

Proposal for the future operation of the CALIFES linac - DRAFT 2016/01/18 -

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Abstract

In this document we propose to operate the CALIFES electron linac at CERN, presently used as the probe beam line of CTF3, as a stand-alone user facility from 2017 onwards when CTF3 is closed down. The possible uses include general accelerator R&D and studies relevant for existing and possible future machines at CERN, involving a potentially large external user community. The resources required are around 2 MCHF/year (M+P).

1. BACKGROUND and MOTIVATION

The CLIC study is addressing primary goals of the European Particle Physics Strategy. It is advancing the design of an energy-frontier electron-positron linear collider (LC), for exploring particle interactions up to the multi-TeV scale, based on a novel two-beam acceleration scheme incorporating advanced high-gradient structures. The accelerator collaboration comprises ~300 members from 50 institutes in 25 countries, and includes ~80 accelerator science/engineering students. The 25-institute physics and detector collaboration provides the key physics performance studies, connected with LHC running and results, for such a forefront particle physics facility.

The CLIC Test Facility (CTF3) has been operating since 2006 and has been pivotal in demonstrating the key elements of the CLIC approach: stable two-beam acceleration via high-gradient (100 MV/m) copper X-band accelerating structures. Currently CTF3 is the only electron accelerator at CERN, and is one of few electron machines worldwide that are available for advanced R&D. Several further key R&D tests will be finalised at CTF3 during the planned beam operations phase through to the **end of 2016**. CTF3 and its related high power X-band RF test stands provide the major experimental facilities for external CLIC collaborators. Many of the collaborators also have keen interest in developing CLIC-related expertise for improving their local electron-accelerator capability via upgrading existing, or planning new, machines that are typically used for research purposes beyond particle physics.

In the MTP published in 2015 the current LC studies at CERN, covering CLIC and ILC, will conclude by the end of 2018, with the main deliverable being a CLIC project plan for input into the next European Strategy update. In the MTP there are also activities relevant to potential future LCs in the project areas of SCRF and AWAKE. However, for the moment there is no overall CERN strategy for LC and electron-accelerator R&D **beyond 2018**.

Given the potential of LCs to provide high energy e-e+ collisions not limited by fundamental limits such as synchrotron radiation, and the versatility and continued evolution of electron linacs (also partly driven by their application to FELs, medical and industrial systems) there is a clear need to secure continuity of CERN expertise in this field **beyond the timescales mentioned above**. A local electron linac beam facility can provide the nucleus for R&D in this field for CERN and its users. There is a large existing

user community within CLIC, and a potentially even larger electron linac user community if one includes closely related R&D areas, that could make use of such a facility. R&D facilities of this type are particularly well suited for providing infrastructure support for future EU projects. Finally there is a pressing need to optimise decommissioning of the CTF3 area and potentially re-use the costly (and in many case unique) equipment for the benefit of CERN and its users. All these elements point to the importance of strategic planning now, in particular for a local beam facility.

Looking further ahead, LC development at CERN could take one of several forms, depending on LHC physics and international development of future projects. Hence the present proposal takes into account the limitations on what longer term plans can be considered at this stage. Experimental facilities at CERN should be essential and attractive to a wide accelerator R&D community covering several technologies and studies – also beyond LC R&D, should enable common developments, must require limited resources, and must be flexible and adaptable for more specific future project developments as needs arise.

2. PROPOSAL

We propose to use allocated CLIC resources in 2017-18 to adapt the CALIFES linac, presently part of the CTF3 facility (see chapter 3 below) to serve as a user facility from 2017 onwards, capitalising on the existing CTF3 investment and infrastructure.

A small electron linac of this type can address the following goals (more details in chapter 4 for each point):

- Advancing high-gradient electron-based energy-frontier accelerator R&D (normal conducting and potentially superconducting).
- Enabling beamline and instrumentation component tests aimed at consolidating and upgrading the CERN accelerator complex, in particular the LHC
- Supporting strategic partnerships with other science fields in Europe that need electron-beam test capability, namely X-ray FELs, medical, space and industrial communities.
- Providing a unique and complementary test capability that serves CERN's European (and worldwide) user community in key areas of accelerator R&D.
- Maintaining an accelerator training capability, unique at CERN, for training the next-generation of accelerator scientists and engineers.

We consider that the proposed programme, at ~ 2 MCHF/year (M+P), with a similar amount of initial investment (a more detailed breakdown is given in chapter 5), could provide the opportunities outlined above. The facility will use 1/3 of the existing CTF3 area and $\sim 80\%$ of the required equipment is available.

Implementing this proposal would establish a versatile small facility that is strategically sound in any conceivable future CERN scenario, with an R&D scope across many projects.

3. THE CALIFES linac

CTF3 contains the drive beam linac, delay loop and combiner rings, as well as the CALIFES probe beam linac. The CALIFES linac (Figure 1) produces electron beams with a wide range of parameters (Table 1). Of particular note are the low emittance, short bunch length, and range of bunch charge capabilities, available in single- or multi-bunch trains. CALIFES provides vital beam test capability at CERN, which can also, crucially, be

available during both LHC operational periods and LHC shutdowns. Appendix A contains a technical description of the CALIFES beam line and its capabilities.

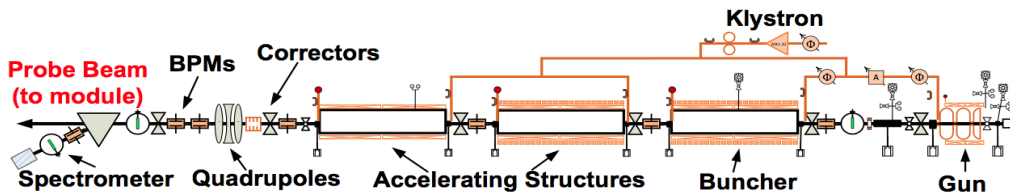


Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.

Beam parameter (end of linac)	Value range
Energy	80 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	2 μm in both planes
Bunch length	300 μm - 1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 1: CALIFES parameters.

4. Main elements of a possible future programme

Following consultation with the relevant communities (see refs.) we conclude that such a facility can serve a number of strategic uses and engage a large user community (also beyond CERN) that has already expressed interest in it.

Three primary R&D areas linked to existing and possible future accelerators at CERN are identified:

- **High-gradient energy-frontier R&D:** Beam tests of next-generation high-gradient accelerating structures are required to progress the CLIC project preparation for the next European Strategy exercise. This activity will also enable further industrialisation studies of high-gradient structures, which have broader relevance e.g. to FEL-based light sources, as well as applications in industry and medicine. SCRF structures can also be tested if such tests are relevant for the R&D in this field; cryogenics systems are however not present in the area and would require some additional effort.
- **Beam instrumentation tests:** LHC and CLIC require development of state-of-the-art beam instrumentation devices: high-precision beam position monitors; transverse emittance and bunch length monitors, including UV, optical, and X-ray monitors and related imaging techniques; beam halo, beam loss, beam breakdown and luminosity monitors. Such devices will also be needed for FCC and AWAKE.
- **Impedance studies:** Impedance qualification of components is required prior to installation in CERN beamlines, in particular the PSB, PS, SPS and LHC, but also the AD and ELENA. CALIFES can allow direct measurements of beam-generated electromagnetic effects, including longitudinal and transverse wake functions (via the drive-/probe-bunch method), inter-bunch cross-talk, and beam-induced heating.

The facility can support European accelerator R&D in three other key areas:

- **Plasma wakefield (PWFA) R&D:** There is intense worldwide interest in plasma-based particle acceleration. The CALIFES beam combined with a plasma source with a density of $\sim 10^{14}/\text{cm}^3$, available from external collaborators, would provide a complementary facility for demonstrating key concepts such as emittance

preservation in a PWFA linear collider. Electron experiments at CALIFES would be complementary to the proton driver experiments at AWAKE.

- **FEL linac studies:** There is rapidly growing worldwide interest in FELs and CLIC X-band technology offers the prospect of more compact (and cheaper) linacs. An international collaboration is currently undertaking a design study for such a compact FEL. In addition to the high-gradient structure tests, CALIFES offers the capability for component tests and technology demonstrations, needed to demonstrate high peak current and good beam quality, which are not normally possible at operating user facilities. These include phase-space linearizers, transverse deflecting cavities (for bunch length diagnostics and RF spreaders) and wakefield monitors. More generally, all future LC technologies (NC and SCRF, plasma) are expected to be initially implemented in FEL linacs, and connecting to the FEL project developments in an effective and constructive manner is strategically very important.
- **Training:** There are relatively few accelerator facilities worldwide where significant time can be made available for 'hands-on' training of students and junior staff. CALIFES can continue to provide such opportunities in the context of a cutting-edge R&D facility with often extreme beam-performance demands. Remote running of the facility would be a possibility; this would require control and operation system development, and offer training potential locally for outside users and students.

Some more specific possibilities have also been identified:

- **Irradiation tests:** Electronic devices for use in extreme environments need to be qualified for radiation-damage effects. For example, the ESA JUICE spacecraft will be located in a severe environment of high-energy electrons with energies extending up to a few hundred MeV. CALIFES can provide relevant electron-beam energies and fluxes for such tests that are otherwise not available today.
- **Medical:** Low-energy (10-100 MeV) electron-beam therapy for certain specialised applications is an area of growing medical interest, and CALIFES could offer relevant beam test capability. The production of X-ray pulses for imaging and treatment remains of high interest. More compact electron-beam sources, e.g. based on X-band technology, could offer significant cost/footprint advantages for hospital-based (commercial) X-ray facilities.

More details about the interest from member state institutes to use CALIFES for R&D are found in Appendix B.

5. Resource estimate

Most of the material for a CALIFES 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 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 500 kCHF.

The running cost of the new facility can be estimated at about 400 kCHF/year (including M to P), with the following distribution:

Cost-item	kCHF/year
RF, maintenance and installation support (M to P)	150
Vacuum	20
Power converters	10
Cabling, diagnostics, controls	70

Laser cathodes	50
Personnel for operation support (M to P)	100
Total	400

The personnel needed for maintenance and operation support is 5.5 FTE/year for staff, 1 FTE/year for fellows (two fellows at 50%) and about 2 FTE/year for students/PJAS (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	1
BE/OP	0.5
BE/RF	2
EN/STI	0.5
TE/EPC	0.5
TE/VSC	0.5
Total	5.5

The total cost for the operation of the facility is hence less than ~2 MCHF (running cost plus personnel). For comparison, the running cost of the current CTF3 is about 1.4 MCHF/year, and the total personnel involved is 12 FTE/year (staff), 2.5 FTE/year (fellows) and about 5 FTE/year for students and project associates.

6. Uniqueness and complementarity

There are electron linacs in Europe with similar beam parameters; these are, however, in general in continual use as injectors for light sources or as FELs. As such, major strengths of the proposed CALIFES facility are its availability for R&D, the supporting CERN infrastructure for RF and instrumentation development, the low marginal cost and easy local access, and the flexible adaptability to specific experiments and future developments. It would, in addition, provide complementary capability to existing R&D beamlines such as ATF and FACET, or plasma R&D facilities in the pipeline, and not compete with them.

7. Conclusions

A number of member state institutes, as well as CERN groups, have shown interest in using the CALIFES electron beam line after its planned shutdown in 2016. The benefit of maintaining electron expertise at CERN is important if CERN is to maintain its role as a potential site for a linear collider. The CALIFES machine, although very versatile, is relatively easy to operate and can be operated and maintained using a minimum of CERN-based resources. It will most likely require no or few resource allocation changes until 2019, but ~2 MCHF/year would need to be foreseen beyond 2019 to make the facility a real long term R&D resource for CERN. We therefore propose to continue CALIFES operation, at least until 2019, as we believe the advantages for the member state user community, as well as CERN, greatly outweighs the cost of beam operation and maintenance.

REFERENCES:

CLIC workshop Jan. 2015: <https://indico.cern.ch/event/336335/timetable/#20150127>

Project meeting October 2014:

<https://agenda.linearcollider.org/event/6389/session/18/#20141009>

Project meeting December 2014: <https://indico.cern.ch/event/356495/>

Project meeting March 2015: <https://indico.cern.ch/event/379754/>

CLIC workshop Jan. 2016: <https://indico.cern.ch/event/336335/timetable/#20150127>

Appendix A: Description of the CALIFES electron linac

CALIFES [1] is an electron linac located in the experimental area of the CLIC Test Facility 3 (CTF3) at CERN [2]. The linac is capable of producing an electron beam with a wide range of parameters. The beam is generated by a photo-injector gun, by shining an UV-laser on a Cs₂Te photocathode [3]. 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. Downstream of the gun, a 3 GHz S-band structure, used as a velocity buncher, compresses the bunch to a length adjustable from 300 μ m 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 [1]. The maximum machine repetition rate is 5 Hz. The beam line includes as well transport and focusing elements and a complete set of beam diagnostics, including a spectrometer at the end of the line. Figure 1 shows a sketch of CALIFES beam line as currently installed in CTF3. The machine parameters are listed in listed in Table 1.

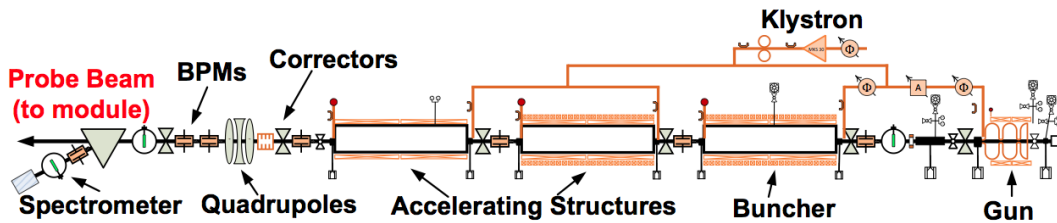


Figure 2: The CALIFES beam line, as installed in the CLIC Test Facility 3

CALIFES was built in order to produce the probe beam for the CLIC two-beam acceleration feasibility demonstration in the CTF3 Two-Beam Test Stand [4]. In the Two-Beam Test Stand RF power is extracted from the high current electron drive beam provided by the CTF3 drive beam complex and is fed to X-band accelerating structures, where the probe beam is accelerated. The demonstration has been very successful, and gradients well above the target of 100 MV/m has been demonstrated [4]. The main goals the CLIC/CTF3 collaboration has defined for the CTF3 complex are mostly fulfilled. It is foreseen to complete the remaining milestones by the end of 2016 and shut down the test facility from 2017.

Beam parameter at the end of the linac	Value
Energy	80 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	2 μ m in both planes
Bunch length	300 μ m - 1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 2: CALIFES parameters

The following infrastructure assets further adds to the usefulness of a CALIFES test beamline :

Availability of 12 GHz RF power from XBox 1

The 12 GHz "XBox 1" klystron test stand [5] is presently installed in the CTF3 complex, in the gallery above the CALIFES beam line. The Xbox operation is part of the CERN X-band development, planned to continue until at least 2019. XBox 1 consists of a 50 MW Modulator/klystron system delivering an up to 1.5 us long RF pulse, and a compressor that can compress the pulse length to 250 ns. The test stand is currently used for testing of X-band RF components, including break down tests with beam loading. For the latter tests, the RF power is transported to a dog-leg linked to the CTF3 linac. It is straight-forward to install waveguides that transport the Xbox RF to the CALIFES beam line instead in order to use the RF power for X-band component tests. This will be especially useful for the X-band Free Electron Laser development work, discussed below, as well for any future X-band accelerator application.

Availability of an additional klystron

At present the RF gun and the three S-band structures of CALIFES are fed by a single RF power station (modulator + klystron). After 2016 it could be possible to recuperate one of the existing power stations that presently feed the CTF3 drive beam linac and connect it to CALIFES. Such upgrade will provide flexibility in operation, extending the available energy range in both directions (up to 300 MeV) and improving beam performances. A third station, possibly shared with other activities (e.g., S-band RF testing) would be useful to feed an existing RF deflector for diagnostics or special operation purposes. The additional resources needed are a few waveguide pieces, manpower to readapt the waveguide runs and continued maintenance of one (two) power stations.

Possibilities for further bunch compression

Some of the uses for CALIFES would profit from even shorter bunch lengths than what is currently available. By magnetic compression in a dog leg chicane, one can estimate [6] that a bunch length compression by about a factor 10 is possible, which would results in bunch lengths sufficiently short for most of the users. All components for a CALIFES compressor chicane (magnets, power supplies and controls) can in principle be recuperated from the CTF3 drive beam line. In addition, PSI has expressed interest in utilizing the compressor chicane previously used at the SwissFEL test facility at a CALIFES test facility.

References

- [1] A. Mosnier et al.. The probe beam linac in CTF3, EPAC 2006, p. 679
- [2] G. Geschonke and A. Ghigo (Eds.), "CTF3 Design Report," CERN CTF3 Note 047, 2002

- [3] M. Petrarca, M. Martyanov, M. Divall, and G. Luchinin, Study of the Powerful Nd:YLF Laser Amplifiers for the CTF3 Photoinjectors, IEEE JOURNAL OF QUANTUM ELECTRONICS, 47, 3, (2011)
- [4] R. Ruber et al., The CTF3 Two-beam Test Stand, Nucl. Instr. Meth. A729 (2013), p 546
- [5] W. Wuensch, Test-stands and structure programme - Status and plans, <https://indico.cern.ch/event/379765/>
- [6] V. Ziemann, Short Pulse Capabilities of the Instrumentation Beam Line, Technical Note, Uppsala University, 2010

Appendix B: Expression of interests to use CALIFES

B1. Beam instrumentation tests

Beam diagnostics are critical for operation of modern accelerator complexes. The CERN accelerator chain culminating in LHC relies heavily on a large number of beam diagnostic equipment in order to ensure the large peak and integrated luminosity required by physics experiments. Testing with beam is critical both for developing new concept involving a non-negligible amount of R&D work, and for testing more “standard” diagnostic tools, which requires an experimental validation in order to validate their design and performance and understand their limitations before they are put in operation on production machines. The current model of operation at CERN, with long physics runs interrupted by one or two years long shut-down periods, makes it very difficult to test with beam new equipment before its final installation on existing machines. Access to beam for diagnostic testing is non-existent during shut-downs and very limited during operation, given the pressure to produce physics results and the limitations (e.g., allowed vacuum levels) inherent to operational accelerators. In the recent past the CLIC study made extensively use of the CALIFES beam to test diagnostics equipment (high precision BPMs, EOS bunch length monitor etc.). The availability of the CALIFES installation and its flexibility in terms of scheduling and installation made such testing very successful, allowing for a fast turn-around and rapid and efficient development and finalization of such devices. There is today a clear interest within CERN to keep using such a facility beyond the CLIC scope, in order to develop, characterize and qualify diagnostic equipment both for the CERN main accelerator chain up to LHC and for new projects (CLIC, FCC, AWAKE...). Relevant testing include:

- Test with realistic signals of state of the art electronic, i.e. response to short pulses with high signal amplitude
- Test of UV, optical, X-ray monitors where no other source can reproduce beam induced radiation, including imaging techniques, beam halo monitoring and use of electro-optical crystals
- Validation of particle detector design (e.g. Beam loss monitor/ Luminosity monitor), with sensitivity checks, linearity (or non-linearity) checks
- Study of the behavior of devices with respect to beam position / bunch length / bunch intensity variations
- Tests of wake field and break down monitors

Beam requirements

Beam requirements vary depending on the particular diagnostics to be tested, however CALIFES' bunch charge range, low emittance and single and multi-bunch options (with the possibility to cover bunch spacings similar to CERN beams - 1ns, 5ns, 25ns, 50ns, ...) satisfy many applications. The capability of reaching shorter bunch lengths would be definitely a plus. Additional requirements for some applications include the possibility of crabbing by RF deflectors, synchrotron radiation sources (e.g. in chicane bends), and an in-air testing area (e.g., for beam loss monitor developments).

Institutes expressing the interest

CERN
Uppsala University

B2. Impedance studies

Collective effects are one of the main limitations in modern accelerators and colliders. A strong effort is dedicated to qualify in term of impedance all equipment to be installed in CERN machines (in particular PSB, PS, SPS and LHC, but also AD and ELENA). Design and approval of new and modified equipment are performed using numerical simulations and bench measurements with wires and probes. Such techniques have intrinsic limitations (e.g., idealized description and lack of accuracy for numerical methods and perturbation of the EM fields for bench measurements). Measurement with electron bunches could be an interesting complement to these existing tools, providing direct access to the relevant physical processes.

Several kinds of beam-based measurements may be considered in a CALIFES based facility. In growing order of complexity/difficulty:

- Direct measurement of generated electromagnetic fields
- Direct measurement of “wake function” (drive + probe bunch method)
- Direct measurement of coherent effects between bunches
- Direct measurement of heating
- Correlation of the results with the reading of wake field monitors, described further in the section on X-band Free Electron Lasers

The first kind is very easy to perform in CALIFES, and for some kind of equipment (e.g., wire scanners) is directly probing the physical quantity of interest (beam induced signal in the wires). However, for most kind of equipment it is an indirect measurement, which will allow to validate numerical simulations. The second kind of measurement, directly measuring the longitudinal and transverse effects of the wake-field on a test bunch, is appropriate for all kind of equipment and can be performed using the CALIFES beam with some limitations (see below). The two last kinds may give important additional information, but more studies are needed to assess their feasibility in CALIFES. Direct measurements of components' impedance as the ones mentioned above cannot be obtained with other means so far and therefore there is a strong interest within CERN to explore the possibility of using CALIFES for this aim. As is the case for beam instrumentation tests, CALIFES availability and its flexibility for scheduling and equipment installation are big advantages.

Beam requirements

CALIFES beam parameters fit impedance measurements requirements for bunch charge, emittance and energy. Bunch length is also sufficiently small, but shorter bunches would be a plus. For direct wake field measurements one would need double bunch capabilities (can be obtained by splitting the laser pulse and using

an optical delay). Spacing of the drive and probe bunches in units of 333 ps (# GHz spacing) is straightforward with the present installation, and it is sufficient for basic measurements. Additional flexibility in bunch spacing would be a big advantage, and studies in this direction should be carried out. Independent control of the transverse position of the two bunches is essential in order to disentangle dipolar and quadrupolar transverse wakes, one of the more interesting tests under consideration. Limitations in resolution of the kick measurements should also be assessed. One additional requirement is the time resolution of the Beam Position Monitors, which should be in the range of 0.1-0.3 ns. At least 2.5 m of space are needed in the beamline to allow installation of most components.

Institutes expressing the interest

CERN
PSI
Uppsala University

B3. Development for an X-band Free Electron Laser

There is rapidly growing worldwide interest in XFELs and a parallel trend to using higher accelerating frequencies for more compact linacs. An international collaboration consisting of 12 institutes worldwide (10 from Europe) is actively studying the design of a compact and cost-effective Free Electron Laser based on acceleration using CLIC X-band technology (the “XbFEL” collaboration). Component tests and technology demonstrations are an important part of this study, and needed to demonstrate that sufficiently high peak current and good beam quality can be obtained. To achieve the required beam parameters a number of X-band components including phase-space linearizers, transverse deflecting cavities (for bunch length diagnostics and RF spreaders) and wakefield monitors must be further developed and tested. Machine accessibility for performing such studies is extremely limited in FEL user facilities. CALIFES would be the only facility in Europe where a significant amount of time could be dedicated to X-band tests. For the XbFEL collaboration it is also of great interest to test novel bunch compression schemes and advanced beam physics including purely magnetic compression systems. In the UK, the S-band based CLARA test-facility is proposed for FEL proof of principle experiments [CLARA, <http://www.stfc.ac.uk/2905.aspx>], focusing on a rich photon production program. After successful X-band technology tests at CALIFES, the CLARA project is planning to demonstrate X-band FEL lasing by replacing the current S-band linac sections with X-band.

Interest from PSI

The SwissFEL is currently under construction at PSI, Switzerland with the start of operations planned for 2017. Accessibility of the facility for new developments will be extremely limited once the SwissFEL is running as a user

facility. It is therefore of interest for the SwissFEL project to have access to an electron beam for hardware development studies beyond 2016, including short bunch studies, X-band RF deflectors and wakefield monitors. In many cases the interests are coinciding with those of the XbFEL collaboration. The SwissFEL project could also possibly contribute hardware to CALIFES test facility, including the magnetic chicane for bunch compression currently installed at the SwissFEL test facility. This chicane could be used for CALIFES bunch compression in general, in addition to tests of advanced bunch compression schemes for FELs.

Furthermore, an on-going PSI program is the development work on wake field monitors. The X-band linearizer structures of SwissFEL, which were developed and built in collaboration with CERN and Sincrotrone Trieste, have integrated wake field monitors to align beam and structure with high precision. As part of EuCARD2, we are currently developing front ends for these monitors. Ideas for future work are more compact designs for the pickups and – possibly of high interest for CLIC – the use of these devices as break down monitors. Given the rather limited options at PSI, testing these devices at CALIFES (possibly with the structure under power for break down applications) would be extremely helpful.

Interest from Ankara University – TAC project

The Turkish Accelerator Center Project team is constructing an Oscillator FEL facility based on 40 MeV linac in order to scan 3-250 μm wavelengths. The team also has been studying on conceptual design reports of a Synchrotron Radiation Facility based on 3 GeV synchrotron and a X-FEL facility based on 6 GeV linac since 2010 with support of Ministry of Development of Turkey.

The TAC team wants to use the advantages of high gradient and high repetition rate operation of X-band structures in order to reduce the cost of X-FEL facility and create new FEL applications. The team will complete the CDR of the facility in 2015.

The tests of X-band structures with/without beam and existing pulse compressor set-ups at CALIFES would let TAC team gain a lot of expertise for the future XFEL project of Turkey. Additionally CALIFES could provide very useful test bench to the TAC team for beam dynamics, electron beam manipulation and diagnostics studies for their future project. The Turkish team may contribute hardware to CALIFES depending on the next period of their XFEL project.

Interest from Elettra-Sincrotrone Trieste

The Fermi FEL at Trieste has been operating since 2010. For upgrades of the machine, many advanced ideas for electron beam manipulation have been studied, including arcs with CSR compensation and experiments to study the microbunching instability. As for the SwissFEL, the accessibility of the production machine for beam dynamics R&D is very limited, and CALIFES could provide an excellent test bed for electron beam manipulation schemes.

Beam requirements

The CALIFES facility as it is provides the beam specifications to perform most of the X-band component tests described above. The Xbox 1 RF source may power X-band linearizers and deflecting cavities. The possibility of using the SwissFEL magnetic chicane for CALIFES is very interesting both for PSI and for the CALIFES test facility.

Institutes expressing the interest

Elettra-Sincrotrone Trieste
 CERN, Geneva
 Jagiellonian University, Krakow
 Daresbury Laboratory Cockcroft Institute, Daresbury
 Shanghai Institute of Applied Physics, Shanghai
 VDL ETG T&D B.V., Eindhoven
 University of Oslo
 National Technical University of Athens
 Uppsala University, Uppsala
 Australian Synchrotron, Clayton
 Institute of Accelerator Technologies, Ankara, Turkey
 Lancaster University, Lancaster
 PSI

B4. Plasma wakefield acceleration

Beam-driven plasma wakefield acceleration (PWFA) has gained momentum recent years with the approval of the AWAKE experiment located at CERN and the two-bunch PWFA experiments on-going at the FACET test facility at SLAC. PWFA has demonstrated that accelerating gradients of the order of 50 GV/m can be sustained in plasma [I. Blumenfeld et al., *Nature* 445, 741–744 (2007)], and that high efficiency two-bunch acceleration can be performed [M. Litos et al., *Nature* 515, 92–95 (2014)]. Both these virtues make PWFA a very attractive technology to develop further with the aim of verifying whether it can be used for a future electron-positron collider. AWAKE studies wake structures generated by a self-modulated SPS proton bunch, investigating whether a single LHC bunch can be used to accelerate electrons and positrons to TeV scale energies in a single plasma stage. A complementary approach to a TeV plasma collider is to use multiple plasma stages, each driven by a single electron bunch to accelerate a witness bunch to high energies, much as in the CLIC concept stages [E. Adli et al., arXiv:1308.1145 (2013)]. Electron driven PWFA has been studied at FACET, however, the acceleration of an independent witness bunch to high energy, with a low energy spread while preserving its incoming emittance has not been demonstrated and must be before the PWFA has been fully demonstrated as a viable acceleration technology, especially concerning the beam quality. The physics of the beam-plasma interaction scales with the plasma density; the electric fields decrease with square root of the plasma

density, while the length scales increase with the square root of the plasma density. Using the CALIFES beam combined with a plasma source with a density of $10^{14}/\text{cm}^3$ (two orders of magnitude lower than what is proposed for a PWFA linear collider) would constitute a scaled down facility to test concepts for a PWFA linear collider, including thorough studies of emittance preservation in PWFA, a topic of immediate interest for establishing the feasibility of PWFA for applications. A plasma source with the suggested density can be based on an ionized gas [J. Machacek, MSc Thesis 2014, MPP, Munich]. Such a source can fit inside the current experimental area and will be compact and not need laser ionization or other major hardware additions to CTF3. The large range of easily varied beam parameters available at CALIFES would make PWFA experiments at CALIFES a significant contribution towards demonstrating the usefulness of PWFA to HEP.

Beam requirements

The CALIFES beam parameters are well adapted for such a test facility, with the exception of the bunch length. In order to be useful for a PWFA experiment, the bunch length must be on the order of 100 μm . As discussed above, this bunch length could be achieved by compression using a dogleg chicane. A second photo injector cavity may be required for precision control of timing between the drive and the witness bunch, however, both the existing klystron and laser could be used to drive the second injector.

Institutes expressing the interest

Department of Physics, University of Oslo, Norway
Max Planck Institute for Physics, Munich, Germany
Imperial College London, UK
Uppsala University, Sweden

B5. ESA irradiation test facility

CERN and ESA have signed a bilateral co-operation agreement (ICA-ESA-0125) in March 2014 in order to facilitate knowledge exchanges and synergies exploitation in key technological fields. One of the most promising areas of potential collaboration is “Rad-hard components and radiation testing and facilities”. An implementing protocol is currently under definition to cover development, characterization and qualification activities related to radiation hardening of electronic circuit for shielding against long-term damaging effects and single-events, as well as activities related to radiation environment experimental facilities, radiation monitoring systems and modeling tools. A particular attention will be given to the possibility to offer to the space community access to CERN facilities (like CHARM or CTF3) where electronic devices and systems can be tested in environments affecting them in terms of Single Event Effects, Total Ionising Dose and Displacement Damage. The increasing need for such facilities has been identified in the frame of the European Space Technology Harmonisation activities on Radiation Environment

and Effects and is also linked to the augmented use of electric propulsion orbit raising for GEO platforms (obliging space systems to operate for significant periods within the most severe parts of the radiation belts and to cope with higher total mission radiation dose budgets) and to the recent selection of missions with particularly stringent requirements in terms of radiation tolerance (like ATHENA and JUICE).

JUICE (Jupiter Icy Moon Explorer) mission in particular was confirmed as an L class science mission; spacecraft and payload design activities were executed and the project is moving into the implementation phase. The Jovian radiation environment is much more severe than that of the Earth and a significant mass penalty will be necessary to embark additional shielding. The spacecraft will be located in an electron dominated environment, including high-energy electrons ranging up to a few hundred MeV. Such high-energy electron radiation test facilities are not available today. The possibility to irradiate components is an important part of the preparation for JUICE. It is of interest both to study electronic component long-term degradation, where current test standards refer to an electron beam energy in the range 10 to 20 MeV, and single event effects, where especially for the latter electron beam energies in the range 100 to 200 MeV have to be evaluated in order to ensure an appropriate radiation hardness assurance strategy.

In a similar way, and especially in view of future electronic technologies, the impact of electrons on electronic components will have to be studied in the context of the HL-LHC future programs (such as the FCC).

Beam requirements

The CALIFES beam has an ideal energy range to perform both single event effect studies (with energies ranging up to 200), as well as radiation tests for long-term damage (where existing lower energy electron beams in the range of 10-20MeV can be compared to the higher energies also available at CALIFES). For the irradiation tests the beam should ideally be relatively large transversally (up to a few cm times a few cm). The CALIFES beam can be expanded transversally to the order of cm. The dose rate should be lower than 1 Gray / minute.

Institutes expressing the interest

European Space Agency
Laboratório de Instrumentação e Física Experimental de Partículas, Portugal
University of Montpellier, France
CERN