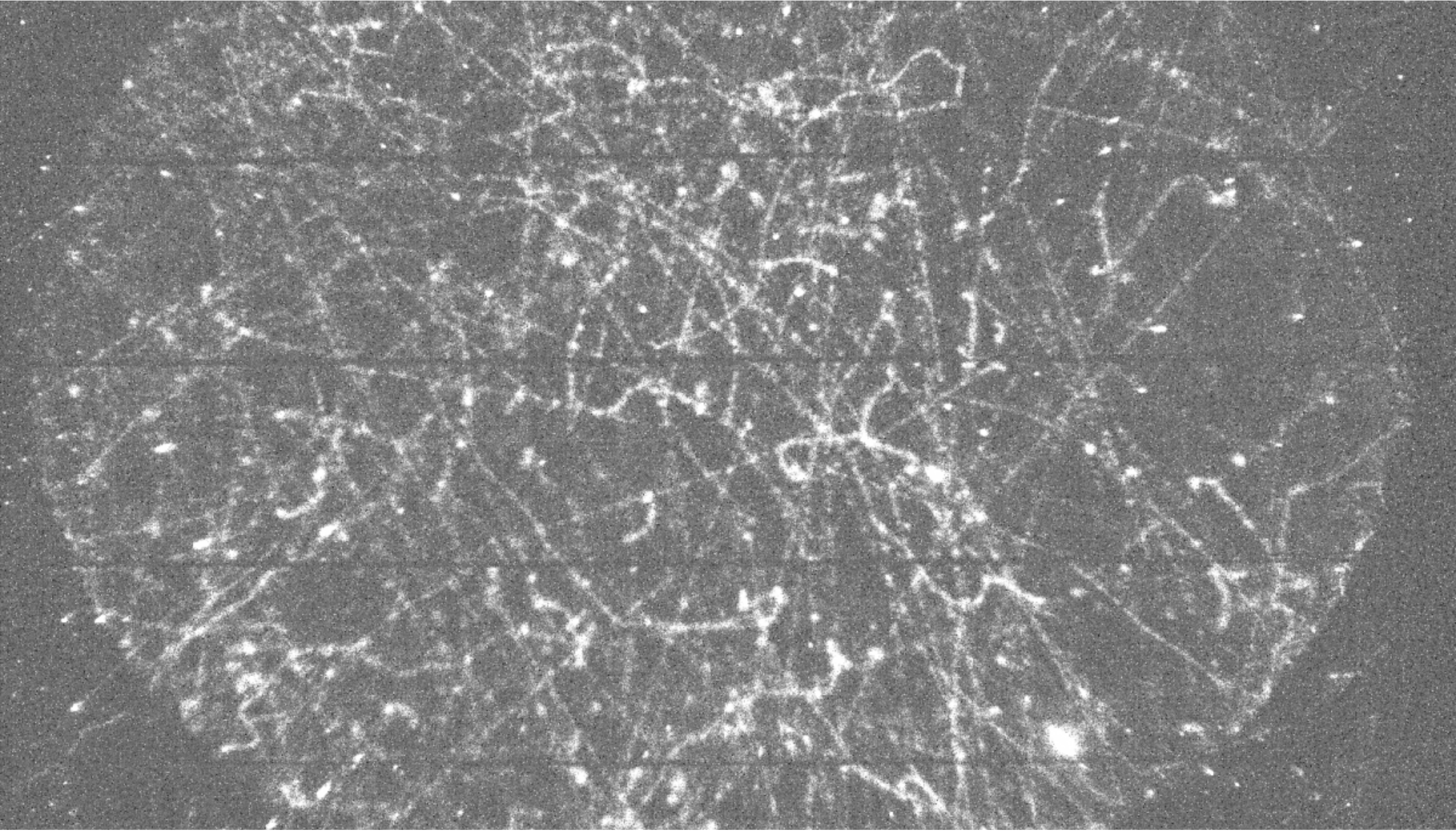
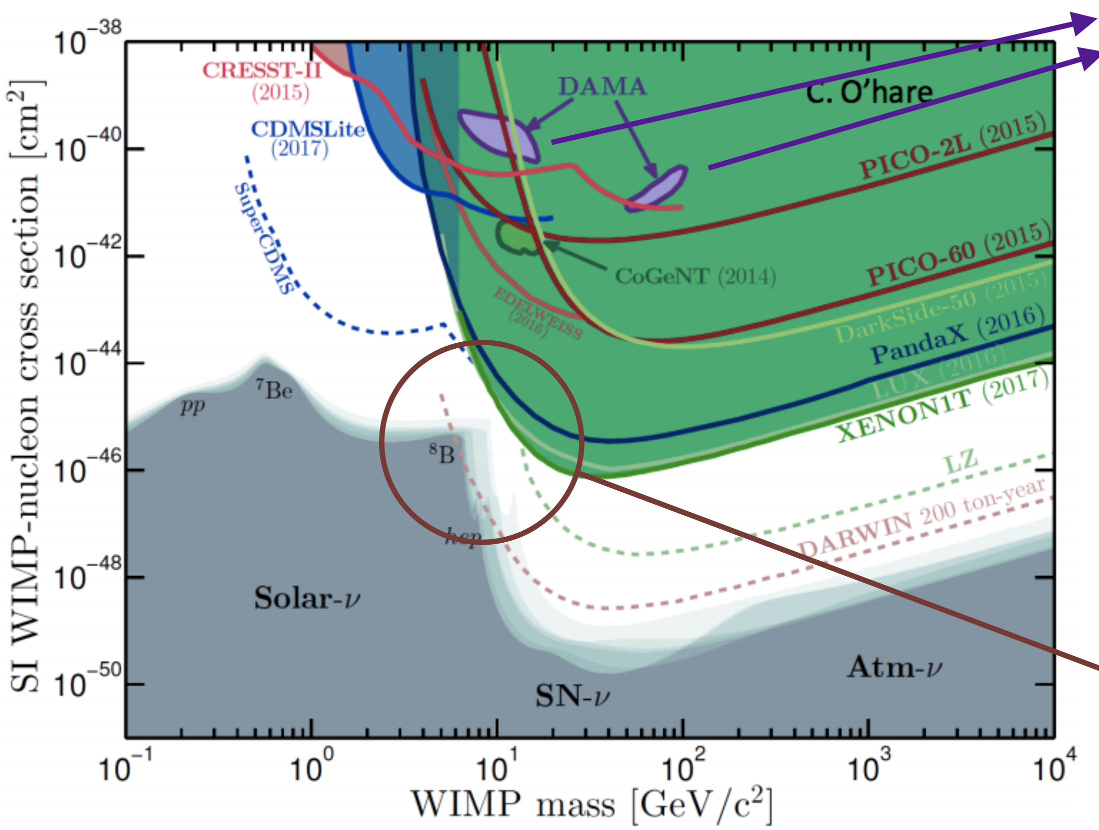


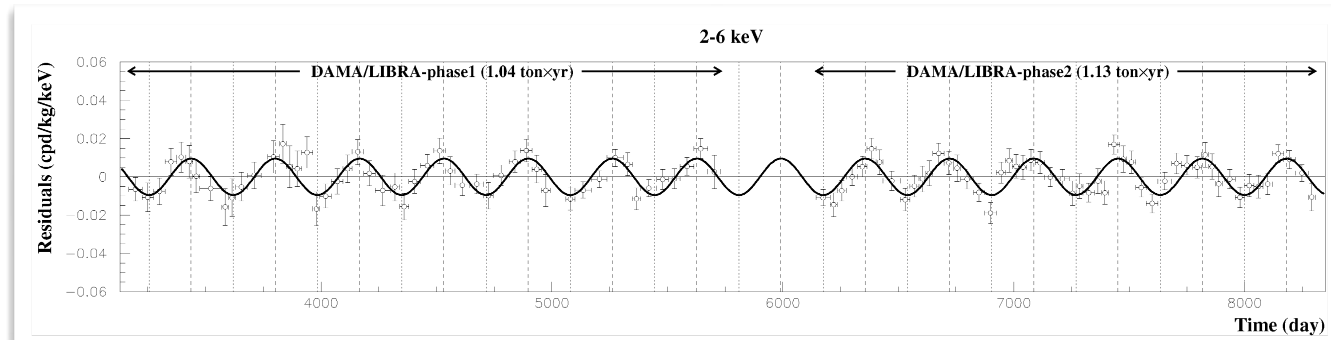
CYGNUS: Rare event searches with directional TPCs

Francesco Renga
INFN Roma

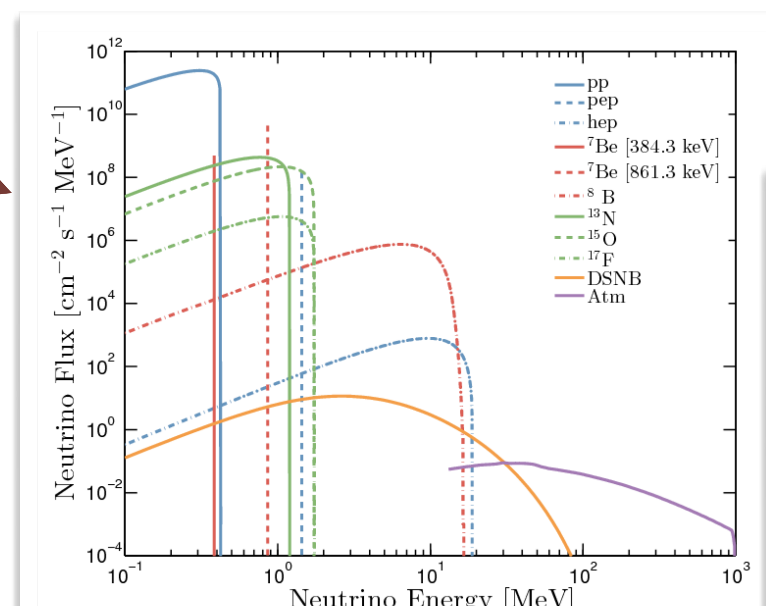
Dark Matter searches

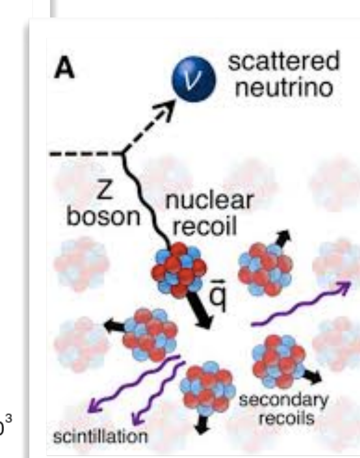
- Dark matter (DM) detectors in the GeV - TeV range exploit nuclear or electron recoils induced by DM scattering, either with or without background identification





DAMA/LIBRA
Universe 4 (2018), no. 11, 116





Identifying a Dark Matter signal

- An **unambiguous evidence** for Dark Matter observation requires the identification of a peculiar feature
- **Discrimination** of dark matter **against coherent neutrino scattering** requires the identification of a peculiar feature

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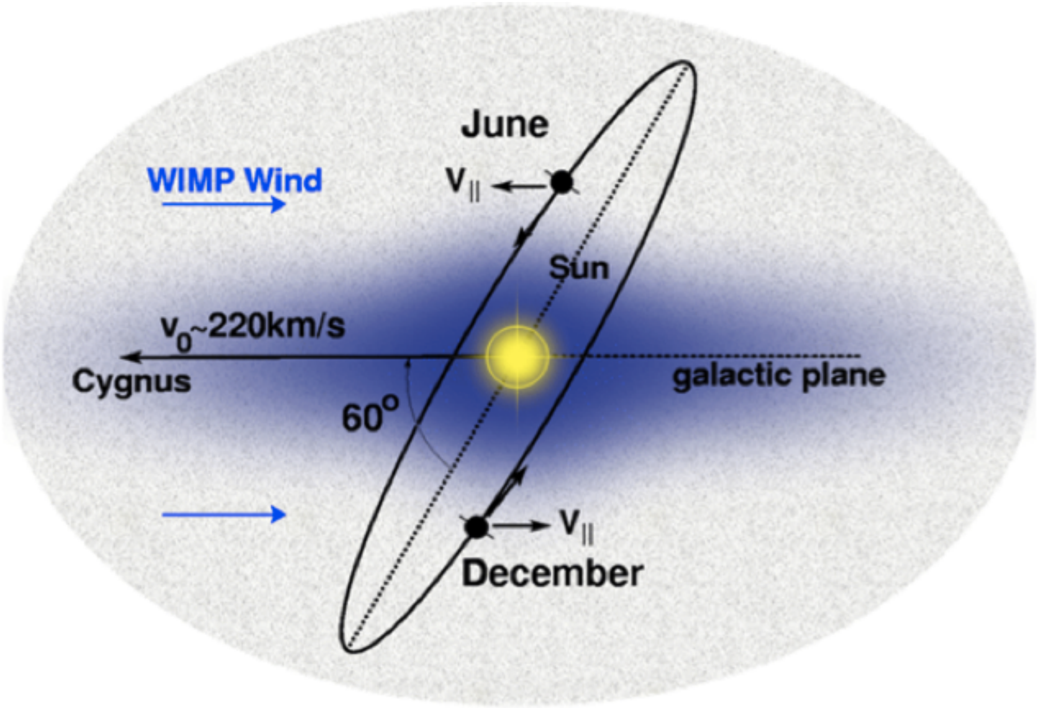

Earth motion in the DM halo enhances the scattering rate for particles observed in the direction of the earth motion (Cygnus constellation)

Identifying a Dark Matter signal

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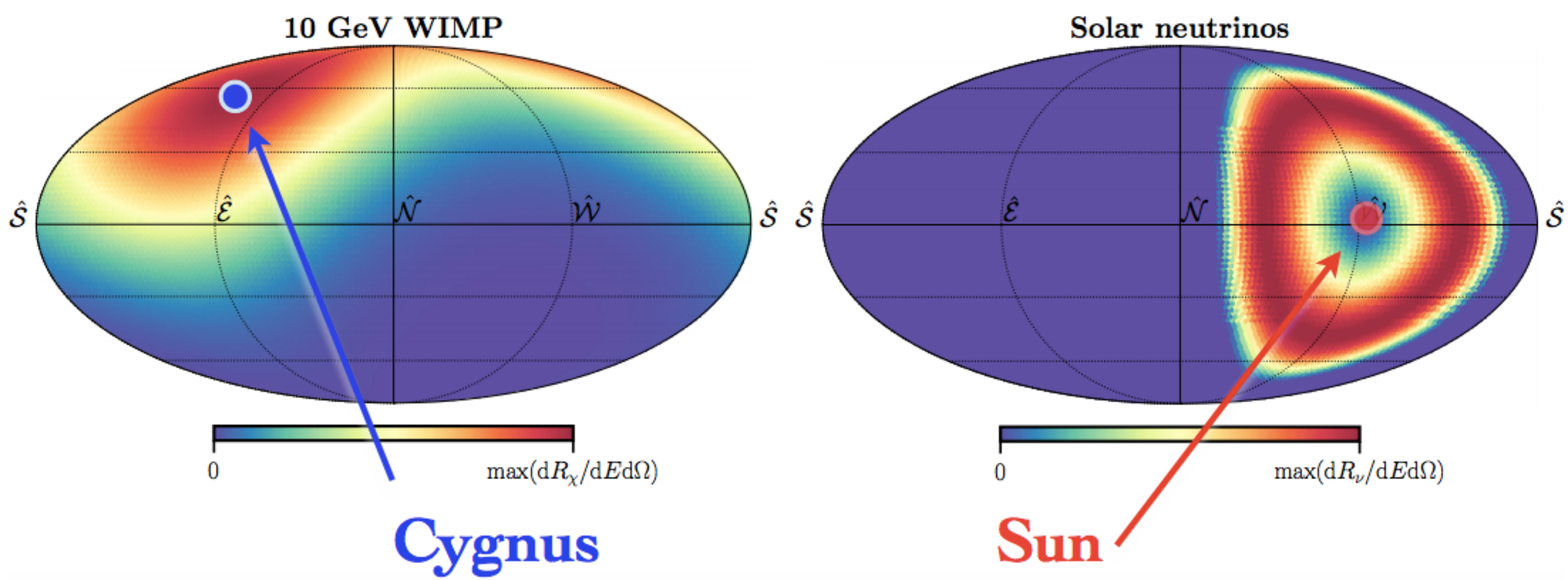
- **Discrimination** of dark matter **against coherent neutrino scattering** requires the identification of a peculiar feature



C. O'Hare, CYGNUS2019

Expected rate of DM-induced recoils

Identifying a Dark Matter signal

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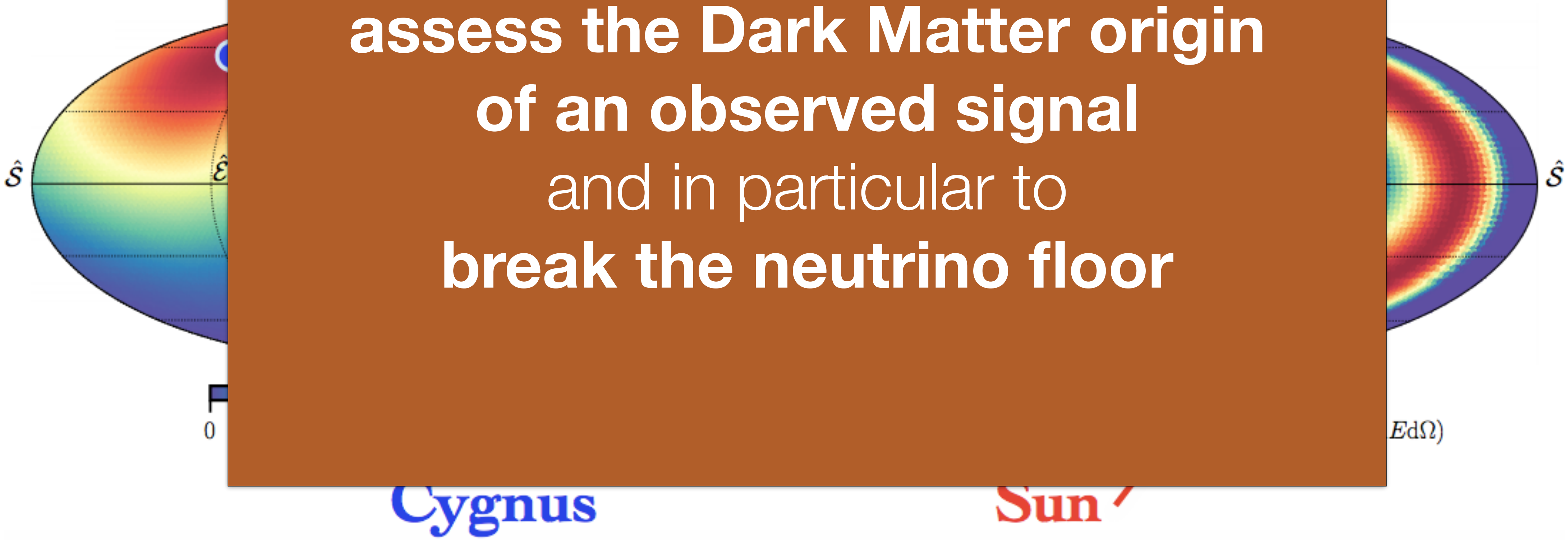
- **Discrimination** of dark matter **against coherent neutrino scattering** requires the uliar feature



Directionality provides a unique tool to **assess the Dark Matter origin of an observed signal** and in particular to **break the neutrino floor**

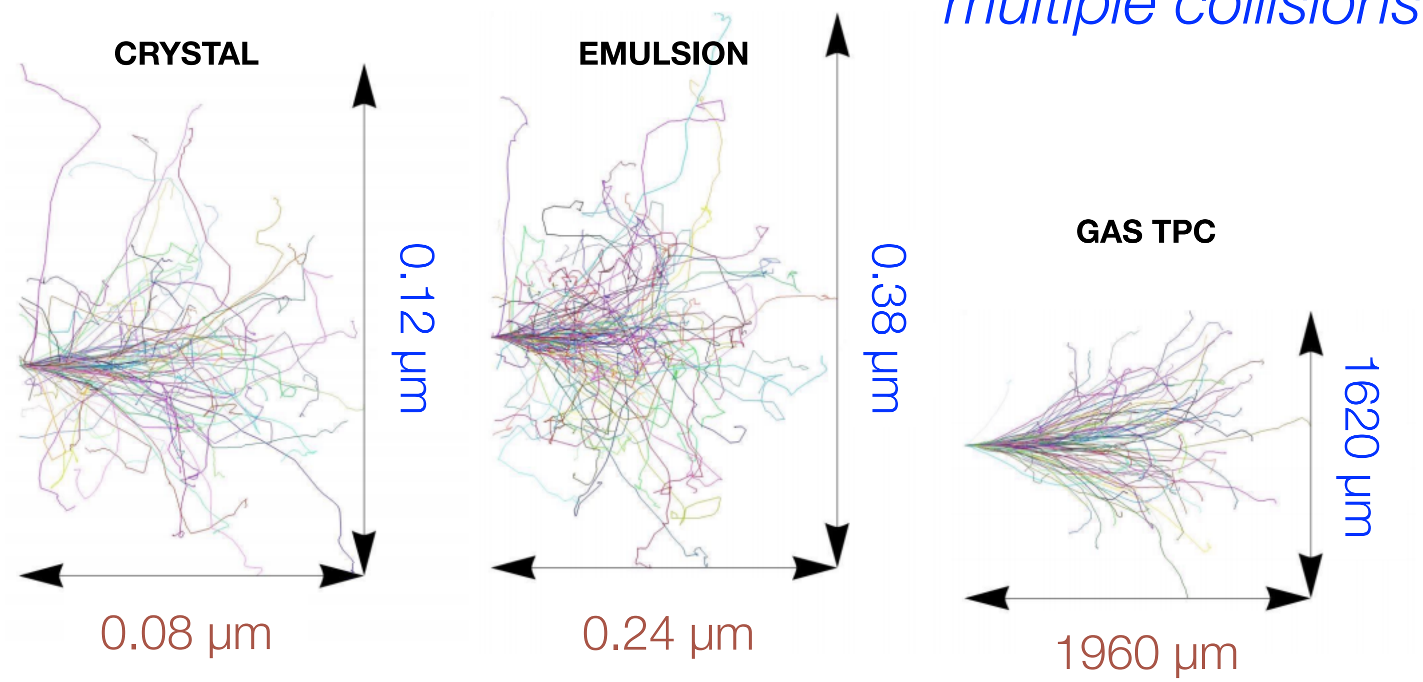
C. O'Hare, CYGNUS2019

Expected rate of DM-induced recoils

Experimental challenges of directional searches

1 TeV WIMP, max. recoil energy

recoil direction information quickly deteriorated by multiple collisions



Very short tracks —> 3 options
1) high granularity
2) strong detector anisotropy
3) tiny statistical effects in isotropic (e.g. columnar recombination) or slightly anisotropic detectors

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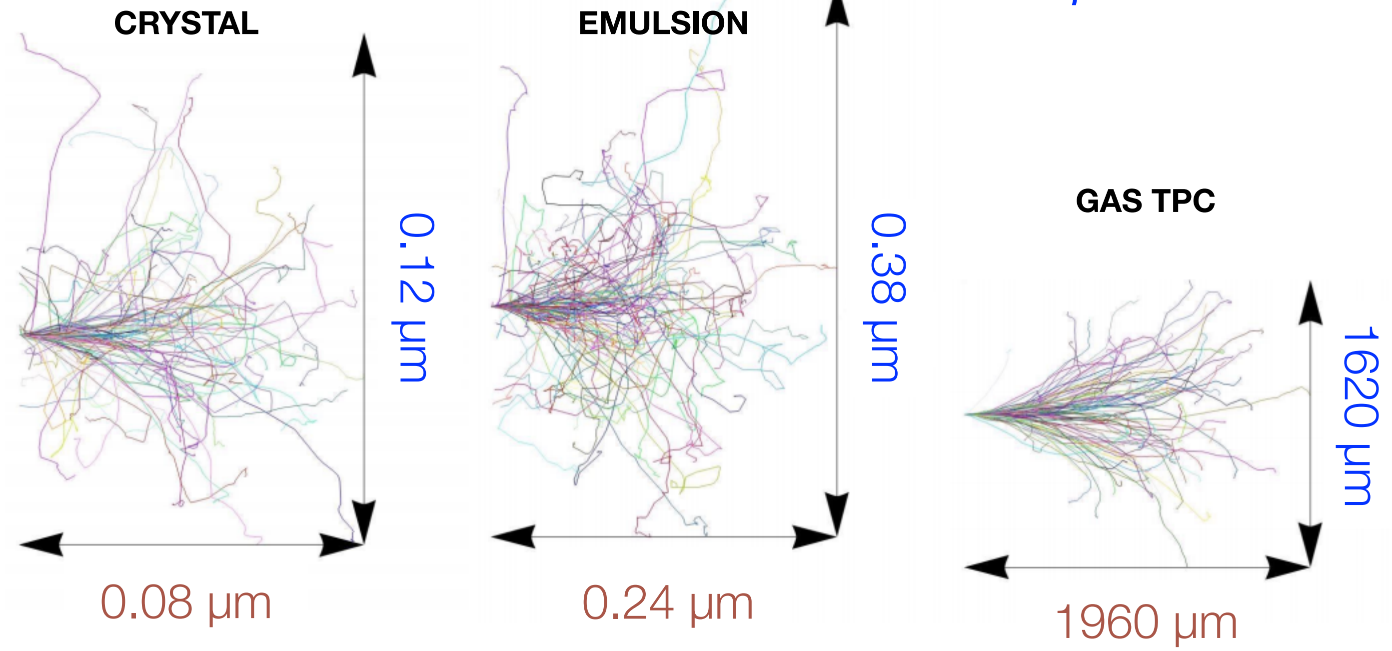

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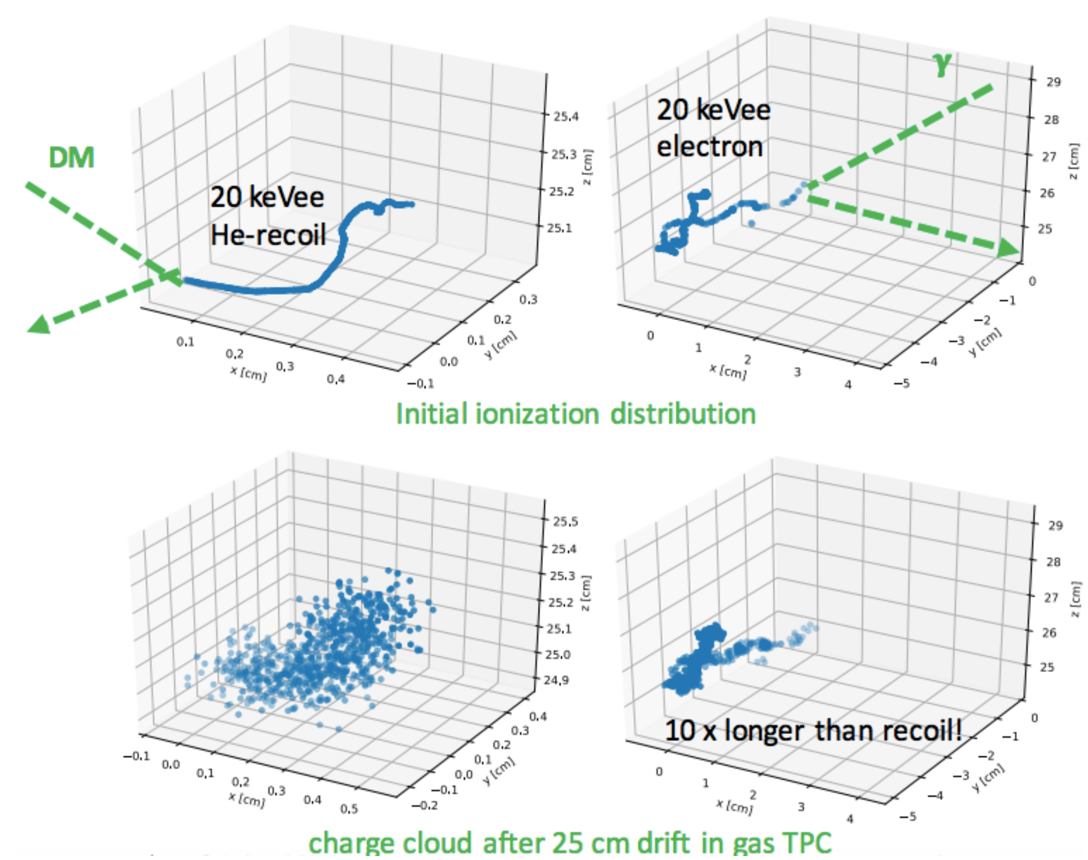
Gaseous TPC = low density = O(mm) tracks
+
high granularity readout

Direction can be reconstructed event-by-event



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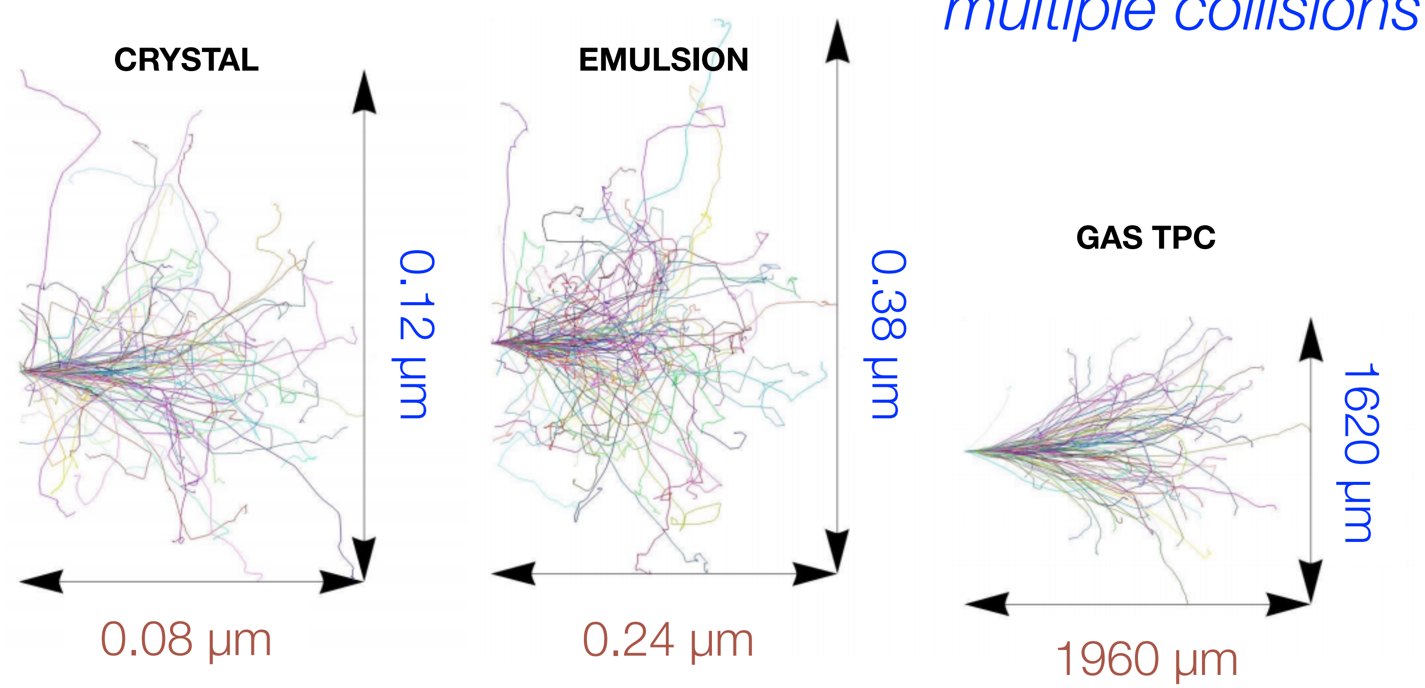

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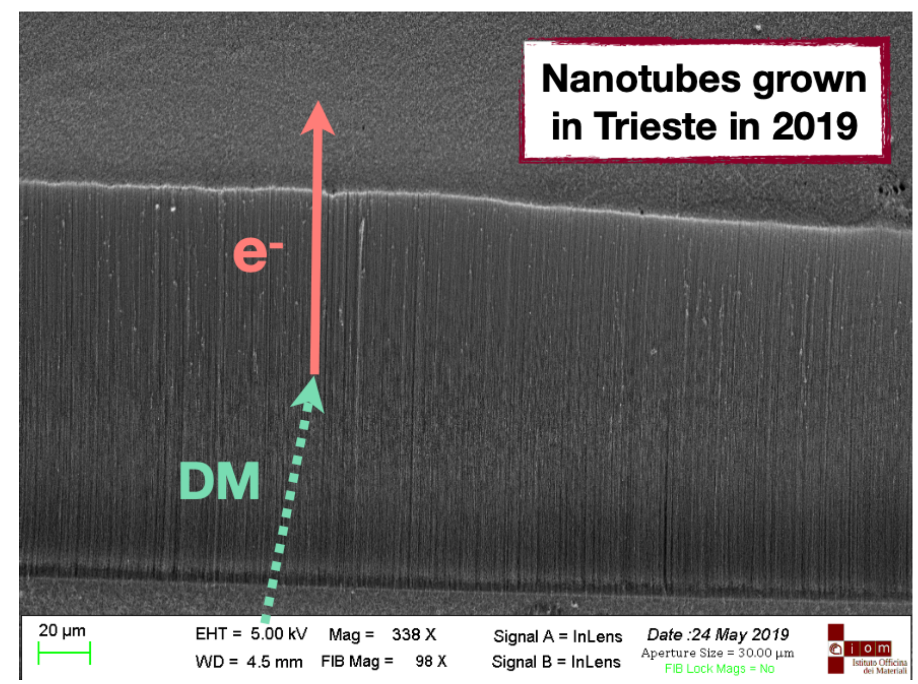
Channeling in carbon nanotubes (CNTs)

Only electron recoils in a specific direction can be efficiently reconstructed



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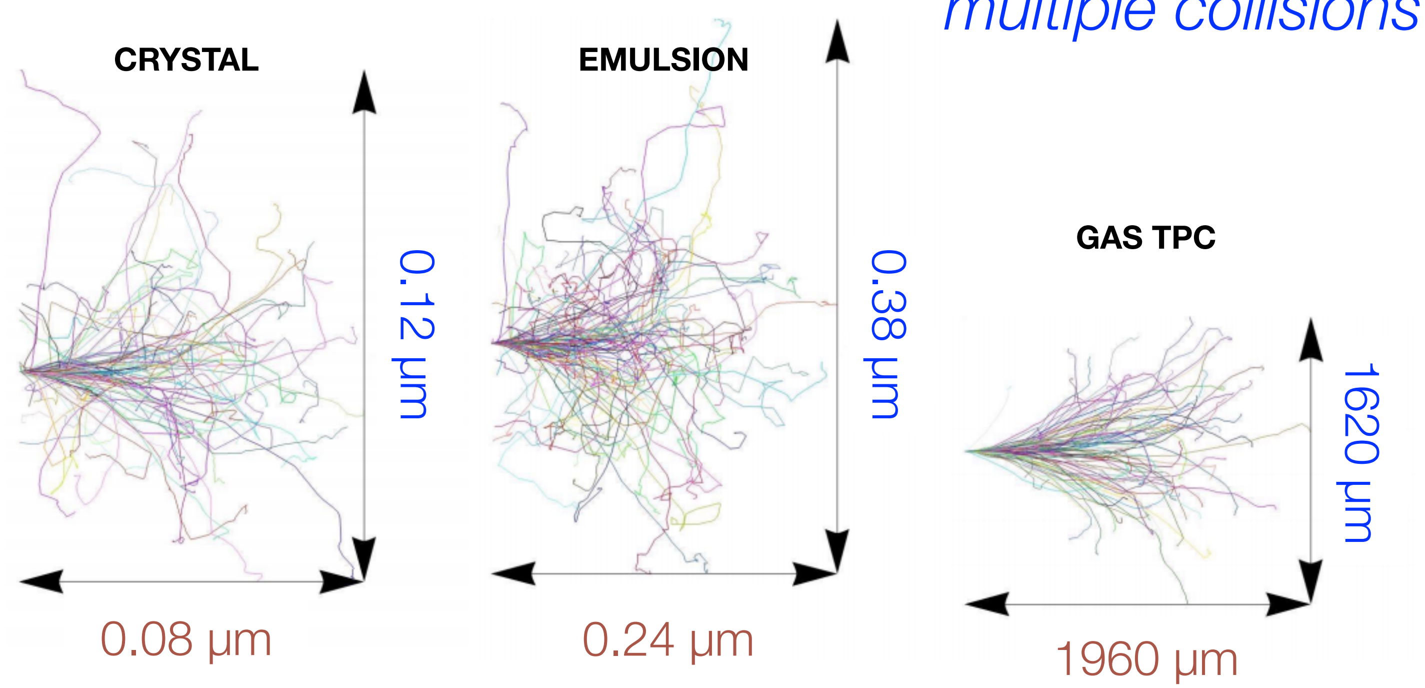

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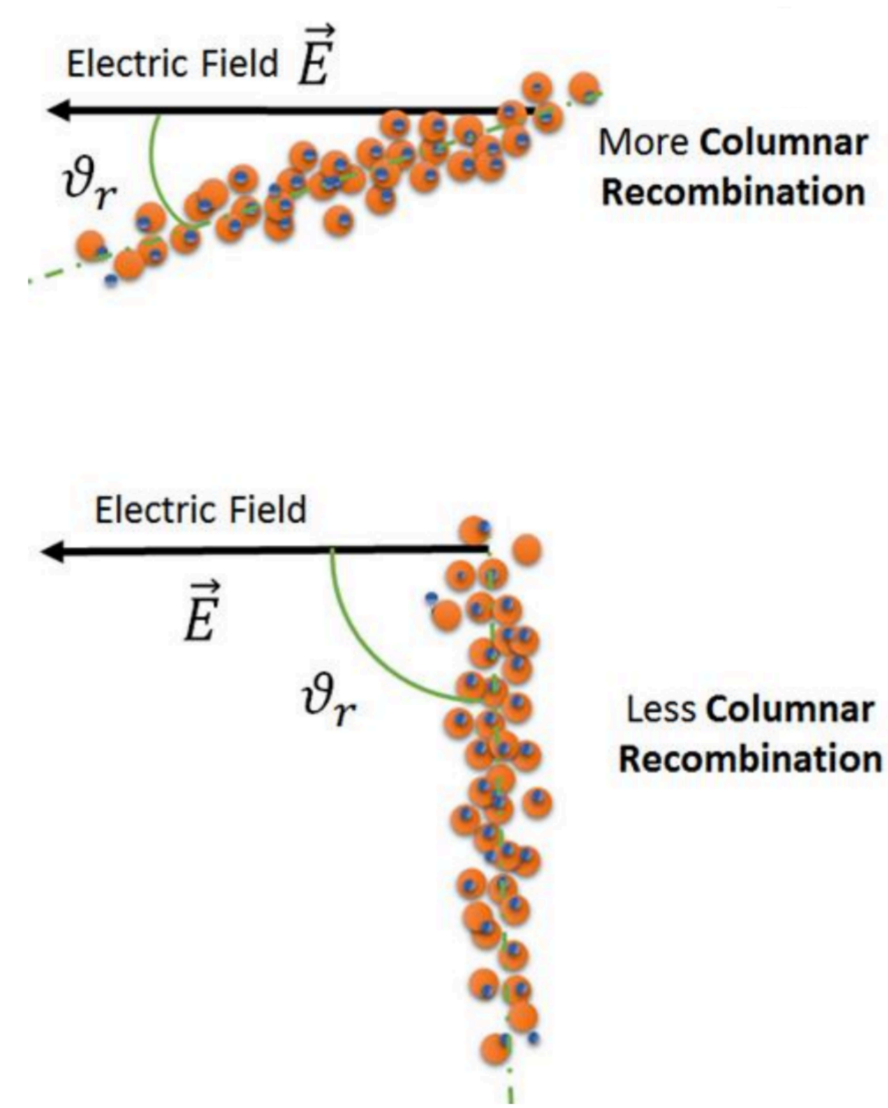
Columnar recombination

Higher recombination (-> less signal) for tracks // E

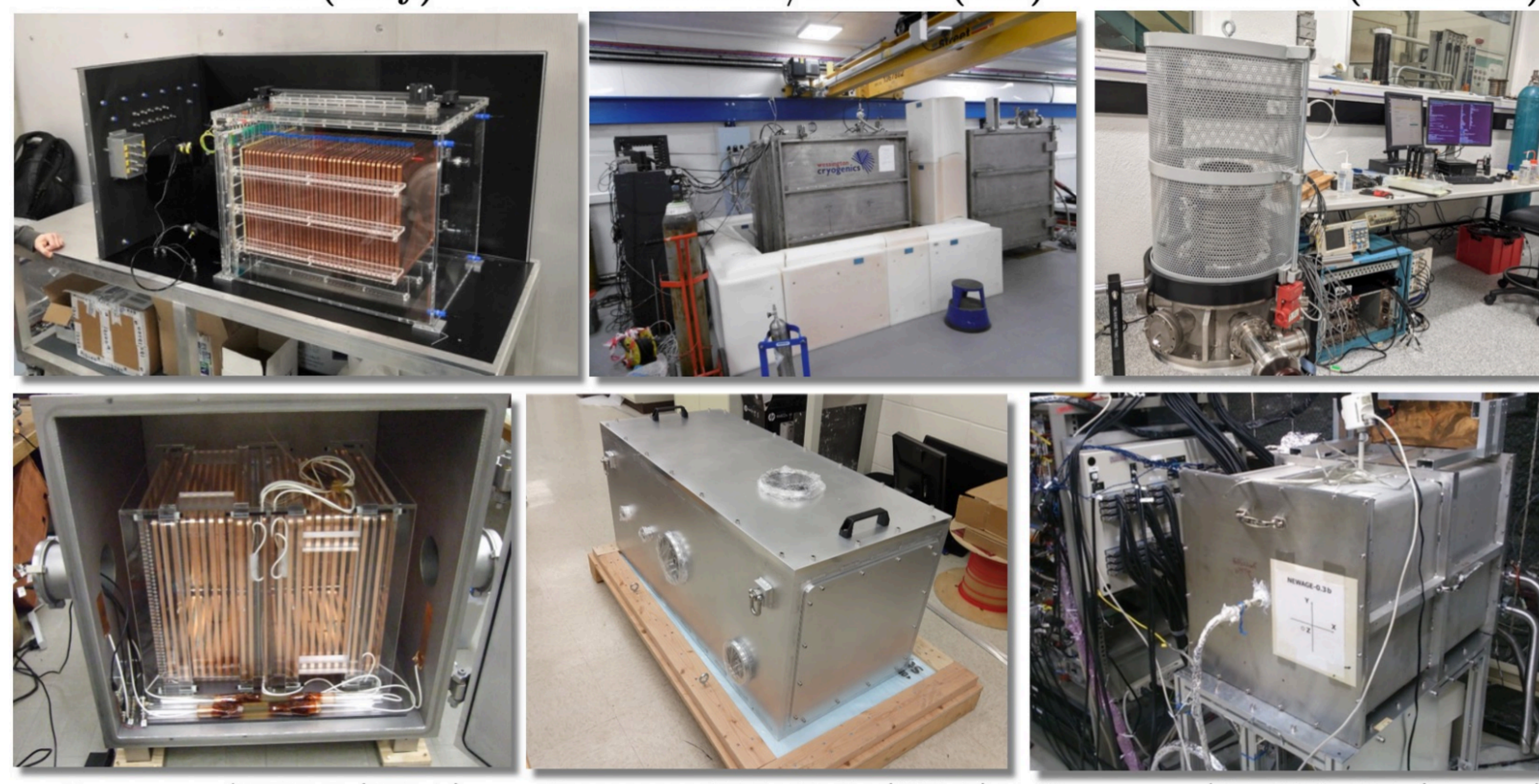


Toward CYGNUS-100k

S. E. Vahsen et al., *CYGNUS: Feasibility of a nuclear recoil observatory with directional sensitivity to dark matter and neutrinos*
arXiv:2008.12587

- The CYGNUS network connects several experimental efforts around the world for the search of dark matter with **gaseous directional detectors**

CYGNO (Italy) CYGNUS/DRIFT (UK) CYGNUS-Oz (Australia)



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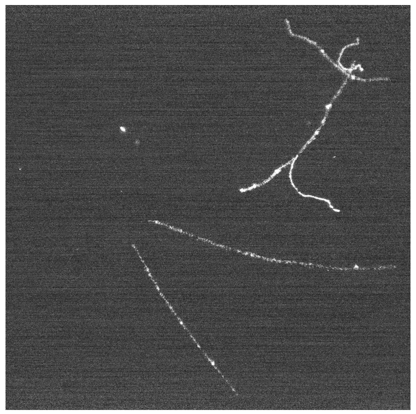
Optical readout of GEMs



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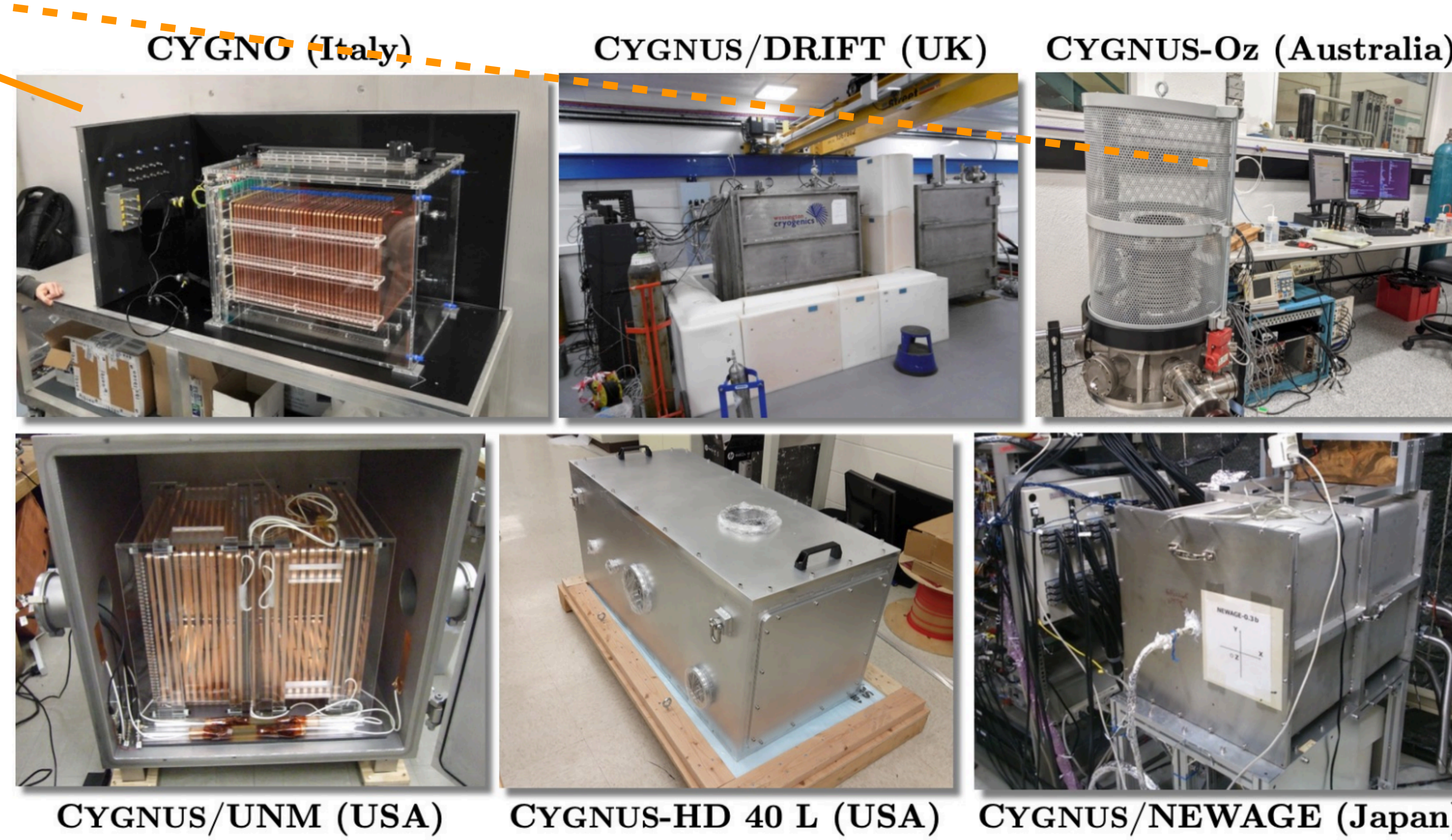

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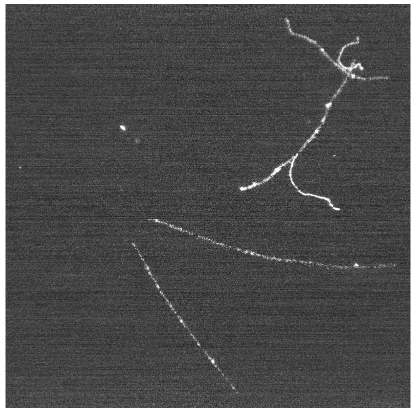
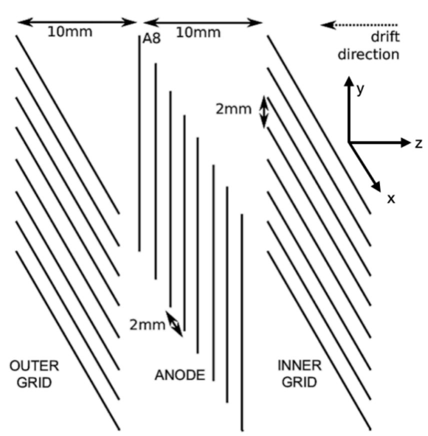
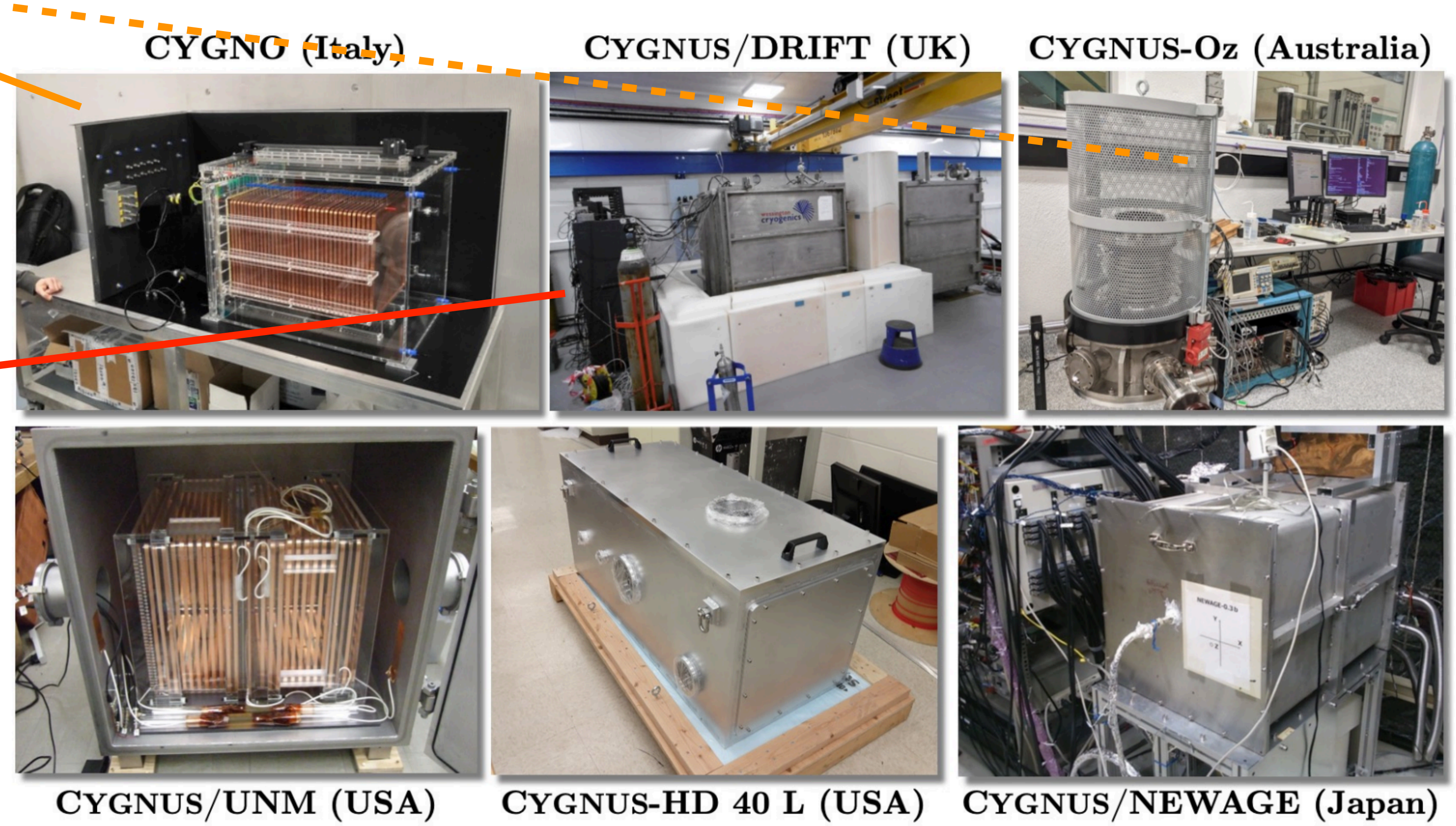


Wire readout (+ R&D on thick GEM)





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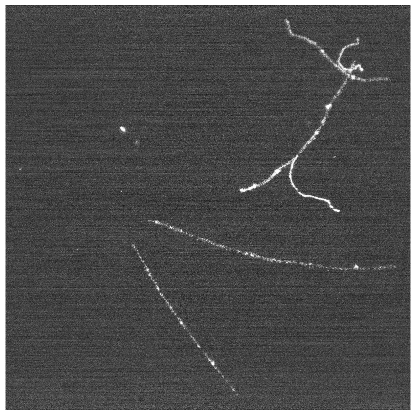

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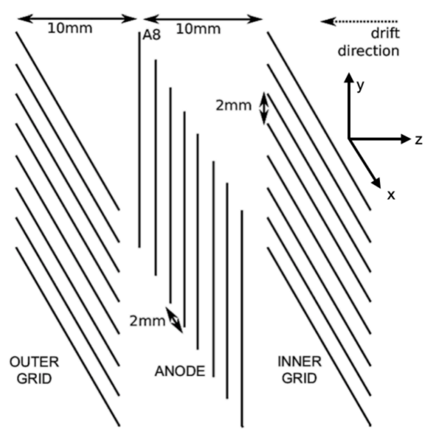
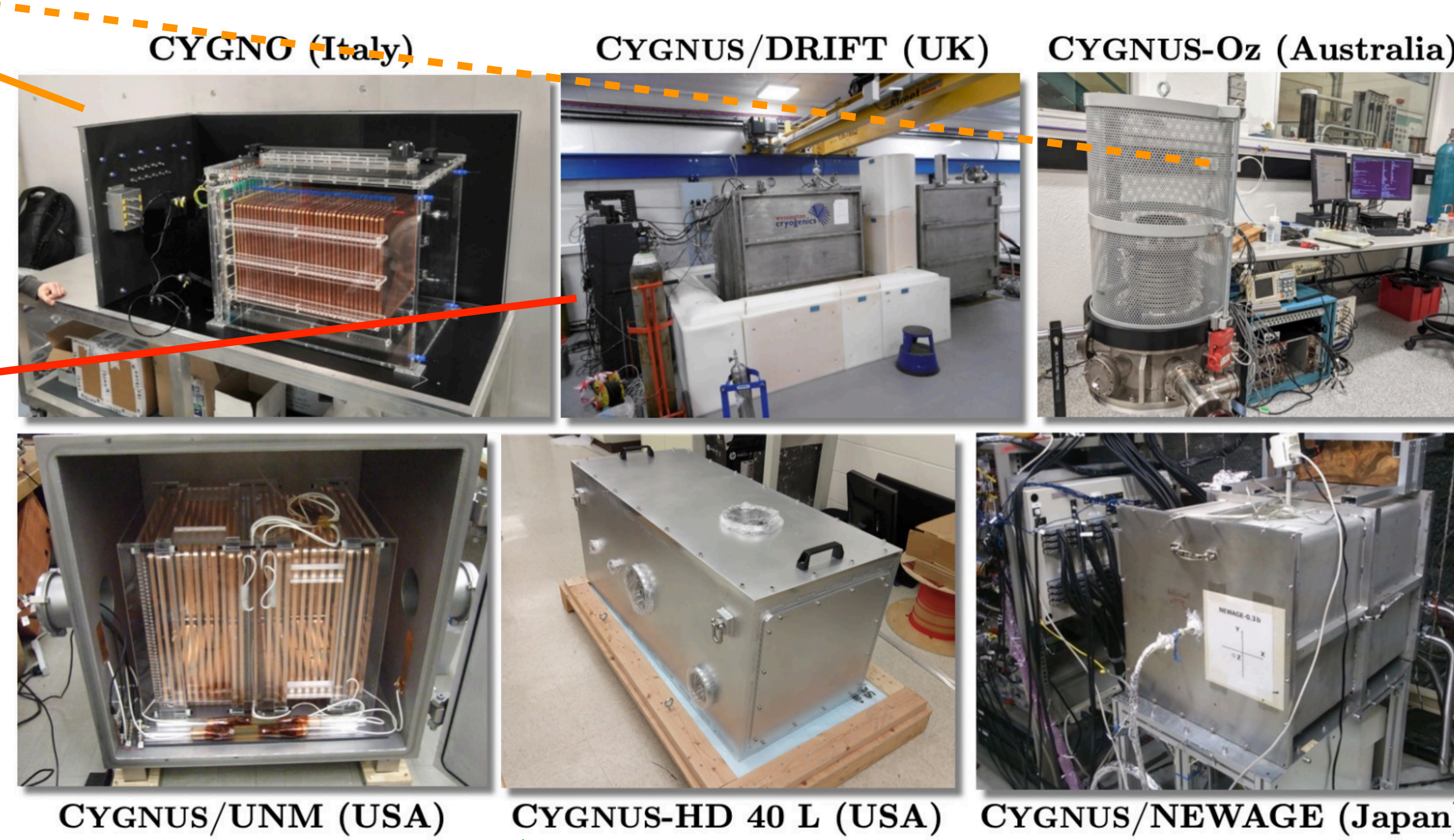
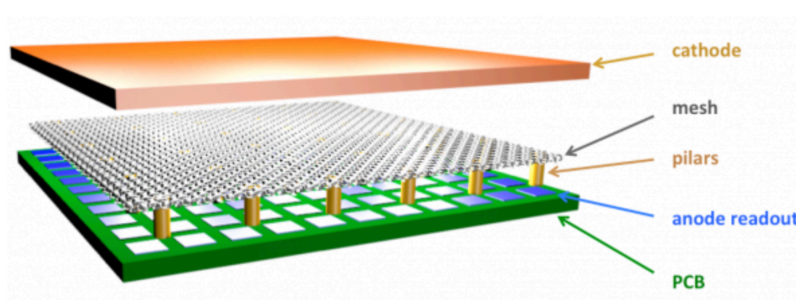




Strip/pixel readout of micromegas



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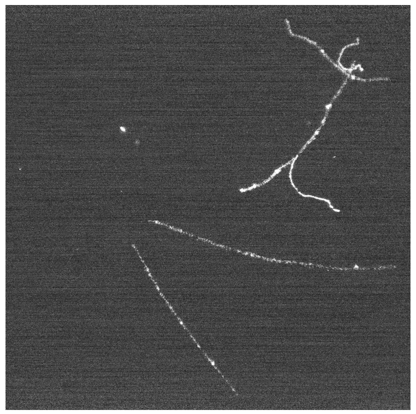

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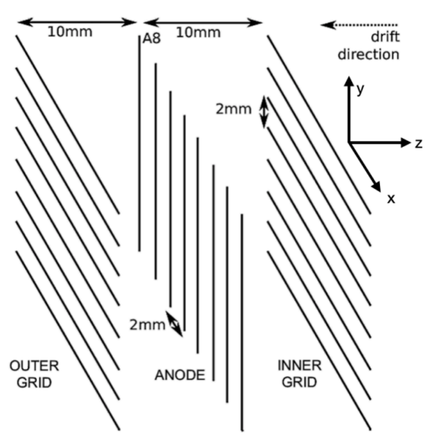

CYGNO (Italy) | CYGNUS/DRIFT (UK) | CYGNUS-Oz (Australia)

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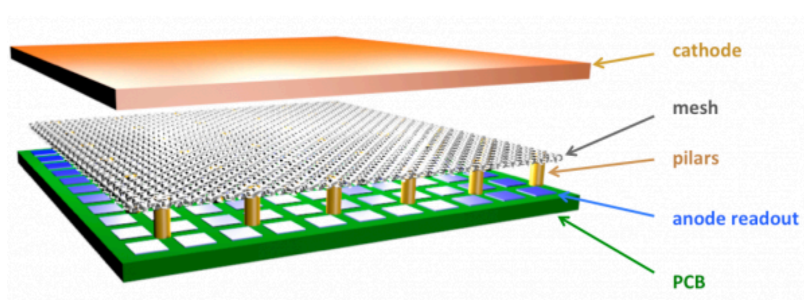
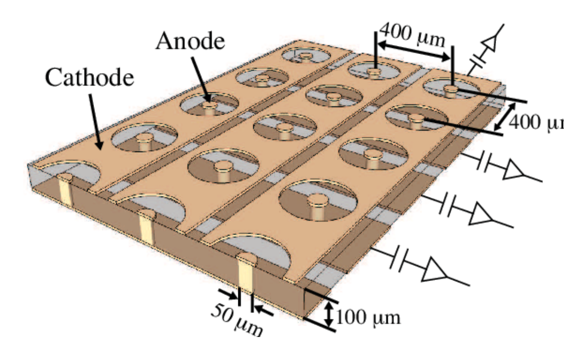


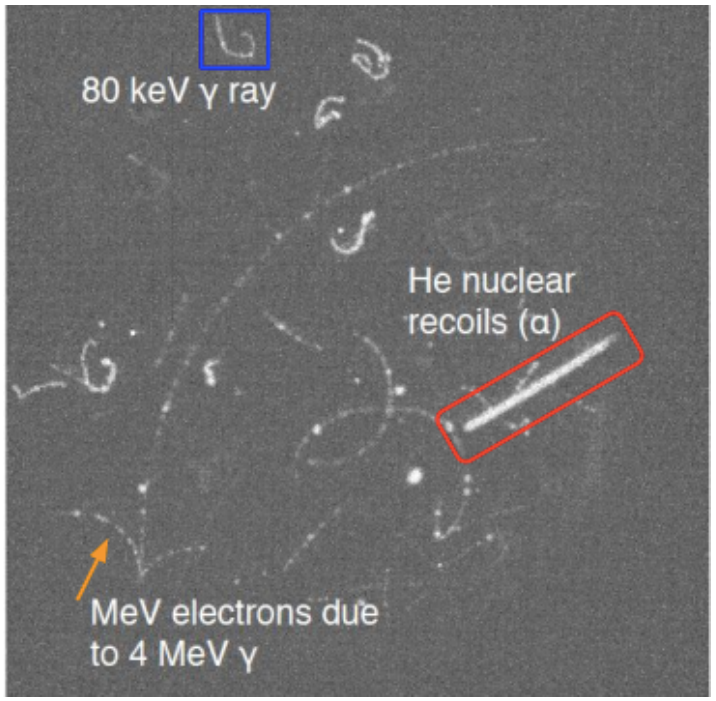
2D strip readout of μ-PIC

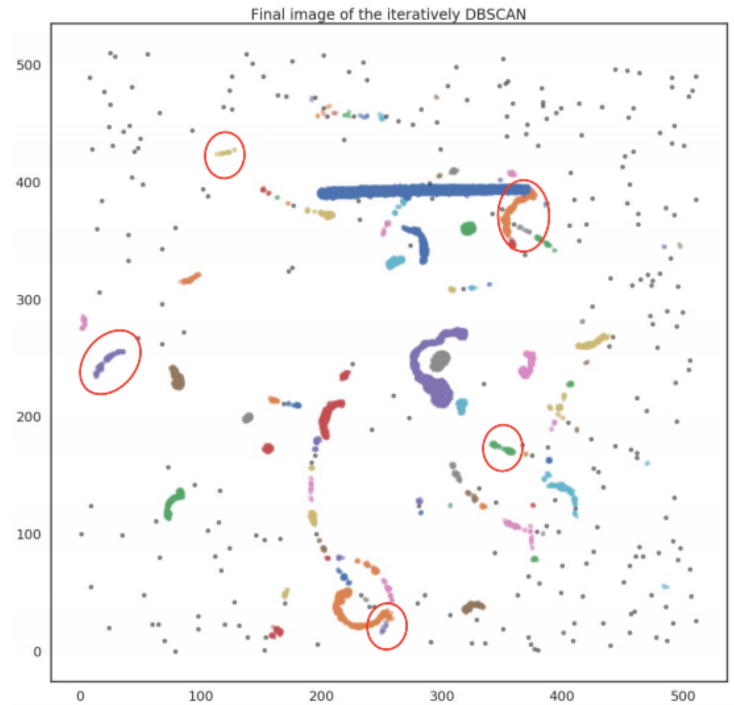


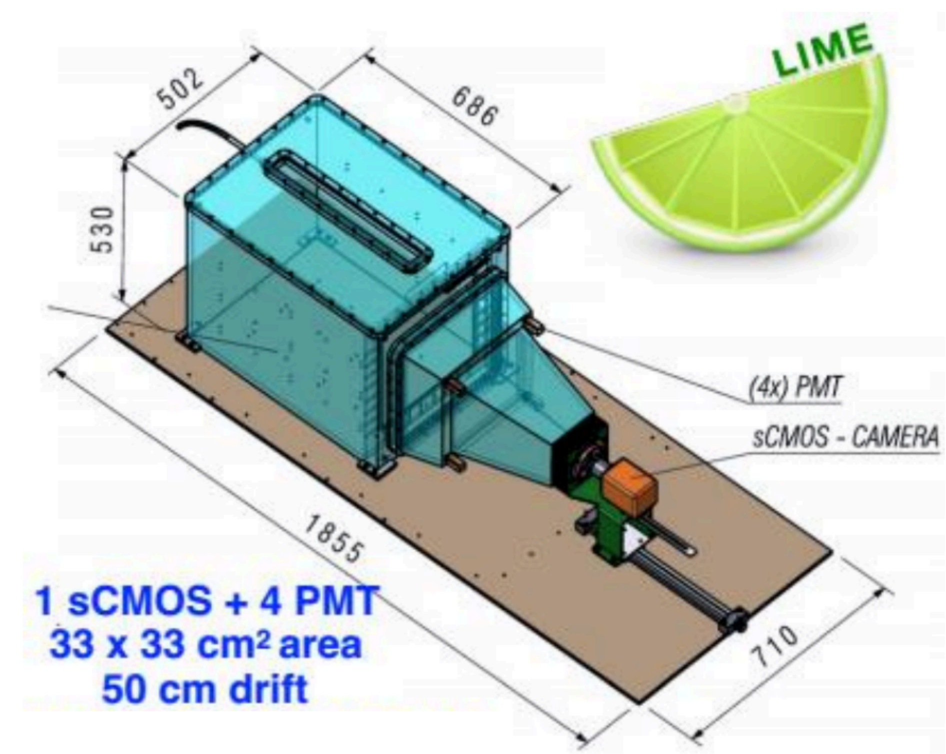
Particle identification & energy resolution

Particle identification

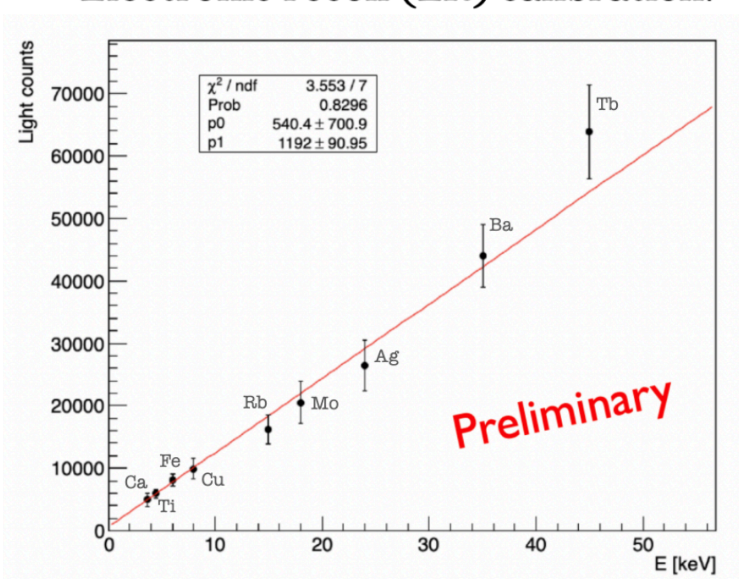
CYGNO (LIME prototype)



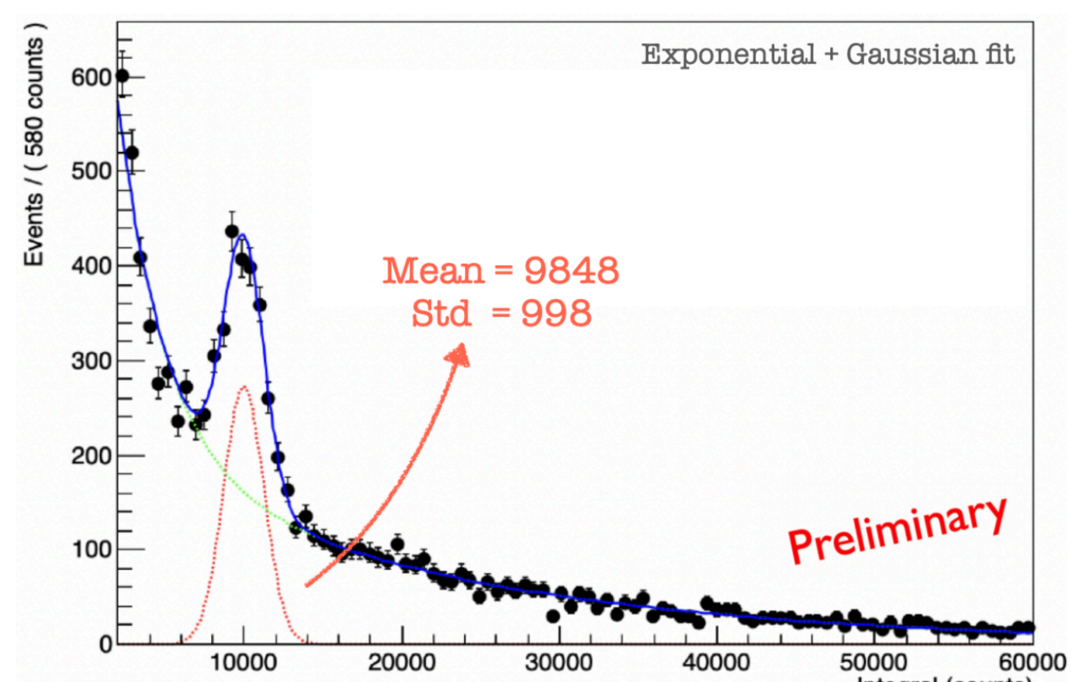




Electronic recoil (ER) calibration:



Example: calibration with the 8 keV Cu X-rays



- **~ 13% energy resolution**
- **good linearity** in the response

How light is a gaseous detector

The usual question: can a gaseous target be competitive (in terms of exposure) with liquid or solid targets?

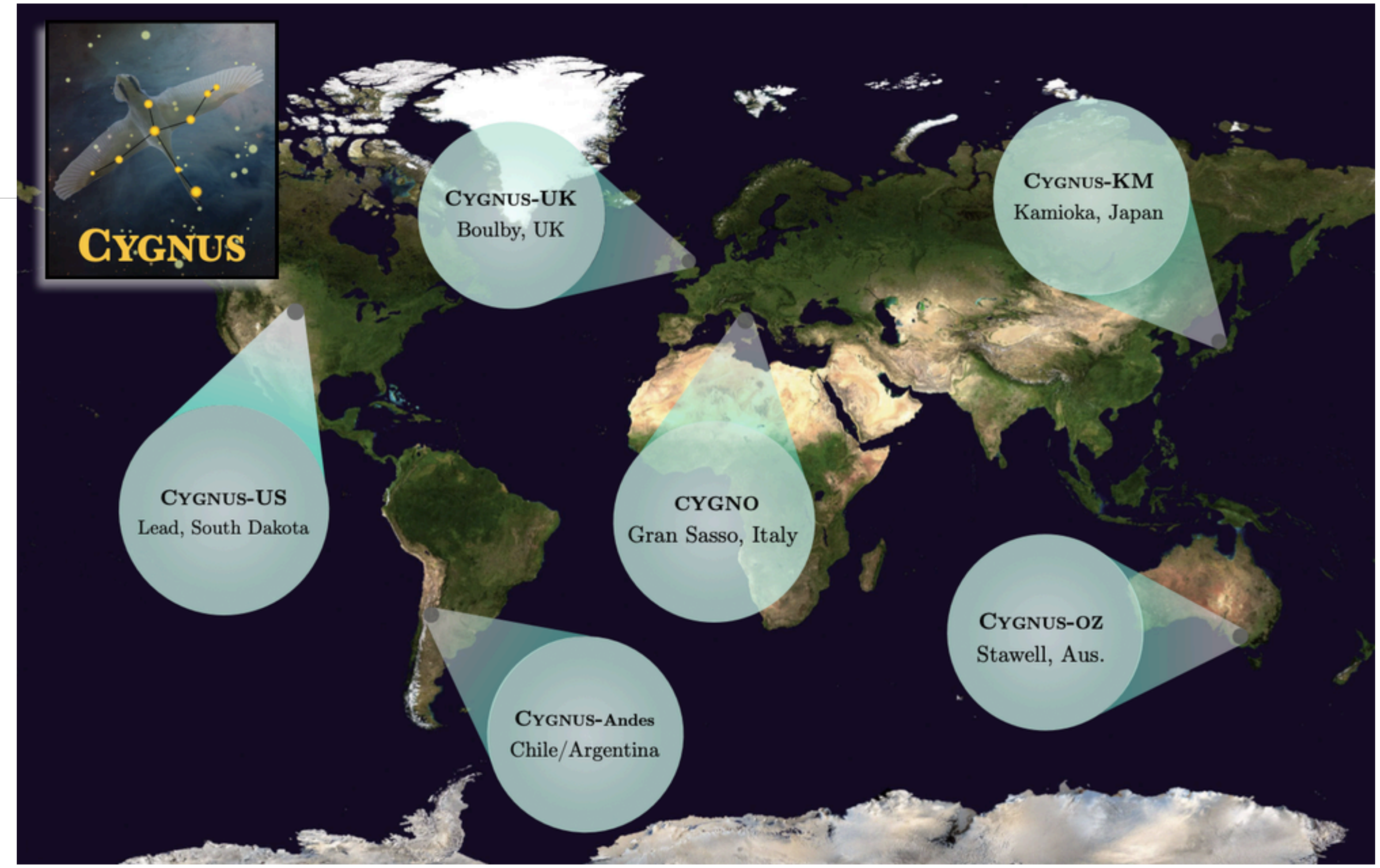
- The typical density of mixtures at atmospheric pressure is O(kg/m^3)
- Building a m^3-scale (—> kg scale) TPC at atm. pressure is easy and relatively cheap
- 100 m^3 (—> 100 kg scale) with extreme uniformity and stability is a standard in collider experiments, is considered for the DUNE near detector and takes not much more than 100 m^3 including infrastructures
- Scaling up to several hundreds of m^3 (—> ton scale) is not much more difficult or incredibly expensive (depending on readout)

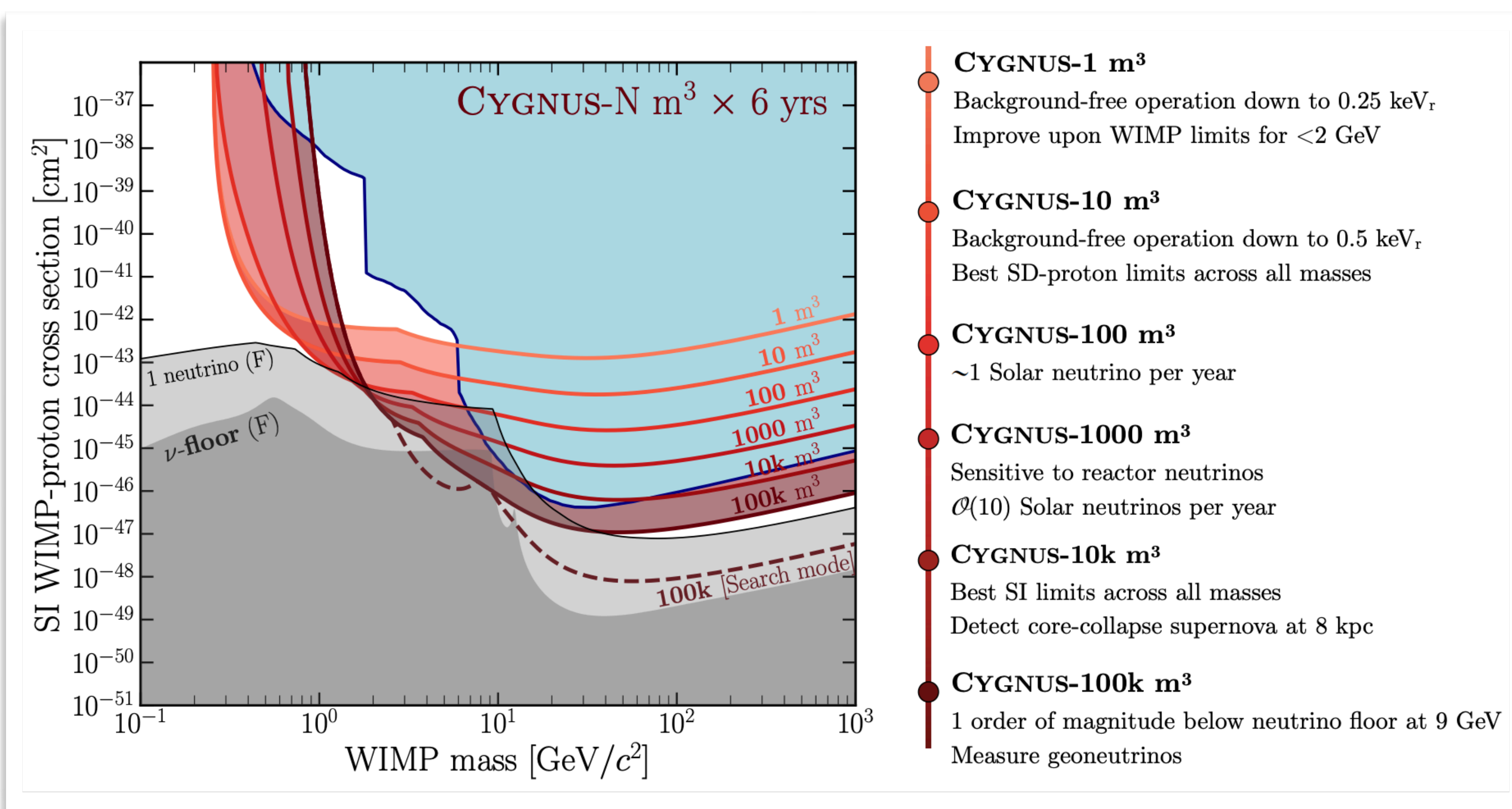
One should not think in terms of density, but in terms of mass and live time achievable with realistic infrastructures

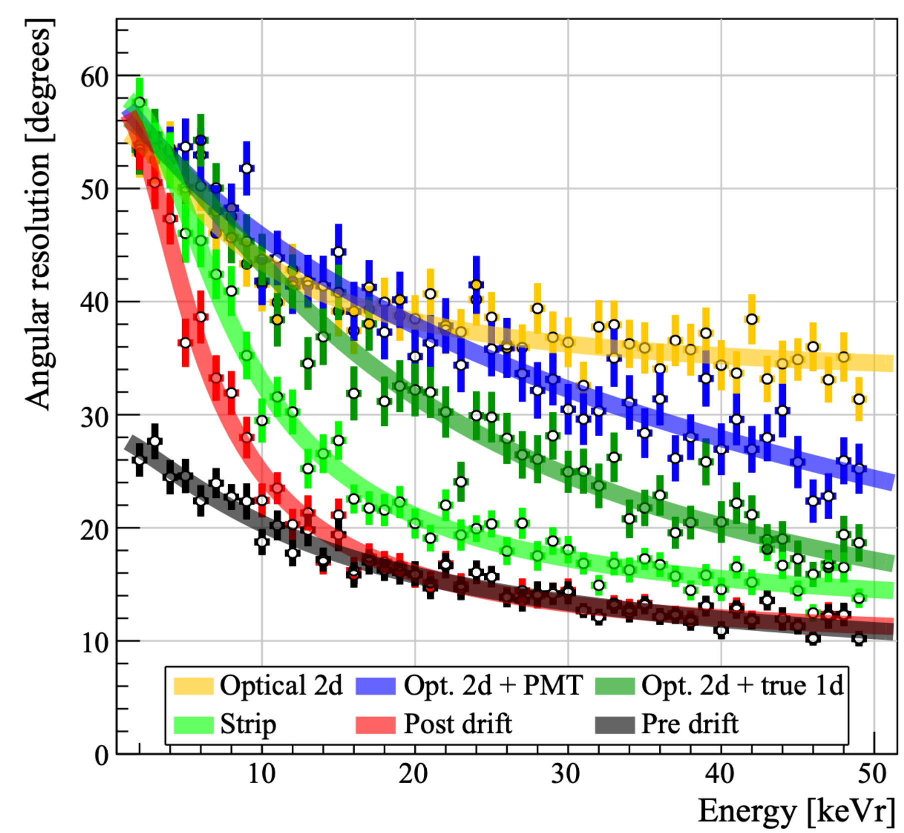
- At the end, space in underground labs and cost of shielding can be the limiting factors

Toward CYGNUS-100k

- A worldwide network of experiments for directional rare event searches





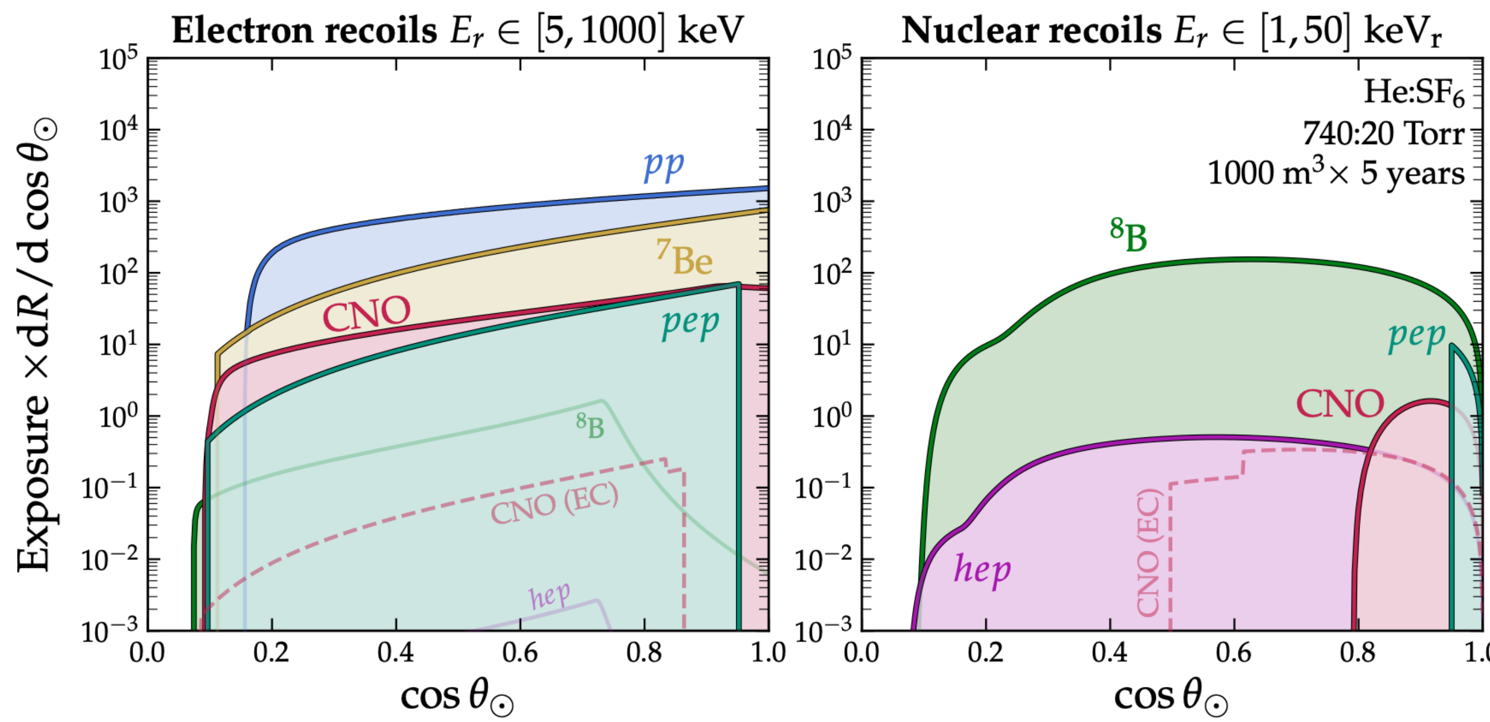


Neutrinos in CYGNUS

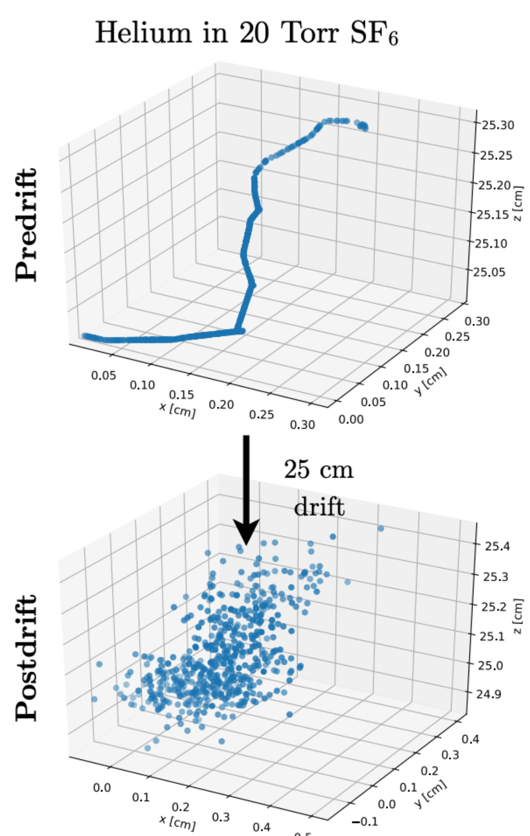
Solar neutrinos detection in CYGNUS

- Gaseous TPCs can detect both **nuclear and electron recoils** induced by neutrinos
- **Directional** resolution helps discriminating backgrounds

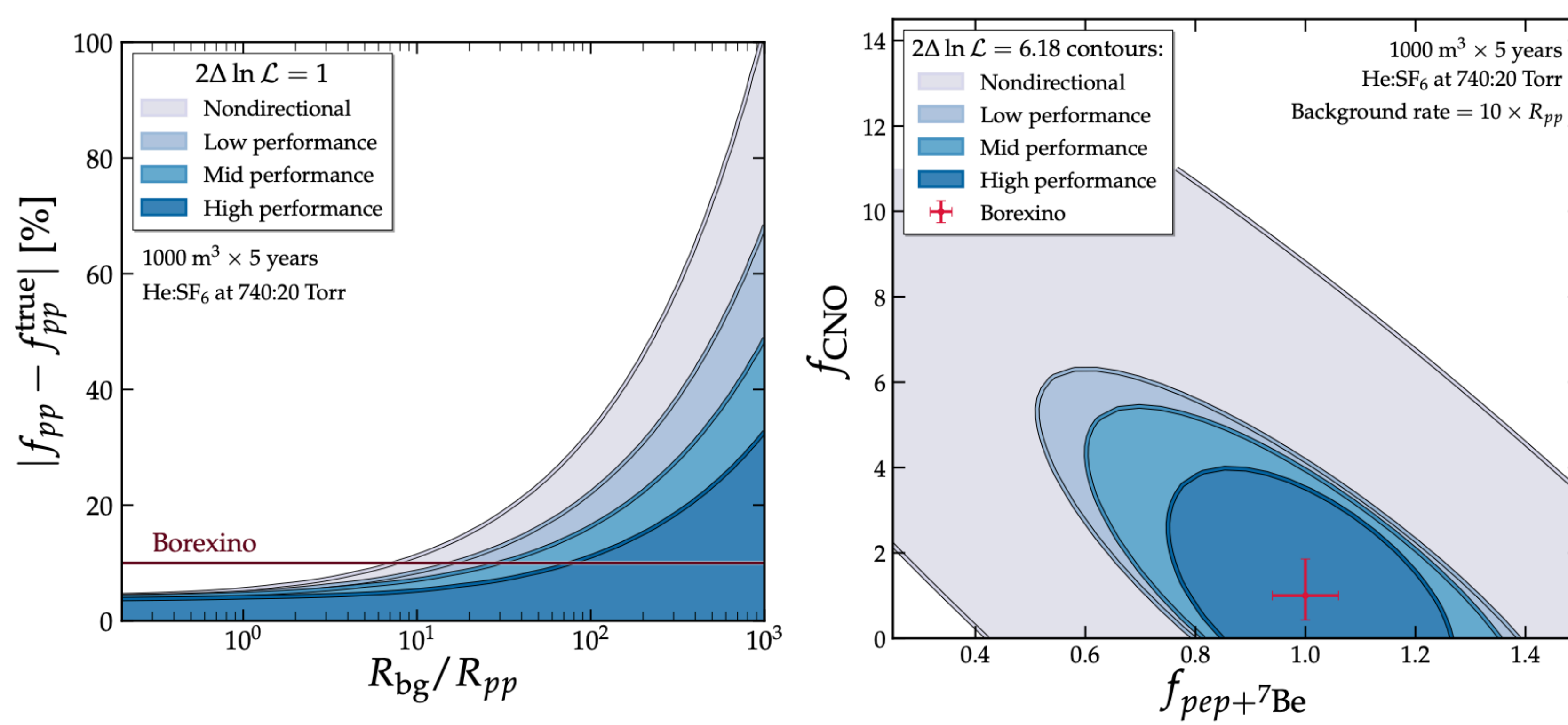
Expected yields



20 keV He nuclear recoil



Sensitivity to flux parameters



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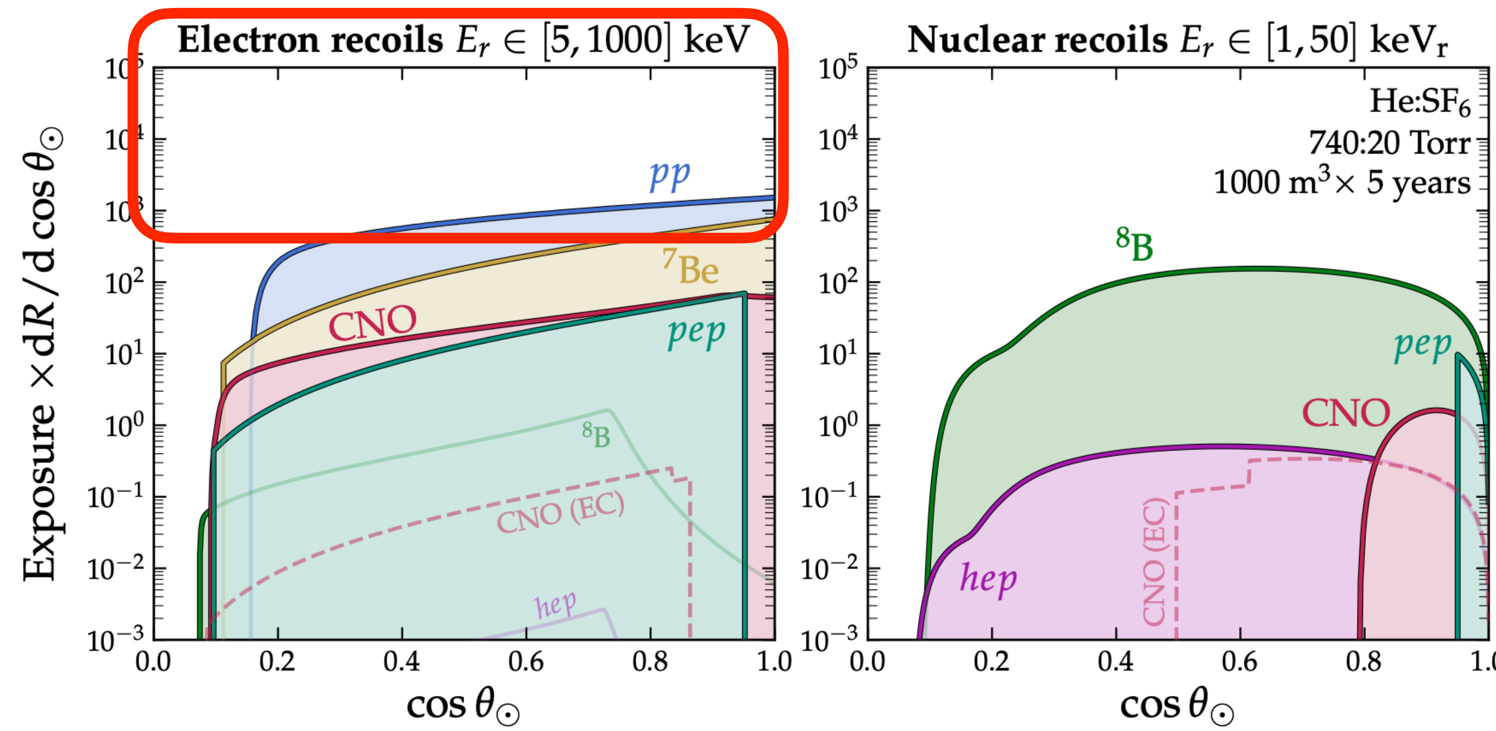
Expected yields **Talk by S. Torelli**



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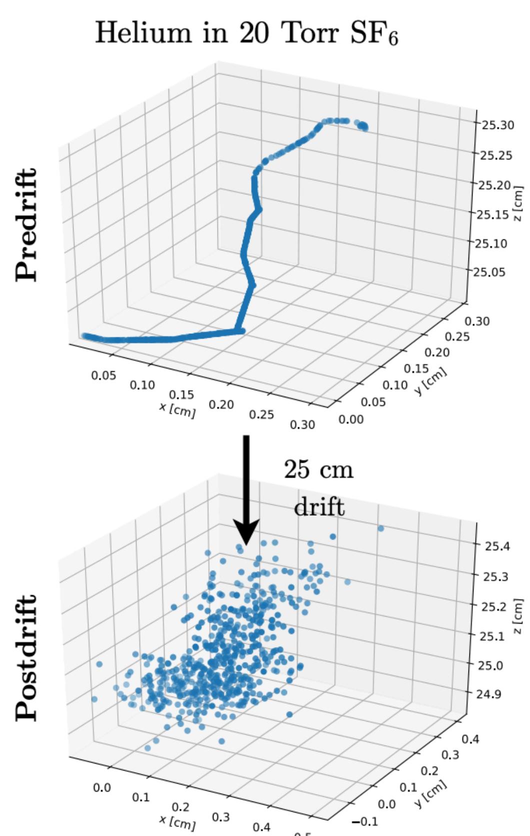

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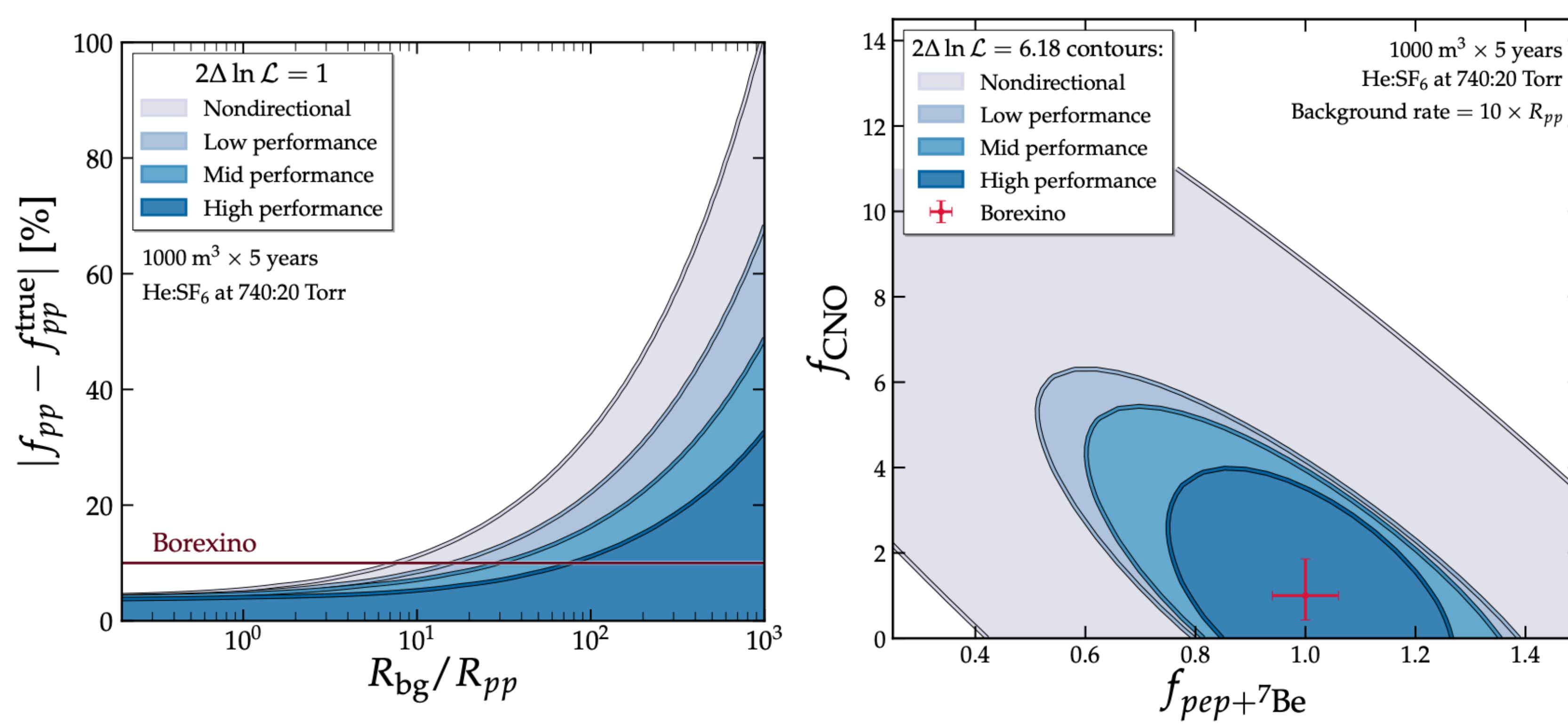
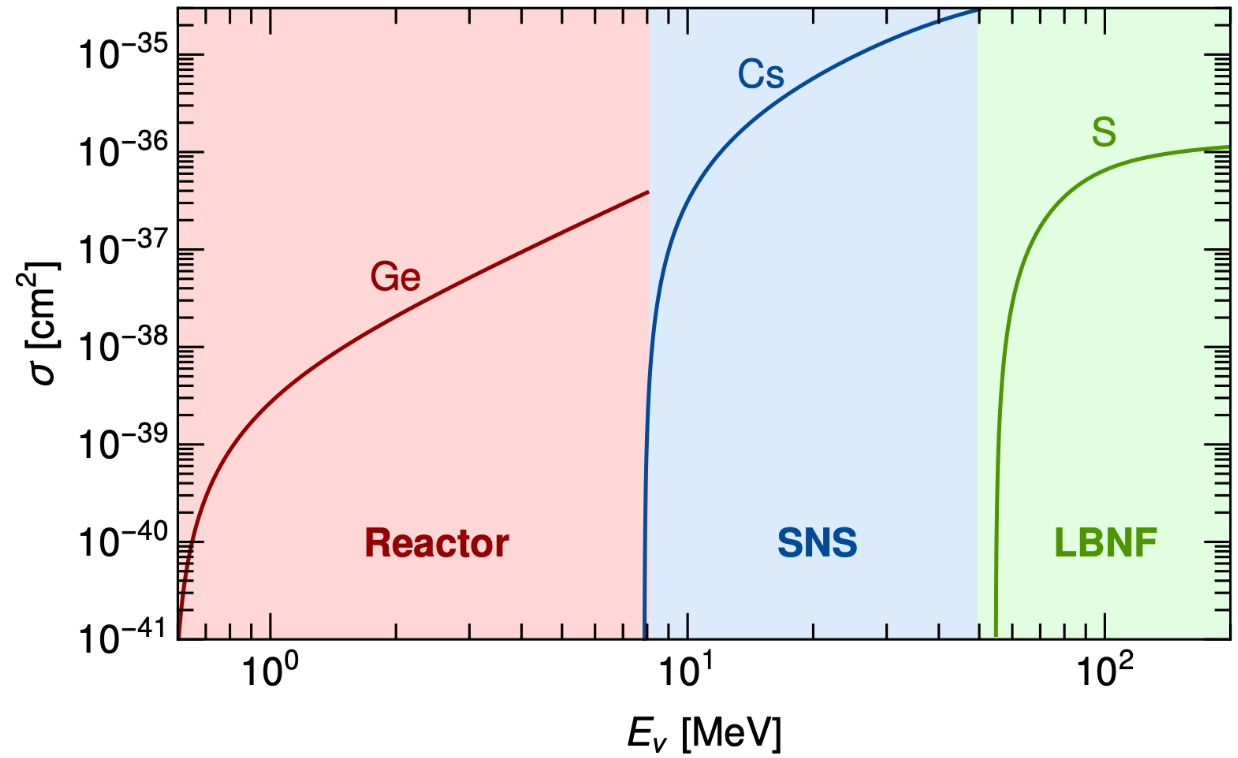
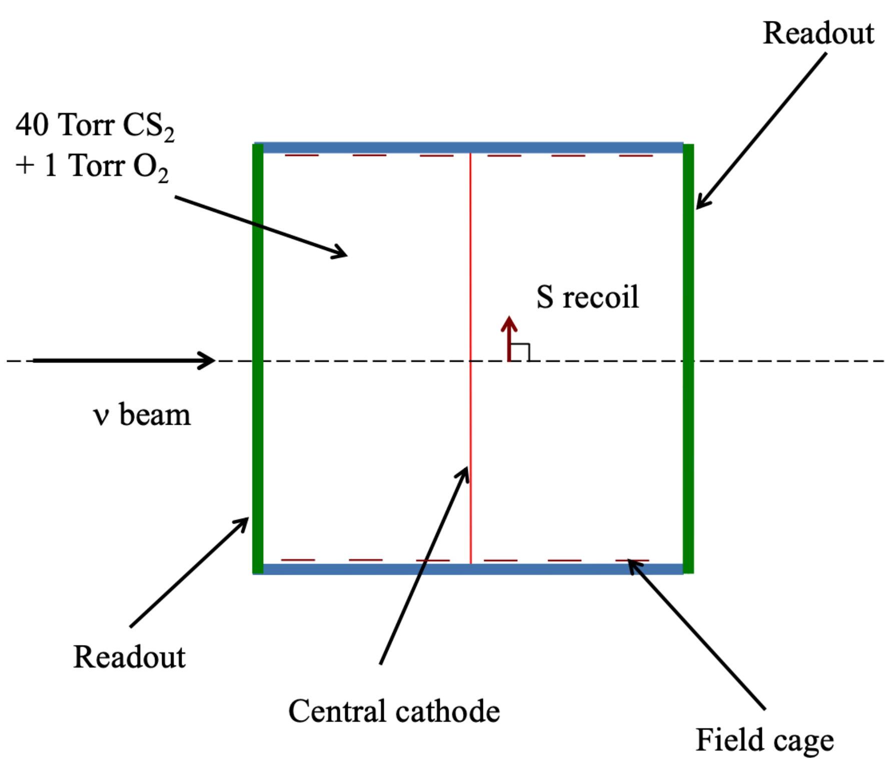
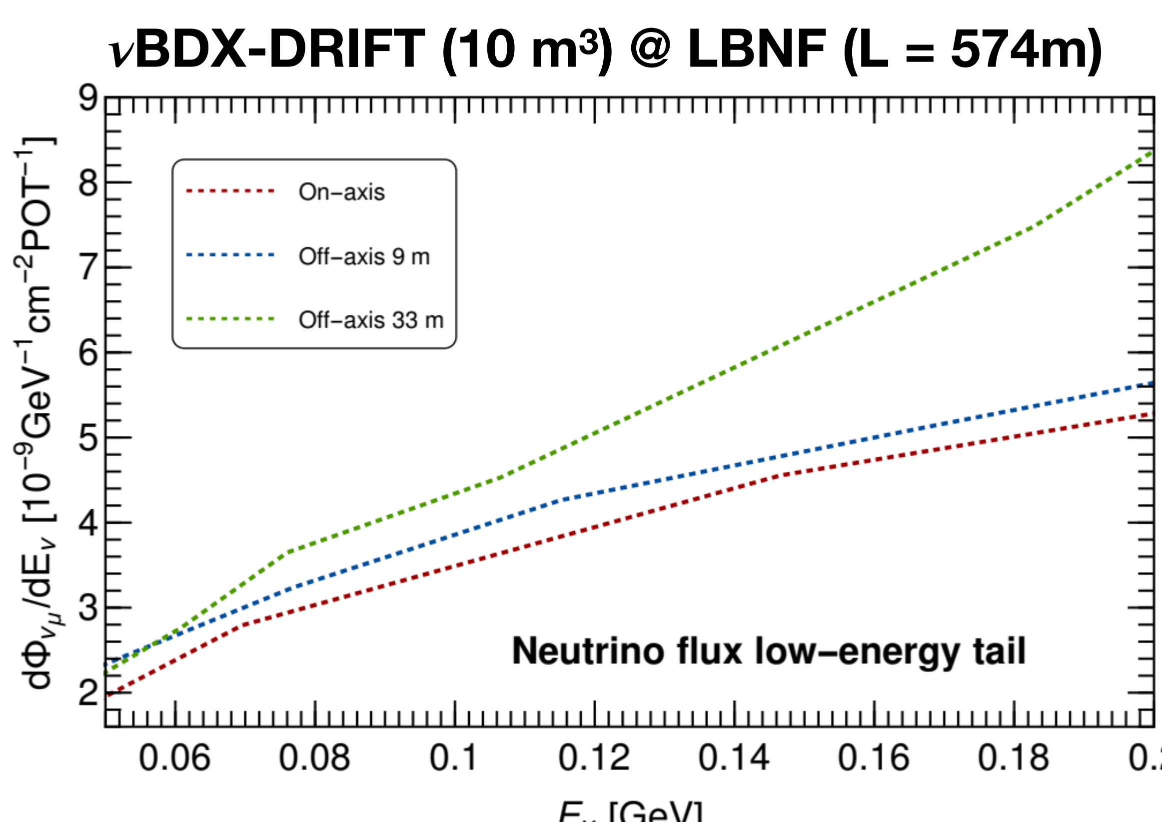


Coherent neutrino scattering in a gaseous TPC

- **Directional** resolution helps discriminating backgrounds and allows to study angular dependences in the SM and beyond







Phys. Rev. D 104, 033004 (2021)

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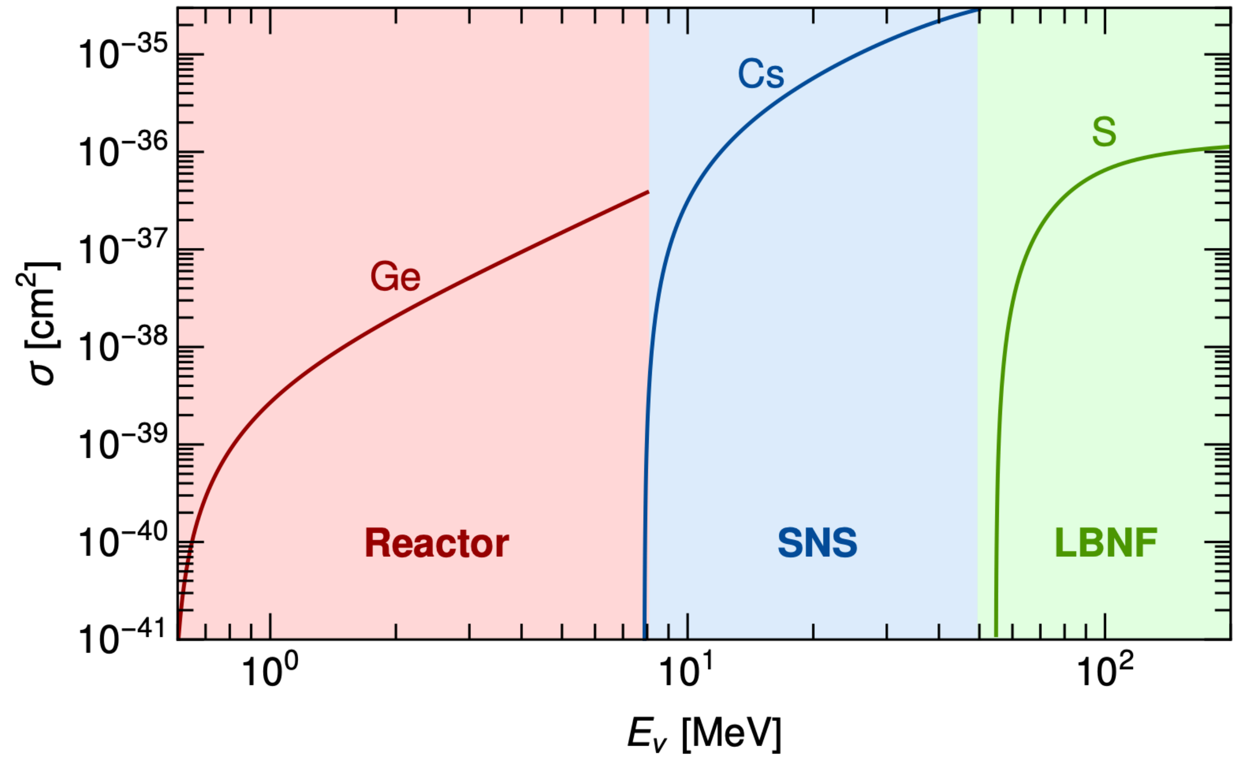

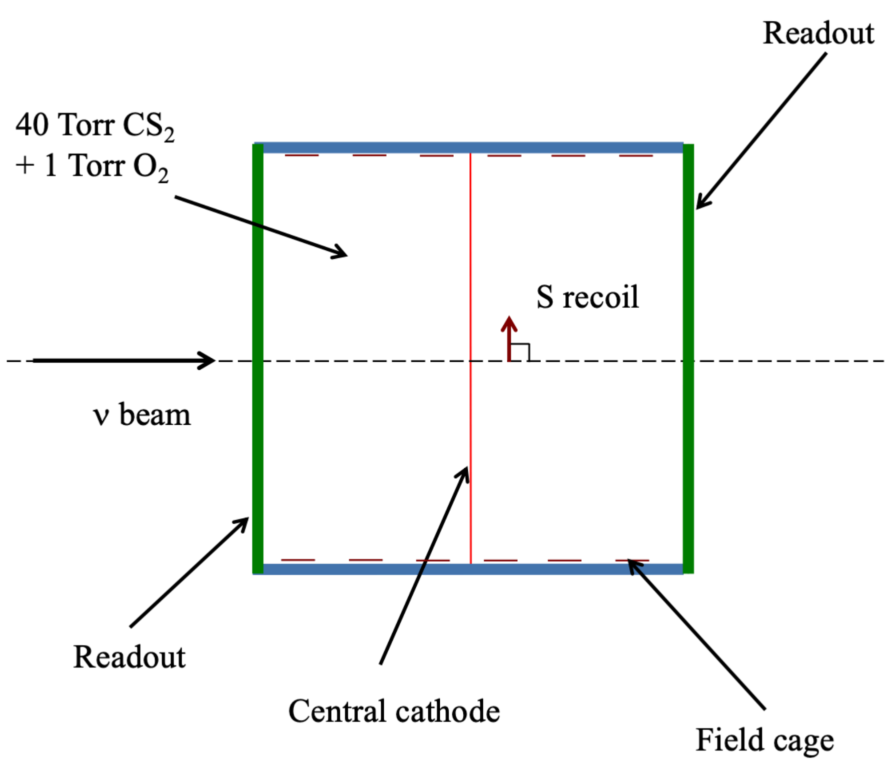

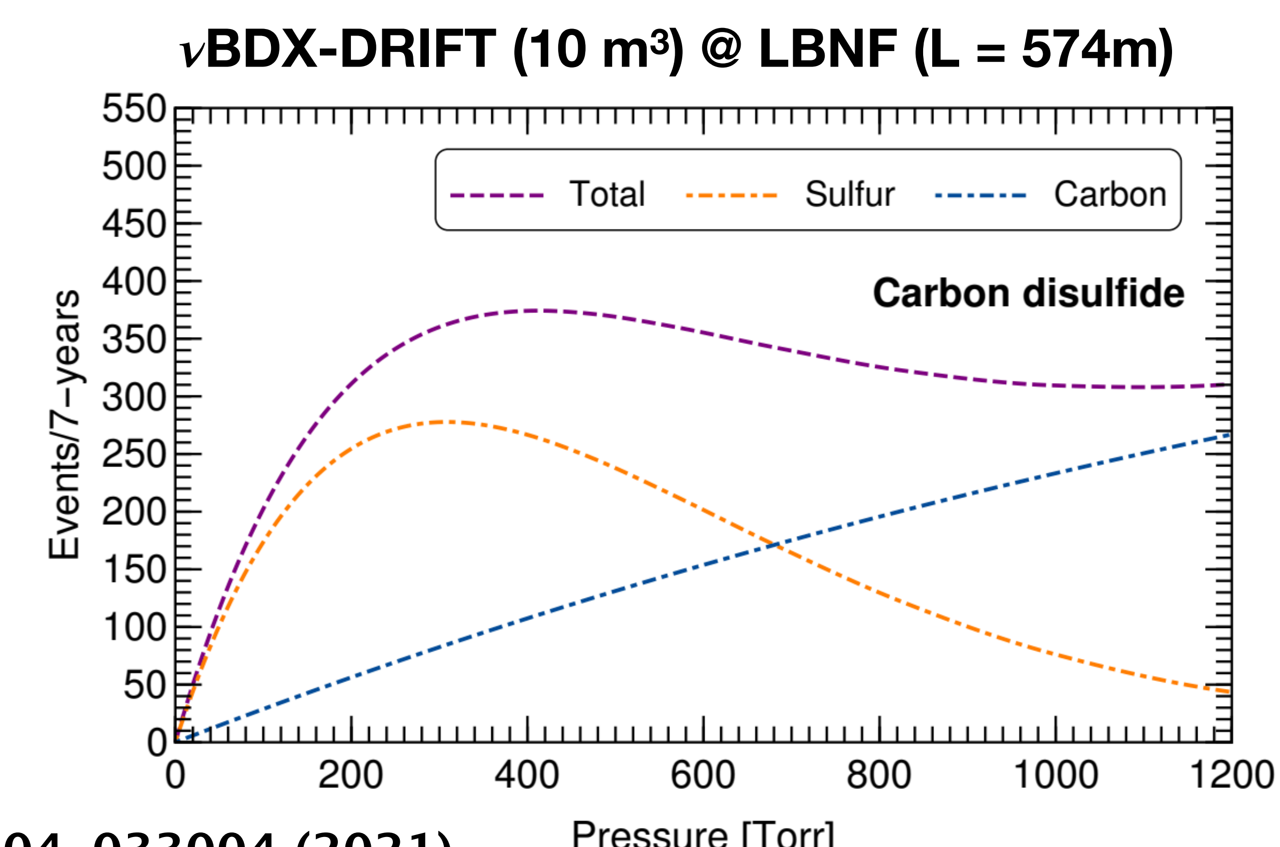

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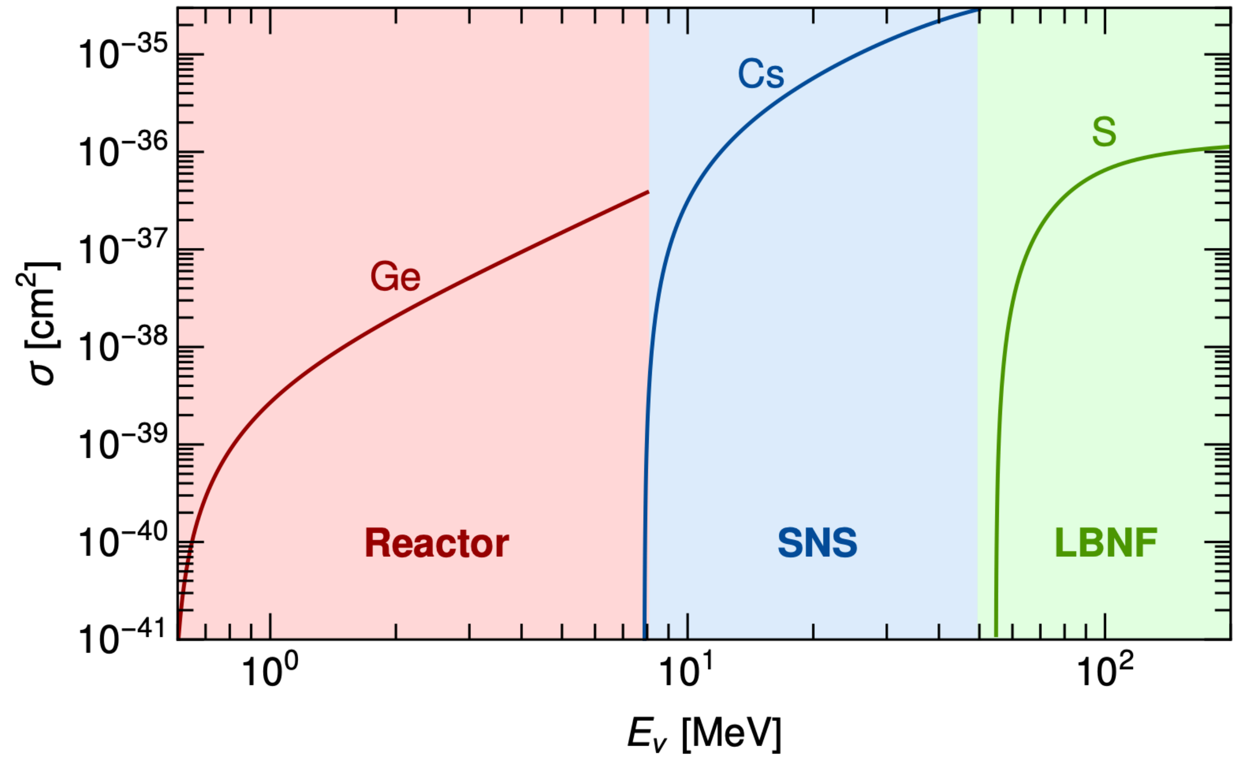

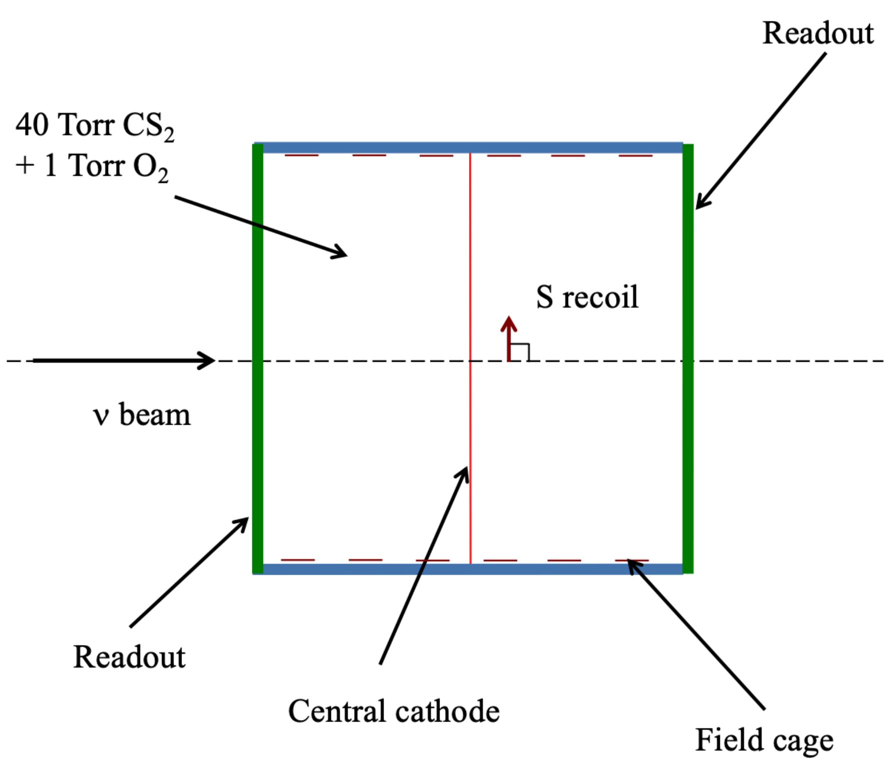

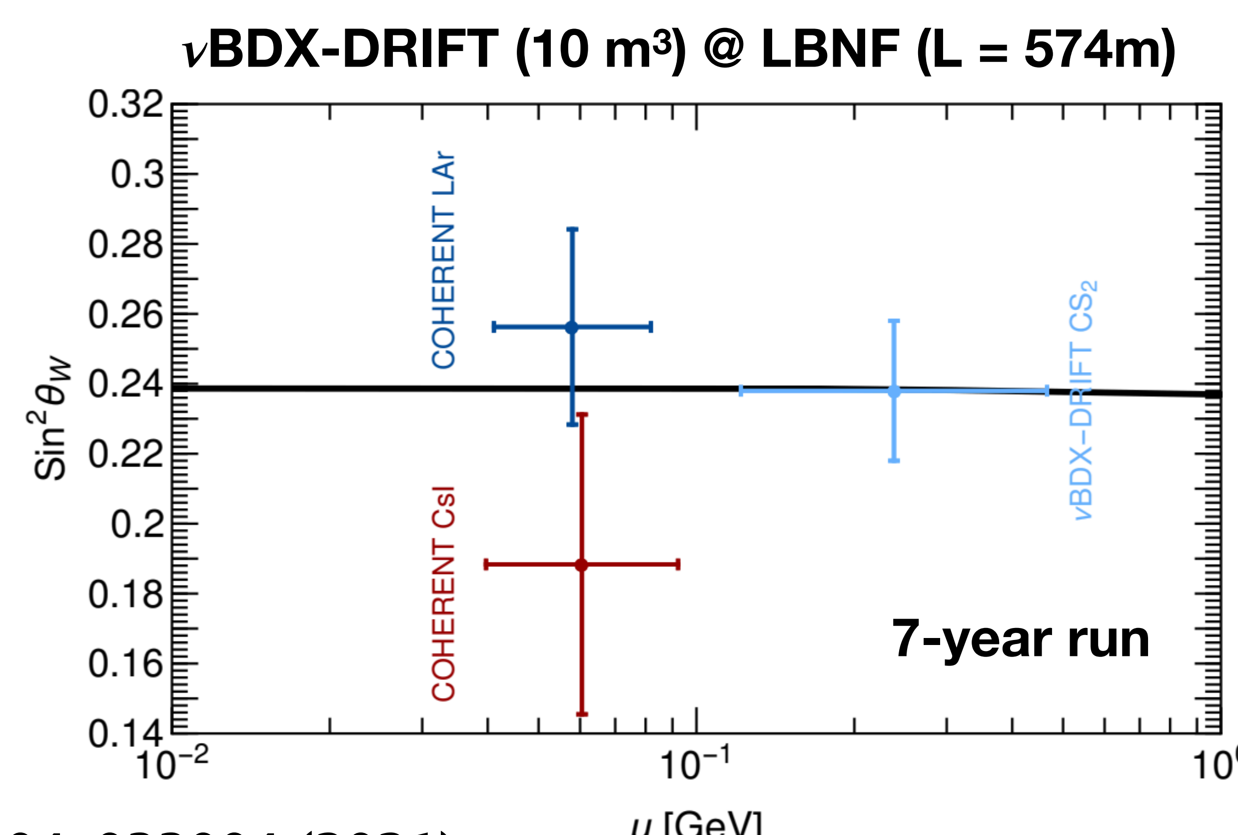

Phys. Rev. D 104, 033004 (2021)

Conclusions

- **Directionality** boosts the discovery potential of rare event searches, thanks to a powerful suppression of isotropic backgrounds
- High resolution gaseous TPCs also provide **excellent particle identification** capabilities for further suppression
- CYGNUS is an international network for the development of gaseous TPCs with directional capabilities
- Both nuclear and electron recoils can be detected and identified:
    - promising applications to neutrino physics (CEνNS, solar neutrinos)