Karta – 1

Questions and Responses: DOE Status Review 2025

Pre-review Questions (9)

CE Questions

General/L2 Managers (4)

1. The to-go scope for the post-baseline part of the project is 60%. What is the cost of the to-go scope and how much contingency has been allocated to your project?

The CTG current estimate is $26.792M, which is a projected VAR at completion of $5.530M on an BAC of $65.985 (projected final CPI of 0.92)

The formally correct answer to "how much contingency has been allocated to your project" is "none, all contingency is held centrally -- none is held by the L2 Manager". Are you asking about how much contingency has been (in the past) consumed by either cost overruns or BCRs? If the question is about the contingency going forward, that is really a question which has to be considered in the whole with the rest of the project and considering risk contingency, which is extremely difficult to assign to a subproject.

2. The CPI and SPI are very low. What is the plan to recover some of that?

Regarding the SPI overall --
At the highest overview level, the Schedule VAR is dominated by the scintillator and cassettes areas.

The scintillator area VAR has a large number of contributors, but the largest single items are the tileboards (both bare PCBs and the assembled PCBs) and the motherboards. Ted will discuss in more detail, but we are actively pushing the process forward to procure the large numbers of tileboards. This effort was somewhat delayed by the HGCROC issues, but has also had some challenges from the shift of the procurement from Maryland to FNAL and the overall load on the FNAL team with the cooling plates and the scintillator procurements to oversee. The motherboards are under final qualification now and orders for PCBs are expected by the end of June.

In the cassettes area, the cooling plates order is underway, but value will not be earned until the plates are delivered. There remain orders to place for machining and cooling tube production, which may replace the bare plate material order as the primary schedule variance.

Regarding the cost variance, a substantial fraction of this is due to standing army costs from HGCROC delays, unexpected events (such as the need to immediately allocate additional resources to study ECON-D issues before it was possible to generate baseline changes) and underestimates of labor cost requirements in scintillator machining and cassette design. BCRs have recently been carried out to address these issues for the future, and the CPI should improve. The absolute variance's behavior will depend more on the future contracts, but is not expected to grow at anything like the rate of the last nine months as we move into regular production.

3. The float for the “Cooling plates 100% complete” is 3 days. What risk mitigation do you have in place?

Regarding risk mitigation for the cooling plates, there are a few aspects to discuss:

(1) A fraction of the cooling plates sufficient to begin pre-production (~5%) have already been procured, with the designs for plates of two of the 21 layers ready to manufacture. This plan does not exactly match the original planning in P6, which envisioned working with 17% chunks. As a result, we have not yet earned the value for these few percent, which makes the schedule somewhat pessimistic as given -- the assembly of the first cassettes is planned to proceed more-slowly than the rest and the availability of these 5% of plates will have an outsided impact on the schedule as a result.

(2) We are actively seeing cost-effective options to reduce schedule risk. For example, we have decided to invest in two soldering tables for the cooling plates, rather than a single table, to avoid possible bottlenecks or downtime issues. We are considering appropriate opportunities to broaden the vendor base where that might improve schedule, within cost constraints (we cannot add very expensive vendors to accelerate the schedule at this point).

4. How much contributed labor is required to complete the project. Does any of that labor come from NSF?

Regarding the contributed labor question, each major site (MAC, TAC[FNAL], Engines/Wagons, Motherboards, Tileboard Testing (Maryland), Hexaboard testing(Alabama), ECON testing) has 1-2 graduate students and 1 postdoc actively engaged in the efforts, for a total of sixteen graduate students and eight postdocs. Roughly half of these students are supported by University funds and half by DOE funds, while effectively all of the postdocs are supported by DOE funds. After review of P6, there are some areas where the amount of uncosted labor may not be fully accounted for in P6, particularly in cassettes.

There is no NSF support planned.

Separately, the integration requires a force of six postdocs/scientists and six graduate students over an extended period of time.

ECON/Silicon Motherboards (4)

1. You are going to procure 50 more wafers of the ECON chip; it will take about 18 weeks to test these chips, which is more than four months. How will this affect the labor cost and what does it mean for the schedule if you will need all these wafers?

Additional labor cost for additional ECON testing related to the ECON-D SRAM issue was included in BCR 083. The cost is 1520 hours for App Physicists Pam Klabbers (Robot Lead, 360 hours) and Danny Noonan (ECON test lead, 1040 hours) and Eng Physicist Paul Rubinov (ECON test hardware design, 120 hours). The rest of the additional labor is uncosted. Additional uncosted effort has been obtained in the same manner as the original uncosted effort – through recruitment and training of US CMS / LPC graduate students and post docs. The Robot and ECON QC test systems are mature and user friendly to allow rapid onboarding of new test effort to mitigate potential delays from turnover of non-expert test effort.

BCR 083 also includes new activities for production and testing of two additional wafer lots. Activities marking completion of testing of specific fractions of ECON ASICs (10%, 25%, 50%, and 100%) are included in the RLS. These activities are used for connecting tested ECON readiness to activities for assembly onto Concentrator Mezzanines, HD Wagons, and Scintillator Motherboards are included in the RLS. In this way, the ECON schedule is fully connected to other parts of the project in the RLS.

2. Could you provide us with an expanded table like the one on slide 25 that summarizes the status of all the boards. It would be nice to have a bit finer granularity, breaking it down in design (are any designs still outstanding), prototyping, pre-series, production/assembly, QC.

Please see the expanded table here:
https://docs.google.com/spreadsheets/d/1VnfiLdBfMX_lVp6zC0BssoIkwAXQMcneeqkU3MIZVzk/edit?usp=sharing
This includes updates as recently as Monday 6/2. .

3. Related to the question above, the dates in the table on slide 20, are those the P6 milestones or the actual projected milestones? For example, the WH-31B1 (Cherry) have to be redesigned and the table on slide 20 says that 50% is done by October. (By the way, I take it that the date for the concentrator mezzanine (2026/10/8) is a typo and should be 2025?)

In general, the dates in the table on slide 20 are based on P6 activity dates from the working schedule. That date for the concentrator mezzanine was indeed a typo.
Specifically for the HD wagons: looking at the dates again, I noticed that I grabbed the date from the wrong batches. I have now updated that. The correct date for 50% completion is 2026/1/30 and for 100% it is 2026/4/24.
For the WH-31B1 (Cherry), the design update should be completed by the end of June or early July. Then follows two months of PCB manufacturing (including shipping), and one month of assembly. That puts the start of the QC in October. Of course, we will revalidate this variant in the system as well at that time.
50% of this variant amounts only to 42 boards (+spares), so the full QC will only take a few days, once we have received all the assembled boards.

4. Slide 21: BCR 83: is that the additional 50 wafers? Can you say a bit more what BCR 83 includes?

BCR 083 includes costs for production of additional wafer lots ($292k), packaging of additional chips ($30k), 1520 hours of additional effort , and knock-on effects for other parts of the project.

Cassettes (5)

1. For the cassette production (slide 15) you have one month for placing a PO. What is the status of procurement at Fermilab these days? How realistic is one month?

You are probably referring to the first row, Raw Cu Material (TK). This table is little bit compressed and does not show that this procurement started sometime in February and we have already placed the PO on May 22.

2. 10% of the design of all variants of the cooling plates is still missing. What is the schedule for completing that design?

The schedule is shown on slide 11.

3. Have all vendors for the various steps in the cooling plate production been identified?

Not yet. We have identified and placed order with TK for the raw material, we will place sole source order with them for cutting the outline when all drawings are ready.
For full machining we have contacted more than 10 companies and received quotes from 3 for machining the pre-series prototypes. We will be starting the bidding process for the pre-production plates (5%) in about 2 weeks and hope to attract more companies besides the identified 3 ones.
The critical bidding will happen in August for the remaining 95% of the plates.
For the bending of tubes, we are targeting the same french company as the LLR group. We are requesting quotes next week for pre-production (5%).
For the full production bidding in August we are planning to attract more companies.
For the plating of tubes, we do not have yet a suitable company and actively searching not only at Fermilab but also at CERN.

4. How can you start production of the cassettes in November (slide 15) if you only start the procurement of the bend tubes, for example, in October (slide 12)?

Apologies, slide 12 should say September as it is in slide 15, that is when the PO is placed. The tube bending is expected to be a quick process. By starting with the right designs for the first 18 cassettes, they can be bent in probably a week. Same for welding, plating and soldering. It will be important to pipeline the activities efficiently.

5. There is 60% of the cost (labor) still to go with a historically very low spi (about 0.7). How will you complete the project on time with currently only having 3 days from the critical path?

Historically, we were mostly delayed by upstream inputs and by procurements. We had a positive phase transition with the procurement after arranging a meeting with procurement and Lia at the end of last year where Lia emphasized the high priority of the project.
My working schedule shown on slide 15 finishes the cooling plates about 3 month ahead of the P6 schedule, so I do have that much of contingency.

Review Questions (29)

Outer Tracker (2):

1) To formulate a question you might want to elaborate further for tomorrow, it would be on the labor plan for the assembly plan in terms of potential interference from other projects that technical personnel are also assigned to. What competing projects will be on-going during production that could become a bottleneck to maintain a steady rate? Is that a risk taken into account in one of those associated to personnel (RT-402-2-91-D and/or RT-402-2-90-D)?

Regarding conflicts between different projects, this is really only a possible problem at Fermilab, not at the universities. As already discussed today, the 6 technicians currently in place for module assembly are mostly (4 FTE) dedicated to OT. The one new technician that is currently being hired, will also be 100% on OT. So overall we are fairly safeguarded against conflicts with other projects (including other CMS upgrades, i.e. HGCal and ETL). There is also a bit of technician need for flat barrel assembly as you will see in Doug's talk tomorrow, but that is one person, or a fraction of one of our technicians. So there will be some sharing.

The technicians mentioned above are all at SiDet and working on micro- and macro assembly there. There is also a technician working on metrology, both for modules and planks. This is a specialized technician that is also sometimes needed by other projects. We have recently injected an OT scientist into the process to help with this to make sure we have enough bandwidth in metrology for OT. In addition, we have two technicians that are working on carbon fiber fabrication for the planks, also at Fermilab, though in a different lab, not SiDet. Here we believe we are the only customers for this skill and this lab space.

The risk RT-402-2-90-D is covering these problems to some degree.

2) I also noticed (while going through the notes from the past review – apologies I should have picked on this number before!) that the 25 modules/week is increased with respect to estimates we were given at the time, 20 module/week. This is most likely the result of optimising the process and the experience already accumulated in pre-production. Could you please confirm this?

The increase in modules-per-week rate at the two US assembly sites is indeed following the optimization that was done internationally. It is basically the realistic number we could agree to after having had some experience of our capabilities during prototyping and pre-production.

Endcap Calorimeter (4+1)

1. The float to the iCMS need-by-date is negative given an aggregate CL of 90% and has a very low probability of 76%. If you were to run the analysis requiring the confidence level of the HGCAL to be 90% to meet the need-by-date, what would the cost implication be for the HGCAL?

The schedule can be advanced by two months (which would more than cover the 1.3 months required to reach 90% CL) by shifting the average assembly rate of cassettes from 2/day to 2.8/day in the second half of the cassette production. This would also require a reduction in cold testing time from 14d to 10d, which is expected to be fully sufficient particularly in the second half of production. Given that the cassette factory has four cassette assembly stations, an acceleration to 2.8/day does not require additional equipment. It may require additional labor, which can be estimated at $200k or less, based on the burn rate differences. In theory, of course, the same total labor is required, but in fact it is likely that additional labor would be required overall. These labor costs are considered to be reasonably represented in the existing "Cassette Assembly Acceleration Required" risk, so they should not substantially increase the ETC presented.

2. To address the ECON issues and reduce the critical max VDD from 1.08V → 1.05V an additional ~50 wafers are required at a cost of $200k. If you need chips from these additional wafers, can you estimate the impact of this activity on the schedule and cost (in addition to the $200k in M&S)?

The 50 additional wafers will yield 46k ECON-D, which will require ~10 weeks to test at a rate of 5k chips per week using both sockets in parallel since ECON-T testing will be complete. Thus, the date at which 100% of ECON-Ds would be available would move from 11-Feb-2026 to 22-Apr-2026. The dates at which 10% and

25% of ECON-Ds would be available would be affected at the ~2 week level. Given the chips available so far, we expect that assembly of concentrator mezzanines and scintillator motherboards could be most-affected. However, analyzing a delay of 10 weeks after the delivery of 60% of the ECON-Ds, we do not see an impact on the cassette assembly, as assembly and test of concentrator mezzanines and scintillator motherboards is substantially faster than cassette assembly.

The associated labor cost for the ECON test lead (Noonan) and Robot expert (Klabbers) would be $35k for 10 weeks of additional testing assuming 20 hrs/wk for Noonan and 7 hrs/wk for Klabbers.

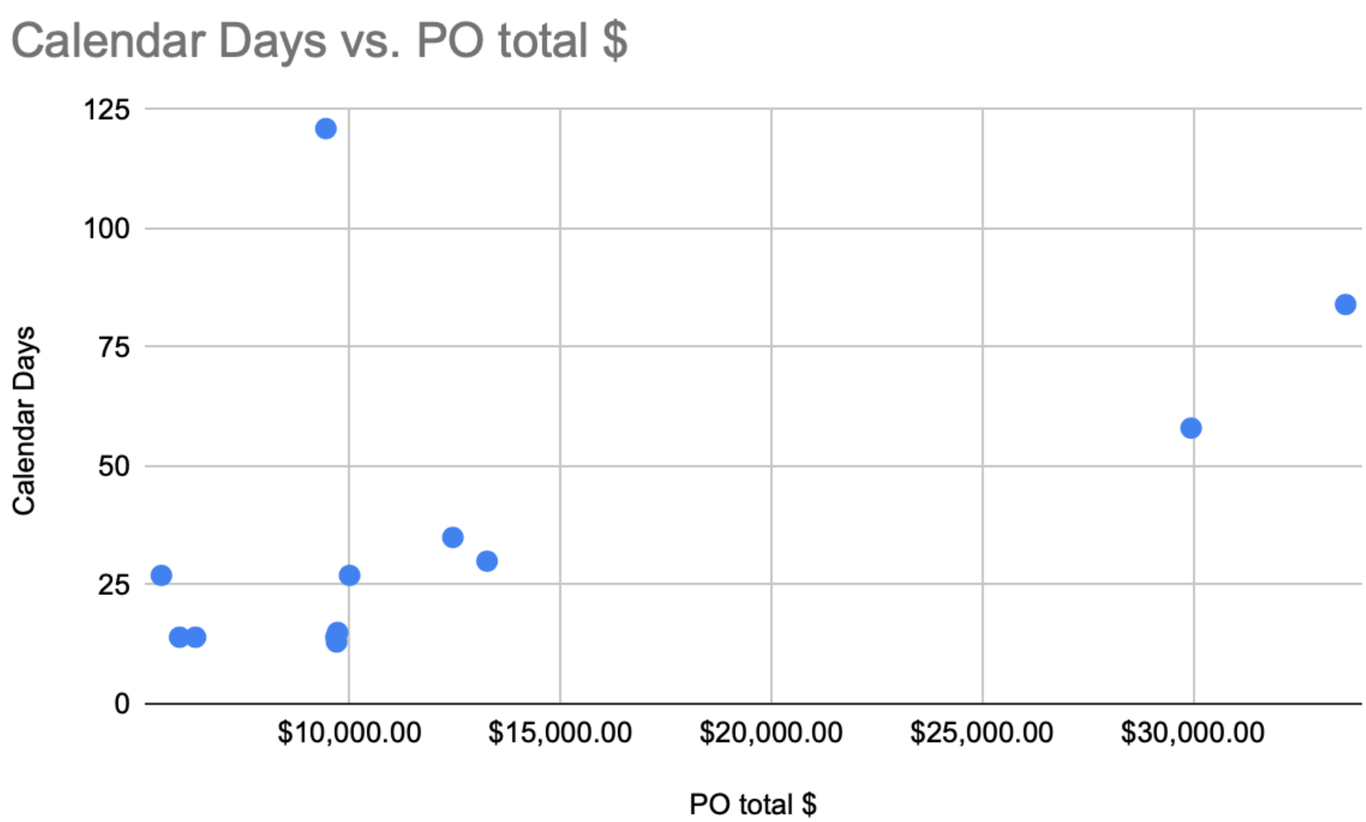
3. What has been your recent experience regarding turn-around on procurement with Fermilab? What is the average time it takes to get a PO out of the lab for the type of POs that are still outstanding?

Looking forward, we have some large expected procurements (e.g. cassette machining) and many smaller procurements (PCB procurement and/or assembly for varieties of tileboards, cassette hardware, etc). Our experience with the large cooling plate procurement was a total duration of 78 days, which matches the expectation. For the smaller procurements, our experience is shown below and typically requires between one and three months.

The table below shows HGCAL purchases for this FY25 made through procurement (not e-marketplace) above about $5,000 originated by P. Gandhi, H. Gutti, Z. Gecse, H. Cheung. The chart below shows the calendar days vs PO value for the time from PR submission to PO approval. The long time for PR # 362938 was due to incorrect PF18 form and questions from the buyer and changes to the PR that needed several PO resubmissions, procurement was also on hold ~12/20/2024 -2/1/2025 due to the transition.

Item	**PR #**	**PO #**	**PR Total $**	**PO total $**	**PR submitted**	**PR approved**	**PO forward/reserve**	**PO approved**	**Calendar Days**
Copper plates	367360	723989	$1,800,000	$1,630,080	3/5/25	3/7/25	5/16/25	5/22/25	78
Hexabond pickup	367332	723092	$13,253	$13,253	3/4/25	3/7/25	4/3/25	4/3/25	30
backbond carrier	367270	722732	$9,707	$9,708	3/3/25	3/5/25	3/18/25	3/18/25	15
module carriers	364812	720397	$29,949	$29,949	11/26/24	12/2/24	12/11/24	1/23/25	58
Sensor pickup tools	363988	721025	$33,613	$33,613	11/1/24	12/19/24	1/24/25	1/24/25	84
McMaster fittings	363895	719722	$9,685	$9,685	10/30/24	11/6/24	11/12/24	11/12/24	13
tube elbows	363716	720152	$12,443	$12,443	10/23/24	10/30/24	11/27/24	11/27/24	35
Bellows and fittings	363715	719485	$9,993	$9,993	10/23/24	10/30/24	11/1/24	11/19/24	27
sensor tray	363499	719568	$5,016	$5,530	10/17/24	10/18/24	11/13/24	11/13/24	27
hexaboard pickup tools	363277	719103	$6,340	$6,340	10/10/24	10/10/24	10/24/24	10/24/24	14

kapton sheets	369597	724759	$5,962	$5,962	5/14/25	5/19/25	5/28/25	5/28/25	14
lifting legs	362938	721245	$9,432	$9,432	10/1/24	1/29/25	1/30/25	1/30/25	121
cooling plate	369532	724850	$9,670	$9,670	5/13/25	5/14/25	5/27/25	5/27/25	14



4. It is our understanding that the 3 day distance to critical path (slide 44) does not take into account a considerable amount of work that has been earned. What would the true float be if all the work were taken into account, so there is a better estimate of actual float?

The 3-day-to-critical-path estimate is for the cooling plates to the start of cassette production. Taking into account the delivery of sufficient blank plates for the first 4% of cassettes, the float to the start of the cassette production should be 45d (which would then be limited by scintillator motherboards). The scintillator motherboards may also be delivered early, which could result in the cooling plate soldering being back close to the critical path, but the critical path would be more than 45d earlier in this case.

5. *From Project Management Addendum to Question 9 regarding schedule pressure vs performance:* Can you address whether a system test of some reasonable scale is being planned for the CE? If so, what is the scale of the planned test and when is it nominally expected to occur? If such a test is not under consideration, please explain the reasoning for omitting it.

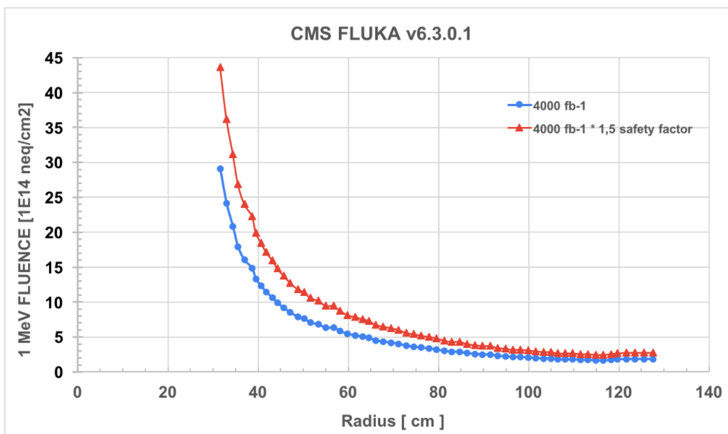
Given the modular nature of the CE, many crucial aspects are validated with the existing system tests, which consist of 2 LD trains + 2 HD trains and a 10-degree scintillator section which includes all aspects of a full cassette. Indeed, previous versions of these tests have identified an issue with the I2C of the HGCROCV3b which would have had a significant negative impact on operations and possibly performance, as well as some bugs in board layouts. In the current system tests, the issues identified have been in the backend firmware and software, which must evolve to handle larger and more-complex systems. This is very useful work, but does not affect the readiness for construction. We are continuing to scale up the testing, with full-cassette tests under preparation to be carried out in June and July.

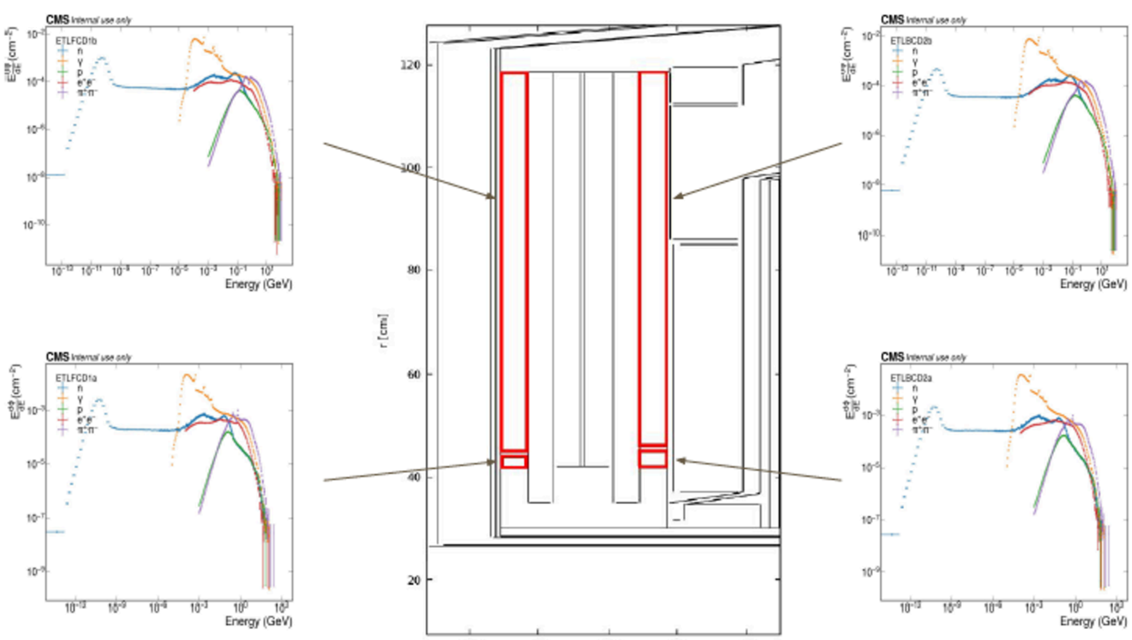
MIP Timing Detector (8)

The team presented an assessment of radiation effects on the ETL leading to the conclusion that both the ETROC and the LGADs would continue to function throughout the run. While encouraging we felt the presentation was not clear and would benefit from more exposition. To that end please explain the following to us.

1. What are the expected ionizing and non-ionizing doses expected at the ETL?

    Details of the expected doses are shown in the link to the sensor PRR and copied below.





2. With regard to TID effects on the ETROC:
    a. Have they encountered anything like the TID bump digital current effect seen by ATLAS, and if so, how was it addressed?

        We did not encounter the TID bump digital current effect during our TID testing for ETROC2 chips. The currents have been monitored all the time throughout all the TID testing.

    b. Are there any measurable effects of TID on the performance of the system - ie on time resolution etc?

        We have tested extensively the ETROC2 time resolution after TID through charge injection up to 400 MRad (the design specification is 100MRad), with no performance degradation observed.

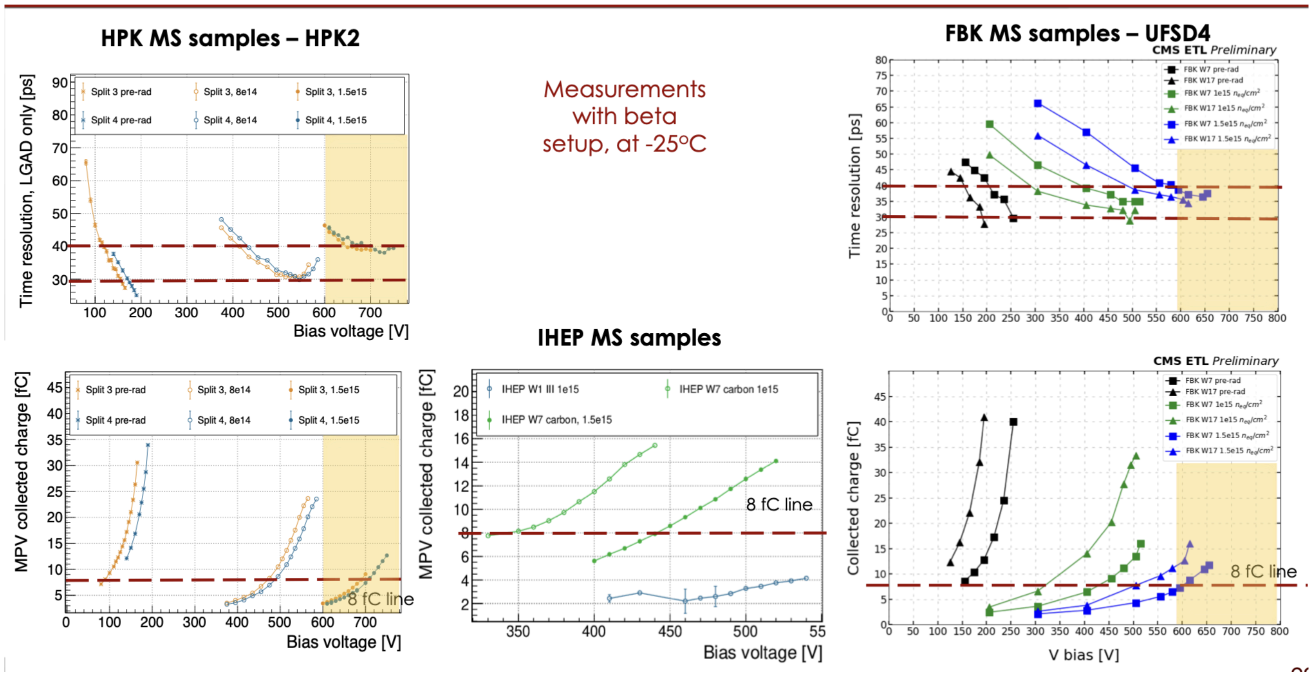
    c. To what extent have they dealt with or measured SEE on the ETROC? Was any mitigation included in the design, such as logic triplication etc?

        The circuits that require TMR have been heavily TMR protected for ETROC2 and carefully checked/verified at block level. This includes the global readout and all configuration bits. For pixel data, Hamming code is used for each pixel TDC data with self-correction. ETROC2 chips have been extensively tested for SEE using heavy ion beams at UC Louvain and proton beam at a local (Northwestern) medical proton therapy center and no real issue encountered. The tests have been repeated multiple times with improved setup and more chips.

3. With regard to the LGADs, what are the effects of non-ionizing radiation on the LGADs? With the expected non-ionizing doses how does performance degrade? Gain? Doping?

    The impact of non-ionizing damage has been extensively studied and has driven the design of the sensors. We have two sensor designs, for the low and high fluence regions. Detailed performance plots are shown below from sensor PRR. The impact of neutron irradiation is reduced gain due to acceptor removal, which is compensated by raising the bias voltage to recover the lost gain. As shown in the plots below, for the low fluence region we are able to maintain the required gain to collect charge above 7 fC until the end of HL-LHC running which corresponds to 1.5 e15 neq/cm2.

    The sensors for the high fluence region (20% of total ETL sensors) have been shown to exhibit slightly lower time resolution but are capable of operating until the end of HL-LHC running, corresponding to 4.0 e15 neq/cm2 in this high fluence region.



4. Generally, please tease out how any and all radiation effects (TID and non-I) impact time resolution.

Please see above for impact of radiation on sensors and ETROC from ionizing and non-ionizing radiation damage. Another aspect of radiation damage is due to increased bias voltage that leads to higher electrical fields in the sensor. We have observed that these may lead to single-event burnout (SEB) events that short the pad, yielding the sensor inoperable. This is not specific to LGAD sensors, as we observe the same effect in pin-diodes as well. Our extensive studies demonstrated that the SEB events do not happen if sensors are maintained below the bulk electric field of 11.5 V/μm. Our operational mode is far away from the limit of SEB events.

5. Has radiation damage effects been accounted for in some aspect of the LGAD sensor design?

The choice of LGADs is driven in part by the radiation environment. The project will procure a LGAD sensor for the high eta region that is suitable for the higher radiation environment. The LGAD sensor design in both the low and high radiation regions have been irradiated and extensively tested.

6. Do radiation effects lead to any operational requirements like maintaining low temperature at all possible times?

Slawek: ETL will be operated at temperatures below -20C at all times. Occasional short interruptions in providing CO2 active cooling should not affect the LGAD recovery or performance. Within RD50, there were a few studies on this topic, and the conclusion is that there is no problem in keeping the sensor warm during maintenance.

Adi : BTL does not need to be kept cold. In fact, the SiPMs benefit from occasional heating as this results in an annealing of the radiation damage of the sensor. This is exploited further by reverse biasing the TECs to heat up the SiPMs to above room temperature. Our default annealing scenario is heating to 40-60 C for a few days during longer shutdowns. Annealing of the SiPMs has been tested at temperatures of up to 110 C to ensure that there are no adverse effects on the sensor. The heating is very localized to the SiPMs. The rest of the detector is kept at 15 C by running the CO2 cooling at this temperature. The LYSO is a rather poor thermal conductor and the LYSO is not in contact with any detector components others than the SiPMs.

7. Are there radiation damage effects to the concentrator card components, or any other components about which they are concerned?

   The only radiation damage effects that can impact the CC is a possibility for the lpGBTv1 to go into non-recoverable state upon power-up due to a bug in the design of this chip. This can occur at most at a 1% level, and since there are two LPGBTs on each board, such a loss of one chip will not compromise the board's functionality.

   Other than this recently discovered effect of the lpGBT - which is a chip design flaw rather than a radiation issue - all components of the CC have been qualified to be radiation hard.

8. Have they irradiated entire ETL modules or just separate components?

   Complete modules have not been irradiated, but the radiation damage on all individual components has been extensively studied, including the effects on the adhesive films used during the assembly.

Project Controls (4)

1. Please provide a breakout of the I&I planned cost by FY and resource type.

AY $k BAC	FY25	FY26	FY27	FY28	FY29
Travel	316	944	1,394	423	68
Labor	498	1,196	2,717	715	111
Material	2,157	21	373	5	4
Total	2,971	2,161	4,484	1,143	183

   Large Material in FY25 is from the last Common Fund payment ~ 1.8 MCHF. In fact BCR 0094, implemented 5/28/25 has pushed this component to FY26 Q2

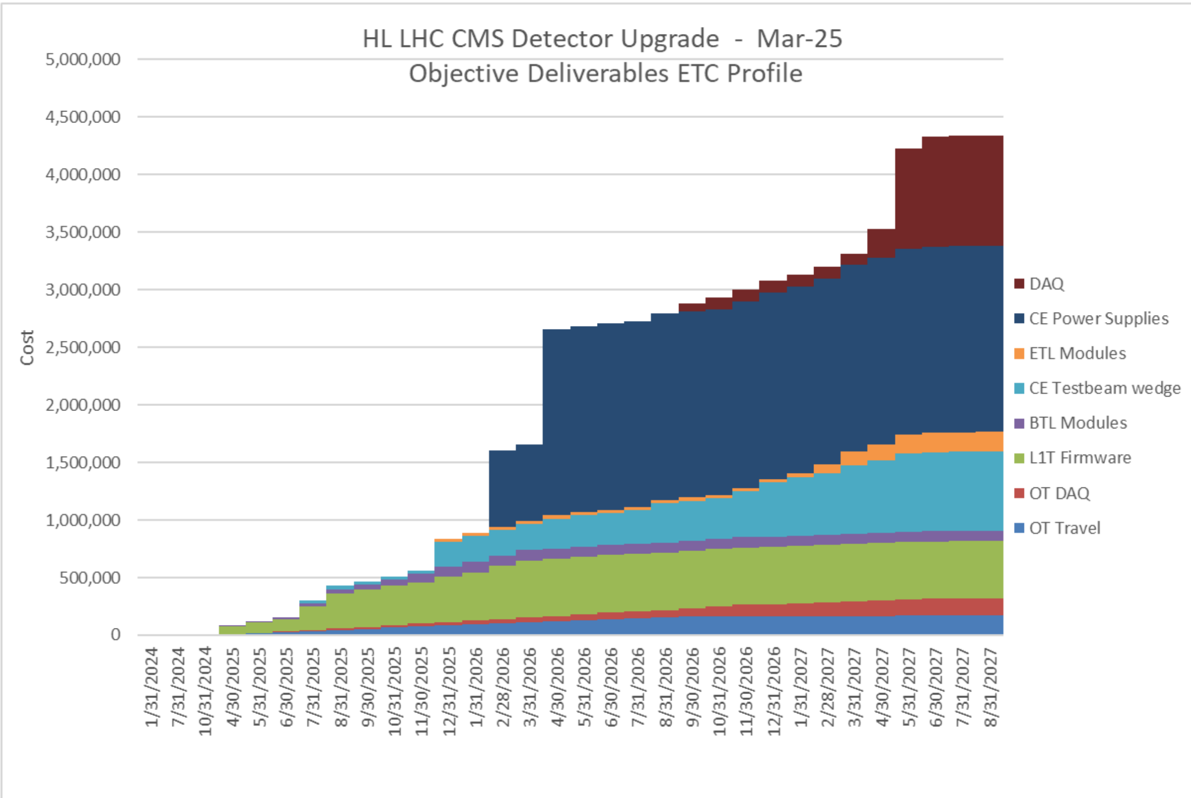
2. Cost and schedule contingency is a concern. What is the time frame for making a decision about delivering the threshold KPPs vs. Objective KPPs? Please provide these decision points by L2.

   The decision on Objective KPPs fall into two categories. First there is the small fraction of deliverables that we labeled as Objective scope, selected specifically to be possible (if painful) to omit or transfer to another Collaboration partner. For the Objective Scope, timing depends on the specifics of the scope under consideration, and break down into specific classes.

   First is where the Objective is just to do an incremental amount of the same work planned for the Threshold scope, where the activity is not unique to the DOE project. This includes OT Modules, OT DAQ, CE Testbeam wedge, BTL Modules, L1T Firmware, and ETL Modules. In many if not all of these cases, there could be partial realization of the scope, such as buying the Silicon sensors but allowing others to build the Silicon modules for the CE testbeam wedge, or reducing the support for the later stages of L1T firmware development.

The other type of Objective scope is the procurement of some specific item, which is completely independent of the threshold work, for both the CE Power Supplies and the STMS of the DAQ. These are both large contributions to a single procurement, which also could be downsized if not completely transferred.

The ETC as a function of date for the Objective scope from the current RLS is shown here:



Some of the incremental items are starting now, while the larger contributions don't start until the end of the year, and the DAQ procurement is not until 2027. In addition, some of this can be offset due to current delays - i.e. the L1T delay implies that the Objective scope does not need to start as early.

Clearly the two most impactful reductions are in the Power Supplies and DAQ. For the Power supplies, we would need to make a commitment towards the end of the summer, and for the DAQ considerably later, towards the end of 2026.

The other part of the Objective KPP is the participation in the Integration and Installation (I&I) activities at CERN. AS explained in the plenary, this is Objective because overall oversight, management, and detailed schedule is the responsibility of International CMS technical coordination. Again here, small parts of the Integration phase of I&I, such as preparations at the Tracker Integration Facility, are already taking place, but with the exception of the common fund payment, the bulk of the expenditures do not take place until FY27 (see Q1)

3. Does the project include in the ETC only upcoming BCPs? What about activities with baseline dates in the past (delayed activities). Are updated estimates for these activities included in the ETC?

The project has made several attempts at incorporating manual ETCs beyond including well-estimated pending BCRs, including a method for re-estimating remaining quantities in the statusing process, but this was found to have limited value with respect to the time required to implement. Activities with baseline dates in the past have not been systematically isolated and considered for potential manual ETC adjustments, but this is an interesting idea.

4. Some durations of future activities in the forecast schedules are shortened compared to the baseline schedule. What is the reason for this?

   These in general were changes done in the working file in response to real time developments affecting the critical path, to make the working file a better predictive tool. For example, the amount of preproduction in the OT was limited by parts availability, thus the durations in the working file were adjusted such that preproduction ended in May of 2025 and subsequently production is starting. In other cases, as a response to the potential reduction in KPP float and examination of the critical path with the CAMS, logic and in some cases durations were adjusted based on revised expectations as well as crashing the schedule.

PM and ESH&Q (10)

1. Has the project analyzed the impact of alternative funding profiles, such as drastically lower FY26 funding than expected? If so, please share this with the committee.

The FY26 funding according to the baselined profile is 13.1M. Given that this number is rather small in the overall DOE HEP plan, it would be surprising to us to see how a drastic cut would significantly help any DOE budget shortfall, and as it could be quite damaging to DOE, given the prominence of the project in the P5 plan and the optics such a decision would project on DOEs international commitments. Thus this option has not yet been analyzed in great detail, although a similar impact analysis was done when the IRA funds were temporarily impounded in early CY25.

That said, due to the IRA funding, which added 34.6M in late FY22, the project has considerable resilience against moderate budget shortfalls. Including the FY25 allocation of 17.5M, which is not yet fully complete due to the CR, the project expects to have received $ 180.1M, with the remaining 19.9M in FY26 and FY27. As the EAC including Objective deliverables (but not I&I) is 178.4M, there is enough carry-over to continue far into FY26 with limited funding, assuming in this case the I&I participation would be curtailed severely until the funding shortage was alleviated. Given the fixed time frame of the Installation, it may mean the US does not participate at a level commensurate with its size in the international collaboration.

2. Please share planned (BOE) vs. actual (award $) for procurements that have been executed, as well as timing information? Need list of procurements, then actual costs

	Executed Production Procurements				
		BOE/costbook $	Actuals $	Time paid	Comments
OT	Si Sensors	$4.3M	$4.4M	10/1/2020 - 6/13/2024; last payment not made yet	92% of total cost paid
OT	BTST	$1.5M	$1.9M	Summer 2024	
OT	Carbon Fiber for modules	$2.0M	$1.87	Summer 2020 - Spring 2025	
OT	Carbon Fiber for flat barrel	$118k	$169k	October 2023 - May 2024	
CE	Si Sensors	$5.10	projected $5.6M	June 2023 - continues	Exchange rates involved (JPY, CHF, USD); 94% of sensors tested; 72% fully billed.
CE	SiPMs	$1.3M	~$1.5M	Feb. 2025 - continues	Exchange rates involved (JPY, CHF, USD); variations batch to batch. Invoices for 3 out of 5 batches paid and 4th invoice received.
CE	ECON ASICS	$0.94M	$0.94M	June 2024 - present	Frame contract between CERN and IMEC
TD	FPGAs	$0.76M	$0.76M	Sep-24	Agreemant to use CERN discounted price
BTL	SiPMs	$2.55M	$2.34M	Apr-24	

Substantial Production Procurements

3. How far into production (in months and % complete) can the project go before funds must start being expended on objective KPP scope? Similarly, assuming you have to draw down on I&I to remain solvent, at what point will these reductions prompt a re-consideration your plan?

This is a similar question to C&S 1 and 4. For the objective scope, the timing depends on the scope in question, but of the 4.3M we expect to have spent about 500k by the end of this FY, and another 2M by this time next year, dominated by the Power Supply procurement. This sets the scale for the earliest date as the procurement of the power supplies should start about 6 months ahead of when the payment is actually made. From then, there is gradual increase on the “incremental” objectives, and then the DAQ procurement which would need to be settled in FY27Q1.

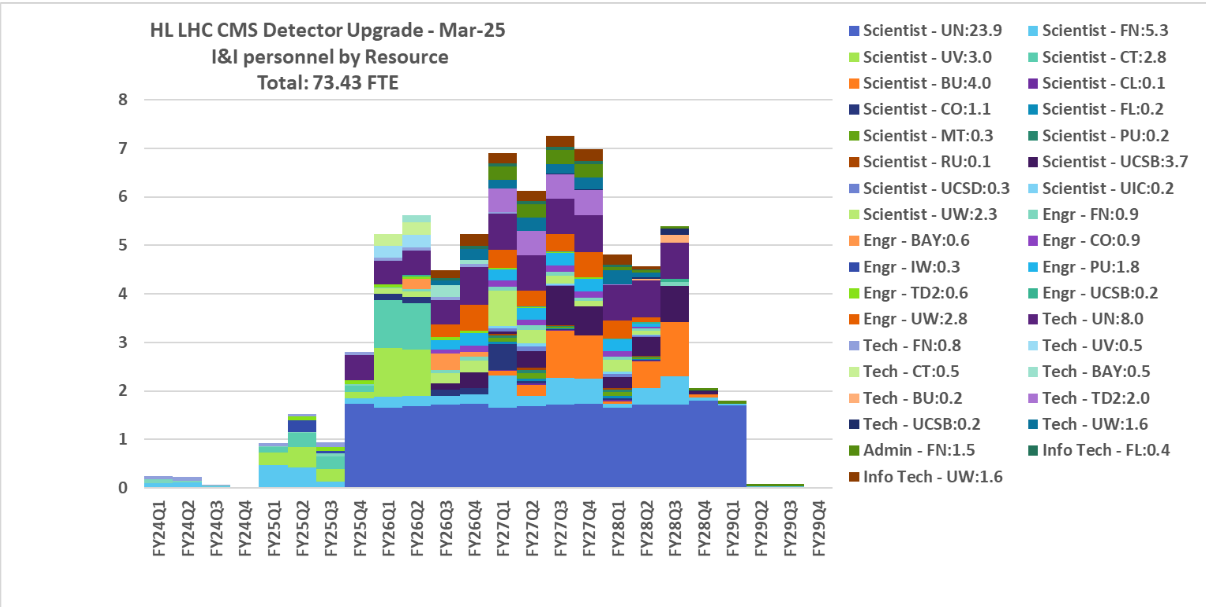
The question of when to start to reallocate I&I for deliverable scope depends considerably on the contingency burn rate in production, which is not yet known but should become clearer in the next 6 months. The large I&I payment in FY25 was moved in a BCR in May to FY26, so the spend down in the next 6 months is expected to be minimal. Thus around the time of the end of this fiscal year we expect to have sufficient information on the burn rate of contingency during production as well as clarity on possible objective deliverables that can be taken on elsewhere to have a defensible plan for using part of the I&I as a cushion.

The other option to be discussed with stakeholders is sort of the opposite approach - convert a large portion of the I&I to Deliverable Contingency, with an opportunity to participate in I&I depending on how the deliverables go. This would also leave open the option of closing the project after all the deliverables are complete, and relinquishing the remaining contingency to supplement the Operations program I&I, very similar to what US CMS did in the Phase 1 upgrade, where 1M of contingency was transferred to operations through an early CD-4a.

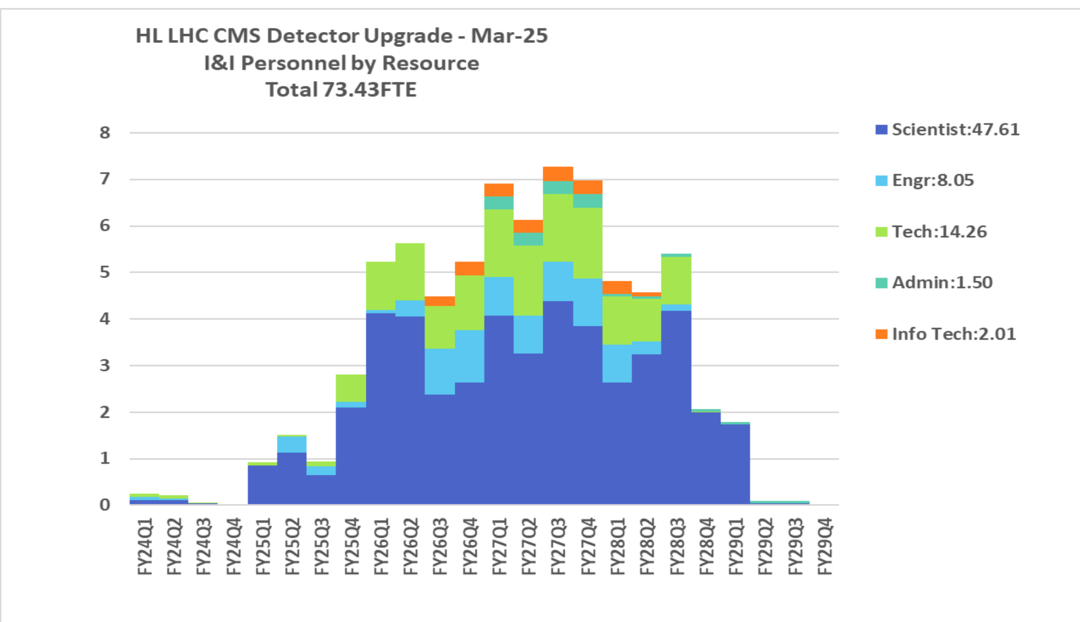
4. During a 2022 NIU site visit (03/28/2022), an observation was made that "The wrapping machine has more than one energy source so a proper lockout/tagout procedure should be developed and instituted before maintenance is conducted." Was this procedure ever created, and if so please provide a copy.

   NIU has provided a copy of the LOTO procedure. I've given Will a hard copy and provided an electronic version to both Will (at FNAL) and Jeff at ANL.

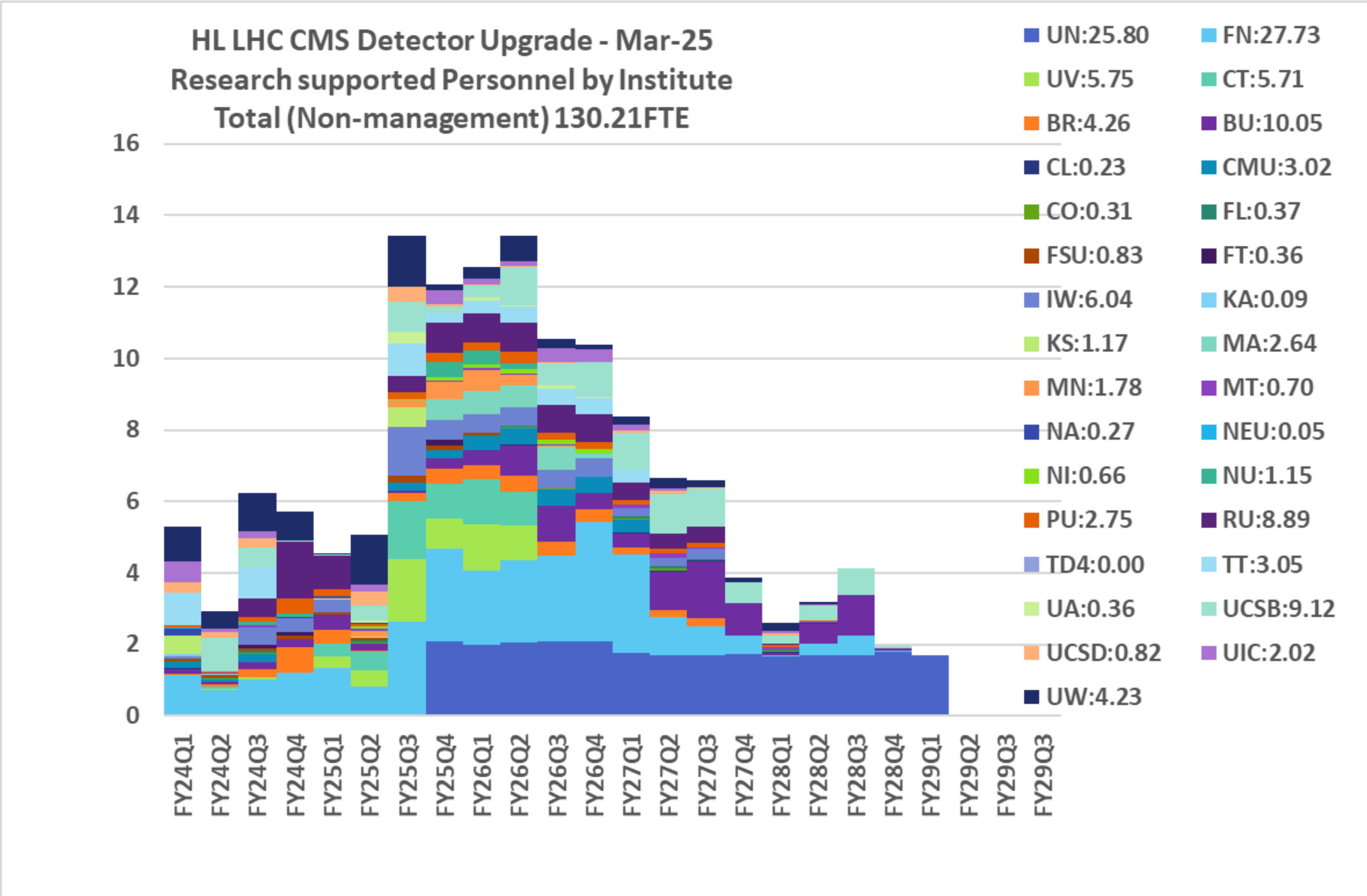
5. Please provide the anticipated FTE labor profile by ~ quarter for I&I personnel, by labor type and institution, if available.



There are a lot of Institutes, which makes this plot difficult to parse, so we remove the Institutes below



6. Please speak to the project's exposure to the 2026 DOE and NSF university grant allocations, and identify those of most concern. An FTE profile by institution would help, it it's easily accessible or generated.



Note - the various Management WBS elements have been filtered out from the above, as these tend to be faculty whose positions are somewhat more robust against funding cuts, although they may cause more distractions from their managerial responsibilities.

What this plot shows is that there are a lot of institutes involved, some more than others, but to get much more insight probably one needs to consider each institute's contribution individually. Perhaps because of the are large contributions at the various assembly centers, FN, BR, PU, RU, UCSB, CMU, TT, UV, CT, BU where postdocs are driving QC armies, these should be highlighted as of particular concern, although that should be balanced with institutes producing unique elements needed by all of CMS

The project does not have (and does not wish to have) an opinion on relative strength and weaknesses of the participating institutes' research proposals, although it is our experience that for the most part critical contributions to the Upgrade correlate well with the outcome of the comparative review process, and under normal circumstances there is a conversation about the specific institute with the agencies where project concerns can be expressed.

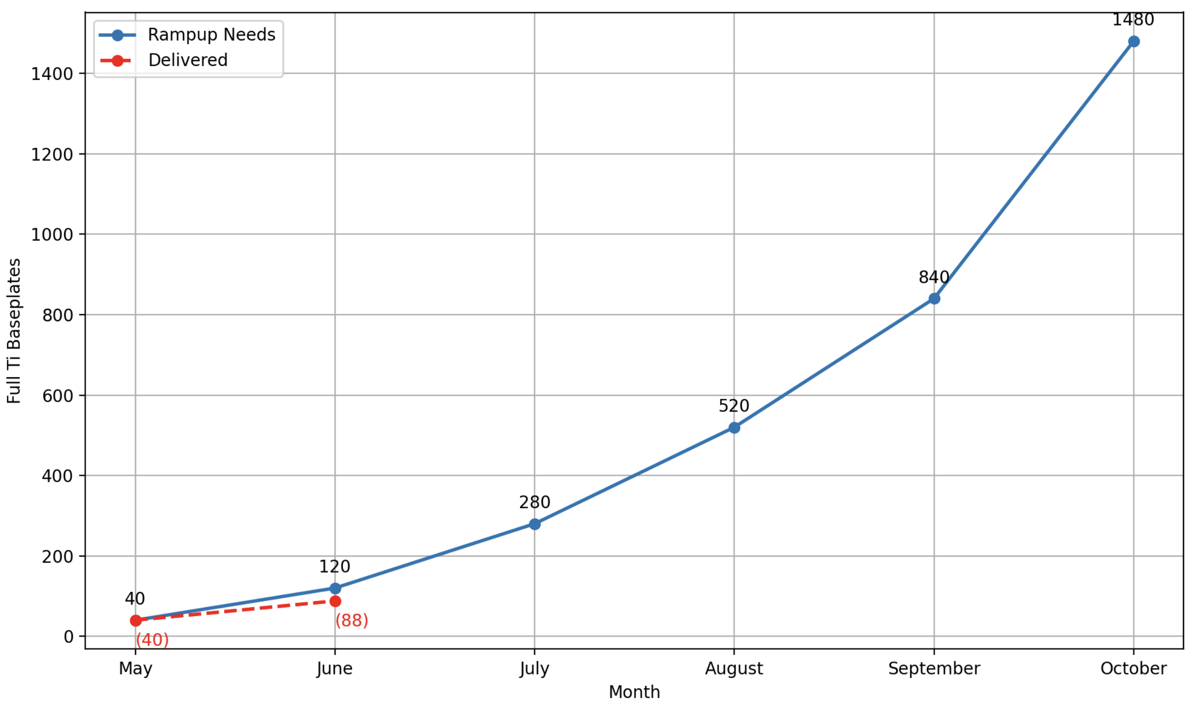
7. Please speak to the project's exposure, including areas of most concern to project management, to the timely receipt of components from international collaborators needed for US construction. Please fold in your estimates of the anticipated rate of ramp up from this point in time forward, as well as increases to date.

OT - hybrids; CERN is working closely with the vendor (Valtronic) and they devised a delivery plan, initially monthly, and later quarterly. This plan shows the ramp up. It can be seen in this table (green=delivered, black=planned, one line per hybrid type). Note "Uncertain performance of Hybrid Vendor" is the highest Schedule risk in terms of P*Impact that the project has, by a factor of 2. (Taylor talk, slide 8)

2025 Schedule	Pre-production (approved)	Pre-production (under test)	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25	Nov-25	Dec-25	Jan-26
2S-FEH-18-L	157		109	92		239	61	168	294	294	294	294	294	294
2S-FEH-18-R	159		110		268		84	168	294	294	294	294	294	294
2S-FEH-40-L	24		57	76	71									
2S-FEH-40-R	28			205	77									
PS-FEH-16-L	28	10	19		49									
PS-FEH-16-R	36	4	42		208	30								
PS-FEH-26-L	29													
PS-FEH-26-R	24	20		4										
PS-FEH-40-L	153					63			94		188	350	140	140
PS-FEH-40-R	38	36								236	140		280	140
2S-SEH	199				39	115	324	540	540	648	648	648	270	
PS-ROH-16_5G	30					26								
PS-ROH-26_5G	29													
PS-ROH-40_5G	70				40	105				324		486		
PS-ROH-16_10G	21					30							108	
PS-ROH-26_10G	30					105							216	
PS-ROH-40_10G	98	10			48	117			216		486			
PS-POH	299		60		225			168			630	630	374	
Total	1452	80	397	377	1025	830	469	1044	1438	1796	2680	2702	1976	868

2025 Schedule	Feb-26	Mar-26	Apr-26	May-26	Jun-26	Jul-26	Aug-26	Sep-26	Oct-26	Nov-26	Dec-26
2S-FEH-18-L, 2S-FEH-18-R, 2S-FEH-40-L, 2S-FEH-40-R		3547			3547			2961		-	
PS-FEH-16-L, PS-FEH-16-R, PS-FEH-26-L, PS-FEH-26-R, PS-FEH-40-L, PS-FEH-40-R		1932			1932			1932		2954	
2S-SEH		1069			1069			1069		-	
PS-ROH-16_5G, PS-ROH-26_5G, PS-ROH-40_5G, PS-ROH-16_10G, PS-ROH-26_10G, PS-ROH-40_10G		922			922			922		491	
PS-POH		842			842			842		1062	
Total		8312			8312			7726		4507	

CE Module baseplates:



CE Bus bars

The expectation is the delivery of 5088 bus bars, deliveries scheduled to start Sept 2025 and continue through March 2026 at uniform rate

CE DC/DC Converters

Expecting 10,248 converters from CERN/CMS Electronics coordination, 5% are available now and 10%/month should be delivered starting September 2025

CE Test System

Serenity ATCA cards for test systems from CERN/UK, should arrive in July, critical as several months needed to gain experience before high-throughput QC is needed in fall

CE Cold boxes for MACs from Turkey? - produced, in process of being repacked for safe shipment (one shipment arrived in a disarray)

L1T - IPMC from India

We have over 25 pre-production IPMCs both made in the USA and India, enough for our needs through August - i.e., we expect to receive at most two new production APx boards and we have 5 unused but tested pre-production IPMCs in hand presently. The production IPMC bare boards made in India have been certified by our lead engineer at Wisconsin. The initial batch of production IPMCs are in test in India currently and are to be shipped by mid June assuming success. The remaining units will follow, to be received in Madison by August 31, 2025.

L1T - DTH from CERN

The DTH boards have pre-series production samples available now for testing DAQ and timing functionality of APx boards. They report that their tender is complete for PCB production, and most of the components for production are in hand or have been ordered. Their DTH400 board production completion date is forecast for the end of November.

ETL - Bump-bonded LGAD and ETROC Assemblies

We expect to have LGADS and ETROCs available for bump bonding by May 2026. They will be bump bonded in four batches. The first batch is expected to be available for assembly by July 2026, and the last batch would be available by Jan 2027.

8. Please speak to what works, and those issues that could use more attention, in the project's relationship with (a) Fermilab management, and (b) DOE.

   a) Fermilab management - First, it should be noted for the record that in the last 6 months the lab has a new (interim) director, a new contractor, and a new Site Office manager. At this point we are still in the "honeymoon" period, although at least with the new director there have been noted positive changes already.

      What has been quite effective in the past is direct meetings on specific issues - the best example was the need to defer the lab accelerator shutdown by one week to continue critical OT tests in the testbeam campaign a few years ago. The directorate also was a continual advocate for implementation of the new University procurement procedure. Project Management enjoys essentially an open door policy with the Directorate to talk about potential issues (presumably, as long as this is not exercised at high frequency) and work on their solutions.
      What has needed work is both in-reach and out-reach on the importance of the CMS portfolio of Research, Operations, and Upgrade.
      In-reach pertains especially to the next level of management, particularly in Mission Support. From the CD-3 lessons learned document this was mentioned as an opportunity for improvement:

      For this period of the project, there has been extensive turn over in senior management, including 2 different lab directors, 4 different Chief Research Officers, 4 different Chief Financial Officers, 4 different Chief Operating Officers, 4 different Chief Project Officers, 5 different Procurement Officers, and significant rotations in the DOE Site Office, and one overall reconfiguration of the Lab Organization structure. With some significant exceptions, there has been limited request for orientation to the project by incoming management, which creates the potential for lack of appreciation for impacts on the project when decisions are made without direct consultation. As other high profile projects at the lab dominate management attention, *stronger connections and more proactive outreach to incoming management would be beneficial to ensure the lab meets the needs of all the projects in the portfolio*

Since then there has been yet more change, but also more activity in communication of the importance of CMS to those just below the highest level of management, which has been helped by the inclusion of the Project in the high level Lab Organization chart and the PM as a participant in the Senior Leadership meetings. Just in the last month this has resulted in a new lab policy on partnerships with CERN being augmented to distinguish bi-lateral vs multilateral agreements as well as the postponement of a “Safety Standdown” such that it wouldn’t interfere with this review.
The other aspect of this, which has been a problem in the past, is the perfunctory implementation of new policies and practices, typically driven by the increased concern regarding compliance or budgetary concerns, with no consideration about the root causes behind the variances from existing regulation nor any assessment of the potential impacts to the lab mission such actions would imply.

Outreach specifically refers to advocating for the HL LHC programs (perhaps specifically CMS) to the agency contacts - not only about Fermilab’s interests, but also about the overall health of the Research Program, and instructing the advocacy apparatus to do the same.

b) DOE - There has been proactive intervention in relation to speeding up university procurements, both by the FPD in the site office and at HEP HQ, including the FPM and HEP management, who have interfaced several times in the past year both with FSO and with Lab Management in order to expedite the approval of the more streamlined new procedure for University subcontracts.
More generally, here as well, candid and open communication in the biweekly IPT and monthly discussion with DOE HQ seems to be working well, as well as the fact that all stakeholders feel ownership of the project mission - that the milestones are not “project milestones” but “HEP milestones” such that any issue that jeopardizes them is a concern for all. There are changes at HQ, but the new people have extensive experience with the CMS portfolio and as such the transition is expected to be smooth.

9. The schedule pressures associated with HL-LHC are quite intense. Has maintaining technical standards as the project ramp up been of any concern? *(+ Can you address whether a system test of some reasonable scale is being planned for the CE? If so, what is the scale of the planned test and when is it nominally expected to occur? If such a test is not under consideration, please explain the reasoning for omitting it.* -> Calorimeter Endcap section)

In general schedule continues to take lower priority relative to performance. For instance, we could have moved forward with HGCROC3b version to favor schedule, with the penalty being both potentially severe operational complications as well as physics performance. A similar case can be made for all the additional work in binning ECON to mitigate the SRAM issue, which could be avoided with a penalty in physics performance. A survey of L2 management produced significant pushback bordering on indignation on the suggestion that there is a general relaxation of quality standards in favor of schedule.

There are cases where there has been a prima facie compromise of “quality” in favor of schedule, but only after extensive testing demonstrated no impact on performance. An example of this is the OT Hybrids, which have visible discoloration on some bond pads, but extensive pull testing shows that there is no measurable impact on wirebond strength. For the HGCROCv3c, studies of the physics impact stemming from a residual imperfection in chip operation determined that the chip, while not perfect, could be used in a large fraction of the detector without significant impact on physics performance.

10. For standard “coded welds”, the code requires:
    - *Welding Procedure qualifications (PQR and WPS)*
      This document exists but has not been updated for plasma welding.
    - *Welder Performance Qualification Records (WPQ)*

All welds are inspected by the welding and certified by their supervisor (In-Process Weld Examination Form).

- *Weld Map – identifying which welder did what joint*
  The weld map is included on the tubing traveler. The In-Process Weld Examination Form specifies the welder. It should be noted only one welder is trained with the plasma welder at Fermilab.
- *Certified Material Test Reports for Materials welded and weld filler*
  Both the tubing and glands have their material certification. I would have to ask the weld shop about the weld filler.
- *Calculations/Analysis & Specifications/Drawings identifying weld details – design depends on the service requirements*
  The welding process and specifications are documented. However, this is for the orbital welding process and not the plasma welding process.
- *Any required inspections reports (visual or Non Destructive Tests i.e. Radiographs) – quantity and type depend on service requirements*
  Yes, all welds are visually inspected and certified, and test pieces are CT scanned.

We learned that the CO2 Cooling pipes will not be “coded welds”. Which fraction of the above requirements will be addressed for the OT Planks welds?

Once the welding process is finalized the documentation will be updated. However, it would be premature to update the documentation now as the plasma welding process is still being investigated and the project may need to switch to vacuum brazing.

Karta – 2