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CMS Submission to the 2015 PPGP Review

Report on Activities and Planned Future Programme

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1. Part A: January 2012-December 2014

1.1 Overall CMS status and the UK contribution to CMS

CMS is a general purpose detector for high luminosity LHC operation optimised for Standard Model Higgs searches and a wide range of other physics. The experiment continued to operate extremely well during 2012, accumulating an integrated pp luminosity of ~25 fb^{-1} for physics. As the first LHC shutdown, LS1, draws to a close, increasing focus is on the LHC Run II scheduled for spring 2015.

Over 250 papers have been published since the beginning of 2012. UK physicists have made important contributions to many of them, in particular in the SUSY, Higgs, top and exotics areas, and have played significant roles in publication reviewing, often chairing Analysis Review Committees. The outstanding highlight of Run I was the discovery of a new scalar particle, and its subsequent characterisation as the Higgs boson.

The UK has responsibility for several important CMS subsystems: ECAL endcaps, Tracker readout and Global Calorimeter Trigger; all are functioning well, as reported in some recent papers [P1-P3]. We have a major role in software for reconstruction and analysis and in development of GRID-based computing and have had many roles in overall scientific management, (Appendix i).

1.2 Tracker Status

In 2012 the Tracker continued stable running with excellent performance. There are no concerns about its ability to adapt to future LHC conditions, including to luminosity above the nominal 10^{34} $cm^{-2}s^{-1}$ maximum. However, radiation effects, mainly leakage current increases, begin to be visible, and it is vital to maintain the detector at low temperature at all times for the remainder of its lifetime, or annealing changes will accelerate operating voltage changes once sensors reach the doping inversion point, which results from charged particle bulk damage. For this reason a substantial effort was dedicated to sealing the system during LS1 and it will operate from now on at -15°C, flushed with dry gas, compared to ~10°C in Run I.

The electronic readout and control system, where the UK made substantial contributions, continues to perform extremely well. Imperial delivered the 75,000 APV25 front end chips to the silicon tracker. Imperial and RAL-TD constructed 500 VME Front End Driver (FED) boards; Imperial commissioned them and has subsequently been responsible for operation and maintenance, including all firmware and software. They have been extremely reliable; a small number have been sent to **RAL-TD** for fault diagnosis and repair, and then returned to CMS.

We also built APVe emulators which model APV25 pipelines and throttle the trigger when needed, either from DAQ problems or potential front-end pipeline overflow. We also veto possible synchronous triggers as a precaution against resonant wire-bond failures.

Work continues to improve track reconstruction software. **Tomalin** led the writing of a comprehensive paper [P1] describing it in detail. He also found that 10% improvement in track p_T resolution could be achieved by better parameterization of the tracker hit resolution.

The majority of operational activities on data quality monitoring (**Magnan,** *Whyntie*[1], **Cole**) essentially stopped in early 2013. However, software developments continued, which were primarily performed by *Leggat*, who was appointed Tracker DQM group convenor for the second half of 2014. The most notable difference compared to our planning was the large, ~100%, load required of **Fulcher**; DAQ activities are extensive and the small international team responsible has gradually been depleted. UK staff contributed operations shift duties.

[1] **CG effort** in **bold** type. *Students* are denoted in *italics*. Non-CG funded effort in normal type.

APV25 support has required modest effort (**Raymond**) over the last three years as the chips are very reliable, with no known failures. Issues which have arisen have been cooling-related module issues, which mostly can be overcome by careful system parameter tuning, or with some control chips, for which work-rounds can also usually be devised. However, these and computer system maintenance tasks (e.g. new Linux releases) generate much time consuming work. For example, in the final stage of the present shutdown, the TTC system was upgraded (actually using the Imperial-designed FC7 board) to provide a new Timing and Control Distribution System. This substantial change required revised APVe firmware and software, in addition to large overall system effects.

The project has been led by **Hall**, with **Fulcher** as the only full-time CERN-based staff member responsible for operations; in the last grant period the other main contributors to operations have been **Raymond, Bainbridge, Magnan,** *Whyntie*, **Tomalin, Cole, Reid,** *Beck*, **Goldstein, Grimes** and *Jacob*.

1.3 ECAL Status

The UK has taken major roles in operations and analysis during Run I and in preparation for Run II. This builds on our responsibilities for design and construction of the ECAL Endcaps (EE), comprising 14648 $PbWO_4$ crystals instrumented with Vacuum PhotoTriodes (VPTs) developed by RAL and Brunel, and the MGPA amplifier developed by Imperial. The UK provides experts with definitive knowledge of EE operation and performance and we hold leading positions in ECAL project management. Service duties, including shifts, were undertaken by all UK groups. Mission-critical items provided by the UK involve daily operation of the VPT High Voltage system and general detector maintenance with cover for possible dismounting. The HV system requires daily 24h on-call coverage, in part provided by trained UK students.

The VPT HV system operated with 100% efficiency during Run I. This was made possible by detailed monitoring, prompt actions and system optimization by dedicated UK on-site experts (**Bell, Cockerill**, **Petyt**), supported by UK-based staff. Maintenance and system improvements were carried out during beam-off periods.

Repair of a previously inoperable EE region was completed in 2013 by **Hill**, **Brummitt** (RAL TD) and **Durkin**, with supervision from **Bell** and **Cockerill**. A plan was executed to repair the problematic region in-situ without dismounting the endcap; the team built an accurate 1:1 scale model to plan the operation. The region is now fully operational, and ready for Run II.

UK physicists contributed significantly to ECAL calibration, in particular to optimize crystal transparency corrections and VPT response changes under irradiation. This was complemented by ongoing studies of long term VPT response under illumination and irradiation using the 3.8T test facility and ^{60}Co gamma source at Brunel (**Hobson, Leslie**). VPTs performed according to specifications during Run I. The measured width of the Z peak, for $Z \rightarrow ee$ decays with both electrons located in EE, was stable throughout 2012.

D. Futyan was e/γ identification convener until May 2013. ECAL clustering and energy corrections are important to achieve ultimate performance. *Kenzie* and *Corpe*, under the supervision of **Dauncey** and **Seez,** made leading contributions to validation and refinement of clustering algorithms and corrections for energy containment applied in Run I and for upgraded algorithms to be used in 2015. The excellent ECAL performance achieved during Run I contributed significantly to the Higgs discovery in July 2012.

Cockerill and **Petyt** led detailed appraisals of ECAL data in support of physics analyses, to ensure integrity of reconstructed events. This included verification of high energy di-electron events relating to the *Z'* search, physics of direct interest to UK exotics studies. ECAL channel status maps were maintained by **Petyt** and *Clement*, permitting fast feedback to mask problem areas and maintain high quality reconstructed data.

1.4 Level-1 Trigger Status

The UK is responsible for vital parts of the CMS Level-1 trigger system, with a leading role in trigger M&O, performance tuning, and improvements to keep pace with increasing LHC luminosity. The Global Calorimeter Trigger is crucial for online data selection of electrons, photons, jets and missing energy. The system is modest in size, but extremely complex, and the most technically advanced part of the original trigger. It was designed to use the largest possible FPGAs for optimum flexibility, which was fully exploited during Run I. Changes of trigger algorithms and incremental hardware improvements have both been successfully implemented. The GCT success provided valuable input for design of the upgraded trigger system now being commissioned, where the UK has significantly larger responsibilities.

The GCT must provide uninterrupted service and well-understood performance at all times. Smooth 24/7 operation requires a team of hardware, firmware and software experts, both at CERN and in the UK, able to provide a fast response to any issues. The GCT project is led by **Tapper**, with **Iles** as the key technical expert. Other team members include **Brooke, G. Heath, Karapostoli, Newbold, Paramesvaran, Rose,** and **Thea**, the latter representing a new contribution by RAL to the trigger. By the end of Run I, hardware and software components had reached a level of maturity where only minimal maintenance was necessary. Essentially no CMS downtime was experienced in 2012 due to GCT issues.

GCT recommissioning for Run II was a major task in 2014, now successfully concluded with the first CMS global runs in early 2015. Successful recommissioning of the entire trigger system depended on UK expertise, with **Thea** appointed in 2013 as trigger online software coordinator.

Building on the GCT success, the UK has taken the leading role in upgrade of the CMS L1 calorimeter trigger, essential to handle increased luminosity and pileup. The UK upgrade project is led by **Newbold** and **Tapper**, who also serve as chair of the Trigger/DAQ Institution Board and CMS calorimeter trigger upgrade project manager respectively. **Buchmüller** coordinates performance studies for long-term upgrades, and **Durkin** and **Harder** have taken responsibility for hardware and software commissioning tasks, along with RAs supported via upgrade project funds. The key UK contributions are:

- Provision of a modular high-performance FPGA processing platform, the MP7, capable of fulfilling many functions in the CMS trigger and DAQ (**Iles, Rose)**
- Proposal and delivery of a novel time-multiplexed trigger processing architecture, allowing a huge increase in trigger performance and flexibility from 2016.
- Simulation, tuning and implementation of new trigger algorithms for both 2016 and longer-term upgrades (**Karapostoli**, **Marrouche**, **Harper**, *students*).

Achieving these goals required substantial effort across the full range of hardware, firmware and software tasks, involving **the entire team**. It was essential for smooth transition to a new trigger that these objectives be met during LS1, and all were achieved well within time and resource constraints. Results were documented in the Level-1 Trigger Upgrade Technical Design Report [Tc1] and the CMS Phase-2 Upgrade Technical Proposal. The MP7 has also been adopted for upgrades of the CMS Global Trigger, Global Muon Trigger and Muon Track Finder, and is under study for several other applications within the experiment. The new trigger architecture was successfully demonstrated in 2014, and preparation of final trigger algorithms is now under way, with commissioning to take place in parallel with data-taking in 2015.

1.5 Computing Status

The Computing and Offline activity covers both operation of UK-hosted computing resources for CMS, and software and computing infrastructure development. In both areas the UK has a high standing, delivering proportionately more than its share of overall CMS authorship. This results from very efficient use of resources, made possible by the presence within CMS UK of a talented and highly experienced team of computing and software experts, led by **Colling** since January 2007.

The highest UK priority has been to provide resources needed by CMS efficiently and reliably. The UK provides a Tier-1 centre at RAL and three full Tier-2 centres at Brunel, Imperial and RALPP with a further partial Tier-2 at Bristol. While the RAL Tier-1 is small (providing 8% of total CMS Tier-1 resources) it has a reputation for high reliability and being very responsive, so that RAL is often used to test developments of the CMS computing model. It was the first CMS Tier-1 to implement separation of disk and tape storage resources which was then rolled out to all other Tier-1 centres.

The primary role of CMS Tier-2s is user analysis, with each centre supporting a collection of physics groups as well as local users. The three main UK Tier-2 centres support 8 such groups, including the high profile Higgs and SUSY groups; only the USA supports a larger number of physics groups. Tier-2 centres also contribute significant Monte Carlo production. CMS also makes use of opportunistic resources at non-CMS sites such as Glasgow, QMUL and Oxford; CMS-specific services at these sites are run from CMS Tier-2 sites. Operation of resources for CMS has been an outstanding success; the key is the members of the UK operations team made up of fractions of **Bauer, Brew, Colling, Fayer, Huffman, Kreczko, Lahiff, Lopes, Reid** and **Richards** supported by GridPP, CG and university funds. It is vital that this team is maintained.

Outside HEP the world is moving away from Grid technologies towards Clouds and an increasing fraction of CMS resources are likely to be offered as Clouds. The UK has led CMS effort to utilise Clouds through the Dynamic Resource group focusing on three areas: use of the High Level Trigger (HLT) farm as a Cloud, use of the CERN Agile Infrastructure (AI) Cloud provisioning, and Clouds outside CERN being used essentially as Tier-2 resources.

The HLT farm is a considerable compute resource comparable in scale to integrated CMS Tier-1 resources, but with very small volumes of local disk space. While running, the HLT is fully committed; however between data taking this resource has so far been completely unused. In 2013 we decided to overlay Cloud infrastructure to be used *between* data taking and quickly shut down when data taking restarts. This required considerable infrastructure development by UK CMS and the HLT team, and is viewed as a great success within CMS. All CERN computing resources are now being run on the AI infrastructure; most experiments chose to ignore this and rely on CERN IT, but CERN plans to pass the virtual infrastructure load to the experiments and CMS is the first to manage this task, which UK people played an important role in building. Outside CERN, Clouds are run at Imperial and RAL and being tested by CMS. The key people contributing to this work are **Bauer, Huffman, Lahiff** and **Colling** who is Level 2 leader of the Dynamic Resource activity within CMS**.**

The UK continued to contribute highly skilled effort to core workflow management software (WMAgent). This is at the heart of CMS computing and is a vital contribution to this important and undermanned activity. The effort is provided by **Richards** who took over from **Wakefield**.

We have also engaged in longer term developments of parallel computing to carry out specific CMS computing algorithms on multicore CPUs and GPUs which potentially offer large efficiency savings. This work is being carried out by **Lopes, Hobson and Reid.**

CMS is the first HEP experiment to make its data publicly available. Publicly funded data is highly desirable but release of it would be meaningless without infrastructure and analysis documentation. CMS released a Virtual Machine to provide this, whose building and system testing was performed in the UK by **Huffman** and **Colling.**

1.6 Physics

The UK groups have a very strong presence in CMS physics leading many high profile analyses. The programme encompasses all key areas of LHC physics: Higgs physics, BSM searches and SM measurements. The Higgs boson discovery was the great triumph of Run I; UK physicists were prominent all the way from providing and understanding critical detector elements through to final data analysis. Excellent detector performance enabled the discovery well before expectations prior to LHC start-up. There is also considerable activity in BSM physics searches, encompassing many high profile analyses such as the hadronic SUSY search and the search for heavy vector bosons, and a diverse programme in top physics has focused on Standard Model measurements. Vital to this prominence is the wide UK detector expertise and close involvement in achieving optimal detector performance. Lastly, collaborative phenomenology work with a variety of UK theorists, primarily within the NExT, IPPP and LCTS Institutes, provides invaluable input to analyses and helps shape the future programme.

1.6.1 Higgs

CMS UK has very strong participation in several Higgs searches and it played a key role in the discovery of the SM-like Higgs boson in 2012. The scope of these activities includes analyses in the context of the Standard Model (SM) Higgs boson as well as searches for Higgs production and decays beyond those expected in the SM.

The CMS detector was designed to have excellent Electromagnetic Calorimeter (ECAL) resolution where the design driver was the anticipated discovery of the Higgs boson through its decay to two photons. UK physicists played major roles, from design and construction of the ECAL, to optimizing its performance in reconstructing photons and electrons. In the Higgs decay to two Z bosons, electrons were of great importance while the greatest sensitivity came from muon decays. Here the tracker was critical by providing excellent momentum resolution. The UK has held leading roles in the tracker and provided the most important elements of its readout. Having been prominent in the creation of a detector capable of finding a Higgs, UK physicists went on to play key roles in the final analysis and its ultimate discovery.

The Imperial group has a long-standing interest in the search for a Higgs boson decaying to two photons and **Dauncey, Davies**, STFC Fellows Futyan and Hays, **Seez and** Virdee**,** with *Kenzie* and *Wardle*, played a crucial role in the analysis [H1] that contributed to the discovery in July 2012. **Seez** was subgroup co-convener during 2011 and 2012 and was co-editor of the CMS discovery paper [H2]. Original work included use of multivariate techniques and energy corrections to improve the sensitivity. Post-discovery the group, **Dauncey** and **Davies**, with *Kenzie* and *Wardle*, has continued the very significant involvement in almost all aspects of the analysis and in the publication, edited by **Seez**, of final results for the full Run I dataset [H3], taking the lead on some key issues. For example, **Dauncey**, **Davies**, *Kenzie* and *Wardle*, developed a technique to handle the uncertainties in background shapes by treating them as discrete nuisance parameters [H4]. Furthermore, members of the group, in particular *Wardle* and *Kenzie*, have taken the lead in producing the actual public results in this channel throughout the grant period and also spearheaded the H to $\gamma\gamma$ spin analysis. Most recently, **Zenz** was appointed to lead a team preparing the new software framework, exploiting recent developments in global CMS software, to be used for the Run II analysis. This task is nearing successful completion and the focus is now on physics testing. Haddad and *Corpe* are also involved in this effort investigating possibilities of improving the treatment and identification of forward jets resulting from the production of Higgs bosons by vector boson fusion.

Another Imperial team made significant contributions to searches for Higgs decays via taus (**Nikitenko, Colling, Vazquez-Acosta** and *Gilbert* and *Lane*). This group played a leading role in the SM search [H5, H6], was involved in all aspects of the analysis, and had particular responsibility for the most sensitive (μ-τ and e-τ) sub-channels. **Vazquez-Acosta** unveiled the result publicly for the first time and the result provided critical evidence that the newly discovered boson also couples to fermions, as predicted in the SM.

In addition to making significant contributions to SM Higgs analyses, UK groups have also been very prominent in a variety of analyses searching for evidence of BSM physics in the Higgs sector. These encompass both indirect evidence through measurement of the properties of the discovered Higgs boson and direct searches for possible Higgs bosons predicted by the MSSM and NMSSM models.

The Imperial analysis team leading the SM Higgs searches with taus also led the MSSM search in this final state, including editing the final paper [H7]. This result now covers a very large fraction of the previously allowed parameter space, and for the first time the SM Higgs has been included as a background. As well as taking leading roles in the analyses themselves we have played key support roles that have enabled them to be carried out. These include leading (**Vazquez-Acosta**) the τ Physics Object Group (τ POG) and calculating the theoretical predictions in the different MSSM benchmark scenarios through our participation in the LHC Higgs Cross Section Group. **Colling**, **Davies**, **Nikitenko** and *Lane* and *de Wit* are leading the search for a heavy Higgs decaying to two SM-like Higgs bosons, in the $bb\tau\tau$ final state, as is predicted in both the MSSM and 2 Higgs Doublet Models. This channel accesses the tan(β) region recently advocated in a number of the theoretical papers considering MSSM scenarios with a very heavy SUSY scale. **Nikitenko** has co-coordinated the CMS Higgs Exotics subgroup since Jan 2013. He is also lead author, and paper editor, of two additional publications [H8, H9].

The NMSSM model, which includes seven Higgs bosons, solves many of the shortcomings of the MSSM. A particular feature is that one of more of the Higgs bosons can be very light, including less than twice the mass of b-quarks. An analysis, developed by physicists from Imperial, RAL and Bristol (**Nikitenko, Shepherd-Themistocleous** plus *Aggleton*, with theorists from Southampton University), where the final state sought consists of four τ leptons, has been performed using 8 TeV data. This has been approved within CMS and is going to publication [H10].

Higgs decays to non-SM particles that are not detected can be accessed via vector boson fusion production modes. A team of Bristol (**Flaecher** and **Brooke**) and Imperial physicists (**Buchmüller**, **Colling, Davies**, **Nikitenko**, **Magnan** and *Dunne*) co-led the first search for invisible Higgs boson decays, exploiting the most sensitive VBF tag [H11]. This analysis requires very detailed understanding of the background and **Magnan**'s past experience as V+jets subgroup convener was invaluable. This topology places powerful constraints on possible dark matter candidates. The improved analysis, exploiting parked data, has been completed and a paper is in preparation, edited by **Magnan**.

In addition to a strong Higgs analysis effort, members of the UK group (**Davies**, *Wardle)* have also been active in the Higgs combinations subgroup, establishing the necessary procedures and code as well as production of the results and public documentation, including the discovery and subsequent characterisation. *Wardle* was recently appointed as sub-group convener. **Davies** was a member of the Higgs combination review committee, and **Virdee** was, and remains, the Chair. With three CMS analysis review committee chairs (**Virdee**;

Higgs combination, **Buchmüller**; $H \rightarrow \gamma\gamma$, **Seez;** related Higgs analyses) the UK group also plays a key role in scrutiny and approval of these high-profile activities and corresponding publications in CMS.

1.6.2 SUSY

The activities of the Bristol and Imperial groups have benefited from the leadership experience of two former convenors of the CMS SUSY group (**Buchmüller** and **Tapper)** as well as the previous convenor of the Third Generation search group (**Flaecher).** In collaboration both groups lead the analysis effort on model-independent signature searches. Initially these searches were performed in the context of supersymmetry (SUSY) but have now evolved to include optimisation and interpretation of generic dark matter production. The SUSY and dark matter effort on CMS is strongly linked with the phenomenology effort of the Bristol (led by **Flaecher)** and Imperial (led by **Buchmüller)** groups.

The UK groups published the first SUSY result from the LHC [S1], using a novel technique to control the overwhelming background from QCD events (**Buchmüller**, **Flaecher,** *Marrouche***, Nash, Stoye** and **Tapper**). A subsequent paper developing the technique with larger data samples is also highly cited [S2]. Between these papers, this analysis has been cited over 500 times, which after the Higgs discovery analyses, is the most highly cited CMS search.

The discovery of a Higgs boson with mass of 125 GeV has interesting implications. A SM Higgs boson at this mass would require new physics to stabilise quantum corrections to its mass. So-called natural SUSY spectra provide a light partner to the top quark to stabilise these quantum corrections. With this increasing interest in natural SUSY, the analysis was extended to include binning in bottom-jet multiplicity to allow better sensitivity to top-quark partners (**Bainbridge, Buchmüller**, *Burton***, Flaecher,** *C. Lucas***,** *Marrouche*, **Meng** and **Tapper)** [S3, S4]**.** The analysis was also extended to lower jet momenta and missing transverse momentum to improve sensitivity to SUSY models with compressed mass spectra by exploiting the parked data taken with lower trigger thresholds. This analysis is currently in the CMS publication approval process and it will build the foundation for the analysis of the first data in 2015 (**Bainbridge,** *Baber***, Buchmüller**, Casasso, *Citron, Ellwood,* **Flaecher,** *Laner, C. Lucas***,** *Marrouche***, Meng, Sakuma,** *Smith* and **Tapper)**. The monojet topology has also been included for the first time in CMS SUSY searches (*R. Lucas,* Malik, **Tapper,** and **Worm)** where a paper is in preparation [S5].

Building on the first measurement of the polarisation of the *W* boson at the LHC [S6] by **Buchmüller**, **Karapostoli** and others, the novel techniques developed have been converted into searches for SUSY in the single-lepton channel (**Buchmüller**, **Karapostoli)** resulting in several publications [S7,S8].

1.6.3 BSM searches

RAL and Bristol have a very strong presence within the Exotics group. **Worm** was co-convenor from Jan 2012 to Dec 2013. The flagship vector boson search analysis (*Z'* search) (**Cockerill, Harper, Olaiya, Petyt, Shepherd-Themistocleous**) has been led by RAL staff since 2006. The decay of a *Z'* to dielectrons provides the greatest sensitivity to new physics and exploits the extensive expertise at RAL on the electromagnetic calorimeter, electron reconstruction and triggering; the vast majority of the methods used in the analysis were originally developed by RAL physicists. These include triggering algorithms, clustering in the ECAL, methods for measuring the background from the data, the definition of high energy electrons, the determination of the frequency of jets being misidentified as electrons and the statistical interpretation of the results. A number, such as electron identification, misidentification procedures and triggering are used by all relevant CMS analyses. In addition several phenomenology papers have been written in collaboration with theorists, the most recent defining an analysis approach to allow results be easily reinterpreted in a wide variety of models (**Shepherd-Themistocleous**)[E1]. Four papers, all written by RAL staff, using the 7 and 8 TeV data have been published or submitted on this analysis [E2,E3,E4].

Two analyses have used and further developed expertise exploited and developed in the *Z'* analysis. The high energy electron reconstruction was modified to enable the reconstruction of two electrons having small angular separation. This was exploited in a generic search for evidence of new physics using *Z* bosons with large transverse momenta (**Newbold, Shepherd-Themistocleous** and *Williams*). The analysis using 8 TeV data is close to final CMS approval. The technique has been adopted by a number of other analyses within the Exotics group. Quantum Black Holes can decay to an e-μ pair. In collaboration with theorists, an analysis has been developed, including a model implementation within the CalcHEP Monte Carlo code [E5], to search for such objects using the electron-muon spectrum first used within the *Z'* analysis **(Belyaev, Olaiya and Shepherd-Themistocleous).** The result using the entire 8 TeV dataset is close to CMS approval. The expertise has also been used to evaluate backgrounds in the Standard Model measurement of the Drell-Yan differential cross section. [SM1, SM2]

Many new physics models can lead to particles with long lifetimes. RAL, Bristol and Brunel have exploited this property in a variety of analyses. To enable reconstruction of vertices at large distances from the primary vertex **Tomalin** developed special software, which is used widely within CMS, and new triggers. This has been exploited in analyses searching for displaced vertices consisting of lepton pairs and jets (**H. Heath**, **Tomalin** and *Clement*) [E6, E7, E8]) and work is underway using electrons or muons alone (**Tomalin**, **Teodorescu** and *Turner*). The phenomenology of long-lived particles in the 'B-L model' was studied and methods developed to reconstruct the masses of these particles, despite the presence of invisible decay products (**Belyaev, Tomalin**) [E9]. A timing based technique to use in signatures without reconstructed tracks has also been pursued (**Goldstein, Tomalin** and *Poll*). A novel analysis searching for particles that come to rest in the Hadron Calorimeter and decay at later date was developed by Bristol (**Brooke, Hill**). This required development of triggers that operated in "beam-off" periods; a result using 7 TeV data has been published [E10].

Searches using ISR jets to tag events and interpreting this observation in the context of dark matter, extra dimensions and unparticles was led by **Worm** at both 7 and 8 TeV. This led to significant work on the topic of interpreting this collider data in comparison to direct dark matter detection experiments. [E11, E12]

1.6.4 Top Physics

Top physics is a strength in the UK with both the Bristol and Brunel groups leading many different top analyses.

Goldstein, G. Heath, Khan, Kreczko and **Clement** and *Senkin, Jacob* and *Symonds* have carried out the CMS top pair differential cross section measurements with respect to global variables (missing transverse energy, total energy etc.) in the lepton + jets channel. These measurements have been made at both 7 TeV [T1] and 8 TeV [T2] and a paper is in preparation. **Goldstein** and *Beck* have worked on Standard Model four top production, in collaboration with VUB, publishing the best exclusion limits to date [T3] with a related BSM phenomenology paper in preparation.

Single top production is a strength at Brunel where **Cole, Hobson** and *Leggat* have made significant contributions to both the *tW* evidence and discovery analysis [T4, T5]. The discovery of *tW* was a very significant achievement for CMS. **Cole, Hobson, Mackay** and *Leggat, Morton* and *Golpayegani* lead the search for single top production in association with a *Z* boson and an additional jet (so-called *tqZ* production) in Run I data. This is essentially *t*-channel single top production with an additional radiated *Z* boson and is, as such, a rare Standard Model process. The cross section is sensitive, both in normalisation and shape, to both the coupling of the top to the *Z* and to the *WWZ* coupling. Indeed, this process is believed by theorists to be as important to determining the *WWZ* coupling as measuring the *WZ* production cross section. The analysis of Run I data is close to completion and the results will be published together with a CMS search for FCNC *tZ* production [T6].

Khan and *Symonds* have made leading contributions to the measurement of the *t-tbar* production cross section in pp collisions at $\sqrt{s}$ = 7 TeV with lepton + jets final states [T7] and 8 TeV [T8]. They are also involved in the measurement of the $tt\gamma$ production cross-section in the lepton jets and di-lepton channels at 8 TeV [T9]

2. Part B: April 2015 – March 2019

UK deliverables require steady support, for hardware, software and firmware; Tracker FEDs and the trigger make extensive use of FPGAs. The ECAL support covers operations and hardware. Details of M&O are in appendices.

A central operations team runs CMS at Point 5 and shift duties have been minimised so that only central duties are required, except for sub-system experts and data quality monitoring, but the load is borne by a few experts, and their number has consistently decreased as physics activities naturally take priority. In addition, significant expertise is needed for complex sub-detector systems, hence a sufficient quota of UK experts is really vital.

In 2014 CMS re-evaluated the effort required to operate and maintain the experiment. It concluded that an average annual FTE commitment of *4 months* is required from each CMS member; this does **not** include management duties, except for special cases such as Spokesperson. This has increased from previous estimates of 3 months per year, and is required on average from each group, from all authors including students. A significant presence in CERN is vital for the UK to deliver its commitments and hence in-kind recognition of some of our M&O contributions has been negotiated to allow travel, especially LTA, to be maintained. A modest amount of upgrade work is included under M&O; clearly this is vital for the trigger for which a new version is already being commissioned [Tc1-Tc3], and for long term developments such as future ASICs for the Tracker [Tc4-Tc6]. The UK contributes significantly to both of these, but they are mostly reported separately via an Upgrade project.

2.1 Future Physics programme

The next three years will be very exciting for particle physics. The LHC will start operation at 13 TeV in 2015 providing access to a new energy regime which will dramatically increase production cross sections for possible new massive particles and very significantly increase sensitivity to a wide range of new physics. UK groups are extremely well placed to play prominent roles in many high profile areas that will produce rapid results, including searches for new high mass resonances, evidence of SUSY and more general evidence for dark matter. These are all high profile, high pressure areas and will require intense activity.

The UK is also very well placed to play prominent roles in areas that require more integrated luminosity to achieve required sensitivities for discoveries and precision measurements. This additionally encompasses SM-Higgs properties, searches for BSM-Higgs, searches for exotic long-lived particles and top physics. The high instantaneous luminosities and 25ns bunch crossing time will result in a much more complex regime in which to analyse data. The challenges posed will be of the order of magnitude of those encountered at first LHC start-up. UK expertise in the ECAL and tracker proved to be immensely valuable to physics analysis at LHC start-up and will similarly be so in Run II. In this context, UK leadership and prominent activity within the trigger, particularly the new L1 calorimeter trigger, will be of immeasurable value to the physics analysis activity. Much of the preparation for Run II physics analysis has revolved around triggering.

2.1.1 **SUSY and Dark Matter searches**

The increase in LHC centre-of-mass energy from 8 to 13 TeV will provide early opportunities for discovery of a missing energy signature in 2015. Heavy mass states such as the gluino and first and second generation squarks as well as heavy mediators in the context of generic dark matter models can be probed with only a few fb^{-1} of data. As in 2010 when first LHC data were recorded, the SUSY/DM team **Bainbridge,** *Baber*, **Buchmüller**, *Citron*, **Casasso** (New RA) *Ellwood*, *Laner*, **Karapostoli, Tapper** (Imperial) and **Flaecher, Sakuma,** *Smith* (Bristol) will lead the early searches for missing energy signatures in the hadronic channel. This team gains support from Penning (Imperial Junior Fellow) and Malik (ERC grant). This effort will again make use of the α_T variable invented by UK groups and exploited so successfully in CMS analyses.

During 2016, when analyses will profit from significant data, the SUSY/DM effort will complement its early portfolio by adding dedicated searches for compressed spectra and the production of third-generation SUSY particles, such as stop and sbottom. This will be achieved by maintaining low thresholds on jet energies and missing transverse momentum as well as binning in jet and bottom-jet multiplicity. For the former the analysis benefits vastly from UK expertise in the trigger and significant investment in this area is ongoing, providing unique sensitivity to this region of parameter space. The search strategy is also unique in the sense that it provides sensitivity to all relevant decay channels of stop and sbottom in a natural SUSY scenario, allowing a comprehensive interpretation. This is not only true for direct production of stops and sbottoms but also for their production in the decay of heavy gluinos. **Karapostoli** will include lepton based topologies, with the emphasis particularly on compressed spectra.

In addition, information on monojets will be added to the analysis, which will further increase sensitivity to dark matter production and compressed SUSY spectra.

In combination with the analysis developed for 2015, this inclusive SUSY search will be sensitive to production of squarks of all generations as well as production of gluinos and their decay via squarks of any generation. The search for dark matter will profit from a search that is inclusive in jet multiplicity, thus vastly expanding the signal acceptance compared to existing searches and at the same time maintaining sensitivity to heavy flavours.

Exploitation of the presence of b-jets and top quarks will continue to progress through the development of techniques to probe the substructure of jets allowing boosted topologies to be explored. The results of these searches will be interpreted in the context of SUSY and Dark matter models and this task will be carried out in close collaboration with the phenomenology effort within the Bristol (**Brooke**, **Flaecher**) and Imperial (**Buchmüller)** groups, which also have very close ties with the IPPP.

2.1.2 **Exotics searches**

The primary early activity will be the search for massive resonances using e^+e^- mass spectra (the *Z'* search), an early and high profile analysis. This has been a strength at RAL since 2006 when the HEEP (High Energy Electromagnetic Pairs) group was assembled by **Shepherd-Themistocleous** to be well prepared for the arrival of data. This analysis depends strongly on a well-understood detector and exploits the extensive ECAL expertise at RAL. All critical aspects, the triggering, electron identification and background estimations are areas of RAL expertise and RAL physicists lead the analysis within CMS. Preparations for 13 TeV data are well underway including triggering and electron identification modifications required. The strong UK presence in the trigger is very relevant to this analysis and **Harper** has just completed his convenorship of the e/γ trigger group. The effect of the increase in LHC energy is most dramatic in this analysis and RAL will devote significant effort to this once in a lifetime opportunity. (**Cockerill, Harper, Olaiya, Petyt, Shepherd-Themistocleous, Williams**)

Many of the searches for long lived particles were initiated by UK staff (**Tomalin**) and significant expertise remains available. The groundwork, such as trigger definitions, to allow a similarly prominent role in Run II has been performed, however the extent of the activity will be defined by the outcome of student allocations.

2.1.3 SM and BSM Higgs

The discovery of the SM-like Higgs boson is the most exciting result in particle physics for decades. This triumph immediately led to considerable activity in establishing its properties and looking for possible non-SM-like behaviour. Searches for BSM Higgs bosons were performed with Run I data and this will become a much more exciting area of activity with the higher energies and integrated luminosity available at Run II. UK groups have been prominent here (see Past Physics section) and will continue to capitalize on this expertise in the future.

In the H to $\gamma\gamma$ channel the initial focus will be on re-discovery at the new centre-of-mass energy and operating conditions (**Dauncey, Davies, Virdee, Seez,** Haddad**, Zenz, Corpe)**. As the integrated luminosity increases the focus will move to exclusive decay modes, and in particular the VBF topology. Here we will exploit the synergy with the invisible Higgs and τ VBF activities at at Bristol/Imperial and Imperial respectively, as well as our links with IPPP through the Higgs Tools post held by Haddad. The larger datasets will also allow us to probe the nature of the actual gluon fusion and diphoton decay loops, by looking at the differential production cross sections. **Colling**, **Davies**, **Lane**, **Nikitenko,** Da Wit will continue to use τ leptons to study the Higgs boson, both within the SM and beyond. Strengthening the evidence for the SM decay to τ leptons will significantly constrain possible deviations in the fermionic couplings. Increasing focus will be given to the VBF production mechanism, and with larger data sets this will allow a CP measurement through studying the angular distributions of the jets. We will continue our leading roles in the MSSM $H \to \tau\tau$ and $H \to hh \to \tau\tau b\bar{b}$ analyses. We will extend the latter by including the $H \to hh \to \gamma\gamma b\bar{b}$ channel, exploiting our $\gamma\gamma$ expertise.

The invisible Higgs decay search in the VBF production mode will continue to be led by UK groups (**Flaecher**, **Brooke, Newbold** and **Paramesvaran** at Bristol and **Buchmüller**, **Colling, Davies**, **Magnan** and **Nikitenko** at Imperial). This will be used by the combinations group, which will derive constraints on dark matter by comprehensively and inclusively combining all the various constraints on 'DM' coming from Higgs searches (**Davies**, **Casasso**).

In models beyond the MSSM, such as the NMSSM, signatures not present in the MSSM are possible. Light Higgs bosons may exist leading to a variety of novel signatures that UK teams will explore (led by **Nikitenko** and **Shepherd-Themistocleous)**. This work will be done in collaboration with theorists from Southampton and non-UK universities. The search for the NMSSM process of a Higgs at 125 GeV decaying to two light (pseudo)scalar Higgs bosons which subsequently decay to four τ s, which has been completed using 8 TeV data, will be performed by the now experienced team at 13 TeV where the sensitivity is much increased. A light pseudoscalar Higgs boson produced in association with two *b*-quarks where the Higgs can decay to either a τ or a μ pair is being completed using Run I data and will be pursued with Run II data providing a significant increase in sensitivity. A programme of work encompassing a number of NMSSM signatures that are not realized in the MSSM will be pursued by the original teams plus future students and RAs. It is possible for the NMSSM to manifest itself in signatures arising from decay chains where detectable light Higgs bosons are produced, but the missing energy is negligibly small. This produces a novel signature to which standard missing energy searches will not be sensitive. This analysis is starting with the addition of a new joint student *Gould* (RAL, Southampton, Bristol) working with **Flaecher** and **Shepherd-Themistocleous**. Staff engaged in analyses most critical at start-up will strengthen this effort at a later date.

2.1.4 **Top physics**

Bristol and Brunel will continue to lead analyses in the top physics area. At Bristol **Goldstein, G. Heath, Kreczko, Clement** and *students* will expand their top pair differential cross section programme to include measurements of inclusive variables such as top p_T via kinematic fitting. This programme has been designated a high-priority analysis for 2015 and will be led by the Bristol group. This programme will continue into the high statistics era over the next few years, and in parallel will exploit this experience and toolset to look for new physics in the top sector. Of particular interest are signatures with missing transverse energy as this ties in with our expertise and other Bristol analyses. **Goldstein** and *Beck* will also play a key role (collaborating with VUB) in the search for four top production. Discovering this in the LHC Run II is a key test of the standard model.

At Brunel **Cole, Hobson, Mackay** and *students* will continue to lead the search for *tqZ* production in Run II data, as it is not believed that the required 5σ for observation will be achieved purely with Run I data. The search for, and eventual observation of, *tqZ* production in Run II data will complement the work being done on the search for *tqH* production by **Khan** and *student* since these share a lot of common backgrounds and signal selection techniques. In the longer term, **Cole, Hobson** and **Mackay** will also use their expertise gained with both the *tW* and *tqZ* analyses in the search for FCNC decays involving top quarks.

Khan and *student* will continue their new collaboration with the **Particle Physics Theory group** at Southampton University to explore and develop novel theoretical models to work on Higgs decay channels in an attempt to work out the sign of the Yukawa coupling of the Higgs to top quarks. The cross section for the production of Higgs bosons in association with single top quarks is particularly sensitive to the sign of Y_t and this process is therefore very sensitive to enhancements in models beyond the SM.

Khan, Shepherd-Themistocleous and *student* and collaborators at Southampton will develop two analysis streams for the upcoming Run 2 data taking; the semileptonic top quark decay channel with the Higgs decaying into $\gamma\gamma$ and $\tau\tau$ final states. **Kyberd** will join this analysis team in 2017 when the MICE experiment finishes.

2.1.5 **Physics effort**

An estimate of the current level of FTE effort is tabulated below.

	Academic	CG	Other	Student
Bristol	1.4	3.4		7.3
Brunel	1.7	0.0	0.3	5.5
Imperial	2.6	5.0	2.8	10.0
RAL	1.1	1.4	0.0	1.1
Total	6.8	9.8	3.1	23.9

The table assumes that staff have additional M&O duties and/or teaching which is not included in the FTE estimate. Students working on analysis are assumed to be 100% on physics; a snapshot of their effort is included.

2.2 Tracker: Future activities

CMS operations give confidence in hardware and software, and in our ability to maintain it. However, as the hardware ages, it is likely that reliability issues will increase. Imperial has responsibility to operate the FEDs, which are the front line of the Tracker DAQ, and which must be 100% available. A full-time staff member (**Fulcher**, with **RAL-TD** support for repairs) has been based in CERN carrying out these duties and his presence is crucial. We require TD engineer and technician effort to maintain the FEDs and other hardware; naturally this was not required in full during LS1 when the Tracker was not in operation.

The pixel and strip tracker DAQ may soon be merged to economise on future operations effort, but this will increase our load, given the FED obligation and our commitment to the Tracker online software. Data Quality Monitoring is an important duty, required as a CMS service obligation. Students and RAs will contribute DQM and shift duties as an M&O duty and training. **Hall** continues to supervise Tracker responsibilities and occasional contributions from **Raymon**d are required to provide guidance on APV25 operations under changing conditions, including radiation, and monitor radiation damage.

2.3 ECAL: Future activities

The UK is responsible for the operation and maintenance of the ECAL Endcaps and provides the leading experts on its performance (**Bell, Cockerill, Petyt)**. The UK is the source of definitive knowledge vital for the optimization of ECAL and EE performance. The UK also provides CERN-resident leadership roles in electron and photon reconstruction (**Harper, Seez**), together with extensive experience in detector performance. These roles, with an appropriate level of RA support, will ensure a detailed level of detector understanding and performance optimization during data taking in LHC Run II. They are critical to maintain the UK lead in analyses involving electromagnetic objects.

The VPT HV system and endcap detector maintenance require a sustained level of technical support, which will continue during LHC Run II with the training of new experts. **Cockerill** must be in residence at CERN to provide on call, round the clock maintenance for the HV system, with backup from trained UK students and **Durkin** (RAL PPD). Serious system-wide HV failure would require urgent input from **Bell** and **Torbet** (RAL TD).

The UK will continue to make a vital contribution to the management and operation of the ECAL, with CERN-resident roles for **Petyt** who will assume the position of ECAL Project Manager in September 2015, and **Cockerill**, who chairs the EE operations working group.

Major upgrades to the ECAL detectors are planned in readiness for Phase II of the LHC (2025+) and UK physicists are well-positioned to assume important roles in these activities. **Cockerill** will study and simulate the long-term response of the EE crystals and VPTs to provide improved predictions of longevity and future performance of the EE. The unique knowledge of EE construction of **Hill** and **Brummitt** (RAL TD) will be crucial to assess the practicality of refurbishment or replacement options and develop engineering solutions.

The design of replacement ECAL readout electronics and new calorimeter trigger architectures, needed for LHC Phase II, is also well-matched to UK interests and expertise. A specific example involves rejection of anomalous ECAL signals, or “spikes”, in the Level-1 Trigger. The effective rejection of spikes in LHC Run I relied upon crucial UK input and expertise, and must be revisited for the higher instantaneous luminosities expected in Phase II.

As part of this activity, **Petyt** and **Shepherd-Themistocleous**, will investigate the potential for improved spike rejection from new functionality in redesigned ECAL electronics.

Hobson and **Leslie**, with new student, will continue to exploit the unique Brunel 4T VPT test facility which is crucially important for optimizing the operating parameters of the VPT LED stability pulser as LHC running conditions evolve, and for quantifying long term VPT performance in the presence of a strong magnetic field. The potential applicability of radiation tolerant VPT technologies for the Phase II upgrade of EE will also be explored in both simulation and experiment.

2.4 Level-1 Trigger: Future Activities

The next grant period will see the restart of the LHC and operation at steadily increasing luminosity, which will place extreme demands upon trigger performance and reliability.

The GCT proved highly reliable during Run 1. However, it will be necessary to maintain the system until LHC LS2 as a known working backup to the new hardware. During this time, it is inevitable that maintenance work will be required by UK experts. We have sufficient spare components in hand to undertake this, but it is also essential that we maintain continuity of expertise within the teams at CERN and in the UK. The individuals are listed later.

The adoption of the new calorimeter trigger system in 2016 [Tc1] will require intensive work both during the preparatory phase in 2015 and for subsequent operation of the system under increasingly challenging running conditions. The adoption of an essentially completely new framework for trigger hardware, firmware and software is ambitious, but has been demonstrated to bring extremely significant benefits for event selection at high luminosities. Evolutionary changes to the currently proposed trigger algorithms will be required at several points during Run II.

Longer-term upgrades of the CMS trigger and readout, especially the incorporation of tracking information into the Level-1 trigger decision, and the proposal for a high-granularity forward calorimeter, have been driven both by intellectual input from the UK, and by our successful demonstration of new technologies [Tc2-Tc6]. During 2015-18, these concepts must be turned into technical reality in preparation for Phase-2 upgrades. UK expertise will be essential in ensuring that these projects are delivered, and that the performance of hardware and software matches CMS physics requirements.

2.5 Computing: Future activities

Colling will continue to lead the UK CMS Computing and Offline project whose success relies on continued funding of the highly skilled people involved by both Consolidated and GridPP grants.

The CMS computing model has evolved using information gathered during Run I to guide efficient use of our resources. There are many details but those that affect CMS computing operations are sharing of data over the WAN to remote sites, blurring of the boundaries between different tiers and dynamic placement of data depending on popularity. Without these efficiency improvements CMS computing operations, and hence the rate at which physics results can be generated, would be resource limited. Similarly any cuts in the hardware resources available to CMS will limit the rate at which the experiment produces physics.

Delivery of sufficient computing resources to CMS efficiently and reliably through Run II will continue to be our highest priority. We expect to continue to run a Tier 1 centre at RAL and three full Tier 2 centres; they will continue to be at Brunel, Imperial and RAL but the Tier 2 at RAL will evolve considerably. Staff from RALPP will no longer run the Tier 2 hardware resources but they will run services on hardware provided by the RAL Tier 1 Cloud. This is a very interesting development, and considerably reduces the effort needed to run the Tier 2 and may provide a good model for other Tier 2 centres running on institute based Cloud resources. It is highly likely that if successful Tier 2 centres at other institutions would follow this model.

During the period of the next grant we anticipate that use of Cloud resources by CMS will gradually change from engineering to operations; the UK will manage this activity up to that point. Operation of the HLT farm cloud may remain a special case with dedicated needs; however it is a sufficiently large resource to justify this.

The UK will continue to provide CMS software programming expertise, in a mixture of core activities (such as the WMAgent development for CMS workflows) and more speculative activities which have very large potential efficiency gains and anticipate the likely move to increasingly multi-core hardware platforms.

Finally we also expect to continue our involvement in the preservation of CMS data through its general open release.

2.6 Project support

The details are given in the accompanying Excel workbook. M&O budgets scale with number of authors and the Tracker, ECAL and Trigger require contributions from all agencies which are scrutinised each year at the RRB meetings. CMS has no Common Fund, other than a small reserve maintained in the M&O A budget.

Both M&O costs in CERN and travel costs are strongly affected by exchange rates which had been reasonably stable *until a dramatic change in the CHF recently*; nevertheless we have assumed a value of **1.5 CHF/£** and **1.2 euro/£**. About half of the actual travel spend is dedicated to Long Term Attachments in CERN. The cases are given in Appendix iii.

2.6.1 M&O

The budget covers commitments to maintain sub-detector systems (M&O B) and support for CMS-UK operations (e.g. van hire, office materials, telephones, computer repairs at CERN, stores costs, instrument hire, etc.). All these costs have been limited to the minimum

Our M&O B estimates are based on figures presented to the RRB in October 2014. We have negotiated some in-kind contributions, e.g. TD effort used on the Tracker, but cash is essential to maintain the detector. CMS has been successful in reducing global M&O costs substantially but further large reductions do not seem likely, especially given the exchange rate situation. UK CMS has endeavoured to manage its overall allocation to maintain travel spend, especially essential LTAs, since this is vital for delivery of our commitments.

We estimate a requirement of approximately £20k/year in support of UK operations to cover the expenses above, almost entirely for activities at CERN.

2.6.2 STFC Technology Department Effort

The requirements are summarised in Appendix ii and the Excel workbook.

2.6.3 Likely requests to the PPRP in the next 3 years

A CMS upgrade R&D project for Tracker and Trigger began in 2009 and continues to 2019. It is possible a supplementary request will be made for support for forward calorimetry; a PRD-funded post has recently been awarded for the HGCAL, if that option is selected by CMS, and other external funding is being sought.

3. Appendices

3.1 Appendix i: UK personnel in coordinating roles

	a) Experiment-wide responsibilities	
Brunel		
J Cole	CMS Tracker Publication Board Chair	
	Tracker Insitution Board member	
	Secretary to CMS Tracker Institution Board	
	Member of 4 Analysis Review Committees	
P Hobson	CMS Collaboration Board Member	
	ECAL Institution Board & Finance Board Member	
	CMS Top Physics Publications Committee Member	2012-
	ECAL Publications Committee Member	2013-
	Member of 11 Analysis Review Committees	
A Khan	Top Cross-Section Physics Coordinator	2014-
P Kyberd	Member of 2 Analysis Review Committees	
D Leggatt	Tracker DQM group convenor	2014-
Bristol		
J Brooke	Long-lived Exotica subgroup convenor	2011-12
	Exotica Future Analysis subgroup convenor	2013
	Level 1 Trigger Upgrade Performance Task Force convenor	2014
H Flaecher	Convenor of 3rd generation Supersymmetry subgroup	2012
	Convenor of gluino mediated and 3rd generation Supersymmetry subgroup	2013
	CMS representative on HepData advisory board	2014-
J Goldstein	CMS Collaboration Board Member	
	Member and chair of analysis review committees	
M Grimes	CMS Offline Upgrade Software Coordinator	
G Heath	Language editor for eight publications in the EXO and B2G Physics Analysis Groups	
H Heath	Member of Standard Model Physics Publications Committee	
	Member of 13 Analysis Review Committees	
L Kreczko	Datasets / T2 space manager for CMS TOP group	2013-
	Software and Documentation contact for CMS TOP group	2014-
D Newbold	CMS Trigger and Data Acquisition Institution Board Chair	
	Member of Collaboration Board	
	Paper editor for trigger performance paper	

	Member of six analysis review committees	
S Paramesvaran	Calorimeter Upgrade Co-ordinator for the L1 Trigger group	2013-
	Deputy Project Manager for the Stage 1 Trigger upgrade	2014-
	CMS Run Field Manager	2014
T Sakuma	Convener of JetMET Algorithms and Reconstruction subgroup	2012-14
	MET Reconstruction contact	2011-14
	AlCa HCAL Alignment contact	2013-
	Member of 7 Analysis Review Committees in SMP, JME, B2G and EXO physics	
Imperial College		
R Bainbridge	Tracker Editorial Board member	2012
	Paper editor: Inclusive SUSY results	
	Inclusive SUSY subgroup cordinator (L3)	from 2015
O Buchmueller	Trigger and Physics Strategy Working Group co-chair (L1)	
	Analysis Review Committee Chair: H-gamma gamma	
D Colling	Co-Leader of the Dynamic Resource Provisioning group (L2)	
	Co-Leader of the Computing Upgrade and evolution (L2)	2012-13
	Analysis Review Committee member:	
P Dauncey	CMS Collaboration Board member	2013-14
	Analysis Review Committee member:	
G Davies	Member CMS Conference Committee	2012-
	Member CB Advisory Board	2014-
	CMS Collaboration Board member	2014-
	Member Higgs Publications Committee	2014-
	Analysis Review Committee Chair, and Member: Higgs Combinations and Properties	
G Hall	UK representative on CMS Management & Finance Board	
	CMS Collaboration Board member	
	Tracker Management Board	
	Tracker Upgrade Management Board	
G Iles	CMS Firmware Coordinator	
L Lyons	CMS Statistics Committee member	
	Analysis Review Committee Chair: Search for New Physics in Multijet Final States	
	Analysis Review Committee Chair: Search for multijet resonances	
A-M Magnan	CMS Tracker Point 5 Operations manager	2012
	V + jets physics subgroup convenor (L3)	2012-13
	Analysis Review Committee Chair: Drell-Yan differential cross sections at 7 TeV	
	Analysis Review Committee Chair: Z rapidity and transverse momentum at 7TeV	
A Nikitenko	Higgs-Exotics group convener	2012-14

	Member Steering Committee of LHC Higgs Cross-Section Working Group	
C Seez	Higgs to gamma gamma physics subgroup convener (L3)	to Dec 2012
	Member ECAL Joint Institution and Finance Board	
	ECAL Editorial Board member	
	HGCAL institute representative & Technical Proposal editor	
	Analysis Review Committee chair: H -> gamma* gamma with Dalitz decays	
	Analysis Review Committee chair: Search for high mass Higgs to Zg decays	
	Paper editor: Higgs discovery paper	
	Paper editor: Higgs to two photons paper	
	Paper editor: Performance of photon reconstruction and identification	
A Tapper	2010 - present L1 Global Calorimeter Trigger Project Manager	
	2012-2013 Level 1 Trigger Upgrade Project Manager	2012-13
	CMS Publications Committee (SUSY sub-committee)	2012
	Trigger/DAQ Institution Board member	
	HCAL DPG Trigger Group convener	2014
	Level 1 Trigger Calorimeter Upgrade Project Manager	Dec 2014-
	Analysis Review Committee chair: Search for New Physics with Photons, Jets, and Missing ET	
	Analysis Review Committee chair: Search for supersymmetry with photons and low missing ET	
	Analysis Review Committee chair: Search for Supersymmetry with Photons and Missing ET	
	Analysis Review Committee chair: 7 Search for RPV supersymmetry …	
	Analysis Review Committee chair: Future Physics Studies for the Level-1 Trigger TDR	
	Analysis Review Committee chair: Search for top squarks in R-parity-violating SUSY…	
	Analysis Review Committee chair: Search for RPV SUSY in the four-lepton final state	
	Analysis Review Committee chair: Search for top quark decays t → cH with H → γγ	
	Analysis Review Committee chair: Search for supersymmetry with photons	
M Vasquez Acosta	Tau Physics Object group convener	2012-14
	MSSM LHC Cross Section Working Group subgroup convenor	2012-14
T Virdee	CMS Spokesperson Advisor	
	CMS Management Board member	
	CMS Collaboration Board member	
	Analysis Review Committee Chair: Higgs discovery	
RAL PPD		
K Bell	ECAL Project: field technical coordinator	
	Member ECAL Editorial Board	
	Member ECAL Steering Committee	
C Brew	Computing Facilities/Infrastructure Operations: Tier-1 coordinator	
R Brown	Member CMS Publication Committee Steering Board	

	Co-Chair of CMS Exotica Publication Board
	Member of CMS authorship committee
A Brummitt (ED)	ECAL project: endcap project engineer
D Cockerill	ECAL Project: endcap project manager
	Member ECAL Steering Committee
	Member ECAL Conference Committee
	ECAL Project: endcap performance and stability working group chair
	CMS Publications Board
	ECAL Publication Board Chair
	Analysis Review Committee member
K Harder	Member Tracker Institution Board Member
	Analysis Review Committee member
S Harper	CMS Exotics Trigger Convenor
	CMS Exotica Physics Analysis Group: Convenor Exotic Resonances Group
	CMS E/gamma Physics Object Group Trigger Coordinator
	Analysis Review Committee member
J Hill (ED)	ECAL Project: endcap project engineer
A Lahiff	Computing Facilities/Infrastructure Operations: Tier-1 Processing Coordinator
E Olaiya	L1 Trigger MC contact
	Analysis Review Committee member
D Petyt	ECAL DPG convenor
	ECAL Deputy System Manager
	Member ECAL Steering Committee
	Member ECAL Institution Board
	Board Member ECAL Editorial Board
	Member ECAL Conference Committee
	Member CMS Executive Board
	Member CMS Management Board
	Member CMS Collaboration Board
	Member CMS Endcap Calorimeter Review Panel
	Member CMS L1 Trigger Project Review Panel
	Analysis Review Committee member
C Shepherd-Themistocleous	Deputy Chair ECAL Institution and Finance Board
	Member of ECAL Steering Committee
	Member of ECAL Conference Committee
	Chair CMS ECAL Finance Scrutiny Group
	CMS Exotica Physics Analysis Group: Z'->ee subgroup coordinator
	CMS Collaboration Board Deputy Chair 2014
	Member CMS Collaboration Board Theory Group
	Member CMS Trigger and Data Acquisition Institution Board

	Analysis Review Committee member	
A Thea	L1 Trigger Project: online software coordinator	
I Tomalin	Member CMS Publication Committee Member Exotica Editorial Board CMS Exotica Physics Analysis Group: Coordinator of displaced fermion searches Analysis Review Committee member	
S Worm	Convenor CMS Exotica Physics Analysis Group Analysis Review Committee member	

b) UK responsibilities

Brunel		
P Hobson	Brunel team leader, Member UK Management Board Brunel Tier-2 Manager Non-Core member of STFC Science Board	 2012-13
Bristol		
H Flaecher	Member UK Management Board	
J Goldstein	Chair Particle Physics Grants Panel Member of UK Management Board	
D Newbold	Bristol team leader, Member UK Management Board UK trigger upgrade project manager Deputy Chair PPRP	
Imperial College		
O Buchmueller	IPPP Steering Committee	
D Colling	UK Computing Project coordinator UK Member Computing Resource Board Member UK Management Board	
P Dauncey	Imperial team leader, UK Management Board	2012-13
G Davies	Imperial team leader, UK Management Board	2014-
G Hall	UK spokesperson UK Tracker Project manager PI: UK upgrade project	
C Seez	Imperial Deputy Team Leader	
A Tapper	CMS UK Management Board UK Trigger project manager	
M Vasquez Acosta	UK Data Manager	2012-14

RAL PPD

C. Brew	RAL Tier-2 manager
D Cockerill	UK ECAL project coordinator Member UK Management Board
K. Harder	UK coordinator for infrastructure & online software of L1 trigger upgrade
A. Lahiff	CMS Tier-1 liaison
E. Olaiya	RAL T2 data manager
D. Petyt	Member UK Management Board
C Shepherd-Themistocleous	NExT Institute co-director RAL team leader, Member UK Management Board UK Physics coordinator Deputy Chair Particle Physics Advisory Panel
I Tomalin	NExT Institute steering committee member

3.2 Appendix ii: UK commitments to M&O and Computing Infrastructure

3.2.1 Tracker

UK responsibilities are major VME electronics, supervision of crates, power supplies and cooling, plus firmware and DAQ software to operate, test and monitor the system, including maintenance and development of offline software.

The system has 440 VME custom FEDs in operation, with 60 spares. New boards are impossible to produce, due to component obsolescence, especially the (expensive) optical receivers. FED hardware and error diagnosis requires **RAL TD** staff. There are 500 Slink transition cards maintained by **RAL TD,** interfacing to the DAQ Frontend Readout Links. Fortunately reliability has so far been high.

Firmware maintenance and development is shared with **RAL TD** and **Fulcher (Imperial),** Front End FPGA firmware is maintained by **Imperial**, and the remainder by RAL TD.

Maintenance of test systems for FED repair, APVe emulator and ReTri boards: I**mperial College**. Online software maintenance & development by **Fulcher.** Data Quality monitoring: **UK staff and students**

The Tracker is inaccessible which precludes actions on the APV25. However expertise must be maintained, e.g. for low temperature operation, understanding SEU. For this we must maintain a local test system, with detector modules, for diagnostics. Technical support for APV25 operation requires **Raymond** (Imperial).

DAQ software & DAQ operation (including optimisation of calibration/commissioning procedures): **Fulcher**.

Our estimate of **RAL TD staff** based on experience is 0.5 FTE/year. For **Imperial staff** we estimate 0.2 FTE **Raymond**, 1.0 FTE **Fulcher** (including minor upgrade contributions), 0.2 FTE **Bainbridge,** and 0.25 FTE **Magnan** and *students*. All supervision will continue to be provided by **Hall**.

3.2.2 ECAL

The UK is responsible for the VPT High Voltage distribution system and for all issues concerning EE engineering design, construction and maintenance, with major input from **RAL TD (Torbet: HV system designer, Hill: EE Project Engineer, Brummitt: Mechanical Engineer)**.

The VPT high voltage system has operated successfully during LHC Run I. Performance data from Run II will be used to evaluate if there are any aspects of operation that need attention at 13 TeV with full luminosity (10^{34} cm^{-2} s^{-1}) for LHC running from 2015 onwards.

CMS has requested input from the UK concerning various EE design details and preparation for possible future EE interventions and detector replacement scenarios. An important development concerns the possible need to remove EE supercrystals that have suffered degraded performance from hadron induced radiation damage. A detailed mechanical study is needed to appraise the practicality of such an approach, which can only be done by RAL engineers. This will also involve the mechanical design for handling and demounting the EE front screen, in the presence of an increased radiation environment, and the possible development of remote handling equipment.

CMS have requested that RAL TD should carry out a study of the layout of services required for redesigned ECAL readout electronics to cater for higher luminosity.

Our estimate of **RAL TD staff** based on experience to date is 0.5 FTE/year. We note that in the last grants round the TD allocation was sacrificed to solve urgent shortfalls in PPD funding; in the interim we attempted to cover the TD effort required to carry out EE maintenance in LS1 from M&O funds. In the next few years, it is important that the EE should continue to operate with optimal performance as radiation damage is incurred and preparations for mitigation are an essential part of our M&O commitment.

All supervision will continue to be provided by **Bell and Cockerill**.

3.2.3 Calorimeter Trigger

The present GCT hardware comprises 63 Source Cards, and 3 VME processor cards (Leaf and Main Processor), plus spares, and optical links from the RCT and to the GT. This must be maintained until LS2 as a backup even though it should be replaced by the new trigger during 2015. From 2015, the UK is required to maintain Layer-2 of the new calorimeter trigger, comprising 12 MP7 boards, plus spares, but may also be required to increase that number to accommodate more algorithms or to replace the Layer-1 hardware from the US, which is behind schedule. During 2015 an interim calorimeter trigger will also be operated, requiring 2 MP7s. Each system also has a large number of optical fibre interconnections, running at 3-10 Gbps, and suitable patch panels, developed by us.

The UK hardware is provided by the upgrade project grant but, once operations begin, the maintenance and operation should be provided, mainly by the same core staff, with the running costs assumed by the M&O budget. Additional existing CG-staff and students will be required to contribute to operations, as they are at present during running, for the GCT.

Therefore we do not distinguish here between M&O requirements for the GCT (running in 2015) and the upgraded trigger system.

Hardware and firmware will be maintained by **Iles**, **Rose** and **Durkin**. We require 0.5 FTE of **Iles** and 0.2 FTE **Rose** for the duration of the grant. The trigger online software is developed and maintained by **Thea** and **Williams**, from whom we each require 0.5 FTE. Offline software is maintained by **Brooke** with support from **Karapostoli**, at 0.25 FTE each, plus 0.25 FTE **Casasso** for algorithms. In addition, **Newbold**, **Paramesvaran** and **Tapper** have recognised management and coordinating roles within the collaboration, and also act as the key operational support personnel, at a load of around 0.25 FTE each.

3.2.4 Computing Infrastructure usage

GridPP is pledged to provide 8% of CMS total Tier-1 resource requirement and 5% of its total Tier-2 resource requirement and to operate these resources within the terms of the WLCG MoU. CMS relies on these pledges being delivered in order to extract the physics from the data collected. These resources are provided through the provisioning of the shared Tier 1 at RAL and three Tier-2 centres at Brunel, Imperial and RAL PPD.

GridPP has delivered the pledged resources within the terms of the MoU and has done so with fewer people than CMS would expect for this level of resource. This indicates that GridPP is providing the resources very cost effectively and efficiently. GridPP has a very high reputation within CMS computing for being flexible and engaged with the experiment in a way that some national computing infrastructures are not.

Experienced GridPP staff also help to guide the evolution of the CMS computing model and the introduction of new computing approaches such as Clouds.

In the future CMS expects GridPP to continue to provide Tier-1 and Tier-2 support at similar fractions of the overall CMS requirement and to continue to do so within the terms of the WLCG MoU. We would also expect experienced members of GridPP at CMS institutions to contribute expertise to CMS-wide computing operations, including the evaluation and, if appropriate, integration of new technologies.

3.3 Appendix iii: Long term attachments

Our success and high profile in the experiment relies heavily on the availability of full time UK staff, and students, in CERN. Important roles are played by those on LTA in physics analysis as well as detector operations.

3.3.1 R. Bainbridge (ongoing)

Rob Bainbridge is an expert on the CMS Tracker readout system who contributed significantly to past operations and is now mainly working on physics exploitation. He leads the CMS SUSY inclusive analysis working group from September 2015.

For the restart of the LHC in 2015 he will lead Imperial College group searches for SUSY and dark matter. He is responsible in CERN for daily supervision of four Imperial students and coordinates students and RAs from other institutions. He directs work designing and testing triggers and developing an analysis framework, to deliver a high-impact, early result. On LTA he will contribute to running the detector through shifts and will play an important role commissioning of CMS for early searches, in particular focusing on jets and missing energy. He is essential for CMS operations, as well as physics coordination duties.

3.3.2 K.W. Bell (ongoing)

Ken Bell has been a key person in the CMS ECAL project since the outset, and brings a wealth of electromagnetic calorimetry experience with him, particularly from OPAL, where he was responsible for the construction and running of the EE detector (read out with first generation VPTs) at LEP. Ken was ECAL Installation and Commissioning Coordinator, responsible for the successful installation and commissioning of both the CMS Barrel and Endcap ECAL in 2007/8. He is now ECAL Field Technical Coordinator, responsible for all interventions on ECAL. This will be a particularly challenging role in Run II, carried out round the clock, and requiring rapid response should any ECAL issues arise. He reports directly to the ECAL Technical Coordinator, ECAL Project Manager and CMS Technical Coordinator.

Ken is a crucial member of the EE team and shares the responsibilities for providing round the clock coverage for the UK mission critical VPT HV hardware system. He will also be a CMS Central Shift leader during Run II operations. His LTA is inexpensive as he is permanently resident in the Geneva area.

3.3.3 O. Buchmüller (ongoing)

Oliver Buchmüller has led front-line physics analyses in CMS which required his presence there, which he combines with teaching duties at Imperial by frequent travel. Recently he joined the CMS Upgrade management being responsible for organising the Trigger Performance and Strategy Working Group (TPSWG), which is charged with developing a triggering strategy for CMS, driven by the needs of an evolving physics program and increasing LHC luminosity.

The group is investigating further potential trigger upgrades and defining the trigger characteristics and specifications for CMS operation at the HL-LHC.

Besides his management activity, Buchmüller and Tapper established a strong SUSY activity at Imperial and this group will play a leading role in the physics exploitation of the early LHC running in 2015, which is especially important for searches for heavy new particles as predicted in SUSY or simplified dark matter models.

His key role in the CMS upgrade as well as involvement in early searches requires Buchmüller to be on LTA at CERN.

3.3.4 **S. Casasso (new)**

There is a request to reinstate this post at Imperial for searches for SUSY and dark matter in Run II, where the UK has considerable expertise and links to existing phenomenology activities, and our trigger M&O activities where we again are leading the activities. Stefano Casasso is uniquely qualified with several years experience of searches at CMS, with particular expertise in the statistical techniques associated with discovery. Casasso will also strengthen the vital task of operating the trigger during 2015, while based at CERN, and contribute to Phase I and II trigger upgrade studies which are relevant to the SUSY and dark matter analyses.

3.3.5 **D. Cockerill (ongoing)**

David Cockerill was the CMS EE Project Manager, responsible for overseeing all details of detector design and construction through to EE installation and commissioning in August 2008. With Bell and Petyt he is responsible for the operation and maintenance of the VPT HV system, a mission-critical UK hardware responsibility requiring round the clock service. David is chair of the EE operations group which brings together EE analysis and hardware teams to evaluate detailed detector response issues on a near daily basis. The group provides input to the ECAL Detector Performance Group (DPG) to ensure the optimal running and performance of the detector. David will be responsible for any EE hardware interventions needed in Run II. These activities require a full time presence at CERN.

David has applied his detailed knowledge of the ECAL to appraise the level of VPT response loss and crystal degradation during Run I. He will continue these analyses in Run II, to give input to the timescales required for forward calorimetry upgrades. His LTA is inexpensive as he and his family are permanently resident in the Geneva area.

3.3.6 **J. Fulcher (ongoing)**

Jonathan Fulcher is responsible for managing all UK CMS Tracker electronic hardware in CERN: 500 Tracker FEDs and several APVe emulators. He is an expert in several high and low level languages and has substantial firmware expertise. He must maintain and develop online software and upgrade FED firmware. The Tracker DAQ and control requires almost 100% of his time.

Fulcher is vital for UK commitments to CMS Tracker operation and his presence in CERN is essential. DAQ software upgrades and PC replacement are regular occurrence and the Tracker is recommissioning for LHC Run 2 are already a substantial effort. During the next grant period he will manage CMS Tracker data taking; his load has increased because of departure of others from the Tracker DAQ team and is much larger than previously anticipated.

3.3.7 **M. Grimes (ongoing)**

Mark Grimes has a key role in development and management of the collaboration software that allows simulation and performance tuning of the upgraded CMS detector. He currently holds the position of Upgrade Software Coordinator. As such, he will play a central role in supporting the week-by-week work of the entire upgrade project, and particularly in the support of studies for the forthcoming Technical Design Reports. As a central coordinator of the upgrade software activity, his presence at CERN is essential. Most of this LTA will be covered by the upgrade travel budget.

In addition, as one of only three Bristol research staff at CERN, he will make an important contribution to operations tasks for the tracker and the detector as a whole.

3.3.8 **S. Harper (ongoing)**

Sam Harper undertakes important roles in triggering for CMS and physics analysis. He has wide expertise in electron and photon triggers and has held several roles including trigger coordinator for the *e/γ* group and trigger convenor for the Exotic physics group. As *e/γ* trigger coordinator he organized a group developing triggers as well as developing them himself. This role encompasses liaising with the physics analysis group using the triggers. He previously held the role of the Exotics trigger convenor where analyses often require rather specialised triggers making this a more difficult task than for any other analysis group. Sam is now also engaged in developing the new L1 *e/γ* trigger that is a major activity of the CMS UK upgrade effort. His accumulated expertise in *e/γ* triggers is invaluable in this activity.

Sam is the main PPD member of staff with considerable engagement in physics analysis resident at CERN. As such he plays a very important role in PPD physics analysis providing the necessary, on the ground, presence at CERN. Sam plays a key role in the *Z'* search analysis, a flagship CMS analysis which will be extremely prominent when the LHC resumes data taking. This is a high pressure activity because it will provide one of the first results when Run I sensitivities are exceeded.

3.3.9 **G. Iles (ongoing)**

Greg Iles is a senior electronic engineer based in CERN whose primary responsibility is the CMS Calorimeter Trigger. This is presently being substantially upgraded, for parallel operation of the "legacy" and commissioning of the Phase I trigger in 2015, with full operation from 2016. In addition, to guarantee trigger efficiency in high luminosity operation in 2015, an interim upgrade is also underway which also requires his effort.

The key new trigger hardware is the MP7 board based on a Virtex-7 FPGA and high speed parallel optics, with 72 input and output links operating at up to 12.5 Gbps. The MP7 is the most advanced board of its type in the world and very challenging; Iles was the chief designer. Iles is an expert firmware designer, among the top experts worldwide in our field.

In the next grant period Iles is required to maintain the current Global Calorimeter Trigger, which we must keep operational until LS2 in 2018 and to commission and operate new triggers for LHC Run II. Further algorithm improvements are expected later; Iles is vital for all this work.

We critically depend on his skills in optical and backplane technologies, as well as FPGAs and firmware. He is responsible for firmware coordination throughout CMS and crucial to the CMS trigger.

3.3.10 **A-M. Magnan (ongoing)**

Anne-Marie Magnan is a senior RA who contributes to physics and detector operations, as well as supervising Imperial students in CERN. She will contribute to Tracker operations duties as well as physics, having already been a Tracker Shift Leader and Strip Tracker Run Coordinator, as part of the Imperial M&O obligations to CMS.

She will contribute to software development and data quality monitoring (DQM) and to daily operation of the silicon tracker as Operation Manager. She will play a significant role in Tracker DQM during Run II, and in particular in monitoring of the FEDs and APV25s. She will also play a front-line role in the first Run II analyses.

She is leading the Run II preparations for Higgs to invisible channels which will be her primary physics focus during Run II.

3.3.11 **T. Sakuma (replacement for Z Meng)**

Tai Sakuma is an expert in jet and missing momentum reconstruction and outgoing convenor of the CMS JetMET Algorithms and Reconstruction subgroup. His main focus will be on SUSY searches in the jets + missing momentum final state. His presence at CERN is vital in ensuring continuity of the Bristol SUSY effort, and expediting searches in the higher energy Run II data, which are time-critical and thus will be carried out under intense pressure. He will help with day-to-day supervision of students at CERN, particularly those in the SUSY group, and contribute to the running of the detector by taking shifts.

Tai is coordinating analysis software development and is responsible for keeping the latest physics object definitions, calibrations and event filters up to date. Being based at CERN will ensure he is on top of ongoing work in the physics object groups and efficiently contribute to their development.

Having been in charge of algorithms and reconstruction of jets and missing transverse energy, with particular emphasis on jet substructure and pile-up mitigation for the past two years, Tai holds a wealth of knowledge that will be essential as the emphasis on jet and pileup reconstruction grows with increasing luminosity. His presence at CERN will ensure maximal contributions to a wide range of physics studies reliant upon hadronic signatures.

3.3.12 **A. Nikitenko (ongoing)**

Sasha Nikitenko is a researcher with wide international recognition in the area of Higgs physics. He has contributed to a wide variety of Higgs analyses performed by the Imperial CMS group and his advice is widely sought by many other groups.

Nikitenko led the CMS Higgs-Exotics group since its creation in January 2013. Many of the Higgs analyses focusing on the MSSM, NMSSM, 2HDM and other models were organised through this group. He is also one of two CMS members of the LHC Higgs Cross Section Working Group Steering Committee and co-convener of the *bbH* sub-group.

In the future Nikitenko will continue to make significant contributions to several of the Imperial high profile analyses for which his presence in CERN is essential. He will act as a shift leader and run manager during CMS operations.

3.3.13 **S. Paramesvaran (continuing)**

Sudan Paramesvaran is in operational charge of commissioning and operation of the new calorimeter trigger system for the 2015 run, and co-manages the 2015 interim trigger project. In addition, he coordinates all L1 trigger commissioning tests. His presence at CERN is therefore vital to the success of the experiment, since the entire functioning of CMS depends critically on the correct operation of the trigger around the clock.

During the 2015-6 run, Paramesvaran will also take significant on-call responsibility for both the UK trigger hardware and the general L1 trigger operations, and will serve at least one 3-week term as Run Field Manager during 2015, in charge of all aspects of day-to-day operation of the entire experiment.

In addition, Paramesvaran is the most senior Bristol researcher at CERN, and therefore has significant responsibility for the day-to-day supervision and care of postgraduate students. In particular, he will supervise the effort of CERN-based students working on DM searches in the Run II data.

3.3.14 **D. Petyt (from mid-2015)**

David Petyt brings a wealth of calorimetry experience from CMS and previously from MINOS. David will assume the position of ECAL Project Manager in the latter half of 2015. This important and highly visible position will require David’s full-time presence at CERN from mid-2015 onwards. He will be responsible for the overall management of the ECAL project during the crucial Run II operating period, and will oversee the preparations for the planned upgrades of the ECAL detectors in readiness for Phase II of the LHC.

David was chair of the CMS ECAL Detector Performance Group during the period 2011-2012. He held the main responsibility for managing and optimising the calibration and reconstruction of data from the ECAL during the period in which the Higgs boson was discovered. David is in charge of the detection of ECAL problematic channels and their treatment in the CMS reconstruction software. He also shares the responsibility to provide on-call, round the clock coverage for the VPT HV system: one of the principal, mission critical, UK hardware responsibilities.

3.3.15 **C. Seez (ongoing)**

Chris Seez is a senior physicist in CMS working on calorimetry and Higgs physics. His presence in CERN is required by Imperial to contribute to high profile analyses, supervise students and develop the future operation of the CMS calorimeter and its likely replacement.

He has been a physics sub-group convener and paper editor, and will continue in such roles in Run II. Seez has a longstanding connection with the CMS ECAL, most recently editing the legacy photon performance paper that has just been submitted for publication. With the realisation that CMS needed to change its endcap calorimeters his expertise and past experience are essential. He was editor of the HGCAL section in the Technical Proposal, and is supervising the simulation work.

For the HGCAL TDR, Seez will play a leading role in the physics validation and confirmation in CERN test-beams.

3.3.16 **A. Tapper (ongoing)**

Alex Tapper is required in CERN to lead the commissioning and operation of the present and new calorimeter trigger. He has extensive experience from commissioning CMS Global Calorimeter Trigger (GCT), with responsibility for all aspects of the underground installation and integration into the CMS trigger chain. He took over as Project Manager for the GCT with overall responsibility for its reliable operation during 2010-12.

He has been a CMS SUSY physics convener, leading the CMS collaboration in SUSY searches, and will continue to devote effort to this.

Having already been Project Manager for the CMS Level-1 trigger upgrade project, he now continues to manage the project as Calorimeter Trigger Upgrade Project Manager from 2015, with responsibility for all aspects of planning the completion of the installation, integration into the CMS trigger chain and commissioning ready for the 2016 run. This important responsibility, where strong leadership is required, makes his presence on LTA at CERN essential.

3.3.17 **A. Thea (ongoing)**

Alessandro Thea has great experience of CMS online software, having previously worked on the ECAL trigger. He was appointed by RAL in July 2013 and works on the L1 Calorimeter trigger including the new L1 trigger system which will deployed in 2015. His extensive experience led to rapid appointment as trigger online software coordinator in 2013, where his contributions and leadership are vital to the successful reorganisation of a critical part of the project. In order to properly perform these activities Alessandro is required to be resident at CERN. Currently he is supported by the CMS upgrade travel budget but is expected to be supported by the operations budget at a later time during the grant period.

3.4 **Excel workbook**

Provided separately.

4. CMS Physics Publications with significant UK involvement

4.1 Higgs

[H1] *Search for the standard model Higgs boson decaying into two photons in pp collisions at* $\sqrt{s}=7$ *TeV*

Phys. Lett. B710 (2012), 403-425, doi:10.1016/j.physletb.2012.03.003

[H2] *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*

Phys. Lett. B716 (2012) 30, doi: 10.1016/j.physletb.2012.08.021

[H3] *Observation of the diphoton decay of the Higgs boson and measurement of its properties*

Eur. Phys. J. C74 (2014) 3076, doi: 10.1140/epjc/s10052-014-3076-z

[H4] *Handling uncertainties in background shapes: the discrete profiling method.*

P. D. Dauncey, M.Kenzie, N.Wardle, and G.J. Davies, Submitted to JINST, 2014.

[H5] *Evidence for the 125 GeV Higgs boson decaying to a pair of* τ *leptons*

JHEP 1405 (2014)104, doi: 10.1007/JHEP05(2014)104

[H6] *Evidence for the direct decay of the 125 GeV Higgs boson to fermions*

Nature Phys.10 (2014), doi: 10.1038/nphys3005,

[H7] *Search for neutral MSSM Higgs bosons decaying to a pair of* τ *leptons in pp collisions*

JHEP 1410 (2014)160, doi: 10.1007/JHEP10(2014)160

[H8] *Search for a light charged Higgs boson in top quark decays in pp collisions at* $\sqrt{s}=7$ *TeV*

JHEP 1207 (2012)143, doi:10.1007/JHEP07(2012)143

[H9] *Measurement of the hadronic activity in events with a Z and two jets and extraction of the cross section for the electroweak production of a Z with two jets in pp collisions at* $\sqrt{s} = 7$ *TeV*

JHEP 1310 (2013) 062, doi: 10.1007/JHEP10(2013)062

[H10] *Search for a very light NMSSM Higgs boson produced in decays of a boson with mass near 125 GeV, and decaying into tau leptons.* To be submitted

[H11] *Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes*

Eur. Phys. J C74 (2014) 2980, doi : 10.1140/epjc/s10052-014-2980-6

4.2 SUSY

[S1] *Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy*

Phys. Lett. B698 (2011)196-218, doi: 10.1016/j.physletb.2011.03.021

[S2] *Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy*

Phys. Rev. Lett. 107 (2011) 221804, doi: 10.1103/PhysRevLett.107.221804

[S3] *Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, or at least 3 b-quark jets in 7 TeV pp collisions using the variable alphaT*

JHEP 1301 (2013) 077, doi: 10.1007/JHEP01(2013)077

[S4] *Search for supersymmetry in hadronic final states with missing transverse energy using the variables* α_T *and b-quark multiplicity in pp collisions at* $\sqrt{s}=8$ *TeV*

Eur. Phys. J C73 (2013) 2568, doi: 10.1140/epjc/s10052-013-2568-6

[S5] *Search for top squarks decaying to a charm quark and a neutralino in events with a jet and missing transverse momentum*

CMS-PAS-SUS-13-009 (2014)

[S6] *Measurement of the electron charge asymmetry in inclusive W production in pp collisions at* $\sqrt{s}=7$ *TeV*

Phys. Rev. Lett. 109 (2012) 111806, doi: 10.1103/PhysRevLett.109.111806

[S7] *Search for supersymmetry in pp collisions at √s=7 TeV in events with a single lepton, jets, and missing transverse momentum*

Eur. Phys. J. C73 (2013) 2404, doi: 10.1140/epjc/s10052-013-2404-z

[S8] *Search for supersymmetry in pp collisions at √s = 8 TeV in events with a single lepton, large jet multiplicity, and multiple b jets*

Phys. Lett. B 733 (2014) 328, doi: 10.1016 / j.physletb.2014.04.023

4.3 Exotica

[E1] *Z' at the LHC: Interference and Finite Width Effects in Drell-Yan*

JHEP10(2013)153: doi: 10.1007

[E2] *Search for physics beyond the standard model in dilepton mass spectra in proton-proton collisions at √s = 8 TeV*

CERN-PH-EP-2014-272, submitted to JHEP

[E3] *Search for heavy narrow dilepton resonances in pp collisions at √s=7 TeV and √s=8 TeV*

Phys. Lett. B720 (2013) 63-82

[E4] *Search for narrow resonances in dilepton mass spectra in pp collisions at √s=7 TeV*

Phys. Lett. B714 (2012) 158-179

[E5] *Quantum Black Holes and their Lepton Signatures at the LHC with CalcHEP*

arXiv:1412.2661(2014)

[E6] *Search for long-lived particles that decay into final states containing two electrons or two muons in proton-proton collisions at √s=8 TeV*

CERN-PH-EP-2014-263, submitted to JHEP.

[E7] *Search for long-lived neutral particles decaying to quark-antiquark pairs in proton-proton collisions at √s= 8 TeV*

CERN-PH-EP-2014-256, submitted to JHEP

[E8] *Search in leptonic channels for heavy resonances decaying to long-lived neutral particles*

JHEP 1302 (2013) 085

[E9] *Displaced vertex signatures at the LHC from B-L heavy neutrinos and MSSM FIMPs*

Les Houches Physics at TeV Colliders New Physics Working Group Report, arXiv:1203.1488 (2012)

[E10] *Search for stopped long-lived particles produced in pp collisions at √s=7 TeV*

JHEP 1208 (2012) 026 doi: 10.1007/JHEP08(2012) 026

[E11] *Search for dark matter, extra dimensions, and unparticles in monojet events in proton-proton collisions at √s=8 TeV*

CERN-PH-EP-2014-164, submitted to EPJC

[E12] *Search for dark matter and large extra dimensions in monojet events in pp collisions at √s=7 TeV*

JHEP 1209 (2012) 094, doi:10.1007/JHEP09(2012)094

4.4 Top

[T1] *Measurement of differential top-quark-pair production cross sections in pp collisions at √s=7 TeV*

Eur. Phys. J. C (2013) 73:2339, doi: 10.1140/epjc/s10052-013-2339-4

[T2] *Measurement of MET and other global distributions in top pair events*

CMS-PAS-TOP-12-042

[T3] *Search for standard model production of four top quarks in the lepton + jets channel in pp collisions at √s = 8 TeV*

JHEP 11 (2014) 154, doi: 10.1007/JHEP11(2014)154

[T4] *Evidence for associated production of a single top quark and W boson in pp collisions at √s = 7 TeV*

Phys. Rev. Lett. 110, 022003, doi: 10.1103/PhysRevLett.110.022003

[T5] *Observation of the Associated Production of a Single Top Quark and a W Boson in pp Collisions at √s=8 TeV*

Phys. Rev. Lett. 112, 231802, doi: 10.1103/PhysRevLett.112.231802

[T6] paper foreseen spring 2015

[T7] *Measurement of the* $t\bar{t}$ *production cross section in pp collisions at √s = 7 TeV with lepton + jets final states*

Phys. Lett. B 720 (2013) 83-104, doi:10.1016/j.physletb.2013.02.021

[T8] paper foreseen spring 2015

[T9] paper foreseen summer 2015

4.5 SM

[SM1] *Measurements of differential and double-differential Drell-Yan cross sections in proton-proton collisions at √s = 8 TeV*

Submitted to Eur. Phys. J. C

[SM2] *Measurement of the differential and double-differential Drell-Yan cross sections in proton-proton collisions at √s = 7 TeV*

JHEP 12 (2013) 030 doi: 10.1007/JHEP12(2013)030

4.6 Technical publications

[Tc1] *CMS Technical Design Report for the Level-1 Trigger Upgrade*

CERN-LHCC-2013-011 (2013) editor: A. Tapper

[Tc2] *A demonstration of a time multiplexed trigger for the CMS experiment*

R. Frazier, et al, JINST 7 (2012) C01060, doi: 10.1088/1748-0221/7/01/C01060

[Tc3] *A time-multiplexed track-trigger architecture for C*MS

G. Hall, D. Newbold, M. Pesaresi, A. Rose, JINST 9 (2014) C10034, doi: 10.1088/1748-0221/9/10/C10034

[Tc4] *CBC2: A microstrip readout ASIC with coincidence logic for trigger primitives at HL-LHC*

D. Braga et al, JINST 7 (2012) C10003, doi: 10.1088/1748-0221/7/10/C10003

[Tc5] *CBC2: A CMS microstrip readout ASIC with logic for track-trigger modules at HL-LHC*

G. Hall et al, Nucl. Instrum. Meth. A765 (2014) 214-218, doi: 10.1016/j.nima.2014.04.056

[Tc6] *Characterization of the CBC2 readout ASIC for the CMS strip-tracker high-luminosity upgrade*

D. Braga et al JINST 9 (2014) C03001, doi: 10.1088/1748-0221/9/03/C03001

4.7 CMS detector performance papers

[P1] *Description and performance of track and primary-vertex reconstruction with the CMS tracker*

JINST 9 (2014) 10, P10009

[P2] *Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at √s=7 TeV*

JINST 8 (2013) P09009

[P3] *Performance of electron reconstruction and selection in proton-proton collisions at* $\sqrt{s}$ *= 8 TeV*, to be submitted to JINST