Compton Scattering

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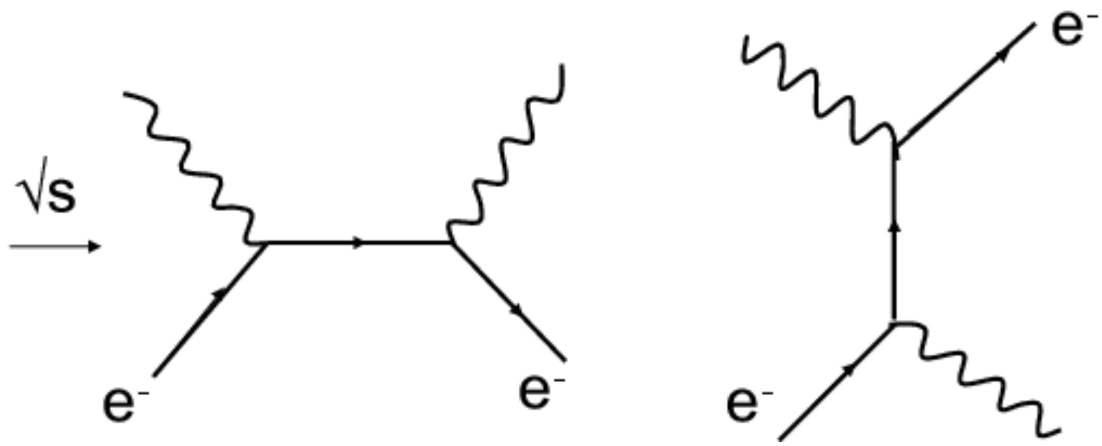


Introduction

The Compton effect occurs when a photon loose part of its energy interacting with an electron having negligible momentum with respect to the photon one. The process is a two body elastic scattering $\gamma e \rightarrow \gamma e$ hence the momentum of the outgoing photon is completely determined by its deflection angle ϑ (i.e. the angle between the incoming photon momentum and the outgoing one) as a consequence of energy and momentum conservation. The scope of the experience is to verify the theoretical prediction:

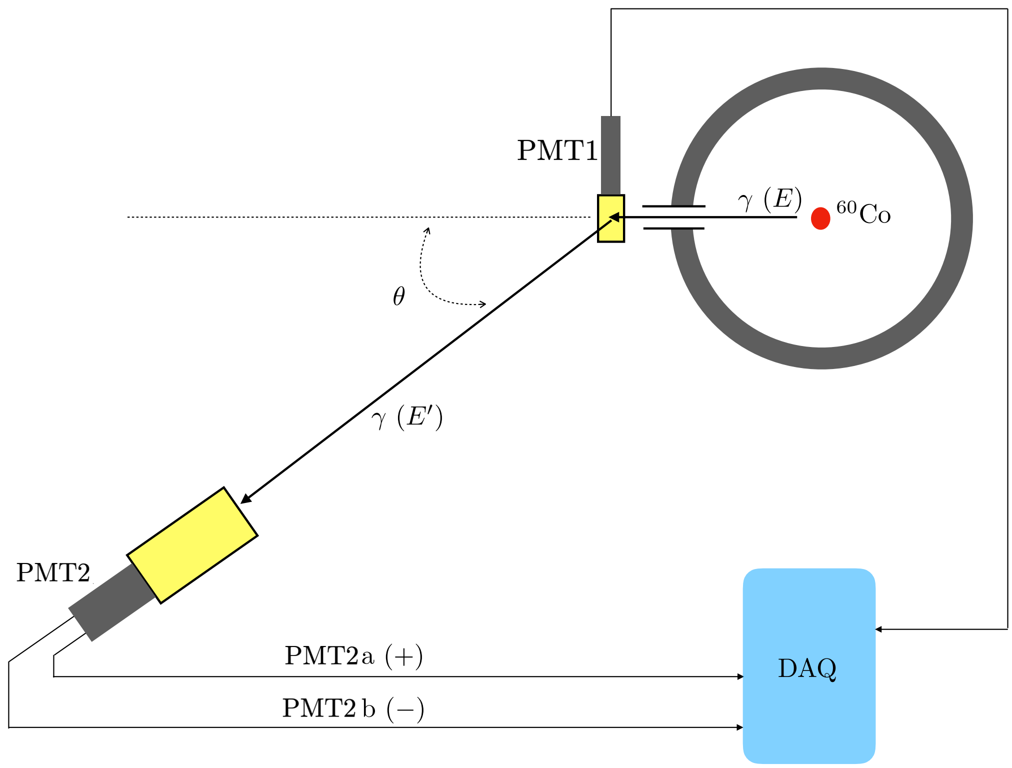
$$E' = \frac{E}{1 + \frac{E}{m_e c^2}(1 - \cos\vartheta)}$$

where E' is the energy of the outgoing photon, E is the energy of the incoming photon, m_e is the electron mass and c is the speed of light.

The experiment will use a plastic scintillator as an active target to detect the scattered electron and an NaI(Tl) scintillator to detect the scattered photon and to measure its momentum.

The challenge of this experience is to select events in which the scattered electron is in coincidence with the detected photon.

Apparatus



Available equipment.

- ^{60}Co source (activity 74 MBq in Feb. 1997, half life ~ 5.27 years). The source is shielded by thick layers of lead. The shield has a circular hole in which a lead + steel collimator is inserted.
- A plastic scintillator coupled with a photomultiplier (PMT1) acting as an active target for Compton scattering.
- A goniometer placed on the table centered below the nominal position of the plastic scintillator.
- An NaI(Tl) crystal coupled with a photomultiplier (PMT2) to measure the outgoing photon energy. PMT2 provides two signals: the direct one (most suitable for timing measurements) that comes from the anode of PMT2 and the amplified one (most suitable for energy measurements) that comes from a charge amplifier connected to the anode of PMT2.
- A shaping amplifier (Ortec 435) to prepare the signal for the multi channel analyzer.

- A multi channel analyzer (CAEN N957) a Wilkinson ADC with 10 V input dynamic range and 13 bit resolution.
- DAQ: Nim crates, Power supplies, discriminators, coincidence units, quad timer, scaler, delay lines, oscilloscope.
- A set of radioactive sources for calibrations.

Objectives

- Observe the Compton scattering by measuring the energy of the outgoing photon at different angle of deflection and verify the theoretical prediction
$$E' = \frac{E}{1 + \frac{E}{m_e c^2}(1 - \cos\vartheta)}$$
- Report the rate as a function of the scattering angle.

Suggested procedures

Safety comes first

A. Consult the laboratory technician and the teacher for the safety instructions that are mandatory to follow in particular regarding the use of the radioactive sources and of the high voltage power supplies. If in doubt ask the teachers before acting.

Preliminary characterization of the PMT2

B. Preliminary characterization of the PMT2

B.1)Read the manuals of the HV power supply CAEN N471. If in doubt ask the laboratory technician or the teachers for any unclear point.

B.2)Place the PMT2 in front of the ^{60}Co source ($\vartheta = 0$, 0 degrees on the goniometer, ~25cm away from the collimator)and connect the direct output of PMT2 (labeled PMT-2) to the CH1 of the Oscilloscope and the amplified output of the PMT2 (labeled PMT-2amp) to CH2 (set the input impedance of CH1 to 50 Ω). Observe the two base line signals.

B.3)Set the voltage of PMT2 to 600V and turn on the HV for PMT2.

B.4)Trigger the scope on the PMT2 fast signal (CH1), negative slope, thr. = -20 mV and observe the two signals from PMT2. Notes the time scales and the typical amplitudes of the signals. Try to estimate the time constant of the charge amplifier. Do you observe pile up in this configuration? Open the collimator (viz. remove the lead cylinder that closes the collimator). Is there a difference in rate? Do you observe pile up in this configuration?

B.5)Set the Ortec 435 shaper to:

1) Coarse gain 10
2) Fine gain fully counter clockwise
3) Input: positive (pos)
4) output switch set to “Unipolar“

B.6)Connect the output to the scope with input set to high impedance, 2V /division

B.7)Connect a T on the signal path of PMT2-amp. Connect the Ortect 435 input to the PMT2-amp signal. Observe as above the time scale and the amplitude of the shaped signal. Is the pileup apparent anymore?

B.8)Put a T on the CH3 input and connect to one side of the T to the output of the Ortec 435. Connect the other side of the T to the Input of the CAEN N957.

B.9)Acquire the energy spectrum of the ^{60}Co source in this configuration (Ask the professor or the technician for assistance).

B.10)Acquire the energy spectrum of the ^{60}Co source at different settings of the PMT2 high voltage (from 500V to 700V in step of 50V). Determine the relative variation of the gain of the PMT2 as a function of the PMT2 voltage.

B.11)Set the PMT2 HV to 550V and acquire the energy spectrum of the ^{60}Co source at different settings of the gain of the Ortec 435 and verify the linearity of the gain setting.

B.12)Is there a linear relation among the peak amplitude of the fast signal from the PMT2 and the peak amplitude of the shaped signal from the Ortec 435? Roughly determine the proportionality factor among the two signals (order of 5.4 V / 26.4 mV).

B.13)Select the High Voltage of the PMT2 in such a way that the amplitude of the fast signal for a 1 MeV photon is comfortably higher than 20 mV (the typical threshold for a discriminator) and keeping at the same time the amplitude of the shaped signal below 10V (the dynamic range of the multi channel analyzer).

Preliminary characterization of the PMT1

C. Preliminary characterization of the PMT1

C.1)Close the ^{60}Co source and place the PMT2 below the PMT1 (ask the technician to have the mechanical support).

C.2)Connect the PMT1 output to CH4 set to 50 Ω input impedance and observe the PMT1 baseline.

C.3)Set the trigger of the oscilloscope to detect cosmic rays with the coincidence of the fast signal from the PMT2 and the signal from the PMT1. (Trigger mode logic: AND goes true, PMT2 on Ch1 Thr ~ -100mV, PMT1 on Ch4 Thr ~ -15mV)

C.4)Set the PMT1 HV to 1900V and turn on the PMT1.

C.5)Measure the average peak amplitude of the PMT2 signal for a MIP as a function of the HV (from 1500V to 1900V step 100V).

C.6)Measure the single rate of the PMT2 as a function of the HV

C.7)Select the working point of the PMT2 in such a way that the energy deposition of 100 kEv corresponds to a peak amplitude of ~ 20 mV.

Signal conditioning for the PMT2

D. Signal conditioning for the PMT2 to avoid discriminator bouncing.

   D.1) Place the NaI(Tl) scintillator in front of the ^{60}Co source opened and set the PMT2 HV at the value determined at B.13. Turn on the HV for PMT2.

   D.2) Connect the fast signal from the PMT2 to the discriminator and to the oscilloscope. Observe at the scope the discriminated signal. Use the timer module to create a logic signal suitable for the coincidence: the discriminated signal is used to open a long gate that in turn opens a short gate (called from now on PMT2 conditioned signal).

   D.3)Observe at the scope the behavior of the fast analog signal, of the discriminated signal, of the long gate and of the short gate.

Observation of the Compton scattering

E. The signature of a photon that undergoes Compton scattering is the coincidence of the signal from a scattered electron and the signal from the scattered photon.
   The PMT1 conditioned signal is delayed with respect to the PMT2 discriminated signal because of the slower light emission from the NaI(Tl) and because of the additional processing of the signals through the two timers hence the PMT2 discriminated signal must be delayed in order to arrive in coincidence with the PMT1 conditioned signal.

   E.1) Turn off the HV. Place the NaI(Tl) crystal close to the plastic scintillator target (distance ~ 20cm) at $\vartheta \sim 30^\circ$. Open the collimator and turn on the HV.

   E.2) Set the high voltage of PMT2 to the value selected in B.13 and the high voltage of PMT1 to the value selected in C.7

   E.3) Connect the PMT2 conditioned signal and the PMT1 discriminated signal to the scope and determine the delay among the two. Use the box with a set of calibrated delay to equalize the the arrival time of the two signals at the input of the coincidence unit. (Suggestion: make use the logic trigger of the scope, use the fast signal of PMT2 and the PMT1 analog signal as input signal for the logic trigger)

   E.4) Use the delay box to equalize the two delays.

   E.5) Use the scaler to evaluate the coincidence rate. Compare the coincidence rate with the accidental rate. The coincidence rate should be sizably larger than the accidental rate.

   E.6) Use the coincidence signal to open a gate long enough to contain the peak of the shaped PMT1 signal

   E.7) Configure the multi channel analyzer to use the external gate.

   E.8) Acquire the energy spectrum of the shaped PMT2 signal. A broad peak should be visible near the head of the spectrum.

Calibration of the energy scale

F. Use the calibration sources to determine the calibration curve γ Energy vs channel number
  F.1) For each calibration source determine the functional form that best fit to the data
  F.2) Determine the energy resolution of the detector
  F.3) Observe how the spectra of the calibration sources changes as a function of the rate, of the entrance position of the photon and of its entrance angle.

Study of the incoming γ beam and planning of the experiment.

G. Characterize the incoming beam: provide an estimate:
  G.1) of the γ flux density at the entrance of the plastic scintillator target, d
  G.2) of the angular divergence of the beam
  G.3) consult the tables:
    https://nvlpubs.nist.gov/nistpubs/Legacy/circ/nbscircular542.pdf
    (Google for: nbs 542 compton scattering)
    to plan the experiment:
    I. Given the energy resolution of your system what is the maximum angle at which the two ^{60}Co peaks can be resolved?
    II. Given the angular resolution of your system what is the minimum meaningful deflection angle ?
    III. Decide at how many angle you want to measure the energy of the scattered photon
    IV. Plan a strategy (angles, distances from the target, gains etc.) to verify the theoretical prediction:
    $$E' = \frac{E}{1 + \frac{E}{m_e c^2}(1 - \cos\vartheta)}$$
    V. Follow the plan.