Direct Detection Techniques Status and Future

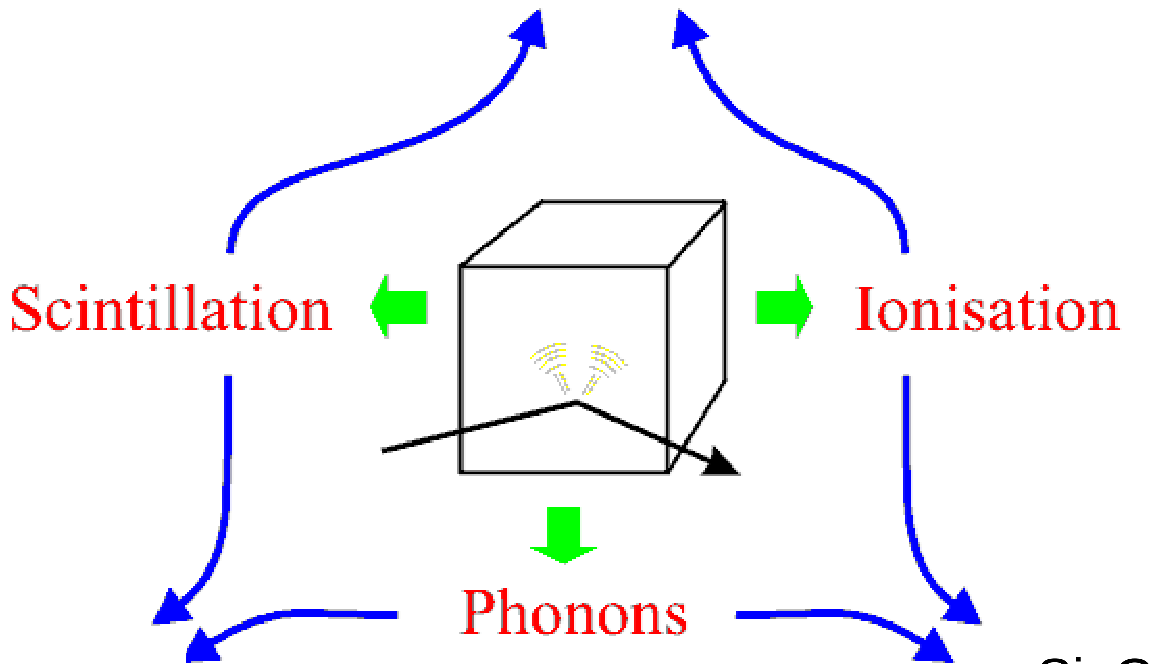
Hans Kraus

- Detector Technologies / Historic
- Current Status
- Future Developments

Direct Detection Techniques

Ar, Xe
ArDM, DarkSide, XENON, ZEPLIN-II/III, LUX, Panda-X, LUX-ZEPLIN

NaI, Ar, Xe
DAMA/LIBRA
ANAIS
NAIAD
KIMS
XMASS
DEAP/CLEAN
ZEPLIN-I
SABRE



Ge
CoGENT
GERDA
MAJORANA
IGEX

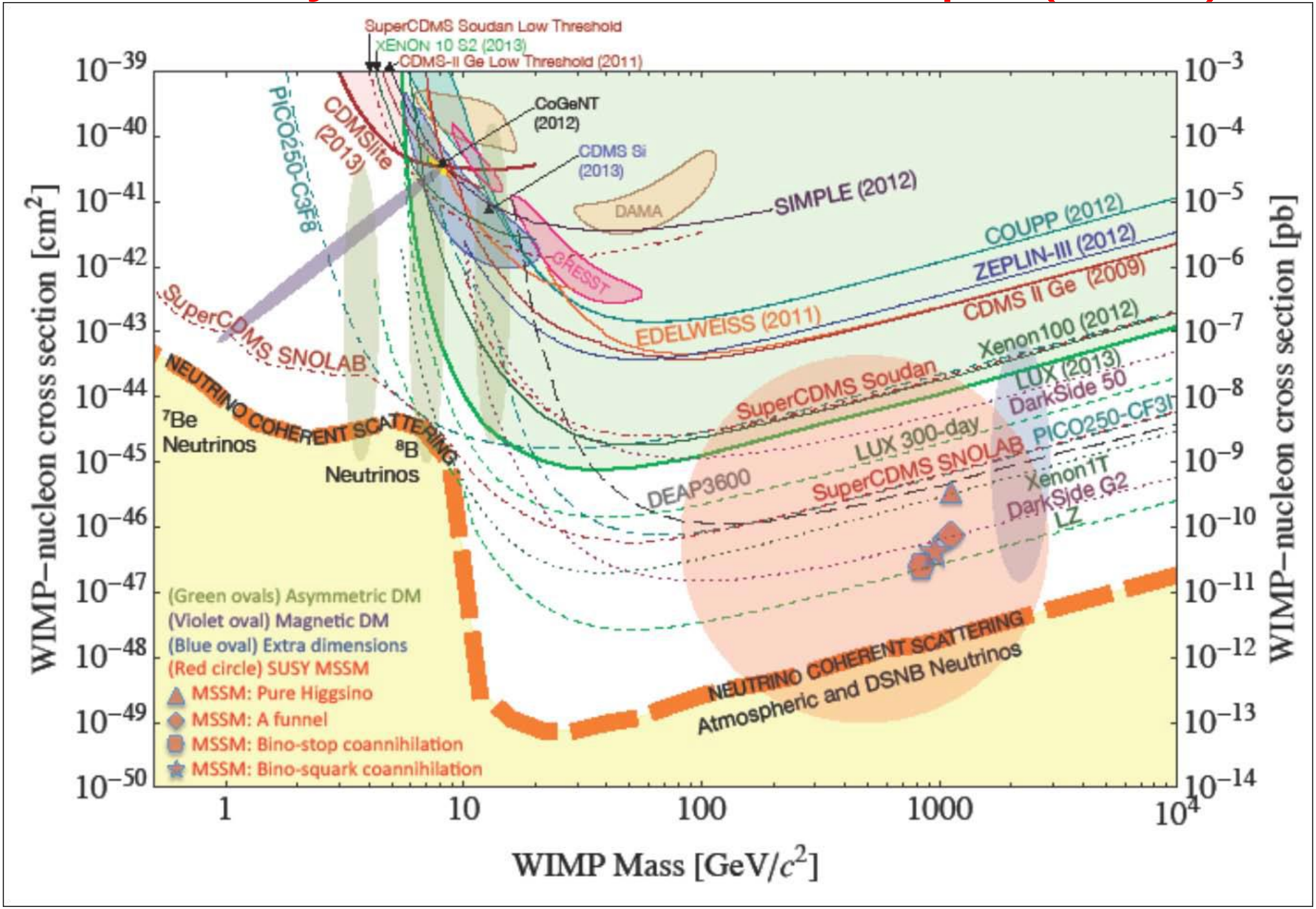
$CaWO_4$, $ZnWO_4$
CRESST II
ROSEBUD
EURECA

Al_2O_3 and others
CRESST I
CUOPP
SIMPLE
PICO

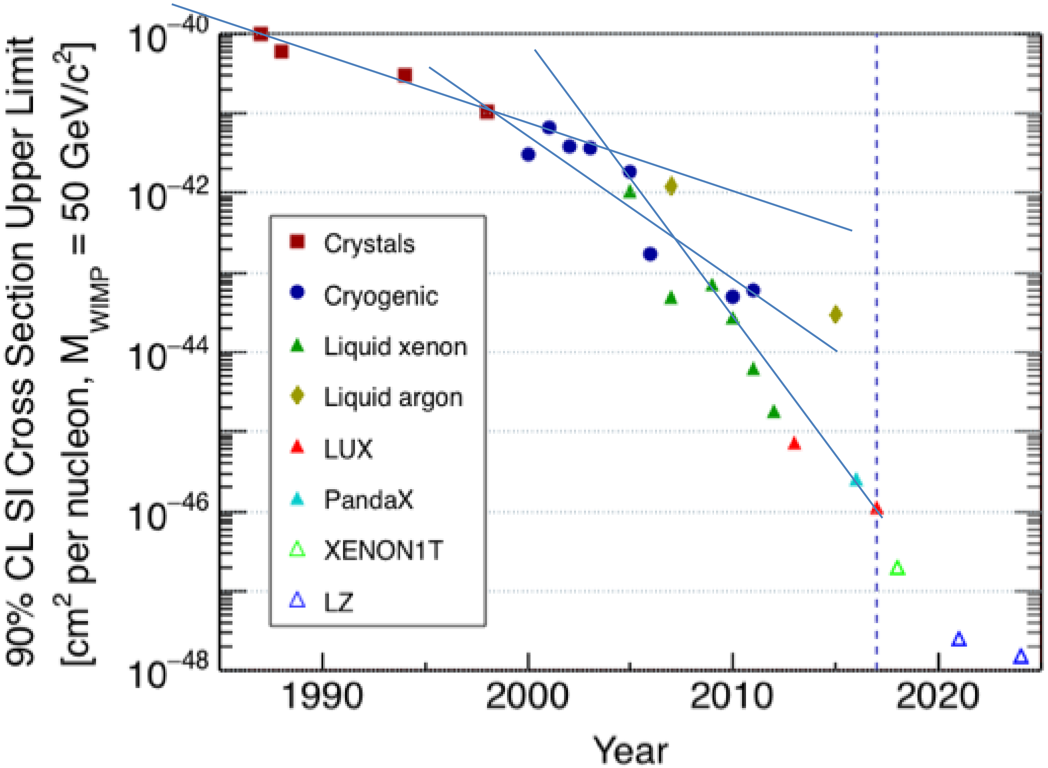
Si, Ge
CDMS
EDELWEISS
EURECA

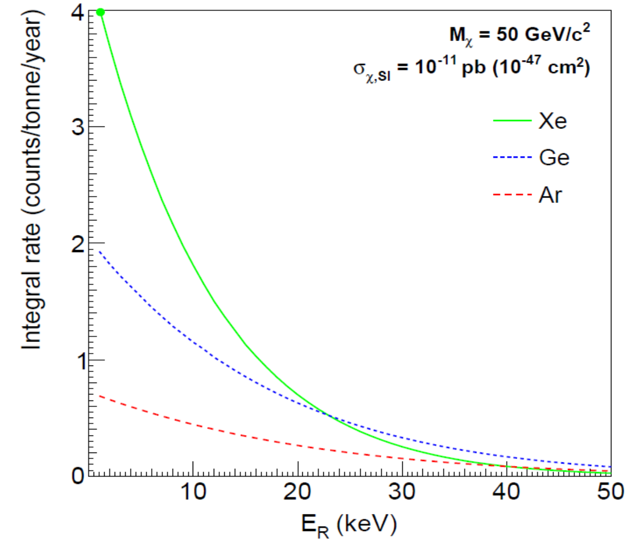
Displacement / tracking: DRIFT, Newage, MIMAC, DM-TPC

The Physics Result Landscape (2013)



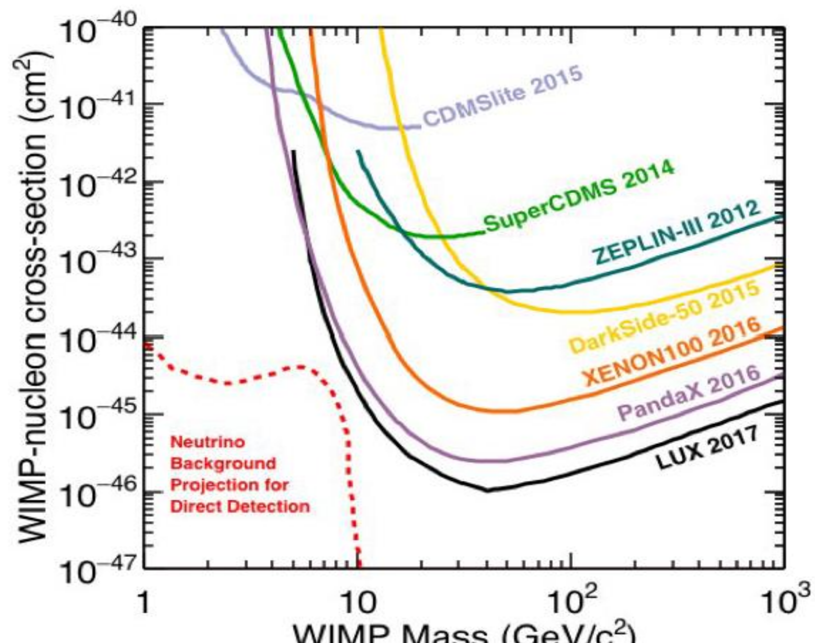
Direct Detection Techniques



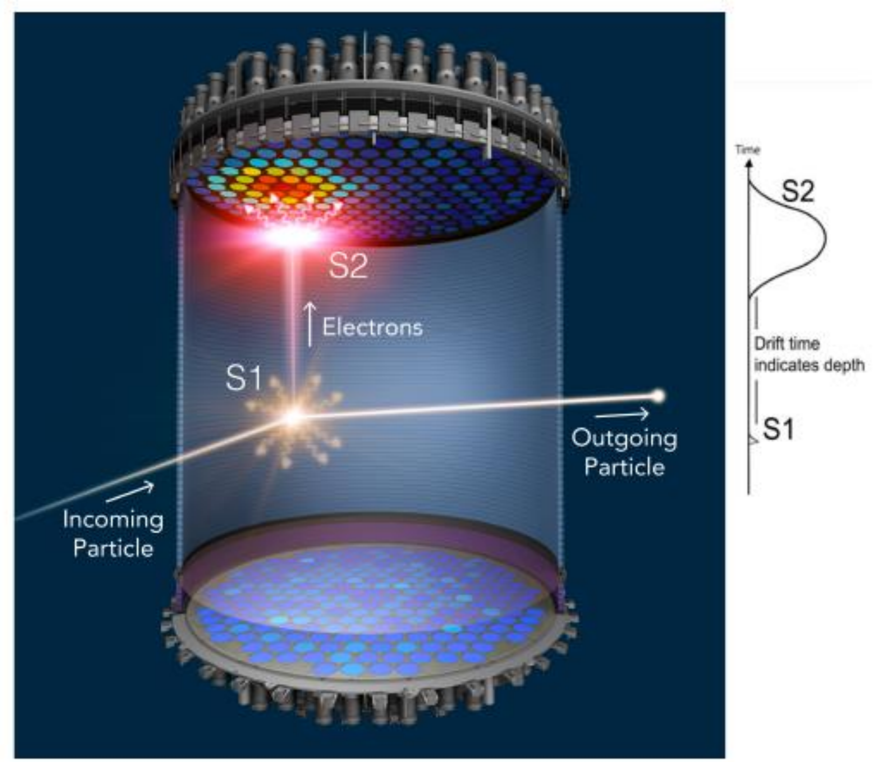


Great progress (every 3 years factor 10) over past 15 years…

Maintaining progress may from time to time require change of technology.



Two-phase Xenon TPC Principle



S1: prompt scintillation signal

- Light yield: ~60 ph/keV (ER, 0 field)
- Scintillation light: 178 nm (VUV)
- Nuclear recoil threshold ~5 keV

S2: delayed ionisation signal

- Electroluminescence in vapour phase
- Sensitive to single ionisation electrons
- Nuclear recoil threshold ~1 keV

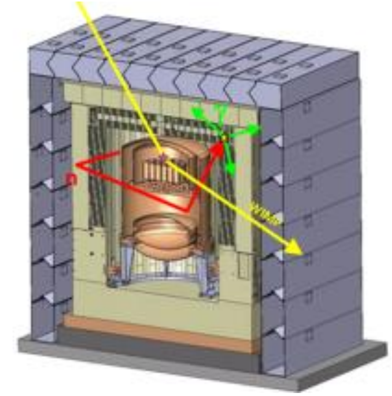
S1+S2 event by event

- ER/NR discrimination (>99.5% rejection)
- mm vertex resolution + high density: self-shielding of radioactive backgrounds

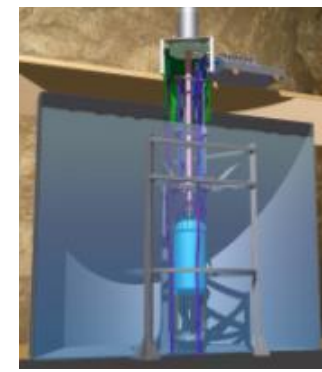
LXe is the leading WIMP target:

- Scalar WIMP-nucleon scattering rate dR/dE ~A^2, broad mass coverage (> 5 GeV)
- Odd-neutron isotopes (^{129}Xe, ^{131}Xe) enable SD sensitivity; target exchange possible
- No damaging intrinsic nasties (^{127}Xe short-lived, ^{85}Kr removable, ^{136}Xe $2\nu\beta\beta$ ok)

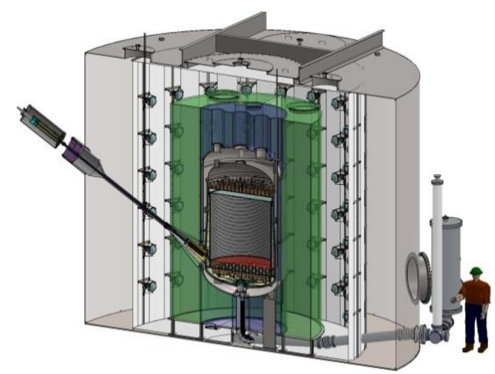
ZEPLIN → LUX → LUX-ZEPLIN



- **UK-led ZEPLIN programme at Boulby (2001-2011)**
  - Pioneered two-phase xenon technology
  - World class results from 3 xenon experiments
  - Fiducial mass ~6 kg

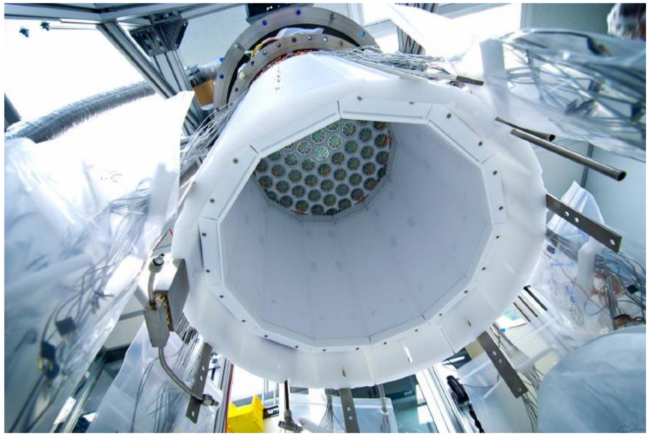


- **LUX operating at Sanford Underground Laboratory**
  - Imperial, Edinburgh and UCL joined after ZEPLIN-III
  - Gave world-leading experiment
  - Fiducial mass ~100 kg



- **LZ: next-generation experiment**
  - LZ formed with MOU between LUX and ZEPLIN-III in 2008
  - Selected in 2013 by DMUK for construction proposal to STFC
  - Fiducial mass ~5,600kg (~10^{-48} cm^2 sensitivity)
  - Technical design completed, construction in progress

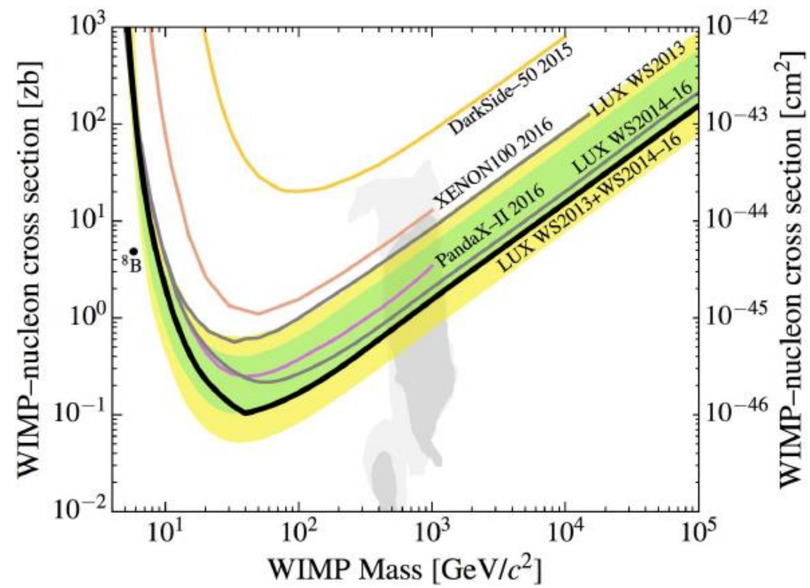
LUX 2013 – 2017

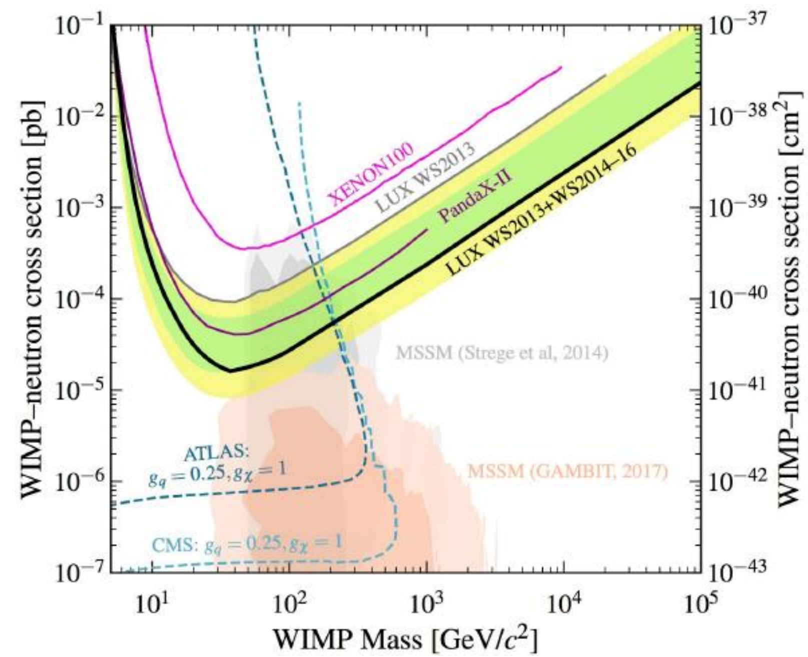


First Science Run in 2013
Second Science Run 2014 – 2016
Full exposure: 47,500 kg.days (427 live-days)

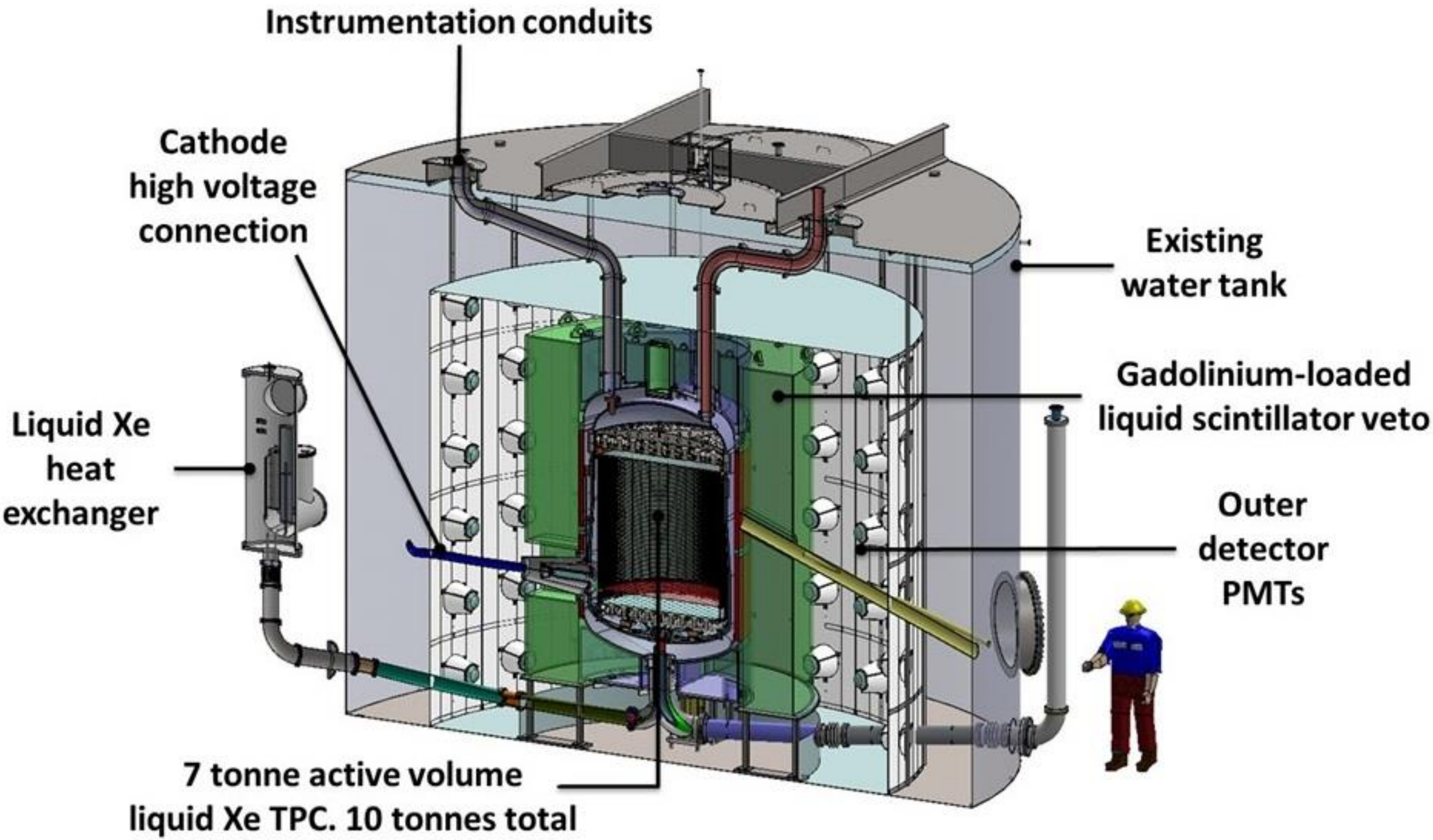
Improved Spin-Indep. WIMP Sensitivity by factor 20 since state prior to 2013.

In parallel: major programme improving LXe ER and NR calibration, which allowed significant improvement in accuracy of Xe response models.

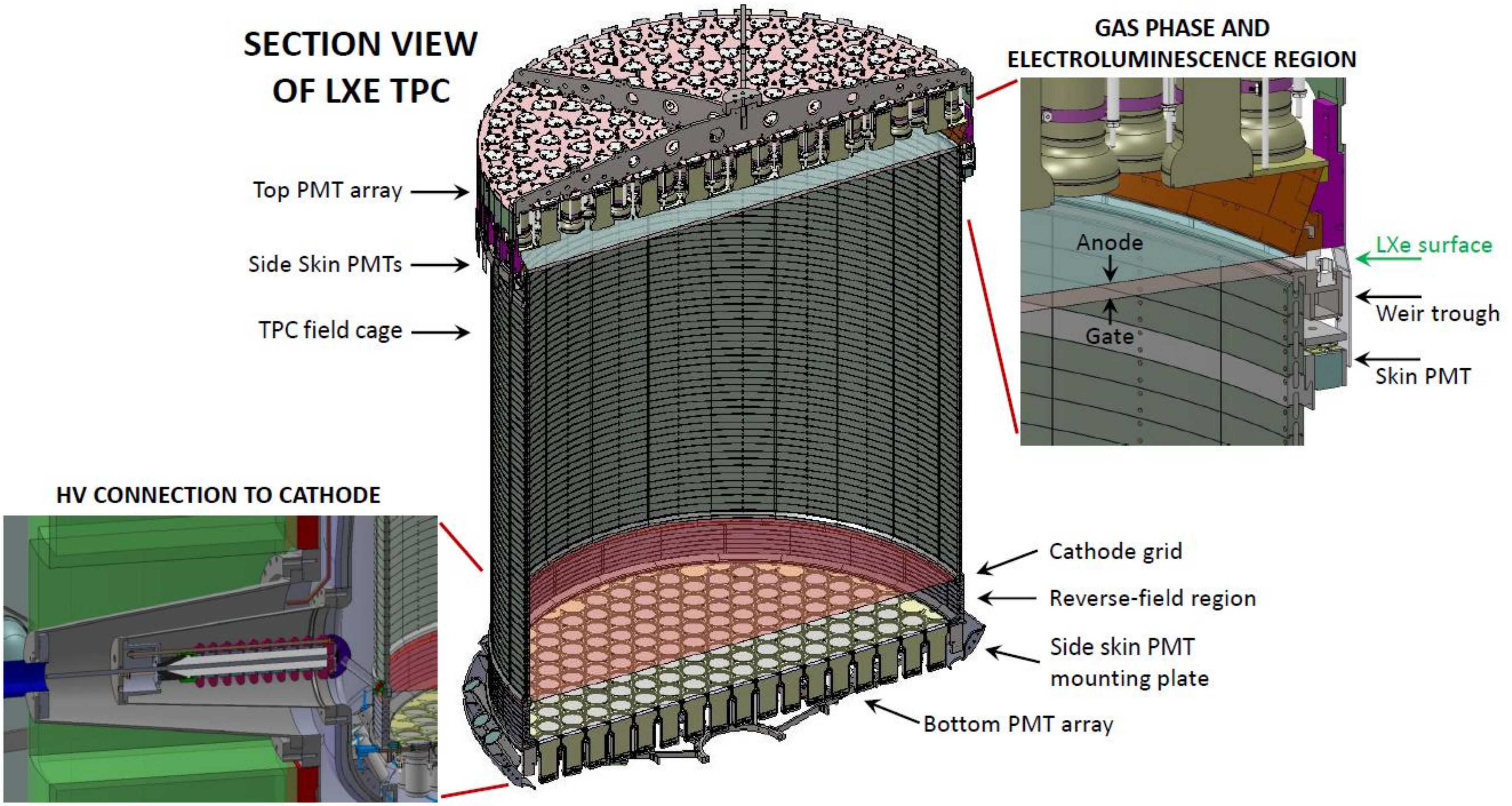




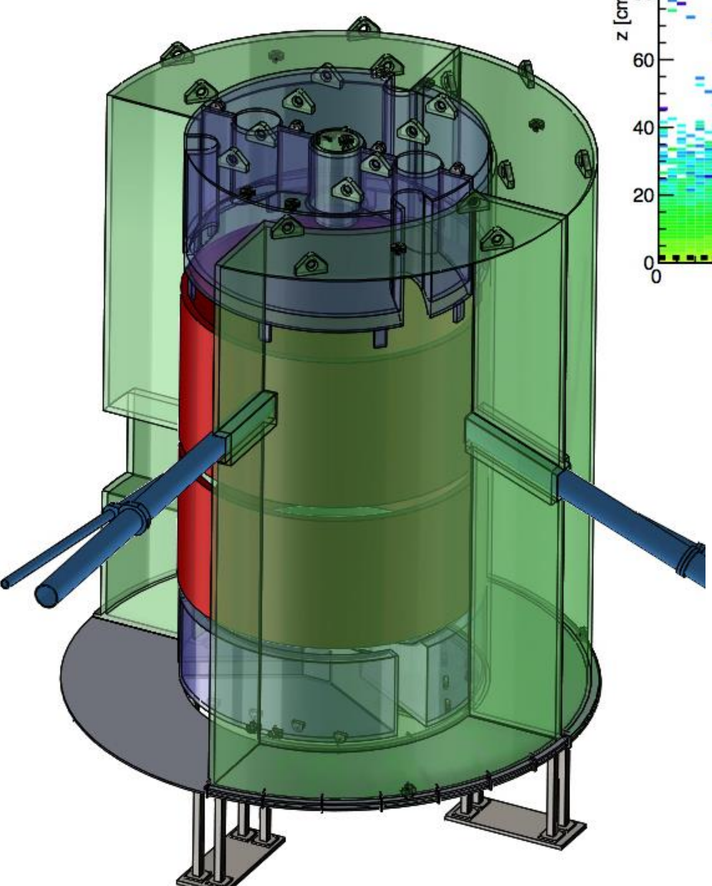
LZ Detector Design



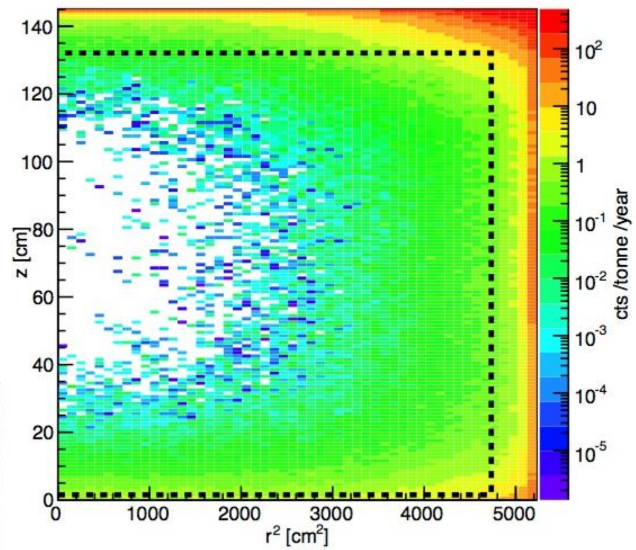
The TPC Design



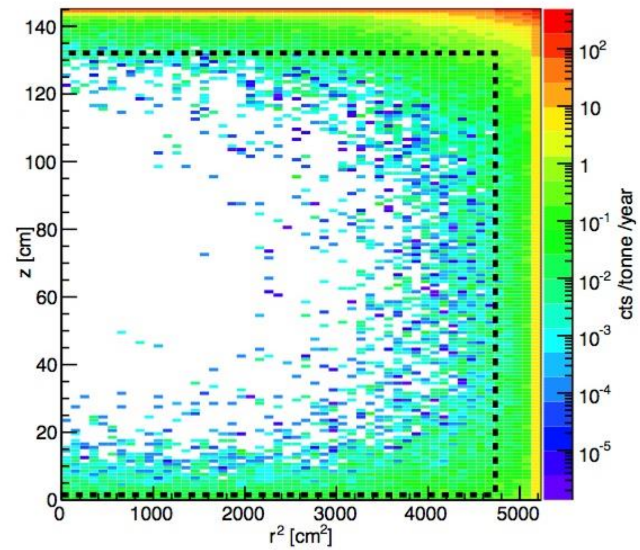
Outer Detector Design and Impact



Lxe TPC only: 3.8t fid

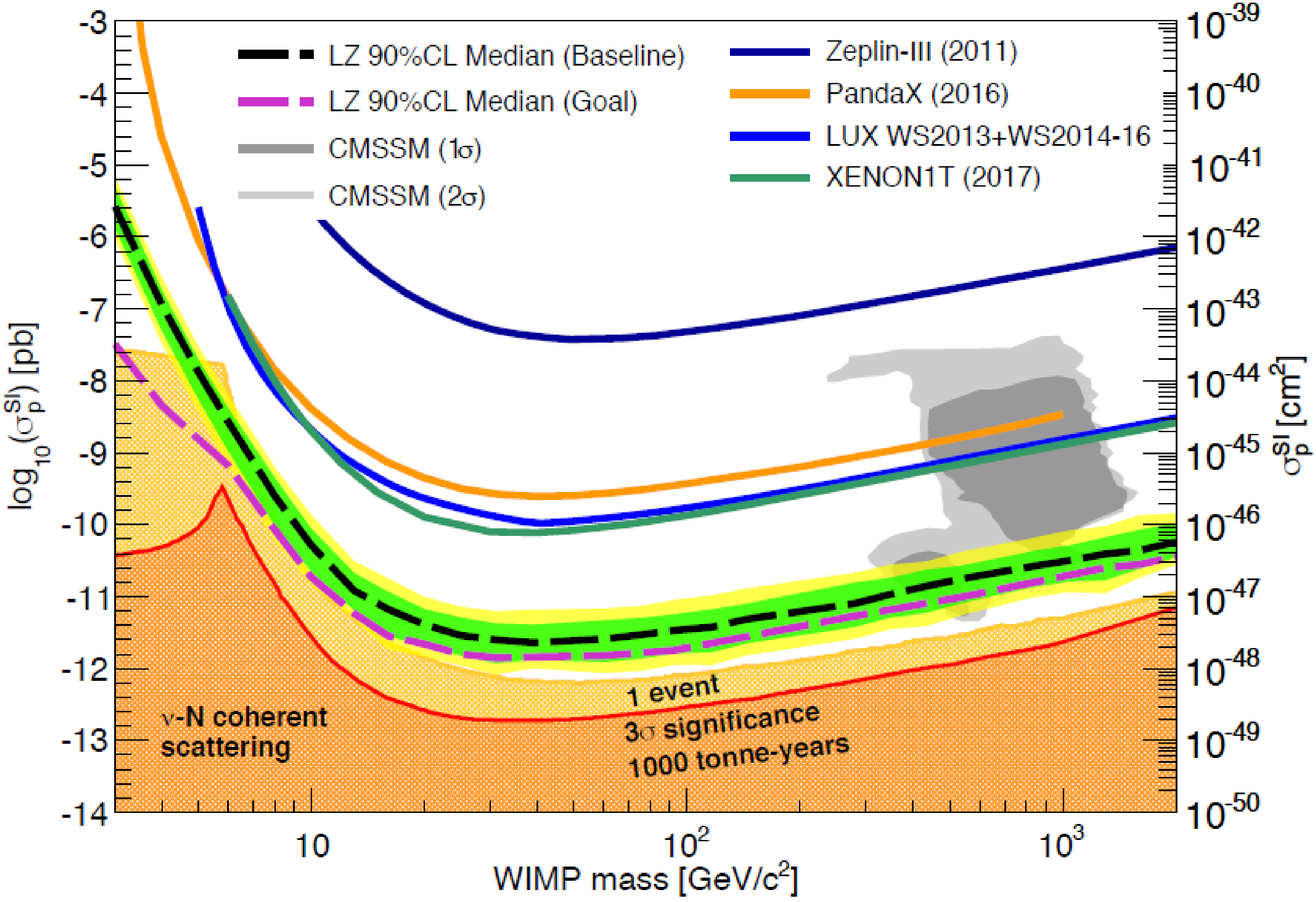


TPC+Skin+OD 5.6t fid



- External tagging allows greater fiducial volume for analysis
- 60 cm thick, 17.2 t of gadolinium-loaded liquid scintillator, 120 8” PMTs
- 97% efficiency for neutrons

Projected Limits



Baseline WIMP sensitivity: 2.3×10^{-48} cm^2 at 40 GeV/c^2

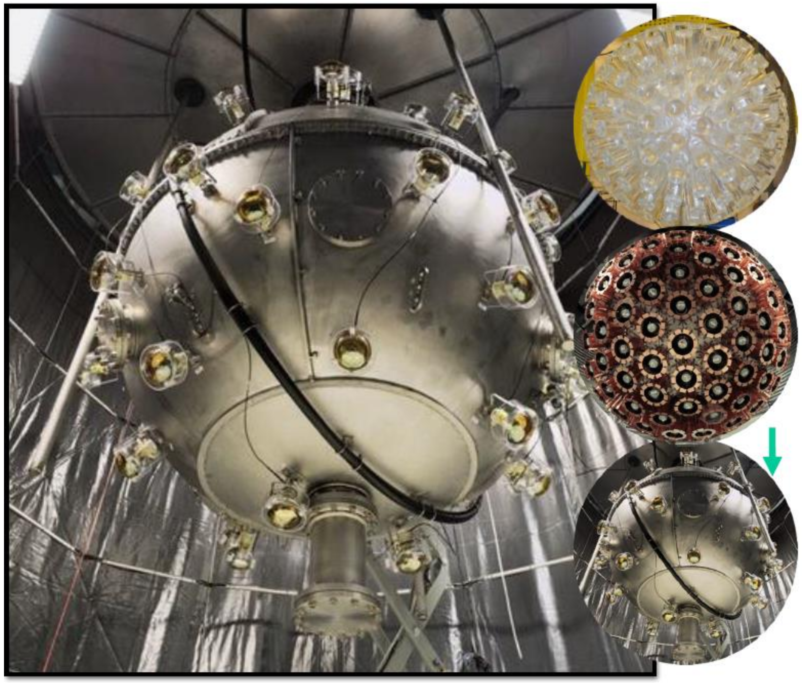
Other promising science targets: $0\nu\beta\beta$, pp and ^{8}B neutrinos, coherent neutrino scattering,

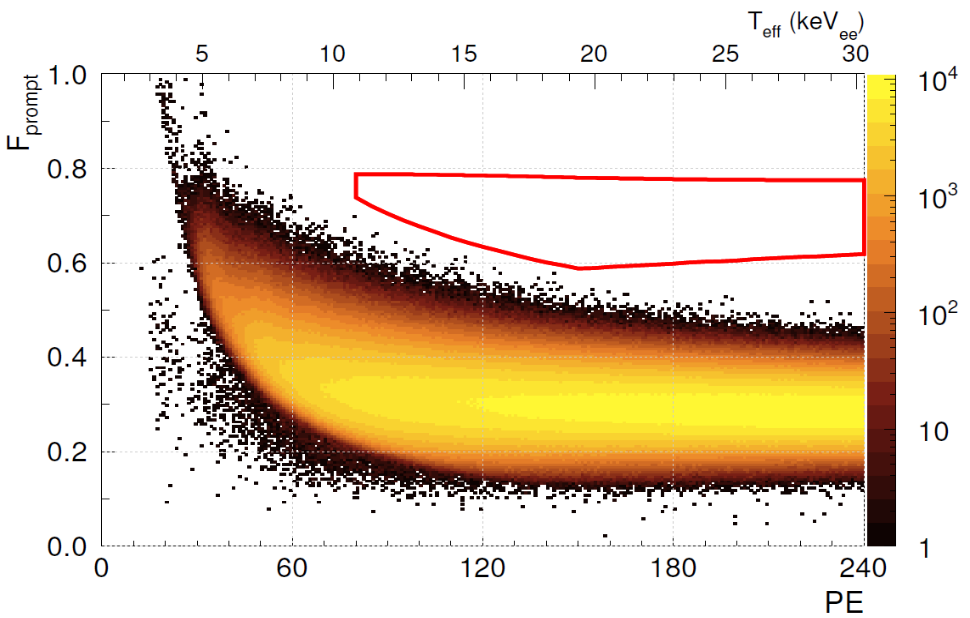
Scaling Liquid Xenon Detectors

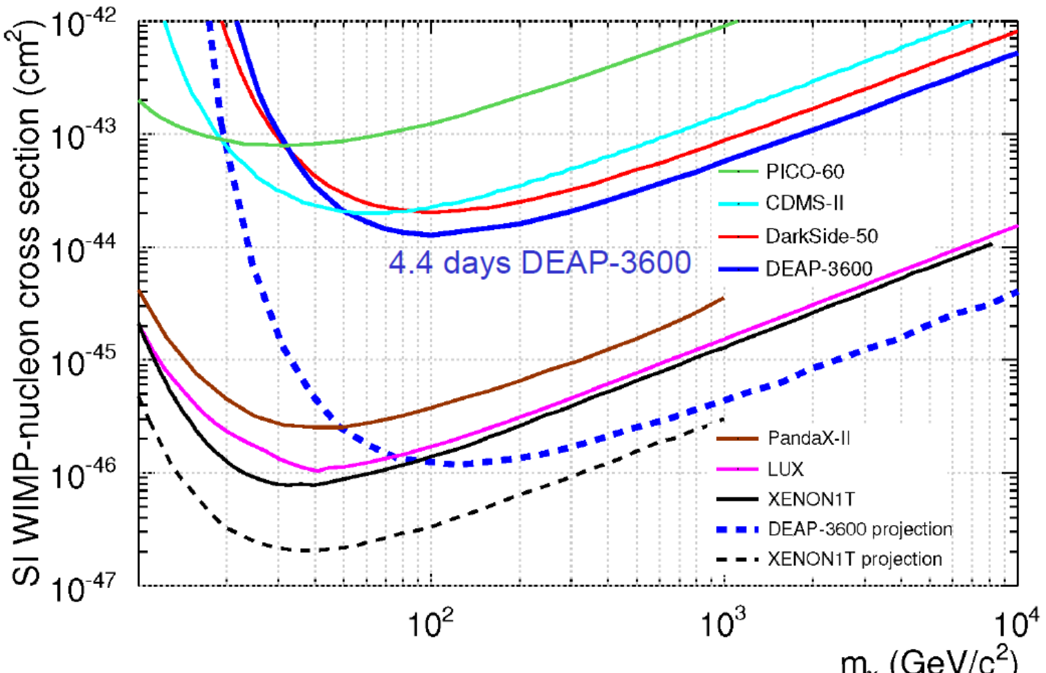
- Can electron lifetime be maintained sufficiently high?
- Larger diameter grid? Sagging, opacity, segment?
- Electric field: higher voltage needed for same field.
- Purification techniques?
- Readout devices (PMT, new forms of photon detectors) – reliability, radiopurity, cost?
- Overall radiopurity.
- Even better understanding of event topologies?

Overall verdict: achievable.

DEAP-3600



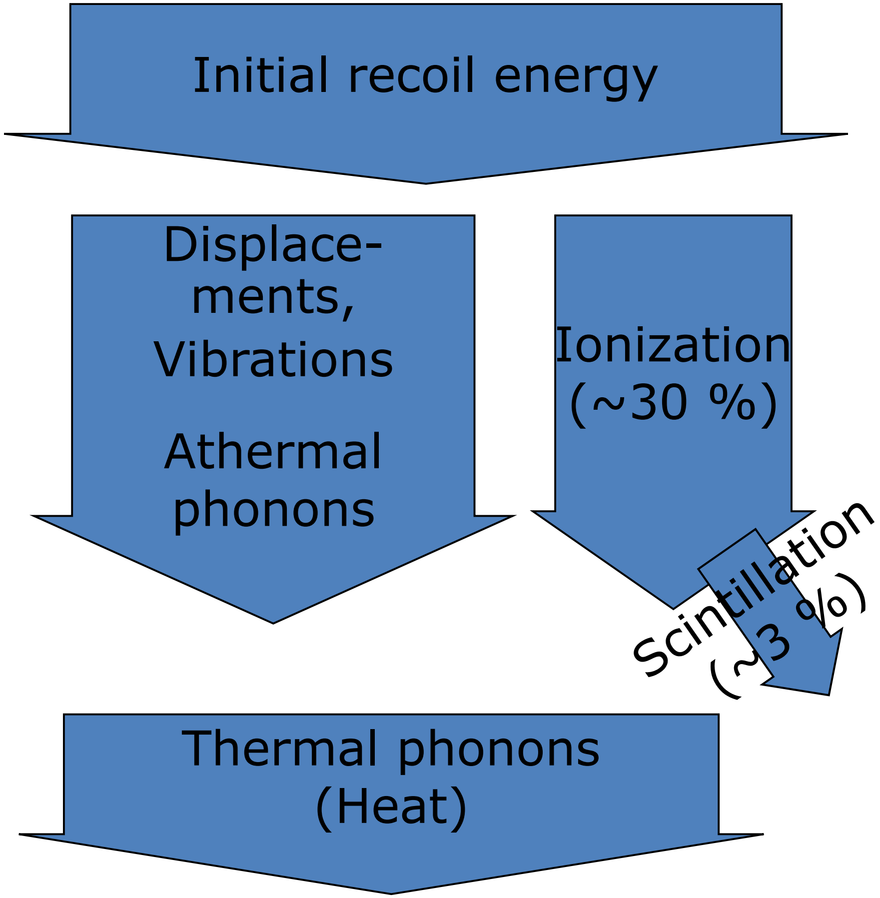




- Will run to 2020.
- Beyond DEAP-3600: significant global collaboration of argon DM searches.
- DS-20K at LNGS and future multi-hundred tonne detector.

Niche of Cryogenic Detectors

Phonon-ionization / phonon-scintillation

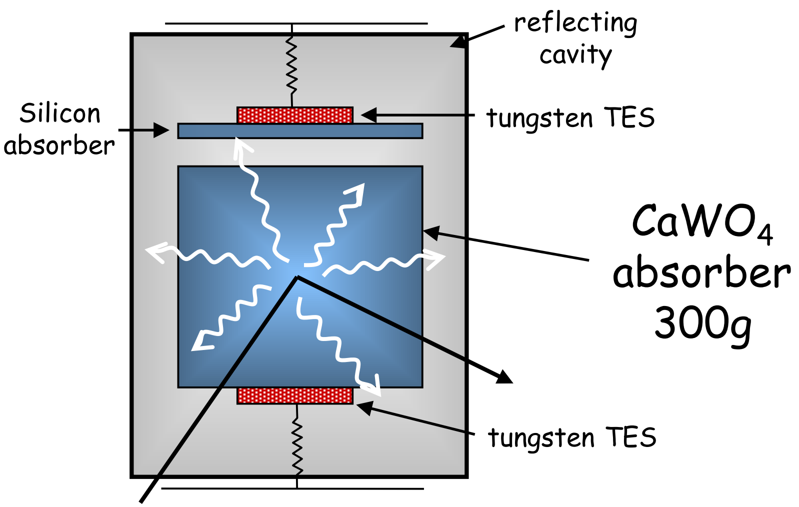


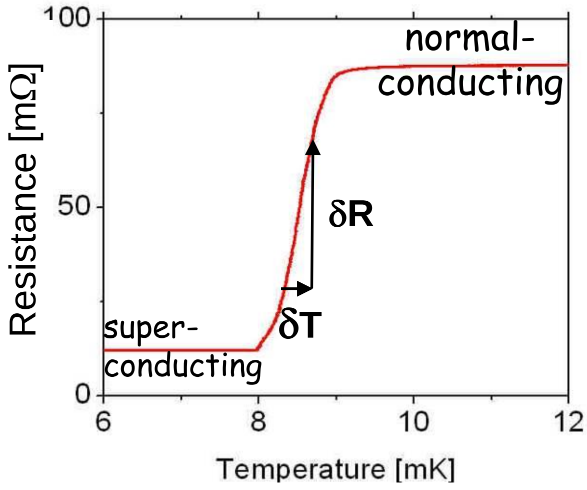
Phonon: most precise total energy measurement

Ionization / Scintillation: yield depends on recoiling particle

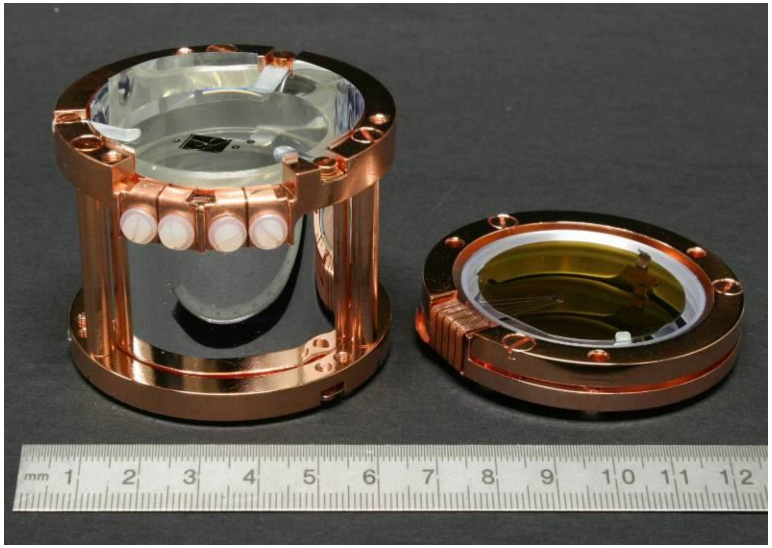
Nuclear / electron recoil discrimination.

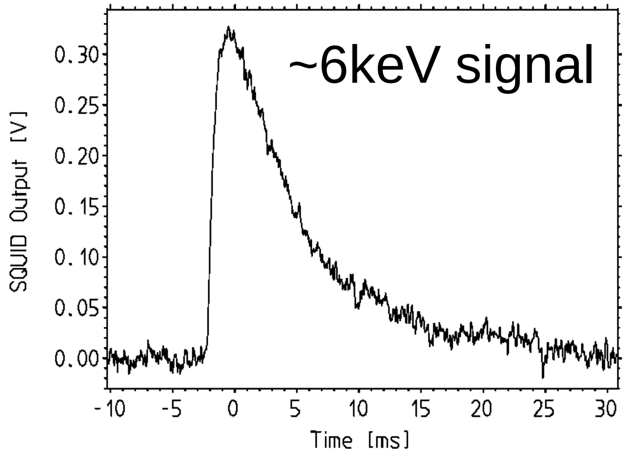
CRESST Detectors



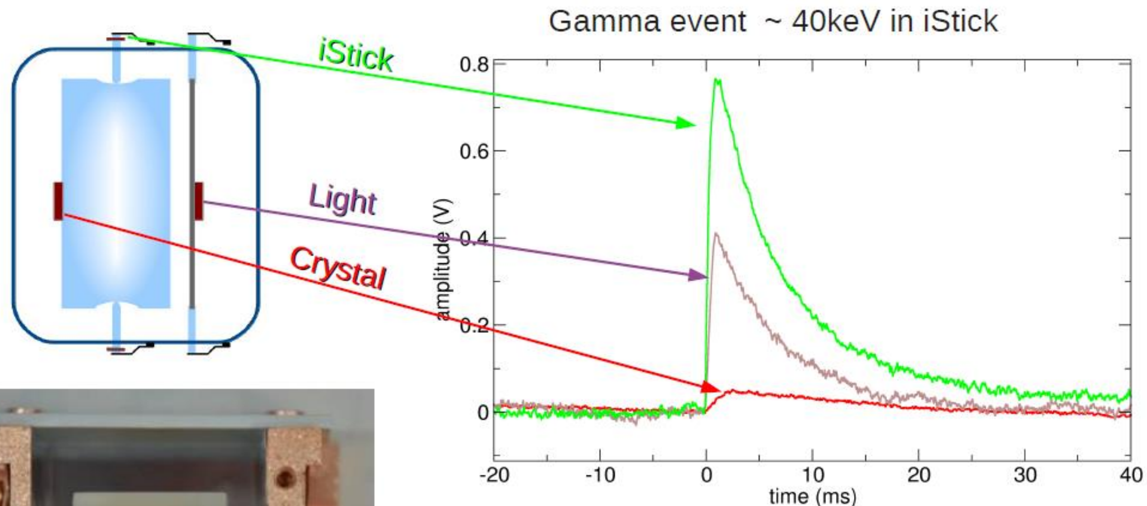


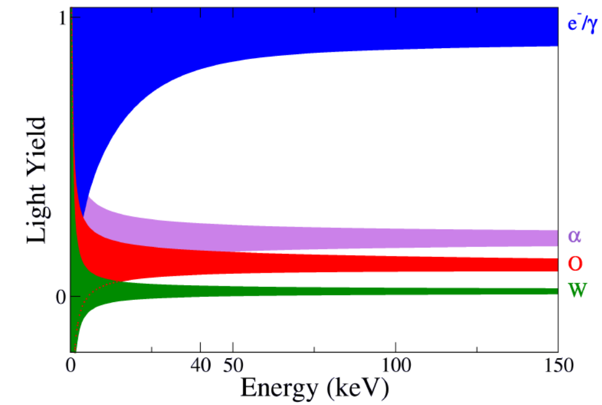
Width of transition: ~1mK
Signals: few μ K
Stablity: ~ μ K

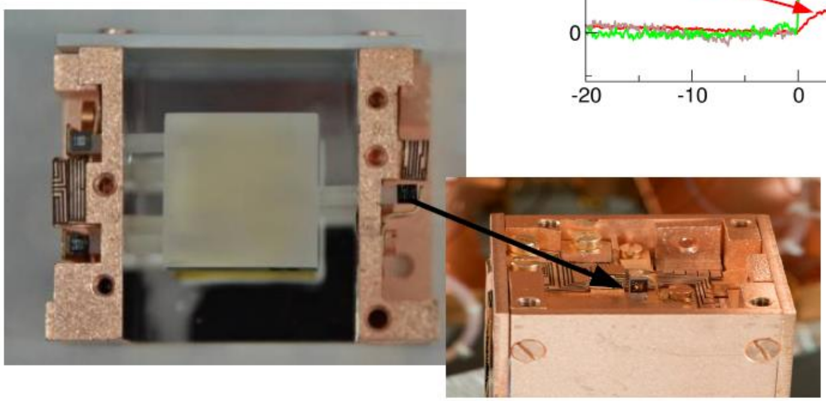


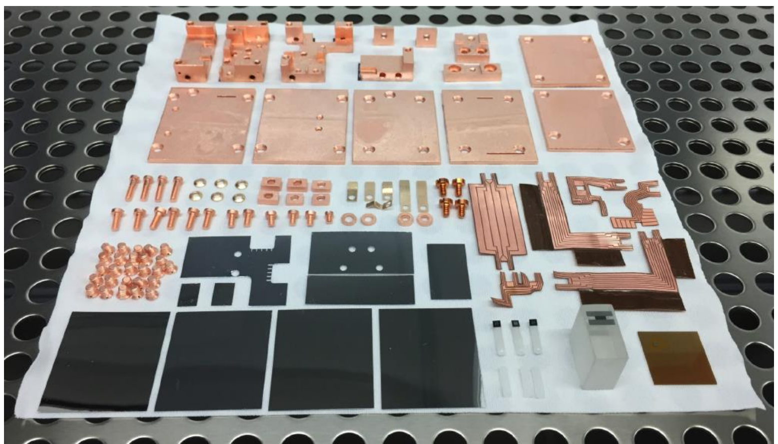


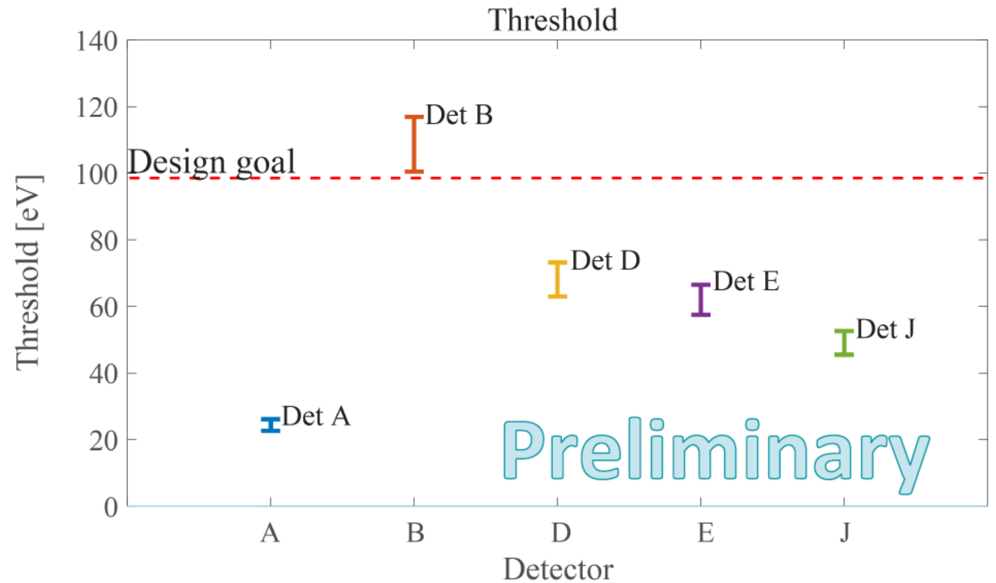
Phonon Scintillation (CRESST-III)



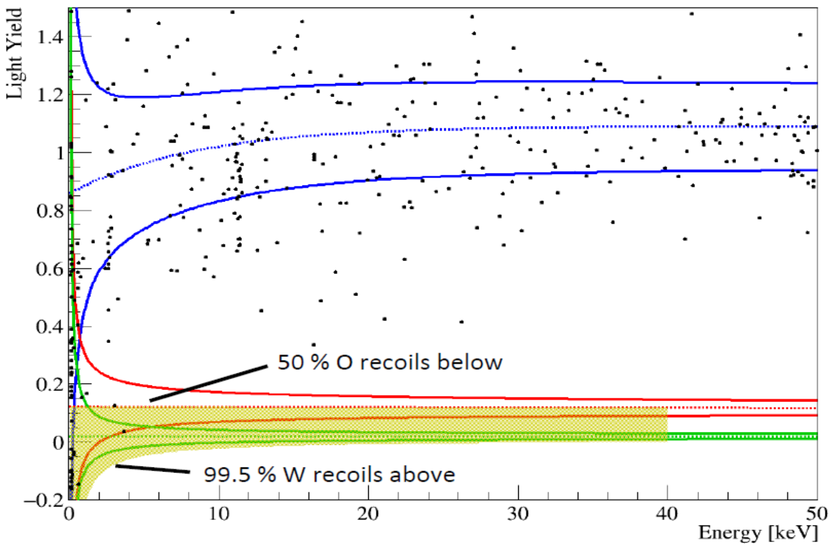


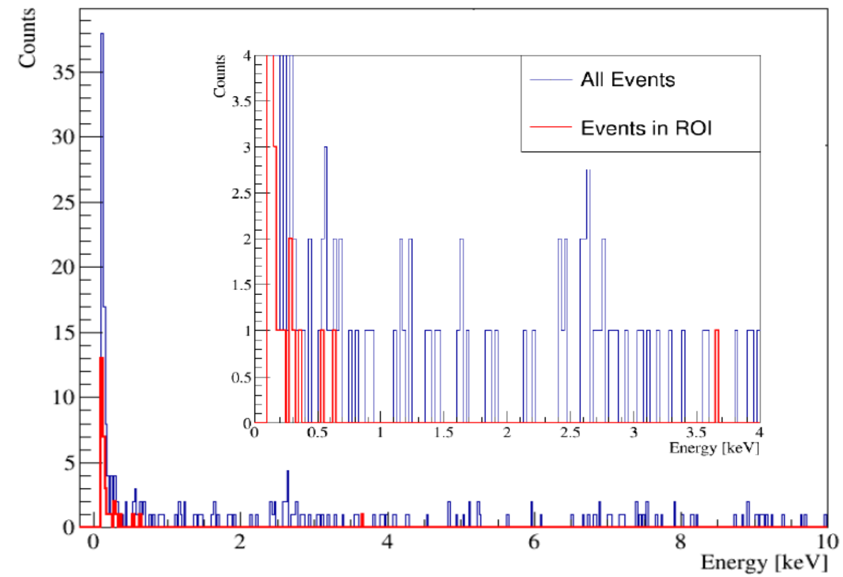




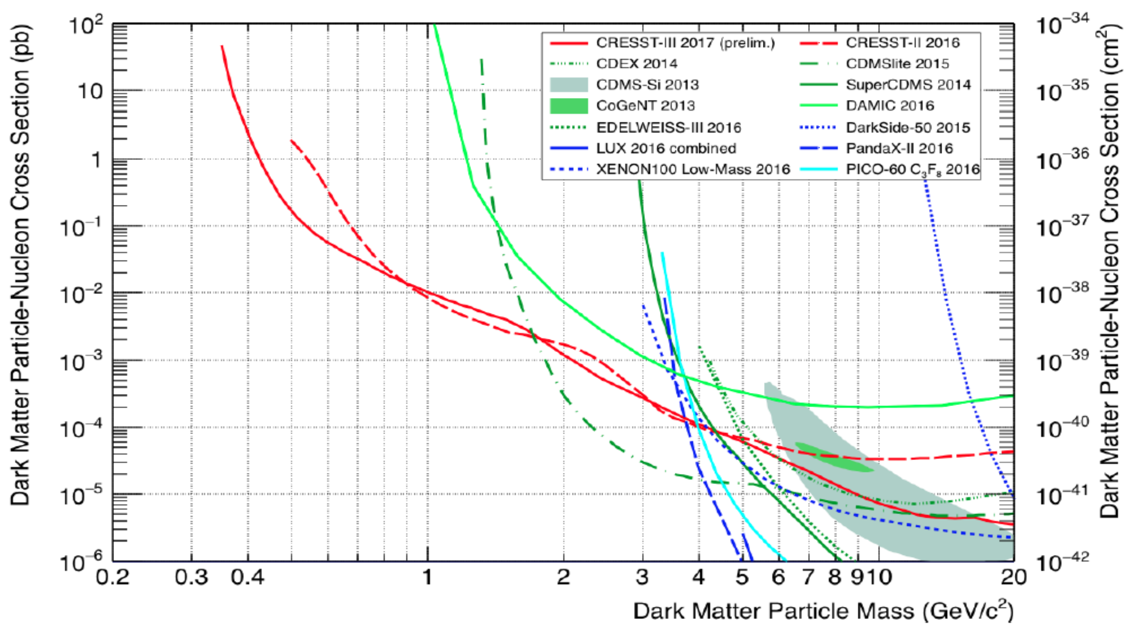


CRESST Status (2017 results)



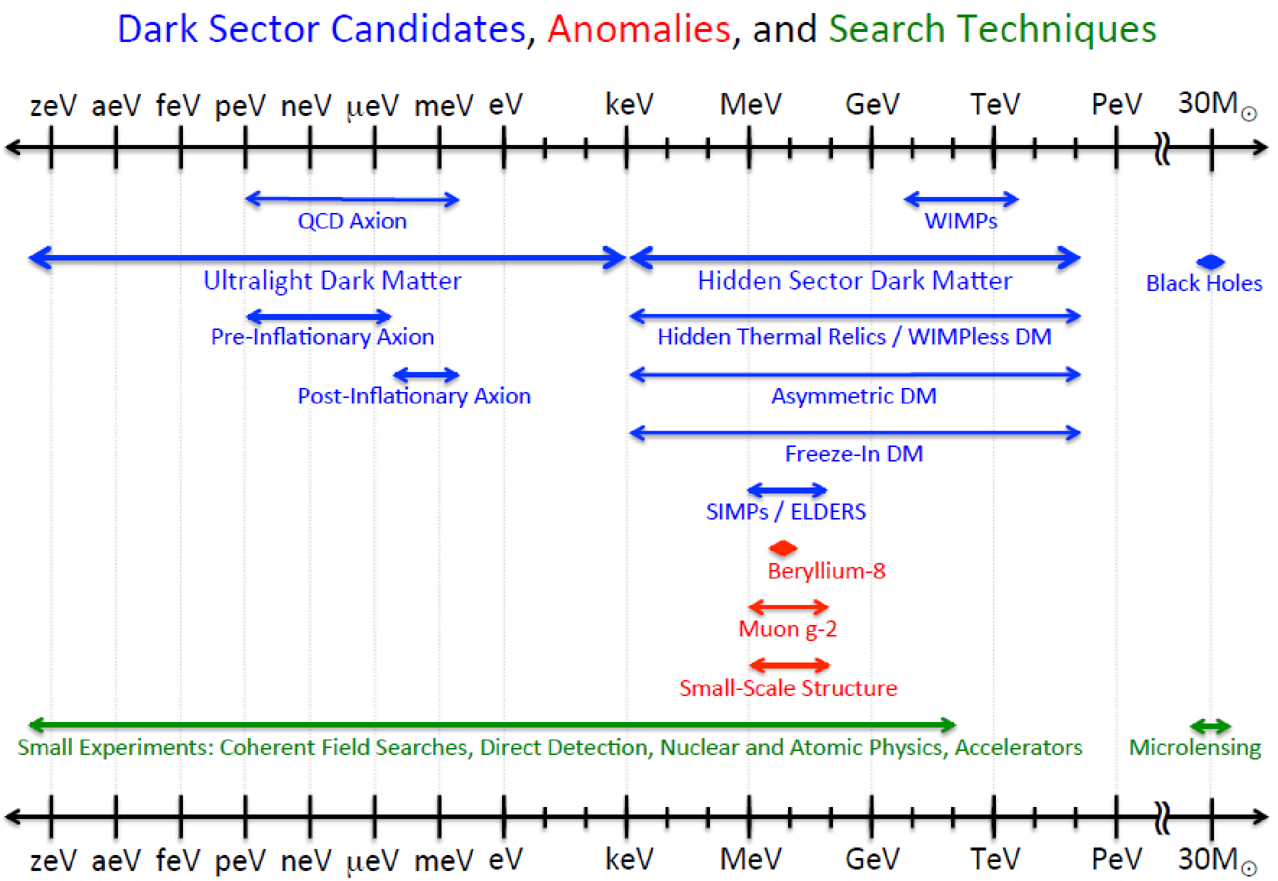


- One order of magnitude improvement at 0.5 GeV/c^2
- Reach of direct dark matter experiments extended to 0.35 GeV/c^2
- Exposure 2.21 kg days
- Absorber volume 24g
- Threshold 100 eV



Future G3 R&D - UK

Largely built on our core expertise with flexibility to change direction if a new, clear direction emerges to which we could make a significant contribution.



From US Cosmic Vision: New Ideas in Dark Matter 2017: Community Report

Future G3 R&D - UK

- Photon Detection Methods: testing and characterizing individual SiPM, developing fast optical photon simulations, and the SiPM readout with DAQ.
- Further Development of LXe-TPCs: focus on measurements related to xenon, properties of key TPC materials and improving position and energy resolution achievable at MeV energies.
- Low Background Techniques: developing new techniques on radon emanation, explore inline radon removal from xenon gas, improve dust control, ICP-MS and HPGe assay capability, and simulations.

Summary

- 3 major 2-phase LXe experiments – in hand, progressing well, major effort.
- Probably one very large LXe experiment beyond G2.
- Cryogenic detectors focussing on low-mass segment – but becoming more complex with needing additional phonon-only background rejection.
- Overall landscape: we may have to broaden our searches – diversification of experimental techniques. But ultimately: it takes about a decade to achieve what one thought was "easy".
- Hence, UK focus on technique where most of UK expertise lies.