

**Addendum No. 10**  
to the  
**Memorandum of Understanding**  
for Collaboration in the Construction of the CMS Detector

**Common Items for the Phase II Upgrade of the CMS  
Detector**

**Considering that:**

The construction of the CMS detector is governed by a Memorandum of Understanding, along with its Amendments and Addenda, setting out the responsibilities of the different participating Institutes and Funding Agencies for the construction of the CMS detector (Construction MoU).

Maintenance and Operation of the CMS detector is governed by a Memorandum of Understanding for Maintenance and Operation (M&O MoU).

In order to be able to take full advantage of the planned High-Luminosity upgrade of the LHC, the CMS Collaboration (hereafter referred to as "the Collaboration") has proposed in document "Financial Plan for CMS Upgrade" (CERN-RRB-2013-045) an Upgrade Phase II Project of the CMS detector consisting of modifications and replacements of existing Sub-detectors as well as new additions to the detector. This process will start in 2018 and is expected to be completed in 2026.

Proposals for Sub-detector Upgrades have been reviewed by the LHCC, based on an Upgrade Technical Proposal (CERN-LHCC-2015-010).

The financing of the Upgrades Phase II Project is agreed to be a common responsibility of the Collaboration. The overall sharing of costs is based on the principle of equity as defined by the proportionate share of PhD physicist authors supported by each Funding Agency.

Following approval by the CERN Director-General, individual Sub-detector Phase II Upgrades would be the subject of addenda to the Construction MoU, signed between the Funding Agencies contributing to these upgrades and CERN as the Host Laboratory.

For the Upgrade Phase II Project, the Collaboration has created a Common Fund to cover infrastructure costs that the Collaboration has agreed to bear at its common expense.

---

<sup>1</sup> Memorandum of Understanding for Collaboration in the Construction of the CMS Detector RRB CMS-D 98-31

<sup>2</sup> Memorandum of Understanding for Maintenance and Operation of in the Construction of the CMS Detector CERN-RRB-2002-033/2007

**It is agreed as follows:****Article 1: Purpose**

- 1.1 The purpose of this Addendum and its annexes is to lay down the rules governing contributions to and execution of the Common Fund in conformity with the Construction MoU along with its amendments and addenda.
- 1.2 All the annexes are an integral part of this Addendum.

**Article 2: Parties**

- 2.1 The Parties to this Addendum shall be all the Institutes, which are members of the Collaboration (hereafter referred as "the Institutes") and their Funding Agencies, and CERN as the Host Laboratory. The current list of Institutes is given in Annex 1 and the current list of Funding Agencies is given in Annex 2.

**Article 3: Duration**

- 3.1 This Addendum takes effect from the date of its signature and shall remain valid until the start-up of the HL-LHC following Long Shutdown 3.
- 3.2 Any institute and its respective Funding Agency that joins the Collaboration subsequent to the signature of this Addendum shall accept the agreements in force and shall be expected to make an appropriate contribution to the Common Fund as shall be specified in a corresponding Annex to this Addendum.

**Article 4: Contributions to the Common Fund**

- 4.1 Annex 3 lists the Common Items components together with their estimated cost.
- 4.2 The Phase II Upgrade Common Fund is established at the level of 25'000'000 CHF (twenty-five million Swiss Francs).
- 4.3 Contributions to the Common Fund will be made by cash payments to a dedicated account at CERN or by an equivalent in-kind contribution to required components in agreement with the CMS Management. This Phase II Upgrade Common Fund will be managed and operated by the CMS Resources Manager together with the CMS Technical Coordinator, taking advice from the CMS Management.
- 4.4 The obligations of the Funding Agencies and their respective Institutes towards the Phase II Upgrade Common Fund are as follows:

- 4.4.1. For current members of the CMS Collaboration the Phase II Upgrade Common Fund will be shared in accordance with the principle defined in Article 9.2 of the M&O MoU (CERN-RRB-2002-033/2007) stipulating that it is proportional to the number of PhD physicist authors supported by each Funding Agency. The actual sharing percentage corresponds to the one established for the M&O-A budget in 2015 and is shown in Annex 4.
- 4.4.2 Any Funding Agency and its respective Institutes, not included in the list specified in Annex 4 (due to not being included in the M&O sharing at the time the list was established in September 2015 in view of having joined the Collaboration after this date), is also expected to make a cash contribution to the Common Fund. This contribution would be at least at a level corresponding to the lowest Common Fund contribution from any current member of the CMS Collaboration, which corresponds to approximately 36'000 CHF (thirty-six thousand Swiss Francs). The actual level of this contribution would be negotiated individually with each new Funding Agency with a view to adhering to the principle specified in Article 4.4.1 (i.e. establishing a level of contribution corresponding to the foreseen number of supported PhD physicist authors).
- 4.5 As the bulk of the financial commitments for the Common Fund fall on the period of 2018-2026, the full payments due into the Phase II Upgrade Common Fund should be made in the course of that period.
- 4.6 Payments into the Common Fund can be made in one instalment, at the start of the Phase II Project, or spread over a longer period as agreed between the CMS Management and the respective Funding Agency, with an emphasis on making every effort to collect the contributions in the early stage of the Phase II Upgrade Project.
- 4.7 All Phase II Upgrade Common Fund expenditures will be reported to the RRB.

### ANNEXES

- Annex 1: List of Institutes and Contact Persons  
Annex 2: List of Funding Agencies and Representatives  
Annex 3: Components of Common Items  
Annex 4: Sharing of Upgrade Phase II Common Fund  
Annex 5: Summary of main Common Item Categories

The European Organization for Nuclear Research (CERN)

and

Ministry of Education and Science, Sofia, Bulgaria

declare that they agree on the Present Addendum to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector.

Signed in Geneva, Switzerland

on 19.12.2017

for CERN



Eckhard Elsen

Prof. Eckhard Elsen  
Director for Research and Computing

Signed in \_\_\_\_\_

on \_\_\_\_\_

for Ministry of Education and  
Science

\_\_\_\_\_  
Mr. Krasimir Valchev  
Minister

**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 Nucléaire et de Physique des Particules, CNRS/IN2P3              | Gadrat, Sebastien         |
|                 | FR7  | Université de Poitiers, Institut de Physique Nucléaire de Saclay   |                           |
| 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         |
|                 | DE8  | University of Würzburg   |                           |
| 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  | Ranjan, 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  | University of Rajasthan  |                           |

|             |      |   |                                   |
|-------------|------|---|-----------------------------------|
|             | 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); Università di Bari (b); Politecnico di Bari (c)   | My, Salvatore                     |
|             | IT02 | INFN Sezione di Bologna (a); Università di Bologna (b)  | Fabbi, Fabrizio                   |
|             | IT03 | INFN Sezione di Catania (a); Università di Catania (b)  | Tricomi, Alessia                  |
|             | IT04 | INFN Sezione di Firenze (a); Università di Firenze (b)  | Paoletti, Simone                  |
|             | IT05 | INFN Sezione di Genova (a); Università 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); Università di Pavia (b)  | Salvini, Paola                    |
|             | IT08 | INFN Sezione di Perugia (a); Università di Perugia (b)  | Fanò, Livio                       |
|             | IT09 | INFN Sezione di Pisa (a); Università di Pisa (b); Scuola Normale Superiore di Pisa (c)  | Bagliesi, Giuseppe                |
|             | IT10 | INFN Sezione di Roma (a); Università 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-Bicocca (a); Università di Milano-Bicocca (b)  | Tabarelli de Fatis, Tommaso       |
|             | IT13 | INFN Sezione di Napoli (a); Università di Napoli "Federico II" (b); Università della Basilicata (Potenza) (c); Università G. Marconi (Roma) (d) | Lista, Luca                       |
|             | IT14 | INFN Sezione di Trieste (a); Università 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, Phillip                   |
| 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 Instrumentação e Física Experimental de Partículas   | 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 Tecnológicas   | 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 | Grynov, 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   | Baarend, 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 Física 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. Etievre          |
| 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. Kyrianiidou        |
| Hungary           | National Office for Research and Technology, (NKTH)   | J. Pálkás             |
| 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. Grünwald           |
| 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. Tagüena 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. Naem               |
| 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                         |
| <b>9.1</b>              | <b>Magnet power and cryo</b>                             | <b>1'671</b>                |
| 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                         |
| <b>9.2</b>              | <b>Beampipe</b>  | <b>499</b>                  |
| 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                         |
| <b>9.3</b>              | <b>Underground Infrastructure</b>                        | <b>1'437</b>                |
| 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                          |
| <b>9.4</b>              | <b>Detector services</b>                                 | <b>1'790</b>                |
| 9.5.1                   | Yoke opening   | -                           |
| 9.5.2                   | TX 54  | -                           |
| 9.5.3                   | Pit head cover & platforms                               | -                           |
| <b>9.5</b>              | <b>Opening/closing systems</b>                           | <b>-</b>                    |
| 9.6.1                   | YE nose remove/repl incl tooling                         | 2'840                       |
| 9.6.2                   | Other custom access/installation tooling                 | -                           |
| <b>9.6</b>              | <b>Heavy Installation tooling</b>                        | <b>2'840</b>                |
| 9.7.1                   | Beam, Rad, Cos tests                                     | 200                         |
| 9.7.2                   | 904 Electrical integration/Test facility                 | 124                         |
| <b>9.7</b>              | <b>Test Facilities</b>                                   | <b>324</b>                  |
| 9.8.1                   | SXA5 assembly & support building                         | 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                   | F5 hard pads & temp bldgs                                | 315                         |
| 9.8.6                   | Future UPS   | -                           |
| 9.8.7                   | CMS-paid hostlab prof. support (EAM)                     | 700                         |
| 9.8.8                   | 904 refurbishment for HGC                                | -                           |
| <b>9.8</b>              | <b>Surface facilities</b>                                | <b>3'376</b>                |
| 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                         |
| <b>9.9</b>              | <b>Safety Systems and Radioprotection (CMS specific)</b> | <b>1'717</b>                |
| 9.10.1                  | Engineer / technical support                             | 492                         |
| 9.10.2                  | 904 & other test beds                                    | 180                         |
| 9.10.3                  | Cabling/corn   | 128                         |
| <b>9.10</b>             | <b>Electronics Integration for upgrade</b>               | <b>800</b>                  |
| 9.11.1                  | Design/drafting team                                     | 2'000                       |
| 9.11.2                  | Integration centre (visitor facilities)                  | 96                          |
| 9.11.3                  | Visitor Subsistence                                      | 400                         |
| <b>9.11</b>             | <b>Engineering Integration for upgrade</b>               | <b>2'496</b>                |
| 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                       |
| <b>9.12</b>             | <b>Contract Support</b>                                  | <b>3'100</b>                |
| 9.13.1                  | YBO services   | 1'500                       |
| 9.13.2                  | YE1 (both) services                                      | 1'550                       |
| 9.13.3                  | Central technical support                                | 1'900                       |
| <b>9.13</b>             | <b>Installation Common tasks</b>                         | <b>4'950</b>                |
|                         | <b>Funding Source Totals</b>                             | <b>25'000</b>               |

**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<sub>2</sub> 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 Preveessin 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 YBO alone was approximately 60,000 FTE-hours.