FNAL AAC

Closeout

10 December 2015

General Remarks

- Many thanks for the excellent hospitality
- Impressed with the breadth of activities
- Significant progress on many fronts
- Good alignment with P5, OS, and international priorities
- The closeout will concentrate on high-level recommendations rather than details on individual activities
- Encourage check on presentation lengths before review, and provide concise delivery

General Remarks

- The Accelerator Division is involved in a large number and variety of activities
  - Project support, operations, R&D, …
  - Laboratory “importance rankings” should guide resource allocations
    - Consider a lower granularity tier structure for importance ranking
- Engagement of world-wide expertise is essential
  - The target, India, HF magnets, … areas are good examples

C1: Have the recommendations from AAC2014 been adequately addressed?

Findings

- Many of the charges were directly responded to.

Comments

- The PIP-II charge/responses were nicely tallied – this effort appreciated, and this approach is requested for future reviews.

Answer: Some previous recommendations were not completely addressed, and these are re-enforced below.

C2: Is the goal of 700 kW on target by mid-2016 technically achievable?

Findings on PIP

- Planning is to demonstrate 700 kW before summer 2016 and have it in operation in December 2016.
- Linac:
  - is being upgraded for reliability and performs satisfyingly.
  - On-going work is aimed at new modulator and klystron as back-up solution for tubes.
- Booster:
  - 23 tasks done at end CY15. 10 remain with 7 to be completed in FY16.
  - performing well in proton flux (1.5E17 p/h) and meets beam characteristics.
  - 15 Hz in operation at end of FY15 with 20 refurbished cavities installed.
  - Additional actions in progress against 3 beam loss points (Notch at 750 keV, RF cavities at transition, RF manipulations at extraction + beam studies & simulations).

C2: Is the goal of 700 kW on target by mid-2016 technically achievable?

Findings on PIP (continued)

- RR & MI:
  - Good progress during 2015:
    - FY15 milestones have been met (521 kW for 1 h on July 1, 2015 with 4+6 and Booster at 3.9E12 p/b - 7.5 Hz but excessive beam loss (93.4% eff.)).
    - 6+6 demonstrated at reduced power on July 2 with Booster at 15 Hz.
  - Plan:
    - 4+6 operation at 460 kW delayed until January 2016 (Booster cavities + RR aperture issues) with upgraded goal of 575 kW (95% eff.).
    - 6+6 with same performance in March 2016 (Booster at 9Hz – 3.6E12 p/b).
    - 700 kW demo. with 6+6 in April 2016 (Booster at 9 Hz – 4.3 E12 p/b).
    - 700 kW (6+6) in operation in December 2016.
  - Extensive work on RR aperture and beam studies.
  - Early Synergia simulations seem OK wrt observations.
  - Collimators in RR are considered mandatory for 700 kW in operation. Conceptual design made. No clear plan for construction.

C2: Is the goal of 700 kW on target by mid-2016 technically achievable?

Comments on PIP

- Linac: none.
- Booster:
  - Excellent progress in beam characteristics and overall performance.
  - Slow down in implementation of 750 keV laser notch scheme is noted.
- RR & MI:
  - Good progress in beam studies and performance.
  - No means to measure beam tails.
  - Little time remains to reach the 700 kW goal in operation.
  - More simulations would help define optimum solutions.
  - Worrying lack of plan for implementation of collimators in RR.
  - Damping with slip stacking in RR needs investigation.

C2: Is the goal of 700 kW on target by mid-2016 technically achievable?

Recommendations for PIP

- Booster:
  1) Use external laser/optics expertise to bring the laser notch system into an operational capability ASAP.
- RR & MI:
  2) Run simulations over relevant time scales with full slip stacking in RR.
  3) Develop a plan for building and installing collimators in RR asap and actively monitor progress.
  4) Pursue means to mitigate damper issues during slip stacking.

Answer: 700 kW in operation by the end of CY16 is at risk if RR collimators are not available on time.

C3: Are the plans in place to overcome beam instabilities and losses in the Recycler during slip-stacking adequate?

Findings

- A horizontal instability is observed in the RR with 10-20 turn rise time, that strongly depends on the bunch length.
- The existence of electron clouds was established by a microwave transmission measurement, and a measurement of the tune shift along the bunch train.
- A simulation showed that up to 2% of the cloud electrons are trapped in gradient magnets.
- A change of 1/3 of the TSPs to ion pumps without subsequent bakeout of the sections with ion pumps did not visibly change the instability threshold.
- The instabilities are now studied by 2 students, and an external visitor.

C3: Are the plans in place to overcome beam instabilities and losses in the Recycler during slip-stacking adequate?

Comments

- Progress is being made.
- 700 kW operation is not limited by RR instability, but PIP-II remains vulnerable.
- The understanding of the electron cloud formation and instability detail is still rudimentary with only limited experimentally benchmarked simulations and calculations.
  - The observation that the second batch is more stable than the first batch, untypical for electron cloud driven instabilities, is not yet explained.

Recommendations

5) We repeat our recommendation from the previous two meetings to simulate the electron cloud formation in the RR, and determine the SEY for electron cloud formation with the RR chamber geometry and a range of beam parameters. Compare the results with simulations of the MI. Revisit previous recommendations.

Answer: Not yet.

C4: Are the MI/RR beam losses understood sufficiently to minimize machine and tunnel activation?

Findings

- A fast activation survey of the whole RR is possible on maintenance days
- Losses in the RR were reduce by realignment and replacement of beam pipes with larger one where possible.
- RR location 421 is presently the limiting vertical aperture, and relocation of the element increased aperture.
- The measured beta-beat reduced the available aperture by up to 2 mm in some locations.
- It was concluded that continuous 700 kW operation will require a new collimation system.

C4: Are the MI/RR beam losses understood sufficiently to minimize machine and tunnel activation?

Comments

- The completion of new collimation system for installation in 2016 appears to be extremely challenging.
- There are presently no diagnostics for beam halo, neither transverse nor longitudinal.
- Losses in the MI are presently not a performance limit as the MI beam pipe is somewhat larger than the RR pipe.

Recommendations

6) Develop a plan for beta-beat correction in the RR.

7) Develop high dynamic range halo diagnostics in the RR and transport lines.

Answer: Not yet.

C5: Evaluate progress of the Proton Improvement Plan (PIP). Are the plans to increase the beam flux in the Booster adequate and the associated accelerator physics understood?

Findings

- PIP goal is to deliver 2.3×10^{17} protons per hour (pph) at a repetition rate of 15 Hz with availability over 85% and residual activity within acceptable levels, anticipating a transition to PIP-II, as stated last year.
- Great progress from 2012, but 1.5×10^{17} (4.3×10^{12} protons per pulse at 10 Hz) at present.
- Beam loss is largest at injection, transition and extraction, as is often the case.
- The beam notch being created at the injection is not sufficient. The proof of principle of the laser notch creation is successfully demonstrated, but the laser notch has not yet been implemented for beam loss reduction.

C5: Evaluate progress of the Proton Improvement Plan (PIP). Are the plans to increase the beam flux in the Booster adequate and the associated accelerator physics understood?

Comments

- Remarkable progress has been made in Booster performance (intensity, stability, loss, beam quality,..).
- Continue accelerator physics simulations and mitigations to further reduce beam loss.

Recommendations

1) Use external laser/optics expertise to bring the laser notch system into an operational capability ASAP.

Answer: Yes.

C6: Are the plans for new Booster cavities appropriate for future Booster upgrades, to serve at least through PIP-II and potentially through PIP-III?

Findings

- PIP requires 1 MV (available early CY16) and PIP-II 1.2 MV.
- The refurbished Booster RF cavities will allow reaching 700 kW, but their replacement is necessary before the end of PIP to guarantee long term performance and prepare for PIP-II.
- The required frequency sweep decreases from PIP to PIP-II and PIP-III
- The new cavities shall use the renovated surface equipment.
- 3D modeling of the cavities is in progress.
- Parallel and perpendicular biased ferrite tuners are considered.
- Perpendicular bias gives twice the gradient.
- The temperature rise of the tuner in the perpendicular bias cavity is about twice as high as that of the parallel bias.
- The 2nd harmonic cavity is using perpendicular bias and will serve as demonstrator. Installation in mid-CY16, beam studies and operation after. Decision early in CY17 for the technology of the main accelerating cavities.

C6: Are the plans for new Booster cavities appropriate for future Booster upgrades, to serve at least through PIP-II and potentially through PIP-III?

Comments

- No clear requirements for cavities for PIP-III. It cannot lead to decisions on hardware.
- More design work seems invested in parallel bias solution so far. The perpendicular case should be further studied, including the understanding of the temperature rise.
- Sufficient long-term stress powering tests for the prototype and the first series production cavity should be conducted for new cavities.

Recommendations

8) Define during 2016 the criteria for choosing cavity technology.

Answer: Yes for PIP-II, No for PIP-III.

C7: Evaluate the plan for commissioning and operations of the Muon Campus accelerator systems. Is the plan sound?

Findings

- A proposed construction and commissioning plan was presented for providing experimental systems that will enable the P5 endorsed g-2 and Mu2e experiments. Installation for g-2 is expected to be completed by mid 2017 and commissioning through early 2018, with early data taking starting in early 2018. The Mu2e installation phase is expected to continue through 2021 with commissioning for single turn extraction and resonant extraction to commence in 2020 and 2021, respectively.

Comments

- Insufficient context was provided on what the stakeholders require and have been promised, to answer the question.
- A DOE approved schedule for the project phase as well as commissioning/transition plan for experiments should be provided and analyzed.

Recommendations

9) Communicate proposed operational plan consistent with overall needs and resources with users and DOE.

Answer: Insufficient detail.

C8: Is the plan and the organization for the LCLS-II cryomodule production and testing sound?

Findings

- 1.3 GHz cryomodule design complete. FNAL is about to proceed to the production phase.
- High Q, N2 doping and cooldown procedures validated for LCLS-II
- 3.9 GHz development is to start up.
- Staffing needs increased in 2017 due to plans to test all cryomodule which exerts significant demands on the existing staff.

Comments

- Transition to the production stage will likely have its hiccups. The current ramp up to full cryomodule production is very optimistic.
- Cooldown procedures for high Q still need to be validated with full module. Be prepared for multiple cooldowns on the P-CM to establish the best procedure.
- R&D identified one batch of Nb to strongly trap flux. A 1000 C bakeout helps but it must be be studied whether mechanical issues arise that impact cavity production. It is not clear whether Nb ordered for LCLS-2 will suffer from this problem. Tests should be carried out.
- XFEL module testing program at DESY (currently ongoing) is an ideal opportunity for participation of FNAL staff to fine tune procedures and work out resources.
- 3.9 GHz development will strain resources. Consider outsourcing some of this activity to other labs.

C8: Is the plan and the organization for the LCLS-II cryomodule production and testing sound?

Recommendations

10) Start training staff for module testing. Consider sending staff to DESY to participate in the module tests.

11) Magnetic hygiene is essential to maintain the exceptionally high Q values: designate a person responsible for this aspect.

Answer: Yes, but staffing is very tight and there is no float to react to problems that are likely to occur.

C9: The PIP-II R&D program and the cryoplant design effort are being jointly executed with India. Evaluate these joint plans and comment on the split between Fermilab and India. Is the split appropriate and is the effort likely to reduce the project risk and/or costs?

Comments

- The 200 M$ in kind contribution will be a major contribution to the success for PIP-II. The commitment and engineering effort discussed will provide important leverage.
- 7 engineers residing at FNAL for 2 years is a major demonstration of that commitment.
- PIP-2 budget is constrained for the next couple of years with major goals to accomplish in particular HWR CM and SSR1 CM.

Recommendations

12) Ensure that sufficient resources are made available by FNAL in the R&D phase to leverage the Indian resources.

C9: The PIP-II R&D program and the cryoplant design effort are being jointly executed with India. Evaluate these joint plans and comment on the split between Fermilab and India. Is the split appropriate and is the effort likely to reduce the project risk and/or costs?

Answer: The split is appropriate. Technical risk is reduced by the CW option, other risks are reduced provided that the Indian partners remain committed through the end of the project.

C10: Are the plans for the first experiments at FAST and IOTA appropriate? Is the organization of this Fermilab effort sound and appropriate?

Findings

- Within Nigel's priority list (#10) "R&D (a core competency) accelerators and detectors.
- Leverages ~$100M infrastructure built up over last few years (NML, ASTA…).
- Good progress since last AAC: 20MeV beam through injector and first experiments (transfer matrix, bunch shaping), IOTA Workshop April 2015
- Commissioning with electrons is underway and expected to evolve from 20MeV (FY15) to 150MeV (FY17) with IOTA experiments in FY18 (e- == Phase I) and FY20 (p == Phase II).
- PIP-III R&D plan to be developed on the order of 1 year and this may inform IOTA priorities, i.e. for RCS feasibility in space charge limit with non-linear integrable optics or electron lens, 0.06% beam losses.

C10: Are the plans for the first experiments at FAST and IOTA appropriate? Is the organization of this Fermilab effort sound and appropriate?

Comments

- The first experiments at FAST/IOTA are certainly appropriate from a stand point of doing interesting beam physics and education, but were not specified with enough detail to understand impact on PIP-III options.
- Schedule as presented is not consistent – develop one based on expected funding and stick to it, note that the benefits of increases funding and corresponding speedup of program not clearly articulated.
- Proton injector for IOTA (HINS RFQ) requires $1M of unfunded M&S and unspecified labor to resurrect, characterize and move, yet presented priorities are 1. IOTA p, 2. IOTA e-, 3. FAST e- (why are timeline and priorities backwards?)
- The committee is concerned that 'Significant effort and resources are needed to establish experiments with protons', i.e. profile monitors, loss monitors, electron lens, etc.
- Encourage collaborations to develop instrumentation capable of providing insight into halo formation and phase space dynamics on turn by turn basis and carry out studies to bench mark/validate simulations.

C10: Are the plans for the first experiments at FAST and IOTA appropriate? Is the organization of this Fermilab effort sound and appropriate?

Recommendation

13) Develop a plan for: 1) define how priorities will be decided between various parties with different funding (LDRD, HEP, DHS, ECA, NSF), 2) transition to operations and prioritize first experiments and 3) a comprehensive suite of diagnostics.

Answer: See recommendation.

C11: Evaluate the program for development of high power target systems. Are the activities likely to result in a conceptual design of a multi-MW target in time for PIP-II/DUNE ?

Findings

- A wide range of target “systems” are being supported (BNB, NuMI) and developed (g-2, Mu2e, LBNF).
- Many original design NuMI targets had early failures
- A new NuMI target design (TA01) is complete and has demonstrated highest exposure to date.
- Target department created in Feb. 2015 to take care of all targets/horns at Fermilab (9 technicians, 8 engineers, 3 physicists).
- Huge workload/experience exploiting/repairing/diagnosing existing devices.
- Design of PIP-II target and horns is ready (scaled to 1.2 MW from NuMI). Development interrupted in F16 and FY17 (lower priority).
- R&D in collaboration with international partners to prepare for future needs.
- Conceptual design of >2 MW target system needs R&D.

C11: Evaluate the program for development of high power target systems. Are the activities likely to result in a conceptual design of a multi-MW target in time for PIP-II/DUNE ?

Comments

- The re-organization of target staff into a new centralized AD group is a positive move, and should pay dividends.
- New NuMI target system optimizations showing promise of 30% improvement in neutrino yield is commendable.
- Attention to the “shelf-consumable” inventory of target system components is important.
- Participation in the RaDIATE collaboration is a cost effective means to understanding end of life limits.
- R&D is essential for future devices (e.g. PIP-III) and must benefit from world-wide test facilities and competences.

Recommendations

- None.

Answer: Yes.

C12: Evaluate the Fermilab High-field magnet program: Is it sound and aligned well with the P5 recommendation to "continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs" for present and future hadron colliders (e.g. LHC upgrades)? Are the allocated resources adequate for the proposed plan and schedule?

Comments

- Given the resources allocated, the HFM program is reasonable and aligned with P5 goal of increasing performance toward 15 T, for accelerator class magnets. The issues related to cost reduction are not fully explored, however. Processes used are very similar to previous ones and it is not clear how this approach leads to cost reduction.
- A balanced effort between conductor R&D (Nb3Sn) and demonstration magnets in a national context is important.
- Exploring reduction of the number of training quenches is needed.
- Pay attention to costs.

Recommendation

14) A national coordinated program is important. Pursue the collaborative paths laid out in the White Paper with other partner labs.

C13: Evaluate the SRF science and technology program: Is the plan sound? Does it address all major SRF-related issues relevant to future HEP Intensity-Frontier CW linacs at Fermilab? How well is it aligned with needs of future HEP Energy-Frontier machines?

Comments

- Excellent results in taking the high Q program from the lab to applying it to production systems, including vendor qualification.
- Cost analysis of cryomodule system: Cavity and couplers are dominant
- Claim is high-Q is an even larger lever in terms of facility cost.
- R&D Program targets High Q (N2 doping, magnetic hygiene, Nb3Sn).
- To a much lesser extent R&D is involved in materials and production cost reduction (thin film, cladded sheets, hydroforming).
- R&D program leverages the limited resources for a significant impact on the LCLS-II/PIP-II projects while benefiting in general CW, intensity frontier LINACs.
- Current thrust seems less compatible with energy frontier activities due to low quench fields of N-doped cavities. Nb3Sn may be able to address this.
- The ability to maintain the very high Q's in an accelerator over time must be demonstrated (e.g., field emission!). Ideally the R&D program would also address schemes to recover in situ the Q following degradation.

C13: Evaluate the SRF science and technology program: Is the plan sound? Does it address all major SRF-related issues relevant to future HEP Intensity-Frontier CW linacs at Fermilab? How well is it aligned with needs of future HEP Energy-Frontier machines?

Recommendations

15) Consider Q recovery schemes in R&D.

16) Analyze the cost of a high intensity LINAC driving a multi-MW facility with state-of-the-art technology (including high-Q) and identify additional cost reduction paths to guide the future R&D program.

Answer: R&D is sound. Its main thrust is minimizing refrigeration cost, thus addressing intensity frontier CW LINACs. To a lesser extent it addresses (LINAC-based) Energy Frontier machines that require highest accelerating fields. Cost effective SRF R&D will help address the options for PIP-III.

C14: Comment on Fermilab's analysis of the proton beam power options beyond the PIP-II goal of 1.2 MW and on the possible R&D scope for these options.

Findings

- P5 recommendation in favor of a high energy ν program needing 600 kT x MW x years (rather 900) requires a multi-MW beam at 60-120 GeV.
- PIP-III aims at delivering 2.5 – 5 MW for that purpose after ~5 years operation at 1.2 MW (PIP-II).
- Status of PIP-III analysis:
  - Main bottleneck: 8 GeV proton source.
  - Options: 8 GeV SC linac, New RCS, New RCS with >800 MeV injector.
  - Issues (approach)
    - Linac: cost (SRF R&D) + charge exchange injection at 8 GeV.
    - RCS: space charge (IOTA experiments), instabilities.
    - MI: new RF system, transition, e-cloud, impedances/instabilities.
    - Target: new target (R&D for material selection and design).
    - In all cases, very low budget for beam loss.
- Plan to involve all partners interested in neutrino research (LBNF/DUNE).

C14: Comment on Fermilab's analysis of the proton beam power options beyond the PIP-II goal of 1.2 MW and on the possible R&D scope for these options.

Comments

- Status of analysis remains quite preliminary.
- Proton energy considered fixed at 60/120 GeV (MI).
- Wide spectrum of challenging questions. A number of them have started to be addressed. Involvement of international partners is necessary.
- IOTA envisaged as source of valuable insight on potential solutions.
- For PIP-III, the additional cost of a CW linac extension needs to be understood.

Answer:

- Search for a global optimum including the experiment(s).
- Creation of a PIP-III R&D plan is an essential preliminary step.
  - Set-up a collaboration on charge exchange injection at 8 GeV.