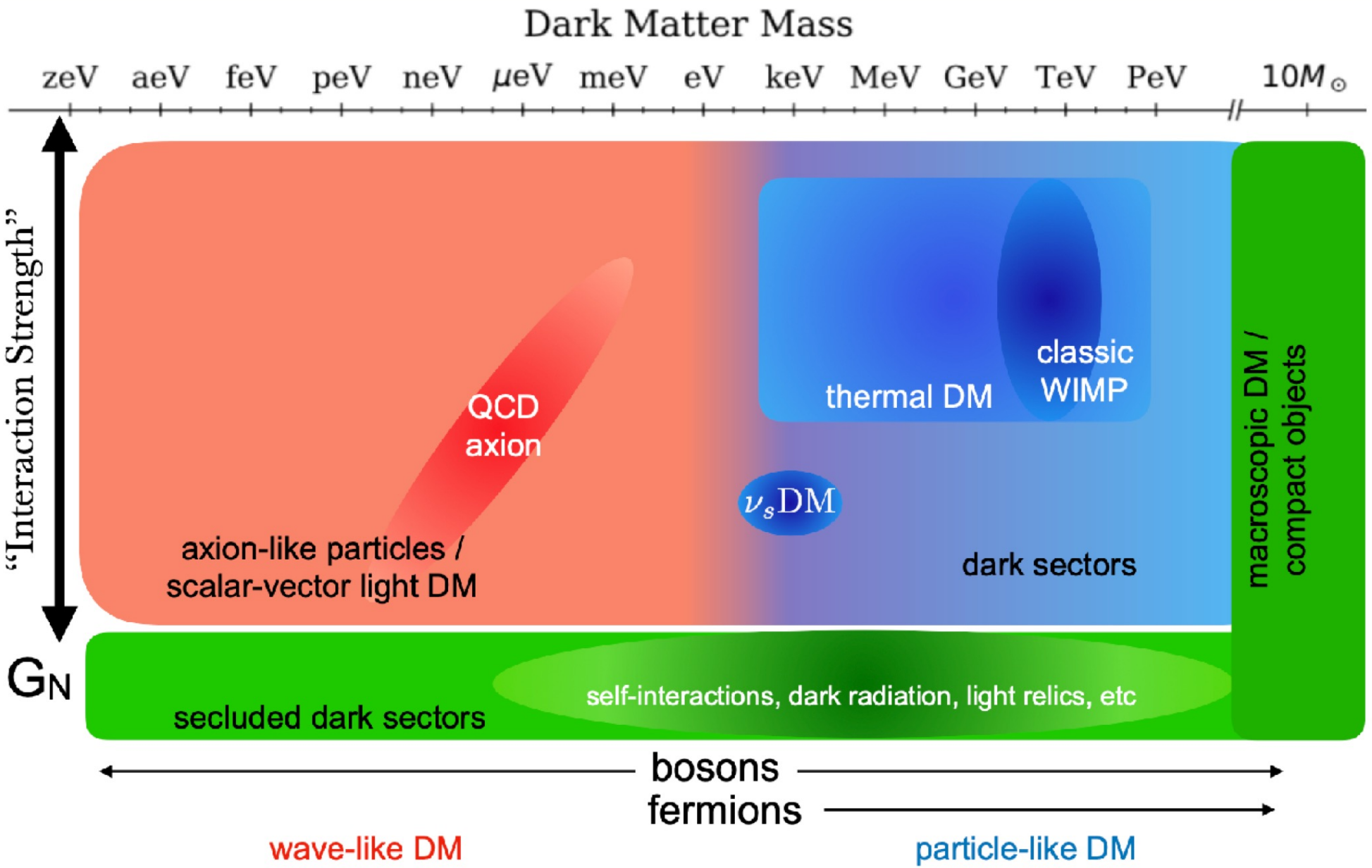
STATUS AND PROSPECTS IN DARK MATTER DIRECT DETECTION

DSU 2022

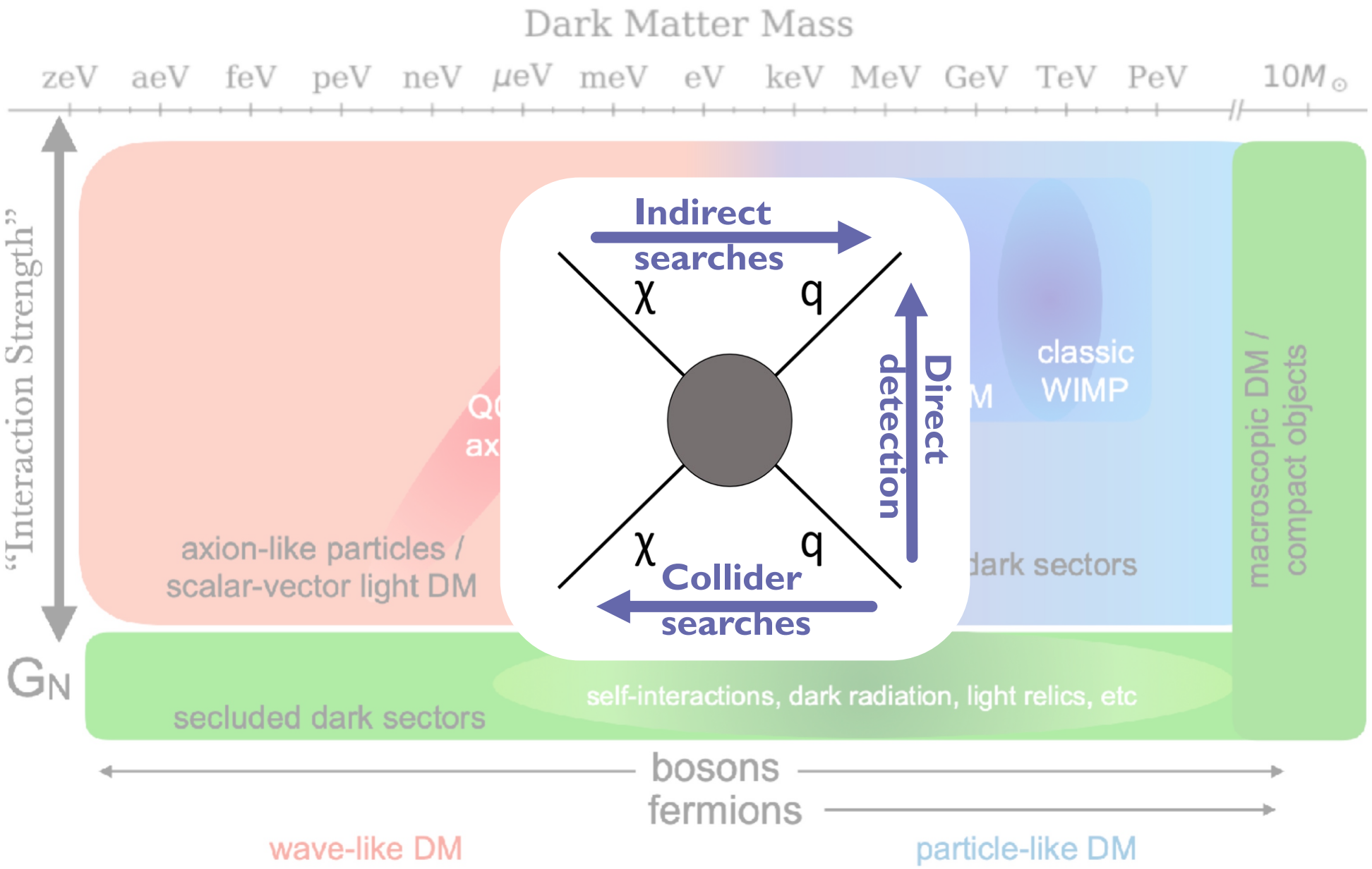
THERESA FRUTH, UNIVERSITY OF SYDNEY

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

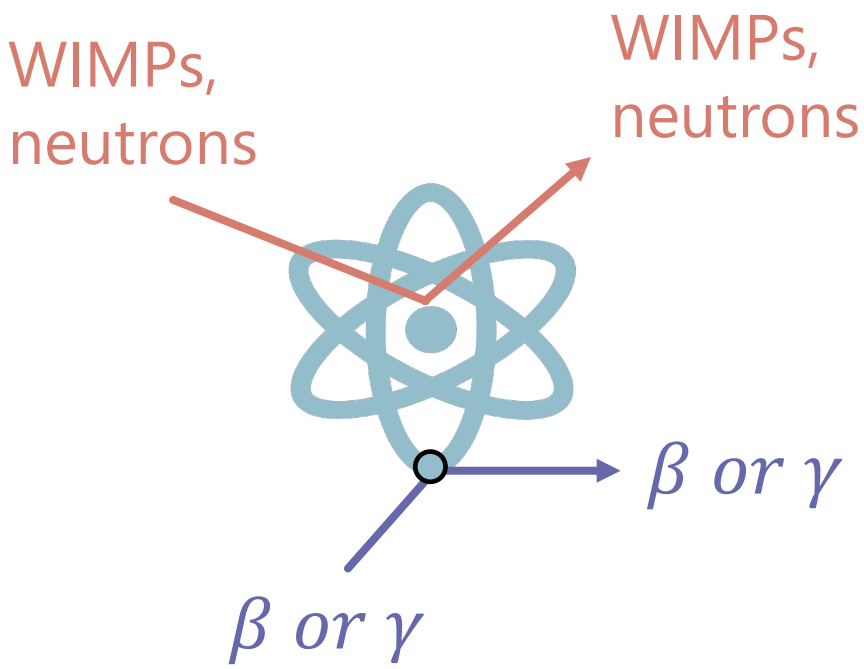
THE UNIVERSITY OF SYDNEY



SNOWMASS 2021, Cosmic Frontiers Report


Dark Matter Mass
zeV aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV 10M⊙
"Interaction Strength"
GN
Indirect searches
χ
q
Direct detection
χ
q
Collider searches
classic WIMP
axion-like particles / scalar-vector light DM
dark sectors
macroscopic DM / compact objects
secluded dark sectors
self-interactions, dark radiation, light relics, etc
bosons
fermions
wave-like DM
particle-like DM

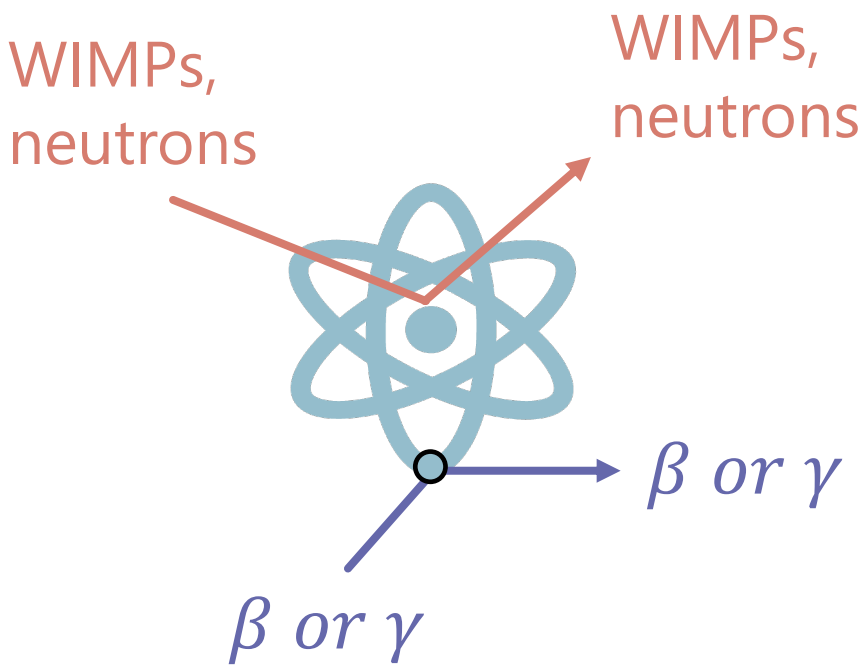
DIRECT DETECTION SEARCHES FOR PARTICLE-LIKE DM



DM particle (mass: GeV-TeV) scatters elastically of nucleus causing a nuclear recoil

- Rare events (< 0.0001 evt/kg/day)
- Low energy (~ keV scattering)

DIRECT DETECTION SEARCHES FOR PARTICLE-LIKE DM



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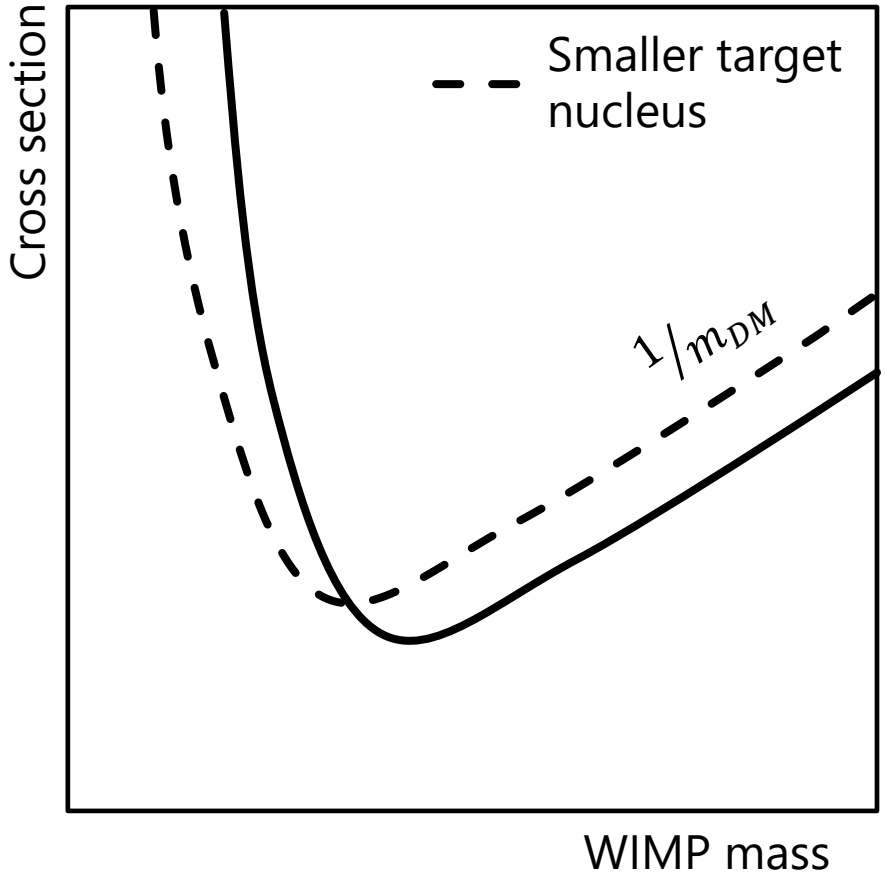
We need to:

- Reduce backgrounds
- Achieve low energy thresholds
- Maximise exposure

DIRECT DETECTION SEARCHES FOR PARTICLE-LIKE DM



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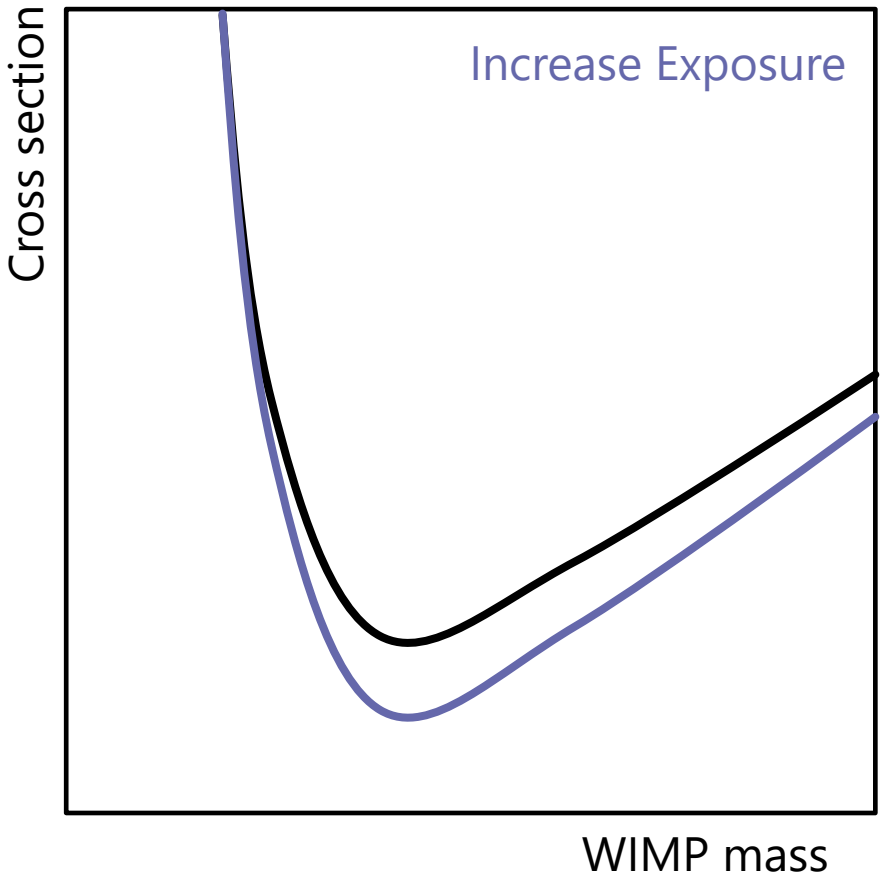

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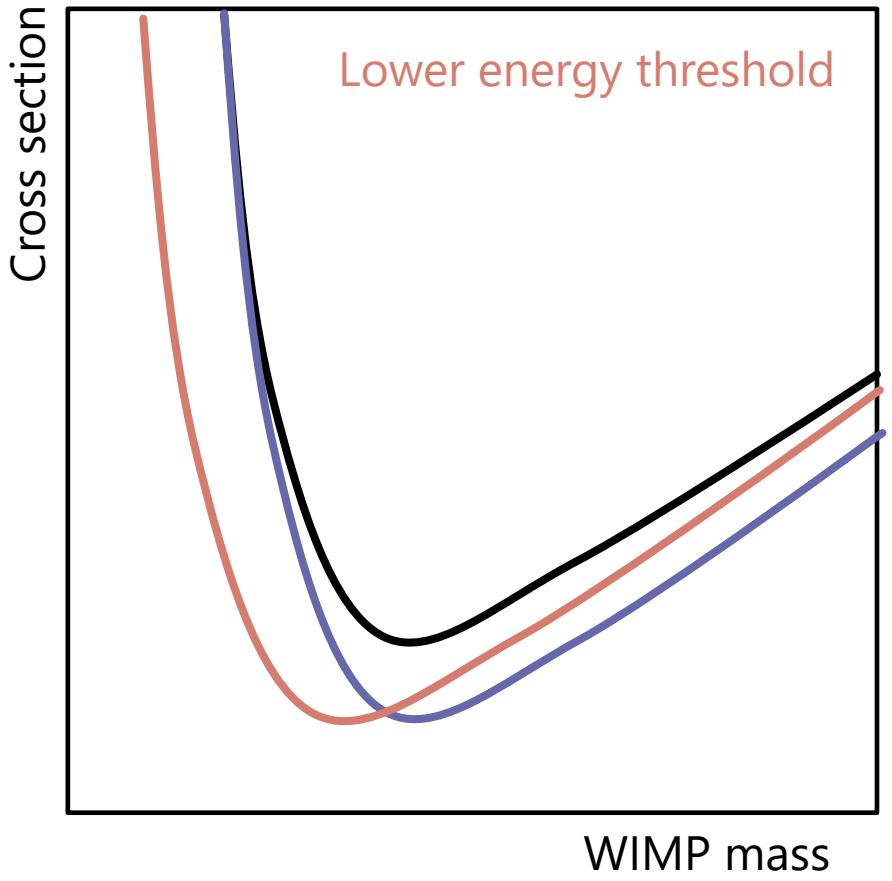

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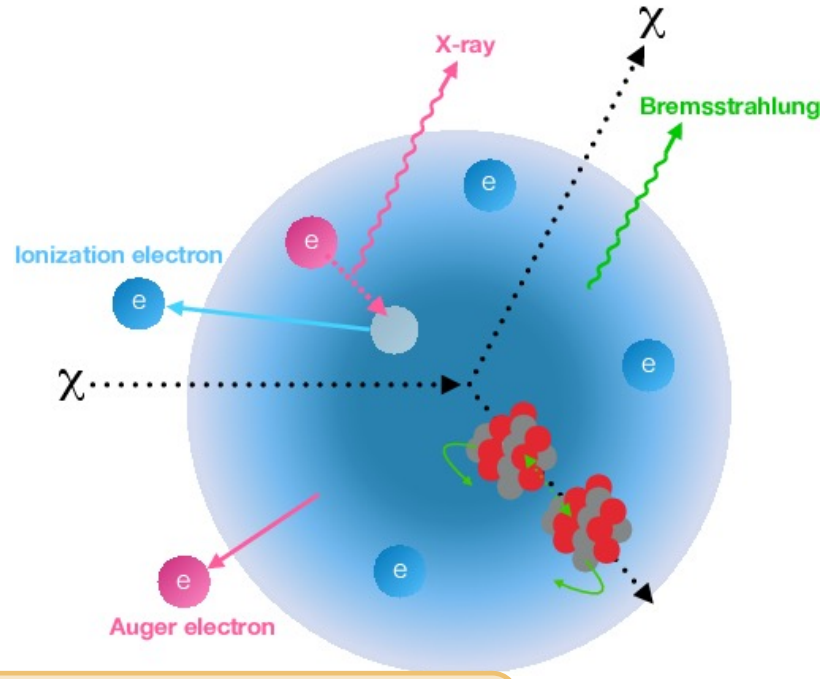
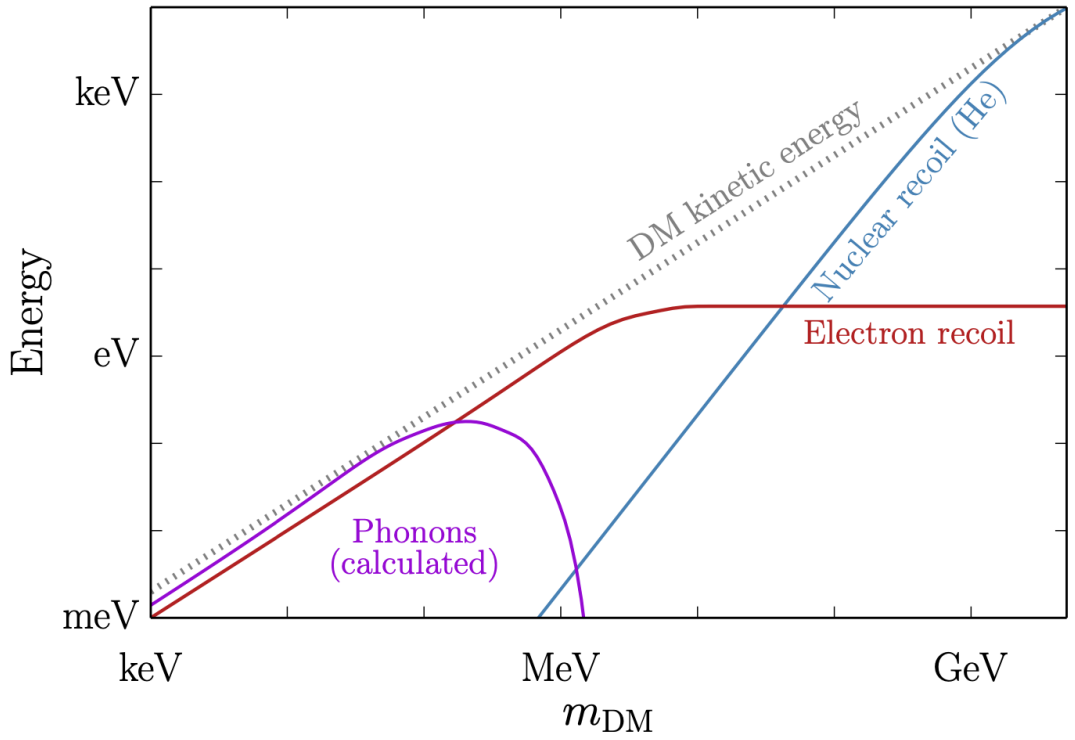
PUSHING TO LOWER DM MASSES

Migdal effect & Bremsstrahlung[1]



Peter Cox's talk,
DM parallel Tuesday 2.20pm

DM – electron scattering[2]

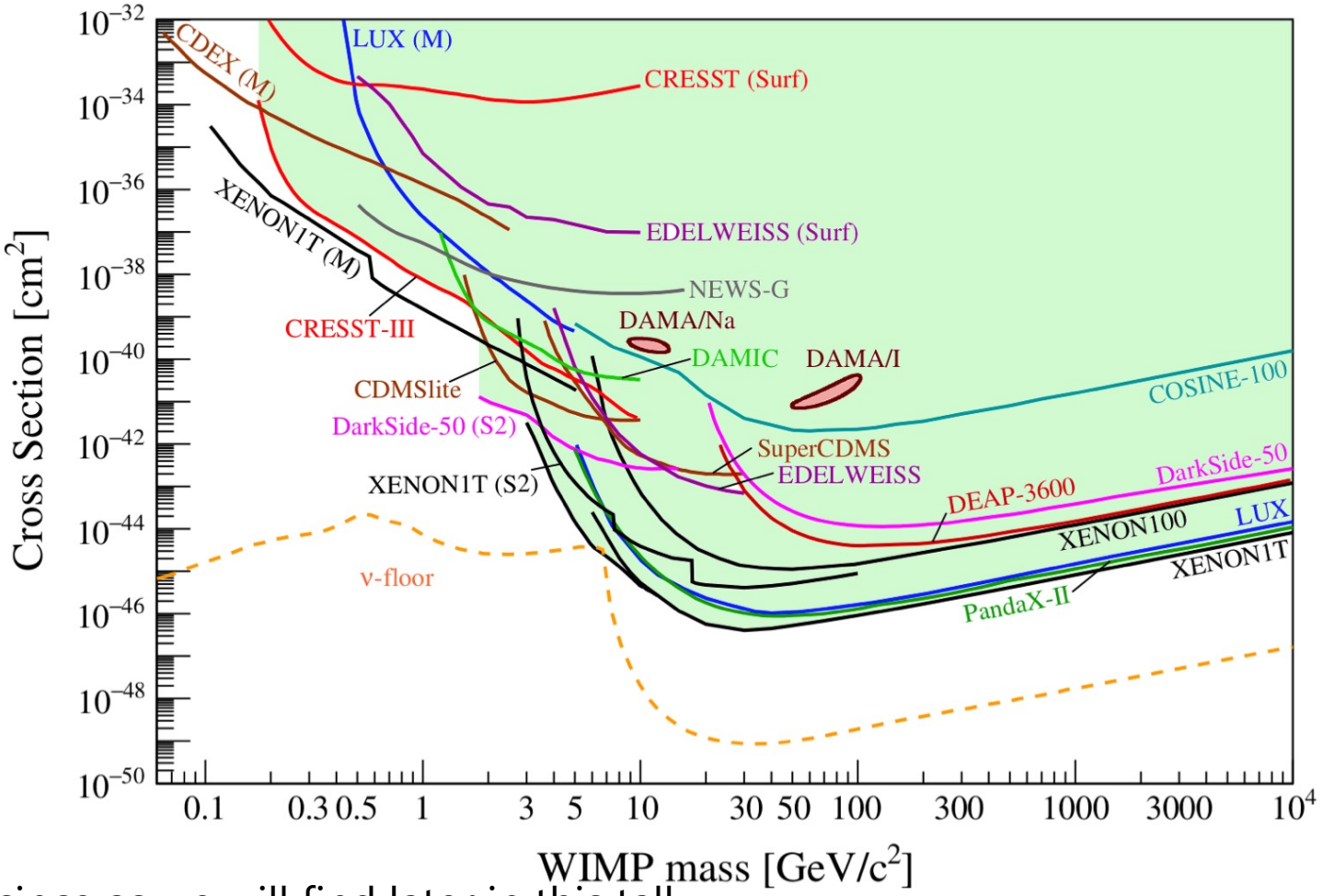


$$DM\ kinetic\ energy = \frac{1}{2} m_\chi v$$

[1]XENON1T, https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.123.241803
[2]TASI lectures on DM (Tongyan Lin) https://arxiv.org/pdf/1904.07915.pdf

APPEC Committee Report 2021, https://arxiv.org/pdf/2104.07634.pdf

STATUS TODAY



*almost – a few updates since as we will find later in this talk

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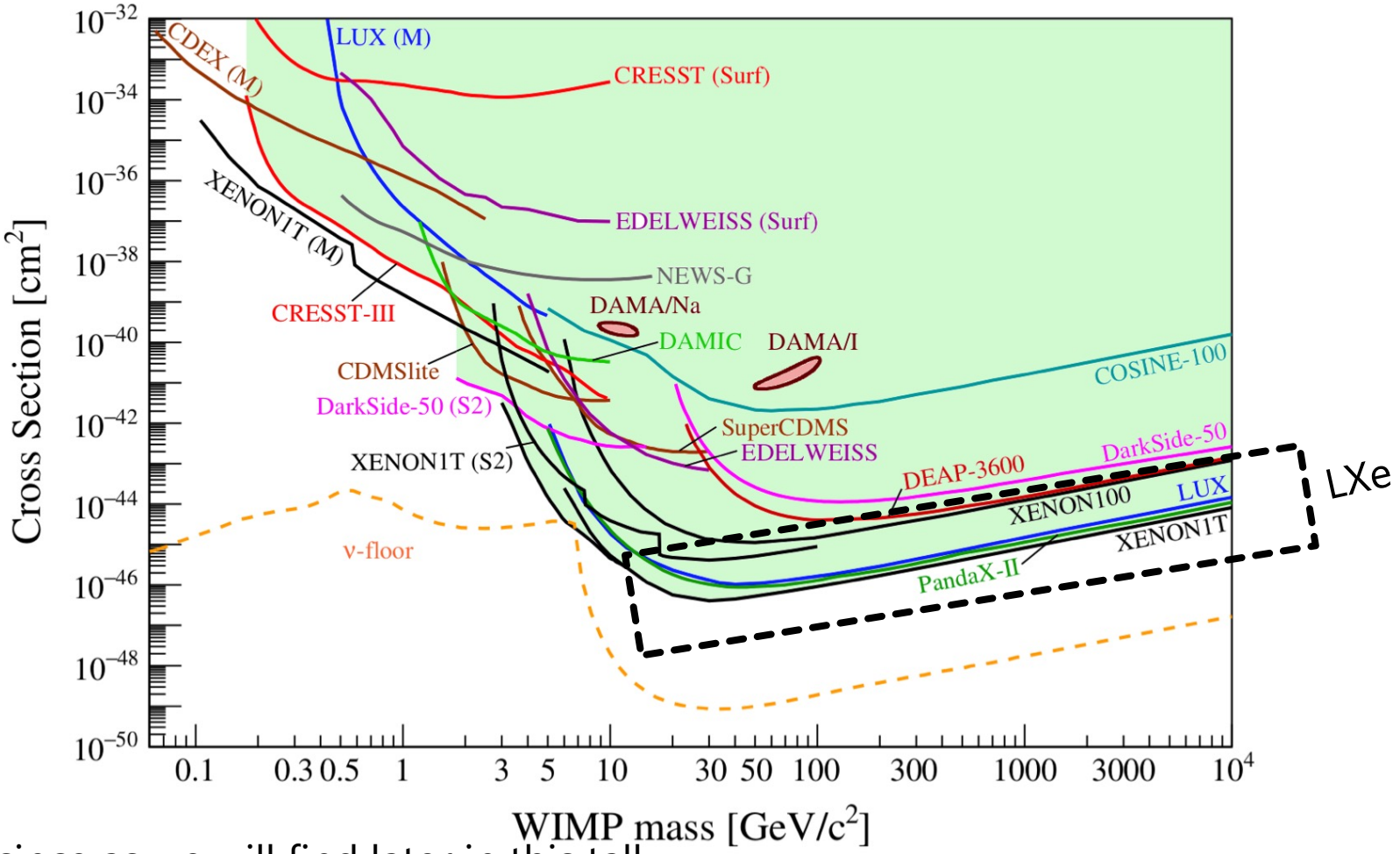

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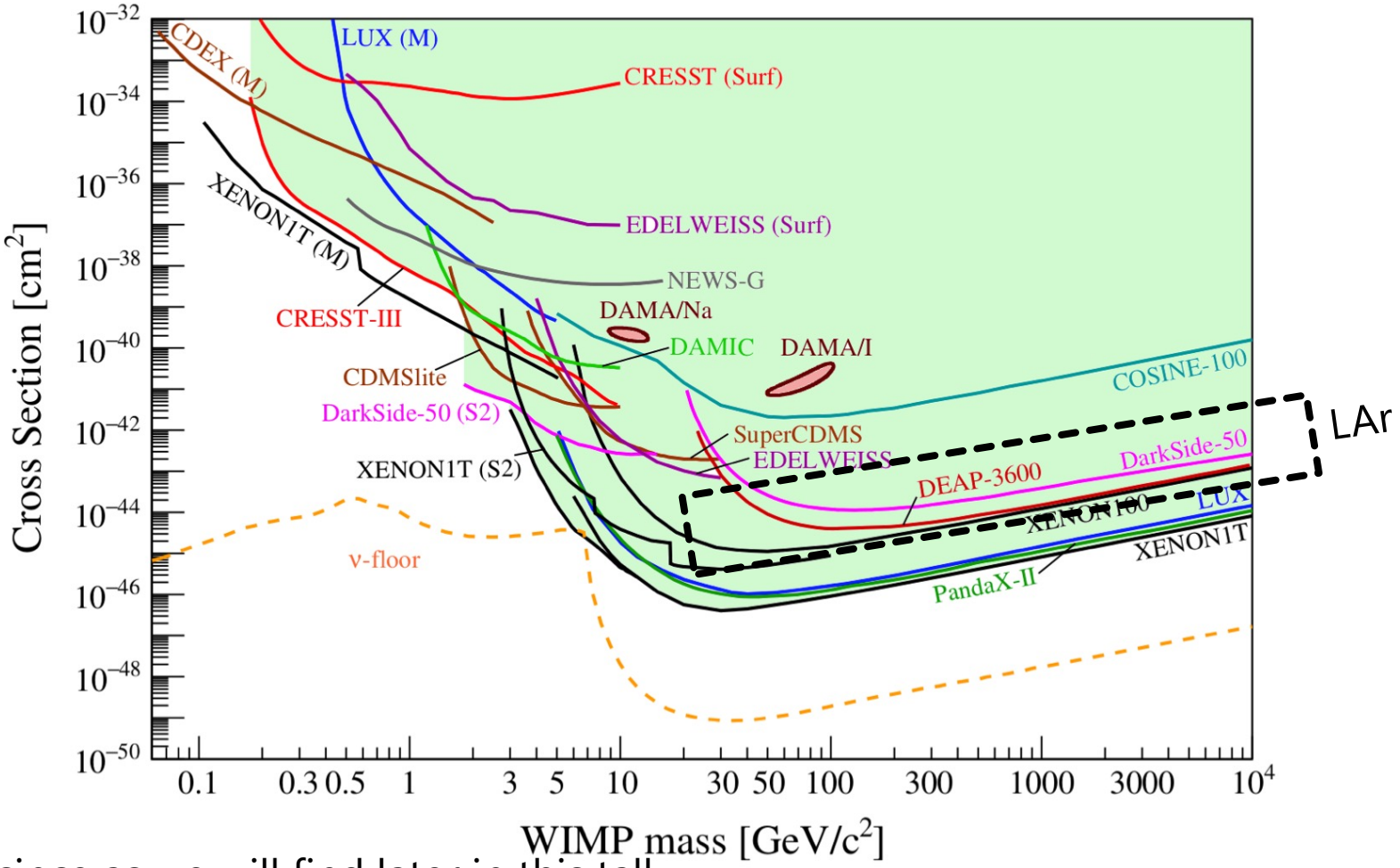

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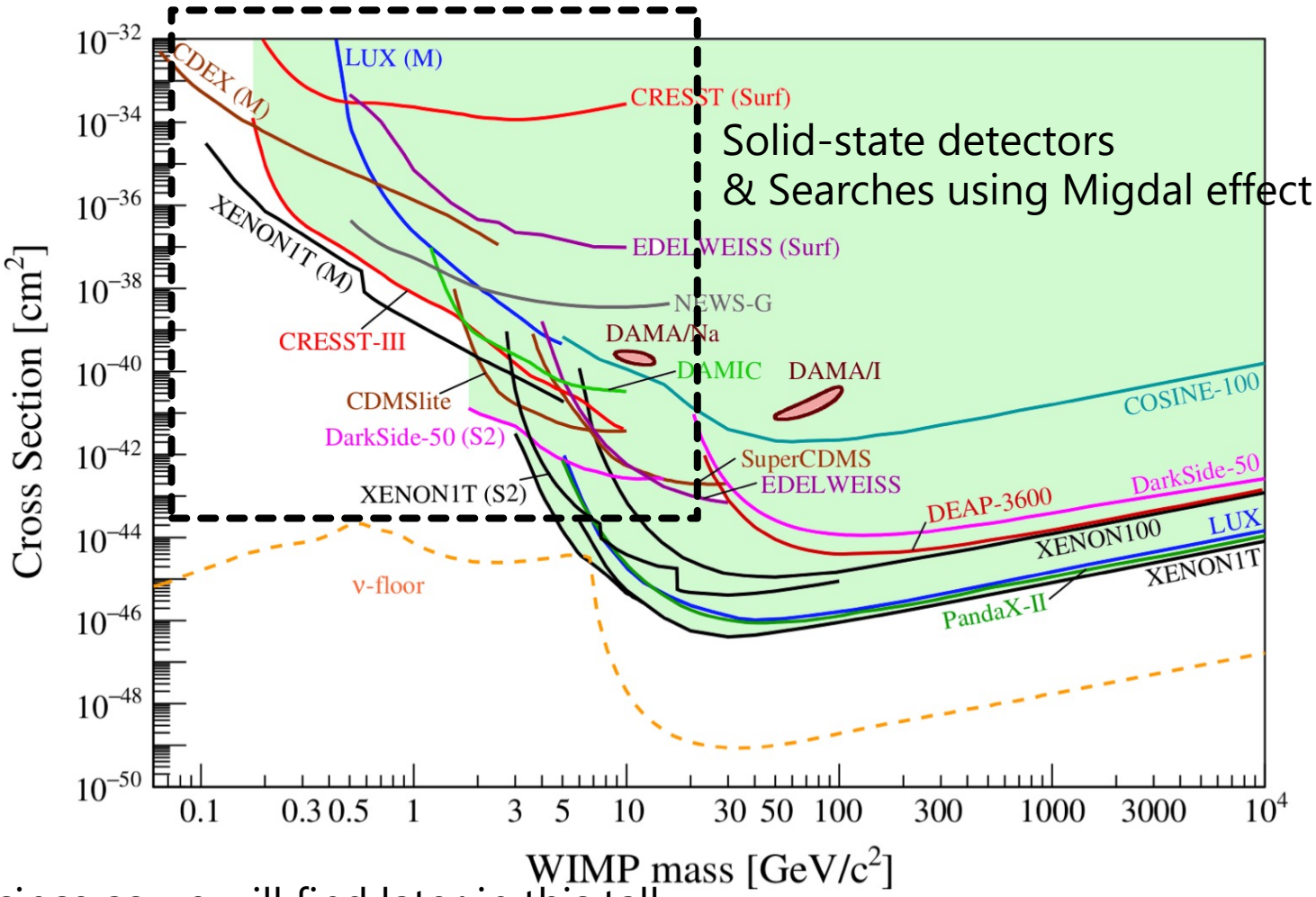

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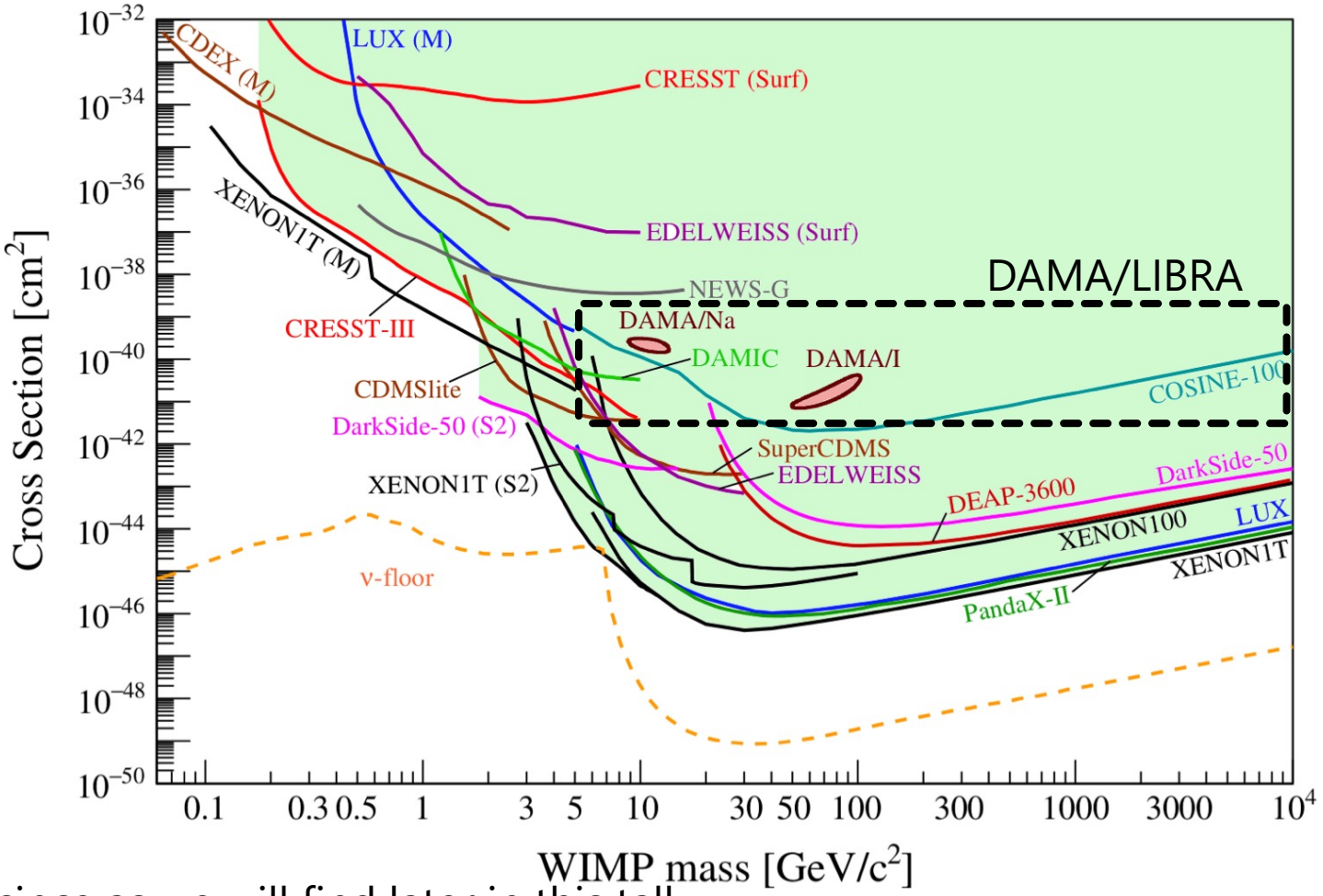

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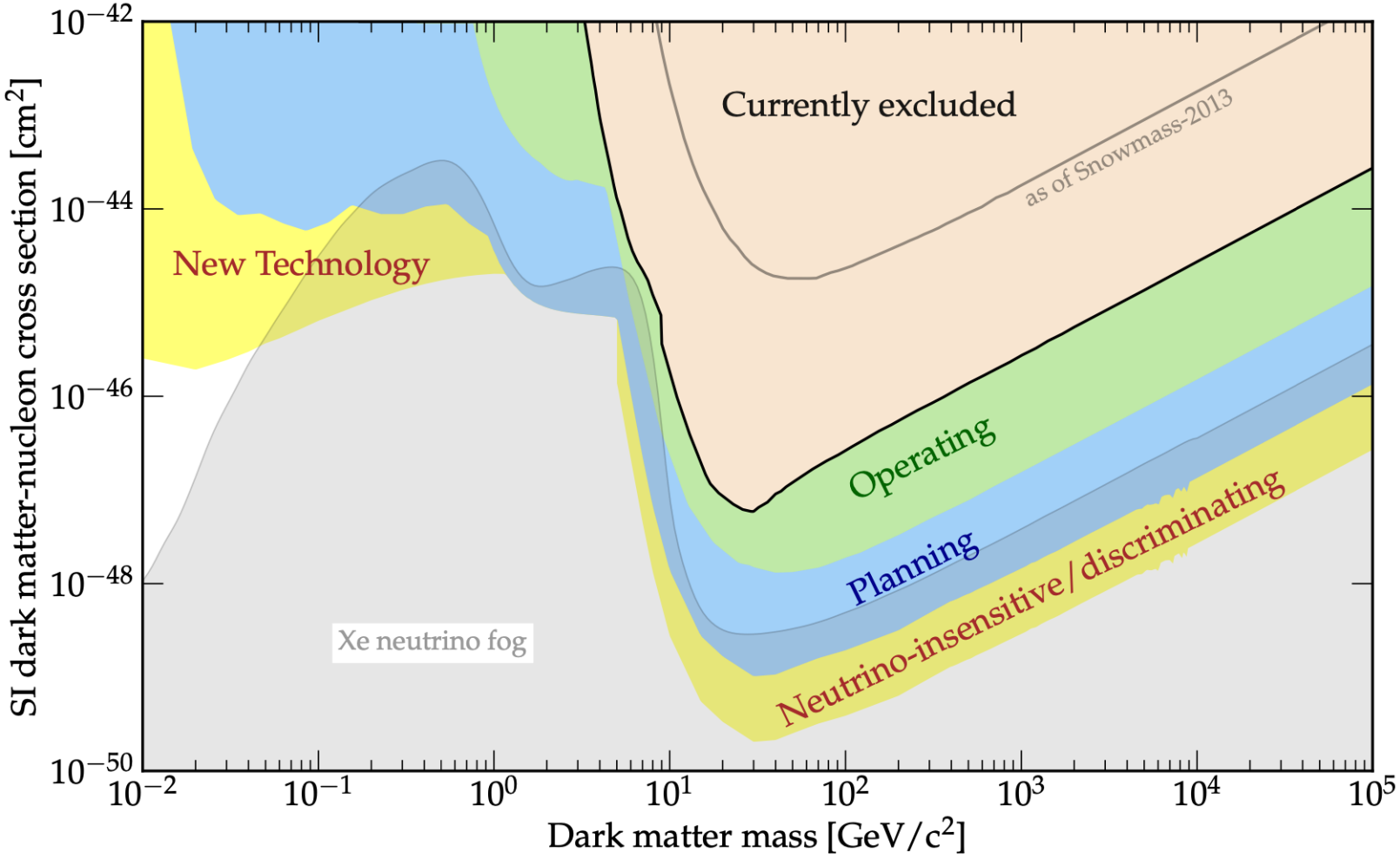
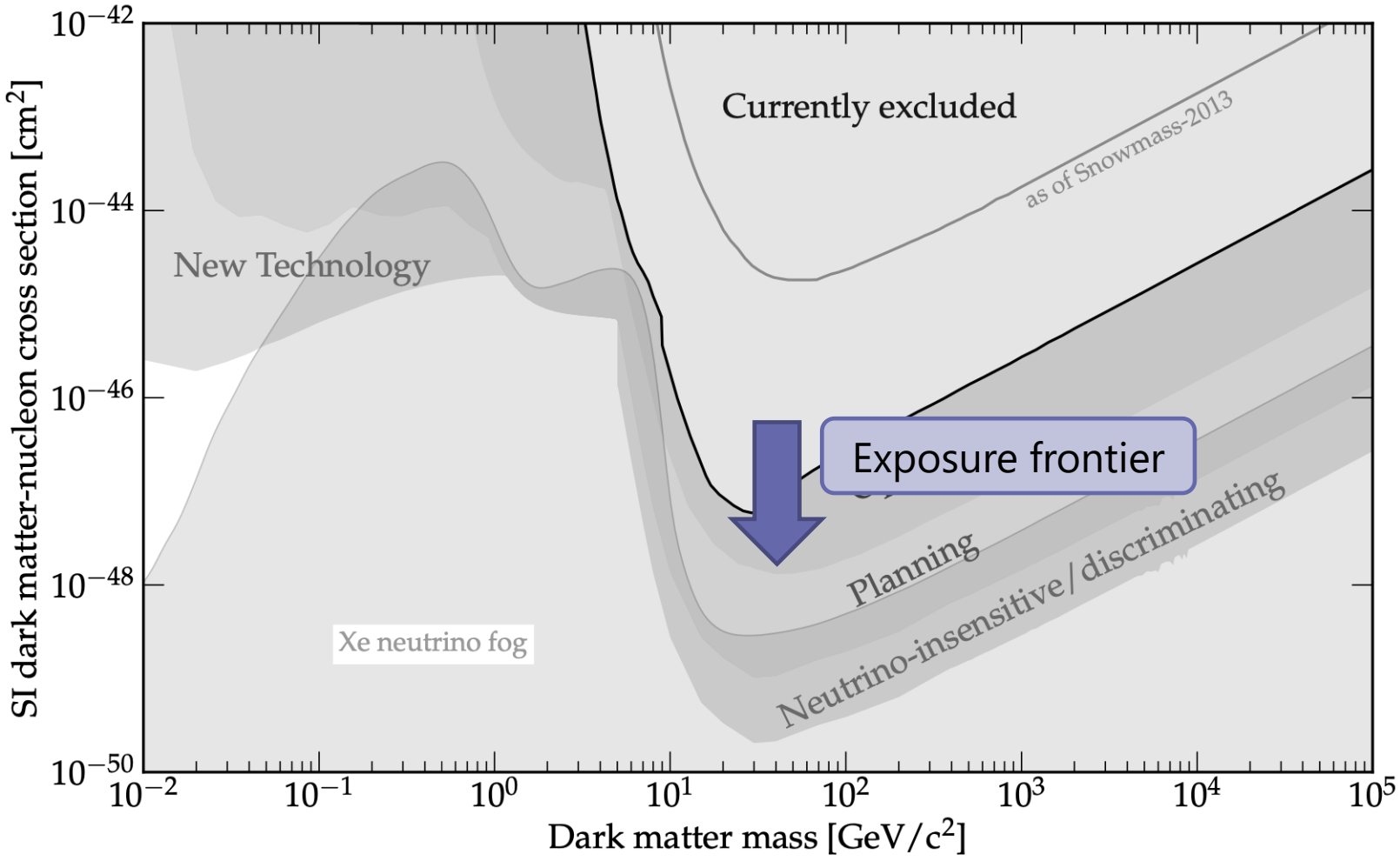
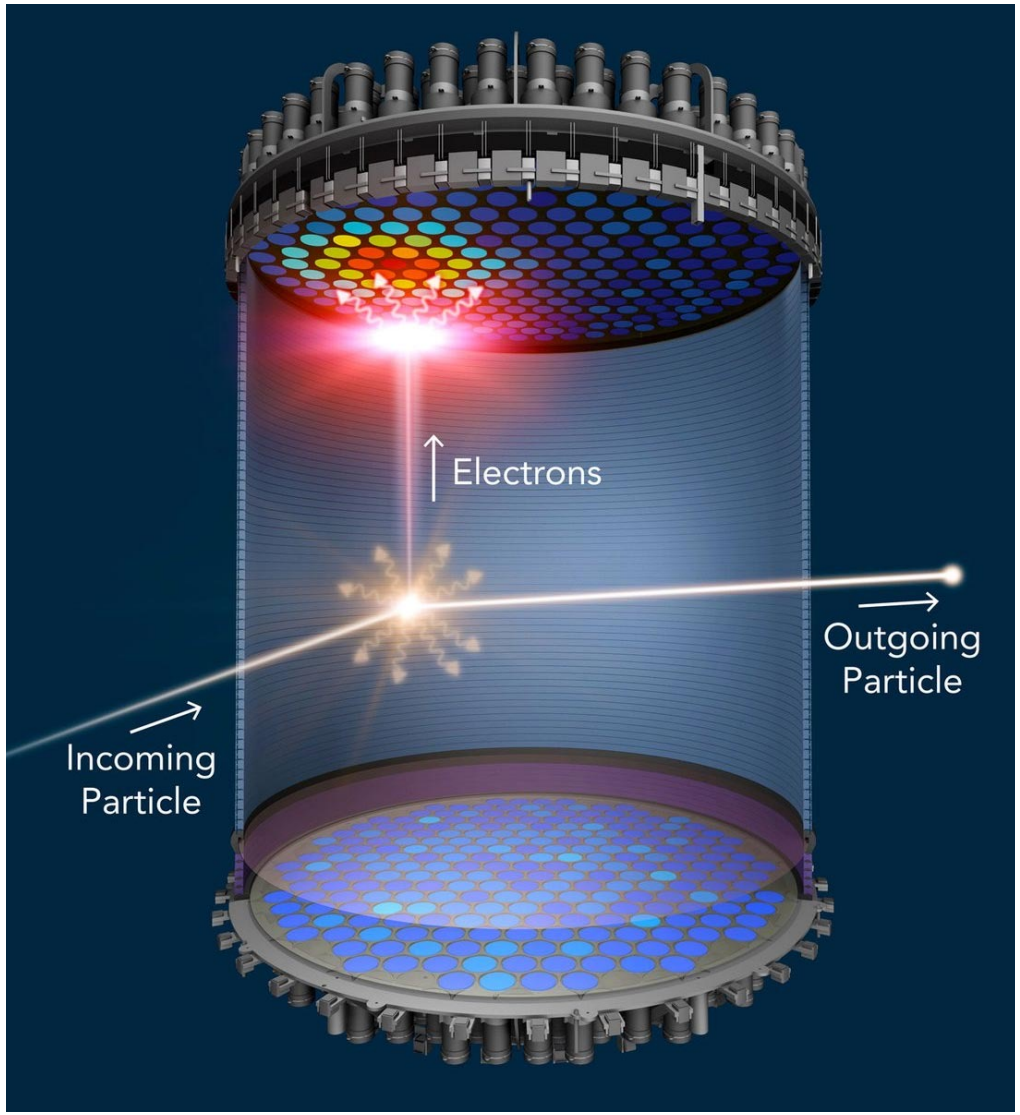


DIRECT DETECTION FRONTIERS



LIQUID NOBLE DETECTORS

Exposure frontier

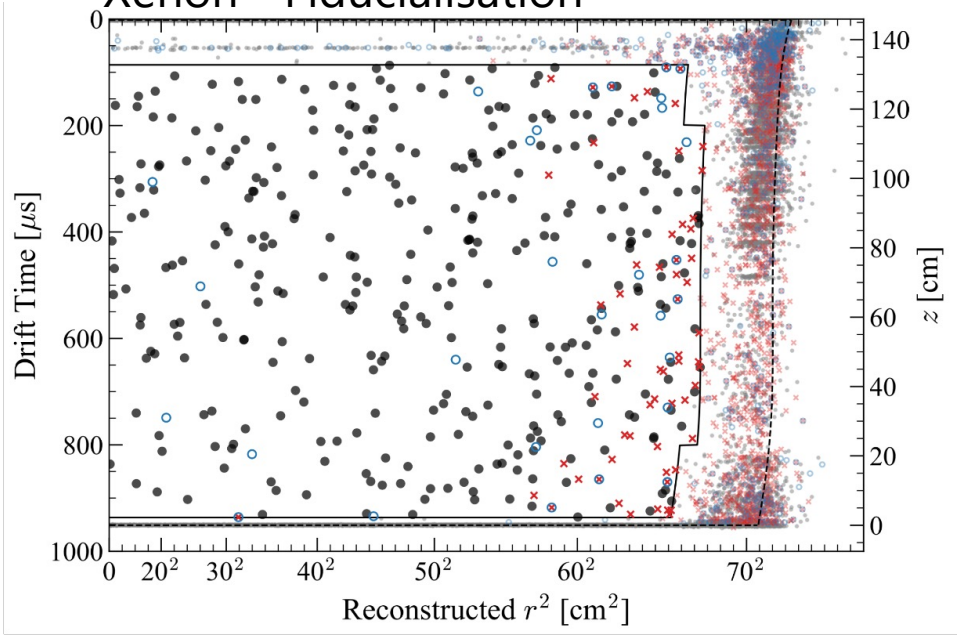


- Noble Liquids: Xe, Ar
- Good scintillators and easily ionized
- Scintillation signal & electroluminescence from ionization charge (in TPC configuration)
- Large target volume, fiducialisation possible
- Event-by-event discrimination by S2/S1 ratio (Xe) or pulse-shape (Ar)

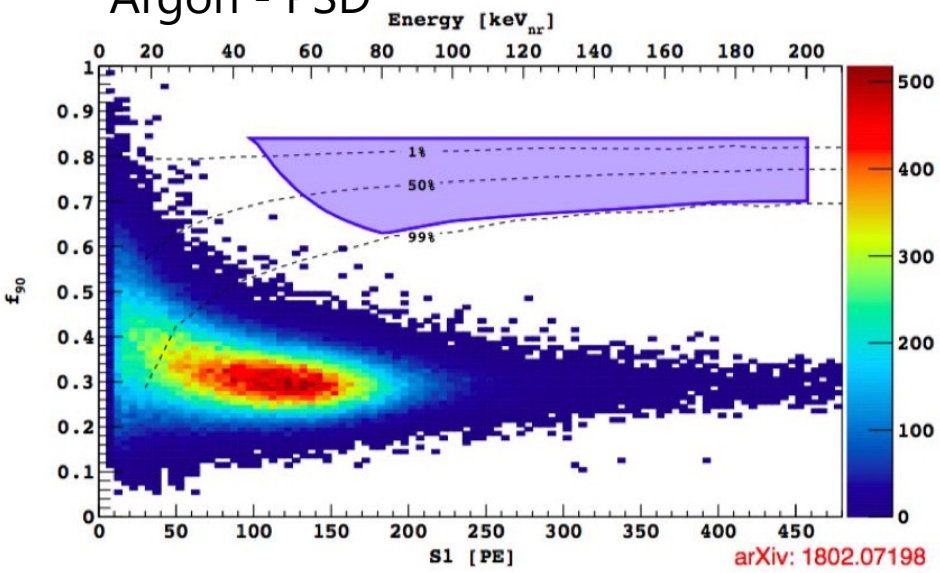
LIQUID NOBLE DETECTORS

Exposure frontier

Xenon - Fiducialisation



Argon - PSD



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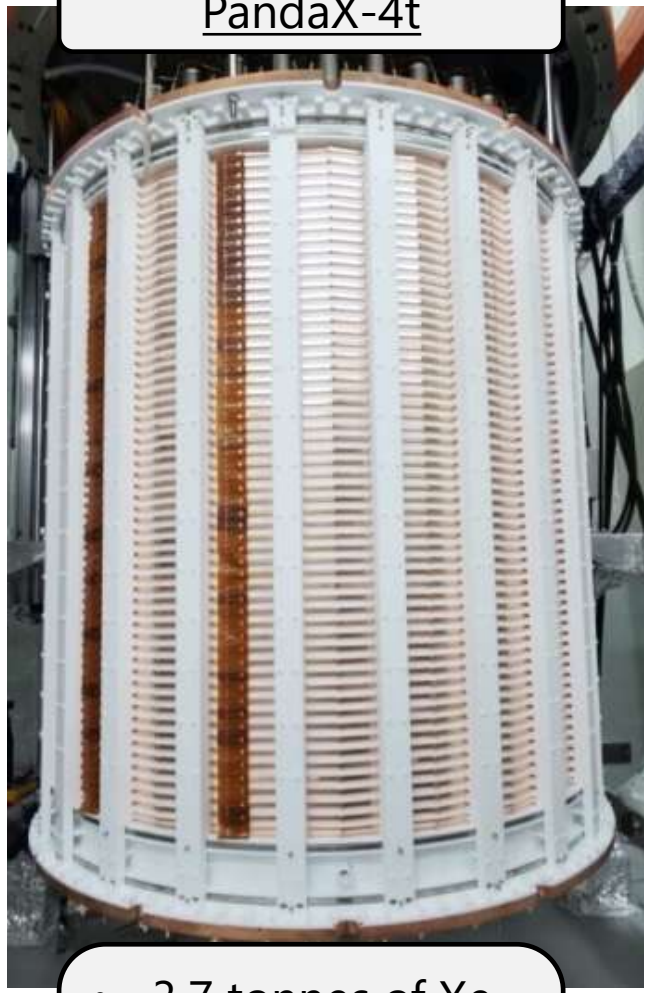
LIQUID NOBLE DETECTORS

Exposure frontier

PandaX-4t



- 3.7 tonnes of Xe (active volume)
- 368 PMTs
- Status: running

XENONnT

- 5.9 tonnes of Xe (active volume)
- 494 PMTs
- Status: running

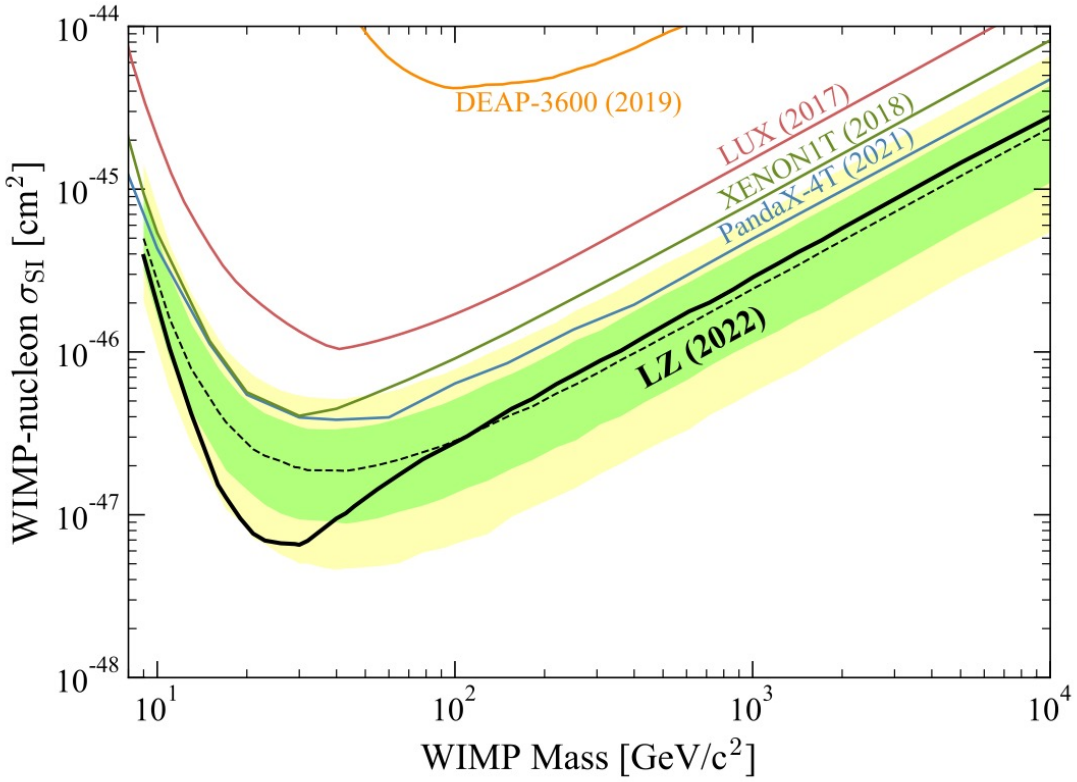
LZ

- 7 tonnes of Xe (active volume)
- 494 PMTs
- Status: running

2022 RESULTS

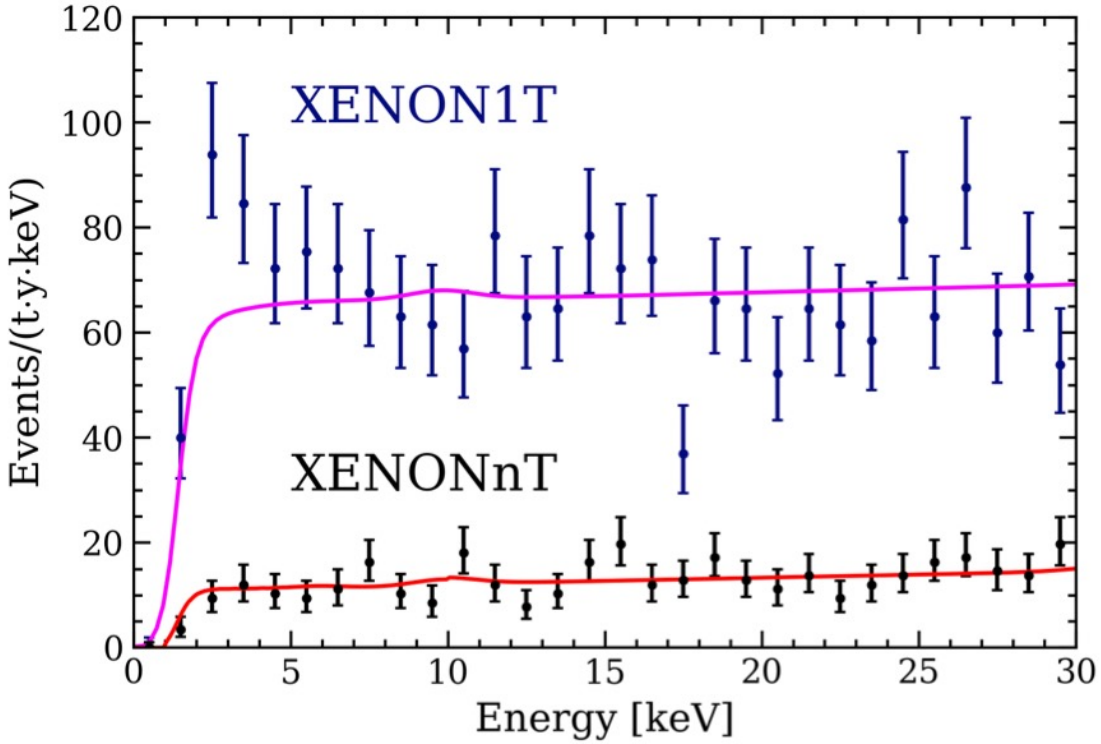
Exposure frontier

LZ[1]



Nishat Parveen's talk,
DM parallel today 2pm

XENONnT[2]



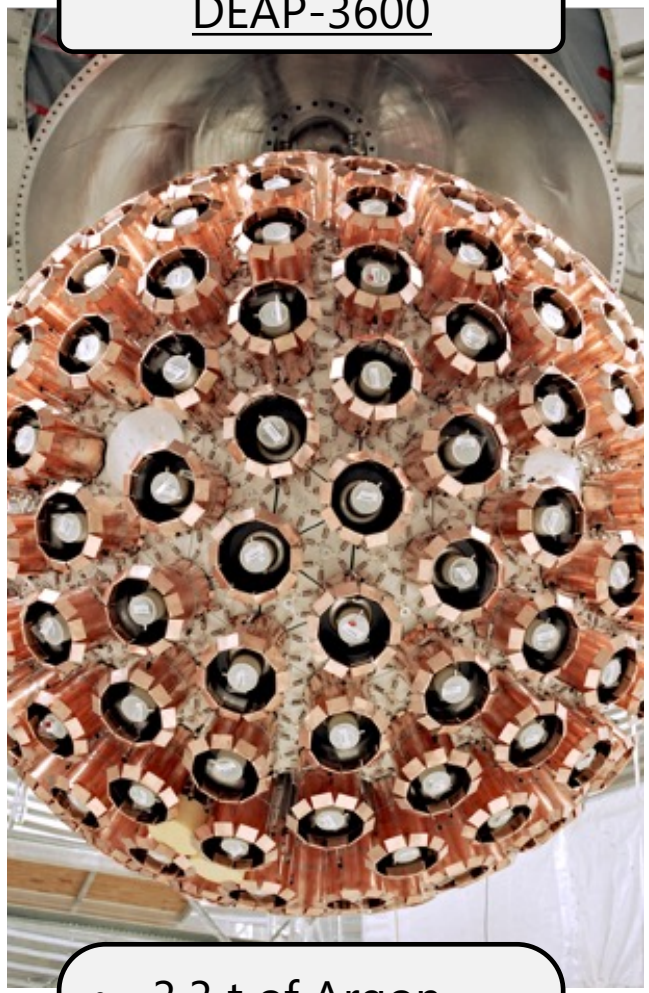
Yajing Xing's talk,
DM parallel today 2.20pm

[1] First dark matter search result from the LZ Experiment (https://arxiv.org/abs/2207.03764)
[2] Search for New Physics in Electronic Recoil Data from XENONnT (Phys. Rev. Lett. 129, 161805 (2022))

LIQUID NOBLE DETECTORS

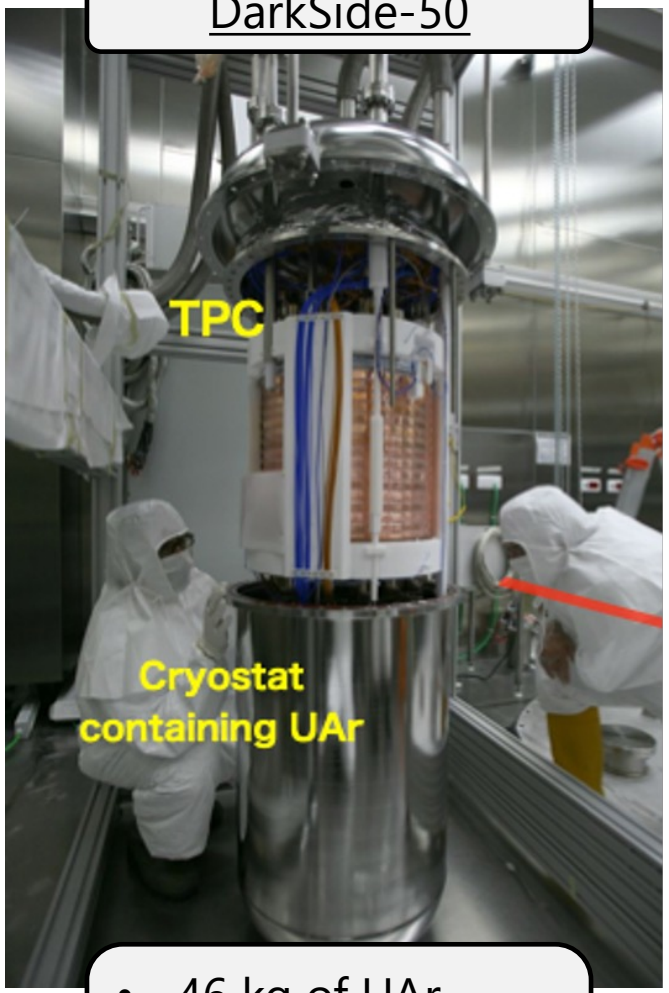
Exposure frontier

DEAP-3600



- 3.3 t of Argon
- 255 PMTs & light guides
- Status: running

DarkSide-50

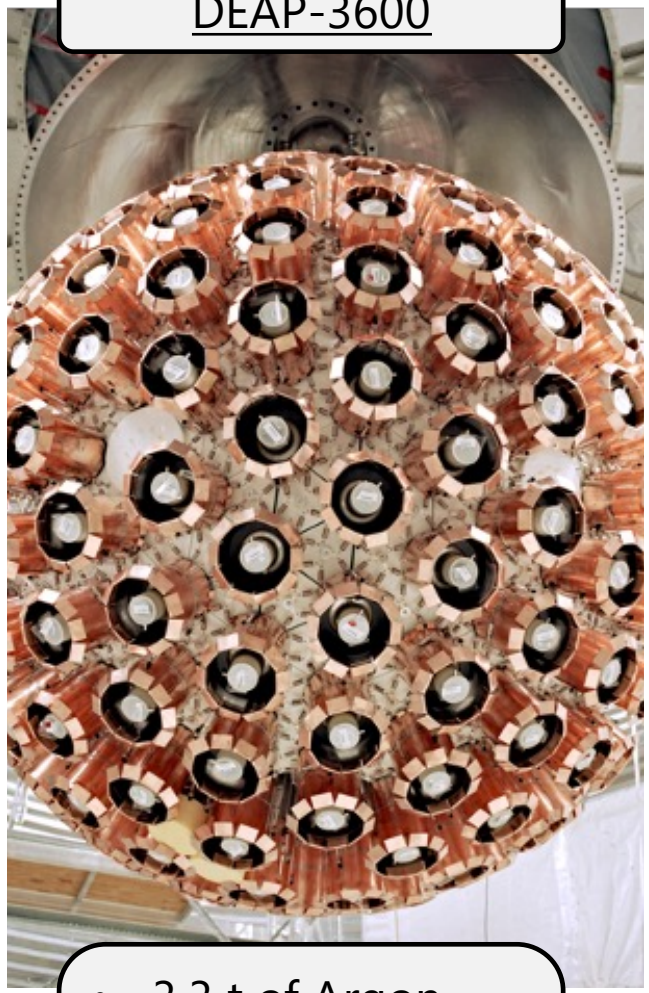


- 46 kg of UAr
- 38 PMTs
- Status: ended

LIQUID NOBLE DETECTORS

Exposure frontier

DEAP-3600



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- 255 PMTs & light guides
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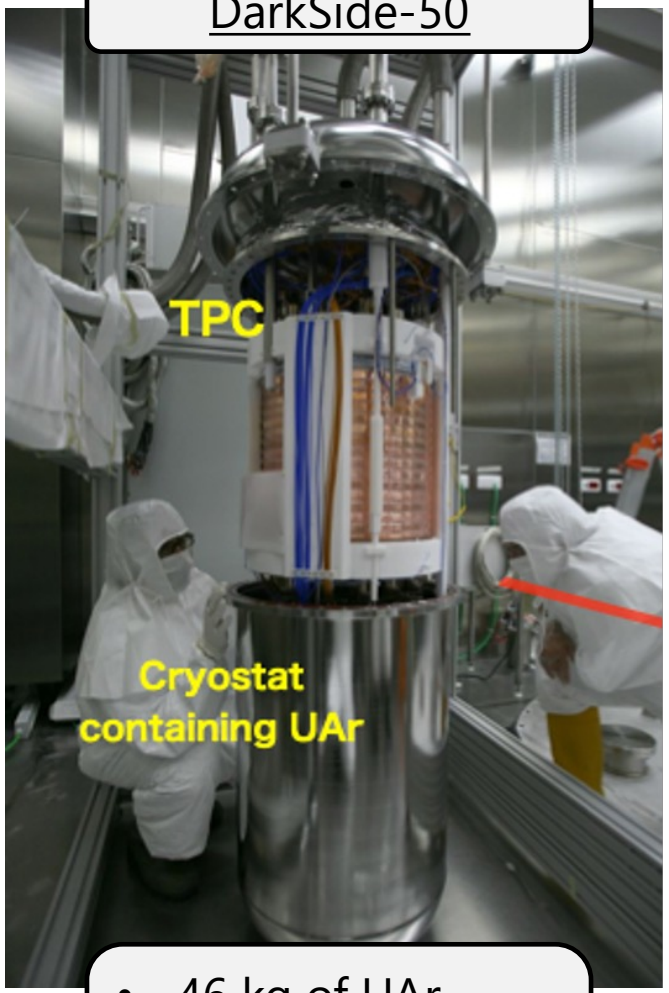
DarkSide-50



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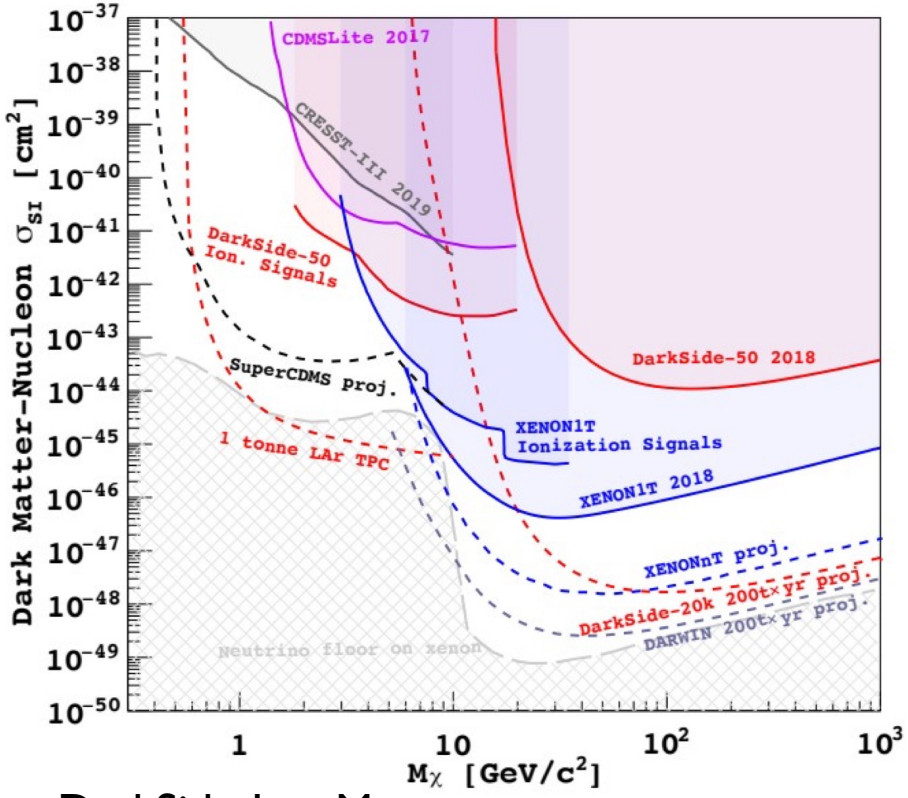


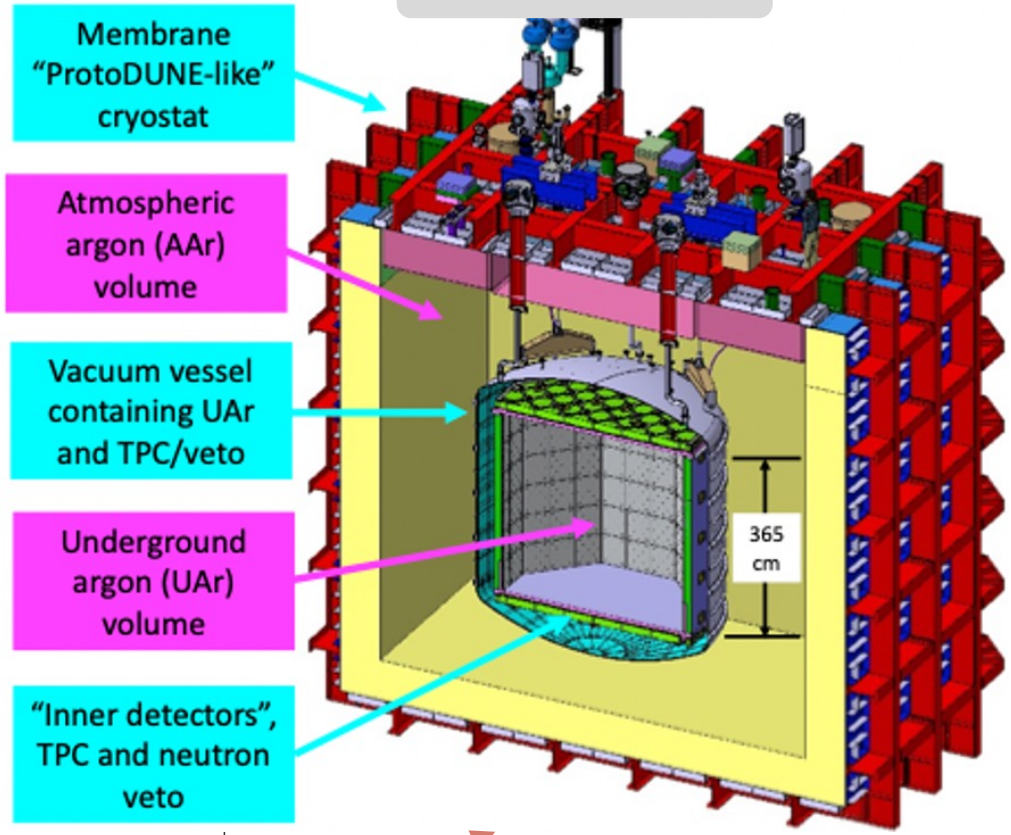
DarkSide-LowMass, SNOWMASS presentation

NEXT GENERATION

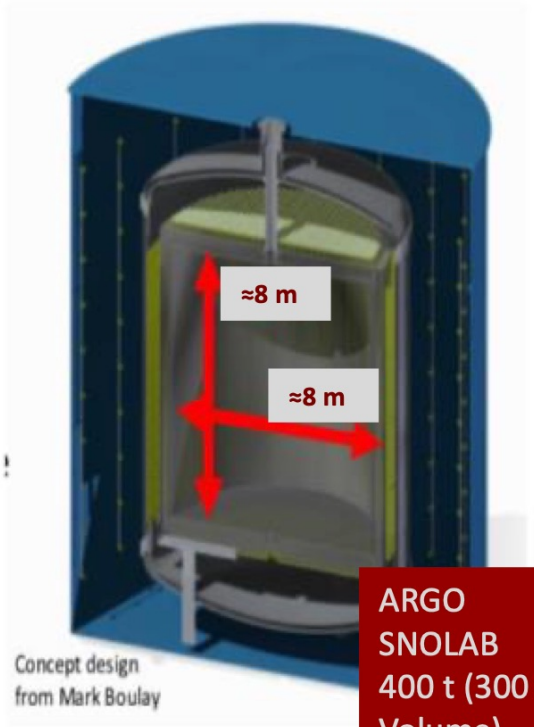
Exposure frontier

Thomas Thorpe's talk,
DM parallel today 3.20pm

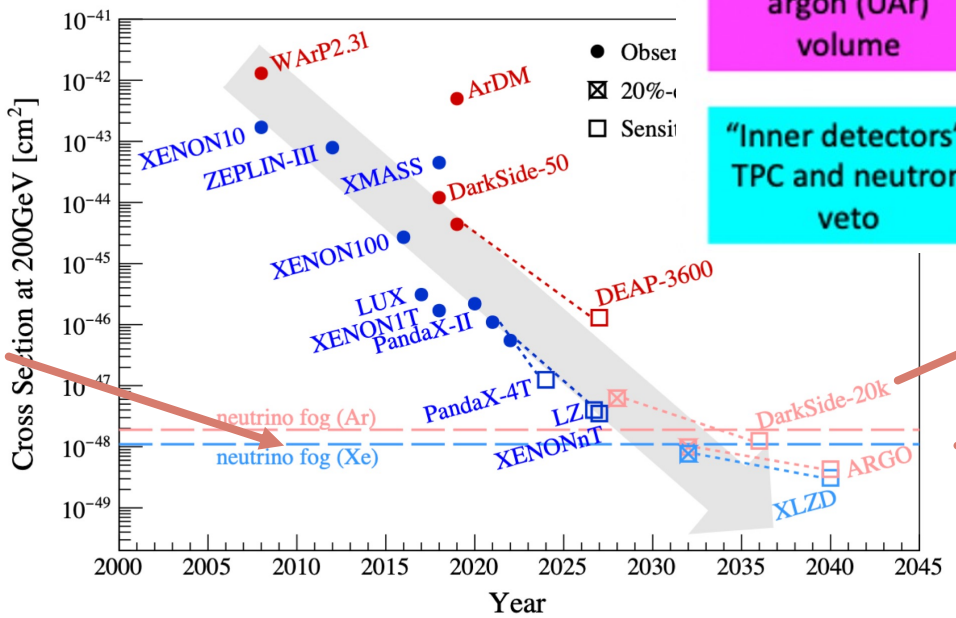
DarkSide – 20k



ARGO



ARGO
SNOLAB
400 t (300 t Fiducial Volume)



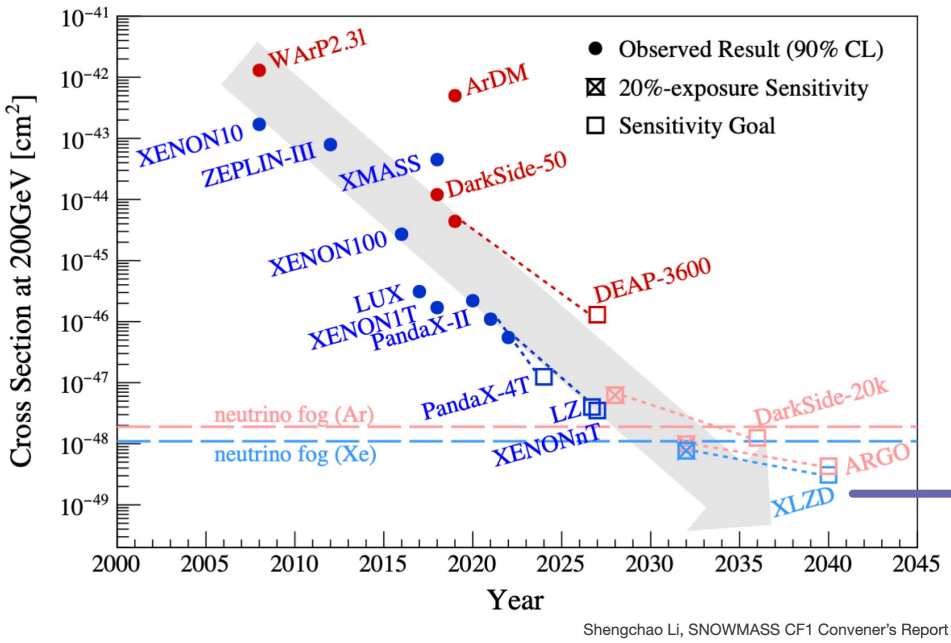
Shengchao Li, SNOWMASS CF1 Convener's Report

Global Argon Dark Matter Community

NEXT GENERATION

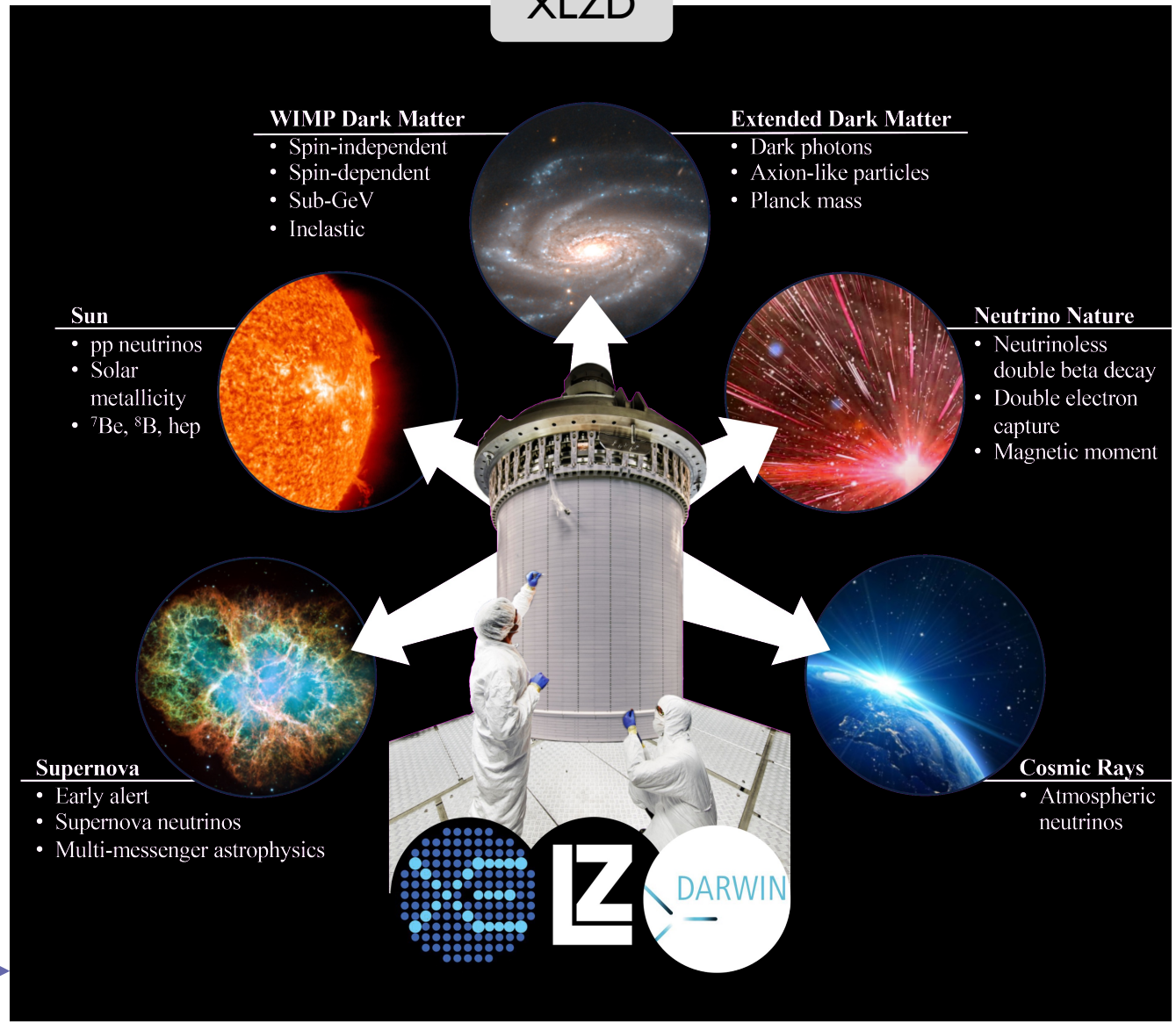
Exposure frontier

Sara Diglio's talk,
DM parallel today 3pm



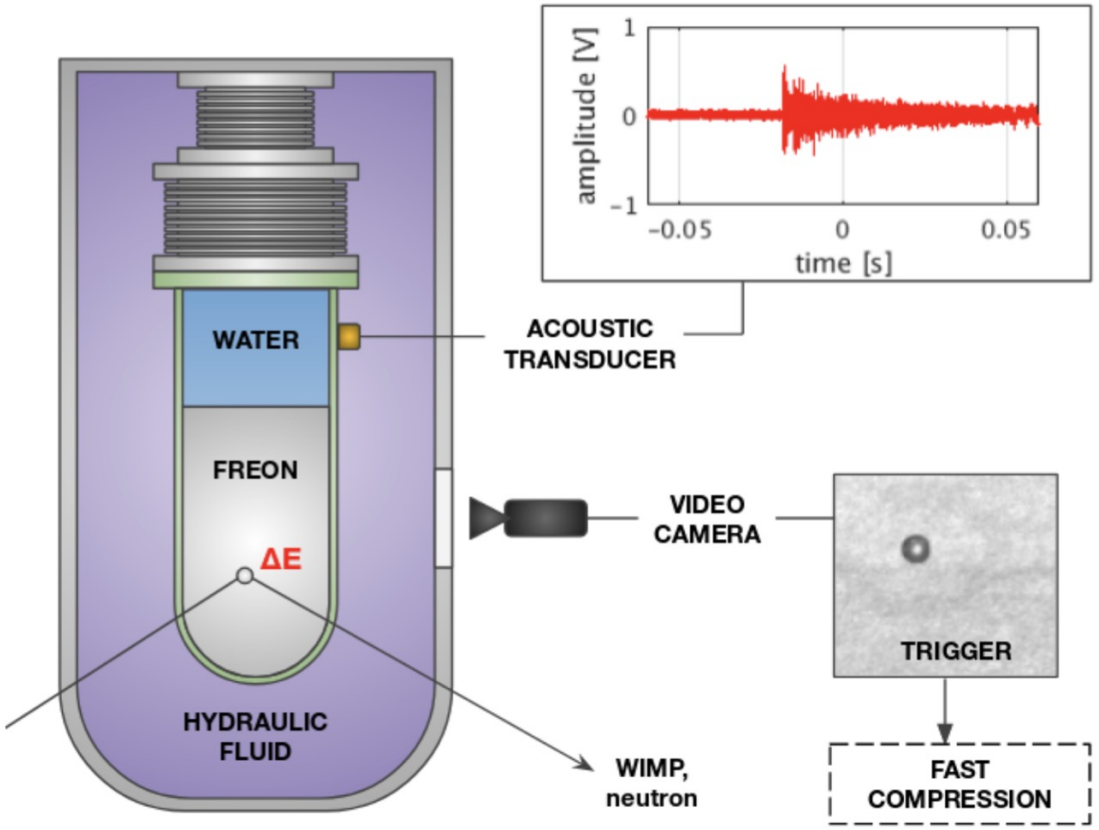
Shengchao Li, SNOWMASS CF1 Convener's Report

XLZD



BUBBLE CHAMBERS

Exposure frontier



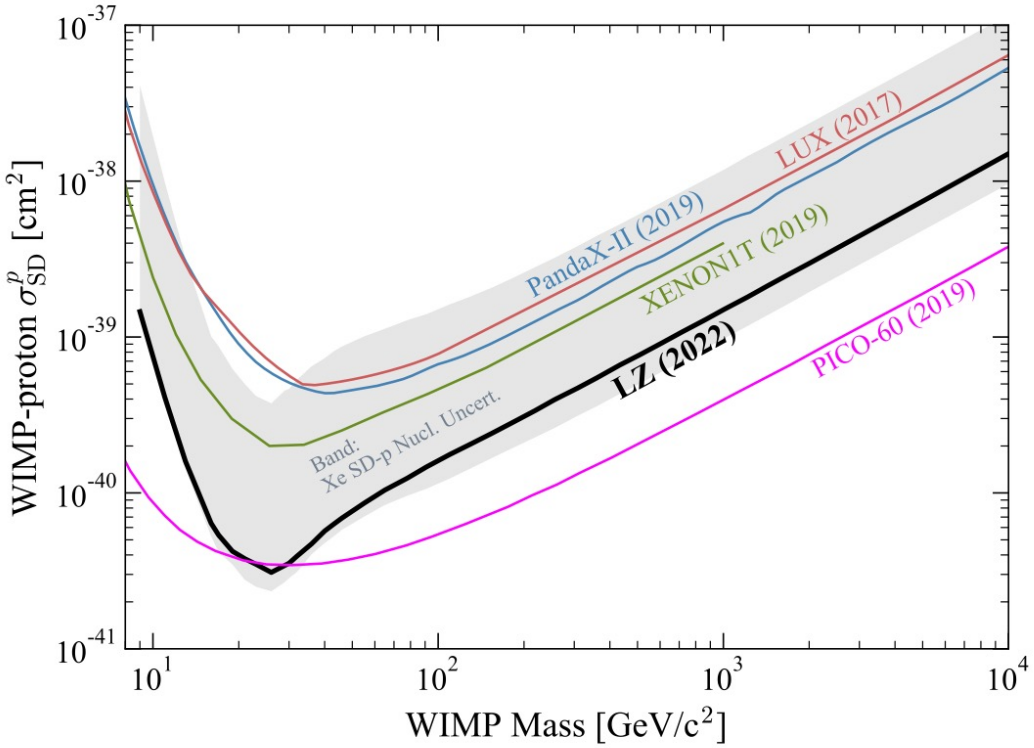
- Bubble chambers using superheated liquids (Freon-based).
- Threshold detector, ER background suppression by energy tuning
- 3D event reconstruction

Guillaume Giroux 2021 J. Phys.: Conf. Ser. 2156 012068

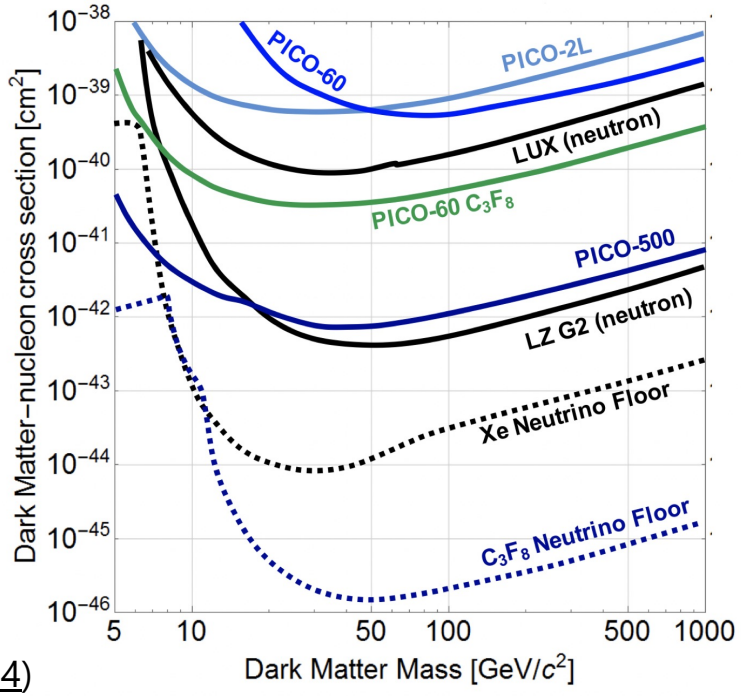
BUBBLE CHAMBERS

Exposure frontier

Russell Neilson on Scintillating Bubble Chambers
DM parallel Tuesday 3pm

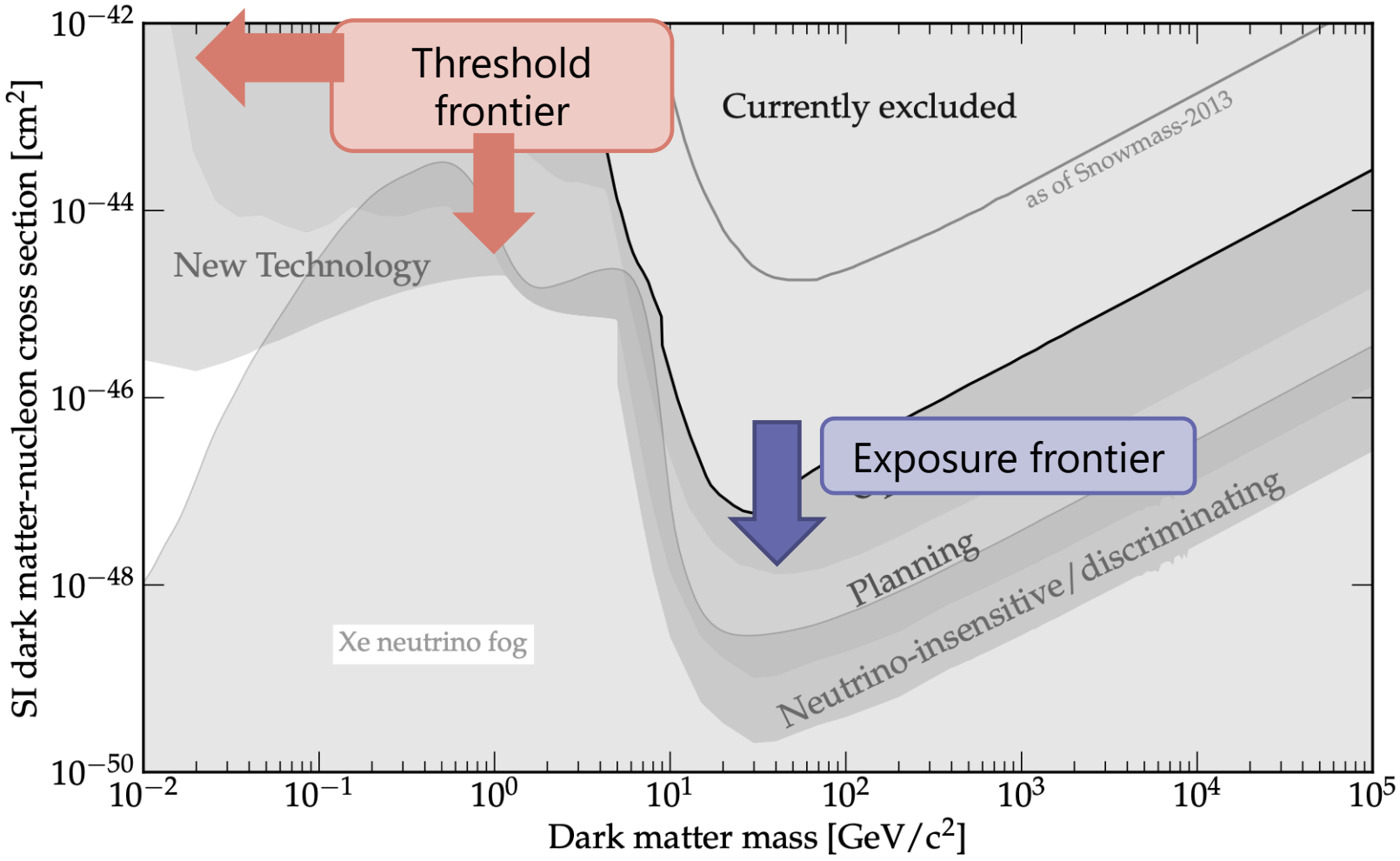


- Leading WIMP-proton spin-dependent limits with PICO-60
- Next generation: PICO-500



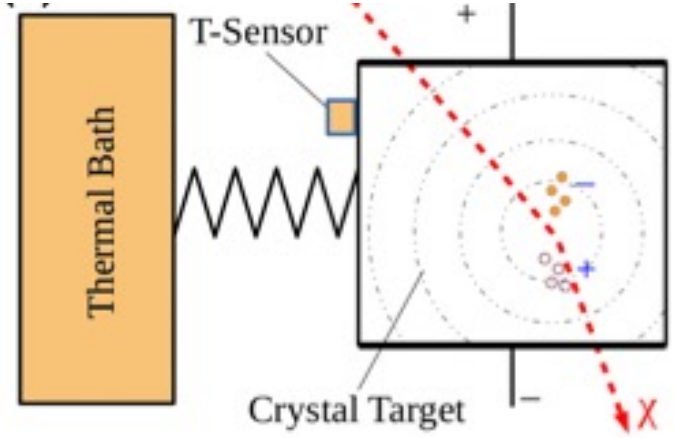
[1] First dark matter search result from the LZ Experiment (https://arxiv.org/abs/2207.03764)
[2] Guillaume Giroux 2021 J. Phys.: Conf. Ser. 2156 012068

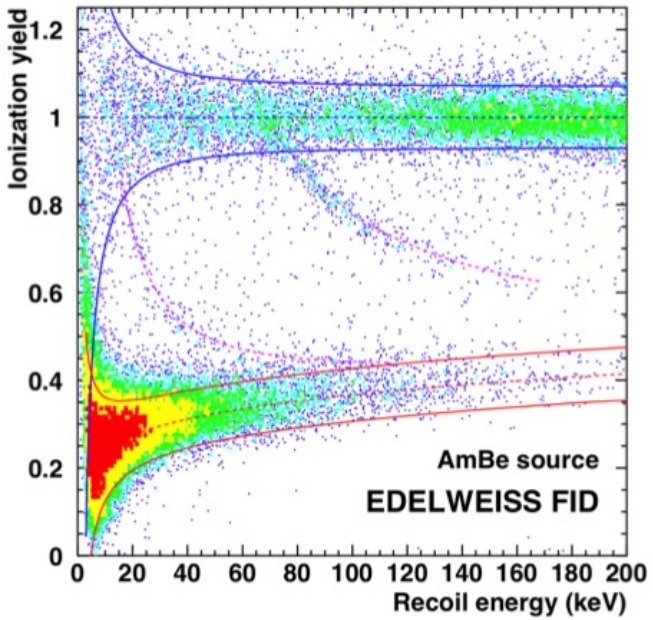
DIRECT DETECTION FRONTIERS



CRYOGENIC BOLOMETERS

Threshold frontier



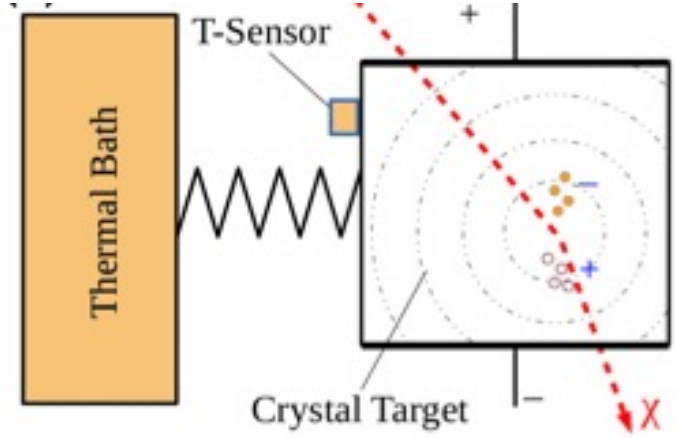


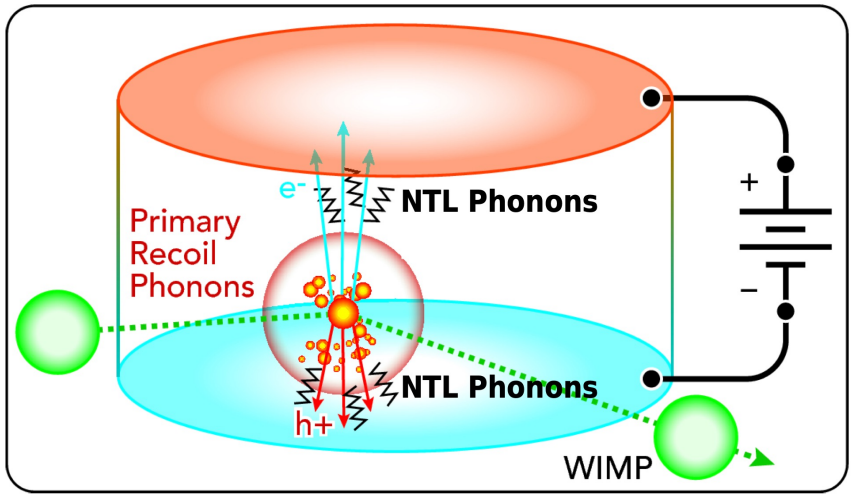
- Crystal targets (Ge, $CaWO_4$) operated < 50mK
- Phonon readout via NTD or transition edge sensors
- Simultaneous readout of ionization or scintillation signal allows background discrimination
- Excellent energy resolution

[1] APPEC Committee Report 2021, https://arxiv.org/pdf/2104.07634.pdf
[2] E. Armengaud *et al* 2017 *JINST* **12** P08010, https://arxiv.org/pdf/1706.01070.pdf

CRYOGENIC BOLOMETERS

Threshold frontier





V_{bias} ~ 100 V

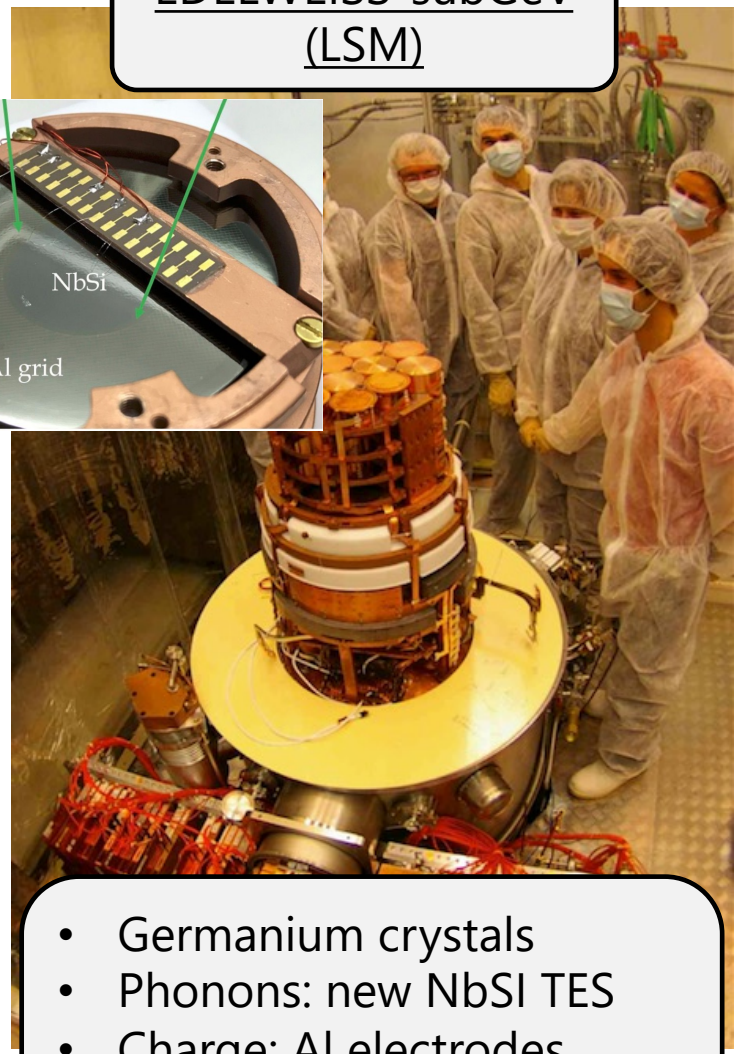
- Crystal targets (Ge, $CaWO_4$) operated < 50mK
- Phonon readout via NTD or transition edge sensors
- Simultaneous readout of ionization or scintillation signal allows background discrimination
- Excellent energy resolution
- Neganov-Trofimov-Luke effect allows lower thresholds

[1] APPEC Committee Report 2021, https://arxiv.org/pdf/2104.07634.pdf
[2] B Krosigk IDM 2018

CRYOGENIC BOLOMETERS

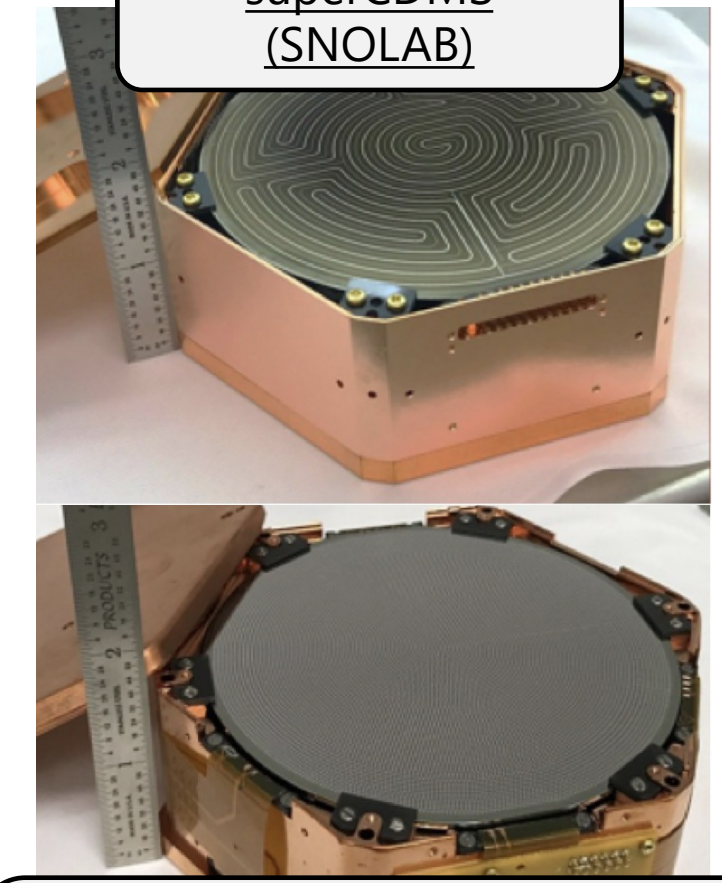
Threshold frontier

EDELWEISS-subGeV (LSM)



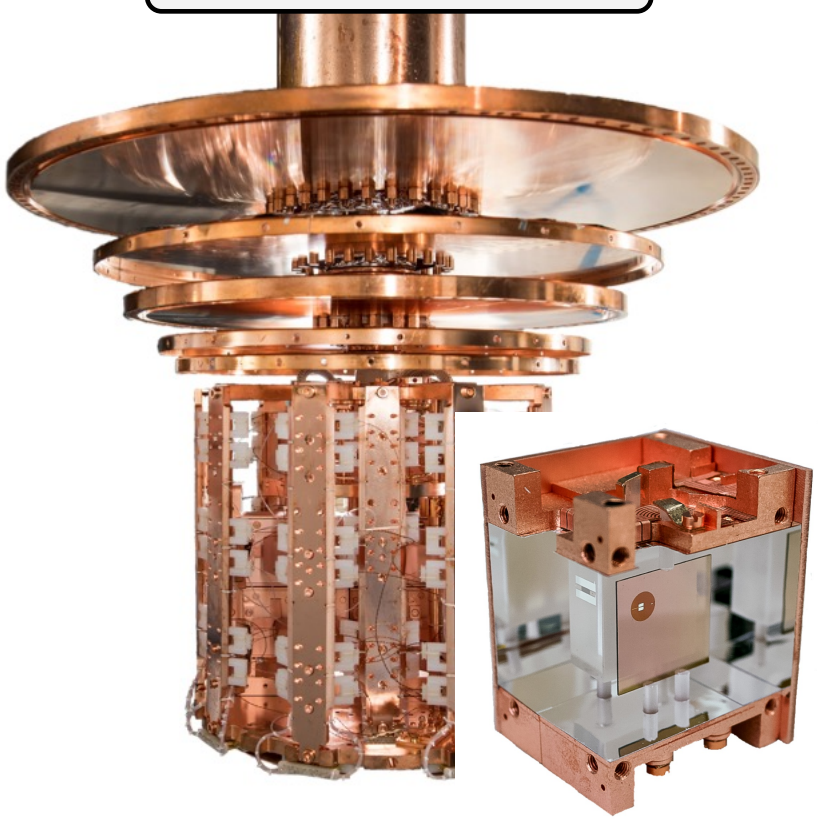
- Germanium crystals
- Phonons: new NbSI TES
- Charge: Al electrodes
- Status: running, R&D for CRYOSEL module

superCDMS (SNOLAB)



- Si and Ge crystals
- Phonons: QETES
- Charge: interleaved electrodes
- Status: In preparation

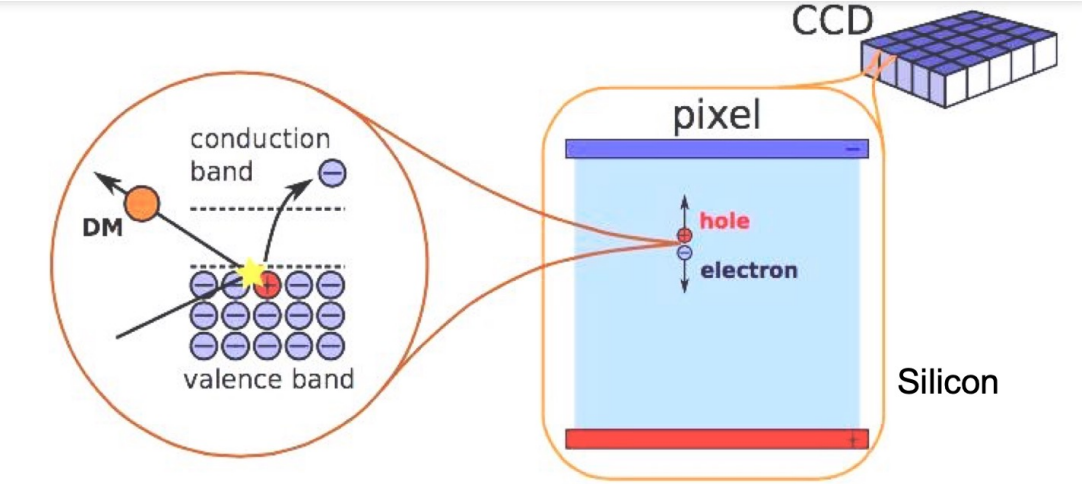
CRESST-III (LNGS)

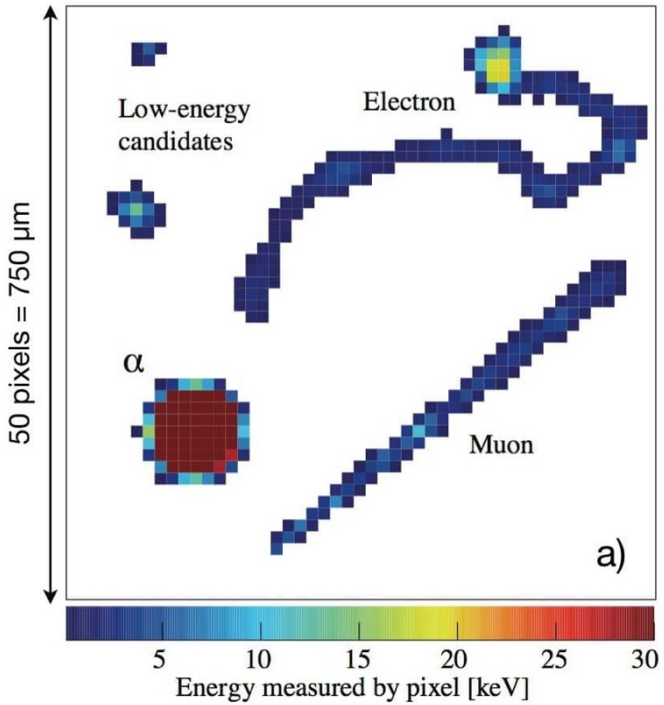


- $CaWO_4$, Al_2O_3 LiAlO2, Si
- Phonons: W-TES
- Light: Silicon-on-Sapphire wafer
- Status: Upgrade work ongoing

SILICON CCDs

Threshold frontier





- DM-electron scattering in silicon CCDs (Charge coupled devices)
- Charge is drifted to pixel gates (readout)
- Position reconstruction form diffusion
- Spatial resolution allows particle ID

https://damic.uchicago.edu/detector.php

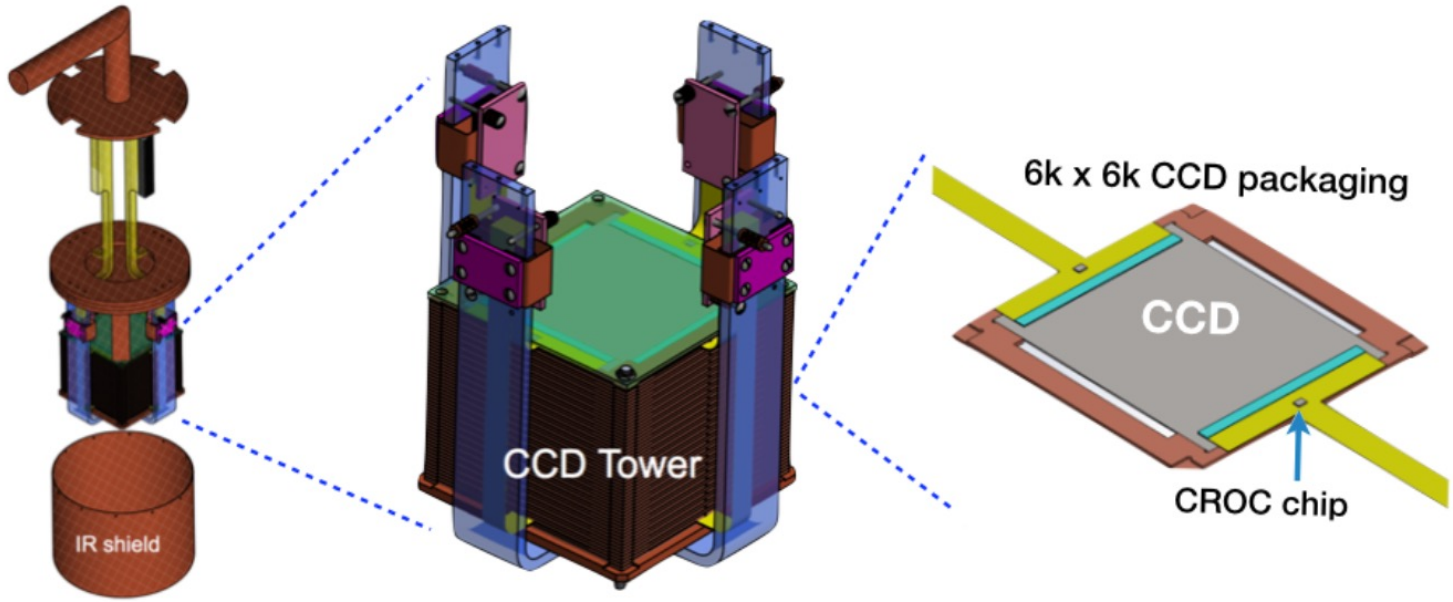
SILICON CCDs

Threshold frontier

SENSEI (MINOS, FNAL)

- 2-gram
- high-resistivity Skipper-CCD (charge readout)
- Status: running & constructing 100-gram version at SNOLAB

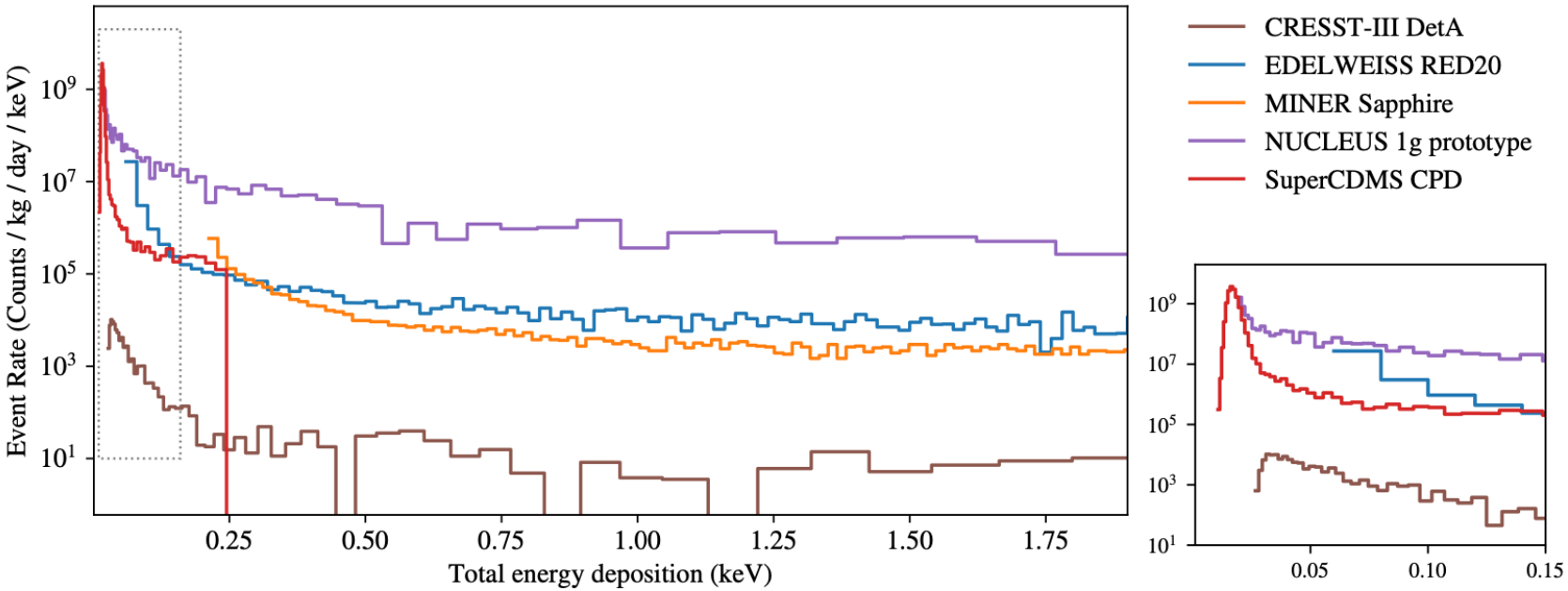
DAMIC-M (Modane)



- 1kg Si
- High resistivity CCD-Skipper (charge readout)
- Status: construction

LOW THRESHOLD CHALLENGES

Threshold frontier



- Low energy excess observed across different solid-state detectors -> EXCESS initiative [1]
- R&D for next generation projects
  - TESSERACT: lowering threshold in transition edge sensors for various targets
  - OSCURA: 10kg CCD Skipper project

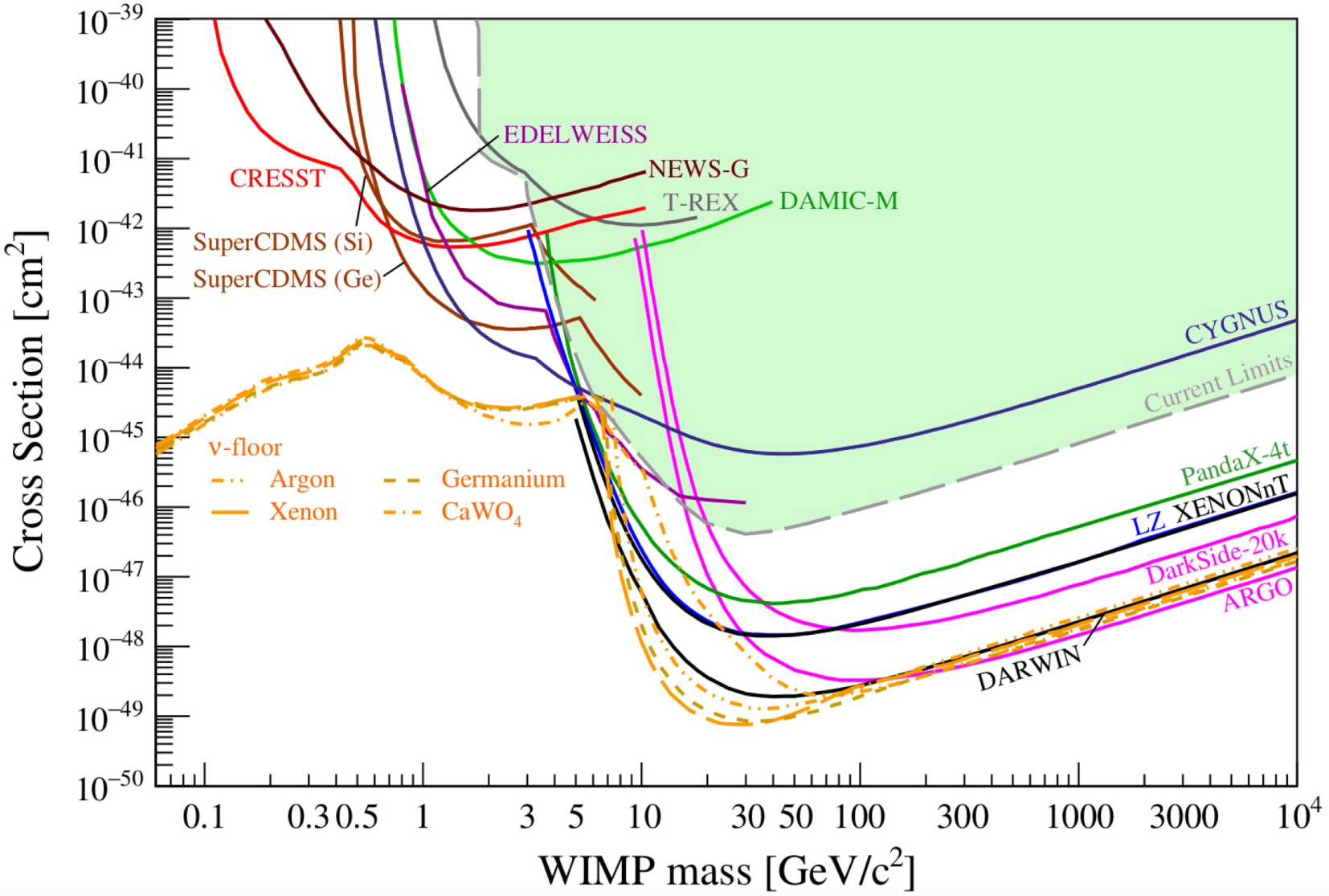
[1] EXCESS workshop https://arxiv.org/pdf/2202.05097.pdf

PROSPECTS

Threshold frontier

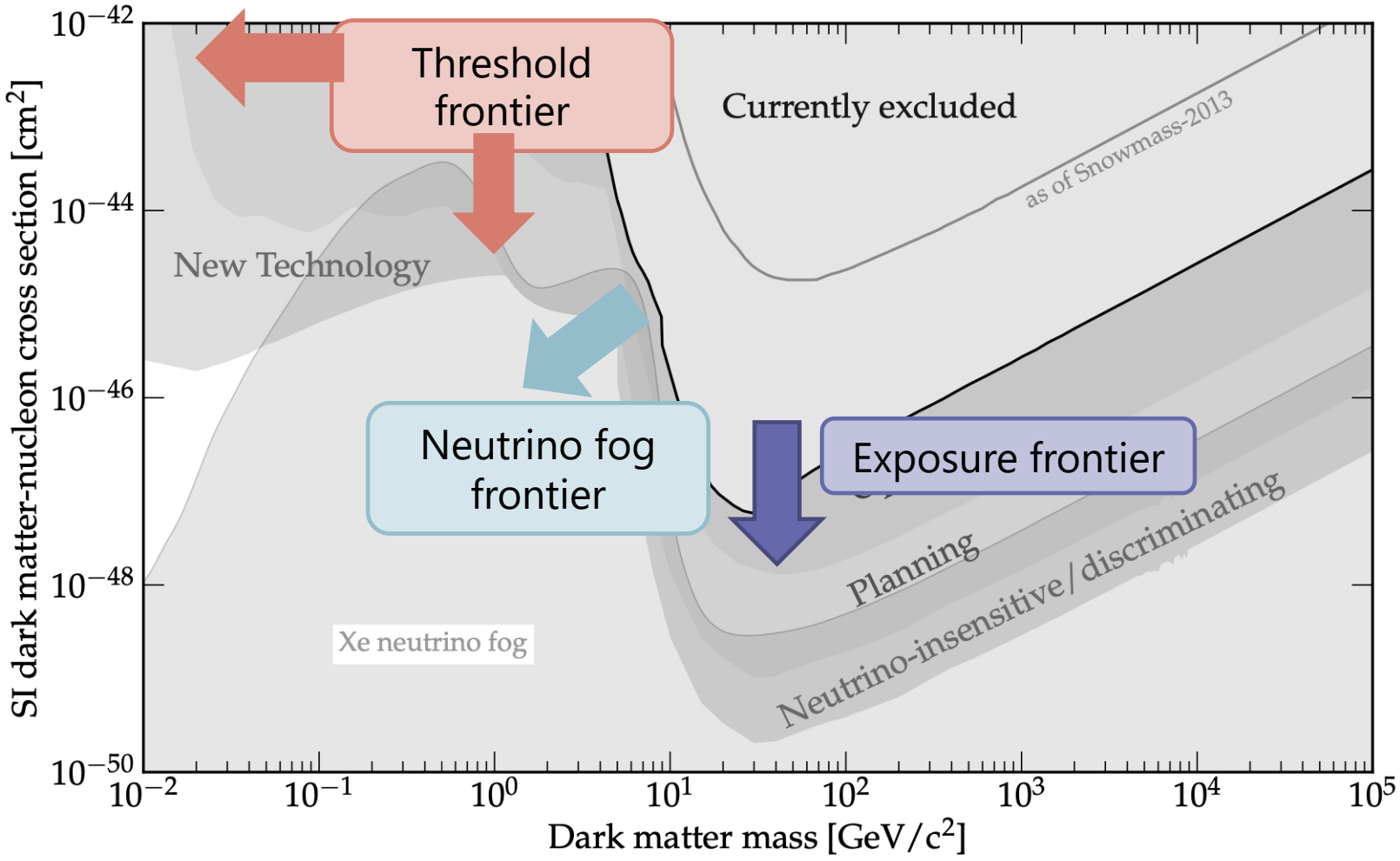
Lowering thresholds & better E resolution

Understanding & reducing backgrounds



APPEC Committee Report 2021, https://arxiv.org/pdf/2104.07634.pdf

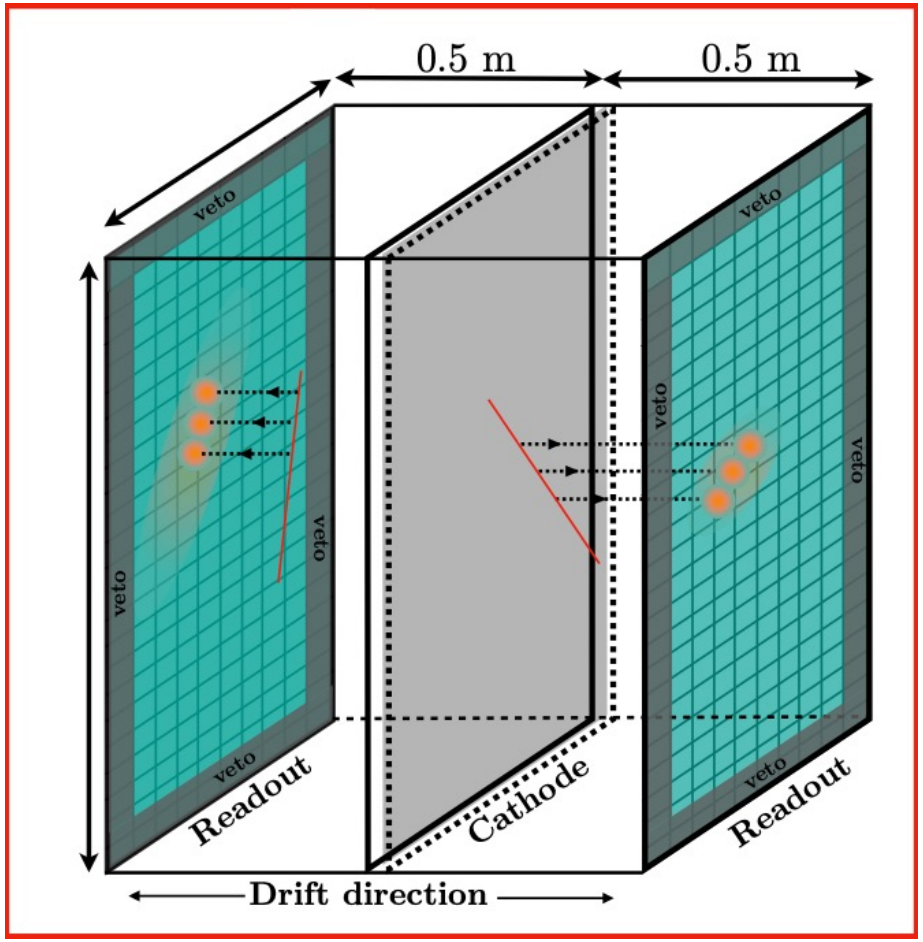
DIRECT DETECTION FRONTIERS



Ferdos Dastgiri's talk,
DM parallel Tuesday 2pm

DIRECTIONAL SEARCHES

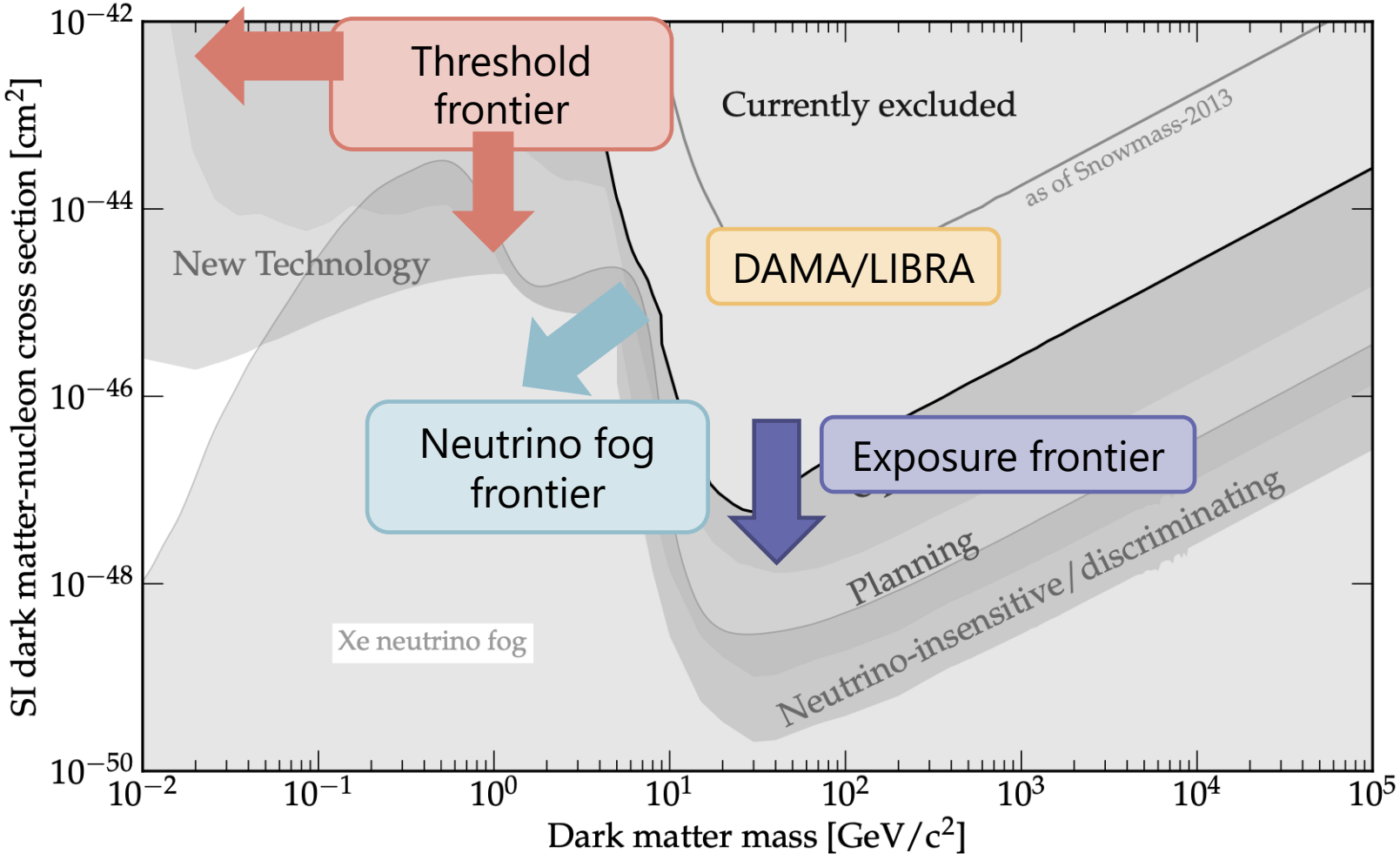
Neutrino Fog Frontier



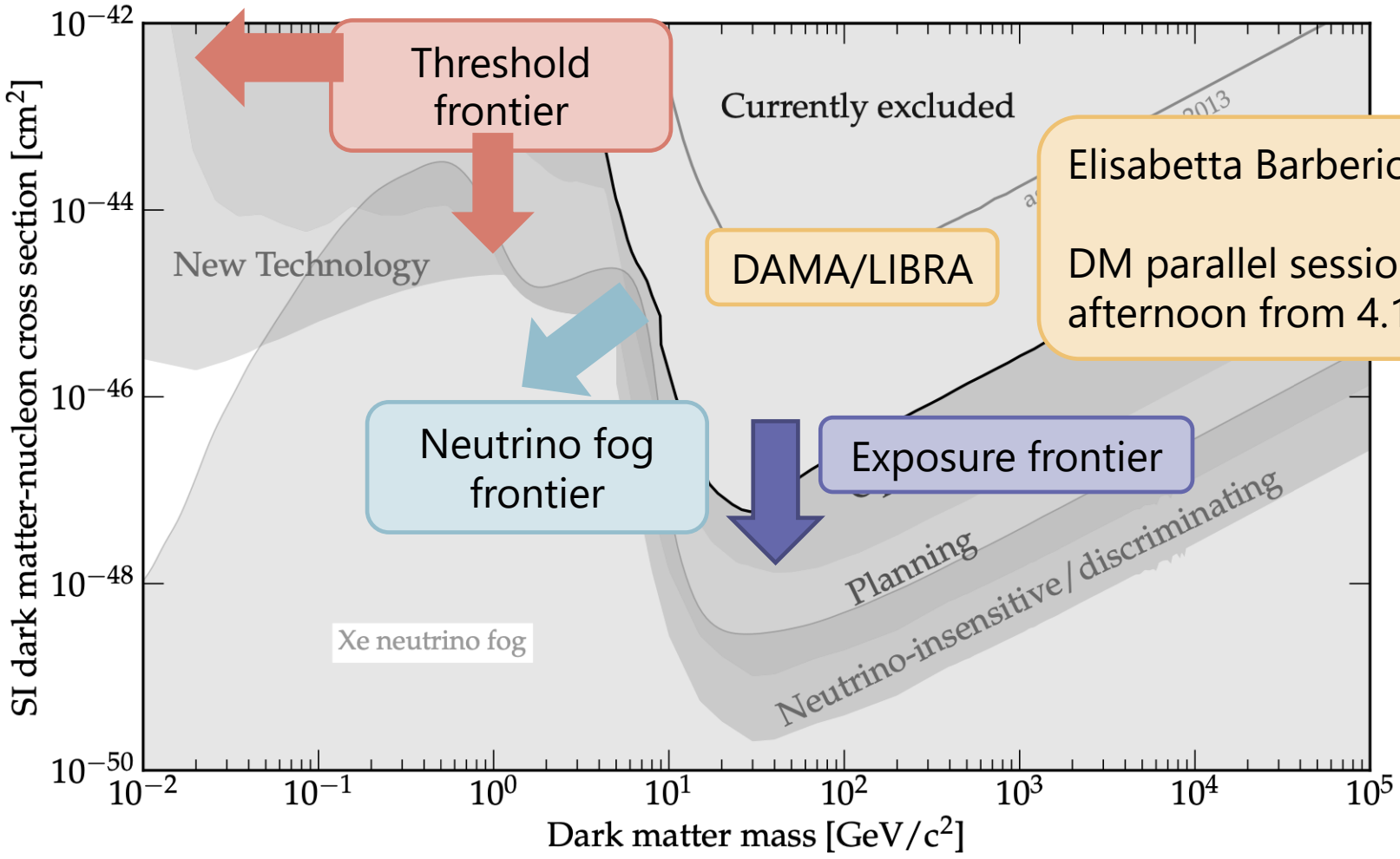
- Directionality as light into the neutrino fog, requires reconstruction of tracks
- TPC with low density gas and charge readout as demonstrated by DRIFT in the UK
- International CYGNUS collaboration R&D towards 1m^3 detector
- Different gas mixtures -> sensitivity to spin-dependents possible

CYGNUS feasibility (2020), https://arxiv.org/pdf/2008.12587.pdf

DIRECT DETECTION FRONTIERS



DIRECT DETECTION FRONTIERS



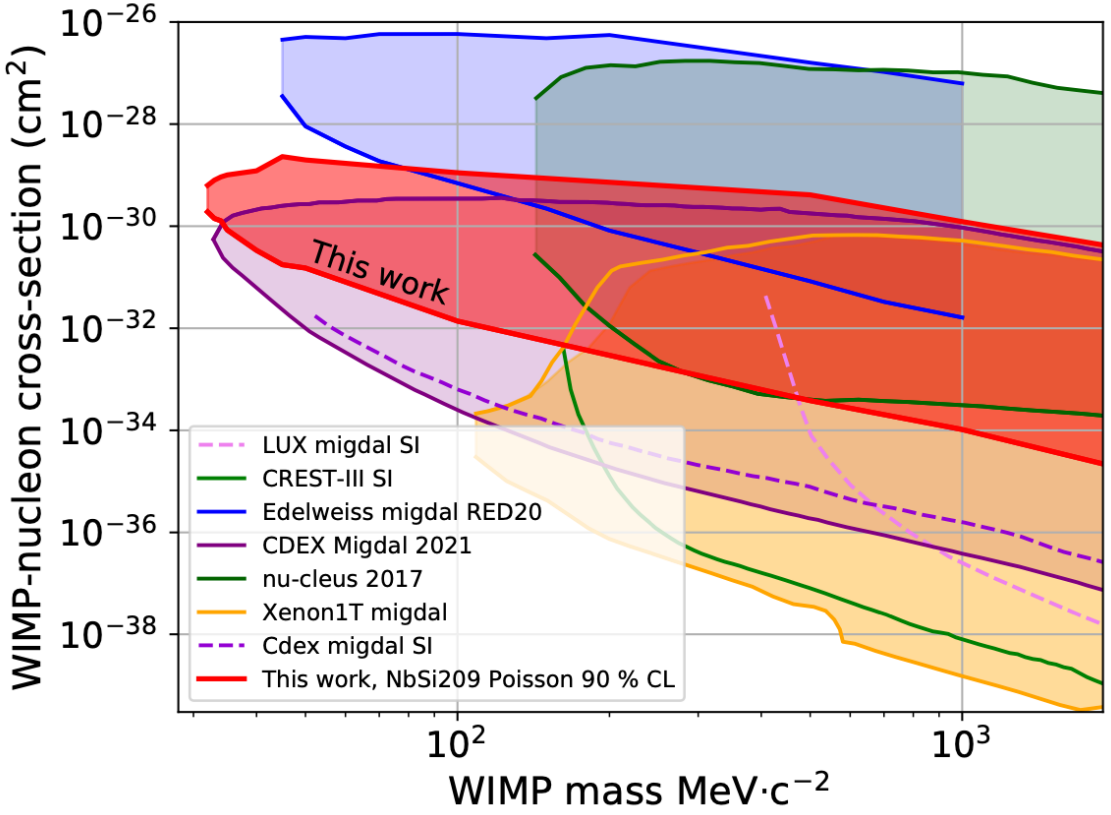
Elisabetta Barberio -> next talk

DM parallel session this afternoon from 4.10pm

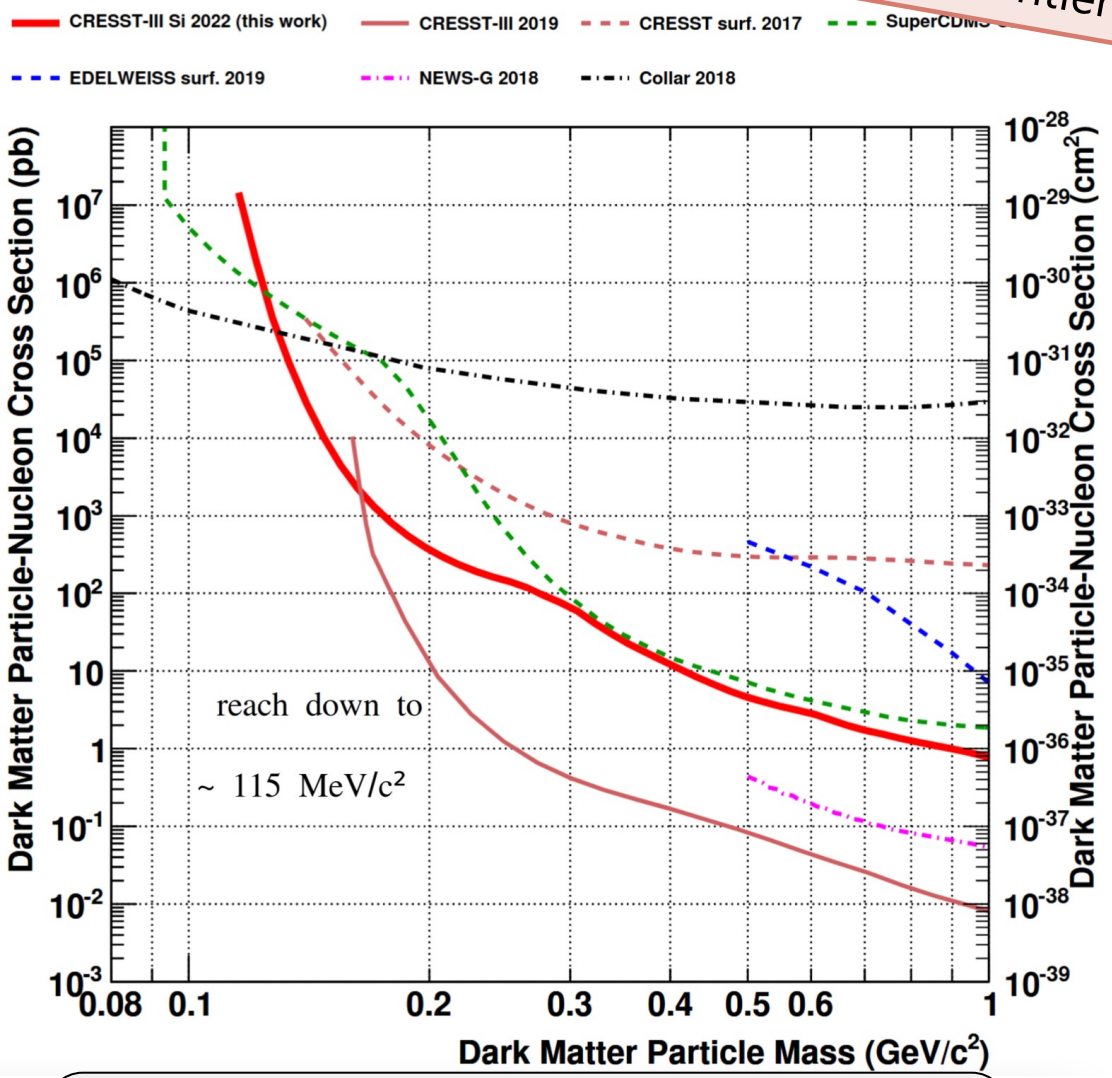

Thank you!

2022 RESULTS

Threshold frontier



EDELWEISS MIGDAL[1]
E_{res} = 4.46 eV_{ee} , E_{thresh} = 30 eV_{ee}

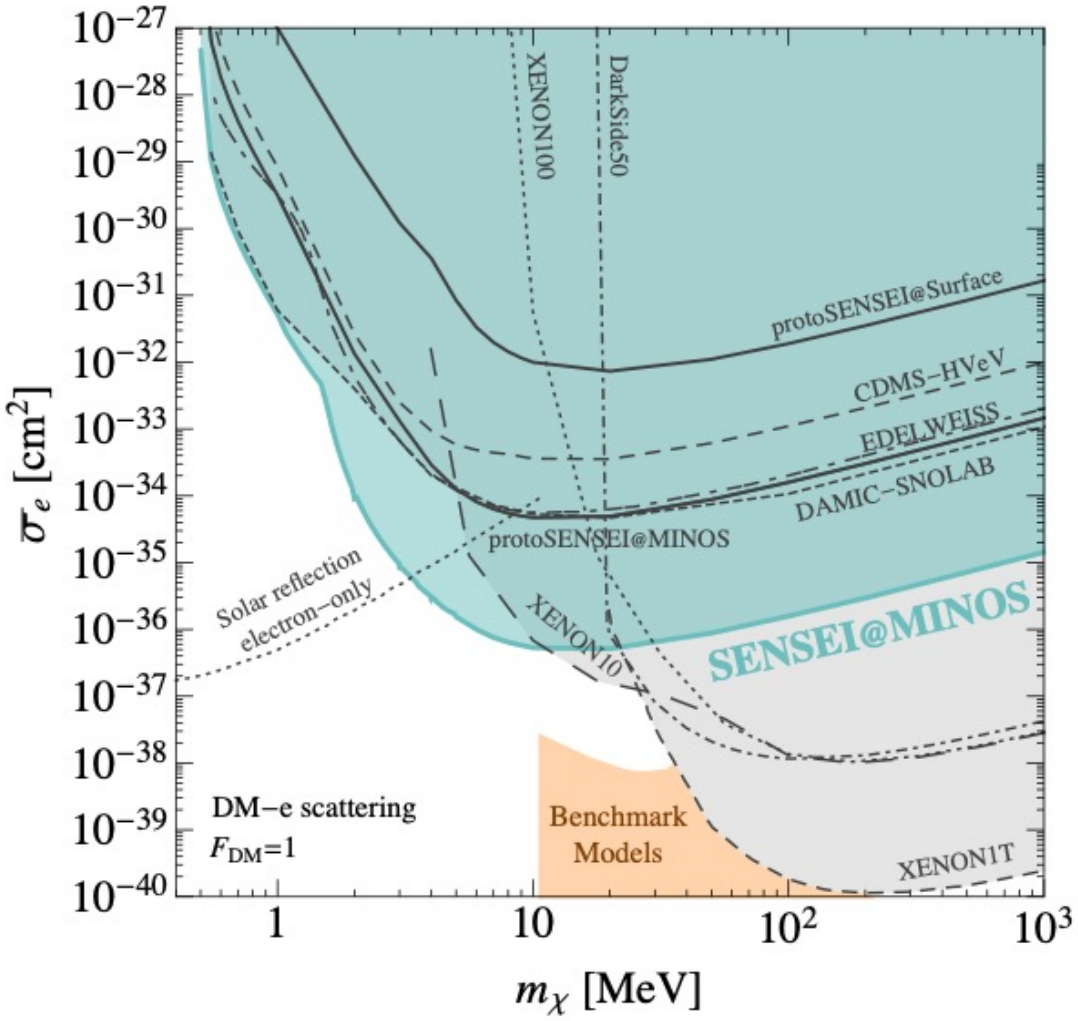


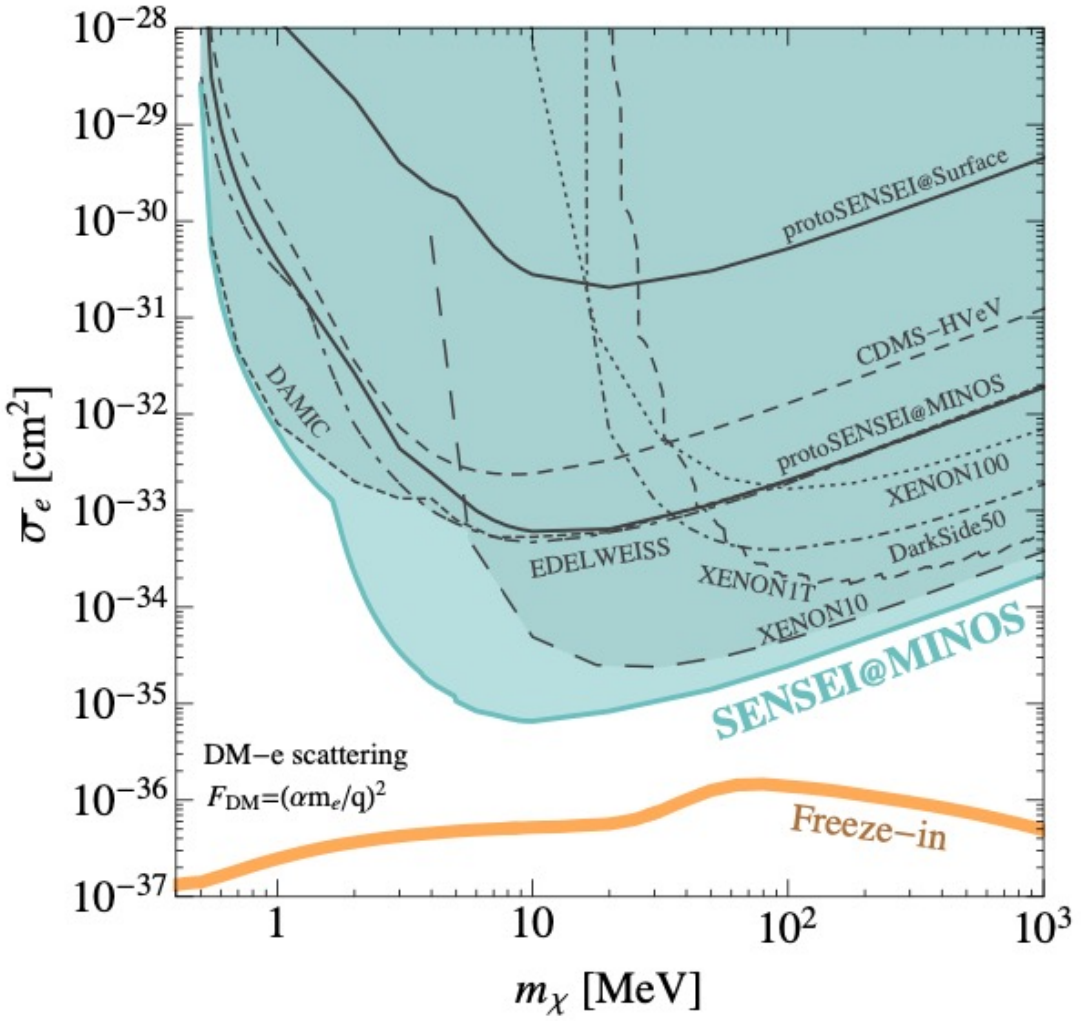
CRESST-III[2]
Silicon-wafer (0.35g) as detector
E_{thresh} = 10 eV

[1]EDELWEISS III (2022), Phys. Rev. D **106**, 062004
[2]C. Strandhagen presentation IDM 2022

DM-electron scattering

Threshold frontier





Phys. Rev. Lett. 125, 171802 (2020)

Name	Detector	Target	Active Mass	Location of Experiment	Status	Start_Ops	End_Ops
XMASS	Scintillator	LXe	832 kg	Kamioke	Ended	2010	2019
XENON10	TPC	LXe	62 kg	LNGS	Ended	2006	2008
XENON100	TPC	LXe	62 kg	LNGS	Ended	2012	2016
XENON1T	TPC	LXe	”1,995 kg”	LNGS	Ended	2017	2019
XENON1T (Ionization)	TPC Ioniz.-only	LXe	”1,995 kg”	LNGS	Ended	2017	2019
XENONnT	TPC	LXe	”7,000 kg”	LNGS	Construction/Run	2021	2025
LUX	TPC	LXe	250 kg	SURF	Ended	2013	2016
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg	SURF	Ended	2017	2019
LZ	TPC	LXe	”8,000 kg”	SURF	Construction/Run	2021	2025
PandaX-II	TPC	LXe	580 kg	CJPL	Ended	2016	2018
PandaX-4T	TPC	LXe	”4,000 kg”	CJPL	Running	2021	2025
LZ HydroX	TPC	LXe+H2	”8,000 kg”	SURF	R&D	2026	
Darwin / US G3	TPC	LXe	”50,000 kg”	LNGS/SURF/Boulby	Planning	2028	2033
DEAP-1	Scintilator	LAr			Ended	2007	2011
DEAP-3600	Scintillator	LAr	”3,300 kg”	SNOLAB	Running	2016	202X
DarkSide-50	TPC	LAr	46 kg	LNGS	Ended	2013	2019
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg	LNGS	Ended	2018	2019
Darkside-20k	TPC	LAr	30 t	LNGS	Planning/Construct	2025	2030
ARGO	TPC or Scintillator	LAr	300 t	SNOLAB	Planning	2030	2035
GADMC	TPC	LAr			Planning	2030	
DAMA/LIBRA	Scintillator	NaI	250 kg	LNGS	Running	2003	
ANAIS-112	Scintillator	NaI	112 kg	Canfranc	Running	2017	2022
COSINE-100	Scintillator	NaI	106 kg	YangYang	Running	2016	2021
COSINE-200	Scintillator	NaI	200 kg	YangYang	Construction	2022	2025
COSINE-200 South Pole	Scintillator	NaI	200 kg	South Pole	Planning	2023	?
COSINUS	Bolometer Scintillator	NaI	?	LNGS	Planning	2023	?
SABRE PoP	Scintillator	NaI	5 kg	LNGS	Construction	2021	2022
SABRE (North)	Scintillator	NaI	50 kg	LNGS	Planning	2022	2027
SABRE (South)	Scintillator	NaI	50 kg	SUPL	Planning	2022	2027
CDEX-10	Ionization (77K)	Ge	10 kg	CJPL	Running	2016	?
CDEX-100 / 1T	Ionization (77K)	Ge	100-1000 kg	CJPL	Planning	202X	

SuperCDMS	Cryo Ionization	Ge	9 kg	Soudan	Ended	2011	2015
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	Soudan	Ended	2012	2015
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	Soudan	Ended	2012	2015
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	Surface Lab	Ended	2018	2018
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg	SNOLAB	Running	2020	2022
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg	SNOLAB	Construction	2023	2028
EDELWEISS III	Cryo Ionization	Ge	20 kg	LSM	Ended	2015	2018
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g	LSM	Running	2019	
CRESST-II	Bolometer Scintillation	CaWO4	5 kg	LNGS	Ended	2012	2015
CRESST-III	Bolometer Scintillation	CaWO4	240 g	LNGS	Ended	2016	2018
CRESST-III (HW Tests)	Bolometer Scintillation	CaWO4		LNGS	Running	2020	
COUPP	Bubble Chamber	CF3I	4 kg	SNOLAB / Fermilab	Ended	2011	2012
PICASSO	Superheated Droplet	C4F10	3 kg	SNOLAB	Ended		2017
PICO-2	Bubble Chamber	C3F8	2 kg	SNOLAB	Ended	2013	2015
PICO-40	Bubble Chamber	C3F8	35 kg	SNOLAB	Running	2020	
PICO-60	Bubble Chamber	”CF3I,C3F8”	52 kg	SNOLAB	Ended	2013	2017
PICO-500	Bubble Chamber	C3F8	430 kg	SNOLAB	Construction/Run	2021	
DRIFT-II	Gas Directional	CF_4	0.14 kg	Boulby	Ended		
NEWAGE-03b’	Gas Directional	CF4	14 g	Kamioka	Running	2013	2023
MIMAC	Gas Directional	$CF_4+CHF_3+C_4H_{10}$		LSM (Modane)	Running	2012	
CYGNO	Gas Directional	He + CF_4	0.5 - 1 kg	LNGS	Planning	2024	
CYGNUS	Gas Directional	He + SF_6/CF_4		Multiple sites	Planning		
NEWS-G	Gas Drift	CH4		LSM	Ended	2017	2019
NEWS-G	Gas Drift	CH4		SNOLAB	Construction/Run	2020	2025
DAMIC	CCD	Si	2.9 g	SNOLAB	Ended	2015	2015
DAMIC	CCD	Si	40 g Si	SNOLAB	Ended	2017	2019
DAMIC100	CCD	Si	100 g Si	SNOLAB	Not Built		
DAMIC-M	CCD Skipper	Si	1 kg Si	LSM	Construction/Run	2021	2024
SENSEI	CCD Skipper	Si	2 g Si	Fermilab u/g	Running	2019	2020
SENSEI	CCD Skipper	Si	100 g Si	SNOLAB	Construction/Run	2021	2023
Oscura	CCD Skipper	Si	10 kg Si	SNOLAB	Planning	2024	2028
SNOWBALL	Supercooled Liquid	H2O			Planning		
ALETHEIA	TPC	He		China Inst. At. Energy	R&D		
TESSERACT	Cryo TES	He		LBNL	R&D		