JLab/BNL collaboration to study high current (mA) polarized beam production

Poelker , November 22, 2015

(Draft)

BNL requests assistance demonstrating polarized beam delivery at mA levels, preferably with long lifetime. This document details goals and lists the challenges that must be overcome to reach these goals. It lists obligations and deliverables for both parties, JLab and BNL. It is hoped the document also serves to manage BNL expectations.

Historical background:

In past years, the JLab source group has successfully demonstrated high current beam production at 1mA and 4mA from high polarization strained-layer superlattice photocathode material using a gun test stand and beamline at the injector test cave, building 58. These demonstrations utilized 780 nm laser light with rf structure, therefore representing realistic accelerator operating conditions, although the laser light was not circularly polarized, i.e., the beam was not polarized. More importantly, detailed experiments were performed at the injector test cave that identified lifetime-limiting mechanisms that must be overcome to achieve sustained beam delivery at milliampere high current (papers attached). One mechanism in particular is now routinely cited as a means to prolong photocathode operating lifetime, namely, distribute ion damage across a larger photocathode area using a large laser spot. This in effect, is the operating principle of the BNL Gatling Gun.

Present Status:

The injector test cave is now called Upgrade Injector Test Facility (UITF). The JLab source group is tasked with building a compact 10 MeV polarized beam accelerator at UITF to help commission the HDIce target. HDIce tests require only nA levels of polarized beam although we expect the keV portion of the accelerator to support operation at higher current. It was hoped this accelerator would be operating by August 2016, but much of the work on this project has been halted for the past three months due to financial constraints. To entertain notions of high current beam tests in support of eRHIC, work on UITF must resume. BNL would like high current tests at UITF to begin soon, ~ May 2016.

The BNL Gatling gun was designed to operate at 50mA average current, providing the required polarized beam for eRHIC from multiple photocathodes. If the charge lifetime of each photocathode is ~ 800 C, the Gatling gun could provide sustained beam delivery at the required current for days without interruption. The Gatling gun was built and now operates at Stony Brook University but at lower voltage and lower current than expected. BNL management is under pressure to demonstrate high current operation as this remains a critical challenge associated with the eRHIC design. BNL has asked JLab to demonstrate high current beam delivery, in support of eRHIC R&D program.

Compatibility with JLab UITF mission:

Demonstrating sustained high current operation at millimapere beam current is a shared goal of JLab and BNL, but of a more pressing concern for BNL. The eRHIC design requires 50mA polarized beam to achieve luminosity goals. High current beam delivery at CEBAF could lead to the production of polarized positron beams at nA levels for Hall B physics, and could be useful for low energy nuclear physics experiments at LERF, such as the parity violation proposed by Roger Carlini and Frank Maas of Mainz.

Key Concerns:

HDIce testing at UITF must take priority over all else. HDIce expects beam delivery three times per year, with each interval lasting 6 weeks (a total of 18 weeks per year devoted to sole customer HDIce). Tests on BNL's behalf must be interleaved with HDIce testing.

The UITF beamline was designed with HDIce tests in mind. HDIce testing requires just nA level beam whereas BNL requests milliampere beam tests. Moreover, the ultimate goal for BNL is to deliver high bunch charge as well. The keV portion of the UITF beamline design can likely accommodate milliampere average beam current – because the previous UITF beamline was very similar to the new design. But high bunch charge operation will likely be problematic, with unacceptable levels of beamloss that will degrade vacuum and hasten QE decay. On the other hand, the new UITF beamline relies on a 350kV gun, whereas old tests were performed using 100 and 200kV guns. Higher voltage operation will help with high bunch charge beam delivery.

JLab does not possess lasers at 780 nm with enough power to deliver in excess of 4mA (our old milestone). Moreover, JLab does not possess lasers at 780nm that can deliver high bunch charge (nC) beam. BNL would need to provide such lasers.

JLab possess a 225kV power supply that can provide 32mA average current, and a 400kV power supply that can provide 3mA. Both power supplies can be used to operate the UITF photogun by merely changing a high voltage cable compatible with each power supply. JLab does not anticipate purchasing other power supplies.

High current beam demonstrations will require a scientist's undivided attention. The JLab source group does not presently have someone available to focus 100% attention on this project. BNL would need to provide a postdoc, and preferably someone working fulltime at JLab. That person would be expected to participate in all jobs, including vacuum work and bakeouts, and photocathode activations, and laser alignment. JLab would train the person to do these tasks. JLab staff would participate in the experiments. In particular, JLab graduate student Wei Lui would participate in this work, with results featured prominently in his doctoral thesis. Besides reaching new high current milestones with standard photocathode material, new high polarization photocathode material will be studied. And there are compelling studies that can be performed using bulk GaAs. We anticipate many publishable results to come from this work.

Today, there is no means to operate a photogun at UITF. Before new high current tests can be undertaken, a number of UITF subsystems must be re-stored to operational. These include:

a) Electricity supplied to electronics racks above the cave, scheduled to be complete by the end of December 2015.
b) Construct an adequately shielded space, approved by RadCon. This space can be new complete UITF as envisioned or a smaller space with a concrete wall to replace the one that was demolished. A new door must be installed.
c) Personnel Safety System. Relatively simple, with interlocks to a laser shutter, the gun high voltage power supply, and two entry/exit doors. There must be an interface to CARMs used to detect radiation, and to shut OFF beam when radiation levels exceed specified limits.
d) Network communications must be restored, connecting the control room terminals to electronics above the Cave.
e) Epics software control must be provided for a number of subsystems including the gun HV power supply, laser power supply and temperature controllers and optical elements for adjusting laser power applied to photocathode and to steer laser light on the photocathode, pockels cell tune mode generator, rf applied to the drive laser with amplitude and phase control, beamline pneumatic valves, viewers, magnets, BPMs, beamline current monitoring elements attached to picoammeters (cups, apertures, harp), ion pump power supplies, and radiation monitoring equipment to detect subtle beamloss. The software for most of these subsystems will be identical to existing software used at CEBAF.
f) We need epics control of the SCAM which serves as machine protection for viewers. The SCAM interfaces to our laser tune mode generator.
g) We need a master oscillator and low level rf control provided to the drive laser. We do not have a master oscillator, but components for the low level rf control boards for UITF were purchased last fiscal year. Construction of the low level rf boards is required. For UITF we expect to operate thelaser at 750 MHz but high current beam tests would benefit from operation at 1497 MHz to keep bunch charge as small as possible.
h) Beam tests will be compared to simulation results. This requires that the solenoid and dipole magnets be field mapped
i) An air core dipole magnet must be manufactured
j) Beamline vacuum components must be manufactured at machine shop (nipples, chopper slit cavity, narrow differential pump can, and dipole vacuum can).
k) Alignment plates and support structures must be manufactured for beamline components.
l) Bunchlength monitoring using the chopper rf deflector cavities would be helpful but not absolutely necessary. We would need (2) rf amplifiers and (2) 1497 MHz low level rf control boards to drive the choppers in one plane. We need a chopper water skid to regulate chopper temperature.

Procurements of approximately $400k are required to implement the tasks listed above. In addition, many hours of labor are required. A large fraction of the labor must be purchased from Engineering (Instrument and Controls, Low level RF, and DC Power).

Once the beamline is constructed and epics control restored, it will take months of beam delivery to fine tune the beamline, to scrub the beamline to improve vacuum and allow sustained high current operation.   Fine tuning beam delivery means that we adjust the magnets on the beamline to deliver 100% of all photoemitted beam to a dump sufficiently isolated from the rest of the vacuum beamline. Beamloss greater than 10^{-6} will prevent long lifetime high current beam delivery.

Field emission from the cathode electrode represents one of the most significant technical challenges for UITF and for eRHIC high current polarized beam production. For HDIce commissioning, the gun must operate at 350 kV to properly "capture" and accelerate the beam through the ¼ cyromodule to MeV energy (FEL experience suggests 320 kV might be acceptable). For eRHIC, field emission represents a challenge because it serves to degrade vacuum hastening QE decay. BNL high current experiments can be performed at voltage below 350 kV, where no field emission is present, but JLab staff must focus on 350kV operation to make MeV beam needed for HDIce. JLab can't stop high voltage R&D to conduct BNL high current lifetime tests. However, it is worth mentioning that operation at higher voltage will result in less ion bombardment, which should prolong the operating lifetime. And beam delivery at nC bunch charge required for eRHIC will benefit from higher gun bias voltage (stiffer beam production, less sensitive to space charge forces). So although not explicitly needed for eRHIC, both projects should benefit from gun operation at 350kV.

The present day gun cathode electrode can accommodate at most a laser beam with diameter of a few millimeters. This should be enough to demonstrate long lifetime at past current 4mA. Extrapolating the previous 4mA result, we believe a laser beam ~ 1 mm diameter should provide 800 C operating lifetime, but of course this requires that we reconstruct a gun and beamline with static and dynamic vacuum conditions identical to our old apparatus, to obtain the old fluence lifetime value we enjoyed.

The present day gun cathode design includes no photocathode cooling.   Lifetime at 10mA and higher could be limited by photocathode heating.   We will be able to determine at what current the lifetime is limited by excessive photocathode heating.   Implementing photocathode cooling will require significant gun modifications ($) and time, but we have some ideas how to do this.

JLab cannot promise to deliver a specific polarized beam current beyond what we have demonstrated in the past (e.g., 10 mA). Moreover, JLab cannot promise to demonstrate new world record beam levels within a certain time frame, especially in the sense that JLab does not share BNL's urgency to do so, because this effort is not part of JLab's present day nuclear physics mission.

If BNL agrees to provide financial support, we prefer that overhead not be paid twice, at BNL and JLab.