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REPORT

THE EUROPEAN INTERNATIONAL LINEAR COLLIDER PREPARATION PLAN (EIPP)

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Preparation Plan for European Participation in the International Linear Collider

Towards a European Contribution to the ILC

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Content

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Executive Summary

The case for a lepton collider to explore the physics opened up by the discovery of the Higgs boson is widely accepted. The International Linear Collider being proposed in Japan with an initial energy of 250 GeV has the potential to study the Higgs sector in great detail. The international - including European - interest for the project is very large.

This document complements the KEK ILC action plan from 2016 and provides an overview of European expertise and possible contributions to the ILC preparation phase. It is based on the assumption that ILC will be realized as an international project led by Japan, with a strong international participation. It does not provide or rely on specific levels of the European contribution to the project, but builds on the European capabilities and technical expertise.

In the first part of the document the on-going activities with relevance to the ILC in Europe are reviewed, identifying the areas where European groups and industries have extensive know-how and expertise. The European expertise and participation in ILC studies during the last decade are very broad and in particular the European XFEL project at DESY has been pivotal in establishing European capabilities.

The ILC Preparation Phase, currently foreseen for 2019-2022, needs to be initiated by a positive statement from the Japanese government about hosting the ILC, followed by a European strategy update that ranks European participation in the ILC as a high-priority item. The preparation phase focuses on preparation for construction and agreement on the definition of deliverables and their allocation to regions. The European groups will concentrate on preparation for their deliverables including working with and preparing European industry. Europe and European scientists, as part of an international project team, will also participate in the overall finalisation of the design, while in parallel contributing to the work of setting up the overall structure and governance of the ILC project and of the associated laboratory.

The construction phase will start after the ILC laboratory has been established, currently foreseen from 2023, and intergovernmental agreements are in place. At the current stage, only the existing capabilities of the European groups relevant for this phase can be outlined in broad terms. As mentioned above, the detailed contributions will have to be defined during the preparation phase and formalised by inter-governmental agreements. The main in-kind contribution from Europe would fall in the time frame beyond 2025.

Being most relevant for the near future, this document outlines how the preparation phase can be organised. In terms of efficiency, impact and industrial contribution a wide European project is desirable, with CERN playing a central role in coordinating the efforts.

1 Introduction

In Autumn 2016, CERN and the E-JADE project[1] received a request from the KEK directorate to prepare a white paper for a potential European involvement in the International Linear Collider (ILC) if the project is approved by the Japanese government and the negotiations with international partners have commenced. This “Preparation Plan for European Participation in the International Linear Collider” is supposed to complement the KEK ILC action plan [1], which was published in early 2016. It is based on the assumption that ILC will be realized as an international project lead by Japan, with a strong European participation. It is also intended to be developed further to serve as an input for the next update of the European strategy for particle physics, which is expected to be concluded in May 2020.

The ILC as described in detail in the ILC technical design report (TDR) [2] is a high-luminosity linear electron-positron collider with centre-of-mass energies of up to 500 GeV. The machine (see Figure 1) has an intended length of 31 km and uses superconducting niobium radio-frequency (RF) cavities to accelerate the particles to their final energy. The ILC design can be extended to provide centre-of-mass energies of up to 1 TeV in the future. During the last twelve months a reduced initial ILC starting at 250 GeV at a length of 20 km has been presented and its physics potential validated, and we consider the 250 GeV project as the baseline plan for ILC in this document.

The superconducting radio-frequency (SCRF) technology used in the ILC is a key technology for many current accelerator projects, and the ILC will build on a lot of experience gained in endeavours like the European XFEL.

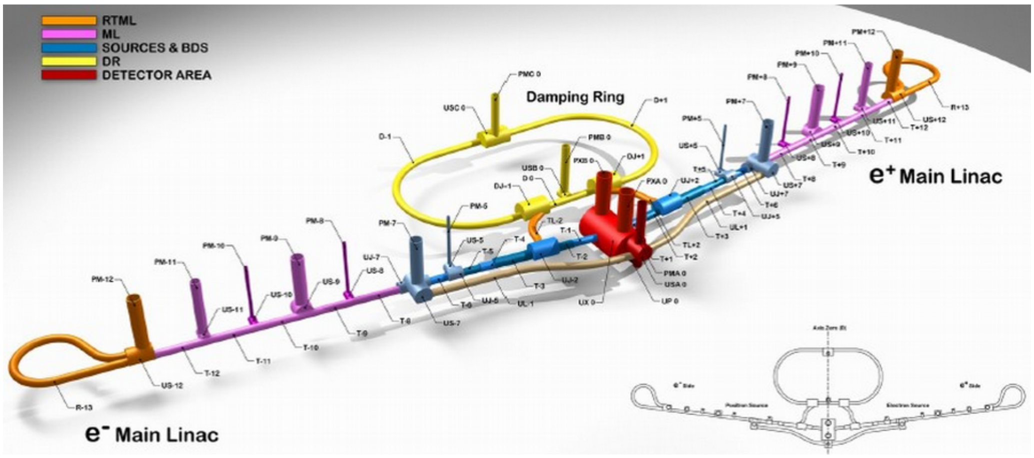

Figure 1: Schematic picture of the ILC.

According to the TDR, the interaction region of the ILC will host two detectors in a push–pull configuration. Two detector concept groups, SiD and ILD (see Figure 2), have designed detectors that are able to make precision measurements of Standard Model (SM) particles and that at the same time are sensitive to a wide range of new phenomena (“physics beyond the Standard Model” or “BSM physics”). The ILC physics programme offers many opportunities for precision measurements that will address a wide range of open questions in particle physics [3].

[1] The Europe-Japan Accelerator Development Exchange Programme (E-JADE) `http://www.e-jade.eu` is a Marie Sklodowska-Curie Research and Innovation Staff Exchange (RISE) action, coordinated by CERN and funded by the EU under Horizon2020. It promotes the exchange of ideas and expertise on R&D and implementation plans of future accelerators for particle physics, among them ILC.

At the time of the ILC TDR in 2013, Japanese physicists indicated an interest to host this facility. A site in the Kitakami mountains has been proposed and site specific studies have been pursued by Japanese scientists and local authorities during the last few years. The European strategy update [4] published in 2013 stated strong support for the ILC project, provided Japan makes an official proposal to host it.

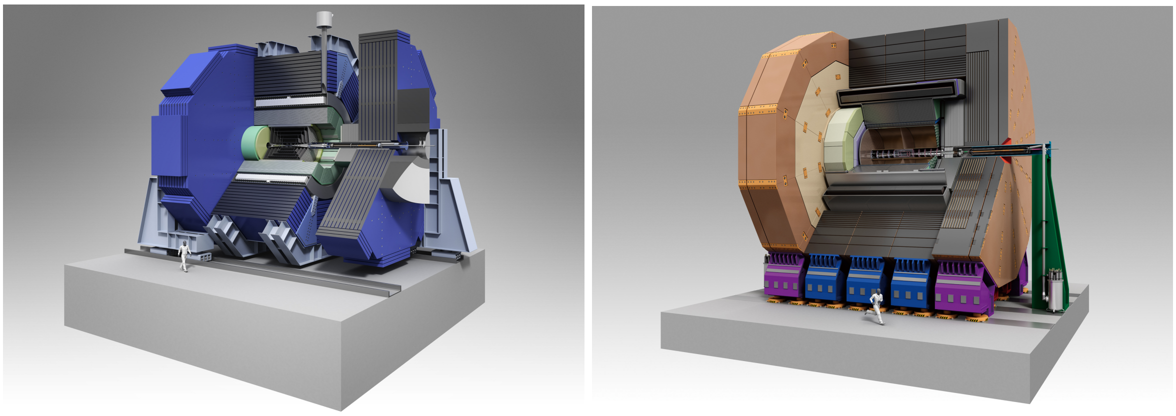

Figure 2: The two detector concepts for the ILC: SiD (left) and ILD (right).

This document is organised as follows. First, a summary of past and present ILC activities in Europe is given in Section 2. The potential activities of Europe in a “preparation phase” are presented in Section 3. It is premature to discuss the European participation in the ILC construction in detail, but a few general considerations are made in Section 4. Finally, possible scenarios for how Europe could most efficiently contribute are outlined in Section 5, concentrating on the “preparation phase”.

This report uses the same steps and timelines as the KEK ILC action plan [1], and the following activities are foreseen for the individual periods in question:

2017–2018: Pre-preparation phase
The on-going activities with relevance to the ILC in Europe are reviewed, identifying the areas where European groups and industries have extensive know-how and expertise.

2019–2022: Preparation phase
This period needs to be initiated by a positive statement from the Japanese government about hosting the ILC, followed by a European strategy update that ranks European participation in the ILC as a high-priority item. The preparation phase focuses on preparation for construction and agreement on the definition of deliverables and their allocation to regions. The European groups will concentrate on preparation for their deliverables including working with and preparing European industry. Europe and European scientists, as part of an international project team, will also participate in the overall finalisation of the design, while in parallel contributing to the work of setting up the overall structure and governance of the ILC project and of the associated laboratory.

2023 and beyond: Construction phase
The construction phase will start after the ILC laboratory has been established and inter-governmental agreements are in place. At the current stage, only the existing capabilities of the European groups relevant for this phase can be described. As mentioned above, the detailed contributions will have to be defined during the preparation phase and formalised by inter-governmental agreements.

With the completion of the foreseen nine-year construction phase in 2032, the European groups will naturally be involved in the commissioning of both the accelerator and detectors. After the commissioning, the operation of the facility and the physics exploitation will start. This phase is not covered in this report.

2 Past European contributions to the ILC and current activities within Europe

Europe has a very strong scientific, technological and industrial basis to make significant contributions to the construction of virtually any part of the ILC machine and detectors. In this section, an overview of past and present ILC-related activities in Europe is given.

2.1 Past contributions

2.1.1 The ILC Global Design Effort

The ILC Global Design Effort (GDE) was responsible for the coordination of the worldwide ILC accelerator design, R&D and cost-estimate development during the period 2007 to 2012, culminating in the publication of the ILC TDR in 2013 [2]. After the publication of the ILC TDR, the GDE was replaced by the Linear Collider Collaboration (LCC). Figure 3 shows the European contributions to the individual subsystem efforts within the GDE, while Figure 4 summarises the estimated European FTE contributions (728 person years in total) during that period, divided into Accelerator Design and Integration (ADI) activities and SCRF technology development (excluding GDE management and EDMS support). Note that the SCRF numbers represent ILC-specific resources and do not include the extensive synergetic contributions from the European XFEL development discussed in Section 2.2.2.

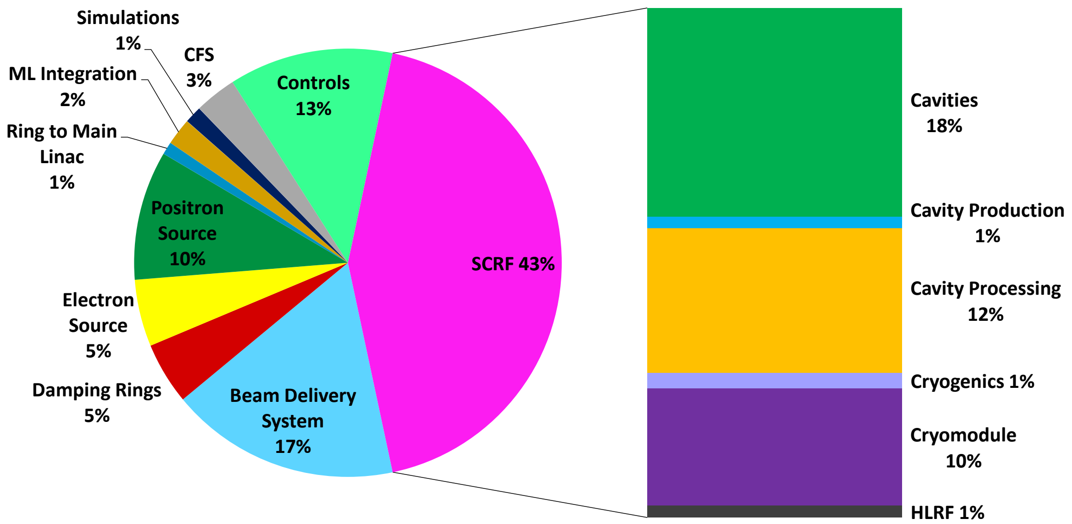

Figure 3: The distribution of the European effort (728 person years in total) to the ILC GDE (2007-2012).

2.1.2 Detectors for linear colliders

Detector R&D for future linear colliders has been very active in Europe since the 1990s. Many R&D collaborations and groups have been working on different aspects and subdetectors, ranging from advanced pixel sensors to large-scale highly granular calorimeter prototypes. This diversity and breadth has proven to be very successful over many years and is still maintained.

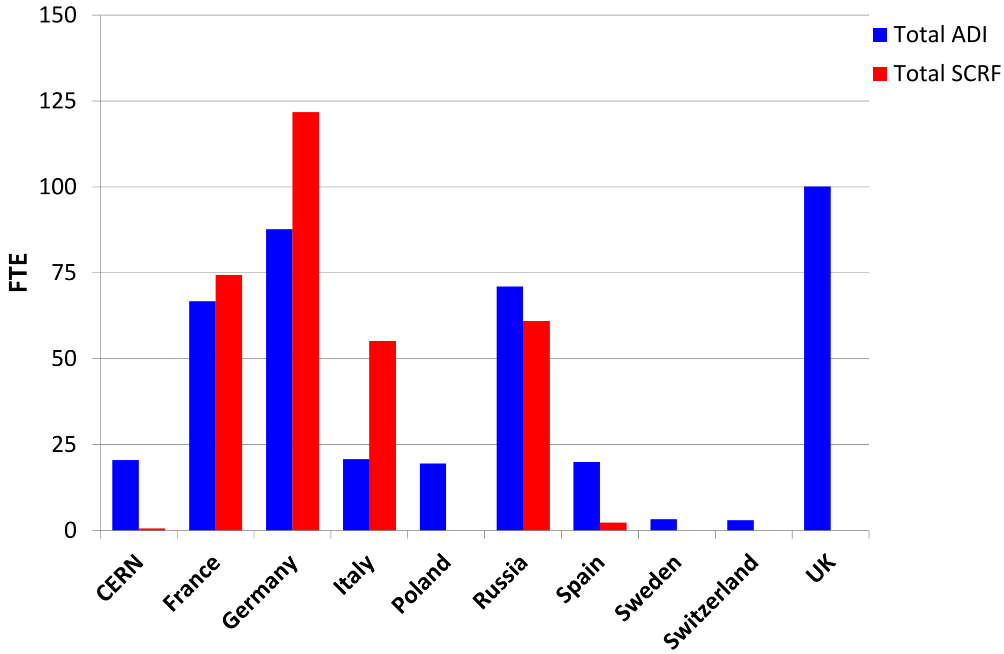

Figure 4: The contribution to the ILC GDE (2007-2012) in staff years per European country, separately for ADI and SCRF.

Within the ILC project, the detector community joined together to integrate their R&D results into detector designs for the ILC. After a call for "letters of intent" in 2009, the two detector concept groups, SiD and ILD, were formed; their concepts were validated and then presented in Volume 4 of the ILC TDR [2]. The results from the ILC detector R&D have found applications in many other experiments, ranging from Belle-II to the HL-LHC upgrades and heavy-ion experiments at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven and at GSI in Darmstadt. The ILC detector community also worked closely together with CLIC to produce the CLIC conceptual design report (CDR) [5] and vice versa.

2.2 Current activities within Europe

There are currently seven ongoing activities in Europe that have a strong relevance to European participation in the ILC project. Most of them are funded for other reasons, i.e. the direct funding of ILC studies in the laboratories and by the funding agencies is very limited, but together these activities provide a very strong basis for European ILC contributions in terms of trained scientific and technical staff, laboratory infrastructure and experience, and industrial capabilities.

These key ongoing activities in Europe with high relevance for ILC are shown in Figure 5 and will be discussed in the next sections: European participation in the GDE and Linear Collider Collaboration (LCC), the European XFEL project, the European Spallation Source (ESS) superconducting linac, the European participation in the Accelerator Test Facility (ATF) at KEK for linear collider studies, the CLIC study, and finally the linear collider detector R&D.

The Europe-Japan Accelerator Development Exchange programme (E-JADE) is a Marie Sklodowska Curie Research and Innovation Staff Exchange (RISE) action funded by the EU under the Horizon 2020 framework programme. The E-JADE programme, running from 2015 to 2018 and funded with approx. 1.1 M€, is intended to foster exchange between European and

Figure 5: The currently on-going ILC-related activities in Europe.

Japanese accelerator scientists working on future energy-frontier accelerators in general and on the ILC in particular. E-JADE is an essential tool for the current collaboration with Japan, especially for the ATF2 and for ILC preparation work.

Given the large efforts for superconducting linacs such as the European XFEL and the ESS, together with important developments aimed at the ILC and CLIC detectors and strong participation in ATF and ATF2 over an extended time period, Europe has a very strong basis for participation in ILC.

2.2.1 GDE/LCC Accelerator Design and Integration

Item/topic	Brief description	CERN	France CEA	Germany DESY	Time line
SCRF	Cavity fabrication including forming and EBW technology,	✓			2017-18
	Cavity surface process: High-Q &–G with N-infusion to be demonstrated with statics, using High-G cavities available (# > 10) and fundamental surface research		✓	✓	2017-18
	Power input-coupler: plug compatible coupler with new ceramic window requiring no-coating	✓			2017-19
	Tuner: Cost-effective tuner w/ lever-arm tuner design	✓	✓		2017-19
	Cavity-string assembly: clean robotic-work for QA/QC.		✓		2017-19
Cryogenics	Design study: optimum layout, emergency/failure mode analysis, He inventory, and cryogenics safety management.	✓			2017-18
HLRF	Klystron: high-efficiency in both RF power and solenoid using HTS	✓			2017- (longer)
CFS	Civil engineering and layout optimization, including Tunnel Optimization Tool (TOT) development, and general safety management.	✓			2017-18
Beam dump	18 MW main beam dump: design study and R&D to seek for an optimum and reliable system including robotic work	✓			2017- (longer)
Positron source	Targetry simulation through undulator driven approach			✓	2017-19
Rad. safety	Radiation safety and control reflected to the tunnel/wall design	✓			2017 – (longer)

Table 1: Current common studies between European institutions and Japan relevant for the ILC.

After the delivery of the ILC TDR in 2013 (see Section 2.1), the LCC took over from the GDE.

The LCC united the activities of ILC and CLIC under one common umbrella; it continued the activities on ILC ADI and SCRF, albeit at a lower scale than during the (pre-)TDR phase.

The present activities under the LCC umbrella that are carried out in close collaboration with Japan are summarised in Table 1.

2.2.2 European XFEL

The European XFEL at DESY is an international project constructed with contributions from eight countries (see Figure 6). Of highest relevance to the ILC is the 17.5 GeV superconducting linac, comprising 100 superconducting ILC-like cryomodules (800 1.3 GHz TESLA cavities) and driven by 25 10 MW multibeam klystrons. The European XFEL linac configuration is very similar to that foreseen for the ILC and can be seen as a 7% (in energy) ILC prototype. The cryomodules were produced by a consortium of six countries together with predominantly European industries. The consortium members and the various responsibilities across the linac-relevant European XFEL work packages (including testing) are given in Table 2.

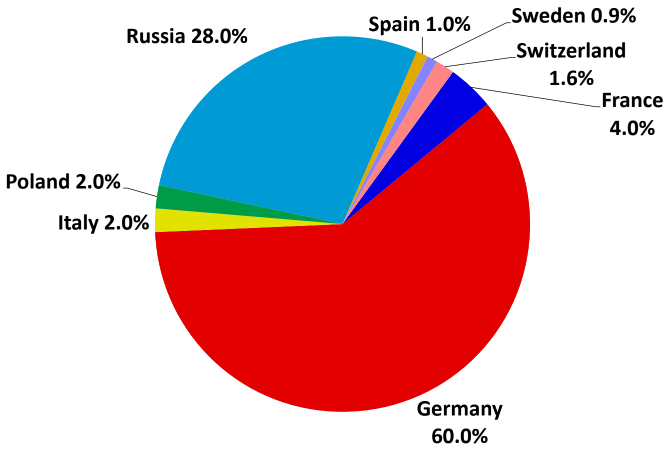

Figure 6: Countries contributing to the European XFEL total project costs.

	Germany	France		Italy	Poland			Russia	Spain
	DESY	CEA Saclay	LAL	INFN Milan	IFJ PAN	WUT	NCBJ	BINP	CIEMAT
Linac									
Cryomodules	✓	✓		✓					
SCRF Cavities	✓			✓					
Power Couplers	✓		✓						
HOM Couplers							✓		
Frequency Tuners	✓								
Cold Vacuum	✓							✓	
Cavity String Assembly	✓	✓							
SC Magnets	✓				✓				✓
Infrastructure									
AMTF	✓				✓	✓		✓	
Cryogenics	✓								
Sites & Buildings									
AMTF hall	✓								

Table 2: Responsibility matrix for cryomodule production and testing for the European XFEL.

Construction of the European XFEL is now complete, and user operation at the facility has started. During the ILC pre-preparation phase 2017–2018, the European XFEL can directly benefit the ILC in the following key ways:

- The experience and knowledge gained during the unprecedented industrial production of 100 cryomodules over a three-year period can provide invaluable input to any future large-scale production for the ILC, including identifying directions where further R&D could be beneficial for cost reduction and performance enhancement (e.g. more cost-effective approaches to mass production). The detailed cost breakdown of the XFEL cryomodules provides a solid basis for any future projection of a possible European in-kind contribution to the ILC.
- The commissioning of the European XFEL and its operation provide invaluable "system testing" for the ILC, including understanding the ultimate performance of the modules with beam loading, beam control (LLRF development), software tools, and more general operational experience. Furthermore, the European XFEL could provide a test-bed for ILC-relevant accelerator experiments, although the time available for this will be limited once user operation is in full swing.
- The infrastructure that was constructed for European XFEL cavity and module testing, high-power coupler conditioning and module assembly will continue to be maintained, and (in the case of the testing infrastructure) will provide a significant support for SCRF R&D.

2.2.3 Construction of the ESS linac

The ESS is a neutron-source facility currently under construction in Lund (Sweden). Several European institutes and laboratories (see Table 3), many of which already have contributed to the European XFEL, as well as European industry, are currently engaged in this project, which is of a size comparable to that of the European XFEL. The official ESS schedule foresees beam commissioning in 2019 and the first 2 GeV beam in 2022.

The ESS is planning to produce 5 MW average-power proton beams on a spallation target. The proton driver is a SCRF linac accelerating a 62.5 mA proton beam pulsed with 4% duty cycle to 2 GeV. In contrast with the European XFEL, the ESS cold linac involves three families of altogether 43 cryomodules with 704 MHz RF resonators. Although the number of cryomodules and cavities is smaller than for the European XFEL linac, the complexity of the technology, the high input power and the maximum cavity surface fields will further develop European SCRF expertise.

Of particular importance to the ILC, the ESS project not only helps to support the existing XFEL infrastructure and SCRF expertise, including industry, but also extends it with new SCRF installations in the UK and Sweden, thus further enhancing Europe's SCRF capabilities.

	Germany	France		Italy		Poland	Spain	Sweden		UK
	DESY	CEA	IPNO	Elettra	INFN-LASA	IFJ-PAN	ESS Bilbao	ESS	Uppsala	STFC
RF systems				✓			✓	✓		
LLRF									✓	
Cryomodules		✓	✓							
SCRF Cavities		✓	✓		✓					✓
Power Couplers		✓	✓							
HOM couplers										
Frequency Tuners		✓	✓							
Cold Vacuum		✓	✓					✓		
Cavity String Assembly		✓	✓							
RF Tests (Cavites)	✓									✓
RF Tests (Cryomodules)		✓	✓			✓		✓	✓	

Table 3: Responsibility matrix for the cryomodule production and testing for the ESS.

2.2.4 ATF2

The ATF was built at KEK to create small-emittance beams [7] satisfying the requirements of the ILC. Measured emittances are typically 2 nm rad and 12 pm rad in the horizontal and vertical planes, respectively, and the beam energy is 1.3 GeV. As a result of an international collaboration, the ATF2 extension [8] was built in 2005 to study the feasibility of an ILC-type beam-delivery system (BDS), with two main goals:

Goal 1: optics design validation of the final focus system (FFS) local chromaticity-correction scheme used for the ILC and achievement of a vertical beam size at the interaction point (IP) of 37 nm;

Goal 2: nanometer beam stabilisation including diagnostic development, feedback techniques and ground-motion studies.

The FFS based on the local chromaticity-correction scheme was successfully validated at ATF2 for the first time. ATF2 provides invaluable experience on operating and stabilising nanometer beams, including the required hardware and correction techniques. Vertical beam sizes smaller than 43 nm for bunch populations of about 10^9 particles have been repeatedly obtained [9]. A feedback system has also been successfully developed to reduce the orbit jitter, both at the entrance to the final focusing section of ATF2 and at the IP.

European scientists form a major part of the ATF2 collaboration and perform key roles towards its success. They are pursuing a robust, rich and varied R&D program also relevant to future linear colliders other than the ILC. The relevant present activities are summarised in Table 4. The educational aspect is an important priority for all European collaborators, with seventeen Ph.D theses completed in the last ten years and another ten theses still ongoing.

	CERN	France		Germany	Spain	UK	
		LAL	LAPP	DESY	IFIC	Oxford	RHUL
Goal 1							
Very-low β	✓						
Ultra-low β	✓						
Halo control		✓			✓		
Wakefield/Intensity	✓				✓	✓	✓
Instrumentation	✓	✓			✓	✓	✓
Ground motion	✓		✓			✓	
Background				✓			✓
Goal 2							
Stabilisation/Feedback		✓				✓	

Table 4: An overview of present European activities in ATF2.

2.2.5 CLIC

The Compact Linear Collider (CLIC) is a CERN-led design study of an $\mathrm{e}^+\mathrm{e}^-$multi-TeV high-energy frontier linear collider based on normal-conducting accelerating structures [6]. In spite of the different RF technologies used, there are common studies for the CLIC and ILC projects, and many common tools and facilities are used for CLIC and ILC performance studies. Some of the activities are listed in Table 5; prominent examples are common beam-dump studies and studies of high-efficiency klystrons. Many developments for one project can thus be adapted for the other, while some remain specific for the ILC like SCRF-related topics, cryogenics and civil engineering (CE).

Topic	Details
Beam-dynamics	Overall accelerator design Modeling and simulation tools
Damping rings **RTML** **BDS** **MDI**	Design Optimisation and performance studies
Cost and power	Cost comparison and reviews Power estimates and comparison
Physics and Detector	Physics studies Detector design Software tools

Table 5: An overview of present common activities between ILC and CLIC.

Common studies in ATF2 are also well established across the two projects. Beyond these studies, common study groups like those shown in Table 5 have existed for many years, covering many of the key design challenges for the two machines. As a result, there is extended knowledge of these systems across the CLIC and ILC project members, which also directly feeds into the activities described in Section 2.2.1.

2.2.6 Linear collider detector R&D

Europe has been playing a very active role in both ILC detector concepts and currently has leadership positions in both. For ILC-related detector R&D, the funding is allocated either from the national funding agencies or also from EU-based funding. In Europe, both CERN and DESY act as hubs of activity and provide common infrastructures and facilities including test beams.

	CERN	DESY	Czech Republic	France	Germany	Italy	Israel	Netherlands	Norway	Poland	Serbia	Spain	UK
Vertexing	✓	✓	✓	✓	✓	✓				✓		✓	✓
Tracking	✓	✓		✓	✓			✓				✓	✓
Calorimetry	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
MDI	✓	✓							✓				✓
System Integration	✓	✓		✓								✓	

Table 6: An overview of present activities in the area of ILC-related detector R&D and integration in Europe.

A summary of the currently ongoing activities in ILC-related detector R&D is given in Table 6. This table includes activities for CLIC, but not the more generic detector R&D that can be applied to the ILC detectors. The strength in R&D as well as the work on the detector concepts has put Europe in a strong position to contribute significantly to the future ILC detectors.

2.3 Pre-preparation phase summary

As can be seen from the sections above and from Figure 7, Europe has an active programme of ILC-related activities both for the accelerator and the detectors.

The capabilities in Europe for contributions to ILC can be summarised in two key statements:

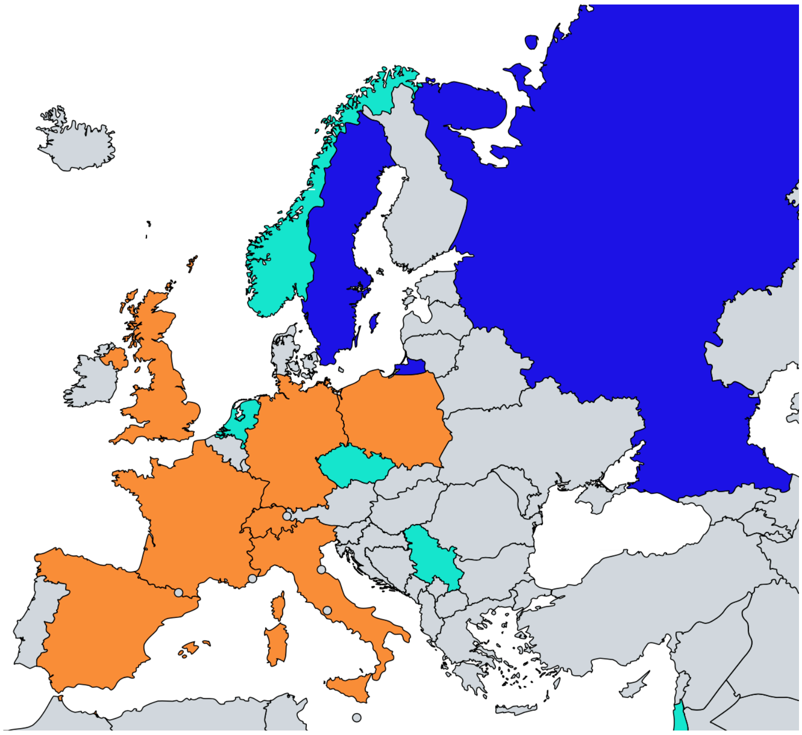

Figure 7: The European countries with current ILC-related activities in the accelerator (blue), detectors (cyan), or both (orange).

- The goals of the European ILC-related efforts in the years 2017–18 are
  - a further optimisation of the SCRF system including RF and cryogenics using European experiences in the European XFEL and the ESS,
  - participation in the ILC site and civil engineering studies,
  - studies for the ILC and CLIC beam-dumps,
  - studies at ATF2 concerning FFS and beam stabilisation,
  - studies for the positron source,
  - detector and physics studies,
  - and overall project management definition and support.
- Beyond this pre-preparation phase, Europe has a very strong scientific, technical and industrial basis to make significant contributions to the construction of virtually any part of the ILC machine and detectors.

In the following chapters, we will describe how this broad expertise built up in Europe for the ILC can be used to prepare important European in-kind contributions to the ILC accelerator and detectors.

3 Preparation phase for the ILC construction 2019–2022

The overall resources needed during the four-year preparation phase are estimated to be 5% of the material and 10% of the personnel foreseen for the initial 250 GeV accelerator project construction. Irrespective of the final level of European investment into the ILC, and to allow the preparation phase to begin after an official expression of interest from Japan and support by the European strategy, it would be appropriate that, given its expertise and previous involvement, Europe invests 1/3 of the overall effort required in the preparation phase. The remainder of this section assumes this to be the case. This would then amount to a total European material budget of 85 M€ and 240 FTE-years, integrated over the period.

Distributed over four years, an average yearly budget of around 30 M€ (covering material and personnel) would be needed with an increasing profile from 2019 towards 2022. The resources required for the activities in the preparation phase are hence similar in scope to those used by existing project studies such as CLIC and FCC.

One important difference will be that the ILC preparation requires a strong engineering team, such that the profile of the ILC personnel will be towards more engineering and technical design and gradually less focused on R&D studies.

On the detector side, the preparation will be similar to the large LHC experiments' construction and upgrade programmes, typically arranged nationally within large international detector collaborators, possibly with some central support at CERN – see Section 5.

The preparation phase will be used for three main purposes:

- Technical preparation of the major European deliverables foreseen for the construction phase. This covers final technical specifications, final prototypes, the preparation of pre-series orders and the preparation of local facilities. A particularly important point for Europe is the transfer of European XFEL know-how and the preparation of the relevant facilities for ILC construction.
- The other key technical activity will be the organisation of a strong European design office for ILC that will liaise with other such offices: there will certainly be a host-lab office in Japan, but additional international design offices will be required. In Europe, the installation of a central European Design Office at CERN with satellite offices in other European laboratories is considered the most viable model.
- The third key activity in the preparation phase will be negotiations about the final European ILC contributions, about the organisation of the project in the construction and operation phase, and about a future governance model for the ILC. These issues are discussed in further chapters of this document.

3.1 Focus on key R&D areas

The European XFEL has successfully demonstrated the knowledge transfer of key SCRF technologies from laboratory to industry. Key components such as cavities and RF couplers, designed and developed by science laboratories, were mass-produced by commercial vendors. The cryomodule assembly was successfully outsourced to and performed by an industrial partner, under close supervision and in an assembly plant set up by CEA-Saclay. Nevertheless, work remains to be done to adapt some of these areas to ILC requirements.

For the preparation phase, the focus will be on a few key areas, which are either major cost drivers, large contributors to the power budget or technologically critical items.

3.1.1 SCRF activities

Superconducting RF is a key technology for several major accelerator projects in Europe, like the European XFEL, the LHC and HL-LHC, the FCC, SPIRAL2, IFMIF, SARAF, bERLinPro, ESS, etc. Thanks to these projects, European laboratories are at the forefront of SCRF science and technology; they can also rely on a solid and long-standing partnership with primarily (but not exclusively) European industries covering all aspects of this technology from the niobium material, the component production to the cryomodule assembly and testing. European SCRF activities, in view of the construction of the ILC in Japan, could develop along four main axes:

1. **Cavity fabrication and preparation:** This activity, potentially led by DESY, would focus on cost reduction of the cavity fabrication process, on better reproducibility and higher yield of cavity performance at the design gradient, on new preparation procedures to reach higher gradient and Q_0, and finally on knowledge and technology transfer of the most promising developments to industry.

2. **Fundamental power couplers:** This activity, potentially led by CNRS LAL-Orsay, would focus on value engineering of the RF coupler production, including potential re-design or re-evaluation of specifications. New industrialisation studies could be undertaken, encompassing fabrication, clean-room preparation, RF conditioning and assembly, in order to minimise the overall cost and risk of this highly complex component. This effort would be directed towards making the coupler production and assembly more efficient, streamlined and cost-effective.

3. **Automation of module assembly:** This activity, potentially led by CEA-Saclay, would focus on the implementation of robotics in the string and module assembly, in particular for the cavity string interconnections and main-coupler connections. The main benefits of robotics would be the reduction of module assembly costs, otherwise dominated by labour, the elimination of assembly mistakes and non-conformities, in particular by avoiding the large turn-over of operators in a multi-year construction project, the standardisation of assembly procedures across several regional assembly plants, and the possibility of implementing a higher level of plug-compatibility in each plant.

4. **Inter-laboratory dissemination:** The former European XFEL collaborating institutes, led by DESY, could initiate a process of dissemination of know-how and experience across ILC partner labs on issues which require global developments and solutions beyond the borders of the three regions, such as: module transport, RF tests and RF distribution, tunnel layout and installation, beam commissioning and operation.

3.1.2 High-efficiency klystron R&D

Conventional multi-beam klystrons, as employed by the European XFEL or foreseen for facilities such as ILC, ESS, CLIC, or FCC, reach efficiencies of around 65-70%. Recent developments, e.g. a better understanding of the bunching mechanism in the klystron, indicate that transfer efficiencies from electron beam power to RF output can be increased significantly. A second way to reduce energy consumption of klystrons may be the application of permanent or high-temperature superconducting magnets in the focusing solenoids.

R&D for the development of high-efficiency klystrons is under way, with collaborators from CERN, ESS, Lancaster University, and Russia, and in collaboration with industrial partners.

High-efficiency klystrons would have a significant impact on the overall power consumption of the ILC, and therefore are of high interest to the project. As European vendors are well poised to provide klystrons for the ILC, Europe is well positioned to intensify R&D in this area.

3.1.3 Cryogenics system

Europe operates several of the world's largest cryogenic systems for liquid-helium supply. CERN's LHC has the largest installation, while the cryo-plant for the European XFEL corresponds to the installation for one of the LHC's octants. ESS will also have a large cryogenic system. With ample experience in the construction and operation of such facilities, and leading industrial suppliers based in Europe, the design of highly reliable, high-efficiency cryogenic plants is a promising field for R&D in close collaboration with industry.

3.1.4 Accelerator design and integration issues

Europe has a multitude of national and international laboratories and universities that are active in accelerator-related research and therefore is capable of contributing to all aspects and in all areas that are relevant for the design and construction of the ILC. Here we list a selection of topics where it is particularly likely that Europe might embark on further R&D activities in the preparatory phase, either because European institutions have made especially important contributions or because the items are considered to be in need of more R&D by the Nomura report [10].

Positron source Groups at DESY and STFC Daresbury have been active in the design and development of the undulator positron source, including the fabrication of undulator prototypes, a proof-of-principle experiment at SLAC for polarised positron production, and beam tests of target materials. European laboratories would be well poised to restart work on helical undulators, which also have potential applications at light sources, and continue design activities for the rotating target, which are listed as critical items in the Nomura report [10]. European laboratories are also capable and interested in studies of a conventional positron source, being a possible alternative of an undulator-based source.

Damping rings The key technology for the damping rings is the capability to produce extremely low emittance beams at high beam intensities, which has many similarities to 3rd and 4th generation synchrotron light sources. Around Europe, a number of state-of-the-art synchrotron sources are in operation or planned (e.g., PETRA-III and PETRA-IV at DESY, ESRF and Soleil in France, ALBA in Spain, MAX-IV in Sweden, Diamond in the UK), and extensive experience exists in the design of such facilities, also at INFN Frascati, which played a leading role in the ILC damping rings design. The recent invention in Europe of the so-called Hybrid Multi Bend Achromat (HMBA) [11], which allows emittance reductions by up to an order of magnitude, is a major breakthrough in the field. Possible R&D activities in the preparation phase range from low-emittance lattice design and beam-dynamics studies (including based on the new HMBA concept) to the design of components such as the accelerating cavities, the wiggler magnets, the high-quality arc magnets, or the vacuum system. The European Low Emittance Ring network, supported by the EU projects EUCARD II, III and ARIES, encompasses the above listed laboratories, and ILC and CLIC damping rings studies are presented, discussed and improved as part of the network activities. Damping ring studies is a also a common ILC and CLIC working group.

Beam delivery system Groups from the UK, France and Spain as well as CERN have been active in the optics design of the beam delivery system, which was tested at the ATF2 facility at KEK, and play a leading role in the development of the necessary feedback electronics that stabilise the beams. Several key technologies for the final focus system are relevant to the ILC as well as CLIC, which has lead to continued R&D activities in recent years. It is possible that such activities would be intensified in the preparatory phase. In addition, there is work on crab cavities, which are considered critical items in the Nomura report [10], in the context of the LHC luminosity upgrade.

Low-emittance beam transport A key technology for the ILC is the transport of the low-emittance beam from the damping rings to the main linac, which has to cover a distance of more than 10 km with minimal emittance growth. This topic has been studied extensively at CERN in the context of the CLIC project.

Beam dumps The ILC will employ a number of beam dumps of varying sizes for average power ratings of 60 kW, 400 kW, and 17 MW. The two smaller dumps have similar requirements as the dumps installed in the European XFEL. Europe could provide a design of such dumps, including the necessary radiological calculations of radioactive isotopes that are produced, possible emanations into the tunnel air, and a concept for shielding and handling of radio isotopes.

A special case is the photon dump for the undulator positron source, which has to cope with very high intensity gamma rays around 10 MeV, for which studies have been made at CERN, resulting in the proposal of a water-curtain dump.

The 17 MW main dumps, which are listed as critical items in the Nomura report [10], are currently planned to be pressurised water dumps operated at 10 bar pressure, with challenging safety and radiological issues (hot, pressurised water, hydrogen/oxygen recombination, tritium handling). A similar dump was operated successfully at SLAC, where the original design was made. For the TESLA project, extensive studies for this dump concept were conducted at DESY. Again, Europe could contribute to the design of the main dump system, including the hydrogen recombination plant and the containment system. In addition, alternative dump systems such as a gas dump have been considered at DESY and could be further developed in Europe.

3.2 Detector and physics preparation

The preparation for detector construction will follow a path similar to that of the ILC accelerator. As was the case for the LHC detectors, a strong host lab basis is needed and will have to be provided by the Japanese ILC organisation. However, deliverables, preparation and technical coordination teams are needed from all international partners. There is less need for a central design team, but strong support with test beams and other facilities will be required.

During the preparation phase, there are four major milestones for the detectors.

MDI studies With the choice of the final location of the interaction region of the ILC, the detector designs need to be adapted to the conditions of the site in terms of hall size, transport capabilities and assembly space. This adaptation process will require close contact with the local experts in Japan, and an European ILC design office can be of invaluable help for this (see below).

Design optimisation The current designs of both SiD and ILD need to be further refined and optimised. For this process — which during the preparation phase will lead to technology selections for the individual sub-detector systems — various considerations like the site-specific conditions, technological developments and others will have to be taken into account.

Technical prototype tests For the selected sub-detector technologies, technical prototypes will have to be produced that demonstrate the feasibility of the proposed designs. These technical prototypes will then be extensively tested during test-beam campaigns, making use of the test-beam facilities at CERN and DESY.

Technical design report All the results from the steps described before will be assembled in TDRs for both SiD and ILD, specifying the baseline detector designs that will be put forward for construction at the ILC. The goal is the completion of the TDRs at the end of the preparation phase.

3.3 Documentation

A reliable and powerful system of documentation must be used coherently by all partners in a major construction project such as ILC. This is particularly important since many ILC activities are distributed around the world. The European XFEL accelerator consortium has employed a full-scale product lifecycle management (PLM) system (EDMS) to ensure that all relevant design documents, all fabrication, assembly and test instructions, as well as the complete quality assurance documentation are reliably stored and managed. It provides integrated storage and access of 3D CAD data, technical documentation, and configuration data. The use of EDMS, which could be a European contribution to the ILC, gives access to the fabrication, test and assembly instructions used by the European XFEL. This ensures continuity for further ILC production at companies which, having successfully completed European XFEL contracts, have gone on to make successful bids for other projects including LCLS-II at SLAC.

3.4 European ILC design office

As mentioned above, a European design office, most likely based at CERN and with satellites in other European laboratories, will be needed in the preparation phase, taking an important role in the final design and parameter optimisations for ILC. Among the most important tasks would be

- the dissemination of existing design experience from the European XFEL and from the CLIC design team;
- important contributions to the final design of the ILC in liaison with the host design team in Japan and possible other international design efforts;
- to involve European expertise in the final technical design of systems where Europe has special expertise or scientific interests, examples being the FFS, MDI, positron source, magnets, beam-instrumentation components, etc;
- provide support and reference information for European industry and the CERN industry liaison network in the process of defining European deliverables for ILC, helping to position European industry and laboratories for contributions to ILC during the construction phase;

- the participation in the definition of the commissioning and running strategy based on, in particular, the European XFEL experience and the ATF2 final focus test facility in Japan.

4 European in-kind contribution to the ILC construction.

As shown in Section 2, European institutes, laboratories and industries have technical capabilities to produce virtually any component of the ILC accelerator and detectors. As there are currently no formal negotiations or agreements concerning the level and nature of in-kind contributions from Europe to the ILC project, we do not suggest specific models in this study. The actual contribution from Europe will be determined by negotiations at a later stage, and no formal commitments can be made at this time.

Four general points can nevertheless be made:

- All models for the external contributions to the project are focussed on some parts of the non-CFS (civil engineering and conventional facilities) components of the ILC accelerator. The CFS work and components will naturally be constructed in — and installed and commissioned by — the host nation. Given European expertise, existing infrastructure, and proven industrial capability arising from the construction of the European XFEL and ESS, it is widely assumed that a dominating fraction of the European in-kind contribution will be in the form of cryomodules. The ILC TDR assumed that three, possibly four, production sites would be required worldwide. Europe not only has expertise in cryomodule production but also in many other of the subsystems required for the ILC, stemming from the above projects but also from CLIC, LHC and others. Hence a European contribution to ILC would naturally include other items in addition to cryomodules. In this context - related to European capabilities and expertise - it is important to notice that the European XFEL project at DESY corresponds to around 16% of the non-CFS ILC project.

- European industry will be very competitive —- relying on the expertise and experience for the European XFEL, ESS also LCLS-II at SLAC — to provide industrial production capacity for not only European in-kind deliverables, but also to other construction centres. As already mentioned, one of the key challenges in the preparation phase will be to qualify and position European industry for delivering key parts of the ILC installation.

- For the construction phase spending, the majority of the linear accelerator associated costs (SCRF cryomodule, HLRF and controls) are assumed to scale with the production rate of cryomodules, over an approximately seven-year period. This is timed to finish at the end of the TDR nine-year construction schedule, to minimise the number of components that need to be stored before installation in the accelerator tunnel. The same profiles can applied to the estimated explicit labour. As a result the major spending during the ILC construction phase can be expected in years four through seven, i.e. 2026-9, when the HL-LHC upgrade will have been completed.

- The financial contribution to the detector construction and operation is typically assumed to be proportional to the number of authors of the detector collaboration. The size of the European participation in the ILC detectors can currently not be exactly specified and needs of course to be determined by negotiations. To gauge the potential interest within Europe, the European involvement in ongoing experiments can be used. The European share in the energy-frontier LHC detectors ATLAS and CMS at CERN is about 48% while the European share in the Belle II experiment at KEK is about 38%. The fraction at the European laboratory is of course higher than for an ”overseas” experiment, but these numbers give a estimate of the size of the potentially interested community.

5 Possible involvement forms of Europe

In this short chapter we discuss possible organisation forms of a European participation in the ILC. Traditionally, European groups have participated in projects outside of CERN using bilateral agreements between the individual European countries and the host nation. One examples for these is the European participation in the B-factories at SLAC and KEK or in the Tevatron programme at Fermilab.

More recently, the European participation in the long-baseline neutrino programme at Fermilab (LBNF/DUNE), while still being negotiated in the traditional bilateral way, has been augmented by the Neutrino Platform hosted by CERN, which offers technical infrastructure and support for European groups working on detector and other contributions to long-baseline neutrino projects. CERN is also now formally a member of the DUNE collaboration.

On the accelerator side, the typical model is based on a leading host laboratory supported by bi-lateral agreements for in-kind deliverables from other funding agencies and laboratories. This was the model used during the LHC construction. The exact organisation of Europe's contribution to the ILC is not clear as of today and beyond the scope of this document. In any case, our current assumption is that CERN will play a central role in the European participation in the ILC.

5.1 Preparation phase

A possible organisational model during the preparation phase is the MoU-based project studies currently on-going at CERN. CLIC and FCC operate through international collaborations with more than 50 institutes each. A similar collaboration could be set up for an European ILC preparatory project running from 2019 to 2022 and providing a basis for preparing the European participation in the ILC. During this period, extensive discussions about the final project structure, governance issues, and final deliverables from Europe would be carried out. Hence, the three main tasks would be the following:

- setup of a European design office at CERN, with satellites in other European laboratories, taking an important role in the final design and in the optimisation of ILC parameters and technical specifications;
- organisation of European stakeholders with a view towards the final negotiations on the project structure, deliverables, and governance;
- preparation for the final deliverables expected from Europe, final technical specifications, pre-series production, facility preparation and tooling, preparation of tendering documents.

As mentioned in Section 3, the resources required for the activities in this preparation phase are similar in scope to those required by the existing project studies CLIC and FCC at CERN. The CERN resources of the CLIC and FCC projects are today substantially strengthened by the collaborative partners, in the form of local studies and facilities, personnel and national funding. This would also be the case for ILC, where the European collaboration contributions for ILC outside CERN have the potential of being very substantial, given the expertise and infrastructure available from the European XFEL construction and the overall European abilities and capacities.

On the detector side, models used earlier - as mentioned above - could be adequate, possibly reinforced by establishing a ”ILC platform” at CERN to support the detector and physics studies for ILC taking place within the CERN member and associate states.

5.2 Construction phase

The organisational structure of the entire project and hence the European role in it is not known at this stage.

From the European side, a significant document was approved by Council [12] during the enlargement process in 2009–2010 concerning the organisation of large international projects, referred to as “global projects”. The CERN Council document states that a participation in global projects, like a European participation in the ILC in Japan, can be organised through CERN, i.e. the coordination of European participation in global projects elsewhere is considered to be within the mandate of the organisation.

Also relevant is the relationship between CERN Council and the European Commission (EC) formalised in a Memorandum of Understanding (MoU) in 2009 [13]. The two most important points are that CERN oversees the execution of the European strategy for particle physics and cooperates with the EC in its implementation, and that CERN Council, based on the European strategy for particle physics, provides input to the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). The practical implementation of the collaborative work plan is described in a regularly updated workplan between CERN and the EC [14]. In order to facilitate the implementation of these points, the EC participates in Councils European strategy sessions. It will therefore be important that the European participation in the ILC is fully confirmed in the next European strategy update.

Given the physics interests in a future $\mathrm{e}^+\mathrm{e}^-$accelerator, the ILC project is likely to imply a substantial investment from the European perspective. This fact highlights the necessity for a high-level agreement about the level of European participation in ILC to be formalised between 2020 and 2023 if the currently assumed time-line of the ILC project is to be respected. Various financing models for European contribution can be envisaged, including bilateral agreements between Japan and European partners and models combining CERN resources with direct bilateral agreements. The organisation of the European efforts towards a coherent contribution to ILC from Europe, scientifically and technically with CERN in a central coordinating role, seems to be the most realistic and effective scenario.

6 References

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7 Glossary

ADI Accelerator Design and Integration

AMTF Accelerator Module Test Facility

ATF Accelerator Test Facility

BDS beam delivery system

BINP Budker Institute of Nuclear Physics, Siberian Branch of Academy of Science, Russia

CE civil engineering

CEA Commissariat àà l'énergie atomique et aux énergies alternatives

CERN Organisation européen pour la recherche nucléaire, Switzerland

CFS Conventional Facilites and Siting

CIEMAT Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain

CLIC Compact Linear Collider

CNRS Centre National de la Recherche Scientifique, France

DESY Deutsches Elektronen Synchrotron, Hamburg, Germany

EDMS Electronic Document Management System

E-JADE Europe-Japan Accelerator Development Exchange programme

ESFRI European Strategy Forum on Research Infrastructures

ESS European Spallation Source

FCC Future Circular Collider

FFS final focus system

GDE Global Design Effort

GSI Gesellschaft für Schwerionenforschung - Society for Heavy Ion Research, Germany

HMBA Hybrid Multi Bend Achromat

HL-LHC High-Luminosity Large Hadron Collider

HLRF High-Level Radio Frequency

IFIC Instituto de Fisica Corpuscular, Valencia, Spain

IFJ-PAN The Henryk Niewodniczański Institute for Nuclear Physics Polish Academy of Science, Krakow, Poland

IKC in-kind contributions

ILC International Linear Collider

ILCU ILC Currency Unit

IP Interaction Point

IPNO Institute de Physique Nucléaire Orsay, France

JAI John Adams Institute for Accelerator Science, UK

JINR Joint Institute for Nuclear Research, Dubna, Russia

KEK Japanese High Energy Accelerator Research Organization, Japan

LAL Laboratoire de L'Accélérateur Lineaire, France

LAPP Laboratoire d'Annecy de Physique des Particules, France

LCC Linear Collider Collaboration

LHC Large Hadron Collider

LLRF Low Level Radio Frequency

MDI Machine Detector Interface

MoU Memorandum of Understanding

NCBJ National Centre for Nuclear Research, Russia

PIP Project Implementation Planning

PLM Product Lifecycle Management

PSI Paul-Scherer-Institut, Schweiz

RHIC Relativistic Heavy Ion Collider

RHUL Royal Holloway, University of London, UK

RTML Ring to Main Linac

SCRF Superconducting radio-frequency

SLAC SLAC National Accelerator Laboratory

STFC Science and Technology Facilities Council, UK

TDR technical design report

UCL University College London, UK

WUT Wroclaw University of Technology, Poland