Dark Matter

(and direct searches for it)

School for Astroparticle Physics 2018
Obertrubach-Bärnfels

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Content

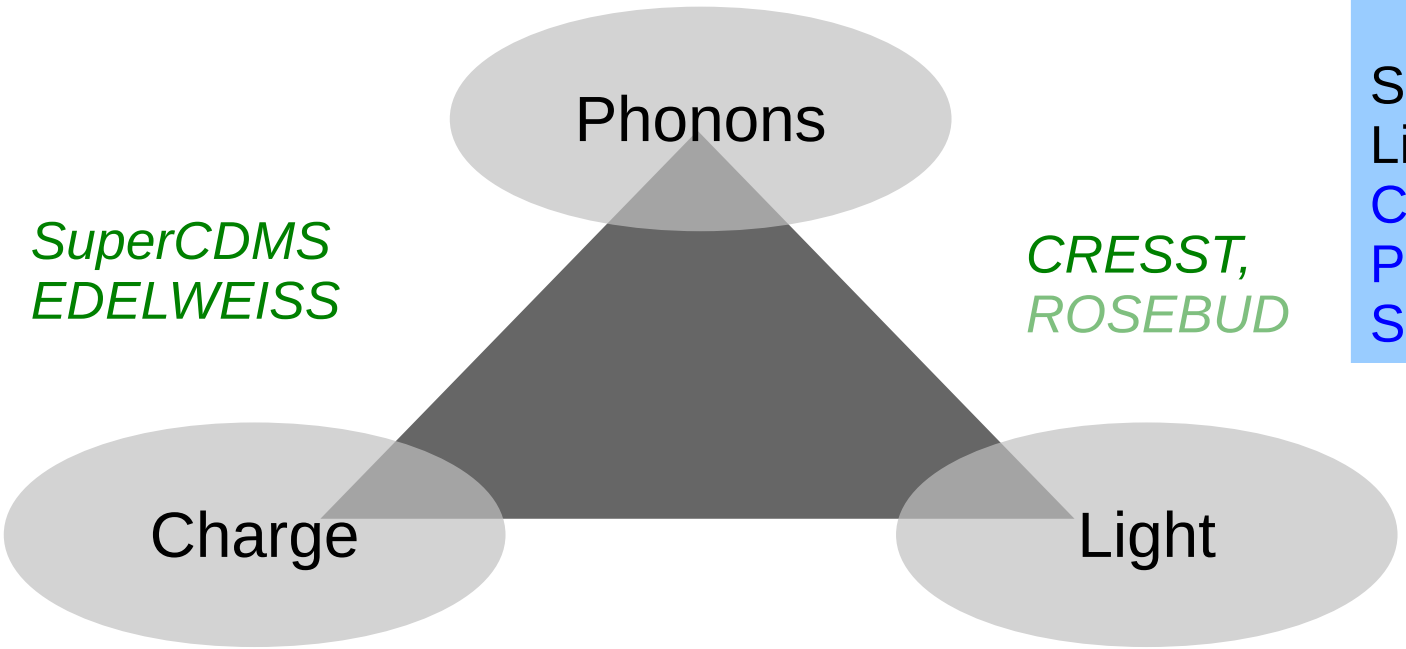
• **Dark Matter**	1	Evidence for Dark Matter	**Wed**
	2a	The Standard Halo Model	
	2b	Dark Matter Candidates	
• **Direct Detection**	3	Basics: Rates and signatures	**Thu**
	4	Backgrounds: Sources, reduction	
• **Detectors**	5	Crystals, cryogenic, directional detectors NaI, Germanium	**Fri**
	6	Cryogenic liquids Xenon and Argon	

Direct WIMP Detection: Experiments

Crystals (NaI, Ge)
Cryogenic Detectors
Liquid Noble Gases

Tracking:
DRIFT, DMTPC
MIMAC,
NEWAGE

Superheated Liquids:
COUPP ↘ PICO
PICASSO
SIMPLE



CRESST-I

SuperCDMS
EDELWEISS

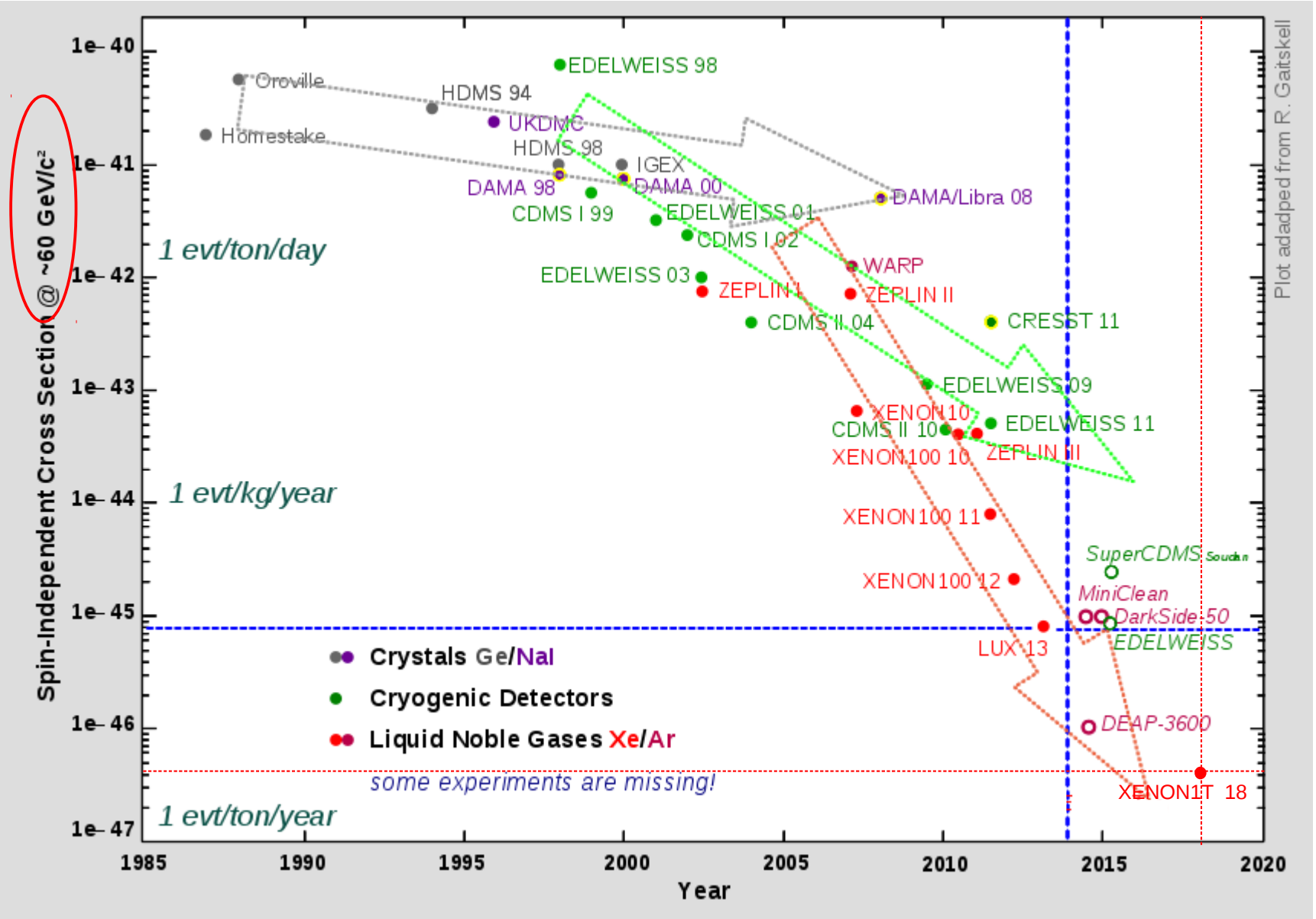
CRESST,
ROSEBUD

CoGeNT
CDEX
Texono
Malbek

XENON, LUX, LZ
ArDM, Panda-X
ZEPLIN, Darkside

DEAP
DAMA
XMASS, COSINE,
Sabre

Experimental Progress

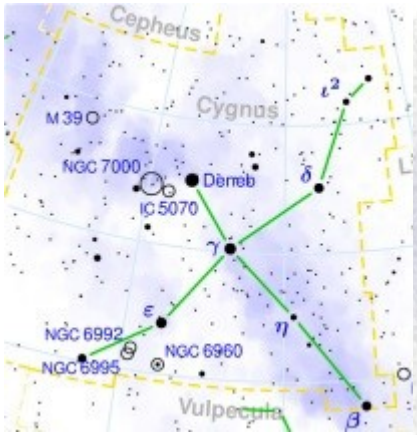


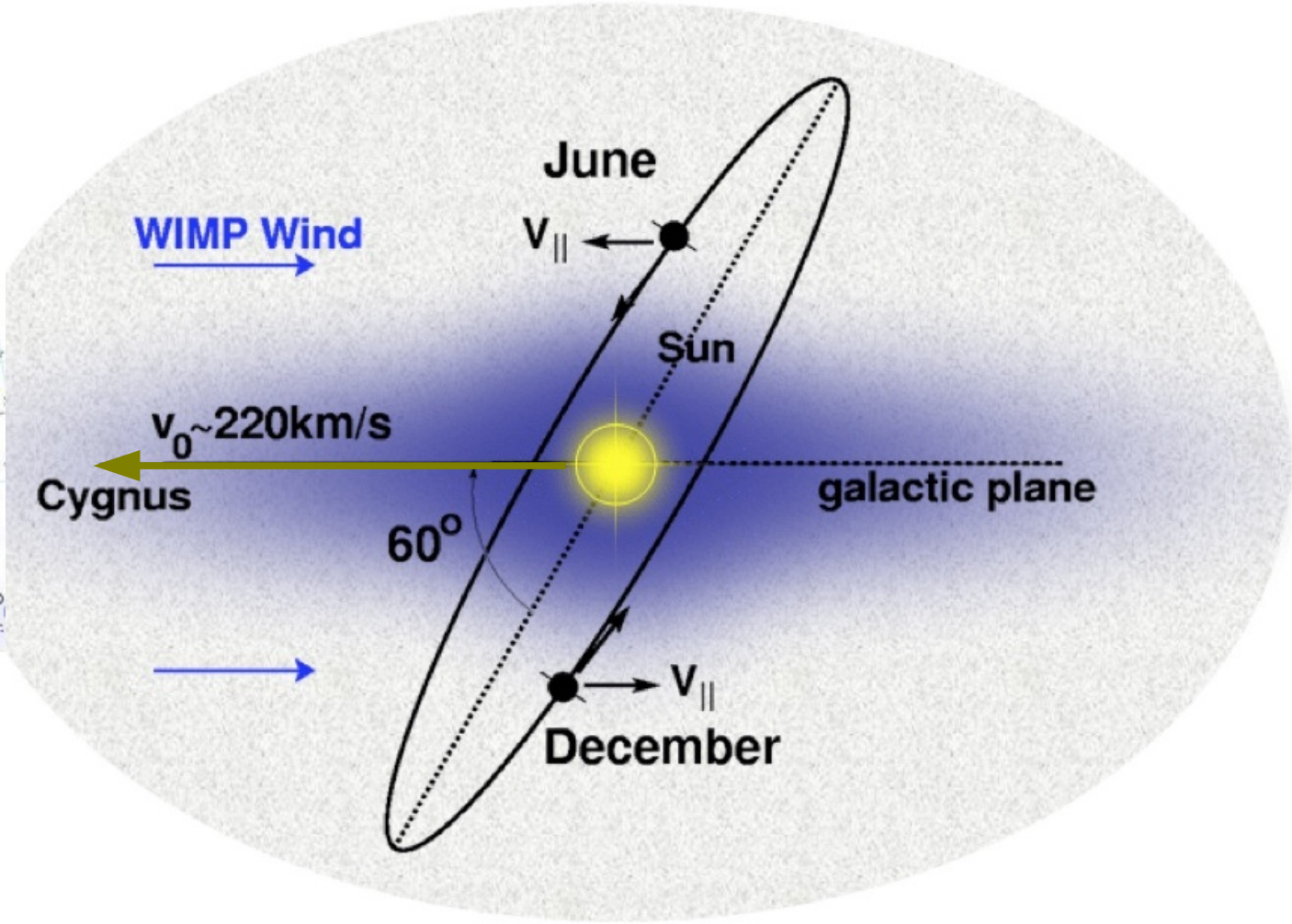
Careful! Results since 2014 not included...

3 Crystals, Cryogenic, Directional Detectors

- Crystal Detectors
  → mainly anorganic NaI, CsI sctintillators
  → also Ge
  → DAMA/Libra, COSINE, Sabre, CoGeNT
- Cryogenic Detectors
  → cooled down to mK measure lattice vibrations
  → two signals (phonons+charge, phonons+light) for signal/background discrimination
  → SuperCDMS, EDELWEISS, CRESST
- Directional Detectors
  → measure direction of nuclear recoils
  → this requires non-dense targets → very low target mass
  → DRIFT, DMTPC, NEWAGE, MIMAC

Annual Modulation



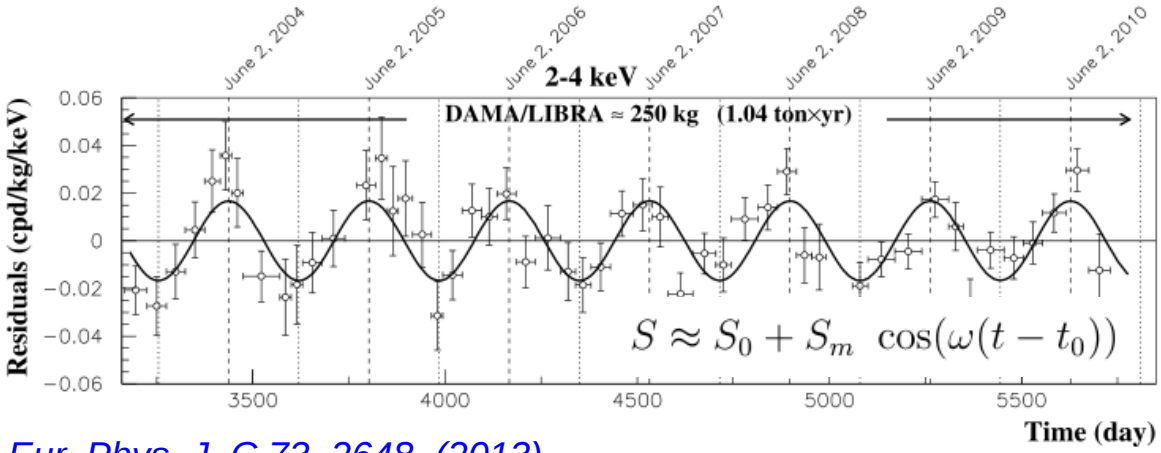


→recoil spectrum gets harder and softer during the year
→ search for annually modulating signal (3% effect)
→does not require many physical assumptions

Annual Modulation: DAMA/Libra

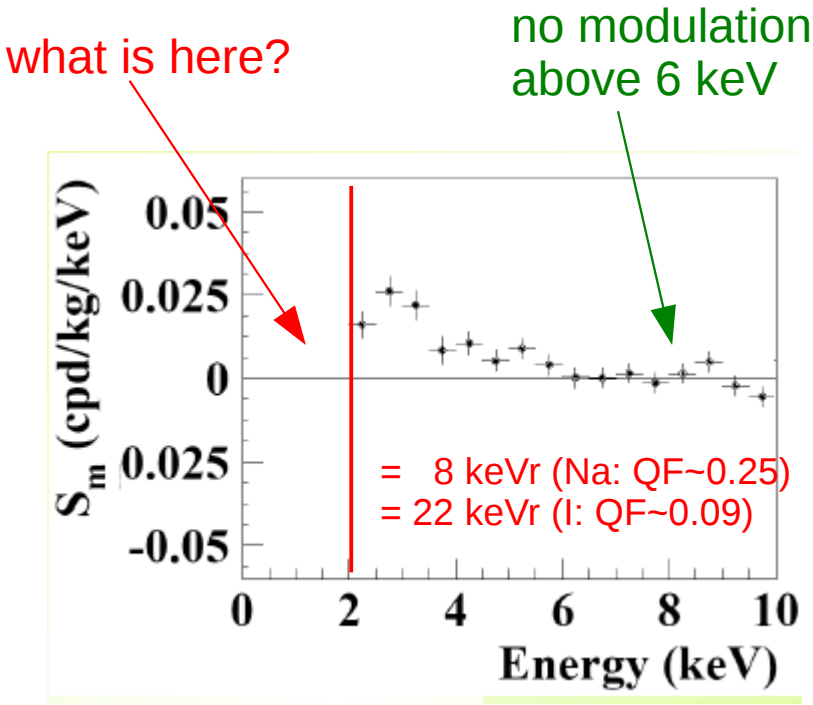
- PMTs coupled to **NaI(Tl)** Scintillators @ LNGS
  → extremely clean background necessary
- looks for annual modulation (~3% effect)
- large mass and exposure: 1.17 ton years

- DAMA finds annual modulation @ 8.9σ C.L.
- BUT: no ER/NR discrimination!



Eur. Phys. J. C 73, 2648 (2013)

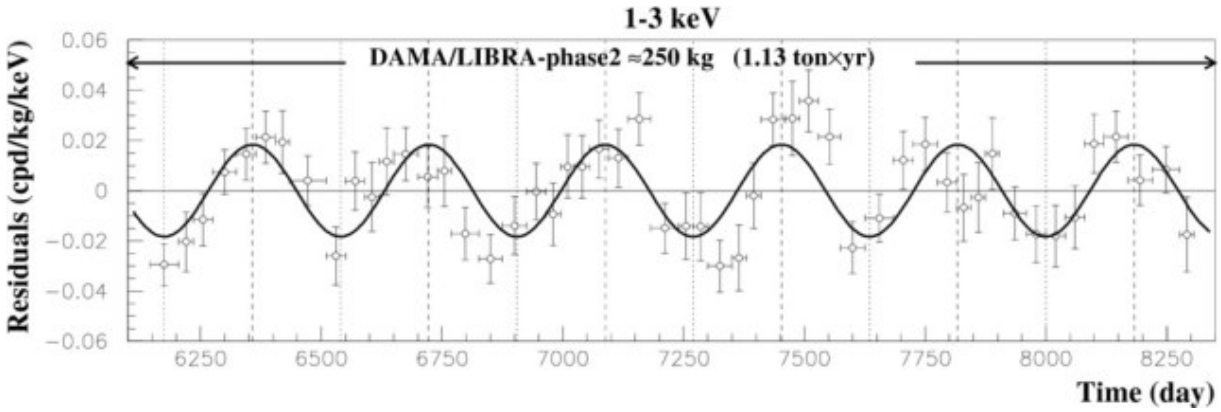
Interpretation as Dark Matter interaction
is in conflict with numerous other experiments



New: DAMA/Libra-Phase 2

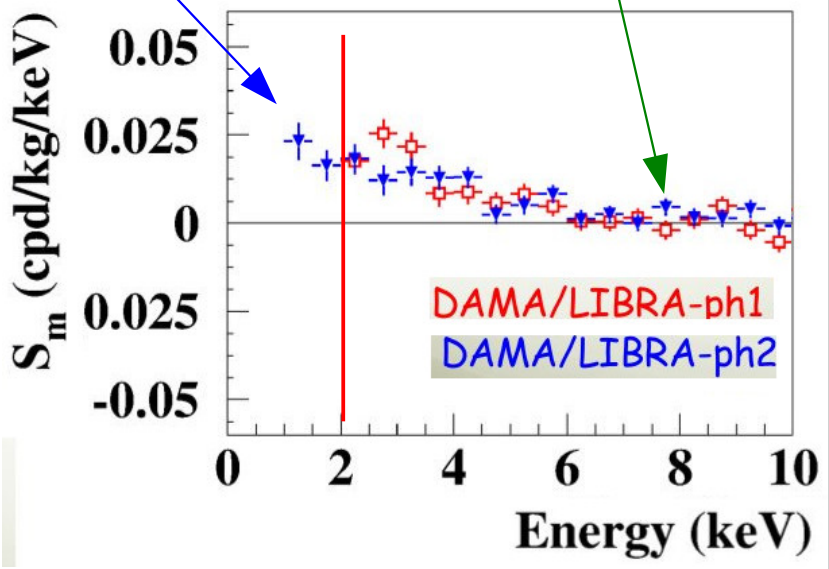
- PMTs coupled to **NaI(Tl)** Scintillators @ LNGS
  → extremely clean background necessary
- looks for annual modulation (~3% effect)
- large mass and exposure: **>2 ton years**

- DAMA finds annual modulation @ 8.9σ C.L.
- BUT: no ER/NR discrimination!



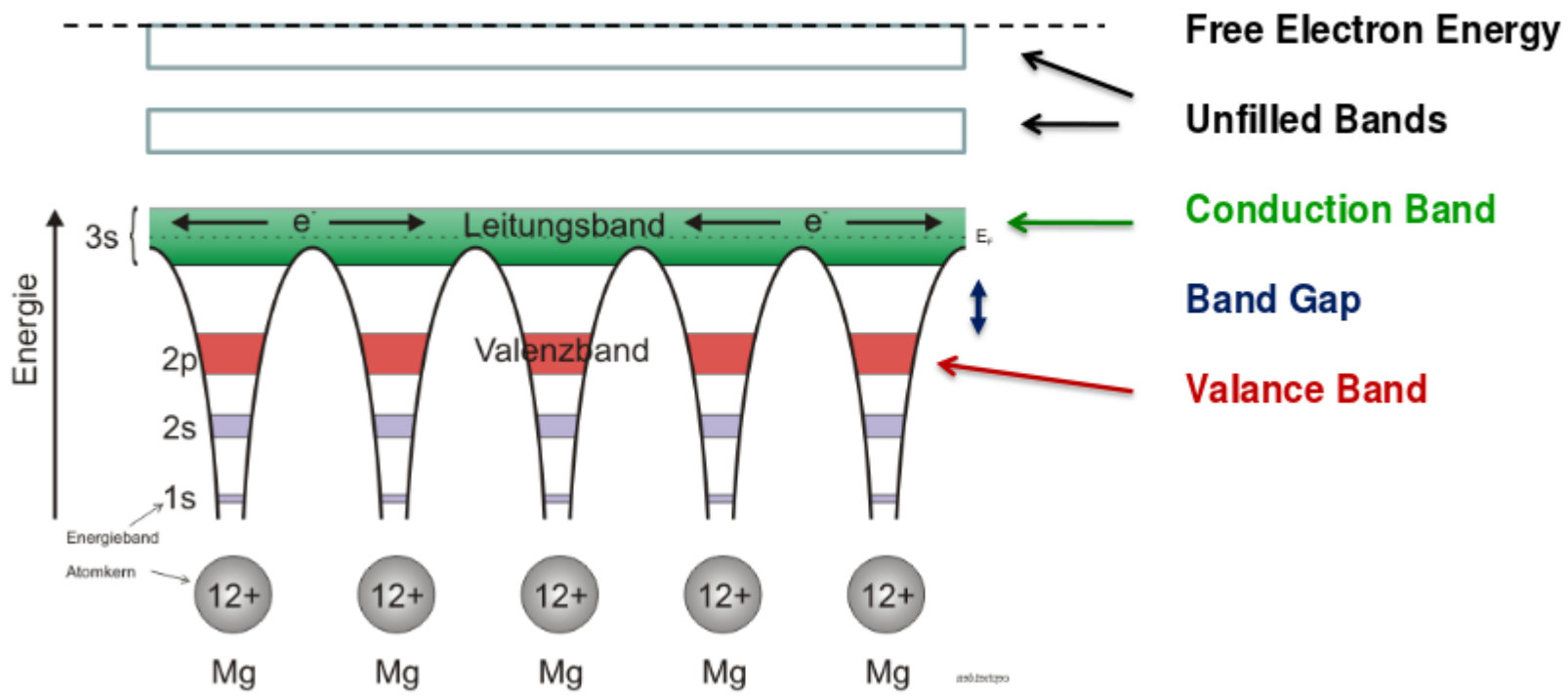
Different shape!

no modulation above 6 keV



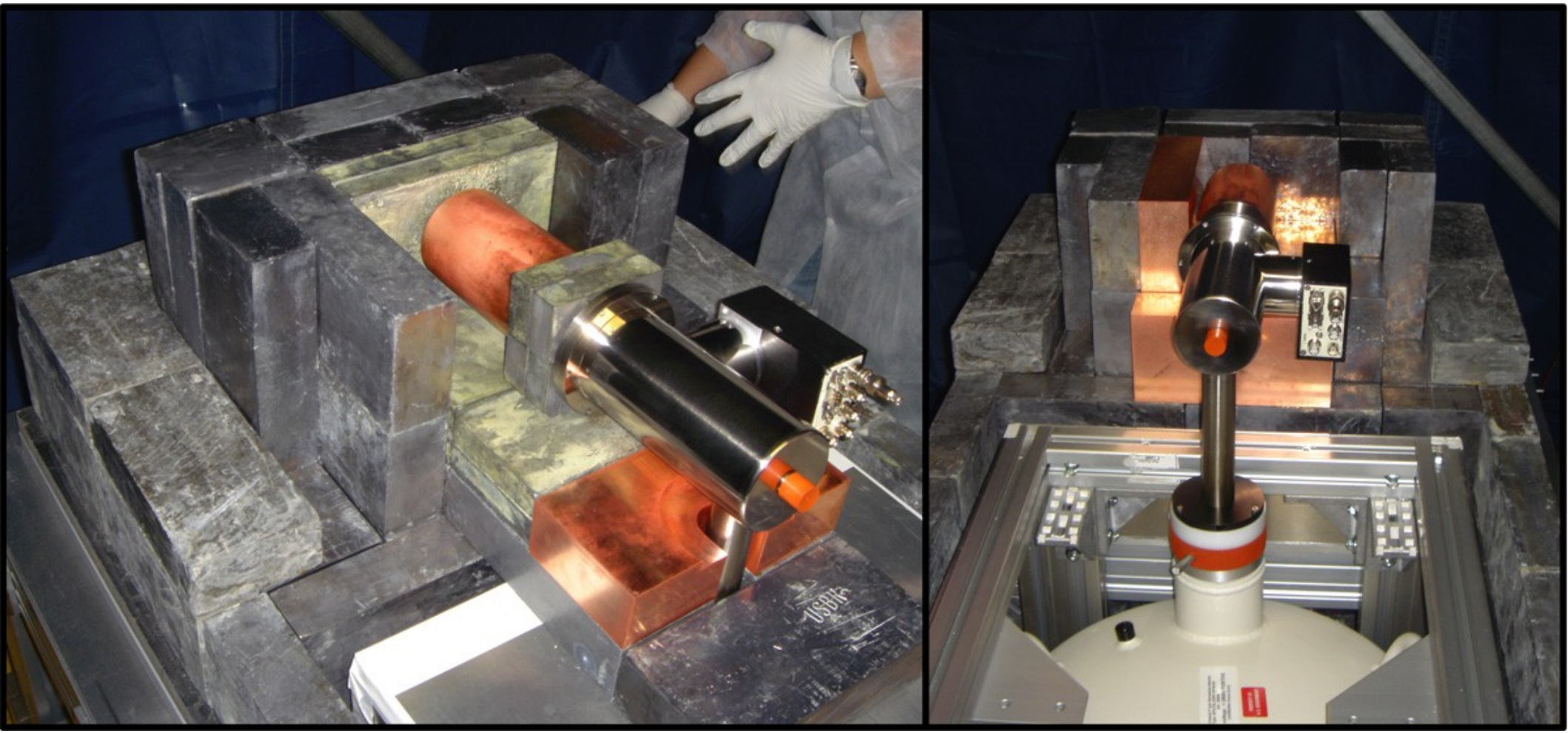
Interpretation of new DAMA results as DM interaction is in conflict with old DAMA result!

Solid state detector

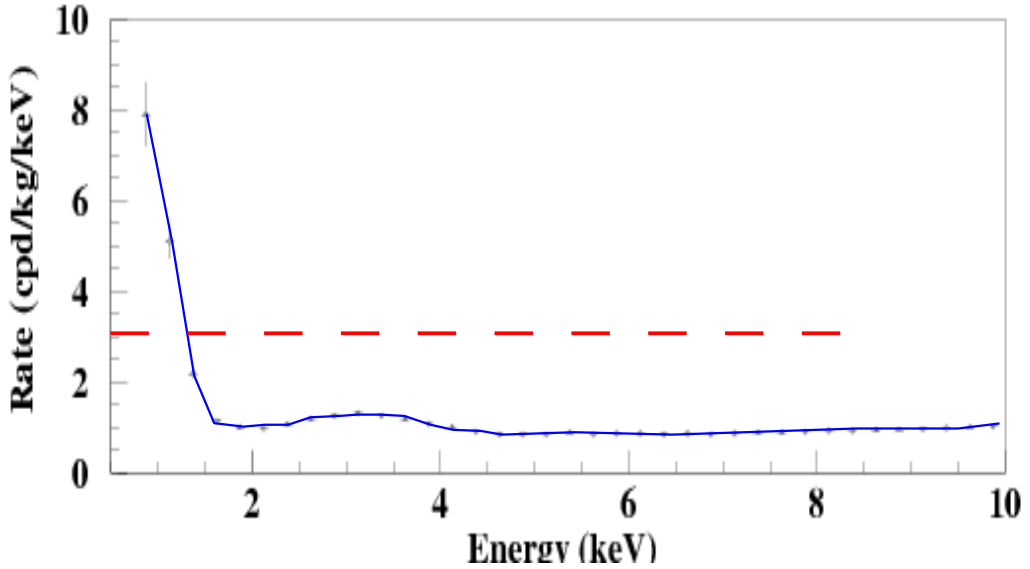


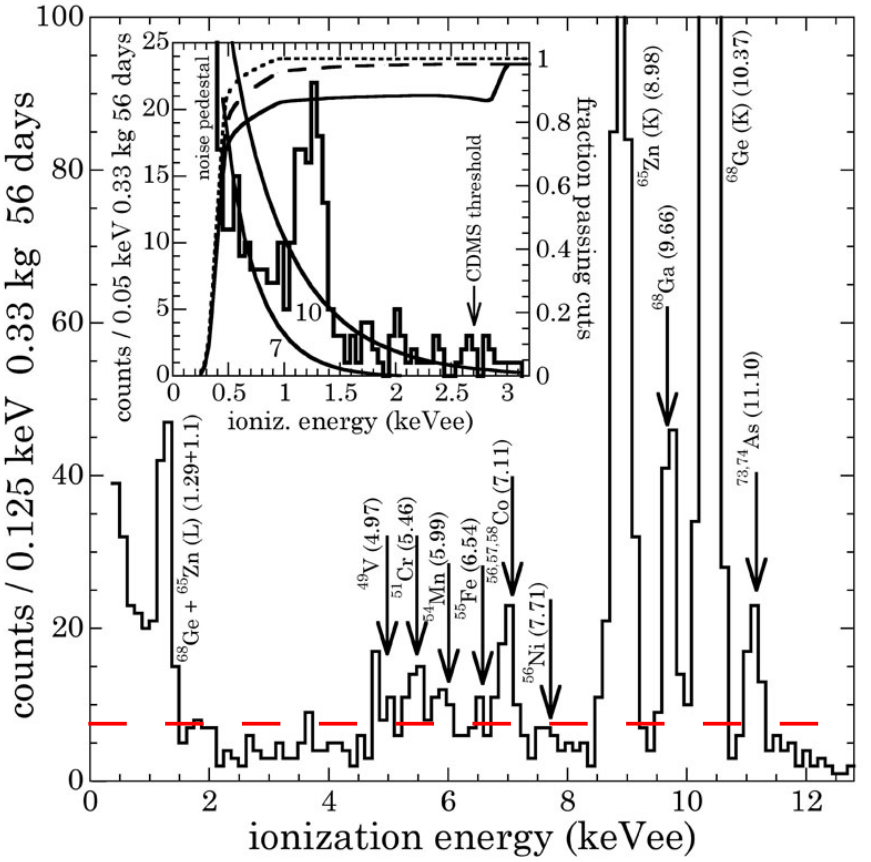
Semiconductor = band gap between valence and conduction band is small
Silicon = 1.12 eV, Germanium = 0.66 eV

CoGeNT



Low Energy Spectra

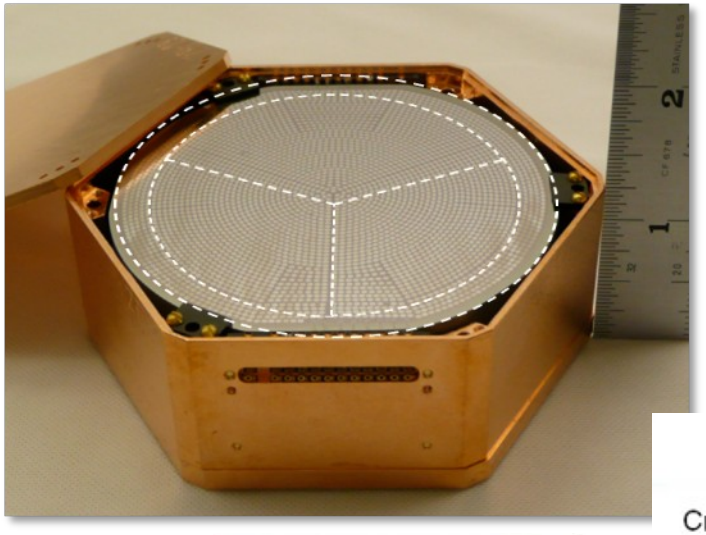


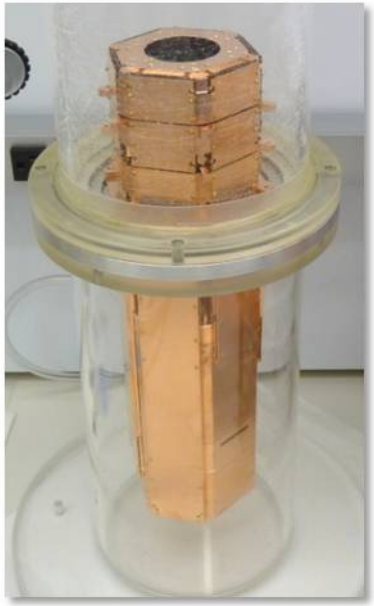


NaI: DAMA/LIBRA

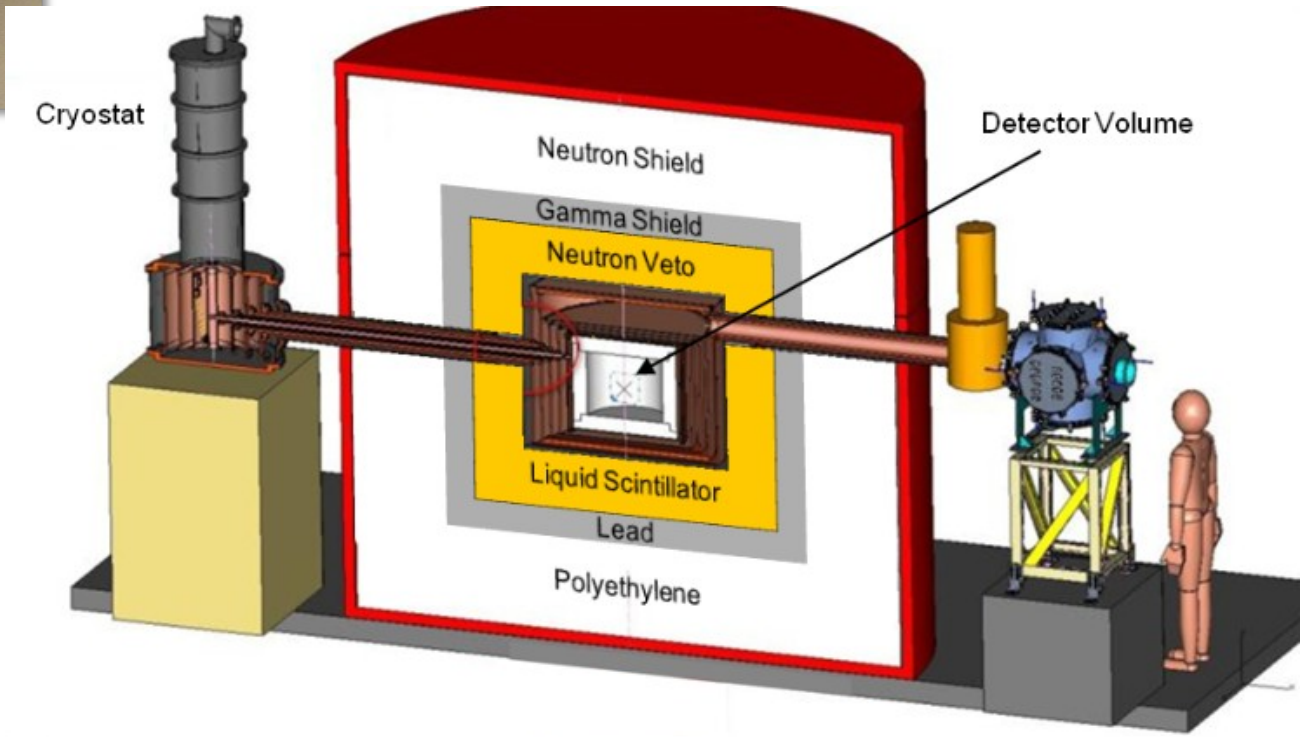
Ge: CoGeNT

SuperCDMS

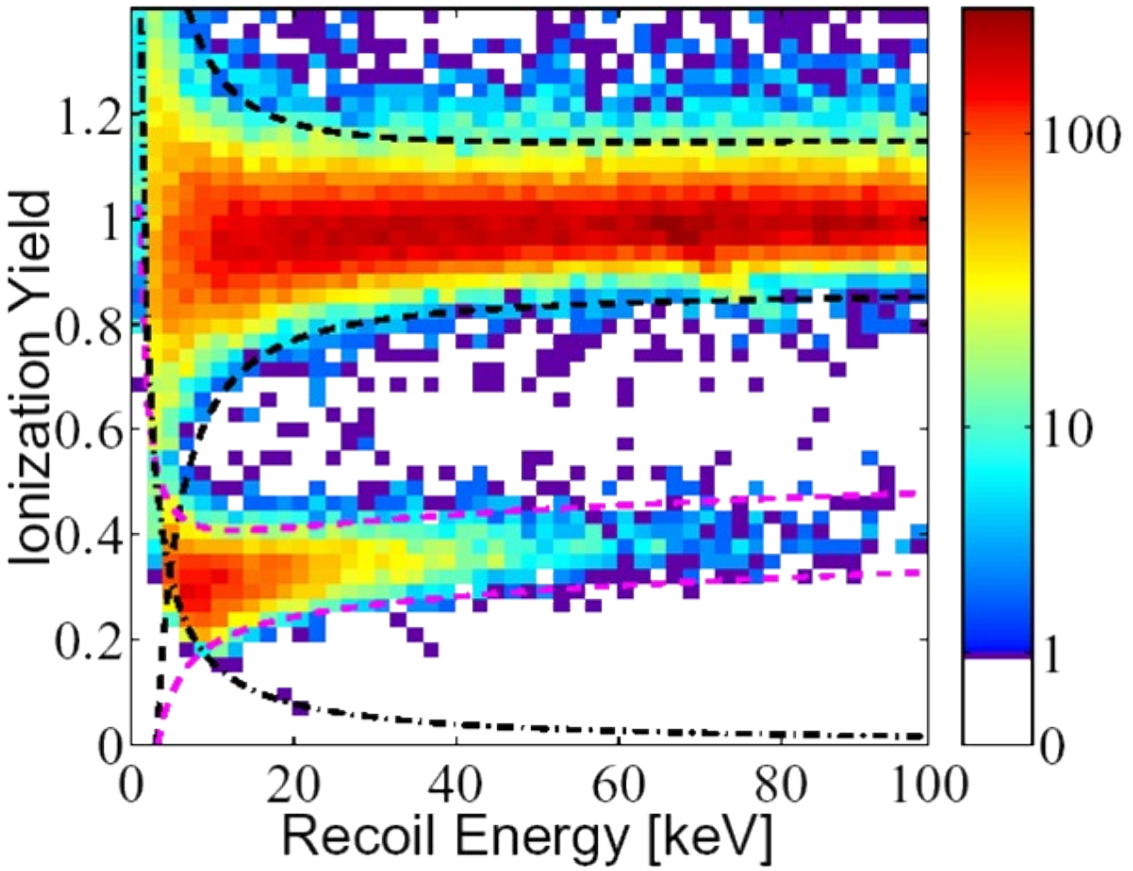




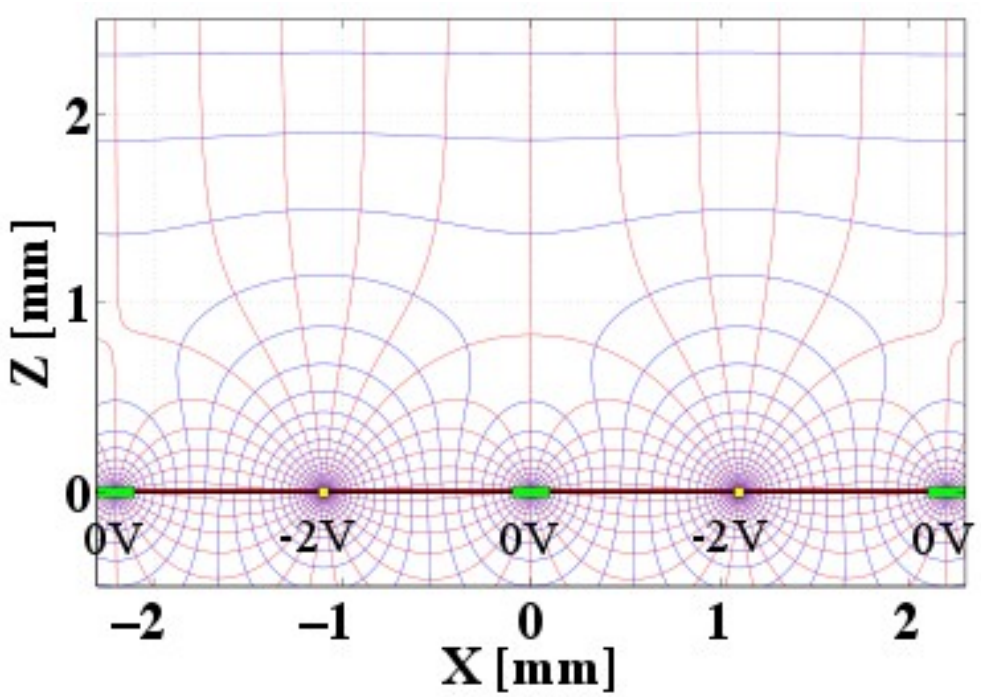
- 600 g iZIP detectors, 1“ thick
  → larger prototypes (10cm x 3.8 cm under study)
- was at Soudan → now moved to SNOLAB

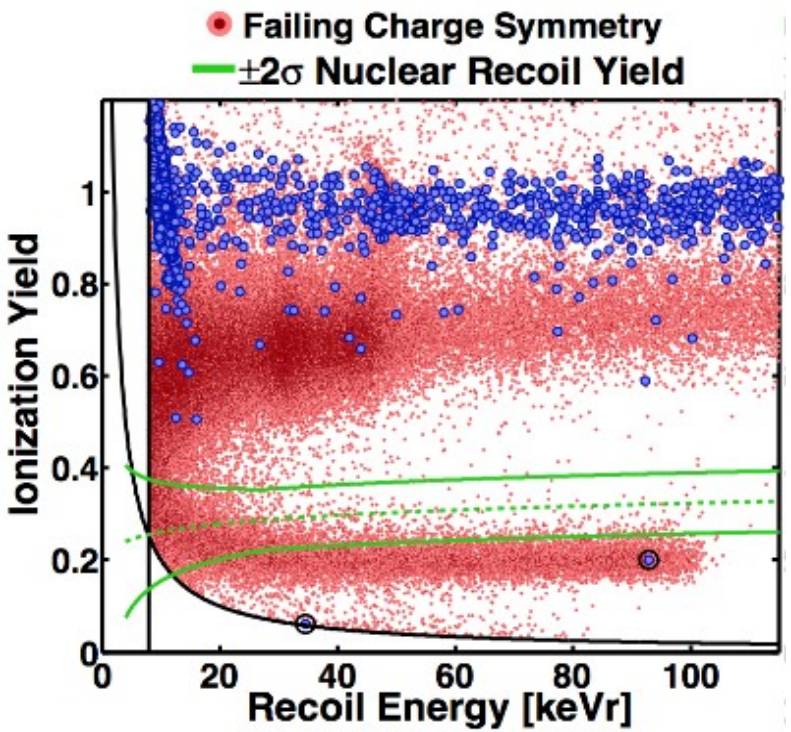


Cryogenic Detectors: Discrimination



SuperCDMS: Surface Event Rejection

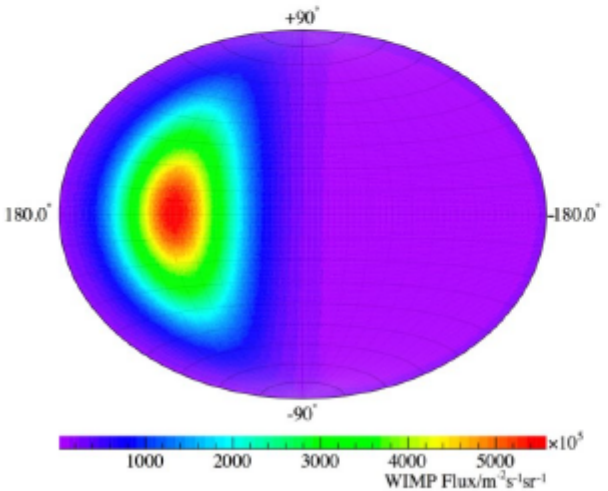




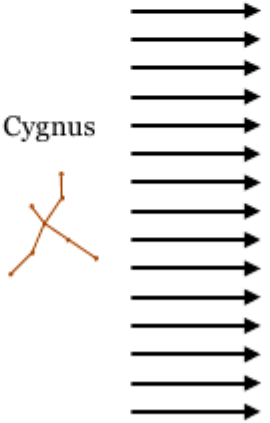
Appl.Phys.Lett. 103 (2013) 164105

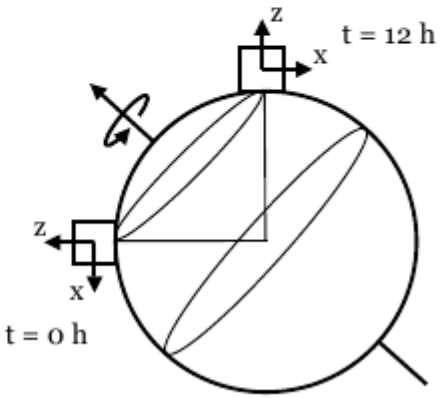
WIMP Signatures: Directionality

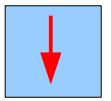
- The Earth's motion with respected to the Galactic rest frame produces a direction dependance of the recoil spectrum
- The peak WIMP flux comes from the direction of the solar motion, which points towards the constellation Cygnus
- Assuming a smooth WIMP distribution, the recoil rate is then peaked in the opposite direction
- In the laboratory frame, this direction varies over the course of a sidereal day due to the Earth's rotation
- This effect can provide a robust signature for a Galactic origin of a WIMP signal



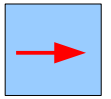
Projection of the WIMP flux in Galactic coordinates







0h



12h

→ daily modulation!

BUT: detector must be able to detect direction of recoils;
up to now this only works in very „non-dense" detectors

Track Detection

DM-TPC

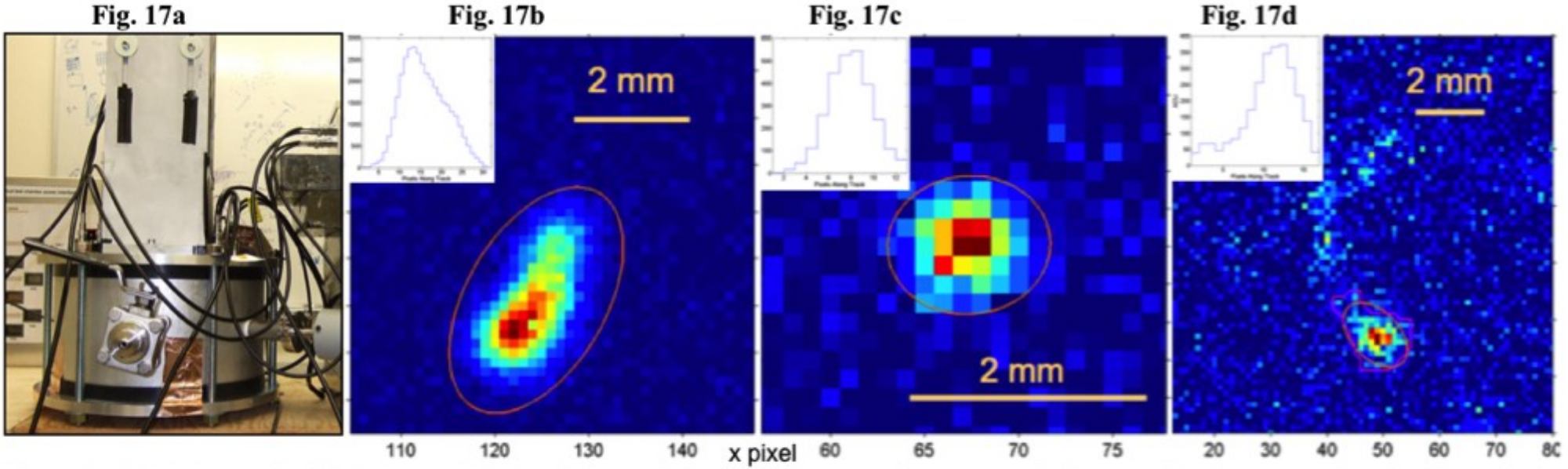
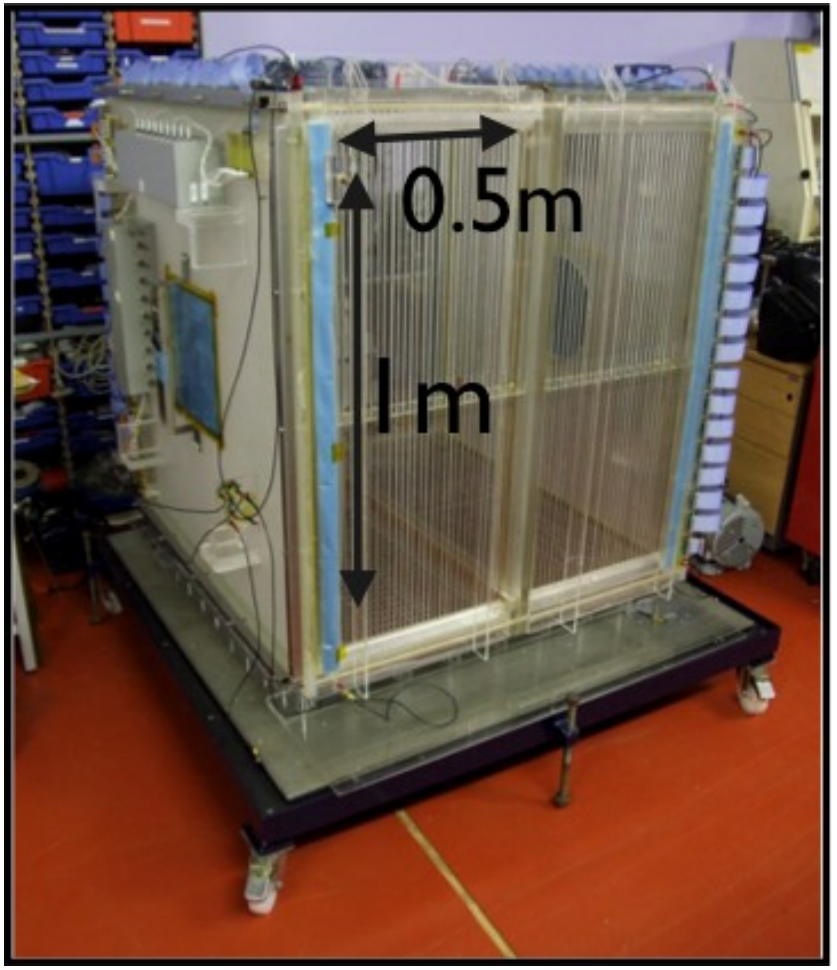


Fig. 17: (a) UNM optical CCD test TCP - with particle tracking event images as follows with skewness head-tail analysis inset, (b) example high energy 178 keV F recoil showing clear head-tail, (c) very low energy F recoil event of 10 keV_{ee} (23 keV_{rec}) still shows asymmetry skewness, (d) similar energy electron recoil (9.7 keV_{ee}) shows clearly different dE/dx morphology with segmentation of track (see text for refs).

DRIFT-II @ Boulby (GB)



4 Cryogenic Liquids

- The liquefied (→ cryogenic) noble liquids Xe and Ar are excellent scintillators and ionizers
  - → single phase: measure as much as light as possible
    DEAP-3600, ~~CLEAN~~, ~~XMASS~~
  - → dual phase TPCs: measure light and charge
    XENON1T, ~~LUX~~, Panda-X, DarkSide → XENONnT, LZ
- The detectors have position sensitivity
  - → fiducialization
  - → multiple scatter rejection
- Background reduction
  - → charge/light ratio and scintillation pulse shape (Ar)
- A path towards massive future detectors
  - → ton-scale experiment already taking science data

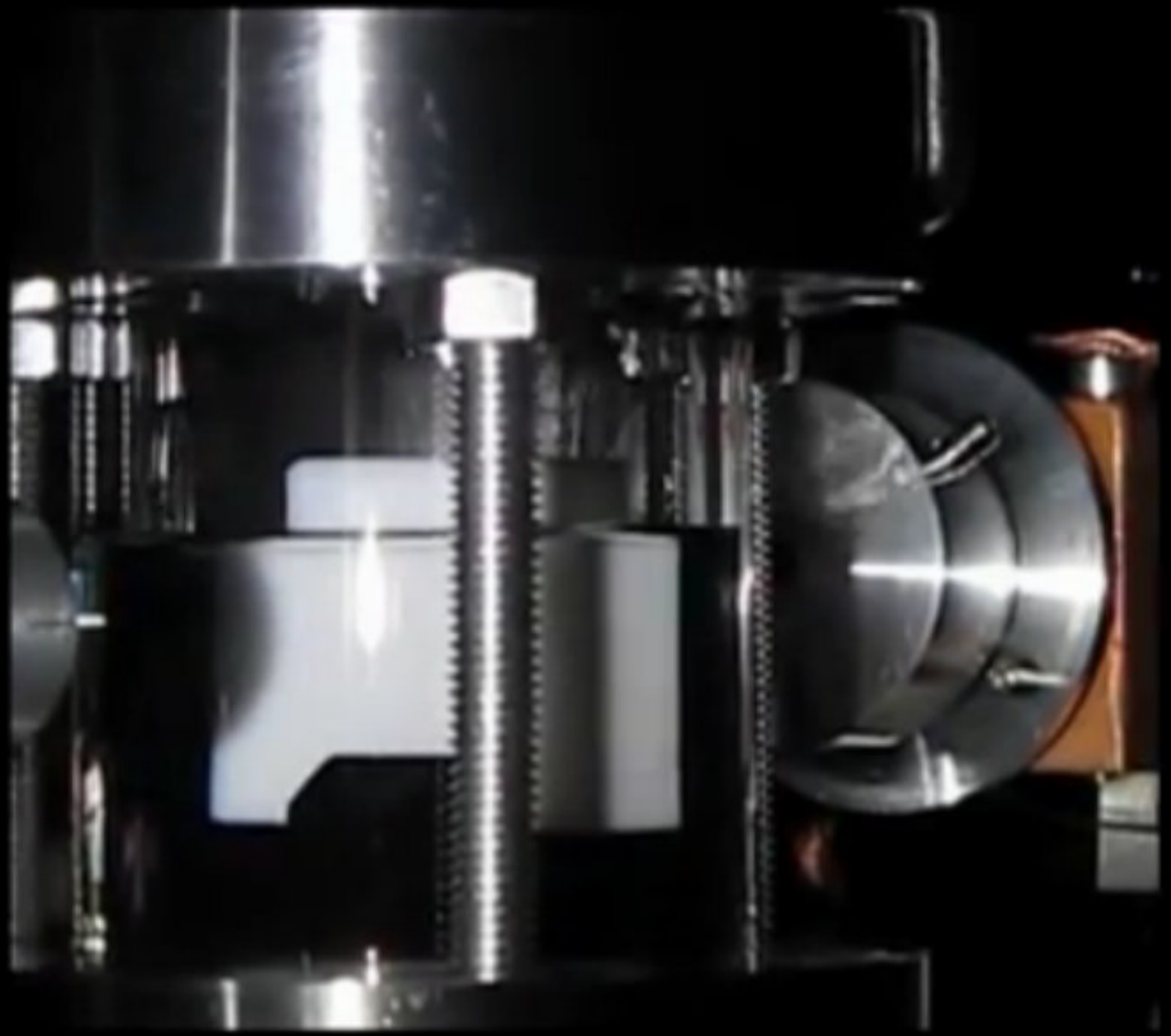
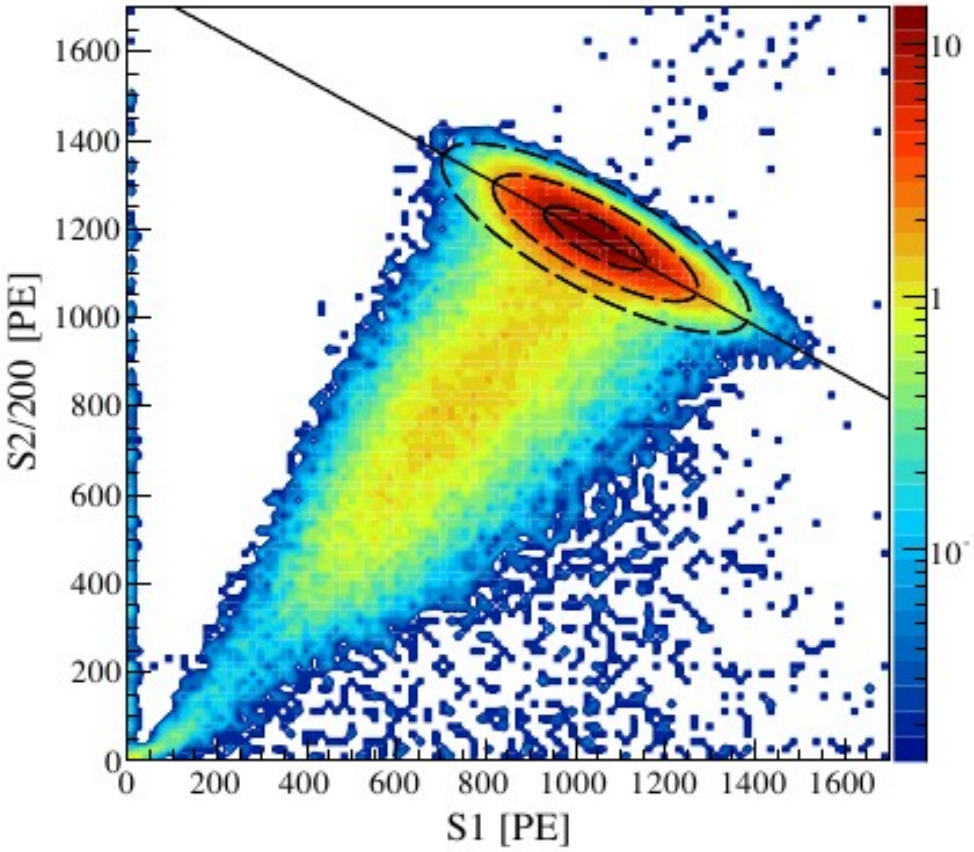


Image from C. Levy (U Münster)

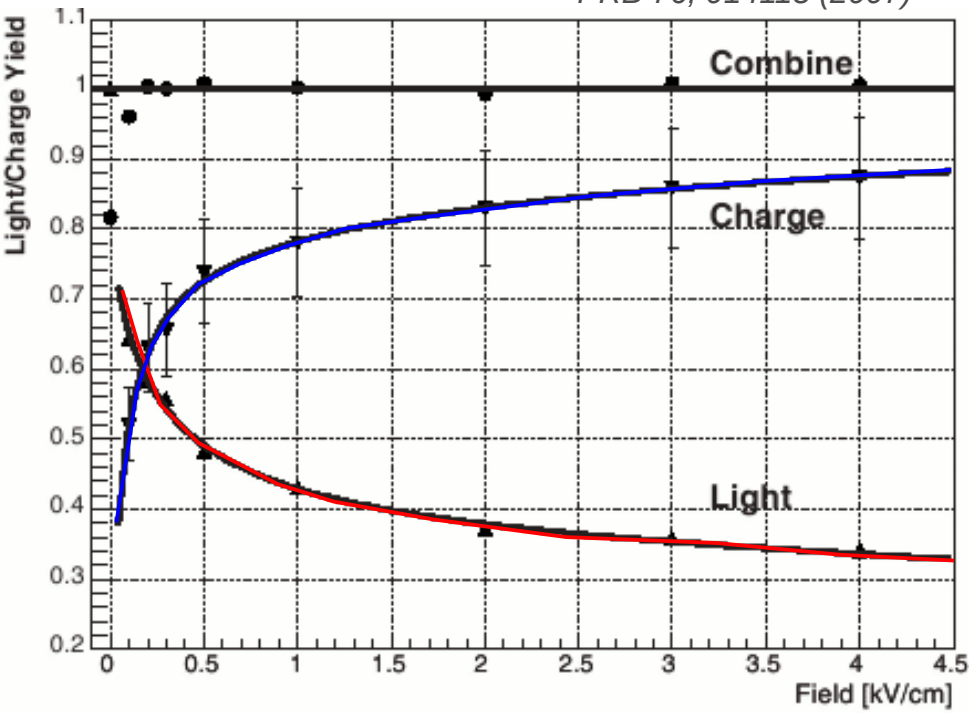
Light-Charge anti-Correlation

LXe examples

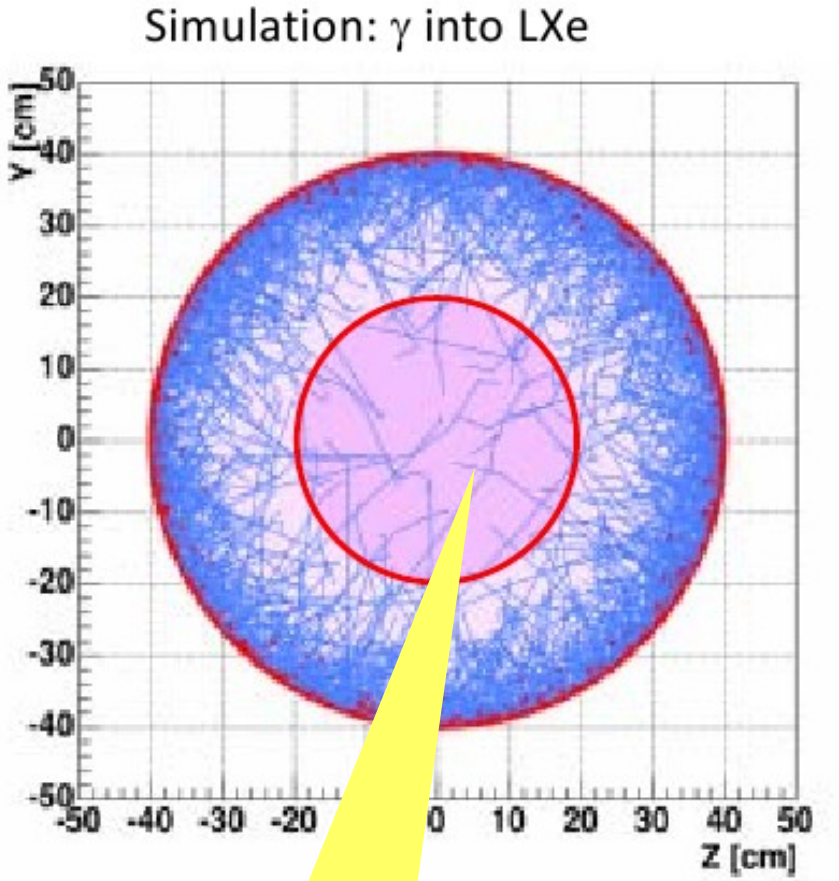
Astropart. Phys 35, 573 (2011)



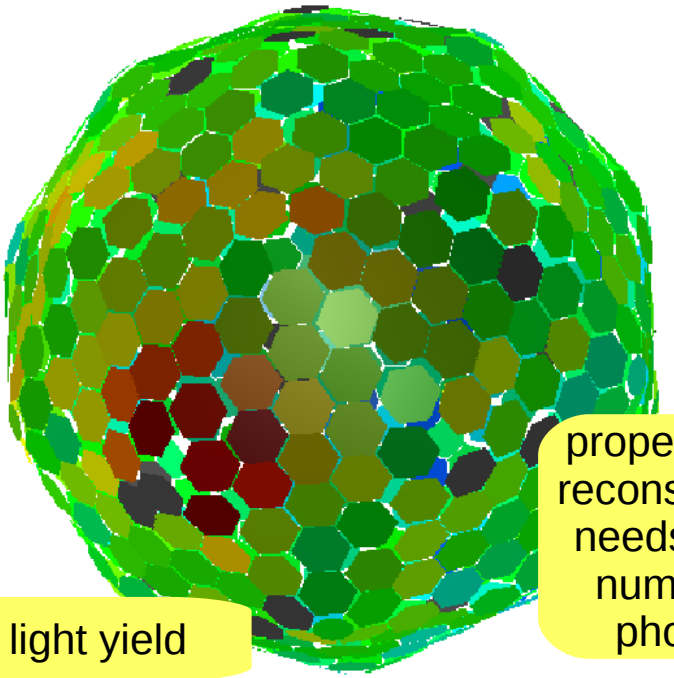
PRB 76, 014115 (2007)



Single Phase Detector

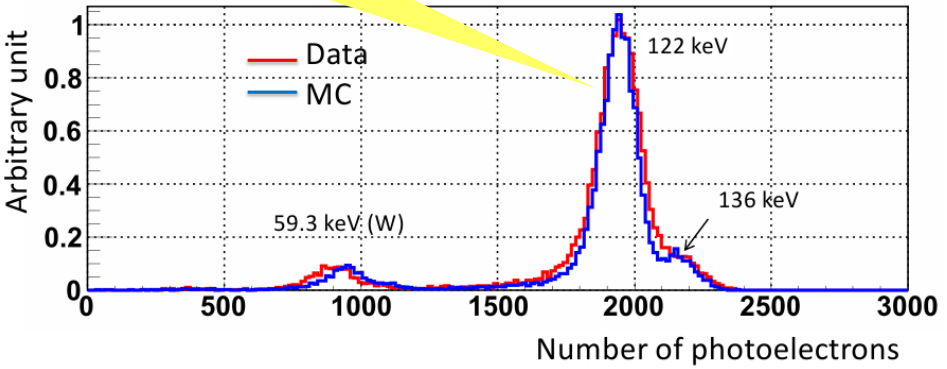


very low background



proper vertex reconstruction needs huge number of photons

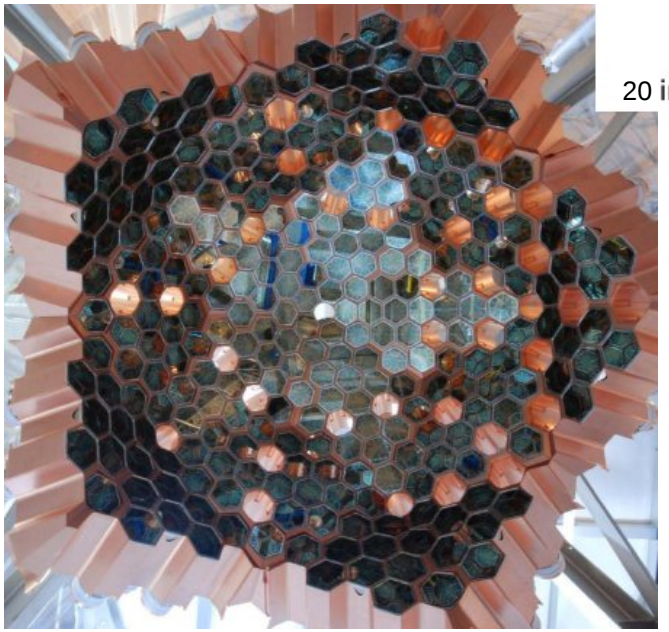
very high light yield

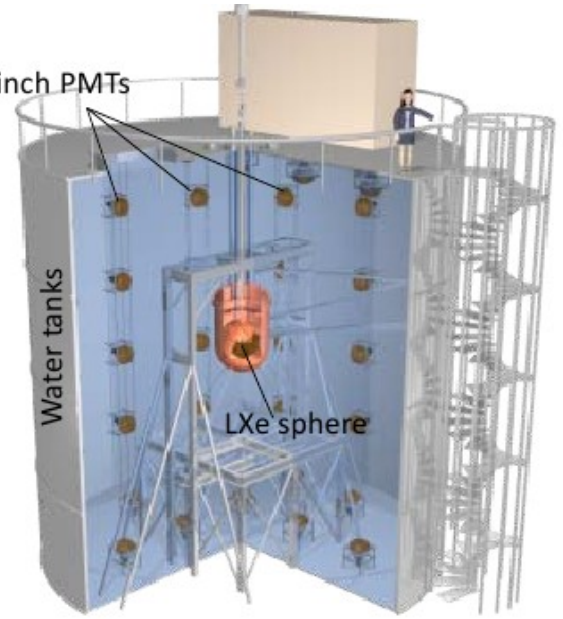


Figures from XMASS

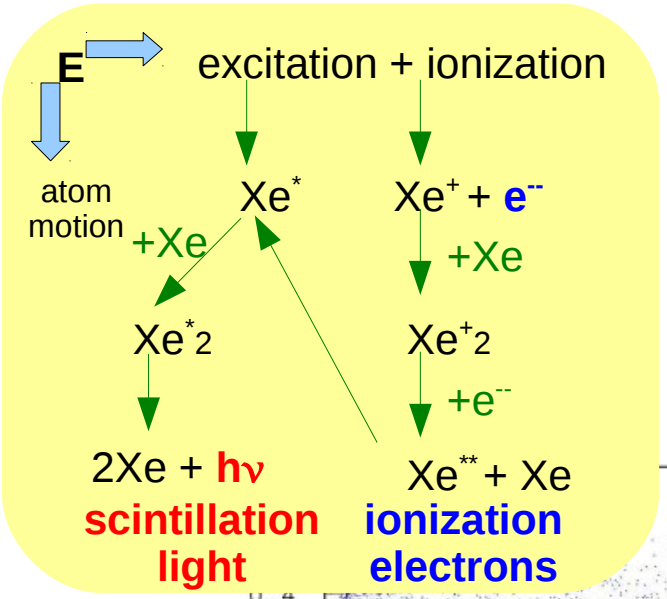
XMASS

- single phase **LXe** detector
- 800kg total, 100kg fiducial mass
- 60% of surface covered with 642 hexagonal PMTs
- very high LY
- located in Kamioka (JP)



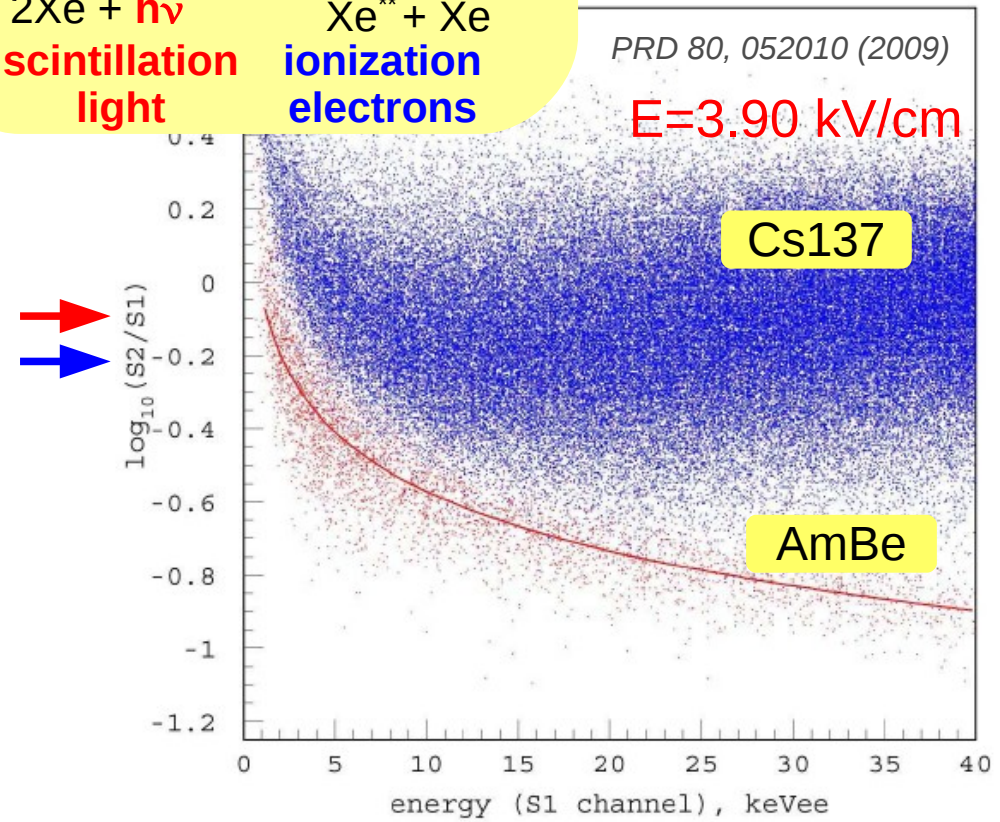


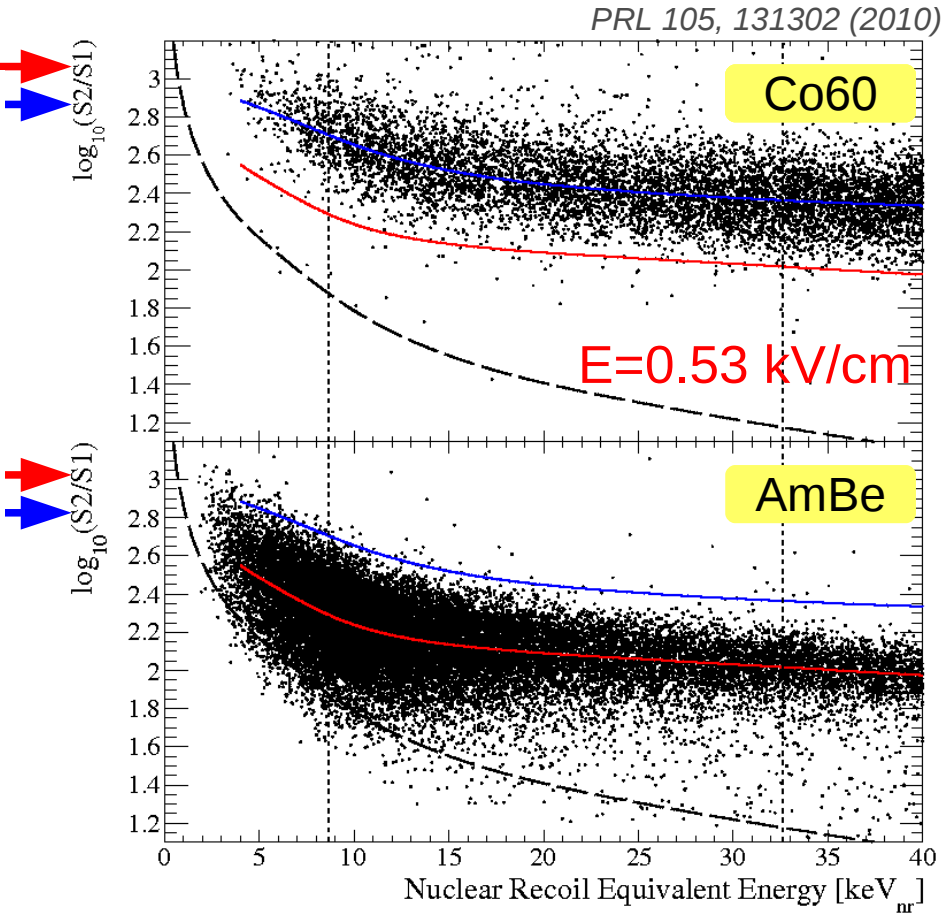
- **→ will not continue beyond 2018**
  most of XMASS collaboration joined XENON project



Charge/Light Ratio

Charge/Light ratio depends on d*E*/d*x* → discrimination

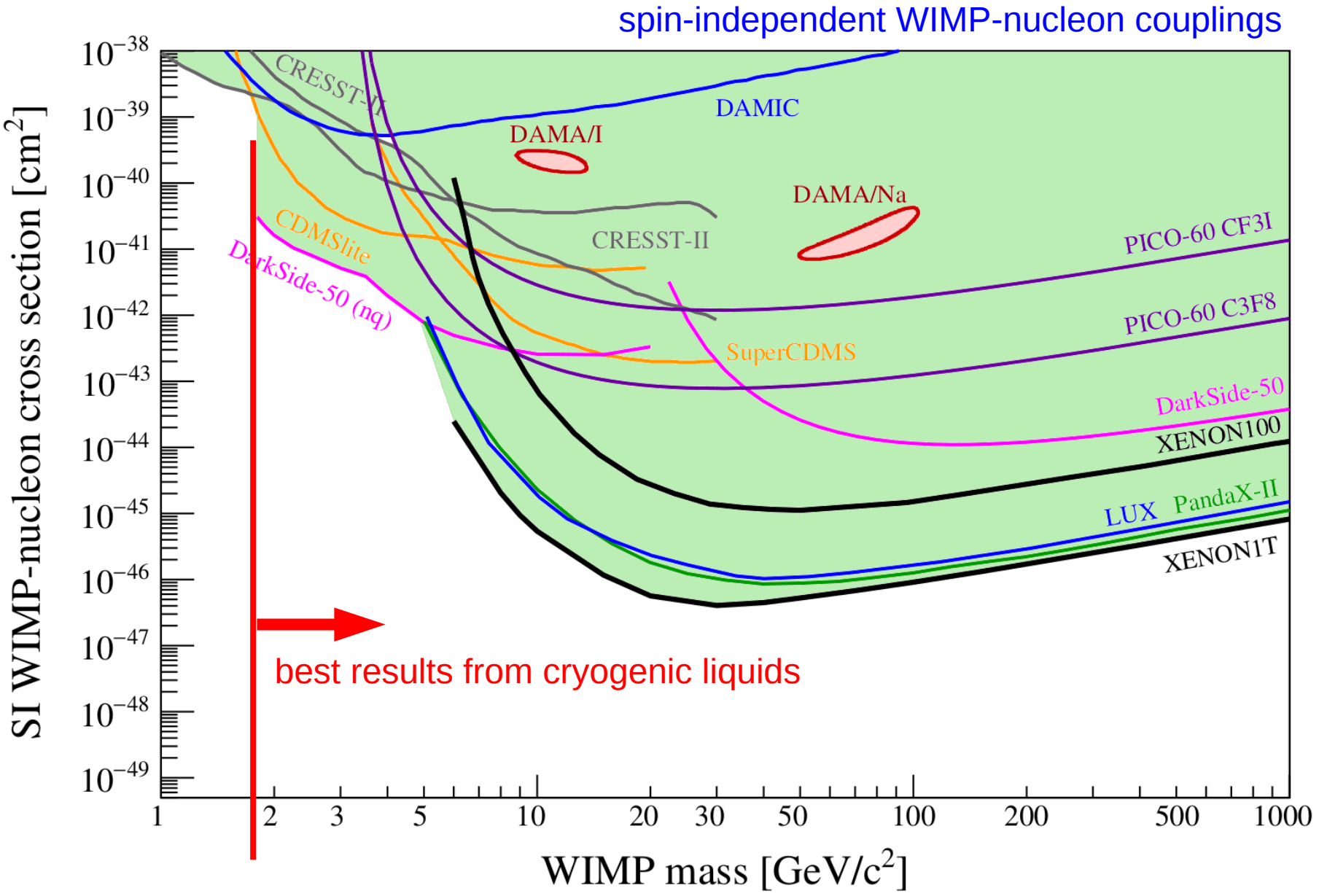




ZEPLIN-III
~99.99% rejection @ 50% acceptance

XENON100
~99.5% rejection @ 50% acceptance

Direct Detection: Current Status




XENON1T @ LNGS
Xe
XENON
Dark Matter Project
EPJ C 77, 881 (2017)
XENON
Matter Project

XENON1T @ LNGS

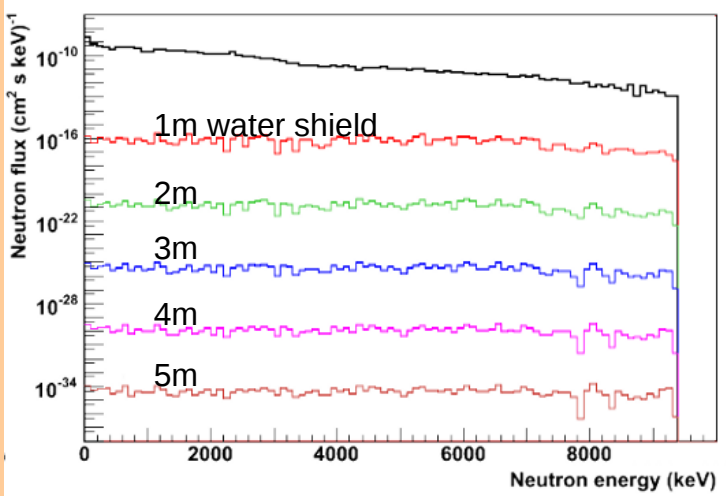
XENON Dark Matter Project

EPJ C 77, 881 (2017)

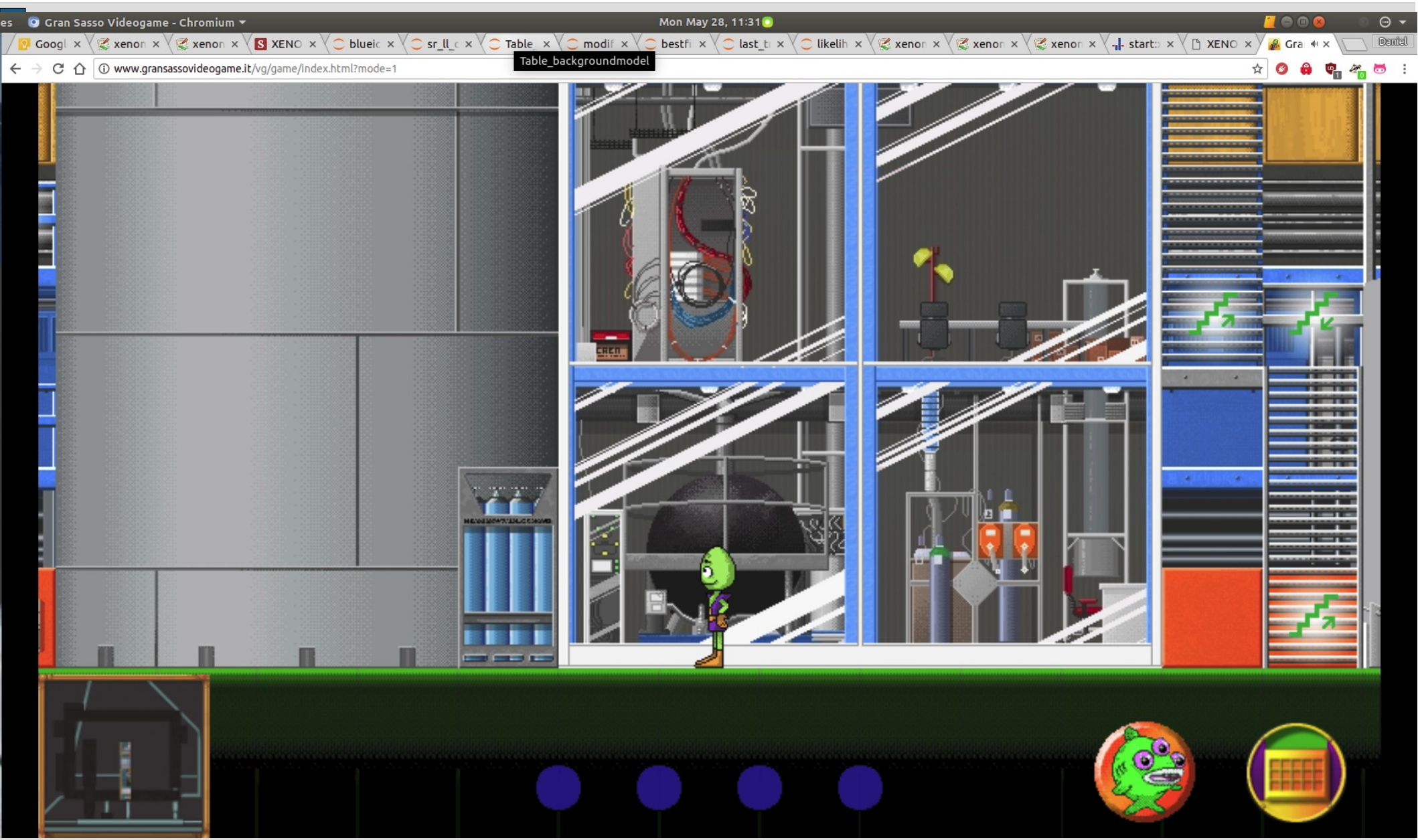
Water Cerenkov Shield

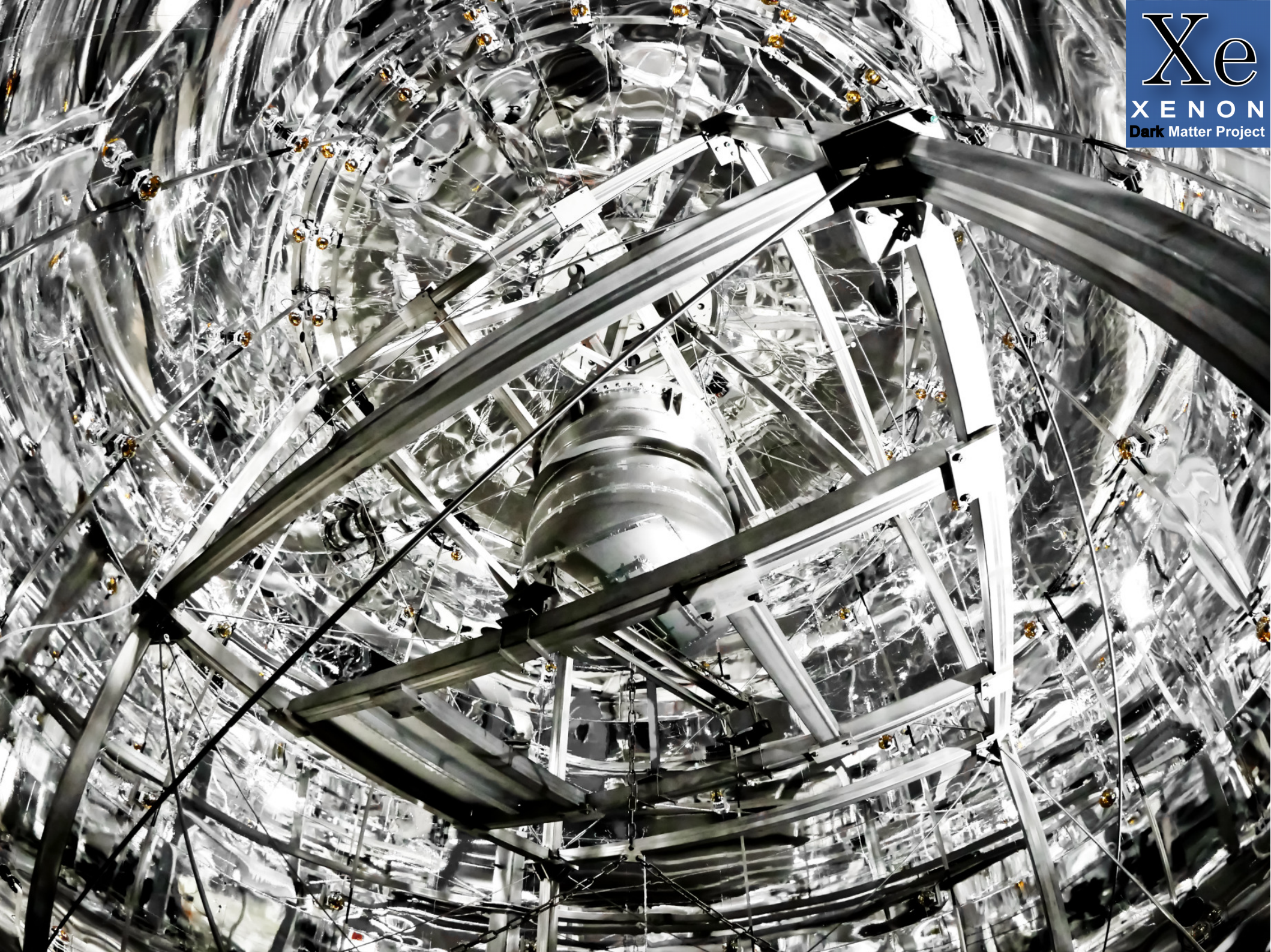
- 9.6m diameter, 10m height
- external γ, neutrons irrelevant
- muon induced NRs irrelevant

→ dominating background of XENON1T will be intrinsic



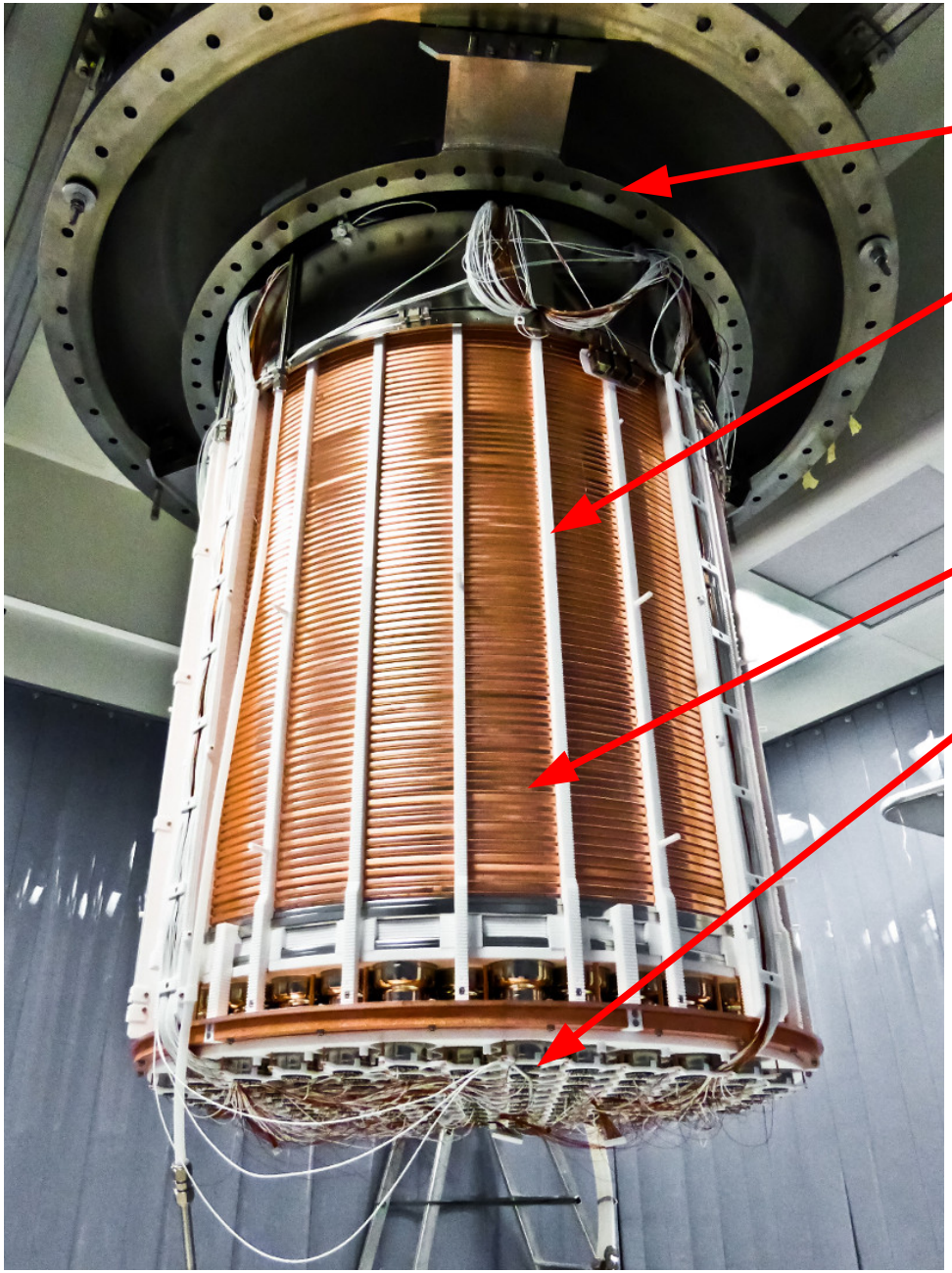
XENON1T @ www.gransassovideogame.it




Xe
XENON
Dark Matter Project


Xe
XENON
Dark Matter Project

XENON1T



Low-background stainless steel cryostats

dual-phase LXe TPC
- total mass ~3.2 t
- active mass ~2.0 t
- fiducial mass: ~1 t

TPC made from OFH Cu and PTFE

248 photomultipliers
- Hamamatsu R11410-21
- low background
- high QE (36% @ 178nm)
- extensive testing in cryogenic environments

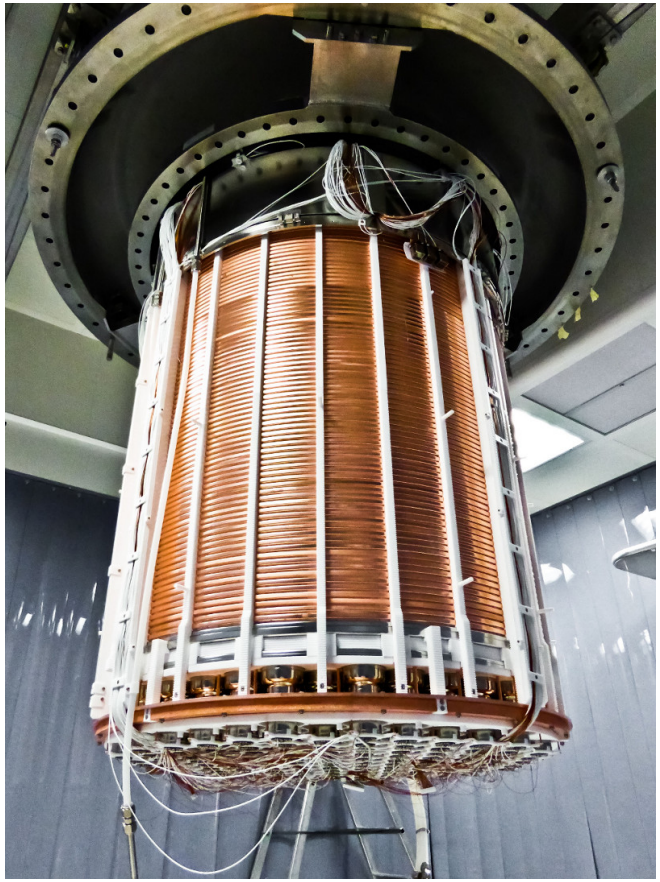
JINST 8, P04026 (2013)

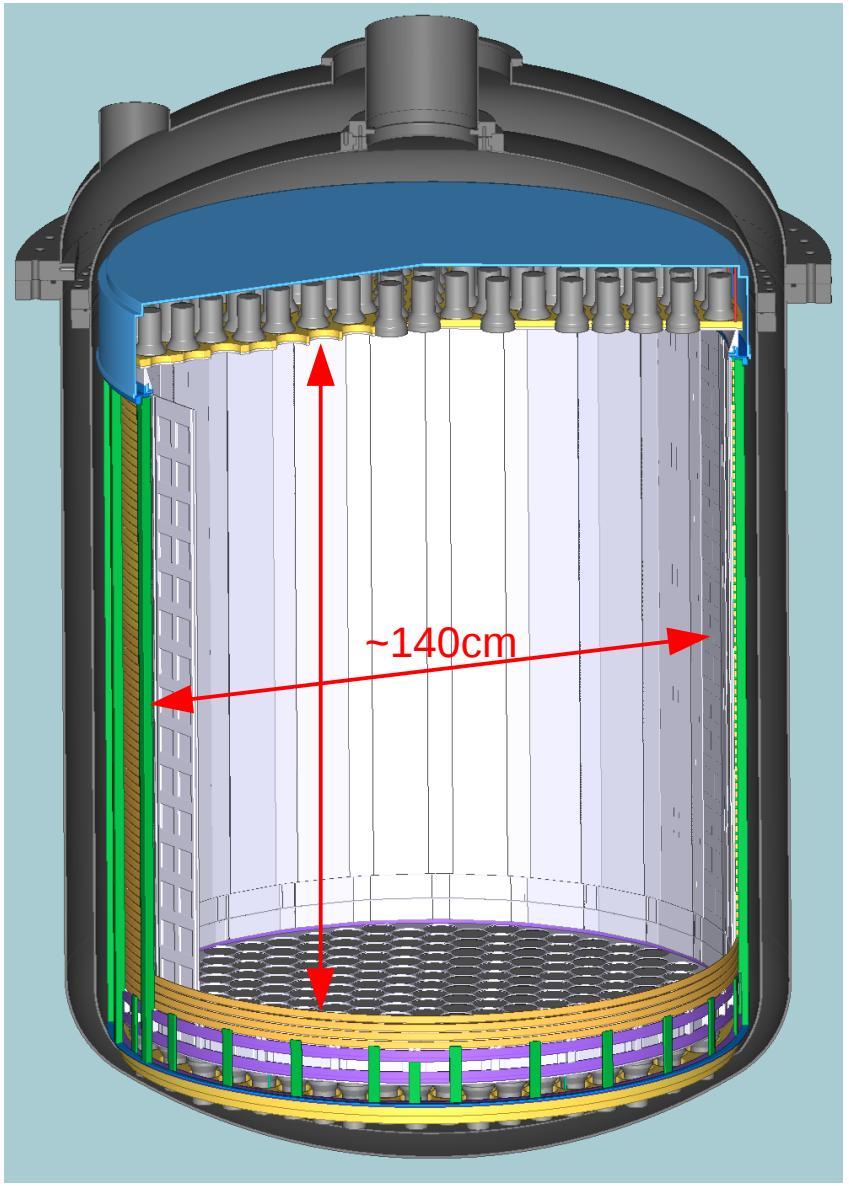
XENON1T → XENONnT

JCAP 04, 027 (2016)

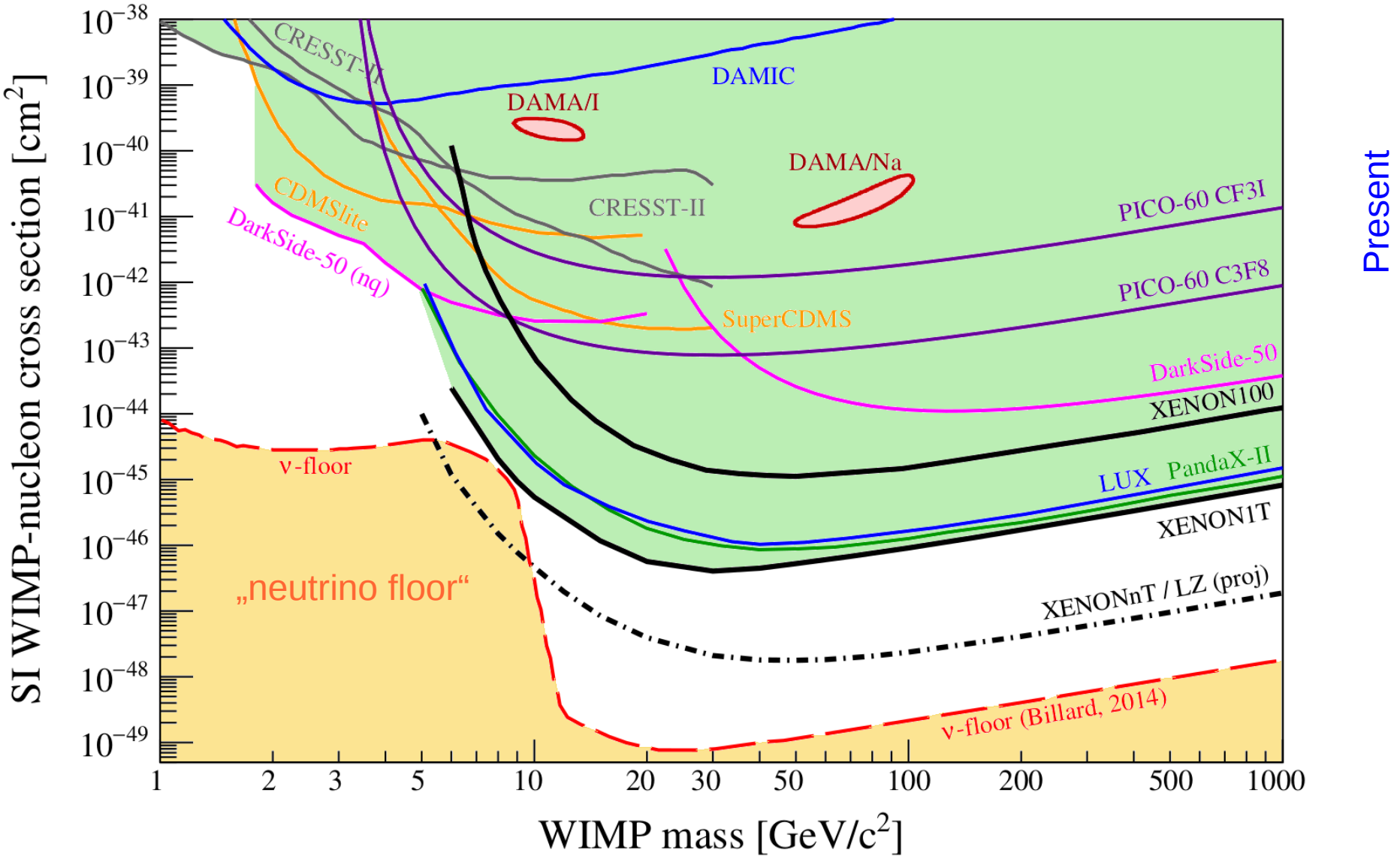
XENON1T
- **2t** active LXe target
- taking data

XENONnT
- **5.9t** active target
- science run in 2019



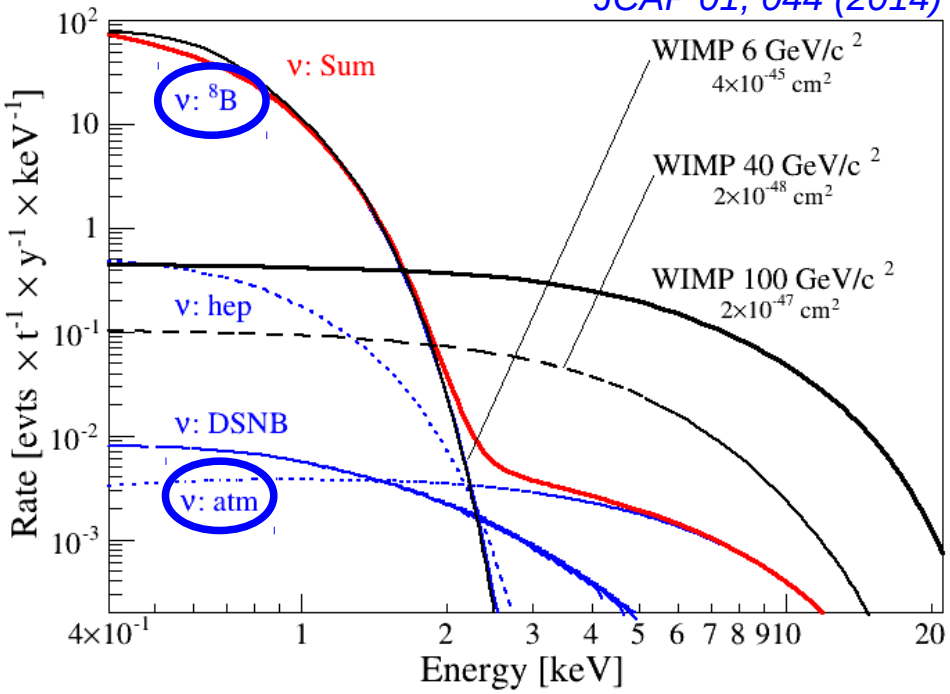


The WIMP Landscape today

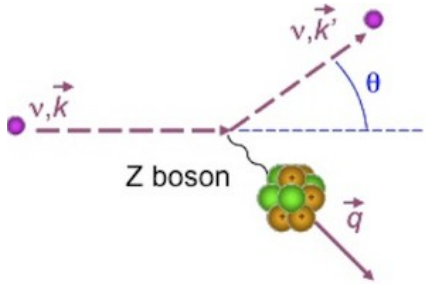


DARWIN and the Neutrino Floor

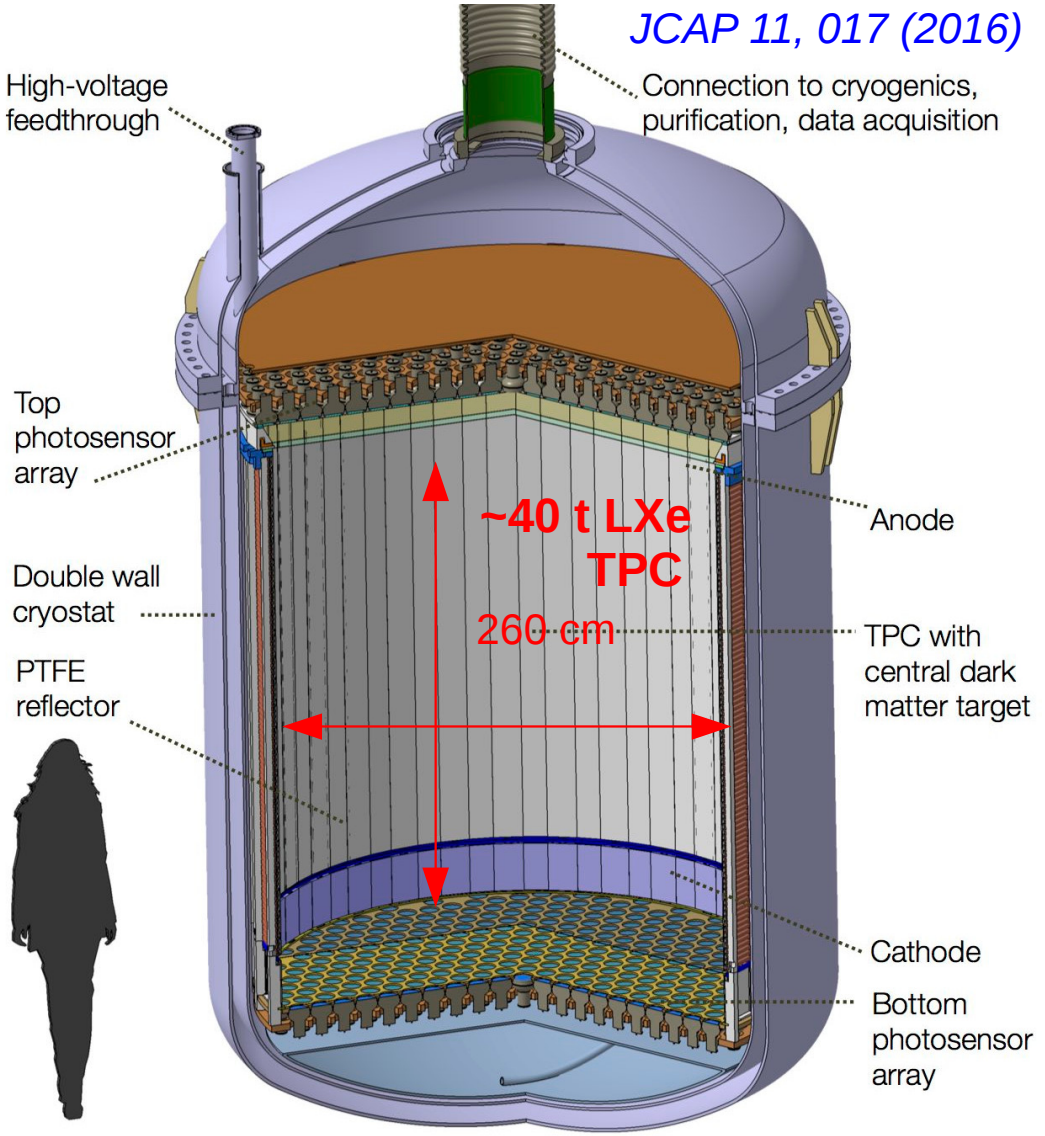
JCAP 01, 044 (2014)



Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



JCAP 11, 017 (2016)



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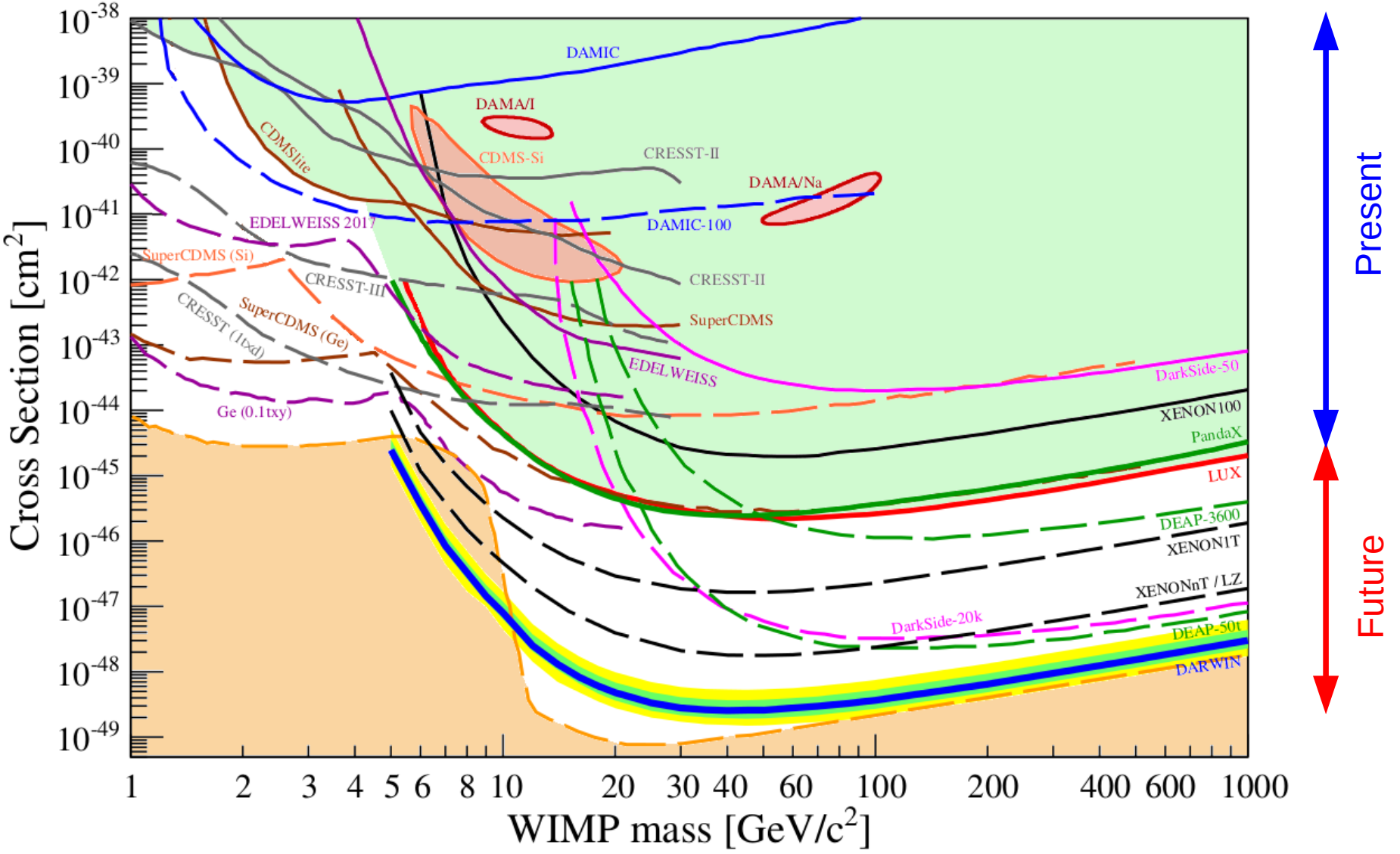
Exciting times ahead of us



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