Some aspects of research and activities at the Centre for Theoretical Physics in 2014: Tales from the dark sector

Amr Elzant

This is a remarkable era for fundamental physics. Take for instance the discipline of cosmology; once an abstract endeavour detached from empirical enquiry, it is now well (over a decade) into its 'precision era', one driven by an avalanche of data incoming from earth bound and space borne observatories, harvesting precious information on the birth and evolution of the universe. One most prominent Promethean scheme of this sort is the Square Kilometer Array (SKA), a set of radio telescopes that are to map the history of formation of structure (galaxies, clusters and large scale density fluctuations) in an initially nearly homogeneous universe. The vast billion dollar array is to be partly built in South Africa, with active involvement and support from its government.

South Africa, as did countries like Chile before it, has recognised the central role basic science plays in development; that in order to contribute to, and genuinely ascend in, the modern world, a nation should apprehend its language, the language in which basic science is written in and made of. Indeed, as I write this article from Cape Town, I can attest to the stunning advancements made in the fields of astrophysics and cosmology at academic institutions here. Even more remarkable are the testimonies of Western scientists who visited the country during the Apartheid era: their expectations that the level of support for basic science would decrease, as the country moved to solve the pressing practical developmental needs of its black communities, proved completely unfounded. Instead of shrinking, fundamental research vastly expanded, in personnel and funding, and increased in quality under the black-majority government. To me, this is all reminiscent of a spirit that dominated Egyptian attitudes towards development in the early twentieth century, following formal independence from Britain. This is a futuristically optimistic attitude that seems to be much less prominent in contemporary Egyptian discourse.

In this context, thanks to generous BUE support over the years, the Centre for Theoretical Physics (CTP) is a rare centre of excellence in basic science in Egypt, and being so it contributes to keeping this spirit alive.

In what follows I will give a brief (and certainly non-exhaustive) summary of some of the research conducted at our centre, as well as some of the associated organisational activities. It is centered on work connected to two phenomena—dark matter and energy—that are likely to lead to radical changes in our picture of the physical world, especially if they remain unexplained by present physical theories. Along the way, as in the first issue of ***ResearchFocus***, I will be mentioning technological links of such research and its methods whenever relevant.

Amr Elzant is an Associate Professor of Physics and the Director of the Centre for Theoretical Physics (CTP), BUE.

Tel. 26890000 | Ext. 1425
Amr.Elzant@bue.edu.eg

The enigma of the dark sector

I am in South Africa (November 2014) to attend a conference termed the Dark Side of the Universe, this is an annual meeting bringing together astrophysicists, cosmologists, and particle theorists in order to discuss the latest results concerning a subject matter with interdisciplinary character. The situation is as follows: we have an extremely successful model of the universe (explaining its history of expansion and structure formation), but it is a model whereby the vast majority of the universe's content is in unknown form. We know of its existence only through its effect on the luminous material we see. The missing matter can be embodied in hitherto undiscovered particles (hence the interface with elementary particle theory and experiment) and the missing energy in novel forms of behaviour of material fields (and here lies one interface with fundamental field theory). However, the postulated existence of either component (or both) could originate simply as a result of incomplete knowledge of physical laws (especially gravitation). This, like the advent of relativity and quantum mechanics a century ago, would revolutionise the field of physics. Indeed, like the advent of said theories, this has the potential, in principle, of transforming how coming generations live (e.g. without quantum mechanics there would be no contemporary television sets, never mind iPads and similar gadgets). Thus, the lack of experimental detection of dark matter particles, for example, is likely to cause a deep modifications in fundamental physical theory; deeper than their mere postulation has implied.

Dark energy and modified gravity

At the CTP, Gamal Nashed and his graduate students are investigating modifications of Einstein's theory of general relativity in order to test whether the missing dark energy, that enigmatic component driving the accelerated expansion of the universe, is in fact a fictitious result, camouflaging necessary modifications of the theory. In particular, Einstein had famously postulated that gravity emanates from the curvature of space−time. In a later work, however, he entertained the idea that an additional 'torsion' element may play a role (roughly speaking this can be envisioned in terms of local twists in space−time, in addition to, or in replacement of, curvature). Nashed and others have shown that such models can indeed reproduce the required 'dark energy' terms in the equations of cosmic evolution.

This work is done partly in collaboration with Peter Dunsby, of the University of Cape Town, funded by a joint grant (supported by the Egyptian side via the Academy for Scientific Research and Technology). This work, as other similar theoretical models for the evolution of the universe, will of course benefit from the empirical examination that high tech observational projects (like the SKA) will provide in the forthcoming years. It will therefore benefit from our South African collaboration, which is expected to expand subsequent to our visit to Cape Town, as we have discussed in its context future mutual visits of staff and students and several joint projects.

One of those projects is to also benefit from the important input and theoretical expertise of Adel Awad, who held discussions with both Gamal Nashed and Peter Dunsby on fundamental issues connected to the theoretical consistency of these modified theories of gravity (a necessary condition to be achieved before any empirical tests can be regarded as necessary is that the theories to be tested be logically consistent and do not violate well established physical principles, as the Lorentz invariance of special relativity for example).

Since his return to the CTP after a stay in Canada, Awad has lead an active research programme, recruiting three graduate students in the process. While in Canada, he has started collaborations on several research points with Mir Faizal, of the University of Waterloo, notably on higher order terms corrections to gravitational theories, particularly relevant to the very early universe. These help to eliminate the singularity plaguing Big Bang models of the universe, where divergences in numerical values of physical parameters herald the breakdown of physical laws beyond the earliest (so called Planck) time. These corrections may also lead to early inflationary eras, similar to the current dark-energy-driven accelerated universe.

The coupling of cosmic scales

There are also several areas of interface between Awad's interests and my own work, including the use of his expertise in 'effective field theory'—a method developed in field theoretic research in order to evaluate the coupling between large and small scales in a given physical system. This is a technique that has attracted much attention lately in the context of the study of the evolution of dark matter structures in the universe where the density field is nearly homogeneous on large scales (and so can be treated via perturbation theory) while strongly clumping on smaller ones—as it helps in evaluating the coupling of the smaller scales to the larger ones, with possible repercussions on the overall expansion rate of the universe. This project is also being discussed with Walid Moslem, the head of the physics department at Port Said University and a part-time member of the CTP. It is hoped that it would benefit from expertise in fluid mechanics, where the same phenomena transpire, and where he has significant expertise and track record, much of which has shown this year in the CTP publication list.

Dark matter and its different forms

Though the dark matter remains undiscovered, constraints on its expected properties can already be deduced from cosmological models, since galaxy formation is dominated by the putative dark matter component. Observations of the galaxy population put limits on what sort of theoretically speculated particle can form the bulk of the cosmic dark matter content. For example, dark matter particles that are too light will travel much faster and clump on larger scales (for, in the thermal equilibrium conditions thought to have prevailed in the early universe, the thermal speed of a particle decreases with its mass). This sort of 'hot dark matter' is inconsistent with cosmological observations, because it cannot cluster at the proper scales so as to form observed galaxy population. The currently favoured 'cold dark matter' on the other hand clusters too much on small scales, parenting too many small and dense galaxies. This state of affairs has lead to suggestions of a 'warm dark matter' component of intermediate mass particles. However this new species has new problems of its own, as it is overproduced in the early universe, giving rise to too large dark matter abundance in comparison with that inferred from observations. With Shaaban Khalil, of Zewail City, and Arunansu Sil, of the Indian Institute of Technology, I have shown that this difficulty can be circumvented in certain particle physics and cosmological models. In forthcoming work, in collaboration with Adel Awad (and a jointly supervised student), we plan to develop and generalise this model further, in particular relaxing some of the assumptions that met some objections from the community to the original form of our work.

Interactions of dark and luminous components: solving small scale problems in concordance cosmology

The aforementioned small scale problems of the current cold dark matter dominated model of structure formation are presently a topic of intense research. One line of investigation goes as follows. Instead of modifying the fundamental properties of the dark matter, one may want to alleviate these problems by invoking interactions with a regular baryonic component. One such model that has had significant influence (since I proposed it in the early 2000's with some collaborators) involves the coupling of baryonic clumps via dynamical friction with the smooth dark matter component (much like a tennis ball moving through air does, heating up the gas while losing energy to it by friction). One of those involved in the original papers was Francoise Combes at the Observatoire de Paris. In the past year we have worked to revive our collaborative work. This was made possible in part by a joint grant (funded on the Egyptian side again by the Academy for Scientific Research and Technology). The project involves graduate students on both sides of the collaboration. We have conducted analytical and numerical calculations that have shown that the effects involved can be regarded as due to diffusion to coupling via stochastic fluctuations. We now aim at a general theory of such coupling between baryonic and dark components during galaxy formation.

The current aim is to test our theoretical model with progressively more sophisticated numerical calculations. This is to be done principally in two ways: from data obtained from major numerical cosmological simulations, conducted on some of the largest supercomputers (made available especially through collaborations with members of the Institut D'astrophysique de Paris); and via smaller controlled experiments to be conducted at the CTP. The latter are to be made possible by the software refurbishment and upgrade of the BUE computing system managed by the CTP. This system is now working properly with Sun Grid Engine, and Message Passing Interface software for distributed memory parallel computing, and has been tested on standard cosmological simulations codes (e.g., Volker Springel's Gadget: http://www.mpa-garching.mpg.de/gadget/right.html). This has been made possible in large part by the recruitment of a new Linux system manager (Yasser Abdellah).

Searching for new physics at the LHC

I have mentioned earlier the interplay between research tackling fundamental questions and its connection to cutting-edge technology. The aforementioned cosmological simulation techniques of course represent one aspect of such interfaces, for some of the largest numerical calculations ever conducted outside of the military domain have been so conducted in the field of cosmic structure formation. Another prominent interface involves the search for new physics at the Large Hadron Collider (LHC) at CERN. Egypt is involved in this endeavour through the Egyptian Network for High Energy Physics, headed by CTP member Amr Radi. Research in this context is also funded by an FP7 grant that has facilitated movement of Egyptian researchers to participating European institutes—Sherif ElGammal for example has spent time in the Ecole Polytechnique in Paris, where he continued work on the Z' particle, believed to be responsible for aspects of the weak fundamental interactions.

In this context we also had several collaborative visits from members of the CMS experiment at the LHC, including Nicola de Filippis (Bari Polytechnic) and Albert de Roeck (CERN and Antwerp), who are helping with our involvement in experimental dark matter searches, to be lead at the CPT by Sherif ElGammal.

Concluding remarks and prospects

This brings us full circle to the discussion opening this article, and may thus perhaps further illuminate the rationale for 'interdisciplinary' meetings between cosmologists and particle physicists. Dark matter is essentially postulated due to its gravitational signature in astrophysics. It is however now being searched for in several different contexts: in laboratory experiments, seeking direct detection; in the LHC, through productions in high energy collisions; and through indirect detection via astrophysical radiation excesses that may result from dark matter annihilations.

With the higher energy run 2 of the LHC to start the coming spring, there lies ahead a host of prospective discoveries (or constraints) as far as the issue of dark matter is concerned. These may again lead to either confirmation of present models or searches for new physics in even more exotic quarters.

I have outlined above several ways in which the CTP is involved in this quest through the research it produces. In addition, logistically, we have also been involved through the past years in organising several conferences and workshops connected to the activities at the LHC, the latest being the Fourth Egyptian School of High Energy Physics (April/May 2014). We now plan to host a major international workshop in 2015, bringing together researchers from the different disciplines who are seeking a fuller understanding of the missing contents of the universe and the nature of physical theory; its possible ramifications and modifications. We believe that Egypt should not be left completely in the margins as these historical developments unfold.

References and further reading

1 A general review, with a historical introduction to the cold dark matter model of structure formation in the universe, including some of the current problems it faces, is given by Frenk and White (two of its major developers and proponents) in Frenk, C., White, S. D. M. (2012) "Dark Matter and Cosmic Structure" Ann. der Physik 524, 507.

2 An extensive review of the issue of dark energy and some aspects of modified gravity and their observational signatures is given in 4 Amendola, L., Tsujikawa, S. (2010) "Dark Energy: Theory and Observations" Cambridge Univ. Press.

3 A review of interactions between dark and luminous sectors leading to modifications of the dark matter distribution in galaxies, as originally proposed by myself and collaborators in the early 2000's, and subsequent work in that direction (including some currently being tested at the CTP as outlined in article), is given in Pontzan, A., Governato, F. (2014) "Cold Dark Matter Heats Up" Nature 506, 171019.

4 Dark matter searches and related work at the LHC are summarised in the web page http://home.web.cern.ch/about/physics/dark-matter. There are links there to general introductions to many of the topics discussed in this article.

Recent selected work involving CTP members that is related to some of the topics discussed (a full list of this year's research is included in the publication list of this issue of ResearchFocus):

5 Awad. A, Ali, A. F. (2014) "Minimal Length, Friedmann Equations and Maximum Density", JHEP 093, 1406

6 Elgammal, S., et al. (2014). "Search for New Physics in the Multijet and Missing Transverse Momentum Final State in Proton-Proton Collisions at $s\sqrt{}= 8$ TeV", JHEP 1406, 055.

7 El-Zant .A.A., Khalil, S. Sil, A., "Warm Dark Matter in BL Inverse Seesaw", Submitted (arXiv preprint arXiv:1308.0836).

8 Nashed L. G (2013) "Spherically Symmetric Charged-dS Solution in F (T) Gravity Theories", Phys. Rev. D 88, 104034

Rogue waves leap out of the ocean

Mohamed E. Y. Kelib

Rogue waves[1] are known as steep mountains of water, up to 30 meters high, with abnormal shapes (Figure 1). They appear suddenly without warnings, not like tsunamis. Away from the oceans, these 'shrapnels' of nature are recognised recently in many physical systems with the aid of the nonlinear Schrödinger equation solutions.

The study of rogue waves is still comparatively recent, despite that this mysterious phenomenon has been known in various environments, such as ocean waves, for centuries. Recent research in Extreme Events (EE) phenomena shed the light on many anomalous phenomena with common rogue wave behaviours. EEs have been recently observed in a variety of systems, ranging from nonlinear lattices[2], fluids[3], super-fluid $_4$He (ref. 4), plasmas[5], Bose–Einstein condensates[6], optical waveguides, optical rogue waves[7], laser pulse filamentation, and optical fibers. Their similar characteristics, which are governed by the Nonlinear Schrödinger Equation (NLSE) solutions (equation below and Figure 2), could be considered as clues to improve our understanding of the nature of these waves;

$$i\frac{\partial\phi}{\partial\tau} + P\frac{\partial^2\phi}{\partial\xi^2} + Q|\phi|^2\phi = 0$$

Mohamed E. Y. Kelib is a Lecturer of Physics at the Basic Sciences Department, the Faculty of Engineering, BUE.

Mohamed.Kelib@bue.edu.eg

Rogue waves are one of the most distinguished embodiments of the EEs nonlinear dynamics. They are attributed to one of the most pervasive types of instabilities in nature: the Modulation Instability (MI). The MI, or sideband instability, is the result of interaction between a strong carrier harmonic wave and small sidebands (wave–wave interactions). In this aspect, the MI plays a great role as an 'intrinsic noise' in triggering self-organisation mechanisms. Instabilities and spontaneous pattern formation in numerous natural and artificial systems caused by these rogue waves can have catastrophic consequences. However, the situation could be better if we know their multiple scale hierarchies.

Quantum effects are expected to play an important role in Gallium Nitride (GaN) under the conditions of EEs. This situation becomes clear when the energy density of the plasma oscillations is equal or comparable to the Fermi electron thermal energy density. Even though the electron density is almost low for considering the typical quantum mechanical effects, such as tunneling, the situation of EE may be supposed to have a quantum nature. This is the focus of my current research in this area. Our proposed collective interactions in these dense quantum plasmas of electrons and holes will be studied using the Schrödinger-Poisson model. It would be interesting to introduce the quantum effects into the MI analysis of the rogue waves and to test the reaction of

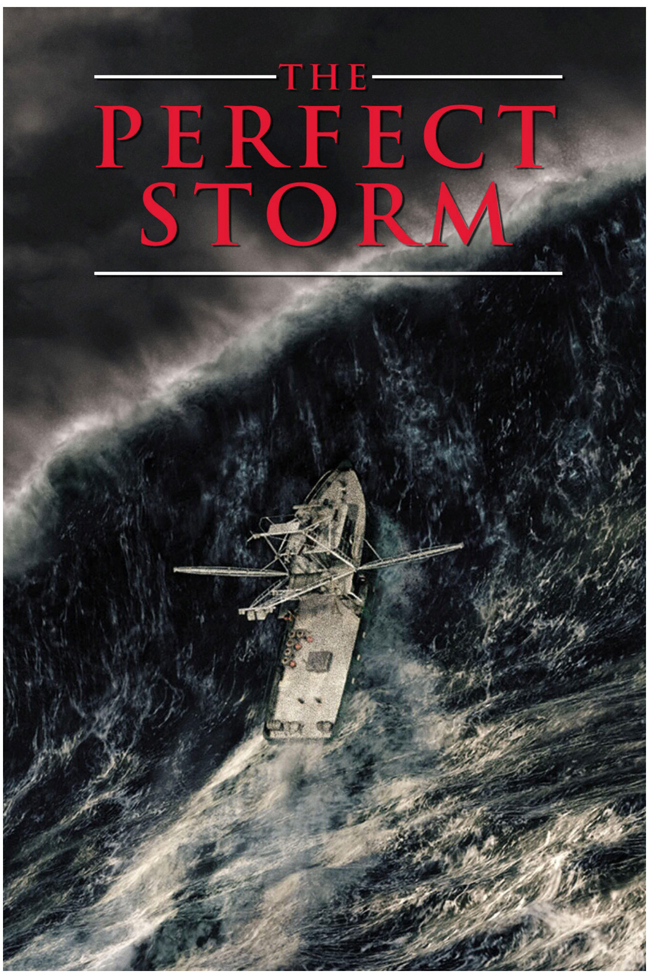


Figure 1. Rogue waves can, indeed, be worse than those seen in *The Perfect Storm* film, which is based on a true story.

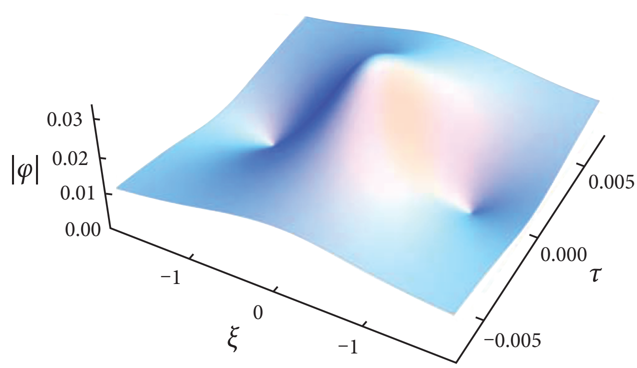


Figure 2. Rogue waves as solutions to the NLSE.

the quantum effects on the wave profile. For this purpose, we extend the study of Wang and Lü[9] for Acoustic Rogue Waves (ARWs) that may appear in electron–hole GaN semiconductor plasma. We focus our attention on the specific scenario of balancing the group dispersion and the nonlinear effects caused by pressure force, Bohm, and exchange-correlation potentials. It would be motivating to assess in more detail spectra of the unstable mode zone, and it would be good to benchmark our results with an experimental observation. Accordingly, the goal of our current investigation (recently submitted to APL) is twofold: (i) to demonstrate the existence region of the ARWs and (ii) examine how the ARWs are influenced by different quantum effects.

References and further reading

1 M. Onorato, S. Residori, U. Bortolozzo, A. Montina, F.T. Arecchi, Rogue waves and their generating mechanisms in different physical contexts, Physics Reports, volume 528, Issue 2, 10 July 2013, Pages 47–89.

2 Y. S. Kivshar and M. Salerno, Modulational instabilities in the discrete deformable nonlinear Schrodinger equation, Phys. Rev. E. 49, 3543– (1994).

3 T.B. Benjamin, J.E. Feir, J. Fluid Mech. 27 (1967) 417.

4 A. N. Ganshin, V. B. Efimov, G. V. Kolmakov, L. P. Mezhov-Deglin, and P. V. E. McClintock, Energy cascades and rogue waves in superfluid 4he, J. Phys.: Conf. Series. 150, 032056 (2009).

5 A. P. Misra and P. K. Shukla, Amplitude modulation of electron plasma oscillations in a dense electron-hole plasma, Phys. Plasmas 14, 082312, 2007.

6 L. Wen, L. Li, Z. D. Li, S. W. Song, X. F. Zhang, W. M. Liu, The European Physical Journal D, October 2011, Volume 64, Issue 2-3, pp 473-478.

7 D.R. Solli, C. Ropers, P. Koonath and B. Jalali, Nature 450, 1054 (2007).

8 B. Kibler, J. Fatome, C. Finot, G. Millot, F. Dias, G. Genty, N. Akhmediev, and J. M. Dudley, Nature Physics 6, 790–795 (2010).

9 Wang and X. Lu, Phys. Plasmas 21, 022107 (2014).

Use of artificial intelligence in the data analysis of proton–proton interactions at the LHC in CERN

Amr Radi

Amr Radi is a Professor of Physics, the Centre for Theoretical Physics (CTP), BUE.

Amr.Radi@bue.edu.eg

High energy physics and particle physics search for the fundamental particles and forces which make up the world surrounding us and help us understand how our universe works at its most fundamental level. Elementary particles of the standard model are gauge bosons (force carriers) and fermions. Fermions are classified into two groups: leptons (muons, electrons, etc.) and quarks that combine to form hardons (protons, neutrons, etc.).

The study of the interactions between these elementary particles requires very high energy collisions, as in the Large Hadrons Collider (LHC)[1–8], whose maximum energy reaches 14 TeV; the highest in the world. Experimental results provide excellent opportunities to discover the missing particles of the standard model. Indeed, the LHC will possibly lead the way in discovering new particle physics that go beyond the current standard model.

The Compact Muon Solenoid (CMS) detector (Figure 1) is one of two particle detectors built on the LHC to discover a wide range of physical phenomena, including particles that could make up dark matter. In July 2012, the European Organization for Nuclear Research (CERN) announced that they have found a boson very similar to the sought after Higgs boson. The Centre of Theoretical Physics (CTP) at the BUE has ongoing collaboration in the CMS experiment at the LHC.

The proton–proton (p–p) interaction is one of the fundamental interactions in high-energy physics. In order to fully exploit the enormous potential it has for physics, it is important to have a complete understanding of the interaction mechanism. The particle multiplicity distributions, as one of the first measurements made at LHC, used to test various particle production models based on different physical mechanisms and provide constraints on model features. Some of these

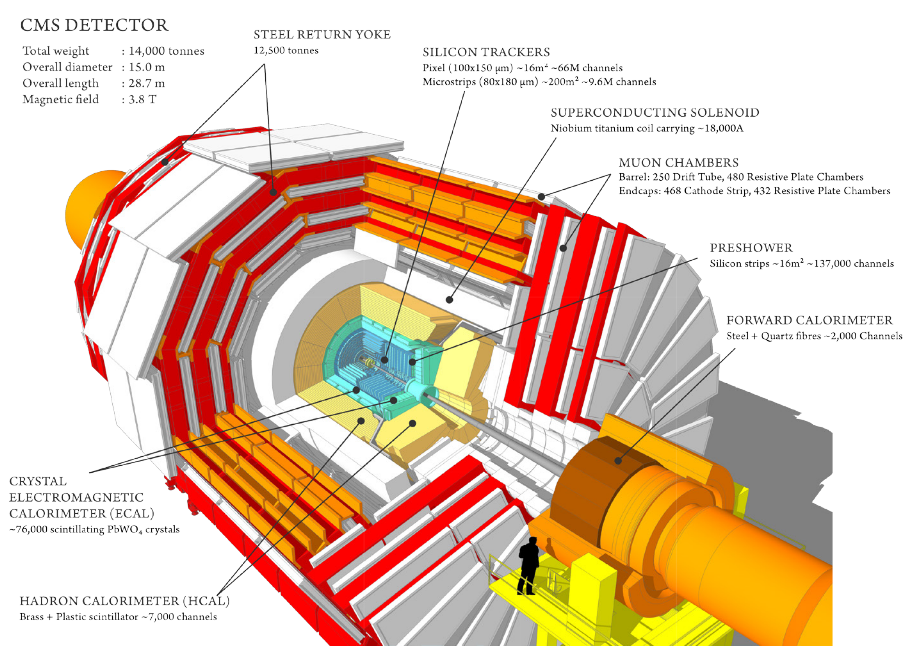


Figure 1. A schematic view of the CMS detector, showing its main components (© CERN).

models are based on string fragmentation mechanism[9–11] and some are based on pomeron exchange[12].

Currently, different modelling methods, based on soft computing systems, make use of the application of Artificial Intelligence (AI) techniques. These evolution algorithms have an important role in high energy physics[13–17]. Due to the nonlinear relationship between the interaction parameters and the output, the behaviour of the p–p interactions often becomes complicated. In order to understand the interactions of such fundamental particles, multipart data analyses are needed and AI techniques become vital. Moreover, these techniques are becoming useful as alternate approaches to conventional ones[18]. In this sense, AI techniques, such as Artificial Neural Network (ANN)[19], Genetic Algorithm (GA)[20], Genetic Programming (GP)[21], and Gene Expression Programming (GEP)[22], can be used as alternative tools for the simulation of these interactions[13–17, 21–23].

As an example, the GEP is a global optimisation algorithm and an automatic programming technique that has been applied in particle physics[24–25]. It is an Evolutionary Computation (EC) method for function discovery and data analysis. GEP is established on the assumption of Darwin's theory of evolution in nature. GEP uses populations of individuals, selects them according to their fitness to given criteria, and produces genetic variation in these populations using one or more genetic operators[26] in order to find the best or the most appropriate equation (solution) for a problem. The strength of this genetic programming approach is its ability to evolve a model based entirely on prior data without the need of making underlying assumptions. Another motivation for applying such machine learning approach (e.g. GP) is simply the lack of knowledge, in most cases, about the mathematical dependence of the quantity of interest on the relevant measured variables[27].

The motivation of using a GEP approach is getting the outcome of its learning algorithm. The latter 'learns' the relationships between variables in sets of data and then builds models to explain these relationships (mathematical dependencies). In ref. 13, the authors applied EC (gene expression programming and genetic programming) to rediscover ten famous physics laws from experimental data.

Artificial intelligence techniques, then, have become one of the important research areas in the field of high energy physics. My work at the CTP, BUE, focuses on using such techniques in the context of the experiments running at the LHC in CERN.

References and further reading

1 V. Khachatryan et al., CMS Collaboration, J. High Energy Phys. 01 079 (2011).
2 B. Toczek, Indian Journal of Physics, 85(7), 1143-1147 (2011).
3 Y. Mao, G. C. Balbastre, Y. Schutz, D. Zhou, Indian Journal of Physics, 85(6), 959-963 (2011).
4 Georges Aad et al., ATLAS Collaboration, Phys. Lett. B 707 330-348 (2012).
5 Mao, Yaxian; Aamodt, Kenneth; Dordic, Olja; Eyyubova, Gyulnara; Lindal, Svein; Løvhøiden, Gunnar; Milosevic, Jovan et al., Indian Journal of Physics, 85(6), 959- 963 (2011).
6 K. Aamodt et al, ALICE Collaboration, Phys. Lett. B 693 53-68 (2010).
7 M. Danish Azmi, S. Bose, S. Chattopadhyay, D. Das, I. Das, M. Irfan, S. Das, A. L. I. Khan, S. Pal, L. Das, B. C. Sinha, T. Sinha, Indian Journal of Physics, 84(12), 1683-1687 (2010).
8 G. Antchev et al., TOTEM Collaboration, EPL 96 21002 (2011).
9 M. Jacob, R. Slansky, Phys. Rev. D 5, 1847 (1972).
10 R. Hwa, Phys. Rev. D 1, 1790 (1970).
11 R. Hwa, Phys. Rev. Lett. 26, 1143 (1971)
12 R. Engel, Z. Phys. C 66 (1995) 203; R. Engel, J. Ranft and S. Roesler, Phys. Rev. D 52 (1995).
13 M., Schmidt, H. Lipson, "Distilling Free-Form Natural Laws from Experimental Data," Science, Vol. 324, No. 5923, pp. 81 – 85, (2009).
14 S. El-Bakr, E. S. El-Dahshan, and M. Y. El-Bakry, Indian Journal of Physics, 85(9), 1405-1415, (2011).
15 E. El-Dahshan," Central European Journal of Physics, 9(3), 874-883, (2011).
16 S. Yaseen El-Bakry, Amr Radi, Int. J. Mod. Phys. C 18, 351 (2007)
17 E. El-dahshan, A. Radi, M.Y. El-Bakry, Int. J. Mod. Phys. C 20, 1817 (2009)
18 S. Whiteson, D. Whiteson, Eng. Appl. Artif. Intel. 22, 1203 (2009)
19 S. Haykin, Neural networks a comprehensive foundation (2nd ed.), Prentice Hall (1999).
20 J.H. Holland, Adaptation in Natural and Artificial Systems (University of Michigan Press, Ann Arbor, 1975)
21 J.R. Koza, Genetic Programming: On the Programming of Computers by Means of Natural Selection (The MIT Press, Cambridge, MA, 1992)
22 C. Ferreira, Gene Expression Programming: Mathematical Modeling by an Artificial Intelligence, 2nd Edition, Springer-Verlag Germany 2006.
23 A.E. Eiben, J.E. Smith, Introduction to Evolutionary Algorithms (Springer, Berlin, 2003)
24 L. Teodorescu and I. D. Reid, Nuclear Science Symposium Conference Record, IEEE, 593-598 (2006).
25 L. Teodorescu., High energy physics data analysis with gene expression programming.
In 2005 IEEE Nuclear Science Symposium Conference Record, Vol. 1, 143-147, (2005).
26 M. Mitchell, An Introduction to Genetic Algorithms, MIT Press, (1996).
27 H. Etemadi, A.A.A. Rostamy, H.F. Dehkordi, Expert Syst. Appl. 36, 3199 (2009).

Monte Carlo simulations for medical linear accelerator using GEANT4

Elsayed Salama, Amr Radi, and Ahmed S. Ali

Radiotherapy is the treatment of cancer and other diseases with ionising radiation by damaging their genetic material, making it impossible for these cells to continue to grow. The overall estimate for radiotherapy utilisation is about 52% for cancer patients, based on the best available evidence[1]. This radiotherapy technique is limited by the tolerable amount of damage to the normal tissue.

Evaluation of dose distribution in oncological radiotherapy treatments is a salient problem that requires developed computing technologies to optimise the clinical results. This could be accomplished by increasing the dose to the cancerous tissues and reducing the dose to the healthy tissues. In recent years, the accuracy of dose calculation has improved together with the computing power available in radiotherapy departments[2]. New mathematical approaches to dose calculation and optimisation have been introduced in the clinical practice[3]. Dose calculation algorithms based on the Monte Carlo method are generally regarded as the most accurate tools among the sophisticated available algorithms[4,5]. Most of the commercial Treatment Planning Systems (TPSs) use analytic calculations, and errors near inhomogeneities in patients can reach 10–20%. Such methods are less accurate for complex practical situations. Small irradiated volumes, limited in lateral and/or forward directions and interface regions, are examples of such complex situations[6].

Alternatively, Monte Carlo calculations using GEANT4 (Geometry and Tracking, Version 4) can be used for accurate dose calculations. This technique represents a powerful tool for simulation of complex geometrical shapes and material composition by using different GEANT4 physics models. The comprehensive validation of this physics models is essential in order to guarantee the accuracy and reliability of GEANT4-based simulations.

Elsayed Salama is an Associate Professor of Physics, the Basic Sciences Department, the Faculty of Engineering, BUE.

Tel. 26890000 | Ext. 1456
Elsayed.Salama@bue.edu.eg

Amr Radi a Professor of Physics at the Centre for Theoretical Physics (CTP), BUE.

Amr.Radi@bue.edu.eg

Ahmed S. Ali is a postgraduate student at the Centre for Theoretical Physics (CTP), BUE.

Simulation of dose distribution in the water phantom Simulation of percentage depth dose distribution (PDD) and flatness symmetry in water phantom were performed for the VARIAN type (VARIAN 600C) using GEANT4. The linac components are an electron gun, collimator, ion chamber, mirror, flattening filter, jaws, and multi-leaf collimator (Figure 1). A 6 MV circular electron beam with a radius of 0.5 mm, with a Gaussian energy distribution, is accelerated down to hit the tungsten target and bremsstrahlung photons are created. These photons and secondary particles are randomly produced. Some of these photons are directed towards the flattening filter, monitor chamber, mirror, and a pair of jaws.

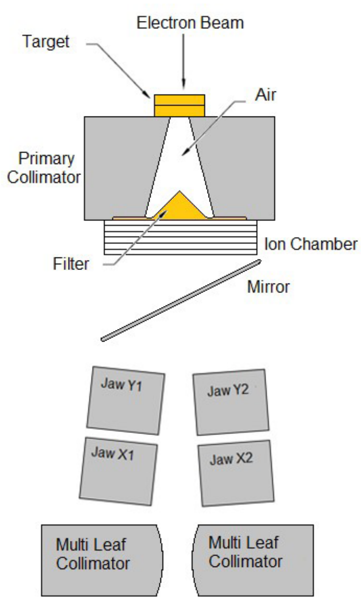


Figure 1. A schematic diagram for a 6-MV beam gantry of VARIAN linear accelerator.

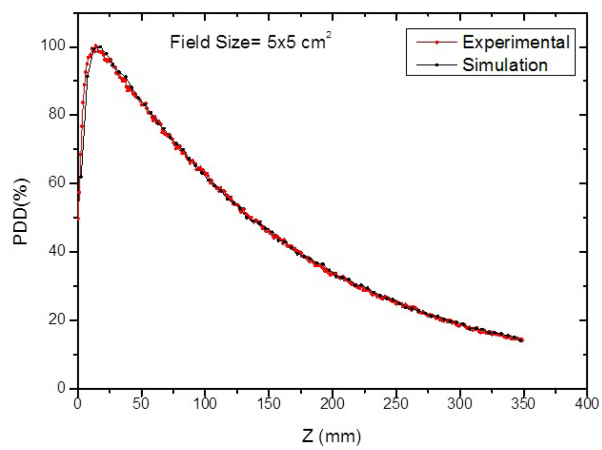


Figure 2. Depth dose profile at 15, 50, and 100 mm depth for 5 cm × 5 cm field with a 6-MV beam.

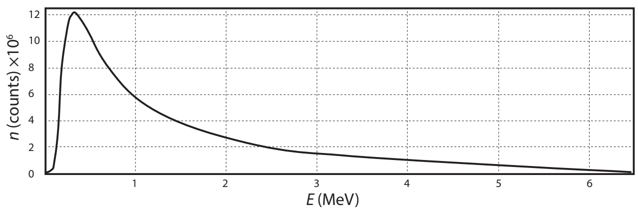


Figure 3. The energy spectrum of phase space particles.

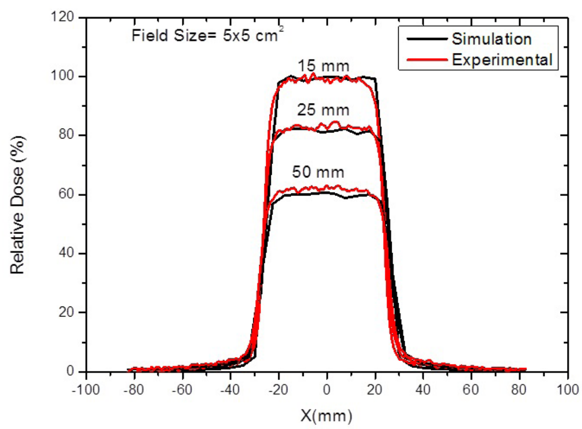


Figure 4. Lateral dose profiles at 15, 50, and 100 mm depth for 5 cm × 5 cm field with a 6-MV beam.

A water phantom with specific dimensions and Source-Surface Distance (SSD) is simulated. The PDD and the flatness symmetry for different field sizes at different depths are calculated. Comparison between experimental and simulated data were executed as shown in Figure 2. All calculations were executed using the computer system at the Centre for Theoretical Physics (CTP), BUE.

The energy spectrum of the obtained phase space particles is illustrated in Figure 3. The results show acceptable agreement between computed and measured PDD, whereas slight discrepancies appeared at higher field sizes. Moreover, the lateral dose profiles are compatible with the measured values, as shown in Figure 4.

Accordingly, this study emphasises that GEANT4 is capable of modelling various types of medical linac gantries, which could greatly assist in estimating dose distributions administrated to patients at critical positions where normal measurements are unattainable.

References and further reading

1 G. Delaney, S. Jacob, C. Featherstone, N. Barton, Cancer, 104 (2005) 1129.

2 A. Fogliata, E. Vanetti, D. Albers, C. Brink, A. Clivio, T. Knoos, G. Nicolini, L. Cozzi, Phys. Med. Biol. 52(2007) 1363.

3 Nederlandse Commissie Voor Stralingsdosimetrie 2006 Monte Carlo Treatment Planning: An introduction NCS Delft The Netherlands, Report 16.

4 B. Caccia, M. Mattia, G. Amati, C. Andenna, M. Benassi, A. d'Angelo, G. Frustagli, G. Iaccarino, A. Occhigrossi, S. Valentini Journal of Physics: Conference Series 74 (2007) 012001

5 Verhaegen F. and Seuntjens V., Phys. Med. Biol. 48 (2003) 107.

6 Sonia M. Reda, Eman Massoud, Magda S. Hanafy, Ibrahem I. Bashter, Esmat A. Amin, Journal of nuclear and radiation physics, vol.1, No.1, (2006) 61.

Book review:

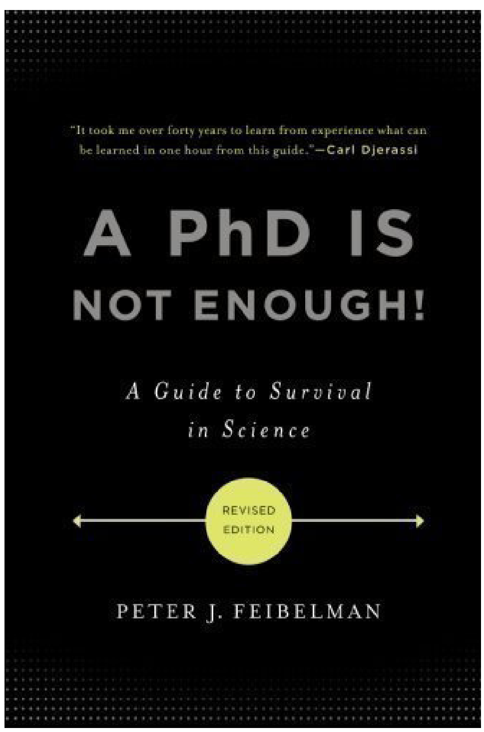
'A PhD IS NOT ENOUGH!'

Adham Naji (Editor)

Peter J. Feibelman has done a fabulous job in writing this book (and its revised edition[1]) for any serious researcher in science or engineering. This timeless gem covers so many important aspects that relate to the career of a budding researcher. It also benefits the experienced researcher in lessons that are never too late to learn.

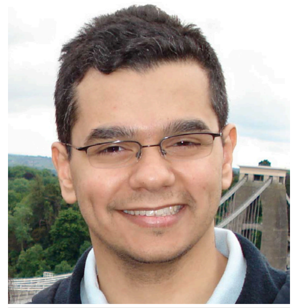
The book starts from the early stages of studying for a PhD degree and how to pick the right supervisor and subject, which can be strategically tricky. It alerts the reader to avoid repeating common mistakes that many researchers fall into, such as being too narrowly focused on certain techniques without understanding the bigger problems that bring about the context that employs such techniques, or morphing into a PhD 'technician' who is skilled in a certain method or lab technique and serves/impresses others while not having a clear goal/plan of their own to pursue. It stresses the importance of getting a good mentor, who has no direct interest in your research, to give you insight and act as a sounding-board for you from time to time.

It then discussed the dilemmas of finding a satisfying postdoctoral position, whether to choose a small or a large research group to work in, which collaborators to pick up, how to get a post that doesn't drown you in admin (or teaching) load or is steeped in bureaucracy, the importance of finishing projects successfully in the pre-tenure phases, publishing frequently to keep your name in the spot light, and the potential and efficiency of industrial/private research labs in accelerating your research. It argues that publishing landmark papers that are few in number may sometimes be less useful to your career than dividing your results into more papers that are smaller in size, which gives you a steadier stream of publications. Such 'publons' can also help increase your ranking in citation indices.



One the of nice things about this book is that it emphasises the importance of job security and tenure in the life of a researcher. It also highlights the typical pitfalls and challenges that lurk in the road to tenure. It reveals that true job security comes from an established reputation in one's field, basically attained through a steady stream of publications that keep one's name under the light.

The author gives priceless advice on how to write compelling and/or snappy papers, the importance of timely publishing, and how to handle referees. It sheds light on the 'human' practices in the peer-reviewing process, which may prove helpful when kept in mind during paper writing.



Adham Naji is a Lecturer at the Electrical Engineering Department, Faculty of Engineering, BUE, and an Honorary Research Fellow at the University of Bristol, UK.

Tel. 26890000 | Ext. 1454
Adham.Naji@bue.edu.eg

The book's usefulness reaches a climax when addressing funding proposal writing. It highlights that one should take pains in researching the literature and previous work in one's field, commending one's competitors (some of whom might actually be the referees) within reason. One should explain how one's proposed project will add something to this body of knowledge and take him/her a step closer to their longer-term aim. Demonstrating an understanding of the 'big picture' of the problem is key. Showing proofs-of-concept or realisability of the proposed work are integral parts of any proposal, to prove that the named goals are achievable within the given time frame and that one can muster the needed resources to finish the project successfully. Explaining the importance of proposed techniques or methods is crucial, even though it means that some of your competitors who happen to be the referees would get to know your ideas—it is a risk that must be taken to get a funding chance.

The book closes by giving advice on how to establish a research programme (group) and to proceed to seniority in your research career.

This little book is truly a treasure to read. Further, its style carries moments of wit, humour, and deep thought. I would recommend all fellow researchers to read it—if there isn't something to learn from it (which is probably unlikely) then at least you might find it refreshing.

References and further reading

1 Peter J. Feibleman 'A PhD is not enough! A guide to survival in science', 2nd edition, 2011, Basic Books, ISBN: 9780465022229.