

Sean Paling. STFC  
Director Boulby Lab

ZEPLIN-III @  
Boulby



Update for the Boulby  
Deep Underground  
Science Facility....



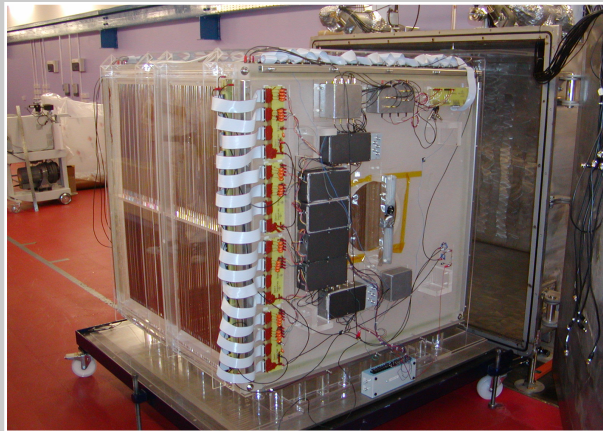
SKY - aerosols, cosmic rays &  
climate



# The Search for Dark Matter



NAIAD



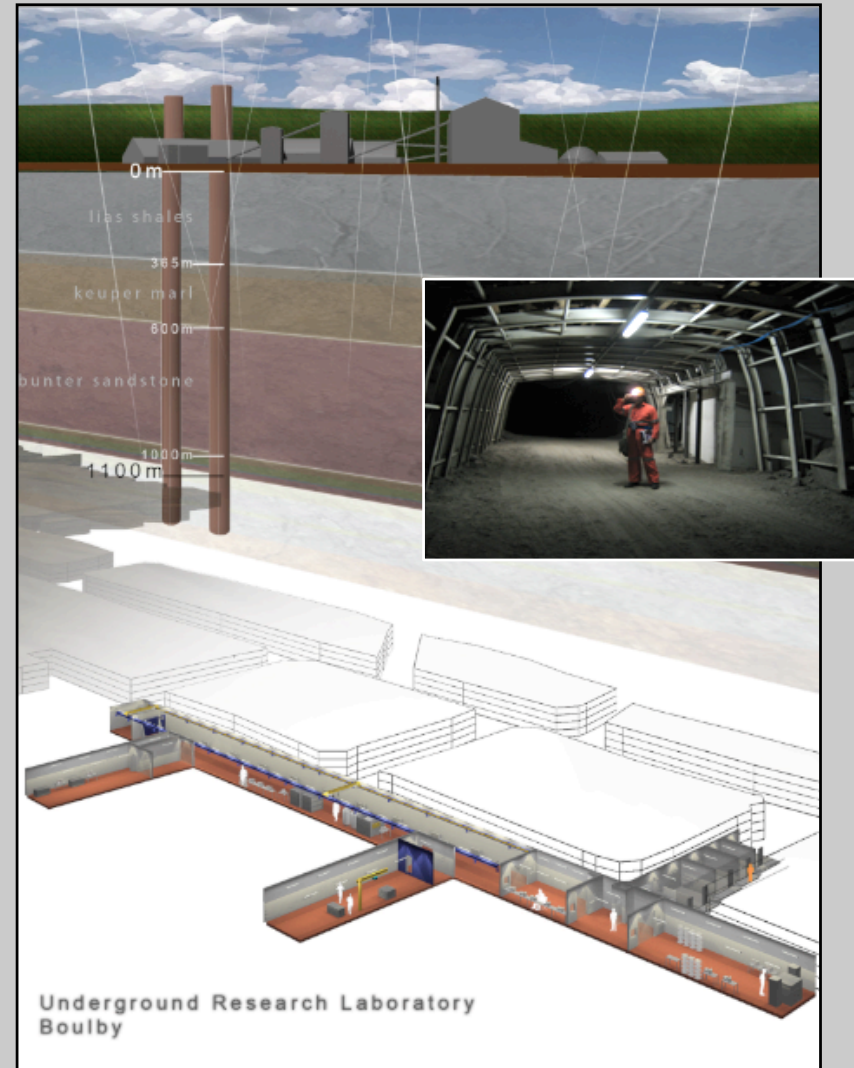
DRIFT-II

**ZEPLIN-III Collaboration:**  
Imperial College London,  
Edinburgh, Rutherford Appleton  
Laboratory, LIP-Coimbra, ITEP-  
Moscow

**DRIFT-II Collaboration:**  
Sheffield University, Edinburgh,  
Occidental College, University of  
New Mexico, Colorado State.



ZEPLIN-III



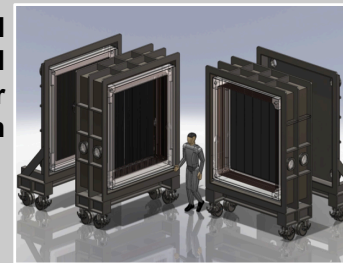


# Future Science @ Boulby

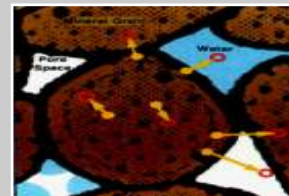
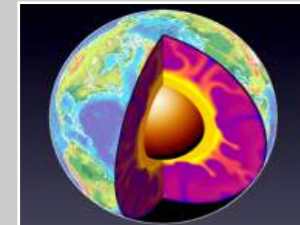
- **NEW - €850k over 3 years (2011-2014) funding secured specifically to develop **inter-disciplinary science** at Boulby.**
- ‘Low- background’ projects...
  - SKY Cosmo-climatology project:
  - Ultra-low Background Gamma Spectroscopy:
- ‘Other’ deep underground projects...
  - Extremophiles, geomicrobiology and astrobiology.
  - Carbon Capture & Storage
  - Muon tomography for geological survey.
  - Etc etc etc...

## Astro-particle Physics and **BEYOND...**

DRIFT-III  
directional  
Dark Matter  
search



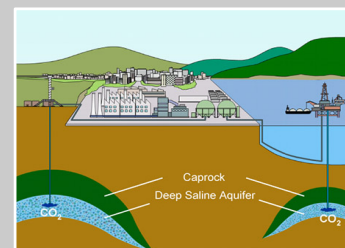
Large-scale rare-event studies?



Geology, Geochemistry,  
Geo-microbiology

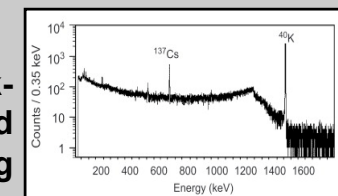


Climatology,  
atmospheric physics



Carbon  
Capture

Low back-  
ground  
counting





# This Talk.....

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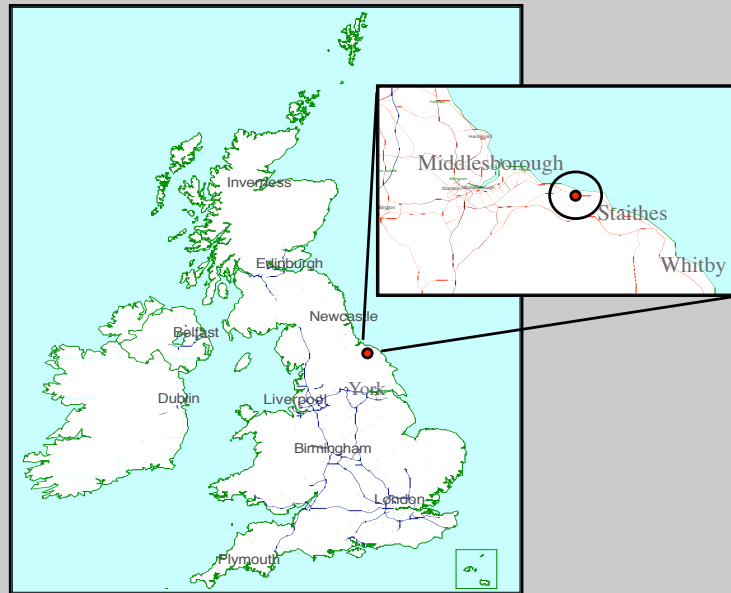
## Update for the Boulby Deep Underground Science Facility...

- Boulby Mine and the ultra-low background science facilities...
- Science Studies at Boulby – Current and future...
  - ZEPLIN-III, DRIFT-II → DRIFT-III
  - SKY: cosmic rays, aerosols & climate
  - Ultra-low background gamma spectroscopy
  - Misc Geo-science studies
  - Future large-scale rare event studies...

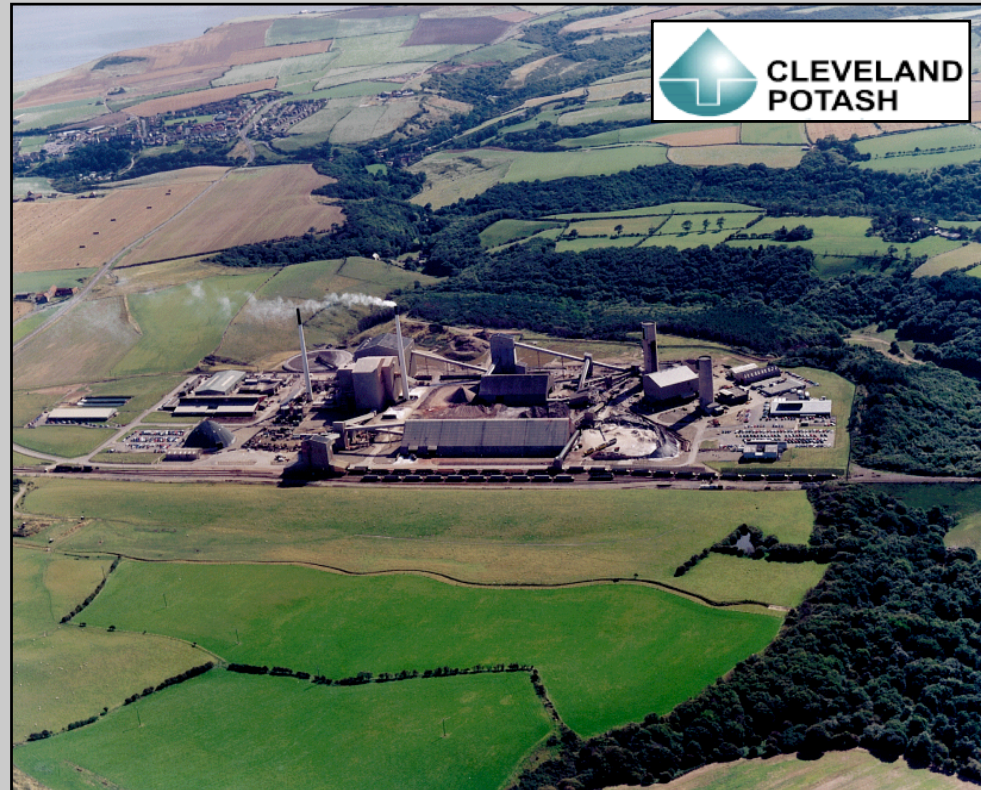


# Boulby Mine

A working potash and rock-salt mine on the North East of England.  
Operated by **Cleveland Potash Ltd.**  
**Major local employer** ~1000 direct and 4000 indirect employment.



Deepest mine in Britain – 1100m deep (2805mwe) – **Cosmic ray muon flux reduced by  $10^6$**



Potash



View from Staithes

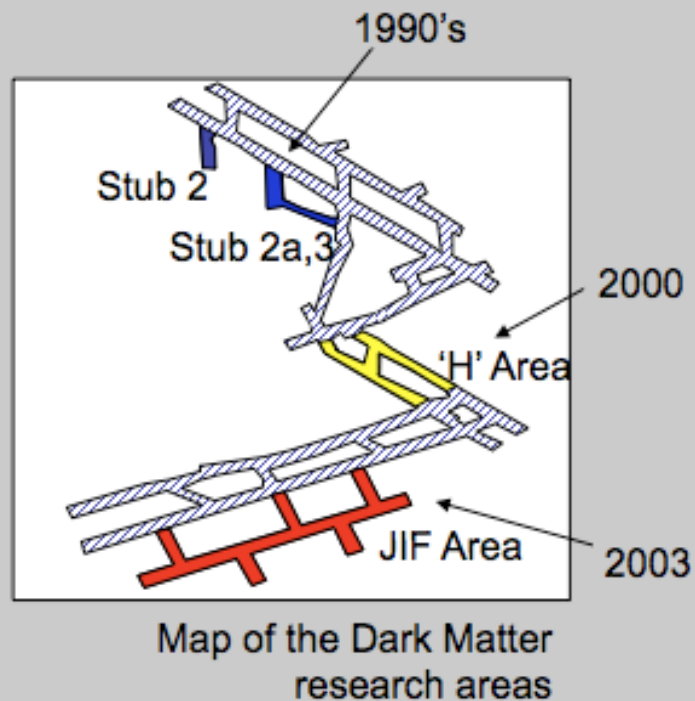


# Boulby Mine

Over 40 kms of tunnel mined each year (now >1,000kms in total)

Long lived roadways cut in salt (NaCl) – giving access to potash (KCl) levels just above

Boulby salt is very **low in natural radioactive backgrounds** (U, Th, Rn)





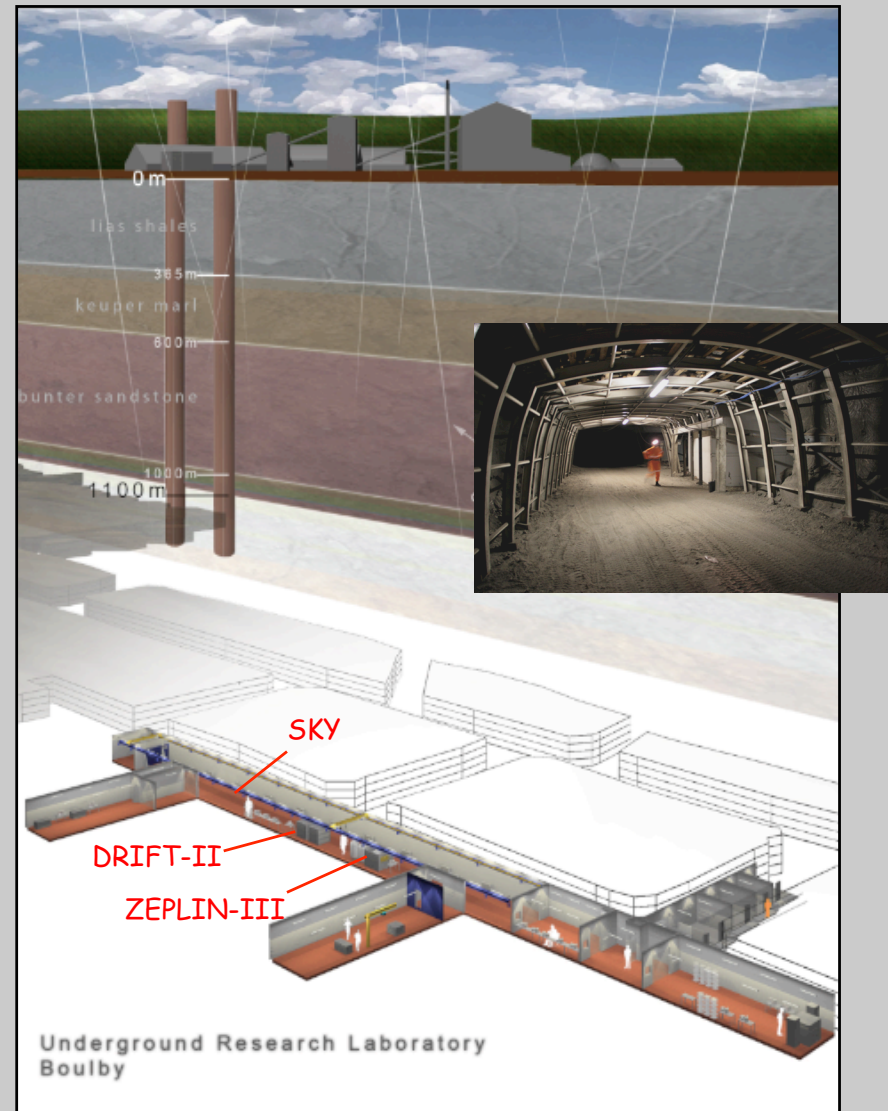
# Boulby Science facilities

**'JIF' Science Facilities (opened 2003).**

- **'Palmer Lab'**: a 100+m, fully equipped underground lab. Power, internet and telephone communications, lifting, air conditioning / filtration, clean room.
- **'John Barton' surface facility**: Workshop, facility monitoring, office and administration, PPE, storage, chemistry lab, changing rooms.



Palmer Lab



# Underground Facilities & Science



Ultra-low BG Ge detector

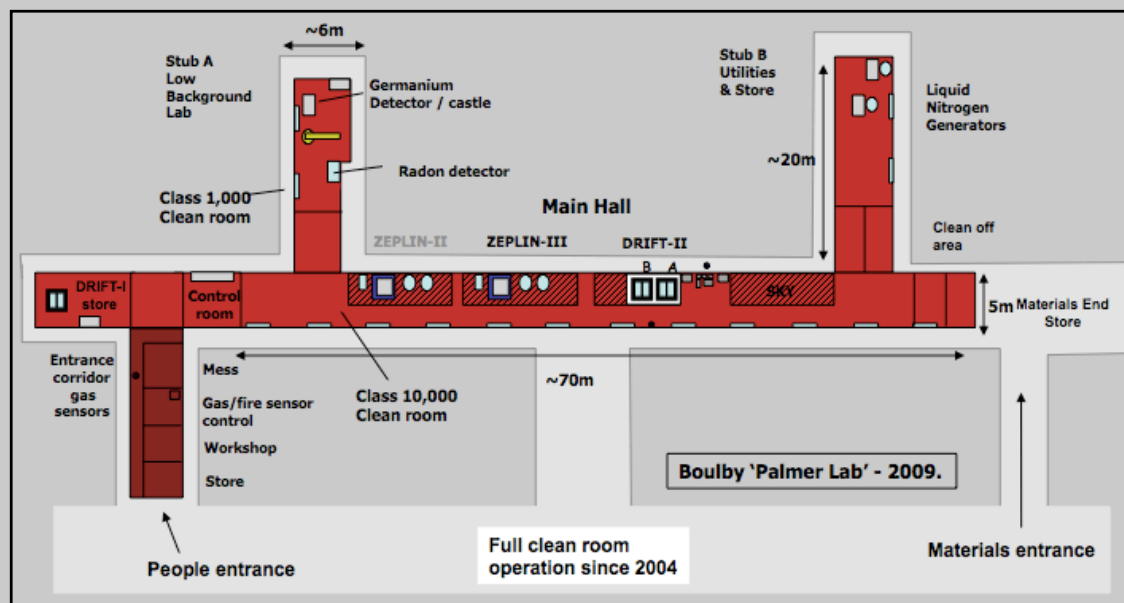


ZEPLIN-III

Cryogenerators



SKY



DRIFT-II



# What Makes Boulby Special?

## Requirements for an underground laboratory...

### Low Backgrounds

- Deep (to shield from cosmic rays)
- Low background rock/lab (and/or adequate shielding)

1.1 km deep (2,805 mwe)  
CR muons attenuated by  $\sim 10^6$

Salt = low in U/Th  
→ Low gamma & neutron backgrounds  
→ Low Radon ( $< 3 \text{ Bq/m}^3$ )

### Plenty of Laboratory space

$> 1000 \text{ m}^2$  existing lab space & v.good potential for expansion.

### Easy access for equipment

Via mine shaft (5m diam. –  $2 \times 2 \times 2 \text{ m}$  cage)  
+ Transport underground

### Proximity of services / civilisation

20 min → Whitby, Saltburn  
1 hr → York, Leeds, Middleborough  
 $< 5 \text{ hrs}$  → London, Manchester, **Glasgow**

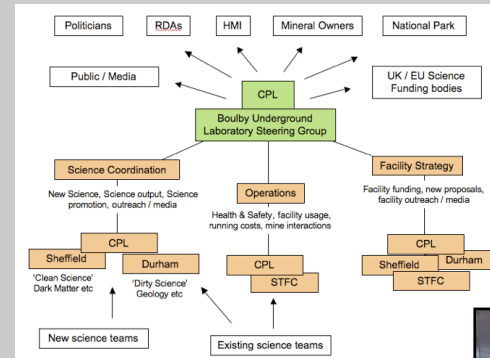
### Good infrastructure + support

- JIF Underground & surface facilities
- **Wide-ranging support from mine operators (Cleveland Potash Ltd)**

**A unique science / industry partnership**

# Facility management & operation

- 40 scientist (UK & abroad) directly using site (100 more widely involved)
- Facility operations managed by **STFC** (Sean Paling, Louise Yeoman + 2 P/T)
- Health and safety all in line with **STFC** (and CPL / mine inspectorate).
- Finance and IT systems through **STFC / RAL**
- Facility strategy coordinated through **Boulby Steering Group** (STFC, Sheffield, CPL, Crown).
- Operations managed through weekly Boulby Operations Meetings (BOMs)
- CPL provide wide ranging operational support (Underground site safety, medical, electricity & water supply, transportation)



## PROJECT RESOURCE SUMMARY (UPDATED)

Project Name:

Contact Person/Institute:

Brief Description:

### Summary of resource requirements from the facility:

Space requirement, Width/Depth/Height	3.0m / 10.0m / 3.0m
Crane requirement (xyz), weight and height	xyz/ 2 tonne / 3.0m
Electrical power/voltage/phase requirements	240V single phase 14 kW
Transportation requirements (Installation & Normal operation)	Installation: Purifier, 2x dump chamber, target, cryogenerator, chiller, DAQ, computing Relocation of lead castle from Sub 2 to IF (80 tonnes?). Operations: None
Maximum tolerable transportation shock	0.5g
Experiment team size underground (installation/operation)	Installation: 4 Operations: 4
Cryogenic requirements (LN <sub>2</sub> )	During cooldown: 150l During emergency recovery: 40l



# Science @ Boulby

- ZEPLIN-III, DRIFT-II → DRIFT-III
- SKY: Cosmic Rays, aerosols & climate
- Ultra-low Background Gamma Spectroscopy
- Misc Geo-Science projects...
- Future neutrino & rare event studies...

# Dark Matter Experiments – April 2011



## ZEPLIN-III

*Imperial College, Edinburgh, RAL,  
LIP-Coimbra, ITEP-Moscow*

**2 phase (liquid/gas) high field Xenon WIMP dark matter detector.** 31 PMTs immersed in ~8.5kg liquid target. High purity Cu construction. Pb shielding & active veto. Installed 2008. FSR (3months – 847kg.d). Running until May2011.

**2<sup>nd</sup> science run completed (>300 day) giving world-class sensitivity. Results out (very) soon**



## DRIFT-II

*Sheffield, Edinburgh, Occidental  
College, New Mexico, Colorado State*

**Low pressure gaseous TPC directional WIMP dark matter detector.**

1m<sup>3</sup> (fiducial) negative ion drift TPC, 167g CS<sub>2</sub> target. Dual 0.5m<sup>3</sup> drift vols with MWPC readout. Installed – 2005. US (NSF) funded to end 2011. 3 year extension bid now in to NSF – **DRIFT-III**

**Now running with CS<sub>2</sub>/CF<sub>4</sub> mix - allowing world-class WIMP-proton SD limit setting**



# Dark Matter Experiments – June 2011



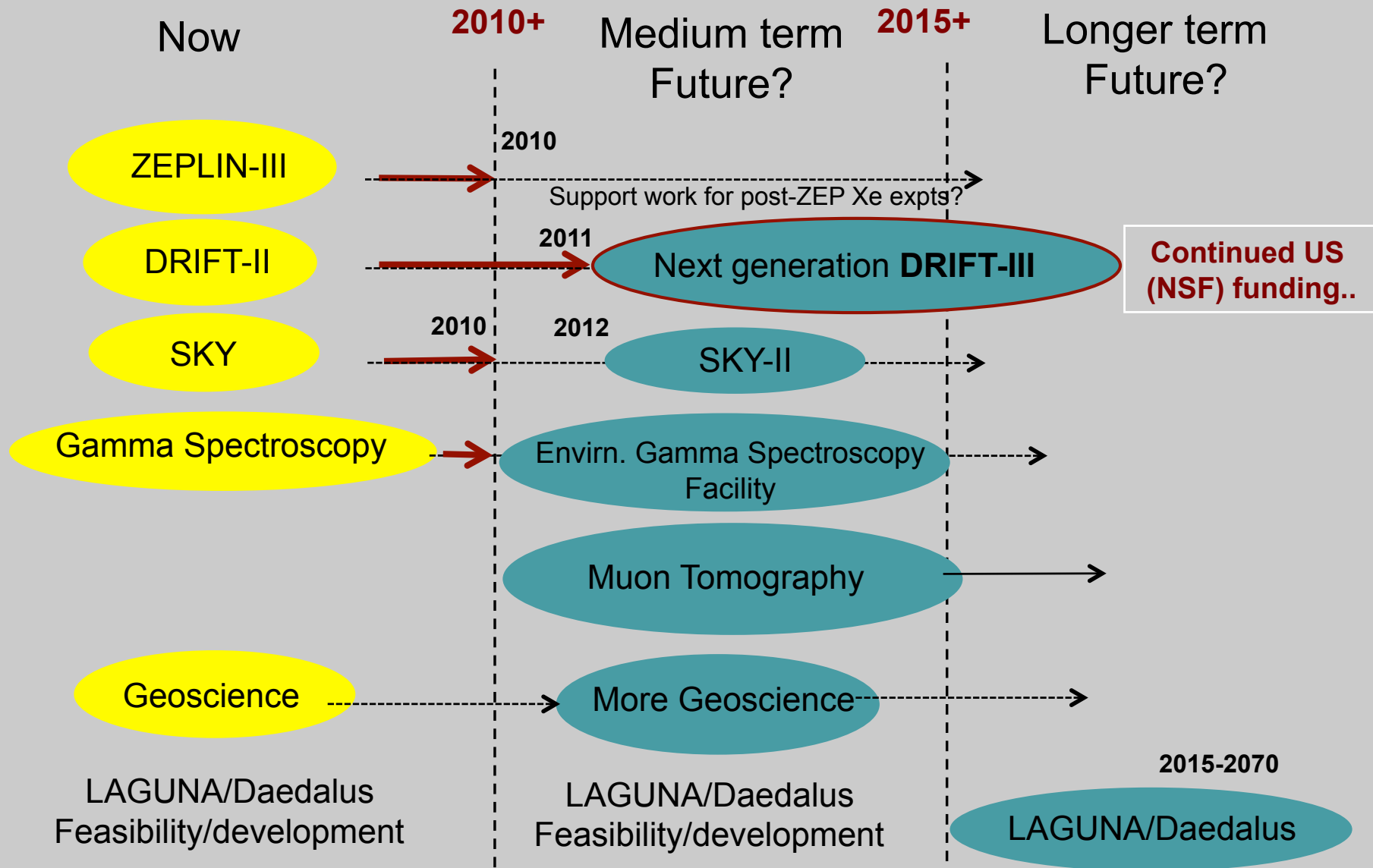
ZEPLIN-III decommissioning



DRIFT-II R&D and limit-setting



# Future Science @ Boulby?



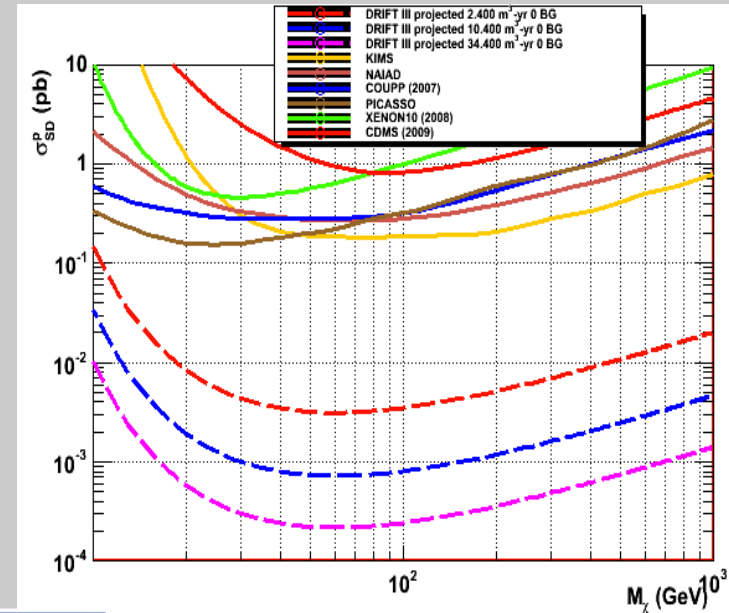
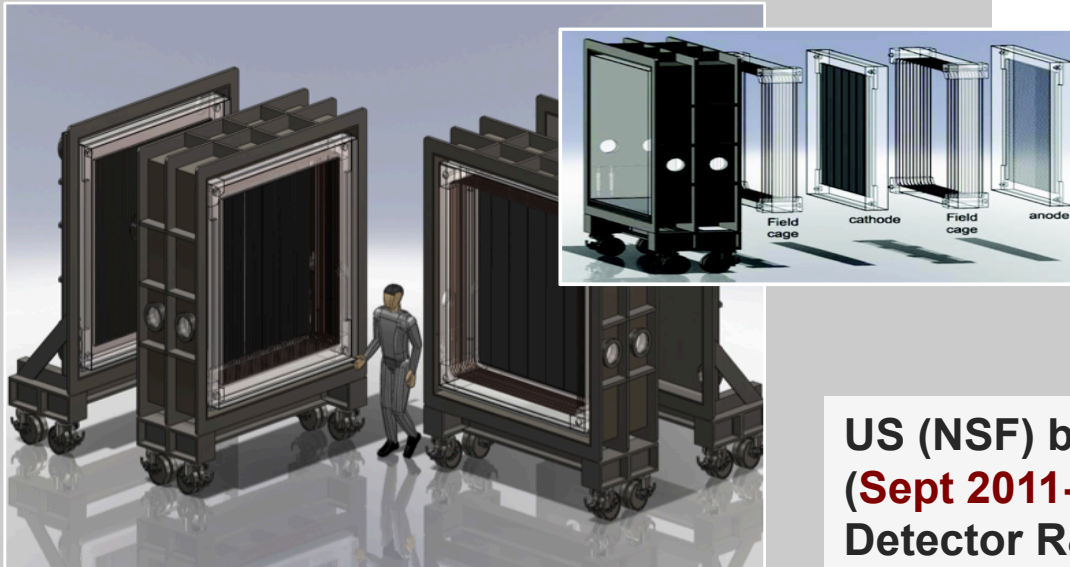


# DRIFT-III

## Next-generation **Directional** Dark Matter detector @ Boulby

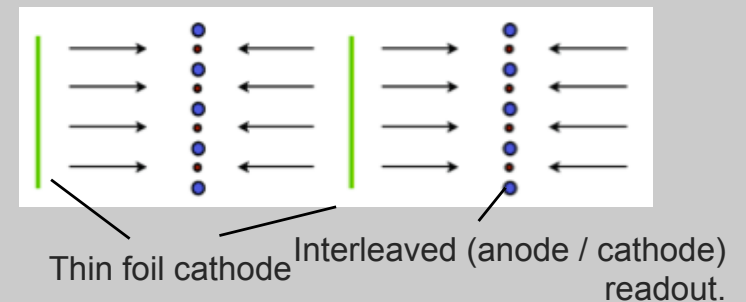
Negative Ion DRIFT TPC using low pressure gas ( $\text{CS}_2/\text{CF}_4$ ) target

- 6 DRIFT volume (anode-cathode) segments per vacuum vessel.  $2 \times 2\text{m}$  planes. 50cm drift.
- $24\text{m}^3$  fiducial volume. 4kg fiducial mass ( $\text{CS}_2$ )
- Thin ( $0.9\mu\text{m}$ ) film cathode. Single plane (interleaved anode / cathode) MWPC.
- 24(+) increase in sensitivity vs. DRIFT-II



SD limits

2.4  $\text{m}^3\cdot\text{yr}$   
10.4  $\text{m}^3\cdot\text{yr}$   
30.4  $\text{m}^3\cdot\text{yr}$



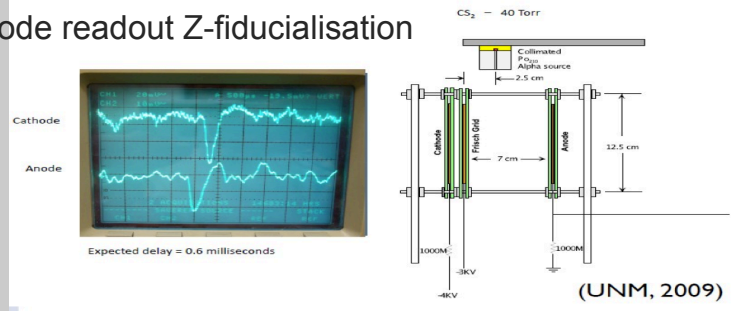
Thin foil cathode

Interleaved (anode / cathode) readout.

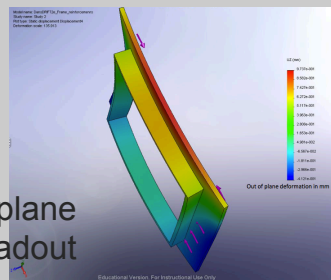
US (NSF) bid submitted for 3 year programme (**Sept 2011- 2014**). Site infrastructure, Detector R&D, construction, operation.

# DRIFT-III

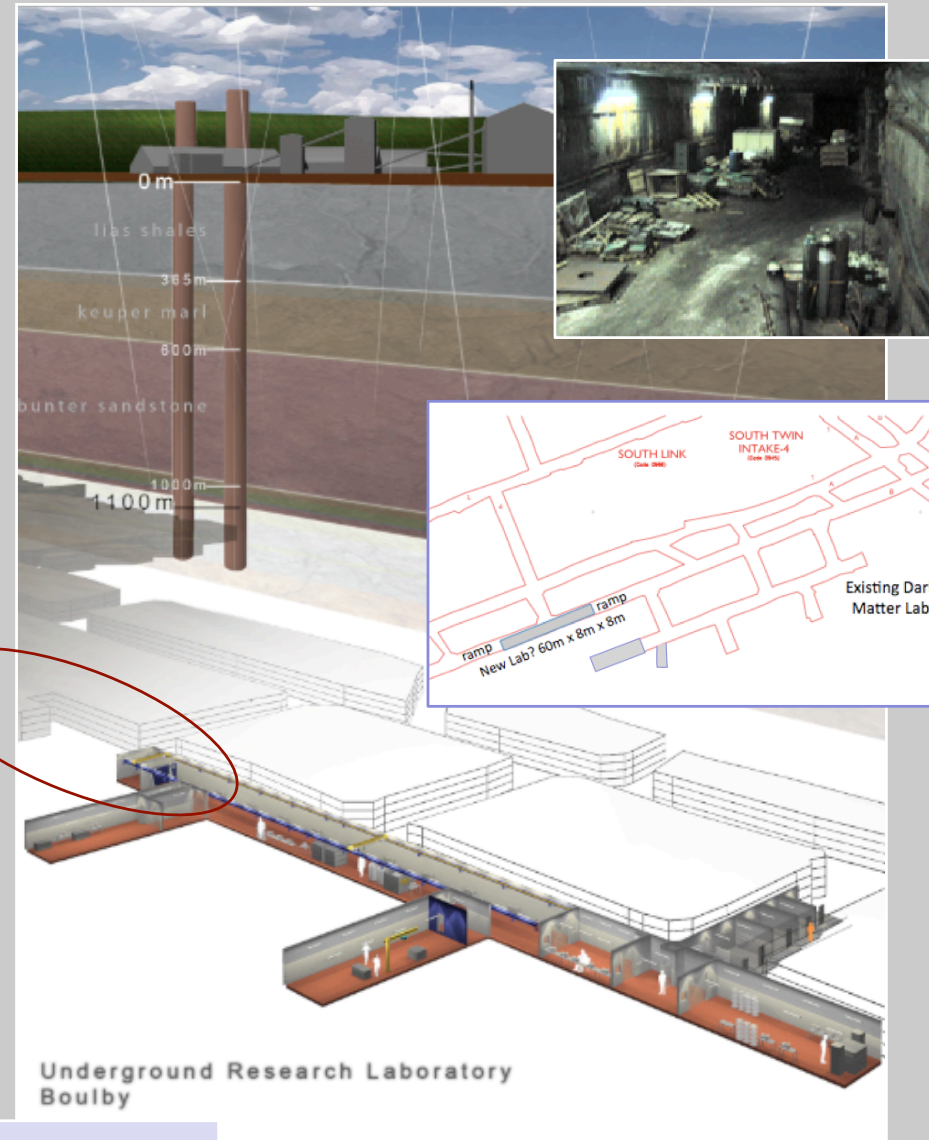
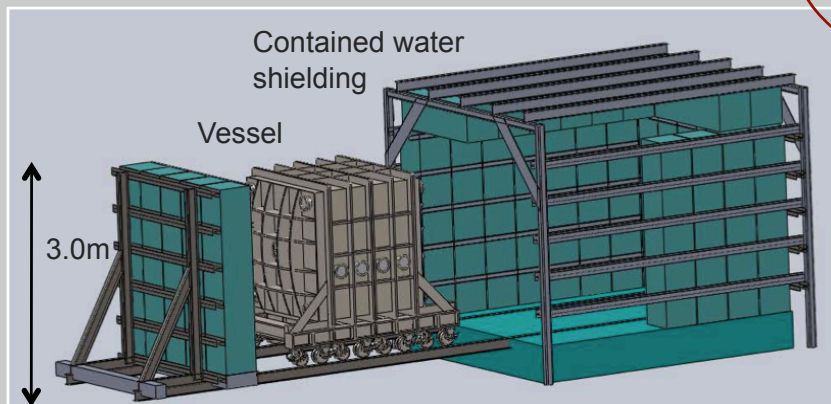
## Cathode readout Z-fiducialisation



Thin film cathode



Single plane readout



Construction & Operation: 2011-2014



# The SKY Project

An Danish/UK (**EPSRC**) study of the effect of ions on aerosol nucleation in the atmosphere - the 1<sup>st</sup> study in an ultra-low background environment.



SKY @ Boulby

**SKY-ZERO:** 2008-2010. Primary science runs @ Boulby completed. **2 paper published – 1 more submitted.**

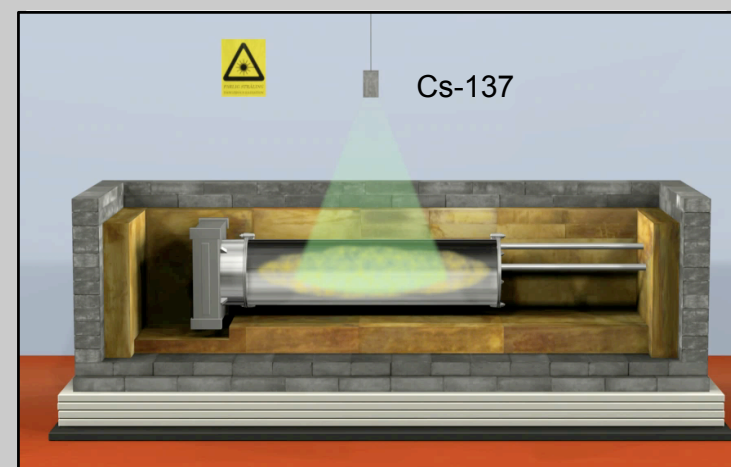
**Next steps:** A bigger & better SKY experiment (**SKY-PLUS?**) for 2012-2014. **Construction funding already secured.** Wider UK collaboration & funding now being sought (NERC).

**Participants:** *Sheffield University, Danish National Space Institute.*



**Important in climatology:** Ionisation from cosmic rays may have an influence on cloud production and mean cloud cover

**Does atmospheric ionisation play a role in aerosol formation and climate?**



# The SKY Project

## Results so far...

SKY-ZERO shows that ionisation IS important...

- Aerosol nucleation rate increases with ionisation present.
- There is also a 'neutral' component at work

*Submitted to  
PNAS - 2011*

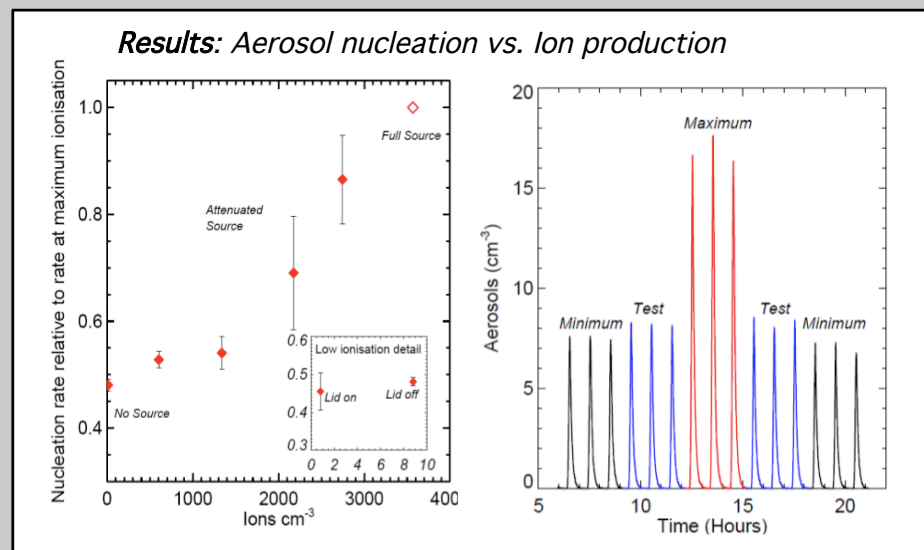


Fig. 2: An impression of SKY-II – a double-skinned chamber with an internal baffle matrix

**Next steps:** A bigger & better SKY experiment (**SKY-II**) for installation at Boulby 2012-2014.

**£300k** construction funding already secured (Danish Space Institute).

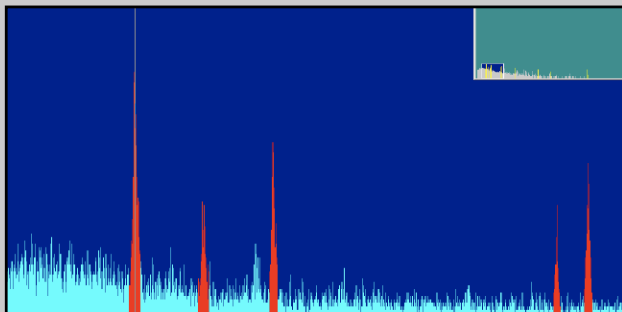
Wider UK collaboration & funding now being sought.



# Gamma Spectroscopy

## Ultra-low background gamma spectrometry for material selection & **Environment studies**

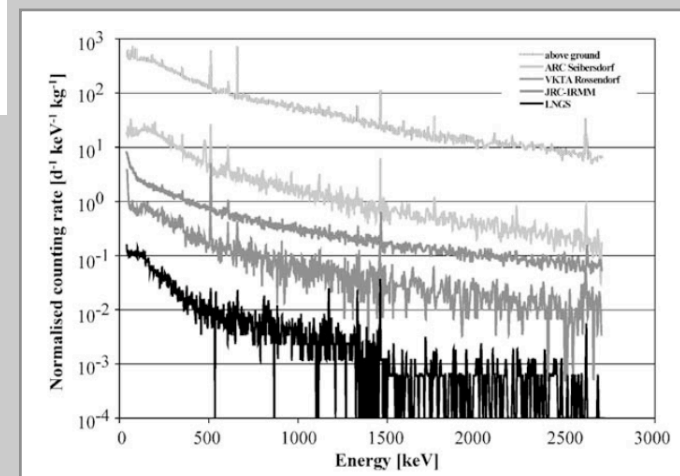
Boulby has a low background, high sensitivity, 2kg Ge detector used for material activity measurements. Sensitivity of  $\sim 1\text{-}10\text{ppb}$  U/Th for typical samples.



Gamma spectrum from ZEPLIN-III PMTs



Deeper = better. At 1.1km below ground at Boulby backgrounds are reduced by a factor **1000**.



# Environmental Spectroscopy

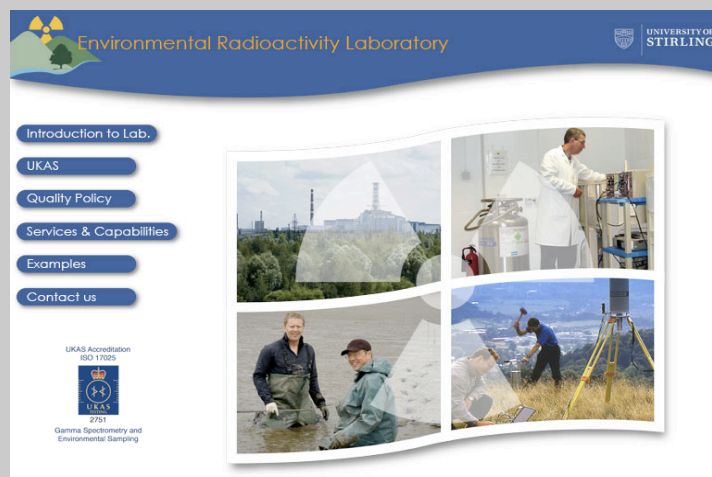


## UK activity:

- Radioactive tracers for atmospheric & ecosystem processes
- Radio-dating: C-14, Pb-210, Si-32
- Dosimetry in the environment
- Marine radioactivity
- Water monitoring

**Plenty of activity in UK** – Many studies limited by sensitivity of instruments...

UK Soil and Herbage Survey (UKSHS): Environmental Radioactivity



The gamma spectroscopy facility at the **Modane underground laboratory**.



**13 detectors - 9 used for environment, industry & defence studies**

**What next? - Towards a national ultra-low background gamma spectroscopy facility - for industry, defense & the environment...**

- Collaboration / Networking
- Pilot studies underway (Glasgow, Manchester)
- Submit proposals...



# Other Underground Projects

Continuation and expansion of existing interdisciplinary 'Geoscience' projects underway at Boulby...

## Improved mining technologies

E.g. enhanced extraction but reduced subsidence?

## Rock deformation studies

E.g. salt deformation and oil reservoirs?

## Carbon Capture and Storage (CCS)

E.g. how can we store waste (e.g. CO<sub>2</sub>) underground?

## Seismology

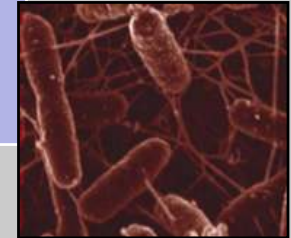
E.g. how does stress change induce earthquakes?

## Extremophiles.

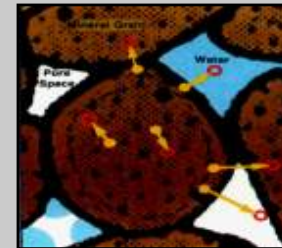
E.g. how do microbes survive in extreme environs?

## Geological survey techniques

E.g. Muon Tomography for survey of geo-structures?



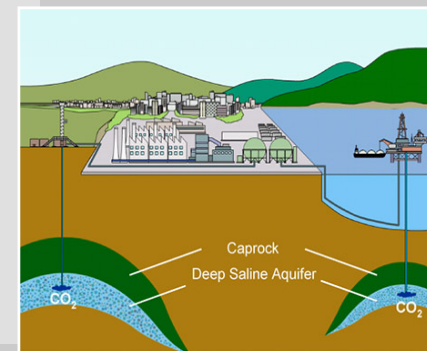
Geo-microbes



Geochemistry



Rock deformation & subsidence



Carbon Capture & storage (CCS)

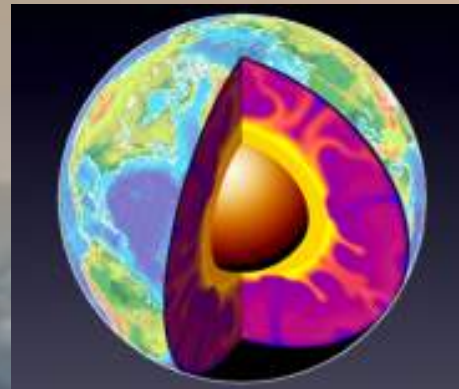
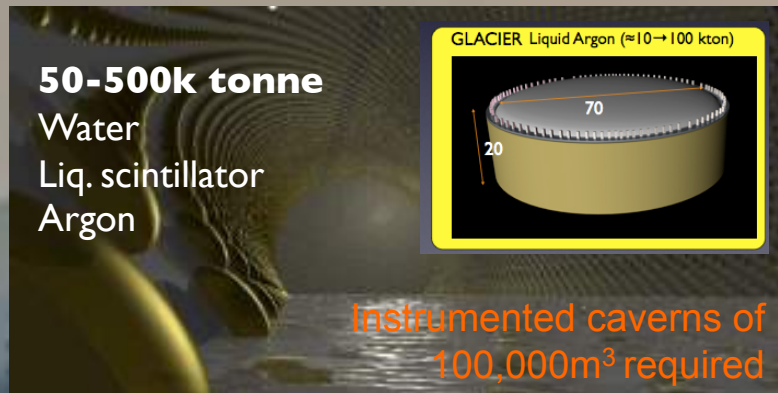
Following £1M stage 1 funding received 2009: 18 month Boulby geo-science proof-of-concept study



# LAGUNA

## Large Apparatus for Grand Unification and Neutrino Astrophysics

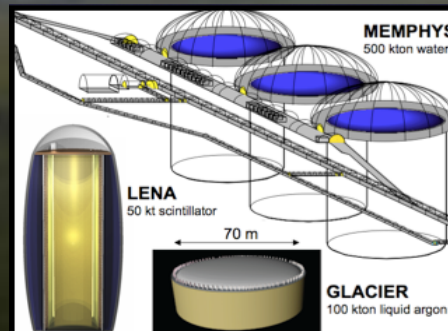
**FP7 (& beyond) funded design study for infrastructure to house a MEGATON 'rare event' observatory**



**BIG QUESTIONS:**

- Proton decay
- Supernova neutrinos
- Diffuse SN neutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Geo-neutrinos
- Reactor neutrinos
- Neutrino beams
- Indirect dark matter (direct DM and DBD)

**Boulby** is one of  
7 potential sites

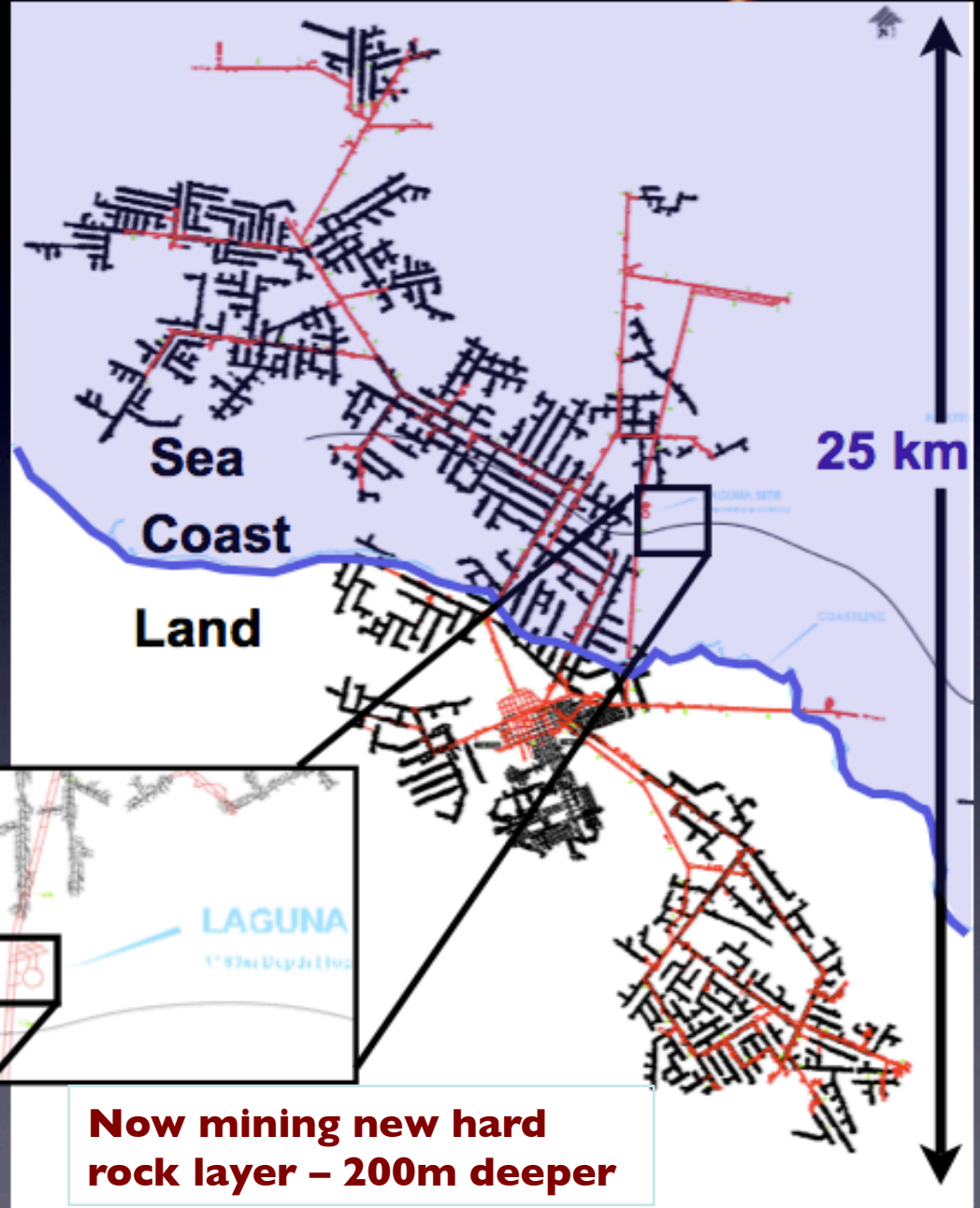




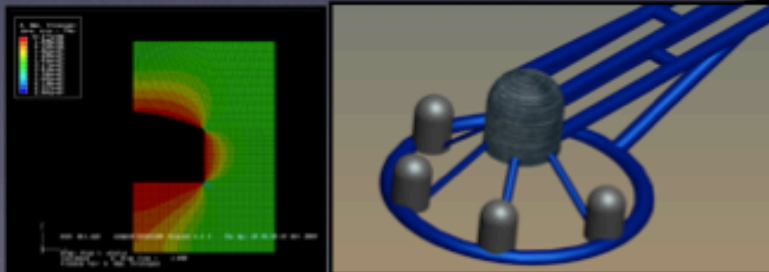
# Layout studies: mines - Boulby



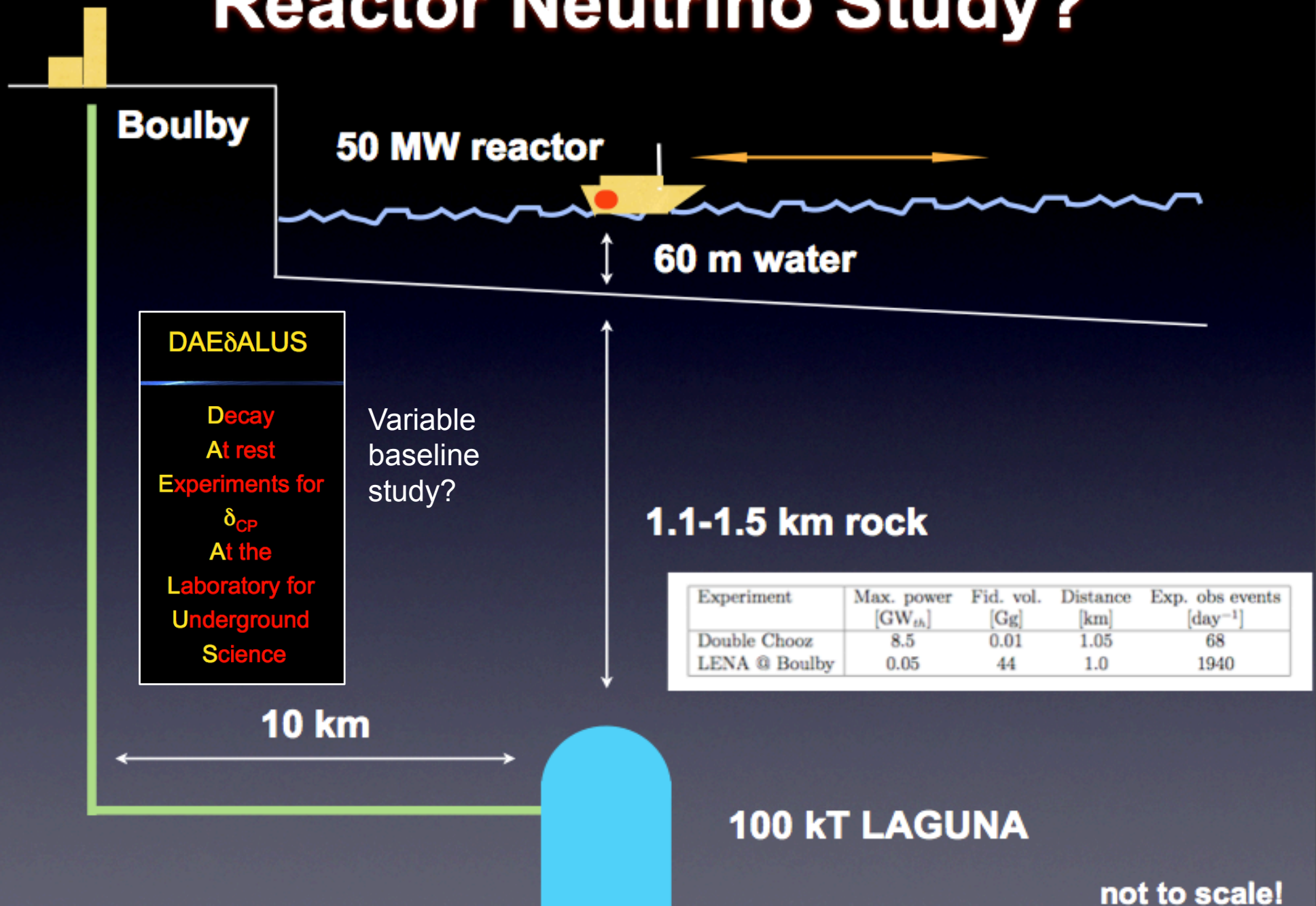
- NE Coast, UK, 1050 km CERN
- Layouts studied for 3 detector options in dolomite hard rock (1050m). 1500m from 2010
- 20 year history of science labs and strong cooperation with mine company CPL
- Prospect of undersea position (reactor neutrino physics with nuclear ship under study)
- Safety, environment, socio-economic well understood



**Now mining new hard rock layer – 200m deeper**



# Reactor Neutrino Study?





# Summary....

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## Deep Underground Science @ Boulby Mine – Update...

- Dark Matter searches at Boulby are continuing. ZEPLIN-III nearing end (now dismantled). DRIFT-II ongoing and we have a US (NSF) bid in for 3 year scale-up programme (DRIFT-III)
- NEW - €850k over 3 years (2011-2014) funding secured specifically to develop inter-disciplinary science at Boulby.
- Diverse immediate future science programme. Astroparticle physics (Dark Matter) to climate & the environment.
- Boulby interested in hosted longer term large-scale experiments (Laguna, Daedalus...). Boulby has plenty of space, 20+ years hosting science, coastal location, mine now developing 200m lower harder rock layer.