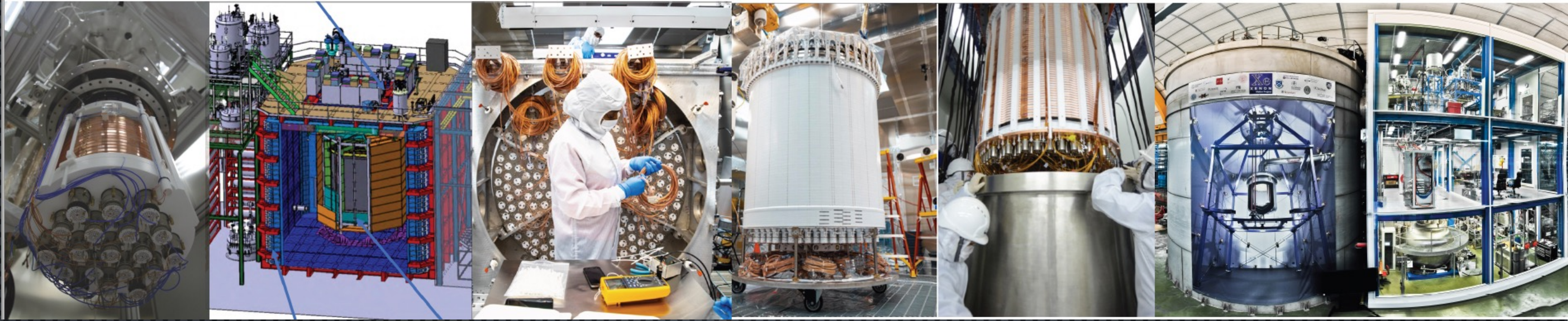
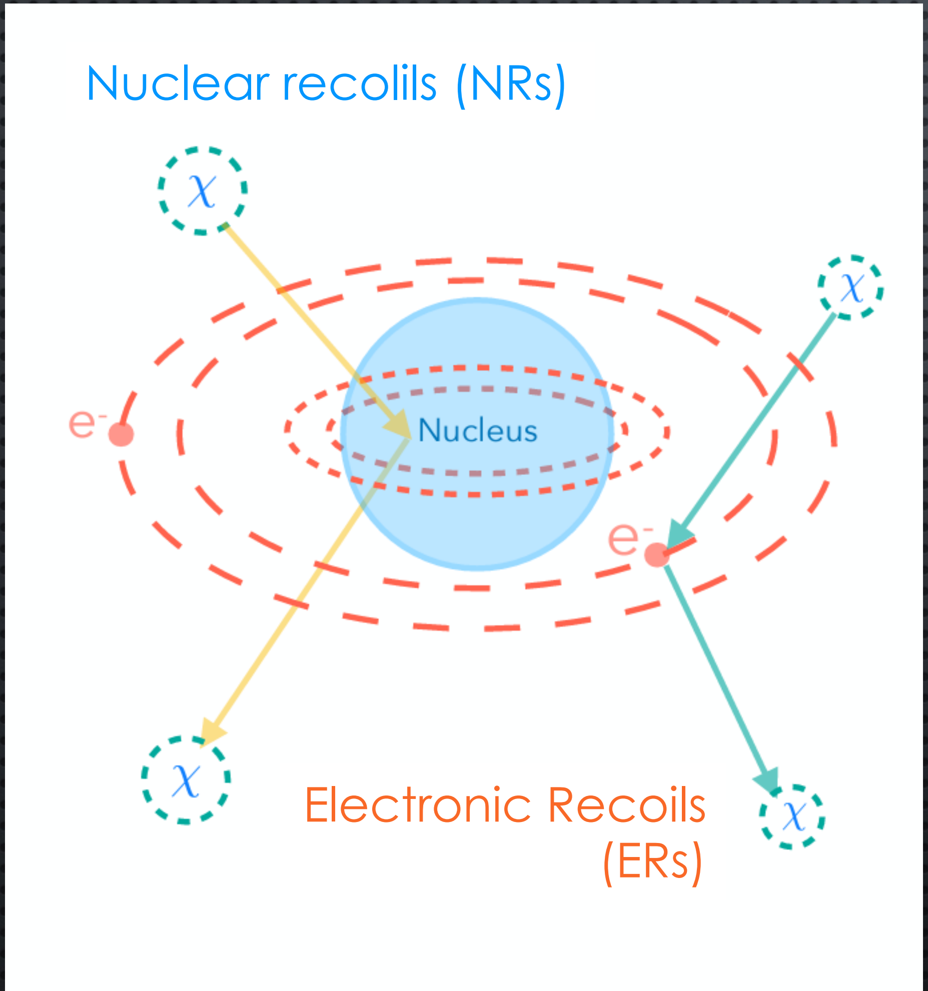


RECHERCHE DIRECTE VIA LES DÉTECTEURS À GAZ NOBLES

Sara Diglio, SUBATECH-Nantes

Journée SFP 2024: Lumière sur la matière noire

HOW TO DETECT A DM CANDIDATE ?



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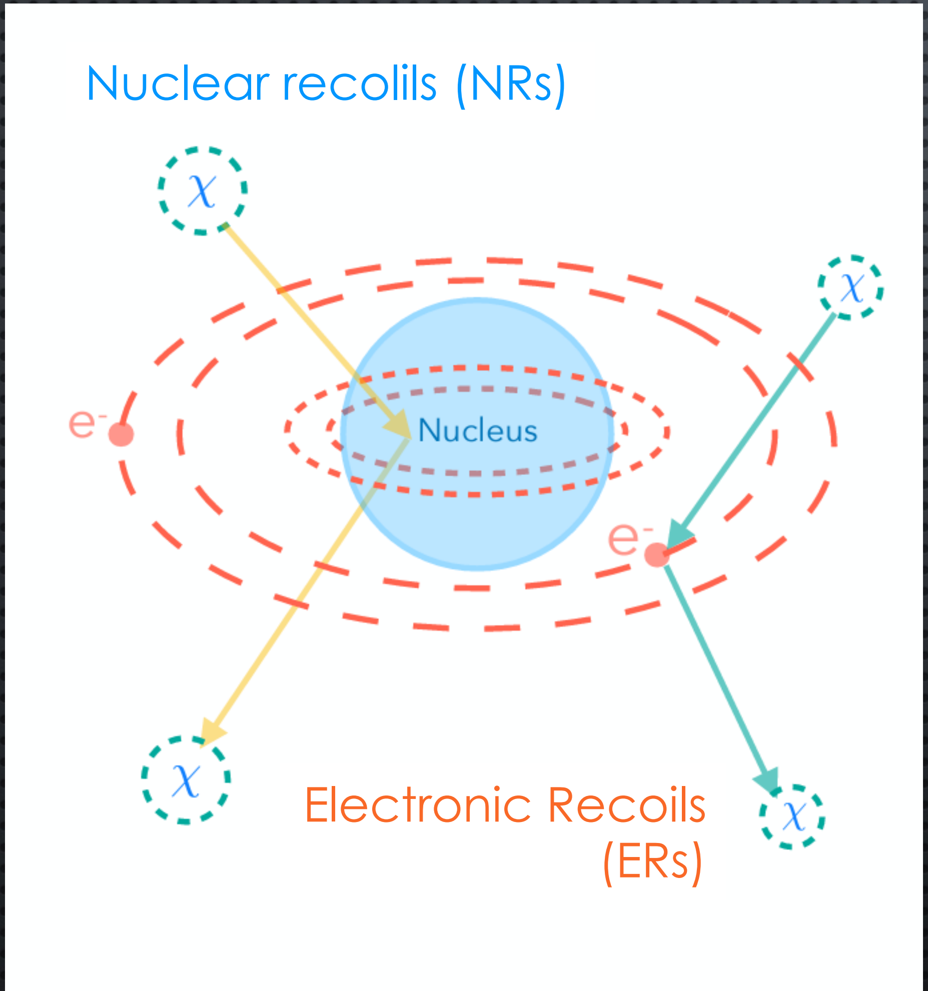
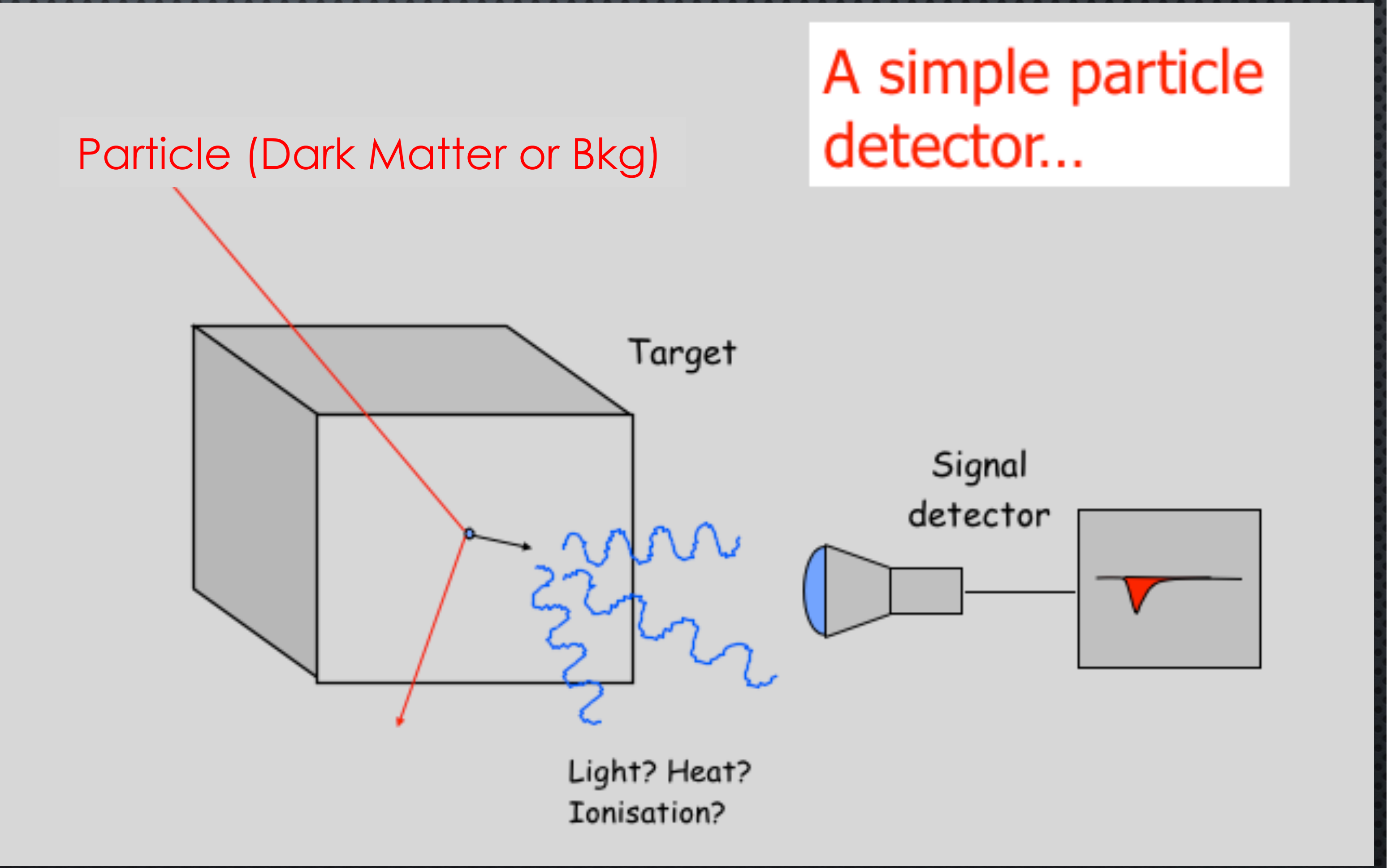
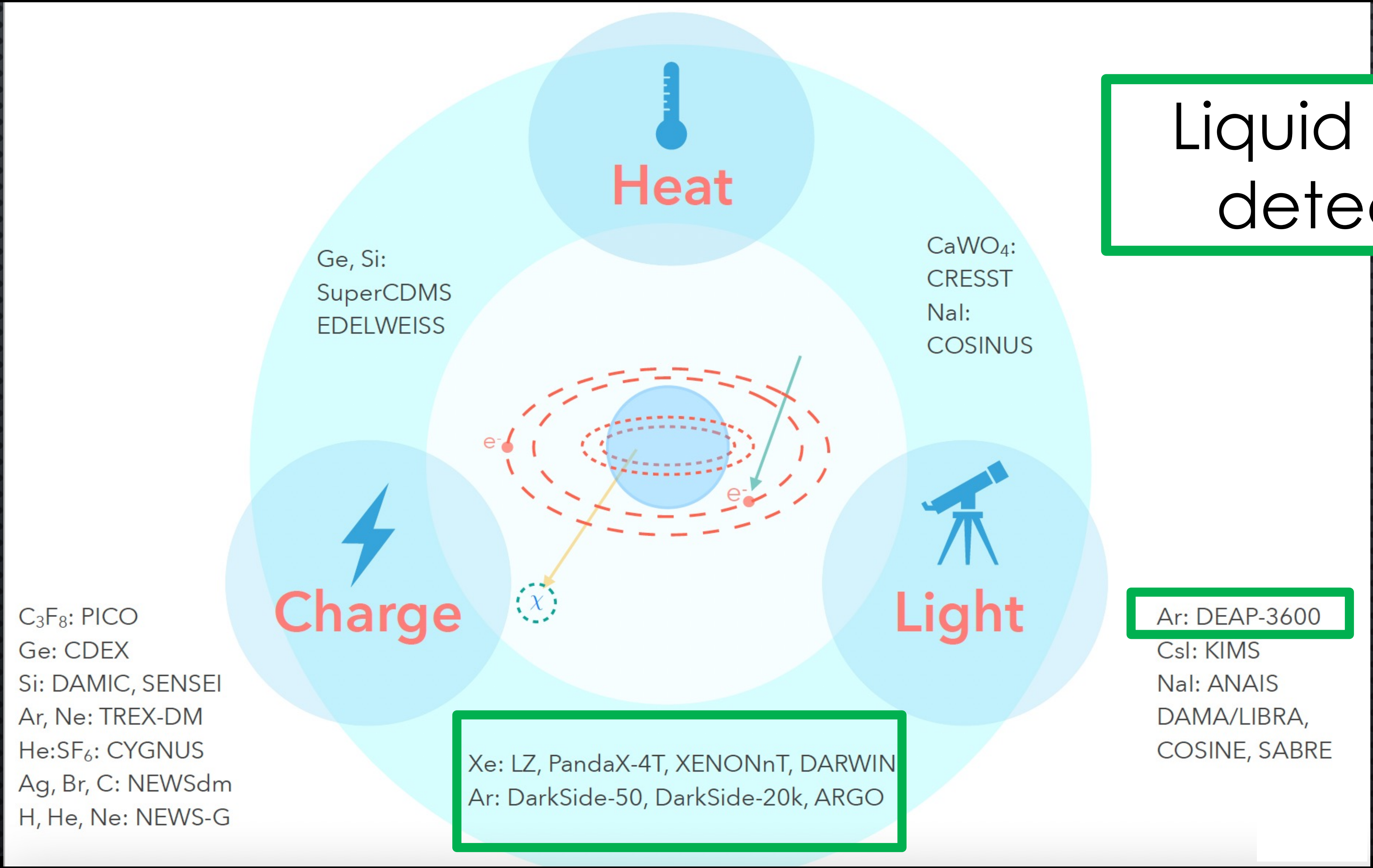




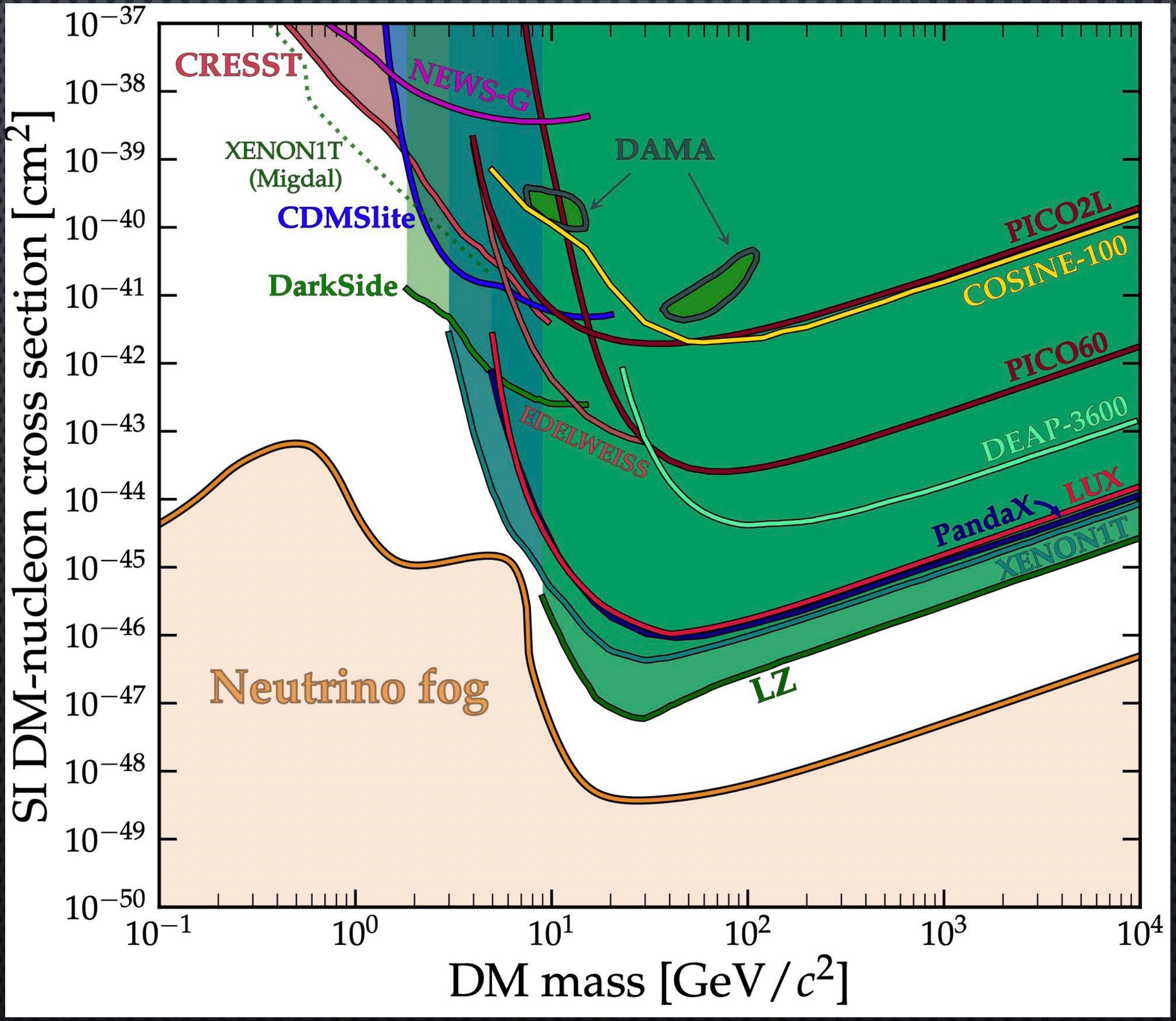
DIRECT DETECTION TECHNIQUES



Liquid Noble detectors

Credit: L.Baudis

DARK MATTER DIRECT DETECTION STATE OF THE ART



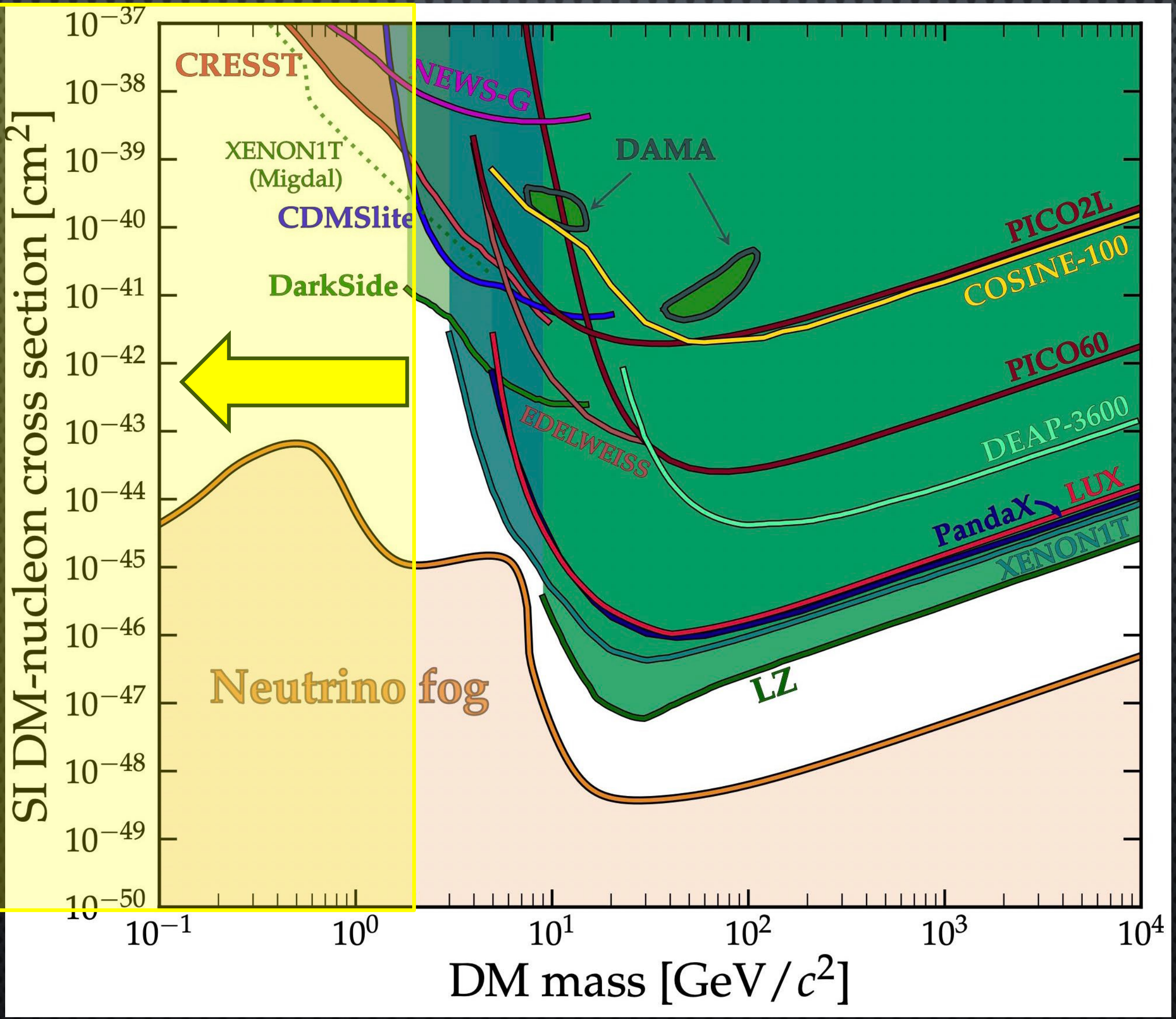
DARK MATTER DIRECT DETECTION STATE OF THE ART

Low Mass Region
m_{DM} <~ 1 GeV

Region dominated by Cryogenic detectors

Low energy threshold

Talk by V.Novati



DARK MATTER DIRECT DETECTION STATE OF THE ART

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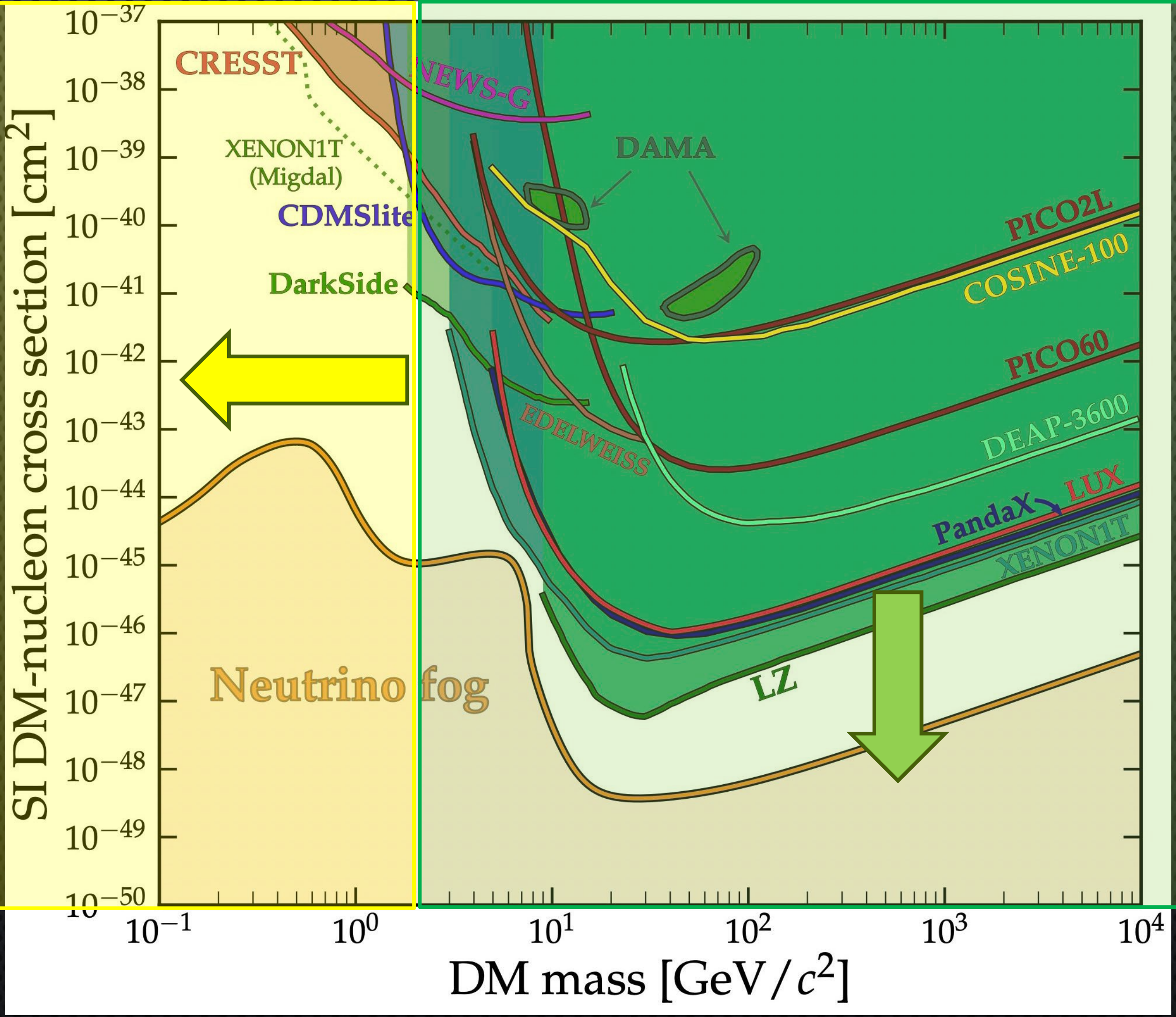


High Mass Region
m_{DM} > 1 GeV

Region dominated by **Noble liquids detector**

Large mass detectors

This Talk

LIQUID NOBLE TECHNOLOGY

WIMP Limits vs Time: principal detector categories

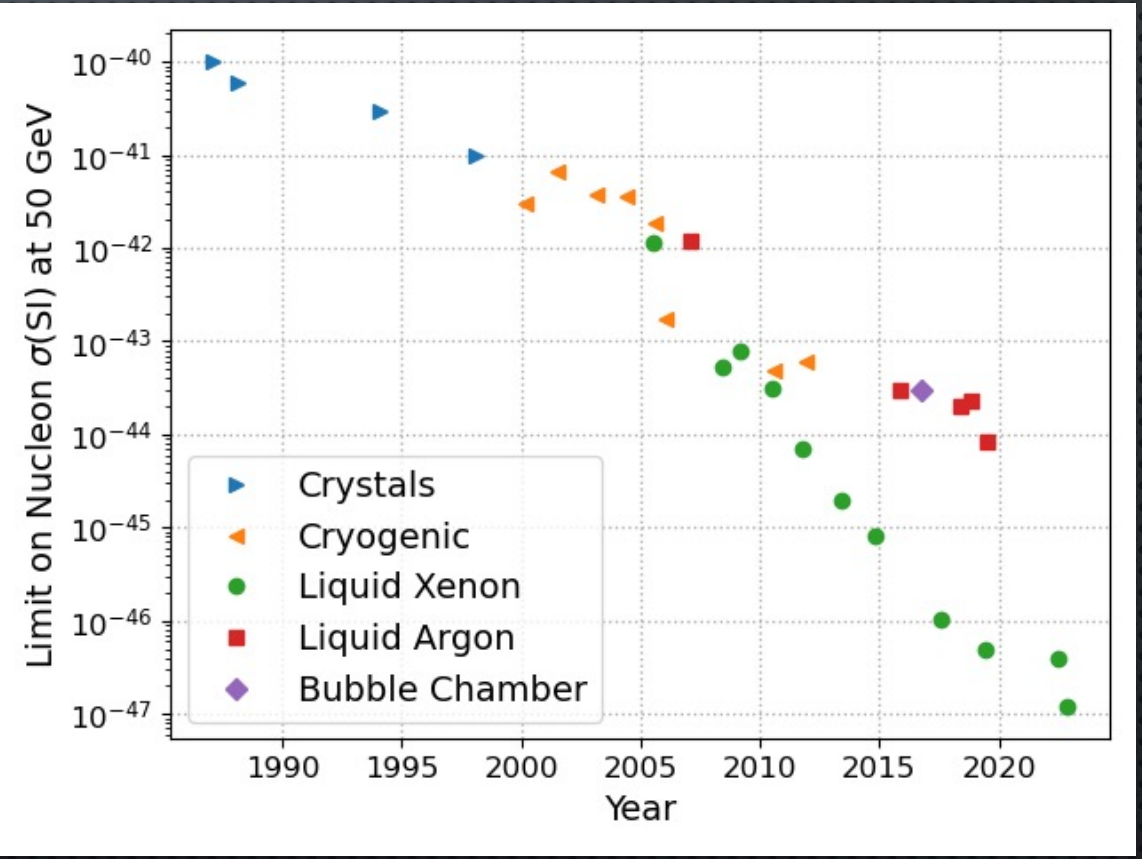


Figure by Tom Shutt, SLAC

LIQUID NOBLE TECHNOLOGY

- Leading sensitivity at intermediate/high DM masses
- Scalability → large target masses
- High Density → Self shielding
- Readily purified → ultra-low bkg
- Easy cryogenic : 170 K (LXe), 87 K (LAr)
- SI and SD (^{129}Xe, ^{131}Xe) interactions
- Many other science opportunities:
  - Double weak decays
  - Solar and SN ν
  - …

WIMP Limits vs Time: principal detector categories

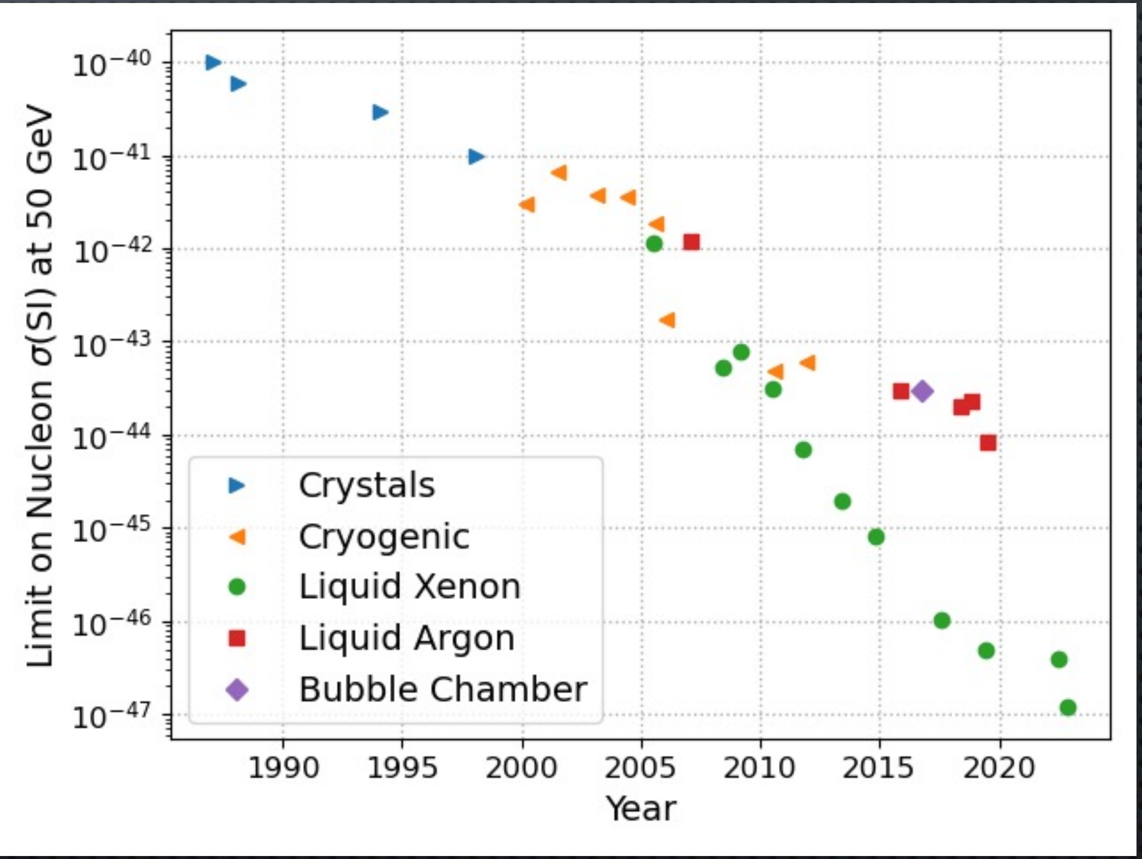
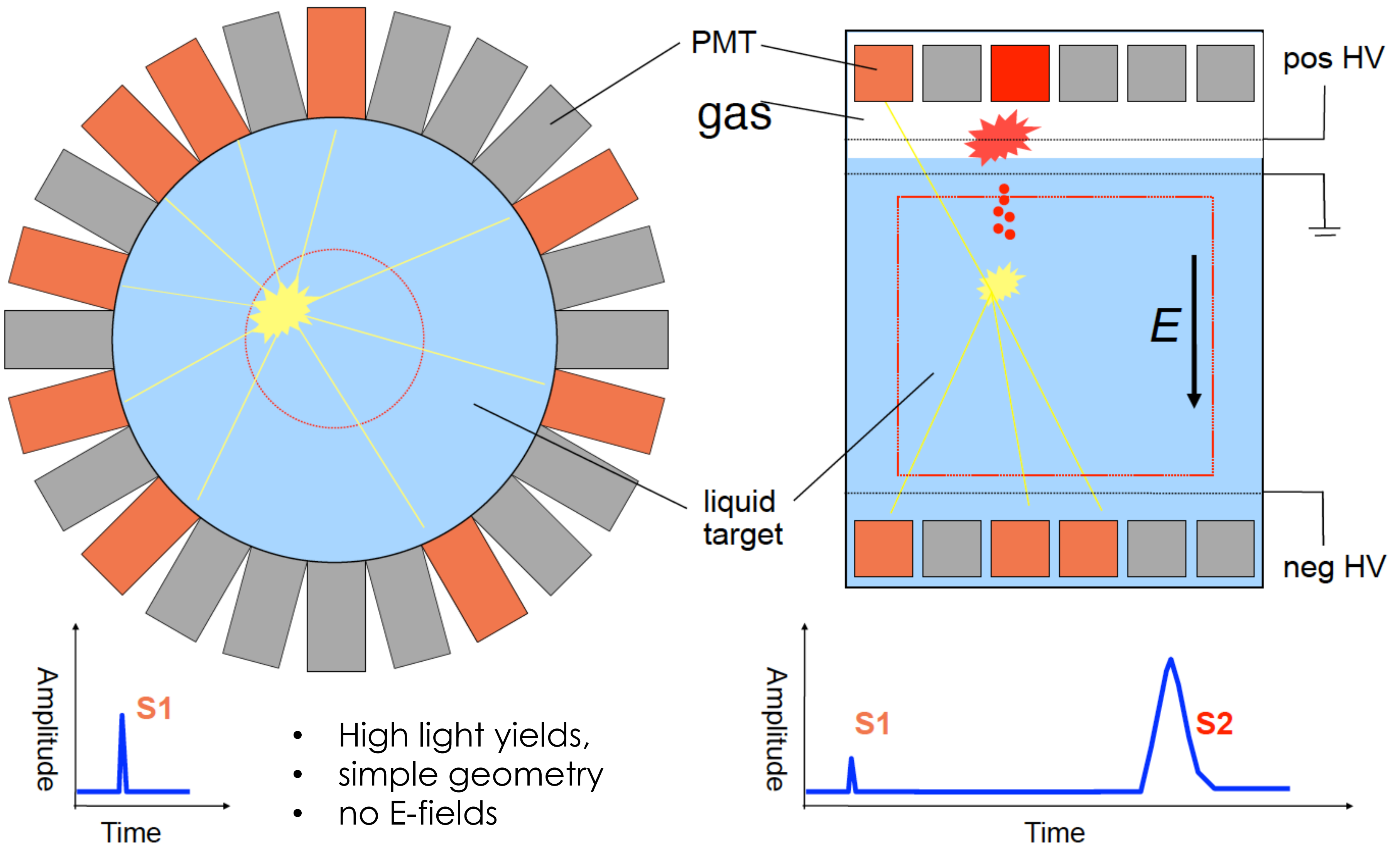


Figure by Tom Shutt, SLAC

DETECTOR TYPES

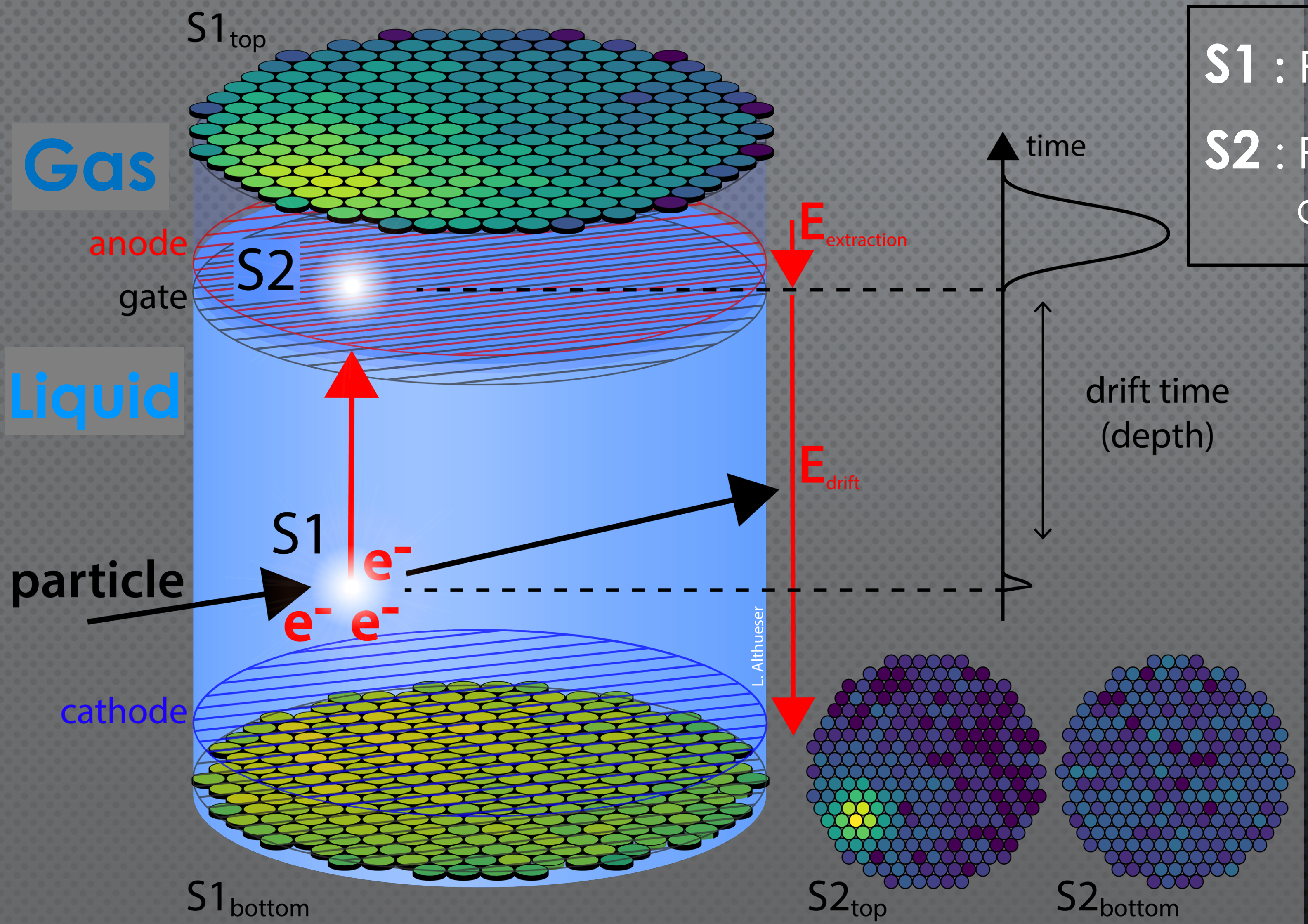
Single Phase

Dual Phase



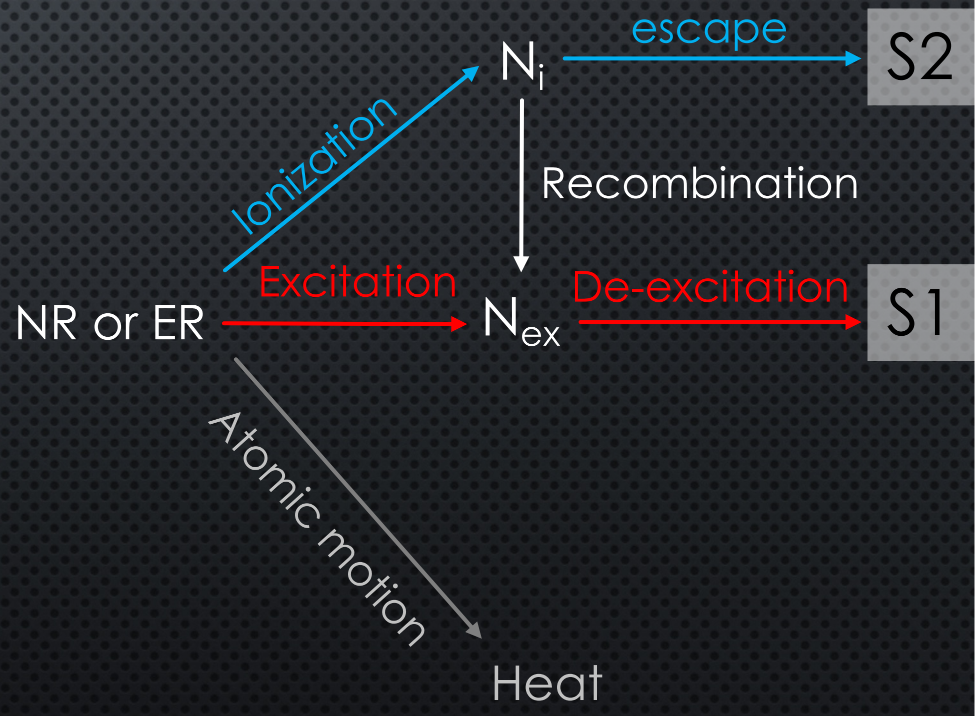
- High light yields,
- simple geometry
- no E-fields

DUAL PHASE TIME PROJECTION CHAMBERS



S1 : Prompt Scintillation (light)

S2 : Proportional scintillation following e$^-$ drift and extraction into gas (charge)



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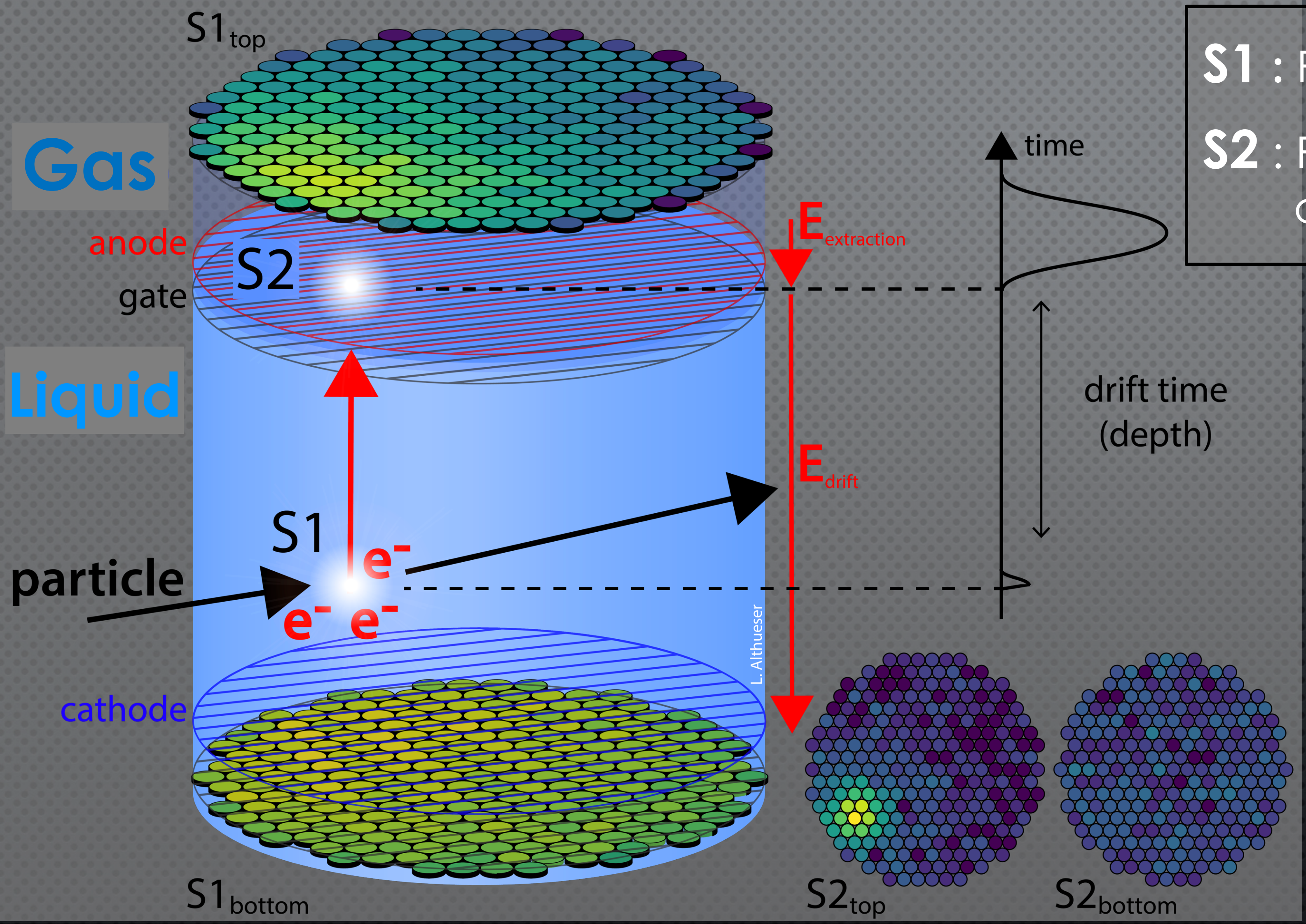

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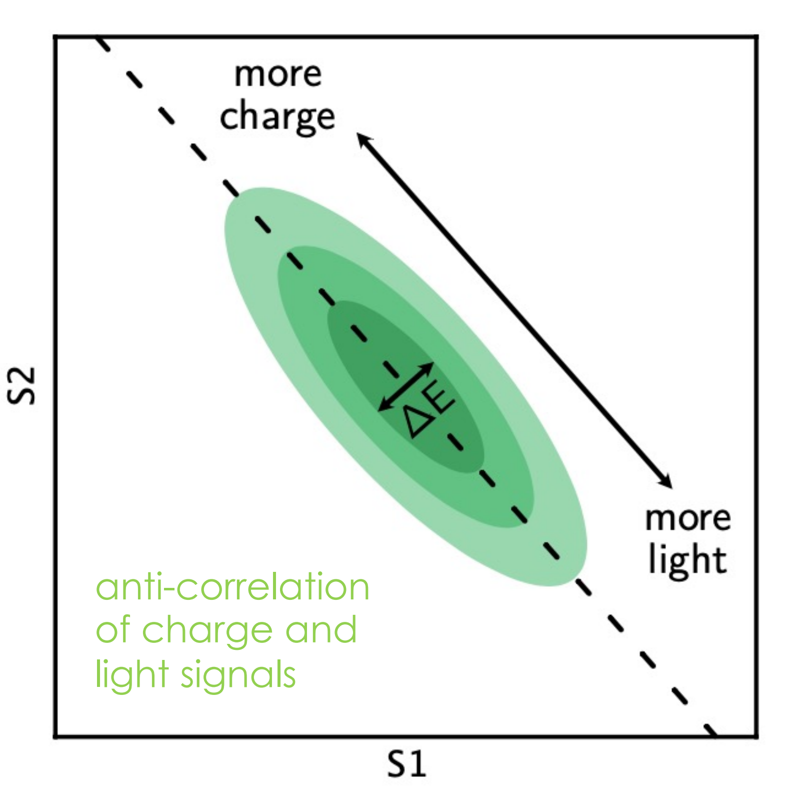

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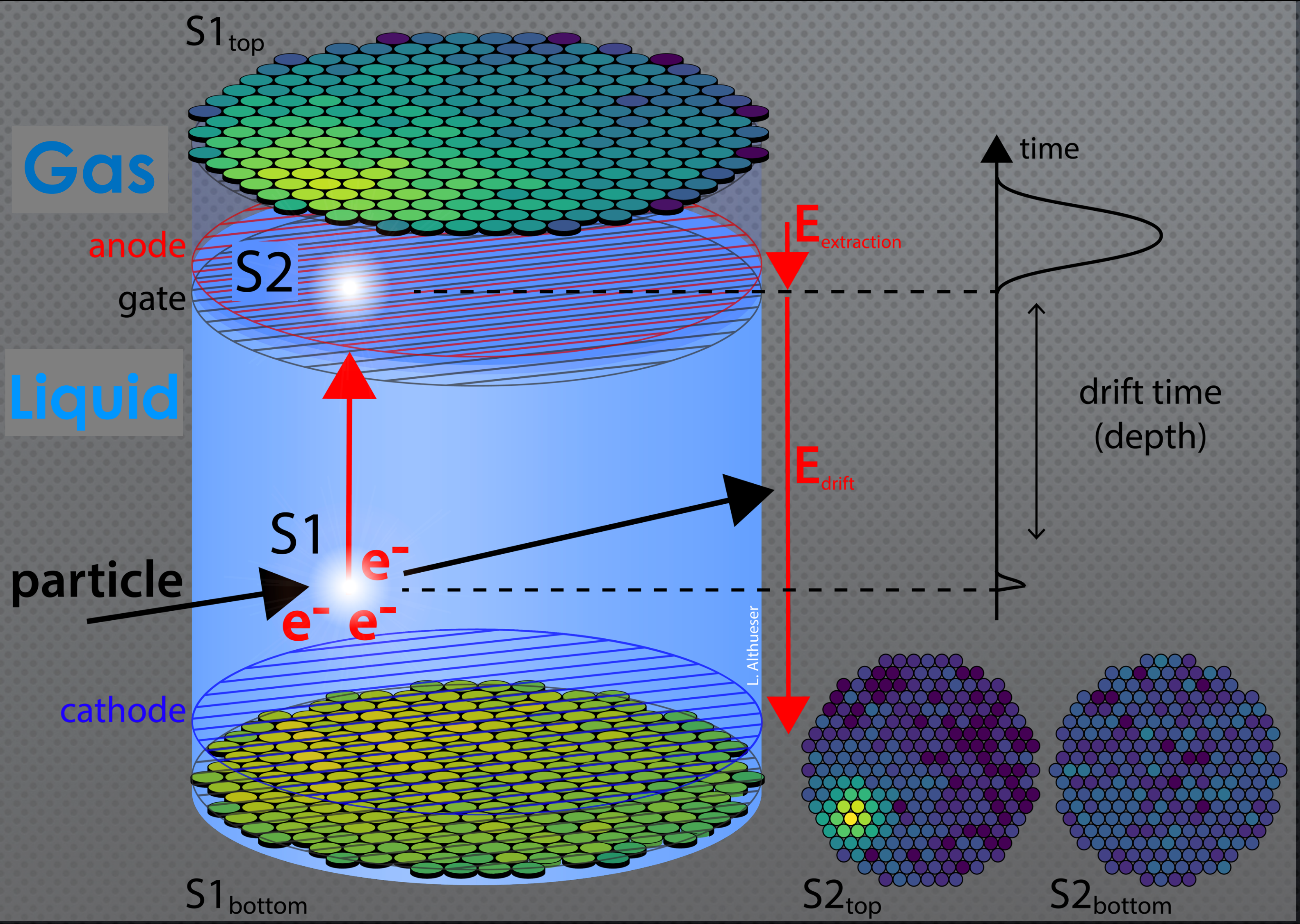
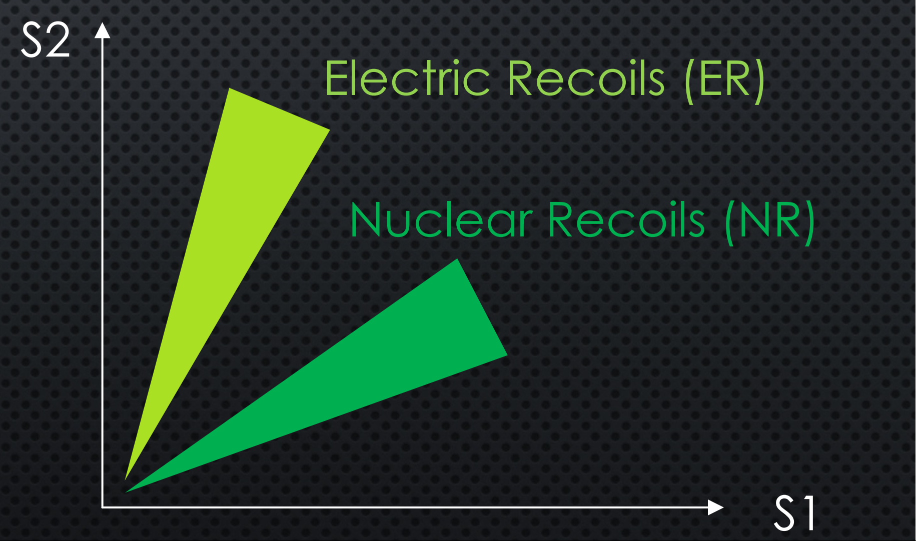
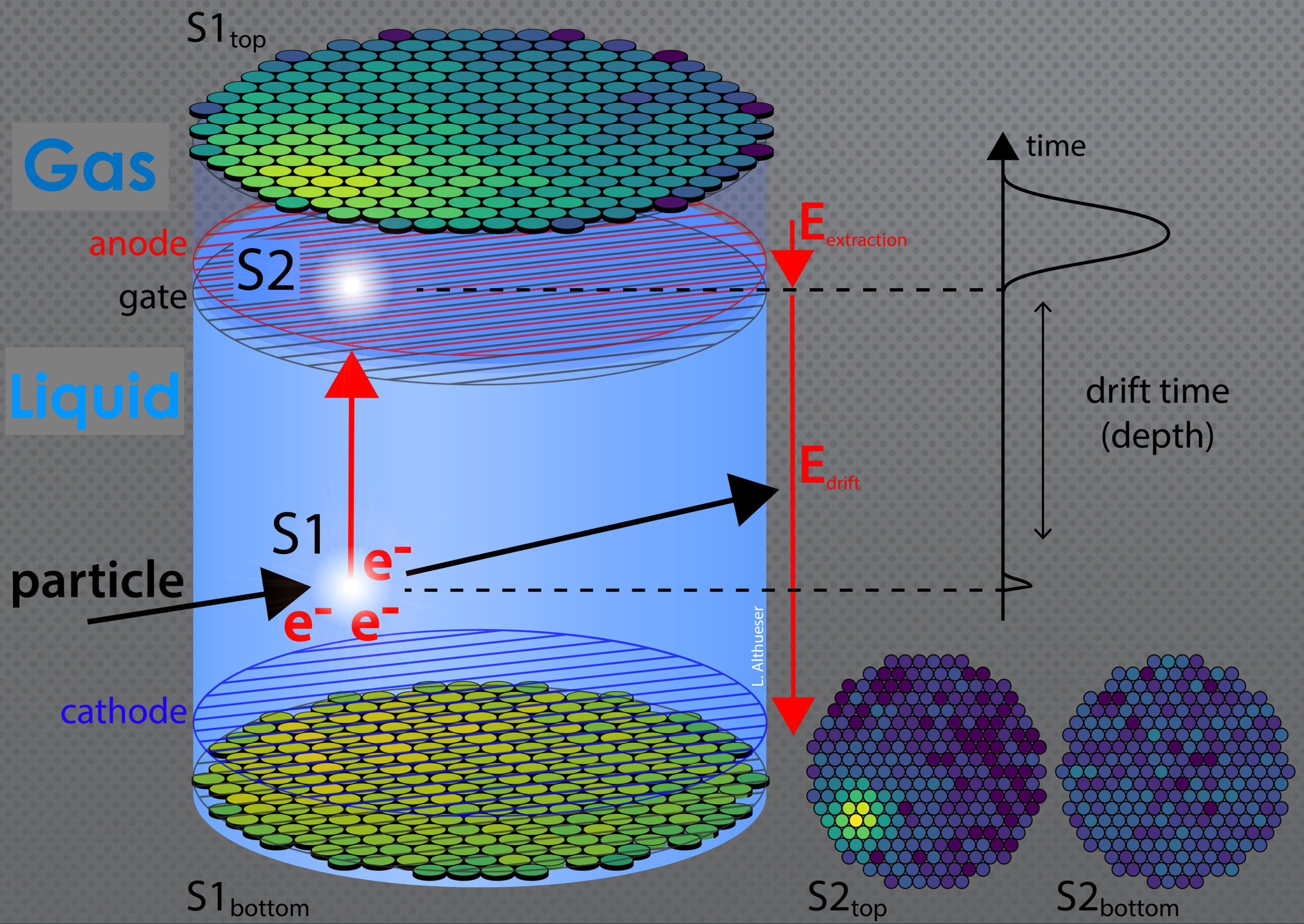


- Energy from S1 and S2
- Separation ER vs NR
- 3D event reconstruction:
  - X , Y from S2 hit pattern on top PMTs
  - Z from electrons drift time



DUAL PHASE TIME PROJECTION CHAMBERS



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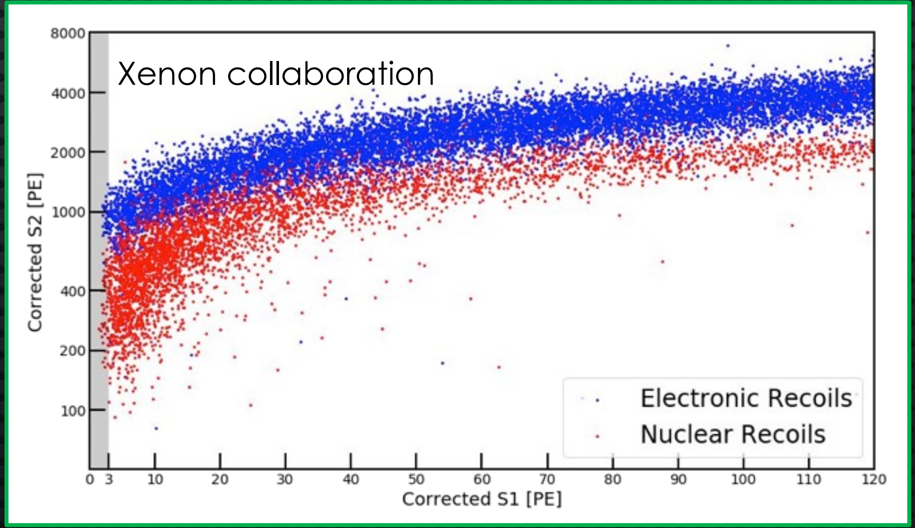
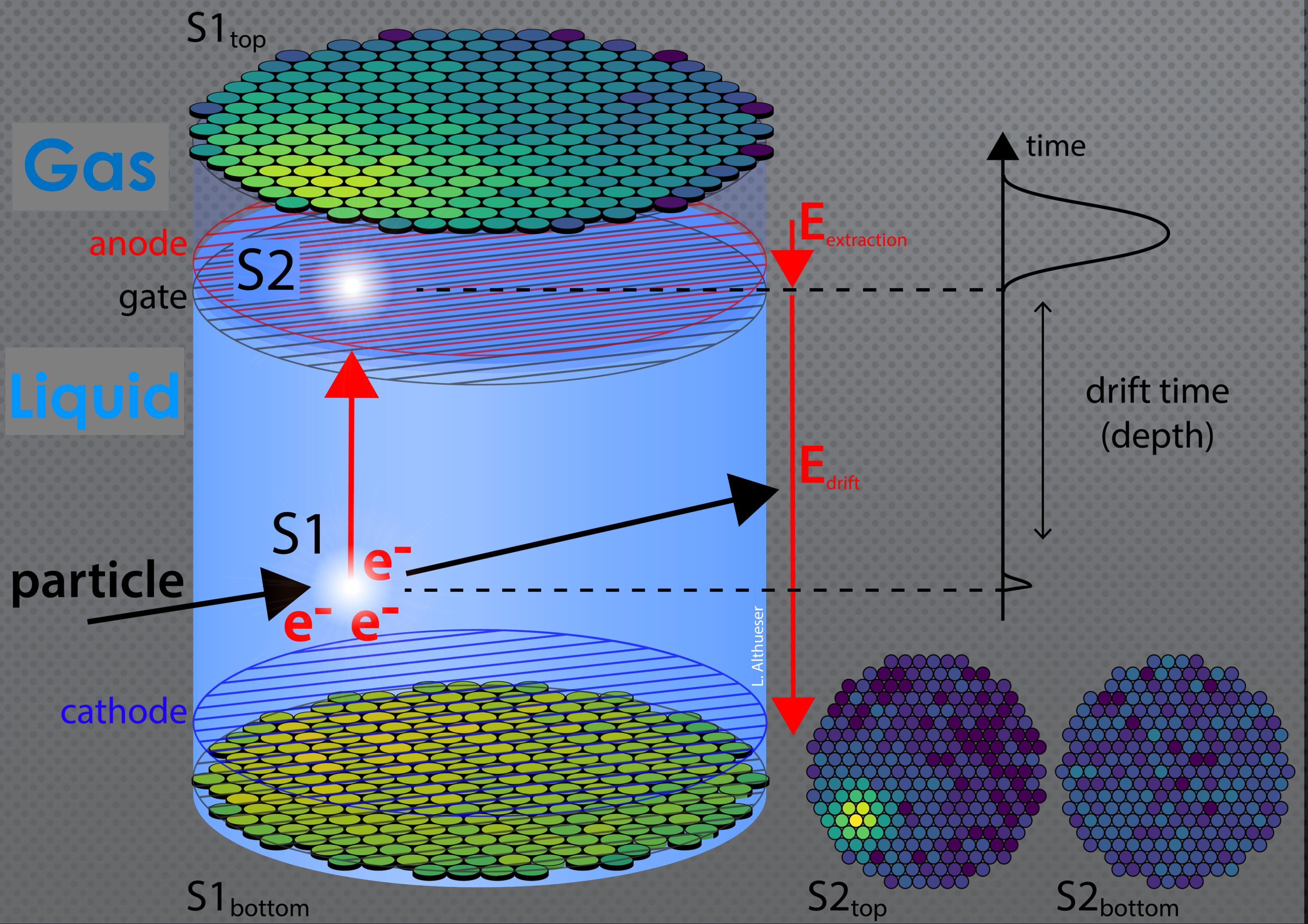
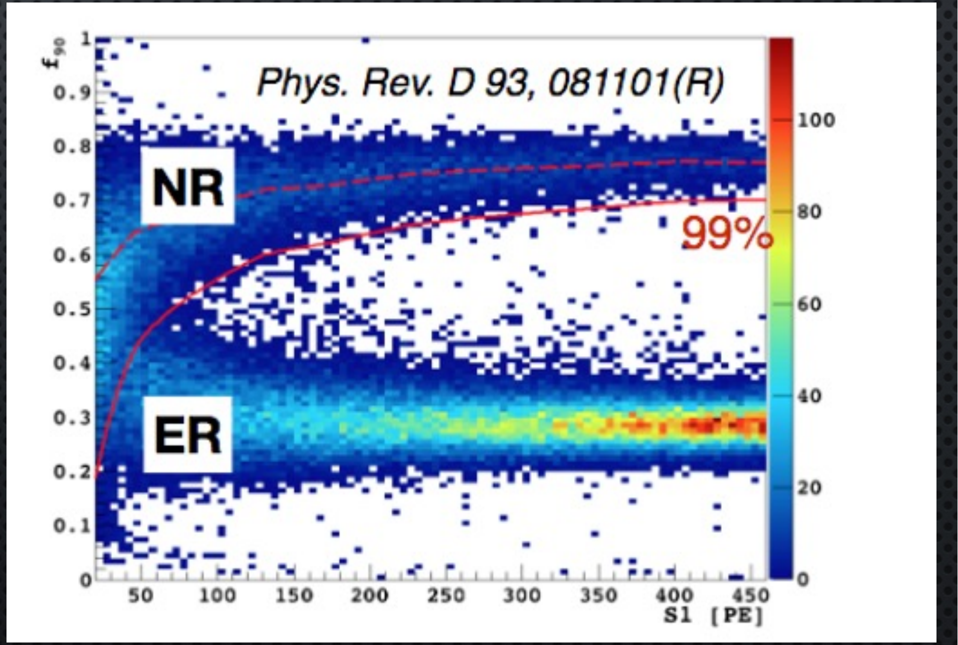


DUAL PHASE TIME PROJECTION CHAMBERS



Additional ER/NR discrimination in LAr TPCs

- Pulse Shape Discrimination(PSD) parameter f_{90} : fraction of light seen in the first 90 sec



PROPERTIES OF NOBLE GASES

Complementarity between LXe & LAr

- Higher mass number in Xe → higher WIMP rate
- Better ER/NR discrimination in Ar
- Higher density in Xe → stronger self-shielding
- …

Noble Gas	LXe	LAr
Atomic mass [g/mol]	131.3	39.95
Density [g/cm^3]	3.06	1.40
Wavelength [nm]	178	128
Average ionization energy W [eV]	15.6	23.3
Ionization Yield [e^-/keV]	64	42
Scintillation Yield [photon/keV]	46	40

CURRENT GENERATION LIQUID NOBLE DETECTORS

LIQUID ARGON DETECTORS

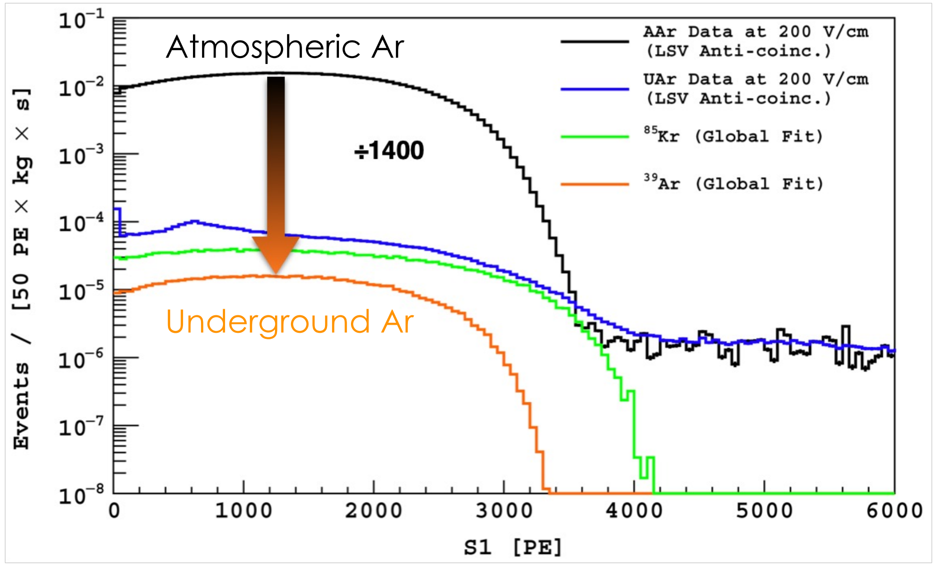
- **DarkSide50**
  - Target: 50 kg (fiducial 31 kg) (depleted in Ar39)
  - 38 PMTs
  - Data taking: 2013 - 2019
- **DEAP 3600**
  - Target : 3.3 t (fiducial 1 t)
  - 255 PMTs
  - Data taking: 2016 - 2020

DarkSide50 @LNGS
Dual phase

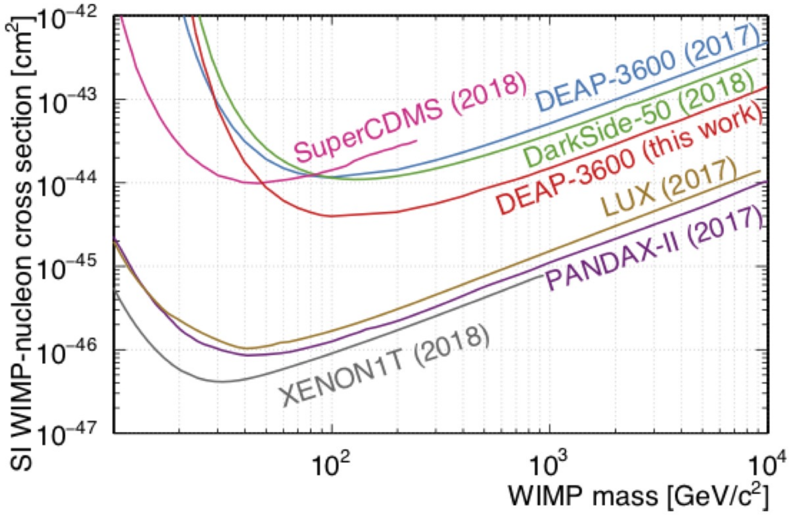
DEAP3600 @Snolab
(Canada)
Single phase

LIQUID ARGON DETECTORS

- **DarkSide50**
  - Target: 50 kg (fiducial 31 kg) (depleted in Ar39)
  - 38 PMTs
  - Data taking: 2013 - 2019
  - Exposure: 532 live-days (0.045 t x year)
- **DEAP 3600**
  - Target : 3.3 t (fiducial 1 t)
  - 255 PMTs
  - Data taking: 2016 - 2020
  - Exposure: 231 live-days (2019) (0.63 t x year)
  - Detector upgrade in progress



Phys. Rev. D. (2018) 98: 102006



Phys. Rev. D. (2019) 100: 022004

LIQUID XENON DETECTORS

- **XENONnT**
  - Target: 5.9 t (fiducial 4.2 t)
  - Data taking since 2021
- **Lux-Zeplin (LZ)**
  - Target : 7 t (fiducial 5.5 t)
  - Data taking since 2022
- **PandaX-4T**
  - Target: 3.7 t (fiducial 2.7 t)
  - Data taking since 2021

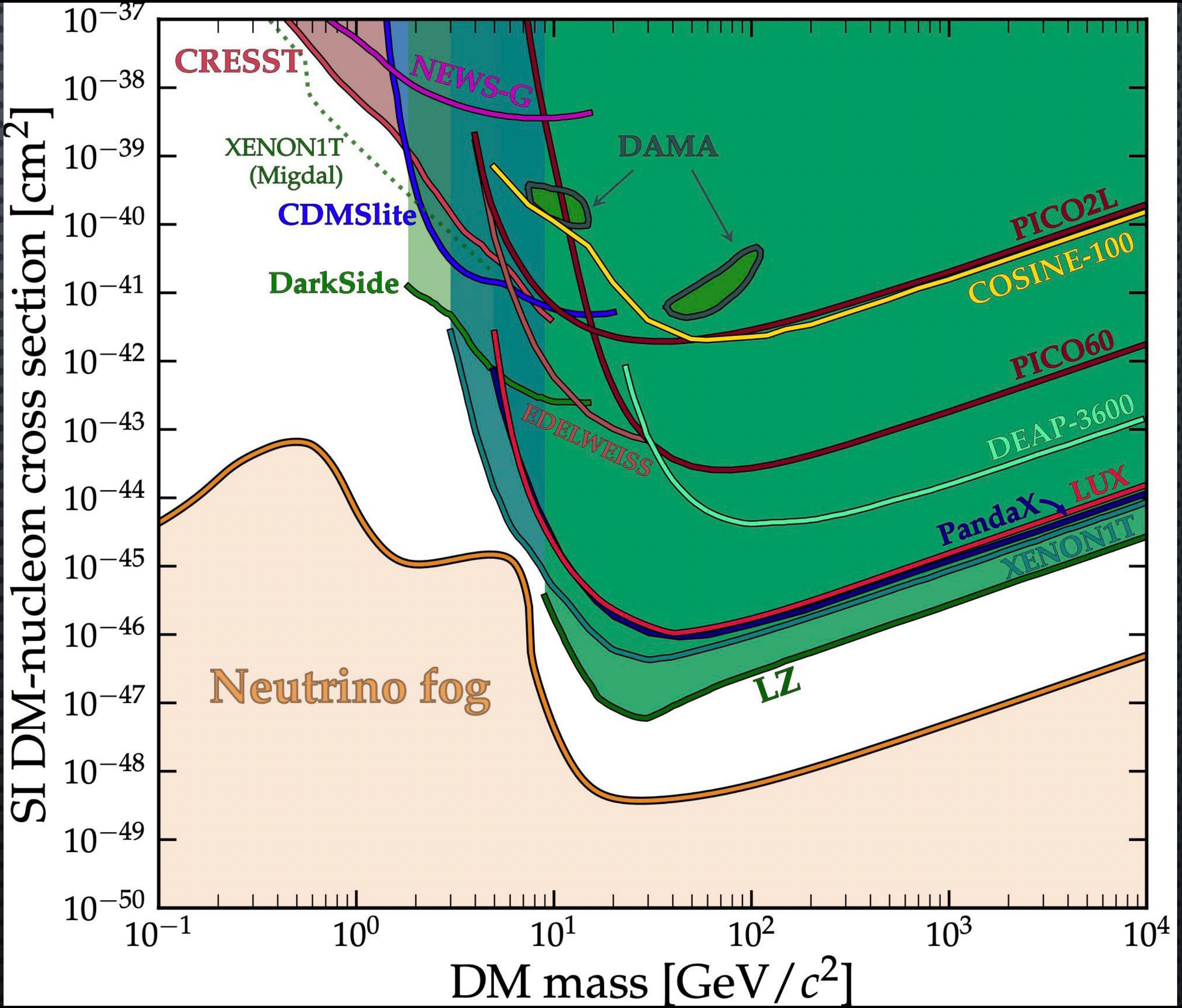
LZ @SURF (US)
Dual phase

XENONnT @LNGS
Dual phase

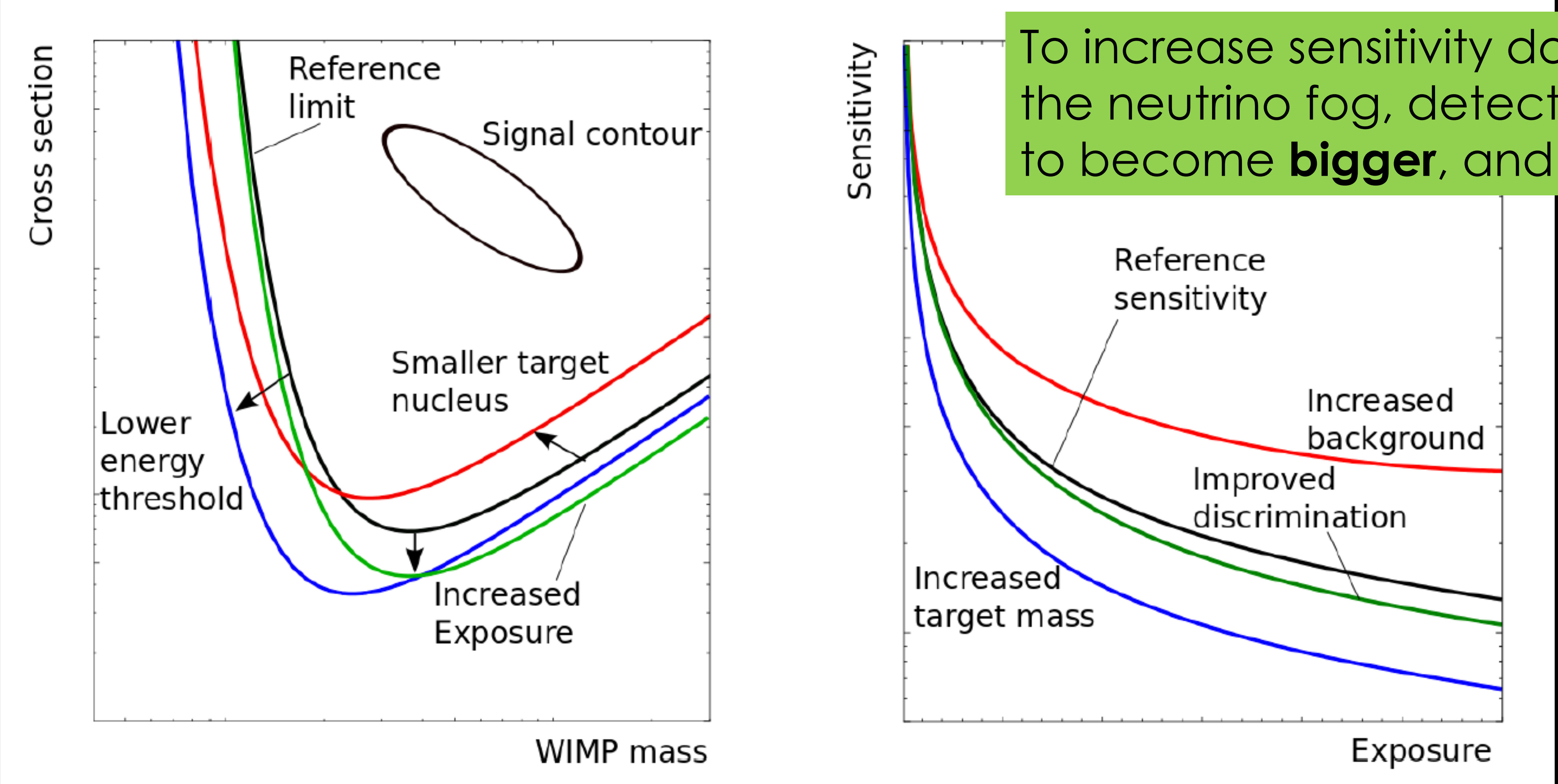
PandaX-4T @CJPL
(China)
Dual phase

LIQUID XENON DETECTORS

- **XENONnT**
  - Target: 5.9 t (fiducial 4.2 t)
  - Data taking since 2021
  - Exposure: 97.1 live-days (1.1 t x year)
- **Lux-Zeplin (LZ)**
  - Target : 7 t (fiducial 5.5 t)
  - Data taking since 2022
  - Exposure: 60 live-days (0.9 t x year)
- **PandaX-4T**
  - Target: 3.7 t (fiducial 2.7 t)
  - Data taking since 2021
  - Exposure: 86.0 live-days (0.63 t x year)



HOW TO IMPROVE WIMP SENSITIVITY?

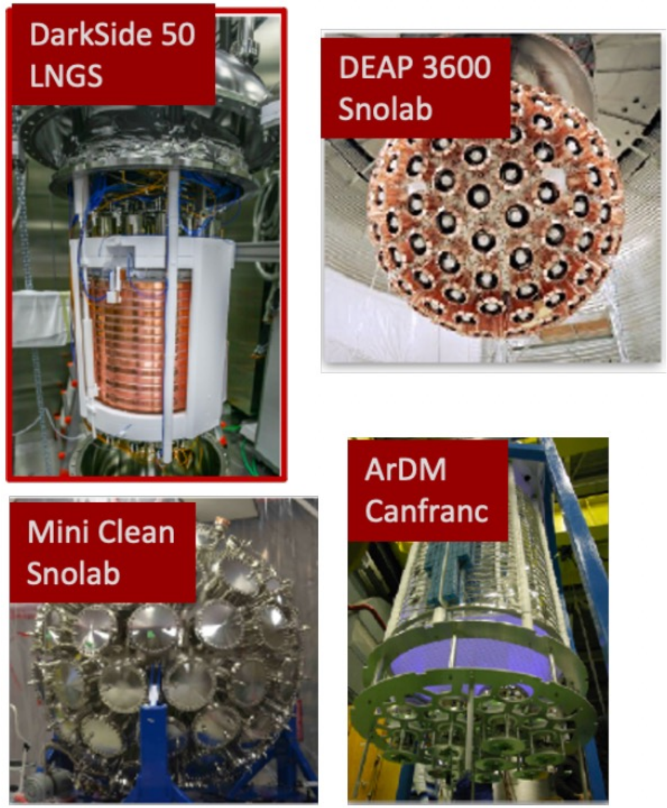


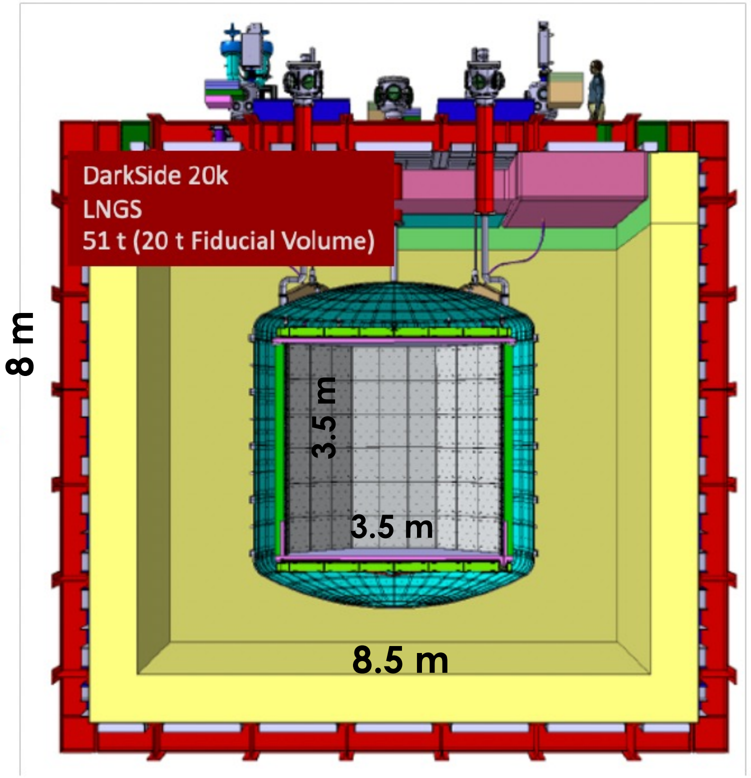
To increase sensitivity down to the neutrino fog, detectors have to become **bigger**, and **quieter**

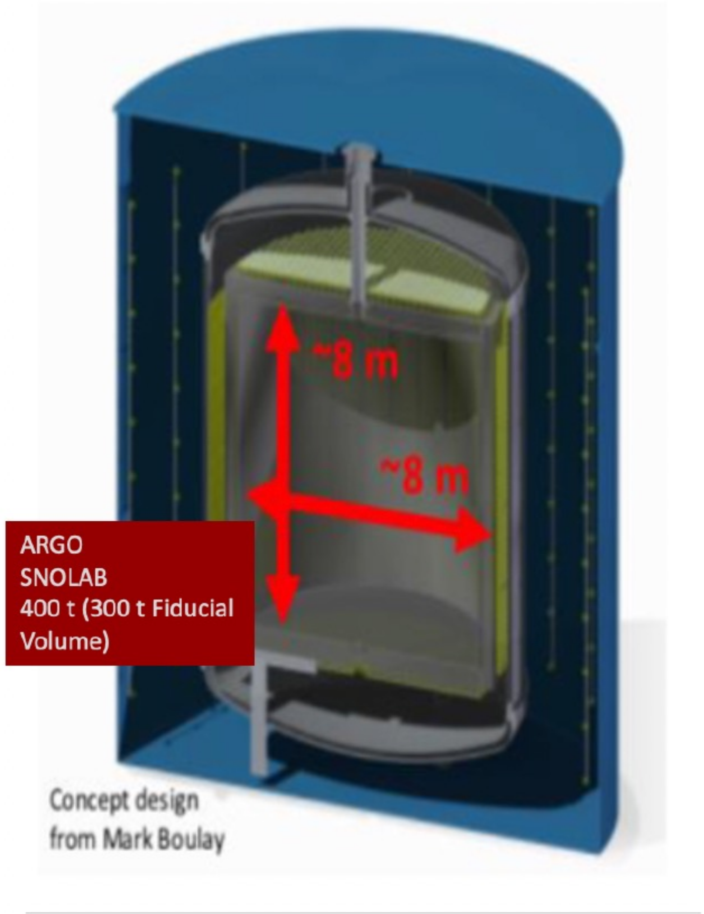
NEXT GENERATION LIQUID NOBLE DETECTORS

THE GLOBAL ARGON DARK MATTER COLLABORATION - GADMC

GADMC includes over 400 researchers from 69 institutions in 14 countries



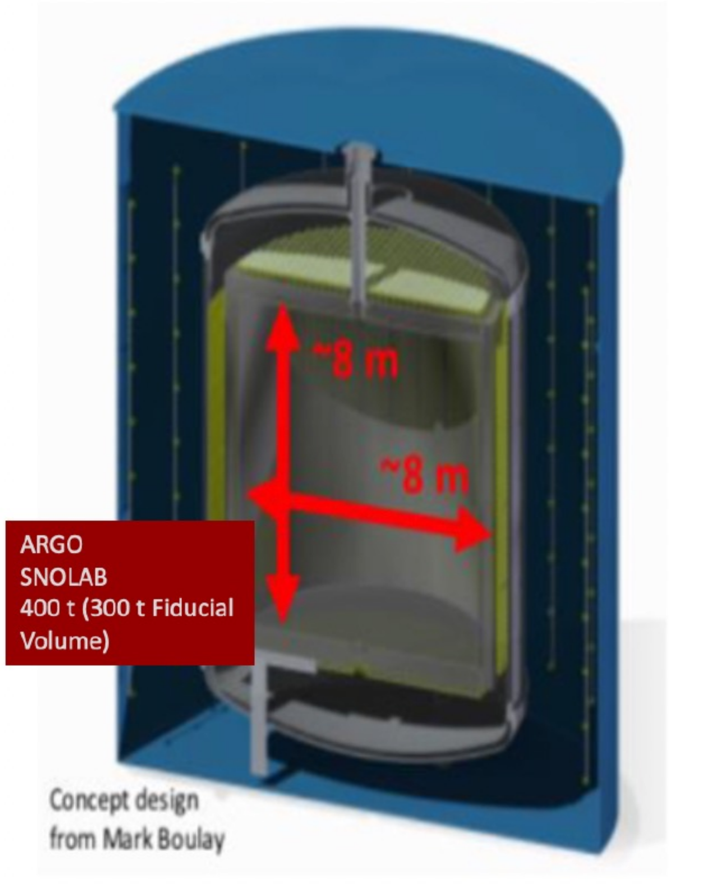




THE GLOBAL ARGON DARK MATTER COLLABORATION - GADMC

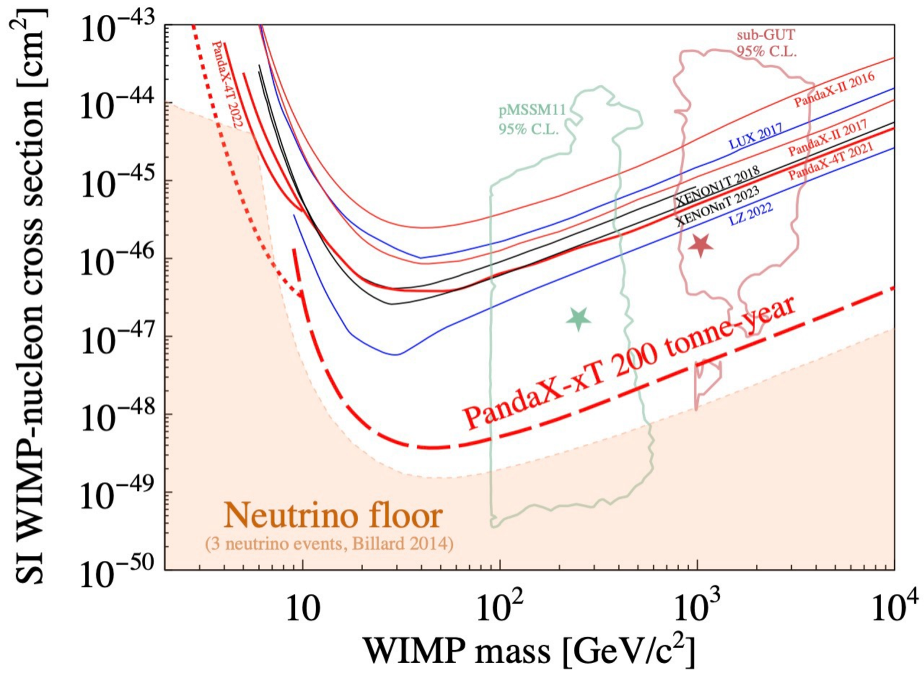
GADMC includes over 400 researchers from 69 institutions in 14 countries

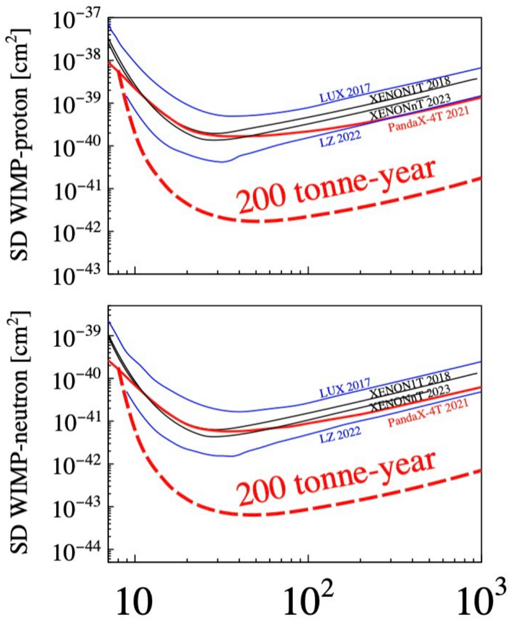
Construction started at LNGS
First physics run foreseen in 2027

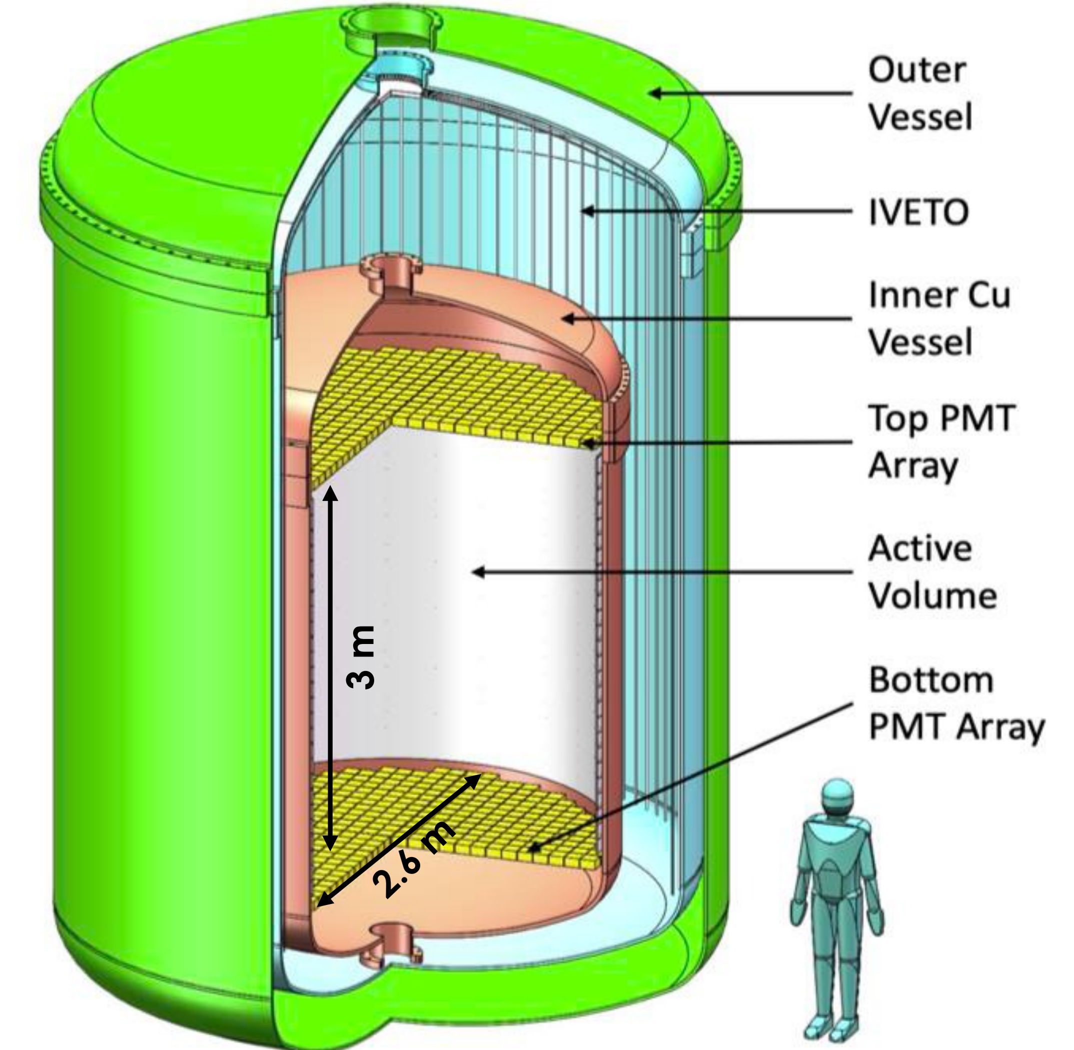


PANDAX - XT

- @CJPL (China)
- Multiple phases: gradually update the detector based on the Xe possession
- Total target mass 43 t
- Operation for >10 years



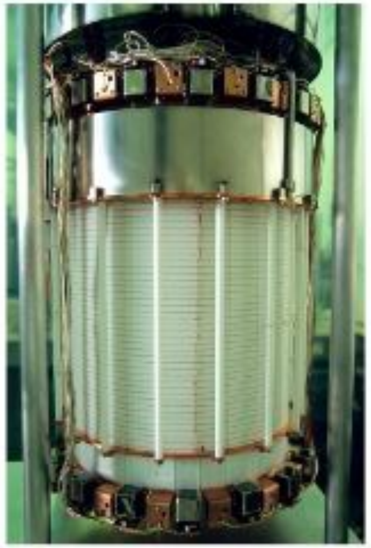


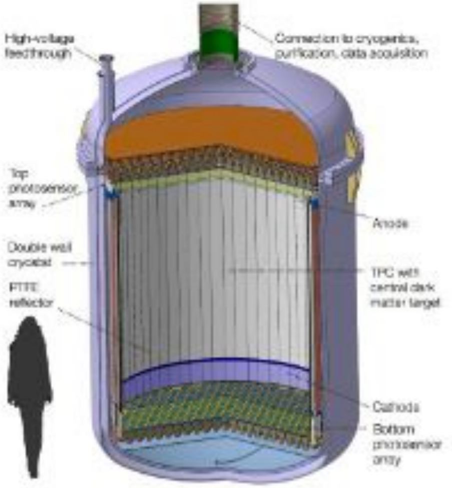


arXiv:2402.03596v1

THE DARWIN PROJECT

DARWIN



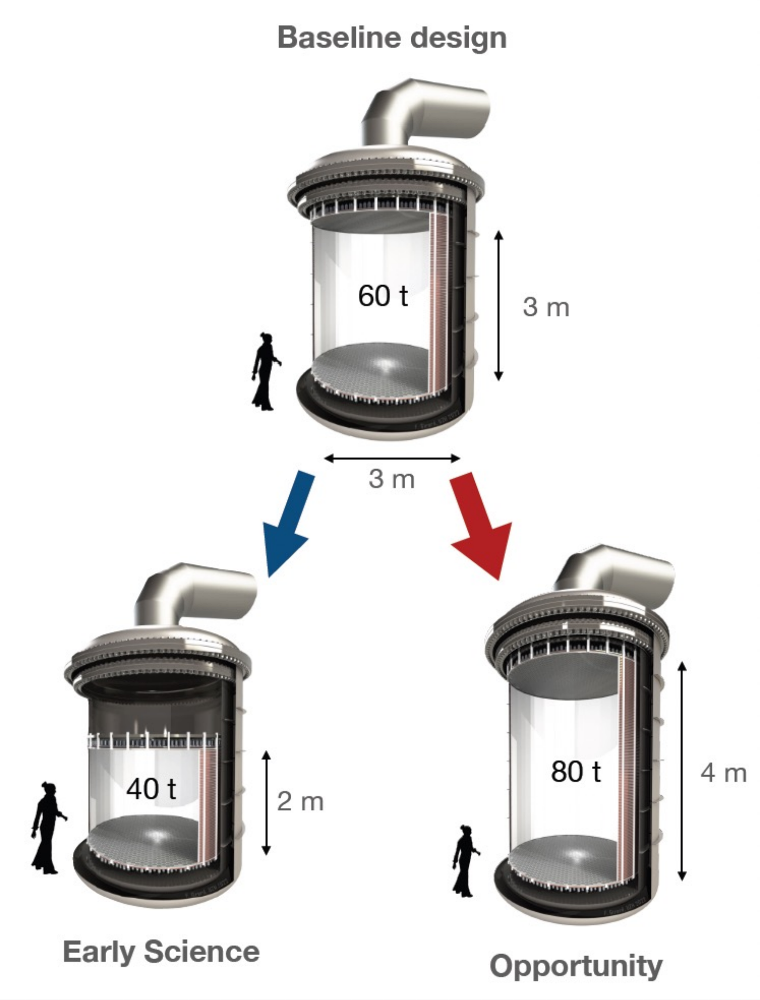


	XENON10	XENON100	XENON1T	XENONnT	DARWIN
Operation period	2005-2007	2008-2016	2012-2019	2020-2026	2030
Xenon mass	14 kg Xe target	62 kg Xe target	2 t Xe target	5.9 t active Xe 8.5 t total Xe	~40 t active Xe ~50 t total Xe
Height **Diameter**	15 cm 20 cm	30 cm 30 cm	96 cm 97 cm	148 cm 133 cm	~2.6 m ~2.6 m

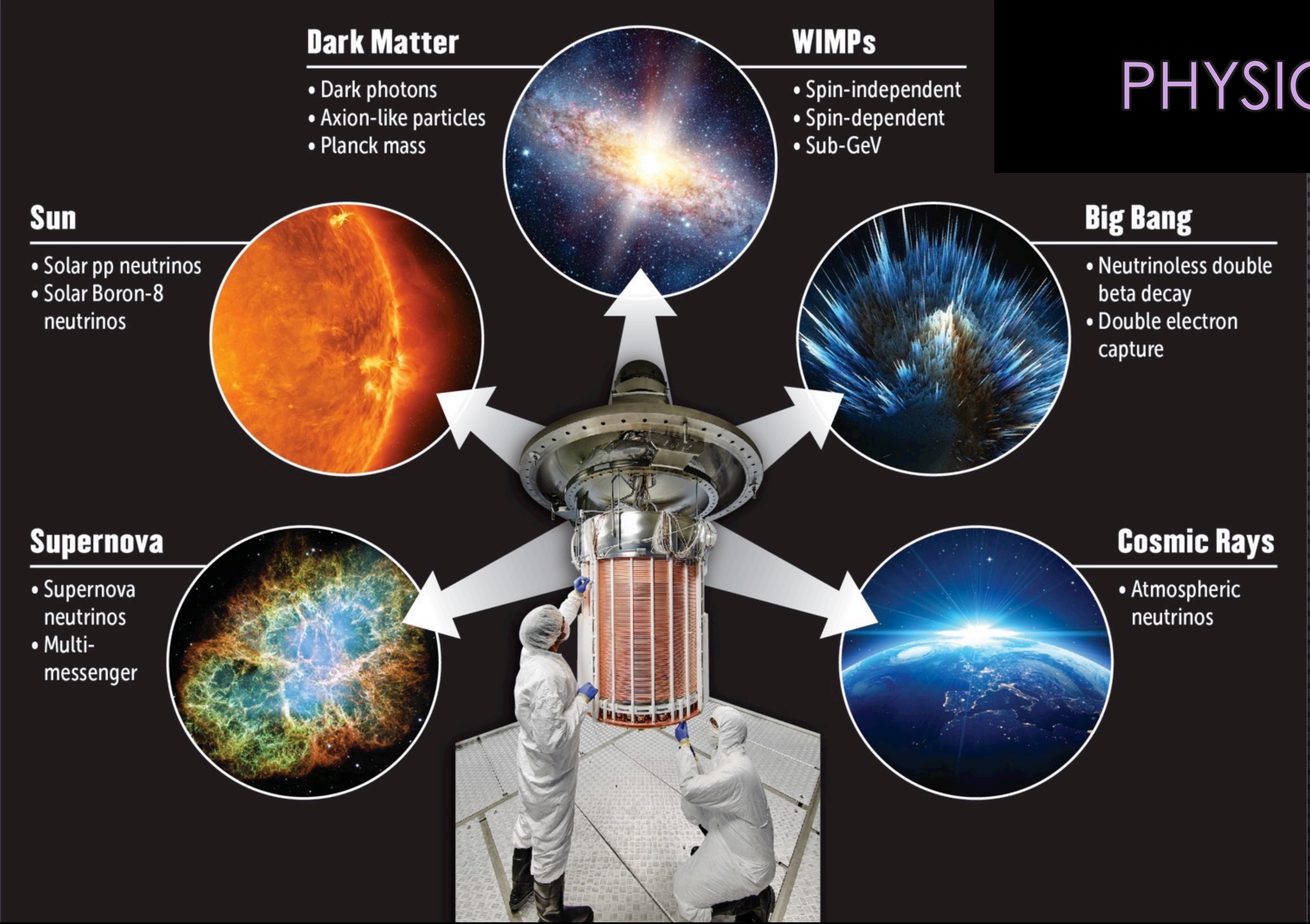
XLZD CONSORTIUM

XLZD consortium (xlzd.org) to design and build a common multi-ton xenon experiment

- Merger of DARWIN/XENON and LUX-ZEPLIN collaborations
  - **XENONnT** and **LZ**: ongoing science programs, technology progenitors
  - **DARWIN**: initiated R&D and design studies
- 104 group-leaders in 16 countries : MoU signed in July 2021
- joint "white paper" on physics reach : 600 authors, 141 institutions



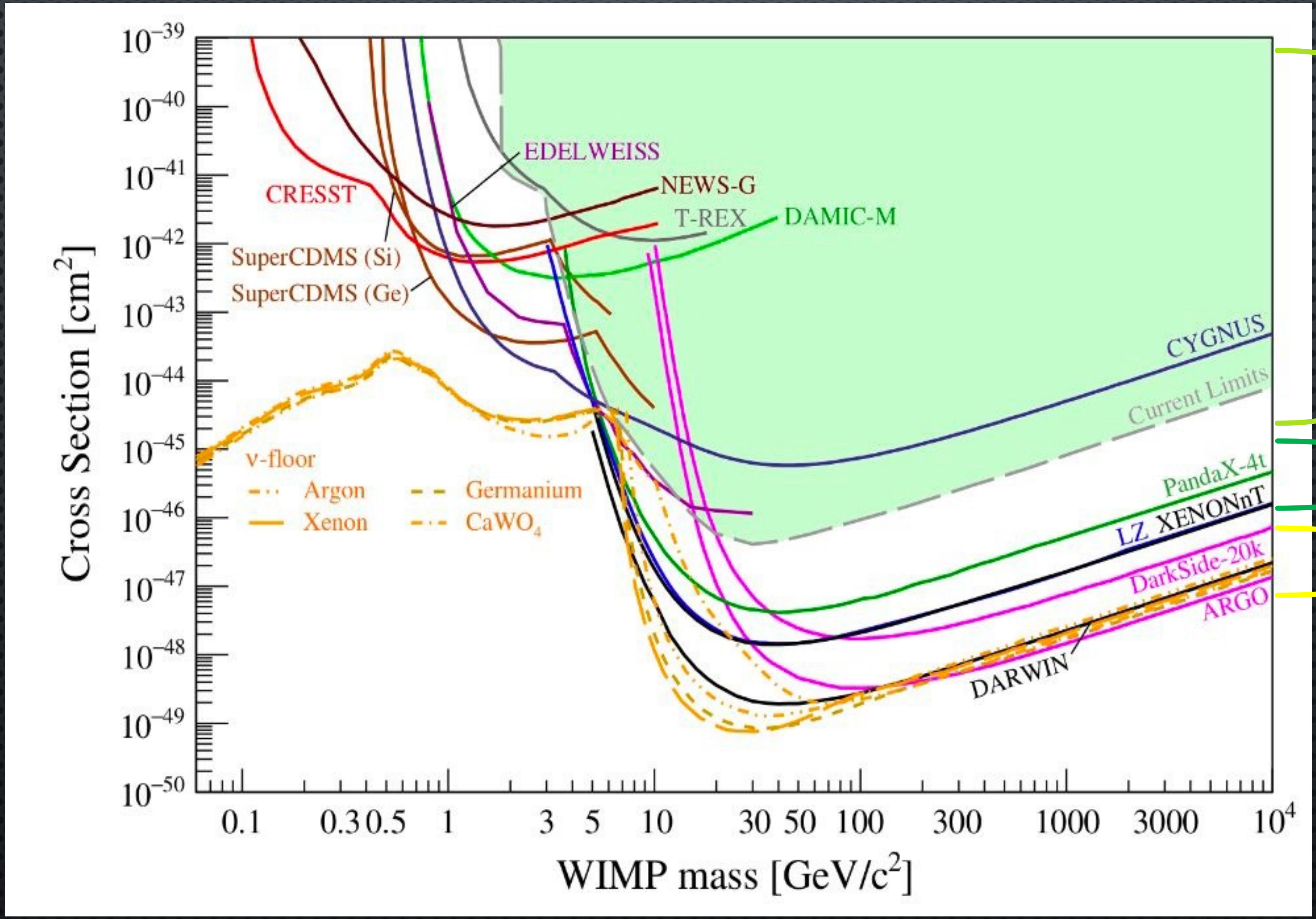
PHYSICS REACH



A Xenon Observatory with a broad science program

ULTIMATE WIMP SENSITIVITY

Ultimate sensitivity dominated by neutrino interactions



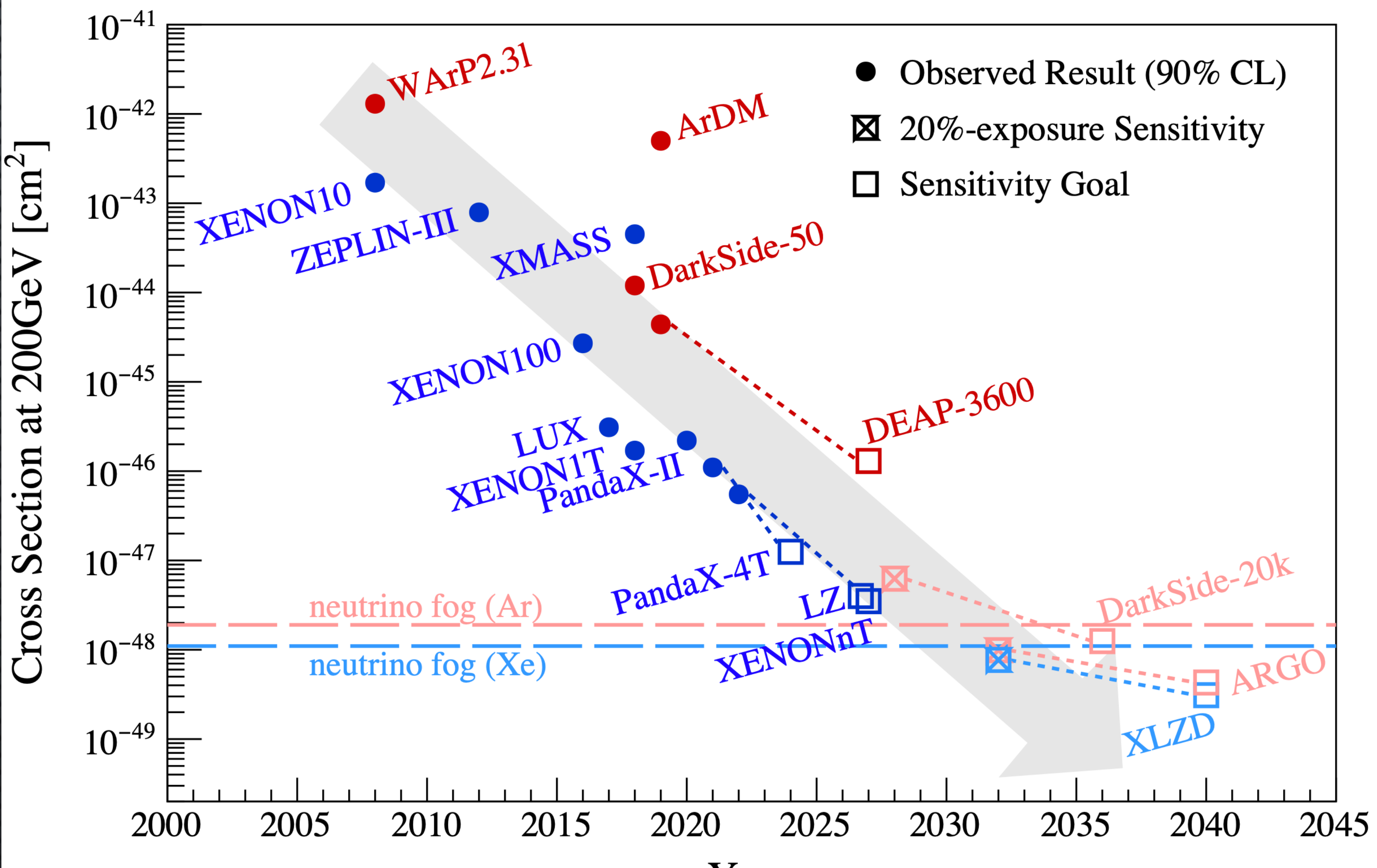
Past

Present

Future:
Darkside 20k
ARGO
DARWIN

Direct Detection of Dark Matter – APPEC Committee Report - arXiv:2104.07634v1

ULTIMATE WIMP SENSITIVITY



Snowmass Summary Chapter - arXiv 2209.07426

CONCLUSION & OUTLOOK

- LXe and LAr TPCs have demonstrated to be the leading technologies to exploit WIMPs searches at masses > 1 GeV / c^2
- Current generation of noble liquid TPCs recently presented first results and continue to take data over the coming years
- They proved to be sensitive to additional rare events too
- An effort is in place in both Xe and Ar communities towards big consortia (GADMC & XLZD) to build giant detectors aiming to explore the WIMP parameter space up to the neutrino fog + other rare events channels
- R&D and design of these next-generation detectors is ongoing