The Fermilab Accelerator Science Program: Beam Sources & Instrumentation A0 Photoinjector (Part 2)

Mike Church
Fermilab
December 3, 2008

Outline

- Introduction *[Helen Edwards]*
- Recent Accomplishments *[Helen Edwards]*
- Proposal for FY2009-2011 *[Mike Church]*
- Organization and Personnel *[Mike Church]*
- Budget Request *[Mike Church]*
- Summary *[Mike Church]*

Schedule for FY2009-2011

- Continue operation of the A0PI at its current location during FY09 and FY10
  - One shutdown of several months to install and commission a new electron gun, replace an existing SRF accelerating cavity, and install a magnetic chicane
- Move the A0PI to the New Muon Lab (NML) at the start of FY11, commission in FY11, and provide >40 MeV beam for testing RF cryomodules for Project X and ILC
  - At the end of FY10, the Tevatron will be shut down. The A0PI will then be required to pay for it's own LHe (~$2000/day). An upgrade to A0PI cryo system to make it standalone would be prohibitively expensive.
  - NML will be ready for injector installation by FY11.
  - Consolidate personnel.

Experimental Program

- Beam Experiments
  - Emittance exchange (ongoing)
  - Ellipsoidal beam from Cs_2Te cathode
  - Flat beam generation and image charge undulator
  - Microbunching experiments and diagnostics
- Instrumentation
  - Electro-optical sampling of bunch length
  - Streak camera upgrade, Martin-Puplett interferometer, longitudinal diagnostics via coherent radiation, waveguide pickup, optical transition radiation interferometery, HOM signal processing, cavity BPM
- Technology upgrades
  - Commissioning of new electron gun
  - Installation of higher gradient SRF cavity
  - Installation of magnetic chicane

- The above lists are in priority order

Emittance Exchange Experiment
(ongoing)

- Personnel: Helen Edwards (FNAL); Tim Koeth (Rutgers grad student); Amber Johnson (NIU grad student)
- Theory: 1st proposed by Y. Orlov, *et. al.* (1991); optics proposed by Cornacchia and Emma (2002); optics improved by K.-J. Kim and Sessler (2006)
- Motivation: Emittance exchange in combination with flat beam transforms can possibly be a path to providing matched beams for high gain FELs, electron beams without damping rings, and high power IR FELs
- Strategy: This experiment uses two doglegs with a deflecting mode cavity between them to exchange the horizontal and longitudinal emittances.
- Goals: Demonstrate proof-of-principle, study the dynamics of the exchange, understand emittance diluting effects in the exchange, and develop mitigating strategies for the dilution. Use emittance exchange to generate a pulse train of microbunches.
- Status: Emittance exchange matrix has been verified. Currently exploring the large parameter space (input transverse and longitudinal phase space, and beam charge) for emittance exchange.

Ellipsoidal Beam Experiment

- Personnel: Philippe Piot (NIU/FNAL); Jinhao Ruan (FNAL); Tim Maxwell (NIU grad student)
- Theory: Three-dimensional ellipsoidal charge distributions produce linear space charge fields and are in principle free of space-charge-induced phase space dilution. Schemes to generate such a distribution have been proposed by Serafini (1997) and Luiten, *et al*. (2004).
- Motivation: This technique may prove to be an efficient way to generate high brightness, low emittance electron bunches, and FEL projects might benefit from it. It has been demonstrated with metal cathodes but not Cs_2Te cathodes.
- Strategy: A Ti:Sa laser will be used for the photocathode laser to produce the ultra-short (~50 fs) beam pulse required for the experiment. No beamline modifications are required.
- Goals: Demonstrate proof-of-principle of the generation of low emittance, low charge bunches from Cs_2Te.
- Status: NIU has placed an order for the Ti:Sa laser (250K$); calculations to optimize the experiment are underway; we are planning to start the experiment in Spring '09. This laser will also be used for the EOS tests.

Flat Beam and Image Charge Undulator

- Personnel: Yin-e Sun (FNAL)
- Theory: Flat beams with emittance ratio of 100:1 have already been generated at the A0PI, and a larger ratio is possible. In principle, a low energy flat electron beam passing a submillimeter grating can produce coherent radiation up to x-rays.
- Motivation: Flat beam transforms in combination with emittance exchange could be a path to providing matched beams for high gain FELs, electron beams without damping rings, and high power IR FELs. An image charge undulator may provide a more compact and less expensive method to generate high intensity x-rays
- Strategy: Start with passing a flat beam close to a pair of simple metal plates to understand wakefields, heat generation, etc. When these issues are understood design and install a suitable grating.
- Goals: Provide proof-of-principle of the generation of coherent radiation in the terahertz range.
- Status: A bolometer has been purchased for the measurement of THz radiation (10 μm – 2 mm). Experiments will start in Winter '09.

Microbunching Experiments and Diagnostics

- Personnel: Alex Lumpkin (Argonne/FNAL); Philippe Piot (NIU/FNAL)
- Theory: Space charge and coherent synchrotron radiation effects of high intensity electron beams passing through magnetic bends can introduce high frequency structure in the beam (microbunching).
- Motivation: Microbunching results in slice energy spread growth, and also induces coherent effects in OTR screens, rendering them useless for beam size measurements in some regimes. These effects have not been documented in the range of 15 – 50 MeV.
- Strategy: Investigate signs of microbunching for a variety of beam parameters in both the dogleg and chicane beamlines using visible, NIR, and FIR imaging techniques. Investigate microbunching as a function of transverse-to-longitudinal emittance exchange. Establish gain factors in the COTR vs. OTR and compare to theory.
- Goals: Document microbunching effects at 16 MeV. Compare microbunching in a dogleg configuration and chicane configuration. Develop mitigating strategies (e.g., laser heater, emittance exchange, ...).
- Status: Collaborative experiments with ANL have displayed microbunching at 150 – 325 MeV with sub-nC charge. Modelling is underway for A0PI.

Electro-optical Sampling of Bunch Length

- Personnel: Jinhao Ruan (FNAL); Philippe Piot (NIU/FNAL); Tim Maxwell (NIU grad student)
- Theory: The interaction of a very short laser pulse and the EM field of an electron bunch in a GaP or ZnTe crystal can be used to resolve the longitudinal structure of a single electron bunch non-destructively.
- Motivation: Currently both the A0PI streak camera and interferometer are not able to reach the resolution required for a single bunch. A more reliable single shot scheme based on EOS needs to be developed.
- Strategy: The spectral decoding technique has been proven to be able to measure a bunch length in the range of 200 fs to 2 ps with a 100 fs laser pulse. This will be sufficient for current A0PI experimental needs.
- Goals: An EOS device based on a Ti:sapphire will be developed first to satisfy the needs of the current A0PI experimental program. A more convenient and compact EOS system based on a fs fiber laser will also be tested.
- Status: Simulation work is done. The Ti:sapphire laser is being purchased by NIU.

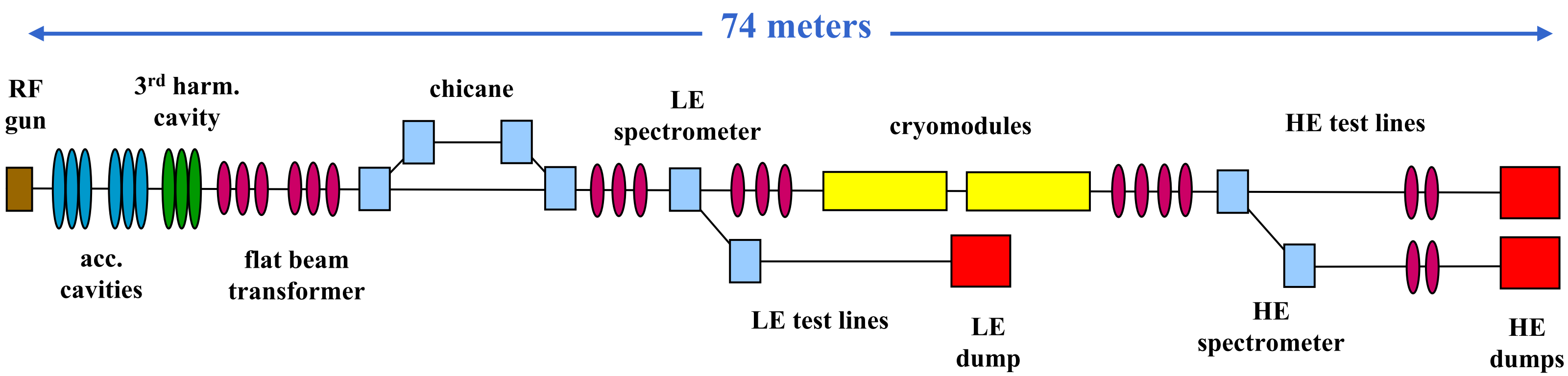
Technology Upgrades

- Commission new electron gun
  - Fabrication of new DESY-style egun is being funded by SRF project
  - New gun will have lower dark current, in situ cathode changer, and coaxial RF coupler (advantage for A0PI)
  - New gun will have longer bunch train length; commissioning prior to installation at NML (advantage for NML)
- Install higher gradient SRF cavity
  - 1st 1.3 GHz SRF cavity installed at A0PI has max. acceleration of 12 MeV
  - 2nd 1.3 GHz SRF cavity (to be) installed at NML has max. acceleration of >24 MeV
  - After the 2nd cavity is used for commissioning cryo system at NML, it will be installed at A0PI (replacing 1st cavity).
  - Higher beam energy, tunability, availability of HOM signals (advantage for A0PI)
  - 1st cavity available for repair and upgrade for higher gradient (advantage for NML)
- Install magnetic chicane
  - For comparing microbunching in beam through a chicane and through a dogleg; compression of bunches for high peak current; short bunches for testing EOS and other bunch length diagnostics

Move to the New Muon Lab (NML)

- A0PI will be moved to NML in FY11; A0 group will be integrated into NML commissioning, operation, and experiments
- Purpose of NML is two-fold: test RF cryomodules; support AARD

New Muon Lab –
Preliminary Schematic Layout (not to scale)



- Injection energy >40 MeV, 2 RF cryomodules, high energy of >500 MeV
- Low energy beamline space available for AARD
- High energy beamline space available for AARD
- Operation at >3 nC, 3 MHz bunch trains 1 msec long, 5 Hz repetition rate
- Possibility of future building expansion for higher energy and more extensive area for AARD

AARD Beyond FY11 – Experiments Under Consideration, Proposed, or Discussed

- Possible continuation of experiments at A0PI
- 3.9 GHz longitudinal mode cavity (for bunch linearization to generate high peak beam currents)
- Development and test of 3.9 GHz transverse mode cavities (as bunch length diagnostic; as crab cavity for future colliders)
- Experiments discussed at a AARD Workshop held at FNAL on 11/06
    - Optical Diffraction Radiation for transverse beam size measurement
    - Laser acceleration of beam; plasma wakefield acceleration of beam; dielectric wakefield structure acceleration of beam
    - Inverse Compton Scattering for generation of x-rays
    - Tests for components of a positron "keep alive" source for the ILC
    - Damping ring test of optical stochastic cooling
    - ....

Organization and Personnel

- The A0 Photoinjector group has ~5 individuals at this time:
  - Laser expert- physicist
  - Eng Physicist - operations
  - Guest scientist
  - Controls specialist (under contract from Univ. of Illinois)
  - Eng Physicist coordinator (part time)
  - H. Edwards (part time)
- The activities are matrix supported by
  - APC ~ 2.5 FTE
  - Instrumentation ~ 2.5 FTE
- Other support groups as needed: mechanical and RF groups mainly
- Students - 2 new students starting
- We are currently under critical mass in personnel and are actively pursuing increased participation, both from inside and outside FNAL

Budget Request (K$)

	FY09	FY10	FY11
A0 Operations			
M&S	335	235	305
SWF	1591	2316	3097
A0 Upgrades			
M&S	114	625	680
SWF	742	772	803
Total	2782	3948	4885
Total FTEs	11	14	17

- The FY09 SWF reflects the current level of support
- The FY10 increase in SWF and M&S is driven primarily by the technology upgrades
- The FY11 increase in SWF is driven by the need for increased manpower for the move to NML

Summary

- The A0PI has produced significant scientific results in the past, and has collaborated with other groups throughout the world to produce these results.
- Collaboration outreach is necessary in order to enlarge the expertise base and to bring in more students. Currently we have good collaboration with NIU and ANL, and are pursuing enlarging this group (Univ. of Maryland, Univ. of Wisconsin, ...)
- The A0PI facility has been a significant source of accelerator science PhDs, and has served as a training ground for scientists and engineers in SRF, photoinjectors, lasers, and electron beam physics.
- The A0PI group has a strong scientific program planned for the near future. Our current resources (personnel and budget) is not adequate to fully implement this program in the anticipated time scale, and we are looking for an increase in support.
- The A0PI will be the basis for the injector for the New Muon Lab starting in FY11. The A0PI group will perform an essential role in commissioning and operation of that facility.
- AARD potential at the New Muon Lab will be greatly increased from current potential at A0PI.