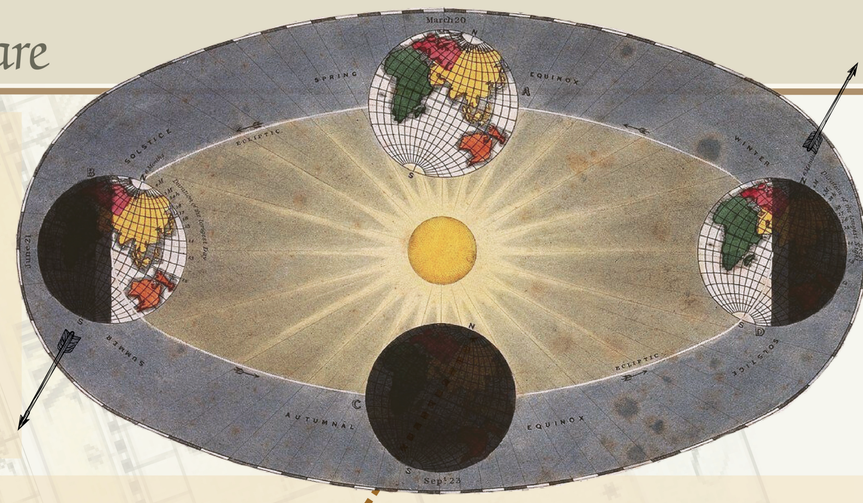
Optimising recoil imaging detectors for extraterrestrial particles

Chiara Lisotti, supervised by Dr. Ciaran O'Hare

Objectives

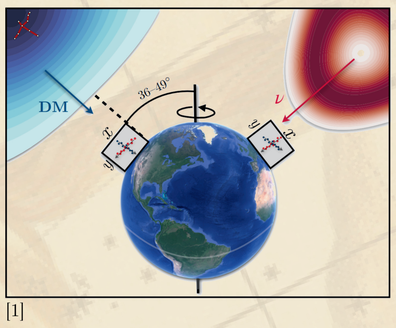
The only way to unambiguously confirm whether a signal is originating from the galaxy is by determining its direction. This information makes it possible to distinguish these signals from any sources of background, be it neutrinos or any other sources of particles.

Recoil imaging directly measures 3D ionisation distributions left by nuclear and electron recoil tracks, and it is the most promising approach for directional detection. These experiments, however, are non-trivially influenced by factors such as geometry, location, and alignment: here, we aim to provide clear and minimally invasive guidelines to optimise their performance.



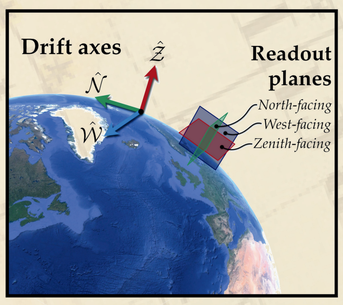
Directional Detectors and Performance Optimisation

Geocentric coordinates

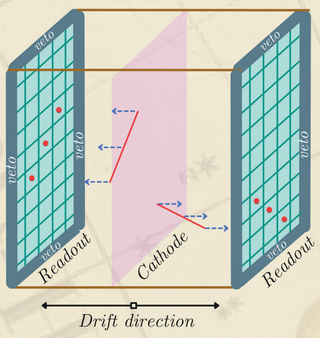


[1]

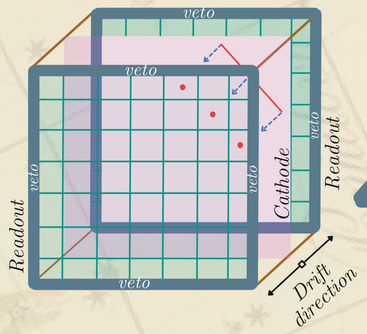
Detector-centric coordinates

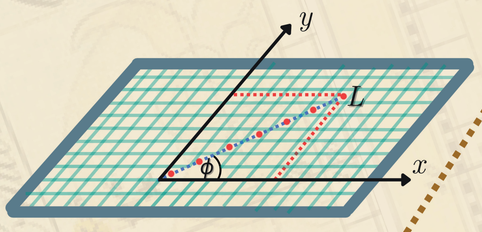


North-Facing



West-Facing





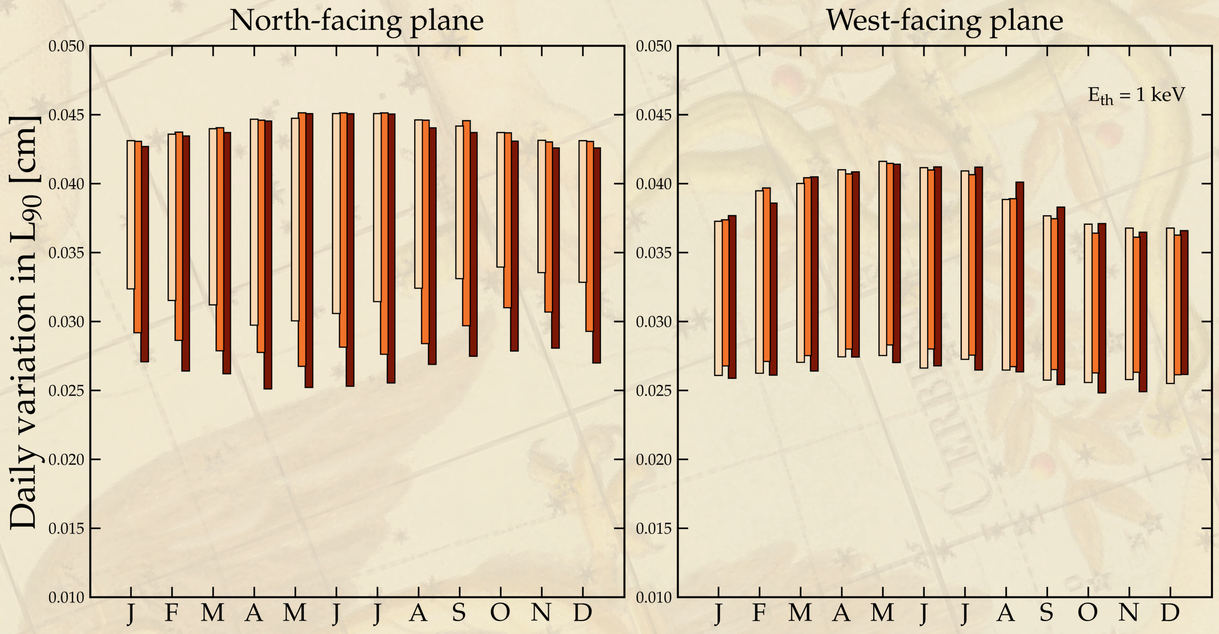
Recoil imaging detectors using Micro Pattern Gas Detectors (MPGDs) will be highly segmented in one plane, so it is vital to maximise the number of pixels covered along it, as well as the variation of orientation in this plane.

Thus, we will consider the case of a gas time projection chamber (TPC) as an example and study how the projected length and the angle ϕ in the readout plane change for the two orientations shown here throughout the year.

For the best performance, we wish to:

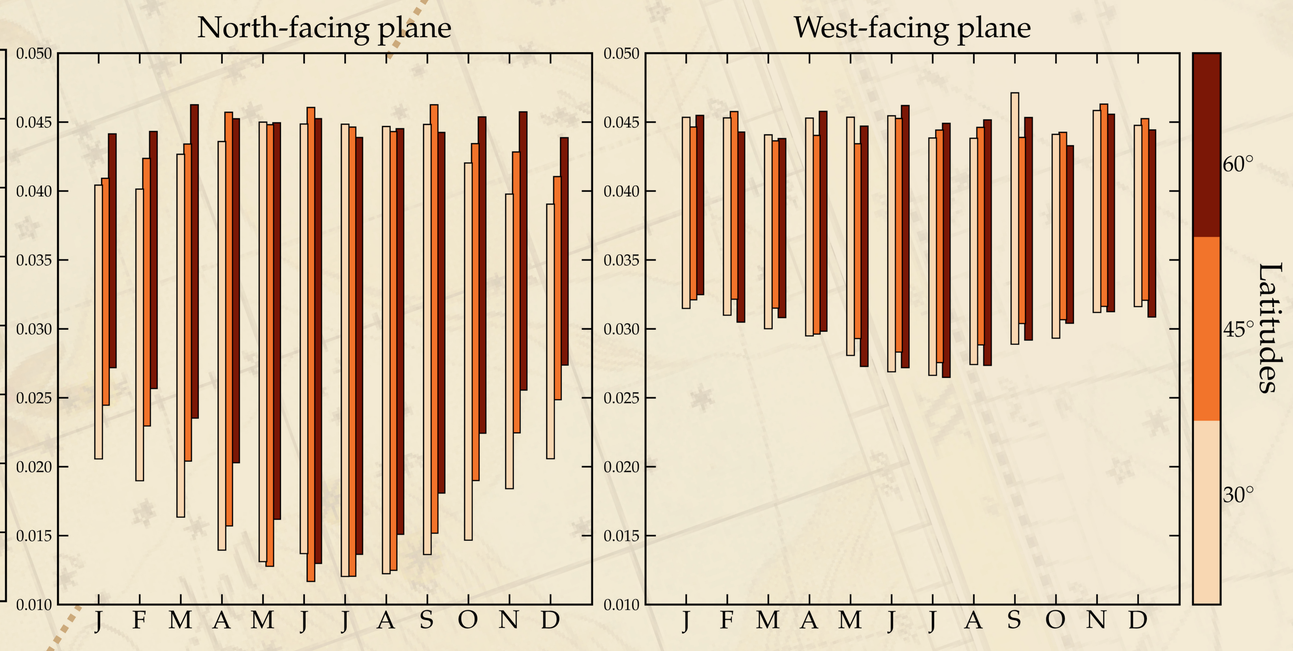
- **maximise the modulation of the signal across the full readout plane to best reduce background**
- **maximise the track length in the readout plane**
- **observe the biggest separation in the total angular distributions of DM and neutrino-induced recoils**

20 GeV DM-nucleon recoils



We consider a 20 GeV dark matter-nucleon recoil and a ^{8}B CEνNS recoil and generate recoil events to study the daily variation in projected lengths along the plane. The lengths and quenching factor used were calculated for fluorine recoils in a 755:5 He:SF_6 gas mixture [2].

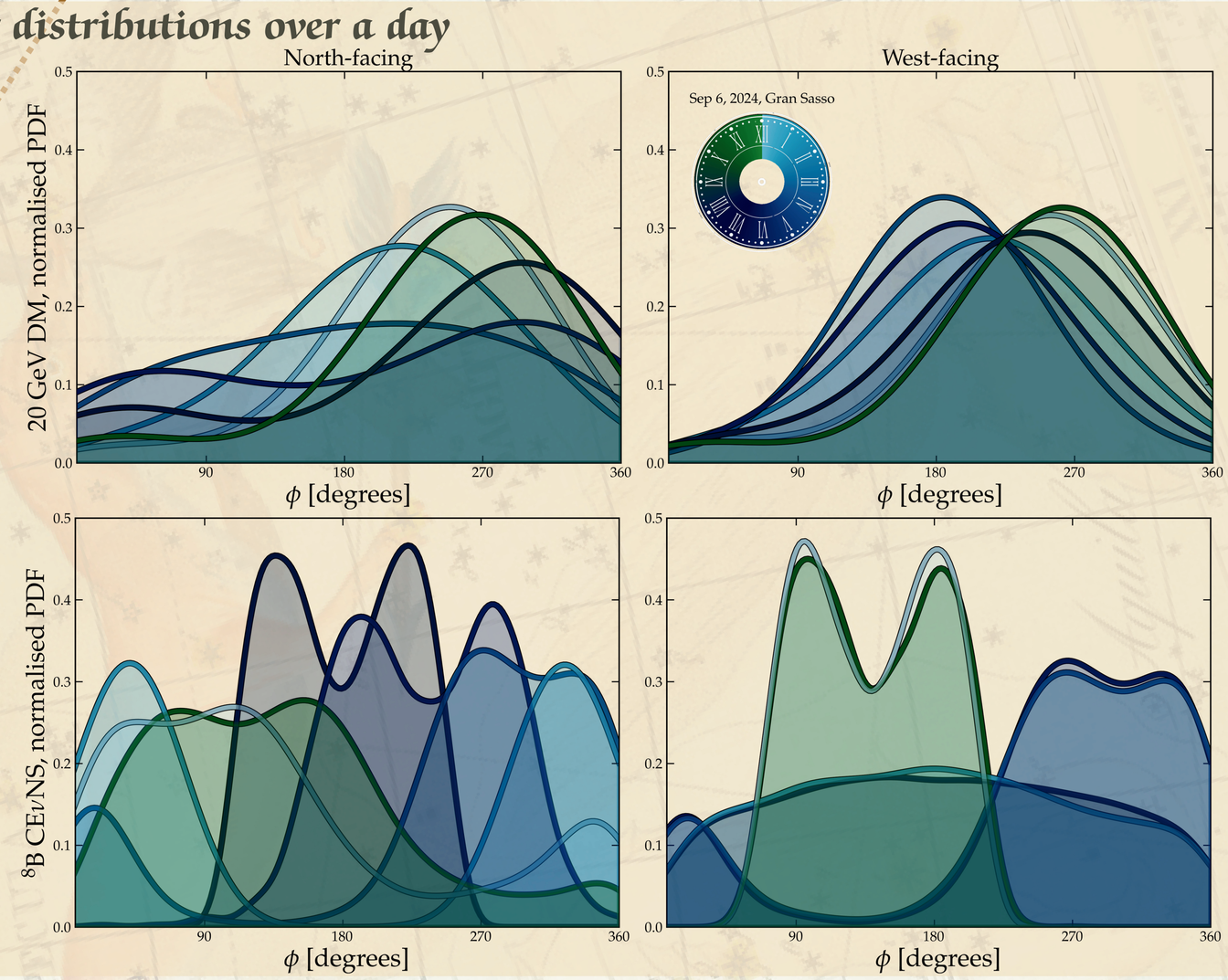
^{8}B CEνNS recoils



90% of the generated recoils will result in a projected length higher than L_{90}; here we show how this varies for the first day of every month of the year. The *West-facing-plane* projections are consistently longer throughout the year, making it preferable in the case of nuclear recoils.

Total angular distributions over a day

We now consider the total angular distributions for DM and ^{8}B CEνNS-induced nuclear recoils. We analyse the same orientations as above for September 6, when the angular separation between the direction of the Cygnus constellation and the Sun is maximised. Once again, the *West-facing readout* results in the biggest separation between the two distributions, making it possible to distinguish the signals.



Conclusions

The *West-facing readout plane* case yields the best performance to discern DM-induced recoils from ^{8}B neutrino-induced ones, providing a minimally invasive modification to maximise the effectiveness of directional detectors.

For future research, this analysis will be supplemented with a global optimisation over many other quantities, such as orientation, location, resolution parameters, and head-tail recognition, and it will be optimised relative to several signals of interest at once, including solar neutrinos, various forms of DM, and isotropic backgrounds, to ultimately define a clear set of guidelines that will enhance directional detection capabilities.

[1] S. E. Vahsen, C. A. J. O'Hare, and D. Loomba, Directional Recoil Detection
[2] S. E. Vahsen et al., CYGNUS: Feasibility of a nuclear recoil observatory with directional sensitivity to dark matter and neutrinos