11.3	7.4	5.6	16.0	170	12.7
^{238}U	92	18.95	6.8	3.2	10.0	105	20.5
Concrete	-	2.5	55	107	41	400	4.28
Glass	-	2.23	51	127	53	438	3.78
Marble	-	2.93	56	96	36	362	4.77
Si	14	2.33	41	93.6	48	455	3.88
Ge	32	5.32	17	23	29	264	7.29
Ar (liquid)	18	1.40	37	140	80	837	2.13
Kr (liquid)	36	2.41	18	47	55	607	3.23
Polystyrene	-	1.032	94	424	96	795	2.00
Plexiglas	-	1.18	86	344	85	708	2.28
Quartz	-	2.32	51	117	49	428	3.94
Lead-glass	-	4.06	15	25.1	35	330	5.45
Air 20°, 1 atm	-	0.0012	87	304 m	74 m	747 m	0.0022
Water	-	1.00	83	361	92	849	1.99

Table 1 Summary of various material properties.