Dark Matter WIMP Searches IDM 2022, Vienna, Austria

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LUX and LZ Experiments supported by US DOE HEP

see information at

http://particleastro.brown.edu

http://cfpu.brown.edu http://lz.lbl.gov

- Thank you to those of you who very kindly provided me with advanced slides from the work your are going to present
- Since there is clearly potential overlap with a number of Plenary Talks I will only show a subset of that material
- Also apologies if I don't explicitly advertise your talk

BBC 2014

Gaitskell / Brown University

Exposure Time....
33 years searching for dark matter

CDMS II: Winter
@Soudan Minnesota

Sanford Lab
LUX & LZ @Lead,
South Dakota

PHYSICS ITALIAN
STYLE XENON10
@ Gran Sasso

Gaitskell / Brown University

Since IDM 2018 @ Brown (our last in person meeting)

- Since the last "in person" IDM at Brown university in 2018
- The Universe has Expanded
- Direct Search Experiments targets are getting substantially bigger
- And I have done both

Getting

- To be more quantitative since the last in person IDM at Brown in 2018
- The Universe has expanded by 0.298 ppb
  (and their is some controversy over H_0)
- The leading sensitivity for dark matter direct detections
  has improved by factor x7 at 30 GeV mass and x3 at 1 TeV
- My weight 1.2x = COVID spread

Acronyms

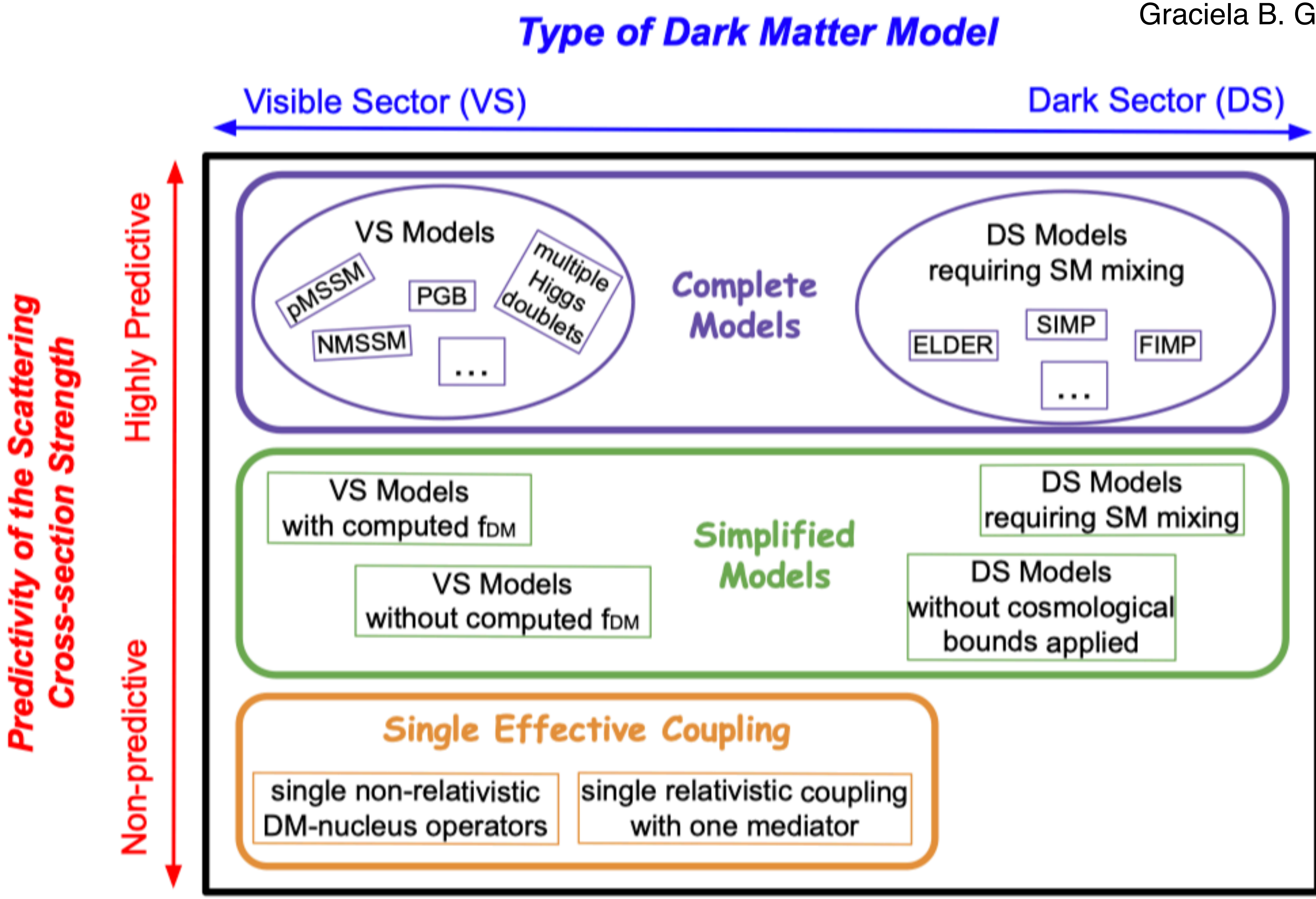
- (WIMP) Weakly Interacting Massive Particles
- (MACHO) Massive Compact Halo Object

- (pMSSM) Phenomenological MSSM
- (NMSSM) Next-to-Minimal Supersymmetric Standard Model
- (FIMP) Feebly interacting massive particles models, couplings so feeble that places them well into the fog

- (CEvNS) Coherent elastic neutrino-nucleus scattering
- 8B Solar Neutrinos <=15 MeV neutrinos
- (AtmNu) Atmospheric neutrinos MeV-GeV neutrinos, 25% u/c at low energy
- (DSNB) Diffuse supernova neutrino background (hides under AtmNu)

DM Particle Models

CF1 WP1 arXiv:2203.08084
Thanks to Ben Loer, PNNL and Graciela B. Gelmini, UCLA



WIMP Spin Independent Coupling

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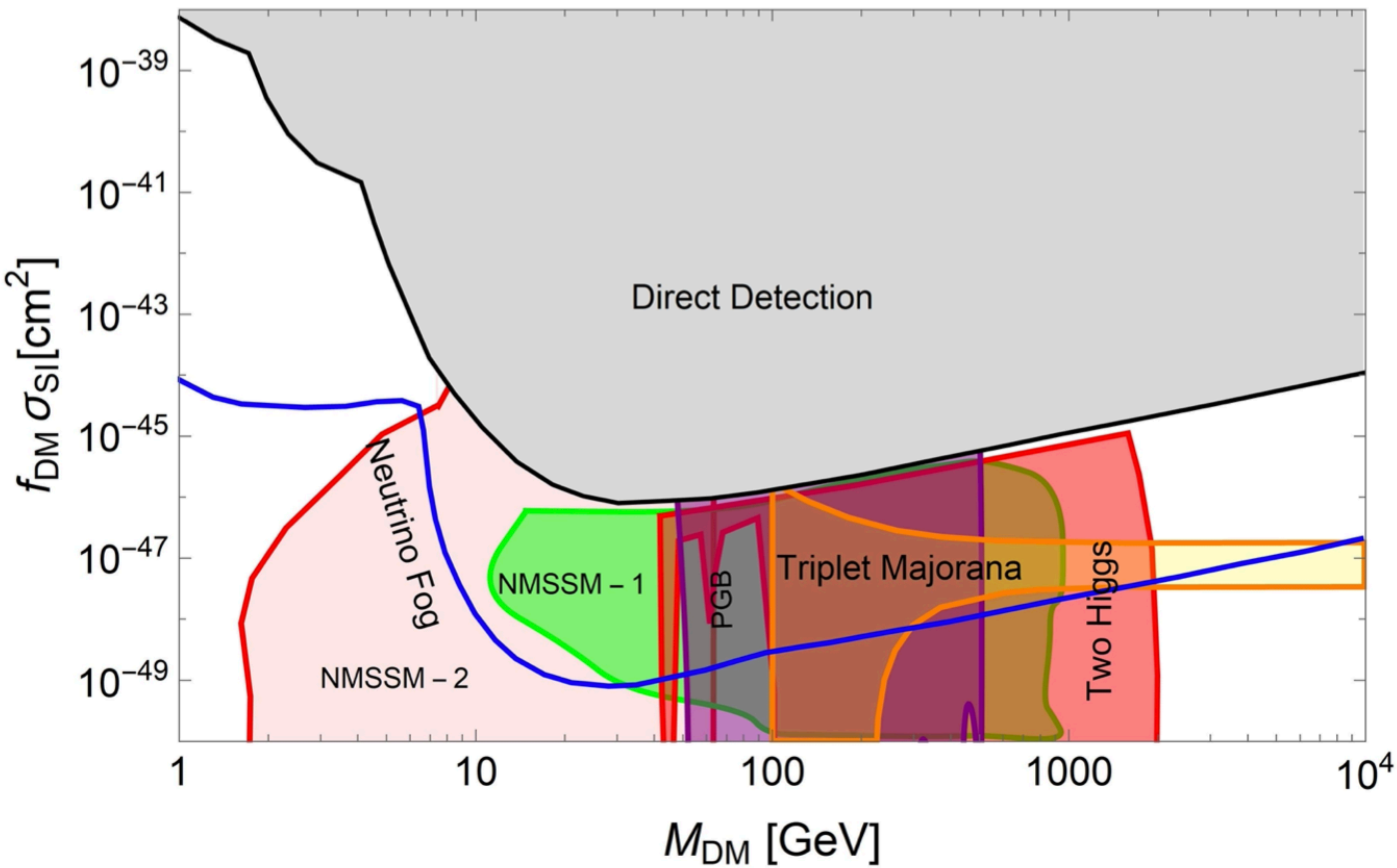

WIMP Spin Dependent Coupling

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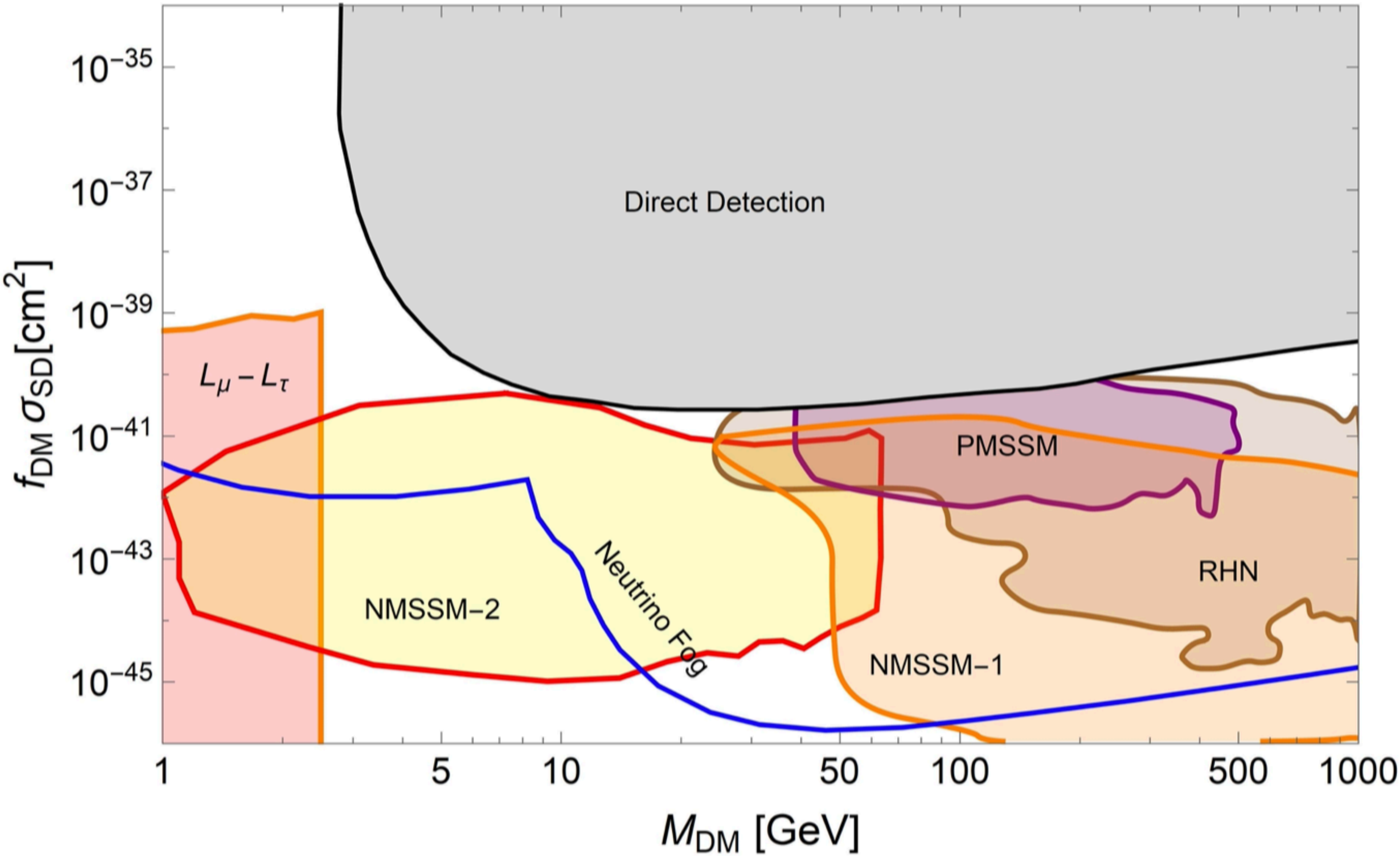


WIMPS

- Multiple well-motivated dark matter candidates remaining in the "traditional" ~GeV-scale mass range.
  - Current building/operational searches are testing new models but the majority require following generation(s)
- Next Gen = "US: Gen 3" x10 sensitivity beyond Current Experiments
  - Fully test some particle candidates
  - Field should be pushing on both on SI and SD (F-p, Xe-n, [Xe-p])
- SI WIMP mass >~30 GeV - raw fiducial mass => sensitivity being covered by relatively mature Xe TPC (reported results from 10 detectors 1,5,10,50,100,400,1000,4000,7000 kg) and also Ar TPC (10, 50, 20000 kg) + Ar Scin. (3600)
  - Sensitivity in this mass range does not depend strongly on experiment threshold unless it gets very high
  - Improvements in sensitivity are driven primarily by increasing exposure (i.e., target mass) and/or reducing backgrounds
  - Discovery does also benefit from reduced bg event rates and lower thresholds (so signal is well resolved above threshold)

WIMPS - Lowering Mass Sensitivity

- Large scale Xe and Ar also provide techniques to push down into <10 GeV
  - Very dependent on accidentals rate
  - S2-only
  - Migdal Coupling (Nuclear recoil deposits energy into atomic x-ray electron system)

- For lower mass WIMPs (and dark sector / light) lower energy threshold with low/zero background provides very significant gains in sensitivity
  - R&D on new techniques will improve established detector performance and provide new methods to mitigate backgrounds and probe complementary parameter space near the neutrino fog

- Substantial well-motivated parameter space will yet remain even post "Gen 3" campaigns.
  - Irreducible CEvNS neutrino backgrounds can cause substantially diminished returns on further increases in exposure.
  - Mitigation by reducing uncertainties in the neutrino fluxes, further increases may become feasible.
  - Light, spin-dependent targets such as fluorine have substantially lower neutrino backgrounds and can therefore scale to larger masses even with current neutrino flux uncertainties.

- Directional detectors are one possible way to reject neutrino backgrounds and thereby reach beyond the neutrino-limited point of current technology.
  - Substantial R&D investment to reach the size and level of background control required to explore this parameter space.
  - Gas TPCs with micro-pattern gaseous detector (MPGD) readout should be advanced to the 10 m^3 scale (but this is still way below cathedral scale needed if we are to lead search with this tech.)

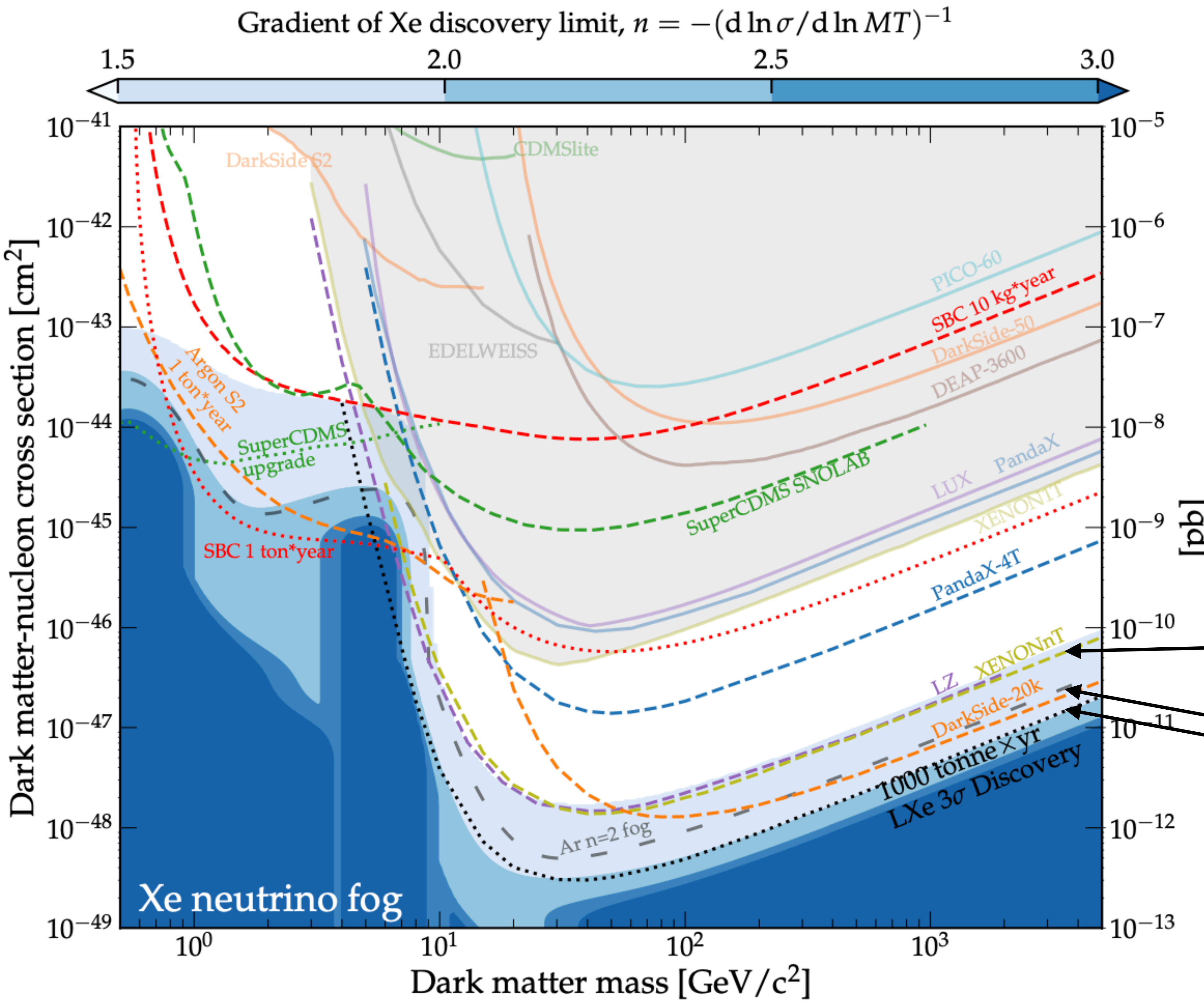
US "SNOWMASS" Process - Cosmic Frontier White Papers

- D. S. Akerib et al. “Snowmass2021 Cosmic Frontier Dark Matter Direct Detection to the Neutrino Fog”. In: 2022 Snowmass Summer Study. Mar. 2022. arXiv: 2203.08084 [hep-ex].
- Rouven Essig, Graham K. Giovanetti, Noah Kurinsky, Dan McKinsey, Karthik Ramanathan, Kelly Stifter, and Tien-Tien Yu. “Snowmass2021 Cosmic Frontier: The landscape of low-threshold dark matter direct detection in the next decade”. In: 2022 Snowmass Summer Study. Mar. 2022. arXiv: 2203.08297 [hep-ph].
- Daniel Baxter et al. “Snowmass2021 Cosmic Frontier White Paper: Calibrations and backgrounds for dark matter direct detection”. In: (Mar. 2022). arXiv: 2203.07623 [hep-ex].
- Yonatan Kahn et al. “Snowmass2021 Cosmic Frontier: Modeling, statistics, simulations, and comput- ing needs for direct dark matter detection”. In: 2022 Snowmass Summer Study. Mar. 2022. arXiv: 2203.07700 [hep-ex].
- Tsuguo Aramaki et al. “Snowmass2021 Cosmic Frontier: The landscape of cosmic-ray and high-energy photon probes of particle dark matter”. In: (Mar. 2022). arXiv: 2203.06894 [hep-ex].
- Rebecca K. Leane et al. “Snowmass2021 Cosmic Frontier White Paper: Puzzling Excesses in Dark Matter Searches and How to Resolve Them”. In: (Mar. 2022). arXiv: 2203.06859 [hep-ph].
- Shin’ichiro Ando et al. “Snowmass2021 Cosmic Frontier: Synergies between dark matter searches and multiwavelength/multimessenger astrophysics”. In: 2022 Snowmass Summer Study. Mar. 2022. arXiv: 2203.06781 [hep-ph].
- Daniel Carney et al. “Snowmass2021 Cosmic Frontier White Paper: Ultraheavy particle dark matter”. In: (Mar. 2022). arXiv: 2203.06508 [hep-ph].

- INPUT ==> Snowmass2022 CF1: Particle Dark Matter - Convener Summary - Jodi Cooley, Hugh Lippincott, Tracy R. Slatyer, and Tien-Tien Yu (which is being finalized right now)

Neutrino Fog

- WIMP is well-covered by predictive theories, down to and well into the neutrino fog.
- Some of these theories will be fully tested by the upcoming generation of funded experiments.
- Subsequent generation of current experiments ("generation 3") is expected to reach toward / into neutrino fog
- Once deep into the neutrino fog to incur significant diminishing returns on further growth - either extreme scaling of detector size or developing new technology less sensitive to neutrino backgrounds

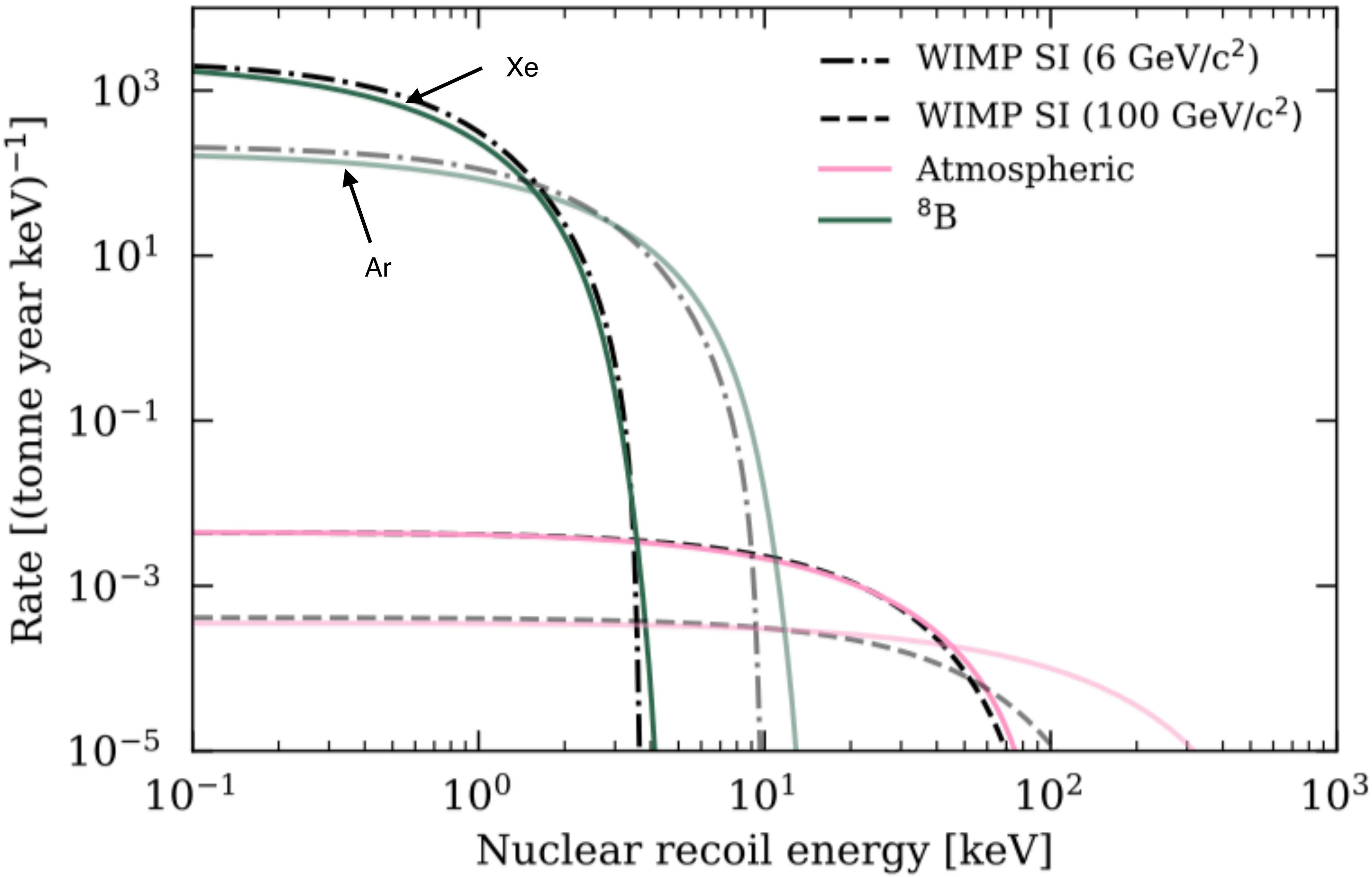


Projections, not results
(See later for LZ result)

Ar n=2 discuss in a moment
Xe n=2 discuss in a moment

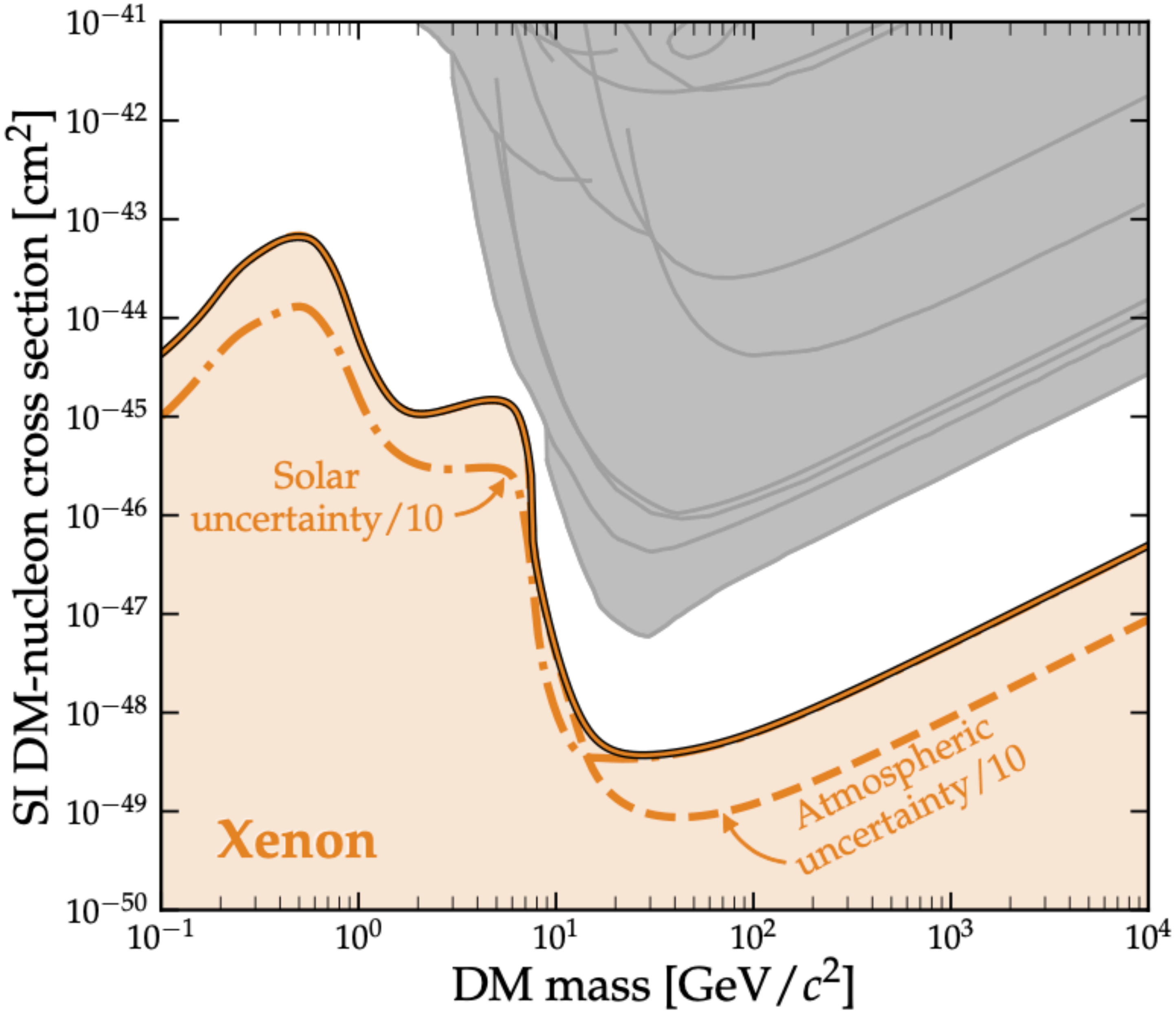
Similarity of 6 GeV WIMP with 8B CEvNS Signal
100 GeV WIMP and WIMP AtmNu Signal

CF1 WP1 arXiv:2203.08084



See O'Hare

2. Effect of Flux uncertainties (for illustration only)



With smaller flux uncertainties the boundary of the neutrino fog is pushed to lower cross sections

(This could make all the difference!)

O'Hare [2109.03116]

The Practical Matter of a Rare Event Search

- Improvements in Dark Matter Search Reach

  - Progress is Incremental...but by orders of magnitude
    - e.g. x10 increases in target mass

  - Innovation
    - e.g. Entirely new target materials C3F8
    - e.g. Higher Field Operation of Ge Bolometric Target
    - e.g. Skipper Amp CCD Readout
    - e.g. Light nuclei (He) for Low Mass WIMP searches

The Practical Matter of a Rare Event Search

- In ~35 th year of searching - now at a sensitivity that 10^6 better than the first round - we need detectors with a

Low Sisyphean Index †

- They must want to work correctly / do so without misleading us / low complexity - mustn't roll back down the hill when we stop paying attention for a moment

- And we will need to push them (pun indented) by another 10^2 before we reach the irreducible coherent neutrino backgrounds

† Experimentalist's Perspective of the Technology itself, not the definition that the task can never be completed

Dark Matter Direct Detection ~~MeV,~~ GeV, TeV

- I prepared a List of the Search Experiments that have been
  - Recently Completed (last 4 years), or
  - About to Start, or
  - Some of the Future (out 10 years)

  (not exhaustive, doesn't include more speculative ideas still in R&D)
- Dates indicate the Start of Detector Operation and Science
- (Forgive me for an omissions or slight errors in dates)

R&D
Planning
Construction
Running
Ended

Dar - TeV

XMASS	Scintillator	LXe	832 kg		Ended	2010	2019	Kamioke
XENON100	TPC	LXe	62 kg		Ended	2012	2016	LNGS
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Construction/Run	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Construction/Run	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Running	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	50,000 kg	200 t yr	Planning	2028	2033	LNGS/SURF/Boulby
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
Darkside-20k	TPC	LAr	30 t	200 t yr	'lanning/Construct	2025	2030	LNGS
ARGO	TPC	LAr	300 t	3000 t yr	Planning	2030	2035	SNOLAB
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc
COSINE-100	Scintillator	NaI	106 kg		Running	2016	2021	YangYang
COSINE-200	Scintillator	NaI	200 kg		Construction	2022	2025	YangYang
COSINE-200 South Pole	Scintillator	NaI	200 kg		Planning	2023	?	South Pole
COSINUS	Bolometer Scintillator	NaI	?		Planning	2023	?	LNGS
SABRE PoP	Scintillator	NaI	5 kg		Construction	2021	2022	LNGS
SABRE (North)	Scintillator	NaI	50 kg		Planning	2022	2027	LNGS
SABRE (South)	Scintillator	NaI	50 kg		Planning	2022	2027	SUPL
CDEX-10	Ionization (77K)	Ge	10 kg	103 kg d	Running	2016	?	CJPL
CDEX-100 / 1T	Ionization (77K)	Ge	100-1000 kg		Planning	202X		CJPL
SuperCDMS	Cryo Ionization	Ge	9 kg		Ended	2011	2015	Soudan
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	~75 kg d	Ended	2012	2015	Soudan
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	0.5 g d	Ended	2018	2018	Surface Lab
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg		Running	2020	2022	SNOLAB
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg		Construction	2023	2028	SNOLAB
EDELWEISS III	Cryo Ionization	Ge	20 kg		Ended	2015	2018	LSM
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g	80 g d	Running	2019		LSM
CRESST-II	Bolometer Scintillatior	CaWO4	5 kg		Ended	2012	2015	LNGS
CRESST-III	Bolometer Scintillatior	CaWO4	240 g		Ended	2016	2018	LNGS
CRESST-III (HW Tests)	Bolometer Scintillatior	CaWO4			Running	2020		LNGS
PICO-2	Bubble Chamber	C3F8	2 kg		Ended	2013	2015	SNOLAB
PICO-40	Bubble Chamber	C3F8	35 kg		Running	2020		SNOLAB
PICO-60	Bubble Chamber	CF3I,C3F8	52 kg		Ended	2013	2017	SNOLAB
PICO-500	Bubble Chamber	C3F8	430 kg		Construction/Run	2021		SNOLAB
DRIFT-II	Gas Directional	CF4	0.14 kg		Ended			Boulby
NEWAGE-03b'	Gas Directional	CF4	14 g	4.5 kg d	Ended	2013	2017	
CYGNUS???								
NEWS-G	Gas Drift	CH4			Ended	2017	2019	LSM
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DAMIC	CCD	Si	2.9 g	0.6 kg d	Ended	2015	2015	SNOLAB
DAMIC	CCD	Si	40 g Si		Ended	2017	2019	SNOLAB
DAMIC100	CCD	Si	100 g Si		Not Built			SNOLAB
DAMIC-M	CCD Skipper	Si	1 kg Si		Construction/Run	2021	2024	LSM
SENSEI	CCD Skipper	Si	2 g Si	2g x 24 d	Running	2019	2020	Fermilab u/g
SENSEI	CCD Skipper	Si	100 g Si		Construction/Run	2021	2023	SNOLAB
ALETHEIA	TPC	He			R&D			China Inst. At. Energy
TESSERACT	Cryo TES	He			R&D			LBNL

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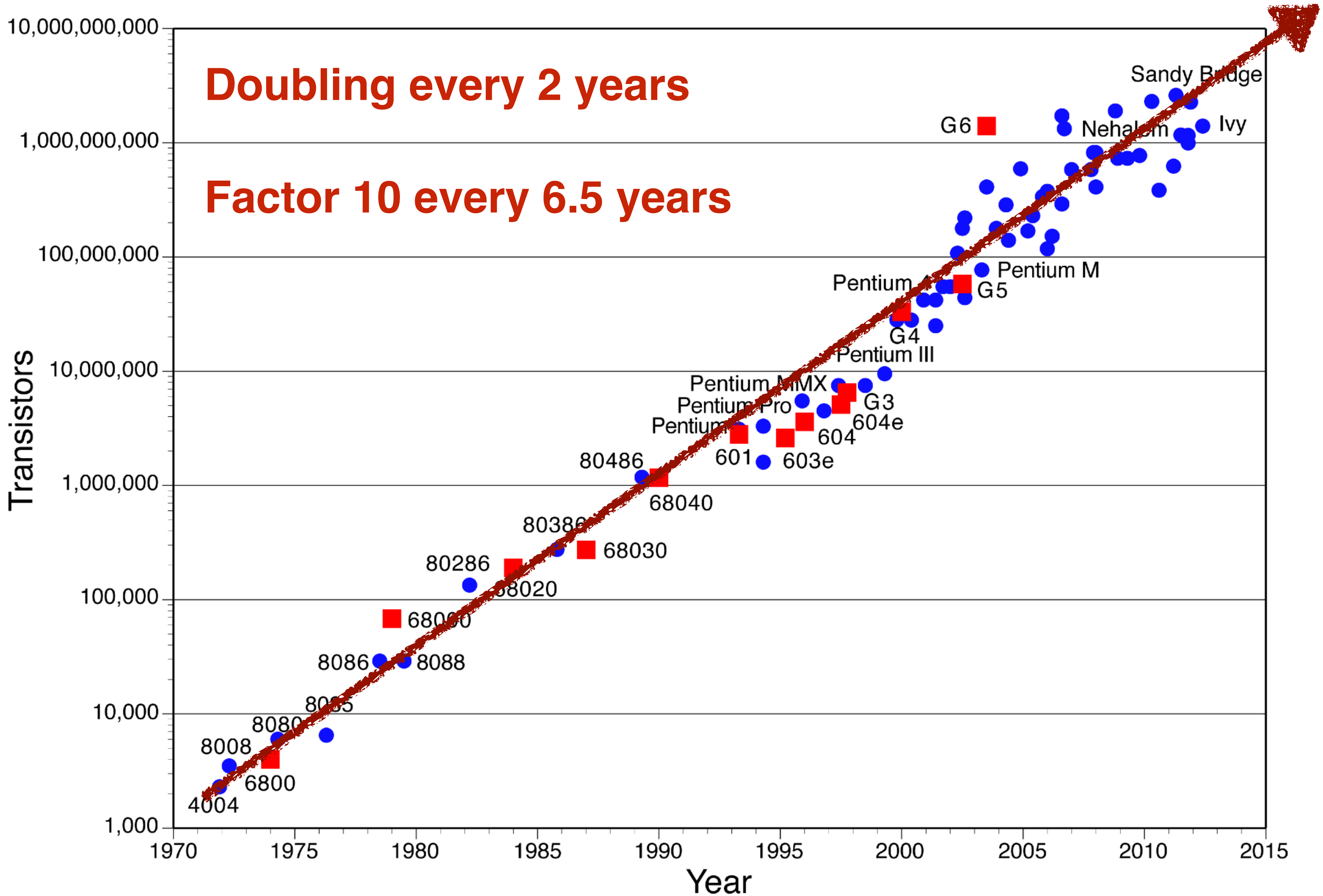

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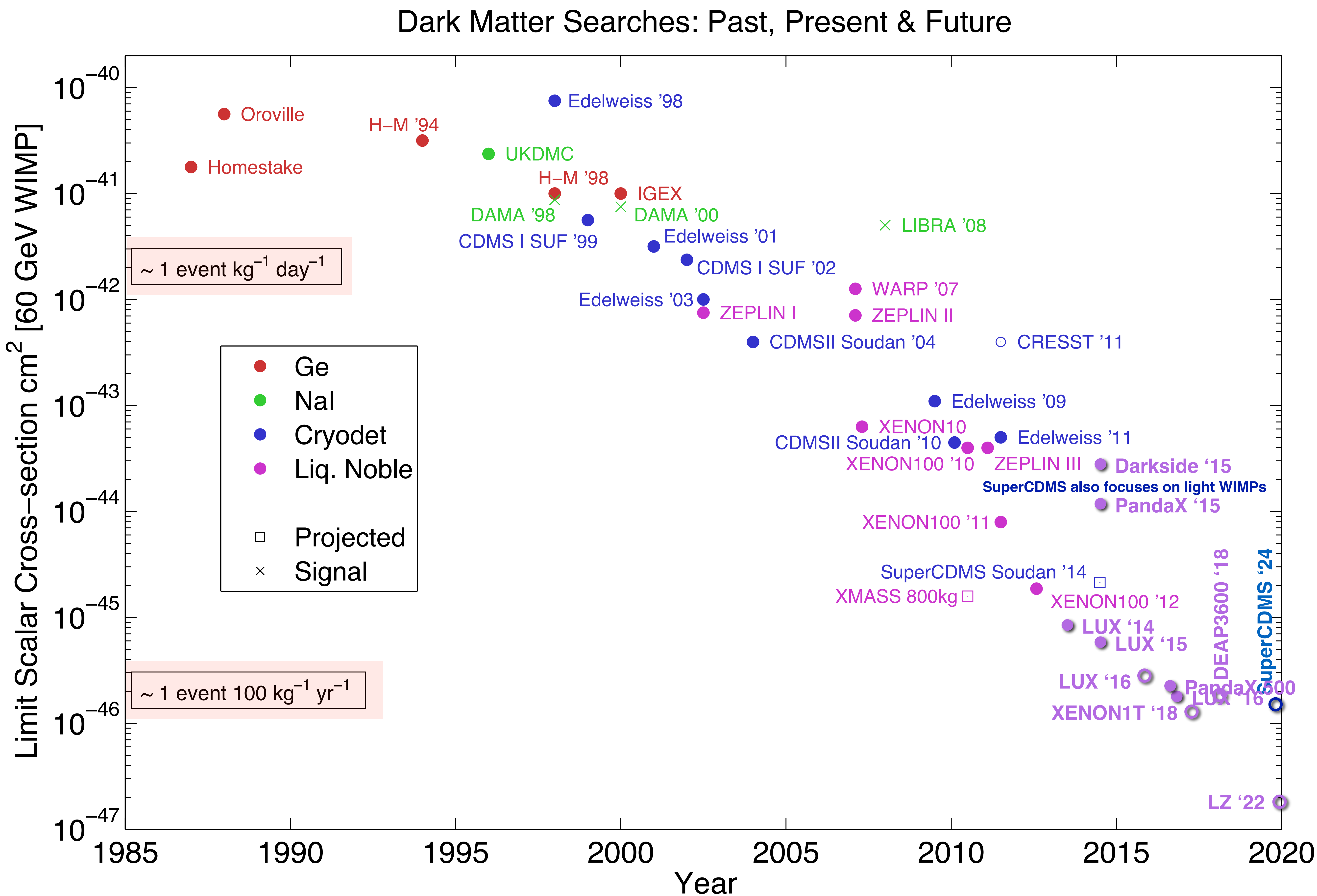
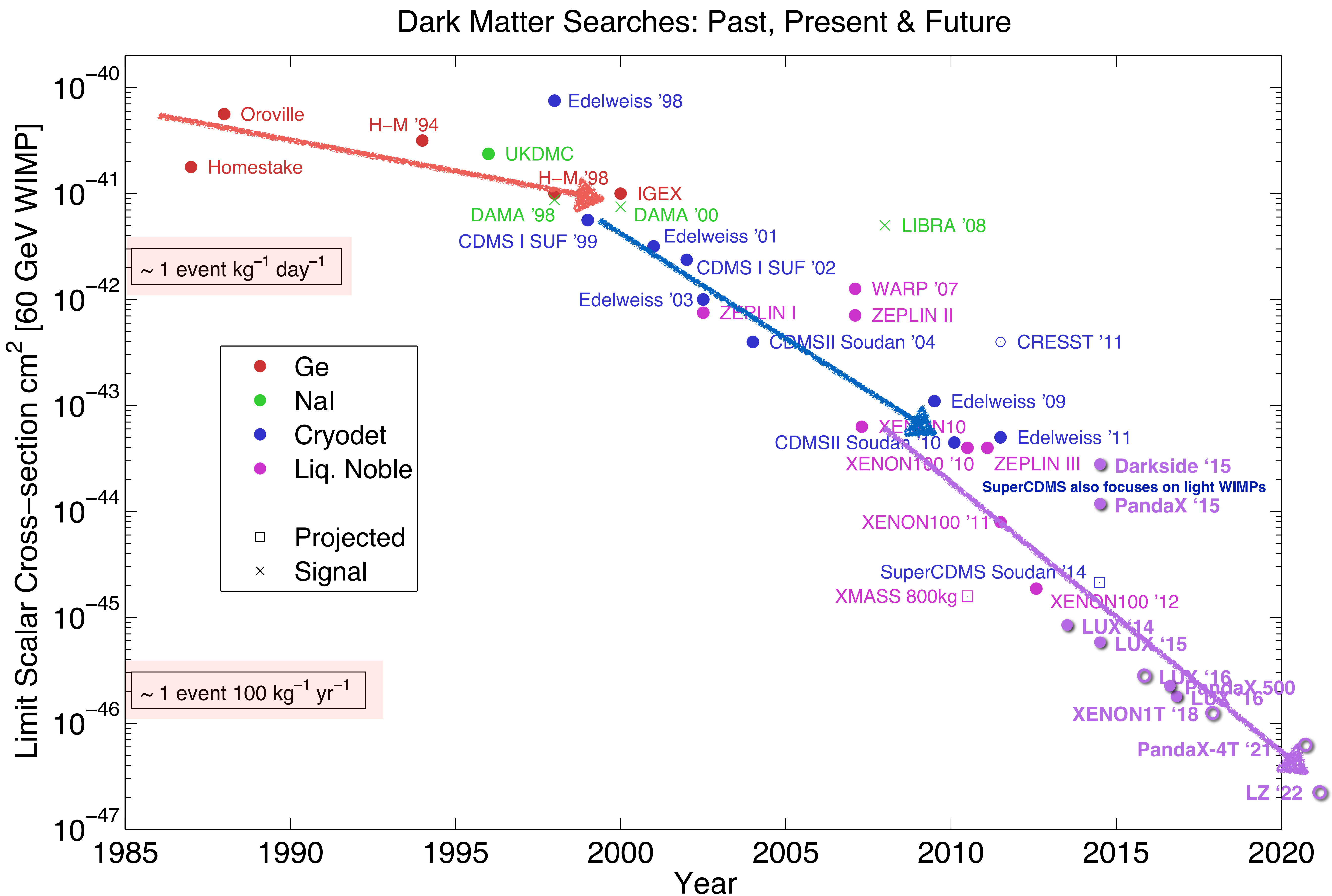
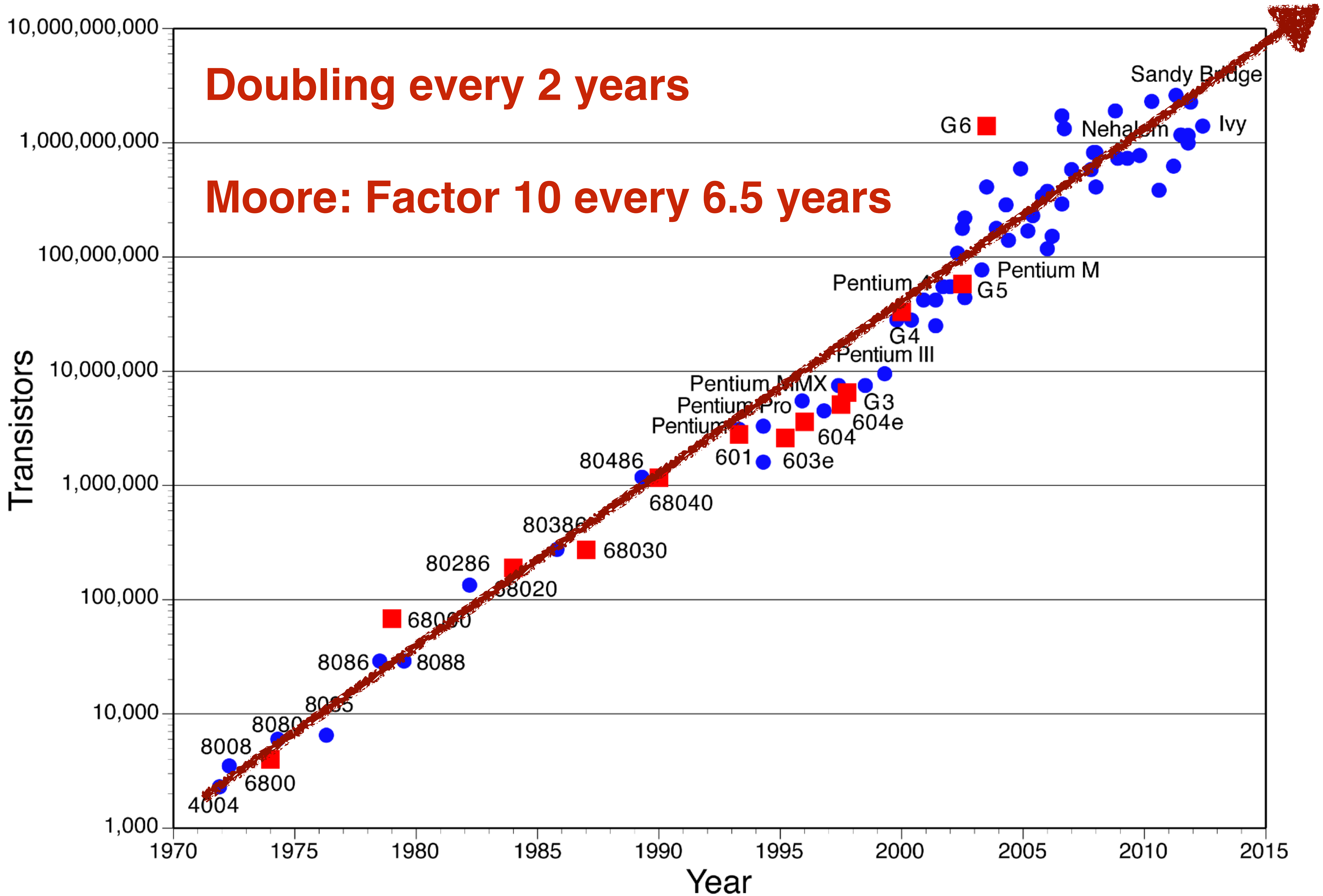


Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section cm² [60 GeV WIMP]
Year
Oroville
Homestake
H–M '94
Edelweiss '98
UKDMC
H–M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
LIBRA '08
CDMS I SUF '02
~ 1 event kg⁻¹ day⁻¹
Edelweiss '03
ZEPLIN I
WARP '07
ZEPLIN II
CDMSII Soudan '04
CRESST '11
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
Darkside '15
SuperCDMS also focuses on light WIMPs
PandaX '15
XENON100 '11
SuperCDMS Soudan '14
XMASS 800kg
XENON100 '12
LUX '14
LUX '15
DEAP3600 '18
SuperCDMS '24
~ 1 event 100 kg⁻¹ yr⁻¹
LUX '16
PandaX 500
LUX '16
XENON1T '18
LZ '22

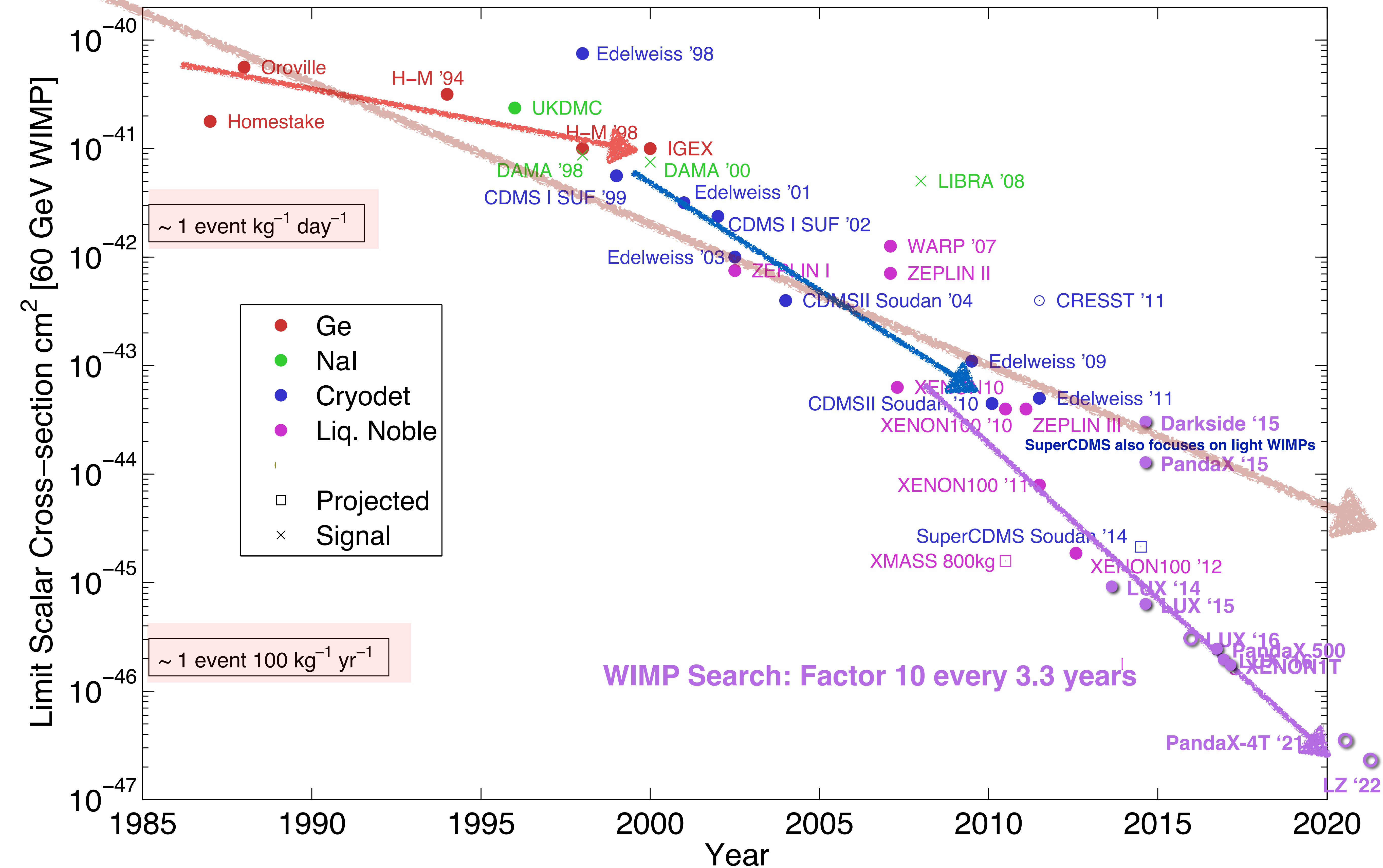

Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section cm2 [60 GeV WIMP]
Year
10−40
10−41
10−42
10−43
10−44
10−45
10−46
10−47
1985
1990
1995
2000
2005
2010
2015
2020
~ 1 event kg−1 day−1
~ 1 event 100 kg−1 yr−1
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal
Oroville
Homestake
H−M '94
UKDMC
H−M '98
IGEX
DAMA '98
DAMA '00
Edelweiss '98
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
LIBRA '08
WARP '07
ZEPLIN II
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
Darkside '15
SuperCDMS also focuses on light WIMPs
PandaX '15
XENON100 '11
SuperCDMS Soudan '14
XMASS 800kg
XENON100 '12
LUX '14
LUX '15
LUX '16
PandaX 500
LUX '16
XENON1T '18
PandaX-4T '21
LZ '22



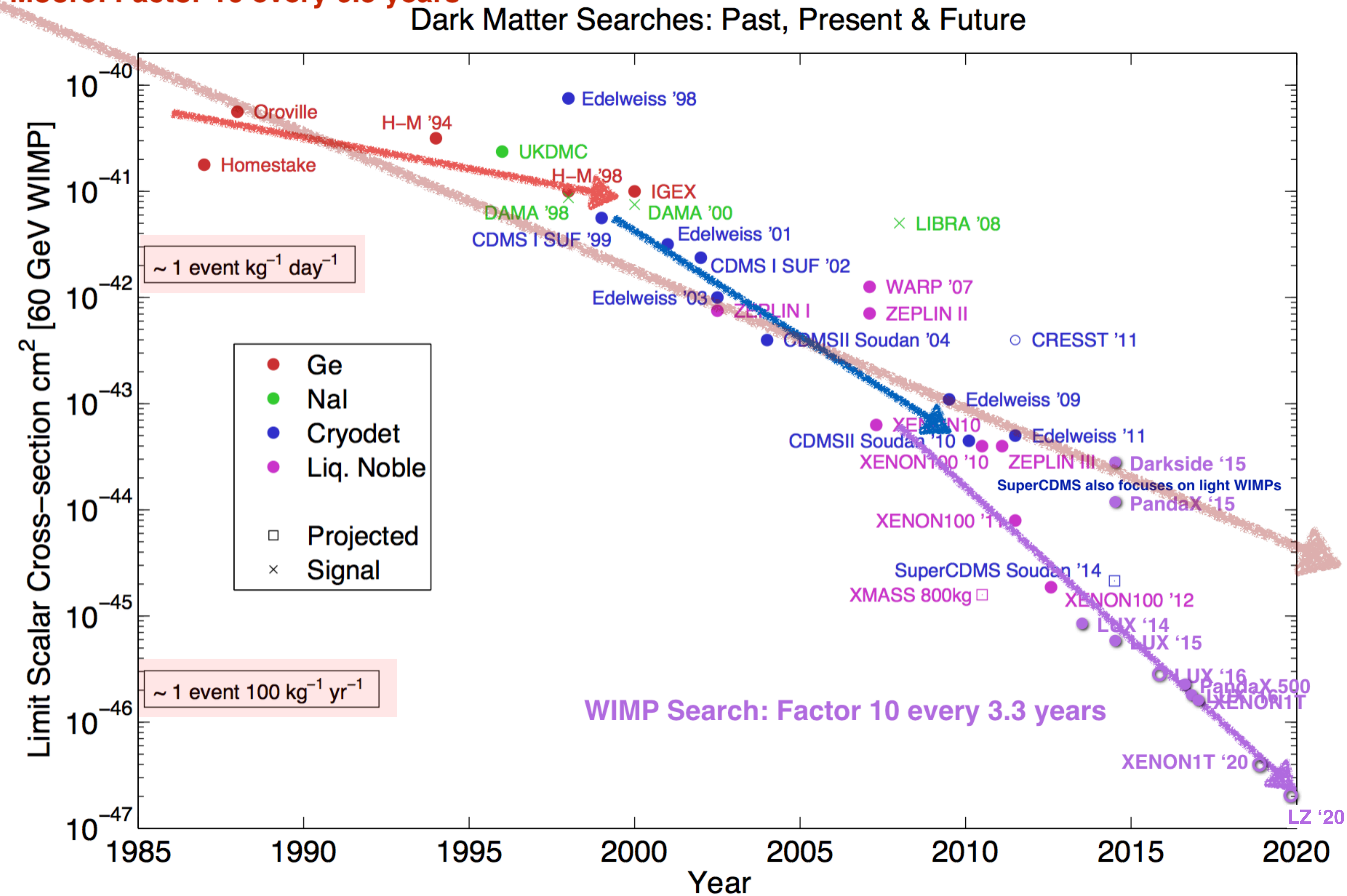
http://education.mrsec.wisc.edu/SlideShow/images/computer/Moores_Law.png

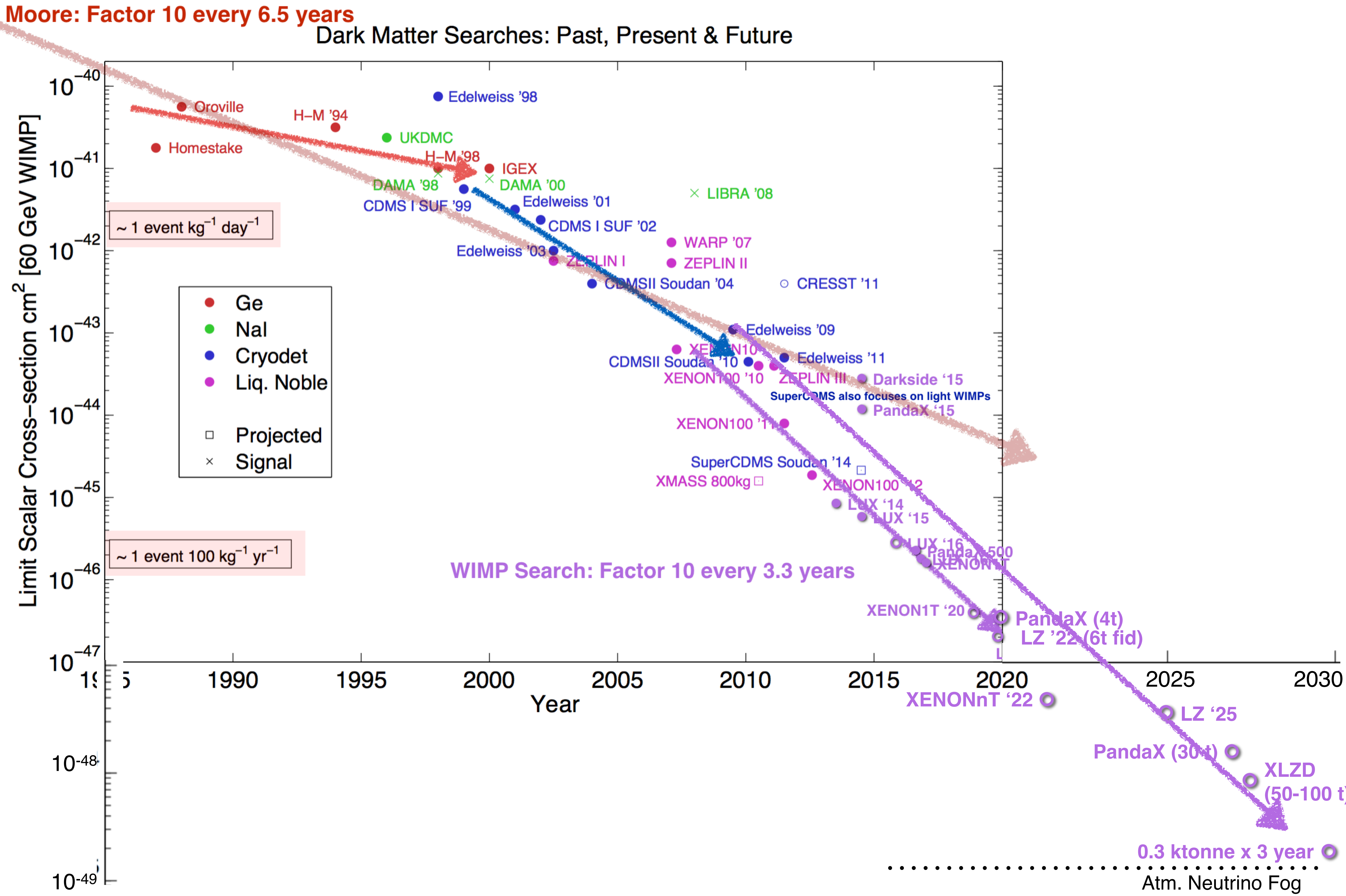
Moore: Factor 10 every 6.5 years

Dark Matter Searches: Past, Present & Future



Moore: Factor 10 every 6.5 years




Moore: Factor 10 every 6.5 years
Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section cm² [60 GeV WIMP]
Year
Oroville
Homestake
H–M '94
Edelweiss '98
UKDMC
H–M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
LIBRA '08
WARP '07
ZEPLIN II
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
CRESST '11
Edelweiss '09
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
Darkside '15
SuperCDMS also focuses on light WIMPs
PandaX '15
XENON100 '11
SuperCDMS Soudan '14
XMASS 800kg
XENON100 '12
LUX '14
LUX '15
LUX '16
PandaX-500
XENON1T
WIMP Search: Factor 10 every 3.3 years
XENON1T '20
PandaX (4t)
LZ '22 (6t fid)
XENONnT '22
LZ '25
PandaX (30 t)
XLZD
(50-100 t)
0.3 ktonne x 3 year
Atm. Neutrino Fog
~ 1 event kg⁻¹ day⁻¹
~ 1 event 100 kg⁻¹ yr⁻¹
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal
1990
1995
2000
2005
2010
2015
2020
2025
2030
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
10⁻⁴⁹

Dar - TeV

XMASS	Scintillator	LXe	832 kg		Ended	2010	2019	Kamioke
XENON100	TPC	LXe	62 kg		Ended	2012	2016	LNGS
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Construction/Run	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Construction/Run	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Running	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	50,000 kg	200 t yr	Planning	2028	2033	LNGS/SURF/Boulby
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
Darkside-20k	TPC	LAr	30 t	200 t yr	lanning/Construct	2025	2030	LNGS
ARGO	TPC	LAr	300 t	3000 t yr	Planning	2030	2035	SNOLAB
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc
COSINE-100	Scintillator	NaI	106 kg		Running	2016	2021	YangYang
COSINE-200	Scintillator	NaI	200 kg		Construction	2022	2025	YangYang
COSINE-200 South Pole	Scintillator	NaI	200 kg		Planning	2023	?	South Pole
COSINUS	Bolometer Scintillator	NaI	?		Planning	2023	?	LNGS
SABRE PoP	Scintillator	NaI	5 kg		Construction	2021	2022	LNGS
SABRE (North)	Scintillator	NaI	50 kg		Planning	2022	2027	LNGS
SABRE (South)	Scintillator	NaI	50 kg		Planning	2022	2027	SUPL
CDEX-10	Ionization (77K)	Ge	10 kg	103 kg d	Running	2016	?	CJPL
CDEX-100 / 1T	Ionization (77K)	Ge	100-1000 kg		Planning	202X		CJPL
SuperCDMS	Cryo Ionization	Ge	9 kg		Ended	2011	2015	Soudan
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	~75 kg d	Ended	2012	2015	Soudan
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	0.5 g d	Ended	2018	2018	Surface Lab
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg		Running	2020	2022	SNOLAB
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg		Construction	2023	2028	SNOLAB
EDELWEISS III	Cryo Ionization	Ge	20 kg		Ended	2015	2018	LSM
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g	80 g d	Running	2019		LSM
CRESST-II	Bolometer Scintillatior	CaWO4	5 kg		Ended	2012	2015	LNGS
CRESST-III	Bolometer Scintillatior	CaWO4	240 g		Ended	2016	2018	LNGS
CRESST-III (HW Tests)	Bolometer Scintillatior	CaWO4			Running	2020		LNGS
PICO-2	Bubble Chamber	C3F8	2 kg		Ended	2013	2015	SNOLAB
PICO-40	Bubble Chamber	C3F8	35 kg		Running	2020		SNOLAB
PICO-60	Bubble Chamber	CF3I,C3F8	52 kg		Ended	2013	2017	SNOLAB
PICO-500	Bubble Chamber	C3F8	430 kg		Construction/Run	2021		SNOLAB
DRIFT-II	Gas Directional	CF4	0.14 kg		Ended			Boulby
NEWAGE-03b'	Gas Directional	CF4	14 g	4.5 kg d	Ended	2013	2017	
CYGNUS???								
NEWS-G	Gas Drift	CH4			Ended	2017	2019	LSM
NEWS-G	Gas Drift	CH4			Construction/Run	2020	2025	SNOLAB
DAMIC	CCD	Si	2.9 g	0.6 kg d	Ended	2015	2015	SNOLAB
DAMIC	CCD	Si	40 g Si		Ended	2017	2019	SNOLAB
DAMIC100	CCD	Si	100 g Si		Not Built			SNOLAB
DAMIC-M	CCD Skipper	Si	1 kg Si		Construction/Run	2021	2024	LSM
SENSEI	CCD Skipper	Si	2 g Si	2g x 24 d	Running	2019	2020	Fermilab u/g
SENSEI	CCD Skipper	Si	100 g Si		Construction/Run	2021	2023	SNOLAB
ALETHEIA	TPC	He			R&D			China Inst. At. Energy
TESSERACT	Cryo TES	He			R&D			LBNL

R&D
Planning
Construction
Running
Ended

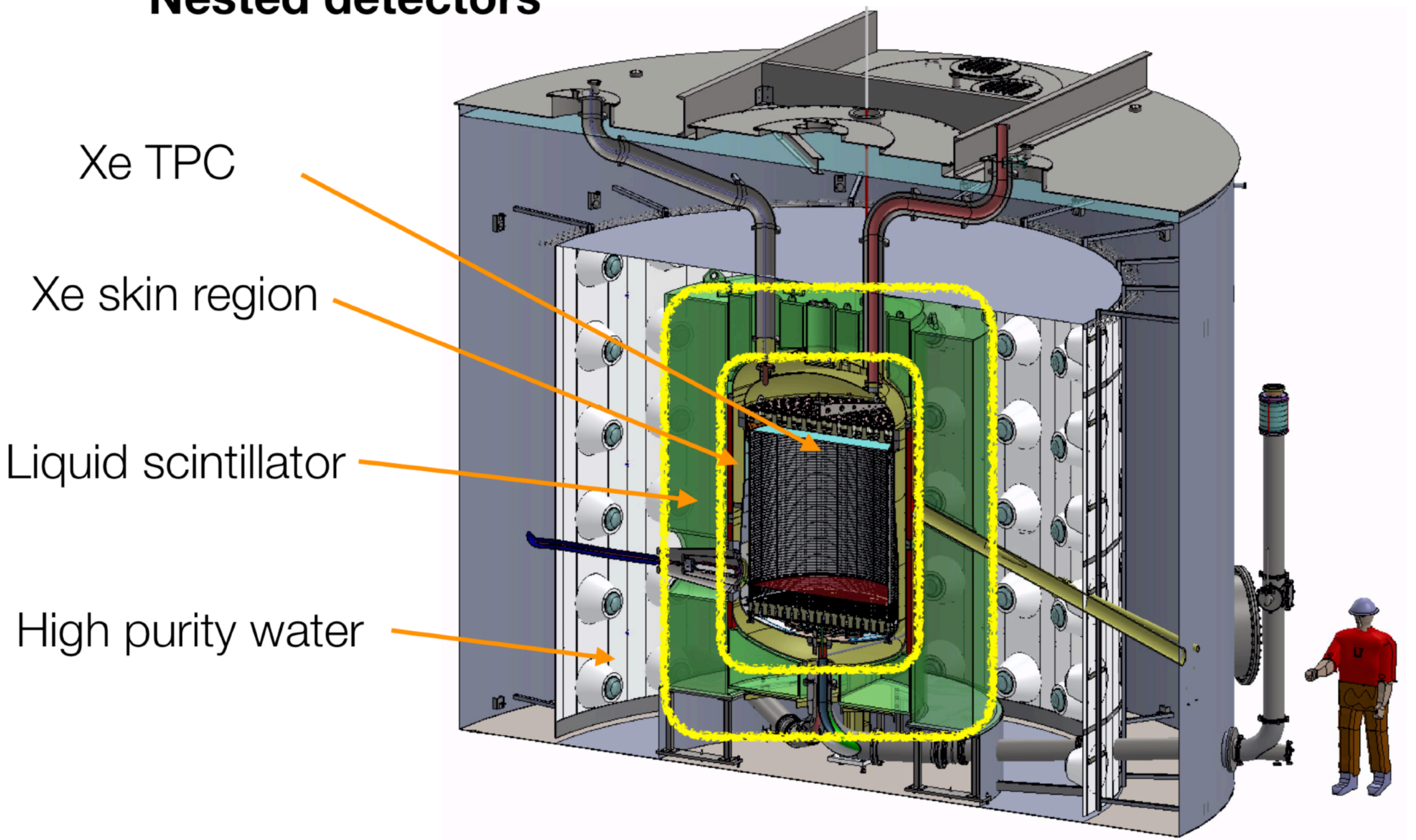
Dark Matter Direct Detection MeV - TeV

Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
XMASS	Scintillator	LXe	832 kg		Ended	2010	2019	Kamioke
XENON100	TPC	LXe	62 kg		Ended	2012	2016	LNGS
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Running	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Running	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Running	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	50,000 kg	200 t yr	Planning	2028	2033	LNGS/SURF/B
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
Darkside-20k	TPC	LAr	30 t	200 t yr	lanning/Construct	2025	2030	LNGS
ARGO	TPC	LAr	300 t	3000 t yr	Planning	2030	2035	SNOLAB
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc

LUX-ZEPLIN @ Sanford Lab (Full Operations Start in 2021)

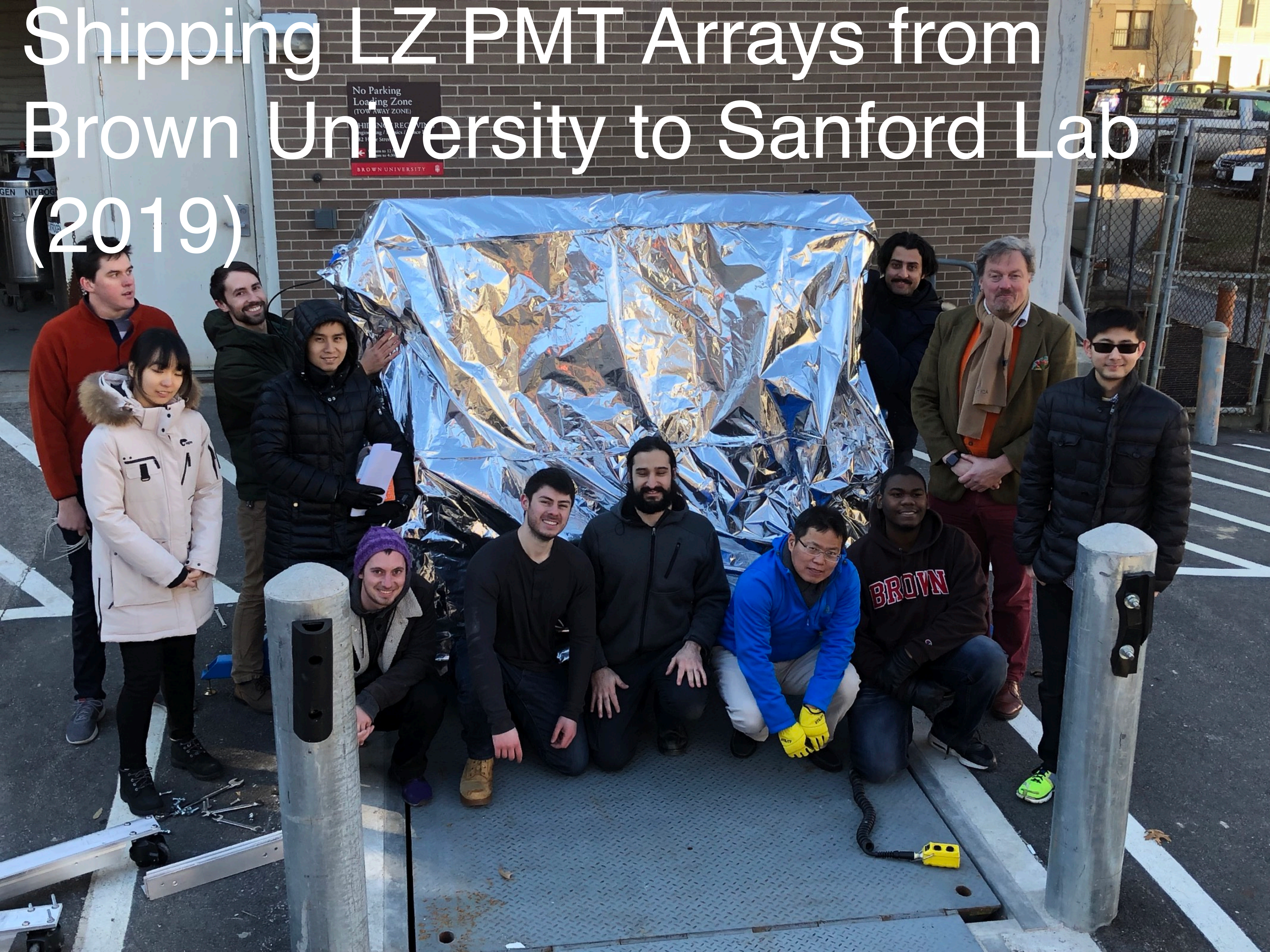
LZ TDR arXiv:1703.09144

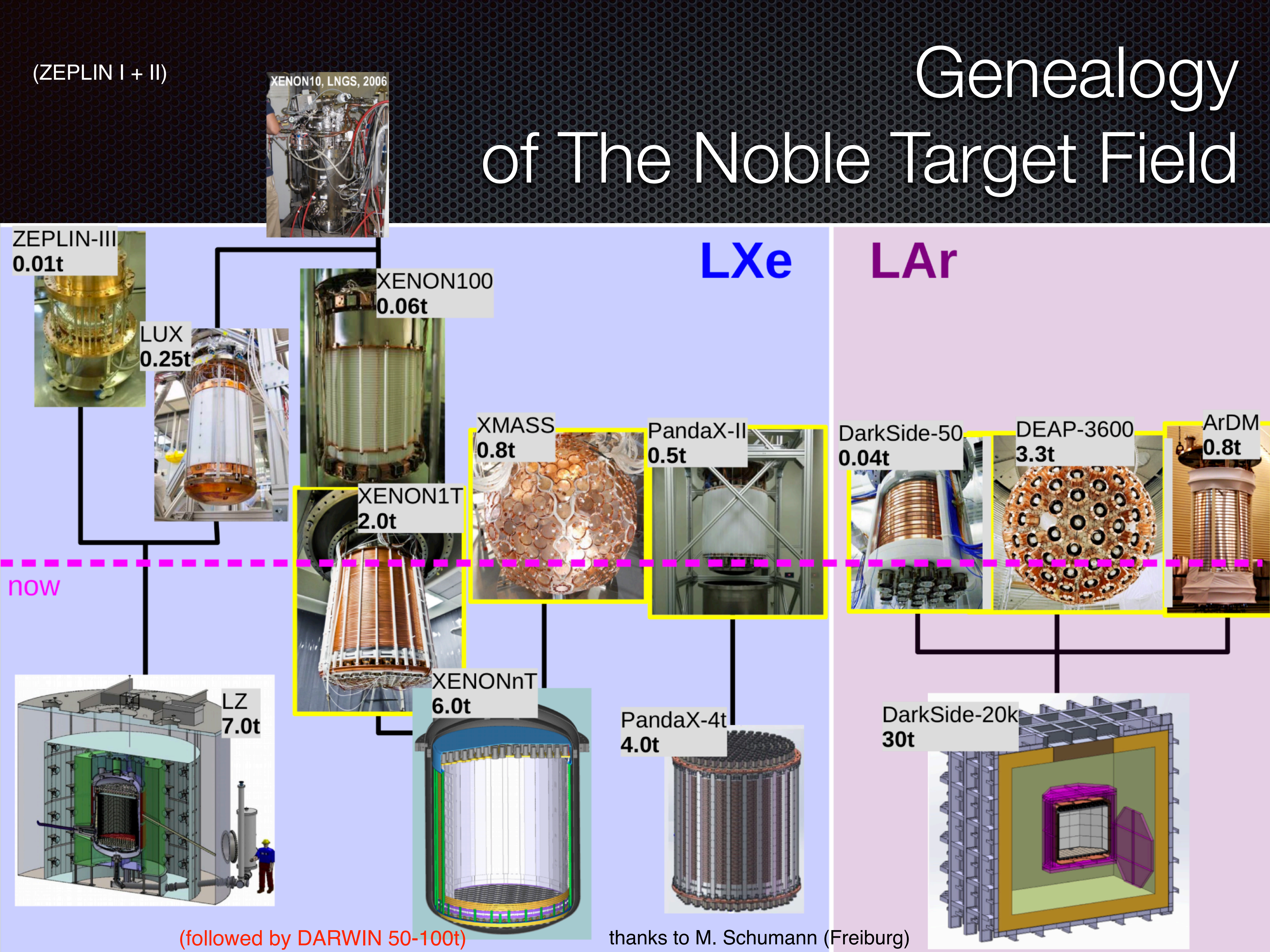
Nested detectors

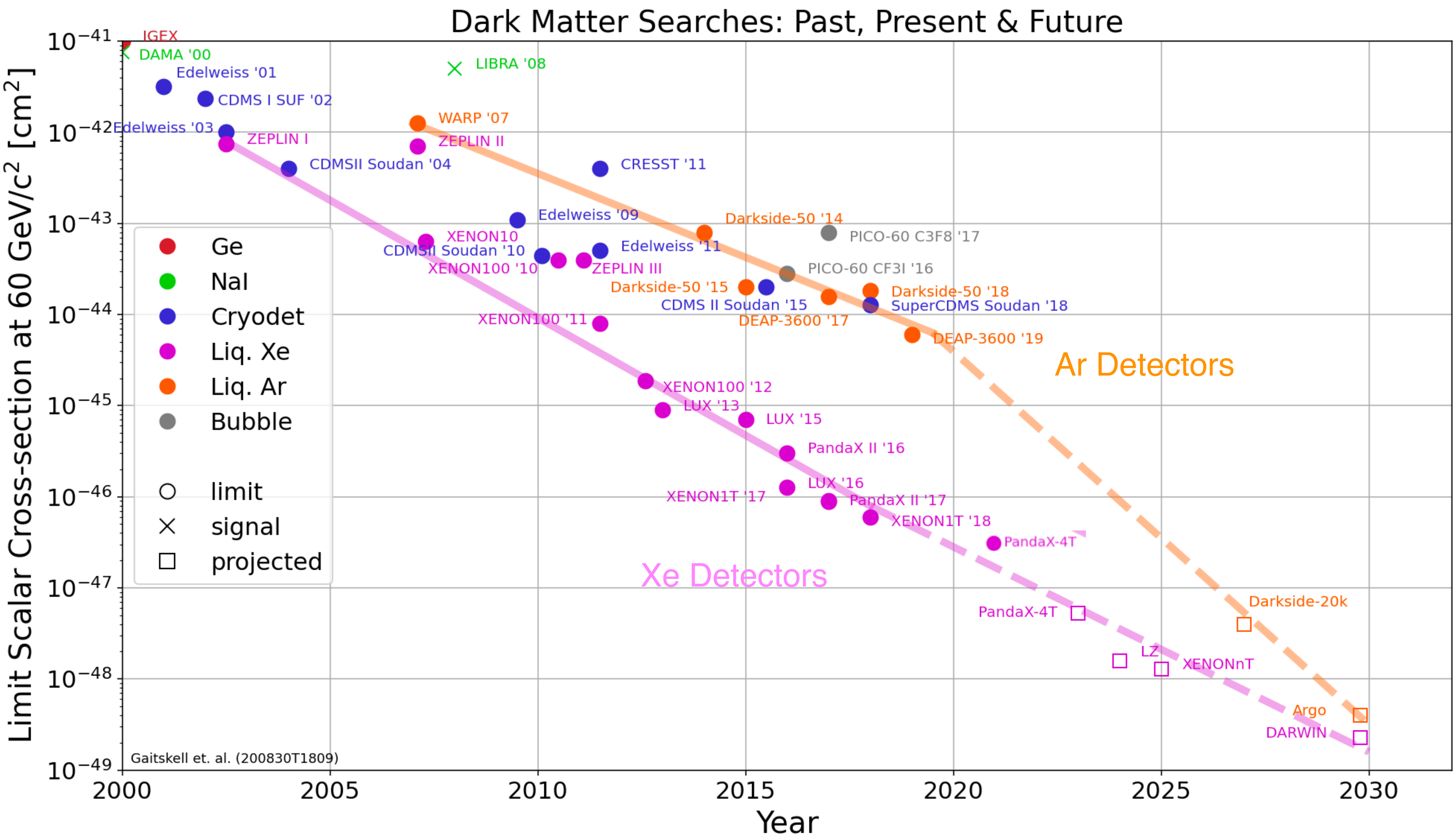


How have we spent the last few years at Brown?

Shipping LZ PMT Arrays from Brown University to Sanford Lab (2019)




Genealogy
of The Noble Target Field
(ZEPLIN I + II)
XENON10, LNGS, 2006
LXe
LAr
ZEPLIN-III
0.01t
LUX
0.25t
XENON100
0.06t
XENON1T
2.0t
XMASS
0.8t
PandaX-II
0.5t
DarkSide-50
0.04t
DEAP-3600
3.3t
ArDM
0.8t
now
LZ
7.0t
XENONnT
6.0t
PandaX-4t
4.0t
DarkSide-20k
30t
(followed by DARWIN 50-100t)
thanks to M. Schumann (Freiburg)



Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section at 60 GeV/c^2 [cm^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
2000
2005
2010
2015
2020
2025
2030
Year
IGEX
DAMA '00
Edelweiss '01
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
LIBRA '08
WARP '07
ZEPLIN II
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
XENON100 '10
ZEPLIN III
Edelweiss '11
Darkside-50 '14
PICO-60 C3F8 '17
PICO-60 CF3I '16
Darkside-50 '15
CDMS II Soudan '15
DEAP-3600 '17
Darkside-50 '18
SuperCDMS Soudan '18
DEAP-3600 '19
XENON100 '11
Ar Detectors
XENON100 '12
LUX '13
LUX '15
PandaX II '16
LUX '16
XENON1T '17
PandaX II '17
XENON1T '18
PandaX-4T
Xe Detectors
PandaX-4T
Darkside-20k
LZ
XENONnT
Argo
DARWIN
Ge
NaI
Cryodet
Liq. Xe
Liq. Ar
Bubble
limit
signal
projected
Gaitskell et. al. (200830T1809)

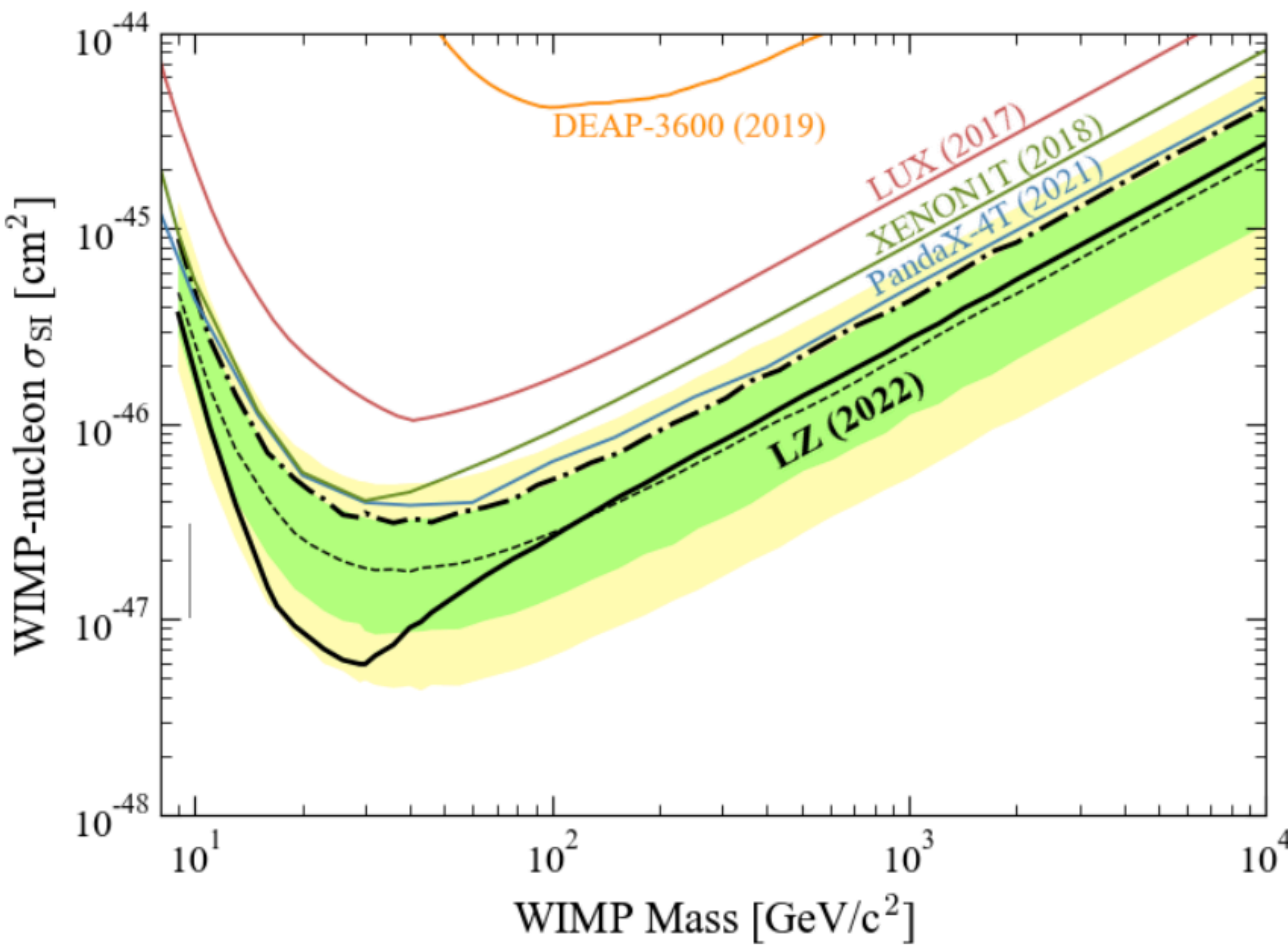
LZ Results from SR1 - Preprint + Talk (July 7, 2022)

- Science Run 1 - ~3.5 month run, exposure is 60 live days x 5.5 tonnes fiducial
  - (7t active in TPC+2t Xe skin+17t Gd-loaded LS)

See IDM Talks by Alden Fan, Ibles Olcina, Alissa Monte

arXiv:2207.03764

- Curves:
  - Solid black: observed limit
  - Dashed-black: median expected sensitivity
  - Dot-dashed black: median 3-sigma evidence
- No evidence of WIMPs at any mass
- Minimum exclusion on WIMP-nucleon cross section (SI) of 6×10^{-48} cm^2 at 30 GeV
- Comparing to existing strongest upper limit:
  - x6.7 improvement at 30 GeV
  - x1.7 improvement above 1 TeV



XLZD - XENON LUX ZEPLIN DARWIN

XLZD Consortium

- MOU between LZ, XENON, DARWIN
- Successful XLZD meeting 27-29 June 2022 at Karlsruhe Institute of Technology
- https://xlzd.org/
- White paper (2203.02309)

Leading Xenon Researchers unite to build next-generation Dark Matter Detector

SURF is distributing this press release on behalf of the DARWIN and LZ collaborations

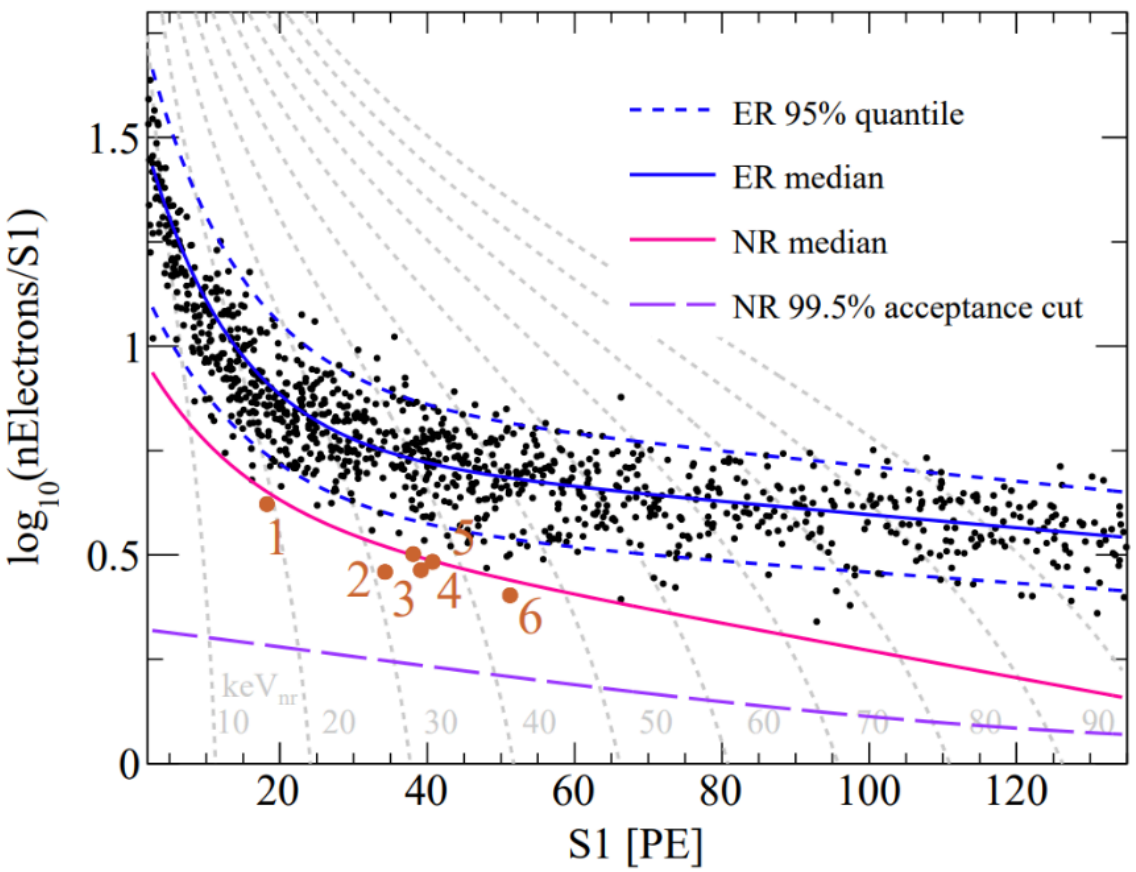
A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

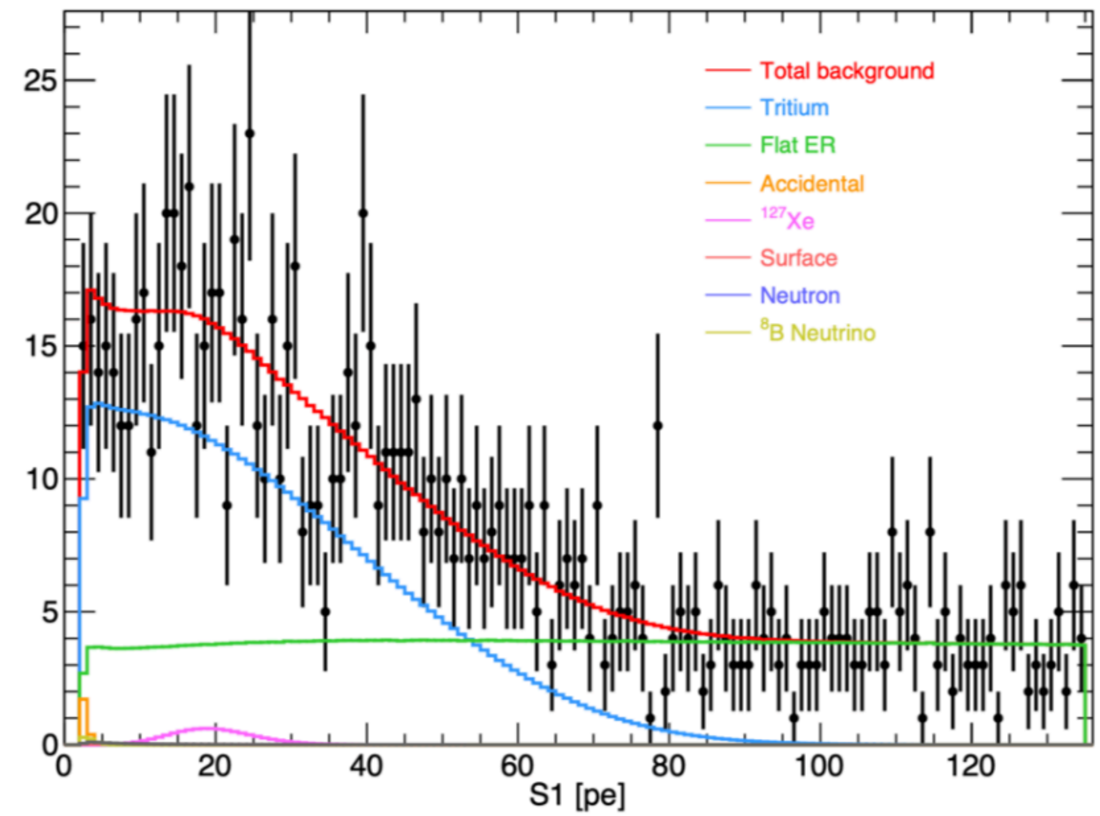
J. Aalbers,[1,2] K. Abe,[3,4] V. Aerne,[5] F. Agostini,[6] S. Ahmed Maouloud,[7] D.S. Akerib,[1,2] D.Yu. Akimov,[8] J. Akshat,[9] A.K. Al Musalhi,[10] F. Alder,[11] S.K. Alsum,[12] L. Althueser,[13] C.S. Amarasinghe,[14] F.D. Amaro,[15] A. Ames,[1,2] T.J. Anderson,[1,2] B. Andrieu,[7] N. Angelides,[16] E. Angelino,[17] J. Angevaare,[18] V.C. Antochi,[19] D. Antón Martin,[20] B. Antunovic,[21,22] E. Aprile,[23] H.M. Araújo,[16] J.E. Armstrong,[24] F. Arneodo,[25] M. Arthurs,[14] P. Asadi,[26] S. Baek,[27] X. Bai,[28] D. Bajpai,[29] A. Baker,[16] J. Balajthy,[30] S. Balashov,[31] M. Balzer,[32] A. Bandyopadhyay,[33] J. Bang,[34] E. Barberio,[35] J.W. Bargemann,[36] L. Baudis,[5] D. Bauer,[16] D. Baur,[37] A. Baxter,[38] A.L. Baxter,[9] M. Bazyk,[39] K. Beattie,[40] J. Behrens,[41] N.F. Bell,[35] L. Bellagamba,[6] P. Beltrame,[42] M. Benabderrahmane,[25] E.P. Bernard,[43,40] G.F. Bertone,[18] P. Bhattacharjee,[44] A. Bhatti,[24] A. Biekert,[43,40] T.P. Biesiadzinski,[1,2] A.R. Binau,[9] R. Biondi,[45] Y. Biondi,[5] H.J. Birch,[14] F. Bishara,[46] A. Bismark,[5] C. Blanco,[47,19] G.M. Blockinger,[48]

SLAC A. Fan 20

PandaX-4T

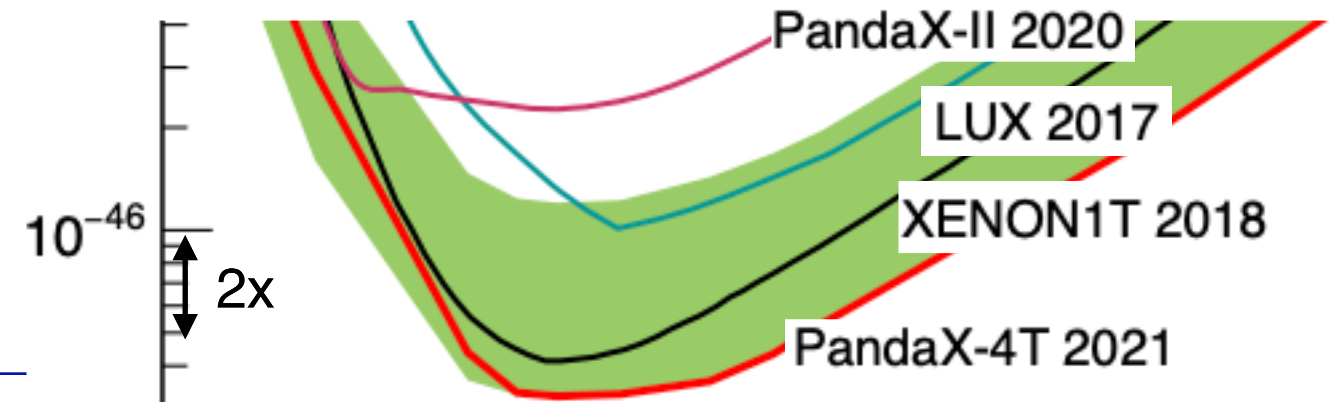
- Collaboration: 18 institutions, 84 scientists / 3.7 tonne active, 2.7 tonne fiducial
- New Search Results - July 2021/arXiv:2107.13438 Commissioning - 86 days of running





- General background similar to XE1T, however, tritium dominates at low energy. 3H was introduced during PandaX-II calibration with intrinsic 3H source. Working to remove.
- New Science Run (reduce 3H contamination) Expect significant improvement in search sensitivity over coming few years

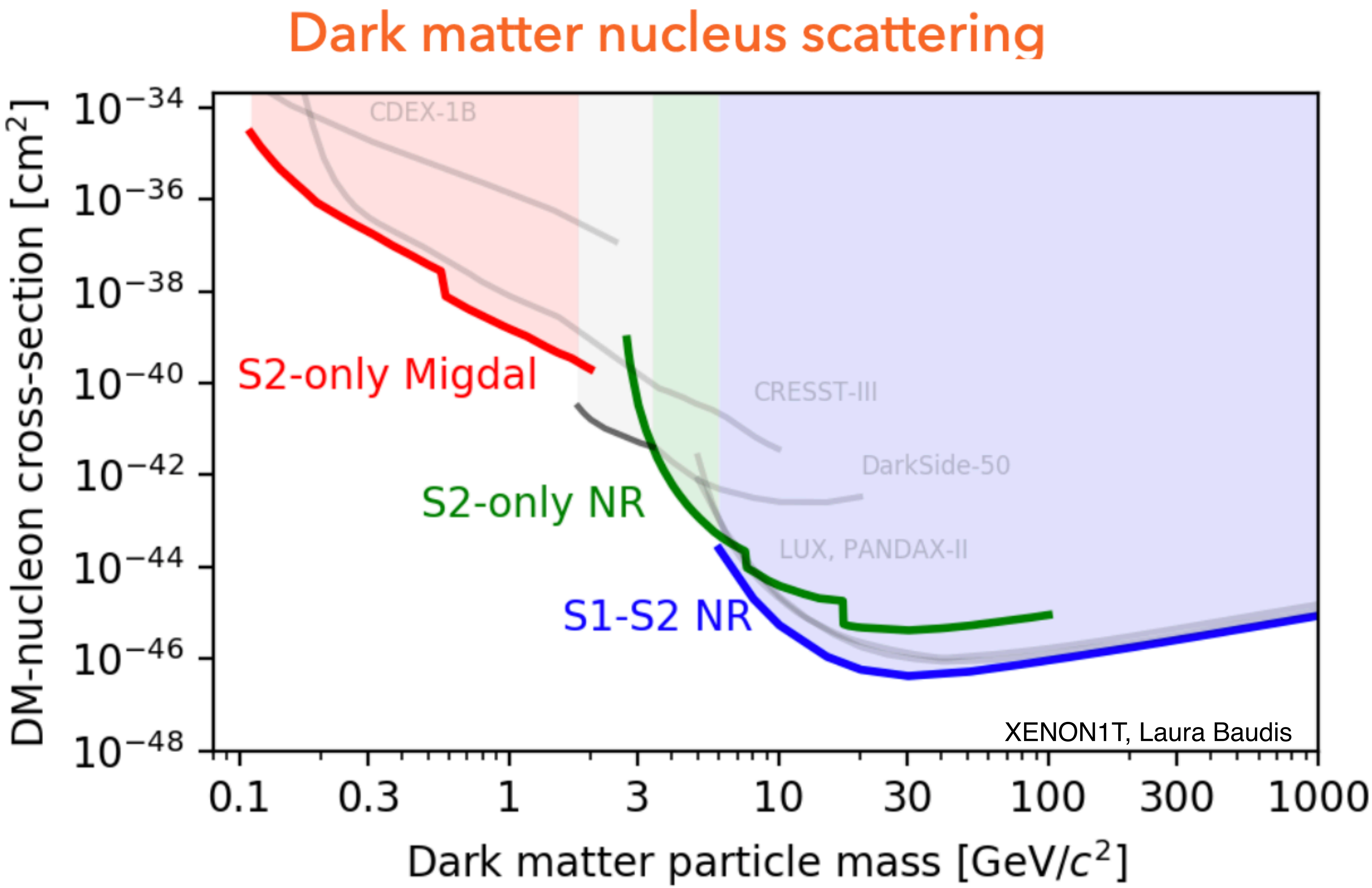
Note PandaX-4T limit appears better than expected sensitivity / downward fluctuation of events rate compared to expected background



XENONnT @ LNGS

- The XENONnT Experiment commissioned in 2020/21 and is currently taking science data
- Dual-phase Xe TPC
  - 5.9 t active target mass (fid mass ~4.5 t)
  - Achieving an e-lifetime >10 ms
  - Low Rn level (< 2 µBq/kg)
  - Reduced n-background thanks to the novel nVeto system
- First Science Run
  - Completed at the end of 2021.
  - After some maintenance and refurbishment we are again taking Science Data.
  - The analysis of the first months of data will be focused on the WIMP search and on the low-ER events, shedding light into the excess of event in the low ER region, seen by its predecessor, XENON1T

LXe TPC's Improving Sensitivity on Multiple Fronts



crystaLiZe (Solid Xe Target ~140K)

- R&D on a crystalline/vapor Xe TPC

See Sorensen Talk

  - Aim to establish if it is a cost-effective path to the neutrino floor
  - Preliminarily, it can operate very much like a liquid xenon TPC, but can deliver O(x1000) or better radon exclusion.
- Several key steps remain to be demonstrated, including:
  - Further quantification of Rn exclusion (and diffusion)
  - Electron signal yield
  - Consistency/stability of the crystal surface
  - Purity (which depends somewhat on design)
  - Evidence that the crystallization can scale to 1.5 m size instruments

Future Noble Detectors

- Future Noble Detectors Summary, Michelle Galloway, Tuesday

Dark Matter Direct Detection MeV - TeV

Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
XMASS	Scintillator	LXe	832 kg		Ended	2010	2019	Kamioke
XENON100	TPC	LXe	62 kg		Ended	2012	2016	LNGS
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Construction/Run	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Construction/Run	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Running	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	50,000 kg	200 t yr	Planning	2028	2033	LNGS/SUF
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
Darkside-20k	TPC	LAr	30 t	200 t yr	'lanning/Construct	2025	2030	LNGS
ARGO	TPC	LAr	300 t	3000 t yr	Planning	2030	2035	SNOLAB
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc

Dark Matter Direct Detection MeV - TeV

Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Construction	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Construction	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Construction	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	40,000 kg	200 t yr	Planning	2028	2033	LNGS / SURF
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
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DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc
COSINE-100						2016	2021	YangYang
COSINE-200						2022	2025	YangYang
COSINE-200 South Pole	Scintillator	NaI	200 kg		Planning	2023	?	South Pole

Results from >2.5 years of new exposure data (→ DEAP-3600)

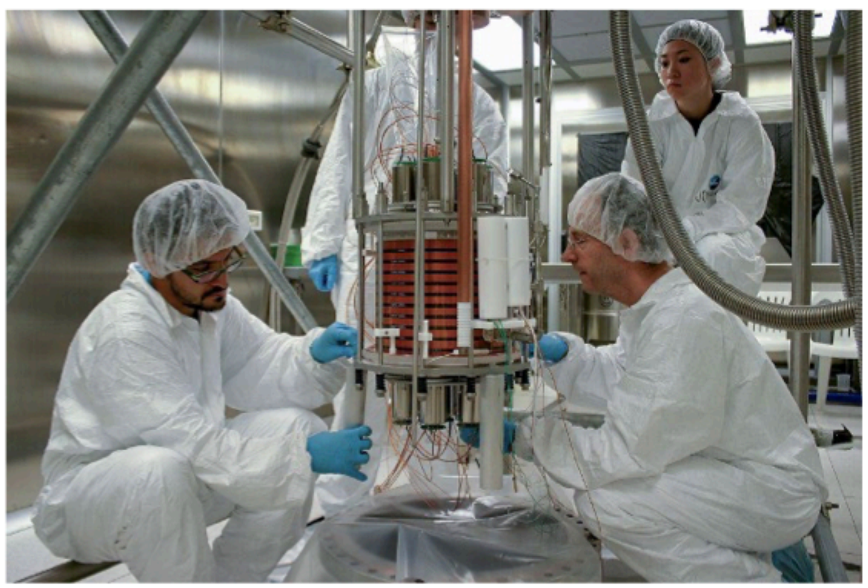
Future Experiments with Noble Liquid

DarkSide Evolution

- DarkSide-20k construction @LNGS Hall C from 2023+

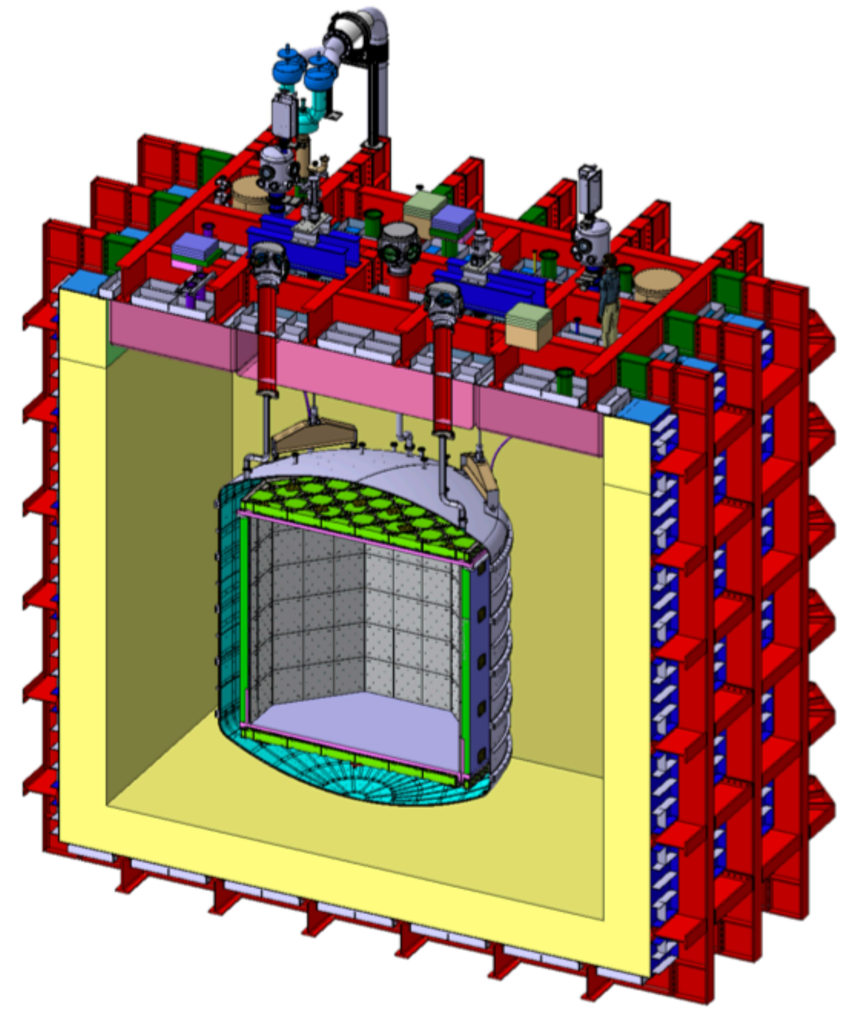
See Talk by Masato Kimora

  - Working with mockups fro HV validation
  - Start filling the detector with UAr in 2026
  - Direct WIMP dark matter search;
  - Dual phase argon time projection chamber (TPC);
  - Deep underground at LNGS, Italy.



DarkSide-10 @PU&LNGS
10 kg
2010~2012

DarkSide-50 @LNGS
46 kg
2013~2021



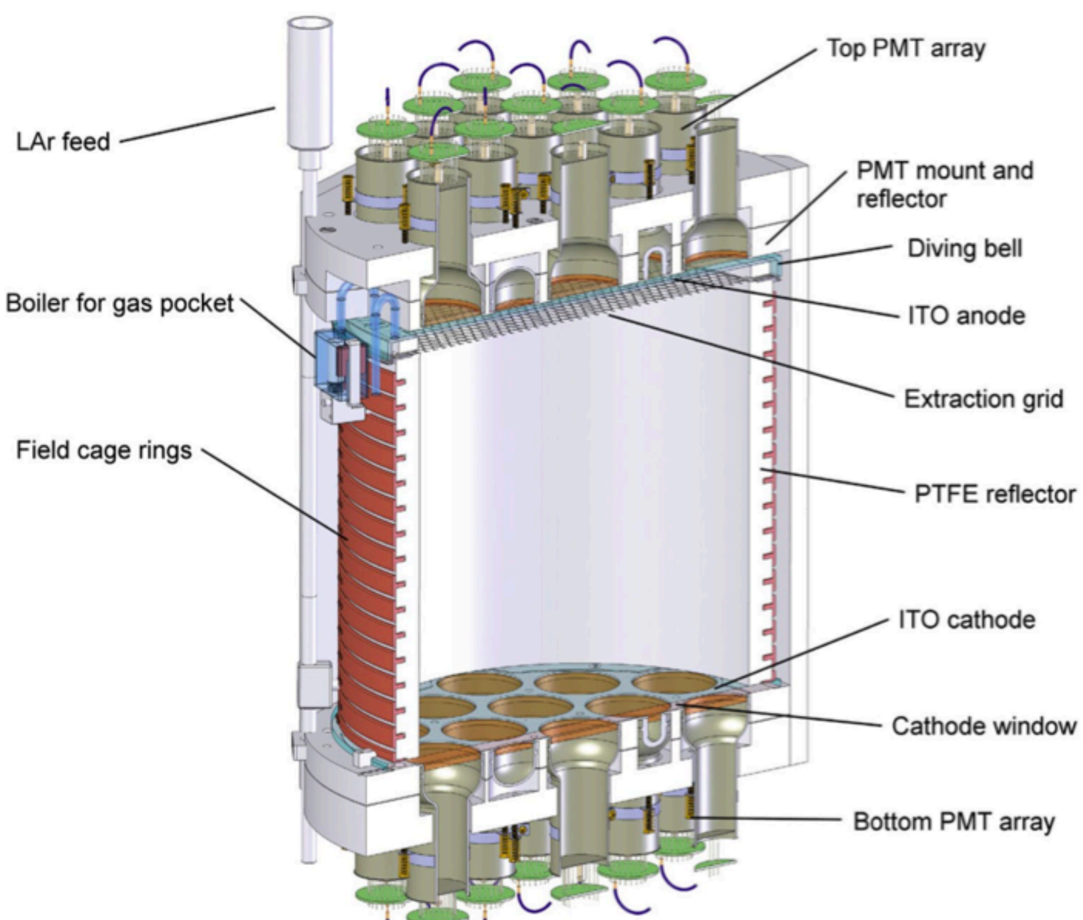
DarkSide-20k @LNGS
20 tonnes
2026~

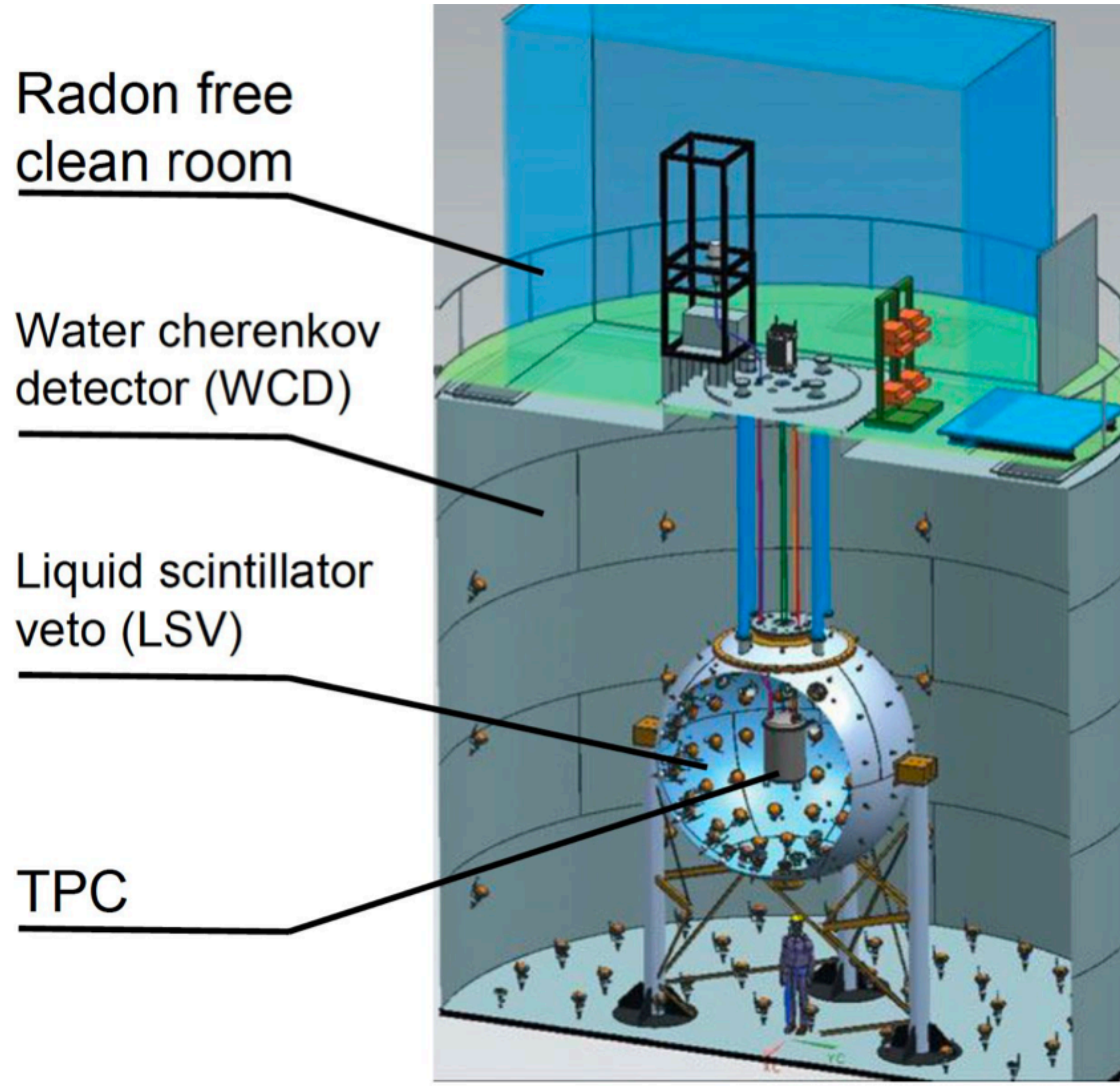
Yi Wang,ICHEP, July 2022

DarkSide-50 (46 kg)

- Data taken in 2018 - 350 live-days dataset (6.8 tonne-days)
- Will be discussing a new analysis with extended exposure 1.8x and improved calibrations - show projected sensitivity (results to follow soon)

- Dual phase argon TPC;
- 46.4 kg active mass;
- Light yield (@null field) ~ 8 p.e./keVee.



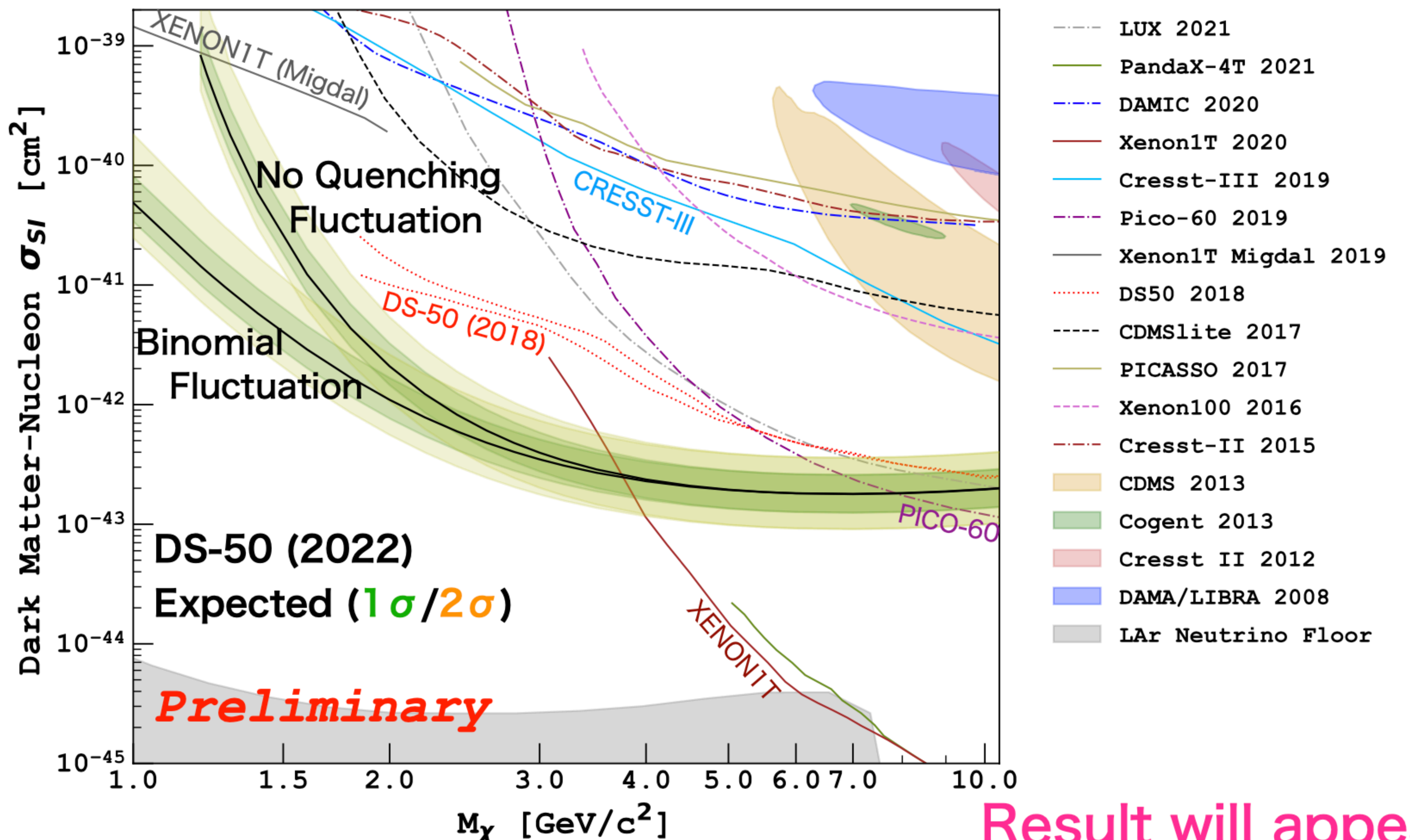


DarkSide-50 New Analysis Projected Sensitivity

Masato Kimura | IDM22 - 19 July '22

Projected Sensitivity

3

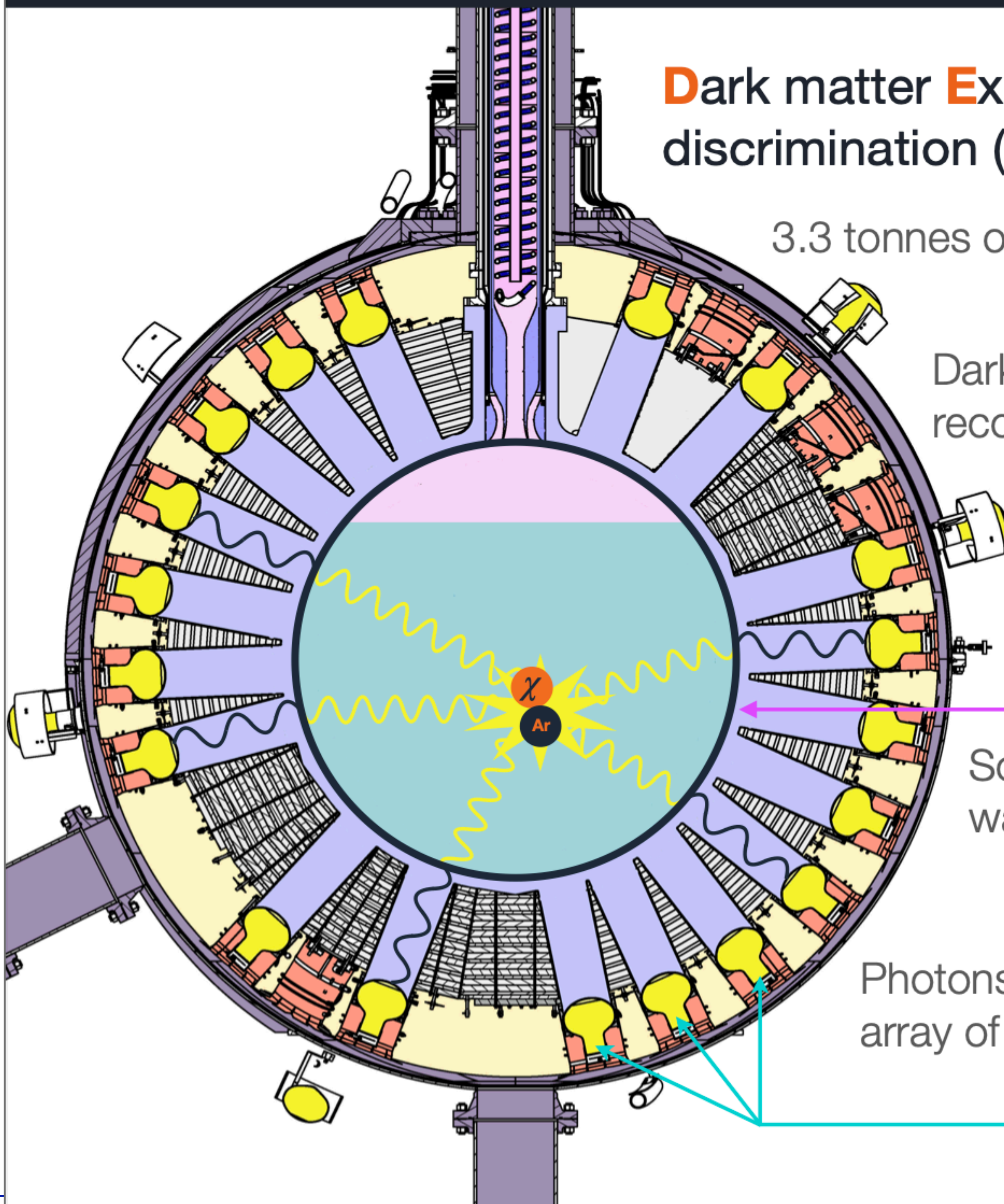


Result will appear soon!

DEAP 3600

Overview of DEAP-3600: The Detector

ROYAL HOLLOWAY UNIVERSITY OF LONDON



Dark matter **E**xperiment using **A**rgon **P**ulse shape discrimination (PSD)

3.3 tonnes of Liquid Argon (LAr) as target

Dark matter elastically scatters off argon nucleus, recoiling argon excites/ionizes nearby argon atoms

Excited/ionized argon form excited dimer states, relax to ground state via scintillation of 128 nm photons

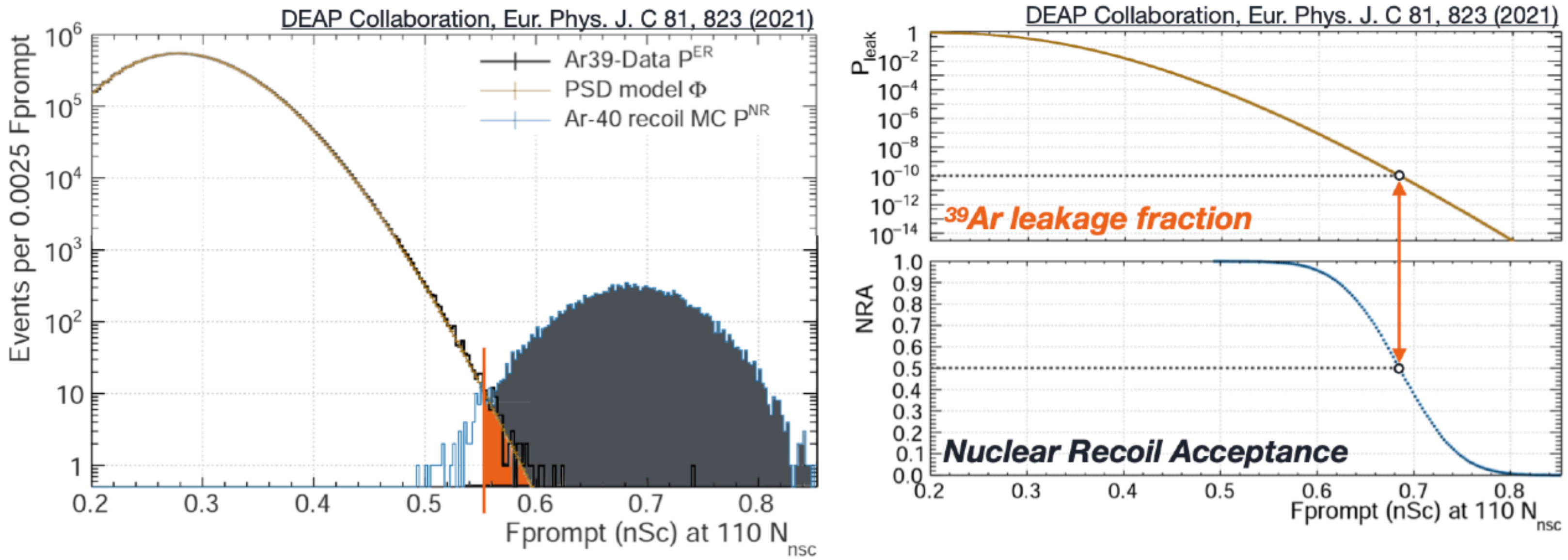
Scintillation photons pass through TPB wavelength shifter, become 420 nm photons

Photons collected by light guides, detected by array of 255 photomultiplier tubes (PMTs)

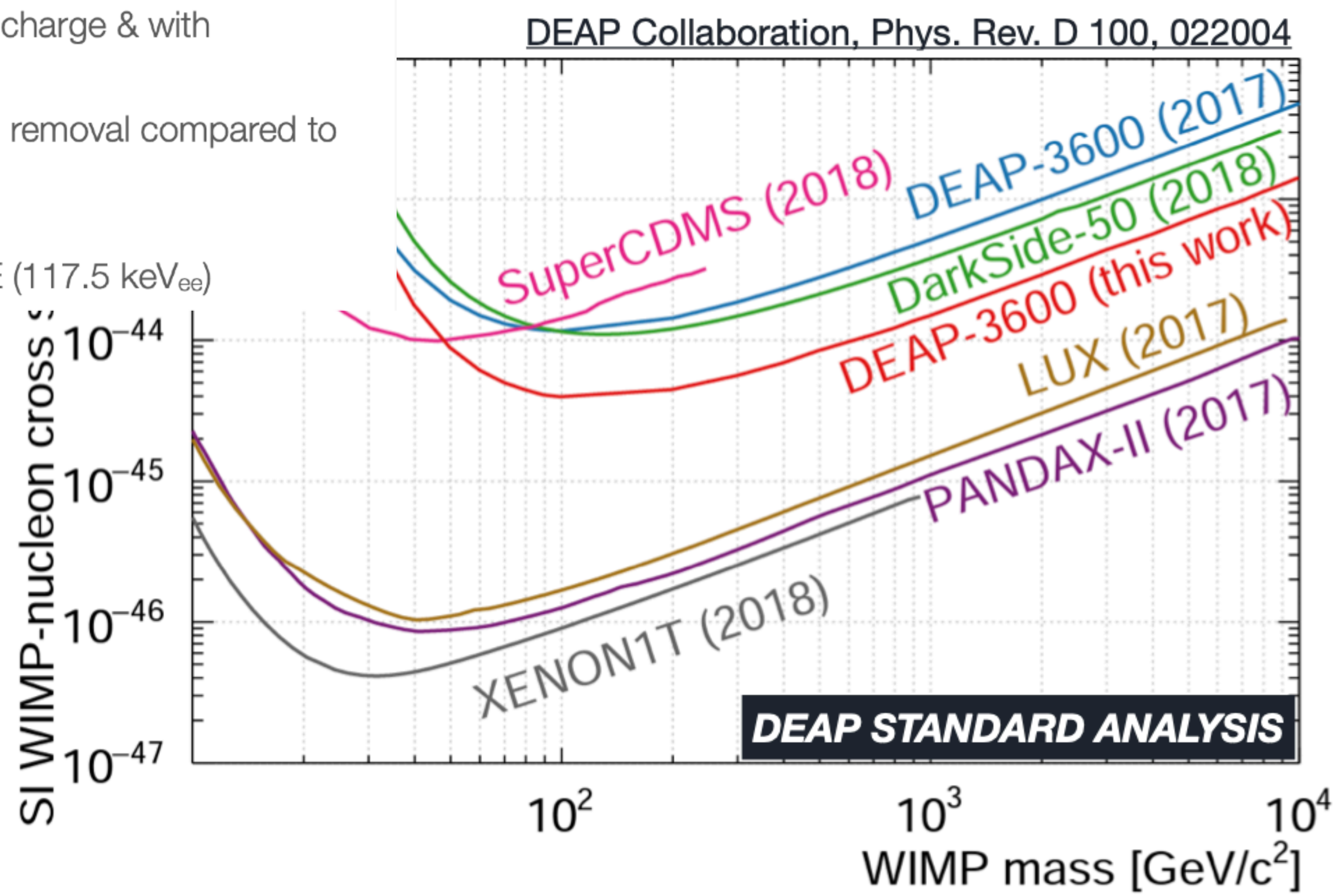
DEAP 3600

Precision Measurements:
PSD in 4.5 Tonne-Year Exposure

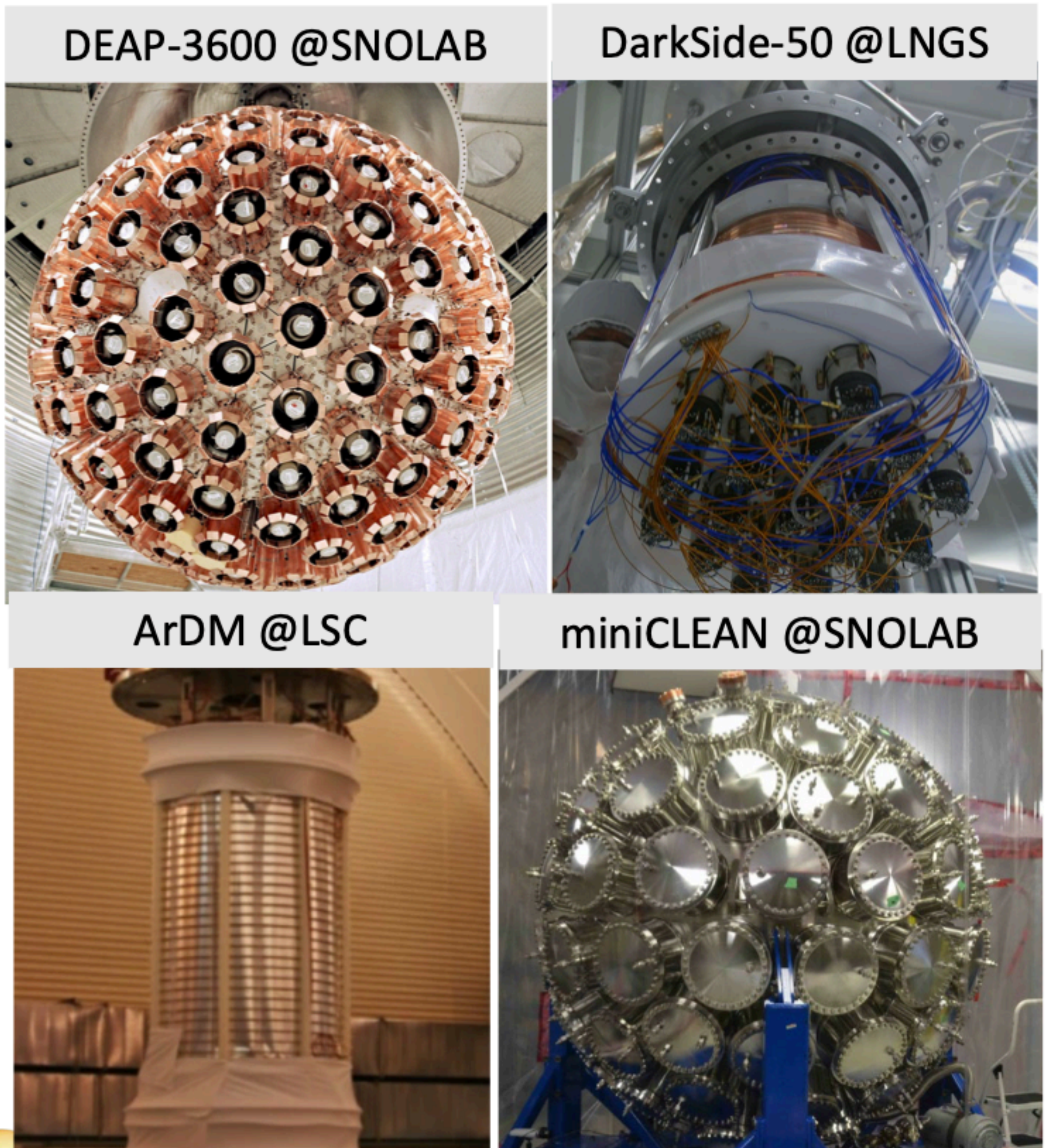
ROYAL HOLLOWAY UNIVERSITY OF LONDON



- PSD model tested with both energy estimators: total integrated charge & with afterpulsing removal
- ^{39}Ar leakage is reduced by an order magnitude with afterpulsing removal compared to total charge integration
- Result: ***world leading PSD!***
  10^{-10} leakage fraction of ^{39}Ar for 50% NR acceptance at 110 PE (117.5 keV_{ee})



The GADMC



- Global Argon Dark Matter Collaboration;
- Established in 2017;
- >500 collaborators, >100 institutes, 14 countries.

Intermediate Goal:

DarkSide-20k
200 t yr exposure

Ultimate Goal:

ARGO
3000 t yr exposure
Neutrino floor

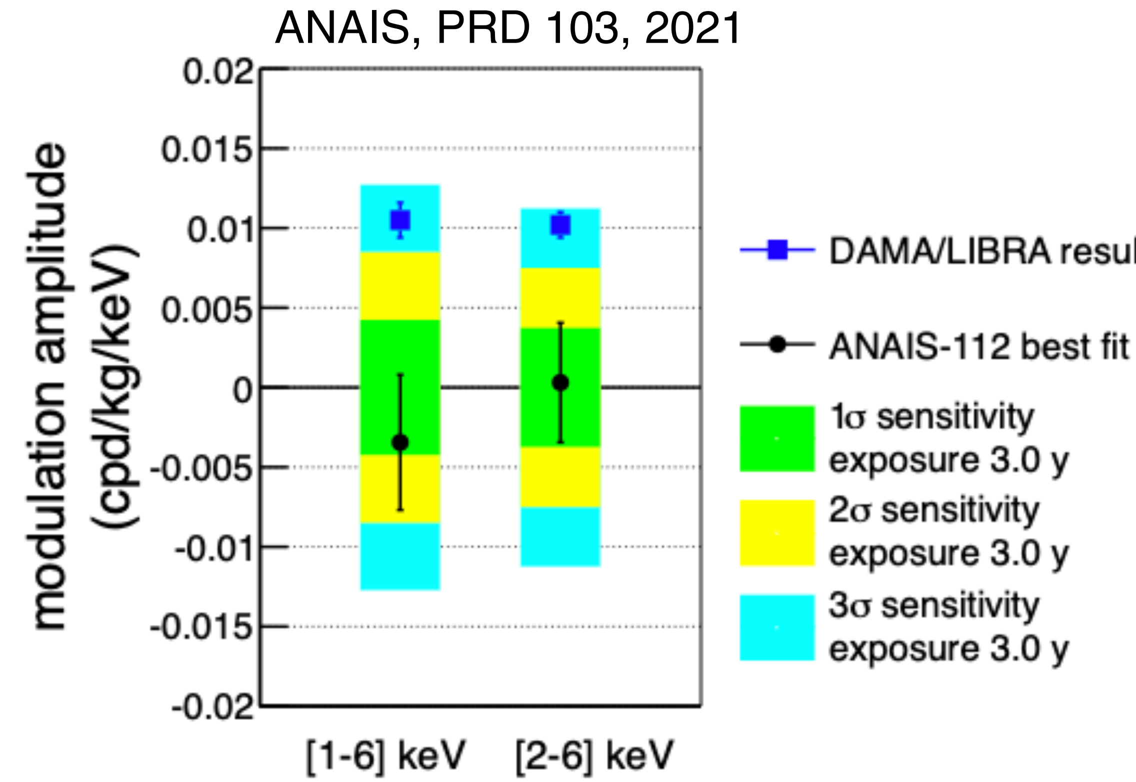
Dark Matter Direct Detection MeV - TeV

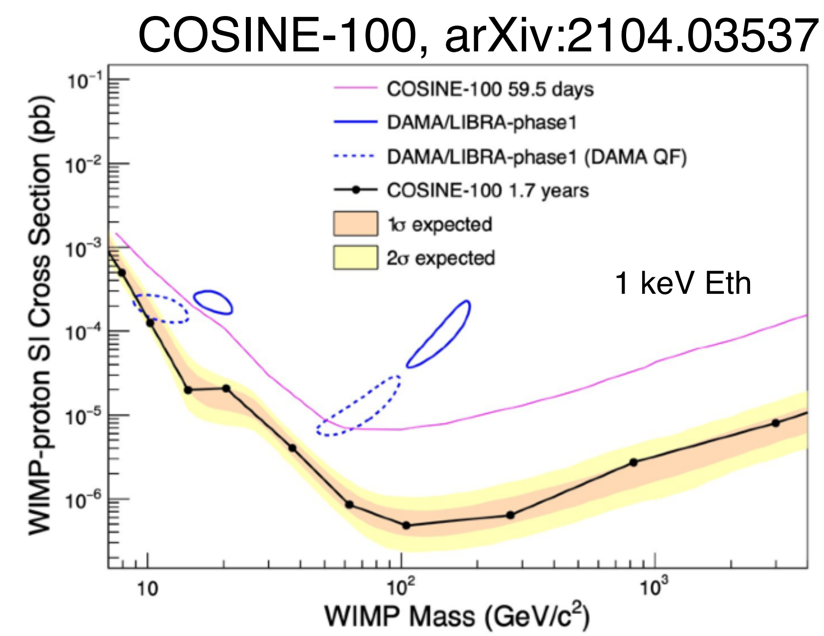
Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc
COSINE-100	Scintillator	NaI	106 kg		Running	2016	2021	YangYang
COSINE-200	Scintillator	NaI	200 kg		Construction	2022	2025	YangYang
COSINE-200 South Pole	Scintillator	NaI	200 kg		Planning	2023	?	South Pole
COSINUS	Bolometer Scintillator	NaI	?		Planning	2023	?	LNGS
SABRE PoP	Scintillator	NaI	5 kg		Construction	2021	2022	LNGS
SABRE (North)	Scintillator	NaI	50 kg		Planning	2022	2027	LNGS
SABRE (South)	Scintillator	NaI	50 kg		Planning	2022	2027	SUPL
CDEX-10	Ionization (77K)	Ge	10 kg	103 kg d	Running	2016	?	CJPL
CDEX-100 / 1T	Ionizatio				Planning	202X		CJPL
SuperCDMS	Cryo Ionization	Ge	9 kg		Ended	2011	2015	Soudan
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	~75 kg d	Ended	2012	2015	Soudan
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	0.5 g d	Ended	2018	2018	SNOLAB
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg		Construction	2020	2022	SNOLAB
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg		Construction	2023	2028	SNOLAB
EDELWEISS III	Cryo Ionization	Ge	20 kg		Ended	2015	2018	LSM
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g		Running	2019		LSM
CRESST-II	Bolometer Scintillation	CaWO4	5 kg		Ended	2012	2015	LNGS

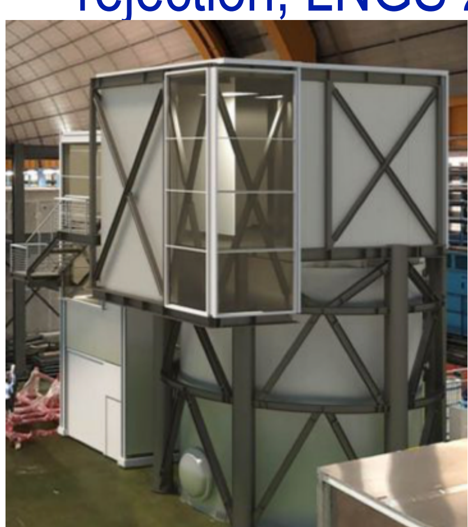
Modulation of DM Signals

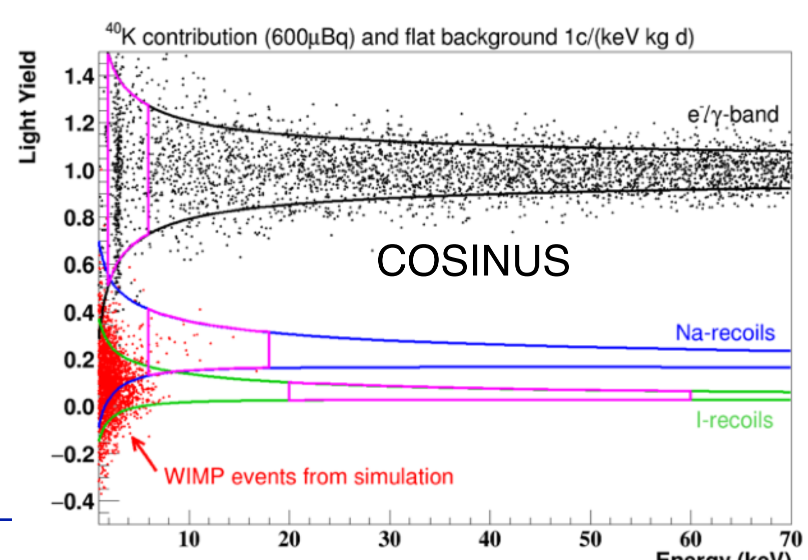
Sodium Iodide (NaI) experiments

- DAMA/LIBRA observed annual modulation with NaI(Tl), now >9σ significance
  - DAMA Reported first observation in 1997 with 100 kg
  - DAMA/LIBRA Operating 200 kg since 2003
- So far, no evidence for annual modulation from
  - ANAIS-112 (100 kg, 3 y of data) Canfranc
    - PRD 103, 102005 (2021) - incompatible with DAMA/LIBRA at 3.3σ [1-6 keV]
      Note: Same threshold but BG is 3x that of DAMA/LIBRA
  - COSINE-100 (106 kg NaI, 1.7 y of data) Y2L
    - Nature 564, 83 (2018), PRL 123, 031302 (2019), arXiv:2104.03537 - excl. DAMA
- New experiments
  - COSINE-200 (200 kg, ultra pure NaI) Y2L
  - COSINUS: phonons+light in un-doped NaI => active background rejection; LNGS 2022/23

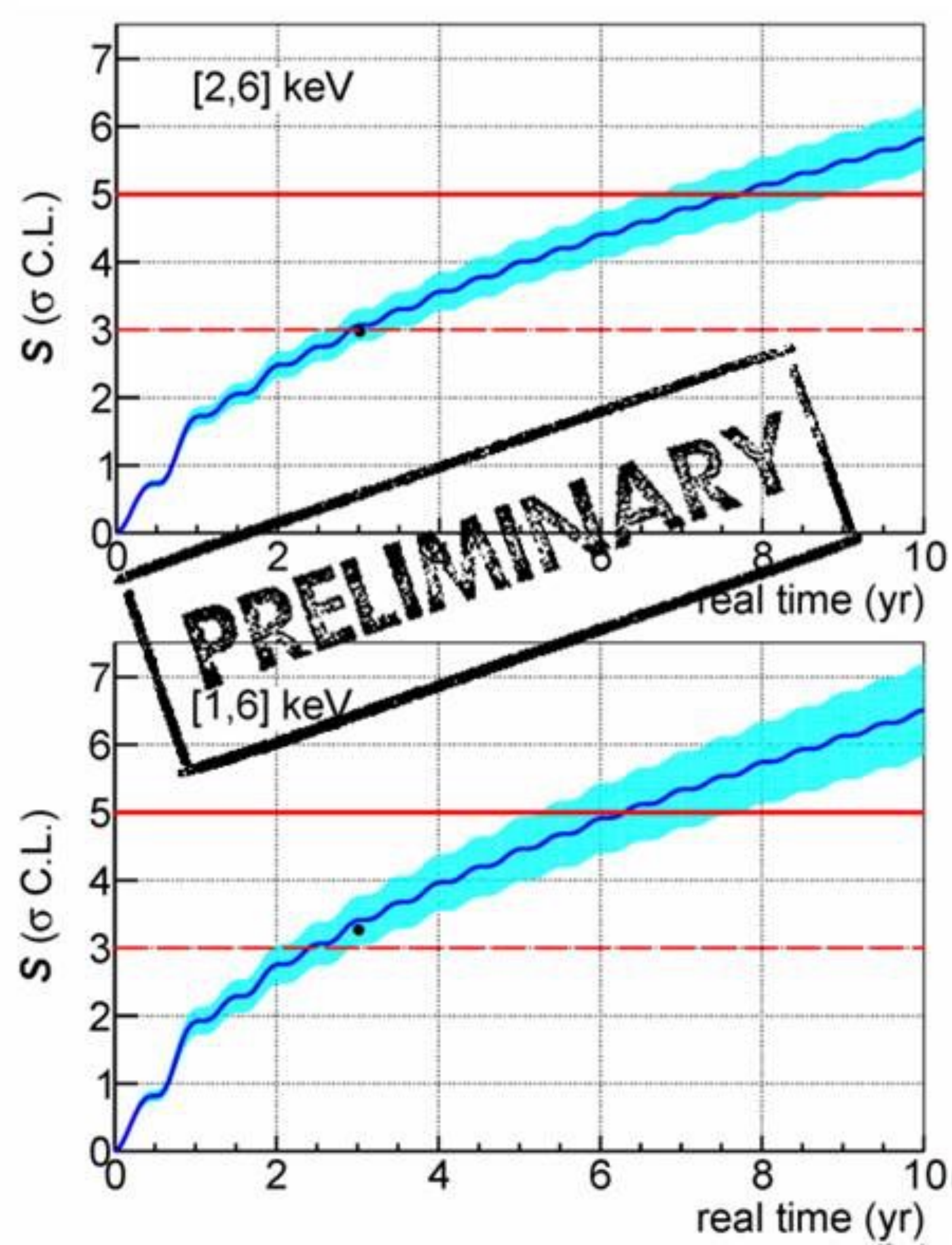


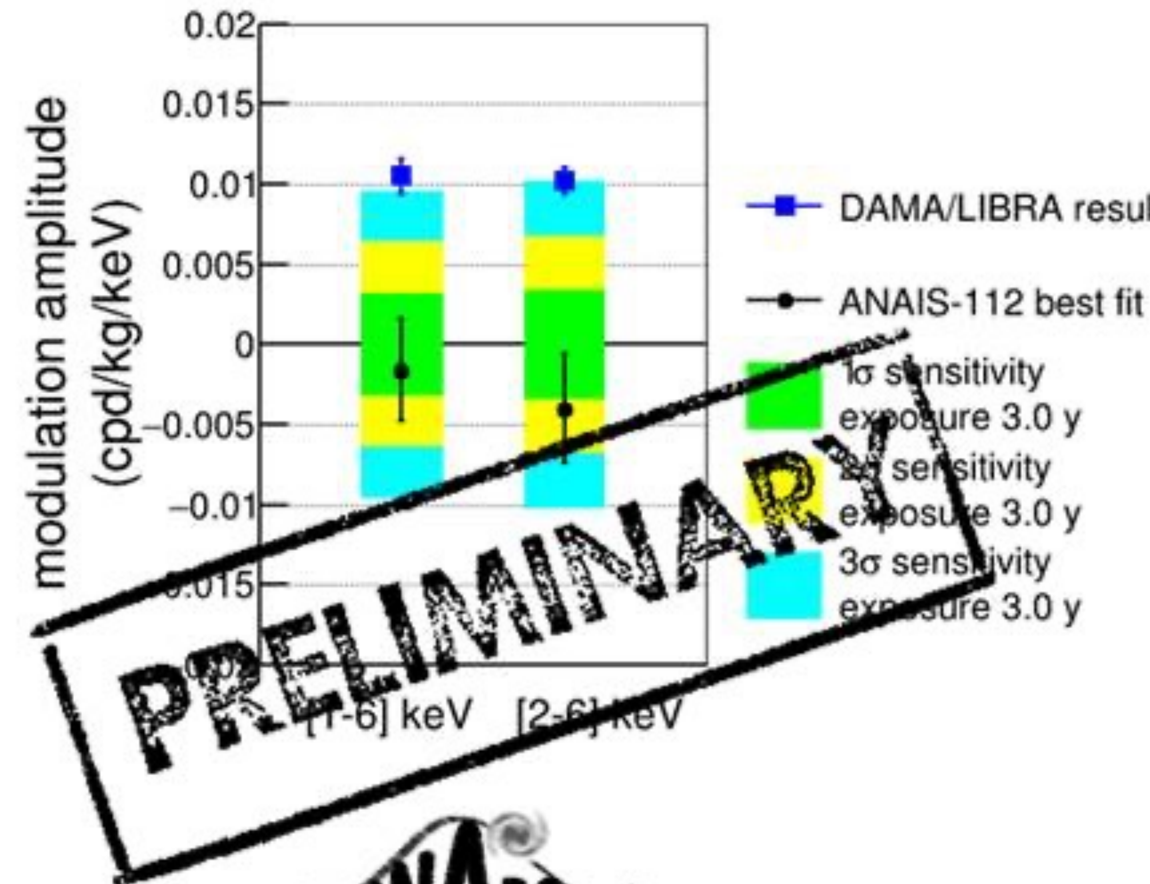






ANAIS Preliminary for IDM2022 (Marisa Sarsa)





arxiv:2103.01175

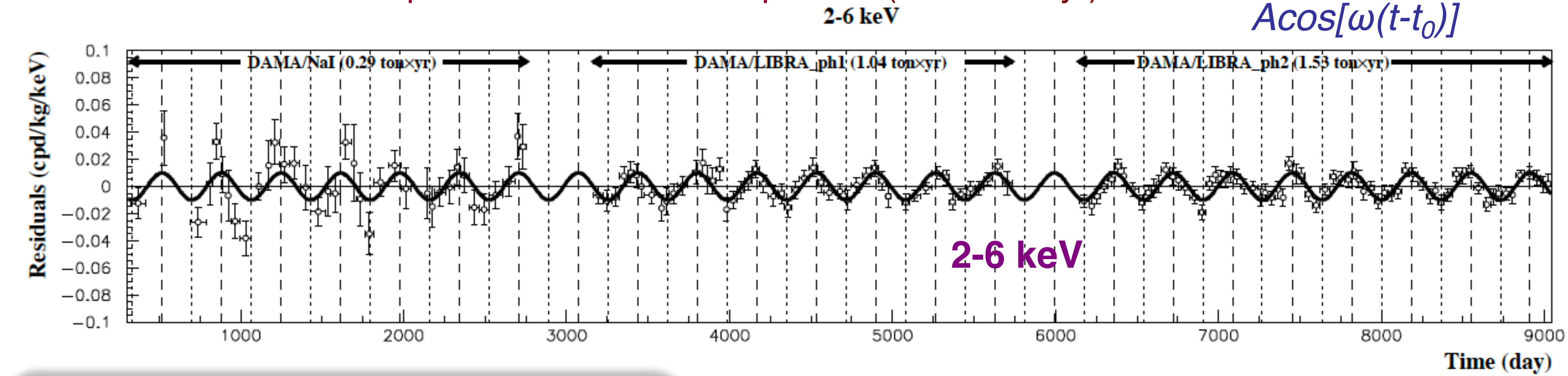
DM model-independent Annual Modulation Result

experimental residuals of the single-hit scintillation events rate vs time and energy

Talk Pierluigi Belli

DAMA/NaI+DAMA/LIBRA-phase1+DAMA/LIBRA-phase2 (2.86 ton × yr)

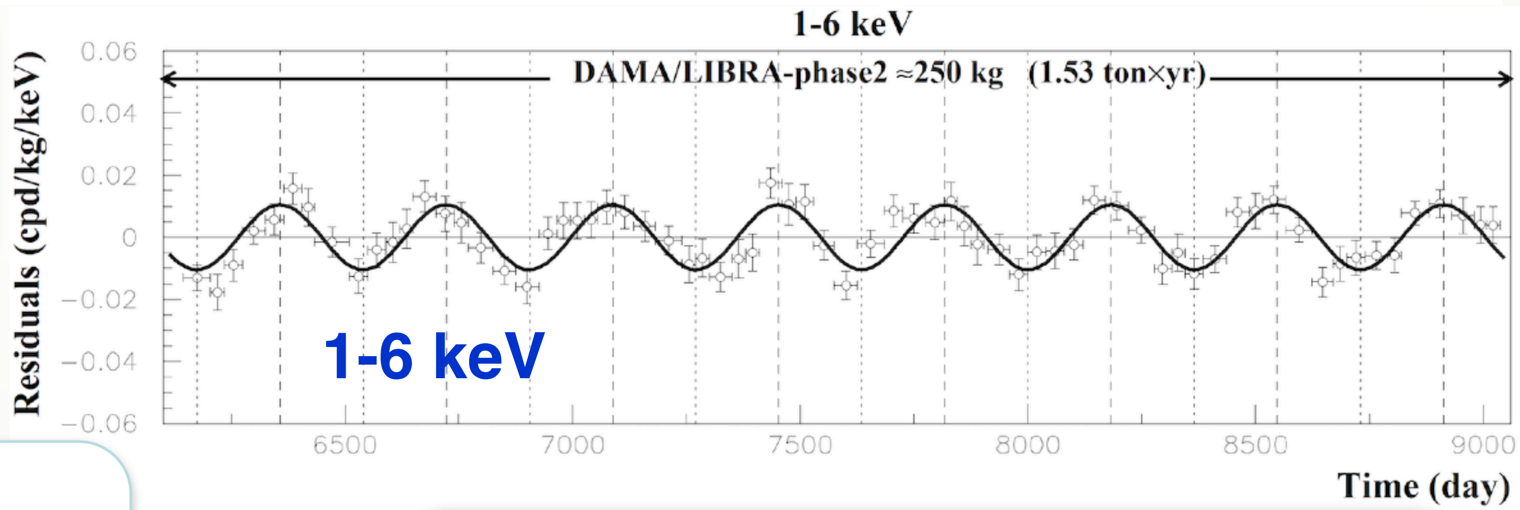
$A\cos[\omega(t-t_0)]$



continuous lines: t_0 = 152.5 d, T = 1.00 y

A=(0.00996±0.00074) cpd/kg/keV

χ^2/dof = 130/155



DAMA/NaI (0.29 ton x yr) – 7 annual cycles
DAMA/LIBRA-ph1 (1.04 ton x yr) – 7 annual cycles
DAMA/LIBRA-ph2 (1.53 ton x yr) – 8 annual cycles

total exposure = 2.86 ton×yr

Fit on DAMA/LIBRA-phase2

1-6 keV A=(0.01048±0.00090) cpd/kg/keV

χ^2/dof = 66.2/68 **11.6 σ C.L.**

The data of DAMA/NaI + DAMA/LIBRA-phase1 +DAMA/LIBRA-phase2 favour the presence of a modulated behaviour with proper features at 13.7 σ C.L.

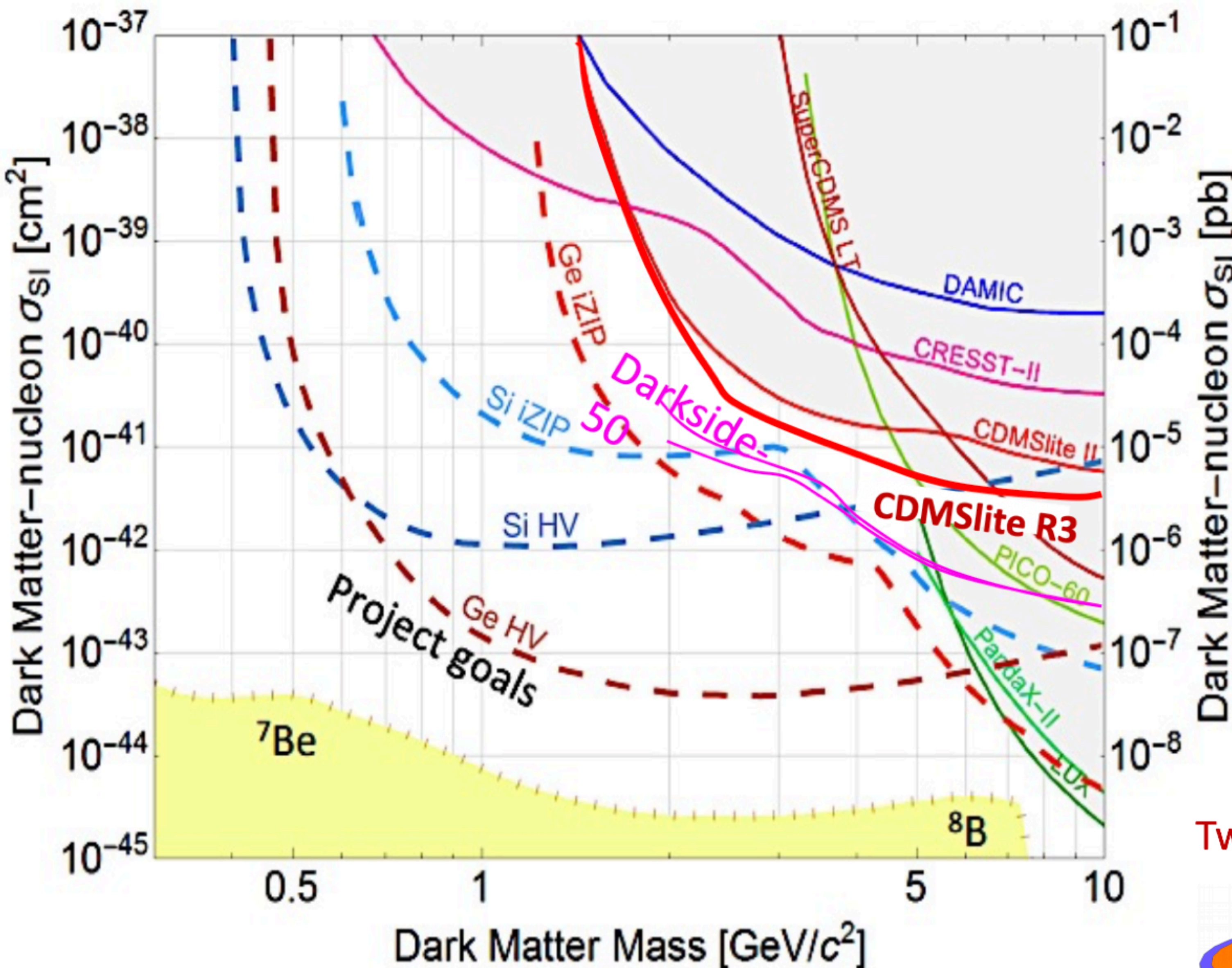
Dark Matter Direct Detection MeV - TeV

Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
SuperCDMS	Cryo Ionization	Ge	9 kg		Ended	2011	2015	Soudan
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	~75 kg d	Ended	2012	2015	Soudan
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	0.5 g d	Ended	2018	2018	SNOLAB
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg		Construction	2020	2022	SNOLAB
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg		Construction	2023	2028	SNOLAB
EDELWEISS III	Cryo Ionization	Ge	20 kg		Ended	2015	2018	LSM
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g		Running	2019		LSM
CRESST-II	Bolometer Scintillation	CaWO4	5 kg		Ended	2012	2015	LNGS
CRESST-III	Bolometer Scintillation	CaWO4	240 g		Ended	2016	2018	LNGS
CRESST-III (HW Tests)	Bolometer Scintillation	CaWO4			Running	2020		LNGS
PICO-2	Bubb[illegible]	[illegible]	[illegible]		[illegible]nded	2013	2015	SNOLAB
PICO-40	Bubb[illegible]	[illegible]	[illegible]		[illegible]uction	2020		SNOLAB
PICO-60	Bubble Chamber	CF3I,C3F8	52 kg		Ended	2013	2017	SNOLAB
PICO-500	Bubble Chamber	C3F8	430 kg		Construction	2021		SNOLAB
DRIFT-II	Gas Directional	CF4	0.14 kg		Ended			Boulby
NEWAGE-03b'	Gas Directional	CF4	14 g	4.5 kg d	Ended	2013	2017	
NEWS-G	Gas Drift	CH4			Ended	2017	2019	LSM
NEWS-G	Gas Drift	CH4			Construction	2020	2025	SNOLAB
DAMIC	CCD	Si	2.9 g	0.6 kg d	Ended	2015	2015	SNOLAB

Future Cryogenic Detectors

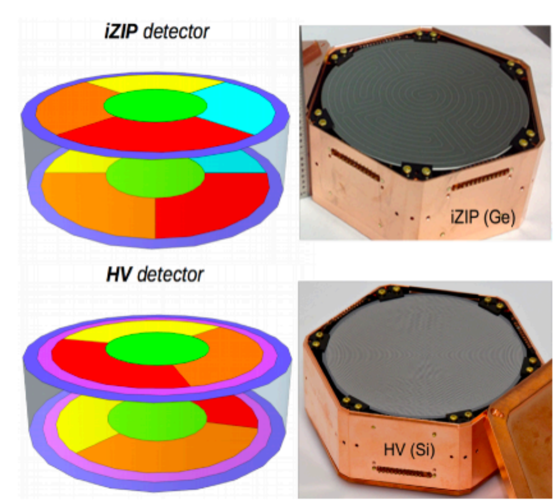
SuperCDMS @ SNOLAB

Talk Matthew Wilson, SuperCDMS

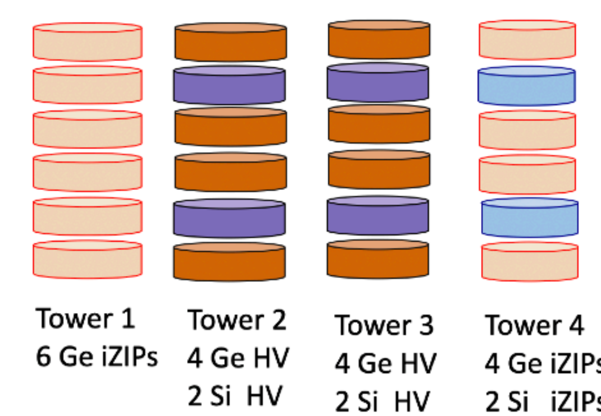


- New Cryogenic infrastructure being installed at SNOLab in order to allow 4-tower (and larger) payloads

Two Types of Detectors



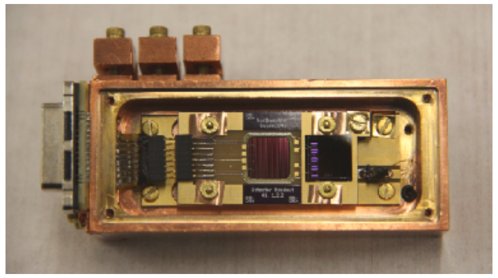
Initial 4-tower payload



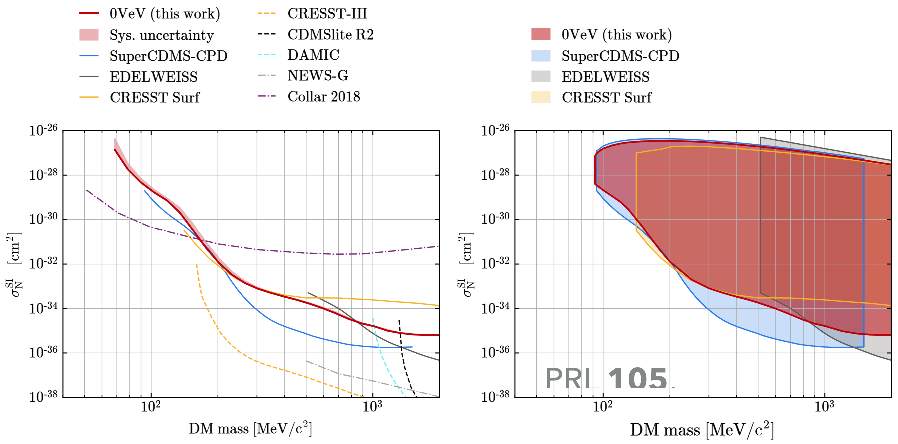
SUPERCDMS RECENT ACTIVITIES

- Low-threshold WIMP searches with R&D detectors
    - CPD
    - HVeV operated at 0V
- Ongoing tower testing at SLAC:
    - First SuperCDMS detector tower (tower 1) tested a SLAC
    - Tower 1 testing at CUTE facility later this year
- 100 eV Ionization Yield Measurements in Si using an HVeV detector

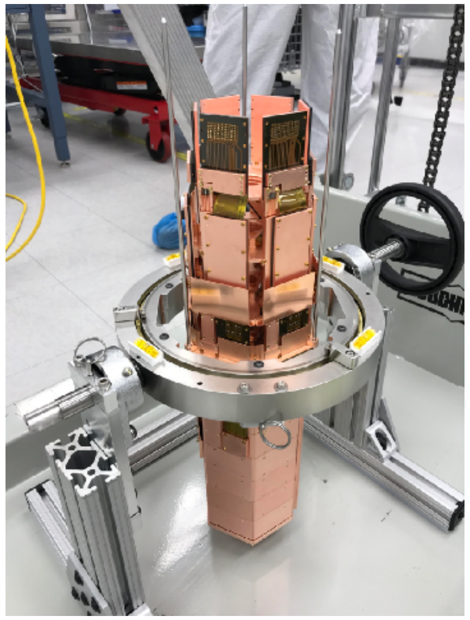
HVeV Detector



Recent Limits from

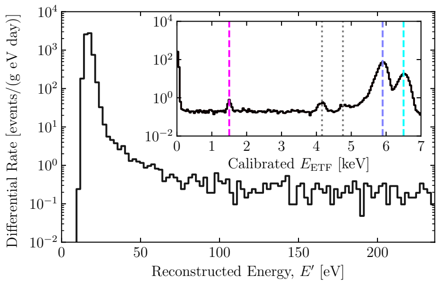


SuperCDMS Tower



CPD Detector and Energy Spectr

PRL **118**, 022601



PRL **127**, 061801

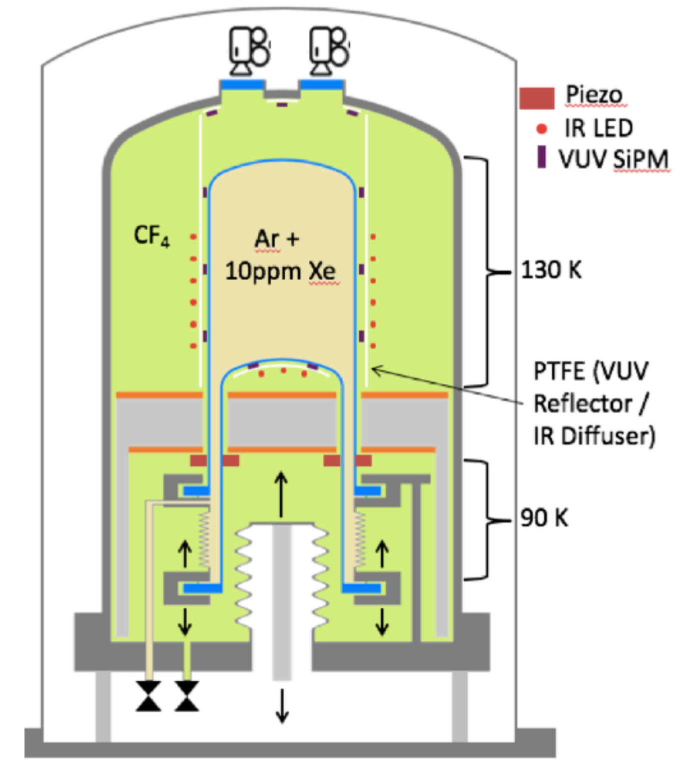
Dark Matter Direct Detection MeV - TeV

Name	Detector	Target	Active Mass	Fiducial Live Exposure	Status	Start Ops (after construction)	End Ops	Location of Experiment
PICO-2	Bubble Chamber	C3F8	2 kg		Ended	2013	2015	SNOLAB
PICO-40	Bubble Chamber	C3F8	35 kg		Running	2020		SNOLAB
PICO-60	Bubble Chamber	CF3I,C3F8	52 kg		Ended	2013	2017	SNOLAB
PICO-500	Bubble Chamber	C3F8	430 kg		Construction/Run	2021		SNOLAB
DRIFT-II	Gas Directional	CF4	0.14 kg		Ended			Boulby
NEWAGE-03b'	Gas Directional	CF4	14 g	4.5 kg d	Ended	2013	2017	
CYGNUS???								
NEWS-G	Gas Drift	CH4			Ended	2017	2019	LSM
NEWS-G	Gas Drift	CH4			Construction/Run	2020	2025	SNOLAB
DAMIC	CCD	Si	2.9 g	0.6 kg d	Ended	2015	2015	SNOLAB
DAMIC	CCD	Si	40 g Si		Ended	2017	2019	SNOLAB
DAMIC100	CCD	Si	100 g Si		Not Built			SNOLAB
DAMIC-M	CCD Skipper	Si	1 kg Si		Construction/Run	2021	2024	LSM
SENSEI	CCD Skipper	Si	2 g Si	2g x 24 d	Running	2019	2020	Fermilab u/g
SENSEI	CCD Skipper	Si	100 g Si		Construction/Run	2021	2023	SNOLAB
ALETHEIA	TPC	He			R&D			China Inst. At. E
TESSERACT	Cryo TES	He			R&D			LBNL

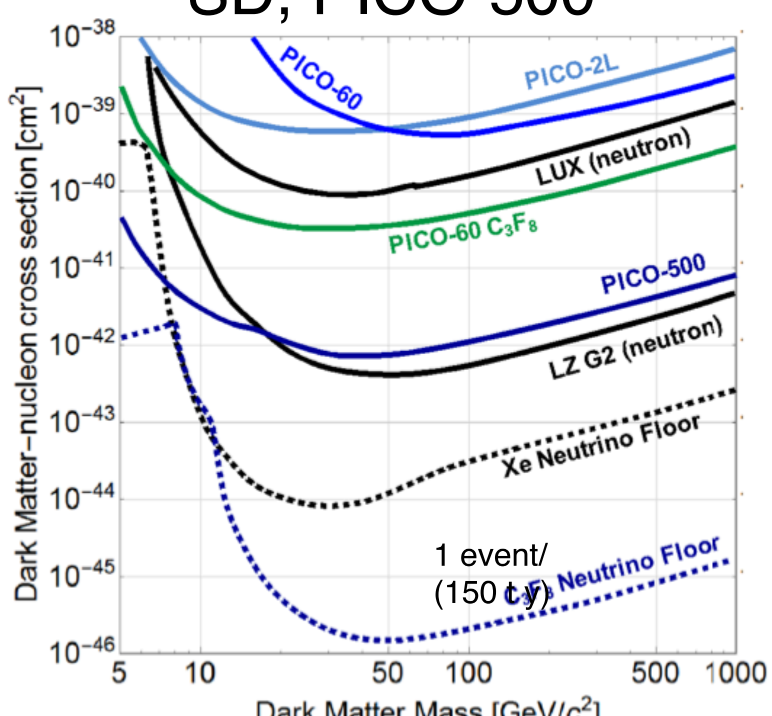
Bubble chambers - PICO & SBC

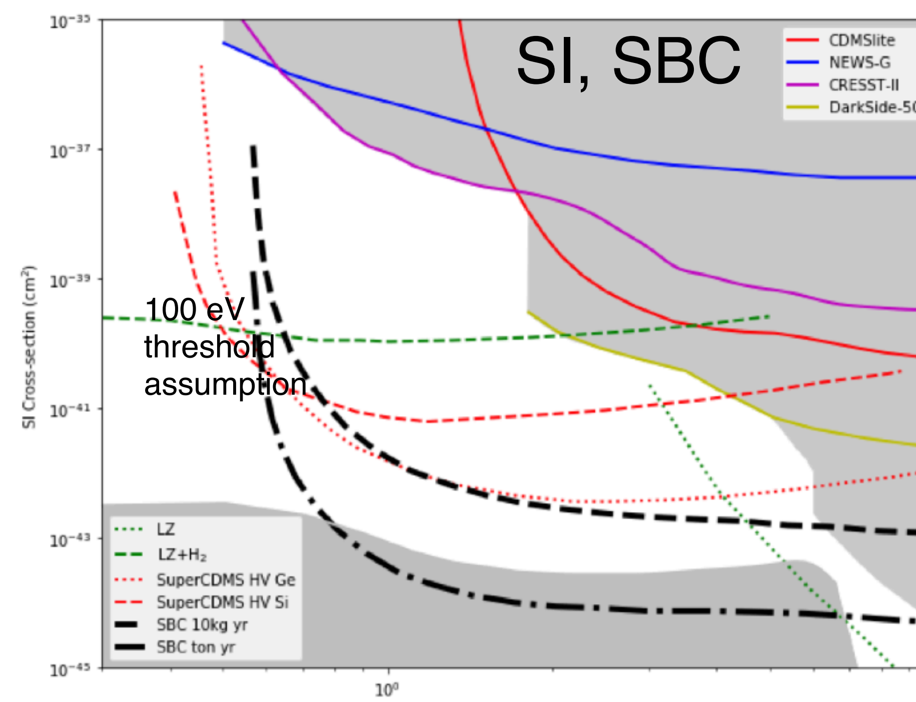
- PICO: superheated liquid C3F8
  - Acoustic + Visual (Camera) readout : ER event rejection
  - PICO-60 C3F8 produced factor 17x in SDp sensitivity
  - PICO-40L RSU chamber coming online Fall 2022 commissioning is underway
  - PICO-500 at SNOLAB: under design+construction in 2022++
- New detector: the Scintillating Bubble Chamber (SBC)
  - Superheated 10 kg Xe-doped LAr, cooled to 130 K, piezoelectric sensors + cameras readout + SiPMs for scintillation signal

SBC



SD, PICO-500





Thank you to Laura Baudis

Dark / - TeV

XMASS	Scintillator	LXe	832 kg		Ended	2010	2019	Kamioke
XENON100	TPC	LXe	62 kg		Ended	2012	2016	LNGS
XENON1T	TPC	LXe	1,995 kg		Ended	2017	2019	LNGS
XENON1T (Ionization)	TPC Ioniz.-only	LXe	1,995 kg		Ended	2017	2019	LNGS
XENONnT	TPC	LXe	7,000 kg	20 t yr	Construction/Run	2021	2025	LNGS
LUX	TPC	LXe	250 kg	30,000 kg d	Ended	2013	2016	SURF
LUX (Ionization)	TPC Ioniz.-only	LXe	250 kg		Ended	2017	2019	SURF
LZ	TPC	LXe	8,000 kg	20 t yr	Construction/Run	2021	2025	SURF
PandaX-II	TPC	LXe	580 kg		Ended	2016	2018	CJPL
PandaX-4T	TPC	LXe	4,000 kg	20 t yr	Construction/Run	2021	2025	CJPL
LZ HydroX	TPC	LXe+H2	8,000 kg		R&D	2026		SURF
Darwin / US G3	TPC	LXe	50,000 kg	200 t yr	Planning	2028	2033	LNGS/SURF/Boulby
DEAP-3600	Scintillator	LAr	3,300 kg		Running	2016	202X	SNOLAB
DarkSide-50	TPC	LAr	46 kg	46 kg year	Ended	2013	2019	LNGS
Darkside-LM (Ionization)	TPC Ioniz.-only	LAr	46 kg		Ended	2018	2019	LNGS
Darkside-20k	TPC	LAr	30 t	200 t yr	Planning/Construct	2025	2030	LNGS
ARGO	TPC	LAr	300 t	3000 t yr	Planning	2030	2035	SNOLAB
DAMA/LIBRA	Scintillator	NaI	250 kg		Running	2003		LNGS
ANAIS-112	Scintillator	NaI	112 kg	Goal 5 years	Running	2017	2022	Canfranc
COSINE-100	Scintillator	NaI	106 kg		Running	2016	2021	YangYang
COSINE-200	Scintillator	NaI	200 kg		Construction	2022	2025	YangYang
COSINE-200 South Pole	Scintillator	NaI	200 kg		Planning	2023	?	South Pole
COSINUS	Bolometer Scintillator	NaI	?		Planning	2023	?	LNGS
SABRE PoP	Scintillator	NaI	5 kg		Construction	2021	2022	LNGS
SABRE (North)	Scintillator	NaI	50 kg		Planning	2022	2027	LNGS
SABRE (South)	Scintillator	NaI	50 kg		Planning	2022	2027	SUPL
CDEX-10	Ionization (77K)	Ge	10 kg	103 kg d	Running	2016	?	CJPL
CDEX-100 / 1T	Ionization (77K)	Ge	100-1000 kg		Planning	202X		CJPL
SuperCDMS	Cryo Ionization	Ge	9 kg		Ended	2011	2015	Soudan
CDMSLite (High Field)	Cryo Ionization	Ge	1.4 kg	~75 kg d	Ended	2012	2015	Soudan
CDMS-HVeV Si	Cryo Ionization HV	Si	0.9 g	0.5 g d	Ended	2018	2018	Surface Lab
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg		Running	2020	2022	SNOLAB
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg		Construction	2023	2028	SNOLAB
EDELWEISS III	Cryo Ionization	Ge	20 kg		Ended	2015	2018	LSM
EDELWEISS III (High Field)	Cryo Ionization HV	Ge	33 g	80 g d	Running	2019		LSM
CRESST-II	Bolometer Scintillatior	CaWO4	5 kg		Ended	2012	2015	LNGS
CRESST-III	Bolometer Scintillatior	CaWO4	240 g		Ended	2016	2018	LNGS
CRESST-III (HW Tests)	Bolometer Scintillatior	CaWO4			Running	2020		LNGS
PICO-2	Bubble Chamber	C3F8	2 kg		Ended	2013	2015	SNOLAB
PICO-40	Bubble Chamber	C3F8	35 kg		Running	2020		SNOLAB
PICO-60	Bubble Chamber	CF3I,C3F8	52 kg		Ended	2013	2017	SNOLAB
PICO-500	Bubble Chamber	C3F8	430 kg		Construction/Run	2021		SNOLAB
DRIFT-II	Gas Directional	CF4	0.14 kg		Ended			Boulby
NEWAGE-03b'	Gas Directional	CF4	14 g	4.5 kg d	Ended	2013	2017	
CYGNUS???								
NEWS-G	Gas Drift	CH4			Ended	2017	2019	LSM
NEWS-G	Gas Drift	CH4			Construction/Run	2020	2025	SNOLAB
DAMIC	CCD	Si	2.9 g	0.6 kg d	Ended	2015	2015	SNOLAB
DAMIC	CCD	Si	40 g Si		Ended	2017	2019	SNOLAB
DAMIC100	CCD	Si	100 g Si		Not Built			SNOLAB
DAMIC-M	CCD Skipper	Si	1 kg Si		Construction/Run	2021	2024	LSM
SENSEI	CCD Skipper	Si	2 g Si	2g x 24 d	Running	2019	2020	Fermilab u/g
SENSEI	CCD Skipper	Si	100 g Si		Construction/Run	2021	2023	SNOLAB
ALETHEIA	TPC	He			R&D			China Inst. At. Energy
TESSERACT	Cryo TES	He			R&D			LBNL

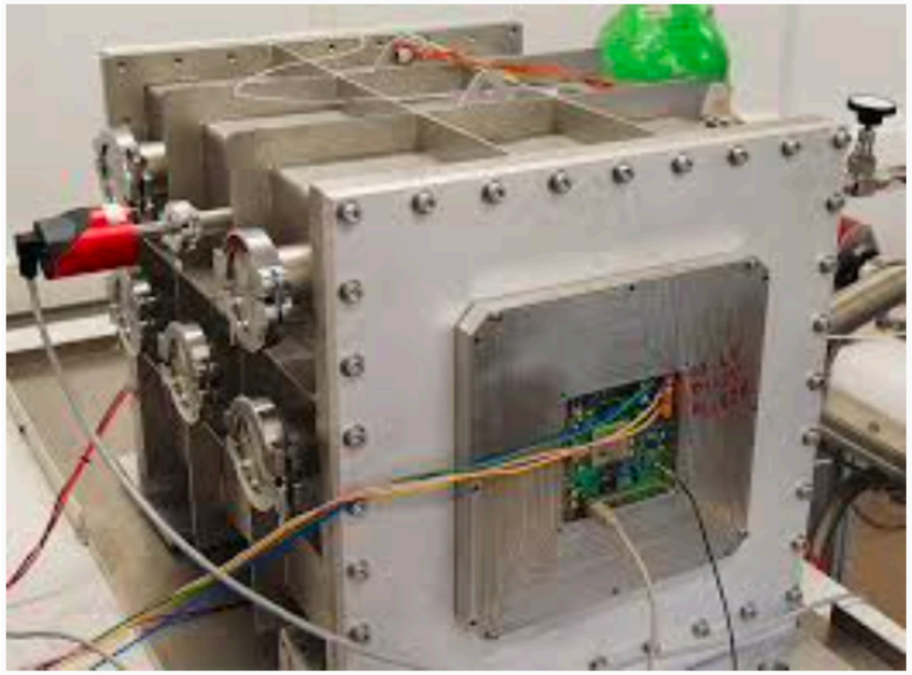
R&D
Planning
Construction
Running
Ended

Directional Detectors

- Moving Through the Neutrino Fog...

MIMAC - Directionality is demonstrated in the keV-range for the first time
Cyprien Beaufort

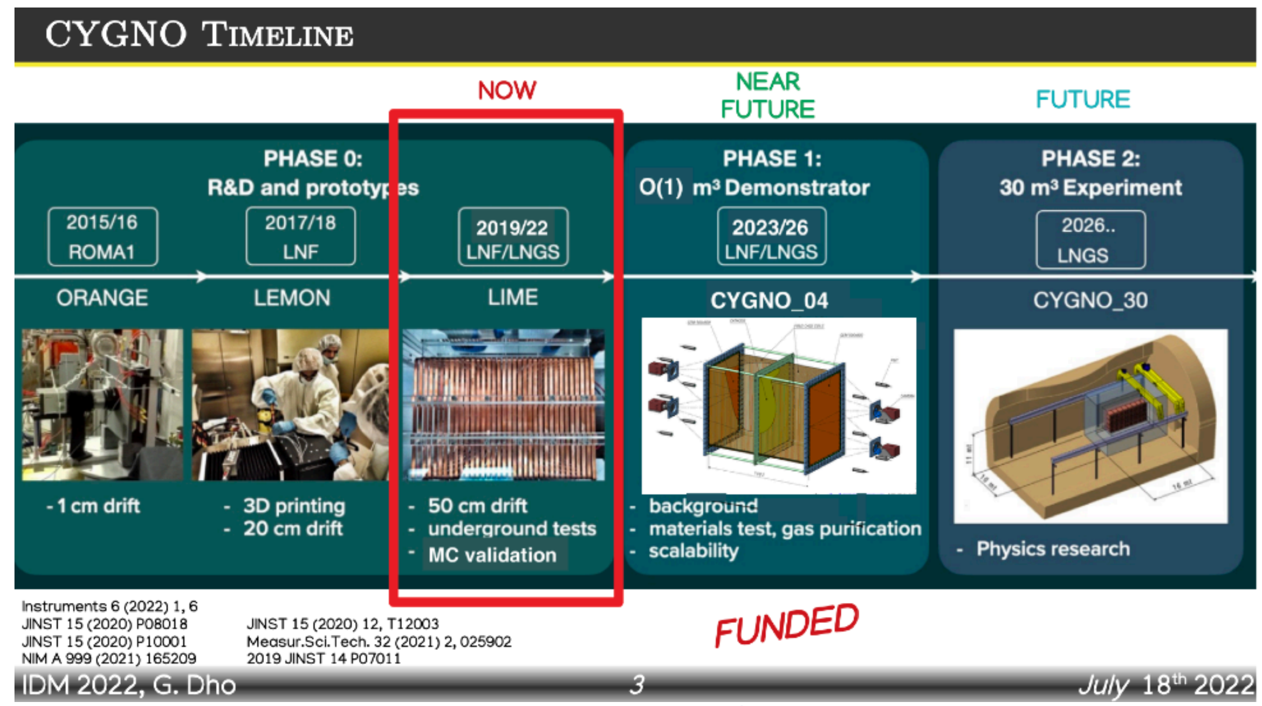
- MIMAC is a directional detector based on a low-pressure gaseous TPC with a Micromegas.
- Properties:
  - Gas mixture i-C4H10 + 50% CHF3 at 30 mbar
    or 70% CF4 + 28% CHF3 + 2% i-C4H10 at 50 mbar
  - Directional detection threshold : 1 keVee
  - Measured angular resolution in the keV-range : 15°



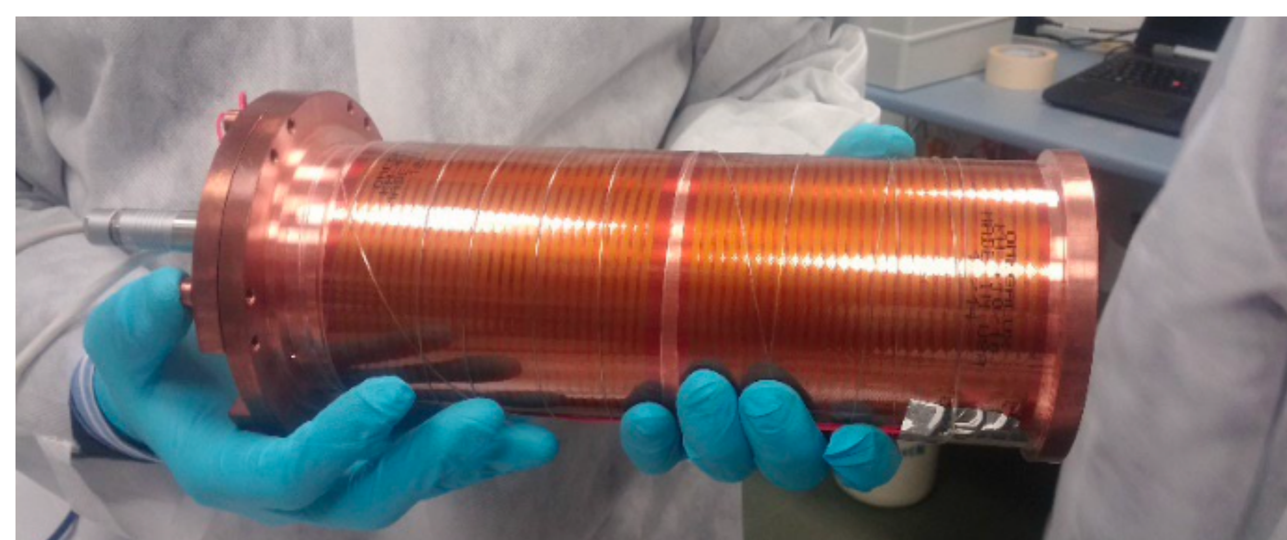
- Status:
  - A 6L prototype has operated for 6 years in the Modane Underground Laboratory (LSM)
  - Currently testing a 60L prototype having a 35x35 cm^2 resistive anode with 1792 strips
- Summary:
  - To detect nuclear recoils in the keV-range, it is required to operate the detector at high gain => some track distortions appear due to the influence of the numerous ions produced in the avalanche. At the same time, it improves the detector sensitivity.
  - Developed a procedure to control the track distortion while taking benefit from the improved sensitivity.
  - This procedure gives access to head-tail recognition <=> determination of the sense of the nuclear recoil
  - Evaluate the MIMAC directional performance by means of neutron signals 8 keV and 27 keV
    - Obtain 15° angular resolution down to 1 keVee
    - Demonstrate that directionality is accessible in the keV-range => for probing WIMPs down to GeV

Directional Detectors

- CYGNO/INITIUM, G. Dho TPC - GEM amplification optically readout



- ADAMO, Vincenzo Caracciolo - DM directionality approach using ZnWO4 crystal scintillators



Directional Detectors

- Cygnus Collaboration - High Gain Negative Ion TPCs with Continuous Radon Reduction - Alasdair McLean
  - Successful operation of the MMThGEM in low pressure (30 torr) SF_6

- Directional Detectors Summary - Elisabetta Baracchini, Tuesday

Our Goal Remains to Create the …

QUIETEST KNOWN PLACES IN THE UNIVERSE

BUT LET'S HOPE NOT TOO QUIET

WE REALLY ARE LOOKING FOR A SIGNAL

Our Goal Remains to Discover Dark Matter …

We have been beating Moore's Law in terms of progress in the search-space (cross-section) for some specific DM particle types. (It's a big space so we need to make rapid progress :-)

However, new models/experiments are also spreading "laterally" in the search-space in terms of candidate particle mass. A challenge will be to ensure that we have multiple experiments able to test possible signals that occur.

New technologies can often introduce new pathologies for backgrounds and we will need a way to differentiate between real DM-related signals and unwanted background pathologies.

Conclusions - Direct Detection

- The Enthusiasm of Experimentalist Pursuing Direct Dark Matter Grows Unabated
  - LUX / PandaX-II / XENON1T reported final results
  - DAMA/LIBRA Phase 2 > 1 tonne x year Ann. Mod. - but new NaI experiments in direct conflict with this result with growing CL
- Noble Targets
  - PandaX-4T operating at Jinping in 2021 (China) - completed commissioning run - results July 2021 - 3H removal - started new science run
  - LZ (7t) reported first science results at Sanford Lab in July 2022 (US-DOE, UK, Portugal, S Korea ...) even better sensitivity
  - XENONnT at LNGS since 2021 (German, Swiss, US-NSF, Japan ...) - looking to release ER results here, NR search soon
  - DarkSide20k (20 tonne - major upgrade on previous 50 kg instrument) has goal of first fill in 2026
- Low Mass DM signal(s) - many new technologies now aimed at sub-GeV and MeV candidates
- Improving Search Sensitivity Continues Apace
  - New larger detectors are being delivered in order to keep rate of improvement for WIMP >5 GeV regime
  - Necessary technologies for 50 tonne+ detectors seems readily achievable - taking close and possibly into neutrino "fog"
    - We should see 8B solar neutrino signal in coming round of experiments (like ~6 GeV WIMP)
    - High Energy Atmospheric Neutrinos are still way off and will only begin to be seen in the 50 tonne+ detectors
      - Diffuse Supernova Background will hide under the Atm. Signal
  - Reductions in threshold deliver major advances in low mass sensitivity (then the challenge will be to scale detector mass)
  - Critically there has also been an improvement in our understanding of potential systematics in detector response
  - Calibration strategies that can provide abundant statistics, and have low systematic uncertainties are critically important
- The Spectre of Discovery is always upon us, and is a great responsibility
  - Clearly, multiple detectors / multiple techniques will be required to build a robust case of discovery

- SLIDES END