Forward Silicon Tracker - internal STAR review

Review Date: August 3rd 2020

Report Date: August 10th 2020

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Important Information Provided to the Review Committee

- Review Webpage
  - https://indico.bnl.gov/event/9021/
- Documents
  - Mechanical Structure
  - Proposal Forward Upgrade
  - Module assembly Proceedure
- Previous Review webpage
  - https://indico.bnl.gov/event/5269/

Review Charge Questions

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

2. Is the QC program in place to ensure the testing and assembly of the component will yield a device that meets the requirements? Are the procedures for mechanical production, and assembly well documented and understood?

3. Does the schedule and workforce allow for installation in 21-22 shutdown period (summer 21)?

4. Are the installation process and the component interfaces sufficiently understood to ensure that the components can be installed safely and without damage? Are the installation procedures adequate?

5. Are safety and ES&H addressed in design for installation and procedures.

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

Yes – Sufficiently to start production. The module performance plots shown at the review contained features that are almost certainly artifacts of the measurement setup. In parallel to the silicon production order, the prototype tests should continue and the setup improved. The collaboration should be prepared to present at future reviews plots that clearly demonstrate the module performance above the KPP thresholds without the setup features.

1.1 Findings

- FST on-detector sensors and electronics will be built with stacked wedges containing HPK pad sensors, APV-25 readout ASICs, PEEK support structures, flex hybrids, and liquid cooling loop.
- Off-detector electronics will be a minor modification of the IST DAQ system
- The team has established a set of key performance requirements (KPPs) based on satisfactory experience with the earlier IST detector. These are loosely defined as hit efficiency >90% (95% goal), SNR >10:1 (15:1 goal), live channels >85% (95% goal) and deadtime (10%@2kHz, 20%@5kHz goal).
- Two test/QA procedures have been developed. For prototypes the modules will be tested with cosmic rays to measure the KPPs. For production, only pedestal and noise measurements will be tested.

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

1.1 Findings continued

- Four FST modules, FST01 – 04, have been built using components which are identical to the production designs, except for the flex hybrid and support structure which are near-final. FST01 and FST02 were partially populated and testing was limited due to assembly and connectivity issues. FST03 and FST04 were assembled in July 2020 and both demonstrated 100% live channels. FST03 has completed cosmic ray tests and results were presented on 3 slides. FST04 cosmic ray test is in progress and results were not available at the time of the review.
- Two slides were presented showing the DAQ hardware, which is repurposed from the IST detector. The full system was exercised in Sept. 2019 and was found to meet requirements with no issues. Smaller versions of the DAQ system are in use in the prototype test stands at UIC. Control software for HV still needs to be integrated into STAR.

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

1.2 Comments

- No performance requirements other than the four KPPs were presented (for example, module flatness and radiation length, on-detector power dissipation, power supply noise and rejection, etc.)
- At the time of the review, the project proposes that verification of module performance will be based on the cosmic ray tests of FST03 and FST04 alone. These modules use hybrids which are not the final design and silicon which is not from the production batches.
- Measurements of the DAQ performance were not presented, and it was not clear if the cosmic ray tests of FST03 were obtained using a complete “vertical slice” signal chain incorporating final system cabling, power supplies, and DAQ firmware. DAQ throughput and deadtime performance is to be validated by simulation and experience with the IST.
- It was not clear if the module KPPs include any allowance for partial areas falling below the threshold value.
- Overproduction of modules is planned, to allow for a final count of 48 modules (36 + 12 spare) with cumulative yield of 75%.

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

1.2 Comments continued

- Lessons learned from the prototype construction have been included into the module design. Precision bushings are included to improve component alignment.
- The flatness requirement for the module mechanical support pieces will be achieved by pre-selection of the finished PEEK components.

1. Has the team demonstrated through prototyping and measurements that the performance of the component meets the physics requirements?

1.3 Recommendations

1) Perform a full signal chain test with a prototype module and production cabling, power supplies, DAQ crates, and control software.

2) Include sample testing of modules with the cosmic ray test stand during production. For example, check every 6th module to insure that the production process is sufficiently repeatable for adequate yield. Consider modifying the test stand with different hodoscope elements to eliminate ambiguities coming from the use of IST staves.

3) The results of the FST03/FST04 cosmic ray tests are important to establish viability of the module design. In future reviews, present the results with charts showing that the KPP thresholds are unambiguously met with margin. This will require improving the analysis and presentation of the data.

2. Is the QC program in place to ensure the testing and assembly of the component will yield a device that meets the requirements? Are the procedures for mechanical production, and assembly well documented and understood?

Partially. The project has in place a QC program that documents the tests performed and records the measurements taken. The 6 month period where the silicon sensors are on order should also be used to review and improve the travelers. It should be clear what the acceptance criteria are for each step.

2.1 Findings

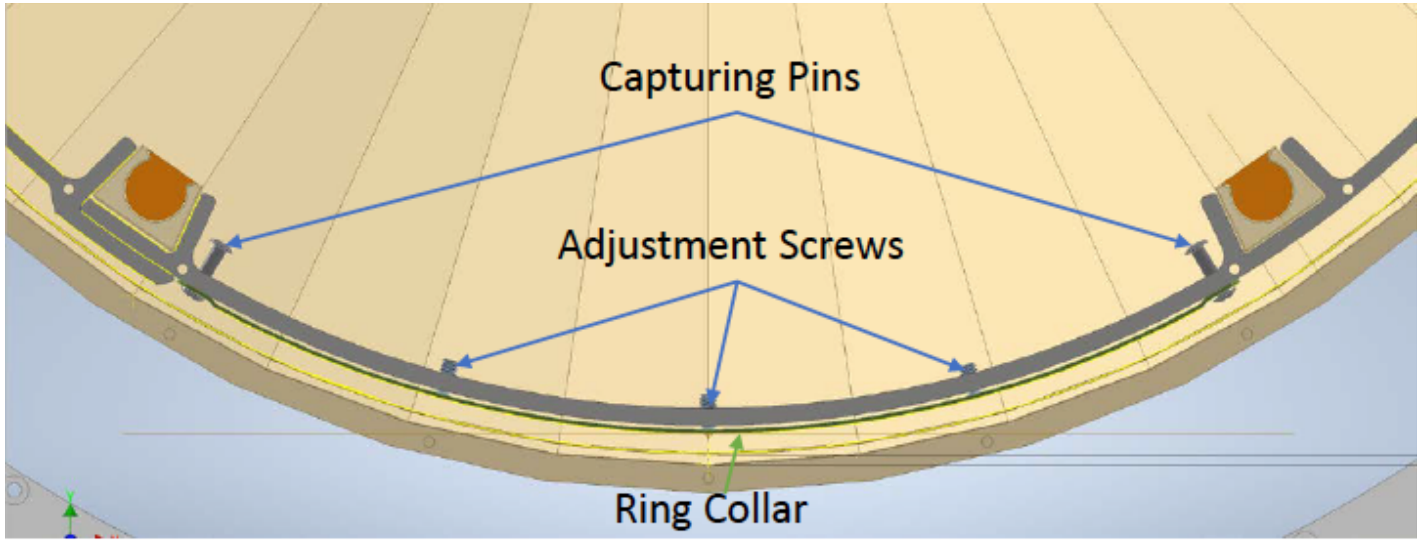
- The flatness specification for mechanical support structures is <500 um.
- The project plans to fabricate 200 PEEK support structures and select 60 that meet specifications.
- The gluing under the chip was tested using clear films and many test runs.
- Passives loading is done after the hybrids are mounted on the structures.
- The accepted structures will be send to the US for readout chip and sensor loading
- A readout test will be performed after every major step in assembly including before and after potting.
- The full detector will be assembled at BNL and extensively tested before insertion.
- The position of the detector will be determined by the surveyed support system inside of the STAR TPC.
- Draft travelers were included in the production manual for this review.
- The DAQ exists as it was used successfully for a previous detector in STAR.

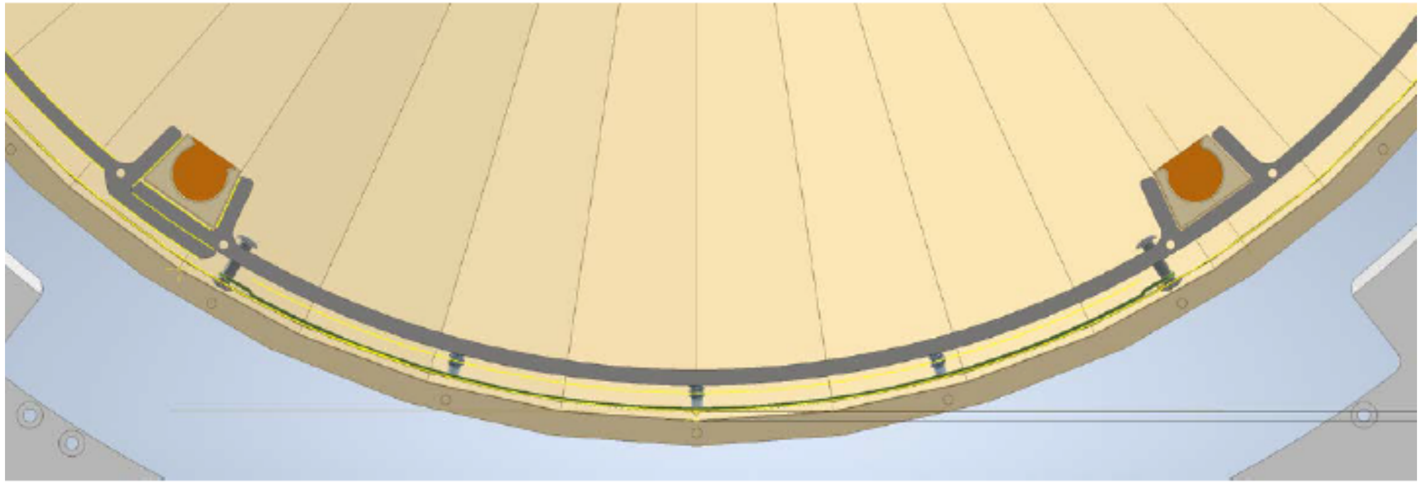
2. Is the QC program in place to ensure the testing and assembly of the component will yield a device that meets the requirements? Are the procedures for mechanical production, and assembly well documented and understood?

2.2 Comments

- 36 modules needed and 12 spares. Will pre-select the best modules. The criteria for grading should be clarified prior to the installation review.
- There should be a specification for the local flatness (bubbles!) after gluing the hybrid to the support structure.
- The cleaning procedure after passives loading need to be carefully documented for the hybrid production.
- The project could consider a thermal test to verify that the fully assembled modules meet the flatness specifications.
- Installation tolerances need to be defined. ¼ inch clearance to the beamline is planned.
- A full installation scenario needs to be developed to minimize damage to the detector and beam pipe.
- Set screws are used to adjust the detector installation tool. Longer screws should be used and nuts installed after survey to lock it into position. The figure showing the adjustment screws is shown on the next slide.
- The cables strain relief and cable management in general should be further refined.
- An attempt should be made to have a fairly complete detector installation scenario ready by the installation review next Spring.
- Information regarding APV25 yield after fully assembling of the modules is done has not been addressed/shown. Is there any plan/possibility of reworking of the modules to replace the bad chips? Such a plan should be worked out if possible.

2. Is the QC program in place to ensure the testing and assembly of the component will yield a device that meets the requirements? Are the procedures for mechanical production, and assembly well documented and understood?





2. Is the QC program in place to ensure the testing and assembly of the component will yield a device that meets the requirements? Are the procedures for mechanical production, and assembly well documented and understood?

2.3 Recommendations

4) The travelers which exist now primarily document that a step is complete and the comment could lead to uncertainty of the quality of the part. Each QC step should be clear and should lead to an acceptance grading of each part. The project should improve the travelers accordingly. The decision that a component can be accepted for the next step should be made according to the grading. An internal review of the procedures and implementation of the QC plans and documentation should be performed after the first 10% of the production is complete before further expensive and sparse parts (sensors and asics!) are committed.

5) T-Board is a weak part of the detector assembly. It seems that T-Board is a simple FR-4, small-size board that place a role of a connected of cabling to the Mechanical Structures. This board receives some number of wires and cables that are soldered directly to the board. This board is also a thin, probably not more that 4-layer board. Cables can either exert planar or rotative forces that can either deform the board, delaminate traces or pass deformative forces down to the module. It was not convincing the description of how the T-Board with cables attached to it will be plugged to the module connected and cables could be smoothly adapted to the mechanical structure of the mechanical support of the forward silicon tracker. Its was not clearly shown what cables arrive to T-Board, maybe it is one cable at the end in the final assembly, nevertheless it was shown that there is a bunch of inflexible cables soldered directly to the T board. It seems that T-Board is a weak part of the concept and needs to be redesigned to be more robust.

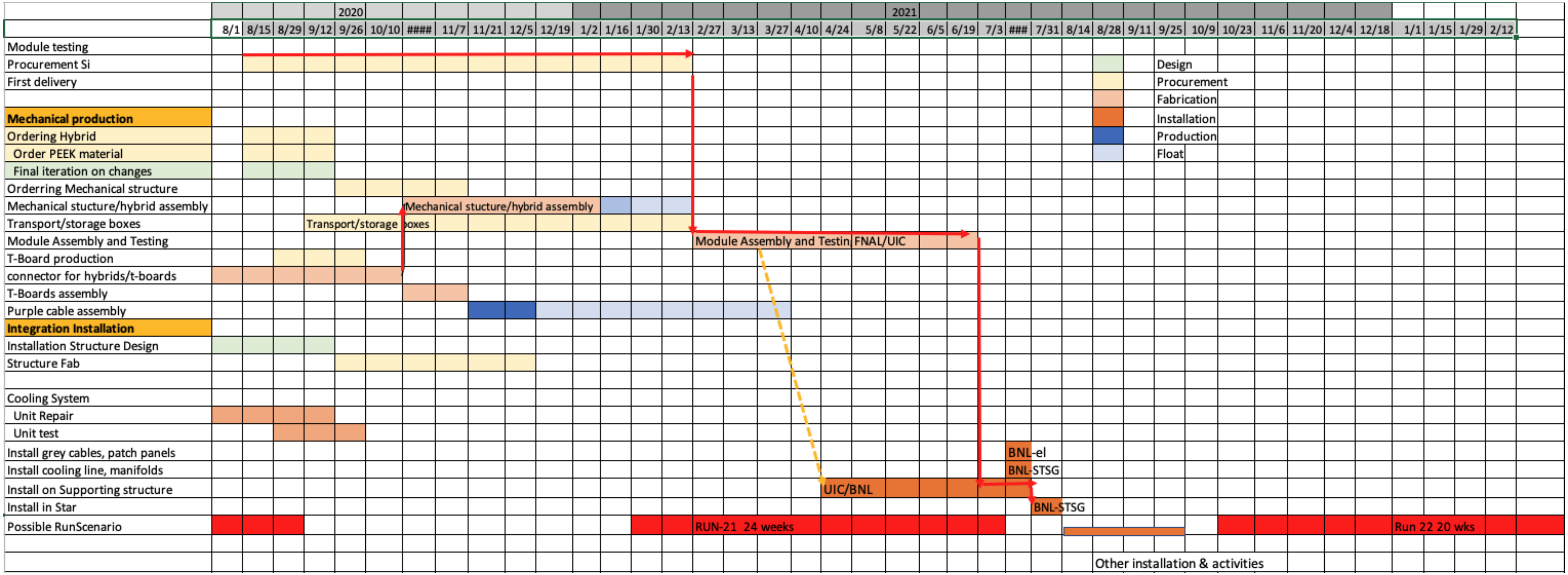
3. Does the schedule and workforce allow for installation in 21-22 shutdown period (summer 21)?

Partially: The schedule is very tight with essentially no float. The project should see if additional shifts or overtime in the fabrication facility can be planned to increase float.

3.1 Findings

- An 8 month integral delay in the FST project to date exists.
- The two main drivers to the schedule are the silicon procurement 27 weeks and the module assembly 18 weeks. These two activities must run in series and account for 45 weeks of the overall 57 weeks available (80% of the available time).
  - The critical path of the project runs through the silicon procurement which has a 27 week duration.
  - The mechanical assembly and testing of the modules requires 18 weeks and is the second longest duration activity in the project plan and is in series with the sensor fabrication.
- Two weeks are planned for installation of the detector.
- A commissioning plan was not presented.

Project schedule



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3. Does the schedule and workforce allow for installation in 21-22 shutdown period (summer 21)?

3.2 Comments

- The project plans an installation safety review in a couple months. Improving the installation process, drafting installation procedures and improving the cable management planning may make this challenging. However, this could be postponed if the work is not complete.
- The overall schedule for the production of the FST has ~2 weeks float over a 53 week period reflecting a 4% schedule contingency. This is extremely tight and the project will need to be very careful to stay on schedule. The project should look through the schedule to seek to add float.
- Component procurement and module structure fabrication is near critical. The project should be prepared to ship components in several deliveries if needed to provide earlier availability of components to the assembly factory.
- A table of procurement milestones should be generated and maintained.

3. Does the schedule and workforce allow for installation in 21-22 shutdown period (summer 21)?

3.3 Recommendations

6) It is critical that a new quote be obtained from Hamamatsu and the silicon order placed as quickly as possible. As part of this process it should be determined if a partial delivery is possible.

7) BNL management should provide any assistance possible to ensure the order is placed as soon as possible.

8) The project should investigate what would be required to accelerate the module assembly and testing if needed. Multiple shifts? Multiple sites? More sets of tooling?

4. Are the installation process and the component interfaces sufficiently understood to ensure that the components can be installed safely and without damage? Are the installation procedures adequate?

Yes the installation process is sufficiently advanced to be sure the detector modules can be installed. However, additional analysis of the modules support structure should be executed prior to its installation as suggested in the Comments section below. The installation procedures should be further documented in preparation of the installation review.

4.1 Findings

- The design is essentially complete, providing very good detail in the solid model. The installation, support, and integration engineer did a fine job in creating a straightforward and simple design for the support structure. He should be commended for his efforts in creating such a nice design. The fabrication drawings were not available for review. However, fabrication should be straightforward. Some minor design decisions need to be made but should not hold up the procurement process of the support structure.
- The fabrication schedule is very aggressive. If there are delays, a test of the support system may not be able to be made until after the ‘21 RHIC run. This however, should not delay the overall installation of the FST.
- Installation tooling mounts directly to the TPC face. Geometrical constraints consist of the TPC and the beamline.
- 1.5 inches of clearance exists on the OD of the detector.
- The detector with cables weighs 35 pounds.
- External cabling uses the existing infrastructure. This is tested and known to work.

4. Are the installation process and the component interfaces sufficiently understood to ensure that the components can be installed safely and without damage? Are the installation procedures adequate?

4.2 Comments

- Complete any remaining design questions prior to award of the fabrication contract for the mechanical support structure.
- A written installation plan must be drafted with stop points for both inspection and survey.
- Pay particular attention to loads that may inadvertently be placed on the FST by the signal/power cables. Consider a more detailed cable management plan including the management during installation.
- Make sure the drawing package for the support structure, Specification, and SOW are completed and signed off prior to issue of package for fabrication.
- Consider adding physical stops so that no inadvertent hitting of the vacuum pipe can take place. An aluminum jig plate with a lead-screw and stop blocks under the detector could be used to allow for careful movement of the detector-half horizontally into position (using the lift jacks to bring the table and detector vertically upward to the installation position).

4. Are the installation process and the component interfaces sufficiently understood to ensure that the components can be installed safely and without damage? Are the installation procedures adequate?

4.2 Comments

- Add removeable handles to the assembly to aid and simplify lifting the detector halves.
- Talk with the C-AD safety and vacuum groups about the installation of the FST.
- Perform a stress/deflection analysis of the support rails under various loading and support scenarios in order to ensure that no damage (to the detector or vacuum pipe) will occur when installing the FST, and that the position of the detector does not change based on support conditions. This can be done in parallel with starting the procurement and fabrication process but should be completed prior to the delivery of the support structure from the vendor in case any slight changes are needed.
- Consider adding lock-nuts to leveling gear so that once the FST is set and aligned, the device will not be able to move.

4. Are the installation process and the component interfaces sufficiently understood to ensure that the components can be installed safely and without damage? Are the installation procedures adequate?

4.3 Recommendations

9) Specify the installation tolerance requirements for the FST assembly inside the detector as well as disk-to-disk spacing and disk face-to-face parallel requirements.

5. Are safety and ES&H addressed in design for installation and procedures.

Yes

5.1 Findings

- Module assembly will be performed at FNAL following FNAL ES&H.
- All components undergo a safety review by CAD upon delivery.
- The mechanical support structure is a BNL deliverable and will be designed under BNL safety regulations.
- The detector will go before the detector review committee.
- NCKU as well as SDU have own ES&H rules and programs or working safely in their laboratories instantiated and they adhere to these guidelines following the statements made during the review.

5. Are safety and ES&H addressed in design for installation and procedures.

5.2 Comments

- Overall it is not possible to develop particularly rich set of comments about respecting ES&H rules. Detailed information on the safety measures and organization were not presented. However, no signs of compromising of the ES&H rules was visible during the review.
- Fermilab, BNL, UCI and UI respect the safety procedures in their labs, prototyping and assembly/fabrication facilities.
- All the elements of the detector system are inspected by the BNL safety committee for respecting the safety standards ad usage of allowed materials. Procedures are established in this regard and inspections occur prior to bringing materials to installation or otherwise using them on site.

5. Are safety and ES&H addressed in design for installation and procedures.

5.3 Recommendations

10) The stainless-steel tubes and the support structure shall be grounded. As SS pipes circulating cooling medium are connected to the inlets and outlets using plastic tubing, they are electrically isolated. The fixing of the electrical potential of SS pipes was not covered in the presentations. It must be grounded.

Review Informaiton

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FST internal STAR review

Monday 3 Aug 2020, 08:30 → 13:00 US/Eastern

Virtual

Description The PRR for the forward silicon review.

Background material:

The initial review for the forward upgrade is available at the indico page

https://indico.bnl.gov/event/5269/

It is protected, you can get the accesscode by contacting F.Videbaek. The particular relevant is the talk on the FST by Zhenyu and the integration talk. Other material is the proposal which is in the material list, and particular the chapter on the FST.

Mechanical_Struct... | Proposal.ForwardU... | STAR Module Assy ...

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Review Agenda

Restricted

09:00	→ 09:20	**Overview** Introduction (15') Detector requirements Design concepts **Speaker**: Zhenyu Ye (UIC)	20m
09:20	→ 09:50	**Module Mechanical Structure** Mechanical sector production Assembly Tests and QA **Speaker**: Yi Yang (NCKU)	30m
09:55	→ 10:20	**Hybrid production and QC** 15' talk + 10 disc **Speaker**: Maowu Nie (Shongdon University)	25m
10:20	→ 10:55	**Module Assembly and Testing** Module assembly at FNAL Tests and QA at UIC (procedures) Performance from the tests **Speaker**: Sun Xu (UIC)	35m
10:55	→ 11:30	**Mechanical integration** Support structures Detector support interface Cooling system **Speaker**: Rahul Sharma (BNL)	35m
11:30	→ 12:05	**Summary and Outlook** Electronics, DAQ and Slow Control Schedule, Milestones, Resources	35m