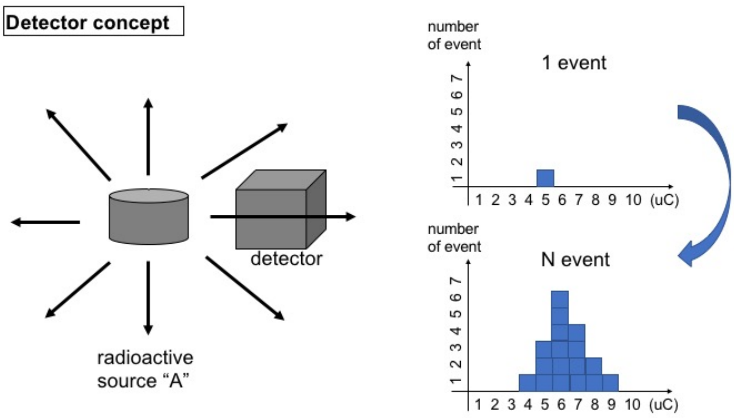
Radiation Detector 2018/19 (SPA6309)

Detector concept

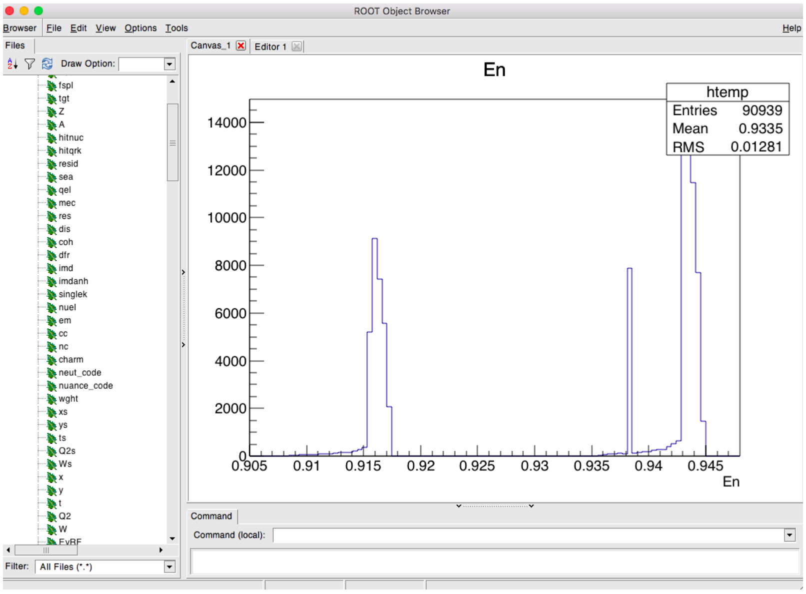
Event and histogram



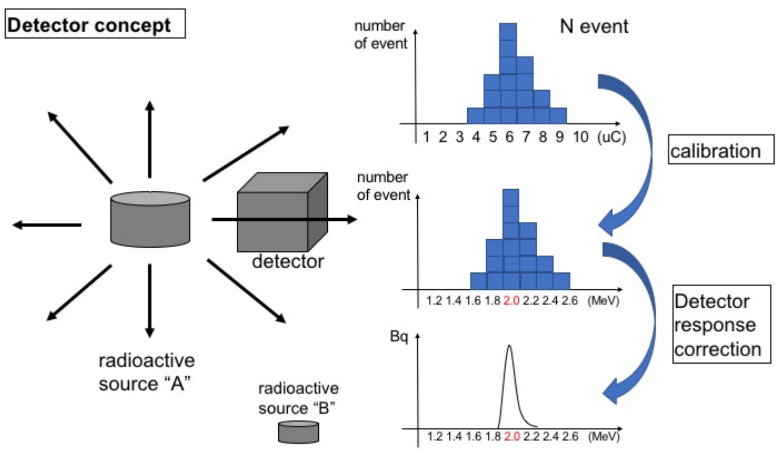
For example, there is a radioactive source "A" which emit 2 MeV γ-ray in all direction. A scintillator detector is located nearby to measure it. What do you measure exactly? A gamma ray makes $e^+ - e^-$ pairs in the scintillator, and they ionize atoms, the energy is then converted to an electric signal..., and in the end, you observe some electric signal in terms of Coulomb. So one gamma ray detected in the detector corresponds to some Coulomb, say 5 μC. This is one **event**, you detect a γ-ray, but you have not much information from 1 event.

After a longer exposure, you accumulate N events, and now the data show some distribution. Such data is called **histogram** (If you call this a graph, you will be punished!). A histogram is data, data is a histogram. Y-axis shows the number of events, so this is a 1-dimension histogram. This looks different from a graph you record temperature and date, which is a 2-dimension graph. 2-dimension histogram, for example, is an accumulation of data of γ-ray energy and angle, look like 3-dimension graph (X-axis is energy, Y-axis is an angle, and Z-axis is the number of events).

1 event can have N-dimension information. For example, you can record γ-ray energy, angle, time, etc. This is called **N-Tuple**. More dimension means richer information. If you fill in Excel table, 10 events with 5 dimensions N-Tuple means there are 10 rows with 5 columns. The table goes to large quickly and unmanageable, so we (particle physicists) don't use Excel (or any Microsoft products). Below is a typical N-Tuple in particle physics, there are 90939 events (called "entries" here), and every single even has 96 values. So it is 96-dimension histogram. But that is insane, so usually, people plot 1 or 2 out of 96 parameters (1 or 2 dimension projections of 96 dimension histograms).



Calibration

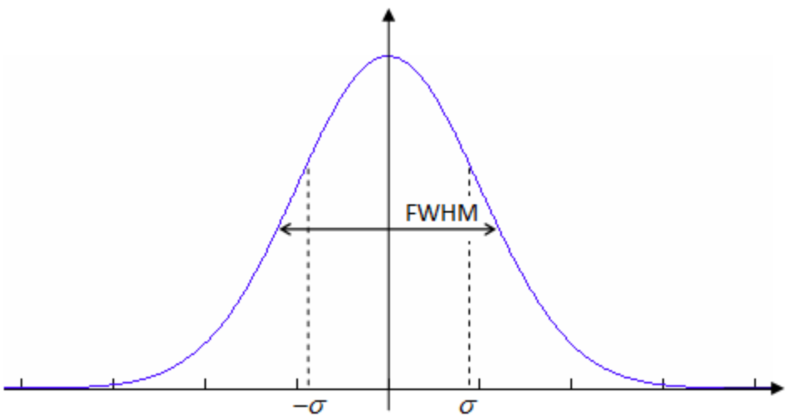


The measured distribution reflects some physics (such as γ-ray energy), but detector does not measure it directly. First, we need to find what "5μC" corresponds in terms of, say γ-ray energy. This process is called **calibration**.

This can be done in several ways. For example, if there is other radioactive γ-ray source "B" with known energy, say 4 MeV, one could place the source in front of the detector to measure γ-ray. If the distribution makes peak at 12 μC, now you know 1μC of electric charge corresponds to 0.33 MeV of γ-ray energy deposit. Therefore, one can find the $5\mu C$ peak observed from radioactive source "A" is actually 2 MeV γ ray signal...

Calibration is very important for any detectors. Every device you buy from stores are pre-calibrated and we don't have to worry such a thing. For example, if you buy a mercury thermometer you know the relationship of the hight and temperature. But in general, radiation detectors (especially ones you built and one and only one, such as detectors on large hadron collider) always need to be calibrated by yourself.

Resolution (Leo, 5.3)



The detectors can measure certain thing only within their **resolution**, the intrinsic precision of the detector (the spread of signals, the granularity of arrays, etc). The **Full width half maximum (FWHM)** is often quoted as the resolution of the detector. Note, FWHM is larger than 2 sigmas.

$$FWHM = 2\sigma\sqrt{2ln2} = 2.35\sigma.$$

So every measurement is performed within the resolution. For example, energy resolution (%) can be shown in the fraction of true energy ($\frac{\Delta E}{E}$).

Detector efficiencies (Leo, 5.6)

Every detector has a finite **efficiency**, which can be defined

$$Efficiency = \frac{events\ detected}{total\ events}$$

First, due to geometric effect, an only partial amount of γ-ray even hit the detector. Second, due to the finite performance of a detector, even γ-ray hit the detector sometimes it fails to detect. Both of them have to be pre-estimated, like calibration process. By knowing the failure rate (called **intrinsic efficiency**), one could recover the total amount of γ-ray which hit the detector from a partial measurement.

Detector response correction

The measured value (say, γ-ray energy spectrum) by the detector is different from the true value due to the smearing of the signal (=resolution) and failure of detection(=efficiency). These are called **detector response**. Purpose of estimating them from the simulation is to retrieve the true quantity of the measurement by correcting detector responses. By correcting detector resolution, you can measure the true shape of γ-ray energy spectrum. By correcting the detector efficiency, you can get the Y-axis unit correctly. In an example here, it is the number of decays at each energy of γ-ray.