Non-Accelerator Experiments

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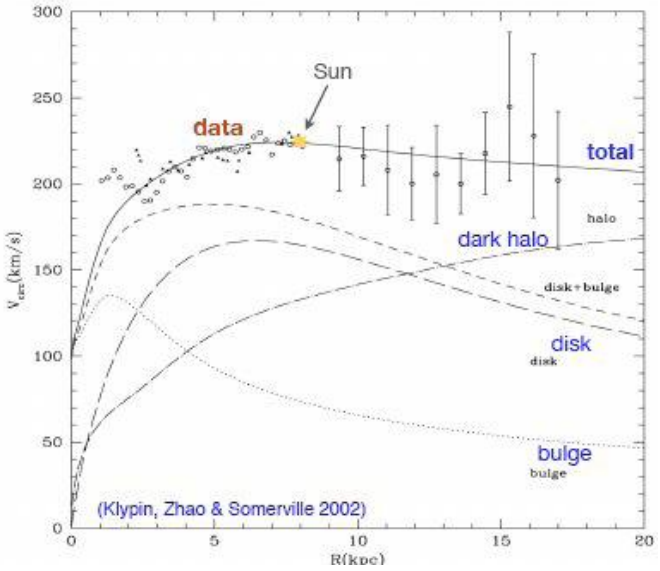
With thanks to Phil Harris, Ed Hinds, Hans Kraus,
Ben Sauer, Neil Spooner, Tim Sumner

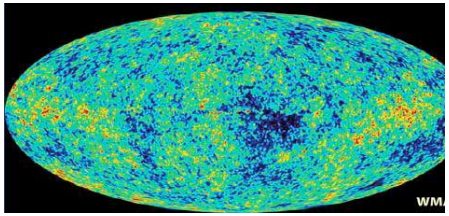
Outline

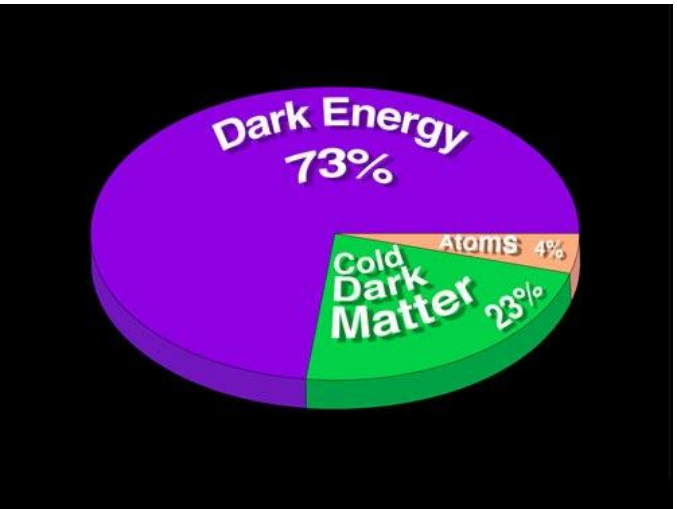
- Direct dark matter search experiments
  - CRESST **Oxford**
  - EDELWEISS and EURECA **Oxford/Sheffield**
  - ZEPLIN-III and LUX-ZEPLIN **Imperial/RAL/Edinburgh**
  - ArDM [-> DARWIN] **Sheffield/Liverpool**
  - DRIFT-II [-> CYGNUS] **Sheffield/Edinburgh**
- Electric dipole moment search experiments
  - CryoEDM **Sussex/RAL/Oxford**
  - eEDM **Imperial**
- Underground Laboratories
  - Boulby Underground Science Facility

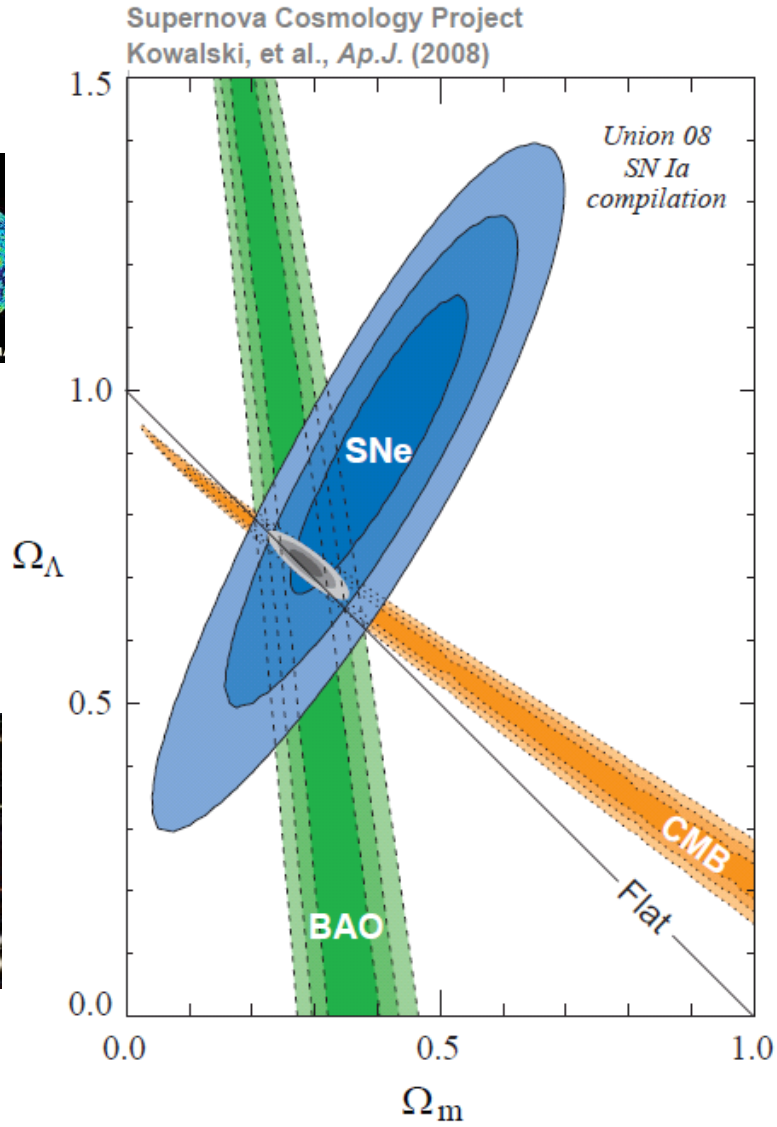
The Key Science Question

Strong astrophysical evidence for the existence of Dark Matter









Current Results and Aims

DATA listed top to bottom on plot
CRESST 2007 60 kg-day CaWO4
Edelweiss II first result, 144 kg-days interleaved Ge
ZEPLIN III (Dec 2008) result
XENON10 2007 (Net 136 kg-d)
CDMS: Soudan 2004-2009 Ge
Trotta et al 2008, CMSSM Bayesian: 68% c
Trotta et al 2008, CMSSM Bayesian: 95% c

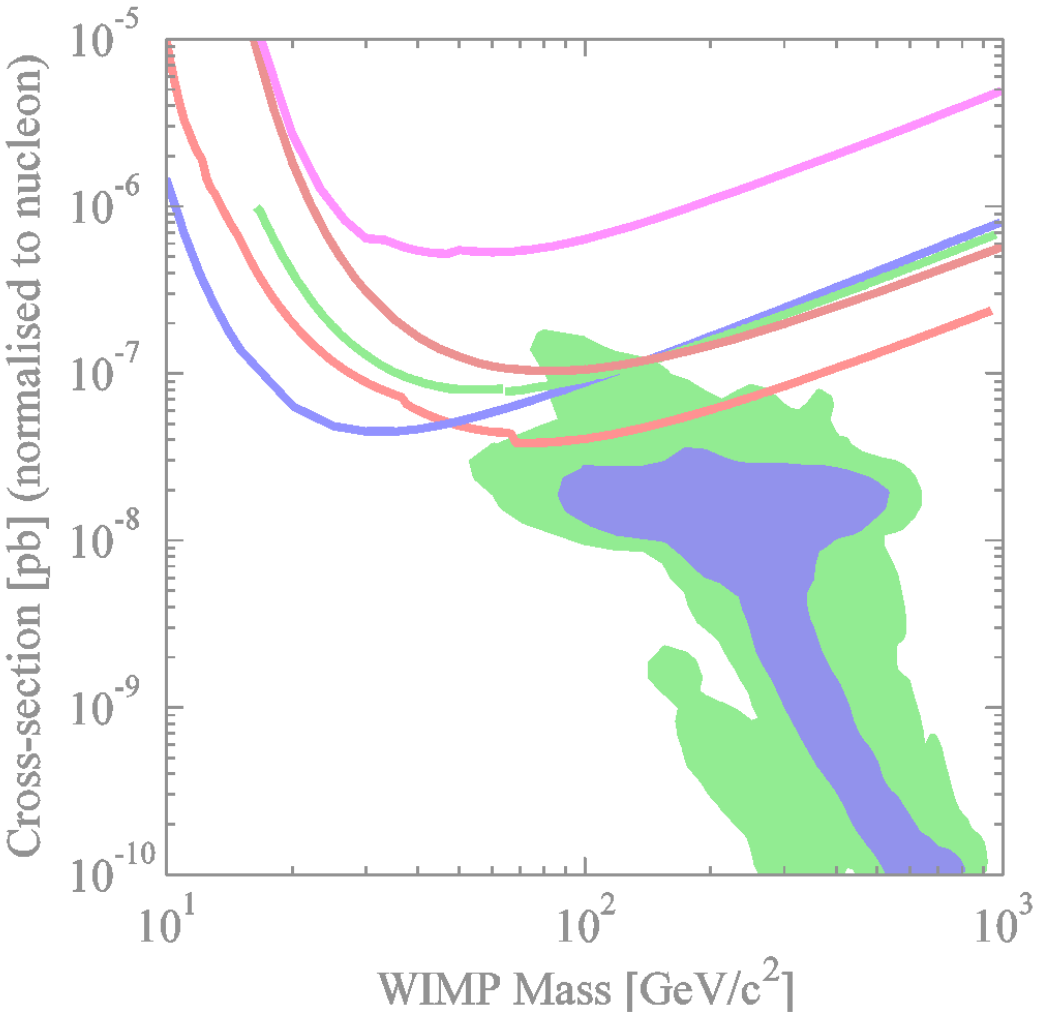
Indication, Confirmation, Study

~1 evt/kg/day

~3 evt/kg/year

Next aim of “ton-scale” experiments

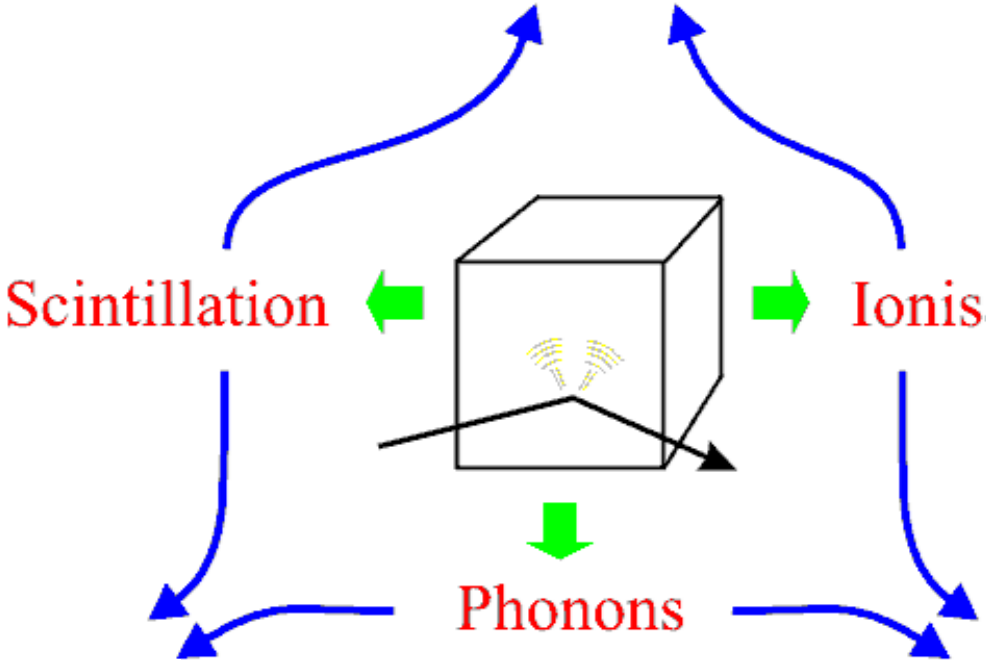
~30 evt/ton/year



Focus on Direct Detection Techniques

Ar, Xe
ArDM, WARP, XENON, LUX, ZEPLIN

NaI, Ar, Xe
DAMA/LIBRA
ANAIS
NAIAD
KIMS
XMASS
DEAP/CLEAN



Ge
HDMS
GERDA
MAJORANA
IGEX

$CaWO_4$, $ZnWO_4$
CRESST II
ROSEBUD

Al_2O_3 and others
CRESST I
CUOPP
PICASSO

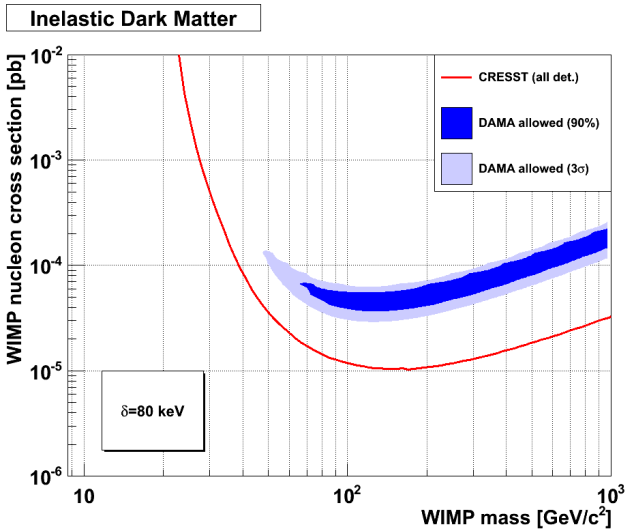
Si, Ge
CDMS
EDELWEISS

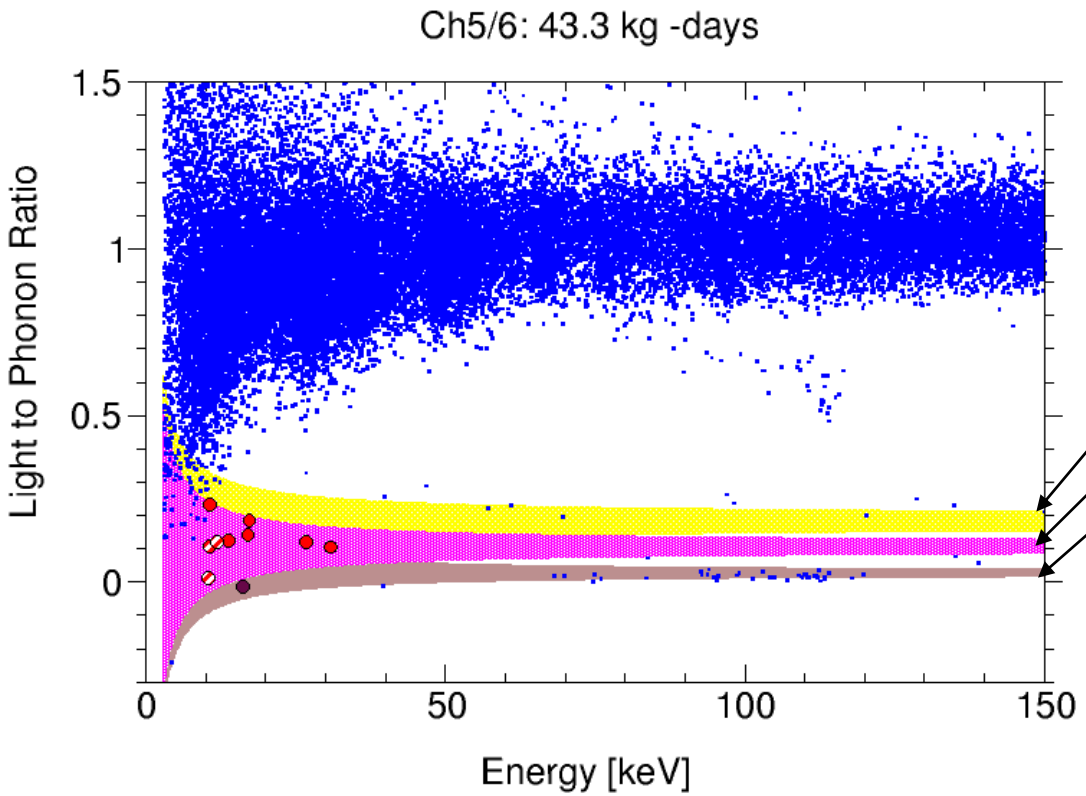
Displacement / tracking: DRIFT, Newage, MIMAC, DM-TPC

CRESST – Phonon-Scintillation ($CaWO_4$)

WIMP mass unkown ➔ need different target nuclei for probing broadly.

From tungsten: inelastic Dark Matter scenario becomes very unlikely to explain DAMA result.





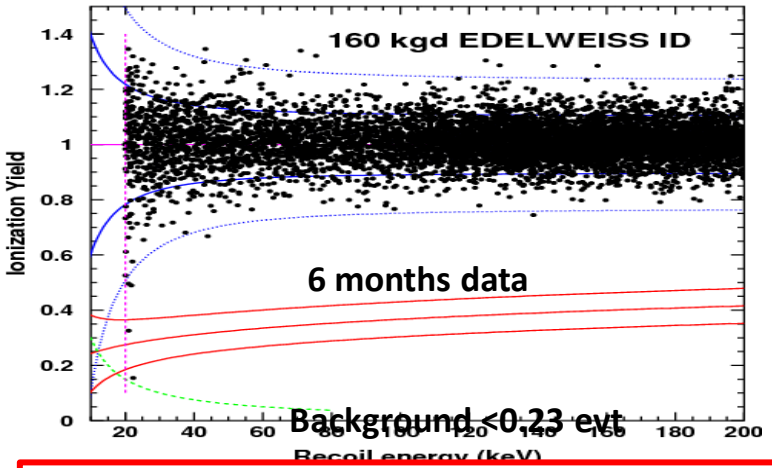
alpha band

oxygen recoil band

tungsten band

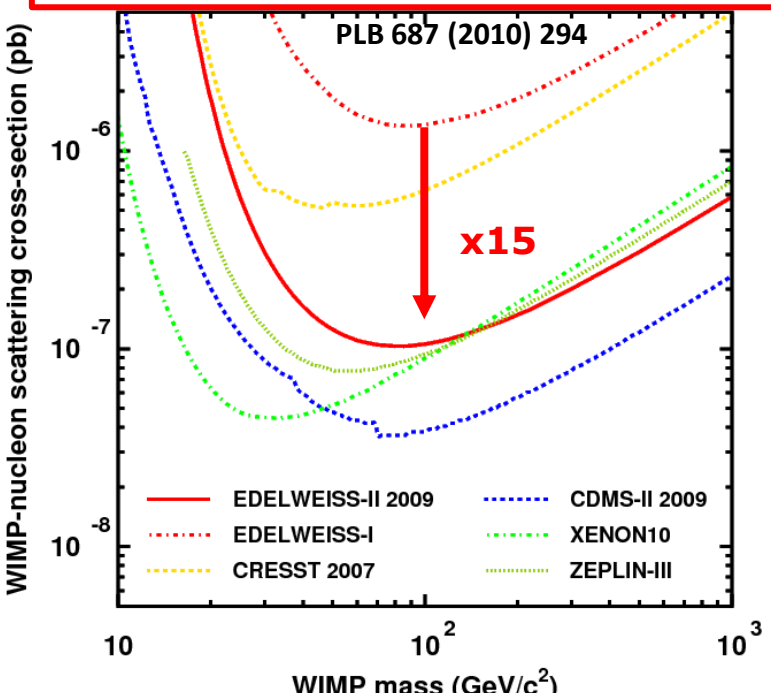
Clear signal in oxygen recoil band. Further analysis ongoing.

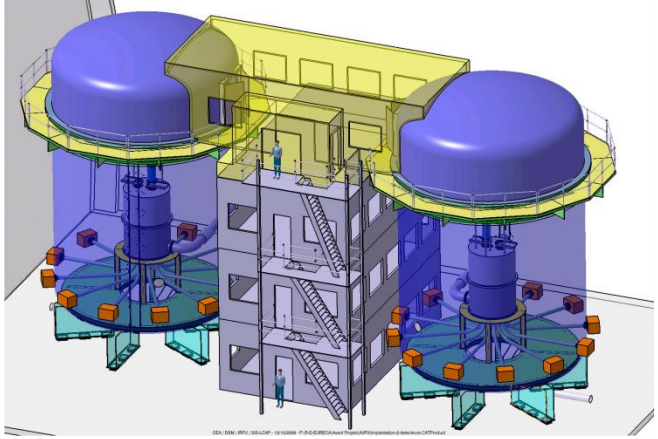
EDELWEISS-II Phonon-ionisation (Ge)

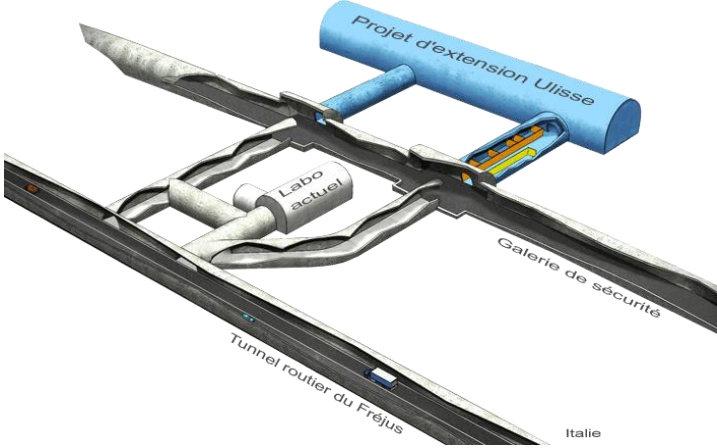


First science run results

- 2009-2010: 1 year physics run
  - 10 ~400 g detectors: 9 for physics, ~2kg fiducial mass
  - **~300 kg.d under analysis (~CDMS)**
- 2010-2011: Additional new detectors with increased fiducial volume
- => six months more data for summer conferences
- => End 2010: ~**9 kg fid mass**
- => Sept 2011: ~**30 kg fid mass**





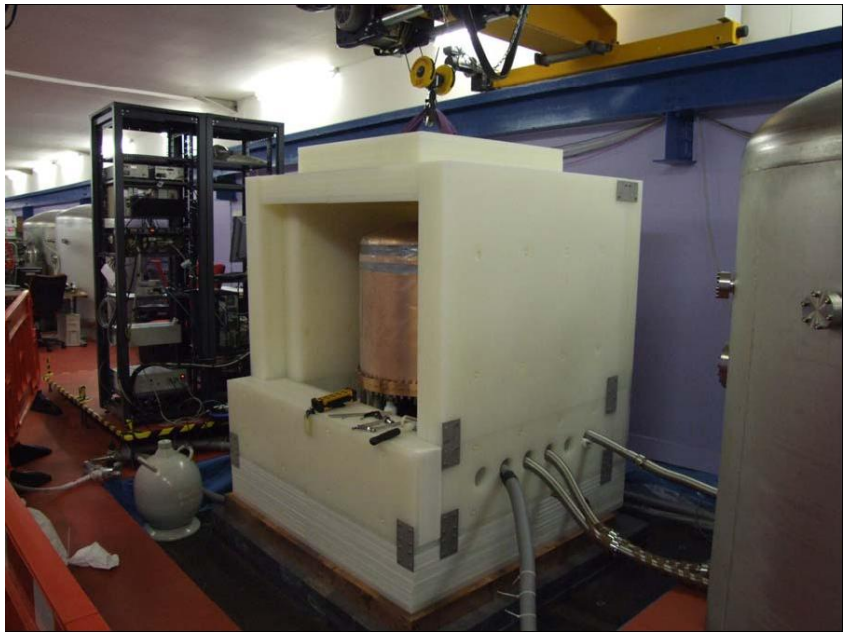


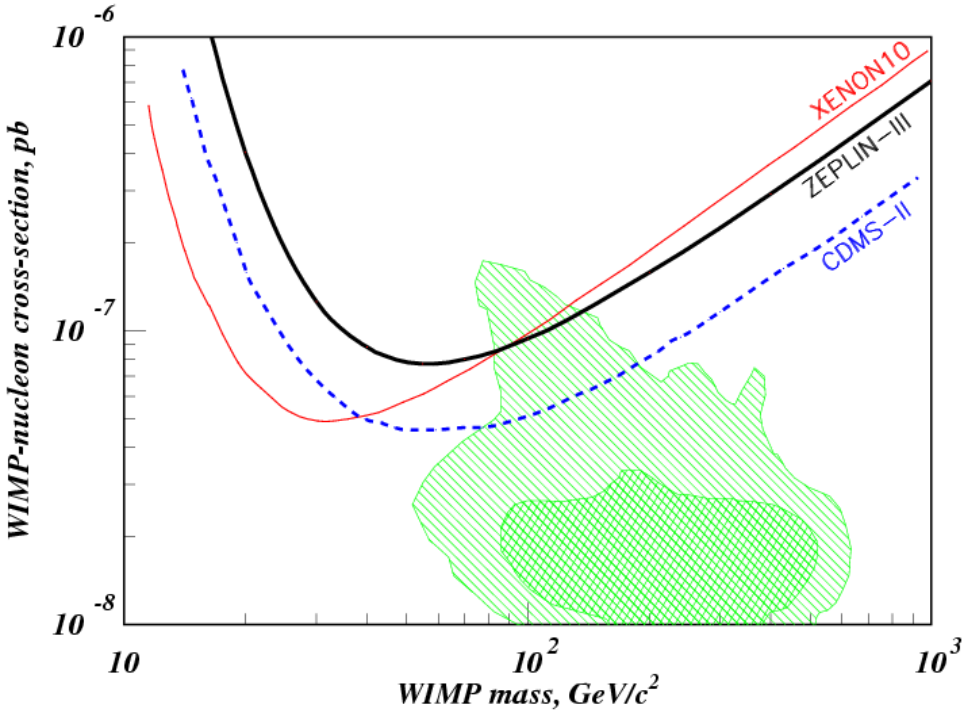
SuperNEMO and EURECA in LSM Extension?

After December 2009:

- H Kraus (Oxf) still EURECA spokesman.
- Oxford focussing on new cryogenic cabling for Edelweiss.
- V Kudryavtsev (Shef) and his team accepted into Edelweiss collaboration with current responsibility for background simulation
- Exciting year: EDELWEISS and CRESST running and collecting data (see summer conferences for new results).
- **UK could remain (and have a leading role) in this with modest funding.**

Zeplin-III scintillation–ionisation (Xe)





83 days continuous run

Feb-May 2008

847 kg.days raw data

V Lebedenko et al. PRD 80, 052010 (2009)

V Lebedenko et al. PRL 103, 151302 (2010)

D Yu Akimov et al, PLB submitted (2010)

First science run results

ZEPLIN III – current status

After December 2009

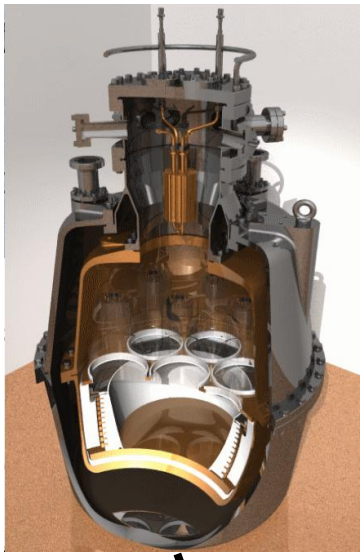
- awarded a 6-month extension in funding to end July, profiled to end October 2010
- teething problems following the completion of its two upgrades with new lower background PMTS and an active veto (including neutron tagging) now been solved
- ZEPLIN-III is currently collecting second run data
- By end October 2010 will have same exposure as first run
- Putting the two runs together, and capitalising on some efficiency improvements, will **improve sensitivity by a factor of just over 3**.

- Zeplin-III will not have reached a background limited sensitivity and another several months running would yield a **factor of 5-10 improvement**
- **No funding, so working instrument will be switched off at the end of October.**

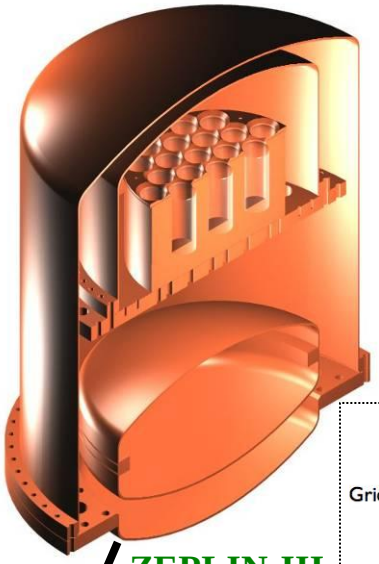
LUX-ZEPLIN

A coming together of global expertise in liquid-xenon dark matter searches from ZEPLIN-II, ZEPLIN-III, XENON10 and LUX300, and others

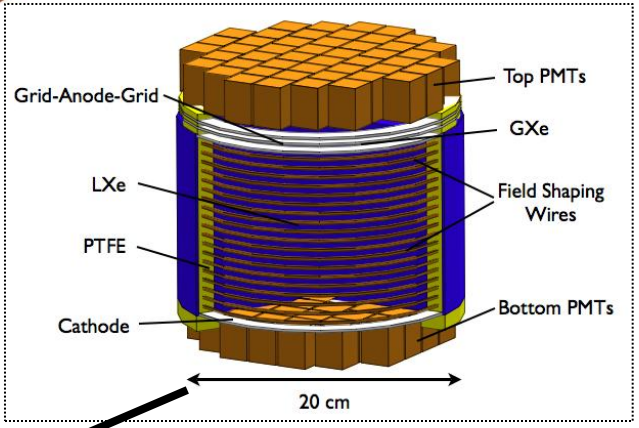
20 Institutes worldwide



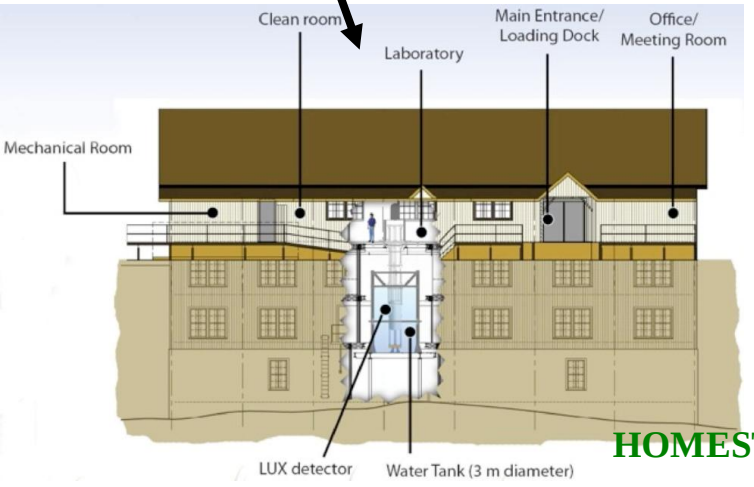
ZEPLIN-II



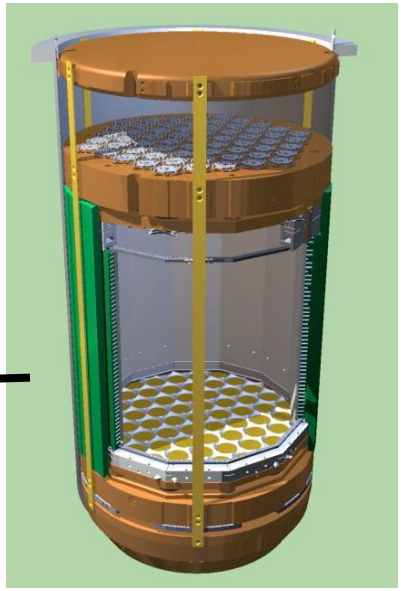
ZEPLIN-III



XENON10



HOMESTAKE SURFACE LAB



LUX300

LUX-Zeplin

After December 2009

- LZS proposal to STFC/NSF/DOE for a new large scale instrument to be deployed in the SUSEL laboratory at Homestake with sensitivities **3 orders of magnitude better** than current world best levels. The UK would be a 50% partner with co-PI status.

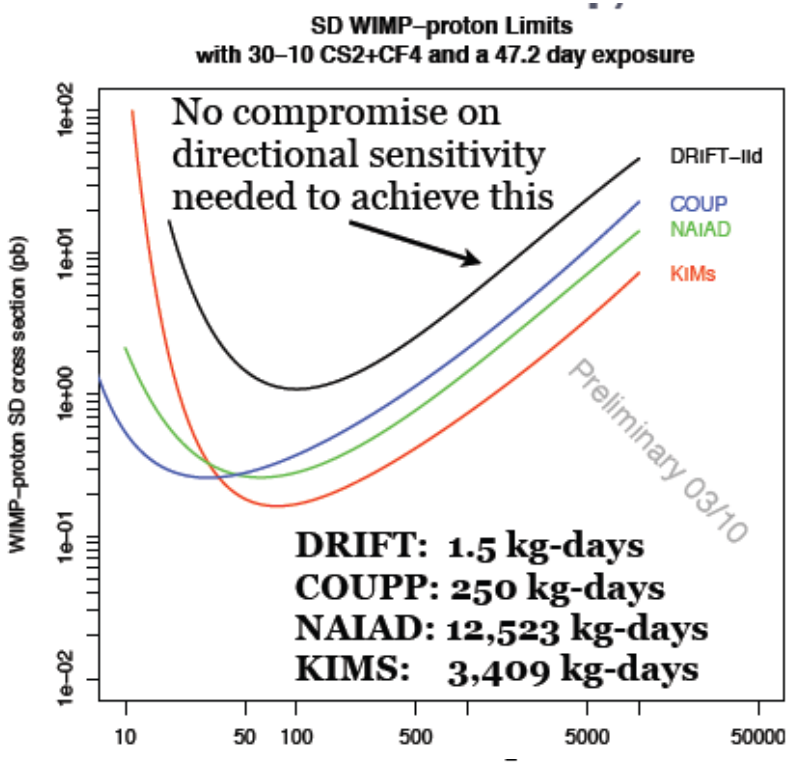
- STFC review of LZS was terminated abruptly following the conclusion that there was **no prospect of funding any new experiment for direct dark matter searches in the foreseeable future**.

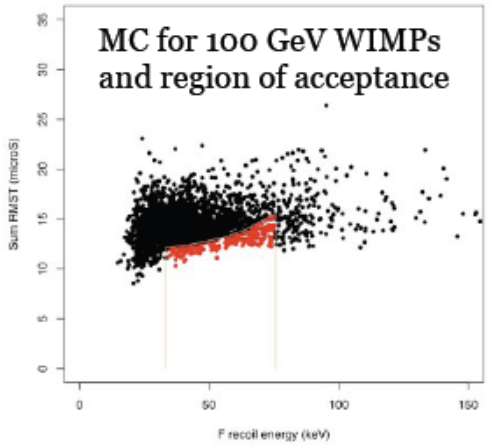
- The ZEPLIN team has de-scoped its immediate plans and, on the suggestion of STFC, put in a proposal to allow our team to become involved with an existing competitor experiment, LUX350 (due to start taking data in 2011) in an exploitation mode.

- This proposal has the support of the LUX collaboration and it is currently under review by the AGP Theory Panel.

DRIFT II – Directional Detection

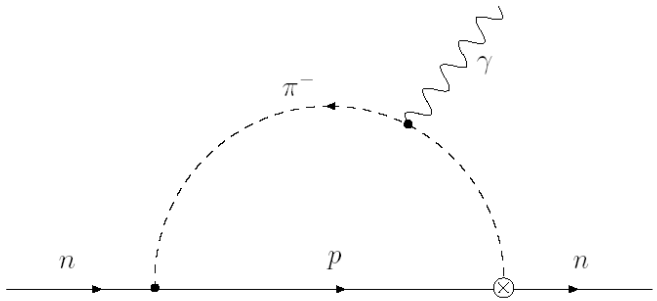
- Vital link to tie WIMP to astronomical origin - Motion of the Earth through a static WIMP ‘halo’
- The Earths rotation relative to the WIMP wind -> Direction changes by ~90° every 12 hours
  - **WIMP Astronomy**
- new **Spin-Dependent** limit is achieved with no compromise on directional sensitivity (other experiments on plot do not have this)
- this is **~x1000** better than any competitor directional WIMP detector (NEWAGE, DM-TPC, MIMAC)
- DRIFT II is now volume limited.... not background limited





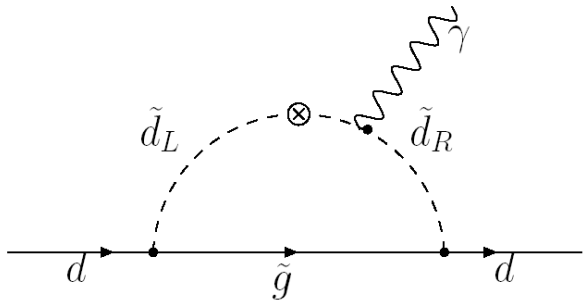
EDM - theory

- EDMs are P, T odd and require flavour conserving CP violation
  - ➔ Crucial test of CPv mechanism outside K, B sector



- SM CPv predicts tiny EDMs (three loops or more)

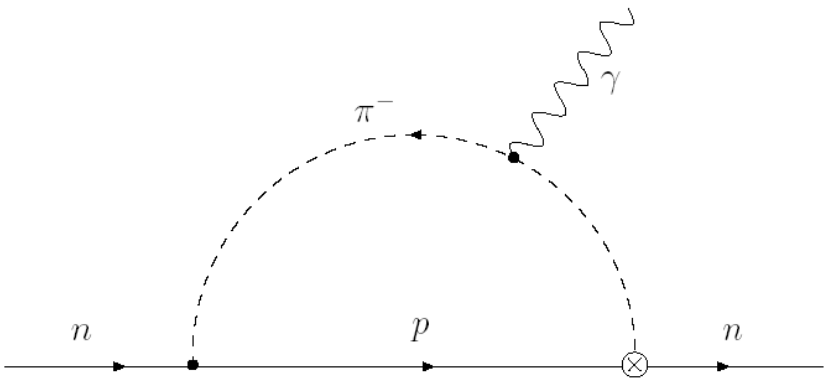
- other models typically happen at one loop and can be much larger e.g. SUSY



$$\kappa_i = \frac{m_i}{16\pi^2 M_{\rm SUSY}^2} = 1.3 \times 10^{-25}{\rm cm} \times \frac{m_i}{1{\rm MeV}} \left(\frac{1{\rm TeV}}{M_{\rm SUSY}}\right)^2,$$

- Tight constraints on models of new physics. For superpartner masses ~few 100 GeV & large phases, predicted nEDM is already 10-100x too large – SUSY CP problem

nEDM and Strong CP problem



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{n_f g^2 \theta}{32\pi^2}F_{\mu\nu}\tilde{F}^{\mu\nu} + \bar{\psi}(i\gamma^\mu D_\mu - me^{i\theta'\gamma_5})\psi$$

CPv phase θ in QCD induces neutron EDM

$d_n \sim 10^{-16}\ \theta$ e.cm $\Rightarrow \theta < 2\times10^{-10}$ rads

Strong CP problem: Why is θ so small?

Peccei-Quinn: Axions?

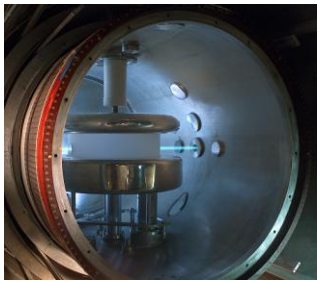
History: nEDM

Factor 10

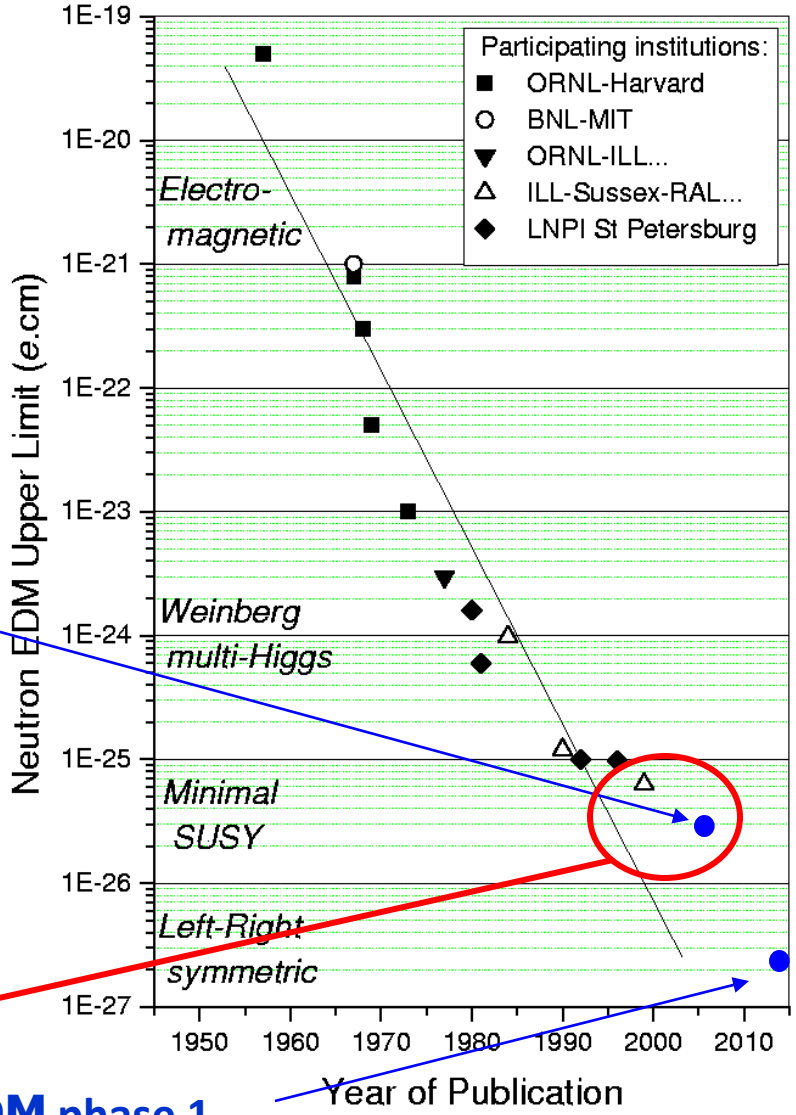
every 8-10 years

Current limit

$|d_n| < 2.9 \times 10^{-26}$ e.cm (90% CL)



C.A. Baker et al., Phys. Rev. Lett. 97, 131801 (2006); hep-ex/0602020



Nearly 500 cites

CryoEDM phase 1

$$d_n^{\mathrm{KM}} \simeq 10^{-32} e \text{ cm}.$$

CryoEDM - Current status

- Discovered last year that, contrary to published findings, the titanium alloy used some of components goes superconducting at liquid helium temperatures
- Currently doing a cryogenic magnetic scan of a provisional replacement vessel.
- This, alongside problems with ageing cryogenics, has caused a **delay of about a year**

- Detector development; much more reliable cryogenic valves; investigation of HV breakdown in helium; data acquisition; simulations of systematic effects.
- Have also demonstrated with a scale model in the lab that can achieve adequate magnetic shielding for experiment at level of 1E-28 e.cm.
- Expect to observe our first neutron resonance in the new apparatus towards the end of this calendar year.
- First results expected in **~2012-3** at **~3E-27 level**
- Finance remains difficult – costs in € - and staffing levels very tight (losing the East-European visiting scientists and no ILL support)

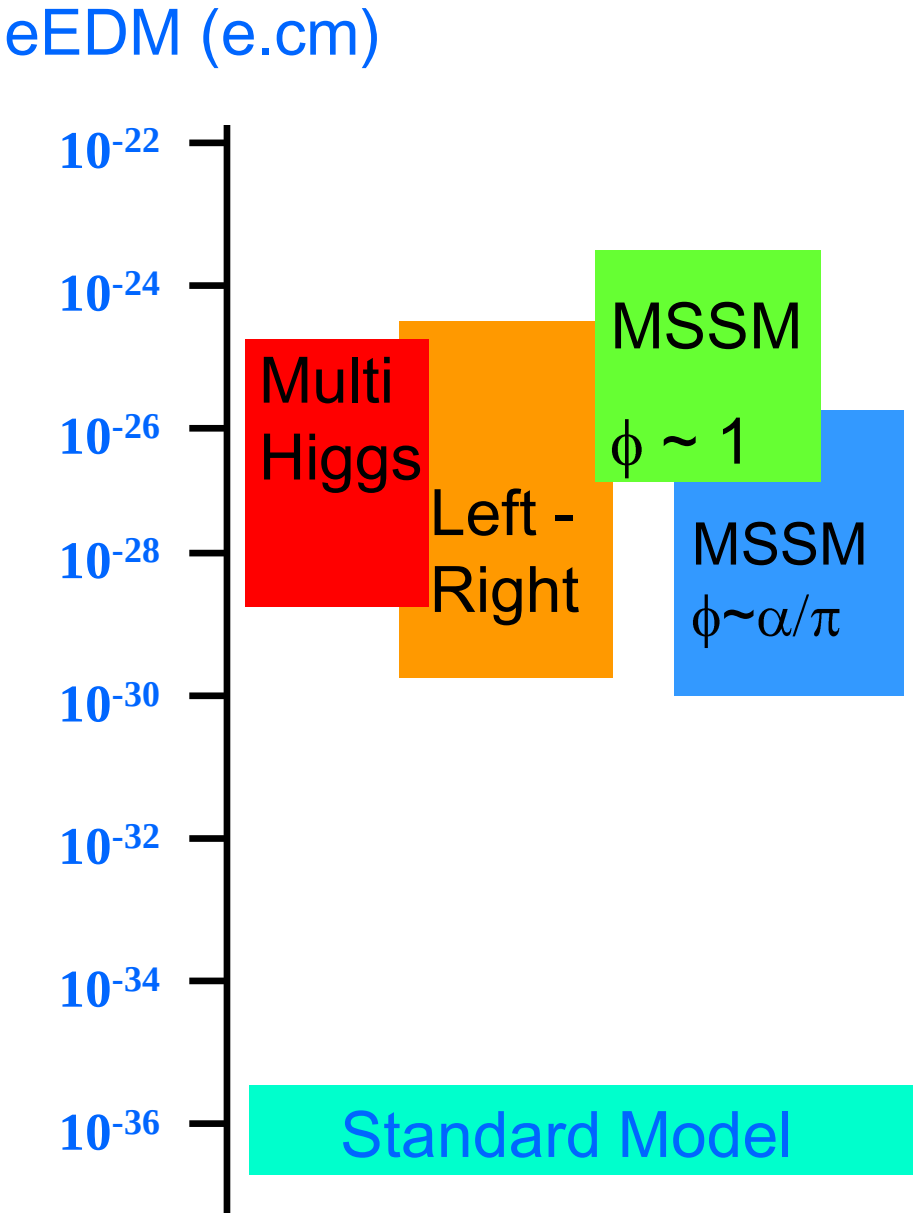
CryoEDM - Future plans

- Expect to observe first neutron resonance in the new apparatus towards the end of this calendar year
- ILL's scheduled year-long shutdown, and the associated move/upgrade to a 6x more intense beamline, anticipated for 2013-14
- Note **may** need increased manpower on site during dismantling/reconstruction
- EPSRC-funded Swansea group collaborating at low level: may grow
- Aim to submit upgrade proposal early-mid 2011 leading to **further factor of 10** improvement by 2017.

Other leading nEDM experiments

Group	# people	Anticipated sensitivity (ecm)	By...
UK: CryoEDM	~25	~3E-27	2013
CryoEDM (new beamline)	~30?*	~3E-28	2017
SNS-EDM	~90	<1E-28?	>2020
PSI (new neutron source)	~50	~5E-27 ~5E-28	2013 2017
PNPI/ILL	~10-20?	~1E-26	2012

Electron EDM



Current Experimental limit: Berkeley, Thallium beam (2002)

$|d_e| < 1.6\times10^{-27}$ e·cm

Standard Model

$|d_e| < 1\times10^{-36}$ e·cm

eEDM – Current status

- YbF beam experiment at **IC** has taken two data sets, each with sensitivity about a **factor of two better** than the current world limit.
- The first was a null data set (applied electric field not reversed) to rule out many systematic errors
- Teething problems with the second data set with the electric field reversed have now been solved by making very minor changes to the apparatus.
- About to re-start second data run (4-8 weeks).
- Expect to measure the eEDM with world-leading sensitivity in summer 2010 **at around ~5E-28 e.cm level**

eEDM – Current status

After December 2009

- STFC support originally to be cut off end October 2010, but now some funding for operations until March 2011.
- Some staff effort still mainly funded by fellowships, but will lose PDRA support, which will be a significant blow to 24 hour running of experiment.
- Plan to apply to EPSRC for a minimal amount of funding, covering technical support and running costs but not our RA or research student.
- Continued STFC funding for project is vital.

eEDM – Future plans

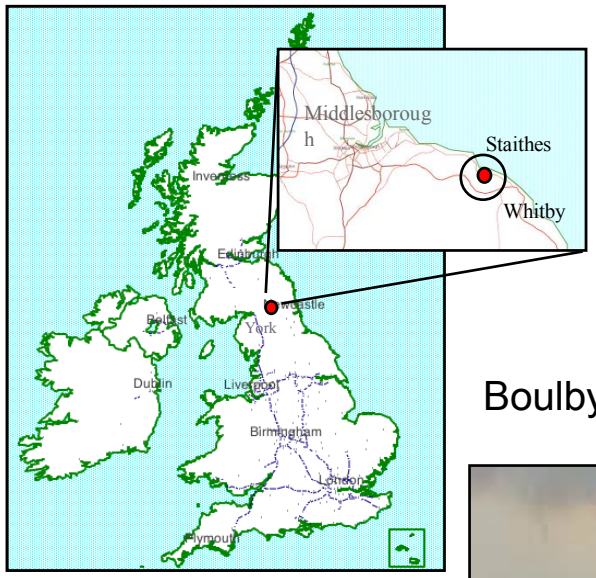
- First upgrade in place to fix some known limitations of current machine would increase sensitivity about a factor of two to around **~2E-28 e.cm** level in spring 2011

- Major change to a new buffer gas source to produce an intense and slow beam of YbF. This his should give a further factor of ten improvement in sensitivity. Source already in operation but need to build a new beamline and incorporate better magnetic shielding.
- First data run with new source anticipated in 2012 with ultimate sensitivity of below **~3E-29 e.cm** level by 2014

- Main competition – Harvard/Yale ThO experiment.
- Preliminary results in 2011/12 and competitive results by 2015.

Boulby Science Facility

- Boulby is a working potash mine in the North East of England. Operated by Cleveland Potash Ltd – a major local employer.
- 1100m deep (2805 mwe giving ~10^6 reduction in CR muons).
- Surrounding rock-salt = low activity giving low gamma and radon backgrounds.



JIF facilities - 2003 .

> 1000 m^2, fully equipped underground 'Palmer lab'

> Surface support facility.

Boulby Mine

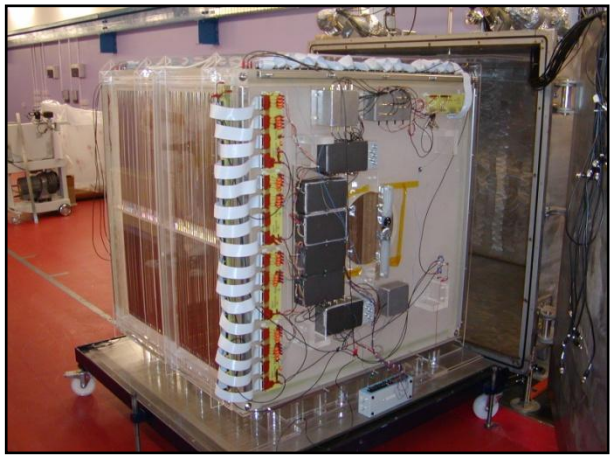
Current Boulby projects (2010)

ZEPLIN-III

2 phase (liquid/gas) high field Xenon WIMP dark matter detector. Installed 2007- now operating

DRIFT-II

Low pressure gas TPC directional DM detector. Installed – 2005. Continuing R&D and operation



SKY-ZERO

Danish/UK expt to study the effect of cosmic rays on aerosols & cloud production. Phase 1 near completion.

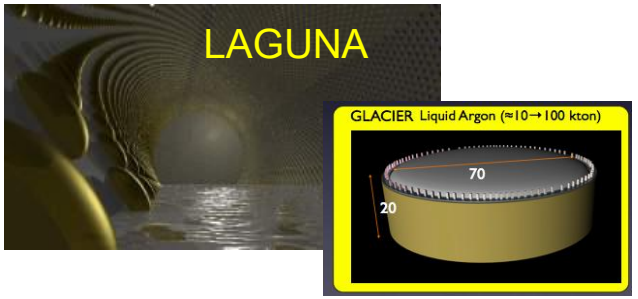
Low-background material screening

High sensitivity low-background Germanium detector and purpose built Rn emanation

Boulby Update & Future

Latest Boulby News:

- June 2009: New facility manager Sean Paling
- Boulby mine and the Underground facility awarded ISO18001 national H&S management award.

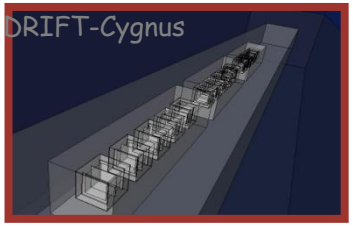


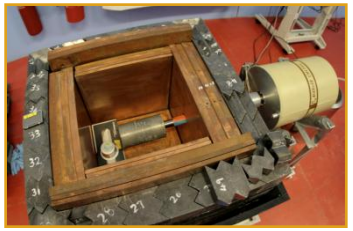
ELENA

ILIAS-next

Future Science Aims / Plans

- Continued hosting / supporting **Dark Matter** searches (DRIFT, ZEPLIN-III and beyond)
- Development of UK centre of excellence for ultra sensitive **low activity material screening**
- Development of **geoscience studies** – (local government funding already secured for geology/geophysics studies.)
- Continued involvement with 'ILIAS-type' **EU underground lab networking.**
- Pursuit of possible future small and large projects – **e.g LAGUNA, ELENA. SKY-II**





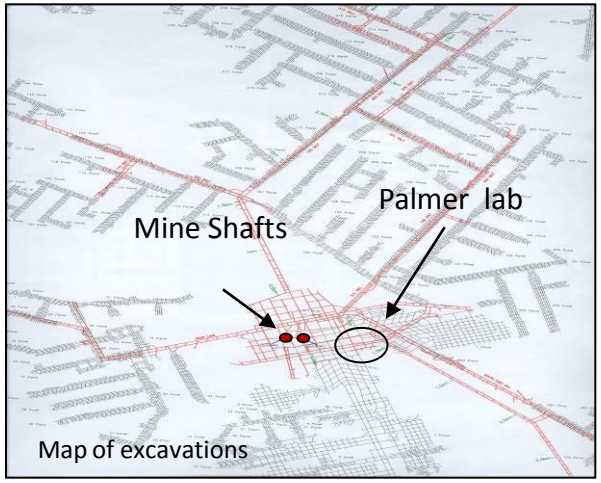
Future expansion?

- Plenty of space and low cost for future excavations @ Boulby
- Proven track record for operations
- Ongoing strong local support

Future Development?

- Boulby compares WELL with EU and world sites: depth, backgrounds, local support, running costs and expansion potential.
- It is an active contributor in both ILIAS and ILIAS-next EU lab programmes.
- Tried and tested as a site for supporting science (from 1988 – today).

- The potential for expansion @ Boulby is excellent.
- Space available in existing lab & lots of existing tunnels to exploit. New tunnels are cheap to cut.
- New and deeeper rock types available (harder rock – bigger labs).



STRONG local support

CPL (the mine owners) are supportive of pursuing expansion of physics and science hosted.

CPL hosting gives the UK a WORLD CLASS facility at relatively low cost

Summary-I

- **Dark matter** and **EDM** experiments directly address key science questions
  - ✓**What is the universe made of?**
  - ✓**Why is there more matter than antimatter?**

  in a complementary way to accelerator based experiments or astronomical observations

- UK plays a leading role in cryogenic and liquid noble gas dark-matter searches
  - While funding continues, **ZEPLIN-III**, **CRESST** and **EDELWEISS** continue to take data with **potential for world leading sensitivity in 2010/2011**
  - The search for dark matter is an active area worldwide and as new global consortia form (**EURECA** and **LUX-ZEPLIN**) continued involvement in **both cryogenic dark matter searches and in liquid noble gas detectors is the highest priority**

Summary -II

- Any observation of a neutron or electron EDM is Beyond the Standard Model

- The UK leads forefront experiments on both neutron and electron EDMs and owns the world leading limit on the neutron EDM.

  - **CryoEDM** is currently being commissioned; results are expected in 2012/13 at the sensitivity level **~3E-27 e.cm** with plans for an upgrade leading to further factor of 10 improvement by 2017.
  - **eEDM** expects to measure the electron EDM with world-leading sensitivity in summer 2010 at around **~5E-28 e.cm** level, improving to **~2E-28 e.cm** by 2011. A planned upgrade to source and beamline should lead to an ultimate sensitivity of below around **~3E-29 e.cm** level by 2014

- There is scope for expansion at the Boulby Science Facility into hard rock to accommodate low-background underground R&D facilities and space for (a) large underground detector(s) in a low background environment.