UK Nuclear Activity

November 2015 Issue 29

In this issue,

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1. Nuclear Physics Publications for November*

If you are publishing a paper that you think would be of media value please let Wendy Ellison wendy.ellison@stfc.ac.uk , STFC Press Officer, know. She can help with press releases and publicity. If you get in touch with her before publication she can also get material ready in advance for the day of publication.

JHEP, 09 (2015) 170 http://link.springer.com/article/10.1007/JHEP09(2015)170
Measurement of jet quenching with semi-inclusive hadron-jet distributions in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE Collaboration, UK Authors: D. Alexandre, L.S. Barnby, M. Borri, M. Chartier, D. Evans, M.A.S. Figueredo, K.L. Graham, P.G. Jones, A. Jusko, M. Krivda, G.R. Lee, R.C. Lemmon, R. Lietava, J. Norman, R. Romita, O. Villalobos Baillie, N. Zardoshti
*Published September 2015

JHEP, 09 (2015) 148 http://link.springer.com/article/10.1007/JHEP09(2015)148
Measurement of charm and beauty production at central rapidity versus charged-particle multiplicity in proton-proton collisions at $\sqrt{s}$ = 7 TeV
ALICE Collaboration, UK Authors: D. Alexandre, L.S. Barnby, M. Borri, M. Chartier, D. Evans, M.A.S. Figueredo, L.D. Hanratty, P.G. Jones, A. Jusko, M. Krivda, G.R. Lee, R.C. Lemmon, R. Lietava, J. Norman, R. Romita, O. Villalobos Baillie
*Published September 2015

JHEP, 09 (2015) 095 http://link.springer.com/article/10.1007/JHEP09(2015)095
Coherent ρ^0 photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE Collaboration, UK Authors: D. Alexandre, L.S. Barnby, M. Borri, M. Chartier, D. Evans, M.A.S. Figueredo, L.D. Hanratty, P.G. Jones, A. Jusko, M. Krivda, G.R. Lee, R. Lietava, R.C. Lemmon, J. Norman, R. Romita, O. Villalobos Baillie
*Published September 2015

*Also including missed publications from previous months.

NIMA, 799, 90 (2015) http://www.sciencedirect.com/science/article/pii/S0168900215008566
The new vertical neutron beam line at the CERN n_TOF facility design and outlook on the performance
C. Weiß[a], E. Chiaveri[a], S. Girod[a], V. Vlachoudis[a], O. Aberle[a], S. Barros[b]… and the n_TOF Collaboration[1]
Published 1 November 2015

Phys. Rev. Lett. 115, 192501 (2015) http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.115.192501
Extension of the N=40 Island of Inversion towards N=50: Spectroscopy of ^{66}Cr, ^{70,72}Fe
C. Santamaria[1,2], C. Louchart[3], A. Obertelli[1,2], V. Werner[3,4], P. Doornenbal[2], F. Nowacki[5], G. Authelet[1], H. Baba[2], D. Calvet[1], F. Château[1], A. Corsi[1], A. Delbart[1], J.-M. Gheller[1], A. Gillibert[1], T. Isobe[2], V. Lapoux[1], M. Matsushita[6], S. Momiyama[2,7], T. Motobayashi[2], M. Niikura[7], H. Otsu[2], C. Péron[1], A. Peyaud[1], E. C. Pollacco[1], J.-Y. Roussé[1], H. Sakurai[2,7], M. Sasano[2], Y. Shiga[2,8], S. Takeuchi[2], R. Taniuchi[2,7], T. Uesaka[2], H. Wang[2], K. Yoneda[2], F. Browne[9], L. X. Chung[10], Zs. Dombradi[11], S. Franchoo[12], F. Giacoppo[13], A. Gottardo[12], K. Hadynska-Klek[13], Z. Korkulu[11], S. Koyama[2,7], Y. Kubota[2,6], J. Lee[14], M. Lettmann[3], R. Lozeva[5], K. Matsui[2,7], T. Miyazaki[2,7], S. Nishimura[2], L. Olivier[12], S. Ota[6], Z. Patel[15], N. Pietralla[3], E. Sahin[13], C. Shand[15], P.-A. Söderström[2], I. Stefan[12], D. Steppenbeck[6], T. Sumikama[16], D. Suzuki[12], Zs. Vajta[11], J. Wu[2,17], and Z. Xu[14]
Published 3 November 2015

Phys. Rev. C 92, 054610 (2015) http://journals.aps.org/prc/abstract/10.1103/PhysRevC.92.054610
Fission dynamics within time-dependent Hartree-Fock: Deformation-induced fission
Philip Goddard, Paul Stevenson[*], and Arnau Rios[†]
Published 11 November 2015

Phys. Letts. B, 750, 176 (2015) http://www.sciencedirect.com/science/article/pii/S0370269315006875
Evidence for Increased neutron and proton excitations between $^{51-63}$Mn
C. Babcock[a, b], H. Heylen[c], J. Billowes[d], M.L. Bissell[c], K. Blaum[e], P. Campbell[d], B. Cheal[a], R.F. Garcia Ruiz[c], C. Geppert[f, i], W. Gins[c], M. Kowalska[b], K. Kreim[e], S.M. Lenzi[g], I.D. Moore[h], R. Neugart[e, f], G. Neyens[c], W. Nörtershäuser[i], J. Papuga[c], D.T. Yordanov[e]
Published 12 November 2015

Phys. Letts. B, 750, 448 (2015) http://www.sciencedirect.com/science/article/pii/S0370269315007182
Lifetime measurements of the first 2^+ states in ^{104,106}Zr: Evolution of ground-state deformations
F. Browne[a, b], A.M. Bruce[a], T. Sumikama[c, b], I. Nishizuka[c], S. Nishimura[b], P. Doornenbal[b], G. Lorusso[b], P.-A. Söderström[b], H. Watanabe[d, b], R. Daido[e], Z. Patel[f, b], S. Rice[f, b], L. Sinclair[g, b], J. Wu[h, b], Z.Y. Xu[i, j], A. Yagi[e], H. Baba[b], N. Chiga[c, b], R. Carroll[f], F. Didierjean[k], Y. Fang[e], N. Fukuda[b], G. Gey[l, m, b], E. Ideguchi[e], N. Inabe[b], T. Isobe[b], D. Kameda[b], I. Kojouharov[n], N. Kurz[n], T. Kubo[b], S. Lalkovski[o], Z. Li[h], R. Lozeva[k], H. Nishibata[e], A. Odahara[e], Zs. Podolyák[f], P.H. Regan[f, p], O.J. Roberts[a], H. Sakurai[i, b], H. Schaffner[n], G.S. Simpson[l], H. Suzuki[b], H. Takeda[b], M. Tanaka[e], J. Taprogge[q, r, b], V. Werner[s, t], O. Wieland[u]
Published 12 November 2015

Phys. Rev. C 92, 054312 (2015) http://journals.aps.org/prc/abstract/10.1103/PhysRevC.92.054312
Identification of a dipole band above the Iπ=31/2− isomeric state in Pb189
D. Hodge[1], D. M. Cullen[1], M. J. Taylor[1], M. G. Procter[1], P. Nieminen[2], T. Grahn[2], P. T. Greenlees[2], K. Hauschild[2,*], A. Herzan[2], U. Jakobsson[2,†], P. Jones[3], R. Julin[2], S. Juutinen[2], S. Ketelhut[2], M. Leino[2], A. Lopez-Martens[2,*], J. Partanen[2], P. Peura[2], P. Rahkila[2], S. Rinta-Antila[2], P. Ruotsalainen[2,‡], M. Sandzelius[2], J. Sarén[2], C. Scholey[2], J. Sorri[2], S. Stolze[2], and J. Uusitalo[2]
Published 17 November 2015

Phys. Rev. C 92, 054908 (2015) https://journals.aps.org/prc/abstract/10.1103/PhysRevC.92.054908
One-dimensional pion, kaon, and proton femtoscopy in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE Collaboration, UK Authors: D. Alexandre, L.S. Barnby, M. Borri, M. Chartier, D. Evans, M.A.S. Figueredo, K.L. Graham, P.G. Jones, A. Jusko, M. Krivda, G.R. Lee, R.C. Lemmon, R. Lietava, J. Norman, R. Romita, O. Villalobos Baillie, N. Zardoshti
Published 19 November 2015

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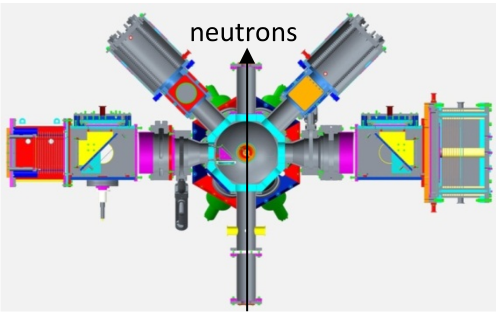
2. News to Report

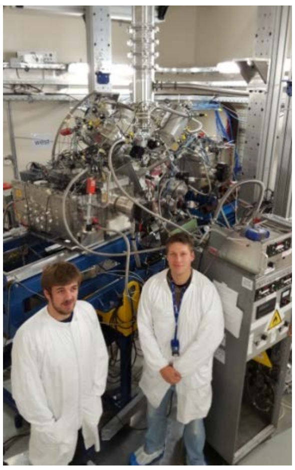
a. Fission of ^{235}U with STEFF at EAR2/n_TOF.

The SpectromeTer for Exotic Fission Fragments (STEFF) has completed its first data-taking run on the new vertical beamline (Experimental Area 2) of the Neutron Time-of-Flight facility (n_TOF). STEFF is a 2E-2v device designed and constructed at the University of Manchester to study a variety of fission reactions. It is currently being used in response to a NEA high-priority request for more precise gamma-ray nuclear data on the fission of ^{235}U. STEFF allows measurement of the velocities and energies of both fragments from the fission event. The masses of the fission fragments may be measured either independently in each arm (Ev), or, by ignoring the momentum and kinetic energy contributions of the emitted fast neutrons and target effects, by the 2E or the 2v methods. STEFF also includes an array of 12 (5"x4") NaI scintillation detectors for gamma detection in time-coincidence with the fission fragments. The fission fragments stop in Bragg detectors, the output of which are digitized as a function of time. The digitized traces may be used to measure energy loss (dE/dx) and range of the fission fragments and hence give information on the atomic number. The experiment was originally installed at the Institut Laue Langevin, the reactor-based neutron source in Grenoble.



Section view of STEFF showing the layout of the detectors

The programme was then moved to CERN, where the experiment is currently being used at the new EAR2 experimental station of the n_TOF neutron time-of-flight facility, to take data across a wider range of neutron energies. The first phase of the experiment was carried out with the small collimator in October/November 2015. A second run will be performed with the new fission collimator in May 2016. Data from the first run are currently being analysed.



Stuart Warren and James Ryan with STEFF and the vertical neutron beamline.

Contribution by A.G. Smith, J. Ryan, S. Warren, T. Wight, and the n_TOF Collaboration gavin.smith@manchester.ac.uk (Manchester).

b. Second Notre Dame Symposium on Nuclear Science and Society: Rome, November, 2015. I have always seen Nuclear physics as, Janus-like, looking always in two directions. On one side it focusses on applications to the health and well-being of Society and on the other it searches for an understanding of the fundamental structure and forces in Nature. Janus was a Roman God, not an import from Greece, so it was very appropriate that the nuclear physics group from the University of Notre Dame held their second annual symposium on applications of Nuclear Physics at Notre Dame's "Global Gateway" in Rome from November 4-6th 2015. Nuclear Physics has been a major research area at Notre Dame for some eighty years. In recent times it has been a major centre for studies of Nuclear Astrophysics in North America. The opening talk of this year's symposium was given by Michael Wiescher, who summarised Notre Dame's activities, capabilities and ambitions. There is a rapid expansion in activity with 70 staff overall in the Nuclear Science Laboratory with the permanent faculty increasing to nine, soon to be ten, and a significant increase in the equipment available and the range of science being studied. The current programme is based on the FN Tandem Van de Graaff and the new 5MV NEC Van de Graaff with a 3 MeV pelletron accelerator, brought from LLNL, under installation and a 1MV machine under construction for use in nuclear astrophysics deep underground at the SURF (Sanford Underground Research facility) laboratory in the old Homestake mine in South Dakota, where Ray Davis carried out his solar neutrino experiments. The increased activity in basic nuclear physics has been accompanied by a rapid increase and interest in applications. It is this increased activity that prompted Umesh Garg, Ani Aprahamian and Michael Wiescher to start this series of symposia relating Science to Society's needs. They have been and will be held in Notre Dame's International "Gateways" in London, Rome, Dublin and Jerusalem. The holding of the Symposia also signals that the Nuclear Science Laboratory at Notre Dame welcomes collaboration across all of its activities. There are already thirty US and international groups who have worked at

Notre Dame and it was abundantly clear that they would welcome others.

Last year the inaugural symposium was held at Notre Dame's campus in London, where the main interest was in applications to Medical Physics and Energy. This second meeting, in what promises to be an interesting series, was devoted to applications of nuclear physics techniques to art, archaeology, architecture and the environment. This was an apposite choice given the location of the meeting in Rome and the large amount of activity in these areas in Italy and southern Europe generally.

The second speaker was Walter Kutschera (Vienna) who talked about Otzi, the ice man. Otzi's body, the best preserved body from 5000 years ago, has not only revealed much about life at the time of his death but also about the glacial environment in the Alps during the Holocene. Based on AMS and other studies of Otzi's belongings, clothes etc and the plants around him, one can deduce much about the environment when he died. Perhaps the striking message is that the Rhone and other glaciers were much smaller in most of the Holocene than they are at present. Kutschera showed us that glaciers are "witnesses of the past, present and future". Their waxing and waning, whether from natural or man-made causes, can be followed using AMS of ^{14}C and other cosmogenic and anthropogenic radioactive nuclear species. This will allow us to better understand the processes that contribute to climate change.

The third speaker, Elisabetta Boaretto from the Weissman Institute, showed us just how careful one must be in integrating modern dating techniques with traditional archaeological methods. There has to be a sampling strategy tailored to the site and applied during the excavation to assemble the best and most useful data. Using information from a number of places in the Levant she made a convincing case that at the beginning of the transition from the middle to upper paleolithic, close to 50,000 years ago, there was a huge migration from the Middle East into Western Europe. There are close parallels with today, with migration driven by over-population and diminishing resources. Our short-term focus today on the collapse of states set up artificially by Sykes-Picot in 1916 may blind us to the real roots of the problem.

I have put some emphasis on these first three talks, not because the others were not interesting, but because they give a feeling of how broad a canvas is painted by these nuclear applications. Slightly closer to home we heard about forensic analyses of paintings and other art objects for a number of purposes. There is of course a thriving commercial market in paintings and objects d'art generally, and it needs an underpinning of established provenance for the artefacts if the market is not to be discredited and undermined. At the same time one has to understand how the materials of which these objects are made have altered with time if we are to conserve them in a sensible way. We may not be able to restore them but we can hope to stop them deteriorating further. Forgers are ingenious and it often seems, to me at least, that they work much harder than the original artists to produce their fakes. Their research on all the elements of a painting, for example, are often painstaking and very difficult to distinguish from the materials used by the artist. We heard of various cases and famous forgers. We were left with the knowledge that proving beyond doubt that this is the work of "X" is often impossible. Most such talks were looking back in time but one looked forward with a suggested remedy. Wolfgang Bauer (MSU) first entertained us with stories of the ingenuity of famous forgers and told us that he and Brad Sherrill have just patented an idea to use sub-surface patches containing rare isotopes characteristic of the piece in question. The artist would simply have the patch made and registered and provenance is assured, at least for the lifetimes of the isotopic mixture used.

I have already indicated that the topics covered were wide-ranging. The methods also are used in many places. Thus we heard about what happens in Seville from M. Respaldiza, in Debrecen from Z. Szikszai and M. Molnar, in Paris from L. Bertand (Saclay), in Germany from A. Dewald (Koln) and S. Bishop (Munich).There were many interesting contributions from Italy and M. Chiari (Florence) gave us a very nice picture of where we are heading with a "Roadmap for Ion Beam techniques".

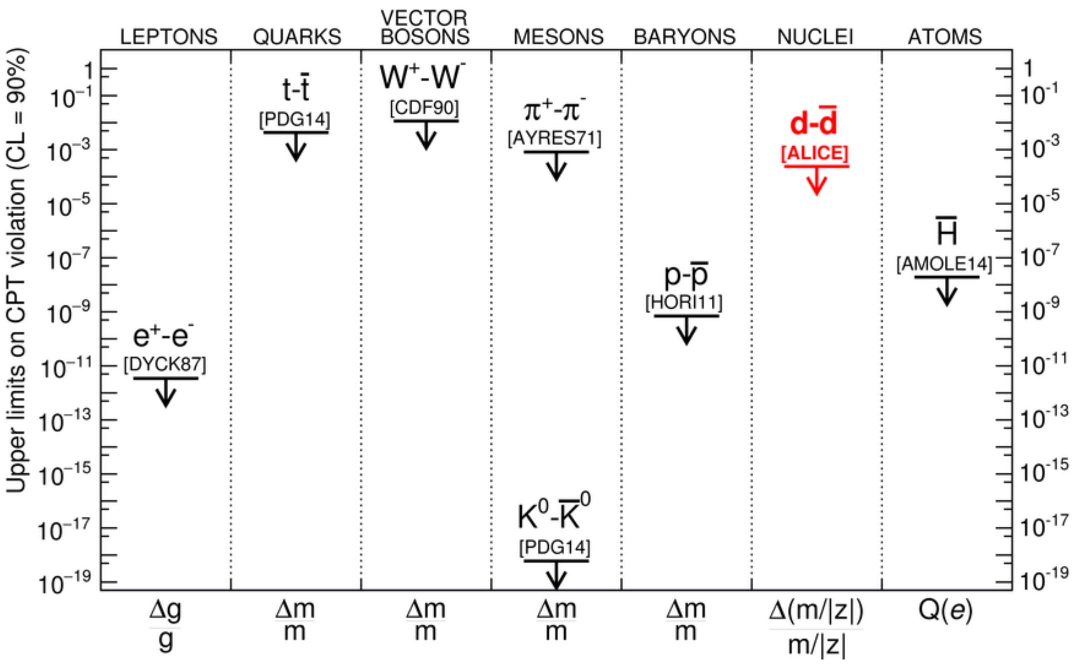
I enjoyed this meeting a lot. I found it satisfying on a number of levels. I learned a lot about what is happening in this area and how it is developing. I felt happy that the fun we

have had studying nuclear physics and developing instrumentation has found many other uses as well. About 50 people attended and that meant it was easy to make direct contact and also have sensible discussions after talks. I must confess that it is over forty years since I enjoyed one of the huge meetings such as INPC. They are more about kudos for the organisers than advancing our science. I stopped attending a long time ago. Meetings a la ECT* are much more useful. The organisers had not yet decided on Jerusalem or Dublin for their next Symposium. Wherever it is I am sure it will be just as useful and enjoyable as this one. More power to their elbow(s).
Contribution by Bill Gelletly
W.Gelletly@surrey.ac.uk (Surrey).

c. The importance of Nuclear data. We are all aware of the many databases that collect together the large amount of information nuclear physicists have produced on nuclear reactions and nuclear structure over the years. These databases are used by many people and for many purposes. A large fraction of these data were acquired, however, for quite a different purpose. Accordingly they are often not fit for that purpose. As a gamma-ray spectroscopist I am conscious of just how useful the Ge detector has been. As a young post-doc at Chalk River in the 1960s I saw Ewan and Tavendale produce the first gamma –ray spectra of real quality with the new Ge(Li) detectors. We moved on to HpGe and large arrays and now AGATA and GRETA. These detectors have only modest resolution and efficiency but they are the ideal tools for constructing decay and level schemes from studies of beta decay and reactions and they have lots of applications. If, however you want to use the data gathered with them to determine the Decay Heat from reactors or the reactor antineutrino spectrum it is often no good. In both these applications we should be able, in principle, to sum the contributions from the decays of all the radioactive species produced in the reactor together with the yields of the individual species and get both the radioactive decay heat as a function of time and also the primary antineutrino spectrum. Unfortunately the information in the databases relies on decay schemes constructed with Ge detector spectra and the B(GT) values for each level in the beta decays are extracted from the differences in the gamma intensities feeding the levels and de-exciting them. At higher excitation energies, a few MeV and above, the efficiencies of Ge detectors are limited. As a result many of the decays from higher lying levels are missed, particularly the weaker decay branches. Accordingly we end up with more apparent feeding to lower energy levels and less to states at higher excitation. The resulting decay heat and antineutrino spectra we obtain are then wrong.
One solution is Total Absorption Spectroscopy, where one uses a large calorimeter that, in principle, is 100% efficient. Then the gamma –ray spectrum gives the feeding to each level directly since all cascades from a level will sum to the level energy. In practice 100% is impossible but one can get very high efficiency and methods [1] have been developed to overcome the difference in efficiency. IAEA working groups have looked at the cases in most urgent need of study and the Valencia-Nantes-Surrey collaboration have been working on them, mainly but not exclusively at Jyvaskyla. A typical example is the case of ^{92}Rb decay [2], where we have measured the B(GT) spectrum and shown that our results make a difference to the reactor antineutrino spectrum. We have also made a whole series of measurements [3, 4] that are of importance in terms of reactor decay heat.
At the same time the future is not being neglected and a new Total Absorption Spectrometer for FAIR has been designed, characterised and tested [5] and will be used at RIKEN until FAIR eventually delivers beam.
References:
1. J.L.Tain and D.Cano-Ott, N.I.M. A571 (2007) 719; *ibid* A571 (2007) 728
2. A.-A. Zakari-Issafou et al., Phys. Rev. Letters 115 (2015) 102503.
3. A.Algora et al., Phys. Rev. Letters 105 (2010) 202501
4. D. Jordan et al., Phys. Rev. C87 (2013) 044318
5. J.L.Tain et al., N.I.M.A 803 (2015) 36-46
Contribution by Bill Gelletly
W.Gelletly@surrey.ac.uk (Surrey).

d. Anti-nuclear Physics! Fortunately not news about protests but progress in the study of anti-nuclei. The ALICE collaboration recently published, in Nature Physics, a measurement of the mass difference between deuterons and anti-deuterons and between ^{3}He and

anti-^{3}He nuclei. This gives an improved limit on the CPT invariance of the nuclear binding force. The context and background behind this novel measurement is given below.
Nuclear collisions at very high energy are produced at the LHC and RHIC with the aim of studying the quark-gluon plasma phase of nuclear matter. Tens of thousands of new particles are created from the several TeV of beam energy. At LHC energies the ratio in the produced yields of particles and anti-particles is very close to one e.g. positive to negative pions, protons to anti-protons, hyperons to anti-hyperons. With the ALICE experiment it is even possible to observe, via their energy loss in the Time Projection Chamber (TPC) and by time-of-flight measurements, deuterons, ^{3}He nuclei and alpha particles in the 'central rapidity" region — at an angle of around 90° to the beam — and furthermore the anti-particles of these three nuclei. This proves that they are created in the collision and not fragments of the incoming nuclei. In fact the production of all the hadron species and light-nuclei can be described by a simple statistical thermal model with a temperature parameter of around 156 MeV (1.8 x 10^9 K), see arXiv:1506.08951. Even the lightest hypernucleus, the hypertriton is following this pattern (see arXiv:1506.08453) which is somewhat surprising, given it's very small binding energy. Further details can be found in this CERN Courier article "ALICE investigates 'snowballs in hell'". Knowledge of the thermal production rates of these composite states can be employed when searching for other light bound states such as Λ-Λ (the so-called H-dibaryon) and Λ-n, plus their anti-particle states, where we are now able to set meaningful limits on their existence (see arxiv.org:1506.07499).
The last example exploiting this source of light anti-nuclei and nuclei was perhaps the most surprising. During my time as the convenor of ALICE's Light Flavour Physics Working Group our colleagues from the Time-of-Flight (TOF) detector group came with a proposal to measure the difference between the mass of the anti-deuteron and deuteron. The ALICE TOF was designed to identify pion, kaons and (anti-)protons with a timing resolution good enough to separate their signals up to a momentum of a few GeV/c. The timing signal, along with knowledge of the momentum from the TPC, enables the mass to be calculated. The measured mass of the deuteron was close to the known value and we could see that several systematic contributions to the uncertainty cancelled out giving an uncertainty on the difference competitive with the existing (rather old) measurements. Some residual effects can be removed by calibrating using the anti-proton to proton mass difference which is known at the 10^{-9} level. Our final results show that the anti-deuteron mass is the same as the deuteron mass with a precision of 10^{-4} and the difference for ^{3}He and its anti-nucleus has a 10^{-3} precision. The figure (Credit: CERN for the ALICE Collaboration) shows how this compares to the limits on CPT violation in other sectors.
The result generated many good news stories around the world thanks to the CERN press



Edited by Elizabeth Cunningham, STFC Particle and Nuclear Physics Outreach Officer.
Elizabeth.Cunningham@stfc.ac.uk or E.Cunningham@surrey.ac.uk

release from and an explanatory video commissioned by the Nature Publishing Group. The first chapter in the life of the 'Nuclei and Exotica' group in ALICE, which I jointly set up, has been a rather successful one!

Contribution by Lee Barnby lbarnby@cern.ch (Birmingham)

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3. Outreach Activity

Physics of Nuclear Medicine Masterclass

Laura Harkness-Brennan delivered a masterclass on the physics of nuclear medicine to 100 year 11, 12 and 13 students. The class aimed to demonstrate the multidisciplinary nature of medical physics and the role that these students could have in addressing scientific challenges in the future. The event was delivered in a refurbished cinema-theatre (see photo) at the Life Sciences UTC in the centre of Liverpool. The topics covered were diagnostic imaging, radioisotopes and radiotherapy. The students were particularly interested in new approaches in radiotherapy.

Contribution by Laura Harkness-Brennan Laura.Harkness@liverpool.ac.uk (Liverpool)

Sir Fred Hoyle centenary Lectures

On 19th November, David Jenkins gave a public lecture on Fred Hoyle's work on nuclear astrophysics as part of a special evening to celebrate the centenary of Hoyle's birth. The event took place at Bingley Grammar School near Bradford where Hoyle had gone to school. Two other contributions to the Hoyle evening were given by Dr John Baruch of the University of Bradford and Professor Chandra Wickramasinghe who spoke on his very longstanding collaboration with Hoyle on the topic of "panspermia" - the theory that microbial life is carried through the cosmos by comets and meteors.

Hoyle is famous for his contributions to Cosmology - coining the phrase "Big Bang" but actually to dismiss that theory which he didn't subscribe to. He also contributed to the famous B2FH paper in the 1950s with collaborators Burbidge, Burbidge and Fowler which explained the main features of nucleosynthesis in stars and in particular, the origin of carbon. Many believe Hoyle should have received the Nobel Prize in Physics along with Fowler for this work.

Contribution by David Jenkins david.jenkins@york.ac.uk (York)

Media and Communications Training

The Science and Technology Facilities Council offers free Media Skills training and Writing about your Research courses for researchers, as part of its Public Engagement programme. The Media Skills training develops skills in working with television, radio, newspapers and other media. The next course date is 17 February 2016, in London

The Writing about your Research course trains researchers to write about their research for non-specialist readers in a variety of contexts. The next course date is 13 January 2016, in London.

A two-day residential combination of the courses is also available. These are held at the Kavli Royal Society International Centre in Buckinghamshire. The next dates are 14/15 March 2016.

STFC offers bursaries to pay the course fees and T&S costs for eligible researchers. The courses are run for us by the Royal Society. To book a place visit the Royal Society website

Once you have a confirmed place, go to the STFC website to apply for an STFC bursary.

The STFC contact for more information is Jane Butt Tel 01793 442030.

4. Media Interactions

Laura Harkness-Brennan was interviewed as part of a BBC Earth online article "How do we know that things are really made of atoms?".

Contribution by Laura Harkness-Brennan *Laura.Harkness@liverpool.ac.uk (Liverpool)*

And finally…

You might notice a familiar face if you travel through Swindon train station in the near future…