Particle tracks reconstruction using passive dosimeters

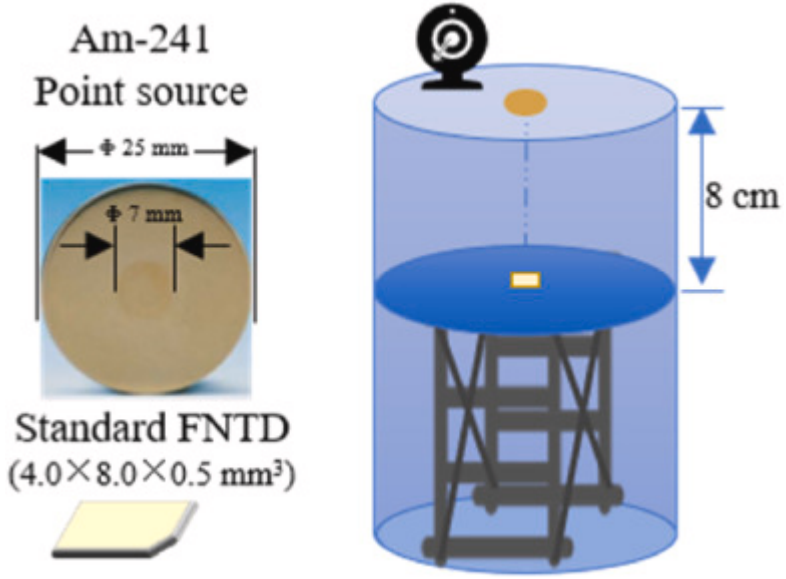
A path towards cell level dosimetry

Mohammed Rehan Tadaptri
Guide: João Gentil Saraiva

Dosimetry

Motivation

- Fluorescent Nuclear Track Detectors



How does it track radiation

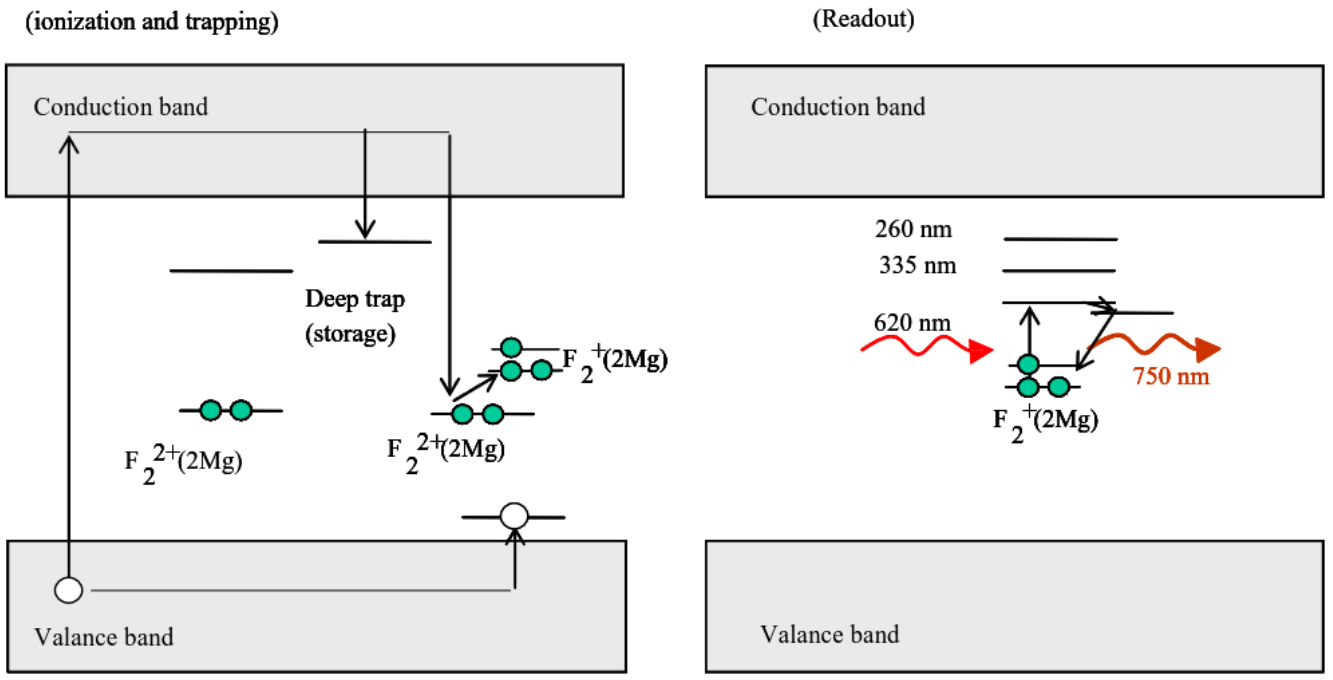


FIGURE 34. Flat band diagram of irradiation and readout of Al_2O_3:C,Mg [90].

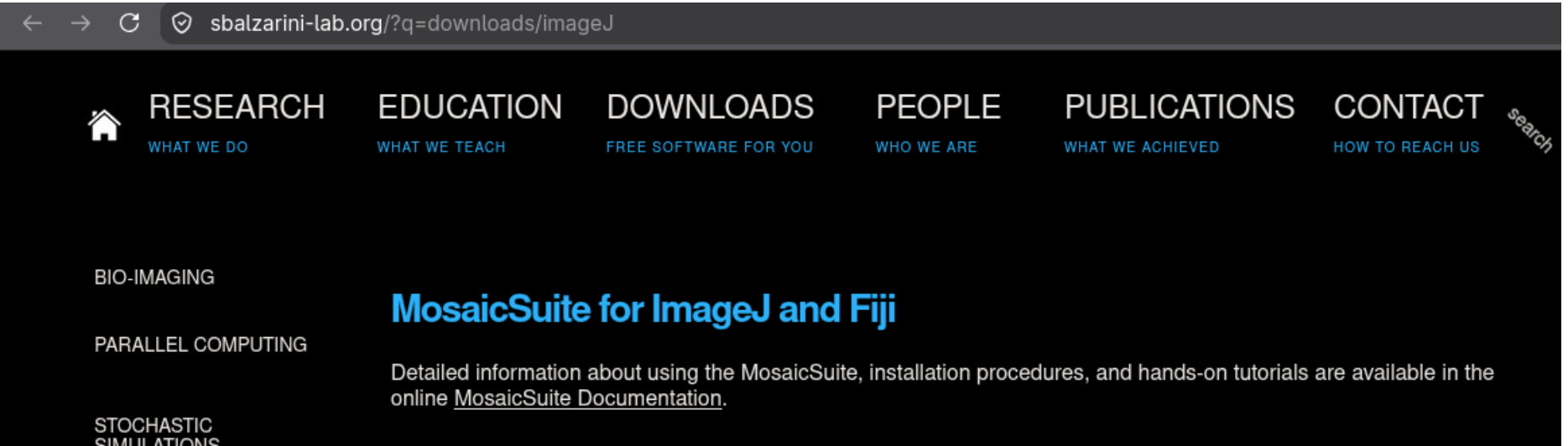
Goal

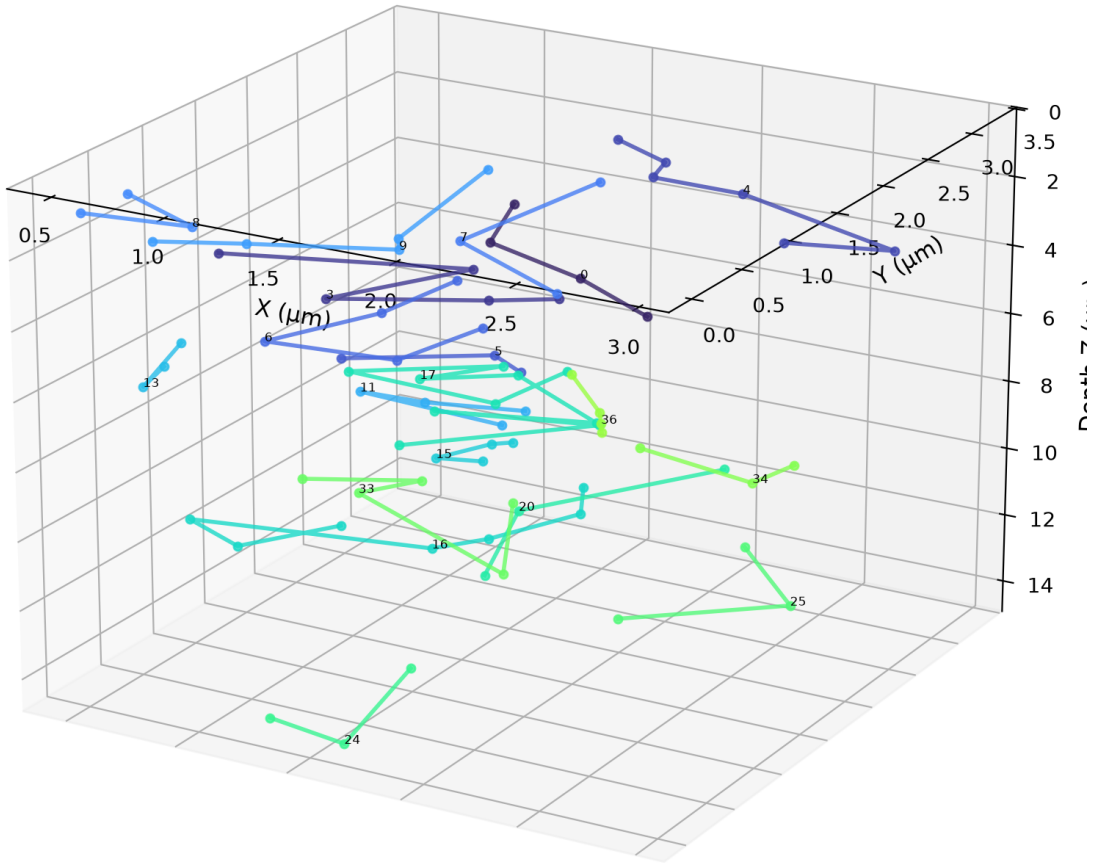
- Detect path of particle track in 3D
- Angle
- Energy

Approach

Fiji

TrackMate



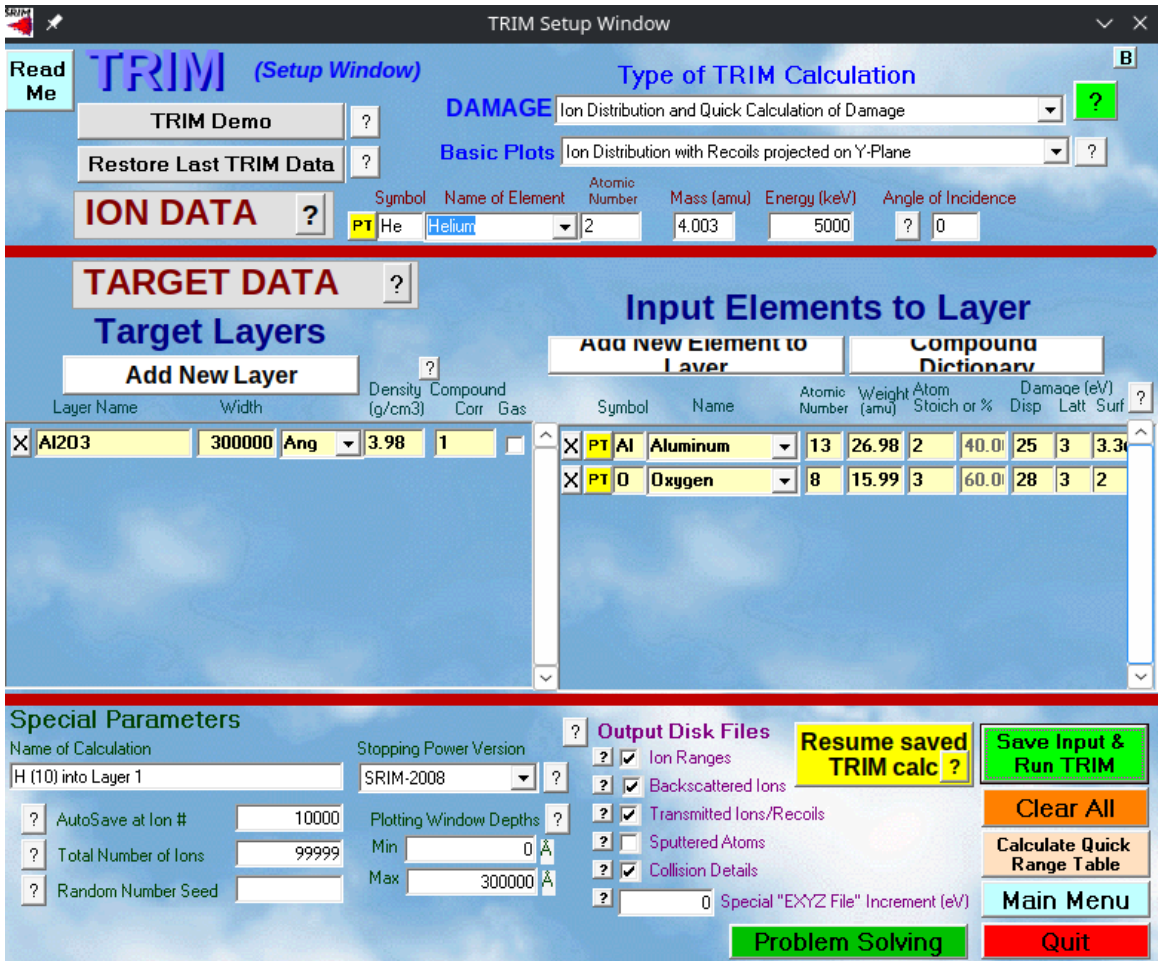


More details...

How do we reconstruct?

- MOSAIC uses Levy Flight algorithm
- TrackerMate uses intesity threshold

Finding LET with SRIM



MOSAIC Particle Tracker 2D/3D

- **Source:** Sbalzarini & Koumoutsakos, *J. Struct. Biol.* 151:182 (2005). `Plugins` → `Mosaic` → `Particle Tracker 2D/3D`.
- Two independent stages: **detection** (Levy's algorithm) then **linking**.
- **Detection params:** *Radius* (particle radius, px); *Per/Abs* (local maxima in upper r-th intensity percentile); *Cutoff* (non-particle score; 0 = off). Each particle → (x, y, z) + momenta m_0–m_4 + NPscore.
- **Linking** minimises a weighted multi-feature **cost** per candidate link (from `ParticleLinker`):

$$C = \underbrace{(dx^2 + dy^2 + dz^2)\, w_{\text{space}}}_{\text{squared distance}} + \underbrace{\sqrt[3]{dm_0^2 + dm_2^2}\; w_{\text{feature}}}_{\text{intensity/size mismatch}} + \underbrace{(\text{dyn.cost})\, w_{\text{dynamic}}}_{\text{velocity or angle}}$$

- *Linked distance* capped: $d^2 > (\text{linkLevel} \cdot \text{disp}_{\max})^2 \Rightarrow C = \infty$.
- **Link Range** R = frames to look ahead (handles occlusion; default 2). **Dynamics:** Brownian | Constant velocity | Straight lines. **Re-link** fixes crossing tracks.

For ions: Kouwenberg (PMB 61:4088) added a 4th feature (φ_{angle} vs. $\theta_{p,\max} = 20°$), recursive minimisation and track relinking.

TrackMate (Fiji)

- **Source:** Tinevez et al., *Methods* 115:80 (2017). `Plugins` → `Tracking` → `TrackMate`. Wizard-driven; segmentation decoupled from linking.
- **Detection:** spot detectors → we used the **intensity-threshold** detector (threshold 2 for 8-bit, 600 for 16-bit); the LoG detector *failed* here (images too dark, max ∼11/255).
- **Linking: Simple LAP / LAP tracker** = a **Linear Assignment Problem**, solved by the Munkres–Kuhn algorithm ($O(n^3)$). Tracking is on *filtered* spots; segments are then linked (gap/merge/split).

$$P = 1 + \sum p, \quad p = 3W \frac{|f_1 - f_2|}{f_1 + f_2}, \quad C = (D \cdot P)^2$$

- No penalties ⇒ $C = D^2$ (Brownian). Our settings: link dist 20–30 px, gap 0.

	MOSAIC	**TrackMate**
Detection	Levy algorithm	threshold / LoG
Linking	recursive cost	LAP (Munkres)
Features	3–4 (dist, int., vel., angle)	distance + penalties
Best for	crossing, ion tracks	Brownian, moderate density
Headless	GUI only	**yes**

Table 6: Complete track reconstruction results. Values are mean ± standard deviation. Z-extent is the axial (depth) span of the tracks. "—" = not processable or not applicable. Datasets acquired 2025-11-12, 2025-11-14, 2025-11-19, 2025-12-10. *Only 633 nm confocal Al_2O_3 series are directly comparable*; 488 nm and WF series are discussed separately.

Dataset & Series	Tracks	Length (μm)	Z-extent (μm)	Angle (°)	Spots/trk
20251112 S1 (40×, 14Z)	15	1.19 ± 0.58	0.91	23 ± 31	3.1 ± 1.3
20251112 S2 (63×, 52Z)	39	1.44 ± 1.22	0.64	50 ± 21	3.2 ± 1.7
20251112 S3 (63×, 52Z)	5612	4.92 ± 1.99	0.58	81 ± 8	3.0 ± 0.6
20251112 S4 (63×, 130Z)	5	3.18 ± 0.92	3.10	2.8 ± 1.7	11.4 ± 2.7
20251112 S5 (488 nm, 76Z)	58	0.96 ± 0.66	0.85	9.4 ± 17.3	3.9 ± 1.8
20251112 S6 (WF, 2583Z)	1	—	—	—	2583
20251112 S8 (5Z)	71	1.40 ± 0.50	1.32	9.7 ± 6.6	3.6 ± 0.9
20251112 S9 (488 nm, 1000Z)	840	5.13 ± 6.16	3.64	27 ± 21	8.3 ± 9.5
20251114 S6 (unirrad.)	0	—	—	—	—
20251119 S3 (LiF, WF)	26	1.82 ± 1.57	1.54	14 ± 25	4.1 ± 3.0
20251119 S4 (LiF, WF)	1	20.0	20.0	0.0	41
20251210 S2 (merged)	—	—	—	—	—

Problems

- Why?

Ahead

- Need to work on better algorithm for tracking particles, or get newer data