Status and Plans for Beams at NML

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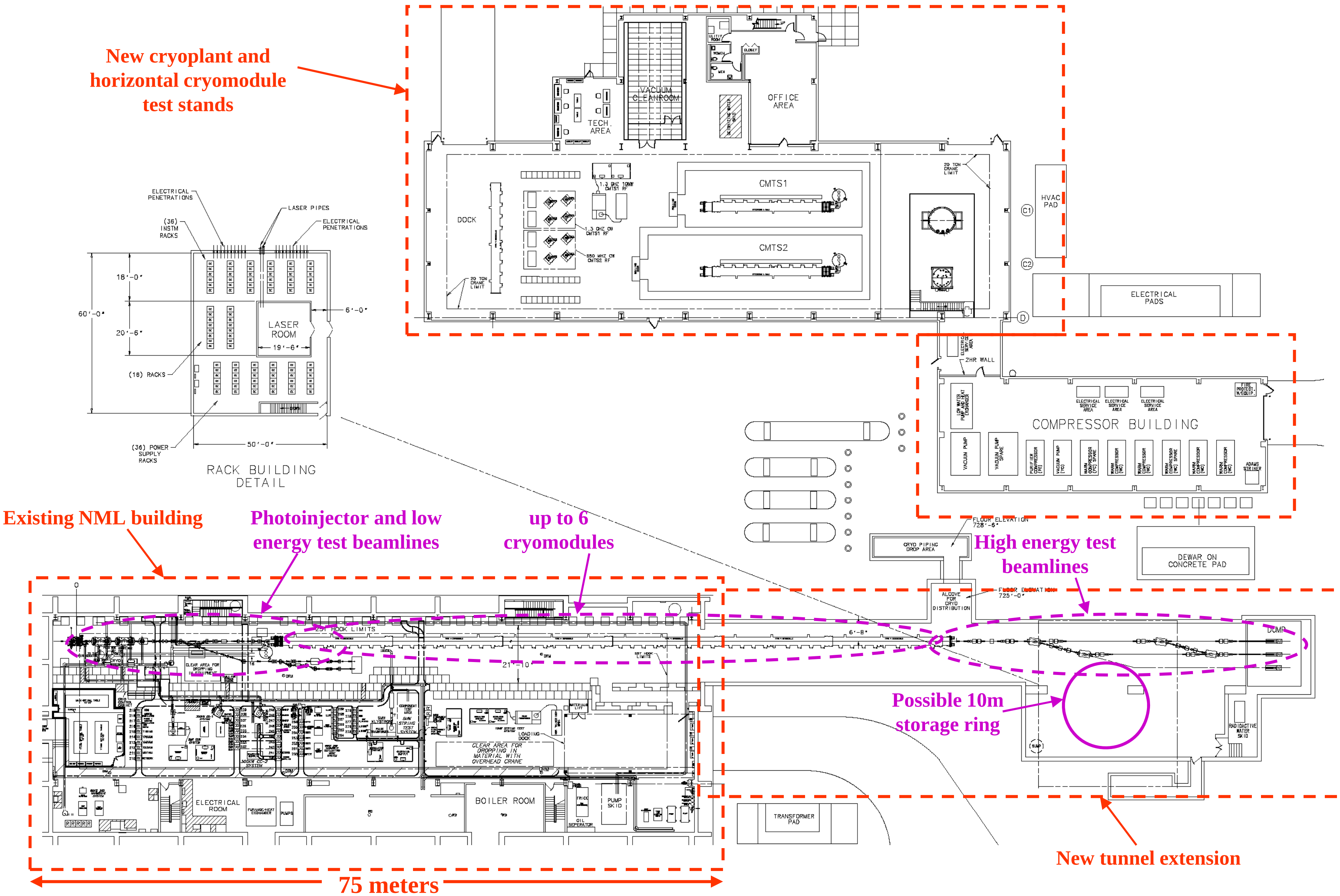
Objectives of the SRF Test Accelerator at the New Muon Lab

- **Test and operate a full ILC "RF unit" with "ILC beam intensity".**
  - **An RF unit consists of 3 ILC cryomodules driven by a single 10 MW klystron.**
  - **ILC beam intensity is 3.2 nC/bunch @ 3 MHz in a 1 msec long pulse (3000 bunches), with a 5 Hz repetition rate. The RMS bunch length is 300 μm.**
- **Establish an advisory committee-reviewed, proposal-driven user beam facility to carry out advanced accelerator R&D.**

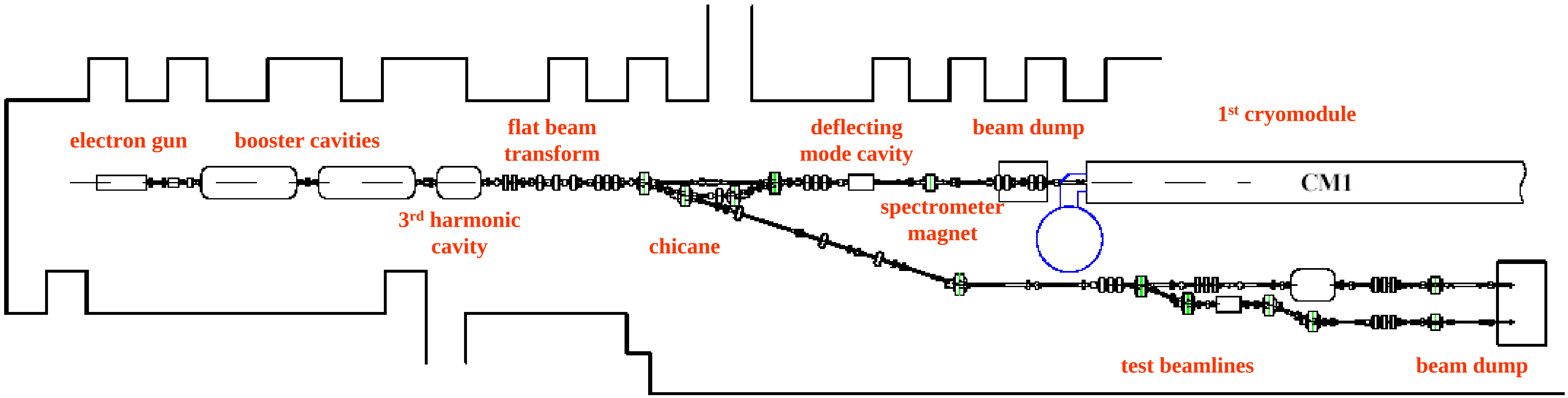
NML building

NML interior

Facility Layout



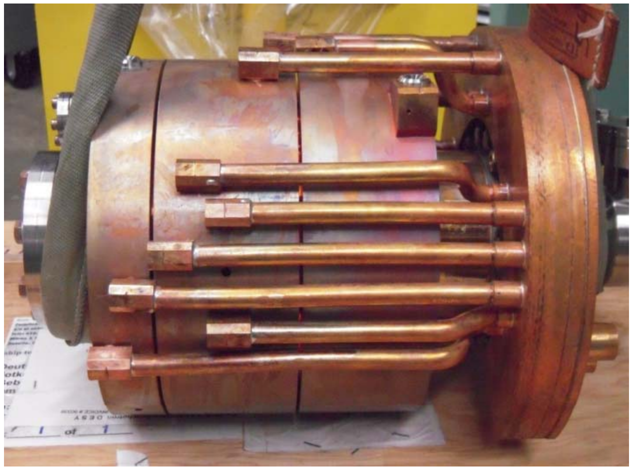
Injection Beamline and Low Energy Test Beamline Layout



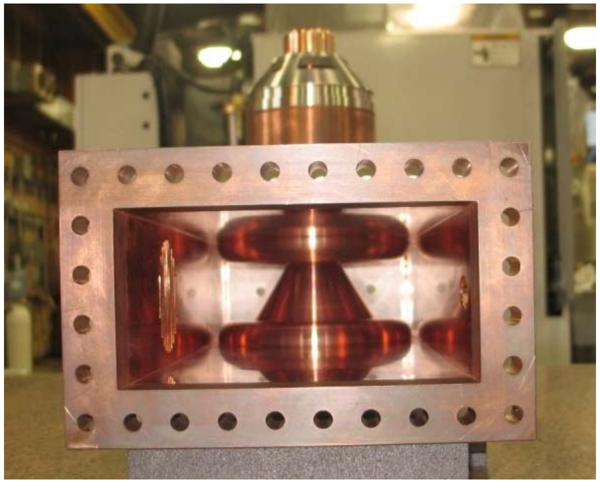
- 1.5 cell, 1.3 GHz electron gun with Cs_2Te photocathode; almost identical to DESY/PITZ design
- Two 9-cell 1.3 GHz superconducting booster cavities
- Superconducting 3.9 GHz cavity (eventually) for bunch linearization
- Three skew quadrupoles for flat beam transformation
- Chicane for bunch compression (R_{56} = 0.198)
- 3.9 GHz, normal conducting deflecting mode cavity for bunch length measurement (from A0PI)
- Vertical spectrometer dipole deflects beam 22.5° to dumps for beam energy measurement
- Test beamlines will be configured to suit experiments; example shown here is for emittance exchange
- ~40 MeV beam energy

Electron Gun

- 1.3 GHz, normal conducting, 1.5 cell copper cavity (DESY/PITZ design)
- Up to 45 MV/m accelerating field at the cathode; requires 5 MW klystron; 20 KW average power at full ILC pulse length and repetition rate
- Cs_2Te photocathode excited by 263 nm UV laser
- 2 identical solenoids for emittance compensation
- Coaxial RF waveguide coupler
- 3 cavities have been fabricated; 1 additional under fabrication
    - 1 by DESY – completed and shipped to Fermilab; 1st spare
    - 3 by Fermilab – 1 completed and shipped to KEK; 1 completed and to be commissioned at NML; 1 under fabrication as 2nd spare
- RF window conditioning to begin in 12/10
- Gun conditioning awaiting installation of water cooling system at NML; conditioning to begin ~3/11

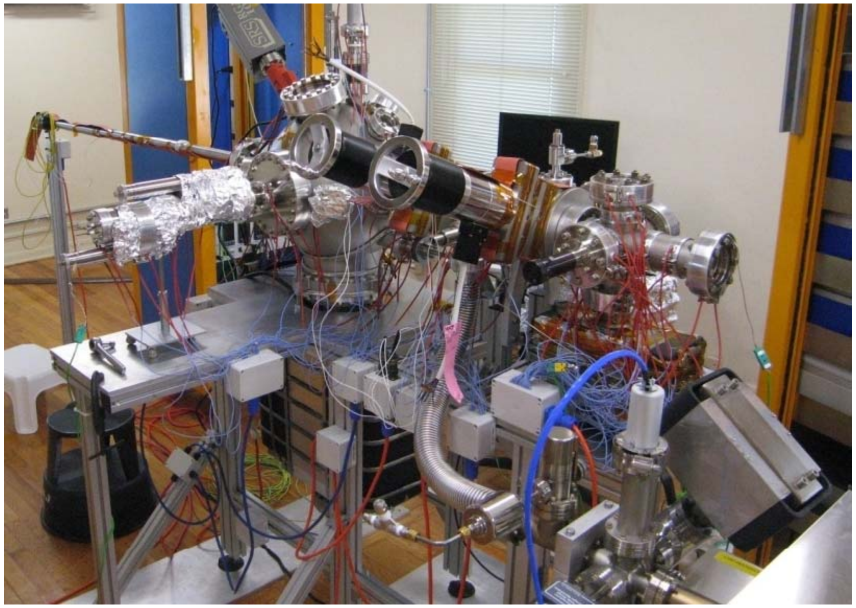

gun cavity


solenoids

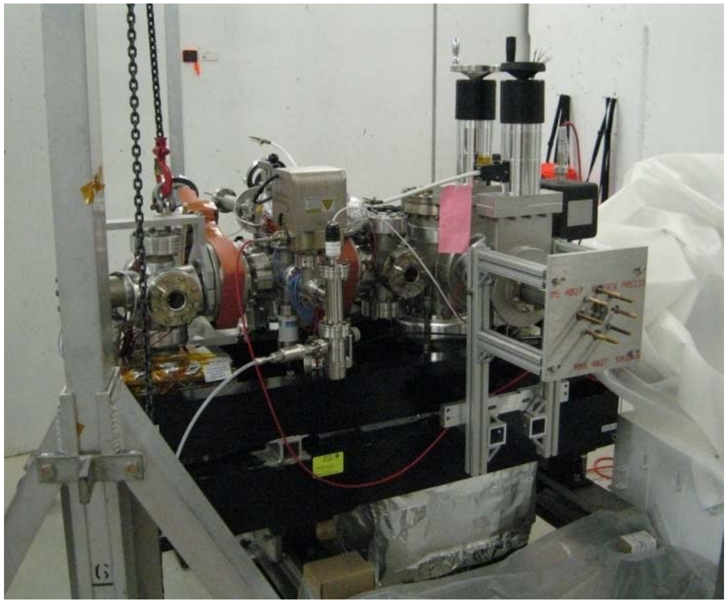

RF coupler

Cathode Prep, Transport, and Transfer Systems

- Cathode chambers were fabricated at INFN Milano under the direction of Daniele Sertore
- Cathode prep chamber
  - Used to prepare and coat cathodes; installed at Lab 7 at the Fermilab Village; under vacuum; will be baked and ready to produce cathodes by 1/11
- Cathode transport chamber
  - Used to transport prepared cathodes from the prep chamber to the transfer chamber attached to the gun
- Cathode transfer chamber
  - Used to insert cathode into the gun; installed at NML; will be baked and ready for operation by 1/11



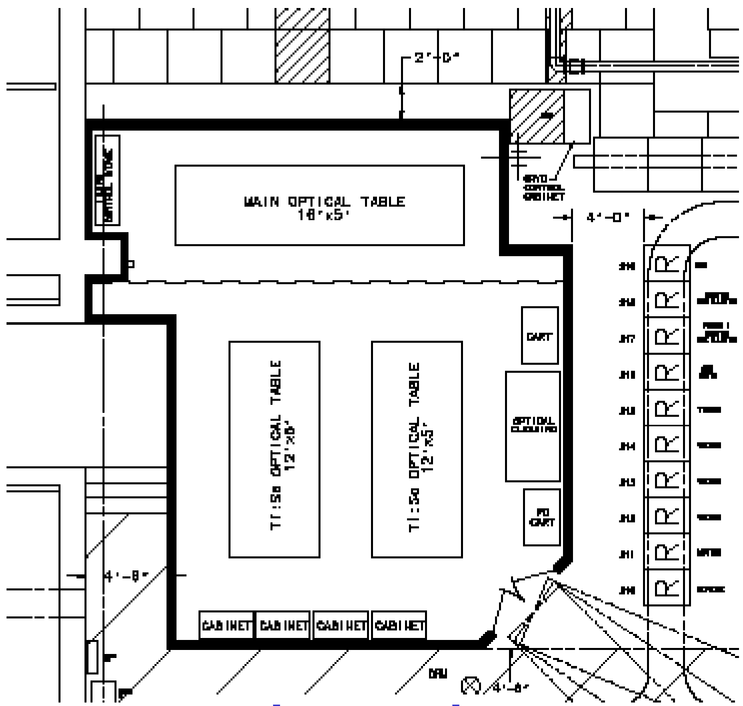
cathode prep chamber at Lab 7



cathode transfer chamber at NML

Cathode Laser System

- Laser room inside NML is under design
- New fiber optic seed laser and diode lasers have been procured
- NIU has purchased new Ti:Sa laser for ultrashort bunch generation; currently under development at A0 photoinjector
- A0 photoinjector laser room has been enlarged to accommodate an additional optical table to start setup and testing of new NML laser system components
- NML laser room will house 3 optical tables – 1 for Nd:YAG laser, 1 for Ti:Sa laser; 1 for laser development



NML laser room layout

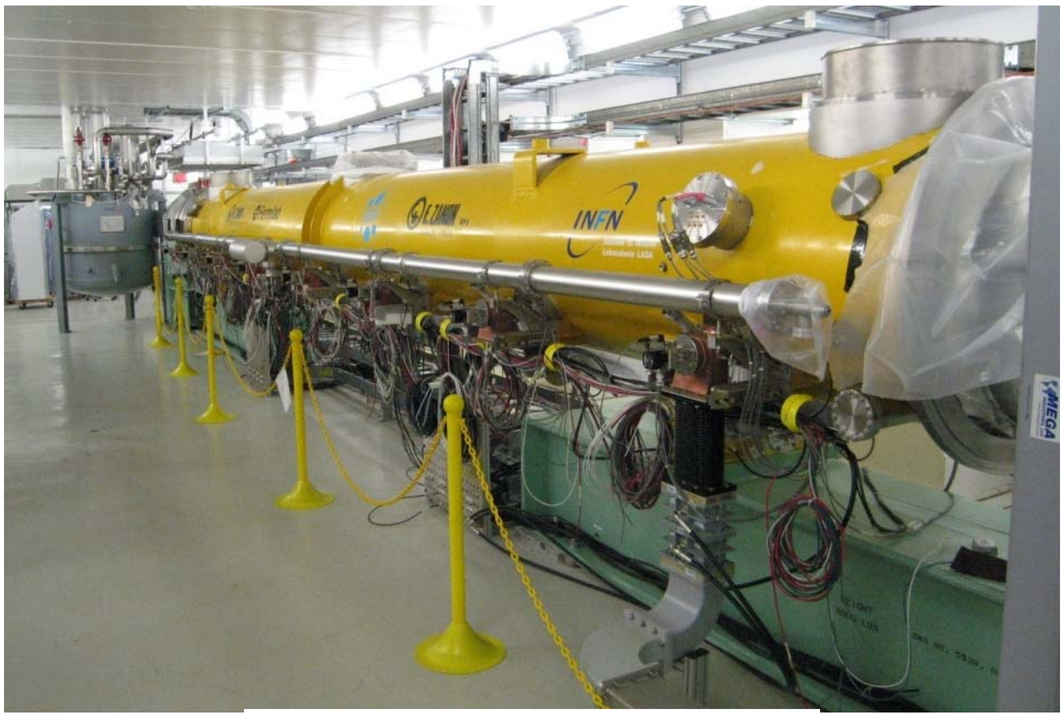
Booster Cavities

- 1 booster cavity installed and conditioned at NML
  - Conditioned at 24 MV/m
- 1 booster cavity in use at A0 photoinjector
  - Currently operates at 12 MV/m
  - At the end of the A0 photoinjector run, a new higher gradient cavity will be installed in the cryostat, tuner repaired, and HOM couplers made accessible from outside the cryostat

booster cavity 2, installed at NML

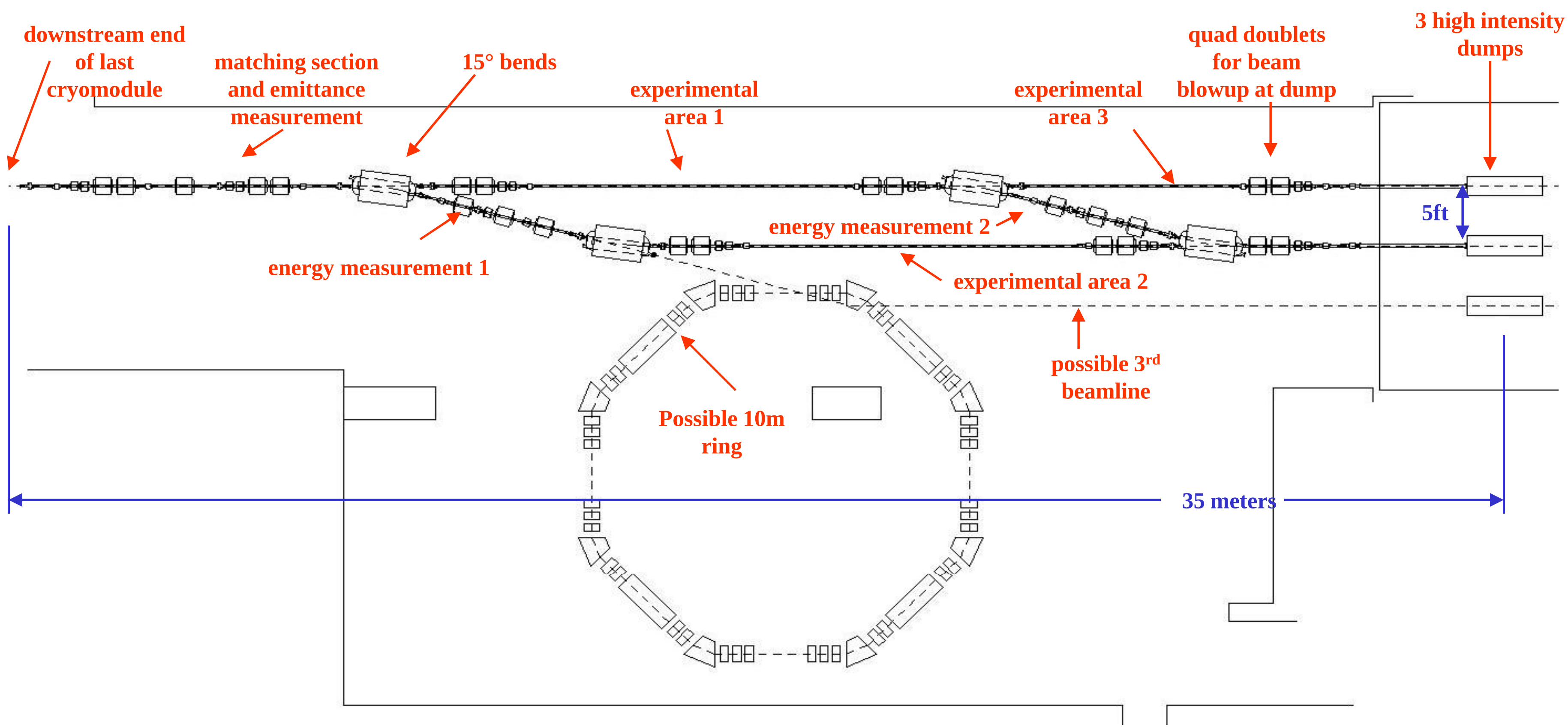
Cryomodules

- Cryomodule 1 is installed at NML – type "TTF III+"
  - Klystron with 5 MW tube has been commissioned
  - Warm coupler conditioning is complete
  - Cavity has been at 2° K
  - Cold coupler conditioning ready to start
- Cryomodule 2 (type TTF III+) to be delivered to NML in 2011
- Cryomodule 3 (type ILC IV) to be delivered to NML in 2012



Cryomodule 1 installed at NML

Potential Downstream Beam Experimental Areas



- 3 experimental areas shown here: 8 meters, 8 meters, and 5 meters in length
- Spectrometer magnets are 15° bends
- Can measure beam energy before and after experimental area 1
- Single beam dump alcove houses 3 separate 75 KW dump cores
- Space for a 10 meter diameter strorage ring or an additional beamline

Instrumentation

Standard instrumentation will consist of:

- **Button BPM's for beam position measurement in warm sections**
  - **Expect single bunch resolution of ~25 μm for 250 pC bunch**
- **L-band cavity BPM's and HOM couplers for beam position measurement in cryomodules**
- **YAG and OTR screens in instrument crosses for beam size measurement**
  - **Have procured and evaluated a prototype instrument cross at A0PI**
- **Toroids for beam intensity measurement**
  - **Have procured and evaluated a flanged, compact toroid at A0PI**
- **Scintillator paddles /photomultiplier tubes for beam loss measurement and machine protection**
  - **Prototype tested; procurement in process**
- **Beam energy and energy spread measurement**
  - **Spectrometer dipoles with BPM's and YAG/OTR screens**
- **Bunch length**
  - **Combination of streak camera, 3.9 GHz deflecting mode cavity, and cryogenic bolometer and interferometer (all currently under use at A0PI)**
- **Bunch timing**
  - **Button BPM's instrumented as phase monitors in warm sections**
  - **HOM coupler signals in cryomodules**

Additional Beamline and Technical Components

- **Beamline Magnets**
  - **All required magnets (quadrupoles, dipoles, and correctors) are currently under procurement (Radiabeam and Everson-Tesla)**
  - **Electron gun solenoids (Danfysik) are ready for installation**
- **Magnet power supplies**
  - **LE magnets, HE correctors and quads to be powered by standard Fermilab Main Injector 4-quadrant regulators and bulk supplies**
  - **High precision HE dipole supplies to be built by Fermilab; NMR system procured for accurate field measurement**
  - **Electron gun solenoid power supplies procured from Danfysik**
- **Beam dumps**
  - **Engineering design for high energy dump cores complete (75 KW)**
  - **Engineering design for low energy dump cores in process (2.5 KW)**
- **Controls system**
  - **Will be ACNET with support for EPICS, DOOCS, Labview, ……**
- **Cryogenics**
  - **Two Tevatron satellite refrigerators have been installed; capable of operating 2 booster cavities and 3 cryomodules at 1 Hz repetition rate**
  - **5 Hz operation for full system at full gradient and full beam intensity will require the new refrigeration plant – scheduled for operation in 2014**

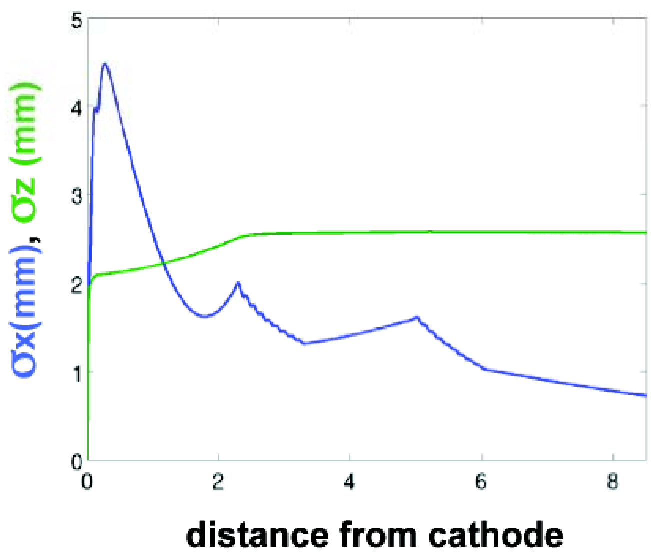
Beam Parameters

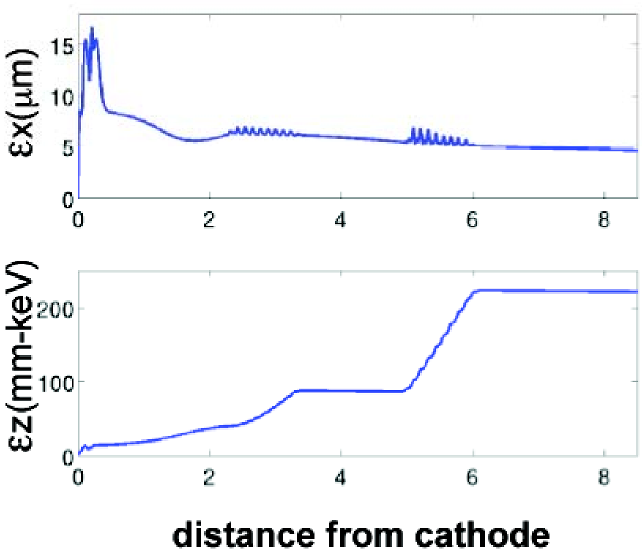
NML will be capable of operating with a wide range of beam parameters. As with all photoinjectors, many beam parameters are coupled, especially to the bunch intensity, due to space charge effects.

parameter	ILC RF unit test	range	comments
bunch charge	3.2 nC	10's of pC to >20 nC	minimum determined by diagnostics thresholds; maximum determined by cathode QE and laser power
bunch spacing	333 nsec	<12 nsec to 10 sec	lower laser power at minimum bunch spacing; max is 1 bunch per bunch train
bunch train length	1 msec	1 bunch to 1 msec	maximum limited by modulator and klystron power
bunch train repetition rate	5 Hz	0.1 Hz to 5 Hz	minimum may be determined by gun temperature regulation and other stability considerations
norm. transverse emittance	~60 mm-mrad	<1 mm-mrad to >100 mm-mrad	maximum limited by aperture and beam losses; without bunch compression emittance is ~5 mm-mrad @ 3.2 nC
RMS bunch length	1 ps	~30 fs to ~20 ps	minimum obtained with Ti:Sa laser; maximum obtained with laser pulse stacking
peak bunch current	3 kA	10 kA (?)	depends on performance of bunch compressor
injection energy	40 MeV	~5 (?) MeV – 50 MeV	may be difficult to transport 5 MeV to the dump; maximum is determined by booster cavity gradients
high energy	810 MeV	40 (?) MeV – 1500 MeV	may be difficult to transport 40 MeV through the cryomodules; radiation shielding issues limit the maximum

Preliminary Injector Simulations – ILC Beam Conditions (P. Piot)

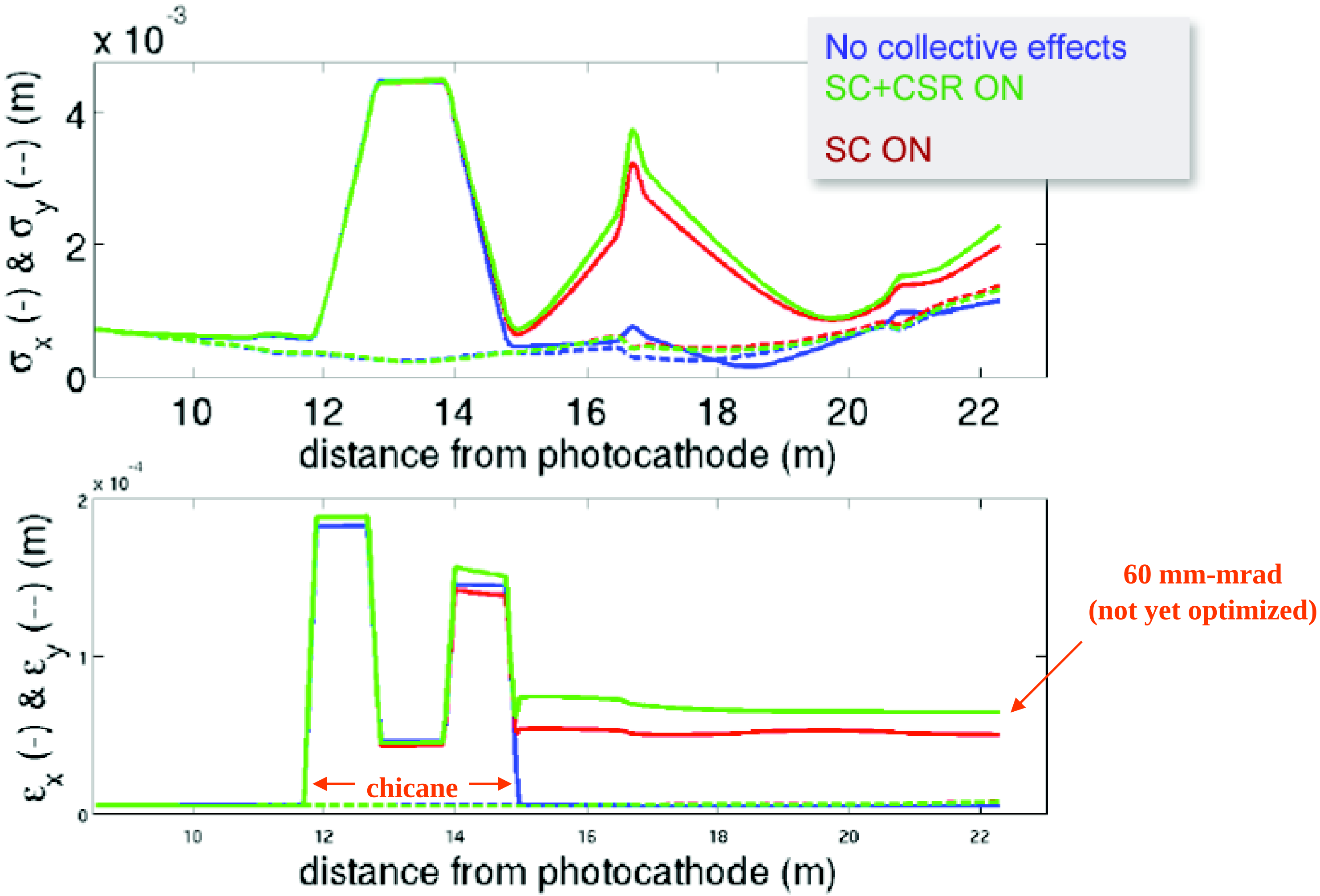
- Beam Parameters: 3.2 nC, 3 ps rms laser pulse
- Optimize gun parameters to minimize emittance after booster cavities
- Vary 2nd booster cavity phase for bunch length <300 μm after chicane
- Simulation tools:
  - ASTRA for tracking from photocathode to downstream of the booster cavities (space charge)
  - ELEGANT for Q=0 beamline (quadrupole) tuning
  - IMPACT-Z for tracking from the booster cavities, through the chicane, and downstream (space charge + 1D CSR)
  - Plan to use CSRTrack eventually (not yet implemented)





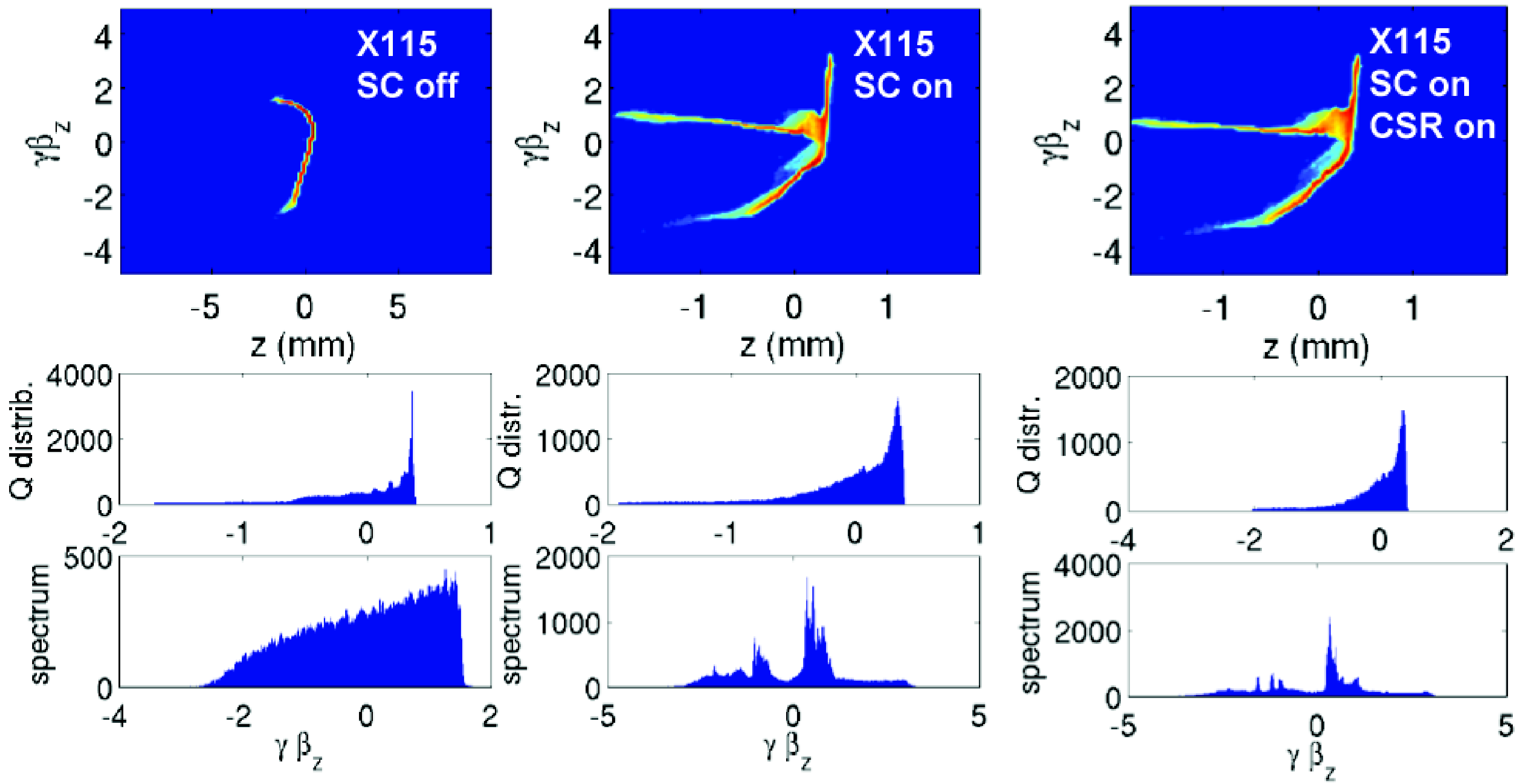
Evolution of bunch size, length, and emittances from cathode to d.s. of 2nd booster cavity (ASTRA)

Injector Simulations – ILC conditions (P. Piot)



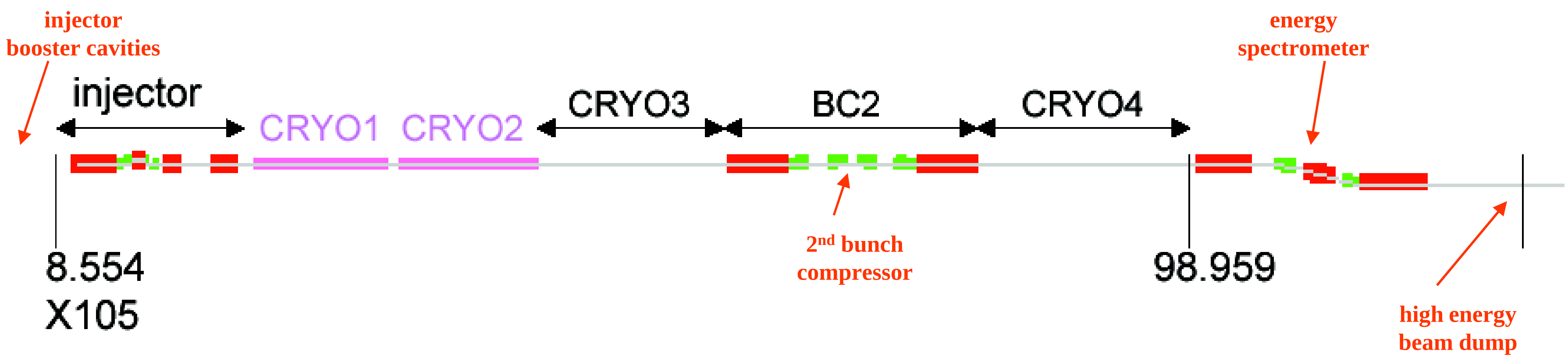
Evolution of transverse bunch size and emittance from d.s of 2nd booster cavity to 1st cryomodule with bunch compression on (IMPACT-Z)

Injector Simulations – ILC Conditions (P. Piot)



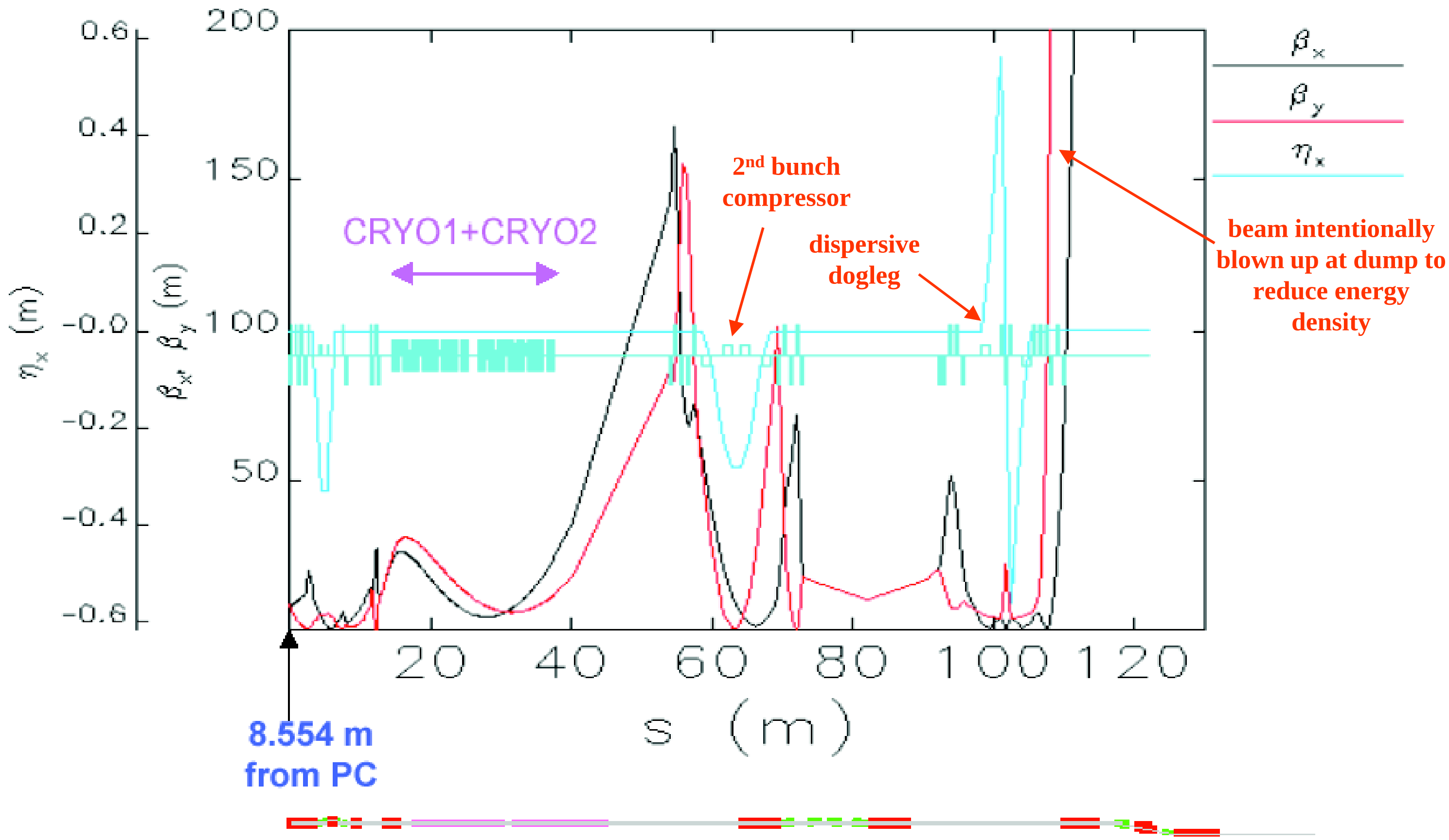
Longitudinal phase space after bunch compression at 40 MeV (IMPACT-Z)

Preliminary Lattice Design for High Energy Beamline (P. Piot)



- The NML tunnel will allow for the possibility of 6 consecutive cryomodules (2 ILC "RF units")
- However, the above configuration allows for more efficient bunch compression, with shorter bunches and lower emittance at high energy. These initial calculations assume 2 cryomodules are installed at the time of 1st beam.
    - Injector layout as previously shown
    - 1st 2 cryomodules in place
    - Leave gap for eventual installation of 3rd cryomodule
    - Place 2nd bunch compressor (chicane) in 4th and 5th cryomodule slots
    - Leave gap in 6th cryomodule slot for eventual installation of 4th cryomodule
- This configuration will allow for more efficient bunch compression, with shorter bunches and lower emittance at high energy
- With 4 cryomodules in place, energy can be as high as ~1100 MeV in this configuration

High Energy Beamline (P. Piot)



Lattice functions from d.s. of booster cavities to high energy dump (ELEGANT)

Schedule Highlights

- **Cryomodule 1 cooldown starts: 11/2010**
- **Completion of NML building extension: 12/2010**
- **Electron gun commissioning starts: 2/2011**
- **Cryomodule 2 delivered to NML: 2011**
- **Beam operations cease at A0PI: 10/2011**
- **1st beam at NML: late 2012**
- **Cryomodule 3 delivered to NML: 2012**
- **New refrigeration plant fully operational: 2014**