Status of the Monte Carlo - Data comparison for LIME underground runs

CYGNO Collaboration Meeting – 4-6 December 2023, Frascati

F. Di Giambattista

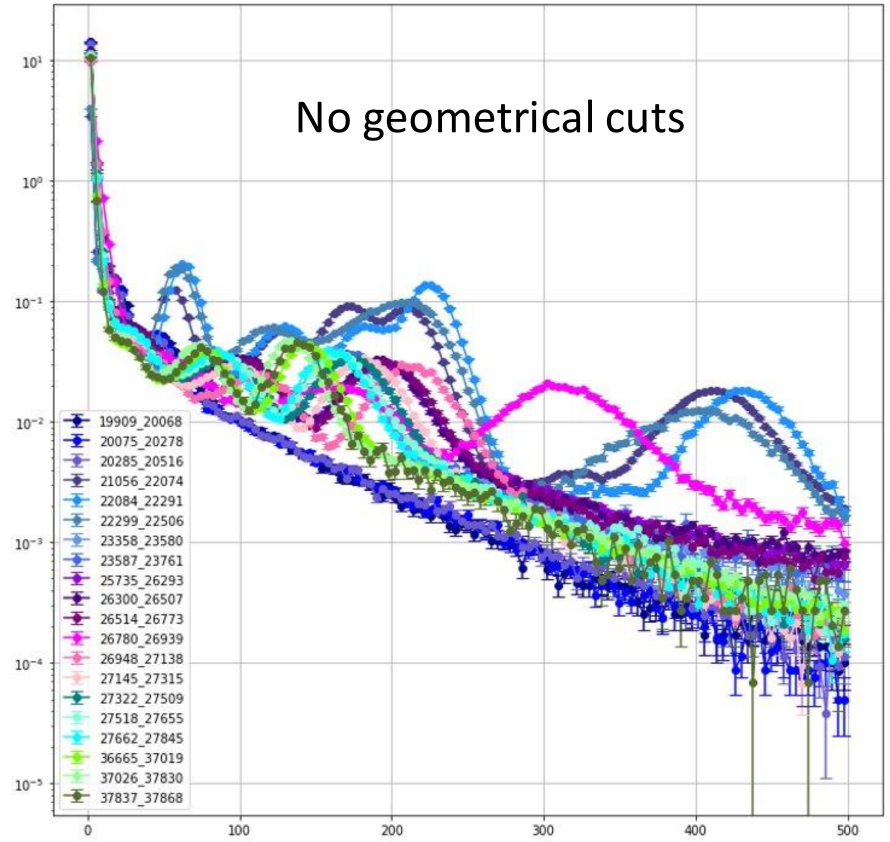
LIME underground data

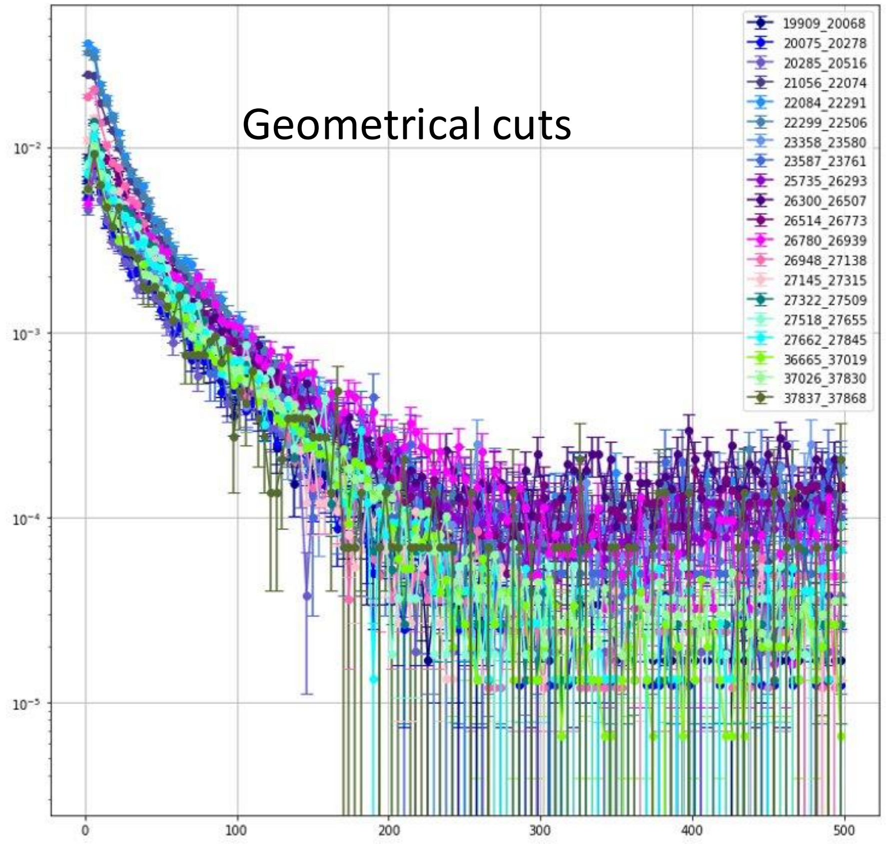
- **Run1: runs 5923-6743 (Autumn 2022) (74h, from 17 nov 22 to 6 dec 22)**
- **Run2: runs 11289-12191 (Winter 2023) (53h, from 6 mar 23 to 9 mar 23)**
- **Run3: runs 19909-20415 (Spring 2023) (53h, from 22 may 23 to 25 may 23)**

- **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
- Tested different methods for calibration :
  - Closest run with 55Fe in central position; Rita variable (LY_30); sampled from the calibration runs (see later)

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?

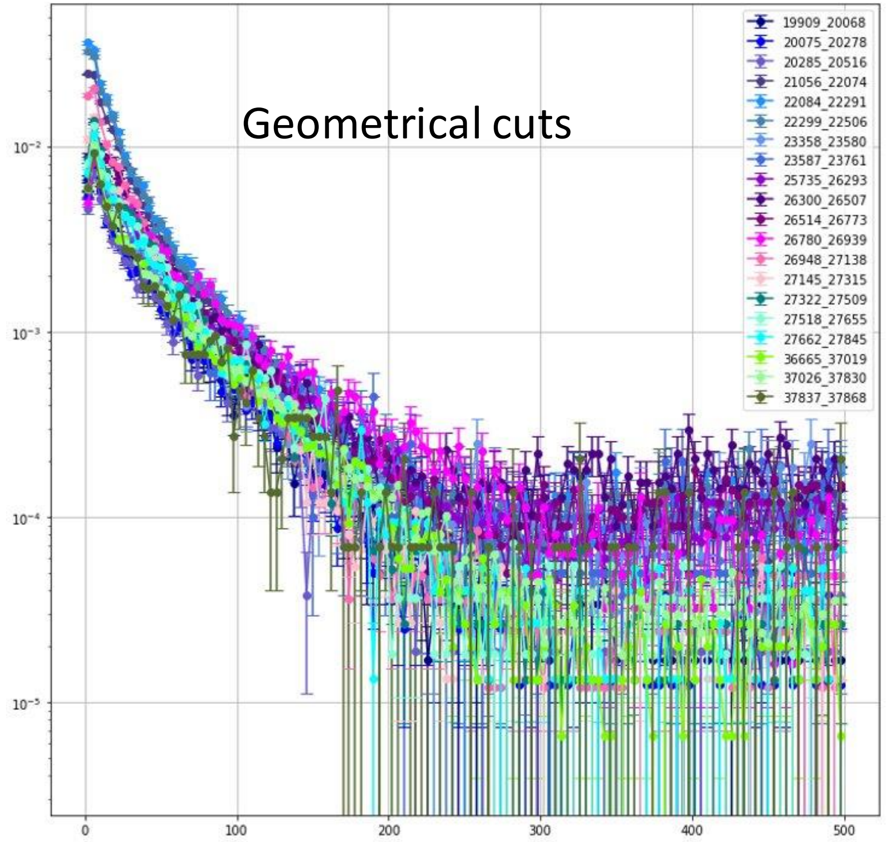




LIME underground data

- 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
    - Why only 19909-20415 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

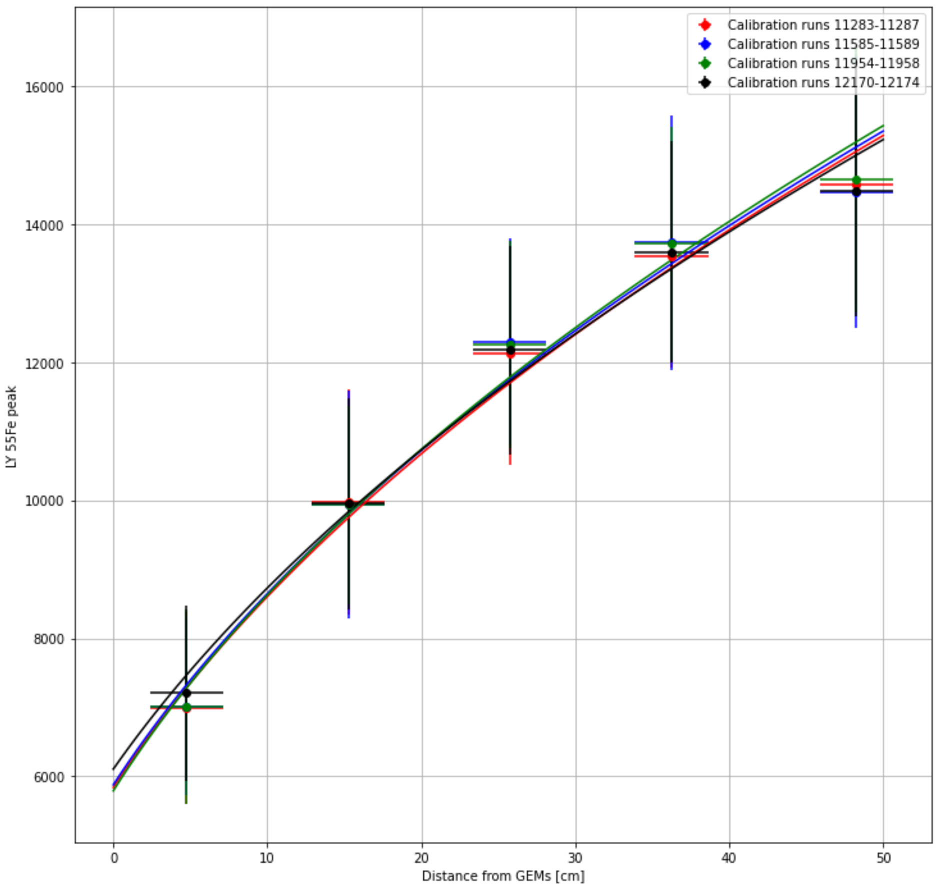
- **GEANT4:**
  - External gammas with no shield (only aluminium Faraday cage), 4cm of copper, 10cm of copper
  - Radioactivity: field rings, resistors, cathode, GEM, acrylic box
    - I simulated an equivalent of 120hr and got 0 events from the camera
  - *What was left out*: shielding radioactivity,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

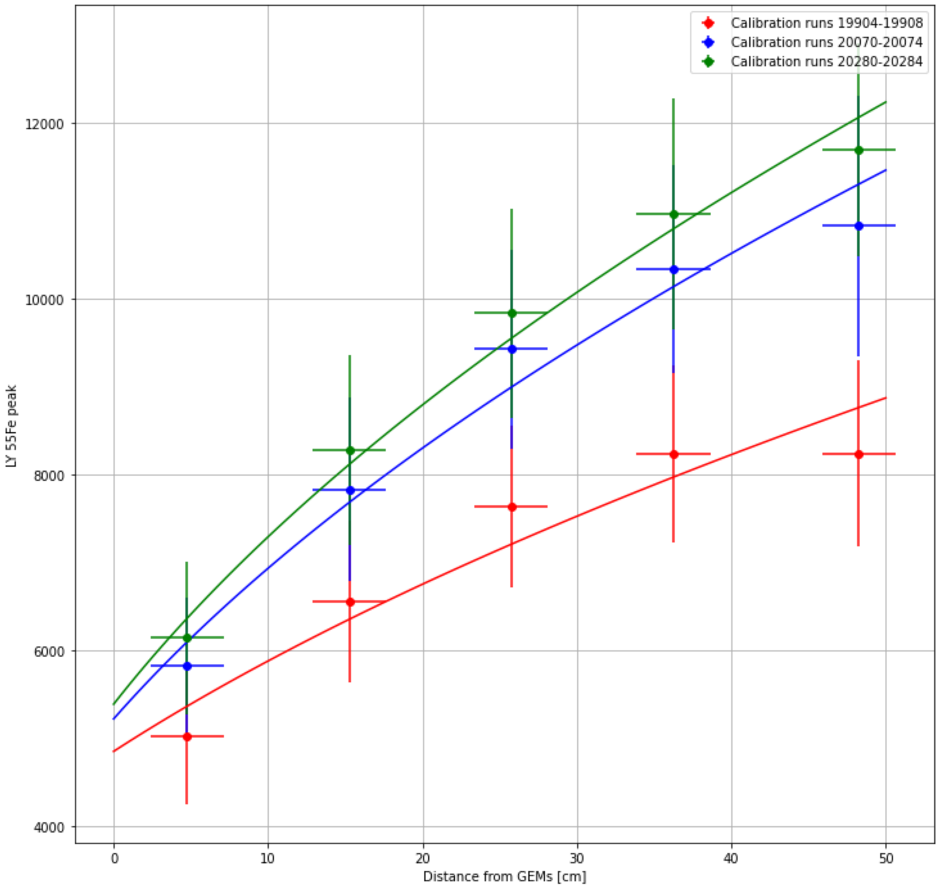
- **Digitization:**
  - I used real pedestal runs from Run1, Run2 and Run3 as a background
  - GEM voltage 420V for Run1, 440V for Run2 and Run3
  - I apply the vignetting map 4117 from an overground **cosmics run** in LNF
  - I implemented the effect of the camera exposure: some tracks are cut (partially 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

Uncertainty

- The **uncertainty on the LY** is included in data
  - I sampled 1000 histograms from the data of each Run; for each sampled histogram:
    - First, I extract randomly the distance of each event from the GEM (the LY varies by 45% depending on position of 55Fe in Run3) divided in 5 bins (5 positions of the 55Fe source)
    - From the selected distance I extract the LY randomly from a gaussian distribution with mean = LY measured with Fe, and sigma = sigma of Fe gaussian peak
  - From the sampled histograms I take the mean and the standard deviation of each bin to produce the final histogram
- I add the **statistical error** (both in data and simulation) considering $\Delta counts_i = sqrt(counts_i)$
- The data have an asymmetric error, to include the upper limit due to the **dead time**
- **Next step: adding uncertainty on the LY also in the MC**

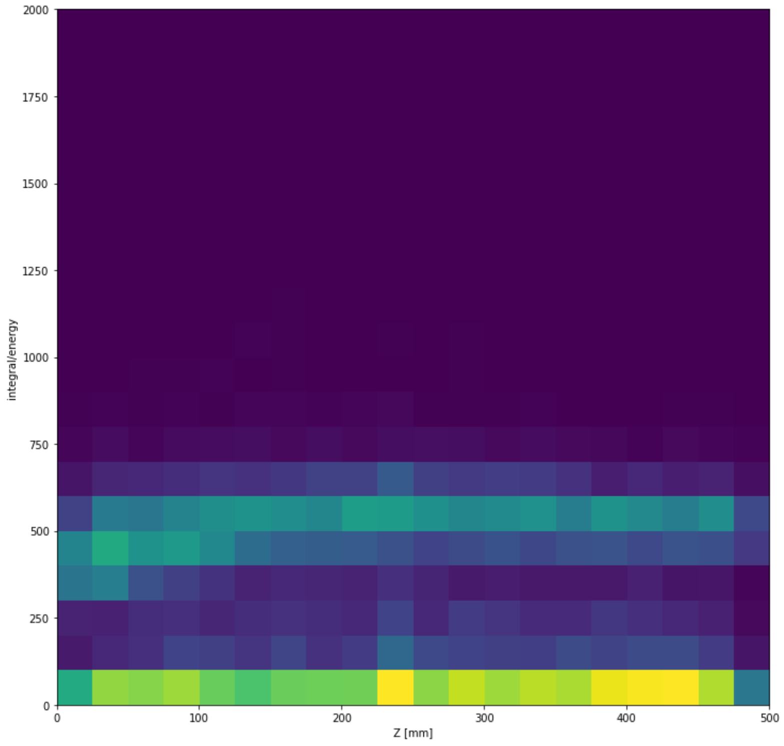
LY vs distance



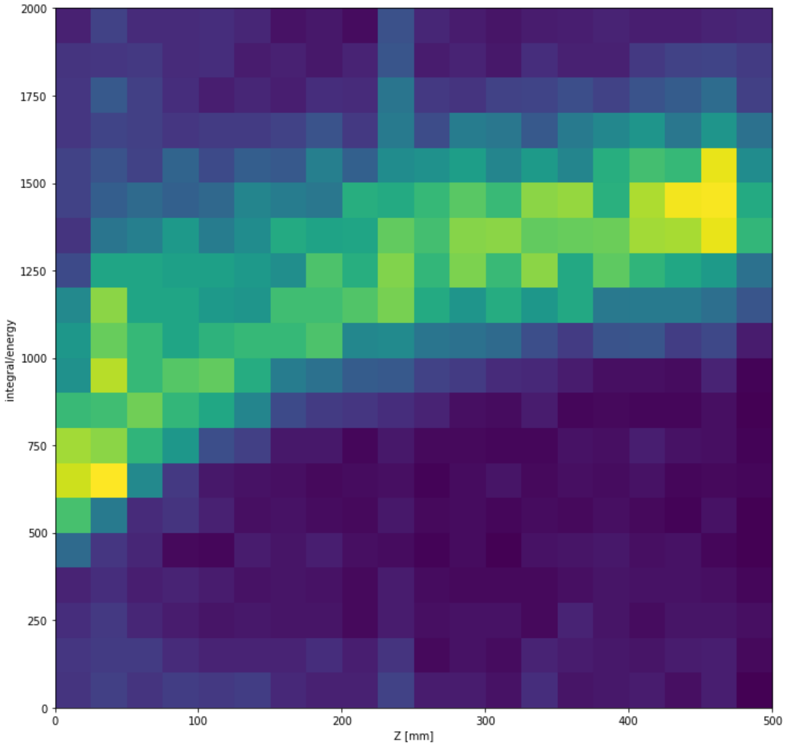


In the same time span, the LY in Run3 had huge variations wrt Run2

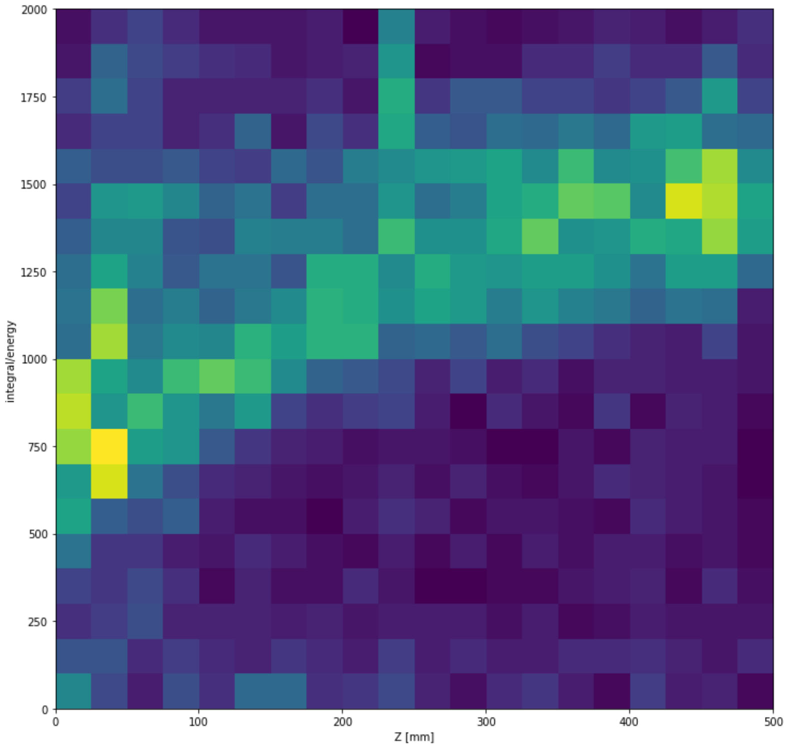
LY vs distance - Monte Carlo



Run1 (lower gain, lower efficiency, less saturation)

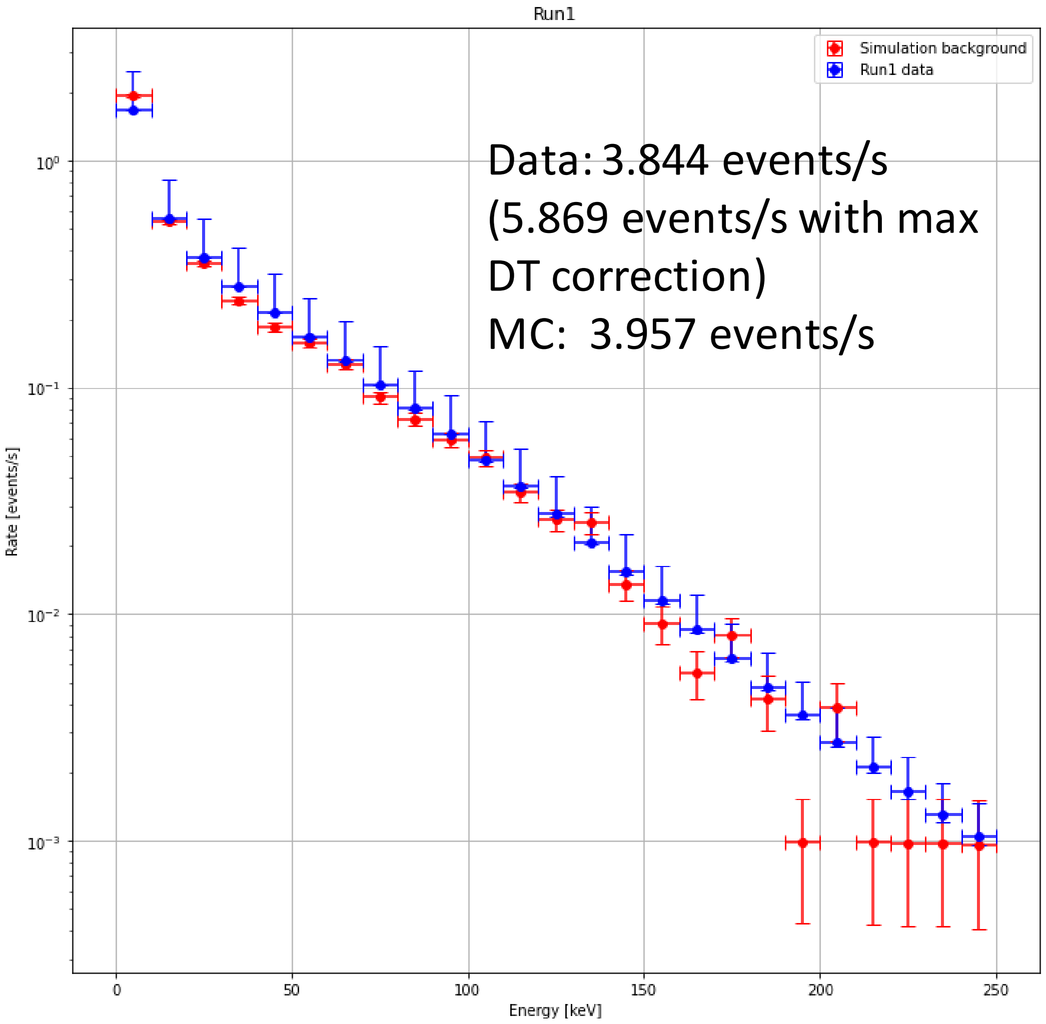


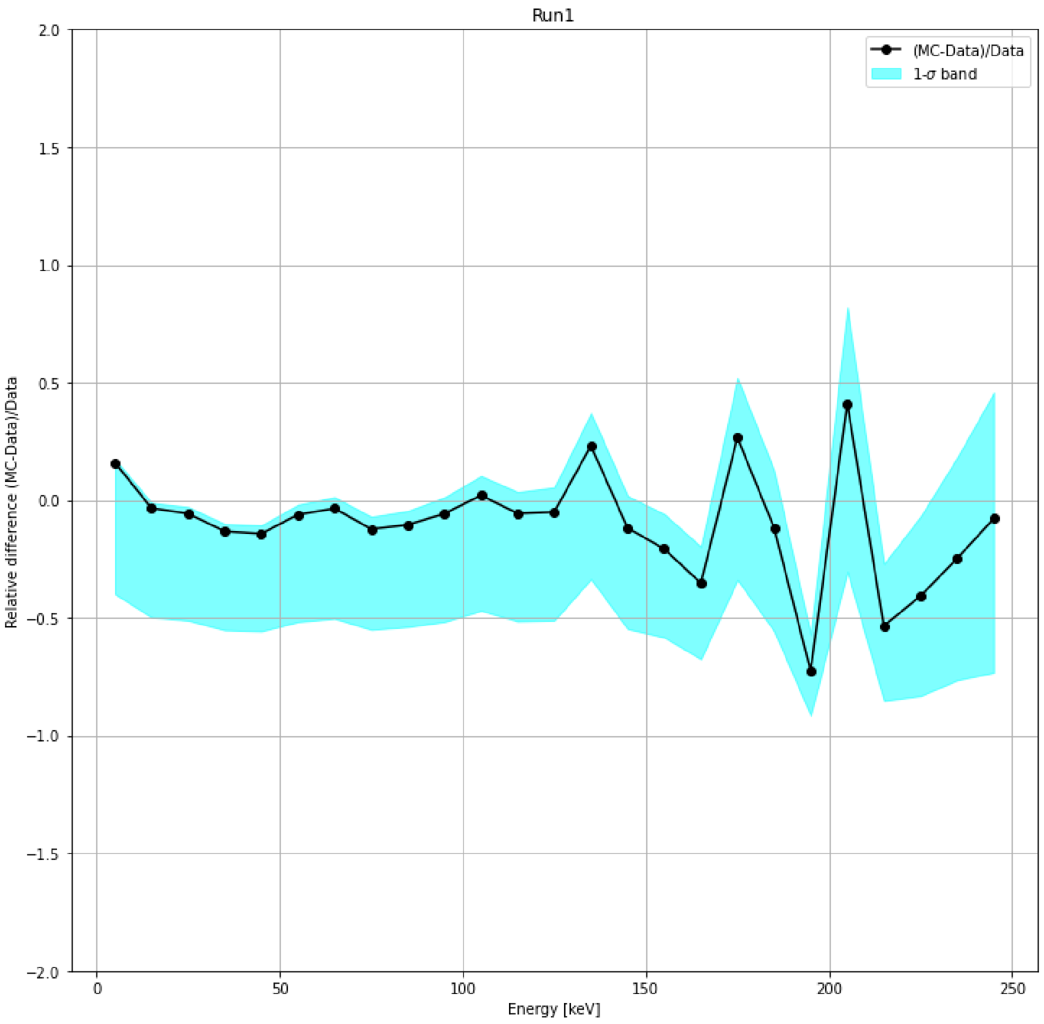
Run2



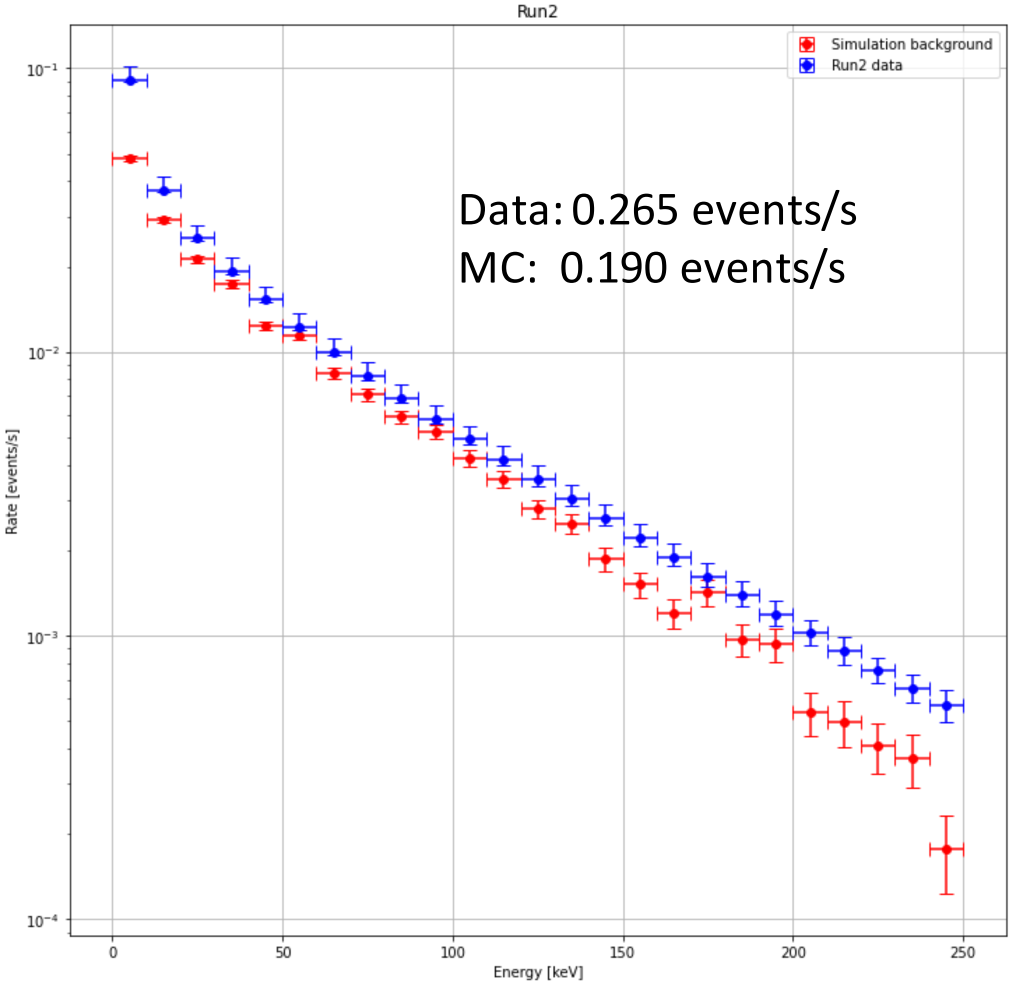
Run3

Run1 energy spectrum

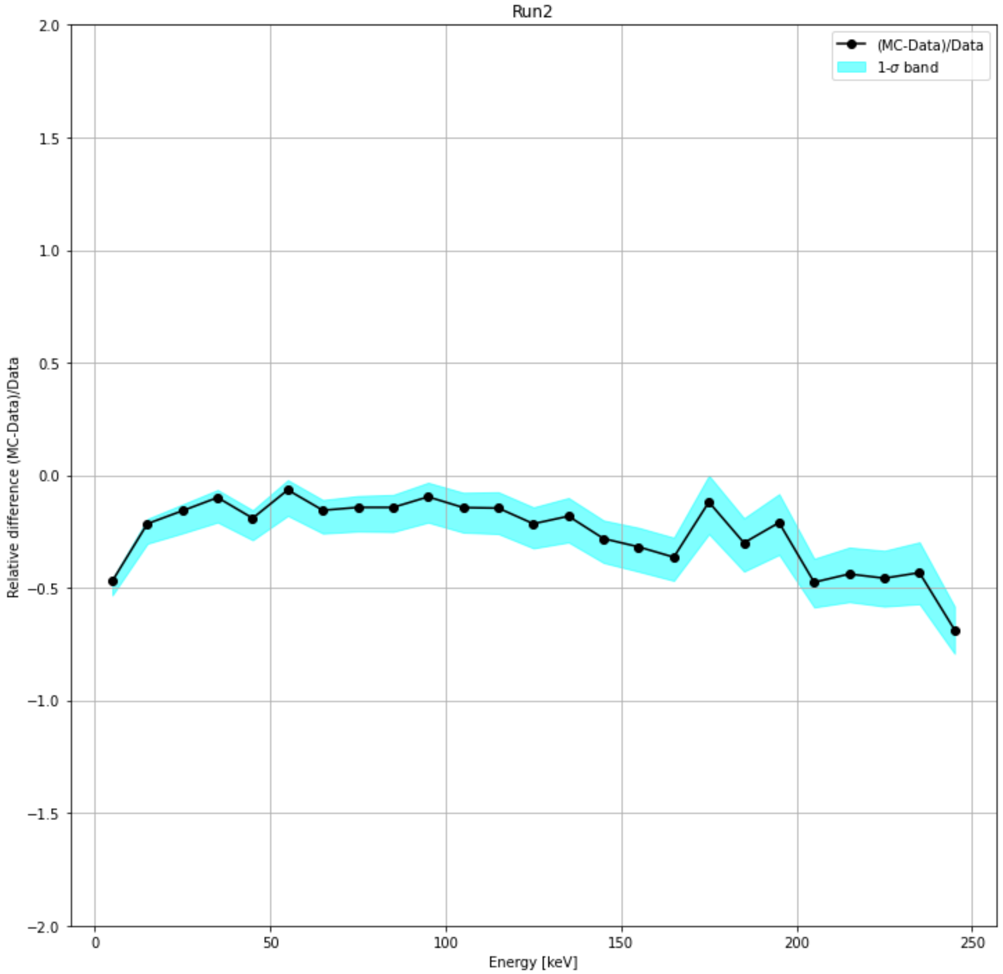




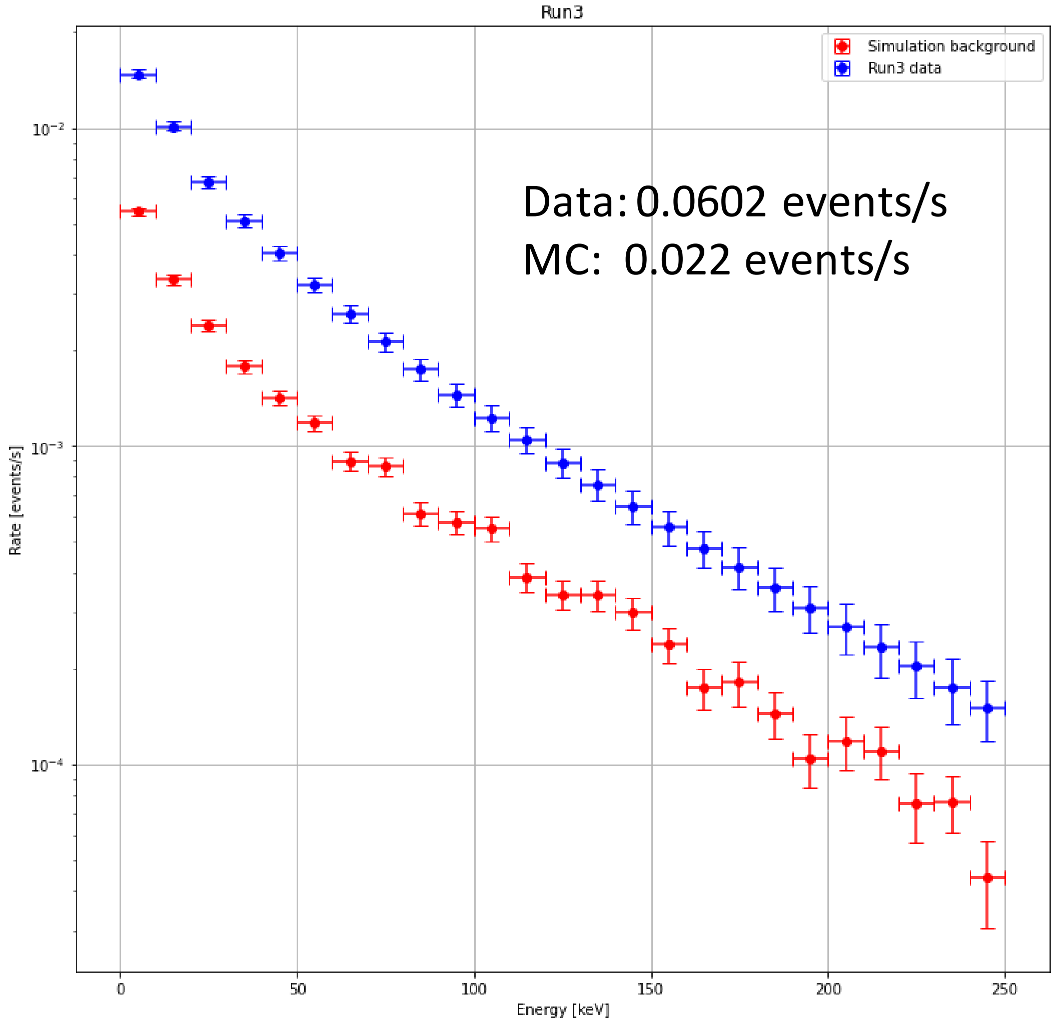
Run2 energy spectrum

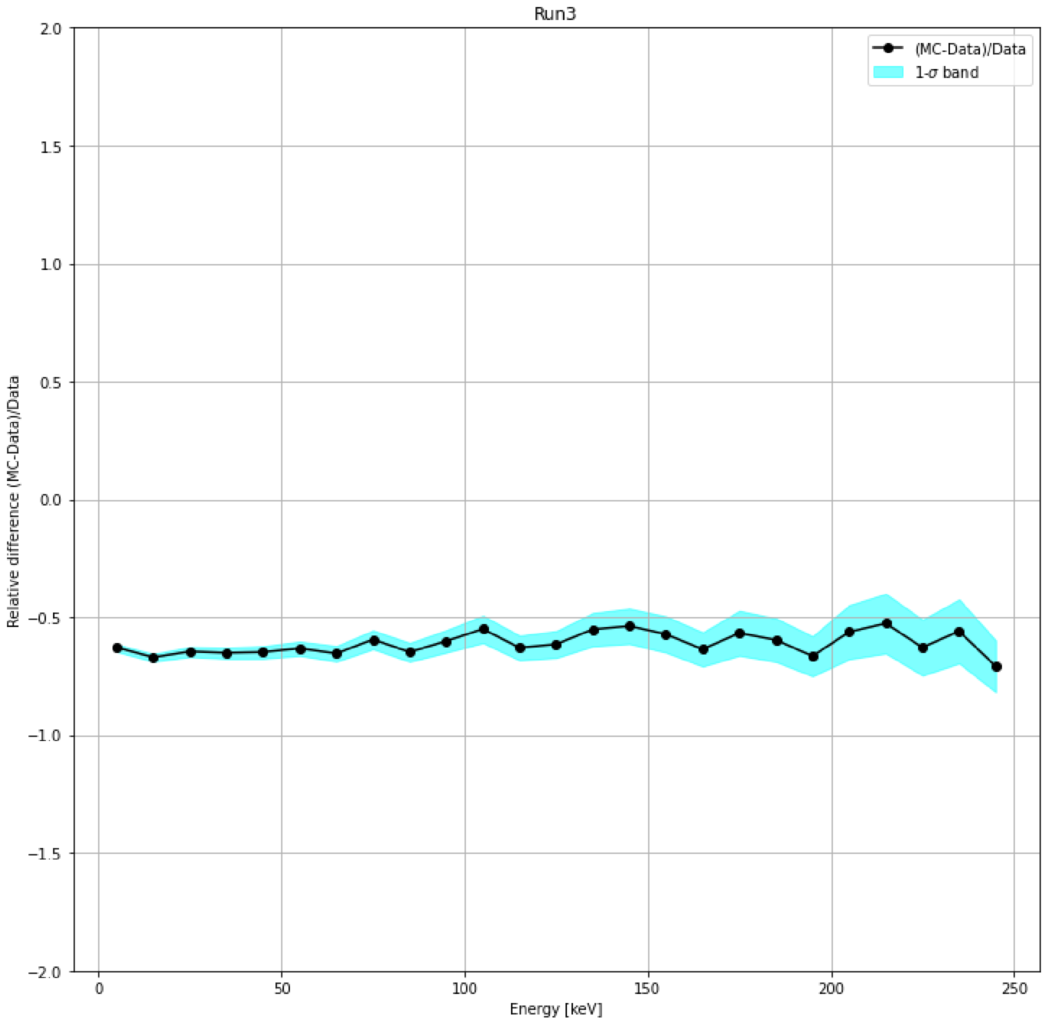


Data: 0.265 events/s
MC: 0.190 events/s

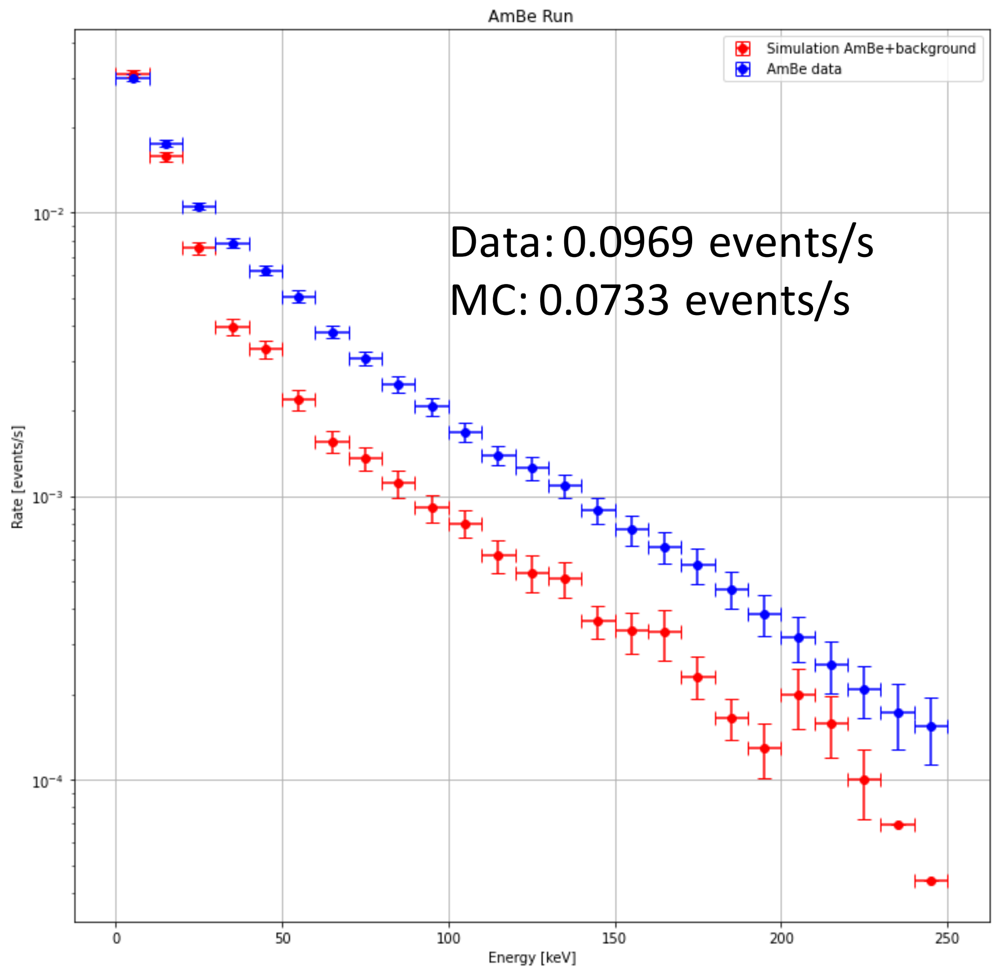


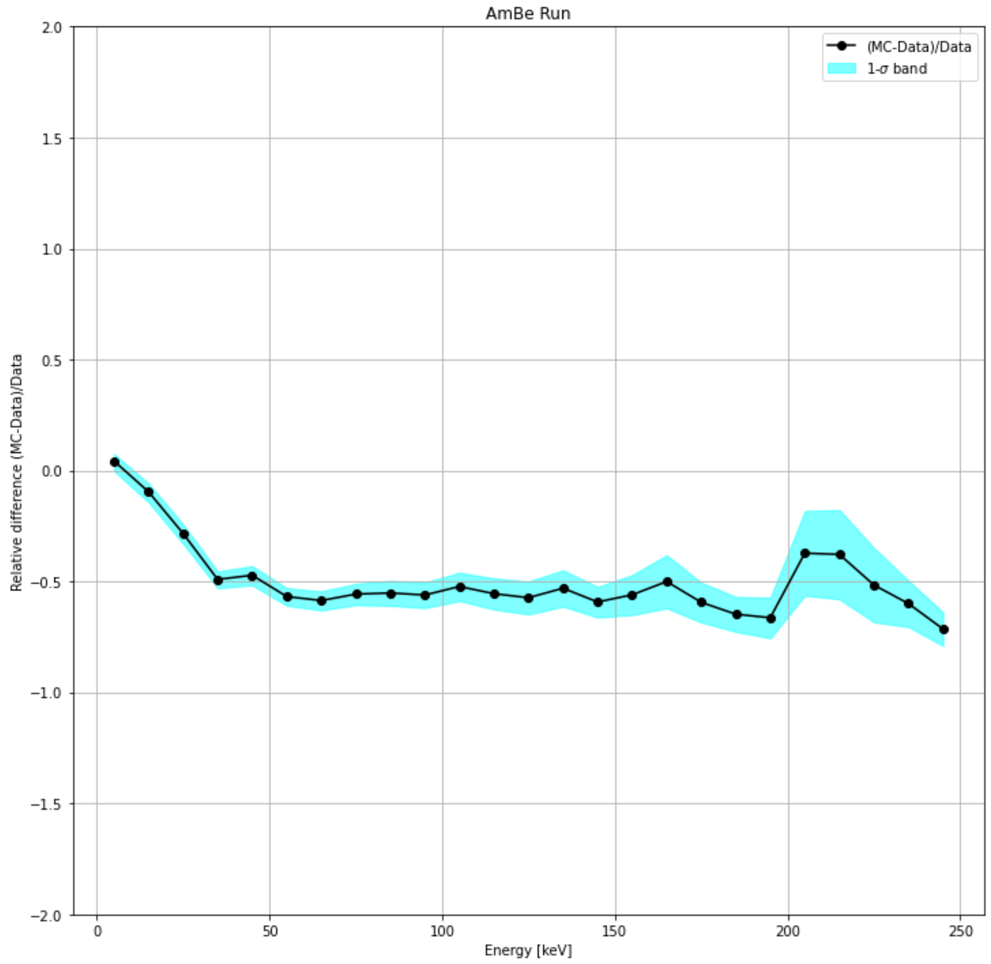
Run3 energy spectrum



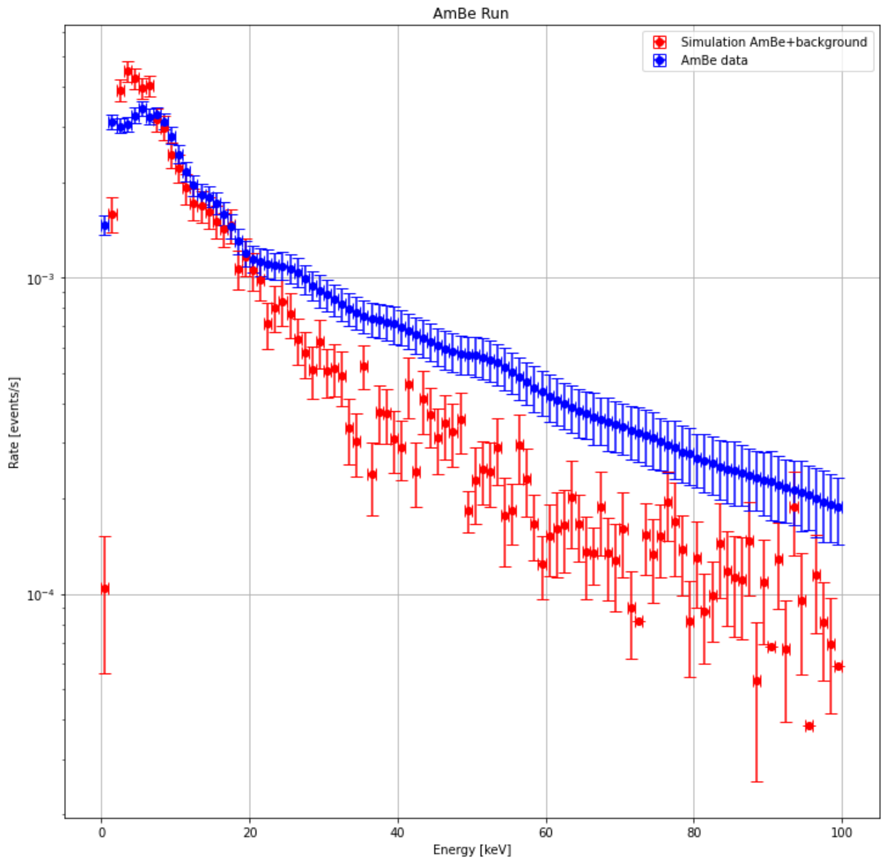


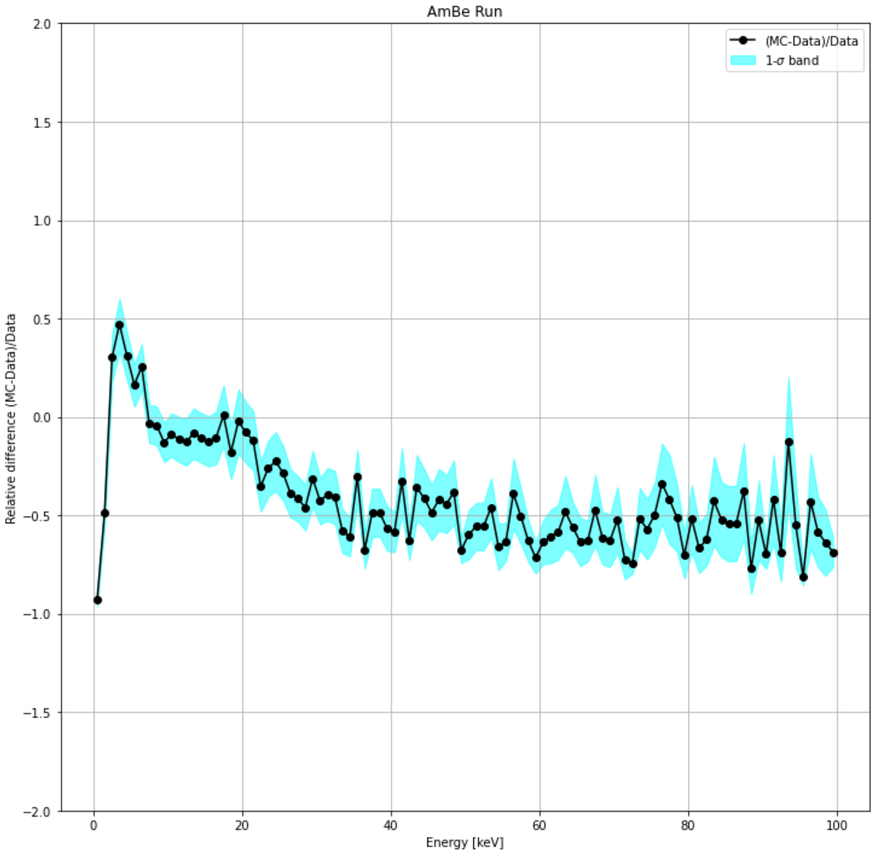
AmBe energy spectrum



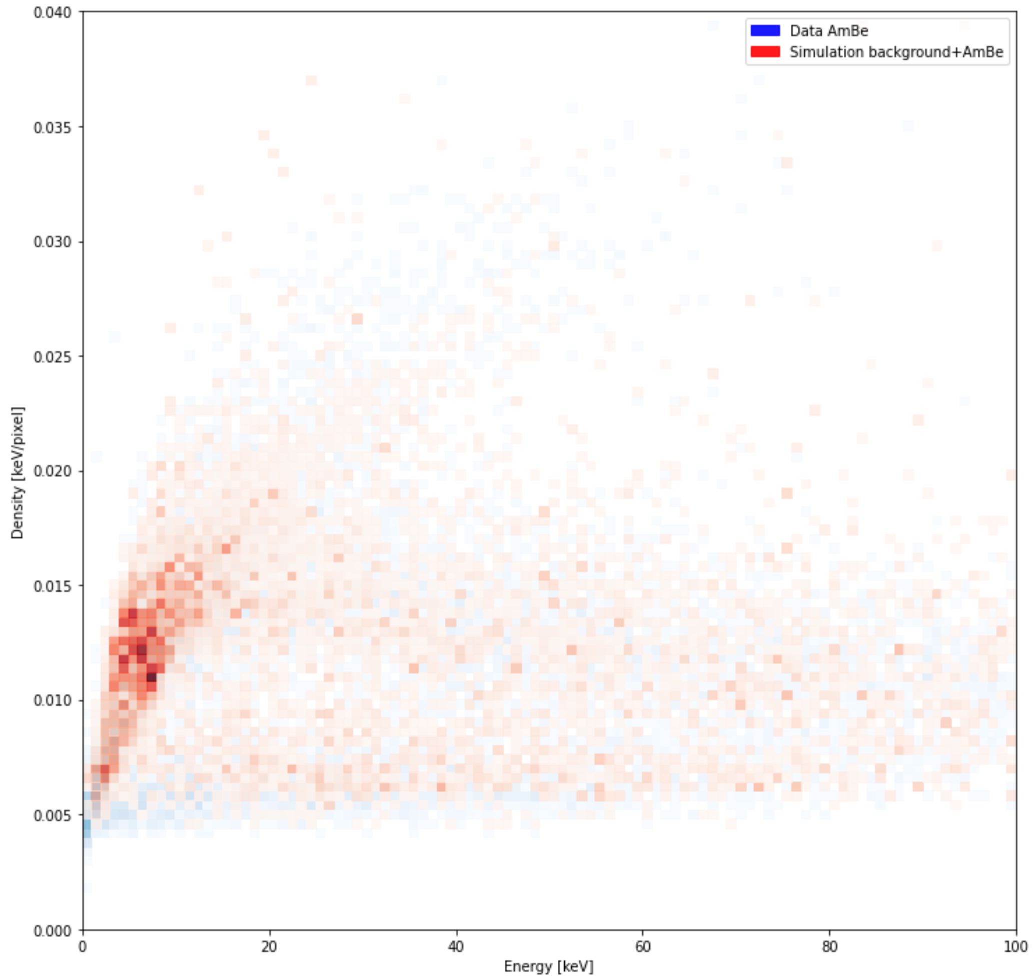


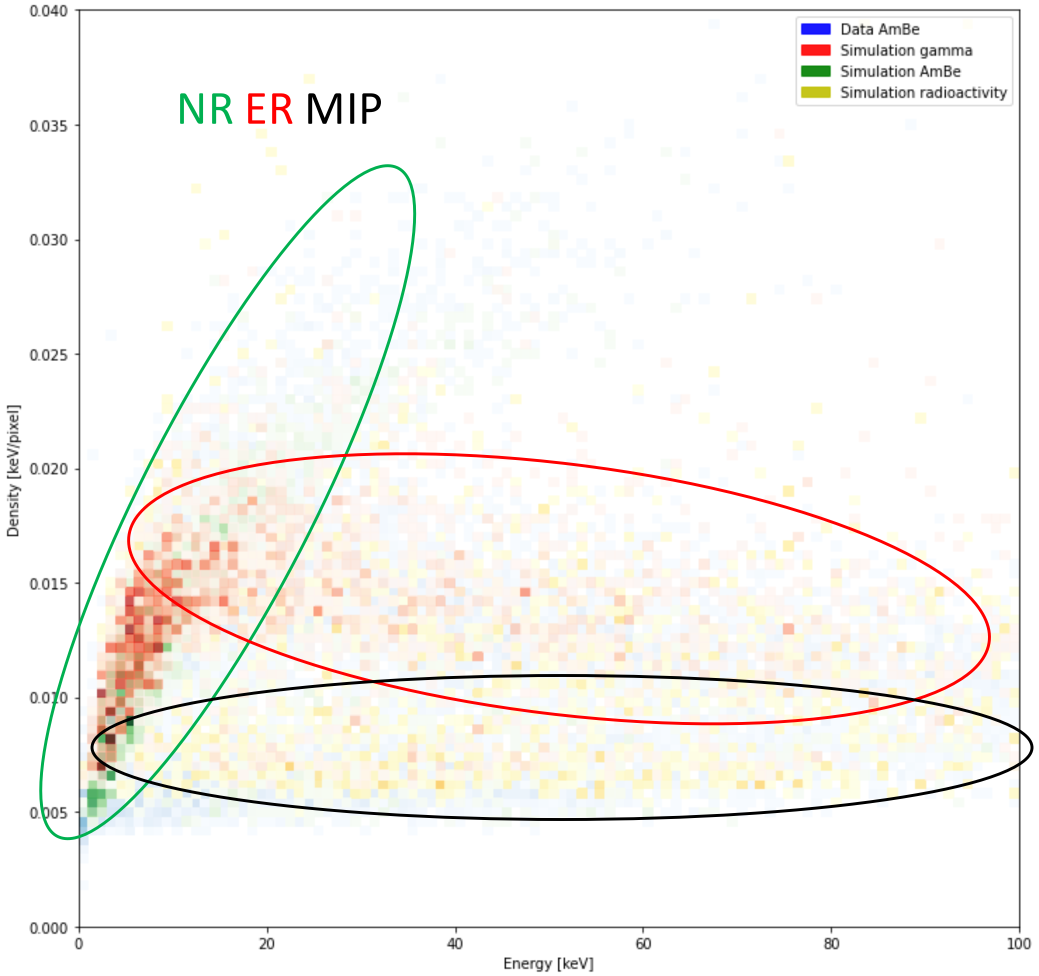
AmBe energy spectrum – 1keV bins



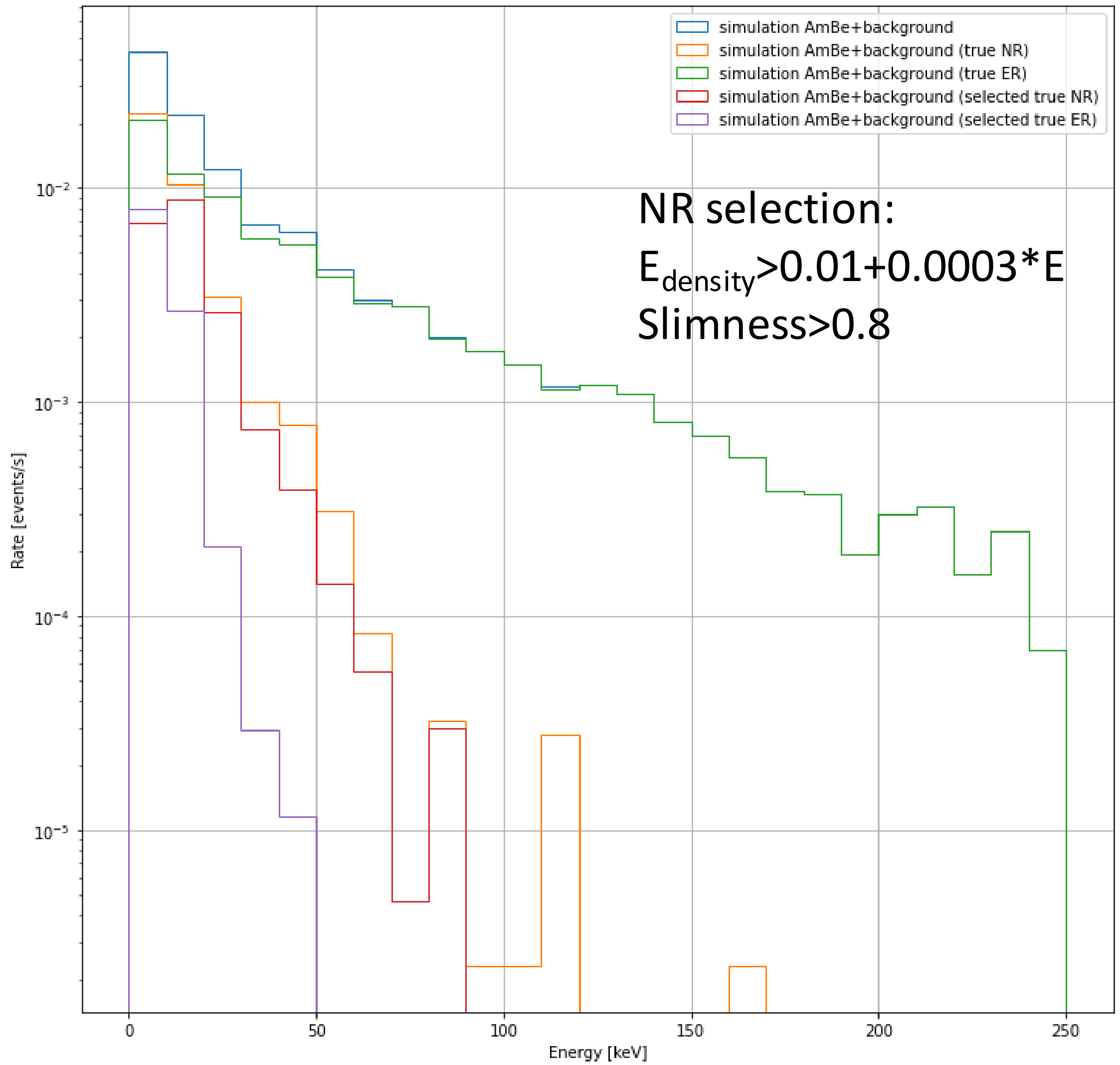


Density (energy/#pixel)

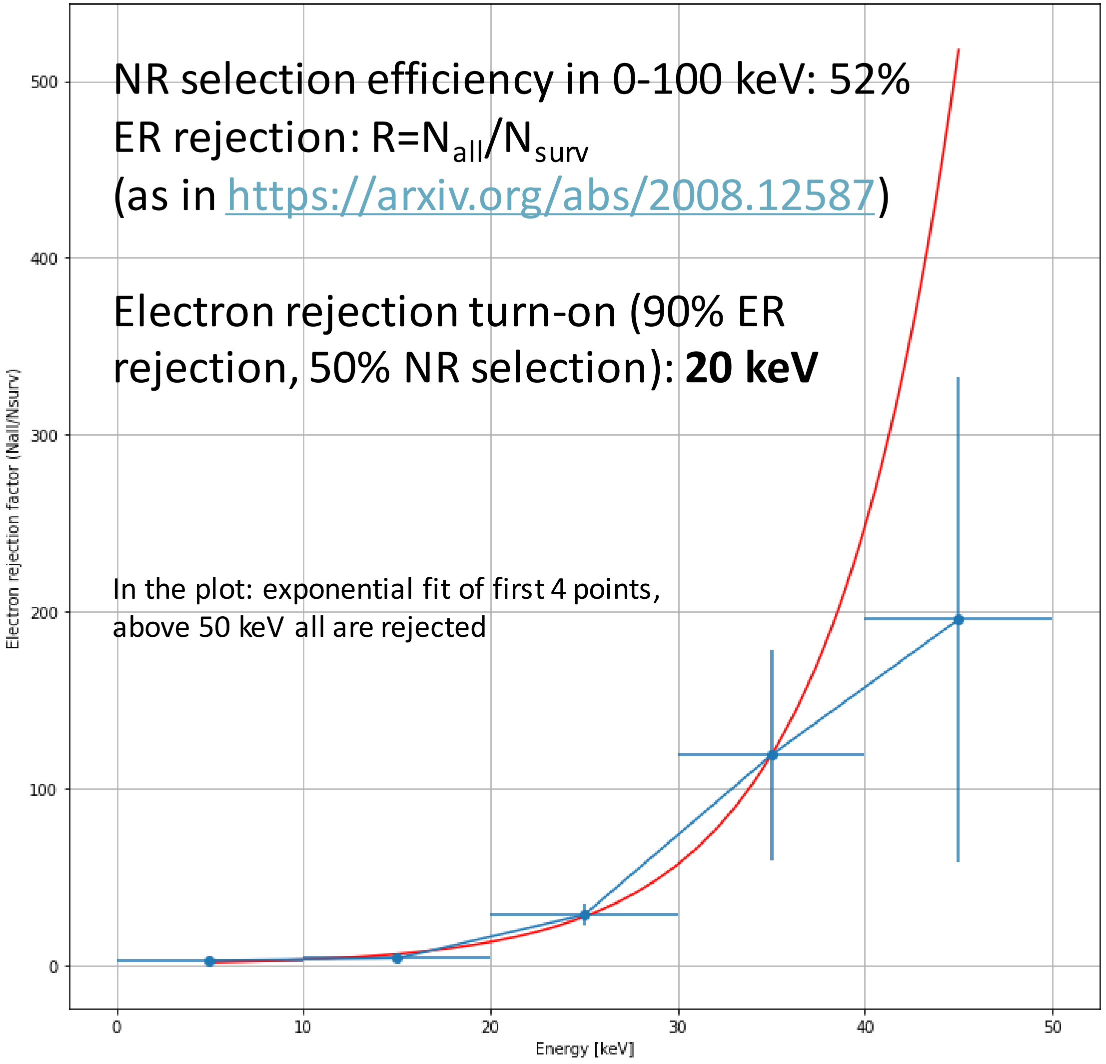




NR selection from AmBe simulation



NR selection:
$E_{density}$>0.01+0.0003*E
Slimness>0.8

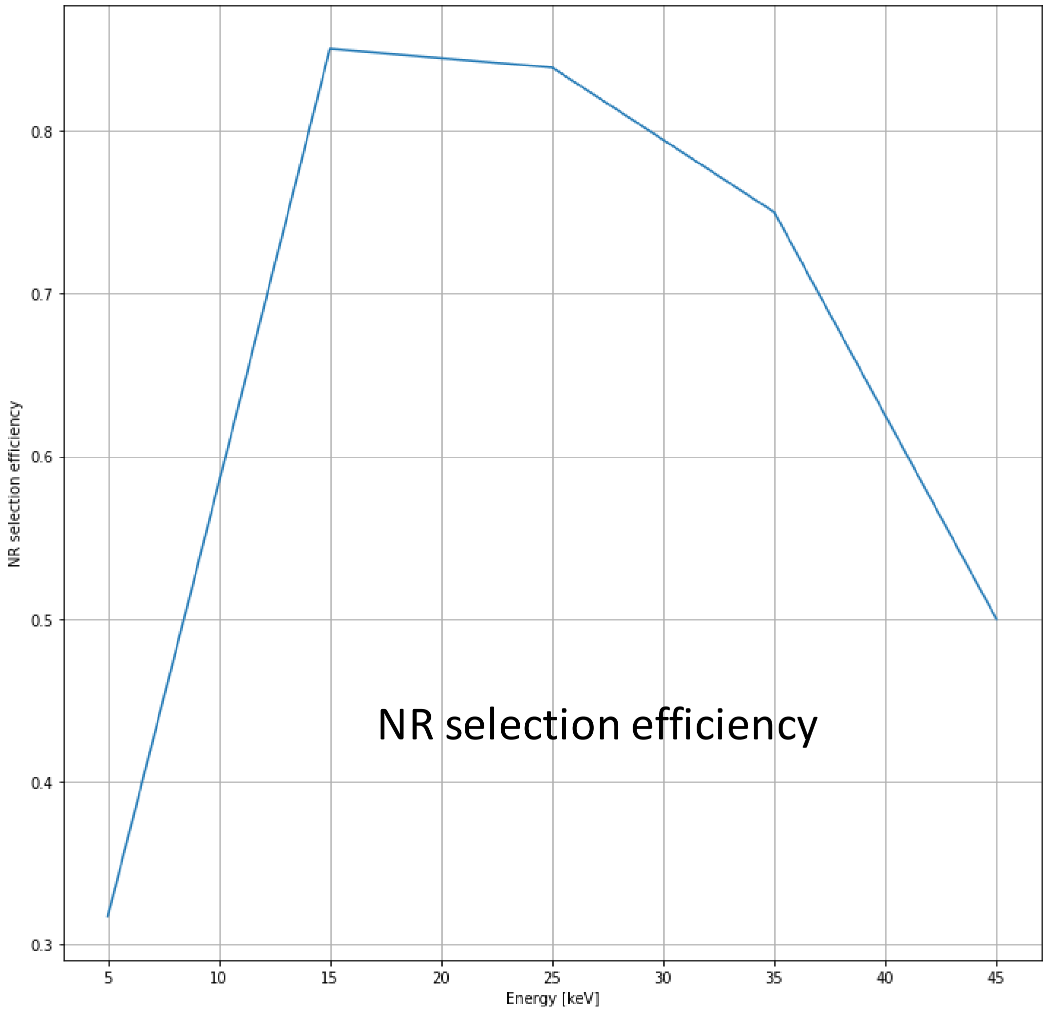


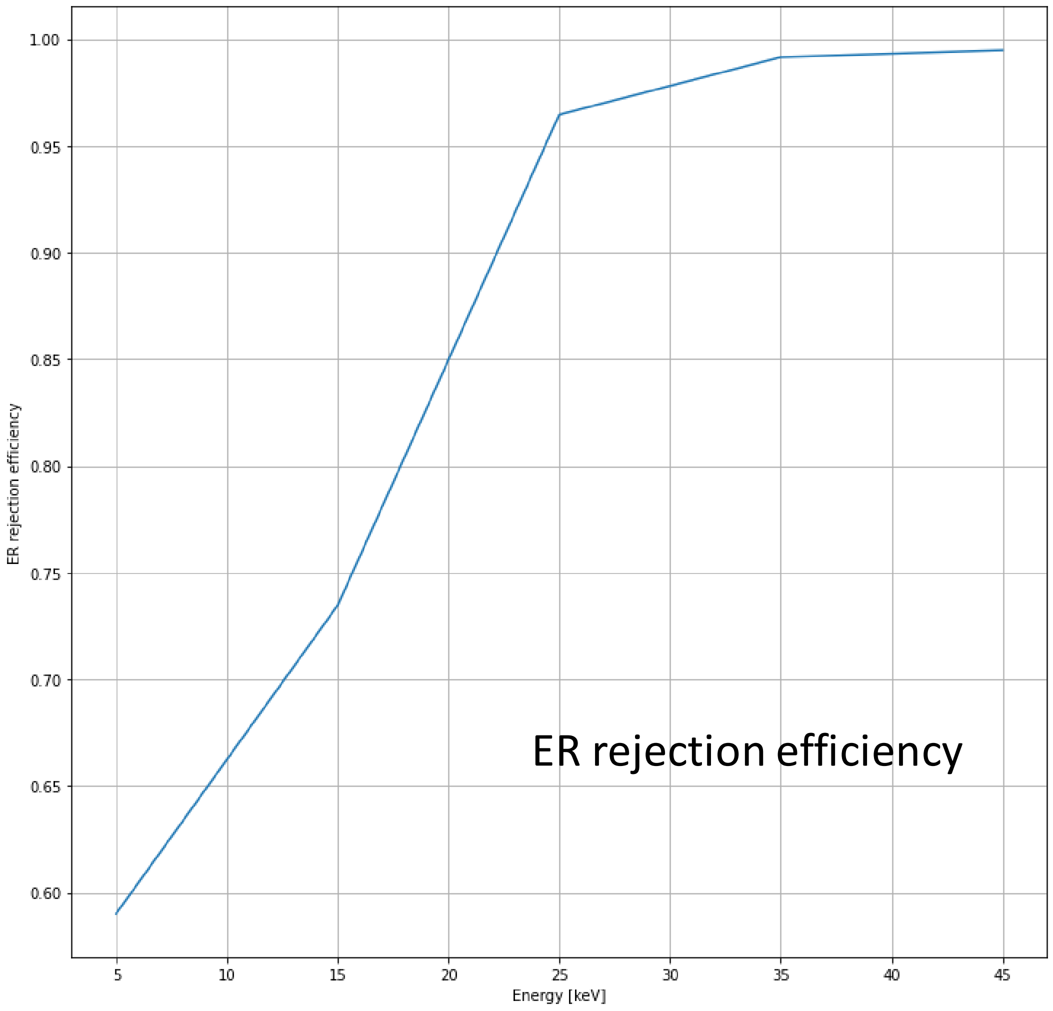
NR selection efficiency in 0-100 keV: 52%
ER rejection: $R=N_{all}/N_{surv}$
(as in https://arxiv.org/abs/2008.12587)

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

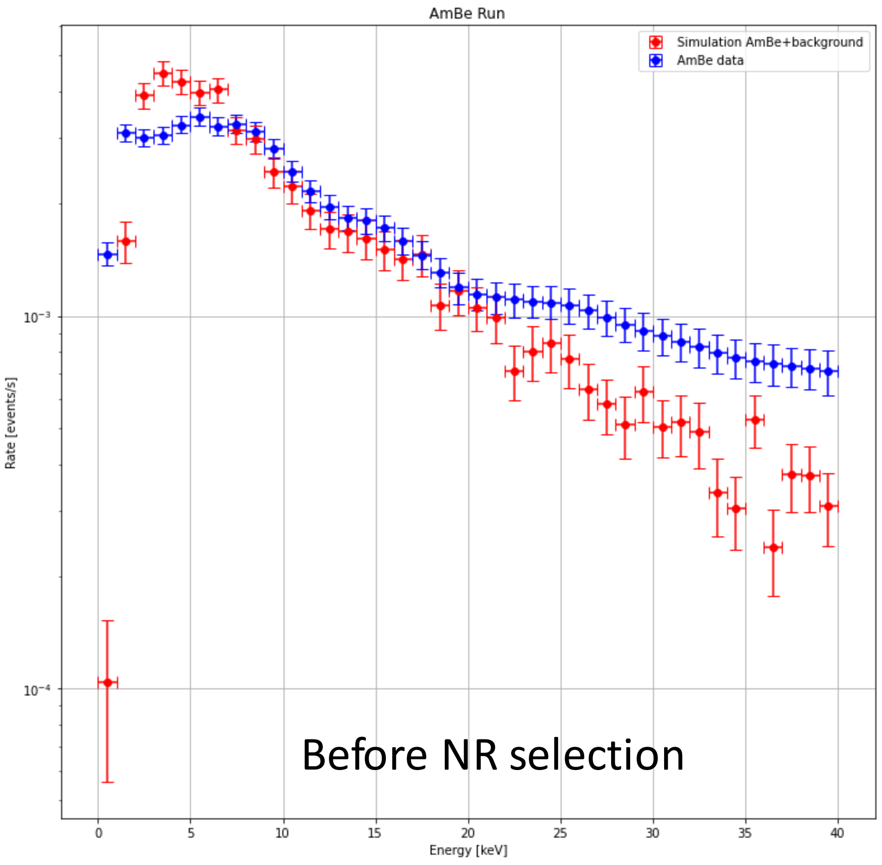
In the plot: exponential fit of first 4 points, above 50 keV all are rejected

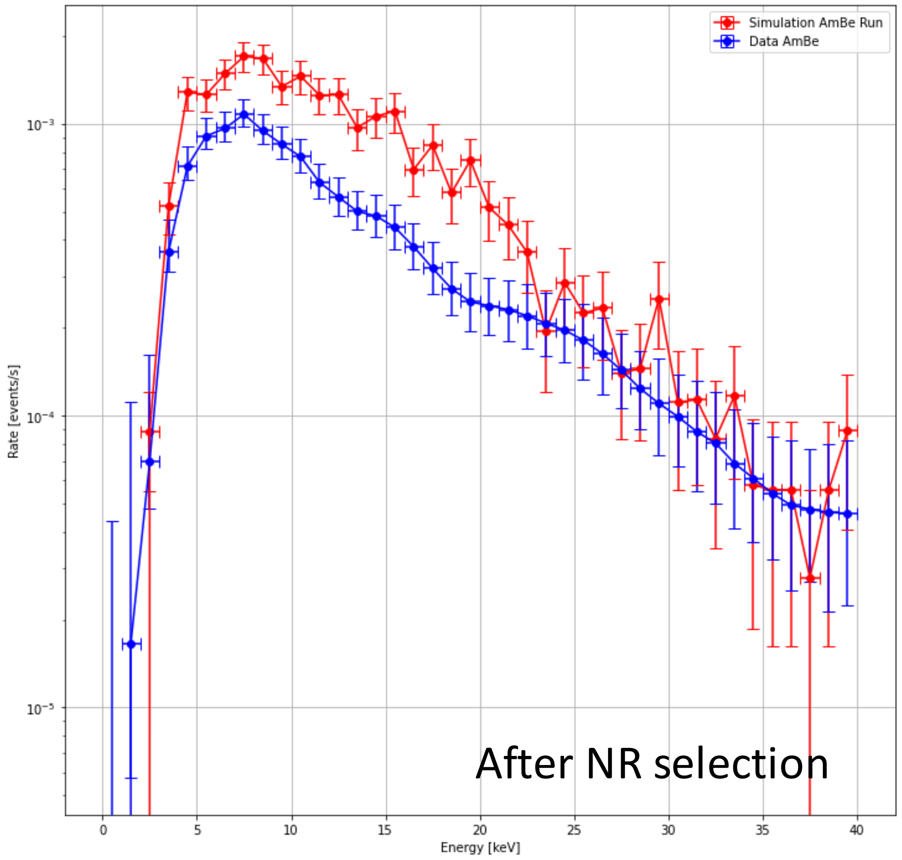
NR selection from AmBe simulation





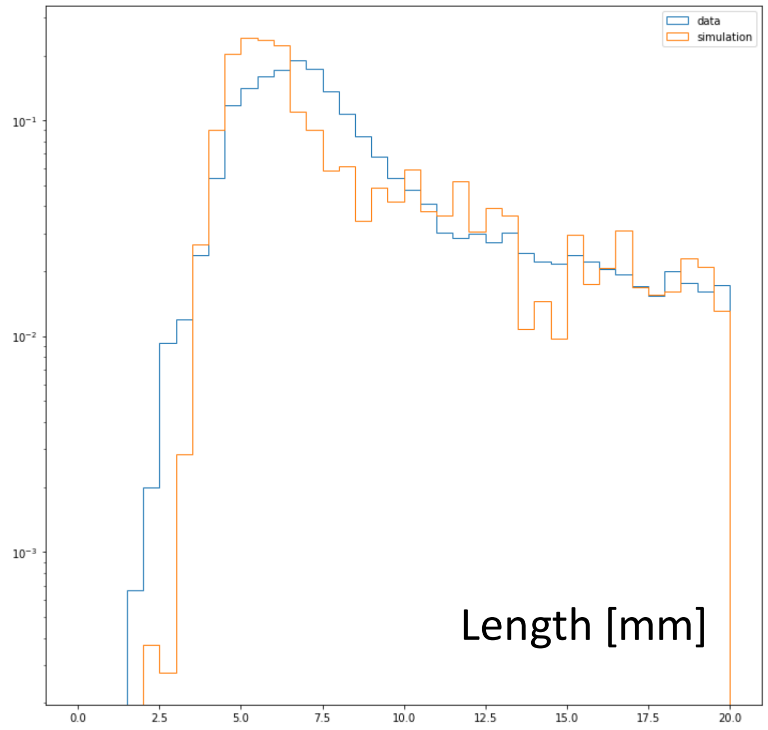
Energy spectrum after NR selection

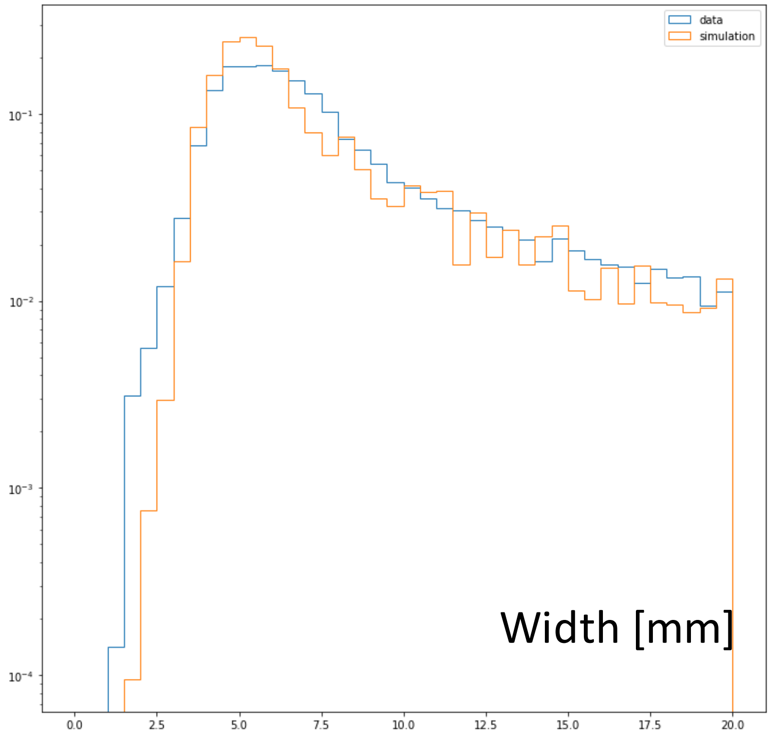


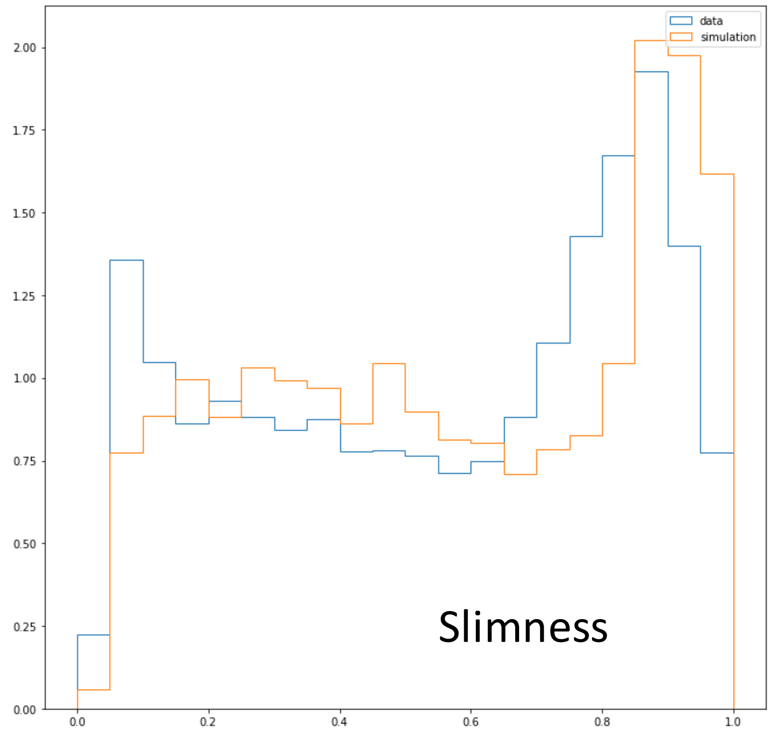


Length, width, slimness

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

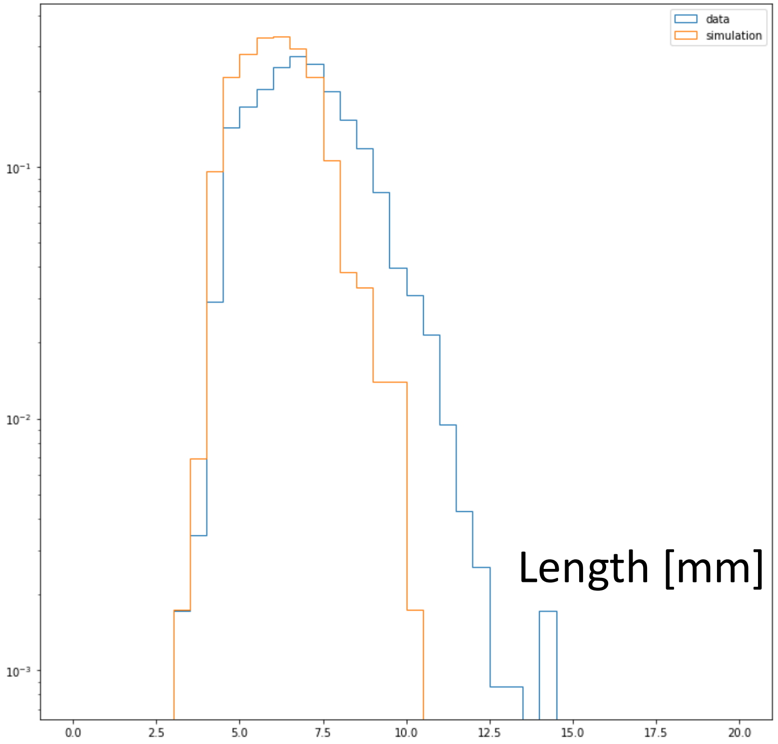


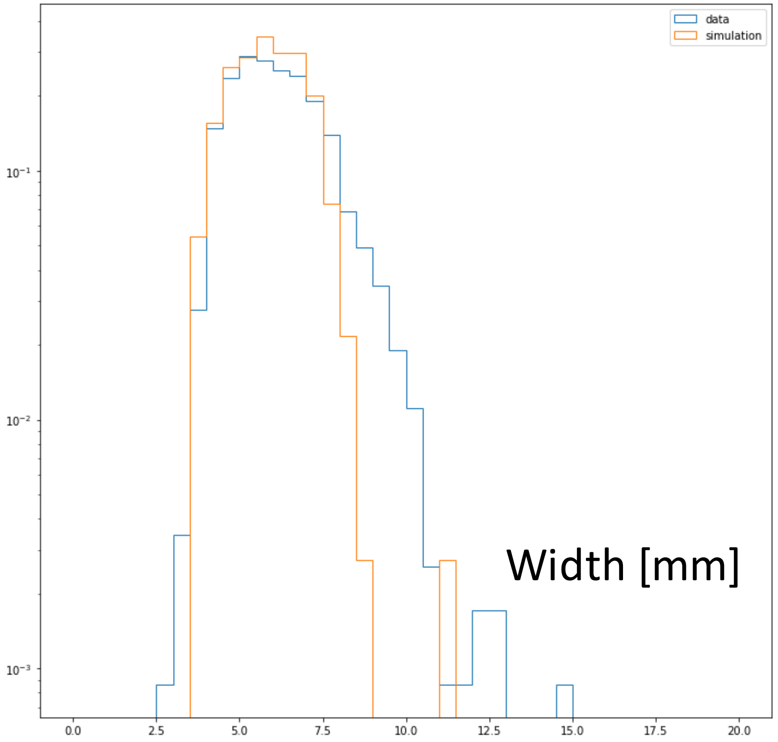


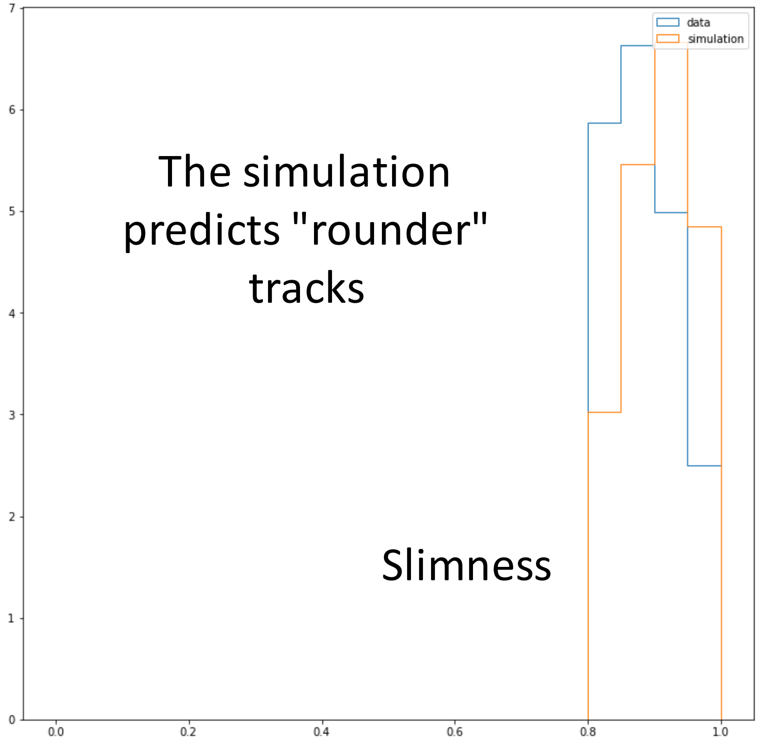


Length, width, slimness

- AmBe data vs background+AmBe simulation
- Length, width and slimness distributions **with** NR selection

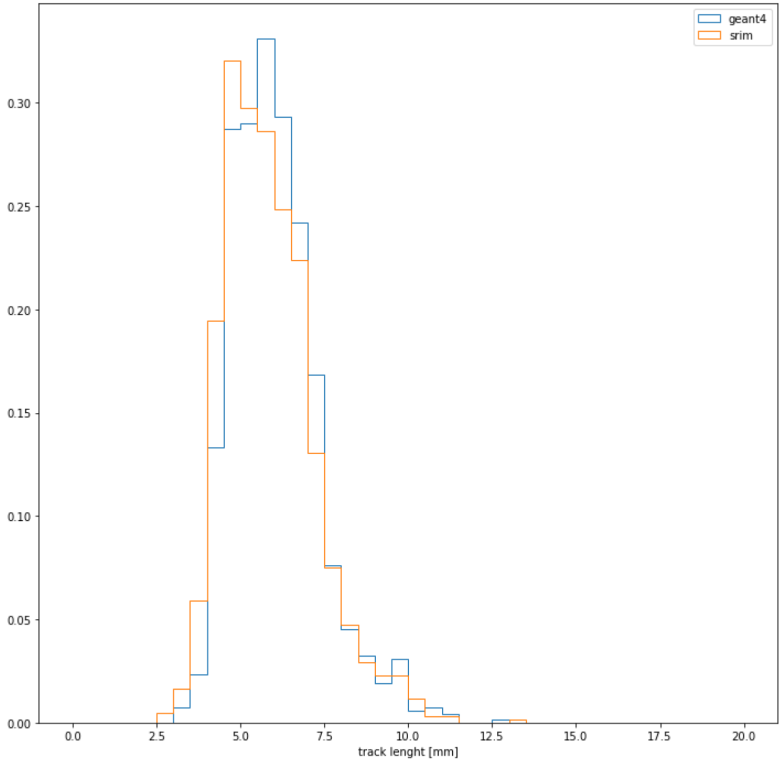




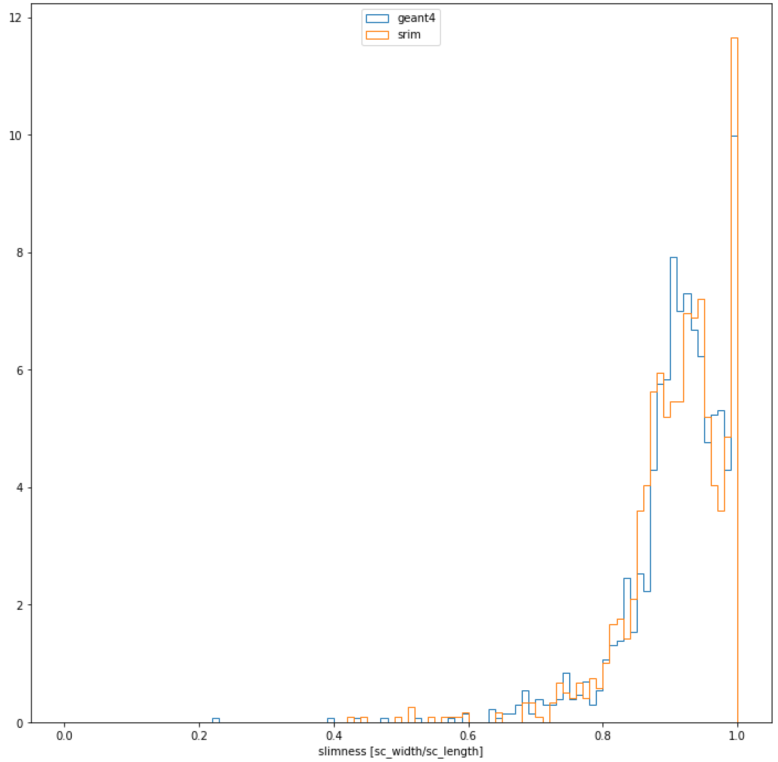


GEANT4 vs SRIM

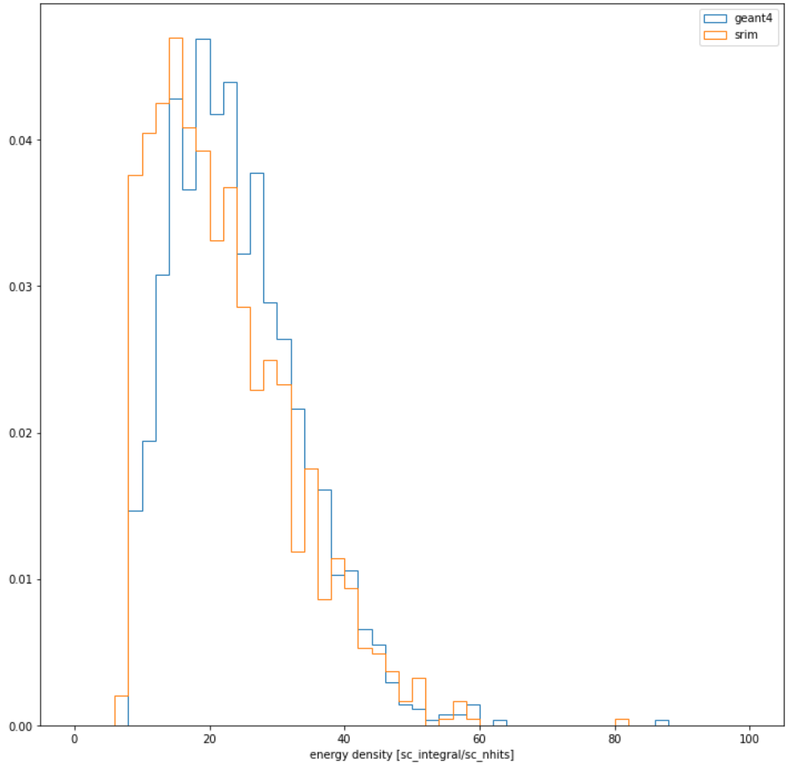
Some variables computed from GEANT4 tracks and SRIM tracks having selected only true NR



track length [sc_length]

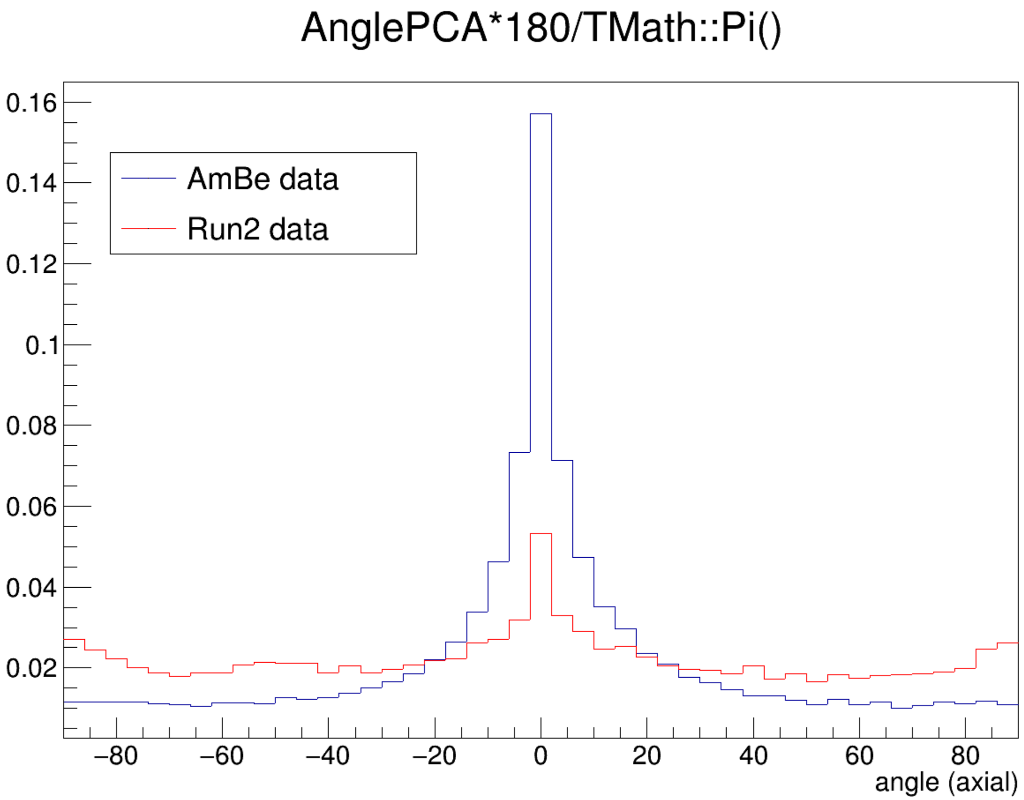


Slimness [sc_width/sc_length]



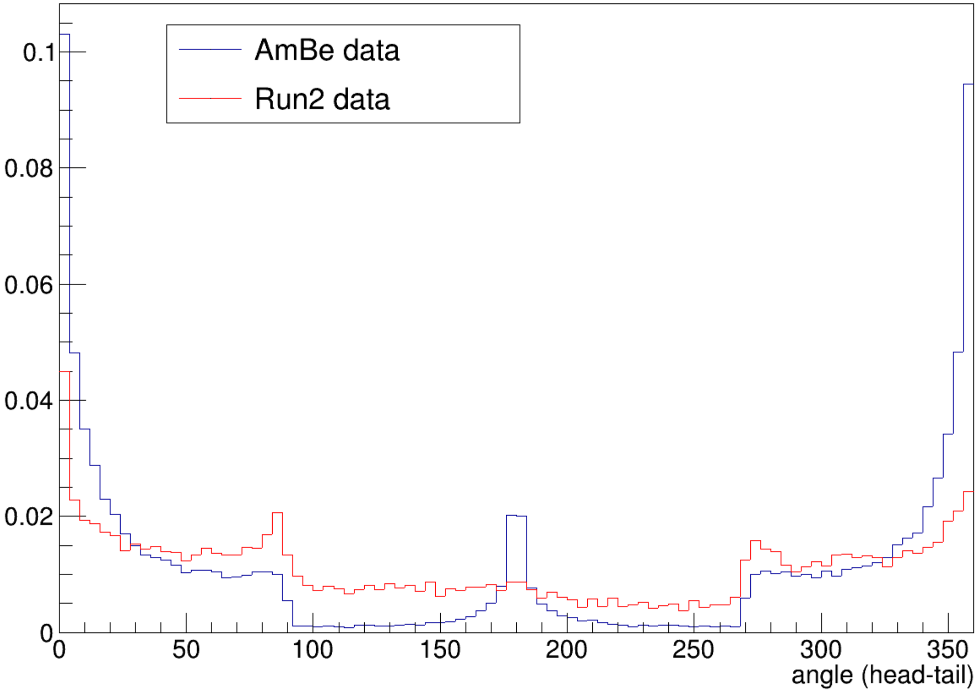
Delta [sc_integral/sc_nhits]

AmBe directionality

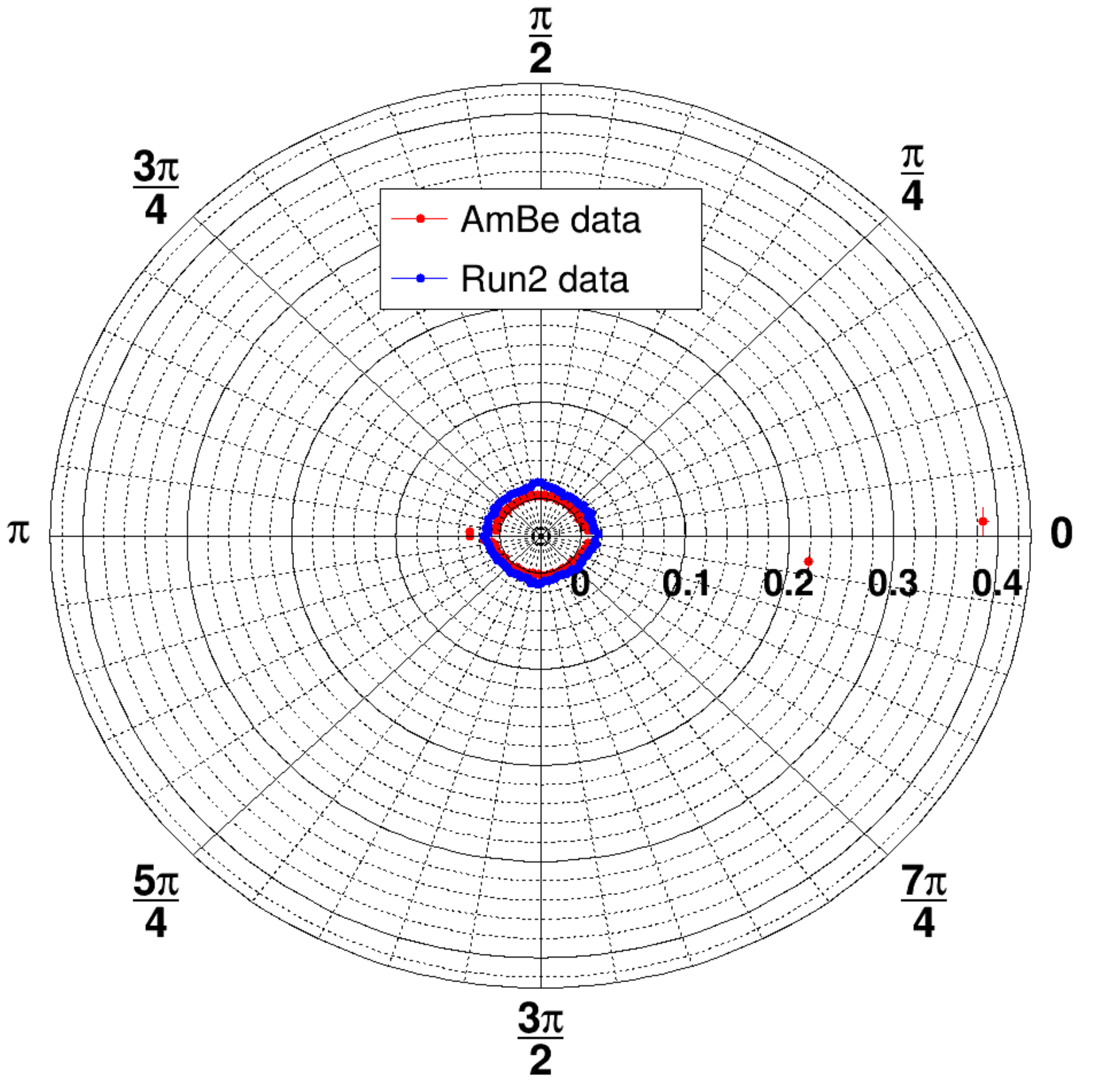


- Simple selection delta>15
- I compute post-reco the axial direction of the tracks from principal component analysis (PCA)
- I compare AmBe data with Run2 data (do not expect excess in a particular direction)
- Just axial direction: excess around 0 degrees in AmBe data
- I tested different definition of the sense (HT): maximum pixel, main peak position, asymmetry in integral and others, computed along longitudinal profile

AmBe – Head-tail



Position of main peak along longitudinal profile wrt barycenter used to assign a sense to the axial direction



Best visualized on a circle: >60% of AmBe tracks (cut delta>15) are identified as being between -4° and 4°
Run2 tracks do not show any excess in any direction

Conclusions

- A **full simulation of the expected background** sources in LIME underground was done including external sources and radioactivity; this was done to compare with Run1, Run2, Run3 and AmBe data
  - Effects of the detector response (included in digitization) are included
  - Simulation and data are reconstructed in the same way
- Regarding Run3, it seems that the expected (simulated) total event rate is 50% lower than the measured one
  - Radioactivity simulation neglects some major background? (unlikely)
    - I fitted the energy spectrum to match the data, it predicts an increased contribution from resistors/GEMs/copper/acrylic depending on the used dataset – but the radioactivity was actually *measured*, so why should it be significantly different?
  - Data are overestimated? (unexpected noise, LY variations, errors in reco)
    - We already know that the total rate from CMOS data varies by almost a factor 10 throughout Run3
- Overall the agreement is *at worst* within 60% (Run3/AmBe) - more towards 20% for earlier runs

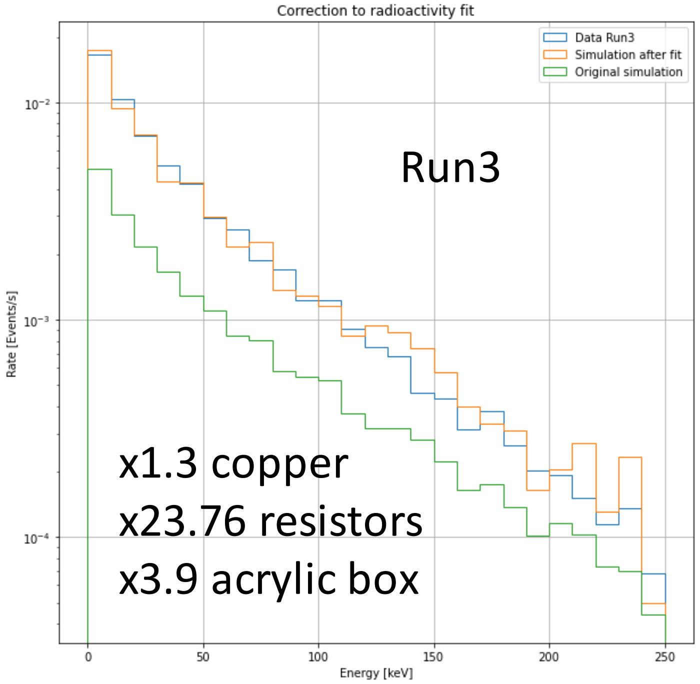
- **A first measurement of direction and HT from AmBe** data was done, with very promising results

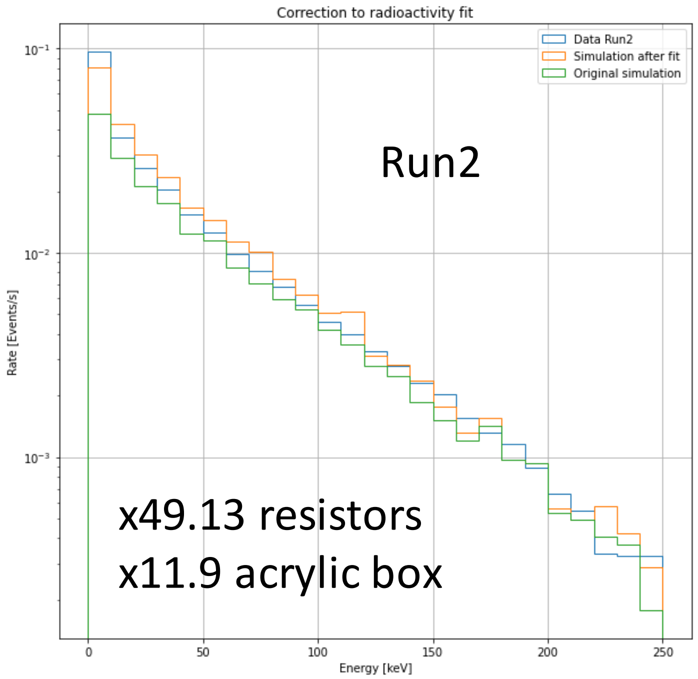
- Next steps: include LY uncertainty on MC, re-reconstruct Run3 data and understand what makes it different from Run2 and Run1, optimize NR cut and better study directionality and HT

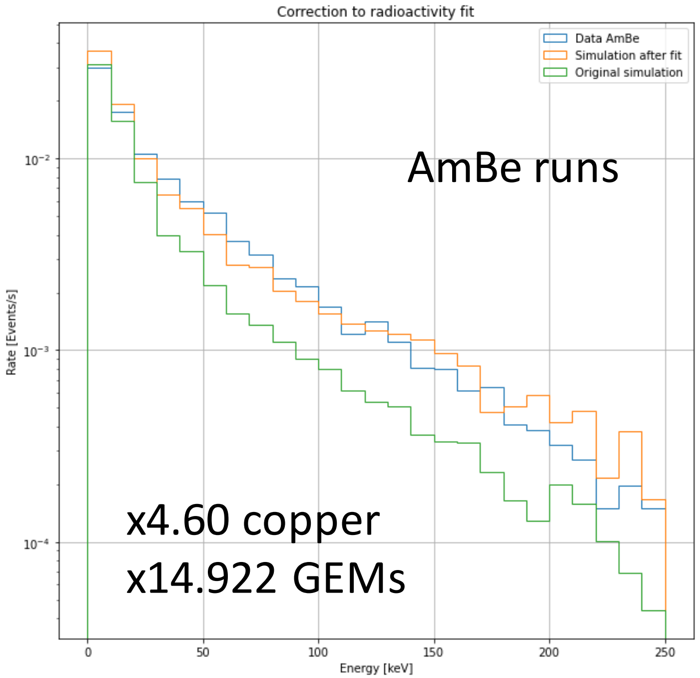
backup

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

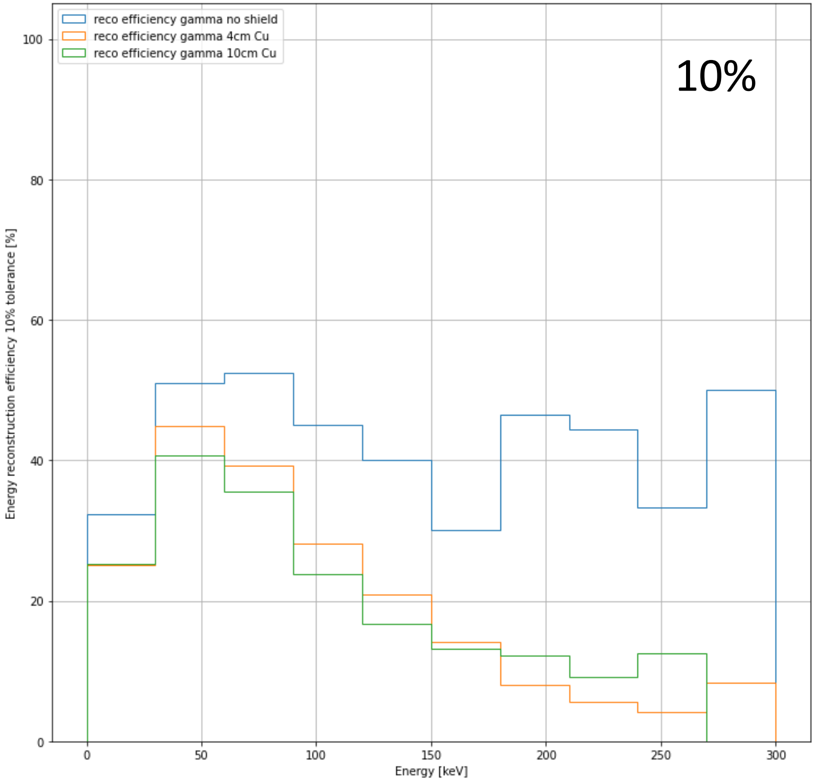


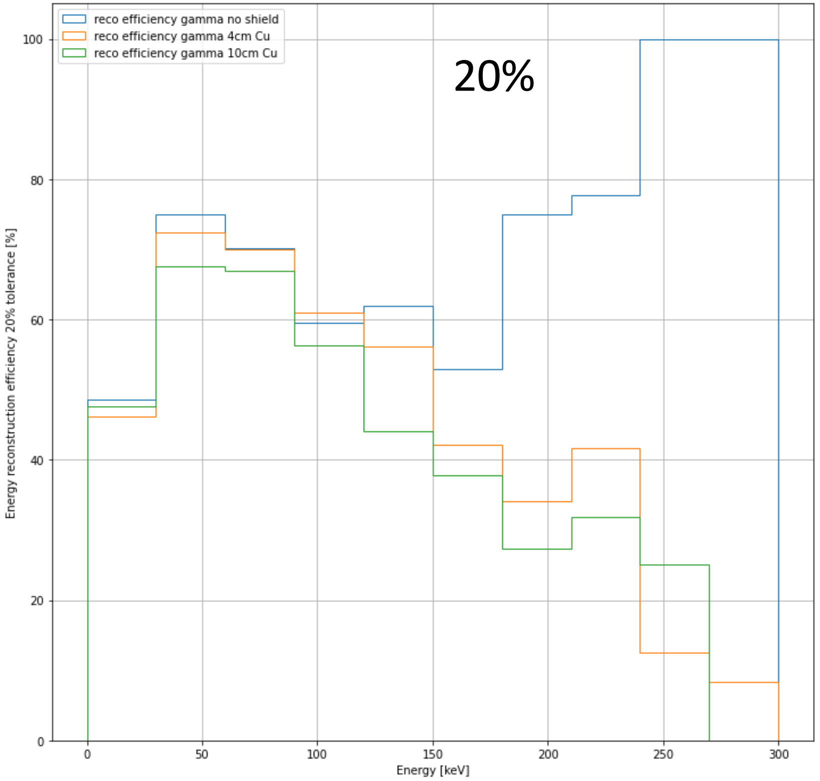


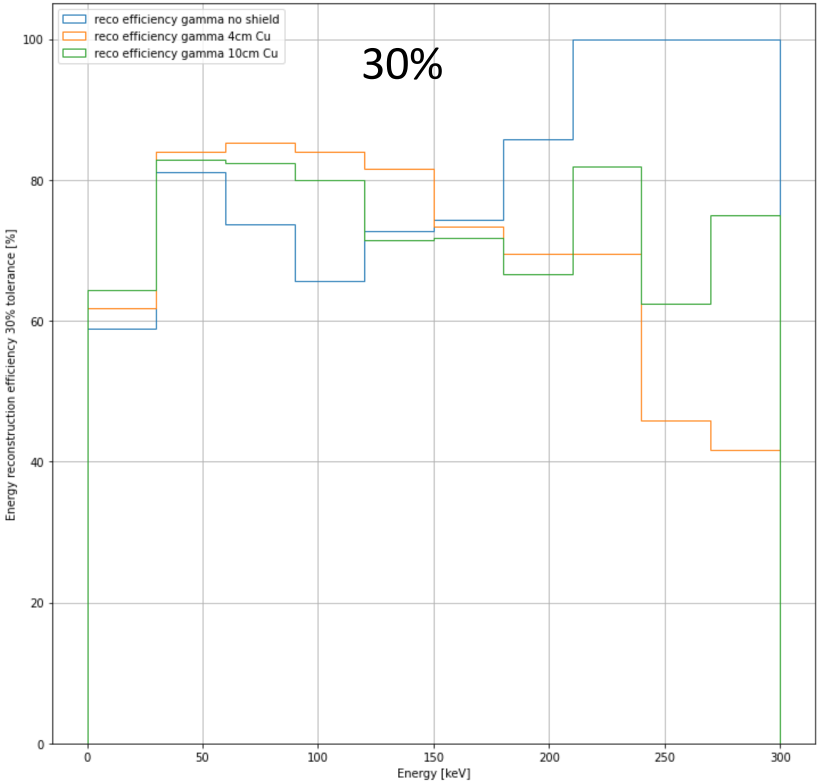


Energy reconstruction efficiency

- 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

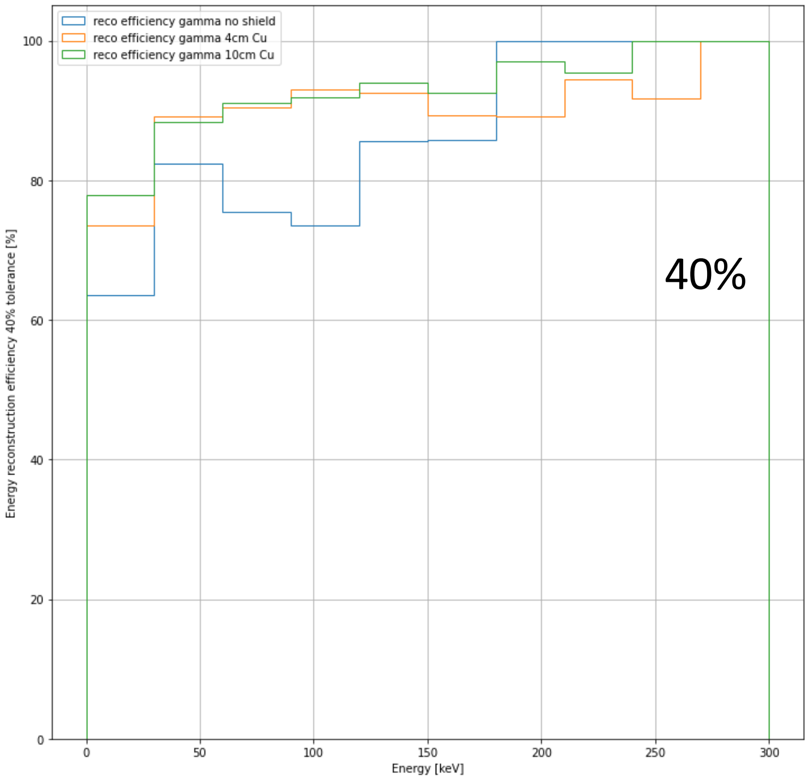


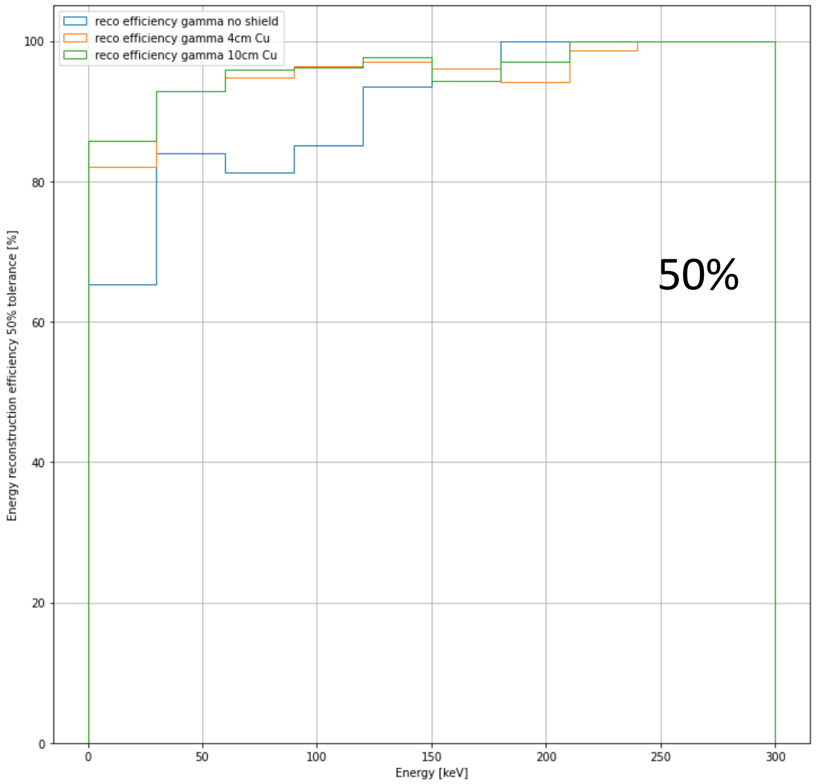


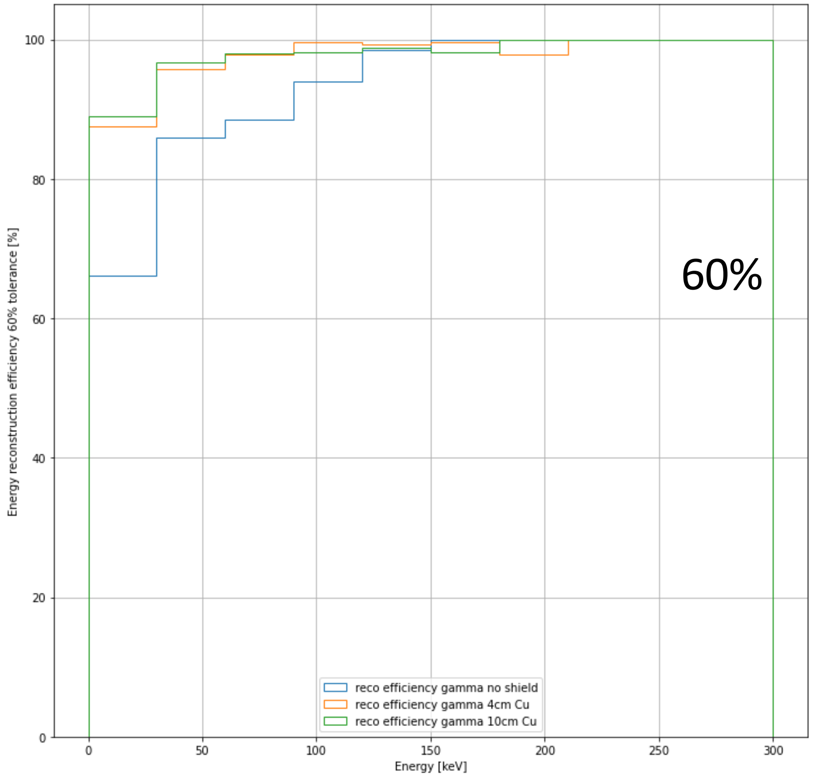


Energy reconstruction efficiency

- 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







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