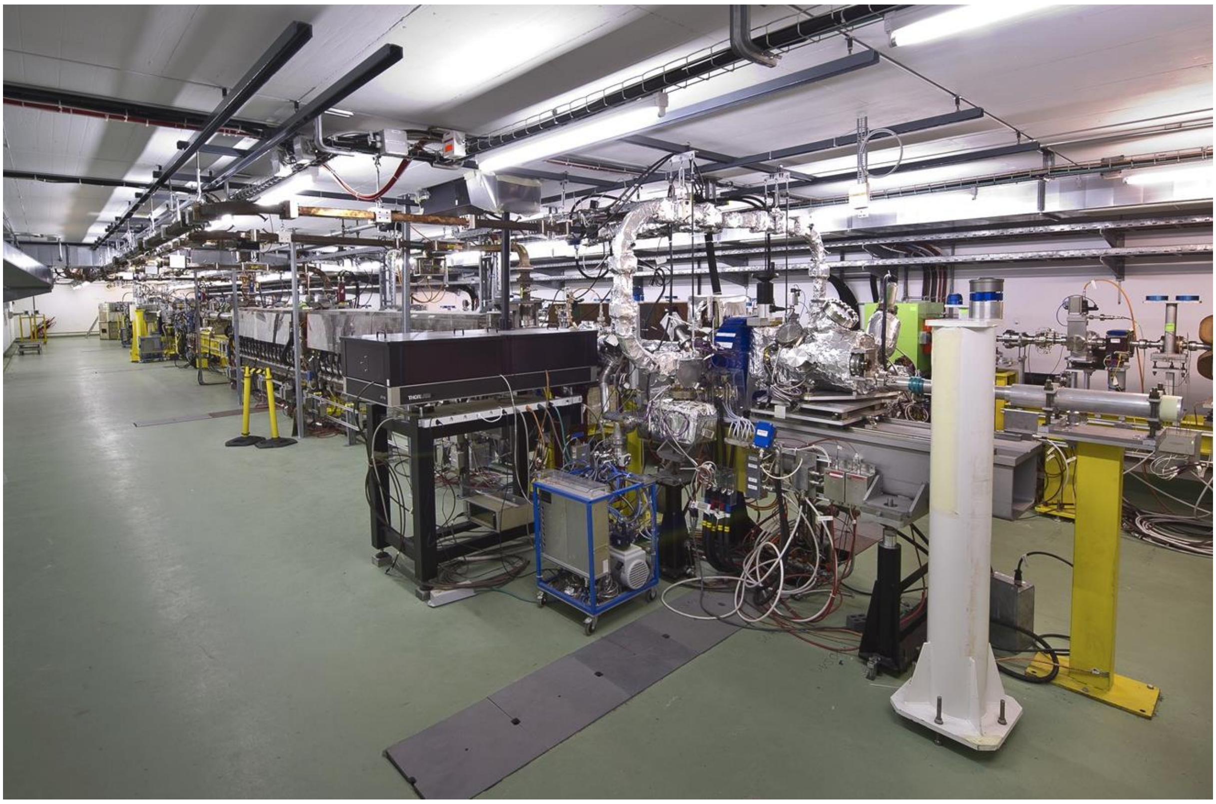
The CLEAR[1] facility at CERN



Prepared by:
M.Brugger, R.Corsini, T.Lefevre, B.Salvant, S.Stapnes, W.Wuensch - CERN
M.Petrarca – "Sapienza" University of Rome and Roma1- INFN
S.Reiche - PSI
C.Welsch - U. of Liverpool
E.Adli - U. of Oslo
P.N. Burrows - U. of Oxford

[1] CLEAR: **C**ERN **L**inear **E**lectron **A**ccelerator for **R**esearch

Abstract

CLEAR is a proposed new user facility at CERN dedicated to accelerator R&D. By reconfiguring the existing CALIFES electron linac, presently used as the probe beam line of CTF3, the new stand-alone user facility - CLEAR - would be available for users from 2017 onwards.

The primary focus for CLEAR is general accelerator R&D and component studies for existing and possible future machines at CERN, based on a broad internal and external user community. The program covers two of the top priorities identified by the European Strategy for Particle Physics, namely the prototyping and validation of accelerator components for the upgrade of the Large Hadron Collider and its injector chain, and studies of high-gradient acceleration methods. The latter cover X-band studies for linear accelerators and also novel concepts as plasma and THz acceleration. The proposed facility would also provide unique training possibilities, as well as irradiation test capability, allowing for example, continuation of the collaboration with the European Space Agency (ESA).

An initial five-year program is proposed including a mid-period evaluation. The main input to this program comes from a dedicated workshop held on 10-12 October 2016 at CERN [Workshop INDICO link]. This document presents a summary of the opportunities and ideas discussed during this workshop, emphasizing those where CLEAR offers unique possibilities in the timeframe considered, 2017-21.

The R&D program proposed for 2017 is presented in detail and requires only minor modifications of the existing CALIFES facility. The possibilities for expanding the testing capabilities and improving the beam quality at modest cost in 2018-2019 are discussed, highlighting the performance potential of the facility. Additionally, an outline of the possible R&D topics for 2018 and beyond is presented, though necessarily in less detail at this stage.

The overall resources needed at CERN amount to ~1.7 MCHF/year (material and personnel) from 2017 onwards. This would cover the operation, maintenance and adaptations of the facility. The facility will use one third of the existing CTF3 area and all essential equipment is available. The personnel estimate for operation and maintenance is about 8 FTE out of which four are expected to come from the CLEAR user community. Local support of personnel from external collaborators and fellows is included in the estimate above. The current LC budget at CERN can be re-prioritized to cover these costs without significantly affecting high-priority CLIC deliverables.

Keywords
CERN, beamline, electron, accelerator R&D, high gradient, impedance, plasma.

1 Motivations and guidelines

CLEAR represents a completely new user facility at CERN, running in parallel with the main CERN accelerator complex, with the primary goal of enhancing and complementing the existing accelerator R&D and testing capabilities at CERN. A workshop focusing on the possible uses of the beamline was held in October 2016 with participation from 80 people covering a broad science community. The scientific and strategic goals set out are the following:

- Providing a test facility at CERN with high availability, easy access and high quality bunched electron beams.
- Performing R&D on accelerator components, including beam-based impedance measurements, innovative beam instrumentation prototyping and high gradient RF technology advancement with realistic beam tests.
- Providing a radiation facility with high-energy electrons, e.g. for testing electronic components in collaboration with ESA or for medical purposes, possibly also for particle physic detectors.
- Performing R&D on novel accelerating techniques – electron driven plasma acceleration and THz acceleration. In particular developing technology and solutions needed for future particle physics applications, e.g. beam emittance preservation for reaching high luminosities.
- Maintaining CERN and European expertise for electron linacs linked to future collider studies (e.g. CLIC and ILC, but also AWAKE), and providing a focus for strengthening collaboration in this area.
- Using CLEAR as a training infrastructure for the next generation of accelerator scientists and engineers.

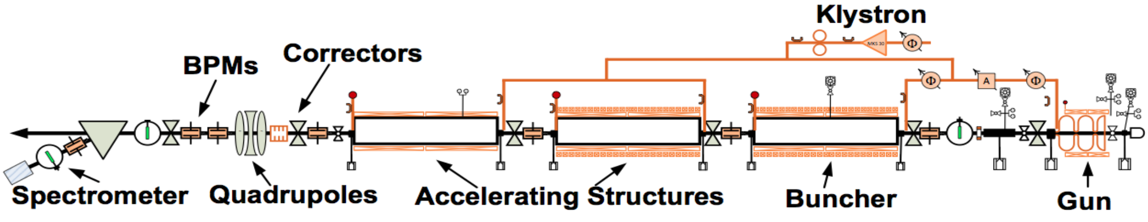
In addition, the proposal for CLEAR has been elaborated within certain constraints and guidelines:

- The proposed R&D work should help deliver the current European Strategy priorities in particular in accelerator R&D. An initial time period of 5 years is proposed in order to provide enough time for a meaningful program with external participation with this goal in mind, while also providing a flexible accelerator R&D platform for the next Strategy period.
- The proposed facility would aim at keeping the personnel effort from CERN staff as low as possible, and external collaborating personnel should be involved in the operation of the facility.
- One should avoid negative interference with the program of other operational or planned electron facilities, in particular in the CERN member states. An International Advisory Committee was set up to prepare the workshop at CERN October 2016, involving representatives from many of the laboratories where existing or planned facilities are based, in order, among others, to make sure that the CERN plans were known and possible conflicts avoided.

2 The proposed CLEAR facility

The proposed electron beam facility is an adaptation of the CALIFES electron linac located in the experimental area of the CLIC Test Facility 3 (CTF3) at CERN. The linac is capable of producing an electron beam with a wide range of parameters. The beam is generated from a photo-injector gun, by projecting a UV-laser on a Cs_2Te photocathode. The gun can produce low emittance bunches (< 2 mm mrad) with high charge (up to 1.5 nC), either in trains with a few 100 bunches spaced at 1.5 GHz, or as single bunches. After the gun the bunch is compressed using a 3 GHz S-band structure used as a velocity buncher, in order to compress the bunch to a length adjustable from 300 μm to 1.2 mm. The beam is subsequently accelerated in two S-band accelerating structures to a final energy of up to 200 MeV. A single 3 GHz klystron equipped with an RF pulse compressor is used to power the accelerating structures. The maximum machine repetition rate is presently 5 Hz, upgradable to 25 Hz.

The beamline includes transport and focusing elements, an experimental area currently used to test CLIC two-beam modules, and a complete set of beam diagnostics, including spectrometers, before and after the experimental area. Figure 1 shows the layout of CALIFES gun and beamline as well as the area available for experimental activities.



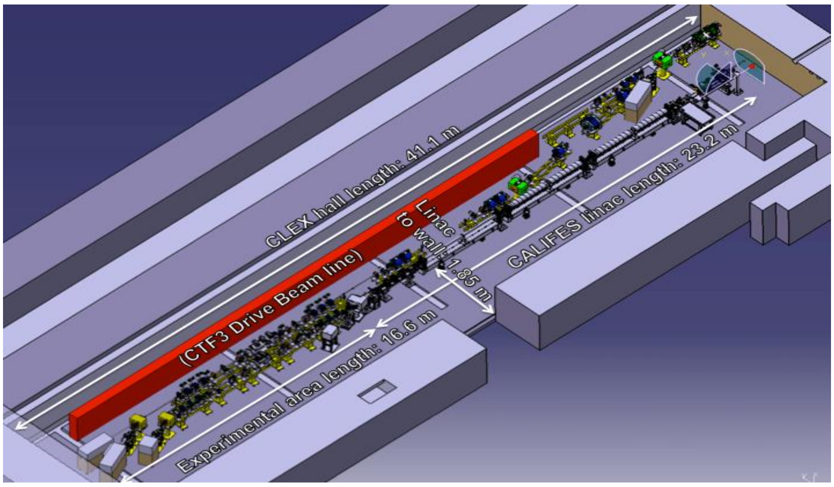


Figure 1: CLEAR with the current CALIFES gun and beamline, as well as the available experimental area.

Beam parameter (end of linac)	*Value range*
Energy	130 - 220 MeV (down to 60 MeV with upgrade)
Bunch charge	0.01 - 0.5 nC
Normalized emittances	3 um for 0.05 nC per bunch
	20 um for 0.4 nC per bunch (in both planes)
Bunch length	~500 um -1.2 mm
Relative energy spread	< 0.2 % rms (< 1 MeV FWHM)
Repetition rate	1 - 5 Hz (25 Hz with upgrade)
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 1: The CALIFES gun and beamline parameters.

The beamline can be available from around the middle of 2017 for experimental activities. The work needed to adapt the facility for the proposed program in 2017, as well as a discussion of possible further adaptations, can be found in section 4.

3 Scientific Opportunities at CLEAR

The scientific opportunities at CLEAR, as identified during the last two years and presented during the workshop held on 10-12 October 2016 at CERN, are summarized in this chapter. The eight research and activity areas discussed are summarised in greater detail in Appendices A1-A4 and B1-B4.

Two general and important conclusions could be drawn from the interests expressed, the numerous proposals presented and comments made by the workshop participants.

It was repeatedly mentioned, both from CERN representatives and external researchers, that the availability of test facilities at CERN but also in Europe in general is critically low. Moreover, even where there are electron linacs in Europe with beam parameters similar to those of CLEAR, they are either permanently used as injectors for light sources or almost exclusively dedicated to other special purposes, such that their availability for R&D is low. Based on these conclusions the major strengths of the proposed CLEAR facility can be listed as:

- Its availability for and dedication to accelerator R&D already in 2017, but also during long shutdown periods when the main CERN accelerator complex is switched off.
- The re-use of the existing CERN (CLIC/CTF3) infrastructure minimizing the need for new investments.
- The low running cost and easy local access.
- The flexible adaptability to specific experiments and future developments in the existing experimental hall.

Both member and non-member state partners are particularly interested in collaborating with CERN in running such a facility, in synergy with the existing and anticipated wide use of electron linacs in their own countries. As an example, numerous such synergetic studies already exist within the CLIC collaboration with its ~50 partners. The CLEAR facility would enable strategic R&D partnerships with other science fields in Europe that require electron-beam test capability, namely X-ray FELs, medical, space and industrial communities. Furthermore, for many European groups (researchers and students), participation in CLEAR will help them connect to and complement their respective existing national and international programs in accelerator research.

3.1 High priorities for the current CERN accelerator program

Key priorities at CERN are the LHC project and its upgrade program, including the injector chain, followed by the R&D work on future projects such as CLIC and FCC, focusing on high accelerating gradients and high field magnets, respectively. We present in section 3.1 in more detail the tests that would be carried out at CLEAR highlighting their relevance for CERN's main goals[2].

3.1.1 High-gradient energy-frontier R&D:

- High-gradient linacs are being considered for an increasing number of applications in addition to linear colliders, including compact light sources (see below) and medical linacs. Significant progress has been made in developing high-gradient accelerating structures with stand-alone RF test facilities, including routine operation of more than 100 MV/m gradients. However, a number of open issues, crucial for all the applications mentioned above, involve the interplay between the beam and the high-gradient fields. The CLEAR facility combined with the nearby X-band power station XBox-1 provide a unique opportunity to study key issues: the effect of a beam on the high-gradient behaviour and the effect of high-gradient phenomena on the beam, including kicks on the beam originating from structure breakdowns. In addition to CERN, a large number of institutes from the CLIC collaboration and the X-band FEL collaboration plan to participate in these studies. Routing of X-band power to CLEAR for beam tests could be carried out from 2018. More details can be found in appendix A1.
- FEL linac studies related to the studies above: There is growing worldwide interest in FELs as well as inverse Compton sources. An international collaboration with about 20 external institutes, in addition to CERN, is currently undertaking a design study for compact light sources using CLIC X-band technology. In addition to the high-gradient structure tests (above) CLEAR offers the capability for component tests and technology demonstrations needed to demonstrate high peak current and good beam quality. These include phase-space linearizers, transverse deflecting cavities (for bunch length diagnostics and RF spreaders) and wake-field monitors. The UK FEL collaborators express interest in collaborating with CLEAR on X-band FEL component tests, also since the UK CLARA facility (under construction at Daresbury Laboratory) is focusing on photon production with insufficient space and beam time left for extensive testing of RF technology and compression dynamic. More details can be found in appendix A2.

3.1.2 Impedance studies:

- Measuring the impedance of accelerator components is crucial prior to their installation on CERN accelerators, especially in high intensity machines (PSB, PS, SPS, LHC, FCC) as the beam coupling impedance may limit the machine performances. The measurement of impedance in CLEAR is proposed by the CERN impedance working group as a new and complementary tool to numerical simulations and RF bench measurements. In 2017 the impedance group is interested in measuring LHC wire scanner prototypes with the CLEAR beam. This can be done without changes to the current setup requiring only the integration of a wire scanner tank and RF measurement devices, although appropriate tapering in the device-under-test must be well controlled. A long-term program would benefit from a second injector in CLEAR, making direct impedance measurements effects possible using a witness beam to probe the wakefields. The CLIC collaboration, including external institutes (U. Uppsala, U. Oslo) are as well interested in continuing impedance studies (both transverse and longitudinal) in CLEAR. More details can be found in appendix A3.

3.1.3 Beam instrumentation tests:

- The LHC and its injector complex as well as CLIC, FCC and AWAKE require development of state-of-the-art beam instrumentation devices. In CLEAR, prototypes of such devices can be tested and calibrated under realistic beam conditions with full flexibility. Such tests have been carried out on the CALIFES

[2] AWAKE phase I and preparation of future phases are also relevant; the connections are however discussed in chapter 4 related to possible improvements of CLEAR.

beamline for some time. In 2017 tests of new stripline Beam Position Monitors (BPM) for HL LHC, high bandwidth electro-optical BPM for LHC and scintillating fibres for the SPS NA are planned. In the coming five-year period, several other devices under development for the projects mentioned above can benefit from such a facility. In the longer term, having shorter bunches would be a valuable feature. It is important to note that in case CLEAR is not available, similar beam tests, involving extra costs and time, must be envisaged elsewhere to validate those prototypes before launching series production. In addition to the CERN BE/BI group, partners from Royal Holloway U. London, U. Oslo, U. Uppsala and U. Tomsk are currently involved in or plan to participate in instrumentation tests at CLEAR. More details can be found in appendix A4.

3.2 New accelerator R&D opportunities

Electron, and positron, linacs have the potential of becoming extremely compact following the progress in novel accelerator techniques such as plasma wakefield and THz acceleration that can provide very high gradients. CERN already hosts AWAKE but has limited contacts with the research activities related to electron driven acceleration. Furthermore, key challenges related to emittance conservation, positron acceleration and energy efficiency need to be addressed in order to progress from the demonstration of acceleration gradients to high-energy collisions. The research proposals presented for CLEAR define a clear path for this type of research at CERN. It is also an excellent way to link the existing expertise at CERN in all aspects of linear colliders to the challenges of using these new technologies in a real machine.

3.2.1 Plasma wakefield (PWFA) R&D:

- There is an intense worldwide interest in plasma-based particle acceleration. Electron experiments at CLEAR would be complementary to the proton driver experiments at AWAKE. The CLEAR beam combined with a novel gas discharge plasma source ready to be provided by ICL/IST will provide a complementary facility for studies relevant for PWFA linear collider research. Such a program could be started as early as 2017, and would include commissioning and demonstration of the novel plasma source technology, plasma beam dump studies, and plasma lens lattice tests. Testing the discharge plasma source has an interest in itself for the AWAKE Run 2 planning. The availability of shorter bunches at CLEAR and a second source would increase the longer term scope significantly, opening for two-bunch acceleration studies, further studies of emittance preservation, drive-witness beam injection tolerances and efficiency. The institutes proposing PWFA research in CLEAR include IST/ICL, Cockcroft Institute, Ecole Polytechnique and U. Oslo. These institutes plan to contribute in terms of manpower and PhD students to install and commission PWFA hardware, and to run the experiments. The program proposed is to a large extent complementary to and coordinated with what is proposed at DESY and INFN-Frascati, where the programs are saturated. More details can be found in appendix B1.

3.2.2 THz acceleration

- Using strong THz fields to produce high-gradient acceleration is another novel technique which has generated strong interest in the accelerator community. While other facilities, including the FLUTE facility at KIT, study THz generation for photon science, there are currently no European user-facilities available where dedicated beam time or experimental space is available to perform THz acceleration experiments. Research groups from INFN/U. Rome, Cockcroft and Uppsala are interested in performing THz generation and THz acceleration experiments at CLEAR. Concrete short term plans (2017-2018) for initial THz production and first tests of acceleration with dielectric structures were presented at the workshop. Also presented were a longer term proposal which contains installation of a dedicated THz test stand with instrumentation, and dedicated manpower from the external institutes including PhD students, post docs and seconded staff to run the experiment and also help run the facility. More details can be found in appendix B2.

3.3 Additional activities made possible by CLEAR

The CALIFES gun and beamline are already used for radiation testing and training purposes. These communities have expressed clear interests and plans to continue their studies in the forth-coming period in CLEAR. Additional ideas of using CLEAR for radiotherapy studies, EU supported projects – even dedicated to CLEAR – focussing on research and training, or as a training facility for CERN staff and users were presented and will be explored.

3.3.1 *Radiation tests:*

- Electronic devices for use in extreme environments need to be qualified for radiation-damage effects. CALIFES can provide relevant electron-beam energies and fluxes for such tests, not available at existing radiation test facilities, notably monochromatic >100 MeV electrons at highly adjustable flux levels. Space and detectors applications: The ESA JUICE spacecraft will be located in a severe environment of high-energy electrons with energies extending up to a few hundred MeV. Irradiation tests for JUICE are already on-going at CALIFES (in the VESPER test bench) and are planned to continue after 2016. These tests involve ESA, U. Padua, Naval Research Laboratory, U. Bern and CERN. High energy electron test beams are potentially also of interest for particle detector development. Medical applications: due to the potential of compact high-gradient electron linacs there is an increased interest in radiotherapy options using high energy electrons, typically up to 200 MeV. There is a lack of dosimetry data in this energy range. Cockcroft institute has proposed to study electron dosimetry using the CLEAR beam, starting as early as 2017. More details can be found in appendix B3.

3.3.2 *Training:*

- There are relatively few accelerator facilities worldwide where significant time can be made available for 'hands-on' training of students and junior staff. As discussed at the workshop CLEAR has an enormous potential as a facility for education and training of early career researchers. This has already been demonstrated; approximately 80 students from the CLIC collaboration have had accelerator hands-on experience at the CLIC Test Facility. In spring 2016 eighteen JUAS students performed accelerator operation and beam handling in the facility over the course of two days. As training facility CLEAR has many attractive features: adequate complexity, limited beam power allowing for unrestrained beam handling, and it is a stand-alone facility not dependent on other infrastructure. An international training initiative, such as a European Training Network involving a number of external institutes, could give both accelerator training and the CLEAR facility itself a significant boost by establishing a cutting edge research program around the existing accelerator infrastructure. Such initiatives could be put forward as EU proposals relatively soon after a go-ahead for the CLEAR facility. More details can be found in appendix B4.

4 Implementation and timeline

4.1 First Year - 2017

We propose to start operation of the CLEAR facility as early as mid-2017, by limiting the modifications of the present installation to the strict minimum.

4.1.1 *Preparation 2017*

In particular, since it has been agreed that the present 3 GHz RF station powering CALIFES will be dismantled and re-installed in AWAKE, it will be substituted by connecting two other existing stations to the gun, buncher and two accelerating structures of CALIFES. The use of two stations will increase the energy range and shorten the minimum bunch length. An upgrade of the RF repetition rate from 5 Hz to 25 Hz will also be implemented at the same time. Another existing RF station will be kept operational and shared between S-band RF tests of accelerating structures for medical applications (in the former CTF2 building) and the RF deflector already installed in CALIFES for longitudinal beam diagnostics.

A reconfiguration of the test area will also be needed and is under study. A detailed proposal should be ready as soon as the experimental program for 2017 is finalized and its precise requirements are defined.

4.1.2 *Tentative running schedule 2017*

The modifications above can take place during the winter shut-down 2016/17, and operation should be possible from the beginning of May. About one month would be needed to re-commission the CLEAR beam. A few operation periods interleaved with short installation stops are foreseen, and the mode of operation is supposed to be similar to the one of CTF3 and CALIFES, with two daily shifts during working hours. However, radiation tests in the VESPER beam line will be mainly carried out with remote supervision during night and weekends, with a few blocks of regular day-time operation for tests needing frequent changes or interventions in the machine.

Initially, only activities already on-going in the CALIFES beam line are planned (i.e., Wake-Field Monitors and wake-field kick studies using CLIC X-band structures, beam tests of the CLIC BPMs and radiation tests in VESPER). From mid 2017 new experiments are expected to start. In the tentative schedule of Figure 2, we have included basically all new experiments proposed in the different sessions of the CALIFES workshop as feasible in 2017 (see appendices A1-A4 and B1-B4 for details). If all hardware would be available as foreseen and we find compatible space in the beam-line, the schedule appears crowded but feasible. We have limited parallel activities to a maximum of two + VESPER operation, which fits with the 2016 experience in CALIFES. Parallel activities will share the shifts, allowing more time for preliminary data analysis and experiment planning.

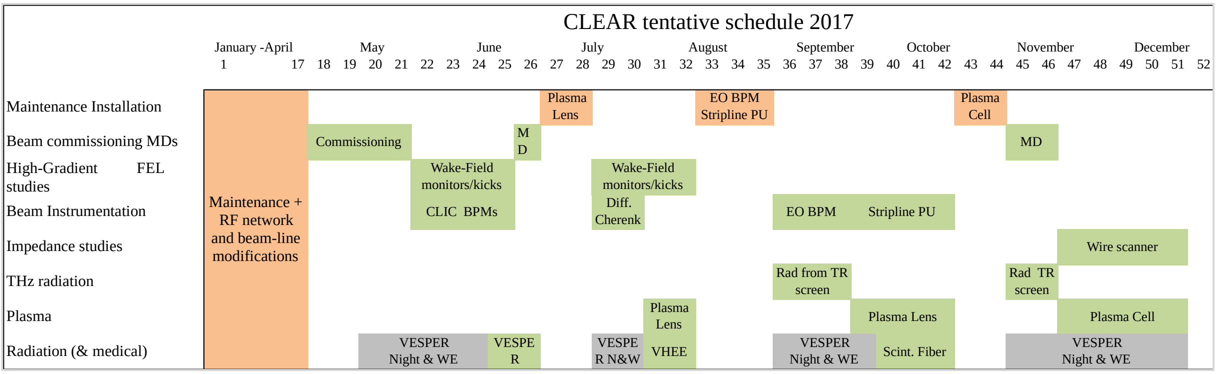


Figure 2 - Tentative experimental program and schedule of the CLEAR test facility in 2017.

4.2 Outlook for 2018-2021

While the short-term experimental programs proposed for the first year of CLEAR operation are already important, the exploitation of its full potential will occur in the following years. We refer to the appendices A1-A4 and B1-B4 for a full discussion, and briefly discuss in the following the mutual implications of the future program and the facility configuration.

During the shutdown 2017-2018 for instance, by rearranging and moving the low-loss RF line presently connecting Xbox1 to the CTF3 linac high power X-band RF will be available for high-gradient energy-frontier R&D and FEL studies.

Consolidation and improvements of the present laser system will provide higher beam intensities and improved charge and position stability, required by several applications. Moving the present laser room closer to the injector (presently, the laser is transported through a 70m long light transfer line) would already provide a considerable gain. Double pulse and/or pulse shaping capability might also be added.

A simple re-configuration of the existing beam-line will free-up enough space to accommodate users for the 2017 run. However, later on more space will be needed. Space requirements, typical times for installation and turn-around for experiments, together with their mutual compatibility and potential synergies will have to be fully evaluated to provide input for a long-term solution. The obvious possibility is to install in the mid-term (end 2017 or during 2018) a second beam line with a dog-leg branching off after the third RF structure in CALIFES, in the area presently hosting the drive beam lines of TBM and TBL. The dog-leg can be used for magnetic bunch compression, reaching down to the 100 fs region, as shown by preliminary studies and as requested by several users. Using a three or four-bend dogleg achromat, some tunability of the momentum compaction can also be obtained for additional flexibility. Most if not all of the main components of such a beam-line (girders, magnets, power supplies, diagnostics, vacuum pumps and other ancillary equipment) may be recovered from CTF3.

Several of the proposals presented in the workshop (e.g. for plasma, THz radiation, impedance measurements) can broaden their program if two independently adjustable beam pulses would be available. Such experiments would therefore greatly profit from a second independent electron source. A new source can also be optimized for short bunches and low emittance, beyond the reach of the present CALIFES gun. This is in synergy with AWAKE, which would need a new short-pulse advanced source (100 fs, ~ 400 A peak current, 50 MeV) for its planned Run 2 where experiments are planned to start in 2021. An interesting option presented in the workshop for a combined effort on a compact injector providing very short bunches, is an S-band RF gun joined to an X-band buncher and an X-band accelerating structure. In such a case, most of the needed hardware is available from the CLIC study. A possible strategy that would benefit both CLEAR and AWAKE is to install and commission an AWAKE Run 2 compatible injector as second injector in CLEAR, giving valuable working experience before this gun, or an identical copy, is installed for AWAKE Run 2 in ~2020.

These upgrades and improvements will depend on the user requests, the scientific relevance of the proposed experiments and the availability of external contributions. A full plan for an optimised upgrade path will be prepared in 2017. More details about short- and long-term upgrade possibilities can be found in Appendix C.

5 Resources

Most of the material for a CLEAR facility is available from CTF3. The capital value of the existing CALIFES linac can be estimated to 14 MCHF (excluding buildings and basic infrastructure). Additionally the CLIC collaboration carries out specific studies in the area and some equipment can be made available also for potential future studies. A rough estimate of the needed capital cost to refurbish CALIFES (including a basic energy upgrade and a reorganization of the test beam line) is about 700 kCHF distributed over 2017-18.

The running cost of the new facility can be estimated at about 700 kCHF/year (including M to P), with the following distribution:

Cost-item	*kCHF/year*
RF (including M to P)	240
Vacuum	20
Power converters	10
Cabling, diagnostics, controls (including M to P)	70
Laser cathodes (including M to P)	110
Personnel for operation maintenance and installation support (M to P)	220
Contingency, travels, visitors support	30
Total	700

The personnel needed for maintenance and operation support is 3.7 FTE/year for staff, 1 FTE/year for fellows (two fellows at 50%) and about 3.5 FTE/year for students/PJAS/FSUs (cost included in material budget above). The rough distribution of staff resources among the CERN groups is as follows:

Group/section	*FTE/year*
BE/ABP	0.5
BE/BI	0.2
BE/OP	0.5
BE/RF	1
EN/STI	0.5
TE/EPC	0.5
TE/VSC	0.5
Total	3.7

The total cost for the operation of the facility is hence around ~1.7 MCHF yearly (running cost plus personnel). For comparison, the running cost of the current CTF3 is about 1.4 MCHF/year (material), and the total personnel involved are 12 FTE/year (staff), 2.5 FTE/year (fellows) and about 5 FTE/year for students and project associates.

Acknowledgements

The ideas presented in this document are summarized from a Workshop arranged at CERN October 10-12 2016. Several of the ideas have been developed over a longer time with the session leaders and speakers at this workshop. The workshop had 97 participants, with ~50 talks – and we would like to acknowledge all the people contributing to the presentations and discussion during the workshop. See appendix D for a complete list of talks.

We would also like to thank the International Advisory group set up to guide the preparation for the workshop: R.Aleksan (CEA and Tiara), R.Assmann (DESY), F.Bordry (CERN), P.Burrows (Oxford and ATF2), J.Clarke (STFC Daresbury), A.Faus-Golfe (Valencia/IFIC and ATF2), M.Ferrario (LNF), M.Hogan (SLAC and FACET), E.Gschwendtner (CERN and AWAKE), L.Rivkin (PSI and EPFL), R.Ruber (Uppsala), A.Stocchi (LAL), M.Vretenar (CERN). Their advice was very important preparing the workshop.

Additional important and very appreciated guidance came during the CLIC project review March 2016 and subsequent discussions where it was recommended to develop further the facility ideas, emphasize an open facility for accelerator R&D using the available electron linac, involving external users in the operation and re-arranging the LC funding line to accommodate the costs.

Appendix A1 High-gradient RF developments

Session chair: Walter Wuensch (CERN)

Introduction

There is growing interest in using high-gradient linacs in an increasing number of applications including linear colliders, XFELs, Compton scattering sources and medical linacs. Significant progress has been made in developing high-gradient accelerating structures using stand-alone rf test facilities. For example, prototype CLIC accelerating structures routinely operate at accelerating gradients in excess of 100 MV/m in the CLIC XBoxes. There are however a number of open issues, crucial for all the applications mentioned above, which involve the interplay between a high-gradient structure and a beam. Operational facilities will of course have beams, so the behaviour of the full configuration of beam and high-gradient structure must be understood and in many cases quantified.

Short term upgrades (2017)

The CALIFES linac combined with the nearby X-band power station XBox-1 provides a unique opportunity to bring together high-gradient X-band acceleration along with a well instrumented relativistic electron beam in order to address these crucial beam and high-gradient interaction issues. Some infrastructure modification will however be needed before such a program can be carried out. There are two options. One is to transport 12 GHz power from the existing XBox-1 location to CLEX using the overmoded waveguide system now used for the so-called "dog-leg" experiment in the CTF3 drive beam linac. The other option is to move XBox-1 above the CLEX area.

Both options could be carried out in 2017 with the tests described in this section starting in 2018. An addition benefit of adding a high-gradient system to CALIFES would be to increase beam energy by well over 50 MeV.

Proposed experimental program 2018+

The experiments and tests which address beam and high-gradient structure using the XBox-1 installation and CALIFES can be grouped into four main categories:

1. The effect of a beam on the high-gradient behaviour of a structure
2. The effect of high-gradient phenomena on the beam
3. Wakefields and structure-based beam measurements
4. Full system tests

Specific experiments and measurements are described below along. Medical linac related tests, using CALIFES S-band equipment, are described in a final section.

The effect of beam on high-gradient performance

The effect of beam loading on breakdown rate – This measurement is of direct relevance to the CLIC project and to multibunch versions of the Compton scattering sources. In these applications a high current beam is accelerated, which changes the field distribution inside a structure. In the experiment the breakdown rate of a structure, and distribution of breakdowns inside it, is measured with and without beam. It is crucial to quantify this effect in order to optimize an accelerating structure for highest gradient and maximum rf-to-beam efficiency.

The effect of beam loss on breakdown rate – High-gradient phenomena include vacuum arcs and multipactor. These processes involve electron emission and initiation processes are strongly dependent on material state. Investigating the direct effect of controlled CALIFES beam loss on breakdown rate, especially in the low breakdown rate regime, in a high-gradient structure is important for both CLIC and XFELs. Additionally, the satellite community has proposed to use the CALIFES beam to induce multipactor in waveguide systems in a controlled way in order to benchmark multipactor simulation codes. This would significantly improve the current technique, which relies on a radioactive source. Finally the long-term effect of beam loss on material state, specifically dislocation density, and the resulting effect on high-gradient performance needs to be understood.

The effect of high-gradient on beam

Breakdown kick – Vacuum breakdown induced currents kick a beam transversely and result in reduced acceleration due to supressed rf power transmission through a structure. Measurement of these effects is important for all the applications mentioned above since an errant beam can damage accelerator components and result in radiation emission in an unexpected direction. The CALIFES beam can be used to measure the size and distribution of these kicks from an operating high-gradient structure. This information feeds directly into the design of collimator and radiation shielding for example.

Dark current – All of the applications listed in the introduction run above the dark current capture limit. Dark current will produce radiation, give background to instrumentation and possibly even deflect the beam. Measurement can be made of emitted dark current characteristics using the well understood and well instrumented CALIFES beam line downstream of an operating high-gradient accelerating structure. Additionally beam instrumentation should be tested in the vicinity of high-gradient accelerating structures to determine any performance degradation due to dark current or damage due to breakdown currents.

Wakefields and structure-based beam measurements

Wakefield validation - Many of the applications for high-gradient also require low emittance electron beams - CLIC, XFELs and Compton scattering sources – and consequently require well-known and well-controlled wakefields. Modern computer codes can give precise estimates but not over all parameter ranges. Combined with additional fabrication uncertainties, a wakefield measurement and/or validation is a very high priority for the high-gradient and low-emittance applications. This challenging measurement is described in section X.

Integrated wakefield monitors – CLIC and XFEL linearizing cavities have so-called wakefield monitors to determine the relative alignment of structure and beam. The CALIFES beam and XBox-1 power source would allow direct characterization of the performance of such monitors in powered and un-powered in order to determine performance limitations.

Full system tests

An early full system test of an rf unit is a major risk reduction for a linac project. The combination of the XBox-1 klystron based power source plus the CALIFES beam provides a near full system test for applications using X-band acceleration and also X-band deflectors and energy spread linearizers. All three are being actively considered in number of electron linac applications including a klystron-based CLIC, XFEL and well as plasma acceleration test beams and diagnostics. An important aspect of a full system test for many applications is to measure beam to rf phase stability.

S-band test stand

There are a number of proton therapy linacs which have chosen S-band as their operating frequency. This includes the LIBO-based linac for LIGHT by the firm ADAM, the KT-group funded high-gradient structure made by the CLIC group for the TULIP project of the TERA foundation and the PROBE proton imaging structure being built by STFC. An S-band rf test stand is needed to test the latter two structures and would remain an important infrastructure for such testing for some time to come. An S-band a test stand is straight forward to implement within CALIFES, by using an existing klystron modulator unit, a copy of the XBox control hardware and software as well as the CLEX radiation controlled area.

Communities and resources

The CLIC high-gradient tests have been performed by members the international CLIC collaboration including, and it is expected that continued high-gradient tests in CLEAR will also involve the external collaboration partners in the CLIC collaboration. In addition, new institutes are expected to join, for example from ADAM in the case of an S-band test stand.

Appendix A2 Light Source R&D

Session chair: Sven Reiche (PSI)

Introduction

Large scale user facilities such as LCLS, SACLA, or SwissFEL always relied on test injector facilities to study key elements (either instrumentation, measurement techniques or beam dynamics verification) to pave the way for a successful commissioning and running of those facilities. As an example, the SwissFEL Injector Test Facility (SITF) demonstrated the so far lowest measured emittance, both projected and slice, which was used as a fundamental assumption to define the overall length of the Swiss facility with the aim to be shorter than any other hard X-ray FEL. It also shows BPM resolution of about 1 micron and screen resolutions of 9 micron while avoiding the disruptive signal from the coherent transition radiation emission.

The CLEAR injector can play an important role if it is associated with a future X-ray FEL project, such as the proposed X-band X-ray FEL or a possible construction of such FEL in Great Britain. As such CLEAR would be an ideal facility to conduct R&D towards these specific facilities; however a more generic R&D platform for light sources in general would be possible as well. The following describes some possible R&D topics, which have been presented in the session.

Importance of CLEAR for the proposed X-band XFEL project

In the context of the proposed X-band based XFEL project the test of RF components are essential and well in line with the previous CLIC and CLEAR program. These tests include: Linearization of longitudinal phase space (in context of the S-band injector of CLEAR), Wakefield Monitors, RF-based bunch spreader, X-Band deflector as well as their associated technologies, such as e.g. timing and synchronization with the electron beam. In general, fabricated X-band structure can be tested there prior to their installation in the XFEL facility, also adding an energy upgrade for the CLEAR injector.

Besides RF component testing, the X-band XFEL will rely on advanced schemes and beam manipulation, which could also be tested at CLEAR, albeit with the requirement of additional hardware. In particular non-linear bunch compression needs to be tested in terms of flexibility, preservation of slice emittance and matching, and uniformity of the current profile, because the proposed X-band facility lacks a higher harmonic cavity to their main X-band linac, unlike SwissFEL, LCLS or even at CLEAR where such X-band RF structure can serve as the higher harmonic cavity for the S-band injector.

In general, compression at CLEAR would yield shorter bunches, which can be used for a various studies beyond the XFEL studies summarized in the report. However understanding the dynamic of compression, including the degrading effects, is of importance for an XFEL facility. To illustrate this: After tests at SIFT the design has been changed to counteract the effects, seen there (chromatic effects, strong stray fields, slice emittance blow up, insufficient matching). With the existence of a compressor, CSR and micro bunch instability can be studied as well as possible countermeasures (such as a reversible laser heater).

Synergies with the UK FEL program

As it has been presented at the workshop the described topics for research would also be beneficial for the UK. Although they are constructing the facility CLARA similar to CLEAR, their focus is on FEL schemes, with no sufficient time and space left for extensive testing of RF technology and compression dynamics.

Other potential light source R&D in CLEAR

The idea to include an FEL in CLEAR was presented as well, however in the context of producing narrowband, phase-locked THz radiation, which is very attractive for FEL user worldwide because the requirements of a phase-locked signal with at least 100 microJ per pulse cannot be fulfilled by laser based schemes. The lack of a defined phase in a SASE process is overcome by pre-modulation of the electron beam (comb beam generation) and a control of the frequency with the control of the compression factor in a magnetic chicane. The required hardware changes for CLEAR would be significant. However it is conceivable to replace at least the about 4 m long undulator with a short dielectric loaded wakefield structure, where a resonant mode is excited coherently by the bunched beam, generating pulse energies of 1 mJ or more. Similar tests with a 50 fs long electron bunch will be done at SwissFEL in the near future.

Conclusions

In conclusion, CLEAR could be an ideal test bed for XFEL technology once the X-BAND XFEL project has been granted to be built.

Communities

The international collaboration studying the design of a compact and cost-effective light sources based on acceleration using CLIC X-band technology consists of about 20 institutes worldwide including CERN. In addition, a number of UK institutes are involved in the UK FEL study.

Appendix A3 Impedance measurements

Session chair: Benoit Salvant (CERN)

Introduction

The focus of the session was to assess the potential of CLEAR as a test bench for beam coupling impedance measurements. The session included a short introduction and 3 talks.

Presentations

B. Salvant (CERN) provided the context for the need to perform impedance measurements. The performance of several accelerators around the world is limited by collective effects, among which beam coupling impedance usually plays a key role. Existing tools to compute impedance are efficiently used but present major shortcomings that are difficult to overcome: simulations require assumptions and can be significantly different from reality, while bench RF measurements are affected by the perturbation of the fields by the RF probing devices (with probes, coils, beads or wires). Measurements with beam in actual machines may not yield enough resolution, and are very expensive in terms of set-up, installation time and machine time. As a consequence, and after the shutdown of FACET in the US, using CLEAR electron beam could be an elegant complimentary tool to measure and study impedances.

A. Latina (CERN) reported the experience of previous direct transverse wake field measurements performed at the FACET facility. These measurements profited from 1.19 GeV proton drive beam and electron witness beam that could be offset inside the device under test, as well as a dedicated setup to separate and measure the resulting angular deflection. The transverse wake could be reconstructed from the measured orbits at the BPMs, and an accurate evaluation of the response matrix of the proton and electron beams. A careful scan in offset and spacing was performed, and allowed reconstructing the wake. The resolution was limited by slow orbit drifts to 0.1 V/pC/m/mm. After a timing correction, the measurements of the CLIC structure clearly agreed with GdifdL simulations. Performing similar type of measurements at CLEAR requires distinct drive and witness bunches, and it was proposed to use alternative methods to differentiate them: energy or notch collimators, since timings between successive bunches cannot currently not be tuned easily without additional hardware. Longitudinal wakefields measurements could already be possible by measuring the energy spread with a spectrometer, and resolution would of the order of a few keV. Similarly, transverse wakefields could be obtained from bunch deformation, and kicks of the order of 40 keV should be visible in CLEAR.

L. R. Carver (CERN) reviewed the possible measurements of impedance-related observables, in particular the possibility to assess electromagnetic fields by analysing the signal from probes (e.g. antenna, wire) installed inside the device, as well as the wake function measurement described in the previous talk. One problem is that many tapers will be required to link the CLEAR pipe to the device under test, and that these tapers will artificially increase the impedance of the device. It was proposed to use a high bandwidth kicker to control the orbit of the source and witness bunch separately inside the device under test. Proposals to increase the kick resolution include using lever arms to amplify the kick and decreasing the energy of the beam.

W. Farabolini (CEA) presented significant charge dependent effects that were observed when the beam is offset transversely. Bunch position, size, shape and stability are affected when increasing intensity and number of bunches. These effects show that the impedance of the existing line can already be measured at CLEAR, but also that they should be understood and possibly mitigated before more accurate measurements can take place (for impedance assessment but also for the other types of measurements envisaged).

Short term plans (2017-2018)

While it is clear that the current setup at CLEAR is not as ideal as in FACET, interesting measurements and information could be obtained with specific case-studies: the upgrade of the wire scanners in PSB, PS, SPS and LHC represents an ideal first case study as interesting information on the wire heating and the resonant modes in presence of the carbon wire could be obtained with an electron beam, while it can neither be easily measured on a bench with classical techniques nor be easily simulated. These measurements could already take place as soon as the wire scanner prototypes for the various machines are ready (planned for 2017 or 2018), with minor changes to the current CLEAR setup (building and installing transitions to and from the wire scanner tanks, building of a dummy pipe for the reference and installation of the RF measurement devices on existing ports of the wire scanner). First ideas of how to improve the set up for direct wakefield measurements could also be tested at this occasion.

Longer term program

Methods for indirect and direct wakefield measurements would be studies and developed further in the first few years of CLEAR operation, and test cases would be suggested based on needs.

Community and resources

The CERN impedance team is the main group that expressed an interest in CLEAR in order to have an easily accessible beam test facility at CERN, including for HL-LHC. In addition external collaborators in the CLIC project (U. Uppsala, U. Oslo) are interested in continuing impedance studies related to transverse and longitudinal wakefields in high gradient structures. These institutes are expected to continue to send PhD students and postdocs to CERN for CLEAR experiments.

Appendix A4 Beam instrumentation studies

Session chair: Thibaut Lefevre (CERN)

Introduction

The use of the electron beam of CALIFES (CLEAR) for beam instrumentation developments has been discussed. It would enrich the testing capabilities already existing at CERN with a high-quality (small emittance, short bunch length, good reproducibility and stability), high-energy electron beams. This facility, disconnected from the rest of the CERN accelerator complex, would guarantee beam availability even during long shutdown periods, offering a great flexibility during R&D phases when hardware modifications/improvements need to be performed regularly. With a relatively low beam current, the amount of radiation generated in such a facility would be limited.

The main advantages of using CLEAR for Beam Instrumentation developments can be summarised as follows:

- Significant reduction in development time for new monitors, driven by the high availability and easy access of CLEAR.
- Testing of operational prototypes under realistic conditions. Such short pulses with high peak currents are nearly impossible to re-produce in a laboratory test set-up.
- Impedance testing under realistic conditions. Allows optimisation at the design phase, avoiding surprises when installed, which has been a serious issue in the past leading to machine down-time and the need for urgent re-design.

Short term plans (next 2-4 years)

CERN projects, such as HL-LHC and Consolidation, would benefit from this facility to test and validate, with beam, instrument prototypes before launching series production. The following tests could start in 2017 :

- HL-LHC Stripline BPMs for the upgraded interaction regions (production of 44 BPMs)
- Electro-Optical BPM for the observation of fast transverse beam oscillations
- Testing of scintillating fiber for SPS NA - This will be tested on VESPER most likely.

Some of this work is conducted in collaboration with external partners who clearly highlighted the importance of performing such tests on a facility with easy access for rapid testing after regular modifications.

In general, the CERN BI group and its external collaborators would be able to use such a facility for ~8 weeks a year to perform the following tests, for which it is difficult to provide non-beam test benches:

- the calibration of operational instruments and detectors (particle detectors, light sensors, acquisition electronic systems)
- the test of prototypes for validation with beam before installation on operational machines
- R&D work studying new concepts for future projects (AWAKE, HL-LHC, FCC, CLIC).

Longer term potential

The tests mentioned above can be carried out using CLEAR in its current configuration. However, several upgrades could be envisaged to fully exploit the potential of such a facility.

- Shorter bunches (down to 100fs)
- More beam lines to accommodate several experiments in parallel

The beam instrumentation hardware required for such an upgrade can be recuperated from instruments developed in the framework of the CLIC study and currently installed on the CTF3 drive beam.

Synergy with other users

The work proposed and discussed during the Beam Instrumentation session has synergy with topics presented in other sessions. e.g.

- The existing irradiation test stand on CLEAR, VESPER, could be used for the calibration of beam instrumentation components.
- The proposed IMPEDANCE measurement capability of CLEAR would be of great benefit for testing and optimising newly developed instruments. For example, new fast Wire scanner (20 units to be built in the next 5years) developed for the PSB/PS/SPS machines in the context of the LIU project.
- Proposals using CLEAR for THz generation and acceleration rely on radiation processes similar to those used for short bunch length measurements, e.g. diffraction radiation.
- The development of short bunch electron gun using CLEAR as envisaged for the phase 2 of AWAKE (in 5 years) would provide a great opportunity to develop high time resolution monitors as required for AWAKE, CLIC and FCC-ee.

Community and resources

CERN beam instrumentation is the main group that expressed an interest in CLEAR in order to have an easily accessible test facility at CERN. There is significant external collaboration for BI development for new accelerators, for example Royal Holloway University of London for HL-LHC BPMs, U. Oslo, U. Uppsala for CLIC wakefield monitors and U. Tomsk for diffraction radiation. It is expected that external collaborators will continue to send PhD students and postdocs to CERN for CLEAR experiments.

Appendix B1 PWFA studies

Session chair: Erik Adli (U.of Oslo)

Introduction

In this session electron beam-driven plasma wakefield acceleration (PWFA) experiments at CLEAR were discussed.

Presentations

E. Gschwendtner (CERN) discussed the relation between the proton beam-driven PWFA experiment AWAKE and PWFA at CELAR. PWFA-experiments in CLEAR would be independent from the AWAKE Run 1 experiments (up to end 2018), and not add to the AWAKE program.. AWAKE is preparing its Run 2, with experiments starting after LHC LS2 (2021). For Run 2 AWAKE investigates new plasma source technology, and new short-bunch electron injectors. Both sources and injectors can be tested in CLEAR before being installed in the AWAKE experimental area. More details below.

N. Lopes (IST/ICL) has developed a gas discharge plasma source at ICL. Such a source may have interest for AWAKE Run 2 (AWAKE is also investigating helicon source technology). Several prototypes have been constructed and tested without beam at ICL. IST/ICL has interest in testing their plasma source with the CLEAR beam. First an about one meter source that can be used for PWFA experiments in clear as well. The plasma densities can be from a few $10^{14}/cm^3$**.** Later, longer prototypes for AWAKE could be tested. IST/ICL has interested in installing and testing the source soon, already in 2nd half of 2017, if possible. Dedicated PWFA experiments with this prototype could then be launched from start 2018.

C. A. Lindstrøm and E. Adli (Oslo) are interested in testing lattices built up of plasma lenses in CLEAR. Plasma lens lattices may be used for example for creating achromatic plasma interstages. Such tests would use capillary discharge technology (developed at Oxford, LNBL and DESY). Single plasma lenses are being tested at other European laboratories (DESY, SPARC_LAB), however, the Oslo group is the first to propose plasma lens lattices. Oslo would like to start experiments using plasma lenses only as soon as possible (2017) and continue with more complex tests of plasma lens lattices combined with a plasma acceleration stage (see previous paragraph) from 2018.

S. Corde (LOA and Ecole Polytechnique) discussed possibilities to do emittance preservation experiments at CLEAR. These experiments assume that a plasma source, like the discharge source described above, is available. With the current CLEAR beam parameters (single bunch), the plasma density must be low ($\sim10^{14}/cm^3$) to drive a wake, with a plasma wavelength of the order of several mm. To study emittance preservation (looking at the accelerating phase of the beam) a tail of the same length must therefore be present at the CLEAR beam. Such single-bunch, long tail experiments could be started once a plasma source has been commissioned. With a second injector, two-bunch emittance preservation experiments would be possible. These experiments would be easier to analyse and be closer to a PWFA-applications. A longer-term emittance preservation program would therefore strongly profit from a second injector.

S. Gessner (CERN) presented an experiment that could be of possible interest for AWAKE in the longer term: using a plasma to energy-chirp a long proton beam for the purpose of creating a train of micro-bunches to drive a plasma wake. This would be as opposed to the present AWAKE scheme relying on the self-modulation instability, which has a disadvantage that more than half of the charge is not used for wake excitation. This experiment would require a magnetic bunch compressor with an R_{56} of about 35 cm.

G. Xia and O. Mete (Cockcroft) presented PWFA studies at the Cockcroft institute. Experiments to study plasma dumps and the effect on beam scattering in plasmas were presented. Plasma dumps is a topic of high interest for the ILC. The status of hardware development at Cockcroft for creating gas discharge plasma sources was also presented. The plasma sources presented would need some development time and tests without beam before it is ready to be used as a plasma source. However, Cockcroft has shown an interest in testing their hardware in CLEAR..

Short term proposals 2017-2018

Due to the interest from IST/ICL of bringing a functioning plasma source to CLEAR in 2017, as well as experienced PWFA-users (Corde, Gessner and other) there exists an opportunity to start an electron-beam PWFA program in CLEAR on a relatively short time scale: plasma source installed last part of 2017, plasma experiments start 2018. In particular plasma experiments for plasma beam dump studies could start as soon as a plasma source is installed,

There is also a concrete proposal for an achromatic plasma lens lattice test program, which could start as early as mid-2017 (plasma lens experiments with the regular CLEAR beam) and continue in 2018 (experiments coupling plasma lenses and a plasma acceleration stage).

Longer term program

Having a gas discharge plasma source installed and commissioned in CLEAR allows for a range of experiments, including emittance preservation studies and beam dump experiments, without major upgrades required for CALIFES, though some studies would benefit from a shorter bunch. Performance study of the plasma source itself is an objective for AWAKE.

If a second electron injector would be available, CLEAR would be a unique PWFA-test facility in having two separately controlled RF-injectors, opening for two-bunch acceleration studies, including studies of emittance preservation, injection tolerances and efficiency.

Community

There is a large interest for electron beam driven PWFA in European laboratories. Facilities, either already operational or planning to start PWFA experiments in the near future include DESY/FlashForward, DESY/Sinbad, DESY/PITZ and INFN/SPARC_LAB. However, their proposed experimental programs are to a large degree already defined with limited beam time available for new experiments. The researchers showing interest in CLEAR come from IST/ICL, Cockroft, Ecole Polytechnique, Oslo and CERN, and the program proposed is to a large extent complementary to what is proposed at DESY and INFN (SPARC_LAB).

Resources

With go-ahead for installation of a plasma source at CERN, IST/ICL would provide the plasma source, and bring the required manpower to assemble, install (with the help of CERN) and commission the source in CLEAR. Oslo, and possibly also Ecole Polytechnique, can provide PhD students to prepare and perform experiments in CLEAR for extended periods of time. PhD students from Oslo would also participate in the operation of the CLEAR beamline. Cockrofte is also positive they can locate funding to send students and senior researchers to CERN for long periods.

Appendix B2 THz R&D

Session chair: Massimo Petrarca (INFN)

Introduction

The research program is directed to develop concepts of high-gradient acceleration and deflection through strong THz fields. THz pulses generated by lasers have proven to produce GV/m THz field strengths with pulse durations up to 10's picosecond scale representing therefore a huge improvement over RF in energy overlap with particle beams. These pulses can offer also a great increase (> 10^2) in deflection temporal gradients over RF deflecting structures with the same peak field gradients, and therefore can open the way to femtosecond slice diagnostics of high energy beams.

The CLEAR facility has the capability to produce high charge (~nC) e-bunch from semiconductor photocathode, which can be routinely produced in the dedicated laboratory in close connection to the facility itself. Moreover the photo-injector has the possibility to exploit also a metallic cathode if very short e-bunch with low charge is required. Therefore CLEAR is a very interesting and flexible facility where it will be possible to test novel THz driven acceleration schemes that require high charge and relatively short (~1ps) or low charge but very short (~100fs) e-bunch. CLEAR in fact can be use in a two-fold ways: it can produce both the e-bunches and the high intensity THz radiation (by CDR, etc..). The THz radiation and the e-bunches can be made interacting in a fashionable and flexible way. Moreover CLEAR can be also exploited to produce e-bunches that will be accelerated by an external laser-driven THz source. Within the general theme of THz high-gradient and high frequency acceleration, the Short and Long term programs of accelerator R&D and the support and contribution to CERN for the activity, are proposed and presented in what follow.

Short Term Program (2017-2018, 2-years):

The short-term program is dedicated to stand alone experiments that would constitute the basis for a further developed R&D activity toward THz acceleration. Within this 2-years time period, no major upgrade are foreseen though the possibility to shorten the bunch at the ~1ps or sub-picosecond level would be of interest.

- 2017-The present beam characteristics of CLEAR will be pushed at best in order to produce high intensity THz pulses by dedicated and optimized CTR and/or CDR schemes. Other methods under study in the CERN-BI group (e.g. coherent Cherenkov radiation) are of interest and will be also examined. To increase the electron bunch charge (>2nC) a laser shaping in which two different laser pulses are superimposed in time and space (at the cathode plane) can be performed. The THz pulses will be fully characterized. The possibility to produce longitudinal THz field will be tested and the longitudinal field will be characterized.
- 2017-Establish interaction region experimental facilities: Installation of vacuum chamber and controls, motion, diagnostics for structures; establish electron beam-optics for transport through structures; establish timing system for THz-electron beam synchronization.
- 2018-The first interaction tests between the THz and the electron bunch (both produced by CLEAR) will be performed. A laser pulse shaping is required although it would be a minor straightforward change. The shaping consist in the generation of a comb of 2 or more pulses separated in time; the first pulse will be used to produce THz while the second will interact with the THz field.
- 2018-Demonstration of deflection and/or chirp generation of <10pC 200MeV beams by THz sources; Demonstration of 1MeV acceleration of <10pC 200MeV beam within a 1cm THz structure
- 2017-2018-The possibility to produce a dedicated train of bunches suitable to drive a particular undulator will be studied. The undulator can be used in the longer-term program, to produce unipolar intense THz pulses that can be useful for THz-driven acceleration test.

It is worth to point out that all these activities have a strong synergy also with the CERN-BI group in particular for what concerns THz generation and characterization as well as the characterization of the THz driven accelerated bunches.

Long Term Program (2019 onward):

On the longer-term program, CLEAR can be upgraded with a new photo-injector laser and the THz acceleration program would make simultaneous use of this laser. In fact the laser can be used as photocathode laser (it will allow to reach 100fs level of e-bunch duration) but also as an external high intensity THz source (e.g. based on the non-linear optical rectification process). In this configuration CLEAR will produce the required e-bunch that will be used to test the THz-driven acceleration where the THz is produced by the laser. The experimental program will be dedicated to the understanding and control of beam loading and space charge in THz driven structures; validation of simulation against experiment for beam loading of 10-1000pC bunches etc.

CI, Rome and Uppsala staff and researchers can be made available assisting in the operation of a photoinjector and laser. In particular, for the case of a dedicated laser, CI and Rome would be willing to support the operation of the laser (within the spirit of contributions in kind) .

In case CLEAR will prove (during the short term program) the capability to produce energetic (~1mJ or higher) THz pulses by the interaction of high charge electron bunches with a target, it can be envisaged to install a second photo injector line to test the THz-driven acceleration process. In this configuration CLEAR will be used as THz source to boost the electron energy produced by a second injector.

Depending on the possibility for CLEAR to produced the required comb of pulses to generate unipolar THz pulses (this possibility will be investigate during the short-term program), a dedicated e-bunch line to install the undulator could be built and the THz generation under this condition can be investigated.

Community: description of the interested institutions

Cockcroft Institute (CI), UK. (STFC Daresbury National Laboratory, Universities of Manchester, Liverpool, Lancaster and Strathclyde): The CI has an established program directed towards 'Dielectric and THz acceleration'. The program has 6 academic and laboratory scientist project leads, directing a cohort of Post-doctoral Researchers and PhD students and laboratory staff. The CI is seeking to establish a program of experimental validation of high-gradient and high frequency acceleration (and deflection) in the following specific areas:

- Laser generated THz for high gradient acceleration in dielectric mediated structures. In particular the CI will seek to prove and advance the methods for strong and efficient coupling of the THz energy into electron beam acceleration.
- Laser generated THz for ultrafast beam diagnostics, though THz frequency deflection mediated by dielectric and metallic structures..
- Dielectric and artificial-dielectric (surface structured metal) structures for beam dechirping and wakefield control.

University of Rome "La Sapienza", INFN:

The THz-R&D group has an established program directed towards high peak power THz pulses generation for particle acceleration and is seeking to establish an experimental activity on high-gradient THz generation and interaction with e-bunches. In particular

- Strong THz field generation by the interaction of high charge short e-bunches with an opportune shaped target. THz generation mechanisms: e.g. coherent transition or diffraction radiation (CTR/CDR) or coherent Cherenkov radiation (CCR).
- THz shaping to produce strong longitudinal or transverse THz field.
- THz driven acceleration.

Uppsala University:

Stockholm-Uppsala Center for Free-Electron Laser Research (SUFEL) is a common virtual center of the two universities for joint FEL research and development. The objective with the Center is to support activities and initiatives to make the universities active and visible partners in development and research at FEL facilities in the international research frontier. One of the main lines of research is the development of a single-cycle linac-based THz source. The ongoing work is outlined in the recently released White Paper "THz Coherent Light Source in Uppsala" and a 4-years grant has been assigned to Uppsala's researcher for this purpose. Another research line is the design of a THz source that can be based on the linear accelerator of the Max IV Laboratory. Both these research developments will benefit from performing proof-of-concept experiments of novel methods of generation of high-field single-cycle THz radiation at the CLEAR facility.

Complementarity of CLEAR experiments with activities at other laboratories :

FLUTE is a new facility at KIT (Karlsruhe, Germany) that will study the generation of strong THz signal. At FLUTE the THz signal will be mainly used for photon science experiments. With CLEAR we would like to carry on accelerator research driven by THz. In general, THz technology is facing a huge development and a strong interest in the accelerator community thus an increasing number of facilities started working on this topic. CLEAR facility has the opportunity to work with very high energy up to 200MeV (while FLUTE for example is designed to go below 50MeV). This is an important aspect for THz based acceleration technique because it can offer "test" electron bunches in a large range of energies (up to 200 MeV). For "test electron bunches" I am referring to the bunches that can be used to witness the THz field (so bunches that can be accelerated). At the same time the energy is an important parameter to take into consideration in order to study and use (for acceleration) intense THz pulses produced by process like CDR, CTR etc. Moreover CLEAR can also make use of a dedicated nearby photocathode laboratory. This is of great interest especially when high charge can be routinely required.

Moreover, we believe that world wide THz beam time is not enough to satisfy the experiments the users would like to perform. For example, at **INFN/SPARCLAB** the main program (plasma acceleration) started few years ago and defined the facility experimental program. Moreover the facility runs with metal cathode and charge higher than 1nC are not available nowadays.

Resources and support to CERN for operation of the THz R&D program

The THz activities presented during the workshop have several synergies within the different groups that could work within a broad collaboration. This collaboration would be able to contribute with a strong support of manpower from the different institutions to the R&D activities and machine operations. Depending on the activity program that will be established, PhD students, Post-Doc and Staff members from the different institutions will be based at CERN (envisaged time for researchers to be based at CERN: 1-3 months prior to the experiment, working with CERN staff to install and commission systems, and learning and contributing to accelerator operation/optimization). PhD, post-doc and staff will also be made available to assist in the operation of the accelerator for other experiments outside their own projects, providing highly valuable training opportunities to the researchers, as well as a contribution in kind to the CERN operational costs.

Appendix B3 Radiation tests

Session chair: Markus Brugger (CERN)

Introduction

The use of the CALIFES (now CLEAR) electron beam for radiation effects testing was discussed during the October 2016 CALIFES Workshop. The main application of a high energy electron beam for this type of testing was identified as the **Jovian environment**, and more particularly the JUICE (ESA, planned launch date: 2022) and Europa Clipper (JPL-NASA, in development phase) missions. In addition, other applications in the **high-energy accelerator** context were identified such as detector degradation (e.g. scintillating materials for calorimetry) and calibration of dosimeter samples and radiation monitors.

The Jovian environment is the harshest in the Solar System owing to the intense magnetic field and internal plasma source from its Io moon. It is the only planet in which the trapped electron spectrum extends above ~5 MeV, potentially reaching the **several hundred MeV range** before falling off.

According to the JUICE Environment Specification document, the Total Ionizing Dose in Silicon (TID(Si)) and Total Non-Ionizing Dose in Silicon (TNID(Si)) levels will be dominated by **trapped Jovian electrons**. For TID(Si) and TNID(Si), values of 50 krad and $6 \cdot 10^{11}$ 1 MeV electron equivalent are expected from trapped electrons for the entire mission and 20 mm of aluminium shielding. Owing to their availability, TID and TNID tests are typically carried out using a Cobalt-60 source (i.e. high energy photons) and proton beams, respectively.

However, the natural question that arises is whether such radiation conditions are **representative** of the damage induced by **high energy electrons**. There are currently a wide variety of ESA research and development activities related to determining whether this is the case for study-case components, and which have so far focused on the energy range typically available in medical electron accelerators (i.e. up to 20 MeV). Other high energy electron test facilities are limited in fluxes (e.g. PSI provides a maximum energy of 115 MeV for a pure electron beam, with a corresponding flux of $\sim 2.4 \cdot 10^5$ e/cm^2/s).

Existing radiation test activities in CALIFES

In order to increase the energy interval of interest, the Very energetic Electronic facility for Space Planetary Exploration in harsh Radiation environments (**VESPER**) test bench has been under development in CALIFES since late 2015. The beam parameters for the initial tests were an energy of 200 MeV and a flux of roughly 10^8 e/cm^2/s. The two main points that needed to be initially addressed in order to render the beam line practical for radiation effects testing were:

- Increasing the beam size to a level for which a standard chip surface (e.g. 2 x 2 cm^2) can be covered with a homogeneity of ±10% (and corresponding dosimetry)
- Including beam instrumentation capable of accurately measuring the beam intensity at the location of the Device Under Test (DUT) in real time

So far experiments have been mainly carried out using the 5 Hz repetition rate **dark current** settings, yielding a charge pulse of 15 pC. Assuming a Gaussian profile of 30 mm FWHM in each direction, this corresponds to a flux of $1.3 \cdot 10^8$ e/cm^2/s and dose rate of 5.6 krad(Si)/h over the central cm^2. This means that the TID levels introduced above as JUICE mission targets for 20 mm aluminium shielding could be reached in roughly 10 hours of irradiation, with less time required for the TNID levels. If the radiation levels without shielding are considered (e.g. for solar panel degradation) a three to four order of magnitude increase is expected, which would require the use of a **laser driven beam** to reach the target levels in a several hour time frame. For the latter, it will be important to evaluate the possible impact of the high pulse intensity (e.g. dose rate, flash effects) on the respective measured effects.

In addition to cumulative radiation damage, Single Event Effects (SEEs) from electrons are also a concern for the reliability of electronic components, especially when considering deep sub-micron technologies potentially sensitive to direct ionization from a single energetic electron.

From a dosimetry point of view, cross-calibration measurements have been performed during 2016 including instruments such as a Beam Current Transformer (BCT), Faraday Cup, RadFET or gafchromic film, as well as a gold foil activation technique. Overall, the cross-comparison of the results is compatible with a 30-40% uncertainty in the flux and dose rate dosimetry determination, whereas standard commercial facilities typically provide a **10% error** and which would be required for the usage of VESPER as future reference facility.

Regarding radiation effects testing, two experiments were carried out in 2016. The first was focused on electro-nuclear and photo-nuclear SEUs in a 0.25 um **SRAM memory**, and the associated results were presented in the RADECS 2016 conference. The second was an SEU measurement on a commercial 20 nm **NAND flash memory**, for a research group in the University of Padova and in the context of their collaboration with ESA.

Short term plans (2017)

For 2017 there are a number of **radiation effects test requests**, which are listed below:

- extension of electro and photo-nuclear studies to a broader range of components and effects (R2E/CERN)
- extension of flash memory testing (Padova University/ESA)
- high energy electron damage in GaAs devices for solar panel applications (Naval Research Laboratory)
- RADEM JUICE monitor and PROPIX pixel ionization chamber (PSI)

In addition, interest has also been manifested by ESTEC/ESA related to deep sub-micron SEU studies and the University of Bern for Jovian detector shielding analysis. From a collaboration point-of-view, while JUICE applications are dominating (thus including ESA and corresponding partners), also CNES has stated possible interest in the facility.

As to what regards the identified main objectives related to the VESPER/CLEAR radiation testing capabilities in the near future, the following points were raised:

- improvement of the **dosimetry accuracy** and beam monitoring capabilities;
- increased **intensity and energy range** for radiation effects testing beam and respective calibration;
- performance of **radiation test campaigns** listed above and analysis/dissemination of results;
- increased **visibility/outreach** of facility in the radiation effects community (e.g. via conferences or website, http://vesper.web.cern.ch/)

From a scientific and application point-of-view (for both the facility design and benchmarking, as well as application studies) the following points have been identified:

- in view of the Jovian mission, quantify the absolute contribution of electrons with energies above 20 MeV (i.e. fluence versus cross section) – a respective analytic study is on-going and was briefly discussed during the workshop in the context of SEE/TID and TNID;
- study and compare the contribution of photons in the relevant radiation fields (especially for accelerator applications);
- compare measurements of both TID and TNID with proton and/or neutron testing at standard facilities and conclude on the TNID scaling assumptions for high-energy electrons;
- linked to the above, study the effect/impact of the pulsed beam (focus TID and TNID);
- conclude on the relevance for today's and future high-energy accelerator projects (part of an on-going CERN/ESA co-funded PhD study)

Short term plans: electron radiation therapy

One option for radiotherapy is to treat tumours with very high energy electrons, in the range of 200 MeV. This option has had the disadvantage that a standard linac and corresponding gantry with bending magnets would be too large. With the routine demonstration of 100 MeV/m gradient, VHEE is generating renewed interest since compact linacs which rotate around the patient is now feasible. There is however a lack of dosimetry data in this energy range. CALIFES, with a 50-250 MeV beam, is an ideally suited in carry out dosimetry measurements. The measurements are made by irradiating so-called "water-phantoms." A concrete proposal to use CALIFES, starting as soon as possible, to perform such measurements. The CLIC high-gradient linac development program also directly benefits the VHEE effort.

Longer term perspectives

From the current analysis we can summarize that on-going studies have shown/confirmed a varying community interest for scientific studies. The latter need to be finalized in order to conclude on the need for corresponding qualification requirements (space and to a lesser extend accelerator applications). In this context also new component technologies are of importance (for effect studies) and first proposals (e.g, power devices) are in first discussions. This combined with a conclusion on the TNID scaling (based on NIEL) can then determine a possible long-term need, either for scientific studies or also towards series (industrial) testing for relevant space missions.

Communities

As described above, a large number of institutes are already involved with radiation tests in CALIFES and/or with plans to continue in 2017: ESA, Padova University, Naval Research Laboratory, Univ. of Bern, PSI as well as the Cockroft Institute for the radiation therapy tests.

Appendix B4 Education and Training

Session chair: Carsten Welsch (U. Liverpool and Cockroft)

Introduction

This session discussed the potential for new education and training innitiatives at CLEAR.

Presentations

C.P. Welsch (U Liverpool/Cockcroft Institute, UK) presented the opportunities associated to a Marie Curie Innovative Training Network. He illustrated how several of these networks had been established in accelerator science and technology and how these had transformed researcher training in the past. He highlighted the specific case of the AVA network (http://www.ava-project.eu) which relates to the antimatter facility ELENA at CERN and targets its full exploitation in simulation and experimental studies. He presented how AVA could be a role model for an initiative that on the one hand trains the next generation of researchers and on the other allows a cutting-edge research program across 3 scientific work packages. In the case of the CLEAR, these could be accelerator design and optimization, advanced beam instrumentation and novel experiments. He was of the opinion that and ITN could be a perfect basis for excellent science at CLEAR, could help boost the reputation of the infrastructure, allow to organize numerous events for the wider research community and could also be a driver for international outreach to highlight the importance of accelerator science.

P. Lebrun (JUAS, France) gave an overview of the history of the School and its established approach to teaching. He highlighted the importance of a profound theoretical training in combination with hands-on training and explained how this could be transformative for accelerator education in general.

W. Farabolini (CEA, France) followed up on this introduction by presenting results and an in-depth analysis of the beam training provided as part of JUAS 2016. He found that CLEAR had a number of features that made it a world-wide unique facility for hands-on accelerator training, including perfect size and adequate complexity of the accelerator, i.e. not too simple, not too complex; safe working environment; limited beam power, allowing for unrestrained beam handling; stand-alone facility that does not rely on other injectors or users; accelerator can be adjusted to a very wide range of beam characteristics. He summarized a number of experiments that were carried out by the students, including studies into the gun properties using dark current only; optimization of dark current extraction using profile monitors; transport of dark current through the accelerating structures; energy, charge and Twiss parameter measurements; determination of RF power in the accelerating structure and observation of the beam loading at the output port. This gave students an excellent understanding of the machine, beam handling techniques and beam instrumentation for in-detail characterization. He presented an overview of the results obtained by different students and showed how this was an experience for everyone involved that went far beyond what JUAS had been able to provide previously.

S. Jamison (STFC / Cockcroft Institute, UK) presented a coherent program into dielectric and THz acceleration. He started by giving an overview of the general accelerator education program at the Cockcroft Institute and how new courses had recently been added to the existing syllabus to include novel ways of particle acceleration and how a coherent R&D program was currently being established at the institute that focused on compact accelerators. He showed how CLEAR could become a central part of this initiative by offering placement opportunities for students and Postdocs for 1-3 months to take data, as well as for longer-term placements so that they could develop new experimental setups and pursue extended research programs. These experiments would be complex and cross-disciplinary and join a whole new user community at CLEAR with the accelerator experts operating the facility.

Conclusion

The session showed that CLEAR has an enormous potential as a facility for education and training of early career researchers. This includes first training in accelerator operation and beam handling as demonstrated in the framework of JUAS, as well as more advanced studies into compact accelerating structures where a comprehensive R&D program could be carried out by international "users" of the facility. An international training initiative, such as a European Training Network could give this an additional boost by establishing a cutting edge research program around the existing accelerator infrastructure. This would join universities, industry and other research centers at CLEAR, allow for the organization of international training events, such as Schools and Topical Workshops and hence boost the impact and visibility of the facility. An ideal time for proposing such new initiative could be in 2018 when the medium-term future of CLEAR had been secured.

Appendix C: Short-term and long-term facility improvements

Session chair: Roberto Corsini (CERN)

Introduction

The main aim of the session was to discuss the modifications needed to the present CALIFES beam-line in order to fulfil the requirements of a possible experimental program covering the next 5 years, taking into account what has been proposed in other sessions of the workshop.

CLEAR upgrades

A few short-term modifications have been clearly identified. The present 3 GHz RF station powering the linac (MKS30) will be dismantled and re-installed in AWAKE, and the plan is to substitute it with two existing stations (MKS31 and MKS11) by modifying the RF waveguide network now in place. The use of two modulator-klystrons will increase the flexibility of the facility, widening the energy range (both upwards and downwards) and improving the efficiency of bunch length compression by velocity bunching. An upgrade of the RF repetition rate from 5 Hz to 25/50 Hz will be desirable and will only require limited resources. Another existing RF station (MKS21) will be kept operational and shared between S-band high power tests of accelerating structures for medical applications (in the former CTF2 building) and the RF deflector already installed in CALIFES for longitudinal beam diagnostics. The reconfiguration of the test area (possibly keeping operational and re-adapting a part of the present Two-Beam module, and increasing the available space by removing the present drive beam dump) was also discussed. A detailed proposal will be made as soon as the experimental program for 2017 and its requirements are defined.

Consolidation and improvements of the present laser system, which was built for operation in conjunction with the PHIN RF gun and was not optimized for CALIFES, were also considered. The present system is adequate for the very short-term, but improvements in beam intensity and position stability may be obtained as well as higher bunch charge potential, by moving the present laser room to a closer location (presently, a 70 m long light transfer line is used). A new commercial laser system may also be considered, as well as upgrades to enable double pulse and/or pulse shaping capability, required by some applications. Laser upgrades may be staggered in time and will depend on user requirements and on external contributions.

One of the assets of CALIFES is its proximity to a high-power X-band RF source (XBox1) presently used for high power testing in the former CTF2 area and for beam loading experiments using the drive beam in the CTF3 linac tunnel. The low-loss RF line connecting Xbox1 to the CTF3 linac can be dismantled, modified and used to power a location in CLEX for beam testing of X-band equipment with the CALIFES beam. An alternative would be to move Xbox1 in the part of the klystron gallery directly on top of CLEX. This second option has the advantage of potentially providing more power to the device under test, however may need more resources. The plan is to evaluate the two options and identify the optimum location of the testing area in CLEX during 2017, and implement the chosen upgrade in the 2017-2018 winter shutdown.

The re-configuration of the test area described previously should free-up enough beam-line space to accommodate users for the 2017 run. However later on more space will likely be needed. Space requirements, typical times for installation and turn-around for experiments, together with their mutual compatibility and potential synergies have still to be fully evaluated and will provide input to any long-term solution. The obvious possibility is to install in the mid-term (end 2017 or during 2018) a second beam line with a dog-leg branching off after the third RF structure in CALIFES, in the area presently hosting the drive beam lines of TBM and TBL. The dog-leg can be used for magnetic bunch compression, reaching down to the 100 fs region, as shown by preliminary studies and as requested by several users. Using a three or four-bend dogleg achromat, some tunability of the momentum compaction can also be obtained for additional flexibility. Most if not all of the main components of such beam-line (girders, magnets, power supplies, diagnostics, vacuum pumps and other ancillary equipment) may be recovered from CTF3.

Several of the proposals presented in the workshop (e.g., for plasma, THz radiation, impedance measurements) make use of the pump-and-probe technique in one form or another thus needing two beam pulses, independently tunable in the longitudinal and in the transverse direction. Such experiments would therefore profit from a second independent electron source. A new source can also be optimized for short bunches and low emittance, beyond reach of the present CALIFES gun. There is a possible synergy with AWAKE, which would need a new advanced source for its planned phase 2 (100 fs, ~ 400 A peak current, 50 MeV). An interesting option for a compact injector providing very short bunches would be an S-band RF gun joined to an X-band buncher and an X-band accelerating structure, operated at about 20 MV/m and 80 MV/m respectively. A lot of the hardware needed for such a source may be available, and expertise exists within the CLIC study. Other attractive options include a fully X-band photo-injector and a plasma-based source. The possibility of ultra short bunches could be a big asset for the future test facility, and a new source of this kind would not just be a tool, but an R&D goal in itself, interesting to other labs and projects, therefore some external contribution might be expected (and most likely needed).

Other issues presented and discussed in the session

In the session, the past experience of the use of the CALIFES beam-line as a user test facility has been presented as well. While its original aim was to provide beam for two-beam CLIC tests, the CALIFES linac proved to be an excellent tool for several other beam tests, initially linked to the CLIC study (e.g. for beam diagnostics) but recently extending to other projects (e.g. AWAKE BPM tests, or irradiation experiments). CALIFES proven flexibility, in beam parameters as well as operational aspects, makes it an ideal machine to satisfy a divers user community.

Finally, a proposal to use the SPS as a lepton damping ring, actually dating back to the late '80s, was revisited, considering potential application to CLIC and FCC-ee. Such a proposal implies to re-establish the lepton production and acceleration chain at CERN, similar to what has been used for LEP, re-using at least in part the CTF3 hardware. While being a feasible task, the level of resources needed is above what can be presently envisaged. However, it may become a concrete possibility if either CLIC or FCC-ee will become a flagship project at CERN.

Appendix D: Agenda of the workshop October 10-12 with links to talks

High-gradient research

Walter Wuensch (CERN), Introduction

Marek Jacewicz (U. Uppsala),

From Two-to-One beam test stand

Frank Tecker (CERN),

The effect of beamloading on breakdown rate

Benito Gimeno (U. Valencia), Induced multipactor experiments satellite communication development

Frank Gerigk (CERN), Superconducting RF Structures R&D and testing with beam

Light source related R&D

Sven Reiche (PSI), Introduction

Jim Clarke (STC), CLARA needs and XBand Testing

Andrea Latina (CERN), XBand FEL Project

Jurgen Pfingstner (U. Oslo), FEL THz pump

Impedance measurements

Benoit Salvant (CERN), Introduction

Andrea Latina (CERN), Experience from FACET impedance measurements and application to CALIFES

Lee Robert Carver (CERN), CALIFES for impedance measurements

Wilfrid Farabolini (CEA), Charge dependent effect in CALIFES

Beam instrumentation

Thibaut Lefevre (CERN), Beam Diagnostics R&D

Stewart Boogert (U. London, Royal Holloway), BI developments for CLIC/Hilumi

Reidar Lunde Lillestol (U. Oslo), CLIC Wake-Field Monitor experimental Tests

Stefano Mazzoni (CERN), Optical Transition Radiation Interferometry (OTRI) experiment in CALIFES

Plasma wakefield acceleration

Erik Adli (U. Oslo), Introduction

Edda Gschwendtner (CERN), AWAKE plans and possible use of CALIFES

Nelson Lopes (IC London and IST Lisbon), Discharge source

Carl Lindstrøm (U. Oslo), Apochromatic plasma lens lattices

Sebastien Corde (Ecole polytechnique and LOA), Emittance preservation studies

Spencer Gessner (CERN), Plasma-based bunch compression techniques

Guoxing Xia (U. Manchester), Compact plasma based beam dump

Oznur Mete (U. Lancaster), Existing equipment at Cockcroft Institute; emittance growth due to scattering in plasma.

THz radiation

Massimo Petrarca (U. Rome "Sapienza", INFN LNF), Introduction

Thibaut Lefevre (CERN), THz radiation using Diffraction Cherenkov radiation

Steven Patrick Jamison (STFC), THz deflector + DATA

Vitaliy Goryashko (U. Uppsala), Unipolar Pulses of Light from a Tapered Undulator

Alessandro Curcio (INFN LNF), THz Shaping

Massimo Petrarca (U. Rome "Sapienza", INFN LNF), THz R&D and Conclusions

Radiation tests

Markus Brugger (CERN), Introduction

Ruben Garcia Alia (CERN), Radiation test challenges with high-energy electrons

Maris Tali (CERN), VESPER status and outlook

Agnese Lagzda (U. Manchester), Very High Energy Electron (VHEE) Simulations and Planned Experiments for a Potential New Paradigm in Radiotherapy Treatment

Education and training

Carsten Peter Welsch (CERN), Introduction and ITN

Philippe Lebrun (JUAS and CERN), JUAS

Wilfrid Farabolini (CEA), Experience from JUAS

Steven Patrick Jamison (STFC), Cockroft DATA project

Long-term facility improvements

Roberto Corsini (CERN), Ideas for medium and long term facility upgrade

Wilfrid Farabolini (CEA), CALIFES past experience as a user facility

Steffen Doebert (CERN), Very short bunches, possible injector for AWAKE or CALIFES

Yannis Papaphilippou (CERN), Damping Ring Injector

Introduction

Steinar Stapnes (CERN), Welcome

Roberto Corsini (CERN), CALIFES description

Erik Adli (U. Oslo), Practical information

Closing session

Steinar Stapnes (CERN), Workshop summary

Erik Adli (U. Oslo), Session summaries

Roberto Corsini (CERN), Thoughts for 2017

CALIFES visit

F. Tecker (CERN) and G. Mcmonagle (CERN)