Numerical investigation of coincidence-correction in gamma spectroscopy

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Goal: simulate HPGE detector → get efficiency curve + get data from literature → calculate coincidence correction for given isotope → analyze spectrum of an old experiment → investigate effect of correction

Coincidence summing

- Radioactive decay → nucleus in excited state → deexcitation - not necessarily 1 step, multiple deexcitations → gamma cascades
- Fast (ps) transitions to ground (/isomer) state
  - Usually gamma emission
  - Can be internal conversion (e^- instead of gamma), internal pair production ($e^- + e^+$)
- Multiple transitions detected as one (ps delay << μs detector time resol.)
- Coincidences sum up as real transition peak → **summing-in**

$$E_{j\to k} + E_{k\to i} = E_{j\to i}$$

- Coincidences sum up → single peaks not detected → **summing-out**

$$E_{j\to i} + E_{k\to l} \neq E_{j\to i}$$

Model: Semkow matrix formalism, a bit modified

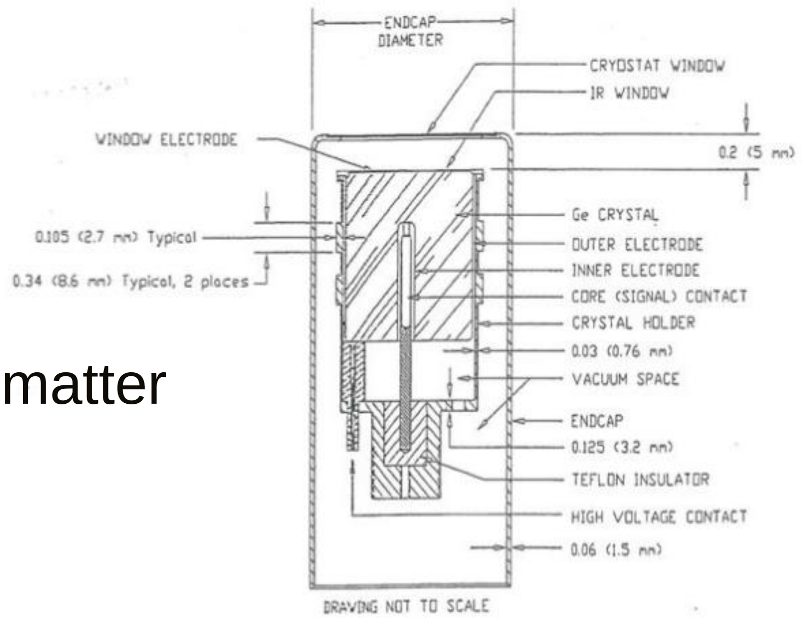
- Goal: coincidence corrected detection chance of j → i transitions
- Inputs:
  - **Transition probability** matrix (X=G+E+W, actually 3 matrices) (from **literature**)
  - **Efficiency** matrices (μ(E) , total, photopeak) (from **simulation**)
  - Feeding rates (f) (from **literature**) (distribution of starting levels)

- **F**ull, **P**artial, **N**ull detection probabilities for each transition
  - → F, P, N detection chains (from E level j to i, through all possible routes)
- Summing up as $E_{j \to i} = f_t * N_{t \to j} * F_{j \to i} * N_{i \to 1}$

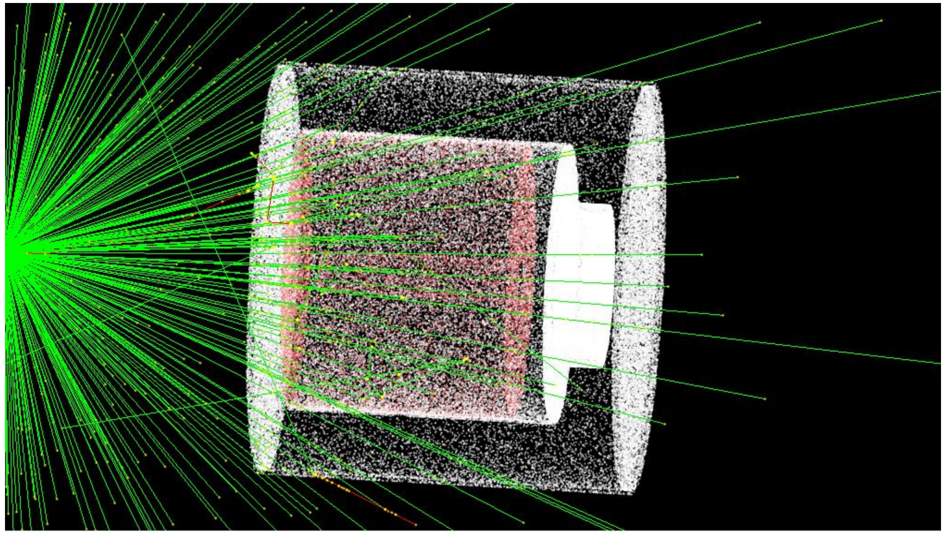
- http://atomfizika.elte.hu/akos/orak/mkm/coszu.pdf

Geant4 simulation

- Geant4 - simulation of the passage of particles through matter
- **Geometry** of HPGE detector:
  - Ge crystal (technical datasheet)
  - Outer Al shell (measured)
  - Inner positions, other elements (technical drawing from internet)
- Penelope physics (good at low energy too)
- Params:
  - **source distance**
  - **gamma E**, angle (**mono energy**, distribution)
  - geometry complexity
  - ^{238}U decay simulation
  - $CaCO_3$ sample simulation
- Various validation (/fun) simulations



Technical drawing



Simulation geometry with point source

Efficiencies – energy dependence

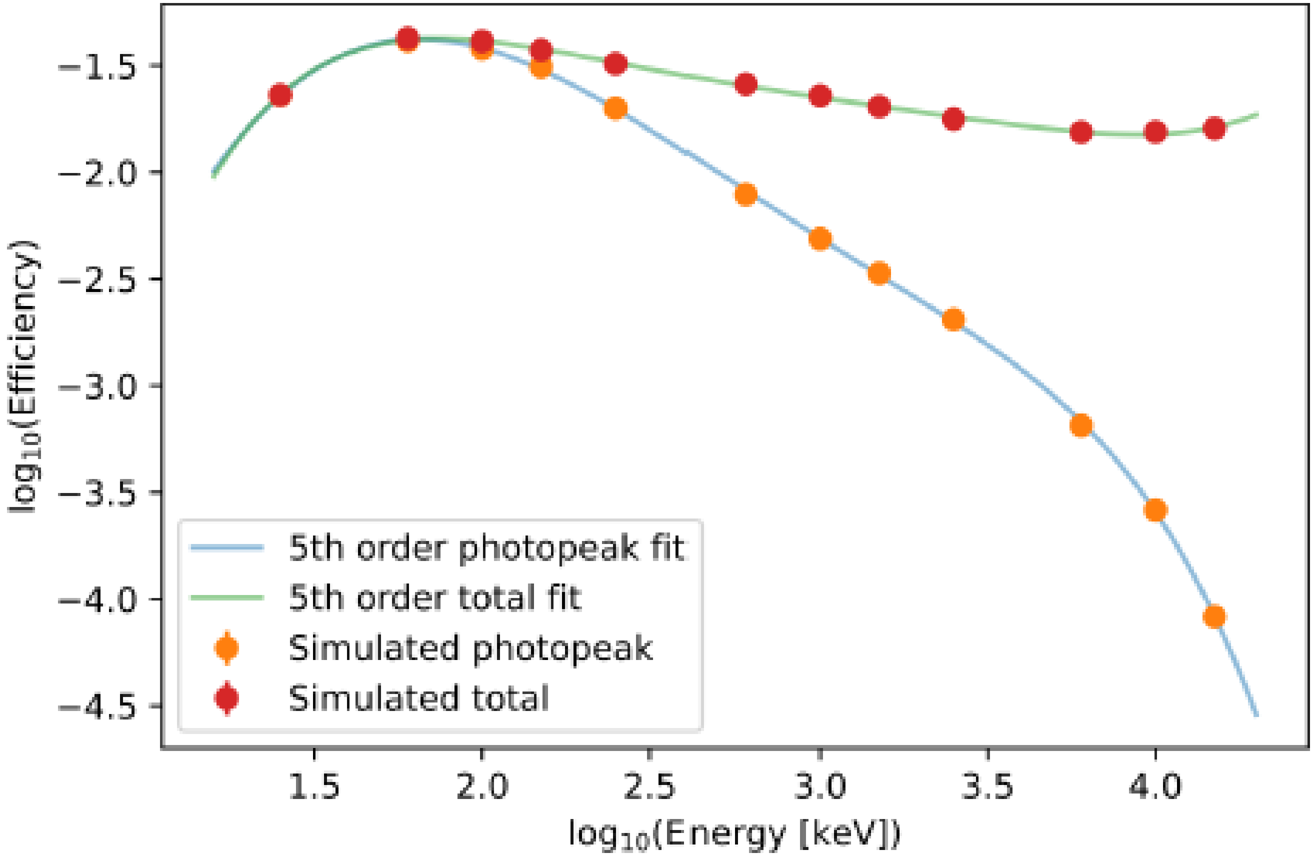
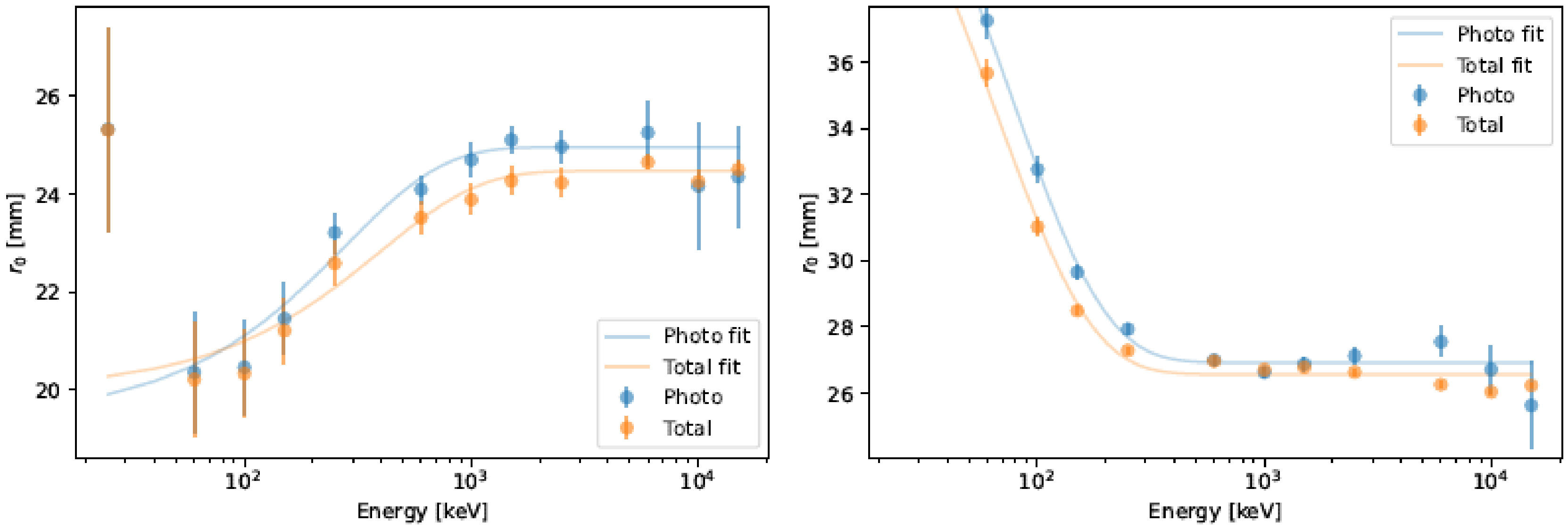


Figure 14: Simulated total and photopeak efficiency at various energies (wide range) with 5th order polynomial fit in log-log scale at 5 cm sample distance

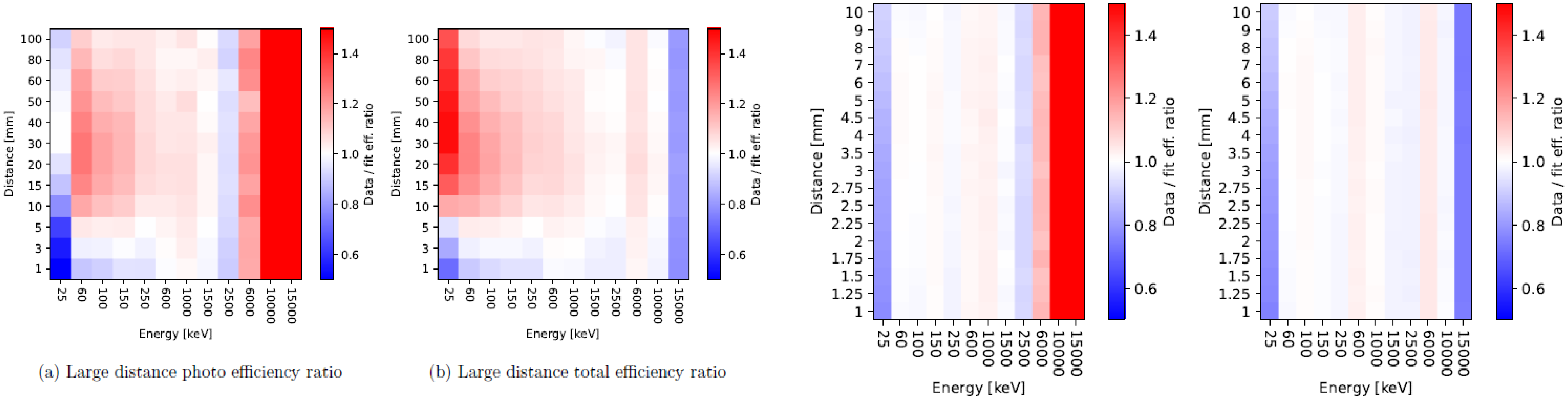
Efficiencies – distance dependence

- r^{-2} with r_0 effective distance (in detector) → $\propto \frac{1}{(r+r_0)^2}$
- Fit $\mu(r)^{-\frac{1}{2}}$ lines to get r_0 intercepts



(a) Large distance (b) Short distance

r_0 is energy dependent, different at low (<10 mm) and large (10-100 mm) distances
Fitted with empirical formula from literature



(a) Large distance photo efficiency ratio

(b) Large distance total efficiency ratio

(c) Short distance photo efficiency ratio

(d) Short distance total efficiency ratio

Figure 18: Ratio of efficiency data points per distance-energy dependent efficiency fit evaluated at simulation points for all 4 fits

- Energy and distance dependent error
- Could be better but is good enough at 100 keV – 3 MeV

^{208}Tl

- Data from NuDat2 (x (I_g), f, alpha)
- Good because:
  - feeding factor of 2614 keV = 0
  - almost all cascades go through 2614 keV
  - guaranteed coincidences
- Calculated corrected intensities:

- Summing-in
  - Impossible transitions
  - 3 strong summing-in effects
- Summing-out

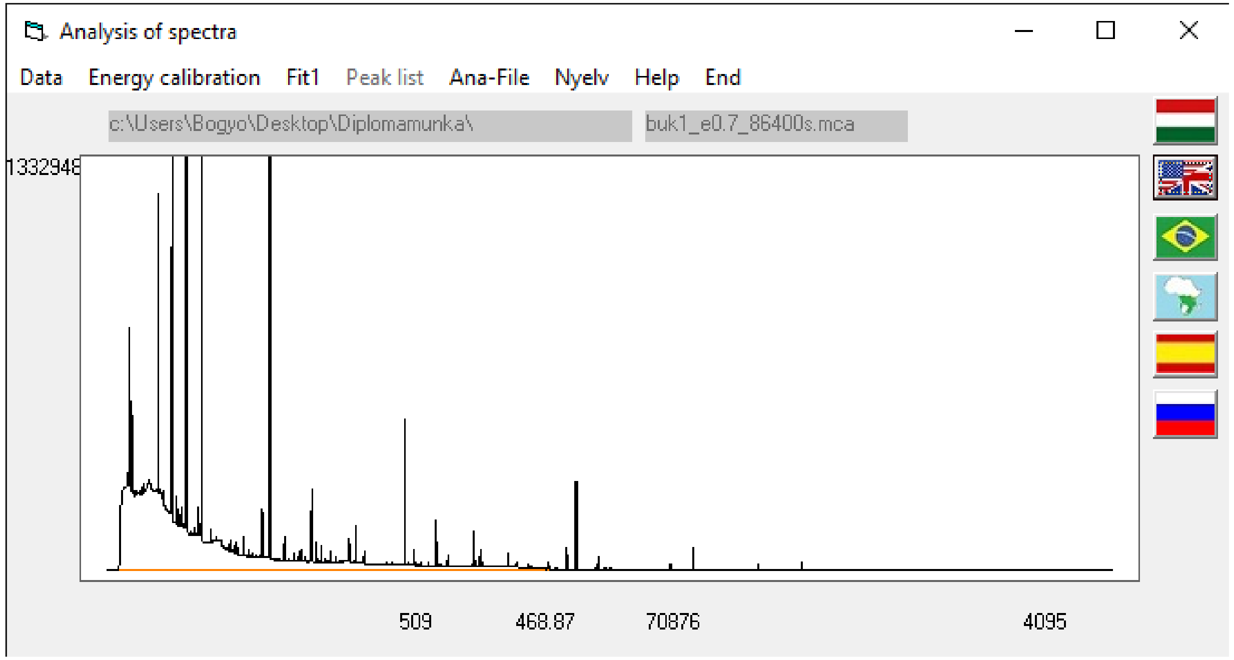
To E level [keV]

From E level [keV]	0	2614.529	3197.717	3475.088	3708.41
0					
2614.529	0.752				
3197.717	1477.834	0.794			
3475.088	521.095	0.951	0.693		
3708.41	83.108	6.620	0.690	0.648	
3919.78	inf	inf	0.819	inf	0.569
3946.42	inf	inf	0.696		
3960.93	7.106	inf	0.760	0.699	0.569
3995.6	inf	0.863			
4125.28	inf	inf	0.712	0.655	
4180.38	inf	inf	0.700	0.655	
4262	inf	0.863			
4296.28	inf	inf	inf	0.658	0.569
4323.4	inf	inf	0.696		
4358.44	inf	1.854	0.797	0.655	
4382.9	inf	inf	0.696		
4480.5	inf	inf	0.696		

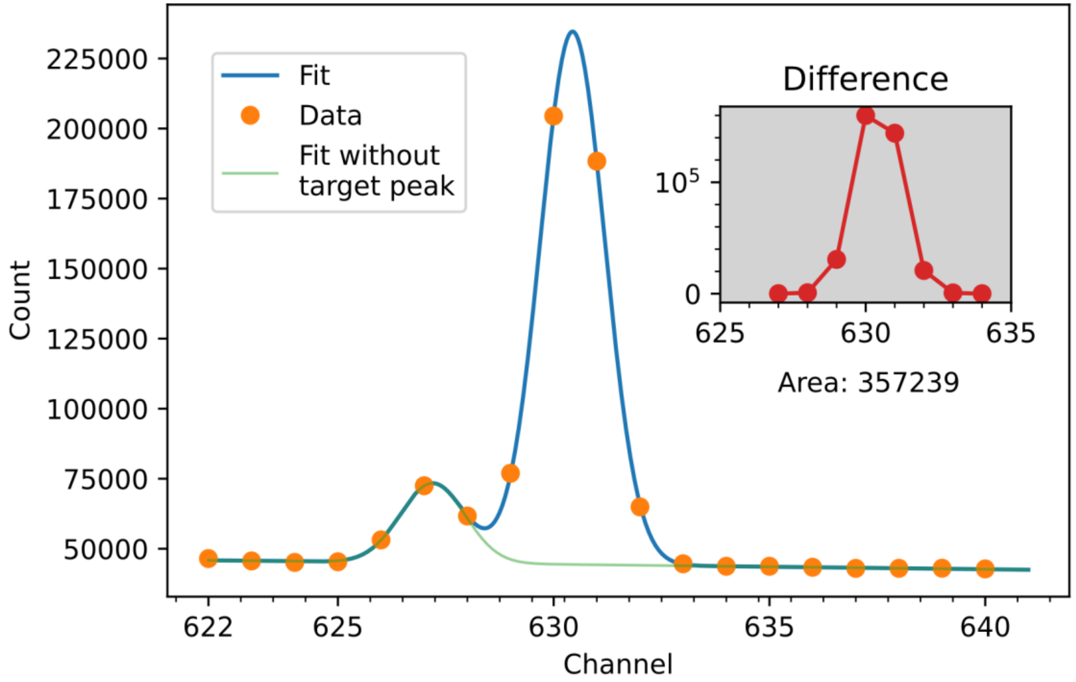
Coincidence corrected / uncorrected intensities for ^{208}Tl

Measurement

- 1-day measurement of mineral deposit from thermal pipe from Bük
- 5-day background measurement
- Calculated ^{208}Tl peak areas (← only this done by me)



Spill spectrum analyzer software, spectrum of sample



Multipeak fitting in python (Spill can't handle it)

Result

- Uncorrected activity: 76.4 ± 5 Bq
- Corrected activity: 96 ± 7.6 Bq
  - ≈+25%

- Last 3 points much better fit
  - 4 000 - 80 000 Bq → ≈50 Bq

3 Blue dots at 1000s of Bq

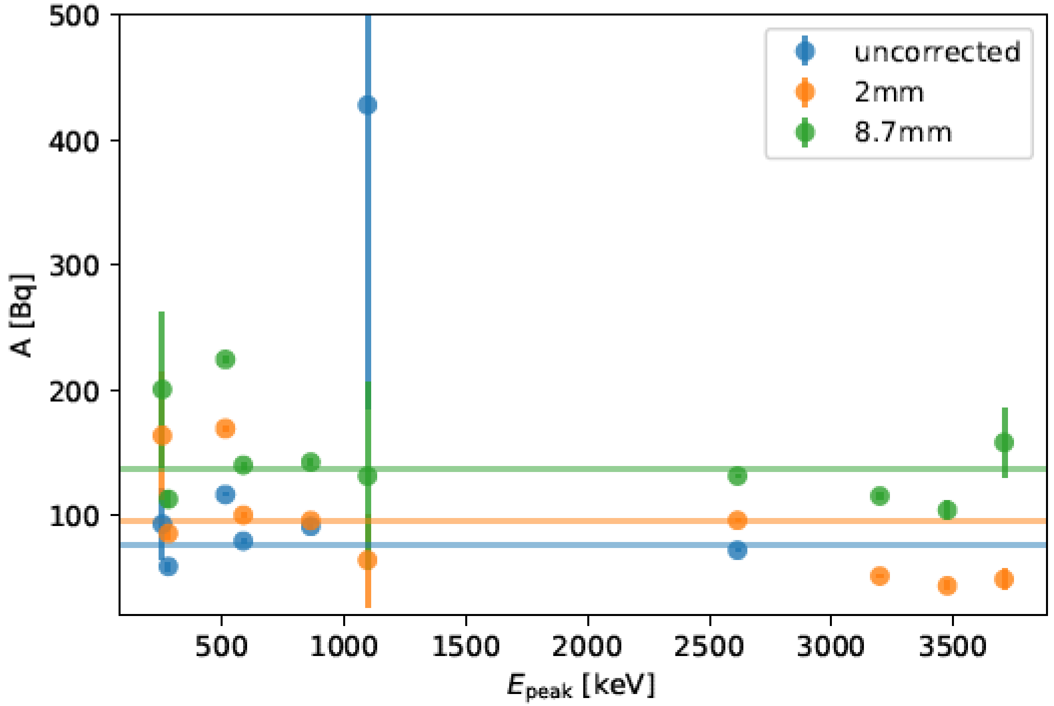


Figure 24: Calculated activities for all peaks, uncorrected, and coincidence corrected at 2 mm and 8.7 mm

8.7 mm was minimal std dev. of activity (not realistic distance)

Possible further research

- Sample self-absorption (significant at low energies)
- Better distance dependence (exact solid angle)
- Simulate dead layer of detector
- Calculate activity for all isotopes
- Simulate readout
- Simulation validation with experiment

Thank you for your attention