

# Contents

<b>1 Executive Summary</b>	<b>1</b>
<b>2 Science Case</b>	<b>7</b>
2.1 Atomic, Molecular, and Optical Science and Astrochemistry . . . . .	8
2.2 Quantum Materials, Magnetism . . . . .	10
2.3 Chemistry, Surface Catalysis and Energy Science . . . . .	13
2.4 Imaging . . . . .	14
2.5 Nonlinear and Attosecond Science . . . . .	15
<b>3 Accelerator</b>	<b>19</b>
3.1 Energy upgrade . . . . .	20
3.2 Photoinjector . . . . .	21
3.2.1 Laser Rooms . . . . .	21
3.3 New Bunch Compression Scheme . . . . .	22
3.3.1 Details of the New Compression Scheme . . . . .	23
3.4 Laser Heater . . . . .	26
3.5 Diagnostics . . . . .	29
3.5.1 Standard Beam Diagnostics . . . . .	29
3.5.2 Longitudinal diagnostics . . . . .	29
3.6 Synchronization . . . . .	33
<b>4 FLASH1 FEL Line</b>	<b>37</b>
4.1 Undulator Concept . . . . .	38
4.1.1 Achievable Wavelength Range . . . . .	38
4.1.2 Influence of Alignment of Components and Electron Beam . . . . .	39
4.2 Seeding Concept for FLASH1 . . . . .	41
4.2.1 Seeding of FELs . . . . .	41
4.2.2 Layout of Seeding Section . . . . .	41
4.2.3 Simulations . . . . .	42
4.2.4 Tolerance Considerations . . . . .	44
4.2.5 Summary and Outlook . . . . .	45
4.3 THz Sources for the THz-XUV Pump-Probe Facility . . . . .	49
4.3.1 THz Doubler at FLASH: Double Pulses for More Flexible Pump-Probe Experiments . . . . .	50
4.3.2 Femtosecond THz-Doubler for Enhanced THz Pulse Energies . . . . .	51
<b>5 FLASH2 FEL Line</b>	<b>53</b>
5.1 Proposed Layout . . . . .	53
5.2 Operation Modes and Advanced Lasing Options . . . . .	54
5.2.1 SASE Mode . . . . .	54
5.2.2 Harmonic Lasing and HLSS FEL . . . . .	54
5.2.3 Reverse Tapering with Harmonic Afterburner . . . . .	55
5.2.4 Frequency Doubler . . . . .	55
5.2.5 Two-color Lasing . . . . .	56
5.2.6 Optical Afterburner (OAB) . . . . .	56
5.2.7 Longitudinal Space Charge Amplifier (LSCA) . . . . .	57
5.3 Few Femto- and Attosecond Pulses . . . . .	57

<b>6 Lasers</b>	<b>61</b>
6.1 Photocathode and Laser Heater Lasers . . . . .	62
6.2 Seed laser . . . . .	64
6.2.1 Requirements and Challenges . . . . .	64
6.2.2 Laser Concept . . . . .	65
6.2.3 Laser Room and Laser Beam Transport . . . . .	65
6.3 Pump-Probe Lasers . . . . .	66
6.3.1 OPCPA Pump-Probe Laser Systems . . . . .	67
6.3.2 Beam Transport and Dispersion Management. . . . .	69
6.3.3 Wavelength Conversion and Flexible Pump-Probe Schemes . . . . .	70
6.3.4 Coupling to the Instruments . . . . .	71
6.4 Modulation Laser for Advanced FEL Schemes . . . . .	72
6.5 Synchronization and Timing . . . . .	72
6.5.1 FLASH2020+ Timing and Jitter Improvement Projects . . . . .	72
6.5.2 Control of FEL XUV to Optical Laser Time Delay . . . . .	74
6.5.3 Ultrafast Optical Laser – FEL XUV Timing Tool . . . . .	74
6.5.4 Seeded FLASH1 Beamline . . . . .	74
<b>7 Beamlines and Instruments</b>	<b>77</b>
7.1 FLASH1 Beamlines . . . . .	79
7.1.1 XUV Photon Beamline in the FLASH1-Tunnel (Planned Upgrades) . . . . .	79
7.1.2 FLASH1 Experimental Hall “Albert Einstein” . . . . .	80
7.1.3 PG Beamlines . . . . .	81
7.1.4 CAMP (CFEL Advanced study group Multi-Purpose chamber) at Beamline BL1	85
7.1.5 Upgrade: THz-XUV Pump-Probe Instrument at FL11 (Present BL3) . . . . .	86
7.1.6 Laser hutch and beamlines . . . . .	88
7.2 FLASH2 Beamlines . . . . .	89
7.2.1 Beamline FL21 . . . . .	89
7.2.2 Beamline FL24 . . . . .	90
7.2.3 FL26 with REMI . . . . .	92
7.2.4 FL23 Time-Delay Compensating Monochromator Beamline (ongoing upgrade)	93
7.3 Mobile Endstations for Users . . . . .	95
<b>8 Photon Diagnostics</b>	<b>99</b>
8.1 Pulse Energy and Beam Position . . . . .	99
8.2 Spectral Distribution . . . . .	101
8.3 Wavefront . . . . .	103
8.4 Timing and Temporal Shape . . . . .	104
8.5 Special Photon Diagnostics for the THz Beamline . . . . .	105
<b>9 Data Concept</b>	<b>109</b>
9.1 General Considerations and Goals . . . . .	109
9.2 Controls and Online Data Analysis . . . . .	109
9.2.1 The control system (DOOCS, JDDD) . . . . .	110
9.2.2 Infrastructure . . . . .	110
9.2.3 Online Analysis . . . . .	111
9.2.4 Data Acquisition and Near-Online / Offline Analysis . . . . .	111
9.2.5 Scientific Computing . . . . .	112