Dark Matter Experiments

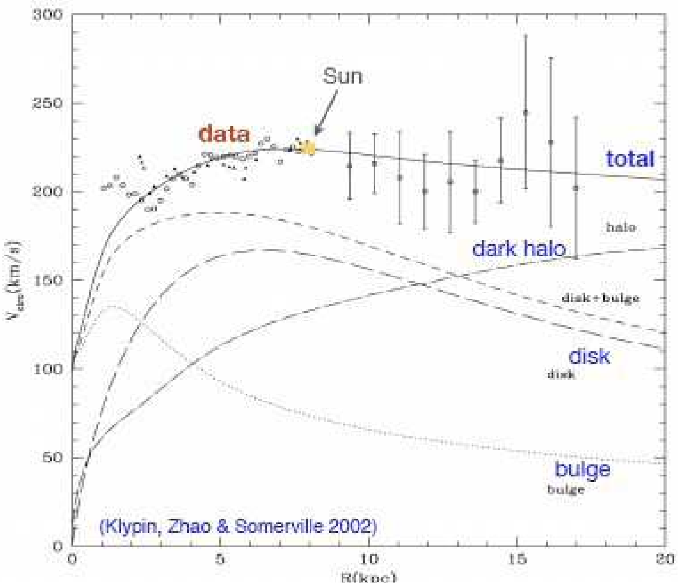
Main Dark Matter Projects:

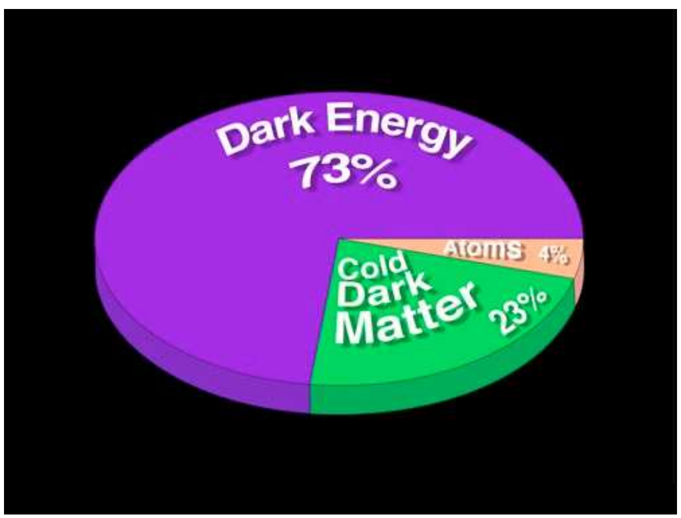
ZEPLIN-III / LUX-ZEPLIN	Imperial, Edinburgh, RAL, (Daresbury)
EDELWEISS/EURECA	Oxford, Sheffield
CYGNUS (DRIFT)	Sheffield, Edinburgh, STFC-Boulby
DEAP/CLEAN/DM-TPC	RHUL

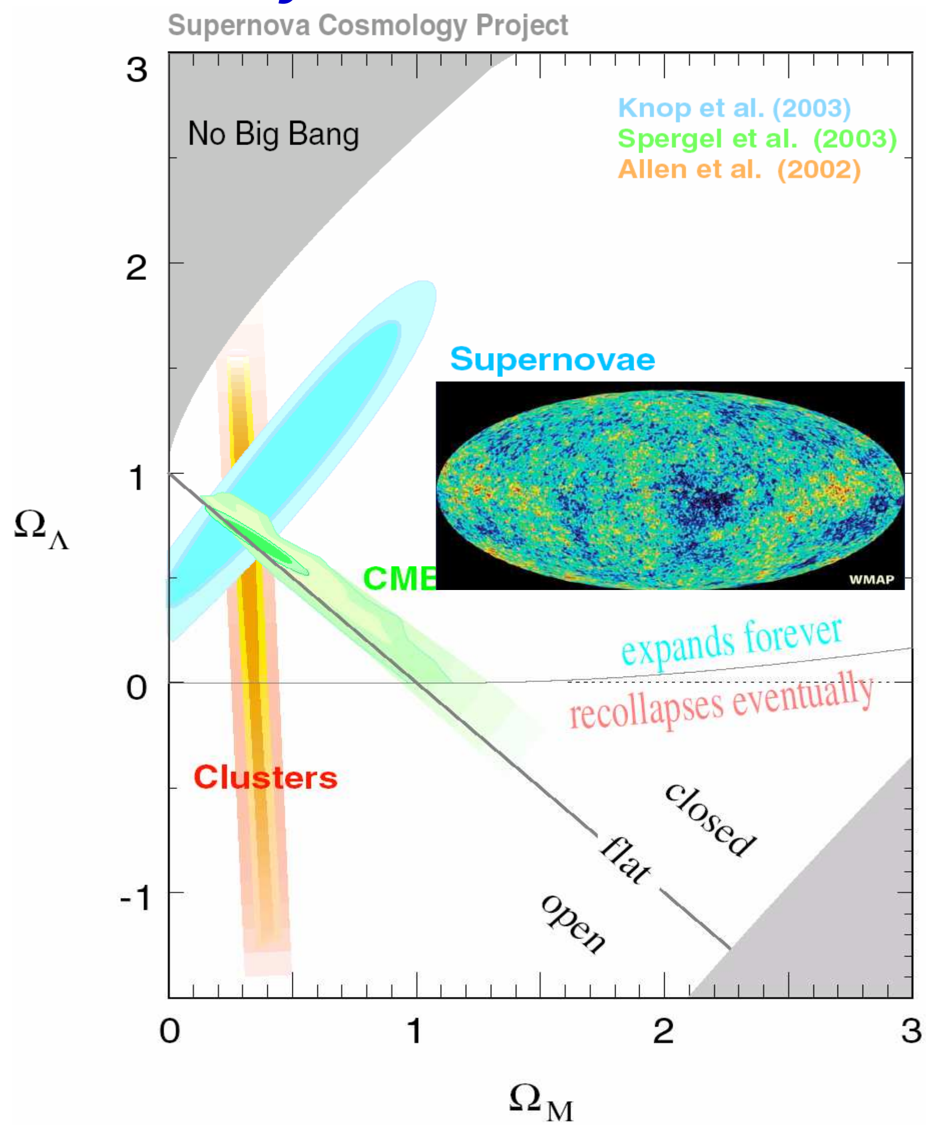
The Key Science Question

Strong evidence for the existence of Dark Matter

Obvious Link to LHC Physics



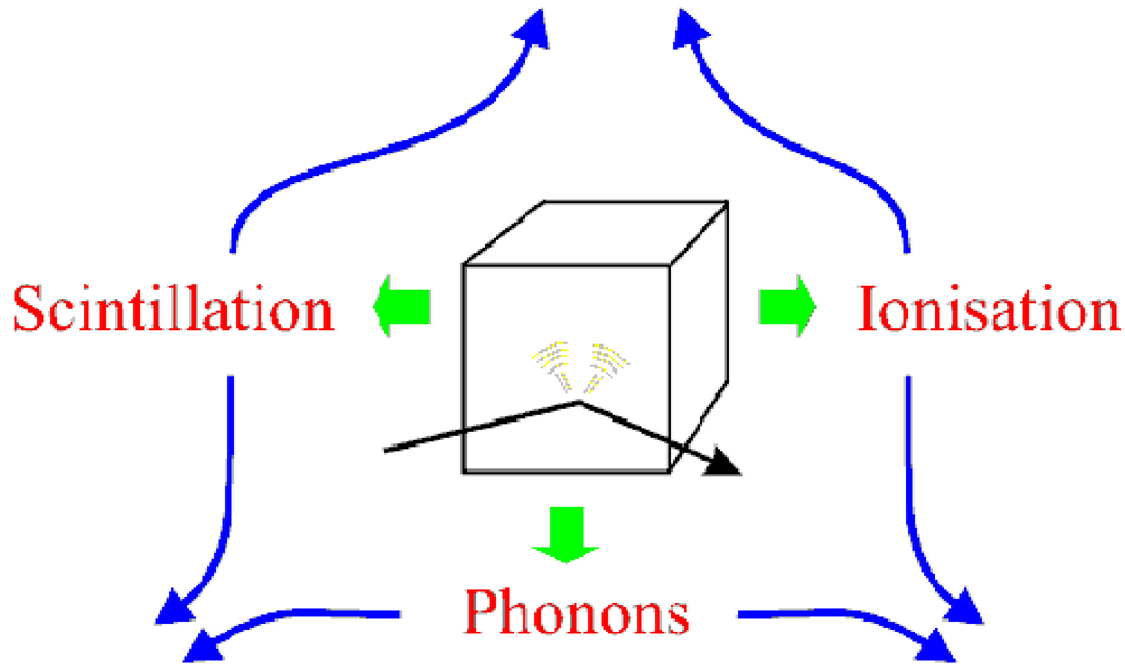




Focus on Direct Detection Techniques

Ar, Xe
ArDM, WARP, XENON, LUX, ZEPLIN-II/III

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
PICASSO

Si, Ge
CDMS
EDELWEISS
EURECA

Displacement / tracking: DRIFT, Newage, MIMAC, DM-TPC, D3

Current Results and Future Aims

kg.d ➔kg.yr

ZEPLIN III (FSR): 127 kg.d

EDW: 384 kg.d

CDMS: ~360 kg.d

ZEPLIN III (SSR): ~560 kg.d (*)

XENON 100: 1471 kg.d

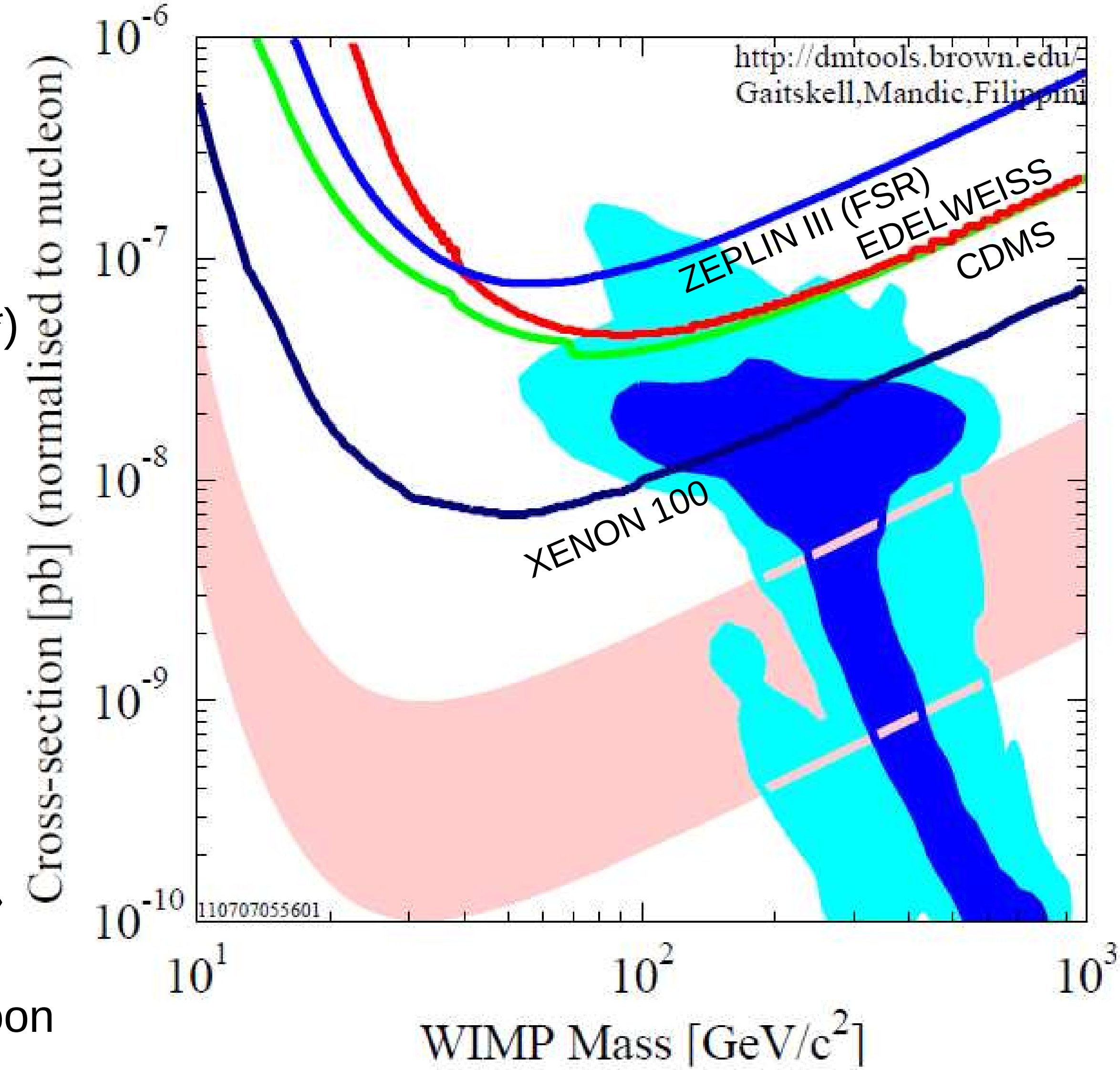
~1 evt/kg/year

Ton-scale experiments:

~10 evt/ton/year

(*) Data still blinded – result soon

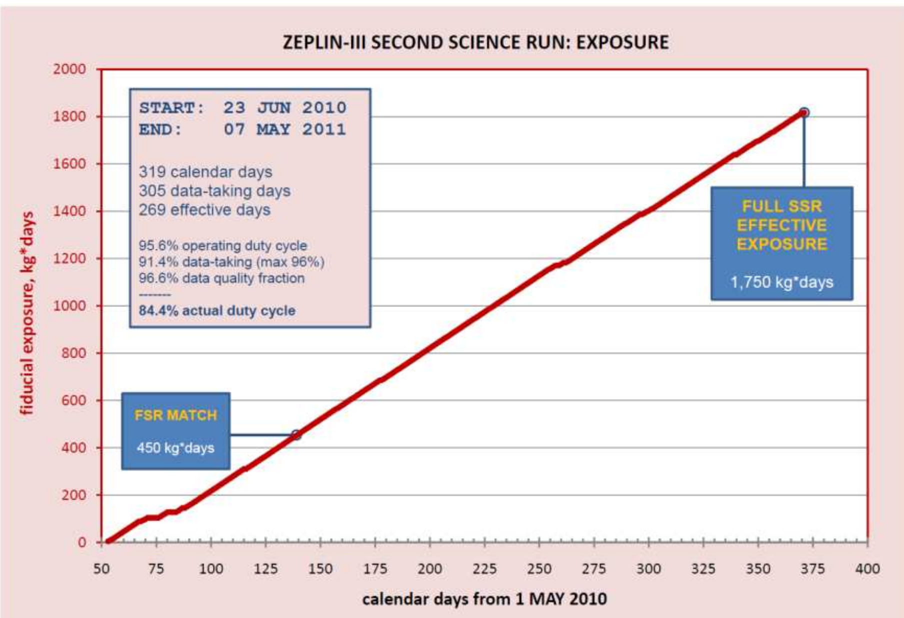
Indication, Confirmation, Study

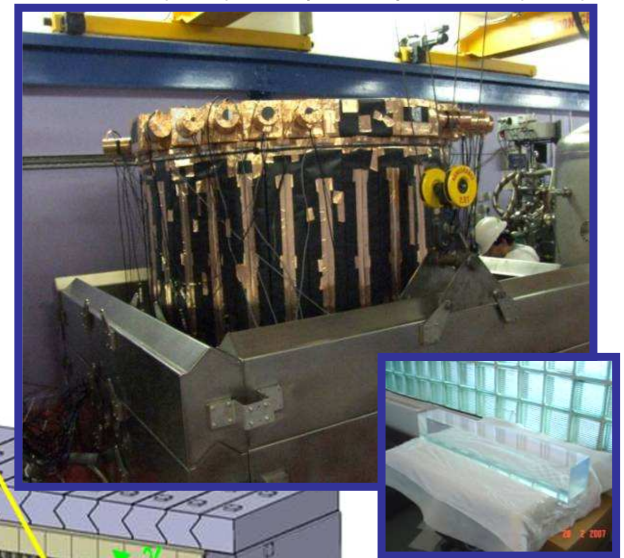


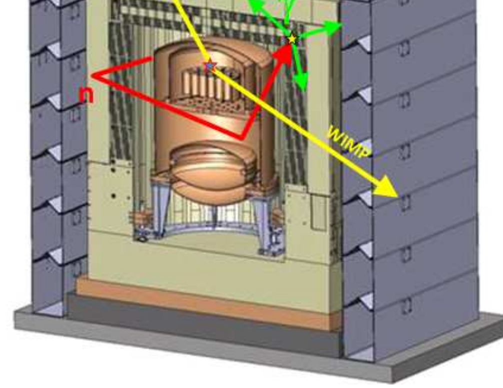
Ghag et al. (2011), arXiv:1103.0393
Akimov et al (2010), Astropart. Phys. 34: 151 (2010)

ZEPLIN-III

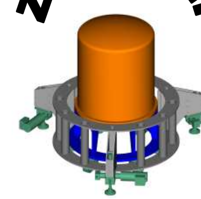
- **First science run at Boulby: 83 days in 2008**
  - Strong constraints on WIMP-nucleon scattering XS
- **Phase-II upgrades commissioned in 2009/10**
  - New photomultiplier array (low background)
  - New anti-coincidence veto (background reduction & diagnostic)
  - New calibration hardware (reduction of systematics)
  - System automation (underground effort, improved stability)
- **Second science run completed at Boulby**
  - Longest run of any noble liquid WIMP detector (319 days)
  - Effective fiducial exposure ~560 kg*days (4x FSR)







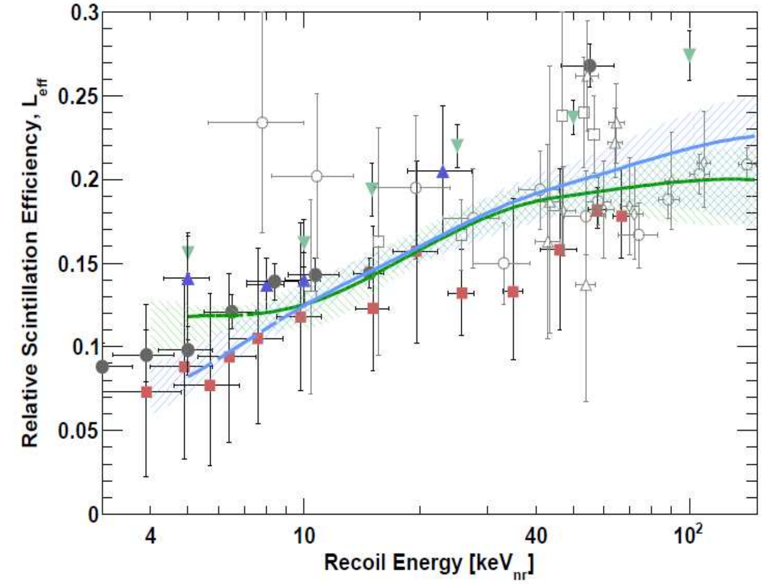
ZEPLIN-III

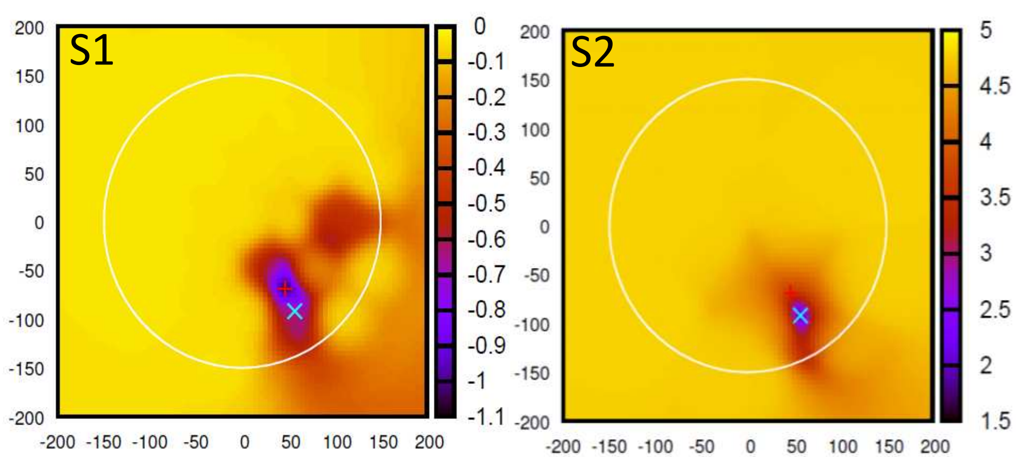


ZEPLIN-III

- New L_{eff} and Q_i measurements for LXe
  - L_{eff} in agreement with new beam data
- Radioactivity backgrounds
  - 18x reduction from first run due to photomultiplier upgrade
  - Confirmed negligible neutron background using new veto
- Development of data processing algorithms
  - New likelihood-based vertex reconstruction (figure below)
- Single electron emission in two-phase xenon
  - Ionisation threshold <<1 keVr for nuclear recoils
    (application to light WIMPs, coherent neutrino scattering, …)

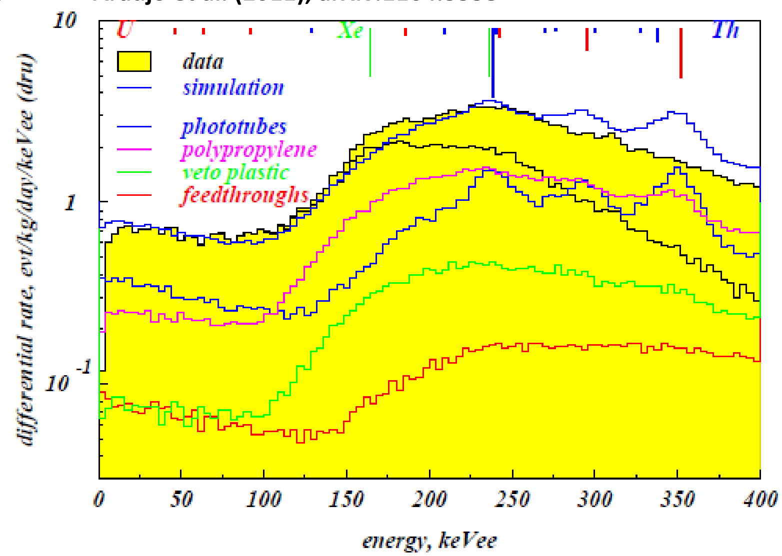
Horn et al. (2011), arXiv:1106.0694





Solovov et al. (in preparation) – spatial likelihood maps for "living-dead" event, with multiple S1 and a single S2 pulse;

Araujo et al. (2011), arXiv:1104.3538



Liquid Noble Gas Expertise

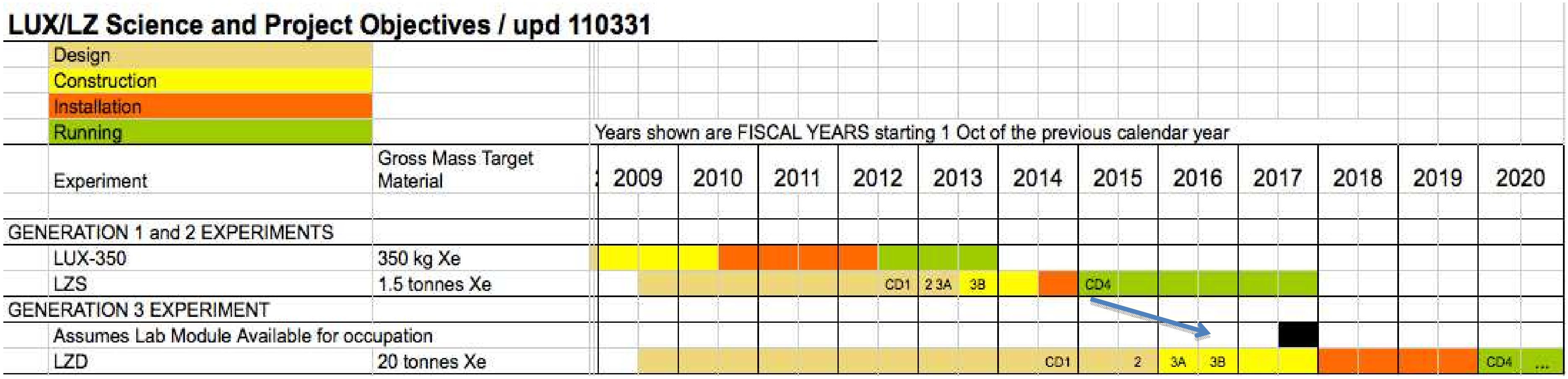
ZEPLIN-III collaboration: Imperial College, STFC-RAL, University of Edinburgh, LIP-Coimbra, ITEP-Moscow (35 authors)

LUX-ZEPLIN: ZEPLIN-III + Brown, Texas A&M, CalTech, UC Berkeley, Case Western, UC Davis, Harvard, UC Santa Barbara, LBNL, Maryland, LLNL, South Dakota, Rochester, Yale, South Dakota School of Mines & Technology, MEPhI (Moscow), STFC Daresbury (~89 members)

Note: UK groups were first in world to use two-phase noble gas technology for DM searches

Co-PIs: Gaitskell, Shutt, Sumner

Evolution of the LUX-LZ Program



TPC ($M)	Homestake 4850	SNOLab
LZS (1.5t Xe)	12.48 - 17.96	16.97 - 24.39
LZD (20t Xe)	60.5 - 88.2	65.23 - 95.64*

LUX350 will stay at Sanford Laboratory (Homestake) and UK groups will formally join that collaboration in time for first underground deployment

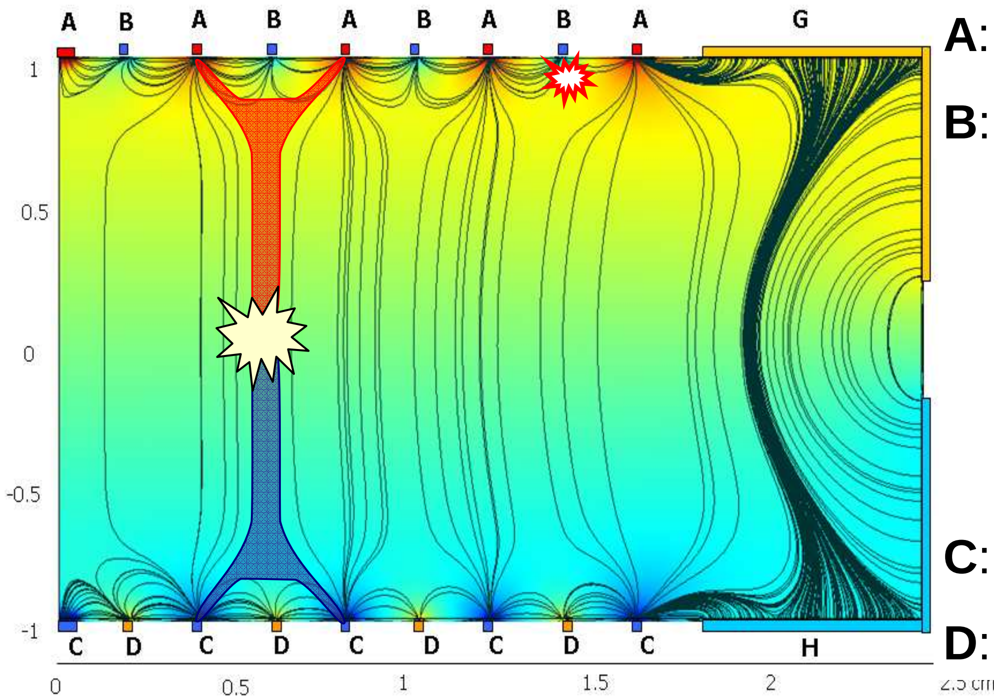




LUX350 Status Summary

- LUX detector is complete with cryogenic test runs underway in water tank in dedicated Surface Laboratory.
- Early 2011 – Davis Complex (4850 level) excavation complete.
- May 2011: $8m contract for outfitting of Sanford Laboratory.
- LUX will move detector underground in Spring 2012.

Cryogenic Detector Expertise

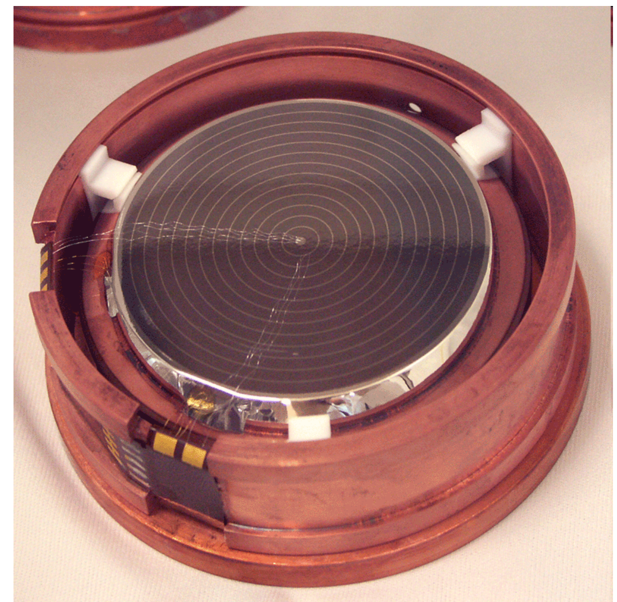


A: +4 V

B: –1.5V

C: –4 V

D: +1.5V



Major EDELWEISS II achievement:

ID / FID detectors with bulk / surface event discrimination.

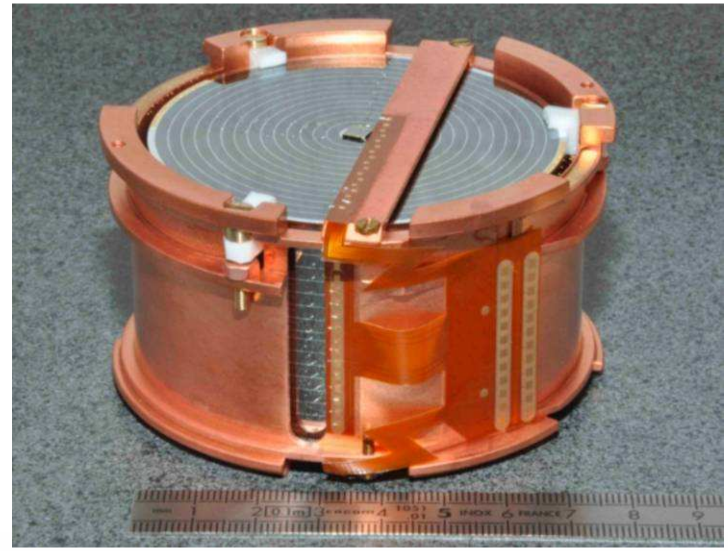
Surface event (β) rejection: 10^5

A. Broniatowski et al **Phys Lett B 681 (2009) 305** [arXiv:0905.0753]

Edelweiss

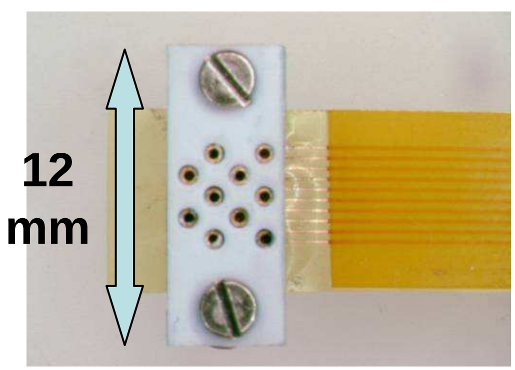
2012-14: Edelweiss-III

40 FID800 (~24kg fiducial)

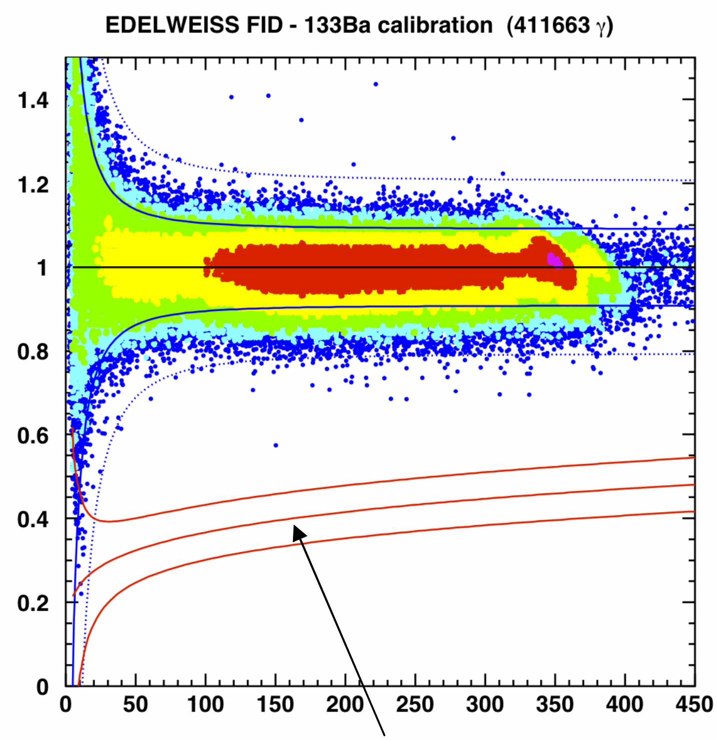


UK contributions to EDW III:

- Ensure low-background setup
- MC modelling expertise
- Low-temperature / clean cabling
- Data analysis (oxrop-software)
- Detector / electronics expertise



Example: Oxford, Sheffield, LSM, CNRS
→ cabling / connectors made from known (clean) materials



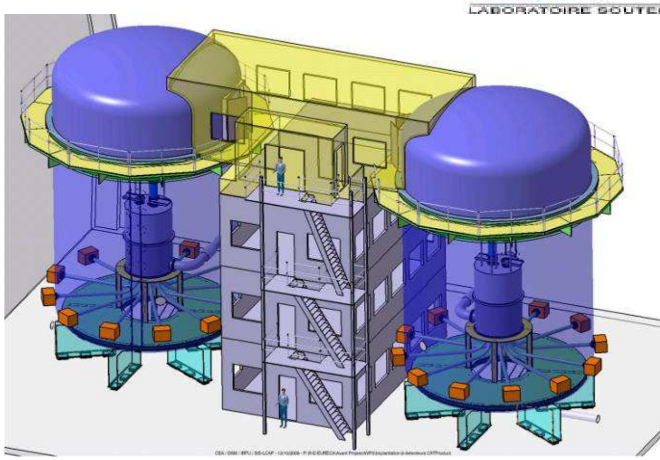
No events in nuclear recoil band

Edelweiss collaboration: CEA Saclay (IRFU, IRAMIS), CNRS-CSNSM Orsay, KIT (IK, EKP, IPE) Karlsruhe, CNRS Institut Néel Grenoble, IPN Lyon, LSM, JINR Dubna, Oxford, Sheffield (52 authors)

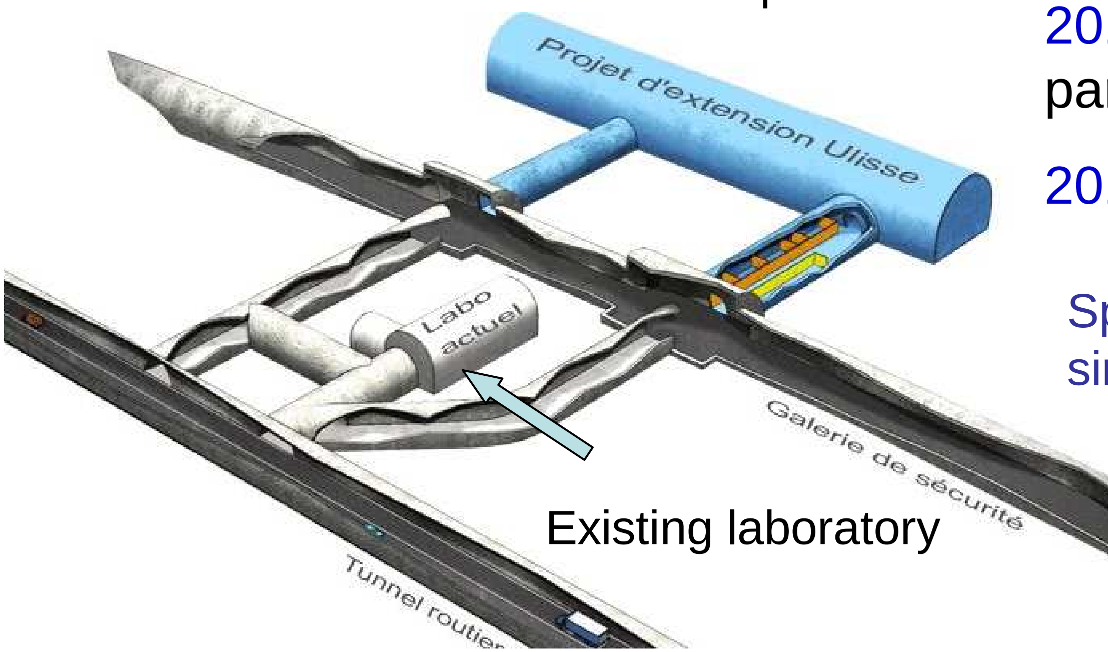
In Europe – EURECA: Edelweiss + MPI, TUM, Tubingen, KINR, Bordeaux, IAS, Zaragoza (~115 members)

Global cooperation: CDMS / Edelweiss combined limit arXiv:1105.3377 (114 authors, 30 affiliations)

MoU between EURECA / SuperCDMS / GEODM.
Working together on shielding and cryostat designs, detector procurement, background studies, etc.



New LSM extension for EURECA / SuperNEMO



Timeline:

2010/2011: Design Study → TDR

2012: Digging out of LSM extension begins. In parallel, begin construction of EURECA components away from LSM. Aim for ~100kg stage (10^{-9} pb).

2014: LSM extension ready to receive EURECA.

2015: Begin data taking and in parallel improve and upgrade.

2018: One tonne target installed.

Spokesman: Hans Kraus (2005-2010), since January 2011: Gilles Gerbier

Maximizing UK Impact

The timescale is summarized here:		2011/2012	2012/2013	2013/2014	2014/2015	2015/2016
EDELWEISS	Ongoing experiment					
EURECA						
LUX350	Ongoing experiment					
LZS						

Joint Imperial, Oxford, Edinburgh, Sheffield, RAL proposal

- **Science first!** WIMPs before technology.
- Increase level of cooperation (rather than competition).
- Follow international recommendations for the field.
- Exploit UK expertise, safeguarding PPARC / STFC investment.
- Joint programme (Imperial, Oxford, Edinburgh, Sheffield, RAL).
- Synergies and cooperation: GEANT, fast electronics, VHDL, MC simulations (radioactivity, muon-induced neutrons, GEANT4 models, SOURCES4), neutron measurements, etc
- Migration (Kudryavtsev, Horn, Walker) allows friendly scrutiny.

DRIFT II & DTM (DRIFT III) 2010/11

Directional Detection of WIMP Dark Matter to Identify Galactic Signal

UK: Sheffield, Edinburgh, STFC

US: Occidental, UNM, CSU

New publications, including world's best limit with direction sensitivity (unblind)

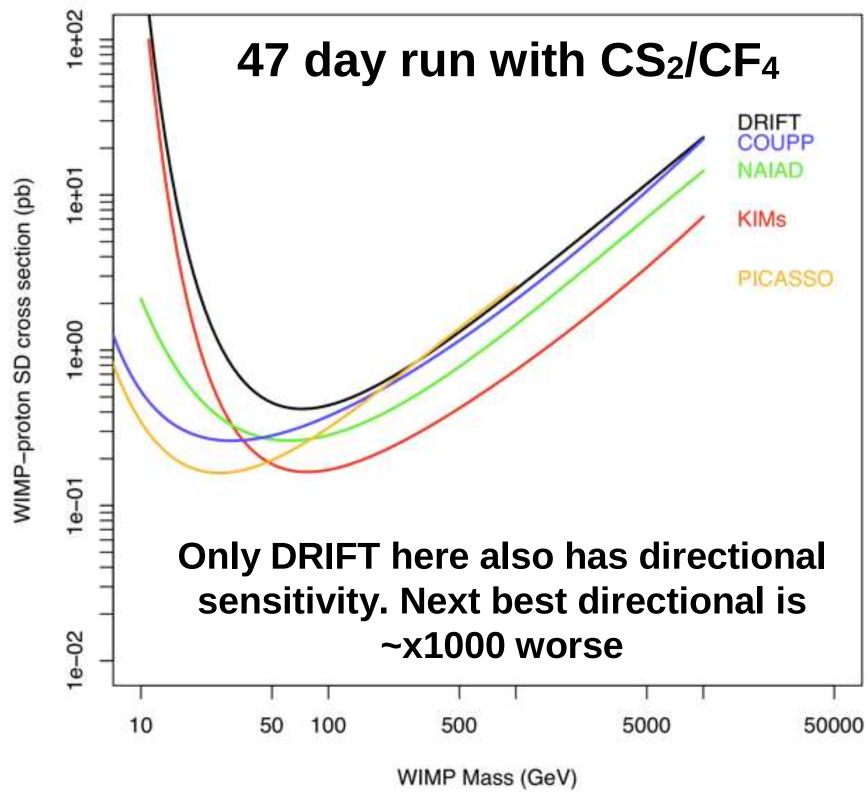
N.J.C. Spooner et al. Astroparticle Physics 34 (2010) 284

E. Daw et al, sub Astroparticle Physics (2011) - arXiv:1012.5796

UK Contributions:

- built and installed new gas system for CF_4 (SI sensitivity)
- Built and installed upgrade to DAQ
- Key analysis of low background and radon reduction and emanation system
- Run all operations

Underway now: new blind analysis with x15 improved background to be released soon



Directional DM Opportunities at Boulby

- Five non-directional DM experiments have "backgrounds" above expectation - the directional sensitivity can provide a clearer signal identification and determine galactic origins - the UK can have a leading role.

- The directional field is rapidly growing, now 5 groups: DRIFT, MIMAC, NEWAGE, DM-TPC, D^3 worldwide (~150 scientists). We started the CYGNUS international cooperation (Boulby2007, MIT2009, Aussois2011)

Workpackages: (1) gas, (2) background, (3) directionality, (4) halo physics

- **Funding for the Boulby Palmer Laboratory secured for 3 years under STFC environment programme even though ZEPLIN has gone - a big opportunity for a re-newed UK effort**

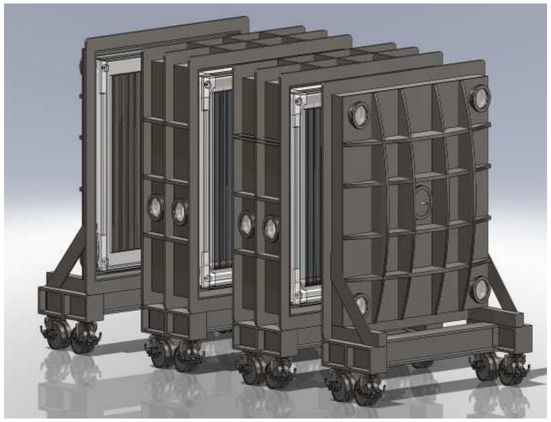
- **NEW (July 11) - NSF supports (3-year) continuation & expansion of operations at Boulby**

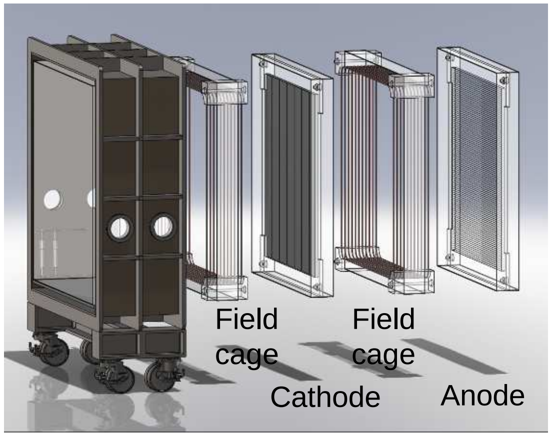
- Mine company CPL supports new excavation for scale-up

Proceed to scale-up at Boulby to 24 m^3 called DTM (DRIFT III module)

Scale-up Design for DTM (DRIFT III Module)

- US-UK design well advanced
- 24 m^3, 4kg target
- 3D readout with track sense
- Modular to allow ton-scale
- Z-fiducialisation by +ve ion detection and thin cathode
- C, S, F targets to include spin-dependent sensitivity





UK current contributions: gas system, radon/background reduction, slow control, shield, site, analysis and data

DEAP/CLEAN Collaboration

17 institutions, ~85 members

MIT PI moved to RHUL Summer 2011, new group funded by ERC Starting Grant
(2 PhD students, 2 PDRA from ERC 5 yr funds: €1M; U.S. NSF 3 yr funds: \$0.4M, STFC 3 yr funds: PhD studentship)

DM-TPC (5 institutions, 27 members, spokesperson J. Monroe), running (WIPP)

MiniCLEAN activities: lead μ veto system hardware/software, neutron calibration system hardware/software, neutron background simulation, WIMP analysis working group

DEAP/CLEAN Program for Dark Matter and ν Physics

DEAP-1 (7 kg) μCLEAN (4 kg) MiniCLEAN (300 kg) DEAP-3600 (3600 kg) CLEAN(100T)

2006 2007 2011 2014 2018

single phase open-volume design

draws on successes of ν physics

Goal: observatory for dark matter, pp solar neutrinos, supernova neutrinos

MiniCLEAN (150 kg fiducial)
construction: 2010-2011, run: 2012-2014

DEAP-3600 (1 tonne fiducial)
construction: 2011-2013, run: 2014-2019

CLEAN (10 tonne fiducial)
proposal: 2016, with depleted LAr

- Best singlet to triplet lifetime ratio: 10^9 electron rejection
- Favorable form-factor for coherent scattering: higher energy threshold
- Excellent scintillation light yield / $$
- No pile-up from drifting electrons in E-fields: kT detectors possible
- Drawback: ^{39}Ar, trade-off between background rejection and threshold, but progress in ^{39}Ar-depletion (x20)

Summary

Ton-scale detectors needed for exploring suggested cross sections and for study of WIMP properties.

Broad international agreement: need multiple targets and need multiple detection techniques.

How to prove we found dark matter? Multi-target, directionality, modulation …

Maintain R&D: performance predictions might look nice, but what is around the next corner (i.e. the next scale-up)?

Convergence of experiments (worldwide) and also increased science-driven (cross-experiment) activity.