Data/MC comparison for LIME underground

CYGNO Simulation Meeting – 27 November 2023

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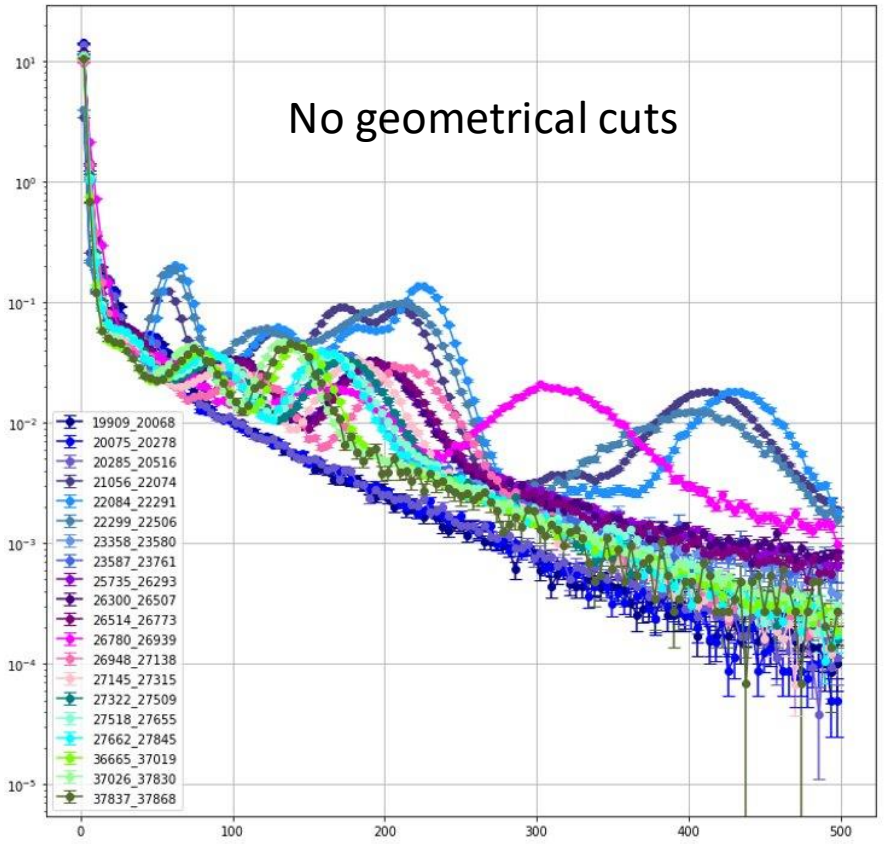
LIME underground data

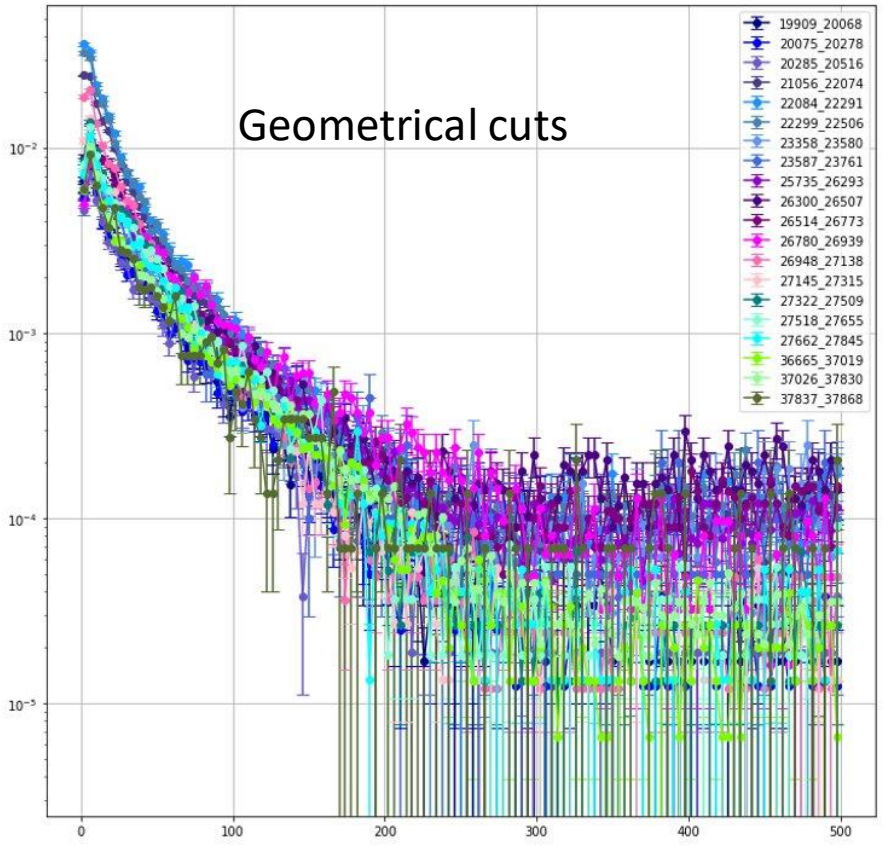
- **Run1: runs 5923-6743**
- **Run2: runs 11289-12191**
- **Run3: runs 19909-20516**

- **Normalization: (# selected sc) * C / T**
  - T = total duration of runs (stop_time-start_time)
  - C = dead time correction
  - Dead time = t_D = 30ms (camera readout) + N_{wf}*12ms (waveforms readout), N_{wf} = R_{PMT} * 480ms
    - During dead time, I expect an average of n_{miss} = R_{PMT} * t_D missed events
    - The correction to the total rate is $(1+n_{miss}/n_{obs})$
      - The fraction of missed events wrt observed one is equivalent to the ratio of the active time and the dead time
      - C = $1+t_D/480$ (**1.48** for Run1, **1.11** for Run2, **1.03** for Run3)
    - R_{PMT} is an overestimation of the rate of missed tracks in the camera because the threshold is different – I consider the dead time correction as an upper limit, including it in the uncertainty on the rate
- I **calibrated** each run with the closest calibration run in position 3 (at the center of the detector)
  - When available, I used Rita's calculated LY

LIME underground data

- Selection cuts: *fake_cut* = sc_rms>6 && 0.152 * sc_tgausssigma > 0.5 && sc_integral>1000
- Geometrical cut: sc_xmin>400 && sc_xmax<1900 && sc_ymax<1900 && sc_ymin>400 (0.424 area of the total)
  - Why this geometrical cut?





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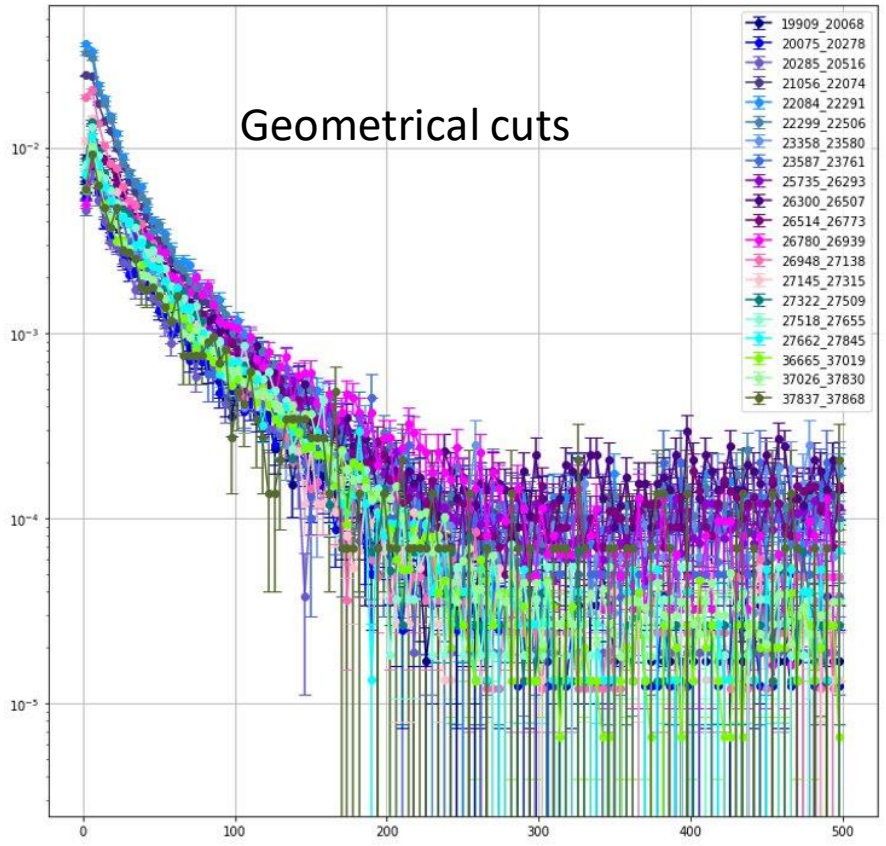
  - Why only 19909-20516 runs?

For the comparison with MC I am only considering the runs in taken in May, before the error in the rotation in the reconstruction, before the filters; these are the only runs where no weird noise (*peaks*) at the borders was observed

Until we do not understand fully everything that happened from july on, I would not consider the other data comparable with the MC (does not mean they are not good)



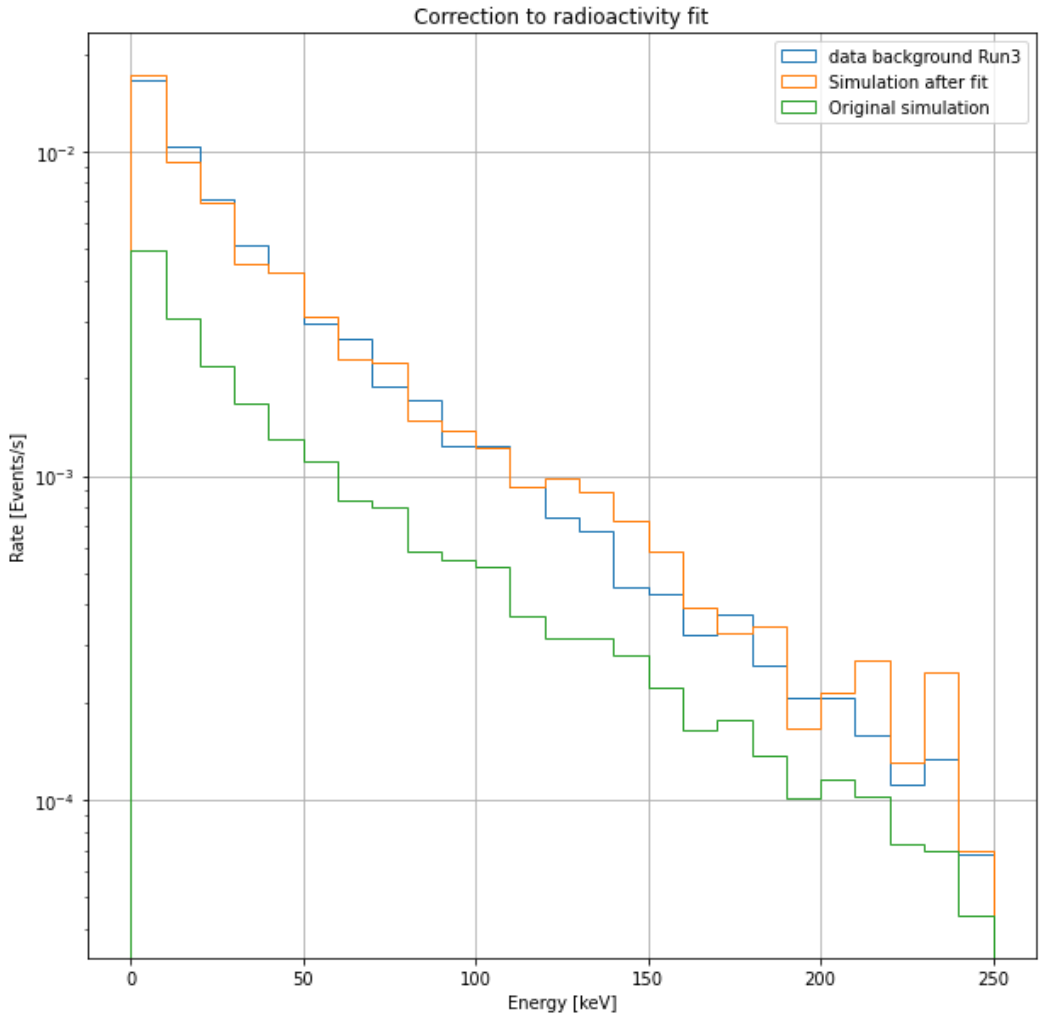
LIME background simulation

- **GEANT4:**
  - External gammas with no shield (only aluminium Faraday cage), 4cm of copper, 10cm of copper
  - Radioactivity: field rings, resistors, cathode, GEM, acrylic box
    - I simulated an equivalent of 120hr and got 0 events from the camera
  - *What was left out*: shielding radioactivity, external neutrons, radiogenic neutrons, cosmogenic neutrons – they should all be subdominant contributions

- **Digitization:**
  - I used real pedestal runs from Run1, Run2 and Run3 as a background
  - GEM voltage 420V for Run1, 440V for Run2 and Run3
  - I apply the vignetting map 4117 from an overground **cosmics run** in LNF
  - I implemented the effect of the camera exposure: some tracks are cut (partially or completely) because the camera is not fully exposed (it's opening or closing)
    - Parameters: exposure time 300ms, readout time 184.4ms
- **Reconstruction:**
  - I used the winter23-patch2 tag for Run2 and Run3, Autumn22 tag for Run1
  - For the vignetting correction I used the only-**optical** map

Radioactivity fit - Run3

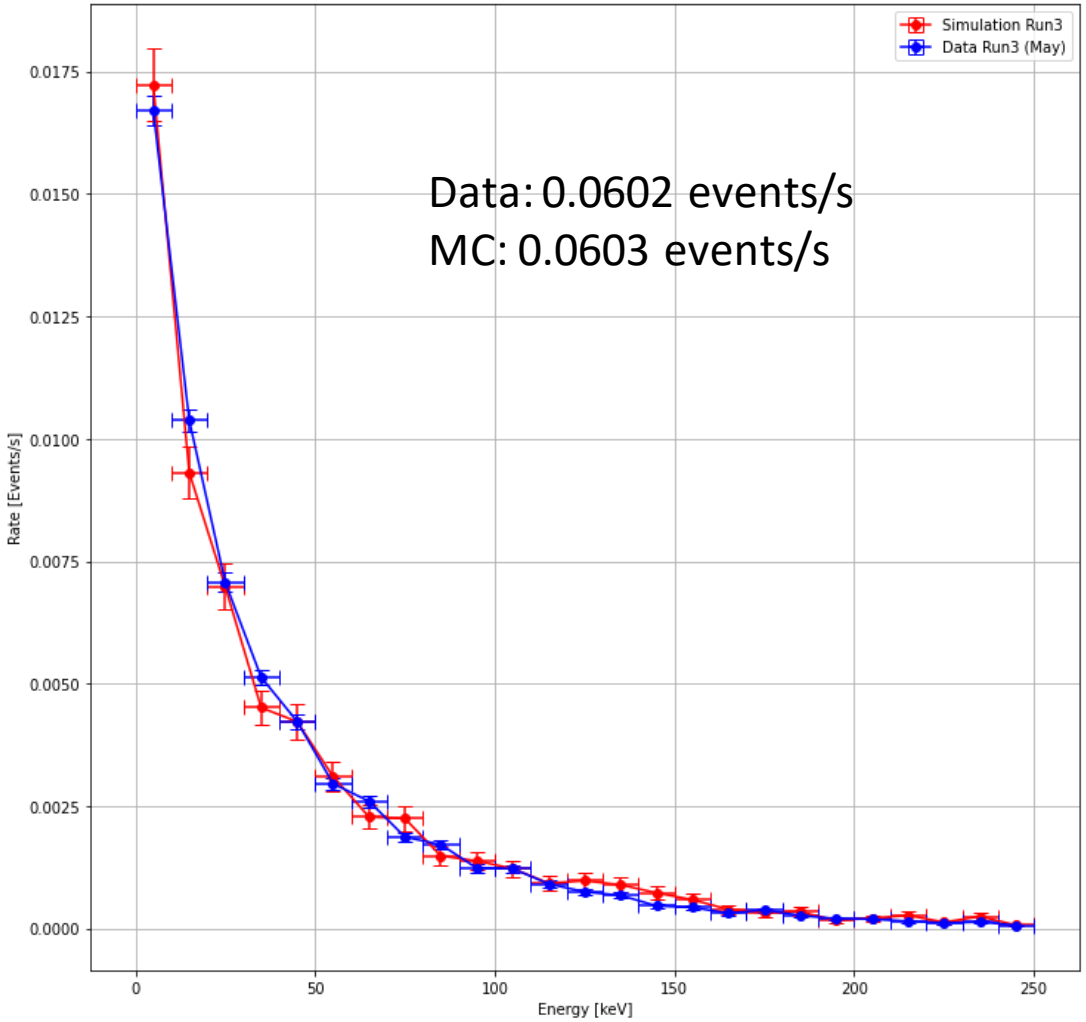
- The simulated spectrum is lower than the measured one, and the *known* neglected contributions cannot justify the difference
- Since the difference is mostly visible in Run3, where the external background is the lowest of all Runs, this difference must come from an internal source (if not produced by other errors in data)
- I fitted the spectrum to match the observed one
  - Free parameters are a multiplicative factor on the spectrum of each radioactive part (rings, cathode, resistors, GEMs, acrylic vessel)
  - The external gamma background spectrum was kept fixed
- The normalization correction parameters were then also applied to Run1 and Run2 simulation

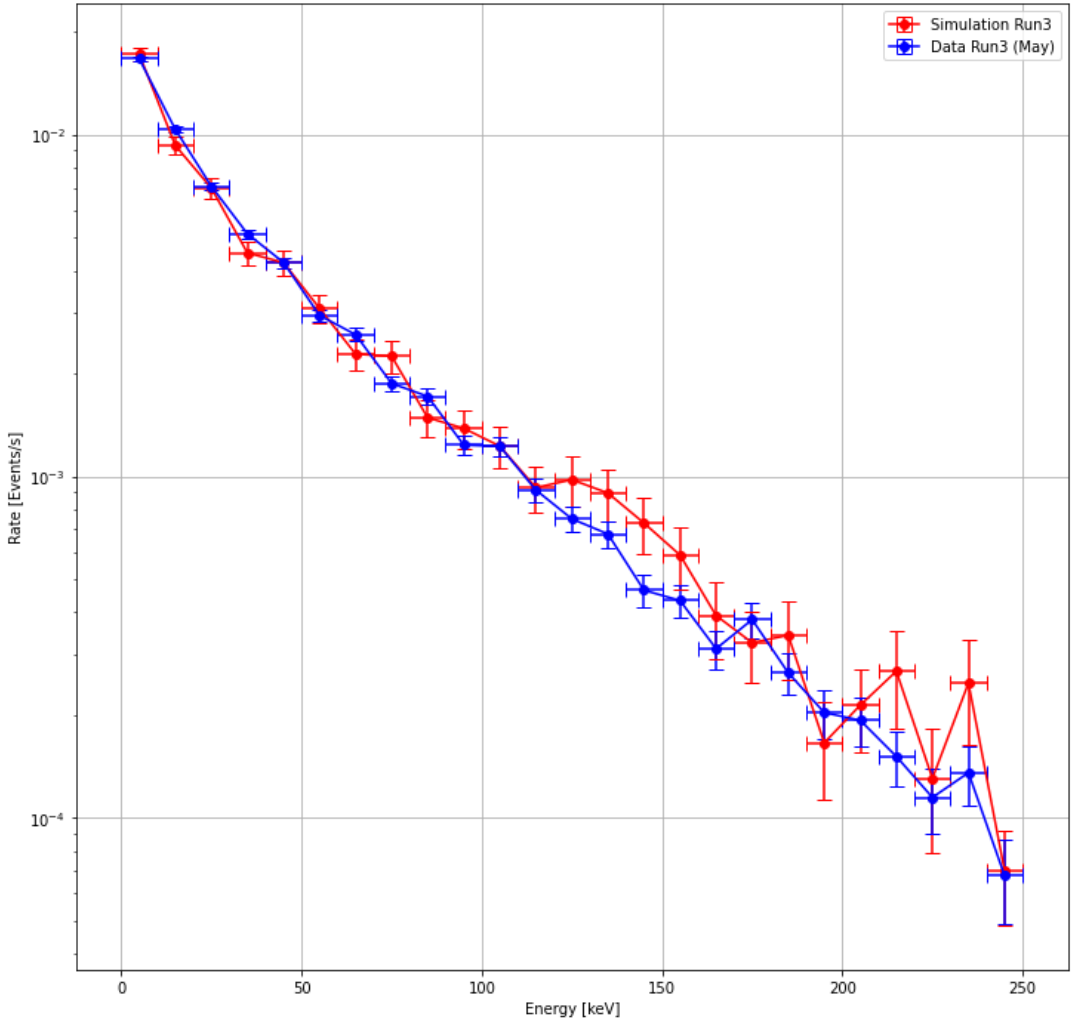


Uncertainty

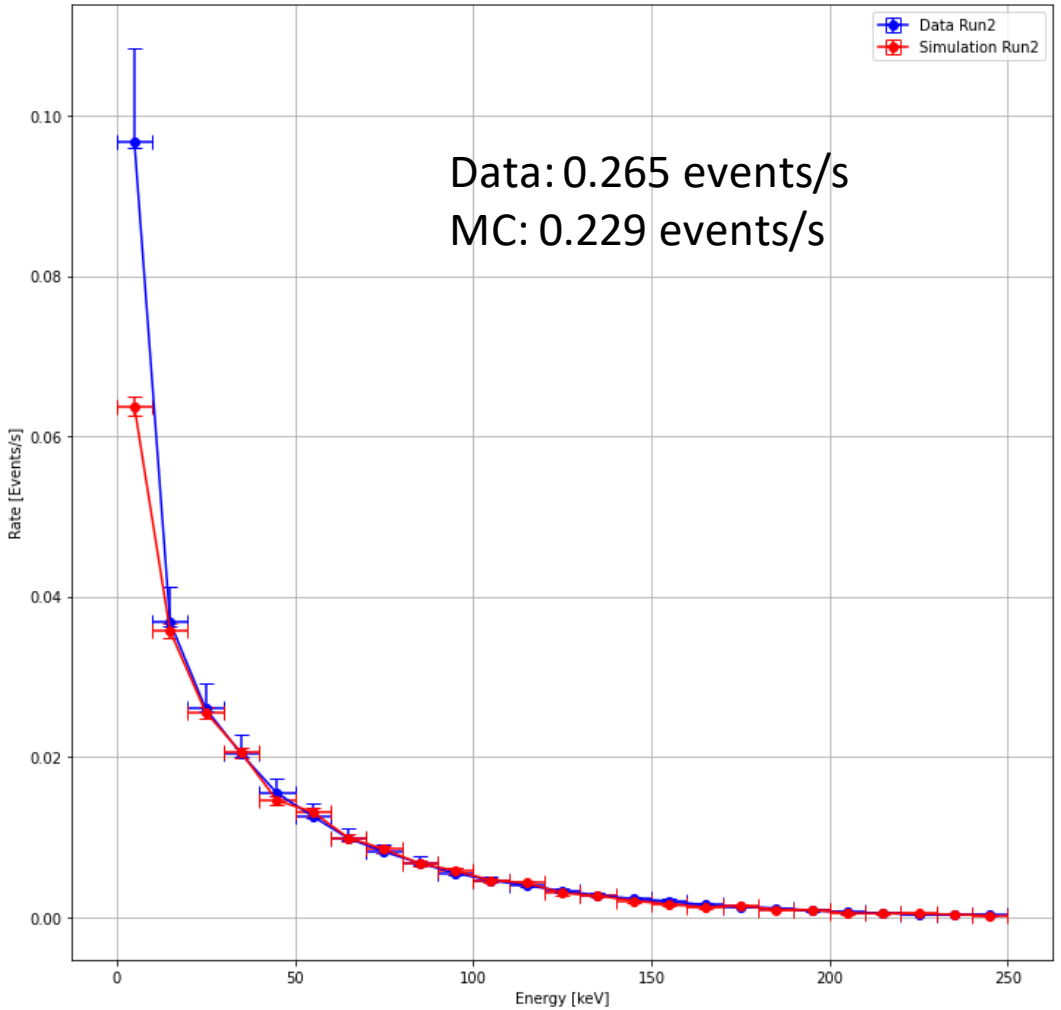
- I include the statistical error (both in data and simulation) considering $\Delta counts_i = sqrt(counts_i)$
- The uncertainty on the LY is another source of error in data, but we need an estimation of that from the Rita's factor (for the iron calibration we could consider the SE of the gaussian mean of the Fe peak)
  - Not sure how to translate that to an uncertainty on the bin height in the spectrum; I tried sampling the calibration from a gaussian centered on the LY and sigma = sigmaFe, then getting the std dev of the bins of the N sampled histograms obtained from this "randomized" calibration (*bootstrap*) - but it's a bit "heavy" computation
  - Due to the "uncertainty" on how to include the uncertainty, this error is **not included** in the following plots
- I included the error on the parameters estimation from the radioactivity fit in the simulation
- The data have an asymmetric error, to include the upper limit due to the dead time

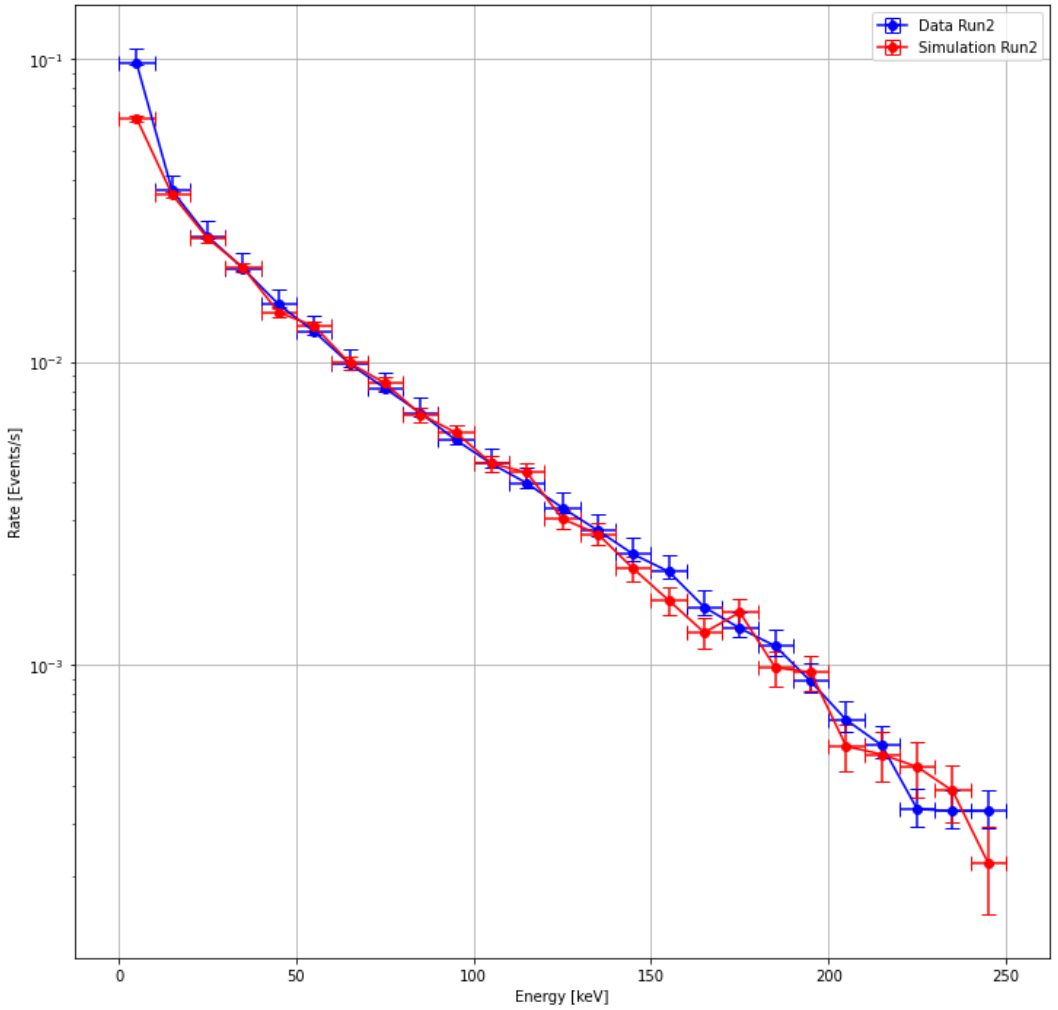
Run3 energy spectrum



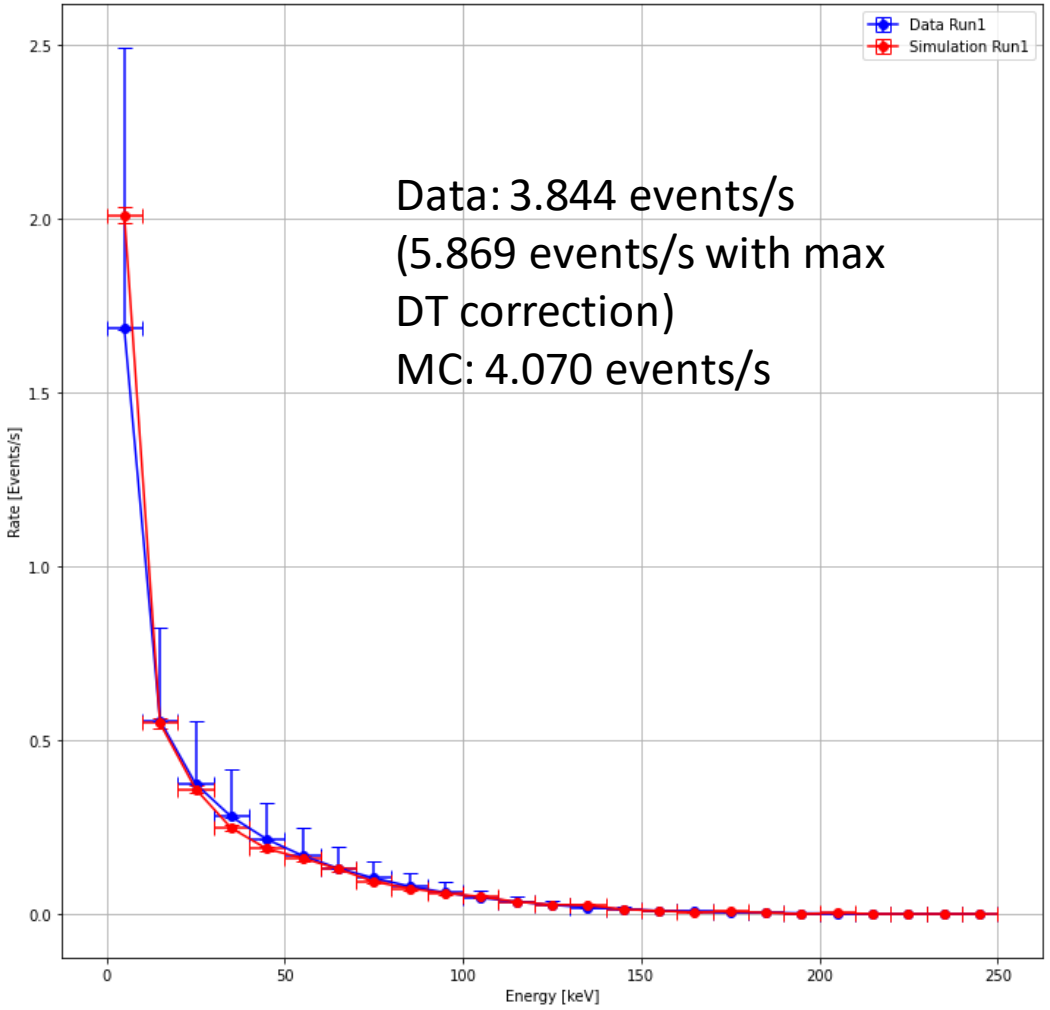


Run2 energy spectrum

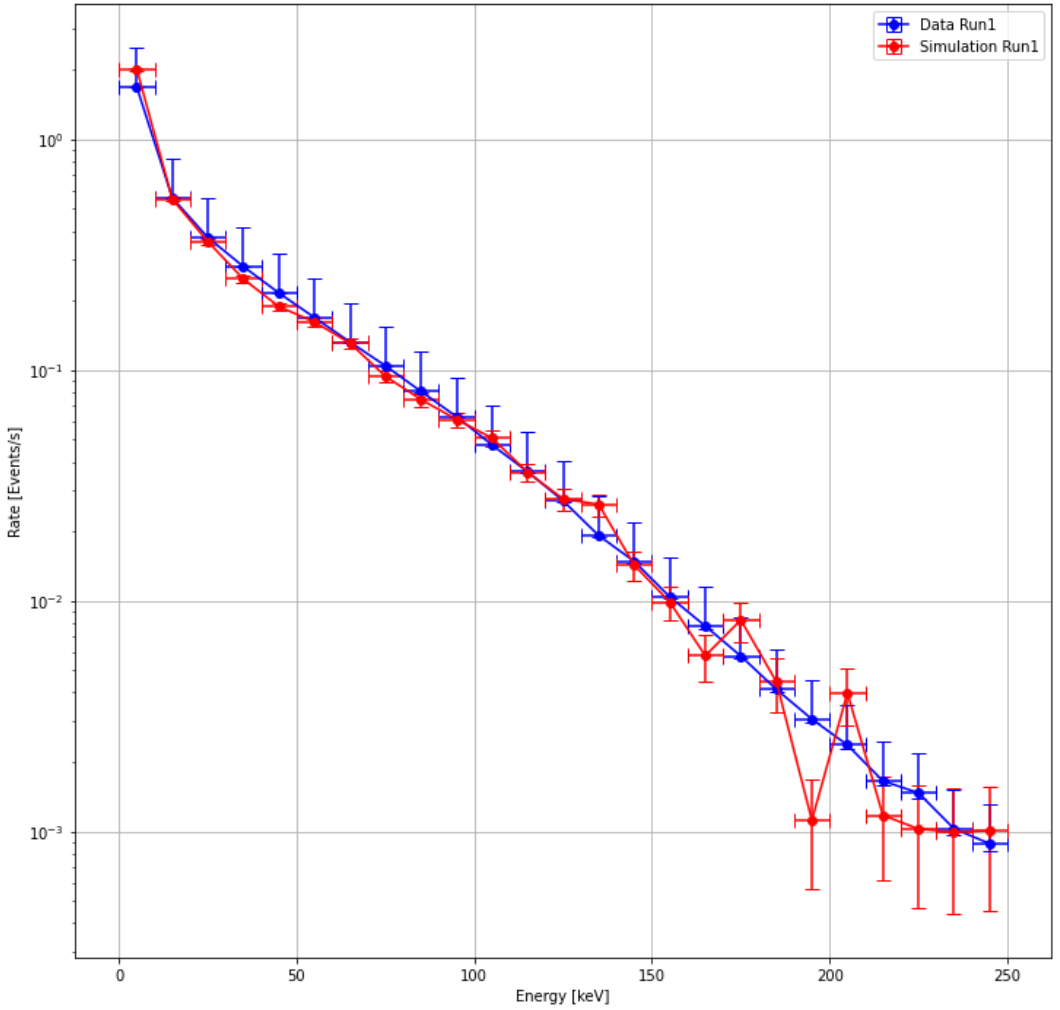




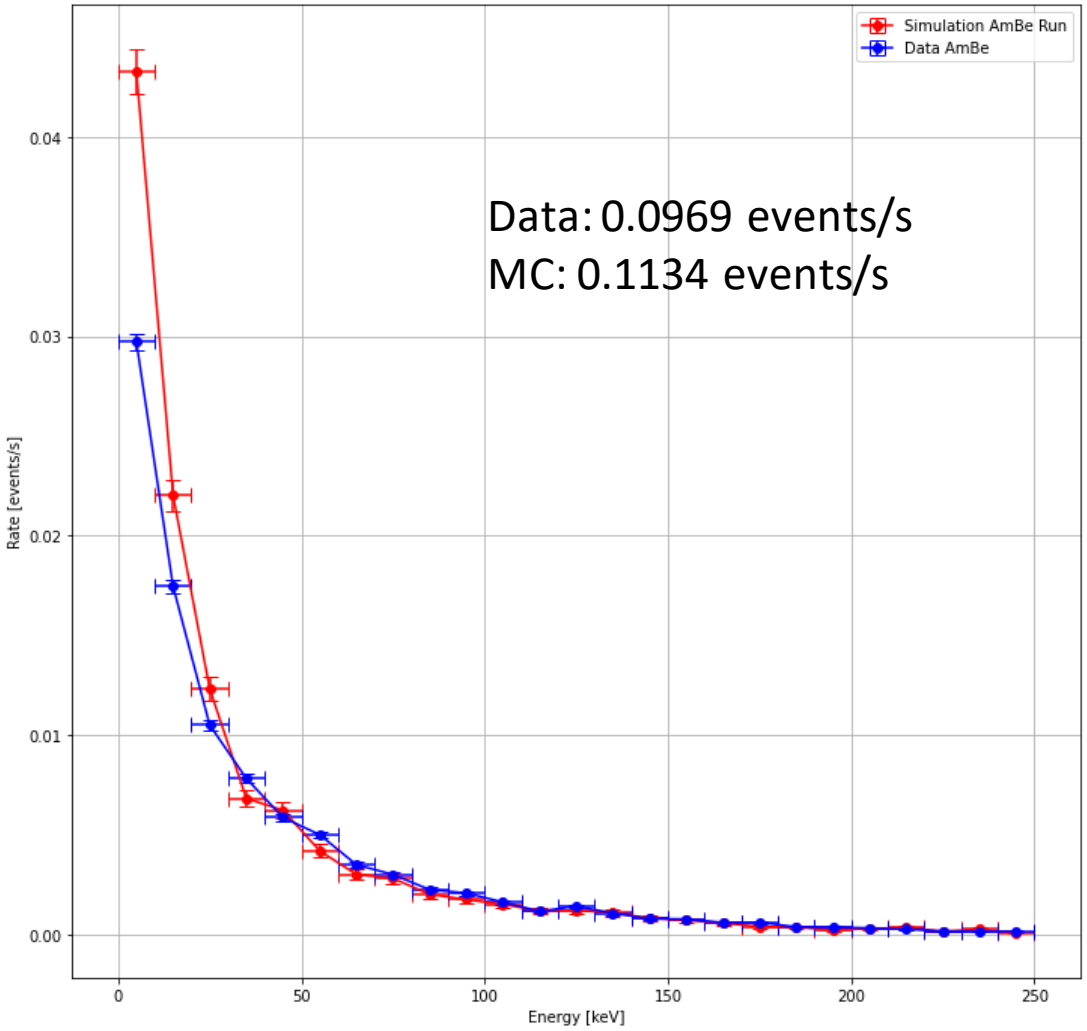
Run1 energy spectrum

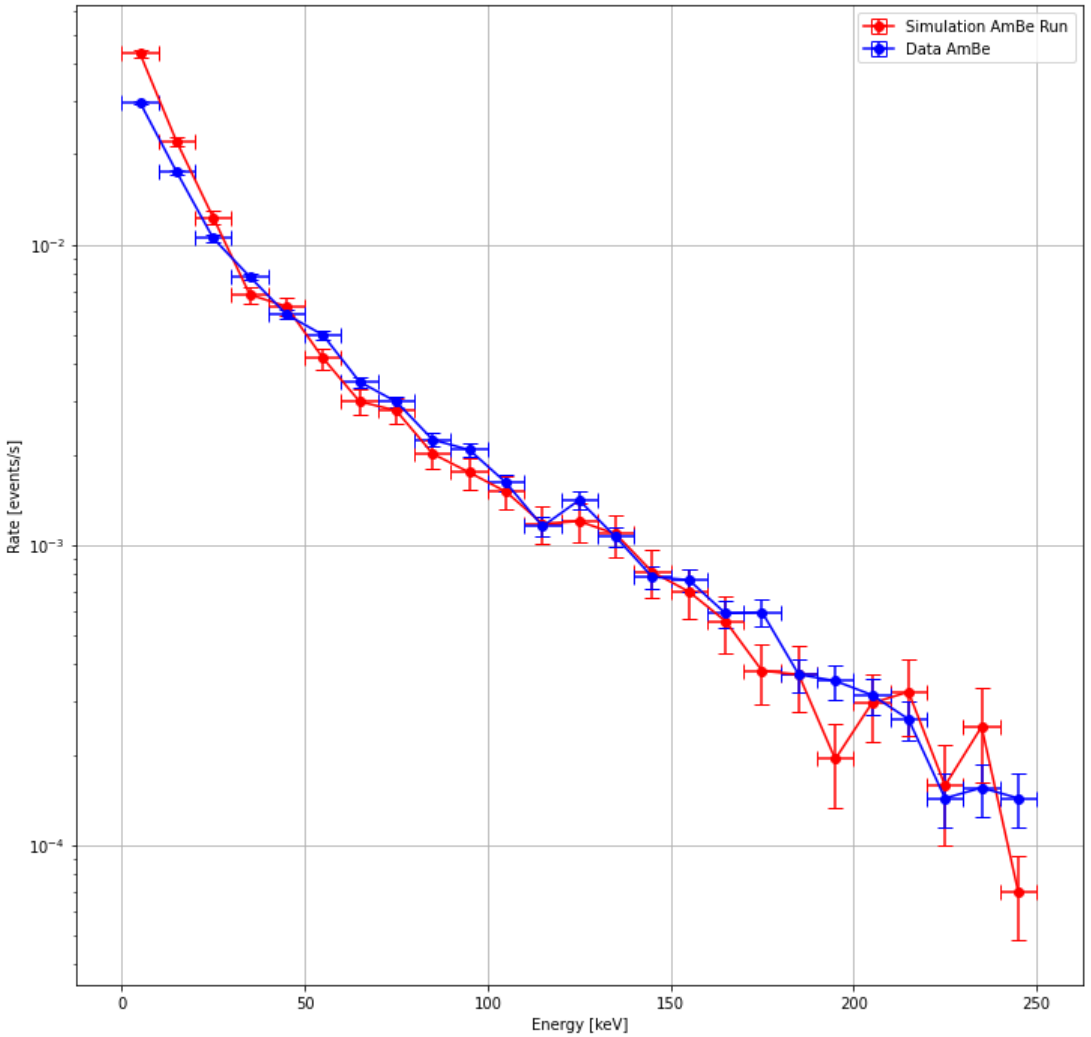


Data: 3.844 events/s
(5.869 events/s with max DT correction)
MC: 4.070 events/s

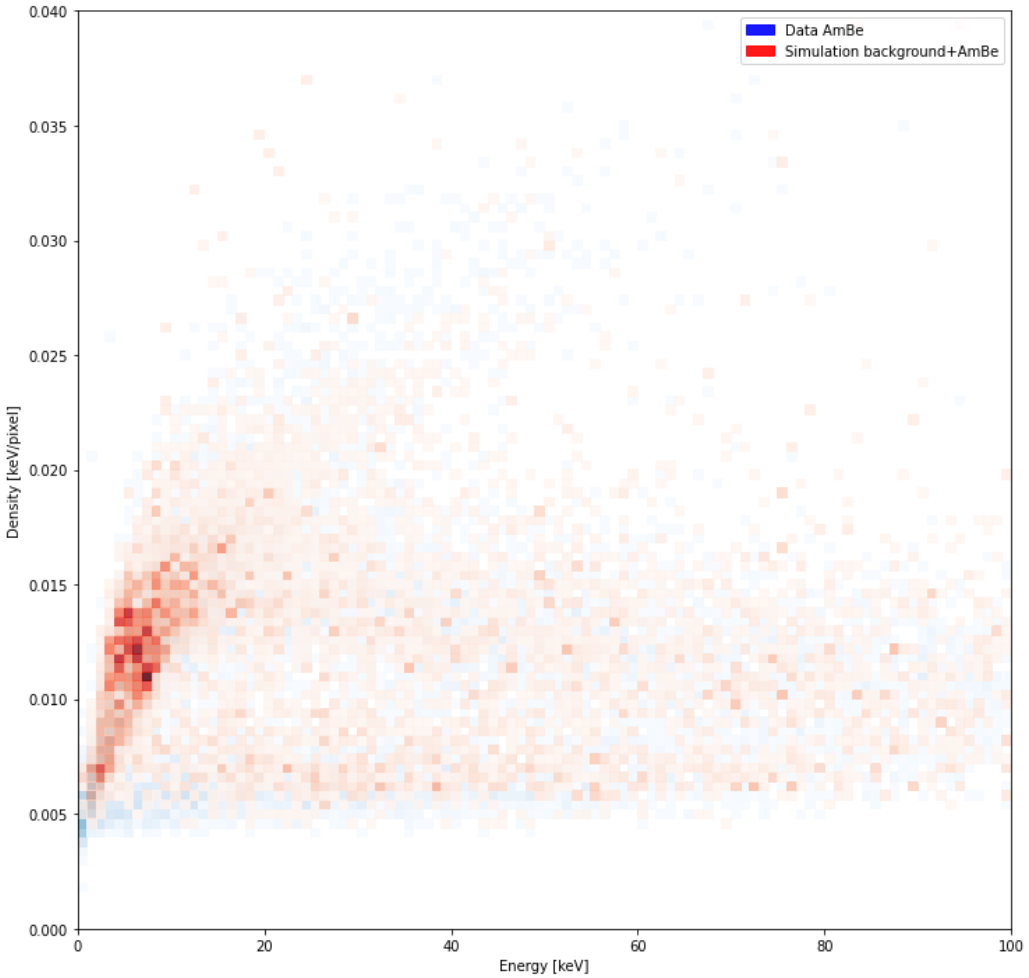


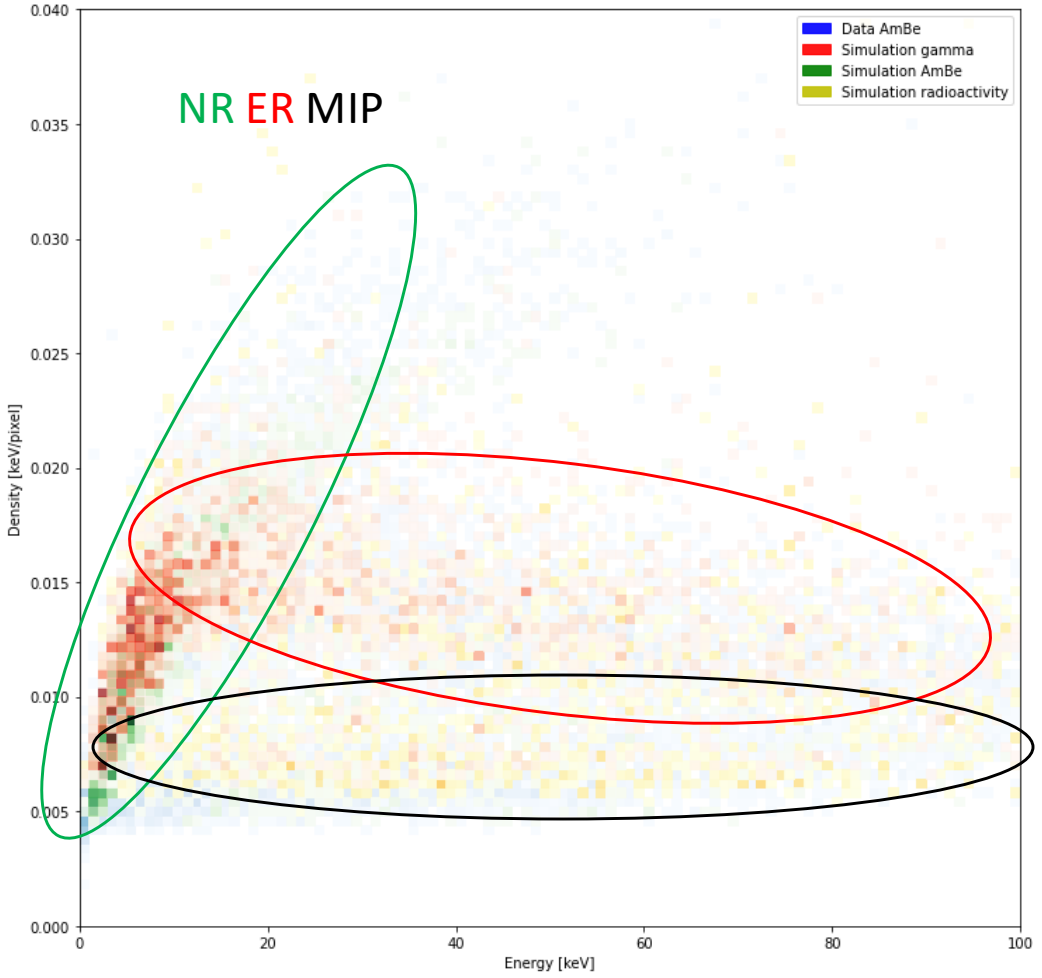
AmBe energy spectrum



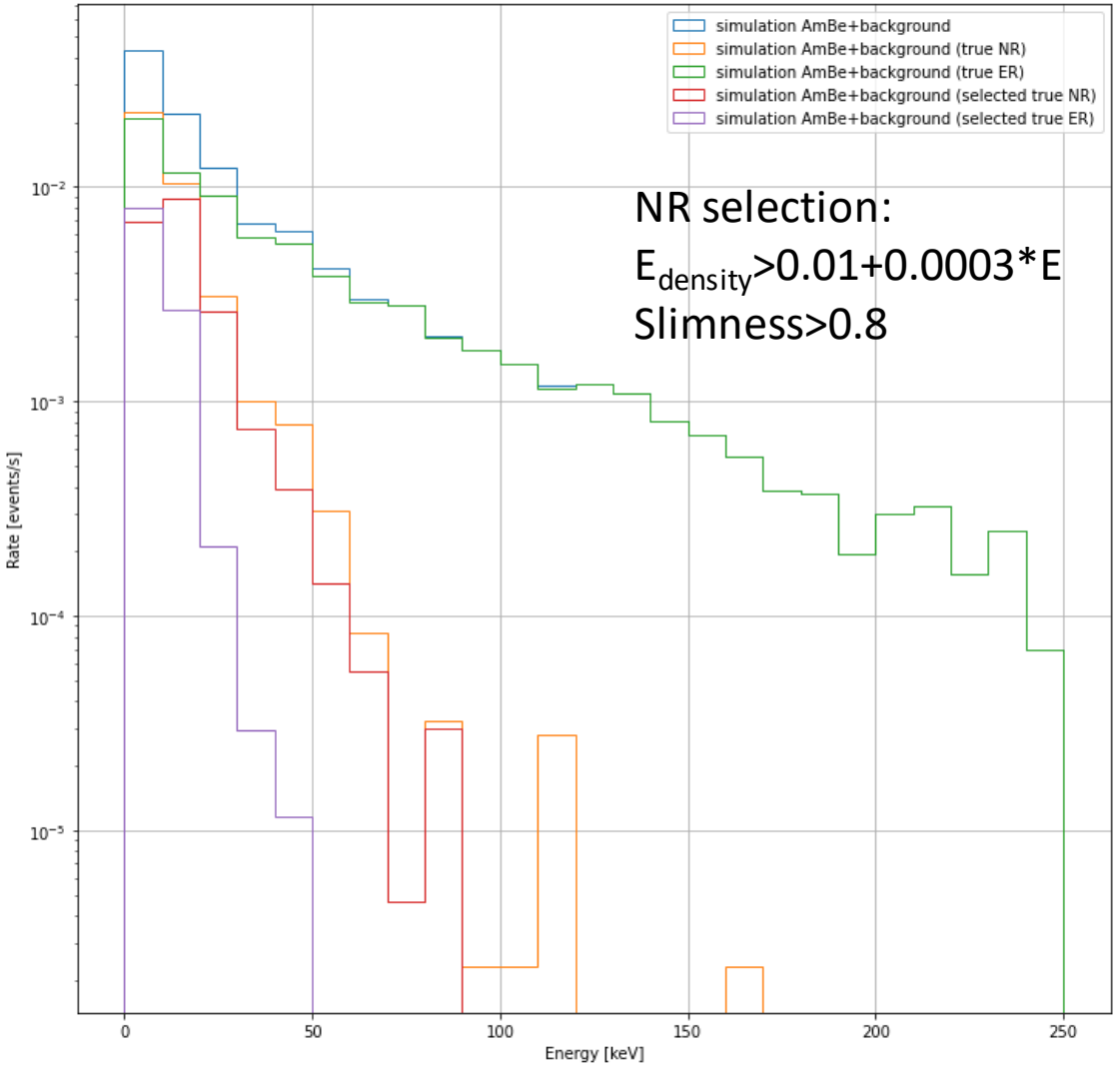


Density (energy/#pixel)





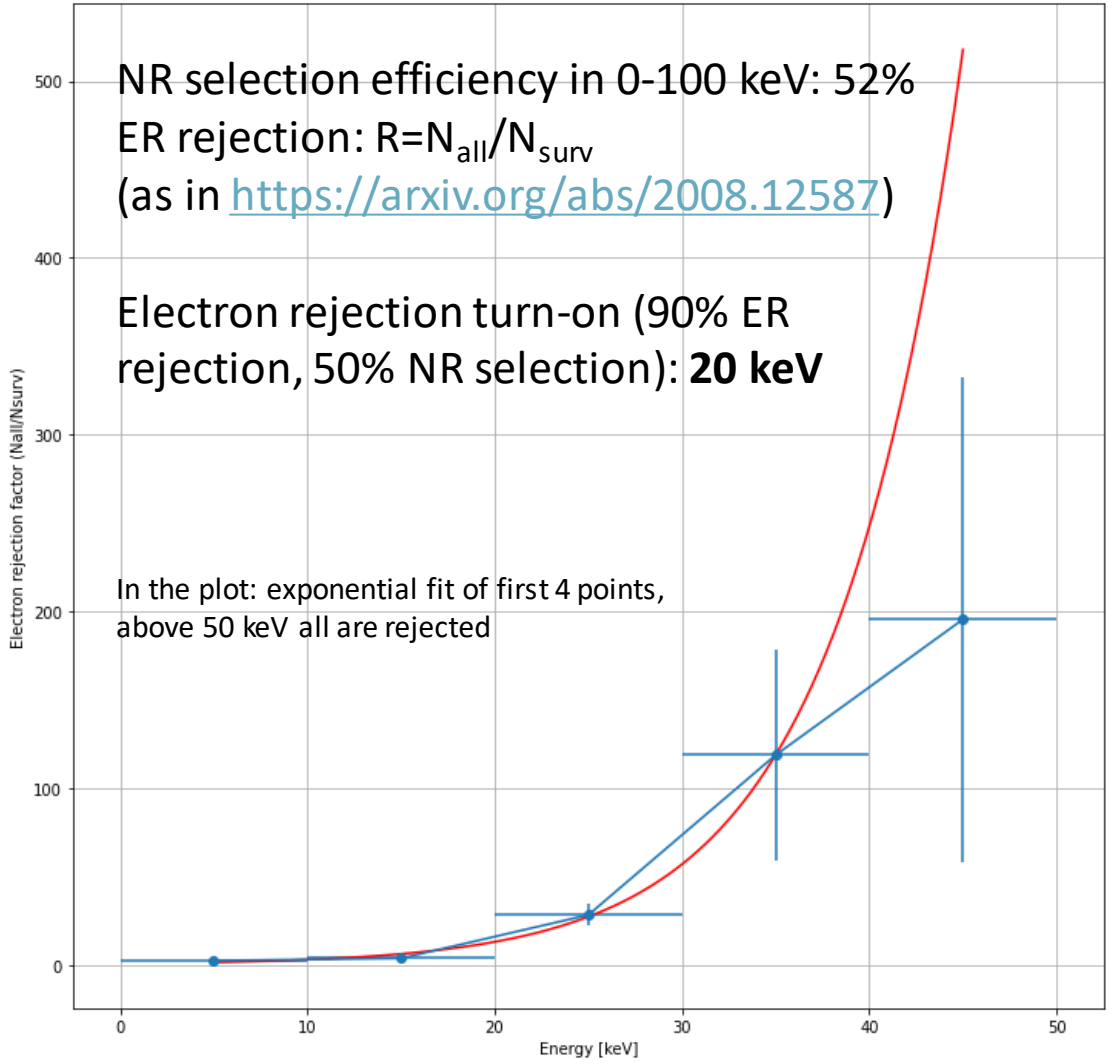
NR selection from AmBe simulation



NR selection:

$E_{density}$>0.01+0.0003*E

Slimness>0.8



NR selection efficiency in 0-100 keV: 52%

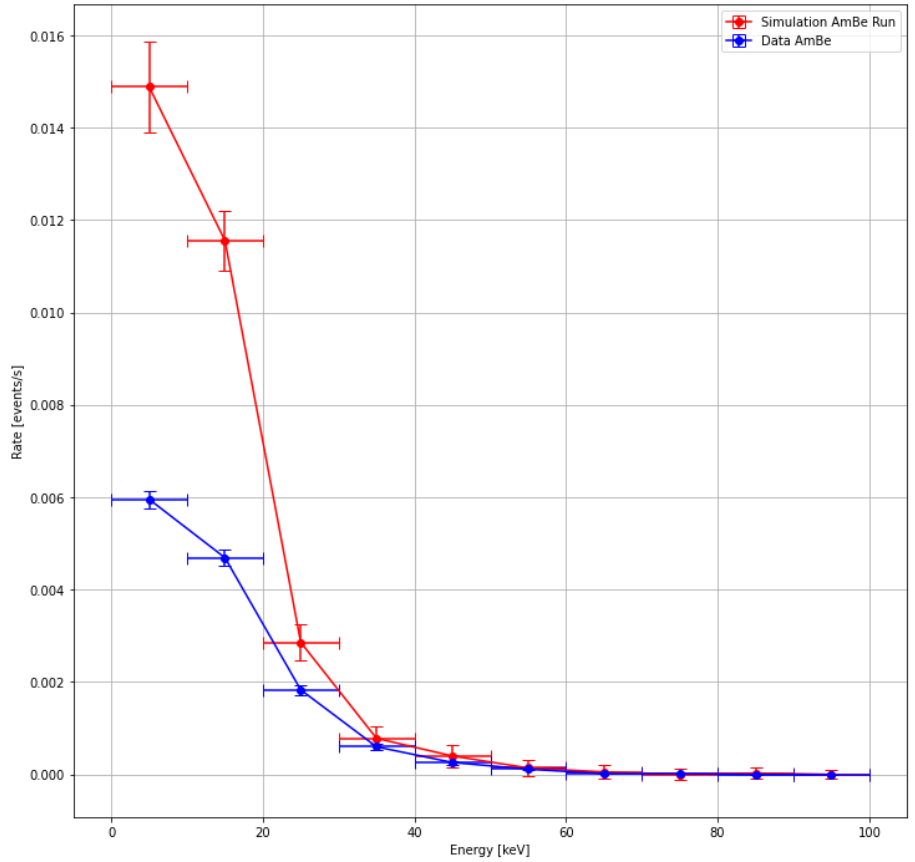
ER rejection: $R=N_{all}/N_{surv}$

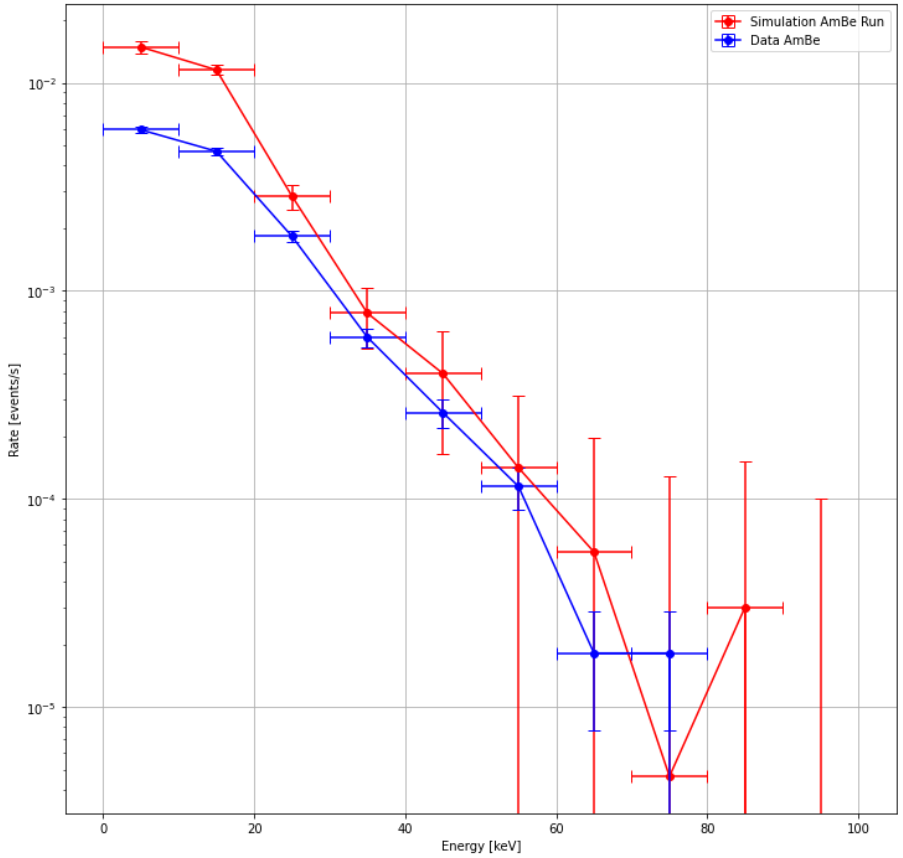
(as in https://arxiv.org/abs/2008.12587)

Electron rejection turn-on (90% ER rejection, 50% NR selection): **20 keV**

In the plot: exponential fit of first 4 points, above 50 keV all are rejected

Energy spectrum after NR selection





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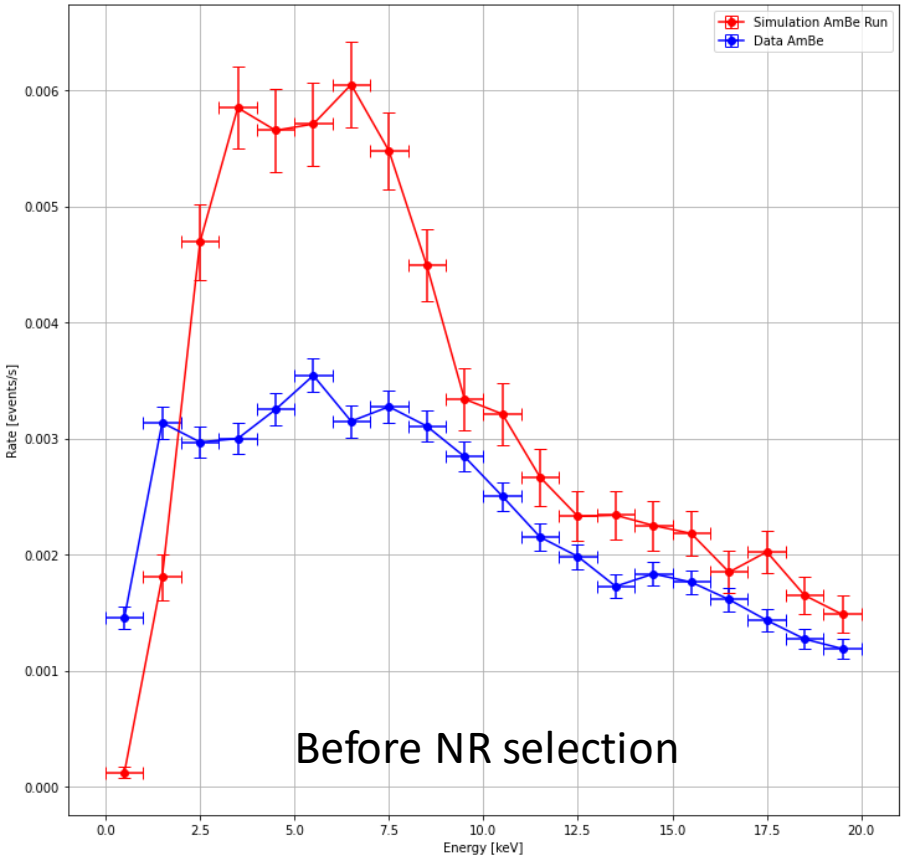
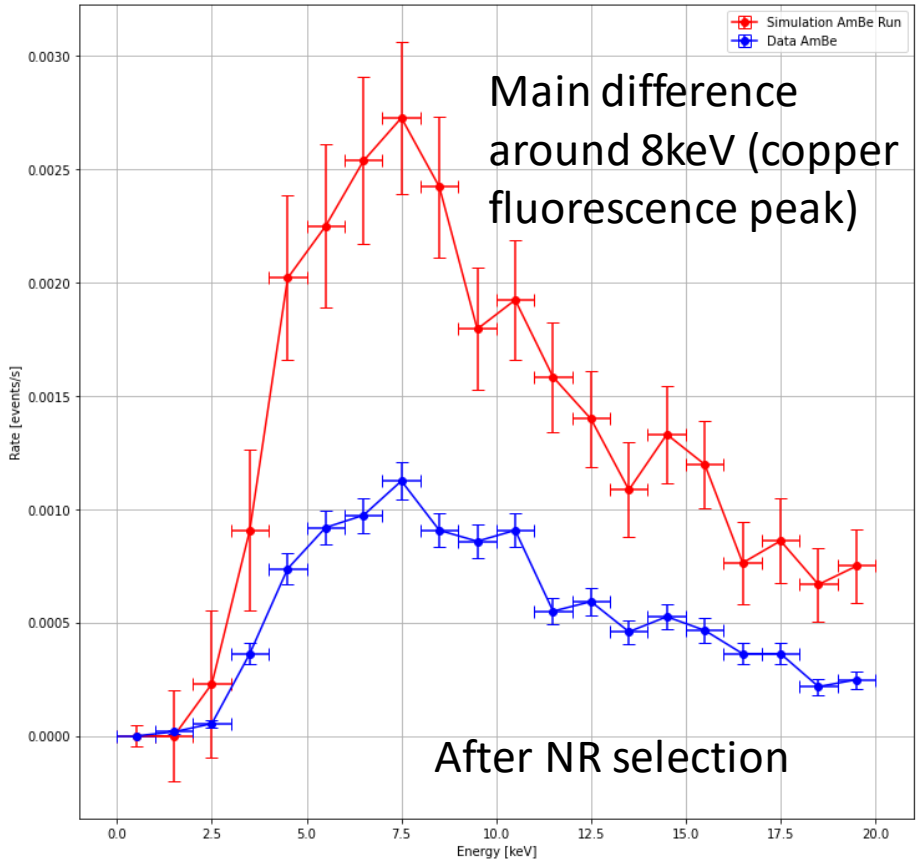
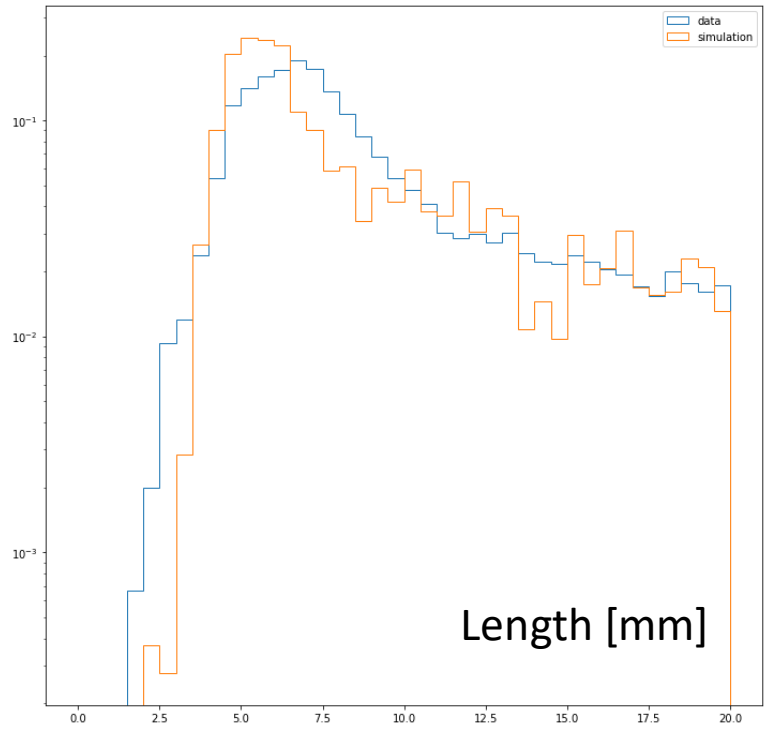
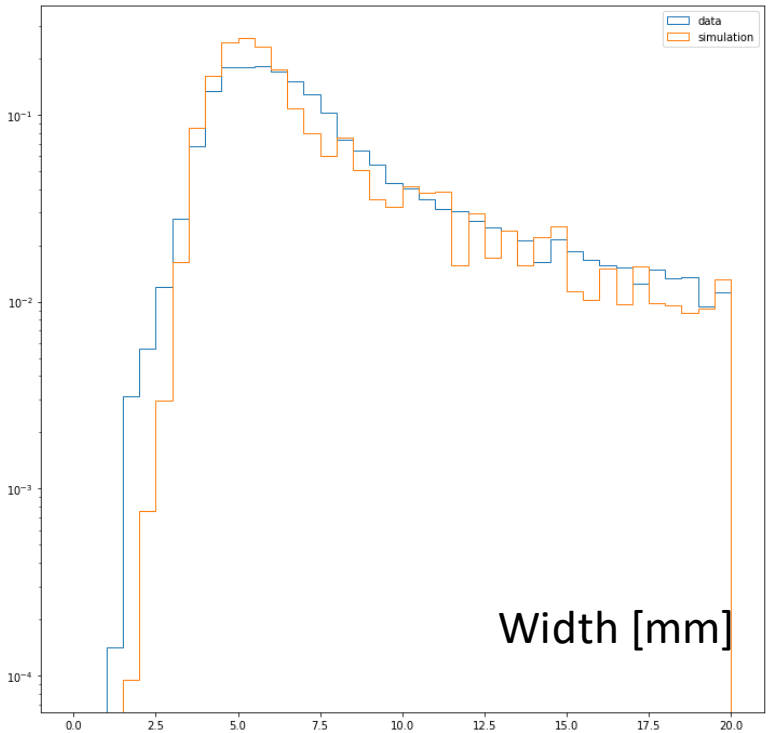


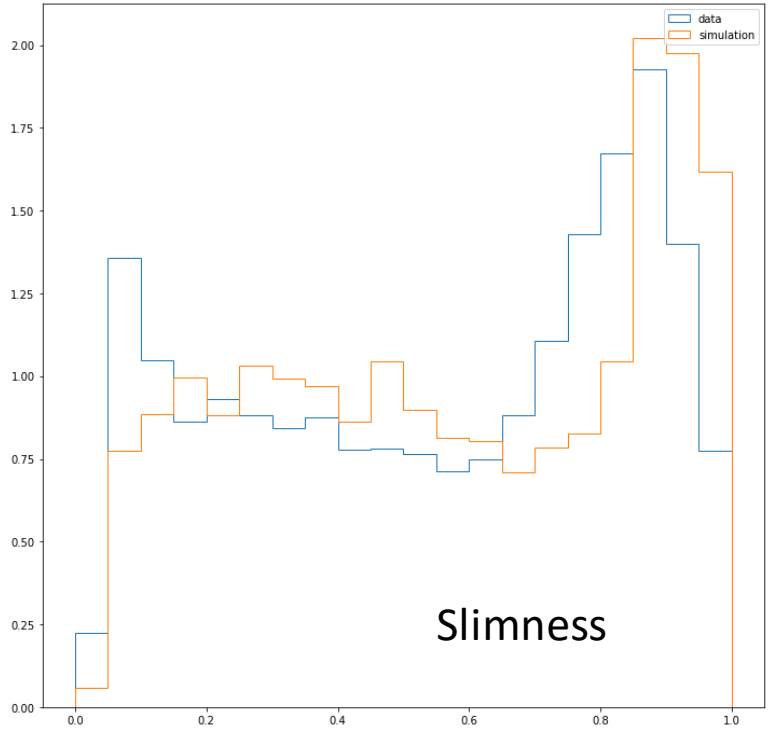


Length, width, slimness

- AmBe data vs background+AmBe simulation
- Length, width and slimness distributions without NR selection







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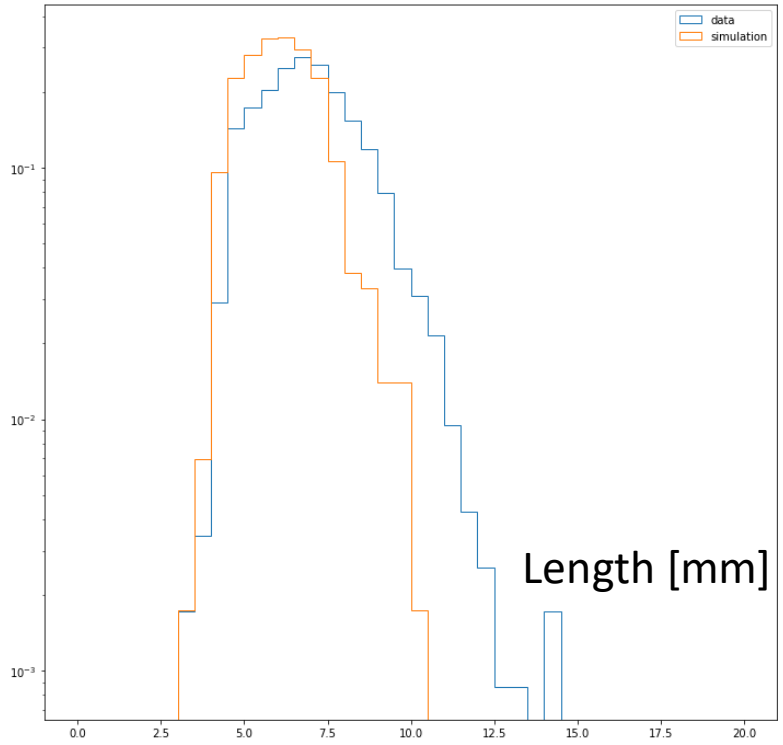
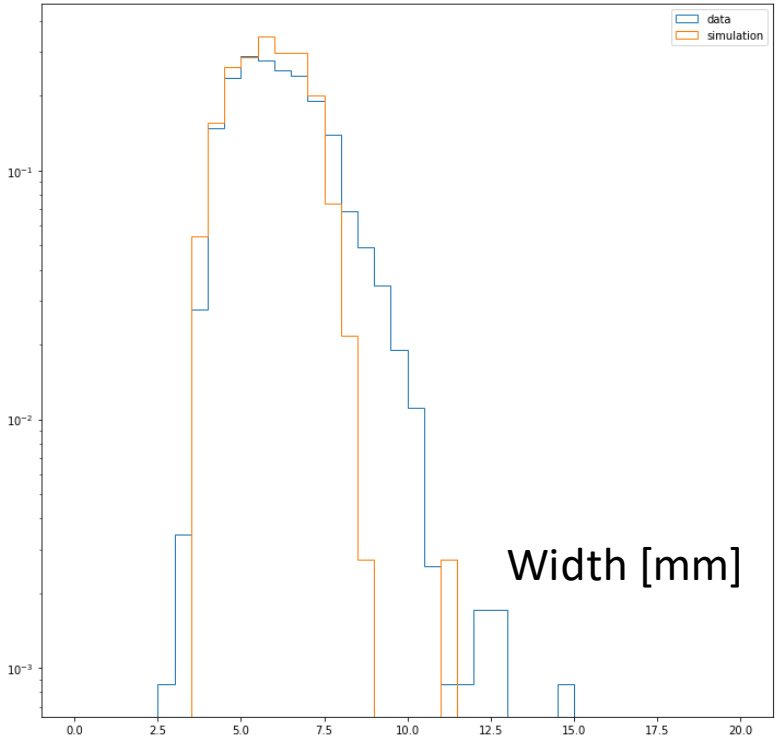
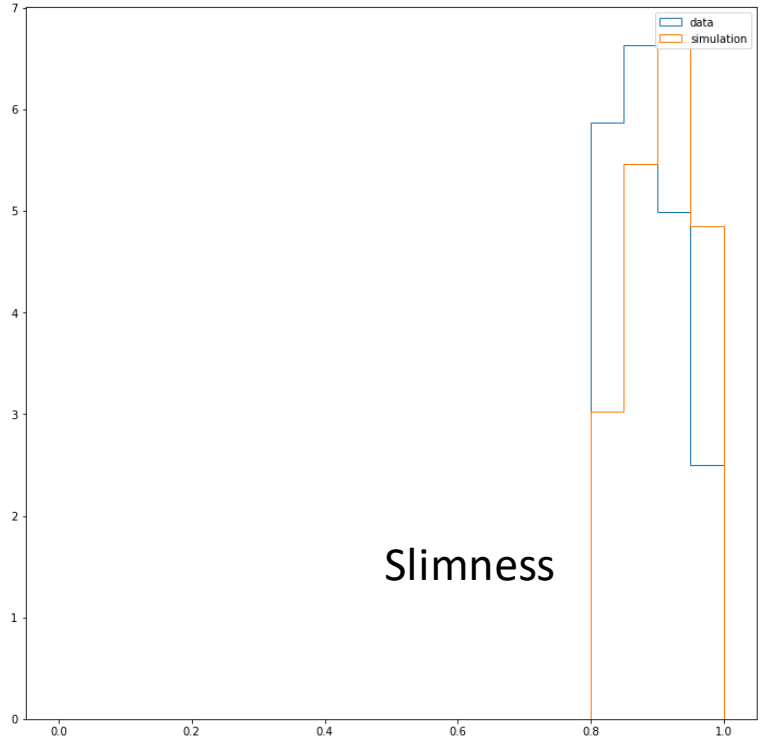
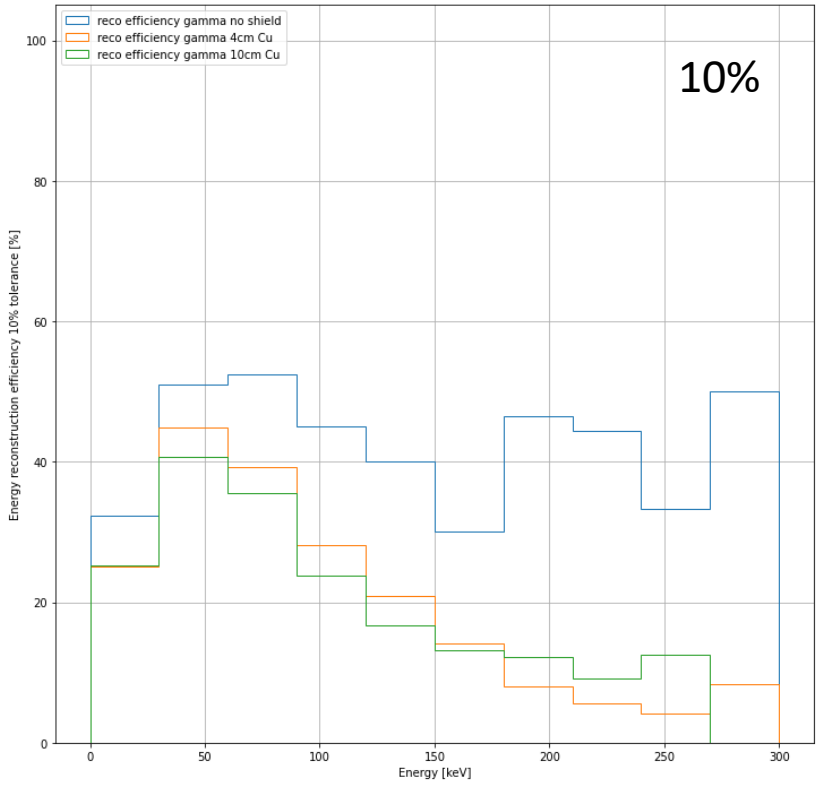


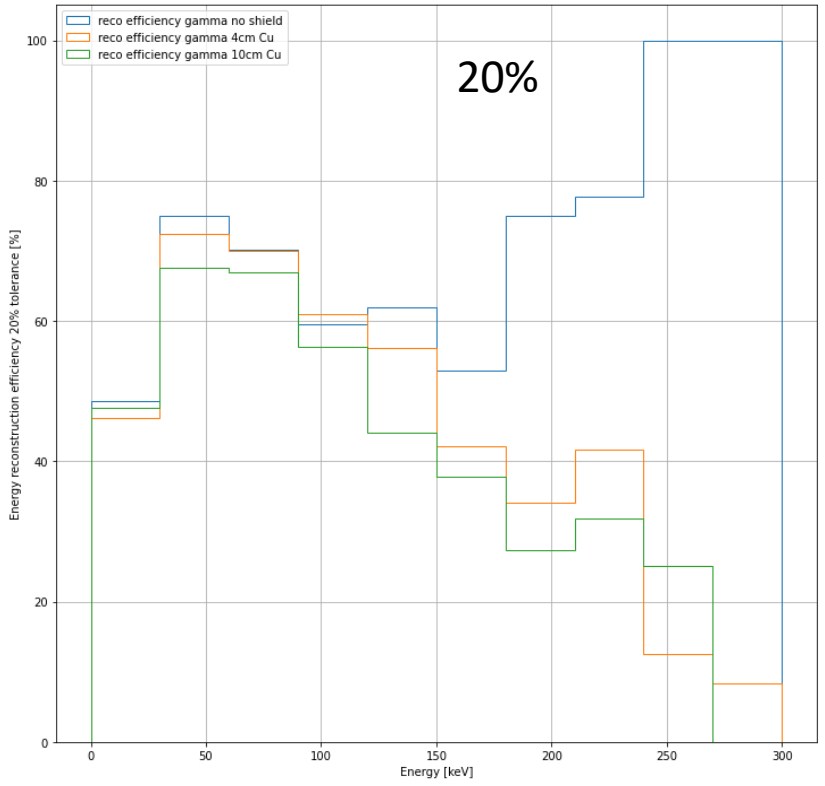


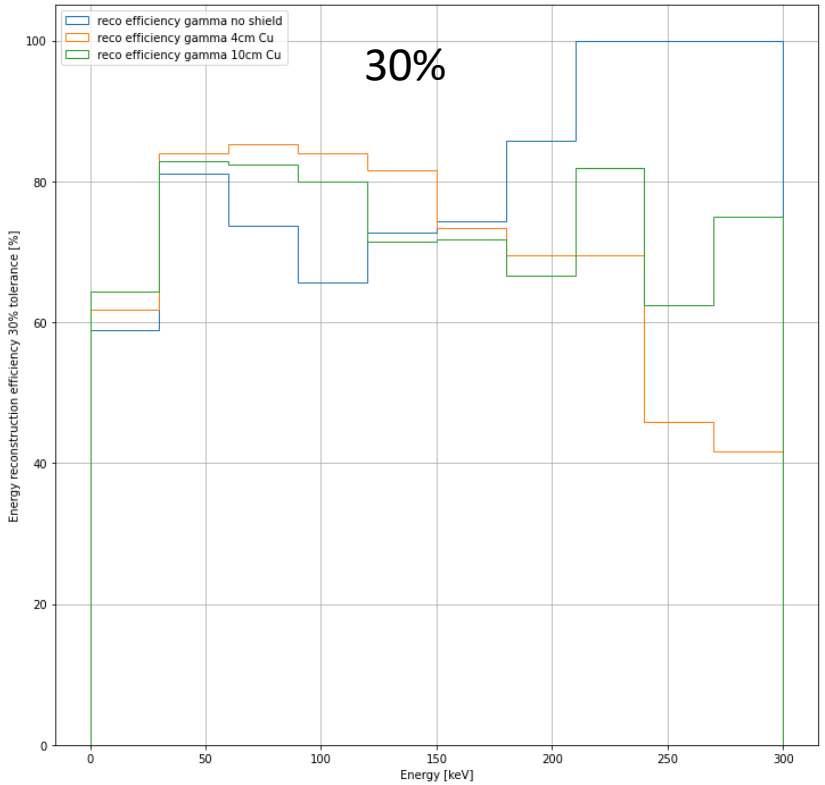


Energy reconstruction efficiency

- I selected from the external gamma simulation (ER) all tracks whose reconstructed calibrated energy differs from the real energy deposition by some percentage (10%,20%,30%,40%,50%,60%)
- It is a measurement of the reconstruction efficiency/energy uncertainty







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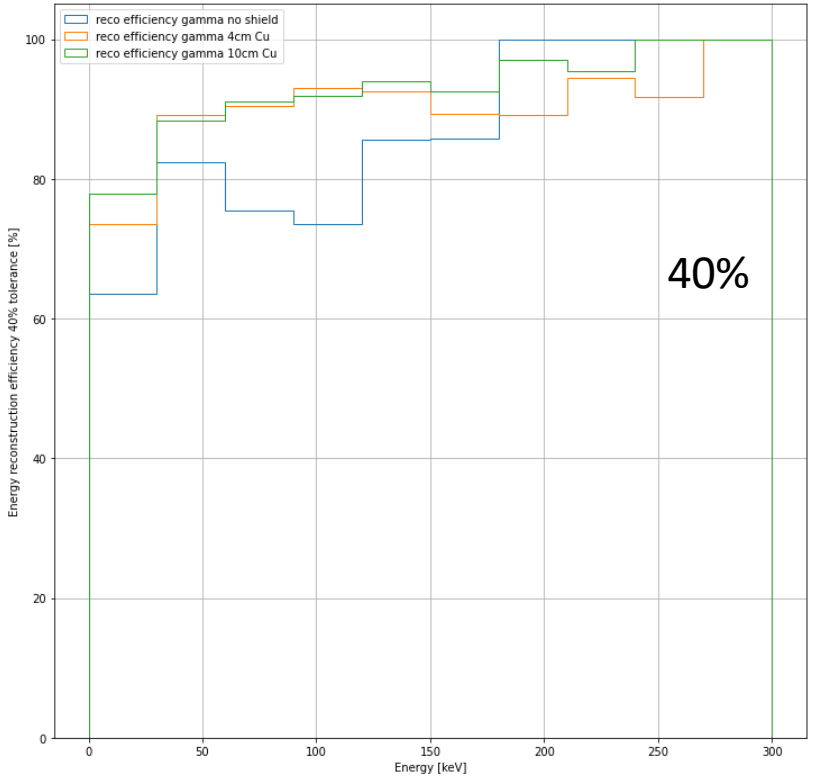

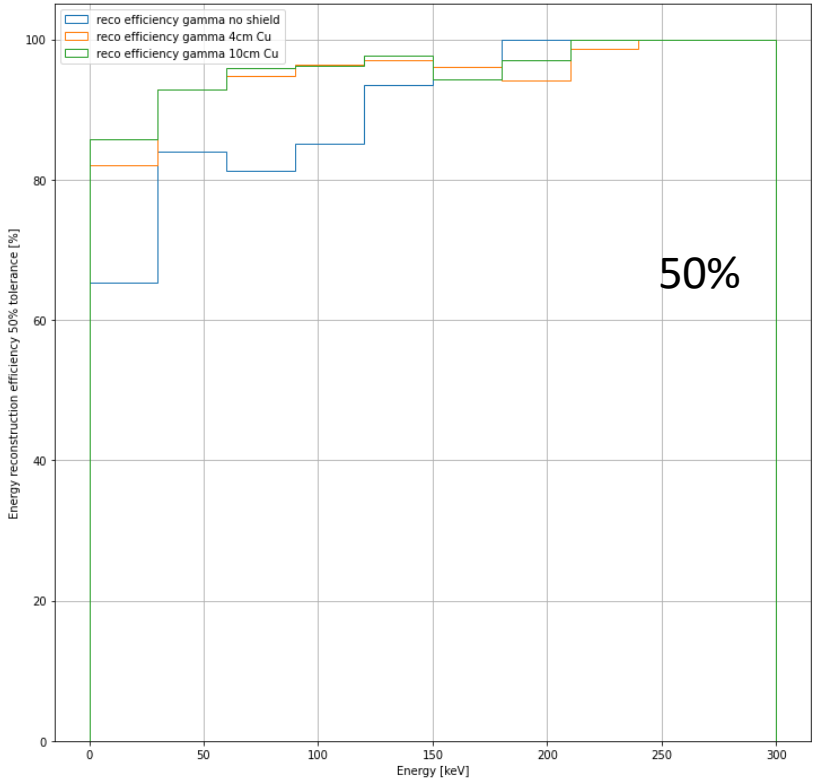

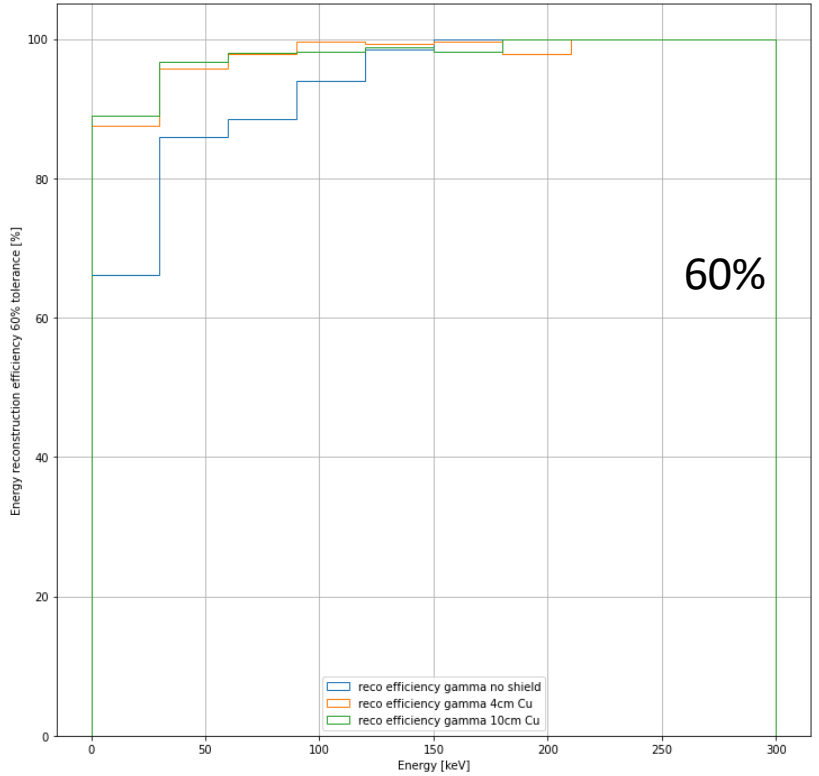

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