Physics of Particle Detection

(Everything from geiger counters to the ATLAS detector: http://pdg.lbl.gov/atlas)

Charged particles passing through matter

- lose energy
- scatter

primarily due to

(a) collisions with atomic electrons

- dominates energy loss, except for electrons

(b) scattering from atomic nuclei

- dominates scattering

These interactions occur frequently

$$\sigma \sim \text{(atomic size)}^2 \sim (1\text{Å})^2 \sim 10^8\text{b} \sim 10^{-20}\text{m}^2$$

Other processes

(c) bremsstrahlung

- for electrons and high energy muons (>0.1TeV)

(d) coherent em radiation

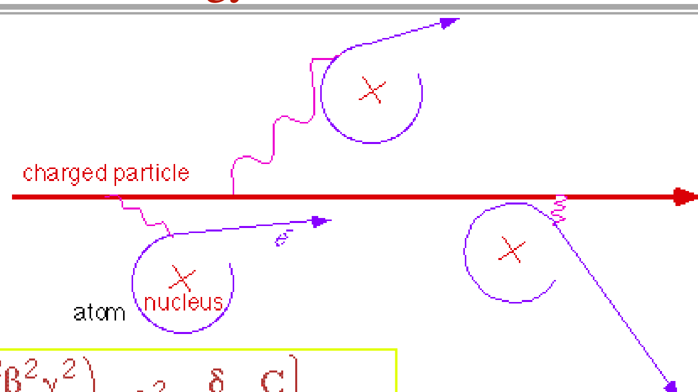
- Cerenkov radiation (e.m. shock wave) for v > c/n
- Transition radiation ($\gamma >> 1$) from layered materials
- Channelling radiation from particles channelled by crystals

(e) inelastic nuclear reactions

- for hadrons always, and for all particles at high enough energies

Ionization Energy Loss

For a heavy ($M>m_e$), fast ($\beta> \alpha$) charged ($Q=ze$) particle, the ionization energy loss per unit distance travelled in a medium is:



$$\frac{dE}{dx} = \frac{-4\pi n z^2 e^4}{m_e c^2 \beta^2}\left\{\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right) - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}\right\}(1+\nu)$$

n	density of electrons in medium
I	effective ionization potential of atoms in medium (~10 eV)
δ	"density effect" due to screening of charged particle's electromagnetic field by polarization of atoms in medium; δ asymptotes to [2 ln(γ) + constant] for $\gamma>>1$
C/Z	"shell corrections" important when $\beta \sim \beta_{\text{atomic electrons}} \sim \alpha$
ν	higher order QED corrections important when $\beta \sim \alpha$

Effective ionization potential (I) / atomic number (Z)

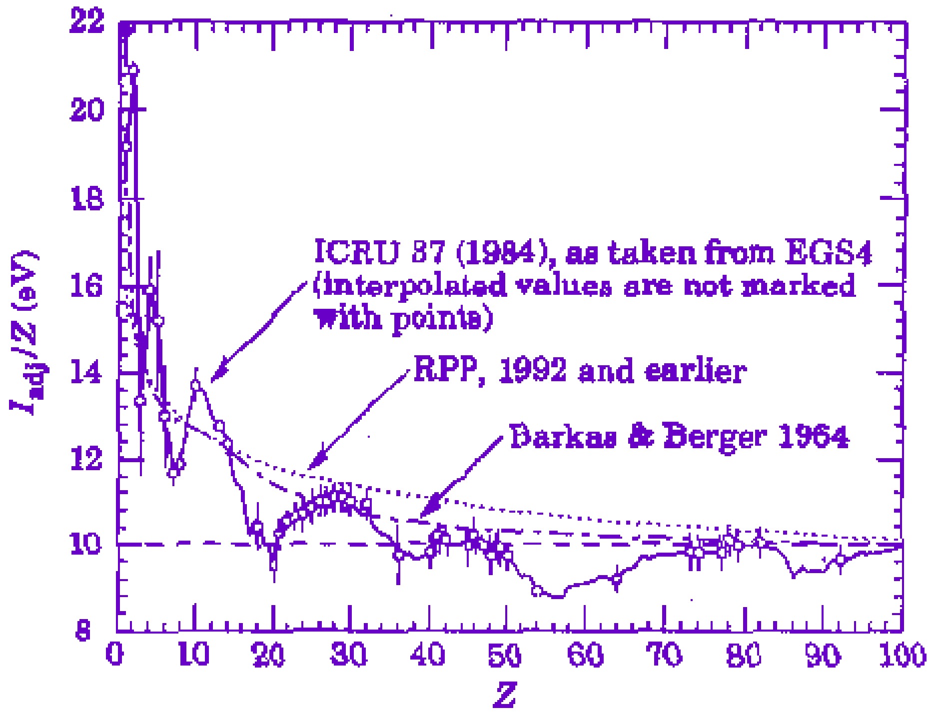
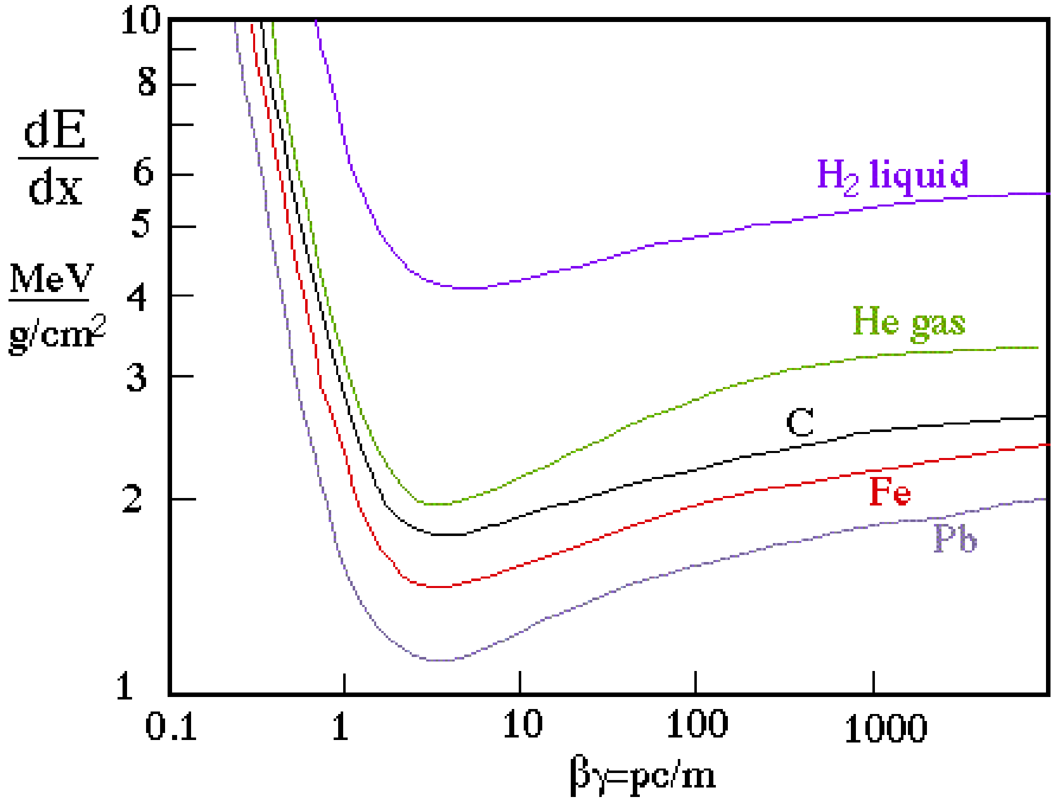
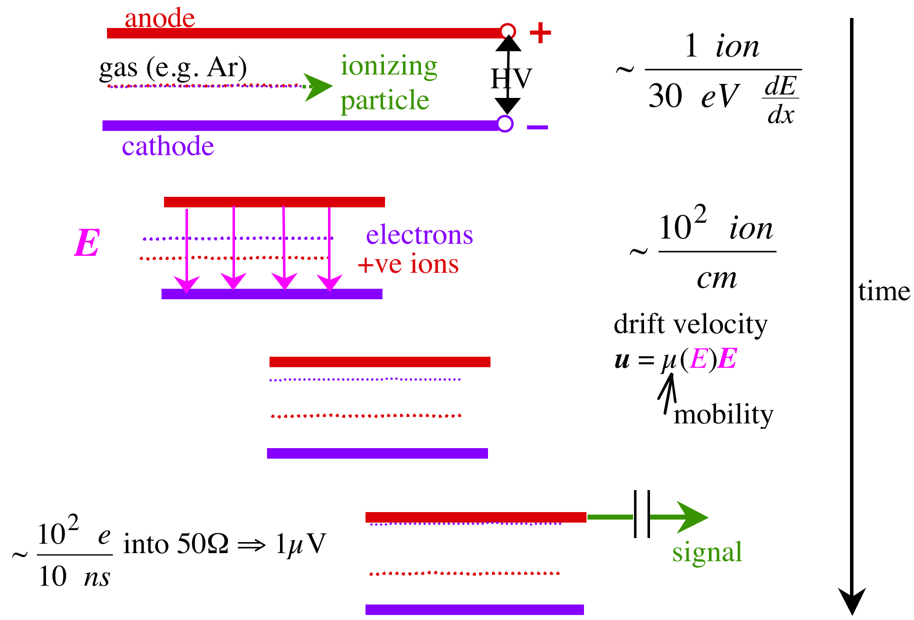


Figure 23.5 of Review of Particle Properties, Z. Phys. C 51, No. 1-4.
(http://pdg.lbl.gov/2001/passagerpp.pdf)
(see also the Mass Spectrometer experiment in the 3/4[th] year labs.)

Ionization energy loss rate in various materials



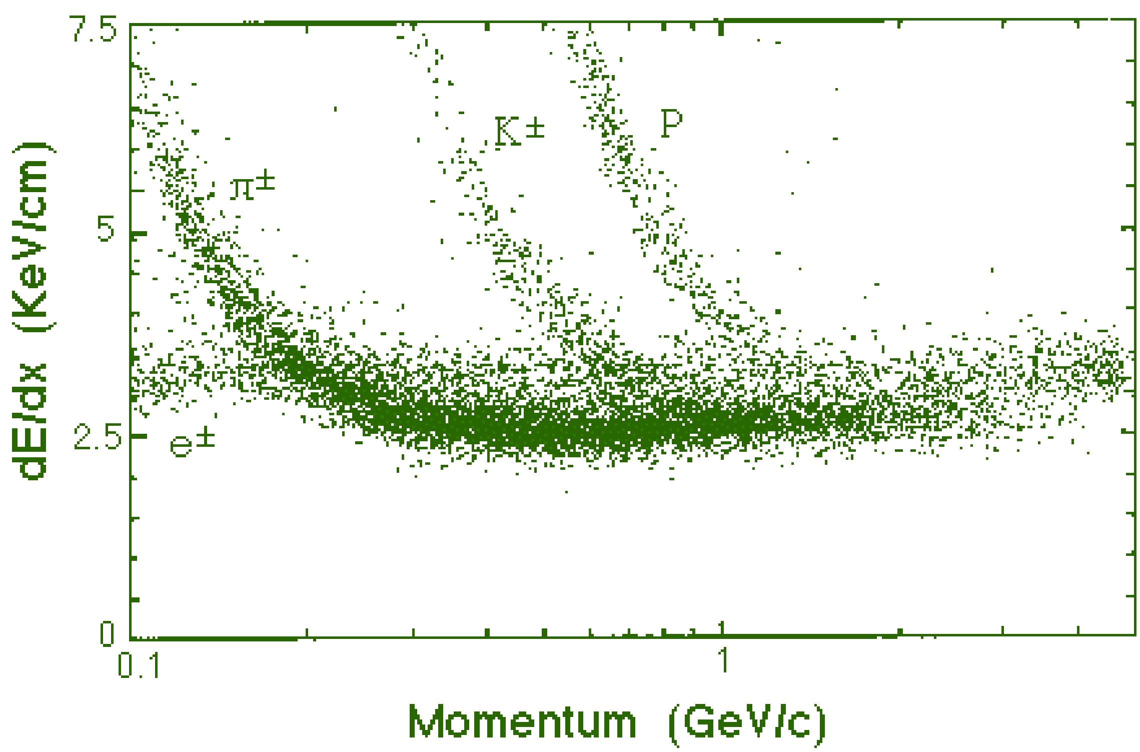
(Gas) Ionization Detectors



Liquids and solid ionization detectors have $\sim\times 10^3$ density $\Rightarrow \sim\times 10^3$ dE/dx; semiconductors produce one electron-hole pair for about 3eV (Ge) or 4 eV(Si).

Ionization energy loss

Measured in ARGUS propane drift chamber.



Bremsstrahlung

All charged particles scatter from the atomic nuclei and electrons when passing through a medium. When a charged particle is accelerated it radiates, so scattering of charged particles produces radiation. The radiation produced by charge particles passing through a medium is know as "bremsstrahlung".

The mean bremstrahlung energy loss of a charged particle (mass M, charge ze) is

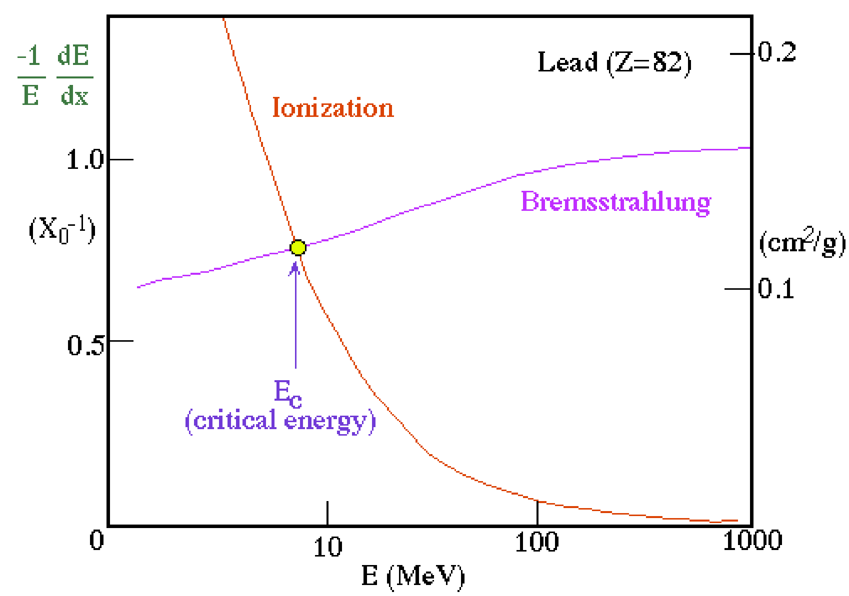
$$dE/dx = -E/X_0$$

where the radiation length, X_0, for the medium (atom density n_a and atomic number Z) is approximately given by

$$X_0 = M^2/[4n_a e^6 z^4 Z(Z+1)\ln(183/Z^{1/3})]$$

Bremstrahlung dominates the energy loss of electrons above the critical energy, E_c; ionization dominates at lower energies.

Energy loss of electrons



The critical energy (in lead) of the electron is about 7 MeV; the critical energy of the next lightest particle (the muon) is about half a TeV.