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Closeout Report on the DOE/SC CD-2/3 Review of the

LHC CMS Detector Upgrade Project

Fermi National Accelerator Laboratory

August 5-7, 2014

Kurt Fisher

Committee Chair

Office of Science, U.S. Department of Energy

http://www.science.doe.gov/opa/

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Review Committee Participants

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Kurt Fisher, DOE/SC, Chairperson

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HCal—Hadron Calorimeter (WBS 1.2)

* Jim Proudfoot, ANL
Jim Pilcher, U of Chicago

SC2
Forward Pixel Detector (WBS 1.3)

* Jim Brau, Oregon
Marina Artuso, Syracuse
Maurice Garcia-Sciveres, LBNL

SC3
Level 1 Trigger (WBS 1.4)

* Charlie Young, SLAC
Kevin Pitts, U of Illinois
Bill Ashmanskas, U of Penn

SC4
Cost and Schedule

* Frank Gines, DOE/ASO
Penka Novakova, BNL
Gail Penny, DOE/BHSO

SC5
Project Management (WBS 1.1)

* Michael Levi, LBNL
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Jim Siegrist, DOE/SC
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LEGEND

SC Subcommittee
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Count: 15 (excluding observers)

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    - Pacific NWest SO — *Roger Snyder*
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Charge Questions

1. Do the proposed technical design and associated implementation approach satisfy the performance requirements? Are the CD-4 goals well defined?

2. Performance Baseline: Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance? Is the contingency adequate for the risk?

3. Final Design: Is the design sufficiently mature so that the project can continue with procurement and fabrication? Baseline Cost and Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Is the contingency adequate for the risks?

4. Are the management structure and resources adequate to deliver the proposed final design within the baselines as identified in the PEP?

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete?

6. Are ES&H aspects being properly addressed given the project's current stage of development?

2.1 Hadron Calorimeter (WBS 1.2)

J. Proudfoot, J. Pilcher / Subcommittee 1

1. Do the proposed technical design and associated implementation approach satisfy the performance requirements? Are the CD-4 goals well defined?
   Yes. *The proposed technical design and implementation satisfies the performance requirements. The scope and CD4 goals are well defined.*

2. Performance Baseline: Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance? Is the contingency adequate for the risk?
   Yes. *The cost estimate and schedule are consistent with the plan to deliver the technical scope and performance baseline. Costs are estimated from prototype design and construction and vendor quotes for devices and components. The contingency is adequate for the risk at this stage for this part of the project*

3. Final Design: Is the design sufficiently mature so that the project can continue with procurement and fabrication? Baseline Cost and Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Is the contingency adequate for the risks?
   Yes. *All key elements of the design have been tested through prototype; a successful integration test of the readout has been carried out; prototype and some pre-production units of several elements of the boards and crates are in progress. Two vendors capable of meeting the performance specification for the SiPM have been qualified; the QIE10and QIE11 ASICs are being tested in an engineering run.*

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete?
   Yes. *The design is well documented in a Technical Design Report, has detailed basis of estimate information, vendor quotes and costing data.*

Findings - I

HF:

The HCAL project will replace the full front end electronics for the two forward calorimeters. The schedule calls for delivery of the hardware to CERN in the September 2015 for testing and burn-in. Installation on the detector is planned for the winter shutdown of 2016 (Jan-Feb). The hardware is needed for improved jet tagging with the forward calorimeter, particularly for the vector boson fusion channel for Higgs production.

The principal items needed are 200 QIE boards using QIE10 custom ASICS, 20 ngCCM clock and control boards and 10 calibration modules.

Prototypes of the QIE10 chips have been produced and an engineering run for 5000 chips was launched in June 2014. This run is expected to supply enough chips to meet the final needs. The other components are largely conventional.

Findings - II

HCAL - HBHE front end:
The project will replace the photodetectors and associated front end electronics for the HB and HE calorimeters. The new hardware will be installed in the existing mechanical enclosures on the detector wedges. These regions are only accessible during a long shutdown and the next one is currently planned to begin in 2018.

The replacements are necessary to cope with decreasing light yield from the calorimeter scintillators, HPD gain drift and discharges, and to provide better performance at high pileup.

This part of the upgrade will involve 26K silicon photomultipliers (SiPM), 18K QIE11 custom readout chips, and 1500 QIE readout boards, 375 sets of three SiPM boards, together with supporting hardware.

Findings - III

HCAL - HBHE front end:
Two vendors have been qualified for preproduction of the SiPMs and price quotes are available from both. The preproduction order is planned for August 2014 and final device selection for HE (HB) in 2015 (2016).

The QIE11 chip only differs from the QIE10 by the addition of a programmable input current shunt. The final design was submitted as part of the same engineering run as the QIE10 chip. If successful it will furnish ~50% of the required units.

The QIE readout boards are relatively low power, low density boards. A pre-prototype has been constructed and the first full prototype is planned for fall 2014.

For the SiPM mounting boards, 8-channel prototypes have been built and evaluated, while 48-channel prototypes are planned in the fall of 2014.

Findings - IV

HCAL - Backend electronics:
The backend electronics is common to all calorimeter sections.

It receives the digitized data from every bunch crossing over optical links, calculates trigger primitives and transmits them to the calorimeter trigger. It also buffers the data while waiting for the trigger decision.

The system requires optical splitters so the new hardware can be commissioned in parallel with existing data taking, uHTR boards to receive the data, and AMC13 boards for crate management and data storage.

Prototype uHTR boards have been built, tested, and approved by CMS.

The AMC13 boards have been produced.

Prototype optical splitters have been built and tested. Two vendors have been identified.

Comments – I

The HCAL project has made significant progress since the CD1 review in 2013:

- SiPMs from two vendors have been tested and shown to fully meet specification – further development work with vendors may realize devices with PDE greater than 30% which could provide greater margin against radiation damage effects. The HCAL team should be prudent in deciding when good is good enough.
- During the review a successful drill down was done for one of the three versions of front-end boards used to readout out the SiPMs, the SiPMs themselves and for their packaging. The documentation and supporting material were found to be in good order and the contingency levels very conservative.
- An engineering run of QIE10/11 ASIC is in progress. The HCAL team are being conservative but it appears that there is high likelihood of success and the team should plan for this.
- The HCAL project has made the decision to adopt the IGLOO2 chip as an alternative to the GBTX, thereby removing schedule risk – a concern at CD1.
- The SiPM packaging issues have been resolved – a concern at CD1.
- A successful integration test has been carried out; the test of a full readout box in a radiation field is planned for early 2015, prior to the PRR – a concern at CD1.

Comments – II

The HF schedule is aggressive but feasible. Prototypes are available almost all components and test beam studies with the planned hardware have been done. A successful engineering run for the QIE10 chips will be an important milestone.

BoE element 401.02.04.05 contains a typographical error: (H110890 Fabrication of full chip M&S $26654k)

This portion of the project contains ~20 FTEs of contributed labor. This effort is associated to the project on a year by year basis through SOWs with collaborating institutions and could be vulnerable to changes in the base program funding .

A drill down into a number of cost drivers in the system demonstrated that the management team had good control of the costs and work performed and that the cost uncertainty was generally applied according to the project rules.

The SiPM procurement is assigned contingency level M4, however two vendors are capable of meeting the specification for these devices and have provided quotes.

Recommendations

Before CD2:

Review data in BoE text and data to identify and correct errors

Apply consistent contingency rules to all elements of the WBS

Work with management to ensure accuracy of accrued cost data

Proceed to CD2/3 approval

2.2 Forward Pixel Detector (WBS 1.3)

M. Artuso, J. Brau*, M. Garcia-Sciveres

1. Do the proposed technical design and associated implementation approach satisfy the performance requirements?

   YES

   Are the CD-4 goals well defined?

   YES

2. Performance Baseline:

   Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance?

   YES

   Is the contingency adequate for the risk?

   YES for most items (see recommendations)

3. Final Design:

   Is the design sufficiently mature so that the project can continue with procurement and fabrication?

   YES

   Baseline Cost and Schedule:

   Are the current project cost and schedule projections consistent with the approved baseline cost and schedule?

   YES

   Is the contingency adequate for the risks?

   YES for most items (see recommendations)

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete?

   YES

2.2 Forward Pixel Detector (WBS 1.3)

M. Artuso, J. Brau*, M. Garcia-Sciveres

- **Findings (1)**

The current CMS Pixel Detector will continue to lose efficiency after LS1 as the LHC luminosity exceeds 10^{34} cm^{-2} s^{-1}, seriously impacting physics performance. Specifically, track seeding, primary and secondary vertex reconstruction, and b-tagging will all be degraded. Upgrades are required to avoid these detrimental effects.

The CMS Collaboration has developed an upgrade design to address this degradation, which is documented in the CMS technical proposal for an upgrade pixel system; the US Technical Design Report (TDR) for the forward pixel (FPIX) upgrade is based on this document.

The upgraded FPIX system comprises 44 million pixels on 672 modules, mounted on 12 half-disks; the upgrade increases the forward pixel layers from 2 to 3, which increases the typical number of hits per track from 3 to 4 for eta<2.5 when combined with the barrel pixel detector. The system is designed to survive an integrated luminosity of 500 fb^{-1}.

The project is budgeted for the Objective Key Performance Parameters, which include production of four half cylinders with three disks each and tested components for a spare half disk . The Threshold Key Performance Parameters specify the four half cylinders but not the spare half disk components. The components for a spare half disk represent scope contingency.

2.2 Forward Pixel Detector (WBS 1.3)

M. Artuso, J. Brau*, M. Garcia-Sciveres

- **Findings (2)**

The FPIX upgrade project involves only US collaborators, no non-US members; however, the project relies on CERN support for aspects that are contributed at no cost to the US. Also, the FPIX project relies on PSI to supply the Pixel Readout Chip as well as test setups purchased by the US FPIX project.

The CMS Pixel Collaboration has assigned responsibilities for the various electronics components. The US team is responsible for the Token Bit Managers (TBM) and relies on foreign collaborators for the Readout chips (ROCs) , DC/DC Converters, Detector Readout cards (FEDs) and optical receivers.

The latest ROC (PSI46digv2.2) was submitted in July and due back in September.

Latest TBM issues have been corrected with 15 specific changes to the TBM08 design in a "Rocket" submission which produced devices in June. Tests of this chip, TBM08b, have proven successful. Irradiation tests are underway and irradiated chips are due back this week for final tests.

Performance and physics studies have been done for the full pixel system upgrade, barrel and forward, and calibrated to test beam data, using the digital readout chip (PSI46dig-v2.1). Significant improvements in signal efficiencies of 50-60% are demonstrated.

- **Findings (3)**

The FPIX upgrade project implements significant cost reduction measures compared to the original detector, such as using a single module everywhere, going to 6 inch wafers for sensors, and using the same US bump bonding vendor used for 60% of the original FPIX.

In order to complete the needed 672 modules plus 20% qualified spares, the construction plan includes production of 1000 modules and assumes 85% yield.

Sensors have been sole source ordered through a collaborating university (Kansas) with NSF funding.

Modules are being produced in parallel at Purdue and Nebraska. To date forty-five pre-production modules using university setups have been built, demonstrating the collaboration can build working modules.

The FPIX critical path is driven initially by the availability of half disk mechanics. Complete designs and procedures for building the disks and cooling system have been produced and full prototypes for the disks and cooling are in progress. Both a four blade prototype and a seventeen blade outer half disk prototype have been built and demonstrated the required heat transfer resulting in less than 10^{o} C differential from sensor to coolant. The schedule also calls for constructing and testing an eleven blade inner half disk prototype soon.

- **Findings (4)**

A pilot system involving eight modules will be installed in the CMS experiment in September, 2014 and operated during LHC Run2. The main purpose of this pilot system is to practice aspects of the installation and commissioning, to facilitate conversion of the software and to gain operations experience for the final project.

In addition to the pilot system, a system test is planned at Fermilab during January-June, 2015, to validate the system performance of the electronics under final realistic conditions (with CO_2 cooling and carbon fiber mechanics).

The planned FPIX installation date in the present LHC schedule drives the US project schedule.

The schedule is designed for delivery to CERN of the last Half Cylinder by August 2016 and handover to CMS operations by September 2016, to meet the installation target during the Extended Technical Stop early in 2017.

Risks are documented in the Risk Register, identifying 23 risks: 20 threats and 3 opportunities.

2.2 Forward Pixel Detector (WBS 1.3)

M. Artuso, J. Brau*, M. Garcia-Sciveres

- **Comments (1)**

The FPIX team brings a **large experience base** to the project based on their significant role in the original CMS pixel project and current CMS pixel system.

Given the performance objectives, the **scope is appropriate** and the **design is mature** and nearly complete. The upgrade is designed to handle 2 x 10^{34} $cm^{-2}s^{-1}$ in luminosity with pileup up to 100 interactions per beam crossing and an integrated luminosity of 500 fb^{-1}. The upgrade results in **higher efficiencies, lower fake rates, lower dead-time/data-loss and extended lifetime of the detector**.

The design is **well documented** in the technical design report with reasonable cost estimates and documented basis of estimates.

The **scope contingency** represented by the difference between Objective Key Performance Parameters and Threshold Key Performance Parameters is **appropriate**.

The Risk Register has a **thorough collection of risks with analysis** of potential impacts. Readout chip and Token Bit Manager development are nearing completion, thereby reducing risk, but **should performance of either chip fall short of success** the project will need to react quickly and effectively to **protect the schedule**.

2.2 Forward Pixel Detector (WBS 1.3)

M. Artuso, J. Brau*, M. Garcia-Sciveres

- **Comments (2)**

Even though the number of spares is large, the module yield assumption (85%) is better than the yield from U.S. experience with the FPIX detector for both bump-bonding and assembly of 72% (Basis of Estimate). The criteria placed on the acceptable dead pixels/ROC and HV requirements have been softened based on experience so the **85% module yield assumption is reasonable at this time**.

The mechanical support design is innovative and very low mass. The prototype half disks under development and test will provide critical validation of the concept and implementation. Completion of **engineering design of the necessary fixtures** needed to fabricate these assemblies is a **critical path item**.

There are several **critical path items needing early procurements**, such as the TPG blades and the high density interconnects (HDI).

The **pilot system will be useful** to gain experience operating this system, in particular on its integration in CMS. Some of the interface issues between the electronics and mechanics performance of the detector need to be validated with studies of modules read out and with mechanics and cooling infrastructure closer to the one implemented in the final system.

- **Comments (3)**

The **bump bonding cost estimate** is currently based on a quote from the same US vendor (RTI) that produced 60% of the original FPIX modules. It is much lower than a second quote from IZM in Germany. RTI's quote is roughly two times lower than an extrapolation with escalation of the original FPIX production. RTI has been asked for an updated quote. The RTI prototype costs per module were also significantly higher than their quote for final production modules. The assumed contingency in the budget is 60%, based on the US CMS single source rules. Given the issues described above, **60% contingency seems low <u>at this time</u>**.

RTI is commissioning a **new automated flip chip bonding** machine which **could reduce cost** by accelerating processing. The FPIX project plans to proceed with this approach if it achieves a successful yield. Given the need to continuously monitor the bump bonding via module electrical tests, such an **accelerated process introduces risks** that could offset any cost savings.

There is currently no electrical testing of diced ROCs prior to flip chip. Depending on the measured yield in prototypes for good chips on module, **a new single chip probing step may need to be added**.

The **funding profile** is much healthier than the profile presented for CD-1 and now **appears adequate**.

- **Recommendations**

Prior to CD-2 approval, review the contingency assigned to bump bonding, considering the two differing quotes and the escalated estimate projected from the original FPIX project involving two vendors.

Work with management following CD-3 approval to proceed with urgent procurements, such as thermal pyrolytic graphite (TPG) blades and high density interconnects (HDI) for the modules.

Approve for CD-2 and CD-3.

2.3 Level 1 Trigger (WBS 1.4)

B. Ashmanskas, K. Pitts, C. Young*

1. Do the proposed technical design and associated implementation approach satisfy the performance requirements? Are the CD-4 goals well defined?
   Yes and yes.

2. Performance Baseline: Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance? Is the contingency adequate for the risk?
   Yes and yes.

3. Final Design: Is the design sufficiently mature so that the project can continue with procurement and fabrication? Baseline Cost and Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Is the contingency adequate for the risks?
   Yes, yes and yes.

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete?
   Yes.

2.3 Level 1 Trigger (WBS 1.4)

B. Ashmanskas, K. Pitts, C. Young*

- **Findings**
  - The proposed design addresses the increase in luminosity, beam energy and pile-up anticipated in LHC Run 2 and Run 3 by expanding the information available to the level 1 trigger and by substantially increasing the trigger's processing power.
  - The trigger upgrade will be commissioned "in beam" by operating it in parallel with the existing system.
  - The key technical goal is clearly defined: a factor of 2 decrease in trigger rate with less than 15% loss of efficiency (for Threshold KPP) relative to the legacy system.
  - Hardware cost estimates are based largely on pre-production items. Estimates of software and firmware effort are based on past experience with the legacy system and validated with recent experience in developing the new system.
  - The trigger sub-project is expected to finish six months before the milestone completion date of end of March 2017.
  - Many pre-production articles have been installed and tested at a system level in CMS.

2.3 Level 1 Trigger (WBS 1.4)

B. Ashmanskas, K. Pitts, C. Young*

- **Comments**
  - The approach to improved performance by using high-bandwidth optical links to bring additional information to the trigger and using powerful modern FPGAs is sound.
  - The trigger sub-project's use of common technical components, such as choosing a single model of Virtex7 FPGA, minimizing the number of distinct uTCA module designs, and reducing the diversity of optical transceivers, allows developers more efficiently to share expertise between systems.
  - The staged commissioning approach allows CMS to benefit from trigger upgrade efforts before completion of the trigger sub-project. The plan allows for further improvements.
  - Commissioning in parallel with CMS operations allows for uninterrupted acquisition of physics data while gaining experience with the upgrade system.
  - Performance goals in KPP address the two key features of a digital trigger: it must meet the physics needs of the experiment and it must operate in a manner that can be reliably modeled.
  - The design and execution of this sub-project is well integrated with the activities of the CMS experiment and upgrade project as a whole.
  - The system design is mature and the major hardware elements are ready to proceed to production.

2.3 Level 1 Trigger (WBS 1.4)

B. Ashmanskas, K. Pitts, C. Young*

- **Comments**
  - Experience gained by building and operating the existing CMS trigger system puts the team in a strong position to complete this sub-project on time and on budget.
  - Although the flexibility of the system will offer opportunities for ongoing algorithmic improvements as physics needs evolve, it is important to retain a clear baseline against which progress on the trigger upgrade sub-project can be measured.
  - Progress towards completing the remaining firmware and software tasks on this sub-project should be closely monitored.

- **Recommendations**
  - Proceed to CD2/3.

3. Cost and Schedule

F. Gines, G. Penny, P. Novakova / Subcommittee 4

2. Performance Baseline: Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance? Is the contingency adequate for the risk?
   Yes. Yes.

3. Final Design: Is the design sufficiently mature so that the project can continue with procurement and fabrication? Baseline Cost and Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Is the contingency adequate for the risks?
   Yes, however the TPC needs to be slightly adjusted to meet the funding profile.

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete?
   Cost and schedule portions of the documentation (e.g., PEP, PMP) need to be updated and finalized.

3. Cost and Schedule

F. Gines, G. Penny, P. Novakova / Subcommittee 4

- **Findings**
  - The Total Project Cost is $33.580M for DOE and $43.364M when the NSF contribution is included. The total DOE funding profile is $33.25M.
  - Cost Contingency includes $5.525M for estimate uncertainty and $1.836M for risk. This equates to 33% on costs to go.
  - Backup cost documentation (e.g., Basis of Estimates, Cost Books, vendor quotes) was provided. Cost estimate uncertainty is estimated bottoms-up via standard contingency rules. Risk based contingency was developed via an uncertainty analysis of the risk register at a 90 % confidence level.
  - CD-4 is planned for December 2019.
  - Critical paths are developed for the three subsystems with HCAL driving project completion. Float is 13 months from the “HCAL Complete” to CD-4. FPIX and Trigger are completed approximately 3 years before CD-4.

- **Findings (cont.)**
  - The resource loaded schedule is well developed with 3474 activities and 25 constraints. The LHC constraints and need-by dates are incorporated.
  - Primavera (P6) and Cobra are used to integrate cost and schedule.
  - Three months of earned value reporting is available. The cumulative CPI is 1.06 and the SPI is 0.9 through June 2014. Variance reports are prepared based on the Fermi default thresholds.

- **Comments**
  - The DOE TPC slightly exceeds the available funding. TEC and OPC estimates differ among documents and presentations.
  - The cost contingency appears reasonable for this stage of the project. It was developed using well defined methodology.
  - Activities to obtain DOE approval of CD-4 are not included in the schedule and can reduce the advertised float.
  - The costs, schedule, and risk analyses were thorough and well developed.
  - The CAMs selected by the Review Committee for the drill down sessions did well, demonstrating knowledge and traceability of costs.
  - The cumulative SPI of 0.9 appears low. Due to the relatively high variance thresholds, this SPI does not require variance analysis reporting that explains the overall delay and corrective action. The project should consider lowering thresholds as the Fermi procedure allows.

- **Comments (cont.)**
  - Pending changes need to be processed and incorporated into the baseline as soon as possible.
  - Lab-wide change control procedures are in flux and should be finalized, with recommended timeframe for processing and implementing BCRs, as soon as possible. The level 3 cost threshold should be revisited.

- **Recommendations**
  - Prior to CD-2/3, reconcile the TPC with the funding and correct the OPC/TEC split in the project documentation.
  - Proceed with CD-2/3 approval.

PROJECT STATUS

Project Type	MIE / Line Item / Cooperative Agreement	
CD-1	Planned: 10/17/2013	Actual: 10/17/2013
CD-2	Planned: 9/22/2014	Actual:
CD-3	Planned: 9/22/2014	Actual:
CD-4	Planned: 30/12/2019	Actual:
TPC Percent Complete	Planned: 19 %	Actual: 15%
TPC Cost to Date	$4,156K	
TPC Committed to Date	$5,173K	
TPC	$33,580K	
TEC	$19,375K	
Contingency Cost (w/ Mgmt. Reserve)	$7,361K	33% to go
Contingency Schedule on CD-4	13 / 17 months	21.70%
CPI Cumulative	1.1	
SPI Cumulative	0.9	

2. <u>Performance Baseline</u>: Is the cost estimate and schedule consistent with the plan to deliver the technical scope with the stated performance? Is the contingency adequate for the risk? **YES**

3. <u>Final Design</u>: Is the design sufficiently mature so that the project can continue with procurement and fabrication? Baseline Cost and Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Is the contingency adequate for the risks? **YES**

4. Are the management structure and resources adequate to deliver the proposed final design within the baselines as identified in the PEP? **YES**

5. Is the documentation required by DOE Order 413.3B for CD-2 and CD-3 complete? **YES**

6. Are ES&H aspects being properly addressed given the project's current stage of development? **YES**

- **Findings**
  - The CMS upgrade project is fully staffed. Most of this team are long-term members of the CMS experiment and were involved in its construction.
  - There are 3 principal WBS elements that comprise this project; the hadron calorimeter, the forward pixel, and the trigger. These three systems areas were also US contributions to the original construction project.
  - The DOE TPC is $33.58M, within the CD1 range and very close to the CD1 TPC.
  - The NSF contribution is $11.95M bringing the combined total project cost to $45.2M.
  - The contingency for the project is 33% of TPC.

- **Findings (cont'd)**
  - There are 13 months of float between project complete and the CD4 date.
  - Within the three principal WBS activities, 77% of effort (hours) and 52% of effort (cost) are external to FNAL.
  - This is a very mature project. The scope is very well defined and there are no remaining technology choices. The project is very far along in terms of their technical design. The project estimates its final design to be 87% complete with at least 77% complete in each of the 3 project areas.
  - All of the required documentation for CD2 and CD3 were provided to the committee.

- **Comments**
  - Given their prior participation on the CMS Project, CMS Operations, and Upgrade preparatory activities, the US CMS Upgrade Project staff has extensive background and experience.
  - We have high confidence that this project team can successfully deliver this project.
  - The new project manager has impressively overseen the transition from CD-1 to CD-2/3, and the implementation of the required project tools.
  - A number of documents have inconsistencies both within each document and across the documents (e.g., within the PEP, and between the PEP and PMP). Some documents require update to final versions (e.g., preliminary reports from CD-1 should formally be designated as final, even if they are unchanged).

- **Comments (cont'd)**
  - Document and prioritize first articles and pre-production items to ensure maximum flexibility regarding funding modalities.
  - Lab-wide procedures for things like change control need to be properly captured and *tailored* for specific projects (their size and their needs). The restrictive change control threshold at the "PM level" will require a high-level of interaction with the PMG. This may force the PM to "manage up", when in fact the PM would need to be working with his L2 managers. The purpose for the PMG interaction is to ensure good access to FNAL resources and oversight, this needs to be balanced against the CMS Upgrade having a large external effort (77% of effort is external to FNAL).

- **Comments (cont'd)**
  - It was noted that milestone "levels" and change control "levels" use completely separate definitions, which leads to some confusion when evaluating procedures (eg. see Table 7 of the PEP). For example, use L3 WBS or L3 milestone vs. Level 3 change control.
  - Several budget inconsistencies were noted. In particular OPC and MIE profiles must be made to match with the overall budget plan. Also there is a small discrepancy in the total project funding and the planned budget profile.
  - The Key Performance Parameters differ in level of detail for the 3 sub projects.
  - The largest "risk" to this project, which happens to be external, has to do with funding profile and how to deal with a potential delayed start of construction.

- **Recommendations**
  - Update and finalize the project documentation.
    - Update the PEP with the latest information.
    - We recommend that the laboratory quickly finalize procedures (e.g., change control) or establish interim procedures that can be used for the CMS Upgrade MIE. Laboratory procedures or interim procedures should be specified in the PMP and the PEP made consistent with those.
    - Change control description within the PEP is not consistent. The change control thresholds for the PM are stringent and should be reexamined.
    - Clarify internal project definitions of various levels so that there is no confusion between areas such as change control and milestones.
  - Develop a fall-back plan in the event of a continuing resolution.
  - **After recommendations are addressed, proceed to CD-2/3 approval.**