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From Gamma Identification To Quantification

CAEN Winter School 2026

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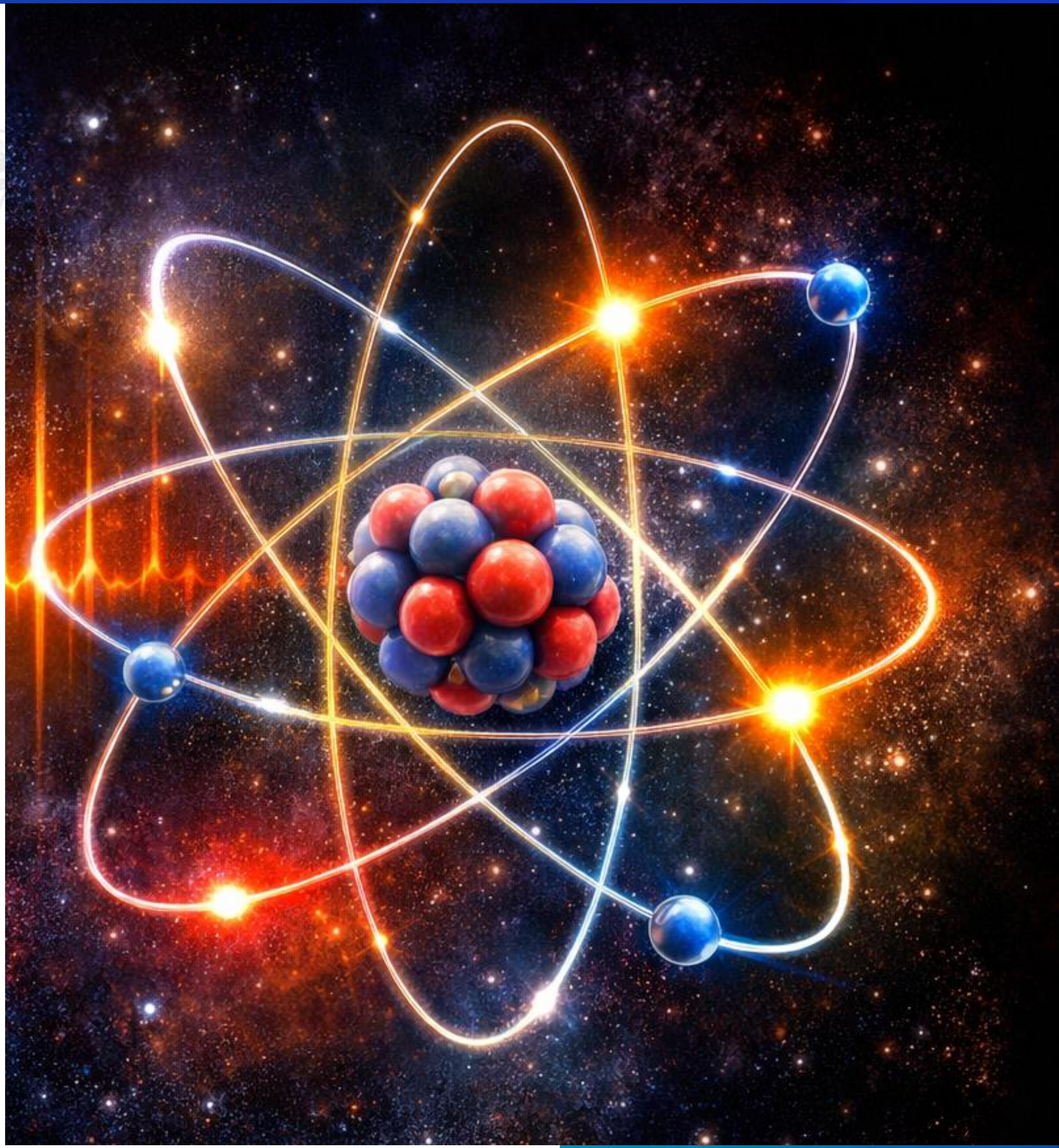
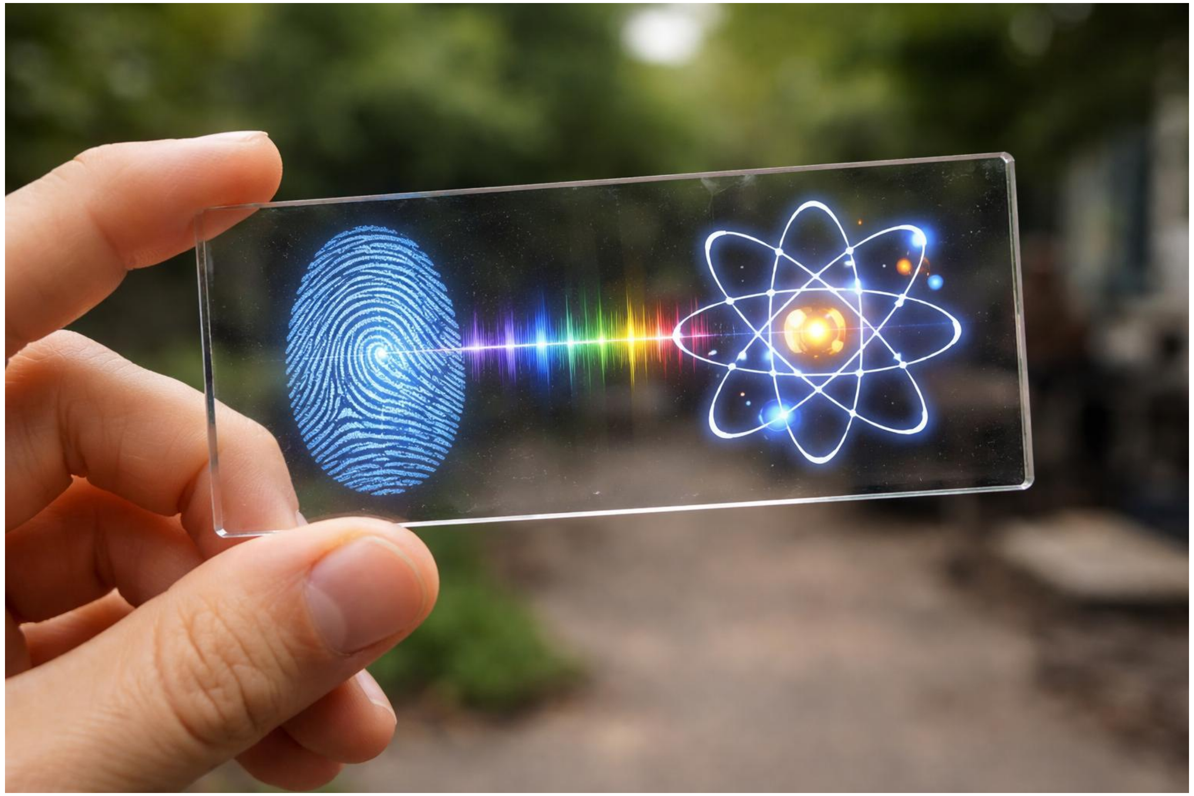
BRIEF SUMMARY

Today I'm going to bore you with…

- Gamma Identification
- Activity Calculation
- Geometrical Efficiency
- Efficiency Curve
- Manual Activity Calculation
- bGamEff and Simulated Efficiency
- bGamEff Tips
- Quantus Tips





The energy of electromagnetic radiation is directly related to its frequency and inversely related to its wavelength

The fundamental law is:

E = h · f **or** **E = h · c / λ**

Where:

E is the energy

h is Planck's constant

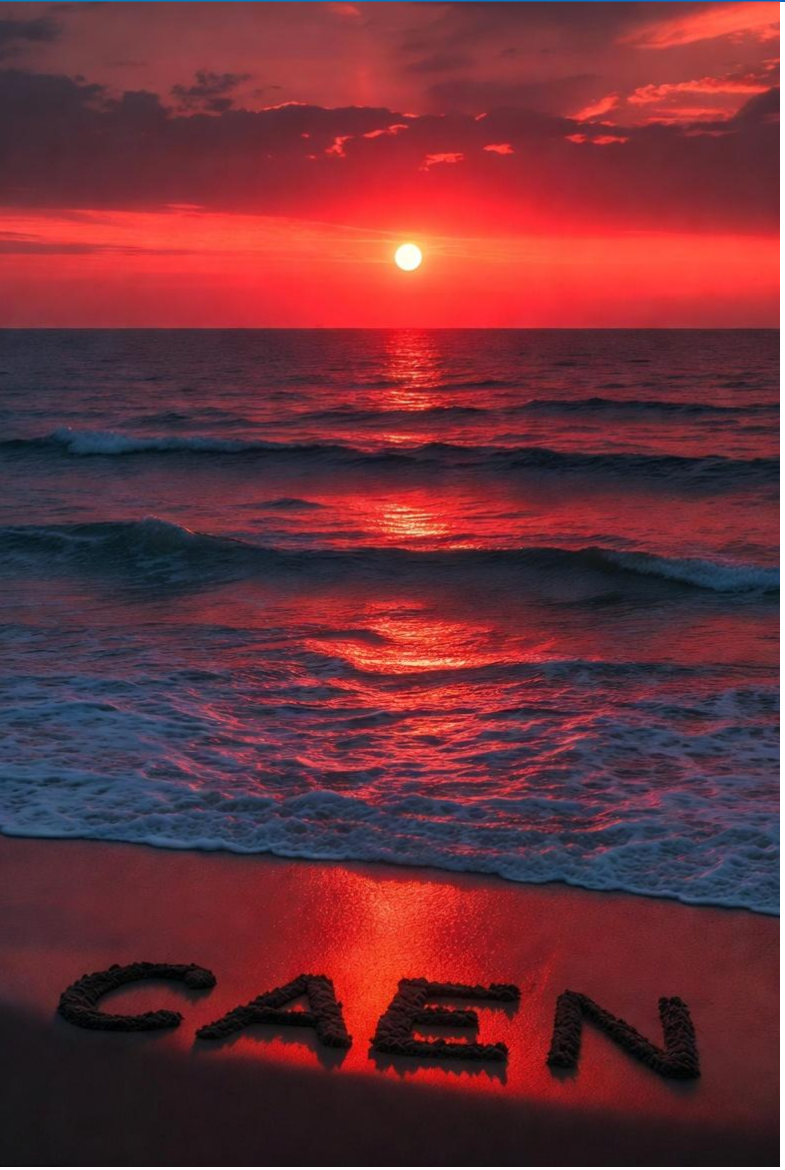
f is the frequency

c is speed of light

λ is wavelength

"If we could see gamma energies as colors, each radionuclide would shine in its own invisible palette… a unique spectral signature written in light beyond our eyes."

The Gamma-Ray Spectrum Serves as a Unique Fingerprint for Radionuclide Identification



So why is the sunset red?

LITTLE DETOUR

- Blue light → higher energy, shorter wavelength
- Red light → lower energy, longer wavelength

Short wavelengths (blue and violet light) are scattered much more strongly by tiny air molecules.
In fact, scattering intensity is proportional to:

$$1/\lambda^4$$

So:
Short wavelength very strong scattering
Long wavelength weak scattering
Blue light gets scattered in all directions very easily.

At sunset:
The Sun is low on the horizon.
Light must travel a much longer path through the atmosphere.
Almost all the blue light gets scattered away before reaching your eyes.

What remains in the direct sunlight? Mostly red and orange light (longer wavelengths).

ACTIVITY CALCULATION

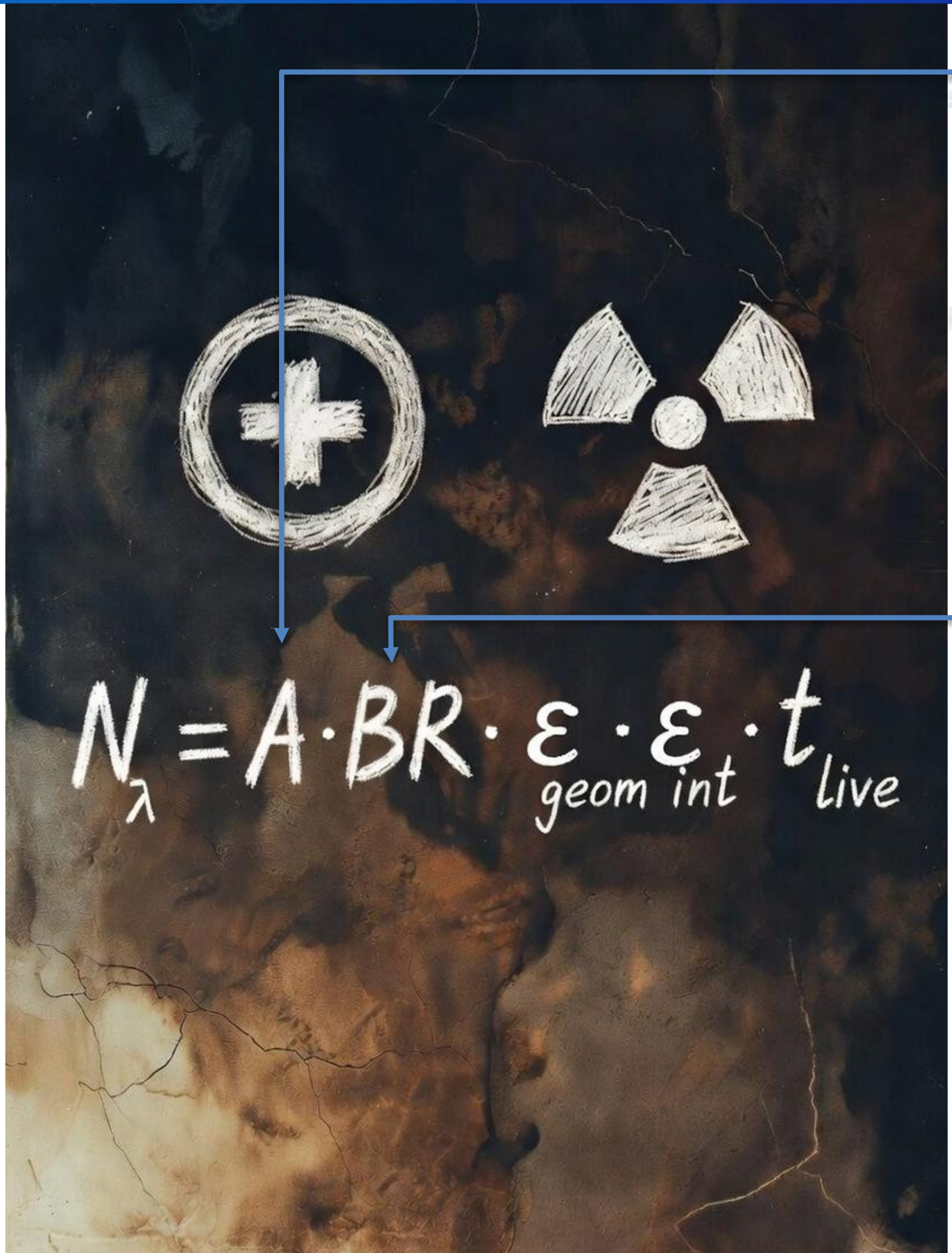
Ingredients to compute the activity

Gamma Activity

- Radionuclide must be determined in advance
- Measured number of particles emitted x unit time
- Detection Efficiency
- Dead Time

ACTIVITY CALCULATION

Nγ
This is the number of gamma rays you actually record with your detector during the measurement. It represents the counted events in a specific gamma peak over a given acquisition time

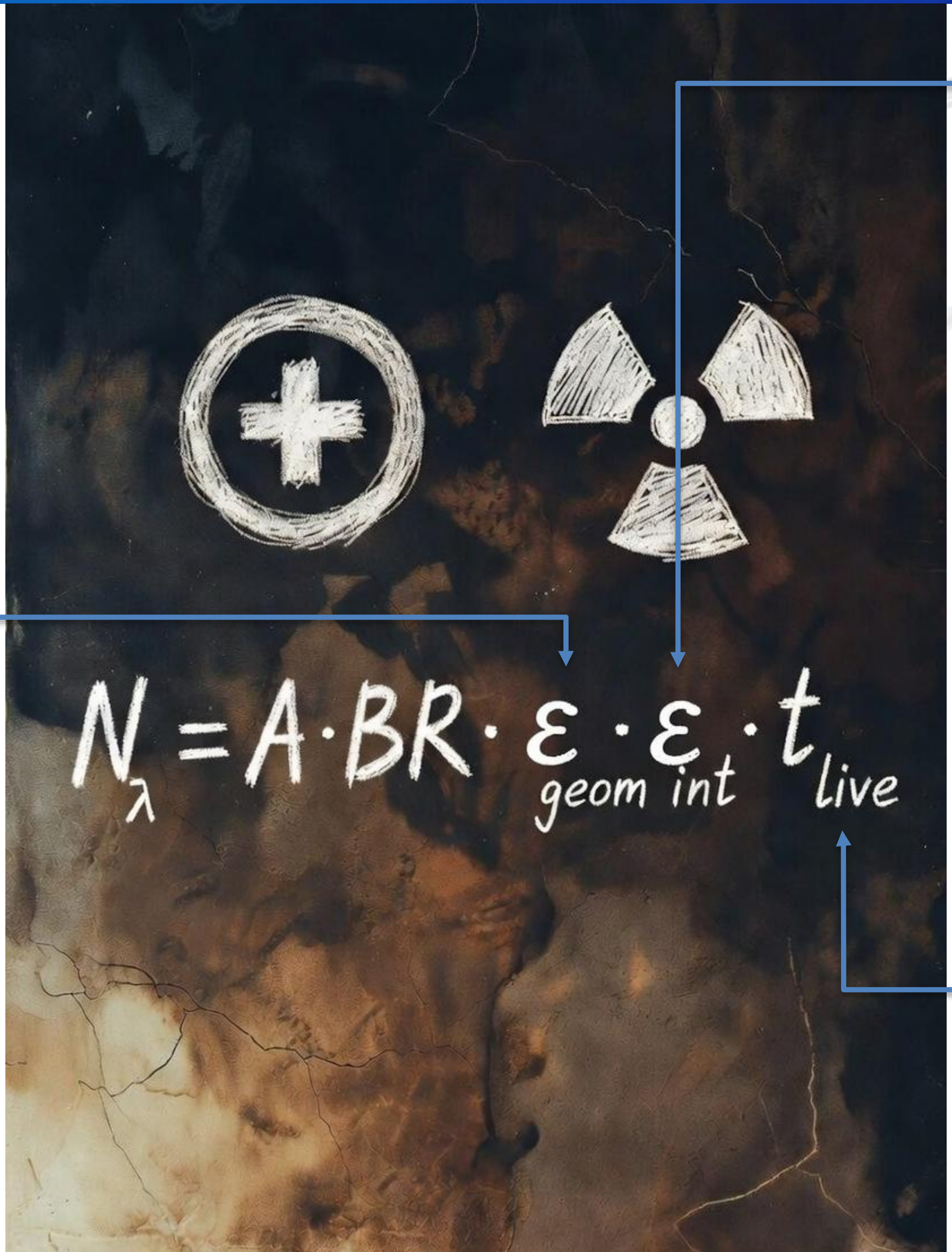


A Activity is the number of nuclear decays per unit time, measured in becquerels [Bq], where 1 Bq = 1 decay per second. It tells you how many decays are happening in the source every second

BR Branching ratio
Not every decay produces the gamma ray you are measuring. The branching ratio is the probability that a decay emits that specific gamma ray.
For example, if $BR = 0.85$, then 85% of decays produce that gamma line

ACTIVITY CALCULATION

ε_{geom} Geometrical efficiency
This accounts for the fraction of emitted gamma rays that physically reach the detector. Since gamma rays are emitted in all directions, only a fraction determined by the detector's solid angle coverage will hit it. This depends on distance, detector size, and geometry.

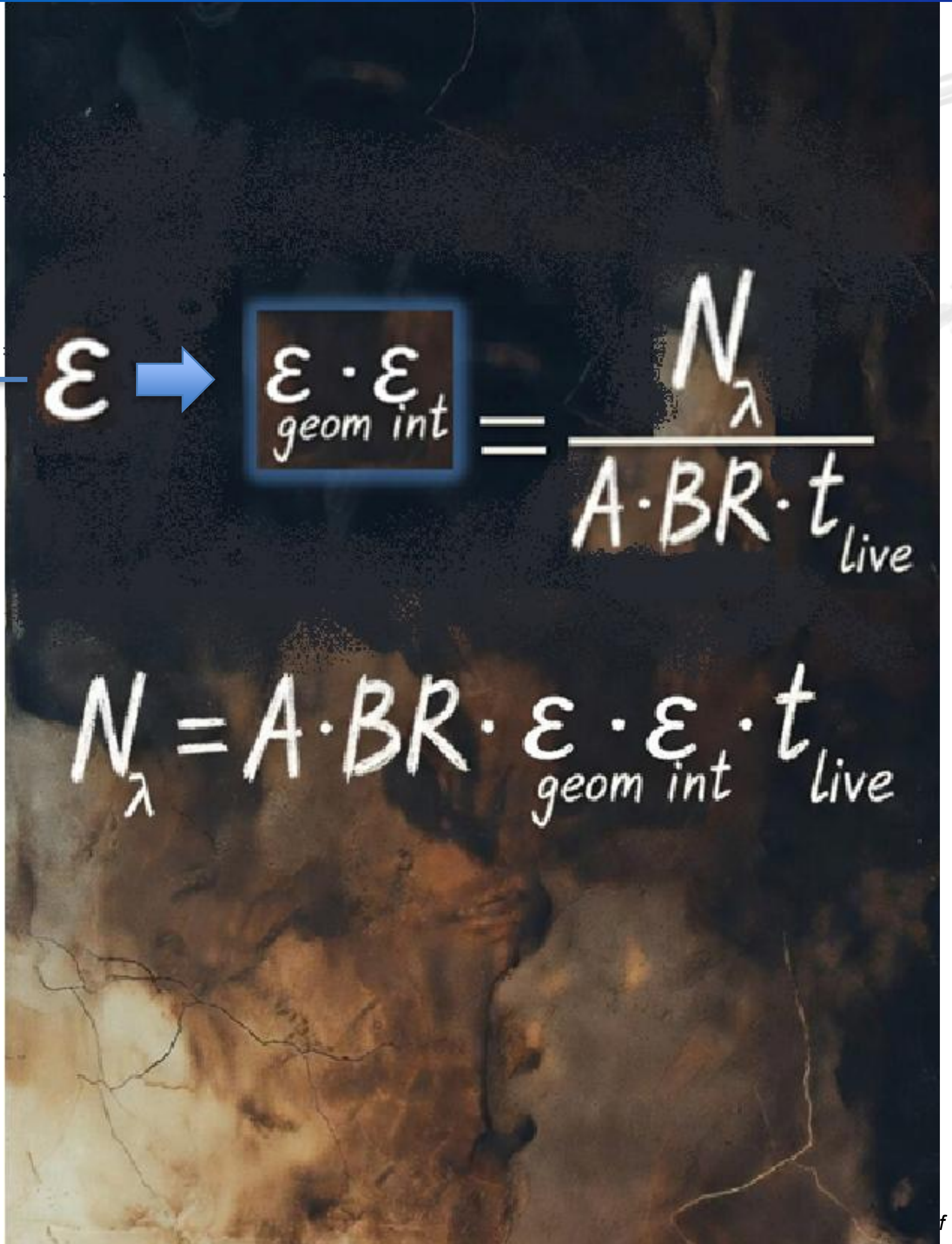


ε_{int} Intrinsic efficiency
Even if a gamma ray reaches the detector, it is not guaranteed to be detected. The intrinsic efficiency represents the probability that a gamma ray interacting with the detector material actually produces a measurable signal in the photopeak. This depends on detector material, thickness, and gamma energy.

t_{live} Live time
This is the effective time during which the detector is actively able to record events.
It is slightly less than the real measurement time because the detector needs short intervals (dead time) to process each event.

ACTIVITY CALCULATION

εtot Detection Efficiency
For convenience, the efficiency is often express in terms of total efficiency: the ratio between the counts recorded and the total number of radiation particles emitted for a fixed live time. Of course, this is a function that depends on the energy of the gamma ray.



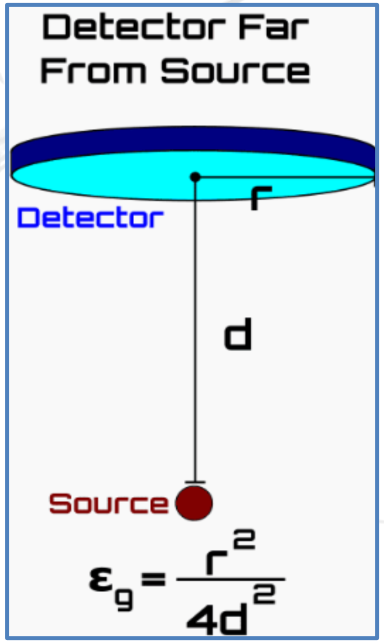
The term **Total Efficiency** usually refers to the **Detection Efficiency**, which includes both the detector's intrinsic response and the geometrical factors of the measurement setup.

GEOMETRICAL EFFICIENCY HINT

Ignoring self-attenuation (attenuation of radiation by the radiation source itself), radiation emissions occur isotropically. Therefore, geometric efficiency is approximately equal to the area of the detector entrance divided by the surface area of a sphere with a radius equal to the source-to-detector distance.

$$\epsilon_{geometric} \approx \frac{r^2}{4d^2}$$

- **r** is the detector radius
- **d** is the source-to-detector distance

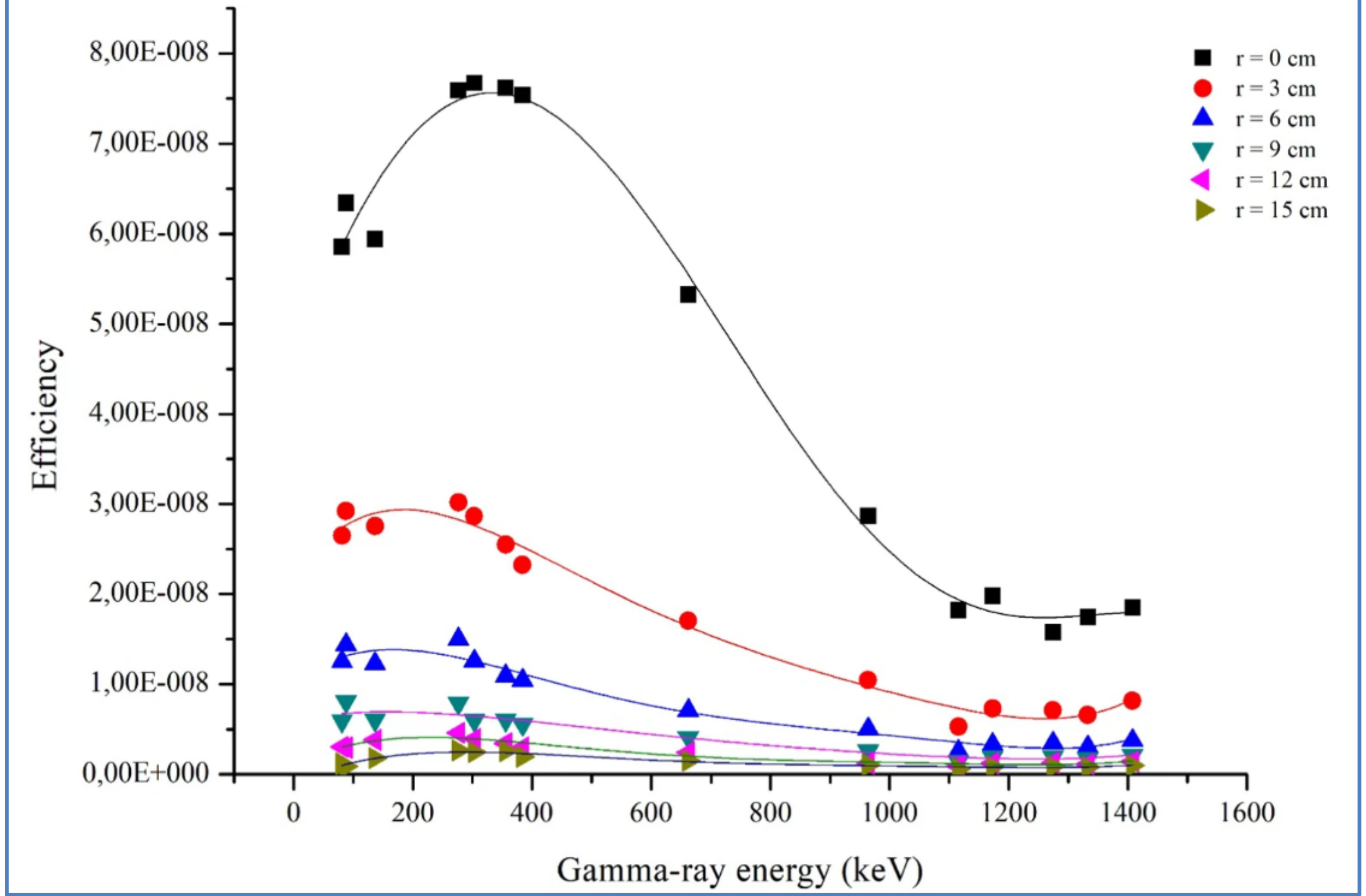


The above equation is valid only when the source may be approximated as a point, the detector surface is a circle oriented to face the source, and the distance between the source and detector is much greater than the detector radius.

EFFICIENCY CURVE

A gamma-ray efficiency curve (total efficiency) typically shows high efficiency at low energies, with a peak around 100-200 keV, and a sharp decline at higher energies.

From: Efficiency and energy resolution of gamma spectrometry system with HPGe detector depending on variable source-to-detector distances



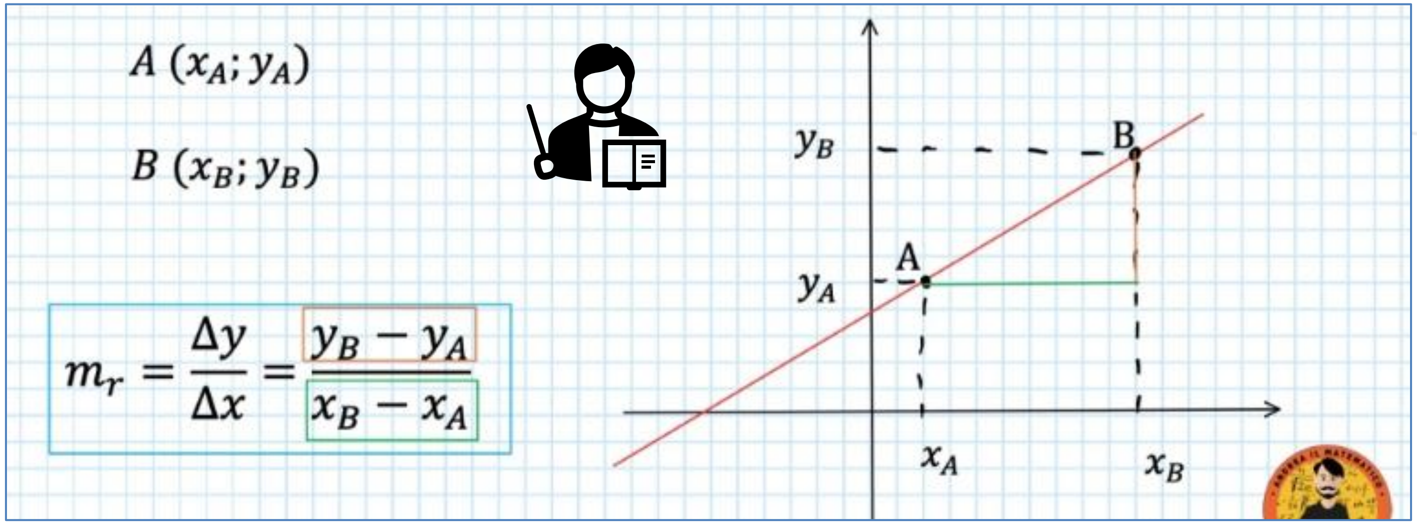
- **Low Energy Behavior**
  Efficiency increases with energy at low values because the detector material is highly opaque to soft gammas, then peaks!
- **High Energy Behavior**
  Efficiency decreases as photon energy increases because higher energy photons have a greater chance of passing through the detector without interacting
- **Low Low Energy Behavior**
  Efficiency decreases again because very low energy photons can not get through crystal's encapsulation/window
- **Modelling**
  Curve is fitted using mathematical functions, such as third to fifth-degree polynomials, to interpolate efficiency values for any given energy

MANUAL ACTIVITY CALCULATION

1. To determine in your geometry the activity of a known radioactive source (specific radionuclide), you need the **detector's total efficiency at the energy of interest**. This means you have already measured a known activity source and determined the detection efficiency for that given line.

2. If the total efficiency at that exact energy is not available, but efficiencies at nearby gamma lines are known, you can interpolate between these values to estimate the efficiency for your energy.

3. As a first approximation, a linear interpolation is often sufficient, though higher-order fits can improve accuracy over wider energy ranges. (Recap straight line formula)



bGamEff and Simulated Efficiency

Determination of Total Efficiency via Monte Carlo Modelling

- Total efficiency curve can be obtained using dedicated calibration software that models the full detector–sample geometry, without the need of any real sources!
- Detector dimensions, source geometry, distances, and material composition are defined in a 3D environment.
- Photon transport is simulated using Monte Carlo–based calculations to generate an energy-dependent efficiency curve.

bGamEff (the software we will use) allows detailed arbitrary geometry modelling and simulated efficiency computation. Similarly, ISOCS Calibration Software (Canberra/Mirion) uses pre-characterised detector response functions derived from Monte Carlo modelling, enabling calibration **without physical standard sources**.

The resulting simulated efficiency curve can be directly implemented in quantitative gamma-spectrometry analysis SW, anyway in real life experiments it is very important to validate your simulated efficiency curve with some real sources!

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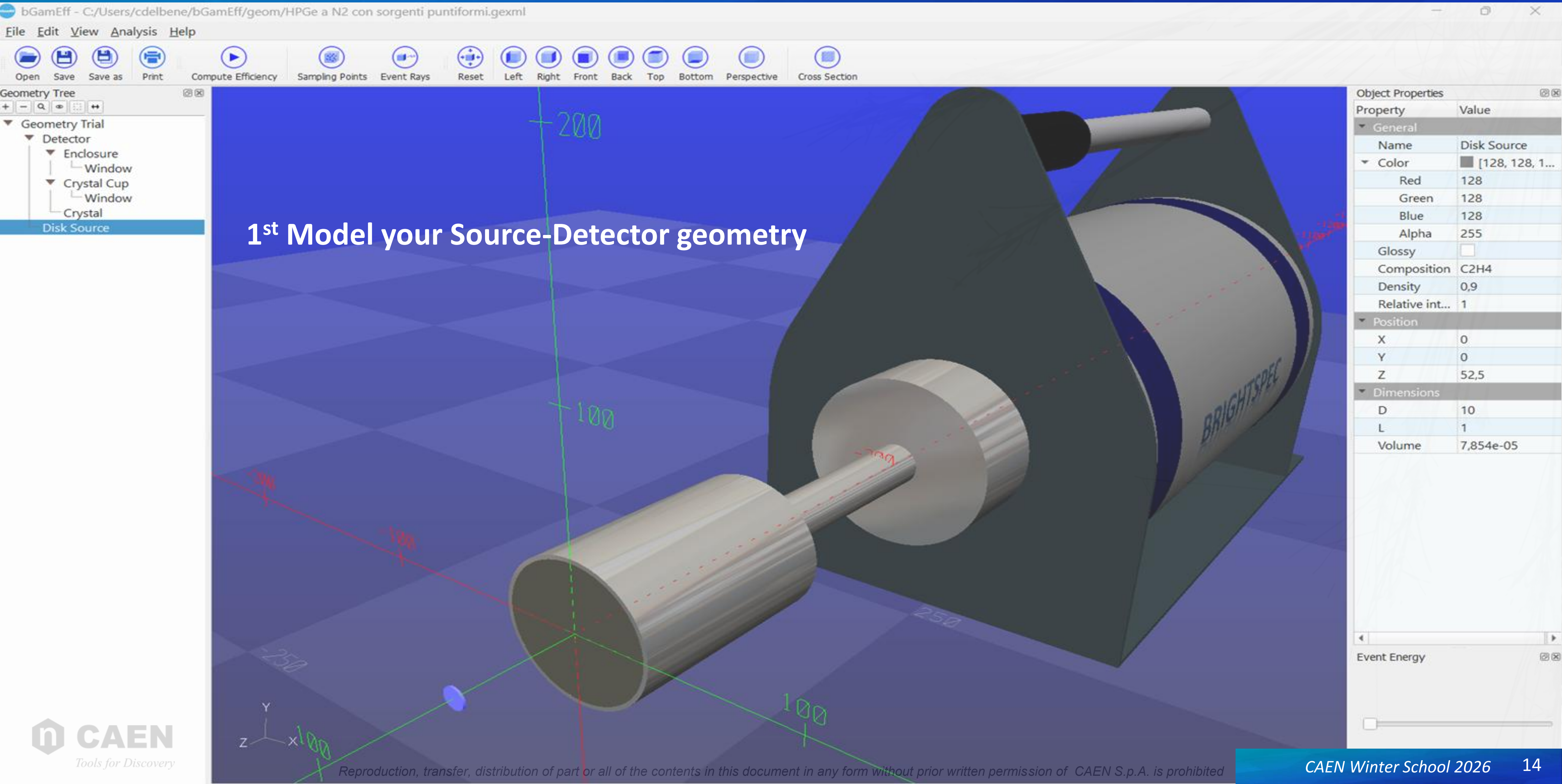
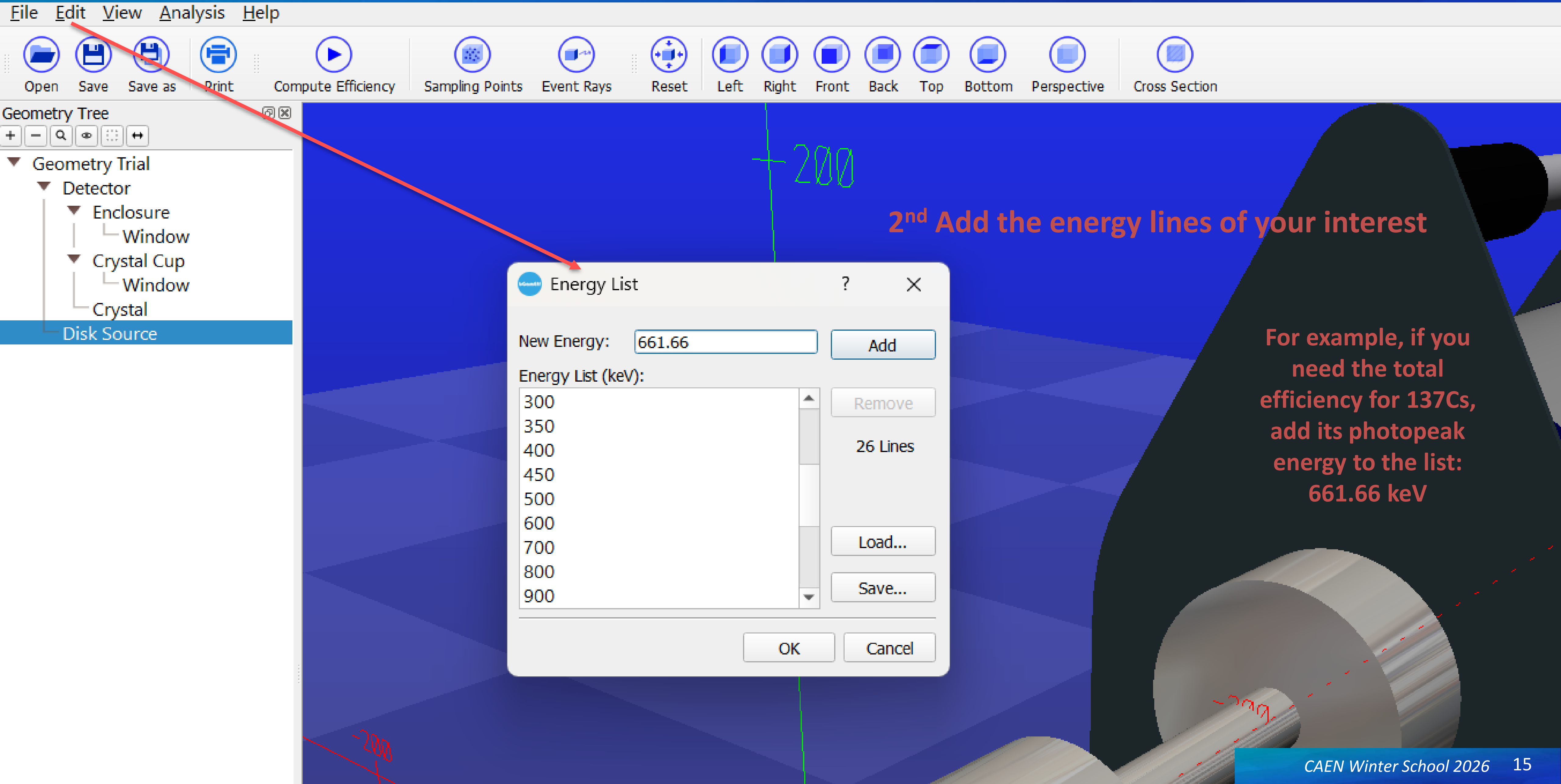
bGamEff and Simulated Efficiency

1st Model your Source-Detector geometry



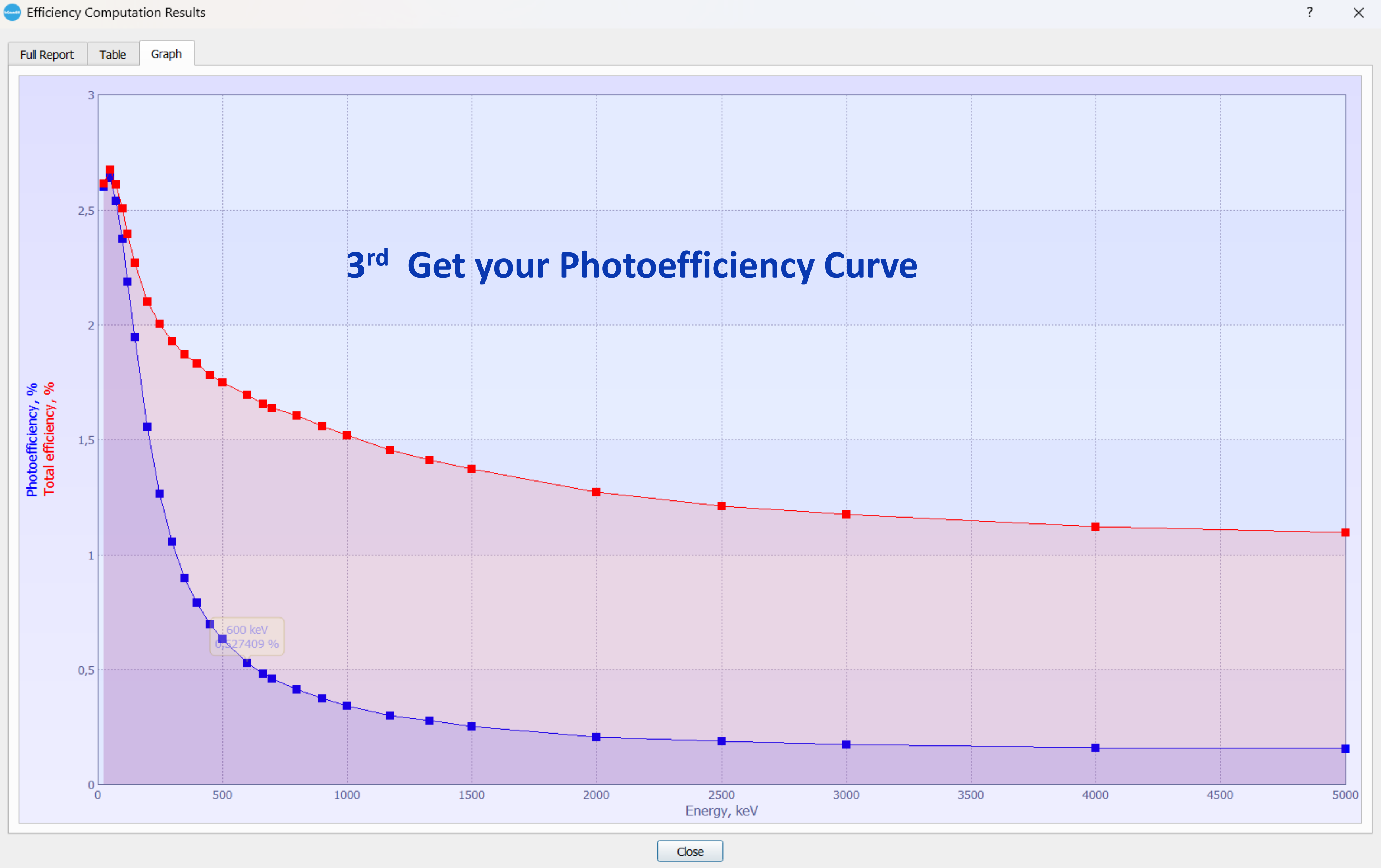
bGamEff and Simulated Efficiency

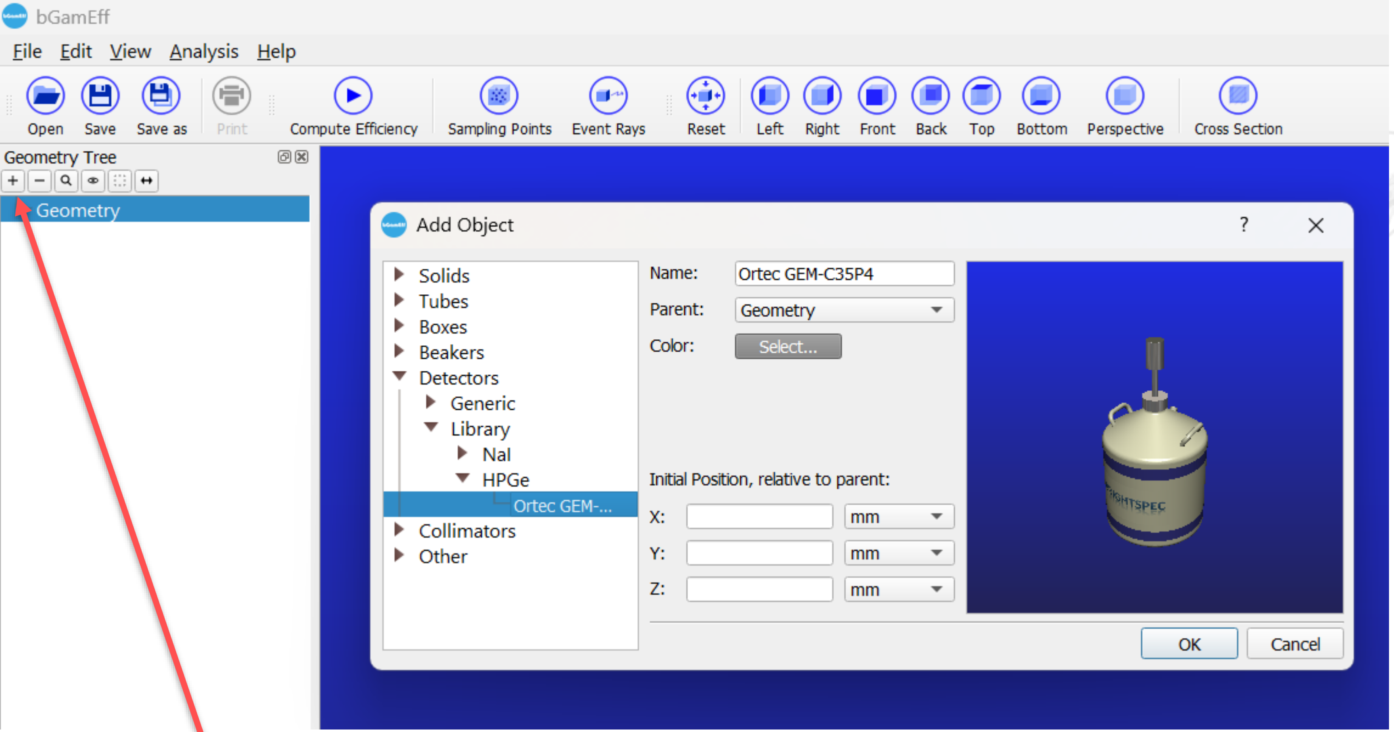


2nd Add the energy lines of your interest

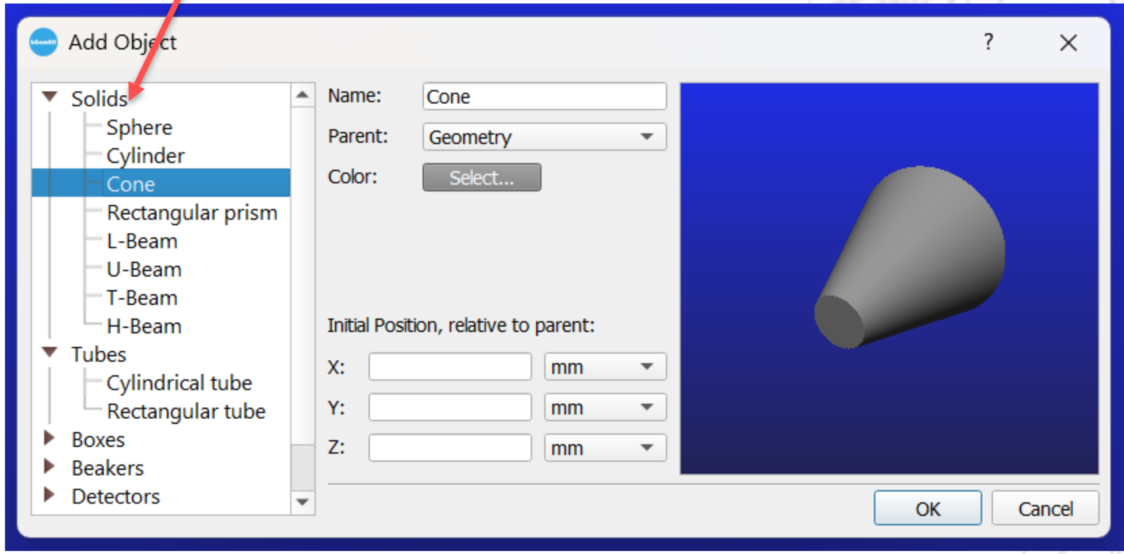
For example, if you need the total efficiency for 137Cs, add its photopeak energy to the list: 661.66 keV

bGamEff and Simulated Efficiency





To add the source, select the right geometry, dimensions, material and assign a relative intensity equal to 1 (which means this is the only radioactive object in your set-up)



Press the "+" button to add the detector. Choose the right one and adjust according to your dimensions!

DON'T WORRY WE'LL GUIDE YOU THROUGH THE PROCESS

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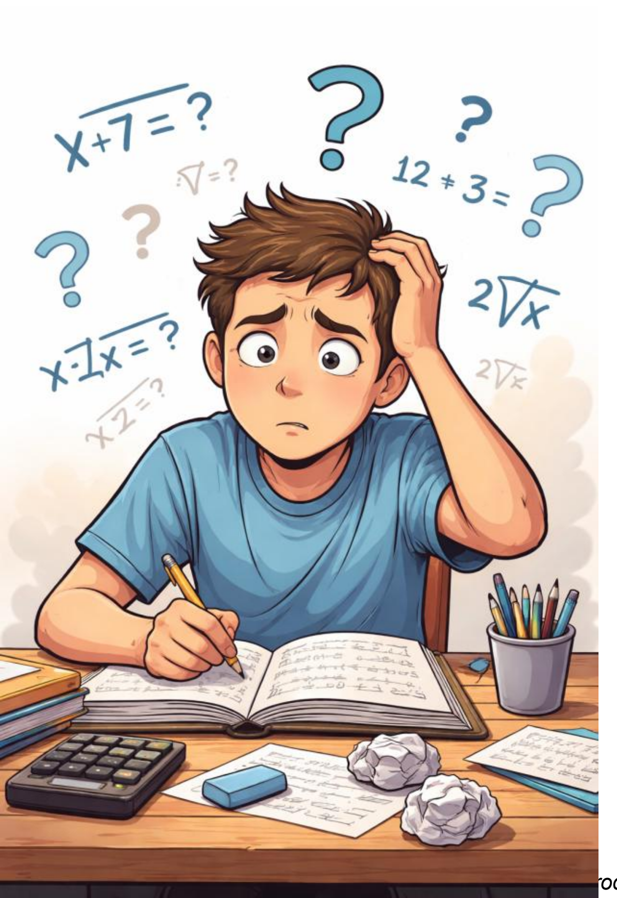
Fine, we have the Total Efficiency Curve.

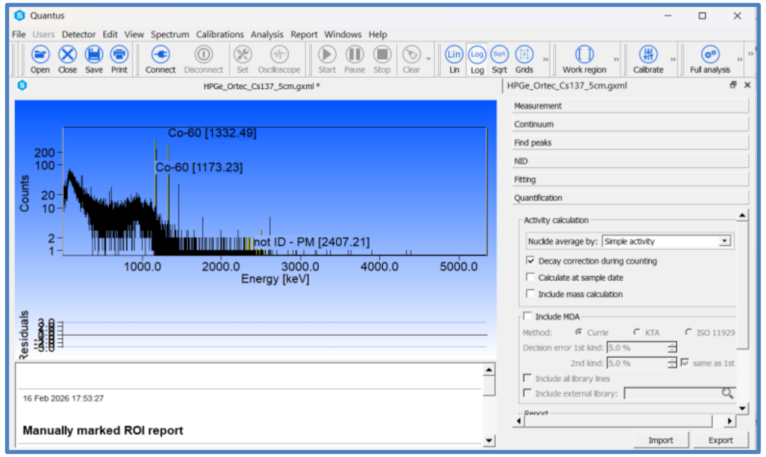


YES, BUT

How do we calculate the Activity from a given Spectrum?

Using another software!

In our case **QUANTUS**, a CAEN high performance software. It can analyze any recorded gamma-ray spectrum for radionuclide identification and quantification



1. Drag spectrum into Quantus
2. Check energy calibration
3. Define the ROI of your interest
4. Adjust the library and consequently, do the NID
5. Add efficiency calibration curve
6. Fitting
7. **Quantification!**

DON'T WORRY WE'LL GUIDE YOU THROUGH THE PROCESS AGAIN

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ROI Selection

We first suggest to zoom in holding the “**Ctrl**” button and selecting the correct area. Then, to select the ROI, hold the **“Shift”** button and highlight your region of interest. To fine adjust the ROI’s limits right-click on it and change them.

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2. Check energy calibration
3. **Define the ROI of your interest**
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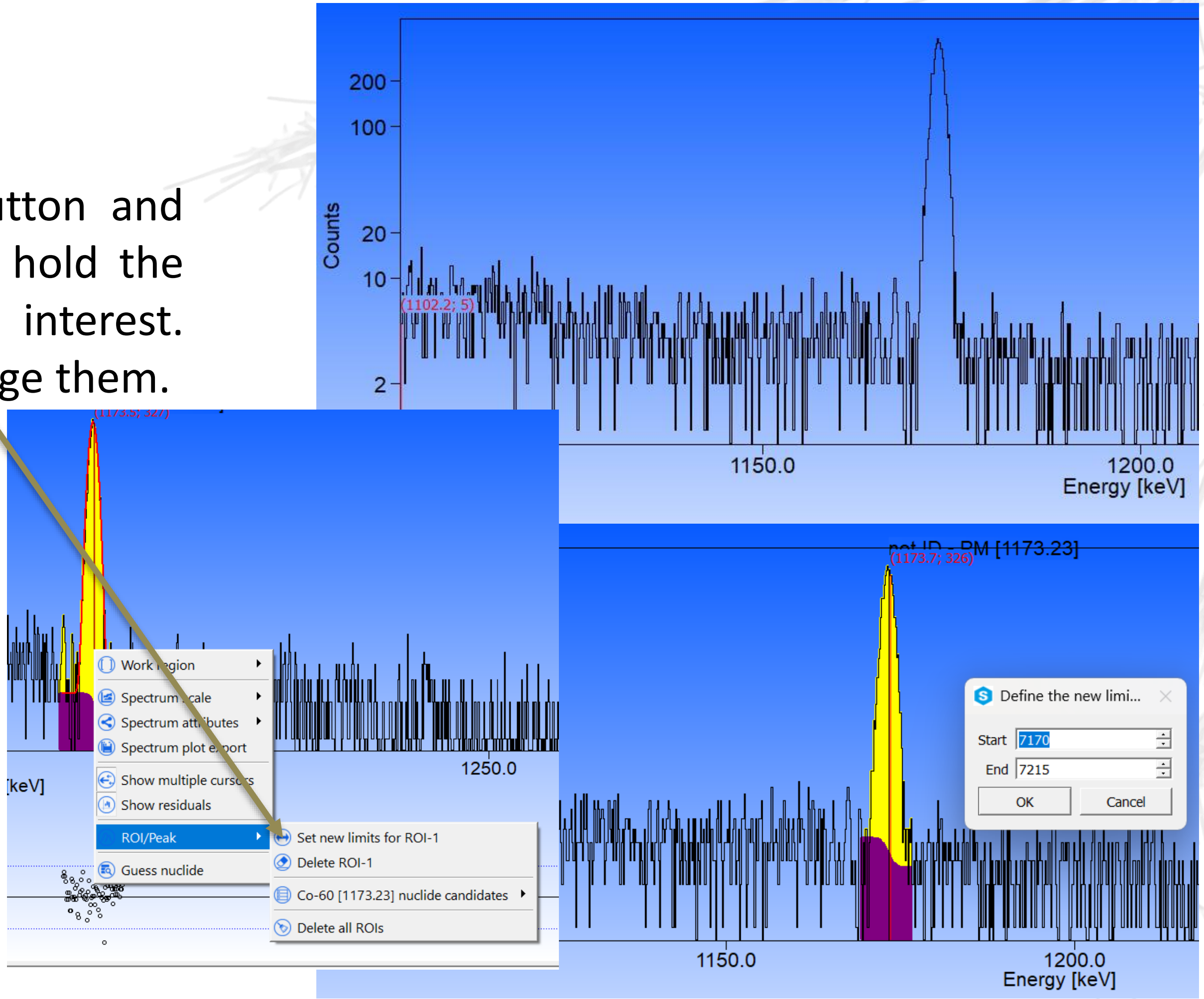
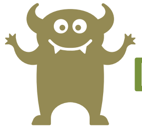
7. Quantification!





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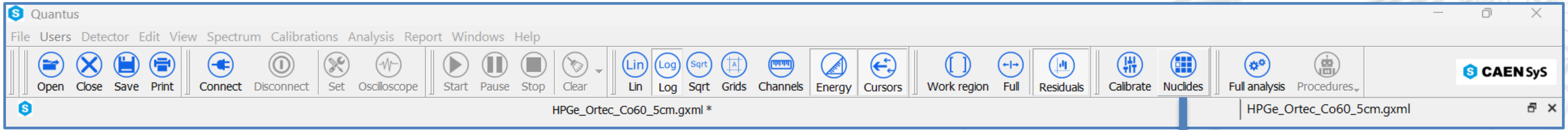
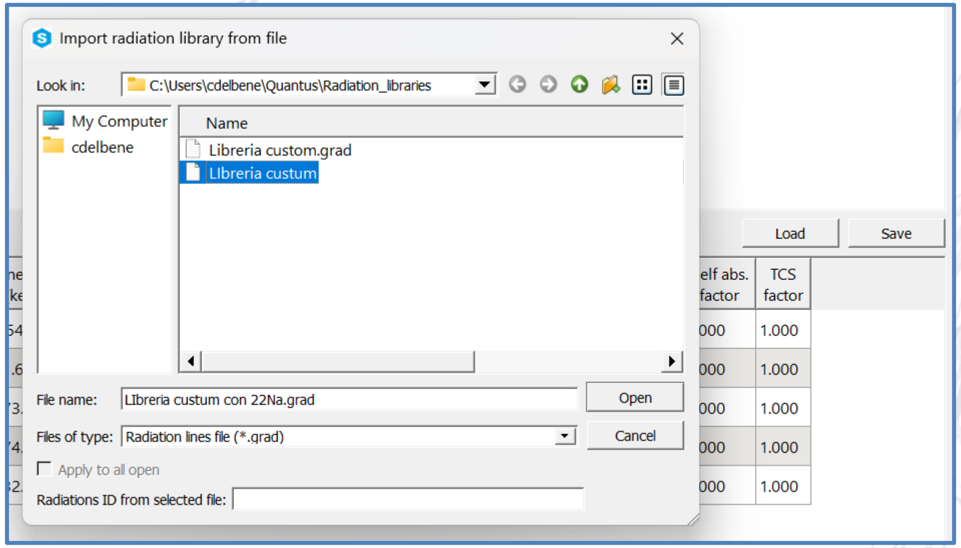
Quantus TIPS: ADJUST LIBRARY AND NID



Press on "**Nuclides**" and load the preset library saved on your PC desktop. Make sure the "**Analytical**" box is flagged for all the radionuclides. Then do NID!



1. Drag spectrum into Quantus
2. Check energy calibration
3. Define the ROI of your interest
4. **Adjust the library and consequently, do the NID**
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7. Quantification!

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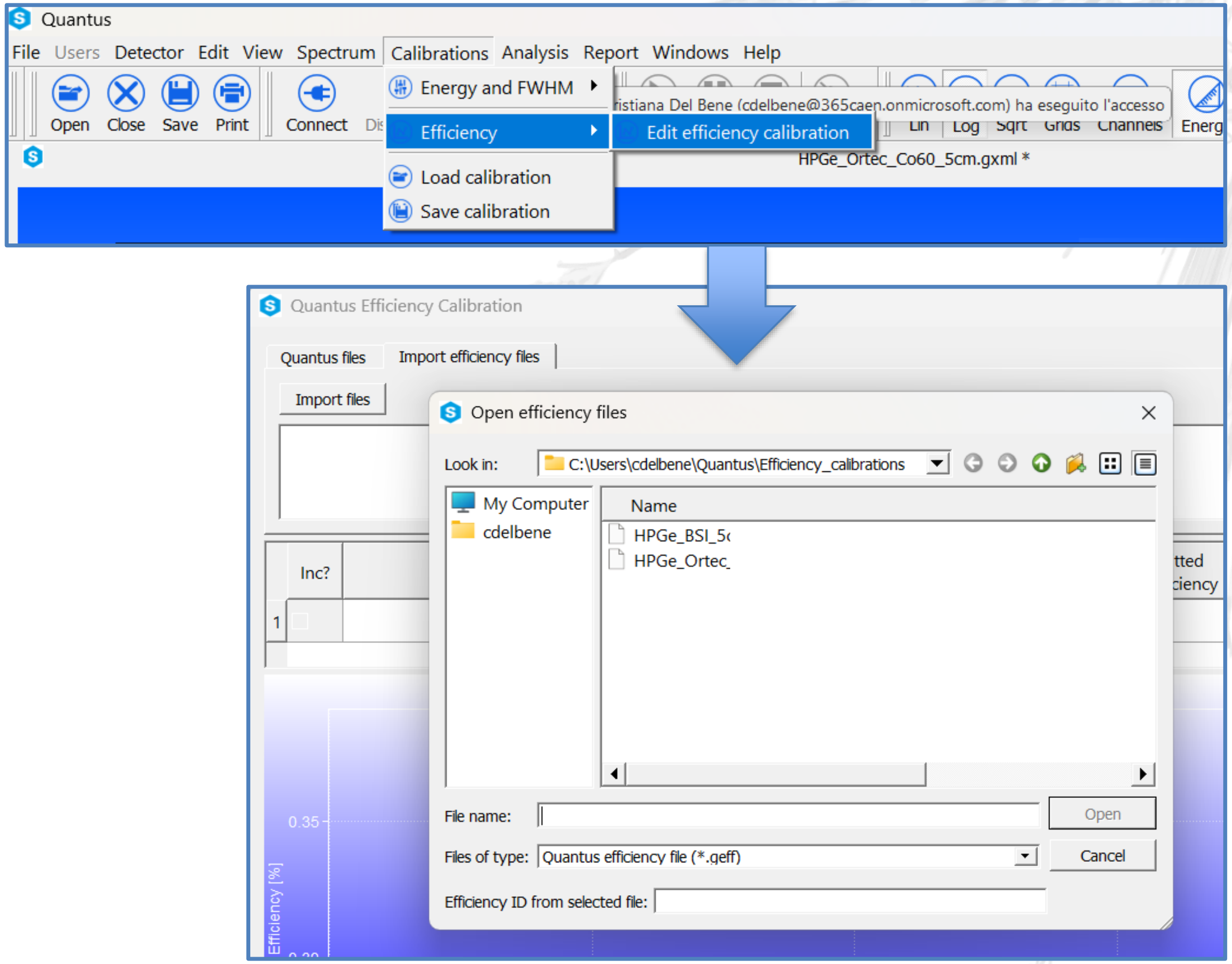
Quantus TIPS: LOAD EFFICIENCY CALIBRATION CURVE

You need to add your simulated total efficiency curve. Go to the “**Edit efficiency calibration**” page as shown in the picture. Then go to “**Import efficiency files**” and select the one you have just generated in bGamEff!



1. Drag spectrum into Quantus
2. Check energy calibration
3. Define the ROI of your interest
4. Adjust the library and consequently, do the NID
5. **Add efficiency calibration curve**
6. Fitting
7. Quantification!

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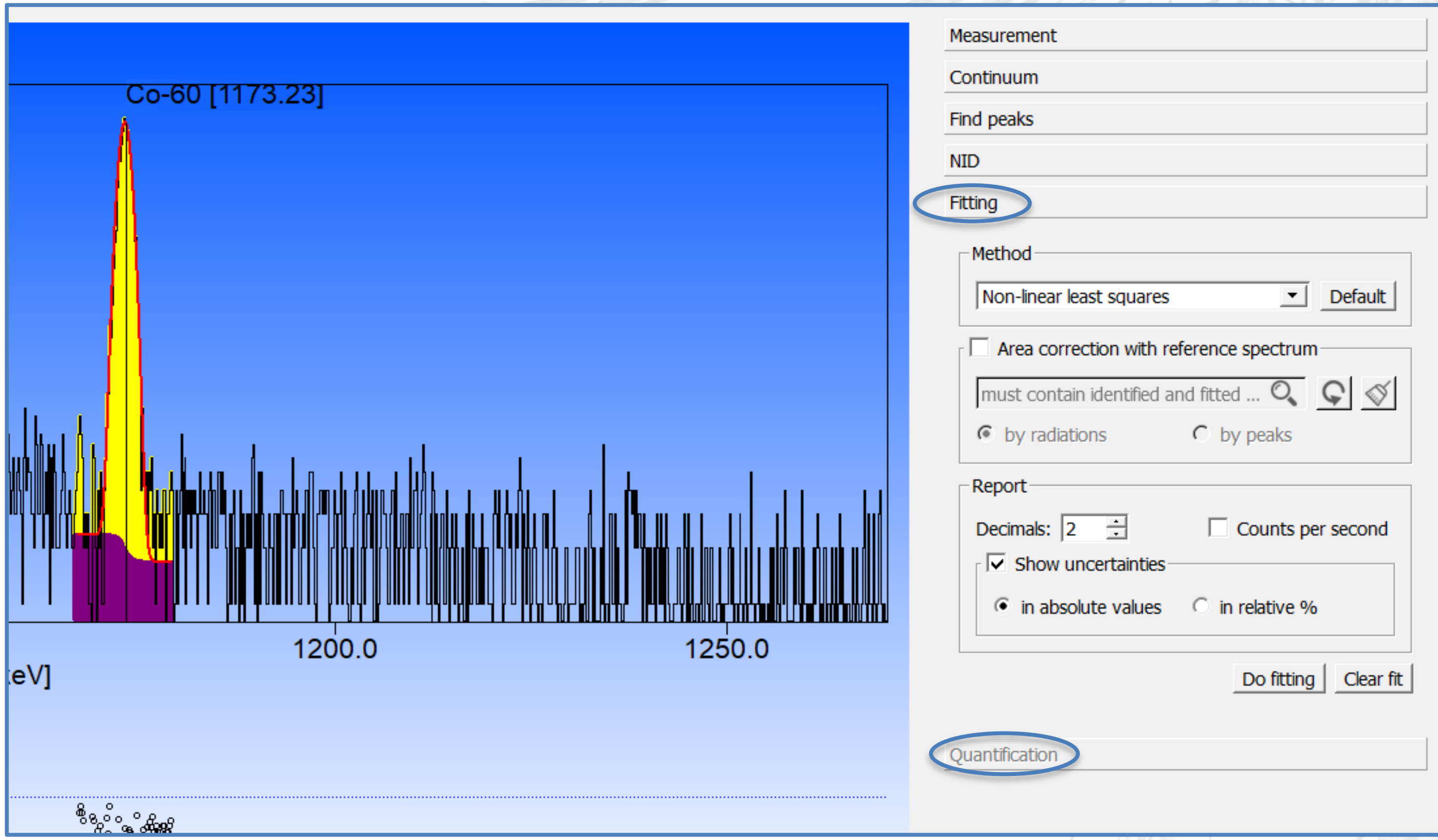
Final Step!

Press the "**Do fitting**" button on the right menu and then the "**Quantification**" one. The activities of your selected ROIs should appear below the spectrum, as computed by the software!

1. Drag spectrum into Quantus
2. Check energy calibration
3. Define the ROI of your interest
4. Adjust the library and consequently, do the NID
5. Add efficiency calibration curve
6. **Fitting**
7. **Quantification!**



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Thank you for your attention!

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