Report of the FNAL Accelerator Advisory Committee 2019

Fermilab, Batavia IL, November 19-21, 2019

The Accelerator Advisory Committee (AAC) meeting took place November 19-21, 2019 at Fermi National Accelerator Laboratory. The agenda of the meeting is shown in Appendix 1, the list of the Committee members participating in this meeting is given in Appendix 2, and the charge to this committee meeting is given in Appendix 3.

General Remarks

The committee wants to thank Fermilab for the hospitality and arrangements. The Committee also thanks the Fermilab team for directly addressing all the charges with generally well-prepared presentations, and for allocating enough time for discussions in the agenda. The AAC appreciate this very much.

The committee congratulates the Fermilab team for significant progress and research results in accelerator sciences in 2019. AAC commends the results achieved in SRF, superconductor and high-field magnet development, in particular the demonstration of 14.1 T in an accelerator type dipole, as well as the results from FAST/IOTA. The Fermilab SRF R&D program is driving the roadmap on High Q and High Field Gradients.

The Fermilab High-Field Magnet R&D program is well integrated into the US Magnet Development Program (MDP). Smaller development activities will be supported, but there is no strategy yet how Fermilab can keep the vast expertise on this technology in the long term for future projects.

The accelerator controls systems for the FNAL accelerator complex is in need of an upgrade as the equipment is reaching its end of life, with many components lacking proper spare components and replacements. The AAC commends the progress Fermilab has made on the strategy on the control system. The PIP-II control system will be based on EPICS, the rest of the complex will be migrated to produce a common control system by the start of PIP-II operations.

The AAC is concerned about the reduced operation scope adjusted to funding available in 2019. However, NuMI and MicroBooNE could achieve their goals, but g-2 could not collect the planned data set.

The Booster Beam studies are a success story and an exemplary example of cross-lab collaboration. The value of dedicated machine time to understand the beam dynamics of a given machine is clearly demonstrated and mandatory for the future high-power operation.

Suggested future AAC charges:

- The plan for staffing, in particular in AD. We could address recruitment plans and training of Highly Qualified Personnel (HQP).
- Following the AAC2017 discussion "Is the workforce organization reasonable…" in view of the large Fermilab projects.
- Plans for PIP-III.
- Assessment of the ratio of funding for ongoing and future projects to operational and modernization needs, using a metrics of overall science output and health of Fermilab.

Brief answers to the Charge Questions

1. Have all the recommendations by AAC 2018 been adequately addressed?

Generally yes, all recommendations have been adequately addressed.

2. The DOE Review of General Accelerator R&D, July 30 – August 4, 2018, listed 12 recommendations regarding Fermilab activities in this area. Assess whether Fermilab has implemented or developed a plan for adequate responses to these recommendations?

Generally yes, all recommendations have been addressed.

3. High-Field Magnet Program

   a. Fermilab has recently performed the first test of the 15 T dipole demonstrator magnet. The magnet reached world-record dipole field of 14.1 T (limited by pre-stress) and is being prepared for the second test. Assess the plan and readiness for testing up to the 15 T design.

   The plan for testing the magnet in two steps, with a first step campaign to prestress for 14 T with minimum risk of damaging the Nb3Sn, and a second step to learn from the results, based on this predict proper and safe prestress for achieving in the 2nd test campaign 15 T, was the correct one and led to the record magnetic field shown. The preparation of the next test for 15 T, by adding instrumentation, adjust radial prestress and enable axial prestress per set of layers looks solid and was properly reviewed. Based on the information given the readiness for testing seems guaranteed.

   b. The Fermilab High-Field Magnet R&D program has integrated into the US Magnet Development Program (MDP). Assess Fermilab involvement in this Program. Are the long-term assignments and goals well defined and resources secured?

   The Fermilab High-Field Magnet R&S program is well integrated into the US MDP. However, resources are not secured for all planned research activities.

4. FAST & IOTA Progress & Research Program

a. Fermilab started the accelerator research program at FAST and IOTA in December 2018.

i. Assess the commissioning results, the operations efficiency, and the science output of FAST/IOTA Run I, including measurement of the beam parameters for IOTA.

The results are impressive so far with good agreement between measurements and calculations. Once the sextupoles are working the decoherence time will increase substantially and the dynamic aperture will improve, allowing for more refined comparisons.

ii. Is the near-term and long-term science program well defined?

Yes, using electrons to probe single particle dynamics and following with multiparticle proton dynamics is a good strategy. We also commend the plan of testing the 40 MV/m ILC cryomodule in FAST.

iii. Are the required resources well defined and secured to optimally and effectively utilize FAST/IOTA and to produce high-impact science? Are the required resources well defined and secured to optimally and effectively utilize FAST/IOTA and to produce high-impact science?

The required resources for 6 month/2 shift per day operations is well-defined. The team has not received enough funding for this (only 3.7 funded out of 5.9 FTE desired). They also report the sometimes challenging matrixed organization.

b. Are the plans, schedules, and requested resources consistent with implementing the proton beam in IOTA within a reasonable time scale (~2020)?

The team showed a plan for acquiring the hardware and performing the installation, including schedules. The main concern with completing in 2020 seems to be related to competition for technical staff with higher priority projects. They also mentioned needing another $500k in funding to complete.

5. Review and assess the Booster study program, assisted by members of CERN, that was accomplished in the Summer of 2019. Assess the results, outcomes and potential impacts of these studies. Are plans and goals for future studies well defined?

Some very good data have been taken. The comparison with calculations has been done for the impedance measurements. We look forward to seeing whether the emittance growth versus tune setpoint can be understood and controlled. At this point the planning seems to be appropriate.

6. The PIP-I+ beam power upgrades, described at AAC-2018, have been incorporated into the PIP-II project. Assess the plans for this integration.

All former PIP-I+ activities are now part of the resource loaded PIP-II project. This includes booster intensity issues, booster D-magnet design, main injector gamma-t jump, and replacement of RF booster cavities. The former PIP-I+ projects are assigned to different *work packages. All upgrades follow the typical project reviews (Preliminary Design Review - PDR, Final Design Review - FDR, Production Readiness Review - PRR) i.e. are part of the PIP-II project review cycle. Booster Dampers and the Booster Collimators are scheduled for completion in FY23 in order to help to increase the beam power for NuMI. The integration into PIP-II seems to be well planned. Care should be taken that the project driven view does not completely exclude more generic R&D. The respective experts' proposals should be heard and discussed.*

7. Assess the Fermilab SRF R&D program progress since last AAC. Is this research program adequately setup to align with and to enable future Fermilab, national and international projects? Assess the Fermilab SRF R&D program progress since last AAC. Is this research program adequately setup to align with and to enable future Fermilab, national and international projects?

   In the past year, there has been an incredible level of improvement in cavity performance due to the efforts of the SRF team at FNAL (and JLAB). The latest gradient and Q results are spectacular, and the committee is sure that the limits of what can be done with doping (or other techniques) has not yet been reached. FNAL scientists are also working on theoretical models to help explain the effects on material properties from doping, which will hopefully guide future directions for improvements. The work has been motivated by needs of LCLS-II and LCLS-II-HE, and those improvements will help other projects around the world. The new results are also driving the need to improve our theoretical understanding of flux expulsion and niobium material properties. The FNAL program aligns well with current and future program at FNAL (PIP-II), in the US (LCLS-II-HE) and around the world (ILC).

8. Assess the Fermilab high-power target R&D. If Fermilab needs to accelerate work on a Multi-Megawatt Target System, are our current facilities and personnel sufficient?

   The high-power target R&D at Fermilab is advancing with irradiation studies, numerical simulations based on the code MARS and with remote handling (RH) developments that allow the handling of high-power target items. However, the team strength and the infrastructure are not yet sufficient for an accelerated program on a Multi-Megawatt Target System. The team has the expertise for such a development.

9. Since AAC-2018, has there been adequate progress in defining, planning, and securing resource support for the Fermilab Accelerator Control System (ACNET) Upgrade?

   Good progress has been made. There is a firm decision that PIP-II will only use EPICS. The project is ready for a CD-2 baseline review in January 2020. The decision has been made to roll out the same technology to the rest of the complex and deploy a common control system by the start of PIP-II operations. The upgrade of the existing complex will be driven as a dedicated project. The definition and planning are in the early exploratory stages. DoE should cover material resources, personnel planning to be done.

10. Assess the efficiency (high-level view) and performance of Fermilab Accelerator operations. Are the goals and plans for the near future (including g-2 and Mu2e) well understood? Assess the efficiency (high-level view) and performance of Fermilab Accelerator operations. Are the goals and plans for the near future (including g-2 and Mu2e) well understood?

    The ability of the Fermilab Accelerator operations to be efficient is hampered by the age of the facility and the lack of sustainable funding. The near-term goals are well understood. The Accelerator Division's understanding of what they can do in FY20 with the likely funding appears sound and complete, including the impact of a year-long continuing resolution.

11. Assess the LCLS-II/LCLS-II-HE progress and interactions with other Fermilab programs / projects. Assess the LCLS-II/LCLS-II-HE progress and interactions with other Fermilab programs / projects.

    There were many challenges with the LCLS-II project, which were eventually solved by excellent interaction between SLAC, FNAL and JLAB. For example, cryomodule transportation issues caused about one-year delay, but raised the awareness for all future projects that transporting critical hardware must be carefully studied and tested. The need for higher gradients for LCLS-II-HE spurred additional R&D, which produced new doping recipes with even better Q and gradient levels. These results will be applicable to PIP-II assuming technology transfer to industry and may lead to reduced cryoplant requirements. The excellent test facilities and infrastructure at FNAL allows quick turnaround for testing new ideas and analyzing material properties.

Charge 1: Recommendations AAC-2018 adequately addressed?

A document with the response to the recommendations has been compiled and reviewed by the committee. All recommendations have been adequately addressed by documents made available and by presentations provided at the AAC2019 meeting.

Charge 2: 2018 DOE Review of GARD

Findings and comments

- The committee did assess that Fermilab has addressed the recommendations and implemented or developed a plan for adequate response.

- The DOE GARD Review Recommendations with AAC Comments interspersed where:

1. FAST/IOTA: Increase operations staff as planned.

   AAC Comments: The necessary funding needs to materialize or be redirected from other activities. The relative value of operations needs to be weighed against other concerns.

2. FAST/IOTA: Cycle young research scientists through operations for experience in and exposure to a wide variety of accelerator issues.

   AAC Comments: The team does plan to cycle young new researcher through FAST/IOTA which AAC does fully endorse.

3. FAST/IOTA: Upgrade the cryo-plant.

   AAC Comments: The necessary funding needs to materialize or be redirected from other activities. The relative value of the cryo-upgrade needs to be weighed against other concerns.

4. FAST/IOTA: Defer the decision to convert to a user facility to allow joint cost and workload sharing with collaborators during early operational years.

   AAC Comments: The AAC agrees that FAST/IOTA should be fully commissioned before opening the facility to users.

5. ABP/AAC: Use FNAL beam expertise to guide and perform experiments at existing top-notch Advanced Accelerator Concept facilities (such as FACET II and others), and also consider contributing to the AWA beam manipulation techniques.

   AAC Comments: FNAL beam expertise is being leveraged in experiments at FACET-II.

6. ABP/AAC: Do not start an Advanced Accelerator Concept program at FAST facility unless and until a comprehensive and convincing plan could be developed.

   AAC Comments: An Advanced Accelerator Concept program at FAST is not foreseen. The facility does, however, offer unique opportunities for dedicated studies.

7. PST: Devote more resources to the design and development activity for targetry.

   AAC Comments: The lab has devoted more resources to activities related to targetry. Embedded in the Target Systems Department (TSD), new staff can be effectively integrated into the targetry activities related to design and development.

8. RFA: Continue to support SRF R&D at the same or higher level, devoting more efforts to further understanding of the field limitation in SRF cavities both experimentally and theoretically.

   AAC Comments: In the past year, there has been an incredible level of improvement in cavity performance due to the efforts of the SRF team at Fermilab (and JLab). The latest gradient and Q results are spectacular, and the committee is sure that the limits of what can be done with doping (or other techniques) have not been reached. Fermilab scientists are also working on theoretical models to help explain the effects on material properties from doping, which will hopefully guide future directions for improvements.

9. RFA: Increase high-pressure water rinsing capacity to increase the throughput of cavity testing.

   AAC Comments: They have added an additional High-Pressure Rinse (HPR) station to service PIP-II work specifically, which will free up additional time on the existing system. The new system is in place and undergoing testing.

10. RFA: modernize and increase redundancy of cryogenic plants in order to fully support cavity testing and operation of SRF modules reliably.

    AAC Comments: They have developed a 10-year plan to address issues with the aging cryogenic systems, which they are in the process of carrying out.

11. RFA: Support the field emission studies as the cavity gradient and surface electric field increase.

    AAC Comments: As part of LCLS-II and PIP-II, the Fermilab team has greatly improved the processes for preparing and assembling SRF cavities, thus reducing field emission problems considerably. Field emission has not been an issue with the newest cavities for LCLS-II, due to these improved controls and processes.

12. SMM: After the test results are known for the FNAL 15 T cosine theta dipole demonstrator and the LBNL CCT5 magnet, initiate an international workshop to bring together magnet developers from US, Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.

    AAC Comments: The DOE workshop, to best motivate the next steps in high field accelerator magnets development in the US, in particular at Fermilab, is planned to occur early December. However, the requested presence of experts from Asia is limited to 1 person from Japan, thereby effectively ignoring representatives of the strongly growing effort in China.

Recommendations

- None.

Charge 3: High Field Magnet Program

Findings

- Nice results have been reported of the Nb_3Sn artificial pinning centers (APC) conductor development program showing current densities at 16 T, beyond the FCC target. The next step is to mature the conductor production for meeting additional requirements that make them suitable for coil application in accelerator magnets.
- Good progress was also reported on high-Cp Nb_3Sn wires to drastically enhance conductor stability and Minimum Quench Energy. However, further work is needed to find a stable wire composition to make long-length wire drawing possible.
- The 15 T dipole demonstrator underwent its first successful test at 14 T, though substantial training is still present. The second test is being prepared using an enhanced and modified prestress configuration assumed correctly for achieving 15 T early 2020.
- Some design effort is present on a next >16 T Nb_3Sn magnet, however, without funding.
- Another topic and related mock-up work concerns a way to perform stress management in outer layers by a block-in-slot design for intermediate interception of angular Nb_3Sn winding pack forces, thereby keeping conductor stress below 150 MPa, in order to avoid conductor degradation. A similar idea proposed is a conductor-on-molded-barrel (COMB) design meant for creating a solution for an HTS-Nb_3Sn hybrid magnet.
- The MDP program is rather limited in volume, essentially addresses some APC and high-Cp Nb_3Sn conductor and cable development, as well as studies to improve understanding of training.
- The flat budget of some 2M$ per year covers 6.5 FTE. Some modest ad-hoc budget on yearly basis is eventually available through grants and internal funding.
- The next steps in the US-wide magnet development program needs to be defined.
- In the next few years, practically all sizable superconducting magnet projects at FNAL will ramp down. First the 15 T R&D magnet, then Mu2e Solenoids, LBNF/Dune and finally the quads for HL-LHC-AUP.
- The FNAL Magnet Development Program 2019-2030 as presented does not show a new substantial magnet construction other than a generic and rather vague 20 T HTS insert for a hybrid magnet. However, funding is not within reach, and not anticipated to start before 2027, about 8 years from now.
- In large-scale hands-on magnet construction, there is about a five years dead period. That period is even much longer when the HTS-hybrid effort does not materialize, and no other plans are yet initiated.
- Some coil winding activity may pop up for undulators that, however, cannot substantially make up the ceasing high-field magnet design and construction projects.

Comments

- The APC and high-Cp conductor programs yield good results and shall be continued.

- Despite the relatively slow execution, the lab is congratulated with the result of the 15 T magnet project. The important question is why this magnet is performing relatively well and it's important to truly understand technically why it has worked well. In order to move forward, it is essential that the magnet community agrees on the pros and cons of this particular design and construction, and defines the lessons learnt.
- FNAL's superconductors and magnet development plan presented is much larger than can be funded. Obviously, given the present level of funding and lack of new projects, the lab needs to develop an optimized descoping plan where priorities are set, and a limited number of core activities are defined and continued.
- The effort proposed for Iron based superconductors IBS is questionable given the weak results in China to boost the material to a level usable for accelerator magnets. Only a cursory effort seems to be justified at this moment. In absence of great ideas, better wait and see as one cannot compete with the Chinese effort anyway.
- Given the ceasing magnet projects in the next few years, and in view of the absence of funded and significant new high-field magnet constructions, as well as the lack of substantial internal support to compensate even partly, the size of the team can most probably not be maintained, leading to a brain and skilled-labor drain, a process difficult to reverse.
- The AAC is of the opinion that at FNAL, a stable and significant magnet team has to be preserved and measures are needed to accomplish this.
- There is a trend that all-ReBCO based high-field magnets will become more cost efficient and feasible, certainly in the time frame of 20 to 40 years relevant for an FCC-hh-like machine. Proposal for funding a technology development of ReBCO based >20 T dipole-relevant magnets in collaboration with the high-field compact fusion community may be worth exploring.
- A second area of magnet expertise to be preserved is for detector magnets. To continue efforts, it may be appropriate for FNAL to lead or take a substantial share in the magnet development and construction of one of the future detectors within the HEP program (ILC, FCC-ee).

Recommendations

- Take measures to maintain a substantial magnet team at Fermilab for accelerator and detector magnet development.
- Develop a new policy on how to prepare the magnet team for the future and define the best possible program to maintain a coherent effort in superconducting magnet development for the next 10 to 20 years.

Charge 4: FAST & IOTA Progress & Research Program

Findings

- A ring facility dedicated to R&D will allow students and early career scientists to get hands on experience. This is difficult to find at production machines.
- The integrable optics studies are interesting from a single particle dynamics point of view since these studies allow detailed comparisons between experiments and calculations. It will be exciting to see a strongly nonlinear integrable system actually realized in hardware.
- The emittance exchange studies in FAST are an important aspect of beam cooling studies for JLEIC. Full and careful comparison between experiment and theory will improve our confidence in the design.
- IOTA can reach full electron performance in an hour, making shut downs and short runs less of a problem.
- FAST and IOTA will provide a useful, low impact, test bed for conversion to the EPICS operating system.
- A test of optical stochastic cooling will provide the first experimental test of the new class of high bandwidth feedback systems.

Comments

- Optical stochastic cooling in IOTA will likely be the first practical implementation of ultra-wide bandwidth feedback. It will be interesting to see the practical aspects of such a system.
- Deferring advanced accelerator concept work at FAST will allow for more focus on IOTA. This seems prudent. Working with the FACET-II team on plasma acceleration ideas is a good alternative.
- A precision test of nonlinear integrable optics will be a fundamental advance to our field.
- The committee recognizes that the FAST accelerator is capable of cutting edge non-Advanced Accelerator Concept-science.

Recommendations

- none

Charge 5: Booster Beam Studies

Findings

- The Booster Beam studies have been a resounding success. The value of dedicated machine time to understand the beam dynamics of a given machine has, again, been, clearly demonstrated. The studies have been an exemplary example of cross-lab collaboration.
- On the back of the success of the studies, one day per month of beam time has been committed for dedicated beam studies.
- Studies have been identified, that, if pursued, offer valuable performance improvement.
- Details results of all studies have been presented at “Capstone” summary event. Results are being written up and the convective instability results are slated for peer-reviewed publication.
- Collaboration continues with visit of Fermilab personnel to CERN, and possible repeat of extended dedicated machine studies in May 2020.

Comments

- Studies performed in 2019:
  - S.01 Convective Instability at Transition
  - S.02 Gradient Magnet Power-Supply Ripple
  - S.03 Flattened Lattice Model
  - S.05 Transverse Impedance
  - S.07 Nonlinear Chromaticity
  - S.09 Space-Charge Emittance Growth

Highlighting 3 things (here acknowledging the input of Frank Schmidt) that should be pursued as a priority:

On the detailed study of the optics of the Booster machine. Without progress with this study there is little chance to make any relevant progress with the understanding and improvement of the Booster. Given the rapid cycling and associated eddy current effects it might be necessary to take an empirical approach here so calibrating instrumentation should get significant attention.

One of the most relevant issues for the Booster is the strength of the vertical ½ integer resonance and its apparent effect via space-charge driven emittance growth. This seems the most relevant single item for substantial performance improvement with high relevance for the goals of PIP-II. It is essential to make sure that the necessary correction currents can be obtained. The laboratory has access to all the computational tools needed to verify the correction scheme in simulations.

The other relevant study is the optimization and calibration of the IPM instrument that has shown surprisingly good performance at the Booster including quick ad-hoc improvements in terms of repetitive measurements etc. A full comparison with the wire-scanners are required and even better control would be very useful. Here too, knowledge of the lattice is essential since errors in the Twiss parameters directly translate into emittance measurement errors.

Recommendations

- Improve the model of the machine, with the immediate goal of attempting correction of ½ integer driving terms.
- Continue collaboration and dedicated studies – essential to achieve required performance goals.
- Do simulations including space charge and verify the half integer correction scheme. This is an excellent chance for the SYNERGIA team to have a significant impact on machine design.

Charge 6: PIP-II

Findings

- The former PIP-I+ Accelerator Improvement Projects (AIPs), now included in the PIP-II resource loaded schedule, are related to Booster Intensity (beam physics, dampers, and collimators), Booster D-magnets, Main Injector gamma-t jump, and to the replacement of booster RF cavities. The scope remained unchanged except for the number of RF cavities to be replaced which now 6 out of the total of 21.
- All AIPs are now assigned to Level 2 and Level 3 project managers, either under 'Accelerator Complex Upgrades' or under 'Linac Installation and Commissioning'. They all follow the PIP-II Project review cycle with its design and production reviews. The scope of all former PIP-I+ AIPs is now included in PIP-II with no dependencies on external AIPs.
- Some details of scope as defined in the PIP-II WBS Dictionary were presented. Also, draft schedules and timelines including all reviews.
- The Booster Dampers and Collimators are scheduled for completion in FY23 in order to help increasing the beam power fur NuMI. The committee was told that some additional other project costs (OPC) support is available.
- The overall PIP-II project is going to have an Integrated Project Review end of January 2020.
- First beam in PIP2IT is currently scheduled for 4/2020.

Comments

- PIP-II project planning requires independency of external AIPs. While this is completely understood, proposals from the respective system experts / system owners should not be ignored and carefully checked in order to avoid any gaps in the improvement program.
- PIP-II may require beam testing (e.g. LLRF related). Taking advantage of possible studies at FAST using the currently installed CM2 module should be investigated.
- The PIP-II control system will be based on EPICS. Plan, cost and schedule are supposed to be ready for CD-2 review in January. The existing accelerator complex will be migrated in phases to EPICS with the goal to have one new common system by the start of PIP-II operations.

Recommendations

- None

Charge 7: SRF R&D Progress and Research Program

Findings

- The PIP-II HWR cryomodule was delivered by Argonne earlier this fall. One leak was repaired, but otherwise met all specifications.
- The SRF R&D program at FNAL focuses on advancing the state of the art in Q and accelerating gradients in bulk niobium cavities.
- Achieved record accelerating gradients of 50 MV/m in TESLA shaped cavities.
- Pioneered nitrogen doping and efficient magnetic flux expulsion, now realized in LCLS-II with hundreds of cavities with Q > $3*10^{10}$ at 2 K in cryomodule and advancing further for LCLS-II HE.
- Reported the highest accelerating gradient ever achieved for Nb_3Sn of ~24 MV/m, with Q > 10^{10} at 4.2 K.
- They have nearly 100 people working on SRF R&D and production.
- Discovered that using a lower temperature EP solved the lower quench field for nitrogen doped 9-cell cavities versus 1-cell cavities.
- Revealed that the origin of the 120C bake effect is due to oxygen diffusion.
- Discovered that efficient flux expulsion depends on the bulk properties of the niobium material, not a surface effect.

Comments

- There has been tremendous progress in 9-cell cavity results in the past year, which will have a big impact on LCLS-II-HE, PIP-II, ILC and other SRF projects around the world.
- The R&D on plasma processing may allow for in-situ cavity improvements, so continued work on this is an important topic.
- The path using lower temperature electropolishing is important. Transfer to industrial cavity treatment should be done as soon as possible, very likely in preparation of LCLS-II HE cavity production.
- The mid T-bake should be checked with respect to all infrastructure constraints. The investigation of the source of Nitrogen is essential to understanding these results.
- Engineering the Oxygen profile is definitely promising, and research should continue in this area.
- You have top-notch test facilities for SRF R&D, which has enabled many of the recent breakthroughs.

Recommendations

- There appears to be a large phase space of parameters for producing high quality cavities, and a strong theoretical understanding can help to guide the optimum parameter selection. Continue to strengthen ties with universities to enhance efforts on SRF theory and SRF material science, and present results at the next AAC.

Charge 8: High-Power Targetry R&D

Findings

- The Target Systems Department (TSD) has to support three operating stations, BNB, NuMI and Muon g-2. The megawatt upgrade of the NuMI target station is in preparation.
- TSD performs R&D for improvement of current and future target facilities in the framework of High-Power Targetry (HPT). In addition, Radiation and Radionuclide management is part of the tasks, as well as the development of the required remote handling (RH) systems and infrastructure.
- Two challenging target developments keep the team busy, the 1.2 MW target for LBNF/DUNE and the high-Z, radiatively cooled target for Mu2e.
- Present workforce has not been adequate to keep up with existing workload, which includes the development of the new target systems and the required R&D. Hiring has happened but was not sufficient to consolidate the required team strength.
- A Target Systems Integration Building (TSIB) will be required to provide long-term space for assembly and development of the Multi-Megawatt Target Stations.
- The examination of BLIP (BNL) irradiated Be- and Titanium alloy- specimens for beam window R&D is underway and the proton irradiation of graphite samples at BLIP in 2020 is in preparation to confirm the elevated temperature annealing.

Comments

- The 1.2 MW target development for LBNF/DUNE is challenging, but achievable, ensured by the 1 MW development for NuMI. The rate of production will be a stretch for the team and the present team strength is not sufficient.
- Challenges for the team by raising the beam power will be faster radiation fatigue and will require more radiation hard instrumentation. More frequent exchange of equipment will be dose intense and will require more storage and modern RH equipment (hot cell, remote trolleys etc). The Czero Long Term Storage and Remote Handling Facility does not provide a modern RH equipment and is at present very rudimentary.
- The team is commended for their RH semi-robotic systems for the Mu2e target and the NuMI beam window exchange and for the strengthened R&D effort on high power targetry.
- Potential space for the TSIB has been evaluated and the evaluation committee did recommend an extension to the existing TSD hall area. Although first steps towards this project have been presented, the AAC did not receive a timeline for this installation that fits into the LBNF/DUNE high power target development plan.
- Fermilab is very successful in materials R&D for high power targetry. The explanation of the NuMI target fracture by modeling of graphite swelling is one success of this activity. In addition, Fermilab is a founding partner in the RADIATE collaboration since 2017, which provides an intense exchange of experience and know how between labs.
- AAC was not presented a plan to develop the R&D infrastructure at Fermilab for the future Multi-Megawatt design and development. However, the required infrastructure for the LBNF/DUNE 1.2 MW production target development and construction should be planned such that it’s sufficient for the Multi-Megawatt production target.

- The High-Power Targetry R&D effort is key to the path towards success in the development of a Multi-Megawatt production target. The systematic approach to high-intensity irradiations and according examination showed already beneficial results. There is the clear need to develop materials science capabilities for irradiated materials, that comprises RH tools and skilled people.

Recommendations

- Develop a timeline and staffing plan for the development of the new target systems. Include a scenario in which the development of a Multi-Megawatt target is anticipated to run in parallel.
- Develop a timeline for the TSIB that is fully integrated into the plan for the high-power target development and can cover the requirements for a Multi-Megawatt target development.
- Provide a priority plan for the required R&D that is key to the development of a Multi-Megawatt target.

Charge 9: Control System Upgrade

Findings

- The accelerator controls systems for the FNAL accelerator complex is in need of an upgrade as the equipment is reaching its end of life, with many components lacking proper spare components and replacements.
- The PIP-II control system will be based on EPICS, the rest of the complex will be migrated to produce a common control system based on EPICS by the start of PIP-II operations.
- The upgrade of the existing system will be realized as a separate DoE project.
- The upgrade of the existing system will involve all four layers of the present architecture: field hardware; front ends; central services; applications.
- The field hardware and front-ends are a heterogenous mix of outdated frameworks and electronics. Around 1000 physical field hardware/front-ends instances are concerned.
- Some features supported by ACNET (e.g. beam destination, security) are felt to missing from EPICS.
- As a possible migration strategy, it is suggested to develop an ACNET interface to EPICS channel access which would allow access to EPICS based systems at the Input Output Controller (IOC) and Hardware level. This would allow the present high-level functionality to remain in place while testing low level EPICS deployment.
- The upgrade program will take advantage of summer stops and PIP-II long shutdown, no additional shut down will be required.
- A survey of existing systems is in progress.
- A Mission Validation Independent Review (MVIR) took place in August. A number of valuable recommendations were made.
- Foreseen next steps include: Formal requirements exercise; IOC integration under ACNET; Expand and generalize EPICS evaluation; Begin formal project planning (CD-1 in under a year); Engage with other labs and add people to the project.

Comments

- The committee is impressed and encouraged to see the decisions and steps that have been taken in the last year. The decision to go EPICS opens the opportunity to get access to a new pool of people with the required skill set.
- New crate and power supply technologies are more efficient, easier to maintain and meet modern safety requirements. There is some really old stuff out there – it should be replaced.
- Main stream technology alternatives have been identified. They are available at all levels and should be embraced (microTCA, Python...). In-house developments should be largely unnecessary.
- There is limited EPICS experience at the lab. Efforts are already underway to ramp up expertise (hires, consultancy) - these should continue.
- MVIR: “It is very likely the requested funding will not be sufficient to fully upgrade all electronics and software components identified in the described plan”.

MVIR recommendations – reproduced for completeness:

- Clearly define which accelerator sections are not being upgraded as part of separately funded projects such as PIP-II.
- Clearly define the scope of the accelerator controls upgrade project, including which physical components and software elements are impacted.
- Create a list of individual sub-assemblies (hardware and driver software) including the cost of each, by accelerator section.
- Create a prioritized list of subsystem upgrades by accelerator section, including cost estimates, which includes items from recommendation 3.
- Create a list of individual partitionable software subsystems with a clear interface description to other systems.
- Create a prioritized list of upgrades, including cost estimates, which includes items from recommendation 5.

  - For the ACNET features that appear to not to be present in EPICS, clearly identify the required functionality and look around – these problems have been solved elsewhere (and probably by the EPICS community).
  - It might be worth revisiting the operational/data model of the complex regarding cycles, destinations, settings etc. At the same, the functionality of the field hardware systems offered to the high level might be revisited – are there features which long experience has revealed as missing?

Recommendations

- Prioritize integration of EPICS into ACNET. This is key part of the migration plan and will allow progressive roll-out of EPICS at lower levels.
- Having established requirements, identify required material and personnel resources and start to develop resource loaded planning (in particular for field hardware/ FE replacement).
- Address the MVIR recommendations.
- Continue to build up the EPICS knowledge base.

Charge 10: Accelerator Operations

Findings

- FY19 accelerator operations scope was adjusted to match the funding that was provided by HEP, which led to a reduction of run time.
- The main injector is getting old and includes 50 year-old components.
- There was an arc flash from a power supply, which has already impacted the FY20 schedule.
- Operations funding has been flat, not even keeping up with inflation. FNAL had requested $93M for operations in FY20 but will only receive $84M. This will lead to a 7 months run schedule that will be reduced further if a year-long continuing resolution persists.
- An operations goal is to engineer the Operations section, so the operations is more efficient.
- 50% attrition is expected over the next 10 years.
- Funding is not available to properly prepare for workforce succession.
- It is hard to find a sufficient number of entry and mid-level technicians and staff for adequate succession.
- FNAL has established strong relationships with Uni Chicago, NIU, IIT, and USPAS.

Comments

- Compared to more-or-less equivalent proton facilities, Fermilab accelerator complex operations appear to be underfunded, resulting in deferring equipment maintenance and replacement and not hiring appropriately for attrition.
- While the $84M FY20 operations funding is an increase from the $79M in FY19, it is still not enough to ensure sustainable operations. Probably funding of more than $93M/year would be needed to ensure improved operational up-time. The current funding level is too low to provide engineering changes to allow operations with less staff.
- Chronic underfunding for operations has been encouraged by heroic activities by operations personnel who manage to keep the complex running with continually smaller funding levels. While admirable, these heroic activities undermine the long-term viability of the complex. They also encourage too much reliance on expert-based execution, which is not easily transferable to succession staff and leads to a ratio of M&S versus personnel that is reduced past sustainable levels.
- Symptomatic issues due to a chronic lack of sustained funding are now becoming visible, including:
    - The arc flash and subsequent month-long safety pause to retrofit the 50-year old power supplies,
    - Reduced Muon g-2 beam time due to lack of sufficient operations funding,
    - Lack of buffer to address continuing resolution funding.
- Compared to other accelerator laboratories, FNAL is in a relatively strong position to find new and replacement staff because the lab is located in a highly populated area and because of its strong relationships with U Chicago, NIU, IIT, MSU, and USPAS.

- The accelerator complex operations plan appears realistic and appropriately recognizes the operations funding limitations.
- Executing the Accelerator Modernization Plan needs to be a high priority.

Recommendation

- Assess the benefits of a more formal tracking system for run-time faults to optimize impact of maintenance and to guide prioritization of upgrades.

Charge 11: LCLS-II

Findings

- Delivered 15 of 17 1.3 GHz cryomodules to SLAC, with two more to be delivered soon.
- Three 3.9 GHz CMs are being constructed with the first to be delivered to SLAC at the end of February.
- The cryo-distribution system work for SLAC has been completed.
- Transportation issues for the 1.3 GHz CMs have been resolved.
- Performing due diligence to prepare for 3.9 GHz CM transportation.
- FNAL produced CMs had an average usable energy gain of 158 MV and average Q_0 of $3.03*10^{10}$.
- They have listed 'lessons learned' during LCLS-II that can be applied to LCLS-II-HE CM production.
- LCLS-II-HE is a high-priority, high visibility project, with weekly updates to the lab director from Senior Team Leader (STL).
- LCLS-II-HE will build one pre-production CM and 10 production CMs, as well as the cryo distribution system design and procurement.
- The HE R&D program on single and then nine cells demonstrated that quench field in nitrogen doped nine cells has systematically improved reaching gradients E_{acc} > 28 MV/m with 80% yield.
- All three projects (LCLS-II. LCLS-II HE and PIP-II) rely on SRF technology and the team is continually pushing to advance the state of art.
- Goal is to avoid competition and view all three (LCLS-II, HE and PIP-II) as important Fermilab projects sharing a common technology.

Comments

- As noted, careful planning will be critical in order to meet the demands of LCLS-II-HE, PIP-II and R&D projects.

Recommendation

- Ensure that you apply all of the lessons learned from LCLS-II cavity and cryomodule production to LCLS-II-HE and PIP-II.

Appendix 1: Agenda

Tuesday, November 19, 2019

08:30 - 09:00	AAC Executive Session
09:00 - 09:30	Welcome, Introduction, and DOE GARD Review Summer 2018 *15 minute presentation + 15 minute Q&A - address Charge Question #2* *see above Materials: 11 Report from 2018 GARD Review* Convener: Sergei Nagaitsev (FNAL)
09:30 - 10:10	Accelerator Division Introduction and Status *including accelerator operations* *20 minute presentation + 20 minute Q&A - address Charge Question #10* Convener: Michael Lindgren (Fermilab)
10:10 - 10:25	Break
10:25 - 11:05	Interfacing PIP-II to Existing Accelerator Systems *20 minute presentation + 20 minute Q&A - address Charge Question #6* Convener: Dr. Ioanis Kourbanis (Fermilab)
11:05 - 12:05	Applied Physics and Superconducting Technology Division Introduction and Status *30 minute presentation + 30 minute Q&A* Convener: Dr. Sergey Belomestnykh (Fermilab)
12:05 - 13:05	Lunch for AAC Members and VIPs
13:05 - 14:20	Fermilab Contributions to the US High Field Magnet Program and Progress on the 15 T Magnet *40 minute presentation + 35 minute Q&A - address Charge Question #3* Convener: Dr. Gueorgui Velev (FNAL TD/MS)
14:20 - 15:20	FAST & IOTA - Status and Plans *30 minute presentation + 30 minute Q&A - address Charge Question #4* Convener: Alexander Valishev (Fermilab)
15:20 - 15:35	Break
15:35 - 16:05	Recent and Future Booster Beam Studies *15 minute presentation + 15 minute Q&A - address Charge Question #5* Convener: Dr. Jeffrey Eldred (Fermilab)
16:05 - 16:35	SYNERGIA - description, features, applications *15 minute presentation + 15 minute Q&A* Conveners: Dr. Eric Stern (FNAL), Dr. James Amundson (Fermilab)
16:35 - 17:00	Questions, Answers, and Discussions *25 minutes*

17:00 - 18:30 AAC Executive Session

must vacate WH1E by 6:45 PM for next meeting
please don't leave anything valuable in the room overnight

18:30 - 20:00 Drinks at Users Center and Dinner at Chez Leon

for map, see Material: 30 Chez Leon

Wednesday, November 20, 2019

08:30 - 09:10 Upgrade of Accelerator Controls

20 minute presentation + 20 minute Q&A - address Charge Question #9

Convener: James Patrick (Fermilab)

09:10 - 10:15 Answers to Tuesday's Questions

65 minutes

10:15 - 10:30 Break

10:30 - 11:30 Meeting with Fermilab Director Nigel Lockyer

nominally 1 hour, will continue as long as Nigel wants

11:30 - 12:30 Preparations for Fabricating a Multi-MW Target System

30 minute presentation + 30 minute Q&A - address Charge Question #8

Convener: Dr. Bob Zwaska (Fermilab)

12:30 - 13:30 Working Lunch for AAC Members (and their invitees)

13:30 - 14:15 Presentations by three Graduate Students in AS&T

each has 10 minute presentation + 5 minute Q&A:
David Tarazona (MSU) Modeling of the Muon g-2 Storage Ring
Crispin Contreras (MSU) SRF Cavity Resonance Control
Bianca Giaccone (IIT) Plasma Processing of SRF Cavities

Conveners: David Tarazona, David Tarazona (Michigan State University), Crispin Contreras Martinez (Michigan State University), Crispin Contreras-Martinez, Bianca Giaccone

14:15 - 15:15 Superconducting RF R&D

including operation of Nb3Sn cavity with cryocoolers
NO Quantum Information Systems!
30 minute presentation + 30 minute Q&A - address Charge Question #7

Convener: Dr. Alexander Romanenko (Fermilab)

15:15 - 15:45 Status and Impact of LCLS-II and LCLS-II-HE

15 minute presentation + 15 minute Q&A - address Charge Question #11

Convener: Richard Stanek (Fermilab)

15:45 - 16:00 Break

16:00 - 16:30 Questions and Discussions

30 minutes

16:30 - 18:00 Tour of Target Station R&D

Bob Zwaska, Patrick Hurh, Cory Crowley

18:00 - 19:30 ACC Executive Session

feel free to stay as late as you want

19:30 - 21:00 AAC Dinner on your own

Thursday, November 21, 2019

08:30 - 09:15 Answers to Wednesday's Questions

09:15 - 11:30 AAC Preparation for Closeout

Coffee refresh at 10:15

11:30 - 13:00 Closeout Presentation and Discussion

12:30 - 13:00 Box Lunches Available for AAC Members

Appendix 2: Fermilab Accelerator Advisory Committee Members, November 19-21, 2019

- Oliver Kester (Chairperson) – TRIUMF, Canada
- Mei Bai – GSI Darmstadt, Germany (could not participate)
- Herman ten Kate – CERN, Switzerland
- Bruce Dunham – SLAC, USA
- Mike Lamont – CERN, Switzerland
- Bruce Carlsten – LANL, USA
- Michael Blaskiewicz – BNL, USA
- Hans Weise – DESY, Germany (Chair PIP-II MAC)

Appendix 3: Charge to ACC-2019

The Fermilab Accelerator Advisory Committee is asked to assess and provide advice on the following topics:

1. Recommendations from prior AAC 2018

Have all the recommendations by AAC 2018 been adequately addressed?

2. 2018 DOE Review of GARD – report released too late for AAC-2018

The DOE Review of General Accelerator R&D, July 30 – August 4, 2018, listed 12 recommendations regarding Fermilab activities in this area. Assess whether Fermilab has implemented or developed a plan for adequate responses to these recommendations?

3. High Field Magnet Program

a. Fermilab has recently performed the first test of the 15 T dipole demonstrator magnet. The magnet reached world-record dipole field of 14.1 T (limited by pre-stress) and is being prepared for the second test. Assess the plan and readiness for testing up to the 15 T design.
b. The Fermilab High Field Magnet R&D program has integrated into the US Magnet Development Program (MDP). Assess Fermilab involvement in this Program. Are the long-term assignments and goals well defined and resources secured?

4. FAST & IOTA Progress & Research Program

a. Fermilab started the accelerator research program at FAST and IOTA in December 2018.
    i. Assess the commissioning results, the operations efficiency, and the science output of FAST/IOTA Run I, including measurement of the beam parameters for IOTA.
    ii. Is the near-term and long-term science program well defined?

    iii. Are the required resources well defined and secured to optimally and effectively utilize FAST/IOTA and to produce high-impact science?
b. Are the plans, schedules, and requested resources consistent with implementing the proton beam in IOTA within a reasonable time scale (~2020)?

5. Booster Beam Studies

Review and assess the Booster study program, assisted by members of CERN, that was accomplished in the Summer of 2019. Assess the results, outcomes and potential impacts of these studies. Are plans and goals for future studies well defined?

6. PIP-II

The PIP-I+ beam power upgrades, described at AAC-2018, have been incorporated into the PIP-II project. Assess the plans for this integration.

7. SRF R&D Progress and Research Program

Assess the Fermilab SRF R&D program progress since last AAC. Is this research program adequately setup to align with and to enable future Fermilab, national and international projects?

8. High-Power Targetry R&D

Assess the Fermilab's readiness to design, fabricate. and install a Multi-Megawatt target system. If Fermilab needs to accelerate work on such a system, are our current facilities and personnel sufficient?

9. Control System Upgrade

Since AAC-2018, has there been adequate progress in defining, planning, and securing resource support for the Fermilab Accelerator Control System (ACNET) Upgrade?

10. Accelerator Operations

Assess the efficiency (high-level view) and performance of Fermilab Accelerator operations. Are the goals and plans for the near future (including g-2 and Mu2e) well understood?

11. LCLS-II

Assess the LCLS-II/LCLS-II-HE progress and interactions with other Fermilab programs / projects.