IRIDE _V4_17/07/2013

I R I D E

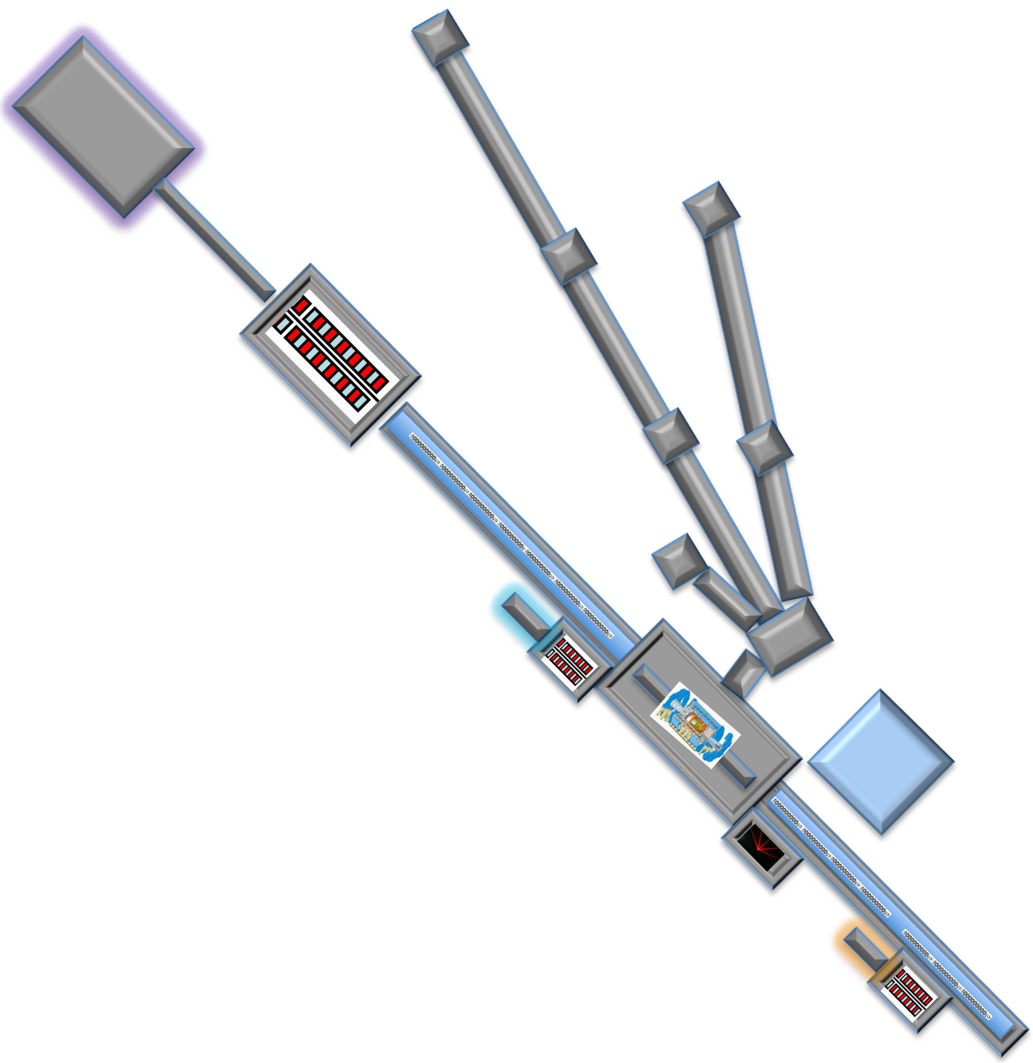
An **I**nterdisciplinary **R**esearch **I**nfrastructure based on **D**ual **E**lectron linacs&lasers

A WHITE BOOK

Astract

This report describes the scientific aims and potentials as well as the preliminary technical design of IRIDE, an innovative tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications. IRIDE will be a high intensity "particle factory", based on a combination of a high duty cycle radio-frequency superconducting electron linac and of high energy lasers. Conceived to provide unique research possibilities for particle physics, for condensed matter physics, chemistry and material science, for structural biology and industrial applications, IRIDE will open completely new research possibilities and advance our knowledge in many branches of science and technology. IRIDE will contribute to open new avenues of discoveries and to address most important riddles: What does matter consist of? What is the structure of proteins that have a fundamental role in life processes? What can we learn from protein structure to improve the treatment of diseases and to design more efficient drugs? But also how does an electronic chip behave under the effect of radiations? How can the heat flow in a large heat exchanger be optimized?

The scientific potential of IRIDE is far reaching and justifies the construction of such a large facility in Italy in synergy with the national research institutes and companies and in the framework of the European and international research. It will impact also on R&D work for ILC, FEL, and will be complementarity to other large scale accelerator projects. IRIDE is also intended to be realized in subsequent stages of development depending on the assigned priorities.



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INDEX

1. EXECUTIVE SUMMARY

1.1. The IRIDE concept: technological breakthroughs as a basis for new research in fundamental and applied science

The proposed IRIDE infrastructure (Interdisciplinary Research Infrastructure with Dual Electron linacs&lasers) will enable new, very promising synergies between fundamental-physics-oriented research and high-social-impact applications. Conceived as an innovative and evolutionary tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications, it will be a high intensity "particle beams factory", based on a combination of a high duty cycle radio-frequency superconducting electron linac (SC RF LINAC) and of high energy lasers. It will be able to produce a high flux of electrons, photons (from infrared to γ-rays), neutrons, protons and eventually positrons, that will be available for a wide national and international scientific community interested to take profit of the most worldwide advanced particle and radiation sources.

We can foresee a large number of possible activities, among them:

- Science with Free Electron Lasers (FEL) from infrared to X-rays,
- Nuclear photonics with Compton back-scattering γ-rays sources,
- Fundamental physics investigations with low energy linear colliders
- Advanced neutron sources by photo-production,
- Science with THz radiation sources,
- Physics with high power/intensity lasers,
- R&D on advanced accelerator concepts including plasma accelerators and polarized positron sources
- International Linear Collider (ILC) technology implementation
- Detector development for X-ray FEL and Linear Colliders
- R&D in accelerator physics and industrial spin – off

The main feature of a SC linac relevant for our facility is the possibility to operate the machine in continuous (CW) or quasi-continuous wave (qCW) mode with high average beam power (~1 MW) and high average current (~300 μA). The CW or qCW choice, combined with a proper bunch distribution scheme, offers the most versatile solution to provide bunches to a number of different experiments, as could be envisaged in a multi-purpose facility.

Europe is in a strategic position in the SC RF technology, mainly due to the strong contribution of European countries to the TESLA Collaboration. *In particular Italy is in a leading position, with knowledge and strong capabilities in the design, engineering and industrial realization of all the main component of a superconducting radiofrequency accelerator,* see Figure 1.1. INFN strongly participated since the early design stages through the final engineering and shares the know-how and has the recognized intellectual property of several main components (one of which is the cryo-module concept and its evolution).

Figure 1.1: A set of pre-series XFEL cavities at the company E.Zanon.

As specific example of IRIDE applications the FEL radiation in the soft X-ray spectrum open possibilities for novel imaging methodologies and time-resolved studies in material science, in biology and in medicine, along with non-linear optics applications. It will allow studying crystals of size of the order of 100 nm edge outside the capability of any micro focus beam line in SR facilities with diffraction measurements of streams of nano-crystals and even of single molecules.

Another example is the high-luminosity Compton back-scattering source would be able to drive both a low-energy $\gamma-\gamma$ collider for fundamental studies on QED, i.e. to observe and measure photon-photon scattering, and would be of great relevance to pursue strategic applications in the fields of nuclear waste diagnosis and treatment, as well as national security applications, not to mention materials science and advanced medical and radio-biological researches made possible by such a new photon source. In this way γ−rays with energies of 10-20 MeV can also be produced and directed head-on against electrons of ~700 MeV. A rich physics program can be studied, which includes – among others – the precise measurement of the π^0 width through the process $e^- \gamma \rightarrow \pi^0 e^-$ (Primakoff effect), and precision tests of QED in the MeV range. These measurements, which provide important tests of the Standard Model, are not possible at present electron-photon colliders due to the low photon intensities of the machines.

The scientific activities foreseen at IRIDE lead to specific and challenging requirements with respect to x-ray instrumentation and in particular to x-ray detectors for FEL and Compton radiation. These requirements ask for detectors that cover a wide energy range, from soft to hard x-ray energies, with specification in some cases exceeding the existing technology. *Successful exploitation of the unprecedented features of the x-ray radiation that will be available at IRIDE calls for a dedicated and substantial detector R&D program which also opens the opportunity to enhance the*

Italian scientific and technological leadership as well as the international links in this cutting-edge field.

The electron beam can also be used to produce neutrons by photo-production. The neutron spectrum produced in this way, peaked around 1 MeV, has important implications both in fundamental (nuclear X section and decay measurements) and applied physics (Neutron tomography and material studies with neutron scattering).

Last but not least, advanced accelerators concepts could be also tested, like Polarised Positron Source in the context of ILC design effort, and Plasma acceleration or Dielectric wake field acceleration to increase the final beam energy giving new opportunities for basic and applied scientific cases.

The realization of such a large facility at the Tor Vergata site in close proximity to the LNF laboratories will allow INFN to consolidate a strong scientific, technological and industrial role in a competing international context both to deploy a national multi-purpose facility along the scientific applications discussed in the following sections, and to prepare a strong role for the contribution to possible future large international HEP projects as the International Linear Collider.

The aim of this report is to illustrate the wide range of applications of a multi-purposes linac as the one foreseen for IRIDE, providing also a consistent set of machine parameters and a preliminary project cost evaluation.

1.2. IRIDE layout: staging and upgrade potentials

The backbone of the IRIDE facility is a superconducting high duty cycle electron linear accelerator, with the required 2 K cryogenic plant, based on the L-band standing wave RF (1.3 GHz) cavities, developed by the TESLA collaboration, which currently drive the FLASH FEL facility in DESY and which, with minimal improvements of the cryo-module cooling system, could be upgraded to CW or qCW operation.

The second core device of the facility is the high energy cryogenically cooled Yb:YAG Laser system operating in a chirped pulse amplification architecture followed by a frequency conversion stage to achieve 515 nm wavelength. This technology allowed achieving recently 1 J at 100 Hz in the picosecond regime with a bandwidth of 0.1%.

By using standing wave SC accelerating structures, that can accelerate beams in both longitudinal directions, one can see an attractive scheme based on two linacs operating at a maximum energy of 2 GeV each, when working in the collider mode, or used in cascade, as a single longer linac, to boost the electron energy up to 4 GeV for higher energy electron beam applications. *In addition when operating in the collider mode both linacs may partially recover the electron kinetic energy of the beam leaving the opposite linac after the interaction, thus increasing the overall efficiency of the system and simplifying the beam dump design.*

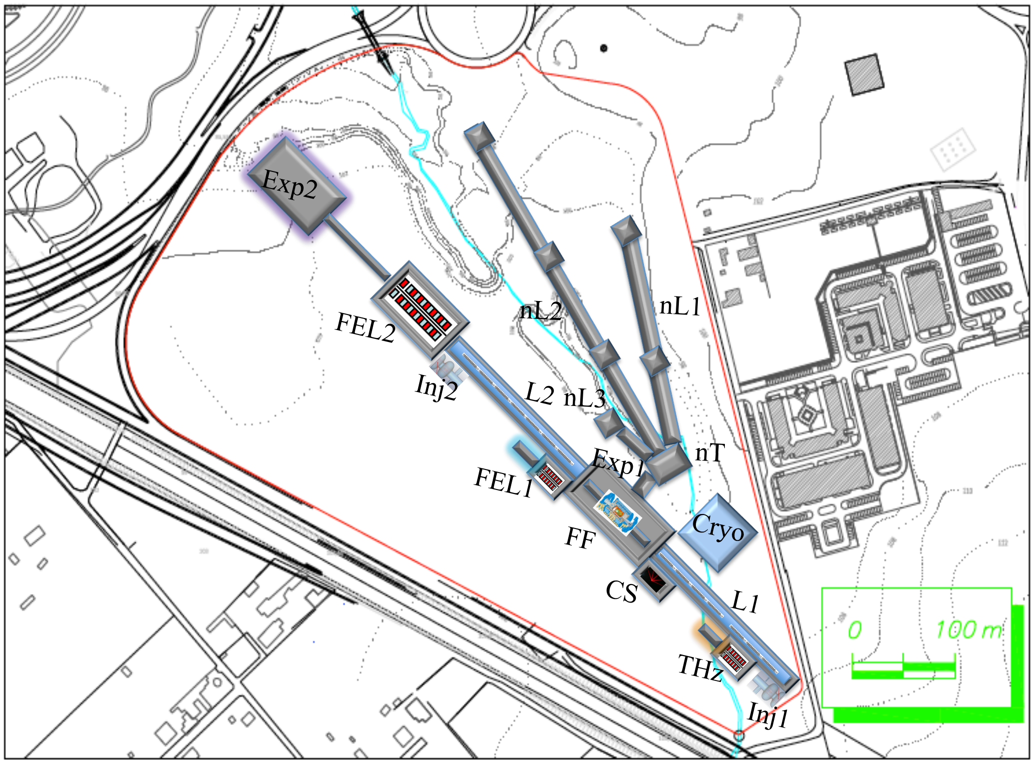


Figure 1.2: Schematic layout of the IRIDE accelerators and radiation sources complex. Some relevant components are indicated: the cryogenic plant hall (Cryo), the electron injectors (Inj1, Inj2), the SC linacs (L1, L2), the FEL devices (THz, FEL1, FEL2) and the user experimental hall (Exp1,Exp2), the laser system for Compton source (CS), the Final Focus beam line (FF) in the experimental hall Exp1 for colliders and nuclear photonics, the neutron source target (nT) with experimental beam lines (nL1, nL2, nL3).

As indicated in Figure 1.2 the first 2 GeV linac system (L1) can drive FEL, Neutron and THz radiation sources, electron-on-target physics experiments and, in combination with the high energy laser, a γ-ray Compton source is also possible with many applications in the field of nuclear-photonics and as a possible tool for developing a polarized positron source as the one required for ILC.

With also the second 2 GeV linac installed (L2) one can envisage a low energy linear collider scheme for electron-electron, electron-photon, photon-photon and eventually electron-positron scattering studies. The combination of the two linacs, boosting the electrons up to 4 GeV, could also drive a short wavelength FEL user facility (Exp2).

The **Neutron source (nT)** requires a medium energy electron beam as the one extracted from L1 driven to impinge on bulk of high Z cooled target (nT), where it loose energy mainly by bremsstrahlung, producing an electromagnetic shower cascade. The photons of the shower can excite the nuclei of the target with which they interact and these excited nuclei go back into the fundamental state by emitting one or more nucleons. At the state of the art of the project, we have mainly focused on the Tungsten as possible choice for the target of IRIDE: the estimated rate emissions of neutrons (up 10^{15} n/s) and other secondary particles, that are described in more details in chapter 6, have been obtained for a Tungsten cylindrical cooled target with 7 cm diameter and 6 cm height. A 3m thick Iron shielding is also foreseen. The beamlines of interest are of three types: short beamlines for Chip Irradiation and Imaging (**nL3**), long beamlines for applications requiring time of flight measurements, like Bragg Edge Transmission, Diffraction and Nuclear Resonance Capture Analysis (**nL1**), and even longer beamlines (~200 m) needed for neutron oscillation studies (**nL2**). Each beam line needs to be equipped with shielding, diagnostics and detectors that are described in detail in chapter 6.

The main components of the **Compton Source** (**CS**), see chapter 7, at the exit of L1 are:

a) a high brighntess *GeV*-class electron Linac (L1) capable to deliver multi-bunch trains, *i.e.* working at 100 *Hz* rep rate with at least 50 electron bunches distributed over the RF pulse duration (from 0.5 up to 1 microsec), carrying a fraction of a *nC* bunch charge at very low rms normalized emittances (< 1 $mm \cdot mrad$) and energy spreads (<0.1%)

b) a high energy, high quality, high repetition rate laser system, delivering pulses carrying at least 1 *J* of energy (in the fundamental), psec pulse duration, 100 *Hz* repetition rate, high quality (M^2<1.2), such to be focused down to typical spot sizes of 10 μm at collision with the electron bunch

c) a laser recirculator consisting of a two parabolic confocal mirror set, capable to recirculate the laser pulse a number of times equal to the electron bunches within the train (<50), by focusing it down to the collision point, recollimating and reflecting it back to the other mirror which in turns refocuses it down back to the interaction.

The expected performances for the γ-ray beam delivered are: tunability between 1 and 20 *MeV*, bandwidth smaller than 0.3%, full control of polarization (linear, larger than 99.8%), spectral density larger than 10^4 $photons/s \cdot eV$, and peak brilliance larger than 10^{22} ($photons/s \cdot mm^2 mrad^2 \cdot 0.1\%$).

Several **FEL source** configurations are possible at IRIDE ranging from IR to X ray wavelength radiation, as discussed in chapter 3.

A Seeded configuration is possible at the exit of L1, by using an externally injected laser signal. In this case the maximum operating energy is fixed by the source exploited as seeding. If we consider the 27-th harmonics of the Ti-Sa (26.9 nm), the beam energy is constrained below 1GeV and the FEL tunability could range from 27 nm to 1.65 nm (**FEL1**). User beam lines can be accommodated in the first experimental hall (**Exp1**).

At the highest energy end of the linac (**FEL2**) a combination of Oscillator, SASE and Seeded operational mode offer an attractive and unique possibility. As shown in Figure 1.3 an oscillator operating in the VUV region is used to produce bunching in the e-beam, which is successively injected into the downstream sections of the undulator chain tuned at higher harmonics of the oscillator.

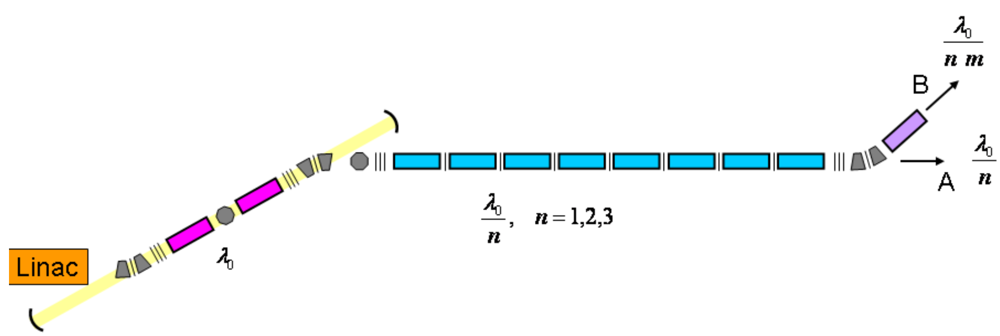


Figure 1.3: Undulator Chain at the S-C LINAC output, the first component is provided by an oscillator

The rather narrow bandwidth of operation of the cavity provides a constraint for the energy of the e-beam at an energy around $2.28\,GeV$. In this configuration a significant amount of third and fifth harmonics allows its use in the successive section to get pre-bunched SASE operation at $4.5\,nm, 2.7\,nm$. Removing the cavity mirrors and operating at full linacs energy (up to 4 GeV) we get an output wavelength of 0.6 nm, which can be extended to 0.2 nm, if the choice of a segmented undulator is foreseen and the last sections are replaced by a super-conducting undulator with $\lambda_u = 1.cm, K = 1$. User beam lines can be accommodated in the second experimental hall (**Exp2**).

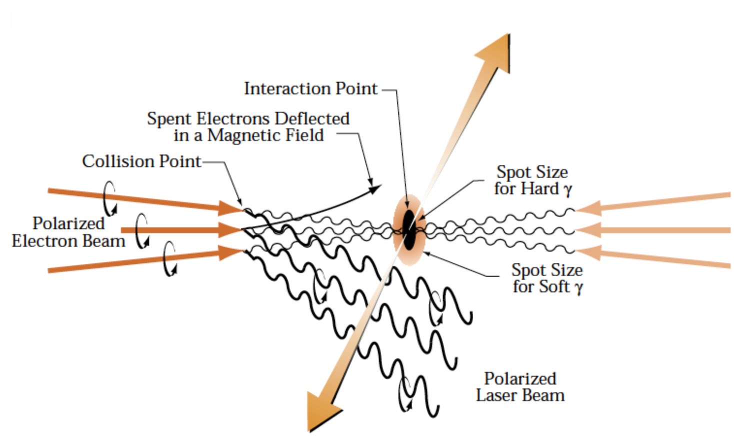


Figure 1.4: Scheme of principle of a photon collider. High-energy electrons scatter on laser photons and produce high-energy photon beam which collides with a similar photon or electron beam at the interaction point IP.

Experimental hall 1 (**Exp1**) will host also the most challenging components of the entire project. The **electron-electron collider option** will be essentially based on the final focus (**FF**) system already operating at ATF2, based on the recently proposed compact final focus optics with local chromaticity correction and where 100 nm electron beam spot sizes have been already achieved. The feasibility of the **electron positron collider** is strongly dependent on our capability to produce low emittance positrons. In the IRIDE R&D program is comprised the development of a positron source based on direct conversion of a gamma ray beam in a solid target as discussed in chapter 9. The **gamma-electron and gamma-gamma options** will require a careful design and development of the interaction region. In a photon collider in fact two high energy electron beams after the final focus system travel towards the interaction point (IP) and at adistance of about 1- 5 mm from the IP collide with a focused laser beam. After scattering, the photons follow their direction to the interaction point (IP) where they collide with a similar opposite beam of high energy photons or electrons. Such a new collider configuration has never been realized so far and is the subject of many design studies around the world. A dedicate design for the IRIDE facility is under way.

Advanced accelerators techniques could be also investigated in the large experimental hall (**Exp1**). The success of the advanced accelerator activity as a vigorous and intense R&D program focused on the enabling technologies of plasma accelerators, Compton converters, gamma beam focusing, polarized positron source, superconducting RF gun and the associated advanced diagnostics instrumentation, could allow envisage a convenient energy upgrade of the facility to tens GeV level in a higher energy range of scientific applications.

The IRIDE facility can be hosted in the 30 hectares area on the University of Rome Tor Vergata campus site a few km southeast of the city of Rome. It will be disposed along a linear geometry, approximately 700 m long. The interested area is just alongside of the CNR territory and it is approximately a couple of km away from the ENEA and INFN sites in Frascati.

Highlights extracted from the IRIDE scientific cases are reported in the next paragraphs, more details are available in the following chapters of this report.

1.3. Science with photons: new insights into the facets of nature and life

Photons are the most important probe to investigate our environment. From radio frequencies to hard X-ray photons are used since many years to get both electronic and structural information on virtually any materials, from biology to condensed matter systems to nuclear physics. Among the different types of sources, storage rings to emit Synchrotron Radiation (SR) have a special place because of the capability to produce radiation with very high flux and brightness in an energy range from infrared to hard X-ray. The development of storage rings with special magnetic components over the past thirty years has led to third generation machines, especially designed for SR research, with the peculiarity to have radiation with unprecedented degree of brilliance.

Last progresses in the physics of the linear accelerators (LINAC) opened the possibility to a new jump in photon sources quality especially in the X-ray energy domain. The LINAC based sources are called Free Electron Laser (FEL). These machines are sources of coherent radiation presenting similar optical properties as conventional lasers. The main difference is in the lasing medium, being in this case an electron beam moving through a magnetic structure made by a very long undulator. *The X-ray FEL has the possibility to generate X-ray beams with a peak brilliance of several order of magnitude* *higher that the third generation SR sources for both the spontaneous and coherent emission. It also offers an extremely short pulse length, typically less than 10^{-13} s (femtosecond (fs) time domain), with some degree of tunability and a high degree of either linear or circular polarization.*

The advent of such short and powerful pulses of fs laser sources has disclosed the opportunity to make real time experiments in the fs time domain using many different techniques, to study the interaction of radiation with matter in a non-linear regime and to use nano-crystals in protein-crystallography. Actually there are four operating FEL facilities (Flash, Fermi, LCLS, SACLA) and three in construction (XFEL, LCLSII, SwissFel), covering the spectral range from soft to hard X-ray. The first experiments performed in the existing facilities begin to enlighten the strong potentialities in many different fields, see Figure 1.5, and at the same time several critical points that should be resolved to fully exploit the possibilities of these new machines.

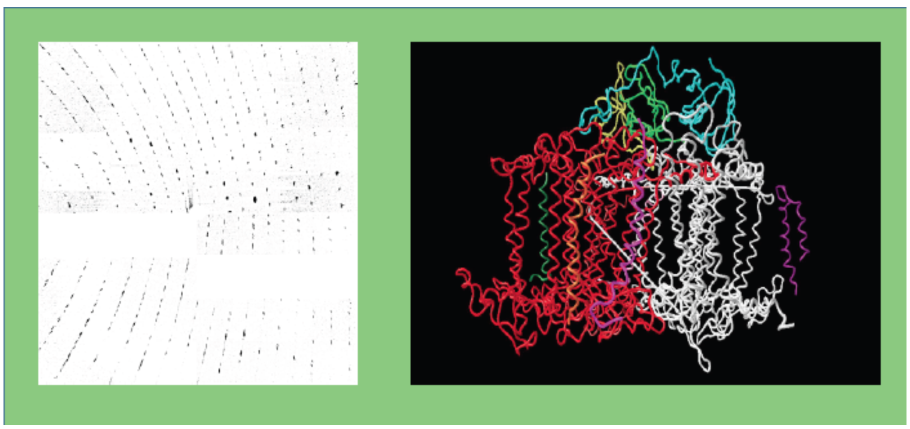


Figure 1.5 Left: diffraction pattern of the Photosystem I complex measured at LCLS with a photon beam of 1.8 KeV and a time length of 80 fs. Right: Electronic density reconstruction at 7Å of structural resolution.

One of the FEL options at the IRIDE facility is a source of coherent X-rays, covering the range of wavelengths (λ) ranging from 0.5 to 4 nm at fundamental harmonics, depending on the electron beam energy, and it will be also able to reach the Ångström region using the third and fifth harmonics. *In some way it covers a radiation region complementary to those of other existing or in construction facilities, and will be provided also with an ancillary equipment to produce radiation down to the infrared and THz region.* The IRIDE FEL has a reasonable wavelengths overlap to satisfy users in many different fields of science and to ensure at the same time a beneficial level of competiveness.

At the same time the IRIDE FEL will provide radiation with the unprecedented characteristics like:

- *Self-seeding: narrow bandwidth, wavelength stability, higher brightness and energy tunability.*
- *Polarization control: tunable linear and circular polarization*
- *Two color pulses: simultaneous delivery of independent wavelength pulses*
- *Delayed pulses: independent delay of two pulses up to a few ps*

An X-ray source with these specifications will allow the investigation of photon-matter interaction in a new regime, and will become a high competitive facility in the worldwide growing FEL framework.

The considered scientific case for IRIDE FEL reports experimental proposals ranging from time dependent spectroscopies in condensed matter to imaging for biological applications.

Among the highlights of the IRIDE Scientific Case, see chapter 4 for more details, of paramount importance is the *Spectroscopy of flying proteins*. Proteins, long linear chains composed by L-α-amino acids joined together by peptide bonds, rule fundamental functions in life processes. To achieve their functional properties the interplay between electronic properties and structural properties is crucial. Proteins take their shape spontaneously after the synthesis in the cell, but the structure depends also on the environment properties (solvent, salt concentration, pH, temperatures and molecular chaperones). The chirality influences the assembly, folding and activity of biological molecules: amino acids that form proteins are all in the L configuration, with the exception of (non-chiral) Glycine. So far the task to determine the structure of proteins~~,~~ and subsequently their electronic properties, was carried out by X-ray diffraction and nuclear magnetic resonance in crystals and in solution. *The characterization of structural and electronic properties of proteins in the gas phase, as is possible at IRIDE, would provide valuable information to understand the folding.* The absence of solvent interaction can reveal the balance of the molecular weak forces that determine the shape of the protein.

To bring un-fragmented proteins into the gaseous phase, the state of the art technique is represented by Electro Spray Ionization (ESI). The ESI technique solved the problem of how to study large molecules in solution by mass spectrometry that needs a high vacuum environment. Pioneering works combining ESI with laser spectroscopies revealed the possible application in the characterization of electronic and structural processes. *These preliminary results envisage the application of ion-spectroscopy to proteomics, but this research field is still completely unexplored.* The low density of the target (space charge limits the maximum ion density 10^6 ions/cm^3) prevents to extend such experiments in the VUV-soft X-ray wavelength range with the present sources. *IRIDE with its high flux and focusing represents an ideal source for these studies. Moreover the IRIDE wavelength range can cover the excitations to the core states, focusing on bond character and local environment, and providing a rich and detailed description.* These results would be complementary with respect to those obtained in crystals or solution, and give insight into the influence of the solvent on the protein shape.

In addition the possibility of reaching wavelength of the order of 1 Å will allow to measure protein crystals of very small dimension, typically of the order of 100 nm edge, which are those produced most of the time in the crystallization trials. The measurement of such samples is outside the capability of any micro focus beam line in the standard Synchrotron Radiation facilities. The fluence of IRIDE in the hard X-ray energy range is still enough to enable structure determination from diffraction measurements of streams of nano-crystals, as recently done at LCLS-FEL facility where diffraction patterns from a large photosystem membrane complex that crystallizes in samples of about 250 nm size have been recorded.

The very broad energy range available at IRIDE will allows a complete structural characterization of protein samples in many different physical-chemical conditions. This is crucial to understand the structure/function relationships from a molecular to a cellular level opening new perspective for the treatment of genetic disabilities and diseases and for the design of more effective drugs.

Powerful THz radiation sources have been also considered in the IRIDE design. The accepted paradigm of condensed matter physics in fact is that the high-energy short-time dynamics affects the low-energy long-living degrees of freedom. Actually, pushing a system out-of-equilibrium, this hierarchy could be reversed. This determines a non-linear coupling among several degrees of freedom providing the possibility to coherently manipulate different states of matter. In this scenario, one can cite for instance the possibility to coherent induce a conformation transition in macromolecules, selectively pumping a low-energy collective mode; or even inducing a coherent structural phase transition through a phonon pumping. THz radiation could be coupled to x-ray light for THz-pump x-ray diffraction probe experiments.

1.4. Science with γ-rays: a deep view of exotic nuclear structures

The technology of producing γ-ray beams by Thomson/Compton back-scattering of high brightness electron beams with high energy lasers is rapidly progressing: in the last decade significant advancements in designing and commissioning Thomson sources is leading this technology to opening the Nuclear Photonics era, see chapter 8.

Thanks to several initiatives world-wide (mainly LLNL in the US, Japan-JAEA and the European ELI-NP) the state of the art in producing high brilliance/spectral density mono-chromatic γ-ray beams will be soon enhanced, stepping up from the present performances (γ-ray beams with bandwidth nearly 3% and spectral density of about 100 *photons/s·eV*) up to what is considered the threshold for Nuclear Photonics, *i.e.* a bandwidth of the γ-ray beam lower than 0.3% and a spectral density larger than 10^4 *photons/s·eV*. γ-ray beams of these characteristics will enable Nuclear Physics studies and Nuclear Applications based on exciting nuclear states not accessible with present machines.

Radiation at short wavelength as γ rays is used to excite the nuclear resonant fluorescence (NRF), so that different nuclei can be identified by the distinct pattern of NRF emission peaks.

In nuclear physics there is large interest at present for the neutron-rich systems. On the one hand, existing and planned radioactive beams facilities aim to locate the position of the neutron and proton drip-lines (i.e., the limits defining whether a nuclear system is bound), and to study the properties of the isotopes in which the neutron/proton ratio differs from the values that characterize stable nuclei. On the other hand, another example of nuclear matter under extreme conditions is the matter that compose the compact astrophysical objects like the neutron stars. From a general point of view, an understanding of these “exotic” nuclear systems cannot be reached without a better assessment of the isoscalar (T = 0) and isovector (T = 1) components of the nuclear Hamiltonian. Even in stable nuclei the isovector properties are poorly known: the neutron radii, the systematics of isovector collective states, the pairing interaction in the T = 0 and T = 1 channel - to name only a few - are still object of strong debate. The possibility of new experiments that clarify these issues is consequently of great importance for the development of nuclear science.

In particular, Nuclear Physics will benefit from the availability of these new generation γ-ray beams for:

A) studies of the nucleus structure at the Pigmy and Giant Dipole Resonance excitation (to probe the structure and isospin properties of nuclear systems) with unprecedented resolution in reconstructing the nuclear states: this is crucial also to understand some unknown processes in the stellar nucleo-sinthesys

B) studies of two level barionc states in the high energy resonance of the nuclei, above 20 *MeV* and up to 60 *MeV*, crucial to reconstruct the equation of state of the nuclear matter

While new Nuclear Applications will be pursued thanks to these γ-ray beams in several fields:

A) detection and imaging of fissile and strategic material with isotopic reconstruction of the components (*e.g.* detection of fissile materials hidden in metallic containers), with large impact on the national security scenario

B) remote sensing and diagnosis of nuclear wastes in containers, with reconstruction of the isotope and nuclear composition of the waste material, with large impact on the atomic energy scenario

C) Medical imaging and therapy

It is interesting to explore also the possibility of generating positrons by direct conversion of a gamma ray beam in a solid target. There are two main advantages in this scheme:

- If the gamma photons are circularly polarized it is possible to produce a positron beam with a high degree of polarization.

- By taking advantage of a thinner target, a reduction in the opening angle of the positron beam is possible. This in conjunction with a smaller source size could bring an order of magnitude improvement to the emittance of the positron beam.

Positron production by photon conversion has *already* been shown superior to the traditional electron bombarding because the high average intensities of the beams required to maximize the collider luminosity would be otherwise seriously limited by the target damage consideration. For the same number of positron generated, a gamma ray based positron source reduces the thermal load problems because one is able to use a shorter target with lower Z material with a higher heat capacity. These advantages quantify in a two orders of magnitude increase of the thermal damage threshold in the positron production.

1.5. Science with neutrons: from fundamental physics to industrial applications

Neutrons represent a unique probe for studying matter on the molecular scale, thus opening a wide range of applications: from material science to life science, from engineering and industrial applications to fundamental physics experiments, see also chapter 6. *They cannot compete with electromagnetic radiation in intensity, but they are complementary with it because they penetrate substances that block the electromagnetic radiation (like metals) and are stopped by long radiation length materials, in particular hydrogenated and deuterated ones*. Highest intensity neutron sources in the world are based essentially on three different production mechanisms: some fission processes (such as that of ^{235}U) in nuclear reactors, proton-driven spallation sources, and electron-driven (photo-production) sources. With a large community using neutrons and due to the high specialization of instruments for the different classes of neutron experiments, photo-production sources demonstrated to be very useful, as the GELINA facility based on a 70-140 MeV electron beam in Geel, Belgium. Another interesting example is the n-Elbe source, driven by a 40 MeV electron beam, at FZ Dresden-Rossendorf. Indeed, photo-production facilities can be more cost-effective than spallation sources for neutron fluxes up to 10^{15}-10^{16} n/s at the target, even though the neutron yield per primary electron is (depending on the primary beam energy) at least 10-20 times lower with respect to proton-induced spallation. *The opportunity of using an intense, high-energy, electron beam – produced in the case of the IRIDE project by superconducting high average current linacs – opens the possibility of having a new photo-production neutron source that can have a significant place in the European panorama in the coming decade and can be a very useful facility*. A source able to produce up to **10^{15} n/s** at the target, i.e. like a medium size reactor, would indeed not only enlarge the access capacity for the large community of European scientists, but also could provide a complementary and original approach with respect to the existing neutron facilities, thus enriching the experimental and application opportunities, and profiting of the large wealth of expertise in the field.

Regarding fundamental physics investigation that are possible with IRIDE neutron facility, **neutron-antineutron oscillations** are very important since they would allow precision testing of the fundamental CPT-symmetry, where C is the charge conjugation, P

is the inversion of space and T is the time-reversal, very closely connected to the quantum field theory through the CPT-theorem. After A. D. Sakharov has clearly put in connection the violation of CP symmetry and the baryon asymmetry of universe and V. A. Kuzmin noticed that baryon number violation could lead to n→nbar oscillations, more recently it was concluded that these oscillations would represent one of the most accurate test of the CPT symmetry. Of course, the observation of such an oscillation also would make the neutron a Majorana fermion (with a tiny Majorana component). *If discovered, n →nbar oscillation will establish a new force of nature and a new phenomenon leading to the physics beyond the SM at the energy scale above TeV. In addition, will help to provide understanding of matter-antimatter asymmetry and origin of neutrino mass.*
An experiment aimed to improve the present limit on the n→nbar oscillation lifetime (i.e. $\tau > 10^8$ s) obtained at Institut Laue-Langevin, would require, in addition to the possibility of producing cold neutrons with a cryogenic moderator, a dedicated long beam-line with high-vacuum and terrestrial magnetic field shielding, and a detector placed around a thin target in order to reconstruct the anti-neutron annihilation products.
In addition impinging the electron beam on a target produces also charged pions that decaying produce muons. High intensity μ^+ beams are used for the search of the lepton violating deacy μ-->e γ. Preliminary simulations show that with a not yet optimized carbon target a rate of 50 times the beam on which the Muon Electron Gamma (MEG) experiment at PSI is currently operated can be achieved. *This solution opens for a huge potential in the search for lepton-flavor-violation.*

As far as applied physics is concerned, the interest from the scientific community (in particular the Societa' Italiana di Spettroscopia Nucleare) and the industrial community. The former stresses the absence of devoted neutron beamlines in Italy and the long time needed to satisfy beam time requests. As far as industries are concerned, several companies have expressed interest in utilizing neutron beams in research and control activities.

Possible applications of the IRIDE neutron source in the field of applied physics are:

Neutron Resonance Capture Analysis (NRCA): Each resonance is the fingerprint of a nuclear specie (isotopical recognition) thus allowing for the elemental material analysis (qualitative and quantitative) especially on metallic samples (e.g. cultural heritages).
Bragg Edge Transmission (BET): By means of this technique, stresses and strain in bulky samples can be analysed. This analysis is very important for both industrial as well as cultural heritages applications.
Chip irradiation : In order to test the robustness of electronic devices to neutron field in a few minutes, neutron beams produced at facilities are desirable as the may provide an almost atmospheric-like neutron spectrum but several order of magnitude more intense.
Radiography and Tomography (NR, NT): By means of radiography it is possible to obtain an image of a object that evidences the internal structure, by rotating the sample with respect to the incident beam and collecting images for each angular position a 3D image of the object is obtained (tomography).
Neutron metrology: In this context, the Italian National Institute of Ionization radiation Metrology (INMRI) is interested in having in Italy (and especially in Roma area) a high

energy neutron source in order to develop primary standards for neutron emission rate and energy spectrum calibration

The characteristics of the neutrons that make them of interest for applied research can of course be used in industrial research. Examples of industrial field with known applications with neutrons are:

- Efficient and cost-effective fabrication of a variety of **advanced materials**. Neutron scattering techniques can be used for the development of novel transformation-induced plasticity steels or precipitation-hardening Al and Ni alloys, to be used, for example, in aeronautics.
- **Pharmaceutical products**. The development of new drugs and drug delivery systems, which is strictly related to the detailed understanding of the mechanisms of disease, as well as the improvement of the product shelf-life can be carried out by the employment of neutron techniques.
- **Thermoelectric materials**. Here, neutrons allows to identify efficient and non-pollutant systems for the development of innovative thermoelectric devices combining low thermal conductivity with high electrical conductivity, to be employed for waste-heat recovery and in the refrigeration industry.
- **Renewable energy** sources. In such a field, more and more effective engines, materials for lower heat loss and less energy spill and greener processes for industry are requested. Novel materials for solar and fuel cells, as well as hydrogen storage materials can be developed thanks to neutrons.
- **Agro-food** systems. Plant strategies and metabolism in resistance to drought can be characterized by neutron methods.

Finally, a neutron facility of the kind we are proposing, can have a positive impact under other two important points: training and education of young scientists, and development of new detection techniques. An interesting example in this respect is the field of neutron detectors, that has gained importance in the last years due to the growing problem of ^{3}He-replacement, and can clearly benefit of an easier access and usability, lower intensity facility.

1.6. Particle physics opportunities: assembling the Standard Model puzzles

It is commonly accepted that the Standard Model (SM) of elementary particles interactions is the model, which describes the visible part of the nature and of the Universe. Recently the experimental results from the Large Hadron Collider at CERN have provided us with very important information on the mass of the SM higgs-like particle. However, the existence of this particle with a given mass does not solve, by itself, all the long-standing puzzles of the SM, such as a problem of the SM hierarchy, the naturalness of the higgs boson and the electroweak (EW) symmetry breaking. Even though all the SM parameters are now measured to a high accuracy, the necessity of the New Physics (NP) existence for explaining the SM puzzles is still an open question. From a theoretical point of view, precise and complicated calculations are required to answer these questions, and high-precision input information on the SM parameters is a must. Due to the intrinsic complexity of the calculations, as one needs to study the running of the non-abelian gauge theory parameters over a dozen of orders of magnitude up to the Planck scale, even small experimental uncertainties in the SM parameters have a drastic impact on the conclusions, which can be drawn from such computations. The implications affect our understanding of the fundamental issues of the "conspiracy" between the SM couplings, the EW phase transition, Universe inflation, the cosmological constant, and also the nature of the Dark Matter (DM).

It is important to stress that the precise values of the SM parameters, due to the renormalization group evolution, can be obtained only by simultaneous studies at high-energy and low-energy scales. The former point highly motivates the International Linear Collider (ILC) initiative, while the IRIDE project can pursue the latter one and serve as an accelerator-technology test installation and a research facility, see also chapter 9. The latter point motivates the possible use of the IRIDE facility as a precision tool for the SM exploration at low- and medium-energy scales, with a high priority on the information about the EW couplings of SM, which drives the evolution of the electromagnetic running coupling and the squared sine of the weak angle. Also a rich hadron phenomenology is accessible at these scales, which allows to study issues of the QCD confinement, where the ordinary perturbation theory approaches fail to work. While the technological aspects are discussed in another Chapter of this White Book, the present Chapter deals with an overview of the fundamental particle physics opportunities of the IRIDE project.

It is anticipated that the construction of the IRIDE facility will be realized step-by-step. We review the particle physics goals of the full accelerator complex according to the order in which one can launch the various steps of the facility. We start with the physics program that can be pursued with an electron beam on target, further we investigate that of the electron-photon collider, of photon-photon collisions and finally of the electron-positron and electron-electron collider. It is important to stress that a synergy of all the proposed measurements can lead to a very reliable and cross-checked experimental exploration of the SM. *In addition with the expected luminosity of IRIDE, in the electron-positron mode the operational time required for the physics program would be limited and well in accordance with the beam requests for the other functioning modes (e.g, FEL) of the machine.*

The **electron-on-target** physics program makes IRIDE a discovery and also a precision physics machine. Among the searched candidates there are the hypothetical particles, like the very-weakly interacting massive U(1) gauge boson (U-boson) as a DM particle candidate and the non-hypothetical, well investigated theoretically, but yet undiscovered, "true muonium" states (TM), which are the bound states of muon and anti-muon with the lifetime of an order of a picosecond. Utilizing the polarized electron beam dumped onto the proton target, one can measure the left-right parity violating asymmetry of electron-proton scattering at the per cent level, and thereby extract precisely the electroweak mixing angle.

The **electron-photon collider** allows to utilize the elementary Primakoff process to produce the light pseudoscalar (and scalar) mesons in order to precisely measure their two-photon decay widths and thus to tackle the triangle anomaly of QCD. In addition, one can perform the U-boson search in the lepton triplet production channel. A special feature here is the availability of the highly-polarized photon beam. This allows to use the lepton triplet production at IRIDE as a research laboratory for development of the methods of polarimetry to be used in astrophysics to measure the polarization directions of incoming high energy γ-rays. Finally, triple Compton effect can be used to study the properties of entangled states. *These measurements, which provide important tests of the SM, are not possible at present electron-photon colliders due to the low photon intensities of the machines.*

Low-energy **photon-photon collisions** give a direct view into the vacuum properties of Quantum Electrodynamics (QED), allowing for precision tests of QED in the MeV range, and more generally of Quantum Field Theory (QFT). *The IRIDE accelerator complex can generate for the first time colliding photon-photon beams by Compton backscattering, and this opens the fascinating field of low-energy photon-photon physics.* The technology needed to carry out a photon-photon physics program at energies close to 1 MeV would disclose new developments at higher energies, where a photon-photon Higgs factory could be a nearly ideal discovery machine.

The high-luminosity **electron-positron** and **electron-electron collider** with variable energy would be an extremely useful tool for the study of hadronic vacuum polarisation effects, measurements of the effective electroweak mixing angle and contributing to the description of the muon anomalous magnetic moment and the running QED coupling constant by providing the hadronic cross sections with high accuracy. In addition, these measurements can contribute to the extraction of the light quark masses, flavour symmetry breaking pattern in the light meson sector and allow to study precisely the meson mixing phenomenology through the various meson decays produced with high statistics in lepton collisions. The gamma-gamma fusion sub-processes in the positron/electron-electron inelastic scattering gives us the opportunity to investigate the two-photon couplings and form-factors of the various hadronic resonances (and also the many-particles states, like $\pi^+\pi^-$ or $\pi^0\pi^0$), which is important for the understanding of the quark contents of these resonances, of hadron phenomenology and for improvement in the estimate of the hadronic light-by-light scattering contribution to the anomalous magnetic moment of the muon. *The LHC, or a future e^+e^- International Linear Collider (ILC), will answer already many questions. However, their discovery potential may be substantially improved if combined with more precise low energy tests of the SM. In this framework an electron-positron collider such as IRIDE with luminosity of 10^{32} $cm^{-2}s^{-1}$ with centre of mass energy ranging from the mass of the ϕ-resonance (1 GeV) up to ~ 3.0 GeV, would complement high-energy experiments at the LHC and a future linear collider (ILC).* The direct competing project is VEPP-2000 at Novosibirsk which will cover the center-of-mass energy range between 1 and 2 GeV with two experiments. This collider has started first operations in 2009 and is expected to provide a luminosity ranging between 10^{31} cm^{-2} s^{-1} at 1 GeV and 10^{32} cm^{-2} s^{-1} at 2 GeV. Other "indirect" competitors are the higher energy e^+e^- colliders (τ-charm and B-factories) that can cover the low energy region of interest by means of radiative return (ISR). However, due to the photon emission the "equivalent" luminosity produced by these machines in the region between 1 and 3 GeV is much less than the one expected in the collider discussed here.

1.7. IRIDE Parameter list

Table 1.1 summarizes the main beam parameter requirements arising from the analysis of the IRIDE physics cases (described in the subsequent chapters of this WhiteBook) and that have been used to assess and propose the RF configuration options for the IRIDE multipurpose linac.

Table 1.1: Beam parameter requirements for the IRIDE physics cases.

	Neutron source	Neutron source with TOF	Nuclear photonics	Thomson source, γ-γ , e^--γ	FEL (SASE, seeded)	FEL (oscillator)	THz radiation	e^+ - e^- , e^- - e^-
E [GeV]	> 0.8	> 0.8	0.1 ÷ 1	0.1 ÷ 1	0.75 ÷ 4	0.03/2.3	0.1/1.5	0.5 ÷ 2
q_b bunch charge [pC]	1000	1000	10	500	150÷600	50÷200	< 500	<350
I_{peak} bunch peak current [kA]	any	any	any	Any	0.75 ÷ 4	1	2	< 500
σ_t bunch length [fs]	any	any	any	Any	150-200	20÷80	≈100	<1000
$\sigma_{x,y}$ bunch transv. size [μm]	any	any	10	10	50	50	100	<1.5
σ_E/E bunch energy spread [10^{-3}]	any	any	0.1	0.1	0.1	0.1	0.1	0.1
ε_n bunch norm. emittance [μm]	any	any	1	1	1	1	< 5	<5
f_b bunch rep. rate [MHz]	1	1000	100	65	< 1	5.0	< 1	1
T_p pulse duration [μs]	CW	0.5	CW	0.9	Any	> 100	any	CW
f_{pulse} pulse rep. rate [Hz]	CW	50	CW	100	Any	any	any	CW
I_p current in the pulse [mA]	1	1000	1	32.5	< 1	0.25÷1	< 5	CW
I_{ave} average current [μA]	1000	25	1000	3	< 250	< 300	< 300	350
$(\Delta E/E)_{train}$ energy spread along the train [10^{-3}]						0.5		0.1
$<P_b>$ ave. beam power [kW]								500
L luminosity [1/cm^2 s]								10^{32}

The above requirements can be largely satisfied by a linac configuration either based on **high duty cycle pulsed operation** or on a **pure CW operation**, providing various beam parameters in the energy span of 1-2 GeV (per linac) with the same machine layout (i.e. number of cavities, modules and gradient settings), but different RF power systems. In table 1.2 a few cases (mainly at different energies and currents) are shown for the two RF architecture choices (pulsed or CW). For each option any of the beam parameter listed within its cases can be delivered by the same machine, operating at different accelerating field values with different current settings. Besides the fact that the two RF options require different RF power systems and a different power coupler, the linac design for each energy range in terms of choice of number of modules and cavities, and cavity accelerating field, are the same. A minimal increase in the linac length for the CW case is due to the necessity of increasing the number of cryogenic connections in order to accommodate the larger cryogenic loads caused by CW operation.

The two options can cover the same energy range with (approximately) the same machine length of about 150 m, with a different RF system (either tubes of SSA) and a different size of cryoplant. The high energy operation at 2 GeV for the CW version can be safely guaranteed by limiting the duty cycle of the RF sources at 60% over long times (~ scale of seconds) in order to decrease the cryogenic losses. This marginal limitation, purely given by a conservative assumption on the cryoplant capacity, is based on the use of a single LHC like cryoplant (18 kW @ 4.5 K) feeding both IRIDE identical linacs. It takes into account all the static losses, as experienced at FLASH, the 2 linac fluid distribution, and a 50% overhead for off-nominal operation, uncertainties on heat load estimations and transients.

Table 1.2: Possible SC linac parameters for the two RF options (pulsed/CW).

	Pulsed Option			**CW/qCW Options**		
	Pulse 1	**Pulse 2**	**Pulse 3**	**CW 1**	**CW 2**	**qCW**
E [GeV]	1	1.5	2	1	1.5	2
I (within pulse) [mA]	5	3.5	2.5	0.5	0.35	0.260
I (average) [mA]	0.58	0.33	0.17			0.155
RF pulse duration [ms]	1.5			CW	CW	1000
Beam pulse duration [ms]	1.17	0.95	0.67			990.74
RF Duty cycle [%]	15			100	100	60
Beam Duty cycle [%]	11.7	9.5	6.7			59.4
f_{RF} [MHz]	1300					
E_{acc} [MV/m]	10.04	15.05	20.07	10.04	15.05	20.07
Q_0	2.00E+10					
Q_{ext}, Design coupling factor	4.00E+06			4.00E+07		
Cavity rise time [ms]	0.98			9.79		
# of cavities	96					
# of modules	12					
P_{beam}/cavity (ave) [kW]	6.09	5.20	3.48			3.22
P_{RF}/cavity (ave) [kW]	8.77	8.21	8.81			3.62
Available P_{RF}/cavity (pulse) [kW]	80.00			7.00		
P_{cryo} (@ 4.5 K) [kW] Cryogenic 4.5 K equivalent power, accounting all loads and 50% margin	1.4	1.9	2.6	4.0	7.3	7.7
Total P_{beam} (peak) [kW]	5000	5250	5000	500	525	520
Total P_{beam} (ave) [kW]	585	499	334			309
Linac length [m]	149			159		

In the following table we summarize the main characteristic FEL@IRIDE SASE emission calculated for three possible scenarios of electron beam energy. The pulse duration will be in the range 200-70 fs.

Table 1.3: FEL performances at 1.5 GeV electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	4/0.413	1.33/1.23	0.8/2.07
peak flux (n/s/- 0.1%BW)	$2.7*10^{26}$	$2.5*10^{24}$	$1.9*10^{23}$
Peak brilliance	$1.56*10^{30}$	$1.4*10^{28}$	$1.1*10^{27}$
photon/bunch	$5.94*10^{13}$	$5.5*10^{11}$	$4.18*10^{10}$

Table 1.4: FEL performances at 3 GeV electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	1/1.24	0.3/3.72	0.2/6.2
peak flux (n/s/- 0.1%BW)	$4.6*10^{25}$	$4.1*10^{23}$	$3.4*10^{22}$
Peak brilliance	$6.4*10^{31}$	$5.7*10^{29}$	$4.7*10^{28}$
photon/bunch	$1.01*10^{13}$	$9.02*10^{10}$	$7.48*10^{9}$

Table 1.4: FEL performances at 4 GeV electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	0.563/2.2	0.188/6.5	0.113/10.9
peak flux (n/s/- 0.1%BW)	$1.2*10^{25}$	$5.9*10^{22}$	$2.8*10^{21}$
Peak Brilliance	$1.92*10^{31}$	$1.8*10^{29}$	$1.2*10^{28}$
photon/bunch	$2.1*10^{12}$	$1.06*10^{10}$	$5.0*10^{8}$

Table 1.5 summarizes the performances of THz/MIR coherent radiation source from the undulator. Beam and undulator parameters also reported.

Table 1.5: Parameters of the THz/MIR coherent undulator radiation (CUR) source.

Undulator	
Period (cm)	40
Number of periods	10
Magnetic field (T)	0.1 -1
Coherent Radiation parameters	
Wavelength (μm)	100 (with K = 6, i.e. B ≈ 0.2 T)-10 (K=1.4, i.e 0.04T)
Peak power (MW)	> 100
Micropulse energy (mJ)	≈ 10
Micropulse duration (fs)	200

Table 1.6 summarizes the performances of THz/MIR coherent radiation source from a diffraction radiation (DR) target.

Table 1.6: Performances of coherent diffraction radiation (CDR) source.

Coherent Radiation parameters	
Wavelength (μm)	> 50
Peak power (MW)	> 100
Micropulse energy (μJ)	≈ 100
Micropulse duration (fs)	200

Table 1.7 summarize the performances of the IRIDE neutron source compared to other existing sources.

Table 1.7: performances of the IRIDE neutron source

Facility Parameters	nElbe	Gelina	nToF	ISIS	IRIDE
Source		e-Linac	p spallation	p spallation	SC e- Linac
Part E (MeV)	40	120	20000	800	1000 (2000)
Max Power (kW)	18	11	45	160	32/1000 (pulsed/continuous)
Neutrons/s	3.4E+13	3.2E+13	8.1E+14	1E+16	7E+14/3E+15

Table 1.8: parameters at the IP of the IRIDE linear collider for 3 GeV c.m. energy

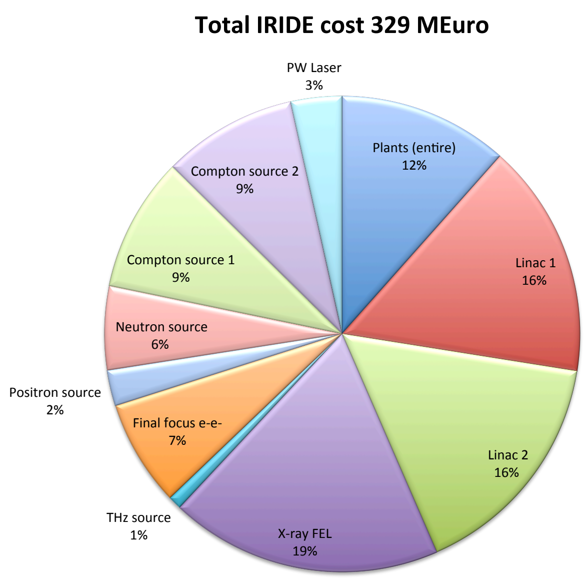
Parameters	Units	Electrons >< Electrons	Electrons >< Positrons
Beam energy	[GeV]	1.5	1.5
Beam power	[MW]	0.45	0.53
Charge	[nC]	0.3	0.35
Bunch length rms	[μm]	270	150
Peak current	[A]	333	700
Rep. rate	[MHz]	1	1
Average current	[mA]	0.3	0.35
Transverse rms spot at IR	[μm]	0.5	0.5
Norm. emittance	[μm]	2	5
Beta at IR	[mm]	0.4	0.15
Disruption parameter	D	2.6	1.23
Beam-strahlung parameter	δ_E	$\sim 10^{-7}$	$\sim 10^{-6}$
Luminosity enhancement factor	H_D	1.6	1.2
Luminosity	$cm^{-2}s^{-1}$	$1.1\ 10^{32}$	$1.3\ 10^{32}$

For the Linear Collider option the parameters listed in Tab. 1.8 have to be obtained at the Interaction Point (IP) in order to achieve the required luminosity, assuming the SC linacs are both operating in CW mode and both electron and positron beams are round.

The third column shows the required beam parameters in the case of electron-electron collider mode. In this case the reasonable low emittance of both beams should allow operating at 500 nm spot size at IP.

The forth column illustrate an example of electron-positron collider in which both beams have the same parameters. The parameters are within the state of the art for low energy electron beams but not yet for positrons. The positron source is still an open problem that might partially overcome by using a Damping Ring or by a new positron source concept based of direct photon conversion.

1.8. Preliminary project cost estimate



The costing for the civil engineering are based on the assumption of a cost per cubic meter of 350 €/m^3 excluding VAT.

The costing for the superconducting linac components is largely based on the XFEL Project, reviewed for the different RF distribution options foreseen for the two operation options. Costs for the RF systems have been assessed through contact with companies potentially able to provide the klystron or Solid State Amplifier systems. For the cryogenic system experience and scaling laws published for LHC has been used.

The costing for the other IRIDE components are based on the experience with similar facilities: NGLS (CW RF injector), SPARX (FEL), ATF2 (Final focus), GELINA (Neutron source), ELI_NP (Compton source), SPARC_LAB (PW laser and THz source).

The total cost of the entire IRIDE facility amounts to **329 M€** as detailed in the following table where the third column show also the incremental cost. In the previuos pie-chart the relative cost of each component is compared.

Components	**Cost [M€]**	**Incremental Cost [M€]**
Cryogenic plant	20	
LHe transfer lines	5	
Building (50m x 20m x 8m x350 Euro/m3)	3	
Total Cryogenic plant	**28**	**28**
Electrical eng. for 8 MW distribution	**4**	**32**
Fluids eng.	**6**	**38**
Injector 1 (RF gun + laser)	6	
Linac 1 modules including CW RF and LLRF	32	
Beam diagnostics	1	
Bunch compressor system	2	
Transfer Lines	5	
Synchronization	1	
Control system	2	
Linac 1 building (170mx5mx5mx350Euro/m3)	1,5	
Additional plants + cabling	2	
Total Linac 1	**52,5**	**90,5**
Injector 2 (RF gun + laser)	6	
Linac 2 modules including CW RF and LLRF	32	
Beam diagnostics	1	
Bunch compressor system	2	
Transfer Lines	5	
Synchronization	1	
Control system	2	
Linac 2 building (170x5x5x350)	1,5	
Additional plants + cabling	2	
Total Linac 2	**52,5**	**143**
FEL undulators and optical cavity	25	
X-ray Transport optics	5	
User end station	5	
X-ray detector	8	
Undulator hall (100x30x8x350)	8,4	
X-ray transport tunnel (80x5x5x350)	0,7	
Experimental hall (80x30x8x350)	6,8	
Additional plants + cabling	2	
Total X-ray FEL	**60,9**	**203,9**
Total THz source	**3**	**206,9**
ATF2 Final focus system e-e- (thanks to Seryi)	11,3	
Diagnostics	2,1	
Experimental hall (100x30x8x350)	8,4	
Additional plants + cabling	2	
Total final focus e-e-	**23,8**	**230,7**

Neutron Target area	8	
Beam lines 4	8	
Neutron transport tunnel (150x5x5x350)	1,3	
Experimental station 5 (10x10x8x350)	1,4	
Total Neutron source	**18,7**	**249,4**
Dedicated injector	5	
high energy Yb:AG laser	7	
Interaction region and recirculator	4	
g-ray beam collimation and diagnostics	3	
User beam line	10	
Laser and users exp hall (20x20x8x350)	1,1	
Total Compton source	**30,1**	**279,5**
Target area	5	
Positron Capture	2	
Diagnostics	1	
Total test positron source	**8**	**287,5**
Second Compton source for gamma-gamma	**30,1**	**317,6**
Laser PW (TiSa)	8,7	
Laser-Plasma diagnostics and control	1,2	
PW target area	1,5	
Total PW Laser for AAC	**11,4**	**329**
Total IRIDE facility	**329**	

Two possible investment profiles are shown in the next plots as examples of the flexibility of the project development. Other solutions downstream the first linac are possible depending on the assigned priorities.