8.08.2007

Polish Free Electron Laser in UV range
POLFEL

Brief Summary

Device:

- Free Electron Laser – source of coherent UV radiation driven by superconducting linear electron accelerator.

Goal:

- Large scale research infrastructure for European science and industry (in the framework of ESFRI „IRUVX FELs Network")
- Research and training center for fundamental, material, environmental, medical and biological research.
- Training and development center for laser, accelerator and detection technologies.

Research potential:

- Studies of electronic properties of molecules and condensed matter
- 3D-imaging of atomic structures
- Registration of physical, chemical and biological properties in atomic and femtosecond scale

Applications:

- Tests of quantum chromodynamics in low (<500MeV) energy range
- Semiconductor and quantum structures studies:
  - phonons, plasmons, binding energies of dopants, energetic levels in quantum wells, wires and dots, relaxation dynamics
  - development of THz and MEMS technologies: hybrid antennas, mixers, filters
  - pump/probe technique:
    - carrier dynamics in superstructures, intraband interactions, cascade lasers
    - absorption in quantum wells and in superstructures, width of emission lines, dispersion
    - optical properties in infrared and THz range of such structures as: Bloch oscillators and quantum cascade lasers
    - coherent resonant effects, Rabi oscillations
- Near-edge microscopy and spectroscopy
- Environmental studies using photo-thermal (PTDB) spectroscopy
- Analysis of atmospheric processes in real time using tunable lidar
- Biomolecular spectroscopy
- Medical diagnosis: precise visualization of organs, identification of molecules
- Medical therapy: FEL-activated nanoplatforms
- Selective destruction of damaged or ill cells via tunable radiation

Basic parameters:

- **Continuous** electron beam with energy **600 MeV**
- Wavelength: primary - **27 nm,** 3rd harmonic - **9 nm**
- Maximum beam power in pulse: **0.22 GW**
- Length of device: up to **400 m**
- Costs: **100 M€** (FEL + one research station) to **200 M€** (FEL + 6 research stations)

Technology:

- Based on extensive use of elements designed and build for XFEL DESY

Site:

- The Andrzej Sołtan Institute for Nuclear Studies (IPJ), Świerk near Warsaw, 44 ha area

- existing technical infrastructure matching nuclear site requirements,
- own transport, maintenance, laboratory services and production workshops
- experience in design, construction and production of particle accelerators,
- participation in TESLA/XFEL projects, cooperation with research centers using or building FELs

1 Scientific potential of Free Electron Lasers

Free Electron Lasers (FEL) are generators of coherent beam of radiation of wavelength tunable from millimeters to UV range. These devices open a brand new area of research of possibilities that can hardly be evaluated today. Intensity, brightness and quality of radiation delivered by FELs are several orders of magnitude higher than currently used sources of radiation. In some cases FELs allow the delivery of radiation in currently unavailable ranges as THz range. FELs may be used in physics, chemistry, biology, material science, environmental science or medicine helping to understand processes in living cells, chemical reactions or material structures. This may be accomplished by:

- studies of electronic properties of molecules and condensed matter
- three dimensional imaging of atomic structures
- registration of physical and chemical processes in atomic and femtosecond scales, e.g. studies of excited states, chemical reactions and biological processes.

The following description does not constitute a complete review of possibilities offered by FELs. The aim of this report is rather to indicate some selected applications of FELs with a special emphasis to Polish research priorities. It is worth to point out that construction of FEL in Poland would lead not only to large experimental device that could be used by Polish scientists but also to integration of national researchers with European Research Area. One of the programs that helps such an integration is "Integrating Activity on Synchrotron and Free Electron Laser Science" (IA-SFS). Schematic distribution of participating institutions is shown below. All these institutions benefit from EU financement in the frames of Large Scale Facility (LSF) program.

Among the IA-SFS installations particularly interesting are free electron lasers. The ESFRI committee created a special network „IRUVX FELs Network – from infrared to soft X-rays", a consortium joining FLASH@DESY - Hamburg, FERMI@Elettra - Trieste, 4GLS - Daresbury, BESSY - Berlin and MaxLab - Lund. Several other devices from The Netherlands, France and Switzerland may join this network as well. The main objectives of this consortium are: to join the resources in construction and planned Free Electron Lasers in Europe into a unique Research Infrastructure, to offer novel and powerful complementary instruments for the microscopic and the dynamical study, as well as an optimal service to users and to prioritise the development and location of the specific beam lines.

It seems that Poland could join this consortium by proposing a new UV-FEL that may complete the IRUVX network being the first large scale research facility in new EU countries.

It's worth notice that the POLFEL project is not competitive with the project of Cracow synchrotron. Those two sources are emitting radiation of different characteristics and are rather complementary systems.

Several possible applications of FELs are listed below.

1.1 Application of FEL in fundamental physics research

Compton scattering on protons and neutrons will help to determine electrical and magnetic polarizability of nucleons. This information is necessary to understand internal structure of nucleons. By applying the effective field theory based on quantum chromodynamics (QCD) it becomes possible to calculate these polarities. It is thus essential to compare the results of calculations with experimental data what will constitute the test of Chiral Perturbation Theory (CPT), hence the confirmation of QCD in low (below 500 MeV) energy range.

1.2 Material studies

1.2.1 Semiconductors and quantum structures

Free Electron Lasers deliver the radiation having wavelength in the range of few nanometers to several hundreds of micrometers, i.e. few meV to several hundred eV. This range corresponds to characteristic excitations in semiconductors and quantum structures as: phonons, plasmons, binding energies of impurity atoms or energy levels in quantum wells, wires or dots. FEL may thus be used in studies involving such structures, e.g. studies of relaxation dynamics. Very high energy should also allow the analysis of non-linear processes.

Development of high frequency technologies requires dedicated emitting and receiving devices; hybrid antennas, mixers, filters etc. Likely these elements should be constructed using MEMS (explain MEMS) technology. An additional advantage of FEL program should thus be development of micro- and manufacturing nanotechnologies.

Modern and very promising spectroscopic technique is pump/probe technique when one pulse serves the purpose of excitation and the next one, slightly delayed, is used for the analysis of the excitation effects. Free electron lasers allow precise control of pulse energy used for both, excitation or analysis. Several possible applications of this concept are:

- Analysis of carrier dynamics in superstructures. It is expected that intraband interactions could be explained what should lead to, e.g. more efficient cascade lasers.
- Studies of absorption in quantum wells and superstructures.
- Optical properties in infrared and THz range of Bloch oscillators and quantum cascade lasers.
- Coherent resonant effects and Rabi oscillations.
- Coherent excitation, electron dynamics.

1.2.2 Electromagnetic radiation in terahertz range

Electromagnetic radiation in terahertz (THz) range covers the area between microwave and infrared bands. This range is very poorly known, what is mainly due to the difficulties in generation and detection of such a radiation. Terahertz radiation offers unique possibilities, among others allows one to directly measure time dependencies for an electric field. In consequence terahertz spectroscopy makes possible direct analysis of amplitude and phase of radiation, without need to use Kramers-Kronig formulas. Energy of radiation in terahertz range corresponds to the frequency of molecules vibration in liquids; this radiation may thus serve the purpose of identification of chemical compounds. Therefore THz radiation is particularly interesting for security services; terahertz gate at the airport would be able to detect even trace concentrations of given chemical compounds.

1.2.3 Photothermal spectroscopy (PTBD)

One of the main problems of ecology is measurement of contaminations in the environment. A typical example is contamination with heavy metals, e.g. lead, cadmium or radioactive isotopes. Infrared spectroscopy is most commonly used for this purpose, however, its main limitation is due to the fact that most of minerals is opaque in IR band. In consequence, the measurements should be made in reflective mode with much worse signal-to-noise ratio than transmission mode. Secondly, the unacceptable concentrations of heavy metals or radioactive isotopes are low, limiting the IR spectroscopy to model studies only. Photothermal spectroscopy is a very sensitive method with a detection limit of the order of $10^{-6} – 10^{-8}$ making possible analysis in real conditions. Combination of PTBD method with FEL as an excitation source appears thus as a powerful tool in environmental studies.

1.2.4 Near-edge microscopy and spectroscopy

Near-edge microscopy allows one to characterize structures with the resolution better than that defined by the wavelength of radiation. Currently this technique uses infrared lasers (typically CO_2). Tunable free electron lasers should allow the analysis of molecular vibrations in biological samples with submicron resolution.

1.3 Biological and environmental studies

1.3.1 Biomolecular spectroscopy

Radiation emitted by free electron lasers may become a powerful tool for biological studies. Intensive, coherent and tunable from infrared to terahertz radiation will allow studies and modification of molecules. It will become possible to study resonant excitation of molecules in proteins, enzymes, cell nuclei and cell membranes.

Expected benefits of the use of free electron lasers are related to the possibility of combination of spectroscopic measurements of characteristic frequencies with ability of modification by using the same radiation. Short length of the pulses allow the registration of modification of molecules, what may be regarded as „movie recording" presenting biological processes as cell death, capture of photon by chlorophyll and many others.

1.3.2 Atmospheric research

Free electron lasers may be used as tunable lidars for real time detection and mapping of processes occurring in atmosphere.

1.4 Medical applications

Medicine and biomedical research seem to be one of the most promising applications of FELs. Human body is almost transparent for far infrared radiation. It becomes thus possible to visualize organs inside the body using very low level of radiation intensity. In terahertz range one may identify chemical and organic molecules what, combined with high transmittance through the body offer unrivalled diagnostic possibilities. FEL allows also the use of non-invasive treatments using so-called nanoplatforms. It is expected that dedicated nanoplatforms will be introduced into body, and then will migrate to a given organ, e.g. cancer tumor. After deposition nanoplatform will be activated using FEL radiation tuned to activators build within nanoplatform. An activator may be, e.g. heavy atoms like Au, I, Gd or Pt. X-rays emitted by FEL would activate K-shell of activators leading to emission of low-energy electrons and secondary X-ray radiation, both processes used for destruction of the ill cancer tissue. FEL may also be used for high definition imaging of human organs.

Exceptional properties of radiation emitted by FEL open brand new therapeutic possibilities. It is envisageable that by precise tuning of the radiation wavelength one may selectively destroy ill cells with negligible damage caused to healthy tissue in their vicinity. Some studies of the use of FEL in otolaryngology has already been started, one of the topics is corrections of vocal chords damaged due to illness or mechanical accidents. Highly precise surgery using FEL radiation may restore voice by mute persons.

2 General assumptions

A Free Electron Laser (FEL) facility in Poland will create for broad scientific community a unique opportunity for active participation in the European R&D programs on physics and technology of coherent light sources and superconducting accelerators. An interdisciplinary character of the research, development of new technology and educational and training possibility at the facility bear out its importance already at the preliminary stage of design studies and for many years of its exploitation. Such a role can and should play in Poland a facility providing a source of coherent light, which is fed by the electron beam from a superconducting linear electron accelerator.

Many research centers in Europe, in the USA, Japan, China and Korea are already interested in FEL facilities. The list of FEL facilities already running and being under construction or at advanced design studies is shown in Table 1 [1]. More than half of the mentioned facilities employs superconducting technology. Two other facilities should be added to complete this group: FEL in TJNAF laboratories in the USA and JAERI in Japan. They are working in a very modern, the so called energy recovery mode. In ER (Energy Recovery Linacs) the energy of the electron beam is recovered after the photon emission has taken place. Those facilities have been built also to prove that in this mode a stable acceleration is feasible.

Table 1

Project	Type	Location	Country	Beam Energy [GeV]	λ photon [nm]	Status
LEUTL	SASE	APS	USA	0.22	660-130	Since 2001
TTF-I	SASE	DESY	D	0.3	125-85	Since 2002
DUV-FEL	HGHG	BNL/NSLS	USA	0.145	400-100	Since 2002
SCSS	SASE	Spring8	J	0.230	40	In 2005
FLASH	SASE	DESY	D	1	6 (2)	Since 2006
X-FEL	SASE	DESY	D	17	0.1	In 2012
LCLS	SASE	SLAC	USA	15	0.15	In 2008
Soft X-ray FEL	HGHG	BESSY	D	2.3	64-1.2	Proposal
SPARC	SASE	ENEA/INFN	I	0.15	VUV	Proposal
SPARX	SASE	ENEA/INFN	I	2.5	1.5	Proposal
VXFEL	SASE	ELETTRA	I	1.0		Proposal
FERMI	SASE	ELETTRA	I	3.0	1.2	Proposal
4GLS	SASE/HGHG	Daresbury	GB	0.6	VUV-XUV	Proposal/ERL
	HGHG	MIT-Bates	USA	3.0	VUV-XUV	Proposal
LUX		LBL	USA	3.0		Proposal/ERL
		Cornell	USA	5-7		Proposal/ERL
Arc-en-ciel		Orsay	F	0.7		Proposal
MAX-IV		MAX-Lab	S	3.0		Proposal

In general, facilities driven by superconducting accelerators (sc linacs) are superior in performance to those based on the normal conducting (copper) structures operating at room temperature, which due to the enormous energy dissipation can operate in pulse mode with a rather low duty cycle. The three main advantages of sc linacs are:

- Flexibility in the time structure of the electron and photon beams, which is crucial for many experiments
- Higher average brilliance, which allows for more experimental photon lines
- Operation in continuous wave (cw) and near-cw mode, ultimately with energy recovery option

A superconducting driving linac is technically more challenging than the normal conducting version but, it offers a broader range of experiments and its operation is less expensive. The FEL facility we are proposing here will be driven by a superconducting linac.

Costs of the sc linear accelerator and its infrastructure (tunnel, cryogenic plant, RF-system, control electronics…) is always a substantial part of the total investment. To distribute the cost over a longer time period, it is proposed to build the facility in a modular manner. In the first stage, the facility can be made of an electron source and one or two accelerating cryomodules. Then, accordingly to the financial situation, it can be upgraded stepwise to higher beam energies and shorter wavelengths, which will increase its experimental application.

The layout of the facility, which will be briefly discussed in the next section, is schematic and as such shall not be treated as a final version. It is intended to initiate a process of the detailed technical design.

3 Technical description

3.1 Generation of photons

Length of the emitted radiation, λ_{ph} , by electron traversing an undulator is:

$$\lambda_{ph} = \frac{\lambda_u}{2\gamma_e^2} \cdot (1 + K^2)$$

λ_{ph} depends on the electron energy (γ_e is the Lorentz factor) and on the undulator: its period λ_u and magnetic parameter K:

$$K = \frac{eB \cdot \lambda_u}{2\pi \cdot m_o c}$$

where B is the mean value of magnetic flux in the undulator.

The radiation process can be spontaneous, so called SASE (self-amplified spontaneous emission), or stimulated by other radiation so called seeding or self-seeding. The seeding process results in a pre-modulation of the charge density in the radiating bunch, which helps to narrow the energy width of the radiated photons and enables very short (<100 fs) photon bursts.

3.2 Electron source

In general, FEL processes require low emittance ($\varepsilon_n < 2$ µrad) bunches with charge of the order of 1 nC. The emittance specification is even tighter ($\varepsilon_n \sim 1$ µrad) for the electron injector, because subsequent acceleration process causes further dilution of the emittance. To fulfil the emittance and charge requirement, the most demanding part of an injector, an RF-electron gun, must operate at high accelerating gradient to mitigate the emittance growth due to the space charge force. The entire injector should operate in the cw and near-cw mode to keep its compatibility with the driving superconducting linac, allowing for these advantageous operation modes enabling a very high average brilliance of the facility. The electron injectors operating at present do not fulfil these requirements, since they operate either in a short pulse mode with high gradients (and low duty factor) or at low gradients in the cw mode (and low charge <<1 nC). The only feasible technical approach to the cw operating RF-gun, generating the low emittance and highly populated bunches is a design based on the superconducting technology (SRF-gun). Several institutions worldwide work on this approach: BNL, Beijing University, Forschungszentrum Rossendorf (FZR), TJNAF and DESY, with contribution from IPJ in Swierk.

In 2002, a half-cell prototype of the Rossendorf gun delivered the first beam for acceleration; in Beijing this took place one year later in 2003. Both beams were far from the specification. Their emittance was higher than 1µrad and the charge was substantially lower than 1 nC.

The FZR gun is the most advanced option (Fig. 1). The FZR gun will be implemented in the soft X-ray FEL at BESSY. Table 2 displays operation parameters of the gun for this application.

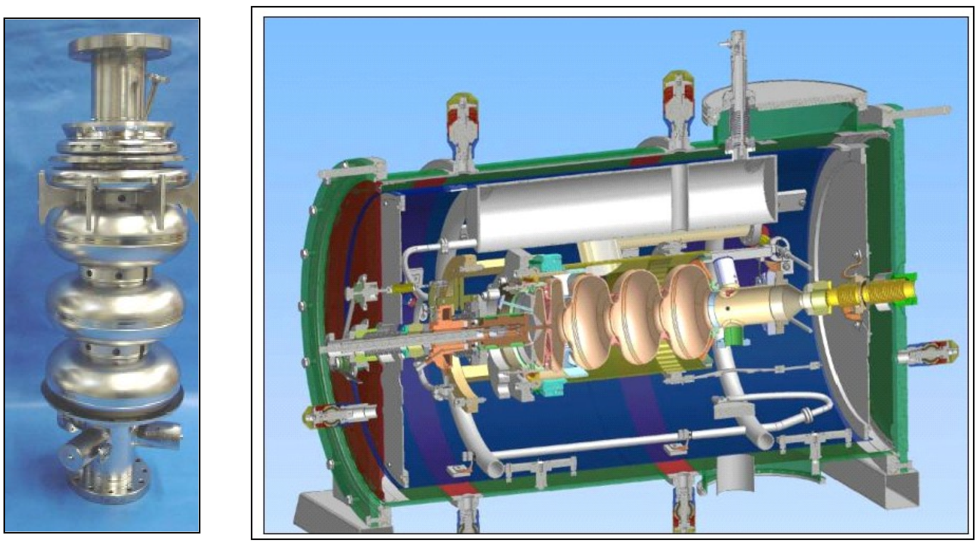

Figure 1. Superconducting cavity of the FZR gun (links) and cross-section of the cryostat (right)

Table 2. Parameters for the FZR gun which will operate at BESSY.

Beam energy	5 MeV
Charge per bunch	2.5 nC
Repetition frequency	25 kHz
Normalized emittance	1.5 µrad

3.3 Superconducting accelerator

The proposed driving accelerator is made of the accelerating units. The unit consists of one XFEL cryomodule (99 cryomodules will be built for the first stage of the European XFEL [3]) and one IOT (Inductive Output Tube), an RF-power source, which can be operated in the cw- and near-cw mode. The unit with the 120 kW IOT, a driving amplifier, a power distribution system and the cryomodule housing eight 9-cell superconducting cavities of the TESLA type, is shown in Figure 2. The accelerating unit was proposed in the frame of the EUROFEL project to provide the highest possible flexibility in the time structure of the electron and consequently of photon beams [4]. The superconducting structures were designed in 1992 for the TESLA collider. Sixteen structures were operated many years in the TTF-I linac to drive the VUV FEL at DESY. In the second stage of the linac, TTF-II, fifty-six structures will accelerate the electron beam up to 1 GeV to drive the FLASH facility, which will deliver in the SASE process 6 nm coherent light in the fundamental mode.

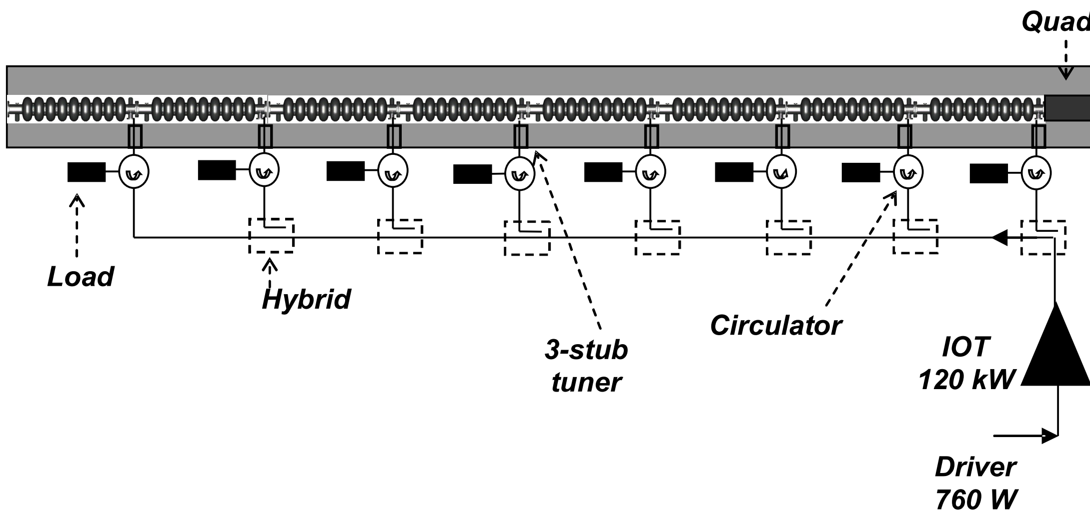

Figure 2: The accelerating unit with the 120 kW IOT, a driving amplifier, a power distribution system and the cryomodule housing eight 9-cell superconducting cavities.

The TESLA superconducting structures demonstrate very good performance, reaching high accelerating gradients above 30 mV/m and maintaining at the same time high intrinsic quality factor Q_0 of 10^{10} (low cryogenic load). Actually, in many proposed FEL facilities the superconducting accelerators are based on the TESLA structures, for example: European XFEL w DESY will have 784 structures, Soft X-ray FEL at BESSY will have 144 structures and the Energy Recovery Linac (ERL) in Cornell University will have 320 structures with 7-cells instead of 9-cells. The choice of the TESLA structures for these prestigious projects indicates that the superconducting technology is mature and satisfactory for these facilities operating at moderate gradients.

Besides the parameter set for the accelerating unit (disused in the next section), in the frame of the EUROFEL project, the first prototype of the high power IOT will be built by the end of 2007. The prototype will be tested first at the vendor laboratory and then at DESY. If the tests are successful both major components of the unit, the cryomodule and IOT, will be technically proven and can be used as core elements for any modular designed linac.

3.4 Operation parameters for driving linac made of three units; an example

The layout of the accelerator is shown in Figure 3. Table 3 lists parameters for the linac made of the injector unit delivering 125 MeV electrons and two accelerating units, for which the dynamic cryogenic load at 2K is limited to 100 W (50W/unit). The limit of 50W/unit allows keeping the low cost of a cryogenic plant. Its total required capacity at 2K is less than 500 W, which is sufficient for a linac consisting of 5-6 units.

Table 3. Example of operation parameters for linac with the injector unit (125 MeV) and two accelerating units

Beam Energyi =125MeV+Linac	[MeV]	275	325	375	425	475	525
Energy gain/unit	[MeV]	75	100	125	150	175	200
Accelerating gradient	[MV/m]	9	12	15	18	21	24
Intrinsic quality factor Qo	[10^{10}]	2.0	2.0	2.0	2.0	2.0	2.0
Dynamic losses at 2 K / structure	[W]	4.3	7.7	12	17.2	23.5	30.6
Total losses at 2 K / structure	[W]	5.6	8.7	12.7	17.8	23.9	31.0
Duty factor	[%]	100	72	49	35	26	19
Beam							
Maximum beam current	[mA]	1.24	0.93	0.74	0.62	0.53	0.46
Time between 1nC bunches	[µs]	0.81	1.08	1.35	1.62	1.89	2.16
Max. number of bunches /s	[10^6]	1.236	0.668	0.364	0.215	0.136	0.090
Coupling and microphonics							
Optimum Q_{load} of the Input Coupler	[10^6]	6.7	11	14	20	27	36
Maximum microphonics		<34 Hz	<34 Hz	<33 Hz	<23 Hz	<17 Hz	<13 Hz
3 dB resonance width	[Hz]	193	123	93	65	48	36
Max. peak beam power	[kW]	350	310	290	270	260	250
Average power in the beam dump	[kW]	347	222	140	94	66	48

Nominal bunches in this table have charge of 1 nC

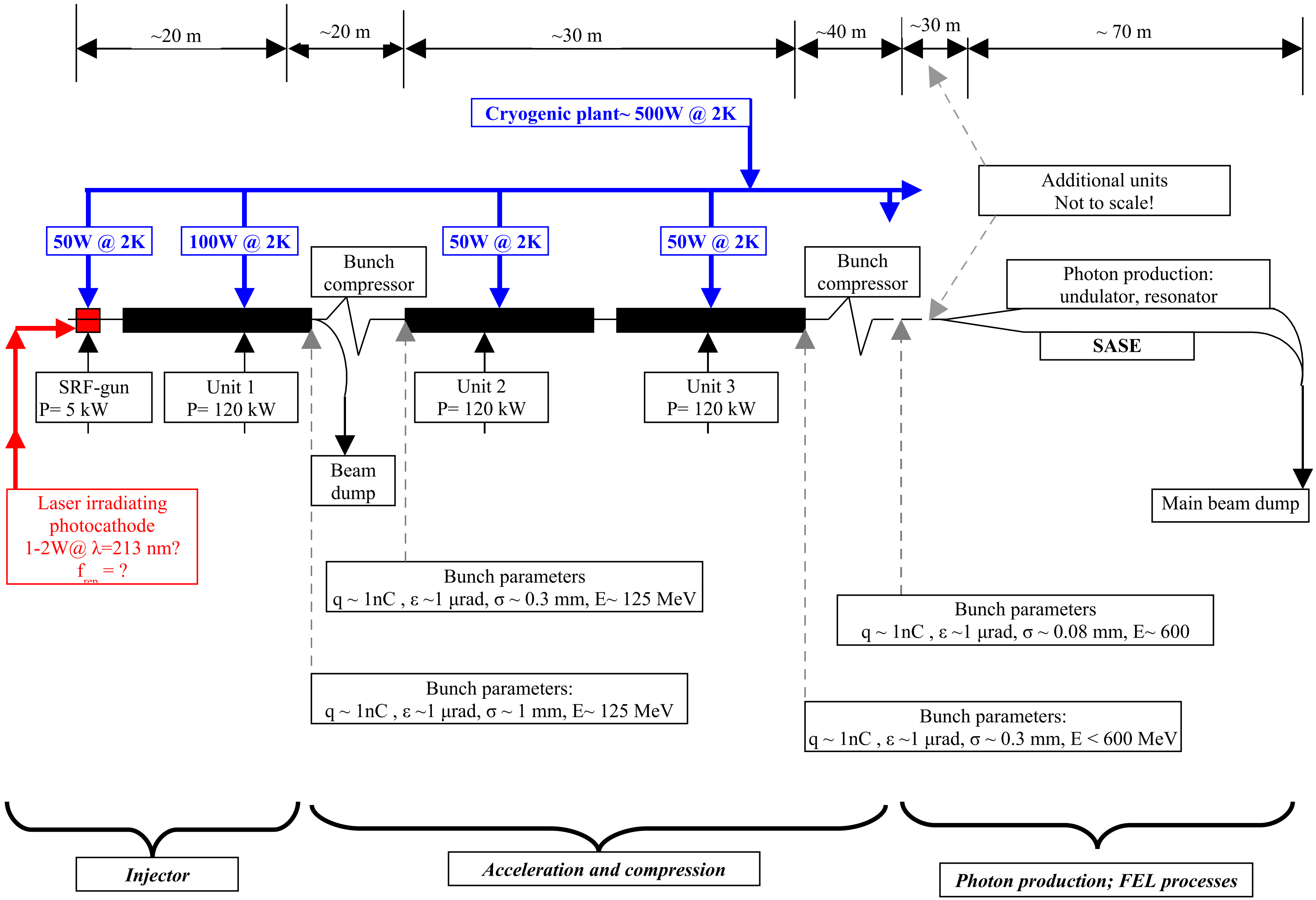

Figure 3: Schematic layout of the FEL facility

The facility has three main parts: the injector, acceleration with compression and photon production. Its total length is ca. 210 m including the space for two additional units. In the first stage the maximum beam energy is 525 MeV, which in the SASE process (similar to the TTF-II at DESY) is sufficient to generate 26 nm coherent light at the fundamental harmonic, down to 5.2 nm at 5-th harmonic. Further processes, for example HGHG (high gain harmonic generation) can be implemented to generate shorter wavelength without an upgrading the beam energy.

The injector, SRF-gun with the first accelerating unit, generates 125 MeV electron beam. The number of generated bunches/s depends on the laser used for the irradiation of the photocathode. Other limitation is the RF-pulse length (cryogenic load) and maximum beam current (installed RF-power). The maximum number of bunches/s resulting from these two limitations is listed in Table 3.

Bunch compressors shorten the bunch from $\sigma \sim 3$ mm length to $\sigma < 0.1$ mm, which enhances the bunch peak current to the value required for the SASE process.

In two accelerating units, the beam gain energy up to 525 MeV (in the first stage). The main limitation here comes from the mechanical vibrations of accelerating structures and resulting from that frequency modulation. The LLRF system needs to be design for cw- and near cw-operation which differs from the very short pulse operation of the TTF-linac.

The photon part of the facility contains undulators, photon beam diagnostics, photon lines and experimental setups. All experimental lines and diagnostics should be designed in cooperation with potential users, to guarantee flexibility for various experiments.

The beam dump(s) must absorb almost whole beam energy which can be as high as 350 kW. The main dump must absorb electrons (up to 525 MeV) and whole spectrum of the radiation generated in the electron absorption process.

The vacuum and cryogenic systems, personnel and accelerator protections, interlocks, ac-power and water requirements, tunnel construction, shielding, control room and computer systems will require engineering effort.

3.5 Light beam lines

POLFEL is designed to serve three kinds of users: FEL developers, scientists and industrial researchers.

Continues wave mode enables to feed several beam lines with enough intensity. It is planned to build 6 beam lines for different purposes:

- FEL developers - 1 beam, financed from the POLFEL budget
- Scientists – 2 beams, financed from scientific grants
- industrial researchers – 3 beams, commercial use

For each beam one can assume ~25 users per year and at least 100 shifts (8 hour each) per year.

4 Realization of the project

4.1 Cooperation with DESY

Cooperation with DESY could create large synergy between FLASH, XFEL and POLFEL projects. IPJ already contributes to TESLA/FLASH/XFEL projects participating in the R&D programs. Using technology developed for XFEL could be beneficial for both DESY and IPJ. Benefits for IPJ - POLFEL are:

- The risk of project failure due to technological problems is minimized.
- The cost and the time for design, R&D and prototyping is significantly reduced.
- Components can be produced as an extension of the XFEL production for the “mass production” price.

- One can profit from the know-how of Polish experts gained during XFEL construction.

Benefits for DESY – FLASH/XFEL includes:

- IPJ could increase its manpower and in-kind contribution to XFEL.
- POLFEL may serve as a cost effective training center for FLASH and XFEL technical staff and users.
- FLASH experiments could be prepared and tested effectively at POLFEL, thus saving the FLASH beam-time.
- New ideas and pilot programs to improve XFEL could be developed and tested at POLFEL.

A good example for the last point is testing the operation in the continuous wave (or near cw) mode.

4.2 The elements of risk in the project.

The presented scheme of the facility constitutes a preliminary concept. Final project will depend on the scientific potential of the experimenters and on financial resources.

Technical assumptions require further analysis and risk estimates. Employing the already obtained results for FEL will limit this risk to concern only the superconducting electron gun. For the moment, for FEL working in continuous mode, this gun could be replaced by the classical Pierce launcher, although this type of source generates bunches of smaller charge and worse emittance.

Microwave IOT sources, with higher output power also need R&D, however they can be replaced by the existing amplifiers (4x32 kW for each section) to lower the risk.

Ageing of the experts in Poland caused by a particularly difficult financial situation of Polish science in recent years and by “brain-drain” by scientific projects in USA and Europe can also create a certain risk.

There is an important necessity of engagement of a new generation of young physicists in this project. It also has to be remembered that Polish scientists working outside Poland as well as foreigner experts are welcome to the project at the stage of its designing, installation and commissioning.

4.3 Project work packages

Table 4 shows schematic and preliminary list of work packages for the project. It has to be completed with the progress of the design.

Table 4. Preliminary list of work packages

Concept of the whole FEL: Range of electron energy, photon energy, amount of photons and the way of their generation, basic version of the facility and its further enlargement…..
Electron gun: Photo-cathodes, laser photo-emission – choice and installation, microwave power, diagnostics, beam dynamics, stabilization of amplitude and phase…..
Accelerating sections: Cryogenic installation, microwave power, vacuum, tuning, testing…..
Beam optics: Calculation of the whole beam optics, designing of the magnets including dipoles, quadrupoles,

steering magnets, power supply, bunch compressor, beam collectors……..
Cryogenic system: Choice, installation, safety……
Electronic inspection systems: Phases, amplitudes, synchronization, etc…….
Vacuum system: Concept, choice of elements, pumps, valves…….
High frequency system: IOT s, input amplifiers, power supply, synchronization, power distribution, control system, security…….
Beam diagnostic system: Monitoring along the whole linac accelerator: charge trajectory, phase, energy, etc………
Personnel and accelerator protection (Interlock): Against high voltage, gases, explosion, fire, radiation, beam collectors and their activation……
Site, tunnel, building and the experimental hall: Construction, protection…….
FEL processes calculations: What kind of processes, quality of the electron beam, undulators type, expected power and photon beam quality as a function of a wave length, synchronization, photon diagnostics
Electric system: Power recruitment estimation, distribution and security……
Central control and computer technique of the whole device: Control room, collection and digitalization of the data etc…….

4.4 Location at the site of the Institute for Nuclear Studies at Świerk

Nuclear Research Center in Swierk, near Warsaw, is well prepared to host POLFEL (Fig.4). The area is shared by two national labs: Soltan Institute for Nuclear Studies (IPJ) and Institute of Atomic Energy (IEA), each heaving almost 500 employees. The site has numerous advantages:

- fenced, guarded area of about 44 ha with nuclear site certification
- technical infrastructure matching nuclear reactor requirements
  - three independent power lines and independent water source
  - security and safety networks
- small distance from the Warsaw center
- unbuilt territory surrounding the Center, to be used for Technology Park
- own transport, maintenance, laboratory supports and mechanical workshops

Institute has also extensive expertise in designing and building accelerators:

- Manufacturing of industrial accelerators LILLYPUT
- Manufacturing of medical accelerators COLINE

•Active participation in R&D for accelerators CLIC at CERN as well as TESLA, FLASH and XFEL at DESY

- Contract for accelerating structures for hadron therapy center TOP in Frascati

Fig.4; Possible POLFEL location at the Nuclear Research Center in Świerk.

4.5 Cost estimate

European Forum for Research Infrastructures (ESFRI) in the document untitled: "Towards new research infrastructures for Europe: The ESFRI List of Opportunities" estimates the cost of one laboratory with FEL for 150-200 M€

A similar to the XFEL project cost structure is to be expected (with scaled global sum).

Apart from the FEL facility itself, an important part of the cost are research stations. The cost of one station should be similar to that of a typical synchrotron station and amount to 20M€.

In the first phase (financing period 2007-2013 with spending till 2015) it will be possible to built FEL with one station which would cost 100M€. In the next financial period (2014-2020) it will be possible to build the next five stations that will raise the total cost up to 200 M€.

It will be possible to speed up the construction in the case of important financial or "in-kind" contribution from other countries interested in the exploitation of the facility.

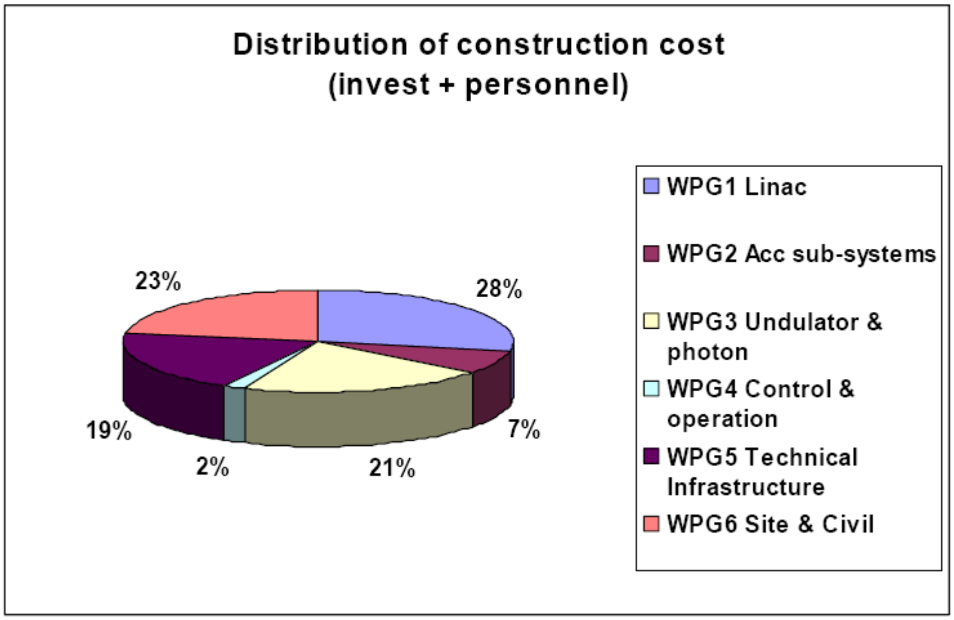

Fig.5; Cost structure of the project European XFEL (status 2006; whole facility is 3 km long with 2.1 km length of the accelerator).

5 Bibliography

[1] Technical Design Report of Soft X-FEL, BESSY GmbH, Berlin March 2004.

[2] J. Sekutowicz, "Superconducting RF Photoinjectors; an Overview", Proceedings of ICFA Workshop on Physics and Applications of High Brightness Beams, Erice, Sicily, October 9-14, 2005.

[3] TESLA-XFEL, TDR- Suplement, TESLA-FEL-Report 2002-99, DESY, October 2002. xfel.desy.de/xfelhomepage/factsfigures/index_eng.html

[4] Drafts of three reports of DS5 group from EUROFEL project. Possible questions about these reports should be addressed to: jacek.sekutowicz@desy.de

Links

- ESFRI IRUVX FELs Network - www.iruvx.eu
- VUV FEL / FLASH project – flash.desy.de
- XFEL-Polska consortium– www.xfel.pl
- The World Wide Web Virtual Library: FEL research and applications - sbfel3.ucsb.edu/www/vl_fel.html