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Efficiency calibration

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Efficiency calibration

- Full energy peak efficiency
  - Definition
  - Experimental calibration

- Monte Carlo simulation

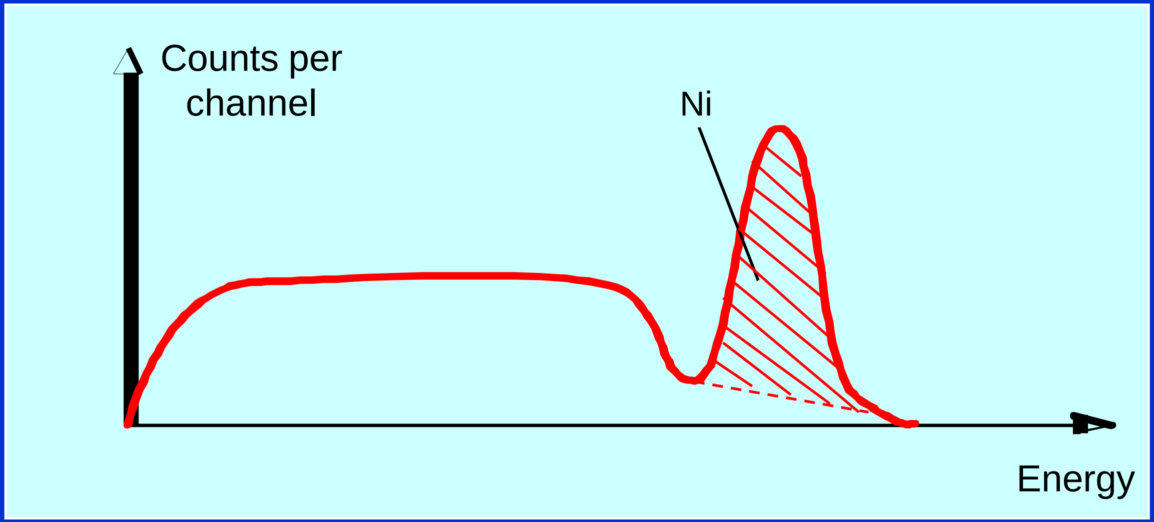
- Uncertainties

FULL ENERGY PEAK EFFICIENCY

Full-Energy Peak Efficiency (FEPE): $\varepsilon(E)$ (ε_i)

Ratio of the number of counts in the full-energy peak corresponding to energy E_i (N_i), by the number of photons with energy E emited by the source (F_i)

$$\varepsilon_i = \frac{N_i}{F_i}$$



ε_i depends on the source-detector geometry and on the energy

Full-energy Peak Efficiency (FEPE): ε_i

$\varepsilon_p(E)$ depends on the geometrical conditions and on the energy

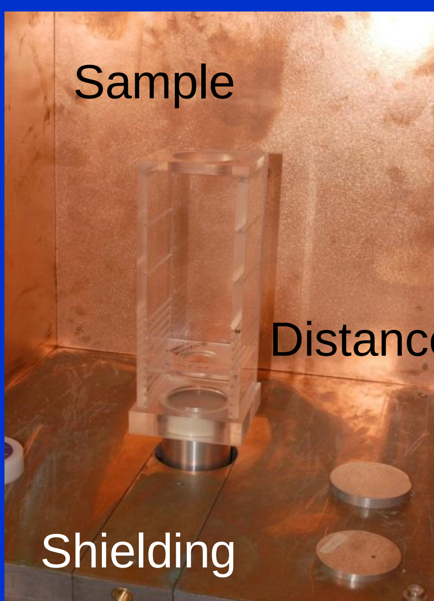
Measurement conditions

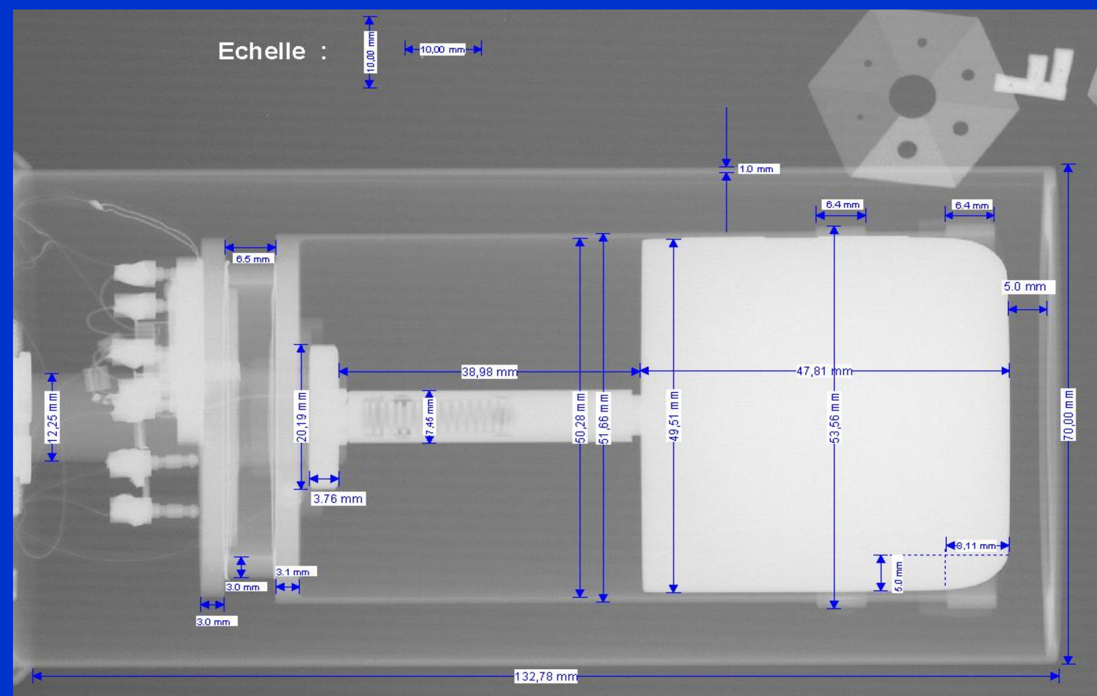
Detector characteristics

$$\varepsilon_i = \varepsilon_G \cdot \varepsilon_{Ii}$$

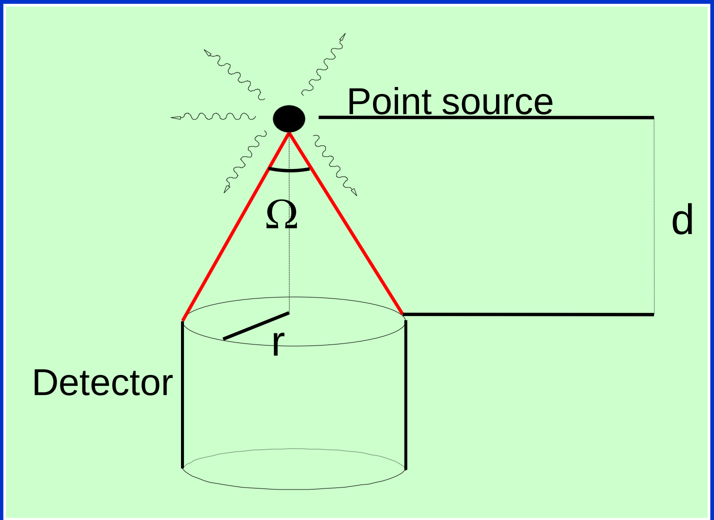
Intrinsic efficiency

Geometrical efficiency





Geometrical efficiency



Ω = solid angle between source and detector (*sr*)

For a point source :

$$\Omega = 2\pi\left(1 - \frac{d}{\sqrt{d^2 + r^2}}\right)$$

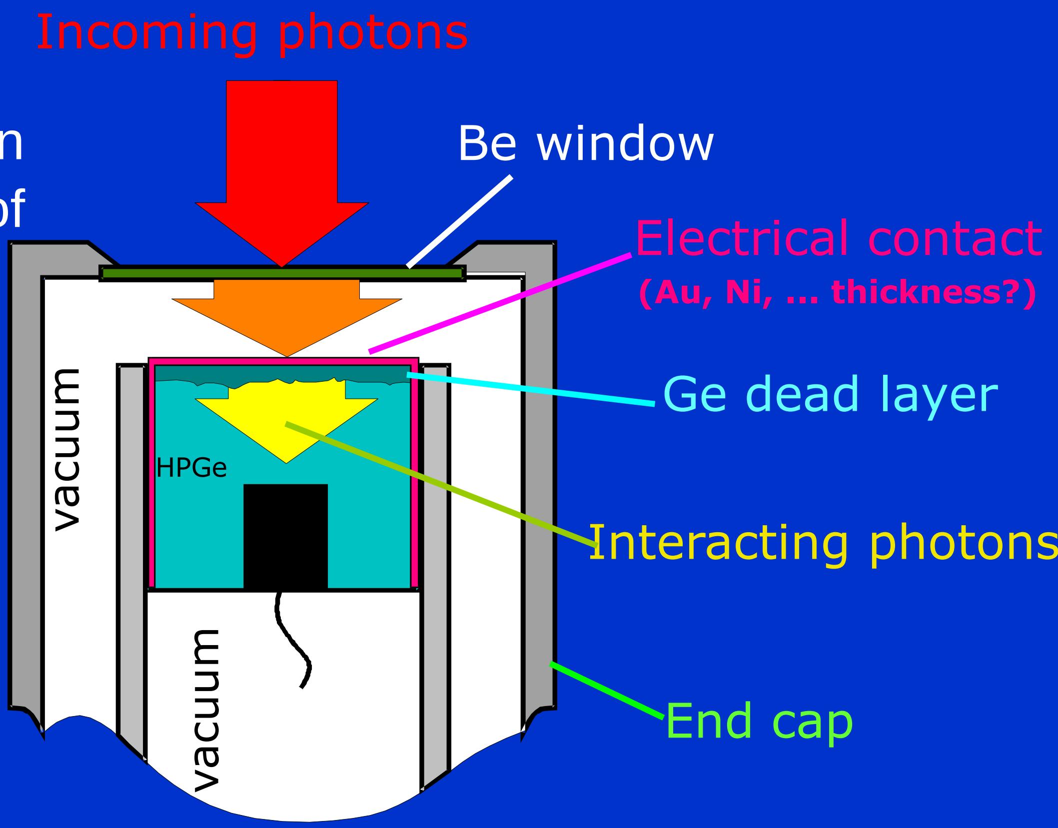
Ratio of the number of photons emitted towards the detector
by the number of photons emited by the source

$$\varepsilon_G = \frac{\Omega}{4\pi}$$

ε_G depends only on the source-detector geometry

Intrinsic efficiency

ε_i = Ratio of the number of counts in full-energy peak by the number of incident photons



ε_i depends on the energy of the incident photons:

transmission

absorption

full-energy deposition

(through one or several interactions)

Difficulty: exact composition and relative positions poorly known

Calculation of the detector FEP efficiency

Transmission probability through material i

with thickness x_i : (Beer-Lambert law) : ⇒ $P_T\ (E, x_i) = \exp\ (-\mu_i(E)\ .\ x_i)$

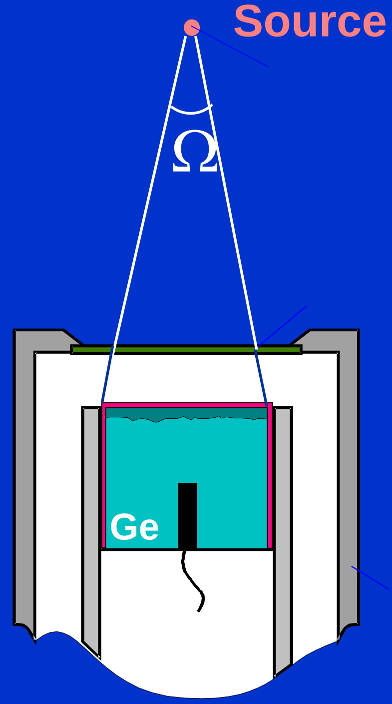
Thus

Interaction probability in the same material: ⇒ $P_I\ (E, x_i) = 1 - P_T(E, x_i)$

To result in a count in the FEP peak:

The photon must :

- be emitted in the Ω solid angle,
- cross the screens (air,n window, dead layer,…) without being absorbed,
- and loose all its energy (full-energy absorption)in the detector active volume.



Calculation of the detector efficiency

Transmission through screens

Interaction in the detector active volume

$$R^P(E) = \int_\Omega \prod_i \left(\exp\left(-\mu_i(E)\cdot x_i\right)\right)\cdot\left(1-\exp(-\mu_d(E)\cdot x_d\right)\cdot P_P(E)\cdot d\Omega$$

Probability of total absorption in the detector

- For the low-energy range: $P_p(E) \approx \tau_d(E)/\mu_d(E)$

(photoelectric effect dominant at low energy)

- For higher energies:

Total absorption is due to succesive effects : multiple scattering

Thus the calcul is not possible

Calculation of the detector efficiency

Many difficulties for an accurate calculation

- Exact knowledge of the detector parameters:

  materials *(composition)*

  geometry *(thickness, position …)*

- Data used in the calculation :

  Attenuation coefficients

  Material density

- Semi-conductor effects: parameters and physical interaction :

  Electrical field

  Electrodes

Radiography of a HPGe detector:
Rounded crystal, axially shifted, tilted …

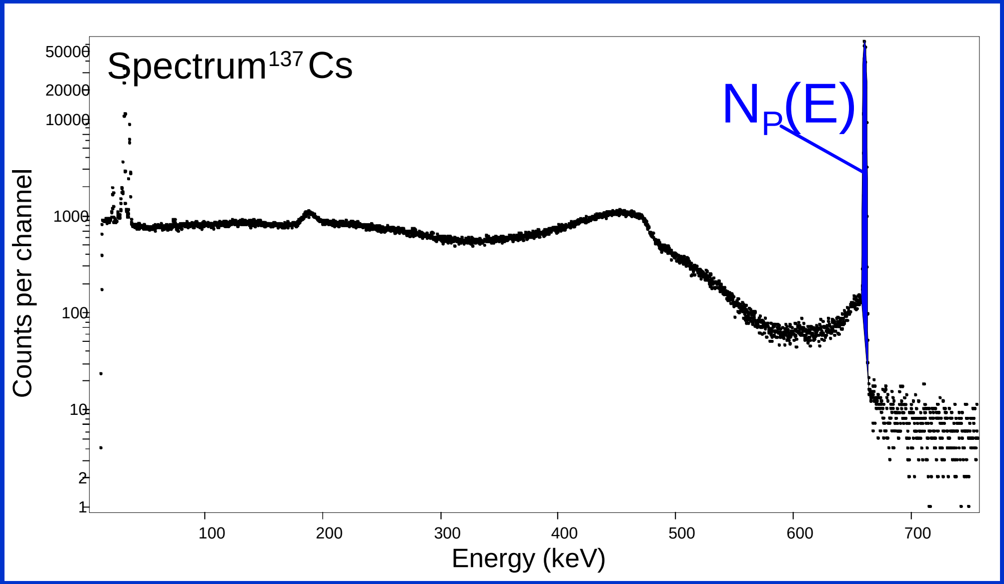
Experimental FEP efficiency calibration

$$\varepsilon_i = \frac{N_i}{F_i}$$

$$\varepsilon_i = \frac{N_i}{A \cdot I_i}$$

This is performed using standard radionuclides with standardized activity A (Bq) with photon emission intensities, I_i well known

N_i : peak net area



ε_i Full-energy peak (FEP) efficiency depends on the energy and on the source-detector geometrical arrrangement

Associated standard uncertainty

Efficiency calibration

$$\varepsilon_i = \frac{N_i}{A \cdot I_i}$$

$$\left(\frac{\Delta\varepsilon_i}{\varepsilon_i}\right)^2 = \left(\frac{\Delta N_i}{N_i}\right)^2 + \left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta I_i}{I_i}\right)^2$$

$$\frac{\Delta N_i}{N_i} = \frac{\sqrt{N_i}}{N_i} = \frac{1}{\sqrt{N_i}} \qquad \frac{\Delta A}{A} = 5 \cdot 10^{-3} \qquad \frac{\Delta I_i}{I_i} = 1 \cdot 10^{-3}$$

Influence of the peak area :

if $N = 10^4$ $\Delta N/N = 10^{-2}$ -> $\Delta\varepsilon/\varepsilon = 1.1\ 10^{-2}$

if $N = 10^5$ $\Delta N/N = 3.1\ 10^{-3}$ -> $\Delta\varepsilon/\varepsilon = 6\ 10^{-3}$

FEP efficiency calibration

To get an efficiency values at any energy : energy calibration over the whole energy range

1. Use different radionuclides to get energies regularly spaced over the range of interest

   Single gamma-ray emitters : ^{51}Cr (320 keV), ^{137}Cs (662 keV)

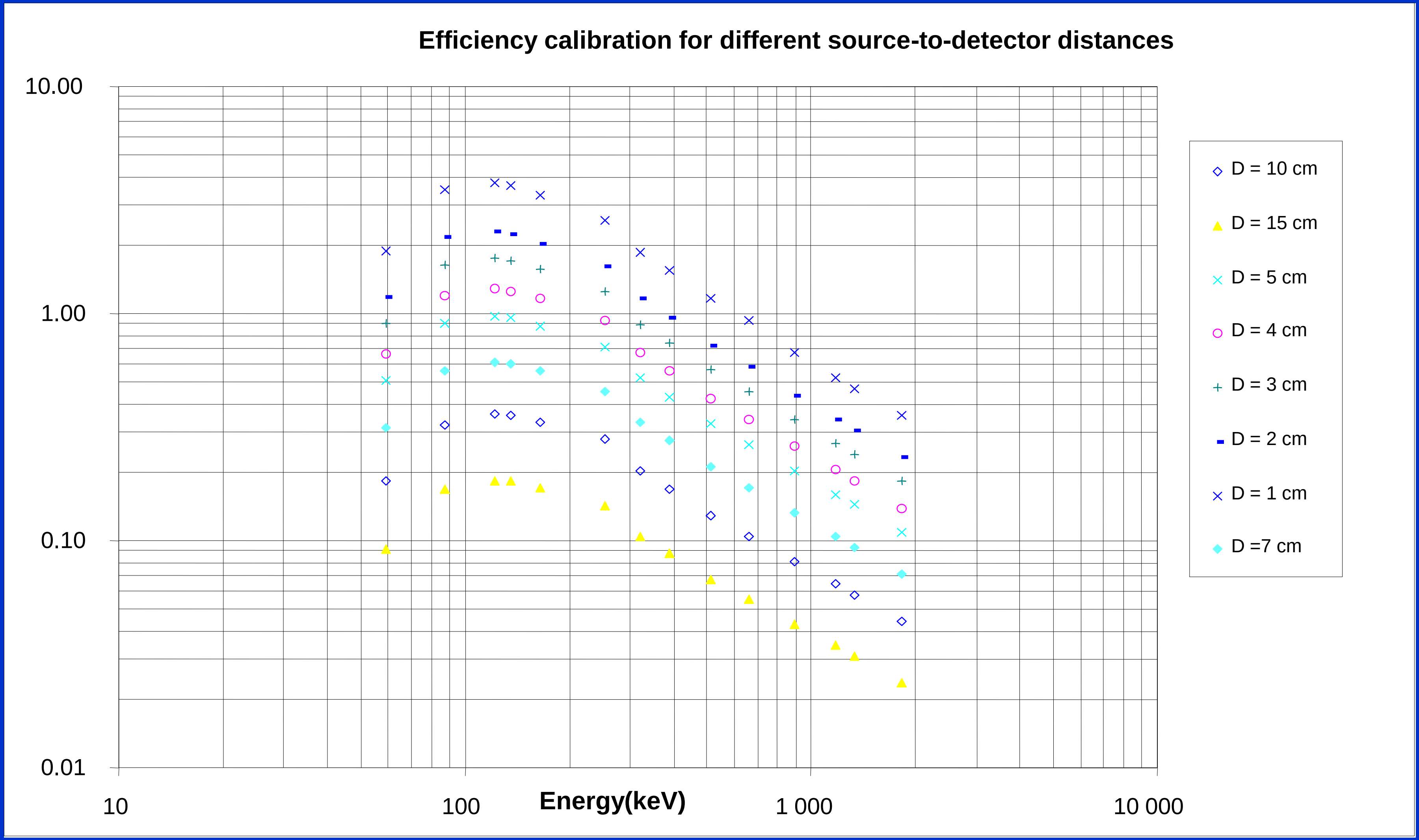
   ^{54}Mn (834 keV) : one efficiency value per one measurement

   Multigamma emitters : ^{60}Co, ^{133}Ba, ^{152}Eu, ^{56}Co : several efficiencies values per one measurement , but coincidence summing effects !

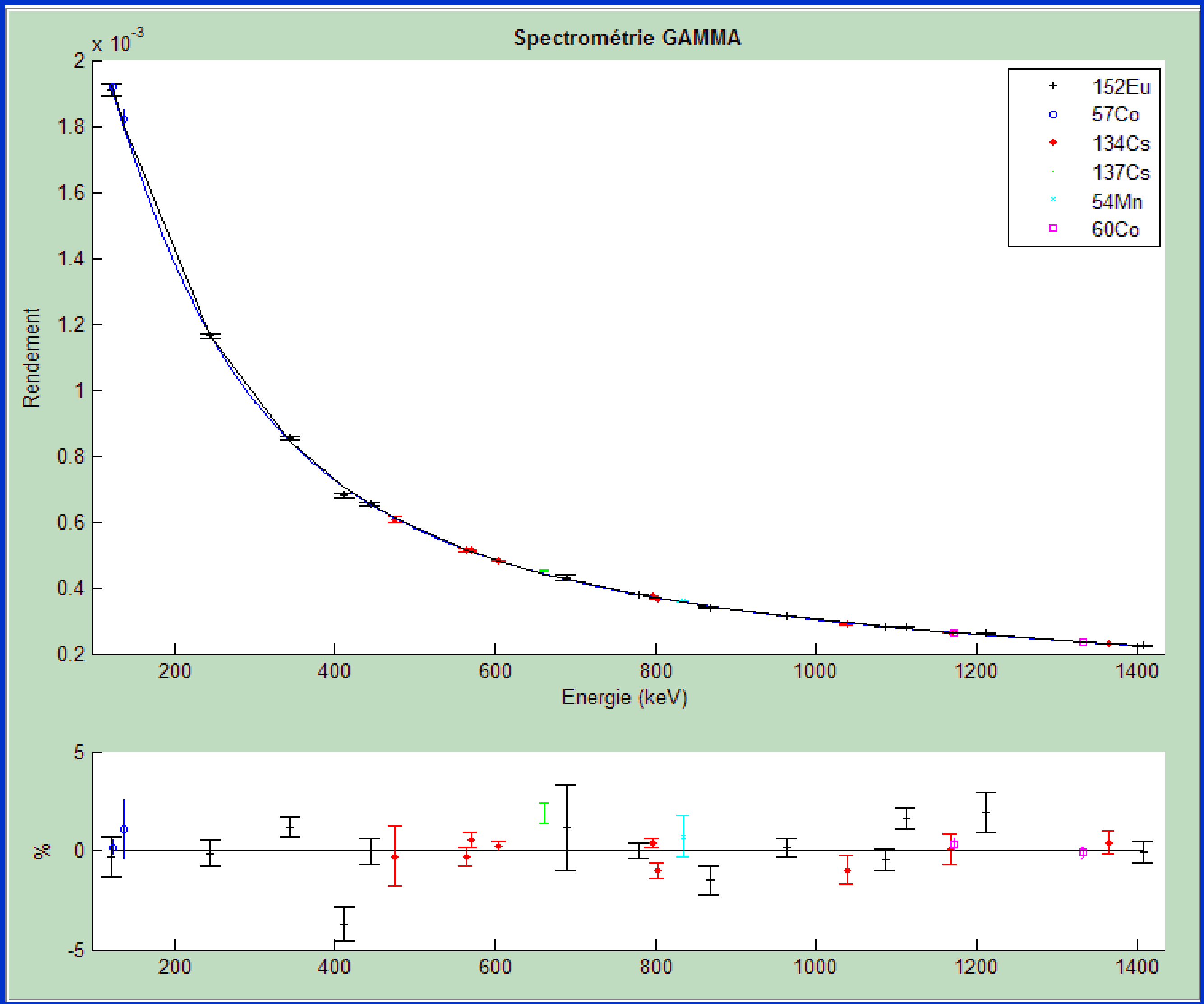
For each energy, discrete values of the FEP efficiency $\varepsilon(E_1)$, $\varepsilon(E_2)$, … ε (E_n)

2. Computation of the efficiency for
   1. Local interpolation
   2. Fitting a mathematical function to the experimental values

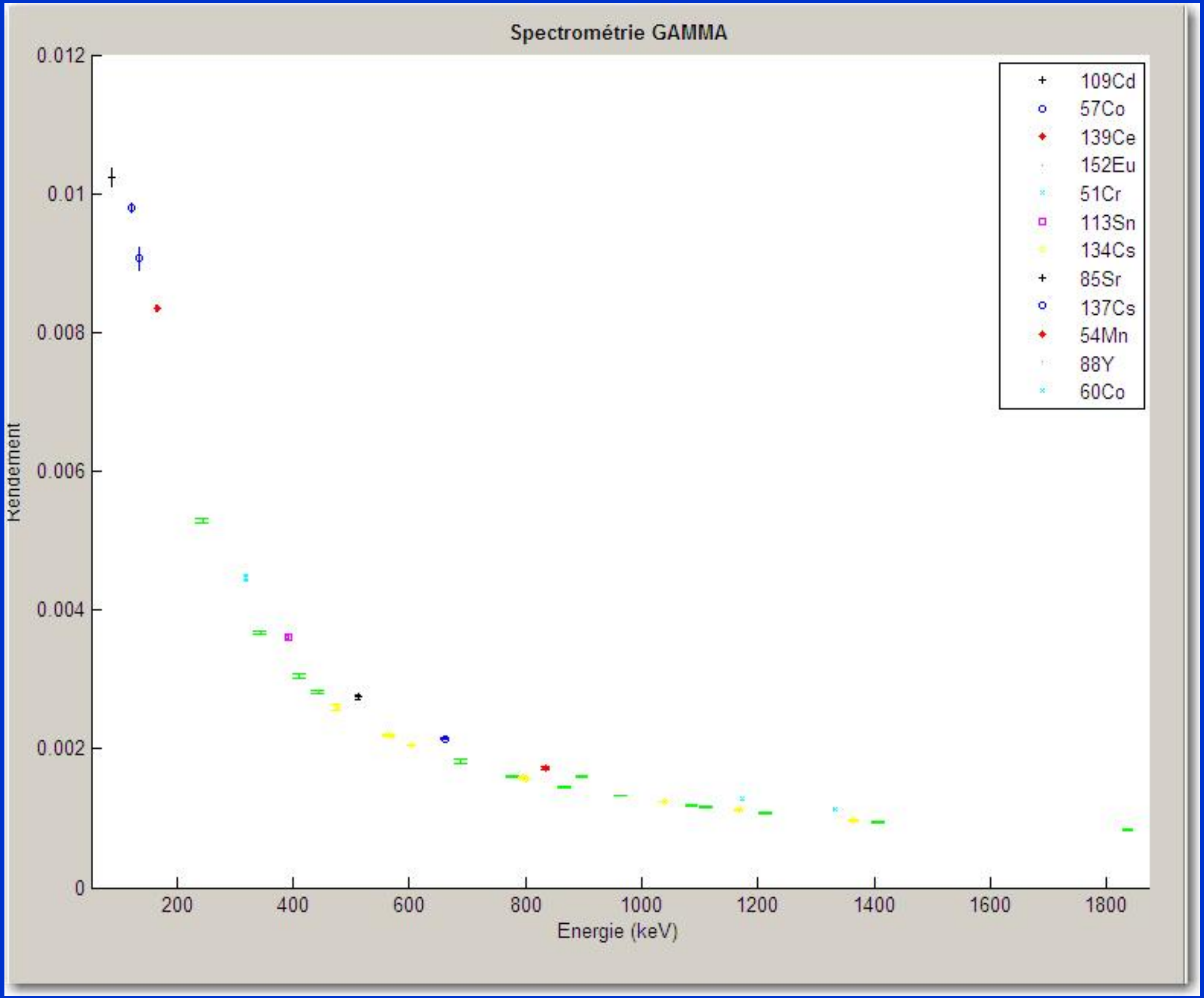
FEP efficiency calibration



Efficiency calibration at 25 cm



Efficiency calibration at 10 cm



Multigamma emitters -> Coincidence summing effets

FEP Efficiency calibration : remarks

- Efficiency calibration for reference geometry
  - For point source : relative uncertainty 1-2 %

- Corrective factors needed if different measurement geometry -> larger uncertainties


MONTE CARLO SIMULATION

Principle

- Follow the path of a particle (photon) from its emission point
- Looking at each possible event (probability distribution)
- Record the amount of energy deposited in the detector -> definition of efficiency
- Repeat many times (10^6 – 10^7)

Main steps

- **Simulation of the source :** Simulation of the emission point, of the direction of propagation, of the energy.

- **Simulation of photon propagation:***Distance to the next interaction for photons* - Photons of energy E and linear attenuation coefficient µ

- **Simulation of the interactions**
- Photon interactions of interest are: photoelectric (µPh), Compton (µCo), production of a pair electron-positron (µPair).

- *Ref : Sima, O. 2012. Efficiency Calculation of Gamma Detectors by Monte Carlo Methods. Encyclopedia of Analytical Chemistry.*

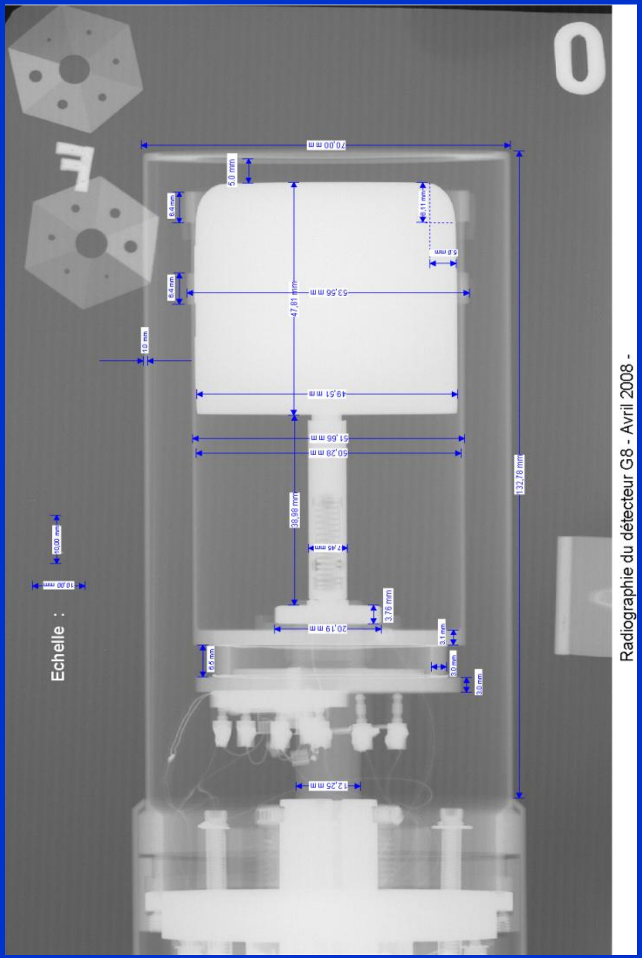
Monte Carlo codes

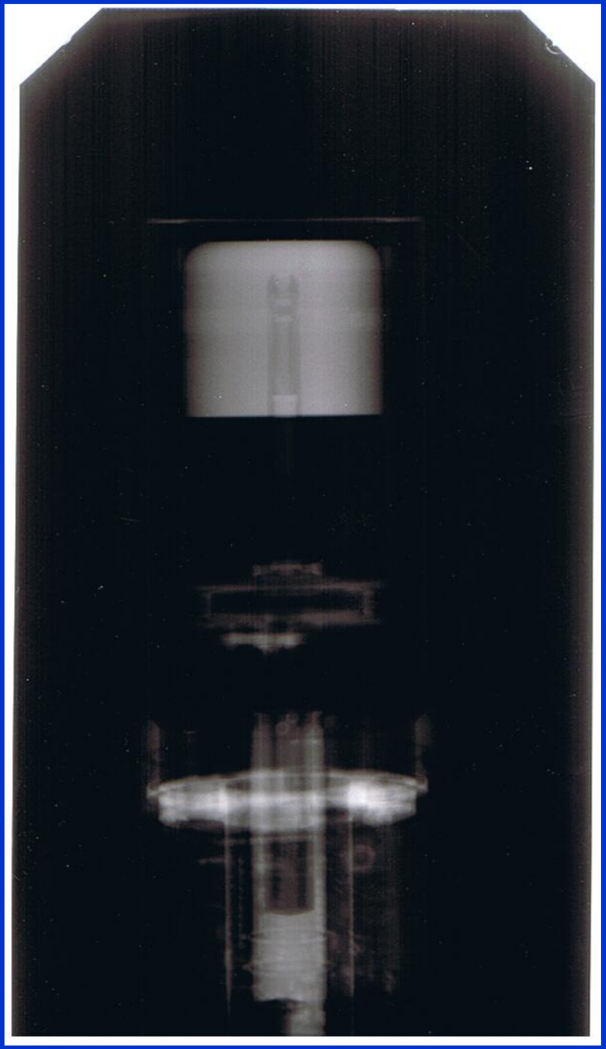
- Generalist : GEANT, PENELOPE, MCNP, etc.
- (multipurpose- must be prepared)

- Dedicated: GESPECOR (Univ. Bucharest), DETEFF (CRPH Cuba) , other ?

Monte Carlo simulation

- Difficulties: bad knowledge of the detector internal parameters
- Accurate description is time-consuming:
  - Radiography (external dimensions)
  - Collimated beam (hole - dead layer)
  - Window to crystal distance (source at different distance)
  - Comparison with some experimental values
    - Different energies
    - Different geometries





X-ray tube ->

Geometrical dimensions

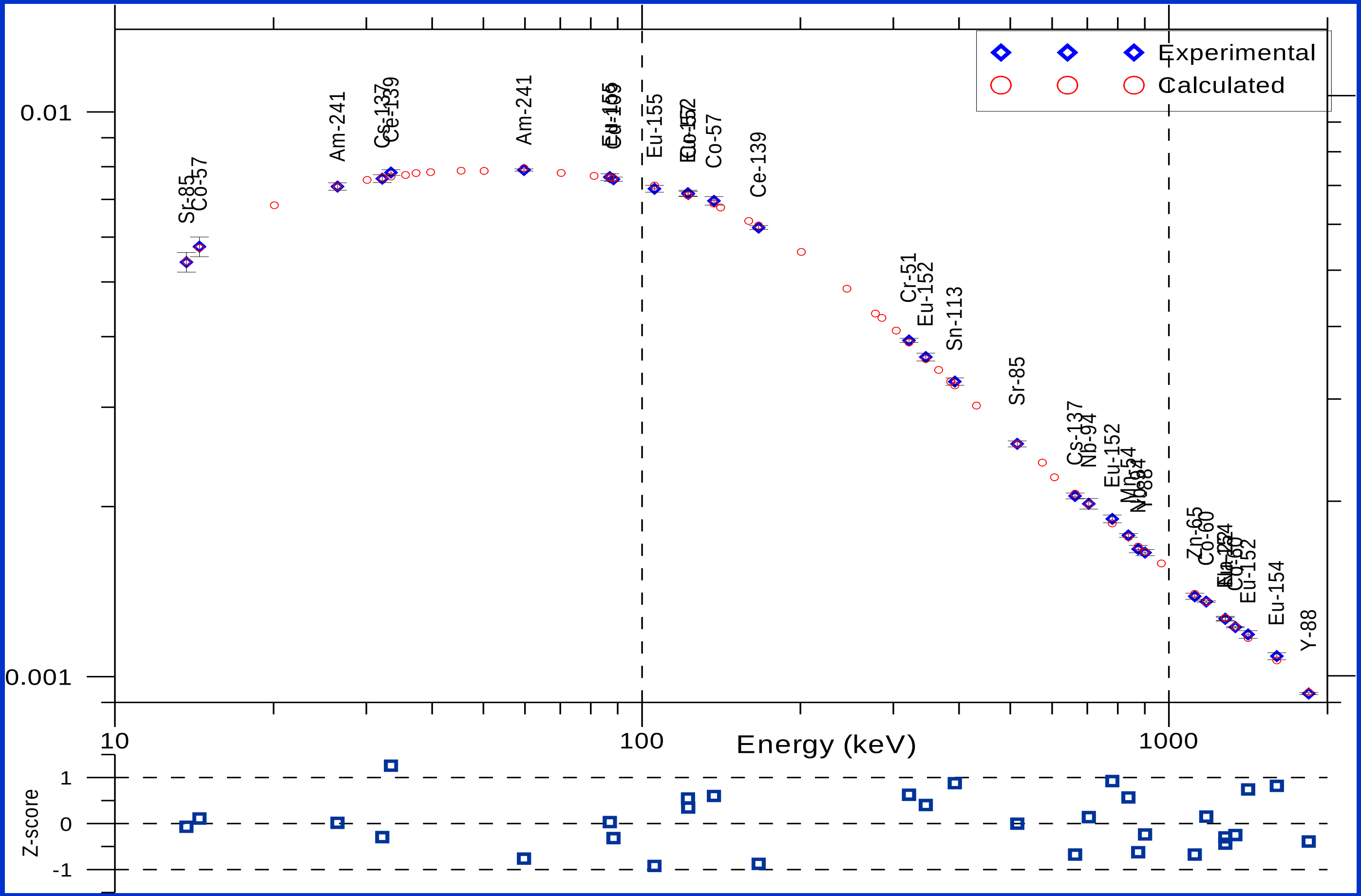
Cristal shape (rounding)

^{60}Co source ->

Hole dimensions

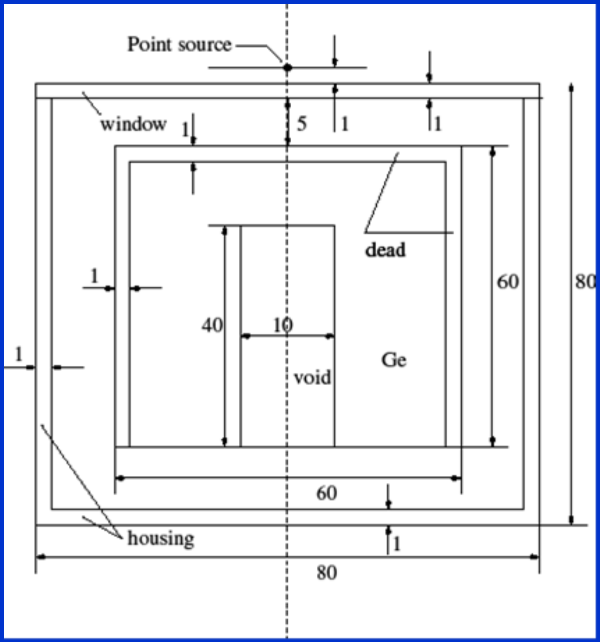
Comparison with experimental data

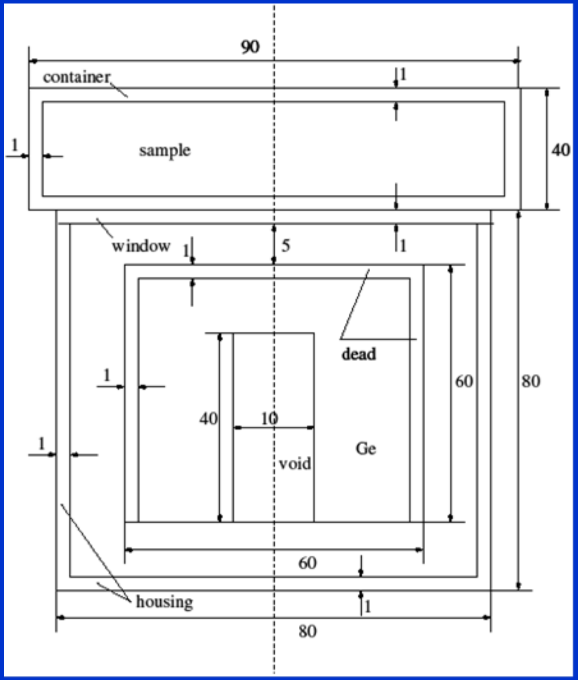
Extended-range coaxial HPGe with carbon-epoxy window (61 x 61 mm)
Point sources at 16 cm from the detector window



Picture from V. Peyres - CIEMAT

Comparison of codes (CRP action)





- Well-defined geometry (P-and N-type detectors)
- Point source – Volume (water – soil- filter)

- Ref: T. Vidmar et al., An intercomparison of Monte Carlo codes used in gamma-ray spectrometry” Applied Radiation and Isotopes, Vol 66, Issue 6-7, p 764-768, 2008.

Monte Carlo simulation

- For non specialized codes:
  - « User effect «
  - Importance of the cut-off energy
  - Importance of the bin size to reproduce the spectrum
- Can provide
  - FEP efficiency
  - Total efficiency (very dependent on the environment)
  - Coincidence summing corrections
  - Absolute calculation should be compared with accurate experimental data
- Strong interest for efficiency transfer calculation