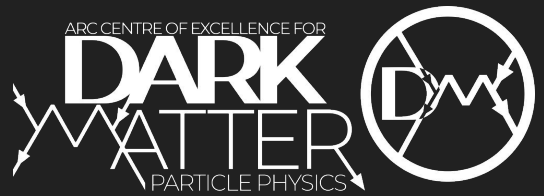
CYGNUS – Directional Identification of Nuclear and Electron Recoils from Dark Matter and Solar Neutrinos

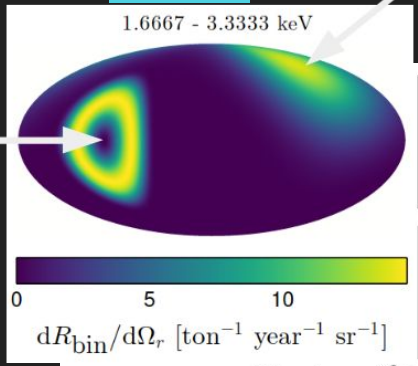
Lindsey Bignell for the Cygnus proto-collaboration

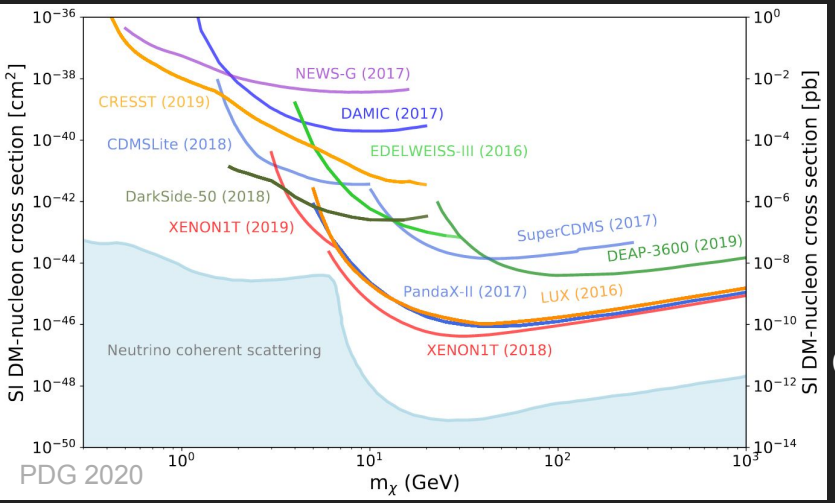
Australian National University

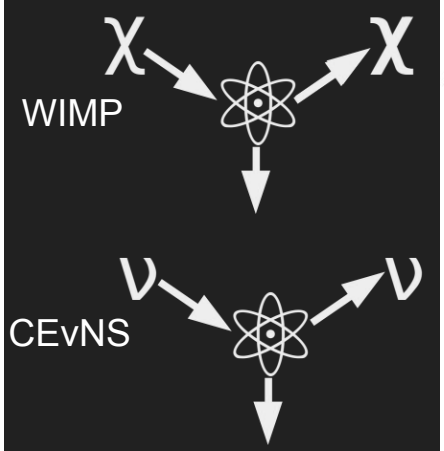


Directional Detection: WIMPs

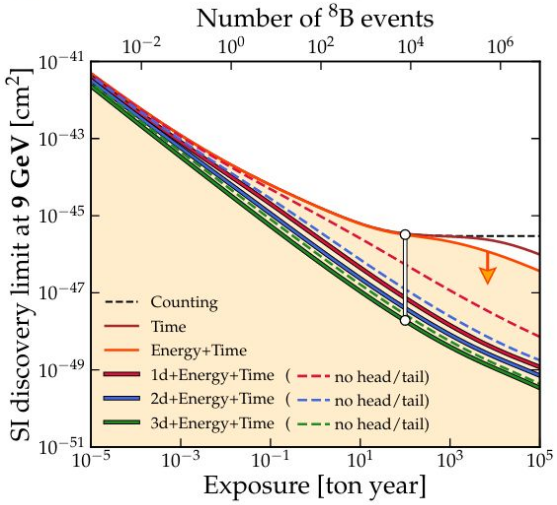
Overcome the neutrino floor (and reject isotropic backgrounds)





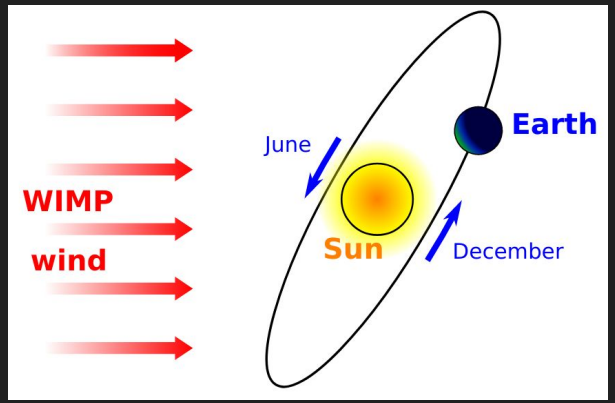


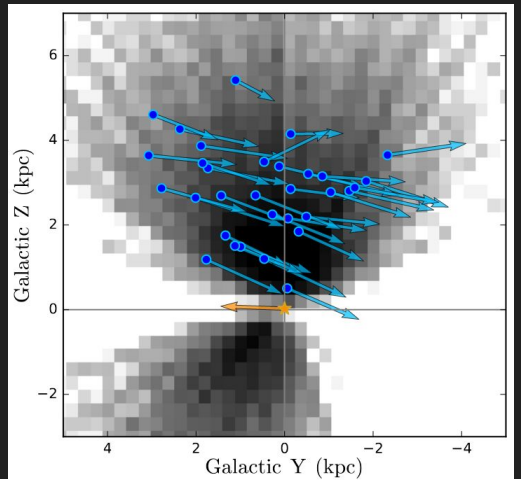
Arxiv: 2102.04596



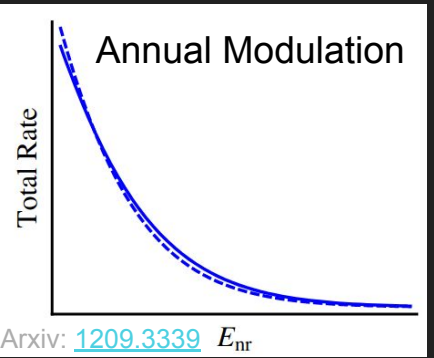
Directional Detection: WIMPs

Astrophysical signature and post discovery science



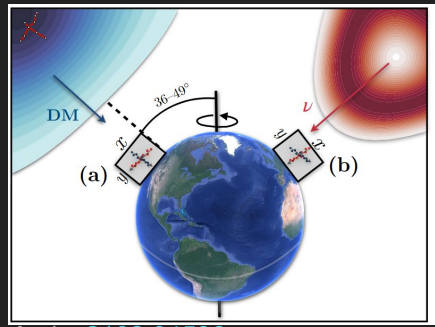


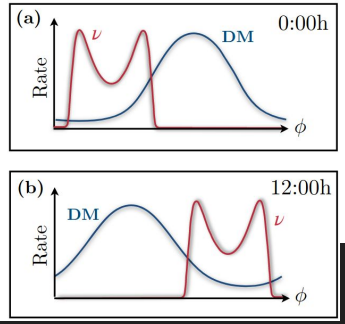
Non-directional



Arxiv: 1209.3339

Pointing + diurnal modulation





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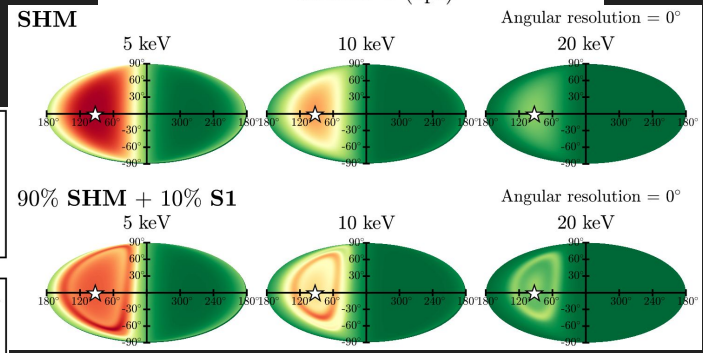
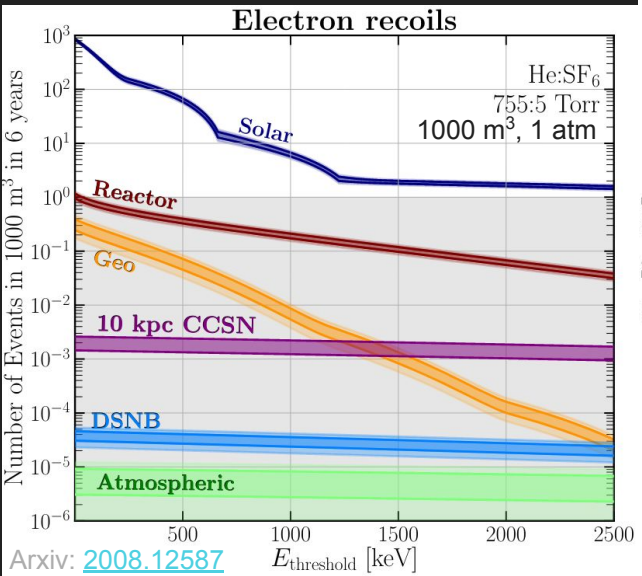


Arxiv: 1807.09004

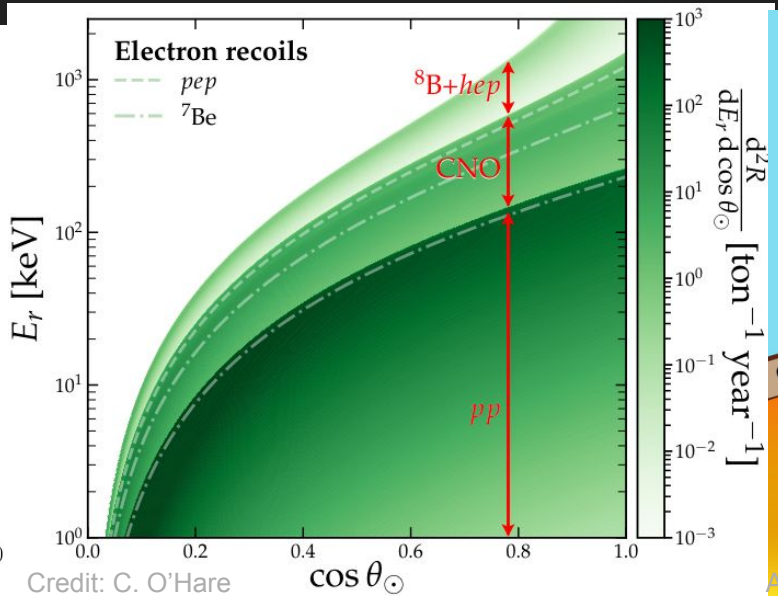
Directional Detection: Neutrinos

CNO neutrinos: event-by-event directionality yields neutrino energy spectrum, breaks degeneracy with pep + ^{7}Be and CNO.

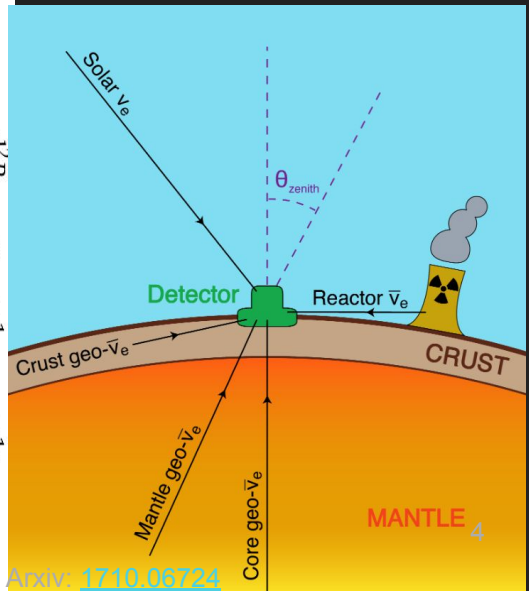
Geoneutrinos: 10 T for 10 years to measure K-40.



Arxiv: 2008.12587



Credit: C. O'Hare



Arxiv: 1710.06724

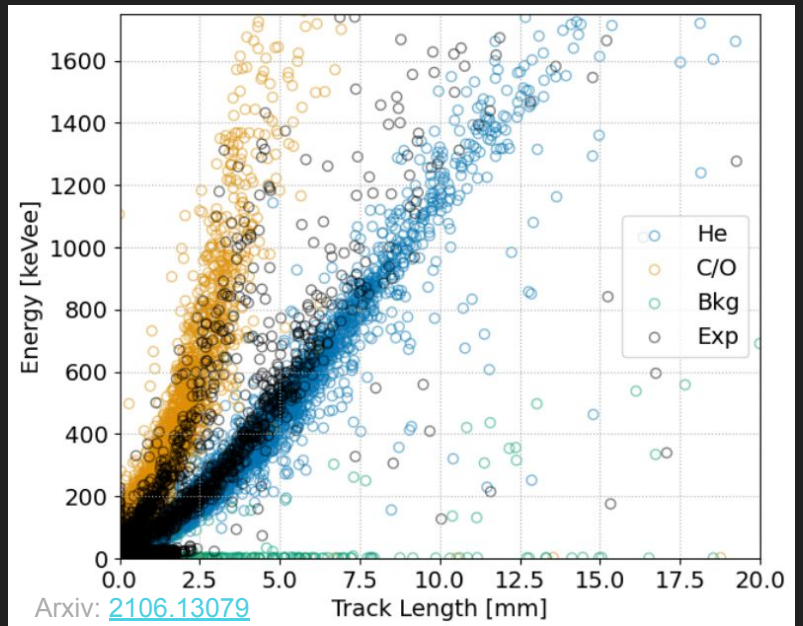
Directional Detection: other physics

Other Neutrinos: galactic SN, beam dump or reactor CEvNS

Non-WIMP DM: various models with NR/ER signals

Applications: Neutron background characterisation, homeland security.

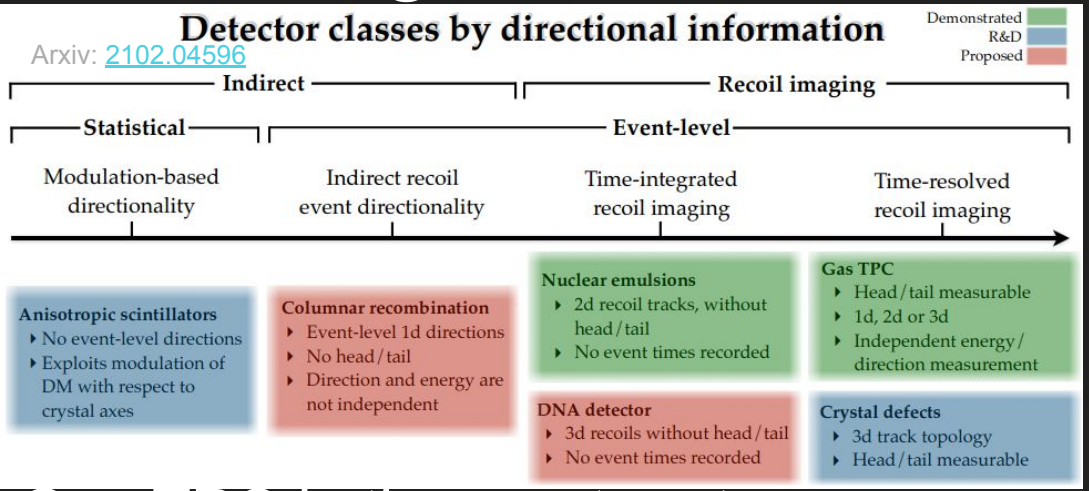
Migdal Effect



Arxiv: 2106.13079

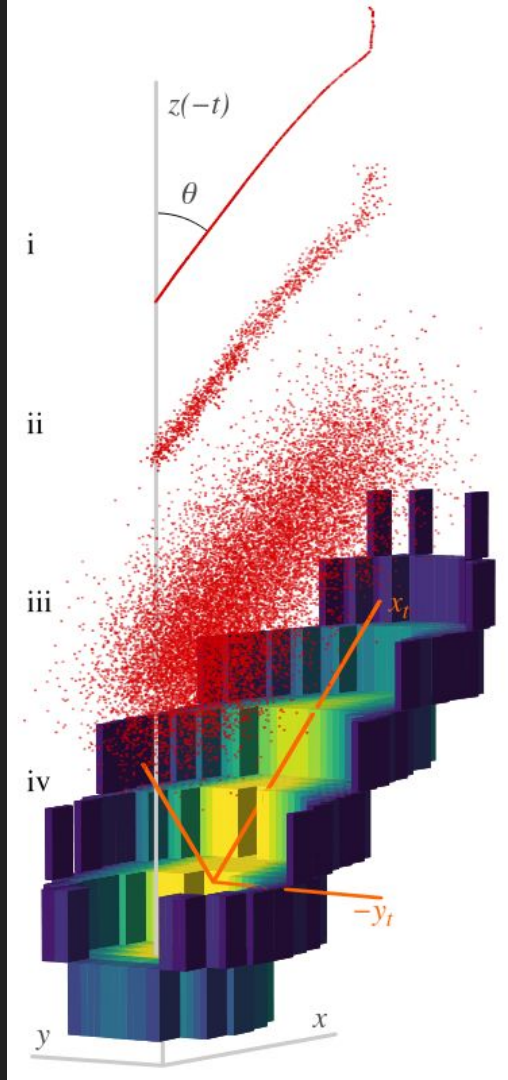
Arxiv: 2106.15829

Achieving directional detection



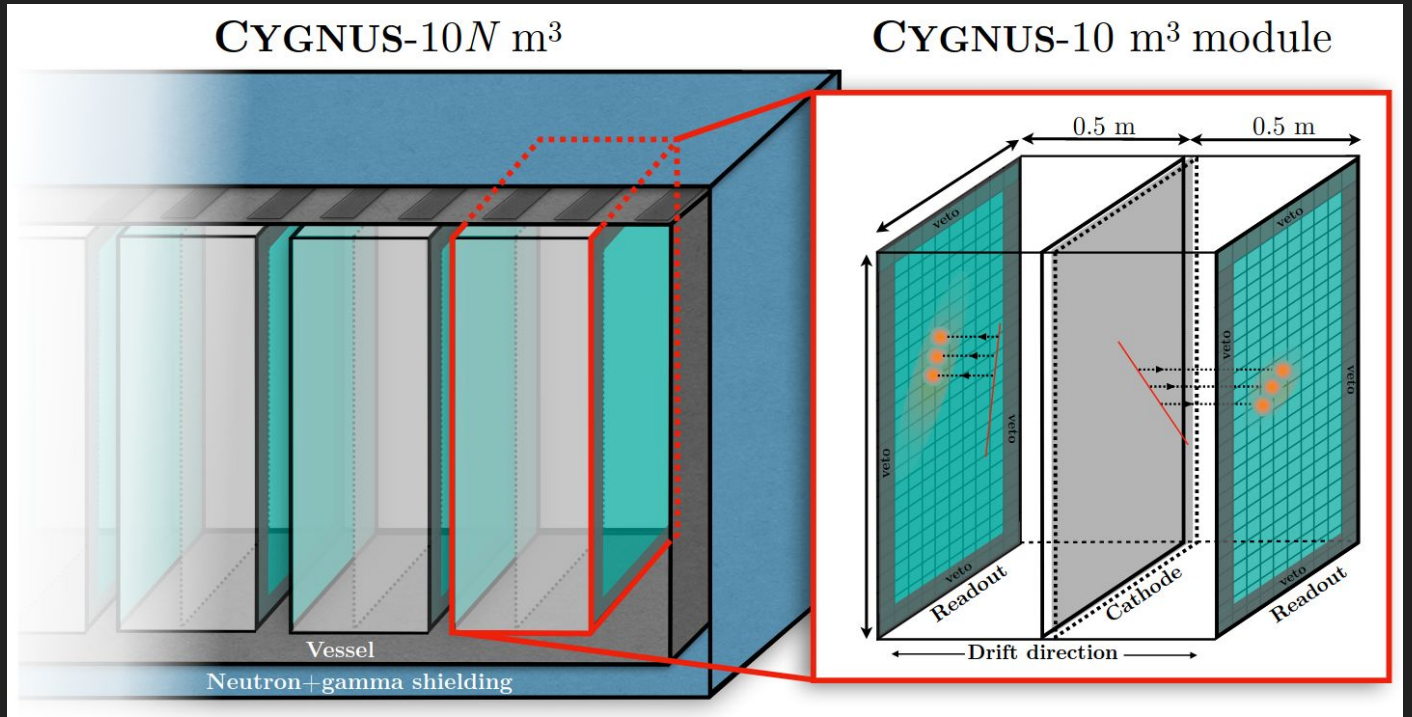
Gas TPC is the most mature event-by-event directional detector.

Directionality:
Track orientation (angular resolution) + vector sense (head/tail)



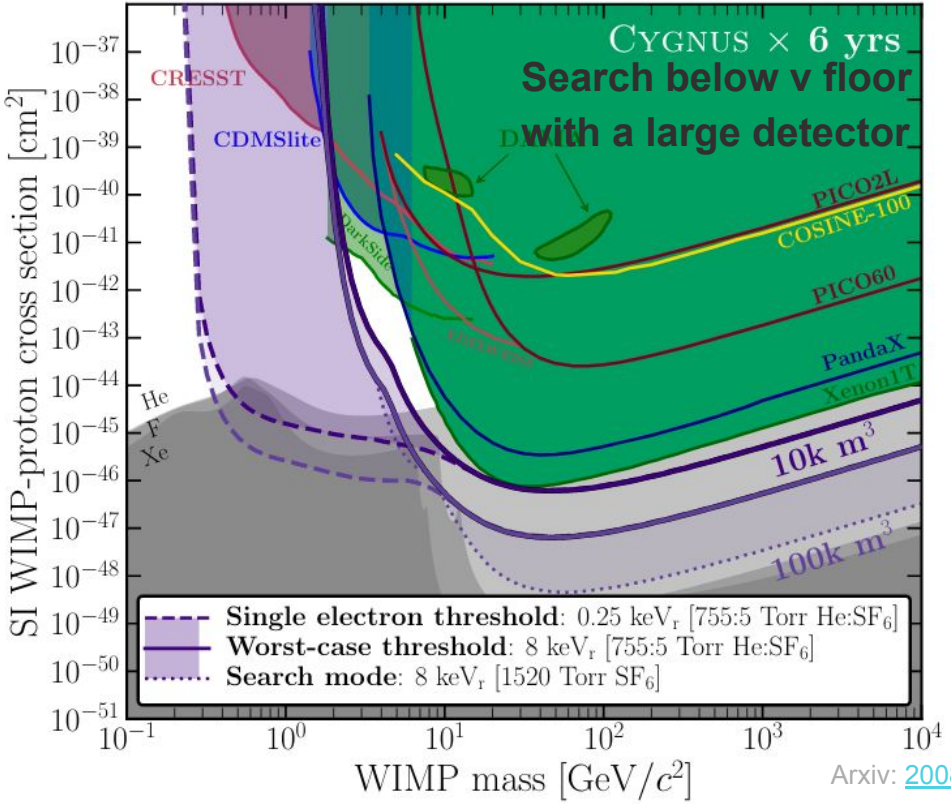
CYGNUS

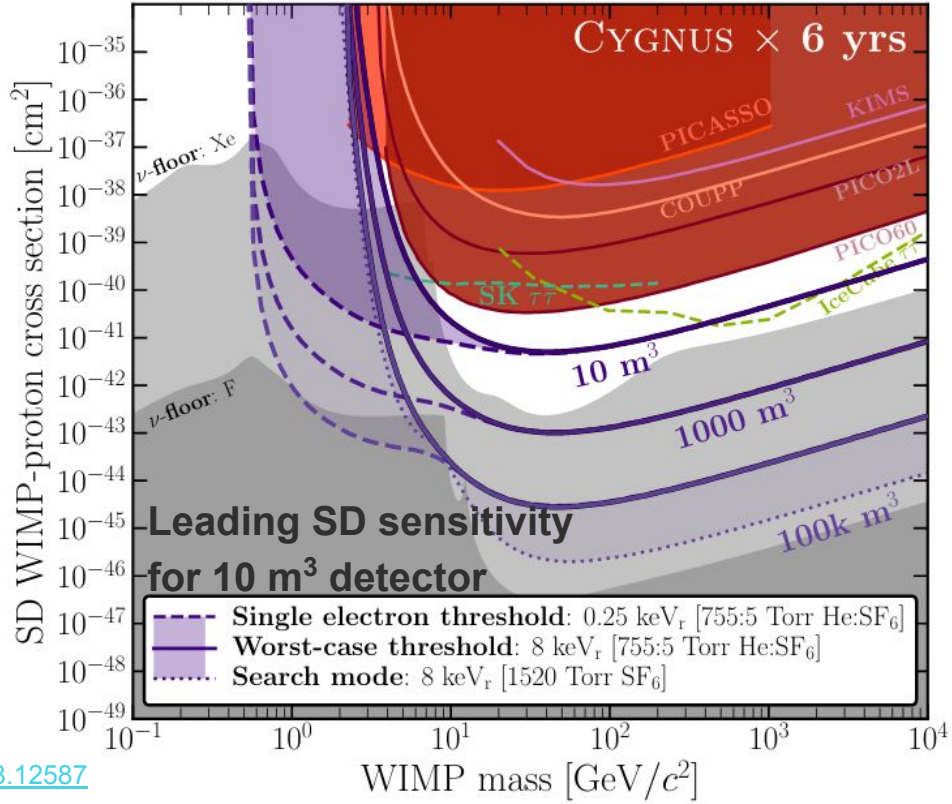
Long term goal: large distributed gas time projection chamber with low-energy directionality.



CYGNUS - WIMP sensitivity

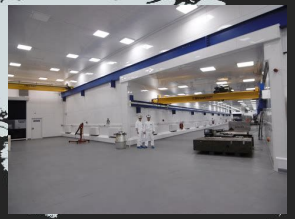
Recent WIMP sensitivity results. ER studies underway.



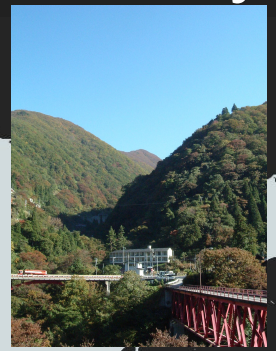


Arxiv: 2008.12587

CYGNUS vision: a multi-site directional observatory



CYGNUS-10
Boulby, UK



CYGNUS-HD10
Lead, USA

CYGNO
Gran Sasso, Italy

CYGNUS-KM
Kamioka, Japan

CYGNUS-oz
Stawell, Aus

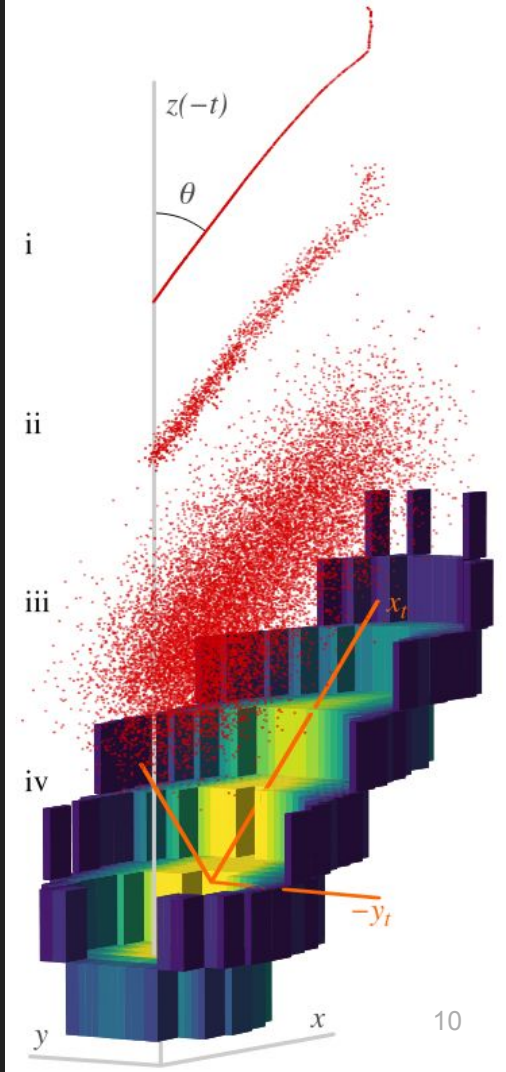
Arxiv: 2106.15829

CYGNUS - R&D challenges

A subset of the challenges:

1. Diffusion (long drift distances for small tracks)
2. Fiducialisation (reject surface radioactivity)
3. Energy threshold (event/directional/particle ID)

Gas properties ⟷ Readout



Negative Ion Gases

CS_2+ O_2 and SF_6

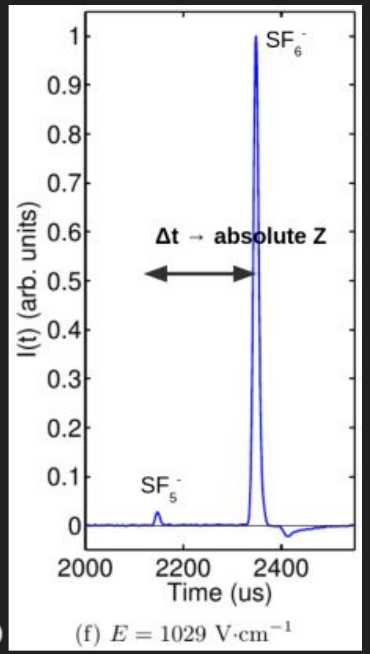
Diffusion at thermal limit

10^3 slower drift speeds

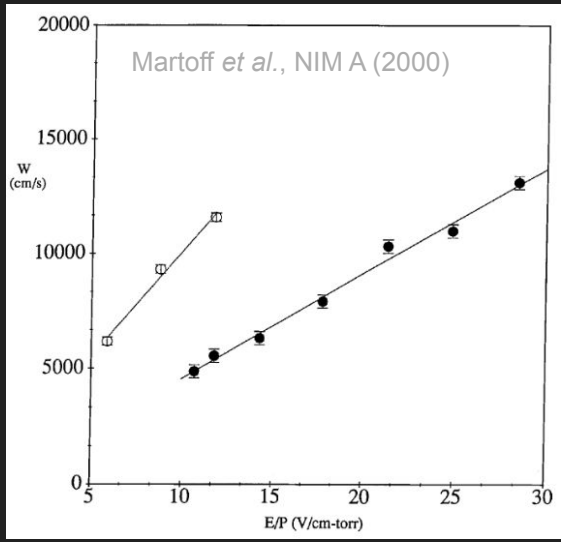
→ slower (cheaper) readout

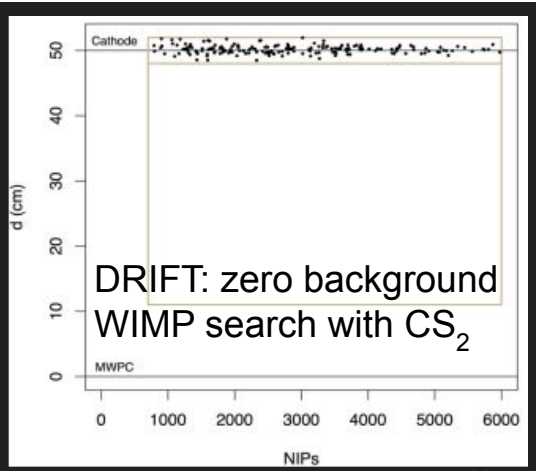
Minority carriers

→ fiducialisation



Arxiv 1609.05249





Arxiv 1701.0171

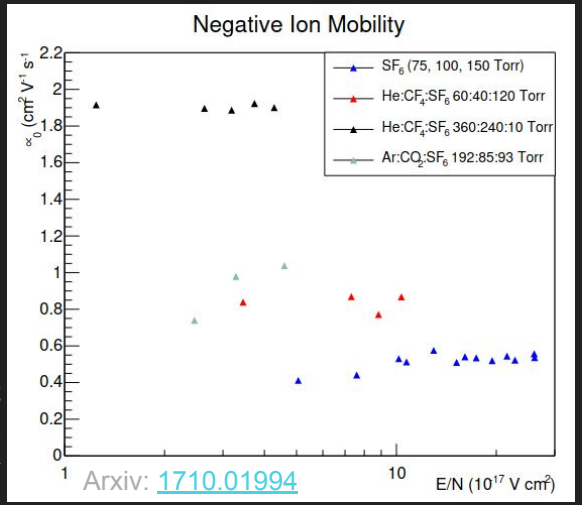
Negative Ion Gases

CS_2: toxic, corrosive, flammable.

SF_6: inert (but potent greenhouse gas)

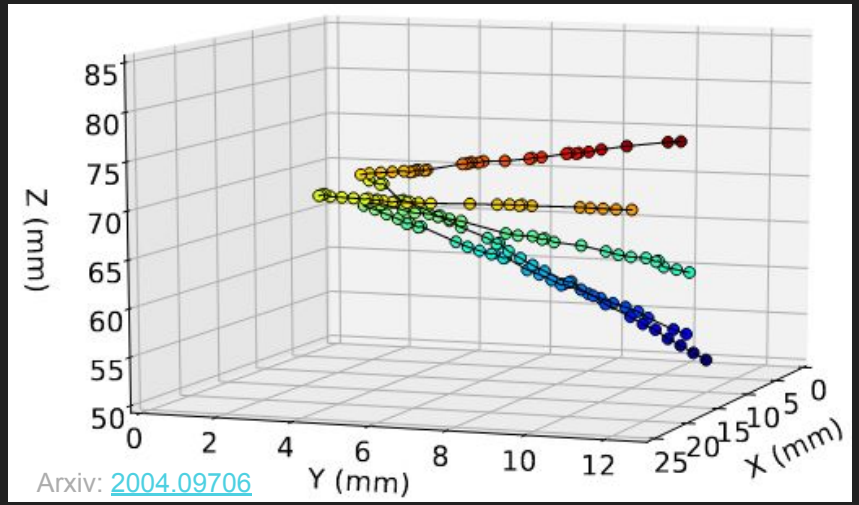
Main focus on SF_6

Nearly atmospheric pressure gas mix

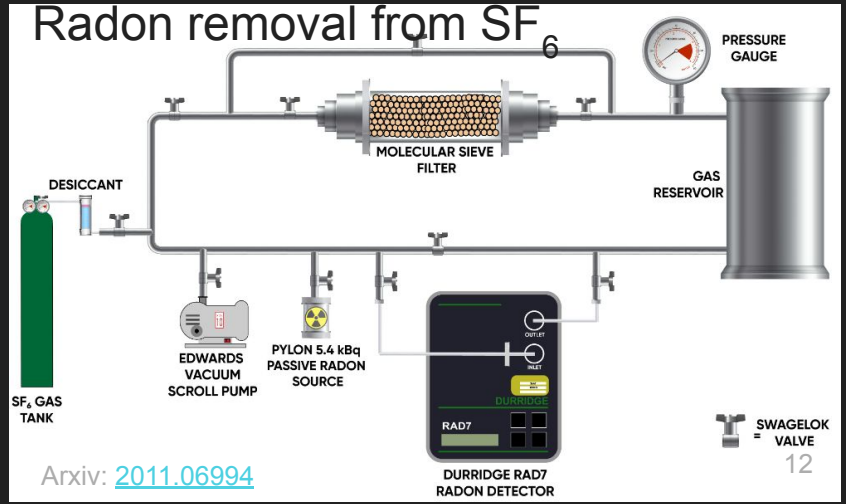


Arxiv: 1710.01994

First absolute z + 3D reconstruction



Arxiv: 2004.09706

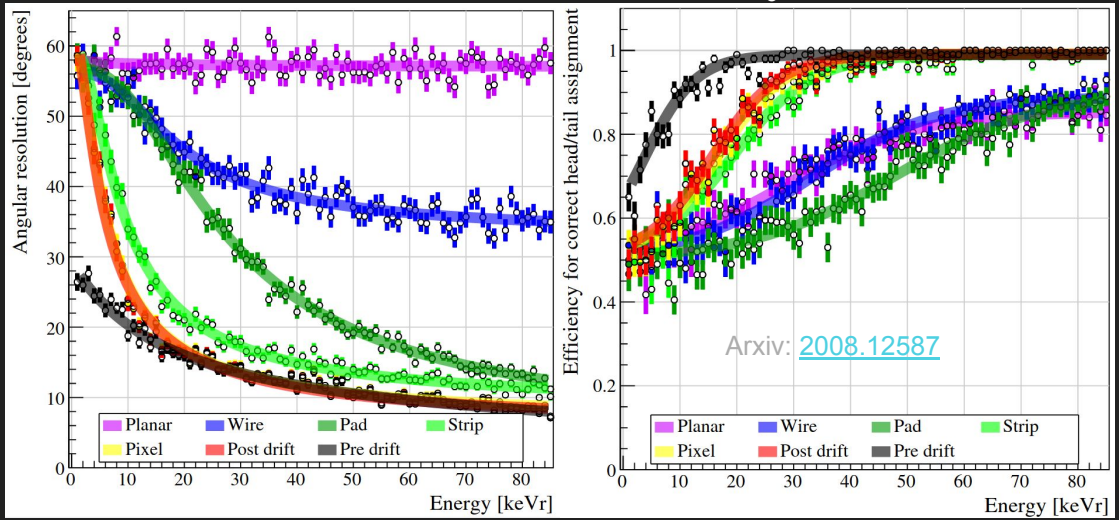


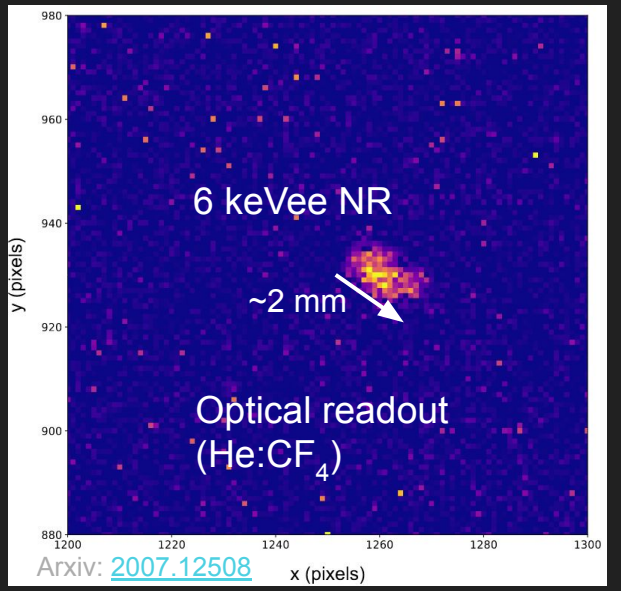
Arxiv: 2011.06994

Highly segmented readout

Typically necessary for low-threshold particle ID and directionality

He recoils in 755:5 Torr He:SF_6





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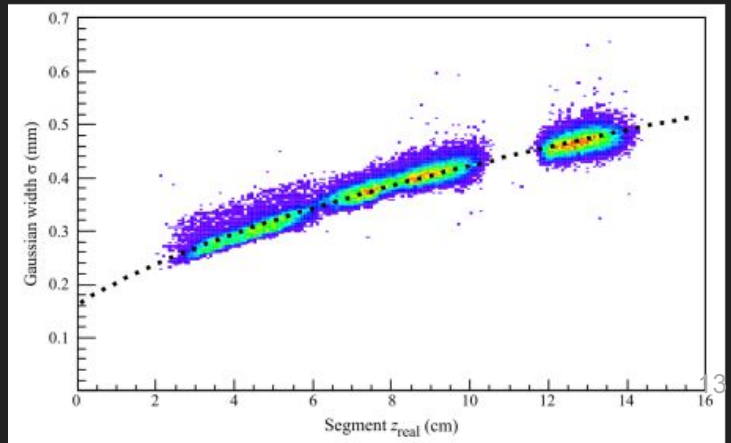
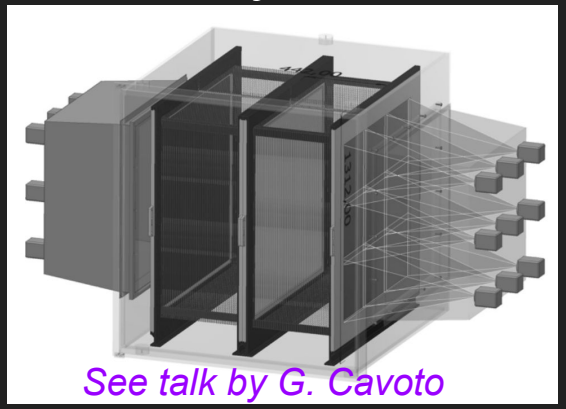


Alternative fiducialisation scheme is possible, based on transverse diffusion

Various stages of R&D/scale-up

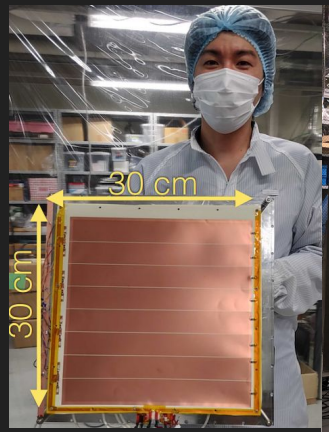
Italy



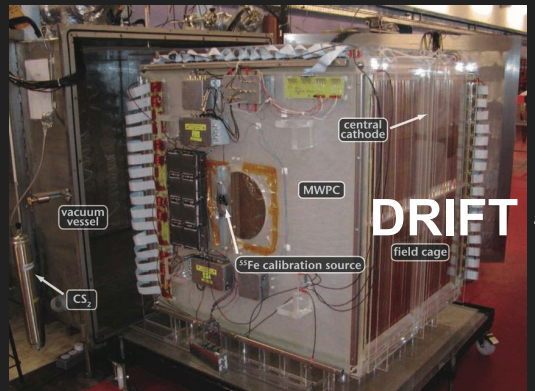
See talk by G. Cavoto

Hawaii

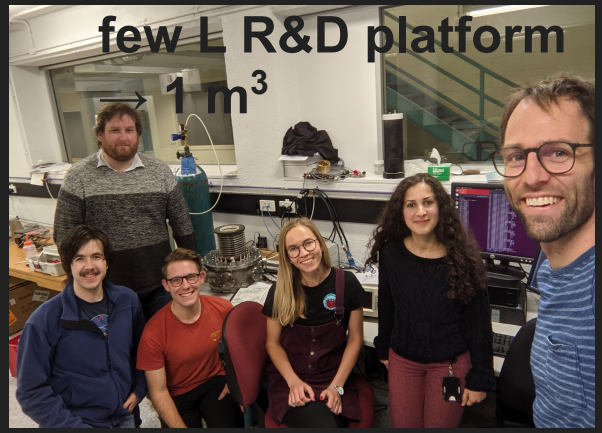
Japan



UK



Australia



Dual charge/HD optical readout

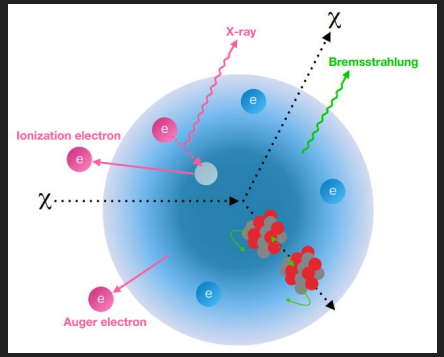
Test gases and readout technologies

Shorter term goal: Migdal effect

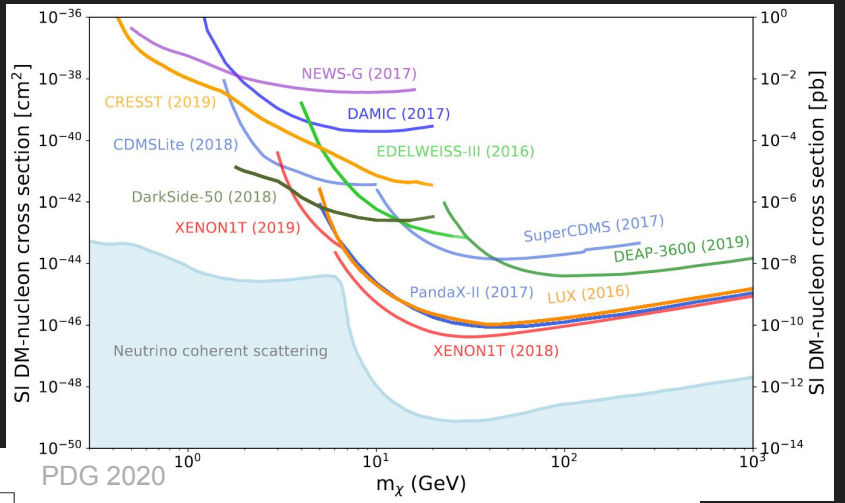
Electron ionisation due to nuclear recoil.

→ low mass limits, but never directly observed!

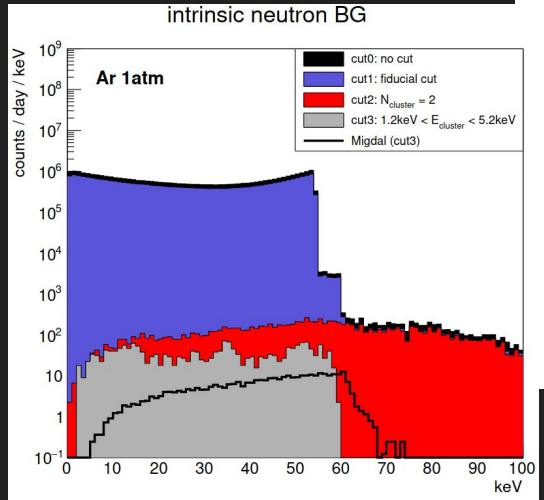
Path to Migdal observation in gas TPC with current technology

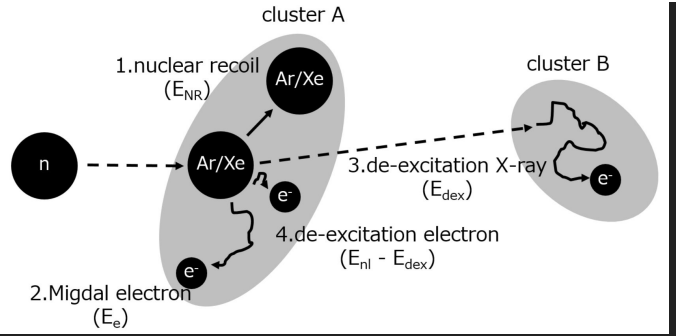


Arxiv: 1907.12771



PDG 2020





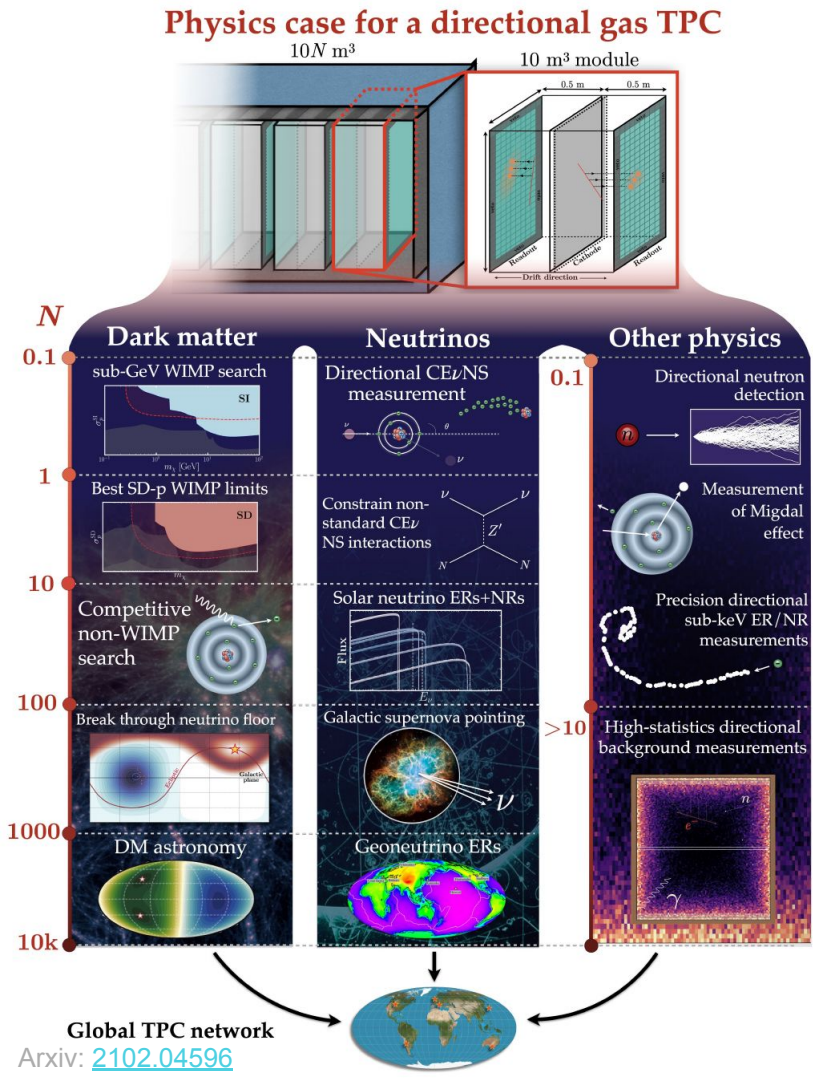
Arxiv: 2009.05939

Conclusion

Directional TPCs are a useful platform for rare event WIMP/neutrino search

R&D challenges remain, but scale-up appears feasible and is already beginning.

Short term prospects for interesting physics (Migdal) and translational opportunities.



Arxiv: 2102.04596