SEMI-ANALYTICAL MODELLING OF NUCLEAR RECOIL TRACKS IN MINERALS WITH SRIM

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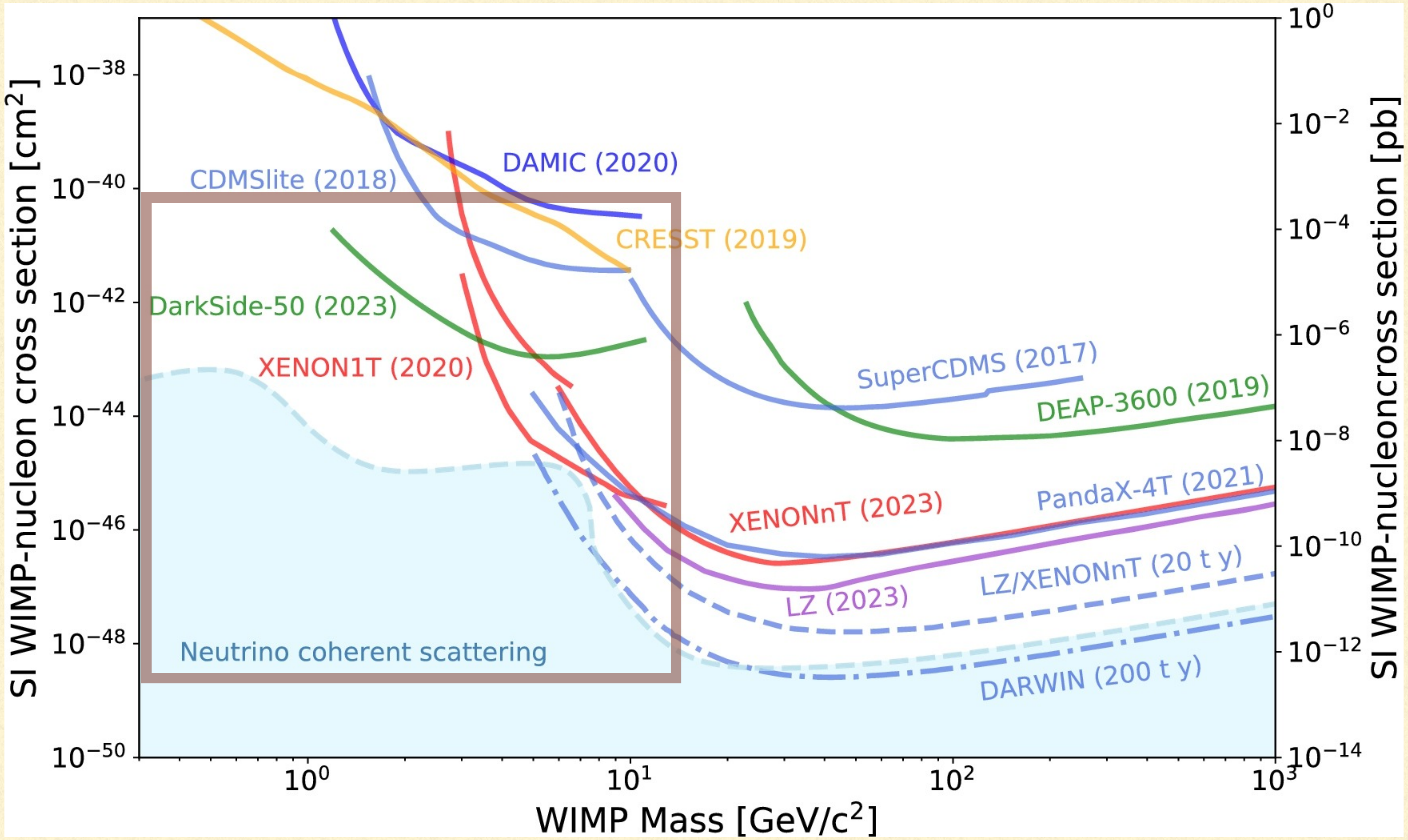
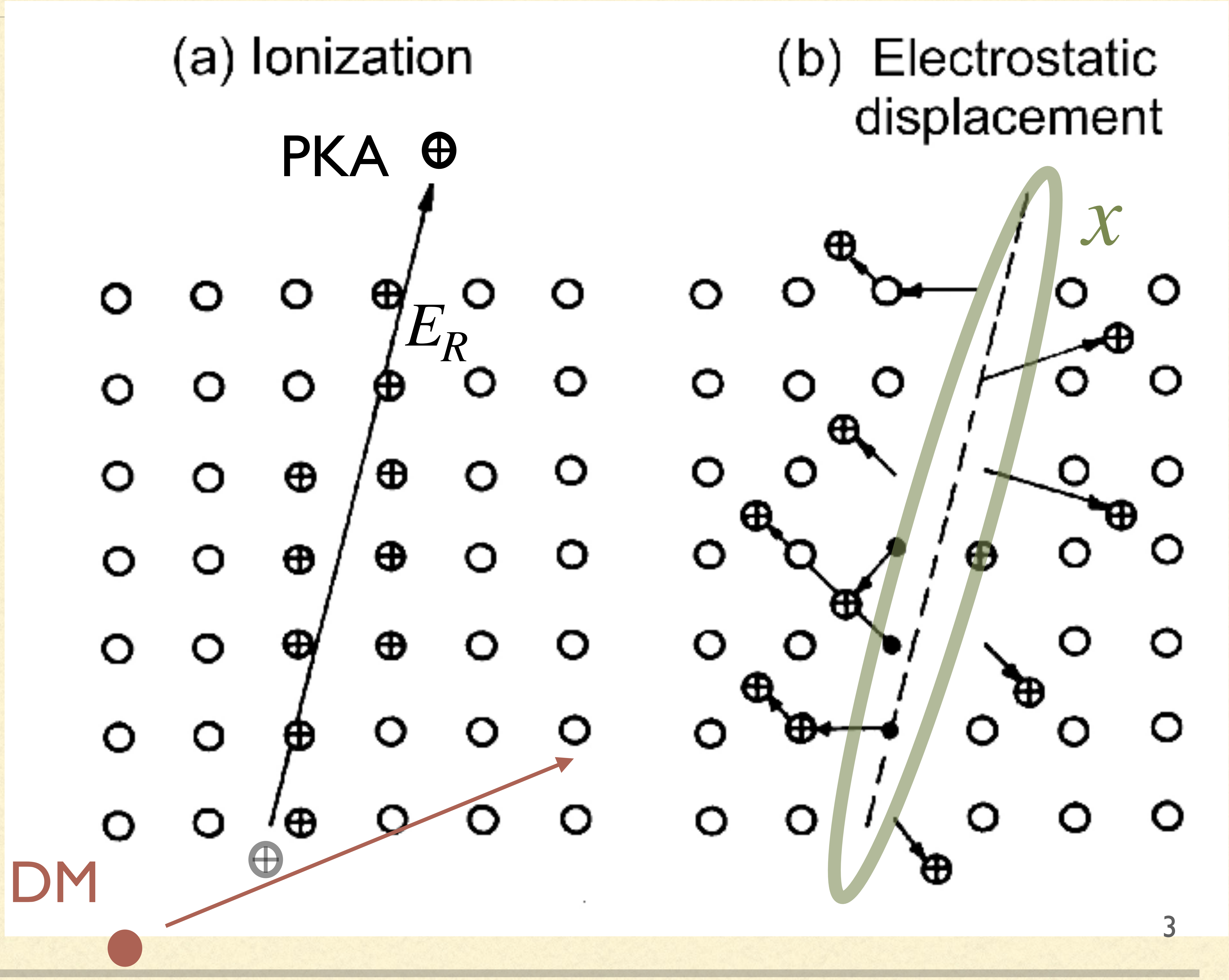
WHY PALEO-DETECTION?



Baudis, L. (2024). DARWIN/XLZD: A future xenon observatory for dark matter and other rare interactions. *Nuclear Physics. B*, *1003*, 116473-. https://doi.org/10.1016/j.nuclphysb.2024.116473

WHAT IS PALEO DETECTION?

- DM or any other incident particles with new physics interactions
- PKA: primary knock-on atom
- E_R: recoil energy of the PKA
- x:length of the damage track (or track length)



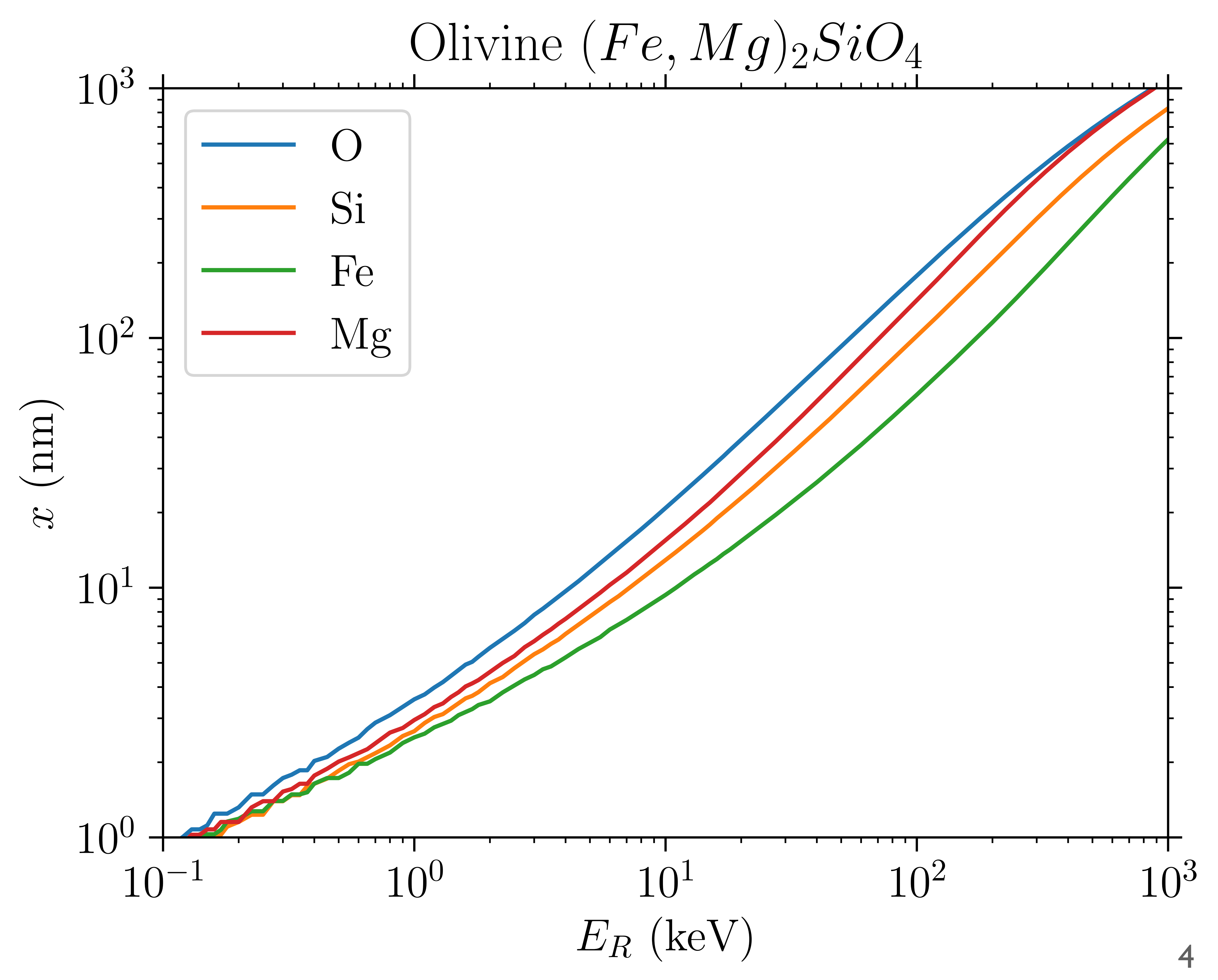
Dickin, A. P. (2005). *Radiogenic isotope geology* (2nd ed.). Cambridge University Press.

E_R - X_T RELATION

$$\frac{dR}{dx} = \frac{dR}{dE} \times \left|\frac{dE}{dx}\right|$$

Energy spectrum of the incoming particle

stopping power of the target

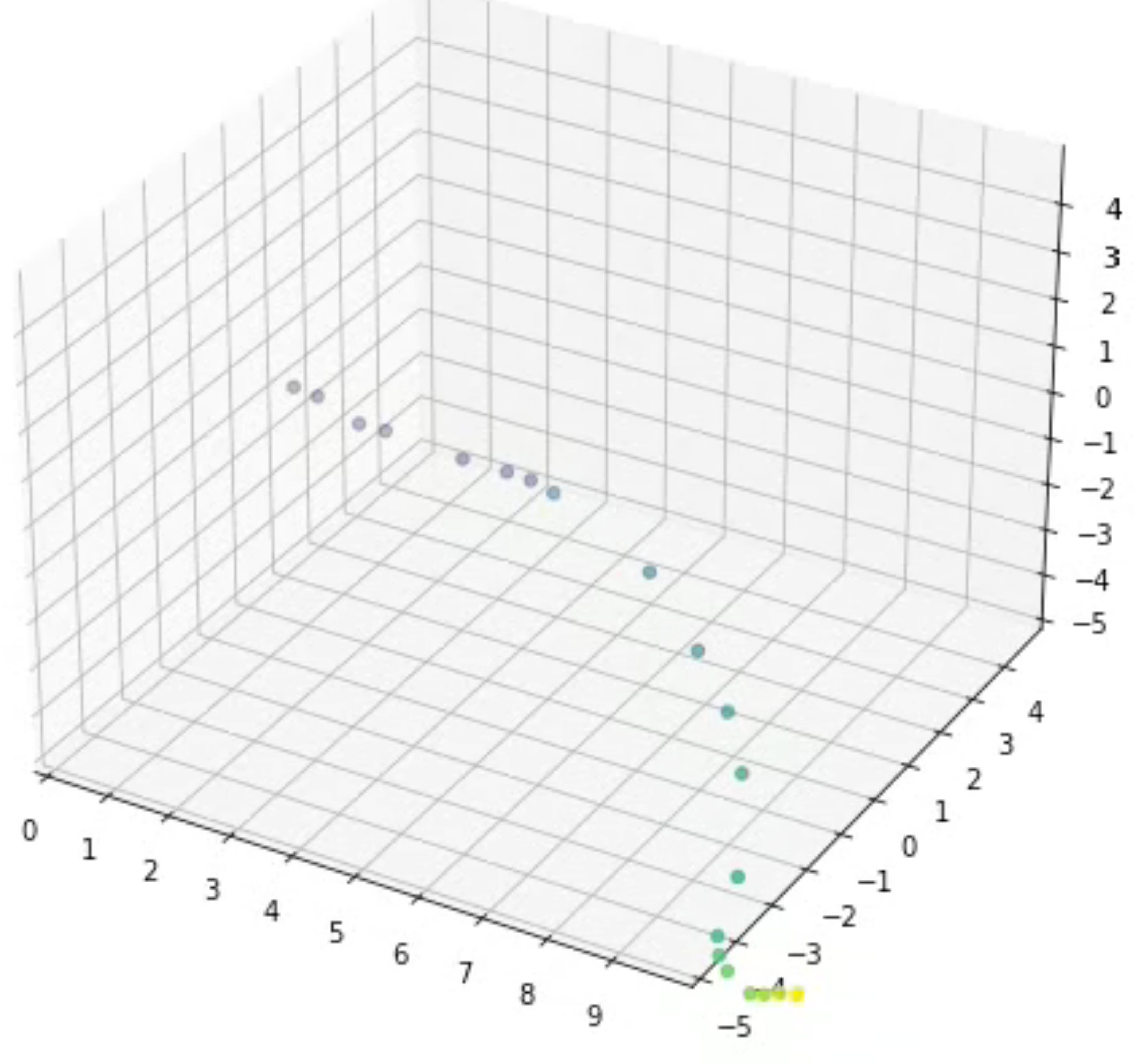


- Stopping power is a statistical average
- Ions of a given recoil energy could give rise to a distribution of track lengths

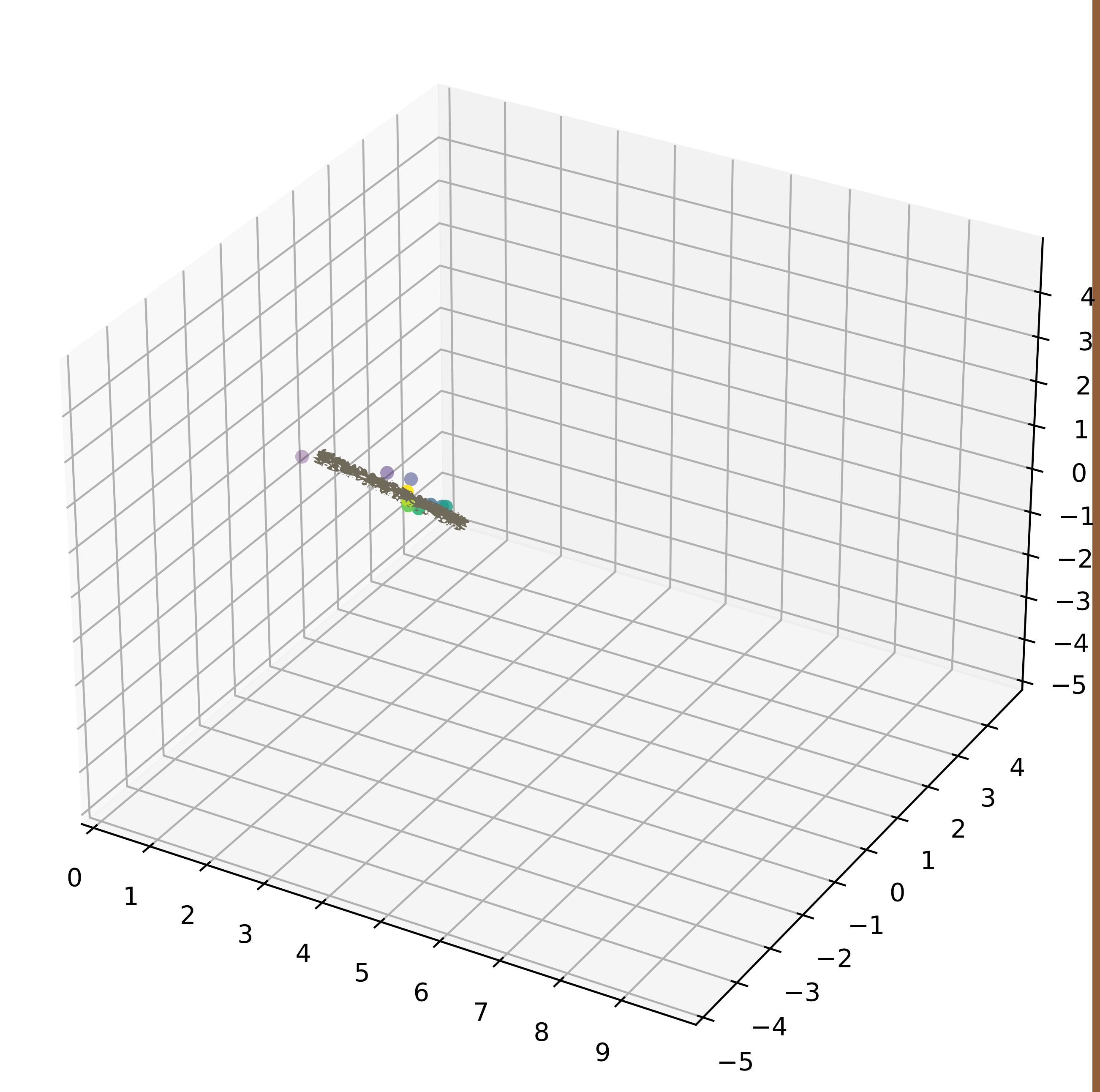
TRIM (TRANSPORT OF IONS IN MATTER)

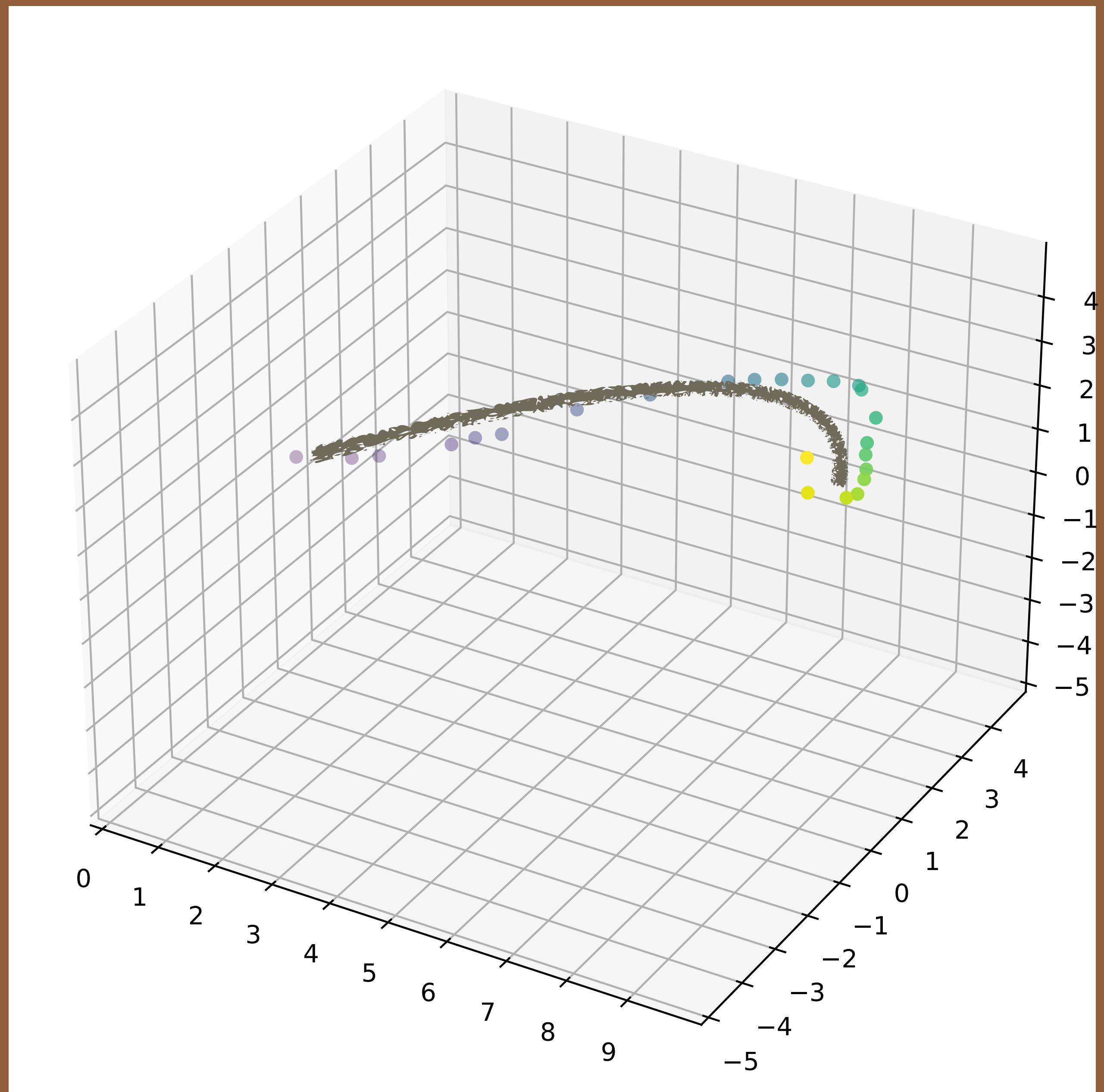
- a Monte Carlo program that calculates interatctions of ions with amorphous targets
  - simulates cascades of produced by irradiated ions
  - record the locations of all collisions between irradiated ions and target atoms
- e.g. irradiate a 5keV ion onto Olivine 40000 times

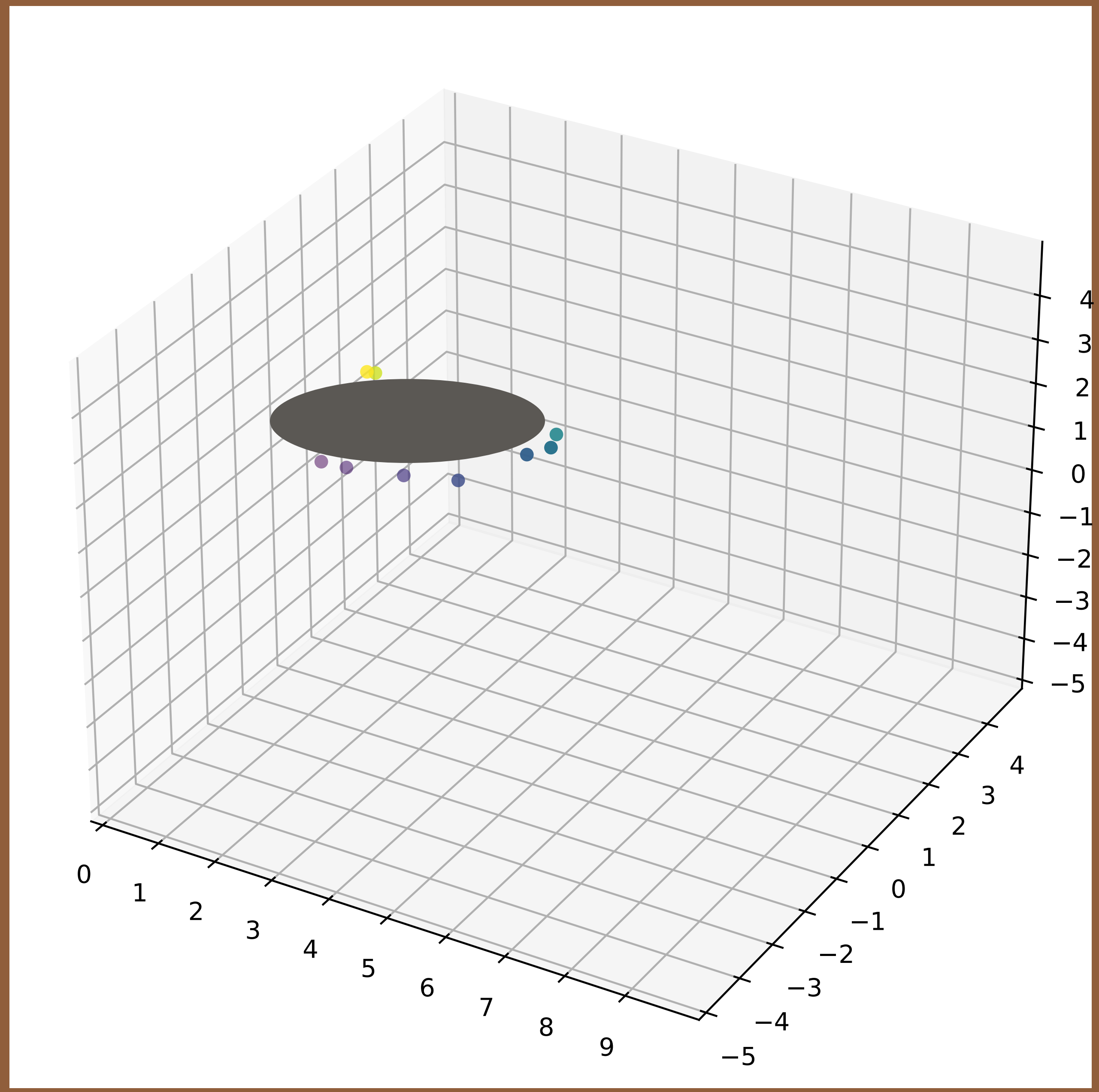
5 keV in Olivine



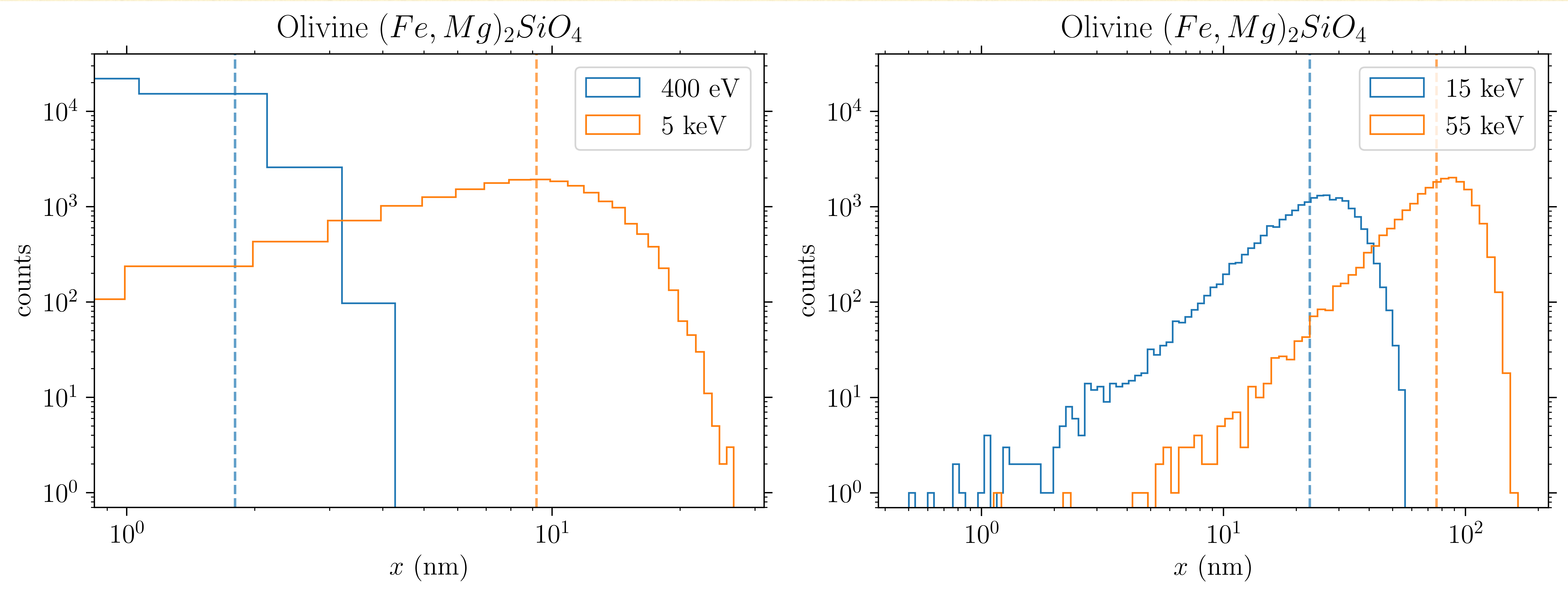
DEFINING TRACK LENGTH



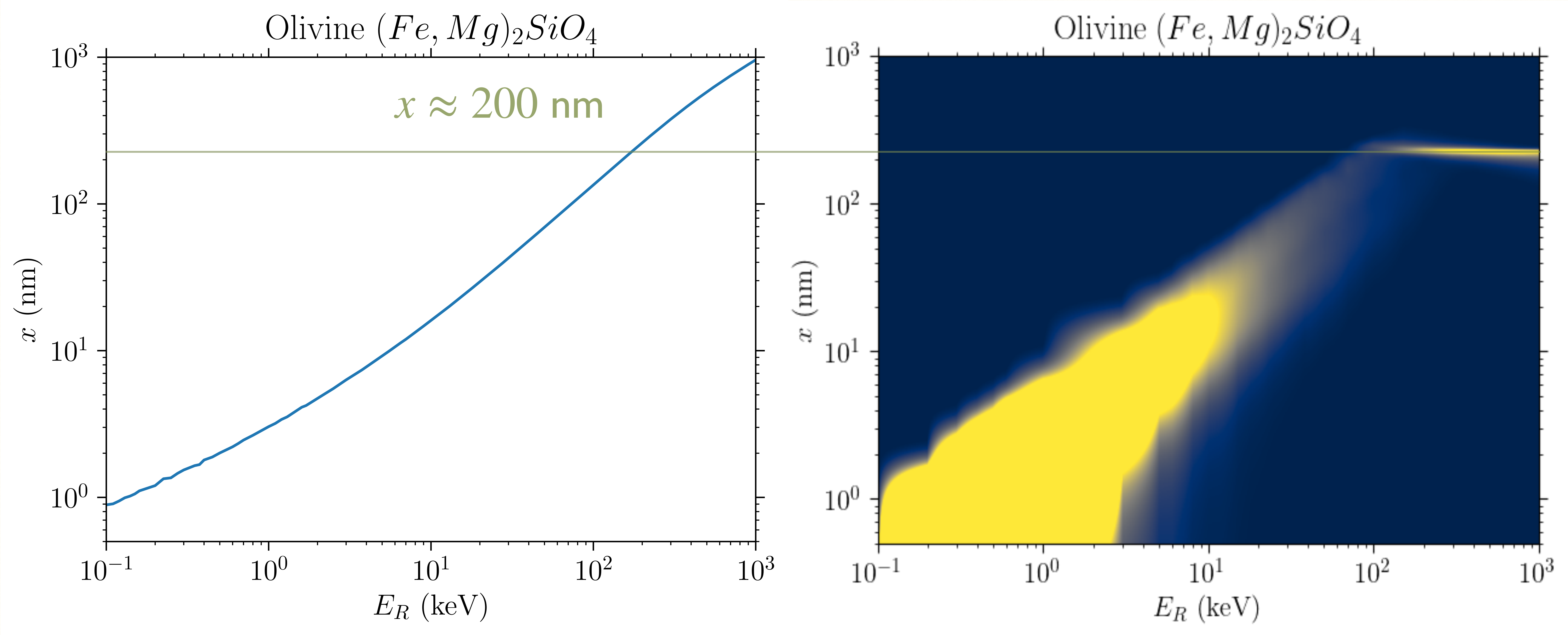




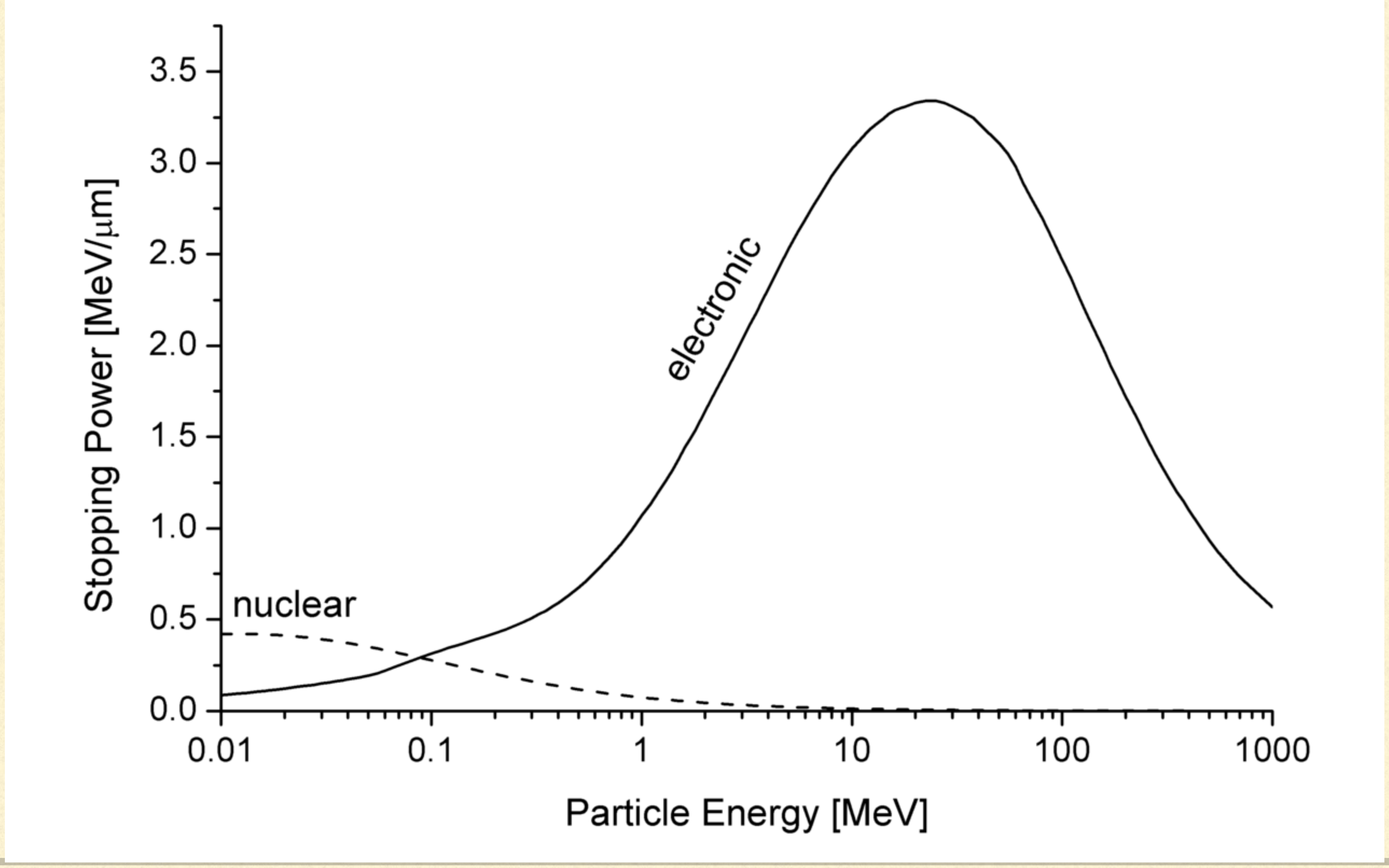
TRACK LENGTH DISTRIBUTION OF $\mathbf{Si}$ IN OLIVINE $(Mg, Fe)_2\ SiO_4$



ONE-TO-ONE VS 2D DENSITY

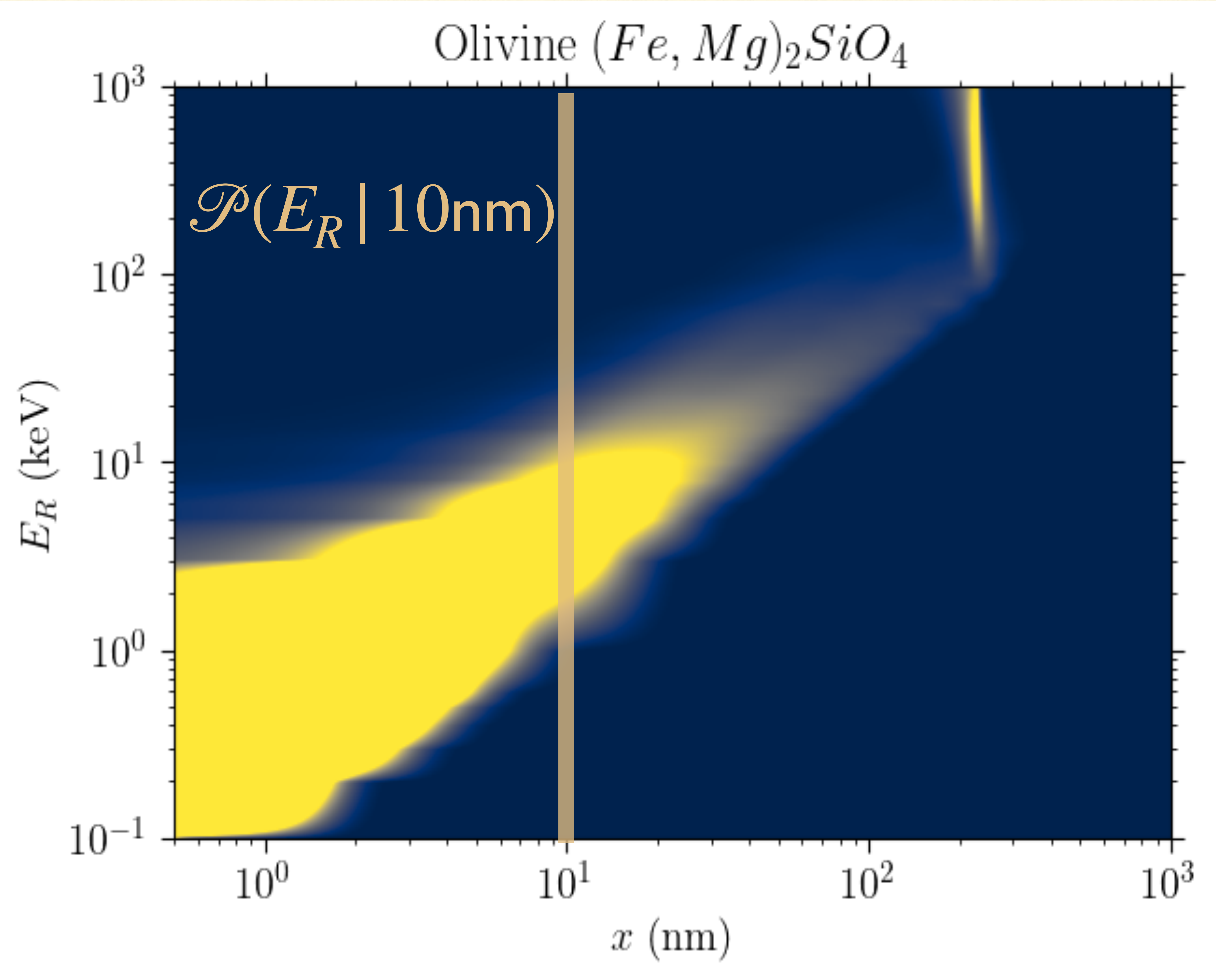


STOPPING MECHANISM

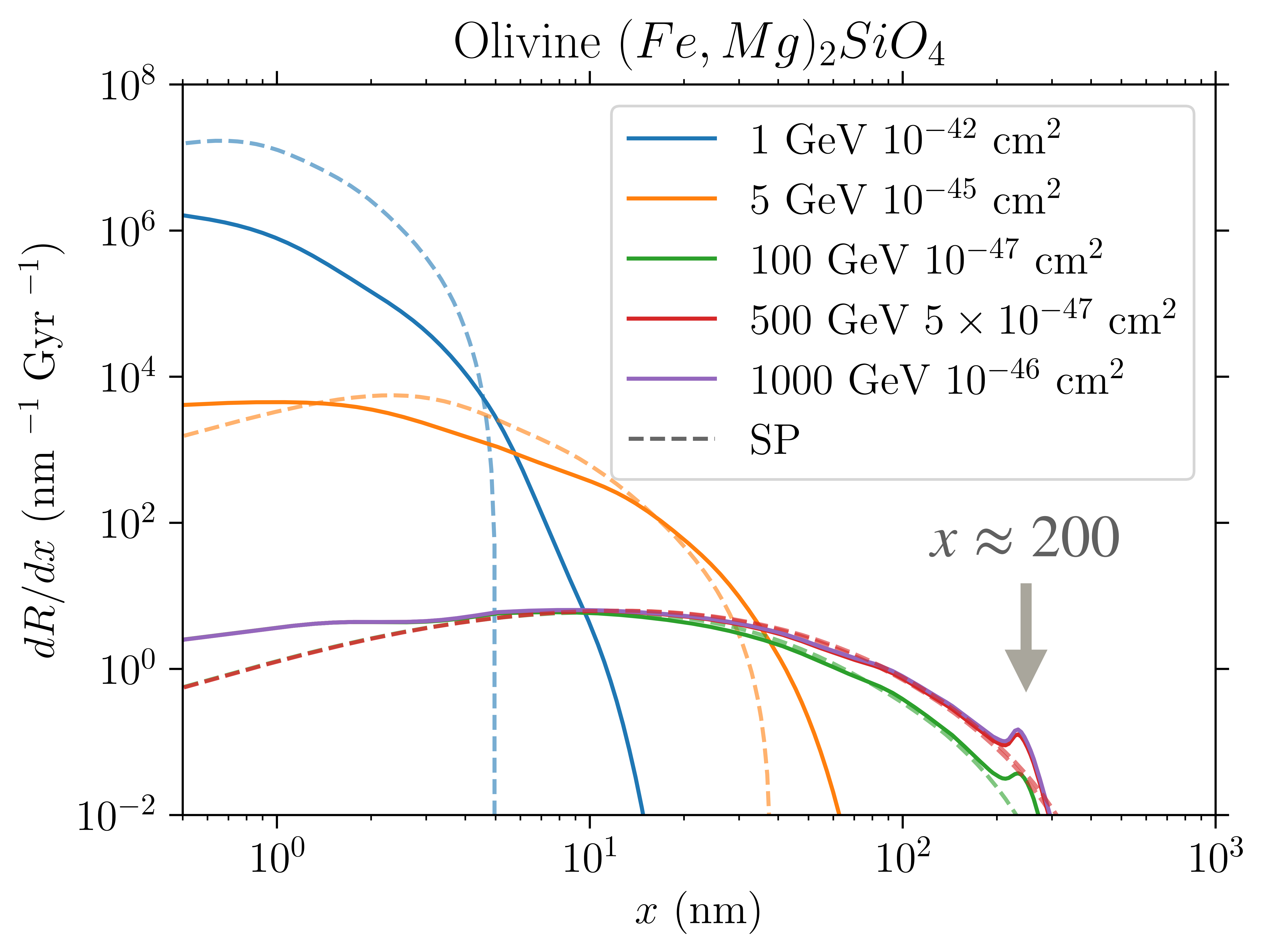


NEW E_R - X_T RELATION

- $\frac{dR}{dx} = \frac{dR}{dE} \times |\frac{dE}{dx}|$
- $\frac{dR}{dx}(x) = \int dE_R \frac{dR}{dE_R}(E_R)\mathscr{P}(E_R|x) \times \mathscr{P}(\text{track})$
- $\mathscr{P}(E_R|x)$: the probability that a track length x is induced by a recoil with energy E_R
- $\mathscr{P}(\text{track})$: the probability that a track is formed

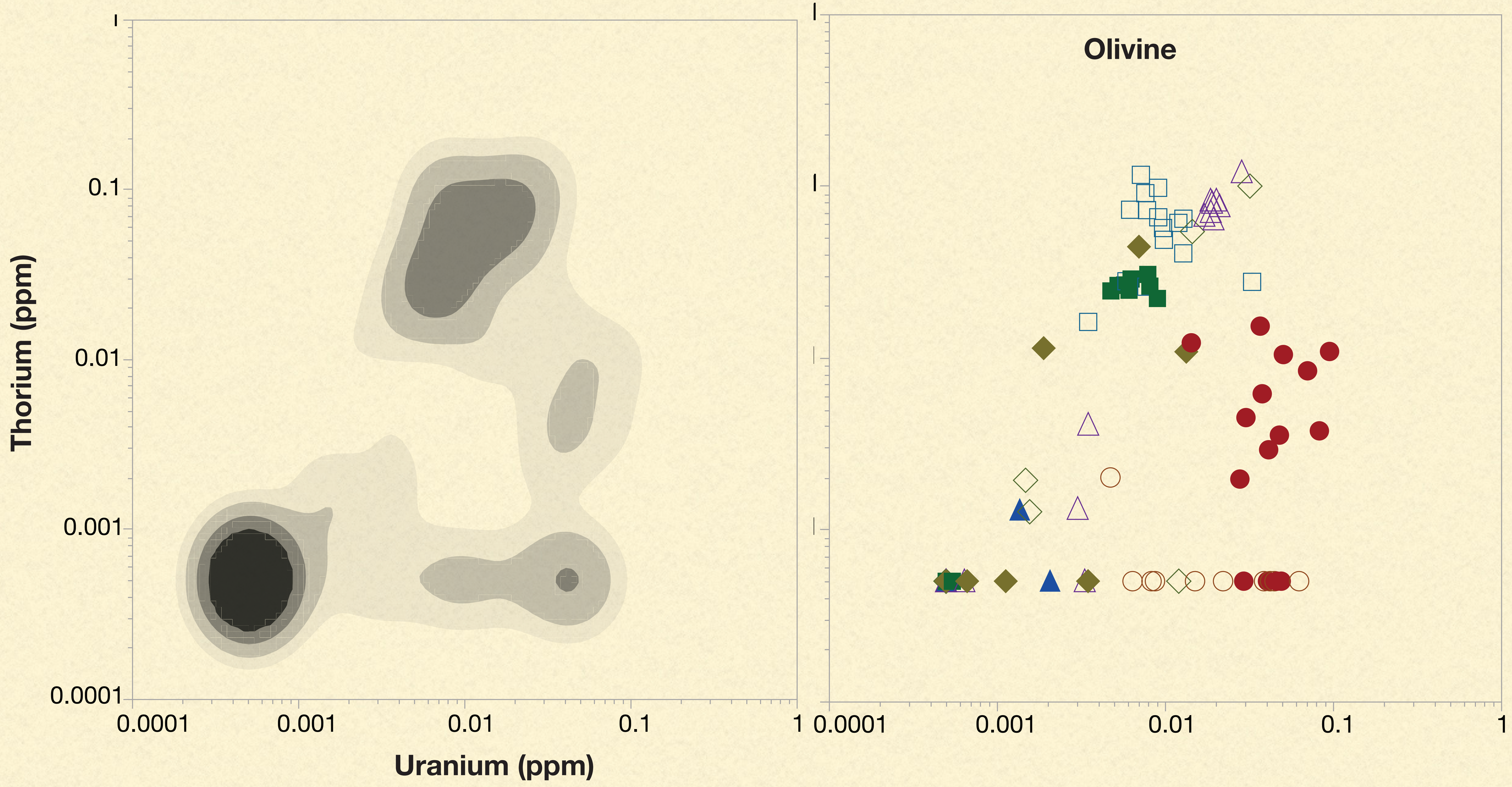


DIFFERENTIAL RECOIL SPECTRA

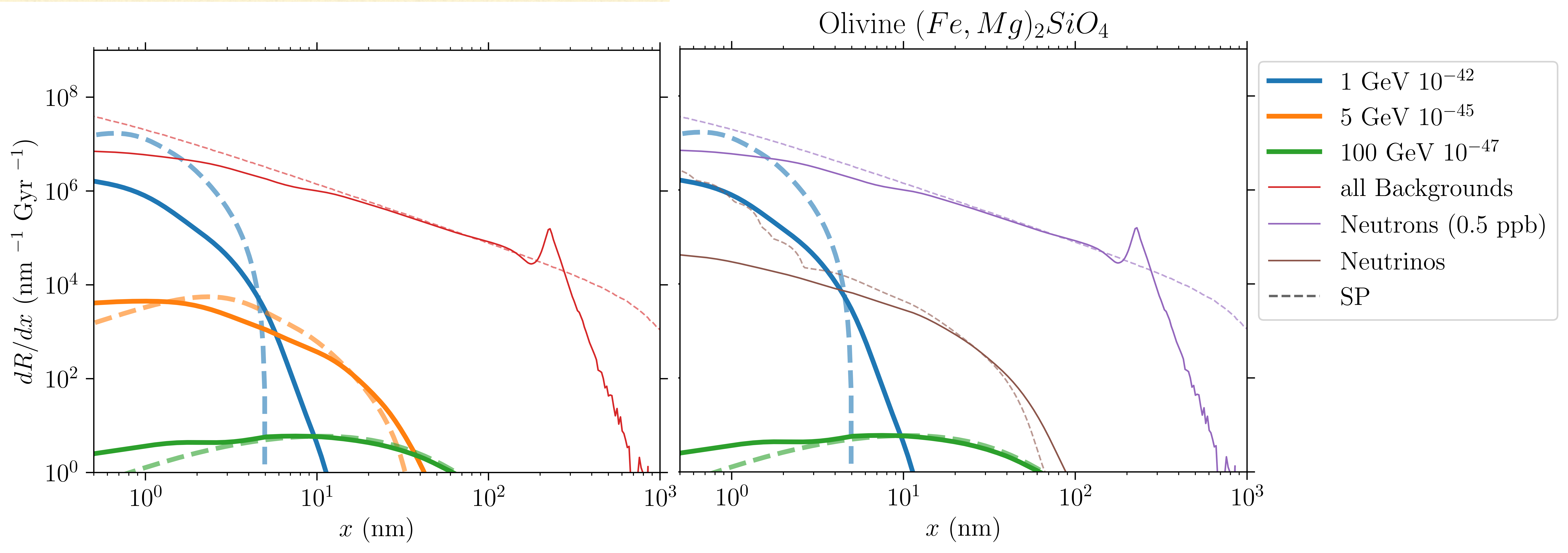


BACKGROUND TRACKS

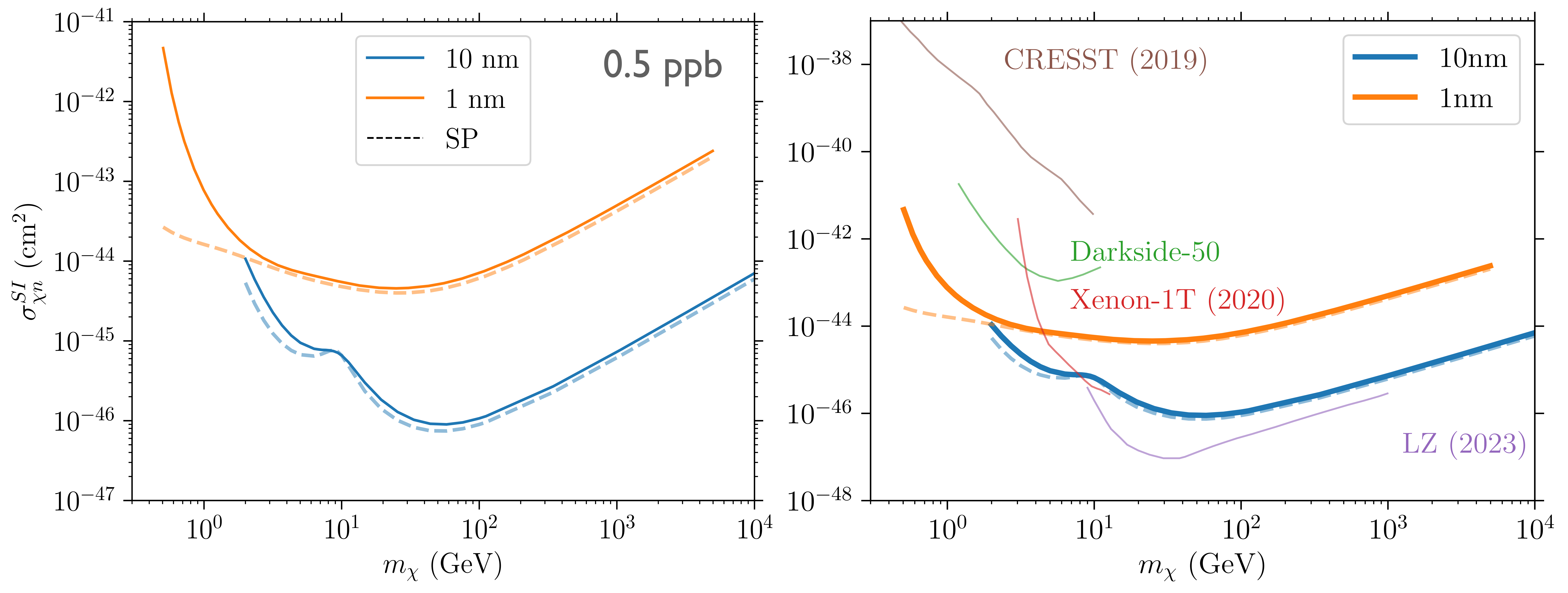
- solar neutrinos
- atmospheric neutrinos
- supernova neutrinos
- neutron from Uranium decay: detection threshold at 0.5 ppb



BACKGROUND SPECTRA



PROJECTED LIMITS



EXPERIMENTAL CONSIDERATIONS

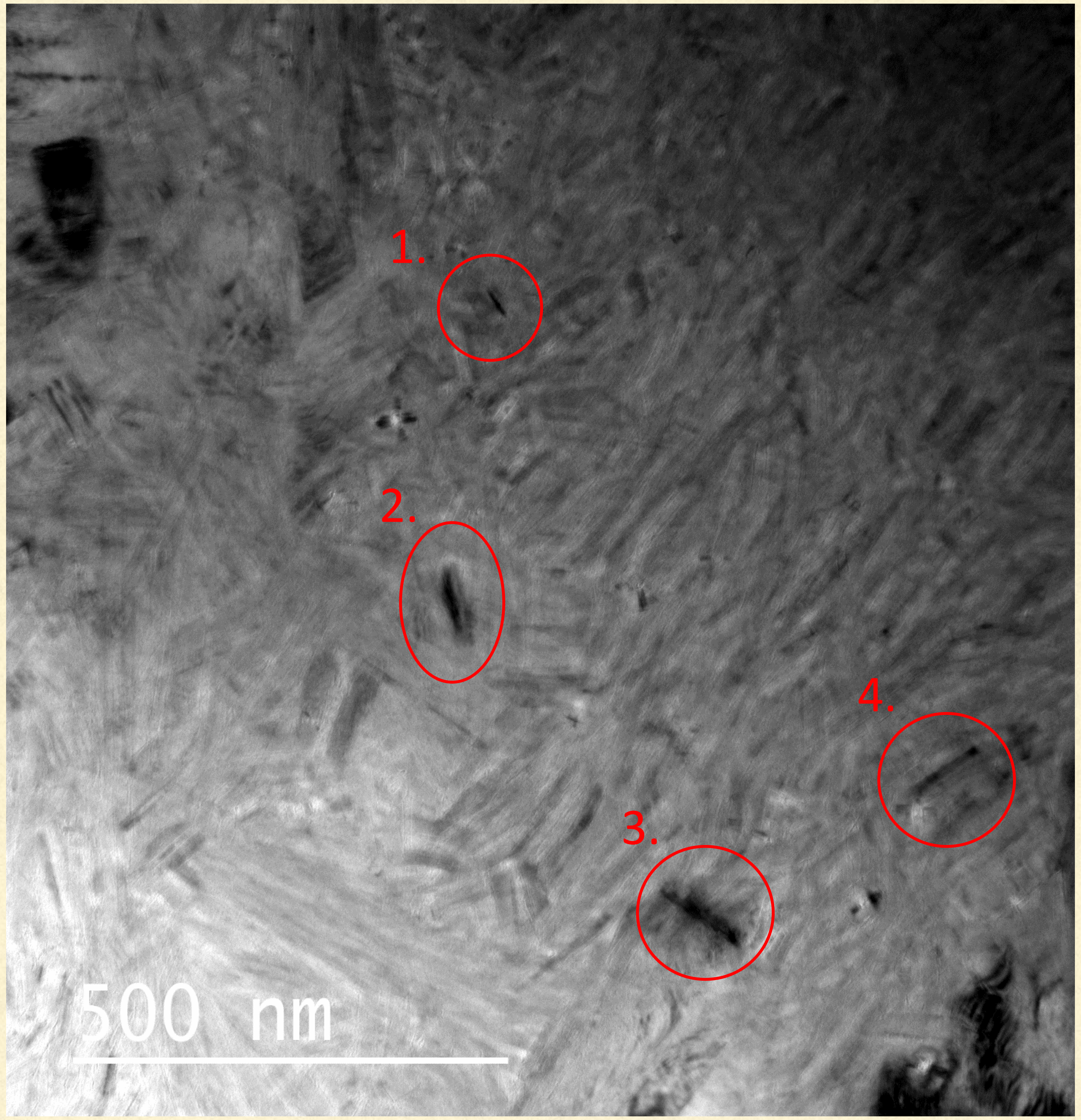
MINERAL SELECTION

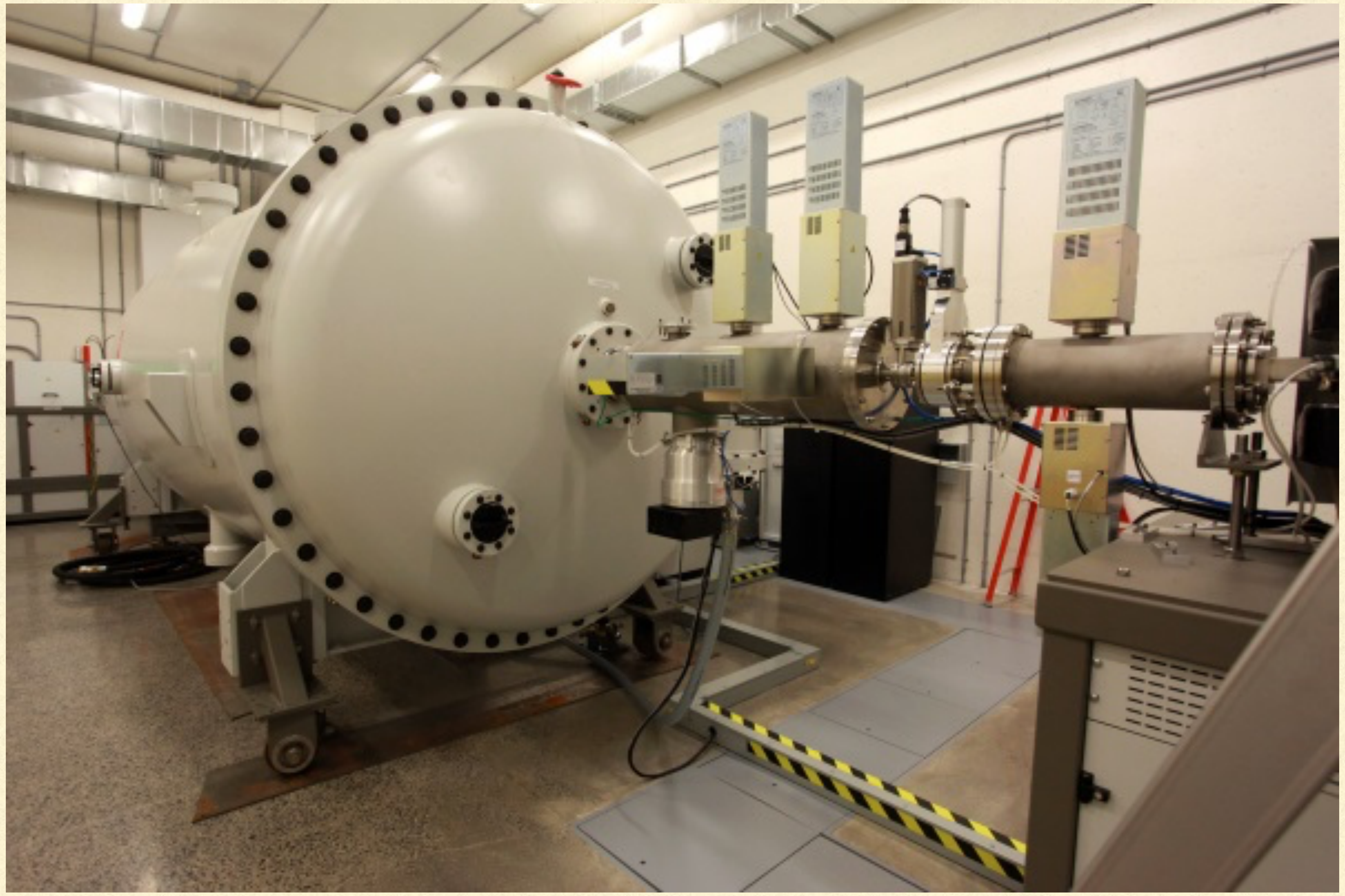
- Near surface minerals: heat and pressure could ‘heal’ damage tracks
- avoid hydrous minerals: generally less stable than anhydrous ones
- low Uranium concentration: reduce backgrounds
- candidates: Olivine*, Galena

READOUT TECHNIQUES

- Scanning Electron Microscope (SEM)
  - 1-10 nm resolution
- Transmission Electron Microscope (TEM)
  - 0.1 - 1 nm resolution
  - very time-consuming

EXPERIMENTAL CALIBRATION AT QUEEN'S





Reactor Material Testing Laboratory

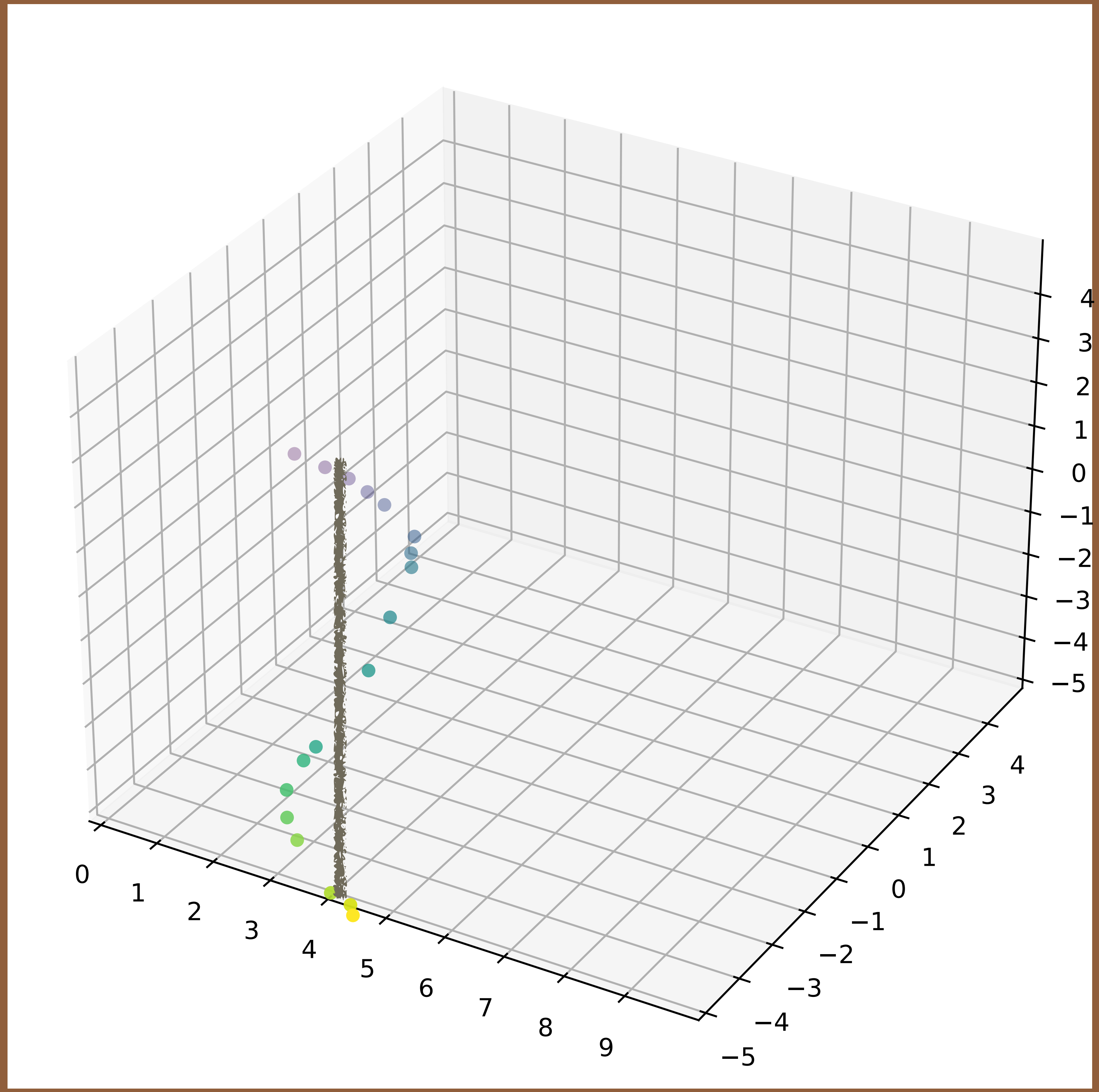
SUMMARY

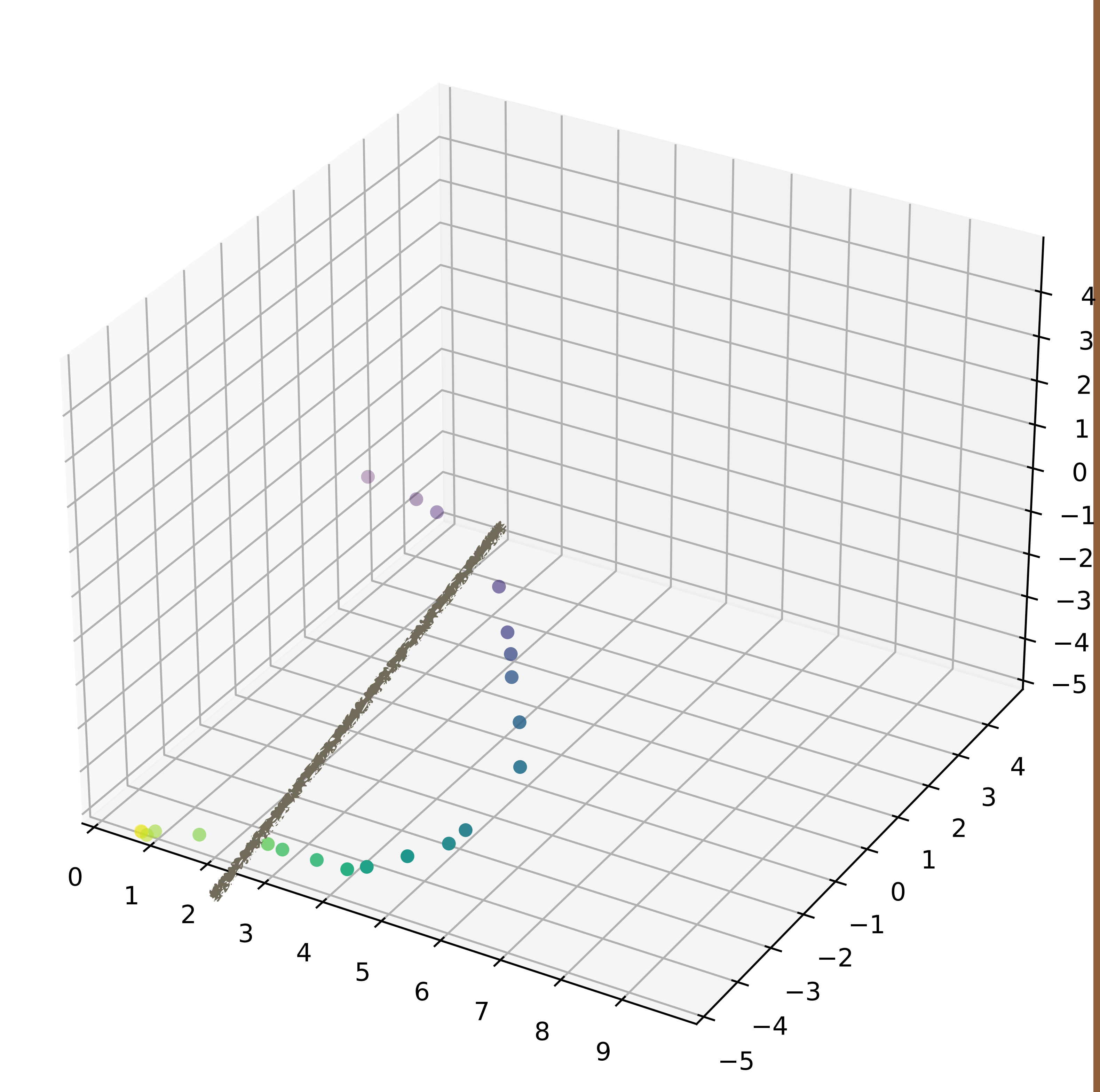
- we see a broad distribution of track lenghths at a given recoil energy
- at low energies, recoils don't always result in tracks
- limits should weaker than expected from stopping power calculation

Thank you for listening!

BACK-UP SLIDES

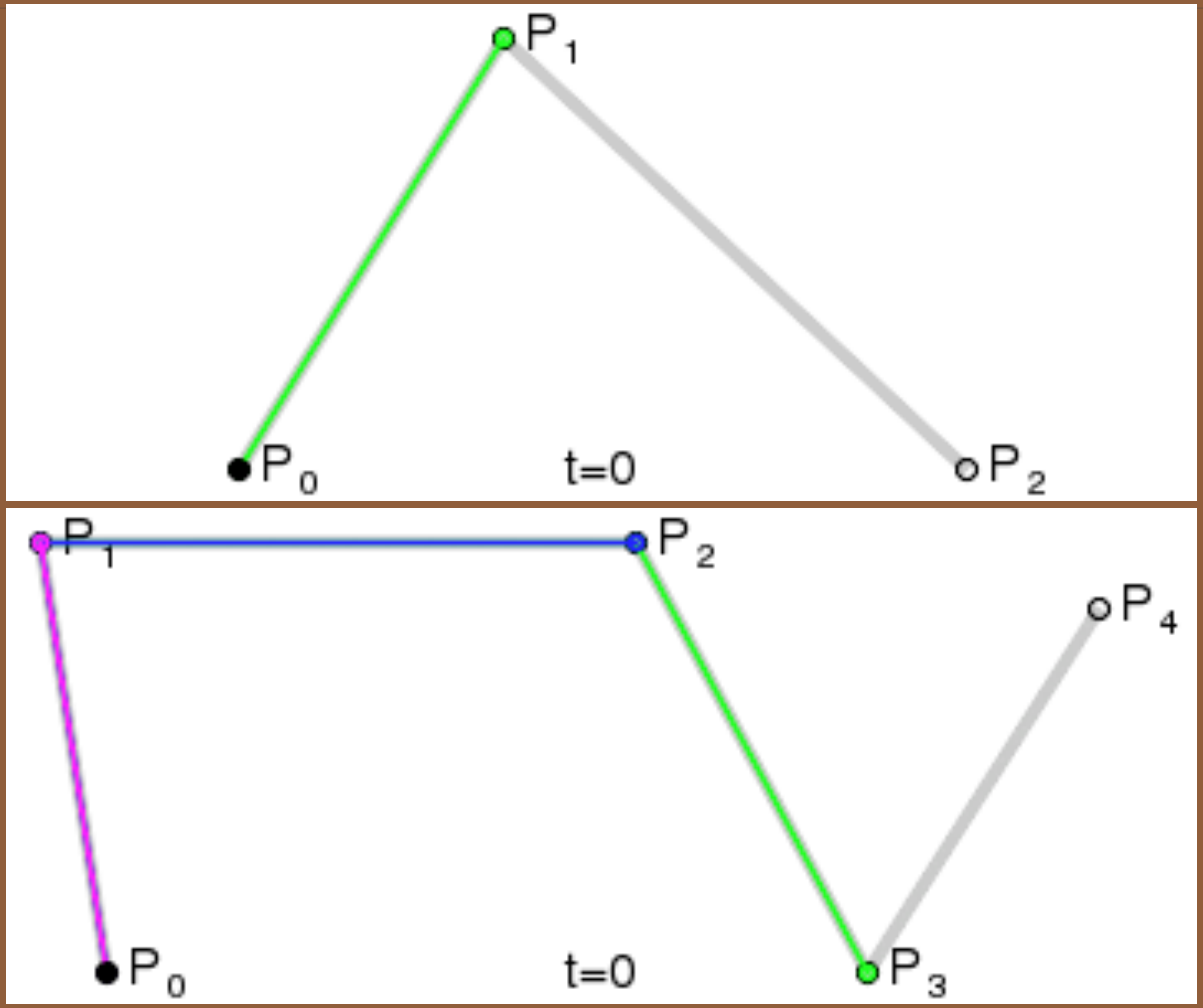
PRINCIPAL COMPONENT PROJECTION



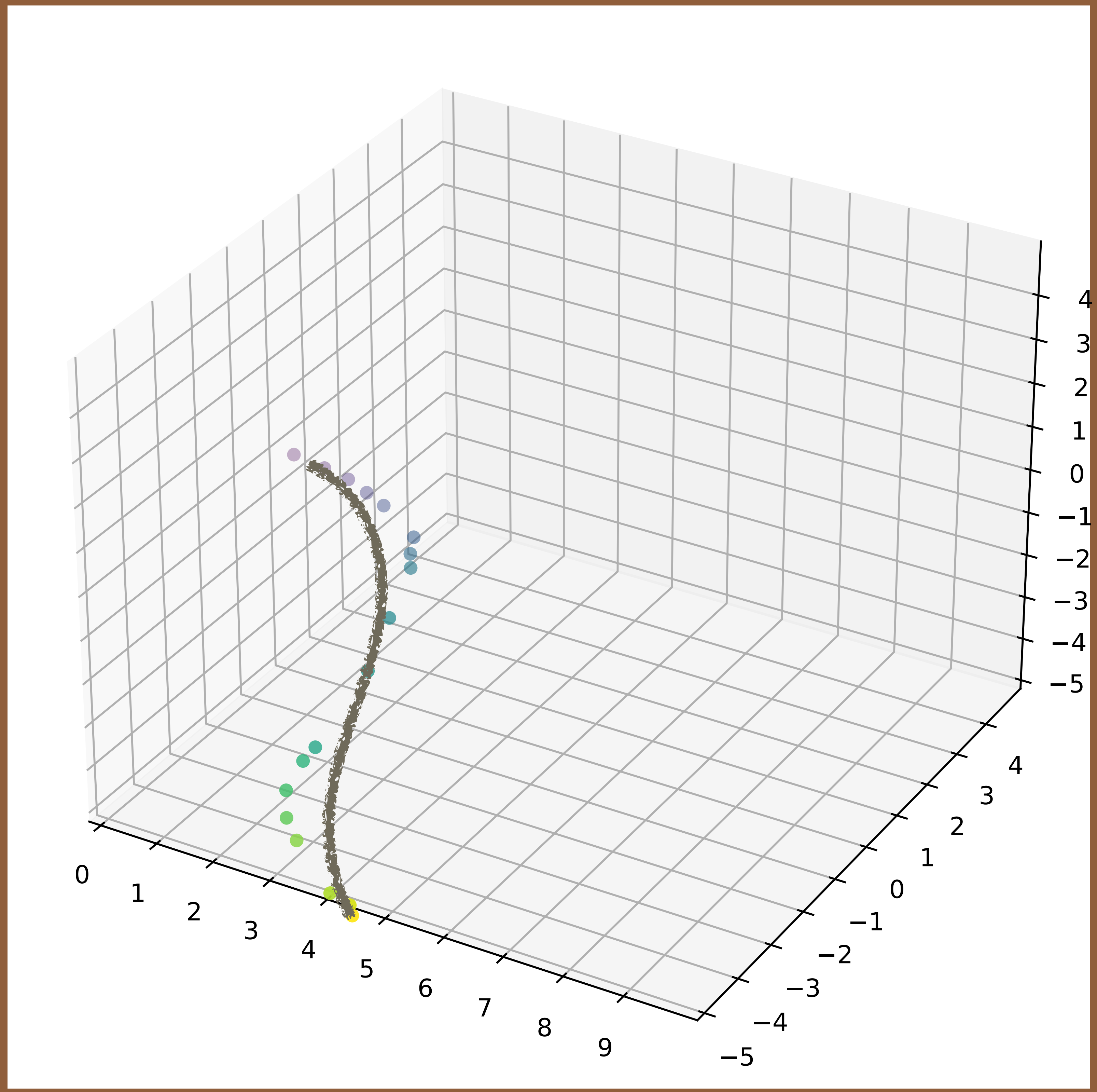


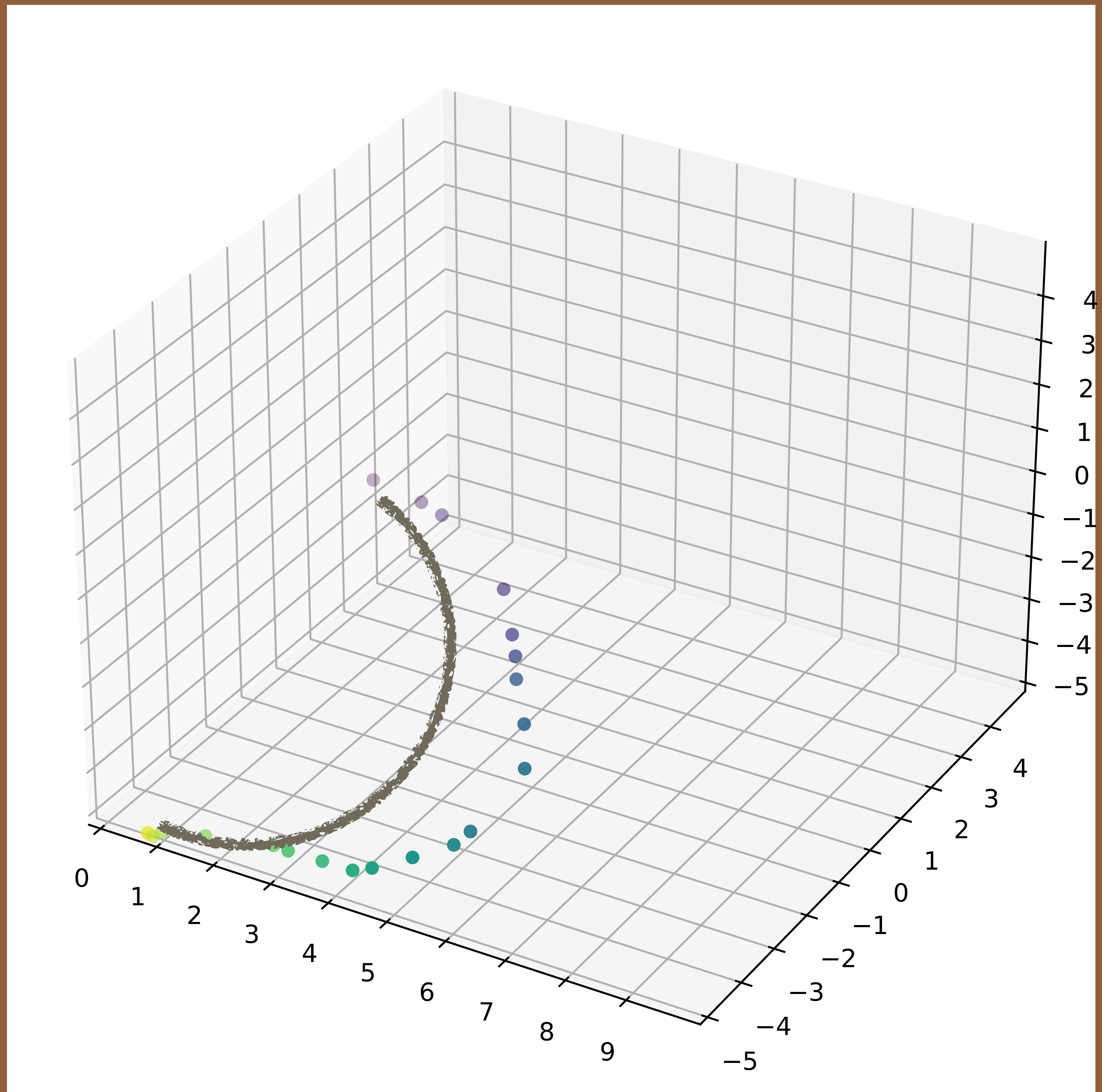
BEZIER CURVE FITTING

- defined by control points
- $\mathbf{B}(t) = \mathbf{P}_0 + t(\mathbf{P}_1 - \mathbf{P}_0),\ 0 \le t \le 1$
- better fits to arbtirary geometric features
- controllable resolution



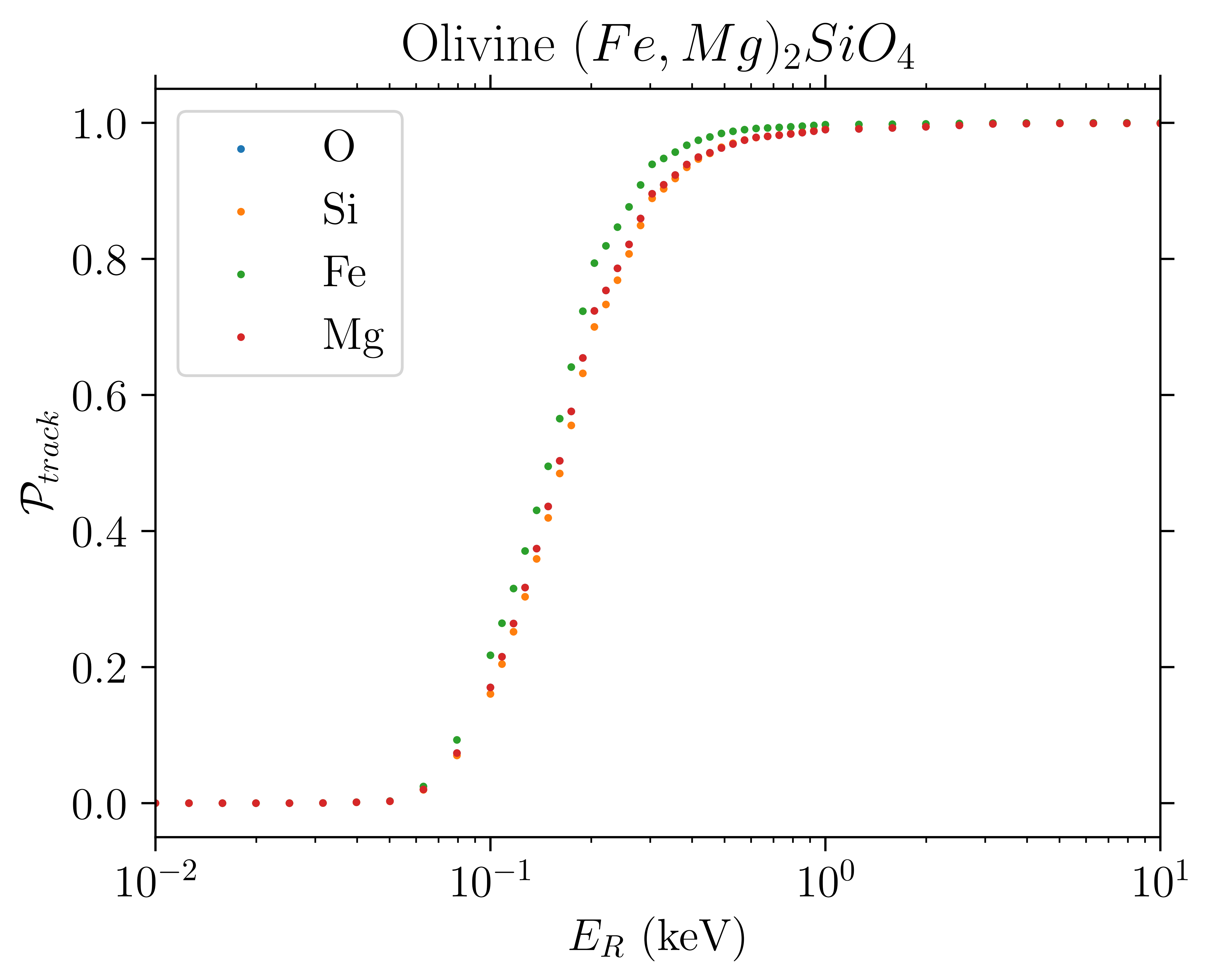
BEZIER CURVE FITTING





BINNED DISTRIBUTION

PROBABILITY OF TRACK FORMATION



OVERVIEW OF PALEO-DETECTORS DEVELOPMENT

- Limits on Dark Matter using Ancient Mica (1995): D.P. Snowden-Ifft, E.S. Freeman and P.B. Price
- Searching for Dark Matter Using Paleo-detectors (2018): S. Baum, A.K. Drukier, K. Freese, M. Gorski, P. Stengel
- Other works on: WIMP DM, composite DM, axions, neutrinos etc.