CYGNO simulations update

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AmBe simulations

AmBe source

- AmBe source is made of $^{241}AmO_2$ and ^{9}Be
- ^{241}Am decay:
  - Radioactive ^{241}Am has a half-life of 432.2 years and decays via α emission (five different energies averaging 5 MeV) to ^{237}Np.
  - The dominant energy of the resulting background gamma-rays from the decay of the intermediate excited states in ^{237}Np is 59.5 keV.
  - Fast neutrons are produced when the decay α particles interact with ^{9}Be.
- (α ,n) reaction with ^{9}Be

$\alpha + {}^{9}Be \rightarrow {}^{12}C + n$ (~42%),

$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$ (~58%),

$^{12}C^{*} \rightarrow {}^{12}C + \gamma$ (4.38 MeV)

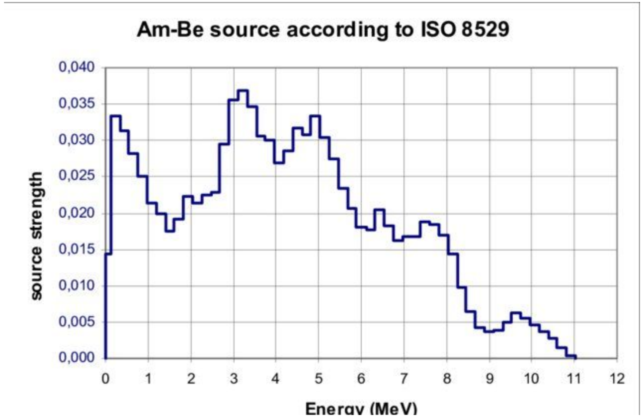
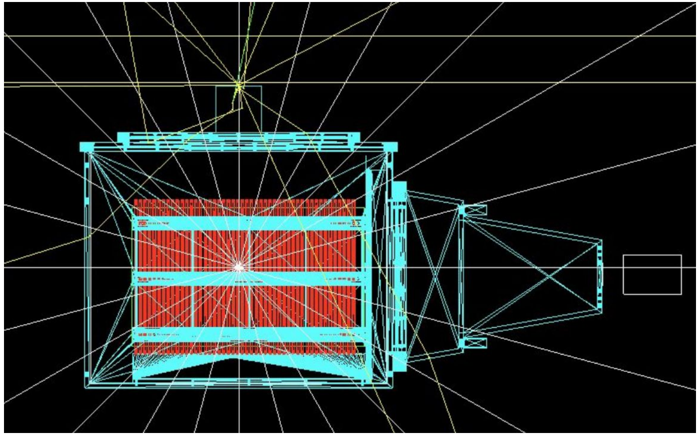


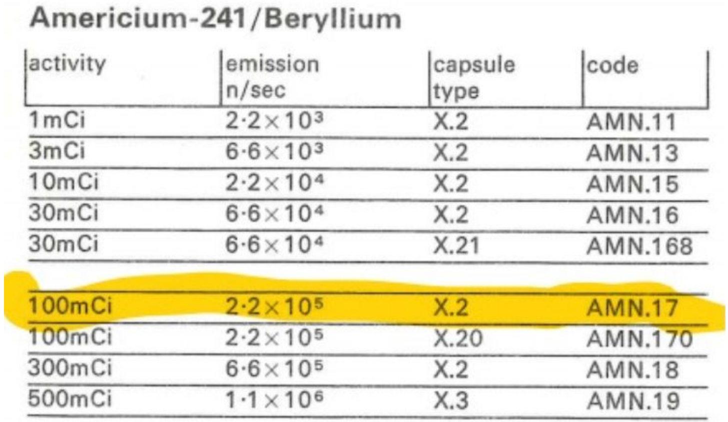
Fig. from https://rifj.ifj.edu.pl/handle/item/217

Ref: https://www.sciencedirect.com/science/article/abs/pii/S0969804307001200

AmBe simulation in LIME

- LIME simulation code https://github.com/CYGNUS-RD/CYGNO-MC/tree/lime
- Added macros in the `macro` directory to simulate separately:
  - neutrons with spectrum from figure in previous slide
  - 4.438 MeV gammas
  - ^{241}Am decay (mostly gammas at 59.5 keV)
- Position of the source above the LIME box + 10x10x10 cm^3 Pb shield



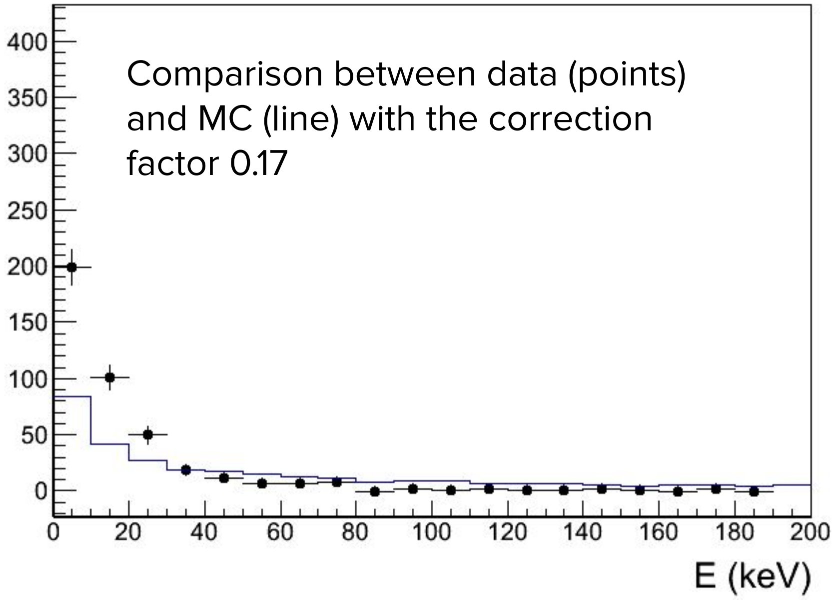


Americium-241/Beryllium

activity	emission n/sec	capsule type	code
1mCi	$2{\cdot}2\times10^{3}$	X.2	AMN.11
3mCi	$6{\cdot}6\times10^{3}$	X.2	AMN.13
10mCi	$2{\cdot}2\times10^{4}$	X.2	AMN.15
30mCi	$6{\cdot}6\times10^{4}$	X.2	AMN.16
30mCi	$6{\cdot}6\times10^{4}$	X.21	AMN.168
100mCi	$2{\cdot}2\times10^{5}$	X.2	AMN.17
100mCi	$2{\cdot}2\times10^{5}$	X.20	AMN.170
300mCi	$6{\cdot}6\times10^{5}$	X.2	AMN.18
500mCi	$1{\cdot}1\times10^{6}$	X.3	AMN.19

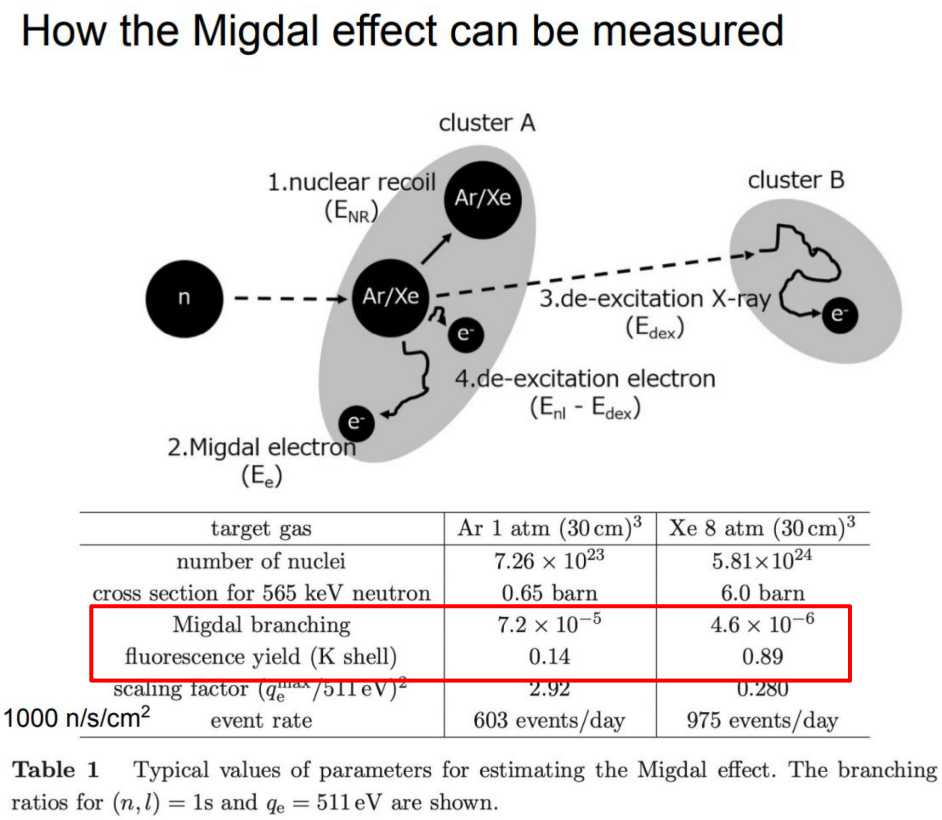
Basic comparison with AmBe data

- **2555** entries for **MC** with **LIME**
  ➜ ~**50 sec** equivalent data taking
- **407** for experimental data in **LEMON**
  ➜ ~**60 sec** live-time
- ratio between the total entries = **0.16**
  ➜ matches with factor obtained considering the volumes LEMON (7), LIME (50) and equivalent time ratio = **0.17**
- distribution in data shows no events at high energy and more events at low energy
  ➜ not surprising: QF not included in MC, maybe saturation not fully corrected, filters in the reco for high density pixels, ...



Comparison between data (points) and MC (line) with the correction factor 0.17

Feasibility of Migdal study with LIME (LEMON)



How the Migdal effect can be measured

target gas	Ar 1 atm $(30\,\mathrm{cm})^3$	Xe 8 atm $(30\,\mathrm{cm})^3$
number of nuclei	7.26×10^{23}	5.81×10^{24}
cross section for 565 keV neutron	0.65 barn	6.0 barn
Migdal branching	7.2×10^{-5}	4.6×10^{-6}
fluorescence yield (K shell)	0.14	0.89
scaling factor $(q_e^{\max}/511\,\mathrm{eV})^2$	2.92	0.280
event rate	603 events/day	975 events/day

1000 n/s/cm^2

Table 1 Typical values of parameters for estimating the Migdal effect. The branching ratios for $(n,l) = 1s$ and $q_e = 511\,\mathrm{eV}$ are shown.

https://arxiv.org/pdf/2009.05939.pdf

Signal: use the (1s, K shell) x-ray de-excitation line @ 3 keV as an event tag. The signature is a NR with an ER separated by O(cm)

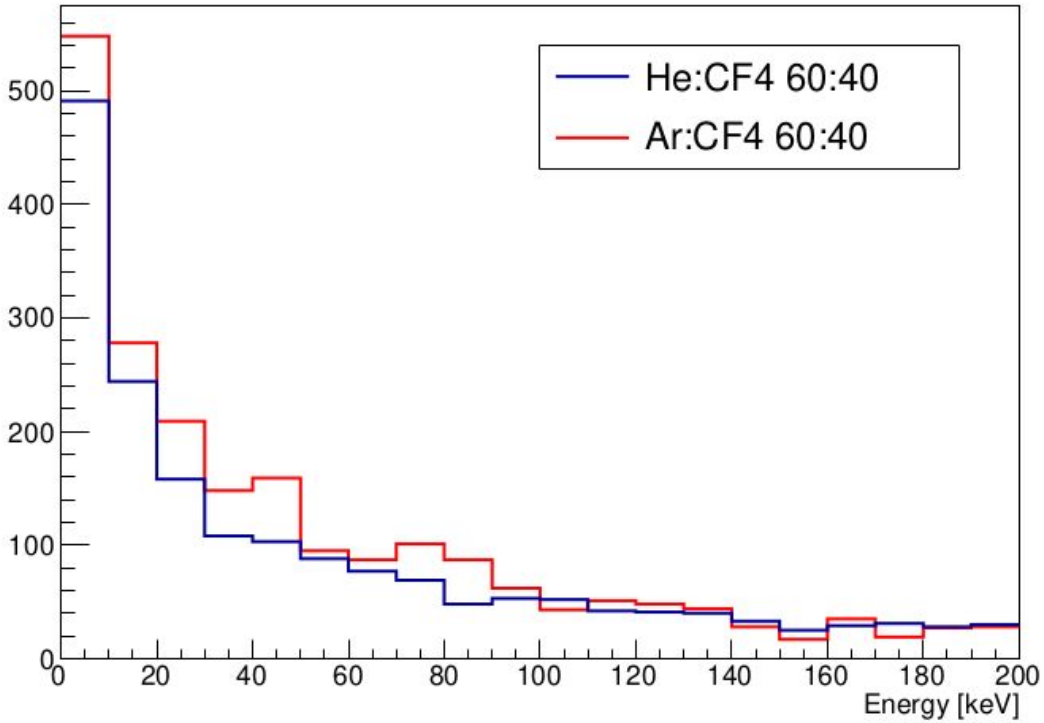
- Source activity: 2.2 10^5 neutrons/sec
    - LIME: 50 NR/sec
    - LEMON: 7 NR/sec
- To study Migdal effect we need at least O(100) interesting events
  ➔ considering the BR of Migdal and probability of X-ray emission, we need **~10^7 NR**
    - LIME: 200000 sec livetime (~3 days)
    - LEMON: 1400000 sec livetime (~17 days)
- Dead time could be a factor 2-3
  ➔ few weeks of data taking

Comparison of the rates (preliminary)

	initial rate/flux	**rate in LIME [s^{-1}]**	**rate in LEMON [s^{-1}]**
neutrons (AmBe*)	2.2 10^5 s^{-1}	50 (NR) + 42 (ER)	7 (NR) + 5 (ER)
gammas 4.4 MeV (AmBe*)	1.3 10^5 s^{-1}	3 10^4 (ER)	4 10^3 (ER)
cosmic rays	0.019 cm^{-2} s^{-1}	20 (ER)	8 (ER)
external gammas	1 cm^{-2} s^{-1}	100 (ER)	20 (ER)
external neutrons	10^{-2} cm^{-2} s^{-1}	~0.01 (NR)	5 10^{-4} (NR)
internal backgrounds	-	4 10^{-3} (ER) + 10^{-5} (NR)	5 10^{-4} (ER) + 10^{-6} (NR)

* Including Pb block of 10x10x10 cm^3 between the source and the detector.
From preliminary simulations the rate of events from gammas at 4.4. MeV are increased of factor ~15 putting the lead, while neutron events are decreased of a factor 3.

First comparison with Ar:CF4 mixture



- 10^7 generated neutrons
- 2555 NR in He:CF4 mixture
- 2585 NR in Ar:CF4 mixture
- The spectrum for Ar:CF4 has more recoils at low energy

Next steps

- Optimize the setup in order to maximize the signal (AmBe neutrons) to noise (all the rest) ratio: ex. change source position, remove lead,...?

- Other possible sources? (AmBe with higher activity, neutron gun...?)

- Double-check the numbers from simulations and compare with data
(gammas of 4.4 MeV from AmBe seem too many according to simulations)

- New student working with Davide and Gianluca will simulate with Garfield the detector parameters with ArCF4 mixture

- Other suggestions?

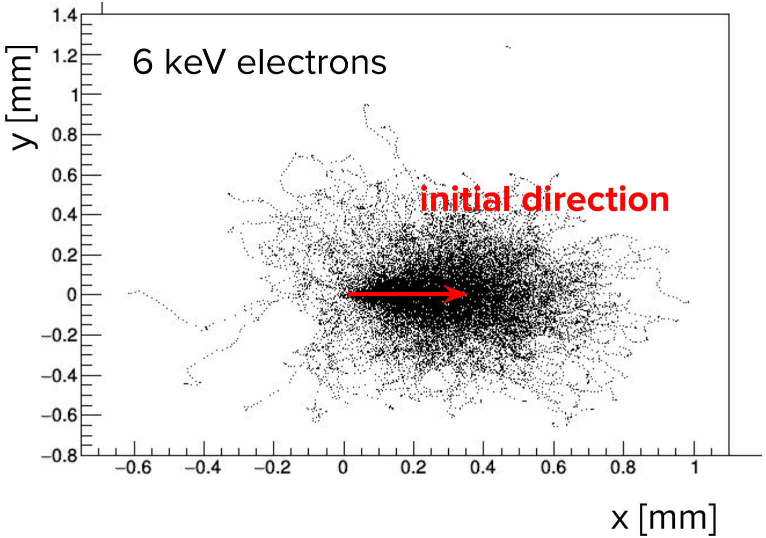
Tests of new reconstruction branch "lime2021"*

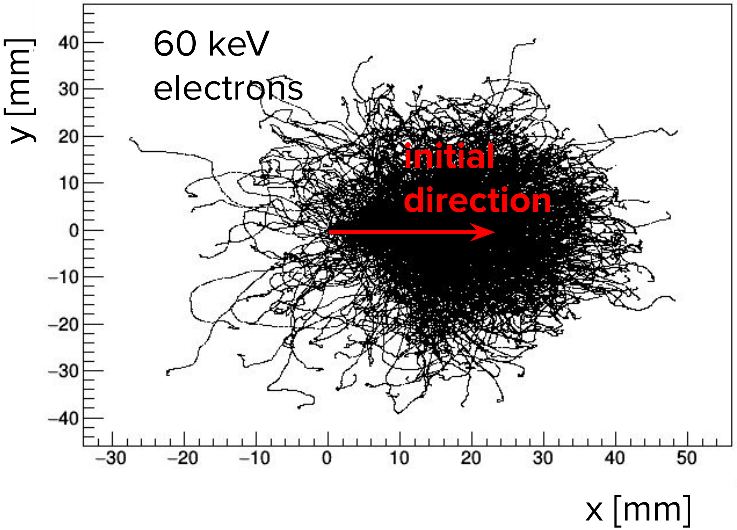
*still under development, version not stable

IDAO samples

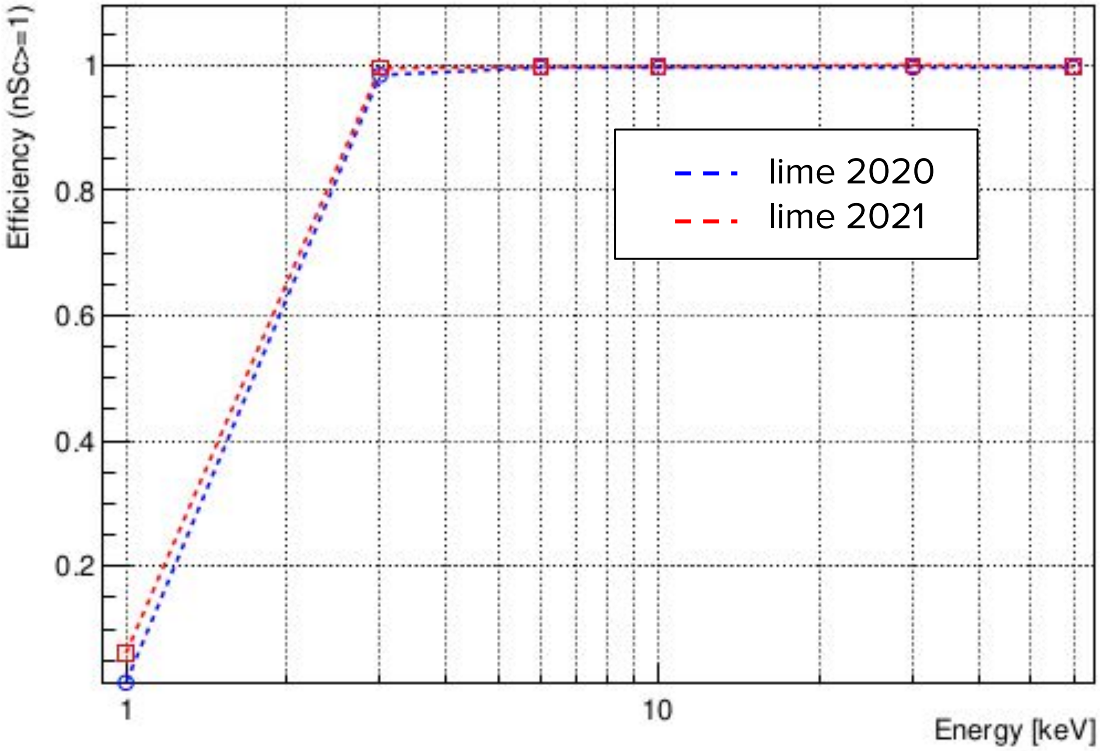
- ER simulated with Geant4
- He NR simulated with SRIM
- 1000 events starting from the center
- Energies 1, 3, 6, 10, 30, 60 keV
- Initial direction (1,0,0)

More results of the analysis with old reconstruction (lime2020) in this presentation https://docs.google.com/presentation/d/12B_H4pDyzcdemhw7tCJse-itwJ3qgU6zb7I3OeTAM2M/edit?usp=sharing



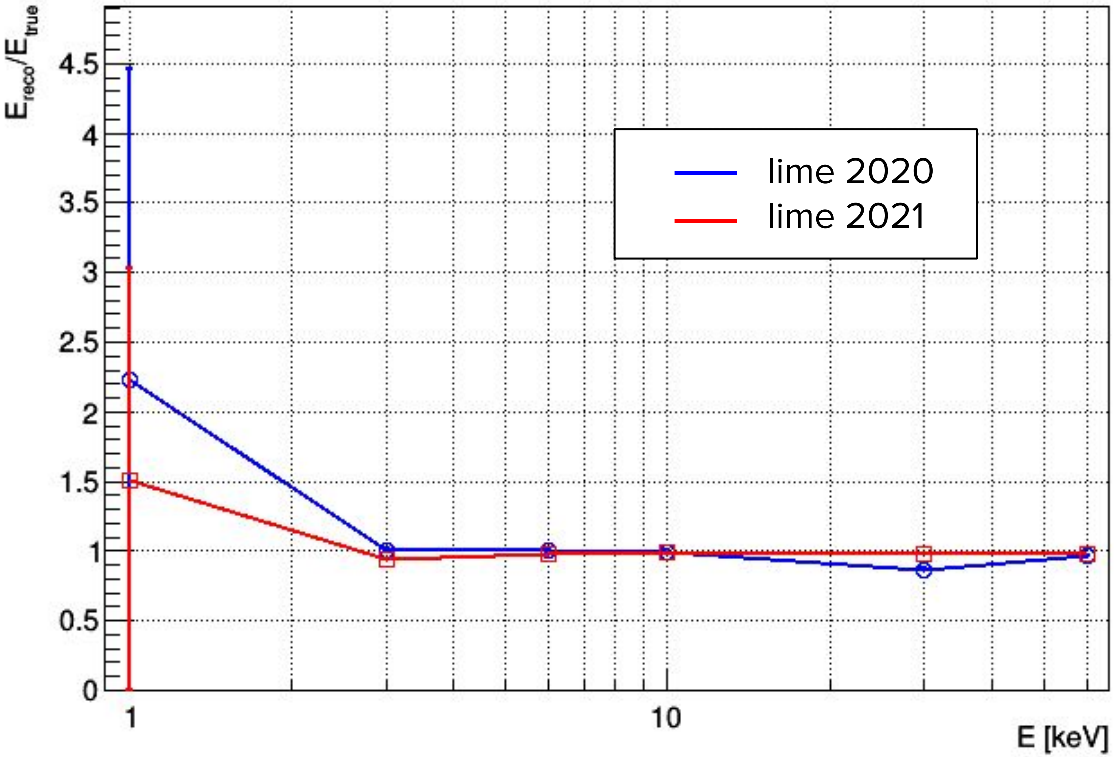


Comparison lime2020 vs lime2021 efficiency ER



- Efficiency is similar and slightly better for energies >3 keV

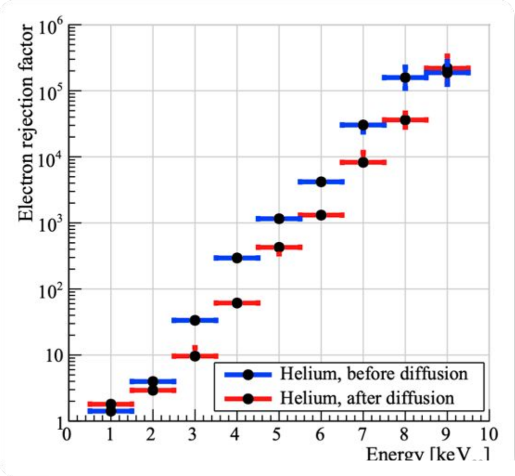
Comparison lime2020 vs lime2021 energy bias



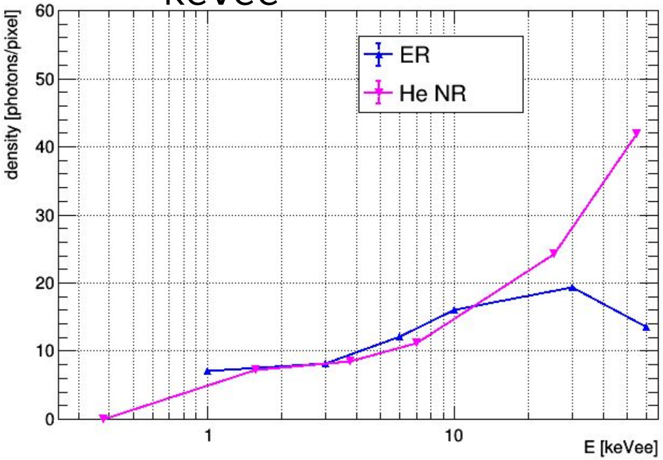
- Containment of the SC seems a little better for energies up to 60 keV

- Need to test at higher energy (now lngs queues are busy for Emanuele's tests)

Next steps



- Obtain a plot of rejection ER vs energy (similar to the one top right)
- Define a selection to separate ER from NR as a function of energy
- Study discriminant variables: ex. density (sc_integral/sc_nhits) as a function of energy in keVee



- preliminary, old reco
- density of 6 keV ER ~13 ➔ compatible with LIME AmBe data analysis
- density of NR increasing with energy ➔ not obvious comparison with AmBe because NR in data have a continuum spectrum