ANNEX 1: List of Institutes and Contact Persons

Country/ Region	Code	Institute	Contact Person
Armenia	AR1	Yerevan Physics Institute	Sirunyan, Albert
Austria	AT1	Institut für Hochenergiephysik	Dragicevic, Marko
Belarus	BY1	Byelorussian State University	Suarez Gonzalez, Juan
	BY2	Institute for Nuclear Problems	
	BY4	Research Institute of Applied Physical Problems	
Belgium	BE1	Universite Catholique de Louvain	Lemaitre, Vincent
	BE2	Universite de Mons	Daubie, Evelyne
	BE3	Universite Libre de Bruxelles	Vanlaer, Pascal
	BE4	Universiteit Antwerpen	Van Mechelen, Pierre
	BE5	Vrije Universiteit Brussel	D'Hondt, Jorgen
	BE6	Ghent University	Tytgat, Michael
Brazil	BR1	Universidade do Estado do Rio de Janeiro	Santoro, Alberto
	BR2	Centro Brasileiro de Pesquisas Fisicas	Alves, Gilvan
	BR3	Universidade Estadual Paulista (a), Universidade Federal do ABC (b)	Novaes, Sergio
Bulgaria	BG1	Institute for Nuclear Research and Nuclear Energy	Sultanov, Georgi
	BG2	University of Sofia	Litov, Leandar
CERN	CERN	CERN, European Organization for Nuclear Research, Geneva, Switzerland	Camporesi, Tiziano
China	CN1	Institute of High Energy Physics	Chen, Hesheng
	CN2	University for Science and Technology of China	Zhang, Zi-ping
	CN3	State Key Laboratory of Nuclear Physics and Technology, Peking University	Mao, Yajun
	CN4	Beihang University	Chengping, Shen
	CN5	Tsinghua University	Wang, Yi
	CN6	Sun Yat-sen University	You, Zhengyun
Colombia	CO1	Universidad de Los Andes	Avila, Carlos
Croatia	CR1	University of Split, FESB	Puljak, Ivica
	CR2	University of Split, Faculty of Science	Kovac, Marko
	CR3	Institute Rudjer Boskovic	Brigljevic, Vuko
Cyprus	CY1	University of Cyprus	Razis, Panos
Czech Republic	CZ1	Charles University, Prague	Finger, Miroslav
Ecuador	EC1	Escuela Politecnica Nacional	Ayala, Edy
	EC2	Universidad San Francisco de Quito	Carrera Jarrin, Edgar
Egypt	EG1	Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics	Khalil, Shaaban
Estonia	EE1	National Institute of Chemical Physics and Biophysics	Raidal, Martti
Finland	FI1	Department of Physics, University of Helsinki	Voutilainen, Mikko
	FI2	Helsinki Institute of Physics	
	FI7	Lappeenranta University of Technology	Tuuva, Tuure
France	FR1	Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Université Paris - Saclay	Sirois, Yves
	FR3	IRFU, CEA, Université Paris-Saclay,Gif-sur-Yvette	Besancon, Marc
	FR4	Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3	Bloch, Daniel
	FR5	Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon	Chierici, Roberto
	FR6	Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3	Gadrat, Sebastien
Georgia	GE1	Tbilisi State University	Tsamalaidze, Zviadi
	GE2	Georgian Technical University	
Germany	DE2	KIT, Institut für Experimentelle Teilchenphysik	Müller, Thomas
	DE3	RWTH Aachen University, I. Physikalisches Institut B	Feld, Lutz
	DE4	RWTH Aachen University, III. Physikalisches Institut A	Hebbeker, Thomas
	DE5	RWTH Aachen University, III. Physikalisches Institut B	Stahl, Achim
	DE6	University of Hamburg	Schleper, Peter
	DE7	Deutsches Elektronen-Synchrotron (DESY)	Gallo, Elisabetta
Greece	GR1	Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos	Loukas, Demetrios
	GR2	National and Kapodistrian University of Athens	Sphicas, Paraskevas
	GR3	University of Ioannina	Fountas, Konstantinos
	GR4	National Technical University of Athens	Tsipolitis, Yorgos
Hungary	HU1	Wigner Research Centre for Physics	Sikler, Ferenc
	HU2	University of Debrecen	Ujvari, Balazs
	HU3	Institute of Nuclear Research ATOMKI	Molnar, Jozsef
	HU4	MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University	Pasztor, Gabriella
India	IN1	Bhabha Atomic Research Centre	Pant, Lalit Mohan
	IN2	Panjab University	Kaur Lal, Manjit
	IN3	Tata Institute of Fundamental Research-A	Aziz, Tariq
	IN5	University of Delhi	Ranjam, Kirti
	IN6	Saha Institute of Nuclear Physics	Sarkar, Subir
	IN7	National Institute of Science Education and Research	Swain, Sanjay Kumar
	IN8	Indian Institute of Science (IISC)	Komaragiri, Jyothsna Rani

	IN9	Tata Institute of Fundamental Research-B	Mazumdar, Kajari
	IN10	Indian Institute of Technology Madras	Behera, Prafulla Kumar
	IN11	Indian Institute of Science Education and Research (IISER)	Sharma, Seema
Iran	IR1	Institute for Research in Fundamental Science (IPM), School of Particles and Accelerators	Najafabadi, Mojtaba
Ireland	IE1	University College Dublin	Grunewald, Martin
Italy	IT01	INFN Sezione di Bari (a); Universita di Bari (b); Politecnico di Bari (c)	My, Salvatore
	IT02	INFN Sezione di Bologna (a); Universita di Bologna (b)	Fabbri, Fabrizio
	IT03	INFN Sezione di Catania (a); Universita di Catania (b)	Tricomi, Alessia
	IT04	INFN Sezione di Firenze (a); Universita di Firenze (b)	Paoletti, Simone
	IT05	INFN Sezione di Genova (a); Universita di Genova (b)	Robutti, Enrico
	IT06	INFN Sezione di Padova (a); Università di Padova (b); Università di Trento (Trento) (c)	Simonetto, Franco
	IT07	INFN Sezione di Pavia (a); Universita di Pavia (b)	Salvini, Paola
	IT08	INFN Sezione di Perugia (a); Universita di Perugia (b)	Fanò, Livio
	IT09	INFN Sezione di Pisa (a); Universita di Pisa (b); Scuola Normale Superiore di Pisa (c)	Bagliesi, Giuseppe
	IT10	INFN Sezione di Roma (a); Universita di Roma (b)	Del Re, Daniele
	IT11	INFN Sezione di Torino (a); Università di Torino (b); Università del Piemonte Orientale (Novara) (c)	Solano, Ada
	IT12	INFN Sezione di Milano-Biccoca (a); Universita di Milano-Bicocca (b)	Tabarelli de Fatis, Tommaso
	IT13	INFN Sezione di Napoli (a); Universita di Napoli "Federico II" (b); Universita della Basilicata (Potenza) (c); Universita G. Marconi (Roma) (d)	Lista, Luca
	IT14	INFN Sezione di Trieste (a); Universita di Trieste (b)	Della Ricca, Giuseppe
	IT15	INFN Laboratori Nazionali di Frascati	Benussi, Luigi
Korea	KR01	Chonnam National University, Institute for Universe and Elementary Particles	Moon, Dong Ho
	KR06	Korea University	Park, Sung Keun
	KR07	Chonbuk National University	Kim, Tae Jeong
	KR11	Kyungpook National University	Son, Dong-Chul
	KR12	Seoul National University	Yang, Unki
	KR13	Sungkyunkwan University	Choi, Young-Il
	KR15	University of Seoul	Park, Inkyu
	KR16	Hanyang University	Kim, Tae Jeong
	KR17	Sejong University	Kim, Hyunsoo
Latvia	LV01	Riga Technical Institute (RTI)	Toms, Torims
	LV02	University of Latvia (LU)	Kaščejevs, Vjačeslavs
Lithuania	LT01	Vilnius University	Bernotas, Andrius
	LT02	Lithuanian Academy of Sciences	
Malaysia	MA1	University of Malaya	Wan Abdullah, Wan Ahmad Tajuddin
Mexico	MX1	Centro de Investigacion y de Estudios Avanzados del IPN	Castilla Valdez, Heriberto
	MX2	Universidad Iberoamericana	Carrillo, Salvador
	MX3	Benemerita Universidad Autonoma de Puebla	Salazar Ibarguen, Humberto
	MX4	Universidad Autonoma de San Luis Potosi	Morelos Pineda, Antonio
Montenegro	MO1	University of Montenegro	Raičević, Nataša
New Zealand	NZ1	University of Auckland	Krofcheck, David
	NZ2	University of Canterbury	Butler, Philip
Pakistan	PK1	National Centre for Physics, Quaid-I-Azam University	Ahmad Ashfaq; Hoorani, Hafeez R.
Poland	PL1	Institute of Experimental Physics, Faculty of Physics, University of Warsaw	Królikowski, Jan
	PL3	National Centre for Nuclear Research	Górski, Maciej
Portugal	PT1	Laboratorio de Instrumentacao e Fisica Experimental de Particulas	Varela, Joao
Russia	JINR	Joint Institute for Nuclear Research	Golutvin, Igor
	RU1	State Research Center of Russian Federation, Institute for High Energy Physics	Tyurin, Nikolay
	RU2	Institute for Nuclear Research	Matveev, Victor
	RU3	Institute for Theoretical and Experimental Physics	Gavrilov, Vladimir
	RU4	Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University	Boos, Edouard
	RU5	P.N. Lebedev Physical Institute	Dremin, Igor
	RU6	Petersburg Nuclear Physics Institute	Vorobyev, Alexey
	RU7	National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI)	Danilov, Mikhail
	RU8	Moscow Institute of Physics and Technology	Aushev, Tagir
	RU9	Novosibirsk State University (NSU)	Skovpen, Yuri
	RU10	National Research Tomsk Polytechnic University	Baidali, Sergei
Serbia	SE1	University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear	Adzic, Petar
Spain	SP1	Centro de Investigaciones Energéticas Medioambientales y Tecnologicas	Alcaraz Maestre, Juan
	SP2	Universidad Autónoma de Madrid	Fernández De Troconiz Acha, Jorge
	SP3	Universidad de Oviedo	Cuevas Maestro, Javier
	SP4	Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria	Martínez Rivero, Celso
Sri Lanka	LK01	University of Ruhuna	Welathantri, Dharmaratna

	LK02	University of Colombo	Sonnadara, Upul J.
Switzerland	SW1	Institute for Particle Physics, ETH Zurich	Dissertori, Gunther
	SW2	Paul Scherrer Institut	Kotlinski, Danek
	SW3	Universität Zurich	Canelli, Florencia
Taipei	TA1	National Central University (NCU)	Kuo, Chia-Ming
	TA2	National Taiwan University (NTU)	Hou, George Wei-Shu
Thailand	TH1	Chulalongkorn University	Asavapibhop, Burin
Turkey	TR1	Cukurova University	Dumanoglu, Isa
	TR2	Middle East Technical University, Physics Department	Zeyrek, Mehmet
	TR3	Bogazici University, Department of Physics	Gülmez, Erhan
	TR4	Istanbul Technical University	Cankocak, Kerem
Ukraine	UR2	National Scientific Center, Kharkov Institute of Physics and Technology	Levchuk, Leonid
	UR3	Kharkov State University	
	UR4	Institute for Scintillation Materials of National Academy of Science of Ukraine	Grynyov, Boris
United Kingdom	UK1	Brunel University	Hobson, Peter
	UK2	Imperial College, University of London	Davies, Gavin
	UK3	Rutherford Appleton Laboratory	Shepherd-Themistocleous, Claire
	UK4	University of Bristol	Goldstein, Joel
USA	US02	Boston University	Rohlf, James
	US03	University of California, Davis	Conway, John
	US04	University of California, Los Angeles	Cousins, Robert
	US05	University of California, Riverside	Hanson, Gail
	US06	University of California, San Diego	Branson, James G.
	US07	California Institute of Technology	Newman, Harvey B.
	US08	Carnegie Mellon University	Paulini, Manfred
	US09	Fairfield University	Winn, Dave
	US10	Fermi National Accelerator Laboratory	Burkett, Kevin
	US11	University of Florida	Mitselmakher, Guenakh
	US12	Florida State University	Prosper, Harrison
	US14	University of Illinois at Chicago (UIC)	Gerber, Cecilia Elena
	US16	The University of Iowa	Onel, Yasar
	US17	Johns Hopkins University	Swartz, Morris
	US18	Lawrence Livermore National Laboratory	Wright, Douglas
	US20	University of Maryland	Skuja, Andris
	US21	Massachusetts Institute of Technology	Paus, Christoph
	US22	University of Minnesota	Rusack, Roger
	US23	University of Mississippi	Cremaldi, Lucien Marcus
	US24	University of Nebraska-Lincoln	Snow, Gregory R.
	US25	Northeastern University	Barberis, Emanuela
	US26	Northwestern University	Velasco, Mayda
	US27	University of Notre Dame	Jessop, Colin
	US28	The Ohio State University	Durkin, Lloyd Stanley
	US29	Princeton University	Olsen, James
	US30	Purdue University	Neumeister, Norbert
	US31	Rice University	Padley, Brian Paul
	US32	University of Rochester	Demina, Regina
	US33	Rutgers, The State University of New Jersey	Gershtein, Yuri
	US35	Texas Tech University	Akchurin, Nural
	US37	University of Wisconsin - Madison	Smith, Wesley H.
	US38	Kansas State University	Maravin, Yurii
	US39	The University of Kansas	Bean, Alice
	US40	University of California, Santa Barbara	Incandela, Joe
	US41	Florida Institute of Technology	Baarmand, Marc M.
	US42	Florida International University	Markowitz, Pete
	US45	Cornell University	Alexander, James
	US46	Brown University	Narain, Meenakshi
	US47	Vanderbilt University	Johns, Willard
	US48	University of Colorado at Boulder	Cumalat, John Perry
	US49	University of Puerto Rico	Malik, Sudhir
	US50	Purdue University Northwest	Parashar, Neeti
	US51	The Rockefeller University	Mesropian, Christina
	US52	State University of New York at Buffalo	Kharchilava, Avto
	US53	Texas A&M University	Safonov, Alexei
	US54	University of Virginia	Cox, Bradley
	US55	Wayne State University	Karchin, Paul Edmund
	US56	University of Tennessee	Spanier, Stefan
	US58	The University of Alabama	Henderson, Conor
	US59	Baylor University	Hatakeyama, Kenichi
	US60	The Catholic University of America	Dominguez, Aaron
Uzbekistan	UZ1	Institute of Nuclear Physics of the Uzbekistan Academy of Sciences	Yuldashev, Bekhzad S.

ANNEX 2: List of Funding Agencies and Representatives

Austria	Federal Ministry of Science, Research and Economy	D. Weselka
Belgium	Fonds voor Wetenschappelijk Onderzoek (FWO)	H. Willems
	Fonds de la Recherche Scientifique (F.R.S.-FNRS)	V. Halloin
Brazil	Rede Nacional de Fisica de Altas Energias (RENAFAE)	I. Bediaga
	Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP)	C. H. de Brito Cruz
Bulgaria	Ministry of Education and Science	K. Valchev
CERN	European Organization for Nuclear Research	E. Elsen
China	National Natural Science Foundation (NSFC)	Y. Zhang
Colombia	Colciencias	P. Patino
Croatia	Ministry of Science, Education and Sports	B. Divjak
Cyprus	Ministry of Education and Culture	V. Tsakalos
Ecuador	Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT)	X. M. Ponce León
Egypt	Academy of Scientific Research and Technology -Egyptian Network of High Energy Physics (ASRT-ENHEP)	M. M. Sakr
Estonia	National Institute of Chemical Physics and Biophysics (NICPB)	M. Kadastik
Finland	Helsinki Institute of Physics (HIP)	P. Eerola
France-CEA	Commissariat à l'Energie Atomique (CEA) Saclay	A.I. Etienvre
France-IN2P3	Institut National de Physique Nucléaire et de Physique des Particules (CNRS- IN2P3)	R. Pain, P. Verdier
Germany-BMBF	Bundesministerium für Bildung und Forschung	V. Dietz
Germany-Helmholtz	Helmholtz Association	M. Fleischer
Greece	General Secretariat for Research and Technology	P. Kyprianidou
Hungary	National Office for Research and Technology, (NKTH)	J. Pálinkás
India	Department of Atomic Energy (DAE)	S. Basu
	Department of Science & Technology (DST)	A. Sharma
Iran	School of Particles and Accelerators, Institute for Research in Fundamental Science (IPM)	M. Alishahiha
Ireland	University College Dublin (UCD)	M. Grünewald
Italy	Istituto Nazionale di Fisica Nucleare (INFN)	F. Ferroni
Korea	Ministry of Science, ICT and future Planning (MSIP)	M. Kim
	National Research Foundation (NRSF)	K.W. Lee
Latvia	Ministry of Education and Science	K. Sadurskis
Lithuania	Ministry of Education and Science	J. Petrauskiené
Malaysia	University of Malaya	M. Amin Bin Jalaludin
Mexico	CONACYT	J. Tagüeña Parga
Montenegro	Ministry of Science	S. Damjanović
New Zealand	University of Canterbury	I. Wright
	University of Auckland	J. Harding
Pakistan	Pakistan Atomic Energy Commission	M. Naeem
Poland	Ministry of Science and Higher Education	D. Drewniak
Portugal	Fundação para a Ciência e a Tecnologia	P. Ferrão
RDMS-DMS	Joint Institute for Nuclear Research (JINR)	V. Matveev
RDMS-Russia	Ministry of Education and Science of Russian Federation	O. Vasilyeva
Serbia	Ministry of Education, Science and Technological Development	V. Popovic
Spain	Secretaría de Estado de Investigación, Desarrollo e Innovación, Programa de Física de Partículas	M. Martínez Pérez
Sri Lanka	Ministry of Science, Technology and Research	U. R. Senevirathne
Switzerland	Rat der Eidgenössischen Technischen Hochschulen	K. Baltensperger
	ETH Zürich	D. Günther
	University of Zürich	M. Schaepman
	Paul Scherrer Institut (PSI)	K. Kirch
Taipei	Ministry of Science and Technology	G.W.S. Hou
Thailand	Chulalongkorn University (CU)	B. Eua-arporn
Turkey	Turkish Atomic Energy Authority (TAEK)	Z. Demircan
United Kingdom	Science and Technology Facilities Council (STFC)	A. Medland
USA-DOE	US Department of Energy (DOE)	A. Patwa, S. Rolli
USA-NSF	National Science Foundation (NSF)	M. W. Coles

ANNEX 3: Components of Common Items

Cost Estimate Reference	Deliverables	Estimated Total Cost (kCHF)
9.1.1	Control & Safety	310
9.1.2	Freewheel thyristor	634
9.1.3	Cryogenics & Vacuum	290
9.1.4	Powering system	171
9.1.5	Cooling system	56
9.1.6	Design, simulation and measurements	210
9.1	**Magnet power and cryo**	**1'671**
9.2.1	Flanges (Al+bi-met)	100
9.2.2	Ext Vac chamber material	-
9.2.3	Central Be chamber	-
9.2.4	Bellows	44
9.2.5	Machining	-
9.2.6	Welding/fabrication	-
9.2.7	Ion pump module cells	50
9.2.8	NEG coating	-
9.2.9	Ion pumps, gauges and ancillaries	100
9.2.10	support pillars/spider	50
9.2.11	specific manpower support	155
9.2	**Beampipe**	**499**
9.3.1	Structural mods	55
9.3.2	Additional Shielding	80
9.3.3	UXC crane 2	370
9.3.4	Access systems	612
9.3.5	Counting Rooms & Racks	200
9.3.6	HVAC & general	120
9.3	**Underground Infrastructure**	**1'437**
9.4.1	Detector primary power & UPS	900
9.4.2	Detector gas	330
9.4.3	Dry gas	500
9.4.4	Cableways	60
9.4	**Detector services**	**1'790**
9.5.1	Yoke opening	-
9.5.2	TX 54	-
9.5.3	Pit head cover & platforms	-
9.5	**Opening/closing systems**	**-**
9.6.1	YE nose remove/repl incl tooling	2'840
9.6.2	Other custom access/installation tooling	-
9.6	**Heavy Installation tooling**	**2'840**
9.7.1	Beam, Rad, Cos tests	200
9.7.2	904 Electrical integration/Test facility	124
9.7	**Test Facilities**	**324**
9.8.1	SXA5 assembly & support buiding	1'701
9.8.2	Bat 3593 offices	60
9.8.3	OSC extension in SX5	300
9.8.4	SCX Control room expansion	300
9.8.5	P5 hard pads & temp bldgs	315
9.8.6	Future UPS	-
9.8.7	CMS-paid hostlab proj. support (EAM)	700
9.8.8	904 refurbishment for HGC	-
9.8	**Surface facilities**	**3'376**
9.9.1	DSS & other detector safety systems	340
9.9.2	Beam Safety Instrumentation	224
9.9.3	Cameras, sensors, remote surveillance & remote handling	60
9.9.4	ALARA training (including full scale models)	120
9.9.5	RP personnel shielding (bp/bulkhd)	93
9.9.6	Radioprotection management	220
9.9.7	Radiation simulations	480
9.9.8	De-commissioning & dismantling	180
9.9	**Safety Systems and Radioprotection (CMS specific)**	**1'717**
9.10.1	Engineer /technical support	492
9.10.2	904 & other test beds	180
9.10.3	Cabling/conn	128
9.10	**Electronics Integration for upgrade**	**800**
9.11.1	Design/drafting team	2'000
9.11.2	Integration centre (visitor facilities)	96
9.11.3	Visitor Subsistence	400
9.11	**Engineering Integration for upgrade**	**2'496**
9.12.1	Transport/rigging	700
9.12.2	Survey	160
9.12.3	External Contracts	640
9.12.4	Field Support Unit	1'600
9.12	**Contract Support**	**3'100**
9.13.1	YBO services	1'500
9.13.2	YE1 (both) services	1'550
9.13.3	Central technical support	1'900
9.13	**Installation Common tasks**	**4'950**
	Funding Source Totals	**25'000**

ANNEX 4: Sharing of Upgrade Phase II Common Fund

Institute FA	PhD #	PhD %
Austria	18	1.3%
Belgium-FNRS	27	2.0%
Belgium-FWO	23	1.7%
Brazil	28	2.0%
Bulgaria	10	0.7%
CERN	73	5.3%
China	14	1.0%
Colombia	4	0.3%
Croatia	8	0.6%
Cyprus	7	0.5%
Egypt	3	0.2%
Estonia	3	0.2%
Finland	13	0.9%
France-CEA	17	1.2%
France-IN2P3	51	3.7%
Germany-BMBF	66	4.8%
Germany-DESY	35	2.5%
Greece	18	1.3%
Hungary	10	0.7%
India	33	2.4%
Iran	8	0.6%
Ireland	2	0.1%
Italy	166	12.0%
Korea	31	2.2%
Lithuania	2	0.1%
Malaysia	5	0.4%
Mexico	11	0.8%
New Zealand	2	0.1%
Pakistan	2	0.1%
Poland	15	1.1%
Portugal	6	0.4%
RDMS-DMS	24	1.7%
RDMS-Russia	60	4.3%
Serbia	3	0.2%
Spain	43	3.1%
Switzerland-ETHZ	21	1.5%
Switzerland-PSI	7	0.5%
Switzerland-UNIV	11	0.8%
Taipei	15	1.1%
Thailand	3	0.2%
Turkey	12	0.9%
United Kingdom	57	4.1%
USA-DOE	300	21.7%
USA-DOE-NP	29	2.1%
USA-NSF	76	5.5%
USA-OTHER	8	0.6%
Grand Total	1'380	100%

ANNEX 5: Summary of Main Common Item Categories

9.1 Magnet Power and Cryogenics

With the prospect of operations continuing for a least another 20 years, with the same performance requirements, several modifications are needed to ensure the magnet system reliability with a particular aim of avoiding major down-time and minimizing magnet ON-OFF cycles. The main focus of Phase II is the addition of a cooled freewheel thyristor, making the magnet operation immune to short-term power converter faults and the control system necessary to engage the redundant helium compressors (installed as a Phase I Upgrade), without having to shut-down the cryogenic plant.

9.2 Beampipe

The existing beam-pipe has to be completely replaced in LS2 in preparation for the Phase II Upgrade. Replacement of all stainless steel parts will reduce activation and the radiation dose to personnel at the beginning of LS3. The central beryllium section has also to be replaced for compatibility with the Phase II Tracking system geometry. In consequence of these changes and the anticipated LHC performance, various changes are also needed in the vacuum system, support structures and shielding in operations and maintenance scenarios.

9.3 Underground infrastructure

Structural modifications to the underground caverns are needed to accommodate the services and readout (e.g. cooling plants, racks) of the Phase II subsystems. A second crane in the experimental cavern will allow for simultaneous work at both ends of the detector, necessary to meet the timetables for upgrade work during the Long LHC Shutdowns LS2 and LS3. Streamlined, simultaneous access to many areas of the detector for upgrade work is provided using a variety of access devices (platforms, lifts and custom scaffoldings).

9.4 Detector services

Compared with existing systems, Phase II detectors require increased electrical power and are generally run at lower temperatures. Their cooling strategy involves a paradigm shift away from fluorocarbons and room temperature water, introducing instead large-scale evaporative CO_2 systems and a dependence on water chilled below the cavern dew point. Substantial changes to primary electrical power and cooling supplies are needed, as well as to the distribution to the experiment.

9.5 Opening/closing systems

Efficient logistics for opening and closing the experiment (movement of 300t – 1500t objects) is a key assumption of the planning for LS2 and LS3. The existing system based on cables and strand-jacks will be replaced by a hydraulic system involving custom-built synchronized telescopic jacks. This should lead to faster, more precise changes in logistic configuration and should be able to be operated with a smaller team of heavy mechanical technicians. Similarly, the opening and closing systems of the heavy shielding doors and the 2000t pit-head cover will be replaced with more modern and precise systems to reduce the time overheads of accesses in short shutdowns.

9.6 Heavy installation tooling

The Phase II detector upgrade logistic concept is consistent with the long-standing CMS philosophy of pre-assembling and testing large detector elements in surface labs at P5 and then using novel lifting techniques to transfer them to the underground experimental cavern. The required heavy lifting and handling techniques and tasks naturally comprise part of the Common Project. In the case of Phase II, the main challenge is the replacement of the two 250t end-caps. The existing units will be detached onto transport cradles as single pieces, transported below the PX56 and PM54 shafts respectively, lifted to the surface & through the roofs of the respective pit–head buildings using a mobile heavy-lift crane and then stored for later de-commissioning and eventual dismantling. The reverse process is then used to install the Phase II endcap units assembled in the surface building on specialist tilting tables, which form part of the heavy tooling.

9.7 Test facilities

Suitably adapted facilities using beams, irradiation facilities or cosmic rays are vital to qualify the Phase II detectors. Similarly vital are realistic electronics test beds, which duplicate (in Prevessin Hall 904) the CMS working environment without impacting the running experiment.

9.8 Surface facilities

Almost all the Phase II Upgrade projects except the Tracker (but including the pixel), rely on new assembly & testing facilities to be installed at the LHC P5 site. These labs are being provided in the existing (and already partially equipped) SX5 assembly building by shifting workshops, maintenance areas, cabling shops and key tooling storage into a new adjacent building SXA5 and also providing substantial temporary storage buildings during the Long Shutdowns of LHC (LS2, LS3). For SXA5, CERN is providing building shell and the CMS Common fund all the specific internal fittings and services.

9.9 Safety Systems and Radio-protection

The safety of personnel and the protection of the installed detector are of paramount importance. The beam-related conditions produced by HL-LHC require substantial upgrades of personnel shielding and beam safety instrumentation, while the residual activation of the existing detector during the upgrade requires a substantial reinforcement of the effort devoted to radiation simulations, radioprotection management, training to minimize doses to personnel, and provisions for de-commissioning and dismantling. Extension of the existing remote surveillance and remote handling systems are also required to adapt to the Phase II challenges. The detector safety systems have to be brought up to date and applied to the new Phase II technologies.

9.10 Electronics Integration

The Electronics Integration team in Technical Coordination has to ensure coherence of power, readout and triggering systems, firmware, controls, cabling and connector choices and routing of services. They are also tasked with identifying and implementing common solutions, as well as oversight of installation and the smooth operation of various related test facilities. Experienced electronic & electrical engineers and technicians, with management and supervisory capability are needed at CERN for the duration of the upgrade to reinforce the existing team.

Reasonable estimates, based on previous experience, have been made of the amount of this long-term effort that can be provided by Collaboration personnel.

9.11 Engineering Integration

The Engineering Integration team is a crucial part of the Technical Coordination task, which has to ensure that parts of the experiment, including services and auxiliary equipment, come together in coherence (mechanics, thermal balance etc) to form a scientific instrument performing as specified. Phase II is a complex upgrade with several completely new systems and technologies to be integrated, subject to the constraints provided by the unchanged features of the experiment. Effective Engineering Integration will depend on a strong central team at CERN (partly composed of long-term visitors from collaborating institutes) embedded in an Engineering Integration Centre that facilitates the contribution of engineers and designers from institutes in the Collaboration. Reasonable estimates have been made of the effort that can be provided by Collaboration personnel, based on previous experience.

9.12 Contract support

As has been the case throughout the construction, operation and maintenance of CMS, the technical team for Phase II will include a substantial fraction of paid contractors, whether through CERN frame contracts (e.g. transport, field support) or specific contracts (e.g. pipework, specialist scaffolding, minor mechanical work).

9.13 Installation common tasks

Based on long experience from the construction and already completed upgrade, the precise removal and installation of services (cables, fibres, pipework), whether detector specific or common, will be entrusted to central teams of specialist technicians, with intimate knowledge of the detector. These teams also prepare the access to specific work areas for specialist sub-detector teams from Institutes or CERN specialist groups, who come to CMS to execute well-defined and time-limited interventions. (Such interventions, whether for maintenance or upgrade, constitute the majority of work-packages in a shutdown period). The central teams themselves are mostly composed of Collaborating Institute staff, completely embedded within the Technical Coordination team structure and detached to CERN for long periods (typically the full duration of a shutdown or longer). The Phase II Upgrade requires two exceptionally complex tasks of services removal and re-integration. One is the re-cabling of the central yoke wheel (YBO) associated with the replacement of the Tracker and the major revision of the Barrel Electromagnetic Calorimeter. The other, similar major task results from the complete replacement of the calorimeter end-caps, which requires a de-cabling/re-cabling of the two (YE1) end-cap disks, an effort of the same order as the YBO services re-work. As a reference for cost estimates, it was noted that, during construction in 2006-2008 (a simpler installation due to the absence of vacuum insulated coolant pipes) the amount of work involved in the installation of YB0 alone was approximately 60,000 FTE-hours.