Experiment Compton Scattering

The Compton scattering is one the processes through which γ–rays in the MeV energy scale can interact with matter.
The energy of the scattered photons (f) is

$$\begin{cases} E_i + mc^2 = E_f + \sqrt{(mc^2)^2 + (p_e c)^2} \\ \vec{p_i} = \vec{p_f} + \vec{p_e} \end{cases}$$

$$(p_e c)^2 = E_i^2 + E_f^2 + 2mc^2(E_i - E_f) - 2E_i E_f$$

$$\vec{p_i} = \vec{p_f} + \vec{p_e}$$

$$p_e^2 = (\vec{p_i} - \vec{p_f}) \bullet (\vec{p_i} - \vec{p_f}) = p_i^2 + p_f^2 - 2p_i p_f \cos\theta$$

$$\Big\downarrow \text{ x } c^2$$

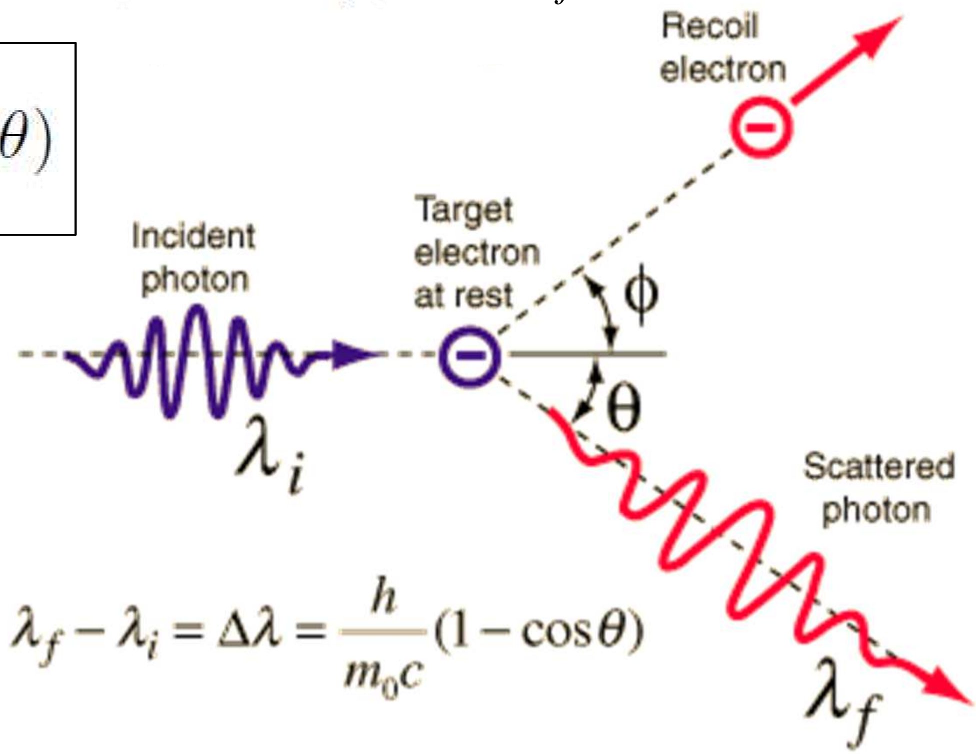
$$(p_e c)^2 = E_i^2 + E_f^2 - 2E_i E_f \cos\theta$$

Recalling:

$$(p_e c)^2 = E_i^2 + E_f^2 + 2mc^2(E_i - E_f) - 2E_i E_f$$

$$\boxed{\frac{1}{E_f} - \frac{1}{E_i} = \frac{1}{mc^2}(1 - \cos\theta)}$$

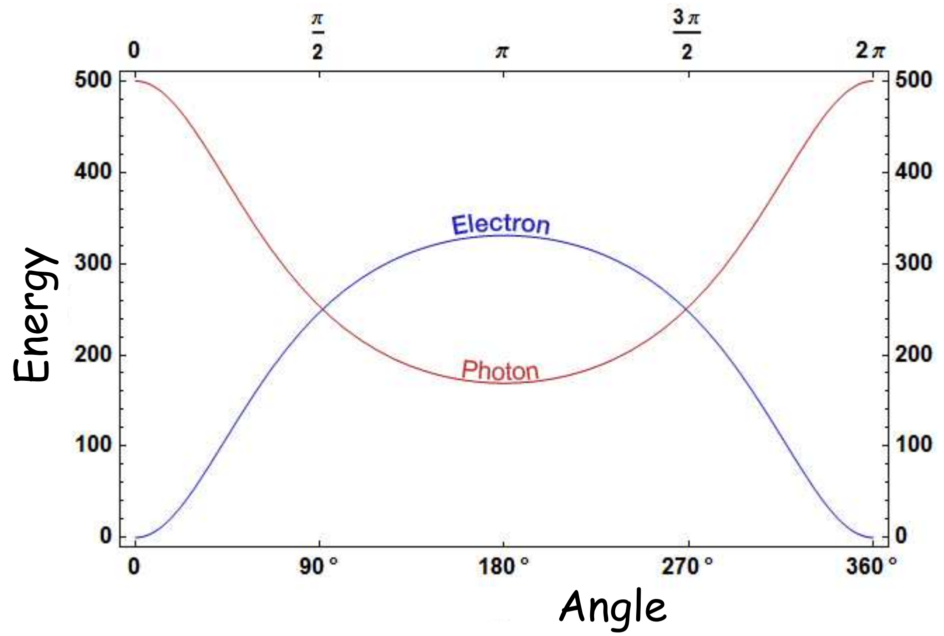
$$\boxed{h\nu_f = \frac{h\nu_i}{1 + \frac{h\nu_i}{m_e c^2}(1 - \cos\theta)}}$$



$$\boxed{\frac{1}{E_f} - \frac{1}{E_i} = \frac{1}{mc^2}(1 - \cos\theta)}$$

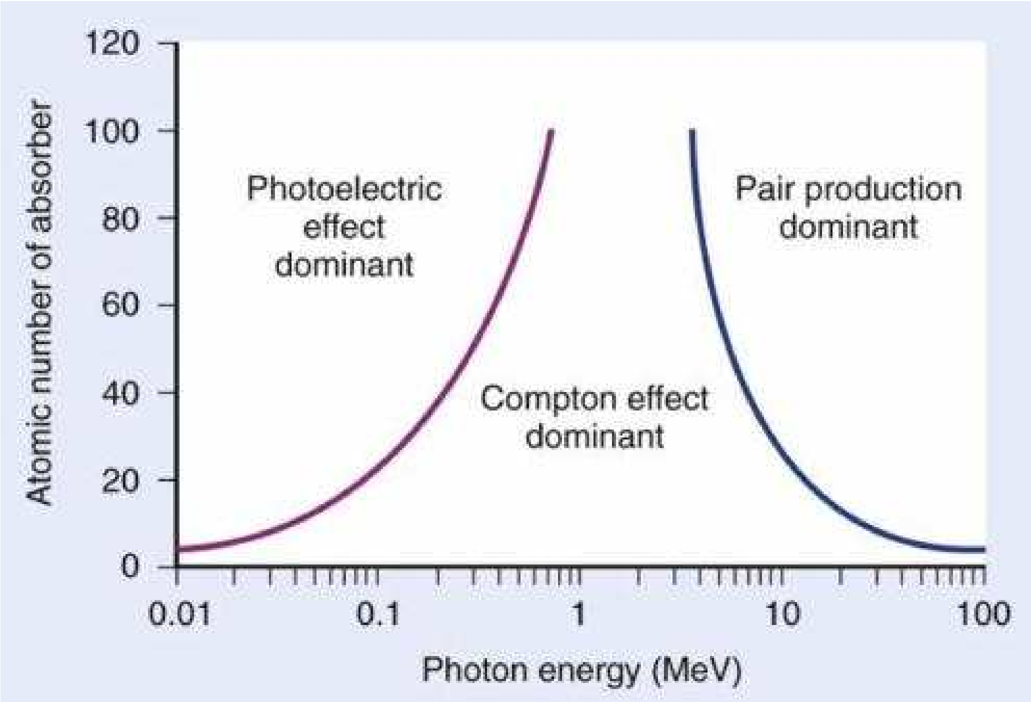
$$m_e c^2 = 0.511\ MeV$$

Energy of the scattered photon (and of the electron) as a function of the θ angle, for a **incoming photon of 511 keV**.



At 90° the electron and the scattered photon have the **same energy**

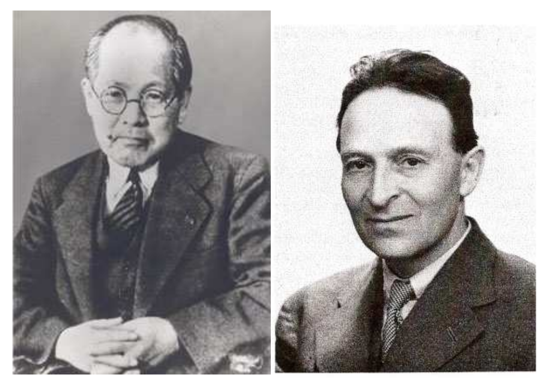
Notice: in the expression above and in all the following we will consider the electron free and at rest



Relative importance of the three kind of interaction of the photons with matters as a function of the energy of the photon and of the atomic number Z of the material.
The lines show the Z at which the cross sections are equal.
The Compton scattering dominates for the energies around 1 MeV

The differential cross section for a photon scattered by a free electron in an infinitesimal angle dΩ is given by the Klein-Nishina formula

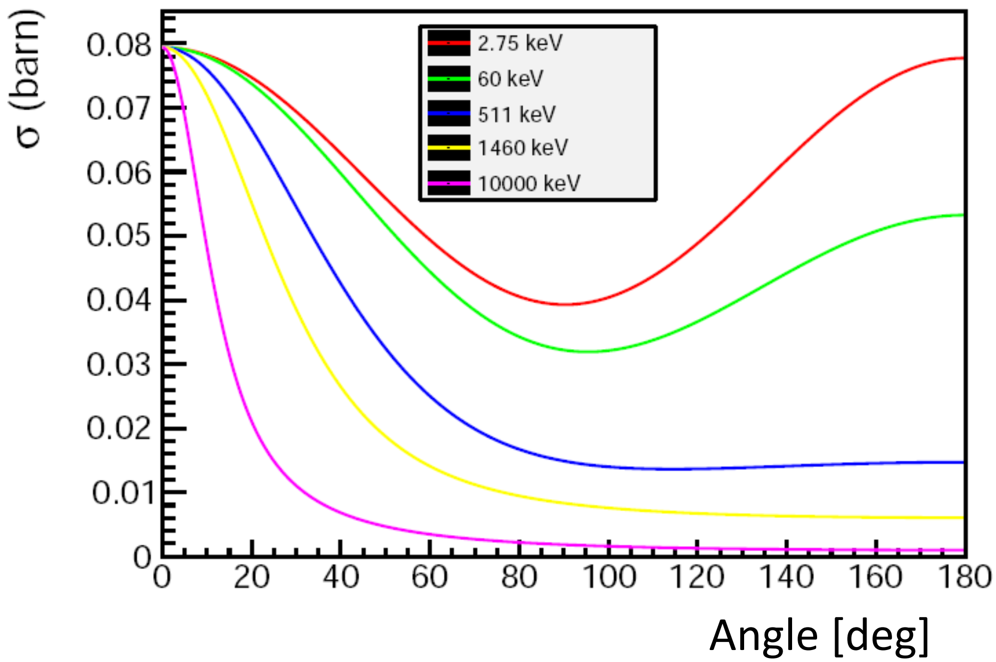
$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}\left(\frac{h\nu_f}{h\nu_i}\right)^2\left(\frac{h\nu_f}{h\nu_i} + \frac{h\nu_i}{h\nu_f} - sen^2\theta\right)$$

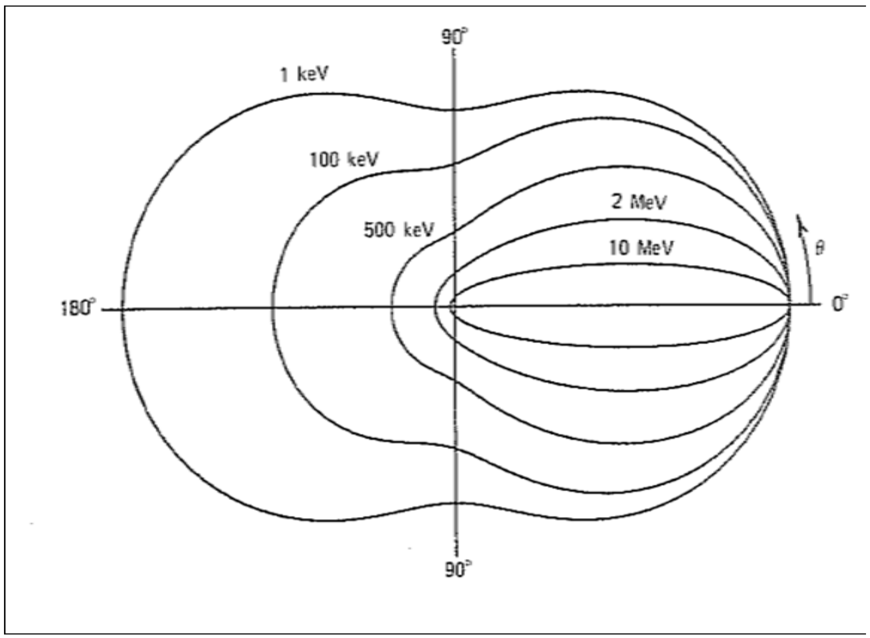


with $r_e = \frac{e^2}{m_e c^2} = 2.8179 \ fm$

Angular dependence of the cross section for photons of different energies. The symmetry classically present for low energy photons (**red line, 2.75 keV**) is lost as the energy increases.

At high energy (**purple line, 10 MeV**) the cross sections is much larger for small angles (i.e. forward direction).



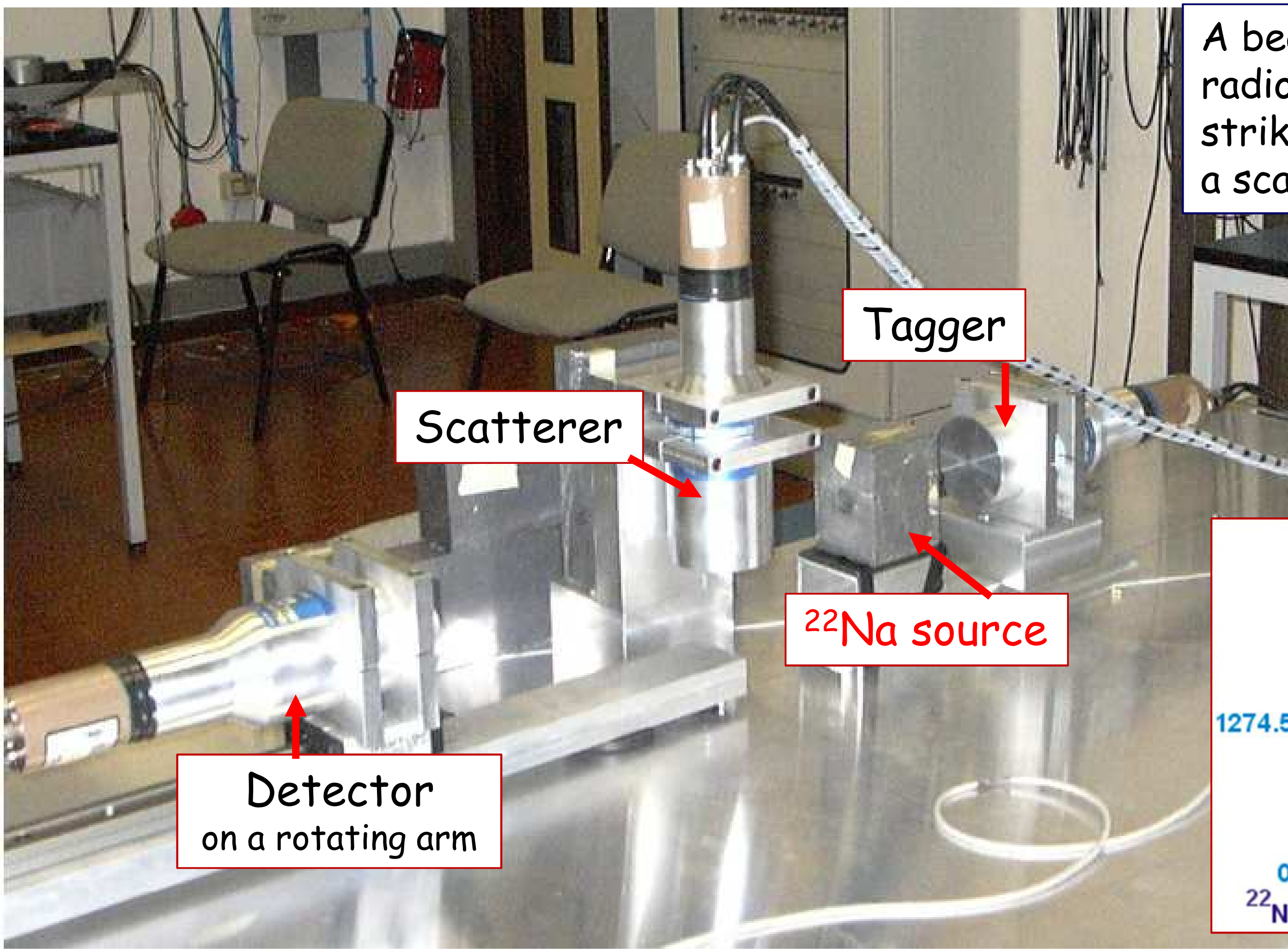


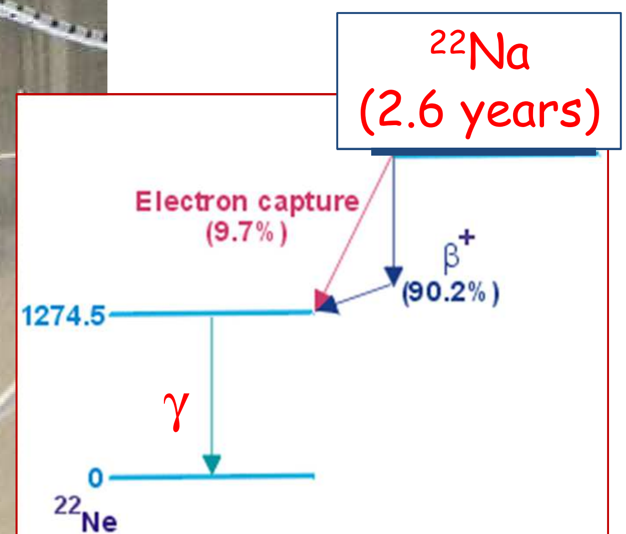
The goals of this experiment are:

a) To verify the dependence of the energy of the scattered photon on the scattering angle

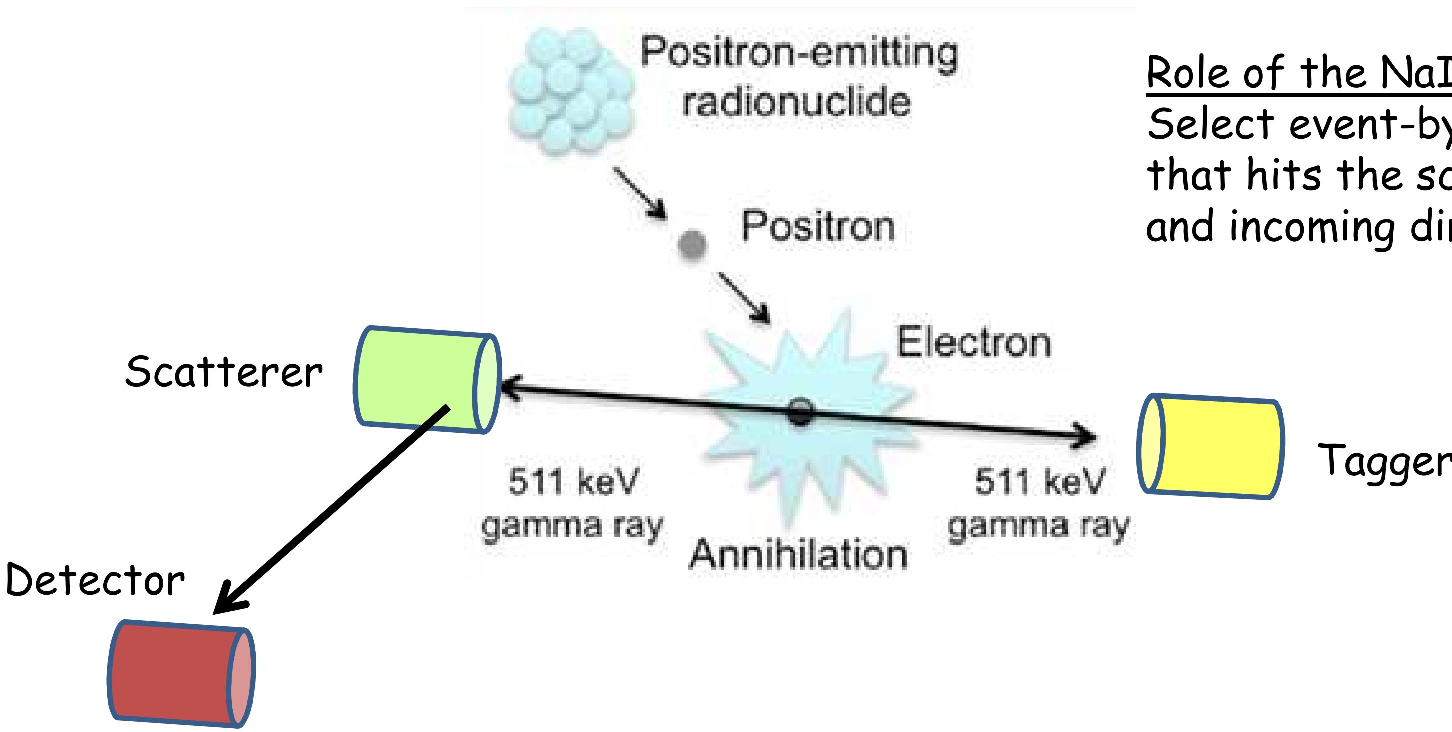
b) To measure the cross section differential in angle

A beam of photons from a radioactive source (^{22}Na) strike a target that works as a scatterer





For the measurement of the angular dependence, as tagger, scatterer and detector, three NaI(Tl) scintillator detectors will be used

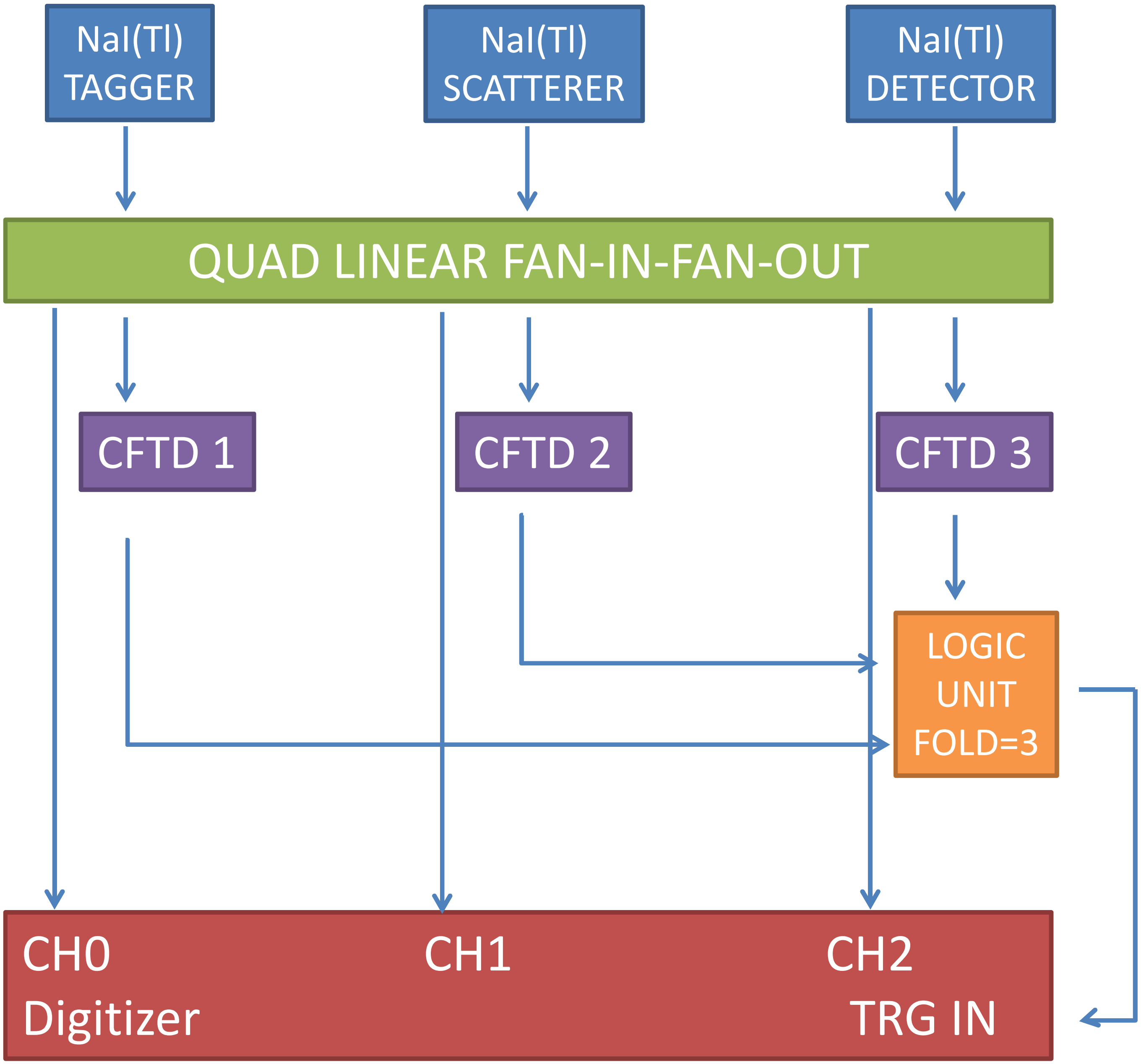


Role of the NaI(Tl) tagger:
Select event-by-event the photons that hits the scatterer (511 keV and incoming direction).

We need to use the detectors in temporal coincidence. In this way it is possible to associate the scattered gammas to the incoming 511 keV of which, using the tagger, it was identified the direction.

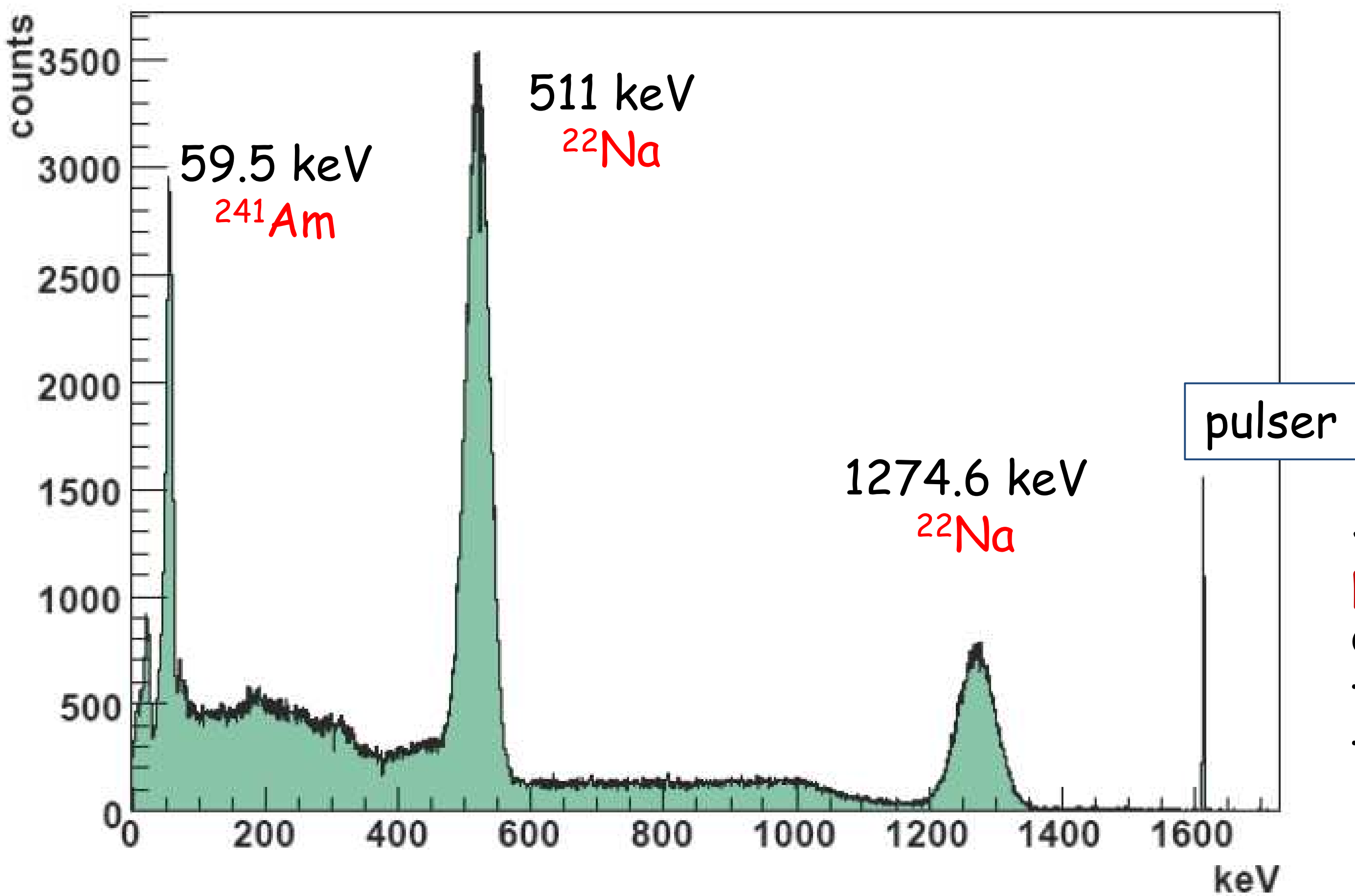
Electronics layout

Compton Scattering - Electronics layout



Energy calibration of the NaI(Tl) spectra

With sources of ^{22}Na + ^{241}Am (for the low energy range)

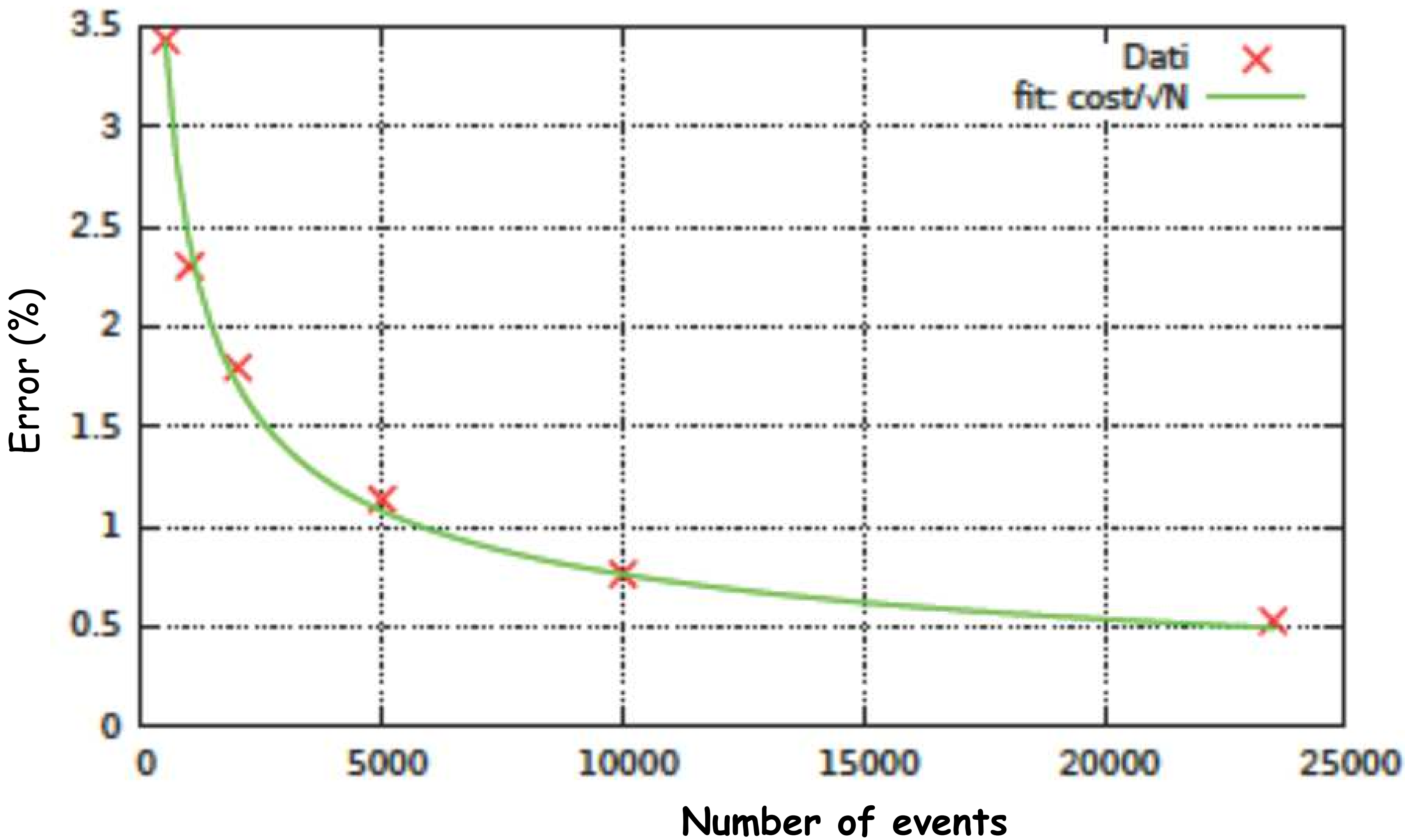


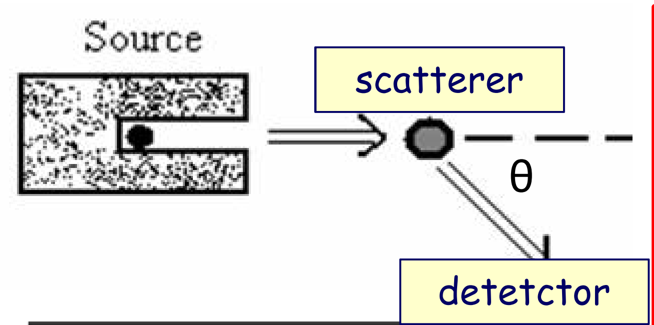
Sometimes a pulser is used in order to check the stability of the electronics.

It is possible to measure the energy resolution and verify →

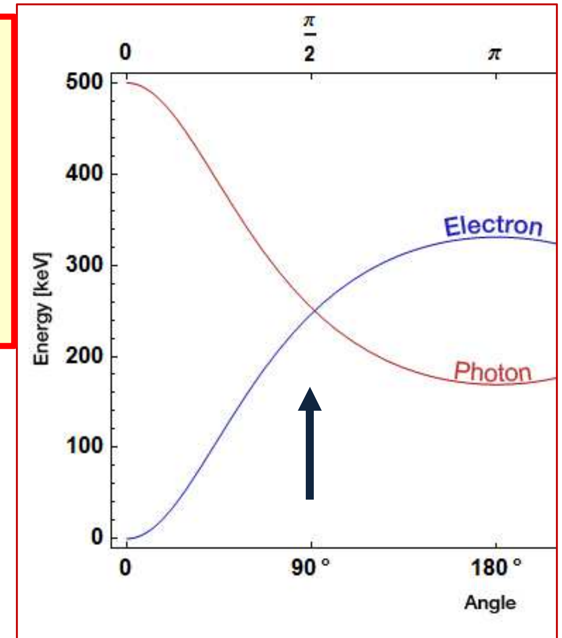
$$R = \frac{FWHM}{H_0} = \frac{2.35}{\sqrt{N}}$$

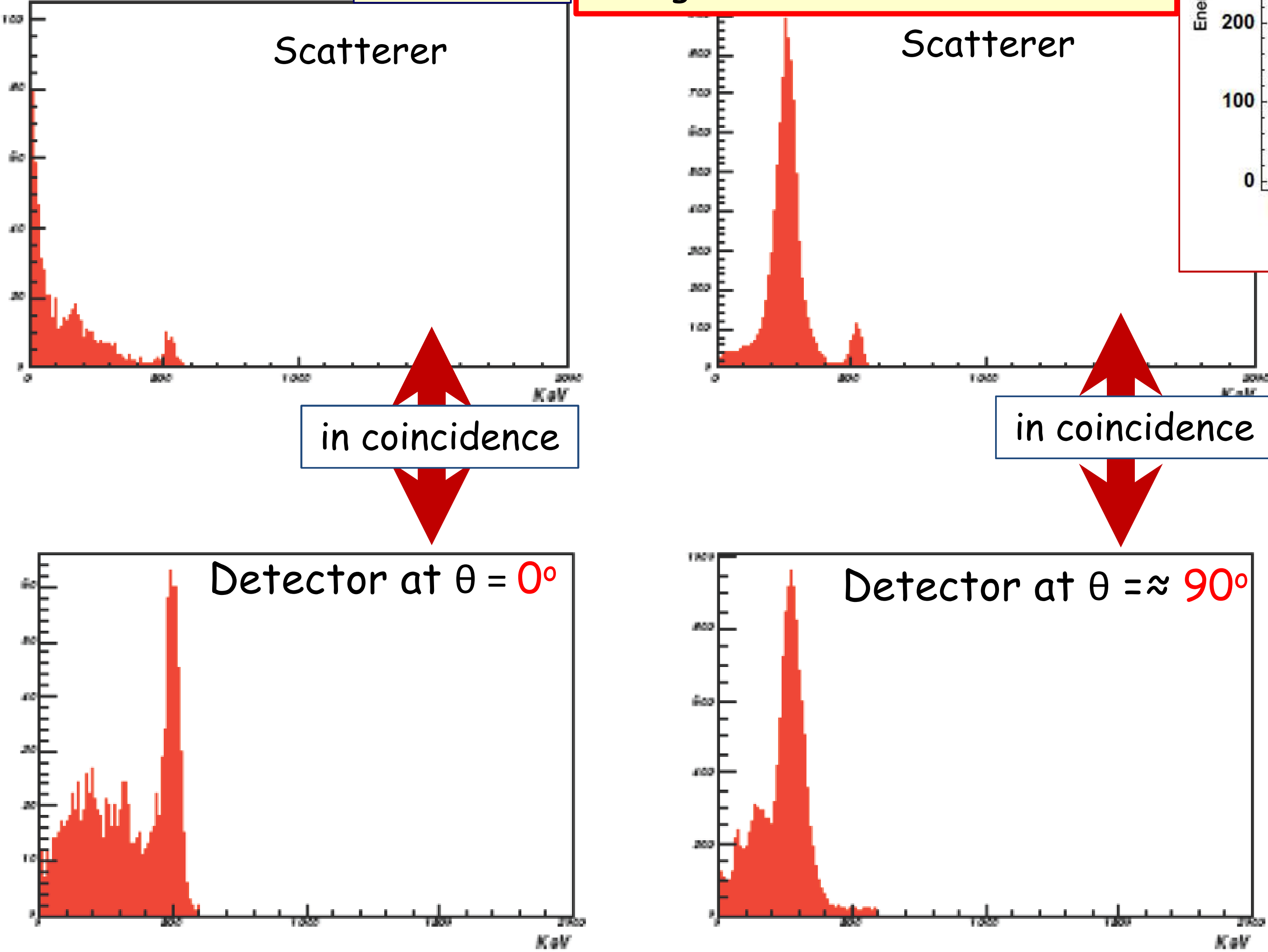
The Gaussian peak at 511 keV gives a centroid and a relative width (to which it is associated the FWHM).
Repeated measurement are performed increasing the statistics.
The error in the estimation depends on the statistics as $\frac{1}{\sqrt{N}}$



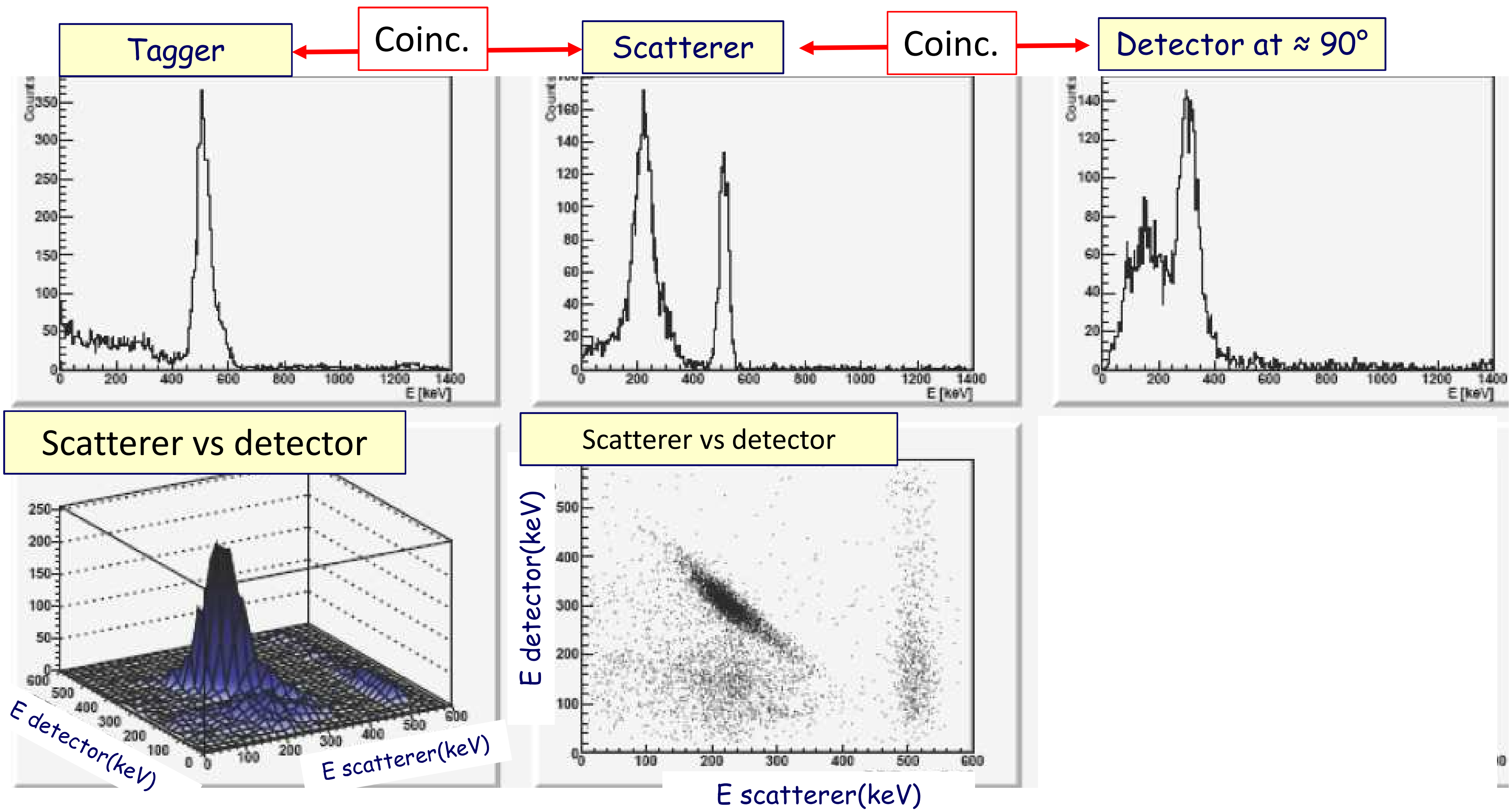


The intensity and position of the peak of the energy of the electron in the scatterer and to the photon in the detector changes as the relative angle is changed

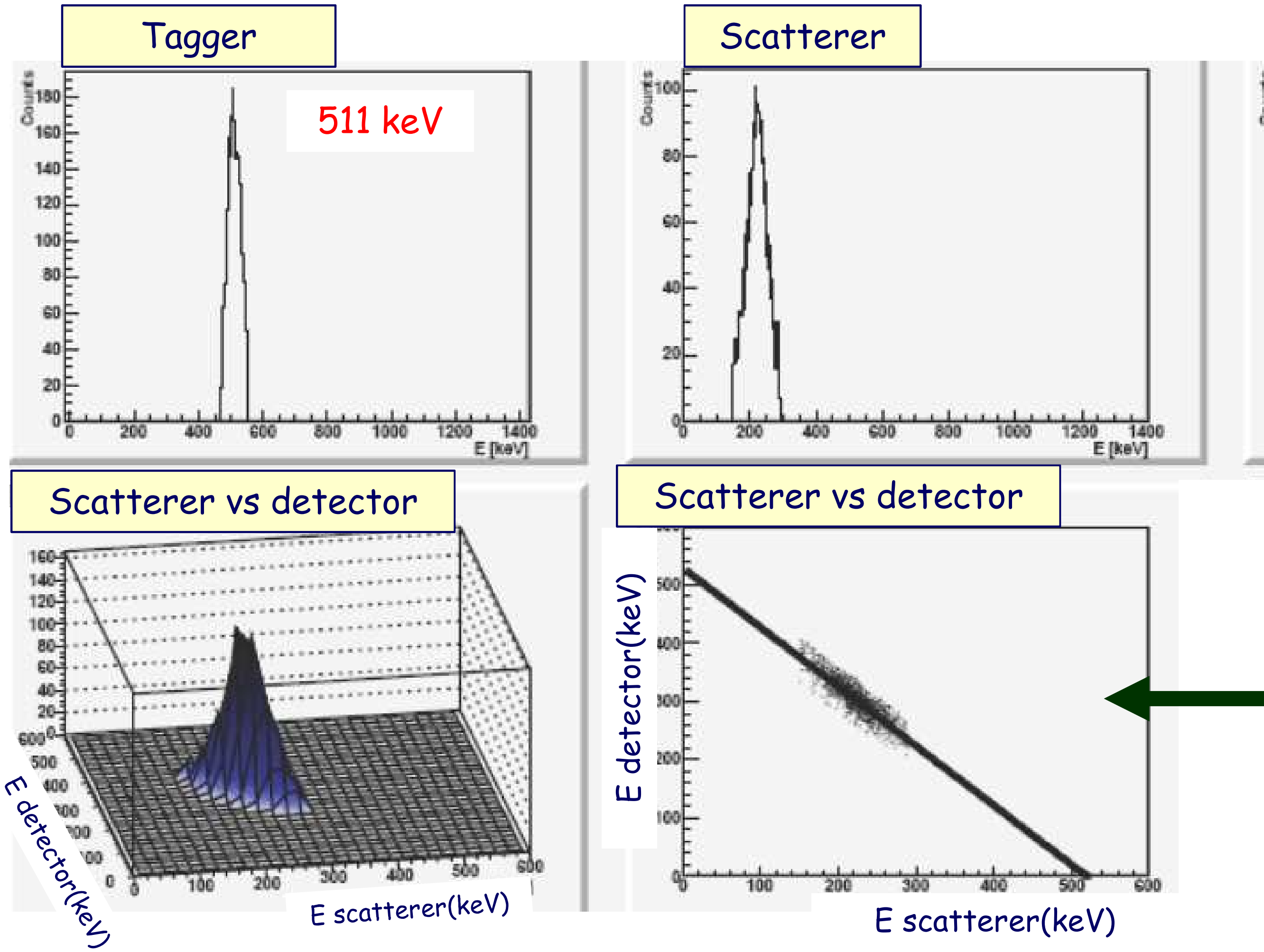




The signals of the two scintillators (scatterer and detector) are in coincidence and this correlation is evident from the experimental data



Selecting the events (by means of a software gate) the correlation is even more precise



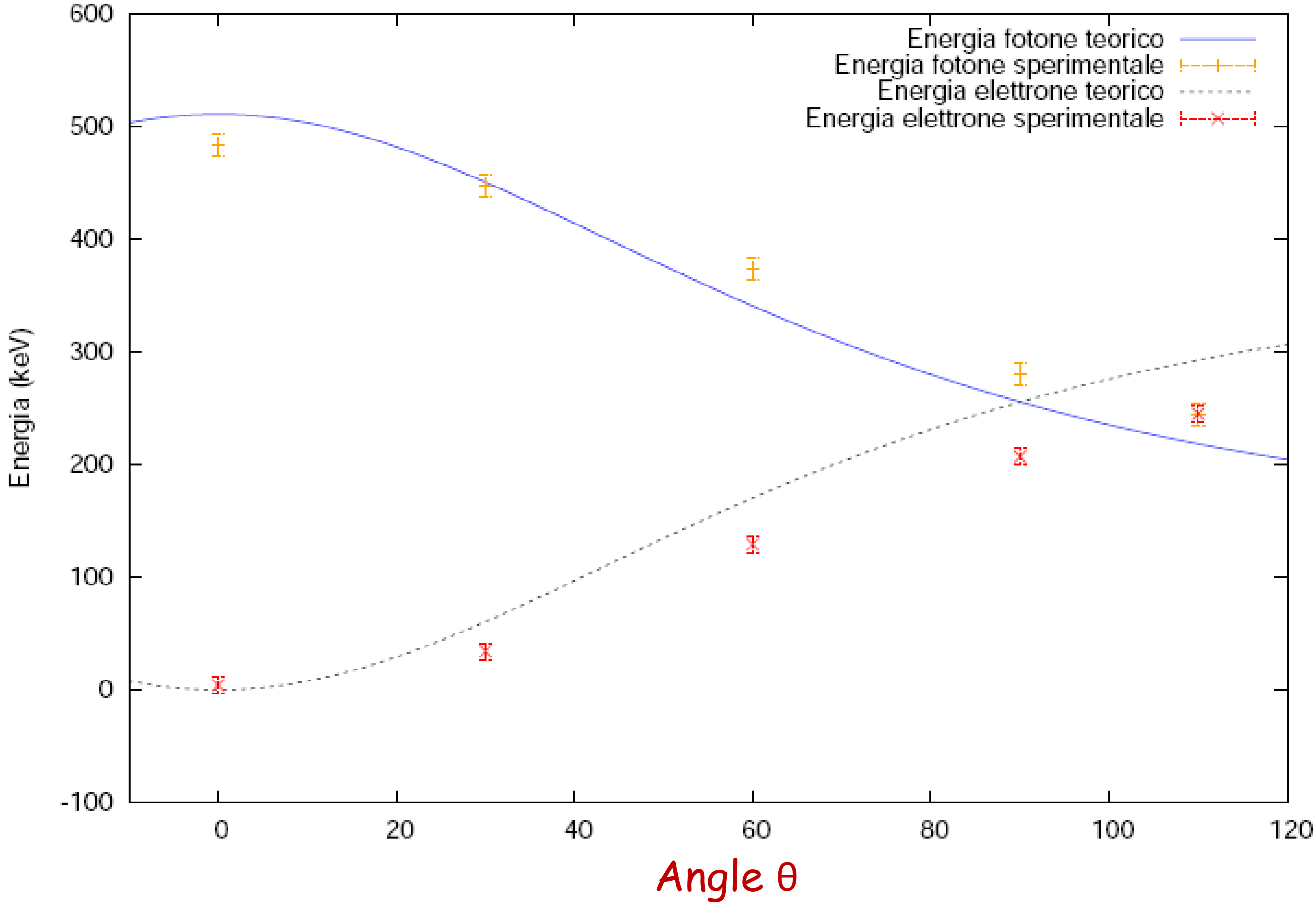
The sum must give 511 keV

HINT

What other gates can we apply for selecting the events?

→ We will use timestamping FADC…

Results: energies of the scattered photon and of the electron as a function of the θ angle of the detector



Summarizing, the goals of the Compton scattering experiment are:

a) To verify the energy dependence of the scattered photon and of the electron from the scattering angle.
b) To determine the cross section differential in angle for the Compton scattering from an Aluminum sample.

For the goal a) three detectors will be used (TAGGER, SCATTERER, DETECTOR) while for the goal b) the detector SCATTERER will be replaced by an Aluminum sample.
The experimental protocol is directly subdivided into the 3 sessions available for the experiment.
The following scheme is to be taken only as a reference but may vary depending on the progress and difficulties encountered during the laboratory session:

- First session: preparation and calibration of the scintillators

- Second session: setup of the coincidences, definition of the geometry and measurement of the energy of the scattered photons for different angles
- Third session: measurement of the Compton cross section for a photon of 511 keV on an Aluminum sample at a given angle