CMS Response to PPRP feedback

1 The Panel would like to explore the priorities and potential options for descope.

- If funding were only available to support, 30%, 50% or 70% of the total request what would be the priority areas for investment in terms of obtaining the best UK science return.

- In each scenario, how would you descope your proposed project? Please highlight where you feel there may be a credible loss of scientific leadership at each level of descope.

- What would be the political and experimental impacts of funding at a much lower level?

- How would you prioritise the work packages and tasks?

We understand that funding scenarios can change unexpectedly, but we prepared our proposal by closely following STFC planning guidelines. Two SoIs were submitted, most recently last December, in view of the significant changes in the LHC schedule since the original submission in 2006. Meanwhile, the UK upgrade R&D proposal was approved by the PPRP in 2008 and the project has been under way since 2009, with an excellent record of achievements. The plan we have put forward builds on those successes and the demonstrated future requirements of CMS, as recorded in a Letter of Intent, a Technical Proposal and recent and imminent sub-detector Technical Design Reports. Very recently, the LHC experiments discovered a boson which is widely thought to be the realisation of the Higgs mechanism, which requires much more study to evaluate its properties. The scientific return on the LHC investment is expected to be immense, with new discoveries still likely and, compared to the much larger investment in an electron-positron collider, certainly represents extremely good scientific value for money over the next decade, or more.

In short, the proposal was prepared with much forewarning of the likely costs and possible scientific programme, over a long period of time. At this stage therefore, drastic reductions in funding could only be achieved by decimating our proposed project, with a huge impact on our international collaborators, who have been kept well informed, along with STFC, about our intentions and expectations of funding. To revise the project to remain within some of these reduced funding scenarios would be a lengthy task and would certainly require deep discussions with our CMS colleagues, on very unfavourable terms, since it is unlikely that this would be welcomed and our positions of scientific leadership, even outside the upgrade project, would be very significantly affected.

The most likely means we could adopt to achieve very large funding reductions would be to attempt to complete hardware developments to the point at which they could be handed over to collaborators, and remove all manufacturing costs from the budget. Clearly this would also remove the long term need for some research and technical staff, whose jobs would be at risk and who would be severely demotivated and likely not to remain with us. No doubt in some cases, they would be recruited by competing international institutions. There would be a knock-on effect in RAL Technology, whose engineers would no longer be required. There would be a reduction in training, since the student recruitments would necessarily be removed, both for budgetary reasons and absence of opportunities. Clearly all these factors would lead to a substantial weakening of our technical capabilities. There would be a loss of business to some UK companies, particularly those involved in the manufacture of FPGA-based trigger processor boards and pixel FEDs. This would be unfortunate, since those companies have been steadily acquiring CERN business through our projects. There would be substantial loss of intellectual property in handing over very mature developments, in hardware, firmware and software. Without doubt, our technical and scientific leadership roles and aspirations would be badly damaged.

Finally, there would be a hole in the CMS upgrade budget which, as we have explained, is intended to be shared in proportion to the number of PhD authors supported by each agency. While this is not a truly hard obligation, UK absence from the CMS budget would generate severe doubts about the commitment of the UK to CMS, and its future standing as a partner. Since the UK is a CERN member state, it would suffer badly from lack of scientific return on its CERN subscription investment, which would have far reaching implications.

In short, a 70% reduction in the budget is unachievable without a complete revision of our planning, and long discussions among ourselves and our collaborators. A 50% reduction could be achieved only by removing one or more WPs completely but we do not wish to propose this before considering all possible alternatives, which would need time.

A 30% reduction would also be very hard, but might be achieved by reducing all working allowances to a minimal level, thereby increasing risk, removing several of the RA posts, again increasing risks of not meeting deliverable targets, and being very tough on some of the tasks, such as complete evaluation of components, which we would otherwise aim to complete. We would aim to pass these to collaborating institutions, if such a thing were possible, which is not certain.

The 30% reduction scenario has been evaluated in a simplified way to explore the possible consequences. A summary is presented in the table below. Some approximations, e.g. in estimating indirect and estate costs, were necessary, but they should not have a big impact.

The new cost total in this model is £8.18M, compared to £11.49M in the proposal; a reduction of 29%. This was achieved by taking the following measures

- Preserving most of the budget for deliverables to CMS, but reducing some prototyping, and working allowances substantially
- Reducing new staff costs from £7.23M to £5.22M by decreasing the total new effort (including students) from 101.2 to 71.2 staff years
- Removing an RA post from each institution, which therefore completely removes Brunel project funding.
- Effectively losing an additional 3 year RA post at Imperial to provide the costs of J Fulcher, who was expected to be fully CG funded (see Q9).
- Removing of two of the five project students requested (one at Bristol, one at Imperial)
- Reducing funds for institute equipment from £245k to 157k.
- Reducing ASIC fabrication costs of £534k to £434k, and the working allowance by £105k.
- Reducing the contributions to module assembly costs and for test equipment by about 50%.
- Reducing the allocation in WP3 for next generation developments, i.e. the early stages of the track-trigger activity.
- The specialist sub-contract effort, for firmware and board design, has been reduced from £300k to £160k
- Reducing the total working allowance (WA) from £977k to £385k, by reducing to zero the RAL TD funding for final two years, and cutting the allowance for a fraction of an ASIC processing run.
- Cutting the RAL TD funding by about 50% in year 4
- Cutting the travel budget from £390k to £300k

There is little latitude in how the savings are made, if the first assumption is maintained, i.e. trying to preserve the deliverables to CMS. If this assumption is abandoned, the logical outcome would be that at least one work package would be completely removed. The answer to Q3 explains why each WP is important to CMS and the impact of removing any of them. Delaying the project start by one year (Q4) would not lead to substantial savings unless it was accompanied by removal of effort, which would then put in jeopardy any WP which was subject to staff reduction, as substantial catching up would be required to meet the CMS schedules.

Therefore the 30% saving would require a substantial effort reduction. The removal of RA posts in the model is certainly not optimal, or even tolerable. Imperial has a large responsibility to deliver the hardware for all three WPs and would be seriously affected by the removal of 1.5 new RA posts. It would be very difficult for Imperial to provide enough staff effort in all three WPs; there was already foreseen to be sharing of effort between WPs. Project students are an inexpensive resource which can be extremely effective, but only with adequate supervision and training, which will be limited by the extra load required of existing staff. The reduction in RAL TD staff effort adds risk and undermines some of the deliverables in WP2 and WP4, as well as removing the working allowance. The reduction of firmware and board design support from Iceberg Technology, which has been hugely important in the R&D project, would increase schedule risk.

The Bristol contribution to online software must be preserved for WP3 and WP4 to be successful; therefore we would need to look hard at the viability of simulation studies, both for the short and long term, until it became clear that the project was on track. The RAL contribution to WP3 would be severely curtailed with this level of funding, with some aspects probably becoming non-viable, as effort would have to be preferentially preserved for their main duty of WP4.

The absence of Brunel effort would mean that several aspects of software optimisation and development will be at risk of non-completion and the Data Quality Monitoring task will become unviable. Overall, it would be necessary to seek to redeploy existing effort onto the highest priority items. Whether this is possible and match the specialist tasks required with the expertise of existing staff would remain to be seen.

Cutting the ASIC manufacture budget runs the risk of not completing the development. It is not thinkable that another group would pick up the manufacture costs, unless the chip were complete and at the pre-production stage at best. In practice, even at that point, UK expertise would be needed during the module evaluation stage, even if we were unable to contribute much effort to the practical studies. Therefore there would be another burden on the design team, particularly Mark Raymond at Imperial. It would remove much opportunity to contribute to the completion of the module development, evaluation studies, and further aspects of the use of track-triggering in CMS, where the UK has had a pioneering role and a leading position in the present early stages of implementation.

Without a more careful analysis of the effort, it is not possible to evaluate the increased risk to the deliverables. However, it is certainly expected to increase dramatically. There would be reduction in the scientific output, since the remaining staff would be forced to concentrate on delivering the detector only and have little or no time to explore its performance or physics applications.

	Full total with CG staff		**New costs only**		**Equipment**		**W allowance**	
	Original	With -30%	Original	With -30%	Original	With -30%	Original	With -30%
WP1	415,713	415,713	306,896	306,896				
WP2	3,010,347	2,640,196	2,163,455	1,793,304	679,911	522,021	212,787	117,968
WP3	5,756,698	4,371,275	3,673,896	2,288,472	1,157,300	901,008	184,370	113,139
Sub-contracts	300,000	160,000	300,000	160,000	300,000	160,000		
WP4	6,391,177	5,490,652	4,230,573	3,330,048	749,995	685,143	158,143	154,197
Staff WA	421,752	0	421,752	0			421,752	0
Travel	390,000	300,000	390,000	300,000				
Total	**16,685,687**	**13,377,836**	**11,486,572**	**8,178,720**	**2,887,206**	**2,268,172**	**977,052**	**385,304**

2 Where is the physics leadership? The Panel would like to see a link between the different work packages and the science that it will deliver.

We feel this question may be based on a misapprehension, that detector contributions have a one to one correspondence with physics analysis and output. The UK certainly has strong physics leadership roles in CMS and we drew attention to the topical areas in which our current work is focussed. These are primarily Higgs boson searches and measurements, particularly in the two photon channel and decays involving taus; searches for Supersymmetry and for heavy gauge bosons decaying into electrons. In all of these the UK continues to have leading roles, contributing physics leaders, convenors of specialist groups, and chairs and members of Analysis Review Committees (ARCs) which supervise the analyses as they approach public results, especially during the highly self-critical phase of preparing publications.

In addition there are other important areas of CMS physics in which UK physicists are active and providing leadership. Examples are top quark studies, searches for exotic particles which exhibit very long lived decays, and searches for non-Standard Model Higgs decaying to taus, among others.

A very important point is that our in-depth knowledge of the trigger and tracker and influence over the design and construction ensures that

- they are built, operate and are calibrated suitably for the physics we want to do, and
- it helps our physics data analysis that we intimately understand detector details and have expert knowledge when performance questions arise.

Some concrete examples are the connection to the GCT construction, since hadronic trigger quantities are heavily used for our SUSY searches. We calibrated jet energies in the GCT because this would improve the performance for SUSY; we realised this and were able to implement the necessary changes because we were experts. Such things ensure we gain, or retain, a competitive edge over ATLAS, for example, as well as within CMS. We introduced the jet seed idea to ensure the HT trigger could continue to operate with low thresholds in high pileup conditions (illustrated in the September presentation), which we also require for our SUSY searches. In the tracker, our development of the analogue signal deconvolution and of analogue optical links were examples of how the system was optimised, to preserve the analogue readout which would be lost in a binary readout system. This provides the ability to do dE/dx measurements in CMS (which is not possible in the ATLAS silicon tracker) as well as robust diagnostics of performance and noise suppression which have added to the physics capabilities of CMS. It is worth recalling that these state of the art systems were enormous extrapolations in size and performance from previous detector generations and the gains they provide were by no means guaranteed from the conceptual stage. They are now almost taken for granted in daily CMS operation.

Although in-depth understanding of CMS high energy resolution electromagnetic calorimetry has been a motivating force in the development of the CMS physics programme, primarily for the Higgs di-photon and heavy gauge boson searches, there is no simple link between physics roles and leadership and the detector activities we have been involved in. Every analysis requires data from the *whole* detector, not just the component we have provided. Tau studies rely significantly on calorimetry, but both the Hadron Calorimeter and the ECAL have important roles; tracking is vital for event selection, momentum measurements, topological studies of event information and background suppression. In Higgs di-photon analyses, the whole detector is brought to bear by identifying electromagnetic showers in the ECAL, also utilising HCAL information, then using tracking for vertex measurements, and background suppression by measuring photon conversions, for example.

Approaching from the direction of the detector hardware, the Level 1 trigger is tightly coupled to the physics CMS can deliver through the trigger menus, which set thresholds and selection criteria for channels of interest. Most of the basic trigger objects are very broadly defined; e.g. single lepton triggers, jets, or missing hadronic energy. As we emphasised, the major challenge we face is to maintain low enough thresholds to capture the primary processes with sufficient efficiency to be able to accumulate the high statistics we require. The low mass of the new boson (125 GeV) makes this extremely important, for example.

Only later in the High Level Trigger do more refined event selections become possible and take place, which then utilise maximal information from the whole detector to narrow down the event samples to pick out very specific channels being studied. Typically the full tracker data is deployed at a late stage after the calorimeter or muon information has been refined using the full precision of the raw data to improve energy measurements and objects (leptons, jets) isolated to improve signal to background. Particle flow methods, using tracker data, improve the energy measurements significantly at this stage.

Thus much of the trigger work, such as improving event selection algorithms, relies heavily on physics input to guide the selection criteria and heavy use of simulations. However, the actual selection procedures are intrinsically rather simple; the difficulty comes in the ability to implement them which is usually restricted by the technical implementation; i.e. the capacity, organisation and speed of the hardware. Indeed, one of the strongest arguments for the Time Multiplexed Trigger is the removal of many of the electronic architectural limits to algorithm design; however the processing speed and decision latency will remain major challenges.

The Tracker is certainly the most general purpose detector in CMS. Apart from measurement of short lived decays, which at LHC energies are produced prolifically, the Tracker has no unique physics role other than measuring particle trajectories and momenta. Short lived decays are no longer an objective in their own right; such (now commonplace) events must be supplemented with other information from the event to isolate potentially interesting physics. For example, b-physics is now most important to allow identification of other decays, of which the Higgs is one, higher up the production chain. The crucial importance of the tracker is to reduce bias by reconstructing tracks with very high efficiency over the full angular acceptance. This allows the deployment of particle flow techniques, which substantially improve the performance of the hadronic energy measurements. The pixel tracker plays a critical role in seeding the track reconstruction with high precision points, and ensuring high accuracy by disentangling high multiplicity event data in the vicinity of the primary event vertices, as well as identifying short-lived decays.

Nevertheless, while the detector hardware development and implementation, and physics data analysis, are often largely separate activities which go on in parallel *at this stage of CMS,* both involving highly specific skills, there is a strong link between them and are inextricably coupled. The hardware roles we have chosen and the skills we have developed to deliver systems over many years, are strongly driven by the physics interests and goals of the UK collaboration. We are also continually striving to extend and enhance those skills (e.g. FPGAs and firmware, ASIC design and detector construction) to give us a technical advantage over our competitors, which also feeds through into our physics work. These skills are also highly valued outside our field.

Examples of the UK roles in CMS scientific planning are plentiful. Apart from the CMS Spokesperson, and other senior management roles, recently the UK provided the CMS Upgrade Project Manager and Tracker Upgrade leadership, and currently provides the Trigger Upgrade Project Manager. Such roles have an important physics element to them, since they define and influence strategy, as well as detector matters. Recently CMS set up a Long Term Trigger and Performance Working Group, one of whose co-leaders is Oliver Buchmueller (Imperial College); the purpose of this group is to ensure the physics objectives for the future are clearly identified and built into the detector upgrade activities. This is another example of the feedback from physics into detector developments (and the involvement of those not formally associated with the upgrade project); and the flow is also in the other direction. We expect others who are engaged on other activities to contribute to issues relevant to the upgrades and physics planning; e.g. Sam Harper (RAL PPD) who is an expert on the High Level Trigger menus.

3 Current financial constraints necessitate focusing on the crucial areas and what needs to be done now. Please could you identify these areas and the implications of delaying parts of the project and the priorities you would set to give the best potential science return for the UK?

Most of the CMS upgrade can be considered crucial, unless the scientific objectives are reduced since, as explained earlier, it is difficult to complete the full physics programme without the capability to measure well *all* the particles emerging from collisions over the largest possible momentum and angular range. It is during the selection of events in the Higher Level Trigger software that the full event data can be used to choose the tiny fraction of events which are written to storage and analysed in full. As we stressed, this choice becomes much more difficult in the increasingly high pileup conditions which the LHC is providing now and in future.

The UK is not involved in all areas, for example the muon system, which was de-scoped during the construction phase to stay within available budgets. This is an example of an upgrade which is already under way, paid by US M&O funds, and will significantly improve the capability to identify muons efficiently at trigger level. It also exemplifies a complementary area to which we do not contribute directly but which is essential to the physics studies of interest to us, such as SUSY or Higgs searches. However, as we also emphasised, the detector items with UK involvement are particularly critical to operation and performance.

The L1 trigger is certainly not able to maintain its performance within the 100kHz bandwidth when the LHC reaches full energy, and exceeds the design luminosity. Performance will degrade further if the LHC operates with 50ns bunch spacing. Therefore failing to complete the upgrade of the trigger will have severe repercussions. The calorimeter trigger identifies electrons, photons and jets, all of which are hugely important for CMS physics.

The pixel detector is essential to maintain performance in the high pileup environment. Without the off-detector readout, the pixel detector is effectively useless so CMS would need to find another experienced collaborator able and willing to take on the project, which seems unlikely (see Q8).

The CBC development is the *only* project under way in CMS which will deliver a new front end readout for silicon sensors for the next tracker generation. It must be completed in the next few years for a new Tracker to be possible. There are no other teams able to take on this work, as the few other experienced ASIC design groups are fully busy, e.g. with the pixel detector. The CBC work has been immensely successful and follows on from the previous pioneering work on the APV25 and the remainder of the Tracker readout system, all of which was very innovative. The CMS optical links, to which we contributed, surpass all other such systems at the LHC and the Tracker FEDs were among the leaders in implementing FPGA technology in CMS. Many of the subsequent developments, including the trigger, have built on that success.

Thus, in addition to the crucial need to meet the physics objectives, the hardware projects we propose are crucial to completing a highly capable detector, and all rather time critical. Within a reasonable budget, to achieve a good scientific return it would be far better to attempt to trim at the margins, rather than severely cut work packages. With a much reduced budget, there would be a big impact on the scientific outcome and the CMS and the UK scientific reputation.

4 If there was a 1 year delay in starting the UK project what impact would this have in terms of UK lead and risk to the whole upgrade project?

A one year delay in starting the project would have a big effect. First, we are working to conform to external schedules, all of which have small margins and are themselves determined by the LHC planning, which is quite aggressive for the future performance targets. The pixel detector should be ready to install by the end of 2016, the upgraded trigger should be commissioned in 2015 to be operable in 2016, and the CBC2 development must converge for a Phase II Technical Design Report with full readiness for large scale manufacture and testing no later than 2017, so that production can start for a new Tracker to be ready for installation by 2022.

The WP2 ASIC manufacture spending is not anticipated until well into year 2 of the project but delays in staff funding for CBC design would put this back even further. It would also delay the module development, feedback from which, by means of detailed evaluation in lab and beam tests, would have a knock-on effect on the subsequent designs.

An example of the effect of delays is the impact of reduced trigger functionality on the overall CMS physics performance in 2015 and 2016. As the LHC performance has continued to surpass expectations, with far more challenging experimental conditions than originally envisaged, it has become clear that the L1 trigger upgrade is urgent, to have new algorithms ready for the LHC restart in 2015. The existing trigger will lose efficiency for selecting important physics events. The single electron trigger threshold will have to rise to ~50 GeV, which makes the WH Higgs channel impossible. For HT the threshold will have to increase from 150 to 500 GeV. So the 2016 run would be wasted for these analyses without a trigger upgrade. If one assumes that 2015 has a slow luminosity growth, then we will still lose 50% of the data before LS2.

An intense effort is therefore required very soon to study and validate new algorithms using 2012 data, and to commission them in first 14 TeV collisions. Commissioning of the new trigger by 2016 depends on successful delivery of the hardware, and on key infrastructure changes during the shutdown period. These operations cannot be carried out at another time, since they require extensive intervention on the existing trigger path. The schedule for this part of the project is therefore critical, and cannot be delayed without jeopardising CMS performance.

Another important practical issue is continuity from the present R&D activities, where posts will be lost if funding is not available by March 2013, which would be difficult to recover from. There are several key people who would be affected, and TD engineers. This would be extremely damaging.

5 For each contributing institution, please can you clarify their primary role in the project? What scientific leadership or unique input will the participation of that institute bring to the project? Which of the people at the institute are key to the project and which academic(s) is/are providing leadership? Please also list the primary contribution of each that institute in the previous R&D funding and in the original CMS construction?

Bristol

Primary roles in project.

The Bristol group is involved in all three work packages, following on from its contributions to the current R&D project. Bristol's primary roles will be to complement the hardware developments in the trigger, pixel and tracking work packages with the software and firmware components required both for demonstrator systems, and for final operation in CMS. In addition, experienced Bristol researchers will help to lead commissioning of both trigger and pixel systems, first in the technical integration of the systems, and subsequently in their operation for physics.

Scientific leadership and unique input

Bristol has played a major role in the commissioning of the CMS detector for physics, and continues to hold leading roles in the physics programme today. The group has provided several physics convenors and sub-convenors since the start of the LHC run, and is contributing to analyses in SUSY and exotica searches, top physics, and Higgs boson studies. In addition, the group is leading the definition of the future trigger menus for the next physics run. The group has a long history of successful development in trigger and readout systems over four generations of collider experiments, culminating in the CMS and LHCb construction. The relevant technical capabilities for this project are in the development and commissioning of complex online software and firmware systems, and in their use both as demonstrator systems and as part of running experiments. The Bristol deliverables will provide the ability to reliably control, configure and monitor the new and complex hardware systems developed in the proposed project, key to their practical exploitation in CMS.

Key individuals and academic leadership

Overall academic leadership at Bristol will be provided by Dr Dave Newbold, with Dr Joel Goldstein overseeing the pixel and tracking developments. Key researchers, each with significant experience from the original CMS construction and commissioning, include Dr Jim Brooke, Dr Rob Frazier, and Dr David Cussans. Their efforts will be supported and enabled by the more junior staff requested in the project.

Primary contribution by institute to R&D phase & original construction

Key Bristol deliverables to the original CMS construction were the design and optimisation of the ECAL endcap detectors, and in particular the link to the calorimeter trigger; the online and offline software components and commissioning of the Global Calorimeter Trigger, and leadership of the overall trigger software project; and the design, testing and commissioning of the CMS Grid computing system. In the upgrade R&D phase, Bristol has led the studies of the physics performance of the planned trigger upgrade, and made key contributions to the optimisation of the new pixel detector; designed and led the development of the IPbus software and firmware; and provided the first iteration of hardware, firmware, and online software for the new pixel readout system.

Brunel

Primary roles in project.

Brunel devotes all of its effort to WP4. We will contribute to software development for the pixel FED and its deployment and testing. The distinct areas with significant contributions from Brunel are; software for verifying the quality of data from the FED, interfaces to the relevant databases, and to the primary reconstruction software framework of CMS.

Scientific leadership, key individuals, academic leadership and unique input

Peter Hobson: A member of CMS since 1995, he has led the Brunel group, as PI, in CMS for nearly a decade. He was responsible for leading the development of the radiation tolerant vacuum phototriode photodetectors for the endcap electromagnetic calorimeter. He has currently roles within CMS on the ECAL and top-physics editorial boards and contributes to physics analysis studies on the properties of the top quark.

Jo Cole: A member of the CMS tracker community since 2005, initially developing on-line software for the tracker FEDs and the tracker status database. Since joining Brunel she has been appointed secretary to the Tracker Institution Board and Chair of the Tracker Publication Board and is also contributing to pixel DQM and top-quark physics studies.

Ivan Reid: A member of CMS for ten years, providing software for the current silicon tracker and involved in the currently funded upgrade project since its inception. He is absolutely key to the Brunel contribution to this project as he has extensive experience, widely recognised within the CMS tracker upgrade project of complex code development and optimisation. He has also contributed to new data quality monitoring techniques, some of which were used during the CMS tracker commissioning phase.

Roger Powell: A recent member of CMS, he has many years of experience in academic and commercial software systems development, particularly involving databases. He has contributed recently to another HEP experiment software development and is currently also investigating new algorithms for track fitting for detector alignment.

Primary contribution by institute to R&D phase & original construction

The key Brunel deliverable to the CMS construction project was the development, construction and commissioning of the endcap electromagnetic calorimeter of CMS. Brunel, with RAL, was responsible for the development of the vacuum phototriode photodetectors (VPTs). Brunel carried out all the development and quality assurance work on the radiation tolerant aspects of the VPTs, including the HV components, connectors and cables and carried out all of the 4T magnetic field (CMS solenoid design field) quality assurance work on both the prototype and production VPTs. We contributed to the evaluation of new scintillating materials for the homogeneous electromagnetic calorimeter including, with RAL, the development of new dense scintillating glasses.,. We were also involved in the silicon tracker commissioning, primarily through the development and implementation of some of the software for data quality monitoring.

Imperial College

Primary roles in project

Imperial College is responsible for most of the hardware development in this upgrade project, being responsible for design and construction of trigger processor boards, the pixel FEDs and the analogue design of the CBC ASIC series. The original concepts embedded in the designs, such as the CBC architecture, and the trigger concepts and trigger algorithms and firmware originate at Imperial. Imperial will continue to evaluate the hardware produced and construct and operate test systems for the trigger and pixel tracker, both in the lab and in test beams. We will develop a new ASIC wafer test system for the CBC and contribute to module design and manufacture. For the trigger, demonstrator systems will be operated in London and CERN. Imperial will have lead responsibility for much of the firmware and will share the implementation of online software systems. Imperial will take lead responsibility for the new pixel tracker online software for the DAQ. Each of the WPs has an Imperial co-manager.

Beyond the detector and upgrade activities, Imperial played major roles in CMS scientific management, most notably with T. Virdee as long-standing Deputy Spokesperson, and then Spokesperson for three years to 2010. The group has contributed several people as physics convenors, especially in Higgs, SUSY (one of whom was Alex Tapper) and tau areas.

Scientific leadership, key individuals, academic leadership and unique input

Geoff Hall: PI. A member of CMS since inception, following R&D on silicon detectors for LHC and the SSC. Responsible for the deconvolution idea used in the APV25, and the conception of the CMS Tracker readout and control system. Steered the development and implementation of the CMS Tracker readout, which continues, and the development of parts of the ECAL readout. Now the UK CMS PI and CMS MB/FB representative. Many roles in CMS management, including leader of Tracker readout system, and PI of current UK R&D project. Remains involved on day to day basis with both tracker and trigger upgrade work, not only administratively.

Alex Tapper: WP3 manager. He is both a trigger and SUSY physics expert, and ex-CMS SUSY physics convenor. Since 2012, he has been CMS Trigger Upgrade Project Manager. He coordinated commissioning of the GCT, including providing much of the software support. He led analysis of LHC data using jet and energy sum triggers, and several SUSY analyses. He continues to be responsible for GCT operations, as well as overseeing the UK trigger work, simulations studies and CMS-wide trigger upgrade.

Mark Raymond: WP2 manager. He is a very experienced analogue ASIC designer (responsible for Tracker APV25 and ECAL MGPA) and detector physicist building systems for lab and beam tests, and also expert on radiation tolerance studies. He is the lead scientist for CBC and CBC2, for which he designed the analogue stages, and the major UK contributor to design of the proposed PS modules.

Mark Pesaresi: WP4 manager. He carried out a PhD on track-triggering in CMS, and he also had had hardware responsibilities for the tracker APV emulator and for trigger rate control, so is proficient in firmware, and quite expert with the Tracker online software. Since his PhD he has been an RA on the upgrade R&D project with responsibility for DAQ software and analysis, and CBC evaluation. He has excellent electronic hardware skills and is the lead designer of the pixel FED.

Jonathan Fulcher: He manages all UK Tracker electronic hardware in CERN. He is an online software expert and a key contributor to the CMS Tracker DAQ, having been one of the small team responsible for constructing the Tracker DAQ online software. He also oversees maintenance and updates of firmware for the Tracker FEDs, with the aid of a part time RAL TD engineer.

Greg Iles: Responsible for the GCT hardware and firmware, and leads those developments of the trigger upgrade R&D. He was the lead designer of the Mini-T5, the MP7, as well as parts of the GCT, which pioneered optical and backplane technology, and has the main responsibility for all our trigger firmware. He also serves as the overall CMS firmware coordinator. He is one of the originators, with John Jones and Magnus Hansen, of the Time Multiplexed Trigger architecture.

Andrew Rose: He worked as an RA on UK upgrade R&D for three years before being appointed to a CG engineer post, following the departure of our previous engineer Osman Zorba (who had made significant contributions to both Tracker and Trigger installation and commissioning in CERN). His PhD was on the GCT, as well as extensive simulation studies of future calorimeter trigger performance. He is an expert in online and offline software, with excellent firmware and hardware skills. He contributed design work to the Mini-T5 & MP7 and is responsible for the construction and operation of the trigger demonstrator system at Imperial. He is one of the originators of much of the IPbus software system, and has contributed to developing the TMT concept.

Primary contribution by institute to R&D phase & original construction

During the original CMS construction Imperial was responsible for the development of the Tracker electronic readout system, whose overall manager was Geoff Hall. This pioneered several important items, several of them in close collaboration with RAL Technology, including ASICs for front end readout of silicon microstrips, especially the APV25 in then novel 0.25μm CMOS technology, and the Tracker FED digital readout boards. We worked closely with CERN on the development of the analogue optical links (40MHz x 10b), which was another ground-breaking development, which were later used for digital transmission at 800 Mbps by the CMS ECAL. The tracker readout system work included significant studies of radiation tolerance of sensors and electronics, including total dose and SEU effects, and the construction of substantial test systems for APV25 wafer measurements, which included all acceptance measurements on the complete delivery of about 150,000 chips, the construction of test systems for the FEDs, which were used in RAL TD and by the manufacturer for

Quality Assurance of assembled FEDs, and beam tests of significant parts of the prototype systems. Imperial College staff oversaw the installation of the Tracker FED system, comprising 440 boards in 45 large crates, in CERN

Imperial and RAL TD designed the MGPA front-end readout chip for the ECAL crystal calorimeter, whose electronic system was completely redesigned in 2002, at a rather late stage. Imperial also contributed to the crystal calorimeter construction and the instrumentation for, and measurement of, PbWO4 crystal transparency, including post-irradiation. Imperial took over the lead responsibility for the Global Calorimeter Trigger in 2006, and saw this through to delivery in 2008 in collaboration with Bristol and CERN.

Currently Imperial is responsible for most of the maintenance and operation of the Tracker FEDs and GCT in CERN including hardware and firmware.

During the R&D work since 2009, Imperial College has been responsible for the development of the mini-T5 and MP7 trigger processor boards for the calorimeter trigger and leading the CBC ASIC development and the analogue design of the CBC. We have continued to play important roles in the overall Tracker system design and the calorimeter trigger design. The Time Multiplexed Trigger concept was an Imperial idea, as was the concept of "stacked" tracker modules for generating track-trigger primitives and this was supported by simulation studies carried out by a number of Imperial students.

RAL PPD

Primary roles in project.

PPD provides one of the two workpackage leaders for WP4 (Harder). He has primary responsibility for coordinating the delivery of the firmware and software aspects of the pixel FED. This is a distributed effort amongst all UK institutes making coordination a critical role. RAL primary responsibilities encompass the FED firmware, the mezzanine card development, testing and integration. This builds on the current effort led by Harder on the development of readout for the pixel detector. Newbold is one of the workpackage leaders for the trigger and will be seconded to RAL (50%) for the next 3 years. PPD will contribute to the L1 trigger and the R&D for a phase 2 track trigger. For the L1 trigger the principal tasks encompass IPbus implementation, trigger emulation, commissioning and performance monitoring. For phase II work will be on the simulation and design studies for a tracker trigger and emulation of such a trigger.

Scientific leadership and unique input

Within CMS PPD has provided leaderships roles in detector design, construction, installation, commissioning, operation and performance. Most prominently this is on the ECAL and also includes the tracker. These include project managers, run coordinators, technical coordinators, convenors for detector performance groups. PPD staff lead many physics analyses including CMS flagship analyse particularly within exotics and have held and hold numerous physics convenor and sub-convenor positions. Expertise in track reconstruction, detector simulation, electron reconstruction, high level triggering and ECAL performance and reconstruction provides a very relevant combination for the proposed project. Firmware, online and offline software expertise and system commissioning are particular contributions of PPD where firmware will be supported additionally by TD engineers.

Key individuals and academic leadership

Claire Shepherd-Themistocleous, a member of CMS, since 2003, is head of the CMS group, a PPD Division Head and provides overall academic oversight of the upgrade project within RAL. She has expertise in physics analysis leading a number of analyses, including the flagship Z' analysis, within the exotics group. She has particular knowledge of the ECAL, electron identification and triggering requirements of analyses. She is currently the CMS ECAL Institution Board Deputy Chair and the Deputy Director of the NExT Institute.

Kristian Harder is critical to the WP4 effort. He has significant expertise in DAQ system and through current activities including providing readout for the test beam activities using the new pixel frontend readout chip designed by PSI, has acquired a detailed understanding of the pixel FED requirements and the behaviour of the new frontend chip. He was one of the Silicon detector group leaders on the D0 experiment. He had particular responsibility for the readout electronics including firmware, hardware, control systems and monitoring. He led a major refurbishment of the electronics to enable stable and robust operation of the Silicon detector.

Ian Tomalin, a member of CMS since 1999 has considerable experience of the current tracker, both of the readout and the simulation and reconstruction. He has been the convenor of numerous groups including tracker simulation and reconstruction and physics groups. He will lead the Physics performance and simulation aspects of the R&D at RAL for a track trigger. He currently leads analysis of long lived particles.

Dave Newbold is one of the work package leaders for WP3 and will be seconded to PPD for the next 3 years for 50% of his time. Joint positions such as this were recommended by the recent PPD review and are designed to foster even closer collaboration between PPD and leaders within the UK university community. Newbold will lead the trigger activity at RAL and particularly contribute where there is overlap between WP4 and WP3 activities.

David Petyt is the ECAL detector performance group convenor and has an in depth knowledge of the ECAL detector, its performance and its input to the L1 trigger. He will work on the emulation of the L1 trigger and algorithm design and commissioning.

Dave Sankey has extensive experience of L1 triggering including firmware, online software and system integration from the H1 and ATLAS experiments. He was also the UK project manager for the H1 track trigger. He will work on IPbus and microHAL development.

Tim Durkin is an engineer with 12 years experience of detector integration, testing and operations on MINOS and T2K. He will contribute to the firmware and integration, testing and commissioning of the pixel FED. Most recently he designed and oversaw the production of the pixel telescope used in beam tests.

Gary Zhang is an engineer with extensive experience of silicon detector development for a linear collider detector and LHCb. He has particular experience of laboratory test systems and will contribute to the testing and commissioning of the FED.

Primary contribution by institute to R&D phase & original construction

During the construction phase RAL PPD's primary areas of activity were in the electromagnetic calorimeter and the tracker.

Dave Cockerill was the ECAL endcap project manager, with RAL as the lead institute responsible for the design and construction of the ECAL endcaps. RAL PPD was responsible for the key simulations of detector response and design optimization, which included benchmark physics channels. The detailed mechanical design, and the procurement of the major and minor mechanical structures were carried out by RAL TD. RAL and Brunel undertook the development, and RAL directed, the mass production of the Vacuum Phototriodes (VPTs), the phototubes used to sense the light produced in the lead tungstate crystals, which were a development of a structure originally invented at RAL. The characterization, primary quality control and procurement of all the VPTs for CMS was carried out by RAL. The VPT high voltage system was designed and installed by RAL, with responsibility for its continual operation and maintenance. RAL was responsible for the construction, installation and commissioning of the endcaps and continues to have major responsibilities for the operation and the data quality monitoring of the sub-detector. RAL was responsible for the overall mechanical design of the ECAL, laying down the blueprints for the structures that are now in CMS.

PPD staff were among the principal authors of the "FED user design requirements" document and contributed to FED online and offline software. In addition, PPD staff performed simulation studies of tracker data rates & FED zero suppression algorithms, which were used when integrating the FED into the DAQ and optimizing the FED design. Tomalin coordinated the offline software group that encompassed tracker simulation and reconstruction. He also led the tracker data handling group and the b tagging and vertexing group.

RAL TD

Primary roles in project.

Mark Prydderch shares responsibility for managing WP2 with Mark Raymond of Imperial College. The RAL ASIC team are responsible for development and delivery of the front end readout ASIC for the new tracker readout system. The ASIC team attend regular meetings at CERN to discuss and develop the requirements and specifications for the ASIC in parallel with other aspects of the development. The team will contribute to defining the module data transmission protocol, evaluating ASIC and module performance, planning the module design and procurement of key elements such as bump bonding.

John Coughlan leads the CMS RAL Technology team within the Electronic System Design group. The team at RAL will be responsible for the development and delivery of the interface of the pixel readout system to the CMS DAQ including the data links. The team will attend regular meetings at CERN to discuss and develop the requirements and specifications for the DAQ links. The team will contribute to defining the architecture and data link protocol, implementing and testing FPGA VHDL designs for the Pixel FEDs, and if required develop custom hardware. The team will also manage the manufacture and testing of the final production boards.

Scientific leadership and unique input

The ASIC Design Group at RAL has specialist capabilities in the design of mixed signal, high channel density, low power, low noise ASICs with the ability to survive harsh radiation environments. We have access to the latest industry standard design tools essential for the delivery of working ASICs in technologies such as the IBM 130nm that we used for the CBC ASICs. The group has a long history and proven track record of successful ASIC design in support of research for areas such as space science, medical imaging, synchrotron instrumentation, particle and nuclear physics experiments. Our involvement in the design of the new front end ASIC builds on past experience from the development of the very successful APV25 ASIC for the CMS Tracker.

The Electronic System Design Group at RAL has specialist capabilities in electronic board design and FPGA VHDL code development with access and support to the very latest EDA design tools. The group has a long history and proven track record of successful board and FPGA design in support of research for areas such as synchrotron instrumentation, particle and nuclear physics experiments. We will build on our experience from the development of the current Strip Tracker FEDs and also plan to exploit our recent DAQ prototypes utilizing 10Gbps data links which are currently being commissioned at the European-XFEL facility at DESY.

Key individuals and academic leadership

Mark Prydderch: leads the ASIC Design Group at RAL. He is the designer of over 20 ASICs for science applications. Mark has authored and co-authored 16 publications and holds a patent 'Accelerated Particle & High Energy Radiation Sensor' (US 2006/0278943 A1).

Davide Braga: lead designer for the CBC ASICs. He has worked on six ASICs for physics applications; and authored and co-authored 4 publications. He is also currently studying for a PhD in Particle Physics at Imperial College.

John Coughlan: PhD Particle Physics, with over 20 years design experience, and has authored over a dozen publications. Specialising in the implementation of DAQ systems, embedded software and FPGA firmware design. Project Manager for Strip Tracker FED system. DAQ system design, FPGA firmware development and test and management of board production.

Mohammed Siyad: 15 years experience of electronic circuit design, advanced FPGA firmware VHDL design for DAQ and Trigger systems, most recently for the T2K project. Currently working on CMS upgrade DAQ link hardware and FPGA firmware design, implementation and test.

Primary contribution by institute to R&D phase & original construction

The ASIC Design Group was responsible for several ASICs used by CMS, culminating in the APV25 used in the current tracker system, and the layout of the ECAL amplifier chip, the MGPA. In the recent R&D phase, in collaboration with Imperial College, the ASIC team developed the CBC front end readout ASIC for silicon sensors for the next generation tracker and recently designed the CBC2 with PT Stub finding capability to provide trigger information for the new tracker system.

The Electronic System Design Group was responsible for the design and delivery of the current system of 500 Strip Tracker FEDs which are successfully operating at CMS. This encompassed all project aspects including electronics board design, FPGA VHDL implementation and management of large scale manufacture and test As part of the upgrade R&D the group has developed a number of FPGA firmware designs implemented on commercial development boards to demonstrate the building blocks of the upgrade DAQ. We have recently delivered firmware to read out pixel data in the current beam tests.

6 How will the overall CMS upgrade project be managed? How does the collaboration decide who is leading each element within the upgrade project? How will you ensure there is no duplication of effort across the groups?

This is a very broad question, which we will endeavour to answer but may be more easily explained in person to the Visiting Panel.

Overall management is at the Spokesperson level, but steered on a day to day basis by the Upgrade Project Manager (actually two co-managers, sharing the very large task, but not with different roles). A significant part of the present activity has been the development of Technical Design Reports, defining the new projects. These have been submitted to the LHCC for the Pixels and HCAL, while the Trigger TDR will be in 2013. Other CMS upgrades are in the muon system, which did not need a TDR because it restores a downscope of the original project; the forward HCAL, which involves replacement of photomultipliers and is considered maintenance and repair work by the US project; and the DAQ, which is not yet well defined.

Other projects which are contained in the upgrade planning involve infrastructure, where additional work is required above the standard maintenance tasks in view of sub-detector upgrades. A major example is the replacement of the beam pipe, in view of the new pixel system. There are also improvements in the magnet power and cryogenic systems, beam instrumentation and integration facilities. These are managed by Technical Coordination, and funded as common projects.

A major part of the upgrade management at present involves open project reviews, called by the upgrade management in coordination with sub-detector upgrade managers. These allow CMS to form an overview of progress and critical items and attempt to focus resources on outstanding areas by means of independent reviewers' reports, which are then reported to the CMS MB and FB.

Financial supervision is in the first instance provided by a Project Resource Manager in conjunction with the sub-detector Project Manager, who compile costs within their project, from the responsible lower level managers. This is lengthy process and also subject to external review, usually at the final stage of the TDR preparation. Recently the pixel and HCAL cost estimates were scrutinised by a sub-committee of the FB, prior to the release of the TDR. Resource Managers and PMs participate in and are answerable to the CMS FB, along with national or regional representatives, e.g. the UK PI, and various ex-officio CMS management members, including the CMS RM and Spokesperson and Deputies.

There is an overlap between the detector design and the physics motivation. While in the past sub-detector organisations provided some physics background and motivation in their designs, a Physics TDR was produced to bring together and examine in more detail the CMS overall physics performance. This is expected for the Phase I upgrade, but probably not until a relatively late stage and most likely will be combined with initial planning of the major Phase II upgrade in 2022. Meanwhile there has been a collaboration between the CMS Physics organisation and those carrying out simulation and modelling work in the sub-detectors. To demonstrate the benefits of the revised pixel detector, for example, a few specific analyses were carried out to simulate the future performance and compare it to the present, and projected, performance without changes. The analyses were subject to the usual approval processes within CMS, so that they were internally critically evaluated by the collaboration.

Ultimately the detector designs, construction and commissioning – and now upgrades - are driven by sub-detectors, but with an iterative feedback process within CMS to match the required physics objectives, and financial and technical aspects, to overall constraints. This is rather complicated to explain, but hopefully this process is reasonably clear. A natural outcome, at one or more levels, is the avoidance of duplication and unnecessary overlap of activities, and thus waste of effort. Of course, at the R&D stage some similar developments take place but usually CMS has been successful in steering them to avoid duplication either by establishing internal collaborations or eventual selection.

The leadership within CMS is generally by appointment, following consultation within the projects. The only fully elected CMS posts are the Spokesperson and Collaboration Board Chair, each of which are two year appointments, with no extensions. The CMS constitution prescribes the procedures for appointments of lower level managers; typically for Subsystem managers this is by nomination by the Spokesperson in consultation with the relevant Institution Board. All these nominations must be endorsed by the Management Board and approved by the Collaboration Board. Then Subsystem managers nominate deputies and other management positions, again in close consultation with their communities. (Unusually, the latest Trigger Project Manager and Trigger Upgrade Manager were appointed at the same time by the Spokesperson following the procedure described above).

The recent pixel and HCAL TDRs are now public documents and it might be useful to the panel to be able to examine them. There are chapters on management and finances. They can be found at

Pixels: CERN-LHCC-2012-016 (CMS-TDR-011) <http://cdsweb.cern.ch/record/1481838>

HCAL: CERN-LHCC-2012-015 (CMS-TDR-010) <http://cdsweb.cern.ch/record/1481837>

7 What are the critical inputs from your non-UK collaborators? Please provide information on the composition, responsibilities, manpower and funding status of your non-UK collaborators.

We assume the question refers to direct input to the UK projects. Of course, there are vital indirect inputs, such as the successful development of the new pixel ROC and TBM chip which define the data to the FED, and the provision of optical splitters and installation in CMS so that a parallel trigger can be operated after LS1.

WP2:

The CBC development is essentially a UK project in its entirety. Regular meetings of the team developing the new Tracker readout system are held, usually in CERN (open to others in CMS to join). These develop the tracker requirements and specifications, share results on simulation studies or empirical studies, and allow us to discuss all aspects of the development. Typical issues concern the data transmission protocol and use of available bandwidth, progress in developing components, or evaluating material and performance, planning of the module design and procurement of the key elements, such as the support hybrid, bump bonding and power conversion. So the critical inputs are the shared development of the full system specifications, which concern us at the module level and as users.

The module development is very much a shared development. CERN is the most crucial partner, being responsible for some significant components, such as the GBT data links and leading the module hybrid design. Aachen are responsible for the DC-DC power converter, also with CERN ASIC design collaborators. Both of these activities are generally well resourced.

While the basic hardware is under development, the overall detector design is under construction. There are good connections between both activities. Software to parameterise the performance of different layouts has been developed, to which we contributed. This allows to understand the impact of parameter changes and swiftly model the impact of assumptions of material and the impact of different detector layouts, power provision and cooling schemes, in a realistic way. The tool reproduces well the present performance, which thereby avoids the time consuming task of full detector simulations, which are hard to compare with alternatives, and difficult to complete in a reasonable time because of the level of detail required. The models can thereby provide good input to physics simulation studies. Most of this work is now a shared effort, with other collaborators, as are developments of new sensors and other major components, such as the optical links, cooling and powering.

WP3:

The original CMS L1 trigger was built by a consortium of around ten institutes, each taking responsibility for a particular subsystem. This sharing of responsibilities will continue into the upgrade phase, albeit with new institutes joining the project, and with efforts made to standardise some hardware and software across subsystems. The cost sharing for infrastructure (e.g. new optical links feeding the calorimeter to the trigger) is currently under discussion, but is likely to be on a roughly pro-rata basis. Most of the countries involved are at a similar stage of discussion with funding agencies to the UK, with the exception of the US (see below).

The current UK responsibility is the Global Calorimeter Trigger, which interfaces to a Regional Calorimeter Trigger provided by Wisconsin. These groups have agreed to share responsibility for the upgraded calorimeter trigger, with the resources of all participants needed to ensure delivery of the system on the required timescale. Both groups have access to significant engineering resources, employ staff with experience of commissioning and operating the current system, and have carried out R&D to produce new hardware exploiting the latest generations of FPGAs and serial links. However, the UK project is in advance by 1-2 years, having already produced the only board (MP7) currently capable of acting as the building block for the new trigger.

The future trigger has two processing layers. Wisconsin aspire to provide the first layer, whose technical requirements are more modest, for a TMT or a conventional trigger, if chosen by CMS. The

UK could deliver both layers, and recommends this to CMS. In view of the US funding situation, it may be necessary for the UK provide all hardware for the calorimeter trigger, which is what we have costed. It would certainly make a strong case for our leadership and responsibility were we able to deliver the hardware in full, and ensure other parts of the trigger based their developments on it. This will avoid unnecessary duplication of hardware, and firmware and software, which is undesirable but hard to avoid. In this case the UW group's contribution would be in the areas of simulation and operations, where they are strong, and their financial contribution would easily be deployed elsewhere in the trigger project; the US has major commitments in the muon trigger for example.

The output of the calorimeter trigger is fed into the Global Trigger (GT). This is the responsibility of the Vienna and Ohio groups. It seems likely that they will profit from our R&D by using the MP7 and will need only to provide firmware and software. The Vienna group are in the final stages of their application for funding.

The trigger architecture decision remains a hot topic, with one idea to choose by mid-2014 on the basis of slice tests. However, recent reviews have concluded this decision should be made much sooner, possibly before the end of this year.

The calorimeter trigger takes input data electrically from the ECAL and HCAL; the upgrade requires that data be transmitted optically. The installation of mezzanine cards (ECAL) and passive splitting and new electronics (HCAL) to achieve this is a critical input from non-UK collaborators. This must be completed during the LS1 shutdown, in time for re-commissioning of the trigger from mid-2014. Responsibility for the engineering is currently with Lisbon, with optical components provided by CERN. LLR (France) will also share the cost, with quite solid funding. Portuguese funding is likely to be lower than requested, but arrangements have been made for a long term loan from CERN to avoid delays. There is a possibility that a CERN group will join the trigger activity. The UK would make a proportional contribution since these items are seen as common shared hardware.

The HCAL work is costed and planned in the recent TDR, which the LHCC has recommended without reservation. It will be a US contribution whose provision may be delayed but funding can be advanced from elsewhere to meet the proposed schedule.

WP4:

The optical transmitters and receivers will be provided by CERN through a commercial procurement, which is well advanced. There are a limited number of suppliers and the parts must be well qualified; they will also be used by other projects. The CERN team is very competent and experienced, and are close collaborators. The components use snap-in connectors so should not be critical, even if delays occur. The work is fully funded.

The specification of the pixel Readout Chip (ROC) and Token Bit Manager (TBM) chip output data stream and encoding is important, although the implications are mainly for the firmware development. The groups responsible are PSI and Rutgers. The new ROC and TBMs are also well advanced in prototyping and should be finalised in 2013.

The specification of a new interface, most likely multi-Gbit Ethernet, to the central DAQ is required, which is a CERN responsibility. The CMS central DAQ is largely a CERN activity and the team is small but sufficient.

Less critical inputs are expected during online software development in support for FECs from Strasbourg and general collaboration on the Tracker DAQ from a few other collaborators.

The total materials cost of the pixel upgrade is estimated to be 17.1MCHF. Of this approximately 56% is available or granted; the remainder is requested. The largest outstanding share of the requested funds is from the US, amounting to 3.9MCHF (23%). While full funding is expected to come late, because of the US approval process, they are confident to be able to provide interim funding to the project via operations budgets.

The Trigger upgrade costs and sharing are at a provisional stage. While there is some uncertainty about the strength of all commitments at present, the total estimated cost of about 5MCHF is less than the projected funding available, which might be as high as 7.8MCHF, if all proposed pledges were realised. However, this includes projections from Greece and Portugal (~1.5MCHF), who may have difficulties in delivering that total, and the US funding (3MCHF) is expected to be committed late, probably from 2015.

If the panel wishes to explore more deeply the overall CMS upgrade funding and commitments of different agencies, it is probably best to do this in the Visiting Panel meeting, where we can draw on material which will be presented to the next RRB on 29-30 October. The financial plan for CMS Upgrades will be presented to representatives of the funding agencies.

8 If certain tasks of the project are not funded, what is the possibility of the other collaborators picking up that work and what will be the implications and risks involved?

First it is important to note that any transfer of work to collaborators would certainly require effort on our side to pass on designs and specifications, add documentation and provide explanations. If there is a significant reduction of our planned commitments, there will therefore be associated costs in staff effort. Apart from the work involved it is likely to be demoralising to the staff involved, so generates an obvious risk, in addition to the inevitable loss of time and danger of errors in transmission. The work we have delivered in the upgrade project has been challenging and of a very high standard; this applies to processing boards, ASICs, firmware and online software in particular. It would need staff of similar capability to succeed in taking it over without too much overhead. Such people do exist, of course, but they are not commonplace and might not easily be assigned to these tasks. This is one reason we are ahead of our competitors in much of our activities.

The implications in all cases, except for minor activities, would be damage to the UK reputation and standing, loss of scientific and technical leadership, and delays to all the projects.

WP2:

CBC design. There is no obvious candidate to take over this work. The only two other groups in the Tracker project with ASIC expertise at present are CERN and Lyon. CERN has substantial ASIC design expertise, although mostly digital, and the resources committed to CMS are already stretched and would not be sufficient to take responsibility for this project at present. Lyon have some expertise but are a small team with little experience and are not likely to be able to take over such a substantial project. Outside the Silicon Tracker, but in the pixels, PSI and FNAL also have ASIC design expertise: PSI are heavily committed to the pixel project and it is extremely unlikely that they would take this on, especially in view of future pixel upgrades; FNAL is not a large ASIC group and discussions have been held in the past on their possible contributions which have not led to anything tangible. Beyond that, INFN have ASIC designers but no track record in CMS, and significant financial support is very unlikely at present.

For module development, although the savings would not be large, we might hope that collaborators could be found to take responsibility for our parts in module design and assembly, in collaboration with CERN. At present, there is no obvious candidate or any group expressing interest. It would also weaken the UK scientific interest in the project to relinquish involvement in the detector modules, just at the point where the design effort has practical implications for CMS operation and triggering.

WP3:

The obvious candidate to take a larger role in the calorimeter trigger development would be University of Wisconsin, and, possibly, other less hardware-oriented US groups. The US financial situation at present is not ideal; following recent approval of CD0 (Conceptual Design, stage 0, in US jargon), upgrade funds are expected to start flowing in 2015, subject to the US DoE processes. Up to now funds for the US elements of upgrades have been very restricted, which has held back their progress. Wisconsin have been developing a counterpart to the MP7; however they do not have the expertise which we possess. At present their board is 1-2 years behind the MP7 and Wisconsin have little firmware expertise, although they hope to increase this in the coming years. It is possible, but unlikely (based on experience), that they would be willing to take over the MP7 design in full and take it through to implementation in CMS. Thus, the most probable outcome of reducing UK effort on the calorimeter trigger would be a complete stall of the trigger project, which is already stretched to deliver new components for muon and global triggers, in addition to the calorimeter.

Online software and firmware responsibilities could also in principle be taken by other collaborators. At present, the trigger project does not have groups available to take extra loads and these are areas where specialist expertise is required which is rather sparse.

Thus, the most likely implications would be delays, while lengthy searches for funding and skilled effort to cover this work took place.

WP4:

As explained in the proposal, the pixel FED project was a natural entry point for the UK into another area of the Tracker, to which we have contributed so much. Our proposal was welcomed by CMS because there were no candidates for an ambitious new FED development and the plan until that point was very weak, based on replacement of daughter boards on the existing FEDs. This would have had severe practical repercussions, such as non-availability of boards for system development until the pixel detector was shut down, as well as relying on antiquated hardware with limited processing power in old FPGAs. Thus, again, there is no obvious candidate to take responsibility for the new pixel FED project and certainly no-one with the μTCA experience or IPbus capability.

Greater sharing of some of the online software tasks might be envisaged, to spread the load. The efficiency would be reduced substantially since the core of such developments is best carried out in close proximity to the hardware development, with dedicated laboratory test systems as we envisage. Strasbourg, who wish to take responsibility for the Front End Controller (FEC) software, might be such a candidate but they have deliberately limited their ambitions to match resources and they emphasise their inability to accept a hardware responsibility. There are individuals in US groups with expertise in pixel online software; these people are widely dispersed and at present mostly able to accept small roles only, and their groups also have other duties within the pixel project.

9 What are the plans to mitigate the shortfall in the funding of posts under consolidated grants? Does this include covering any of these posts in the current application? If so, what would be lost from this application in order to stay within the suggested descope envelopes?

Posts affected: J Fulcher (Imperial College). The PPGP requested his activities be 50% funded by the upgrade project for the next three year grant period, therefore at least 18 months must be found within the project. This is a key post, since Fulcher is the outstanding expert on CMS DAQ with substantial hands-on experience of the Tracker DAQ system, having been one of the builders and working 100% on it during CMS operation, with long term responsibilities. While the final project award remains undefined, our provisional plan would be to fund the shortfall by a combination of a reduction in the staff working allowance, and a reduction in the budget for new RA posts by all institutes.

The Brunel CG RA post which was requested was not granted. In the short term Brunel would be able to provide, from non STFC resources, the matching 50% FTE funds for the RA post bid for in this application. Guaranteeing this matched funding beyond the end of the current Consolidated Grant period is currently challenging but likely.

10 The Panel would like to understand the future plans of the proponents – What likelihood is there of future requests for funding?

We expect a future request around 2017, for delivery of the Phase II upgrades. It is most likely to be aimed at tracker and trigger again, following on from these developments. The magnitude is not yet clear, but we would expect to be sharing ~4% of total cost of the Phase II upgrade, plus staff effort. The total Phase II materials cost might be ~200MCHF, of which a new tracker would be the largest part. However, the total is still very uncertain and would depend on the scope, as well as other factors.

11 Are the time and resources set out in the proposal sufficient to achieve the stated goals?

Yes, if funded in full. We have firm plans, with cost estimates which are as accurate as they could be at this stage and believe we have allocated sufficient working allowances to achieve the objectives.

12 The Panel would like to explore further the workpackage structure and management. Much of the staff effort per workpackage is allocated in small fractions of a FTE. Would you be able to identify someone within the project who could dedicate at least 50% of their time to leadership of the project?

The FTE fractions of some technical and administrative support staff are naturally modest and should not be allowed to create misleading impressions. Academic FTE in the cost tables is only that which is STFC-funded, so should be a lower limit. Where fractions of CG-funded research staff are allocated to the project, it is in order to capture their expertise and experience from the original construction project. These individuals are likely to focus a substantial effort on the project at critical times, such as first commissioning for physics of the trigger and pixel systems.

In the proposal (see page 10, and the summary of WP1) a request was made for funding for the PI which would permit him to continue to devote at least 50% of his time to management of the project, also using CG-awarded research time. Currently upgrade activities and CMS management duties already occupy most of his time, since the STFC funding has largely freed him of teaching commitments. The UK CMS PI duties (i.e. *not* upgrades) probably take up about 30% FTE. They also now overlap to an extent with upgrade work since, for example, CMS upgrade funding requests and upgrade sub-project scrutiny, are occupying an increasing part of CMS management discussions.