Review of the STAR forward upgrade

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Executive summary

Good progress has been made on an intriguing concept for a cold-QCD experiment to run in the near future. Plausible plans for funding exist, as do conservative designs for all detectors, electronics and support infrastructure to perform the measurement. Some further advancement on designs for the silicon and its infrastructure is needed. Prototypes are being exercised for the calorimetry, are being prepared for the sTGC, and also being readied for electronics, DAQ and firmware. More definition of QA/QC to accept final detectors for installation into STAR is needed. The lead risks are identified, including the significant funding shortfall should a proposal to one of the agencies not be approved and funded. The experiment does appear positioned to be ready for first operation in FY21, with the caveat that the critical path, which is the silicon detector, does presently have very little float.

Answer to the charge questions

1. Is the conceptual design technically sound and likely to meet the objectives of its scientific case?

    Yes - technically sound and conservative, prototyping is moving along well for calorimeters & sTGC, but needs to be done for silicon detectors
2. Are the resources needed, including workforce, adequate and likely to be provided?

    Likely. Personnel are from known current collaborators, however dependencies exist on multiple funding agencies, with proposals still to be submitted and approved in more than one case. University groups indicate they are committed and in fact are pursuing prototype work. Significant groups from China and Taiwan are involved. This model has worked well for STAR in the past
3. Are the material and workforce costs to BNL properly understood?

    Partially. A definite cost to BNL, of around 10% of the total cost, was presented. If the MRI to the USA-NSF is not approved, there is little recourse other than to BNL for over $1.5M in funding for the calorimetry and its electronics if the FY21 schedule is to be met. There is likely to be more formal involvement from ES&H and QA on accepting detectors for installation. There are concerns about amount of Mechanical Engineer and Designer work needed.

4. Is the schedule consistent with the RHIC FY21 run plan?

    Yes, the run plan is taken into account. Only STAR is running currently, thus negotiations about one-month RHIC schedule shifts are possible. There is concern about when the Silicon can be ready, therefore a plan for installing it later than the FY21 run is needed as a contingency.

5. Are the risks understood, including external dependencies, and is there a plan that mitigates the risks?

    Partially. The funding risks are acknowledged. The schedule risk for Silicon needs attention; in particular the hybrid flex circuit design may consume more time than presently estimated. The cost estimate for direct cost appears conservative but firm assurances are needed that universities will waive overheads and support shop costs.

6. Is the project being properly managed?

    Yes. The group has defined all the management leads, identified institutions handling each technical aspect, and defined L2 & L3 persons. The group needs to define reporting mechanisms to BNL to advise BNL of progress on the various detector parts that are done at other institutions.

7. Is there a capable team in place to effectively manage risks and ensure quality?

    We think so. Better definition of QA/QC procedures, in particular acceptance criteria for detector elements, is needed. Each detector should define commissioning and test procedures to be carried out prior to installation.

8. Are the interfaces properly understood?

    Yes, but this is a bit early in planning. The calorimeters appear straightforward. The sTGC has to integrate with the existing EPD and sit in the gap in the West pole tip. The Silicon has to mesh with the inner support in STAR. The status of these should be reported to BNL as engineering and design work proceeds. The electronics and DAQ interfaces make use of existing STAR standards and build on known working solutions. The firmware and software aspects appear to build on the operating STAR solutions.

9. Are the ES&H aspects being properly addressed?

    Partially. Those for the calorimeters and sTGC are straightforward and were noted. There is a safety check to be made just due to the mass of the calorimetry coupled with the fact that it must move to permit access to beamline vacuum pumps. The sTGC gas needs definite study for alternatives, since gas safety could prove to be a significant issue for n-pentane.

The Project needs to talk to BNL Safety with respect to gluing scintillator parts in the STAR assembly hall.

Physics Focus and Forward Spectrometer Design

The proposed spectrometer is an upgrade of STAR with emphasis on forward polar angles, specifically at pseudorapidity between 2.5 and 4.0. The spectrometer includes two tracking stations, an inner one close to the interaction point and composed of three disks of silicon-strip sensors, and an intermediate-distance one comprised of four sets of small ThinGap Chambers. These two tracking stations are then followed by a downstream pair of calorimeters, first an electromagnetic one for spotting electrons and photons plus measuring part of the energy of jets, and followed a hadronic one for stopping hadrons and completing the measurement of jet energies. The calorimeters are well-segmented transversely. A preshower detector is placed in front of the electromagnetic calorimeter to improve electron/photon separation. The entire upgrade will include pipelined electronics and triggering coupled to a fast DAQ and master timing system which in turn are integrated with the existing STAR readout systems.

The forward spectrometer would be mounted without moving the main STAR cart, which is an important consideration for meeting the proposed schedule. The silicon tracker will be mounted without breaking the beamline vacuum, which in turn means the disks must be formed of at least two halves. The intermediate tracker is made in quadrants, thus can be more easily mounted, but must keeps its readout electronics outside of the acceptance of the Event Plane Detector in STAR as well as the acceptance of the calorimetry. The electromagnetic calorimeter must be mounted so that movement is possible in order to have access to beamline and pumps.

This choice of kinematics gives access to processes where one of the struck partons is at large Bjorken x, but will accordingly require good momentum resolution and charge-sign determination out to particle momenta above 20 GeV/c. There are three key topics proposed for the polarized p running that is planned starting in FY21. One is measurement of the Collins asymmetry in p-p scattering, which requires spotting jets and measuring azimuthal angular correlations with respect to the jet. This requires good calorimetry, both electromagnetic and hadronic, to determine the jet energy and emission direction cosines. A second is Drell-Yan scattering in p-A collisions, taking advantage of the forward kinematics to have one parton with large Bjorken x and thus a D-Y pair mass above 4 GeV/c2, where one gets away from the charm decay backgrounds. This requires good electromagnetic calorimetry coupled with good spotting of hadrons in order to reject them. A third measurement is study of gluon saturation in heavy nuclei, again using p-A scattering, with the measurement performed using photon-jet correlation measurements. Once again this requires both good electromagnetic calorimetry to spot the photons and reject pair conversions, coupled with good electromagnetic and hadronic calorimetry to identify the jet and measure it accurately.

All these measurements also require tracking extending to near the interaction vertex to determine momenta and particle charge sign, as well as to spot and remove unwanted particles, such as pair conversions, from the dataset.

The tracking coverage also enables a program studying long-range correlations during the A-A running planned for the sPHENIX experiment. These would be aimed at large spatial correlations developed early in the event, which would manifest as correlations at large rapidity gap. In this case the primary measurement uses the tracking, but the full calorimetry proposed brings to bear an essential ability to trigger on the rare events of interest.

A proposed run plan incorporating p-p collisions in FY21-FY22, p-p,p-Al, and p-Au collisions in FY24, and Au-Au collisions in FY23 and FY25 was presented. This matches with the proposed run plan for sPHENIX starting in FY23, when sPHENIX installation has concluded.

The installation of the forward spectrometer would be accomplished in three stages tied to planned shutdowns of RHIC. In the first the calorimeter support platform and electromagnetic calorimeter would be installed. During the second the hadron calorimeter, SiPMs for all calorimeters, front-end electronics and DEP plus trigger would be installed, together with the intermediate tracker. The forward tracker, comprised of silicon strips, would need to be installed during a third period and will be the sub-detector on the critical path for the overall project.

The main schedule challenge apparent to the reviewers was having the Silicon tracking detector ready in time for the FY21 run dates. STAR is the only running experiment at that time, and sPHENIX is still assembling in their Assembly Hall during CY21, thus there is the possibility to negotiate a detailed run schedule with CAD that year, in particular if a few weeks delay would allow completion of installation of the SIlicon tracker.

Forward Silicon Tracker

Findings

The Forward Silicon Tracker (FST) relies heavily on the experience with the Intermediate Silicon Tracker (IST) which operated successfully in the STAR Heavy Flavor Tracker (HFT) from 2014 thru 2016. The FST proposes 3 disks of wedge-shaped silicon-strip sensors, placed at 140cm, 163cm and 186cm from the interaction point, to form the inner part of the tracking system. Each layer would comprise about 1% of a radiation length. (The downstream part of the tracker, composed of small Thin Gap Chambers, is discussed in the following section.) The sensors would be procured from Hamamatsu Corp., which has produced numerous different types of silicon strip sensors for various experiments at RHIC, JLab and the LHC. The IST readout system and possibly the cooling system will be reused for the FST. Although the amount of FST detectors elements (sensors) is very similar to the amounts in the IST, the number of FST readout channels is about one third that of the IST. The FST will use the same readout chips as the IST, namely the APV25-S1, and the sensors will be very similar also. This makes for a conservative design. There are a total of 36 wedges, with each wedge having one inner-radius sensor with 4 APV chips and two outer-radius sensors sharing another 4 APV chips, for a total of 288 APV readout chips and 36,864 channels. S/N is predicted to be 10:1 for early operation, improving to 15:1 as the device is tuned up, which are calculated to result in 90% improving to 95% efficiency for single particle hits. The APV chips are in hand. The flexible hybrid circuit will be a new design with vendor to be determined. The current assembly plan involves use of the FNAL SiDET facility for assembly, notably wire-bonding. The wedges would be made of carbon-fiber loaded injection molded polyphenylene sulfide to address radiation hardness issues. This approach is novel and noted further in the comments.

Comments

The earlier STAR IST was a stave-based design with rectangular sensors. The FST will build disks out of 2 different wedge shaped sensors, with fine segmentation in phi and coarser segmentation in R. This will result in hybrid designs and mechanics designs that are sufficiently different from the IST designs that prototyping of at least one FST wedge is necessary. This is not only important to show proper functioning of the new silicon sensor design, but also of the new hybrids. It was unclear to the committee who was responsible for these hybrids designs.

Reusing the existing IST readout system and possibly the existing IST cooling system makes this design more viable than when new systems would need to be developed. Although these systems functioned excellent during the IST running period they have been sitting idle for a while. Problems with the actual systems themselves or compatibility issues with the STAR upgraded system could be present and should be identified.

It is proposed that the support wedges are made from injection molded and carbon fiber loaded PolyPhenylene Sulfide by a Taiwanese company. Cooling pipes will be incorporated in the injection molding in case that a fluid based cooling system is chosen. It can be assumed that even air cooling would need air channel structures as part of the supports. The PPS approach differs from the carbon fiber supports that have become almost standard for silicon trackers. Having the PPS injection molding done by the Taiwanese company constitutes a significant external risk. No mitigation was shown in the case this approach fails.

It is expected that the first full prototype will be ready for testing by October 2019. Production will start in January 2020 and is expected to take a little over one year. Even with this aggressive schedule there is practically no float between the end of production and the start of installation.

The detector envelope and integration in STAR can be considered very preliminary at this moment. Apart from some sketches there is no information on how the three silicon disks are supported and how this support gets inserted in the STAR carbon fiber cone structure. Because the beam pipe cannot be disassembled, the FST disks have to come in parts that can be ‘clamped’ around the beam pipe. It is unclear how this non-trivial mounting will be accomplished.

Recommendations

- Build a prototype wedge as soon as possible. Showing proper functioning of sensors, hybrids, support structure and readout chips at an earlier stage than currently scheduled could prove the only way to generate some float.
- If Aluminum cooling lines are used then it should be proven that corrosion would not become an issue because they are properly sealed from contact with carbon fiber.
- Test the existing IST readout system and cooling system as soon as possible to get an estimate on the time and effort it will take to make these systems fully operational again.
- The integration information is very preliminary and has to be soon gotten into a state that feasibility can be assessed properly during a subsequent review. Since

this should happen in the next couple of months more design manpower might be needed.

sTGCs

Findings

The intermediate tracking station is to be comprised of four layers of small Thin Gap Chambers (sTGCs), placed at 273cm, 303cm, 333cm and 363cm from the interaction point. Each layer is made from four quadrants with double-sided readout and presents about 0.5% of a radiation length of material per layer Readout electronics would be the same as those used for the long-successful STAR TPC, with some 24k channels needed. A position resolution per station of 100 microns is expected. This chamber sits "in" the pole-tip beamline opening of the west end-cap of the STAR main solenoid, thus in a region of non-uniform magnetic field. The electronics and water cooling needed to extract heat must be configured to install in the limited space in the pole-tip beamline opening without obstructing the active region of the spectrometer. These chambers will be made by the same group that is making similar but larger sTGC modules for the ATLAS experiment at the LHC.

Comments

The group in charge of sTGC production is also responsible for the production of the much bigger ATLAS sTGC module production. Nevertheless a QC procedure needs to be outlined to monitor the production process.

Different gas admixtures need to be studied to identify whether less-flammable gas options are possible, in addition to the baseline option of 55% n-pentane and 45% CO_2. Run19 can be used for such R&D.

In case of delays in the installation of the FST, charge identification with sTGC-only tracker detector is possible, and vertexing can rely on the central tracker. Under these conditions, the sTGC-only tracker detector is a viable option for the pp run.

Recommendations

- We recommend to include studies of physics performance under the possible scenario in which the FST is not ready in time for installation.

- We recommend to identify effort and resources needed at BNL to address concerns with the use of flammable gas.

Trigger

Findings

The proposed trigger builds upon the operating design for STAR. The trigger algorithms would be based upon information from the calorimetry. The planned topology for the trigger is defined and requires two variants of the DEP/triggering board noted above to implement. Digitized information from all towers from all three elements of the calorimeter system will be combined to form the trigger inputs. The physics functionality required of the trigger algorithms has been defined, but algorithm development work will be needed to implement this. Electron, photon, hadron and jet triggers as well as electron pair and jet pair triggers and even photon-jet pair triggers will be formed, resulting in a flexible system able to cope with the highest expected RHIC luminosities. The DEP/trigger boards incorporate significant FPGA arrays, as is now common practice for programmable pipelined triggers. This enables straightforward adjustment of the size of trigger patches in order to specialize for eg. photons at one extreme vs jets at the other.

Comments

Detailed studies of trigger algorithms were not presented in great depth, however there is extensive expertise in the Collaboration on algorithm development and optimization. The trigger is not a major cost or risk for BNL.

Recommendations

No recommendations

Integration into STAR

Findings

The planned spectrometer has four major detectors to locate: the hadronic calorimeter (30 tons, near the west wall), the electromagnetic calorimeter (10 tons, on the existing FMS platform in the West Cavity), the sTGC intermediate tracker (800 pounds, and placed in the west poletip center opening) and the Silicon tracker disks (50 pounds, located inside the existing carbon-fiber cone, and installed as half-disks to avoid breaking beamline vacuum). The calorimeters must be moveable to allow access to the RHIC beamline vacuum and pump plus cryostat. The support structure for them will be located in the 1006 Hall's West Cavity and will need some reinforcement to handle the cantilever loads. The collaboration has access to the BNL machine shop plus four university machine shops in the USA for fabrication, namely those at Texas A&M, Rutgers, UI Chicago and Wayne State. The STAR machine shop at BNL can be used for small items and minor needs during installation. QA efforts are lead by the STAR chief engineer. The STAR Technical Services Group and FEE groups are relied upon for most installation, with cable installation dependent upon university-based student groups.

Comments

- While the integration and installation design is still in its preliminary design stage, the path forward is clearly identified.
    - ie. sTGC will use EPD-style T mounts. Silicon Disk housing will use FTPC mounts and pushers to relieve cantilever.
- Additional mechanical design requires subsystem interface designs to develop further and provide keep-in envelopes.
- A contingency of 30% is too low for a design in this state.
    - Certain materials and installation procedures are still unknown.
- One half-time designer will be used to design integration needs with the potential ability to pull more designers from CAD.

Recommendations

- Silicon Disk mounting, housing, and material need to be identified and developed further.

- HCal and EMCal designs could be more mature, since multiple features are being reused and are therefore identified. Preliminary analyses can be completed to identify support specifications.
- Identify beam-pipe obstacles, such as flanges, that may create installation complications.

Calorimetry and Electronics

Findings

There are three major sections in the calorimetry, noted here in order of increasing distance from the interaction point. The presence of each is necessary for all of the main areas of the proposed physics program, although the roles played vary a bit with physics topic.

The preshower counter will consist of the slats of scintillator plastic recuperated from the existing STAR FMS preshower counter and reconfigured into the proper geometry for the new forward spectrometer. It will be read out by Silicon Photomultipliers, as will the other elements of the calorimetry. It will have 240 slats and be placed just in front of the two sections of the electromagnetic calorimeter. The SiPMs and readout electronics are also recuperated from the earlier FMS preshower counter of STAR.

The electromagnetic calorimeter will be formed from one recuperated sector of the former PHENIX “shashlik”-type calorimeter. The lead plates, scintillating tiles, and WLS fibers plus local support structure will be re-used as-is. The photomultiplier tubes, which are now nearly 25 years old, will be replaced by new SiPMs (4 SiPM per calorimeter tower) which have the essential advantage of not being sensitive to the magnetic field present at the calorimeter position. The SiPMs will be coupled to the bundled WLS fibers where these fibers exit the back-face of the electromagnetic calorimeter, replacing the PMTs placed there earlier. Some 1496 channels of the shashlik calorimeter will be instrumented. The electromagnetic calorimeter is organized into two main sections, one sitting on each side of the beam-pipe, and is placed on a platform allowing it to move transversely to permit access to beamline vacuum pumps.

The hadronic calorimeter is of new construction and represents a new addition for RHIC experiments. Prior RHIC experiments focussed on the central rapidity region, where particle energies are typically a few GeV and hadronic showers are not well formed, thus electromagnetic calorimetry alone proved adequate. However the current spectrometer moves into the very forward region where particle energies reach from 20 up to 50 GeV, hadronic showers are well-developed, and a robust hadronic section of depth of 4-5 absorption lengths is required to make jet energy measurements of good resolution. The design is based on steel absorber, plastic scintillator active elements and wavelength-shifter plates, all arranged in a clever design that permits assembly not unlike a LEGO-block cube, resulting in a compact device with few cracks and thus little unwanted shower-energy leakage. Vendors for all components are identified, prototype quantities have been acquired, and the time and personnel effort to produce and handle all components has been estimated and checked by observing the fabrication of prototype quantities. The hadronic calorimeter is transversely segmented to form 520 towers. The readout is again accomplished using SiPMs coupled to the WLS plates with 6 SiPM per waveshifter plate and thus tower.

All three sections of the calorimetry use the same SiPMs, preamplifiers and following electronics, resulting in an economy of design and purchasing power. The STAR electronics group has already developed SiPM readout electronics for other detectors used in STAR and has thus confronted and solved the usual issues of noise control, bias voltage control and current measurement, and temperature measurement that must be addressed for a successful SiPM readout. The daughterboards carrying the SiPMs as well as their LV and HV, the preamplifier/shaper boards, and the following digitizer data-collection and triggering boards comprise the balance of the electronics plant that must be built. The ensemble will support an event readout rate of 2 kHz with less than 10% deadtime and integrate with the existing STAR DAQ and trigger. The DEP (Detector Electronics Platform) board supports both the 12-bit digitizers and the triggering, can reuse existing firmware and software and is already integrated into the STAR DAQ. Some development work to meet desired final channel counts per board and perform testing remains for the two principal DEP versions, as commented below.

SiPMs have known susceptibility to total ionizing radiation dose and in particular neutron dose. Estimates of dose backed up by calibration measurements in the STAR interaction hall have been made to address and quantify the expected dose and increase in SiPM leakage current. A 1 MeV equivalent neutron dose of 10^{11} n/cm^2 is expected over the operating time of the experiment, which would result in an increase of SiPM leakage current of perhaps 100 microamps which can be handled by the proposed electronics design.

The planned topology for the trigger is defined and requires two variants of the DEP/triggering board noted above to implement. Digitized information from all towers from all three elements of the calorimeter system will be combined to form the trigger inputs. The physics functionality required of the trigger algorithms has been defined, but algorithm development work will be needed to implement this. Electron, photon, hadron and jet triggers as well as electron pair and jet pair triggers and even photon-jet pair triggers will be formed, resulting in a flexible system able to cope with the highest expected RHIC luminosities.

The Silicon strip forward tracker will use the APV25 readout chip, which is the same one as used in the prior STAR IST. The following readout electronics for the IST are still installed in STAR and indeed function, are more than sufficient for the new Silicon strip counter, and thus will serve as the balance of the readout for that detector.

The sTGC intermediate tracker will need 24576 channels of readout electronics which can be recuperated from the existing STAR TPX, now that the new iTPC is installed. Readout cards, fibers and power chassis can also be recuperated, and working software exists. Thus this detector will not require new hardware for its readout electronics.

Presentation of ES&H items was abbreviated. There is a reliance on staying within the practice of prior STAR runs, meaning cabling systems, fusing, power usage and so forth have been reviewed earlier and found acceptable.

Comments

- FEE test fixtures will be needed for production test. The lead engineer will build them but no schedule has been established.
- New FEE components should be tested for susceptibility to expected radiation dosages.
- Manpower for PCB layout and testing of all electronics is not specifically shown.
- DEP32 is under development and is believed to build on an existing design but the trigger firmware is not yet designed and tested.
- Operation of DEP/IO stage 2 and 3 connection scheme hasn't yet been tested.

Recommendations

- We recommend establishing a schedule for producing FEE test fixturing and allocate manpower requirements for testing.
- Radiation exposure should be identified and any new FEE components tested accordingly.
- We recommend allocation of specific manpower for PCB layout, testing and possible design iteration.

- We recommend a full chain test of the new DEP system to establish full confidence in the DAQ production schedule going forward.

Cost, Resources, Schedule

Findings

The total estimated cost of the forward spectrometer is $3.5M direct, or $3.9M with the proposed contingency This includes $1.1M for the Silicon tracker, $220K for the sTGC systems for the intermediate tracker, $160K for the preshower counter and electromagnetic calorimeter, $1.1M for the hadronic calorimeter, $260K for calorimeter electronics and new SiPMs, $428K for DAQ, and triggering devices, and $190K for support structure, infrastructure, and installation costs. Some $410K, or around 10% of the overall planned cost would be supported by funds available from BNL. About 4.5 FTE-yr of BNL staff support is required; with 35% personnel contingency this is 5.7 FTE-yr. The current STAR technical groups together with several technical specialists (e.g. on FEE and DAQ) from the STAR scientific staff are assumed available to the project, plus a less-defined set of technical experts from CAD

The Collaboration has planned that the Silicon tracker would be supported by funds from in particular NCKU in Taiwan and Shangdong U in China, with proposals made to the MOST and NSFC in China. The sTGC tracker supported by startup funds from Shangdong U plus an existing allotment of BNL LDRD funds for the prototype development. An estimated $142K would be transfered to BNL for LV, HV and mechanical integration, with Shangdong guaranteeing to deliver the rest of the sTGC system. The preshower and electromagnetic calorimeter would be recuperated from STAR and PHENIX respectively. The hadronic calorimeter is to be proposed to the USA - NSF as an MRI via a proposal led by Indiana U and involving the other eleven institutions working on the calorimetry; this MRI would include the SiPMs needed for reading out the electromagnetic calorimeter plus triggering hardware needed. This MRI is proposed for funding starting October 1 2019, which date figures significantly into the overall schedule. The support structure, infrastructure and installation would be supported by BNL funds.

The group has defined all the management leads, identified institutions handling each technical aspect, and defined L2 & L3 persons. The lead scientists, engineers and designers are identified for each major section, all summarized in a proposed organization chart shown at the review. The BNL personnel are planned to come from the STAR and medium energy groups in the Physics Department, with some support needed from CAD (fewer than 10 FTE) on engineering and design effort.

The installation of the forward spectrometer would be accomplished in three stages tied to planned shutdowns of RHIC. In the first the calorimeter support platform and electromagnetic calorimeter would be installed. During the second the hadron calorimeter, SiPMs for all calorimeters, front-end electronics and DEP plus trigger would be installed, together with the intermediate tracker. The forward tracker, comprised of silicon strips, would need to be installed during a third period and will be the sub-detector on the critical path for the overall project.

The group performing engineering and design will be drawn from the STAR staff in Physics. The chief designer also has assignments for the sPHENIX support cradle, thus some added design support from CAD is needed.

The electronics, DAQ and trigger work is scheduled to test prototypes (or re-deployment of existing hardware) by mid-CY2019 and complete final preparation for production and testing by mid CY2020. Production of all new elements would be complete by early CY2021, in advance of when they are needed for installation.

The group preparing the sTGC has the ATLAS sTGC modules under construction, with those planned to be complete by August-September 2019. This is soon enough to allow time for constructing all the STAR sTGC modules and having them ready to install by 2020 during the second shutdown noted above.

The main schedule challenge apparent to the reviewers was having the Silicon tracking detector ready in time for the FY21 run dates. STAR is the only running experiment at that time, and sPHENIX is still assembling in their Assembly Hall during CY21, thus there is the possibility for STAR to negotiate a detailed run schedule with CAD that year, in particular if a few weeks delay would allow completion of installation of the Silicon tracker.

Comments

More definition of which groups and even which people are performing various electronics, firmware and software tasks is needed. There is some concern about adequate personnel being available to meet the testing and deployment schedule as presented. A possible way to communicate this could be a matrix of all known board design/fabrication efforts as well as testing and firmware efforts, versus institutions and specific personnel to perform them.

There is some concern about the number of parallel mechanical design tasks for the support structures in FY19 and FY20 versus the amount of designer effort available. The personnel effort estimates presented appear to be conceptual and would benefit from updating once the support concept matures.

Consider drafting a MOA with CAD about potential resource needs.

Recommendations

- Report to BNL on status of various funding agency decisions as they develop, both non-USA and the USA-NSF regarding the MRI for the calorimeters.
- Report to BNL on the outcome of the prototyping efforts, in particular those using STAR in Run 19, not only for detector performance but also for electronics, DAQ and trigger performance and status.
- Develop and deploy a reporting method to keep BNL apprised of progress on various subsystems including resolution of any open design issues. This should include both schedule, such as number of units produced to date, as well as sufficiency of remaining funding to complete the work.
- Develop a plan for installing the Silicon detector if the planned FY21 date cannot be met.
- Develop a mitigation plan in case the NSF MRI to build the calorimeters is not funded.
- Increase contingency based on material variables and dependency on concrete platform safety analysis.
- An updated cost analysis should be completed once materials are identified for Silicon Disk support structure and after an HCal cavity analysis is completed to identify support requirements and approve existing concrete platform.