ALICE: STATUS, DEVELOPMENTS AND SCIENTIFIC PROGRAMME

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Abstract

ALICE (Accelerators and Lasers In Combined Experiments) is a multifunctional ERL based R&D facility that operates in various regimes, both energy recovery and non energy recovery, depending on the project undertaken (beam energy 10-28MeV, bunch charge 20-100pC, train length from a single bunch to 100us). The overview of the ALICE scientific programme including IR-FEL lasing and its application for scanning near field optical microscopy, generation and applications of coherent broadband THz radiation for life sciences and solid state physics, studies of the first non-scaling FFAG EMMA for which ALICE serves as an injector and accelerator physics research are presented.

ALICE ACCELERATOR

ALICE (Accelerators and Lasers In Combined Experiments) has evolved from being an energy recovery linac prototype for a 4GLS project [1] to a multifunctional facility hosting a wide range of projects from accelerator physics to life sciences. Figure 1 shows a current layout of the machine including the EMMA ring. The HV DC photoelectron gun with GaAs photocathode injects beam into the first superconducting accelerator module, the booster, that provides the exit beam energy of 6.5MeV. The main linac accelerates the beam to the energy required for particular projects, e.g. 26.0MeV for IR FEL operation and generation of THz radiation, 12.0MeV to inject the beam into the EMMA ring.

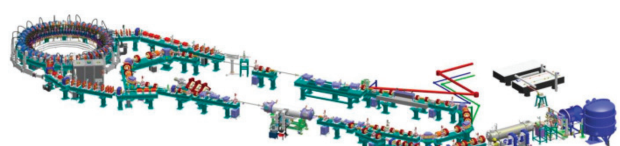

Figure 1: ALICE and EMMA layout.

Nominal bunch charge is 60pC (limited mostly by beam loading effects in the booster) but some projects are conducted at lower 20-40pC bunch charges. In energy recovery mode, the trains of bunches of up to 100us are generated with either 40.63MHz (THz generation) or 16.25MHz (IR FEL) frequency. Train repetition frequency is also variable up to 10Hz.

Until recently, the HV DC gun operated at reduced voltage of 230kV due to restrictions imposed by a smaller diameter HV insulating ceramic. This had a detrimental effect on the beam quality both transverse and longitudinal. In 2012, a larger diameter gun ceramic was installed, the gun was successfully conditioned and the gun currently operates at 325kV. The change of the beam energy in the gun beamline necessitated re-establishment of all ALICE setups and their evaluation is currentlty under way.

ALICE SCIENCE PROGRAMME

Several projects are currently being pursued on ALICE. They are very different not only in nature of the science involved but also in accelerator setups and operational conditions.

Over the past year, demonstration of beam acceleration in the first NS FFAG EMMA and commissioning of the IR near-field optical microscope were two major highlights of the science programme on ALICE. A brief overview of the programme is presented in this Section.

EMMA

Non-scaling FFAG (Fixed Field Alternating Gradient) accelerators have a variety of applications from hadron therapy, Accelerator Driven Systems (ADS) to the rapid acceleration of muons for a Neutrino Factory or a muon collider. A proof of principle machine for this new accelerator concept has been built over the last few years and is being commissioned at the STFC Daresbury Laboratory in the UK. This proof of principle machine is called EMMA or the Electron Model for Many Applications.

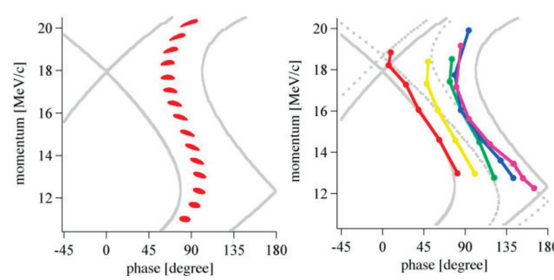

Figure 2: Predicted and measured serpentine channel longitudinal trajectories for different momenta.

EMMA has recently demonstrated successful acceleration in the serpentine channel [2]. The diagnosed beam in the extraction line clearly demonstrated acceleration by up to 10 MeV. Figure 2 shows the predicted and the measured serpentine acceleration channel. Thus a new form of acceleration was validated together with a new kind of beam transport, one that has a much higher energy acceptance than traditional beamlines. Moreover, the crossing of resonances was clearly shown to have very little effect on the tune and the time of flight (ToF) in the EMMA ring. More details can be found in [2,3]. Notwithstanding this success, a lot of work remains to be done in investigating the properties of the only non-scaling FFAG in the world and these are detailed in [4] and references therein.

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ISBN 978-3-95450-115-1

IR FEL studies

The ALICE facility includes an oscillator FEL operating in the infra-red (5.5-9μm), which was successfully operated for the first time in October 2010. In the past year, a beamline has been commissioned to transport the radiation to a diagnostics room for detailed characterisation and optimisation. Details of the FEL operating parameters and performance are given in [5].

A key performance indicator for the FEL is the gain in radiation intensity per pass, determined from the exponential rise at the start of a macropulse (Fig. 3). A Mercury Cadmium Telluride (MCT) detector was used, with no pre-amplifier (since this increased the response time and introduced an artificial limit to the measurement). A real-time gain measurement system was established and the electron beam setup and cavity mirror alignment were optimised for maximum gain. A maximum single pass gain of ~25% was attained, consistent with simulations for the operating parameters. A factor of >2 increase in gain is expected if the energy spread can be reduced from ~0.5% rms to ~0.1%. This is an aim for the present operating period, which should be aided by the increased operating voltage of the gun.

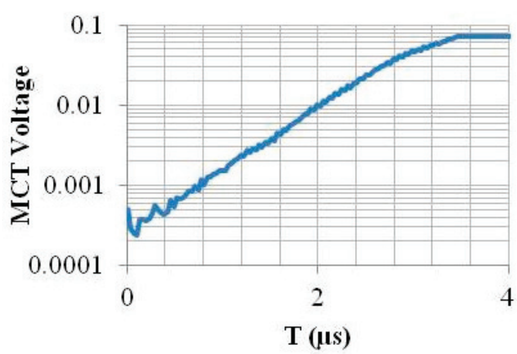

Figure 3: Example of exponential rise of FEL output power, as recorded on the MCT.

The radiation is outcoupled from the FEL cavity by a 0.75mm radius hole in the downstream mirror. This is close to optimum for FEL operation with the present parameters, however the beamline (designed for 4 μm operation, and 1.5mm radius outcoupling hole) shows some overfilling of mirrors, limiting transmission to ~35%. Increasing the FEL gain would allow the outcoupling hole size to be increased, for increased output power, and improved transmission efficiency through the beamline.

A real-time spectrometer has been commissioned, for recording single-macropulse spectra. This has been used for stability studies, and in monitoring the wavelength of the output during experiments using the FEL output. The degree of polarisation was measured to be highly linear (>95%), and the higher harmonics of the output have been observed, with the power in the second and third harmonics measured at 4.7×10^{-4} and 5.0×10^{-4} relative to the fundamental, respectively. The FEL output has been integrated with a scanning near-field optical microscope for studies of oesophageal cancer tissue, and studies to make cross-correlation measurements of the FEL pulse duration have been initiated.

Scanning Near-Field Optical Microscopy

The ALICE IR FEL tuning range of 5.5 – 9 microns is matched to the molecular fingerprint region, i.e., that part of the mid-infrared spectrum in which characteristic molecular vibration occur.

The radiation is being utilised in a collaborative project with the Universities of Liverpool and Rome to develop *Scanning Near field Optical Microscopy* (SNOM) for sub diffraction biochemical imaging of human tissue. The research programme is aimed at development of diagnostics and understanding of mechanism and drug action in oesophageal cancer.

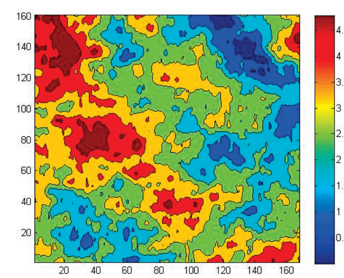

Figure 4: Nano scale spatial resolution from tissue: SNOM image showing the variation of 8.05 micron light absorption. The DNA in the sample contributes strongly to this absorption.

Typical FEL output of 4 mJ per 100 μs train from the outcoupler is transported *in-vacuo* to the Alice diagnostics room by a multi-optics beamline with a transmission efficiency of typically 35%. The infrared beam in the diagnostics room is split such that half is sent to an Acton 0.5m Czerny-Turner spectrometer (Princeton Instruments) with a pyro array detector (Delta Developments) providing single train spectral line measurements. The other beam is focussed onto an optics table on which the SNOM is located in air.

Detection of the SNOM is by coupling the fibre to a cooled MCT detector. The 100 μs FEL pulse trains are ideally matched to the detector response and boxcar integration techniques. The SNOM data can now be normalised to the intensity and spectrum from the array detector on a shot to shot basis.

High quality SNOM images (example is given in Fig. 4) require good intensity and wavelength stability over the 1 – 2 hours scan times. Our suite of on line single shot beam quality diagnostics allows real time monitoring of the accelerator during these scans and offers the potential for feedback to the accelerator for maintaining of optimum lasing in the future.

THz Programme

The coherent THz emission from ALICE is transported to a Tissue Culture Laboratory (TCL) where living cells are irradiated under strict biologically controlled environment. In part, this research aims to determine the

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safe level of human exposure to THz radiation. The TCL satisfies the requirements for research on live human tissue.

Human stem cells are particularly sensitive to their environment and are ideal specimens for assessing the safe level of human exposure to THz radiation. In recent experiments human stem cells have been exposed to peak powers of THz radiation in the range 3–11 kW for several hours (Fig. 5). The time structure of ALICE, in which THz power is delivered in 100 μsec bursts with a 10 Hz repetition rate, is ideally suited to these experiments since the corresponding average powers are in the range 0.4–1.2 mW which makes it possible to eliminate thermal effects. Several other smaller scale studies using THz radiation from ALICE are also being conducted.

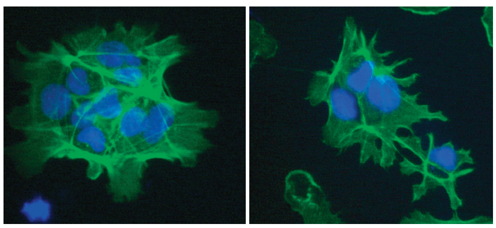

Figure 5: Representative photomicrographs of hES07 cells irradiated (left) and control (right). The cells display good attachment and spreading under both conditions.

Accelerator Physics Studies

Accelerator physics studies are conducted on ALICE with an emphasis on beam dynamics at relatively low beam energies (4-12MeV) and in a presence of space charge effects. The longitudinal beam dynamics is studied in the ALICE injection line using zero-phase measurements of bunch length. The transverse dynamics is mostly investigated using a beam tomography section in the EMMA injection line. The longitudinal structure of electron bunches generated with DC photoelectron gun and the effects of the gun voltage are being also investigated in detail with a preliminary conclusion that the structure developed in the bunch is a result of complex processes during the initial acceleration from low, several 100s of keV, beam energy [6]. As such it should be present, to more or less extent, in all injectors employing the relatively low voltage (<500kV) DC photoelectron guns.

The Daresbury International Cryomodule

An international collaboration comprising STFC, Cornell and Stanford Universities, LBNL, DESY, HZDR-Roseendorf and TRIUMF have developed an optimised cryomodule design for ERL application [7]. All cavity string sub-components have been qualified and the cryomodule (Fig. 6) has been fully assembled at Daresbury and is currently undergoing final cold testing, [8] prior to installation on ALICE in late 2012.

Figure 6: The Daresbury International Cryomodule undergoing final cold testing prior to installation on ALICE.

Digital LLRF Developments

Work continues on an upgrade programme to provide a digital low level RF control system for the ALICE cavities. The system uses the LLRF4 FPGA board designed at LBNL [9] as its motherboard, which has been modified to include an Ethernet port, also the analogue up/down conversion stages have been moved off the board to a temperature stabilised plate. On bench tests, the system achieves 0.03 degrees RMS error and 0.04% amplitude error. The system is currently being tested using ALICE RF buncher.

ACKNOWLEDGMENT

This paper was prepared by the author on behalf of ALICE and EMMA teams and our national and international collaborators.

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ISBN 978-3-95450-115-1