LIME background study

26/07/2021 CYGNO Simulation meeting

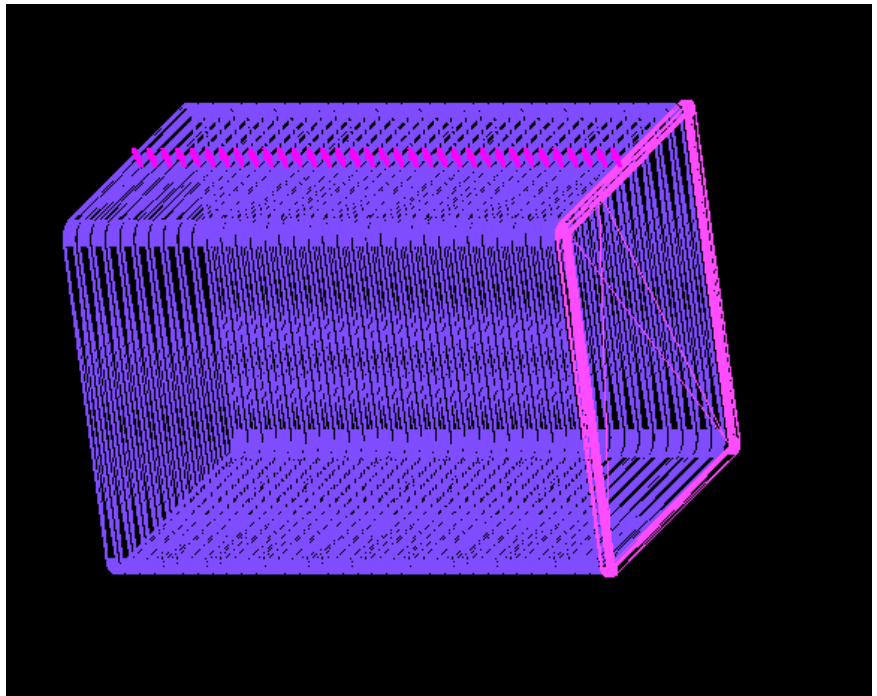
F. Di Giambattista

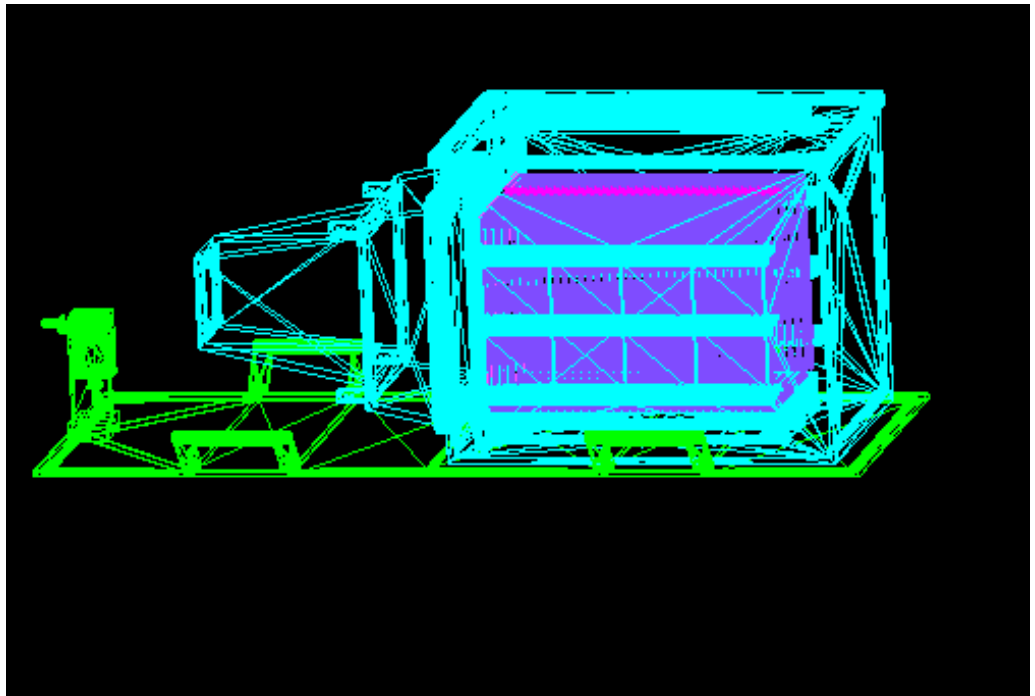
LIME materials radioactivity

- Internal background simulation is about to start
- The activity of the materials was already partially measured by M.Laubestein:
  - GEMs
  - Camera body
  - Camera lens
  - Acrylic
- Activity still unknown:
  - Copper (field cage rings and cathode)
  - Field cage resistors
- Measurement of radioactivity of field cage rings and resistors is foreseen
- In the meantime we will use the measurements done by TREX experiment (https://link.springer.com/content/pdf/10.1140/epjc/s10052-019-7282-6.pdf) - but ×10 on activity values for a more realistic estimate of our background

LIME geometry update

- I updated the geometry of LIME: new cathode, new field rings and resistors (which were not included) - Thanks to Cesidio Capoccia for the CAD design
- I can not use the GEANT4 graphical interface so it takes a while to blindly define the source volumes





Ionization profile from SRIM simulations

A brief summary and some news

New SRIM tracks sample

- I simulated 1000 He ions at different energies, enlarging the sample – now at energies
  1, 3, 6, 10, **12, 14, 16, 18, 20, 22, 24, 26, 28,** 30, **35, 40, 45, 50, 55,** 60 and 100 keV

- I changed the structure of the ionization profile .txt file:

  | Ion | Hit | **Primary/Secondary** | x [mm] | y [mm] | z [mm] | E_{dep} [keV] | E_{dep} ioniz [keV] |

  - The third column is 1 if the hit is referred to an energy deposit by the primary ion (the primary recoil), and it's 2 if it's a secondary recoil (it's a big fraction of the total energy loss)
  - The last column represents the visible energy (the fraction of energy deposit which goes to ionization)

- The ionization energy is calculated by multiplying the (total) energy deposit by a suitable conversion factor
  - Why? Because SRIM **does not** provide explicitly the ionization energy deposit as a function of the **3 coordinates**, but only as a function of the depth along the initial direction x

Ionization energy profile

- Two main SRIM issues: no 3D ionization profile and ambiguous description of cascades

Cascades

- When the primary ion (what we would call "primary recoil" or just "recoil") hits an atom of the medium, it could produce a recoil (a "**secondary recoil**"), which in turn can do the same… A lot of parent and daughter recoils to deal with
- SRIM only gives which kind of atom was hit (He, C or F) and how much energy was transferred in the collision, but it's not explicitly given who the "parent recoil" was (was it the primary recoil? A secondary recoil? A tertiary recoil? …who knows)
- **Solution**: whenever there's a collision along the ion path with an energy transfer high enough (I set it at $5\ eV$) I add hits in the profile with a total energy deposit of 130eV (unless the available energy is lower). The position of these deposits is computed from the expected distance traveled by an ion of that energy, in a random direction starting from the "parent hit"

Ionization energy profile

- Two main SRIM issues: no 3D ionization profile and ambiguous description of cascades

3D ionization profile

- The x position of a deposit does not uniquely identify the point in 3D space where the deposit occurred
- We need a conversion factor between the total energy deposit (for each hit) and the ionization energy deposit
- The fraction of energy deposited by an ion with an initial energy E which is lost to ionization is what we call the (ionization) quenching factor (QF); it is a general property of whole track
- The ionization fraction in each collision is not, in principle, constant along the track; this is of primary importance for our **head-tail** studies
- Is the QF the best conversion factor to use to get the 3D ionization profile?

Ionization energy deposits

The total ionization energy deposited by a recoil of energy E is given by $E_{ion} = QF(E) \times E$

An infinitesimal ionization energy loss (in our case, the deposit corresponding to one hit) is

$$dE_{ion} = \frac{d(E \times QF)}{dE} dE = F(E) dE$$

where dE is the total energy deposited in one hit; dE_{ion} is the ionization energy lost by an ion of energy E which deposits an energy dE

Two approaches were considered:

Conversion factor as a **function of the energy**: $dE_{ion} = \frac{d(E \times QF)}{dE} dE = F(E) dE$

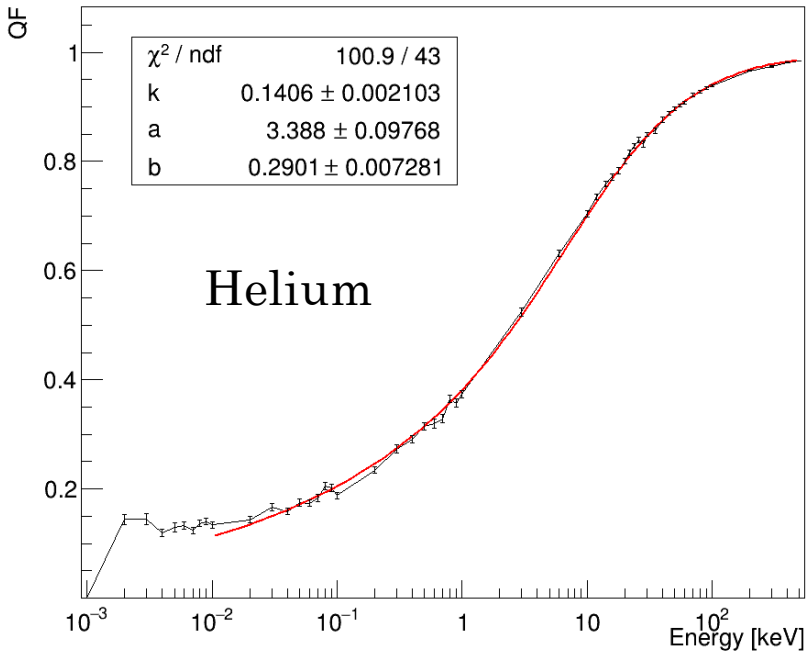
Constant conversion factor: $dE_{ion} = QF(E_{initial}) dE$

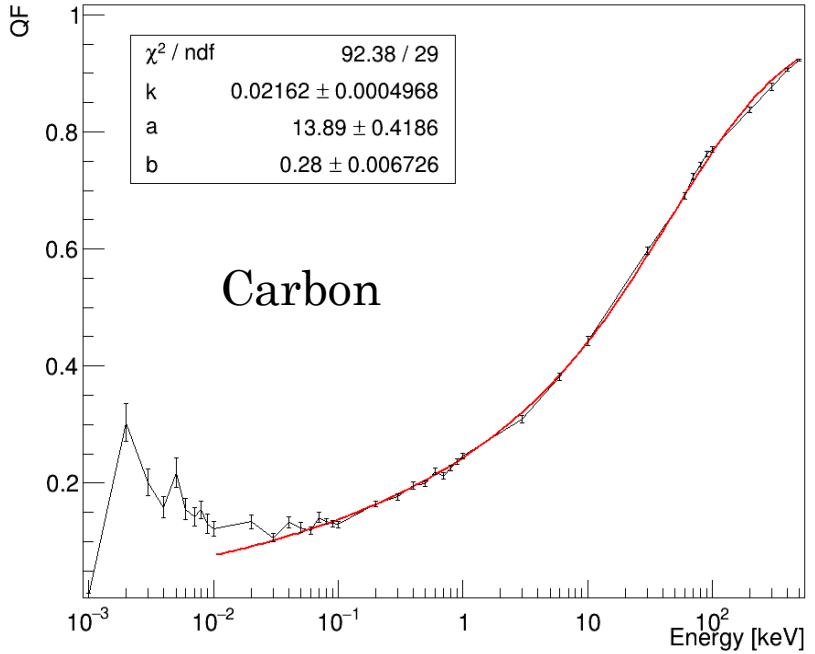
In both cases, integrating dE_{ion} results in $E_{ion} = QF(E) \times E$

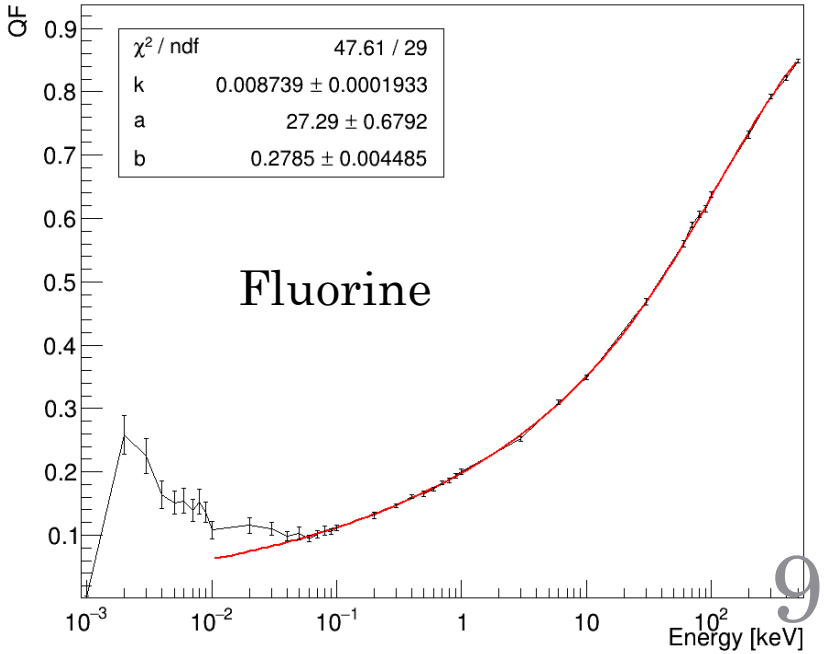
QF and F(E) fit function

Once the QF is computed (energies from 1eV to 500keV, 100 ions), the points are fitted with a function

$$QF = \frac{k(E + aE^b)}{1 + k(E + aE^b)}$$

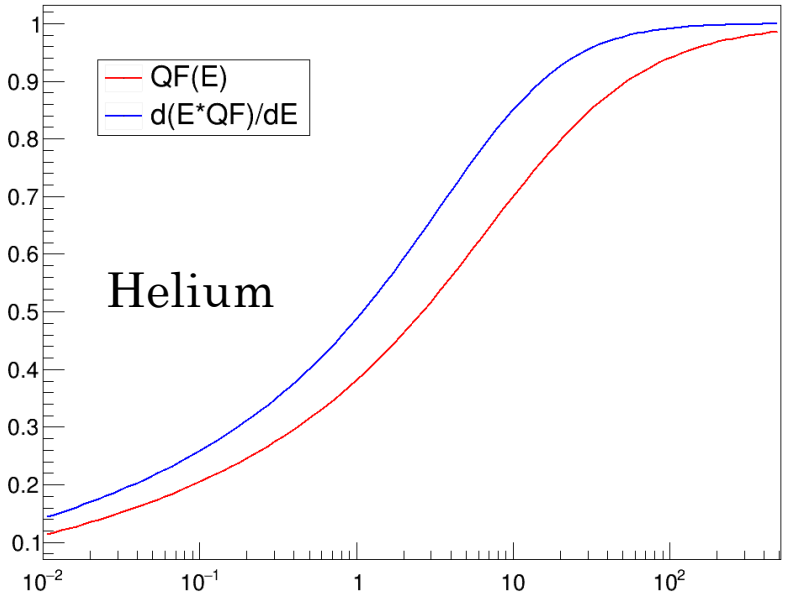


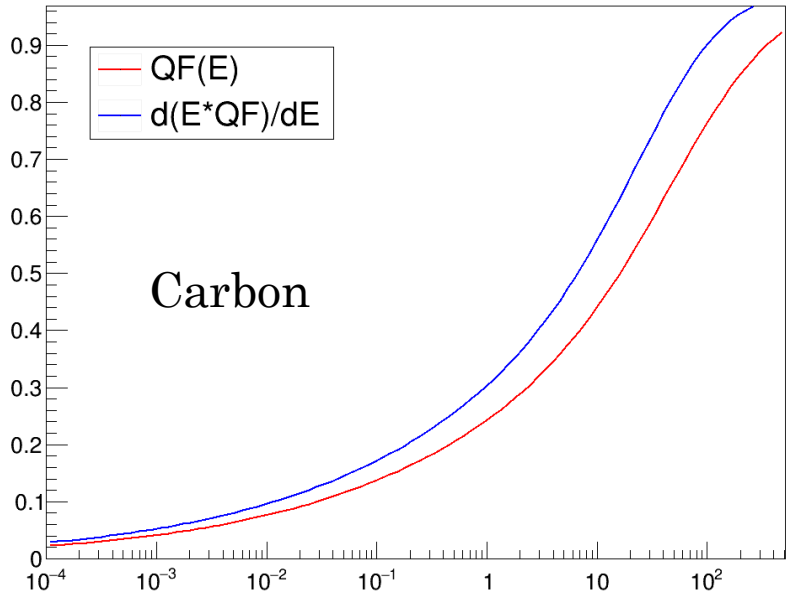


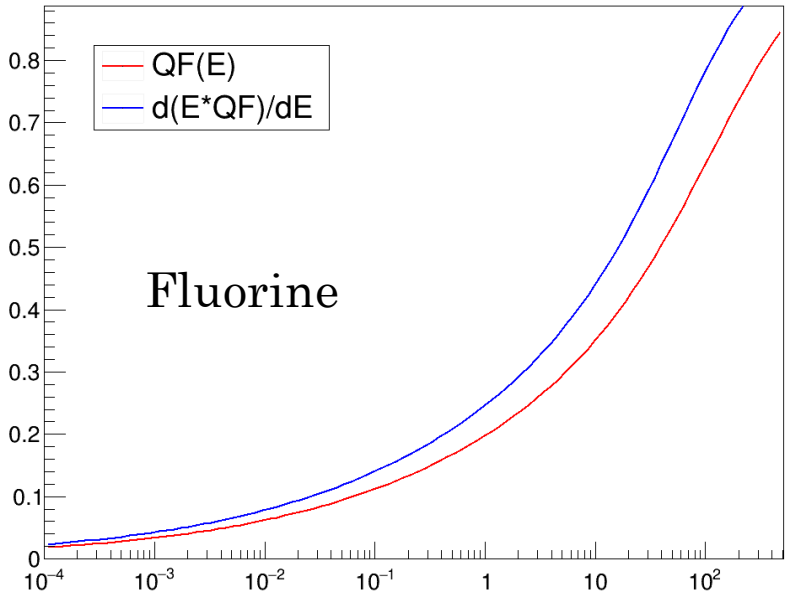


QF and F(E) fit function

- F(E) is computed as the derivative of QF(E), with the same parameters k, a and b
- Whenever the energy E_i of the ion along the track falls below the w value (46.2 eV) the conversion factor $F(E_i)$ is set to 0



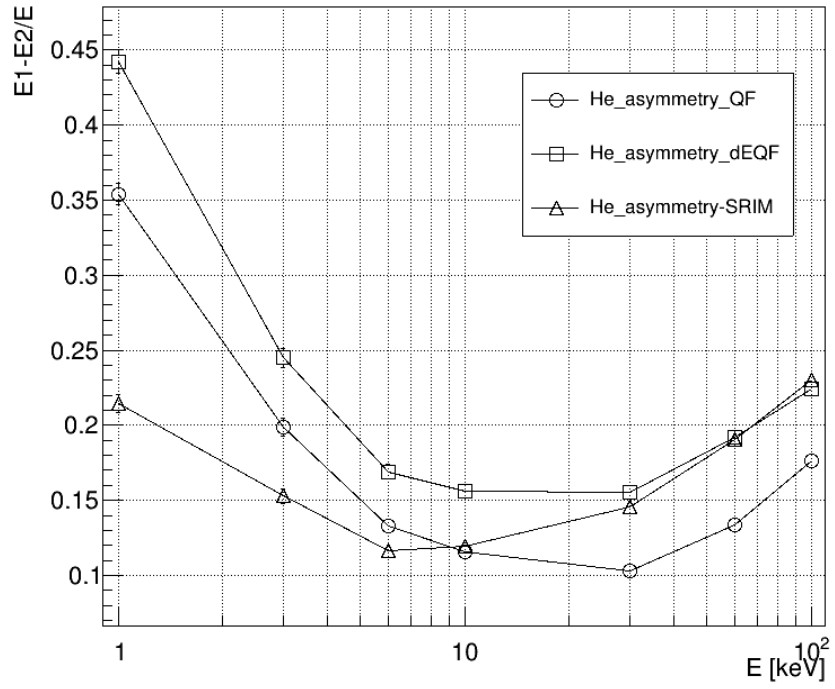


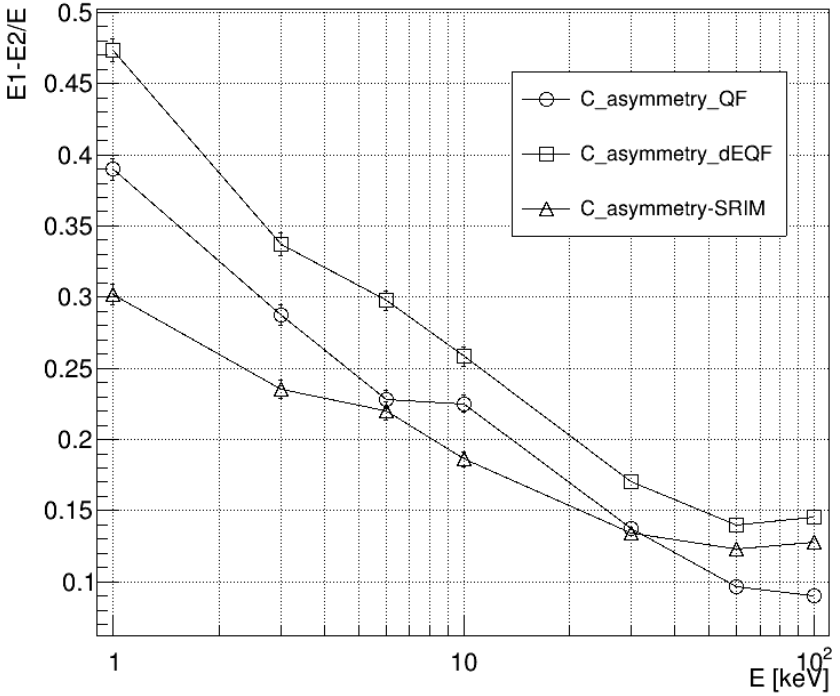


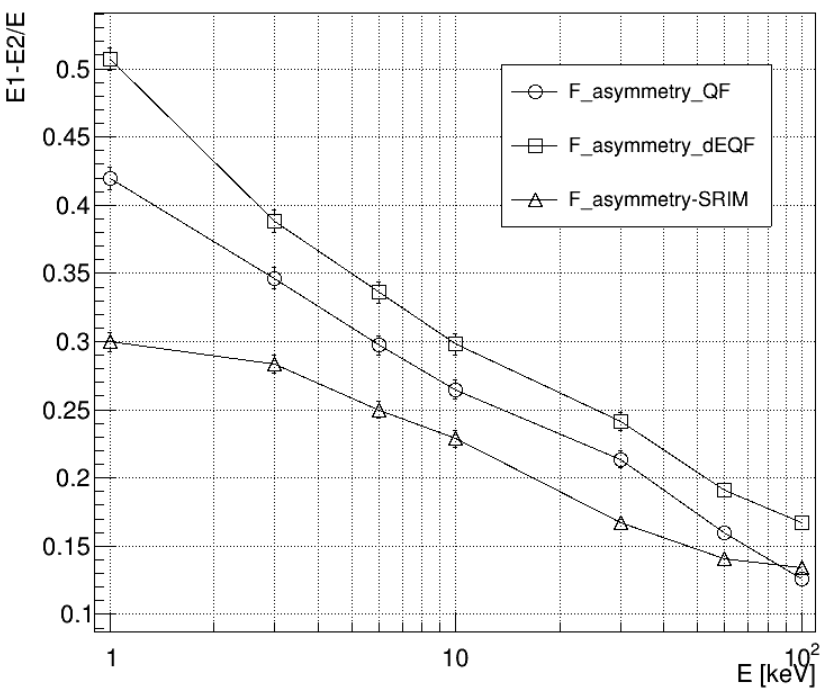
F(E) and QF comparison - asymmetry

From the ionization profile I compute the energy deposit asymmetry of the track projected on the x-axis (to compare directly with SRIM results)

(Asymmetry = relative difference in ionization energy deposit between the first and the second half of the track)



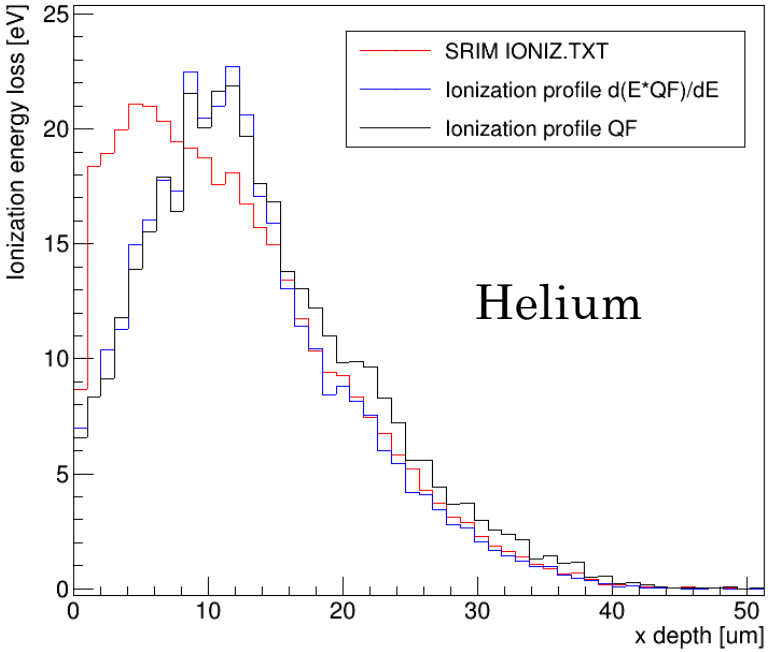


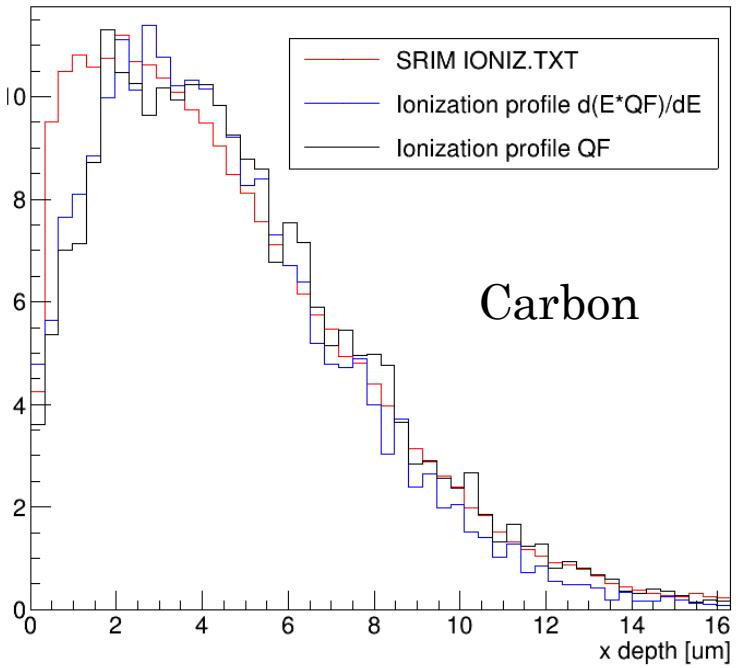


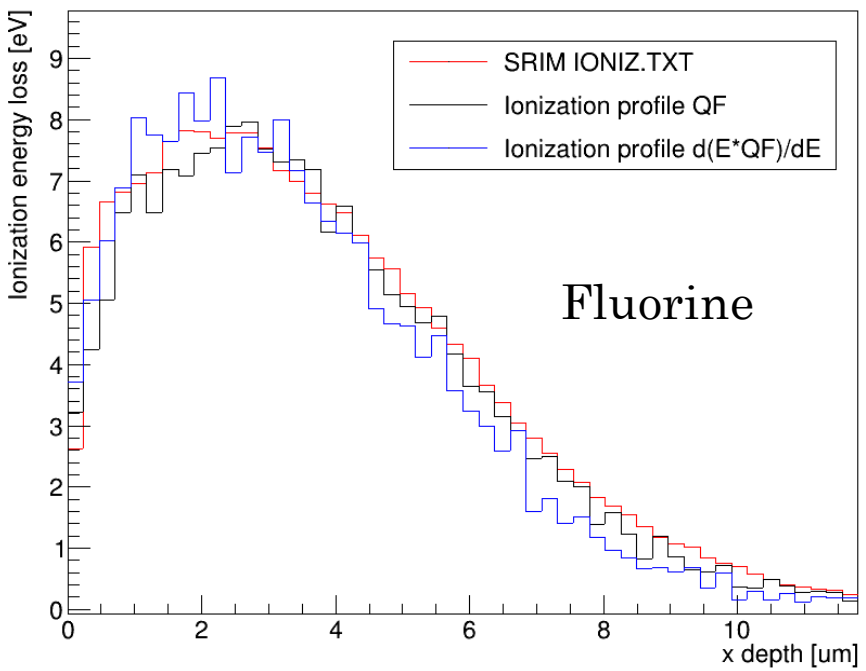
F(E) and QF comparison - profile

At 1 keV (average profile over 1000 ions):

- Both approaches don't reproduce very well the beginning of the track (especially for lighter ions)
- No clear advantage in using a constant conversion factor or F(E) (for He, F(E) seems better; for F, QF seems better; for C, it doesn't show significant differences)



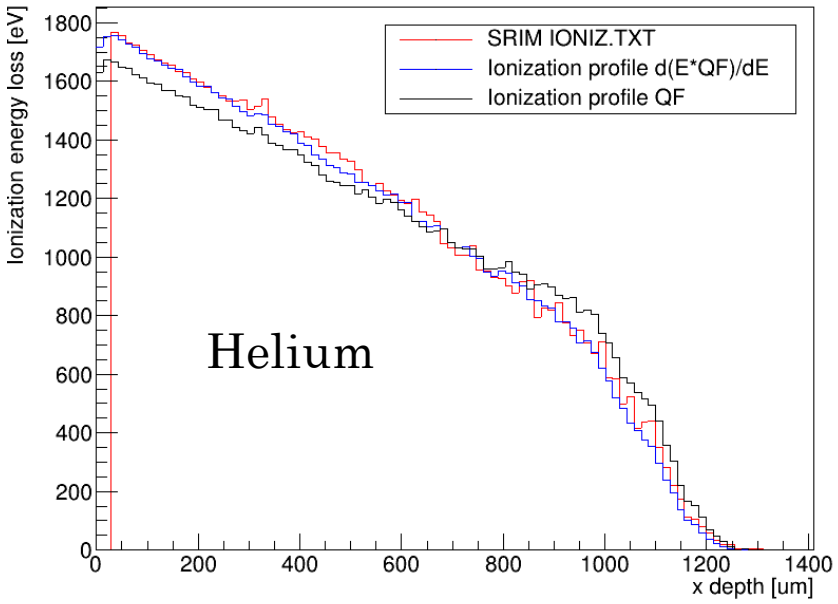


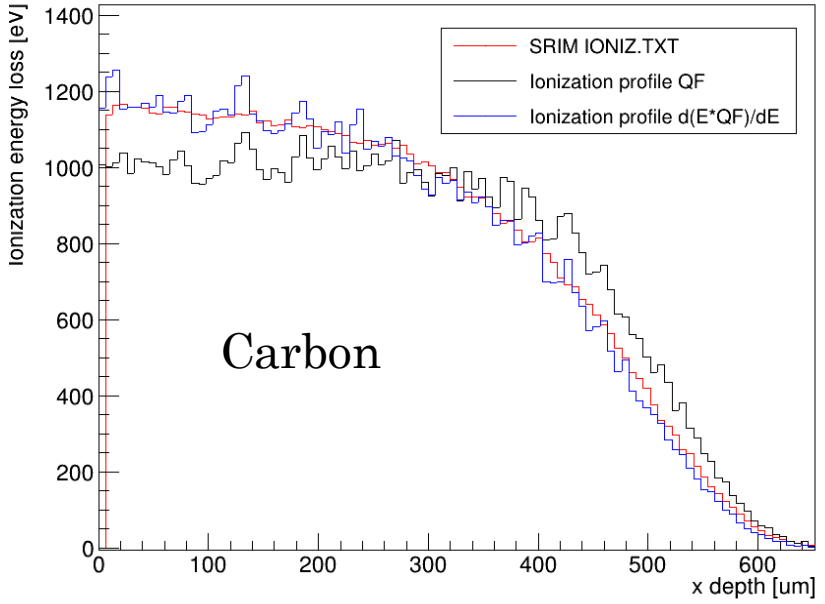


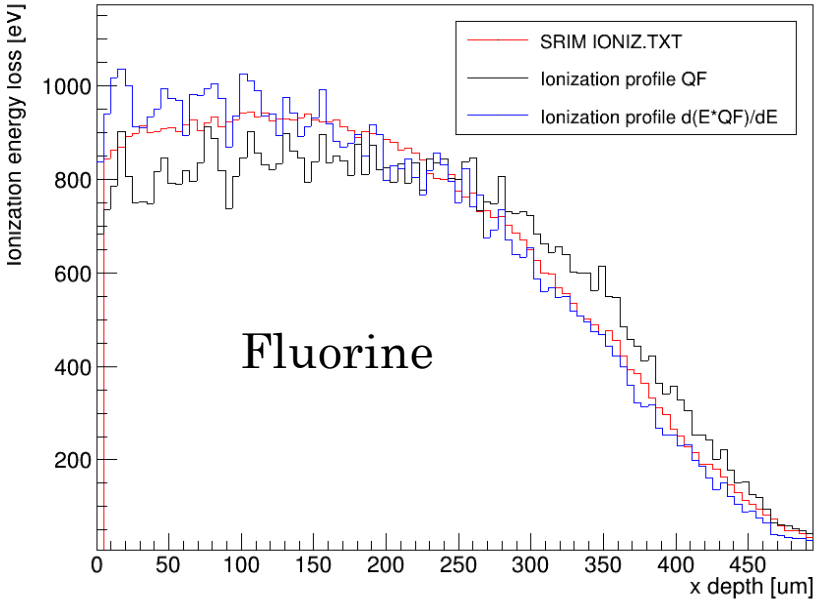
F(E) and QF comparison - profile

At 100 keV (average profile over 1000 ions):

- The shape of the ionization profile is well reproduced along the whole depth
- Applying a conversion factor which is a function of the energy is clearly consistent with the profile provided by SRIM







Conclusions

- A conversion factor for ionization energy deposition *dependent on the energy* reproduces better the ionization profile of tracks, especially at higher energies (>10 keV)
- The ionization profile now includes the new ionization fraction approach, which is closer to SRIM ionization energy profile estimation (better for head-tail studies)
- Samples ready for digitization (Atul already started)
- Carbon and fluorine simulations will be done to match the energy sample already available for helium (between 10keV and 60 keV)

- Internal background simulation in LIME will start soon, with the updated geometry and also including ceramic resistors
- The simulations can be updated once we have the results of the measurement of our copper sample and the resistors