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FOR FUNDAMENTAL PHYSICS

Dark Matter – Experimental Searches

XVIII Frascati Spring School
„Bruno Touschek“ – Spring 2016

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Slides:
`http://www.lhep.unibe.ch/schumann/dm_2016.html`

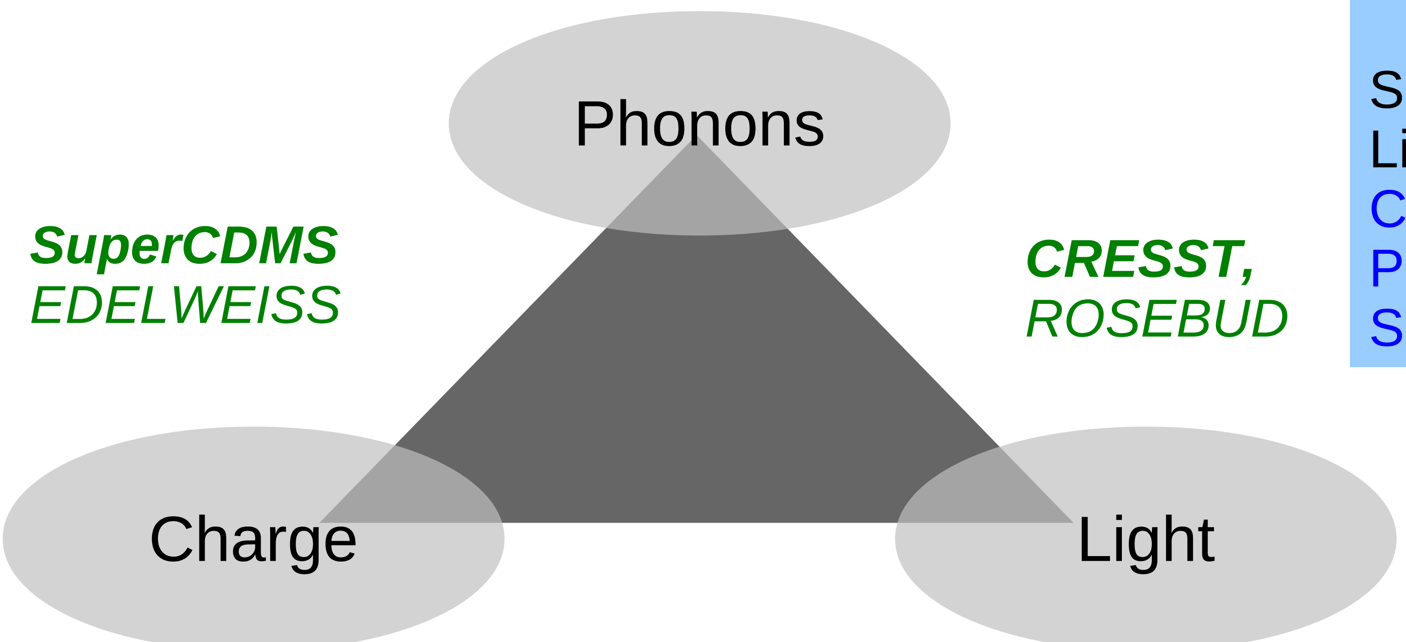
Direct WIMP Detection: Experiments

Crystals (NaI, Ge)
Cryogenic Detectors
Liquid Noble Gases

Tracking:
DRIFT, DMTPC
MIMAC,
NEWAGE

Superheated
Liquids:
COUPP
PICASSO
SIMPLE
PICO

CRESST-I
CUORE



SuperCDMS
EDELWEISS

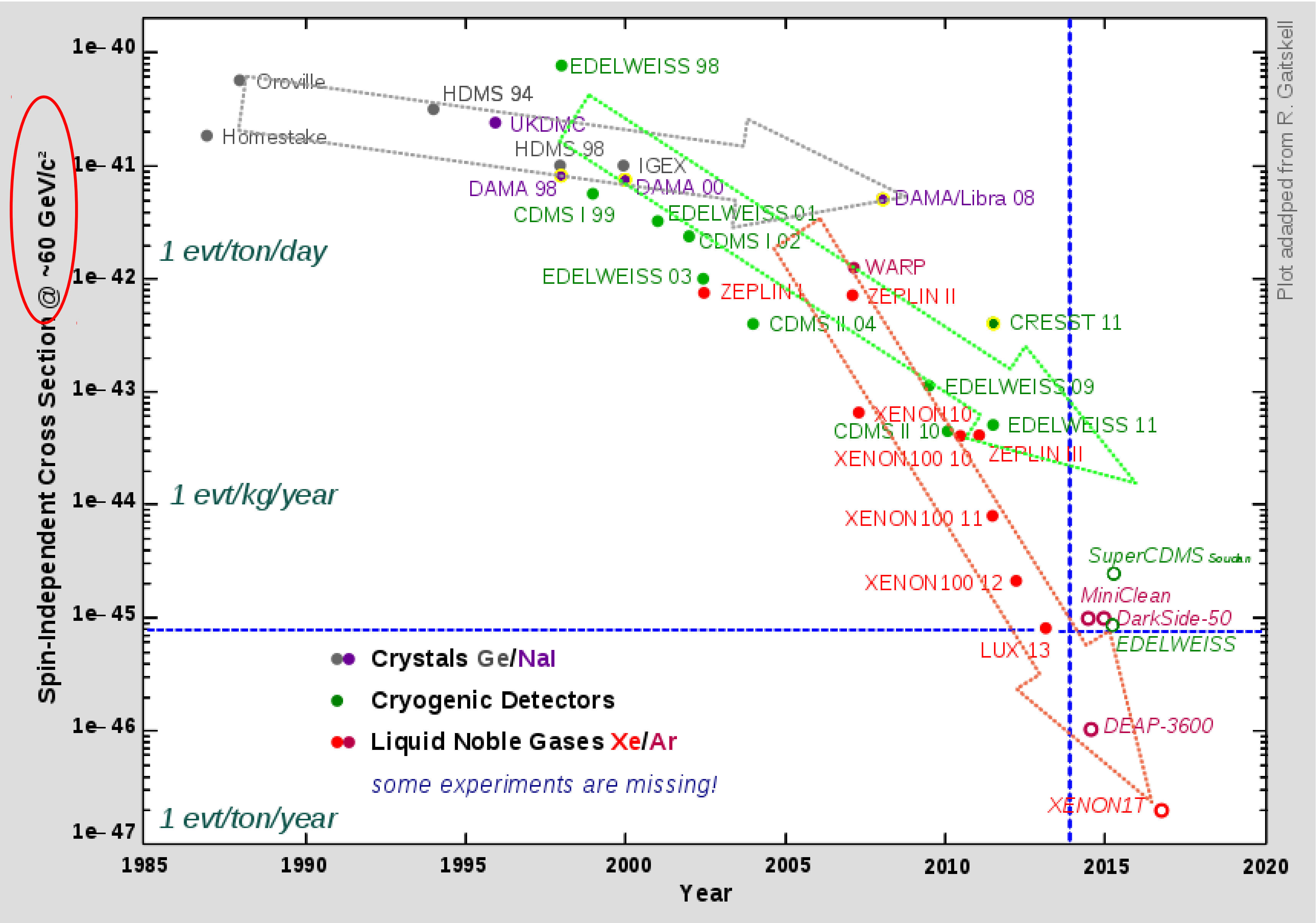
CRESST,
ROSEBUD

CoGeNT
CDEX
Texono
Malbek

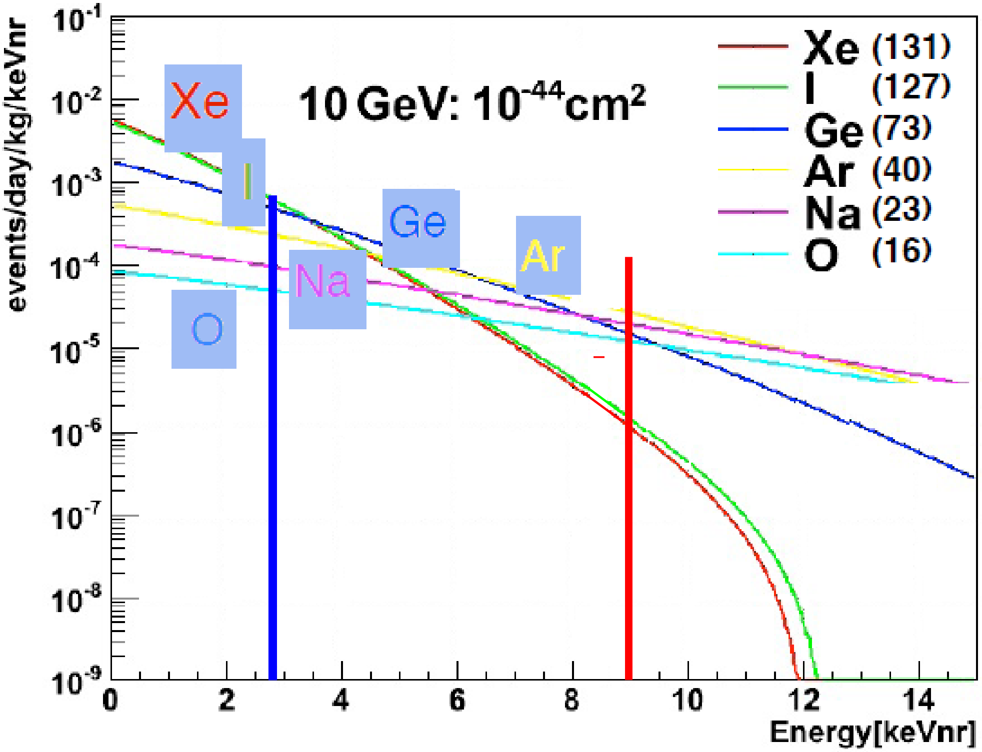
XENON**, **LUX
ArDM, Panda-X
ZEPLIN, Darkside

DEAP/CLEAN
***DAMA**, KIMS*
XMASS, DM-Ice,
Sabre

Experimental Progress



Light and heavy WIMPs



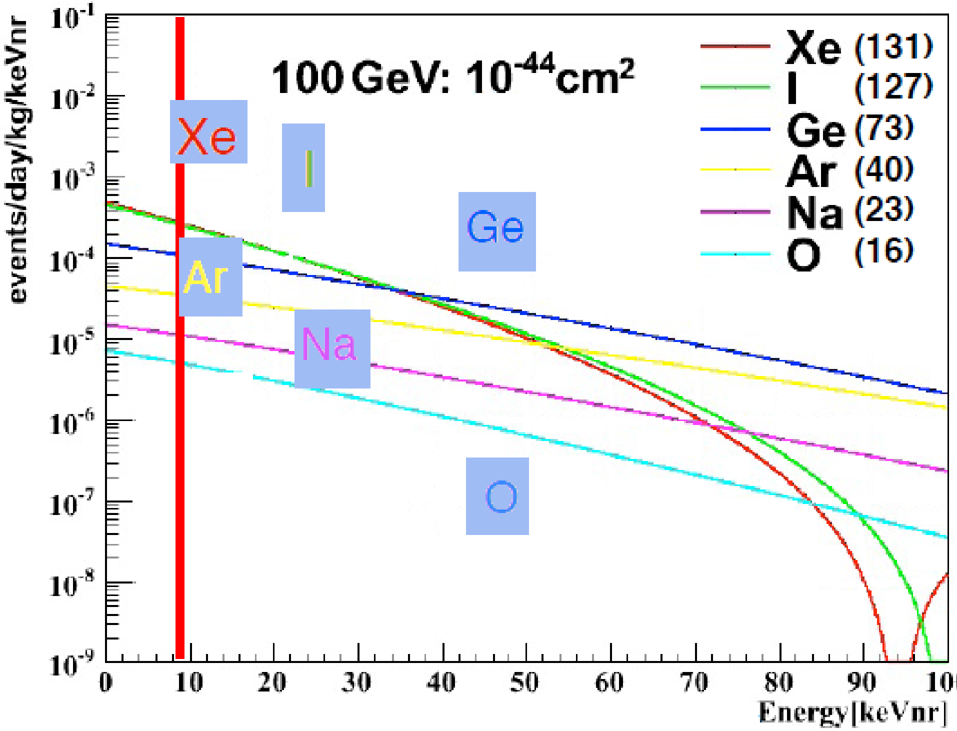
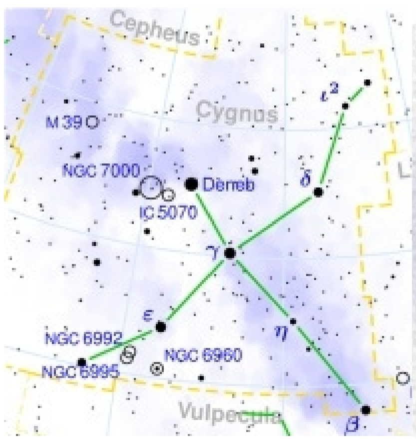


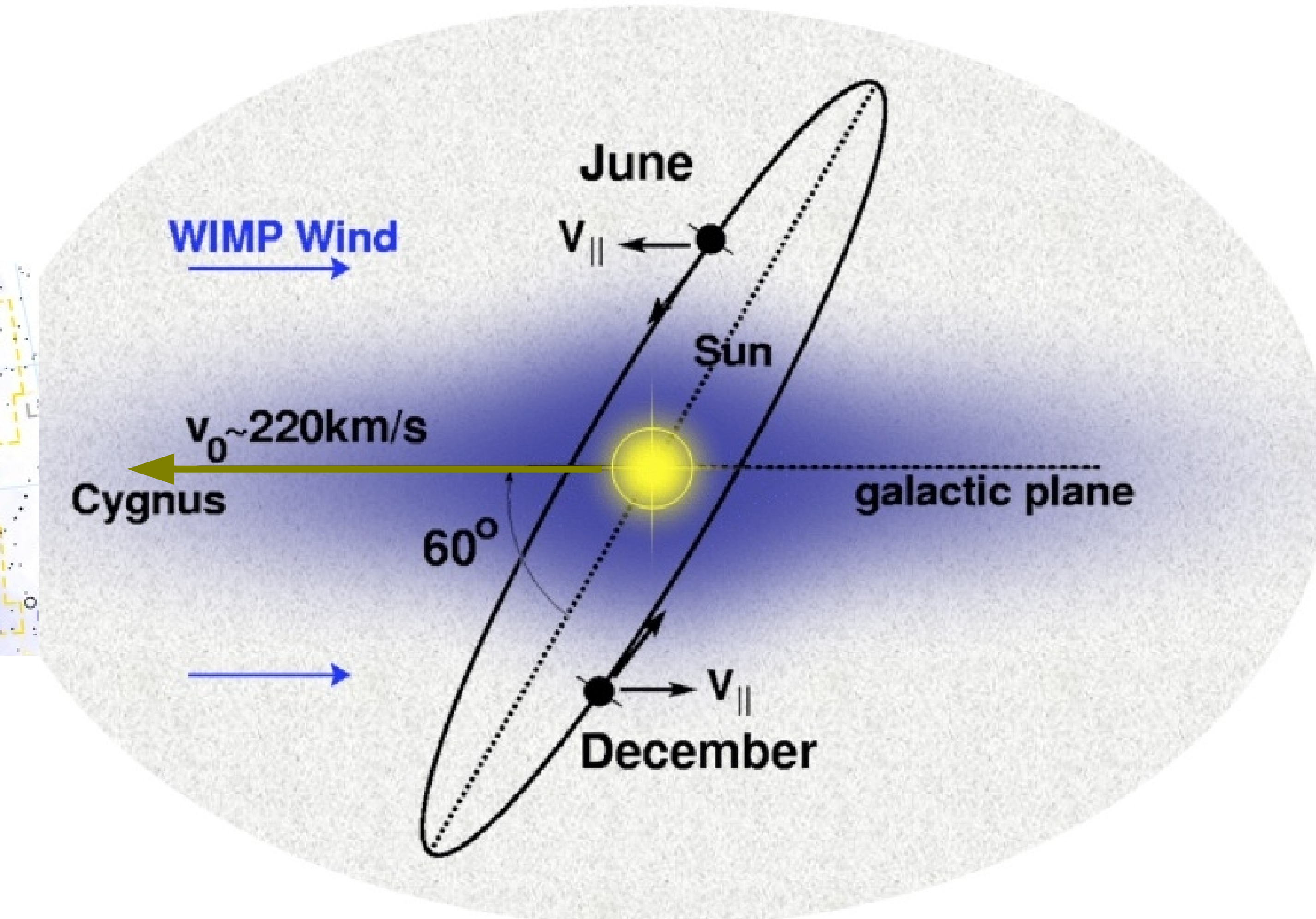
Fig. adapted from M. Yamashita

3 Crystals, Cryogenic, Directional Detectors

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

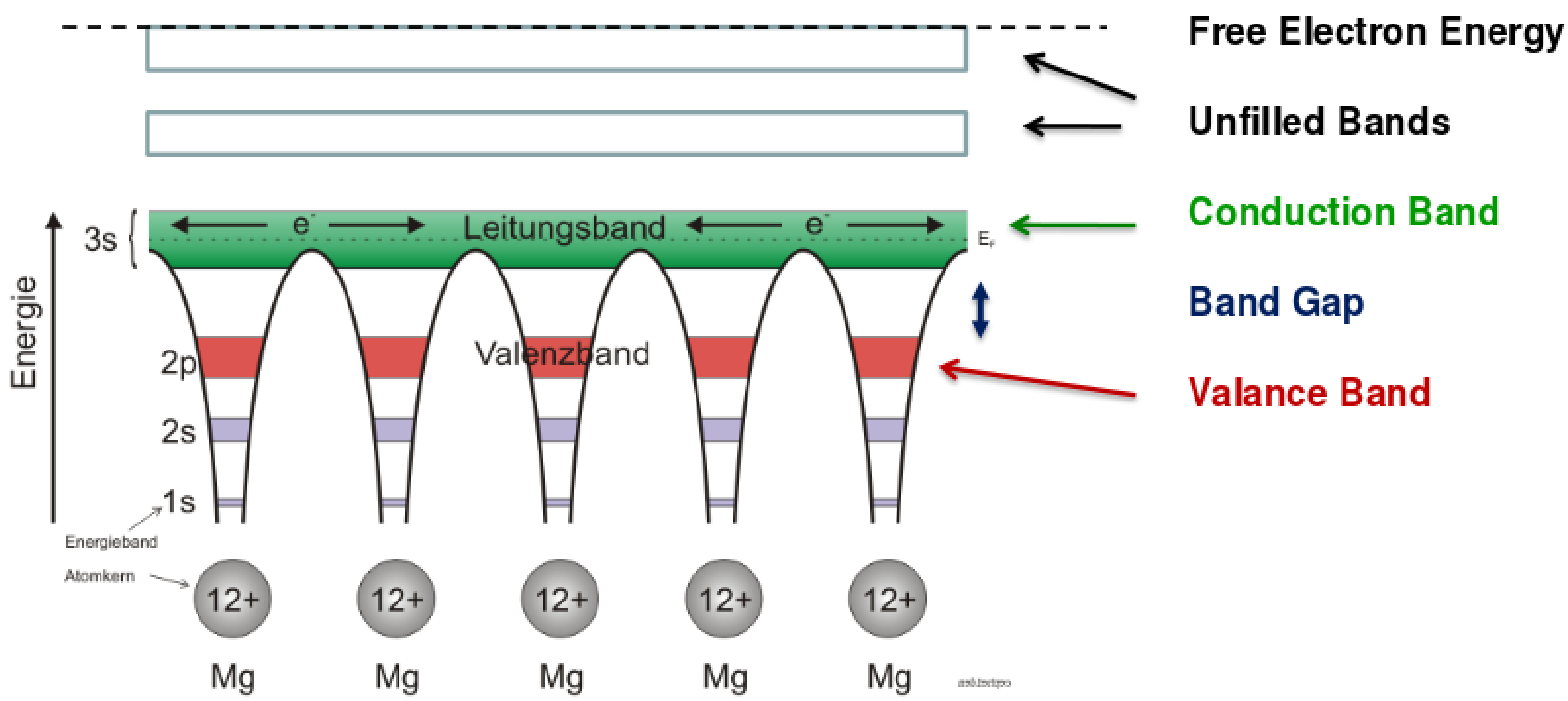
Annual Modulation





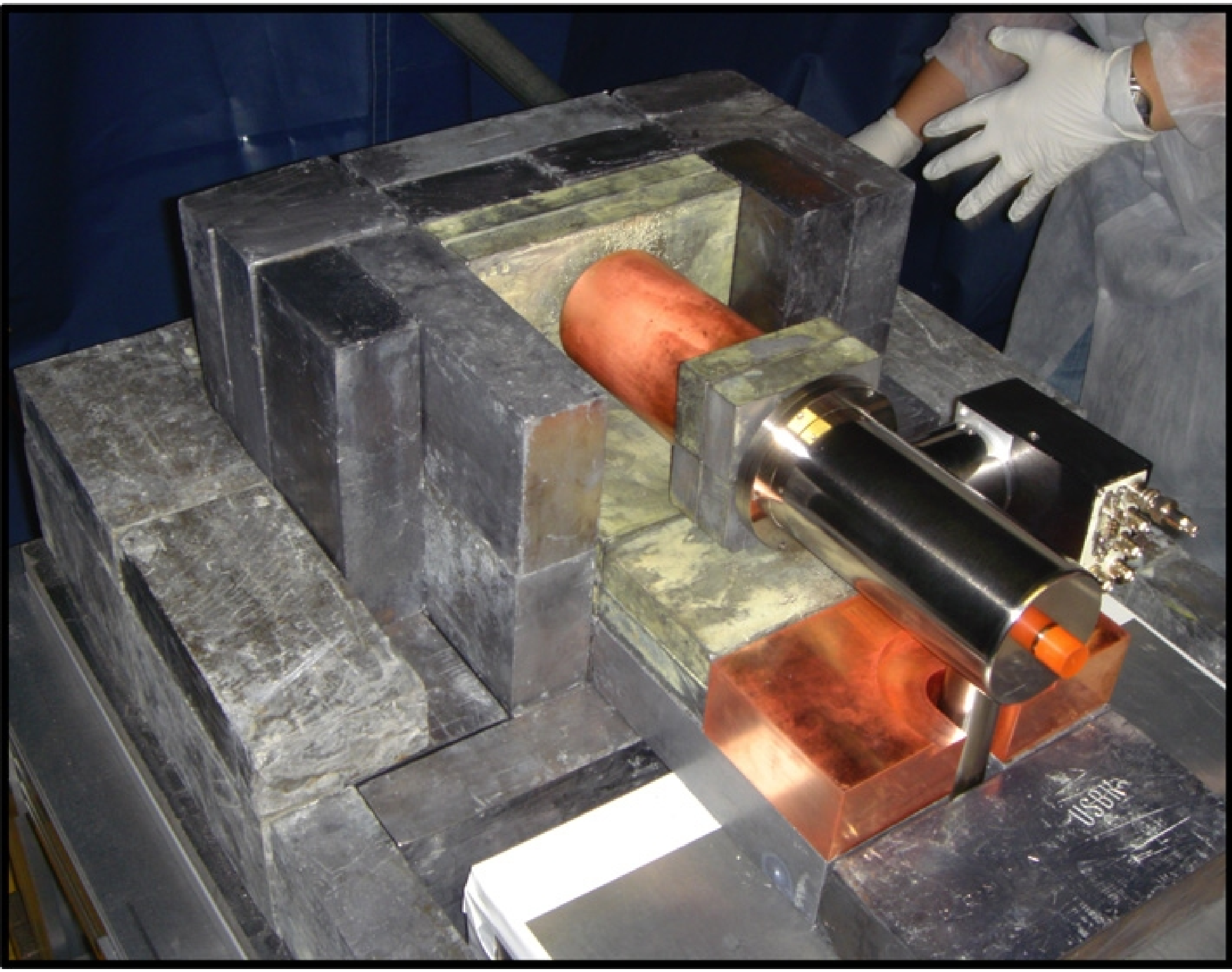
→recoil spectrum gets harder and softer during the year
→ search for annually modulating signal (3% effect)
→does not require many physical assumptions

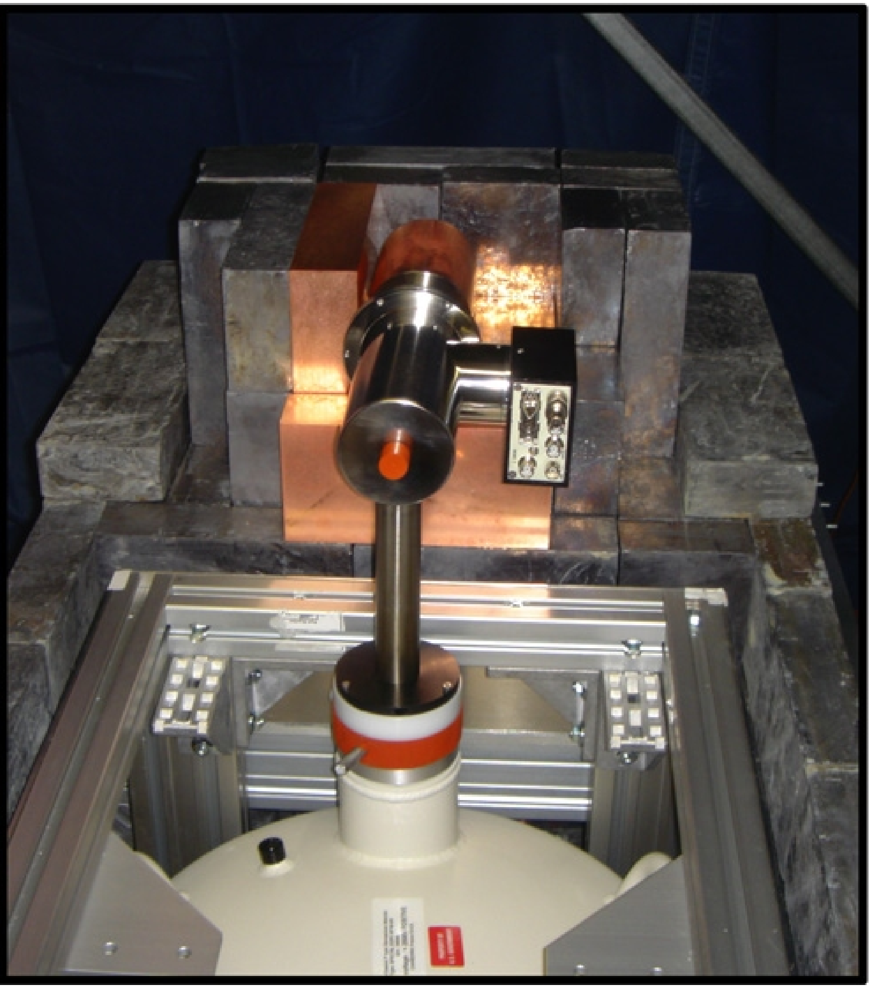
Solid state detector



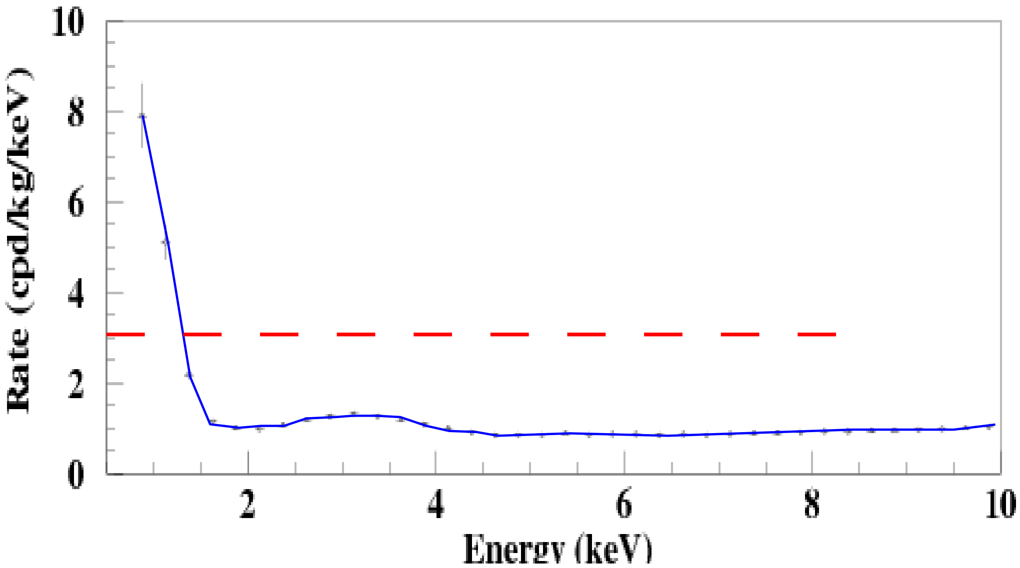
Semiconductor = band gap between valence and conduction band is small
Silicon = 1.12 eV, Germanium = 0.66 eV

CoGeNT

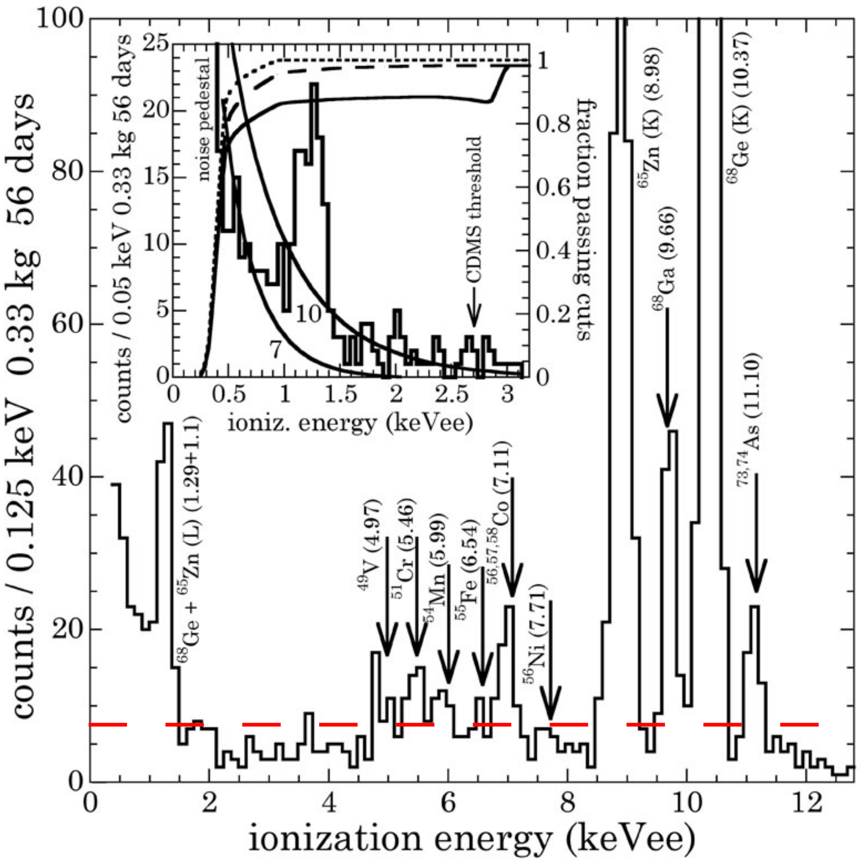




Low Energy Spectra

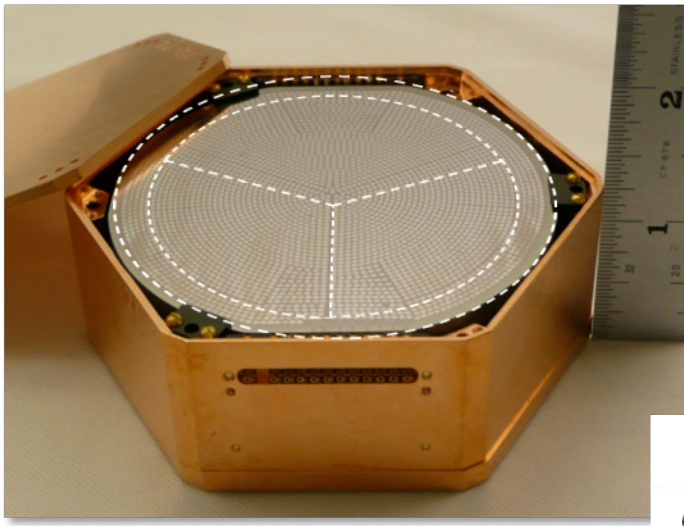


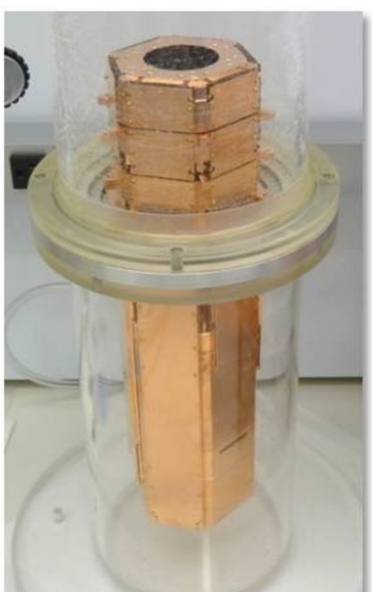
NaI: DAMA/LIBRA



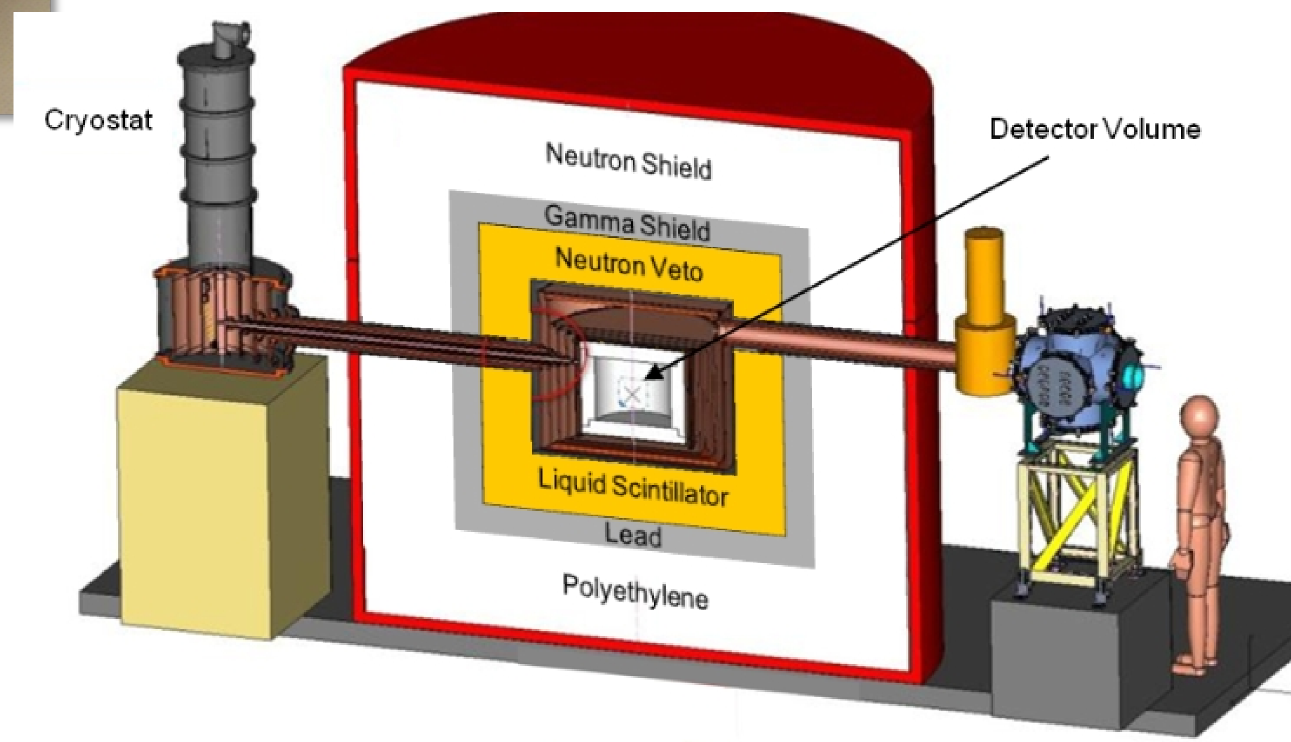
Ge: CoGeNT

SuperCDMS

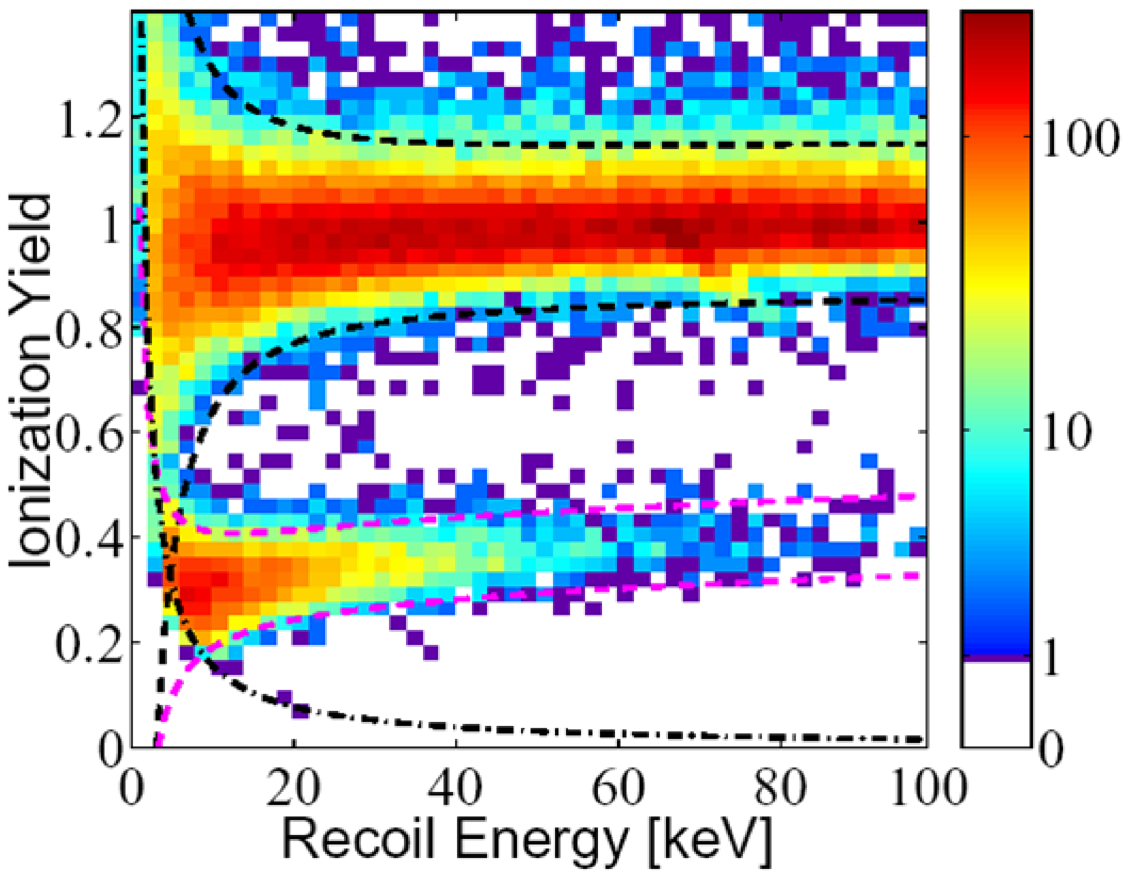




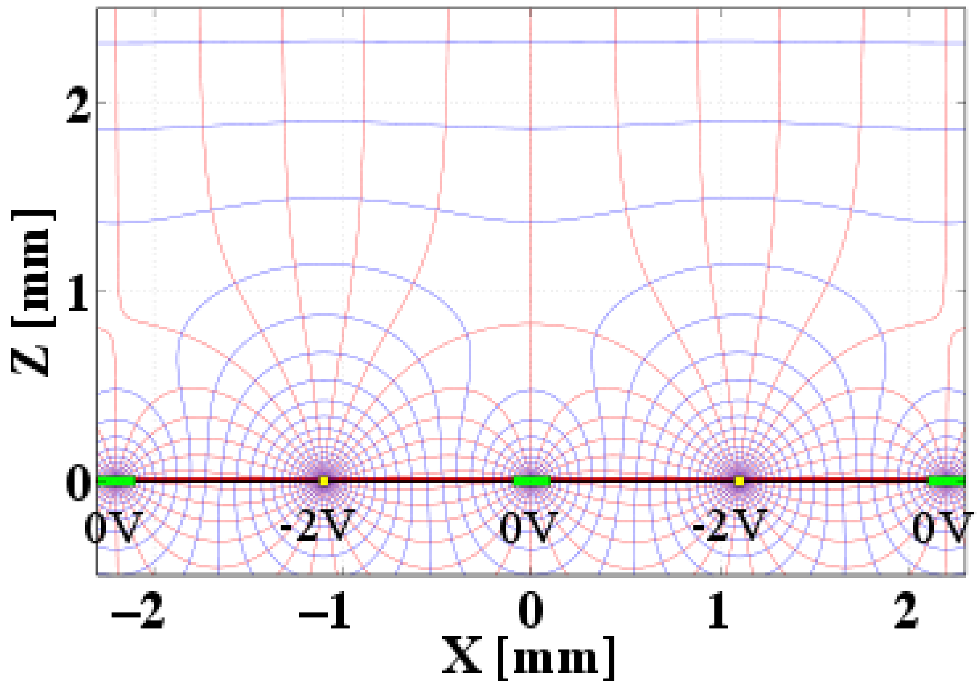
- 600 g iZIP detectors, 1“ thick
  → larger prototypes (10cm x 3.8 cm under study)
- was at Soudan → now moved to SNOLAB

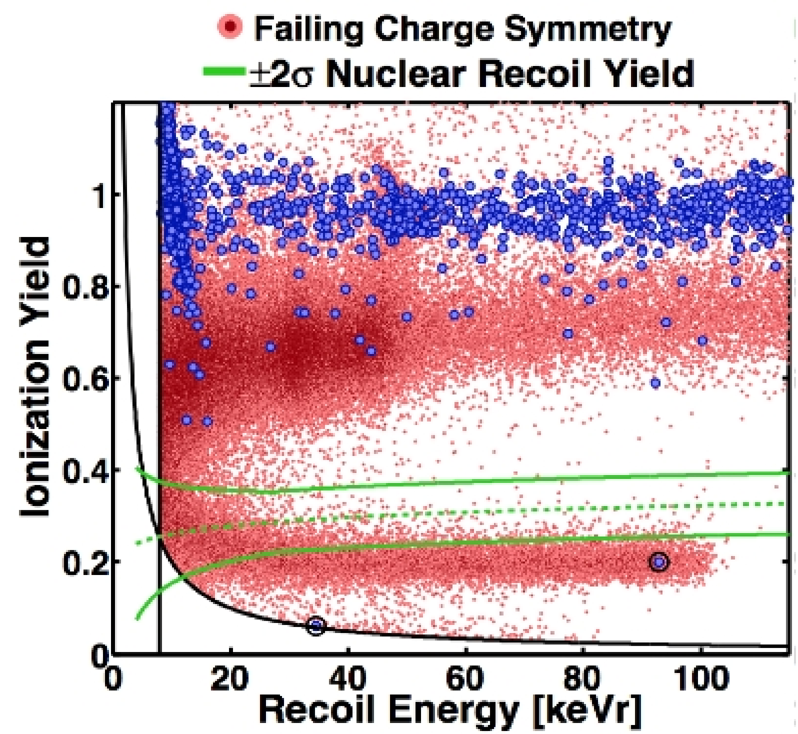


Cryogenic Detectors: Discrimination



SuperCDMS:
Surface Event Rejection

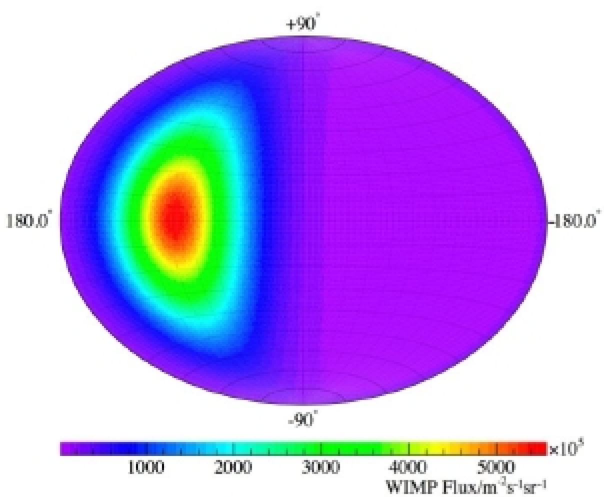




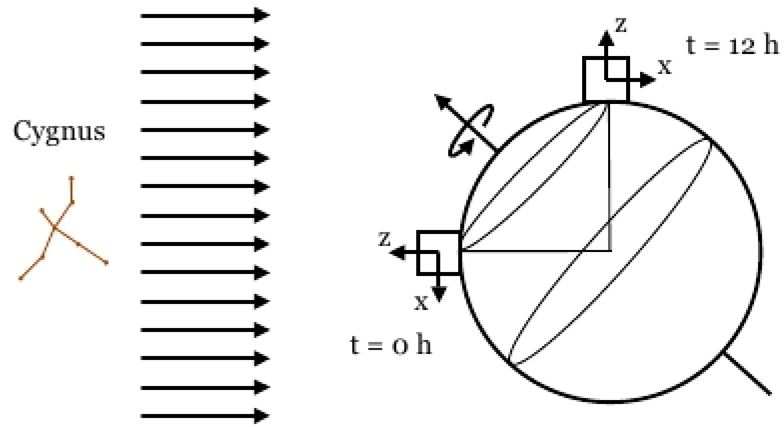
Appl.Phys.Lett. 103 (2013) 164105

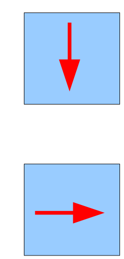
WIMP Signatures: Directionality

- 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

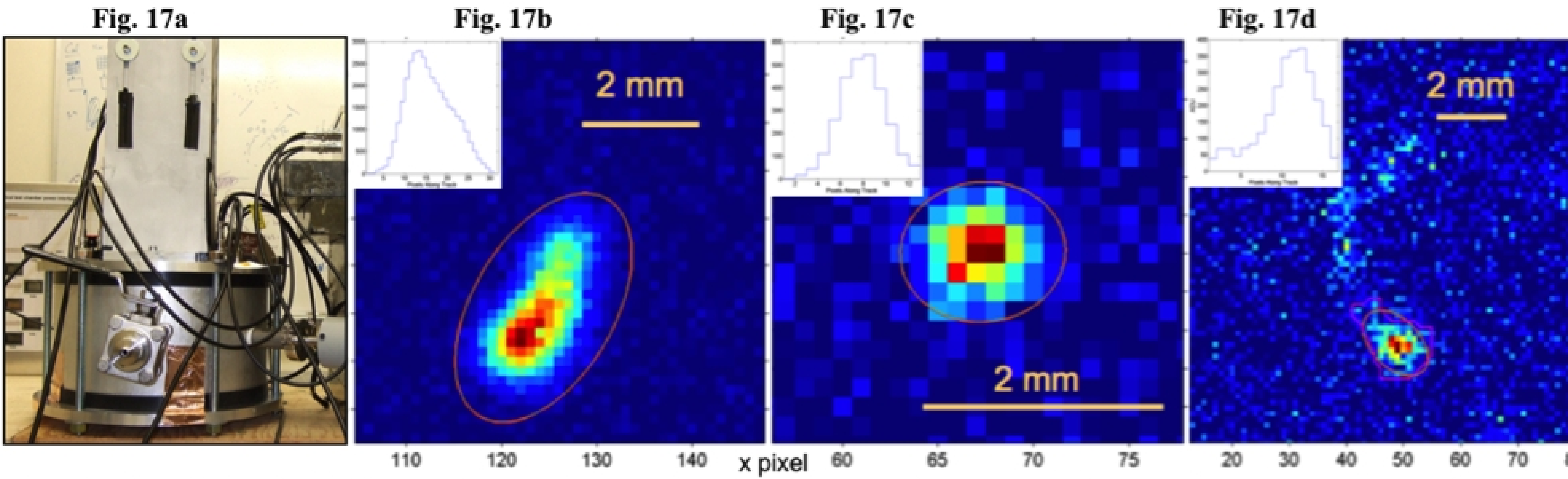
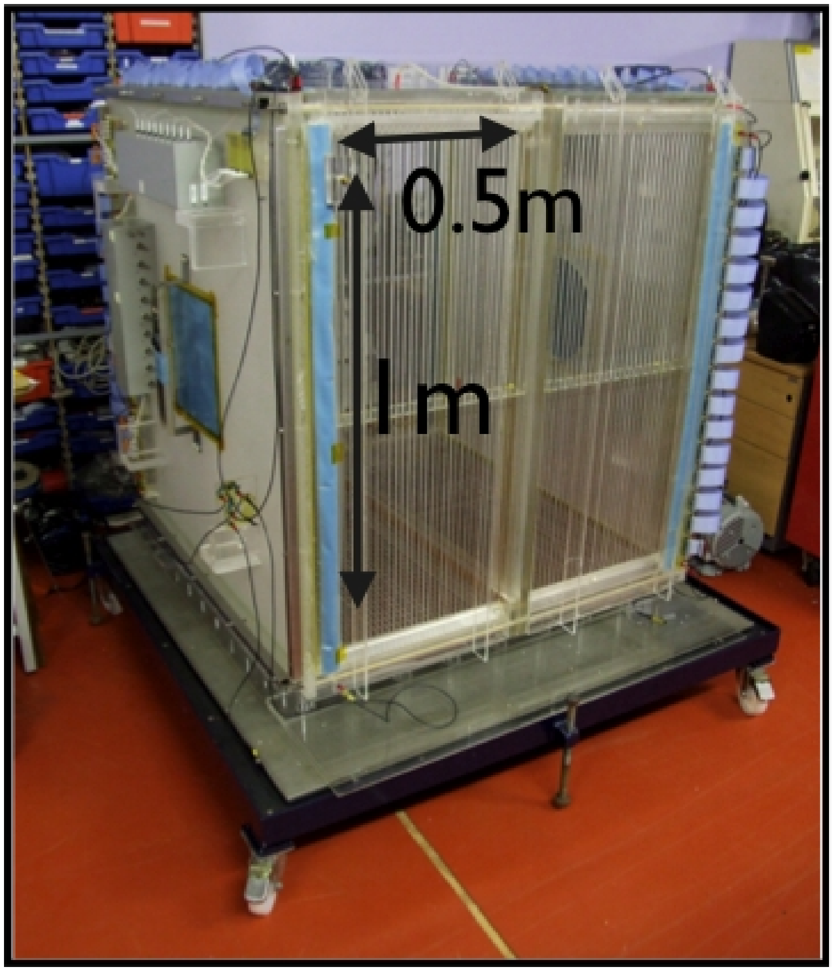


Fig. 17: (a) UNM optical CCD test TCP - with particle tracking event images as follows with skewness head-tail analysis inset, (b) example high energy 178 keV F recoil showing clear head-tail, (c) very low energy F recoil event of 10 keV_{ee} (23 keV_{rec}) still shows asymmetry skewness, (d) similar 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)



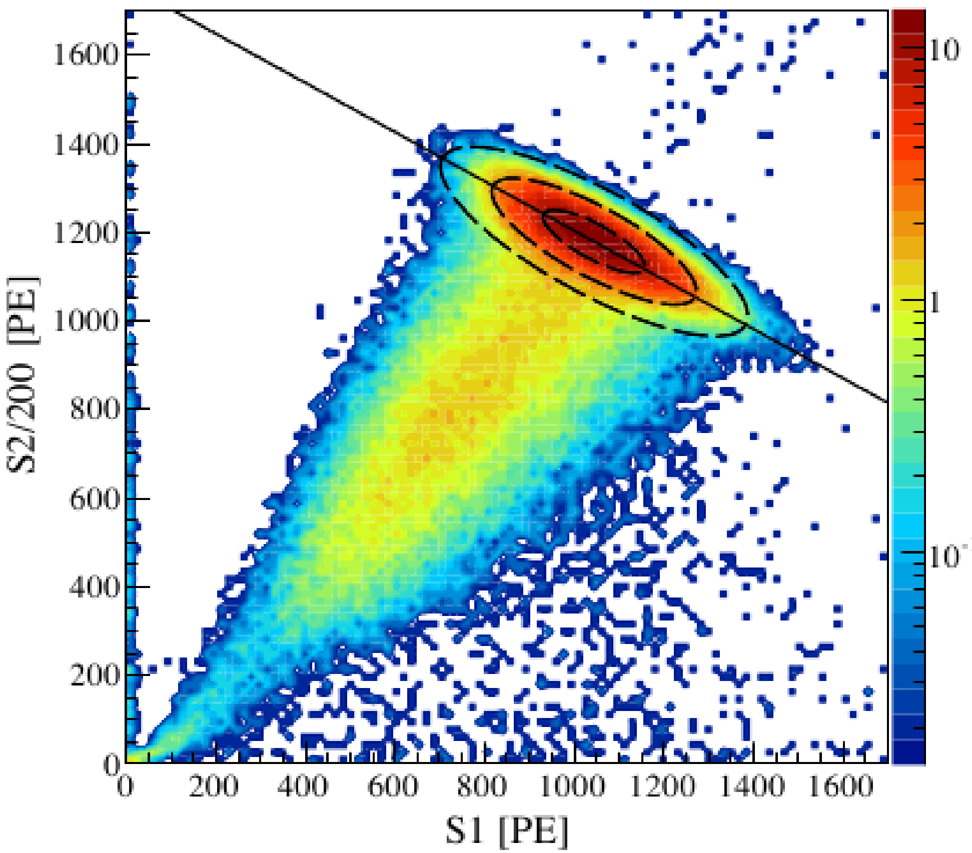
4 Cryogenic Liquids

- The liquiefied (→ 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
  XENON100/1T, 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 experiments under construction

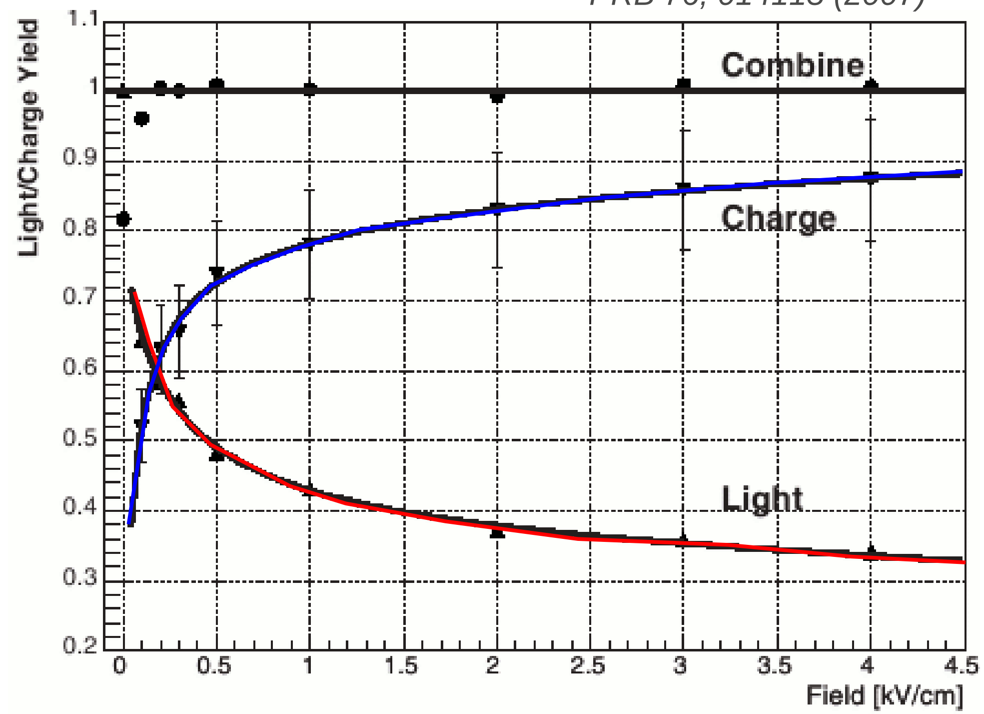
Light-Charge anti-Correlation

LXe examples

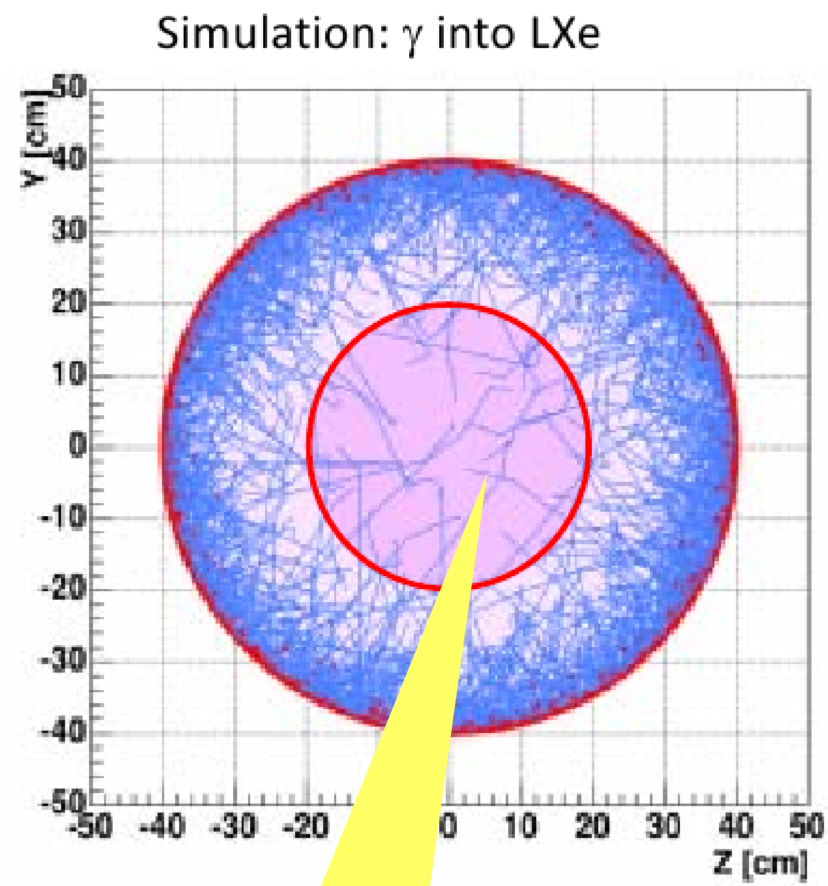
Astropart. Phys 35, 573 (2011)



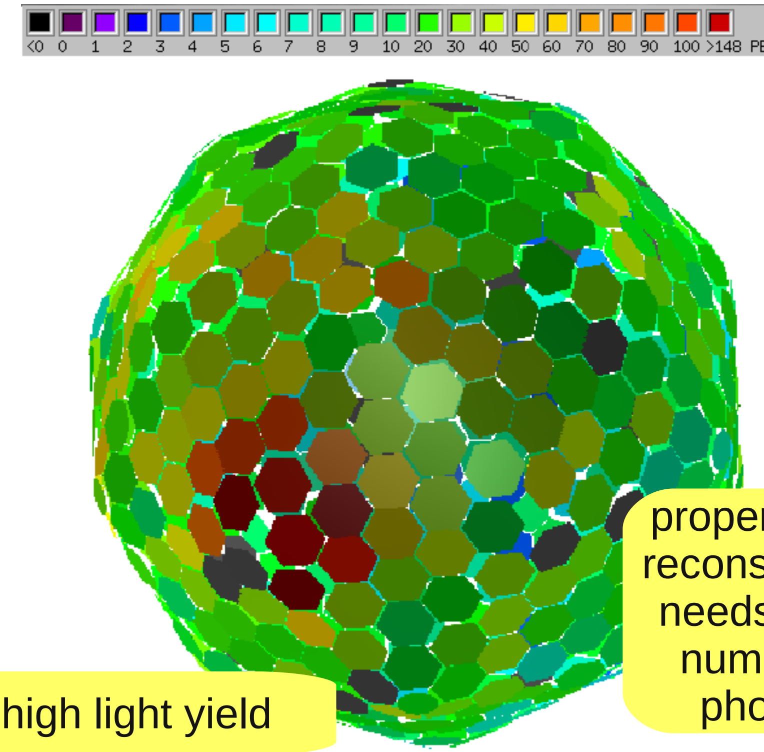
PRB 76, 014115 (2007)



Single Phase Detector

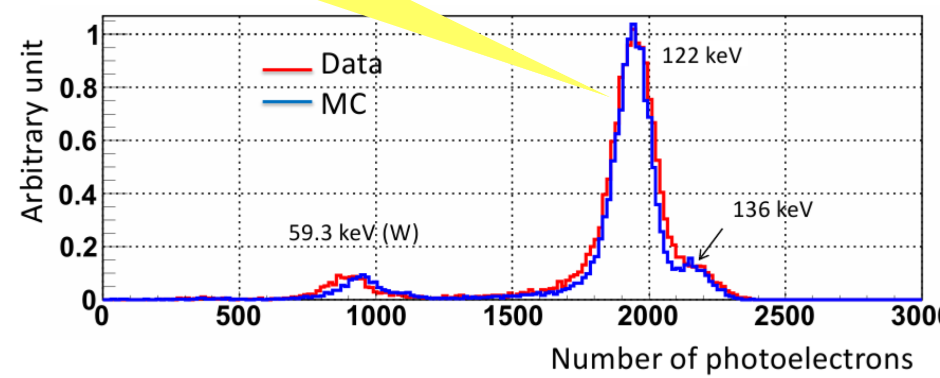


very low background



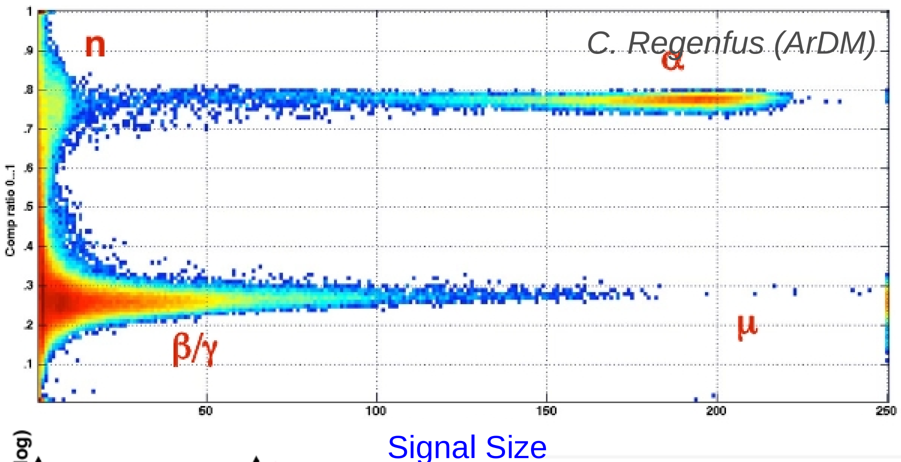
proper vertex reconstruction needs huge number of photons

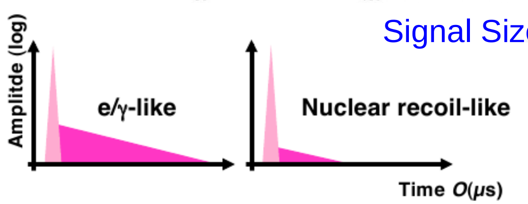
very high light yield



Figures from XMASS

LAr: Pulse Shape Discrimination





Singlet and triplet excimer states have characteristic lifetimes:

Ar: 5 ns, 1.6 μs
Xe: 4 ns, 22 ns

The ratio N_{trip}/N_{sing} depends on the ionization density → the particle type

LAr Discrimination levels of 3×10^{-8} achieved in test setups

arXiv:0904.2930, PRC 78, 035801 (2008)

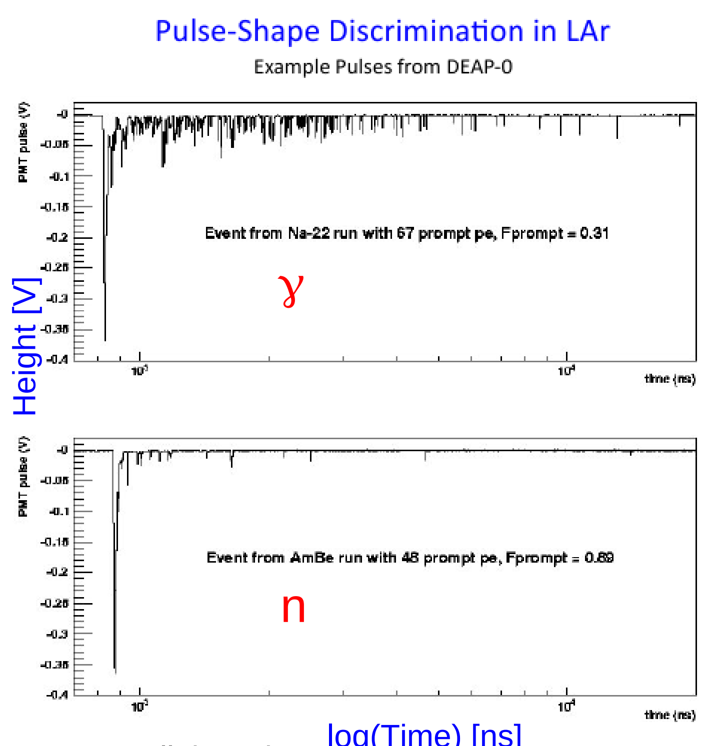
→ mandatory because of huge Ar39 background (~1Bq/kg)

LXe O(10)% rejection at low E

NIM A 612, 328 (2010)

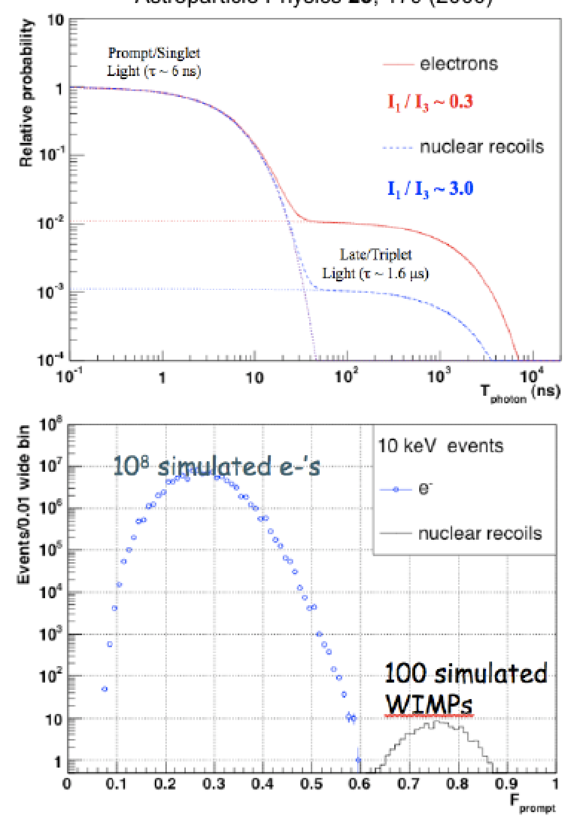
Better for very high LY
(8×10^{-2} @ 50% NR acc.)

NIM A 659, 161 (2011)



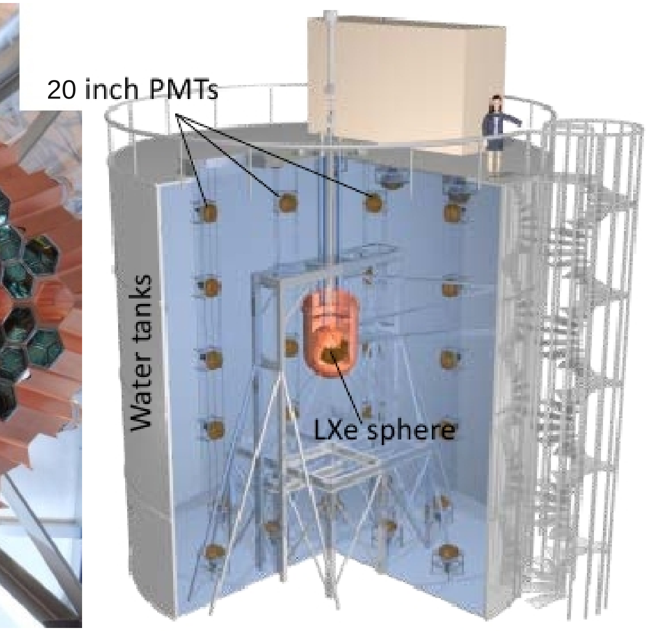
DEAP collaboration

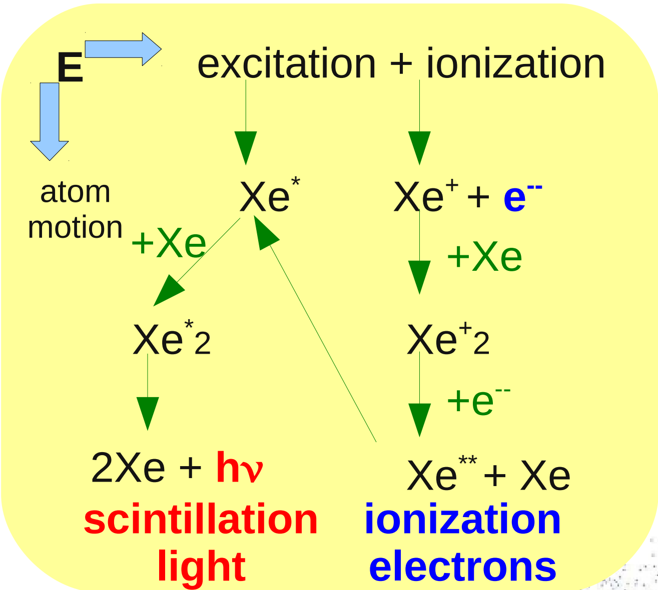
M.G. Boulay and A. Hime
Astroparticle Physics **25**, 179 (2006)



XMASS

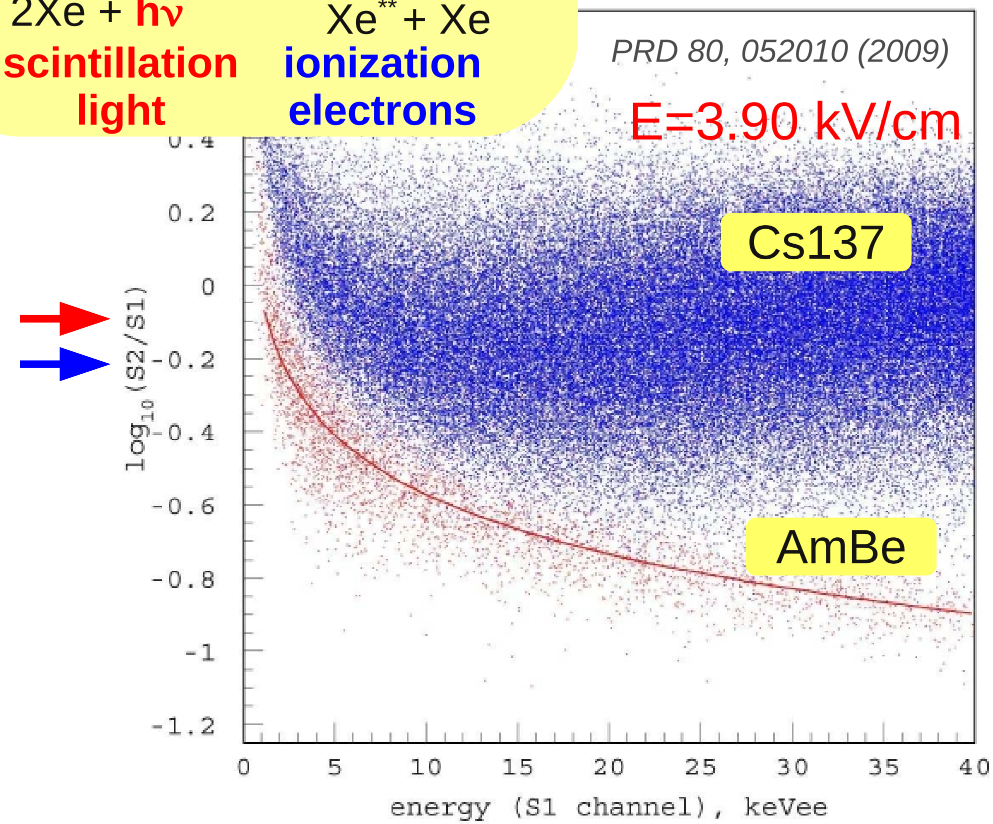
- single phase **LXe** detector
- 800kg total, 100kg fiducial mass
- 60% of surface covered with 642 hexagonal PMTs
- very high LY (~7x higher than Xe100)
- located in Kamioka (JP)

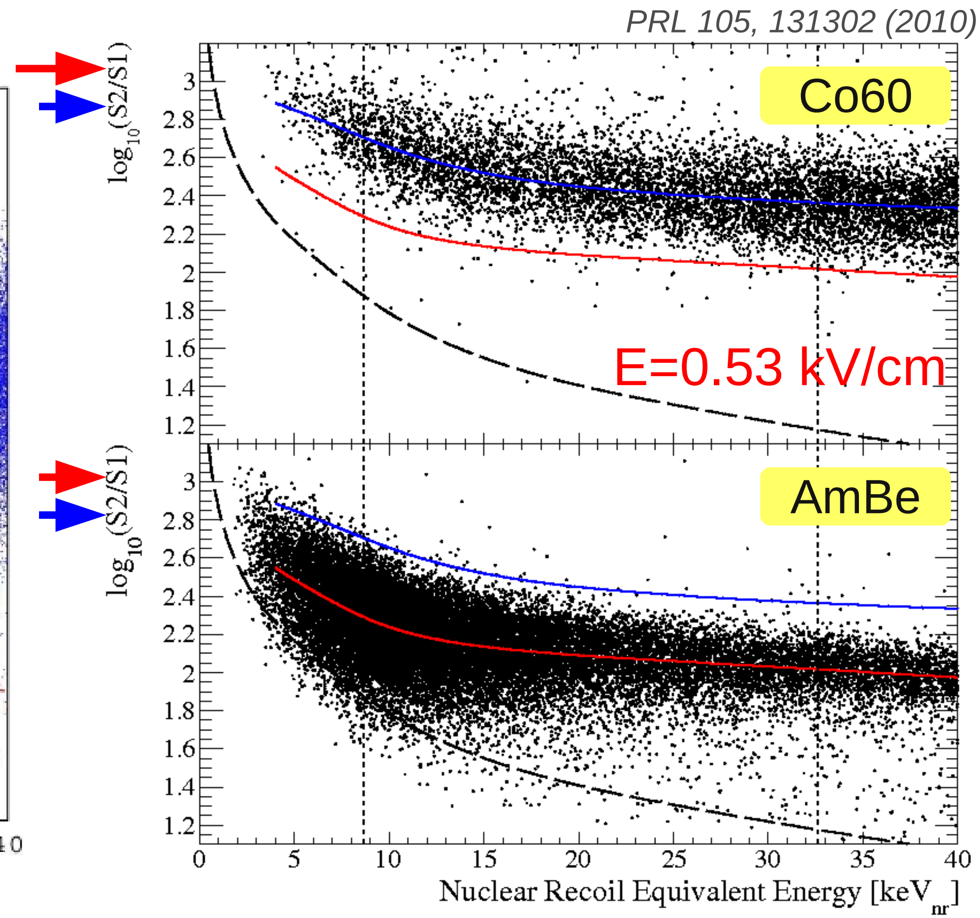





Charge/Light Ratio

Charge/Light ratio depends on dE/dx → discrimination





ZEPLIN-III
~99.99% rejection @ 50% acceptance

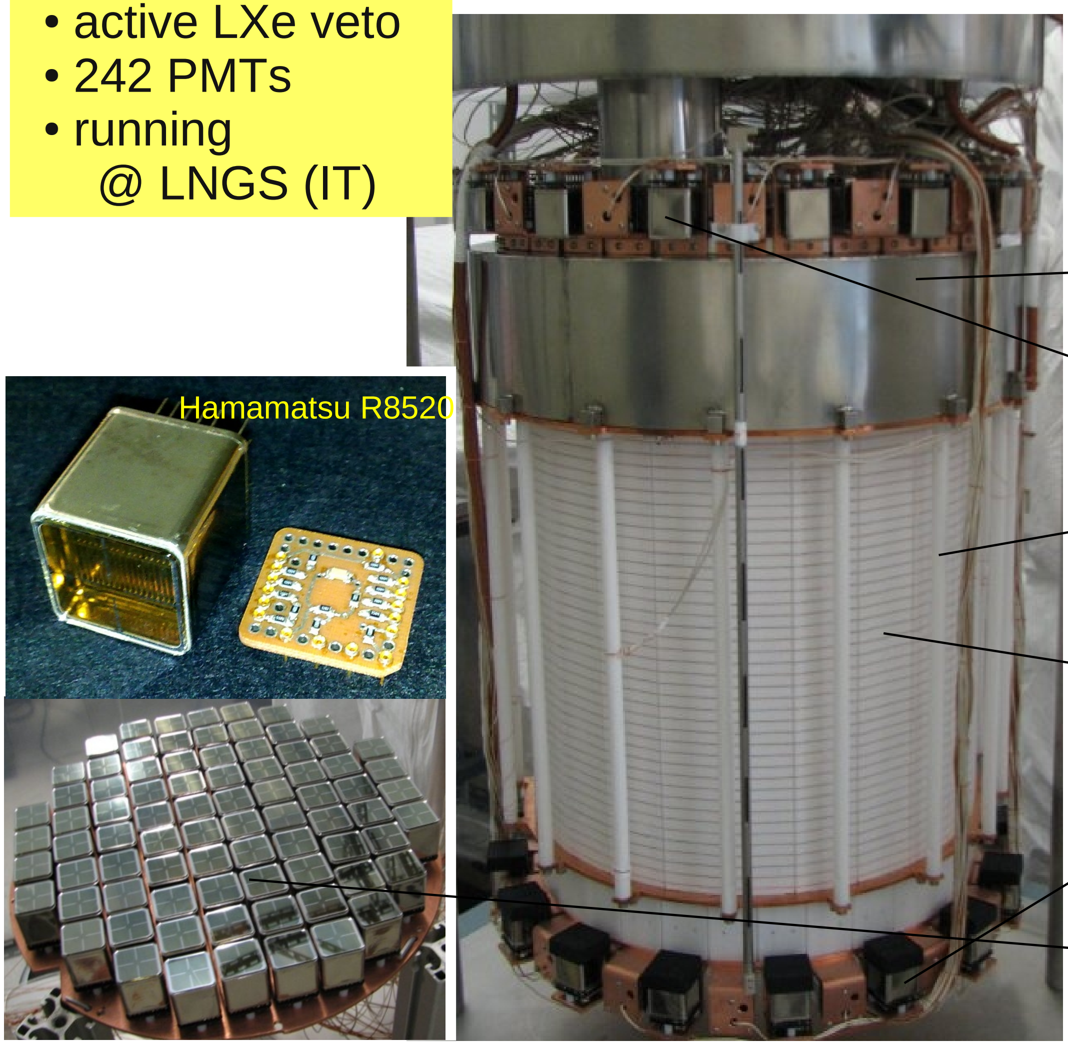
XENON100
~99.5% rejection @ 50% acceptance

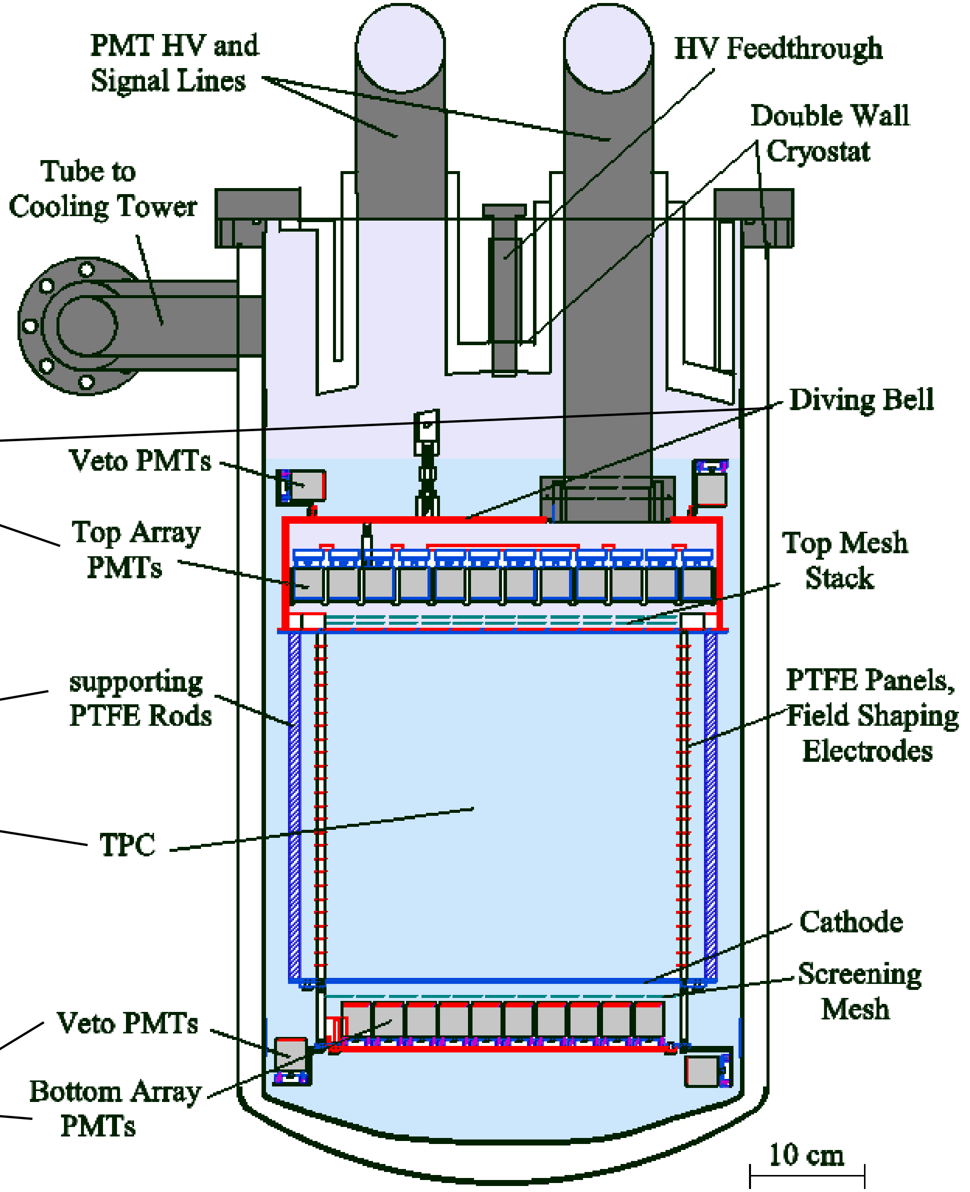

Xe
XENON
Dark Matter Project

The XENON100 Detector

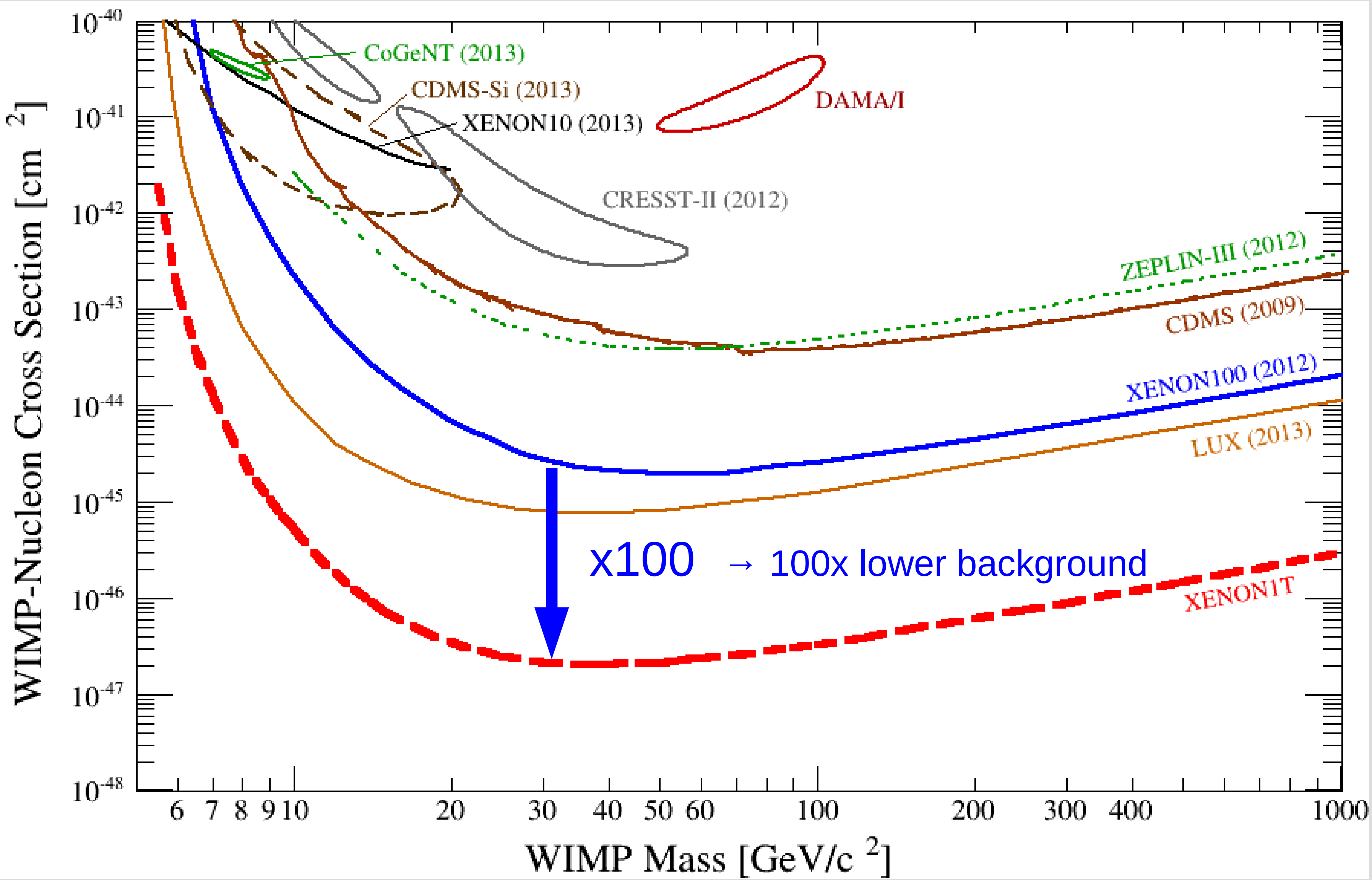
Astropart. Phys. 35, 573 (2012)

Quick Facts
- 62 kg **LXe** target
- dual phase TPC
- active LXe veto
- 242 PMTs
- running
  @ LNGS (IT)

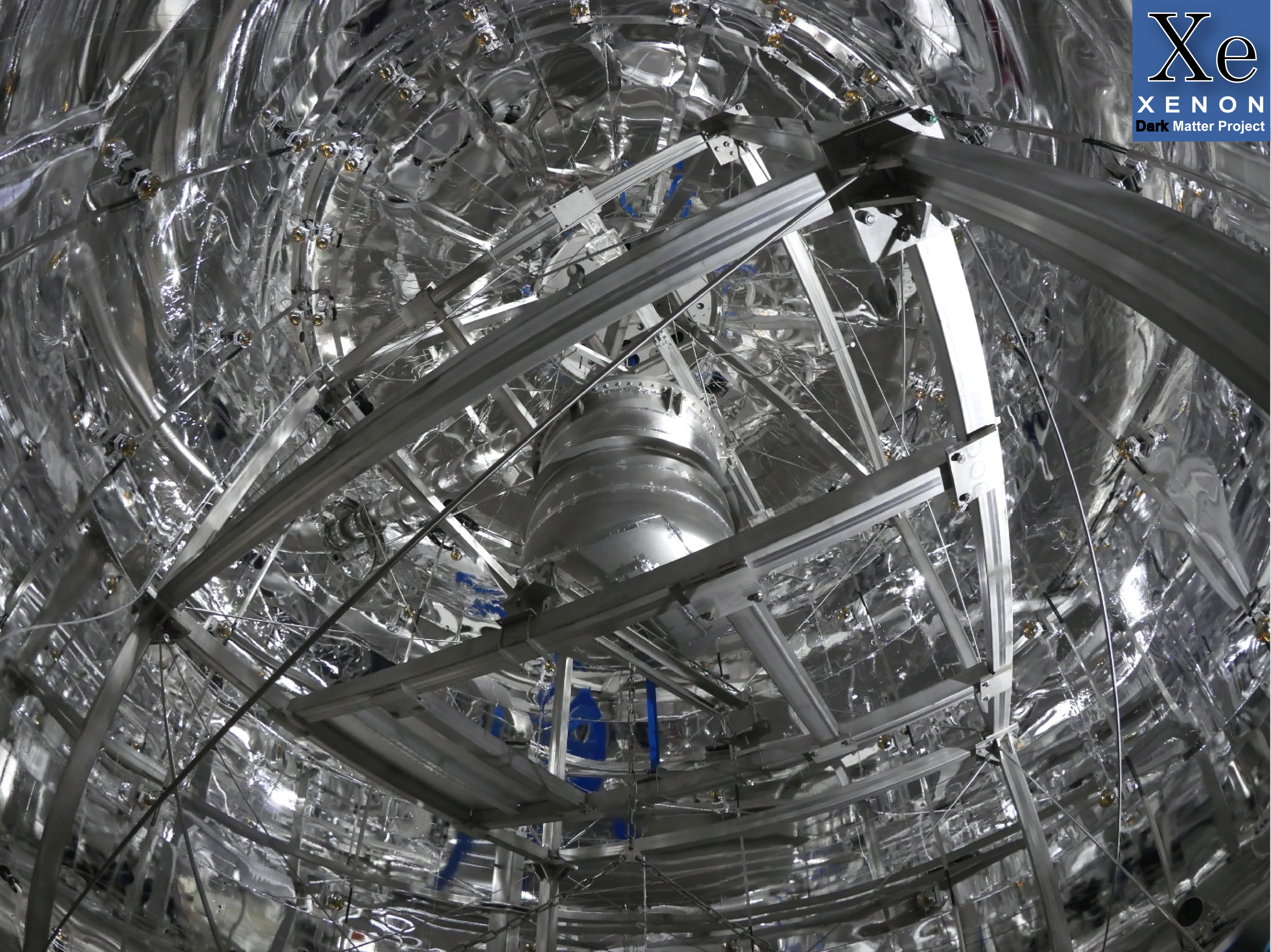




The XENON Future

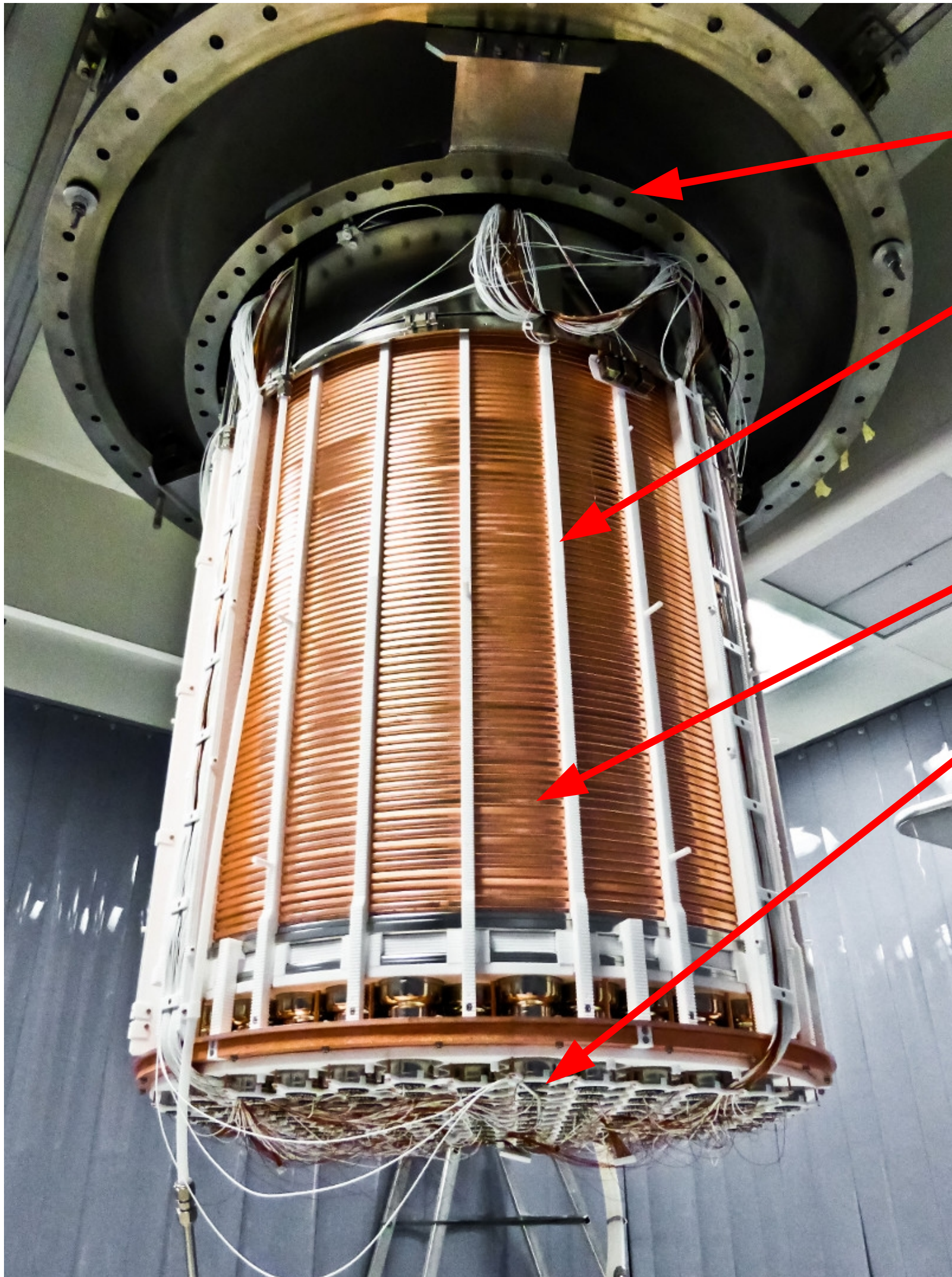


XENON1T @ LNGS


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 OFHC and PTFE

248 photomultipliers
- Hamamatsu R11410-21
- low background
- high QE (36% @ 178nm)
- extensive testing in cryogenic environments *JINST 8, P04026 (2013)*