Responses to the Fermilab 2019 AAC recommendations
Dec 3, 2020

AAC2019 Charge 5: Booster Beam Studies

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.**

Response:

Many of the planned studies in Booster were highly impacted by COVID19. However, we have analyzed the measurements taken before the lockdown.

1. **½ integer driving term studies** A lattice group was formed to investigate this problem.
    a. The effects of the vertical ½ integer were studied to see whether the theoretical corrections can reduce the size of the ½ integer. The correction was done using 2 families of 6 quads spaced approximately π apart (group A) and its orthogonal family that are approximately $\pi/2$ apart. However, although scans showed that the vertical ½ integer was reduced, as of yet the corrections have not improved efficiencies. (see https://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=7905).
    b. To better understand the modeled and undermodeled aspects of the Booster lattice we decided to conduct a "bare lattice" study. First all higher order corrections (quadrupoles, skew quadrupoles, sextupoles, skew sextupoles) are removed from a specific interval of time within the cycle. Next the beam orbit and TWISS functions were measured. Next, the half-integer resonance is excited and the correction circuits are used. The comparison between this study and the previous study will enable us to validate our MADX lattice model as well as our ½ integer correction strategy.
    c. Subsequent studies may examine the interplay between the injection matching, early space-charge dynamics, and half-integer correction. Recent improvements in the speed and accuracy of IPM diagnostics will provide critical insights.
2. **Continued collaboration.** No on site visitors were allowed on site and the machines were shut off mid March 2020 and almost everyone teleworked. Furthermore, our international collaborators were unable to travel as well. However,
    a. International collaborations: US-CERN collaboration and US- JPARC-Japan collaboration continued via email or zoom meetings with the previously collaborated members.

b. Since January of 2019 one-day/month dedicated Booster studies continued with mutual collaboration between members from PS Department and from AD Accelerator Science & Technology, Accelerator Physics Department. As a result of this plan, we had 2 one-day study in 2019 and 3 one-day study in 2020, until mid-March 2020 (unfortunately, due to COVID19, all of the studies between mid-March 2020 and before the 2020 shutdown were cancelled).
c. Startup studies: multiple day dedicated time were allotted for Booster beam studies after long-shutdowns of 2019 and 2020.
d. Also, parasitic and semi-parasitic Booster studies utilizing one or more beam events in timeline were carried out throughout the year.

3. **SYNERGIA simulations** We have started working with Eric Stern (SYNERGIA expert) and others for simulating the entire Booster cycle. Our first meeting was held on 22 Oct 2020 that concentrated on transition crossing (https://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=8735). In addition to this, we are also carrying out simulations using PyOrbit (J.-F. Ostiguy), ESME (C. Bhat) and BLOND-CERN code (P. Derwent). We plan to use the accelerator data at operational intensities to bench-mark the simulation codes and use the results for PIP-II intensities.

AAC2019 Charge 8: High-Power Targetry R&D
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.**

Response:

Timeline and staffing plan for the development of the new target systems:

- The timeline for new target systems is an area of constant analysis. Present expectations are: [operations dates]
    - Mu2e starting in 2024
    - LBNF @ 1.2 MW in 2029
    - LBNF @ 2.4 MW in 2034 – only minimally defined
    - Mu2e-II: not defined, and no timeline (>2029)
    - PIP-II experimental suite: not defined, and no timeline (>2029)
    - PIP-IIIff experimental suite: not defined, and no timeline (>2034)
    - AP-0 likely to stop operation 2023, BNB and NuMI likely to stop in 2027.
- TSD has added some labor within 2020:
    - Net +3 FTE of engineering (including approval to make one permanent)

    - Net +3 FTE of scientists (HPT R&D, LBNF, and MARS)
    - Net -1 FTE of technicians due to multiple departures (one approved position is open)
- For 2020 level of effort on Projects, Operations, and R&D, identified shortages of:
    - Shutdown and Integration Coordinator
    - Fabrication specialist for target station devices
    - 2 FTE of engineering (dominated by design tasks)
    - Operations Physicist for Mu2e
- LBNF @ 1.2 MW will require ramp-up by ~ 2023 of:
    - 1-2 Physicists / Engineering physicists for design and project management
    - 2 technicians
    - If the above 2 FTE of engineers is satisfied, effort can move from design to production, and no addition is needed for this task.
    - Target design and construction provided by partner lab: RAL
    - These estimates assume availability of effort from ramping down of existing target stations
- LBNF @ 2.4 is not well defined, nor is it clear whether our partner lab would provide the upgraded target (they prefer to). Additionally, new horns, windows, and analysis are needed. Thus we would expect to ramp up 2022-2027 an additional:
    - 1-3 engineers, 1 physicist, 2-4 technicians
- Future target stations associated with Mu2e-II, PIP-II, and future accelerator upgrades are expected, but not at all defined. At moment, there is little additional labor available.
    - Each of these require physicist and engineering at each level of design, likely multiple FTE at a time. Technicians labor is needed upon construction and operation.
- Radiation Modeling & Simulation
    - A specific need, in addition to target station design is the MARS group which is responsible for radiation modeling and simulation. This includes both development of the code, and execution of the simulation. The group presently is adequate for execution, but has minimal available overhead for development. Enhancement of this group is necessary for additional new target stations.
- Succession
    - 5-7 TSD members are expected to retire within the next 5 years, requiring additional emphasis on hiring and skills transfer in this period.
    - Additional members may be expected to move on to other leadership, research, or project activities.
- Identified are shortages of labor in key skills areas that are matrixed into target systems activities:
    - Drafting/Designing has been short-handed, and new projects have intensive needs
    - Machining resources are limited at the laboratory, requiring outsourcing and greater oversight
    - Welding has been similarly limited

- Alignment has been limited, requiring alternatives for metrology

Timeline for the TSIB:

- An integrated timeline has been developed for TSIB incorporating the requirements of:
    - LBNF 1.2 MW construction
    - High-Power Targetry R&D
    - Existing Target Station effort
- This facility scope includes:
    - Fabrications, Assembly, and testing faciliteies for 1.2 MW LBNF targets & horns
    - R&D and hotcell facilities for HPT R&D and operations support
- Fermilab has recognized TSIB as its highest priority small construction project and is negotiating with DOE for an early start
    - A preliminary design has been developed with Fermilab and A/E resources
    - Funding is expected in early Fy21 for final design resources of the building
    - An aggressive schedule has been developed to deliver the facility by FY23 to allow LBNF construction and testing, and HPT experiments for mulit-MW target development.

Priority plan for the required R&D that is key to the development of a Multi-Megawatt target:

- The current R&D program has fundamental material R&D as priority number one and on technology R&D as a priority number two if we have limited budget to pursue both in parallel. Material R&D can be divided in 3 phases
    - The present phase that will benefits the ongoing Neutrino program and LBNF 1.2 MW
        - Irradiated material behavior study of identified materials (Be, Ti-alloys and graphite) and high-energy proton irradiation, thermal shock test and autopsy of used Fermilab targets.
        - Identify alternative methods of irradiation Material Characterization (MIMiC) and alternatives to high-energy proton facility irradiations.
        - Explore ab initio and molecular dynamics to model irradiated material behavior
    - Mid-term (in the next ~10 years) program which will benefit LBNF 2.4 MW design and next-generation HEP experiments,
        - Continue to focus on the current program on irradiated material behavior but with extended list of novel material. These new materials will push the limit compared to conventional materials, and will be resilient and capable of withstanding increased particle beam intensities of next generation multi-MW accelerator facilities.
        - Develop MIMiC ideas into valid experimental techniques suitable for demonstrating the capabilities of new materials

- Long term program (beyond 10 years) which will benefits next-generation HPT Facilities
    - Systematic approach with MIMiC techniques and alternative irradiation methods.
    - Develop and validate ab initio/MD modeling
    - Continue to develop novel materials, but also narrow and select some promising targetry material for future application
    - Qualify the selected materials to be tested with MIMiC techniques and validated with high energy-proton irradiation

The team actively participates to the Snowmass process and lead the subgroup related to the HPT under the topical group Accelerator Technology R&D. We are in the process to identify the needs for HPT for the next-generation facilities and the above program will be adjusted and consolidated based on the Snowmass process findings in the next years.

AAC2019 Charge 9: Control System Upgrade
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.**

Response:

A bridge to EPICS IOCs has been added to the production Data Pool Manager (DPM) in the ACNET control system. This process interfaces applications to front-ends, and provides ACNET support for EPICS process variables. This is in use for some EPICS based RF equipment at the PIP2IT test facility. Higher level EPICS tools are under investigation at PIP2IT for local use there.

The modernization plan submitted to the DOE in the fall of 2019 was restructured to break out the control system into a separate project. This project, now called ACORN for **A**ccelerator **Co**ntrols **O**perations **R**esearch **N**etwork, received CD-0 approval August 28, 2020. With the delay in getting CD-0 approval and minimal funding in FY20, limited progress was made on developing a resource loaded schedule (RLS). A project manager, Erik Gottschalk, started in February, 2020. An experienced project controls specialist from the lab's Office of Project Support Services (OPSS) has been assigned and a draft work breakdown structure (WBS) has been developed. Initial steps for developing use cases and requirements have begun, and development of a RLS suitable for a CD-1 review will begin during the second quarter of FY 2021. Much of this work will be done by two new hires together with existing personnel. A software developer with expertise in developing use cases and requirements development was hired and will begin in January 2021. A software architect will be hired, but this position has not yet been filled. The requirements analysis that will be performed will address the recommendations from the 2019 MVIR review.

The EPICS knowledge base will initially be expanded by gaining experience at PIP2IT and the followup cryomodule test stand. A requisition to a control system consulting firm to develop a self paced online training course for EPICS will be submitted shortly. Currently there are approximately 75 people interested in this training.

AAC2019 Charge 10: Accelerator Operations
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.**

Response:

As a response to a 2019 DOE PEMP notable, the Accelerator Division undertook an in-depth study of underlying issues that could have a potentially negative impact on reliable machine operations. The study used a three-prong approach to cross check the completeness of the information. Data was obtained from.

· Operations Downtime logger

· Survey filled out by frontline maintenance staff

· Information obtained from two department downtime and failure databases.

The summary of these findings led to the report: "Accelerator Reliability Report 24 Aug" which was then submitted to DOE. As a response to the report, a list of critical items was generated and compared to the previously collected items for Accelerator Modernization. A central database building on the two existing departmental databases will continue to be pursued for the remaining departments. A funding request has been sent into DOE for this effort. Two high level findings of the report were the following.

1. The results of this exercise showed that good communications exist between front line workers and department/division management. There were no major system deficiencies or risks uncovered in the study that were previously unknown.

2. It was also determined that there are no major systems that lack a resident expert for repair or modifications. Succession planning and overlap training will need to continue to ensure the supply of experts needed for repair or modifications of the equipment are available.

AAC2019 Charge 3: High Field Magnet Program
Recommendations:

- **Take measures to maintain a substantial magnet team at Fermilab for accelerator and detector magnet development.**

Response:

Maintaining a substantial magnet team and keeping the knowledge is the main priority of the Superconducting (SC) magnet R&D group management. In the past 4 years we hired 4 new team members - 2 scientists, one engineering physicist and one young magnet design engineer - who are working on optimization of the Nb3Sn superconductor, developing new fiber quench detection paradigm for HTS magnets and developing new computer tools for quench simulation. Moreover, we have just started the process to hire a Research Associate (postdoc) who will work on Nb3Sn and high-temperature superconducting magnets and associated materials. One of our young scientists was awarded a prestigious Early Career Award by DOE with a research budget of $2.5 M for 5 years to optimize and prepare for production a NB3Sn wire which meets FCC specifications. In the past, five of our team members won Lab Directed R&D (LDRD) grants, which gave us ability to perform specific research in HTS magnets, quench detection and minimizing the quench training in NB3Sn magnets, as well as specific conductor R&Ds in Nb3Sn and iron-based superconductors (IBS). Along with increased funding from external sources, we are involving younger scientists and engineers, who are typically busy with the projects (mu2e and AUP). For the last year, they have increased their research time.

The Fermilab team has always had strong participation in the design and building of detector magnets. In the last 7 years we built Torus coils for JLab CLAS12 experiment, designed the Production and Detector solenoids and in the process of testing and assembly of the Transport Solenoid for the mu2e experiment. Recently, we have started a discussion to design and build, together with NHMFL, a large aperture 30 T solenoid for a proposed upgrade of the ADMX experiment for dark matter detection.

- **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.**

Response:

Fermilab SC magnet R&D is an integral part of the US Magnet Development Program. Recently, the Program went through replanning of its future R&D activities. It included plans for the next 4 years, short term, and next 10 years, long term. Fermilab participates in all four directions of the Program: Nb3Sn magnets, HTS (BI-2212, REBCO) magnets, Technology development, and Conductor development. Over the next several years we will align our effort with the recommendations from the HEP Community Planning Meeting 2021 (Snowmass) and the following P5 recommendations. Around 2023-2024 our SC magnet projects (mu2e, HL-LHC AUP) will start to wind down and depending on the Snowmass direction we are expecting to start a DOE directed R&D to satisfy the needs of the HEP community.

In 2025, Fermilab will become a center for cable testing in very high dipole fields. We have just started construction of a new test facility. This facility, called High Field Vertical Magnet Test Facility (HFVMTF), will serve the U.S. MDP for testing magnets with 16-20+ T accelerator dipole fields, including hybrid magnets, as well as the U.S.

DOE Fusion Energy Sciences (FES) programs for testing HTS samples in very high dipole fields. For the U.S. FES community, this facility will provide similar or better capabilities than the European test stands FRESCA2 at CERN and EDIPO at PSI, Switzerland. This facility is a part of our 20+ years plan.

AAC2019 Charge 7: SRF R&D Progress and Research Program
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.**

Response:

Under the Office of CTO, APS-TD and Fermilab-Northwestern CAPST continued and expanded the theoretical work in collaboration with Northwestern and other universities. In addition to improved understanding of the gradient-limiting factors for SRF accelerators, the expanded theoretical efforts allowed to come up with several SRF-cavity based fundamental physics experiments targeted on understanding the possible origins of the dark matter, hidden fundamental forces of nature, explore possible existence of millicharged particles, as well as to put the best lab-based bound on the photon rest mass. Furthermore, this collaborative multi-institutional theoretical effort is an important part of two of the focus areas of the new Fermilab-based National Quantum Initiative Quantum Center – SQMS, which has Fermilab-led SRF technology in the quantum regime as its primary foundation.

AAC2019 Charge 11: LCLS-II
Recommendation

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

Response:

The cryomodule production for LCLS-II-HE will be done by practically the same team that was working on LCLS-II. Hence, transferring all the lessons learned from LCLS-II to LCLS-II-HE is straightforward and being implemented. The PIP-II LCLS-II / LCSL-II-HE and cryomodule assembly crews of engineers and technicians have significant overlap, which makes the knowledge transfer relatively easy. One very critical lesson from LCLS-II is on cryomodule transportation. Developing a common approach to transportation is important not only to LCLS-II-HE and PIP-II, but to other Fermilab projects, e.g., HL-LHC AUP. As a result, Fermilab has decided to add a special chapter on transportation to the Engineering Manual. This work is in progress.