

Simulation update

Giulia D'Imperio for the simulation working group

CYGNO general meeting 11/02/21

Nuclear recoils simulations

Update of NR simulations with SRIM

- Ionization quenching factor (IQF):
fraction of energy released by a recoil in a medium through ionization compared with its total kinetic energy
- IQF measurement in He4 ([arXiv:0810.1137](#)) is in agreement with SRIM simulation within 10-20%

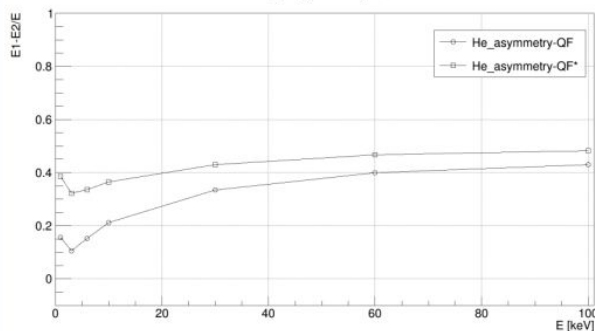
- $$IQF = \frac{n_{pair}^N}{E_N} / \frac{n_{pair}^X}{E_X} \rightarrow n_{pair}^N = E_N \times IQF \times \frac{n_{pair}^X}{E_X} \rightarrow n_{pair}^N = E_N \times IQF \times W^X$$
 1 keV
(see [arxiv:1806.05880](#))

- Developed in SRIM two approaches: QF *constant* or *varying* over the track
→ same average QF, but reconstructed spatial distribution of ionization energy along the track different

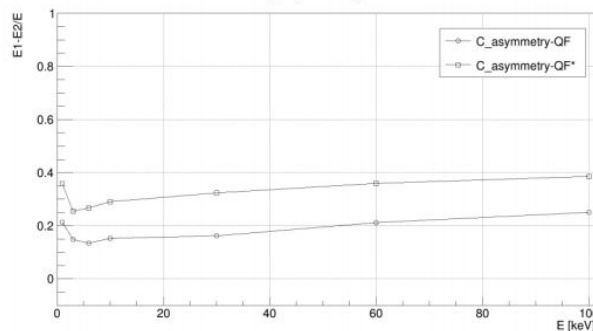
TRACK ASYMMETRY

The difference between the two proposed methods to reproduce the ionization energy deposit spatial distribution can be expressed by an asymmetry parameter $(E1-E2)/E$

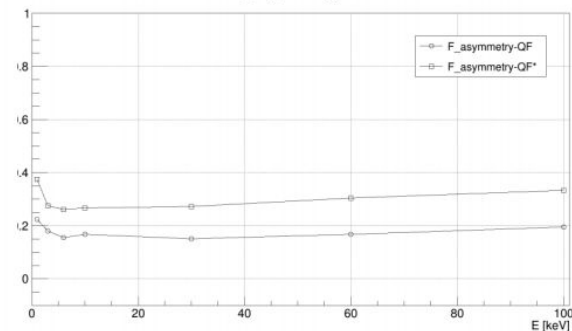
He_asymmetry-QF



C_asymmetry-QF



F_asymmetry-QF



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Comparison with AmBe or FNG data may help to validate the method and find which approach is in better agreement with data, but for the moment we think that our SRIM simulation framework is ready for “official” MC production .

Simulation of AmBe in LIME

AmBe simulation in LIME

- LIME simulation code <https://github.com/CYGNUS-RD/CYGN0-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)

Lead 10x10x10 cm³ block

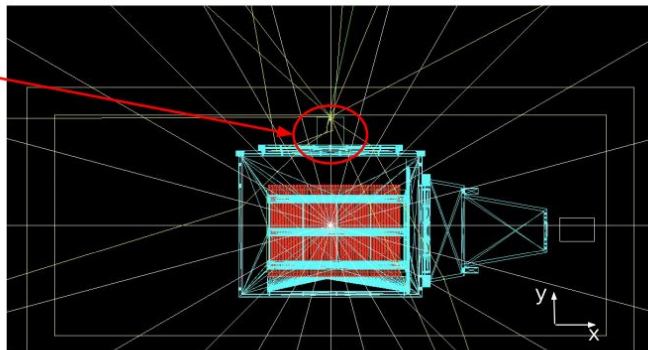
A 10 cm³ block of lead between the detector and the source has been added.

10⁵ neutrons:

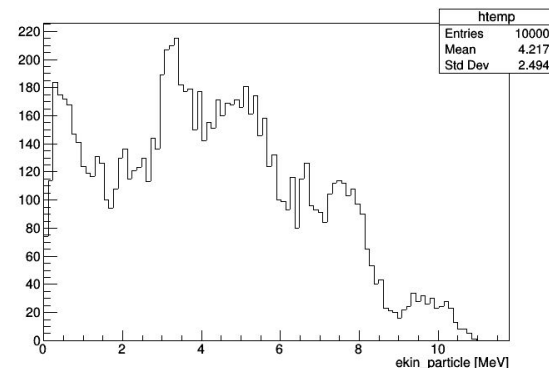
- 45 events (55 without the lead box)

100 gammas:

- Adding the lead box really slows down the simulation
- 16 events

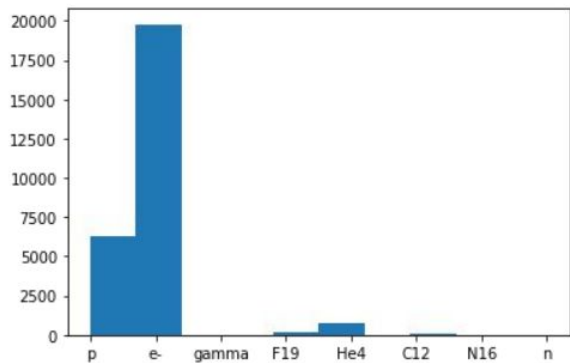


cross-check
neutrons spectrum

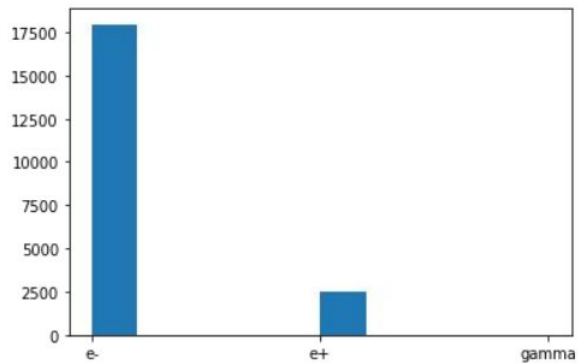


Qualifying the events

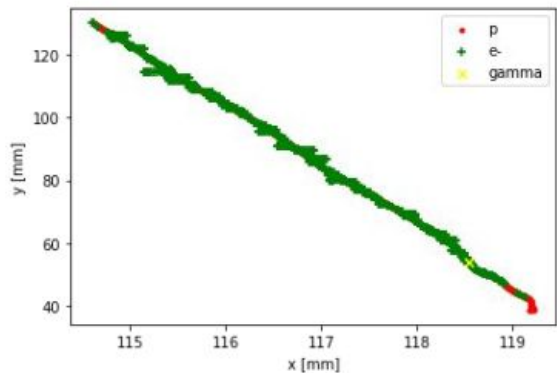
10^5 Neutrons simulation [45 events]



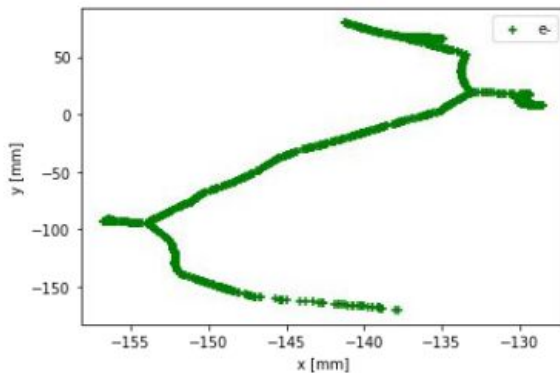
100 gammas simulation [16 events]



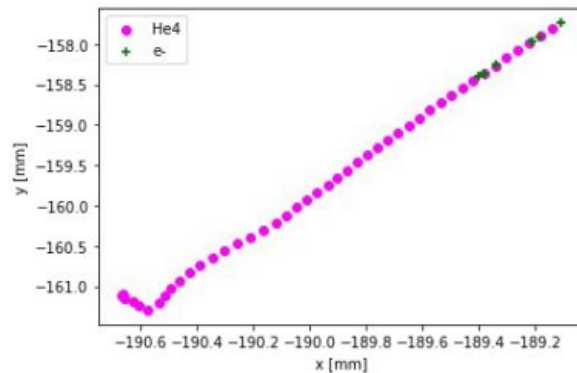
Ionization induced by a proton - neutrons sim.



Electron Recoil - neutron sim.



Nuclear Recoil - neutron sim.



Shielding simulations for LIME

Goal & context

- We focused on the [0,20] keV energy range since from literature (measurements and simulation) ER background discrimination is expected to exceed 10^6 at 20 keV
- LIME background assessment towards CYGNO development
 - Neutron + gamma shielding (5 cm Cu or more) allowed by available space
 - We know the available space will not allow external radioactivity reduction at the level we can expect for CYGNO
 - We need to reduced external radioactivity **left after background discrimination** enough to **characterise internal gamma backgrounds** for additional material screening and MC simulation towards a realistic estimate of CYGNO sensitivity that properly includes background
- Neutron flux measurement:
 - no neutron (i.e. water) shielding
 - Faraday cage only (2 cm Cu) or gamma shielding acting also as Faraday cage (Shield cage, 5 cm Cu or more)
 - **NR induced by external and internal radioactivity needs to be negligible w.r.t. expected neutron yield**
 - Can allow larger gamma background at low energies **after background discrimination (which we assume we can reach $O(10^4)$ at keV energies)** w.r.t. WIMP searches since the requirement to reach very low energy threshold is reduced in this context

Internal background contribution is about $0.5\text{--}1 \times 10^5$ gamma/year in [0,20] keV

Background assessment for CYGNO: full shielding

From external neutrons:

Shielding – 50 cm water plus 5 cm Cu

Number of events in [0–20] keV: 0.035963 ± 0.0078479 cpd/kg/keV
Resulting in about 18.0445 ± 3.93764 events/year

ER coming from secondary gammas

No NR expected (0 events/yr)

From external gammas:

Shielding – 50 cm water plus 5 cm Cu

Number of events in [0–20] keV: 924.815 ± 19.8165 cpd/kg/keV
Resulting in about 464023 ± 9942.84 events/year

For each additional 25 cm water
the secondary gamma flux
decreases about a factor of 3.

Shielding	Evts/yr [0–20 keV]
5 cm Cu	464000
10 cm Cu	54100
15 cm Cu	6771
20 cm Cu	970

With 5 cm Cu might be difficult to fully characterise internal background

With 10 cm Cu (faraday cage + additional 5 cm external shielding) and slightly reducing water shielding, external background can be suppressed of ± 1 order of magnitude w.r.t. internal

All the details can be found in

https://agenda.infn.it/event/25766/contributions/129971/attachments/78801/102024/CYGNO_LIME_backg_round_summary_08_02_21.pdf

Conclusions & recommendations

- We focused on the [0,20] keV energy range since from literature (measurements and simulation) ER background discrimination is expected to exceed 10^6 at 20 keV
- LIME background assessment towards CYGNO development
 - 40-50 cm H₂O + 2 mm Al (Faraday cage) + 10 cm Cu gamma shielding (5 cm + 5 cm) to suppress external background below internal background
- Neutron flux measurement:
 - 2 mm Al (Faraday cage) + 5 cm Cu gamma shielding
 - (+ possibly other 5 cm Cu, analysis needs optimisation)
 - Still large gamma background at low energies, but no need to get to 1 keV threshold
 - Analysis needs to be optimised for neutron flux measurement, Flaminia working on this