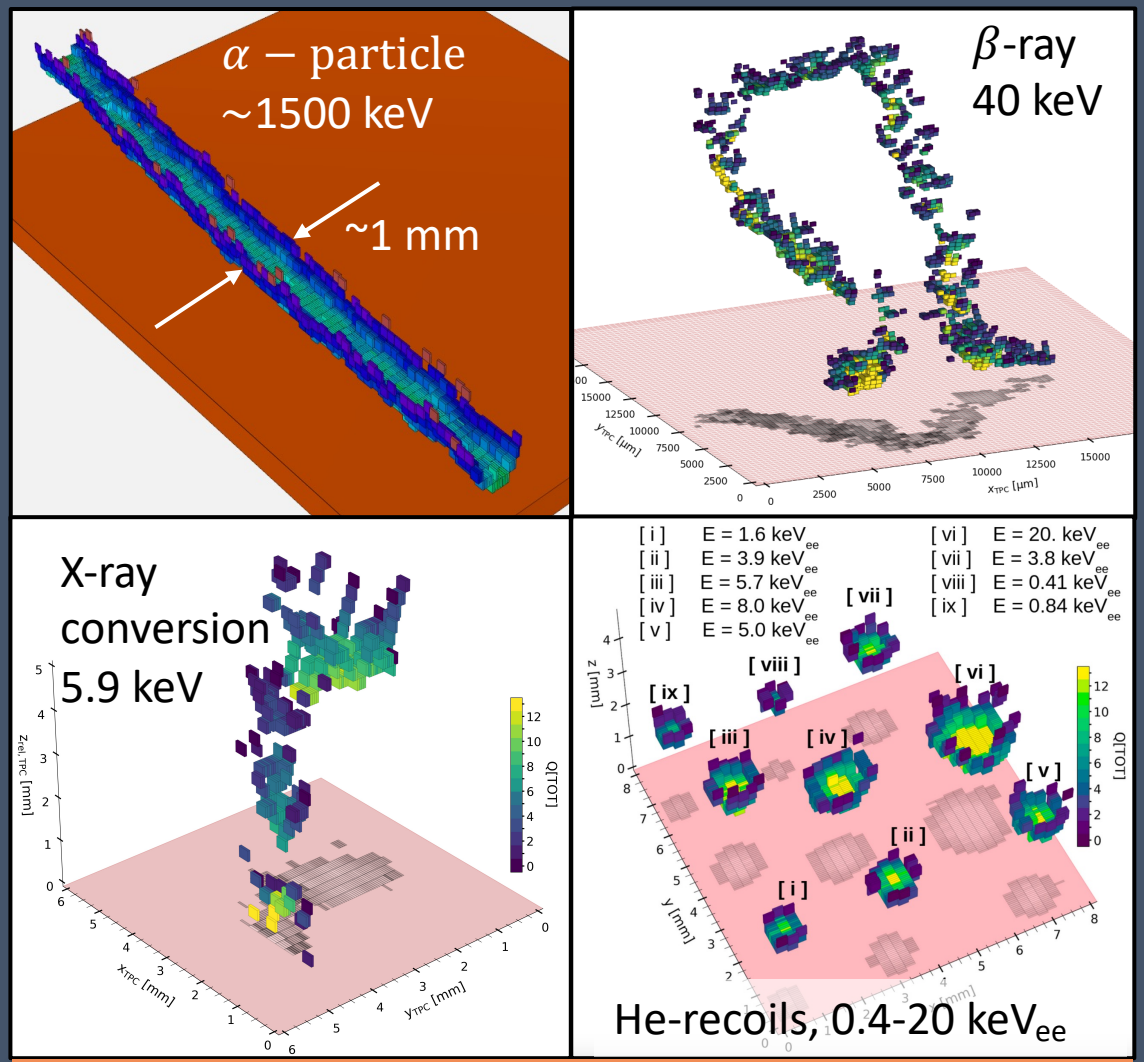
# Gaseous Detector R&D Aimed at Recoil Imaging




- Experimental data from BEAST TPC directional neutron detectors
- He:C02 gas @ 1 atm
- Each colored voxel: ionization density in 50 x 250 x 250 µm$^3$

- "Recoil imaging": Topological and directional reconstruction of low-energy nuclear and electronic recoils
- A Snowmass working group of 167 physicists considered the case for this technique (arXiv:2203.05914)
  - Conclusion: enables new experiments!
- Blue sky R&D challenges: can we advance this technique to the fundamental limit?
  - Detect every single electron in 3d
  - In volumes up to DUNE scales
  - At HEP-feasible cost

# Opportunities for a 30+ year physics program

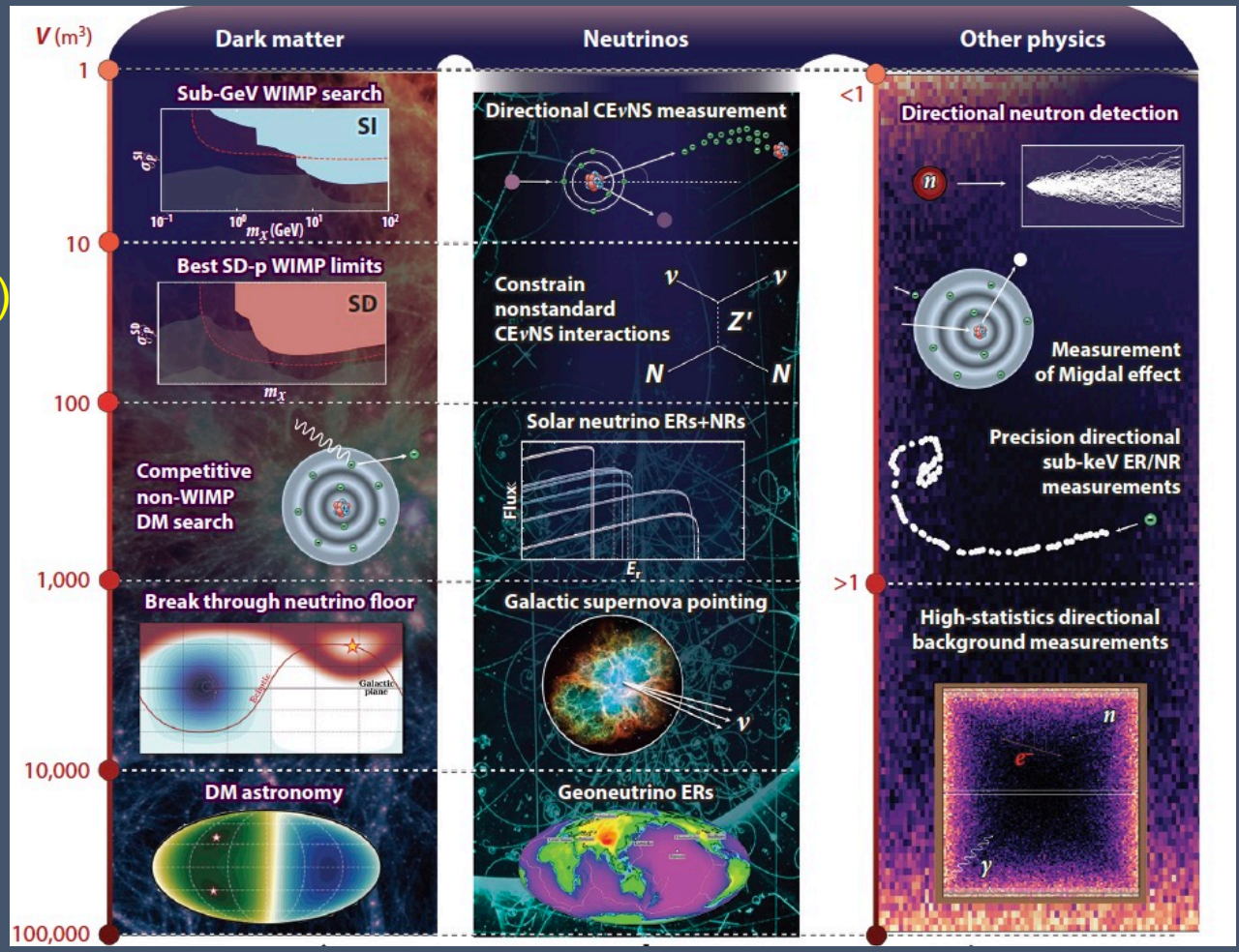
arxiv:2102.04596

With *recoil imaging* directional detectors,
a smorgasbord of opportunities

- Quenching factor and recoil physics (TUNL)
- Migdal Effect measurement
- Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) at ORNL (SNS) or Fermilab (NuMI and later LBNF)
- Competitive DM limits in SI and SD
- CEvNS and e-recoils from solar neutrinos
- Efficiently penetrating the LDM ν floor
- Observing galactic DM dipole
- Measuring DM particle properties and physics
- Geoneutrinos
- WIMP astronomy

Exposure, size

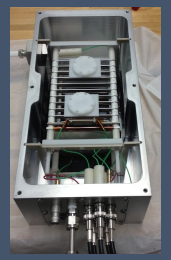
Approx. volume of gas TPC required.
Expect 10 $m^3$ modules eventually



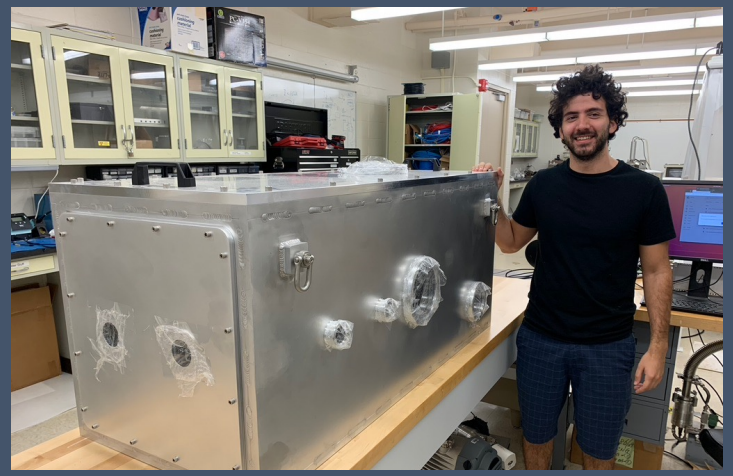

- New physics opportunities for each factor of 10 increase in exposure
- Both guaranteed measurements (yellow text) and novel, exciting searches --- across frontiers!

# But how to best scale up in practice?

x1000



BEAST TPC
Neutron
detector



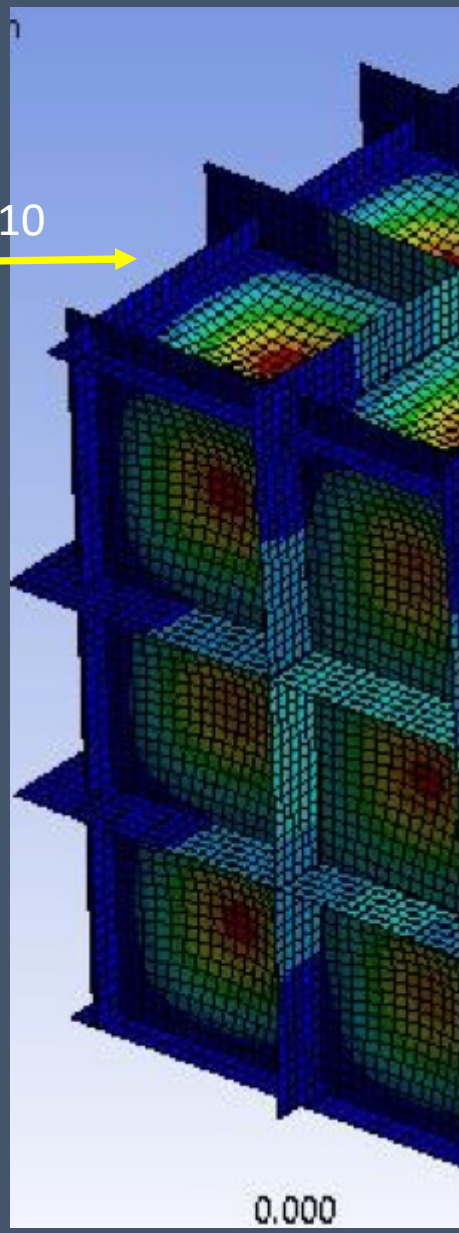
BEAST TPC x 1000 (40 l fiducial)
Neutrino / Dark Matter Detector Prototype
for technology down-select

x25

Vessel now at U. Hawaii!

CYGNUS HD-1 Demonstrator (1 $m^3$ fiducial)
Unit-cell technology demonstrator for
future, large CYGNUS neutrino/DM observatory

x10




CYGNUS HD-10

# Thoughts on RDC6 work packages and WPs

CYGNUS activities are very much blue sky R&D

Could become a separate work package / white paper

But also fits well into three potential broader & collaborative work package and white papers:

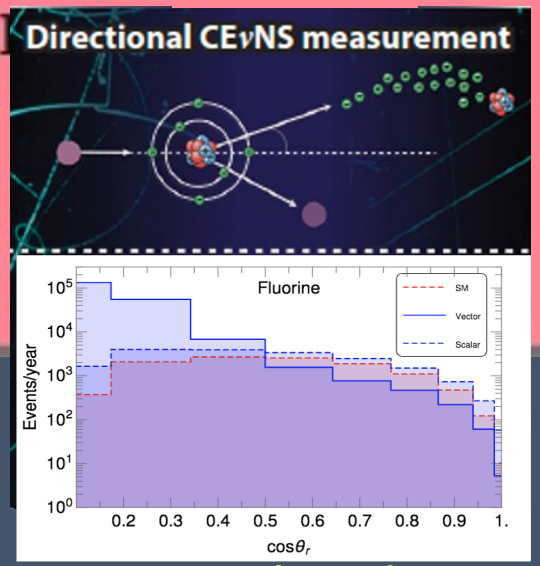
1. Advancing gaseous TPC readout to the fundamental sensitivity limit
2. Advanced gas amplification structures
3. Achieving cost-effective scaling of gaseous TPCs

# BACKUP

# CYGNUS: US Program Vision

CYGNUS

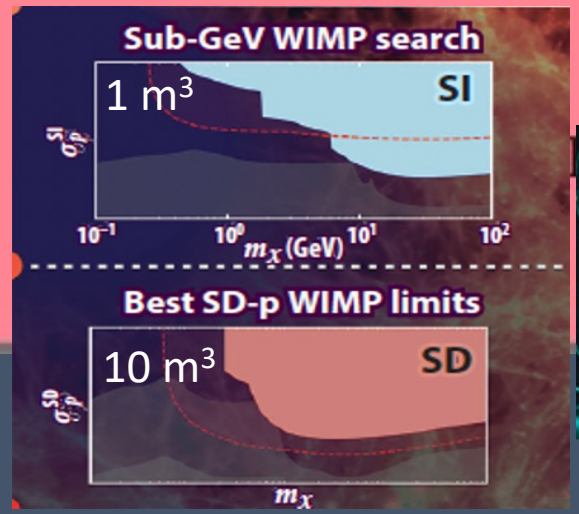
**1-10 m³**




SNS, Oak Ridge, TN

Directional BSM-search in CEvNS

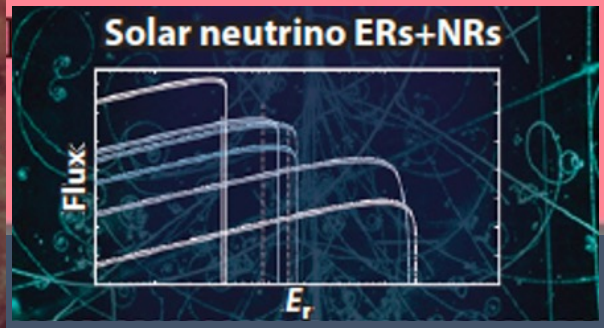
**10 m³**

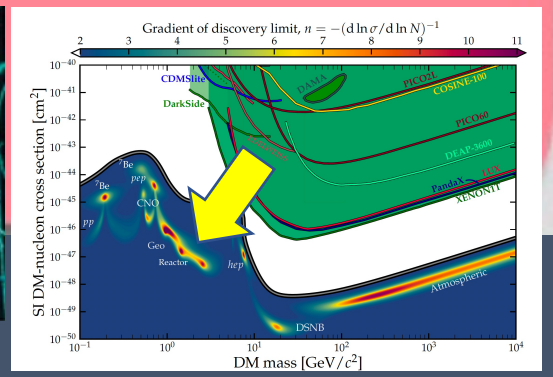



SURF, Lead, SD

World-leading DM limits

**Modular/multisite experiment: CYGNUS-1000**




Arxiv:2008.12587

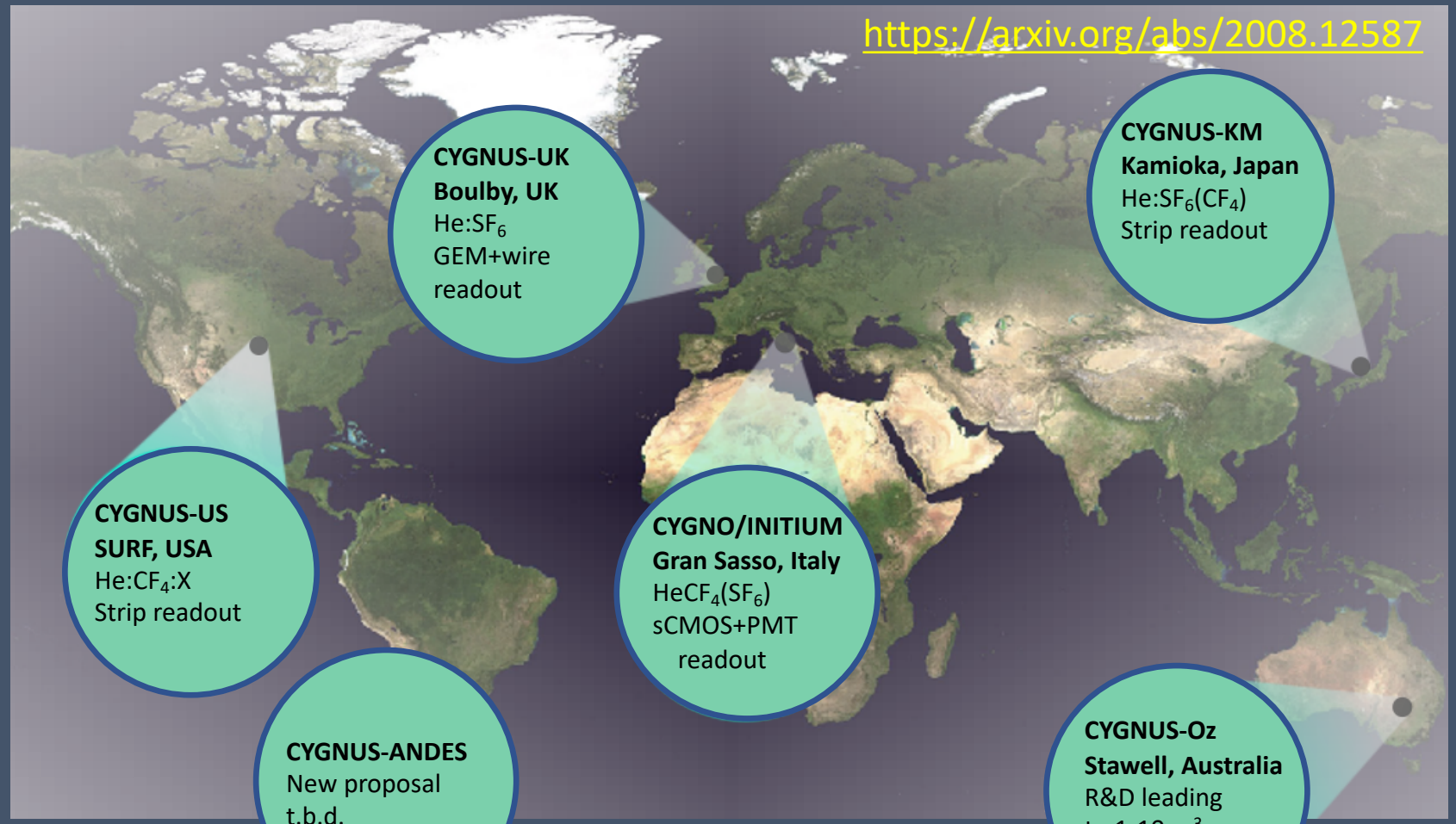
International, multi-site

DM search in the neutrino fog!

- 3 years of R&D to establish electron counting & 1-keV recoil directionality
- Directional BSM search in 1-10 m³ ν-scattering experiment, aboveground
- Radio-pure 10 m³ experiment, underground (DM)
- MIE for large-scale, underground observatory (solar neutrinos + DM below neutrino floor)

# Long term CYGNUS Vision: Multi-site Galactic Recoil Observatory

## with directional sensitivity to WIMPs and neutrinos




3/23/23

# Summary and final thoughts

- Recoil imaging capabilities greatly expand physics reach of detectors
  - Dark matter, neutrinos, and precision measurements
- Aiming to reach the fundamental performance limit of ionization detection
  - 3d single-electron-counting, at DUNE-scales, at feasible cost
- Expected detector charge readout requirements
  - Order 200-micron-feature size MPGDs for amplification and detection
  - Gain/noise ratio sufficiently high for single electron counting
  - Ideally even with negative ion drift (to slow drift and reduce diffusion)
  - Eventually radio-pure
  - Matching front end electronics with suitable dynamic range
  - Highly (trigger-)multiplexed digital readout for cost-effective scaling
  - AI/ML techniques, including at trigger level
  - Cost < $ 10k / $m^2$
- Micromegas + pixel ASIC readout (e.g. GridPix) currently closest to achieving these
- R&D needs overlap with those for future trackers (see talks by Garg and Lewis)

→ Good opportunity for an RDC6 work-package and consortium