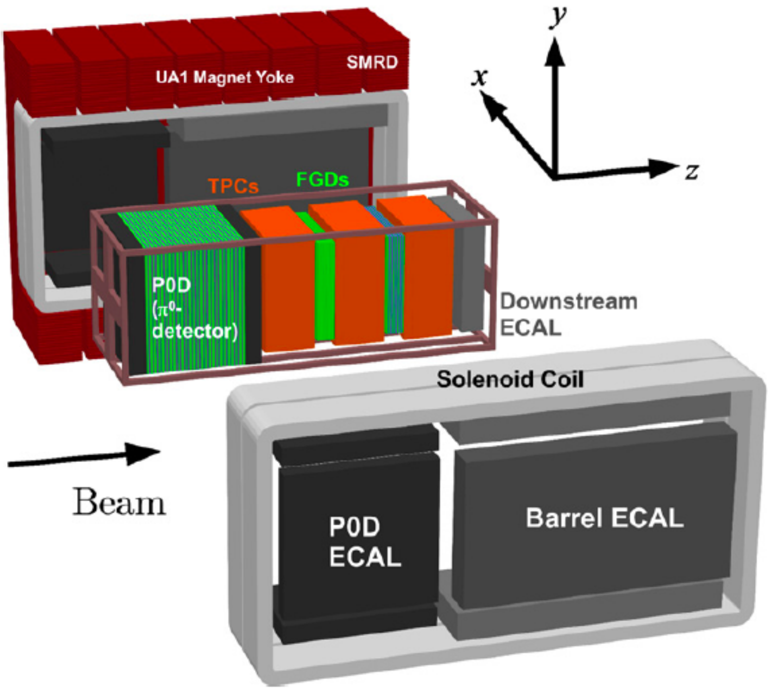
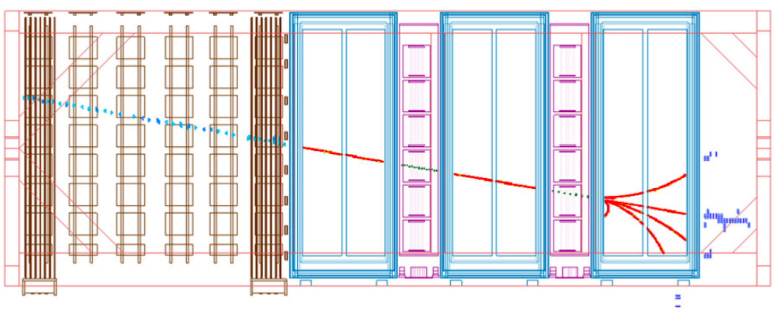
Radiation Detector 2018/19 (SPA6309), Homework 2

Name:
ID:

Problem (10 points)





The picture is the T2K near detector 280 (ND280) with a cosmic muon event (NIMA659(2011)106, http://arxiv.org/abs/1106.1238 (http://arxiv.org/abs/1106.1238)). It consists of several detectors, from left to right, P0D scintillator detector, gas time projection chamber (TPC1), then FGD scintillator detector (FGD1), TPC2, FGD2, TPC3, and finally Downstream electromagnetic calorimeter (ECal, this is made in Queen Mary). All scintillators are made by plastic (CH^2, 1g/cm^3). ECal is made by alternative layers of lead (11g/cm^3) and scintillator with 1 to 10 ratio. TPCs are filled with gas. In this problem, we ignore interactions with gas. There are detectors surrounding the main region (P0D ECal, Barrel ECal, SMRD), but in this problem, we will ignore them.

P0D, TPC1, FGD1, TPC2, FGD2, TPC3, and Downstream ECal have lengths of 2.4m, 0.6m, 0.4m, 0.6m, 0.4m, 0.6m, and 0.55m in z-direction (=direction of the beam). For simplicity, all of them are 2m in width in the x-direction and 2m in height in the y-direction. A muon neutrino beam enters from the left, and mainly produces muons through CC weak interaction with neutrons (cross section is 1×10^{-38}cm^2 at 800 MeV), although other types of interactions are possible (for example elastic scattering, $\nu_\mu + e \to \nu_\mu + e$). For simplicity, we consider all particles are travelling in the z-direction only. Also, we ignore all materials not specified.

The T2K experiment uses the pulsed neutrino beam, which is created at the J-PARC neutrino beamline and has an average energy of 800MeV. The beam pulse is roughly 5μs in length, has frequency 0.5 Hz, and each pulse has a sub-structure which contains 8 sub-pulses equally separated by 15ns (10^7 neutrinos/cm^2 per sub-pulse).

[1] What does the highest energy measurable muon track made by the neutrino interaction look like in the figure? Also, estimate the energy of such muon. Note for simplicity we assume all muons produced by neutrino interactions propagate straight +z direction only.

[2] The ECal contains only a few layers of lead and so it is not sufficient enough to stop muons. What is the purpose of the ECal?

[3] What is the cosmic ray rate in the entire ND280 detector system?

[4] What is the total CC interaction event in the entire ND280 detector system per year?

[5] Naively, the rate of cosmic rays is much higher than the rate of neutrino interactions, and the data is overwhelmed by the cosmic ray background. To avoid this, the data acquisition system (DAQ) only records the data when the neutrino beam passes through the detector. However, sometimes cosmic rays accidentally hit the detector at the same time the beam passes the detector. Is cosmic ray contamination a serious problem for the T2K ND280 neutrino detector?

Solution

Highest muon track is the one produced at the beginning of the P0D, and stop at the end of the ECal. For such muon, energy losses are

In [1]:
```
P0D=240*2
TPC1=0
FGD1=40*2
TPC2=0
FGD2=40*2
TPC3=0
ECal=5*11*2+50*2
Total=P0D+TPC1+FGD1+TPC2+FGD2+TPC3+ECal
print "total loss is",Total,"MeV"
```

```
total loss is 850 MeV
```

Since lead is high Z material, it has short radiation length and effective to measure electromagnetic particles, including electron and gamma ray. Thus ECal is useful to distinguish muons from electrons.

In [2]:
```
Area=200*(240+60+40+60+40+60+55)
print "Total cosmic ray rate is roughly",Area/10,"Hz"
```

```
Total cosmic ray rate is roughly 11100 Hz
```

In [1]:
```
xs=1E-38
flux=1E7*8*0.5*3600*24*365
NA=6.022E23
P0D=240*200*200*1*6.0/14.0*NA
FGD=40*200*200*1*6.0/14.0*NA
ECal=5*200*200*11*125.0/207.0*NA+50*200*200*1*6.0/14.0*NA
Total=xs*flux*(P0D+FGD*2+ECal)
print "total count of candidate events are",Total,"per year"
```

```
total count of candidate events are 58274651.9231 per year
```

From previous problem, neutrino interaction rate is 2Hz.

11 kHz cosmic ray means roughly 1 cosmic ray at every 0.1ms period. So naively there are 5000 times more cosmic rays per second. However, this is not right since data taking is a significantly short period. If the data taking is significantly shorter than 0.1ms, you don't expect cosmic rays to come in your data. Since total beam pulse size is 5μs, one can design a data taking trigger to take data only during beam pass through the detector, which is order 5μs. Then you expect only 0.05 cosmic rays per second (where 2 neutrino interactions per second). So, in fact, cosmic ray contamination is very low.