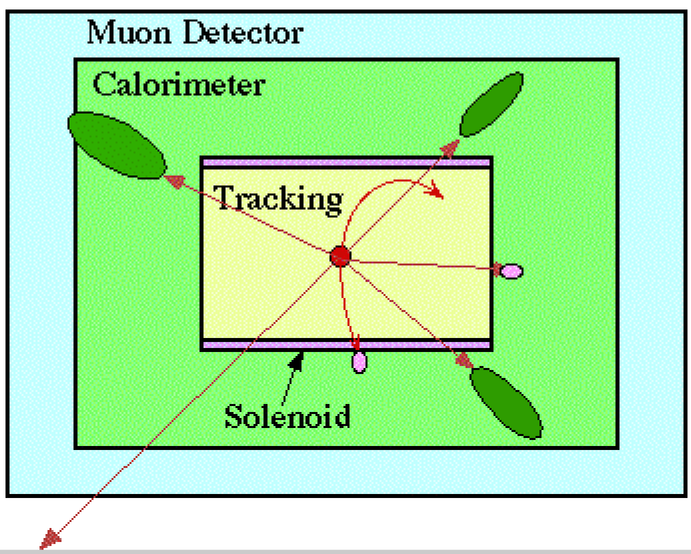
# Subatomic Physics Detectors

Measure for every particle produced in an interaction.

| | |
|---|---|
| position | (x, y, z) |
| •momentum or energy | **P** or $(E,\theta,\phi)$ |
| mass | m |
| electric charge | Q |




Tracking detectors measure the positions of charged particles.

A solenoid provides a magnetic field so the momentum of charged particles can be determined from their radius of curvature.

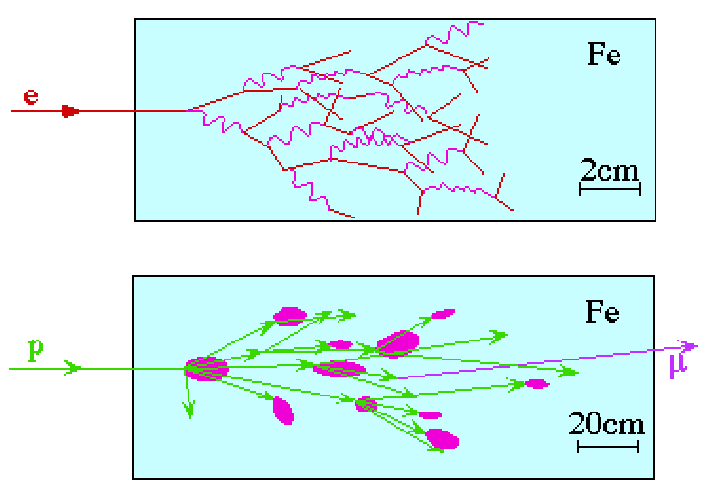
Calorimeters measure the energy of hadrons, photons, and electrons.

Muon detectors identify muons because muons and neutrinos are the only particles which can pass through the the calorimeters, but muons ionize and neutrinos don't.



# Measuring energy

**Calorimeters** measure energy by absorbing particles. Most calorimeters measure the ionization energy deposited by all the charged particles in the "showers" produced as the particle is absorbed. The scale length of electromagnetic showers is the radiation length, $X_0$ (~2cm in Fe), relevant for both bremsstrahlung pair production; the scale length for hadronic showers is the mean hadronic interaction length, $\lambda_I$ (0.2m in Fe).




Ionization observed is proportional to energy lost

$$N_{ions} \propto E$$

This is statistical process

$$\sigma_N = N^{-1/2} \Rightarrow \sigma_E/E \propto E^{-1/2}$$

The resolution degrades rapidly if all the particles are not absorbed. i.e. The fluctuations in how much energy leaks out can be much higher than the statistical uncertainty on measuring the energy that does not leak out.

# Natural Radioactivity observed by a Germanium detector

The common long-lived natural radioactive isotopes are Potassium-40, Uranium-235, Uranium-238, and Thorium-232

(see http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/radser.html)

Natural potassium (Z=19 protons) has 3 isotopes (N=20, 21, or 22 neutrons):

( from http://ie.lbl.gov/education/parent/K_iso.htm )

| ${}_{Z}K^{A=N+Z}$ | Natural Abundance | Half-life |
|---|---|---|
| ${}_{19}K^{39}$ | 93.3% | stable |
| ${}_{19}K^{40}$ | 0.012% | $1.25 \times 10^{9}$y |
| ${}_{19}K^{41}$ | 6.7% | stable |

Potassium-40 decays ( from Table of Nucleides http://www2.bnl.gov/CoN/)

| Decay | | % | ΔE (MeV) |
|---|---|---|---|
| $\beta^-$ | ${}_{19}K^{40} \Rightarrow {}_{20}Ca^{40}+e^-+{}_e$ | 89.3 | 1312 |
| $\beta^+$ | ${}_{19}K^{40} \Rightarrow {}_{18}Ar^{40}+e^++\nu_e$ | 0.001 | 1505 |
| electron capture | ${}_{19}K^{40} + e^-_{atomic} \Rightarrow {}_{18}Ar^{40*}+\nu_e$<br>$({}_{18}Ar^{40*} \Rightarrow {}_{18}Ar^{40}+\gamma)$ | 10.7 | 1505<br>(1461) |



# Unstable Isotopes

If particles can decay to a lower energy state, they will. Looking at some mass 40 isobars, predict which isotopes will undergo beta decays and by what process:

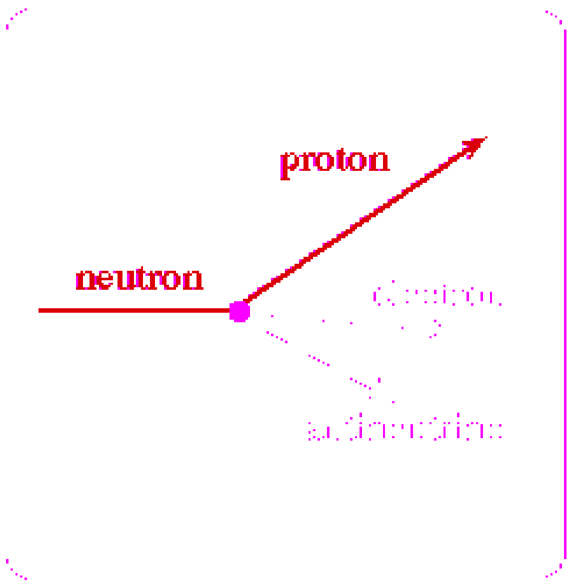
| Isotope ${}_{Z}X^{A}$ | Atomic Mass Excess $(M_X - A \cdot u)$ |
|---|---|
| ${}_{17}Cl^{40}$ | – 27.558 MeV |
| ${}_{18}Ar^{40}$ | – 35.040 MeV |
| ${}_{19}K^{40}$ | – 33.535 MeV |
| ${}_{20}Ca^{40}$ | – 34.846 MeV |
| ${}_{20}Sc^{40}$ | – 20.526 MeV |

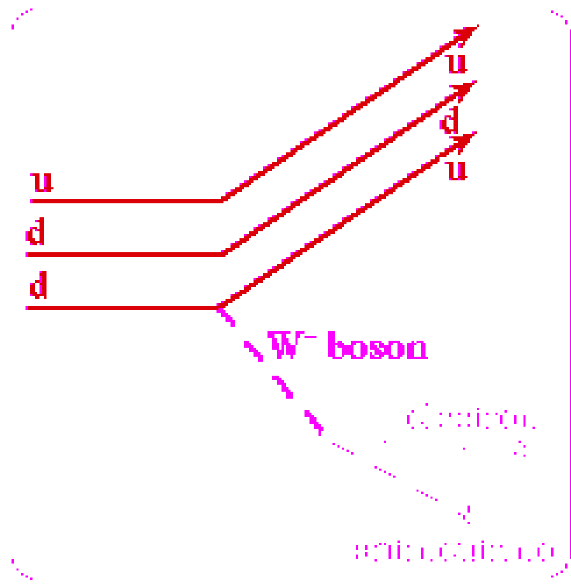
atomic mass unit (u) ≡ (mass $^{12}C$ atom)/12 = 931.49432(28)MeV

# Beta decay

Mediated by the weak interaction.

If proton is changing into a neutron, then either $\beta^+$ emission or atomic electron capture may occur with relative probabilities determined by the available energy and the atomic and nuclear wave functions.






# Radiation Dose

A typical 70kg human body has 140g of potassium, and 17mg of K40, corresponding to a decay rate of 4.4kBq, and an annual dose of about 0.2mSv (out of a typical total of about 3.6mSv).

| | **SI Unit** | **Old Units** |
|---|---|---|
| **Activity:** | Bequerel (Bq) = 1 decay/s | Curie (Ci)= $3.7\text{x}10^{10}$ Bq |
| **Absorbed Dose** | Gray (Gy) = 1 Joule/Kg | Rad = 0.01 Gy |
| **Equivalent Dose** | Sievert (Sv) = Gray x Q (Q = radiation weighting factor) | Rem = 0.01 Sv |

**The dose (*D* in $\mu$Sv/hr) from nuclear gamma rays** is approximately given by

$$D = 2A\frac{E}{R^2}$$

Where

$A$ = the activity of the source (in MBq)

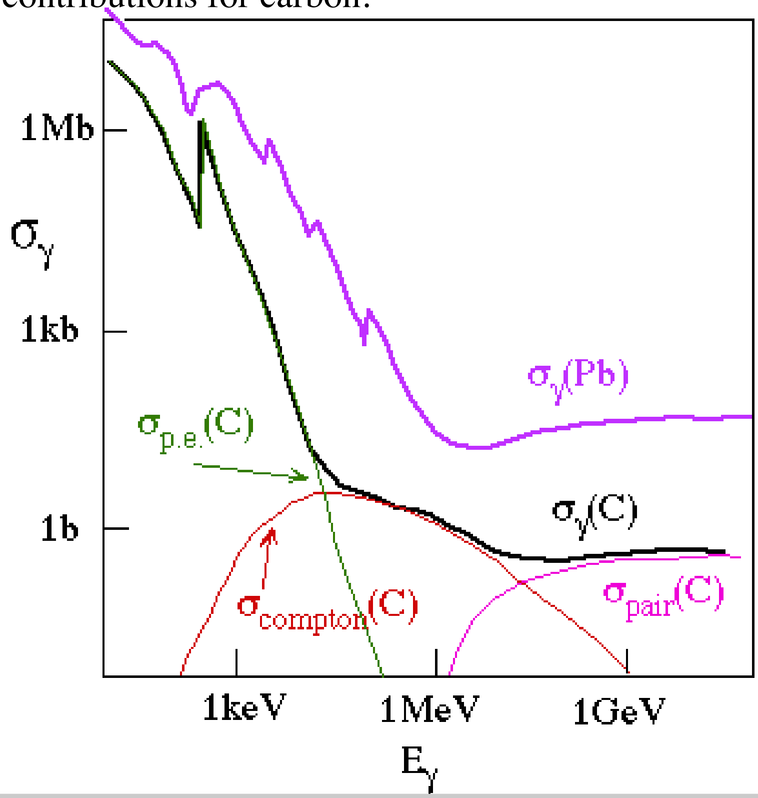
$E$ = the total gamma energy emitted per disintegration (in MeV)

$R$ = the distance from the source in metres

Typical doses from natural radiation are a few mSv/year (http://www.umich.edu/~radinfo/), but a few places have a natural background over 100 mSv/year (http://www.taishitsu.or.jp/radiation/index-e.html)

# Photon Interactions

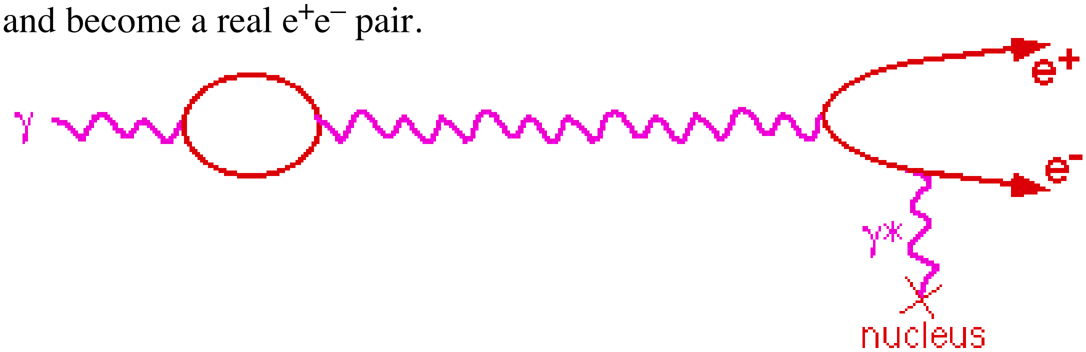
Photon total cross sections in Carbon (Z=6) and Lead (Z=82), showing the dominant contributions for carbon.






# Pair production

Real photons spend part of their time (about $\alpha$) as a virtual electron-positron pair. These virtual $e^+e^-$ pairs can scatter from the virtual photons in the electromagnetic field of a charged particle, e.g. an atomic nucleus or electron, and become a real $e^+e^-$ pair.




In the high energy limit ($E_\gamma >> 2m_e$), the mean distance a photon will travel before pair producing is

$$X_p \sim 9/7\ X_0$$

(Note: The reason the radiation length and the pair production length are almost the same is because bremsstrahlung and pair production are simply time and space rearrangements of the same process: a real photon coupling to an electron which is coupled via a virtual photon to a nucleus.)