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LHCC-152
December 2022

LARGE HADRON COLLIDER COMMITTEE

Minutes of the one-hundred-and-fifty-second meeting held on

Wednesday 30 November and Thursday 1 December 2022

OPEN SESSION – STATUS REPORTS

1. Status of the Accelerator: Daniele Mirarchi
2. ALICE Status report: Federico Ronchetti
3. ATLAS Status Report: Trevor Vickey
4. RD42 Status Report: Harris Kagan
5. FASER Status Report: Anna Sfyrla
6. SND Status Report: Giovanni De Lellis
7. CMS Status Report: Andrea Massironi
8. LHCb Status Report: Christina Agapopoulou

CLOSED SESSION

Present: C. Biscarat, R. Calabrese, D. Calvo, G. Casini, M. Demarteau*, F. Di Lodovico, I. Efthymiopoulos, C. Hearty, J.J. Hernández-Rey, T. Higuchi*, E.B. Holzer, A. Ianni, M. Krammer, R. Leitner, M. Mangano, J. Mnich, L. Moneta (Scientific Secretary), F. Moortgat, J. Nagle*, D. Newbold, S. Niccolai, B. Panzer-Steindel, P. Salabura, F. Simon (Chairperson), S. Smith, B. Petersen, A. Weber, P. Wells*, E. Worcester.

All sessions were held at CERN with some participants (*) connected remotely via Zoom.

1. Procedure

The chairperson welcomed the committee members. The minutes of the previous session were already approved by email. The chair welcomed Rupert Leitner (Charles University, Prague) as a new member of the committee, who joins the LHCb referee teams. The chair also reported that R. Calabrese will retire from the committee after the present meeting after 5 years on the committee and thanked him for his many contributions to the LHCC during his term. Discussions with members that have served for 4 years on possible further extensions are ongoing. The committee also heard a report on lessons learned from the review process of the Phase I and Phase II projects by the UCG chair Stew Smith, and thanked him for his two decades of extremely valuable contributions to both the LHCC and UCG.

2. Report from the LHC Programme Co-ordinator

The LHC restarted operations on September 20 after a four week stop to recover from a cryogenics failure in the RF modules. Due to the ongoing energy crisis in Europe, the end of the 2022 run was advanced by two weeks and the running time in 2023 was reduced by six weeks. It was therefore decided to cancel the Pb-Pb run in 2022 and replace it with an extra week of Pb-Pb running in 2023 and a two-day test with Pb ions in 2022.

The LHC availability and performance after the stop was excellent with new records in integrated luminosity per fill and per day. In total, more than 40 fb^{-1} of data were delivered to experiments in IP1/5 in 2022. Many special tests were also carried out in parallel or using dedicated fills. LHCb successfully managed to fully insert the VELO and inject several types of gas into the SMOG2 system. High rate tests were carried out in all experiments. The two-day ion test period was used to validate the use of slip-stacked 50 ns Pb beams, collimation using crystals and a new collimator installed near IP2 for luminosity debris. Two fills with Pb-Pb collisions in Stable Beam conditions, though with very low luminosity, were provided to the LHC experiments to test their detector systems. A special low pile-up run was carried out for LHCf which delivered almost 80 nb^{-1} of collisions at pile-up of 0.02 in a single 57-hour long fill, completing the proton-proton program of LHCf.

No new magnet training quenches were observed after the stop and the ate of UFO induced beam dumps also continued to decrease rapidly, indicating that neither of these are expected to be performance limitations in 2023. While the e-cloud in the LHC arcs also continued to decrease, this only improved slowly and limited the bunch intensity and filling schemes throughout 2022. For 2023, the e-cloud effect is expected to be mitigated by using hybrid trains consisting of "8b4e" trains and regular 36 or 48 bunch trains. This will allow the bunch intensity, but not the number of bunches, to be increased further. Based on this and the foreseen number of physics days, it is expected that the LHC could deliver at least 60 fb^{-1} to IP1/5. Further gains in luminosity can be obtained by levelling at a higher pile-up in IP1/5, as machine test at the end of the run showed that the inner triplet heating limit is about 25% higher than expected. For Pb-Pb, it is expected that the LHC can deliver 2.5-3.5 nb^{-1} of Pb-Pb collisions to IP1/2/5, thanks to the extended running period. The β^*=90 m run for the new TOTEM T2 detector was postponed to 2023, where a 4-5 day special run at β^*=3/6 km is also still planned during the proton-proton period.

3. Report from the Director of Research and Computing

The DRC reported that the start of Run 3 in 2022 has been an extraordinary success for the laboratory and the experimental collaborations.

He presented then the CERN answer to the energy crises. The first consequences have been the shortening of the 2022 run by 2 weeks and a reduced 2023 run schedule. The management is then working on defining long-term plans to deal with the cost increase of electricity and their impact after 2024. The scenario considered is from the current price of around 50 EUR/MWh up to 100-150. Prices have fluctuated for a short period of time up to 1000 EUR/MWh, but this is not considered a realistic possibility. However, an increase of the price to 150EUR/MWh will result in an increased cost for the CERN budget of around 100 MCHF/year. This will increase the CERN cumulative budget deficit in the long-term, affecting the possibility to invest in future large projects. The strategy to mitigate this deficit increase is to save money at the expense of scientific

output, by reducing the operation time of the accelerator and applying other measures such as reducing services and other scientific projects. The CERN proposal being submitted to the Council is that the savings should account for half of the increased energy costs, and the other half should come from an increase in the member state budget contributions.
A detailed investigation with the experiments is ongoing to establish what are the consequences of the reduced running time on the physics program.

4. Test Beams

The shortening of the accelerator runs 2022 by two weeks due to the European energy shortage, reduced the physics time of several activities. Proton test beam activities and all irradiation programs were not impacted, with the exception of the CHIMERA ion program which was reduced from two weeks to five days and the IRRAD and CHARM programs, which were cut by five days to make room for CHIMERA.

The availability of the different beams in the injectors in 2022 was very good, mostly 90% or above. The SPS North Area beams only achieved an availability of 73% though.

2022 saw an exceptionally high number of user schedule changes following user requests. Four weeks and 17 weeks of beam time were cancelled in the PS and SPS respectively. Several more weeks have been rescheduled due to delayed activities or to compensate for beam unavailability. Some additional beam time requests could be granted as well.

The injector physics period 2023 will be considerably shorter than in 2022. The SPS projects 26 weeks in 2023, compared to 33 / 31 weeks in 2022 original / reduced respectively. While most users will see a reduction to around 80% in 2023, the SPS proton fixed target program is reduced to 74%.

The new EU funded EURO-LABS project brings together the three research communities of nuclear physics, accelerators and detector technologies for high energy physics. Amongst others, it provides economic support for transnational access to 33 different testing facilities across Europe. At CERN, the test beam activities in the PS and SPS and the irradiation programs at IRRAD, GIF++ and HiRadMat are participating, as well as CLEAR / XBOX, ISOLDE and nTOF.

5. General Comments

The following comments are applicable to more than one project.

- The **LHCC congratulates** all experiments, the WLCG and the accelerator complex on the excellent performance during the year of Run 3.
- For the first time after the beginning of the COVID-19 pandemic, a LHCC poster session took place again during the LHCC week. The committee **was impressed** by the quality of the posters and the wealth of results presented by the early-career researchers.

The current geopolitical situation continues to create a challenging environment for the LHC experiments, and for CERN as a whole.

- The **LHCC is concerned** about the impact of the current energy crisis on the experimental program. The committee **fully supports** the measures taken to

reduce the energy consumption of CERN is this critical time, but at the same time **stresses the importance** of achieving the physics goals of Run 3 and of HL-LHC.

- The **LHCC appreciates** the significant efforts of the experiments and of WLCG to prepare for the potential loss of Russian, Belarussian and JINR contributions, and **encourages** all collaborating institutes and funding agencies to support these efforts.

On the Phase II upgrades,

- the **LHCC notes** that a consistent messaging on the integrated luminosity goals for HL-LHC is important in view of the investments made and technical decisions taken to maintain the design specifications of the Phase II upgrades, which ensure adequate detector performance to 3 ab^{-1}.
- The **LHCC shares** the concerns expressed by ATLAS and CMS about an understaffing of the CO_2 project, which carries the risk of delays in this critical infrastructure for the Phase II projects.
- In view of the critical schedule situation in key Phase II projects, the LHCC **strongly recommends** to accept financial risk and price increases in the purchasing strategy to maintain schedule or prevent further slips.

6. Discussion with ALICE

Scientific output and current activities:

- ALICE continues to have a rich scientific output, with 17 papers submitted since the last session of the LHCC, bringing the total number of publications to 417. These include a new review paper summarizing the key results of ALICE obtained with Run 1 and Run 2 data. The recent ALICE results include the measurement of the $\psi(2s)$ suppression in Pb-Pb collisions, measurements of the lifetime and the binding energy of the Hypertriton and studies of the production of strange baryons and mesons within and outside jets. Several new results have also been presented by ALICE students at the LHCC poster session.
- The ALICE detector has shown excellent performance during the 2022 pp run at 13.6 TeV, with 17.6 pb-1 collected. The detector was extensively commissioned for pp operations, about 7.5 nb-1 have also been collected for diffractive physics during the LHC Van der Meer scan. In addition, ALICE recorded 1.1M minimum bias events during the two Pb-Pb fills.
- The data taking and the new O^2 system performed well, with full synchronous processing exceeding the design throughput rate of 650 GB/s, achieving 1 MHz of sustained rate in pp collisions without instabilities or data corruption. Limitations are still observed for higher rates due to incomplete optimisation of some elements. Very good data samples have been collected for physics analysis. The O^2 system has shown impressive performance in asynchronous reconstruction, outperforming the TDR goal by a factor of 12 thanks to a larger usage of GPU in the reconstruction software.
- The readiness for 2023 Pb-Pb data taking is well underway. During the 2022 run a larger-than-expected number of clusters has been observed in the TPC. This has many potential implications, such as an increased processing time for the EPN. Several options for mitigation are currently being investigated, including adding additional EPNs in early 2023.

- The cancellation of the 2022 Pb-Pb data taking has created challenges in particular for students and young collaborators in the collaboration.

ALICE upgrades:

- The FOCAL upgrade for Run-4 had a successful September-November SPS/PS test beam, where results are critical for the TDR preparation. At the last LHCC meeting, the FOCAL group presented a clear set of milestones towards the TDR expected in Q3 of 2023 with a potential preview in March 2023.
- The ITS3 upgrade for Run 4 is making excellent progress and is planning to complete the TDR in 4th quarter of 2023.
- ALICE-3 R&D is underway, and the overall scope and necessary resources are being mapped out. Key discussions and work on R&D and the scoping document for ALICE-3 are underway.

- The **LHCC** congratulates the ALICE collaboration on its continued physics output with 17 new papers submitted since the last meeting. The results are of high impact and demonstrate a very broad physics program.
- The **LHCC congratulates** the ALICE collaboration on the successful data taking in 2022 with 13.6 TeV pp collisions.
- The **LHCC recognizes** the challenges created by the cancellation of the 2022 PbPb running in particular for early career researchers planning with this data set for thesis work, and **notes** that support by the collaboration is critical to minimize the impact on individual careers.
- For the FoCAL upgrade the **LHCC notes** the importance to have specific physics-driven performance metrics demonstrated with test beam for next LHCC meeting in the process towards the TDR.
- The **LHCC encourages** continued engagement with broader field on the physics case and physics priorities for the ALICE-3 upgrade.

7. Discussion with ATLAS

Scientific output and current activities:

- ATLAS continues to make excellent progress on its physics programme, with 1106 papers on collision data submitted to date, of which 179 use the full Run 2 data set. Since the last session of the LHCC, 26 new papers have been submitted. Recent new results include evidence for off-shell Higgs production and constraint on the Higgs width, searches for invisible Higgs decays, measurement of the VH cross section and searches for new physics in events with $H \rightarrow \gamma\gamma$ decays. There is still a large effort to speed up the remaining Run 2 analyses to reduce the backlog.
- ATLAS had a very successful data taking during Run 3, collecting overall an integrated luminosity of 37.8 fb^{-1} with 40.7 fb^{-1} delivered by LHC, making the recording efficiency of 92.8%. The efficiency is slightly lower than Run 2. The average pile-up has been 20% higher than Run 2 ($<\mu>$ = 40.9). Some deadtime at high luminosity has been observed. ATLAS reported a first result obtained with the Run 3 data, the measurement of the tt/Z cross section ratio at 13.6 TeV.

- Studies are going on for using alternative gas mixtures in the RPC system, but finding solutions that retain an acceptable performance remains difficult. As a first step, the mixture is adjusted to reduce the consumption of gases with high global warming potential (GWP). The use of GWP gasses in other systems should also be reconsidered.
- The LS2 upgrades have been successfully completed and the commissioning of the components is proceeding at a good pace. Some problems have been observed in some subsystems, such as gas leaks in the RPC, and in the TRT Front-End cooling system, and problematics LV power distribution in NSW. Plans have been established to treat them during the coming YETS.

Phase-II upgrades:

- The Phase-II upgrade activities are progressing. A detailed report was received by the ATLAS P2UG, as detailed below.
- The lack of sufficient contingency in some of the upgrade projects is worrisome and the coming months will be particularly demanding.

- The **LHCC congratulates** the ATLAS Collaboration on the continuous physics output using Run 2 data and on the first Run 3 result. The LHCC is pleased to see that ATLAS is strongly committed to speeding up Run 2 analyses to avoid clashing with those of Run 3.
- The **LHCC congratulates** the ATLAS Collaboration on the performance of the detector during 2022, and the good progress in commissioning the upgraded systems. The **LHCC supports** the actions taken by ATLAS to solve or mitigate the problems observed in some systems, and welcomes the plans to address these issues during the YETS.
- The **LHCC takes note** of the ATLAS decision not to pursue an HL-LHC forward proton programme and fully supports the considerations that led to this decision.
- **The LHCC is pleased** to see that the plans to face the consequences of the possible suspension of the collaboration with Russia, Belarus and JINR by the end of their present cooperation agreements with CERN are progressing well and seem to indicate that it is possible to cope with such a termination in a satisfactory manner.

8. P2UG Report on ATLAS

The ATLAS P2UG met with the upgrade project leadership from 7th-9th November 2022. An in-depth review of the TDAQ, ITk-Common, ITk-Pixels and Tile Calorimeter projects was held, while for the other projects, an overview was given.

The P2UG observed significant and sustained progress on all fronts. The project is now at a critical phase of many final reviews of subsystems, and the decisive questions of balance between cost, schedule risk, and technical risk are now fully in focus. The preparation for design and production reviews has also exposed new technical problems and supply chain issues, which in some cases are burning schedule contingency at a worrying rate. Sufficient schedule contingency is no longer available to guarantee delivery of the tightest deliverables at the need-by dates. After discussions at the review, that the remaining float for the tightest project (ITk-Pixels) is assessed to be near to zero.

The TDAQ project is overall in very good shape. After restructuring of EF Tracking, the new design is evolving and the whole project is settling accordingly. Algorithm development for L0 and EF processes becomes increasingly important. Procurement problems, e.g. due to the silicon crisis are still a significant risk. A major design change is currently proceeding in the dataflow project, where the removal of the disk buffer results in new data management challenges.

The ITk-Common project has also made good progress in the last 6 months. The schedule float has been reduced by 18 days since April. The subprojects have had many recent internal reviews (3 FDRs, 1 PDR, 1 MRR in the last quarter) and have two more PRRs scheduled in the next quarter. A major focus is preparation for the beginning of barrel strip integration at SR1, anticipated for summer 2023.

The ITk-Pixels Detector project continues to move steadily from the final design phase to production but faces severe challenges in several areas that are threatening a completion within the given timeframe. It is observed that the project continues to consume schedule contingency at a non-sustainable rate. The submission date for the FE-ASIC ITkPixV2 by the RD53 collaboration will now be further delayed to early 2023. Production ramp-up for hybridisation and modules, and therefore the full project, depends critically on the availability of ITkPixV2. Further concerns are the procurement of carbon foam, the high-speed data cables, and the site qualification process.

The TileCal project is overall in good shape. The schedule float across the project is healthy helped by the extension/delay to LS3. In particular, the distance-to-critical-path for partition assembly (LB-1, LB-2, EB-1, and EB-2) is now greater than 300 days in all cases. The completion of radiation tests remains a challenge for the projects (i.e. Main Board component testing, LV Bricks and the Daughter Board components). All remaining tests are now scheduled for completion by Q1 of 2023 and the P2UG will continue to monitor progress.

The LAr project is also overall in very good shape and has made important progress since the last review. In general contingencies are comfortable (~200 days). FEB2 and LAPS are near the critical path, but important progress has been made and confidence of meeting the schedule is high. Many milestones are planned for end of 2022 and the beginning of 2023.

The ITk-Strips Detector project presented strong progress across the major deliverables of the project, indicating that the transition from design to approval to production is now fully in hand. Strip sensor production is now fully under way for barrel and endcap, though delivery rates consistently fall behind those required to maintain the schedule. A significant new issue has been discovered during testing of assembled barrel modules, manifesting as noise peaks occurring only under cold conditions. This is a significant issue with the potential to substantially affect the delivery schedule, and so P2UG will conduct a mini-review of progress at the interim meeting in early 2023. The project currently has around 3 months of schedule contingency in hand, as measured against the expected availability of pixels for integration, though there is an additional ~6 months contingency available to the ITk system as a whole.

The Muon project has made good progress, however there is a long way to go with a lot of vunerability to supply-chain issues, and the schedule must be watched carefully. The project has around 115 days of schedule contingency. There is still the pending decision on which gas will be used in the upgraded system.

The HGTD project has made a clear and substantial progress on several fronts since the last review. The critical path for HGTD is the development, testing and production of the

ALTIROC3 ASIC. The schedule for HGTD remains extremely tight, with remaining float of around 151 days to the current need-by date.

A more extensive report with key project-by-project observations is attached in Appendix A to these minutes.

The LHCC agrees with the observations and recommendations made by the P2UG. In particular:

- The **LHCC and the P2UG congratulate** ATLAS on the progress in all aspects of the challenging Phase II upgrade projects.
- The **LHCC and the P2UG note** that despite best efforts, there is now almost no contingency left, and there is significant risk of delayed delivery to some subsystems.
- The **LHCC and the P2UG urge** ATLAS to continue to explore every avenue to accelerate the schedule in particular in the production phase, including the possibilities for additional resources to be provided by institutes and funding agencies.

9. Discussion with CMS

Scientific output and current activities:

- CMS continues to make excellent progress on its physics programme, with 1170 papers on collider data submitted to date, including 12 since the last LHCC. Recent results include evidence for four-top production, searches for HH production in the $WW\gamma\gamma$ final state and for light scalar partners of the Higgs, produced in Higgs decays ($H \rightarrow aa \rightarrow \mu\mu\, bb$). A large number of Run 2 analysis are still ongoing, with 150 additional results expected. The analysis of Run 3 data has started.
- CMS had a successful and fruitful first year of data taking at Run 3 after 3 years of LS1, collecting an integrated luminosity of 37.65 fb^{-1}, with an average data taking efficiency of 91.7% and certification efficiency of 89.4%, both increasing in the last month of data taking.
- The overall performance of the detectors has been very satisfactory with only some minor issues. The ECAL positive endcap has suffered from a water leak, which has affected 7% of the channels in one of the two endcaps. The global impact of this incident to the physics is however small. The repair of this leak is the highest priority for the coming YETS.
- An in-depth review session has taken place focused on the lessons from LS2 and the road to LS3. The review has been complemented by a site visit of Point 5. CMS has presented the plan of the surface and underground activities during Run 3. One of the lessons learnt from LS2 is that the higher work density in LS3 will require more coordination and better organization of the work, with work structured by area rather than on a sub-system level. Significant issues were encountered with the construction of the HGCAL clean room, where the selected company was not suitable for the work. Technical personnel for LS3 is another major concern, in particular given the expected loss of contributions from the Russian teams. Discussions with several other institutes are ongoing to find replacement teams from other countries.

Phase-II upgrades:

- CMS supports the proposal for a new PPS detector at HL-LHC, which, at least until LS4, will be the only forward-physics Detector at HL-LHC, after ATLAS's decision to not further pursue their plans for a forward-physics program in Run 4 and beyond. The LHCC is still waiting to receive estimates for the accelerator related costs for the detector installation and integration.
- There has been good overall progress for the Phase-II upgrade activities, but the schedule is considered no longer viable. A detailed report was received by the CMS P2UG, as detailed below.

- The **LHCC congratulates** the CMS Collaboration for the steady output of physics results.
- The **LHCC congratulates** CMS for its successful run this year, with remarkable data taking and certification efficiency.
- The **LHCC agrees** that the new installation philosophy of grouping the work by regions instead of detectors is the right path forward to meet the challenges of LS3 and **looks forward to** seeing it implemented.
- The **LHCC is concerned** about the difficulties encountered with the contractor for the construction of the HGCAL clean rooms. The **LHCC recommends** that stricter criteria are applied in future tendering processes of this kind and that the requirements for contractor personnel are clearly communicated and thoroughly validated prior to the award of the contract, in particular when the company in question is new to CERN and European quality and safety standards. The **LHCC recommends** that CMS and CERN make every effort to ensure that the problems with the HGCAL clean rooms do not impact the already tight upgrade schedule.
- The **LHCC reiterates** the importance to study ways to make the shift coverage more effective and robust, and share more evenly the load over the Collaboration, avoiding overload on locals. The **LHCC welcomes** the creation of a dedicated working group to solve this issue and expects to see a proposal by the next LHCC meeting.
- **The LHCC recognizes** the efforts made by CMS to reduce the impact of climate-active gases but **is still concerned** about their continued use. The **LHCC recommends** continuing the search and qualification of alternative gases and **requests** a dedicated presentation on the overall environmental impact of CMS and on the ongoing efforts to find alternatives to all CMS pollutants (like C2H2F4-R134a, SF6, CF4) at the next LHCC meeting.
- The **LHCC acknowledges** that PPS2 is now the only remaining option for forward physics at the HL-LHC. The **LHCC appreciates** the ongoing discussions of the PPS team within the TREX Working Group, and r**ecommends** a timely availability of the cost estimates for the machine integration, which is crucial to allow the project to move forward towards approval. The **LHCC** also **recommends** that the (de)installation activities of PPS including cables removal are integrated and carried out together with the planned activities for HL-LHC in the areas.

10. P2UG report on CMS

The CMS P2UG met with the upgrade project leadership on 16 – 18 of November 2022. The Committee noted the overall impressive progress of all the Phase II projects, with

significant technical advances in the last months. The project has also reacted very swiftly and efficiently to the new geo-political situation and has successfully shifted scope to other institutions, mitigating various risks. Unfortunately, the new reality and the continuing effects of supply chain issues are estimated to result in an increase in core cost by 15-20%, with subsystems affected differently. Despite the great technical progress, the schedule has further eroded and negligible schedule contingency is left, with large exposure to potential future delays.

The HGCAL has seen a delay in the submission of the ECON-D chip, which sets the critical path. Currently, the schedule contingency is little more than one month, though there remains some internal float. The first version of the ECON-T chip has been received and only a few minor issues have been observed. It is noted that the addition of the CERN ASIC engineers has had a tremendous positive impact on the progress. The future production schedule for the ECON ASICs, however, is very aggressive. Not just maintaining but increasing the person power on the ASIC team is required to keep schedule with frequent exchange of engineers between CERN and Fermilab.

The Beam Radiation, Instrumentation and Luminosity (BRIL) project is well-advanced having a very robust system of diverse technologies and counting methods with different systematics to obtain an absolute measurement of the luminosity at the 1% level. The BRIL trigger board requires a sophisticated interface with the Timing and Control Distribution System and Global Trigger and needs to be able to handle varying clock frequency. The Fast Beam Condition Monitor, which measures beam induced background and bunch-by-bunch luminosity, is a detector that is required for day one operations. The readout ASIC required is at an advanced design stage with a prototype submission planned in early 2023. The project is exposed to loss of manpower.

The BTL has developed a path to obtain the required timing resolution and the projections indicate that this will be achieved. A test beam is planned for early 2023. These results will inform the final design. The P2UG encourages the project to implement the necessary changes, if funding allows, to obtain the required timing resolution at end-of-life with sufficient margin.

The ETL sensors are showing good timing resolution even after irradiation. A full-size version of the ETROC2 ASIC has been submitted.

The GEM foil production in Korea for the GE2/1 and ME0 detectors has been halted. The production facility will be moved to another site in Korea and will need to be re-qualified. The P2UG has concern that this may take a significant amount of time and recommends that it be investigated if all foil production can be done at CERN. The VFAT3 readout chip has a worse timing resolution than required and channel losses have been observed that seem correlated to HV events. The cause is being investigated.

Good progress has been made with the outer tracker. The project has only one vendor to produce all the hybrids, which exposes it to some risk. Good communication with this vendor is strongly encouraged. The MAPSAs production has seen further delays and now drives the critical path for the outer tracker. Expeditiously qualifying vendors for the MAPSA production is a priority. Noise mitigation of the PS modules is in progress.

The submission of the readout chip for the inner tracker, the CROC chip, has been delayed due to issues found in the ATLAS pixel chip. The CMS chip will be submitted after the ATLAS chip. The CROC drives the schedule for the inner tracker. The P2UG supports the implementation of the CROC in parallel with fixing the ATLAS chip. More resources to help the design would be very beneficial. Higher noise has been observed for some of the 3D sensors for the inner tracker after irradiation, which is being studied.

The project uses K9 carbon foam in several subdetectors. There is not enough material on stock for the full upgrade program and the supplier has not been responsive to inquiries from the collaboration. An alternative material needs to be found, or an alternative vendor. Judicious use of the existing stock material is required.

The progress with the Level 1 Trigger, the data acquisition system and the high-level trigger is quite impressive, and these systems are very robust. Supply chain issues for electronics components are adequately managed.

The CMS Phase II project is in desperate need of experienced mechanical and electrical engineering, and applications physicists exceeding the 20 FTE level. The effect of the addition to date of experienced personnel has been impressive. The extra engineering for the ECON and RD53 chips, for example, and the additional engineering for the hexaboard design have seen these tasks progress much more quickly. Not just maintaining these resources, but adding resources recruited from the collaboration and supporting institutions will be required to maintain the current schedule.

As noted in our previous report, the upgrade project is at a pivotal moment, entering the final verification phase of many components before moving to production. This phase is crucial to ensure the performance of the upgrade. CMS is one experiment, and this is the time for the collaboration to come together. The collaboration would do well to develop a shared sense of urgency to maintain schedule and ensure that all the components meet specifications.

A more extensive report with key project-by-project observations is attached in Appendix B to these minutes.

The LHCC agrees with the observations and recommendations made by the P2UG. In particular:

- The **LHCC and the P2UG congratulate** CMS on the progress in all aspects of the challenging Phase II upgrade projects.
- The **LHCC and the P2UG** note that despite best efforts, there is now almost no contingency left, and there is significant risk of delayed delivery to several subsystems
- The **LHCC and the P2UG urge** CMS and the collaborating institutions to increase the effort and prioritize the upgrade program to ensure its success and avoid additional delays, and **strongly support** the request of CMS for more personnel in key areas of the upgrade project.

11. Discussion with LHCb

Scientific output and current activities:

- LHCb continues to deliver high quality physics results, with a total of 646 publications to date, including 15 new papers since the last session of the LHCC. New results include the exciting simultaneous measurement of R(D) and R(D*) testing lepton flavour universality, studies of charm baryons in $B^- \to \Lambda_c^+ \bar{\Lambda}_c^- K^-$ decays and a new combination of the CKM angle γ.
- LHCb has collected 760 pb-1 of data for commissioning the full detector during Run3 and has successfully operated the full DAQ and trigger systems. One third of the data has been recorded with the VELO in closed position.
- The commissioning of the detector and online system has been proceeding successfully. Here, having a significant time of stable beam during working hours

has been of critical importance. The average number of interactions per bunch crossing has been scanned up to μ=5, while most data have been recorded at μ=1.1. The HLT1 tracking trigger has been tested up to 20 MHz with pp collisions, and to the target rate of 28 MHz with simulated data.

- A movement of the VELO C side during fills has been observed, possibly due to the shims added to shift the modules relative to the RF foil. It is planned to remove these shims over the shutdown, which may fix this issue.
- A non-linear response of the PLUME luminometer has been observed which is being worked on to provide the correct calibration. The system will be used to provide the luminosity for the machine.
- The subsystem commissioning is expected to be finalized in the first few months of 2023 operations, including the Upstream Tracker.
- The UT C side has been completed and lowered into the pit. The assembly of the A side is on track and the last stave is supposed to arrive at CERN next week and it is planned to be lowered before the Christmas shutdown. A major effort is ongoing to complete the installation by February 22. This will allow for three weeks of detector-open commissioning before the closure of the cavern on March 22. The cabling work represents the main schedule risk at this point.

LHCb upgrades:

- The TDR for some or all of the planned smaller LS3 upgrades for the PID systems is expected to be delivered to the LHCC in September 2023, for a completion of the review by the end of 2023. Progress continues also on the Upgraded II with active R&D.

- The **LHCC congratulates** LHCb on the continued high-quality physics output, and in particular notes the highly anticipated combined R(D)/R(D*) result.
- The **LHCC commends** the collaboration for the strong progress on commissioning, including the milestone of VELO closing and the successful high-rate operation of the GPU based HLT1.
- The **LHCC appreciates** the careful planning for UT installation, noting that the collaboration recognizes the importance of leadership, communication, and reasonable work levels for individuals. The **LHCC recommends** that UT installation proceeds in a way to not jeopardize the expected closure and LHCb turn-on in case of delays in the cabling of the A side.
- The **LHCC recognizes** the significant remaining effort to finalize commissioning of the existing subdetectors, integrate UT, and transition to physics operation.

12. Discussion with WLCG

The 1st year of the LHC Run 3 is concluding. WLCG is operating efficiently and is successfully supporting the computing activities of the experiments. The CPU pledged capacity continues to be delivered by WLCG, with an additional 40% available opportunistically. There is however a worry that the opportunistic CPU capacity could be impacted in the future by the increased cost of energy.

The first in-person WLCG workshop after the start of the pandemic took place. The very good attendance demonstrates the vitality of the community. One subject discussed was the use of HPC facilities. Given several successful integrations of HPC facilities in LHC computing, the WLCG document describing the set of requirements to use the HPCs will be updated. Such a document, harmonised between experiments, and with state-of-the-art techniques, will help to establish a dialog with HPC centers and engage with other sciences. Another subject, discussed at the workshop, was the energy needs in WLCG. Energy consumption for computing is expected to increase with HL-LHC, with a peak coming in 2036 at the start of Run 5. Additional software and computing R&D may limit this growth, with the steady reduction of required energy per analyzed fb^{-1}.

The status of the WLCG network has been presented to the LHCC. The infrastructure is in good shape and keeps up with providing adequate bandwidth for the LHC experiments. The evolution towards the HL-LHC era is well accompanied by specific end-to-end data and network challenges. The community is active and communication channels between all parties, network providers, sites and experiments are well established and working well.

The experiments consider the Russian sites as opportunistic, as approved by the LHCC. Despite the extra capacity offered by some FA, there is for 2023 a deficit of pledges versus needs mainly affecting CMS and to a lower level also ALICE. The needs of the experiments are being re-assessed in view of the modified LHC schedule. To compensate for the loss of their second largest T1, which is located in Russia, CMS presented two long term solutions to the LHCC: finding a new CMS T1 or the current CMS T1 centres could adjust their pledges upwards.

The ATLAS study of the total cost of ownership in using Google cloud services progresses as planned. This is seen as an opportunity to diversify the system, and also creates an attraction for those working on software and computing.

- The **LHCC commends** the WLCG, the experiments and the sites for the success in operating efficiently during Run 3 and for the support of the computing activities.
- The **LHCC is impressed** by the continuous software improvements achieved by ATLAS and CMS, due to both algorithmic improvements as well as other optimisations. Following a concern expressed at the last Software and computing HL-LHC review, the **LHCC is pleased** to note the reconstruction of HGCAL has been shown to contribute to a few percent of a full event reconstruction in CMS. The **LHCC will follow** with interest the impact of the CMS RAW prime data format on the Heavy-Ion analyses performance.
- The **LHCC fully supports** the developing R&D network projects. The **LHCC is convinced** the network and the facilities will have to be shared with other big science communities and the **LHCC commends** the WLCG network community for developing collaborations. It is essential for the sustainability of the network infrastructure.
- The **LHCC welcomes** the work on estimating the power needs by the experiments for HL-LHC, which is seen as an important preparation for the future.
- The **LHCC emphasises** that a shortage of storage needs to be avoided, in particular for tape, and **encourages** sites and FAs to ensure enough tapes can be provided. The loss of the Russian sites capacity is worrying and could delay the

completion of the physics program. The FAs are encouraged to work together with the experiments to find an appropriate long term solution.

- ALICE measured a larger, compared to simulation, CTF average event size during 2022 pp data taking. The **LHCC is concerned** about the possible impact on the resource needs in the coming years and **recommends** that this impact is assessed as soon as possible for better planning.
- In view of increasing energy costs, the benefits of investing in improvements to the software stack are further increasing. The **LHCC stresses** that mechanisms for the long-term support of these activities, and for the recognition of those doing them, is of central importance for the success and sustainability of the field.

13. Report on FASER

FASER had a successful first run, collecting of the order of 40 fb^{-1}, with a data loss of less than 2.5% due to operational issues now understood and resolved, and less than 2% DAQ dead time. All indicators of detector performance and data quality are positive, and data reprocessing will take place once all final calibrations, alignment, magnetic map and software improvements are implemented. The background level, while slightly larger for some components, is consistent with expectations and well within tolerance. YETS activities will include the preparation of the upgrade of the EM calorimeter readout, with the addition of a PMT to each of the 4 detector modules, to better cover the full energy spectrum from 100 MeV to 3 TeV. The new system will be deployed during the TS.

The FASERν detector had an equally successful run, with the exposure of 3 sets of emulsions, covering the initial phase of the run (0.5 fb^{-1}), and two successive periods of high luminosity (~10 and ~30 fb^{-1}, respectively). The first two modules have been developed and analyzed, showing excellent track resolution ($\sigma(\Delta x)= \sigma(\Delta y)=0.2\mu m$) and an overall track density consistent with simulation. According to simulations, a total of about 2000 neutrino interactions are expected to emerge from the analysis of the full dataset. Further thermal insulation of the emulsion box is under consideration, to minimize the impact of temperature fluctuations. As already shown at the time of LHCC 151, the combined operations at the emulsion facility with SND@LHC have been very smooth.

For the pre-shower upgrade project, the tests of the pre-production ASICs have been completed, indicating the need for design adjustments. These, along with delays in the delivery of the pre-productions chips, will likely delay the delivery of the final chips, resulting in the decision to postpone the installation to the YETS 2024-25, which would provide the project with a 4.5 month contingency. The initial goal to collect ~90 fb^{-1} during run 3 remains however within reach, although now this luminosity will need to be integrated entirely during the 2025 run.

- The **LHCC congratulates** FASER for the successful run and the excellent performance of both its detectors.
- The **LHCC recommends** that a plan for the installation of the multiple emulsion boxes expected for 2023 be prepared for the next committee's meeting.

14. Report on LHCf

LHCf had a very successful special run, with a total of 300M recorded interactions, greatly exceeding the run 2 statistics. Particularly noteworthy is the combined data taking with ATLAS, which recorded data from each event triggered by LHCf, and provided LHCf with its ZDC data. Clear π^0 and η diphoton mass peaks have already been obtained, with a mass resolution that will significantly improve after the calibration process, benefiting also from the positive test beam run that followed the data taking. The goals of the collaboration now include the extraction of a $K^0_S \rightarrow 4\gamma$ signal, and the eventual data taking during pO and OO collisions. A fruitful cooperation with ATLAS is ongoing, both for the analysis of the run 2 and of these new data.

- The **LHCC congratulates** LHCf for the successful data taking and the excellent detector performance.
- The **LHCC commends** LHCf and ATLAS for the coordination of the data taking and the plans for a joined data analysis

15. Report on MoEDAL

The installation work of the MoEDAL detector has continued according to plan. Part of the work has been postponed due to LHCb operations, but a window of two weeks (20 February to 7 March) has been negotiated between the two experiments. The installation of the MAPP detector has likewise made progress, with the mounting of additional scintillator bars and services. The acquisition of the remaining 100 PMTs has been completed. Their installation with the remaining 100 scintillator bars is planned during the YETS. Both the MoEDAL and MAPP detectors are therefore expected to be ready to take data at the start of the 2023 run. The hardware for the additional out-rigger detectors of MAPP is now available.

- The **LHCC congratulates** the MoEDAL collaboration for the progress in the installation of its two detectors.
- The **LHCC recommends** that MoEDAL swiftly undertakes the formal procedures to prepare the installation of the out-rigger detector.

16. Report on SND

SND had a successful first run in 2022 detecting its first collision in July only 16 months after its approval. Despite the international difficulties, the problems with the procurement of the emulsions have been solved and they were delivered for the 2022 run. Future emulsion needs will be fully covered by Nagoya University. The replacement of emulsion targets was working very efficiently, with the final intervention needing only 4 hours, which enables replacements in shorter access periods outside regular Technical Stops.

The emulsion facility at CERN has been completed and is now in regular use for both SND and FASER. Sharing of equipment and coordination between different users appears to be working very well.

The first data results show a muon track rate lower than that predicted by the simulation. The discrepancy is under investigation with the FLUKA group and could be caused by

the description of the magnetic field outside of the pipe in the simulation. Given a larger than expected background observed from beam 2, a shielding wall will be installed downstream of the detector to reduce this background. Additional consolidation work addressing smaller technical issues, such as the observed failure of one electronics board, and overall improvements of detector and environmental stability will be carried out during the YETS.

SND is planning a test beam in Spring 2023 which is important for the improvement of the energy calibration of the HCAL.

- The **LHCC commends** SND for the rapid installation and commissioning of the detector which has been ready to collect pp data for physics in complete configuration since the end of July.
- The **LHCC congratulates** SND for the efficient solution of the film procurement, which is now fully guaranteed by Nagoya University for run 3. The **LHCC** also **appreciates** the special effort to procure the needed films for the unexpected extension of the pp running time.
- The **LHCC congratulates** SND, FASERnu and CERN on the well-coordinated development and use of the Emulsion Facility (EF) which now also includes the new scan station.
- The **LHCC recommends** for the next meeting the definition of the process allowing the timely replacement of films during Run 3 for SND and the other experiments and the sharing of the EF with the other users.
- The **LHCC endorses** the energy calibration test beam foreseen in spring 2023 and strongly supports the request for two weeks of beam time.

17. Report on TOTEM

Service work is required during the current YETS to repair the pixel detectors of the horizontal roman pots. This is expected to be completed on time for installation before the start of the 2023 run. The vertical roman pots, relying on silicon strip detectors, are in order and ready to take data. The new T2 detector has been completed. TOTEM is therefore on track for the special β^*=90 m run. The installation sequence for the T2 detector, during the TS1 that is planned to precede the run, is ready; it foresees the ramp down of the CMS magnet, followed by the run at B=0. The magnet will be powered again at the end of the run, following the removal of T2. It is expected that a very-high β^* run will then take place later in 2023.

18. Report on RD42

RD42 is pursuing a rich program in R&D on diamond sensors. This also includes work for the ATLAS BCM'. Extensive studies on radiation damage have shown a universal behaviour for both polycrystalline (pCVD) and single-crystal diamond (scCVD). For large integrated fluence, the uniformity of pCVD and scCVD diamond approach a common value. A rate dependence of the pulse height in irradiated diamonds was excluded by new measurements, but measurements to higher fluence will be performed. New techniques in the production of 3D diamond sensors using lasers with spatial light modulation have been developed successfully, achieving column yields in excess of 99%.

RD42 is contributing in an important way to the ATLAS BCM', including providing the Calypso-C ASIC, interfacing with vendors and contributing to sensor selection and testing.

- The **LHCC congratulates** RD42 on the progress made on scCVD and pCVD planar sensors and new 3D diamond detectors, and **recognizes** the importance of the development of the Calypso ASIC and of the diamond sensor activities in collaboration with ATLAS for the BCM' development.
- The **LHCC recommends** continuing the support for RD42 in 2023 and notes that this is crucial for the conclusion of the approved two years program and also for the continuation of the contributions to the ATLAS BCM' project.
- The **LHCC recommends** that RD42 engages in the process of the implementation of the ECFA Detector R&D roadmap, and **notes** that the general comments on RD collaborations and their relation implementation of the roadmap reported in the Minutes of the 151st LHCC week also apply to RD42

REFEREES

The LHCC referee teams for this session are as follows:
ALICE: D. Calvo, G. Casini, J. Nagle (Co-ordinator), P. Salabura
ATLAS: C. Biscarat, R. Calabrese, F. Di Lodovico, J.J. Hernandez-Rey (Co-ordinator), S. Smith
CMS: A Ianni, S. Niccolai (Co-ordinator), A. Weber
LHCb: T. Higuchi, C. Hearty (Co-ordinator), R. Leitner, E. Worcester
LHCf, TOTEM: F. Di Lodovico, M. Mangano (Co-ordinator)
MoEDAL: F. Di Lodovico, M. Mangano (Co-ordinator), E. Worcester
WLCG: C. Biscarat (Co-ordinator), P. Salabura, A. Weber, E. Worcester
FASER: G. Casini, M. Mangano (Co-ordinator)
SND: G. Casini (Co-ordinator), F. Di Lodovico, M. Mangano
R&D projects:
RD42: D. Calvo
RD50: D. Calvo
RD51: C. Hearty
RD53: R. Calabrese

The LHCC received the following documents:

CERN/LHCC-2022-014	Minutes of the one hundred and fifty-first meeting of the LHCC held on 14-15 September 2022

DATES FOR LHCC MEETINGS

Dates for 2023
8-9 March,
24-25 May,
13-14 September,
29-30 November

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Appendix A: **Report of the ATLAS Phase-II Upgrade Project Review (P2UG)**

Appendix B: **Report of the CMS Phase-II Upgrade Project Review (P2UG)**

A. Summary report of the ATLAS Phase-II Upgrade Project Review (P2UG)

G. Barker, J.-L. Faure, G. Hall, R. Mankel, M. Moll, M. Morandin S. Nahn D. Newbold (Chair), P. Paolucci, D. Wood and A.J.S. Smith

The ATLAS P2UG met with the upgrade project leadership from 7th-9th November 2022. This was the first review organised in conjunction with the new ATLAS upgrade management, and the first since 2020 with a majority of the panel members and ATLAS experts physically present.

An in-depth review of the TDAQ, ITk-Common, ITk-Pixels and Tile Calorimeter projects was held. This comprised a plenary overview talk, followed by several sessions of focussed presentations and a Q&A session. For the other projects, a plenary overview talk was given, and in some cases written questions answered by the project managers. As at previous reviews, the materials and presentations provided by ATLAS were excellent in quality and coverage, and the surrounding discussions were helpful and transparent. We thank the ATLAS upgrade coordinator and the entire team for their efforts and responsiveness.

The P2UG was able to form a clear impression of the project status and trajectory for each project, and to make concrete recommendations. As we noted at the previous meeting in May 2022, the pace of development and steps towards production in the project is currently extremely rapid, making it difficult to track all important details at intervals of six months. To that end, it will be necessary to formalise and extend the interim P2UG meeting in early 2023, in order to focus on a number of the important issues highlighted below.

Progress against schedule

- The current schedule presented to P2UG follows three baseline changes in the last quarter, for pixels, strips, and TDAQ respectively. In the former two cases, these result from further optimisation of anticipated production procedures and rate, or revisions to the ATLAS internal review schedule to decouple projects and allow faster progress towards production. In the latter case, the schedule revisions reflect the results of the past conflicts between the upgrade project and Phase-1 commissioning, but the affected tasks are in any case not close to the critical path.
- The P2UG assesses the current schedule situation as follows:
- Significant and sustained progress is being made on all fronts, with a noticeable emphasis on collective work across the collaboration to jointly address technical challenges and schedule issues. Despite several recent changes of senior management, and the challenges presented by the hangover from COVID and the international political situation, the project is functioning well.
- The project is now at a critical phase of many final reviews of subsystems, and the decisive questions of balance between cost, schedule risk, and technical risk are now fully in focus. The effects of ‘review pile-up’ that concerned P2UG in its last report have not materialised, due to the efforts of the management to ensure efficient progress.
- The preparation for design and production reviews has, of course, exposed new technical problems and supply chain issues, which in some cases are burning

schedule contingency at a worrying rate. This was to some extent foreseen, and we continue to encourage ATLAS to prioritise technical certainty and not cut corners on verification of systems or QA/QC procedures. We are pleased to see the pragmatic approach being taken in decouple systems for review when appropriate. Nonetheless, given the overall schedule situation, the further delays being accumulated will place extreme pressure on the project during the production phase.

- Despite the current level of progress, sufficient schedule contingency is no longer available to guarantee delivery of the tightest deliverables at the need-by dates. Indeed, after discussions at the review, we assess that the remaining float for the tightest project (ITk-Pixels) is near to zero. We remain optimistic that further improvements in the originally foreseen production rate can be achieved, but this cannot be further assessed until the rate of production of real modules has been experienced. Given the complex nature of this project and several technical and procurement risks still in play, it would now be prudent to consider the implications for the overall schedule of a delayed delivery of the ITk.

Other comments:

The international political situation concerning Russia will impact the project, and a number of in-kind deliverables, financial contributions, and industrial contracts were originally foreseen from or via Russian institutes. The majority of this will now not be possible. The P2UG are confident that the extent of these impacts is understood by the ATLAS upgrade coordination and resource management teams, and we see evidence across projects of investigations towards alternative routes. The financial implication of the situation has been clearly stated, along with the procedures being followed to address the shortfall in cooperation with national contacts and funding agencies. The issues surrounding assembling the necessary effort at CERN for integration and installation are less clear, however.

A repeated cause of risk and delay is procurement procedures, not restricted to large common contracts, but also now including relatively low-cost items. The professional efforts of the CERN procurement office and the ATLAS procurement experts are essential in ensuring efficient tendering procedures with minimum risk. There is of course a tension – as in all projects – between the need to follow these procedures and the need to make the maximum possible progress. Is it therefore essential that all ATLAS managers inform themselves fully of the realistic schedule for tendering and procurement. In addition, the upgrade coordination should be prepared to be proactive in ensuring a global optimisation of the schedule, for example by establishing the relative priority of outstanding procurements at CERN, and by approving the start of procurement in advance of final reviews where appropriate, even where this involves financial risk.

ATLAS continues to demonstrate the necessary clear understanding of the status of all components of the project, tracking against a well-established set of milestones with appropriate change control. As the importance of a detailed understanding of schedule contingency continues to grow, however, it may be necessary to confirm that the ‘need-by’ dates of all subsystems are firmly understood and calculated on the same basis. In a few cases, it was not possible to understand from the written materials alone the complex interplay between delivery and integration of different subsystems; this obviously affects most keenly the ITk (where integration between pixels, strips, and common services is a

major task) and the TDAQ (which by its nature has connections to all other parts of the project).

As requested at the last review, ATLAS presented a clear estimate of the level of effort required at CERN for the integration and installation phases of the project, summarised in the figure below. The level of effort required is extremely large, peaking at almost 250 FTE in 2026. Securing, organising, and accommodating this level of effort at CERN (and bearing in mind that 250 FTE could represent far more than 250 individuals) will pose a major challenge to the collaboration and to CERN, and it is good to see that the next step of identifying the sources of effort in each subsystem has begun.

Recommendations from the ATLAS P2UG review

General:

- ATLAS should maintain its rigorous approach to review and approval of subprojects, despite the pressure on schedules. The outcomes of reviews, particularly where they are passed only with recommendations, should be documented promptly, with clear deadlines for follow-up.
- Efforts to qualify all sites for production and test of components should be prioritised, including cross-working between sites to pass on knowledge and practical know-how. All possible steps necessary to refine and streamline procedures should be taken, even at the price of increased cost, with a view to maximising production rate from the start.
- The effects of procurement latency should be minimised by prioritizing the queue of outstanding procurements, and by taking a pragmatic approach to procurement-at-risk when justified in terms of the global project outcome.
- ATLAS should continue to work closely and proactively with national contacts to funding agencies to: address resourcing issues as they arise; explore the possibilities for additional resources to increase production rates; and establish a firm basis (e.g. via MoUs) for the necessary commitments of effort at CERN for integration and installation.
- ATLAS should begin concrete discussions with CERN management on the practical requirements of a substantially increased number of collaborators at CERN during the integration and installation period.
- Noting the complex and interlocked nature of the integration and installation planning, ATLAS should begin to explore the practical effects on the overall schedule if delivery of any subsystem were delayed from the currently foreseen date.

General comment to LHCC:

- LHCC should take note of the significant risk of delayed delivery of one or more ATLAS subsystems and consider any possible implications for the optimisation of the overall LHC schedule.

TDAQ:

- The TDAQ project should check and if necessary, revise the "needed-by-ATLAS" dates which are used to define the float. Too generous "needed-by-ATLAS" dates might lead to an overly optimistic impression of schedule reserves. The definition of float should be rather uniform across the ATLAS Phase-II projects.
- The viability of the new dataflow architecture should be clearly established. P2UG requests an update on this development at the next interim meeting.
- Particular care should be taken with the interface specifications between the detector components and the Global Trigger and Readout systems. This requires intensive communications with the detector groups, also outside of the specification reviews.

ITK-Common:

- Procurement priming and advance procurements should be pursued for long-procurement-time items that have been noted in the project (FPGA for MON backend for interlock, PCL components for CO2 cooling). Efforts should continue to identify any other items that might present a risk due to procurement times.
- The effort needs of the CO2 cooling effort should be assessed, together with a plan of resource sharing between the experiments and CERN and presented at the next interim meeting.
- ITk is asked to provide a presentation at the next interim meeting on the software effort including the results of the task force, the deliverables, the timeline and milestones, management structure and responsibilities.

ITK-Pixels:

- Continue to work with high priority on the carbon foam availability problem and start preparing for the procurement of carbon foam from an alternative producer to avoid procurement delays if this becomes necessary. This means: begin the procurement process in parallel with technical investigations of the alternate product.
- Push module site qualification to site readiness (as far as possible without production chip assemblies). Given recent developments, avoiding any further delay in this area is now critical. P2UG will review in detail the progress of site qualification at the next interim meeting.
- We would like to see in the May P2UG an update on the expected module production rate and in the November P2UG an in-depth analysis on the module production across the production clusters, the potential for further optimisation in the production and the according risk as well as a production rate forecast.

TileCal:

- Component procurement/availability is the largest remaining risk for some sub-projects (e.g. Daughter Board). Groups must monitor the situation with vendors closely and be prepared to purchase outside or in advance of the usual FDR/PRR cycles to reduce risk if necessary.
- Now that hardware is starting to be produced in large quantities (e.g. Mini-Drawer mechanics, Active Voltage Dividers, Main Boards), the question of safe and optimal storage at CERN is becoming important. Storage areas in Bat. 175/171 with controlled temperature/humidity environments are likely to be necessary in some cases and so planning needs to start.
- We heard that dedicated installation teams are going to be necessary in LS3. We urge the Tile Group to be proactive now in securing key personnel from around the collaboration.
- The Cs calibration hydraulic system development has made good progress towards identifying a replacement fluid for water. We recommend that priority is now also given to studying how the system can be run at under-pressure – this will be important to achieve regardless of whether water is the fluid used or not. We recommend that this should include the construction of a mock-up and not just be based on simulation.

LArl:

- A Vertical Slice test that demonstrates functionality of a200 full 128 channels, is considered by the P2UG group as a mandatory step.
- The project should ensure close collaboration with TDAQ in specifying readout interfaces, as this is essential for the LAr project to progress detailed design of the boards.

ITk-Strips:

- Investigate the origin of the sensor delivery rate issues, and work with the vendor to bring the delivery schedule back to target.
- Resolve the cold-noise problem with the highest possible priority, using additional resources if possible, and including external experts where relevant.

HGTD:

- More details of the staged installation approach should be provided, in order to maintain confidence that the project will be delivered in all possible scenarios, and to assess the technical and resource implications should staging be necessary. An update on this scenario should be presented at the next P2UG meeting.
- HGTD should adopt validated technical solutions from other projects for ancillary systems and software, wherever possible.

B. Summary Report of the CMS P2UG review

F. Bedeschi, A. Cardini, M. Demarteau (chair), A. Kluge, G. Kramberger, M. Martinez-Perez, R. Pöschl, P. Riedler, C. Roda, M. Stanitzki

At the end of calendar year 2022 CERN released a new long-term schedule of the LHC, with Run 3 extended by one year and LS3 extended by six months. The project very thoughtfully developed a new baseline schedule, incorporating prior experience and judiciously revisited all tasks. Since then, many tasks have unfortunately continued to slip, and the work completed has not kept pace with the work scheduled. A multitude of factors has contributed to this delay, not in the least the war in Ukraine, which forced the project to reallocate scope across other institutions. The pressure of supply chain issues has continued undiminished as well. Unfortunately, the schedule is no longer viable. The task now is to maintain schedule going forward.

Despite these setbacks, the project has made impressive progress on many fronts. Great progress has been made on the validation of the HGCROC-V3 and the testing of the ECON-T-P1. High-density (HD) hexaboards have been produced and a full-size ETROC-2 chip has been submitted. A full system test of the Barrel Calorimeter system has been carried out and the TOFHIR2C chip is being prepared for submission of the final design. There has also been very good progress on the sensors for the inner tracker and the tracker in general. The team is to be congratulated for its dedication and creativity under unprecedented circumstances.

This P2UG meeting BRIL, the Muon system, and the MTD were reviewed in-depth. Status reports were given by the HGCAL, Tracker, Barrel Calorimeter, L1 Trigger and DQ and HLT system. The Beam Radiation, Instrumentation and Luminosity (BRIL) project is a set of 14 systems for radiation monitoring, beam timing and abort, beam-induced background, and sub-bunch-by-bunch luminosity measurements to constrain individual luminosity uncertainty contributions to sub-precent precision to reach the ambitious goal of 1% total uncertainty. It is a very robust system diverse technologies and counting methods with different systematics. The neutron and radiation monitoring system, a Russian responsibility, will be extended with new gas filled proportional counters (GFPC) and a Bonner sphere spectrometer (BSS) to better measure the CMS radiation field. The latter will measure the spectral neutron fluence in the range 10 μeV $< E <$ 10 MeV. Due to the current international situation the funding for the GFPC system is frozen and no existing agreement between CERN and Russia exist for their use in CMS. It could be difficult to move production outside Russia as cadmium and lead are used in the moderators.

The Beam Condition Monitor for Losses (BCML) and abort system is installed in two locations in CMS at $|z|$=1.8m (BCML1) and $|z|$=14.4m (BCML2). Sensor options are under study for deployment during Phase II. The list of suitable sensor technologies for BCML2 has been narrowed down to pCVD and Sapphire. Sapphires and diamond sensors have an in-kind contribution component from Tomsk Polytechnic University (TPU). Sufficient sapphire sensors for BCML2 for the initial stage are available, however availability of diamonds is a concern.

The BRIL Trigger Board (BTB) is a board that has a complex interface with the Timing and Control Distribution System (TCDS) and the Global Trigger to collect data for the luminosity measurement, for which pixel cluster counting using TEPX will be one of the primary sources. The development of the BTB is in an advanced state and a well-defined

roadmap for its implementation was presented. Currently four different example trigger algorithms as well as a mechanism for dynamic trigger rate allocation are under development.

The Fast Beam Condition Monitor measures Beam Induced Background and Bunch-by-Bunch luminosity. This detector, which is an upgrade of the existing BCM1F system, is needed on day one. Exchange of modules is foreseen as needed. The readout ASIC in 65nm technology is a key feature of the detector and the first submission of a prototype chip is planned for May 2023. The manpower situation is a concern to complete this system on schedule.

The BTL has developed a path to obtain the required timing resolution and the projections indicate that this will be achieved. A test beam is planned for early 2023. These results will inform the final design. A production readiness review (PRR) of the TOFHIR2C was held in October 2022 and the chip is ready for submission. This is expected to be the final version of the chip. The wafer will be shared with the Raphael and ALDO chips, which is an excellent use of wafer real estate. The performance expectation at the end-of-life (EOL) is approximately 66 ps for 25 μm SiPM cell size and 61 ps for 30 μm SiPM cell size. The P2UG encourages the project to implement the necessary changes, if funding allows, to obtain the required timing resolution at end-of-life with sufficient margin.

The ETL has made great progress overall. Safe operation conditions of 10 V/μm have been established and sensors have been qualified to meet all specifications, even in the very radiation hard inner region. A comprehensive test beam campaign at FNAL showed very good performance using HPK sensors. The team is to be commended for developing an emulator of the ETROC2, which has greatly aided the overall development. A full-size full-functionality version of the ETROC2 ASIC (ETORC2) has been submitted.

For the muon system various pressures have recently emerged, mainly for GE2/1 and ME0. The GEM foil production in Korea for the GE2/1 and ME0 detectors has been halted. The production facility will be moved to another site in Korea and will need to be re-qualified. The P2UG has concern that this may take a significant amount of time and recommends that it be investigated if all foil production can be done at CERN. The PCB production has been halted due to funding issues. The VFAT3 readout chip has a worse timing resolution than required and channel losses have been observed that seem correlated to HV events. The cause is being investigated.

Progress on the iRPC system is good. The Gent assembly and QC site has been recommissioned and mass production will start in December 2022. The Mexico City site is getting ready with final validation planned for next year. There is opportunistic installation of 1 of 4 disks at YETS23/24 with + endcap crane under maintenance; the remaining disks can be installed during YETS24/25

The drift tube, cathode strip chambers and longevity studies are all progressing well.

The HGCAL encountered a serious issue during the pre-series wafer processing at HPK where some 120um epi-wafers broke during fabrication. The production for all 8-inch sensors, part-way through pre-series, was halted. At the moment this does not impact the project since enough material is available, but the source of the problem needs to be understood by HPK. A possible mitigation strategy is to substitute part of the 120um with 200um sensors. The testing of the HGCROC-v3 is essentially complete and the chips is performing well and ready for the launch of the engineering run in Dec. 2023. The HGCAL has seen a delay in the submission of the ECON-D chip, which sets the critical path. Currently, the schedule contingency is little more than one month, though there remains some internal float. The first version of the ECON-T chip has been received and

only a few minor issues have been observed. It is noted that the addition of the CERN ASIC engineers has had a tremendous positive impact on the progress. The future production schedule for the ECON ASICs, however, is very aggressive. Not just maintaining but increasing the person power on the ASIC team is required to keep schedule with frequent exchange of engineers between CERN and Fermilab.

CERN and FNAL are proceeding well with the specification of cassette assembly and quality control. Five module Assembly centres on track, one still to be completed. Excellent progress has also been reported on the productions of first version of cooling plates including integration of cooling pipes. The project has demonstrated swift action to mitigate the impact of the war in Ukraine. There has been a nice influx of new resources, which is very much welcomed. The project has proposed an early installation of flexible cooling lines instead of (external) rigid transfer lines to gain schedule. The team is to be commended for their pro-active thinking.

There has also been swift action to move scope for the scintillator section of the HGCAL due to the war in Ukraine, which minimizes the impact on the overall project. A decision has been taken to proceed with 4 mm^2 SiPMs over $2mm^2$, which provides for better overall performance. The P2UG was very pleased to see the remarkable progress with the test beam studies with a v3 low-density Si Module and very much congratulates the team with continuing their physics studies and publications.

The barrel calorimeter is making great progress with only a minor issue observed due to CATIA SEU-induced reset on the system, which are being studied.

Good progress has been made with the outer tracker. The project has only one vendor to produce all the hybrids, which exposes it to some risk. Good communication with this vendor is strongly encouraged. The MAPSAs production has seen further delays and now drives the critical path for the outer tracker. Expeditiously qualifying vendors for the MAPSA production is a priority. Noise mitigation of the PS modules is in progress.

The submission of the readout chip for the inner tracker, the CROC chip, has been delayed due to issues found in the ATLAS pixel chip. The CMS chip will be submitted after the ATLAS chip. The CROC drives the schedule for the inner tracker. The P2UG supports the implementation of the CROC in parallel with fixing the ATLAS chip. More resources to help the design would be very beneficial. Higher noise has been observed for some of the 3D sensors for the inner tracker after irradiation, which is being studied.

The project uses K9 carbon foam in several subdetectors. There is not enough material on stock for the full upgrade program and the supplier has not been responsive to inquiries from the collaboration. An alternative material needs to be found, or an alternative vendor. Judicious use of the existing stock material is required.

The progress with the Level 1 Trigger, the data acquisition system and the high-level trigger is quite impressive, and these systems are very robust. Supply chain issues for electronics components are adequately managed.

The CMS Phase II project is in desperate need of experienced mechanical and electrical engineering, and applications physicists exceeding the 20 FTE level. The effect of the addition to date of experienced personnel has been impressive. The extra engineering for the ECON and RD53 chips, for example, and the additional engineering for the hexaboard design have seen these tasks progress much more quickly. Not just maintaining these resources, but adding resources recruited from the collaboration and supporting institutions will be required to maintain the current schedule.

As noted in our previous report, the upgrade project is at a pivotal moment, entering the final verification phase of many components before moving to production. This phase is crucial to ensure the performance of the upgrade. CMS is one experiment, and this is the time for the collaboration to come together. The collaboration would do well to develop a shared sense of urgency to maintain schedule and ensure that all the components meet specifications.

The full report by the CMS P2UG is available as a separate report.

Recommendations from the CMS P2UG review

BRIL: Neutron and Radiation Monitoring

- Guarantee that personnel and/or expertise for proper operation and calibration of the legacy GFPC system and other existing monitors is available.
- Evaluate impact of project cancellation vs. investigating alternate producer for GFPC and BSS
- Explore collaboration across other experiments and/or CERN for activation analyses.

BRIL: Beam Condition Monitor for Losses

- Investigate resources and possible supply options for diamond detectors and for the metallization of the sapphire and diamond detectors.
- Proceed with the PCB design for BCML1, the definition of cabling/connection and location of the tunnel cards.

BRIL: Trigger Board

- Verify managing LHC frequency ramps without loss of phase lock or data corruption with final versions of all ASICs, firmware and hardware.
- Specify the requirements for the external interfaces to: TCDS, Global Trigger and Machine Interface.
- Clarify and formalize (together with the other experiments) the requirements to the successor of the BST system and the synchronously distributed information needed from the machine to implement the dynamic trigger rate allocation between BTB and the Global Trigger.

BRIL: Fast Beam Condition Monitor

- Specify the timescale and criteria for decisions between different options for the FBCM.
- Plan manpower allocation in particular for key positions to follow the ASIC development and the development of the electronic board.
- Clarify the plan and time schedule for radiation hardness tests of the electronics.
- Secure the engineering resources for the ASIC (65 nm) and the manpower to ensure availability on day 1.
- Maintain the schedule, given the importance of this detector.
- Increased noise level after irradiation of the sensors calls for eventual exchange of FBCM modules. Irradiation studies should be carried out for both types of

sensors and the ASIC to verify the operational limits for irradiated modules and determine the replacement frequency of the front-end modules, driven by leakage current in the sensors.

- Monitor performance after ASIC delivery to plan for the frequency of FBCM replacements.

Muons: Drift Tubes

- Evaluate the new timeline considering delays due to components lead time.

Muons: Cathode Strip Chambers

- Try to keep the project schedule to profit of continuous access to off-chamber electronics throughout LS3 for global installation schedule optimization.

Muons: GE2/1

- Evaluate if both the GE2/1 and ME0 GEM foil production could be fully done at CERN.
- Urgently find a solution to purchase part of the PCBs in order not to stop module production.
- Continue studies to understand how to reduce VFAT3 channel losses, both during module assembly and during operations with beam and their origin.
- Define in-situ chamber repair procedures related to the VFAT3.
- Evaluate impact of possible further delays of GE2/1 schedule.

Muons: ME0

- Evaluate if ME0 GEM foil production could be done only at CERN without delays in schedule.
- Understand origin of gain losses at large eta and find mitigation strategy.
- Understand consequences of VFAT3 effective time resolution.
- Understand origin of VFAT3 channel losses at production and in operation.
- Re-evaluate a global ME0/GE21 construction/installation schedule taking into account that ME0 chambers can only be installed in January 2027 at the surface while GE21 chambers could also be installed opportunistically during various YETS.

Muons: iRPC

- Complete physics performance studies to decide on the iRPC production strategy.
- Complete analysis of radiation test to decide which FEB (v2.2 or V3) will be used in production.
- Accelerate the Mexico City assembly site certification.

Muons: Eco-friendly gases and Longevity Studies

- None

MTD-BTL

- Obtain the test beam results at FNAL timely and base your decision on these, which is required to place large orders.

- Optimize the thickness of the LYSO crystals throughout the BTL, which is scientifically justified, if the funding can be secured.
- Increase in operating margin for the timing resolution is strongly supported.
- Evaluate impact on physics for eta=0 tracks for the timing resolutions achieved.
- Carefully study the annealing process to obtain lower dark count rate over the lifetime of the experiment.

MTD-ETL

- Consider adding the measurement of the leakage current on pad level in the ETROC3
  monitoring.
- Invest effort in understanding the grounding and sensor-ASIC coupling
- Strive to be ready (parts, hybridization…) for building first full modules as soon as ETROC2 arrives.

Barrel Calorimeter

- Continue the system qualification using full system tests in and outside of test beams, assigning sufficient resources for the preparation and implementation.
- Study the effect of CATIA SEU-induced reset on the system side, even though it is a minor effect, and study the effort to repair CATIA before submission and decide whether CATIA should be repaired.
- Plan ahead with the manpower required for the BCP firmware.

HGCAL

- Fully verify that the problem with wafer breakage is understood and solved.
- Define mitigation strategies: how many 120um can be substituted and fully understand the implications of this change: impact on physics, radiation damage, timeline to decide.
- Decide latest in spring 2023 whether or not to enact the mitigation strategy.
- Ensure packaging of the ASICs can be done on the desired timescale.
- Add both CERN and Fermilab manpower to the ECON project; this will be essential to maintain schedule.
- Try to satisfy the request for even more resources for testing, verification and implementation.
- Establish frequent, long-term exchange of personnel between Fermilab and CERN to collaboratively work on the submissions, which is also essential to maintain schedule.
- Produce and test quickly also high-density version of Si modules.
- Ensure that the current staffing for the board design, layout and verification is maintained if not strengthened.
- Ensure the production of 10 modules per MAC for the 5 MACs between now and next P2UG.
- Provide a clear schedule to reach the 10 modules production rate for the Mumbai MAC.
- Make a careful record of the production process.
- Verify that the MACs are fully qualified and can handle the maximum
  throughput with the appropriate staffing.

- Continue the encouraging mitigating actions with respect to the situation in Ukraine.
- Plan without expecting Russian and Belorussian contributions.
- Maintain open communication channels in order to keep Russian/Belorussian expertise and benefit from their “savoir-faire”.
- Work out fully the strategy of an early installation of the cooling services in UXC on YE1.
- Conclude the radiation tests of tile boards in hypoxic atmosphere as quickly as possible.
- Ensure enough trained staff at NIU and FNAL to take on the extra load for the scintillator scope.
- Proceed with the procurement of the SiPMs.
- Proceed with procurement of Engine and Wagons
- Train enough personnel to test the hardware of slice and system tests.
- Reserve beam test slots to qualify the Si Modules expected from the MACs in 2023
- Provide results for all channels of a Si Module.
- Ensure that the software follows quickly hardware changes (e.g. change of inner Si Sensors).
- Continue to study the impact of these changes and actual performance metric through updated simulation and reconstruction and present results at the next P2UG

Tracker

- Engage closely with the single hybrid vendors to address the issues occurring during hybrid manufacture and continue to actively explore options, in collaboration with the vendors, to meet the fabrication capabilities of the vendor through adjustments to the design.
- Invest all effort to solving the observed noise issues in the completed modules.
- As the OT hybrid are the most critical object, the P2UG suggests a dedicated session with the Tracker Project at the end of the tendering process.
- Proceed with the preparation and qualification of all module assembly centres, moving them to the next stage and assemble more modules of both types.
- Continue with systematic tests on module level as well as on system level tests to increase statistics.
- A strategy to mitigate material procurement shortfalls should be developed to address potentially long lead times, non-availability of material or non-optimal performance.
- Present and finalize the plan to qualify the hybridization vendors based on available material (including CROC modules)
- Ensure that all aspects of chip operation are checked and that the two months between ATLAS final chip and CROCv2 submission are used most efficiently
- Fully understand the parylene coating and masking procedures, which is very delicate.
- Adopt all necessary actions for a sufficiently robust thermal performance of TBPX

Level 1 Trigger

- Carefully balance early procurement of active parts with need-by date for data taking.
- Design and implement the strategy for electronics component purchase for final production.

DAQ

- Monitor component situation closely and purchase early when possible.
- Continue to coordinate with DAQ-subdetector development.
- Continue the evaluation and modernization of the online software stack.

HLT

- None