

Dark matter – investigating the universe's hidden secrets

One of the biggest mysteries of the Universe is that, through observations, we know we can only account for a sixth of the mass out there. The rest is put down to a mysterious substance called 'dark matter', and we need physics beyond the Standard Model of particle physics to explain it. **Professor Richard Milner** and **Professor Peter Fisher** from the Massachusetts Institute of Technology (MIT) are helping us get closer to understanding the mystery with a new experiment, soon to begin its first set of data collection.

The Standard Model of particle physics describes the most basic building blocks of matter, from electrons to quarks, and the forces that govern the way they interact. It is arguably one of the best scientific theories to date, describing with great accuracy how atoms stick together, how radioactivity works in the sun and how the Universe was formed. But it is incomplete. There are a few observations we cannot explain using the Standard Model, and one of these is called dark matter.

When astronomers peer into the Universe, they can measure the amount of mass in

galaxies by studying how the galaxies move. But when the total mass from everything we can actually see is added up, there is a huge amount missing. Particles described by the Standard Model, the ones we can see, only make up a sixth of the mass of the Universe – so where is the rest of the mass coming from?

This mysterious substance has been given the name 'dark matter', because it does not interact with light the way normal matter does, so we cannot see it. It could be one kind of particle, or it could be thousands of different particles, but at the moment we do not know.

DARKLIGHT

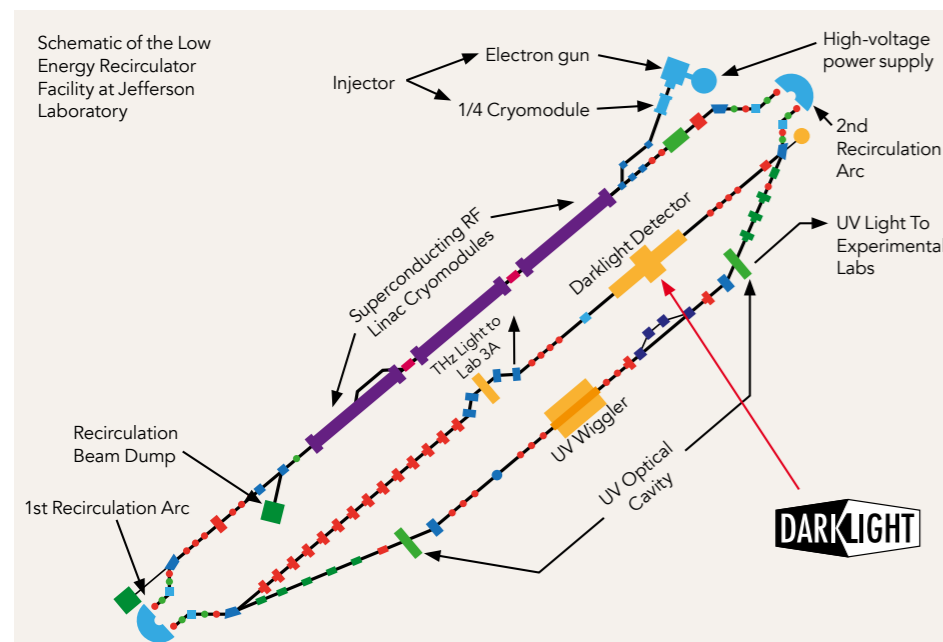
Physicists like Professors Richard Milner and Peter Fisher from the Massachusetts Institute of Technology (MIT) are seeking to find out what dark matter is. The two now lead an MIT-conceived experiment called Detecting A Resonance Kinematically with electrons Incident on a Gaseous Hydrogen Target – or DarkLight for short. The experiment will use the latest technology to look beyond the Standard Model, to try and delve into the world of dark matter. The MIT DarkLight group led by Milner and Fisher includes four PhD researchers, five graduate students, several undergraduate students, and technical support from the Bates Research and Engineering Center. MIT theoretical physicist Professor Jesse Thaler and his group have provided key calculations that have guided the design of the DarkLight experiment.

In 2013, a paper was published in the journal Physical Review Letters, revealing the potential of electron beams for use in particle physics experiments. One year later, in 2014, a group of physicists from MIT, alongside others from Hampton University, Arizona State University and Temple University, were awarded a grant to build the first phase of the DarkLight experiment, at the Thomas Jefferson National Laboratory in Virginia.

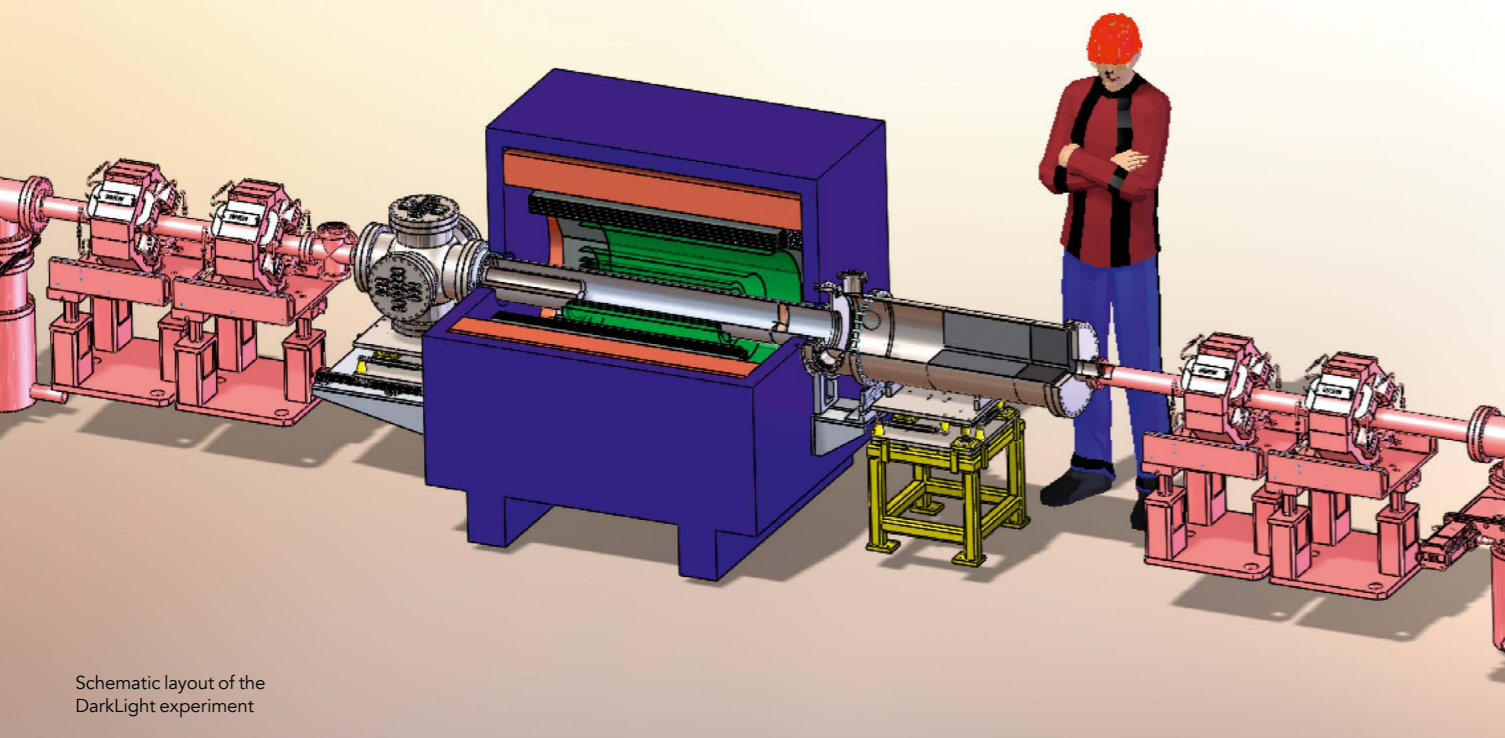
The experiment will send powerful beams of electrons through a linear accelerator on to a target of hydrogen atoms, which they will scatter off to create electron and positron pairs. For this purpose, the DarkLight experiment uses one of the most powerful electron beams in the world, located at Jefferson Laboratory, Newport News, Virginia, USA.

DARK PHOTONS AND NEW FORCES

The experiment was originally motivated by the possibility of a new A' gauge boson, giving rise to a dark (massive) photon. DarkLight is designed to search for new particles having a mass between 10 and 90 MeV, so we need energies up to about 100 MeV to see it. The dark photon, if it exists, ▶



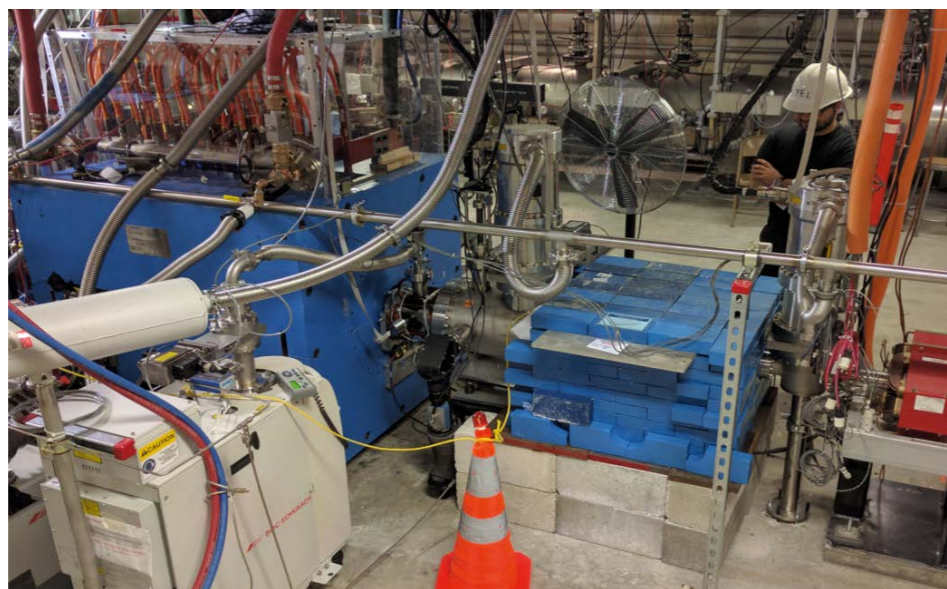
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would be exciting because it would interact with both light and dark matter. This would provide a window through which we could study the mysterious properties of dark matter. Recent theoretical work has shown that DarkLight is sensitive to a broad class of new (fifth) forces.

This new force could also explain another mystery in the Standard Model. The muon, a heavier cousin of the electron, has been an enigma for some time. Although it is 207 times more massive, the particle acts like a tiny magnet – just like the electron. But curiously, in 2001, an experiment at the Brookhaven National Lab (BNL) in New York measured the particle's magnetic moment and found it was larger than the predictions of the Standard Model. This could have been a statistical fluke, or it could mean something else is at play. If a new force exists, it may explain this discrepancy.

Construction of the initial phase of Profs Milner and Fisher's experiment was completed in August 2016, and is ready for testing. In the past year, the researchers



optimised the design of the experiment and its ability to gather data. As of now, it is ready to go, with the first phase of the experiment due to be finished in the next several years.

The DarkLight experiment will use the latest technology to look beyond the Standard Model, to try and delve into the world of dark matter

One of the first sets of data to be taken by the experiment will be a search for a particle with a mass around 17 MeV for electron positron pair decays. This search at 17 MeV is exciting because an experiment at the Hungarian Academy for Science's Institute for Nuclear Research, in Drebecen, Hungary, found something surprising when looking at the decay of the Beryllium-8 nucleus, in 2015. The results hinted at the possibility of a particle weighing in at 17 MeV, only 34 times heavier than the electron, but these data alone are not enough to come to a conclusive result.

Q&A

What is your involvement in the DarkLight experiment?

We realised that an experiment to look for electron-positron final-states in elastic electron-proton scattering at low energies offered a unique means to search for new physics that could bear on understanding the elusive dark matter. The mass region 10 to 100 MeV is difficult to access at high energies. Thus, we were motivated to propose the experiment. We oversee the collaboration and the sizable MIT group that leads it.

Why are you personally interested in the search for dark matter?

Dark matter is a profound mystery at this time. Astrophysical observations tell us that the amount of dark matter significantly exceeds the amount of visible matter, which is what physicists have studied since the dawn of history. If we wish to understand the physical universe, we must understand dark matter.

How could the dark photon explain the muon magnetic moment mystery?

The dark photon or a similar new particle can produce a new contribution to the

theoretical expectation and does bring it in line with the measure value. We note that physicists are mounting a more precise determination of the muon magnetic moment and results are expected within several years.

When do you expect the results of the 17 MeV search to be gathered and analysed by?

If funding and beam time become available in a timely way, we expect to have data within two years. However, government funding of science in the US at present is uncertain.

What would it mean if we found a particle or force not described by the Standard Model?

It would be a huge deal for physicists. Newton gave us the gravitational force. Maxwell described electricity and magnetism in his famous equations. Quantum mechanics has allowed us to describe and generalise these fundamental forces. Discovery of a new interaction beyond those described in the present Standard Model would be revolutionary.

If we wish to understand the physical universe, we must understand dark matter

If it does exist, this mysterious particle could hint at a fifth fundamental force – beyond the Standard Model, because the data does not fit with any previous experiments. It may or may not be a dark photon, but even if it is not, a new kind of particle would bring completely new possibilities for understanding physics beyond the Standard Model. This is why DarkLight will be searching in that energy region, to either find the particle, or to find the limits of how it interacts with other kinds of matter.

After this run, future data taking with the experiment will be looking for electron positron pairs with masses between 30 and 70 MeV. New accelerators are under construction at Cornell University, New York and at the University of Mainz, Germany to pursue the DarkLight experimental approach.

Whether a dark photon is discovered or not, the DarkLight experiment will bring us one step closer to a complete understanding of the most fundamental rules that govern everything around us.

Detail

RESEARCH OBJECTIVES

Prof Milner and Prof Fisher's current research mainly focuses on particle physics in the areas of dark matter detection and the development of new kinds of particle detectors.

FUNDING

US National Science Foundation and US Department of Energy, Office of Science

COLLABORATORS

The DarkLight experiment is carried out by a collaboration of physicists and engineers from MIT, Jefferson Laboratory, Arizona State University, Hampton University, Temple University in the US and from CEA-Saclay in France.

BIO



Prof Peter Fisher is a Professor in the MIT Physics Department and currently serves as department head. Prof Fisher received a BS Engineering Physics from Berkeley in 1983 and a PhD in Nuclear Physics from Caltech in 1988.



Prof Richard Milner is a Professor in the MIT Physics Department. He received his BSc in Experimental Physics in 1978 and MSc in Theoretical Physics in 1979 from University College Cork, Ireland. He later received a PhD in Nuclear Physics from Caltech in 1984.

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