This document provides response to the pre-FDR charge and a set of recommendation and guidance received from NSF in preparation for the final design review. This document consists of six parts. The first part is the charge for the pre-FDR, the second part is general guidance for immediate consideration, the third part is general guidance towards the FDR, the fourth and last part is specifics about cost.

The text in black below is from the NSF charge/guidance/recommendations. Text in blue are our responses.

References to DocDB can be found at: https://cms-docdb.cern.ch/cgi-bin/DocDB/DocumentDatabase

If you have problems with access to DocDB see (or contact Anders.Ryd@cornell.edu):

https://web.fnal.gov/project/CMS-HL-LHC-Upgrades/SitePages/Access%20to%20documents.aspx

Part I: pre-FDR Charge

I. **General PDR follow-up Questions:**

a. **Scientific Labor:**

i. Review the status of plans to increase scope contingency to offset a possible 10, 20, or 30% decrease in scientific labor from DOE's base research program in any single federal fiscal year during the construction period. Consider the annual profile for use of DOE-funded scientific labor involved with the NSF MREFC scope, the institutional affiliations of DOE-funded participants, and the impacts on various labor categories (faculty, post-doc, student). Advise NSF of any suggestions for improvement to each project's plan for mitigating the impact of this risk.

The overall plan for scope contingency has been reviewed and are being updated. However, our main response to the loss of scientific labor from the DOE's base research program is addressed as a risk (RT-402-1-07-N). The details are provided in the the risk register. Since faculty is supported by university funds and not DOE base research funds we consider the loss of postdoc and graduate student labor for the project. Faculty would be able to continue working in the case of grant funding losses, in fact they might consider continuing their involvement with the upgrade project as an important part of reviving funding. For graduate students and postdocs we have assumed that this labor can be replaced with mid-range technicians. (In some cases undergraduates might also be suitable, but this was not assumed in the model we used in the risk register.) However, not all tasks that were planned for graduate students or postdocs is suitable for being replaced by technician. However, in such cases we would work to find students or postdocs at other institutions that can take over these tasks and have technicians cover their original tasks. As explained in the risk description, for the worst case of a 30% loss of scientific labor in a year from DOE institutions this corresponds to about 4800 hours, or near 3 FTEs of effort.

ii. Assess the adequacy of the project's response to PDR recommendations to identify additional milestones in the Project Execution Plan (PEP) to track construction progress where scientific labor is a key factor.
Need to summarize the progress here.

b. **Broader Impacts:** Review the status of planning to leverage (rather than spend) Major Research Equipment and Facilities Construction (MREFC) funding to promote education and public outreach, and broader impacts enabling the project to showcase its plans at FDR. These plans should span the participating NSF-funded institutions to realize benefits in education, workforce development, scientific literacy, etc.
This plan is outlined in the projects EPO plan and will be presented by S. Rappoccio's presentation (S. Rappoccio is the project's education and public outreach coordinator). The EPO plan is included in the material for the pre-FDR and is available in DocDB-13722. The MREFC for the HL-LHC Upgrades provides a world-class opportunity to educate future scientists via participation in a major research instrumentation construction project. We propose a workforce development plan that involves an experiential learning environment for undergraduate students and high school teachers from the QuarkNet program, where they can participate in the MREFC HL-LHC Upgrades project directly. This provides unique, in-depth training for participants, who will gain valuable experience that can be transferred to their careers.

c. **Configuration Control of the Project Baseline:** Assess the effectiveness of the configuration control process that has been implemented. Examine sample change control actions and supporting materials, to offer suggestions for process improvement.

The baseline of the project was defined based on the cost and schedule presented at the PDR. As we prepare updates towards the FDR we are tracking these changes with a baseline change control process described in the CMP. We use the Fermilab Baseline Change Request tool (fBCR at https://fBCR-dev.fnal.gov). The first change we have implemented was a rebalancing of the common fund payment between NSF and DOE for the U.S. collaborators on CMS. This change involved moving about $979k from NSF to DOE, reducing the NSF contribution. However, with this change we also moved some PO support from DOE to NSF to compensate for the change in the CF payments. After discussions with NSF it was agreed to split this into two separate CRs. These are in DocDB-13731. The change request describes the affected WBS areas, the cost impact, backup documentation, risks, and the sign-off.

In addition to these baseline change requests, the project has processed a number of configuration updates. This includes updates to e.g. requirements and project management documents. The list of approved documents are maintained in the configuration index:
https://web.fnal.gov/project/CMS-HL-LHC-Upgrades/Lists/Project%20Documents/Approved-documents.aspx

II. **CMS-specific PDR Follow-up Questions:**

a. The PDR noted that some elements of the contingency descoping plan were only exercisable early in construction, minimizing their use in risk mitigation, especially late in

the construction schedule when the availability of budget contingency may be limited. Review the status of the CMS collaboration's progress revising their descoping plan to identify a reasonable level of available options midway through late in construction program.

We don't agree fully with the characterization of the descoping plan described above. In particular, the NSF guidance is to have 10% of descoping options available at the time of the PDR. Our plan as presented at the PDR had more than 10% descoping options available at the start of the construction in April 2020 and almost 10% more than two years into the project. In the PDR review report it was pointed out that some of the down scope options were considered to be 'unrealistic' or 'not realizable'. This referred to descopes where scope was moved outside the project; e.g. to groups supported by other funding agencies or to be supported through the OPS program. We are updating the descoping plan to:

- Remove or update some descope options that involve change of scopes to other entities in HL-LHC upgrades or the OPS program
- Reduce (or remove) descope options that involve reduction of spares.
- Introduce new descope option for firmware development for the trigger.
- Some descope options can be extended later in time by 'strategic planning' to make use of schedule float.
- Update cost impact with costs including escalation.

b. Assess CMS's progress revising their descoping plan to document science impacts of the various options.

   This will be presented by C. Hill (project scientist).

c. Review CMS's progress updating their Basis of Estimate (BOE) documentation to address areas of concern expressed at PDR (see p. 37 of the CMS PDR report).

   We have discussed with NSF (M. Coles, R. Yasky, and D. DiGiovanna) how to address these points. The agreed on updates to BOEs and costbook formats are summarized here. We updated the CEP with a flow diagram similar to figure 4.XXX in the LFM that explains the flow of information. A key point here is the role of the BOE, it provides the basis of estimate. We use the BOE to build the resource loaded schedule (in P6) from which costs are derived that includes escalation and indirect rates. To address the questions raised here, and in the NSF cost guidance, see Part IV below, we have made a few updates to the BOEs. They now contain a summary of the direct M&S costs as well as summary of the hours for both the on-project and the scientific labor. (These are now separated into two tables following the guidance from NSF, or presented in the tables such that the scientific and costed labor is easily separated.) In addition, we now provide a new costbook summary sheet corresponding to each BOE. This summary provides the yearly expenditures by the NSF cost categories as well as a totals for the M&S cost and labor hours. These totals (three numbers) can be compared to the BOEs. An example of this is the ECAL FE BE presented at the pre-FDR; the BOE is available in DocDB-12843, and the costbook summary sheets are in DocDB-13730.

d. Review CMS's Quality Assurance Implementation Plan. Does it provide effective guidance in preparing for FDR? Advise NSF on CMS's progress to ensure that design assumptions and quality assurance criteria are consistently applied across the project to be ready for FDR.

This is described in the Quality Assurance Plan (DocDB-13093) and presentation by C. Wilkinson. The QAP has been substantially updated and contains a more detailed description of how the HL-LHC upgrades manage quality assurance. The document contains appendices for each L2 area where the subsystem specific plans are outlined. More detailed will also be provided in the presentations of the TFPX Mechanics and ECAL Frontend plans.

e. Review the CMS Project Development Plan (PDP) to determine whether updates since PDR offer sufficient detail concerning prototype and preproduction testing, and verification of performance specifications. *(Example: At PDR the forward pixel detector R&D plan was not yet finalized, pending tests in 2018 (see p. 8 of the PDR report). Does the R&D plan now satisfactorily converge on a final design path?)*

The plan has been updated in the PEP (DocDB-13279), Sect. 3. In particular, milestones during the final design have been reviewed and updated. These milestones are used to track the progress in the the monthly reports to NSF. In view of developing these milestones a very careful consideration was made to the available R&D funds in 2019. The project is funding limited; additional funding would allow faster progress in many areas and reduce risks (sooner) for the MREFC. It is however, our belief that with the funding allocated to the upgrades in the U.S. CMS Operation program budget, in agreement with the operations program managers, we will have the project construction ready by April 1, 2020.

III. **FDR Readiness Questions Applicable to ATLAS AND CMS:**

a. Review the status and development schedule for all ASICs to be fabricated with NSF MREFC funding, and the current delivery schedules for ASICs to be incorporated into the MREFC scope that are fabricated by others. Does each experiment have plans in place to deal with foreseen uncertainties in ASIC delivery/production?

The U.S. CMS HL-LHC Upgrades supported by NSF MREFC funds are not developing any ASICs. However, a number of ASICs that are developed elsewhere in the upgrades are used in components to be built by NSF MREFC funds. The ASICs used are:

- lpGBT - BCAL, TFPX, Muons depend on this. Delays have different impacts on each subsystem and we have specific risks for each L2 area.
- RD53b - TFPX readout chip. Schedule allows additional prototype run and is included in risk register.
- ECAL VFE chip
- Muon readout chip
- DCDC converter chip

The project has considered the risks with each of these deliverables (DocDB-12897); the risk register describes these risks and mitigations in case they are delayed or will not perform as planned. Presentations at the pre-FDR will address these plans.

b. Examine one work package, selected by the project as a representative FDR-ready example. Advise NSF on the following:

We have prepared two areas; the ECAL frontend board (WBS 402.3.3.2) and the TFPX mechanics (WBS 402.7.6).

i. Confirm the traceability of project science goals to the work package's specifications.
This is documented in the requirement documentation. For TFPX this is in DocDB-13304 and for BCAL this is DocDB-13317. The requirements documents have been update to reflect guidance and recommendations from the PDR. In particular, many requirements have been made more quantitative to avoid vague language. Some additional requirements that was missing before has been added. These were requirements that we were designing to meet, but had not written down explicitly. These updates to the requirements have no significant impact on the designs or the costs of the project; but we think more accurately reflects what we will deliver.

ii. Is the work package based on construction-ready plans and specifications, confirmed technological developments, and resources that are certain to be available at the time the work package will be executed? Is the scope of work documented appropriately within the Work Breakdown Structure (WBS) and WBS dictionary?
The WBS dictionary is available in DocDB-13165. The status of the plans will be discussed in the presentations of the TFPX Mechanics and the ECAL FE Boards.

iii. Is the budget adequately substantiated, with appropriate externally provided information such as vendor estimates or quotes, publicly available supplier prices, etc.?
The BOEs have been updated for the TFPX Mechanics (DocDB-13080, DocDB-13081, DocDB-13083, DocDB-13084) and ECAL FE (DocDB-12843). These updates includes updates to rlabor, F&A, escalation and use of FY19 base year for the costing. (We have struggled with technical difficulties in updating these rates due to tools that were not compatible with new oracle software versions. We have not deployed the updated labor rates we collected in the fall. They are now available and are ready for use, but we did not have time to include them before the pre-FDR.)

iv. Examine the adequacy of substantiation justifying the schedule for execution of the work package. Are there objective progress milestones in place to allow effective oversight by the Project Management Office?
The relevant milestones will be presented in the TFPX and ECAL talks.

v. Examine and comment on the adequacy of the risk management plan pertaining to this scope of work.
The risk registry (DocDB-12897) has been updated following guidance from NSF and the PDR, see below for more detail, and also with input from further technical development.

c. Examine the work package management plan. Advise NSF on the adequacy of plans for monitoring and reporting technical and financial status (using Earned Value Management Systems - EVMS) and enabling effective PMO oversight. Are reasonable plans in place for managing sub-awardees and contractors, and for managing interfaces (if applicable) with other upgrade activities, within the NSF scope and externally?

Talks will include description of the management plans as following project documentations.

d. Examine and comment on the adequacy of plans for quality assurance and acceptance testing.

The Quality Assurance Plan (DocDB-13093) provides the overall QA plan, on the TFPX Mechanics and ECAL FE presentations more details will be presented about the implementation of quality assurance in these areas.

Part II: General guidance

For immediate consideration:

1. In the future, please refer to uncosted or contributed labor as "scientific labor." The number of scientific labor hours (not dollars) needs to be included and time-phased in each BOE so that the total effort is explicit. (Further discussion of the required level of detail and presentation should occur before the pre-FDR).
   We have adopted the term "scientific labor". The costed, on-project labor, and the scientific labor are shown in separate tables in the BOEs. (Not all BOEs has been updated yet, but this will be done before the FDR.)
2. Provide a report to NSF within 30 days listing all scientific labor not included in the MREFC budget that will be part of the overall scope delivered by the MREFC project. List labor hours by WBS and by category (faculty, postdoc, grad, undergrad), institution, and source (DOE or NSF) of base program support.
   This was provided to NSF on June 17, 2018. The document is in DocDB-13555.
3. Update scope contingency planning to cover a possible loss of 30% of DOE-supported scientific labor and present this, with scientific impacts at FDR. Please be sure the de-scoping plan provides a reasonable range of options that could be exercised in the mid or later stages of construction.
   The guidance for this was updated in the pre-FDR charge. See above for more details about our response.
4. The CMS Risk Management Plan (RMP) included in the PDR PEP references the 2014 version of the Fermilab Risk Management Procedures for Projects document. The November 2016 version of Fermilab Risk Management Procedures for Projects was provided with the PDR material. This 2016 version indicates Cost Estimate Uncertainty is not within the purview of this document. The process CMS is different than the 2016 Fermilab Procedures, but is in accordance with the NSF's Large Facilities Manual (LFM). Please update the RMP to reflect current procedures at FDR.
   We have corrected the reference in the PEP. The plan is to propagate the changes into the Fermilab procedures such that they are consistent with the process we need to follow. L. Taylor, Fermilab Risk Manager, has reviewed this and agrees that these changes should be propageted to the Fermilab risk procedure documentation.
5. The PEP indicates that risks are reviewed monthly and workshops are held at least yearly. Fermilab OPSS Procedure indicates risk are reviewed as required and at least annually. During the PDR, one of the L2 system presentations indicated all risks will be revisited 1-2 times per year. Risks should be reviewed and reassessed monthly or quarterly at most. Also, the LFM requires the Project to establish a risk-adjusted TPC with updated ETC and EAC at least on an annual basis. The Risk

Management Plan should clearly identify when risks are reviewed and any updates to the risk assessment.
We are working on updating this in the Risk Management Plan (http://ppp-docdb.fnal.gov/cgi-bin/ShowDocument?docid=65&asof=2099-12-31). The PEP (DocDB-13276) has been update to reflect this.

6. In the PEP Section 6.3 Contingency Management under Risk Management, the Project identifies any use of contingency funds have to be associated with specific risks and documented in the change control documentation. The Risk Register contains only the risks that have residual risks associated for development of the budget contingency. Per the Large Facilities Manual (LFM), contingency allocations must be supported by analysis demonstrating that the proposed amounts to be allocated are considered reasonable and allowable and should be linked to the WBS and/or Risk Register ID. The Risk Register should document all identified risks including those with no residual risk. Based on the Risk Register ID numbering sequence, there appears to be identified risks that are not included in the register.
   The risk register as extracted in the pdf format for the the PDR (DocDB-12897) only contained the open risks; the live - online - risk register contains all risks. We will include all risks in the future.
7. NSF review of the CMS risks presented at PDR and found two additional threats that may be underestimated and one threat that appears to fall into the category of unallowable costs for unforeseeable risks:
   a. Risk ID RT-402-1-01-N Change to scope or interface to CMS (NSF) with an estimated mean probability impact of $126K seems low. During the PDR Presentation, the Project clarified that this threat is to the interfaces that are already established and Level 2 subsystems include the risk for where interfaces have not been established yet. Two of the four subsystems have identified a threat that include interface changes (RT-402-5-01-N and RT-402-7-10-N). For FDR, suggest the project-wide interface risk (RT-402-1-01-N) be broken into a separate risk for each Level 2 subsystem since the L2 subsystems have risks that are independent of one another. This will provide better risk assessment for contingency development and better risk management and assessment updates during execution.
      We implement the guidance above and the risk RT-402-1-01-N has been rejected as risk is now split into separate risks for each L2 area. Specifically these risks are RT-402-3-09-N, RT-402-5-01-N, RT-402-7-14-N, RT-402-9-03-N, and RT-402-9-06-N for BCAL, Muons, TFPX, and Trigger respectively.
   b. Risk ID-402-3-01-N IGBTX optical links do not meet requirements has a low probability of 5% and a high maximum impact of $1.8M. It is not clear that mitigation strategies have been incorporated into the baseline to support the very low probability.
      We have developed in 2018 a successful prototype FE board based on the fallback GBTx (5Gb/s) optical links. This decreases the schedule impact and labor cost from 12 to 6 months. The lpGBT's are behind schedule currently by 6 months but they are expected to be available for developer testing in early 2019. We cannot verify the performance until we get the lpGBT's so the risk remains open. However we have done everything we can to prepare for the testing.
   c. Risk ID RT-402-1-13-N MREFC funding delay at start of project (NSF) with an estimated mean probability impact of $269K. This threat is specific to the start of the project due to delayed funding. NSF, not the Project, holds this risk. Please remove it from the risk register.

This risk has been rejected.

Further refinement as noted below is required for the final design review and the construction award.

d. Update the risk management procedures and the Project Execution Plan to reflect the process used by the Project to develop the budget contingency that aligns with the LFM. The cost estimating plan indicates the EAC/ETC is updated at least annually. Per the LFM, a risk-based updated estimate of completion (EAC) is required at least annually.
Will update this.

e. Complete the Risk Register, CMS-doc 12897, to include documentation of risk mitigation strategies, cause or triggers, start and end dates, and impacted activities.
The online risk register contains this information.

f. Expand the TFPX subsystem threat RT-402-7-03-N Chip Quality Problem into separate risks for each silicon deliverable.
We have separated the ASIC risk into two risks, one for the readout chip RT-402-7-12-N and one for the DC-DC ASIC RT-402-7-13-N. (We already carry a separate risk for the lpGBT ASIC and optical transceiver RT-402-7-11N.) The risk probabilities and cost/schedule impacts are now evaluated separately to more closely track the status and probable impacts on the project.

g. At FDR, provide the basis for the Project selected confidence level for the budget contingency.
This has been updated in the PEP; the main justification for the 90% C.L. is that, though the overall risks are not that significant, the nature of the upgrade project makes it hard to find good downscope options. This is reflected in the comments about the downscopes in this guidance. To reduce the possibility that we have to exercise the descope options we have kept the confidence level high.

8. The budget profile below is the one you sent me following PDR, aligned by NSF fiscal year. This alignment helps NSF to plan for the Congressional appropriation request process. Please confirm the first-year appropriation (for FY 2020) before September 1, 2018, as NSF will need to include this in the budget negotiations with the Office of Management and Budget that will begin in the fall of FY 2018 in preparation for the FY 2020 NSF Budget Request to Congress. There is potentially latitude to adjust the profile for FY 2021 and subsequent years during the Final Design stage. (Please be aware that NSF looks two years ahead in budget planning, so the FY 2021 MREFC budget needs to be confirmed by August 2019.)

CMS ($K)								
Labor	2682	5153	4887	4312	2172	275	55	19536
Material	5899	11782	10364	4947	531	110	43	33676
Travel	296	591	634	513	486	146	32	2698
Contingency	3818	5727	3818	2864	2863	0	0	19090
CMS Total	**12695**	**23253**	**19703**	**12636**	**6052**	**531**	**130**	**75000**

Align the project year budget profiles with the NSF fiscal years for presentation at FDR. The PDR panel noted CMS's plans to request funding for 30% ($5.8M) of its contingency in the last 2.5 years of the Project when less than 13% ($7.1M) of the effort remains. Given that most of the project will be completed

by Year 3, please re-examine the profile for the funding of contingency to assure there are adequate early resources to cover risk.
We have confirmed the budget above and will review the contingency allocation for the FDR.

9. NSF would like to have focused discussions about how to make the education/outreach programs "shine" at FDR. We have recruited an expert from the E H R Directorate to give us internal advice, and we will recruit an education professional with relevant experience to participate in the pre-FDR and FDR. We think it would be helpful for you to consult with other recent large projects funded by NSF to get ideas on how to leverage MREFC funding as an opportunity to expand outreach activities through the contemporaneous research program. NSF will be happy to provide feedback to you as your plans become more developed.
   See the response to the general charge questions earlier.
10. Place the project baseline under configuration control soon, maintain change control log, report changes, set approval thresholds. NSF suggests implementing a baseline change proposal form that includes the technical impact and the associated risk identification similar to the sample in the Large Facilities Manual (see https://www.nsf.gov/pubs/2017/nsf17066/nsf17066.pdf figure 4.2.5-1). NSF plans to amend the current Cooperative Agreement with CMS to establish mutually agreed thresholds that would trigger NSF approval during Final Design.
    The approval thresholds are documented in the Configuration Management and Change Control Plan (DocDB-12907). The thresholds for NSF approval were provided by NSF in the update to the NSF operations program cooperative agreement. The change requests are managed using the Fermilab Baseline Change Request (fBCR) tool. See further description above in the response to the pre-FDR charge.
11. Augment milestones in the Final Design development plan where recommended in the PDR report, and report against milestones in monthly reports to NSF. The project should consider documenting and reviewing all of the planned prototype testing procedures early in the Final Design phase. Such documentation will further support risk management, as well as cost and schedule control of R&D activities. Furthermore, reviewing the procedures will ensure consistent assumptions (like radiation safety factors, for example) and test conditions across the project.
    As discussed in the response above to the pre-FDR charge the milestones have been reviewed and updated. We report against these milestones in the monthly reports to NSF (e.g. the November 2018 monthly report is available in DocDB-13717).
12. Continue quarterly financial status reporting through the completion of Final Design.
    We are doing this (and expect to continue this through the construction project)..
13. Plan for the Final Design Review (FDR) in October 2019. In view of the extensive post-PDR processes at NSF and the likelihood that the post FDR processes will be similar, we think the FDR needs to be moved forward from earlier projections of December 2019 or January 2020 to assure an April 2020 start date for the MREFC award.
    We are planning for FDR in Sept. 2019.
14. We think it could be helpful to provide EVM reports from CMS to NSF for comment during Final Design, once you are ready to do so, so that there is a good mutual understanding of expectations by the start of construction and so that the transition to construction can be smooth. While the work to be reported on will all be level-of-effort, so that the EVM data itself isn't very useful as a management tool, there is likely to be added training value for the CMS team to gain experience with this and promote timely implementation as a management tool during construction.

We are working towards this goal. We are now collecting the actuals data and will take the step towards EVM report in early 2019. We have established the Control Accounts and the Chargeable Task Code structure for this reporting, see DocDB-13714.

15. Refine the R&D plan and path to converge on the final design of the forward pixels sensors and modules. Update the risks and dependencies based on the R&D results that should now, or soon become available.
    The development plan in the Project Execution Plan was updated in September (section 3.1.5). With the radiation hard RD53A, sensor irradiation and beam tests have been conducted to qualify the radiation tolerance of different sensor and cell designs. Evaluation of irradiated modules will be conducted in Feb and May 2019 in test beam, and additional irradiations and test beam campaigns are scheduled in 2019, in both the US and Europe with US participation. Module design is proceeding, with US contributions to the HDI specifications, material and connector selection and irradiation qualification, and prototype modules based on the RD53A chip will be assembled in the US to demonstrate construction at the module factories and provide articles for system tests.
16. The PDR panel noted that external dependencies in the Sensors/ROCs and Electronics WBS create serious risks for the TFPX schedule. They are identified but likely underestimated in the risk register. The roadmap for bringing each of these to final design and validation is unclear. Please revise the CMS Project Development Plan to allow sensor testing prior to availability of the final ROC.

    Risks for external chips have been separated in the risk register (cf 7f) so probability and impact can be separately assessed. We plan to incrementally update this; separation is done and current assessment of risk updated. As R&D progresses before the FDR we will update the risks in the risk register.

    The roadmap for each of these is briefly indicated below. The plans were updated in the Project Development Plan, section 3.1.5 of the Project Execution Plan.
    - Read Out Chip - RD53A demonstrator works and can be used for prototypes and testing; a full size chip for CMS is being assembled within RD53/CMS in 2019 and submitted end of CY2019, which will be tested and used for full-size prototype modules and beam tests for validation.
    - lpGBT - - chips available in Q1 CY2019, prototype port card in 2019, chain testing in 2019
    - DC-DC converter ASICs (two stages) - chips available Q1 CY2019, prototype port card in 2019, chain testing in 2019.

    We updated the PDP in September 2018 to include sensor radiation testing with the RD53A, until the final chip is available. So far this is not a limitation for validating the sensor design.

17. Provide additional detail concerning prototype and preproduction testing, verification of performance specifications, as indicated in the CMS PDR report. Provide the project implementation plan to NSF following approval to advance to Final Design stage. It would be useful to provide a sample of the plan for testing and performance verification for review at pre-FDR. NSF will assess the entire plan at FDR.
    The framework for this is in the QAP (DocDB-13093). At the pre-FDR we have e.g. the testing plan for the BCAL.

18. Update design assumptions and quality assurance plans so that they are consistently applied across the project. Provide NSF with CMS's implementation plan following approval to advance to Final Design stage.
    This is covered in the QAP.
19. Update the cost book to clearly present the total cost of each WBS element, with a summary of labor hours and M&S dollars. (This will help facilitate the reconciliation with the ICE as well as FDR process). Adopt a consistent format for each of the various types of tables so that they are consistent across all WBS elements and form a set of building blocks by which the user can see the 'roll up' to the total cost. Provide a sample revision at pre-FDR for panel review.
    This has been discussed with the NSF (M. Coles, R. Yasky, and D. DiGiovana). More details about this is given below in the response to the cost guidance.

Part III: General guidance for FDR

For FDR:

1. Make decisions on a majority of technical choices, which will help to reduce uncertainties on cost and schedule and assure timely deliveries of MREFC components to CERN. Technical designs of all systems and testing of prototypes are expected to be either completed or close to completion and dependencies on external factors are expected to be minimized to the extent possible. Expand the Risk Register to include all risks identified including those with no residual impact after mitigation strategies have been incorporated into the project plan.
   This is work in progress; at the pre-FDR we will present some of these. Much progress has been made so far on making prototypes and by the time of the FDR in Sept. 2019 significant further progress should have been made.
2. For FDR, please be sure that requirements, including high-level requirements, avoid generic, hard to verify statements. The project should be consistent in using the regular validation and verification nomenclature: system validation evaluates the system relative to its purpose (built the right system), system verification compares functions and performance to requirements (built the system the right way), and requirements validation establishes that the requirements describe the intended system.

   The requirements have been updated to avoid generic statements, see earlier.

3. Update the BOEs to include the total cost of the respective WBS element and separate tables for M&S and labor. Update the BOEs to ensure that scientific labor is clearly segregated from costed labor in the supporting information in the cost book, and that it is accompanied by proposed metrics for management to monitor and report on its use during construction.
   We have agreed with NSF how to handle this; see discussion below in response to the NSF cost guidance. All BOEs will be updated by Feb. 1, 2019 to have these separate tables.
4. Update the BOEs for purchased labor and materials so that the first year of the project's budget is based substantially on externally-based estimates for the activities to be conducted during that time. NSF strongly recommends CMS use a more objective method than expert opinion for determining earned value for critical/high risk scientific labor - for example, by using milestones, labor hours, or manufactured units as a basis of measurement.

BOEs are being updated to have budgets based on quotes etc. for the M&S. Examples will be presented at the pre-FDR for TFPX Mechanics and ECAL FE Boards. We will not track scientific labor with earned value; however we will have milestones to track progress by tasks that make use of scientific labor.

5. Revise budget estimates to reflect CERN Common Fund contributions based on author "fair share".
   This has been done. This change is used as a sample baseline change request.
6. The boundary between Pre-MREFC and MREFC activities should be very clear for every work package and based on specific scope completions. The pre-MREFC development activities need very clear definitions of completion so that there is an unambiguous definition for the use of MREFC and Research and Related Activities (R&RA) funds. This will be especially important in future financial audits during construction. The milestones for the key Pixel R&D areas to settle the designs for the start of construction are especially important to have a clear overall view of all key elements of design progress and to enable the project to track it systematically. The PDR panel also noted that the muon system needs an FDR milestone.
   We have strived to have a clear distinction between pre-MREFC and MREFC activities; the pre-MREFC activities culminates with the completions, and testing, of prototypes to validate the design choices. The MREFC starts with the pre-production, including any required updates to the design for the pre-production. The goals of the pre-MREFC R&D activities are described in the PEP with clear milestones.
7. Include additional technical milestones in the project development plan for the trigger, describing activities during the final design phase to ensure timely readiness for the MREFC. The PDR panel recommended CMS consider including additional milestones to ensure the Trigger pre-production demonstrator tests stay on schedule.
   The project development plan has been updated to include additional milestones for the technical developments needed to achieve readiness for the MREFC in Table 3.6 of the project execution plan.
8. For the pixels, the PDR panel was concerned that risks are underestimated, since external dependencies pose serious risks to the TFPX schedule. The PDR panel recommended:
   a. Developing a plan to enable sensor testing prior to the availability of the final Readout chips and that a more thorough test plan is needed at the sensor, SRA, and module stage. Sensor testing is proceeding with the RD53A prototype chip; The QC/QA plan for sensors, SRAs, and modules is not developed in full detail at this point, however, starting in 2018-2019 efforts based on Phase 1 QC procedures & other experience are being applied to sensor, SRA and module testing plans: SRA testing with a wafer probe station is under development at UTK, module testing will be supported by OSU and UIC, with first demonstration modules, and sensor testing is underway as part of the sensor R&D plan.
   b. Revise the risk register to include independent risks for each silicon deliverable. Use a more rigorous methodology to estimate probability of occurrence, i.e. past performance by the responsible organizations, and cost/schedule impact.
      We now carry separate risks for the ASICs (ROC, lpGBT, DC-DC converter) and have updated probabilities and impacts based on developments since PDR. The methodology is based on past experience with the vendor or external agency (e.g. CERN microelectronics group); e.g. here we have a 50% probability assigned to the DC-DC risk, with impacts and responses taken from phase 1 DC-DC experience.
   c. Assess the feasibility and necessity of using 3D sensors for the inner ring and make the down-select decision by FDR or earlier.

3D sensors may be required to meet radiation tolerance requirements. Irradiation of planar (2018 & 2019) and 3D sensors (2019) are in the development plan, though a down-select at FDR is aggressive due to high demand for irradiation facilities. If planar sensors are demonstrated to be adequate a down select is possible. US groups have invested heavily in use of Los Alamos for the high-dose testing and will seek to further advance the schedule. A new facility at FNAL is also coming online.

d. Show the path from the ROC demonstrator to the final TFPX ROC, including down-select between design options, number of ASIC prototype iterations, and the test plan.
The PDP has been updated to reflect the joint decision for RD53 to continue to develop and implement chips for ATLAS and CMS using a common design (but different sizes), sharing engineering resources and staggering initial prototype submissions to benefit both experiments at lower risk. That is, a problem discovered with the ATLAS chip can be corrected before the CMS chip is submitted. Testing experience with RD53A demonstrators has prepared RD53, ATLAS and CMS to undertake further testing in common, as for RD53A. The front-end design is under review by a committee including external ASIC developers, and a down-select will be made in January 2019. The ATLAS and CMS full-size prototypes will be finalized, validated and submitted in mid and late 2019, followed by testing of the CMS version in 2020. If required, a second full-size CMS prototype can be prepared by end of 2020 and produced in early 2021. The production chip is planned for submission in July 2021. While not involved in the ASIC engineering, TFPX groups are involved in reviews, requirements and work extensively on testing, test beam and irradiation campaigns to validate the ROC (and sensors).

9. For the Barrel Calorimeter electronics, insert external milestones for critical deliverables (lpGBT, Versatile Link Plus, etc.). Revise the risk register to include a schedule risk for the Barrel Calorimeter electronics for late delivery of the lpGBT/Versatile Link Plus ASICs.
We have added risks for this. Milestones still need to be added.
10. The PDR panel stated the largest risk to the Track and Muon Triggers is from the management of the firmware needed for the trigger algorithms. According to the schedule presented there will only be a few months to test the Track Trigger before first beam in the LHC. At FDR, please respond to the panel's recommendation to consider producing a realistically test data for the track trigger that will mimic the likely output of the tracker to allow the system to be thoroughly debugged, prior to first beam in Run 4 of the LHC. This may require a large surface test facility.
Testing for the track trigger will include full simulated inputs as will arrive from the outer tracker DTC to the track finding boards. We will test the full set of input fibers for the track finding boards with simulated events played back into the track finding boards at the rate expected from LHC collision data operation.

11. Please provide description of the scientific impact of scope opportunities and descope options. Include decision logic for exercise of the option. Prior to FDR, compile and centrally manage a full list of all potential descope options and scope opportunities and set criteria, priorities and schedules for their implementation. Scope opportunities need to be costed. Include all of this in the PEP and present the overall plan for managing scope contingency for review at FDR.
For the pre-FDR we will present (C. Hill) the status of this. The science impact will be (better) documented in the scoping plan.

12. AT FDR, provide copies of all MOUs between Cornell University and all subawardee participants in the MREFC project, and MOUs between Cornell University and all collaborators or partners for which there will be project dependency in accomplishing the overall upgrade program.
    We have the subawards covered though the MREFC proposal. We will also provide MOUs for use of other resources, such as test beams and radiation facilities.
13. At FDR, provide current copies of all MOUs and SOWs pertaining to the use of scientific labor (from either NSF or DOE supported institutions) to the MREFC-supported construction activities.
    This will be in overview SOWs for the MREFC proposal.
14. At FDR, provide a substantive computing roadmap and development plan for supporting HL-LHC computing, describing the impacts on scientific goals. Include significant milestones and decision points, with impacts on science goals, that will occur during the 2020-2026 period.
    This will be developed with the operations program.
15. Provide an activity-based estimate, accompanied by underlying assumptions supporting the BOE, for the full life-cycle cost of operation during the HL-LHC experimental program (FY 2026-FY 2037).
    This will be developed with the operations program.
16. Include provision in the MREFC budget to provide annual incurred cost data to NSF to support an audit. support annual incurred cost audits during MREFC construction. It might be good to talk to your administration now concerning how much of this burden will fall on you as the PI, vs. how much your administration will do without additional assistance from the project.
    This has been discussed with Cornell (J. Silber). Between the administrative and financial support in the project plan and the university administration the support level seemed sufficient. However, we should probably check that the assumptions here are correct with the NSF LFO (R. Yasky).
17. Project completion milestones should be uniformly defined over all WBS elements and documented in the PEP presented at FDR.
    This needs to be reviewed/updated.
18. For FDR, present the impacts on science goals of detector over- and under-performance.

    This is a very broad questions; some further guidance would be helpful

Part IV: Cost guidance

1. Develop easily traceable calculations so that a third-party analyst not familiar with the project can quickly replicate the calculations for costs contained in the cost books. Ensure that labor rates, travel, and M&S rates are accurate and updated in the BOE's and ensure calculation refinement (ie., formula in the excel cost workbook) instead of hard key data to replicate costs in the cost book. You will want to have this done prior to the start of the Independent Cost Estimate (ICE), whose schedule will be defined soon after we receive formal authorization to commence Final Design (expected July 17, 2018). Also, please follow the below guidance for preparing the FDR Cost Books:
    a. Do not include pre-MREFC costs in the Cost Books provided for cost analysis.
    b. Remove any DOE scope costs from the Cost Books provided.
    c. At FDR, Cost Books must allow for mapping individual cost lines to NSF budget categories as required by the Large Facilities Manual, section *4.2.3.4 Construction Cost Book Detail*.

This points have been addressed. In particular we have provided a spreadsheet to the NSF with the cost information including the NSF 1030 cost categories (DocDB-13726).

2. Plan for a Financial Capacity Review by NSF's Division of Institution and Award Support Cost Analysis and Pre-Award Branch (DIAS/CAP) during Final Design. This effort will impact the University's Office of Sponsored Research, but we want to alert you to this likely future activity.
   This has been discussed with Cornell (Jeffrey Silber) and they are familiar with this.
3. Plan to support an Independent Cost Estimate (ICE) by an NSF contractor during FD. This will require the provision of technical information used to produce the estimate and will require effort by the project (and NSF) to resolve differences between the project's estimate and that of the ICE estimator. The ICE is intended to determine the project baseline's budget accuracy and completeness and the quality of the estimation methods. This may involve non-negligible effort to provide design documentation to the contractor, and assistance to NSF in reconciling differences between the baseline and contractor's estimate.
   The plan for the ICE has been extensively discussed with NSF. We will do a trial in Jan. 2019 with the material submitted for the pre-FDR.

4. NSF recommends following Cornell University's cost policy on "award" work vs. "employment" work for undergraduate student participants as certain federal and state income tax provisions may apply.
   This was further discussed and clarified with NSF; the hourly rates have been adjusted for future increases in the NY State minimum wage and adjusted more closely to the expected skills from the students. (The terms "award" vs. "employment" work does not exist at Cornell as far as we can determine.)

5. For FDR, NSF recommends that Cornell strengthen each WBS BOE by differentiating between items that are to be purchased by the prime and the subawardee. Further, the BOE should include cost estimates in then-year dollars with escalated amounts for traceability.
   The BOEs already lists the responsible institutions and if it is not Cornell then the subawardee will handle the purchasing. After discussions with NSF (Mark, Rebecca, DeAnna) we have agreed that propagating escalated costs back into the BOE is not maintainable. Rather, we plan on providing a summary sheet for each BOE that has the base year and actual year costs.

6. Update cost data stated in the Basis of Estimate documents so that it clearly maps to the NSF budget form values in accordance with Section 4.2.2.2 of the Large Facilities Manual before Final Design Review.
   We have the costs by NSF cost categories in the summary sheet for each BOE.

7. The Indirect Cost rate used at PDR is per the rate agreement by the Department of Health and Human Services dated July 10, 2017 and effective through June 30, 2018 as predetermined and until amended as provisional. Please update and use current rates for FDR in 2019.
   We updated all rates in the fall of 2018 (DocDB-13272). (But with 30 institutions there will always be some institutions that are near the end of their rate agreements.)

8. For FDR, reallocate subaward overhead costs into the indirect cost line item of the NSF budget summary form 1030.
   This has been corrected - it was an oversight at the PDR.

9. NSF noted variances in some travel estimates due to apparent inaccuracies in data uploaded into P6 from the BOE document. Please take care to ensure that data entry into P6 reconciles to the BOEs.

   We will check this carefully. The new format of the BOE tables with summaries should allow a simple check.

10. NSF's review of vendor quotes revealed that a few items did not reconcile to the BOEs. NSF's review noted those items of cost were allocated to the Cooperative Agreement for CMS Operations which is managed by Princeton University and are not requested under this MREFC project. For FDR, only include the MREFC project costs and exclude any references to "contributed labor" or "NSF CA" costs that create confusion for the costs analysis.

    We have removed all 'NSF CA' costs in material we proved for review.

11. Update the BOEs to include the total cost of the respective WBS element and include separate tables for M&S and labor. The Project must document specific historical escalation rates for its key hardware components /commodities to demonstrate why its 2% M&S escalation factor plus the associated escalation element in the risk register is adequate to cover escalation costs. Update the BOEs to ensure that scientific labor is clearly segregated from costed labor in the supporting information in the cost book, and that it is accompanied by proposed metrics for management to monitor and report on its use during construction.

    We have separate table for M&S and labor. We will update the BOEs to have separate tables for the scientific and costed labor.

12. We advise to begin the planning process for the eventual implementation of the subawards proposed for this construction upgrade. AT FDR, NSF would like to see evidence that the institutions agree to the proposed statements of work and budget proposals agreed to with Cornell University. This will ensure the accuracy of the proposed cost estimate at the time of proposal submission through NSF's proposal systems (Fastlane) and potentially eliminate cost discrepancies not agreed to between the Universities.

    As part of the MREFC proposal there will be the overview SOWs that outline the institutional responsibilities. Cornell will require the institutional approval of budgets and scope.