Report of the Second Fermilab/NIU Phoinjector Laborarory Advisory Committee Meeting

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Summary

The Fermilab/NIU Photoinjector Laboratory (FNPL) Advisory Committee thanks the A0 staff for their hospitality and the speakers for their excellent presentations during the review meeting on October 15-16, 2002.

The FNPL has made an impressive effort at organizing itself during the past year, with new personnel added at all important levels. The budget, although tight, looks healthy with funding from NIU.

Scientifically FNPL has been vigorous; the experiment on flat beams has been carried much farther and has received wide recognition. This experiment should continue to resolve the remaining issues such as the role of the thermal emittance. Remote operation of A0 from DESY and/or LBNL is another achievement that effectively widens the reach of the FNPL. The continuing work on cathode characterization is also significant for future development of rf photocathode guns. Finally, the completion of the helium recovery system was a necessary step that will allow longer and far less costly operation of FNPL.

The progress was made despite the problem with accelerator operation, especially with the laser stability. In fact, the available beam time during the past year was alarmingly low due to various failures of the laser and the accelerator hardware. These problems must be fixed so that experiments can proceed according to the plan. With the increase in staff it should be possible to solve these problems.

Due in part to the accelerator problem, progress in other experiments scheduled for FY 2002 was slower than expected. Among these, the plasma wake-field acceleration (PWFA) and the laser acceleration in open iris-loaded structures are in the advanced stages in the experimental plan and should proceed when the beam time becomes available. The proposal for bunch compression and CSR can benefit from a more thorough modeling of the process using sophisticated codes available in the beam physics community.

In view of the delays in the current experiment, it is not likely that FNPL can support new experiments in FY2003 presented during the EOI session. An exception is the proposal to develop a novel interferometer, which is ready to be tested.

There were also presentations on an ambitious plan to move FNPL to another site as a first step to expand the FNPL to a significantly larger facility called HBPI (high-brightness photoinjector) providing electron beams up to 200 MeV with additional SCRF accelerating modules. However, it is felt that the project is beyond the scope of this Committee at this time due to uncertainties, including the budget.

The facility will benefit from a clear statement of goal, whether the FNPL is a test bed for advanced accelerator research or a facility for demonstrating the TESLA concept. If it is the former, how important is the multi-bunch capability, which is the origin of most of the hardware difficulties? We note that most of the FNPL experiments in progress or being proposed do not require multi-bunch capability.

1. Facility Management

1.1 Manpower and Funding

As of this fall there are six postdoctoral fellows, two graduate students, and one technician working full time at FNPL. This is a healthy level of manpower for a laboratory as small as this. With the funding from NIU, the budget is also rather healthy.

1.2 Leadership

Helen Edwards stated that in view of her other commitments, she would like to see another scientist to take over the leadership role and provide the direction and supervision of the large scientific staff. This is understandable, given her long commitment to and her outstanding leadership of the A0 project.

1.3 HBPI Proposal

The Advisory Committee last year recommended that an energy upgrade to 100-200 MeV would enhance the research capability at FNPL. The HBPI is a proposal in this direction. However, it contains many political aspects and budget uncertainties at this time. The Advisory Committee therefore feels that it is premature to make any comments at this time, other than requesting that the scientific case for HBPI be clearly spelled out: How does the operation of the HBPI complement TTFII and the DESY-Zeuthen program? Will the HBPI still need to support very long pulse operation? What is new in HBPI besides energy that can't be done at the current FNPL? Why is the high energy necessary?

1.4 Goal Settings for FNPL

Fermilab and NIU should clarify the goal for FNPL, whether it is a test bed for advanced accelerator research or a TESLA test facility. This question has obviously far-reaching effects on the choice of accelerator system, laser, and diagnostics equipment.

2. Improvement of Accelerator System

2.1 Drive Laser

The performance of an accelerator facility based on an rf photocathode gun depends directly on the performance of the laser system. The A0 drive laser system had been performing adequately until two years go, but has deteriorated since the departure of the expert. At present the stability and reliability of the laser are recognized by everybody as a serious issue.

The situation could change in the future with the recent arrival of Yang Xi at the FNPL. If she is to be effective as the designated laser expert, she will likely devote most, if not all, of her time to the laser to get it in acceptable operating condition. The laser system must also have adequate hardware allocation. Thus spares must be kept on hand for those items that burn out, and instrumentation must be improved to quickly recognize problems. An oscilloscope with sufficient bandwidth and memory to observe a complete pulse, as was requested by J. Santucci, is an essential instrument for the maintenance and tuning of such a laser system. It is also recommended that, if money permits, the unreliable flashlamp supplies be replaced.

The laser system is seven years old; therefore, some thought should be given as to how the system should eventually be replaced. In particular, it would be wise to invest in a new, preferably commercially produced, laser oscillator if funding is available. A desirable option, albeit costly, is to procure a laser from the Max Born Institute in Berlin, which built the laser currently used at the TTF. This laser produces pulse trains of the desired specifications and has demonstrated short and long-term stability. Such lasers are not available from commercial manufacturers. This option is especially attractive if it is desired to upgrade FNPL to the HBPI facility at a later time.

2.2 Gun

The gun, like the laser, is a critical component of the photoinjector. The removal of a working gun (Gun 4) to swap with Gun 3 at DESY was a gamble, especially considering the unacceptable performance (5% breakdown rate) of Gun 3 (in contrast to 0.5% breakdown rate of Gun 4). We hear that DESY is now ready to release Gun 4. Thus FNPL has several options: recover Gun 4, use the original Gun 1, or construct a new gun. Each of these options contains risks. The Committee recommends that the FNPL staff evaluate these risks and prepare a plan to secure a gun that will satisfy the needs of FNPL operation.

Some more technical remarks are as follows:

1) The field balance and solenoid alignment issues would have been easier to measure and fix had they calibrated the four rf pickup loops in the gun cavities. From these loops (one in each cell, located at 12 o'clock and 3 o'clock positions around the cell) they could have learned the field balance (both static and dynamic) and the beam's position with respect to the electromagnetic center of each cell (because the loops couple strongly to the horizontal and vertical TM110 dipole modes).
2) At the next venting of the gun, they should inspect its interior with a boroscope and recalibrate the rf pickup loops.
3) The solenoid misalignment can also be easily quantified to better than 0.5 mm by a B_r(theta) measurement. See the Colby thesis for details.
4) Optical spectrometry of light emitted during breakdown (or even during "multipactor therapy" can potentially give clues as to the breakdown site. The gun is copper, that cathode is molybdenum, the QE surface of the cathode is cesium and tellurium, and the cathode spring is beryllium copper. Spectral lines of any non-copper species will give insight as to the location. Ask Marc Ross about similar work at the NLCTA.

2.3 Photocathode Study

W. Hartung's systematic approach to understand the causes of the rf gun dark current and QE behavior is remarkable. The Committee recommends that this study continue, augmented by a serious computational model. Efforts should be made to diagnose the microscopic surface physics of these emission-changing effects. This could be a fundamental contribution and could in the longer term lead to a new gun design with an acceptable breakdown rate.

What work is being done to understand the thermal emittance contribution? There are conflicting reports from the BNL-ATF and the SLAC-GTF as to measurements of the thermal contribution. The highest number we have heard to date is 0.7 pi mm-mr, which, if true, spells trouble for achieving 1 pi mm-mr at 1 nC. Thermal emittance will set the ultimate limit to the small emittance obtainable in the flat-beam scheme. A similar comment applies to the uniformity of photoemission from the cathode—no measurements were presented to indicate that this important question is being investigated.

2.4 Accelerating Cavity
The completion of the helium recovery system is good news; it will allow longer and far less costly operation of A0.

Helen reported possible trouble with the klystron and the tuner motor. A similar situation exists with the 9-cell cavity tuner, which is in intermittent failure. A strict plan for repair of this intra-cryostat device needs to be formulated and implemented at the earliest possible time.

The accelerator needs to be better/fully characterized. The discrepancy in the calculated and measured transfer matrix must be resolved.

2.5 Beam Line
The current beam-line layout, in which the chicane optics overlaps with the optics for flat beam transformer, is awkward. There is an opportunity to reoptimize the layout next year when the beam line needs to be modified to accommodate the CKM harmonic cavity.

It is good news that that six BPMs from DESY are all installed. Are these sufficient?

3. Experiments in Progress

General remark:
The experiments, both in basic high-brightness beam phenomena and in advanced accelerators, require dedicated efforts in beam modeling and diagnosis. Sophisticated resources are available within the current collaboration as well as from willing potential collaborators. One cannot contemplate making serious contributions to the high-brightness beam community without expansion of these efforts.

3.1. Flat Beam Generation
The Committee wishes to congratulate Don Edwards and his collaborators for their outstanding flat beam results, achieving a flat beam ratio of forty with significant strides in analysis. Two graduate students are currently working on this experiment for their Ph.Ds.
However, the central question: "How does emittance compensation work in a beam having non-zero angular momentum required for flat beam generation?" needs to be answered. The computational and analytical tools presented by S. Lidia are on the right track, and should produce a relevant study. This will allow the experiment to progress to where real conclusions about the limitations of this scheme, due, for example, to thermal

emittance, are apparent. This experiment should continue to gain a better understanding in this regard.

3.2. Bunch Compression and CSR Characterization
Fragmentation of beam distribution as a function of energy was observed at FNPL for beams under compression, as observed in other laboratories. There has been some progress in theoretical understanding of the stabilities due to CSR. In general, FNPL may be an interesting test bed for examining collective effects in compression, but more work is needed to refine exactly what the relevant physical process and what diagnostic equipments will be necessary for observation. Some Committee members feel that there will be very little CSR at 15 MeV.

3.3. Global Accelerator Network (GAN)
This is an original experiment demonstrating remote operation of accelerators. The experiment was highly successful. Remote shifts of FNPL are done from DESY and LBNL on a weekly basis, effectively enlarging the reach of the FNPL. It is particularly impressive how little financial resources (less than 3K) were necessary to implement it.

3.4. Plasma Wakefield Acceleration (PWFA)
There was no progress in the beam experiment since the window failure in September 2001. However, progress was made in plasma source development and in wake-field theory. The Committee recommends that the pulse compression of the drive and witness pulses be thoroughly simulated to understand the correct experimental setup and to estimate what the drive and witness pulses will actually be.

This experiment is another example where more serious modeling could make a significant difference in the FNPL program. The PWFA experiment could make more use of internal and external collaboration resources, as N. Barov is stretched somewhat by his duties to the infrastructure at A0.

3.5. Laser Acceleration in Open Iris Loaded Structure
Some progress was made with structure manufacture, but most of the effort has gone into moving the laser used for the experiments. The experiment is very promising and is a Ph.D. project for Rodion Tikhoplav. The Committee suggests that a thorough quantitative analysis be carried out to answer the following questions: Is it necessary to add focusing to transport the beam through the 1 mm $\times$ 250 mm long hole? Will the electrons develop sufficient induced energy spread to measure, given damage threshold limits on the real structure? What instrumentation will be needed?

4. Expression of Interest (EOI) Proposals

General remarks:
Since several approved experiments are still pending, most of the EOI experiments discussed here will likely not take place within the next year, except the interferometer development.

It should also be noted that the request to attach a statement of support from the home institution to an EOI (c.f. the 2001Advisory Committee Report) was not followed.

4.1 CTR and CSR Interferometry

The instrumentation proposal from Uwe Happek for measuring CTR and (perhaps) CSR is first rate. His wave-front splitting apparatus is innovative and new, and will allow single-shot characterization of the coherent spectrum. It has the potential to improve the FNPL experimental capabilities, and it is of general interest for many accelerator applications. Happek has a proven track record in this area. It should get full support.

4.2 Electro-Optic Sampling

The electro-optic sampling experiment presented by Yang Xi is very ambitious. The Committee feels that there may be additional complexities than those explicitly discussed in her presentation and is afraid that, if she is charged with fixing the laser, she will not have enough time to pursue this. An incremental approach (splitting the experimental goals into more manageable subsets) may be recommended to keep this effort alive during the time needed for the drive laser to be brought up to speed.

4.3 Space-Charge Induced Phase Space Dilution

Understanding phase mixing is important and fundamental work. It is not clear that the experimental program has been thought through at all, however. Making small charge density perturbations and observing the washout will be a tough way to uncover this phenomenon, as the washout will be driven by many things: space charge, rf time-dependent focusing, aberrations in the transport, etc. This proposal would benefit enormously from a modeling study to clarify what can be learned from the (as yet unspecified) measurements. Appropriate beam manipulations and diagnostics could then be designed.

4.4 Plasma Density Transition

This experiment, a Ph.D. thesis topic for Matt Thomson, represents an evolution of the collaboration in PWFA physics between UCLA and FNAL/NICADD. The preparations for this experiment (plasma source, spectrometer, beam-plasma simulations) are in progress at UCLA. However, a more complete, integrated modeling of the compressed beam, the experiment, and propagation to diagnostics would be desirable.

It is noted that Thompson and UCLA will be aiding N. Barov in finishing the initial PWFA experiment, and that many relevant techniques will be understood in the process of completing the initial PWFA investigations.

4.5 RF-Driven Inverse Cerenkov Acceleration in Plasma

This proposal suffers from lack of a credible experimental scenario. A more detailed feasibility study should be performed before bringing this possible experiment up for further discussion.

One of the Committee members feels the proposal to use an rf power source instead of a charged particle beam to excite the plasma wave is a questionable idea at best. The shunt impedance is much worse than for a conventional structure, and the availability of high power very high frequency sources to power high gradient versions of this experiment is non-existent. The damage to the accelerated pulse if the electron density remaining in the plasma channel is appreciable.

5. Summary of Recommendations on Machine Development and Experiments

This is a lengthy report, and it may be worthwhile to summarize the most important points of our recommendations.

The first priority is to improve the machine operation:

- Improve the laser operation at least to the previous level of performance

- Make a plan for gun replacement

Recommendation for experiments in the order of the priority:

- The photocathode study and the flat beam experiment should continue.
- The PWFA and laser acceleration experiments can start in FY2003.
- The interferometer experiment can be finished in FY2003.
- The density gradient experiment can start in FY2003 after PWFA has finished.
- The proposals for CSR characterization and phase-space dilution experiments require further modeling to determine required diagnostic equipments.
- The electro-optical sampling experiment should start only after the PI has fixed the laser performance and after a thorough evaluation of the experimental difficulties.
- The rf-driven acceleration proposal needs to have a concrete experimental plan prepared.