Nuclear recoils simulations with SRIM

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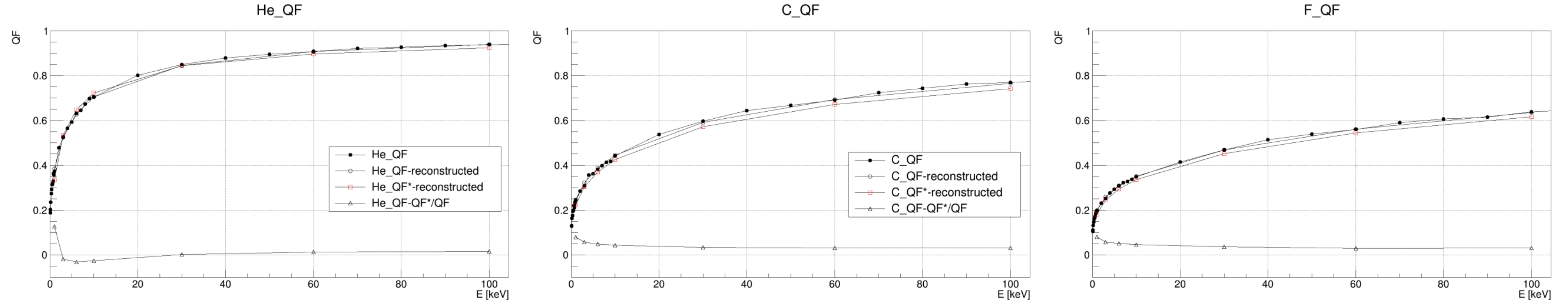
Ionization energy losses - QF

- We want to reconstruct the energy deposition along the nuclear recoils tracks – and obtain the spatial distribution of electron-ion pairs
- The quenching factor represents the fraction of ionization energy release
  - It depends on the energy of the nucleus interacting with the gas
- The quenching factor is $QF(E^{initial}) = \frac{E^{ioniz}}{E^{initial}} = \frac{\int_0^{x_{max}} dx\, dE^{ioniz}/dx}{E^{initial}}$, as calculated from SRIM output files
- The spatial distribution of ionization energy deposition is lost in the integral
- We can define a function that describes the ionization energy loss as a function of the (current) energy of the ion (not the initial energy of the recoil)
  - The track is divided in segments ΔE – in each segment, the fraction of energy lost to electrons is different, depending on the current energy of the ion

- $F(E) = \frac{\Delta E^{ioniz}}{\Delta E} = \frac{Ionization\ energy\ lost\ between\ E\ and\ E-\Delta E}{\Delta E} = \frac{E\times QF(E)-(E-\Delta E)\times QF(E-\Delta E)}{\Delta E}$

Quenching factor

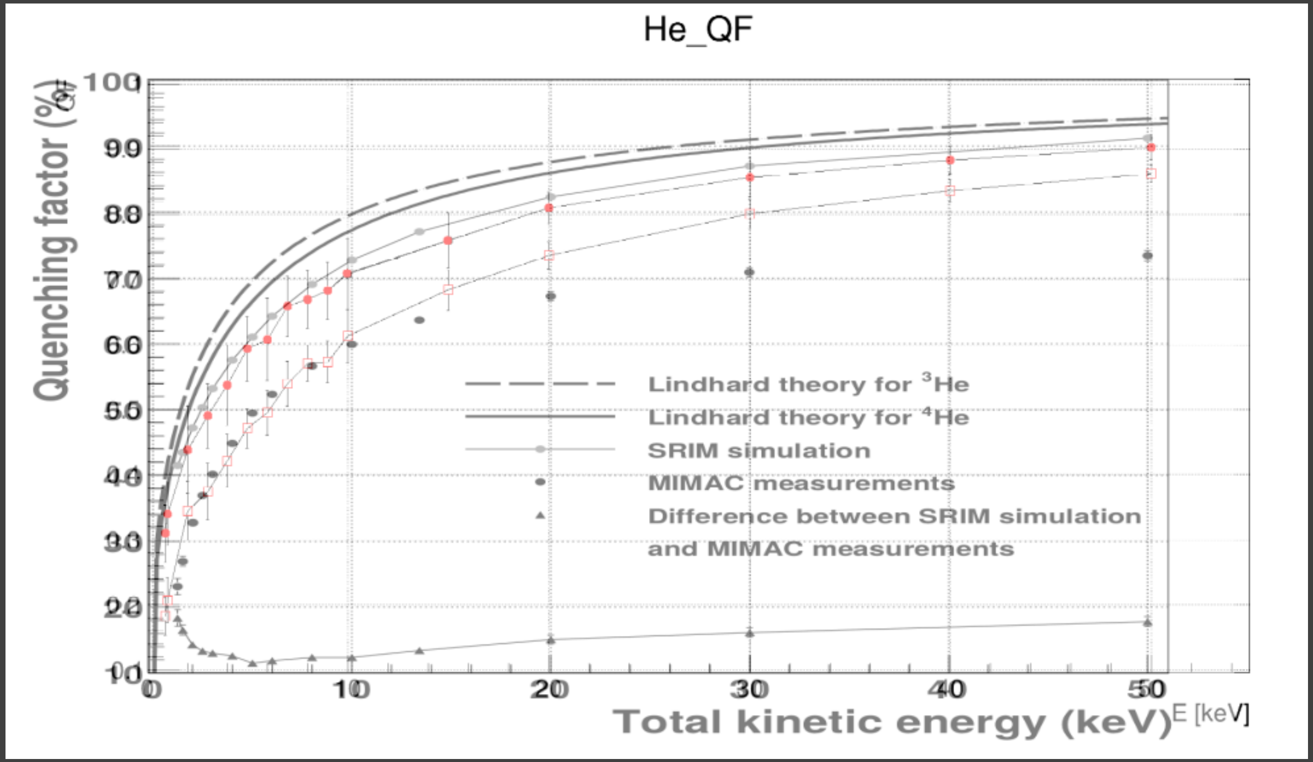
- At each step in the track, the energy deposit is multiplied by $QF(E^{initial})$ or $F(E_n)$ (E_n = n-th step energy) to obtain the ionization energy E_n^{ioniz}
- For each track, the QF is computed as $\frac{\sum_n E_n^{ioniz}}{E_{initial}}$; the results are then averaged over 1000 ions per energy
- The reconstructed quenching factors (obtained with the two approaches) are consistent with each other



Comparison with MIMAC results

- A comparison with the results of the MIMAC collaboration was done (to check our method of estimation of the QF)
- Our estimation of the QF is consistent with their SRIM simulation (red dots)

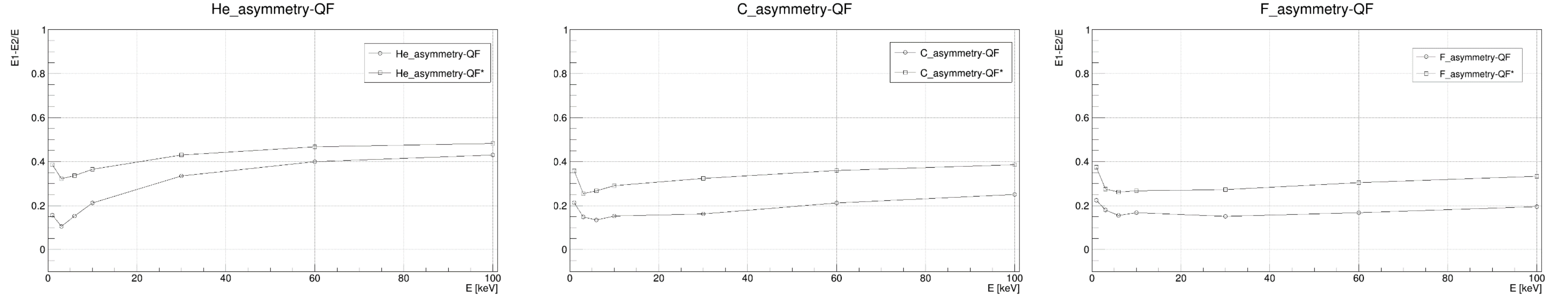
- If the F-factor is applied to the recoiling nuclei generating cascades, the resulting reconstructed QF is lower than expected and consistent with measurements up to 10 keV (probably a **coincidence**)



Spatial distribution of ionization

The difference between the use of QF or F is how the resulting total ionization energy is distributed along the track.

Relative difference in energy deposition in first and second half of the track: $\frac{E_1^{ioniz} - E_2^{ioniz}}{E^{ioniz}}$



Conclusions

- The quenching factor was evaluated at different energies (1, 3, 6, 10, 30, 60, 100 keV) for different elements (H, He, C, F) and in different mixtures (He: CF_4 60/40% at 1atm, $He + 5\%\ C_4H_{10}$ at 700mbar), with two different approaches (QF and F)
- The two approaches return the same average quenching factor along the tracks
- Our method of calculating the QF is consistent with MIMAC SRIM simulations
- The reconstructed spatial distribution of ionization energy along the track changes between the constant QF approach and the varying F approach – which one is more likely to reproduce the real distribution?

He ions in He gas simulation

$$E_{cascade}^{ioniz} = F(element_{primary\ ion}, E_{ion}) \times \Delta E$$

$$E_{cascade}^{ioniz} = F(element_{recoil}, E_{recoil}) \times \Delta E$$