

Contents

FCC Collaboration	3
Executive Summary	5
1 Physics Opportunities and Reach	13
1.1 Requirements and Opportunities	13
1.2 Standard Model Processes	13
1.3 Higgs and EW Symmetry Breaking	13
1.4 Beyond the Standard Model Phenomena	13
1.5 Physics with Heavy Ions	13
1.6 Lepton-Hadron Physics	13
1.7 Physics Opportunities with Injectors	13
2 Collider Design and Performance	15
2.1 Requirements and Design Considerations	15
2.2 Key Parameters and Layout	15
2.2.1 Layout and Beam Energy	15
2.2.2 Luminosity and Beam Parameters	17
2.2.3 Integrated Luminosity	19
2.2.4 Additional Experiments	19
2.2.5 Alternative Bunch Spacings	19
2.2.6 Injection Considerations	19
2.3 Design Challenges and Approaches	20
2.3.1 Arc Vacuum	20
2.3.2 Experimental Areas	21
2.3.3 Machine Protection	22
2.3.4 Injection	22
2.3.5 Extraction and Dump	23
2.3.6 Collimation	23
2.3.7 RF system	25
2.4 Optics Design and Beam Dynamics	25
2.4.1 Lattices	25
2.4.2 Dynamic aperture and correction schemes	26
2.4.3 Impedances and mitigation	28
2.4.4 Electron cloud considerations	30
2.4.5 Beam-beam effects	30
2.5 Operation and Performance	32
2.6 Ion Operation	34
2.7 Lepton-Hadron Operation	37

3	Collider Technical Systems	43
3.1	Requirements and Design Considerations	43
3.2	Main Magnet System	43
3.2.1	Introduction	43
3.2.2	Superconducting Main Dipole	43
3.2.3	Magnet Protection	45
3.2.4	Other Design Options	47
3.2.5	Low Temperature Superconductors	47
3.2.6	Other Magnets in the Arcs	48
3.2.7	Low-beta Triplets	48
3.2.8	Other Magnets	49
3.3	Cryogenic Beam Vacuum System	49
3.3.1	Overview	50
3.3.2	Beam Screen	50
3.3.3	Vacuum	50
3.4	Radiofrequency System	50
3.4.1	Overview	50
3.4.2	Superconducting Cavities	50
3.4.3	Powering	50
3.4.4	Feedback	50
3.5	Beam Transfer Systems	50
3.5.1	Overview	50
3.5.2	Injection	50
3.5.3	Extraction	50
3.5.4	Dumping	50
3.6	Collimation Systems	50
3.6.1	Overview	50
3.6.2	Collimation	50
3.6.3	Protection	50
3.6.4	Dump and Masks	50
3.7	Other Systems	50
3.7.1	Overview	50
3.7.2	Beam Diagnostics Requirements and Concepts	50
3.7.3	Magnet Powering Requirements and Concepts	50
3.7.4	Machine Protection Concepts	50
3.7.5	Controls Requirements and Concepts	50
3.8	Radiation Environment	50
4	Civil Engineering	51
4.1	Requirements and Design Considerations	51
4.2	Layout and Placement	51

4.2.1	Collider Layout	51
4.2.2	Collider Placement	52
4.3	Underground Structures	54
4.3.1	Tunnels	54
4.3.2	Shafts	55
4.3.3	Alcoves	56
4.3.4	Experiment Caverns	57
4.3.5	Service Caverns	57
4.3.6	Junction Caverns	57
4.3.7	FCC-eh Requirements	58
4.4	Surface Points	59
4.4.1	Experiment Surface Site	59
4.4.2	Technical Surface Site	59
4.4.3	Access Roads	59
5	Technical Infrastructures	61
5.1	Requirements and Design Considerations	61
5.2	Piped Utilities	61
5.2.1	General introduction to piping systems	61
5.2.2	Cooling plants	61
5.2.3	Chilled water	63
5.2.4	Drinking water	64
5.2.5	Fire fighting network	64
5.2.6	Reject water	65
5.2.7	Compressed air	65
5.3	Heating, Ventilation, Air Conditioning	65
5.3.1	Design	65
5.3.2	Indoor conditions	65
5.3.3	Ventilation of underground premises	66
5.3.4	Machine tunnels	66
5.3.5	Experimental caverns	66
5.3.6	Other premises	66
5.3.7	Operational modes	66
5.3.8	Working parameters	67
5.3.9	Ventilation of surface buildings	67
5.3.10	Safety	68
5.4	Electricity Distribution	69
5.5	Emergency Power	69
5.6	Cryogenic System	69
5.6.1	Overview	69
5.6.2	Proximity Cryogenics and Heat Loads	69

5.6.3	Cryogenic Plants	69
5.6.4	Cryogen Inventory and Storage	69
5.7	Equipment Transport and Handling	69
5.8	Person Transport	69
5.9	Geodesy, Survey, Alignment and Element Support	69
5.10	Communications, Computing and Data Services	69
5.11	Safety and Access Management Systems	69
6	Injector Scenarios	73
6.1	Requirements and Design Considerations	73
6.2	LHC	73
6.3	Superconducting SPS	73
6.4	Transfer Lines	73
7	Experiments and Detectors	75
7.1	Physics and Detector Performance Considerations	75
7.2	Detector Reference Design	75
7.3	Magnet System	75
7.4	Detector Subsystem Concepts	75
7.4.1	Tracking	75
7.4.2	Electromagnetic Calorimeter	75
7.4.3	Hadron Calorimeter	75
7.4.4	Muon Detector	75
7.4.5	Trigger and Data Acquisition	75
7.5	Radiation Environment	75
7.6	Infrastructure Requirements	75
7.7	Special Purpose Experiments: Ions	75
7.8	Special Purpose Experiments: Lepton-Hadron	75
8	Safety	77
8.1	Safety Policy and Regulatory Framework	77
8.1.1	Legal Context of CERN	77
8.1.2	Hazard Register and Safety Performance Based Design	78
8.2	Occupational Health and Safety	78
8.2.1	Fire Hazard	79
8.2.2	Oxygen Deficiency	79
8.3	Radiation Protection	80
8.3.1	Particle Beam Operation	81
8.3.2	Activation of Solids	81
8.3.3	Activated or contaminated liquids	82
8.3.4	Activated or radioactive gases and radioactive aerosols	82

9	Energy Efficiency	83
9.1	Requirements and Design Considerations	83
9.2	Power Consumption	83
9.3	Energy Management and Saving	83
9.4	Waste Heat Valorisation	83
10	Environment	85
10.1	Requirements and Approach Considerations	85
10.1.1	Legal Requirements	85
10.1.2	Environmental Compatibility Management Concept	85
10.2	Environmental Impacts	85
10.2.1	Radiological Impacts	85
10.2.2	Conventional Impacts	85
10.3	Waste Management	85
10.3.1	Radioactive Waste Management	85
10.3.2	Conventional Waste Management	85
11	Education, Economy and Society	87
11.1	Requirements and Approach Considerations	87
11.2	Host State Realization Concept	87
11.2.1	France	87
11.2.2	Switzerland	87
11.3	Socio-Economic Opportunities	87
11.3.1	Scientific Publications	87
11.3.2	The Value of Training	87
11.3.3	Opportunities for Industries	87
11.3.4	Cultural Effects	87
11.3.5	The Value of Knowledge	87
12	Strategic Research and Development	89
12.1	Strategic Considerations	89
12.2	Accelerator Related R&D	89
12.3	Detector Related R&D	89
12.4	Infrastructures Related R&D	89
12.5	Risks	89
	Appendices	91
A	Collider Parameter Tables	91
A	Collider	91
B	LHC as Injector	91
C	Superconducting SPS	91

B	Experiment Parameter Tables	93
C	Infrastructures Parameter Tables	95
A	Layout	95
B	Civil Engineering	95
C	Resource Use	95
	Glossary	95
	References	100