Fermilab/NICADD Photoinjector Laboratory (FNPL): Collaborative R&D

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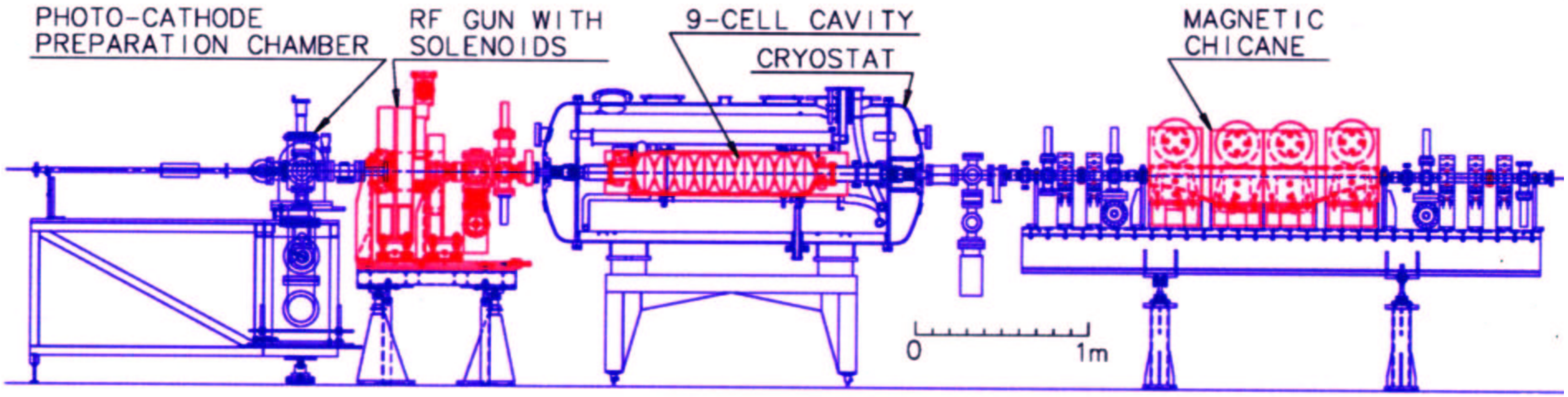
A guideline reminder:
Stay clear of political issues
Interdisciplinary
Feel free to express ignorance

Fermilab
April 5, 2002

FNPL

- Electron source @ A0
- Jointly operated by Fermilab/NICADD
- Beam Physics
- International Facility (Chicago, Georgia, Michigan, NIU, Rochester, Fermilab, DESY, CERN, LBL)

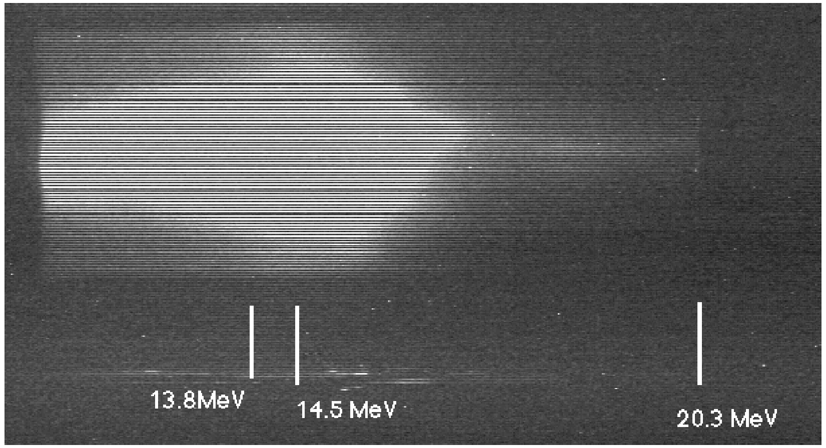


Dissertations

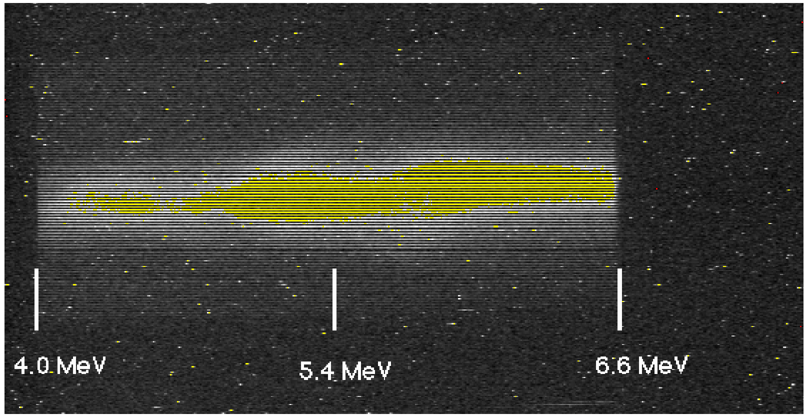
- **Completed**
  - *E. R. Colby, Ph.D., UCLA, 1997. Design, Construction, and Testing of a Radiofrequency Electron Photoinjector for the Next Generation Linear Collider*. RF guns currently operating at Fermilab and DESY were constructed in the course of this work.
  - *A. Fry, Ph.D., Rochester, 1996. Novel Pulse Train Glass Laser for RF Photoinjectors.* Design and initial performance of the laser at the Fermilab photoinjector.
  - *S. Fritzler, Diplomarbeit, Darmstadt, 2000*. This thesis covers the *first observation of channeling radiation in the high flux environment* of A0, and extends observations as a function of bunch charge two orders of magnitude higher than any earlier measurement.
  - *M. Fitch, Ph.D., Rochester, 2000. Electro-Optic Sampling of Transient Electric Fields from Charged Particle Beams*. In addition to the discussion and measurement of wakefields induced by bunch passage through the photoinjector, further data on laser and injector performance is given.
  - *J.-P. Carneiro, Ph.D., Universite de Paris-Sud, 2001. Etude experimental du photo-injecteur de Fermilab*. This is a thorough documentation of the performance of the photoinjector, including comparison with the predictions of E. Colby.
- **Current**
  - *D.Bollinger, NIU,* Plasma Acceleration
  - *R.Tikhoplav, Rochester,* Laser Acceleration.
  - *Y-e Sun, Chicago,* Flat Beams.

The plasma wake-field acceleration experiment

Accelerated electrons up to 20.3 MeV



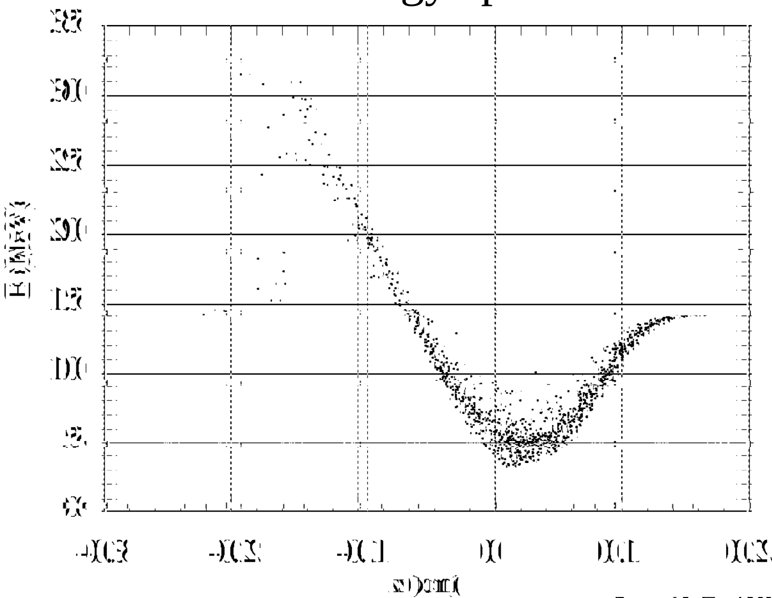
Decelerated electrons down to ~3 MeV:



Parameters:

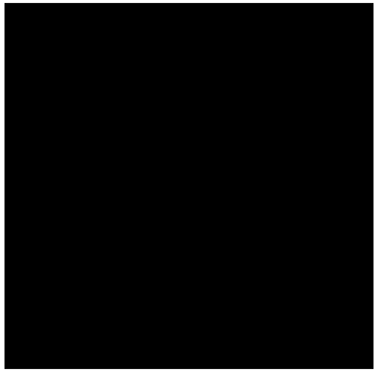
- Charge: 6-8 nC
- Bunch length: < 1 mm RMS
- Plasma: L=8cm, 10^{14}/cc density
- Initial energy: 13.8 MeV
- Acceleration gradient: 72 MeV/m

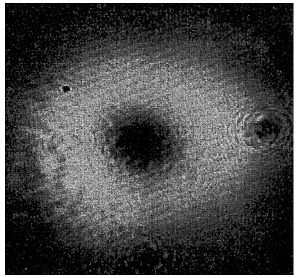
Simulation result:
final energy spectrum

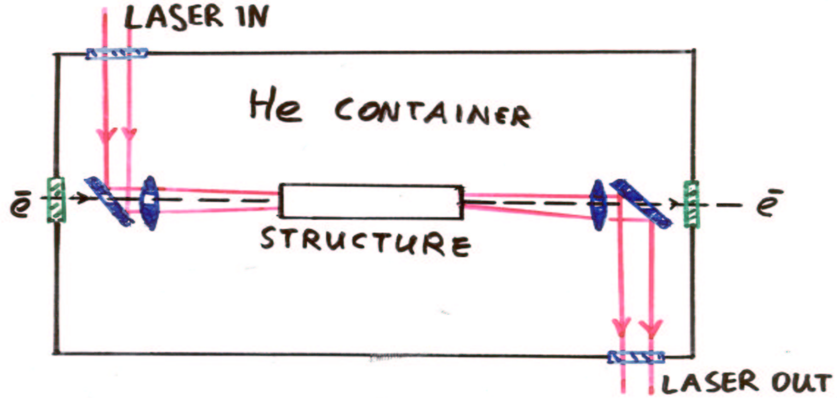


LASER ACCELERATION OF ELECTRONS

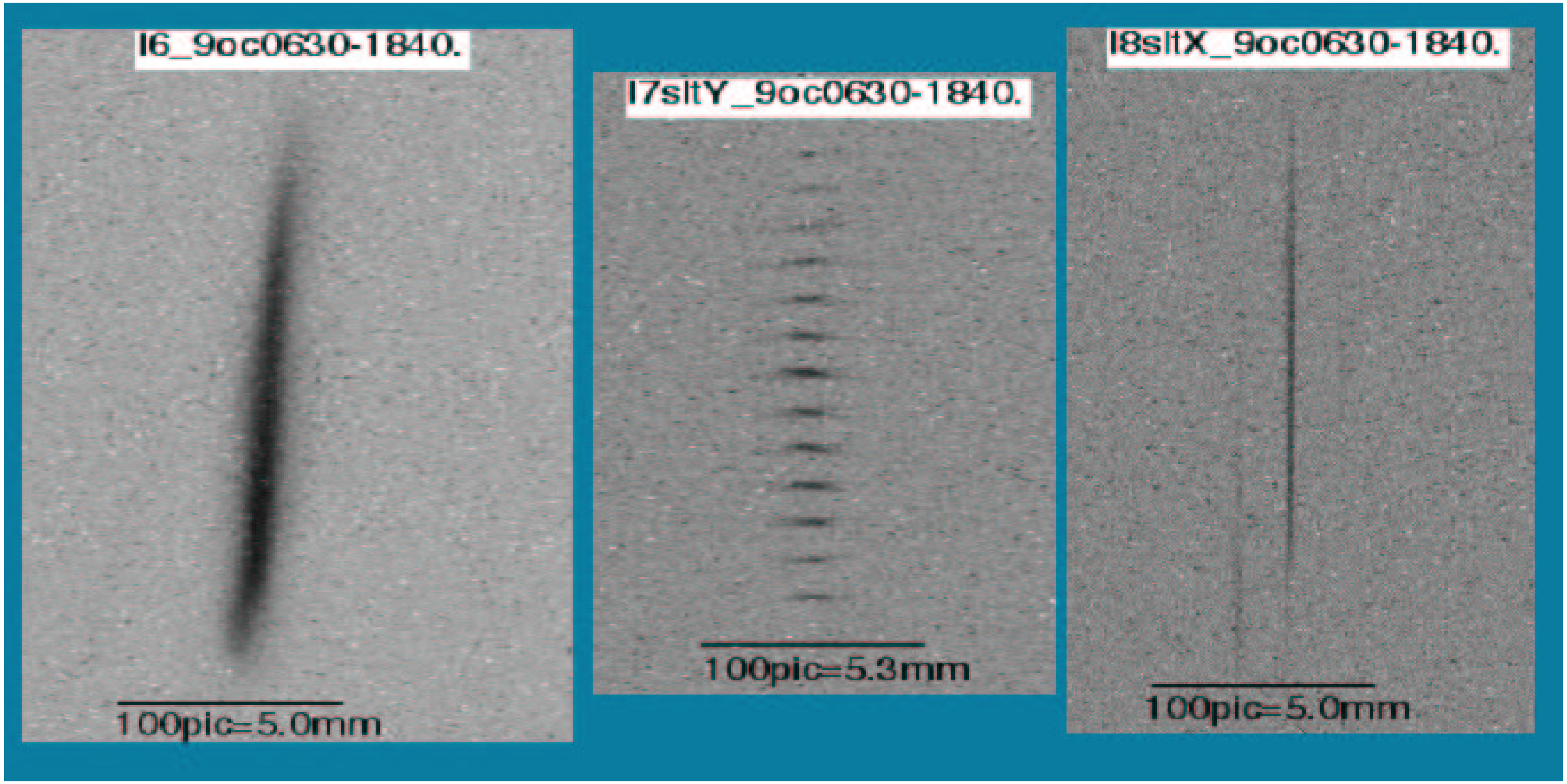
- Study the possibilities of using a laser beam to accelerate charged particles in a wave guide structure with dimensions much larger than the laser wavelength
- The laser operates in the TEM_{01}* mode which provides the largest possible longitudinal component of the electric field.
- For 34 TW of laser power (the maximum that that can be supported by the structure) the accelerating field E_a=0.54 GV/m.







Flat Beams



Flat beam generation could simplify requirements for
Linear collider electron damping rings!

Energy Fragmentation from Bunch Compression

(taken 6 Feb 02 via remote operation from DESY-GAN!)

Beam Energy ~ 15 MeV, Bunch Charge ~1 nC
Compression essential for FELs

Global Accelerator Network

- **Successfully operated the photoinjector from DESY and LBNL – and a major milestone.**
- **A web based system in initial stages of development**
- **Would benefit from the type of controls experience common to experiments**
  - **Remote operation**
  - **Transmission of data**
  - **Standard analysis packages**
- **Contact Nick Barov (barov@nicadd.niu.edu)**

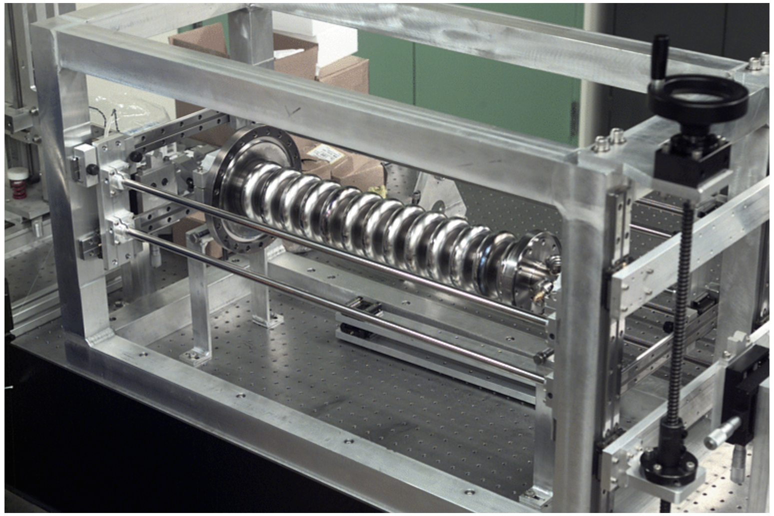
Additional Dissertations

http://nicadd.niu.edu/fnplres.html

- Electron-Beam Diagnostics
  - electro-optic crystal
  - Michelson interferometer
  - diffraction-radiation
  - deflecting srf cavity
- Superconducting RF Cavities
  - “kaon-separator” (deflecting) cavity
  - “beam-shaper” (accelerating) cavity
- RF Gun
  - high-duty-factor (srf?)
  - polarized beam
  - dark current and photocathode
- Fundamental Studies of Space Charge, Coherent Synchrotron Radiation

Superconducting RF

- **Measurement of CP violation in $K^+ \rightarrow \pi^+ \upsilon \upsilon$ (fixed target experiment E921) requires a few 10^{14} K^+**
- **We will create a pure K^+ beam with ~ 6 meters of SCRF cavities operating at 3.9GHz in TM_{110} at 5MV/m P_{TRANS}**
- **One and three cell structures have been run up to B_{MAX} of 85 to 104 mT on inside surface – compare TESLA TM_{010} mode (110 mT at 25 MV/m E_{ACC}); CKM separators need 77 mT**
- **Contact Helen Edwards (hedwards@fnal.gov)**



13-cell prototype deflecting cavity

Nb shaped at FNAL, e-beam welded at nearby contractor, chemical and heat treatment for prototypes has been done at Jefferson Lab.

Proposal for a High-brightness Photoinjector

- A collaboration modeled on large detector collaborations for the construction and operation of a high-brightness electron beam at Fermilab.
- Five year construction, then operation
- Advanced beam research and machine development.
- The collaboration presently includes seven universities and three laboratories.
- An Expression of Intent submitted 02/11/02 to FNAL, ANL, LBNL, DOE, and NSF asking for encouragement to begin a design report.
- Have encouragement from FNAL, ANL, LBNL.

Motivation

- **Fundamental beam and accelerator physics**
  - Wakefield & laser acceleration.
  - Bunch Compression.
  - Flat & Polarized Beams.
  - Emittance Reduction.
  - All of which will promotes growth and innovation through university training of accelerator physicists.
- **Support for the new generation of linear colliders, FELs, and synchrotron radiation sources (1 micron emittance and <270 micron pulses)**
  - Demonstrate that injector specifications can be met.
  - Platform to study generation of required beams.
  - Develop expertise and infrastructure for LC efforts.
- **Utilizes superconducting RF cavities and will foster Midwest and national development of the technology.**

Notional Layout of Photoinjector

(as envisioned by DESY)

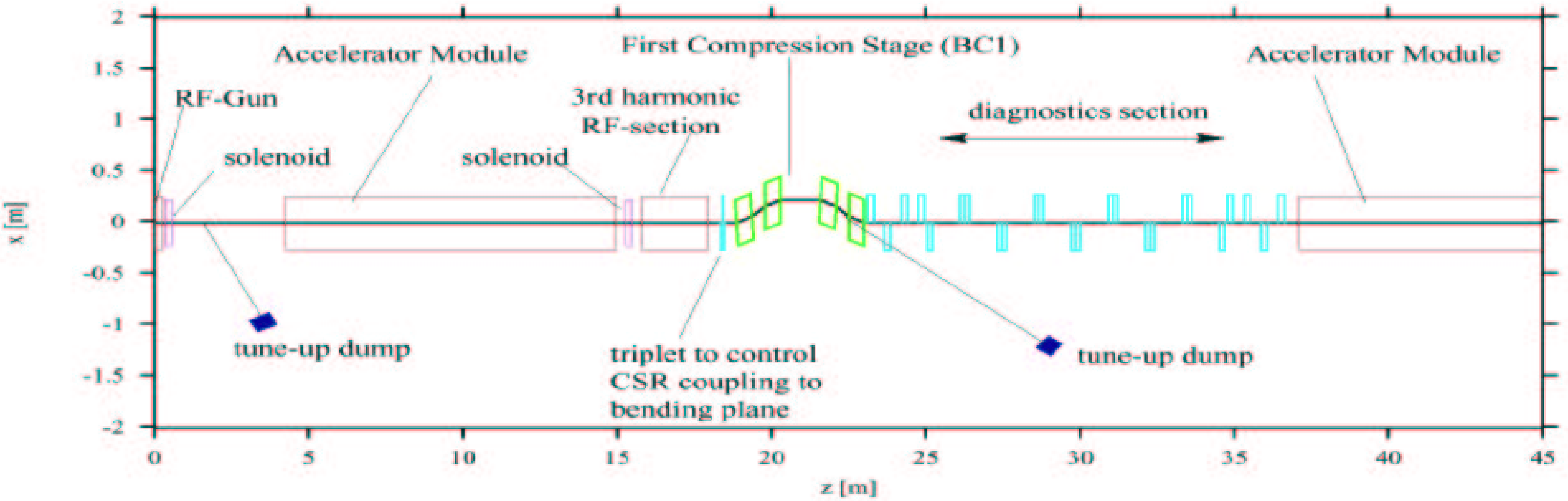


Figure 1: Layout of the X-ray FEL injector at TESLA. The represented elements are rf-cavity (red), dipoles (green), solenoids (violet), and quadrupoles (cyan).

Emittance ~1 micron, Bunch Length <270 microns

Energy 140à300 MeV

Major Components

- Drive laser (provides a flexible pulse structure and train) with a CsTe photocathode (high QE).
- Emittance compensating solenoids.
- A DESY donated 1.3 GHz, 8 cavity cryomodule (immediate acceleration reduces emittance growth due to space charge).
- 3rd Harmonic superconducting RF section to correct non-linearities in longitudinal phase space.
- Four-dipole compression stage.
- Diagnostic & matching section.
- A domestically developed cryomodule.

Collaboration

- Envision the laboratories (Fermilab, Argonne, LBNL, DESY) taking responsibility for larger projects.
  - Infrastructure (Fermilab)
  - RF Gun (ANL), High repetition RF Gun (LBNL)
  - Cryomodules (DESY, Pi3)
  - 3rd Harmonic (Fermilab/LBNL)
  - Compressor (Fermilab/ANL)
- While the universities (Chicago, Michigan, NIU, Northwestern, Pennsylvania, Rochester, UCLA) .
  - Contribute personnel to laboratory based projects
  - Take responsibility for smaller projects
    - Simulations
    - Laser
    - Diagnostics
- An open collaboration!

Simulations

- **Need to simulate all aspects for the design proposal**
- **Complete simulation of a photoinjector is done with several separate packages (HOMDYN, PARMELA) each with limitations**
  - **Gun**
  - **3^{rd} Harmonic**
  - **Compressor**
- **An integrated simulation would be a tremendous step forward**
- **Well suited to the skill set familiar to HEP types**
- **Contact Court Bohn (clbohn@fnal.gov)**

Laser Development

- **An interesting instrument requires flexibility:**
  - **1 MHz train of up to 800 equal-amplitude pulses**
  - **1 mJ per pulse (0.8 J per macropulse)**
  - **1054 nm**
  - **10 ps pulses**
- **Clearly cross-disciplinary.**
- **Contact Adrian Melissinos (meliss@pas.rochester.edu)**

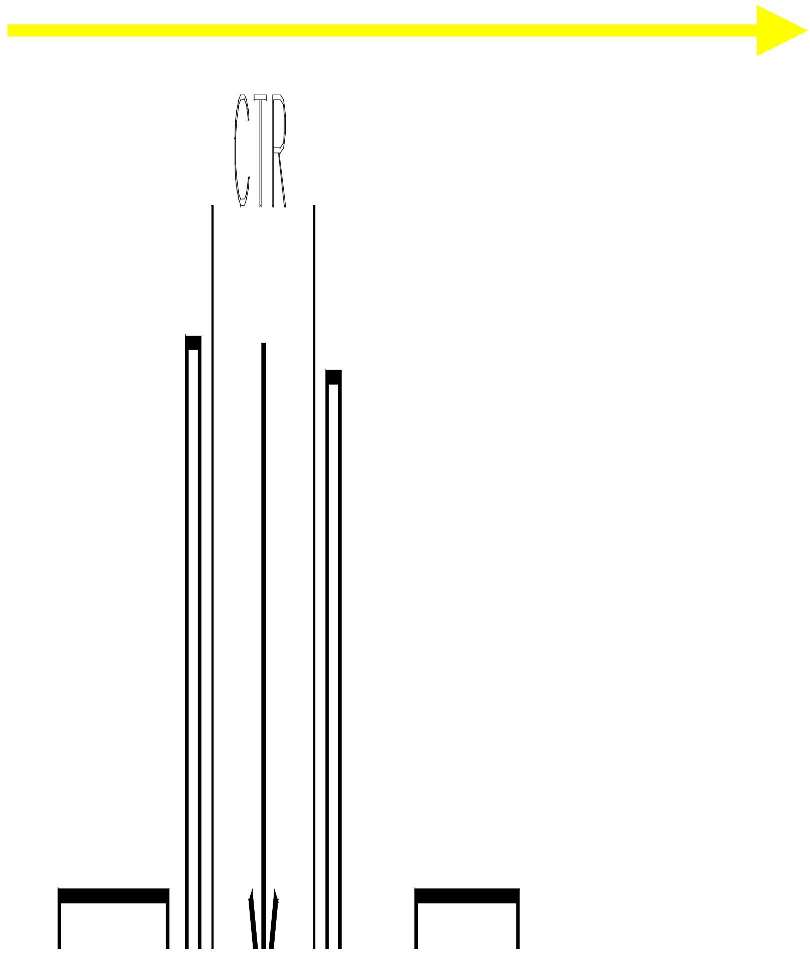
Conventional Diagnostics
(both FNPL and Pi3)

- Faraday cup for bunch charge
- Button beam-position monitors
- Multi-slit transverse emittance
- Optical-transition-radiation (OTR) viewers
- Dipole-magnet spectrometer for energy and energy spread
- Michelson interferometer for longitudinal bunch profile

Interferometer

(both FNPL and Pi3)

- A good example is development of an interferometer to measure pulse length
- Intensity and frequency of emitted radiation is sensitive longitudinal distribution of charge.
- With an interferometer the spectrum can be sampled and the bunch length measured.
- To be designed and built at Georgia but help installing commissioning needed



Innovative Diagnostics

(both FNPL and Pi3)

- **Non-intercepting diagnostics**
  - **electro-optic crystal**
  - **diffraction radiation**
  - **improved beam-position monitors**
  - **micro-undulator**
- **Future generations of interferometers**
- **Deflecting-mode cavity as spectrometer**
- **Tomographic techniques**
- **Many projects – talk to Court Bohn (clbohn@fnal.gov)**

Conclusions

- **FNPL offers immediate opportunities**
- **Pi3 will strengthen HEP and the laboratories:**
  - **A collaborative model to promote accelerator physics (open to additional institutions).**
  - **Strengthens accelerator physics infrastructure.**
  - **Supports development of new technologies and machines.**
- **Join!**