

## Impact case study (REF3b)

<b>Institution:</b> Swansea University
<b>Unit of Assessment:</b> 9 - Physics
<b>Title of case study:</b> Antimatter: From Hollywood to CERN
<b>1. Summary of the impact</b>

In public perception, antimatter used to be associated with science fiction, but the **creation and trapping of antihydrogen at CERN** by the ATHENA and ALPHA Collaborations has sparked **world-wide media interest** in the real science of antimatter. Building on this, we started a campaign of public dissemination and education to promote and explain our work through media interviews, popular articles, and public lectures including a Welsh language component. We developed **software simulators** that have been used by school pupils in **Masterclasses** to re-create virtually CERN's antihydrogen production. YouTube clips and webcasts with over **100,000 hits** have been produced and we have hosted **thousands of visitors** per year in CERN. These activities resulted in improved understanding of antimatter among school students and the wider population, and a radical change in the public perception of antimatter, which is now associated with the experiments at CERN rather than with Star Trek.

<b>2. Underpinning research</b>
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The underpinning research is a series of **world firsts in fundamental physics**: namely the production, trapping, storing and initial spectroscopy of cold antihydrogen atoms by the ATHENA ([athena.web.cern.ch/athena](http://athena.web.cern.ch/athena)) and ALPHA ([alpha-new.web.cern.ch](http://alpha-new.web.cern.ch)) collaborations at CERN. These research milestones have been published in Nature (2002, 2010 and 2012) and in Nature Physics (2011) (see [R1-R4] below), with supporting publications in other leading physics journals such as Physical Review Letters and Physics Letters B. The capture of small quantities of atomic antimatter in a neutral atom trap has opened up the new field of antimatter spectroscopy and we have been deeply involved in the first experiment of this type ever to be performed as well as the earlier preparatory phases, as summarised in [R5].

The Swansea Atomic, Molecular and Quantum Physics group, led by Prof Charlton (at Swansea since 1999) and including Bertsche (Swansea 2007-2011), Madsen (since 2005) and van der Werf (since 1999), has played a **leading role** in this antihydrogen research. We have the **largest representation** of any institution in CERN's antihydrogen experiments, and the **Swansea authorship out-numbers any other institution's** in the main underpinning references [R1-R4].

The first production of cold antihydrogen (ATHENA, see [R1]) was achieved by injecting antiprotons with a few electron-volts of kinetic energy into a positron cloud. Though antihydrogen atoms were copiously formed, detailed work indicated that they had retained some of the injection energy and were too hot to trap.

An intense development period followed in which a new apparatus was developed by ALPHA which incorporated a neutral atom trap superimposed upon the charged particle traps for the positrons and antiprotons. Colder antiparticle plasmas combined with a new antiproton injection scheme based upon autoresonant excitation allowed some of the very coldest antihydrogen atoms to be trapped [R2]. The cryogenic environment inside the apparatus meant that the gas pressure was extremely low, and we were able to demonstrate storage of antihydrogen for over 15 minutes [R3]. This allowed us to insert microwaves into the apparatus to promote resonant interaction with the trapped anti-atoms [R4], the **first ever spectroscopy of an antimatter atom**.

<b>3. References to the research</b>
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**Publications (R1, R2, and R4 best represent the quality of the research.)**

[R1] M. Amoretti et al. [ATHENA Collaboration], "Production and detection of cold antihydrogen atoms", Nature 419 (2002) 456. [doi:10.1038/nature01096](https://doi.org/10.1038/nature01096). [Impact factor 36.3] Total number

## Impact case study (REF3b)

*of authors = 39 from 9 institutions. Number of Swansea authors = 7 which makes Swansea the largest contributing institution.*

- [R2] G.B. Andresen et al. [ALPHA Collaboration], “Trapped antihydrogen”, Nature 468 (2010) 673. [doi:10.1038/nature09610](https://doi.org/10.1038/nature09610) [Impact factor 36.3] Total number of authors = 42 from 16 institutions. **Number of Swansea authors = 10 which makes Swansea the largest contributing institution.**
- [R3] G.B. Andresen et al. [ALPHA Collaboration], “Confinement of antihydrogen for 1,000 seconds”, Nature Physics 7 (2011) 558. [doi:10.1038/nphys2025](https://doi.org/10.1038/nphys2025) [Impact factor 19.0] Total number of authors = 40 from 19 institutions. **Number of Swansea authors = 7 which makes Swansea the largest contributing institution.**
- [R4] C. Amole et al. [ALPHA Collaboration], “Resonant quantum transitions in trapped antihydrogen atoms”, Nature 483 (2012) 439. [doi:10.1038/nature10942](https://doi.org/10.1038/nature10942) [Impact factor 36.3] Total number of authors = 43 from 20 institutions. **Number of Swansea authors = 10 which makes Swansea the largest contributing institution.**
- [R5] M. Holzschneider, **M. Charlton** and M.M. Nieto, “The route to ultra-low energy anti-hydrogen”, Phys. Rep. 402 (2004) 1. [doi:10.1016/j.physrep.2004.08.002](https://doi.org/10.1016/j.physrep.2004.08.002) [Impact factor 19.4]

These publications have been cited a total of around 700 times, with the 2002 breakthrough paper alone attracting well over 400 citations.

### Recent major grants include:

- [G1] **Charlton** (PI) “The Spectroscopy of Antihydrogen”, EPSRC Critical Mass Award (2010-14) [EP/H026932/1](https://epubs1.embl.org/EP/H026932/1) £2.3m
- [G2] **Charlton** (PI) “Senior Research Fellowship: Antihydrogen Physics”, EPSRC grant (2007-12) [EP/E048951/1](https://epubs1.embl.org/EP/E048951/1) £835k
- [G3] **Charlton** (PI) “Trapped Antihydrogen – Towards Spectroscopy”, EPSRC grant (2006-10) [EP/D038707/1](https://epubs1.embl.org/EP/D038707/1) £787k
- [G4] **Madsen** (PI) “First Spectroscopy of Antihydrogen with Laser-Cooling assisted Antihydrogen Trapping”, EPSRC Standard Award (2013-18) [EP/K017373/1](https://epubs1.embl.org/EP/K017373/1) £1.5m
- [G5] **van der Werf** (PI) “Research Fellowship: Probing the Rydberg levels of Positronium”, Leverhulme Trust (2012-14) RF-2012-495 £41k

In 2005 the project was selected by **EPSRC** as one of the **highlights of their first 10 years** ([www.epsrc.ac.uk/newsevents/news/2005/Pages/newsline33.aspx](http://www.epsrc.ac.uk/newsevents/news/2005/Pages/newsline33.aspx)). In 2010 our advance in antihydrogen trapping was selected by **Physics World** as **The Physics Breakthrough of the Year** ([physicsworld.com/cws/article/news/44618](http://physicsworld.com/cws/article/news/44618)). Four Swansea-based physicists (Bertsche, Charlton, Madsen and van der Werf) along with seven other ALPHA colleagues from five institutions, were awarded the **American Physical Society’s 2011 John Dawson Award** for Excellence in Plasma Physics Research for their contribution to the trapping success ([www.aps.org/programs/honors/awards/dawson.cfm](http://www.aps.org/programs/honors/awards/dawson.cfm)).

## 4. Details of the impact

Recent discoveries in fundamental physics have resonated with the public’s imagination and the world’s media and offered a perfect platform to **engage, enthuse and educate** both the young and not-so-young with science. Our UoA grasped the opportunity given by this media attention to develop a systematic programme of public engagement, centred on our antimatter research.

The trapping and storing of antihydrogen (November 2010) produced **extensive global media interest**; many TV channels, such as the BBC [C1] and CNN featured the story in their news bulletins, articles appeared in over 100 newspapers in 25 countries in 15 languages [C2] as well as in all of the UK’s national broadsheets [C3], and a Guardian profile of Charlton was published in 2009 [C4]. UoA researchers regularly appeared in the media continuing our group’s public engagement by describing our research [C5].

## Impact case study (REF3b)

As well as articles on ALPHA in the popular press, the results have also been featured in **scientific magazines** and websites that are read by the public as well as researchers, such as Nature [C6], Scientific American [C7], Physics World [C8] and New Scientist [C9]. Other accounts have appeared in RCUK articles [C10] and in the Times Higher Education Supplement [C11]. Charlton and colleagues wrote educational articles [C12] and gave **public lectures at Science Festivals** including Cheltenham in 2013 [C13].

We have hosted two annual events for high school students for a number of years: Particle Physics **Masterclasses** [C14] and **Schools Lectures** designed to inspire young people to study physics. Both these events are heavily over-subscribed: 2,500 students have attended our Schools Lectures since 2008 and last year, there were over 150 students registered for the Masterclasses. As a result of this demand, we have doubled the number of Schools Lectures and trebled the number of Masterclass events we hold each year.

Having established this foundation in our engagement work with school students, we broadened and refined our events by creating a **virtual ALPHA experiment** “*Hands on Antihydrogen*”. This bespoke software was written by a programmer employed within the UoA by an EPSRC “Pathways to Impact” grant totalling £39k [C15]. It is analogous to the Atlantis event display software developed by the LHC’s ATLAS collaboration, but is interactive rather than static. The user injects positrons, antiprotons and electrons and manipulates the electromagnetic trap parameters in order to confine and then cool the particles before antihydrogen can be produced, recreating virtually the actual CERN experiment.

**Using questionnaires, we measured the impact** of using this software and the associated antimatter lectures on the students’ understanding. The statistics show that, as a result of our antimatter Masterclasses, the students’ knowledge of antimatter increased by 150%, there was a 50% increase in the number who understood both the relevance of antimatter and where it is produced, and a significant increase in the number who understood its interactions.

In 2012, we exhibited our antihydrogen work at the National Eisteddfod aided by an STFC “Science in Society” grant [C16]. Our presentation attracted 26,000 visitors to the Science Pavilion, and was broadcast on the **Welsh language** TV channel S4C. A centrepiece of the Physics stand was a large, bilingual (English and Welsh) exhibition board, summarising the ALPHA antihydrogen experiment staffed by bilingual presenters from our UoA. In addition we presented our antihydrogen research at the Urdd (Youth) Eisteddfod each year from 2011, with an average attendance of 14,000 in the GwyddonLe (Science Tent) [C17].

Outreach is a core activity at CERN. The antimatter facility is open for weekly **public tours** regularly led by our UoA’s Madsen who is an official Antiproton Decelerator guide, and the content of the tours draws directly on the research described above. The impact of these visits to the antimatter hall (**several thousands per year**) is clear from the emails and letters sent to CERN [C18]. These include those from students stating that as a result of the visit they want to study physics and come back to CERN, for example: “*so many thanks for a brilliant, amazing, inspiring day*” – School pupil visitor.

ALPHA has access to CERN’s media unit, and educational videos about the antihydrogen experiment have been produced for CERN’s **YouTube** channel [C19] receiving over **100,000 hits**. We also produced a special CERN interactive **webcast** on antimatter in November 2012 [C20] which had a record number of viewers [C18], and the ALPHA website in CERN received 10,000 hits in 2012 [C21].

The plot of the 2009 film **Angels and Demons** (which grossed \$500m) exploits the CERN antihydrogen project and is based on the best-selling 2001 novel of the same name [C22]. The film and book credit CERN and the book acknowledges the Antiproton Decelerator and CERN’s “*advanced antimatter production facility*” on page 9. Although the plot centres on the creation and storage of antimatter in CERN, it contains a number of scientific gaffes. An associated book *Secrets of Angels and Demons* [C23] correctly explains the science behind the actual CERN research and contains extensive coverage of ATHENA. CERN also maintains a website for members of the public curious about the facts behind the *Angels and Demons* fiction [C24].

**Impact case study (REF3b)**

**Summary:** Swansea's antimatter research has achieved significant **impact through public engagement** building on our world-leading research in CERN. This has accomplished:

**Reach:** Global media interest; scientific magazine articles; Science Festival lectures; *Angels and Demons*; CERN public tours; YouTube educational videos and webcasts.

**Significance:** Masterclasses; school lectures; improved public understanding of science; software for a virtual antihydrogen experiment; Welsh language exposure.

As a result the **public perception and understanding** of antimatter has moved from the stuff of science fiction and Star Trek to real science and actual experiments in CERN.

<b>5. Sources to corroborate the impact</b>
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- [C1] [www.bbc.co.uk/news/science-environment-11773791](http://www.bbc.co.uk/news/science-environment-11773791), <http://www.bbc.co.uk/news/science-environment-13666892>
- [C2] The ALPHA Collaboration maintains a list of media stories about their work: [alpha-new.web.cern.ch/trappedNews](http://alpha-new.web.cern.ch/trappedNews); [alpha-new.web.cern.ch/trappedHbarNews](http://alpha-new.web.cern.ch/trappedHbarNews); [alpha.web.cern.ch/node/254](http://alpha.web.cern.ch/node/254) Many more stories are not captured by these lists.
- [C3] List of UK broadsheets covering the antimatter trapping story, November 2010: [Guardian](#), [Independent](#), [Daily Mail](#), [The Telegraph](#), [The Times](#)
- [C4] The *Guardian*, "[Angels and Demons: the Swansea connection](#)", 17 Nov 2009
- [C5] **Charlton:** BBC Wales broadcast, February 2011; **Isaac:** S4C (Welsh language TV) interview at the Urdd Eisteddfod; **Madsen:** TSR (Swiss TV news) 18/11/2010, BBC Material World 18/11/2010 [www.bbc.co.uk/programmes/b00vy38g](http://www.bbc.co.uk/programmes/b00vy38g), France Culture 07/01/2011 [tinyurl.com/pm9k5ro](http://tinyurl.com/pm9k5ro); **van der Werf:** BBC radio "Good Evening Wales" (6/3/12 & 12/6/12), Radio Cardiff (26/3/12 & 2/4/12)
- [C6] [Nature 468, 355 \(2010\)](#)
- [C7] *Scientific American*, "[Making cold antimatter](#)", June 2005, 57
- [C8] *Physics World*, "[Probing the antiworld](#)", M. Charlton and J. Hangst, October 2005, 22
- [C9] *New Scientist*, "[Why isn't there an antiworld](#)", April 2009, 36
- [C10] *EPSRC Newslines*, "Antimatter research", Spring 2005, 7; *PPARC Frontiers*, "Trapping antihydrogen", Winter 2007, 36; *CERN Courier*, "[ALPHA Collaboration gets antihydrogen in the trap](#)", February 2011
- [C11] *Times Higher Education*, "Critical Mass Award", February 2010, 21
- [C12] M.Charlton, "Antihydrogen on tap", [Physics Education 40 \(2005\) 229](#); M. Charlton, S.Eriksson, C.A.Isaac, N.Madsen and D.P.van der Werf, "Antihydrogen in a bottle", [Physics Education 48 \(2013\) 212](#), Welsh translation: [tinyurl.com/n9qffxc](http://tinyurl.com/n9qffxc) and Danish translation: (Antibrint på flaske) in LMF-bladet 1/2013, p30
- [C13] Cardiff Science Festival 14<sup>th</sup> July 2012, Times Cheltenham Science Festival 7<sup>th</sup> June 2013, [www.cheltenhamfestivals.com/science](http://www.cheltenhamfestivals.com/science)
- [C14] [www.particlephysics.ac.uk/teach/master-classes.html](http://www.particlephysics.ac.uk/teach/master-classes.html)
- [C15] EPSRC "Pathways to Impact" grant, [EP/I500375/1](http://EP/I500375/1)
- [C16] STFC Science in Society Grant "CERN@Eisteddfod Particle Physics Exhibition" [ST/J501360/1](http://ST/J501360/1)
- [C17] The Urdd Eisteddfod [urdd.org](http://urdd.org)
- [C18] Visitors' correspondence sent to, and statistics collated by Research Physicist, CERN
- [C19] YouTube playlist: [tinyurl.com/oroenpr](http://tinyurl.com/oroenpr)
- [C20] Webcast: "Hangout With CERN: Antimatter" [tinyurl.com/pl5x6bw](http://tinyurl.com/pl5x6bw)
- [C21] Web statistics from Research Fellow, ALPHA Experiment, CERN (now at Imperial College London)
- [C22] *Angels and Demons*, Columbia Pictures 2009, D. Brown, Pocket Books Publishing, 2000
- [C23] [Secrets of Angels and Demons](#), D. Burstein and A. de Keijzer, eds., Orion Publishing, 2005
- [C24] [public.web.cern.ch/public/en/Spotlight/SpotlightAandD-en.html](http://public.web.cern.ch/public/en/Spotlight/SpotlightAandD-en.html)  
[angelsanddemons.web.cern.ch/](http://angelsanddemons.web.cern.ch/)