

# TRAINING THE NEXT GENERATION OF ACCELERATOR EXPERTS

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## Abstract

Close collaboration between academia, research centers and industry has turned out to be crucial for the advancement of accelerator science and technology. This cooperation is also ideal for providing an efficient training of the next generation of particle accelerator experts and for linking the global accelerator community. Five international research and training networks (DITANET, oPAC, LA<sup>3</sup>NET, OMA and AVA) have been initiated and coordinated by the University of Liverpool/Cockcroft Institute since 2007. These networks have provided training to nearly 100 Fellows from all over the world and organized dozens of international schools, topical workshops and international conferences for the accelerator community. The research activities of the networks have led to hundreds of journal publications and conference proceedings. This paper presents best practice in establishing such international collaborative projects, benefits from working across multiple sectors and countries, and highlights key research and training results that have arisen from the collaborative programs.

## INTRODUCTION

The ESFRI Roadmap identifies new Research Infrastructures (RI) of pan-European interest corresponding to the long term needs of the European research communities, covering all scientific areas, regardless of possible location[1]. Similar roadmaps exist for the USA, Asia and others. A very considerable fraction of these infrastructures rely on the use of particle accelerators. The 2016 roadmap includes for example the Facility for Antiproton and Ion Research (FAIR) [2], the European Spallation Source (ERIC) [3], the Large Hadron Collider (LHC) and its upgrades [4], and upgrades to the European Synchrotron Radiation Facility (ESRF) [5]. These cutting edge accelerator projects require innovative solutions to fully exploit their potential. The associated R&D needs to be carried out by international consortia, involving the respective research center, partner universities, as well as industry. It is of crucial importance that along with the technical planning of these infrastructures, the required experts are trained. Although this is nothing new, surprisingly, very limited training in the relevant areas has been provided internationally and ten years ago dramatic skills shortage was observed.

To overcome this, the Innovative Training Network (ITN) scheme within the European Union's Marie Skłodowska Curie (MSCA) has provided unique support since 2007 to the accelerator community. The scheme supports competitively selected research networks which

combine partnerships of universities, research institutions, research infrastructures, businesses, SMEs, and other socio-economic actors from different countries across Europe and beyond. Each ITN enables cutting edge R&D and provides network-wide training to its Fellows during the 4 year project duration. Any subject area can apply and the best ideas are selected in a bottom-up approach. ITNs exploit complementary competences of the participating organisations, and enable sharing of knowledge, networking activities, the organisation of workshops and conferences to train their Fellows which are usually employed by different host institutions for 36 months. With a success rate of only 5-7%, the ITN scheme is amongst the most competitive funding schemes. The University of Liverpool/Cockcroft Institute has been exceptionally successful in coordinating ITNs in accelerator science. These programs started in 2007 with DITANET, a research network focusing on R&D into advanced beam diagnostic techniques for particle accelerators and light sources [6] which was proposed to the physics panel within MSCA in Framework Program (FP) 7. The network was an enormous success: With a funding of 4.2 Million Euro it trained 22 Fellows (PhD students and Postdocs), organized 4 international schools with up to 100 participants, as well as 9 international workshops for 30-70 participants, as well as an outreach symposium and final conference on beam diagnostics for the world-wide accelerator community. Presentations from all events remain accessible via the project home page and continue to serve as a unique knowledge base for the accelerator research community.

Building up on the successful collaborative model of DITANET, two further ITNs started within FP7 in 2011: oPAC (Optimization of Particle Accelerators) which was submitted to the physics panel and received 6 Million Euros to train 23 Fellows [7], making it one of the largest ITNs ever funded, and LA<sup>3</sup>NET (Laser Applications at Accelerators), submitted to the engineering panel which received 4.6 Million Euro to train 19 Fellows [8]. The two networks ran in parallel and shared a number of training events and also stimulated researcher exchange programs. Taking the oPAC approach further, but focusing on a more specific area within accelerator science, OMA (Optimization of Medical Accelerators) was evaluated by the life science panel and the first ITN that ever received a 100% evaluation mark. OMA started 2016 to train 15 Fellows with a budget of 4 Million Euro and will run until the end of 2020 [9]. Finally, AVA (Accelerators Validating Antimatter research) started in 2017 and was selected by the physics panel to train 15 Fellows with a budget of again 4 Million Euro [10]. Other networks have copied this successful training model, e.g. [11].

## RESEARCH

The ITN frame enables collaborative research involving partner institutions based in various countries, bringing

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together unique skills and expertise that no single institution would possess. Below are selected research outcomes which illustrate the strength of this approach.

### *DITANET*

A comprehensive set of diagnostics for low energy antiproton and ion beams was developed [12]. This included a sensitive Faraday Cup with special noise shielding for measurement of fA beams, a diagonal cut capacitive beam position monitor, and profile monitors based on scintillating screens and secondary electron emission.

The output factor (OF) for dose measurements in axial and perpendicular planes was determined using a silicon strip detector. The OF is an intrinsic characteristic of the respective accelerator and is measured periodically to make sure that the accelerator is operating properly in order to treat patients. A new detector system was characterized and the dose given by various square fields was also measured in an in-house designed cylindrical phantom, normalized to the reference field [13].

A longitudinal density monitor (LDM) for the measurement of the LHC particle population in nominally empty rf buckets. The high dynamic range of the system allows measurement of ghost bunches with as little as 0.01% of the main bunch population at the same time as characterization of the main bunches. The LDM is a single-photon counting system using visible synchrotron light. The photon detector is a silicon avalanche photodiode operated in Geiger mode, which allows the longitudinal distribution of the LHC beams to be measured with a resolution of 90 ps [14].

At GSI, two complementary tune measurement systems were studied in detail. Analytical, as well as simulation models predicted a characteristic modification of the tune spectra due to space charge and image current effects in intense bunches. The position of the synchrotron satellites corresponds to head-tail tune shifts and depends on incoherent and the coherent tune shifts. The modification of the tune spectra for different bunch intensities has been observed in the SIS-18 at injection energy, using the TOPOS and BBQ systems. These measurements give a clear interpretation of tune spectra at all stages of acceleration under typical operating conditions [15].

### *LA<sup>3</sup>NET*

Laser-plasma technology promises a drastic reduction of the size of high-energy electron accelerators. However, applications are hindered by the lack of suitable lens to transport this kind of high-current electron beams mainly due to their divergence. R&D in the project showed that this issue can be solved by using a laser-plasma lens in which the field gradients are five orders of magnitude larger than in conventional optics [16].

Dielectric laser-driven accelerators (DLAs) based on grating structures are considered to be one of the most promising technologies to reduce the size and cost of future particle accelerators. They offer high accelerating gradients of up to several GV/m in combination with

mature lithographic techniques for structure fabrication. R&D in LA3NET investigated the beam quality for acceleration of electrons in a realistic dual-grating DLA. The emittance, energy spread, and loaded accelerating gradient for modulated electrons were analyzed in detail, paving the way for future applications [17].

Radially and azimuthally polarized picosecond (~10 ps) pulsed laser irradiation at 532 nm wavelength led to the permanent reshaping of spherical silver nanoparticles (~30 – 40 nm in diameter) embedded in a thin layer of soda-lime glass. The observed peculiar shape modifications consist of a number of different orientations of nano-ellipsoids in the cross-section of each written line by laser. The approach developed within the network may lead to sophisticated marking of information in metal-glass nanocomposites [18].

### *oPAC*

In the region of the Bragg peak where ions are almost stopped experimental studies with low-energy particle beams and thin biological samples can contribute valuable information on the biological effectiveness in the stopping region. This requires beam optimization and special dosimetry techniques for determining the absolute dose and dose homogeneity for very thin biological samples. Calibration in absolute dose of EBT3 films for proton energies in the region of the Bragg peak was carried out. Energy degradation was achieved by beam energy degradation through Mylar foils. Experimental results were benchmarked against simulations [19].

A design and possible integration of the LHeC interaction region into the existing HL-LHC lattice was also studied. A novel optical technique called *achromatic telescopic squeezing* and the flexibility of the interaction region design were studied to find the optimal solution that would produce the highest luminosity while controlling chromaticity, minimizing synchrotron radiation power and maintaining dynamic aperture [20].

SQUID-based cryogenic current comparators (CCC) have been used for measuring slow charged beams in the nA range, showing a very good current resolution. But these were unable to measure fast bunched beams, due to the slew-rate limitation of SQUID devices and presented a strong susceptibility to external perturbations. A CCC system developed for the AD at CERN, optimized in terms of current resolution, system stability, ability to cope with short bunched beams, and immunity to mechanical vibrations was developed [21].

Research results from the OMA and AVA networks have just started to emerge and are presented elsewhere at this conference [22, 23].

## TRAINING

A structured combination of local and network-wide trainings is the central concept of all training projects within an ITN. Existing and well proven training schemes are typically exploited, but at the same time novel training opportunities have to be made available which no single partner alone could offer. For example hands-on training

through research at accelerator facilities is a unique training opportunity which seldom can be provided within standard university doctoral programs. With the exception of several Postdocs who were employed in DITANET (the option to employ Postdocs did no longer exist in later projects), all Fellows were registered for a PhD. This embeds them into a structured course program at their host university or, if their work contract is with an industry partner or a research center, with a collaborating university. Courses are selected at the start of their project in discussion with their supervisors, based on their project needs and their own background and reflected in their individual career development plan (CDP). In addition, network-wide trainings bring the Fellows together on a regular basis. This ensures that in addition to research-based overlap and links between projects, interpersonal links between the Fellows are established. Most network-wide events also include external participation and hence efficiently link the Fellows to the wider scientific community.

Within higher education there has been a move to provide graduates with the skills and knowledge required in society, equipping them for the world of work, often referred to as the 'skills agenda'. For example in the UK the development of transferable generic skills, in addition to those relating to subject disciplines, have been included in PhD research training [24]. However, such training is not formalized in all European universities. The ITNs presented here guarantee international competitiveness of the researchers trained within them by providing them with the necessary skills for a future career in either the academic sector or in industry. For that purpose, an interdisciplinary 5-day training program, designed for the particular needs of early stage researchers, is held in the first few months of each project at the University of Liverpool. This training is organized in collaboration with central university PGR teams, as well as key industry partners, including Fistral Consulting, Holdsworth Associates and Inventya. It consists of a 'project specific' part and a part addressing more 'general skills', which are based on group work. This school program was developed and tested during DITANET and has since been adopted as standard for all first year postgraduate students in the School of Physical Sciences. This approach was specifically praised during mid-term reviews of DITANET, oPAC and LA<sup>3</sup>NET as 'best practice' in Europe. A final year advanced researcher skills training complements the general training. It focuses on the next career step and includes sessions on CV writing, interview skills, international networking, grant writing opportunities, technology transfer, and international career avenues for researchers.

In terms of the scientific training, each ITN organizes two international schools on their core R&D areas. Each school is open for 70-100 participants and all course materials remain available via the respective event indico page which can be accessed easily through the project home page.

In addition, the networks have already organized dozens of targeted scientific workshops at venues across Europe, and there are many more in the planning. Each workshop lasts 2-3 days, is open for network members, as well as external participants, and focuses on expert topics within the respective network's scientific work packages.

Towards the end of a project cycle, a network typically also organizes an international conference. These include sessions on all R&D aspects within the respective network and highlight the research outcomes. Past conferences have taken place in Seville and Mallorca. Following the example of DITANET, oPAC and LA<sup>3</sup>NET joined forces and organized an international Symposium on Lasers and Accelerators for Science & Society took place on the 26 June 2015 in the Liverpool Arena Convention Centre. With speakers including Professors Brian Cox (Manchester University), Grahame Blair (STFC), and Victor Malka (CNRS), the event was a sell-out with delegates comprising 100 researchers from across Europe and 150 local A-level students and teachers. A joint Symposium between the OMA, AVA and LIV.DAT projects is now in the planning and will take place in the Liverpool ACC on 28 June 2019.

## CONCLUSION AND OUTLOOK

Thus far, almost 100 early stage researchers have been trained within MSCA networks coordinated by the author of this paper. They have produced remarkable research results and trained an entire new generation of accelerator experts. Further collaborative projects on this basis have already emerged and have driven science and technology in this field. The training approach behind these initiatives has impacted very significantly on the world-wide accelerator community where several 1,000 researchers have already participated in one or several of the international schools, workshops and conferences. It has also served as an example for postgraduate training schemes outside of accelerator science and was commended as "best practice" by the EU as part of several formal project reviews.

The career development of Fellows who were part of previous ITNs has been exceptionally good. This is certainly due to the high quality of researchers who were recruited in the first place, but their feedback has clearly indicated that the training, international networks, and cross-sector experiences they had access to, has boosted their skills and career prospects.

Despite such a large number of researchers already trained, there is still a shortage of experts to drive R&D in accelerator science. Future initiatives are strongly encouraged to base their training model on the ideas presented in this paper as this has proven many times to achieve maximum benefit for the Fellows, the R&D projects, as well as the institutions involved.

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