# Direct Dark Matter Searches

Hans Kraus

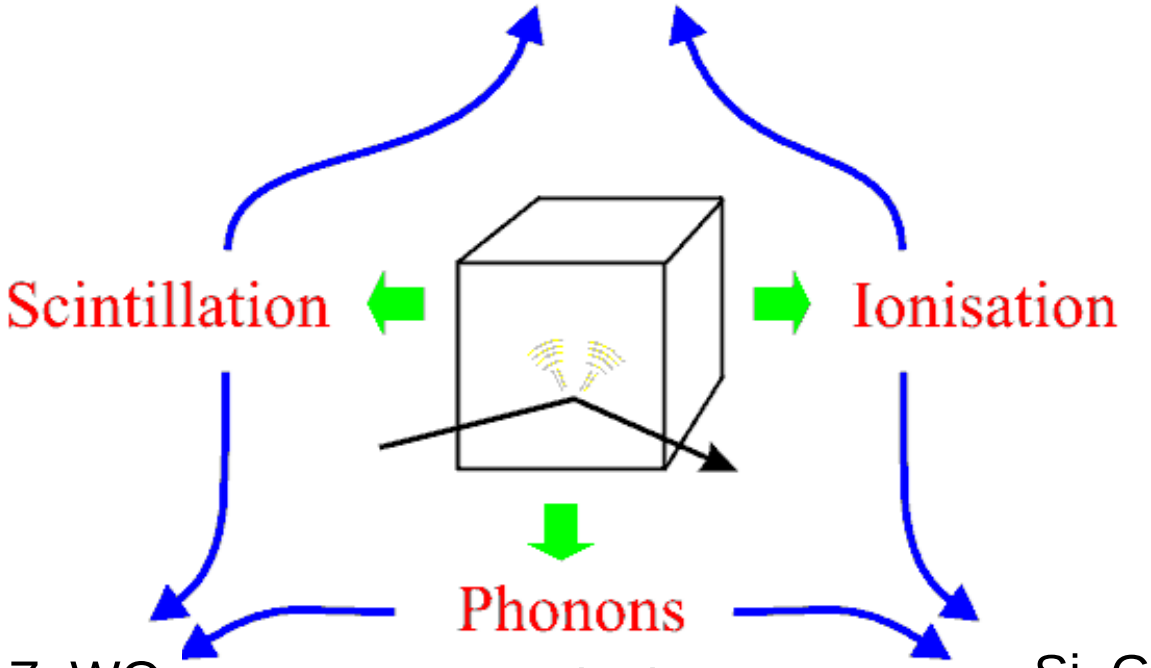
- Detector Technologies / Historic
- Cryogenic
- Noble Liquids
- Directional

A rather selective summary of dark matter search experiments

# 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




Ge
CoGENT
GERDA
MAJORANA
IGEX

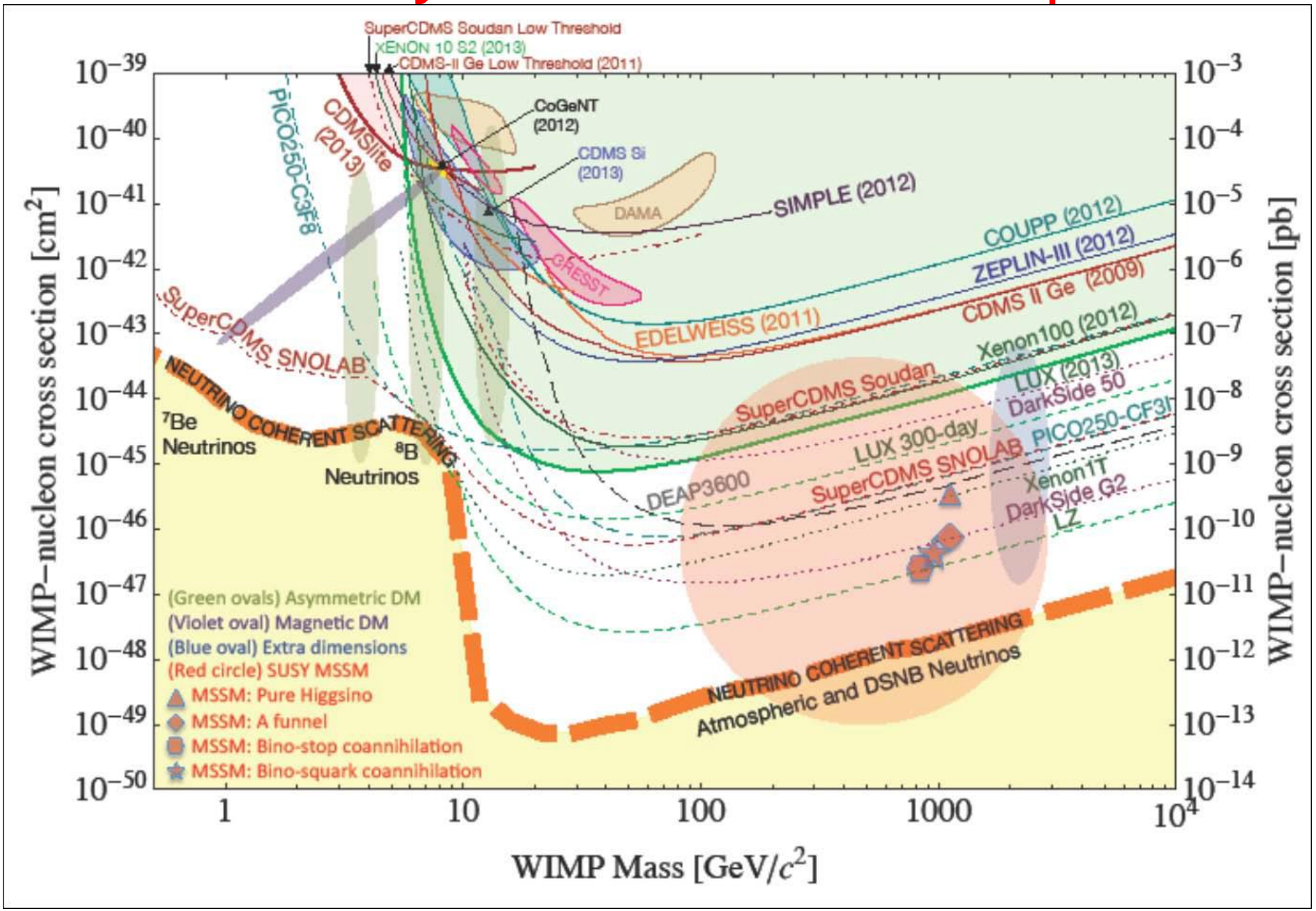
$CaWO_4$, $ZnWO_4$
CRESST II
ROSEBUD
EURECA

$Al_2O_3$ and others
CRESST I
CUOPP
SIMPLE
PICASSO

Si, Ge
CDMS
EDELWEISS
EURECA

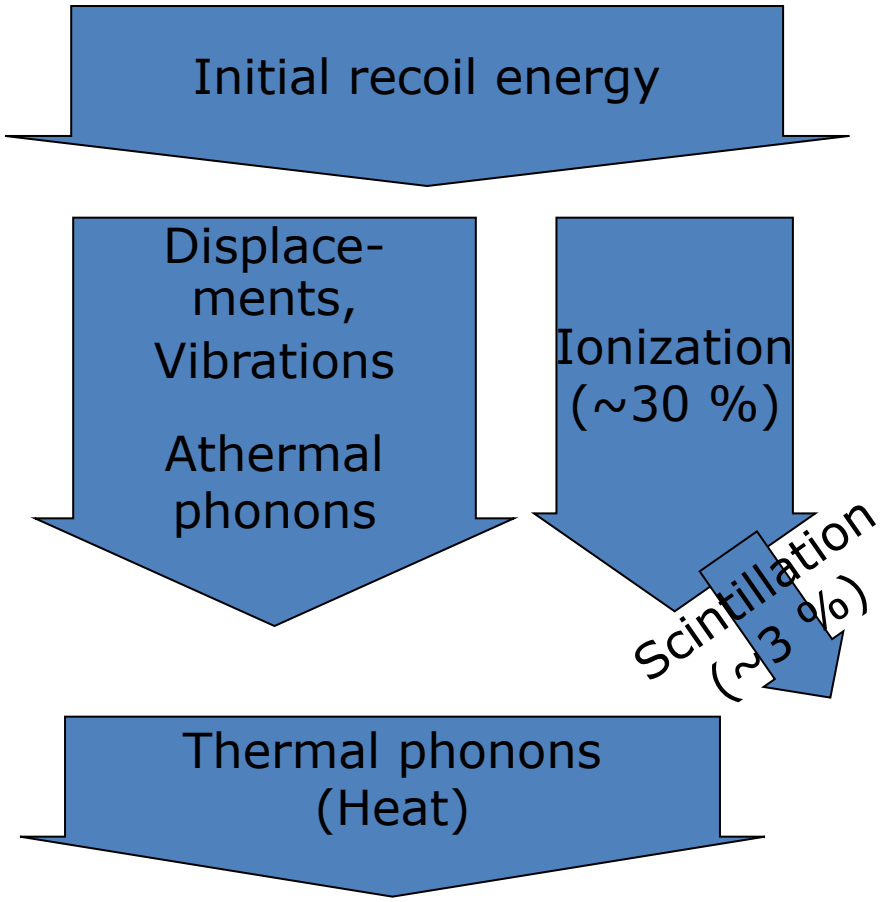
Displacement / tracking: DRIFT, Newage, MIMAC, DM-TPC

# The Physics Result Landscape



# Cryogenic detectors

## Phonon-ionization / phonon-scintillation

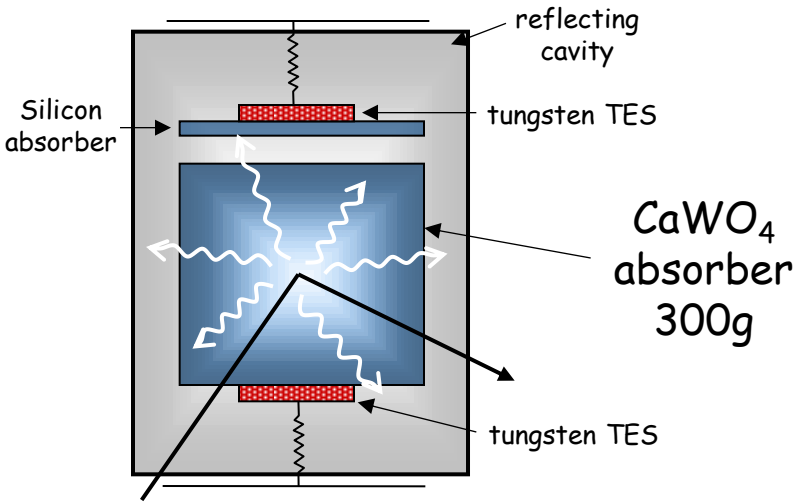


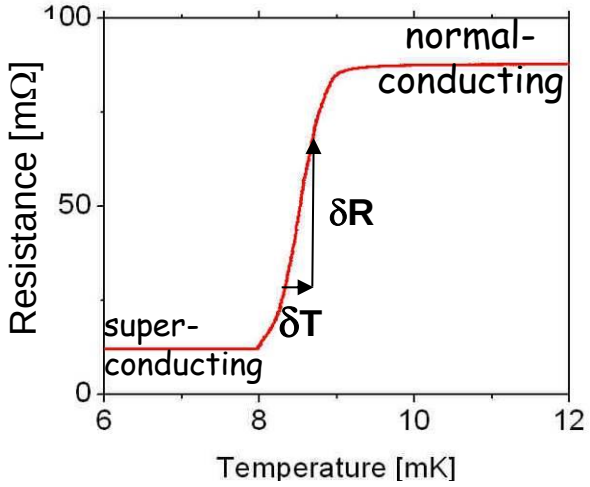

**Phonon:** most precise total energy measurement

**Ionization / Scintillation:** yield depends on recoiling particle

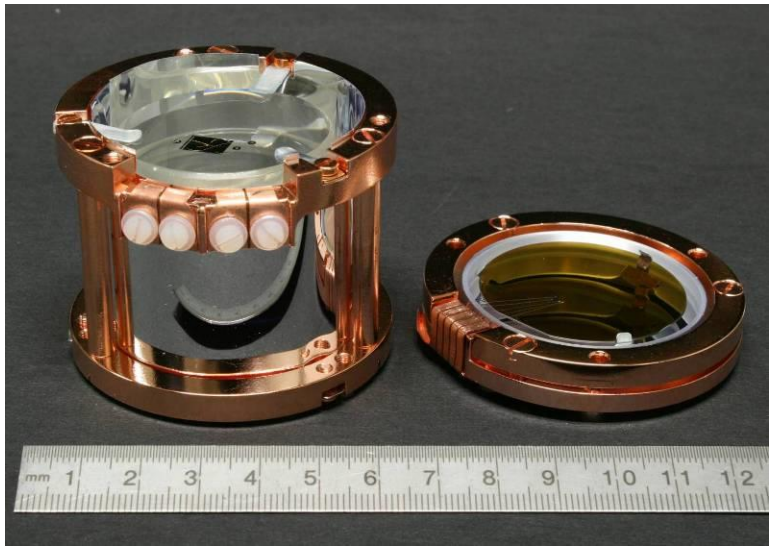
Nuclear / electron recoil discrimination.

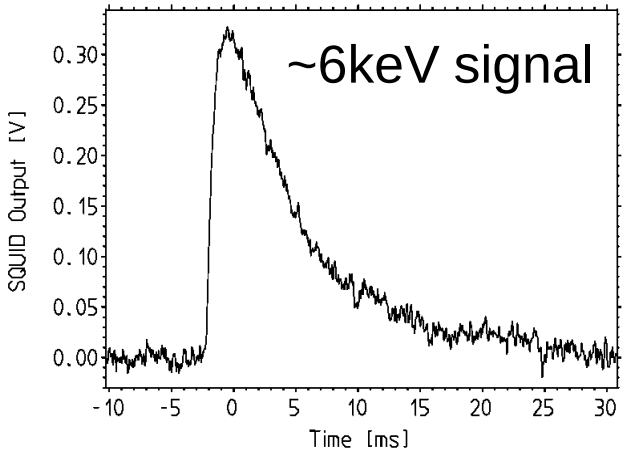
# CRESST Detectors



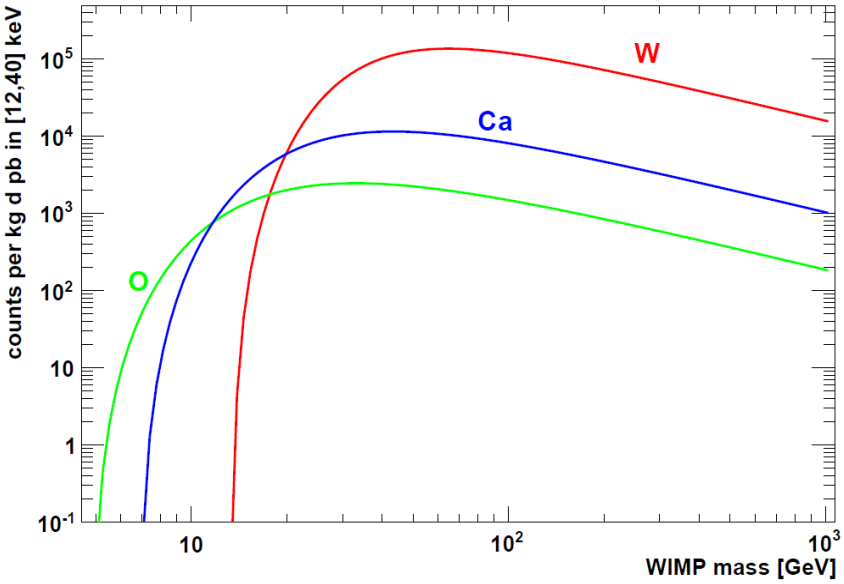



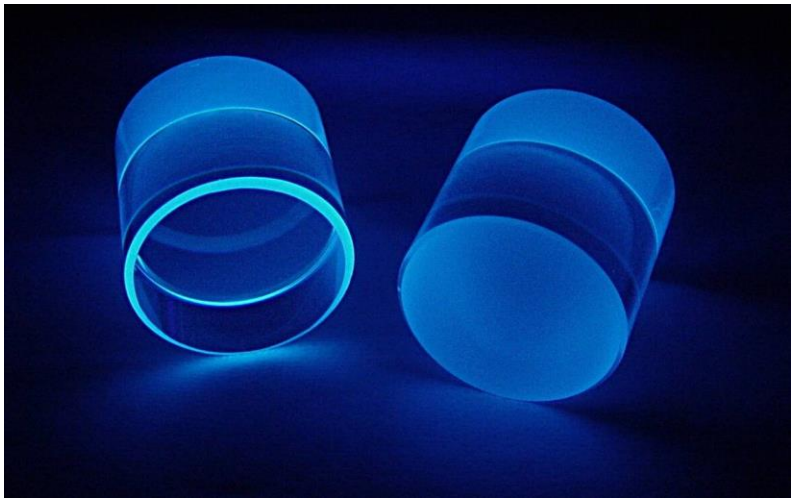

Width of transition: ~1mK
Signals: few μ K
Stablity: ~ μ K

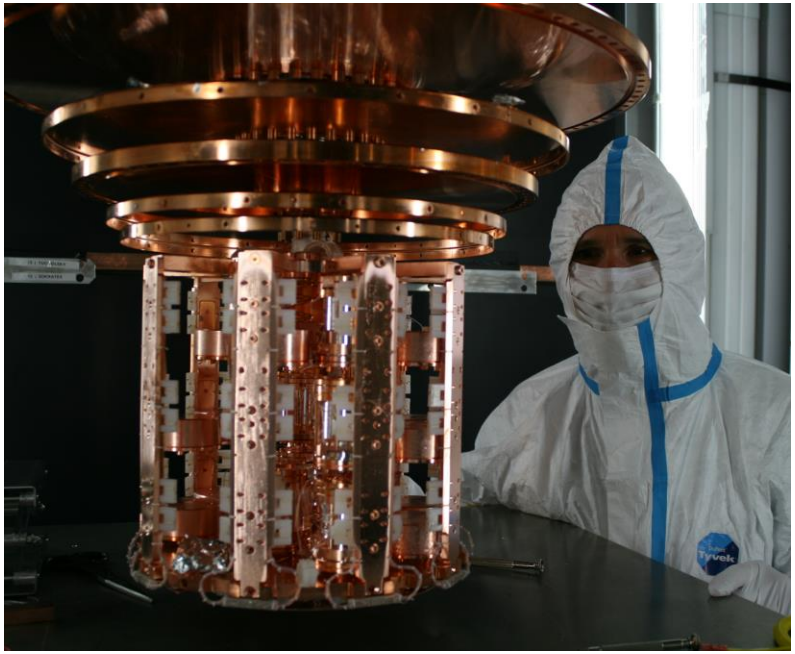


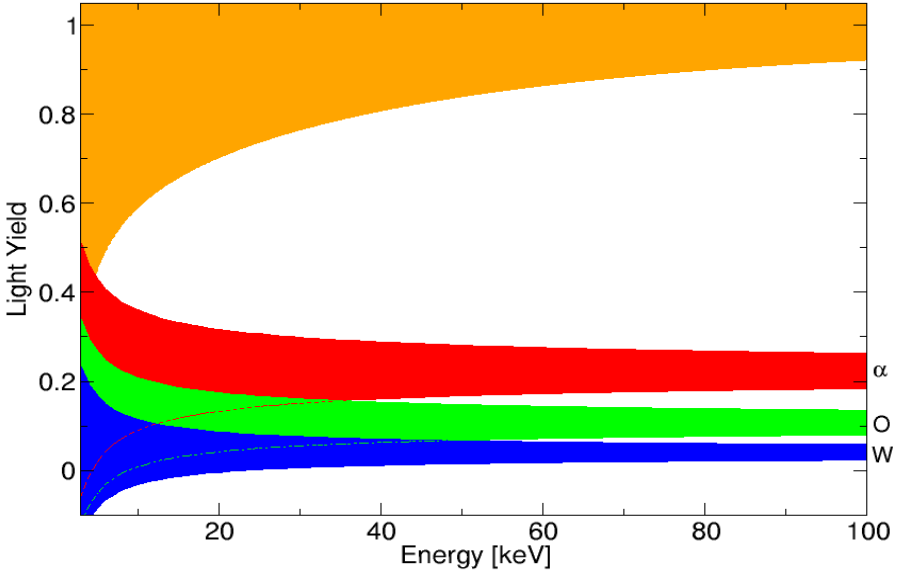


# CRESST

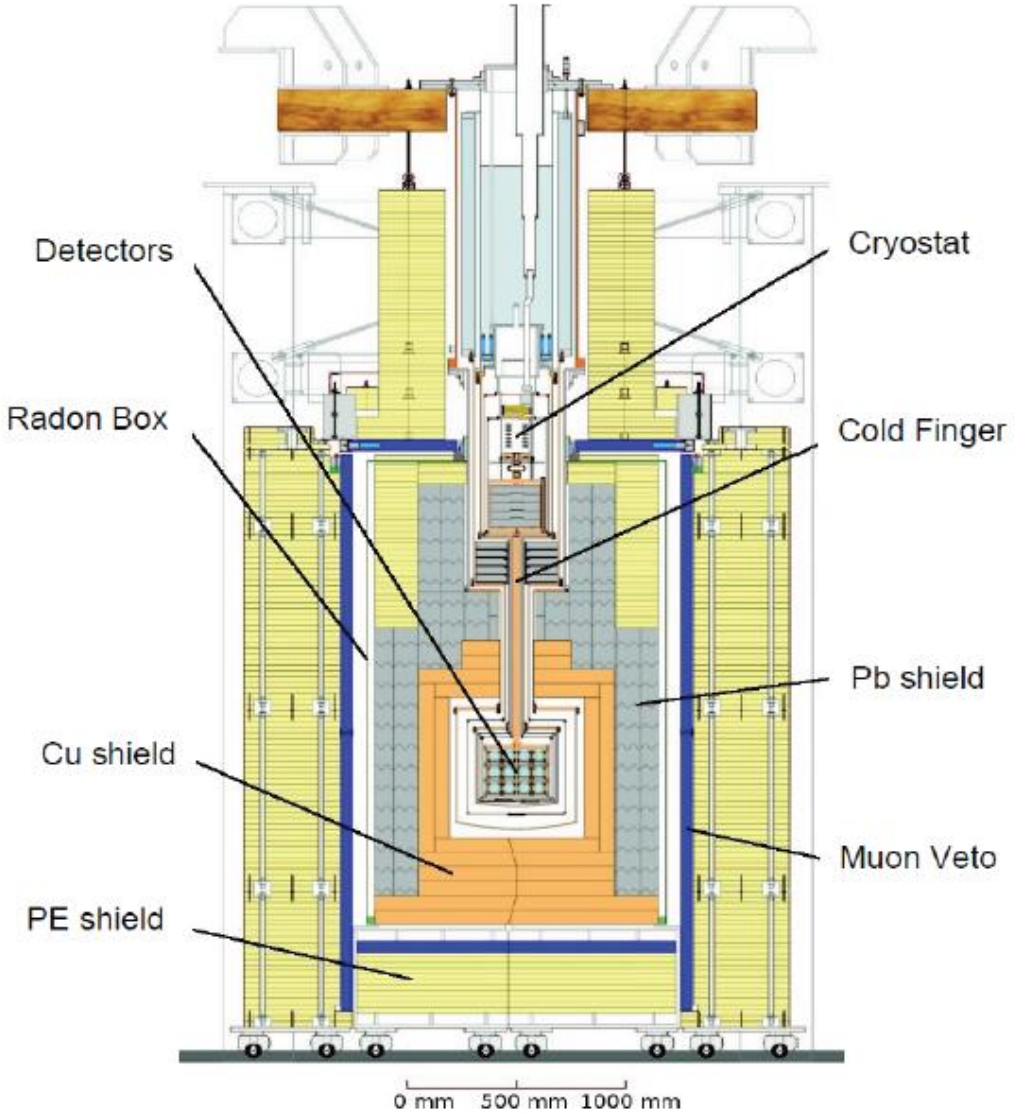

counts per kg d pb in [12,40] keV
$10^5$
$10^4$
$10^3$
$10^2$
10
1
$10^{-1}$
W
Ca
O
10
$10^2$
$10^3$
WIMP mass [GeV]






Light Yield
1
0.8
0.6
0.4
0.2
0
α
O
W
20
40
60
80
100
Energy [keV]

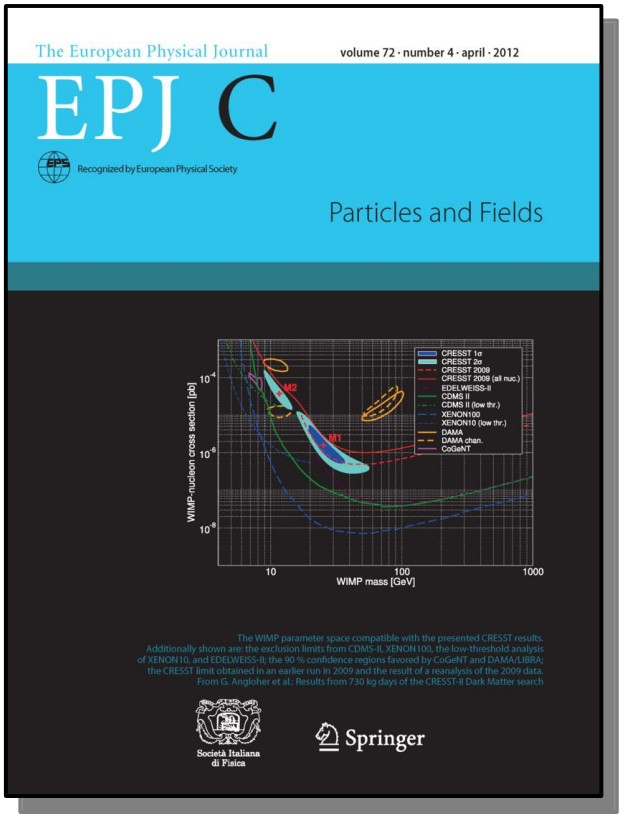
# CRESST in Gran Sasso



# The previous CRESST run (Run 32)

- Extended Physics Run from June ‘09 to April ‘11
- 8 $CaWO_4$ modules used for Dark Matter analysis
- Net exposure after cuts: 730 kg days
- 67 events observed in WIMP search region

| | M1 | M2 |
|---|---|---|
| $e/\gamma$-events | $8.00 \pm 0.05$ | $8.00 \pm 0.05$ |
| $\alpha$-events | $11.5^{+2.6}_{-2.3}$ | $11.2^{+2.5}_{-2.3}$ |
| neutron events | $7.5^{+6.3}_{-5.5}$ | $9.7^{+6.1}_{-5.1}$ |
| Pb recoils | $15.0^{+5.2}_{-5.1}$ | $18.7^{+4.9}_{-4.7}$ |
| signal events | $29.4^{+8.6}_{-7.7}$ | $24.2^{+8.1}_{-7.2}$ |
| $m_\chi$ [GeV] | 25.3 | 11.6 |
| $\sigma_{WN}$ [pb] | $1.6 \cdot 10^{-6}$ | $3.7 \cdot 10^{-5}$ |




**High contribution from backgrounds**

A. Brown, S. Henry, H. Kraus and Ch. McCabe (Phys. Rev. Lett. D 85 (2012) 021301) point to mild tension between above WIMP interpretation and previous data from CRESST.

# CRESST Status (Run 33)


- 18 detector modules mounted (12 standard design, 6 with active veto for $^{206}$Pb recoils)
- Non-blind data set (Aug ’13 to 7$^{th}$ Jan ’14), 377 kg.day to evaluate performance and define / adjust cuts.
- Data since 7$^{th}$ Jan ’14 to be used in blind analysis.
- Smooth running conditions (>90% duty cycle), 5% removed due to instabilities (from heavy works in the tunnel).

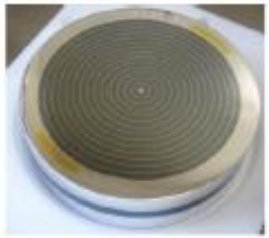
**E**xpérience pour **DE**tecter
**L**es **W**imps **E**n **SI**te
**S**outerrain

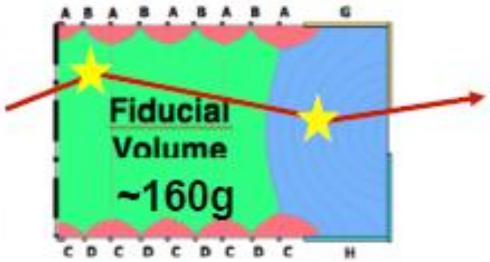
- Search for WIMP dark matter (scattering: ~10keV nuclear recoil with <0.01 events/kg/day)
- Need:
  - Sensitive Detectors (cryogenic germanium phonon-ionization detectors)
  - Low background (passive shielding and ultra-low background materials)
  - Excellent background discrimination (active rejection by muon vetoing and surface event identification)
  - Extended running periods / stability (good cryostat performance and calibrations)
- Laboratoire Souterrain de Modane

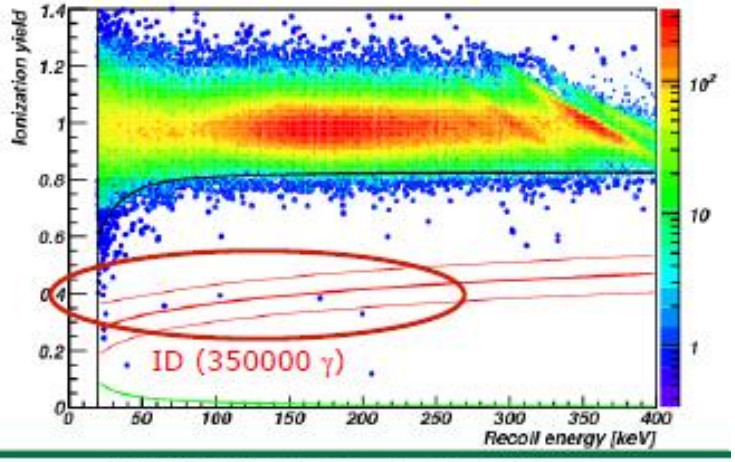
# EDELWEISS-III Detectors

From ID detectors to FID detectors

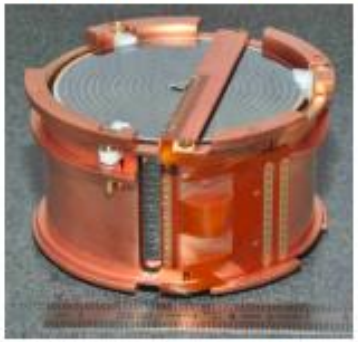
**EDELWEISS-II**
**ID 400g** with 10x **160g** fiducial mass



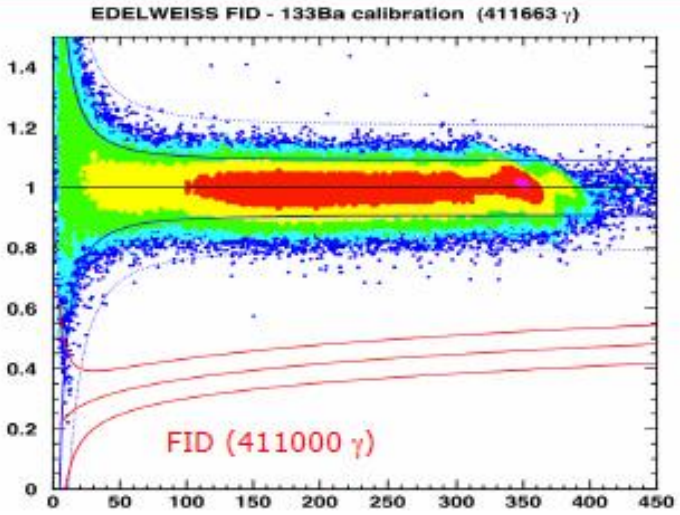



**EDELWEISS-III**
**FID 800g** with 40x **~600g** fiducial mass




« **F**ull **I**nter**D**igitised »



# Towards a few × $10^{-9}$ pb: EDELWEISS III

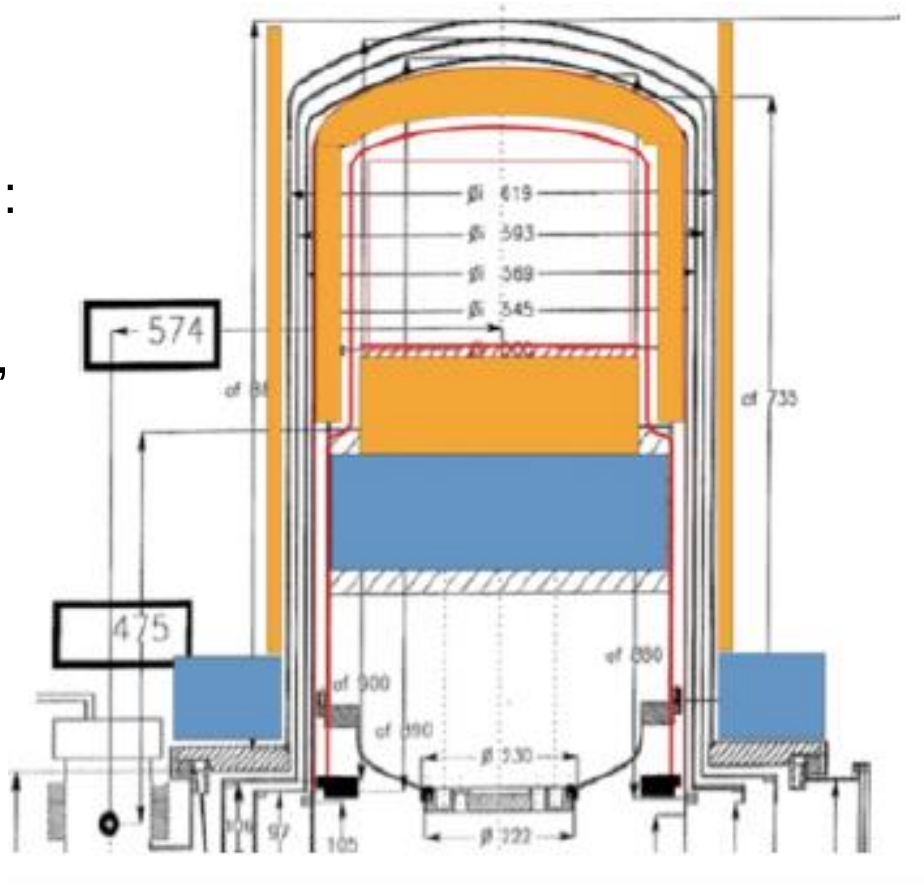
## Programme under way, funded.

## Detector improvements:

- ~40 FID800 detectors to be installed: 24kg fiducial
- 2 NTD heat sensors (better heat ch), 4 ionization channels, instead of 6.

## Infrastructure improvements:

- **Within the Edelweiss-II setup** – upgrades of cryogenics, cabling, DAQ, shielding.
- Extra internal PE shield.



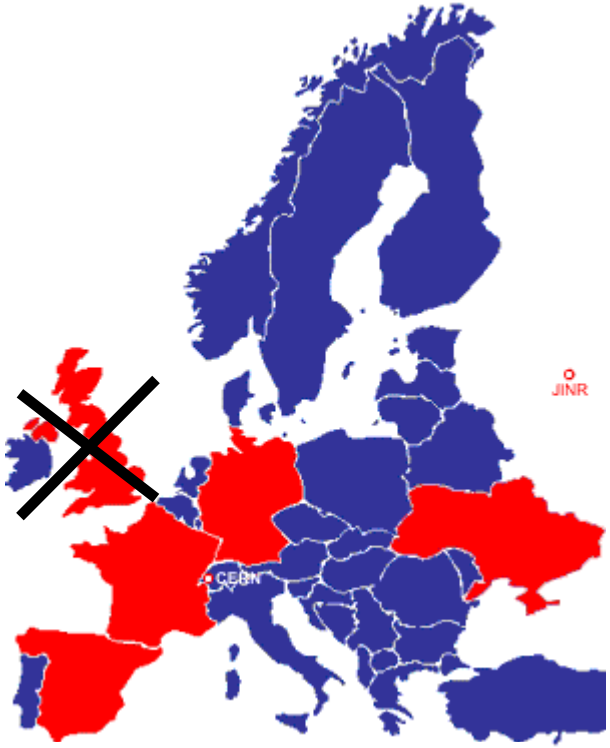
# EDELWEISS Infrastructure

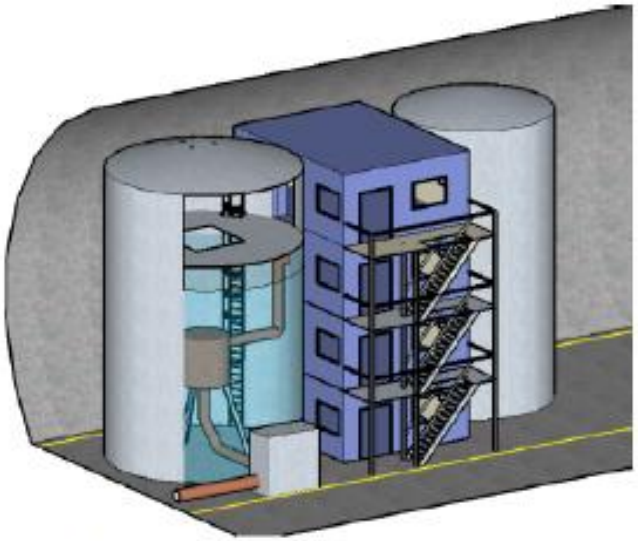
# EURECA

- Further investment into Germanium (EDELWEISS) and CaWO4 (CRESST) detectors.
- Together with Super-CDMS: target especially low-mass WIMP window.
- Design Study published.
- CRESST: background removal, increased scintillation yield.
- EDELWEISS: HEMT readout – lower threshold.
- Next steps: 100kg scale cryogenic bolometer experiment.
- Then: move to tonne-scale.

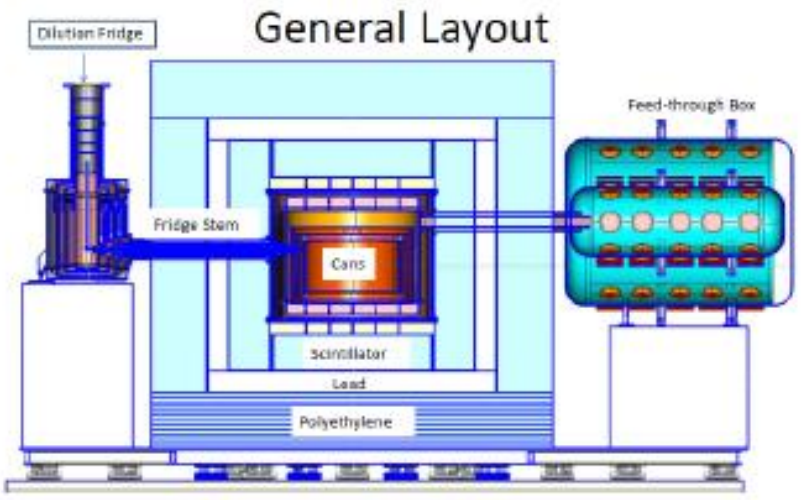
# EURECA

- Webpage moved to KIT.
- No UK involvement anymore.
- New spokesperson: Klaus Eitel.
- Future strategy shaping up.



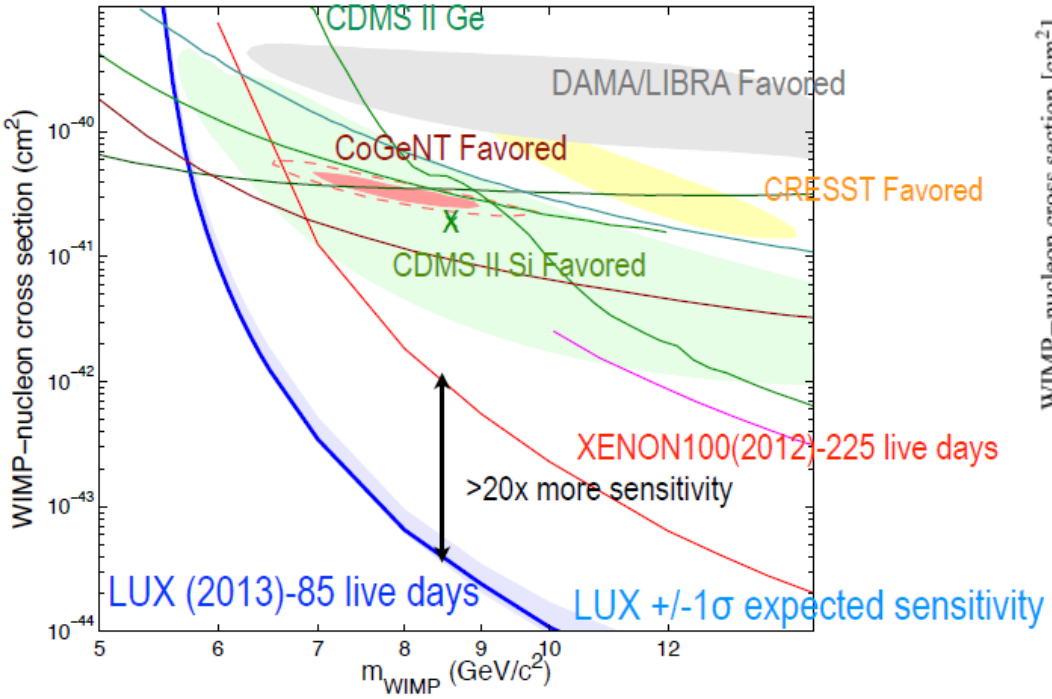



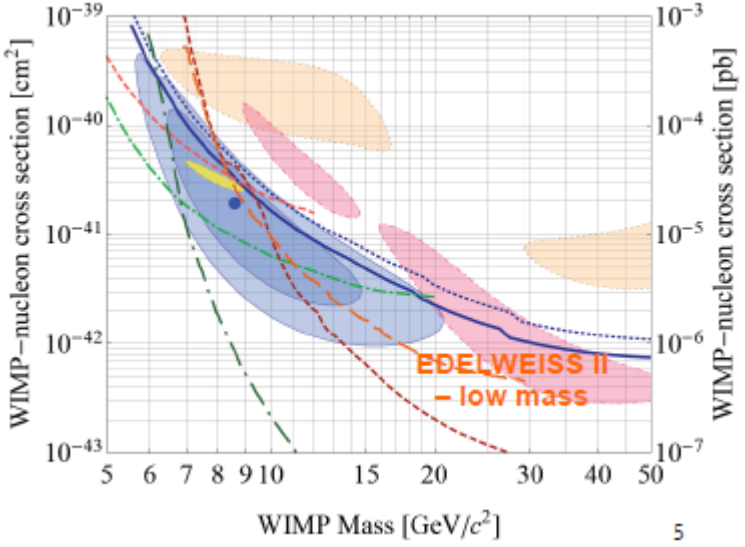
from EURECA conceptual design report (2013)

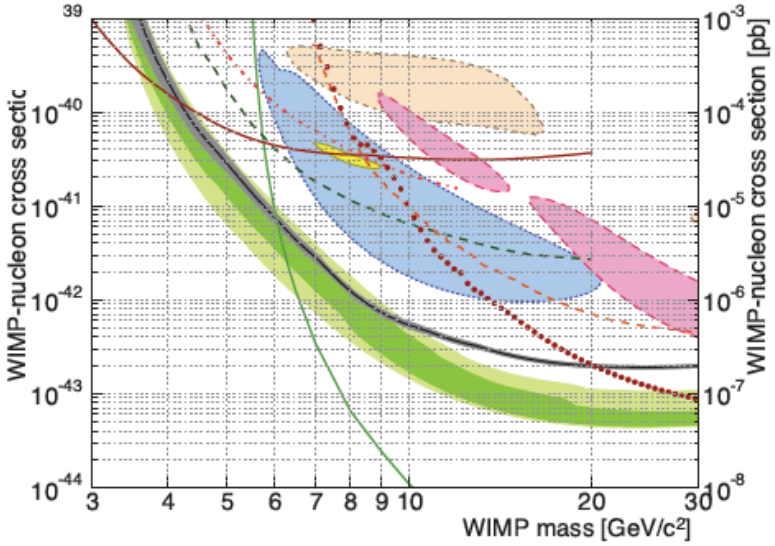



SuperCDMS design for SNOLAB

# The low-mass WIMP scenario




Low-mass WIMPs:
focus of cryogenic experiments
(EURECA – SuperCDMS).
[but also sensitivity for medium – high mass WIMPs]

# A Simple But Important Statement:

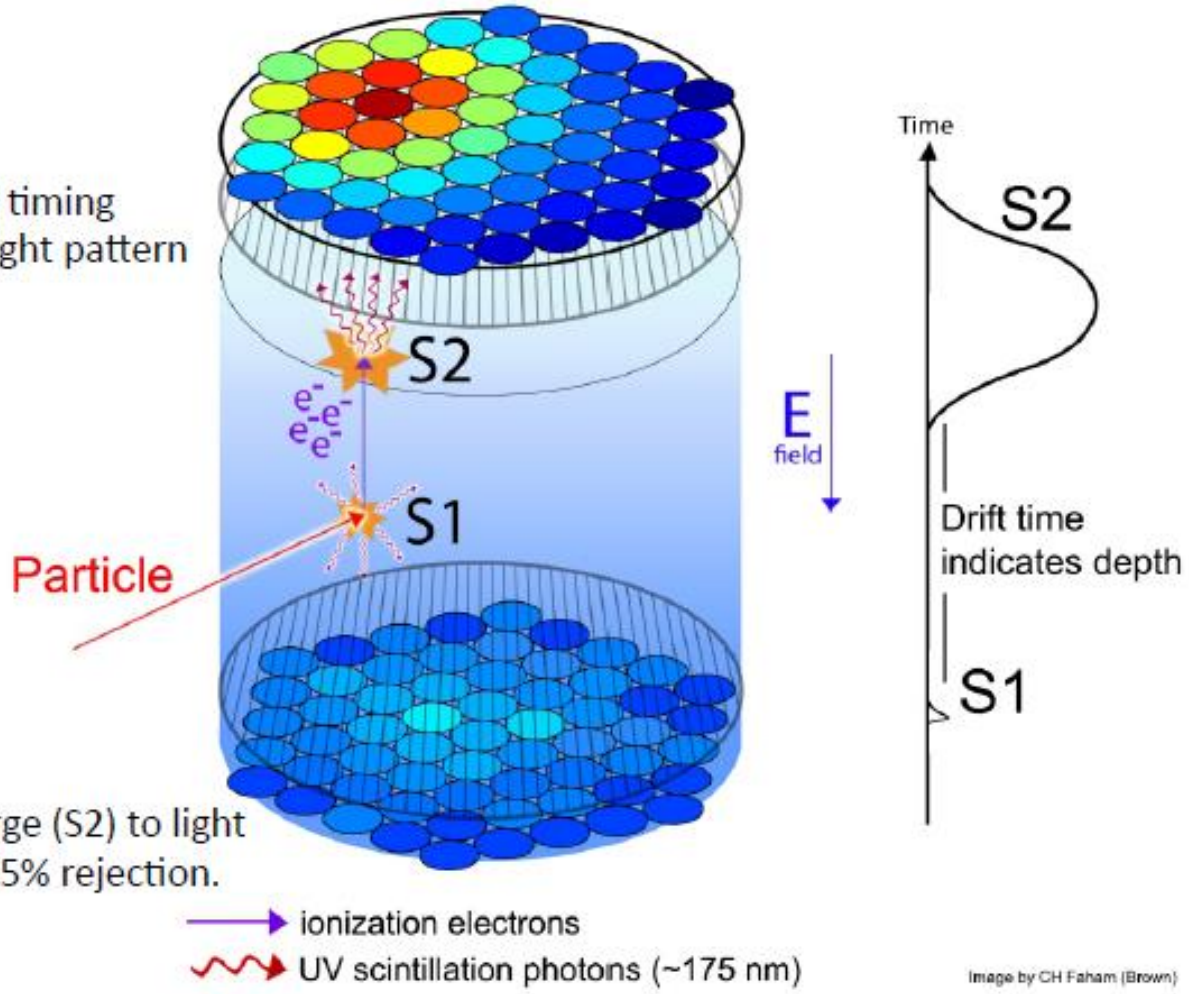
"The Sensitivity of a Dark Matter Experiment Scales as its Mass"

"The problems scale as its Surface Area"

# LUX - LUX-ZEPLIN (LZ)

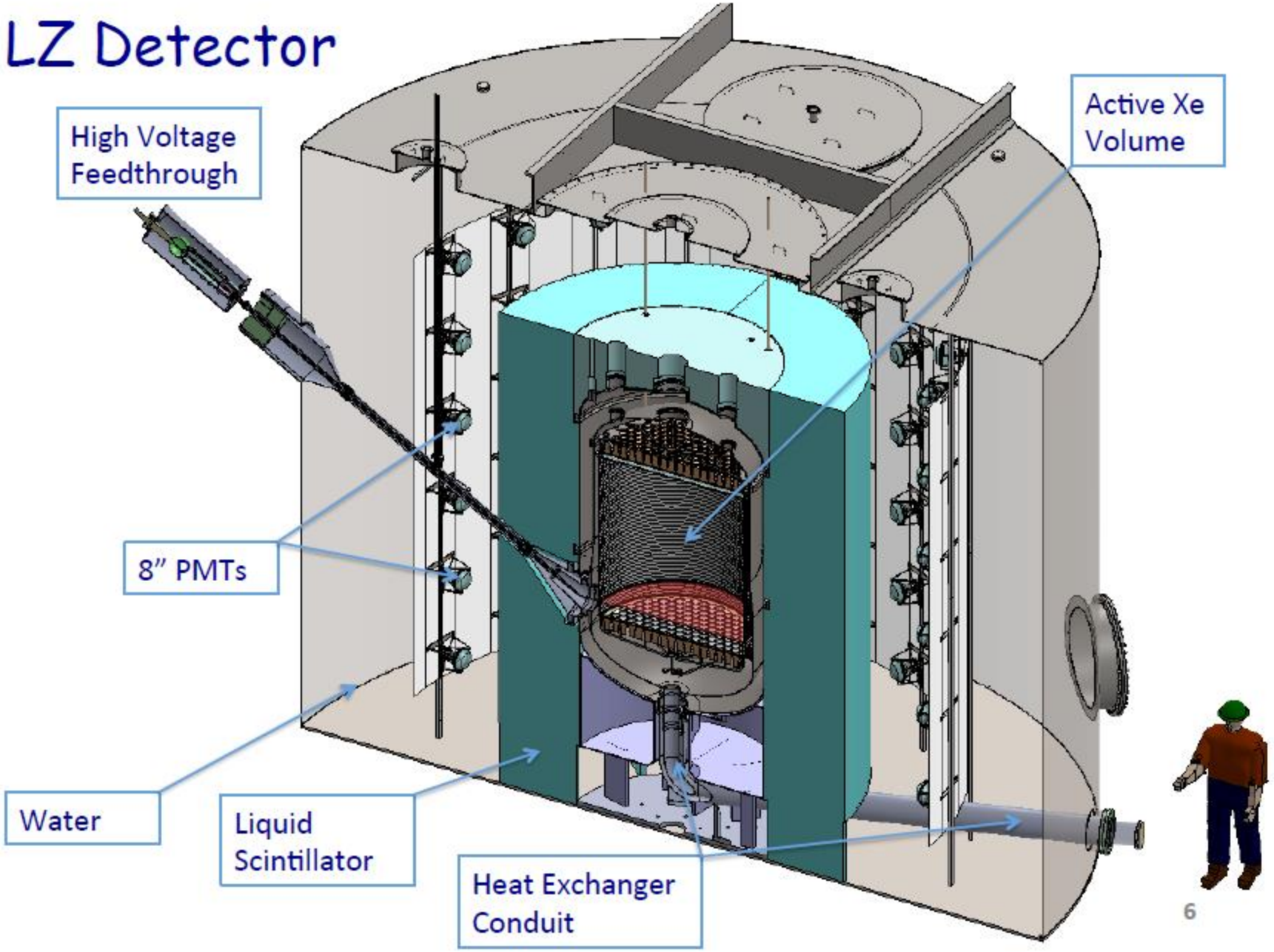
# Two-phase Noble Liquid Detectors

Z position from S1 – S2 timing
X-Y positions from S2 light pattern

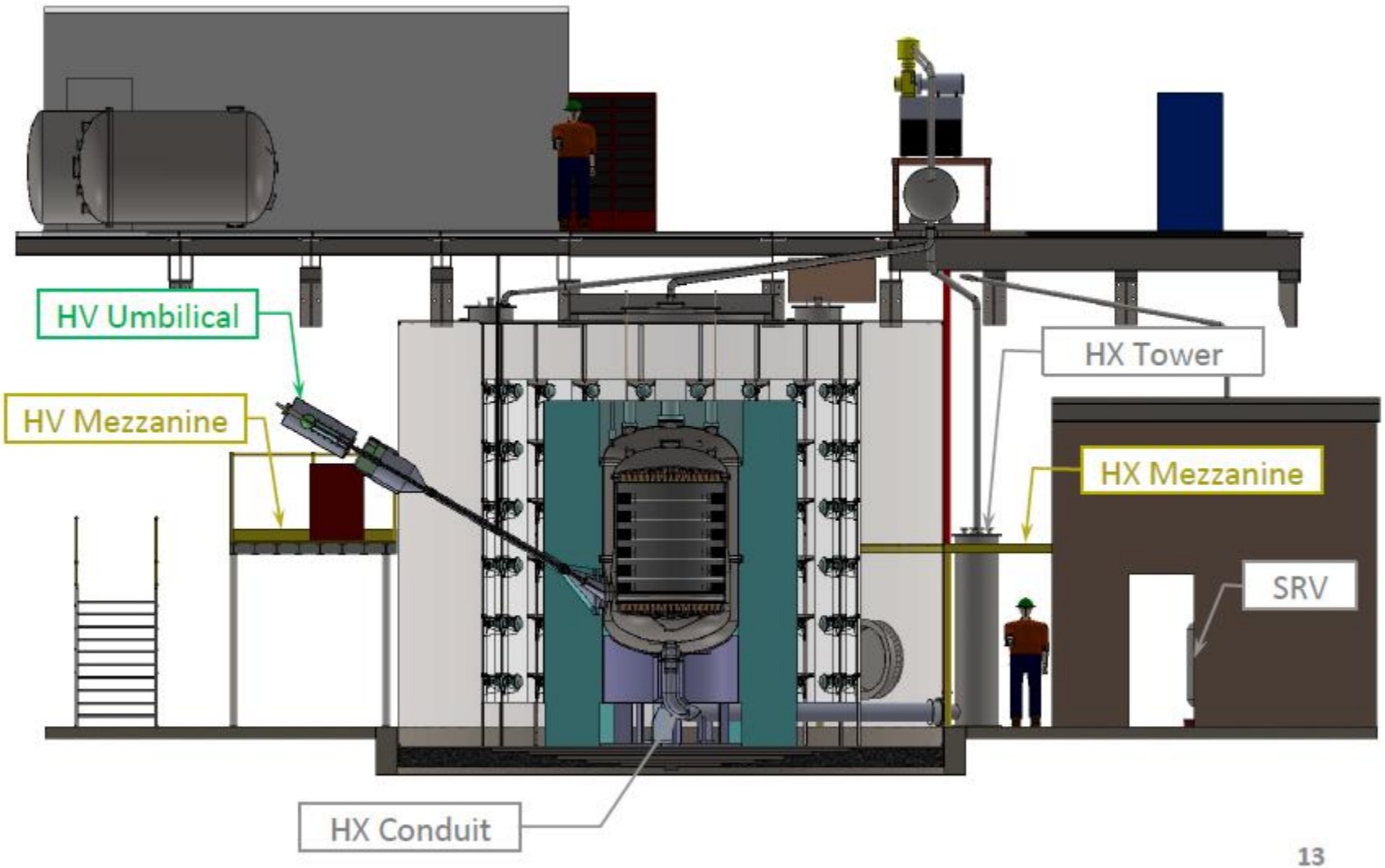



Reject gammas by charge (S2) to light (S1) ratio. Expect > 99.5% rejection.

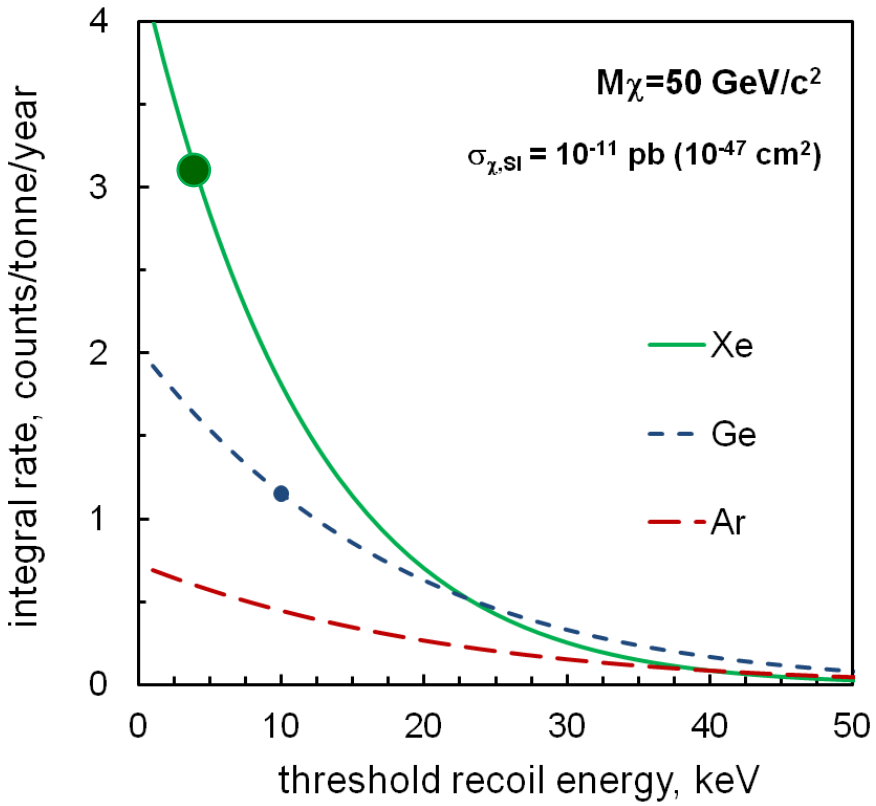
# LZ Detector

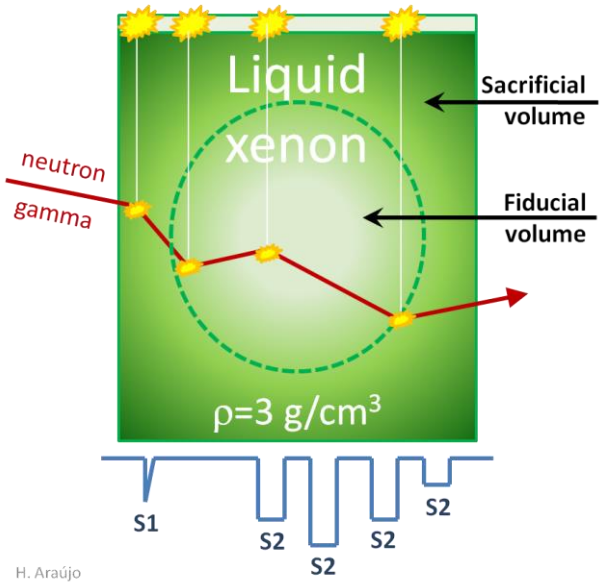

High Voltage Feedthrough
Active Xe Volume
8" PMTs
Water
Liquid Scintillator
Heat Exchanger Conduit

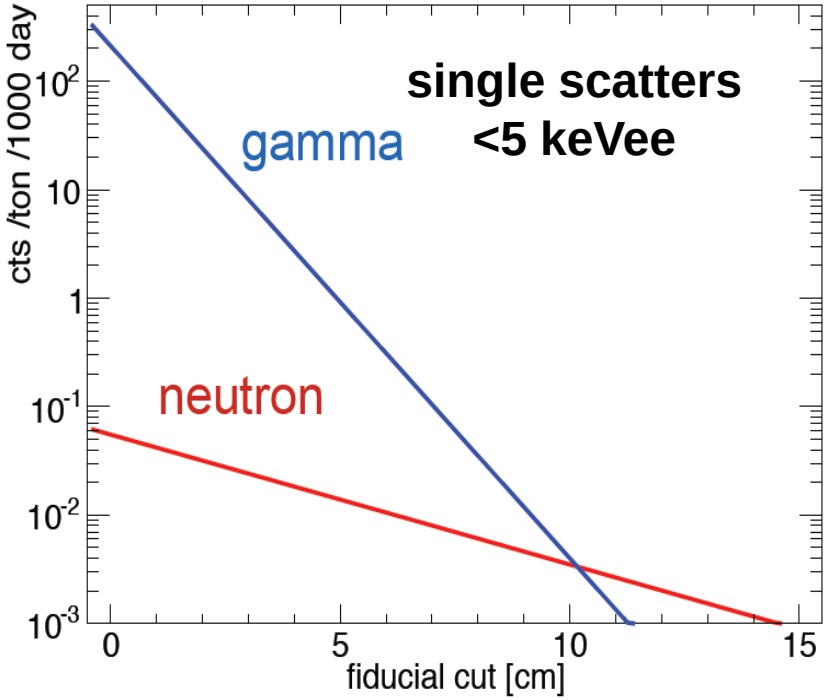
# LZ Cross sectional view



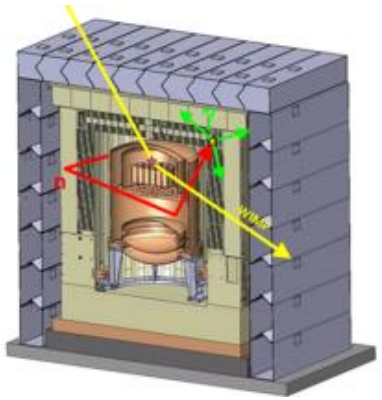
# The Noble Liquid Xenon



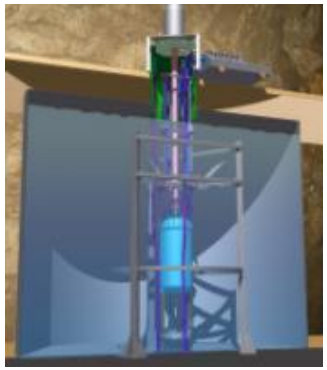



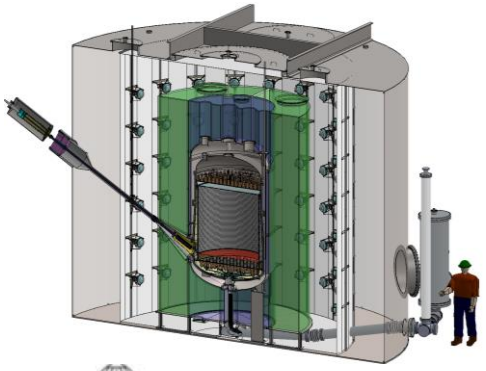
# ZEPLIN→ LUX→ LUX-ZEPLIN



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

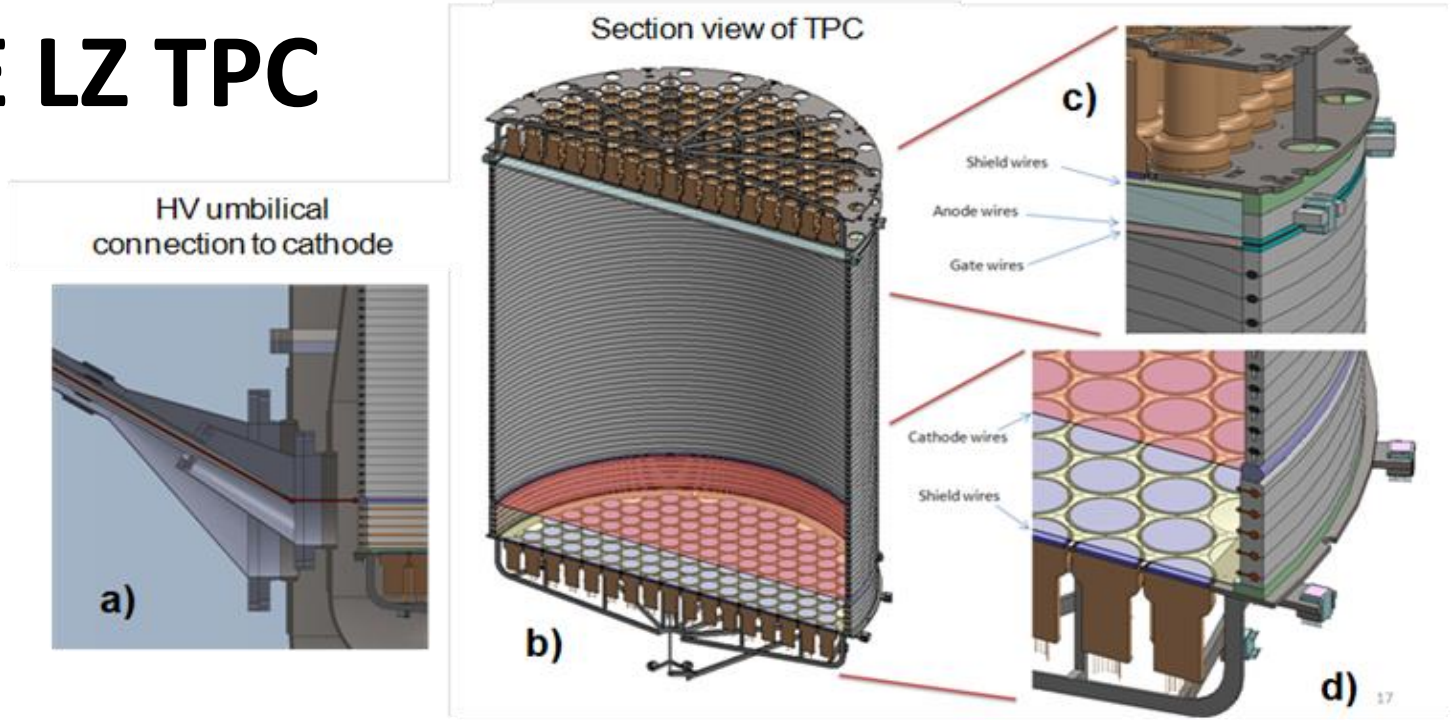


- **LUX operating at Sanford Underground Laboratory**
  - Imperial, Edinburgh and UCL joined after ZEPLIN-III
  - Present world-leading experiment
  - Fiducial mass ~100 kg



- **LZ: next-generation experiment**
  - LZ formed with MOU between LUX and ZEPLIN-III in 2008
  - Selected by DMUK for construction proposal to STFC
  - Fiducial mass ~6,000 kg (~$10^{-48}$ $cm^2$ sensitivity)
  - Conceptual design nearly completed, construction f/ 2015

# THE LZ TPC




## TPC PARAMETERS

- 1.5 m diameter/length (3x LUX)
- 7 tonne active LXe mass (28x LUX)
- 2x 241 3-inch PMTs (4x LUX)
- Highly reflective PTFE field cage
- 100 kV cathode HV (10x LUX)
- Electron lifetime 3 ms (3x LUX)

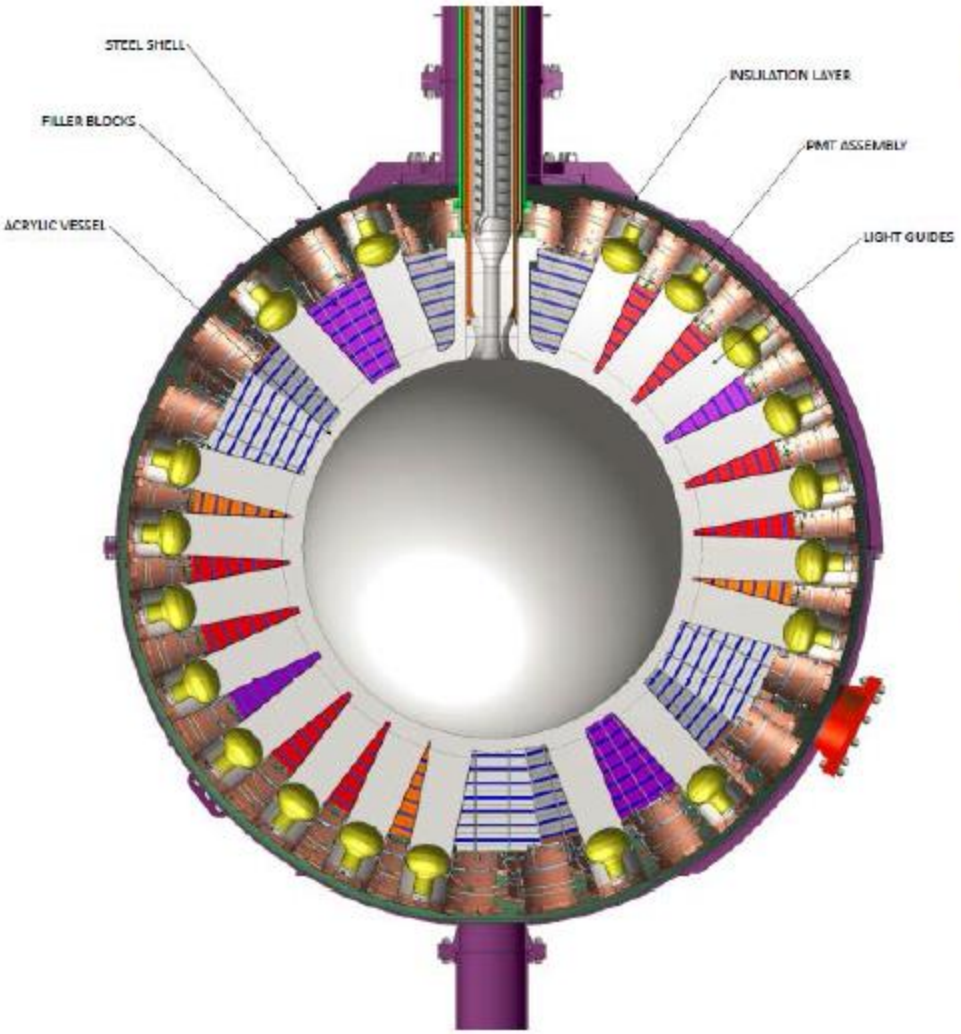
## PHYSICS PARAMETERS

- 5.8 keVr S1 threshold (4.5 keVr LUX)
- 0.7 kV/cm drift field, 99.5% ER/NR disc.
- (already surpassed in LUX at 0.2 kV/cm)

## TPC CALIBRATION

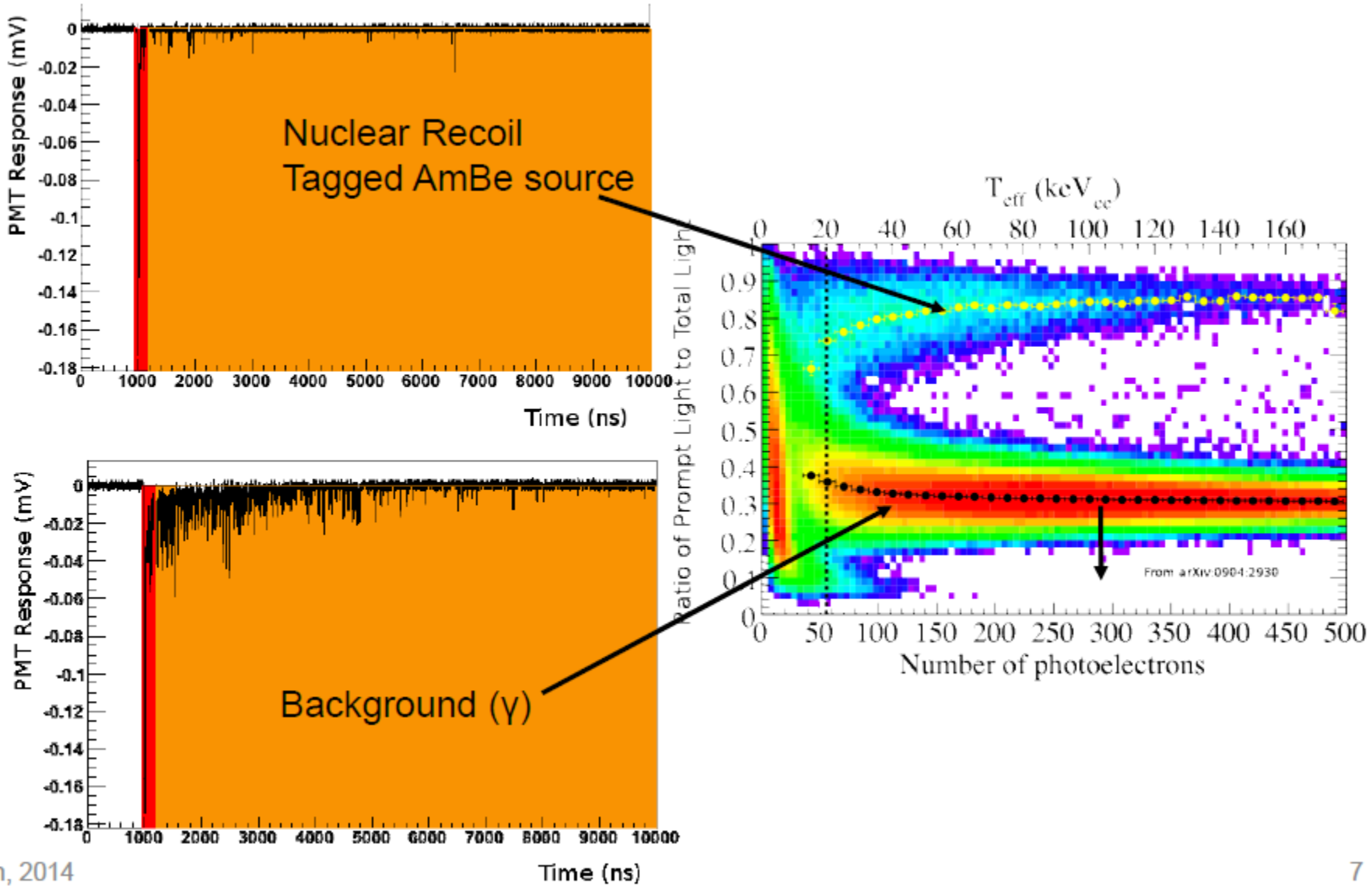
- ER: Dispersed sources: Kr-83m, CH3T
- NR: AmBe, YBe, D-D generator

# DEAP-3600 Concept




- **3.6 tonnes of liquid Argon**
  - Enclosed in 85 cm radius acrylic ball
  - 1 tonne fiducial
    - Excluding surface events
- **Scintillation only**
  - Aka single phase
  - Light viewed by 255 photo-multiplier tubes

# DEAP-3600 Pulse Shape Discrimination



# Introduction to DRIFT


- Directional Detector (PRD, **61** (2000) 1, NIMA, **600** (2009) 417, AstroPle, **31** (2009) 261)
- DRIFT has been operating in Boulby since 2001
- DRIFT-I -> DRIFT-II (a-e)
- DRIFT-IId volume = 0.8 m^3, 40 Torr gas
- MWPC readouts (NIMA, **555** (2005) 173)
- Negative CS2 anion drift to limit diffusion (PRD, **61** (2000) 1)
- Phenomenal Compton background rejection (AstroPle, **28** (2007) 409)
- Many gas mixtures possible
- DRIFT-IId used a 30-10 Torr of CS2-CF4 to optimize for spin-dependent limits, 139 g target mass. (AstroPle, **35**(2007) 397)
- Relatively cheap, clean, stable and scalable technology.

# DRIFT: near future

From DM2014 DRIFT talk:

- With 54.4 live-days of data last fall we were able to improve our spin-dependent limits by a factor of ~3.
- But for a high threshold issue and poor gas quality our limits would now be a factor of ~10 better.
- These issues have now been resolved and we hope to quickly improve our limits this spring and publish.
- This spring will also see the deployment of DRIFT-IIe in Boulby along with an improved thin-film cathode and other improvements.

- DRIFT is no longer background limited and we are starting to dream big.

# Summary

A great field to work in. Almost everybody has heard about Dark Matter.

Neutrino floor within reach.

For the UK: clear focus on LZ.