GEK-80: Dark matter and non-accelerator physics

Nigel Smith

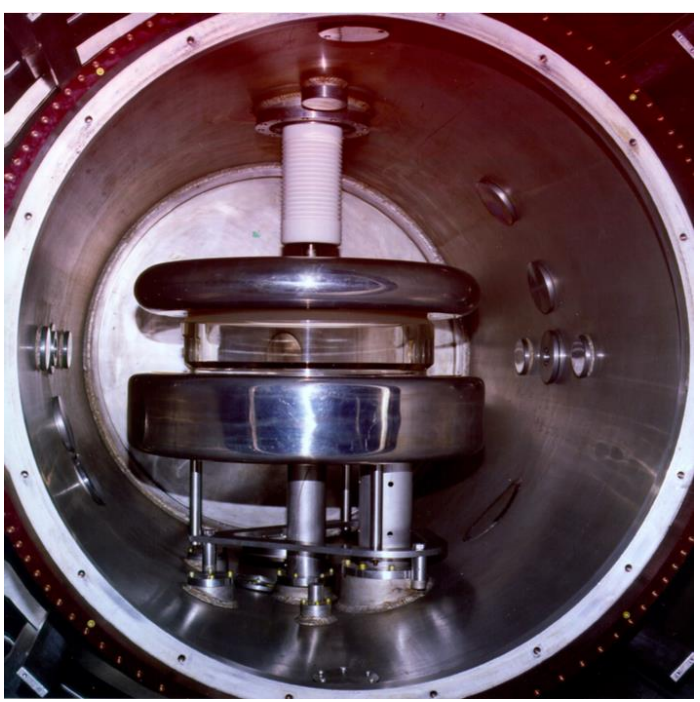
SNOLAB

Connections

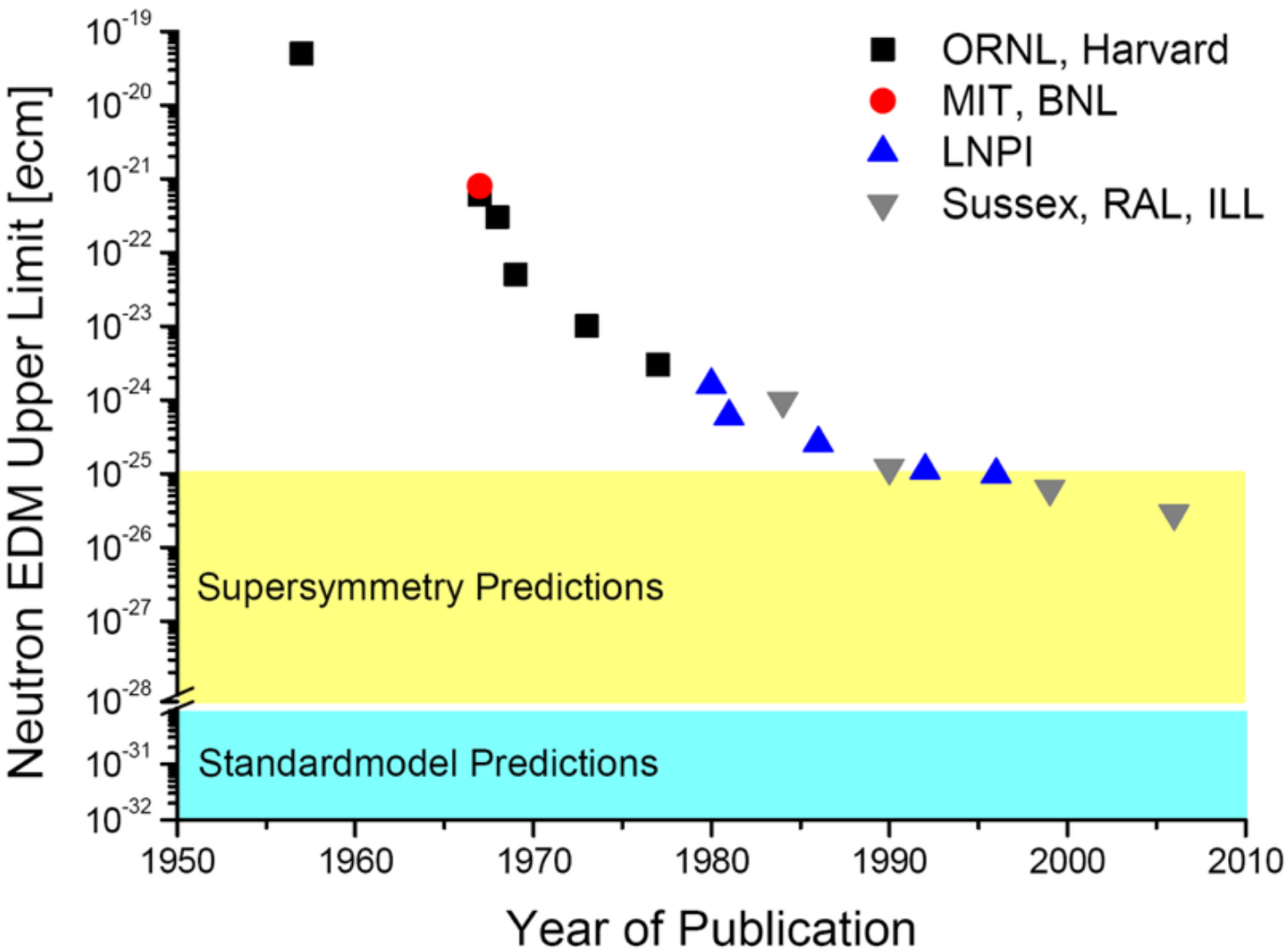
- As Director, PPD, George provided support to the early non-beam programmes RAL was involved in:
  - Keith Green and nEDM (RAL/Sussex (Pendlebury))
  - Peter Smith and Dark Matter (RAL/ICL (Quenby))
- These were viewed as“high risk, high impact” projects, very precise difficult experiments with paradigm shifting potential
- I came to RAL in 1992 to work with Peter Smith on the UKDMC Dark Matter programme
  - initially as a post-doc at Imperial College, London
  - keeping George informed of what was happening at the Boulby mine, where the project was based, over coffee(s)
  - subsequently taking over Peters group in 1998, tutored by GEK and KP in “the PPD way”
- George joined the ZEPLIN project in 2007, working with us on the development of the ZEPLIN-III experiments (two phases)
- I now learn, shares a birthday with my wife (and the Queen)

Neutron EDM

- An electric dipole moment is the separation of +ve and -ve charges in the internal structure of the neutron
- Alternative approach to CP violation studies
  - Standard model nEDM is very small
  - Great probe of physics beyond the standard model.
- RAL/Sussex mounted a campaign at ILL using ultra-cold neutrons to study nEDM, measuring the precession frequency of UCN in E,B fields



nEDM Results

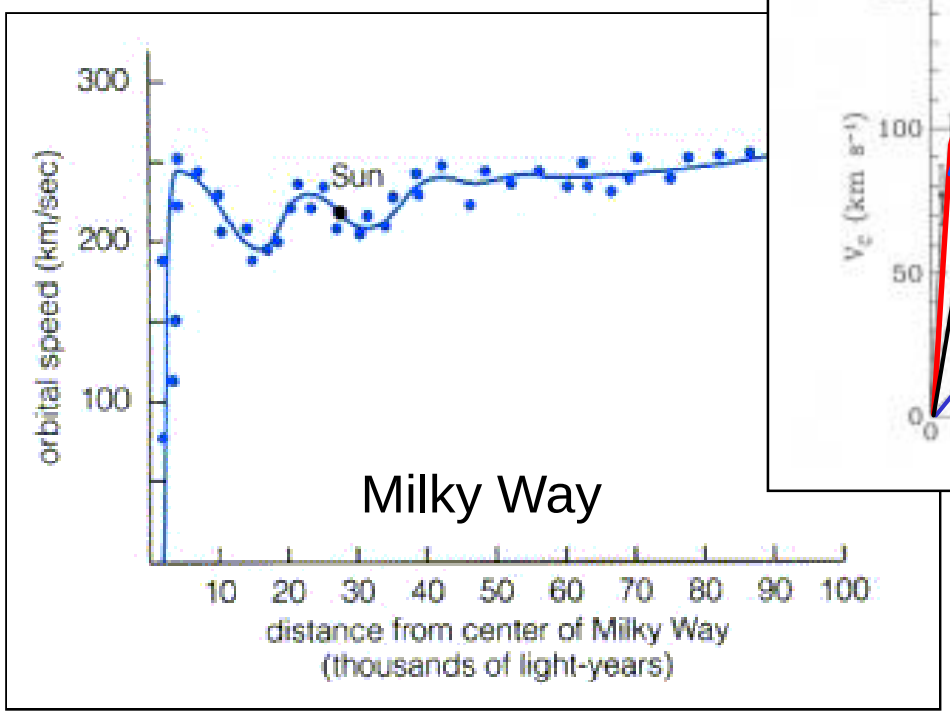


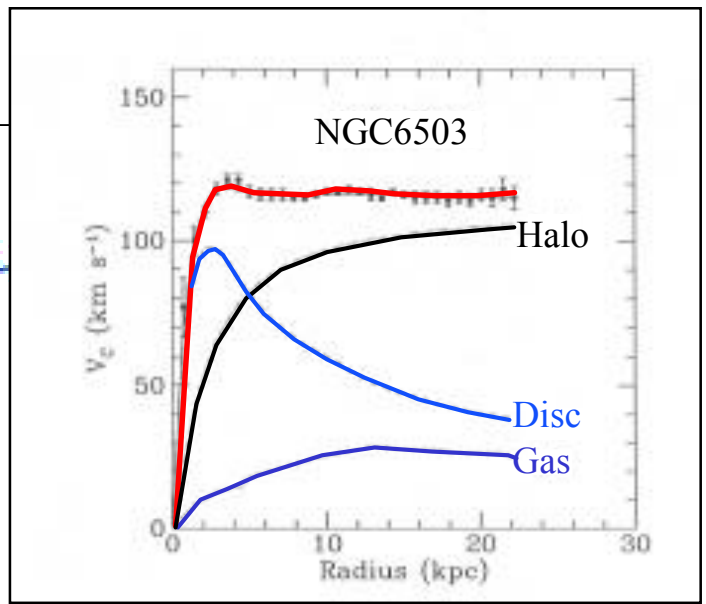
Galactic dark matter

- Uses Doppler shift of light from star in spiral galaxy to give velocity (red shift)
- Expect velocity to fall off with distance from centre

...but it doesn't

... $\rho_{dm} \approx 0.3$ GeV/cc

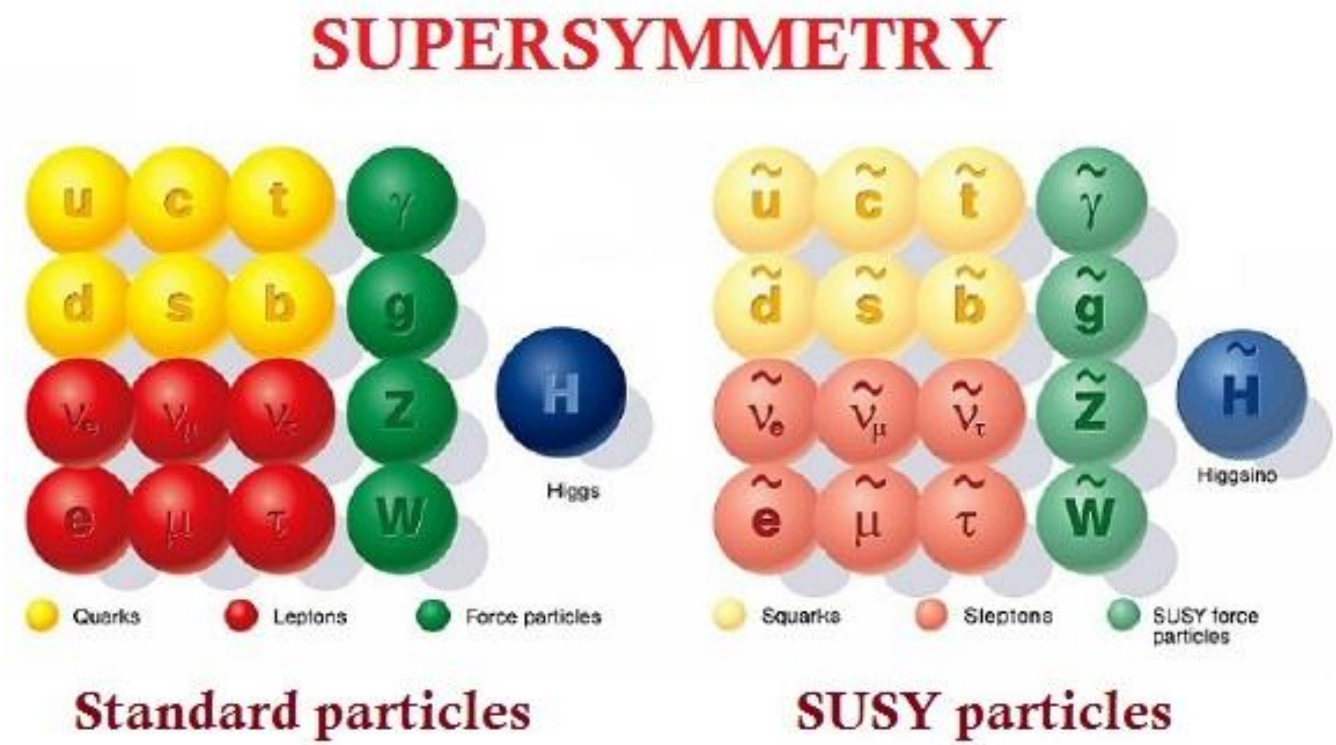




Beyond the PP Standard Model

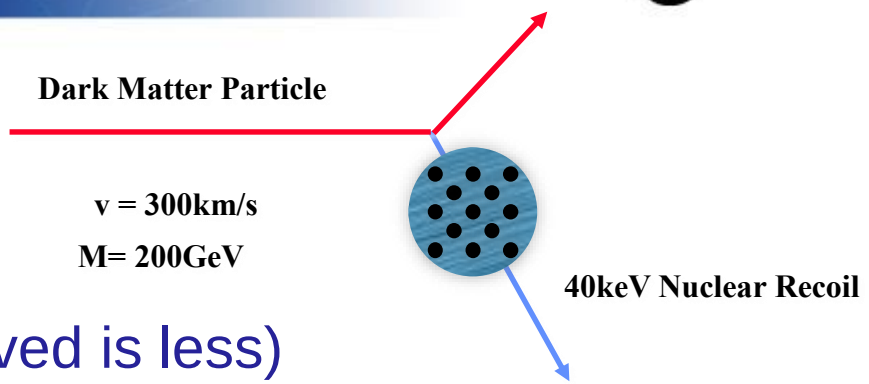
- There are some technical problems with the Standard Model of particle physics at high energies which suggest an even higher symmetry - supersymmetry
- All SM particles have a partner particle to resolve these problems
- These supersymmetric particles would have been produced in the Big Bang and still be with us today...

...but would interact gravitationally and weakly, some have mass and would be 'dark matter' (Weakly Interacting Massive Particles)



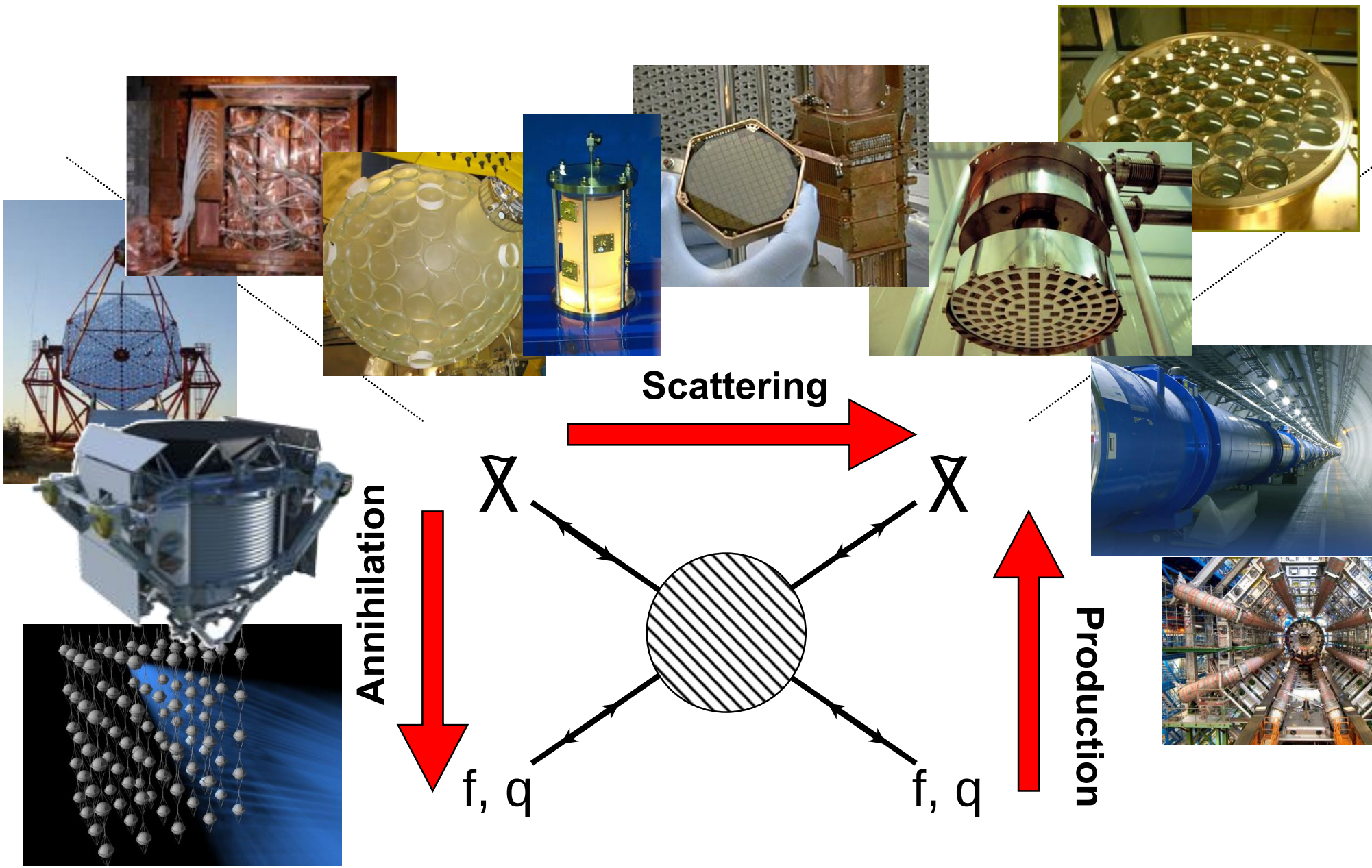
Graphic: CERN/IES de SAR

Experimental Challenge



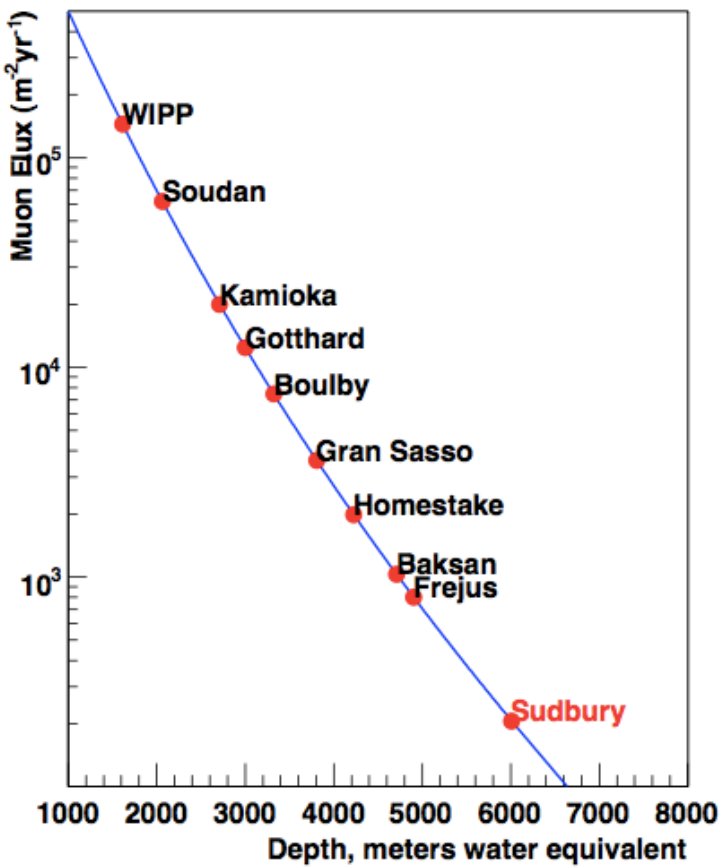
- WIMP nuclear recoil signal is:
  - Low rate (0.1 - 10^{-5} events/kg/day)
  - Small energy (1-100keV actual: observed is less)
- Detection technique must be:
  - Low background
    - Gamma, beta: from U/Th/Co/Pb/etc radio-impurities
    - Neutron: from U/Th radio-impurities and c.r. μ spallation
  - Low threshold
    - To minimise form factor, maximise spectrum
  - Discriminating - Position sensitivity
    - Difference between WIMPs/n and γ/β, background rejection, directionality
  - Large mass (ultimately to reach 10^{-10} pb)

Experimental techniques



Why go underground?

- Studies for rare events, either decays (eg proton or 0νββ) or weak interactions (dark matter, natural or generated neutrino), require very radio-quiet environments to undertake searches
- Deep underground facilities provide significant rock overburden and commensurate reduction in c.r. flux, and c.r.-spallation induced neutrons
  - Additional science programmes possible with such infrastructure - nuclear astrophysics, extreme biosystems, geology, geophysics, ...



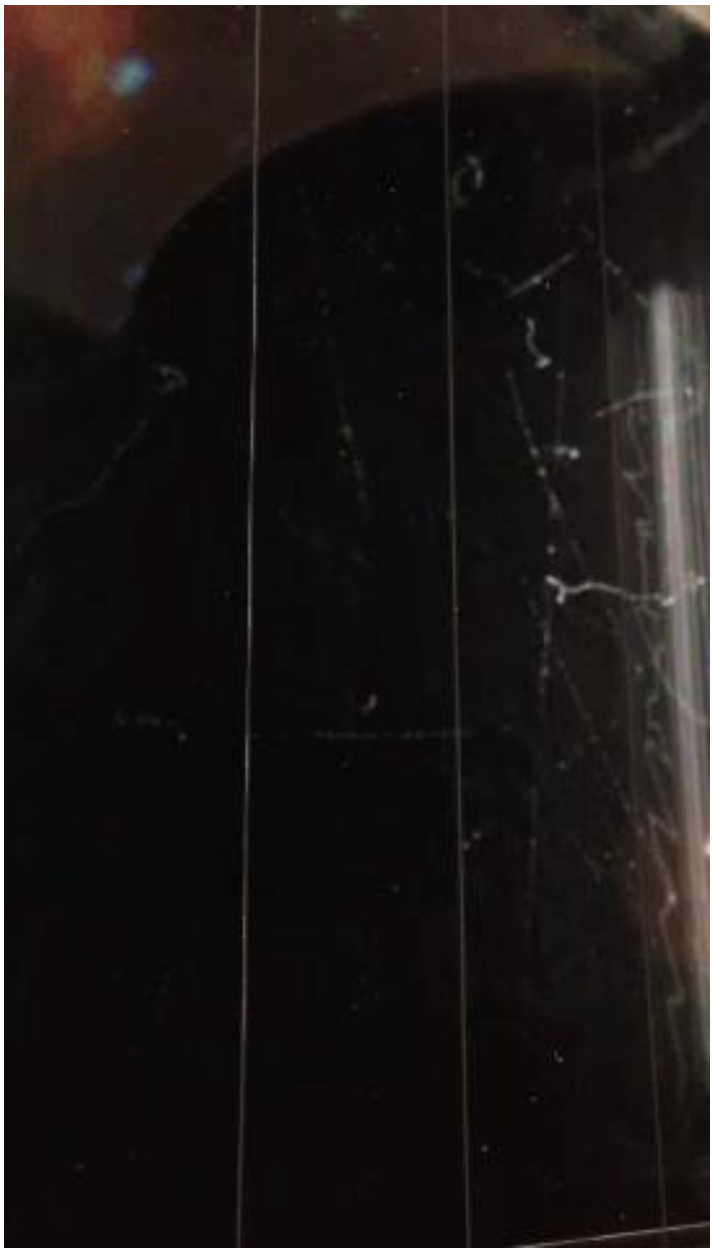
Cosmic Rays

- High energy particles from outer space raining down on the Earth
- Discovered in 1912 by Viktor Hess in high altitude balloon flights†
- Ionisation decreased with altitude... as expected...
  - ...until a certain height and the ionisation increased!

The first balloon flights studying ionisation were made in 1903 by a meteorologist, Franz Linke, who observed the same effect, but he did not make the direct correlation to cosmic rays, for which Hess was awarded the Nobel Prize.
F. Linke, *Luftelektrische Messungen bei 12 Ballonflgen*, Berlin 1904

Early particle physics

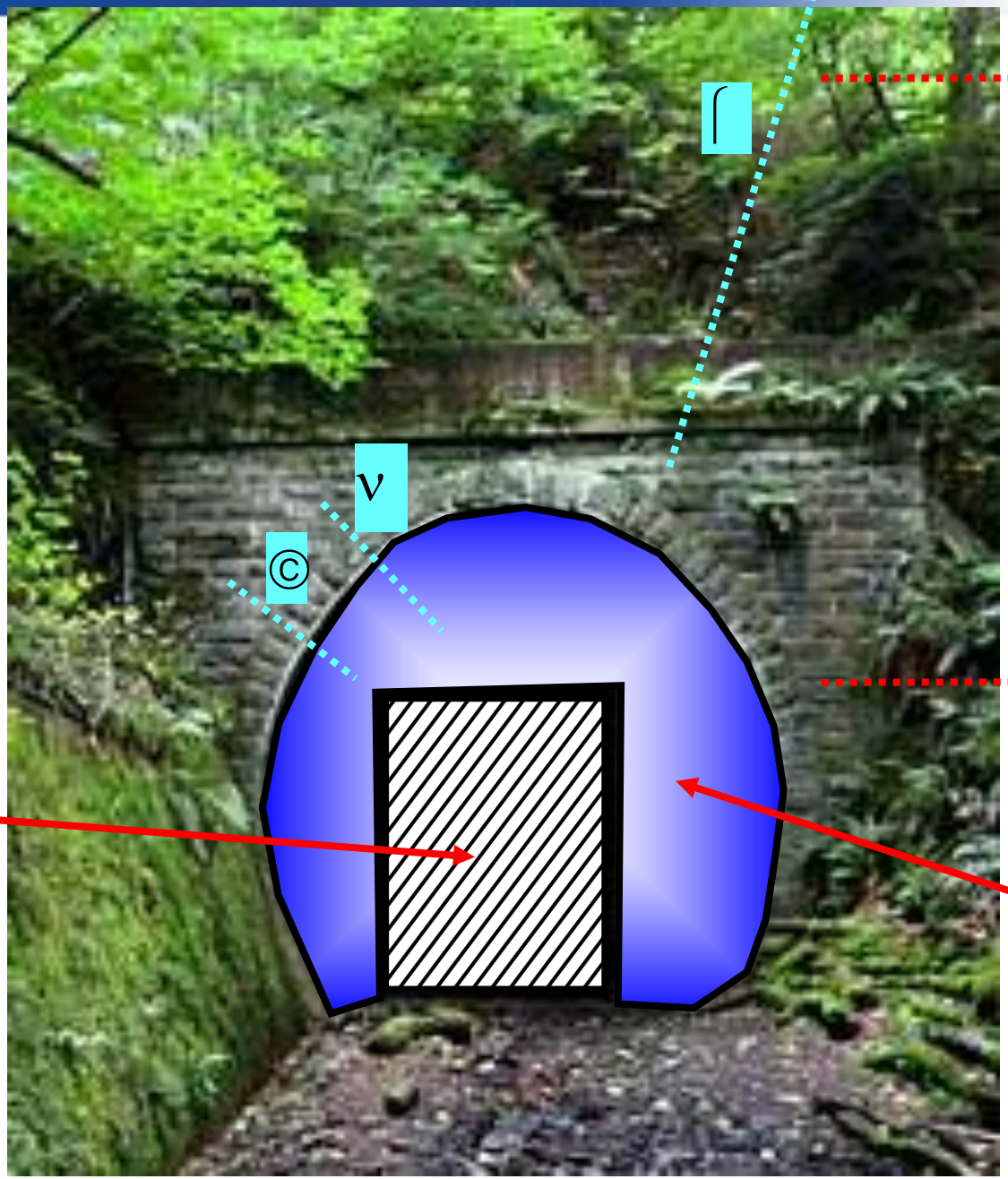
- Using particle detectors (cloud chambers and photographic emulsions) on mountain tops or in balloons for cosmic rays...
- ...and accelerators in labs for man-made cosmic rays...
- ...many new particles discovered!



Early infrastructure

Neidpath tunnel: First underground physics experiments conducted by CTR Wilson, early 20th century

Fundamentals of facilities



Over-burden to reduce cosmic ray flux

Accessible space for detectors and services

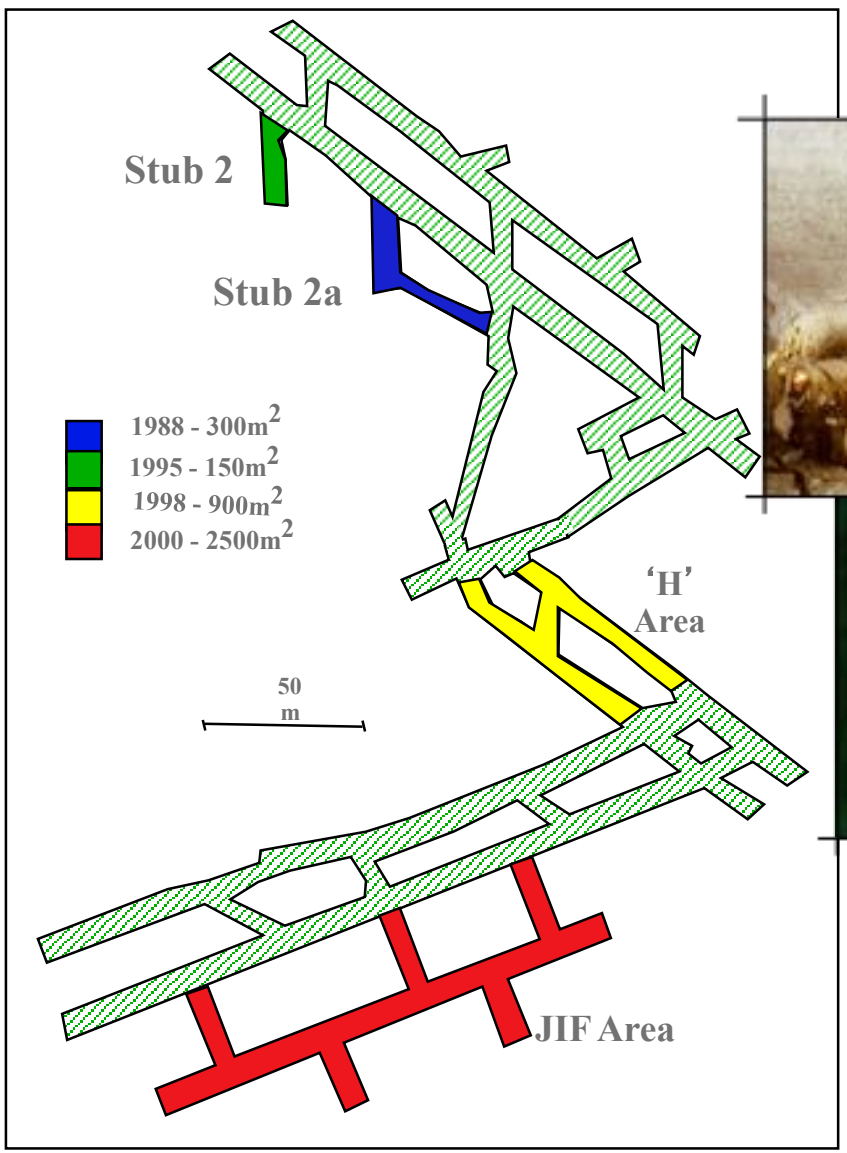
Shielding to remove environmental radiation

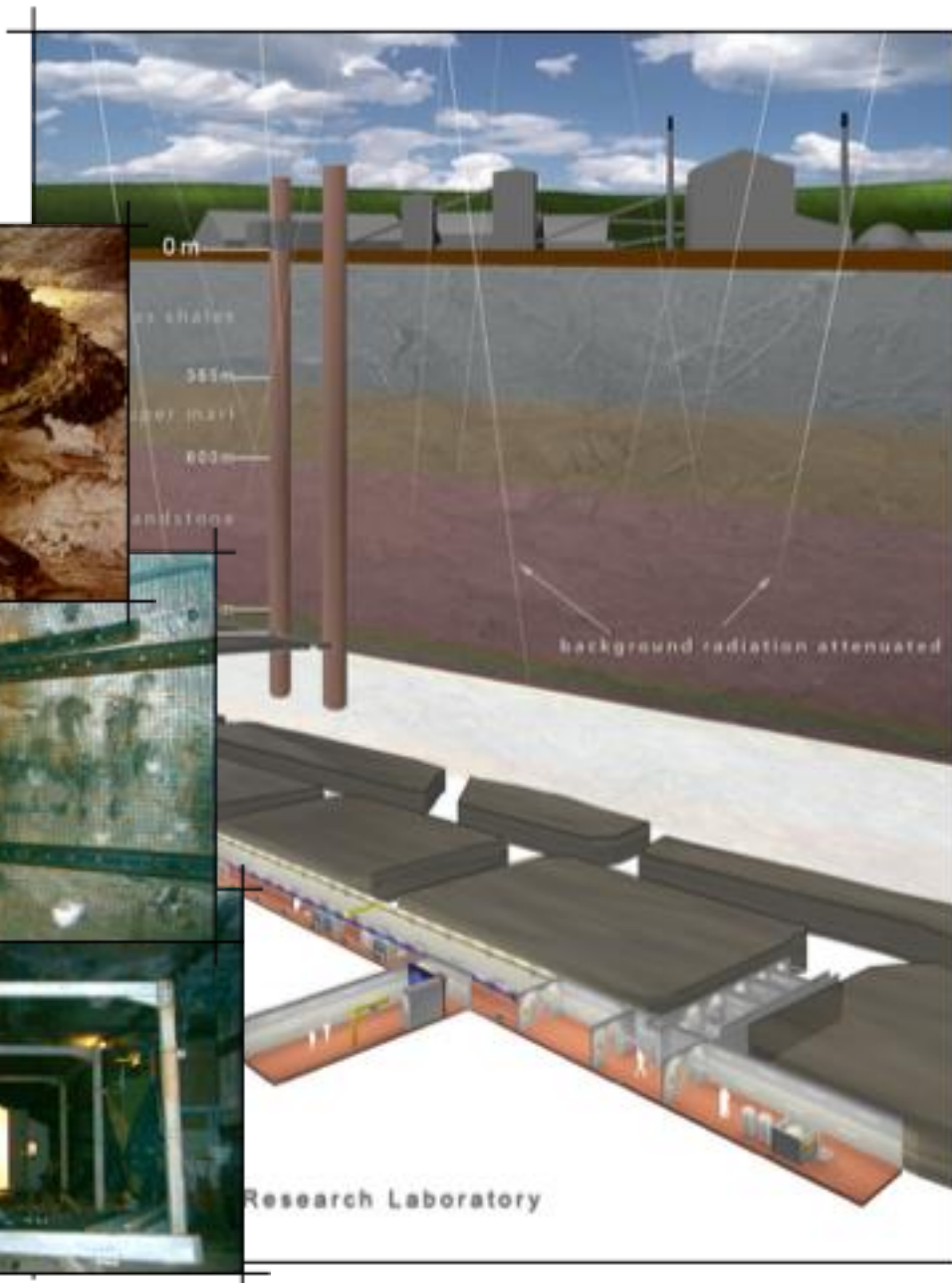
Boulby Potash Mine

Early Infrastructure - 1994/5

Underground facilities

- Working salt/potash mine @1100m

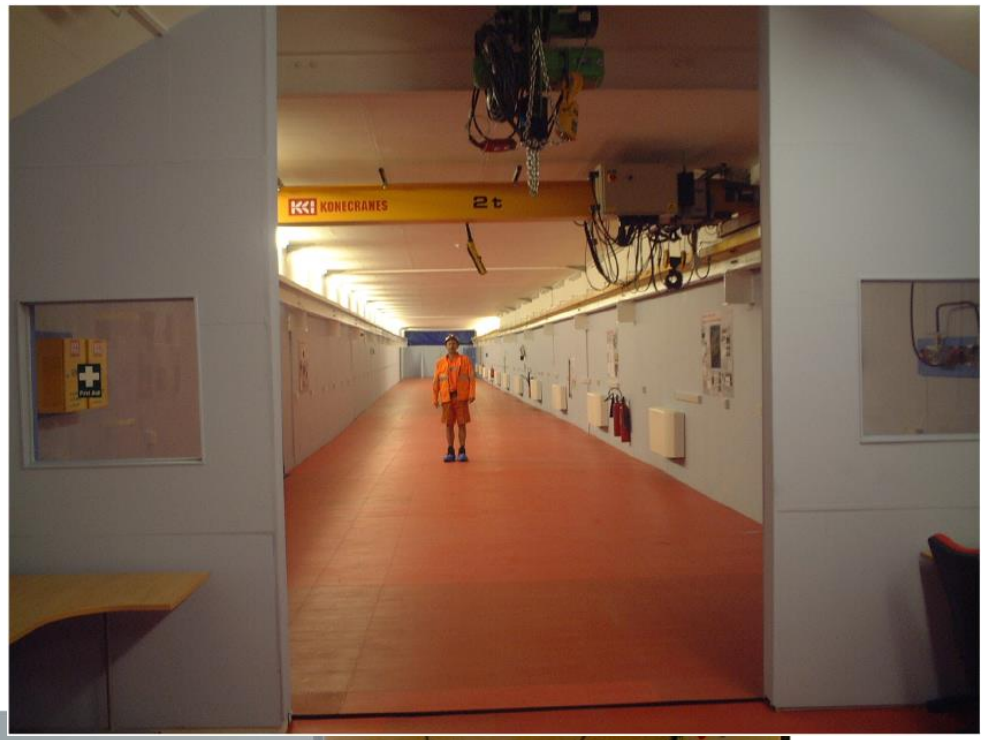




JIF Construction

From this...

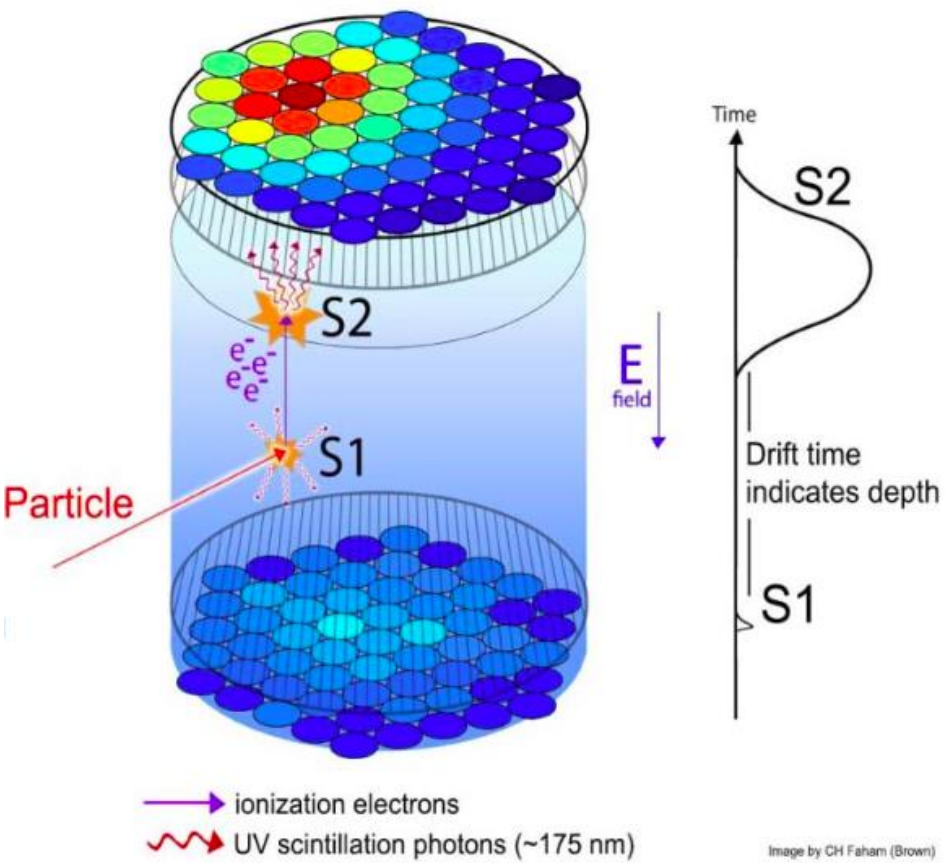
... to this



WE PAY £3M TO HUNT INVISIBLE PARTICLES

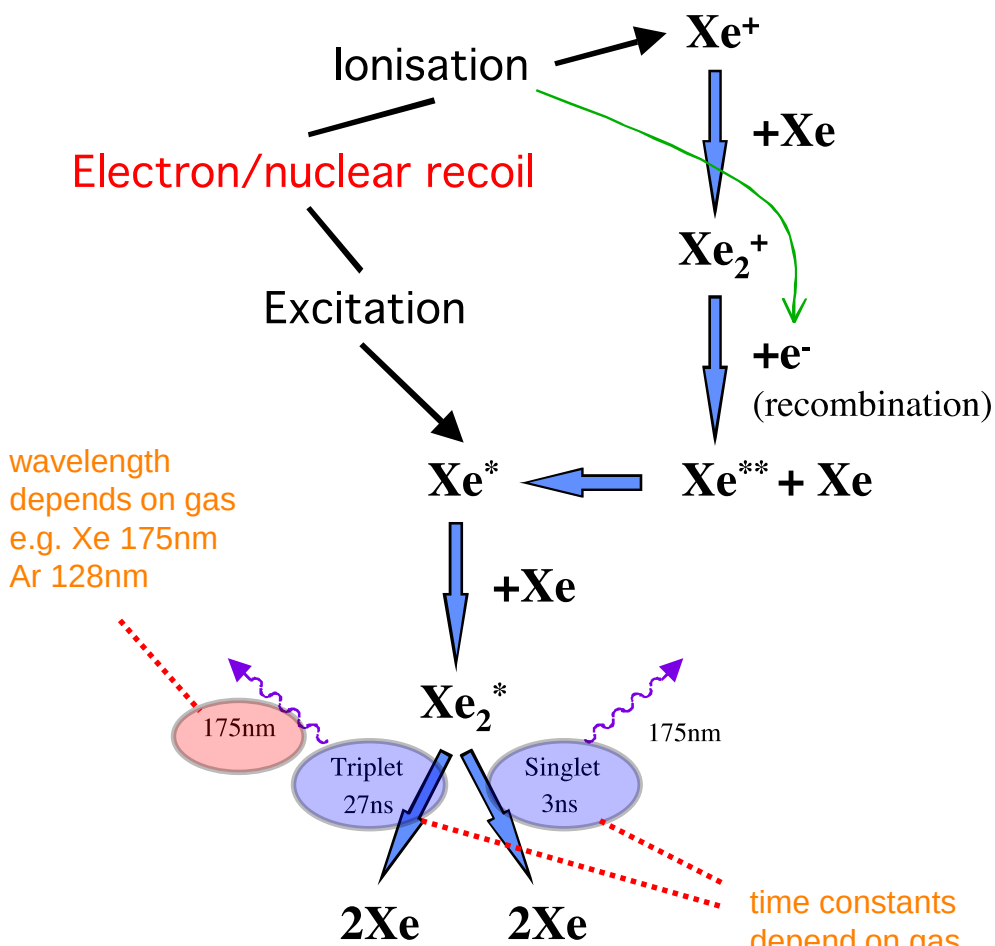
(...and they may not even exist)

Liquid Noble Gas detectors

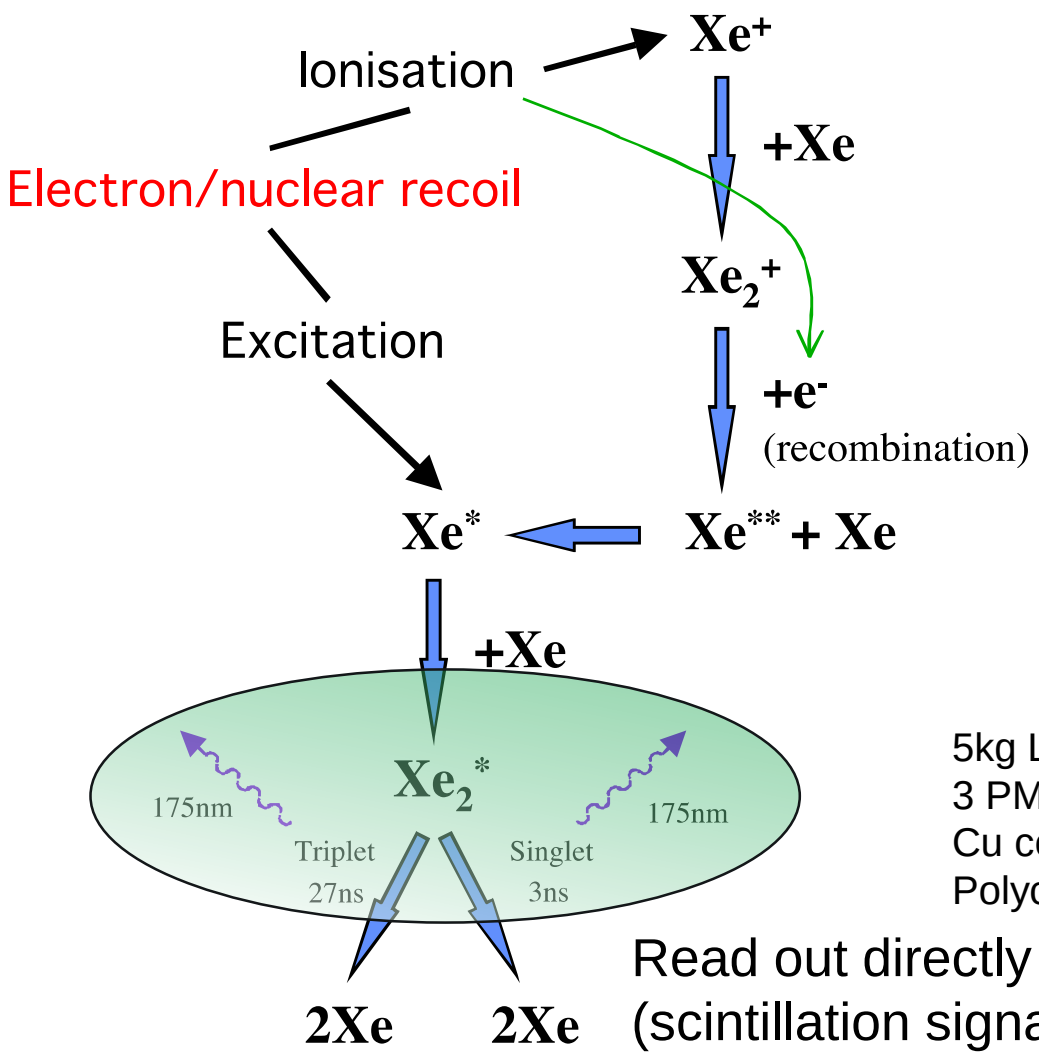


Two phase detector process

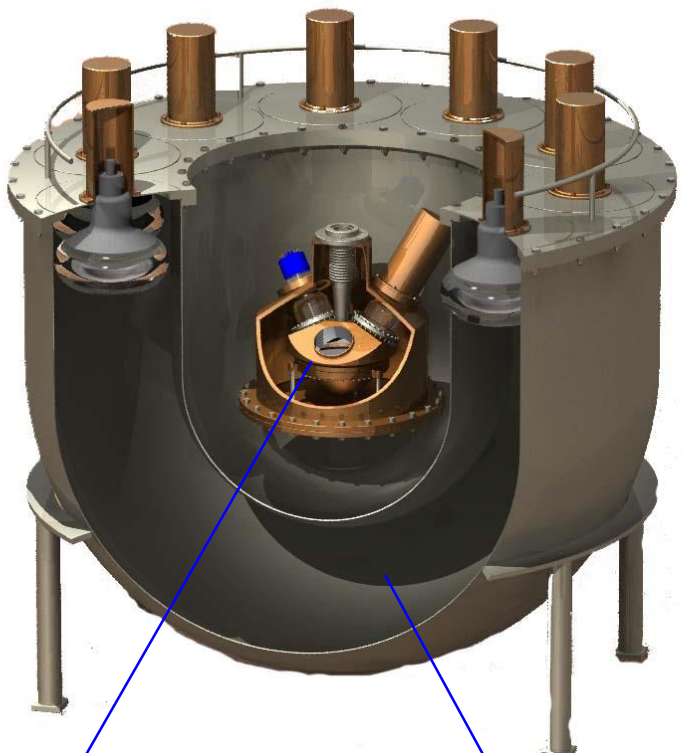
noble gas interaction process



ZEPLIN I



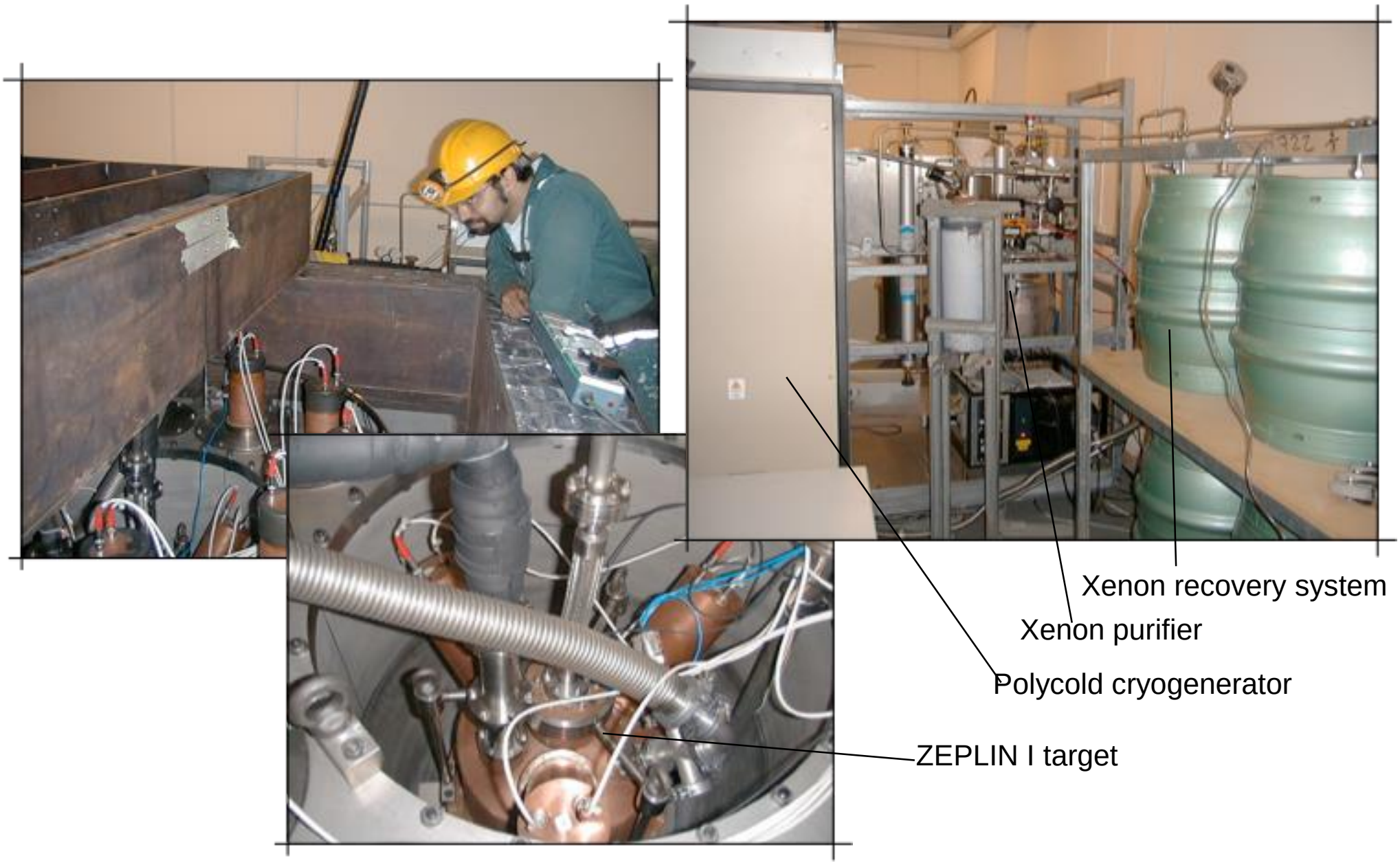
Read out directly
(scintillation signal)



5kg LXe target (3.1kg fid)
3 PMTs
Cu construction
Polycold cryogen cooling

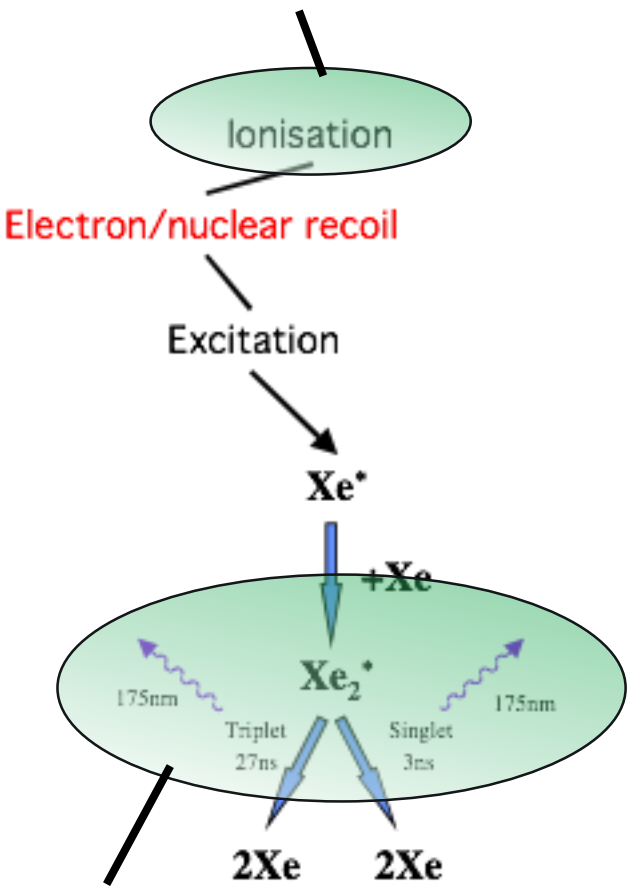
1 tonne Compton veto
PMT background tag
Gamma calibration
Neutron monitor

ZEPLIN I


Xenon recovery system
Xenon purifier
Polycold cryogenerator
ZEPLIN I target

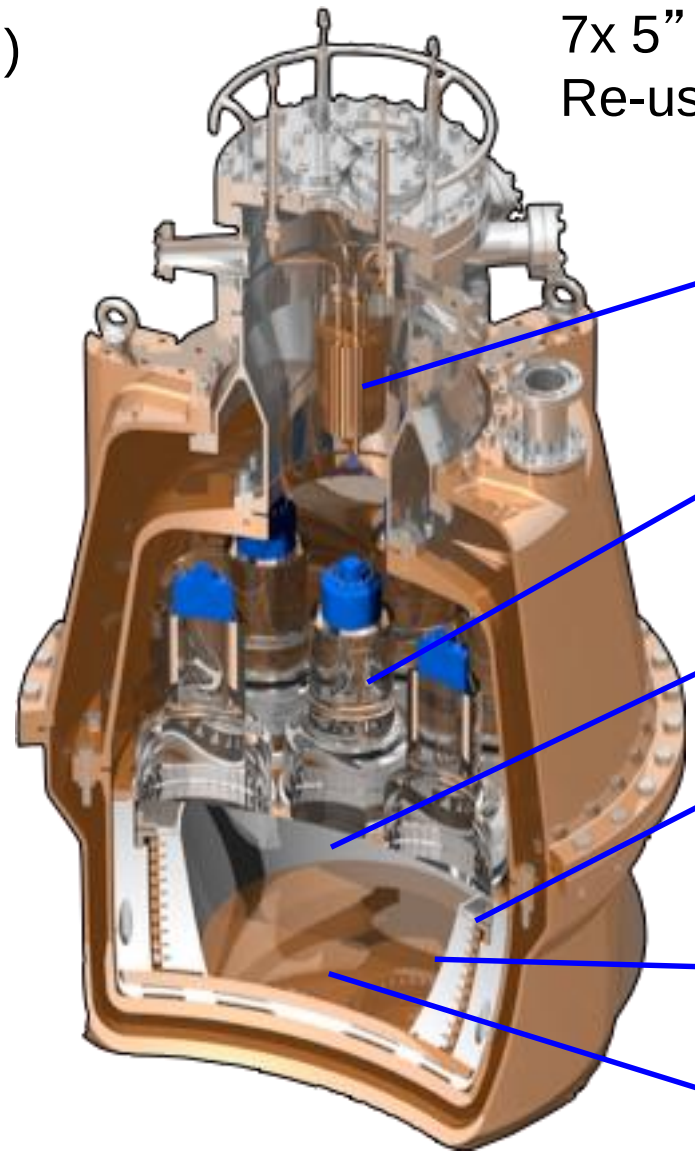
ZEPLIN-II Detector

Read out directly
(electroluminescence signal)



Read out directly
(scintillation signal)

30kg xenon, two phase operation
7x 5" PMTs, 0.25-2kV/cm drift
Re-use ZI shielding/veto



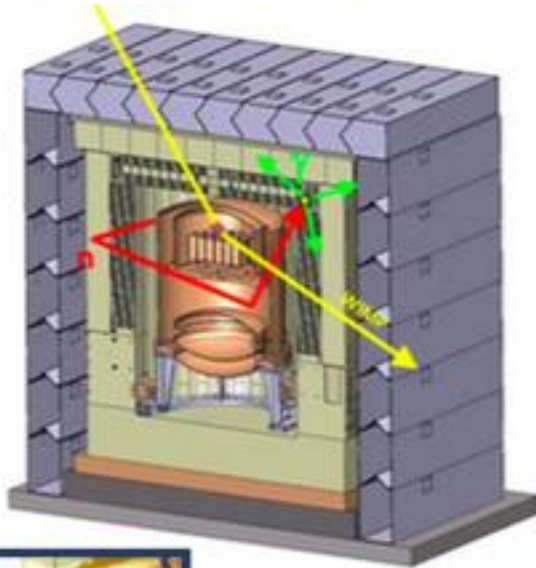
ZEPLIN III

- 8kg fiducial mass
- PMTs in liquid to improve light collection
- 3.5 cm drift depth – higher E-field
- 31 small PMTs for fine position sensitivity
- open plan – no surfaces - reduced feedback

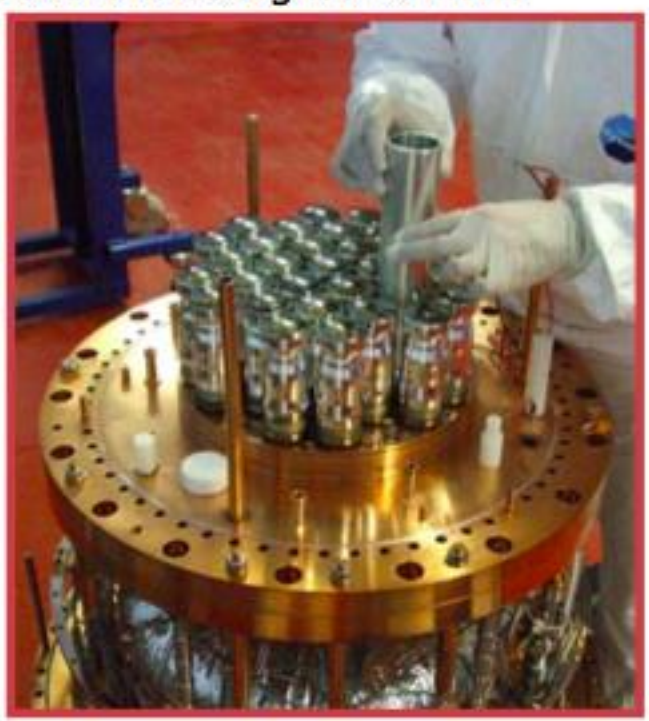
UPGRADES: NEW PMT ARRAY AND VETO

- PMT γ-rays limited sensitivity of first run by a large factor
- New PMT model developed with manufacturers (ETEL)
- 20-fold reduction in γ-ray activity, but poor optical performance

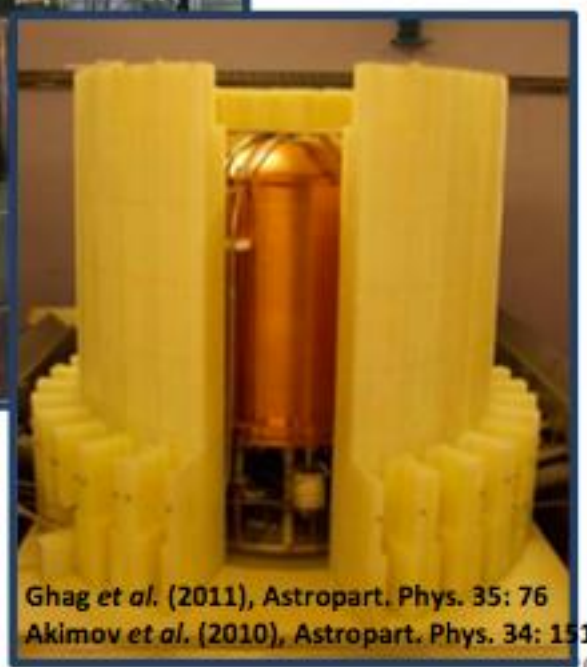
- 52-module neutron veto installed around WIMP target
- Gd-loaded polypropylene surrounded by 1t of plastic scintillator
- 60% neutron efficiency, diagnostic tool



Assembly of bespoke low-background PMTs



ZEPLIN-III Veto



Ghag *et al.* (2011), Astropart. Phys. 35: 76
Akimov *et al.* (2010), Astropart. Phys. 34: 151

GEK involvement in ZEPLIN

- Provided great advice to both the RAL team and the collaboration as a whole
- Was placed in charge of‘sanity checks’for the ZEPLIN-III analysis
- Pitched in wherever needed, including manual labour, political positioning, analysis strategies, dialogue with funders

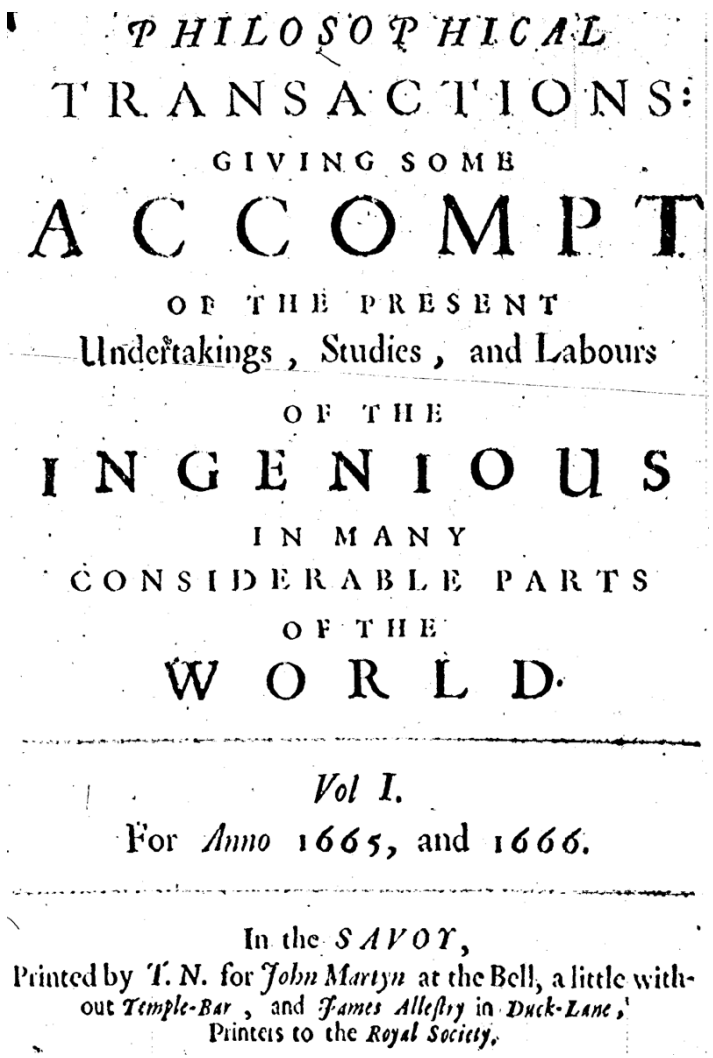
Z3 DATA ANALYSIS RESPONSIBILITIES

Analysis Whip HA	Strategy Lords Institute Board	Independent Ombudsman GK
Analysis coordination; golden/platinum definition;	Science & publication strategy; "blindness" decisions	"Independent" auditing; sanity & consistency checks

Data Pipeline Ministers CG,MH	BE LR	Reduction "handle"; transport & storage; golden/platinum datasets; veto datasets; hardware & system management;
ZE3RA/GOLDEN Keepers FN/MH	AL,VS PRS,HA	ZE3RA and golden software; development; maintenance; installation; documentation; position reconstruction algorithms; SPE analysis software; veto integration
Calibration Bigwig BE	MH,LV AL,PAM	Neutron and gamma calibration analyses; S1 and S2 light yields; anti-correlation; calibration note; DAQ settings
	LV,MH BE,RW	System stability; environmental data; daily background rates; purity; corrections database; SPE and noise database; system stability incremental note (databases etc)
	AL,HA CG,LR	Gamma background rates; expected recoil rates; discrimination power; (x,y,z) fiducialisation; backgrounds incremental note
	HA,MH CG,LR	Comparison with simulations: backgrounds, calibration, detector response; extraction of physical parameters; simulations incremental note
	VB, AH LR,PRS	Veto reduction software; calibration; efficiency; stability; simulation; final veto cut function; veto performance incremental note
	AC,BE CG,PRS	Official cuts registry; software efficiencies; hardware efficiencies; overall efficiency curve; cuts incremental note; golden/platinum definition

Royal Society Discussion Meeting

- "*The search for dark matter and dark energy in the Universe*"
- 2003 RS Discussion Meeting, proposed (and pushed) by George
- Timed around WMAP first results release
- Who's who of the field at the time:
  - Martin Rees (Introduction)
  - Richard Bond (CMB)
  - Saul Perlmutter (Dark Energy)
  - John Peacock (Large Scale Structure)
  - Paul Steinhardt (Dark Energy)
  - Julio Navarro (CDM Halos)
  - Dave Wark (Neutrino Mass)
  - Karl van Bibber (Axions)
  - John Carr (Indirect WIMPs)
  - Hans Kraus (Direct WMPs)
  - John Ellis (Summary)
- Entryway to the most fun party in London!

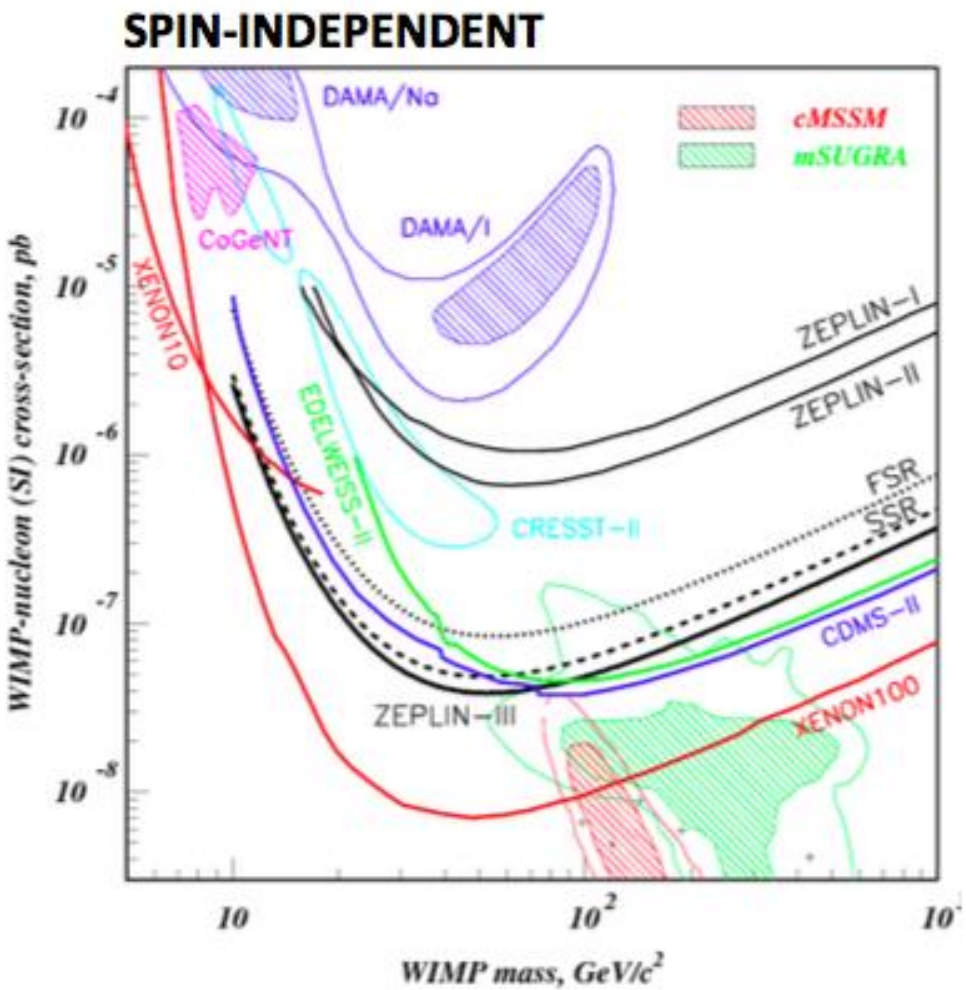


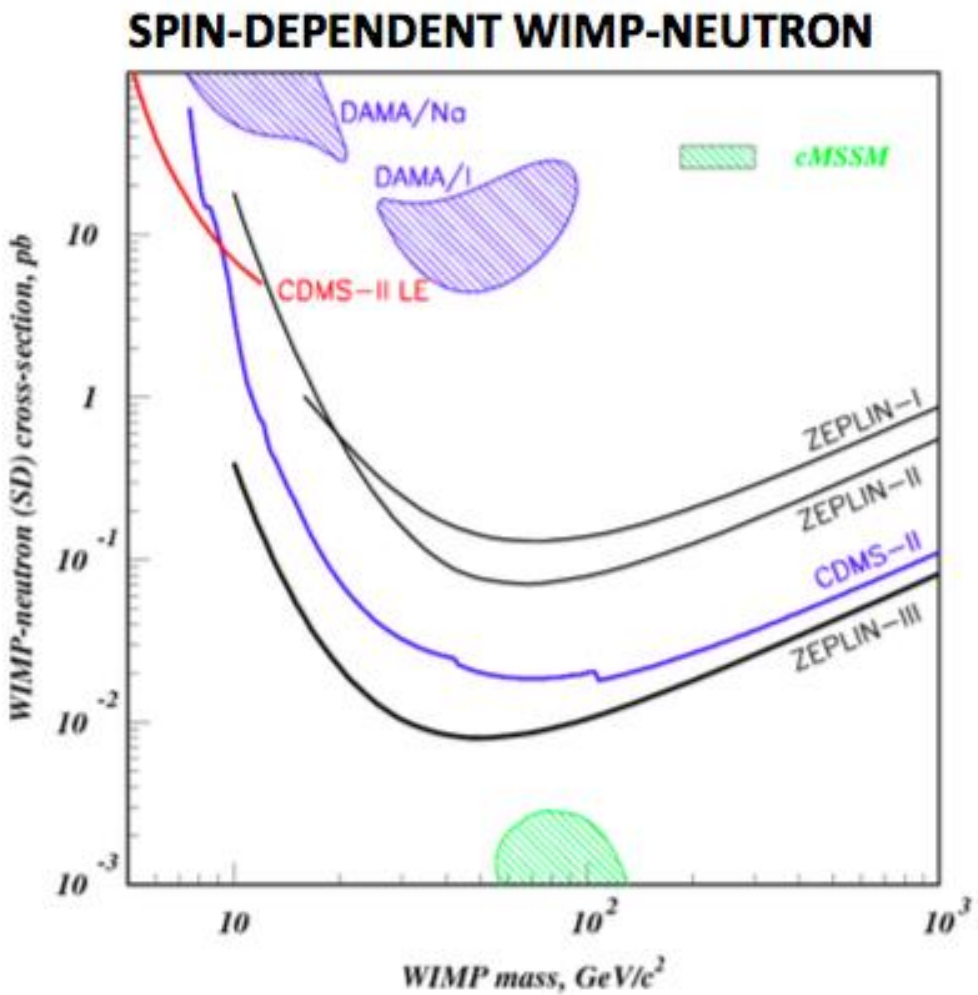
PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.

Vol I.
For Anno 1665, and 1666.

In the SAVOY,
Printed by T. N. for John Martyn at the Bell, a little without Temple-Bar, and James Allestry in Duck-Lane,
Printers to the Royal Society.

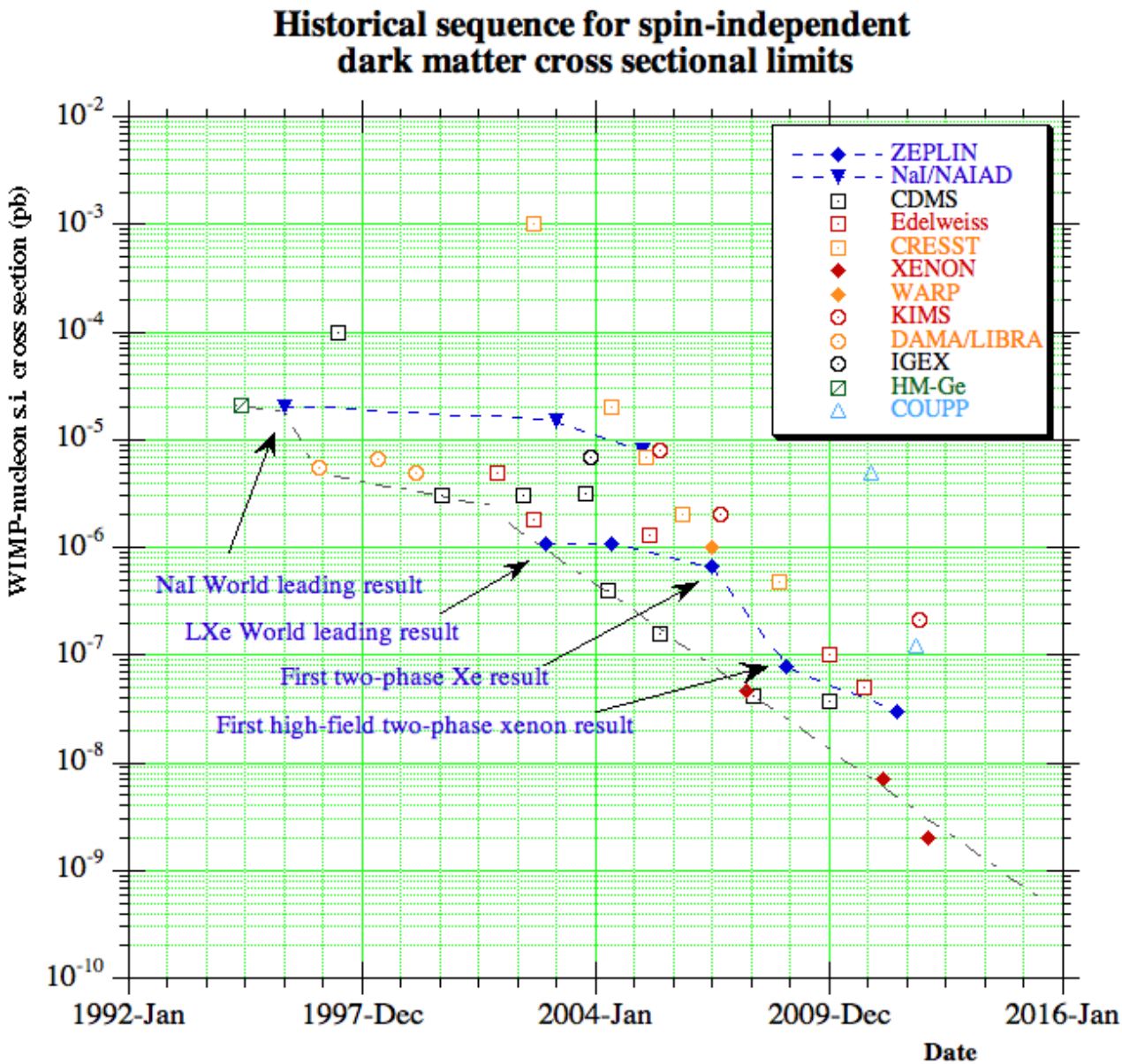
ZEPLIN Results





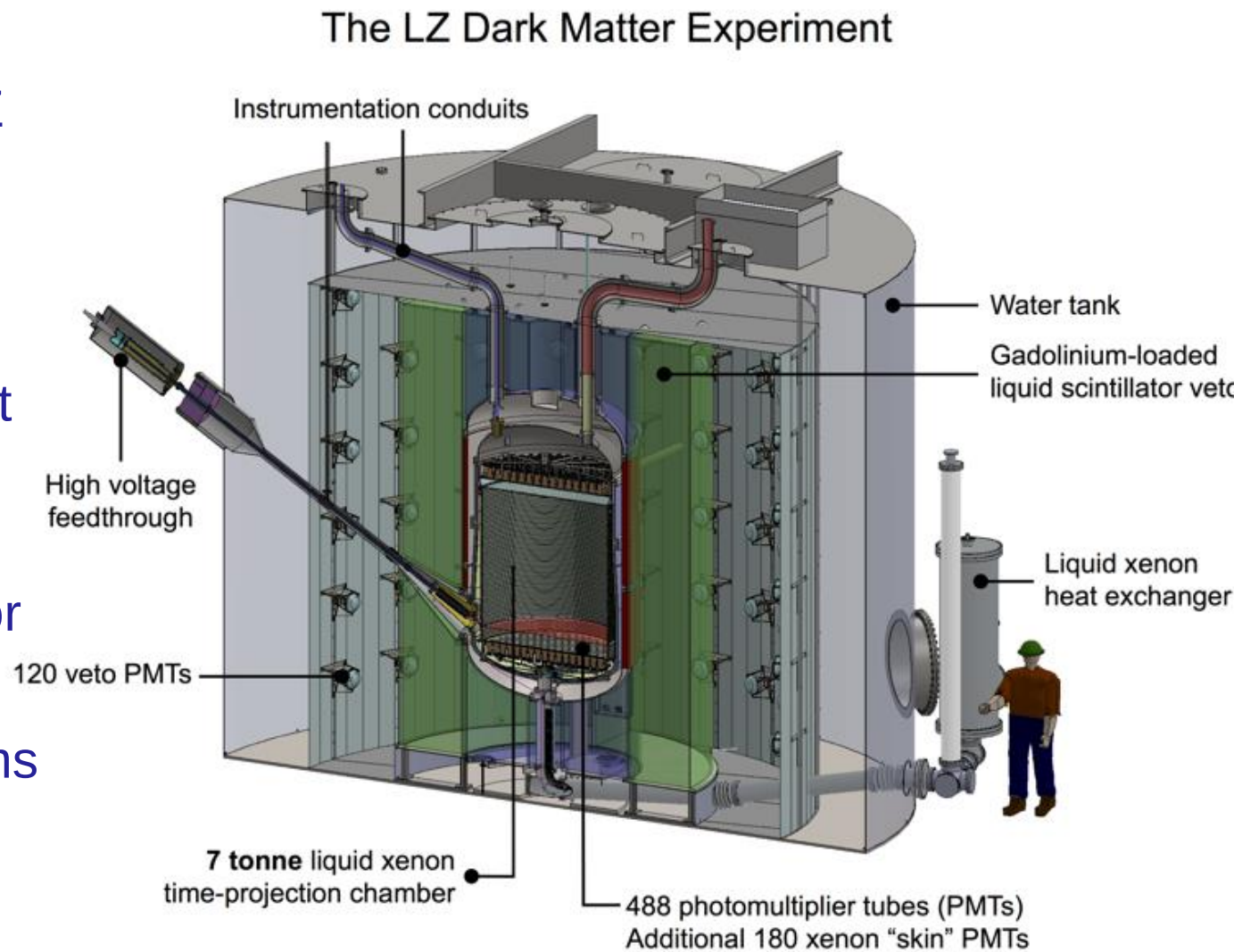
The UK Dark Matter Programme

- From 1987 the U.K. programme has improved sensitivity by three orders of magnitude
- Included world leading results from NaI and single phase liquid xenon
- Also demonstrated first results from two-phase liquid xenon and high field operations



ZEPLIN legacy

- UK groups have now joined up with the LUX team to develop the LZ detector
- LUX is current world leading project
- Strong intellectual input from ZEPLIN team
- LZ selected as one of the US “G2” projects for future funding (of 4)
- Strengthening UK teams
- Future is bright for UK dark matter groups



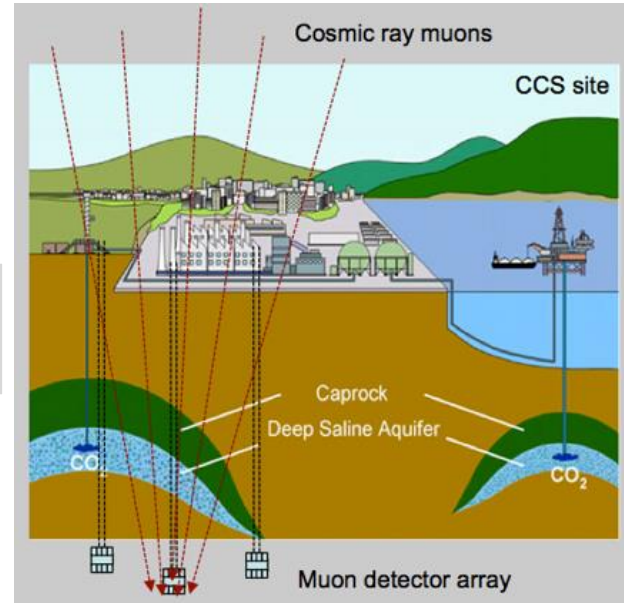
Expanding Multi-Disciplinary Studies

ERSaB: Gamma spectroscopy & low background counting environmental radioactivity studies

Boulby, Scottish Universities Env. Research Ctr (SUERC)

DEEP-Carbon: Muon Tomography for deep geological mapping applications including CCS

Boulby, Durham, Sheffield, Bath, Premier Oil, CPL.



MINAR: Space Technology Development

Boulby, Edinburgh, NASA, DLR, CPL etc.

Plus Misc. Geology & Geoscience (& more to come)…

BISAL: Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond

S.M.Paling - Boulby@stfc.ac.uk

A NEW LABORATORY now being built at Boulby

To replace current facility and host **planned & new projects** for the next decade and more…

Science & Technology Facilities Council

BOULBY UNDERGROUND LABORATORY

Project Completion date: end 2015

Materials Entrance 2

Main hall: Internal Lab height/width of 4m/7m

Entrance 1

Offices & People Entrance

Mars Analogue Area & outside testing area

MaterialStore

Low Background laboratory

Large Expt. Cave Area: Internal lab height/width of 6m/7m

50m

Fully-equipped 1000m² lab. Class 10K & 1K clean room throughout. 5-10T lifting capacity.

S.M.Paling - Boulby@stfc.ac.uk

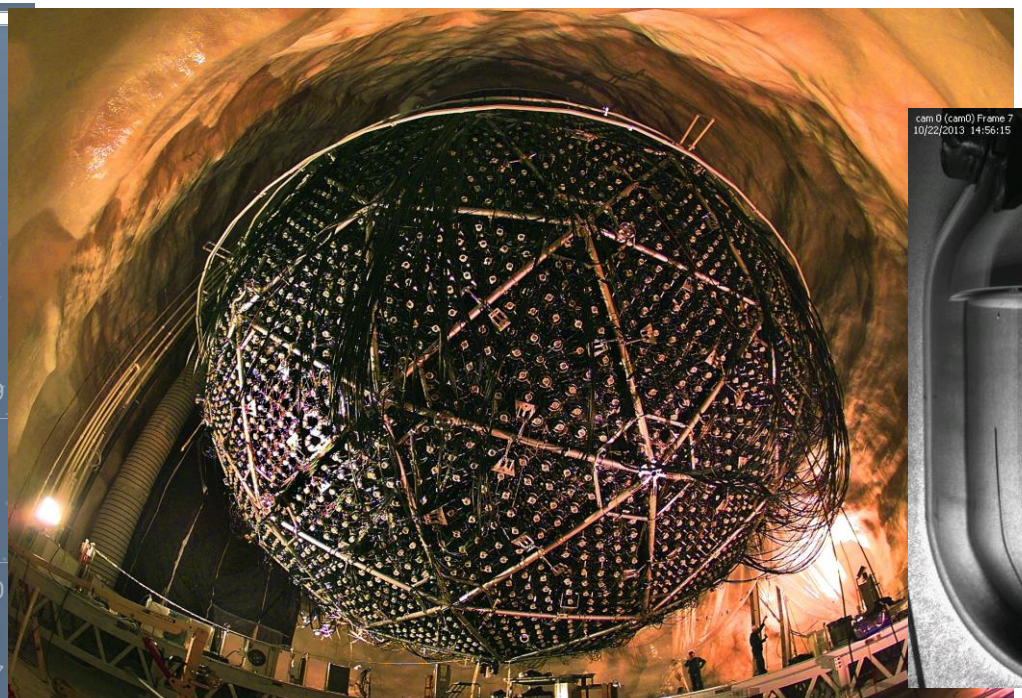
GEK and NAPP

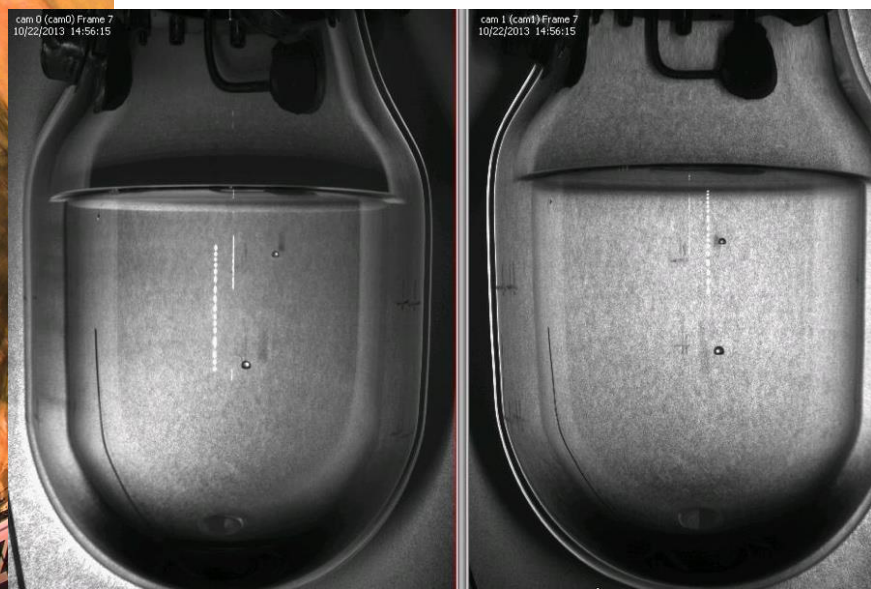
- Substantial contribution to the non-accelerator particle and particle astrophysics programmes within the U.K.
- Support for development of early phases of projects in nEDM and dark matter when Director, PPD
- Promotion of non-accelerator physics through meetings, such as the Royal Society Discussion meeting
- Direct engagement in ZEPLIN-III and beyond
- All providing strong support to the UK dark matter community
  - world leading and world class research results
  - development of sought-after research expertise for future projects
  - development of world-class underground facilities

My personal thanks to George!

- The RAL group, and the UK programme in Dark Matter provided a tremendous proving ground in physics and research management techniques

- Sufficient to allow me to head to Canada to work with 2 litre bubble chambers...





But beware, George

- But beware of the dark side. If once you start down the dark path, forever will it dominate your destiny, consume you it will…