Experimental Dark Matter Search at Mass > 1 GeV

Maria Elena Monzani, SLAC/KIPAC

IDM - L'Aquila, July 10, 2024

Your Presenter at Gran Sasso Lab, circa 2002 (?)

...

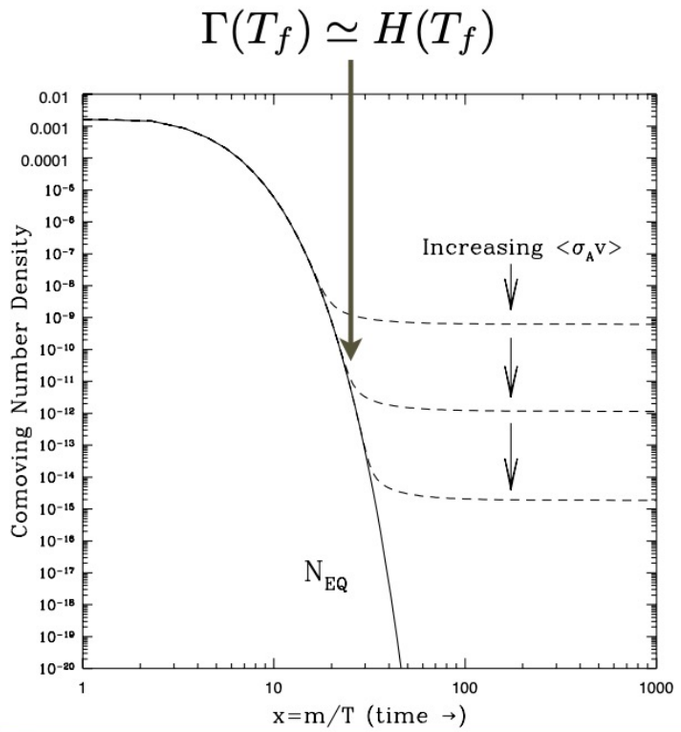
Thanks for Having me Back!!!

Recap: Direct Detection of WIMP Dark Matter

WIMPs as Thermal Relics

A trigger from naturalness versus the hierarchy problem, and thermal relic **WIMPs** as natural dark matter candidates.

Thermal relics directly coupled to the baryon/photon primordial bath: $\chi\,\bar{\chi} \leftrightarrow \mathrm{SM}\,\overline{\mathrm{SM}}$ (with SM is some lighter Standard Model state)



$$\Omega_\chi h^2 \simeq \frac{3 \cdot 10^{-27}\mathrm{cm}^{-3}\mathrm{s}^{-1}}{\langle \sigma_A v \rangle_{T=T_f}}$$

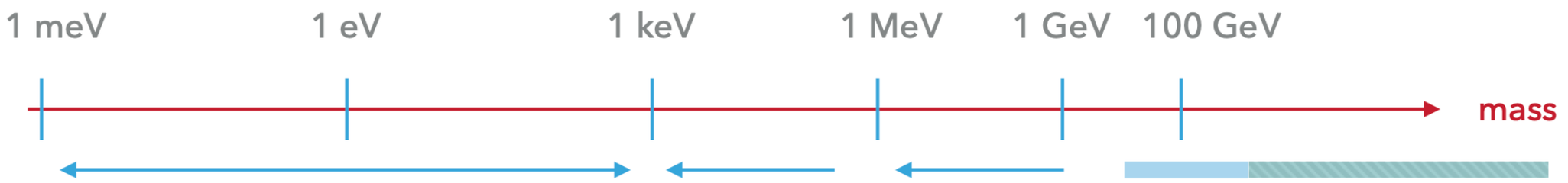
WIMP miracle: "fixed" DM pair annihilation cross section into "visible" particles.

A recipe that can work below about **100 TeV** (unitarity limit *[Griest & Kamionkowski 1990]*; in realistic models up to about 15 TeV) and gets inefficient below about **1 GeV**.

Experimental Panorama

L. Canonica

D. Baxter ⟼ ⟻ ⟼ This Talk ⟼



Absorption

Super-conductors

Dirac Materials

Polar Crystals

Superfluid Helium

Semiconductors

SuperCDMS

DAMIC, SENSEI

Graphene

Traditional WIMP

XENON1T

LZ

QCD axion, "ultralight frontier"

~meV energy resolution

Collective excitation

~eV energy resolution

Electron excitation

~keV energy resolution

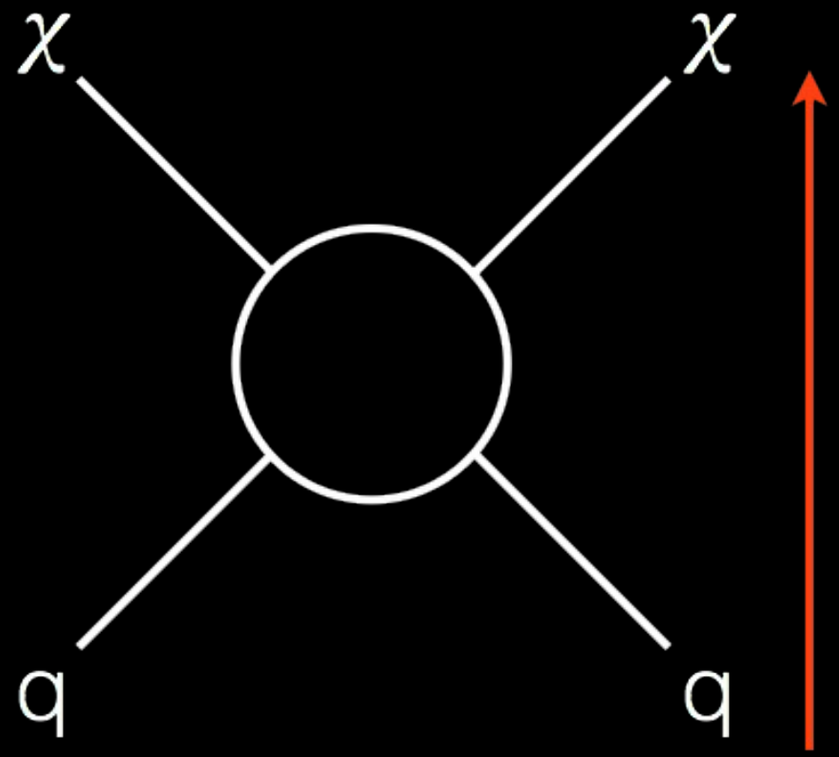
Nuclear recoil

[Zurek, UCLA Dark Matter 2023]

Three Ways to Look for WIMPs

Annihilation

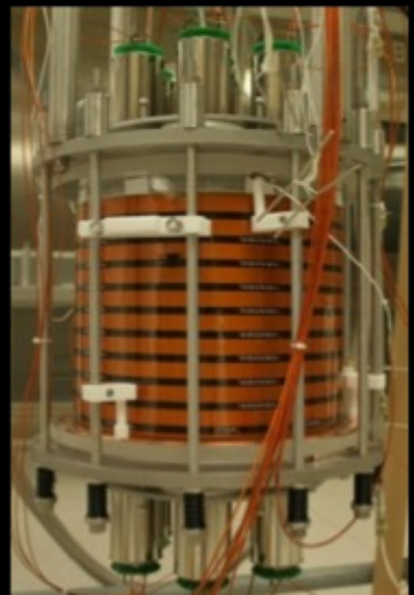
Indirect Detection



Production

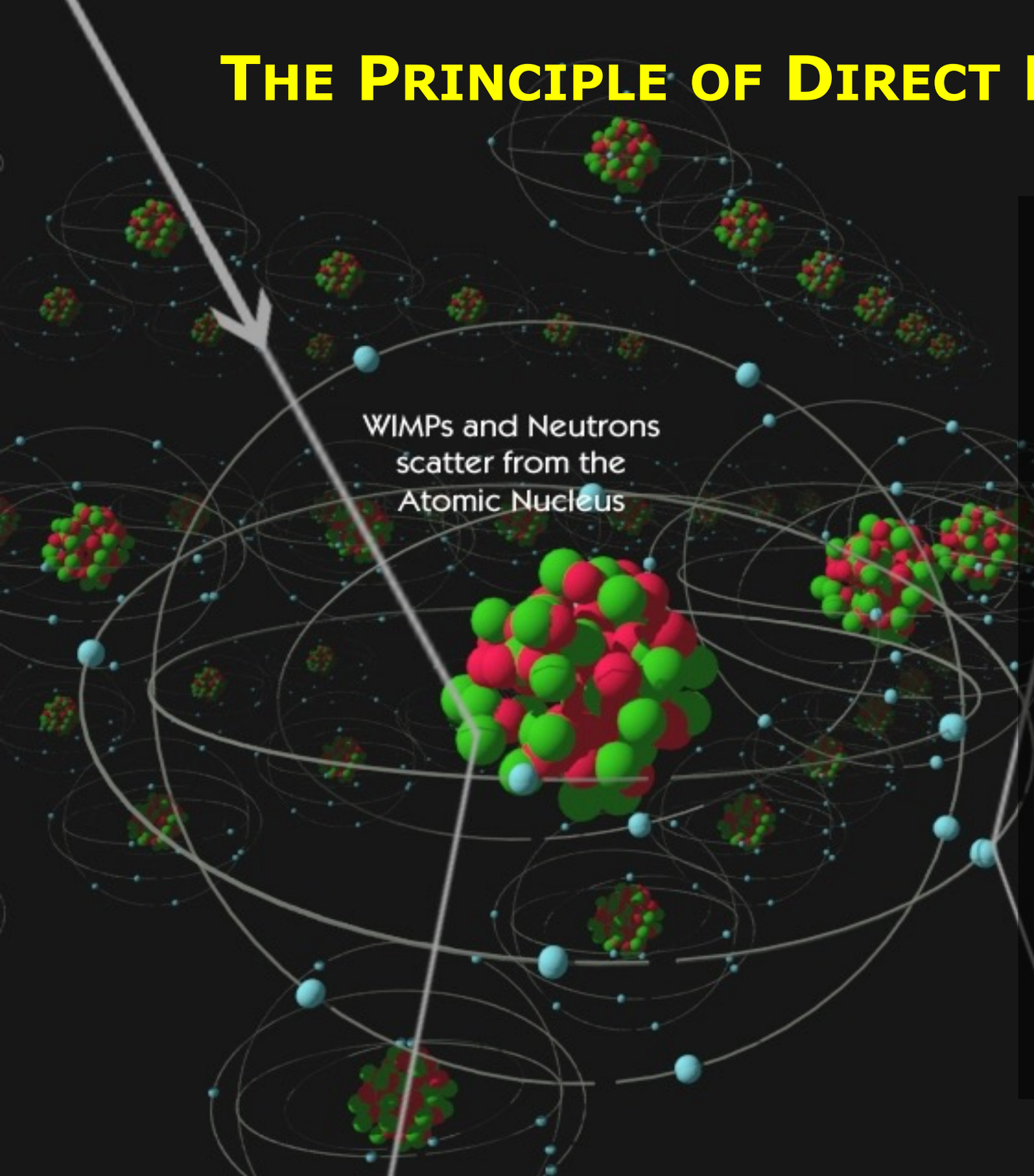
Colliders

Scattering



Direct Detection

The Principle of Direct Detection

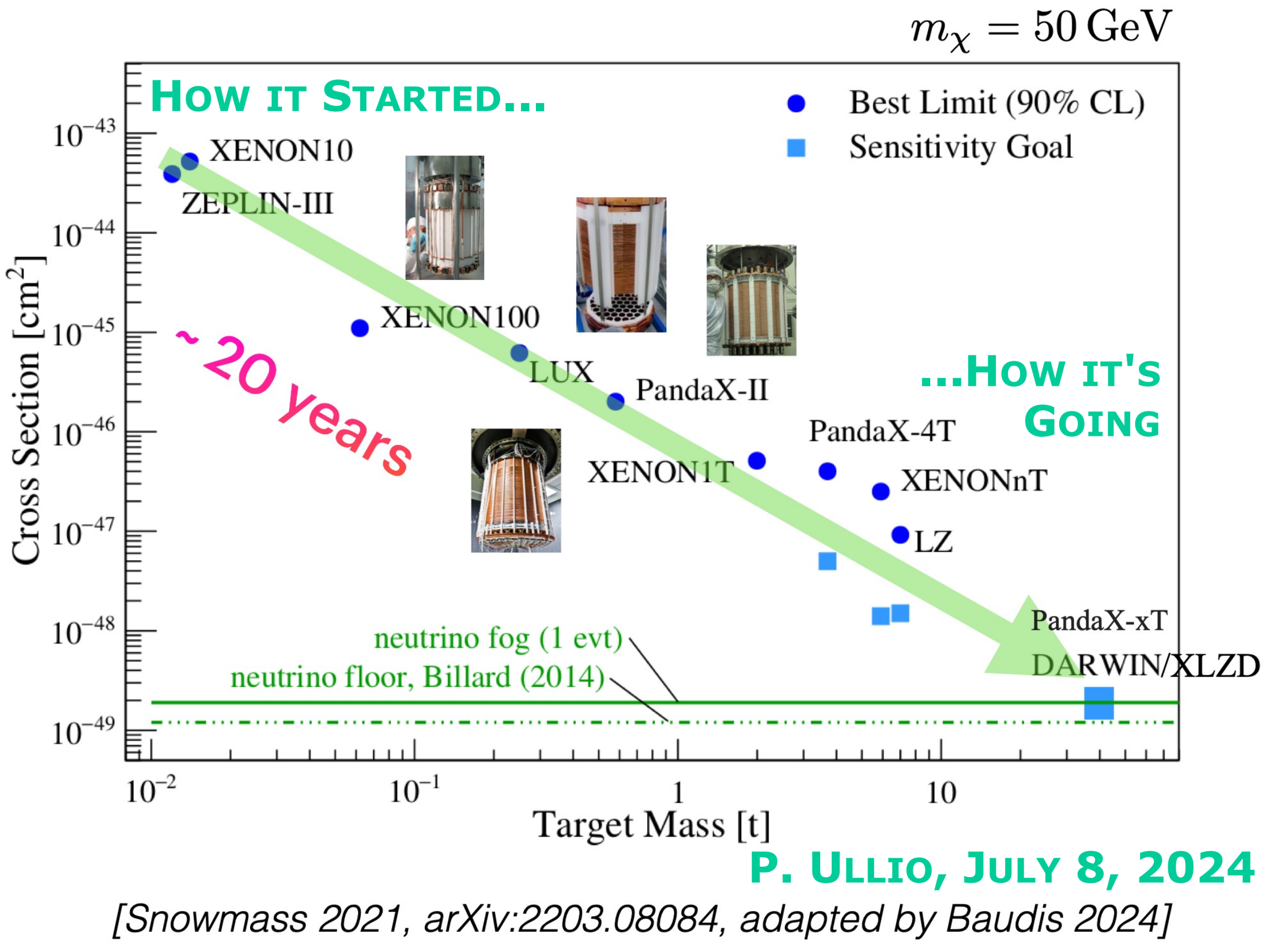


Build A Massive Tank (or Tower) of Nuclei

"Hide" it Deep Underground

Wait for WIMPs to Hit the Nuclei

Look for Recoils from Nuclei that have been Bumped by a WIMP



P. Ullio, July 8, 2024

[Snowmass 2021, arXiv:2203.08084, adapted by Baudis 2024]

The Search for WIMP DM in the Noble Liquids Era

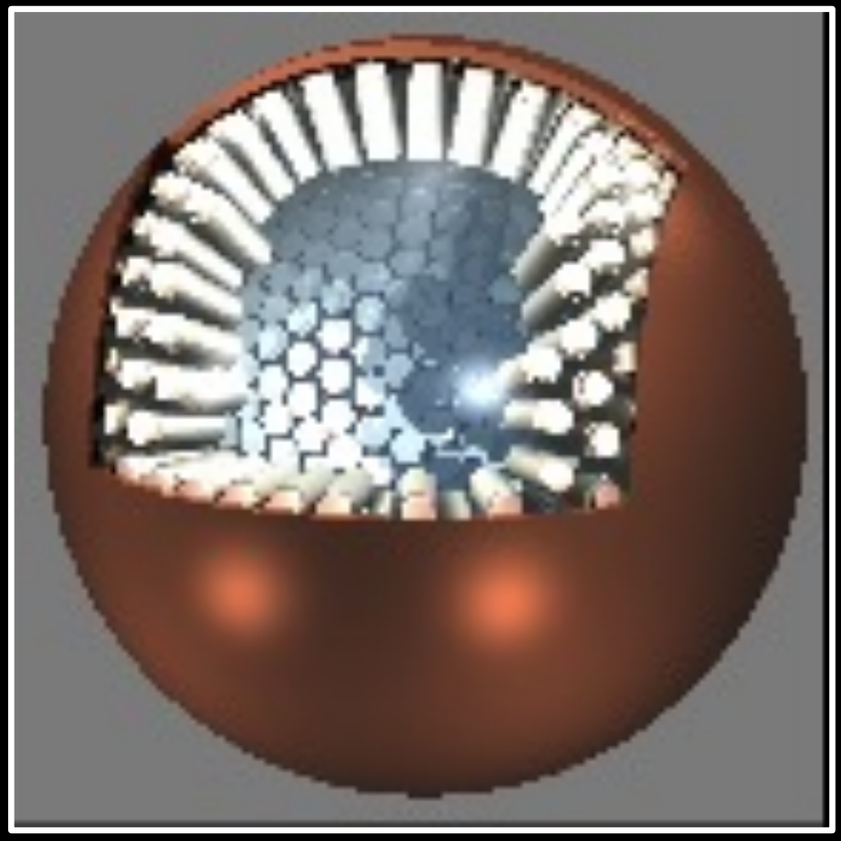
Why noble Liquids?

- Kinematic Matching to WIMPs
- Lots of Nucleons per Atom
- Transparent to their own Light

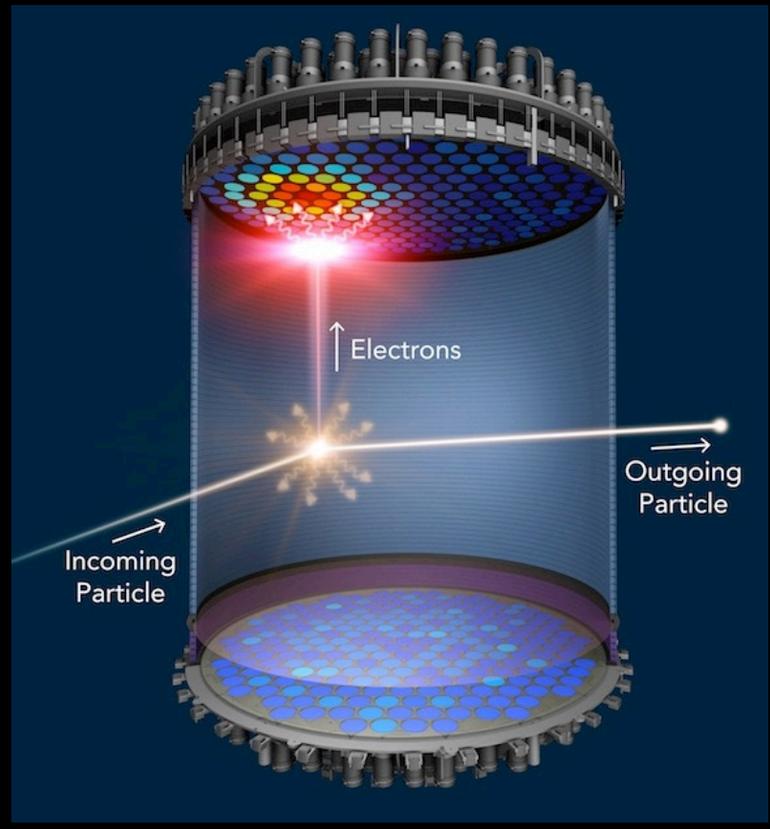
Why noble Liquids?

- Kinematic Matching to WIMPs
- Lots of Nucleons per Atom
- Transparent to their own Light
- Very Dense (Self-Shielding)
- Background Rejection (Charge/Light)
- Liquid: can be Purified in a Loop
- "Easy" to Make a Larger Detector

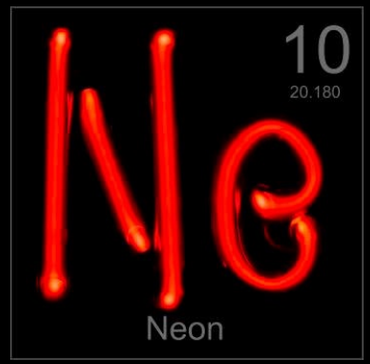
Single Phase vs Dual Phase



4π Scintillation



Time Projection Chamber (TPC)



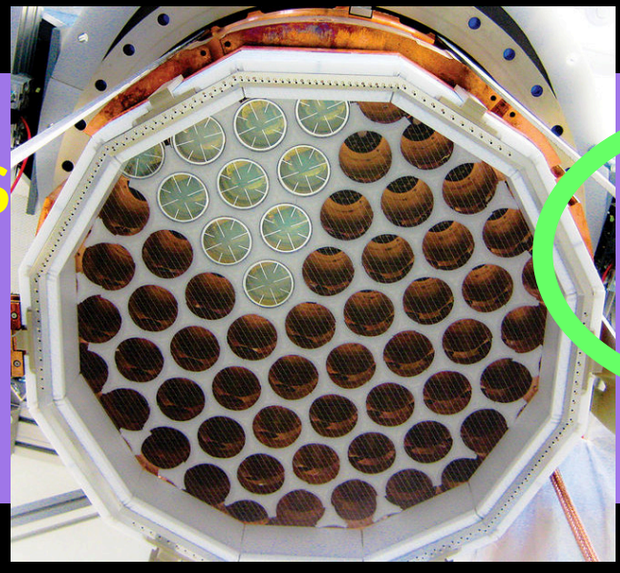
Single Phase

Dual Phase

DEAP
MiniClean

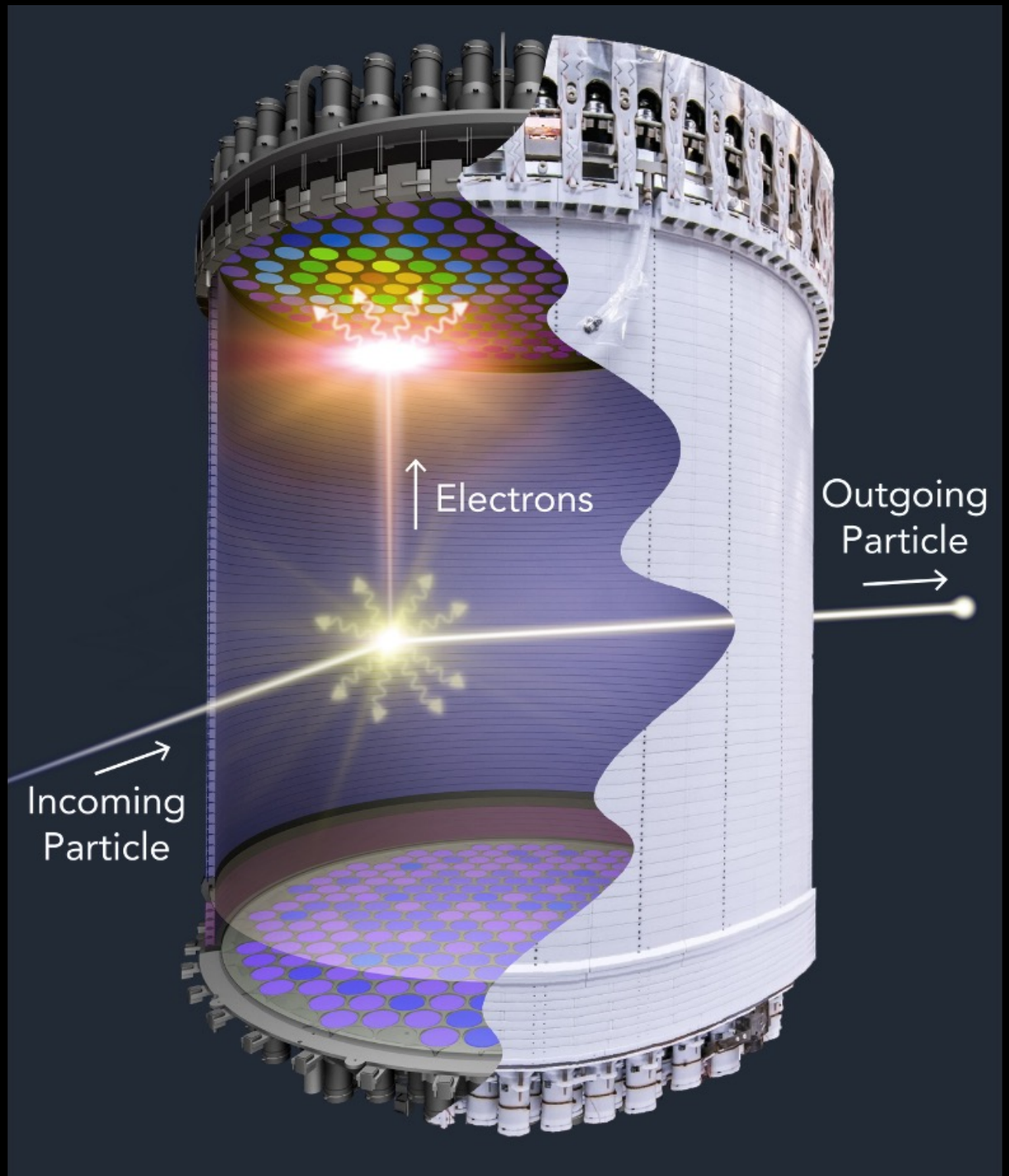
DarkSide
ARGO

XMASS

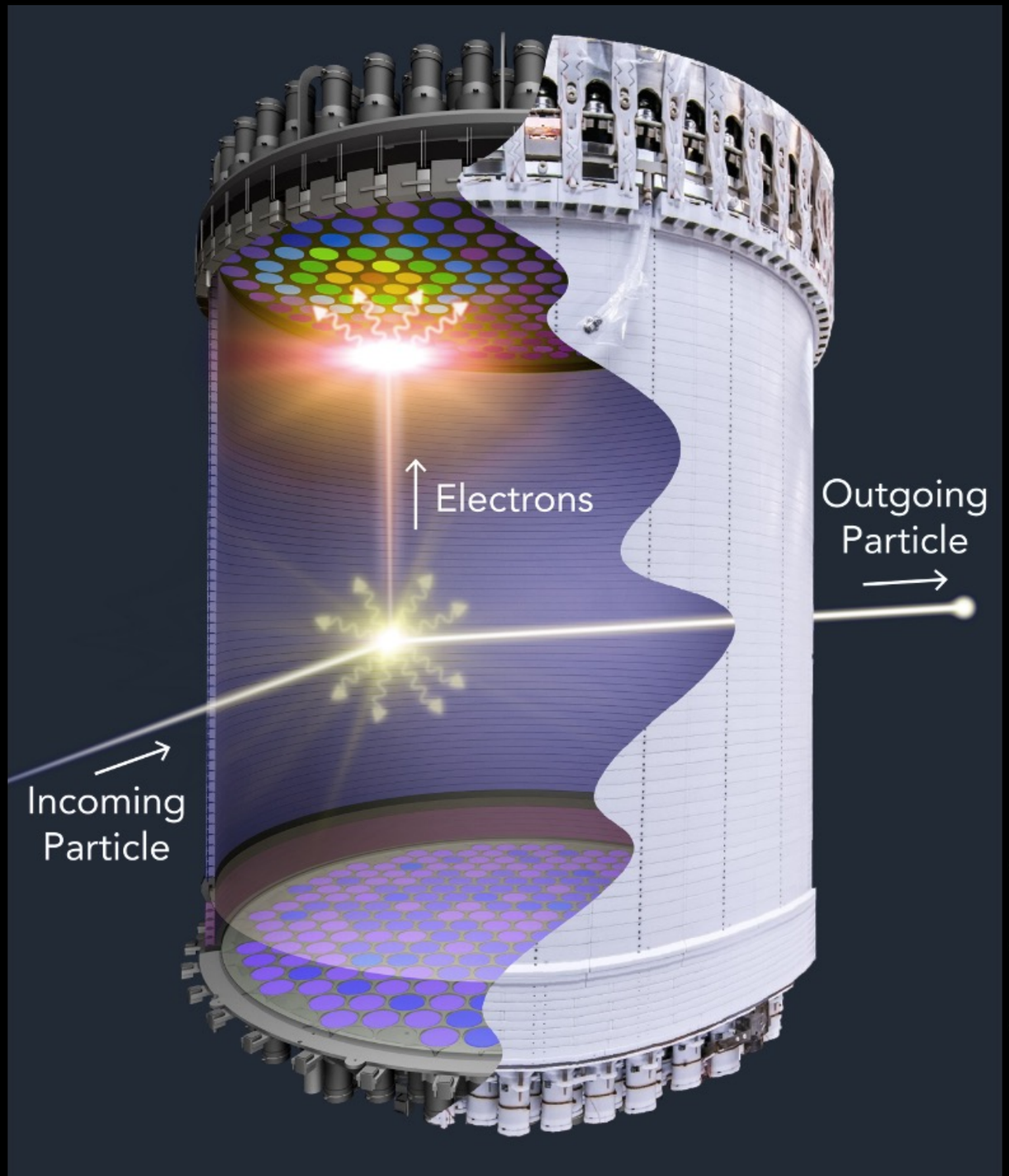


LUX/LZ
XENONnT
Panda-4X

(Dual Phase) Noble Liquid TPC



(Dual Phase) Noble Liquid TPC

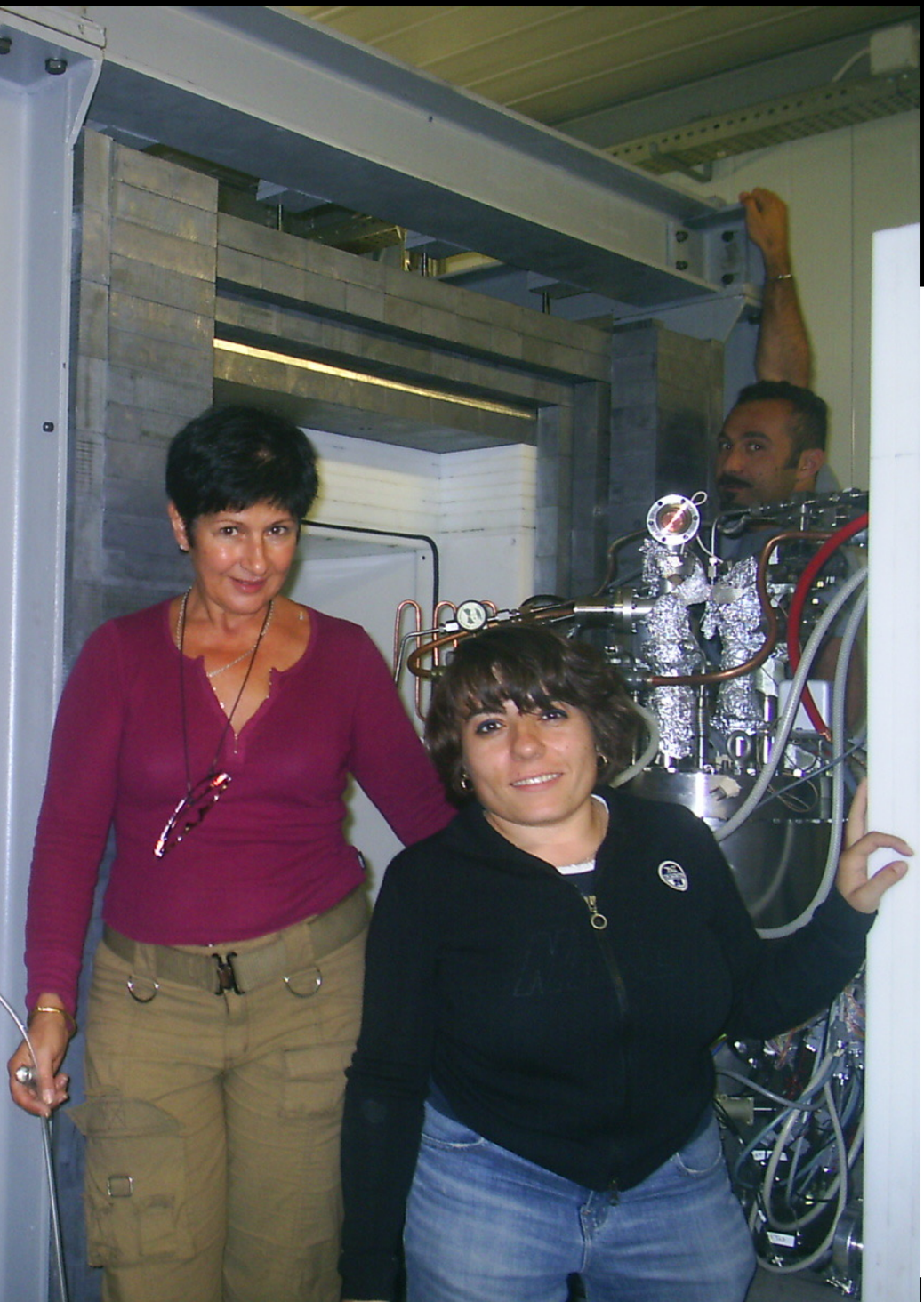


- WIMP-induced nuclear recoils: ~ few keV energy
  - S1, S2 → event energy
  - S2 image → xy coordinate
  - S1-S2 timing → z coord.
  - S2/S1 (Xe) → recoil type
  - S1 PSD (Ar) → recoil type

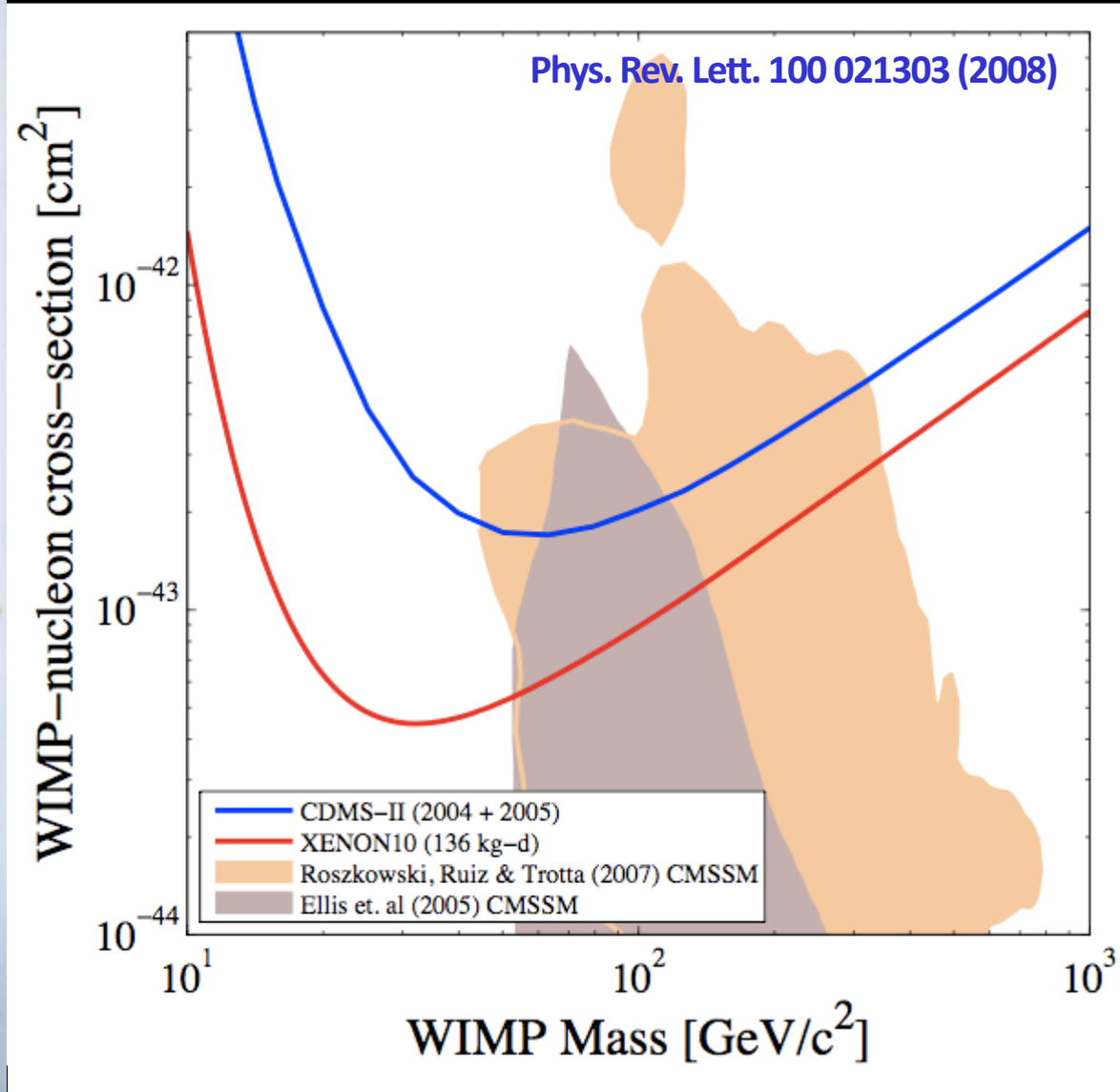
- No long-lived isotopes (Xe)
- Self-shielding
- Recoil discrimination

The Xenon10 Experiment at Gran Sasso

The XENON10 Experiment at Gran Sasso



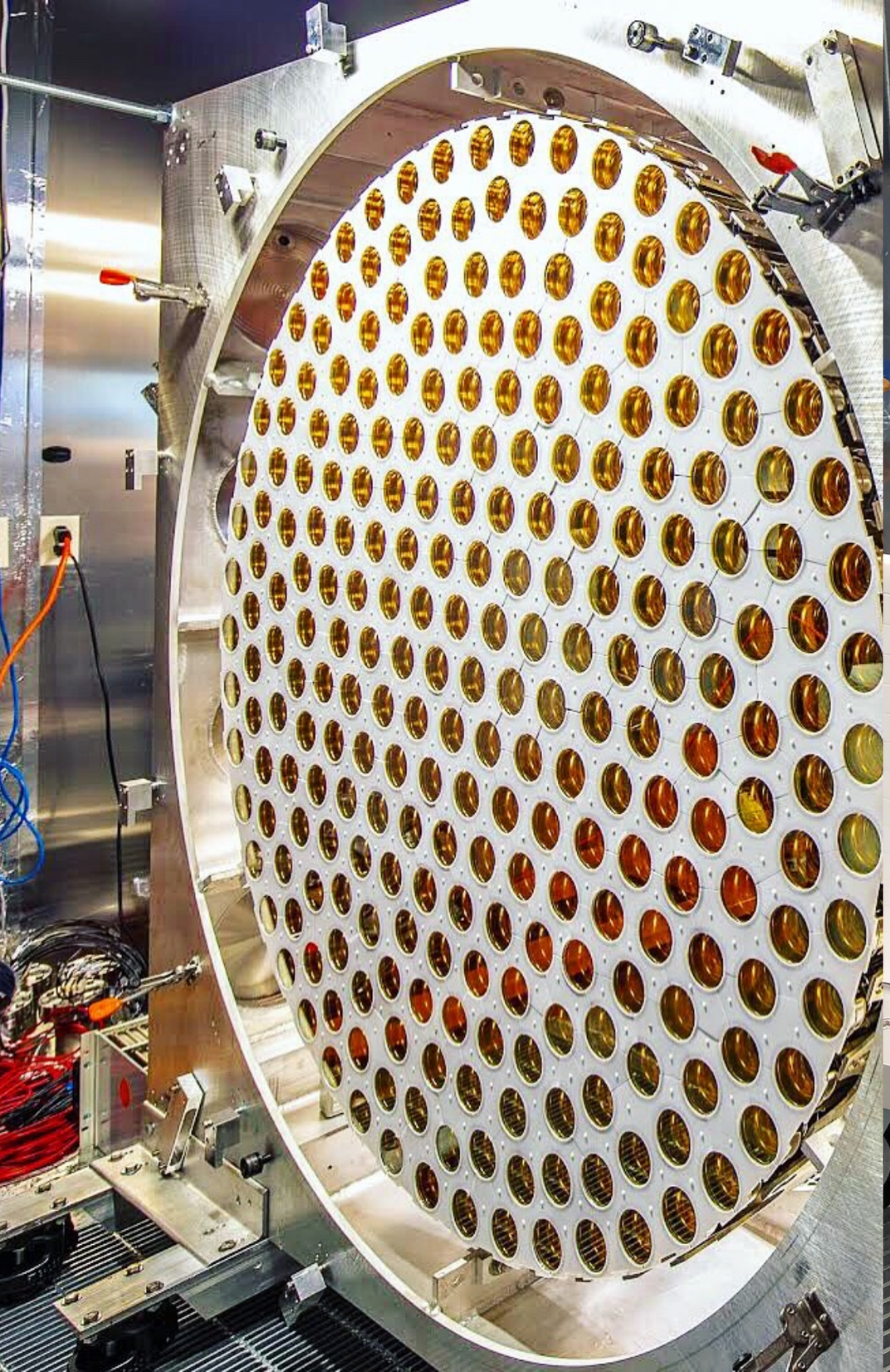
- Operated in 2006-2007
- 15 kg Liquid Xenon target
- $\sigma < 4.5 \cdot 10^{-44}$ cm^2 @30 GeV

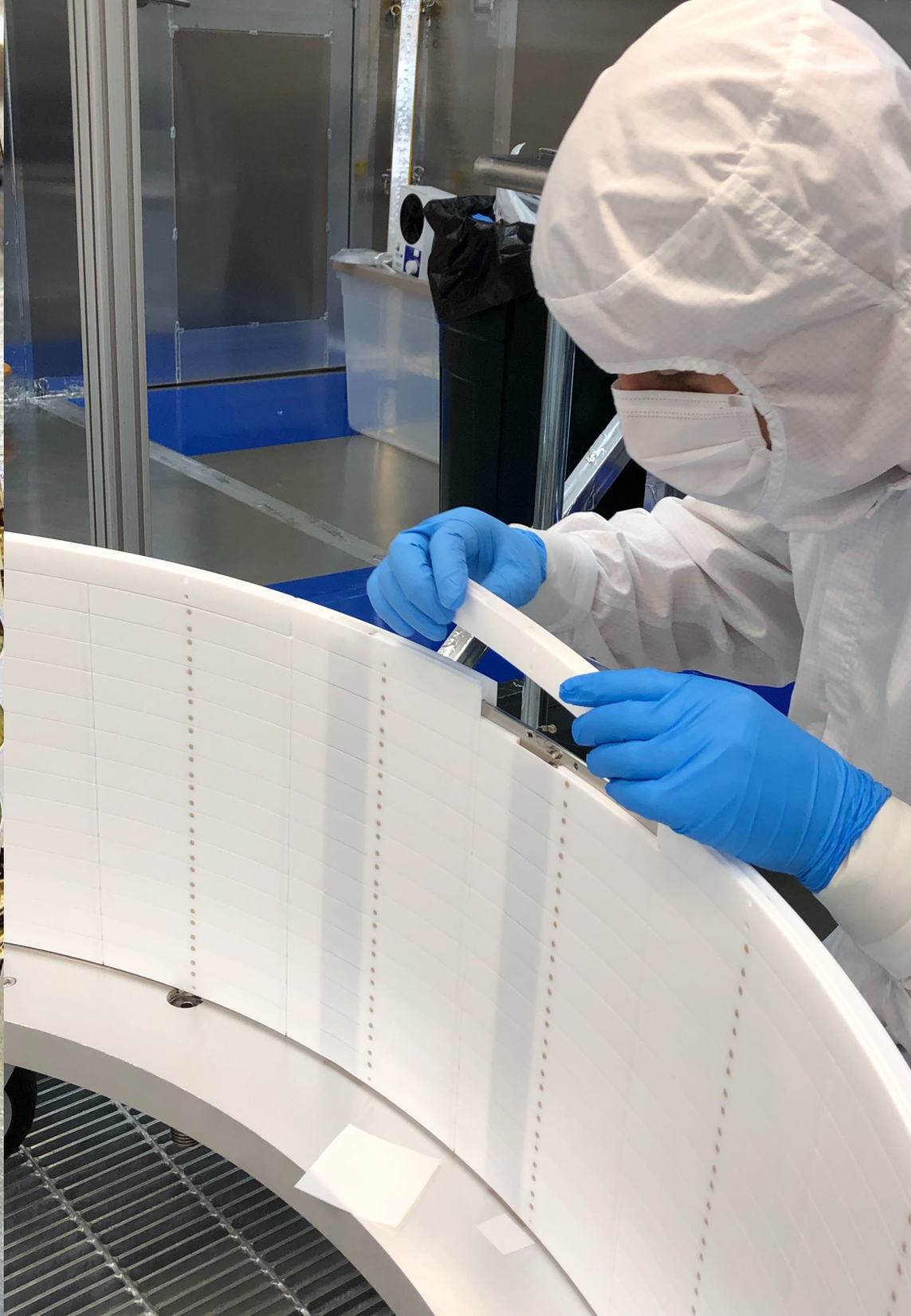


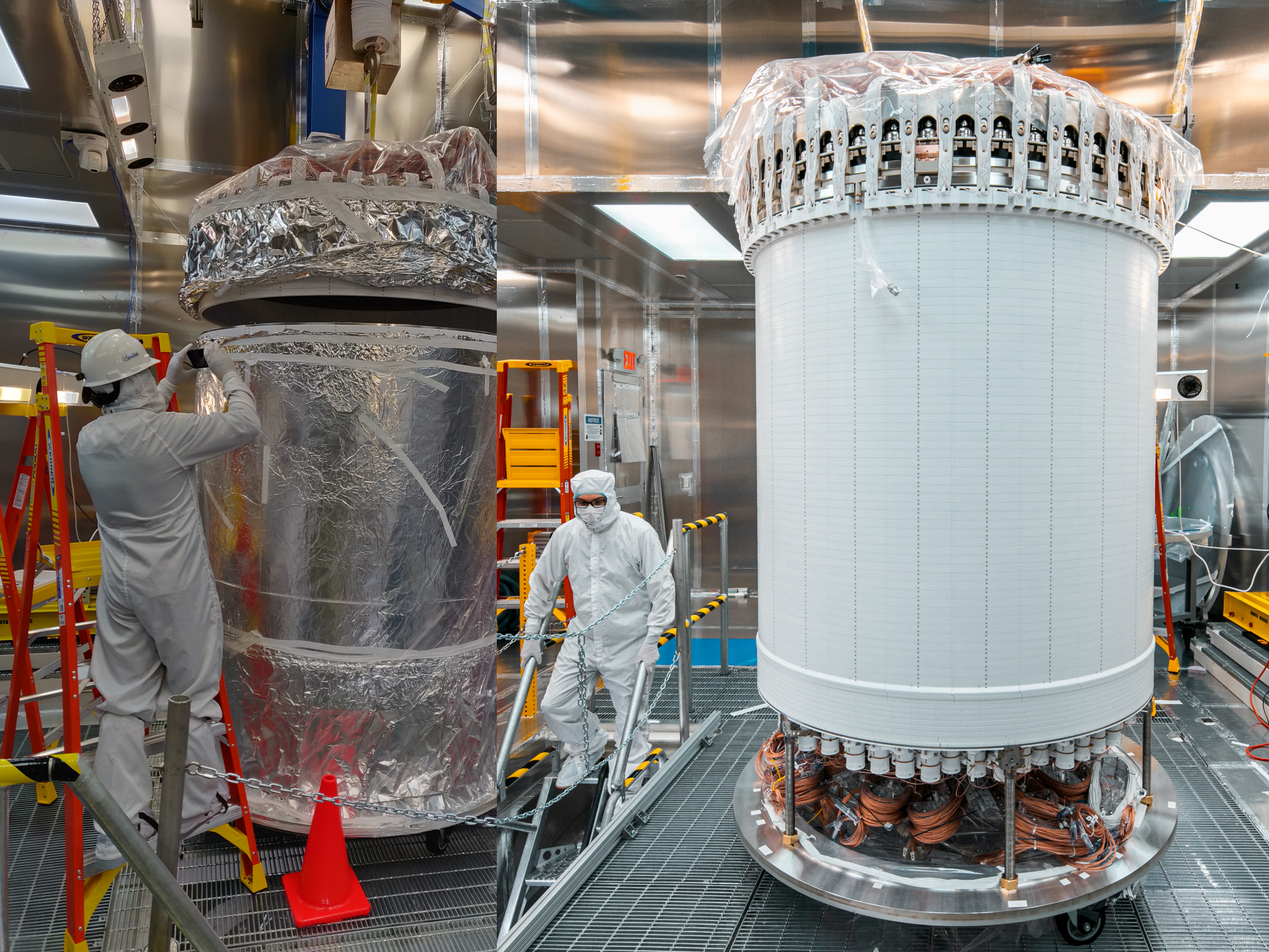

2006
2019

How to Build a 10-Ton LXe TPC


PHOTOSENSORS

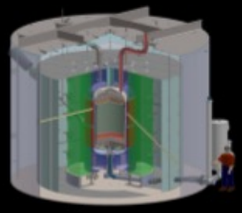





EXIT
NOTICE


HOMESTAKE

LZ Construction & Data Taking Timeline

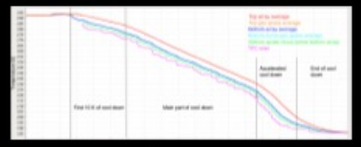


CD3 and TDR

TPC Complete

Underground

Cold GXe



Science Running!

MDC1

MDC2

MDC3

2017

2018

2019

2020

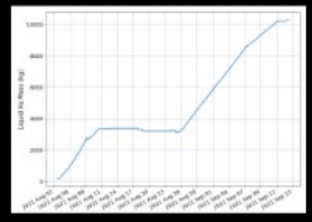
2021

2022

Cryostat arrives

Sealed Up

LXe fill



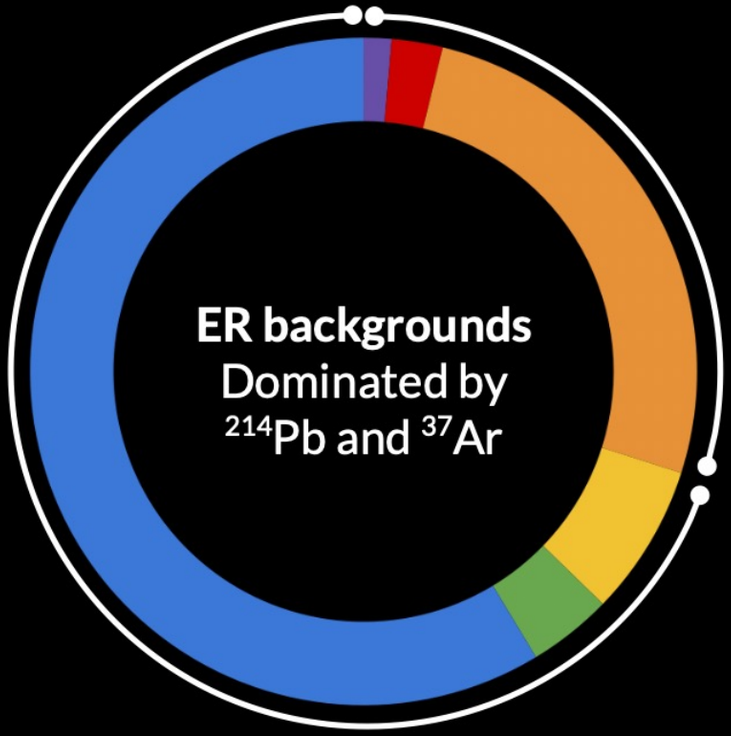
First results!

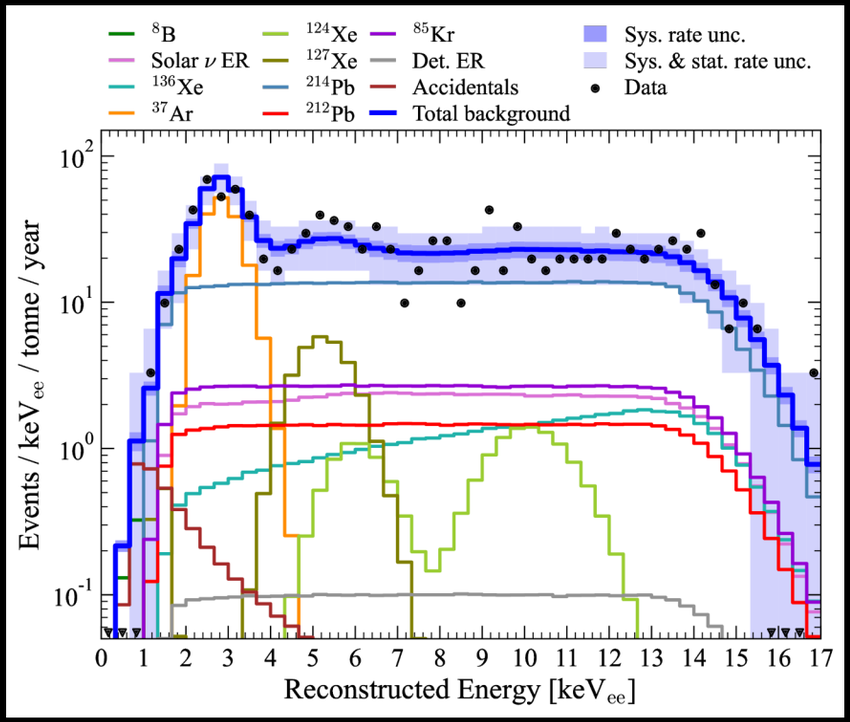
Enabled by an Extensive Campaign of Mock Data Challenges (MDC)

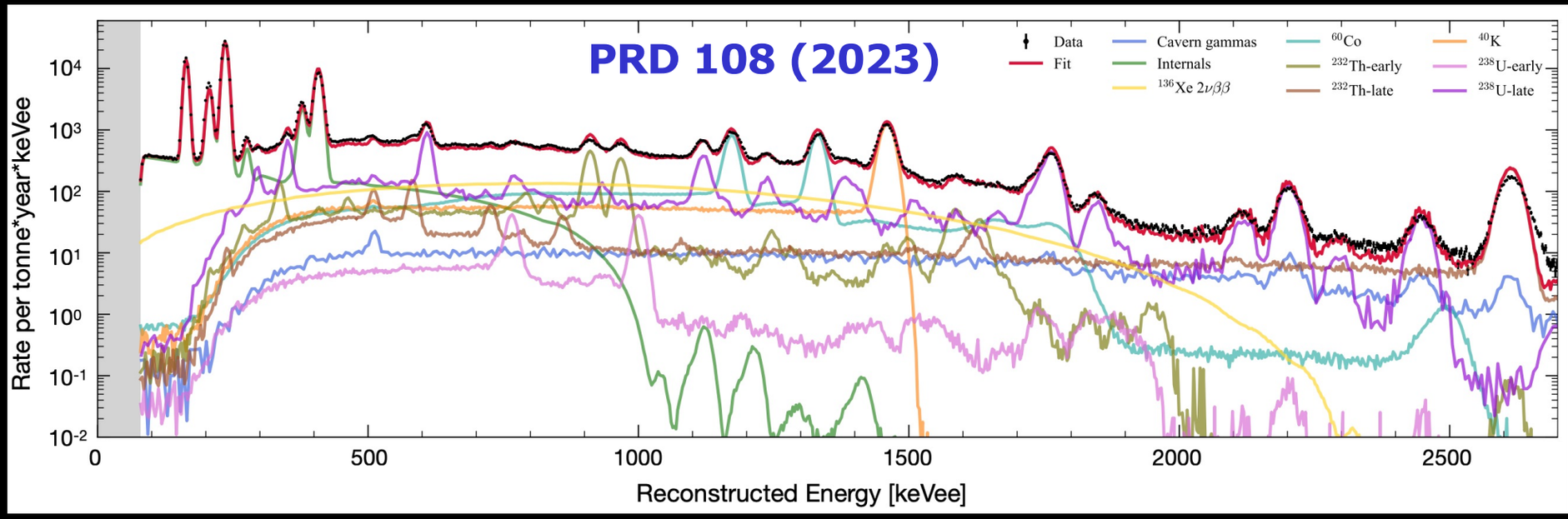
Searching for WIMPs with Supercomputers

- Automatic 24/7 Processing of all Detector Data
- Large-Scale Simulations with Detailed Modeling
- Extensive Campaign(x3) of Mock Data Challenges

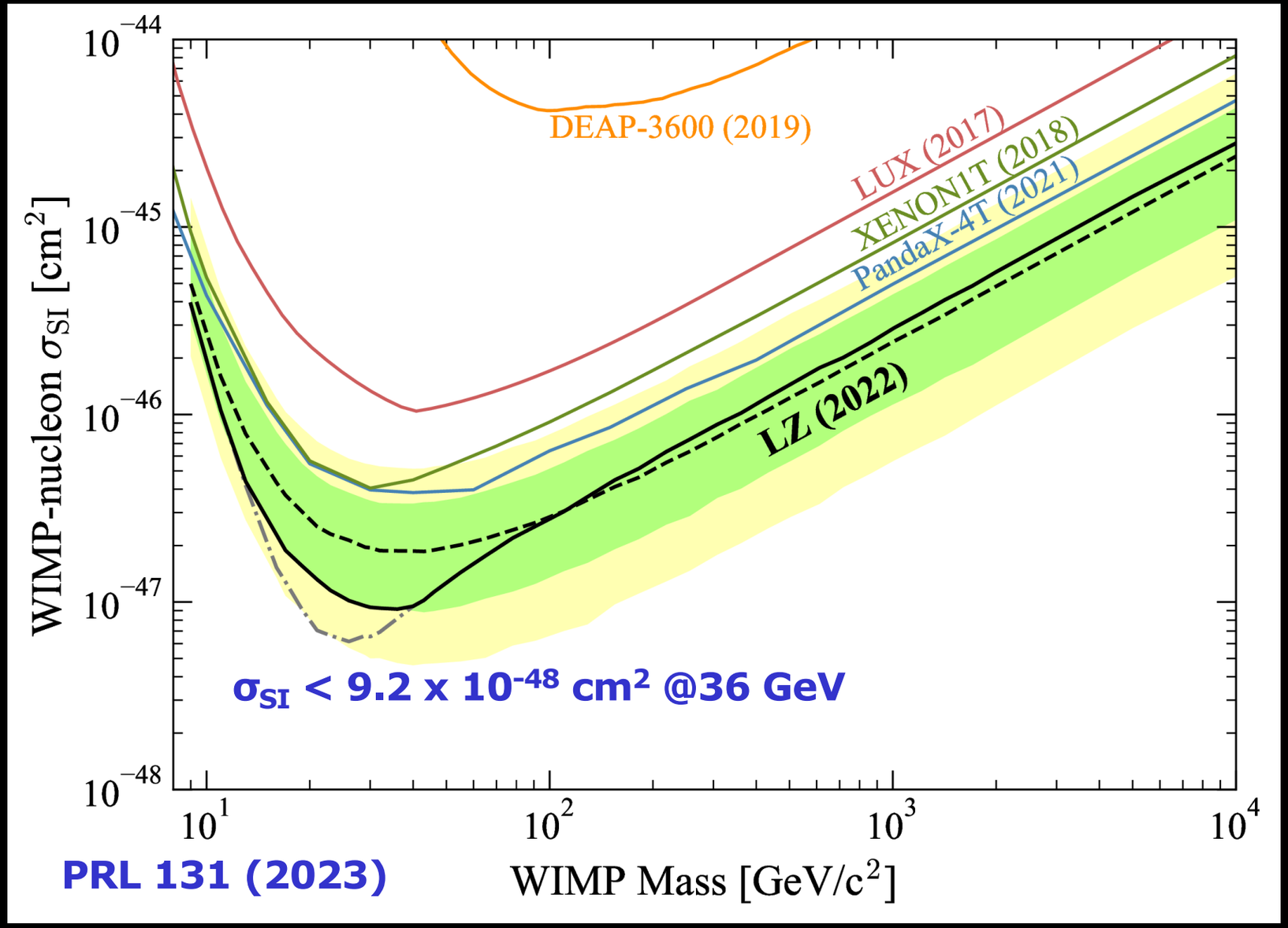
Extremely Detailed Background Model







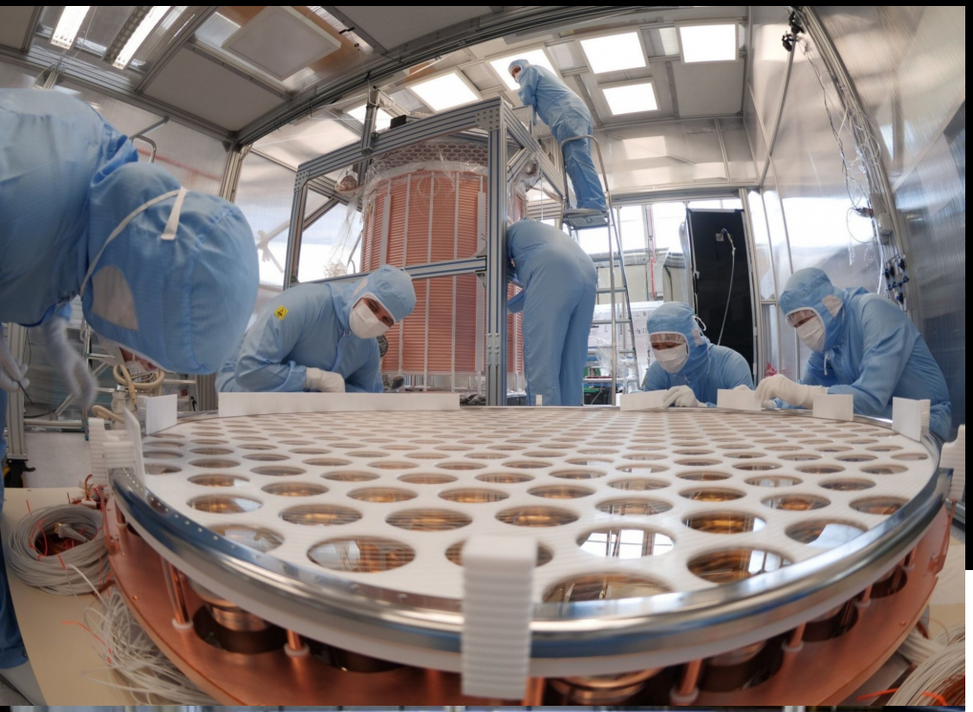
World Record WIMP Sensitivity (SI, 2022)



PRL 131 (2023)

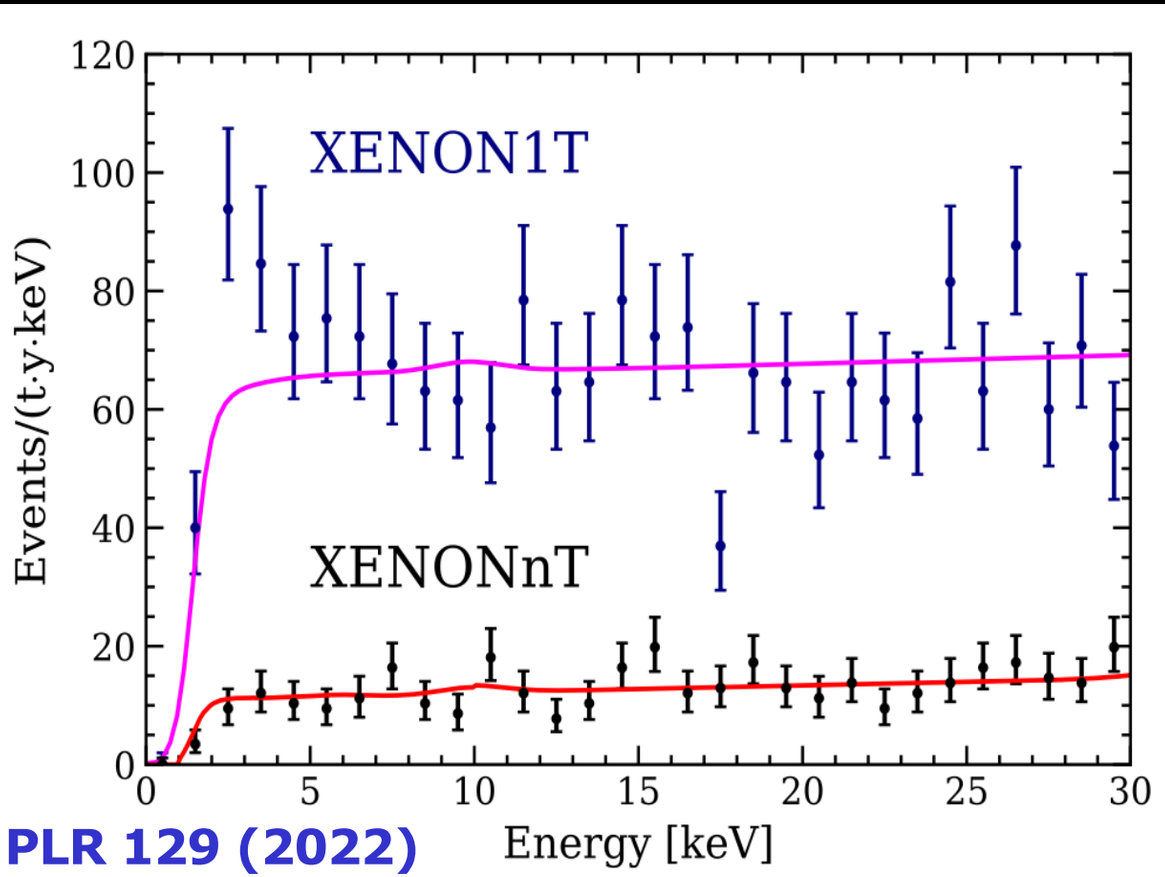
See also: Olcina, Uson, Dey, Green, Swain

XENONnT at Gran Sasso (2020+)



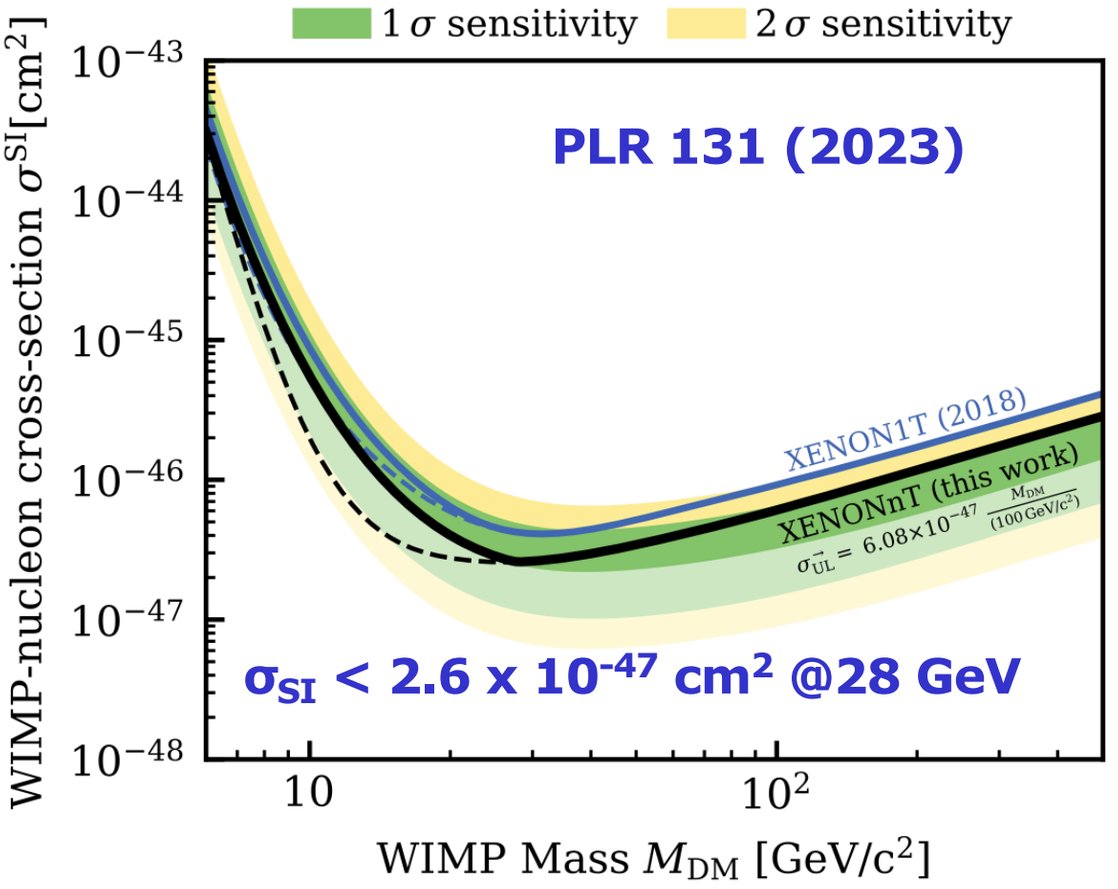
Initial results with 97.1 live days (2022)

- 6.9 tons active LXe volume
- 5x bckg reduction wrt Xenon-1T
- Unfortunately ER excess ruled out
- No axions this time around 😭



PLR 129 (2022)

XENONnT at Gran Sasso (2020+)

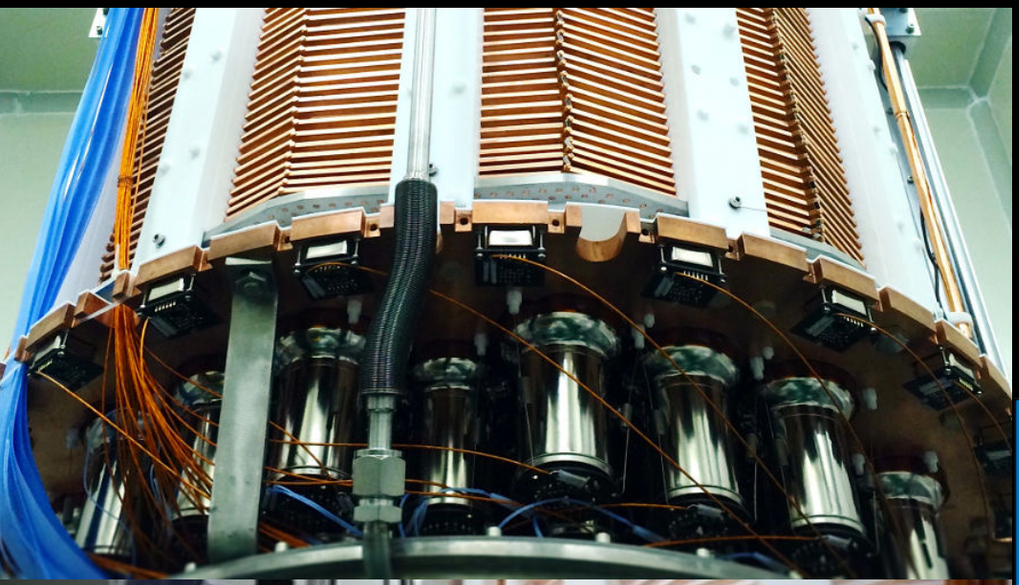


See also: Eißing, Liu, Selvi, Gao, Ferrari

New results from XENONnT

Palazzo dell'Emiciclo, Sala Ipogea

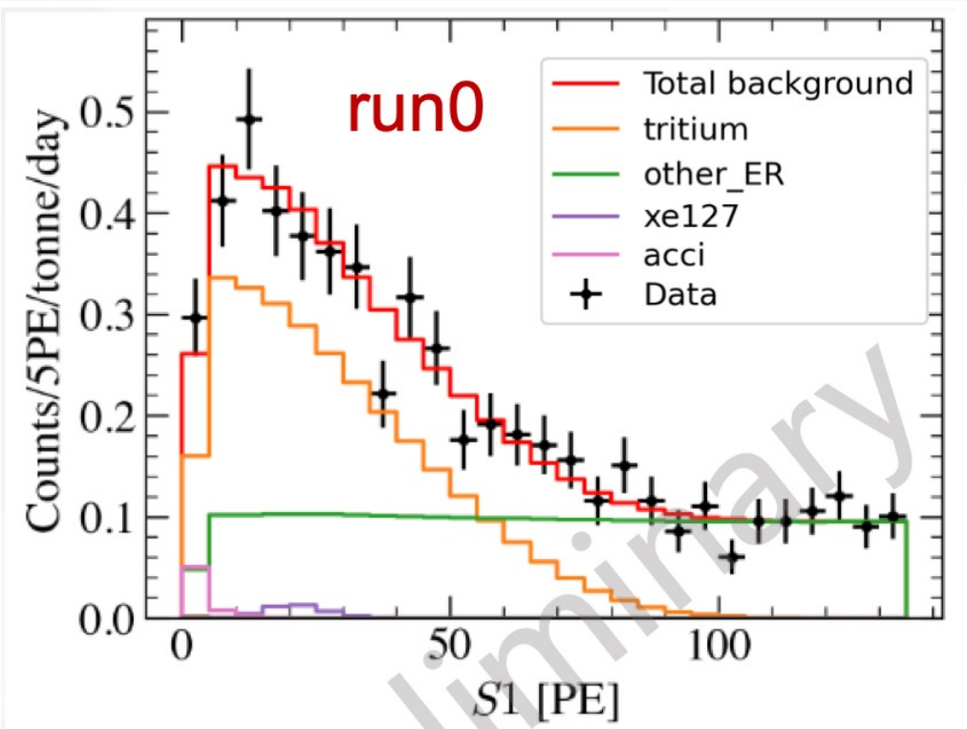
PandaX-4T at Jinping Lab (2020+)

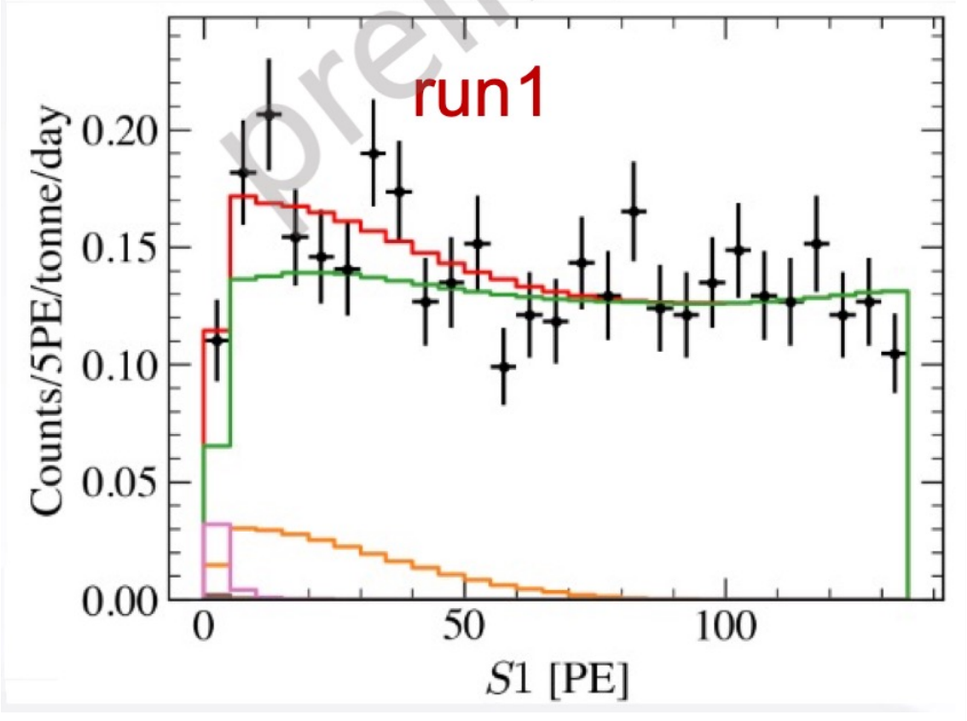


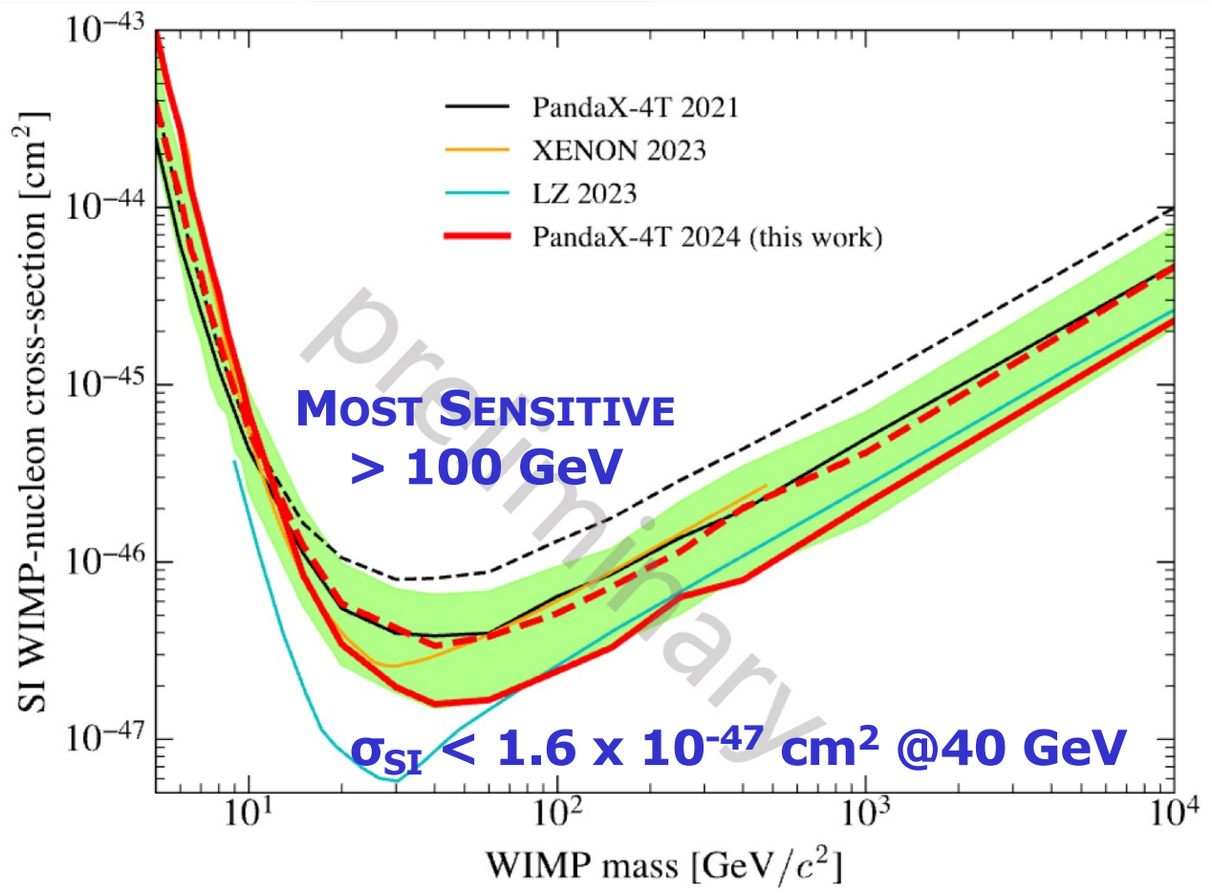
- Jinping Lab (China), 6800'
- Deepest underground lab on 🌍
- 3.7 tons active LXe volume

2020/11 – 2021/04	**Commissioning (Run 0)** 95 days
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run 1)** 164 days NEW!!! 🎉
2022/09 – 2023/12	**CJPL B2 hall renovation** xenon recuperation, detector upgrade
Current Status	**Resuming physics data-taking**

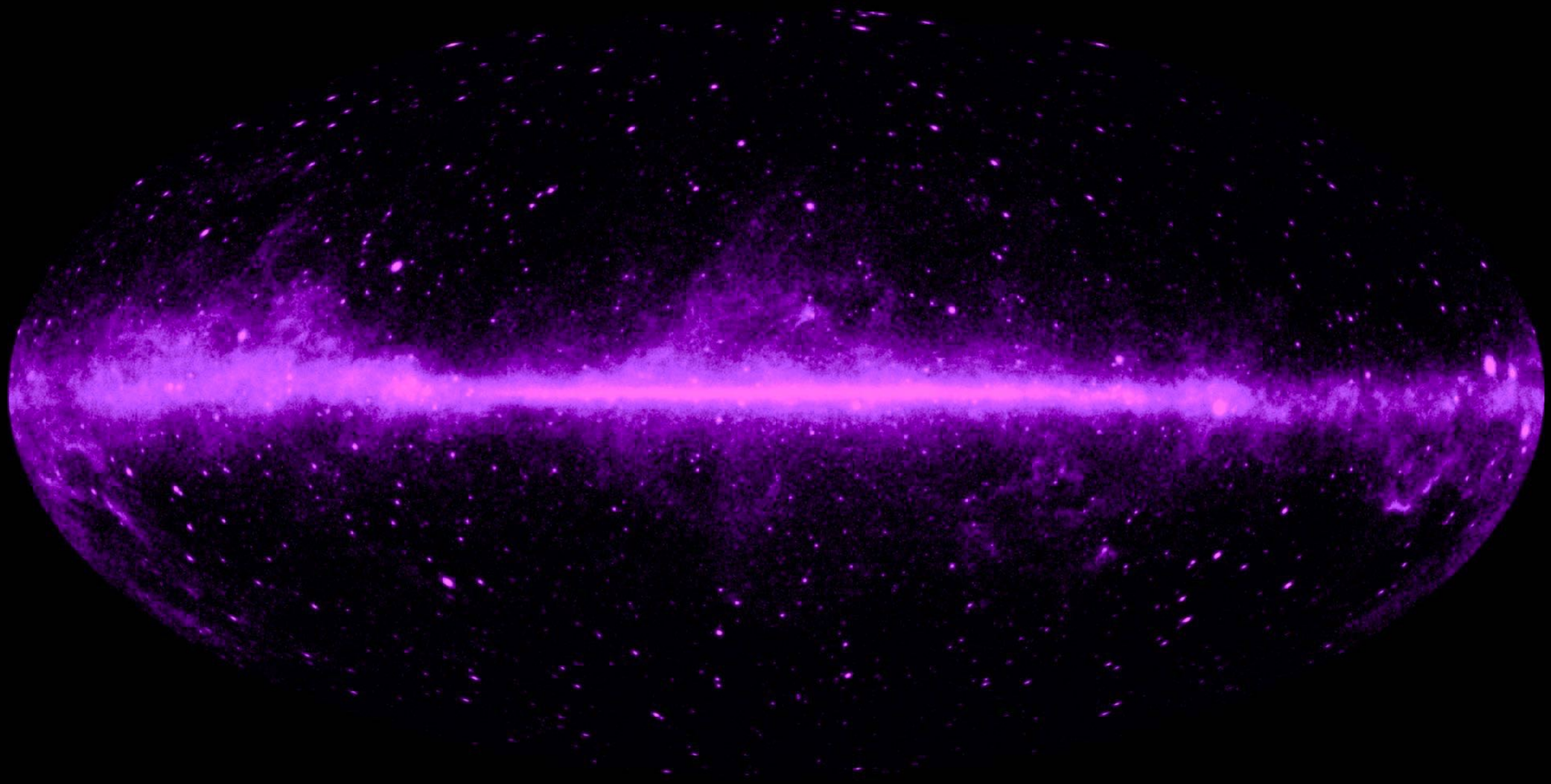
PandaX-4T at Jinping Lab (2020+)







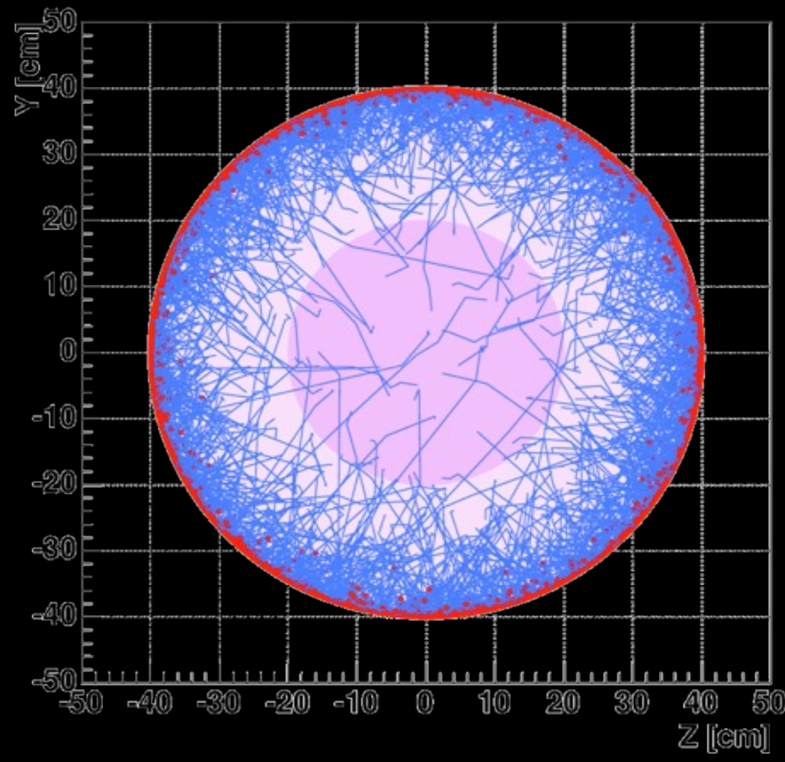
See also: Lin and Li

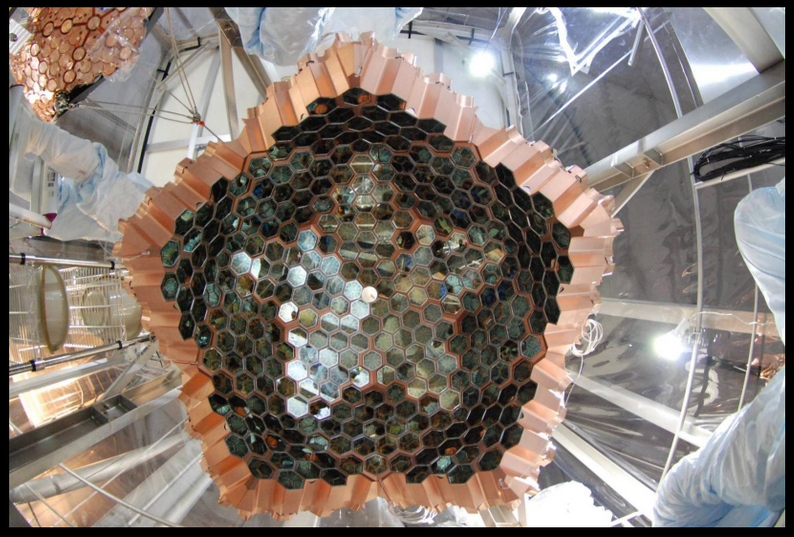


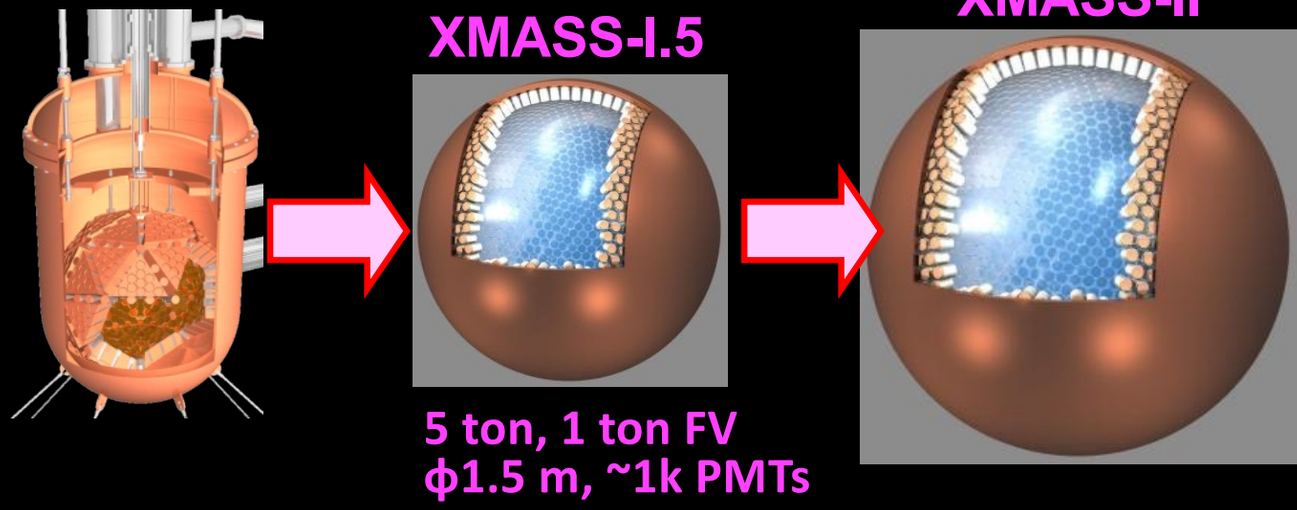
"Other" Techniques: Single Phase & LAr

Single phase Xe: XMASS @Kamioka

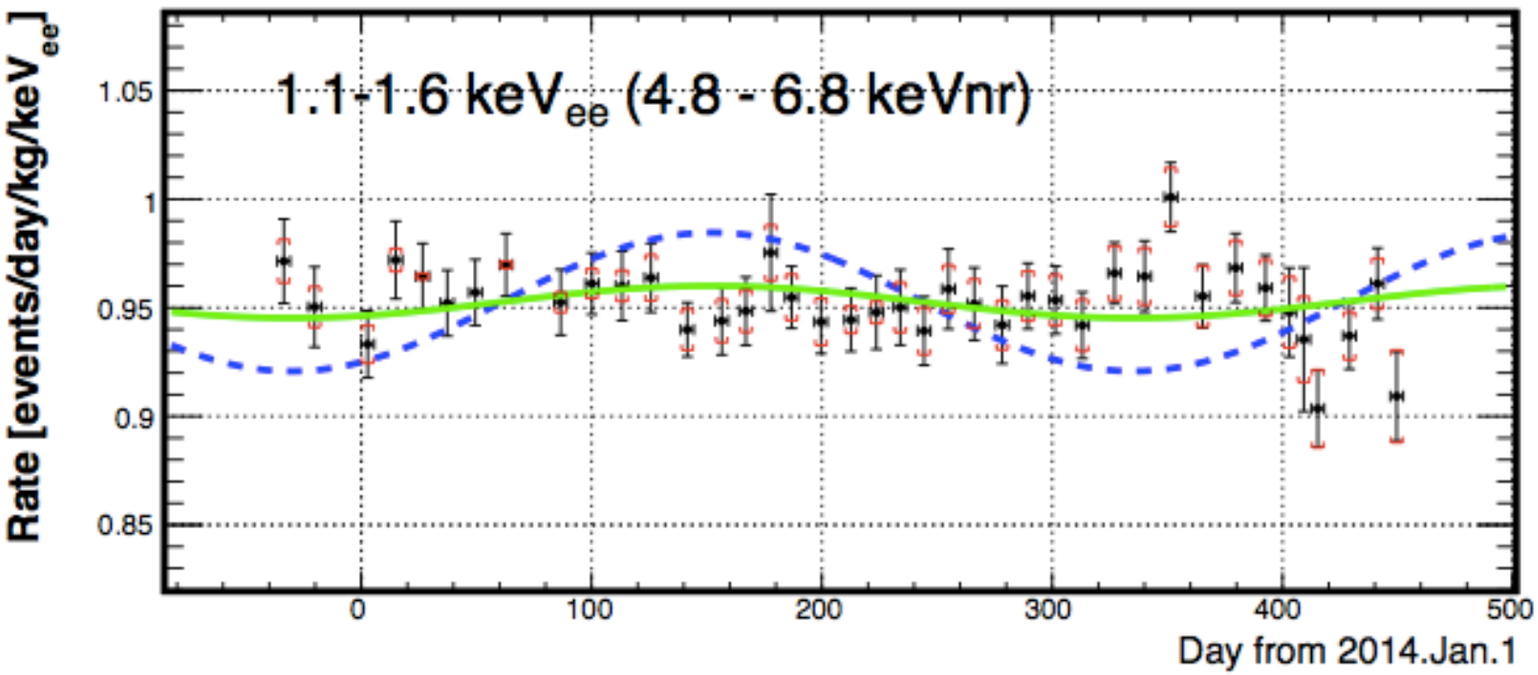
- XMASS-I: 835 kg / 642 PMTs
- Simple concept, good light collection
  - 14 pe/keVee
- Position reconstruction/self-shielding
- Surface Rn-backgrounds crucial
  - 10x lower than LUX, XENON-100
- 40 kg fiducial at 40 keV threshold







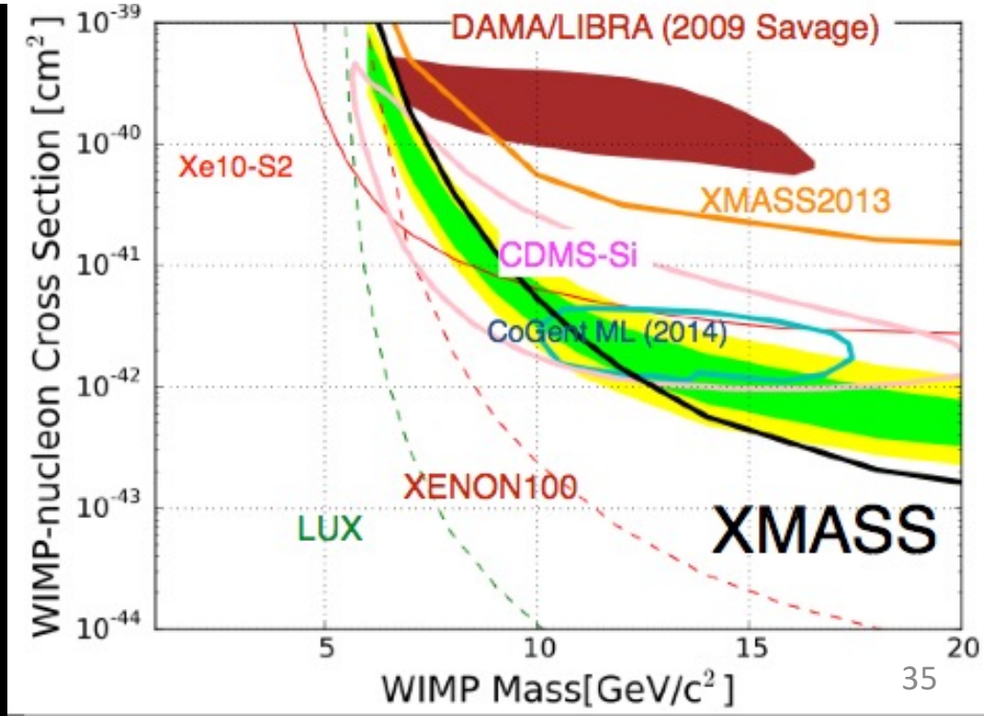
XMASS: Annual Modulation Searches



- 7 GeV/c^2 x10^{-40} cm^2
- 8 GeV/c^{2}x10^{-40} cm^2

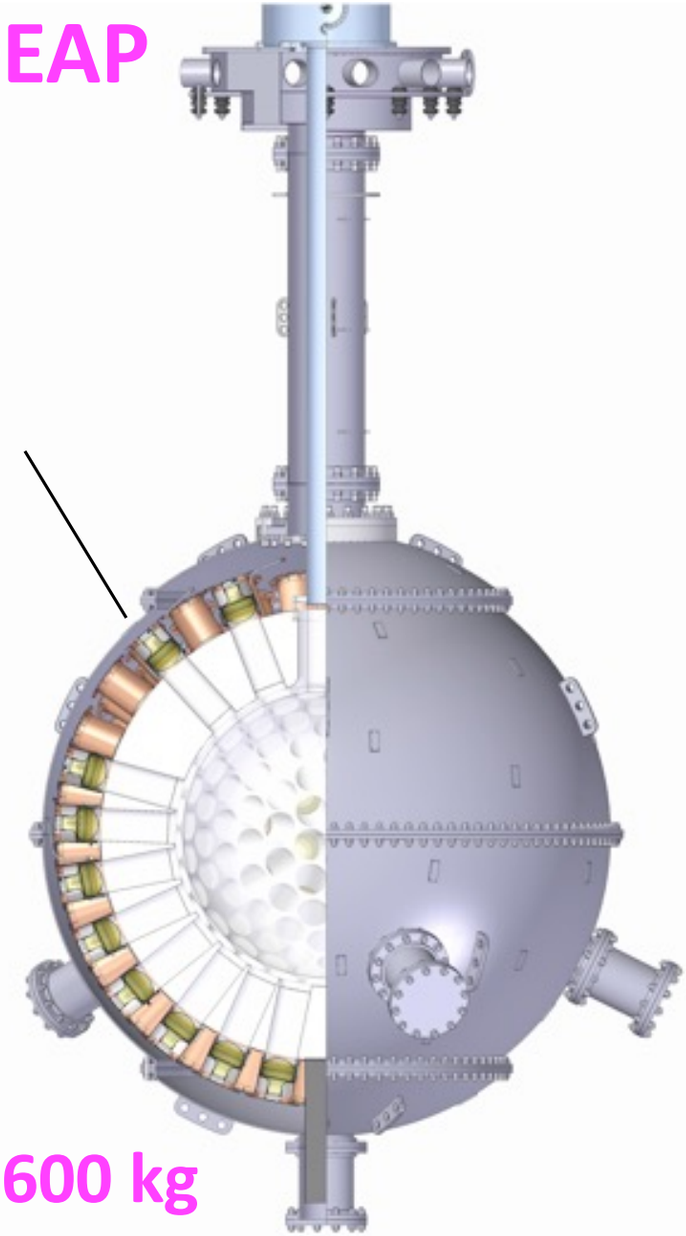
PhysLett B 759 (2016)

- Annual modulation, 2 WIMP cases
  - A^2 nuclear recoil signal model
- Full modulation analysis
  - fixed phase
  - limits consistent with previous Xenon-100 results



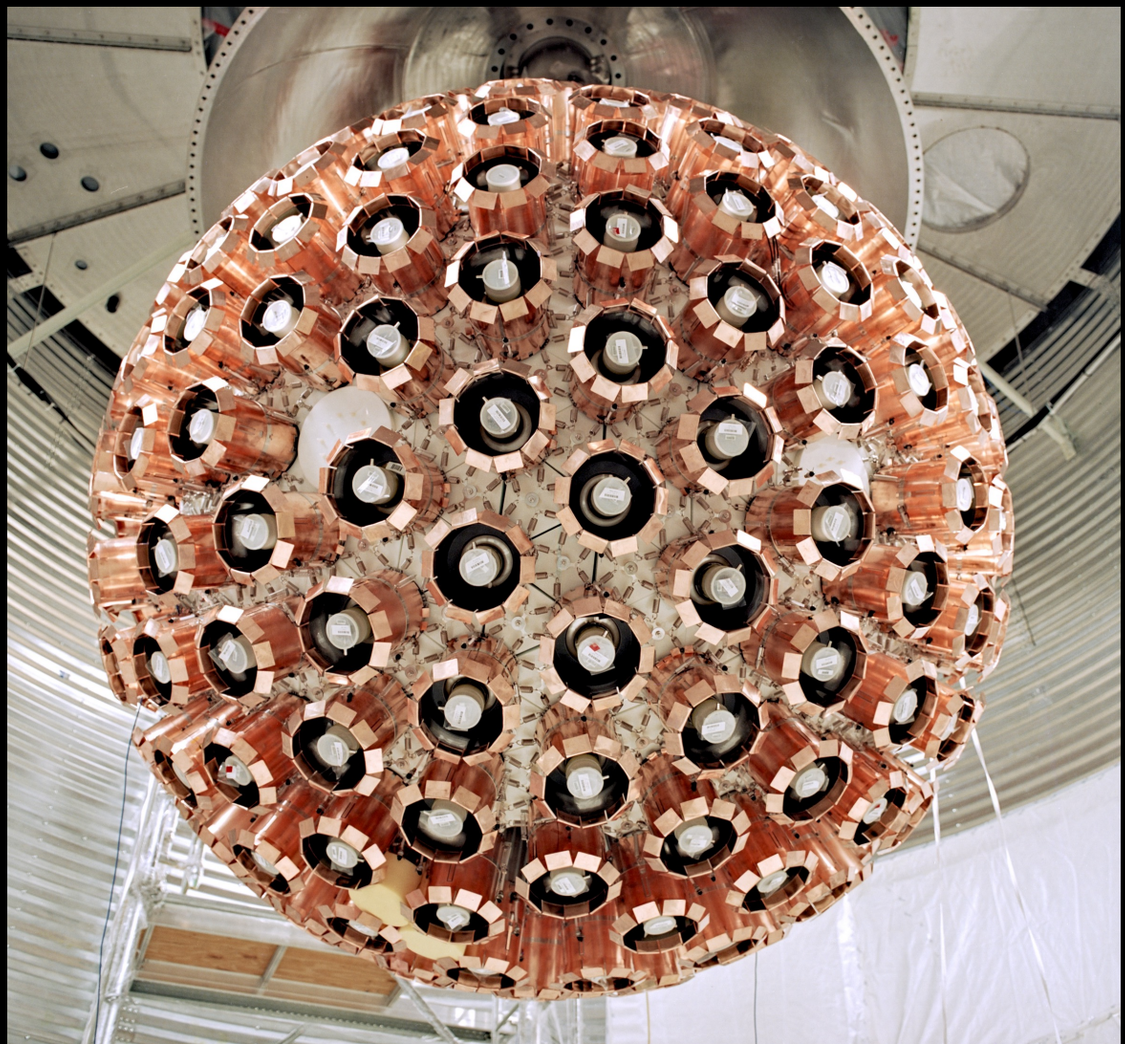
Single Phase LAr: DEAP @ SNOLAB

DEAP

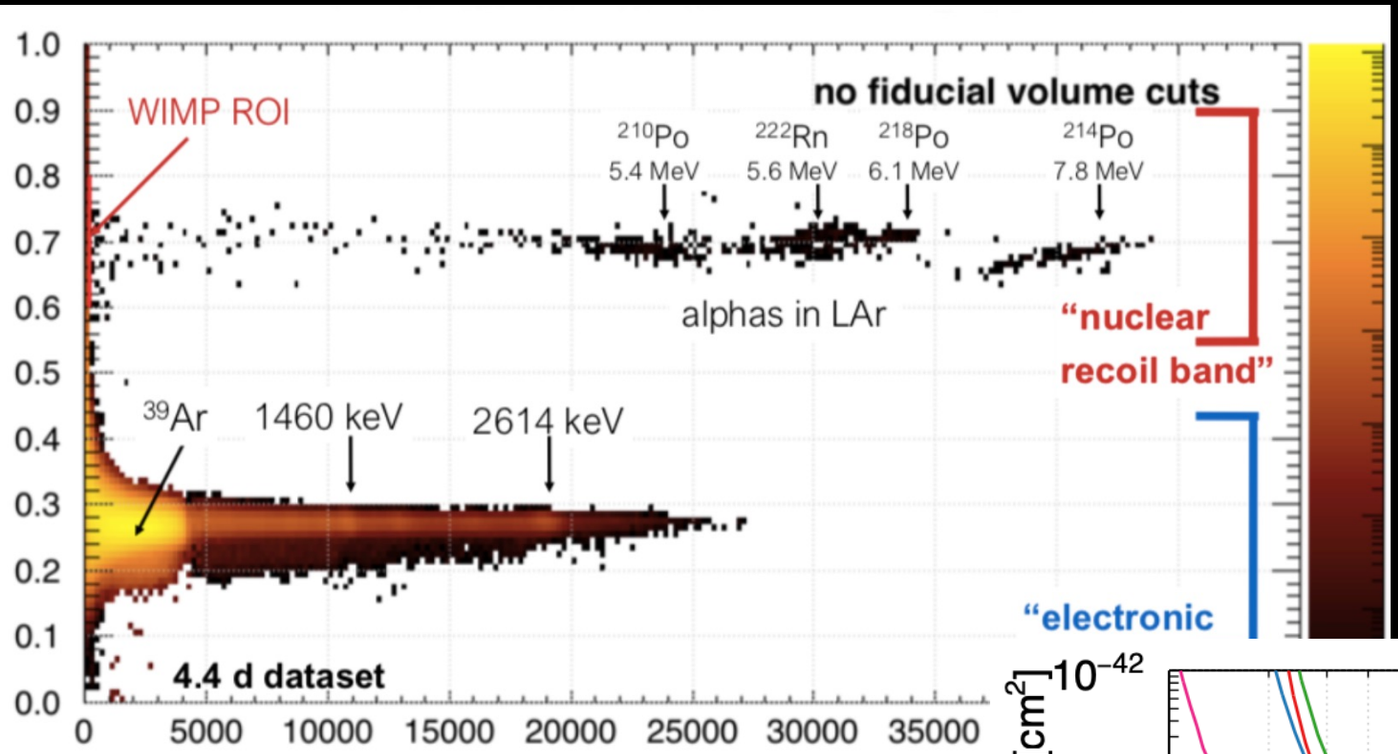


3600 kg
instrumented
1000 kg fiducial

- Significant pulse shape discrimination
- Ar is abundant (1% of Earth's atm.)
  - Intrinsic background: ^{39}Ar, ~600 keV endpoint beta (~1 Bq/kg atmosph. Ar)



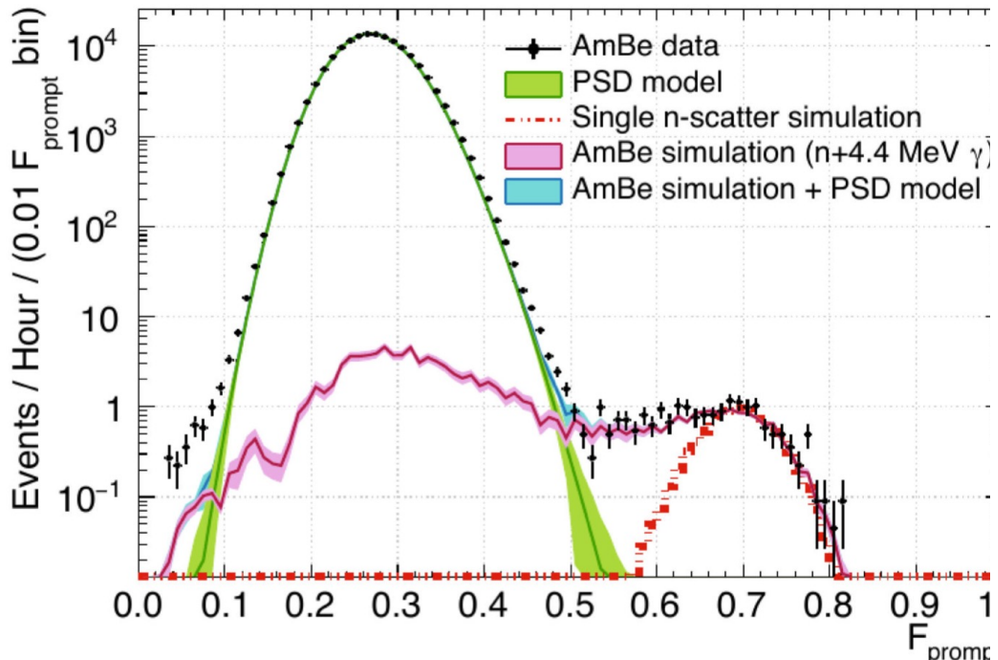
SINGLE PHASE LAR: DEAP @ SNOLAB

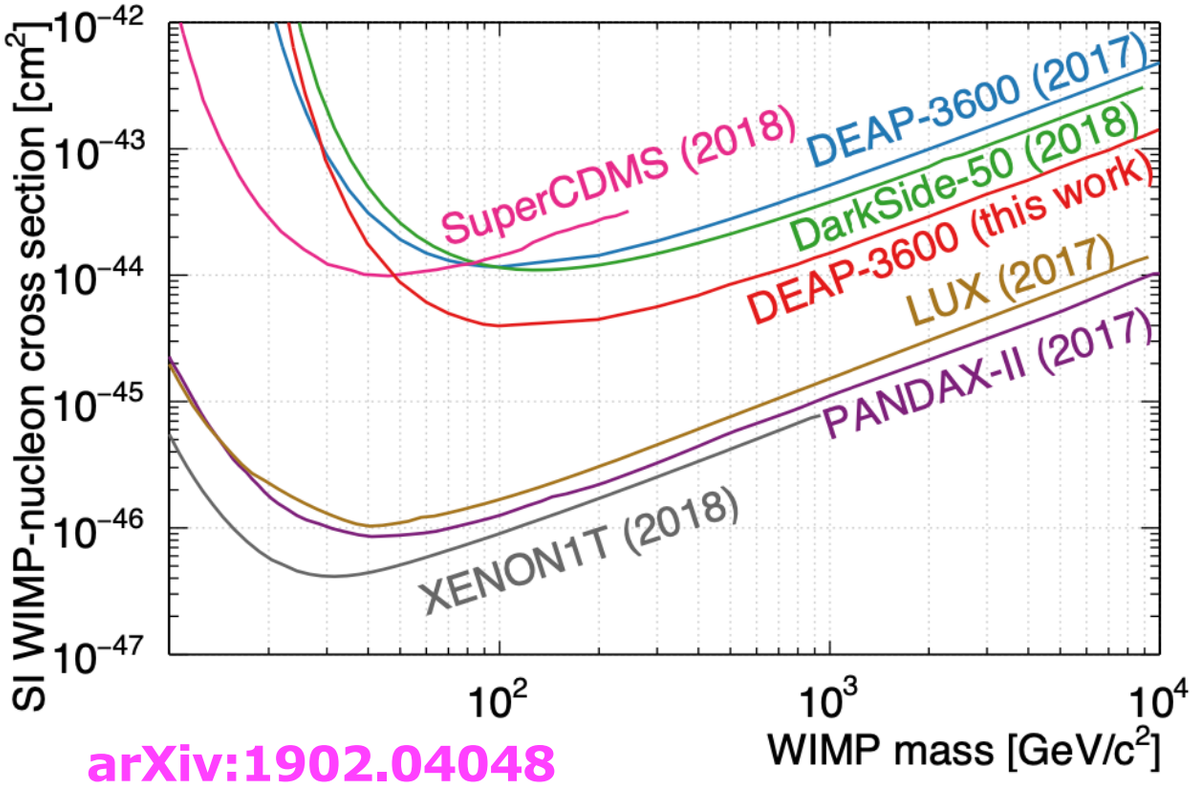


Exceptional Pulse-Shape discrimination (>10^8)

(see P. Adhikari's talk)

- WIMP search: 231 live days, 3.3 t target
- $\sigma < 3.9 \times 10^{-45}$ cm^2 @100 GeV (2019)



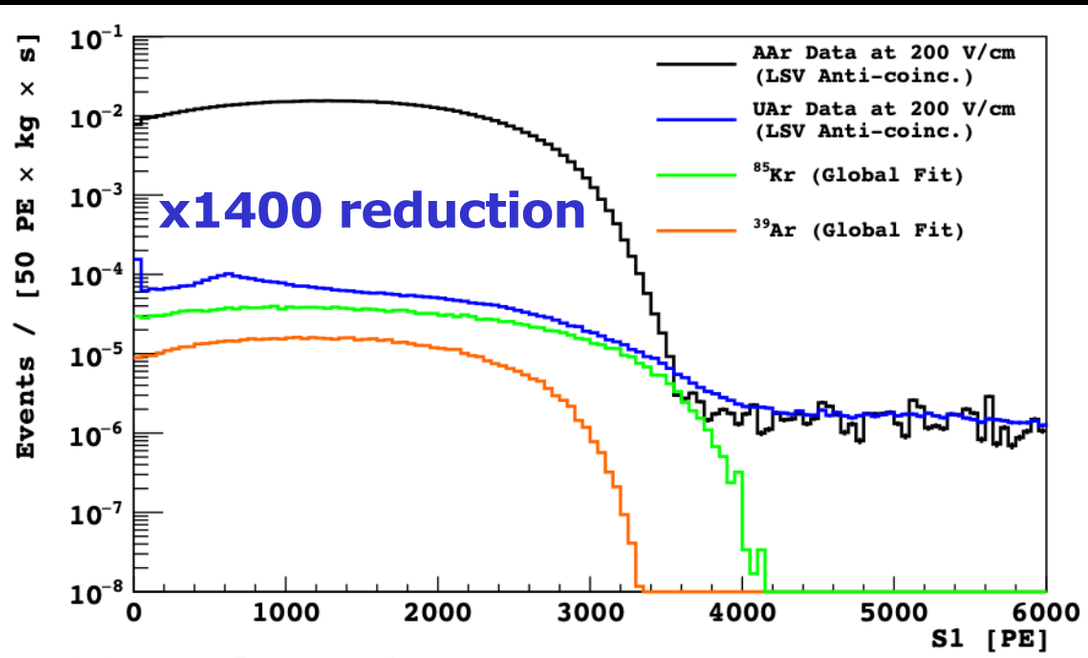


arXiv:1902.04048

LIQUID ARGON TPC: DARKSIDE-50 @ LNGS

- 3-fold discrimination (S1 pulse shape, S2/S1, 3D-reconstruction)
- Underground Ar, depleted in ^{39}Ar
- x1400 ^{39}Ar depletion observed
- UAr WIMP search in 2015-2107

LIQUID ARGON TPC: DARKSIDE-50 @ LNGS



UAr WIMP search in 2015-2108

– 532 live days, 50 kg target

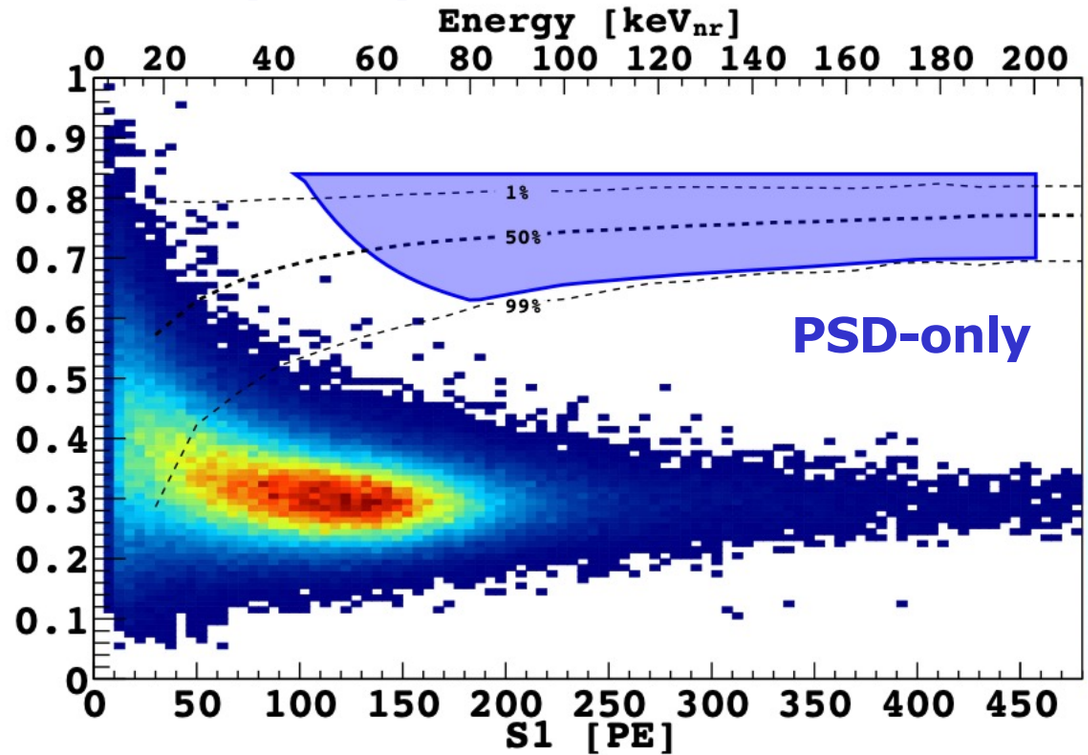
– x1400 ^{39}Ar depletion observed

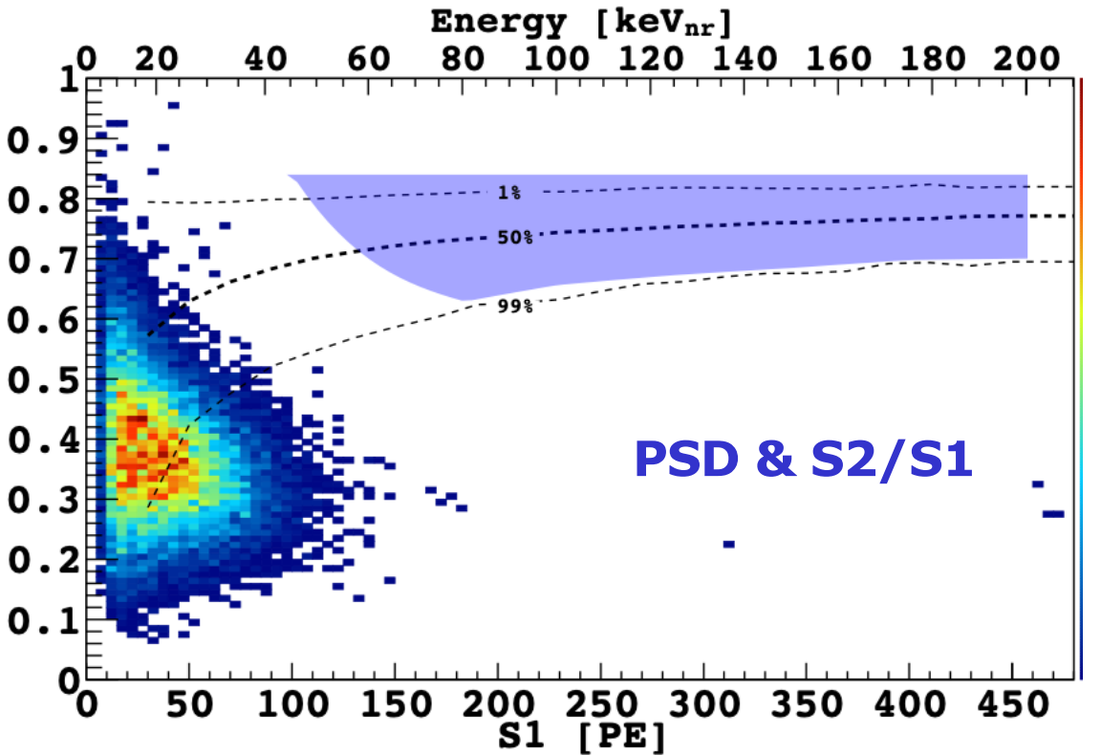
– active neutron & muon vetoes

– entirely background-free!

– $\sigma < 1.14 \times 10^{-44}$ cm^2 @100 GeV

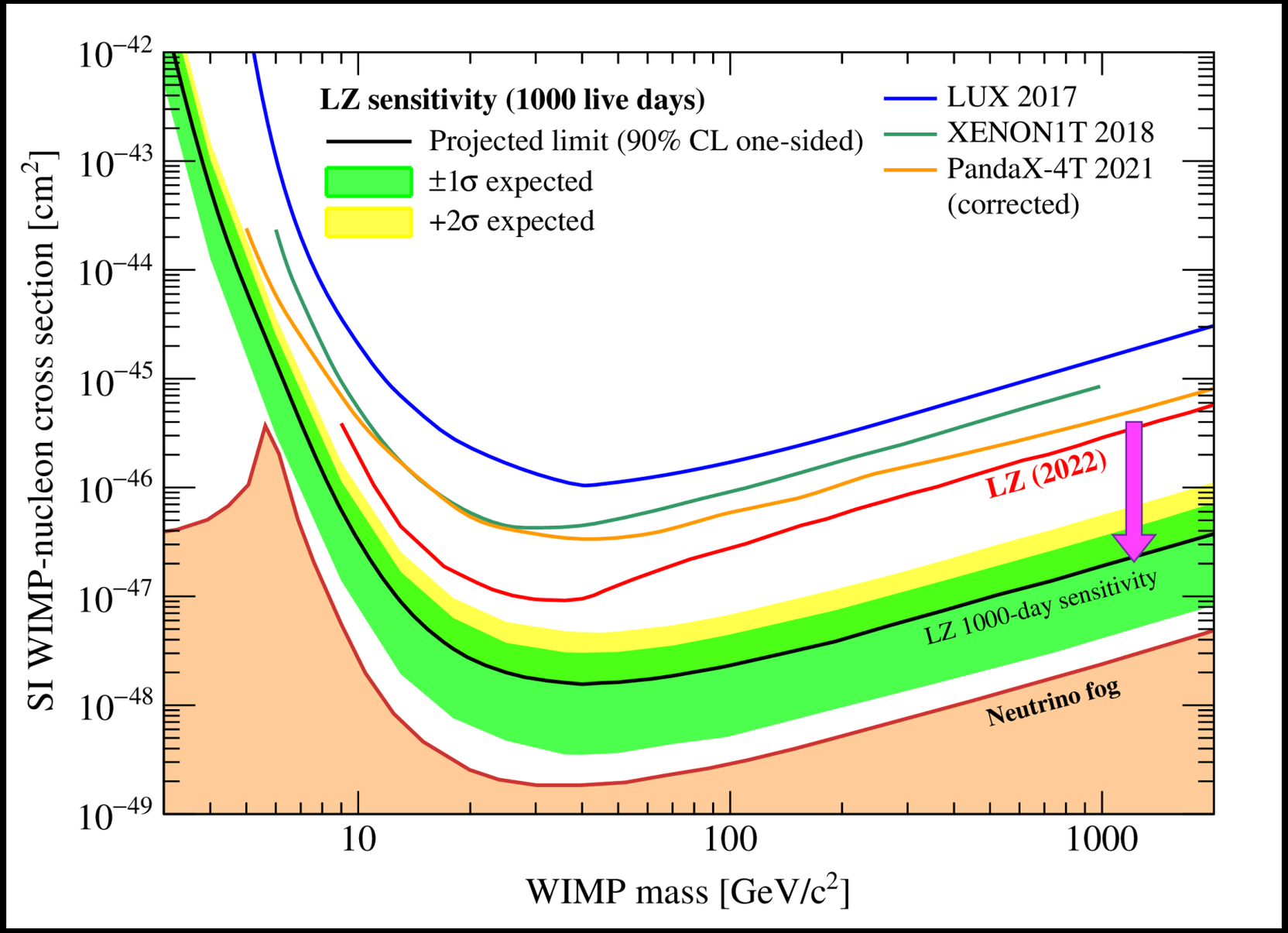
PRD 98 (2018)





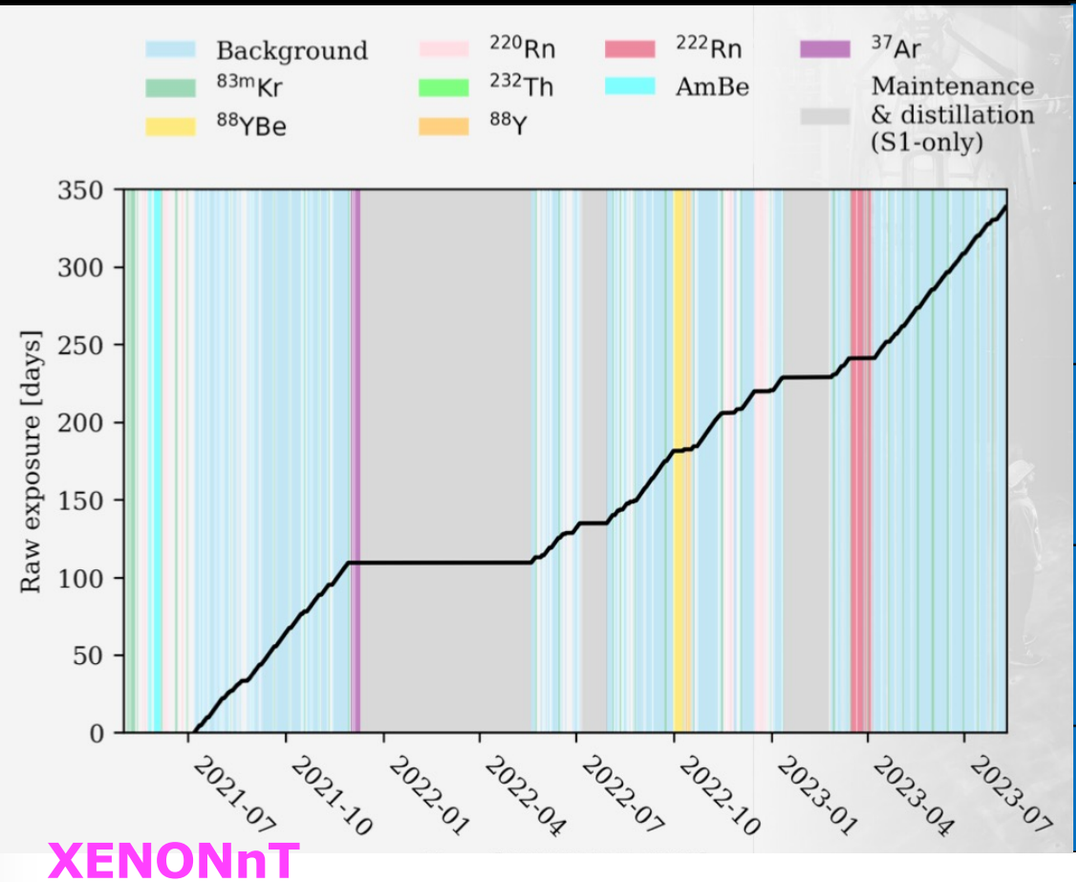
The Near-Future Plan (next ~5 years)

LZ Operations Extended through 2028



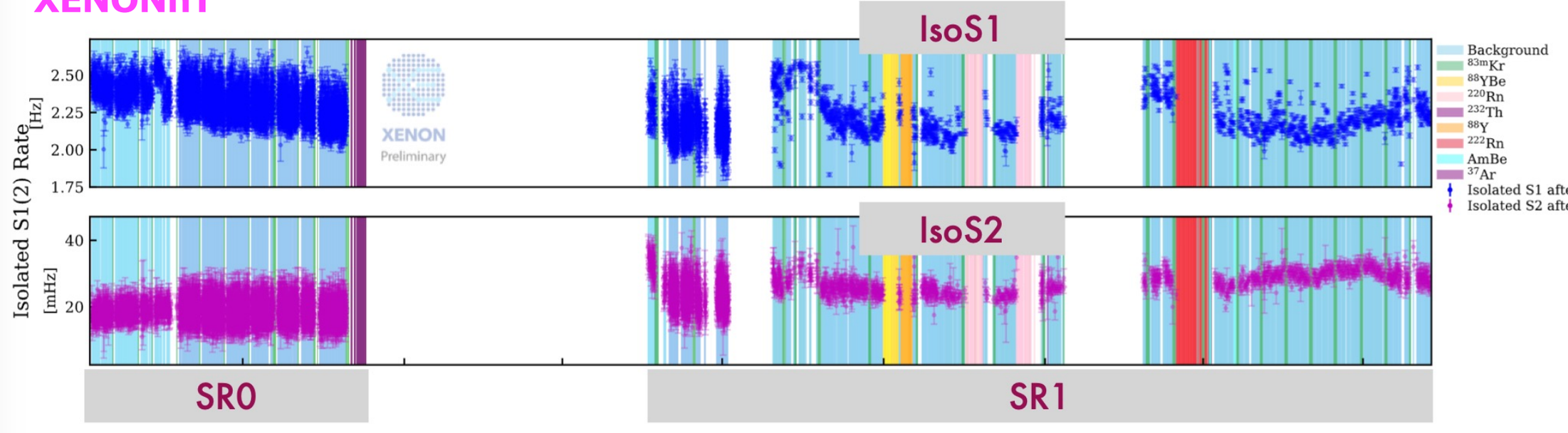
What's Next for LZ? Lots. More. Data.

XENONnT & PandaX-4T Taking Data too



2020/11 – 2021/04	**Commissioning (Run 0)** 95 days
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run 1)** 164 days PandaX-4T
2022/09 – 2023/12	**CJPL B2 hall renovation** xenon recuperation, detector upgrade
Current Status	**Resuming physics data-taking**

XENONnT



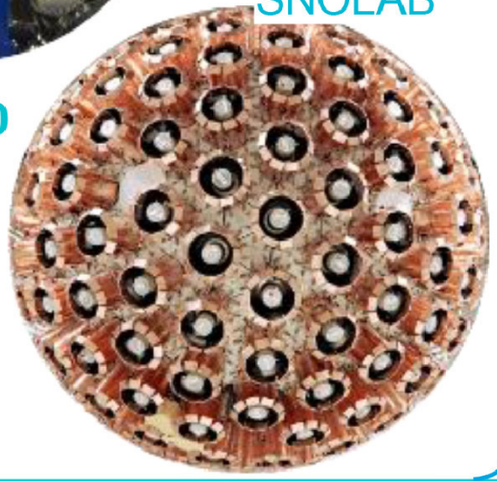
The Grand Unification of LAr Experiments

Global Argon Dark Matter Collaboration

ArDM
Canfranc

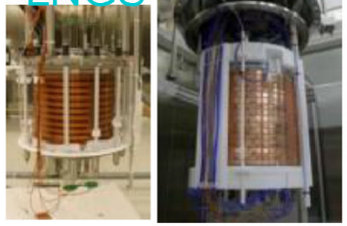
MiniCLEAN
SNOLAB

DEAP-3600
SNOLAB



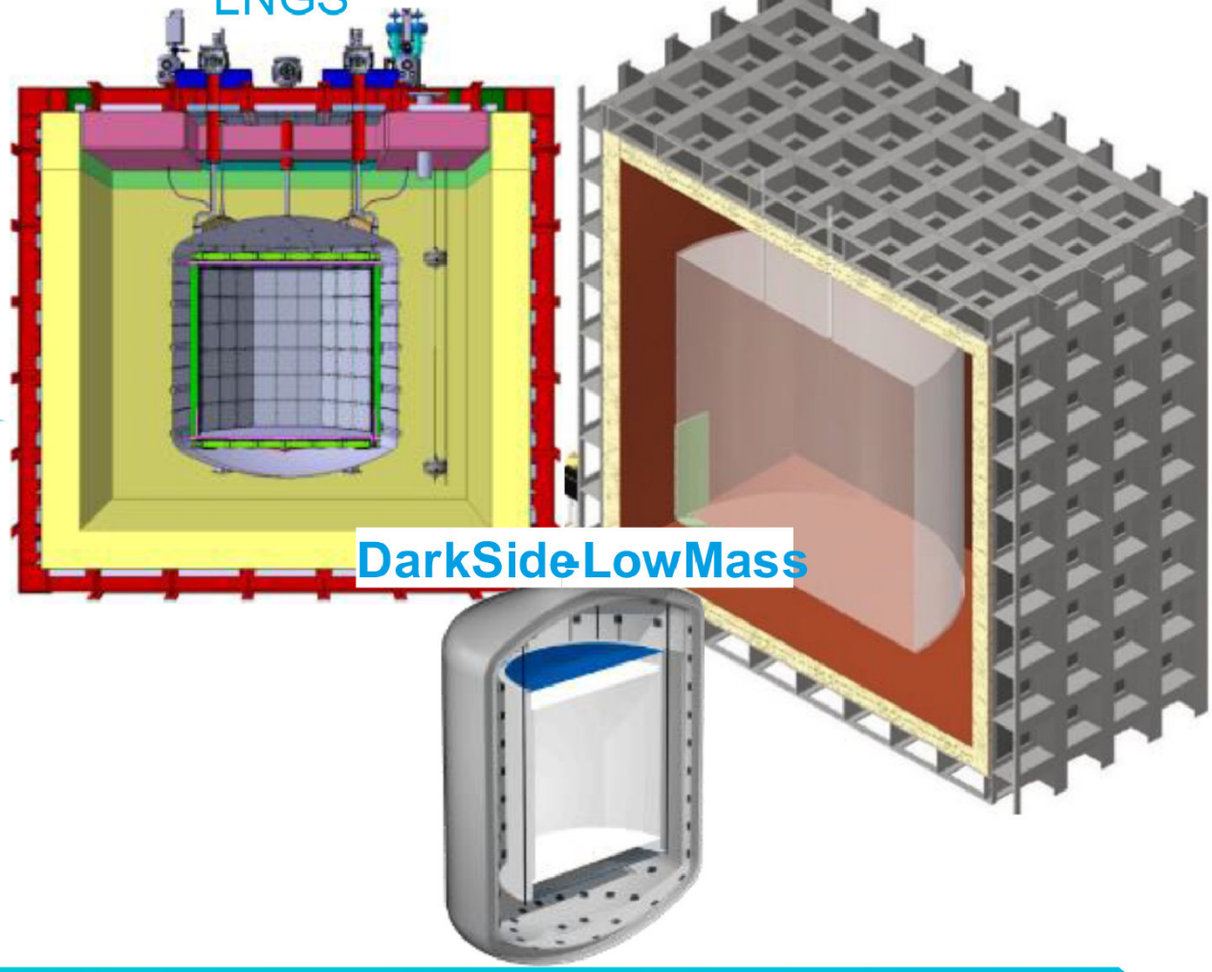
DarkSide50
LNGS

DS-10
LNGS



DarkSide-20k
LNGS

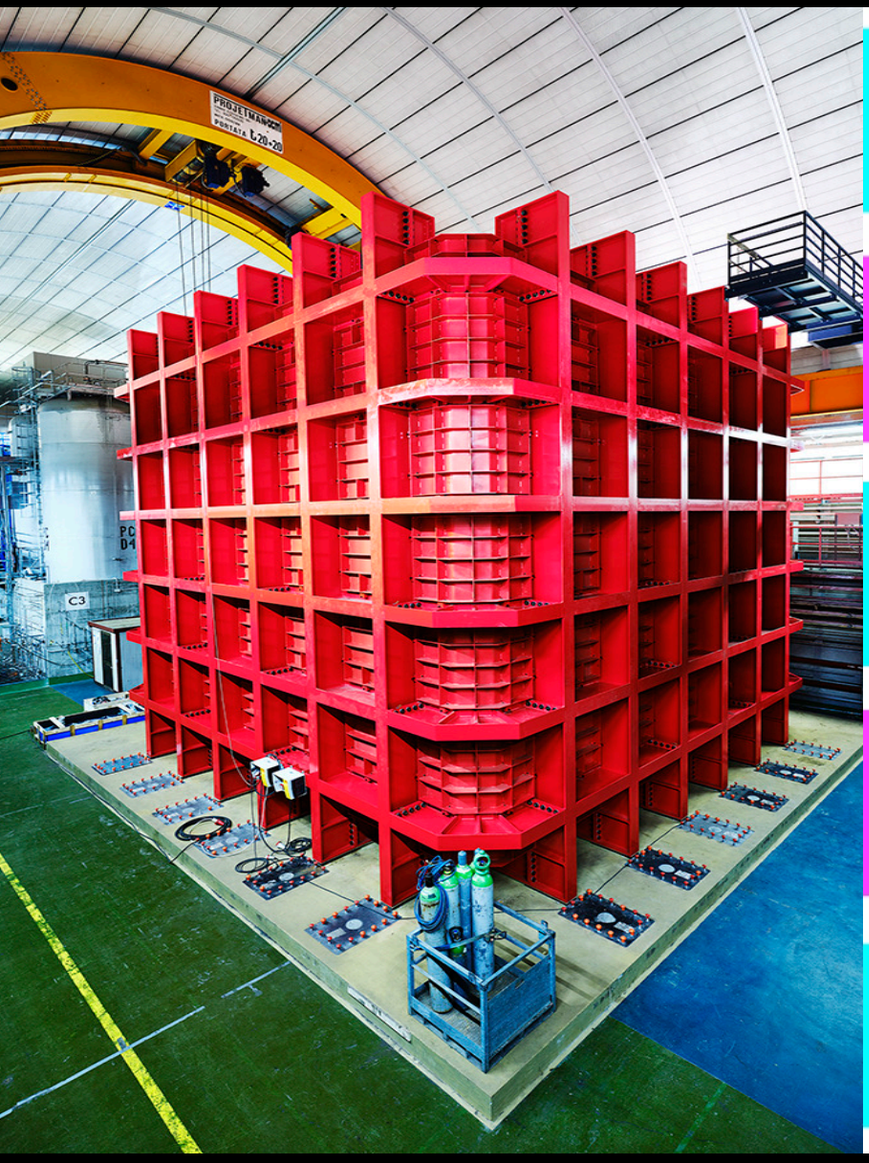
Argo
SNOLAB

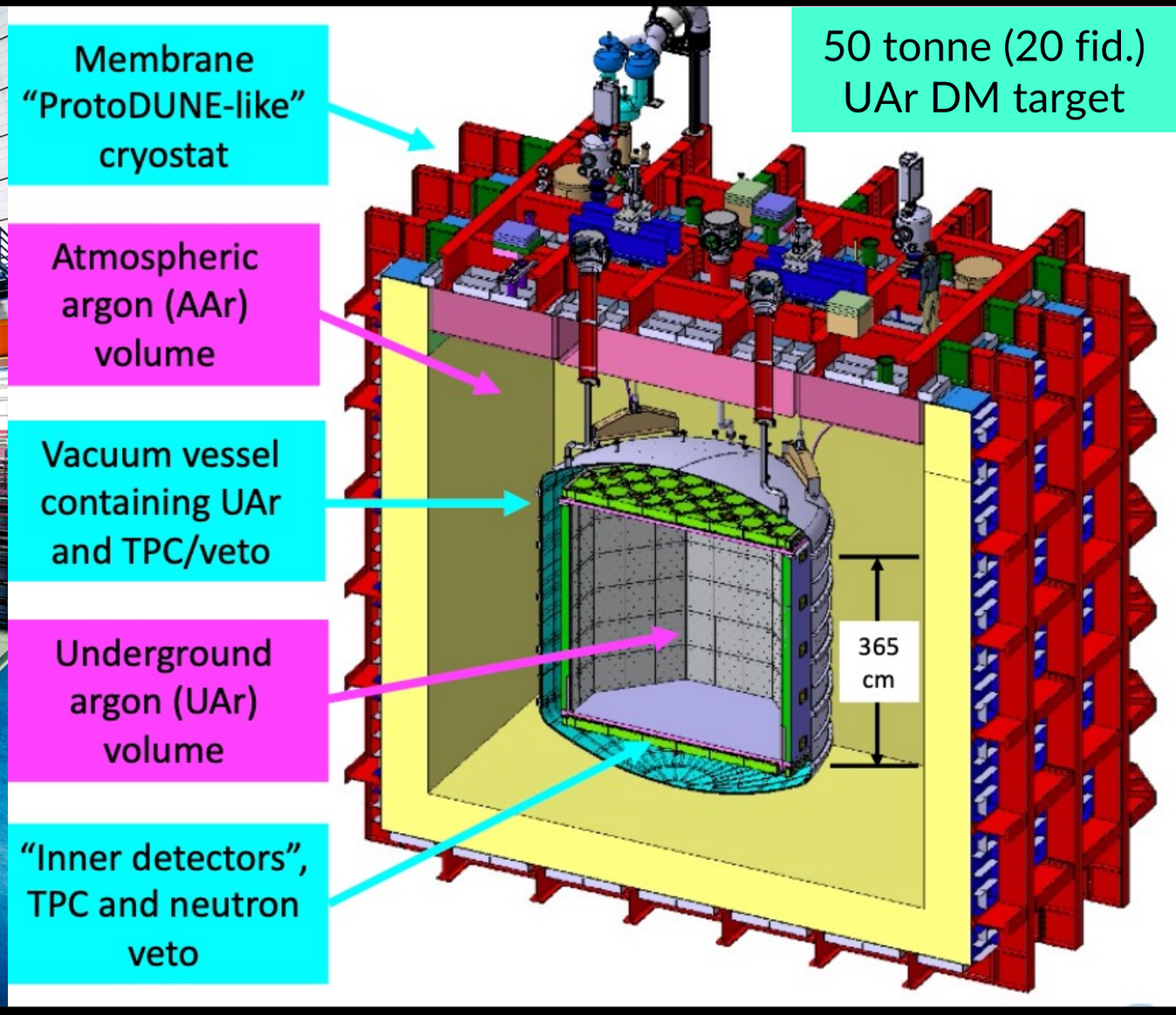


2011 2013 2016 2026 2030+

Nucl.Phys.B 1003 (2024)

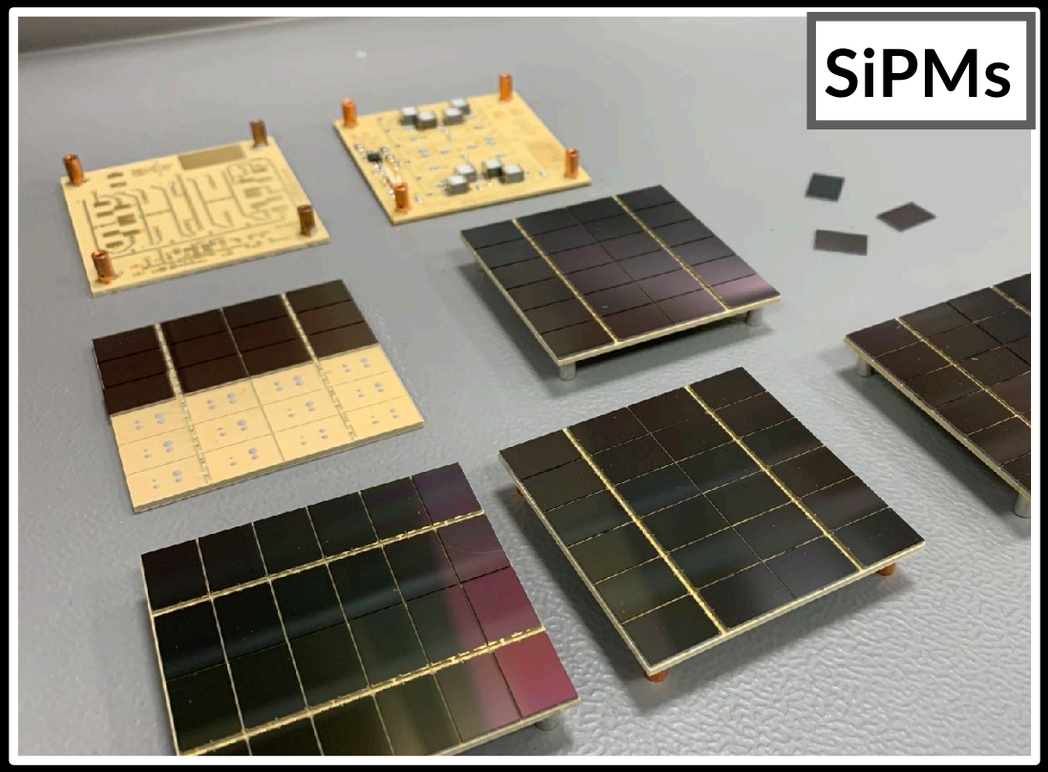
DarkSide-20k at Gran Sasso

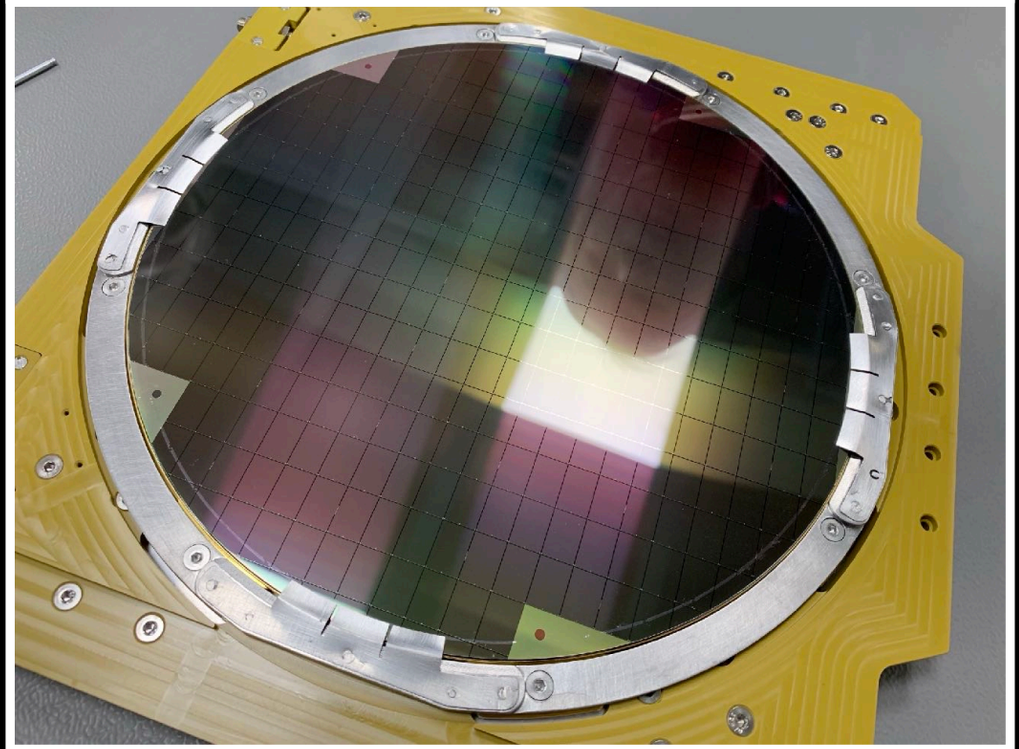


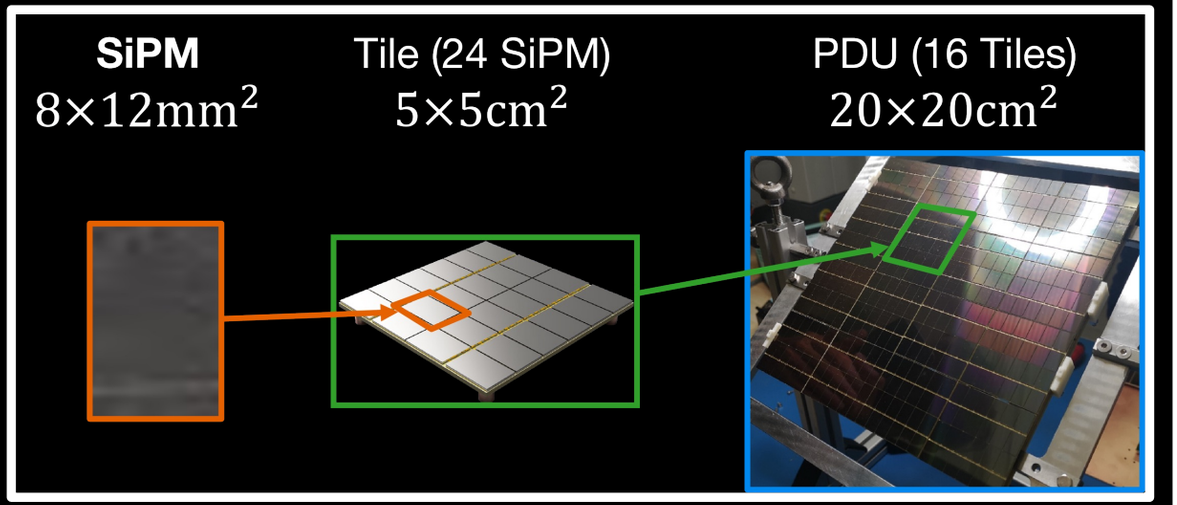


See also: Ahmad, Stefanizzi, Pesudo, Santorelli, Calabrese, Pandola, Van Uffelen, Marasciulli, Pino, Salomone, Thieme

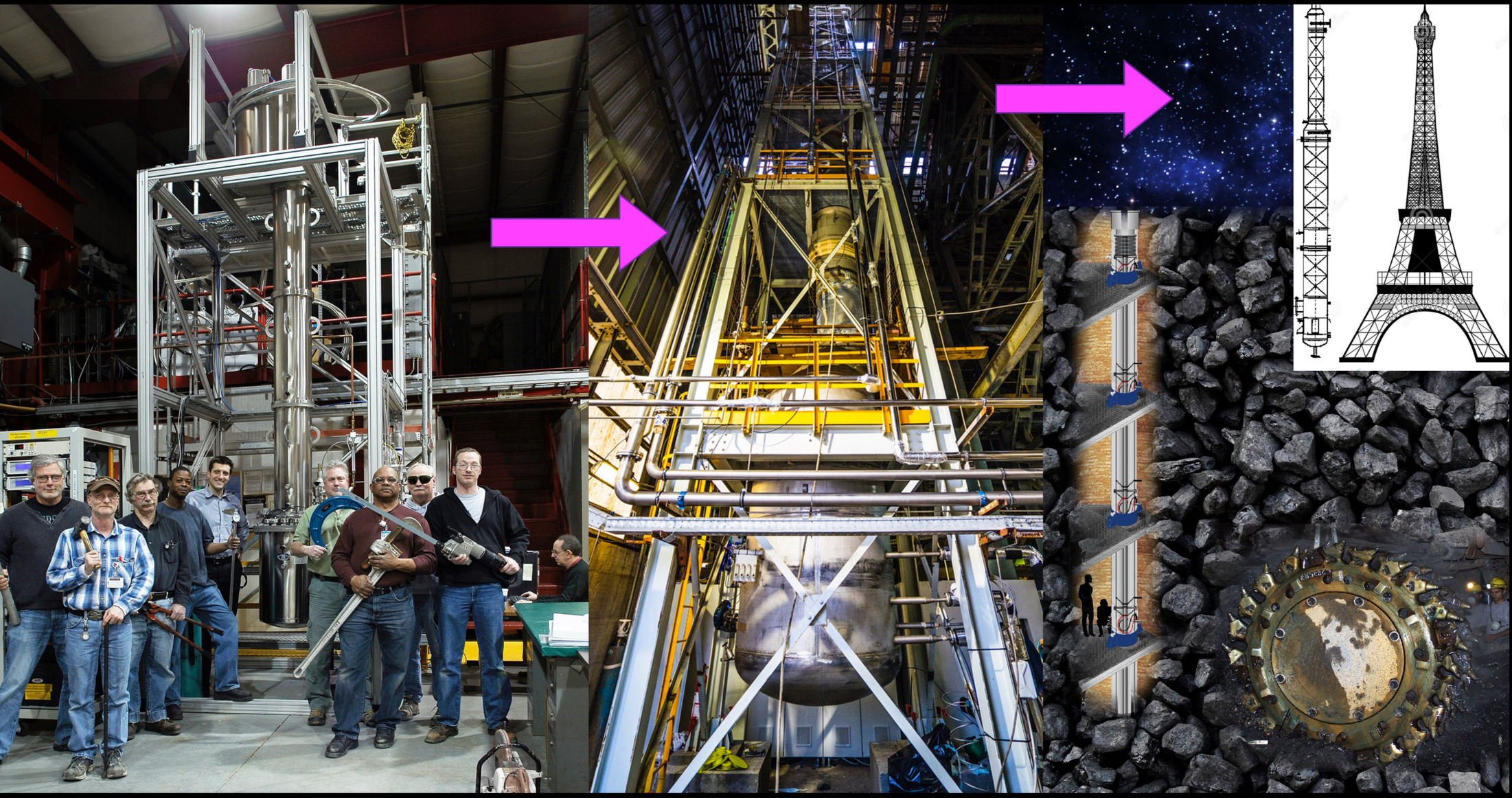
DarkSide-20k: Photodetector Technology







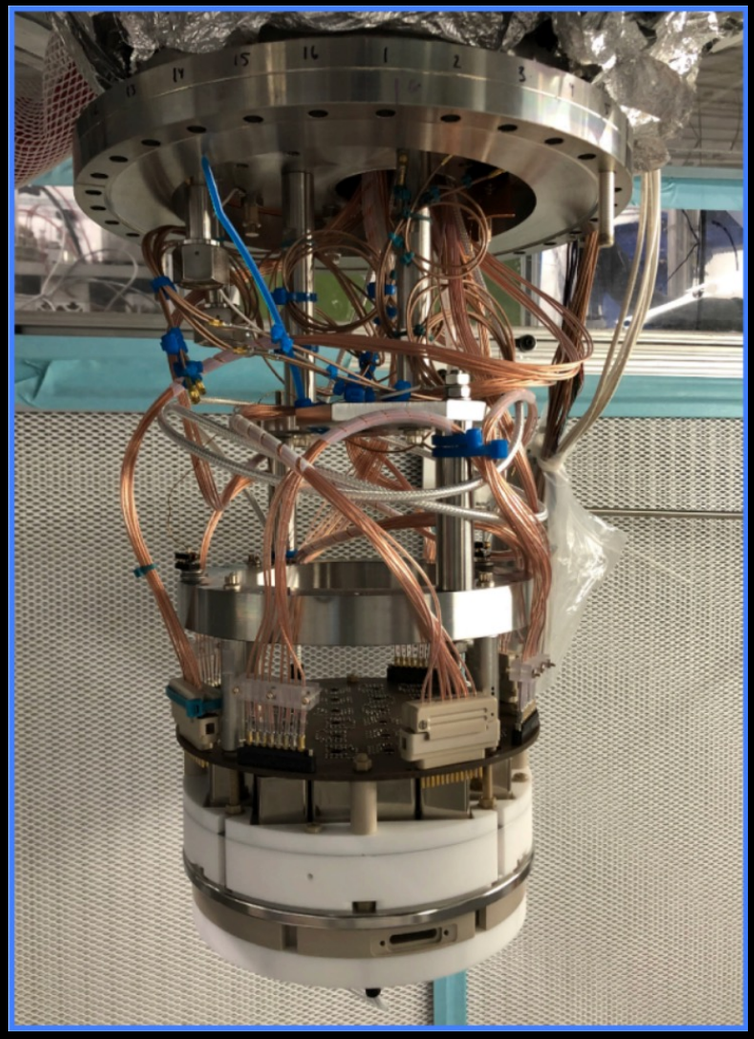
DarkSide-20k: UAr Purification



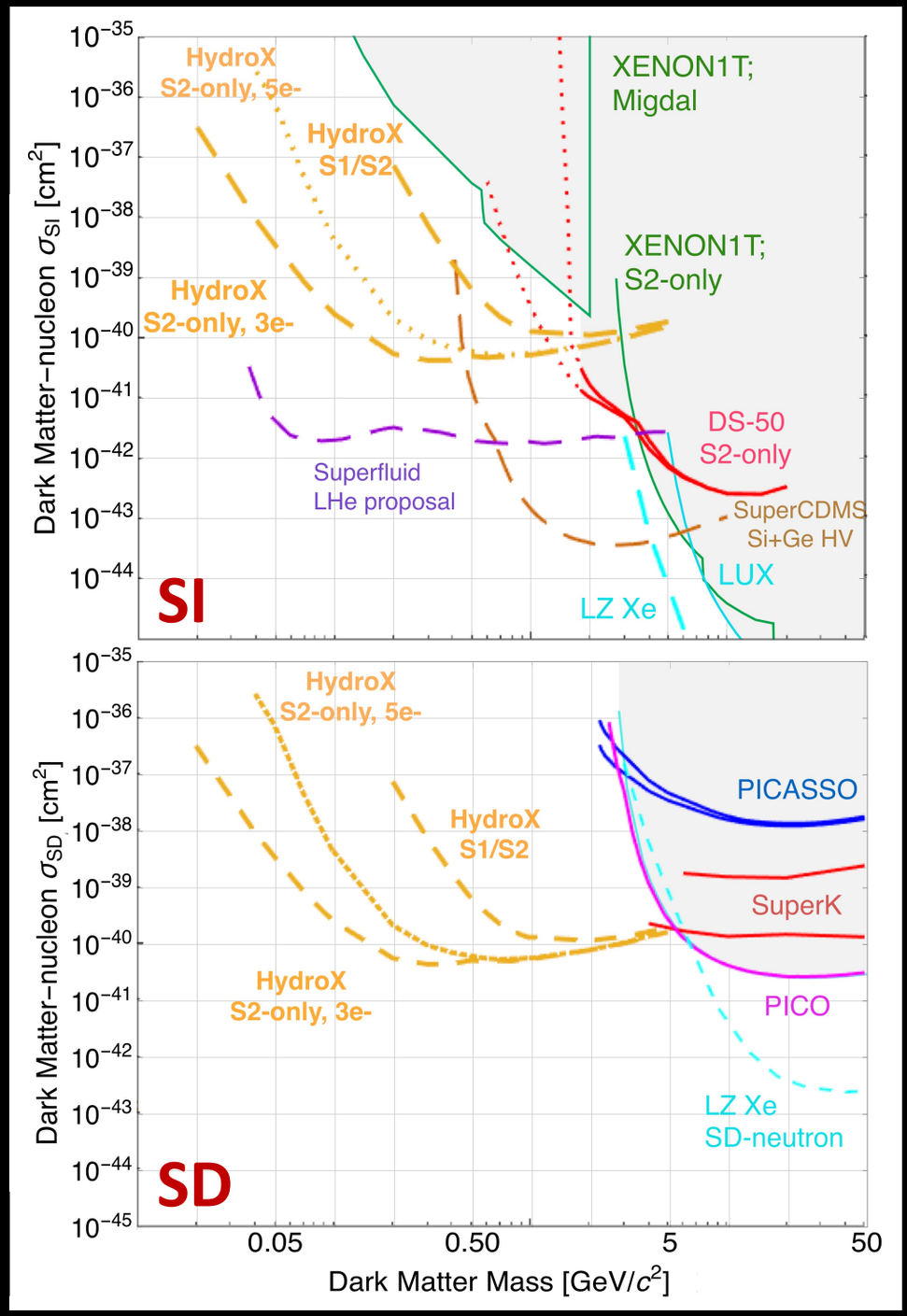
Goal: Chemical + Isotopic Distillation

What Else is Fun on this Time Scale?

HydroX (Hydrogen in Xe): Potential LZ Upgrade

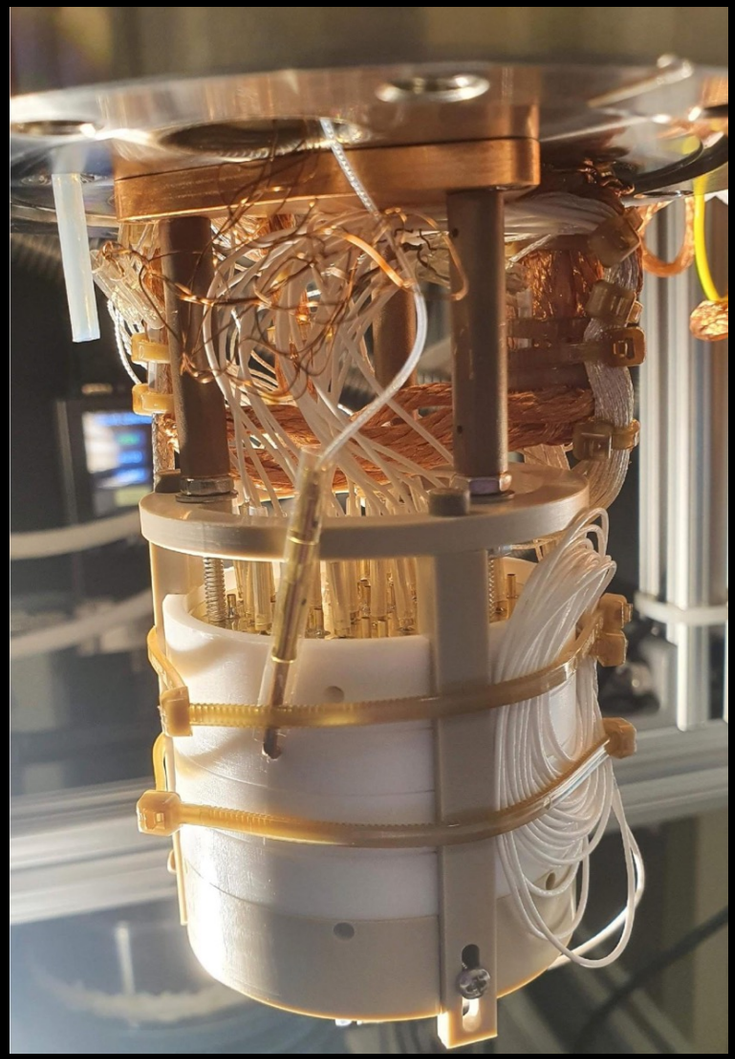


See A. Wang's Talk

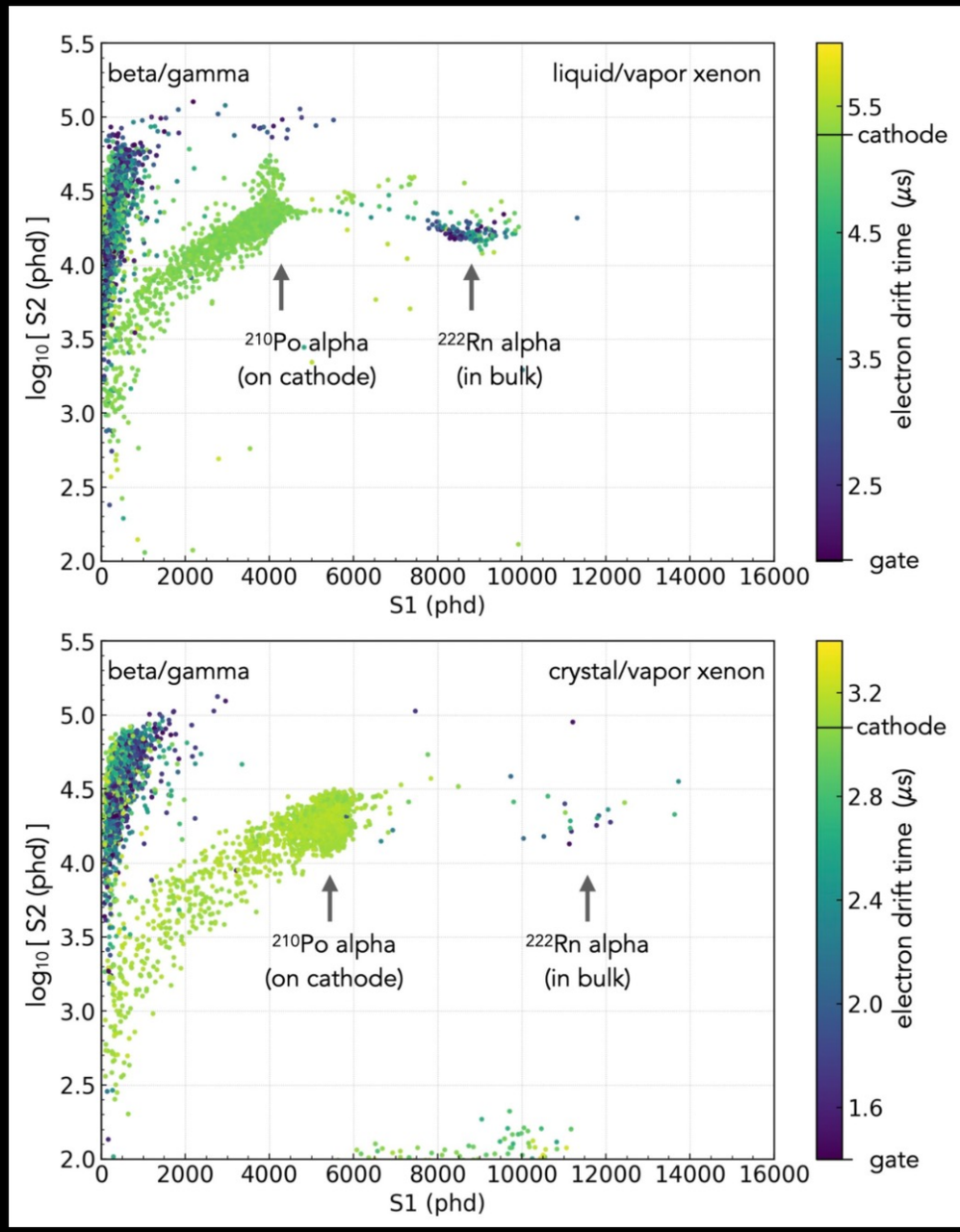


What Else is Fun on this Time Scale?

CrystaLiXe (Crystal/Vapor Xe): Potential LZ Upgrade



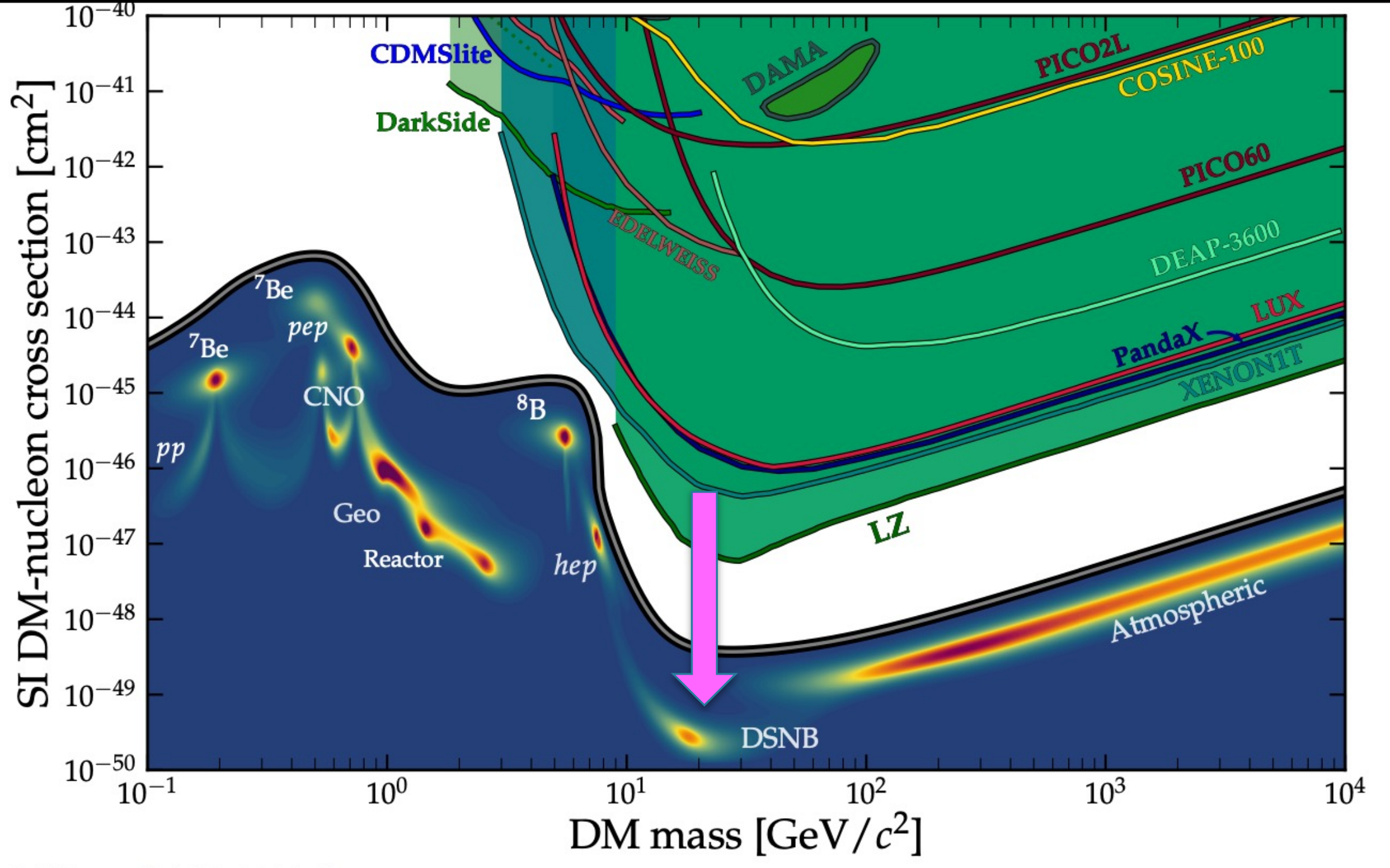
See P. Sorensen's Talk



arXiv:2312.15082 [hep-ex] 2023

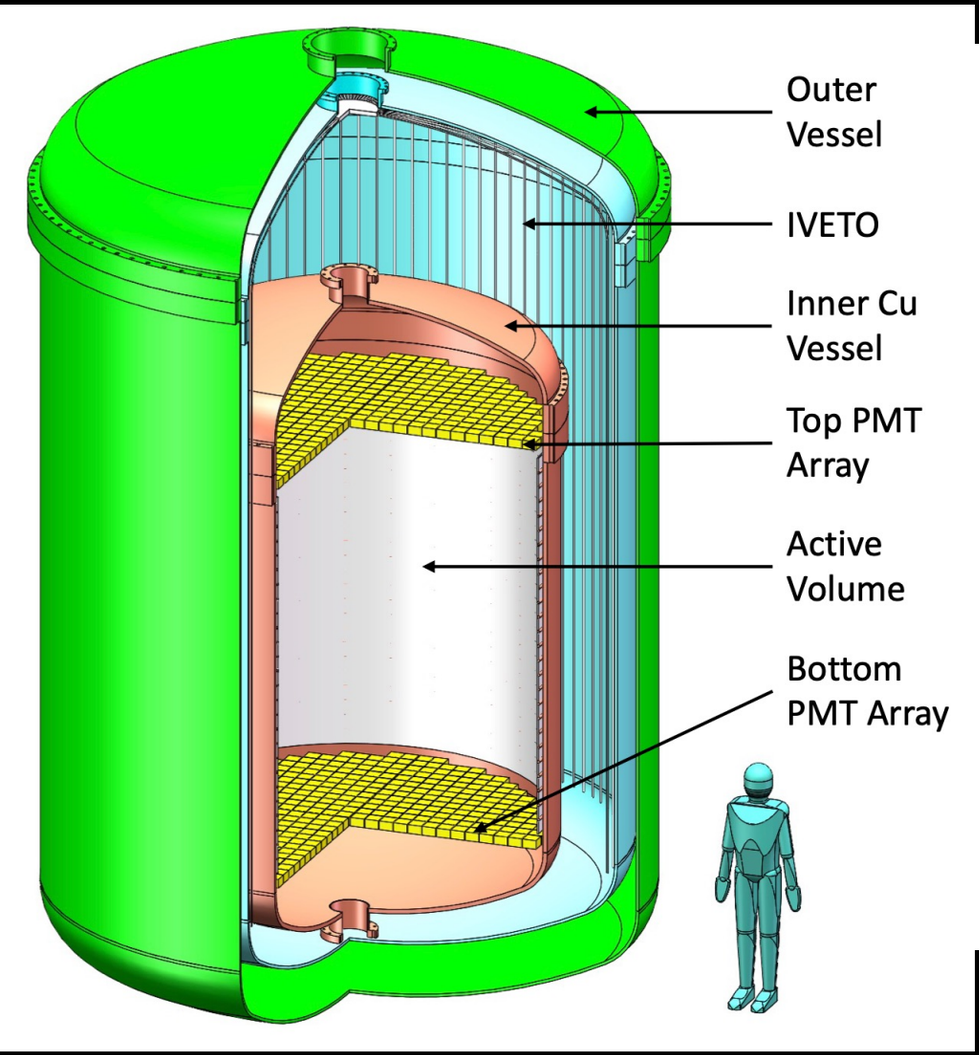
The Future-Future Plan (Next Decade?)

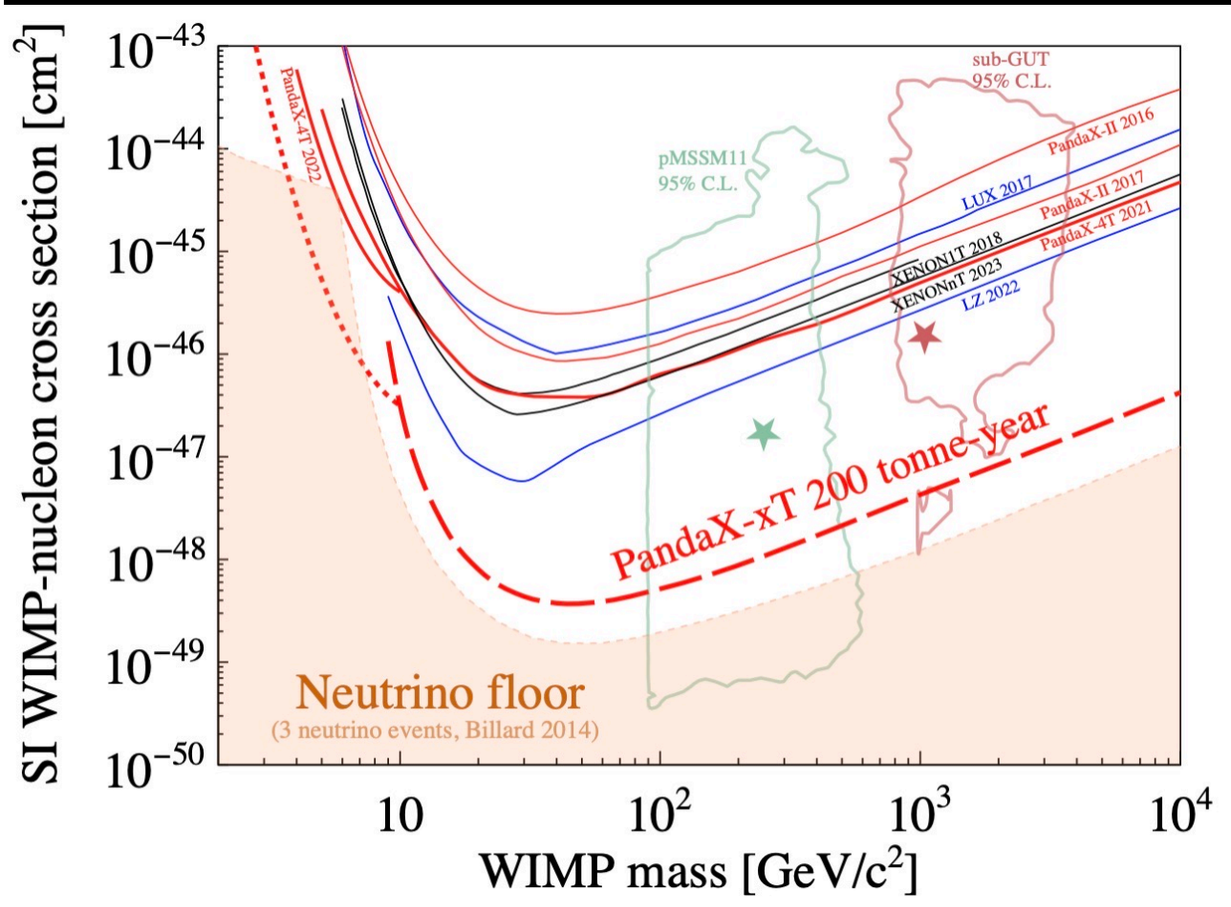
Race to the Bottom? Or WIMP Discovery?



O'Hare [2109.03116]

PandaX-xT: Multi-Ten-Tonnes LXe

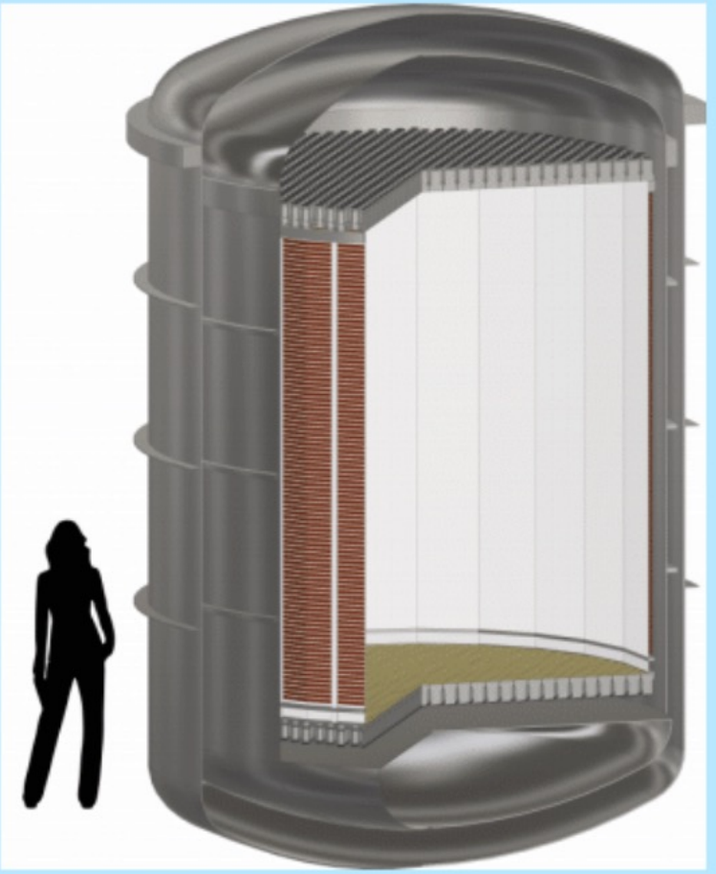




43 tonnes, 10-year run

arXiv: 2402.03596 [hep-ex] 2024

The Grand Unification of LXe Experiments



XLZD = Xenon + Lux-ZEPLIN (LZ) + Darwin

MOU (2001) → Consortium (now) → Collaboration
to Build the ULTIMATE LXe Dark Matter Detector

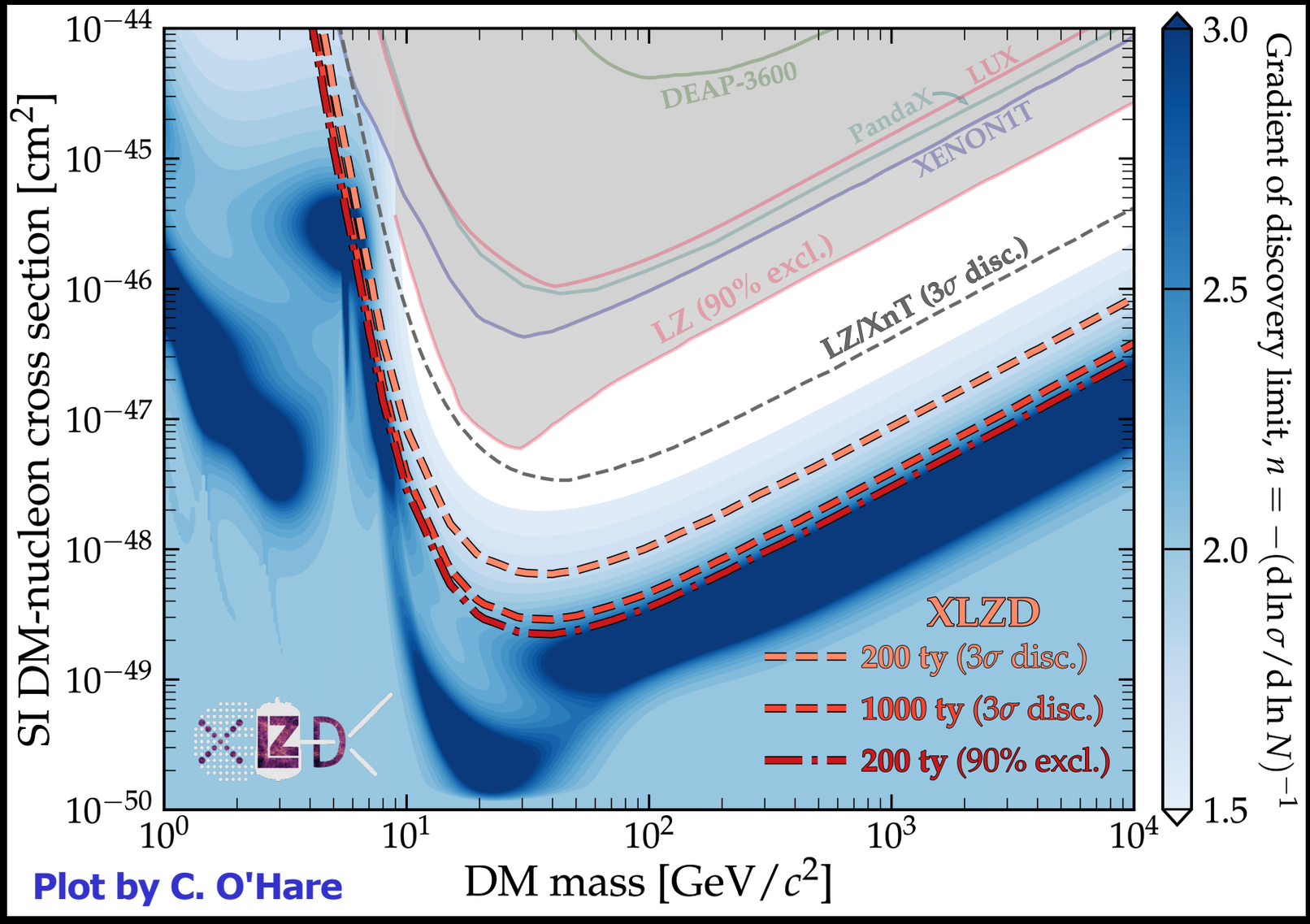
The Grand Unification of LXe Experiments

MOU (2001) → Consortium (now) → Collaboration to Build the ULTIMATE LXe Dark Matter Detector

60-tonnes scale LXe ~~detector~~ observatory

Reach Down and Into the Neutrino Fog

See Talks by L. Baudis & C. Capelli



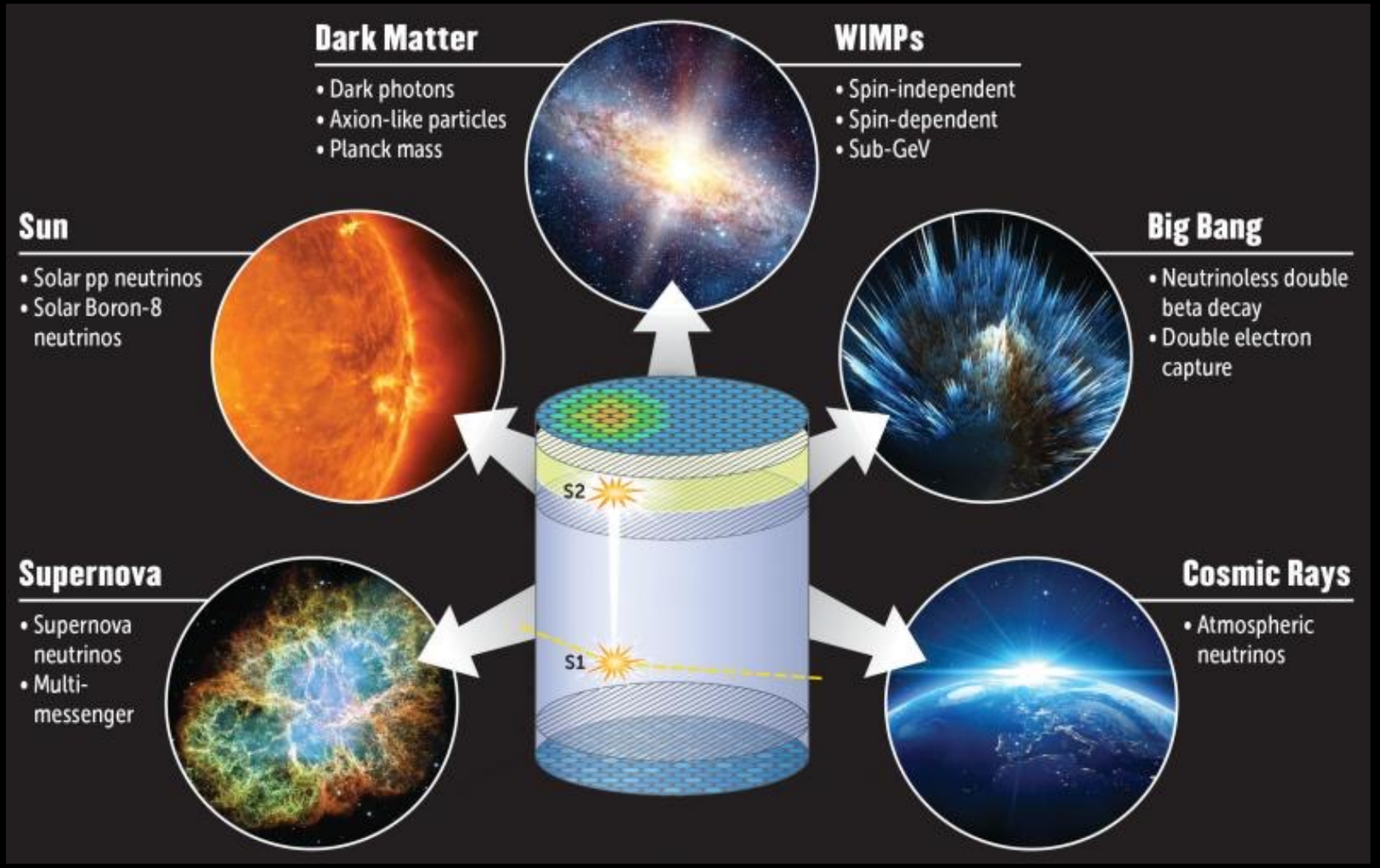
The Grand Unification of LXe Experiments

MOU (2001) → Consortium (now) → Collaboration to Build the ULTIMATE LXe Dark Matter Detector

60-tonnes scale LXe ~~detector~~ observatory

Reach Down and Into the Neutrino Fog

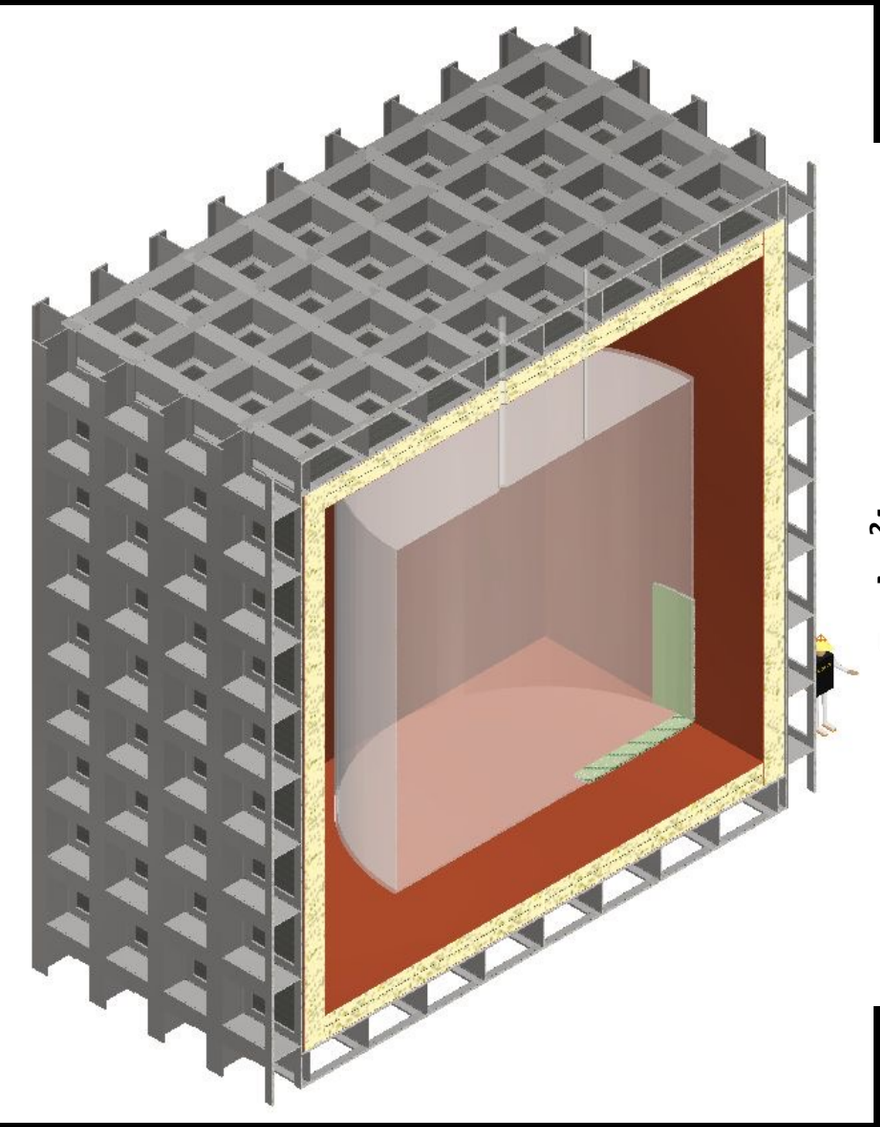
See Talks by L. Baudis & C. Capelli

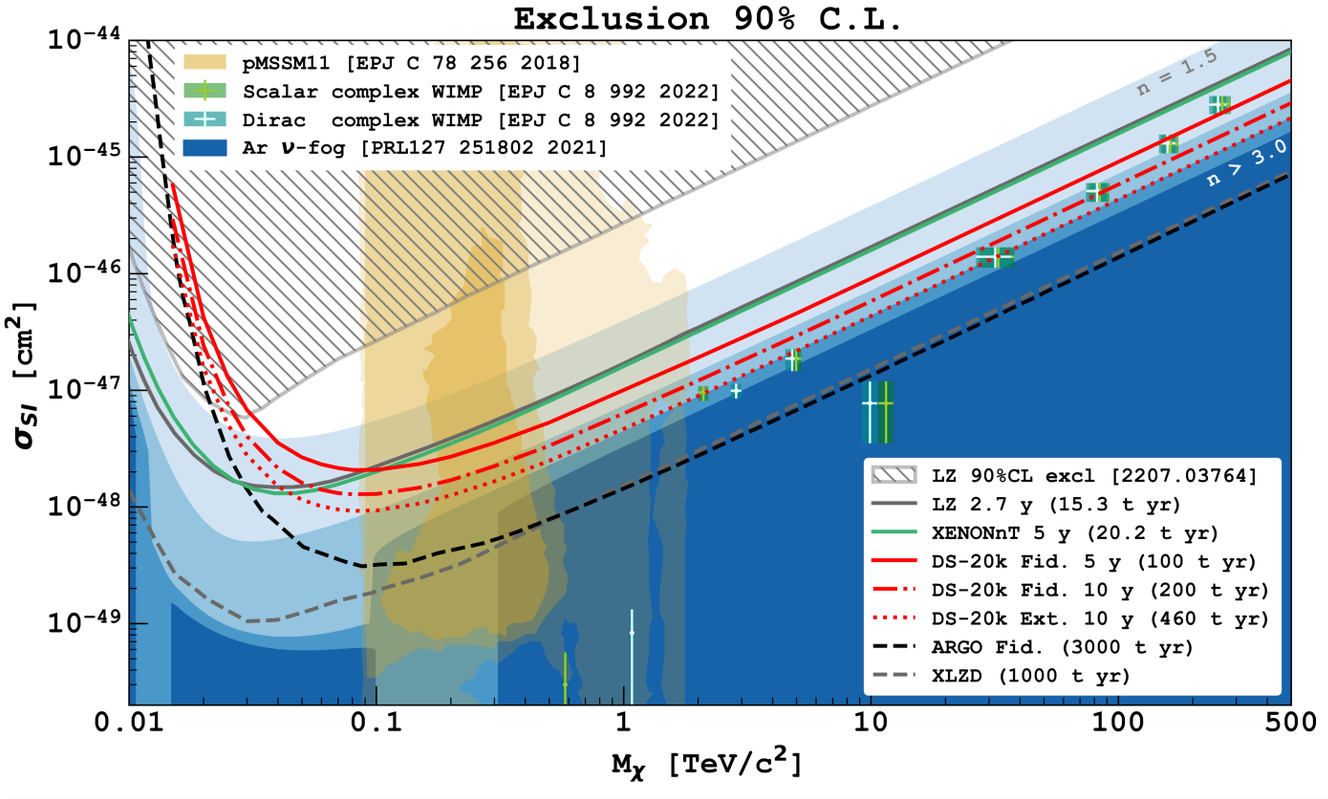


The Ultimate Detector: Argon Version

ARGO: 400 tons UAr (300 fiducial), 250 m² PDCs

covering full acrylic vessel surface





New results from XENONnT *Fei Gao*

Palazzo dell'Emiciclo, Sala Ipogea 12:00 - 12:30

Join at menti.com | use code 44 65 82 6

What are the new XnT results?

0	0	0	0	0	0
Migdal effect	CNS Boron-8	EFT models	2nBB, 0nBB	ER channels	Other Results

https://www.menti.com/altuoh1wbtg9