ZEPLIN-III: The Hunt for Dark Matter

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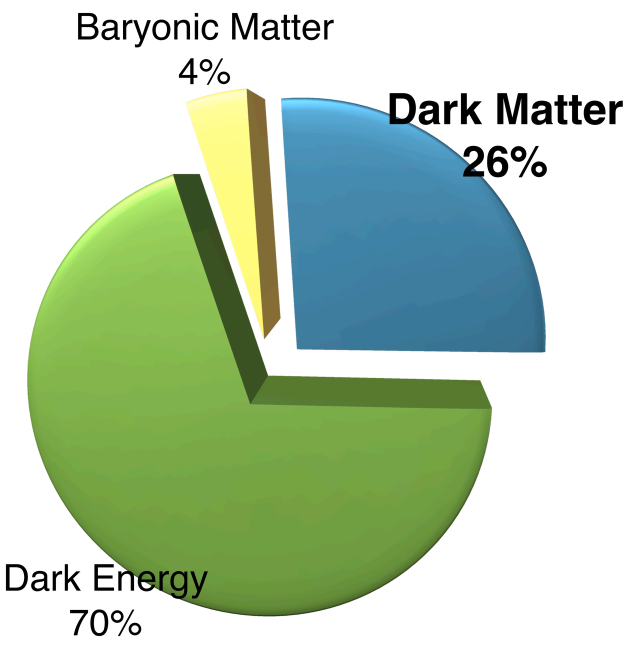
on behalf of the ZEPLIN-III collaboration

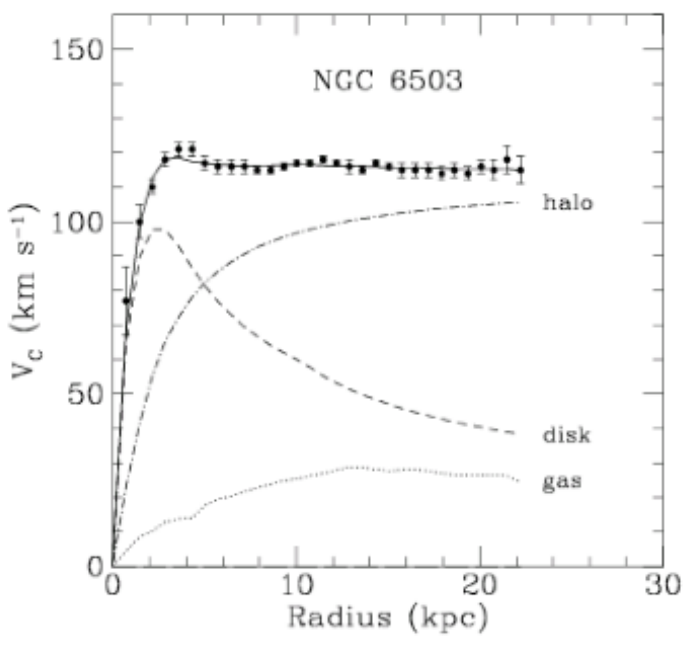
World-class astroparticle physics over a kilometre beneath the North Yorkshire Moors.

What is Dark Matter?

Most our Universe is missing!!

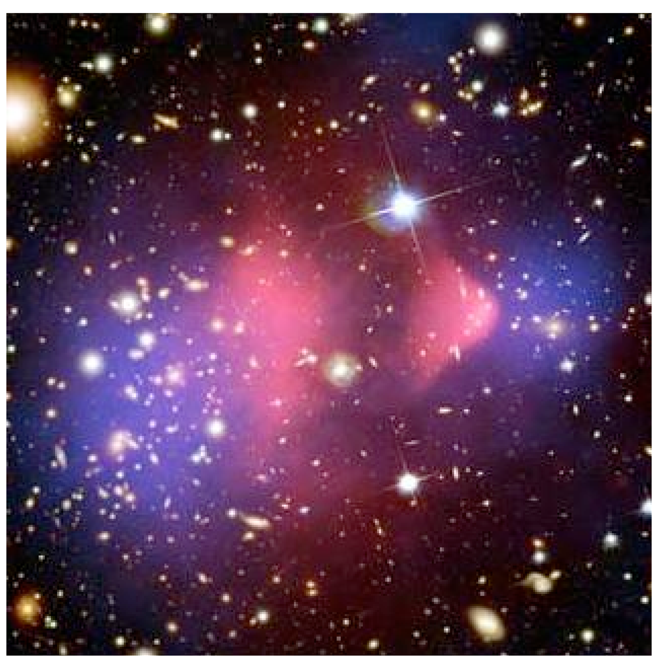
All the matter we can see (stars, planets, gas, me and you) is made up of baryons. But if you add up all of this matter, the mass only accounts for about 4% of the Universe as a whole. The rest is made up of Dark Matter and Dark Energy.

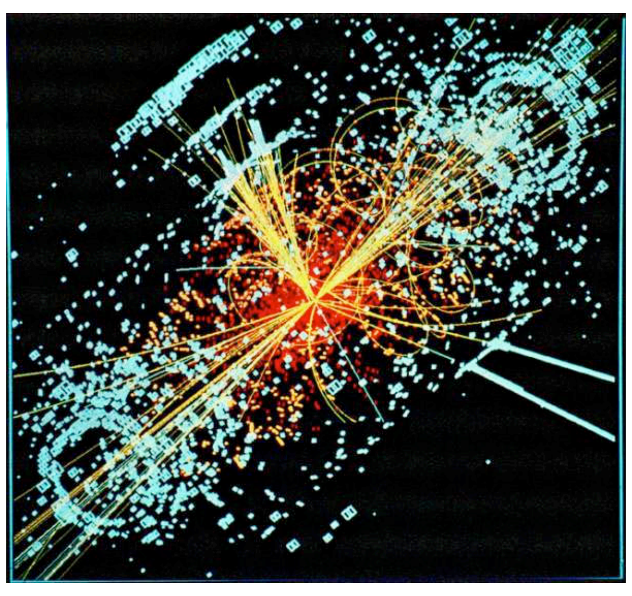




Dark matter cannot be directly observed as it doesn't emit or absorb electromagnetic radiation. But its presence is inferred by its gravitational influence on the matter we can observe. Two excellent examples are:

- Observations of the motions of stars and gas moving around galaxies, allowing their mass to be calculated.
- A recent image of the Bullet cluster showing the separation of the majority of ordinary matter (pink) from the dark matter (blue), following a collision.





This dark matter is in the form of a new type of particle not previously detected. The currently favoured candidate particles are WIMPs or Weakly Interacting Massive Particles.

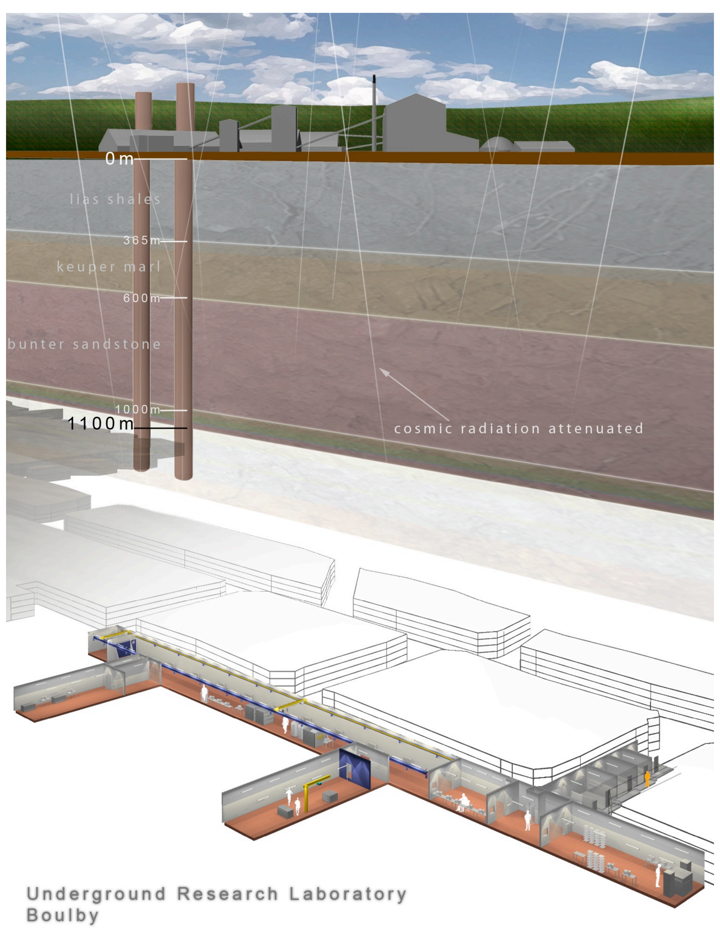
The most probable type of WIMPs are called neutralinos, supersymmetric particles predicted by particle physics. Such supersymmetric particles should be created by higher energy particle collisions in the Large Hadron Collider at CERN, providing clues to the particles making up dark matter.

Where should we look?

To look for these very rare interactions we need an extremely low-background environment. We do this by constructing our detectors out of carefully selected low-background materials in a cleanroom environment.

The detectors are placed inside a shielding castle to block gamma-rays and neutrons, but even this excellent setup would not prevent the large background from cosmic rays.

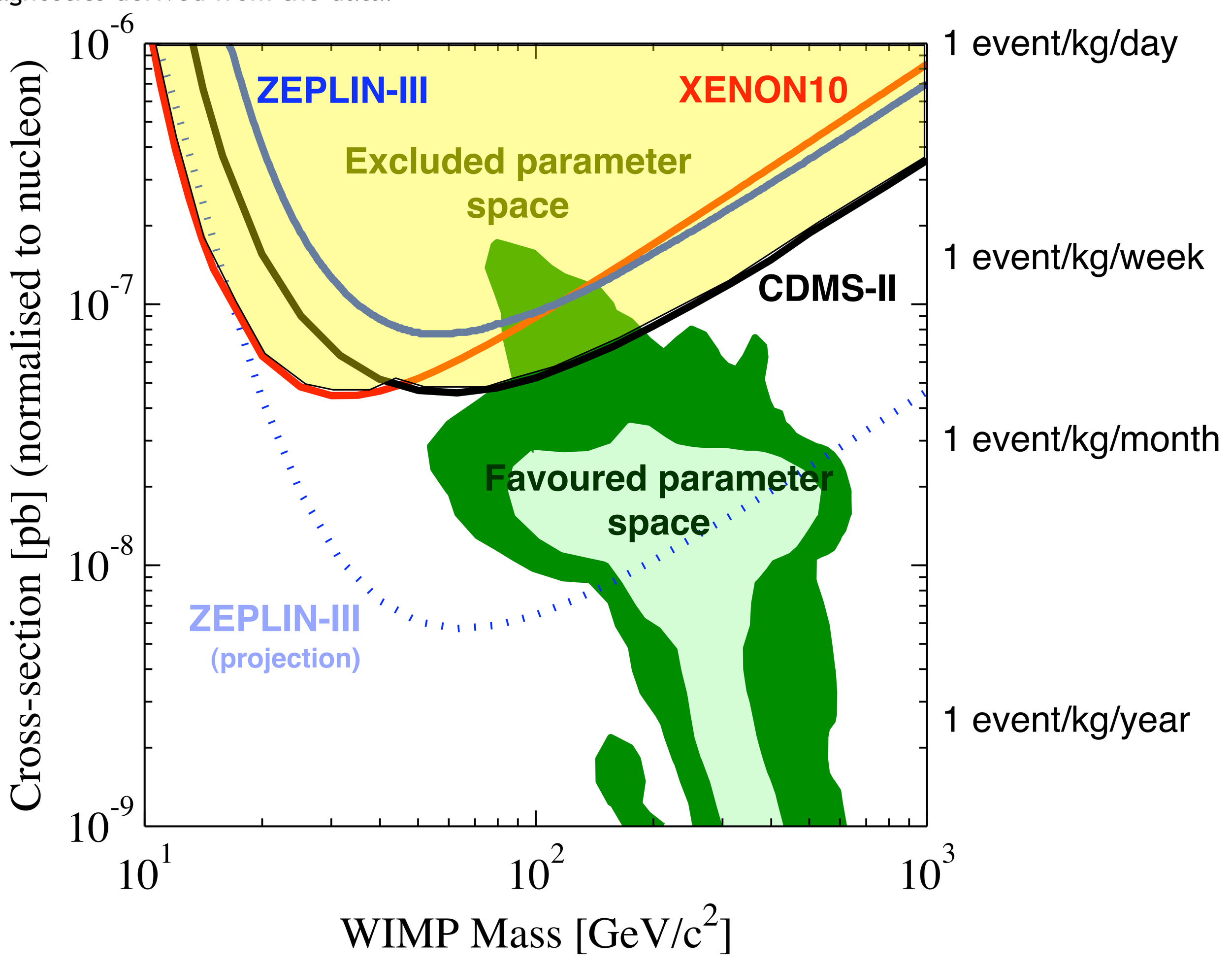
To shield against cosmic rays we take our detectors deep underground. ZEPLIN-III is operated at the **Palmer Underground Laboratory, Boulby Mine, North Yorkshire,** where the 1100m of rock above the lab reduces the flux of cosmic rays by a factor of **1,000,000.**



The mine is operated by Cleveland Potash Ltd with the underground lab being an excellent partnership of academia and UK industry.

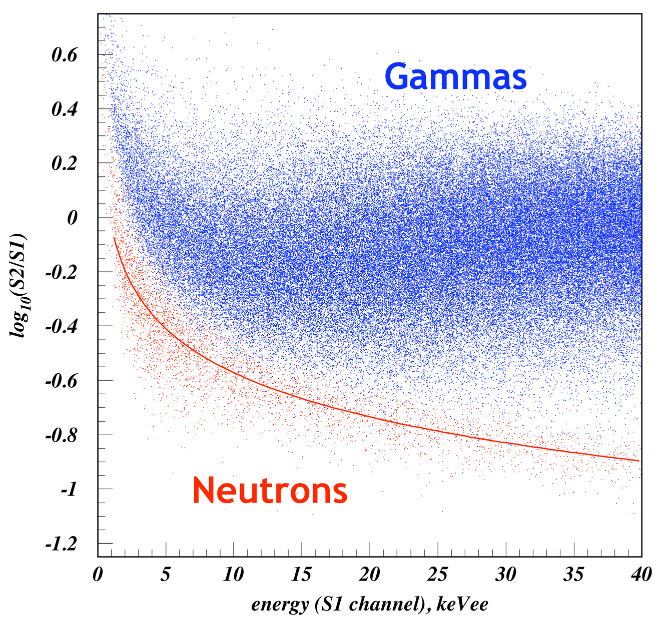
What are the results so far?

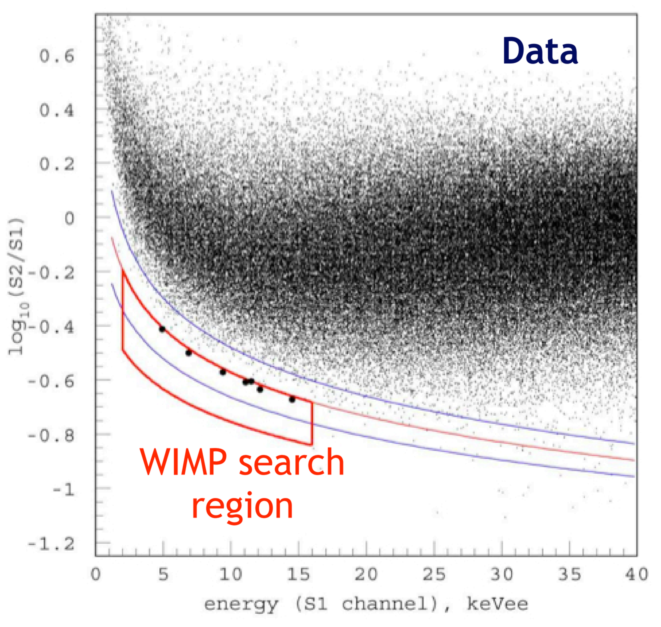
The first science run of ZEPLIN-III lasted for **83 days**, collecting 453 kg.days of exposure. During this period the instrument was extremely stable and was monitored with a range of sensors along with diagnostics derived from the data.



The response of the detector to electron and nuclear recoils, mimicking the gamma-ray background and expected WIMP signal, is done with gamma and neutron calibrations.

The expected signal region is examined in the background data, with the observed events statistically evaluated as a possible signal. The 7 events observed were consistent with background, leaving **no evidence of a WIMP signal.**





As a result of the analysis, constraints can be placed on the properties of the WIMP particles. WIMPs have not yet been observed, although the leading experiments in the world are beginning to exclude significant regions of the theoretical parameter space.

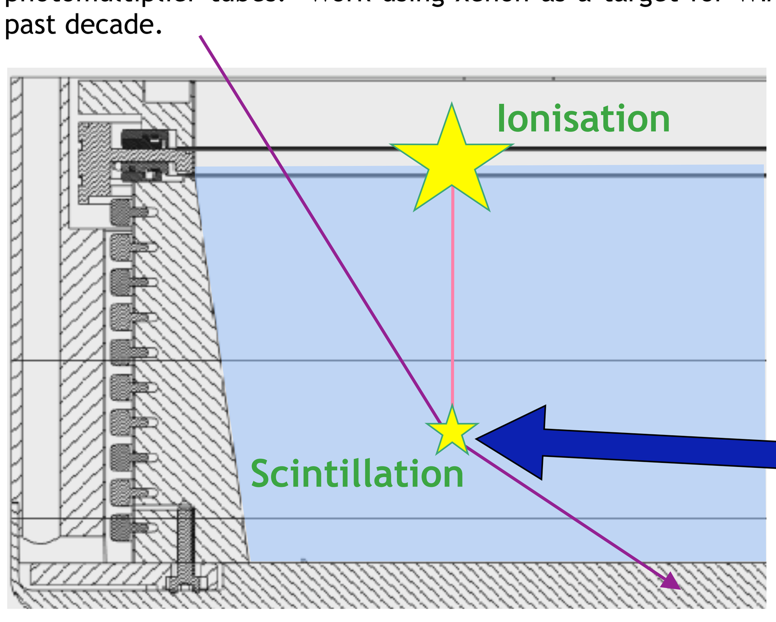
The result from the first science run of ZEPLIN-III places it among the **top experiments in the world**, setting a limit on the WIMP-nucleon cross-section of **7.7×10^{-8} pb** for a WIMP mass of 55 GeV/c^2. The detector upgrade should provide an excellent opportunity to push the limits to an even more significant level.

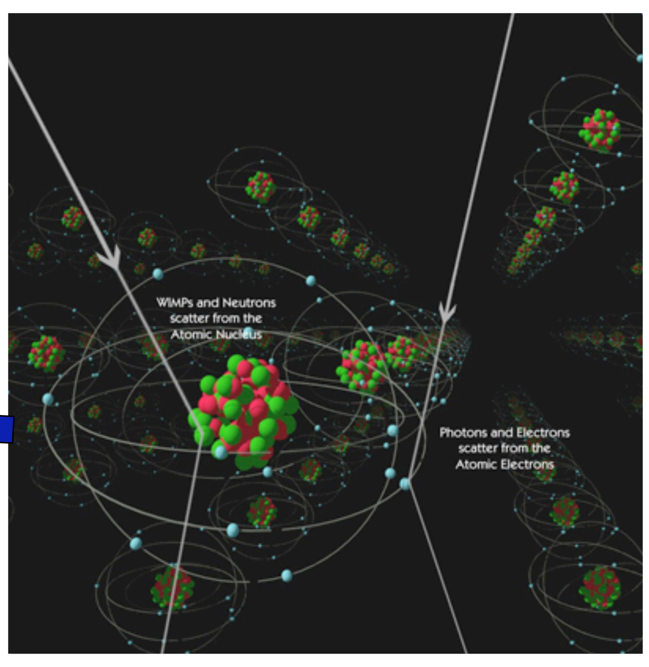
Results submitted to Phys. Rev. D (2008). Available from: V.N.Lebedenko et al, arXiv:0812.1150

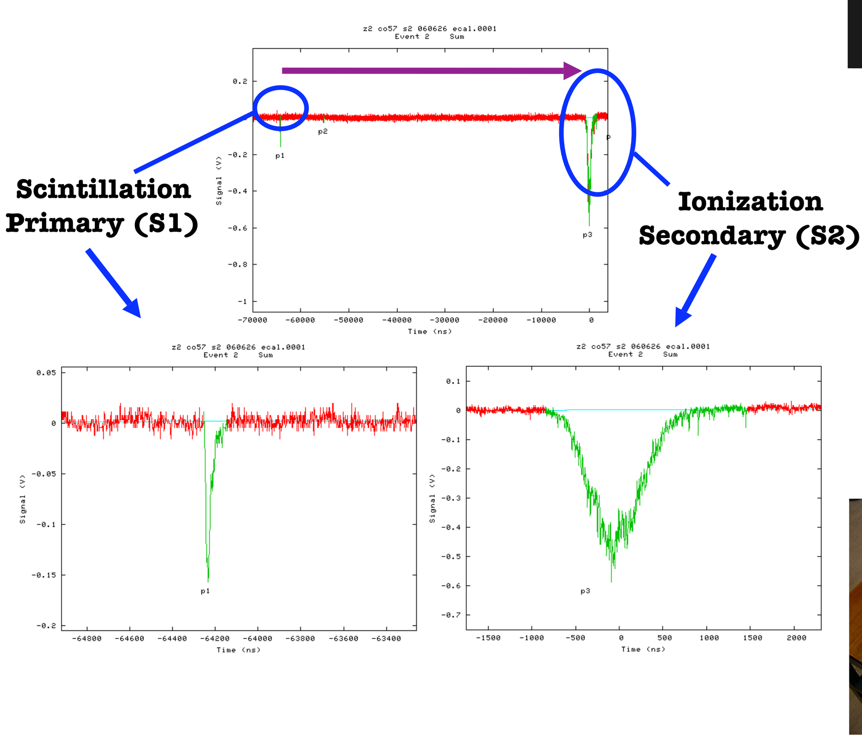
How can we detect it?

WIMPs are expected to interact with baryonic matter very rarely, causing low-energy **nuclear recoils**. To detect these we need to build a low-background detector with a target material providing the maximum number of these recoils.

Liquid xenon is chosen for its high Z number, density and radio-purity. When a WIMP interacts with a xenon nucleus it causes it to recoil, producing both scintillation and ionisation. These signals can be detected by an array of photomultiplier tubes. Work using xenon as a target for WIMP detection has been **spearheaded by the UK** for the past decade.

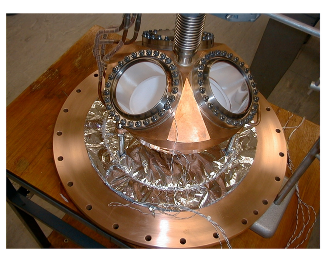




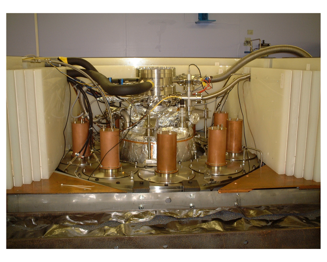


These nuclear recoils have a **different scintillation/ionisation** ratio than the electron recoils produced by the gamma-ray background. This difference allows for **discrimination** between the background events and a WIMP signal.

The UK has been a major part in developing detectors using liquid xenon as a WIMP target, with ZEPLIN-I and ZEPLIN-II producing important results and demonstrating the potential of the technique.



ZEPLIN-I



ZEPLIN-II

What is ZEPLIN-III?

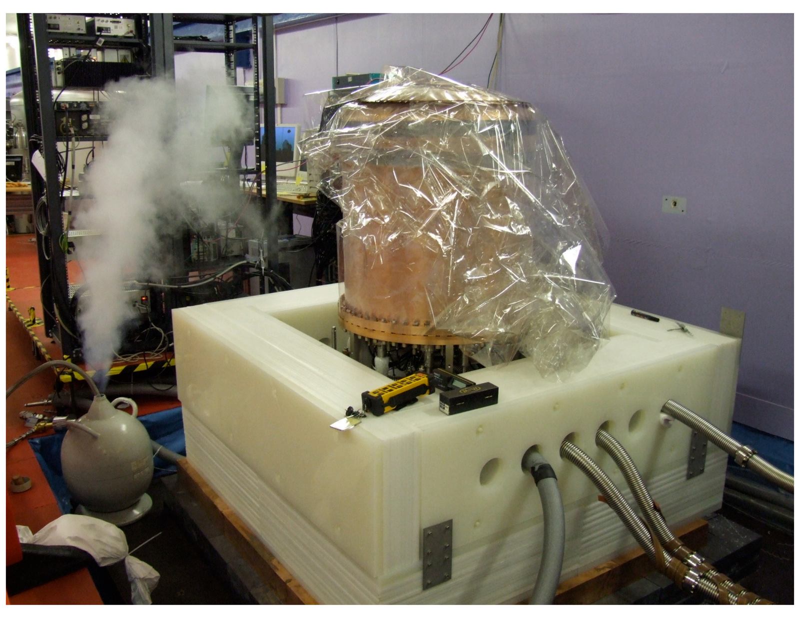
ZEPLIN-III is a UK-led experiment operated by an international collaboration, using two-phase xenon as a target for WIMP interactions. It is the culmination of the ZEPLIN programme with almost a decade of development, resulting in a design including many unique features designed to enhance its performance and demonstrate the power of the two-phase xenon technique.

The Collaboration

ZEPLIN-III is a collaboration between Imperial College London, STFC Rutherford Appleton Laboratory, University of Edinburgh, ITEP Moscow (Russia), LIP-Coimbra (Portugal).

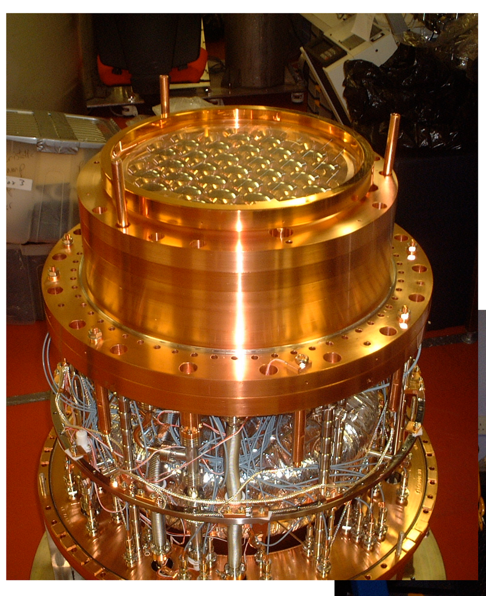
Cooling

The instrument is cooled by liquid nitrogen, maintaining the liquid xenon at about -100 °C, with excellent stability (< 0.5 °C).



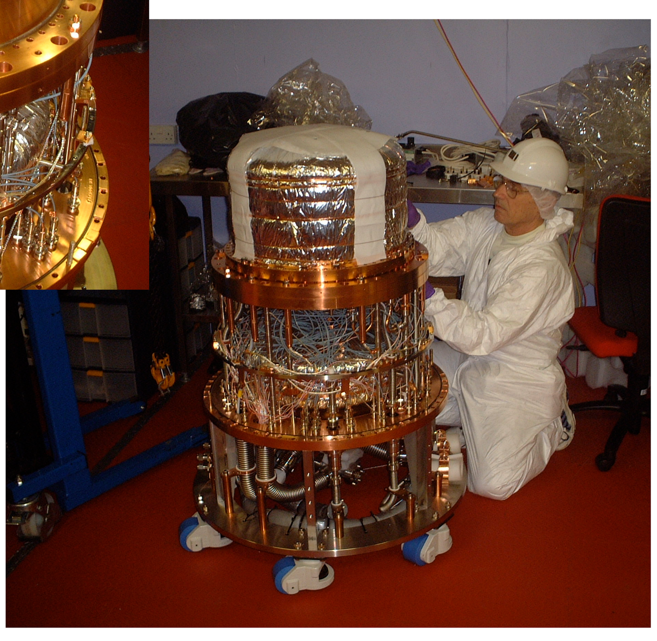
Photomultiplier tubes

An array of 31 PMTs record the signals produced by the scintillation and ionisation with good efficiency. New ultra-low-background PMTs have been developed for the detector upgrade by British company, ETL.



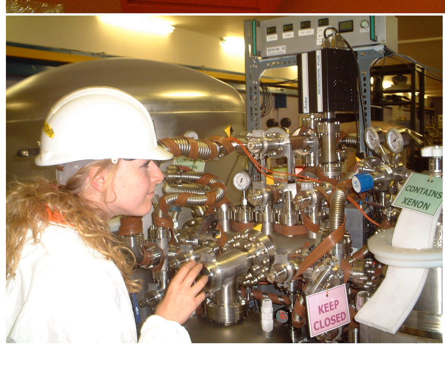
Detector target

The target is constructed out of low-background copper, with great care to maintain cleanliness and protect the delicate detector components.



Shielding

The detector is housed within a castle consisting of 20 cm of Lead and 30 cm of hydrocarbon.



Gas system

The xenon gas is managed and purified in a ultra-clean stainless steel system, with large dumps providing the safety mechanism.