Dark Matter Direct Detection

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PPAP Community Meeting
University of Birmingham
September 18, 2012

Outline

1. Dark Matter Direct Detection Overview

- What are the top scientific challenges in Particle Physics to be solved in the next 20-30 years?

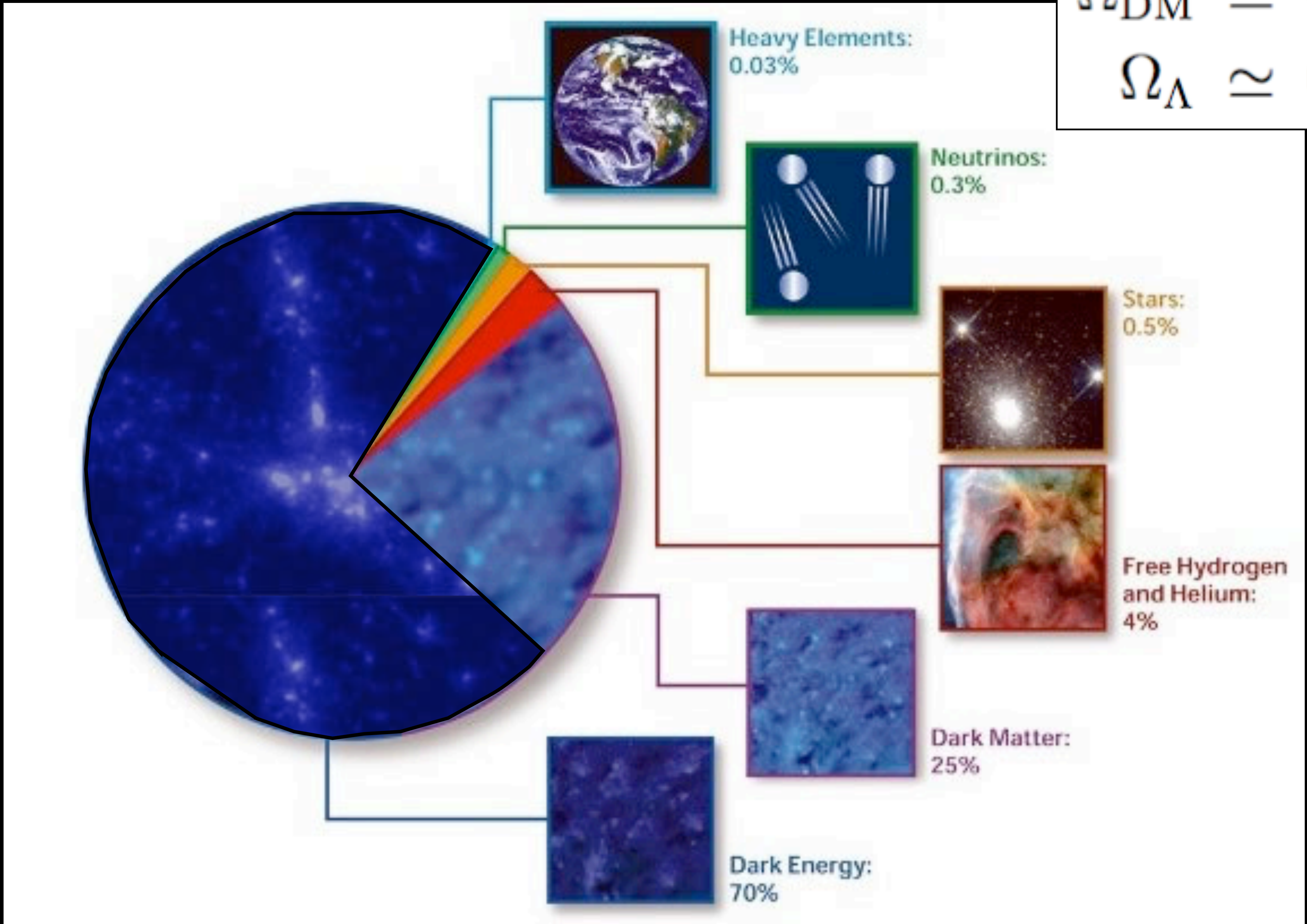
2. Current and Future UK Efforts

3. DMUK Collaboration Input to PPAP

- What current and future facilities will be needed for the UK to make significant contributions to these areas?
- What are the technology needs for each key priority?
- What is the appropriate programmatic balance between construction, operations, exploitation, and R&D?

4. Conclusions (my opinions)

The Standard Model of Cosmology



$$\Omega_B \simeq 0.0456 \pm 0.0016$$
$$\Omega_{DM} \simeq 0.227 \pm 0.014$$
$$\Omega_\Lambda \simeq 0.728 \pm 0.015 \ .$$

E. Komatsu et al., Astrophys. J. Suppl 192 (2011) 18

evidence from
CMB,
galaxy clusters,
large scale structure,
supernova data,
distance
measurements,
gravitational lensing

Dark Matter is ~25% of the universe.

We only understand 4% of the universe!

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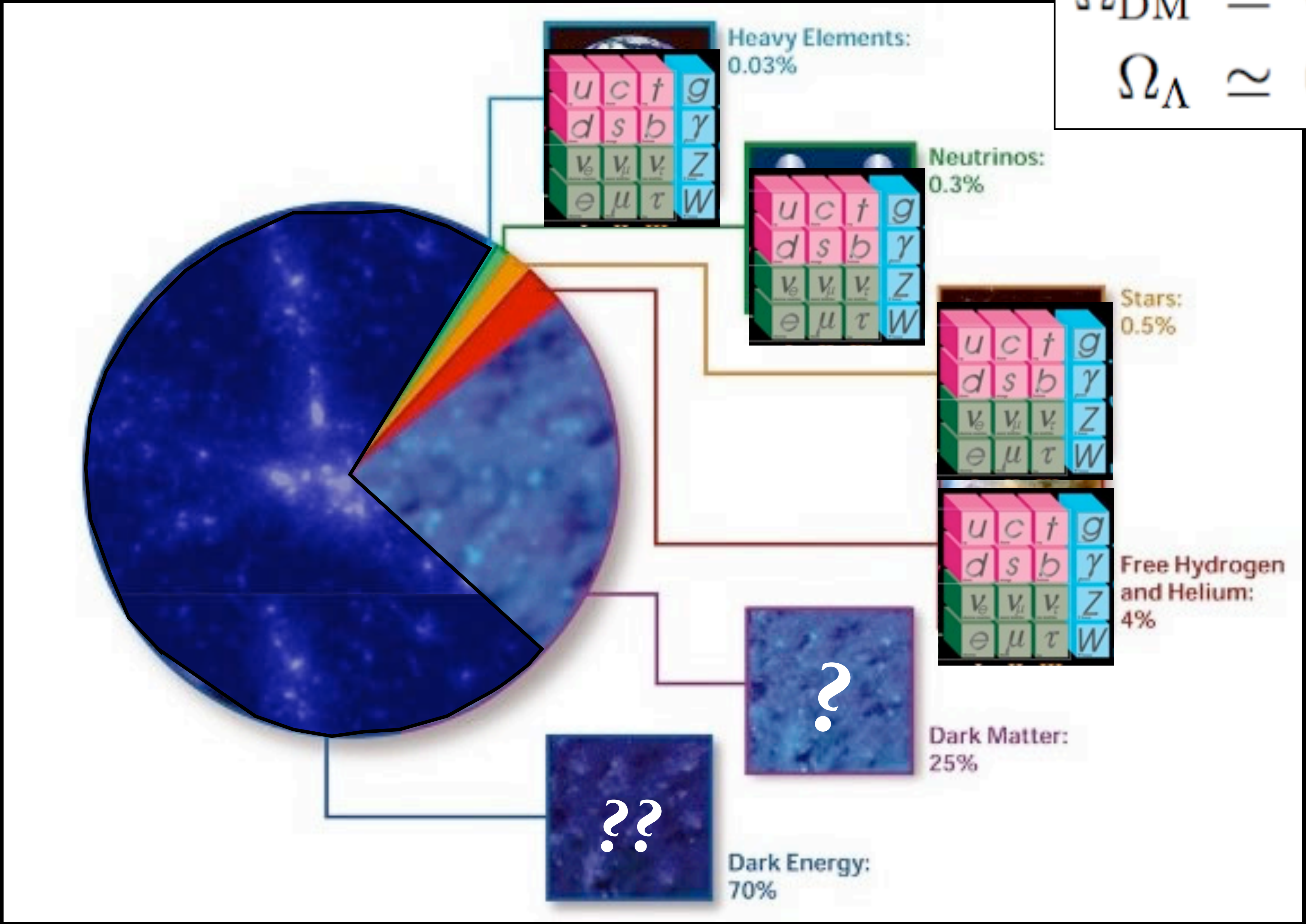
E. Komatsu et al., Astrophys. J. Suppl 192 (2011) 18

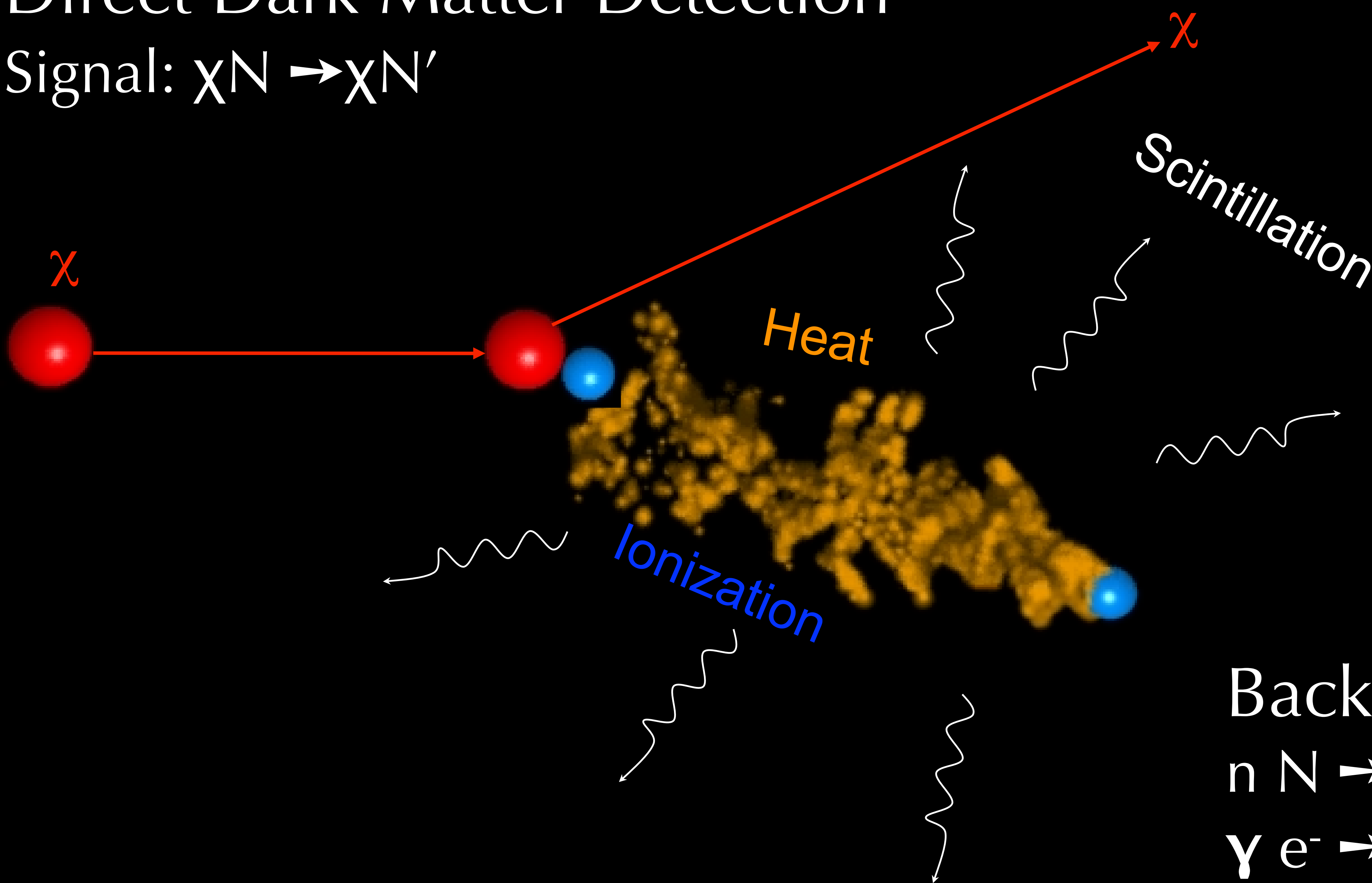


No good Standard Model dark matter particle candidates... new physics required.

Dark matter is globally acknowledged to be one of the top scientific challenges in Particle Physics to be solved in the next 20-30 years, perhaps **the** top challenge.

Direct Dark Matter Detection

Signal: $\chi N \rightarrow \chi N'$



Backgrounds:

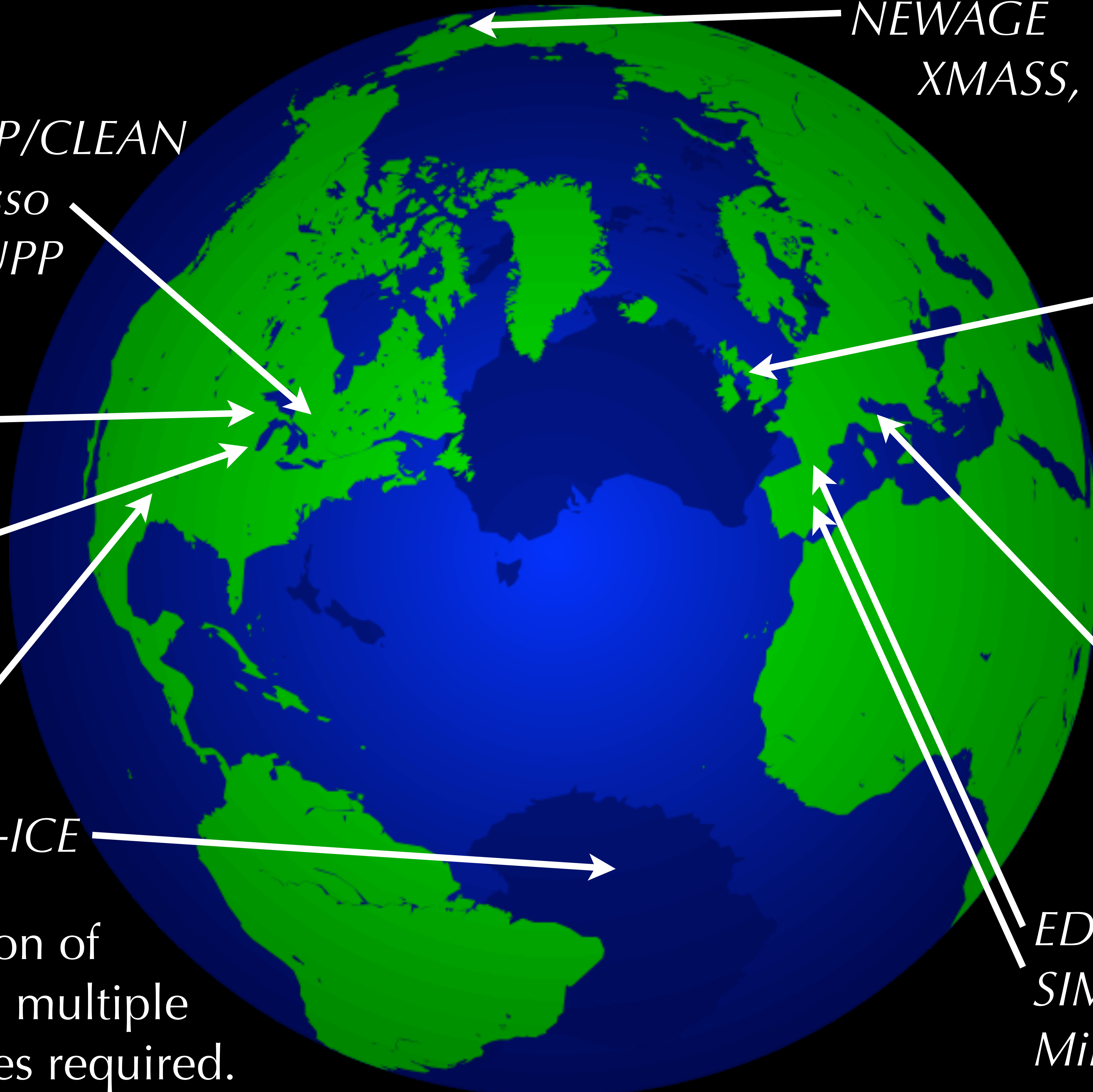
$n\ N \rightarrow n\ N'$

$\gamma\ e^- \rightarrow \gamma\ e^{-\prime}$

$N \rightarrow N' + \alpha, e^-$

$\nu\ N \rightarrow \nu\ N'$

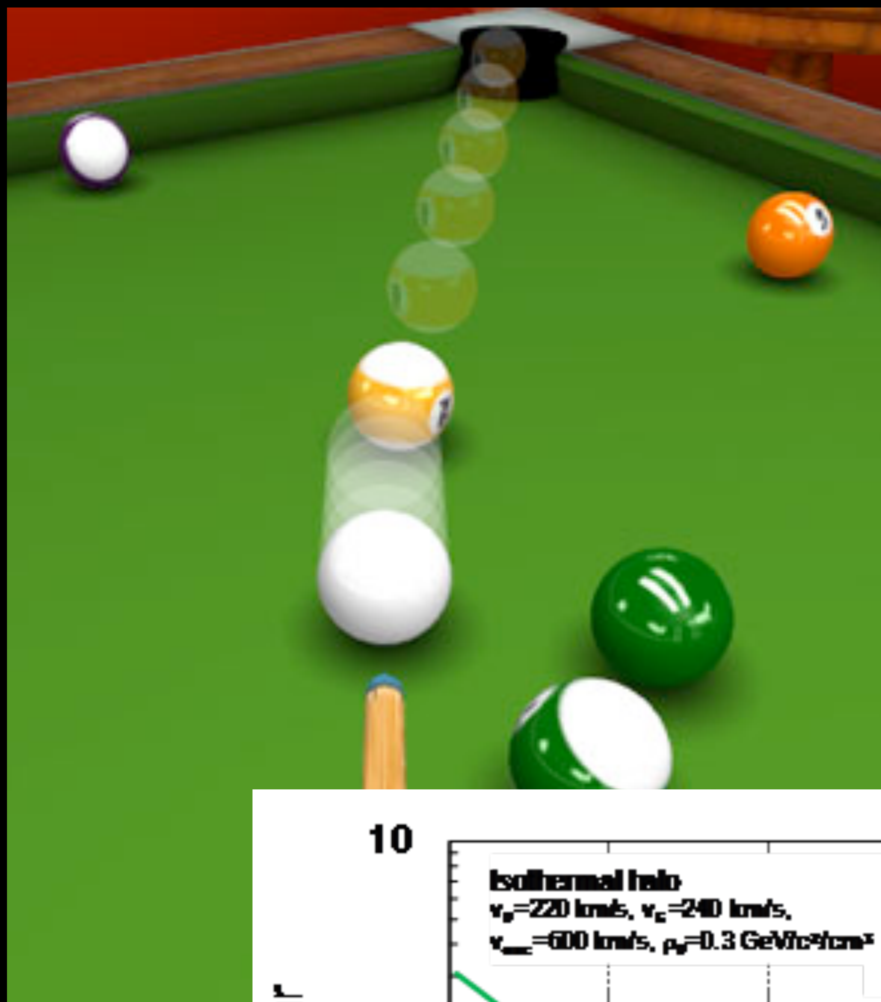
Around the World

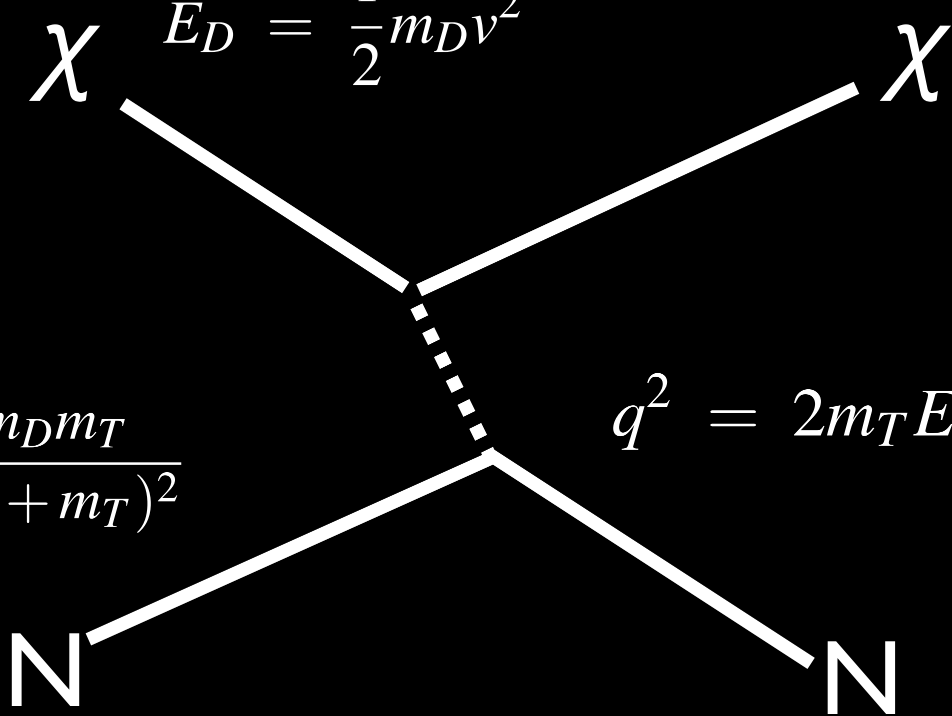


Confirmation of signal from multiple technologies required.

Dark Matter Scattering

kinematics: *v/c ~ 8E-4!*



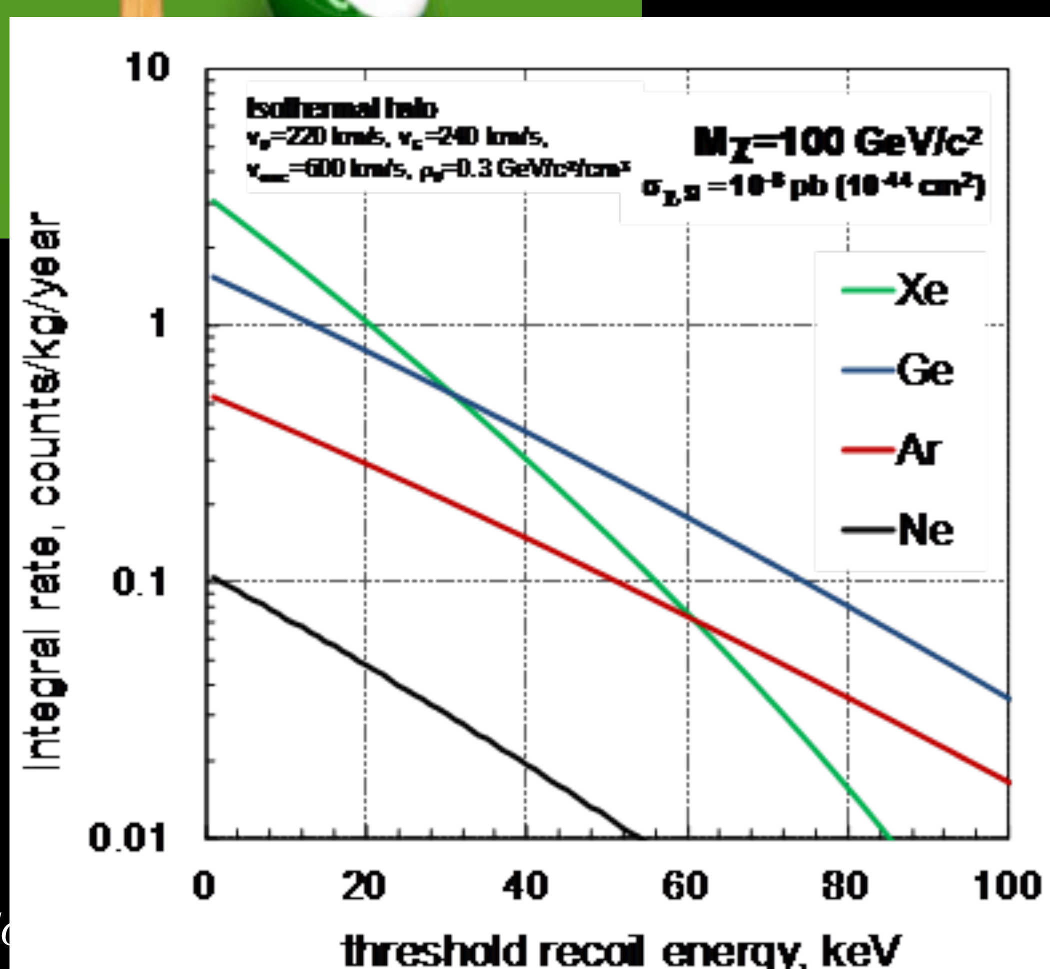


$$E_D = \frac{1}{2} m_D v^2$$

$$r = \frac{4 m_D m_T}{(m_D + m_T)^2}$$

$$q^2 = 2 m_T E_{recoil}$$

$$E_{recoil} = E_D r \frac{(1 - \cos\theta)}{2}$$



<u>Spin Independent:</u>

χ scatters coherently off of the entire nucleus A: $\sigma \sim A^2\, F(Q^2)$

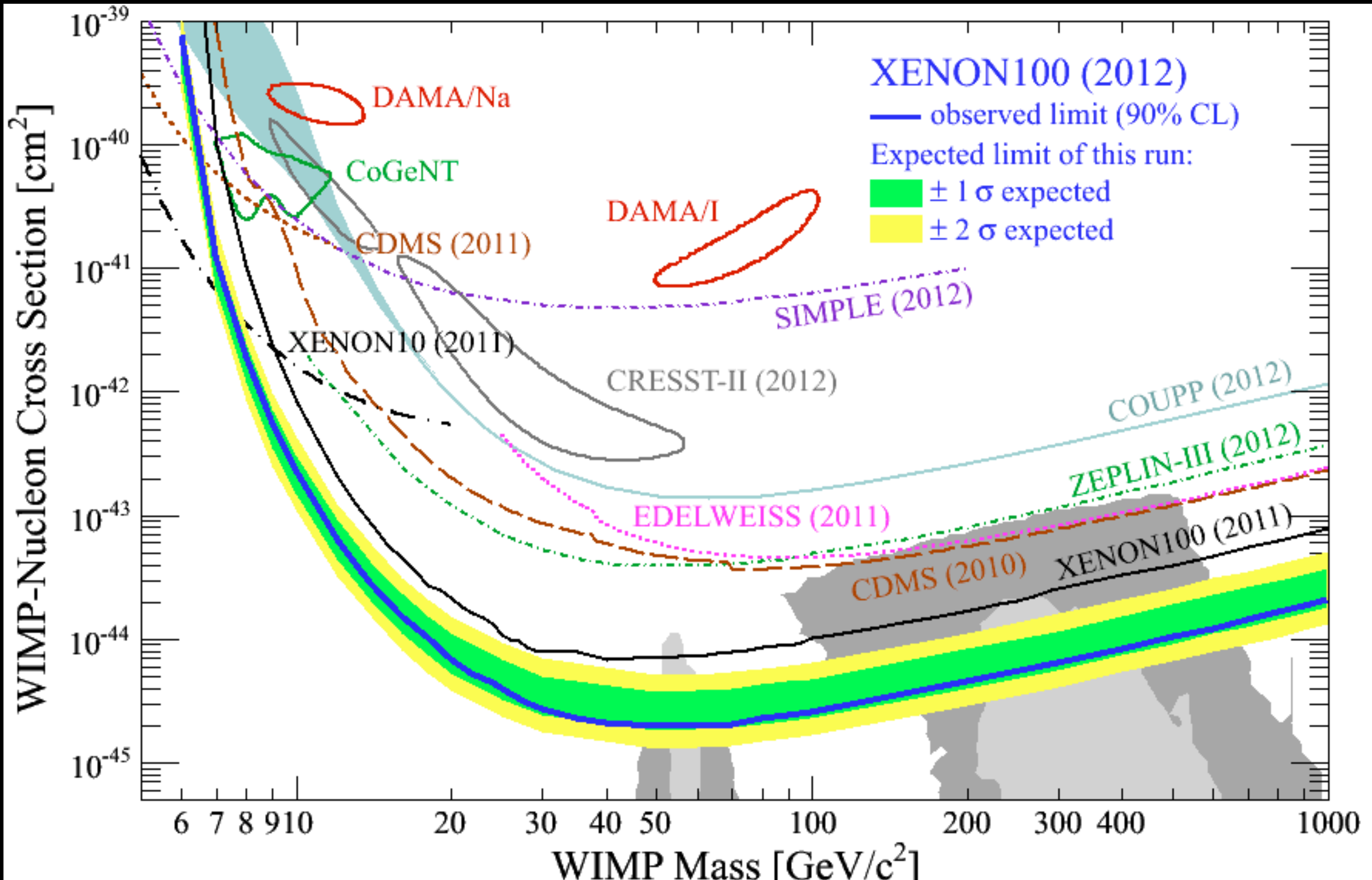
D. Z. Freedman, PRD 9, 1389 (1974)

<u>Spin Dependent:</u>

only unpaired nucleons contribute to scattering amplitude: $\sigma \sim J(J+1)\, F(Q^2)$

Spin-Independent Cross Section: Latest Experiment Results

IDM2012, E. Aprile et al., arXiv:1207.5988



1 event/ kg/day ←

1 event/ 100 kg/day ←

tonne-scale detectors likely required for discovery

Spin-Independent Cross Section: Latest Theory Results

O. Buchmuller et al., arXiv:1207.7315

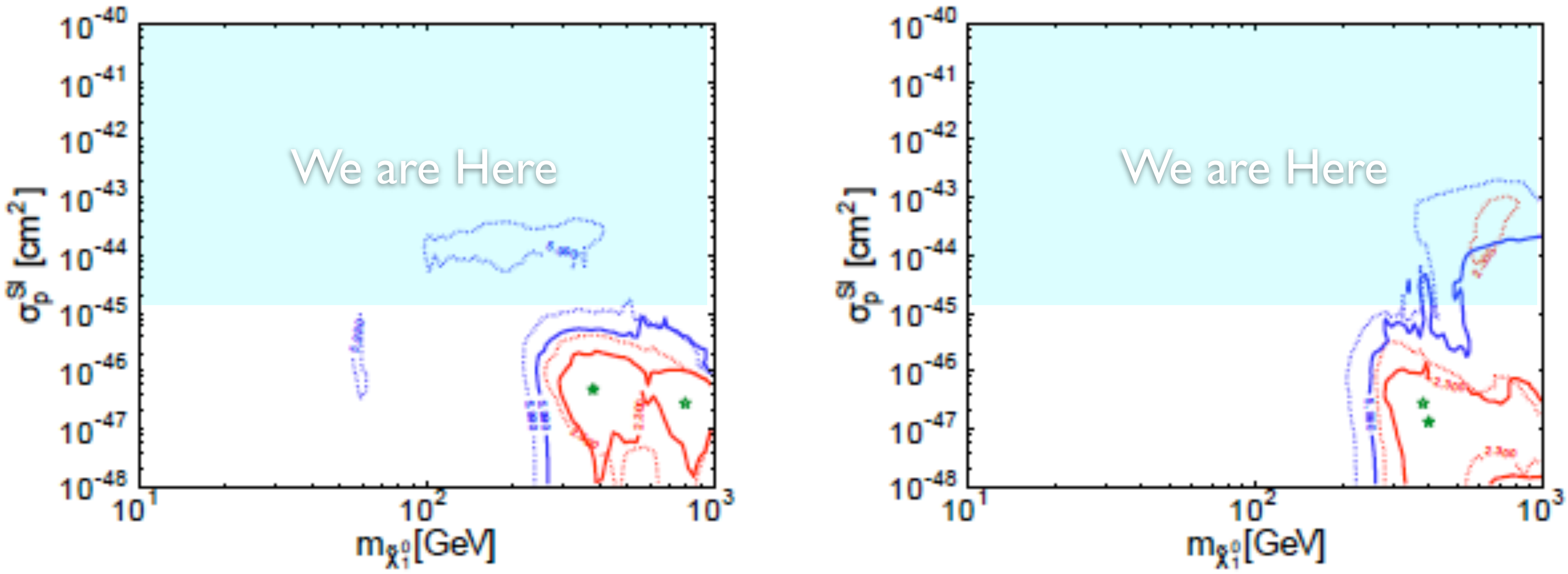


Figure 17. *The* $(m_{\tilde{\chi}_1^0}, \sigma_p^{SI})$ *planes in the CMSSM (left panel) and the NUHM1 (right panel). The* $\Delta\chi^2 =$ 2.30(5.99) *contours, corresponding to the 68(95)% CL are coloured red (blue). The solid (dashed) lines are for global fits to the* $LHC_{5/fb}$, $BR(B_s \to \mu^+\mu^-)$ *and new XENON100* ($LHC_{1/fb}$) *data, and the corresponding best-fit points are indicated by solid (open) green stars.*

Scalability of Detector Technology

New Techniques for Backgrounds

CAVEAT: many more exotic models (Asymmetric DM, Dark Forces Models, Magnetic Inelastic DM, Sterile Nus + Freeze-In, Isospin-Violating DM, Emergent DM and L# models .....

need 100-1000 dark matter events to measure mass, cross section

Complementary with High-Energy Frontier

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4. Conclusions (my opinions)

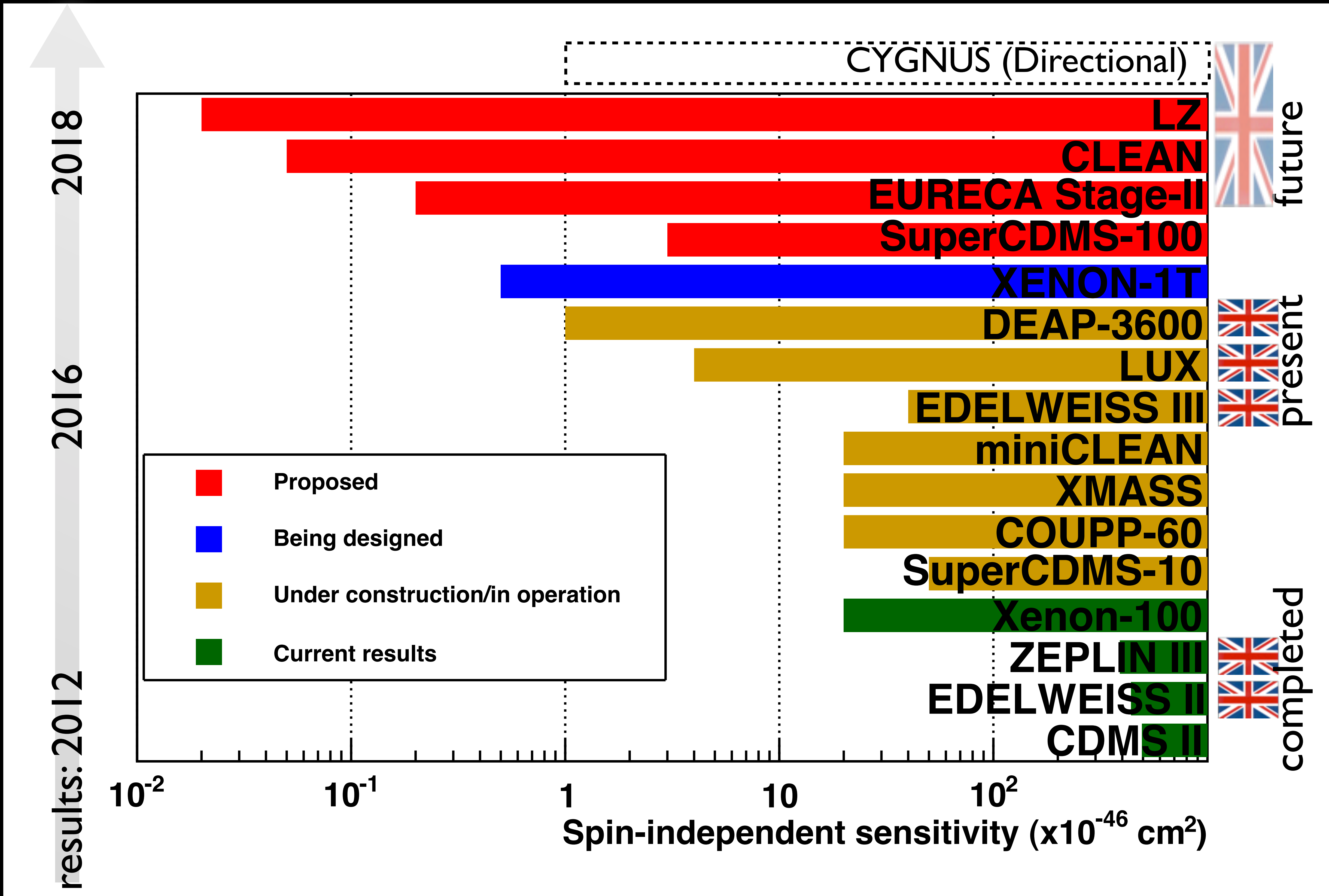
UK Activity in the Global Dark Matter Programme

Technology	Current	Future	2013	2014	2015	2016	2017
liquid Xe TPC	LUX	LUX-ZEPLIN					
cryo. Ge Bolometer	EDELWEISS	EURECA					
liquid Ar Single Phase	DEAP/ CLEAN	CLEAN-100					
Directional (Gas TPC)	DRIFT, DMTPC	CYGNUS					

Stages:

- Exploitation of current effort, R&D on future effort (closely connected)
- Funding proposal period
- Construction
- Commissioning
- Exploitation

Global Dark Matter Programme, Sensitivity Reach



NB: projected sensitivities (all except green) assume zero background.

The LUX Collaboration

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Chang Lee	Graduate Student
Kati Pech	Graduate Student
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Mongkol Moongweluwan	Graduate Student

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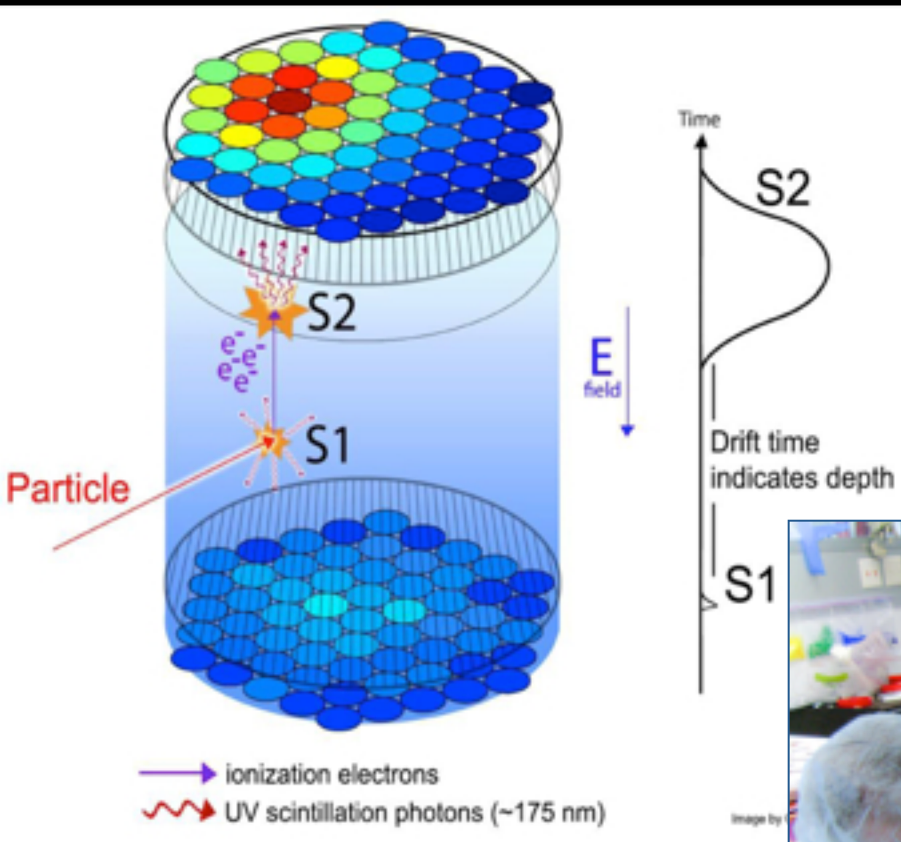
UK Groups

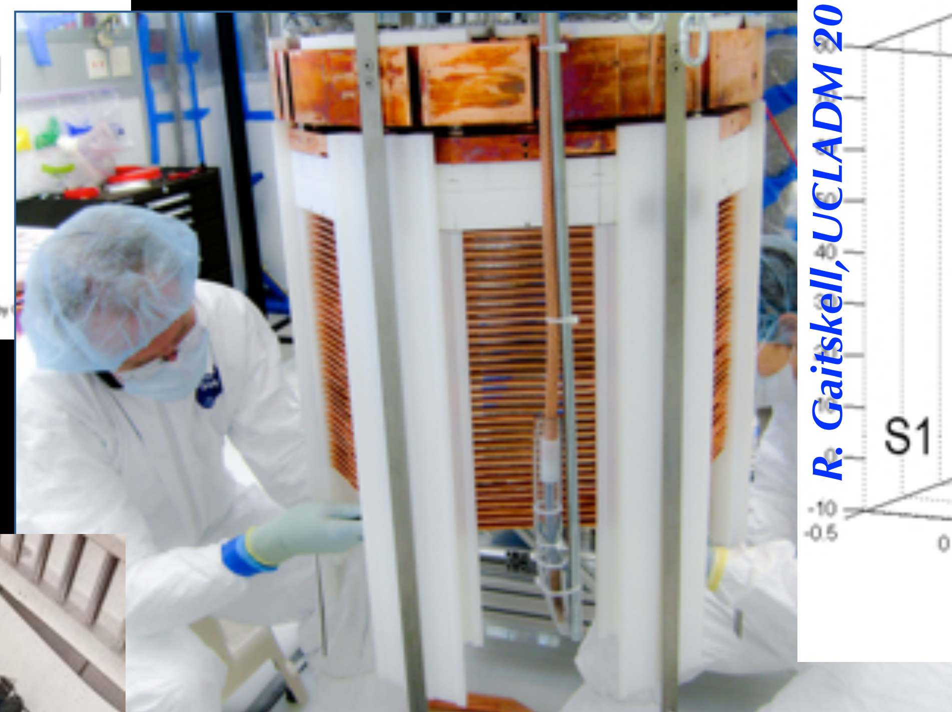
LUX

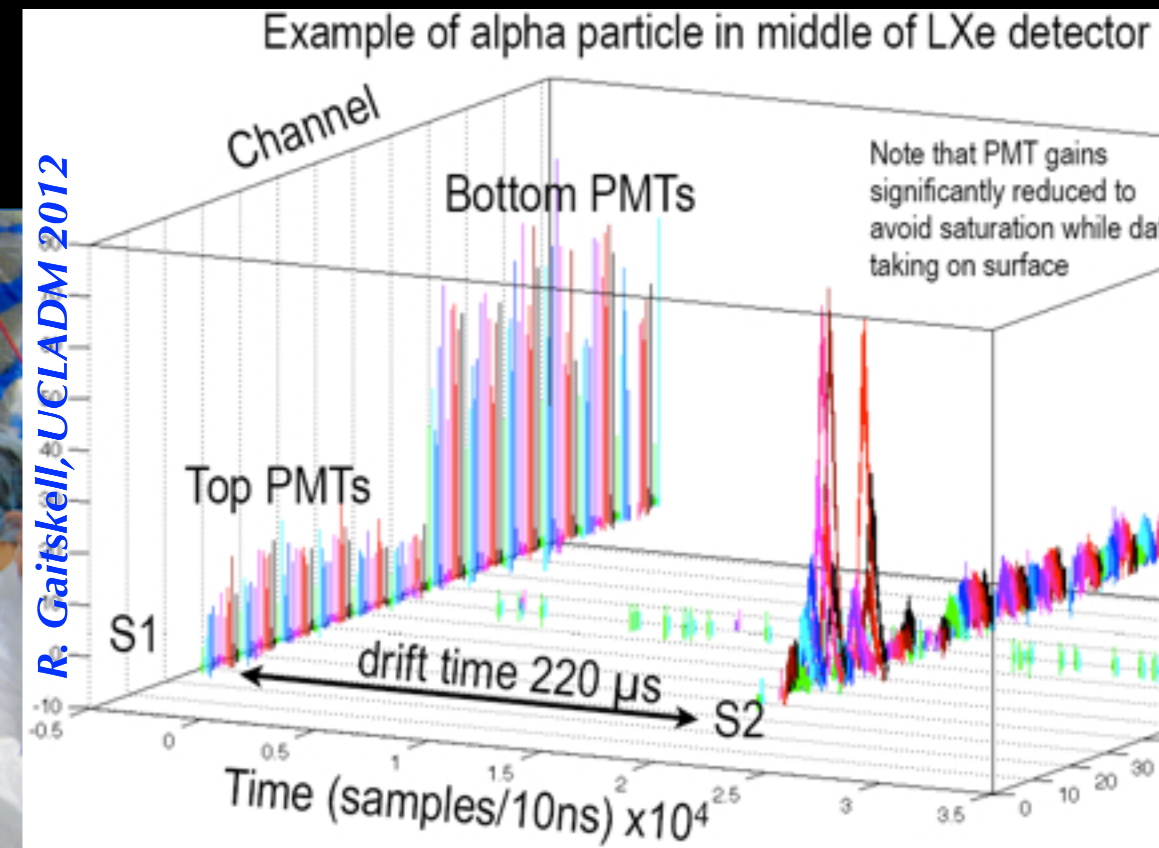
(material thanks to H. Araujo)



Two-phase LXe TPC, 150 kg fiducial mass, PMT read out

- background strategy: self shielding, S1/S2 discrimination
- 5-10 keV recoil threshold, sensitivity to light WIMPs



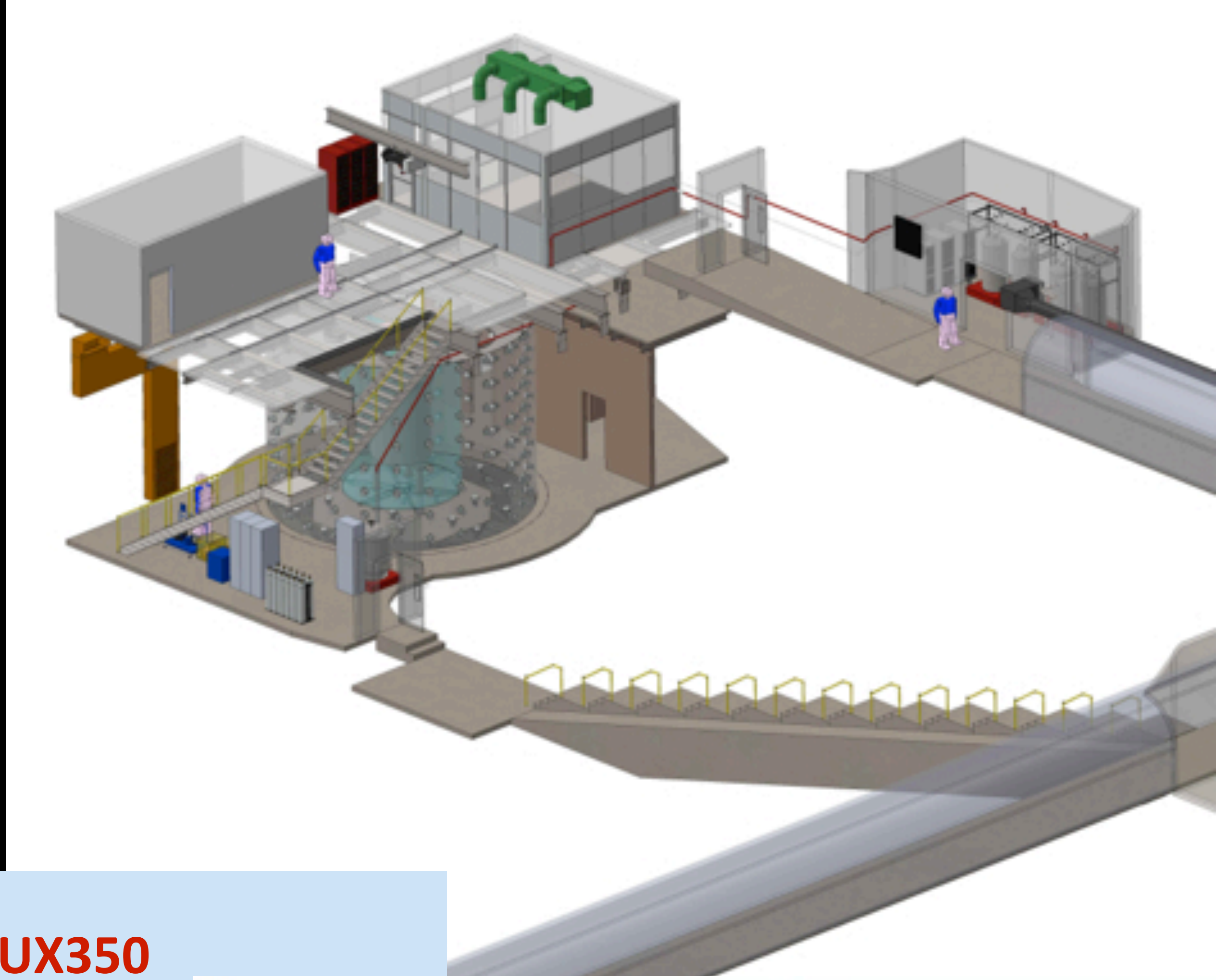


- construction complete, operated at surface 2011-12, underground installation in 4850′ level of Homestake now, science run to start late 2012 (main physics 2014)
- UK groups contributing expertise from Zeplin to underground commissioning, operations
- university support

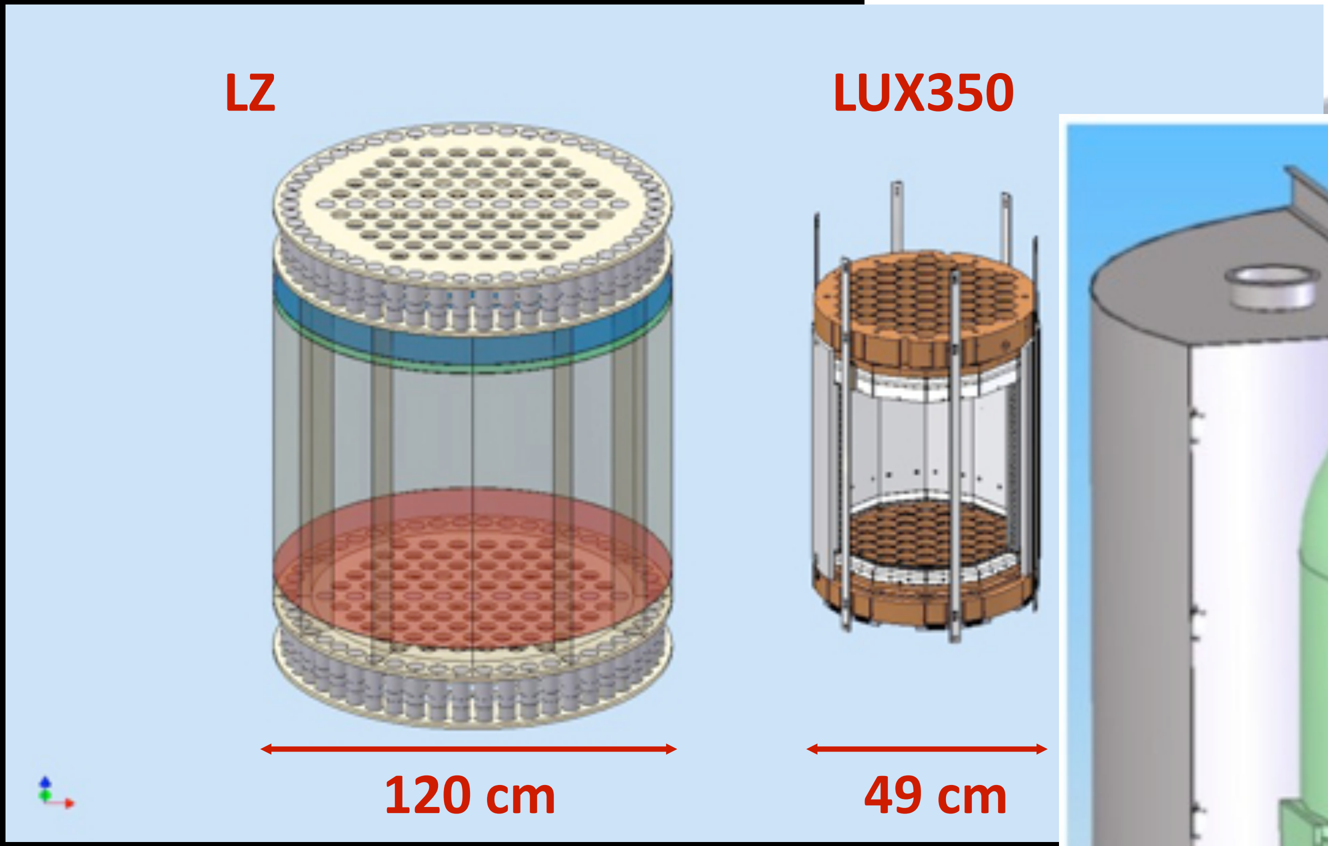
LUX-ZEPLIN

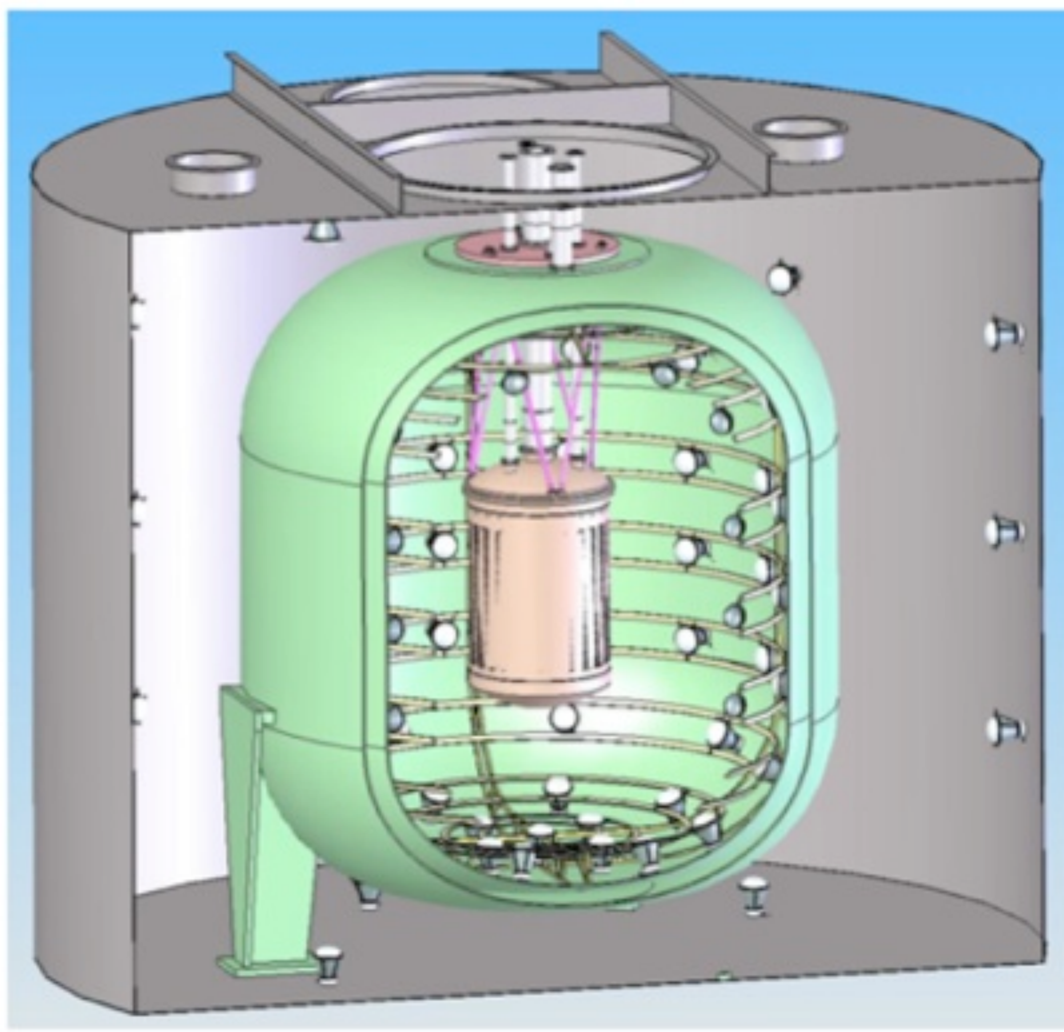
Concept design: 7 tonne active mass LXe TPC, with PMT readout, in LUX water tank in Homestake Davis cavern

- modest increase in linear scale from LUX
- active shield with instrumented Xe + scintillator + water veto in LUX tank



- MOU between ZEPLINIII and LUX groups (2008)
- LZ in US G2 process (coordinated proposals to DOE/NSF/STFC late 2013)

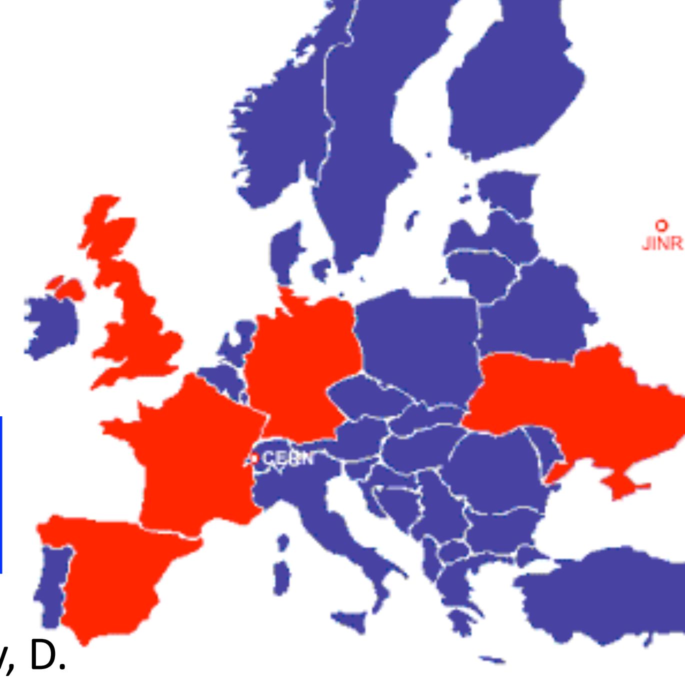




- UK groups seeking significant construction roles

(material thanks to H. Araujo)

EURECA / EDELWEISS Collaboration



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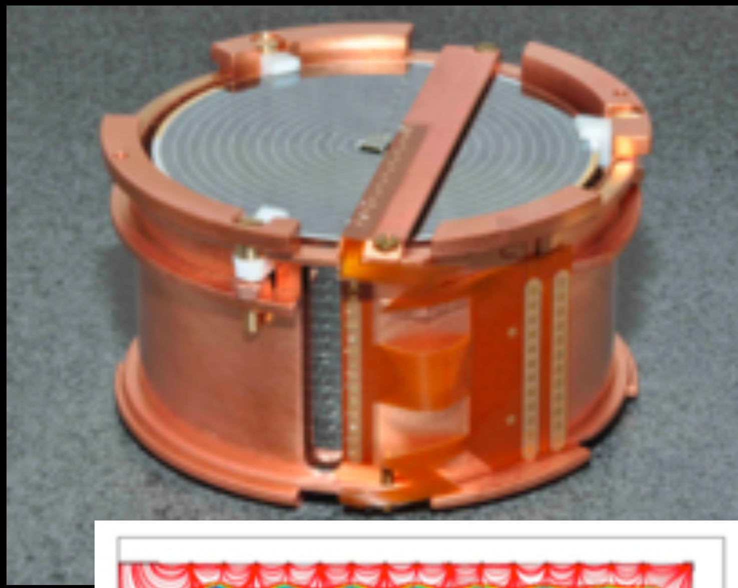
UK Groups

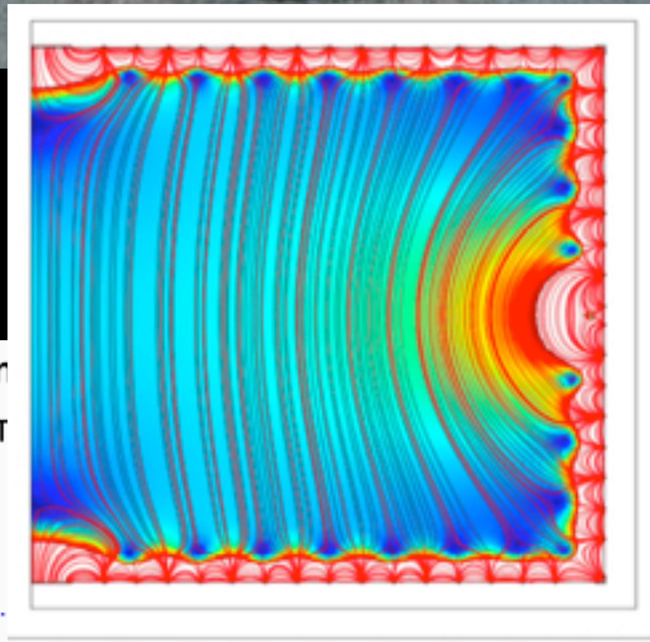
EDELWEISS-III

(material thanks to H. Kraus)



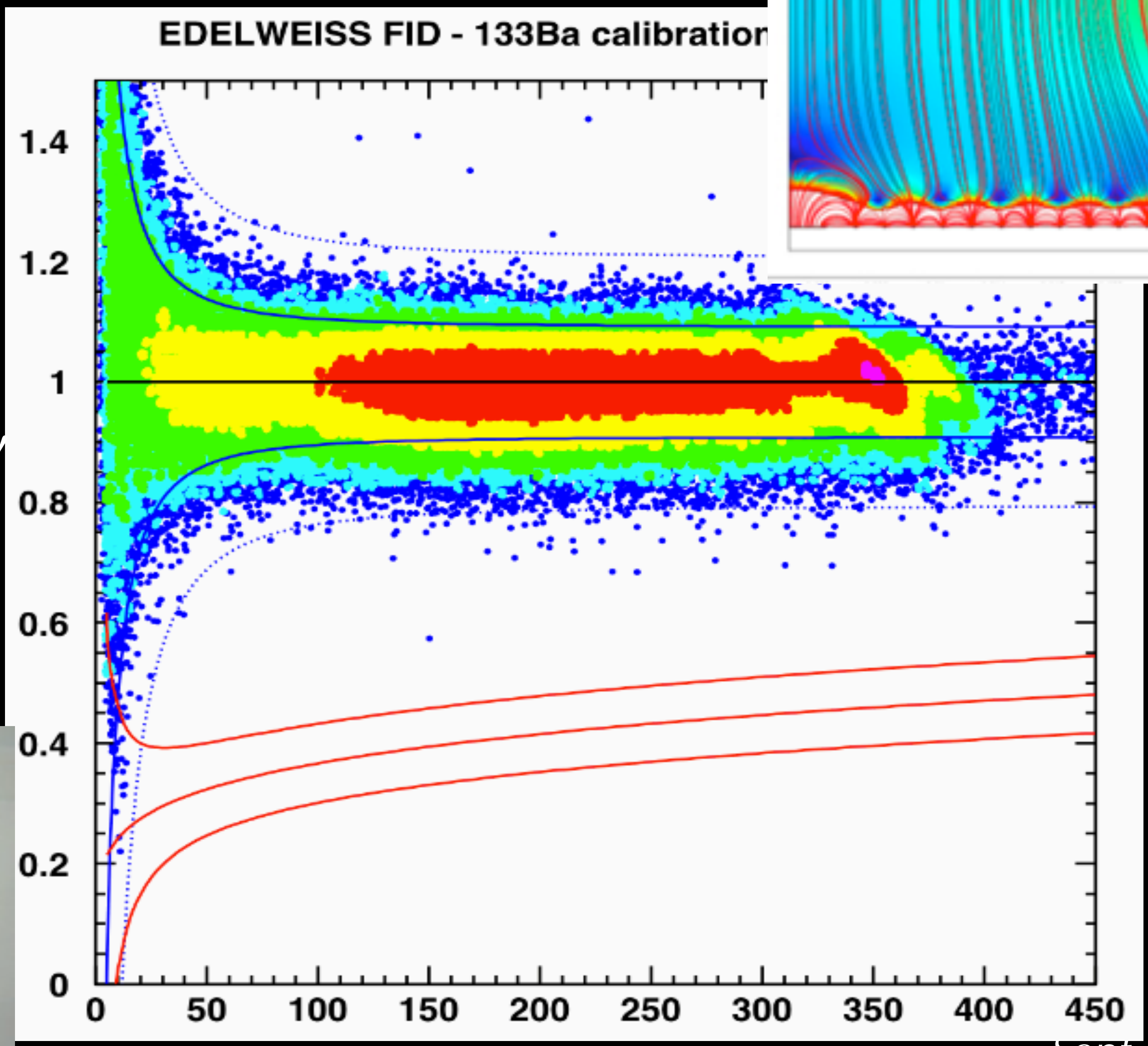
Ge bolometers, readout of phonons and ionization

- 40 800 gm Ge detectors (~600 gm fiducial) with interleaved bias electrodes, 2 NTD, 4 ionization channels
- background strategy: ionization/phonon energy, fiducializing
- 10 keV recoil threshold, light (and heavy) WIMP sensitivity



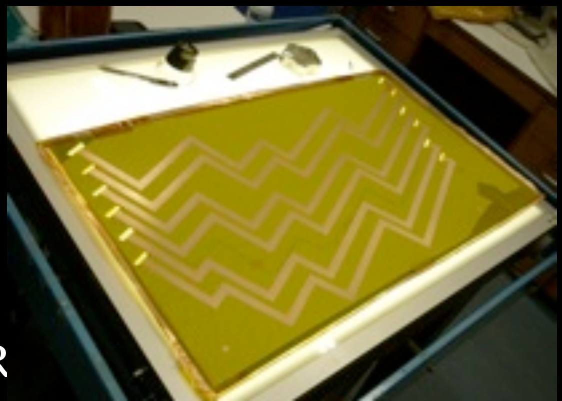
Construction builds on EDELWEISS-II at LSM

- upgrades of cabling, DAQ, cryogenics, shielding
- operations start 2012



UK workpackages:

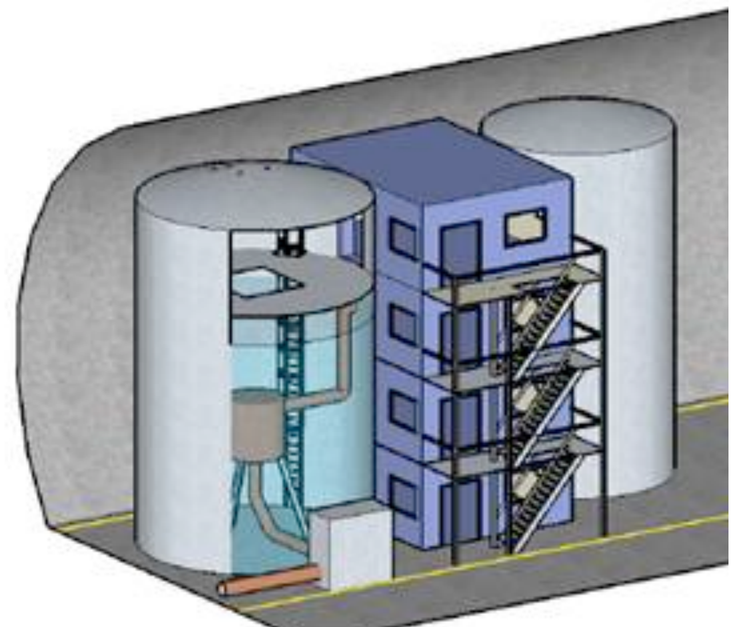
- cryogenic cabling (largest n source), background simulations
- pursuing STFC funds

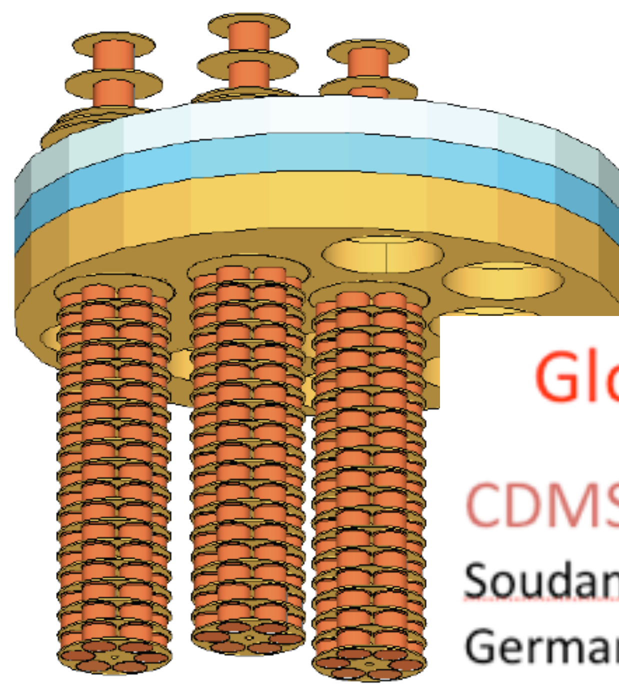


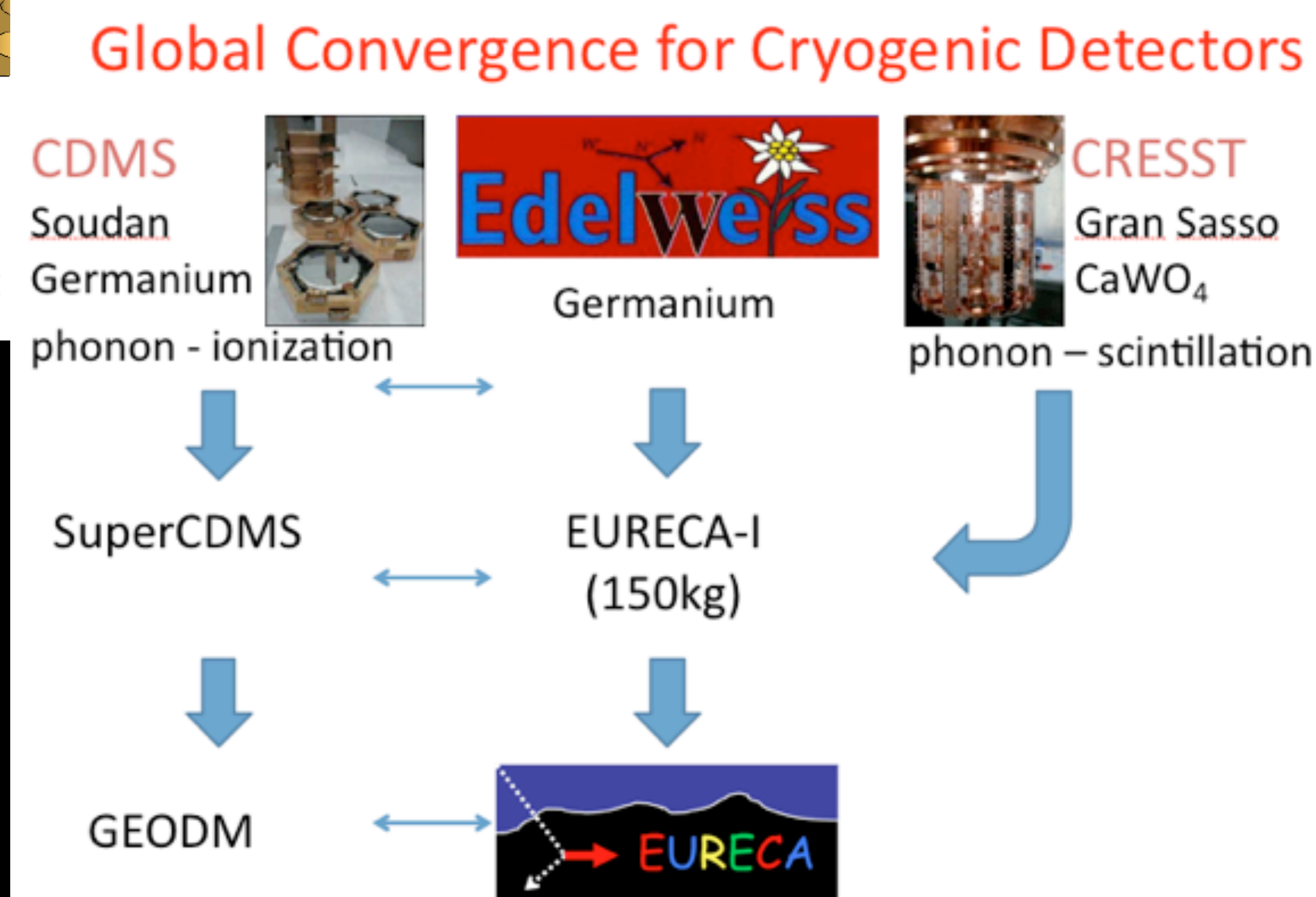
EURECA

Concept design: staged programme of 150 to 1000 kg of EDELWEISS and CRESST detectors, in LSM extension

EURECA	Goals
Phase 1	
Cross section (SI)	$3 \cdot 10^{-10}$ pb
Mass to be operated	150 kg
Residual background (all sources)	10^{-2} evts/kg/y in RoI
Duty cycle	70 %
Time of operation	1 year
Phase 2	
Cross section (SI)	$2 \cdot 10^{-11}$ pb
Mass to be operated	1000 kg
Residual background (all sources)	$< 10^{-3}$ evts/kg/y in RoI
Duty cycle	70 %
Time of operation	3 years







- collaboration founded at Oxford (2005)
- EURECA has CDR, working towards TDR 2013, proposals to EU countries / STFC late 2013
- UK groups active in cryostat, electronics, cabling design

(material thanks to H. Kraus)

DEAP/CLEAN Collaborators

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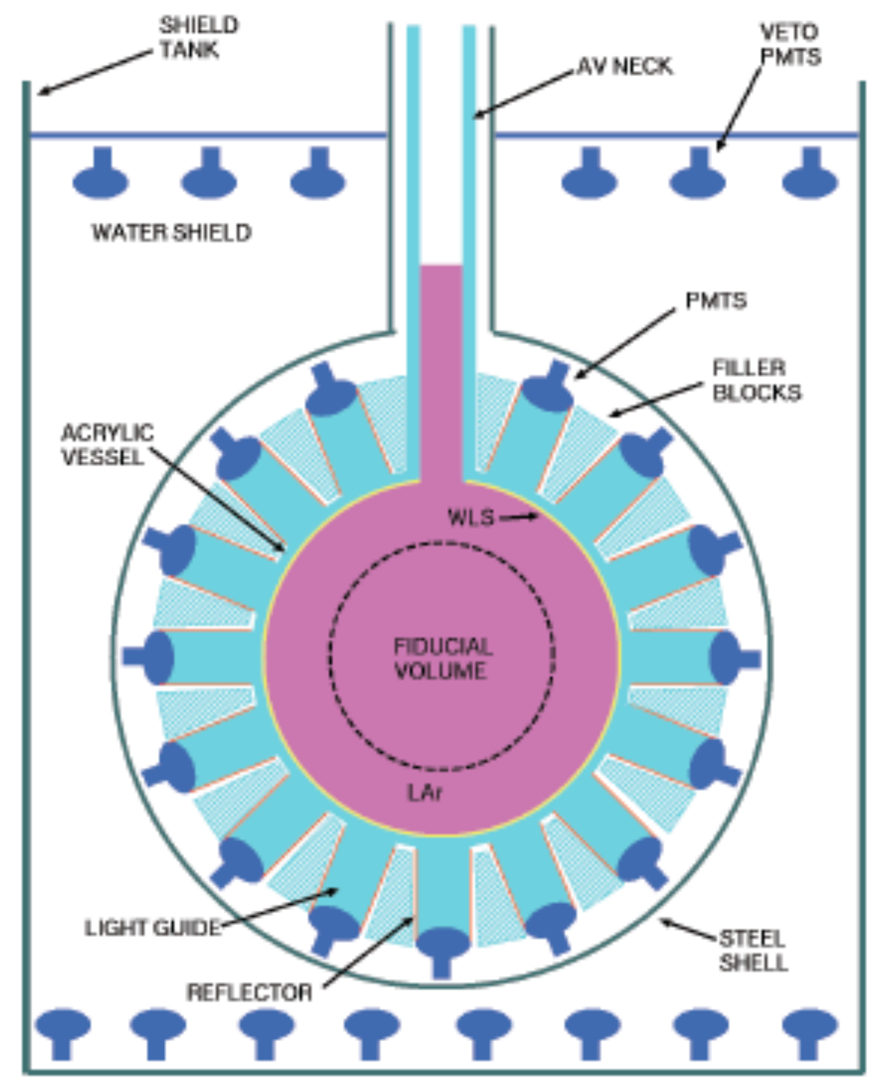
UK Groups

DEAP/CLEAN

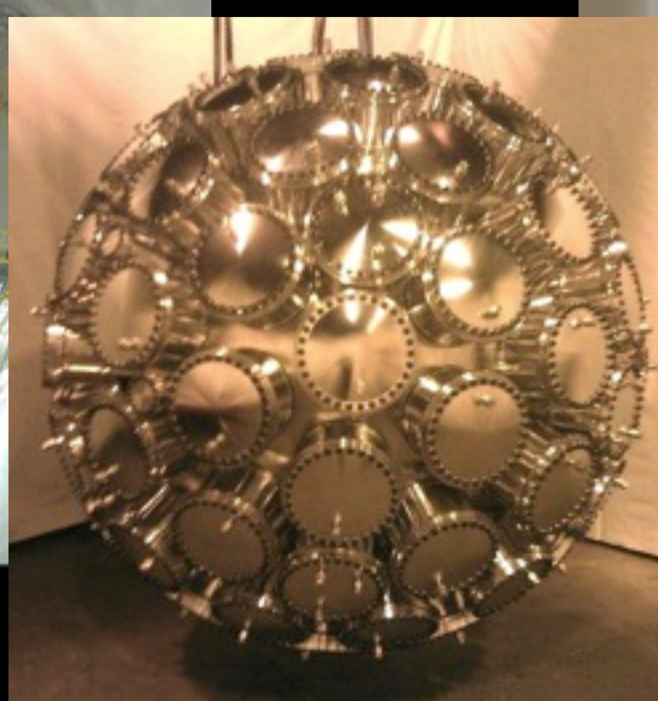


Single-phase LAr/LNe detector development program, goal: kT-scale low-background observatory for dark matter + solar neutrino physics with target exchange

- background strategy: self shielding, fast/slow scintillation
- 40-50 keV recoil threshold to mitigate ^{39}Ar bgnd

Staging: construction underway at SNOLAB

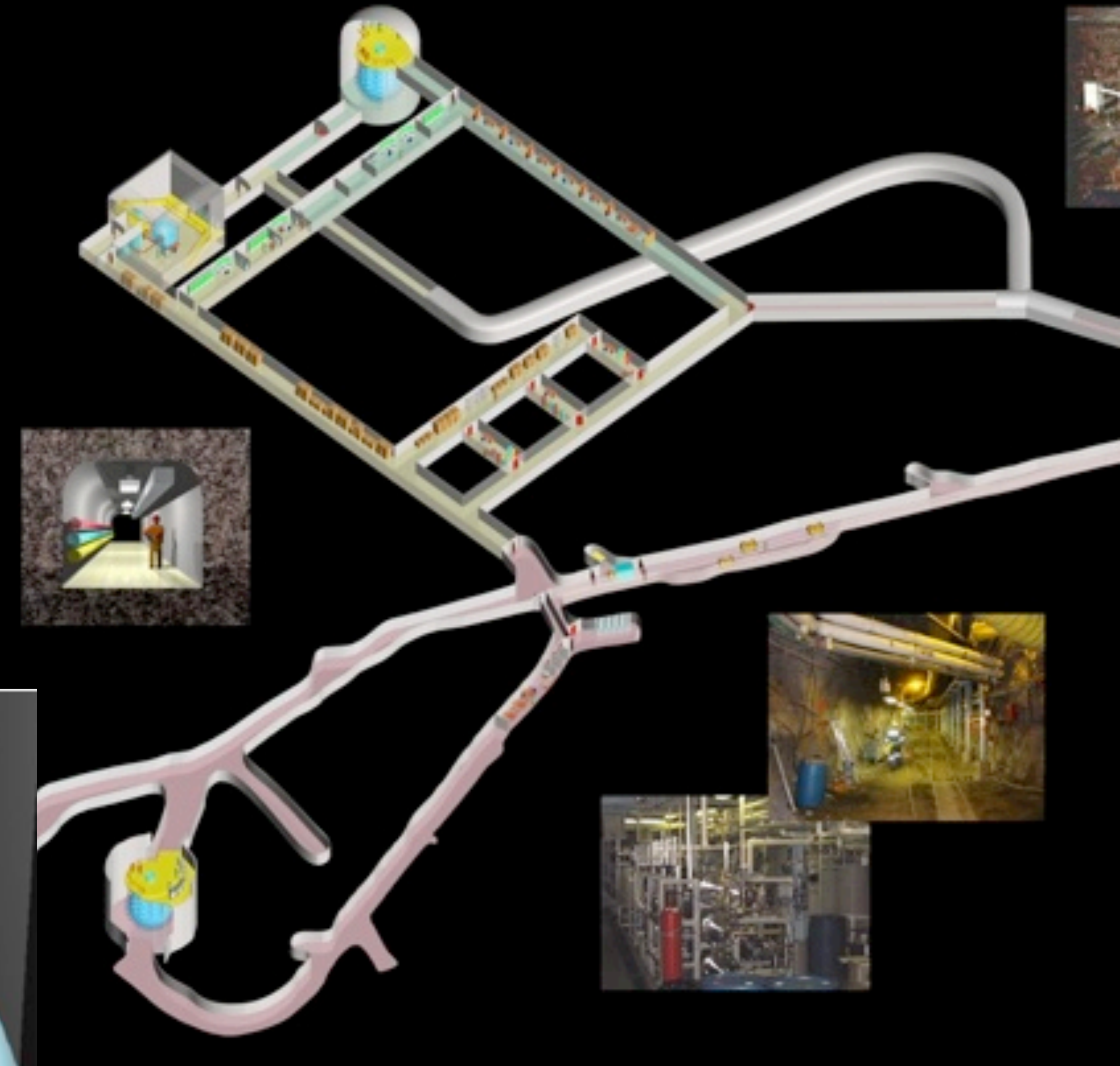
- MiniCLEAN (150 kg fiducial) to prototype LAr/LNe target exchange, science run to start 2013
- DEAP3600 (1000 kg fiducial LAr) for discovery potential, science run to start 2014



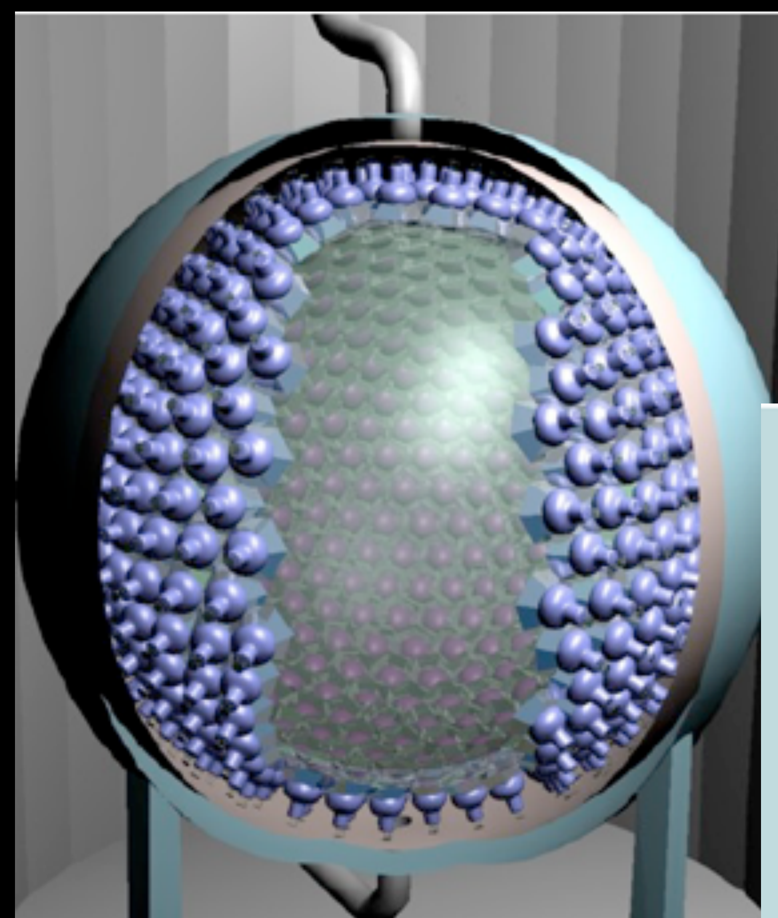
- UK workpackages: cryogenics, veto systems, Detector Coordinator (MC), Calibration System, Executive Board Chair-Elect (DEAP3600)
- ERC and STFC PRD funding

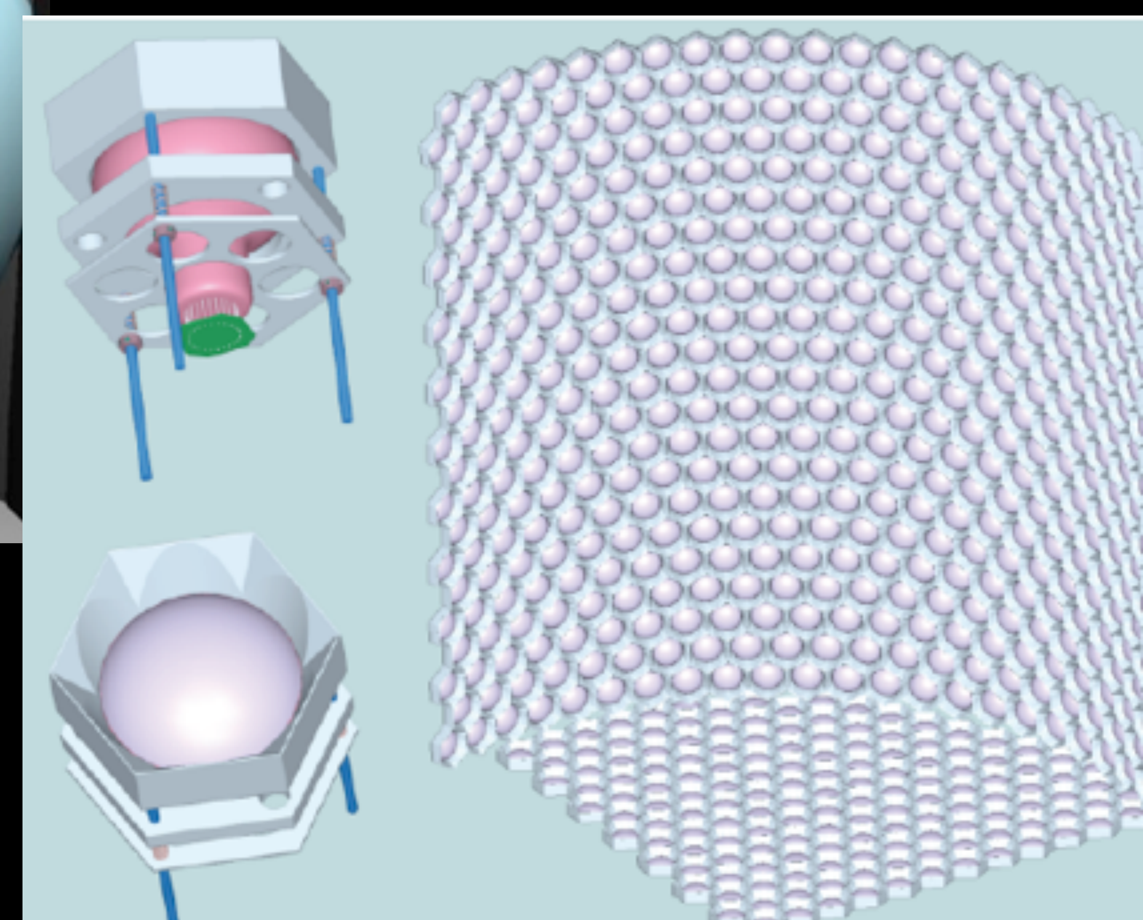
CLEAN

Concept design: 140 tonne fiducial mass LAr single phase detector, with PMT readout, in SNOLAB Cryopit Hall



- technical design based on MiniCLEAN, DEAP3600 technology R&D + MicroBooNE
- active Gd-doped veto
- founding collaboration members now in UK
- US groups on CLEAN in G2 process, CA groups in NSERC process (coordinated proposals to DOE/ NSERC/STFC 2014)



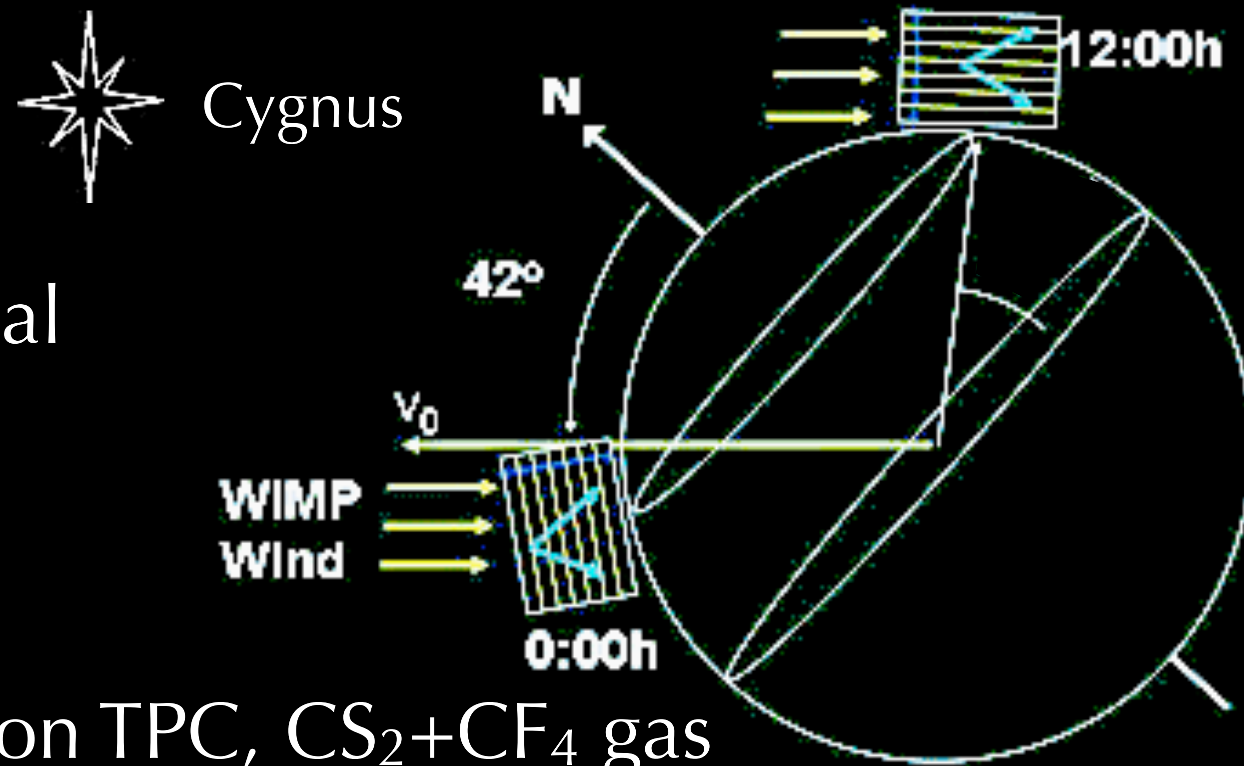


- detector design, background model, calibration R&D by UK groups, interested in synergy with LAr nu efforts

Directional Detection

Measure recoil track direction, test astrophysical origin of a candidate signal signal with sidereal modulation

Spergel, Phys. Rev. D37:1358 (1988)



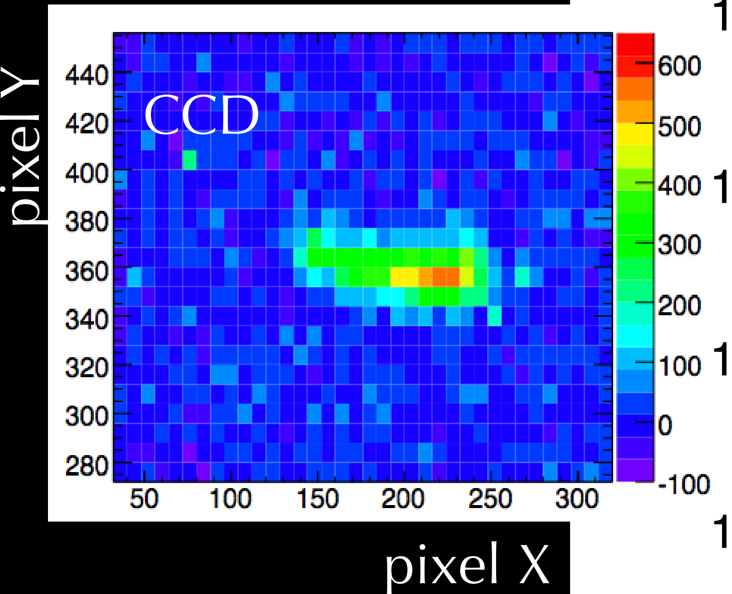
DRIFT: negative ion TPC, CS_2+CF_4 gas

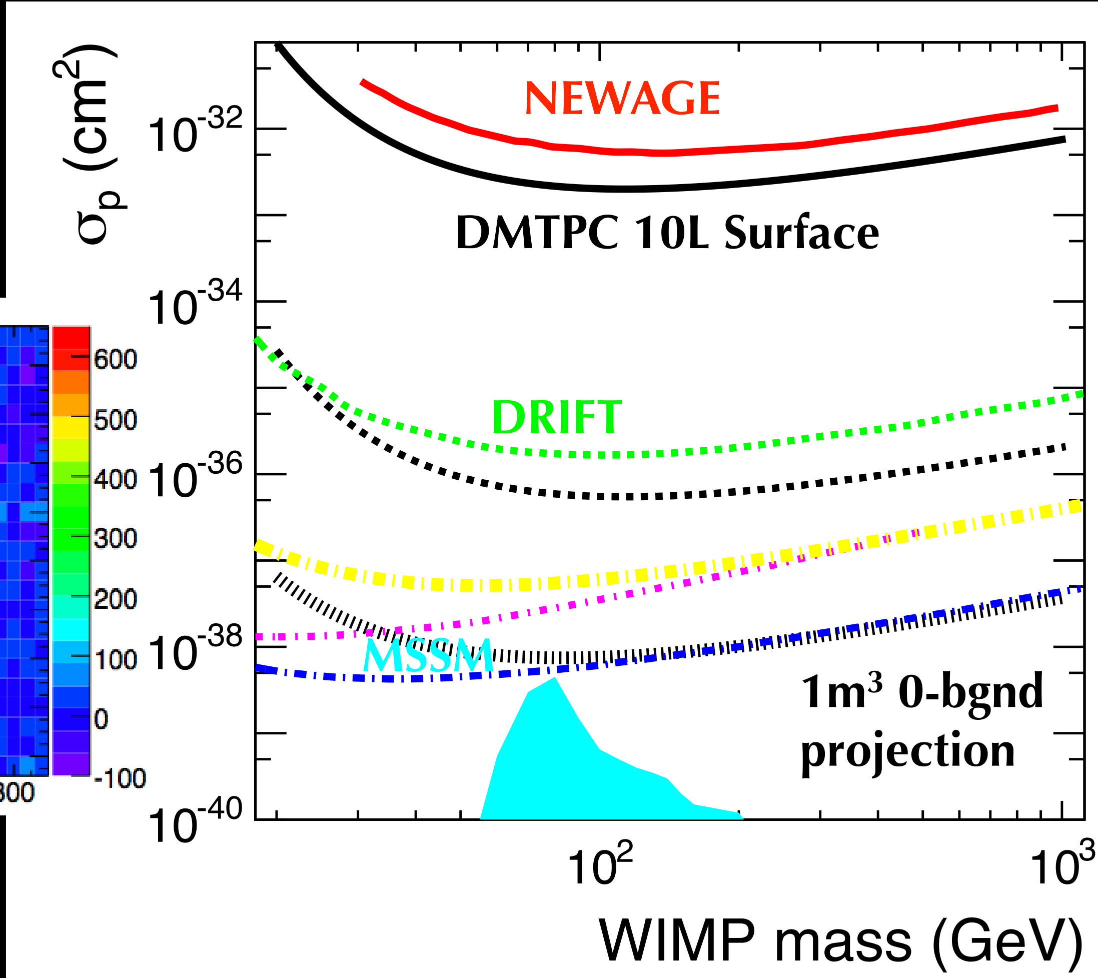
- 1 m^3 volume with MWPC readout, at Boulby since 2001
- UK groups contribute operations, DAQ, vacuum system, low-noise electronics
- pursuing STFC PRD funds

(material thanks to N. Spooner)

DMTPC: CF_4 gas TPC with optical, charge readout, at WIPP

- 20L prototype, 1m^3 construction
- UK: readout R&D, spokesperson
- DOE/NSF + STFC funding





CYGNUS: global collaboration for 1T detector

Outline

1. Dark Matter Direct Detection Overview
   - What are the top scientific challenges in Particle Physics to be solved in the next 20-30 years?

2. Current and Future UK Efforts

3. **DMUK Collaboration Input to PPAP**
   - What current and future facilities will be needed for the UK to make significant contributions to these areas?
   - What are the technology needs for each key priority?
   - What is the appropriate programmatic balance between construction, operations, exploitation, and R&D?

4. Conclusions (my opinions)

New Collaboration: **D**ark **M**atter **UK**

DMUK organized August 2012 to consolidate UK dark matter efforts.
We aim to take a leading and focussed role in the global programme,
and urge appropriate support for this high-priority area of STFC science.

Dark Matter direct detection is a growth area:

- UK experimental dark matter faculty has ~doubled in the past 5 years, to 14 academics at 9 universities+labs
(Boulby, Edinburgh, Imperial, Oxford, RAL, RHUL, Sheffield, Sussex, UCL)

Current funding does not reflect this:

- post Zeplin-III completion, identified funding for dark matter = 750k
(PPRP -> Science Board -> Dark Matter Subgroup -> process ongoing)
Subgroup report: http://www.stfc.ac.uk/Resources/pdf/DM_report_final.pdf

DMUK Input (submitted to PPAP):

Consolidation: The community is working on making a transition towards capital investment.

- likely some natural migration between experiments, where skills are easily transferrable
- external events and decisions could naturally limit the choices
- new information could identify an instrument as the most attractive for capital investment
- if none of the above, DMUK will review the options to assess the prospect for leading science results, likely with external experts and theory participation

Further clarity on STFC resources will be needed to help focus the strategy further, when it comes to submission of proposals for the period 2014/5 and beyond.

Funding: "Members of **DMUK recommend that a funding scenario at the Higher End should be pursued with high priority,** given the standing of UK-based researchers in the world, the fact that dark matter searches are a high-priority area of STFC science, because of the outreach and societal impact potential, because of the potentially disastrous contraction of the field in the UK without appropriate funding, and **most importantly because of the outstanding science opportunity for the UK to lead in the discovery of dark matter, which would fundamentally change our understanding of the universe."**

DMUK Input:

- What is needed for the UK to make a significant contribution to dark matter physics?

Main need is funding. Each group gave input to the Sub-Group on the cost of a major UK capital contribution to the next-generation instruments. We concur with the Sub-Group:

> ”The capital-phase cost of these experiments will be around £20-30M. Optimum UK capital-phase contributions (equipment and staff) are anticipated by the proponents, on the basis of authorship fraction, to be of order £6M, to be spent over 3-4 years.”

We also concur with the Sub-Group recommendation:

> “In the long term (early 2014 onwards) the SG recommends capital-phase support for construction over a 3-year period of no more than 2 tonne-scale experiments based on different nuclear targets. Should > ~£6M be available major participation in and significant leadership of at least 1, possibly 2, major world leading experiments is feasible. With ... ~ £3M to ~£6M significant leadership in no more than 1 such experiment is feasible. With < ~ £3M significant leadership as a result of strategic investment is unlikely to be possible.”

We urge the PPAP to recommend support of the Higher End funding scenario in the upcoming programmatic review as a high priority. *Dark Matter was not invited to submit a pro-forma, so Advisory Panel input is critically important!*

DMUK Input:

- What are the technology needs?

The UK has world-leading expertise in

-cryogenic system design

-low-noise cryogenic electronics and readout systems

-low-background radiation measurements (Boulby), simulation

-low-background calibration systems

-active veto instrumentation

-underground operations

-gas TPC R&D

-high voltage delivery systems

relevant areas to *all* future UK dark matter search options- opportunities for DMUK collaboration and path to consolidation

Access to engineering resources is critical to major construction responsibilities.

- What is the appropriate programmatic balance between construction, operations, exploitation, and R&D?

The highest priority of DMUK is to increase the capital funding for dark matter in the programmatic review. That said, exploitation is an important part of the R&D towards, and developing leadership in, next-generation dark matter detectors. We concur with the Sub-Group's support for R&D proposal submission to PRD for directional detectors.

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4. **Conclusions (my opinions)**

Conclusions (my opinions)

Dark matter is an area of huge scientific opportunity now.

Discovery by definition is a moving target, and funding priorities need to be (modestly) modified to stay at the cutting edge.

The UK is well-positioned to lead in discovering dark matter ***iff*** funding is at an appropriate level.

The Higher End scenario we are asking PPAP to endorse will support ~25% capital contribution to a next-generation project. In this best possible case, the UK will not drive the technology choice or proposal timeline. Coordination between STFC and international funders is very important.

The UK community is working to consolidate on a time scale of few years. DMUK Collaboration has formed to do this, and agreed on the process. Not clear what the best technology/experiment choice is yet, but we have intellectual leadership now in the major options in the global program.