Report of the ATLAS Phase-II Upgrade Project Review (P2UG)

Sixth ATLAS-P2UG Meeting, 8-12 November 2021

In-Depth Review: TDAQ, ITK-Common, ITk-Pixel, Tile projects

Regular Review: ITk-Strips, LAr, Muon, HGTD projects

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The agenda and presentations can be found here:
https://indico.cern.ch/event/1092230

Introduction

The ATLAS P2UG met with the upgrade project leadership from 8th-12th November 2021, following an intermediate update meeting on 2nd August 2021. 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 two afternoons of focussed presentations and a Q&A session. For the other projects, an overview talk was given, and in some cases written questions answered by the project managers. The only part of the project not reviewed was the Event Filter track-finder, as the new proposal for this system this is currently under review by UCG.

The P2UG was able to form a clear impression of the project status and trajectory in each case. However, it was clear that the meeting format (fully virtual, due to COVID restrictions) compressed a very large amount of information into a condensed schedule. We hope to be able to return to a more conventional format and level of discourse at the next meeting. It is also clear (as commented in our previous report) that the rate of developments is such that an annual in-depth review for each project is currently not sufficient to follow events in the necessary detail. Consideration needs to be given to the format and frequency of meetings, especially if we are now to enter an intense phase of re-planning of the project.

As at previous meetings, the materials presented by ATLAS were comprehensive, transparent, and overall well-suited to the task of judging progress and upcoming challenges. We thank the ATLAS upgrade coordinator and the entire team for their efforts and responsiveness.

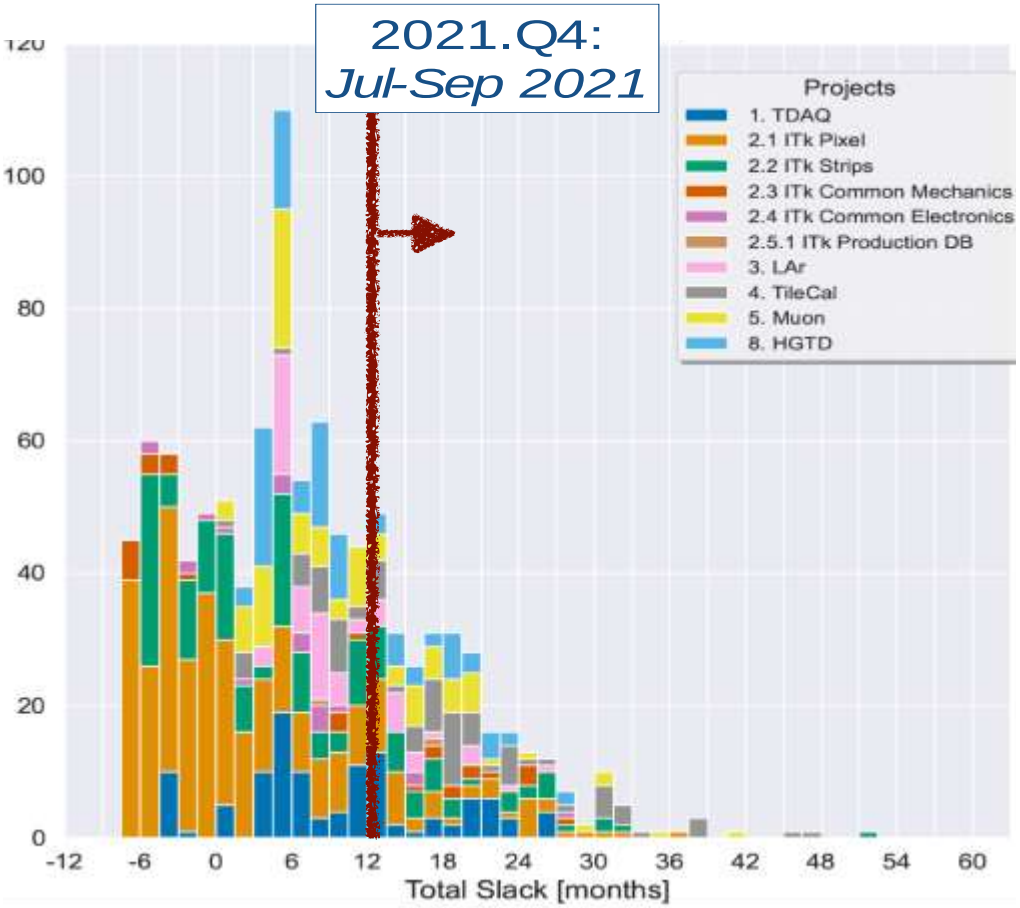
Progress against schedule

Two key sets of progress metrics are shown in figures below:

- The completion to date of P2UG reporting milestones up until 2021-09-30 (these are an indicative subset of the full ATLAS project milestones), along with progress in the last quarter (2021 Q4) on both expected and previously delayed milestones.
- The current distance-to-critical-path of the tightest milestones, where zero DCP represents delivery exactly on the need-by date required by the current LS3 installation schedule, and 12 months DCP corresponds to the current expectation for schedule contingency.

Project	Baseline Overall (until 2021-09-30)				Baseline Reporting Quarter (Jul-Sep 2021)			Expected milestones from previous report					
										2021.Q4	2021.Q3	2021.Q2	2021.Q1
	No. P2UG Milestones	No. Expected	Completed	Completed (%)	No. Expected	Completed	Completed (%)	No. Expected	Completed	Completed (%)	Completed (%)	Completed (%)	Completed (%)
1. TDAQ(*)	164	15	10	67	5	0	0%	**2**	**-**	**0%**	**33%**	**50%**	**100%**
2.1 ITk-Pixel(*)	339	55	23	41	16	0	0%	**11**	**2**	**18%**	**14%**	**37.5%**	**40%**
2.2 ITk-Strips(*)	217	92	47	51	20	0	0%	**10**	**5**	**50%**	**54%**	**27%**	**23%**
2.3 ITk-CM(*)	36	8	7	88	0	0	-	**-**	**-**	**-**	**-**	**-**	**-**
2.4 ITk-CE(*)	37	21	15	71	2	0	0%	**5**	**1**	**20%**	**33%**	**50%**	**25%**
2.5.1 ITk-PDB	4	3	2	67	0	0	-	**-**	**-**	**-**	**-**	**-**	**-**
3. LAr	91	38	24	63	3	0	0%	**2**	**1**	**50%**	**33%**	**33%**	**75%**
4. Tile	124	53	37	70	7	1	14.3%	**2**	**-**	**0%**	**12.5%**	**40%**	**25%**
5. Muons(*)	151	75	48	64	6	2	33.3%	**11**	**5**	**45%**	**27%**	**10%**	**37%**
8. HGTD	153	8	5	63	3	1	33.3%	**3**	**1**	**33%**	**0%**	**-**	**-**

(*) re-baselined over summer



A summary of the situation is as follows:

- The COVID situation continues to affect the projects severely. The effects are not uniform across ATLAS. For some projects, we have seen good progress and even some recovery in the last quarter; for some a further reduction in float, but at a controlled level; and for others, a further worsening not just of the overall schedule situation, but of the rate of slip.
- The immediate practical effects of COVID, as relayed by the collaboration management, are mainly related to the inability to travel, and inefficiencies imposed by local restrictions at institutes and laboratories around the world. However, the indirect effects of COVID on the global supply chain, particularly for microelectronic components, are now also being felt. This has affected not just upgrade deliverables, but also those needed for Run-3.
- The worst-affected project appears to be the ITK-Strips, where a worse-than-real-time level of slip has occurred in the last quarter, owing to a combination of COVID effects and re-appraisal of the longer term schedule. Although the causes and consequences of this slip seem to be understood, it is nevertheless worrying, and a clear sign that the full effects of COVID are yet to be seen.
- The overall distance-to-critical-path based on the need-by dates for installation (dictated currently by the ITK-Strips project) is around minus six months, as compared to an expectation of plus twelve months. No project currently has a twelve-month float for its tightest deliverables, though there are projects for which many subcomponents maintain an acceptable float, as shown above.

In general, P2UG is concerned that the very difficult situation over the last eighteen months has removed momentum from the project, and in some cases reduced the effectiveness of internal communication such that the projects are insufficiently cohesive and therefore not in the optimum state for rapid recovery once the direct effects of the pandemic decline. This is not a reflection on the management, who are uniformly taking proactive and pragmatic actions to the extent they are able. However, we are also concerned that the planning for some projects is becoming increasingly 'success-oriented', whereas in practice there is every reason to expect further delays and difficulties.

In response to schedule pressure, in some projects a re-appraisal of the level and breadth of QC procedures is taking place. In others, sub-components with interfaces and dependencies, originally intended to be reviewed together, are now to be reviewed separately in order to save time. We regard these steps as potentially increasing the technical risk of the project in a poorly controlled way. Rationalisation of QA/QC is not an incorrect step *per se*; excessive conservatism should be avoided, and a continuous re-appraisal of the risk profile is of course necessary. However, we remind the collaboration of previous recommendations not to compromise quality in order to preserve schedule, bearing in mind the potentially severe long-term consequences for the ATLAS physics programme. Any such changes need to be accompanied by a full statement of the overall movement in risk profile, since in practice if risks manifest, no time or cost may be saved.

It is becoming clear that a measurement of distance-to-critical path based on a nominal 'need by date' does not give a full picture; it will also be necessary to examine the complete picture of the construction schedule combined with the installation schedule in order to judge the situation.

Changes to the schedule

At the forthcoming LHCC discussions on the overall LHC schedule, the collaboration will request an extension of eighteen months, based upon a one-year extension of Run-3 and then a six-month extension of LS3. Although the P2UG is not called upon to make an explicit recommendation here, we did consider three related questions during the meeting:

1. Is an eighteen-month extension to the schedule justified in terms of cost-benefit, and has the collaboration taken all available steps to optimise the existing schedule?
2. Are there acceptable descopes to the project that could represent an alternative to a schedule extension?
3. Would an eighteen-month extension address all issues with the current schedule, and allow reasonable certainty for delivery against the full current scope?

For question (1), the answer is clearly 'yes'. We are convinced that the project has a clear and justified plan and a clear understanding of where it sits in relation to that plan. For the tightest projects, schedule task forces have worked over several months to review the planning in depth, and have concluded that there are no major savings of time to be made if the full project scope is to be preserved.

The answer to (2) is 'no'. The level of descope required to make a significant time saving *without compromising quality* would clearly be extremely damaging to the performance and physics potential of the experiment. The sole exception is the postponement of the HGTD detector, which will compromise initial physics performance, but which can be installed at a year-end stop after one or two years of running. The correct approach is therefore to identify an appropriate length of schedule extension that can allow installation of the fully-scope of the upgrade with sufficient margin and attention to quality, but minimise the additional resources required to do so.

For question (3), it is not currently possible to give an answer with certainty. The panel feels that, as things stand at present, an eighteen-month extension will move the project prospects from 'impossible' to 'challenging'. It is clear that a significant replanning of the project schedule will be needed in order to re-assess the optimum strategy and associated risks. This may entail movement of resources or responsibilities, in consultation with the wider collaboration and its funding agencies, in order to ensure a balanced programme where schedule contingency is properly distributed across projects. It is very likely that steps will need to be taken to streamline and optimise the distribution of work and logistical issues. We recommend that, before a final decision is made on a schedule extension, a re-baselining of the project schedules is made, and if necessary, revisions to MoUs are considered.

General recommendations

To ATLAS:

GE-6-1: ATLAS should prepare for an intense period of re-baselining of the project schedules in order to generate a detailed plan for an eighteen-month extension of the construction schedule, and demonstrate that delivery of the full project scope is possible under those conditions with reasonable certainty. The recommendations of the ITK schedule task forces should be adopted where relevant as part of this process.

GE-6-2: ATLAS should build into that process the expectation that further significant supply-chain delays due to COVID will be experienced over at least the next 24 months. The new schedule should be flexible enough and sufficiently well-provisioned with contingency to withstand the delay of any single component by up to twelve months. This may require an increase in the rate of deliverables that are in the hands of the collaboration, in order to offset delays in supplies.

GE-6-3: As part of the overall schedule replanning, a detailed update of the schedule for LS3 installation should be made, in order to understand the necessary contingency provision. The personnel need for the post-installation commissioning phase should also be examined, as should the overlap with the installation period, since these also affect the total cost of the project as seen by the funding agencies.

GE-6-4: ATLAS should begin discussions and negotiations with funding agencies and NCPs at technical level, to understand (a) how recovery from COVID and re-convergence to the necessary rate of progress can be best accomplished in each country, and (b) what flexibility exists on responsibilities, personnel, and funding profiles to allow optimisation of risk and schedule.

GE-6-5: ATLAS should not allow projects which do not dominate the critical path analysis (e.g. muons, calorimetry) to relax from their current rate of progress or lose further time; the early delivery of these projects will be a vital element in maintaining flexibility in both the construction and installation schedule.

GE-6-6: Any proposals to reduce or redefine QA/QC procedures should be the subject of a full documented risk analysis.

To LHCC:

LH-6-1: LHCC should define clearly the time scale on which a detailed revised schedule is expected from ATLAS, and the steps that will be taken to review it before a final decision is made.

LH-6-2: LHCC should recommend that, where necessary, CERN negotiates changes to the global delivery schedule by common vendors for CMS and ATLAS (for instance, for silicon sensors) to allow the construction schedule of both experiments to meet the respective need-by dates for installation.

LH-6-3: LHCC should recognise that an optimal plan for ATLAS upgrade delivery may require re-negotiation of deliverables already documented in MoUs, and set down the thresholds and procedures governing the need for further review.

TDAQ (in-depth review)

General observations / comments

The in-depth review of the TDAQ project proceeded through one plenary report and eight parallel session reports. All speakers should be commended for the excellent quality and clarity of their reports. The TDAQ project has made very important structural changes since last P2UG meeting in May 2020. A decision has been taken to terminate the Hardware Track Trigger (HTT) development and instead base the EF tracking on a heterogeneous commodity technology. This carefully prepared step, which involved all relevant executive levels of the collaboration, has eliminated some major technological risks and simplified considerably the overall layout of the TDAQ system. As the tracking part of the EF is thus currently under major restructuring and subject to a TDR amendment currently in the UCG review process, its internals have been excluded from this in-depth review. Nevertheless, it is very apparent in the other TDAQ areas that the overall complexity has been greatly reduced, which clearly benefits the successful execution of the project.

In general, the TDAQ project seems not now to be suffering significantly from further direct effects of the pandemic. However, delays occur due to key person-power being occupied with tasks related to Phase 1 upgrades and the preparation of Run-3. These effects are expected to be relatively short term and cease by the summer of 2022. Taking these circumstances into account, the TDAQ project is overall found to be in a rather good shape, though there are various points which need continued attention.

Comments on subsystems

L0Muon

The L0Muon trigger processors are somewhat delayed by addressing the comprehensive feedback they received at the PDRs. In case of TGC and RPC which share similar technology, much float can be recovered by shortening the allotted schedule for final prototype and pre-production. This expectation is backed up by recent experience with the prototype TGC/RPC FE electronics development. The MDT trigger processor is delayed by sixteen months to apply modifications in the command module that became mandatory in course of the PDR, as the FPGA logic resources were found insufficient. As a result, the two FPGAs have been replaced by a single, more powerful FPGA. For the NSW, a new trigger processor board had to be designed, and the respective group is currently busy with Run-3-related work. After BCPs, the current float across these projects is typically four to five months.

For the Muon Sector Logic, which requires a total of 80 ATCA blades, the first board prototype was delivered in October and is being prepared for tests. The firmware for both barrel and endcap systems is planned to proceed to PDR in December.

L0Calo

It was already noted in the past that L0Calo had been delayed due to resource conflicts with Phase-1 upgrade work. This effect continues to not only affect the legacy feature extractors that are already used in Phase-1 and will be reused in Phase-2 but also new developments like the forward feature extractor (fFex). The L0Calo project has still plenty of float left, almost 1.5 years, but it is important that developments get back on track once the Run-3 has started.

L0Central, MUCTPI and TTC

The Central Trigger Processor project was delayed due to a significant amount of existing engineering and physicist effort diverted into the corresponding Phase-1 upgrade, which is also delayed. In addition, some effort was directed into the study of EF tracking options. With a more realistic assessment of the date when the whole CTP is needed by ATLAS, the float is currently still about nine months. Upcoming milestones are the specification review at the end of 2021, and the PDR in summer 2022. For the MUCTPI system, there is much positive experience from the testing of the Phase-1 prototypes and the commissioning of the Phase-1 board. There was no baseline change, and the project has still twelve months of float. The TTC project has gained valuable experience from a recent optical link test. There are new timing requirements from the HGTD which needs low phase jitter, and corresponding measures are being devised. The specification review was successfully passed in May 2021.

Global Trigger

The Global Trigger is primarily a firmware development project. Initial versions of the essential firmware are in place and are being tested. This also includes initial versions of trigger algorithms. Sustained availability of an engaged firmware system engineer, and successful annual release cycles are essential. There is still the issue of the Global Common Module's power utilization, which was found to exceed the limits set by Technical Coordination for ATCA modules, and whose estimation is subject to sizable uncertainties. While various detailed technical modifications to the blade are investigated, a change to the PCIe architecture is also being considered.

Network

The Network project has adapted its architecture to accommodate an increased number of readout servers (by 20%) and a doubled throughput requirement from Dataflow. The project is also preparing a major technological decision: The evaluation of Infiniband has suffered long delays due to the difficult procurement of the equipment, and it is expected that the global situation on this shortage may not improve soon. It is thus strongly considered to move to Ethernet instead, employing either iWARP or RoCE as RDMA protocol. After careful evaluations this decision is planned to be taken by November 2022.

Dataflow

The Dataflow system is undergoing a significant design change regarding the transport of data between Readout system and Event Filter nodes. The originally foreseen large intermediate disk buffer became a risk due to throughput performance uncertainties and SSD cost developments being less favorable than originally expected. The new design foresees that data from the readout handlers will be directly written into the memory of the EF nodes. This results in a doubling of the required data bandwidth, which the Network system technology is able to provide. The storage handler will still provide capacity for the storage of selected events, based on HDDs.

Online software

The Online Software team has significantly gained experience with the management tools employed for the EF nodes. The Kubernetes software was successfully operated on a prototype cluster with 36 workers, and pilot services have been operated and monitored, passing two corresponding milestones. Tests with larger systems are being prepared. The DAQ to SoC subproject, which focuses on the communication between DAQ and embedded systems, has entered the prototyping phase. The requirement document is completed.

Event filter

The task of the Event Filter has been simplified by the removal of the HTT, but the CPU power requirement has more than doubled (from 4.5 to 11.4 MHS06). The actual procurement of EF

processing units is strongly related to the decision about accelerators, which is expected in 2025. An important part of the project is now the production of the EF selection software, which ramps up slower than expected due to the Run-3 startup delay. A BCP will be required once the new EF tracking is settled.

Recommendations

TD-6-1: The TDAQ project should keep a very close eye on the evolving procurement delays of electronic components. These might result in the need to place orders considerably further in advance, which should be proactively anticipated.

TD-6-2: Concerning the ATCA/PCIe choice in the Global Common Module, it might be advisable to clarify with Technical Coordination whether the issue could not be mitigated with exceptional arrangements in USA16, like wider spacing of ATCA modules, and preferably not keep this ambiguity of the architecture unresolved until the FDR.

ITK-Common (in-depth review)

Good progress was reported in all areas but, at present, the ITk readiness date is more than seven months late without any float. The integration and commissioning schedule depends most crucially on the availability of modules and sub-assemblies, i.e. on sensors, ASICs and hybrids, which are known to be problematic. Therefore, the credibility of this part of the schedule depends to a very large extent on confidence in the schedules for the major components.

The sub-assemblies come from distributed sites so uniform standards will be important, and objects must be well tracked via the database.

Comments on subsystems

Common Mechanics

There were no major concerns about common mechanical components and common structures. The global mechanics collects work on several different sub-elements, such as Barrel and Endcap systems, so a lot of interfaces are involved, managed by different collaborators. However, this appears to be proceeding according to plan.

The CO2 cooling system is complex but seems to have many experts available, is well resourced and is being developed in common with CMS and CERN. Significant elements of the system have been tested with prototypes, identifying some issues which are being addressed. Questions about maintainability and access to spares because of the diversity of some components were satisfactorily answered. A secondary issue is the proximity monophase cooling of cables. While all the cooling developments appear to be proceeding satisfactorily, assessment must rely heavily on expert internal reviews and management to ensure these systems remain on track.

There are a number of common mechanical structures such as support tubes, outer cylinders and bulkheads, as well as beam pipe interfaces. All appear to be compatible with the final ITk delivery schedule, although with some delays caused by COVID and a minor problem identified with a small crack in the outer cylinder, which has been carefully studied.

The final integration and commissioning was a major topic. Planning appears to be proceeding well, but subject to the caveat already mentioned about the availability of modules and sub-assemblies which will eventually determine the final schedule. At this stage, a lot of emphasis is on the surface installation area where the integration and preliminary testing will take place, and plans for the necessary services. A significant change to the plan was a recent decision to drop the two-month surface commissioning period preceding installation underground, on the grounds that it would mostly repeat what should already have been done thoroughly as individual layers

are integrated. It would only be possible to test 1/8 of the detector anyway on the surface, which raises some questions about cooling and powering of a partial system. As the integration and evaluation of individual layers must be very thorough, because it becomes increasingly difficult to access and repair anything after assembly, the decision is plausible.

The collaboration appears to be anticipating potential issues very well. At present, the plans for services in the surface integration facility, such as provision of power cables and fibres, are not complete, so we would expect future reports on these items.

The schedule for ASIC manufacture and test was not scrutinized in this session, and is a concern. It is known to still be very demanding, with some components (HCC*, AMAC*) not final and others (ABC*) not yet having commenced production deliveries. ASIC manufacture currently involves significant uncertainties of cost and delivery times because of the impact of COVID on the industry and global demand. Until this is well underway, doubts will remain over the reliability of the overall schedule.

Environmental monitoring, interlock and protection system

For the Environmental Monitoring, progress on all three types of detectors (temperature, humidity, radiation), as well as on the design of the readout chains was shown. Two internal reviews were conditionally passed in 2021 but follow-up still to be completed.

Other milestones with execution dates in 2021 have been postponed by six to seven months. bringing the DCP in a couple of cases into negative territory. Detectors have to be validated and some design choices remain to be made before production can start next year.

For the Interlock system the FDR follow-up was completed in May 2021 and preproduction of modules has subsequently started. However, PRR and production completion milestones have been shifted meanwhile by one year. The firmware FDR is foreseen in 2022.

The general impression is that, although there is still sufficient float in the subprojects, it is important that, especially for the Environmental Monitoring deliverables, no further delays are introduced and that progress is carefully monitored until production of the various components has successfully started.

BCM'

Significant progress has been made since the last in-depth review:

- the sensor prototypes were ordered from the vendor, are expected to arrive soon and will be tested to provide the data for passing the FDR/PRR review;
- the 3rd iteration of the FE chip (Calypso_C) was received in December 2020 and tested OK, except for a very large offset spread in the threshold calibrations curves. After 300 Mrad irradiation, small analogue parameter deviations have been observed. SEE tests were also successfully carried out.

The next FE submission (Calypso_D), planned for May 2022, should address the offset spread and include additional features. Modules, readout and services are expected to be finalized next year.

Overall, the R&D program on the key components of the BCP' system (sensor+FE chip) is well advanced, but it is expected that the engineering support for electronics next year will no longer be available. This is a first reason of great concern, since clearly the lack of support could jeopardize the possibility to complete the development of the FE chip in due time.

Covid seems also to represent still a risk for the upcoming work to to be carried out at JSI, the institution that carries most of the responsibilities in the project.

There is still approximately one year of contingency in the schedule. However, for completing the design and the construction of the system, it is essential that the institutions involved can consolidate a team with the required set of expertise, technical capabilities and manpower resources to carry out the remaining work. The recent engagement of CERN personnel, providing mechanical and readout support, is a very promising and important step forward in this direction, but not sufficient since other areas remain uncovered.

Common Items

Ongoing work to develop the Production DB, the Online SW and the DAQ/DCS SW and FW has been presented.

The Production DB is progressing steadily and first plots of test results stored in the DB have been produced. The completion of the Production DB has been slowed down by the delayed final design of some components but seems to be on track for the start of the production activities. Development and long-term maintenance are to be provided by different entities, so it's important the transition from one to the other is carefully planned and executed.

For the Online SW, two milestones were passed this year, as scheduled, but for the DAQ/DCS most milestones have been delayed by several months. However, next important goal of serving assembly and integration sites seems to be feasible next year.

Recommendations

IC-6-1: The collaboration is very attentive to issues of infrastructure (cables, power, cooling, DAQ) and should continue to be so. This includes the services needed for the surface integration activities, which are still being defined. Continue implementing and deepening all three proposed schedule slip mitigation actions, while focusing on completing the pre-productions.

IC-6-2: Everything possible must be done to ensure the ASIC schedule is maintained and that preparations are well in hand for high throughput once deliveries start.

IC-6-3: The BCM' is a small project on the scale of the overall upgrades, but it's quite an essential element for the functions it provides to ATLAS. The project will have to evolve soon from R&D to the final design of all components and interfaces and therefore a solid and viable team in charge of the activities is essential. We would like to see, at the next Review in May, an updated and consistent resource loaded schedule for the BCM' system, with the time profile of the engineering/technical resources that are needed versus those available or pledged.

ITK-Pixel (in-depth review)

The ITk-Pixel team provided a comprehensive set of presentations to accompany the P2UG project status reports, with a substantial volume of information conveyed in a short period of time, and candid discussions of challenges ahead and potential mitigation strategies. Overall for the schedule, there are compensating influences – additional delays delay stemming from the delays in producing RD53A modules, due to issues with hybridization as well as other factors, all in the background of the continuing pandemic which creates labour inefficiencies as well as supply chain delays. This is mitigated by active management of the schedule, particularly through the actions of the Schedule Task Force (TF), which has suggested changes from the original plan to recover the delays. Overall, the overall seven-and-a-half-month delay has stayed essentially constant, with moderate fluctuations in both directions, stemming from interim progress updates, for the last year.

That said, the Pixels are still late compared to the nominal LS-3 schedule, and with the scrutiny in evidence from the TF effort, as well as previous scrutinization discussed in the last four P2UG reports, there is no remedy to regain six months of float, short of descoping the project. To

respond to the request from CERN Management, ATLAS has looked at staging/phasing in terms of time gained vs. physics impact, and reported to the P2UG. Essentially, there is no staging/phasing scheme for the Pixel detector which does not substantially compromise the physics performance of ATLAS for the entirety of the HL LHC period. The committee agrees with the proponents that the future physics program should not be mortgaged to satisfy the current schedule.

This is not to say that progress has not been made. The project completed two FDRs and a PDR, sensor market surveys are complete and preproduction sensor delivery has commenced for the 3D sensors, and most importantly the production of the penultimate ASIC ItkPixV1.1 is complete, testing is progressing, and Modules with this ASIC will be available soon. Overall, the prototyping effort is closing the remaining R&D questions as the pixels move into the pre-production era.

Detailed Observations

- 2.2.1 Sensors

  As mentioned, sensor preproduction is underway for the 3D sensors, and expected soon for the planar sensors. The preproduction era is brief, with an expected PRR in May 2022 and production starting in June 2022. With the schedule pressure, the project has discussed with vendors to accelerate the delivery schedule, completing the sensor delivery six months faster than previously planned. Sensor QC site qualification is complete, and QC documents are written. The QC results for one 3D vendor are 66% yield, better than the expectation of ~50%. One issue with the sensors is with a specific variant, the 3D 25x100 μm, where the preproduction essentially failed for the preferred vendor. The project presented two different strategies should the vendor not be able to produce these sensors: moving partially or completely the production of this variant of sensor with production of other variants at other vendors, in a dovetailed fashion. In addition, this particular variant is only needed at the inner layers, which are the smallest and therefore quickest to fabricate, so this problem is not yet critical.

- 2.1.2 Front End ASICS

  The highlight of the ASICs is the production of the ItkPixV1.1 ASIC, expected to be the penultimate version before the production chip. 50 wafers were received earlier this year; of those roughly 50% have been tested, and the yield is a satisfactory 86%. There appear to be ample resources for the QC program, and the batching of production was modified to ensure that the QC testing pipelines are never waiting for more ASICs to arrive. The PRR and production submission are expected for August '22. There are important tests remaining, particularly performance once integrated into modules, as well as serial powering, and effects due to acute (SEE) and chronic (leakage current, depletion voltage) radiation exposure.

- 2.1.3 Modules

  Module assembly consists of hybridization, connection of the ASIC to the sensors forming a 'bare module' and then assembly, attaching the module PCB to the bare module, and running the full QC to validate the functionality. The hybridization process, done mostly in industry with some capacity for flip-chipping at institutes, conditionally passed the FDR in November 2020, and completed the FDR process in March 2021. The tender process for preproduction commenced in spring 2021, but only was completed in October, much longer than expected. The real problem in the hybridization was the slow delivery of RD53A modules which are necessary for the module FDR. As a result, the module FDR will not wait for the completion of the RD53A program, but be based on the results from digital modules (no sensor) and the results from the fraction of modules already

produced. This is planned for November 2021, to launch the preproduction. Much of the tooling, assembly procedures, and some performance validation has been carried out with the RD53A modules. However, final performance will have to be demonstrated with the preproduction ItkPixV1.1 modules, which are expected to be available in 2022 and 2023. There is also an open concern regarding bump stress in thermal cycling, which the project is addressing appropriately. Finally, the schedule Task Force has recommended an analysis to understand what limits module assembly rates, as a possible mitigation of future schedule delay, similar to what has happened in ITK-Strips.

- 2.1.4 On-Detector Services

  The on-detector Services scope is the electrical services from the Module to PP1, with the exception of event data transmission (2.1.10). Here as elsewhere the focus is on the push to preproduction, with an FDR based on the RD53A campaign scheduled for August 2022. There are multiple variants of components based on detector location, but a representative sample of these will be used for validation results for FDR, with all designs complete but not necessarily prototyped. Here there is also some future schedule optimization, splitting the PRR between the Local Support services and module-end services There has been reasonable work on closing R&D and no major concerns in this area, although halogen-free fabrication may pose a procurement delay, so for prototyping they have not yet addressed this.

- 2.1.5 Local Supports

  The Local Supports (LS) WBS consists of fabrication of the carbon fiber/foam Bare LS and the attachment of modules, to make Loaded LS. In this area, Bare LS is proceeding well, with a few tractable issues to close, while Loaded LS has clearly been delayed as a knock-effect from delays in RD53A module production. As such, these two areas have separate reviews, with the Bare LS already having passed FDR, and aiming for PRR in September 2022. Here there has been some schedule optimization exploiting the different free float for the Inner LS vs. the Outer LS. On the same timescale of September 2022, Loaded LS is aiming at FDR, based on results from the RD53A campaign. In the interim, testing with dummy modules has shown good results in terms of position accuracy and glue application.

- 2.1.8 Off Detector Services

  This completes the electrical path, from PP1 to the Service Cavern, including the power supply procurement, hub for slow control, and necessary cables and patch panels. Here the goal is a system test in December 2021 which supports the FDR in April 2022, releasing pre-production. There have been some delays due to extended market surveys which for the power supplies turned out to be invalid, as well as preparation of the tender. Here as well there is some schedule optimization, in that the assembly process will not wait for the production power supplies. Final FDR/PRR requires testing performance with the ItkPixV1.1 modules and is timed to coincide with the completion of the preproduction campaign. There is concern about lack of institute commitment for the MOPS hub (slow control) components, and finally, the rather complex service mapping from PP1 to the Service Cavern has been completed.

- 2.1.10 Data Transmission

  This scope of this WBS is specifically Data transmission from PP0 to the DAQ (Felix card), via the twinax 'Type-1 E-link' from PP0 to the Optobox, and electrical-optical conversion via the GBCR – lpGBT-VTRx+ ASICS and to the Service Cavern. Here the custom components are the GBCR ASIC, the twinax cable, and the Optobox and components, the rest (basically cables) is COTS procurement. There has been an optimization of the

connectivity to maximise fibre usage, which has caused a proliferation of flavours and increased complexity, but allows cost reductions due to fewer optical conversion ASICs and DAQ channels. This area is aiming for completion of prototyping for an FDR for the Type-1 link in late 2021, and for the Optolink portion February 2022, to be ready for the Services FDR in August 2022, with a PRR in June 2023. Further divisions of PRRs are being considered to avoid long lead times. Technically this is proceeding reasonably well. The GBCR2 ASIC looks like it could be the final version, and full chain tests with increasingly mature components continue to meet specifications, although final validation will come only in pre-production.

Comments

Most of the reflections from the review committee stem from the general observations above. The schedule now appears to be a reliable tool, and the project team are using it to optimize as much as possible, which is good. Nevertheless, there are still delays, some of which are lingering effects of the pandemic, but others seem to be under the project control. Perhaps this is just perception, but the committee is concerned about a lack of urgency, not at the top levels but within the project, manifested for example in the delays in the RD53A campaign and knock-on effects, which is really critical for the fundamental validation of the ITK-Pixel design. It appears likely that there will be an adjustment to the overall project schedule, but we urge a revitalization of the sense of urgency in every area, to shake off the ennui stemming from the pandemic.

In the next year there are seven FDRs and nine PRRs, which will require the constant efforts of the project team to achieve successfully. In several cases we have seen reviews associated with a full system split out into reviews for each constituent components, to allow progress for the early component without waiting for later ones. This is a viable manner of contending with schedule issues; however, it does pose increased risk that interface issues between the components may be missed. The project is aware of this risk and has taken mitigation steps, but residual wariness is important, lest a design has to be reopened after production is started.

The delayed Module FDR situation, clearly the issue during this review, also highlights a correlated concern; while much functionality and assembly capability is validated through use of RD53A, final performance will only be established with ItkPixV1.1 modules during pre-production. Thus, there is a risk of redesign after the FDR, and it would be prudent to consider how this should be handled ahead of time, as well as the potential for pre-production to be less of a 'dress rehearsal' for production and more of a second round of R&D, which may lead to surprises.

Recommendations

PI-6-1: Set as 'mission critical' the test beam and irradiation studies on full modules equipped with ItkPixV1.1 ASICs. We would like to see even preliminary results in the May 2022 P2UG.

PI-6-2: Keep on working (even harder).

TileCal (in-depth review)

The project continues to make progress and there were no major worries. There have been however some baseline changes since the last P2UG across many areas (on-detector and off-detector electronics, LV, HV and calibration) which in many cases relate to delays imposed by COVID and supply chain issues.

It has been particularly pleasing to see progress with outstanding radiation testing (HV active dividers, Daughter Board and LV bricks) and integrated or Vertical Slice Tests (VST) where the

last period has seen VST activity for LV, HV, Pre-Processor and test beams for the on-detector electronics chains.

Schedule float across the project is currently healthy. In particular, the DCP to be ready for partition assembly (LB-1, LB-2, EB-1 and EB-2) is 200 days or greater in all cases.

Comments on subsystems

There were detailed status reports from all subsystems, summarised below:

HV active dividers

Production run start has been delayed by the batch radiation qualification requirement (RETF2020). Radiation testing should be complete by the end of this year and submitted for approval from the PRR panel. All components have now been purchased and production is expected to start early in 2022 and will complete 9/23.

PMTs

Three identical PMT qualification test stands are now operational at CERN, Pisa and Bratislava. All parameter measurements have been demonstrated at the percent level. The proposed PMT replacement from HPK (R7877) has been fully characterised. The PRR is scheduled for November this year and PMT procurement to start early next year at the rate of 100 PMTs/month. HPK are confident of the delivery schedule. The schedule assumes qualification takes twelve weeks per 100 PMTs. This part of the project is comfortably on track.

On detector electronics: FENIC boards

About six months delay was incurred by difficulty sourcing halogen-free PCBs. The PRR is now scheduled for Q3 2022. A high-throughput test station and burn-in station are almost ready and all production components (apart from PCBs) are purchased. The first batch of pre-production boards are already qualified for the PRR (24 boards tested with beam and twelve boards in life-time test). Start/end of production is Q4 2022/Q4 2024 and the boards are needed for installation seven months after the start of LS3. The project is on track.

On detector electronics: main board

The successful vertical slice test (VST) of v4 with Daughterboard v6 triggered completion of pre-production in October this year. All passive components for production were ordered in January 2021 (for delivery by February 2022) and the order/contract placed for all 963 PCBs and their assembly. Following the PRR in December, production is expected to start early in 2022. Throughput of production and testing is 20 boards/week for a total production run of 23 months to finish in late 2023. Further radiation tests to satisfy the revised RETF guidelines are to happen in Summer 2022.

On-detector electronics: daughter boards

The project has suffered from delays dur to a new FPGA choice and RETF radiation tests. The last radiation tests (NIEL) are happening now and v6 is part of VST in the test-beam with MBv4+TilePPr (Sept and Nov). The PDR (follow-up) will happen in December 2021 and the FDR is planned for July 2022. A major worry is the recent price rises of Xilinx FPGAs. A unit cost increase of ~20% can probably be accommodated in the current budget but further hikes may cause a real issue.

Off-detector electronics: pre-processor, TDAQi and read-out fibres

Some good progress over the last year has resulted in final versions for all components: PPR (Carrier Board-v2, CPM-v2) and TDAQi-v2. A Pre-Processor VST is set up in Valencia and will test

the full readout chain before FDRs around Q1 of 2022. There are worries that supply-chain issues could affect the current pre-production schedules for Carrier, CPM and TDAQi.

LV distribution system

The switch to a more efficient power MOSFET has been made which halves the power dissipation in each LV box and should mean the current cooling system is sufficient (upgrading the cooling system will happen if needed and is resourced). All components are undergoing radiation tests, to be finished by end of Q1 2022, at which point the FDR (follow up) can happen for LV bricks and LV boxes. Successful prototype tests for ELMB (PRR passed) and AUX board (PDR passed) were made at the LV VST (Bat 175).

HV distribution system

The system has seen delays, partly COVID-related but also from supply-chain issues and development complications. Prototypes of all components are now in VST (HV supplies + HV remote + HV bus + DCS). FDRs will happen in 2022 and PRRs in 2023. A suitable HV cable has been found but prototype must be tested in January 2022. Component availability is a noticeable risk here since there has not yet been any large scale purchasing of components. This might be a particular issue for the FPGA Bus Board which has already gone through three redesigns due to poor component availability. End of production is expected in mid 2025.

Calibration system

There has been significant progress in this project over the last period but the prototyping phase is going to be crucial for successful FDRs. The laser system control board ILANA has now passed PDR (June'21) and will move to FDR in 2023 with the laser optics FDR in 2024. The Cs-system development has been hit by delays: electronics was delayed by the move to EMCI for monitoring and the Cs hydraulics development has been affected by COVID. The group is confident however that there is still over one year float compared to the current LS3 schedule.

A lot of work remains in the effort to identify a suitable replacement for water: Novec, recommended by a CERN study, does not seem ideal for ATLAS and ideas for reducing system pressure via changes to the plumbing segmentation must be demonstrated.

Mini-drawer mechanics, tools and services

Production of the Mini-Drawer mechanics is well under way, and will be 64% complete by the end of the year. Services are ready for PRR (December) and production will start in 2022 and the assembly/installation tooling production is complete.

Assembly and integration

An assembly and installation work plan for the new drawers exists. The effort and schedule for each stage have been evaluated and infrastructure needs and floorspace in 171/175 identified. The issue of whether the activation level of the PMTs extracted from the experiment at the end of Run-3 will be high enough to require a special supervised area is still to be resolved. Activation levels of a Superdrawer extracted at the end of Run-2 were OK, but it is planned to test a Superdrawer from a high-radiation region in Run-3 during a future maintenance access period. Continued close cooperation with ATLAS TC is needed to ensure the infrastructure required for TILE LS3 operations are allocated and the personnel to staff the various teams are identified.

Conclusions and Recommendations

TI-6-1: Almost all subsystems are facing issues with supply chain delays and associated price increases from pre-COVID levels. Sub-systems where this is a worry must ensure that a dedicated risk is assigned. The project must learn from experience of pre-production, and moving towards

production it is prudent to start looking to procure as much as possible e.g. the Main Board project found their production components took a full year from order date to be delivered.

TI-6-2: If a Cs-based calibration remains mandatory for TILE calorimeter performance monitoring during Run-4, it is clear that using the existing system is not a realistic solution. It is important to distinguish the two aspects of the Cs calibration system development. Separate milestones are needed for the water replacement investigation and the system segmentation study, so that the P2UG can track progress from this point on. The installation of the new system may not be easy and there could be consequences for the rest of the detector – hence collaboration with the ATLAS TC is going to be particularly important.

ITK-Strips

The ITK-strips team presented a summary of their activities since the in-depth P2UG review of the project in May, including several important advancements in this period:

- Sensor pre-production QC & QA tests are completed
- Production sensors are starting to arrive and be tested
- Pre-production HCCStarV1 and AMACStar are submitted
- ABCStarV1 passed the PRR, with first wafers released for manufacture
- First hybrid/module sites are qualified for PPA & PPB hybrids
- The Petal core has been received from industry and passed QC
- Type-III cables are installed in SR1 for barrel system tests
- Stave insertion has been demonstrated in the Outer Cylinder mock-up.

On the other hand, the site qualification process evolved more slowly than foreseen, and the ASIC developments continue to introduce significant delays in the schedule.

The P2UG recommendations from May were followed up and implemented as far as possible. The recommendation to evaluate the pre-production A experience and feed gained experience back into plans to accelerate the production has been carried forward to the in-depth review in May 2022 as it turned out to be too early for this review.

Schedule

The current negative float in the ITK-Strip schedule against the required delivery date is -127 days. It was -79 days in May 2021, +17 days in November 2020, and +111 days in May 2020. The most recent increase of negative float by about three months over the last six months was already predicted in the May 2021 in-depth review. However, the total negative float could only be limited to six months by condensing the pre-production schedule and gaining ~45 days by dropping the ITK surface commissioning task, as a statusing in October 2021 revealed the need for an additional 70 days in the schedule. The schedule therefore keeps losing significant float despite ongoing mitigation measures. If measured against the original need-by date (i.e. without the drop of the surface commissioning task) the loss of float amounts to about 100 days within the last six months.

A ITK-Strip schedule optimization task force (TF) performed an in-depth analysis and released a report in October 2021. The report underlines the need for an at least 18 months extension of Run3/LS3 to safely complete the ITk-Strip project. P2UG welcomes the very detailed report and seconds the need for an 18-month extension. The report is presently being analysed by the project management including the recommendations for accelerating the module production to gain

three to four months in the schedule. There is an apparent discrepancy, as ITK-Strip is proposing twelve months as adequate float while the recommendation of the TF is fifteen months. The latter could be reachable in an 18-month extension scenario with accelerated module production. In-depth risk assessments are under way to clarify the required float.

ASICS

The PRR for the ABCStar was passed in October 2021. The FDR Follow-up for the HCCStar was in August 2021 with a following submission of HCCStar/AMACStar to the foundry. The wafers are expected to arrive from the foundry in late December 2021 and will undergo immediate testing and validation. Bringing the HCCStar to the PRR and production dictates the critical path of the ITk strip project. The need for a re-submission would delay the full project by about an additional nine months.

Recommendations:

IS-6-1: Continue following the three major schedule mitigation actions (Pre-production A/B, Priming production, Accelerated Production) across the project (see P2UG May 2021).

IS-6-2: ITK strip is expected to give detailed feedback on the Schedule Optimization Task Force report and all of its recommendations including a risk assessment that clarifies the adequate float for the project by the May 2022 P2UG.

IS-6-3: Continue to closely monitor the path of the HCCStar project towards PRR and production and deeply evaluate and mitigate risks of delays.

IS-6-4: Identify and realize opportunities to gain contingency, in particular in accelerating the module production rate. Carefully consider the pitfalls of reduced/relaxed QA and QC procedures.

IS-6-5: Assure that the tasks fully under project control, such as the site qualification process, do not introduce further delays.

LAr

The project has progressed quite well despite delays related to COVID (availability of irradiation facility) and foundry planning which have not been recovered. The schedule float is however still positive (~six months) and the distances to critical path have not increased.

The front-end ASICs ALFEv2 and COLUTAv4 are, or will be, available by the end of this year and have FDR deadlines for the Spring and Summer of 2022 respectively. The next year is crucial for the project as, in addition, there will be PDRs for FEB2, calibration boards, and FEC and HEC power supplies.

Irradiation tests for the latest versions of ALFE and COLUTA are already planned.

The slice test board (FEB2) with a reduced number of channels (32) is currently under test. An integrated test with the latest versions of ALFE and COLUTA should happen in December this year on a four-channel test board. A half-crate test of all prototype ASICs together in an integrated test will not happen until April 2023, but preparations for this start next year.

We would like to note that tests with the actual FEC Power Supplies and cables of the full length, as installed in the experiment, are mandatory. This is also true for the HEC.

Muon

General observations/comments

The review of the Muon project proceeded through one plenary report in addition to the regular documentation provided to the committee. Since the last P2UG in April 2021, the Muon project implemented a significant baseline change proposal to the RCP Chamber and Front-End Electronics (WBS 5.3). Several internal reviews have been passed (3 PDRs, 2 FDRs, 1 SPR2/FDR1).

In general, the DCP did not have significant slippage in the last two quarters with respect to the previous working schedule, apart from the TGC trigger and readout electronics (WBS 5.6), which went from 285 days float to 173 days.

The sMDT chamber production continues to keep up with the schedule originally foreseen, despite pandemic conditions.

In the MDT electronics, the TDC2 was fully validated. Progress was made in radiation testing. A suitable LDO regulator was qualified for the mezzanine, but the LDO regulator for TDCv2 will require additional tests because of ambiguous results.

The RPC gas-gap prototype needed to be discarded because the Bakelite was not of sufficient quality.

A fully functional prototype pf the RPC FE ASIC was received in October, but test results are not yet available. The front-end board is under design, and the first version is planned to use a legacy ASIC.

In the TGC electronics, the PS board preproduction is on hold due to difficulties procuring components.

Recommendations

MU-6-1: Prepare a backup plan with schedule updates if original vendor is not able to deliver Bakelite of sufficient quality

MU-6-2: For next review, present more detail about how the RPC front end ASIC will be qualified on a readout board and tested with a chamber.

MU-6-3: Consider proactive actions to avoid delays due to component procurements such as those delaying the PS board preproduction.

MU-6-4: If a global change is made to the Run 3 + LS3 schedule: (a) resist any tendency to slow down except where it is justified by mitigating risk; (b) review in detail the muon installation plans for LS3 and their impact on the LS3 schedule.

HGTD

The project was not reviewed in depth, but an update was provided in the overview session. Good progress was reported on some items but, while it is useful to keep scrutinizing the overall schedule, it is doubtful if any gains can be taken too seriously until the project is more advanced. In particular, the later stages depend crucially on availability of the final ALTIROC ASIC, success with hybridising ALTIROC-sensor modules, and demonstration that suitable LGAD sensors will

be available, sufficiently resistant to radiation damage. Some largely understandable small delays have been accumulated on these items, at least partly caused by the effects of COVID.

It was encouraging to see that beam test evaluations of LGAD sensors have been undertaken. Although this is quite recent, preliminary results are encouraging, but more statistics will certainly be needed and how to evaluate the robustness of LGAD sensors in the LHC is not yet entirely clear.

ALTIROC2 was delivered in September and preparations for testing are well underway, including sensor-ALTIROC assemblies. However, it is too soon to have obtained many results. The ALTIROC3 submission is now scheduled for June 2022, and design changes are already underway. However, it is questionable if this allows sufficient time to incorporate design changes arising from ALTIROC2 studies. The design and verification team has been strengthened, which will help.

It was noted that the project believes that evaluation of modules can be achieved without pre-testing at wafer level of ALTIROC chips, to identify Known Good Dice. While this may be true, it will certainly raise questions if problems are identified, to confirm which element, ASIC, sensor or interconnection, is at fault, and the project should not assume a success-oriented plan.

We are pleased to note that the recommendations from the last P2UG review have been acted on, although we still encourage the project to prepare wafer probe testing as soon as possible, since this is expected to need time, and is crucial for production, even if avoided during prototyping.