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

Seventh ATLAS-P2UG Meeting, 16-18 May 2022

In-Depth Review: ITk-Strips, LAr, Muon, HGTD projects

Regular Review: TDAQ, ITK-Common, ITk-Pixel, Tile projects

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The agenda and presentations can be found here:
https://indico.cern.ch/event/1155188

Introduction

The ATLAS P2UG met with the upgrade project leadership from 16th-18th May 2022, following an intermediate update meeting on 22nd February 2022. An in-depth review of the ITK-Strips, LAr, Muon and HGTD projects was held. This comprised a plenary overview talk, followed by one-and-a-half days of focussed presentations and Q&A. For the other projects, an overview talk was given, and in some cases written questions answered by the project managers.

The provision of project tracking information and style of reporting from ATLAS to the P2UG committee has now converged to a highly efficient and effective format, allowing a comprehensive review of the project in a compact three-day format of plenary and parallel sessions. The return to in-person attendance was highly welcome and allowed some good discussions to take place both with the collaboration and in the panel.

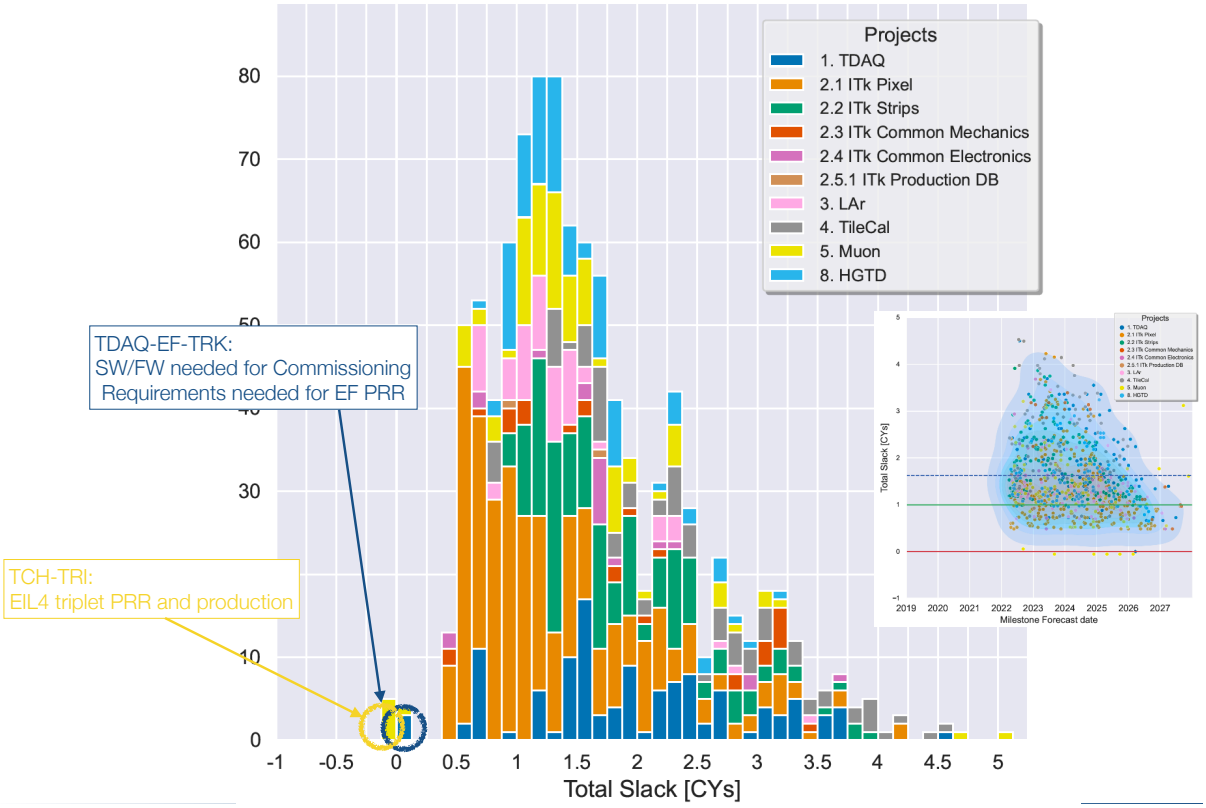
We note that this was the final P2UG meeting organised by the current ATLAS upgrade coordinator, who is standing down later in 2022. The success of the project in coping with COVID, and indeed in making positive and accelerating progress over the last months, is in no small part due to the leadership shown by the upgrade management. We thank Francesco for both his intense efforts to make this so, and his productive relationship with the panel since its inception.

Progress against schedule

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

- The completion to date of P2UG reporting milestones (effectively a high-level summary of the full ATLAS project milestones) up until 2022-03-31, along with progress in the last quarter (2022 Q2) 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 a one-year DCP corresponds to the current expectation for schedule contingency.

Project	Baseline Overall (until 2022-03-31)				Baseline Reporting Quarter (Jan-Mar 2022)			Expected milestones from previous report					
										2022.Q2	2022.Q1	2021.Q4	2021.Q3
	No. P2UG Milestones	No. Expected	Completed	Completed (%)	No. Expected	Completed	Completed (%)	No. Expected	Completed	Completed (%)	Completed (%)	Completed (%)	Completed (%)
1. TDAQ	132	24	13	54	4	1	25%	**6**	**2**	**34%**	**-**	**0%**	**33%**
2.1 ITk-Pixel	339	93	31	33	25	0	0%	**17**	**6**	**36%**	**15%**	**18%**	**14%**
2.2 ITk-Strips	215	106	53	50	9	0	0%	**14**	**2**	**15%**	**33%**	**50%**	**54%**
2.3 ITk-CM	36	8	7	88	0	0	n/a	**1**	**0**	**-**	**-**	**-**	**-**
2.4 ITk-CE	36	25	15	60	2	0	0%	**5**	**0**	**-**	**-**	**20%**	**33%**
2.5.1 ITk-PDB	4	4	2	50	0	0	n/a	**1**	**0**	**-**	**-**	**-**	**-**
3. LAr(**)	91	28	28	100	4	4	100%	**5**	**3**	**60%**	**-**	**50%**	**33%**
4. Tile	127	67	47	70	8	1	13%	**4**	**2**	**50%**	**67%**	**0%**	**12.5%**
5. Muons(*)	151	89	52	58	13	0	0%	**10**	**1**	**10%**	**25%**	**45%**	**27%**
8. HGTD (*)	110	11	10	91	3	2	67%	**2**	**0**	**-**	**n/a**	**33%**	**0%**



It is clear that the recovery from COVID is still very much under way as recently as 2022 Q1, with less than half the expected rate of milestone completion (and noting that on the original schedule, many of these milestones were due some time ago). The granularity of P2UG milestones does not permit a more exact assessment of current work rate, but the assessment of the upgrade coordination team based on internal milestones is that work is proceeded at around 75% of the pace originally foreseen, albeit on a rising trajectory. Although this number is not sufficient to complete the project on time, it does represent a significantly more positive picture than we might have expected at the last meeting. The focus for COVID now needs to turn to the long-term effects on the supply chain, since we observed that almost every subproject is suffering delays or increased risk due to non-availability of components or supplier failure.

More positively, we see strong evidence of a 'phase transition' beginning to occur across many subprojects. Key deliverables are now entering the era of preparing for series production, activities in labs are ramping up strongly, and there is substantial progress across the board. The coming year will be packed with crucial PDR, FDR and PRR reviews allowing construction to being in earnest. It is arguable that the next twelve months are the most critical yet for the project, and we are confident that this is understood by all concerned. P2UG will seek to participate directly as observers in selected PRRs.

In late 2021, and in recognition of the very difficult situation faced by the experiments, CERN Council approved a change of schedule for the LHC, resulting in a net eighteen months additional time for completion of the upgrade projects. This nominally comprised twelve months of additional running plus an extension of LS3. However, the interplay between construction, assembly, installation and commissioning is complex; ATLAS is still in the process of planning the detailed schedule for the steps following construction, and in some cases the re-optimisation of installation has resulted in significant changes in 'need by' dates for some subdetector components. This is an area that will need significant attention from both the collaboration and P2UG in coming meetings, noting that the requirement for detailed planning or tracking of the

project does not stop on delivery of objects to CERN. A particular concern is the transition points between phases, where there may be the requirement to provide a significant body of experts at CERN for relatively short periods of intense activity. This clearly needs planning carefully, and in close conjunction with the collaboration and its funding agencies.

Overall, the additional time available in the LHC plan now permits a reasonable – though not optimal – level of schedule contingency for all upgrade subprojects except ITK-Strips and ITK-Pixels. This statement can be made with increasing confidence due to improved risk-based ('Monte Carlo') assessments of expected use of float. In the case of ITK-Strips, the expected use of float approximately matches the amount available, and we are confident that further efficiencies can be found in production, without excessive additional cost or risk, that will allow the project to be delivered on time. However, for ITK-Pixels this does not appear to be the case. Significant further action will required to accelerate the pixels construction schedule through use of additional resources or simplification of work flows. A helpful first analysis of the problem was presented in response to written questions during the review, but it is clear that much more work is needed.

We note that even in the 'safe' projects, there are still many effects due to COVID with the potential to cause significant unforeseen delays. There is therefore likely to be a significant burn down of float in the coming year, and the situation may not be as comfortable as it seems. It would be useful in the presentation of the schedule to distinguish between 'burnable float' (i.e. schedule slack that according to a risk-based analysis is likely to be wholly or partially used) and 'contingency' (additional time allocated in the schedule for currently unforeseen risks). The ongoing quantitative tracking of float used and expected-to-be-used, against a clear baseline schedule, is a very useful tool. We encourage ATLAS to make further use of this approach, particularly since we do not expect the rate of float consumption to be linear throughout the project.

Russia – Ukraine situation

A discussion of the impact of the Russia – Ukraine situation was held during the closed session with management; reviewers attempted to avoid speculative discussions in the subproject review sessions.

P2UG is convinced that the ATLAS management have made a clear and realistic assessment of the financial and schedule impacts of the direct consequences of the war, and of a potential cessation of collaboration agreements with Russia. These largely lie in three aspects:

- The shortfall in CORE contribution
- Specific missing in-kind contributions from Russia
- Reduced effort for construction, installation, and commissioning of the upgrades

Quantitative estimates were presented in each case. It is hoped that the schedule impact can be limited to around three months, albeit probably in the most sensitive area of the schedule. The financial impact is a small fraction of the overall project cost. Overall P2UG is confident that the situation is under control by management to the extent possible under current conditions.

General recommendations

GE-7-1: ATLAS should ensure that all necessary resources and attention are devoted to the successful conduct of the many crucial review processes happening in the next six months, marking the transition of many areas of the project into full construction.

GE-7-2: Work should continue, with greater intensity, to examine how the ITK-Pixels production schedule can be accelerated through the injection of additional resources and effort, without increasing technical risk.

GE-7-3: The development and use of quantitative risk-based tools for tracking of schedule float should continue and be expanded, noting that this will also require further review and validation of the assumptions and risk assessments used as input.

GE-7-4: The detailed planning of the assembly, installation and commissioning phases of the upgrade project should continue, including top-level estimates of the required profile of effort over these phases (therefore demonstrating that the schedule is compatible with the human resources available to the collaboration).

ITK-Strips (in-depth review)

The ITK strips project presented in ten hours of presentations and discussions the full scope of its project, including: the schedule status and delays; recent technical progress; technical challenges and risks; focal points for the coming year. The project has embedded the new LS3 schedule in its planning and accomplished several major milestones and achievements since the last in-depth review in May 2021. Highlights including the facts that: the ASICs are no longer of major concern; sensors as well as ABCStar wafers are in production; and qualification of sites for module production is converging. Complete modules irradiated to HL-LHC lifetime fluences have been evaluated in test beams. Furthermore, pre-production petals and staves as well as first barrel cylinders and other global structure parts have been produced and the project is heading towards system tests and the systems FDR in late summer.

The coming year is loaded with eighteen FDR or PRR reviews and thus marks the entering of the production phase for the project with the schedule-critical module PRR in September 2022. Leaving the COVID-crises and the R&D phase behind, activity is seen to ramp up across the various components production centres revealing also some new technical issues as described below.

Schedule

In February 2022, the ITK Strips underwent a BCP, taking into account the findings of the Schedule Task Force, and gained four months of float in the schedule. This brought the negative float in the project from minus seven months to minus three months. With the implementation of the new LS3 schedule and the new LS3 installation plan, the need-by date for the ITK Strips moved from October 2026 to end of February 2027. Taking this shift into account, the present ITK Strip project float comes to seven months against the ITK Strips need-by date, and to thirteen months when taking the six months overall ITK project float against the full ITK detector required date into consideration. A Monte Carlo risk analysis has been performed based on the 44 active risks in the risk register. The resulting prediction is that the ITK Strips project will acquire 8.5 months of delay (with 90% CL), which exceeds the float in the ITK Strips project, but could be covered by the overall ITK project float. Finishing the project in the given timeframe seems therefore possible, but the contingency remains too low for the size and complexity of the project.

Comment: We commend ATLAS ITK for the successful implementation of the concepts of splitting the pre-production into PPA and PPB as well as priming the production ahead of the PRRs in several areas. The predicted benefit to the schedule has materialized. However, the project must remain very vigilant in the use of the remaining contingency.

Sensors

The production of the 20800 sensors has been under way since August 2021. After a slow turn-on for the barrel sensors, both EC and barrel sensors are being delivered at the rate agreed with

the vendor. The QC and QA procedures, including the complex distribution logistics and the four months testing period that includes radiation testing of the newly delivered sensor batches, has been demonstrated to be in place and functioning. The fraction of rejected sensors is below 5% and a recent issue on the charging up of sensors due to inappropriate packaging is being addressed in conjunction with the vendor.

ASICs

The HCCStar development has advanced very well. This was the critical path in 2021 but has now successfully entered preproduction and is in a very promising state for passing the PRR in July 2022 together with the AMAC chip. The ABCStar passed a PRR in October 2021. Unfortunately, the production of the 700 wafers had to be put on hold after receiving the first 250 wafers, as a problem attributed to the SRAM on the chip when operated at a voltage of 1.2V was found. The problem has surfaced in form of a reduced and non-uniform wafer yield. Further investigations are ongoing to understand if operation after irradiation and in different temperature scenarios could point to a more fundamental problem in using the chip.

Comment: As the ITK Strip team has presented several measures that could potentially mitigate the ABCStar problem, there is only marginal concern that a re-submission of the chip will be required.

Modules

The qualification of the eleven barrel and twenty endcap module production sites took longer than planned but is recently making good progress with the EC centres approaching the readiness of the barrel centres. First PPB modules for both EC and barrel have been produced, advancing the project towards the module PRR, and twith he aim of starting production in early 2023. While gathering experience in producing modules in all centres, the path for descoping the QC procedures without compromising module quality is being explored, with the aim of accelerating production. The close-down of a company providing glue, and some excess noise of EC split modules on test-frames, are concerns that are expected to be solved within the coming months.

Procurement / production management / logistics / databases

The procurement team is advancing well and is building up experience that allows for a smooth continuation towards acquiring the missing items for the production phase. The logistics for handling material reception, intermediate storage, and transit, especially at CERN, is challenging but well under control. Production and procurement databases are in place and are recording pre-production and production data. They are also used for reporting on status and progress and have been implemented in a transparent way that allows all collaboration members to access status information.

Comment: The committee formed the impression that the logistics, especially storage and handling at CERN, requires an increase in the associated workforce, which ITK is well aware of and about to establish.

Local support

Local support subprojects (electronics, tapes, cores, module mounting) are advancing with site qualifications well underway or achieved. The first lpGBTv1-based EoS boards have been produced and are under test. For the stave tapes a radiation-damage problem was detected for one supplier, requiring the baseline production plan to be shifted towards the CERN MPT workshop as single producer. The cores and tapes are preparing for their common PRR in June. The glue SE4445 which is used during the module mounting has proven to be difficult to procure as its shelf life is in the order of the time it takes for order and delivery. The team is searching for

alternative solutions including the possibility of buying bigger quantities or using the glue after expiry of the shelf life.

Integration and installation

All areas related to integration made significant progress and the according integration procedures and requirements have reached an advanced level of development. The integration facilities at CERN-SR1, DESY, and NIKHEF are facing some open issues but are generally prepared and ready for the upcoming integration challenges. The committee welcomed a first presentation of the detailed schedule for the installation of the ITK, including a detailed work force effort profile. Some optimisation within the ITK project and with TC, as well as the levelling of the activities to smooth a large peak in Q3/2028, is still needed.

Recommendations

IS-7-1: Schedule and close-to-critical-path items – explore if additional resources (monetary and/or work force) would allow the generation of additional float in the schedule, and in particular in the module production.

IS-7-2: We would like to see in the P2UG November meeting a first evaluation of the expected rate of module production against the presently planned rate for the production starting in 2023.

IS-7-3: The replacement glue matching the viscosity of the previously used glued should be qualified including tests with irradiated and thermo-cycled modules.

IS-7-4: ABCStar SRAM issue – perform an in-depth investigation of the observed problem as function of radiation level, temperature, and voltage with high priority.

LAr (in-depth review)

Overall, the LAr team have made remarkable efforts to continue to make progress, in very difficult circumstances throughout the pandemic, and to try to recover the delays induced.

A BCP was recently performed to revisit the pre-COVID baseline schedule, taking into account the delays experienced so far, and the knowledge gained during prototyping. This includes the longer design time of the LASP prototype mainly linked to the decision of which FPGA to use (see below). The new schedule also includes more details for the coming years before the production phase and reflects the new LS3 schedule.

The net result is an estimated 300 working days of float for FEB2 installation and 200 working days of float for LASP, both approximately in line with the requirements of the project.

Preamp / shaper and ADC / HEC shaper

The ALFE2 ASIC was submitted as a prototype in April 2021. COVID and related difficulties in the microelectronics industry made the fabrication process slower than usual.

An extensive series of tests was performed: performance (verifying that the ALFE1 analogue performance has been preserved), I2C communication, and radiation tolerance. It was verified that the expected improvements were achieved. The results of irradiation tests, including SEU performance (validating the logic-triplication autocorrection), were found to be fine.

The new version of the HEC ASIC (HPS2) has suffered from COVID delays, and some work is still needed. First tests are imminent but should be OK following the ALFE progress.

All ASICs (ALFE and COLUTA) will have BGA196 packaging, and the fabrication company has been selected. An important aspect is the input (diode) protection network. Tests on the LAUROC2

(test board and FEB slice test board) show that the same network as used on the FEB does not cause degradation of analogue performance.

The major milestone of the FDR is scheduled for September 2022.

The development of a custom ADC prototype (COLUTA v4) is complete and testing is underway. Radiation testing is scheduled for July at MGH in Boston, and the team is confident that the v3 behaviour will be maintained.

An ADC pre-production run submission is targeted for the Autumn, in preparation for the FDR in September 2022.

Front-end board

The design is progressing via the following steps:

1. A slice test board (2020 - 2022) with only 32 channels, using v3 pre-prototypes of the LAUROC preamp and COLUTA ADC, plus v1 prototype of lpGBT
2. ALFE2 – COLUTAv4 Integration Test (2022) validating the ASIC final versions, which is an important milestone prior to the ASIC FDR.

Some issues experienced with the I2C interface have now been understood and will be revisited for the FEB2 prototype design.

Powering tests with the slice test board at INFN Milano are about to get underway. They will include tests with a radiation-tolerant LVPS candidate plus long power cables. They will also test radiation tolerant options for FEB2 on-board power distribution, and performance measurements (particularly of coherent noise) will provide input for the choice of the final FEB2 power distribution scheme, as well as feedback to the LVPS PDR. This test is also needed as the slice test board has used LAUROC version of the preamp / shaper, but ALFE has now been chosen as the final baseline and must be validated.

This activity is on track for the FEB2 PDR in late summer, and the beginning of FEB2 prototype fabrication in the Autumn. At this stage, a full 128 channels will then be produced based on a preproduction ALFE.

Comment: These next steps leading to the FEB2 Prototype are a key development for the whole LAr project; the next few months are crucial.

Calibration

The CASA is the calibration ASIC for ATLAS. A new version, CASA v4, has been designed and includes the CLAROCv4 (HF switch XFAB 180 nm) and LADOCv2 (DAC 16 bit TSMC 130 nm). This is a new design addressing the issues encountered in the previous version. It is now the main risk item, but the choice to have the full DAC dynamic range in the TSMC version (and no longer inside XFAB ASIC) should minimize the risk and the group is confident that this will close the issue.

Power supplies

Having now identified viable accessible locations for all power supplies, the decision has been made to bring 48V to the FE crates with down-conversion on the FEB2 & calibration board (with the bPOL48V choice to be confirmed). The group now has in hand pre-prototype power supplies, cables, FEB2 power mezzanine test boards, and FEB2 slice test boards. A test setup in Milano will allow measurement of coherent noise for different designs.

Radiation tests on the mezzanines need to be completed and the plan is to hold a PDR this summer before launching production of a full-power prototype.

This remains part a of the project where a full technical solution is not yet confirmed.

For the HEC LVPS, progress has been made in filling key technical positions in the project overseeing infrastructure and mechanics. The PDR was completed in March 2022.

Off-detector electronics

The project is targeting a substantial firmware development in the coming period.

A major technical choice remains regarding the LASP FPGA. The current test board uses high-end STRATIX 10 FPGAs. The next-generation Intel FPGA family (Agilex) provides higher data bandwidth and processing power, using a smaller number of higher speed transceivers. A final choice between the two options is not yet made and will require more testing with the current boards. However, the team believe that the new FPGA is the better choice "at >70% CL". Such a choice may allow for four FEB2s to be read out per FPGA, with three FEB2s definitely feasible. A further beneficial side effect is that the power limit of 400W per board will be respected.

The LSB design is more complex than expected. Pre-prototypes have been built and will be tested with the FEB2 slice test board. Further prototypes are being tested to improve on the pre-prototype design.

The LATOURNETT prototype v1 schematics are in progress. However, there are concerns about the availability of components for fabrication in 2022 or early 2023.

Recommendations

The LAr group is to be congratulated for the way in which it has made huge efforts to recover from COVID-induced difficulties. The impact remains in difficulties with the procurement of parts.

The year 2022 will hopefully see the start of pre-production and production steps across the project.

LA-7-1: Prepare formal documentation for the LASP, specifying requirements on TDAQ, in conjunction with the TDAQ group. The necessary time scale for provision of TDAQ support for testing should be agreed.

LA-7-2: A slice test programme should be planned for HEC.

Muon (in-depth review)

General observations/comments

The project continues to make progress in all aspects. There has been positive news since the last P2UG across many areas, including: RPC Bakelite production, front-end electronics, and power system tendering.

Thanks to the good work done by the Muon collaboration and the technical coordination team, we now have an overall schedule and the installation schedule updated in accordance with the latest HL-LHC plan.

It was very useful to see a dedicated talk on the high-level schedule analysis in the in-depth review, and we hope to have this in future reviews. It was also very important to see the analysis of resource needs for integration, installation, and commissioning. Attention should be paid to installation of services, including exploration of opportunities to use a YETS/EYETS before LS3.

With the new start date and duration of LS3 now approved, we will need to follow up on the availability of person power and experts during LS3. Some key personnel are close to retirement, and it is important to plan for transfer of knowledge. Another risk to consider is the increased cost of raw material and electronics that could affect some projects.

Specific observations/comments

sMDT chambers

The sMDT chamber production continues to keep up with the schedule originally foreseen, at both the production sites (MPI Munich and Univ. of Michigan). 34 chambers have been produced at Munich and 23 are already at CERN ready to be tested. 20 out of 48 chambers have been produced at Michigan and 12 are at CERN. Around 55% of the total chamber production is done. The yield obtained is very good. All the chambers will be re-tested at CERN after the shipment.

sMDT production should finish soon (January 2023 at Munich) and this will give the opportunity to move resources to other parts of the muon project. There are already plans being made to shift some effort to the RPC project.

MDT electronics

The TDC has shown a high current draw during power-up. Possible solutions are under test. Pre-production and production orders will be combined into a single run with a modest increase in cost. A change was made to the CSM design to increase the number of mezzanine board interfaces from eighteen to twenty, thus solving a space issue for the BIS chambers. The updated CSM layout is expected to be completed in May 2022.

BI RPCs and FE electronics

The problem with poor quality HPL (Bakelite) appears to be solved; it was traced to a change in the paper used. A new set of paper has been used and the quality of the foils has improved and meets the specifications. The gas gap BIL and BIS final prototypes were produced and delivered (across Christmas break 2021) and have been successfully tested. While it is positive news that the existing vendors are able to deliver the needed quality, a second qualified HPL producer is in on board in case of trouble or to speed up the production. A second gap production company is also under validation. The process should finish before the end of the 2022.

It is important to underline that all the tests have been done with the present gas mixture and not with any eco-gas as requested by CERN. The eco-gas mixture studies are going on but for the moment we do not have an official proposal.

A first prototype of the front-end ASIC was received in December 2021 and analysed; the second prototype is expected in May. Two important problems have been found. Fixes have been identified and are now under validation. A second production is likely to be necessary, and this item is still on the critical path. The present prototype ASICs can still be used for FE board development.

The BIM layout is under study. The originally proposed location of BIR and BIM for Sectors 11 and 15 appears to present significant difficulties for installation. Alternative geometries would instead install chambers at larger radius with larger area. The large chamber area would lead to some increase in costs but would produce delays in the schedule. Specific proposals are being discussed in the muon community.

RPC trigger and readout electronics

For the BMBO-DCT, lab tests have been completed on the prototype and show no issues. Tests on an RPC detector and with a SL board are expected to be completed in 2022. Many components

have already been radiation tested (lpGPT, LDO voltage regulator, flash memory), and some will be radiation tested later this year (the new choice for SFP+ optical transceiver, and the particular model of Artix-7 FPGA and LVDS receiver).

The BI-DCT design and review schedule has been impacted by delays in the FE ASIC, but firmware is ready and board design is expected to be completed this year.

EIL4 TGCs

The prototype production has been completed. Prototype 2 is expected to be tested at GIF+ at CERN in June 2022. The FDR for EIL4 is anticipated in the next few months.

The possibility is under study to change the installation plan to take advantage of an earlier window in LS3. The corresponding change in the construction schedule has not yet been implemented, and this results in a negative float in the schedule. While it is understood that there is considerable flexibility in the installation timing, it is important to harmonize the construction schedule with the installation schedule so that all parties are working under a common set of expectations.

TGC Trigger and Readout Electronics

The FDR of TGC electronics has been passed. The JATHub pre-production has been delivered and the power supply board pre-production is on-going. A full slice test with Phase-2 sector logic is ongoing.

Power System

The market survey was sent to 52 companies around world (including two in Asia). Seven answered and three were qualified. The process was very long due to the bureaucracy and legal aspects.

The technical specification document is almost completed and has been through reviews by the project office. The plan is to open the tender during Summer 2022 and have the results before the end of the year.

Recommendations

MU-7-1: Continue to pursue backup plans with alternate vendors for HPL and gap production for RPC.

MU-7-2: For next review, present an update on the eco-gas studies and plans for the RPCs.

HGTD (in-depth review)

General observations

Overall, there has been excellent progress, as illustrated by detailed reports with images of equipment and much attention to detail. A lot of items have been constructed and are under test in various ways and several different places, or are beginning to be ready for more extensive studies. Among many examples, this was shown for developments of the DAQ, modules, beam tests, sensors, ASICs, and services.

However, it is important to recall that time resolution is a crucial parameter for this project and so far all measurements providing proof-of-principle are with single, or few, channel prototypes using discrete electronics measured with oscilloscopes. It will be very important to demonstrate performance as soon as possible using more realistic components and systems closer to the final DAQ, including clock systems. Naturally, this relies on some crucial developments converging, especially ASICs, sensors and modules.

A lot of detail was presented on planning, schedule, and risk management, which appear to be under good control. There are some risks which are not under direct project control, such as supply chain issues, the situation with Russia, and competition for ASIC designers, where attentiveness will be key, even if direct influence over affairs is not possible.

The critical path is still driven by the ASIC, sensors and module assembly, in that order.

The project managers should be complimented on a lot of good progress, which seems to have been well managed, since in many cases close coordination over several items must have been necessary to achieve what has been done.

Sensors

There has been an impressive effort on beam tests using devices from several manufacturers to study in particular the breakdown phenomena which had been observed correlated with the transit of charged particles. An important result that has been established is that a safe operation region has been identified where no breakdowns are observed. It requires an average electric field below about 12 V/μm in the gain region of the LGAD, and an operational requirement of below 11 V/μm has been adopted.

Enhanced carbon doping has been shown to be necessary to guarantee sufficiently low field operation for the lifetime of the sensors, although there may be alternatives in future that would require demonstration. Three manufacturers have shown they can produce sensors meeting this requirement, and other vendors may soon be able to do so. There are manufacturing variations, including wafer size up to 12-inch diameter, but the end results seem consistent.

Irradiation results look satisfactory but more data are needed on long term behaviour, using full size devices, modules and with a (probably 24 GeV) hadron beam; 100 MeV p, and 5 GeV electrons have so far been used.

The cost of sensors is still uncertain until tender, but a market survey has been completed and at least three vendors meet the technical requirements, with others likely. QA and QC methods are being developed but still to be fully established.

Overall, progress has been good but nevertheless plenty of work still remains.

ASIC

As elsewhere, there has been a lot of encouraging progress but the ALTIROC development is still very much on the critical path.

Two preamplifier designs were included in ALTIROC2 and have been evaluated. It is now clear that the transimpedance variant has superior TOT (Time-Over-Threshold) behaviour and will be adopted for ALTIROC3.

Noise performance is below ideal in the bare ALTIROC2 but the threshold non-uniformity can be improved by managing voltage drops across the chip in ALTIROC3. However, noise performance is significantly worse with a sensor attached – and outside the specification – with the reasons not yet understood. The most likely possibilities are grounding issues on the hybrid or some feedback path via the sensor. Improved hybrid design variants are being prepared and other studies have started. If this is the reason, the solution should hopefully be simple. If the sensor is

implicated, things could be more difficult. This behaviour was not observed with ALTIROC1 but that had fewer channels, which might be the explanation.

Meanwhile, the ALTIROC3 design is progressing, with triplicated logic ready to be added. This additional circuitry puts pressure on the chip size (and designers), but it seems that some areas can be reduced, e.g. by using a smaller FIFO. Clearly the design cannot be fully completed until the noise issue is resolved so the date of the PDR, originally foreseen for June, is uncertain.

Engineering resources are tight. Removal of the extra effort provided by CERN via CHIPS would be a serious loss, and there is competition from industry for engineers.

Preparations for wafer probing remain important, so that Known Good Die can be identified for the module construction, and this should be expedited despite the delays elsewhere.

Other observations

Module assembly looks promising with good results from bump-bonded prototypes, but numbers are still small and evaluations are limited at this stage. The final ASIC in pre-production quantities is needed to become confident about rate of assembly and cost. Significant in-kind contributions seem likely. The bump-bonding vendors so far are in Spain (collaborating lab) and China (collaborating industry) using different UBM methods.

For other items: a lot of detailed presentations generally looked very good, so there are no major concerns at this stage. Involvement of Russia in some important tasks is noted but is being managed at a higher level.

Additional comments

Sensors – despite good results it is too soon to fully retire the breakdown risk.

ASICs – if possible, CHIPS help should be maintained, despite pressure on CERN to engage in other projects. It is not yet clear how much delay will be incurred in solving the noise problems.

The project does not yet have a single point of responsibility for the timing measurement, which is a distributed task; this is being addressed.

Preparations for detector assembly, services installation and DAQ/DCS development look promising but are still at an early stage.

Radiation protection during installation is a general concern, and likely to be a significant issue for the HGTD.

Recommendations

HT-7-1: ASICs and sensors are the most critical items and the effort on both should be maintained or even supplemented if possible.

HT-7-2: Be ready to ramp up module assembly as soon as possible after sensors and ASICs are available.

HT-7-3: In all areas, the preparations for evaluation and qualification should continue to be given high priority, e.g. DAQ developments and hardware, and ALTIROC wafer probing.

HT-7-4: ATLAS technical coordination should anticipate difficulties during installation because of radiation safety and this cannot be simply solved by adding or rotating unskilled personnel. A plan is needed as input to the TC planning of installation.

HT-7-5: A discussion on the future availability of CHIPS-related resources should be held between CERN and ATLAS management as a matter of urgency.

TDAQ

General observations/comments

The TDAQ project has made very substantial progress since the last in-depth review in November. The introduction of the new EF tracking strategy has had a consolidating effect on the overall project flow. With the new schedules for LS3 and Run 4, the project has generally a very solid float. This shows directly in the L0 trigger, where the float ranges from well above one year to about three years. For the DAQ and EF, the schedule still needs to be updated. The "needed-by" dates are strongly governed by the principle of buying the commercial hardware as late as possible. While this approach is justified, it is also important to balance this with the risk of delays in the delivery of electronic components.

Several important milestones have been passed recently, albeit conditionally in some cases. This includes the PDR2's of the TGC/RPC sector logic firmware and the MDT trigger processor, as well as the SR of the global trigger and the PDR of the readout system. Various L0 projects continue to suffer from delays due to resource conflicts with the Phase 1 upgrades. These effects seem to prevail longer than originally expected.

For the EF tracking, the TDR amendment has been approved by CERN RRB in March 2022. A new organization and management structure has been set up, and a baseline schedule is in place. This schedule appears still quite 'schematic', and it will be necessary to see more details. While the concept is based on commodity servers, an important part of the project is the evaluation of several accelerator technologies, using for example GPUs or FPGAs. Two generations of such accelerators will be developed and tested, and the final choice of technology is planned to be made in Autumn 2025. It is important to establish clear criteria on which the decision will be based. One should also ensure that there will be enough time to adapt the full online tracking code on the accelerator hardware.

In the dataflow system, the removal of the disk buffer from the design has necessitated very substantial development work to arrive at a functional solution where the readout handlers write their data directly into the memory of the EF nodes, and the event building is performed there. A PDR is targeted for the first quarter of 2023.

Recommendations

TD-7-1: Please produce a more detailed EF Tracking schedule, with detailed set of deliverables and time allocation for each step.

TD-7-2: Please provide details on the required developments in the EF Tracking reconstruction software, once the technology decision has been taken.

TD-7-3: Conclude on the definition of need-by dates for provision of TTC and readout (FELIX) capabilities to support detector construction and testing. It is important to understand whether this constitutes the critical path for the TDAQ project.

ITK-Common

Two general aspects of the ITk project were addressed during the presentation in the plenary session: overall ITk schedule status, with implications already previously discussed in the Pixel and Strips sections; and the preparation of a resource loaded schedule (RLS) for the final Integration Installation and Commissioning (I2C) activities.

The P2UG was positively impressed by the effort in planning the I2C activities well in advance and looks forward to the completion of the remaining work that should confirm: the availability of the resources to be provided by FAs; the clarification of any residual grey areas not yet considered in the RLS; and the successful coverage of all key roles. In total there are more 250 FTE-years of effort foreseen, with nearly half represented by engineering and technical staff, and it is important that the estimates include sufficient contingency or provision of backup resources so that possible unexpected needs during such critical phases do not introduce delays.

The second part of the presentation was dedicated to a status report of specific ITk-Common sub-projects. Overall, none of the twelve milestones planned between November 2021 and May 2022 were met, and delays have continued to accumulate in several activities. In some cases, this was in fact a consequence of shifts in the Pixel and Strips schedule, e.g. for the production database.

Common Electronics

For the environmental monitoring, progress has been slower than expected but the P2UG was told that, with closer monitoring, the rate of progress has recently improved. Achieving the pending milestones in the coming months will be crucial for demonstrating that the schedule of the sub-project is under control.

In the BCM', the charge collection distance of recently produced diamond sensors was measured to be unacceptably low (~100 μm versus >240 μm expected) for reasons that are not yet clear and there is concern that this might be linked to loss of internal expertise by the current (and apparently only) supplier. The group is still confident that the quality can be recovered in the coming months, although production delays may exacerbate the shortage of dedicated manpower at OSU. There has been a recent injection of new resources into the project by CERN, with clearly visible effects, and this has mitigated the general lack of available manpower that however is not yet completely solved.

Common Mechanics

There has been significant progress, especially in getting SR1 ready for the start of the integration phase and in the execution of the CO_2 cooling project. Delays in procurement of components and materials have affected the work on the ITK common structures, but without major impact so far on the overall schedule.

Recommendations

IC-7-1: Although a list of resources available for the BCM' has been provided, a resource loaded schedule should be presented at the next review to demonstrate that the upcoming reviews can be achieved on time.

ITK-Pixels

There was a single extended presentation from ITK pixels summarizing the developments in schedule refinement and technical progress since the last update. Overall there is good progress, and yet significant challenges are still to be faced, even after the adjustment to the shift and extension of LS3.

In terms of schedule, the pixels continue to be the critical path for ATLAS. After the LS3 shift and moderate rework of the installation schedule, the project has six months of float to installation. A preliminary analysis of potential schedule risks shows that at the 90% C.L. the pixels will complete at latest 7.25 months after the current completion date. While the analysis is still yet to be fully validated there is clearly still substantial schedule tension. The project is fully aware of this, and has an upcoming BCP that is expected to add 44 working days (two months) to the schedule float. Further reduction will then have to come from acceleration of module production.

The collaboration may wish to consider if resources can be diverted into the Pixel project to help with schedule acceleration, and if so where they are best deployed.

There are six FDRs and eight PRRs scheduled for the remainder of the current calendar year, reflecting the fact that the project is, in some areas such as sensors and hybridization, advancing into production. Of particular importance is the Module FDR at the end of May, and Loaded Local Supports FDR in the fall, which are keystone reviews for the validation of the overall design. There has been good progress on module validation from the RD53B campaign as well as results from the test-beam studies of the first iTkPixV1.1 modules to support the FDR.

There remain some challenges. In addition to the schedule issues, there are technical challenges, such as the final mechanical design and routing of Type-1 data cables, and logistical challenges, such as the difficulty of procuring carbon foam from the preferred vendor. These are typical of the sort of issues one might expect, and while they need attention, they are not insurmountable.

Recommendations

PI-7-1 Given the tension that remains with the schedule, continue to explore potential areas to parallelize tasks and increase the rate of module production to at least maintain if not increase the schedule contingency. We would like to see a discussion of this in the November P2UG review.

TileCal

The project gave a plenary presentation covering both technical progress and the current status of the schedule. The project has undergone several PDR and FDR reviews since the last P2UG meeting, including for sensors, mechanics and high-voltage systems.

Further delays have been encountered in several aspects of the project, largely due to the non-availability of irradiation facilities due to COVID. However, none of the delayed items are on the critical path for the project. The overall schedule float in the project is around 440 days, which is felt to be more than adequate given the recent rate of development. This assessment should be confirmed by the passing of the remaining FDRs for electronics and LVPS during 2022.

There are concerns around the development of the new Cs-based calibration system, where a clear recommendation was made by P2UG at the last (in-depth) review to develop an explicit schedule and milestones for (a) the remaining R&D / design work for the system, and (b) studies of the appropriate system segmentation. This recommendation does not appear have been addressed, which is disappointing. We understand that this aspect of the project depends almost exclusively on Russian collaborators; nonetheless, a clear plan is still needed, even if the scope of the project changes.

Recommendations

TI-7-1: For the calibration system, provide a detailed account of the remaining R&D tasks, design decisions, and implementation plan for both water replacement and new segmentation.