The saga of MAX IV, the first multi-bend achromat synchrotron light source

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A B S T R A C T

This paper describes how MAX IV, the first Multi-Bend Achromat (MBA) Synchrotron Radiation Light Source, was developed and realized. It describes the process of defining the scientific case and the development of the accelerator concepts. This was a highly interactive and intense optimization process, which went on during a long time with tight communication between the lab and the various user communities as well as with the funding agencies.

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1. Introduction

Already at the end of the 1990’s, the MAX-lab management realized that it was necessary to start planning for a possible next step in the development of the laboratory. Although MAX II, one of the first 3rd generation light sources in the world and the flagship of the laboratory, had just recently come into operation, the long lead times made it necessary to start exploring possible further developments already at that stage. Plans for new and more powerful light sources were appearing at various places around the world and it was evident that MAX II should be surpassed by a number of more ambitious projects within one or two decades.

In the present paper we describe the development of the MAX IV project, from the initial ideas to its realization. We start by describing the early development of MAX-lab, with the initial MAX I facility, followed by the 3rd generation storage ring MAX II. We also discuss the special importance of the relatively small MAX III project as a step towards MAX IV. We then describe the development of the scientific case and the accelerator design for the MAX IV project, see Fig. 1.

Already from the beginning it was clear that the boundary conditions for MAX IV were tight. A new facility had to be squeezed into a relatively tight investment and operational budget, in order to be handled by a small country like Sweden. However, it was also clear that a new advanced facility would anyway require a budget exceeding any other national project in Sweden. For this reason it was obvious that a new facility had to have a unique performance. A successful project also required that it had to be well established within the Swedish research community. Furthermore, the project had to be developed in tight contact with the funding agencies.

2. The early days of MAX-lab: MAX I and MAX II.

In the 1960s a 1200 MeV electron synchrotron (LUSY) was started up for nuclear physics research in Lund [1]. Some first attempts were also made in the beginning of the 1970s to use LUSY for synchrotron radiation research (P.O. Nilsson and W. Stiefler, unpublished). In the late 1970s the idea of a synchrotron radiation storage ring in Sweden was born. At that time a project had started in Lund with the aim of...
building a new facility for nuclear physics research. The plans were modified already at an early stage and the MAX I project started. A ring was built which could be used both as a pulse-stretcher for photonuclear research and as a 550 MeV storage ring for the production of synchrotron radiation [3]. The build-up was handled by a very small staff and on a very limited budget. In spite of that the MAX I facility could be taken into operation in 1985.

The synchrotron radiation research took off in a very good way. One important factor was that an experienced and motivated user community already existed in Sweden. A number of young researchers and postdocs had gained experience in the field at the first synchrotron radiation facilities in the world, such as SSRL at Stanford, DORIS at DESY, Hamburg, Tantalus at Madison, Wisconsin and at ACO in Paris. There was a strong tradition in the field of X-ray based spectroscopies and instrument development in the country, as evident for instance from the Nobel prizes to Manne Siegbahn for X-ray emission spectroscopy and to Kai Siegbahn for his development of ESCA (Electron Spectroscopy for Chemical Analysis) or XPS (X-ray Photoelectron Spectroscopy [3–5], Fig. 2. Also in the field of angle-resolved photoemission, Swedish researchers were among the pioneers [6,7]. Swedish researchers were also advanced in diffraction techniques, not the least in the field of life science. Several groups were also very early when it came to using synchrotron radiation in their structural research. At that time they could not use MAX-lab, due to the limited photon energy range at MAX I, but the strength also of this community became very important for the long-term development of MAX-lab.

The Swedish funding agencies played a very important role for making MAX-lab a highly competitive laboratory. The Swedish Natural Sciences Research Council (NFR) immediately recognized the potential of MAX-lab. At a very early stage a couple of beamline projects were funded at a level, which allowed the build up of equipment which utilized the capabilities of the storage ring in an optimum way. The level of funding of a few beamlines also allowed advanced beamline solutions and made it possible to make new designs [8]. The funding came from NFR and FRN (Swedish Council for Planning and Co-ordination of Research) as well as from the Knut and Alice Wallenberg (KAW) foundation.

Not the least the tradition in the development of spectrometers made it possible to create efficient systems where all parts of the beamline were optimized together [9,10]. In this way the potential of the MAX I storage ring could be fully used. Based on these developments and the fact that there were many experienced spectroscopists involved, the laboratory managed to place itself in the absolute front line in photonuclear research and as a 550 MeV storage ring for the production of synchrotron radiation [3]. The build-up was handled by a very small staff and on a very limited budget. In spite of that the MAX I facility could be taken into operation in 1985.

Already when the MAX I facility started to operate, there were ideas at MAX-lab for a next facility. After some years, the ideas developed into the MAX II proposal for a 1.5 GeV 3rd generation storage ring. The laboratory presented plans for a highly competitive storage ring. The proposal was very well received and the project was approved already in 1991. In this way MAX II became one of the first third generation facilities to be built in the world, Fig. 3.

The design contained several new ideas, which made it possible to reach an emittance of below 10 nm rad with a storage ring with a circumference of only 90 m [13]. To achieve a sufficient compactness and also to make the construction of such a storage ring possible at a small laboratory a few actions were necessary. The most important one was the introduction of large CNC-machined girders on which all the magnets in one sector were placed without any other alignment methods. This required that the girders and the magnets were very precisely constructed and manufactured. This concept is now standard at other laboratories. Furthermore, different magnet types were combined into the same magnet item. The focusing quadrupole magnets were for instance machined to have the chromaticity correcting sextupoles integrated. The tuning possibilities were of course reduced, but the ring behaved according to theory and no large tuning was necessary. However, minor tuning was made possible by special tiny coils. The RF system consisted of a 3-cell DESY linac accelerator, which was kindly donated by DESY, and a 75 kW klystron amplifier. However, the ring showed a rather strong coupled-bunch instability at higher circulating currents and the beam lifetime became uncomfortable short. To solve this problem we started playing with harmonic passive cavities in the ring to fight these problems [14]. This was quite an unconventional way at that time, but at the end of the day, we had a very effective harmonic cavity system, which actually solved both issues. Harmonic cavities are now seen at many light sources.
Again an ambitious program for beamline build-up was initiated, supported by FRN, NFR and KAW. A set of spectroscopy beamlines were built up which came to define state-of-the-art in their respective disciplines [15–17]. The build-up was again heavily dependent on the engagement of a number of external user groups. This was necessary due to the very limited operational budget for MAX-lab at that time. This had the drawback that some of the beamline projects took longer time than if MAX-lab would have had the resources to take a more active role in the build-up of all beamlines. However, the advantage of this situation was that a very skilled and engaged user community was created in the country. MAX-lab developed into a truly national lab with very many researchers all over the country heavily engaged in the operation. There was also a strong international character of the laboratory. MAX-lab became the center for several international networks and collaborations, not the least involving the Nordic and Baltic countries.

The energy of the MAX II storage ring created opportunities also for hard X-ray activities. One of the very first beamlines was a multipurpose multipole wiggler beamline [18], which was used for macro- and small molecule diffraction as well as powder diffraction experiments. After a couple of years, it was evident that it was necessary for the laboratory to further strengthen this field of research. For this reason, two superconducting small period multipole wigglers were developed [19]. One of these was used for a material science beamline [20] and the other one was used for Life science research (Cassiopeia) [21–23]. The Cassiopeia set of beamlines used the wide fan of radiation from the wiggler for one central tunable wavelength station and four fixed-wavelength side-stations. A consequence of incorporating the superconducting devices in the ring was that the RF power demand for the storage ring grew significantly so we needed to boost up the RF system. To simply add RF power to our 500 MHz RF system was out of the question, since the construction budget for MAX II had been very slim, a consequence of the fact that the construction budget for MAX II had been very slim, a consequence of the fact that there were four national laboratories in the country, which all were successful in their respective disciplines. At the same time the general development of the funding situation in Sweden was such that the research council (NFR) had to keep essentially a fixed total budget for the national laboratories. This situation became increasingly difficult, not only for MAX-lab, but also for the other national laboratories.

After two evaluation processes, in 1997 and 2002, the research council took the painful decision to close down two laboratories in order to accommodate a reasonable increase for the remaining two laboratories. These were MAX-lab and the Onsala Space Observatory. Although the budget was still small on an international scale, the operation could with time be handled in a much improved way. If this change would not have happened it would have been impossibility to go further with the MAX IV plans. In fact, some initial plans for a MAX IV facility were presented already during the second of these evaluations. Although these long-term plans were not evaluated in detail, the fact that we were actively planning for the next step in the development of the laboratory was very well received by the evaluation committee.

A very important factor behind the continuous development of MAX-lab has been the existence of the academic research programs in accelerator physics and synchrotron radiation instrumentation, which have been well integrated in the activity. These programs are funded partly by the Faculty of Science and partly directly by Lund University. This has made it possible for MAX-lab to undertake long-term development projects, without these being in conflict with urgent needs connected to the daily operation. In this way there were all the time new and demanding accelerator projects at the laboratory. This made it possible to conduct a number of prototype projects, which were necessary for developing and evaluating the technologies used e.g. at MAX IV. The small staff also implied that all personnel had to take a large responsibility. These factors have been important for creating the expertise at the laboratory, which was necessary in order to define and undertake such a demanding project as MAX IV.

3. The MAX III project

The MAX III facility played a special role in the development of the laboratory. Although ideas for a new advanced facility had already started to develop it was clear that there were urgent needs that had to be handled more rapidly at MAX-lab. With a large and rapidly increasing user program, the reliability of the operation was a major concern. Due to the fact that the construction budget for MAX III had been very slim, a number of technical solutions had been chosen which did not influence the optimum performance of the facility but which constituted a risk for the operation. As the volume of the operation grew this risk became less and less acceptable.

The injection scheme for MAX II was based on the MAX I microtron injector. Electrons were injected into MAX I at 100 MeV. MAX I was then used to ramp up the electron energy to 500 MeV before injection into MAX II, where the energy was further ramped to 1.5 GeV. In this way the operation of MAX II was dependent also on the status of MAX I. This interconnection furthermore complicated the scheduling for MAX I, which still hosted high performance synchrotron radiation beamlines as well as the photonuclear activity. Another major concern was that
the microtron was aging and constituted a high risk for the operation. A breakdown of the microtron would cause an unacceptably long shutdown. A new injector was needed, and the most straightforward solution would be to build a booster synchrotron.

Another problem at MAX-lab was that MAX II, which only had a tenfold symmetry, was running out of straight sections for insertion devices. This generated the idea to build a small 700 MeV storage ring [24], which could host a few low energy beamlines. This could be made in a very cost effective way since it could be placed together with the booster synchrotron in the same radiation protection. A proposal to build a booster synchrotron and a 700 MeV ring was produced, and the proposal got funded without delays.

At that time MAX-lab also produced a proposal for preparing a Conceptual Design of a new facility (MAX IV). The proposal was successful and funding was granted by the Knut and Alice Wallenberg (KAW) foundation. When this happened it was decided to modify the MAX III and injector projects such that they could also be used to prepare for the MAX IV CDR in the best possible way. Among other things it was decided to choose a Linac solution as injector instead of the more conservative solution with a booster synchrotron. This was done in order to get experience from this technology [25]. The Linac was also used for a FEL test facility [26]. Also the MAX III project was modified such that it could serve as a prototype for some technologies to be used in MAX IV. These modifications of the MAX III and injector projects of course extended the time until the new injector was in place and also before the new storage ring came into operation. However, the possibility to combine these projects and build a test facility and a Linac was invaluable for the MAX IV project. Without these steps it is questionable if we would have managed to present a realistic project plan and furthermore, considering the new technologies involved it is questionable if we would have been able to convince the evaluation committees about the feasibility of the solutions.

4. The MAX IV science case

There were a number of different options, which had to be considered for a next facility at MAX-lab. A new improved storage ring was one possibility. Another possibility would be a Free Electron Laser (FEL). This is a unique X-ray source in terms of its enormous peak brilliance and short X-ray pulse capability. FEL projects were planned at several international laboratories at that time. Another option would be to aim for an energy recovery Linac. All these sources have very different characteristics. The necessary first step was therefore to identify the needs of the science community. This involved the strong MAX-lab user communities at MAX I, II and III. It was also important to consider the Swedish user communities that were using other synchrotron radiation laboratories, such as ESRF. It was also important to identify what completely new scientific opportunities would open up if different types of facilities were chosen. This could also involve science areas, which were not at all represented at the existing laboratory. Furthermore it was important to build a facility, which would be highly attractive internationally. In particular it was important to consider the interest from various science communities in the Nordic and Baltic countries.

These issues were discussed at a number of MAX-lab user meetings as well as at several smaller workshops, some of which were directed towards areas, which were not represented at MAX-lab before. One important event in the process of defining the scientific case for MAX IV was the workshop “Our Future Light-Source” which was arranged in Lund in 2004. This workshop gathered well over 400 participants who took active part in a number of parallel activities. This workshop created an excellent basis for the scientific case and the design of the facility. The intense work continued with further workshops, with discussions in the MAX-lab board and discussions with the MAX-lab Program Advisory Committee (PAC) and the Science Advisory Committee (SAC). These activities resulted in a scientific case, which was presented in the CDR report in 2006 [27].

This process led to a number of conclusions about what type of facility would best serve the Swedish science community: (i) Considering the large number of synchrotron radiation users in the country and with the potential of a new facility it was concluded that continuous radiation provided by storage rings was of highest priority. A storage ring has also the advantage that it can host many beamlines and a large number of users in parallel. (ii) It was also concluded that both soft and hard X-rays are important. The soft X-ray spectroscopy community in Sweden is very strong. At the same time it was clear that a storage ring of electron energy around 3 GeV was needed in order to be fully competitive in the X-ray regime. The possibility of adding a low-energy ring for the production of soft X-rays was therefore brought up as an option. (iii) For a new storage ring, top-up injection was mandatory. This implies that a full energy injector was needed. (iv) It was concluded that the storage ring (or storage rings) should be optimized for average brilliance. This excludes going for very hard X-rays for a 3 GeV ring, since the strong wigglers needed for that would influence the electron beam emittance negatively. There are also interesting opportunities for time resolved experiments in the ps time range, which can be handled very well by a storage ring. However, optimizing the storage rings also for time structure implies compromises, which would affect the optimum average brilliance. The decision was therefore not to include any options for achieving shorter electron bunches in the storage rings. (iv) One reason for taking this decision about time resolved experiments was also that a Linac driven source is a better choice for creating short bunches and high peak brilliance. Since this line of research is becoming of increased importance, it was concluded that a Linac would be the preferred type of injector. Even if the injector is used for top-up, it is most of the time available for other purposes. A linac injector gives opportunities for short bunch studies with spontaneous emission from an undulator or a wigglar. Furthermore, choosing a Linac also provides opportunities for a future development of a Free Electron Laser. If this will happen, it may turn out that the electron energy of the MAX IV injector will not be sufficiently high for the planned scientific program. In that case one would need to add additional accelerator elements, and hence a lengthening of the linac. There should also be sufficient space for the FEL beamlines after the Linac. It was therefore emphasized that the site for the MAX IV facility should allow such a future expansion.

With MAX IV, the laboratory would get access to a drastically increased brilliance, access to harder X-rays, a higher degree of coherence and much improved spatial resolution. With the choice of a linac injector, which could also be used for X-ray beamlines, the laboratory would also get improved possibilities for time resolved measurements. One important development, which was identified, was to create opportunities for nanometer resolution probes to meet the needs within the nanoscience and nanotechnology fields. Other important fields are basic materials science and materials engineering. A new facility should also ensure easy and timely access for data collection on macromolecules, for academic users as well as for industry. There is also a geoscience community with interest in studies under extreme conditions. Another area, which was emphasized was environmental science on the atomic and molecular scale. A large interest was also expressed for the study of chemical reactions and processes under relevant conditions and time frames. One important area, which has always been very strong at MAX-lab, is the study of fundamental scientific problems on atoms, molecules and free clusters of importance for the formulation of more complete theories, and for the further development of the spectroscopic probes. The facility should also provide a platform for advanced industrial research. It was also emphasized that the new facility should expand and facilitate the access to state-of-art synchrotron radiation to the Nordic/Baltic region and that it could play an important role as a focal point for interdisciplinary research and research education in natural sciences.
5. Accelerator design considerations

At the time when the ideas for the facility started to take form, i.e. around the millennium shift, the construction of 3rd generation sources had turned into a real success story. One after the other, facilities were completed, delivering and even surpassing the design performance in time and on budget. But at the same time, the ring technology was seen as mature. No major further improvements were judged to be possible. The reason for this was that when trying to reduce the electron beam emittance, stronger chromaticity correcting sextupoles had to be introduced and this implied that the dynamic apertures shrunk to unacceptable small values. This was seen as the “chromaticity brick wall”.

However, we had a hope of finding a hole in this solid wall of instabilities. Instead of tuning the lattice towards the Theoretical Minimum Emittance (TME) we started working with another parameter, the number of elementary cells in the ring, since the electron beam emittance decreases with the third power of the number of such cells. The main reason why this way of reducing the electron beam emittance had not been seen as realistic was that the rings became prohibitively big. Moreover, it was not clear how to correct the natural negative chromaticity to positive values in a good way.

The road to solve these problems was to strongly miniaturize the magnet elements and to correct the chromaticity at the places they were formed. This is easily said, but this solution implied severe problems. All accelerator subsystems, which work in harmony with each other in 3rd generation light sources, had to be re-designed. The new rings had to be more stable, the diagnostics had to be improved, sufficient beam lifetime had to be achieved, etc. When reducing the size of the magnets, conventional vacuum systems could not work since the necessary small sizes led to vacuum conductances, which were much too small. The small magnet apertures also introduced very tight mechanical tolerances. Furthermore, the high electron density gave too short beam lifetimes since the collisions between the electrons (Intra-Beam Scattering) became serious. The mechanical stability of the machine must be increased if beam movements should not ruin the high performance etc. The simplified sketch below demonstrates the situation. Almost all technical systems must be redesigned if the machine should work properly (System integration), Fig. 4.

When it comes to covering a broad spectral range, the evident solution was to use two storage rings. Using only one ring, it is hard to cover the entire spectral range since it is hard to design high performance undulators with broad spectral ranges. Making two rings, operating at different electron energies seemed to be an attractive solution. The added cost for the low energy ring is relatively marginal since all infrastructure in terms of injector, cooling water, electricity etc., is anyway needed for the first ring.

The first solution which was proposed was to build two identical storage rings. Each of them housed 12 achromats and the 3 GeV ring had a natural emittance of 1 nm rad. At that time, this emittance value was judged quite aggressive and we hesitated to push the emittance reduction further since the dynamic aperture was reduced when going to smaller beam emittances. The two rings should be placed above each other, one operating at 3 GeV and the other one at 1.5 GeV. The natural emittance of the latter ring was only 0.34 nm rad. In this way one could cover the broad spectral range needed with reasonable insertion devices. The small size of all magnet elements made it possible to propose this solution with two rings on top of each other. This is the solution, which was described in the CDR. When the CDR was completed, a proposal for funding of MAX IV was submitted to the research council. The proposal and the CDR were evaluated and it was recommended that the project should be funded.

An unfortunate limitation with this size of the 3 GeV ring was the relatively small number of possible X-ray beamlines. With time we also started feeling quite convinced that the reduced dynamic aperture in a 3 GeV ring with 20 achromats was acceptable. In spite of the fact that the original proposal had already been accepted and recommended for funding, we decided to present a modified proposal with a larger 3 GeV ring. With this solution the size of the 1.5 GeV ring was instead reduced in order to make the modification relatively cost neutral. Since this was such a major modification of the project a new evaluation had to be undertaken. Also the new proposal was evaluated in a positive way and we again got a recommendation for funding, Fig. 5.

A FEL, could of course not be included in the original MAX IV design. We could, as mentioned above, prepare for a coming FEL by choosing a linear accelerator as injector for the storage rings instead of the more conventional solution with a booster synchrotron and a pre-injector. By doing this, the main capital investment for a future FEL should already be taken by the MAX IV project. Admittingly, the investment cost for a linear accelerator was estimated to be some 20% higher than the cost of a solution based on a booster synchrotron. This situation was communicated to the funding authorities, and wisely enough, they fully understood the advantage of a linear accelerator. In fact, the work on a Conceptual Design Report for a soft X-ray Free Electron Laser based on this linear accelerator (financed by the Knut and Alice Wallenberg foundation), is now being prepared.

One interesting aspect of the 1.5 GeV ring was that the European Union had at the same time provided funding for a storage ring in Krakow, Poland. Due to the limited experience in the field of accelerator physics in Krakow, MAX-lab was contacted in order to find out if MAX-lab could assist in this process. A collaboration agreement was signed between MAX-lab and the Jagiellonian University in Krakow. A solution was worked out where the SOLARIS facility in Krakow, should be built as an identical twin to the MAX IV 1.5 GeV storage ring [28].

6. Machine design realization

When the backbones of the design had been established, all the difficult parts remained. How should the ideas be turned into a realistic design? Furthermore, the project had to be squeezed into a realistic and thus lean budget Technical realizations had to be found for all the advanced scientific solutions. These issues were handled in the Conceptual Design Report (CDR) which was also needed in order to start discussions about the possible funding of the project.

This CDR covered two parts; the scientific case (see above) and the conceptual design of the accelerator complex. As mentioned above, the work needed to produce the latter part was funded together with the work on the MAX III storage ring and the new injector.

The key strategy was to solve the instability problems due to the large negative chromaticity necessarily introduced by the emittance reduction. The chromaticity correcting sextupoles had to be strong and these strong sextupoles generally reduce the dynamic aperture with the consequence that the machine gets unstable. The way to fix this problem was to arrange the sextupoles in such a way that their instability action could be minimized while their chromaticity correcting effect remained. This was realized by introducing the multi-bend achromats. Putting in several (in our case 7) bending magnets (instead of 2) in an achromat opened up the opportunity to reduce the instability effect from the sextupoles. Alas, this implied that the achromat had to house the associated focusing magnets as well as the chromaticity correcting sextupoles so a conventionally designed machine would grow substantially in size. This implies that everything had to be minimized. The conventional method to put discrete magnets on a strong, tightly machined girder (as pioneered for MAX II) was out of the question. We also had to solve the stability problem and we were also facing the fact that our resources were too limited to put up some 1400 magnet elements with high precision in a realistic time. The solution was to introduce magnet blocks made of solid soft steel where everything was CNC-machined out. This offered the demanded compactness and we got a very rigid construction, Fig. 6. Another consequence of this was that the number of items to be handled reduced with one order of magnitude. However, this miniaturization introduced

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another problem; the vacuum conductance of the small vacuum chamber bore did not allow for lumped pumps, the gas molecules could not find their way to the pumps any longer. A linear pumping system had to be used in the form of NEG-coated inner surfaces, a technology being developed at that time. The list of new solutions needed was long. Intra-beam scattering, rf systems, diagnostics, instability issues etc. introduced new demands which had to be handled [29–31].

Once the CDR was completed, a Detailed Design Report (DDR) had to be produced [32]. In the DDR, as the name indicates, all the conceptual solutions have to be turned into final constructions.
for the commissioning of our 1.5 GeV ring, which went into operation
Meanwhile, a copy of the 1.5 GeV ring was started up at SOLARIS in
reasons, the priority was put on the commissioning of the 3 GeV ring.
electrons went around in the 3 GeV ring in the fall of 2015. For obvious
and clear and distributed responsibilities.
short, the installation and commissioning went well. For the installation,
procurement could start up in September 2010. To make a long story
provides the specifications needed for the civil engineering processes.
Furthermore, the DDR should stand a final critical evaluation and also
form a basis for a realistic cost estimate. The DDR also contains the
detailed technical specifications needed for the procurement. It also
provides the specifications needed for the civil engineering processes.

7. Machine realization

The final funding decision was taken in the summer of 2010. To make a long story
short, the installation and commissioning went well. For the installation,
we relied heavily on consultants and friendly laboratories. This was a necessary and economically sound solution considering the small staff
available. For this, as well as for the commissioning, the advantage of
having a small staff became evident. It is our strong belief, that a small,
dedicated staff can outperform larger organizations in terms of easier
decision taking, short communication routes, professional pride and
clear and distributed responsibilities.

The linac delivered a stable beam at the end of 2014 and the first
electrons went around in the 3 GeV ring in the fall of 2015. For obvious
reasons, the priority was put on the commissioning of the 3 GeV ring.
Meanwhile, a copy of the 1.5 GeV ring was started up at SOLARIS in
Krakow. The experience from this commissioning was quite beneficial
for the commissioning of our 1.5 GeV ring, which went into operation
2016.

8. Present status and outlook

In the beginning of 2018 the two storage rings were in a normal
operational state. The 3 GeV ring was operating with top-up operation
using a multi-pole injector kicker at 350 mA with a quiet beam. Work is
in progress to damp instabilities at higher currents. The 1.5 GeV ring
was operating in mainly decay mode at 200 mA circulating current. The
Linac serves the two storage rings and it delivers beam to the Short
Pulse Facility (FemtoMAX) as planned, see Fig. 7. The repetition rate at
FemtoMAX [33] was still only 2 Hz. The rate will be increased as soon
as the required radiation safety permission is obtained.

Some 15 beamlines have been funded so far. Most of these are completely new beamlines, but a few are based on beamlines from
MAX II, which have been relocated and upgraded. The beamlines are
at different stages of build-up and commissioning. The first beamline
went into user operation during 2017.

As discussed above, the lead-times for new upgrades are long and it is
vital for the laboratory to keep a continuous planning for the future. For
this reason plans for an upgrade of the newly started facility has started to
be prepared with the goal that the MAX facilities should stay in the
frontline of Synchrotron Radiation research for all foreseeable future.

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