



PhD opportunities in Dark Matter searches

Konstantinos Nikolopoulos
University of Birmingham



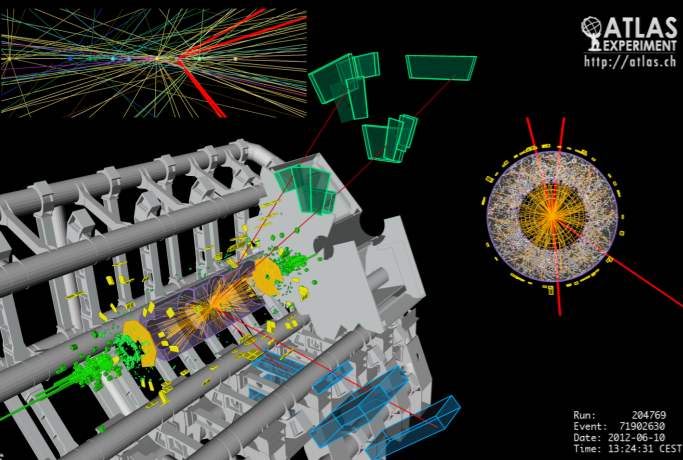
UNIVERSITY OF
BIRMINGHAM

ATLAS experiment at CERN

STFC RAL Studentships Open Day
February 23rd, 2023



This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement 714893-ExclusiveHiggs and under Marie Skłodowska-Curie agreement 841261-DarkSphere, 895168-neutronSPHERE, 101026519-GaGARin

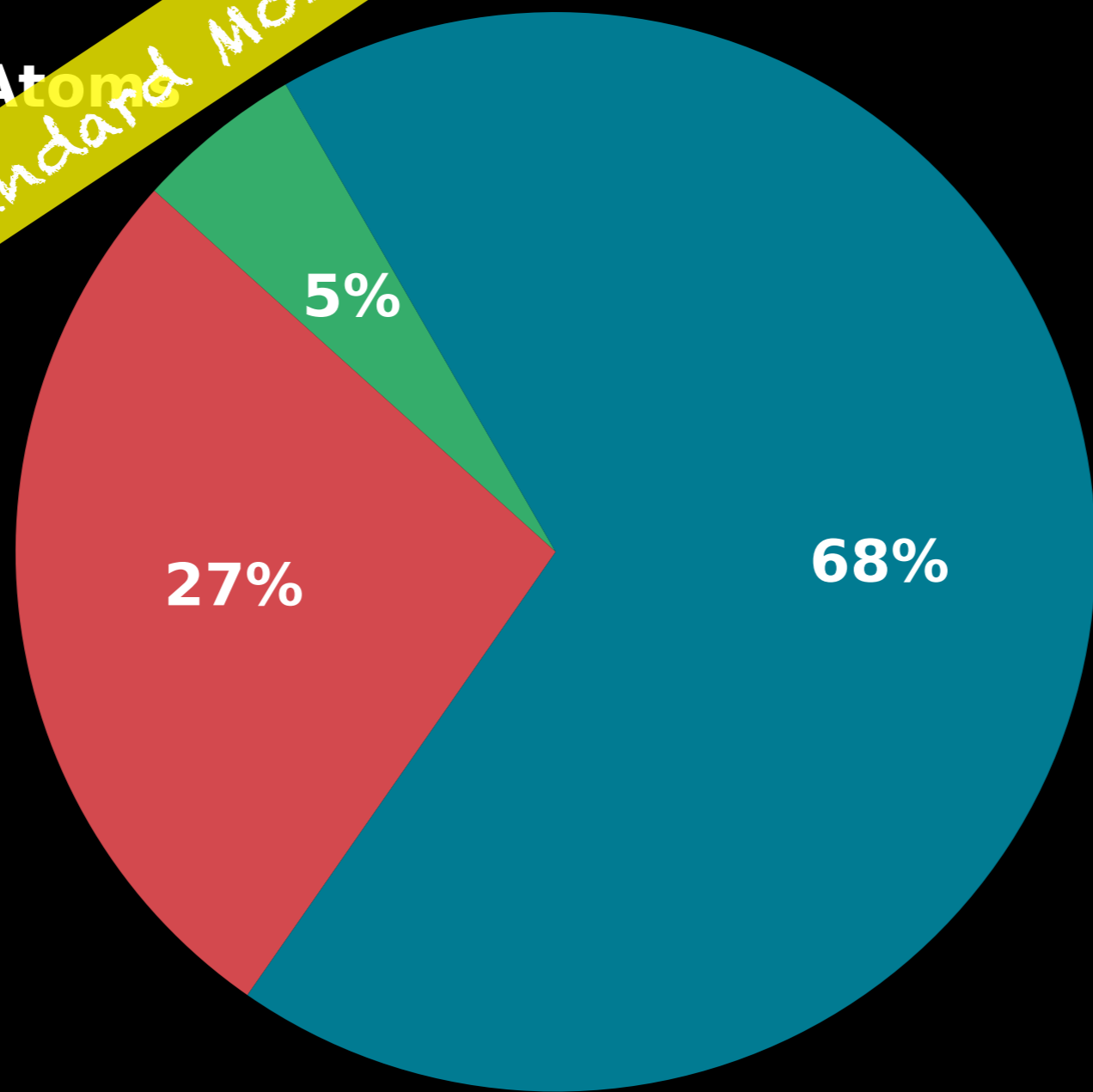


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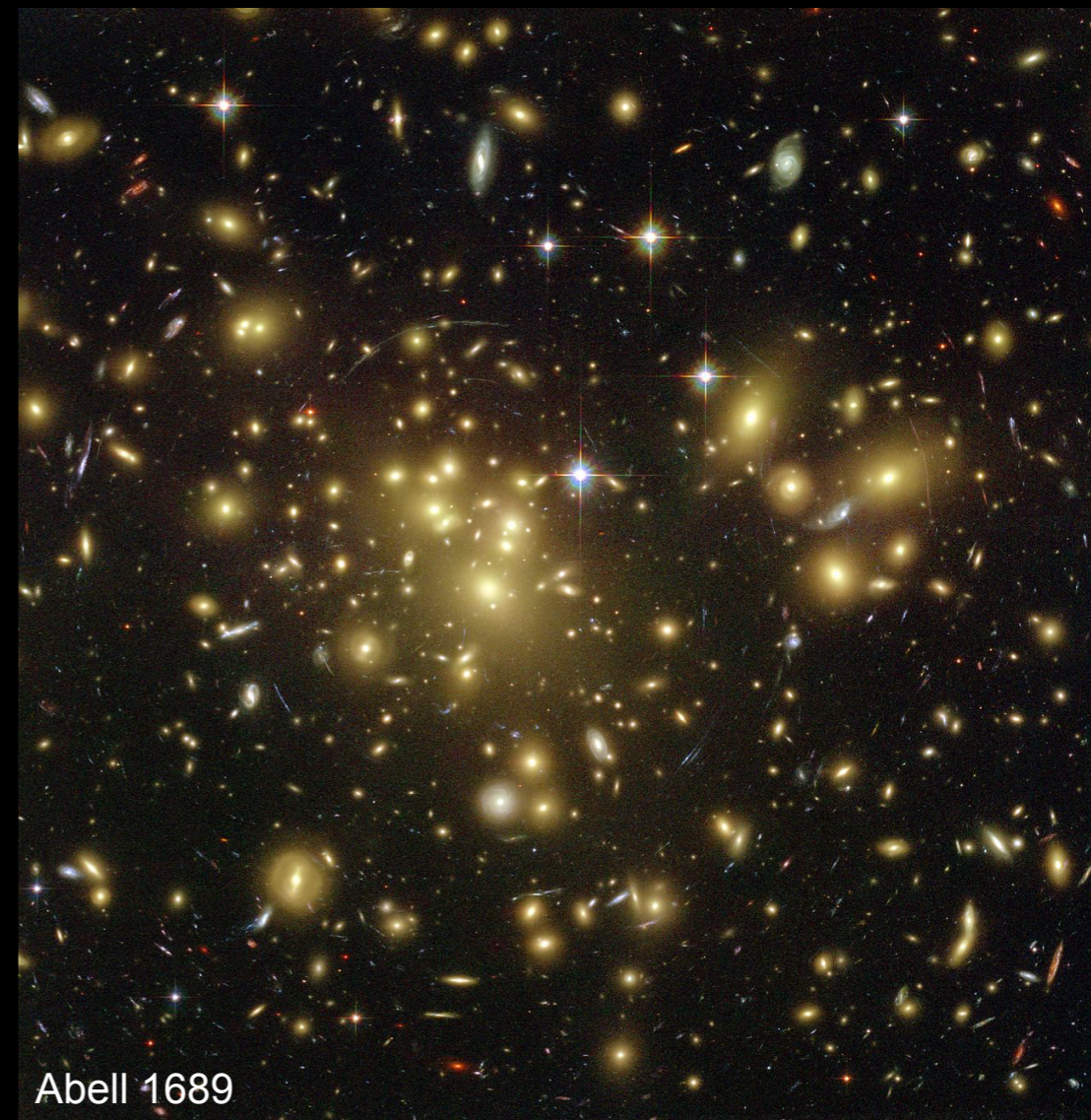
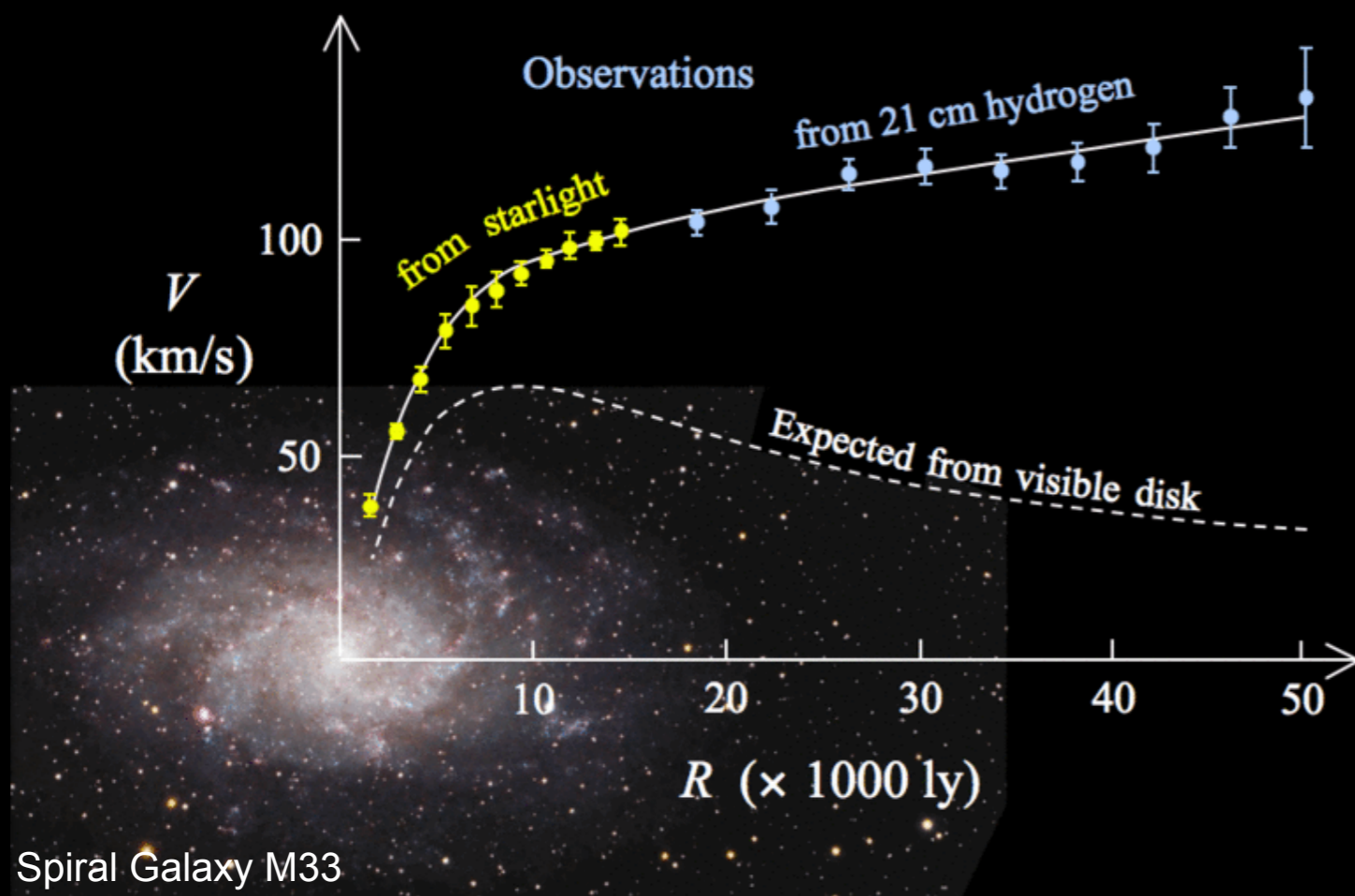
Atom

Standard Model

Dark Matter

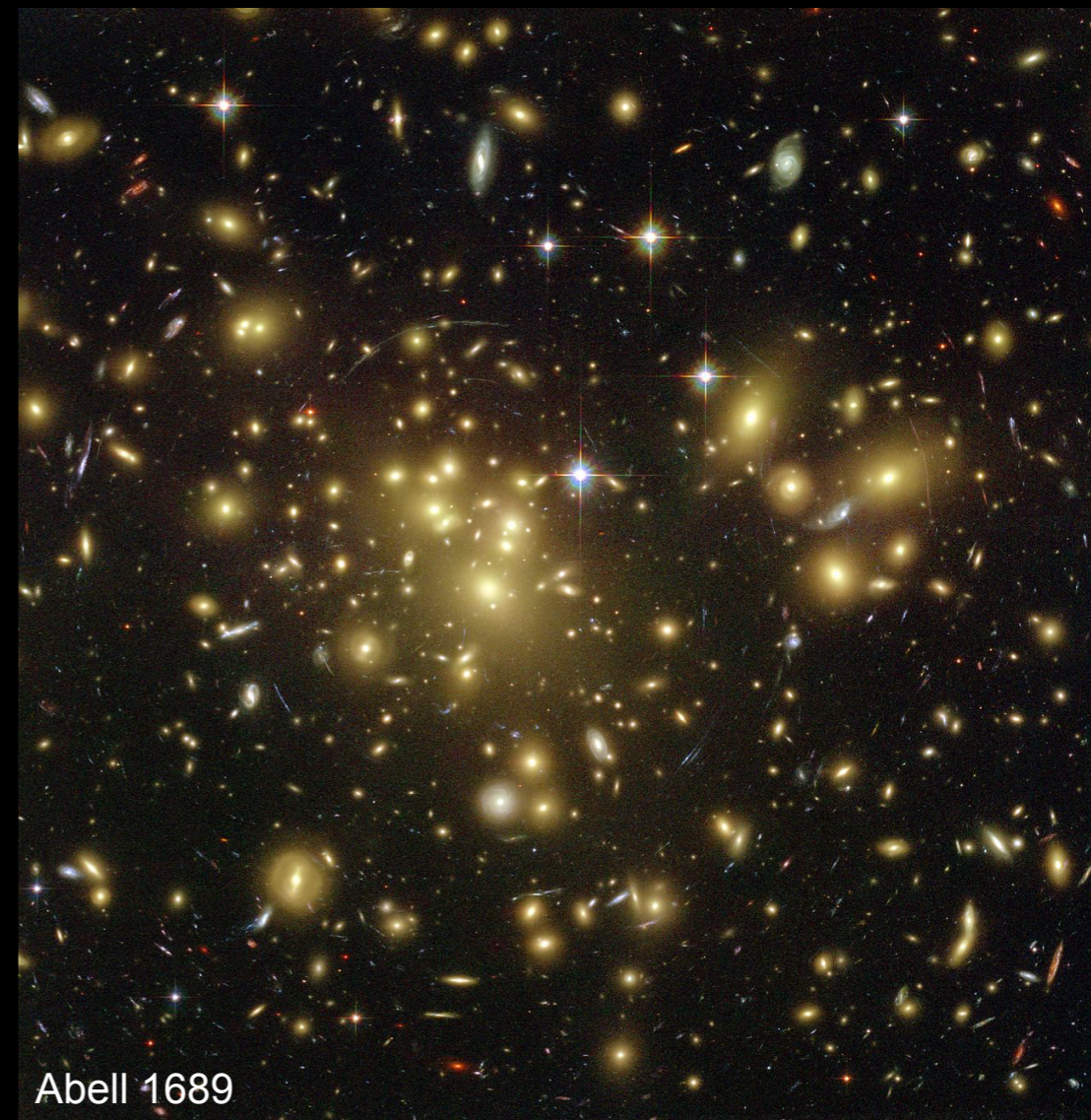
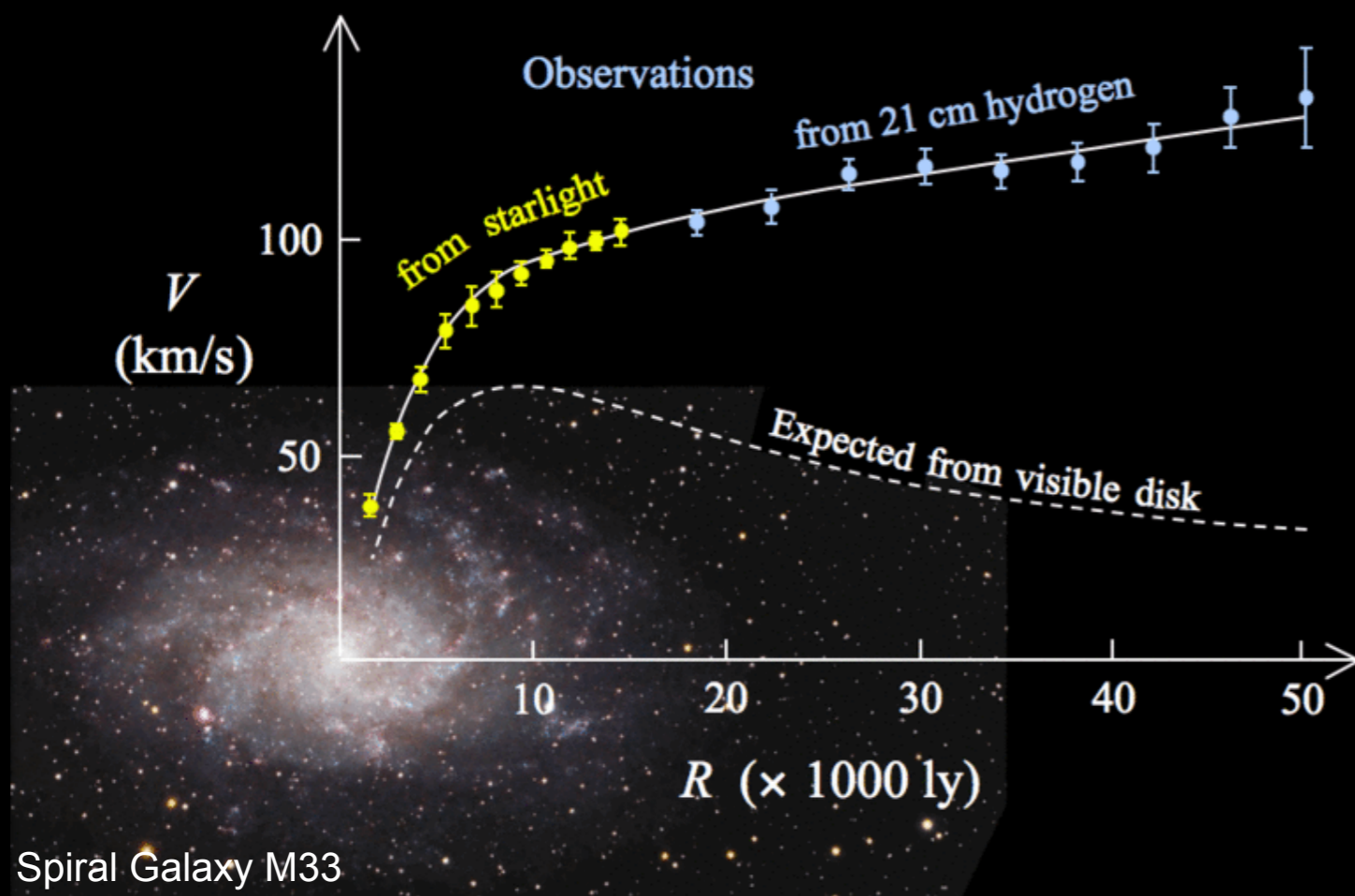


Dark Energy



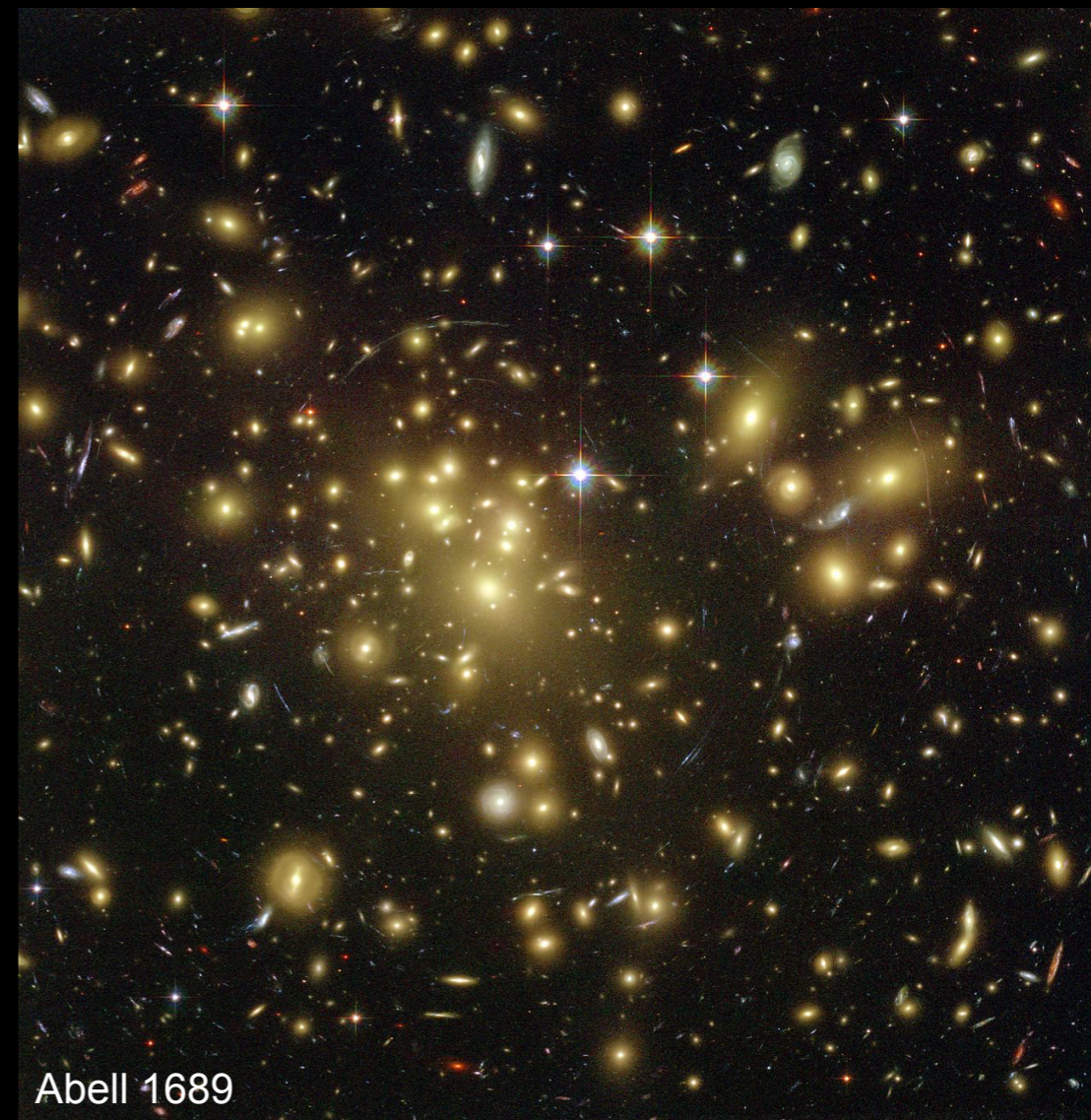
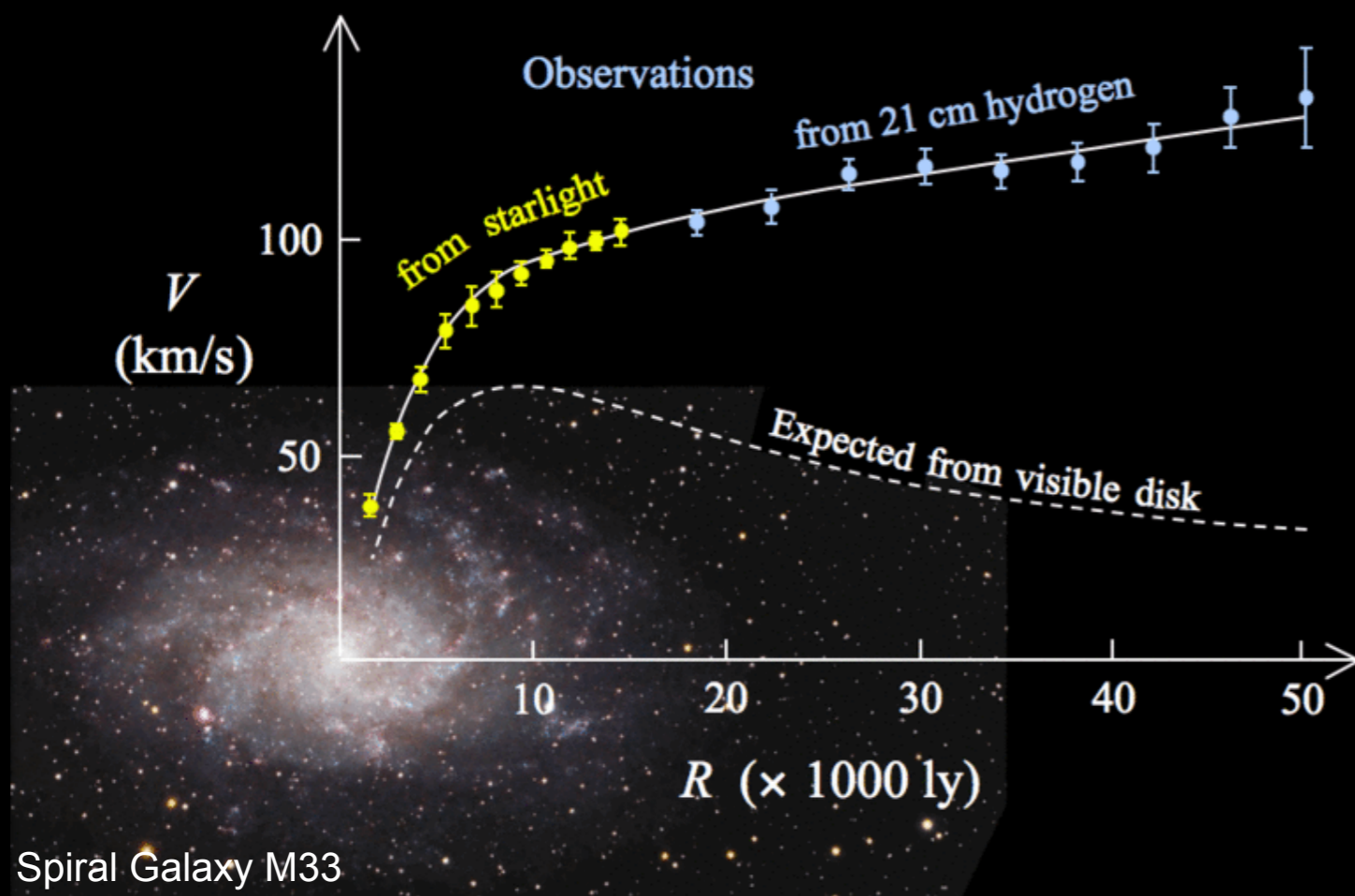
👁 Evidence from gravitational interactions over many distance scales

- ▶ Rotational curves (galaxies and galaxy clusters)
- ▶ Gravitational lensing
- ▶ Cosmology
 - ▶ Cosmic microwave background
 - ▶ Large scale structure formation
- ▶ Big Bang Nucleosynthesis



👁️ What we know about Dark Matter

- ▶ Non-Baryonic
- ▶ Mostly “cold”
- ▶ Electrically neutral (or milli-charged?)
- ▶ “Weakly” interacting
- ▶ $\Omega_{\text{DM}}h^2 = 0.120 \pm 0.001$
- ▶ Stable or $T_{\text{DM}} \gg T_{\text{u}}$

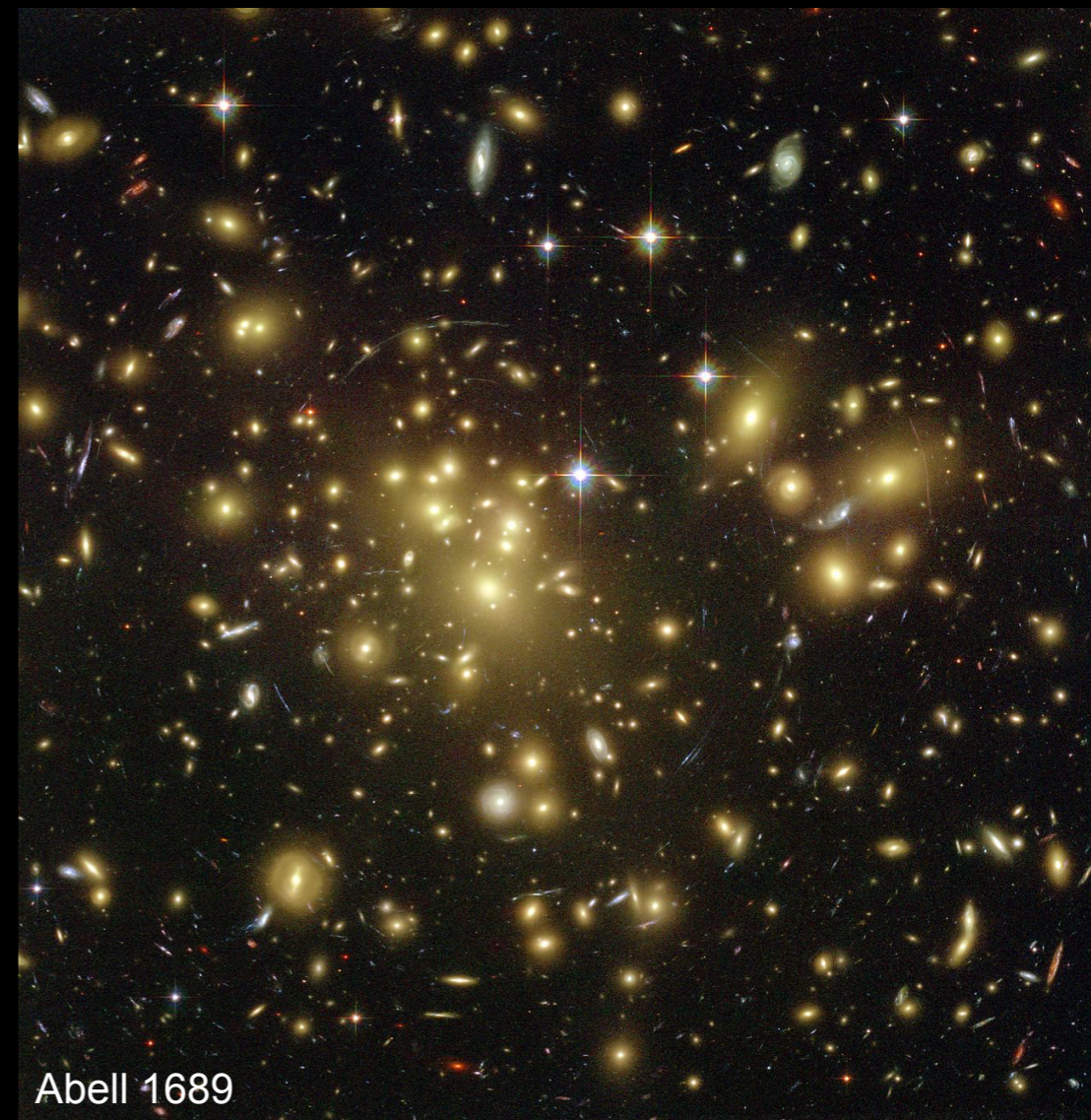
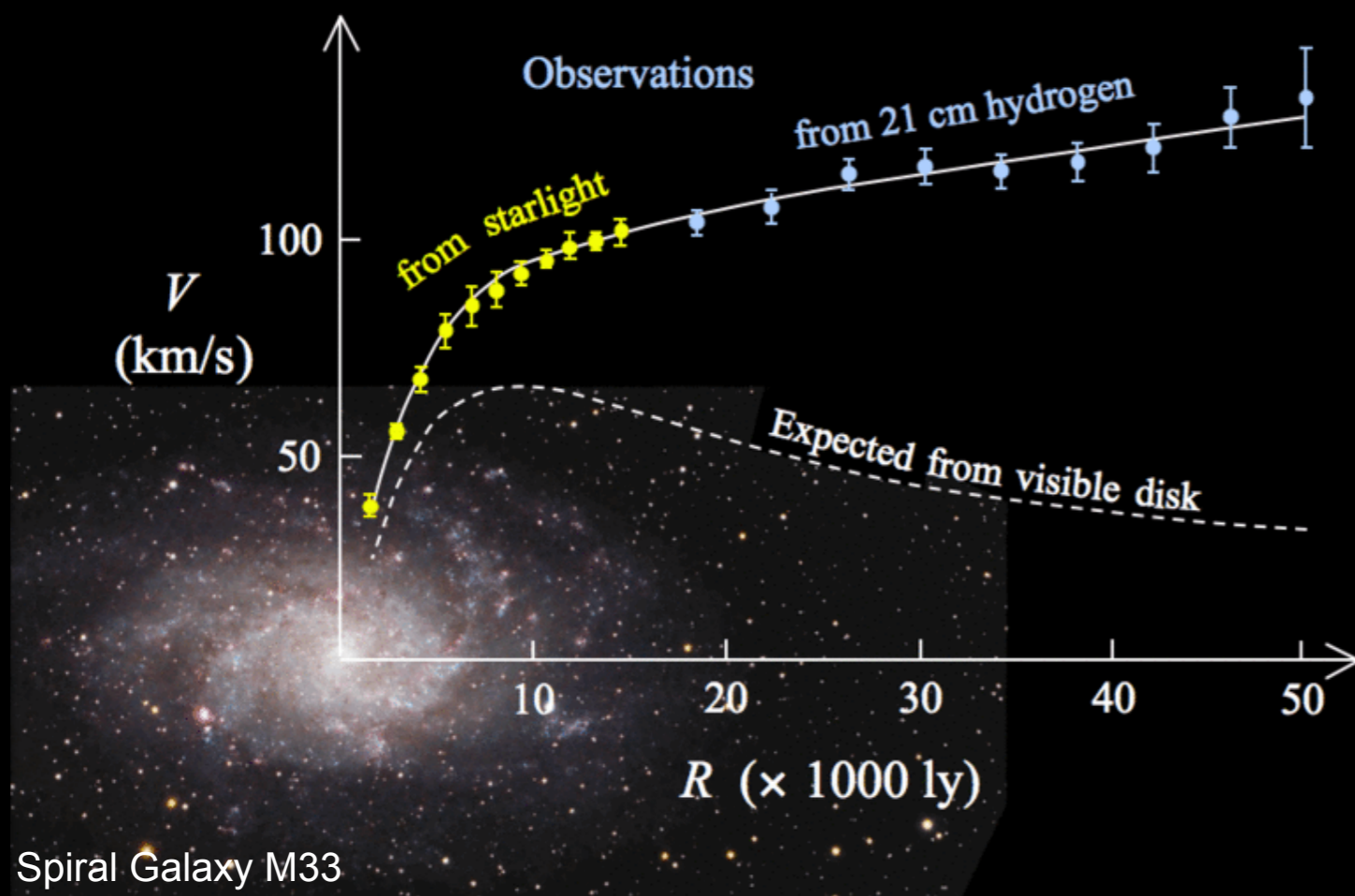


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Dark Matter Particle (X^0)

- X^0 mass: $m = ?$
- X^0 spin: $J = ?$
- X^0 parity: $P = ?$
- X^0 lifetime: $\tau = ?$
- X^0 scattering cross-section on nucleons: ?
- X^0 production cross-section in hadron colliders: ?
- X^0 self-annihilation cross-section: ?



👁️ What we know about Dark Matter

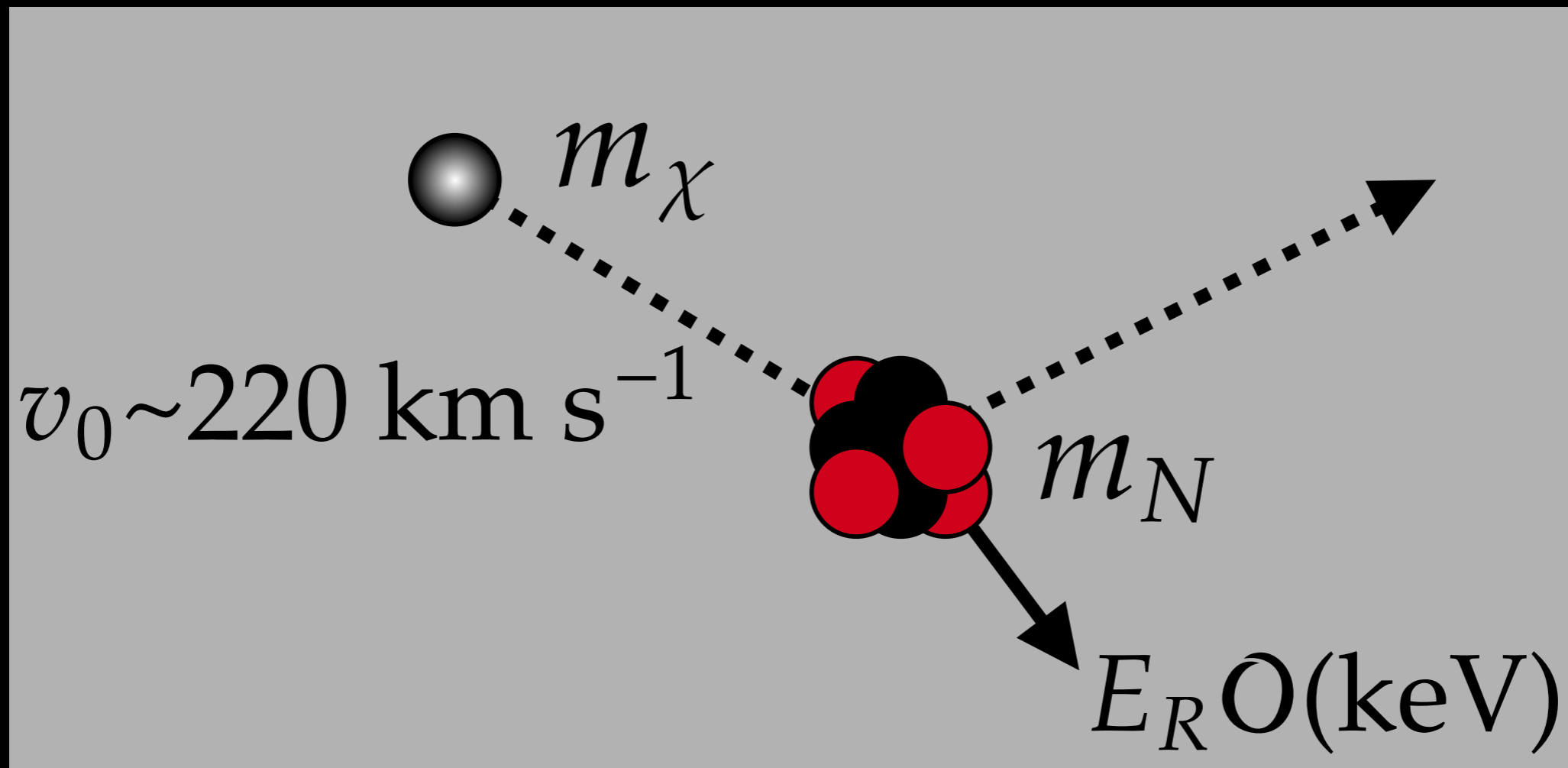
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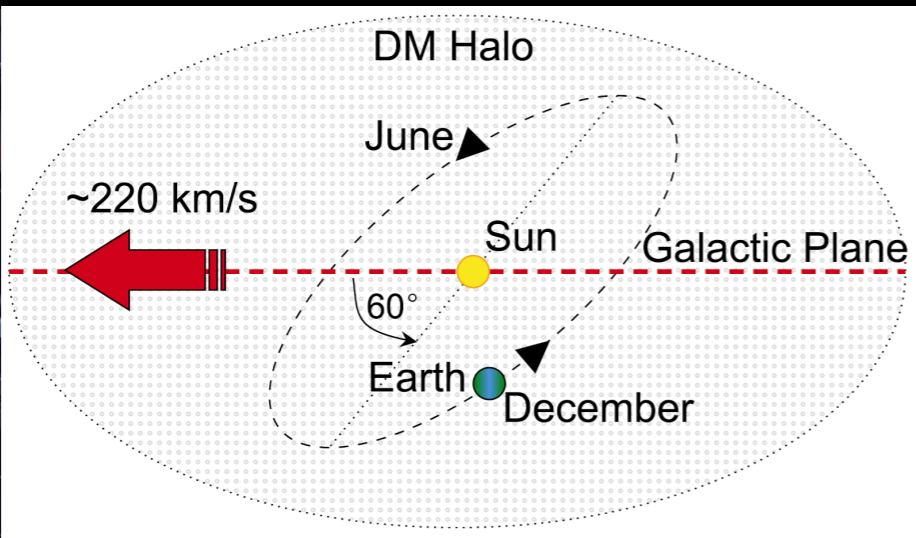
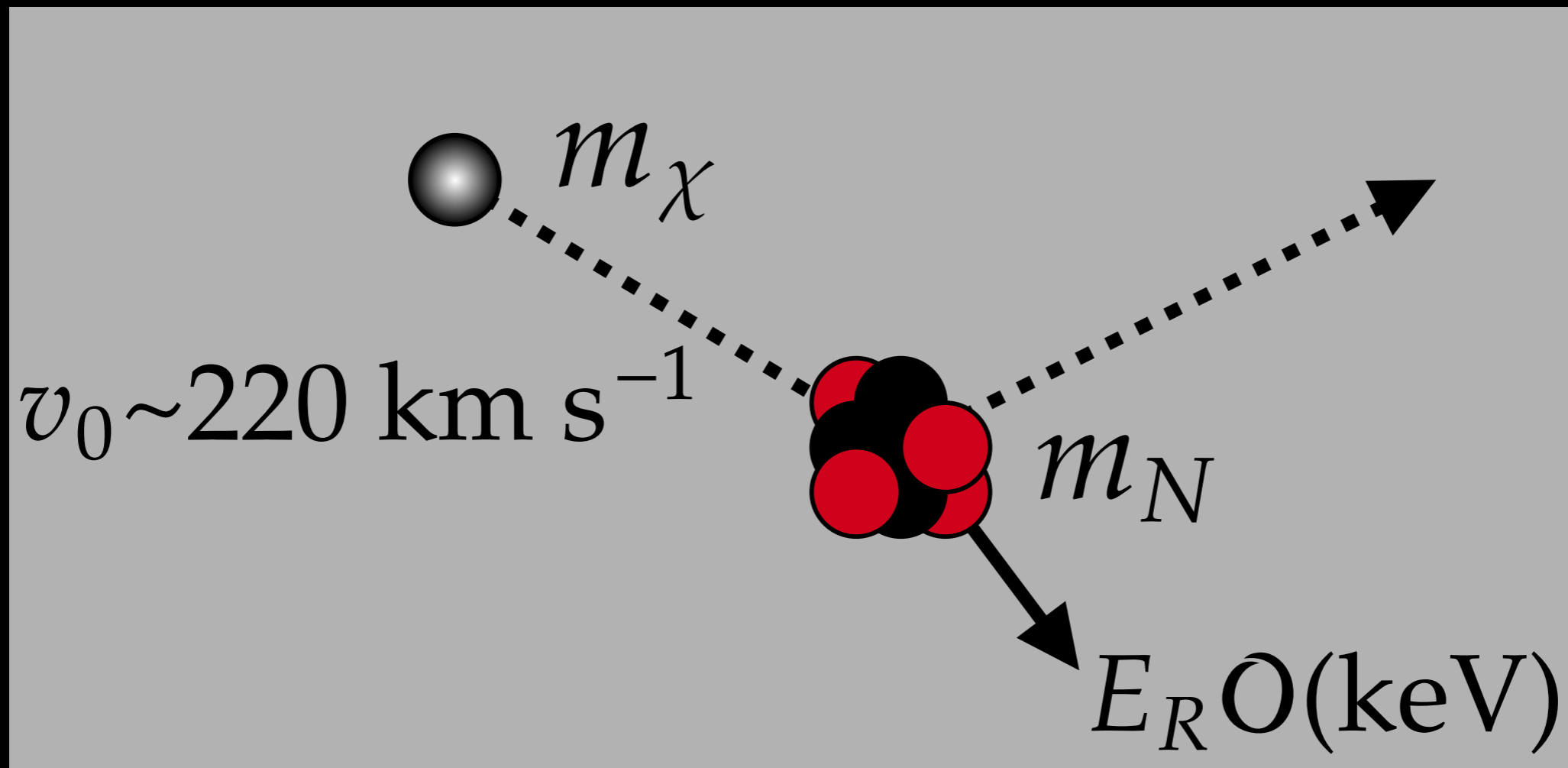
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No known particle fits the bill!!

Direct Dark Matter detection

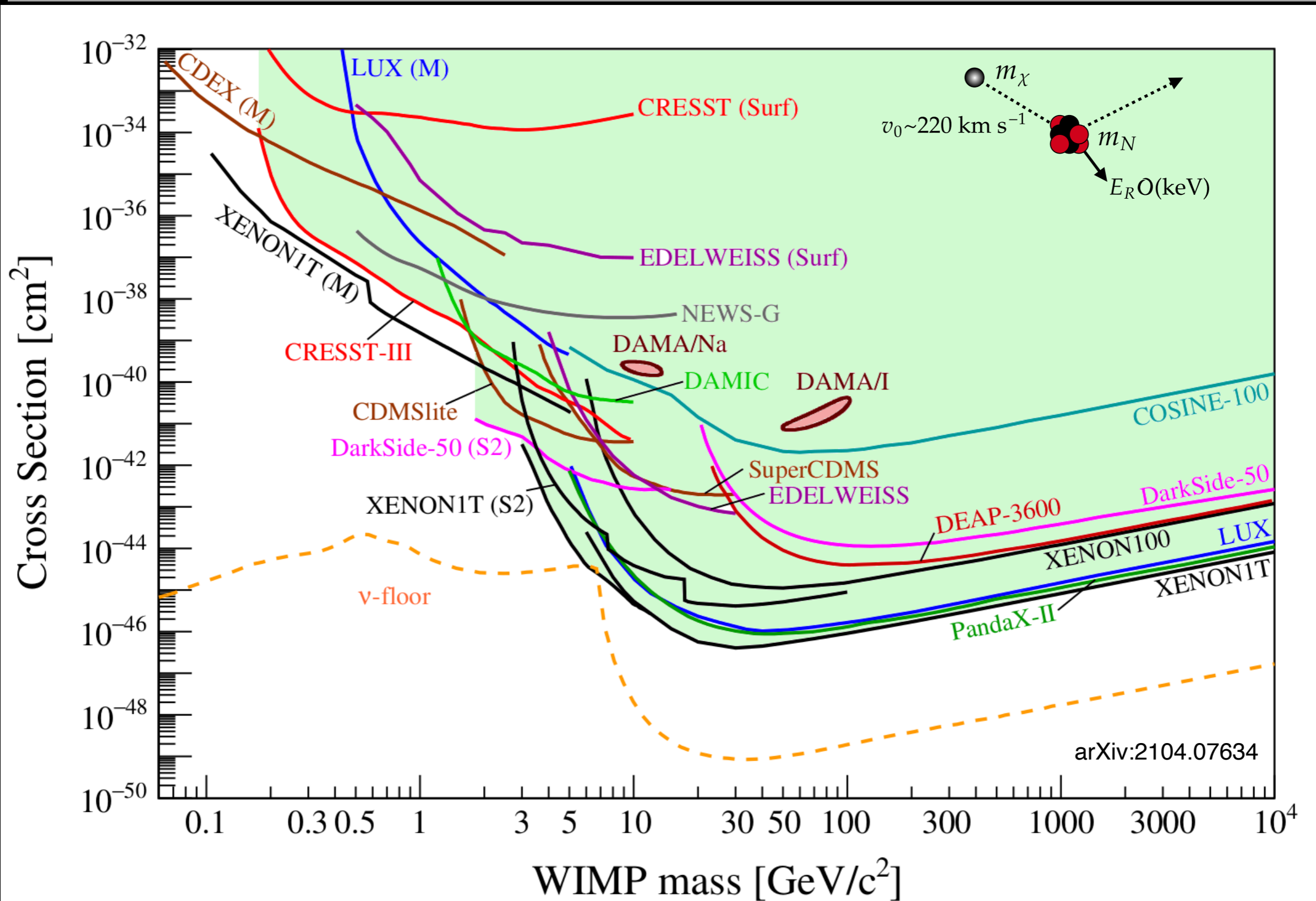


Direct Dark Matter detection



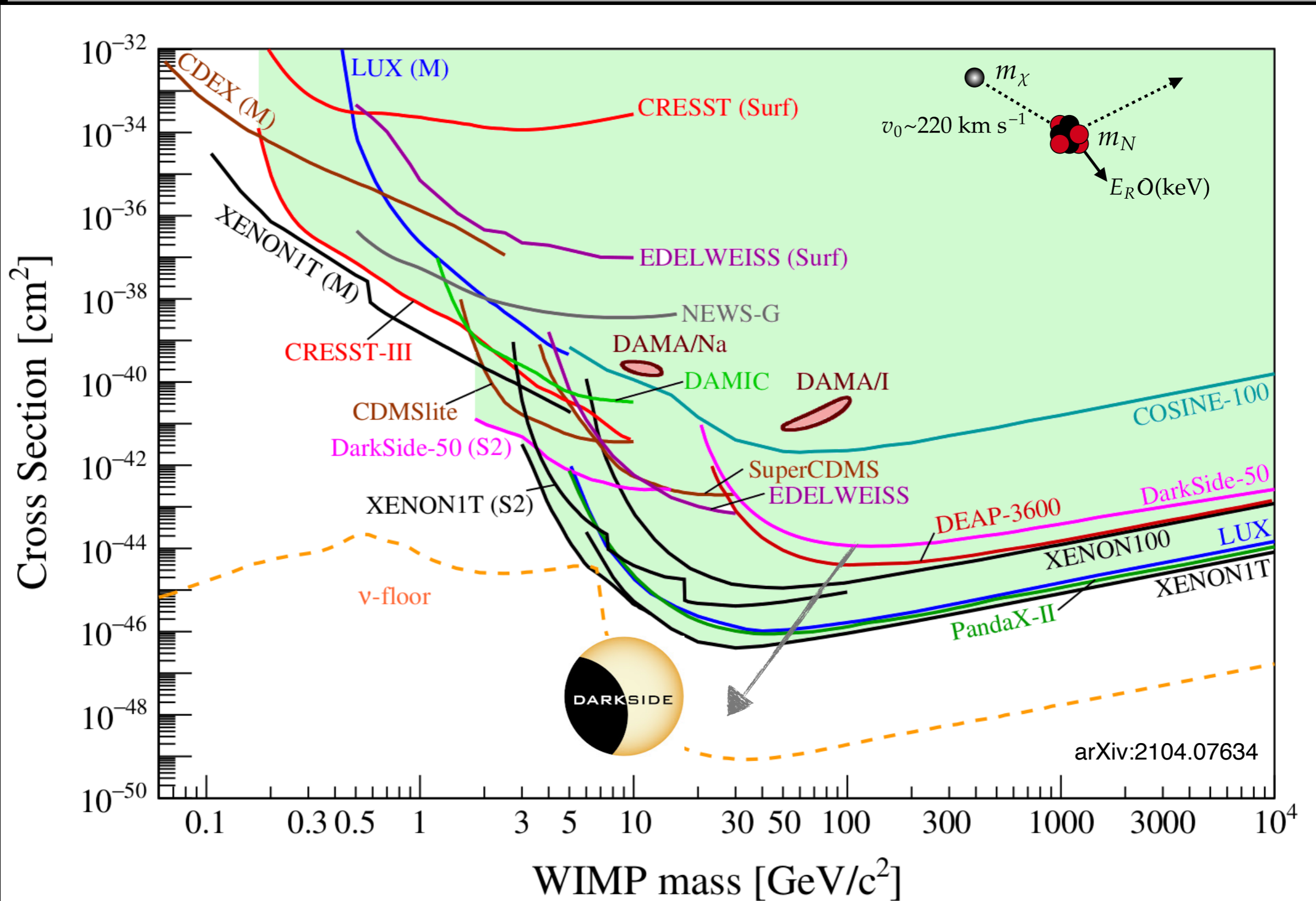
- ◉ Handles to confirm possible signal
 - ▶ Recoil energy distribution
 - ▶ Seasonal flux variation
 - ▶ DM velocity is season dependent
 - ▶ Directional detection
 - ▶ DM signal should point to Cygnus

Landscape of Direct Detection searches



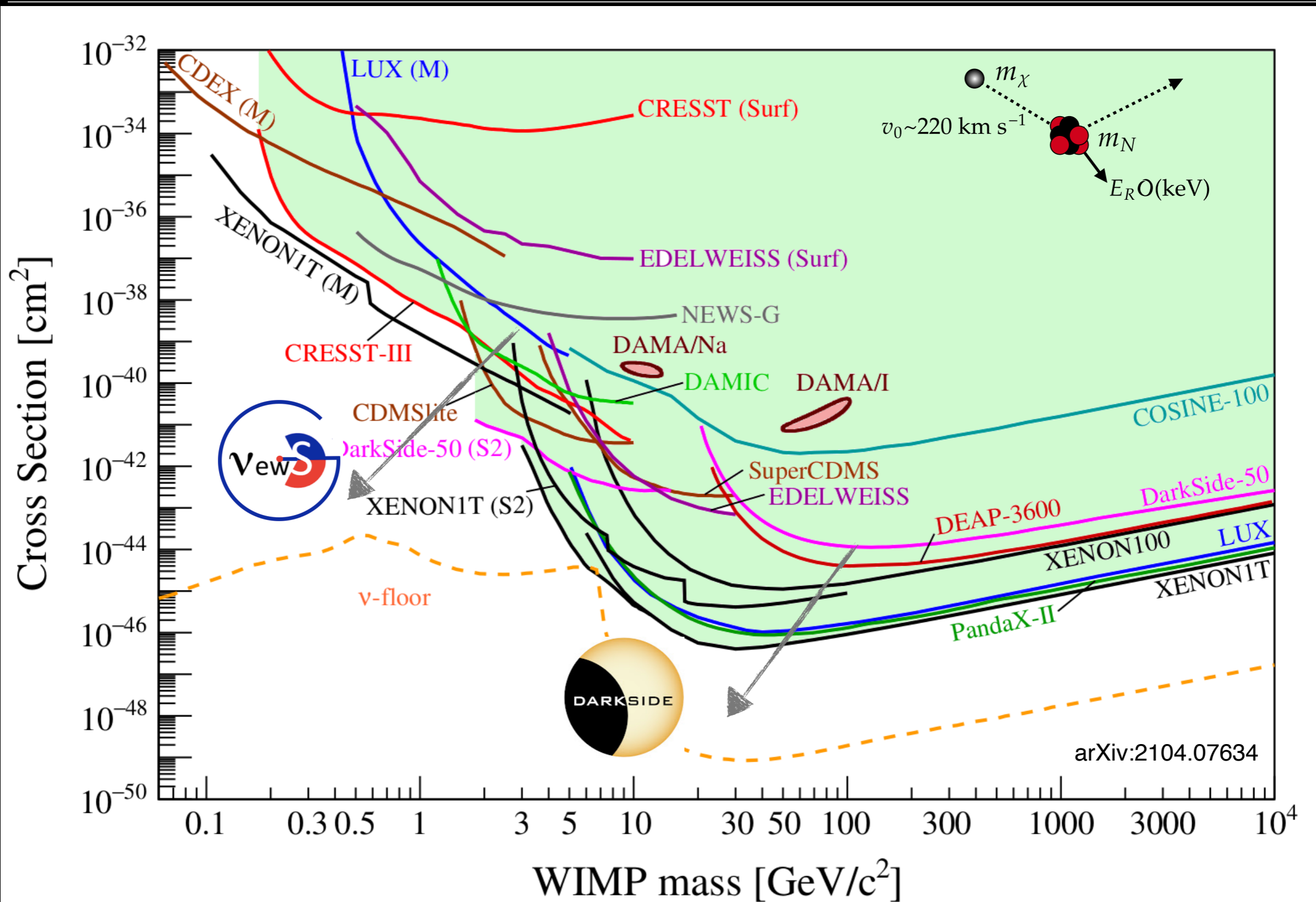
Also constraints on spin-dependent proton/neutron-DM interactions

Landscape of Direct Detection searches



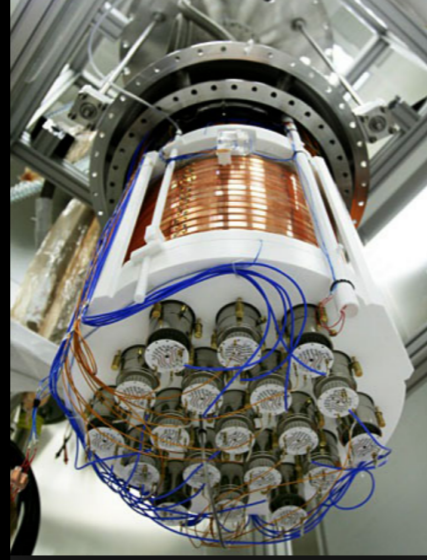
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Landscape of Direct Detection searches



Also constraints on spin-dependent proton/neutron-DM interactions

Argon Detectors



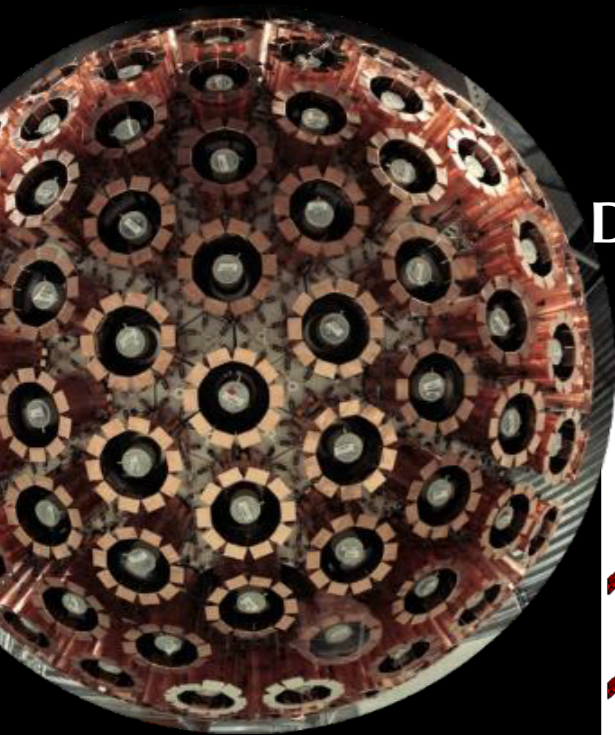
DarkSide-50
(50 kg, LNGS)

10 kg

2010

100 kg

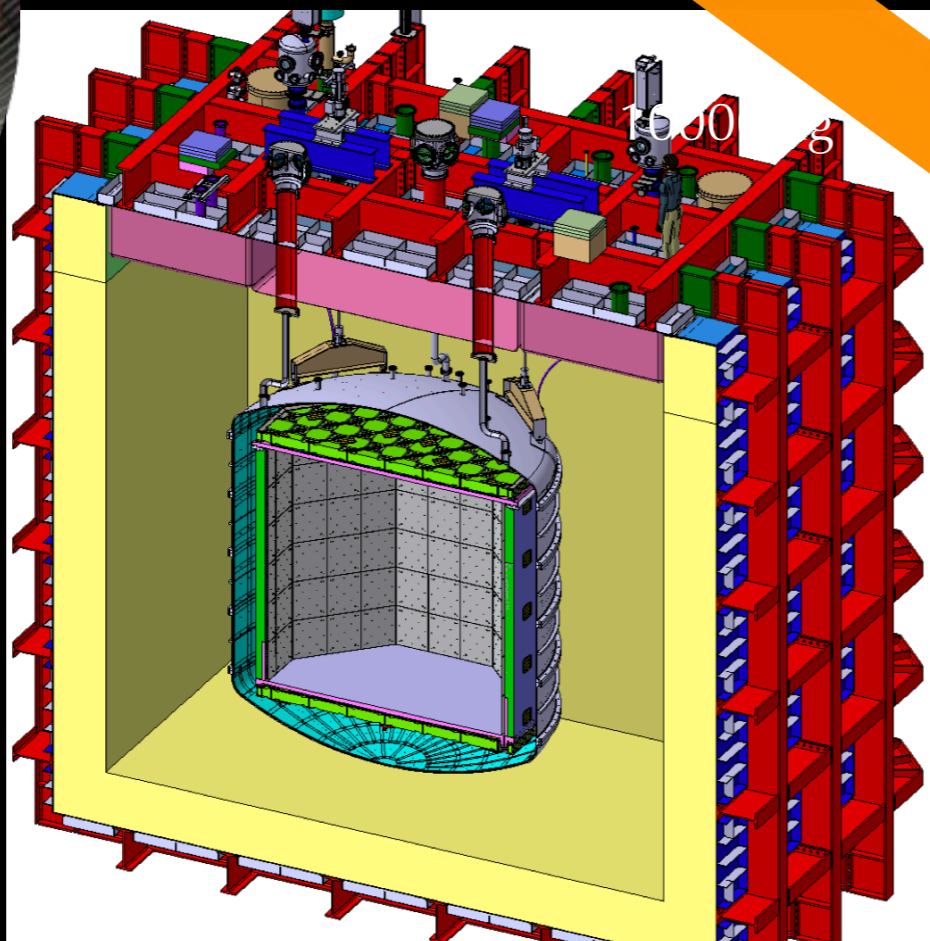
ArDM
(1t, LSC)



DEAP-3600 (3.6t, SNOLAB)

1,000 kg

2015



DarkSide-20k
(50t, LNGS)

2020

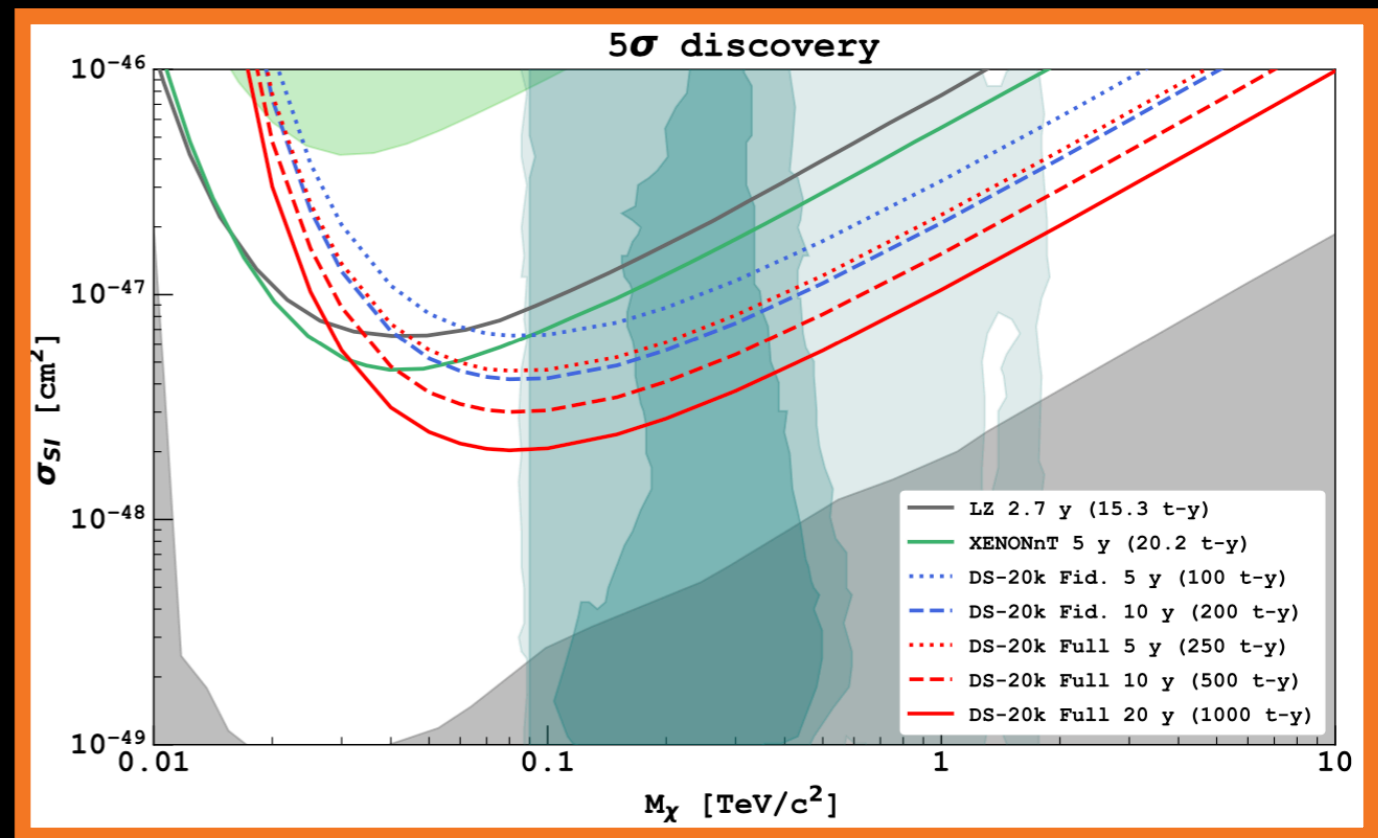
*Global Argon Dark Matter
Collaboration formed*

10,000 kg

100,000 kg

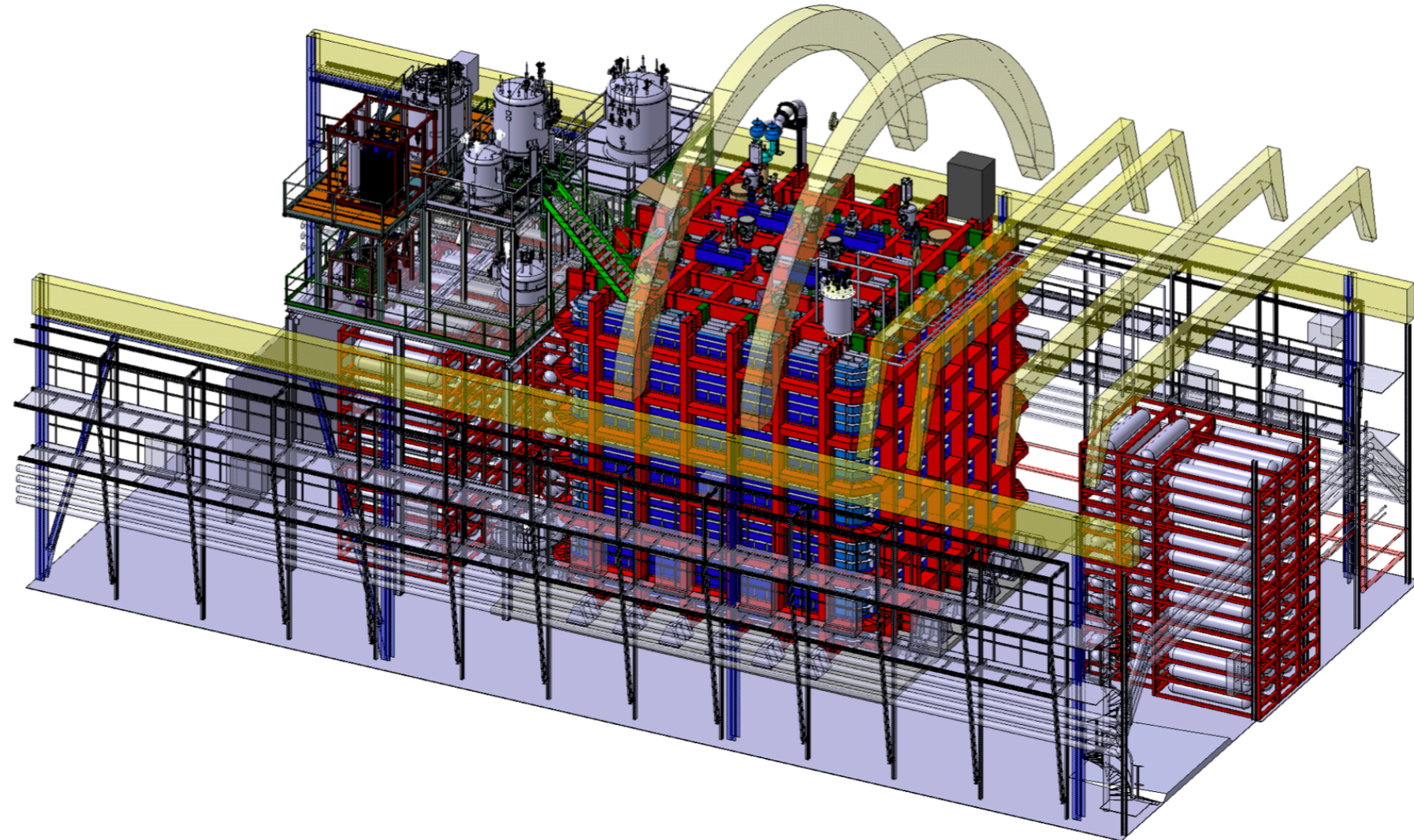
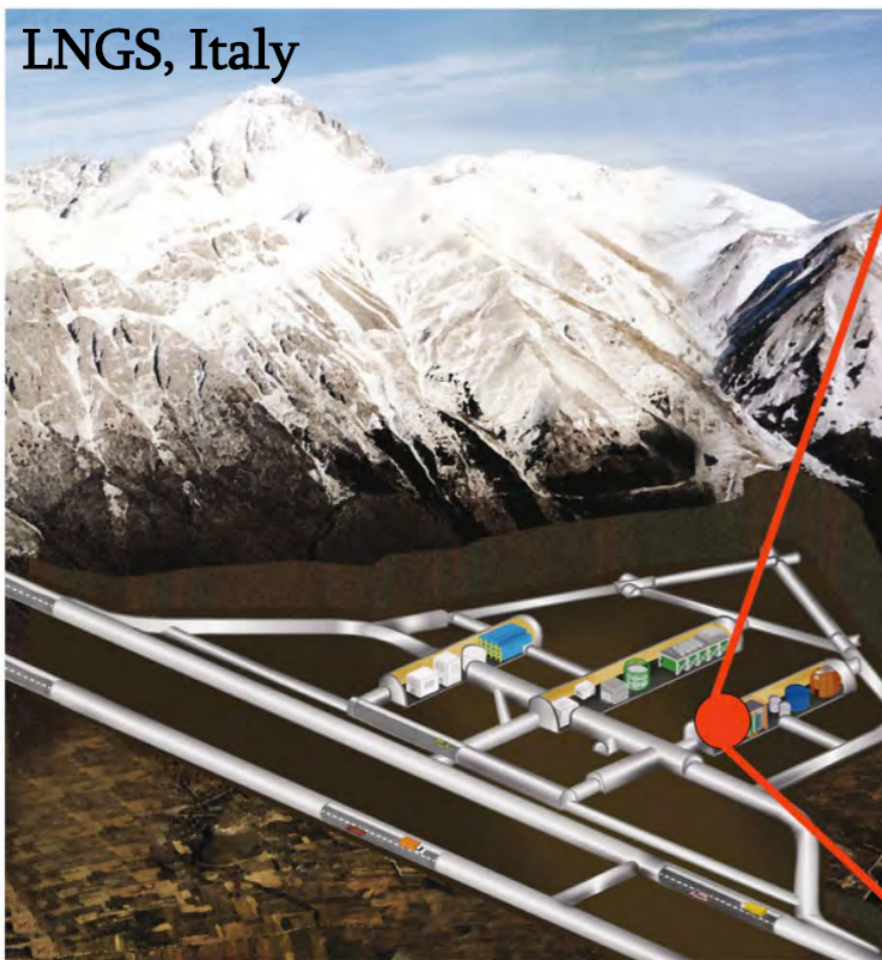
*Future:
ARGO
kt-scale*

DarkSide-20k: observatory for dark matter and ν



DarkSide-20k

50 tonne observatory for dark matter and neutrino physics, under construction at LNGS



Global Argon Dark Matter Collaboration:

11 countries

>100 institutions

>400 collaborators

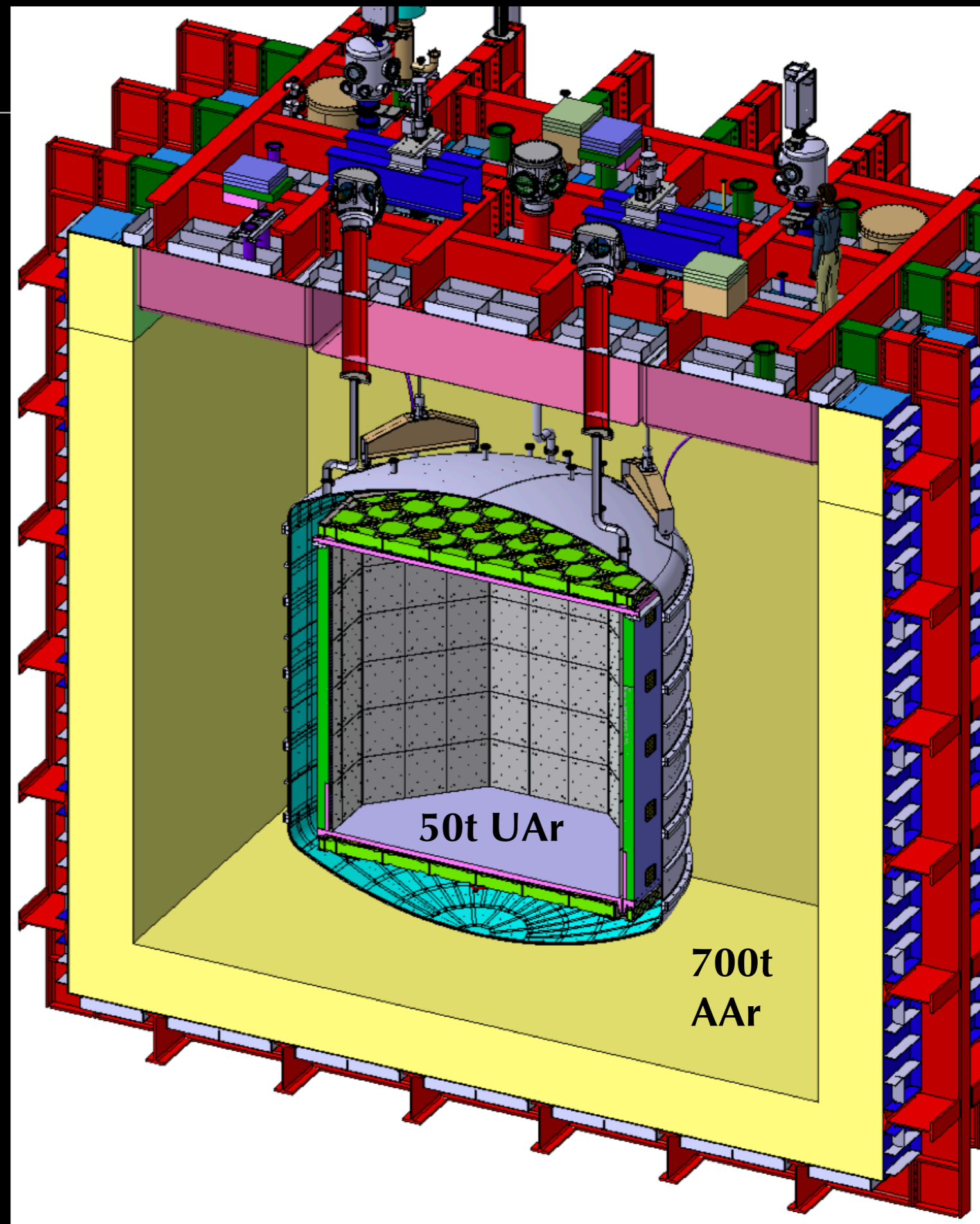
INFN, CFI, NSF, DOE, STFC, IHEP, European Commission, Horizon 2020

DarkSide-20k

50 t liquid underground Ar (UAr)
dark matter target, in a dual phase
TPC. inside a 700 t liquid
atmospheric Ar (AAr) outer detector

Two key innovations:

1. first large-scale use of large-area cryogenic Si photon detection modules (PDMs) instead of PMTs.
2. liquid AAr outer detector to veto the limiting background: neutrons

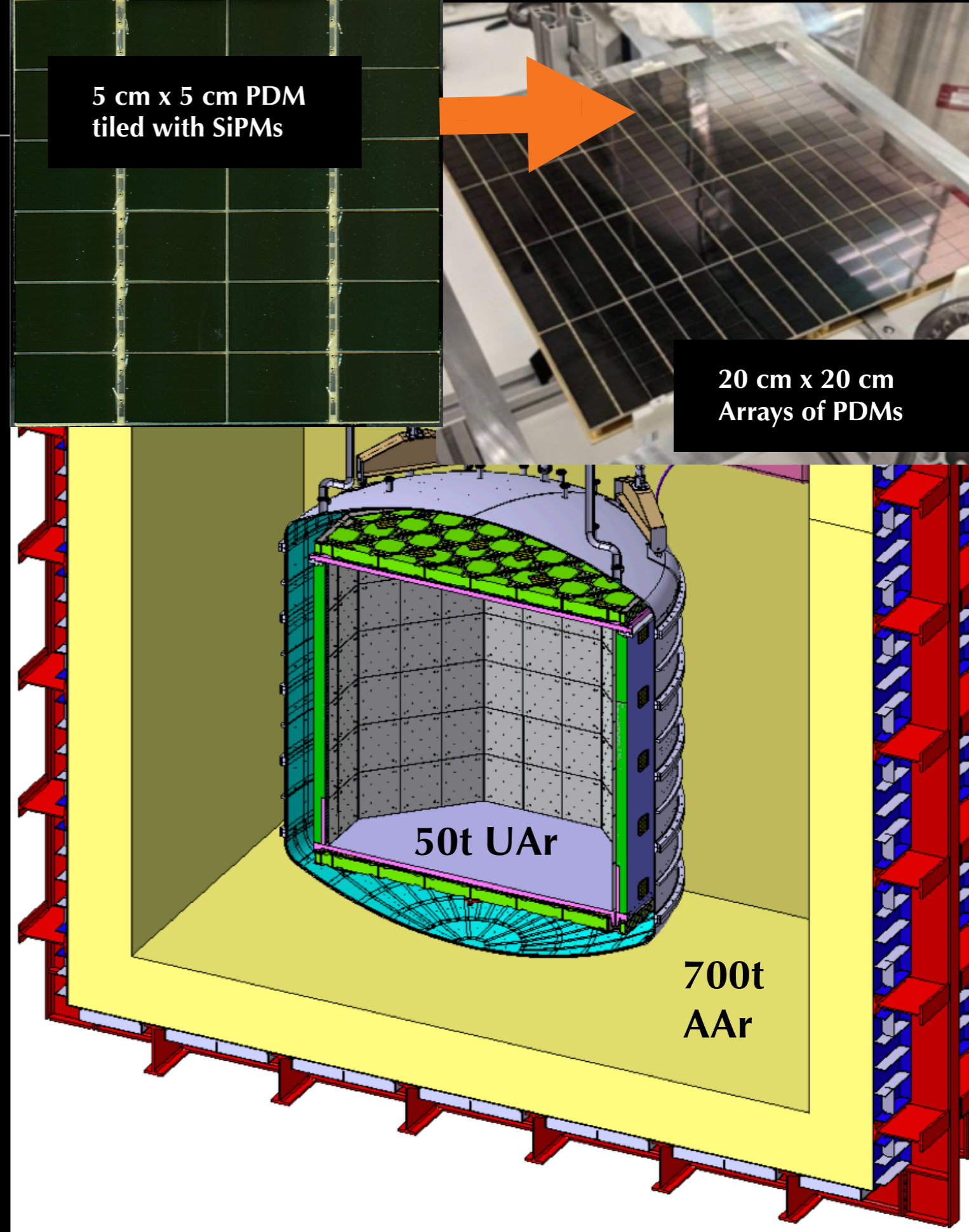


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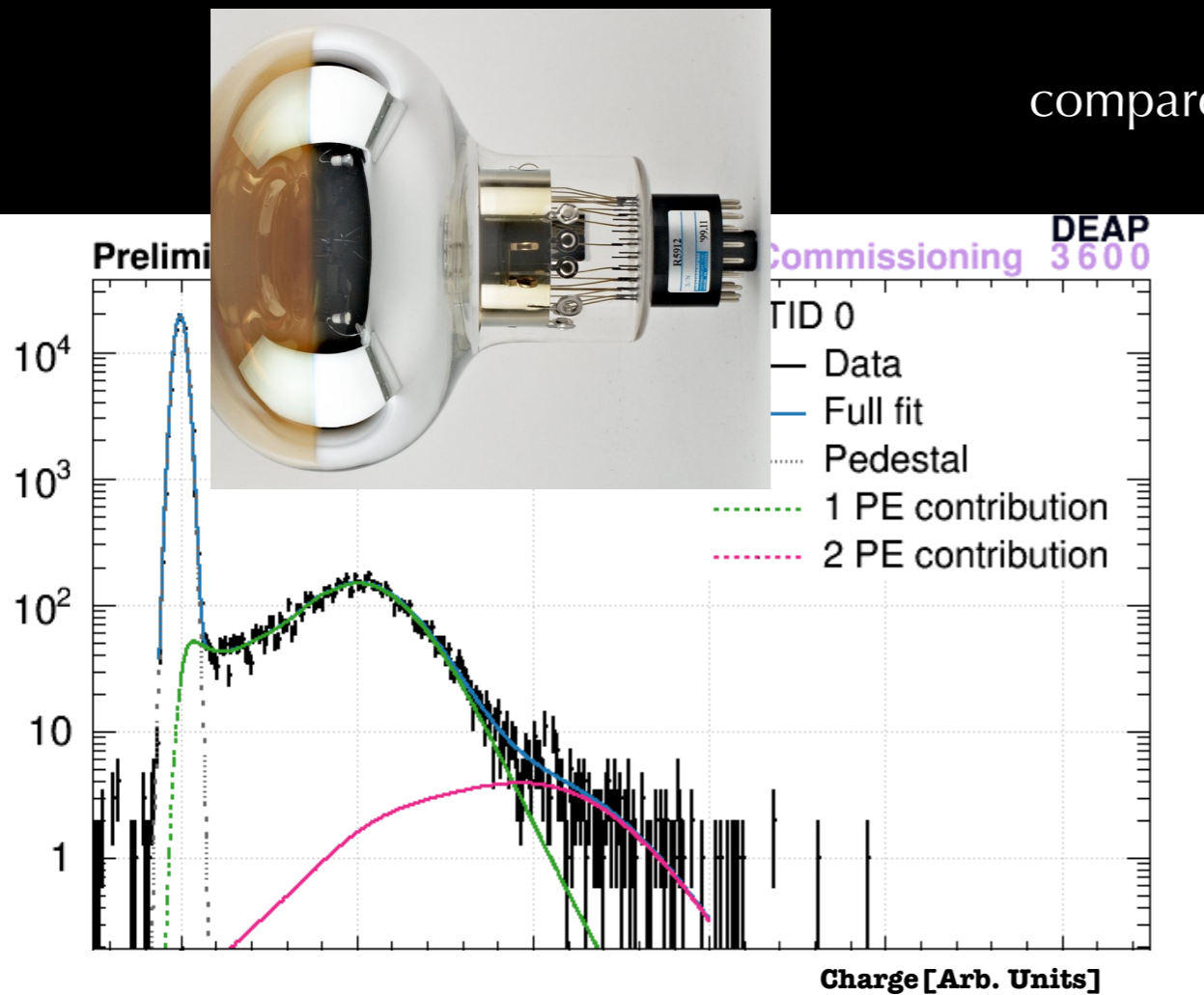
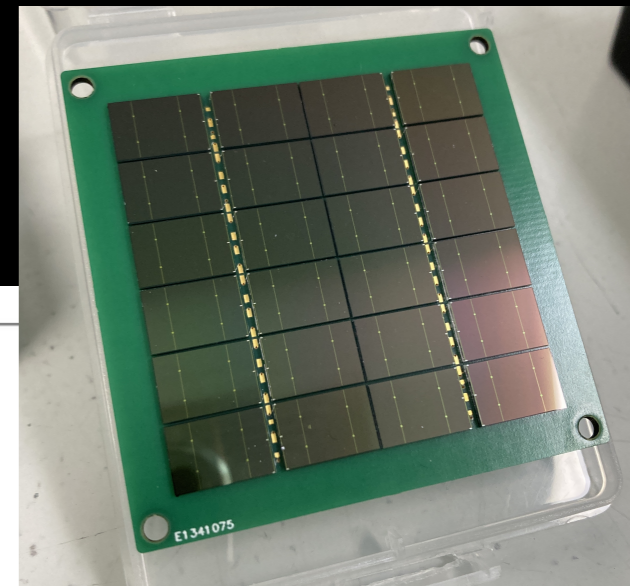


Photodetector Technology Development

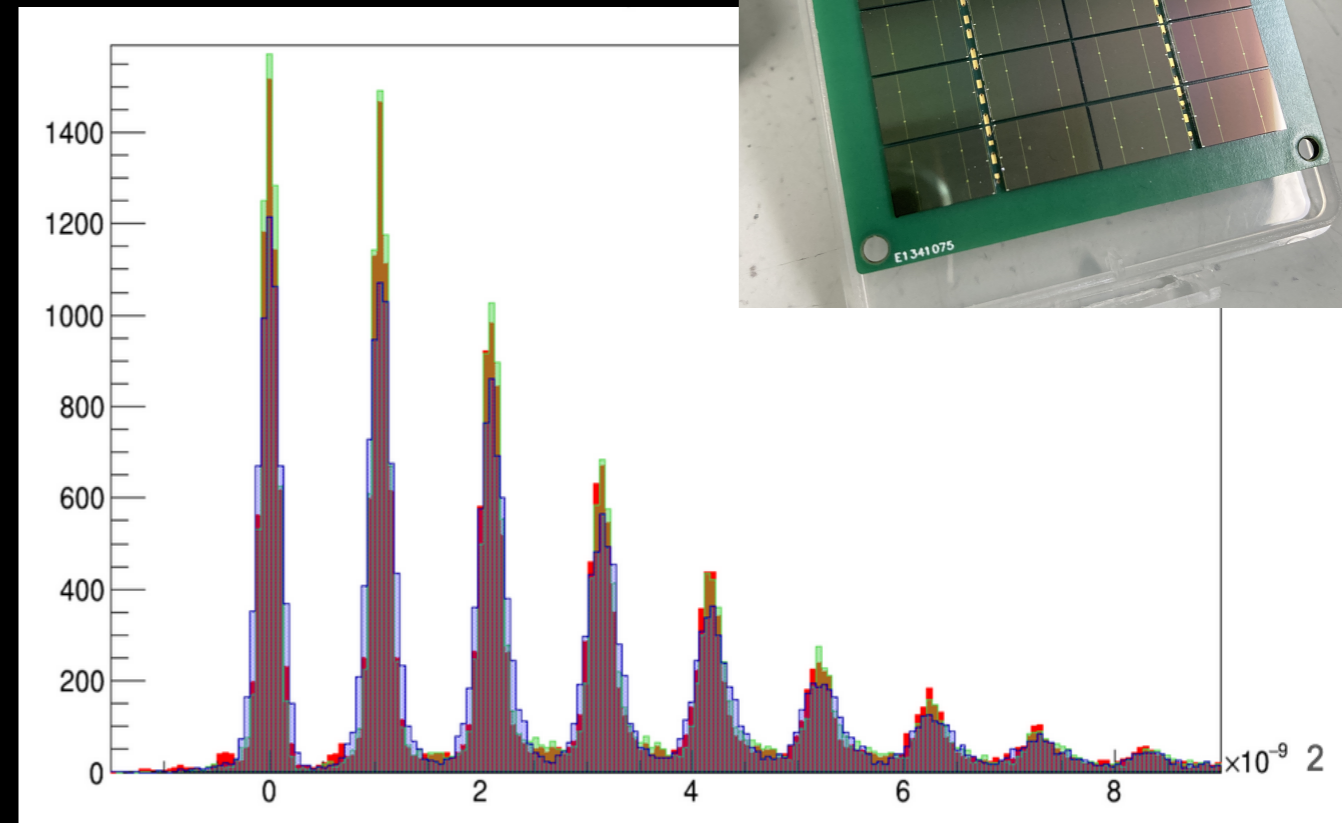
Photon Sensors: low noise, high efficiency, tiled arrays of cryogenic Si sensors developed in collaboration with FBK, achieving $>45\%$ PDE and 1 mHz/mm^2 dark noise

compared with:

**Delivering
7 m² of PDMs,
25% of total,
in the UK!**



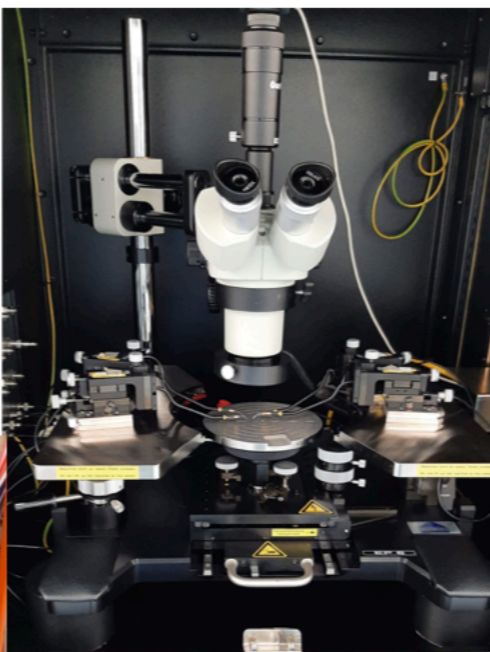
Amaudruz, JM, et al. NIM A 922 (2019) 373



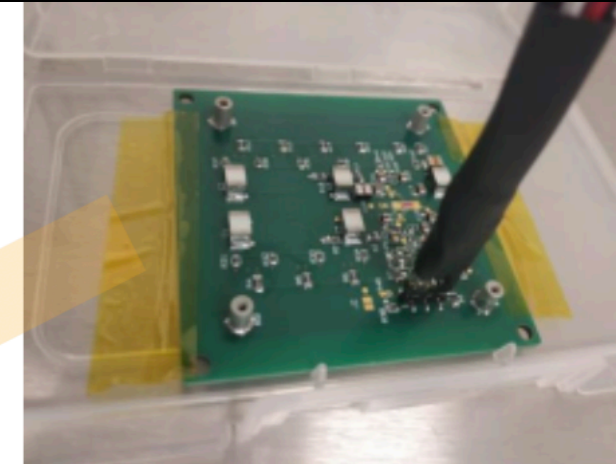
*>3x photon detection efficiency, 10x lower noise, >50x lower radiogenic backgrounds than PMTs,
+ finer granularity ... potentially enabling tracking at at >few hundred keV*

DarkSide-UK Production Flow

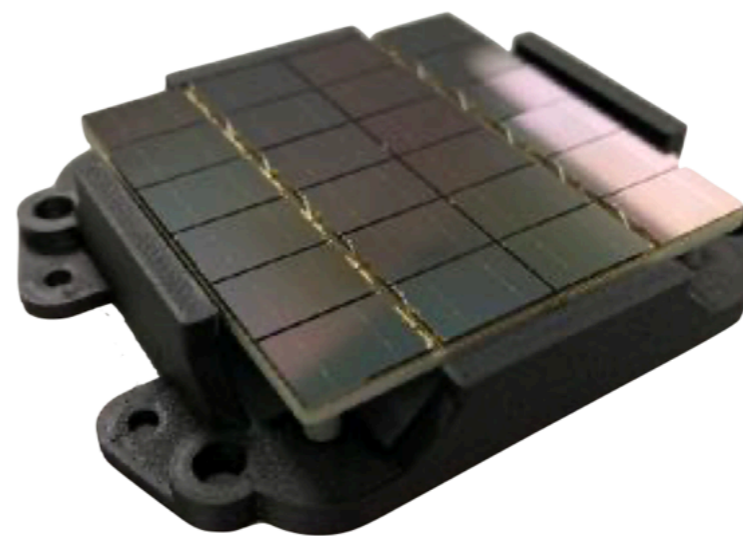
- Production
- Qualification
- Radio-assay
- Assembly
- Testing
- Installation



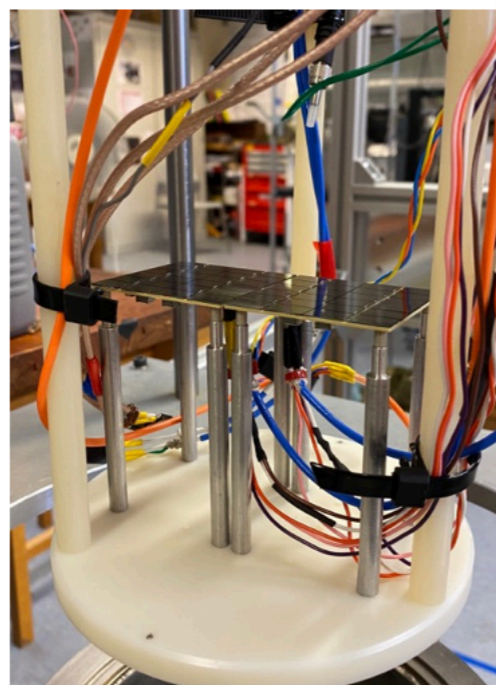
STFC Interconnect
+Liverpool



Birmingham
ICL

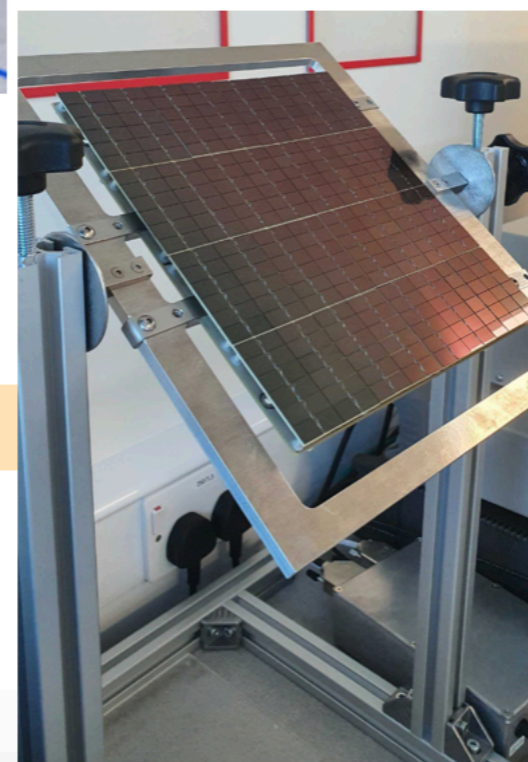


Liverpool
+Edinburgh

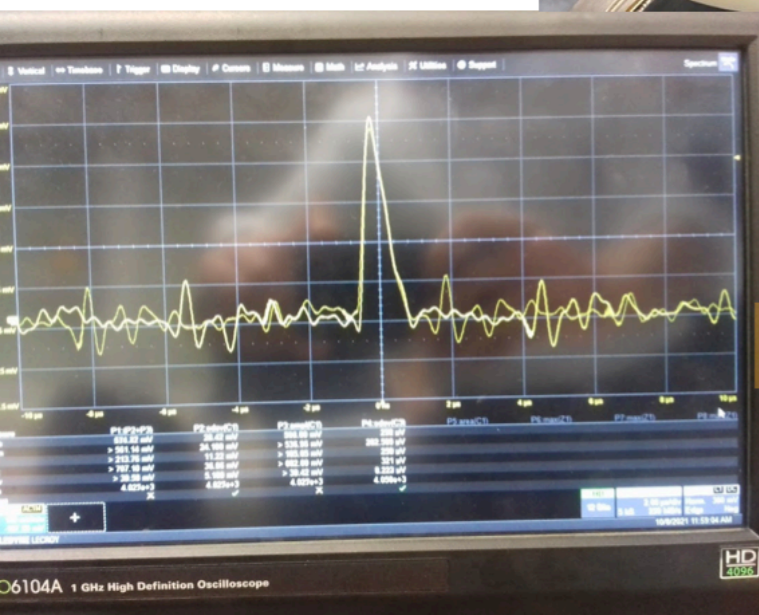
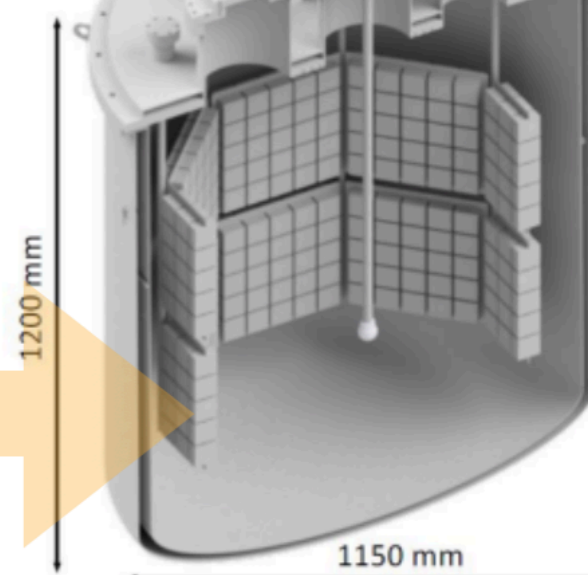
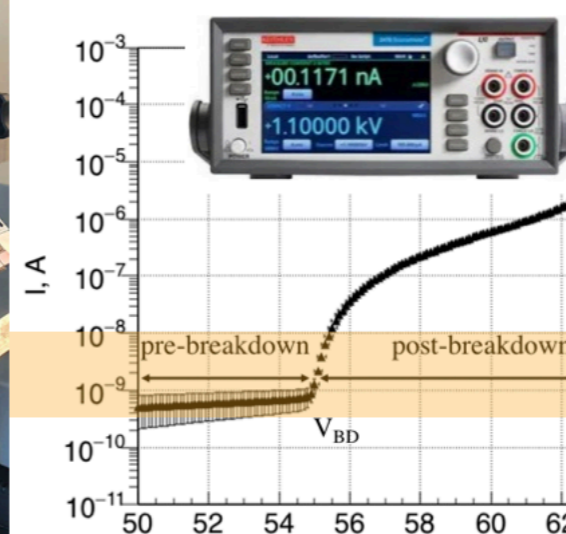


RHUL

Manchester



Warwick



(SW) +RHUL+Lancaster+Edinburgh

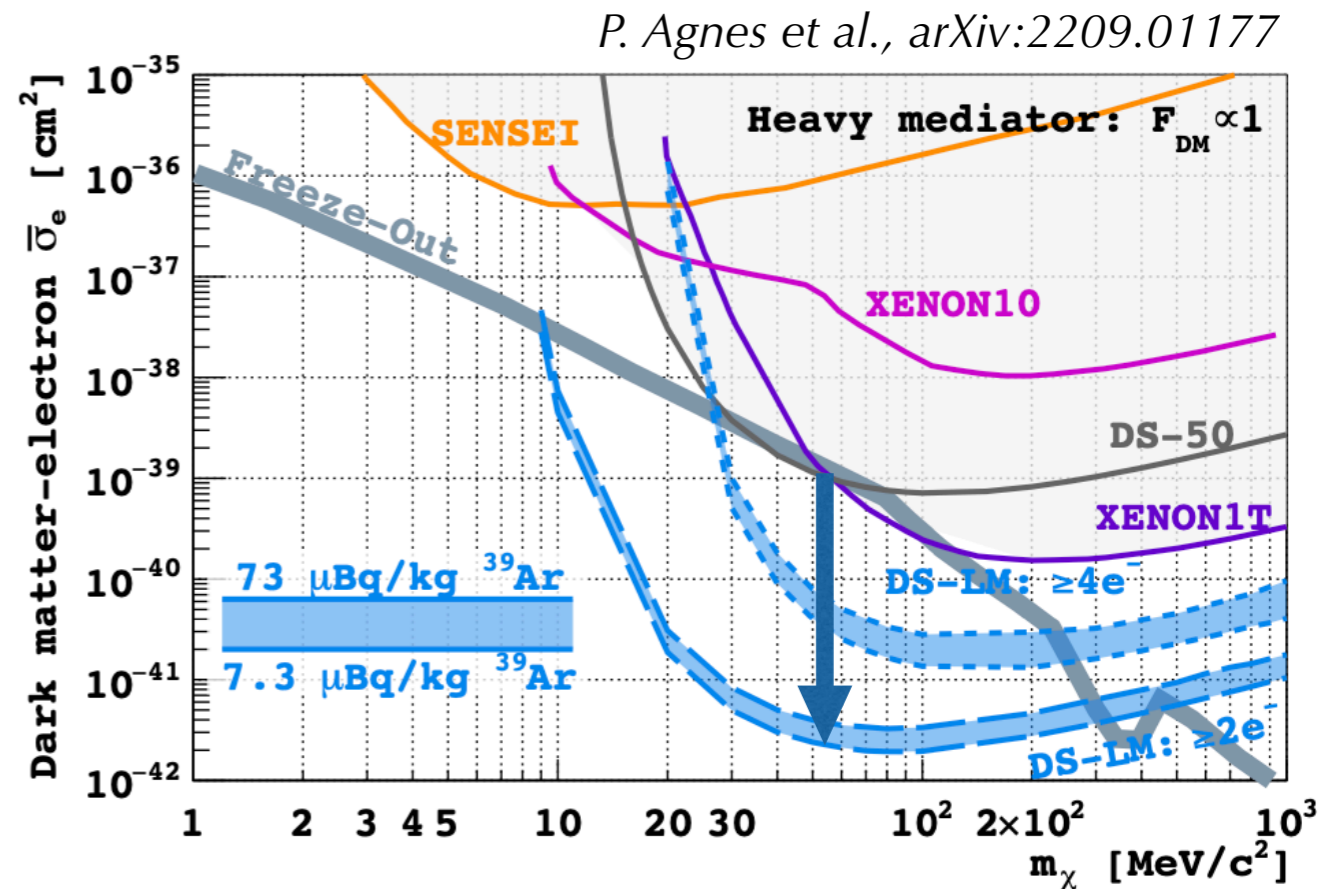
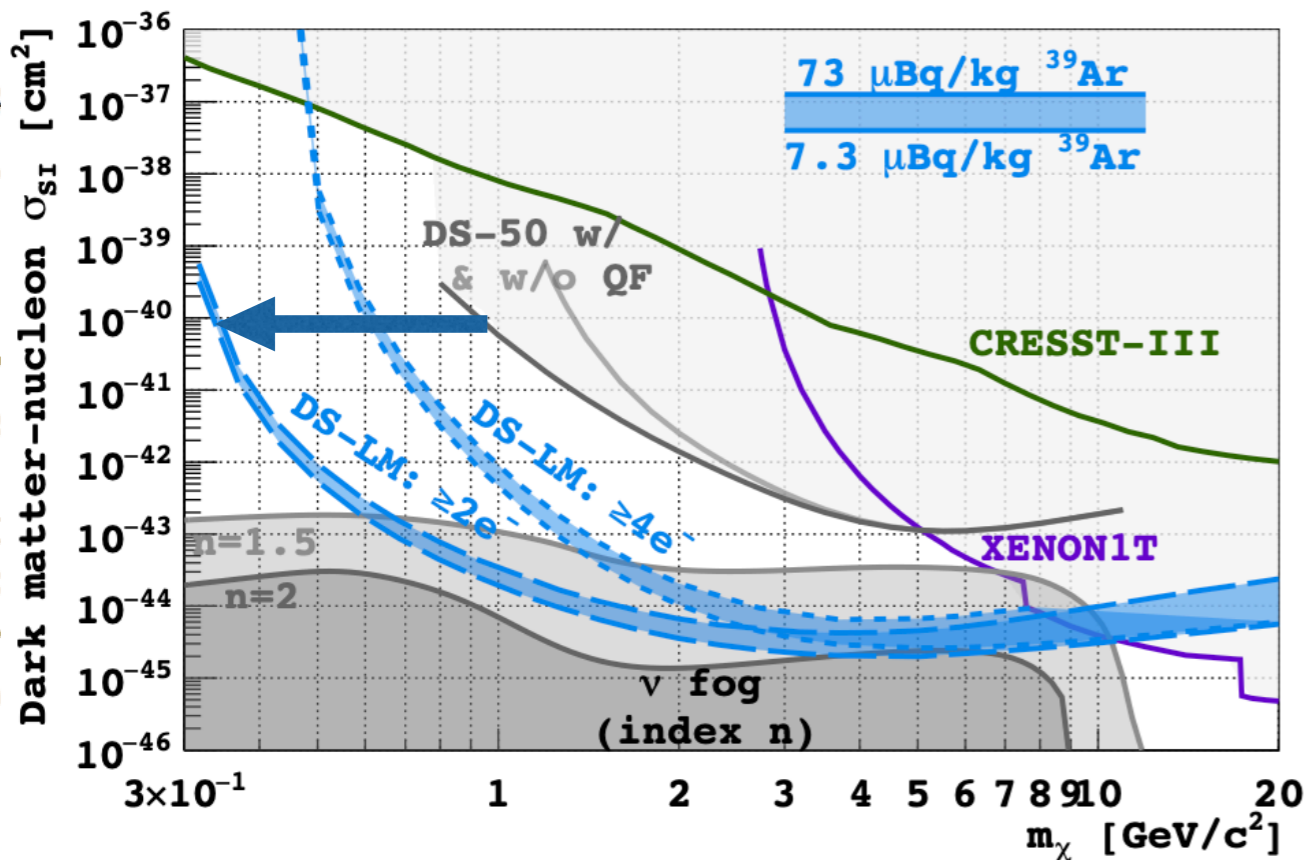
Physics Enabled by Next-Generation PDMs

1. Expanded dark matter cross section reach $\times 10^n$ suppression needed!

2. Expanded dark matter mass reach:

- low mass dark matter reach (below, left) — **GeV** mass range
- access to dark matter search *in* the Si target (below, right) — opens up **MeV** mass range
- sidereal modulation potential using the Si crystal target (*Heikinheimo et al., Phys. Rev. D 99, 103018 (2019)*)
- SOLAIRE Preliminary Infrastructure bid to develop next-gen DarkSide-LowMass @ Boulby

... and more! ([arXiv:2207.11966](https://arxiv.org/abs/2207.11966), [arXiv:2207.11968](https://arxiv.org/abs/2207.11968), [arXiv:2207.11967](https://arxiv.org/abs/2207.11967))



P. Agnes et al., arXiv:2209.01177

...And Sensitivity to Searches for Dark Matter beyond WIMPs!

1) Nuclear recoil final states:

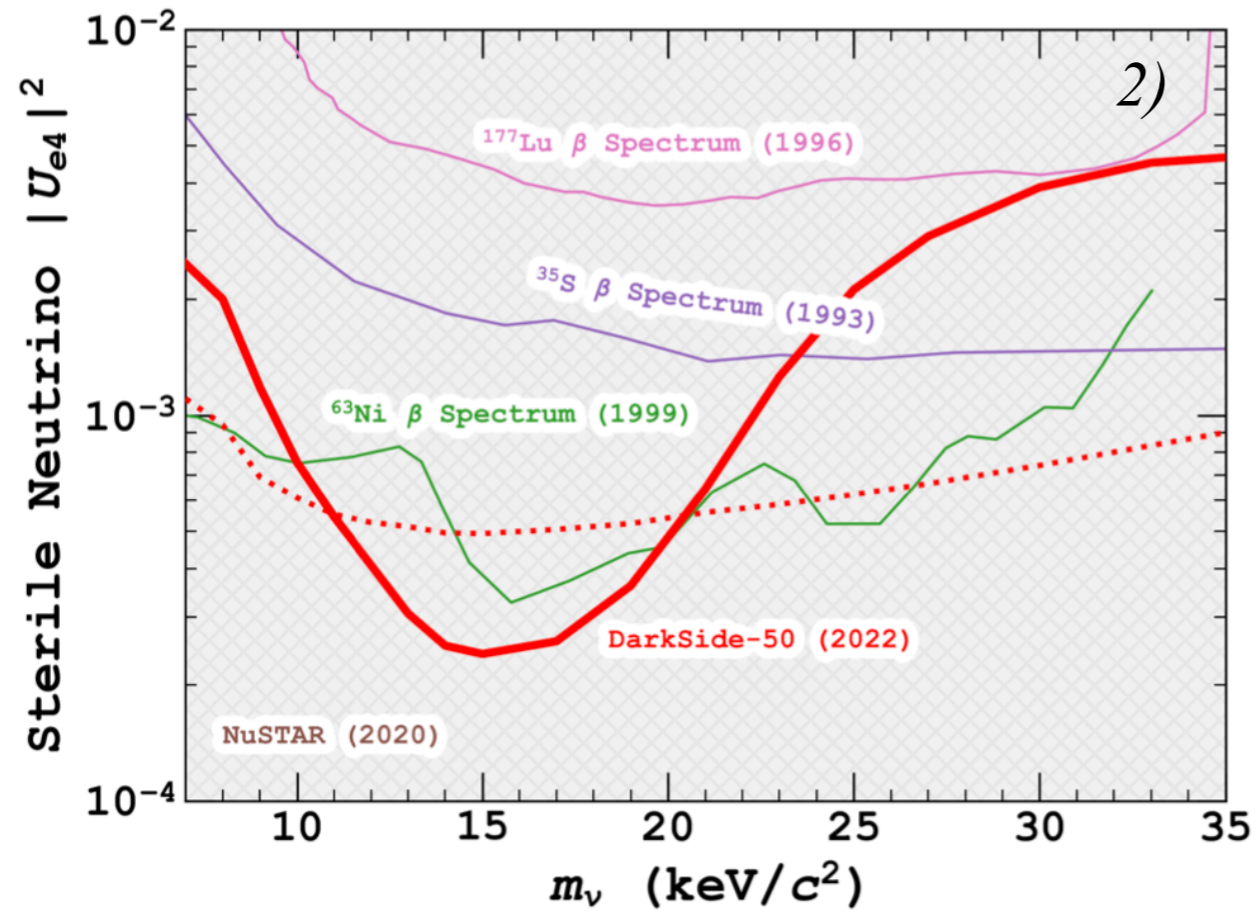
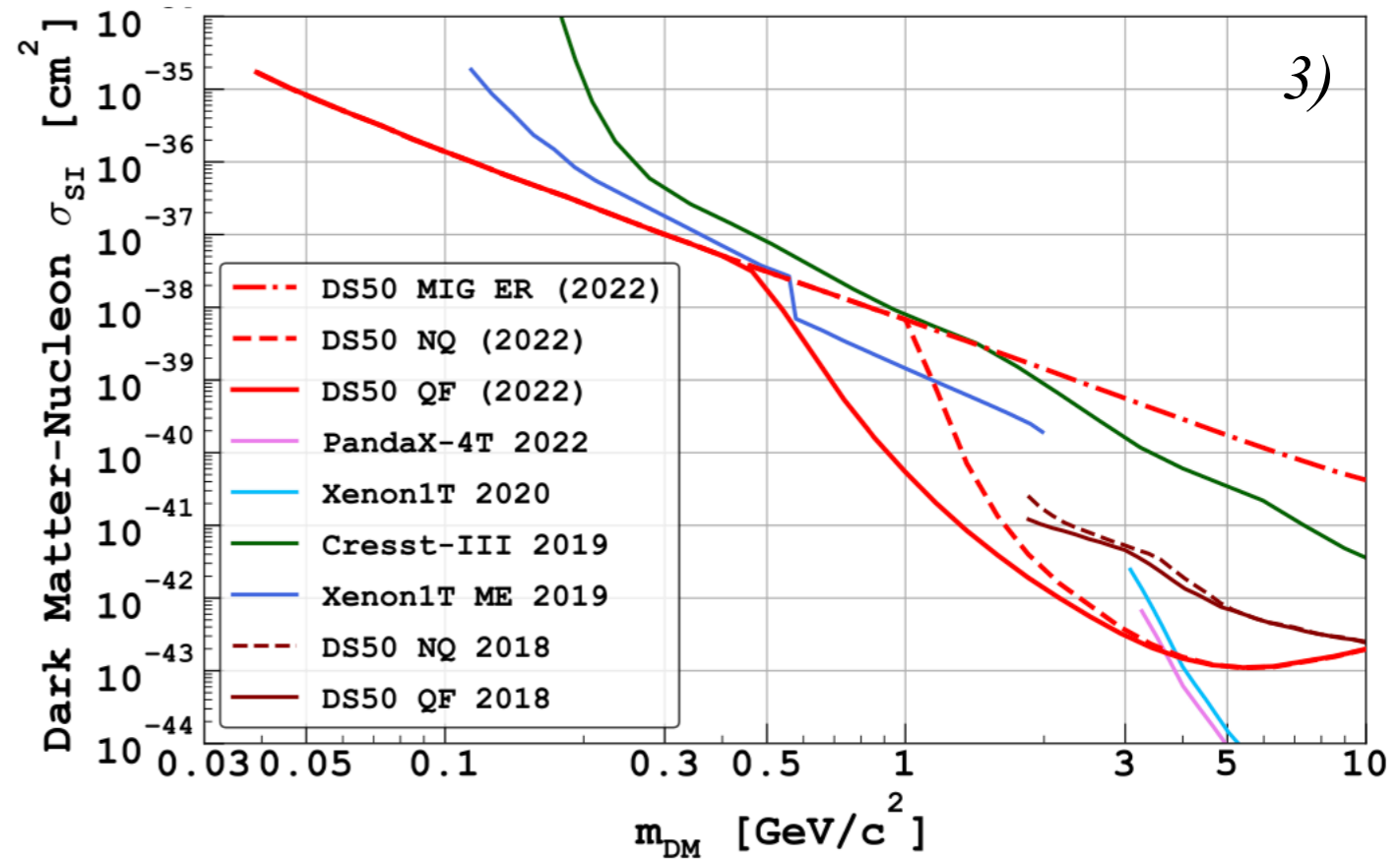
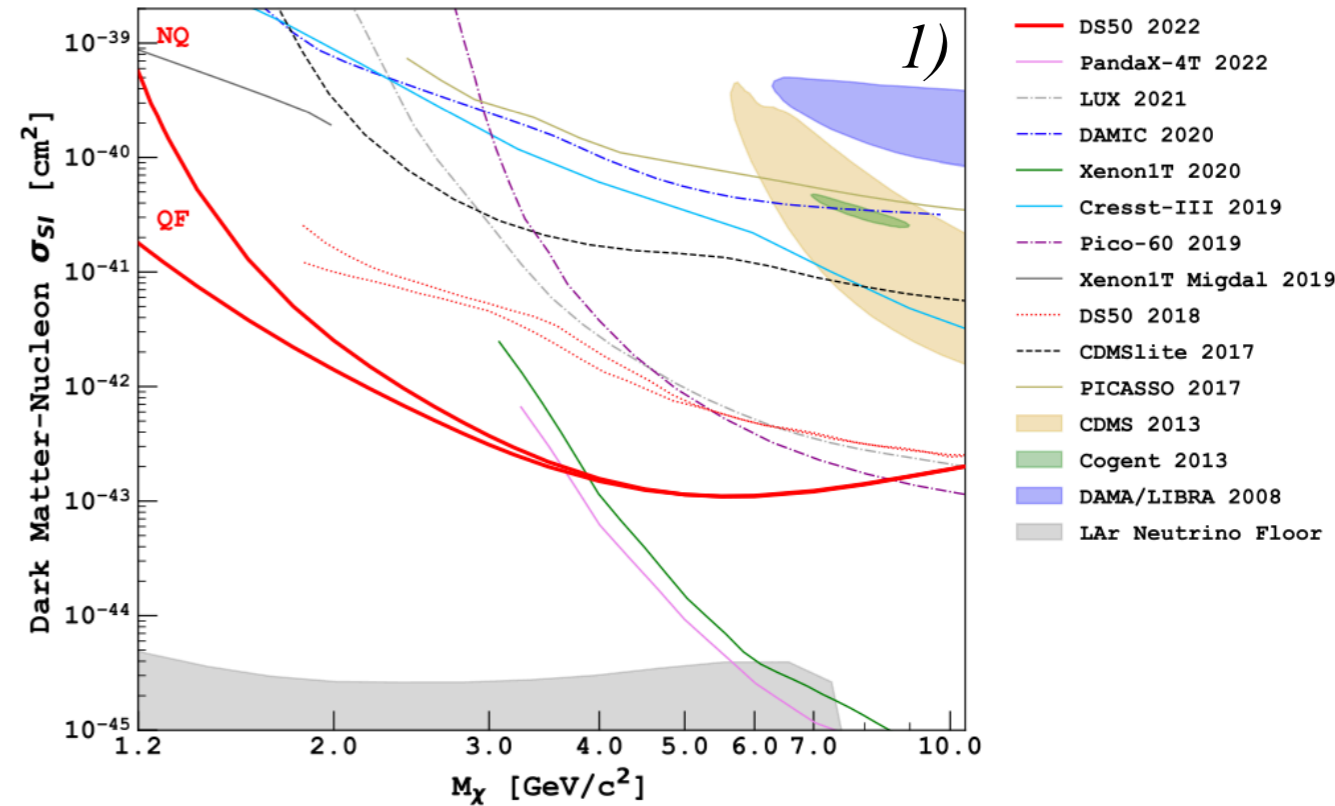
-DS-50 data set with improved energy response modelling & systematics: 10x improvement in compelling GeV mass range! (arXiv:2207.11966)

2) Electronic recoil final states:

-new constraints on vector, pseudoscalar, sterile neutrino DM candidates (arXiv:2207.11968)

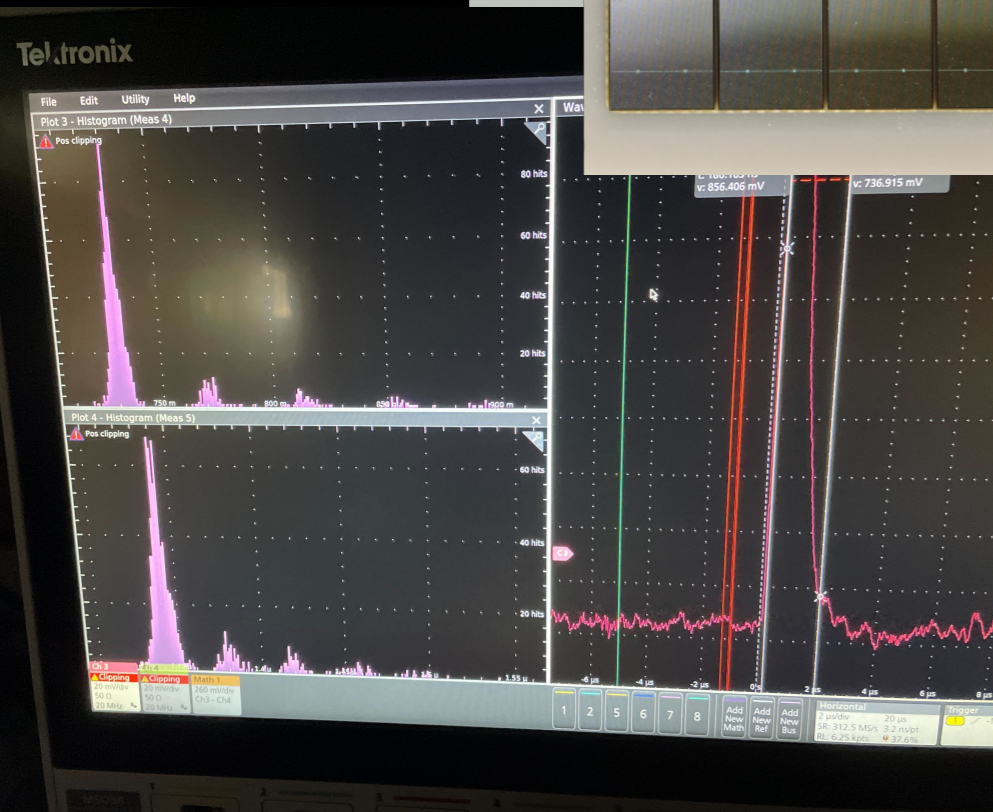
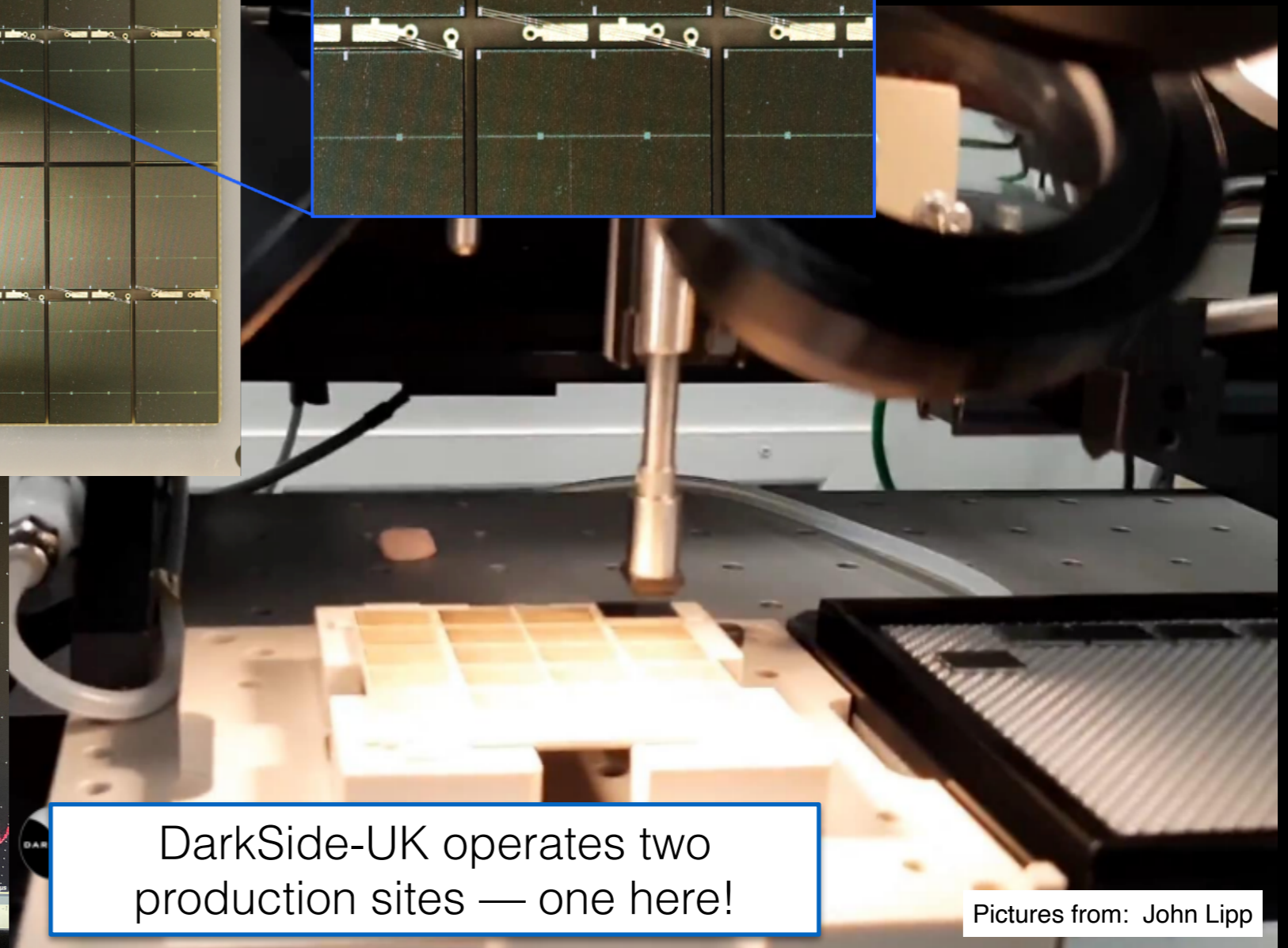
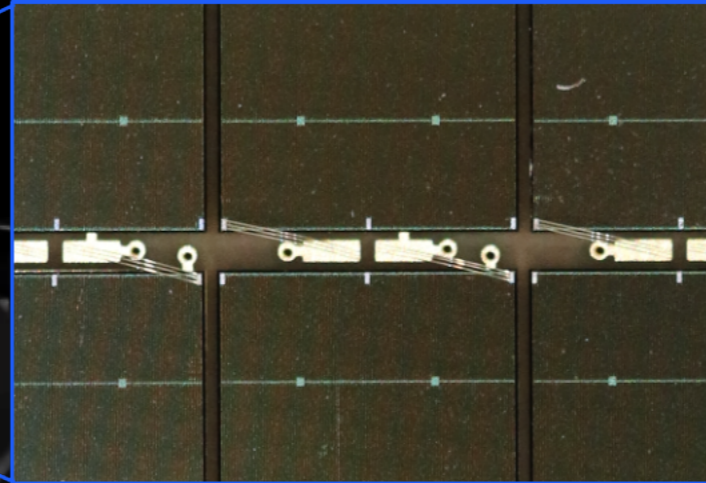
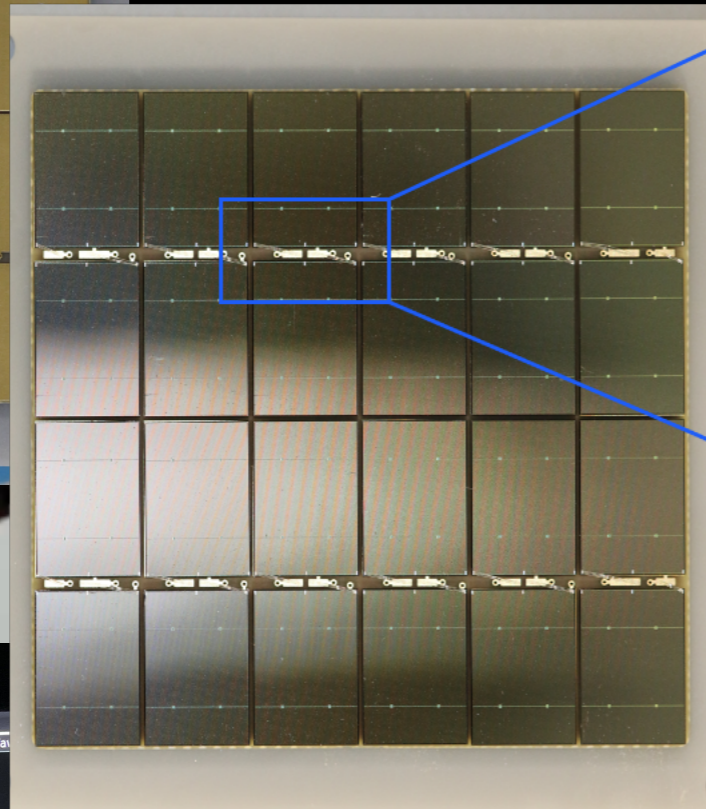
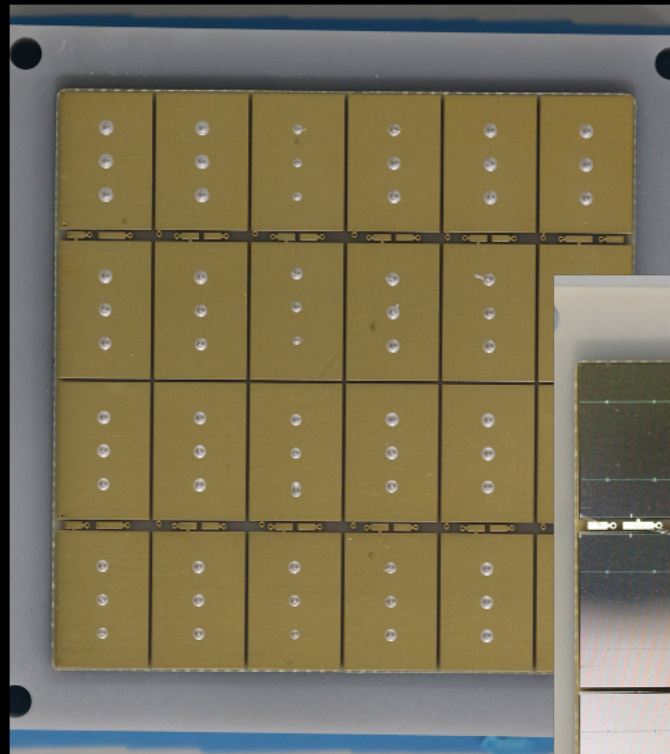
3) Interpretation including Migdal effect:

-new nuclear shell model calculation, reaching sensitivity down to 40 MeV DM mass! (arXiv:2207.11967)



STFC Interconnect at RAL

- + Automated die placement, glue deposition, bonding
- + Wire Bonding
- + Automated LCR testing



DarkSide-UK operates two production sites — one here!

Pictures from: John Lipp

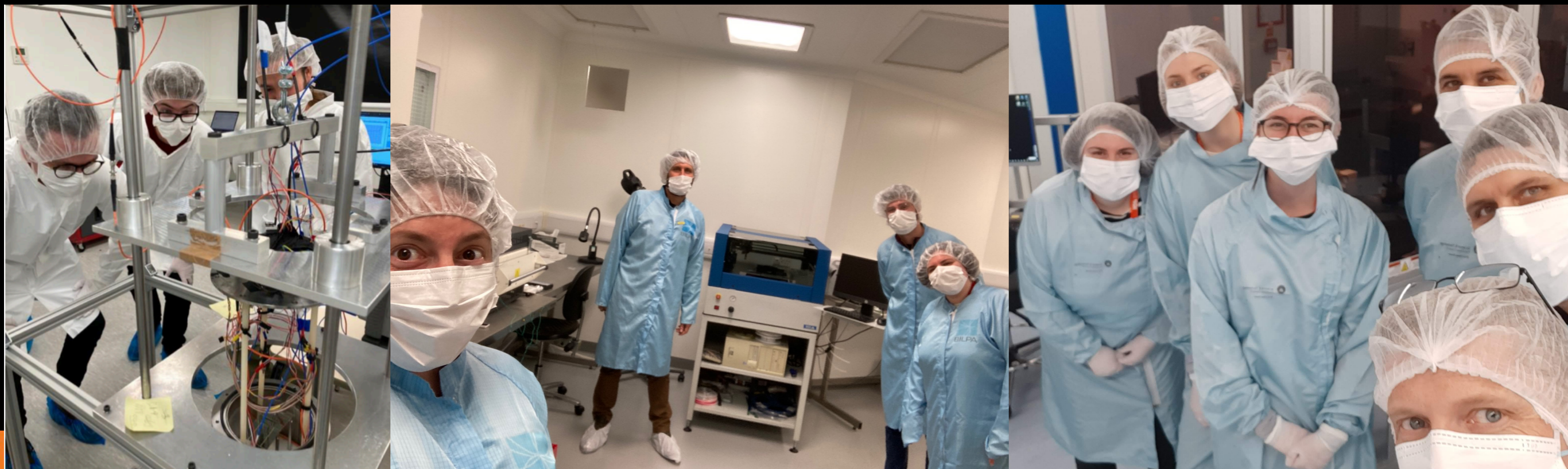
DarkSide-UK PhD Project

PhD Studentship Tasks:

- Contribute to photosensor testing at STFC Interconnect Production site
- Participate in installation of UK photosensors on the DarkSide-20k detector, on-site at LNGS
- Develop DarkSide-20k dark matter search, with emphasis on single photon signals (building on photosensor testing work....)
- Get involved in R&D towards next-generation tiled SiPM array detectors!

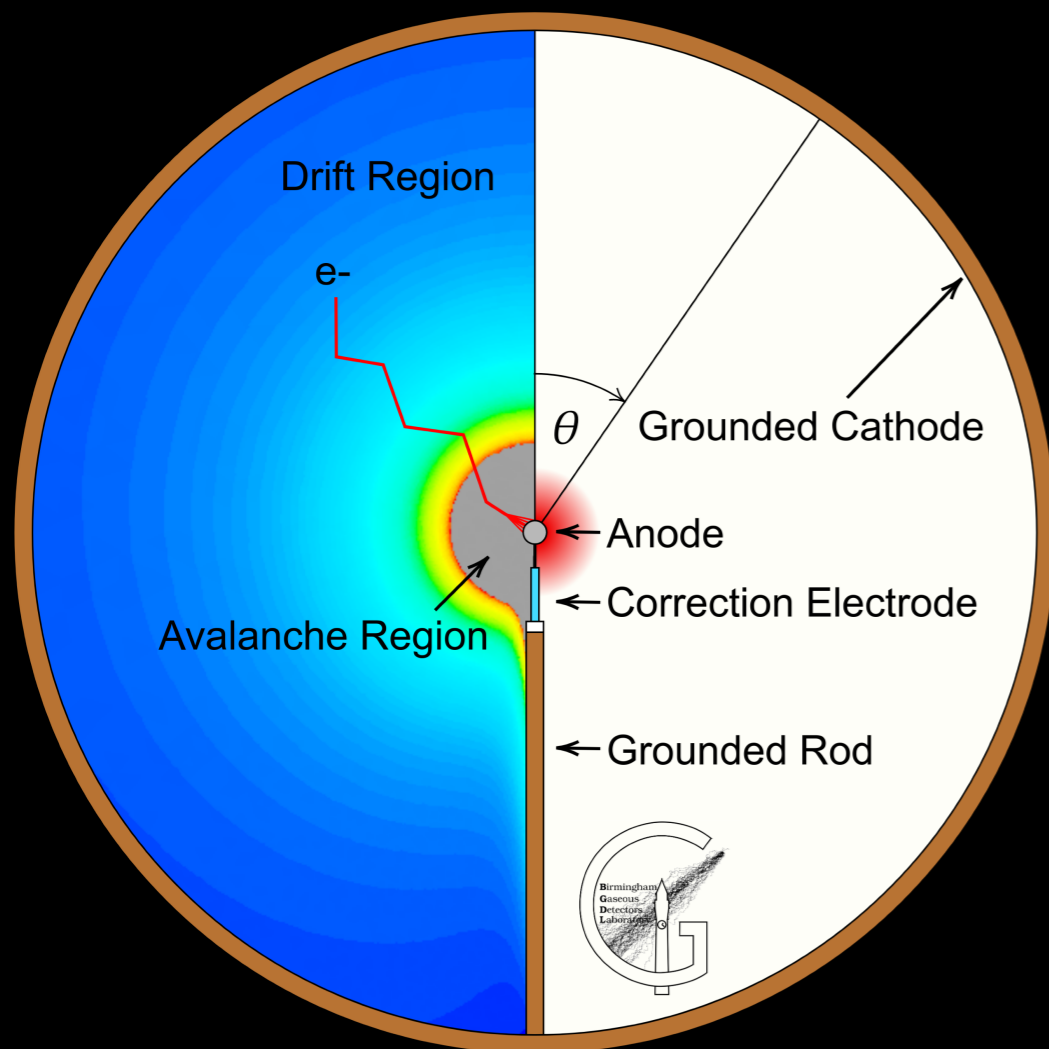
Co-supervised by John Lipp (STFC Interconnect Head) and Jocelyn Monroe (DarkSide-UK PI and DarkSide-20k Deputy Spokesperson)

It's a great team, with outstanding students! This could be you...



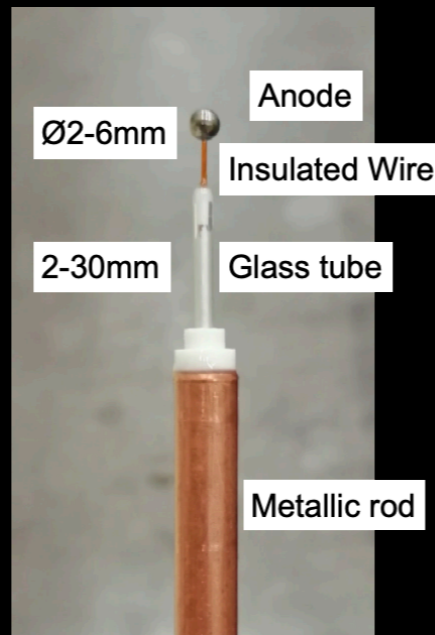
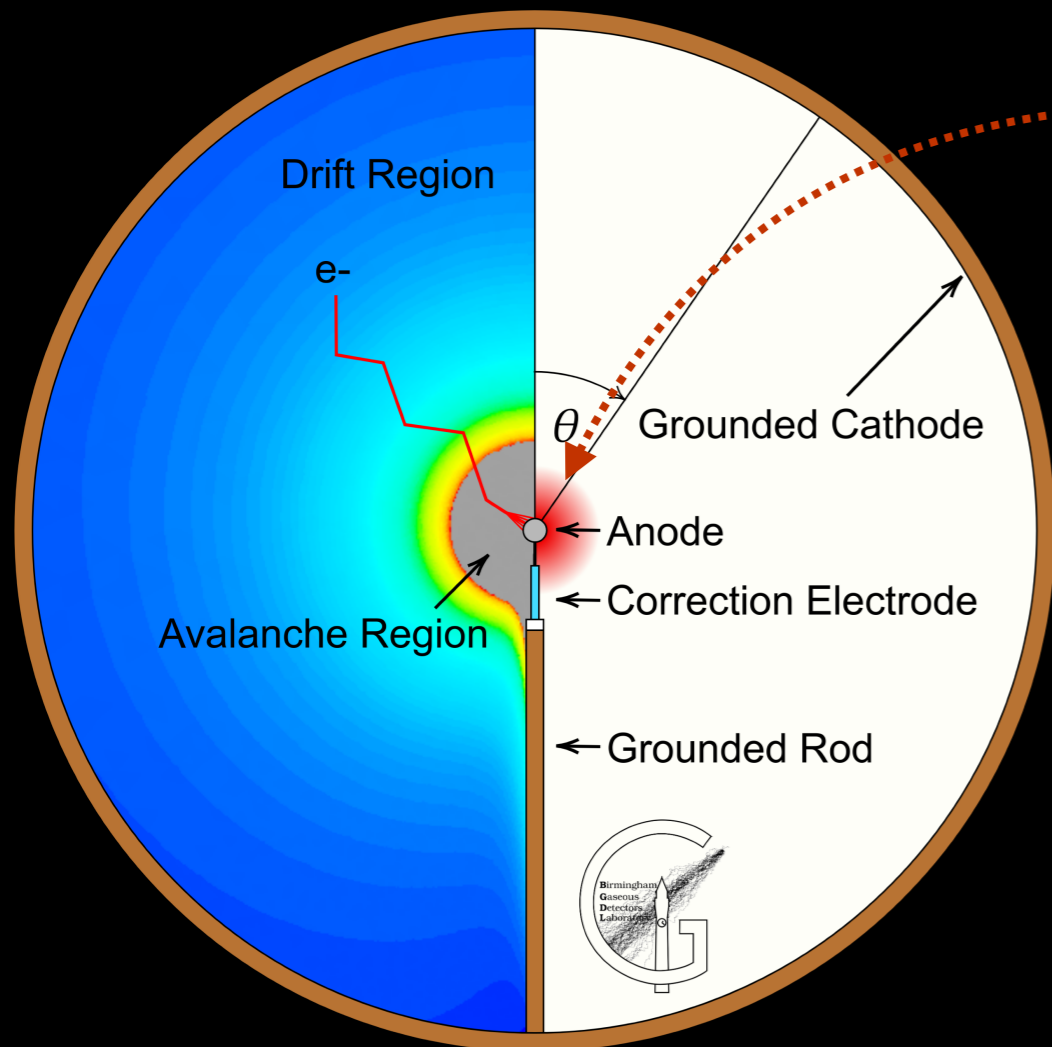
Spherical Proportional Counter

Electric field scales as $1/r^2$, volume divided in: “drift” and “amplification” regions
Capacitance independent of size: low electronic noise



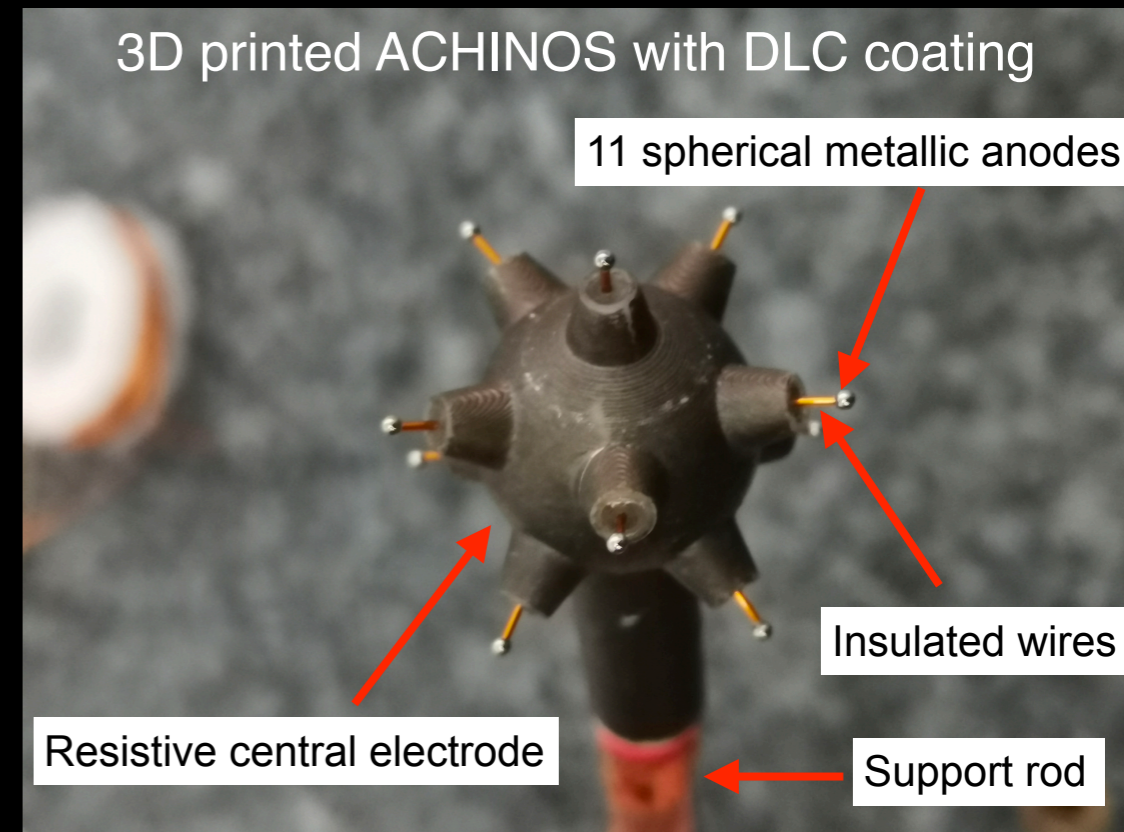
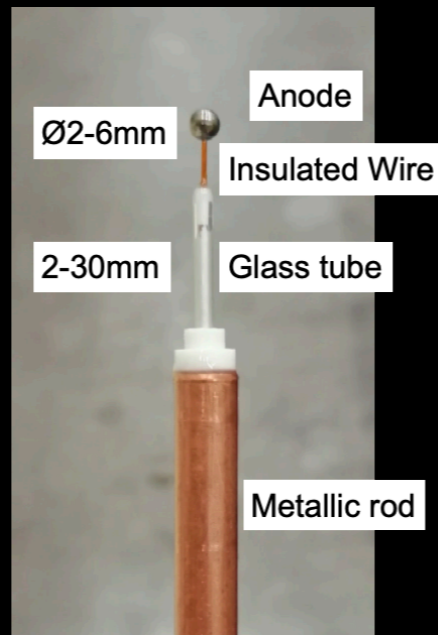
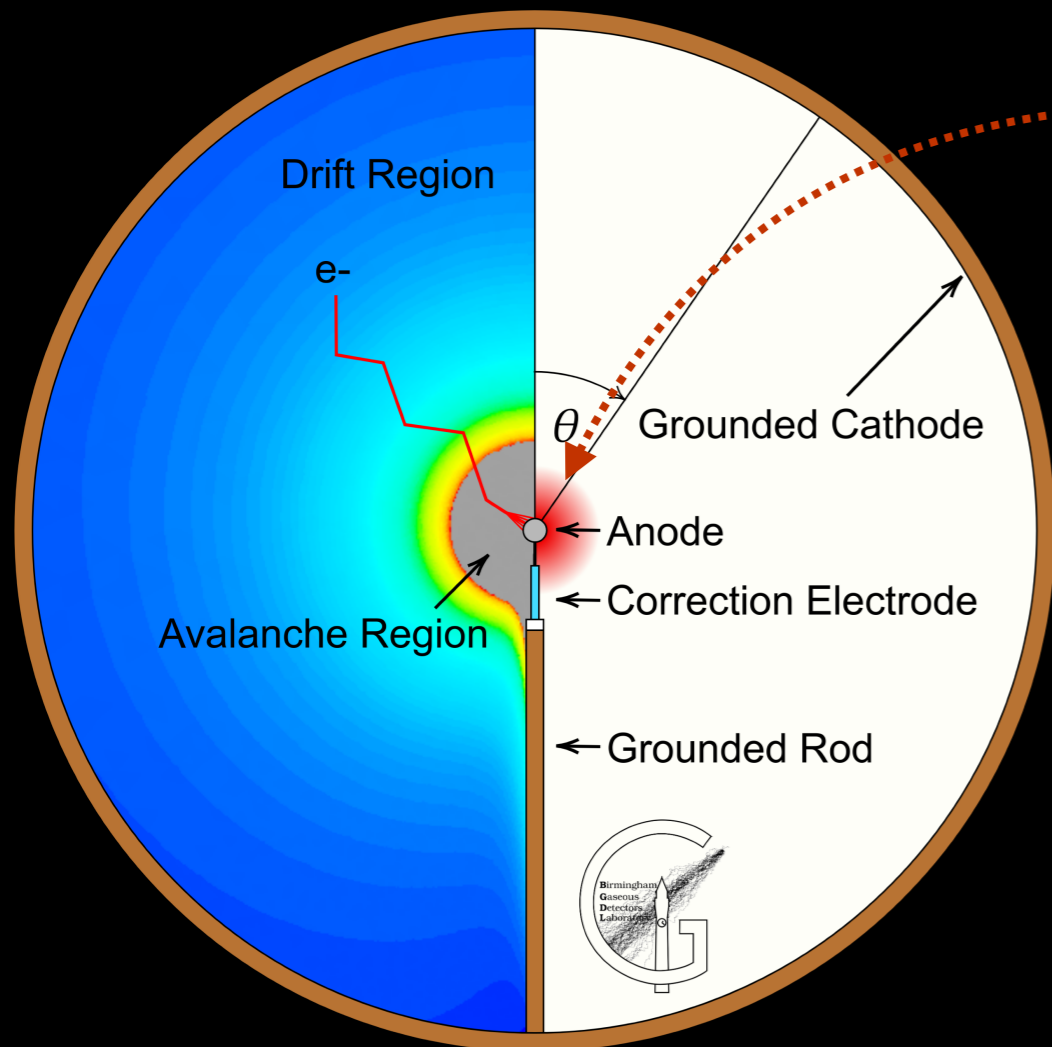
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JINST 15 (2020) 11, 11

JINST 12 (2017) 12, P12031

- ACHINOS: Multi-anode sensor
 - Multiple anodes placed at equal radii
 - Decoupling drift and amplification fields
 - Opportunity: individual anode read-out

New Experiment With Spheres - Gas



11th collaboration meeting, August 2022

NEWS-G Collaboration

- ▶ 5 countries
- ▶ 10 institutes
- ▶ ~40 collaborators
- ▶ Three underground laboratories
 - ▶ SNOLAB
 - ▶ Laboratoire Souterrain de Modane
 - ▶ Boulby Underground Laboratory
- ▶ Significant UK leadership!



New Experiment With Spheres - Gas



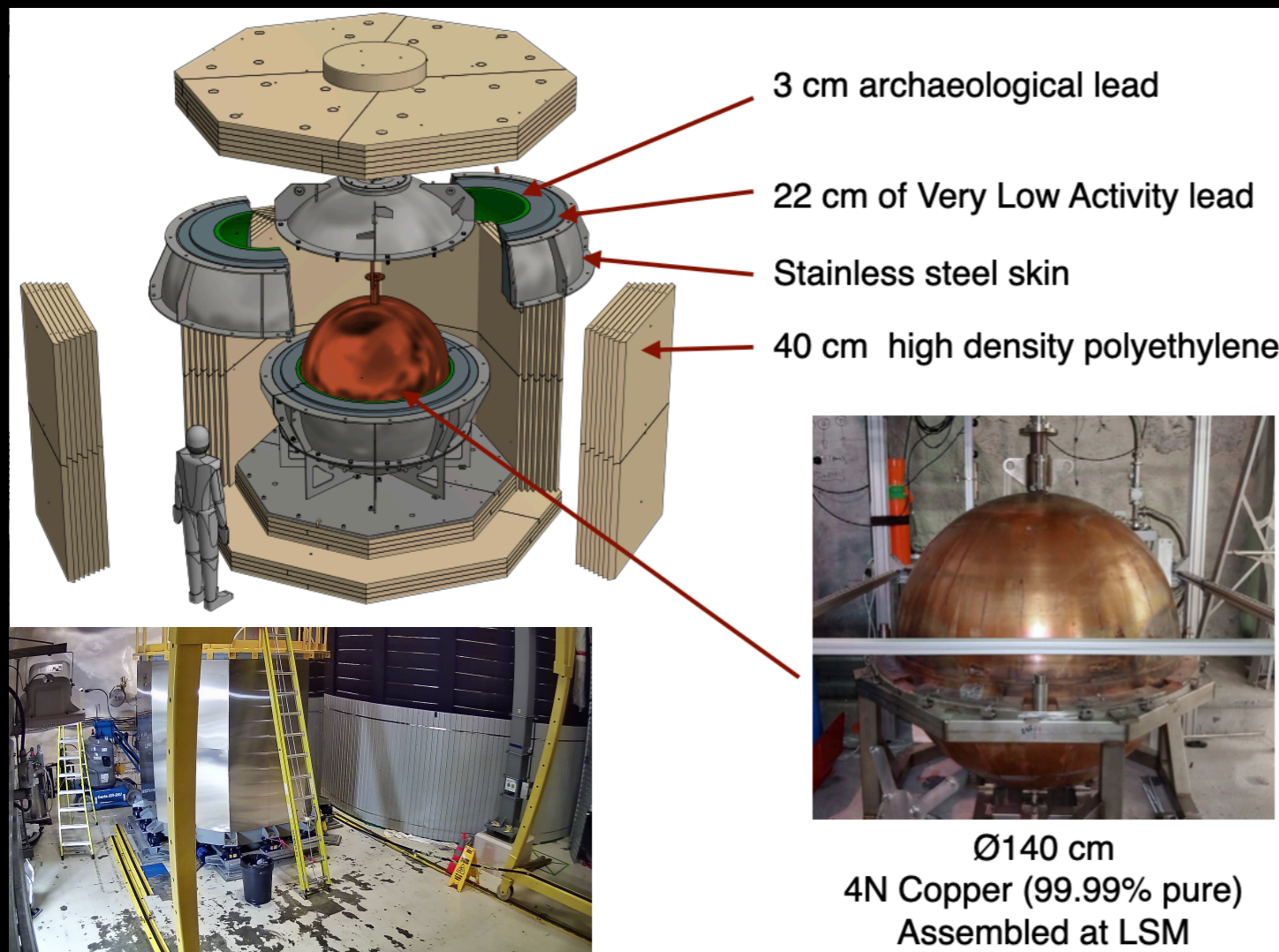
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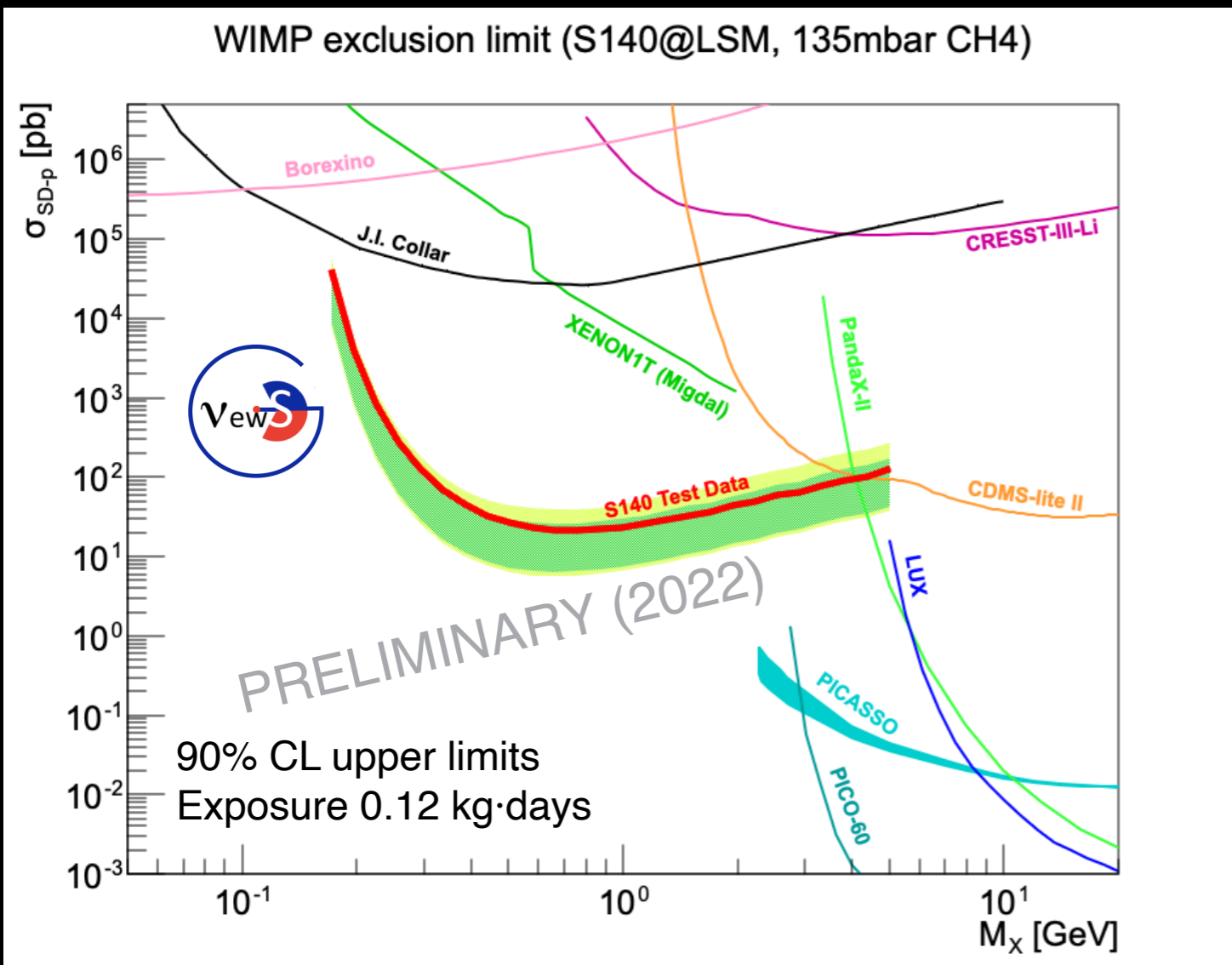
Three underground laboratories

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New Experiment With Spheres - Gas

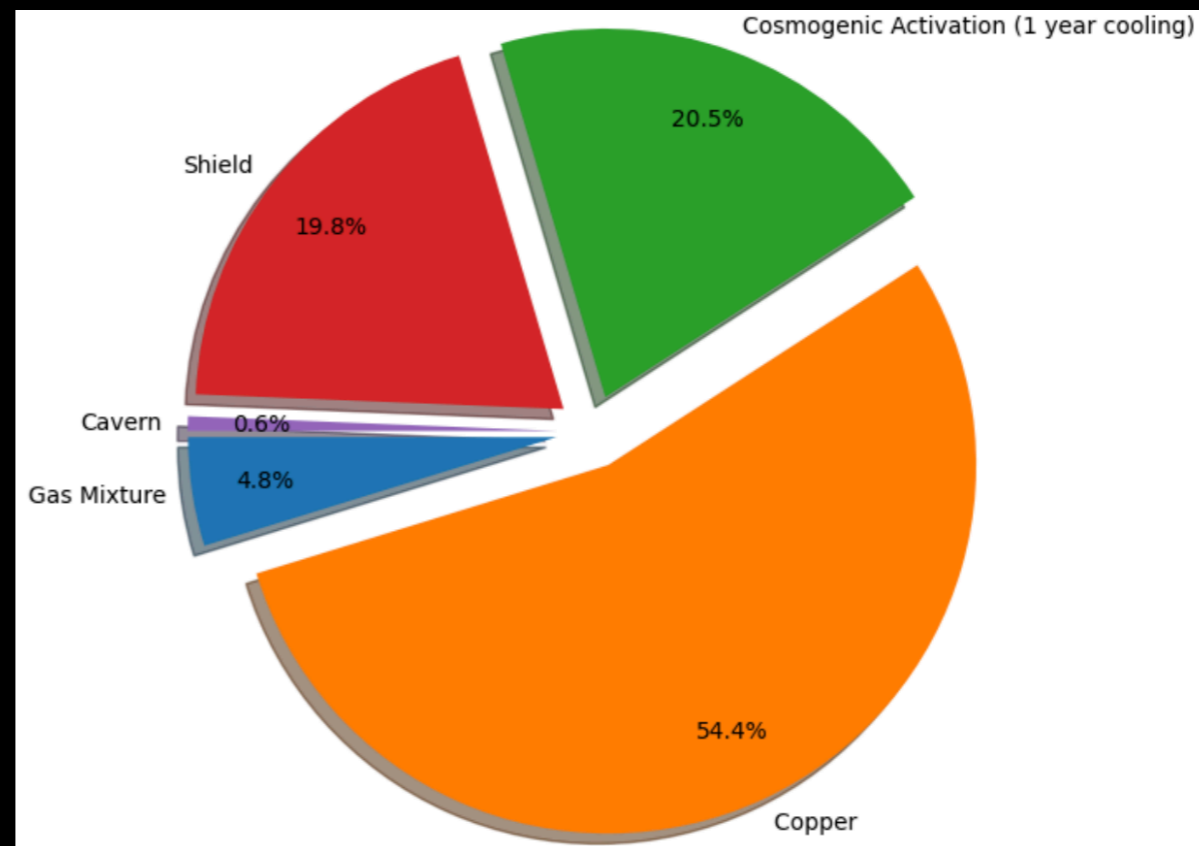


NEWS-G Collaboration

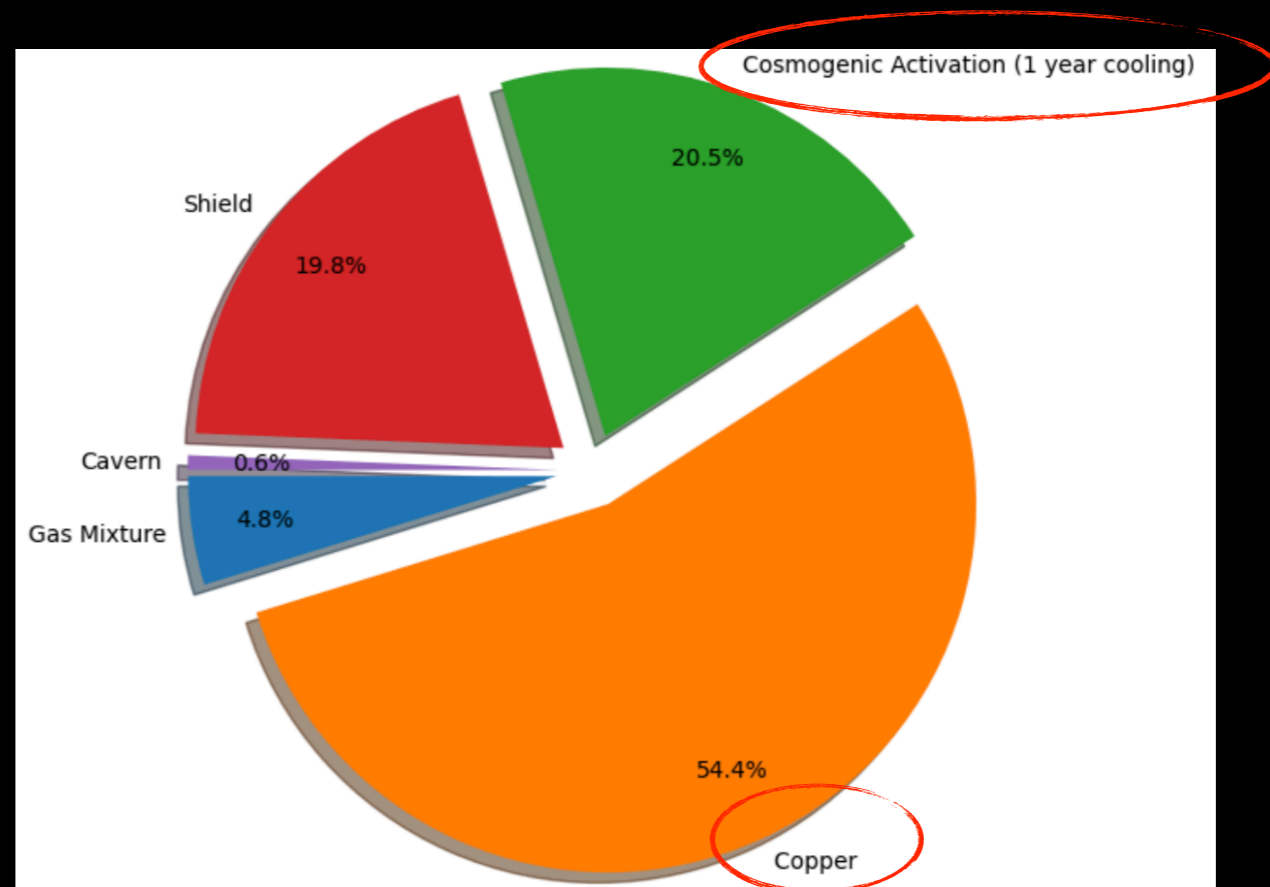
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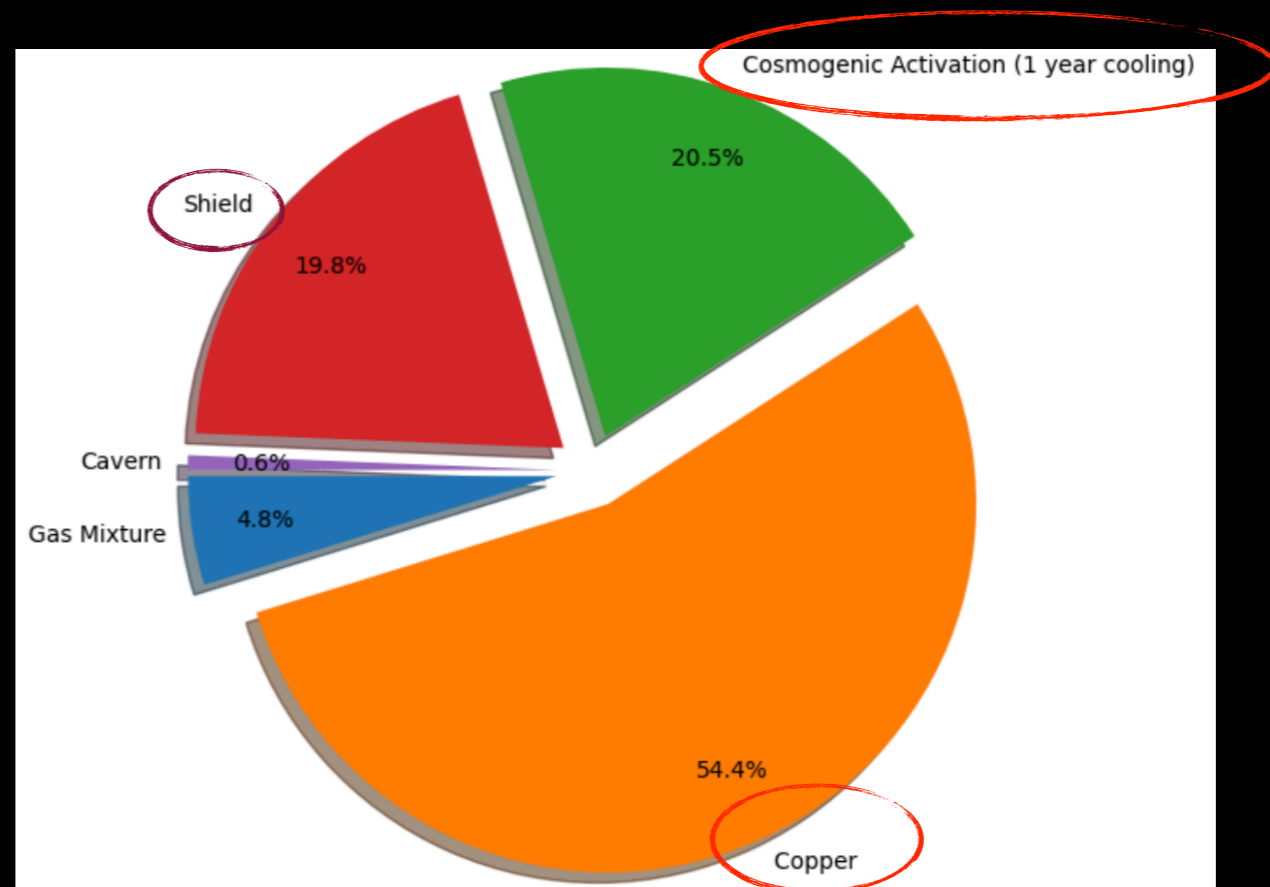
DarkSPHERE at Boulby



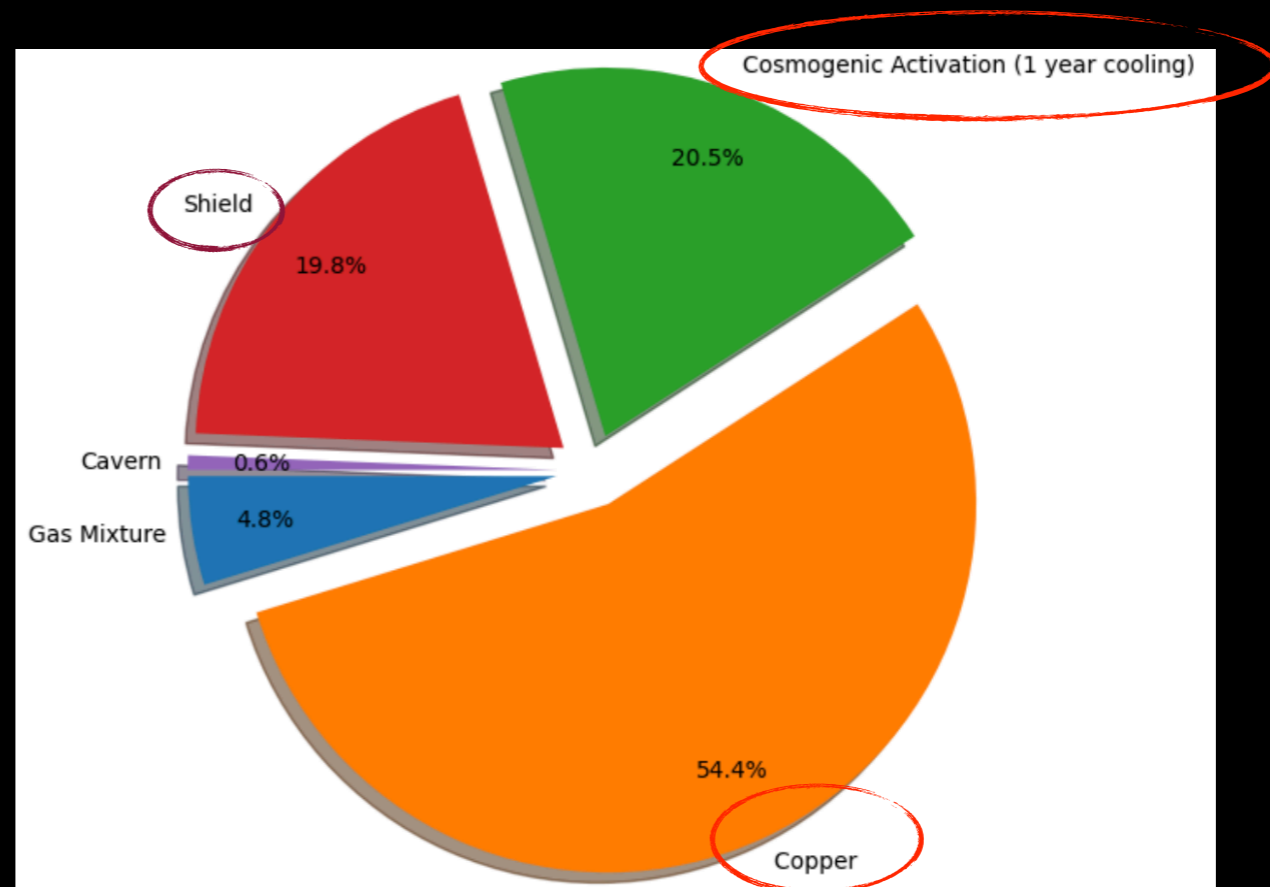
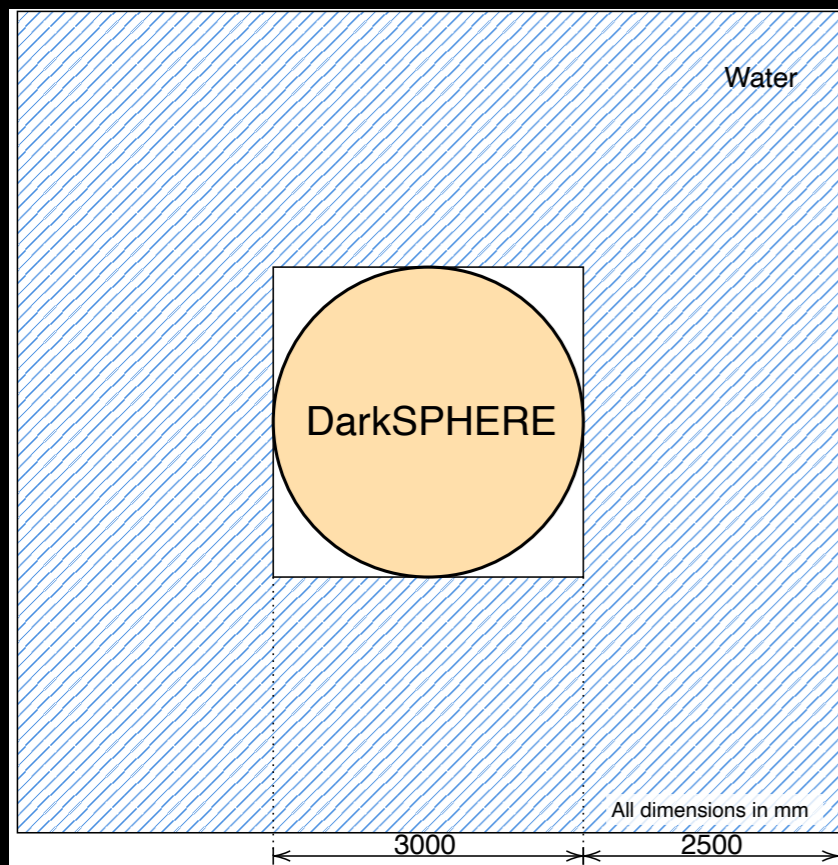
DarkSPHERE at Boulby



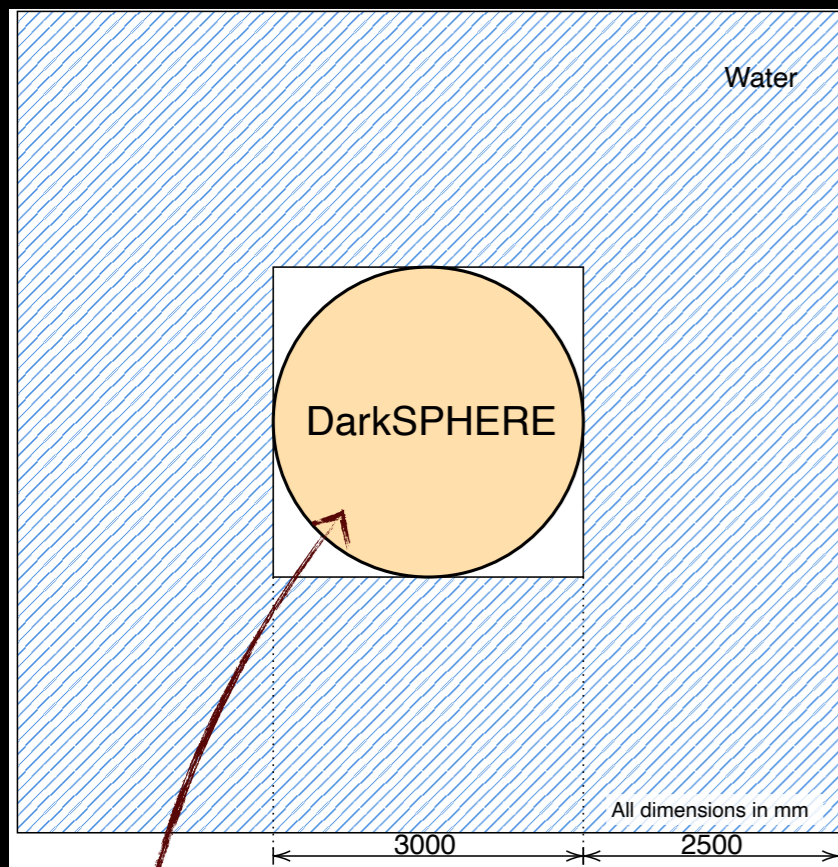
DarkSPHERE at Boulby



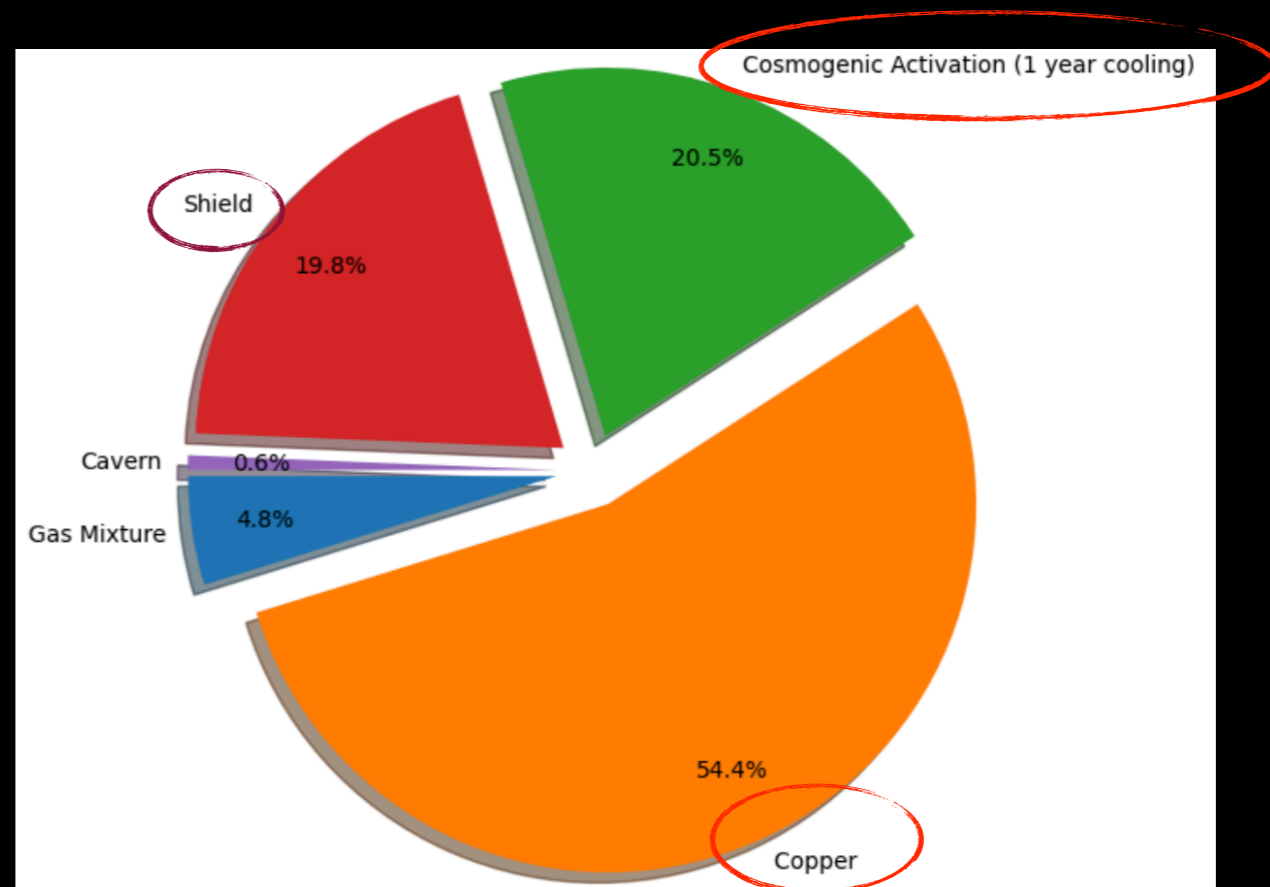
DarkSPHERE at Boulby



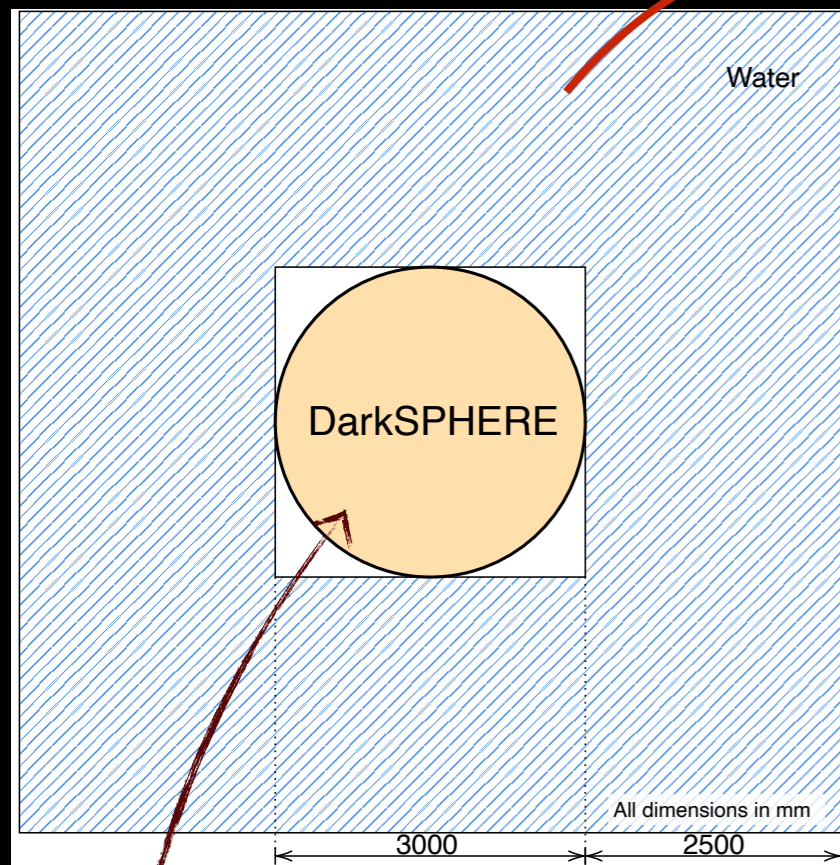
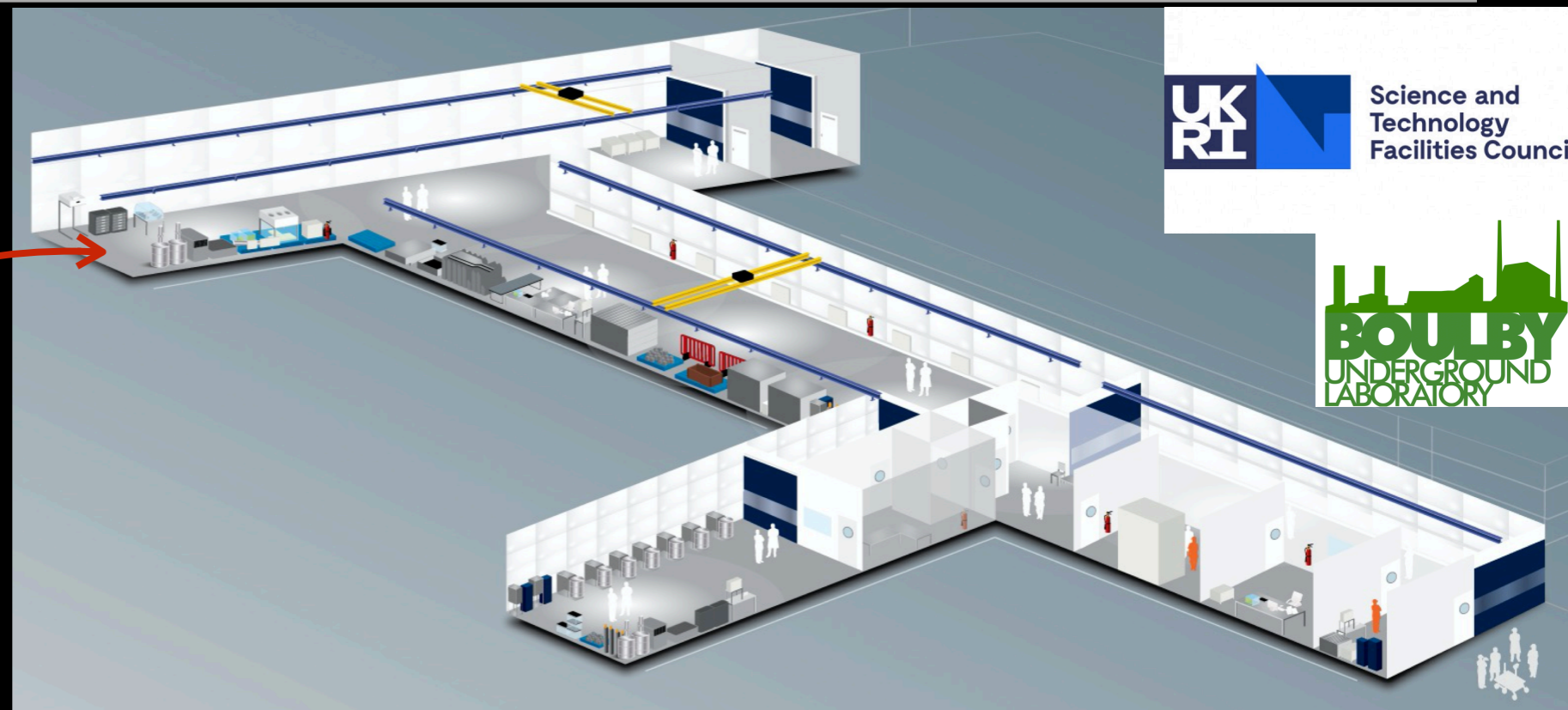
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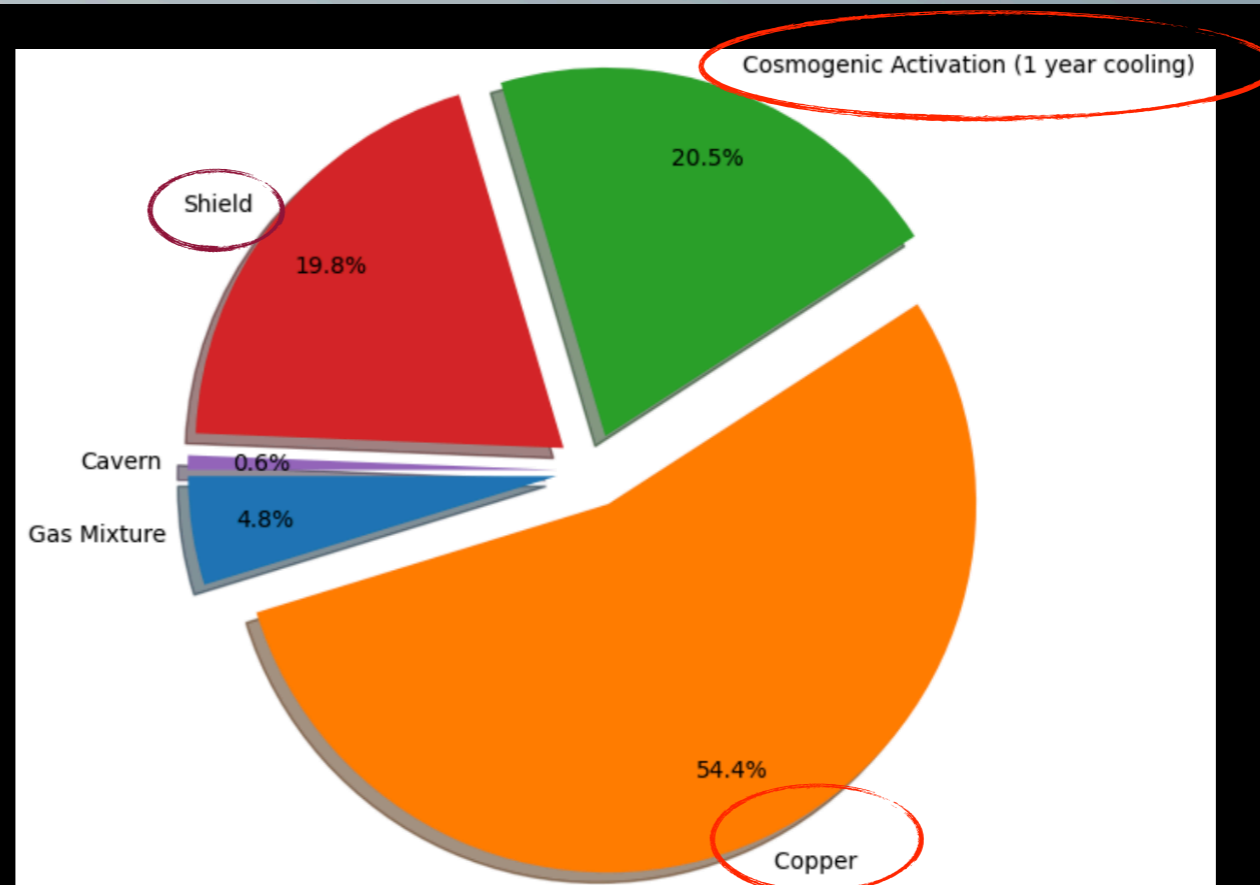
5 bar He:C₄H₁₀ (90%:10%)
(27 kg target mass)



DarkSPHERE at Boulby



5 bar He:C₄H₁₀ (90%:10%)
(27 kg target mass)



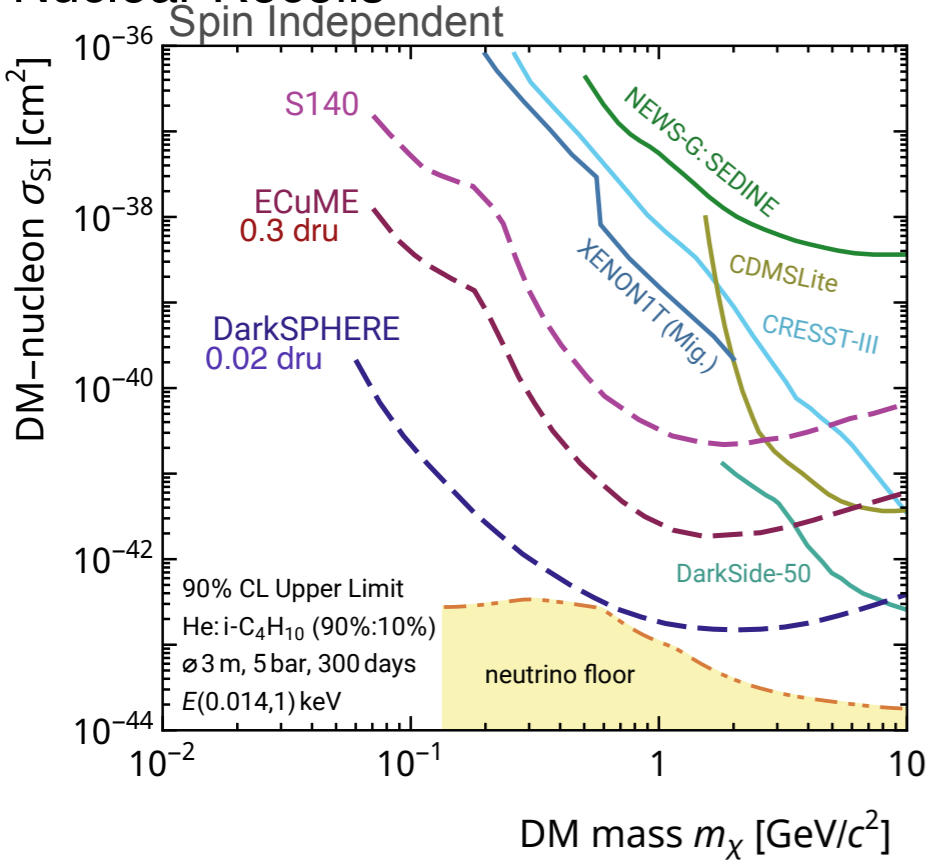
DarkSPHERE: Physics Potential

arXiv:2301.05183

DarkSPHERE: Physics Potential

arXiv:2301.05183

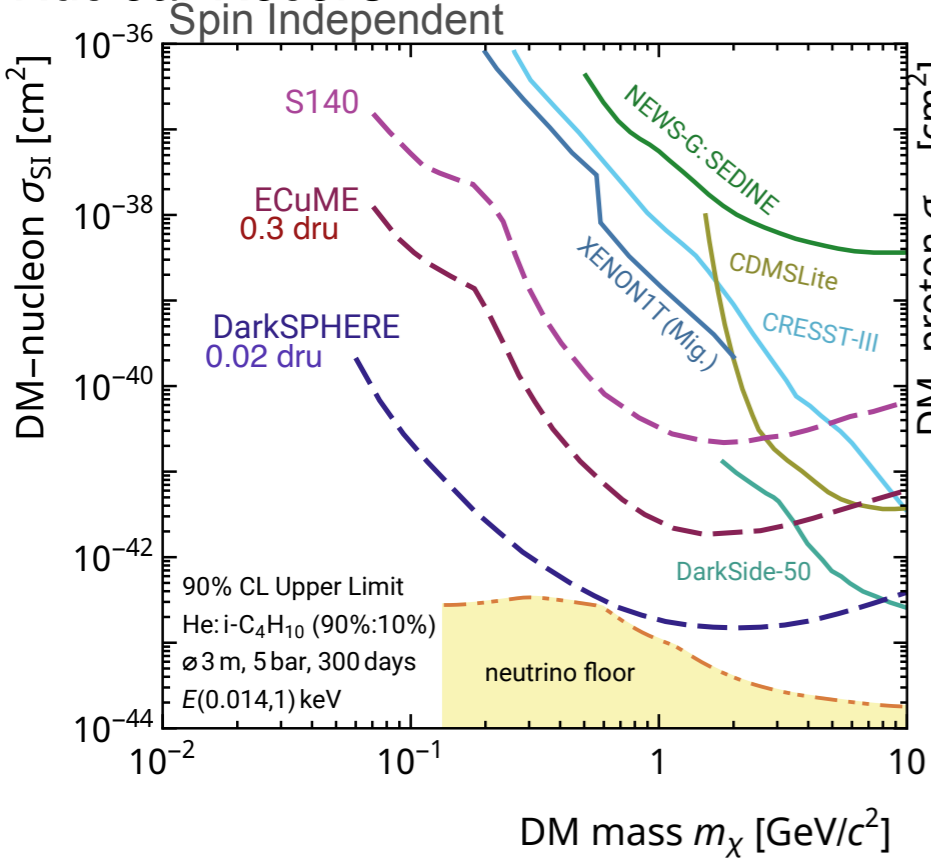
Nuclear Recoils



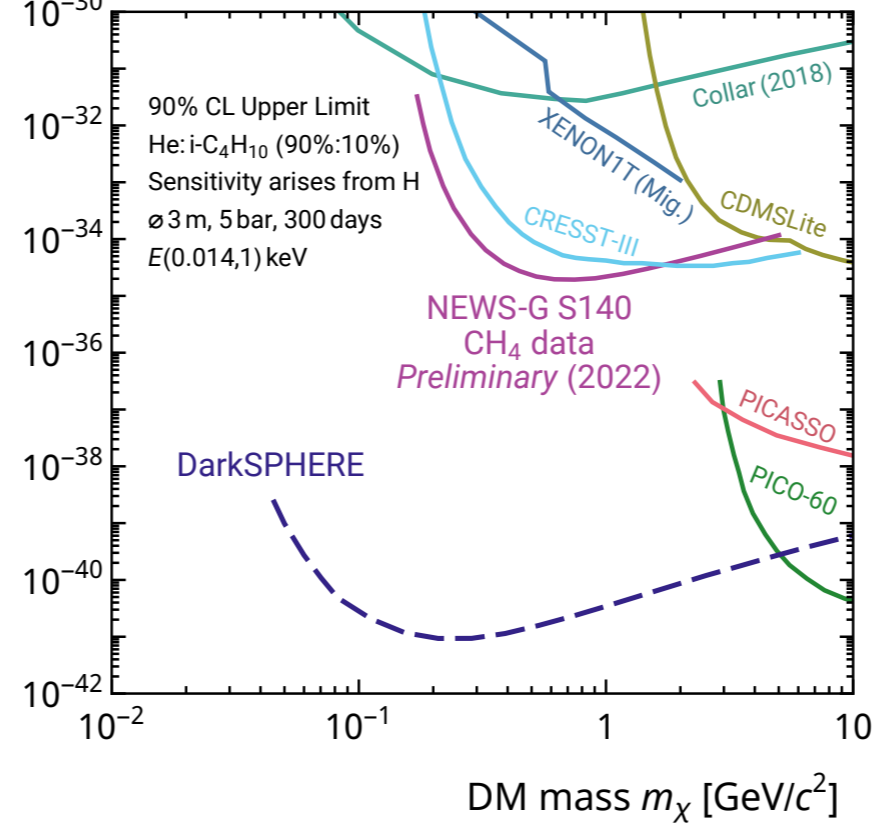
DarkSPHERE: Physics Potential

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Nuclear Recoils



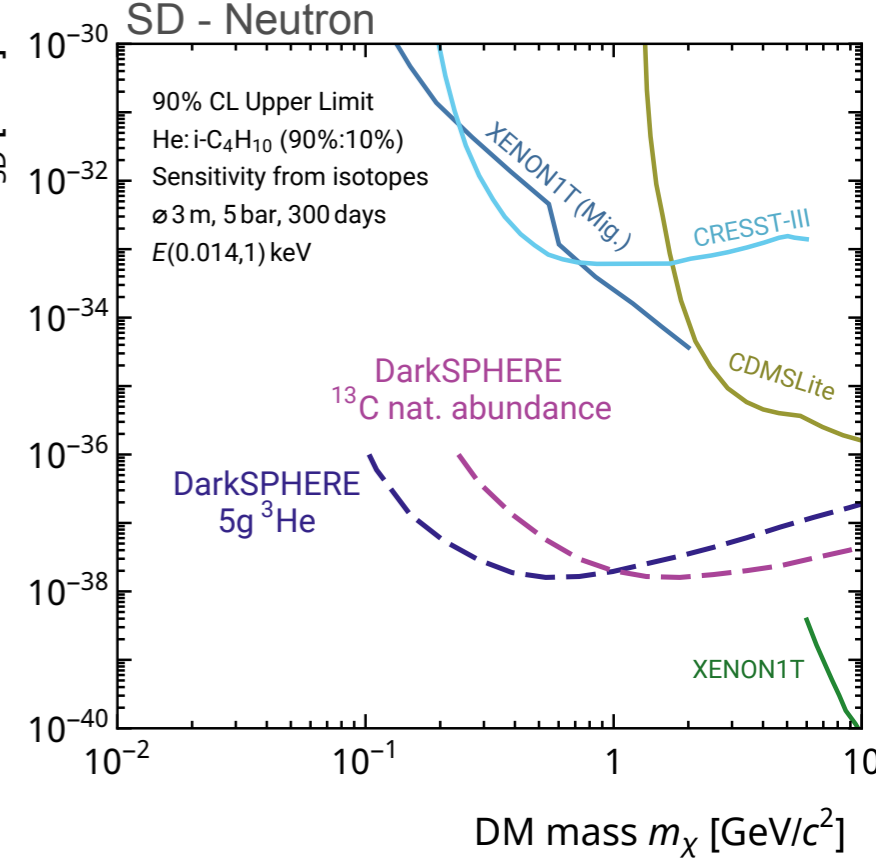
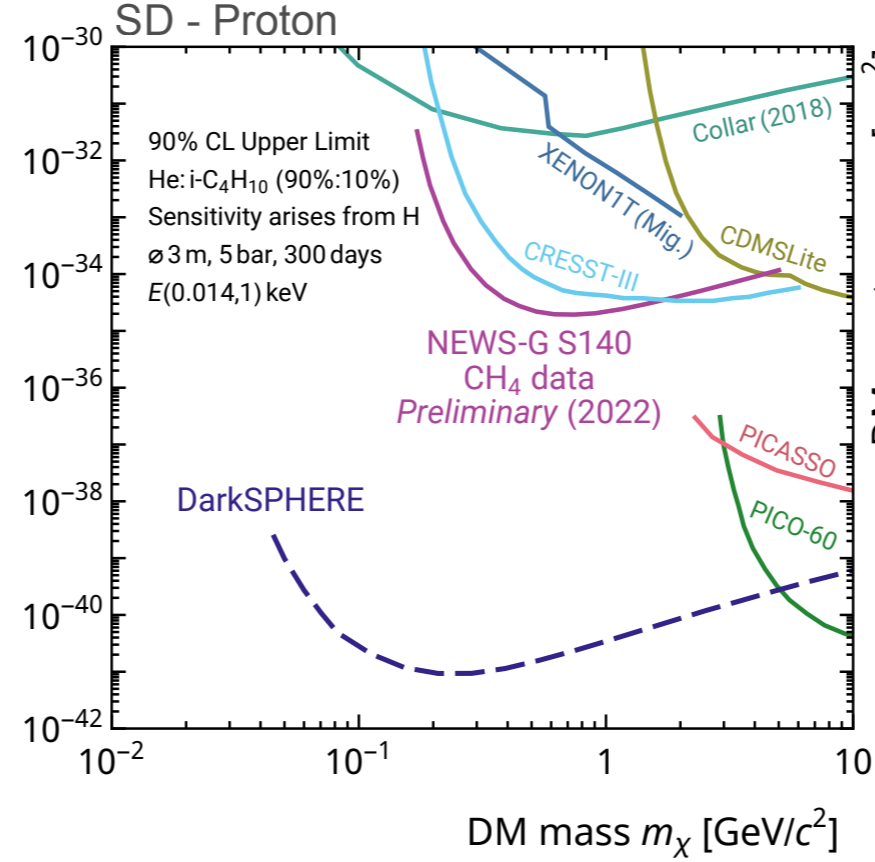
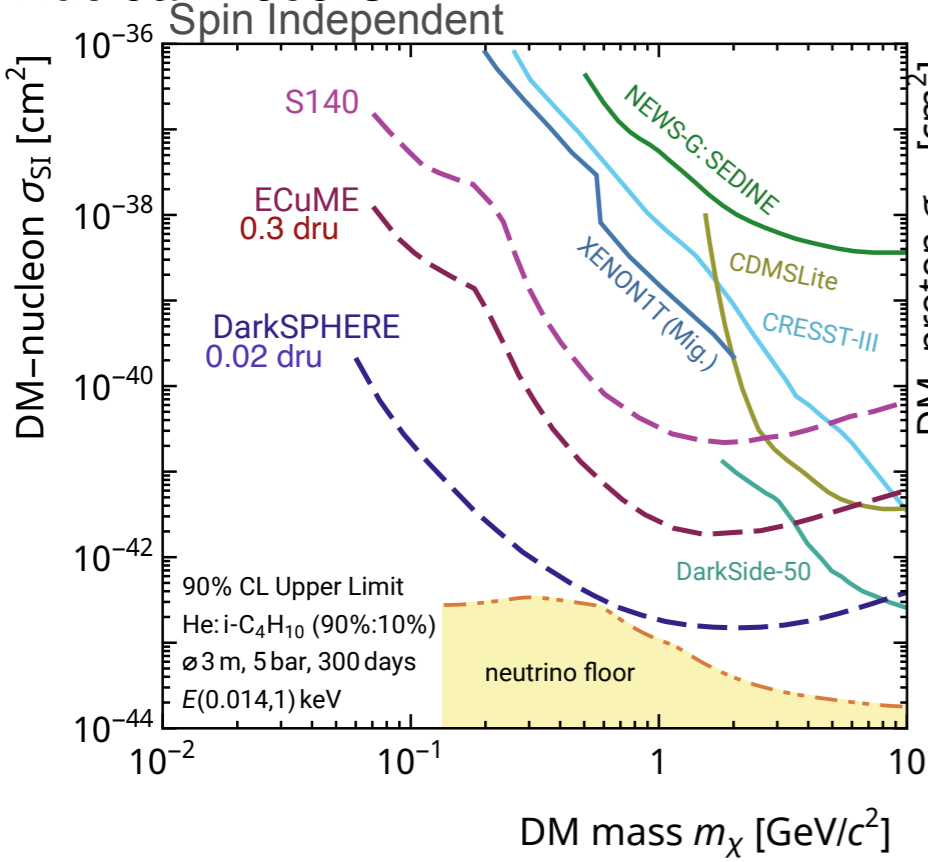
SD - Proton



DarkSPHERE: Physics Potential

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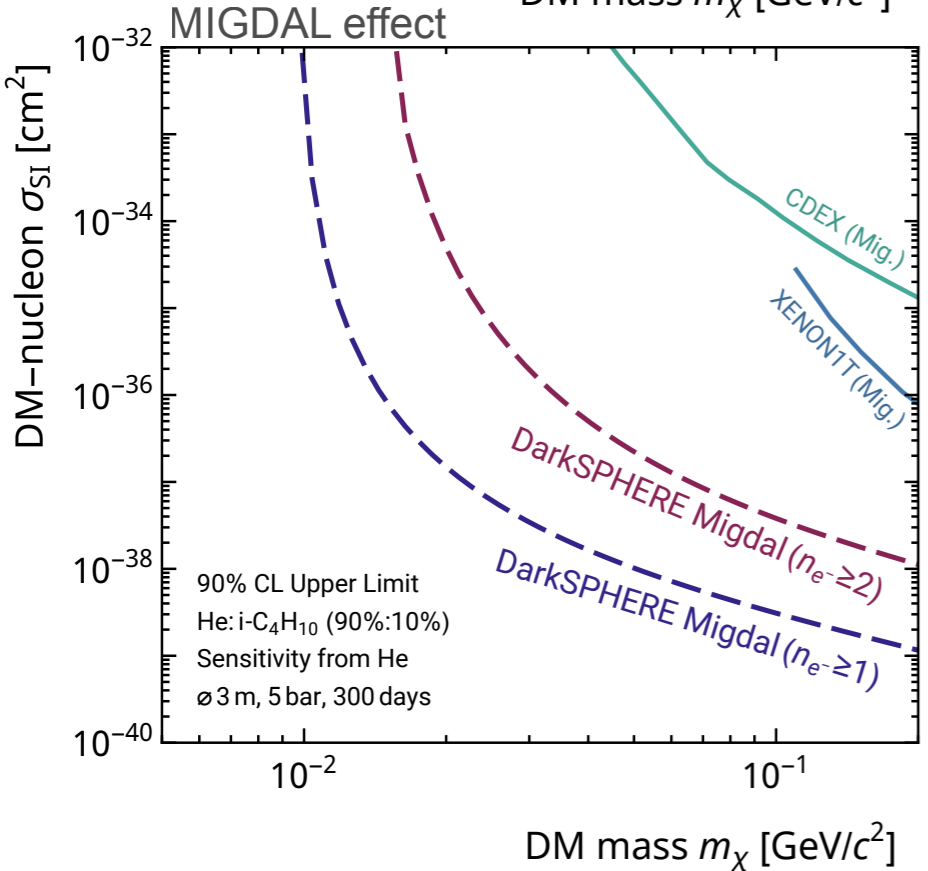
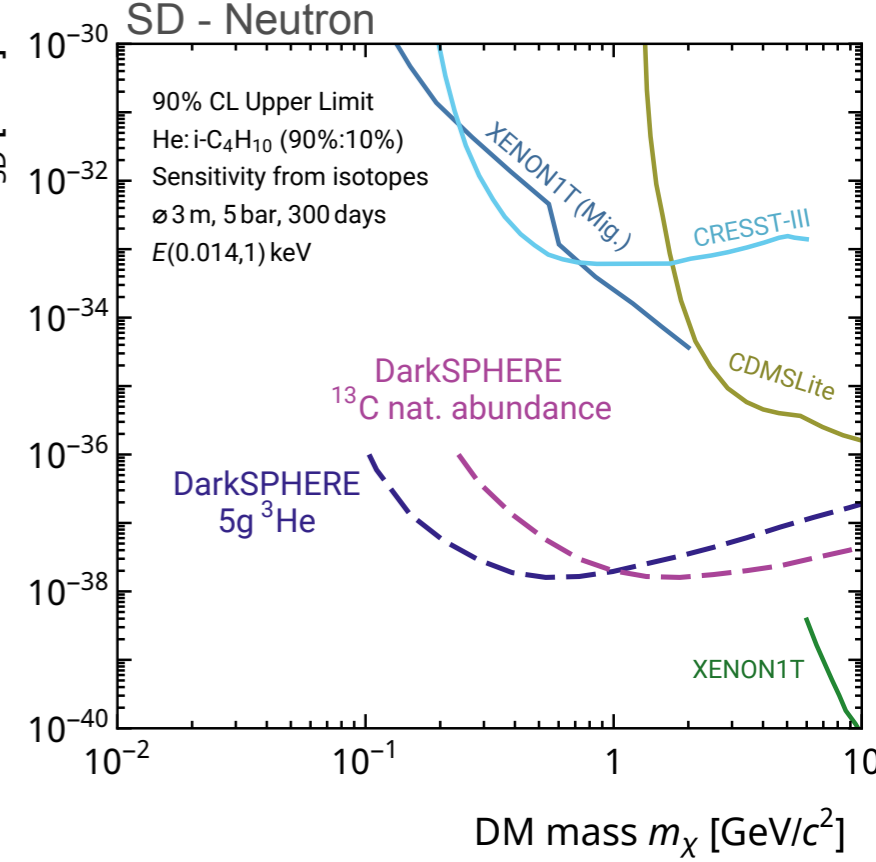
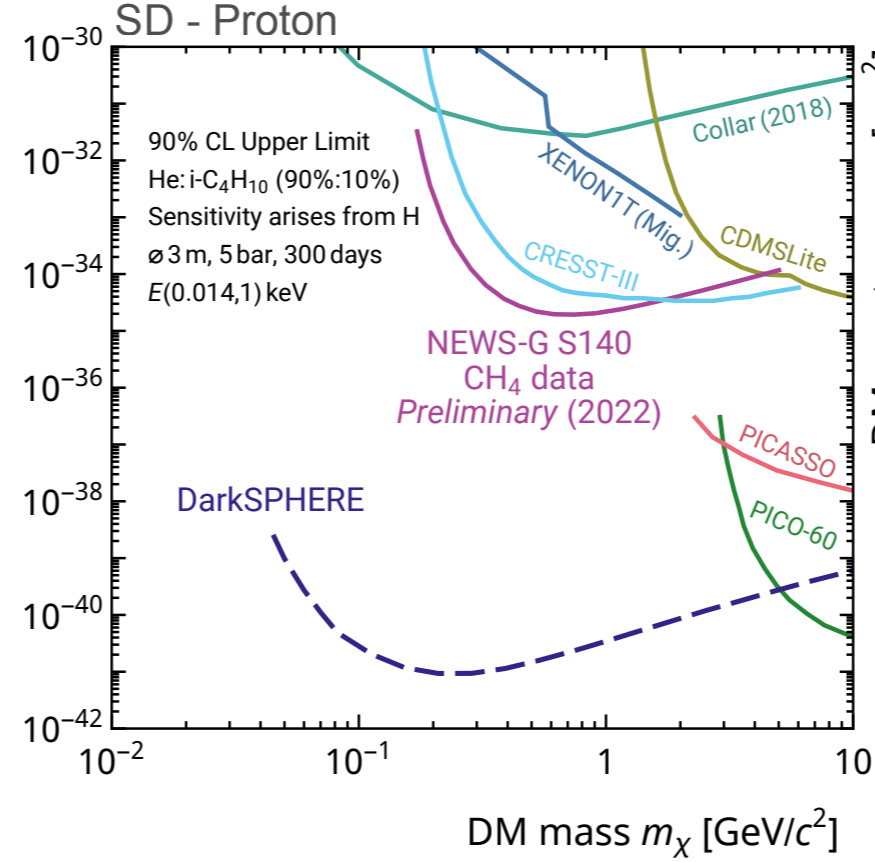
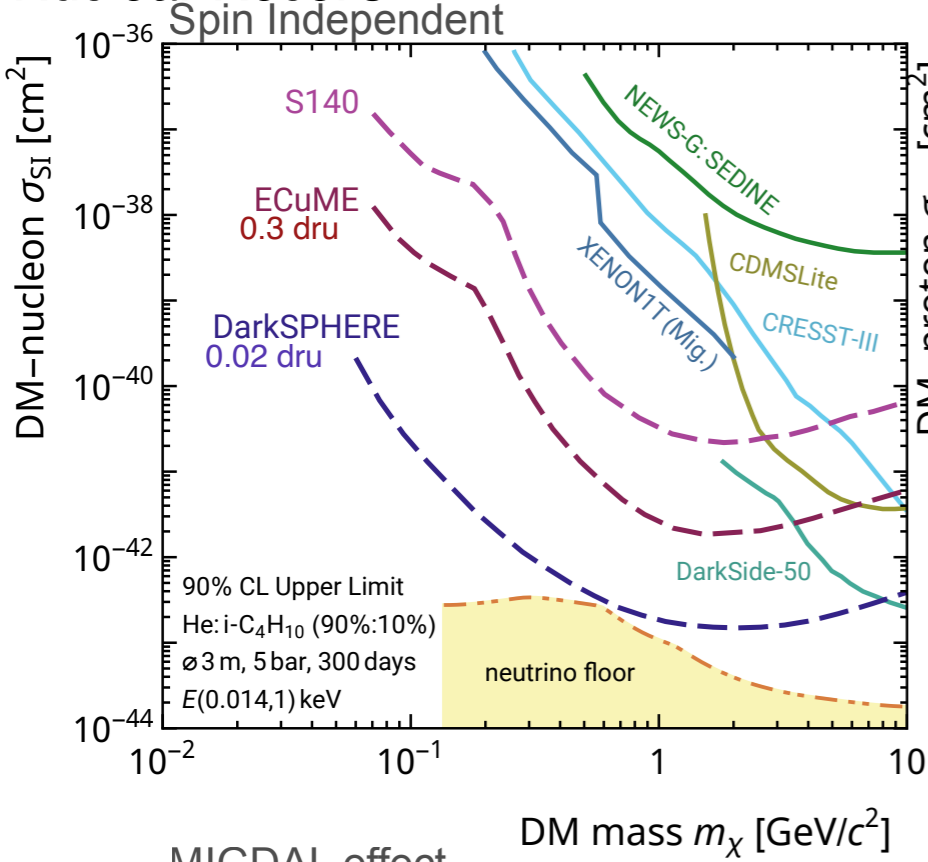
Nuclear Recoils



DarkSPHERE: Physics Potential

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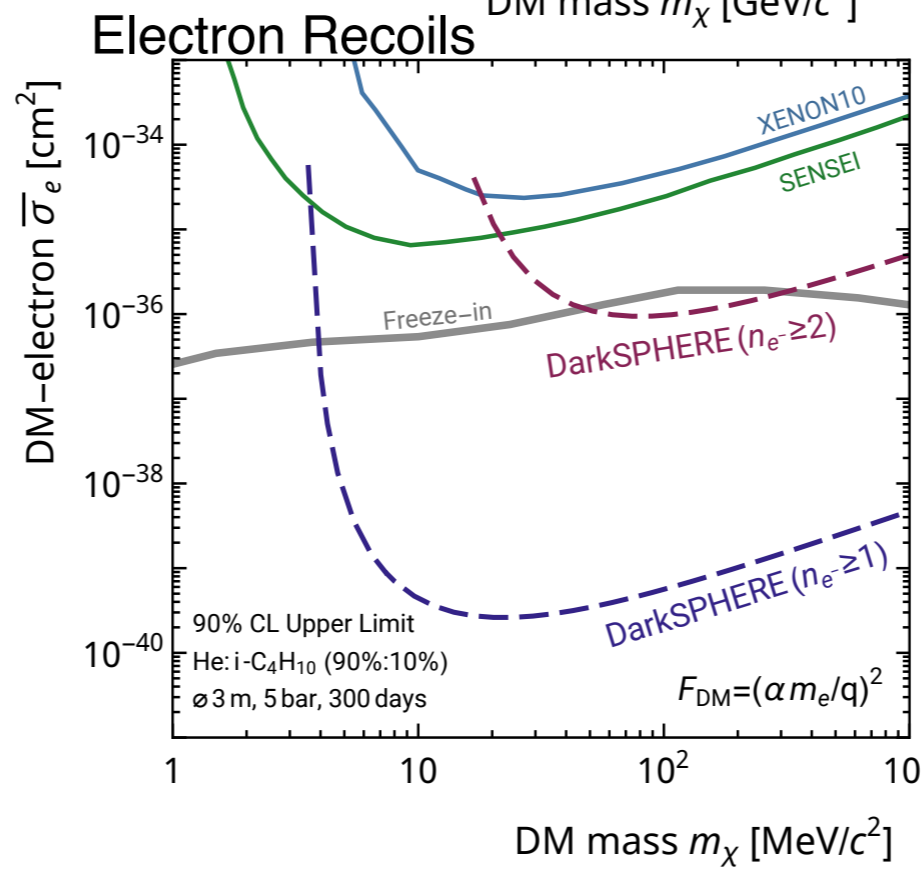
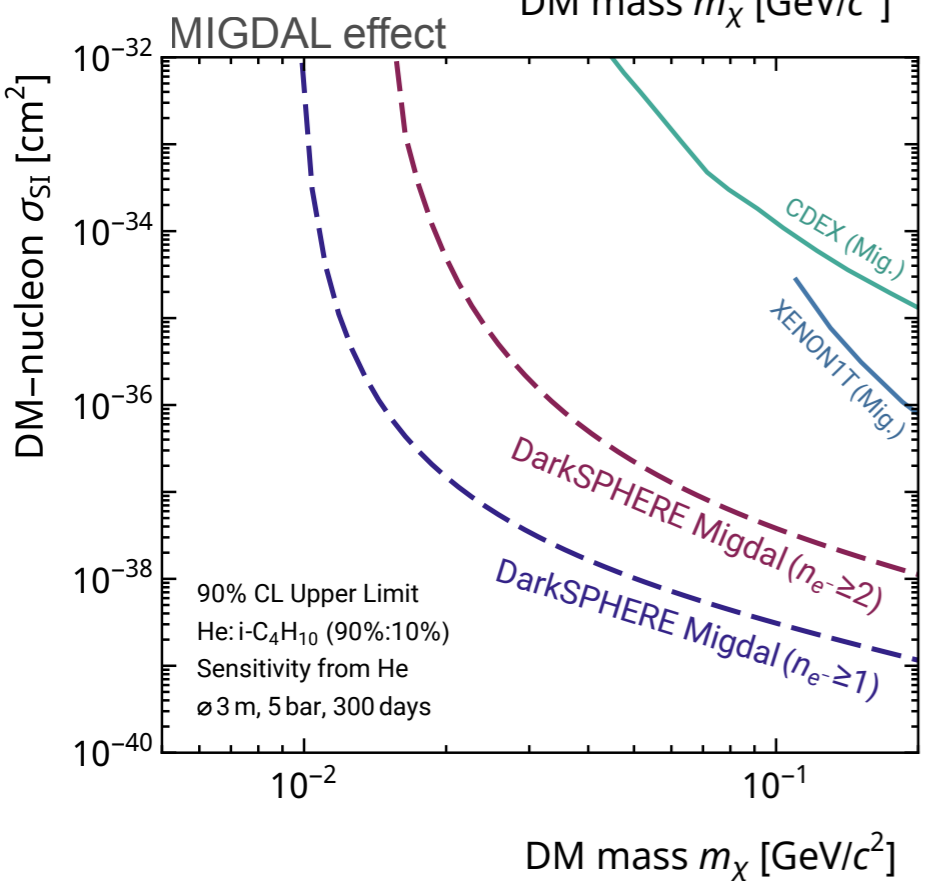
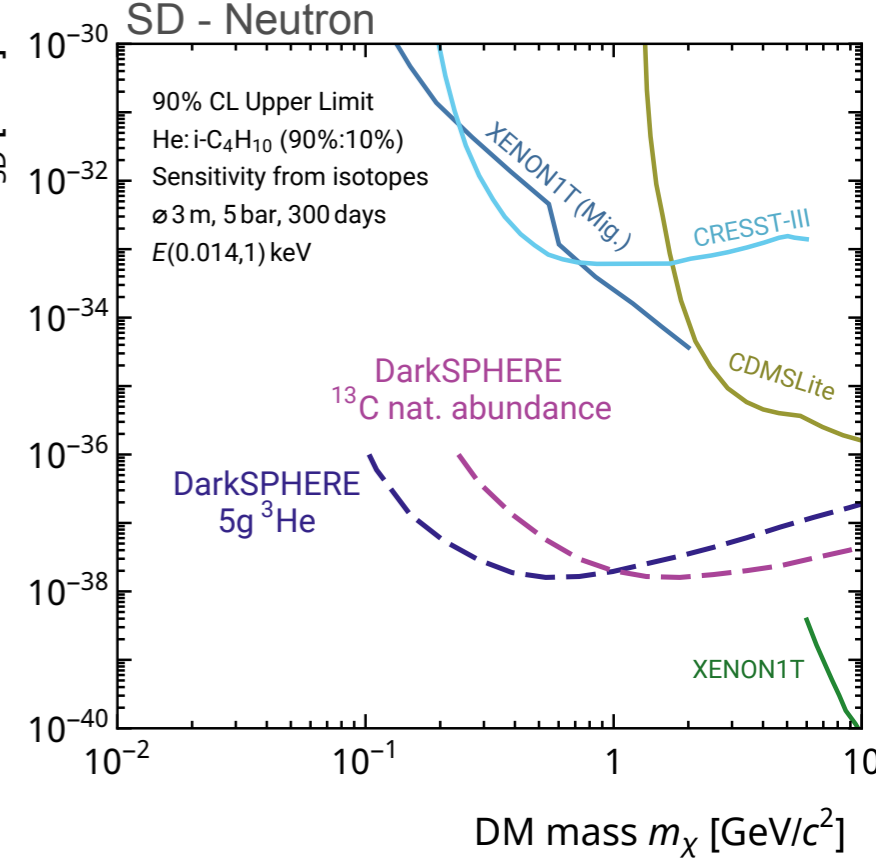
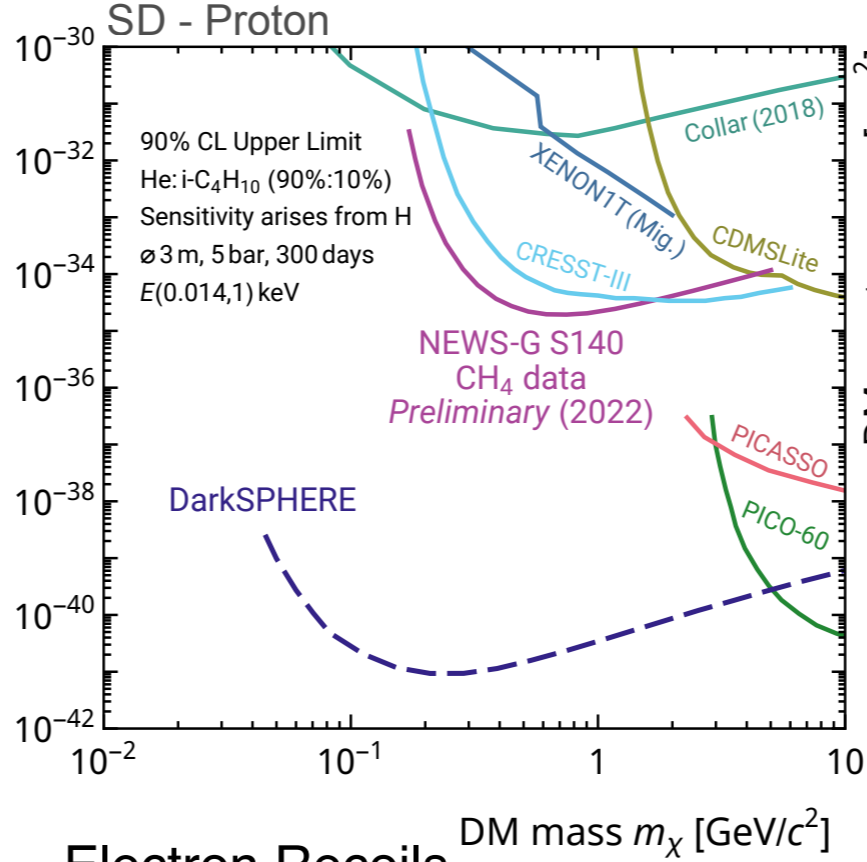
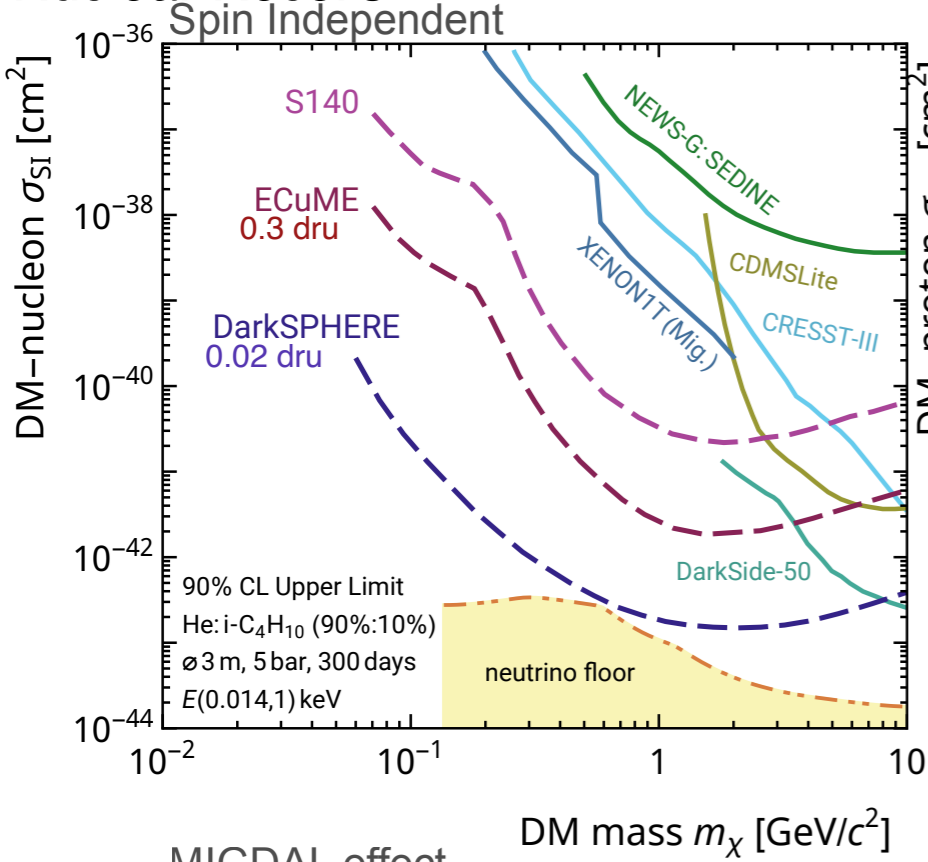
Nuclear Recoils



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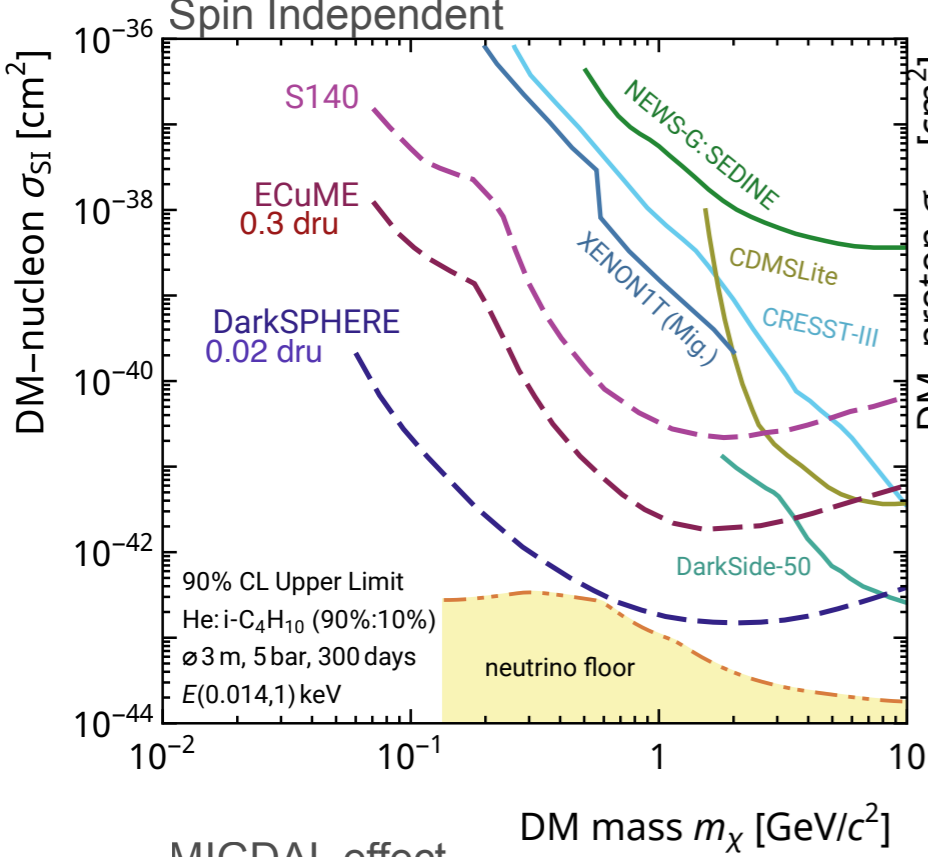
Nuclear Recoils



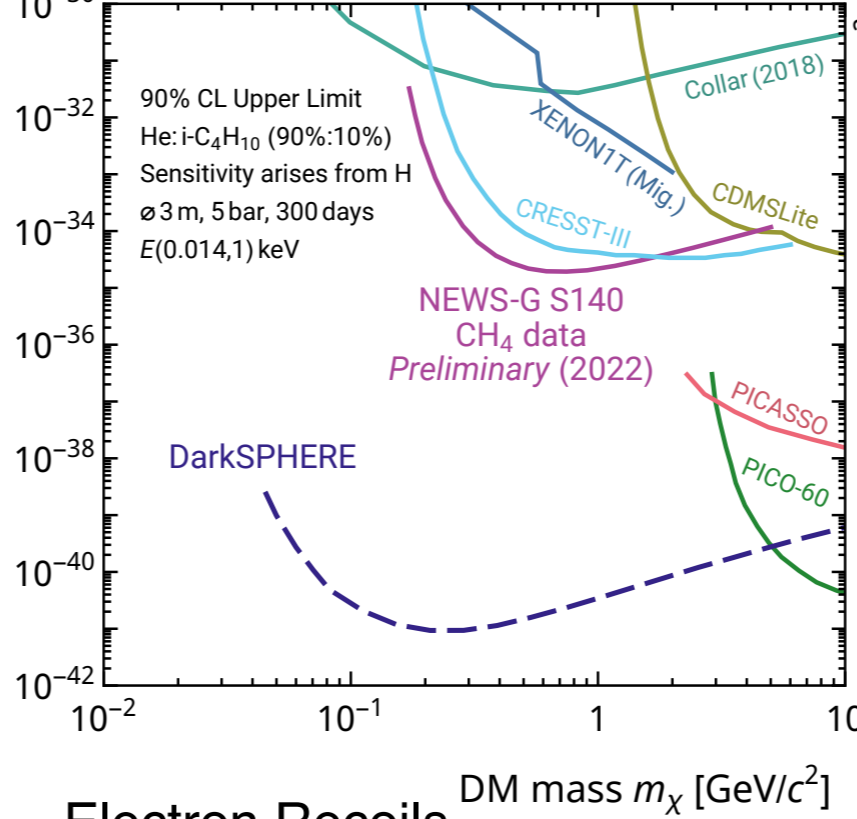
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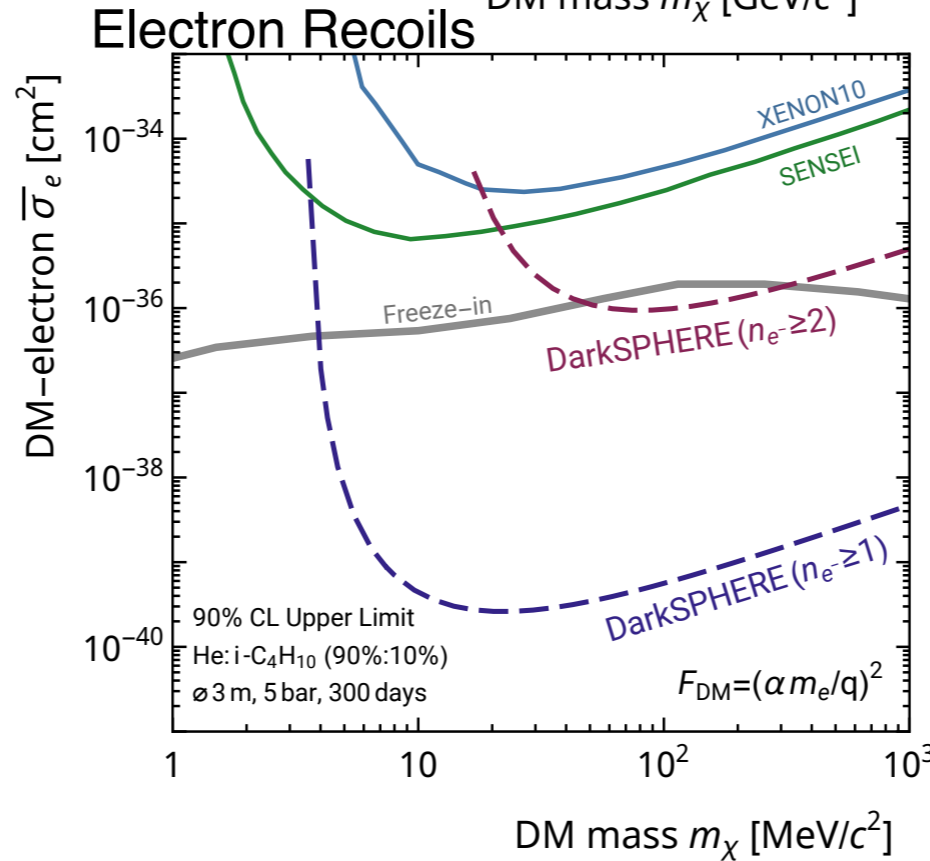
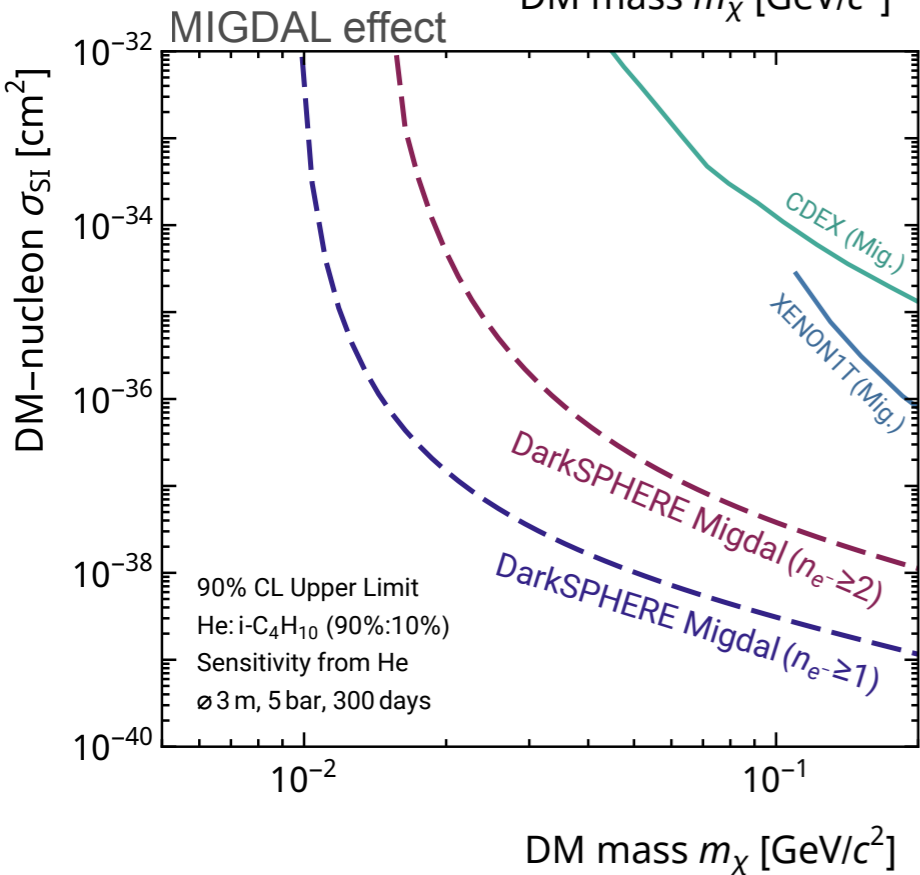
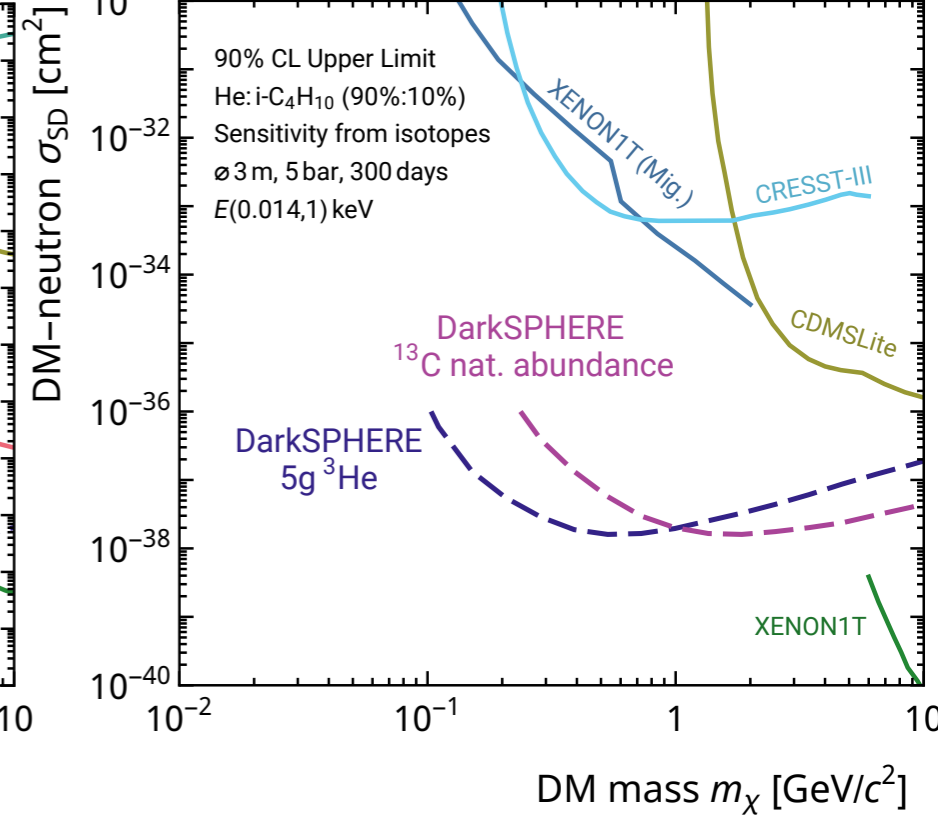
Nuclear Recoils



SD - Proton



SD - Neutron



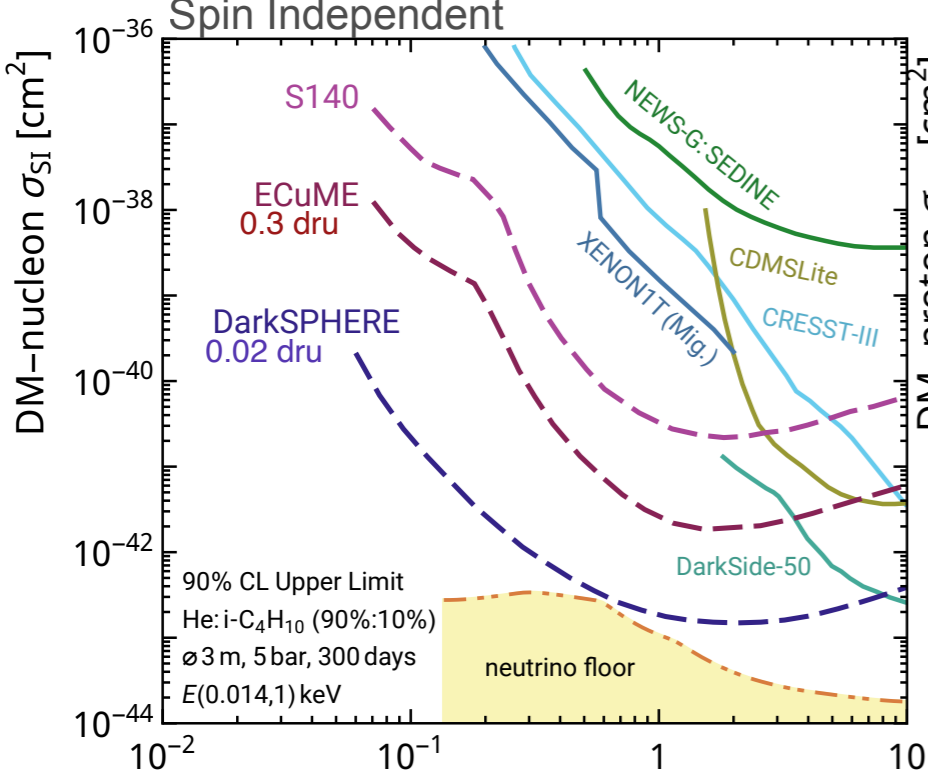
DarkSPHERE has the potential to probe uncharted territory in light Dark Matter searches

- ▶ Nuclear recoils: Spin-independent and spin-dependent
- ▶ Electron recoils

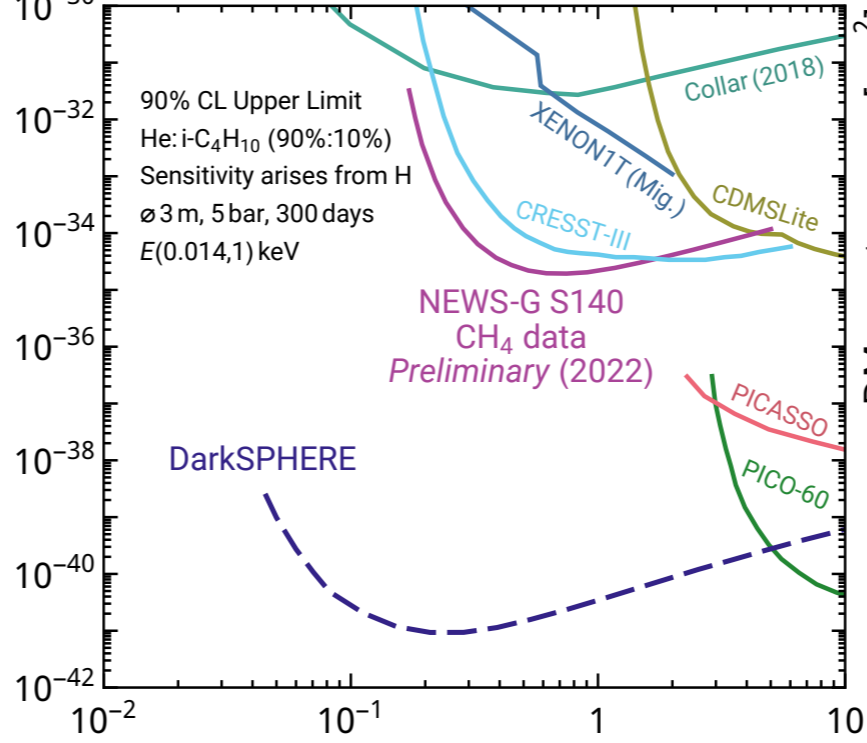
DarkSPHERE: Physics Potential

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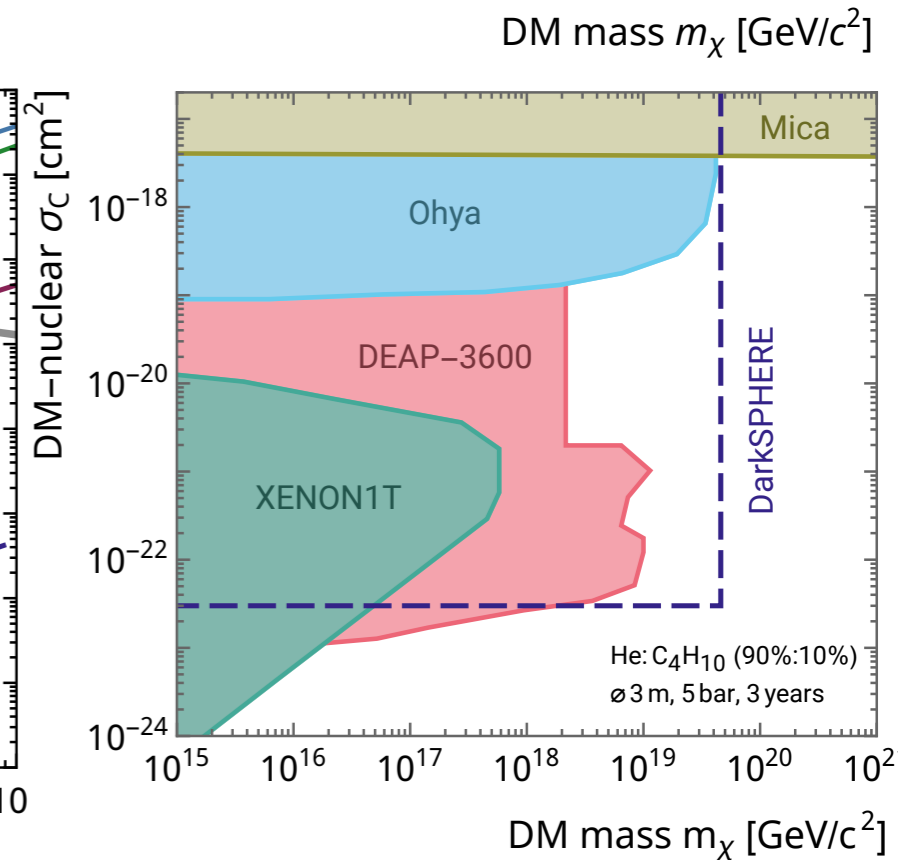
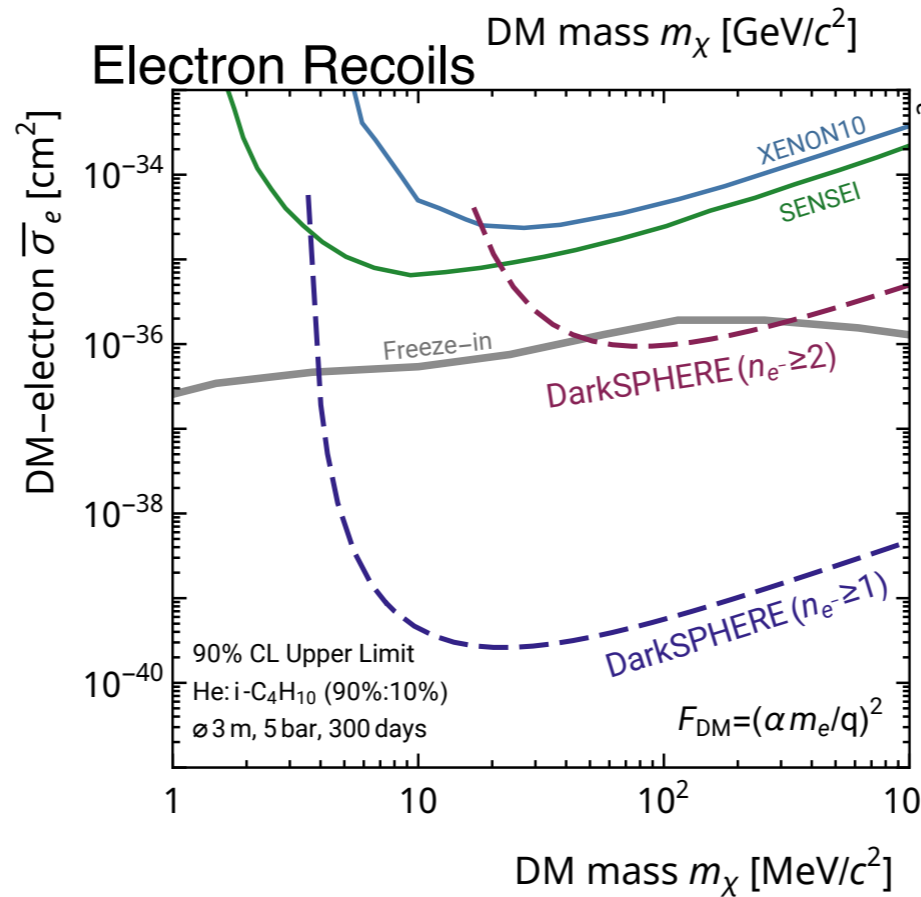
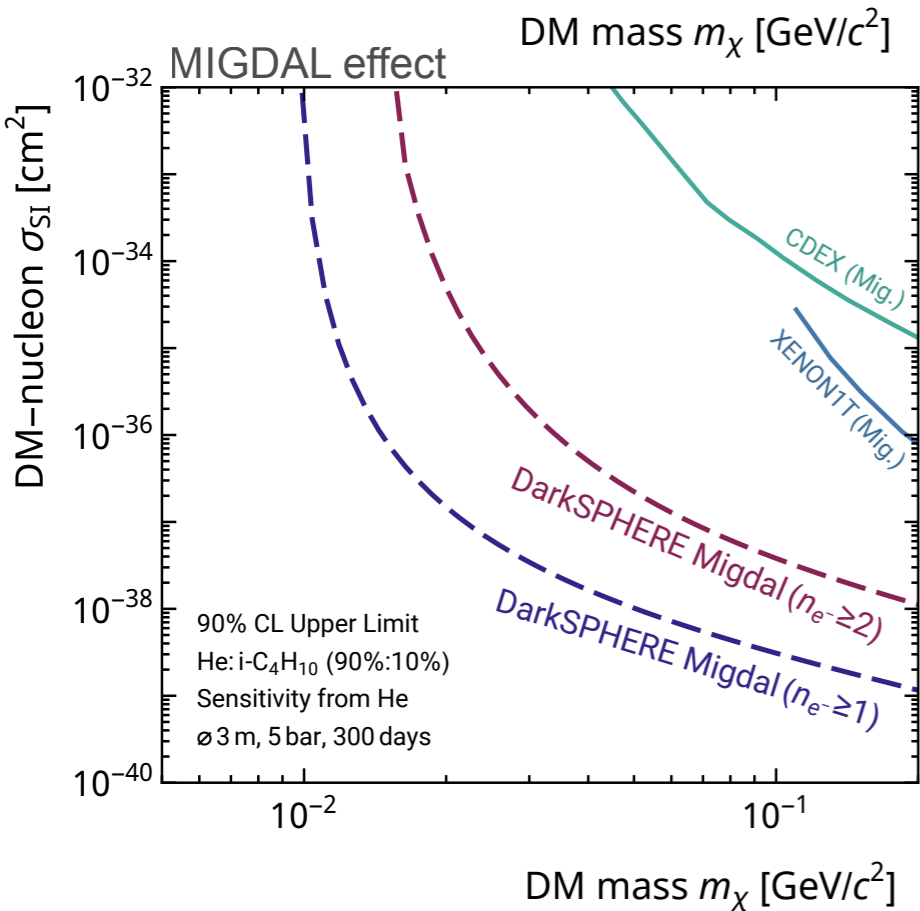
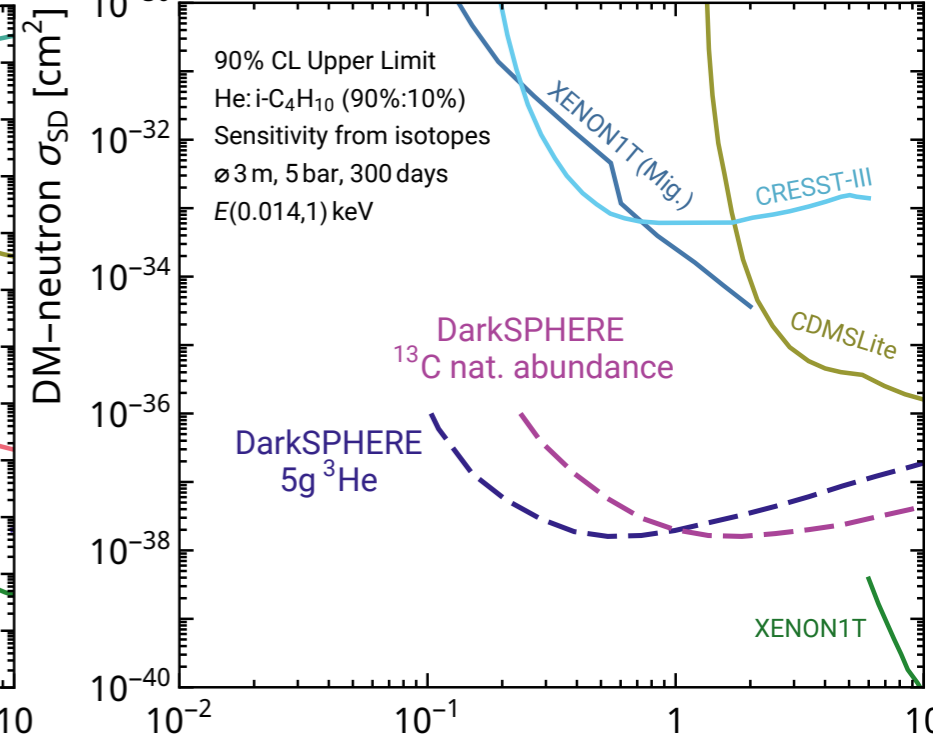
Nuclear Recoils



SD - Proton



SD - Neutron



DarkSPHERE PhD Project

- Construct and operate a prototype detector at Boulby
 - Contribute to the electroforming of miniDarkSPHERE
 - Characterise detector in terms of radiopurity
 - Commission and operate miniDarkSPHERE
 - Extract first physics results!
- The PhD student will be fully integrated in the NEWS-G Collaboration
- Benefit from world class facilities and expertise!

