Summary and Collaboration Plans for US-JAPAN Laser Manipulation of H- Beams

March 28, 29, 2018 Fermilab

1. **Meeting Summary:**
   1. Principal attendees
      1. J-PARC
         1. Dr. Pranab Saha
         2. Dr. Shin-ichiro Meigo
         3. Dr. Akihiko Miura
      2. Fermilab
         1. Mr. David Johnson
         2. Mr. Todd Johnson
         3. Dr. Jinhao Ruan
         4. Dr. Vic Scarpine
   2. We heard excellent presentations on laser activities at both labs (as seen in the agenda).
   3. We held discussions on overlapping activities regarding manipulation of H- beams with lasers and potential areas of collaboration.
2. **Goals of Efforts on Manipulation of H- beams with lasers**
   1. Bob Zwaska’s opening presentation laid the groundwork for our discussions by providing a broad perspective of how laser manipulation of H- ions fits into the larger picture of high-power beams for HEP. He illustrated the birth of laser manipulation of H- with a paper on the concept of using lasers to create polarized proton beams by Zelenskiy in 1983, noting that the required laser power was prohibitive at the time. In 1998 I. Yamane and in 2002 V. Danilov, et.al. proposed two techniques for H- charge-exchange by laser interaction, thus eliminating the power limiting foil stripping technique. This has taken advantage in the technological growth of lasers over the past several decades which has led to POP experiments and the further development of enabling technology at SNS.
   2. Bob proposed a National Roadmap for Laser Manipulation of H- Beams with the ultimate goal of Laser Stripping of H- for Injection into synchrotrons to include Laser Notching and Laser Chopper. It has been proposed that there are other natural laser system developments that can lead to further advancement of laser applications to Particle Accelerators
      1. On-ramps (enabling technology)
         1. Laser technology
         2. Machine Protection
         3. Machine Stability
      2. Off-ramps (applications)
         1. Instrumentation
         2. Extraction/ Beam splitting
         3. Linac Collimation
         4. Phase Space Sculpting
         5. Ion beams
         6. Technology
         7. Polarization
      3. Peer Systems
         1. Laser-Plasma Wakefield Acceleration
         2. Photoinjectors
         3. Optical Stochastic Cooling
         4. Light source Seed lasers
         5. High-Energy-Density Physics
         6. Photon Colliders
         7. Interferometers
         8. Electron Back-scatter
   3. Goal for this workshop is to discuss progress and identify areas for future collaboration.
3. **J-PARC area of interest/current status/planned activity**
   1. **General areas of interest**:
      1. Diagnostics – development of multi-laser wire (Dr. Miura presentation)
      2. Beam extraction with laser for utilization in TEF-P (Dr. Meigo presentation)
      3. Laser Stripping injection at 400 MeV for 3 GeV RCS (Dr. Saha presentation)
   2. **Current Status**
      1. Development of Multi-laser wire for H- profiling:
         1. Design and POP experiment performed to verify the advancement of the laser on axis using HeNe laser.
         2. Measurements of laser spot size and intensity on cavity axis performed using micro mirror and photodiode. 24 laser spots identified on top half of the center axis cavity.
      2. Development of laser system for H- beam extraction at TEF-P:
         1. Ion beam requirements: beam power < 10W; repetition: single shot – 25 Hz;
         2. Based on the ion beam requirements for TEF-P, concluded that a Nd:YAG laser is suitable for charge exchange
         3. Set up a POP experiment at 3 MeV RFQ test stand
         4. Laser interaction in middle of dipole
         5. Verified extraction of H- ions with 28 hr test last June
         6. Investigated laser profile, timing jitter and a long run test (250 hrs) for laser stability.
         7. Investigated long and short pulse beam extraction
         8. Investigated utilization of CW diode laser for extraction
      3. Laser Stripping injection at 400 MeV for 3 GeV RCS
         1. Based on expected injected beam power, parasitic hits, energy deposition, foil heating and expected foil lifetime at 1 MW of 2 weeks, laser stripping is very attractive, if not necessary.
         2. Design of LS section is based upon using Nd:YAG laser for the 1st and 3rd steps of the three step process and ArF Eximer laser for promotion of ground state H0 to n=3 excited state.
         3. Established collaborations with Kyoto University and University of Electro-communications in Tokyo for extensive R&D of both IR and UV lasers.
         4. Further discussions with Dr. Timofey of SNS concerning LS design and strategy
   3. **Planned Activity**
      1. Development of Multi-laser wire for H- profiling
         1. Available funding for this project is uncertain and will determine how much progress can be expected for FY18
         2. Open questions include
            1. How to match laser and H- beam
            2. Decision on electron detector
            3. Deign, fabricate and test at 3 MeV beam line
            4. Determine application to 400 MeV line
      2. Development of laser system for H- beam extraction at TEF-P:
         1. Since budgetary condition at JAEA is not clear, the present system will actually be utilized at J-PARC with potential applications for
            1. Linac diagnostics for transverse and longitudinal
            2. Linac beam notcher to reduce extinction of the RCS
            3. ADS accelerator (30 MW) H+ beam diagnostics
      3. Laser Stripping injection at 400 MeV for 3 GeV RCS
         1. Preparation of POP experiment at 400 MeV in progress
            1. Vacuum chamber installed in beam line
            2. R&D of the lasers in progress
            3. Simulation of H- beam manipulations underway
         2. Location of POP demonstration determined to be end section of Linac to 3 GeV beam transport. Vacuum chamber installed.
         3. Goal to demonstrate ~90% stripping efficiency for a single micro pulse
            1. Study expected required laser power and techniques to reduce laser power
            2. Determine experimental strategy and measurement techniques

Use existing devices and monitors for POP demonstration

* + - 1. First trial of complete set of experiments planned JFY2018
      2. More studies needed for
         1. Laser and H- beam manipulations

1. **Fermi area of interest/current status/planned activity**
   1. **General areas of interest wrt laser - H- interaction**
      1. Advancement of bunch-by-bunch laser neutralization for accelerator applications
      2. Diagnostics and the development of new techniques
   2. **Other laser activities at FNAL**
      1. Photoinjector laser system development and operation
      2. Inverse Compton scattering laser system development
      3. Optical stochastic cooling activities
   3. **Current Status (of H- applications)**
      1. Bunch-by-bunch neutralization for Linac Laser Notcher
         1. Operational Laser system installed end of January
         2. Continuing to refine operational parameters, documentation, and software
      2. Low power amplitude modulated laser and narrow band lock-in amplifier
         1. Vacuum enclosure complete
         2. Laser systems and modulation components in-hand
         3. Detailed design for final optics underway
      3. Nd:YAG laser profile monitor in Booster 400 MeV injection line
         1. System is installed, need to replace galvanometers with linear stages and test system
   4. **Planned Activity** 
      1. Continuation of the development of a low power amplitude modulated laser and narrow-band lock-in amplifier detection with the goal of initial PIP2IT beam tests in Summer 2018.
      2. Re-start the 400 MeV laser wire integration
      3. Development of neutralization enhancement non-resonant interaction cavity
      4. Development of high peak power/high average power efficient laser system for neutralization
      5. Combine iii & iv to test momentum collimation in linac in Fermi FY19
2. **Action plans**
   1. Fermilab to send 400 MeV neutralization calculations to J-PARC for comparison with their experimental data.
   2. Reconcile differences in laser power prediction for neutralization between “saturation density in particle rest frame and fractional neutralization described by exponential of (flux\*cs\*interaction time).
   3. J-PARC suggested additional frequency analysis of Fermilab time domain neutralization data for the measurement of neutralization efficiency.
3. **Future Meetings:**
   1. Next meeting to be at J-PARC during Japanese FY18 (April 1, 2018 to March 31, 2019) , tentatively either Fall CY 2018 or Spring CY 2019.