A journey to ITACA

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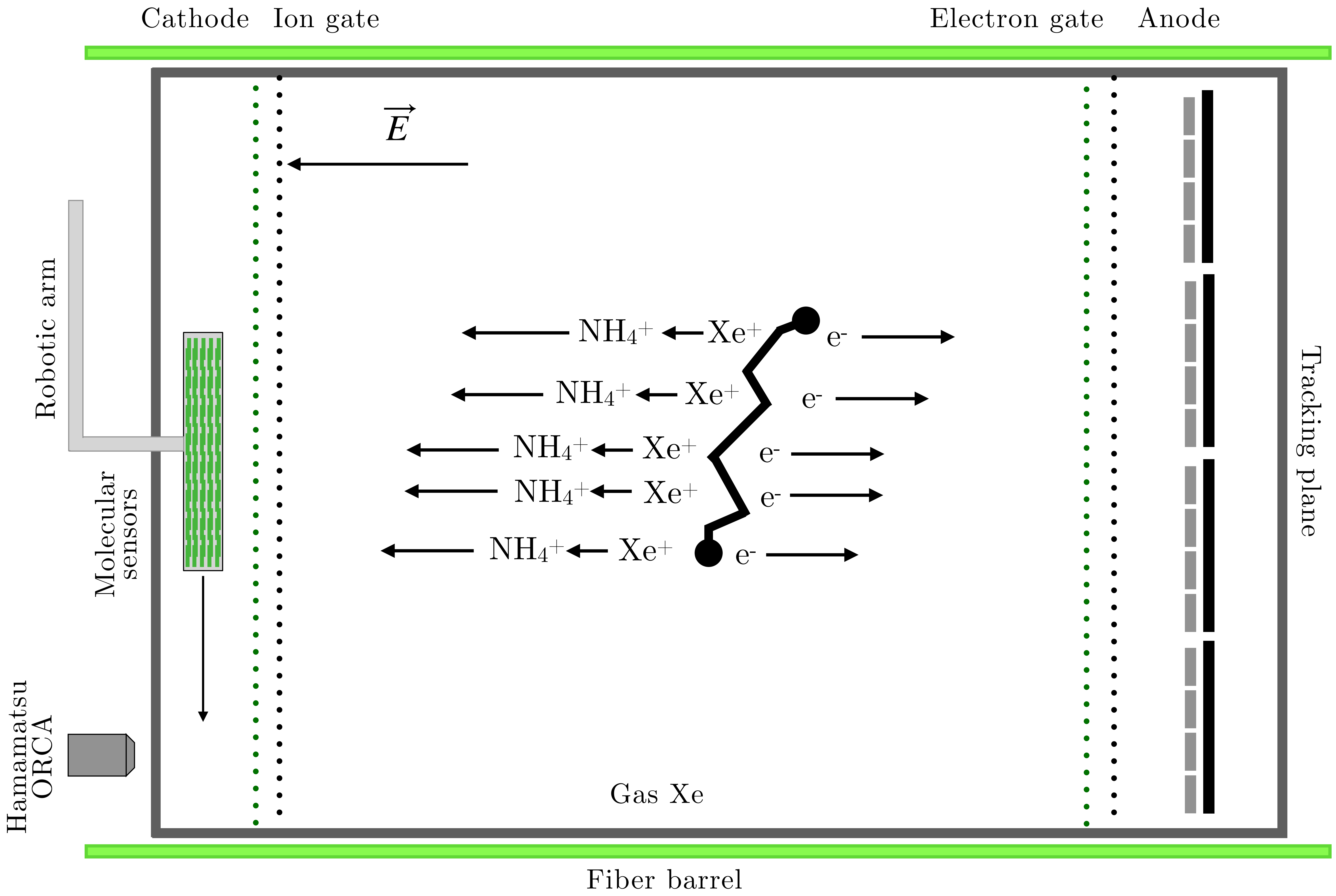
NEUTRINOLESS DOUBLE BETA DECAY SEARCH IN XE - NEXT-GENERATION EXPERIMENT WORKSHOP

Ion Tracking with Ammonium Cations Apparatus



- **Trace amount** (1-10 ppb) of **ammonia** (NH_3) are added to the xenon.
- Positive xenon ions are **transformed into ammonium** (NH_4^+)
- The NH_4^+ ions travel towards the cathode, where they are detected by **molecular sensors**.

Charge transfer and ion chemistry

1. **Xe_2^+ conversion** via three-body association

$$\mathrm{Xe}^+ + 2\mathrm{Xe} \rightarrow \mathrm{Xe}_2^+ + \mathrm{Xe}$$

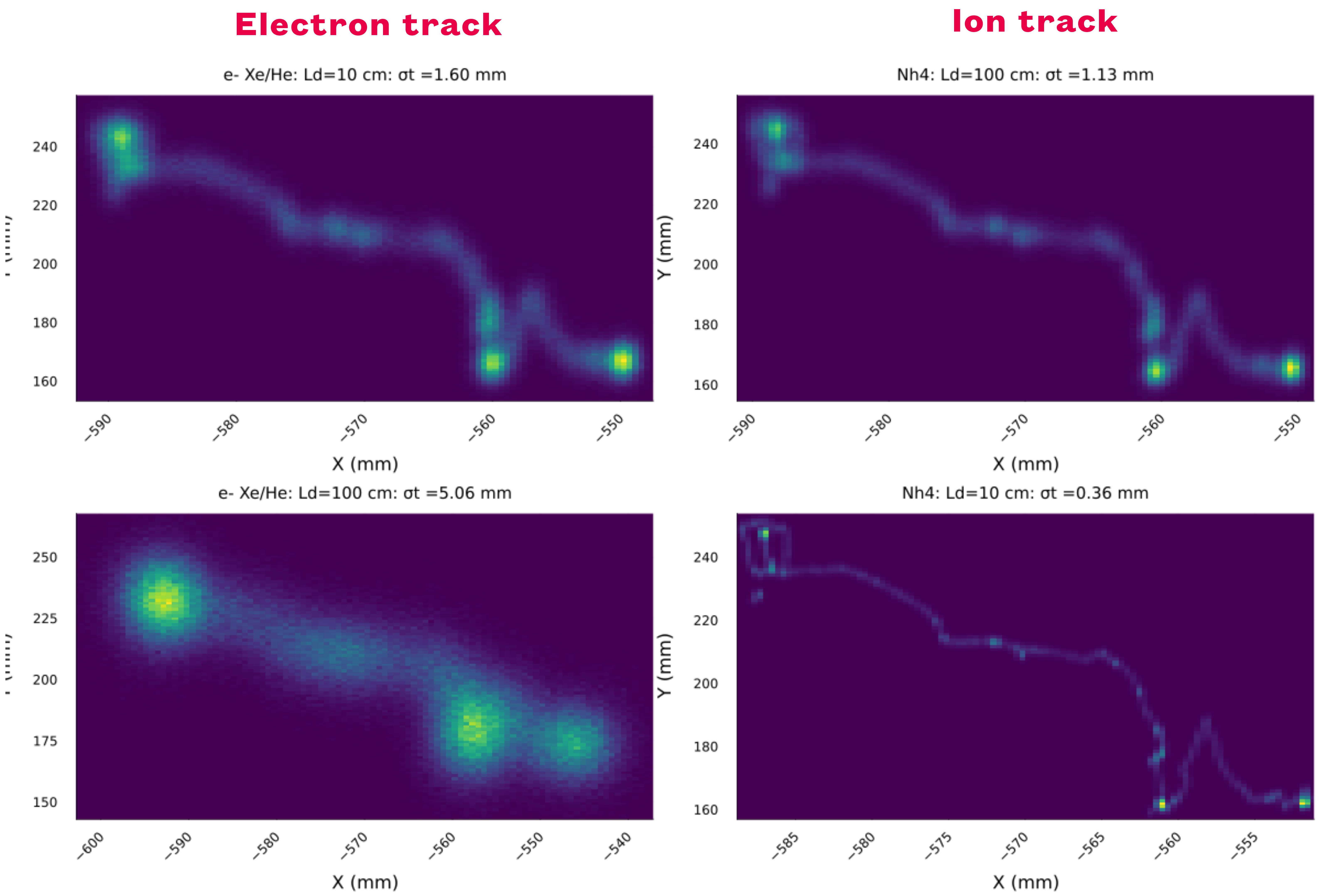
2. **Charge-transfer step** with ammonia, fast exothermic reaction (approx. 4 ms at 1 ppb and 15 bar, collision limited)

$$\mathrm{Xe}_2^+ + \mathrm{NH}_3 \rightarrow 2\,\mathrm{Xe} + \mathrm{NH}_3^+$$

3. **Proton transfer step**. NH_3 has a very high proton affinity, exothermic reaction and ammonium ion creation (approx. 1.5 ms at 1 ppb and 15 bar)

$$\mathrm{NH}_3^+ + \mathrm{NH}_3 \rightarrow \mathrm{NH}_4^+ + \mathrm{NH}_2$$

Ion and electron diffusion



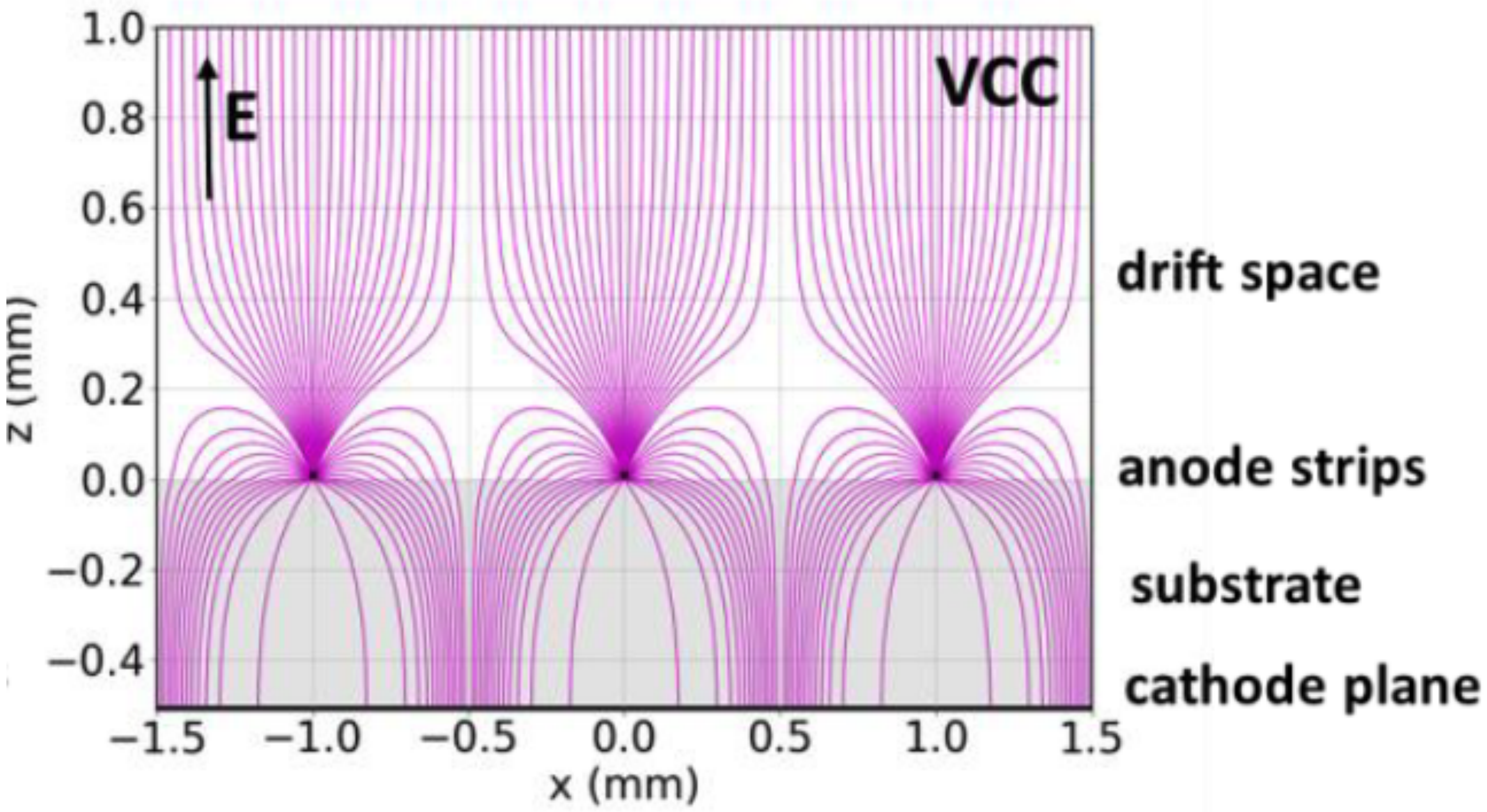
- **Thermal regime**

$$\sigma = \sqrt{2Dt} = \sqrt{\frac{2k_B T}{e} \frac{L}{E}}$$

- For a drift of 1 m this corresponds to approximately 1 mm.
- **The diffusion of ion and electron tracks is anticorrelated** (upper panel 100 cm, lower panel 10 cm).
- The availability of the ion track allows a **uniform topological reconstruction across the detector**.

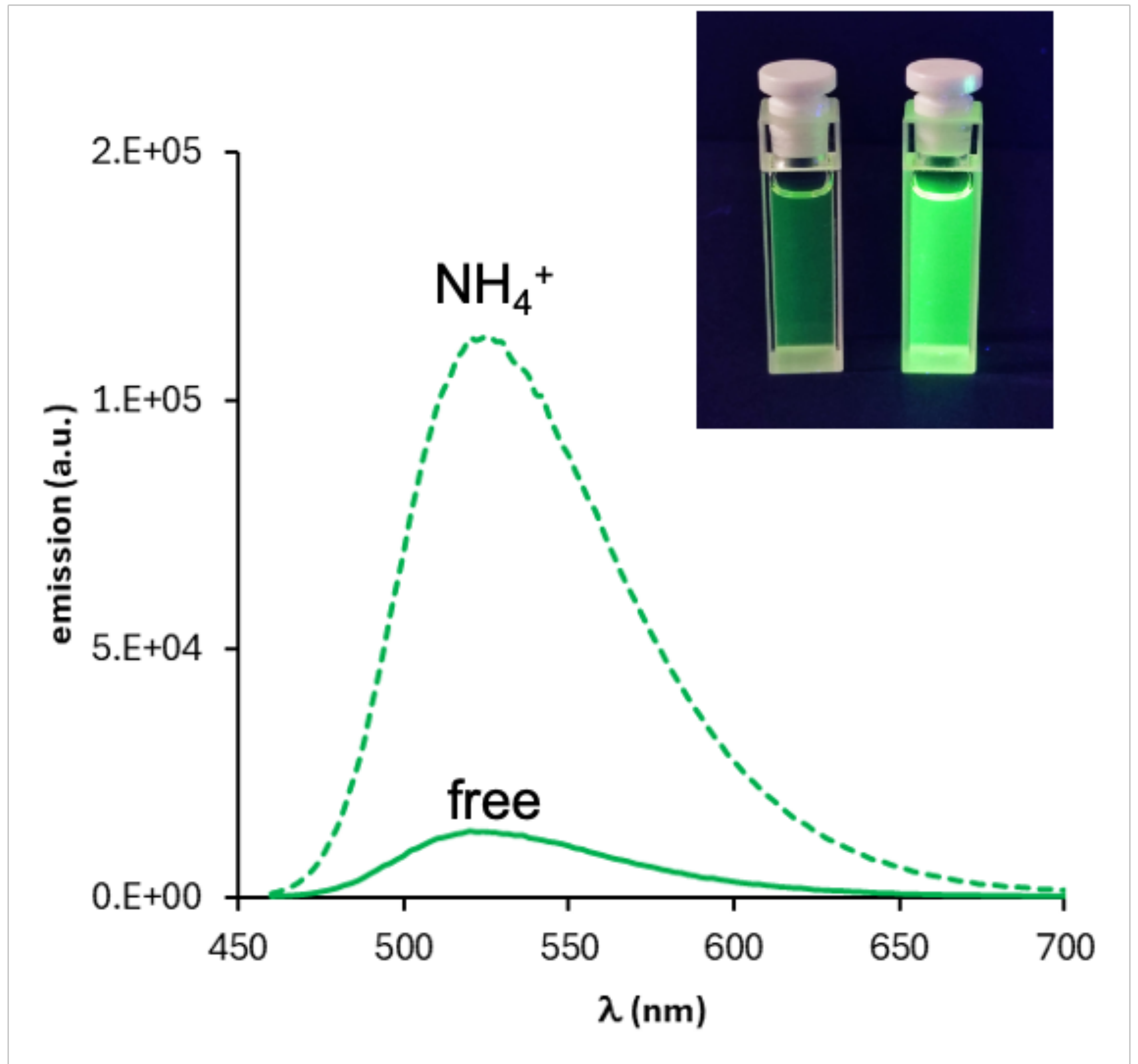
Ion track collection

- The electron cloud is collected in the SiPMs at the anode, about 1 ms after t_0.
- Defines the fiducial region as being about 20 cm from the cathode. Then one has **O(~350ms) to measure the event energy and do a rough reconstruction of topology**.
- Require that the **energy of the event is in the ROI and that only one connected track**, with no floating low energy clusters is reconstructed.

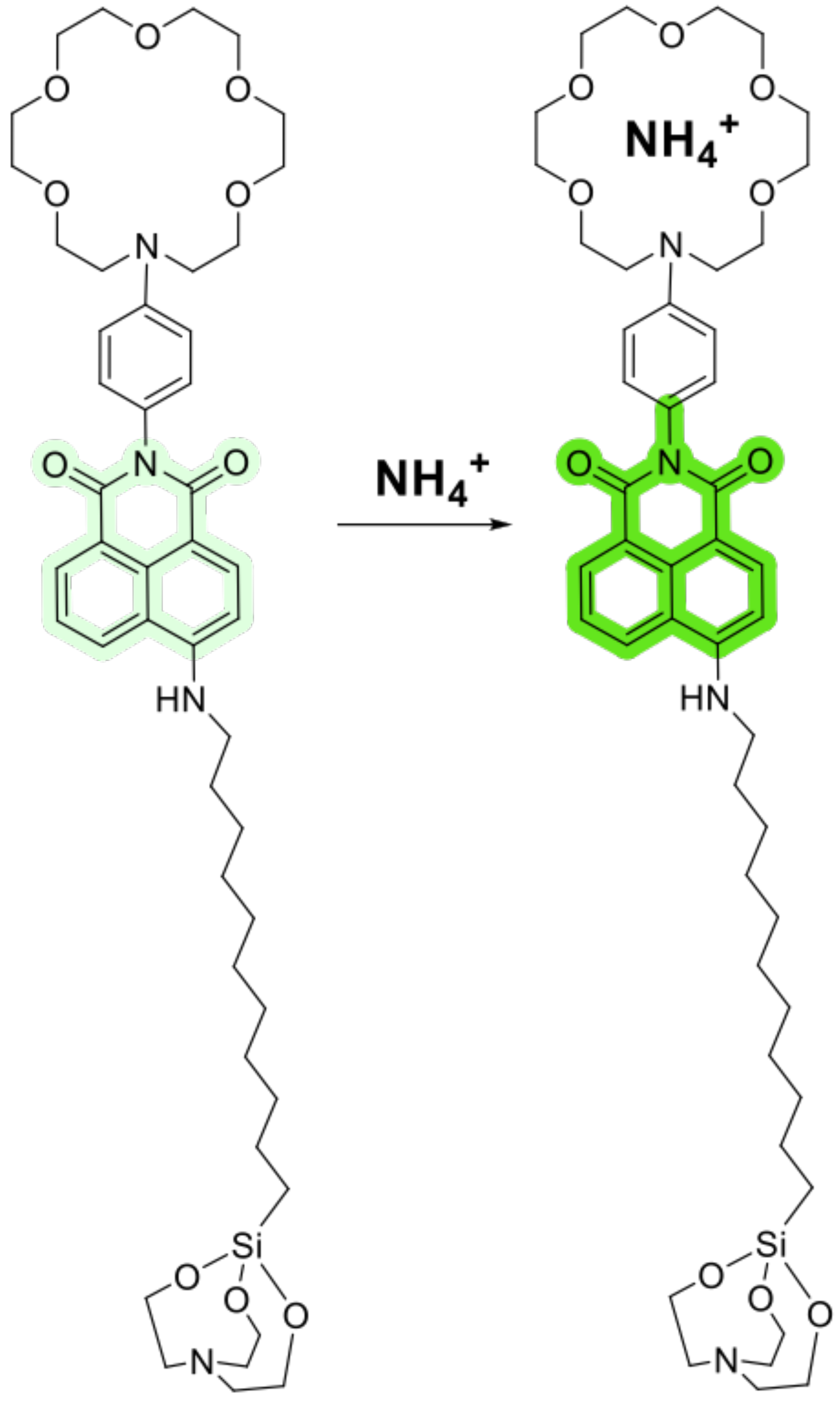


- If both conditions are fulfilled, a "**ββ0ν candidate trigger**" is activated, and a robotic arm moves a target large enough to contain the ion track. The target is located such the target center matches the extrapolated barycenter of the track.
- **The target includes an electrostatic grid set up to positive voltage** (few tens of volts) which is reset to zero right at the time of ion arrival (known with μs precision). Finally a micro-structure (e.g., VCC) concentrates the ions (in strips or scanning pins).

Molecular sensors

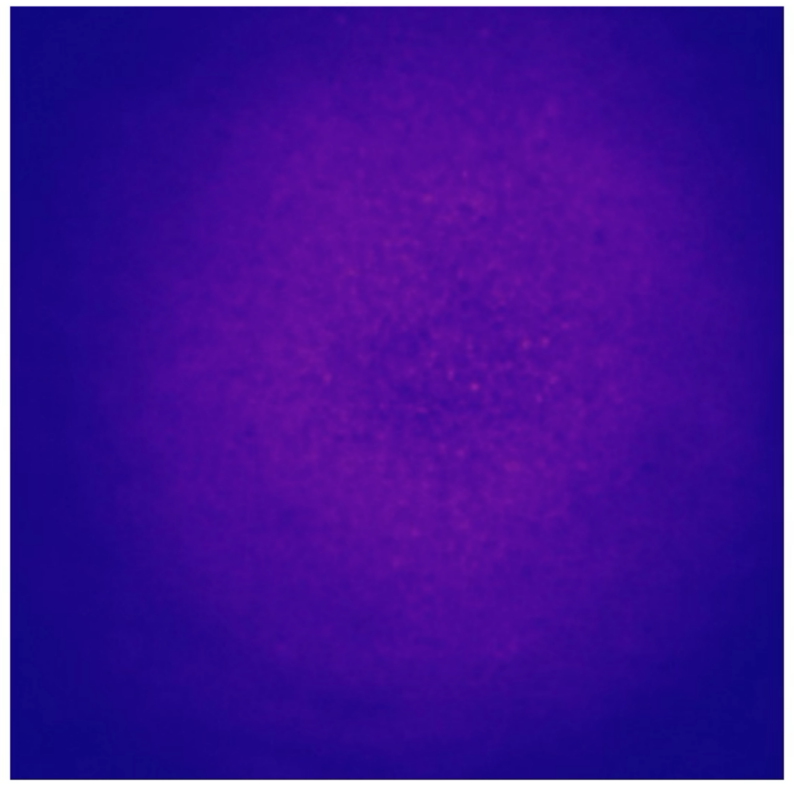


1E-5 M in ACN, excitation at 436 nm

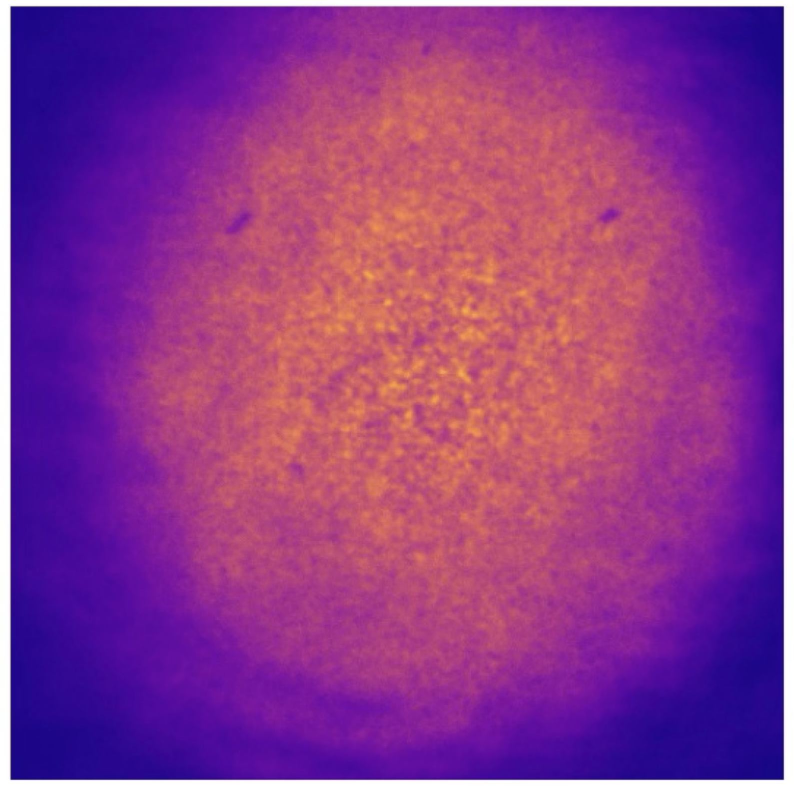


- The **same techniques under development for Ba^{2+} tagging** can be applied here for NH_4^+ sensing, e.g. the use of a fluorescent chemical sensor deposited on the surface of the cathode able to offer a clear luminescent response to the ions.
- In particular, we have checked that **one of our sensors (NAPH3) works**

NAPH3 w/o NH_4^+



NAPH3 w/ NH_4^+



Outlook

- **Measurement of ion tracks with a diffusion of order 1 mm appears feasible** in a high-pressure gas TPC. Implementing this concept requires extending the current technology to include controlled trace concentrations of NH_3 and an ion-detection system located in the cathode region.

- The **additional discrimination provided by the sharply defined ion track** further enhances the power of the high-pressure gas TPC technology. Notice that this includes rejection of near-track satellites (such as the characteristic X-rays from Bi-214 decays).

- The sharp ion track **may ultimately allow running a gas TPC at higher pressure** (40 bar), thus compressing large masses in relatively small volumes.

- Given the difference in drift velocity between Ba^{2+} and $NH4^{+}$ ions (the latter drifting about five times more slowly), it appears feasible to deploy **both "barium tagging" and "ammonium tagging" simultaneously.**

- The deployment of this technology **might be considered also for a LXe detector** with two caveats: (1) the "aspect ratio" (diffusion/length) is one order of magnitude smaller, blurring the details of the track (assuming 400 V/cm), and (2) ion drifting time is in the order of minutes, making it more challenging to open the gate at the right time.