Report from the Fermilab Accelerator Advisory Committee Meeting
December 6-8, 2016
FNAL, Batavia IL

AAC Committee:

Present: Mei Bai (FZJ), Frederick Bordry (CERN), Wolfram Fischer (BNL), John Galambos (ORNL) (chair), Wim Leemans (LBNL), Jens Knobloch (HZB)

Absent: Roland Garoby (ESS), Yoshishige Yamazaki (FRIB)

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Introduction and General Remarks

The focused charge, well prepared presentations and allocation of adequate discussion time is greatly appreciated.

We are impressed by the breadth of the ongoing accelerator activities at FNAL. Machine performance (beam power and availability) has steadily improved. The efforts on accelerator science and technology have been well aligned with those that were identified by P5: pursue the physics associated with the neutrino mass (intensity frontier area). However, given funding limitations, activities should be globally prioritized to ensure concrete advances.

A global analysis needs to be conducted by both the particle physics and accelerator scientist communities on what the best strategy is to ensure delivery of key physics results as outlined in the P5 report. With the strong competition from–JUNO, achieving physics goals on NOvA may require expedited execution of elements of the PIP-I+ upgrade, before the full implementation of PIP-II, judicially chosen to maximize the number of protons on target (POT) for the users over the next several years.

We strongly encourage the timely completion of IOTA/FAST, which can have a very high impact on Fermilab and the accelerator community in general. The facility will be a unique asset across the DOE complex and these R&D activities are also invaluable to the existing alliances with local universities for training the next generation.

We are pleased to see the coordinated effort between simulation and machine operations. Understanding halo and beam loss generation is challenging and will require coordinated simulation and measurement campaigns to ensure predictive capabilities for future machine upgrades. Community engagement is encouraged, as demonstrated in the multi-code benchmark effort.

1. Have all the recommendations by AAC 2015 been adequately addressed?

Answer: Generally, yes. However, there are still a number of items that were recommended in the past but are not yet fully addressed (see below).

2. What issues, if any, need to be overcome to achieve reliable 700 kW operations to NuMI?

Answer: With the laser notcher, further Booster improvements and RR collimation reliable

700 kW operation to NuMI should be possible (we note that the time averaged power will be less than 700 kW to NuMI, as ~10% is diverted for other applications).

Findings:

- Beam power for NuMI is limited by losses in RR.
- Laser notching tested, about ½ of all particles removed in gap in test
- 7835 tube inventory for 2 years only (policy of 4 years).
- Reliable laser notching operation planned for Spring of 2017.
- 200 MHz klystron certified and delivered to Fermilab.
- Running Booster at safety permit limit, shielding is under review and loss monitors will be used to limit losses and are part of the personnel protection system - expect to be ready.
- New Linac modulators increase stability.
- Laser notcher - new seed source, test before end of calendar year, laser ran for 2 weeks at 25% of required energy per pulse level (0.5 mJ produced vs 2.2 mJ needed).
- Developing replacement cavity, plan to replace all Booster cavities by 2020, new cavity will be usable in a Booster replacement machine.
- Proton source capable of 700 kW operation since 2015.
- Although 700 KW with 6+6 slip-stacking was demonstrated in June 2016, the losses were unacceptably high to sustain continuous operation and more work is required.
- Full demonstration of 15 Hz operation with beam for multiple users expected to be demonstrated in 2016.
- A fixed mask, and vertical primary and two secondary collimators were installed in the RR; further collimator are under consideration; commissioning has begun.
- RR losses due to high chromaticity, needed to suppress instabilities.
- Presently no problems with e-cloud.

Comments:

- The laser-notcher has not yet reached the desired 98% efficiency nor the required operational reliability.
- An external review of the system was done after it was built.
- It is ambitious to plan for a fully commissioned operational laser notcher by February 2017. If it becomes clear that the laser cannot be made fully operational, a fully commercial solution can still be considered, with specifications guided by what has been learned on the home-built system.
- We agree that the back-up laser notcher system is needed to ensure reliable operations.
- The Linac modulator upgrade needs to be finished for the proton source to be reliable.
- Reliable RR operation with 700 kW requires loss control but collimation RR collimation was unfortunately not yet commissioned with beam.
- With an operational RR collimation system all slip-stacking losses are expected to be controlled.
- No fundamental limits are expected from the MI.

- The increase in the Accelerator Safety Envelope (ASE) limit for Booster safe operation is a critical step in the path for raising the power to NuMI and other applications. The new safety credited loss detectors must be extremely robust to avoid safety violations.

Recommendations

- Commission the RR collimation system with the highest priority.
- Closely manage the commissioning and deployment of the laser notching system (continuation of previous recommendation) for full operation at the 24/7 level.
- Closely manage the increase in the ASE limit for Booster operation.

3. Considerations for increased beam power of up to 900 kW to NOvA substantially before PIP-II are being technically evaluated. Assuming that the physics motivation is sound, please comment and provide guidance whether these considerations are worth pursuing.

Answer: Absolutely, these considerations are worth pursuing.

Findings:

- Booster PPP increase from 4.3 to 5.5e12 (+28%); MI cycle from 1.33 to 1.2 s (+11%); Booster cycle 15 to 20 Hz (to maintain proton delivery rates to other users).
- Campaign could be over 3-4 years, FY 2019-2022.
- Only 4% beam loss allowed in Booster.

Comments:

- We encourage the continued push to squeeze out the maximum power from the existing accelerator complex.
- It may be possible to make significant progress towards 900+ kW with a fraction of the original list of tasks.
- Factor in machine downtime and time to re-commission after shutdown when picking upgrade tasks (maximize POT over years).
- Funding for PIP-I+ has to be balanced with infrastructure renewal funding.

Recommendations

- Prioritize the proposed PIP-1+ activities and their execution in order to deliver the maximum number of POT.

4. Would the PIP-II R&D strategy, if properly executed, support a construction start around 2020, and are the resources required to support the R&D phase adequate? Are the plans to upgrade the Booster/Recycler/Main Injector to deliver 1.2 MW beam with the PIP-II linac coherent and credible?

Answer:

- For the linac, the identified R&D path forward seems reasonable for the 2020 timeframe. Currently the program progress appears funding limited. Resources are identified as a potential issue, however we were not provided sufficient material to judge this.
- The present status of the rings upgrade plans are conceptual, and more detailed plans should be developed to assess risks and develop mitigation strategies.

Findings:

- PIP-II: 1.2 MW proton beam from the Main Injector in an energy range 60 – 120 GeV. CD4 in is planned for FY2026. The budget range is $465M – $650M not including foreign contributions.
- The main PIP II Components are:
  - an 0.8 GeV CW capable LINAC consisting of 116 cavities, 5 cavity types, 3 frequencies.
  - new LINAC to Booster transfer line.
  - upgrade of the Booster to 20 Hz ops with 800 MeV injection, including RF.
  - upgrade of the Recycler and Main Injector incl. RF, collimation, gamma_t jump.
- The injection energy into the booster is flexible and may be as low as approximately 650 MeV.
- For the SRF LINAC, active Lorentz-force and microphonics detuning compensation is considered a significant challenge due to the 60 Hz cavity bandwidth. Long-term measurements are planned.
- By CD3 four of the five cryomodule types would be operational (2 with beam). The LB650 system will not be ready by then.
- India is providing a significant contribution for module design, cavity production, rf system design.
- For PIP-II, India is slated to procure a “CW ready” cryoplant as an in-kind contribution.
- The total LINAC cryo load is 315 kW in pulsed mode vs. 1676 in CW mode. The goal is to take advantage of the high-Q results for LCLS-II. The design Q’s have been increased to 2.2E10 and 3E10 for LB and HB Cavities, respectively, exceeding the LCLS-II specification of 2.7E10.
- PIP-II timeline:
  - CD0: Q1FY16
  - CD1: FY17
  - CD2/3A: FY18
  - CD3: FY20

  - CD4: FY26
- A significant fraction of the LINAC complex will be tested in the construction of the 25 MeV PIP2IT Injector Test Stand:
  - H- source: Operational
  - LEBT: Operational
  - RFQ: Operational
  - MEBT: Commissioning in Q3 2019
  - Two types of cryomodules (HWR, SSR-1): Beam through cavities in Q1 2020
- Funding falls short of the level required for 2020 completion of R&D program: Requested/Received are 2016: 20 M$/19.5 M$, 2017: 30 M$/18.2M$, 2018 25 M$/22-25 M$ (tentative statements). It was stated that the schedule is funding constrained rather than by resources.
- SRF Module status:
  - HWR nearing completion (Argonne collaboration)
  - SSR1 under construction
  - SSR2, LB650, HB650 in design phase (FNAL + India), cavity testing

Comments:

- PIP2IT represents very useful test infrastructure for risk management of the LINAC.
- Implementation of PIP1+ may help to reduce technical risk of some components but work out the priorities in light of the science driven program (see Charge 3).
- Learn as much as possible from the LCLS-II production run to reduce LINAC risk.
- The India collaboration is critical for project success.
- CW operation (LINAC SRF only) from the outset may reduce the SRF complexity/risk.
- PIP-II R&D appears over constrained especially given the budget shortfalls. It does not appear that the original goals can be achieved by FY2020.
- Consider shifting some (lower-risk) prototype testing into the PIP-II project phase.

Recommendations

- Develop the plans for the Booster, Recycler, and Main Injector to the same level of maturity as the linac plans.

6. Please, provide comments on the progress of Fermilab's Accelerator and Beam Physics (a part of General Accelerator R&D) Program and whether and how it fits in the strategic plans of the Office of High Energy Physics (the P5 report) and the DOE Office of Science (BESAC and NSAC reports)?

Answer: The current R&D efforts are strongly in-line with the HEP P5 report for intensity frontier facility as well as next generation high energy colliders.

Findings:

- Very focused activities around IOTA/FAST.
- Slip stacking simulations for multiple bunches were presented. However, there were no specific presentations about the status of benchmarking with measurements.
- Integration of NIU and FNAL educational and research activities is continuing well. It provides students with access to unique accelerator systems.
- Involvement in FCC R&D for beam collimation is well matched with the local expertise.

Comments:

- Congratulations on first beam in FAST.
- The continued build out of the NIU-FNAL partnership is commendable.
- The development of detailed academic programs such as a tailored curriculum for graduate students and integration with FNAL activities was not presented. Opportunities for leveraging USPAS may exist.
- Metrics for success of the partnership were not presented.
- IOTA is a unique asset for the community. Its success can be a major breakthrough for addressing the space charge limit in high power compact accelerator, and can have significant implications for Fermilab's longer term future plans at the intensity frontier.
- IOTA R&D also provides an excellent platform for training the next generation and a potential pipeline for recruiting future accelerator scientists.
- The development of beam halo diagnostics is not yet in place.
- Consideration of how IOTA will be operated is important, including educational interfaces.

Recommendations:

- Ensure that IOTA/FAST resources are allocated for a timely completion of the facility and operations.
- Engage the future IOTA/FAST users in the development of beam diagnostics (e.g., halo measurement) as well as other aspects.
- Develop a concrete plan and establish metrics to grow and evaluate the success of the NIU-FNAL partnership, including integration with USPAS.

7. Is the Fermilab and the US Magnet Development Program plan sufficient to maintain the US leadership in the Nb3Sn Magnet Technology? How well is this plan coordinated with international efforts in this area?

Answer: Yes, the US Magnet Development Program (MDP) plan is sufficient for maintaining the US leadership in the Nb_3Sn Magnet Technology if adequate funding is provided. The content of the plan is well coordinated with international efforts.

Findings:

- The US Magnet Development Program plan is very well defined and provides a good roadmap for the US program (http://science.energy.gov/hep/community-resources/reports/ .)

Comments:

- The execution of the MDP plan does not yet seem to be well coordinated within US partners.
- It is not clear how the baseline design of the proposed 15 T magnet at FNAL addresses the key goals of the MDP and is in-line with the stated deliverable milestones in the MDP plan.
- The current program funding limits addressing all the programmatic goals.
- No synergies with the HL-LHC magnet program were presented.

Recommendations:

- Ensure the MDP goals are adequately addressed with the chosen efforts.
- Leverage limited funding with good communication and collaboration for a fully engaged partnership, closely coordinated with international partners.

Appendix 1: Charge

Fermilab Accelerator Advisory Committee Meeting Charge

December 6-8, 2016

Fermilab's goal is to deliver the highest power neutrino beams in the world. To this end, the number of protons delivered for the production of our neutrino beams must be increased to the NOvA experiment in the near term and to LBNF in the longer term. The current components are the Proton Improvement Plan (PIP) to provide the capability of proton flux up to 700 kW to the NOvA target and PIP-II to deliver proton beams of 1.2 MW to the LBNF target. Additional upgrades to the Booster and Main Injector will be required to realize the 1.2 MW goal. The delivery of multi-MW beams for the future program will require additional upgrades beyond PIP-II.

The Fermilab Accelerator Advisory Committee is asked to assess and provide advice on the following topics with a concentration on the accelerator physics and engineering:

1. Have all the recommendations by AAC 2015 been adequately addressed?

<u>The Road to Higher Beam Power:</u>

2. What issues, if any, need to be overcome to achieve reliable 700 kW operations to NuMI?
3. Considerations for increased beam power of up to 900 kW to NOvA substantially before PIP-II are being technically evaluated. Assuming that the physics motivation is sound, please comment and provide guidance whether these considerations are worth pursuing.
4. Would the PIP-II R&D strategy, if properly executed, support a construction start around 2020, and are the resources required to support the R&D phase adequate? Are the plans to upgrade the Booster/Recycler/Main Injector to deliver 1.2 MW beam with the PIP-II linac coherent and credible?

<u>Other Topics</u>:

5. (withdrawn by Fermilab)
6. Please, provide comments on the progress of Fermilab's Accelerator and Beam Physics (a part of General Accelerator R&D) Program and whether and how it fits in the strategic plans of the Office of High Energy Physics (the P5 report) and the DOE Office of Science (BESAC and NSAC reports)?
7. Is the Fermilab and the US Magnet Development Program plan sufficient to maintain the US leadership in the Nb3Sn Magnet Technology? How well is this plan coordinated with international efforts in this area?

The Fermilab Director would welcome any other comments the AAC has on any of the topics presented, or on other issues beyond the topics presented.

In addition to a verbal closeout with the management of the Accelerator and Technical Divisions on the final day of the meeting, the AAC is requested to submit a written report of their findings, comments, and recommendations to Sergei Nagaitsev by February 1, 2017.

25oct2016
revised 30nov2016

Appendix 2: Agenda

AAC Review at Fermilab - Dec. 2016

Tuesday 06 December 2016

Executive Session - Comitium (WH - 2SE) (08:30-09:00)

Greeting & Discussion with Fermilab Director Nigel Lockyer - Comitium (WH - 2SE) (09:00-10:00)

Introduction - setting the stage - Comitium (WH - 2SE) (10:00-11:00)
Sergey Sergei Nagaitsev (Accel. Div.) and Sergey Belomestnykh (Tech. Div.)

Fermilab's Plans and Progress toward developing high-field Nb3Sn Magnets for Future HEP Accelerators as part of the US Magnet Development Program - Comitium (WH - 2SE) (11:00-12:00)
Alexander Zlobin

Light Lunch for AAC Members - Comitium (WH - 2SE) (12:00-13:00)

Fermilab's Place in the DOE Accelerator Science Programs - Comitium (WH - 2SE) (13:00-15:30)
V. Shiltsev – Accelerator Science in the FNAL Roadmap
A. Valishev – Progress on FAST and IOTA
J. Amundsen – Accelerator Modeling with SYNERGIA and MARS
S. Chattopadhyay – The NIU-Fermilab Center for Research Excellence in Accelerator Science
M. Syphers – Activities on the CERN Future Circular Collider
P. Piot – Experiments at FAST

Further Discussion - Comitium (WH - 2SE) (15:30-16:30)

AAC Executive Session - Comitium (WH - 2SE) (16:30-18:30)

Drinks & Dinner at Chez Leon - Comitium (WH - 2SE) (18:30-20:30)

Wednesday 07 December 2016

Questions and Answers from Tuesday - CANCELLED - start presentations instead - Comitium (WH - 2SE) (08:29-08:30)

Reliable Operations at 700 KW - Comitium (WH - 2SE) (08:30-10:30)
- W. Pellico – Proton Improvement Plan, Linac, and Booster
- P. Adamson – Recycler and Main Ring

1.2 MW PIP-II - Comitium (WH - 2SE) (10:30-12:30)
- S. Holmes – Linac & Booster/Recycler/Main Injector Performance Requirements
- P. Derwent – PIP-II Linac R&D Program
- I. Kourbanis – Booster/Recycler Ring/ Main Injector R&D Plan

Working Lunch for AAC - Comitium (WH - 2SE) (12:30-13:00)

Considerations for Interim 900 KW (aka PIP-I+) - Comitium (WH - 2SE) (13:00-15:00)
- V. Shiltsev – Introduction & Scope
- W. Pellico – Proton Source
- I. Kourbanis – Main Injector, Recycler Ring, and Muon Campus
- R. Zwaska – Targetry

Further Discussion - Comitium (WH - 2SE) (15:00-17:00)

AAC Executive Session - Comitium (WH - 2SE) (17:00-18:30)

AAC dinner on their own - Comitium (WH - 2SE) (18:30-21:30)

Thursday 08 December 2016

Questions & Answers from Wednesday - no presentation,
just examples of Benchmarking Simulations - Comitium (WH - 2SE) (08:30-09:30)
- W. Pellico, R. Ainsworth, J. Amundsen

Preparation for Closeout - Comitium (WH - 2SE) (09:30-11:30)

Closeout - Comitium (WH - 2SE) (11:30-12:30)

Box Lunch Available for AAC - Comitium (WH - 2SE) (12:30-13:00)