The Dual Sided CCD

arXiv:2307.13723

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The Dual Sided CCD (DCCD) is a proposed imaging device that measures *both* the electrons and holes created in ionization events. This strategy leads to *strong dark count suppression*, by a factor of ~10^3, and *significant enhancements* of a a CCD's timing, typically by the same factor. These advancements have wide-ranging implications for dark-matter searches, near-IR/optical spectroscopy, and time-domain X-ray astrophysics.

Detector concept

Figure 1

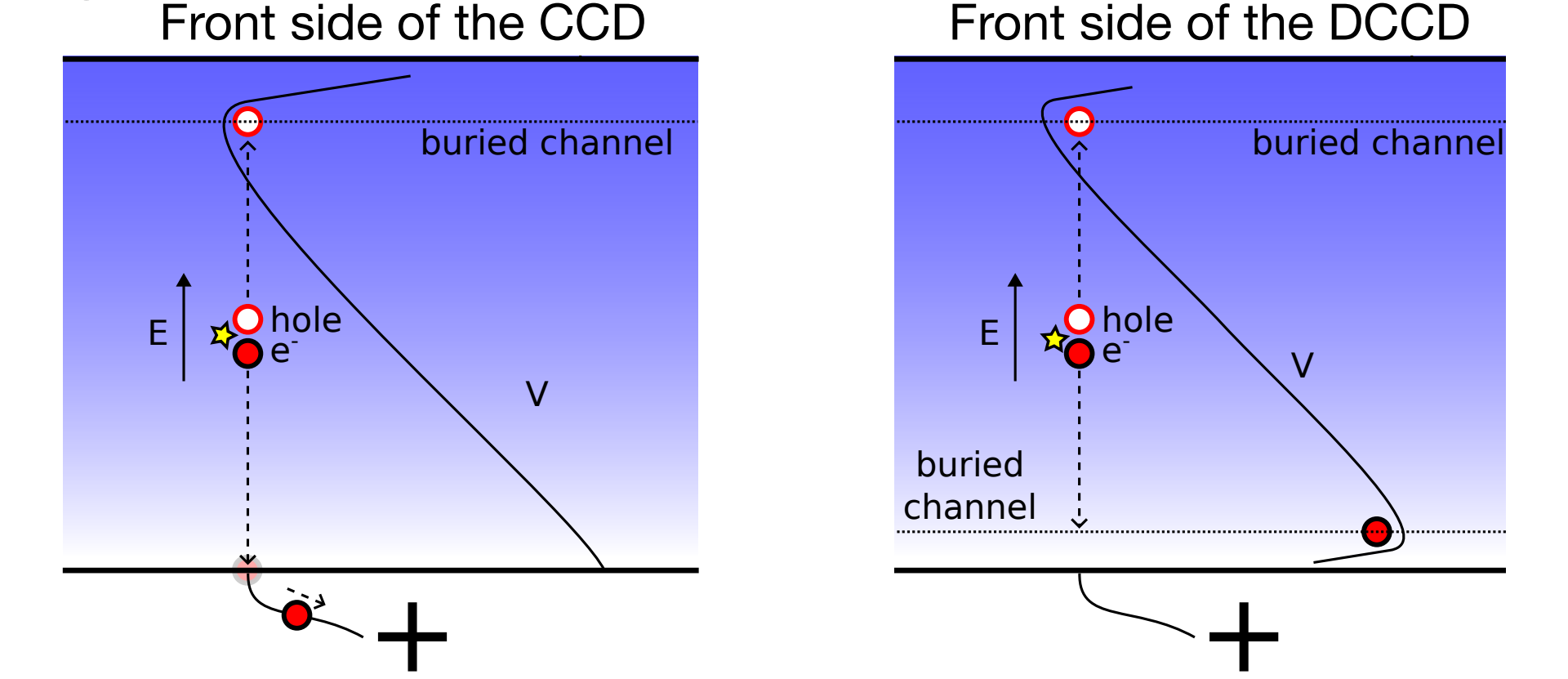
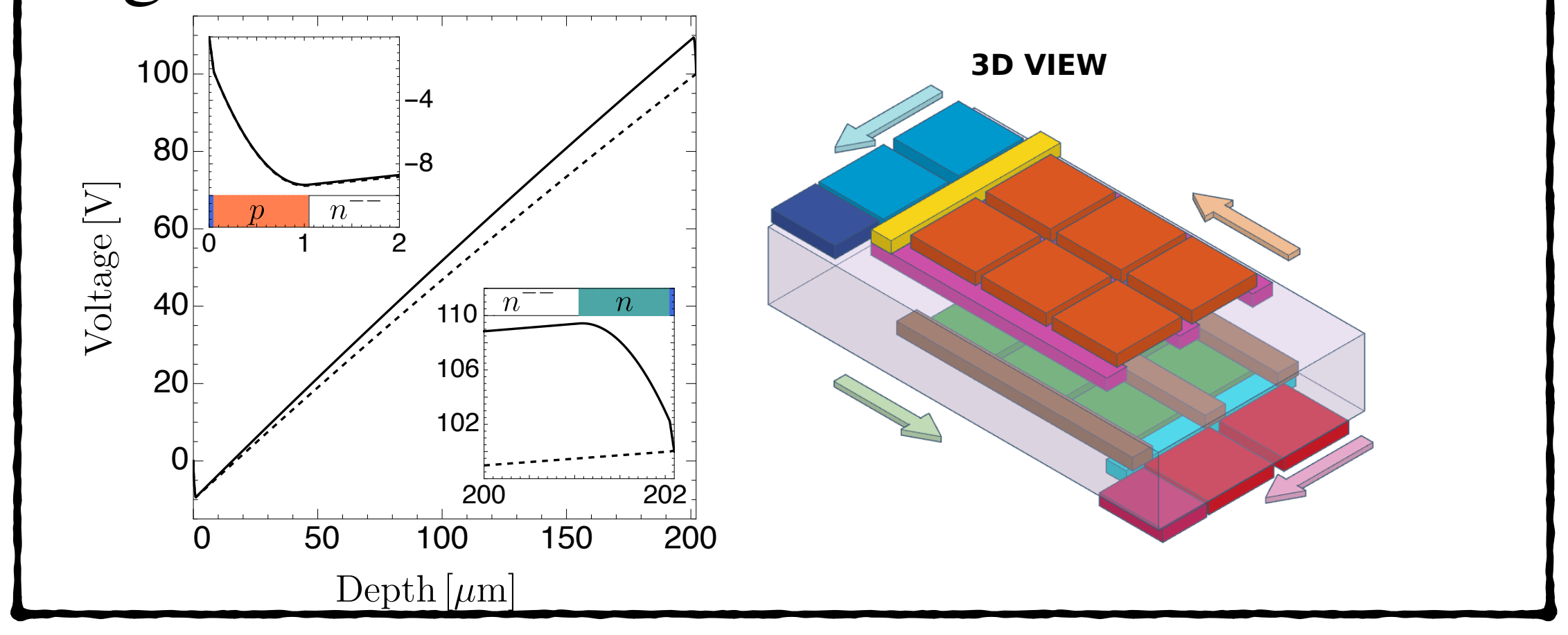


Figure 2



In standard CCDs an event is detected by establishing an electrostatic potential that drifts *either* the electrons or holes towards a "buried channel" (Fig. 1, left). To collect both positive and negative charge carriers, a DCCD is equipped with buried channels of opposite polarities on the detector's front *and* backsides (Fig. 1, right).

The dual-buried channels are fabricated by implanting opposite-polarity dopants in the front and backside of the device: a p-type channel will be used to collect holes at the front, while an n-type channel will collect electrons at the back (Fig. 2, left). The device will then have front (red) and back (green) pixels for hole and electron collection (Fig. 2, right).

Dark count and spurious charge rejection

Figure 3

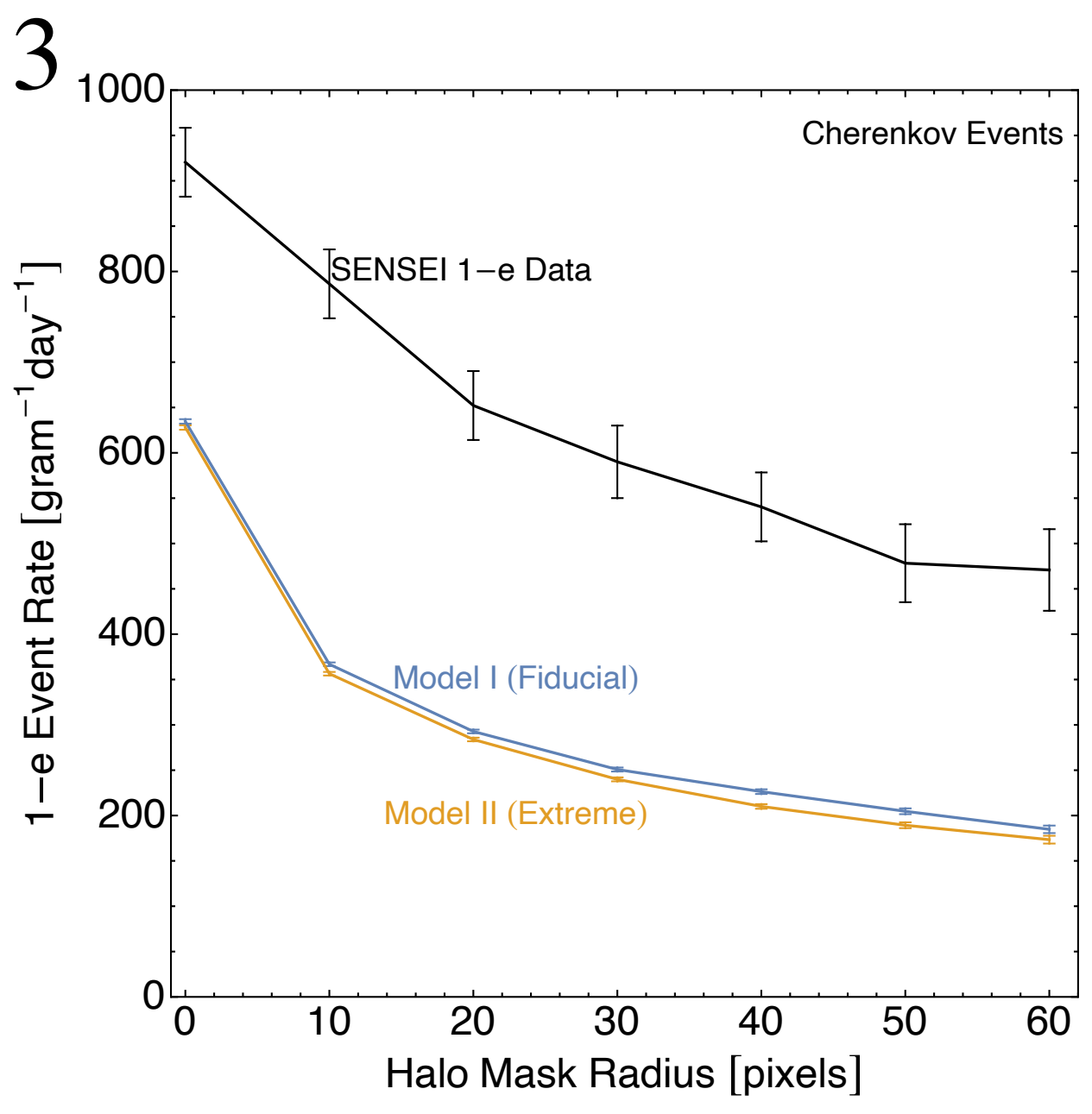


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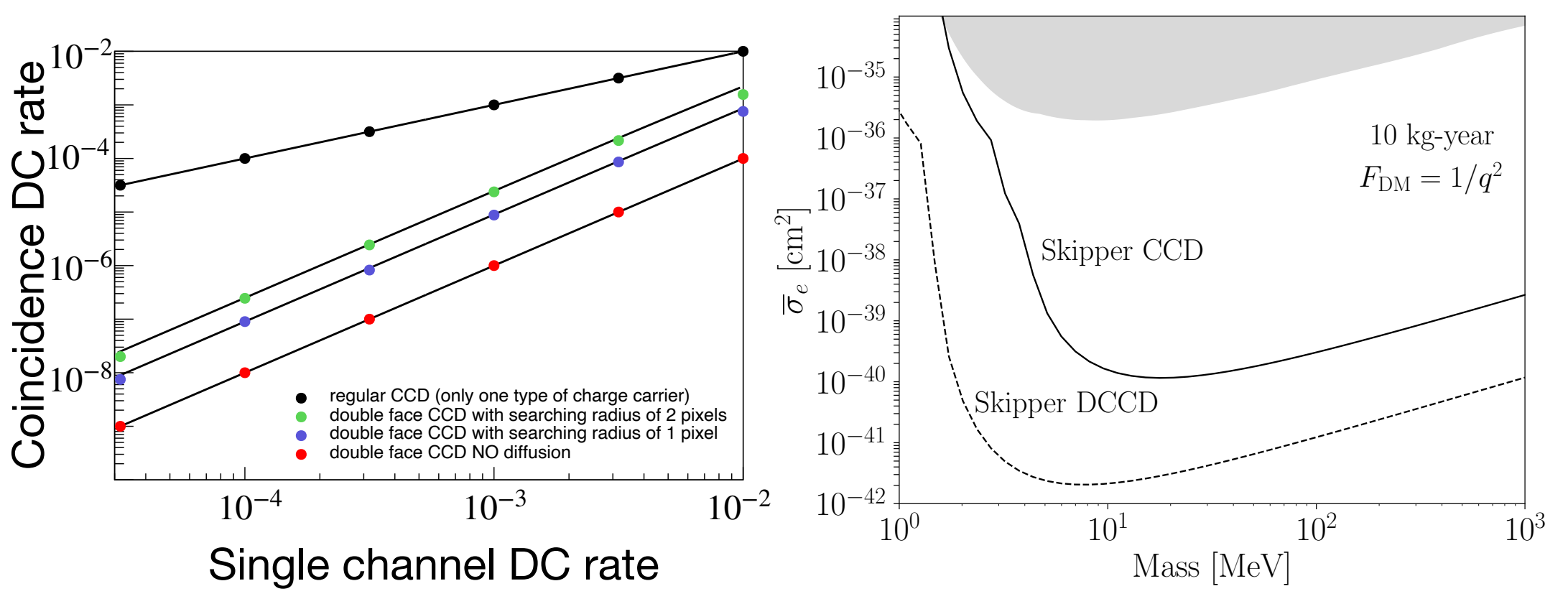
Figure 4



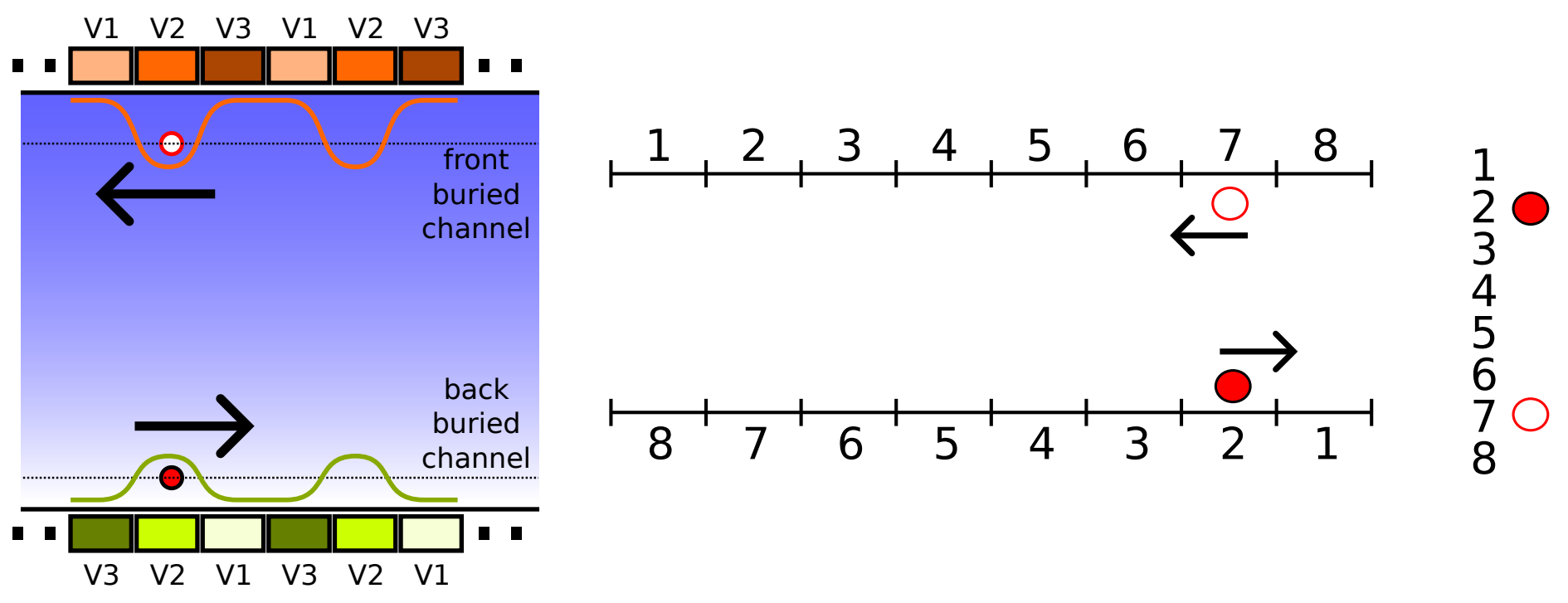
Bulk signal events populate both the front and back channels with opposite-polarity charges. Bulk dark counts (DCs) in state-of-the art devices arise from Cherenkov photons and simulations show that they are subdominant (Fig. 3). Surface DCs/spurious charge likely dominate the rates instead.

Given the potential profile near surfaces, surface DCs *only populate either the front or back channels with a hole or electron*, as any charge with the opposite polarity is drifted away towards the gates. The DCCD can thus discriminate DCs against true *dual-channel* signals.

Dark counts and spurious charge events can be suppressed up to front-back in-pixel coincidences (Fig. 4, left); this represents a factor of 10^3 improvement with respect to current devices. Dark counts as low as one per pixel per *hundred-thousand years* (10^{-12} Hz) could be achieved after masks. The projected reach of a future Skipper-DCCD as a dark matter detector is compared against a standard Skipper CCD detector in Fig. 4, right.

Timing improvements

Figure 5



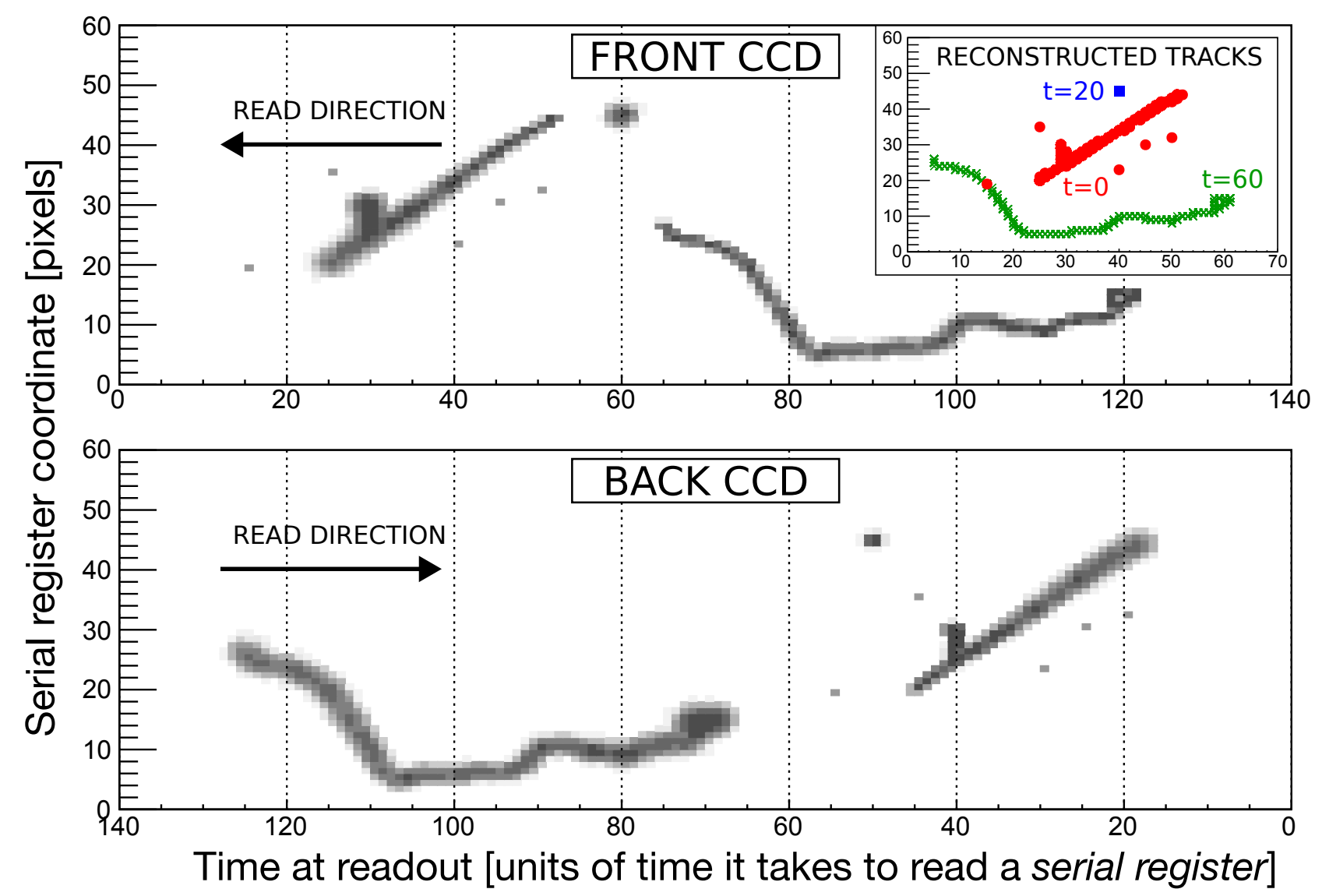
Position y and time t reconstruction

$$y = \frac{1}{2}(t_f - t_b + L_{\rm VR})$$
$$t = t_f - y = \frac{1}{2}(t_f + t_b - L_{\rm VR})$$

$L_{\rm VR}$: column length in pixels

$t_{f,b}$: arrival times to SR

Figure 6



In standard CCDs in continuous readout, events that occur on a pixel can be mimicked by events that occurred *earlier upstream* in the vertical register. As a result of this ambiguity, the time resolution is limited by the time it takes to read out all the CCD pixels.

In a DCCD this is solved by reading out the front (hole) and back (electron) vertical registers in opposite directions (Fig. 5). The event's vertical register position is obtained by matching the back and front charges: only one pixel position produces the recorded times of arrival (2 and 7 in the Figure example). This allows to reconstruct the timing within the time it takes to read a *single row* of the CCD. In megapixel CCD this is a three-order of magnitude improvement, potentially leading to $\sim 10\,\mu s$ and $\sim 1\,s$ resolutions in EMCCDs and sub-electron noise Skipper CCDs.

Example application: Fig. 6 shows a GEANT simulation of a 70 × 60 pixel DCCD with three energetic events, with one leading to isolated single *eh* events by e.g. secondary luminescence. The DCCD's reconstructed time is shown in the inset, from which we can uniquely associate the secondaries to the straight track, a task that would not be possible with a standard CCD.