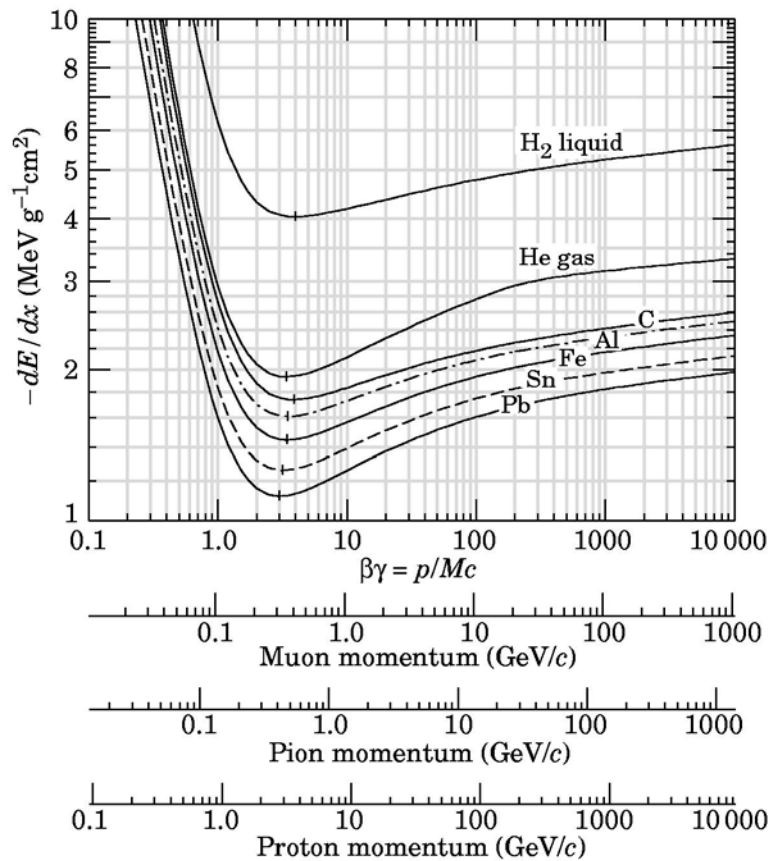


Ionization energy losses

Fast charged particles moving through matter interact with the electrons of atoms in the material. The interaction excites or ionizes the atoms. This leads to an energy loss of the traveling particle. The Bethe-Bloch formula describes the energy loss per distance travelled of charged particles (protons, alpha particles, atomic ions,...) traversing matter. The non-relativistic version was found by Hans Bethe in 1930; the relativistic version (shown below) was found by him in 1932.

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1 - \beta^2)}\right) - \beta^2 \right]$$

The Bethe formula is only valid for energies high enough so that the charged atomic particle (the ion) does not carry any atomic electrons with it. At smaller energies, when the ion carries electrons, this reduces its charge effectively, and the stopping power is thus reduced. But even if the atom is fully ionized, corrections are necessary. Bethe found his formula using quantum mechanical perturbation theory. Hence, his result is proportional to the square of the charge Z of the particle. The description can be improved by considering corrections which correspond to higher powers of Z . These are: the Barkas-Andersen-effect (proportional to Z^3 , after Walter H. Barkas and Hans Henrik Andersen), and the Bloch-correction (proportional to Z^4). In addition, one has to take into account that the atomic electrons of the material traversed are not stationary ("shell correction"). The introduction of the Bloch correction may be another reason for the common name Bethe-Bloch formula. But logically, one would then have to speak of the Bethe-Barkas-Andersen-Bloch formula, and nobody does that...



Goal of these exercises

The aim of these exercises is to plot the energy losses for (simulated) protons crossing the silicon detectors of the PAMELA apparatus.

Basic informations: you will work on a set of events coming out from a PAMELA experiment simulation. The given file

```
/home/mocchiut/pamela/data/pamsimu2013.root
```

contains the TTree `pamcalotree`, storing data with the `PamCalo` class, header file:

```
/home/mocchiut/pamela/PamCalo/inc/PamCalo.h
```

so library:

```
/home/mocchiut/pamela/PamCalo/lib/Linux/libPamCalo.so .
```

The ROOT file contains a mixture of different particles: protons, antiprotons, electrons and positrons in an energy range from about 1 to about 20 GeV.

In these exercises, we will create a variable to select protons from the sample ($qt \equiv q_{track}/q_{tot}$) and we will save this and other variables on a different file for positive particles. Then we will use a script to select protons and to plot their energy losses versus energy. Finally, we will fit the profile distribution using two different functions and we will compare the χ^2 of the fit to determine which one is representing better the point distribution.

Exercise 1

Write an executable compiled program which reads the input file

```
/home/mocchiut/pamela/data/pamsimu2013.root
```

and gives as output a new ROOT file containing a TTree with four variables (a TBranch for each one):

- dEdx
- energy
- qt (\equiv qtrack/qtot)

Save into the new file events which satisfy the following condition:

1. each event has energy greater than zero.

Hints:

- to compile, remember to add also the compilation flags:

```
-I/home/mocchiut/pamela/PamCalo/inc
```

```
-L/home/mocchiut/pamela/PamCalo/lib/Linux/
```

```
-lPamCalo
```

- to run, remember to export LD_LIBRARY_PATH:

```
export LD_LIBRARY_PATH=/home/mocchiut/pamela/PamCalo/lib/Linux/:$LD_LIBRARY_PATH
```

Exercise 2

Write a ROOT-CINT script which reads the output file of exercise 2 (should be similar to this one: `/home/mocchiut/scripts/EM_output_160714.root` use this file if you are not able to complete or run exercise 1) and gives as output on the screen and on the disk (pdf format) a TCanvas divided into two pads (one column, two rows – hint: `TCanvas::Divide`) which contain from top:

1. a scatter plot (TH2D, use `nbins=1000` for both axis) of dE_{dx} vs energy (with colors and palette) for events with $q_t > 0.9$ (this condition selects protons from the sample);
2. the same scatter plot with overlying the profile as function of X (`TProfile`, `TH2D::ProfileX()`).

Set the range properly in order to look close to the event distribution.

Try to answer the following questions:

1. Is the profile over the peak of the distribution (try to use interactively `TH2D::SetShowProjectionY`)?
2. Are the distributions in projected slices used for the profile calculation symmetric?

Exercise 3

Update the script of exercise 2 in order to draw a new TCanvas divided into three pads (one column, three rows – hint: `TCanvas::Divide`) which contain from top to bottom:

- the profile of dE/dx vs energy for events with $q_t > 0.9$ fitted with the function $f(x) = a + b/x$ (hint: fit range [1.5,18.]). The resulting fit line must appear (in red) over the distribution and the resulting χ^2 must be printed by the script on the STDOUT.
- The profile of dE/dx vs energy for events with $q_t > 0.9$ fitted with the function $f(x) = a + [(b+x^2)/x^2]$ (hint: fit range [1.5,18.]). The resulting fit line must appear (in green) over the distribution and the resulting χ^2 must be printed by the script on the STDOUT.
- The dE/dx vs energy scatter plot (with colors and palette) for events with $q_t > 0.9$. Draw also, in the energy range from 1 to 20 and on the same plot, the line corresponding to the function for which the fit gave the smallest χ^2 (hint: inside the script compare the two χ^2 and perform the choice with an `if` statement).

Save the output on the disk as pdf file.

Answer the following question:

1. What happens if the fit range is extended up to 20 GeV? Why? What can be done to fit up to 20 GeV (hint: read the TH1 reference page)?

Preparing the output

- create a directory and put inside this directory ALL the files you want me to correct and look at.
- create a README text file (named like EM_README.txt), inside the file write:
 - **your name and surname**
 - a list of the files you are submitting
 - **in details** how to compile and run the programs
 - any other comment and answer to question(s)
- create a compressed tarfile containing the directory:

```
bash> ls
Mocchiutti/
bash> tar zcf Mocchiutti.tar.gz Mocchiutti/
```
- copy the tarzipped file on the USB key I will circulate

Timing and rules

- You have four hours time to do your work.
- You can search the web, look at manuals, look at any note you wrote during the course, etc.
- We will discuss what you have written at the oral examination on 2014/07/18, until that (if needed) you can change and improve your programs. In that case prepare an electronic version we can look at during the oral examination, we will compare it to the one handed in today and we will discuss any change and/or correction.