ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

LONG TERM ACCELERATOR R&D AS AN INDEPENDENT RESEARCH FIELD

R. Brinkmann, DESY, D-22607 Hamburg, Germany

Abstract

High energy physics projects have been important drivers of accelerator R&D for several decades. The resulting accelerator technology was used to construct frontier accelerators for HEP but was also very successfully applied in accelerators for other science fields, in particular photon science, nuclear physics, medical applications, ... Fewer HEP projects and at the same time a growing number of projects in other areas require a modified approach to accelerator R&D. Efforts and progress to perform accelerator R&D as an independent research program with its own, independent funding are described for the example of the Helmholtz ARD program in Germany. Links to efforts in other countries are discussed and an outlook to future accelerator research is given.

INTRODUCTION

Accelerators have a long history as enabling technology for a broad range of science and applications. A main driver for performing accelerator R&D was often High Energy Physics. HEP will certainly maintain a strong role for years to come [1], with ongoing and planned projects like LHC with its upgrades [2], SuperKEKB [3], future extremely high energy circular colliders [4], linear colliders [5 – 8] and muon colliders/neutrino factories [9]. At the same time the usage of accelerators in other fields is continuously broadening, with challenging technological and accelerator physics demands and new concepts and ideas emerging in many areas. Considerations of these developments have recently led in the Helmholtz Association, Germany's largest research organisation [10], to the implementation of accelerator R&D (ARD) as an own research topic. The basic ideas of this approach and a brief overview of the ongoing and planned scientific activities in this programme are given in the following.

ARD IN HELMHOLTZ

The six Helmholtz centres (DESY, GSI, FZJ, HZB, HZDR, KIT) and two Helmholtz institutes (HIJ, HIM) which are involved in the development, construction and operation of accelerator facilities in 2010 launched the initiative to implement ARD as an own program topic in the portfolio of the research field Matter. This led to the approval for starting the implementation of ARD by the Helmholtz Senate in June 2011. A total funding of 16.7M€ was granted for the implementation phase 2011 – 2014. In the 3rd period of programme-oriented funding (PoF-III, 2015 – 2019) ARD is fully implemented in the Helmholtz research portfolio. As one of two topics in the programme Matter and Technologies (the 2nd one is Detector Technology and System, DTS) ARD is part of the PoF-III proposal for the research field Matter which has recently completed the evaluation process. The planned funding for ARD amounts to about 30M€/year. In March 2014 the ARD topic was presented to the international evaluation committee by a team of scientists and PhD students (Figure 1) and received very positive feedback from the committee.

Figure 1: The ARD team at the rehearsal for the PoF-III evaluation at HZDR, February 2014.

Research and development in accelerator physics and technology was always a prerequisite for the successful research in Helmholtz. Germany has traditionally been one of the leaders in accelerator technology and it is our goal to maintain leadership capabilities and strengthen resources by synergy between the Helmholtz labs and partners in universities and industry. In the past these activities were generally directly related to specific facilities and projects and thus linked to and allocated in the different programs of POF II (and POF I). The implementation of ARD and its continuation as an own topic in POF III maintains this strong link to other programs and its impact on the research field Matter. Successful R&D activities will foster improvements and the invention of new concepts for existing accelerator facilities or ongoing projects (e.g. ANKA, BESSY II, FAIR, FLASH and EU-XFEL). This R&D will remain critical for the healthy development of research in Helmholtz. However, the objectives of ARD go beyond this direct impact on the other programs in Matter. An independent accelerator program can give dedicated support to generic, future oriented research. This research must also include more "risky" activities with ambitious goals, where a potential for high-impact applications comes together with significant initial technical

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

uncertainties whether "it can be made to work". Important benefits for other research fields (e.g. Health, with compact accelerators for medical treatment and imaging) and for industry are possible. Regarding industry, an important impact of ARD is also the transfer of technology and expertise from the research labs, thus advancing the skills and manufacturing capabilities of companies involved in the accelerator business.

A central aspect of ARD and strong driving force for its implementation is the improvement of networking and cooperation between the Helmholtz centres and with Universities participating in the program. Several new ideas for joint projects between Helmholtz labs and universities, common usage of infrastructure and exchange of newly developed technology have already emerged during the first two years of implementation phase.

The creation of the ARD program had a profound and very positive impact on visibility and international recognition of German accelerator R&D. The visibility of accelerator R&D and its attraction to students at the partner universities[#] has considerably improved. Furthermore, several new co-operations with international partners have already been launched, will be carried out and further extended in the POF III period. As of today, 16 German universities and more than 30 international institutes are cooperating on activities within ARD. Links to European programmes like EUCARD[2] [11] are well established.

RESEARCH PROGRAMME

The ARD activities are structured into four sub-topics (ST1 – ST4) and will in the following be briefly summarized according to this structure - without ambition of being fully comprehensive in this short overview paper. Each of these four sub-topics represents a highly relevant and future-oriented strategic research area. This groups the well-defined ARD activities in a logical way and helps to organize the joint research work from a practical point of view. However, there exists a large amount of overlap, synergy and co-operation across the borders of the sub-topics, which strengthens the coherence of the programme.

ST1: Superconducting RF Science and Technology

An example of very successful R&D on SRF technology is the development of the TESLA technology. In 1993 the international TESLA collaboration, coordinated at DESY in Germany, launched the development of high performance SRF systems with the goal of building a high energy linear collider [12]. The X-ray laser originally integrated in the TESLA project is now under construction in Hamburg as the European XFEL project [13], the linear collider is pursued by the worldwide ILC collaboration [14] and the TESLA *Technology* Collaboration continues the R&D in a broader and more generic fashion. Industry has by now delivered hundreds of TESLA cavities for the EU-XFEL project [15] with an average gradient of close to 30MV/m, and R&D towards highest gradients for ILC is still continued in Helmholtz [16]. Within ARD, the emphasis in sub-topic 1 is on the potential of SRF technology for the efficient acceleration of high intensity and high quality beams in CW mode with low parasitic impedance coupling to the beam. Pushing the limits of CW-SRF enables a great variety of applications ranging from new concepts for storage rings [17] to upgrades [18] and new construction [19] of FELs, ERLs [20] and proton and ion accelerators [21 – 23]. Furthermore, there is growing interest for industrial applications [24, 25] and nuclear energy production [26].

For the improvement of Q_0 in medium to high gradient Niobium cavities, crucial for the investment and operation cost of SRF projects, different aspects are addressed in ARD-ST1. It has been found that the cool-down rate through T_c can significantly impact Q_0 [27, 28] and this effect needs to be better understood especially since results for different set-ups show an apparently inconsistent behaviour. Cavities fabricated from large-grain Niobium have shown a systematically higher Q_0 than those fabricated from the usual fine grain material [29]. In a recent test of a EU-XFEL prototype cryomodule equipped with 7 large grain cavities (and one fine grain cavitiy) a Q_0 of $4{\cdot}10^{10}$ was measured at an accelerating gradient of 15 MV/m and 1.8 K helium temperature. Further Q_0 improvements seem to be possible at least at medium-high gradients with a recently discovered beneficial effect of baking Niobium cavities with Nitrogen, followed by chemical removal of a few micron thin layer from the surface [30].

With regard to high beam currents, HOM damping and power extraction is an important R&D item. ST1 is focusing on the development of waveguide-damped units, which will be installed and tested with electron beam up to 100mA in the energy recovery linac test facility BerLinPro at HZB [31].

CW-SRF guns as efficient injectors for high-quality intense electron beams [32] are a core item of R&D in ST1. An L-Band SRF gun is successfully in operation at the ELBE facility since several years. However, high-brilliance electron beams require higher peak fields on the cathode and an improved version of the HZDR-gun is at present under test [33]. Additional test infrastructure is being built up at HZB [34]. A critical R&D item is the integration of non-superconducting cathodes into the Niobium cavity. For low beam current (<1 mA) a technically simpler superconducting PB-cathode is an option [35]. Higher intensities require Cs_2Te, multi-Alkali [36,37] or GaAs [38] material. In addition to the generation of a brilliant "wanted" beam, the avoidance of unwanted beam (halo, dark current) is indispensable for high intensity CW accelerators and this aspect is receiving much attention in the ST1 activities [39].

#RWTH Aachen, HU-Berlin, U-Bochum, U-Bonn, TU-Darmstadt, TU-Dortmund, TU-Dresden, U-Frankfurt, U-Giessen, U-Hamburg, TU-Harburg, U-Jena, U-Mainz, U-Rostock, U-Siegen, U-Wuppertal

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

For hadron accelerators the SRF R&D is directed to ß<1 systems and primarily focused on crossbar H (CH) structures [40]. The main objective here is towards future developments for the FAIR facility [22], but there is also international interest from and cooperation with projects such as SPIRAL2@GANIL, FRIB@MSU, ISAC@TRIUMF, RISP@IBC and HIAF@IMP. The R&D challenges here include pushing the gradient of mechanically complex Niobium structures which are difficult to clean, developing high rf power couplers and handling the shielding of very strong magnetic solenoid fields in the vicinity of the cavities.

The cooperating partners for the ST1 activities are the German universities TU-Dortmund, U-Frankfurt, U-Hamburg, U-Mainz, U-Rostock, U-Siegen, U-Wuppertal and international institutes BINP, BNL, Cornell-U., Daresbury Lab, JLab, LBNL, Moscow State-U, NCBJ-Swierk, St. Petersburg State Polytech.-U, SLAC and TRIUMF.

ST2: Concepts and Technologies for Hadron Accelerators

A large fraction of the R&D programme in ST2 is devoted to the challenge of ultimate heavy ion intensities connected with the future development of the FAIR facility [22, 41]. The main themes here are the following:

Ion sources development will go into the direction of superconducting design (such as at RIKEN [42]) as well as to the improvement of spin-polarized sources. The latter can be tested at the COSY ring at FZJ [43].

Superconducting magnet development is aiming at very fast cycling magnets, injection/extraction septum magnets and very large aperture quadrupoles for heavy ion final focus systems.

Dynamic vacuum is a serious issue with high intensity beams in heavy ion synchrotrons [44]. Experimental and simulation studies will be performed regarding sticking and desorption of gas molecules on cryogenic surfaces and vacuum stability.

Feedback system development is aiming at the longitudinal stabilization of hadron beams [45] with broadband pickup, signal processing and cavity-kicker devices.

Beam diagnostics and detection devices will be developed for a very broad range of heavy ion beam parameters.

Injector linac design studies are being performed and improved H-type accelerator structures are under development [46].

Beam cooling is addressed [47] with developments on stochastic cooling [48], high-energy electron cooling [49, 50] and laser cooling [51] of ion beams.

In addition to the above themes ST2 includes investigations towards precision experiments aiming at the search for electric dipole moments of protons or deuterons. The studies, conducted within the framework of the JEDI collaboration [52], include the development of hardware, spin dynamics simulation [53] and first exploratory experiments at COSY [54] before construction of a special EDM-search storage ring can be envisaged.

Besides German universities RWTH-Aachen, U-Bonn, TU-Darmstadt and U-Frankfurt, international cooperation partners on ST2 include ASG-Genova, BINP, CERN, IHEP-Protvino, IMP-Lanzhou, INFN, INR-Troitsk and RIKEN-Nishina.

ST3: Ps and Fs Electron and Photon Beams

Sub-topic 3 of ARD can be categorized in three main areas: **beam dynamics and photon sources**, **ps-fs beam diagnostics** and **stability, controls and synchronisation**.

For storage ring-based photon sources the R&D programme includes low- to zero-α_c lattices with highly non-linear longitudinal beam dynamics and studies of THz generation [55] from microbunching instabilities. Both the BESSY-II and ANKA storage rings operate part time in low-α_c mode for users and further systematic studies are planned towards the understanding and control of short-bunch operation. For BESSY-II a new approach is under development [17] in which two additional rf systems at higher frequency will permit simultaneous storage of bunches with one order of magnitude difference in bunch length. The development of strongly HOM-damped superconducting rf structures is crucial for this development and is an example for the strong links and synergies between the sub-topics of the ARD programme. In yet another approach of bunch manipulation at the DELTA ring (TU-Dortmund) the generation of coherent radiation is enabled by seeding with a laser pulse [56].

For linac-driven photon sources the generation of brilliant radiation with femtosecond resolution is a central theme and is being pursued at the ELBE [57], FLASH [58] and FLUTE [59] facilities. The electron beam brilliance is a decisive factor here and the continuation of rf gun development [60] and the above mentioned SRF gun R&D are crucial in this context. The interaction of electron and laser beams is a rapidly growing field and within ARD concepts for seeded FEL radiation [61-63] and Compton-backscattering X-ray sources [64,65] are being pursued. With an innovative ansatz using THz waves [66,67] aiming at even sub-femtosecond X-ray photon pulses a group of accelerator and photon scientists (a cooperation of DESY, U-Hamburg and Arizona State University) recently won an ERC synergy grant and plan to integrate their activities with the new ARD infrastructure SINBAD [68] under design at the DESY site.

Making high-brilliance, short beam pulses usable requires extremely good beam stability and femtosecond diagnostics and synchronization. The concept of transverse deflecting rf structures for longitudinal bunch profile diagnostics was pioneered at SLAC, is being further developed and has recently at LCLS achieved a resolution approaching the single femtosecond level [69]. The development of precision electronics for the control of linac rf parameters is crucial for beam energy and timing stability [70]. In a process of successful

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

technology transfer [71] the new MTCA.4 standard (originally derived from telecommunications industry technology) is being developed which has applications in a broad range of scientific projects. Optical-to-rf synchronization concepts are approaching the single femtosecond resolution and stability [72,73]. Bunch arrival time monitors (BAM) at femtosecond level are used at FLASH to stabilize the beam timing [74], utilizing the intra-bunch train fast feedback option only possible in a superconducting linac, and further BAM development is ongoing [75,76].

The cooperation partners in ST3 are the German universities HU-Berlin, U-Bochum, TU-Dortmund, TU-Dresden, U-Hamburg, TU-Harburg, and international institutes JINR, JLab, MIT, NCBJ, PTB, PSI, SLAC, TU-Lodz and TU-Warsaw.

ST4: Novel Acceleration Concepts

Sub-topic 4 is focusing predominantly on compact acceleration of hadron and electron beams with extremely high accelerating fields achieved in plasmas excited by laser pulses or particle beams. This is a very active and competitive field being pursued by more than 50 research groups worldwide. In the ARD program we are merging plasma acceleration expertise with more conventional but high level available concepts, technologies and infrastructures and aim our activities at the production of ***usable*** beams [77]. Regarding protons/ions, the Target Normal Sheath Acceleration (TNSA) regime enabled in Helmholtz by the Terawatt to Petawatt laser infrastructures at GSI, HZDR and HI-Jena is promising for controllable and reproducible beams, including the potential for medical applications [78 – 80]. With even further improvements of laser technology the Radiation Pressure Acceleration (RPA) regime will come in reach with excellent perspectives for the achievable beam quality [81].

R&D on laser driven plasma wakefield acceleration of electrons (LPWA) addresses challenges like stable and reproducible generation of high-quality beams, extraction from the plasma and beam transport without intolerable chromatic emittance growth and external injection and staging. Very compact radiation sources are a direct application of LPWA and demonstrators for monochromatic spontaneous radiation [82], FEL beams [83] and X-ray Thomson backscattering sources [84] are part of the programme. First exploratory experiments with external injection of pC bunches into a plasma wakefield will be performed at the 5 MeV REGAE accelerator at DESY [85]. Further experiments can be done at the ELBE accelerator and Petawatt class laser installations at HZDR and in the future at new dedicated ARD infrastructures [68].

Particle beam driven excitation of plasma wakefields is an approach complimentary to LPWA. Such experiments have been pioneered at SLAC and are part of the actual programme at FACET, in particular with respect to the very promising controlled internal injection of electrons into the plasma wakefield [86,87]. Within Helmholtz, the FLASH facility is particularly well suited for beam-driven plasma acceleration R&D [88]. An additional beam extraction line in the new FLASH2 beamline tunnel will be used and the experiments will profit from the excellent stability of the FLASH superconducting linac and the availability of femtosecond technology for synchronization and arrival time diagnostics (another example of strong links between the ARD sub-topics). Precursor experiments of plasma wave excitation will take place at the PITZ facility at DESY, where results on self-modulation of electron bunches in a plasma [89] will also be relevant for the proton-driven PWA experiment AWAKE at CERN [90].

The cooperation partners in ST4 are the German universities TU-Darmstadt, TU-Dresden, U-hospital Dresden/Onco-Ray, U-Frankfurt, U-Hamburg and U-Jena and national/international institutes CERN, INFN-LNF, J. Adams Inst., LBNL, MPP-Munich, SLAC and U-Strathclyde.

OUTLOOK

With the implementation of accelerator R&D as an own topic in Germany's largest research organisation, the future perspectives in this area at the Helmholtz centres and partner universities are excellent. New dedicated ARD infrastructure for which a strategic funding proposal to Helmholtz is in preparation will further enhance the highly synergetic joint research projects. The quality of the work and the ambitious goals defined are competitive with top-level similar activities ongoing worldwide. At the same time, ARD represents a well suited platform for efficient cooperation with many international partner institutes on a broad range of exciting accelerator physics and technology. The visibility of accelerator physics and technology is increased and more young talents are attracted to this science. This is a healthy development which is good for our field.

ACKNOWLEDGMENT

Many colleagues in the Helmholtz centres/institutes and collaboration partners have contributed to shape the research programme described in this paper. As the ARD spokesperson I am particularly grateful to the ARD core team which has worked out the R&D plans, compiled the material and presented our case at the Helmholtz PoF-III evaluation.

REFERENCES

[1] F. Gianotti, "Options and prospects for accelerator-based High Energy Physics", this conf. FRYCA01.
[2] hilumilhc.web.cern.ch/HiLumiLHC/index.html
[3] K. Akai, "Construction status of SuperKEKB", this conf. WHOCA01.
[4] F. Zimmermann, "Challenges for highest energy circular colliders", this conf. MOXAA01.
[5] T. Behnke et al. (eds), "ILC technical design report", arXiv:1306.6327[physics.acc-ph].

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

[6] K. Kubo, "Towards an international linear collider: experiments at ATF2", this conf. WEZA01.
[7] W. Farabolini, "Recent results from CTF3 two-beam test stand", this conf. WEOCA02.
[8] P. Burrows, "Status of the CLIC-UK R&D programm", this conference TUPME008.
[9] J.P. Delahaye, "A staged muon accelerator facility for neutrino and collider physics", this conf. WEZA02.
[10] www.helmholtz.de/en/
[11] Eucard2.web.cern.ch
[12] R. Brinkmann et al. (eds), TESLA Technical Design Report, Part-II, DESY-2001-011 (2001).
[13] www.xfel.eu
[14] www.linearcollider.org
[15] H. Weise, "how to produce 100 superconducting modules for XFEL in collaboration with industry", this conf. WEIB03.
[16] A. Navitski et al., "Progress of R&D on SRF cavities at DESY towards the ILC performance goal", this conf. WEPRI011.
[17] G. Wüstefeld et al., "Simultaneous long and short bunches in the BESSY-II storage ring", Proc. IPAC2011 San Sebastian, THPC014.
[18] R. Brinkmann et al., "Prospects for CW and LP operation of the European XFEL in hard X-ray regime", DESY 14-025, arXiv:1403.0465 [physics.acc-ph] (2014).
[19] J. Galayda, "The LCLS-II project", this conf. TUCA01.
[20] C. Mayes, "Recent advances in energy recovery linacs", this conf. FRXBB01.
[21] J. Wei, "The very high intensity future", this conf. MOYBA01.
[22] O. Kester, "Status of the FAIR accelerator facility", this conf. WEPRO060.
[23] H. J. Kim, "Superconducting linac for rare isotope science project", this conf. WEOBA02.
[24] C. Pagani et al., "Design considerations of a MW-scale, high-efficiency, industrial-use, ultraviolet FEL amplifier", Nucl. Instr. Meth. **A 455**, 733-758 (2000).
[25] Y. Socol et al., "Compact 13.5nm FEL for extreme UV-Lithography", PRST-AB **14**, 040702 (2011).
[26] W. Pan, "Overview of worldwide accelerators and technologies for ADS", this conf. FRXCB01.
[27] J.-M. Vogt, O. Kugeler and J. Knobloch, „Impact of cool-down conditions at Tc on superconducting rf cavity quality factor", PRST-AB **16**, 102002 (2013).
[28] R. G. Eichhorn, "Investigation of thermocurrents limiting the performance of superconducting cavities", this conf. WEPRI060.
[29] W. Singer et al., "Development of large-grain cavities", PRST-AB **16**, 012003 (2013).
[30] A. Grasselino et al., "Nitrogen and Argon doping of Niobium for superconducting radio frequency cavities: a pathway to highly efficient accelerating structures", arXiv:1306.0288.
[31] M. Abo-Bakr et al., "Status of the ERL prototype BerLinPro", this conf. MOPRO106.
[32] J. Teichert, "Superconducting rf guns: emerging technology for future accelerators", this conf. MOZB01.
[33] A. Arnold et al., "Commissioning and first results of the second 3.5 cell Rossendorf SRF gun", this conf. MOPRI022.
[34] J. Voelker et al., "Introducing GunLab: a compact test facility for SRF photoinjectors", this conf. MOPRI020.
[35] J. Smedley et al., "First demonstration of electron beam generation and characterization with an all superconducting rf photoinjector", Proc. IPAC2011, THPC109.
[36] M.H.A. Schmeißer et al., "In-situ characterization of K2CsSb photocathodes", this conf. MOPRI019.
[37] T. Rao et al., "K2CsSb photocathode preparation and its performance in SRF gun", this conf. MOPRI059.
[38] R. Xiang et al., "NEA-GaAs (CS,O) photocathodes for the ELBE SRF gun", this conf. MOPRI024.
[39] Unwanted beam workshop, HZB 17-18 Dec 2012, indico.helmholtz-berlin.de/conferenceDisplay.py?confId=2
[40] W. Barth et al., "Further R&D for a new superconducting CW heavy ion linac at GSI", this conf. THPME004.
[41] P. Spiller, "Status of the FAIR synchrotron projects SIS18 upgrade and SIS100", this conf. WEOBA01.
[42] T. Nakagawa et al., "Status of RIKEN sc-ECRIS", Proc ECRIS2010, MOCOAK03.
[43] R. Gebel et al., "Long term performance of the COSY/Jülich polarized ion source", Proc. 25th Int. Workshop on Polarized Sources, Targets and Polarimetry, Charlottesville, Sept. 2013.
[44] P. Puppel et al., "Dynamic vacuum stability in SIS100", Proc. IPAC2011, WEPS094.
[45] D. Lens et al., "Stability of longitudinal bunchlength feedback for heavy ion synchrotrons", PRST-AB **16**, 032801 (2013).
[46] A. Almomani and U. Ratzinger, "A 325MHz high gradient CH – test cavity for ß=0.16", this conf. THPME010.
[47] C. Dimopoulou, "Beam cooling systems and activities at GSI and FAIR", this conf. MOPRI067.
[48] H. Stockhorst et al., "Simulation and experimental studies of stochastic momentum cooling with barrier bucket cavity and internal target for the HESR at COSY", this conf. MOPRI071.
[49] M.-W. Bruker et al., "Status of the HESR electron cooler test setup", this conf. MOPRI073.
[50] V. Kamerdzhiev, "2MeV electron cooler for COSY and HESR – first results", this conf. MOPRI070.
[51] M. H. Bussmann et al, "Cooling of bunched relativistic ion beams using a CW laser with frequency scanning range greater than the bucket acceptance", this conf. MOPRI068.
[52] collaborations.fz-juelich.de/ikp/jedi/about/introduction.shtml

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-FRYBA01

[53] S. Chekmenev, "Estimation of systematic errors for deuteron EDM search at a storage ring", this conf. THPRO056.
[54] A. Lehrach et al, "Precursor experiment to search for permanent EDMS of protons and deuterons at COSY", arXiv:1201.5773v1 [hep-ex] (2012).
[55] A.-S. Müller et al., „Simultaneous studies of bursting CSR with different detector systems at the ANKA storage ring", this conf. MOPRO063.
[56] M. Huck et al., "Ultrashort and coherent radiation for pump-probe experiments at the DELTA storage ring", this conf. WEOAA03.
[57] P. Michel et al., "Status of the radiation source ELBE upgrade", this conf. WEPRO113
[58] M. Vogt, "Status of the free electron laser user facility FLASH", this conference TUCA02.
[59] M. Schwarz et al., "Status of FLUTE", this conf. MOPRO066.
[60] M. Khojoyan et al., "Studies on the application of the 3D ellipsoidal cathode laser pulses at PITZ", this conf. THPRO043.
[61] S. Ackermann et al., "Generation of coherent 19 and 38nm radiation at a free-electron laser directly seeded at 38nm", Phys. Rev. Lett. **111** (2013).
[62] J. Bödewadt and C. Lechner, "Results and perspectives of the FEL seeding activities at FLASH", Proc. FEL2013 New York, WEPSO02.
[63] K. Hacker, "A concept for seeding 4 – 40nm FEL radiation at FLASH2", report TESLA-FEL 2013-02 (flash.desy.de/reports_publications).
[64] A. Jochmann et al., "High resolution energy-angle correlation measurement of hard X-rays from laser Thomson backscattering", this conf. WEPRO054.
[65] J. M. Krämer et al., Final focus system for Thomson scattering at ELBE, this conf. THPRO055.
[66] A. Fallahi et al., "Complete simulation of laser induced field emission from nanostructures using a DGTD, PIC and FEM code", this conf. MOPRI026
[67] E. A. Nanni et al., Electron linear acceleration in THz waveguides, this conf. WEOAB03.
[68] R. Aßmann et al., "SINBAD – a proposal for a dedicated accelerator research facility at DESY", this conf. TUPME047.
[69] P. Krejcik et al., FEL dynamics measured with the X-band transverse deflecting cavity, this conf. WEOBB03.
[70] C. Schmidt et al, "Performance of the MTCA.4 based LLRF system at FLASH", this conf. WEPME067.
[71] T. Walter et al., "MTCA.4 for industry: A status update on the introduction of a novel crate standard", this conf. WEPME081.
[72] T. Lamb et al., "Femtosecond stable laser-to-RF phase detection for optical synchronization systems", Proc. IBIC2013 Oxford, TUPC33.
[73] E. Janas et al., "Design and integration of the optical reference module at 1.3 GHz for FLASH and for the European XFEL", this conf. WEPRI115.
[74] F. Löhl et al., "Electron bunch timing with femtosecond precision in a superconducting free electron laser", Phys. Rev. Lett**. 104** (2010).
[75] A. Angelovski et al., "High bandwidth pickup design for bunch arrival time monitor for free-electron lasers", PRST-AB **15** (2012).
[76] M. Kuntzsch et al., "Progress on bunch arrival time measurement at ELBE", this conf. TUPRI106.
[77] R. Aßmann, "Accelerator physics challenges towards a plasma accelerator with usable beam quality", this conf. TUOBB01.
[78] M. Roth et al., "Breaking the 70MeV proton energy threshold in laser-proton acceleration and guiding beams to applications", this conf. WEXB01.
[79] S. Busold et al., "The LIGHT beamline at GSI: shaping intense MeV proton bunches from a compact laser-driven source", this conf. TUPME030.
[80] L. Obst et al., "Scaling of TNSA-accelerated proton beams with laser energy and focal spot size", this conf. TUPME033.
[81] P. Schmidt et al., "Radiation pressure acceleration and ion beam transport methods", this conf. TUPME031.
[82] V. Afonso Rodriguez et al., "Construction and first magnetic field test of a superconducting transversal gradient undulator for the laser wakefield accelerator in Jena", this conf. WEPRO036.
[83] T. Seggebrock et al., "Bunch de-compression for laser-plasma driven free electron-laser demonstration schemes", PRST-AB **16** 070703 (2013).
[84] J. Grebenyuk et al., "Simulations of laser-wakefield acceleration with external electron-bunch injection for REGAE experiments at DESY", Proc. 15th AAC Austin, 2012.
[85] M. Bussmann et al., "All optical free electron lasers using travelling wave Thomson scattering", this conf. WEPRO053.
[86] G. Wittig et al.:, "Progress report: Trojan horse hybrid plasma wakefield acceleration", this conf. TUPME072.
[87] A. Martinez de la Ossa et al., "High quality electron beams from beam-driven plasma accelerators by wakefield-induced ionization injection", Phys. Rev. Lett. **111** 245003 (2013).
[88] V. Libov et al., "FLASHForward – future oriented wakefield accelerator research and development at FLASH", this conf. TUPME066.
[89] M. Gross et al., "First experiences with the PITZ plasma cell for electron beam self-modulation studies", this conf. TUPME074.
[90] E. Gschwendtner et al., "The AWAKE experimental facility at CERN", this conf. MOPRI005.