Optimization of high resolution 3D charge reconstruction in gaseous TPCs with strip micromegas

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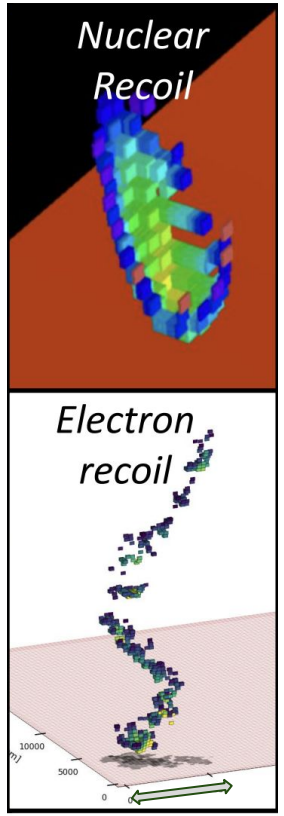
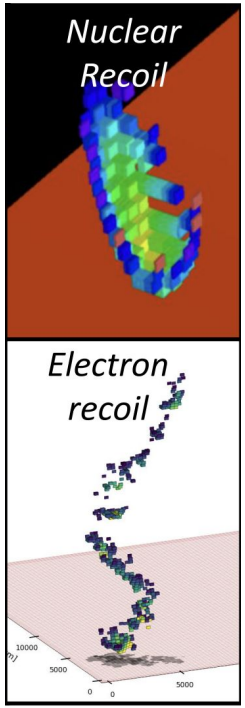


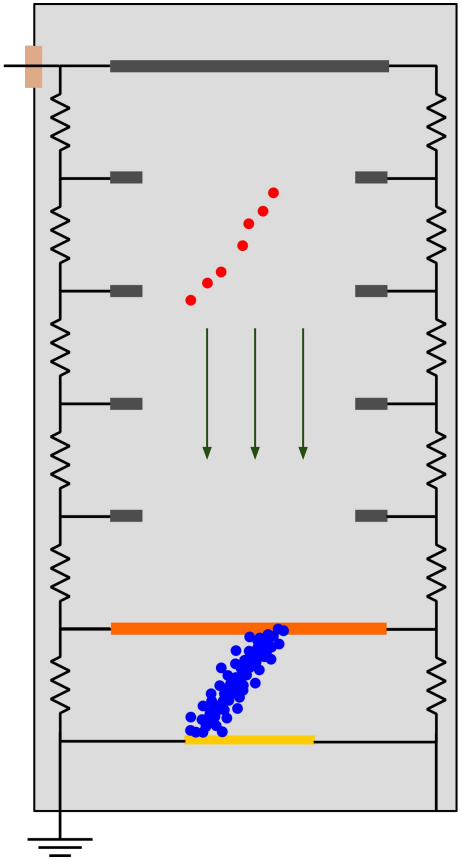
3D charge reconstruction in gaseous TPCs

Previous generation detectors

Highlights [1]

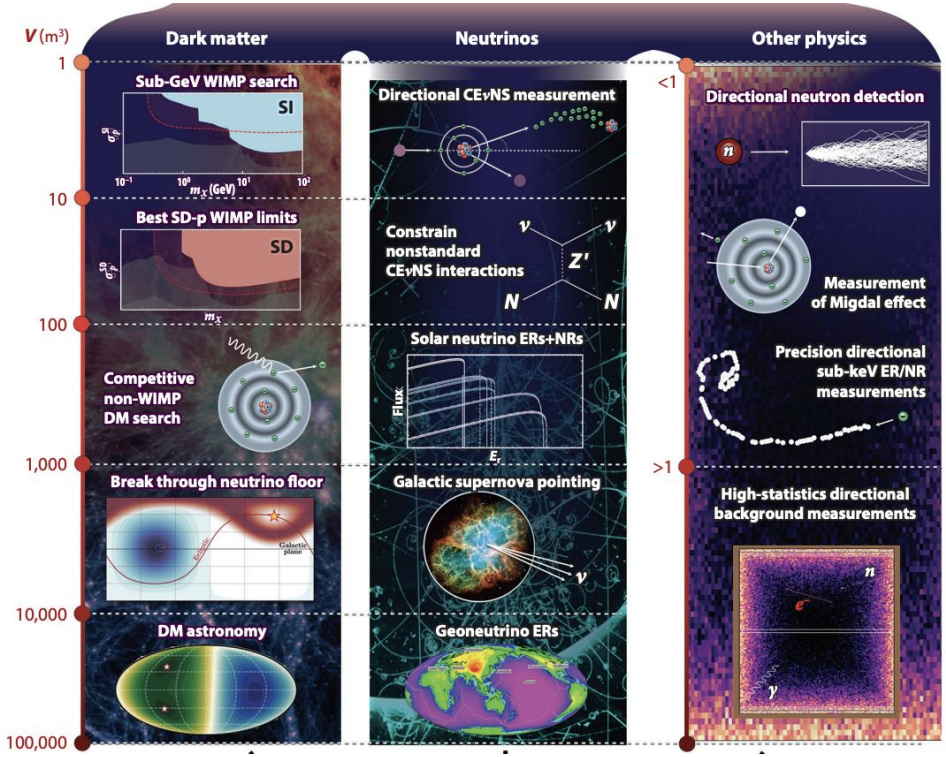
- Gains up to O(50,000)
- (250 x 50) μm^2 pixels
- Noise floor ~100 electrons
- Single electron efficiency at ~20k gain

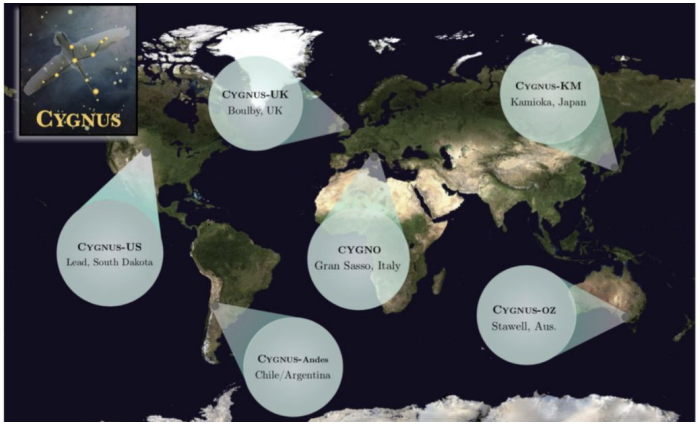




- Neutrons, neutrinos, dark matter
- Modern gas TPCs are coupled with highly segmented MPGDs
- Enables imaging 3D event topology and measuring energy
- Push to fundamental limit
  - Electron counting
- Pixel chips are expensive!

CYGNUS vision for a directional recoil observatory



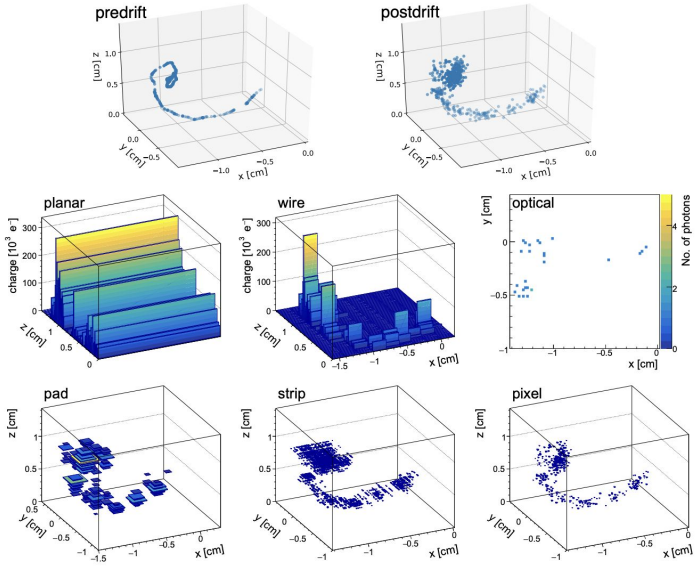


- Multi-site Galactic Recoil Observatory with directional sensitivity to WIMPS and neutrinos
- https://arxiv.org/abs/2008.12587 Vahsen et. al.
  - Technical feasibility
  - Detailed simulation of readout options
  - Background discrimination studies
- https://arxiv.org/abs/2404.03690 Lisotti et. al.
  - Utility as solar neutrino observatory

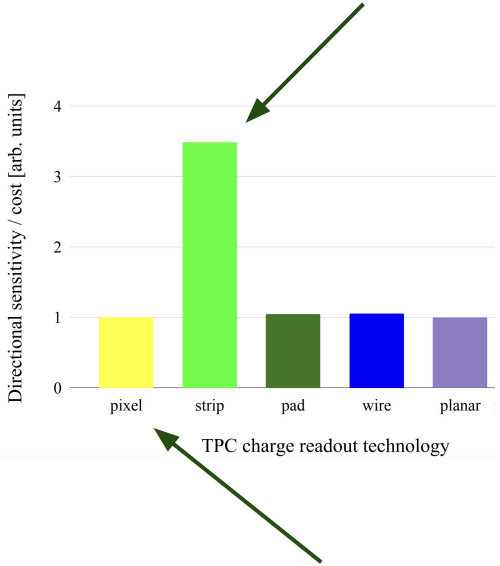
https://www.annualreviews.org/content/journals/10.1146/annurev-nucl-020821-035016

Scaling up in Vahsen Lab at U. Hawaii

Detailed simulation of readout technologies [2]

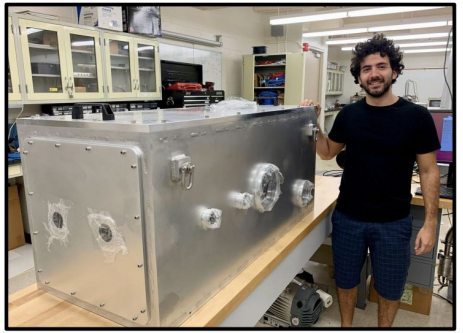


Best directional WIMP sensitivity / unit cost



Best Raw Performance

We are scaling up by an order of 10^3!



Expected Summer 2024

Experimental Comparison of 2D strip Micromegas

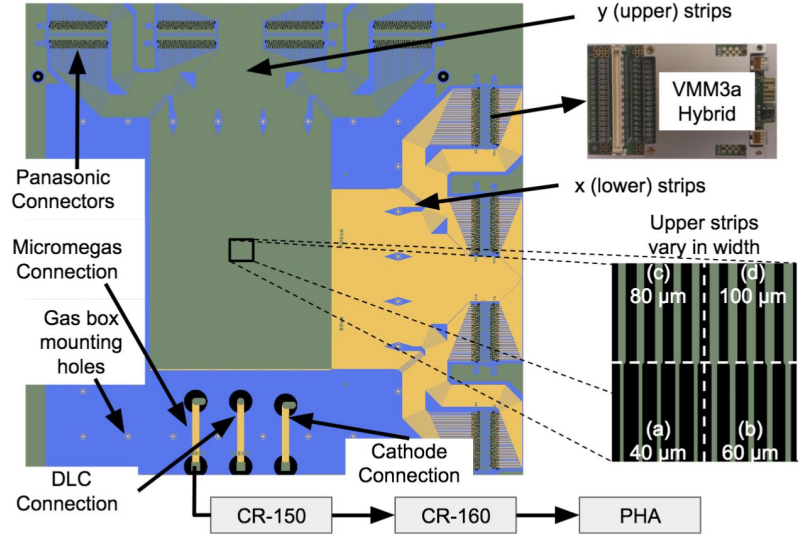
We compare nine different 2D strip configurations

- DLC: Diamond like carbon (with / without)
- Strip geometry
- Amplification Gap

Comparing:

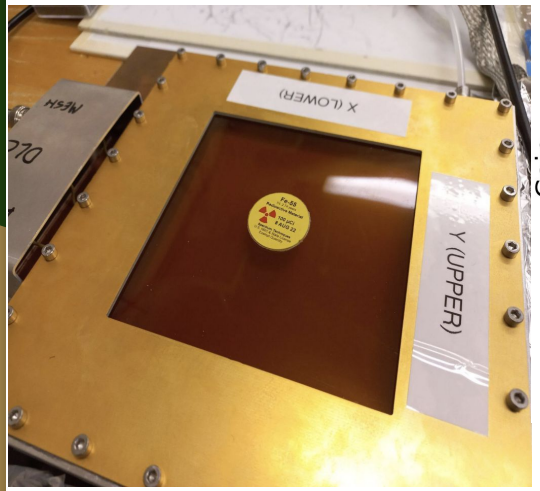
- Gain
- Gain Resolution
- x/y charge sharing (see backup)
- Point resolution

Detector Name	UH DLC	UH NoDLC	UoS
Amplification gap [µm]	128	128	256
DLC Resistivity [MΩ/sq]	70	N/A	50
Pitch [µm]	200	200	250
Quadrant Names	a,b,c,d	a,b,c,d	N/A
y (upper) strip width [µm]	40, 60, 80, 100	40, 60, 80, 100	100
x (lower) strip width [µm]	140	140	220

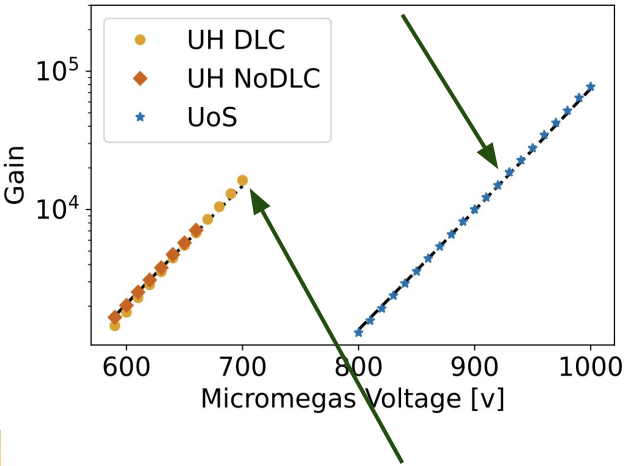


Gain and Gain Resolution

Fe55 source induce 5.9 keV calibration signal

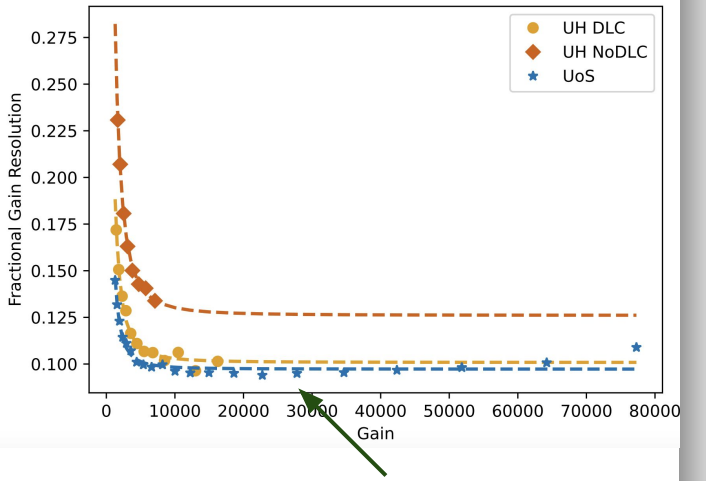


Larger amplification gap enables higher gain



DLC delays onset of sparking to higher voltage

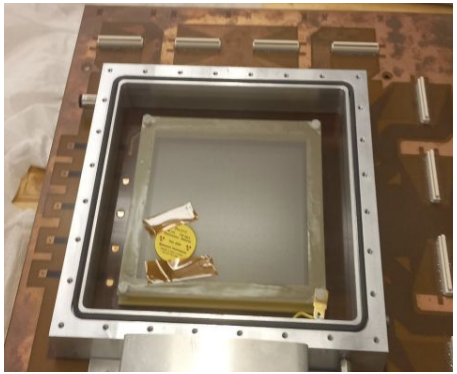
Preliminary

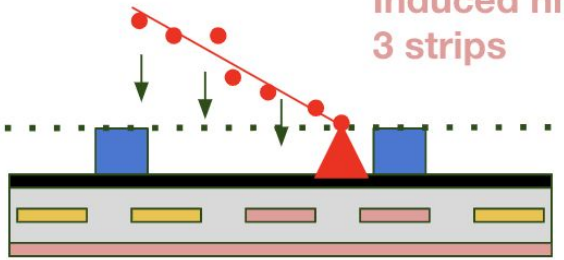


DLC improves energy resolution

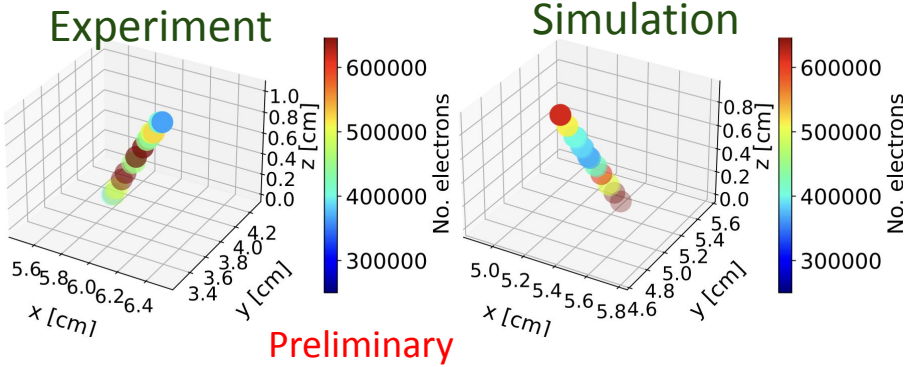
3D Reconstruction and Point Resolution

Po210 source emits α-particles

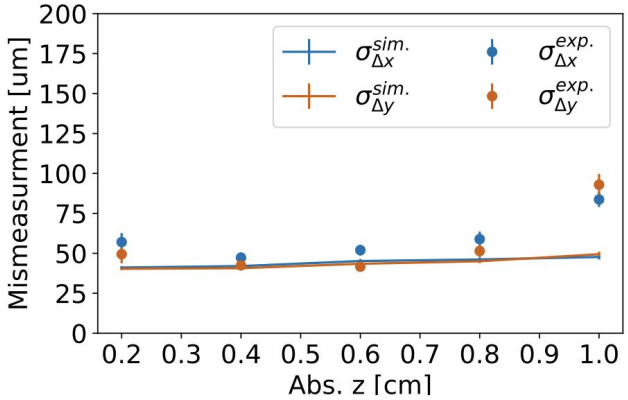




3D reconstruction algorithm developed and implemented



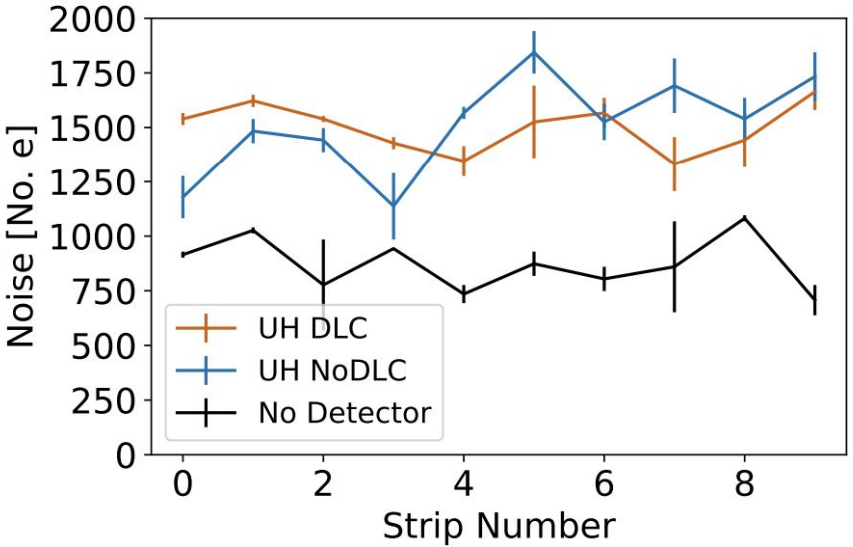
Preliminary



Good agreement with simple simulation.

Measured point resolution of 35 µm.

Outlook



- Noise ~1500 electrons
- Typical thresholds 5-10x the noise
- We expected detection of single electrons should be feasible with 256 μm amplification gap
- Single electron counting with a NID gas will likely require an improved MPGD avalanche device
  - Attempted in the past but never fully achieved [5]

Conclusion

- Compared nine 2D strip configuration to find the optimal one.
- Strip readouts promising for scalable directional recoil detectors.
- Single electron detection and performance similar to pixel chip readout but at much lower cost.
- True 3D electron counting with negative ion drift will likely need an improved a gas amplification device.

keep an eye out for the preprint!

References

[1] Jaegle, Igal, et al., (2019) Compact, directional neutron detectors capable of high-resolution nuclear recoil imaging, NIMA 2019. https://doi.org/10.1016/j.nima.2019.06.037.

[2] Vahsen, Sven E. ... Ghrear, Majd, et al. (2020). Cygnus: Feasibility of a nuclear recoil observatory with directional sensitivity to dark matter and neutrinos. https://arxiv.org/abs/2008.12587.

[3] Lisotti, Chiara, et al. "CYG $\nu $ S: Detecting solar neutrinos with directional gas time projection chambers." arXiv preprint arXiv:2404.03690 (2024).

[4] Vahsen, Sven E., Ciaran AJ O'Hare, and Dinesh Loomba. "Directional recoil detection." Annual Review of Nuclear and Particle Science 71 (2021): 189-224.

[5] Sorensen, Peter, et al. "Towards energy resolution at the statistical limit from a negative ion time projection chamber." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 686 (2012): 106-111.

Thank you!
Questions?

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