Energy resolution measurements of a PET system

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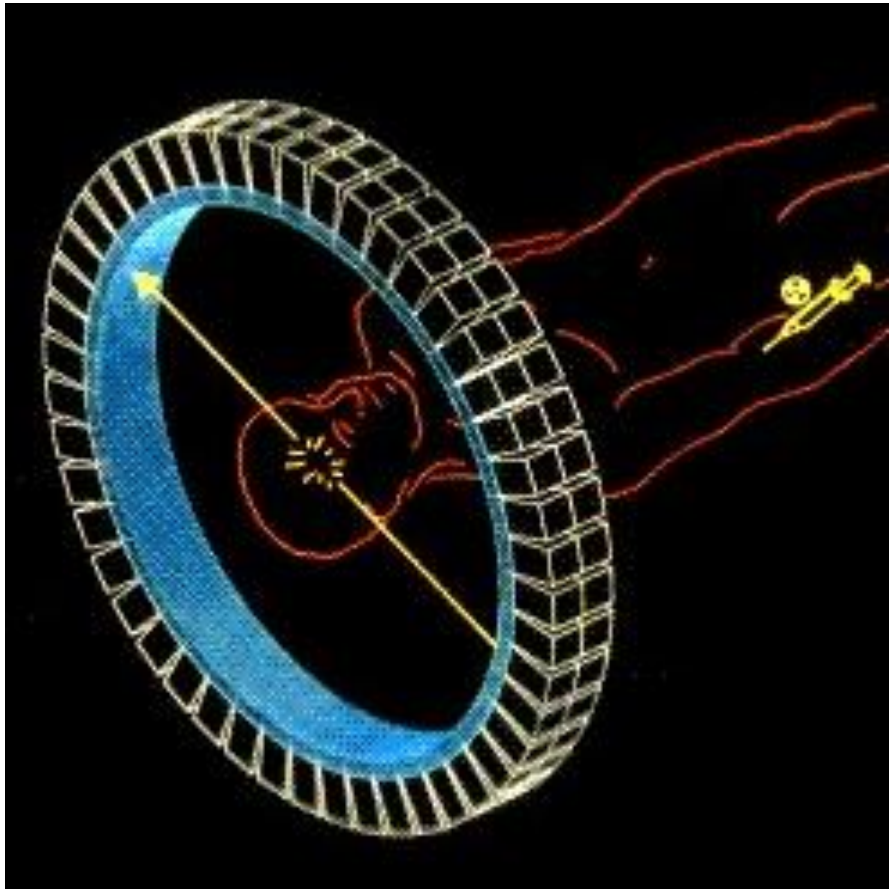
Introduction



PET system scheme

- What we measure:

$$N = T + S + R$$

N – number of detected events (coincidences)

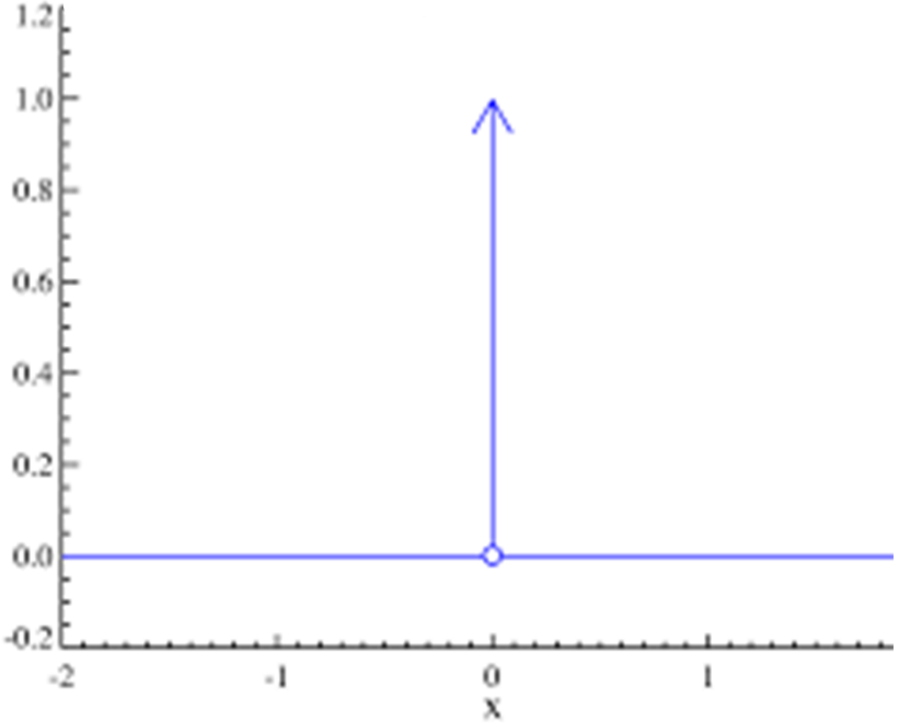
T – number of true coincidences

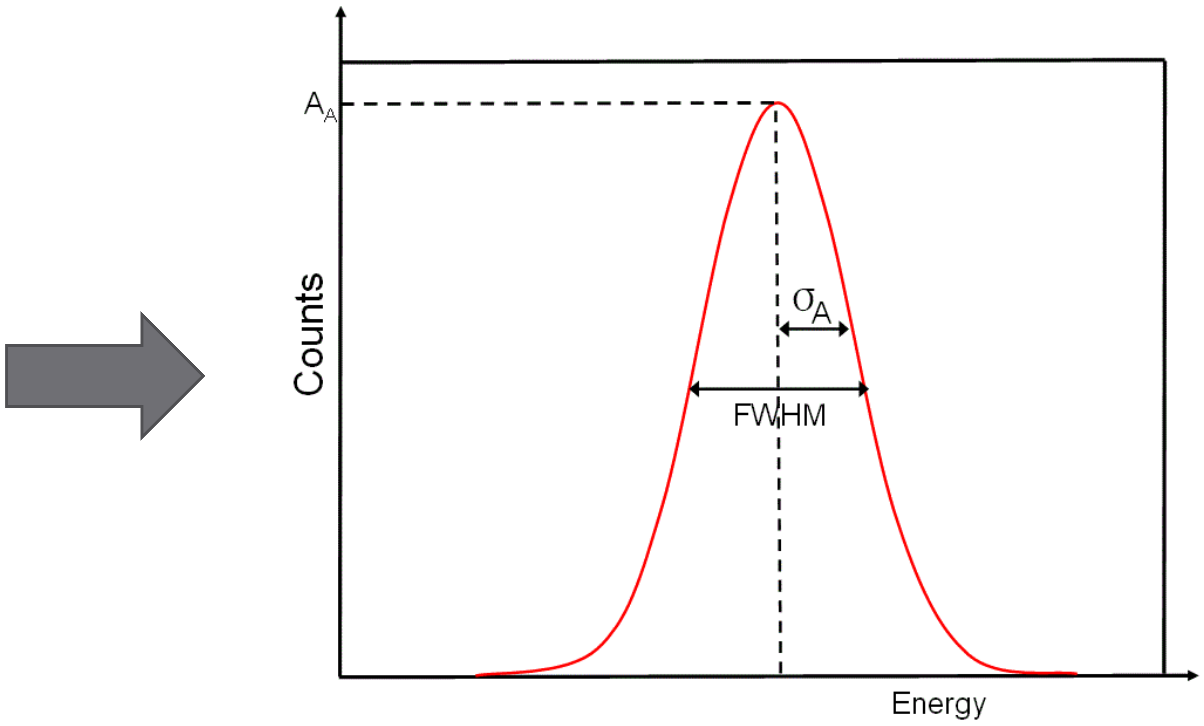
S – number of scattered coincidences

R – number of random coincidences

- **We want to remove scattered and random coincidences**

- We can remove scattered coincidences by measuring energy resolution of the system
- Ideally, we would expect a peak represented by delta function. In reality, peak has a Gaussian form:





- Energy resolution can be calculated as:

$$R = \frac{FWHM}{E} = \frac{2.35 * \sigma}{E}$$

Some theory…

- For a Gaussian peak:

$$R = \sqrt{{R_{int}}^2 + {R_p}^2 + {R_{noise}}^2 + {R_{stat}}^2} \quad *$$

- ○ R_{int} - intrinsic scintillator resolution
- ○ R_p - partial resolution due to the variation of photon transport probability for transport from an emission point into the crystal to the photomultiplier
- ○ R_{noise} - resolution related to the noise in electronic circuits

- Here, focus is on the $\boldsymbol{R_{stat}}$ - statistical term:

$$R_{stat} \propto \frac{1}{\sqrt{N_{pe}}}$$

➡ **In order to improve energy resolution, we want to increase the number of recorded photoelectrons**

*A. Gektin, A. Vasil'ev, "Scintillator energy resolutionand a way to improve it by kinetic waveform analysis", Radiation Measurements, 2019

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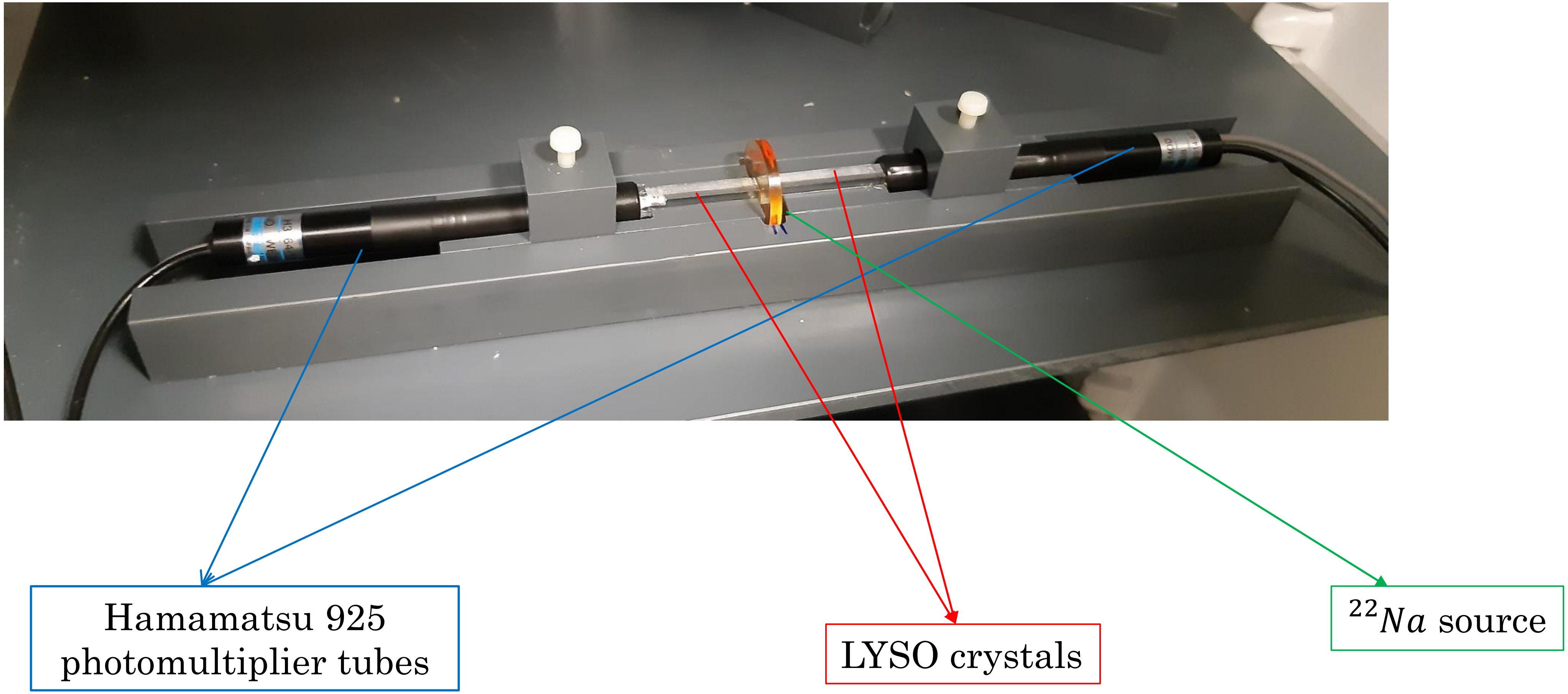
Materials & Methods

- Experimental setup:

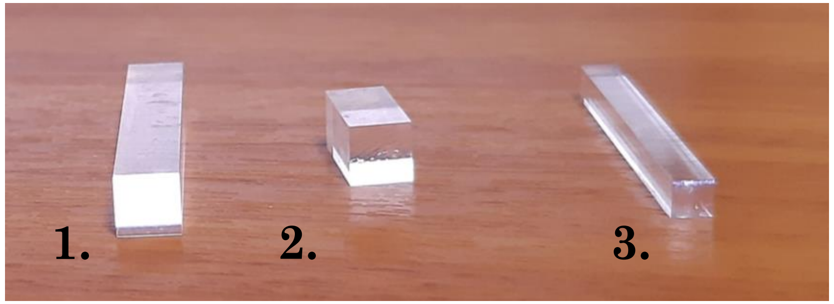


- Photomultipliers are connected to the source of high voltage and to the oscilloscope

- Pairs of **LYSO crystals** of different dimensions are used as detectors

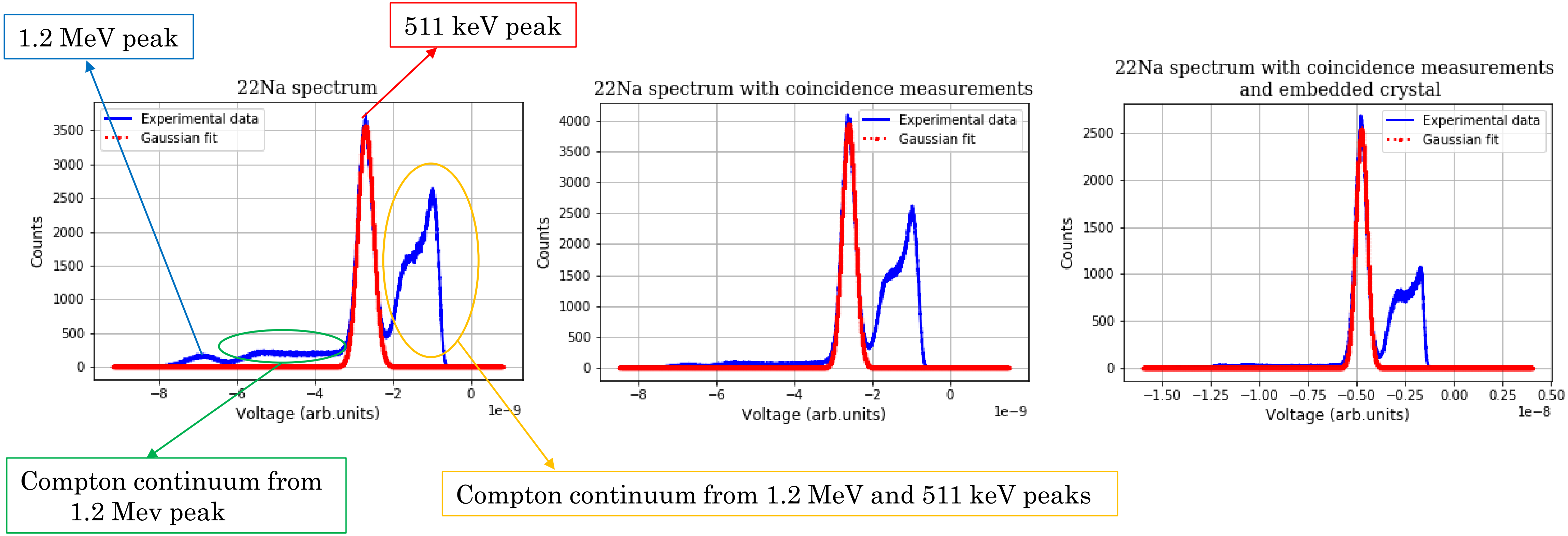
Density (g/cm3)	Dead time (ns)	Light yield (photons/MeV)
7.1	36	33000

- Dimensions used:
  1. Cross section $3x3mm^2$ and thickness of $3cm$
  2. Cross section $3x3mm^2$ and thickness of $1cm$
  3. Cross section $1x1mm^2$ and thickness of $3cm$



- Later on, crystals were embedded in teflon:

- For each crystal size, spectrums were obtained in three different acquisition modes:
  1. Raw acquisition mode – 1 crystal and 1 PMT
  2. Acquisition mode that includes coincidence measurements – 2 crystals and 2 PMTs
  3. Acquisition mode that includes coincidence measurements and embedding the crystal in the reflecting material (teflon)



- For all obtained spectrums, 511keV peak was fitted with a Gaussian function in Python

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Results and Discussion

- <u>How can we improve the energy resolution?</u>

  1. Coincidence measurements

  2. Embedding the crystal in a reflecting material

- First set of measurements (3 different acquisition modes) were done on a crystal which thickness is $3cm$ and cross section $3x3mm^2$
- Obtained results are presented in the table below:

Spectrum	Center	Sigma	Resolution (%)
Raw	-1.87E-09	1.51E-10	(18.89±0.21)
Coincidence	-1.86E-09	1.48E-10	(18.61±0.08)
Coincidence + embedded	-5.60E-09	4.97E-10	(19.48±1.22)

Furthermore, we examined the influence of changing the size of the crystal on the energy resolution:

1. Reducing the cross section: thickness of the crystal is $3cm$, cross section is $1x1mm^2$

Spectrum	Center	Sigma	Resolution (%)
Raw	-2.7E-09	1.96E-10	(17.05±0.67)
Coincidence	-2.61E-09	1.67E-10	(15.06±0.44)
Coincidence + embedded	2.87E-09	2.87E-10	(14.19±0.40)

2. Reducing the thickness : thickness of the crystal is $1cm$, cross section is $3x3mm^2$

Spectrum	Center	Sigma	Resolution (%)
Raw	-2.68E-09	1.85E-10	(16.18±0.32)
Coincidence	-2.64E-09	1.85E-10	(16.45±0.71)
Coincidence + embedded	-4.53E-09	2.43E-10	(12.61±0.06)

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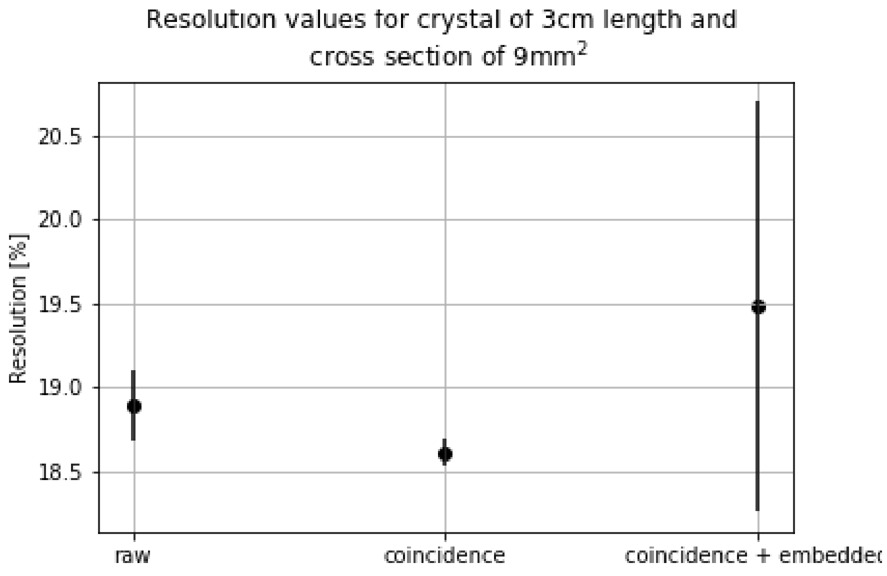
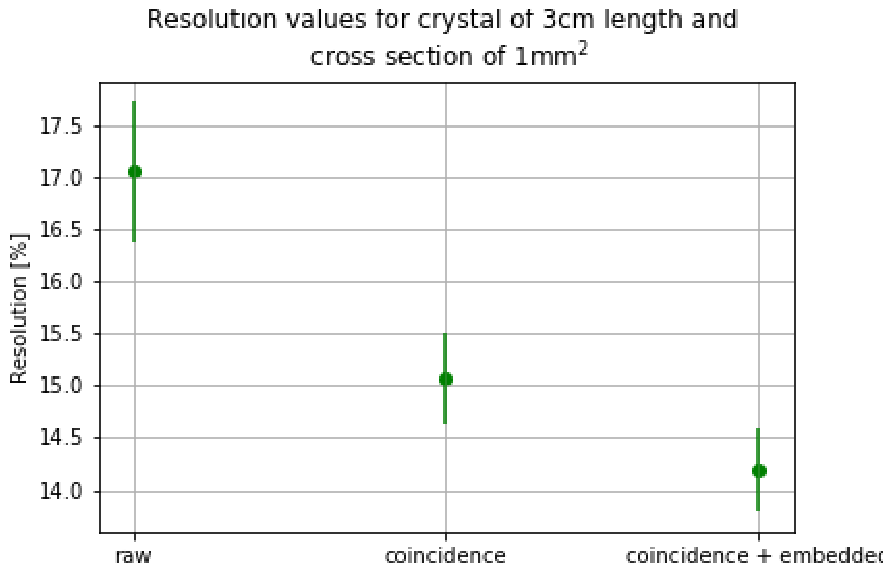
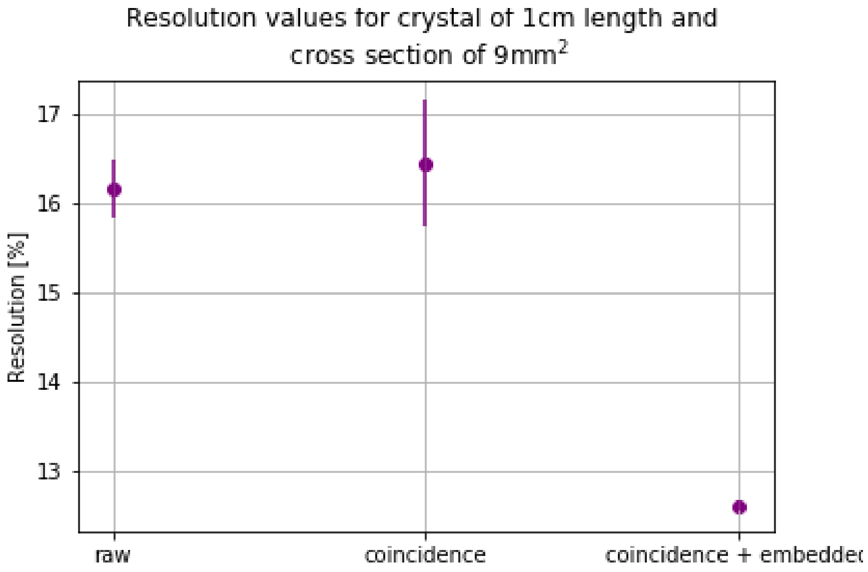
Discussion

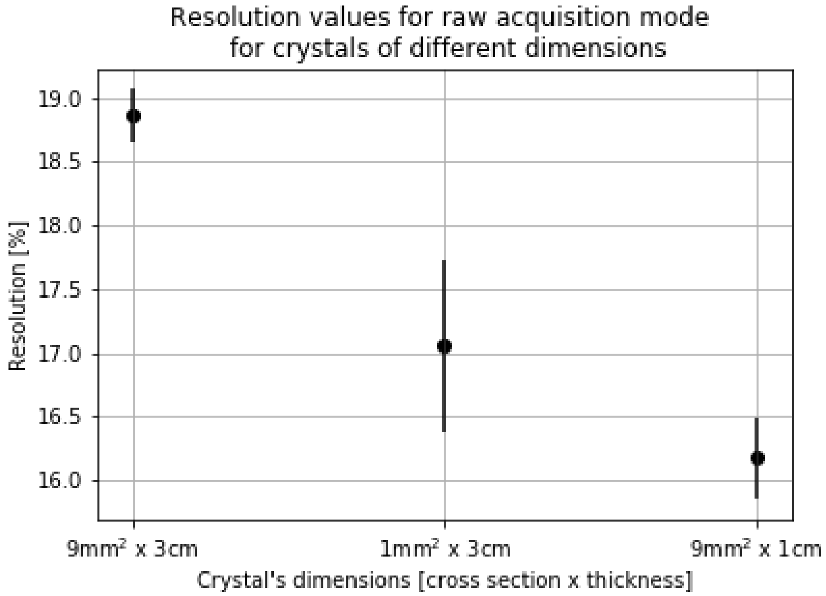
1. Comparing different methods of spectrum acquisition for a given crystal size:

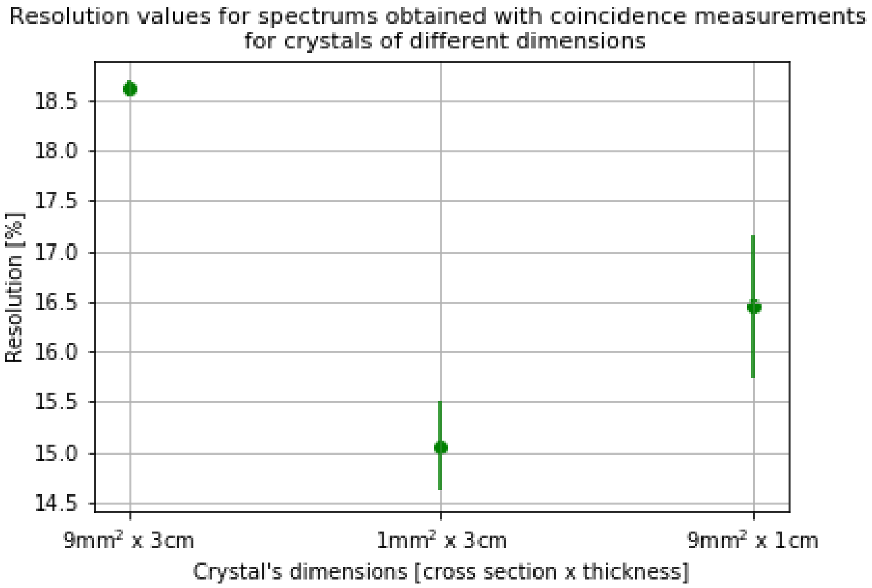


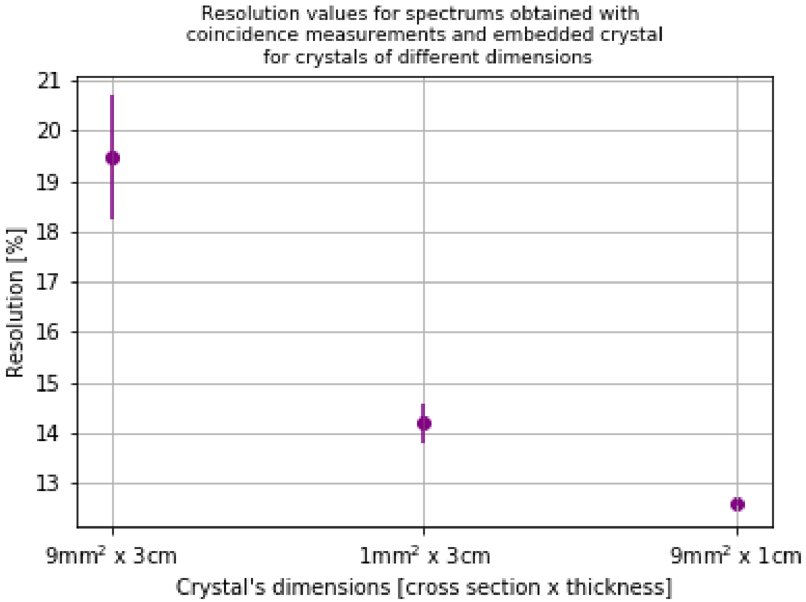




2. Comparing how different crystal size influences the energy resolution for a given mode of acquisition:







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Conclusion

- By coincidence measurements and embedding the crystal in teflon we were able to remove successfully Compton continuum coming from 1.2MeV peak of 22Na source – energy resolution improved
- Reducing the thickness of the crystal and reducing its cross section both result in better energy resolution due to the larger angle of the crystal that photomultiplier subtends (number of photons that interact with photocathode increases)
- Errors on the obtained resolution values vary in orders of magnitude - this can be due to the different acquisition time and other factors mentioned (such as electronic noise) that have influence on the energy resolution
- For having more precise conclusions, it would be necessary to repeat the measurements with large error bars
- Although reducing the volume of the crystal has positive influence on the energy resolution of the system, it can degrade other characteristics of the system such as efficiency – compromise between those two has to be made

Furthermore: random coincidences can be removed by measuring the time resolution of the system in a similar way