Beam Activities and Experiments at the NML Test Facility

Mike Church

All Experimenters Meeting

June 13, 2011

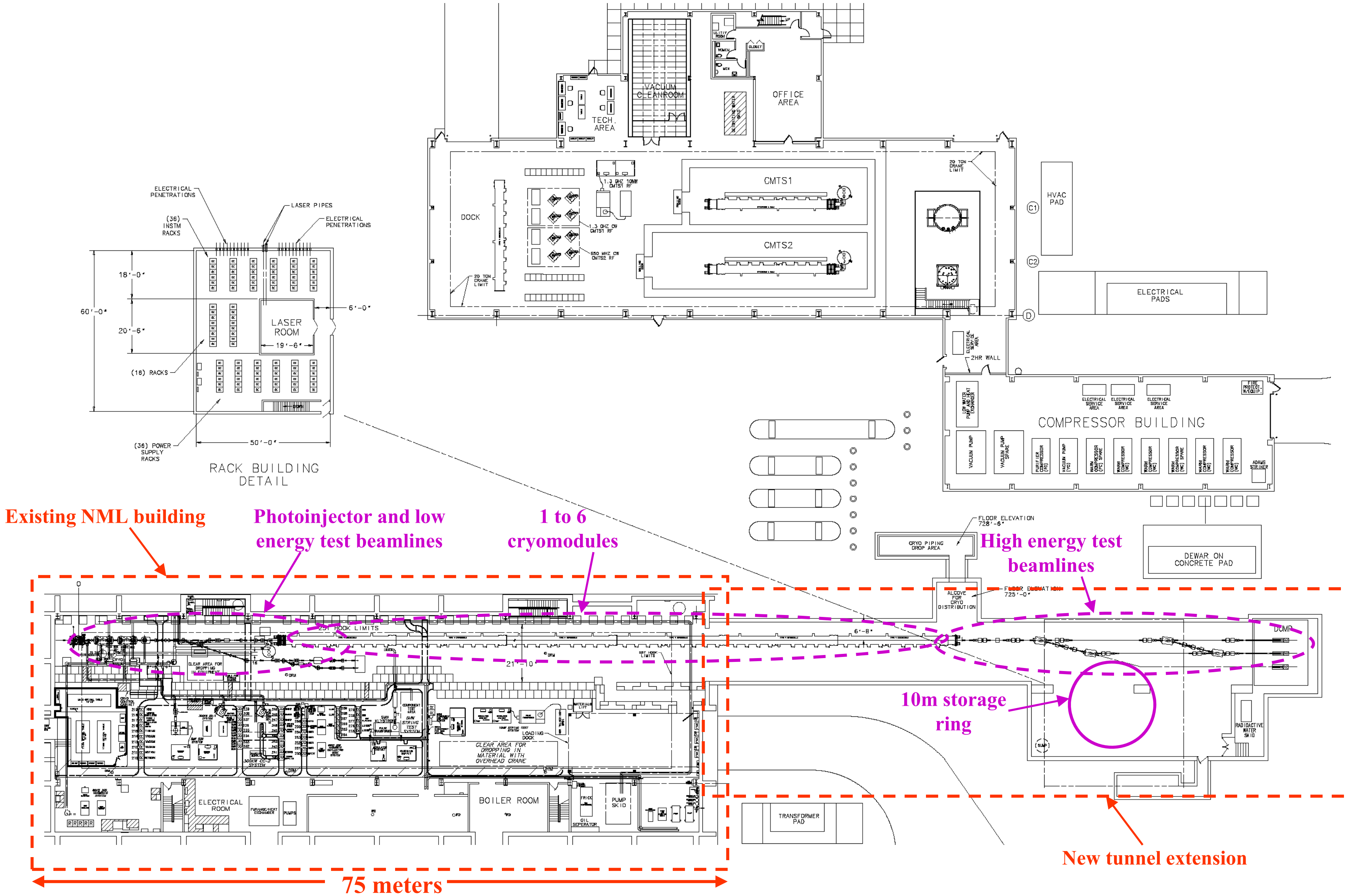
Objectives of the SRF Test Accelerator at the New Muon Lab

- **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. (45 KW beam power.)**
- **Establish an advisory committee-reviewed, proposal-driven user beam facility to carry out advanced accelerator R&D by the accelerator physics community.**

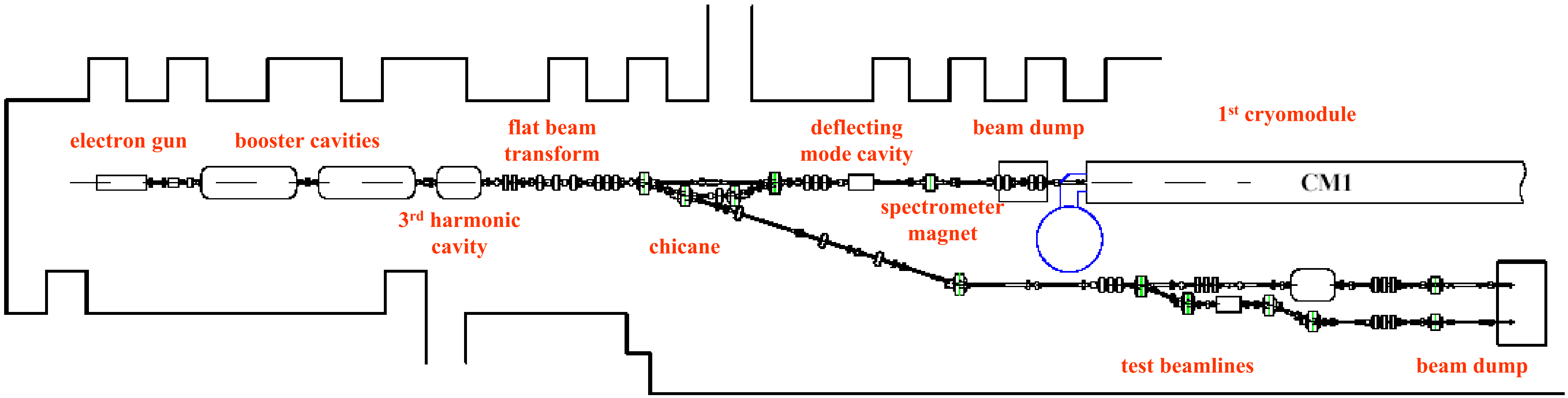
NML building

NML interior

Beamlines Layout



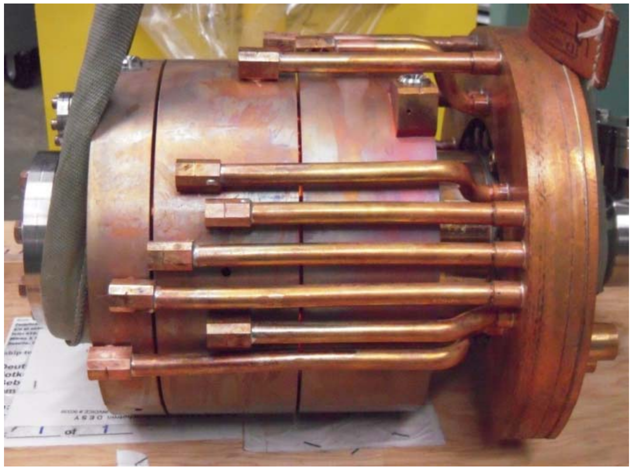
Injection Beamline and Low Energy Test Beamline Layout



- 1.5 cell, 1.3 GHz electron gun with Cs_2Te photocathode; identical to DESY/PITZ design
- Two 9-cell 1.3 GHz superconducting booster cavities (one currently installed, one from A0PI)
- 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 longitudinal beam diagnostics (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

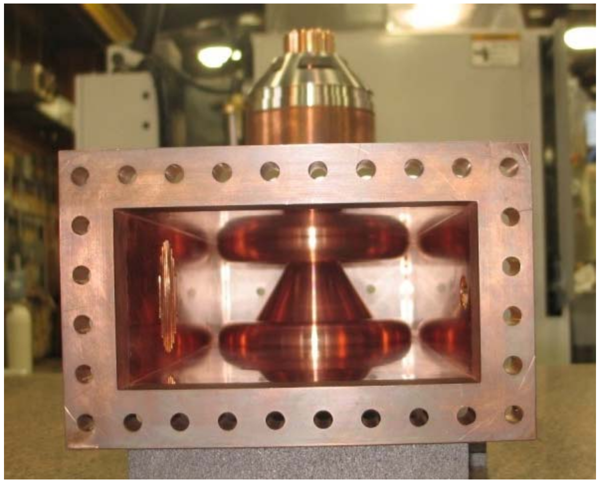
Electron Gun

- 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 windows (from Thales) are currently being conditioned



gun cavity

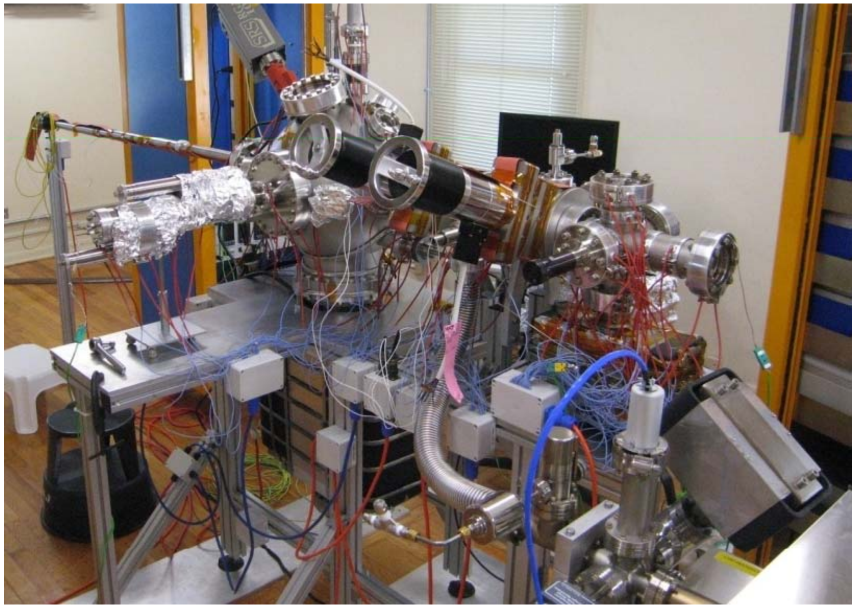
solenoids



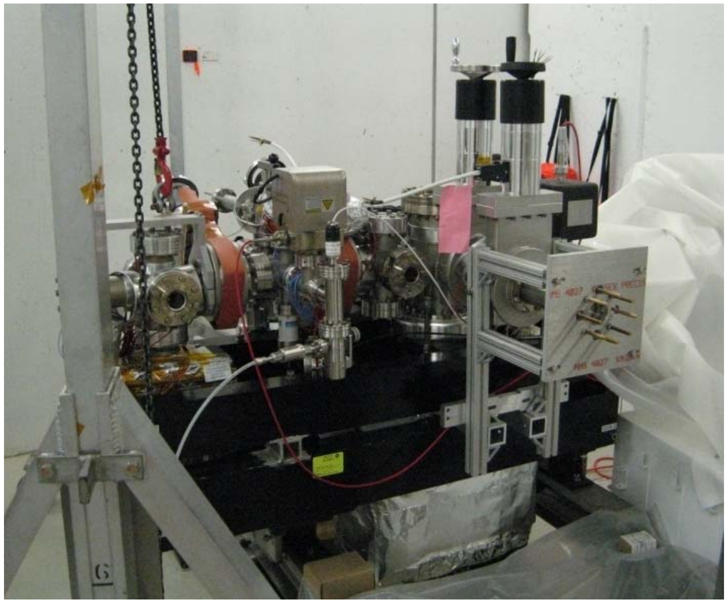
RF coupler

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; first cathodes have been coated in 4/11
- 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; first coated cathodes inserted in 4/11



cathode prep chamber at Lab 7



cathode transfer chamber at NML

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

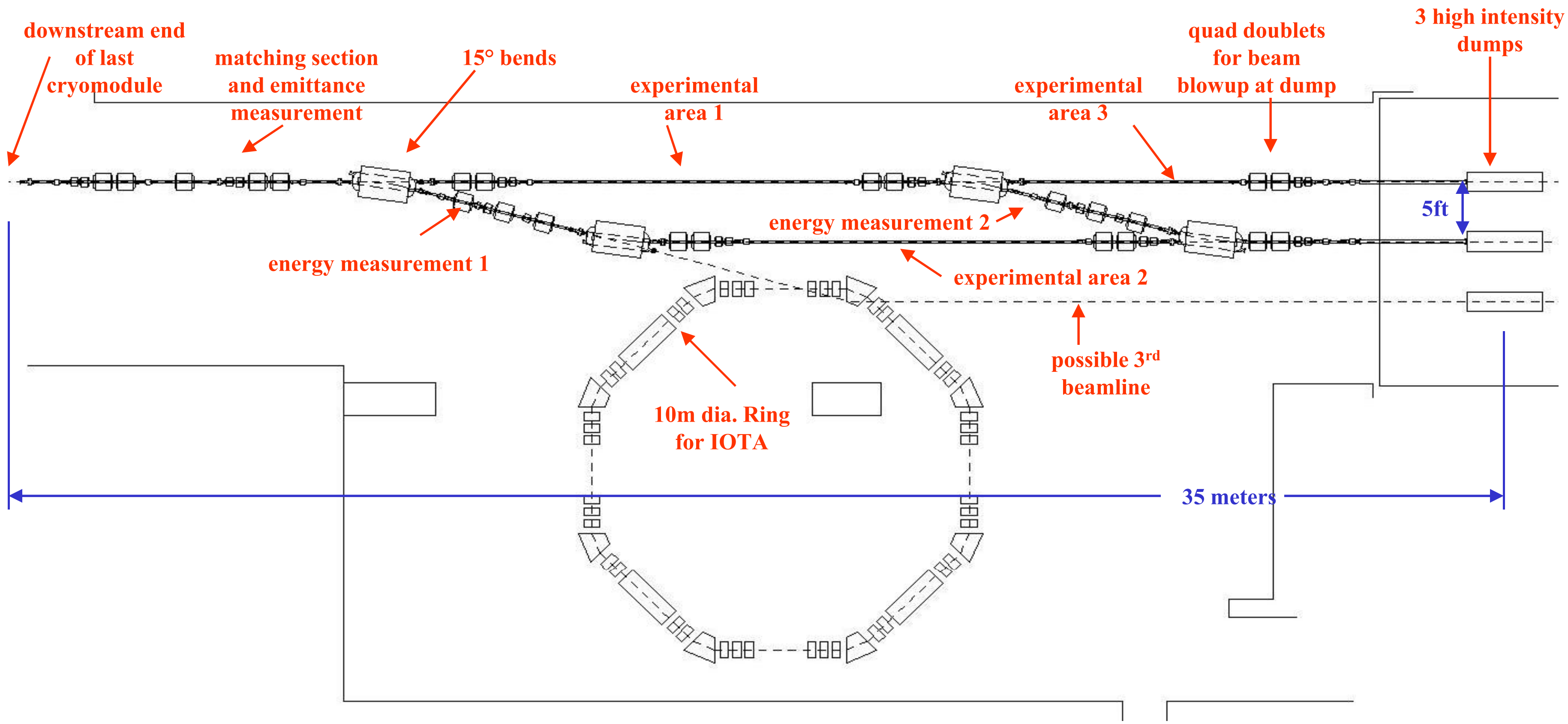
booster cavity 2, installed at NML

Cryomodules

- Cryomodule 1 is installed at NML – type “TTF III+” – contains 8 9-cell cavities
  - Klystron with 5 MW tube has been commissioned
  - Cavity is at 2° K, and all 8 cavities have been tested at high gradient: 16 – 28 MV/m
- Cryomodule 2 (type TTF III+) to be delivered to NML in late 2011
  - It will replace cryomodule 1, and is expected to have acceleration gradient of 32 MV/m (250 MeV total acceleration)
- Cryomodules 3 and 4 (type ILC IV) to be delivered to NML in 2013 - 2014

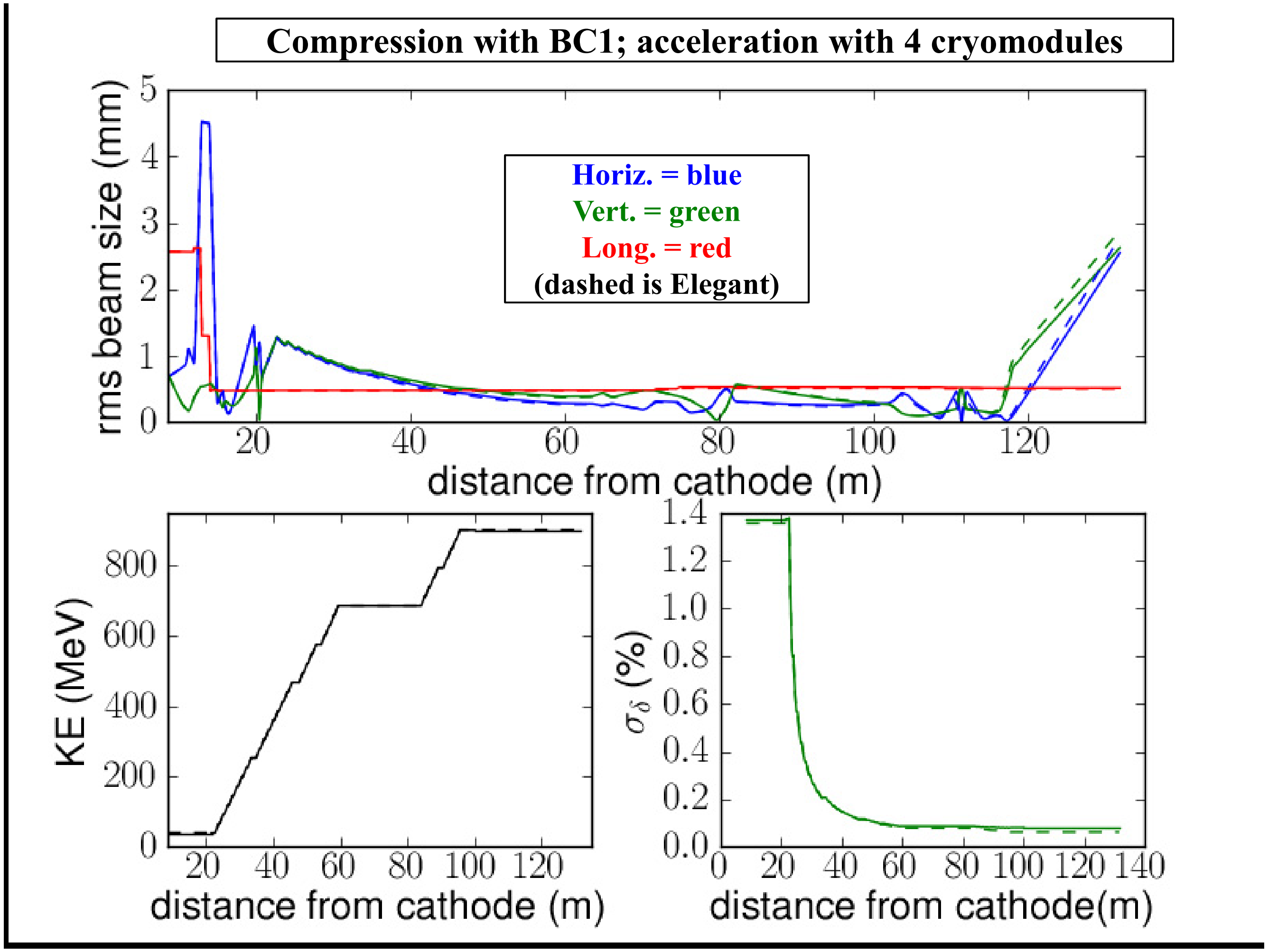
Cryomodule 1 in NML cave

Potential Downstream Beam Experimental Areas



- 3 experimental areas shown here: 8 meters, 8 meters, and 5 meters in length
- 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

Start-to-End Simulation with Impact-Z (single particle) (C. Prokop)



Simulation tools: ASTRA, Elegant, Impact-Z, CSRTrack

Beam Parameters

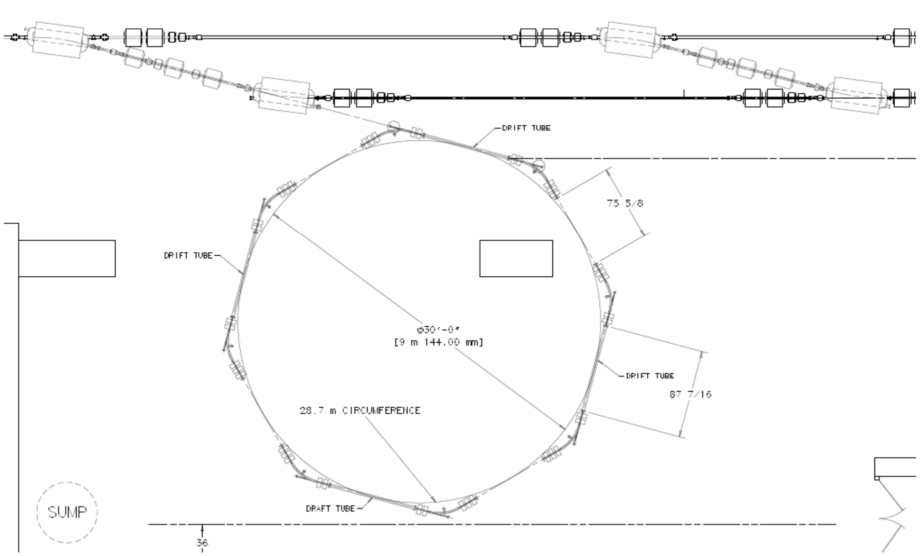
NML will be capable of operating with a wide range of beam parameters. As with all photoinjectors, many beam parameters are coupled, especially to the bunch intensity, due to space charge effects.

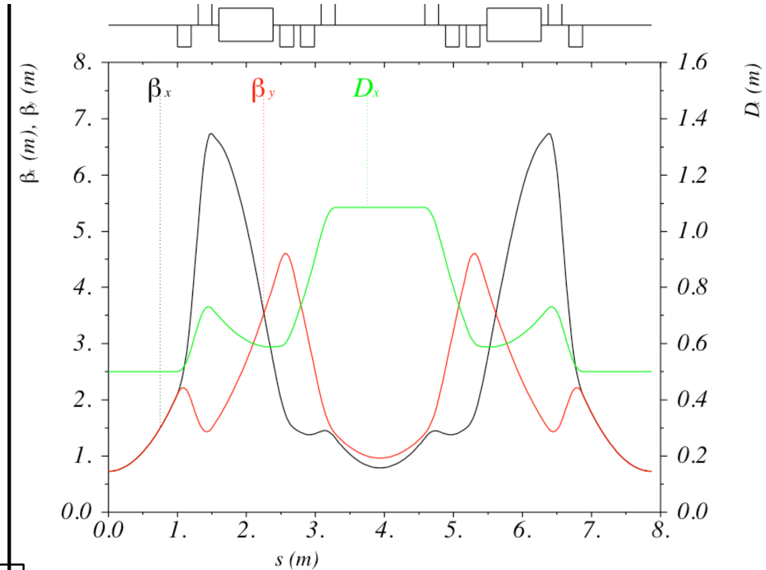
parameter	ILC RF unit test	range	comments
bunch charge	3.2 nC	10's of pC to >20 nC	minimum determined by diagnostics thresholds; maximum determined by cathode QE and laser power
bunch spacing	333 nsec	<10 nsec to 10 sec	lower laser power at minimum bunch spacing
bunch train length	1 msec	1 bunch to 1 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	<20 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	~10's of fs to ~10's of ps	minimum obtained with Ti:Sa laser; maximum obtained with laser pulse stacking
peak bunch current	4 kA	> 10 kA (?)	4 kA based on Impact-Z simulations with low energy 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	radiation shielding issues limit the maximum

Beam Experimental Proposals Solicited at 2 Workshops

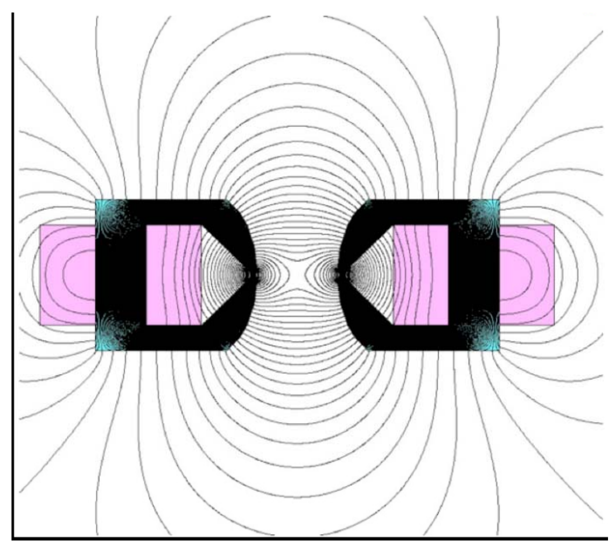
Experiment	Energy	proponent	Motivation/ application
Emittance exchange experiments	Low, high	FNAL/ANL	Proof-of-principle; applications to FELs and X-ray sources
Test of integrable beam optics	high	FNAL	Proof-of-principle; future high current proton machines
γ-ray enhancement by crystal channeling	Low	NIU/Vanderbilt/ FNAL	high intensity γ source; e^+ source
Microbunching investigations	low, high	ANL	Beam physics; diagnostics
ODR instrumentation development	high	ANL	Non-invasive emittance diagnostic
Microbunch generation	low	FNAL	For wakefield acceleration
Photoproduction of muons @ 300 MeV	high	FNAL	Homeland security; verify production model
Measure plasma wakes with long bunch trains	high	USC	Application to 2-beam plasma acceleration
6-D muon cooling	high	IIT	Proof-of-principle for muon collider
Optical stochastic cooling	high	IIT	Proof-of-principle; muon collider
High gradient wakefield acceleration with dielectric structures	Low, high	ANL/NIU	Beyond-next-generation accelerators

Integrable Optics Test Accelerator (A. Valishev, et al., PAC11)

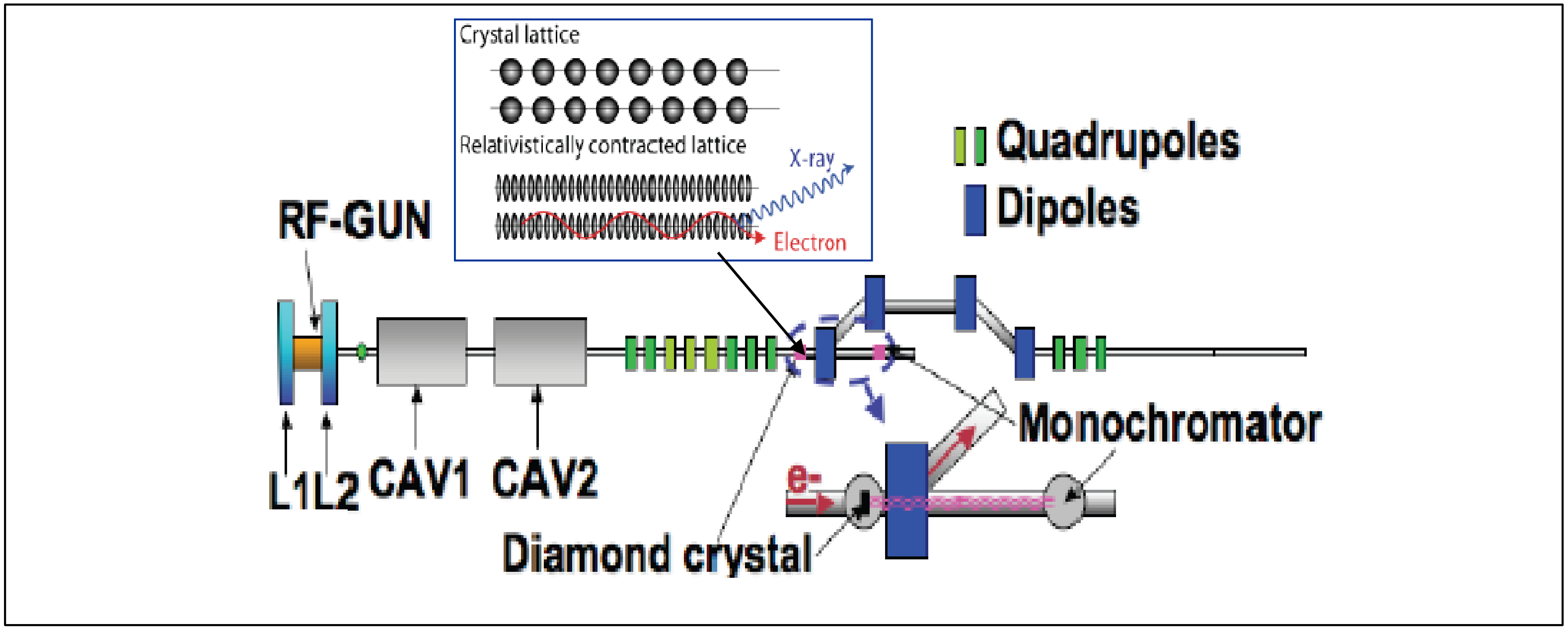




- **Recent theoretical calculations (Danilov, Nagaitsev, PRSTAB 13, 084002) indicate a solution using nonlinear focusing elements to produce a highly nonlinear lattice in a storage ring capable of supporting stable beam with tune spreads of ~50%. (Linear lattices typically have tune spreads of ~1%.) The large tune spread provides sufficient Landau damping to support stable super intense beams. Recent numerical simulations support these analytical calculations .**

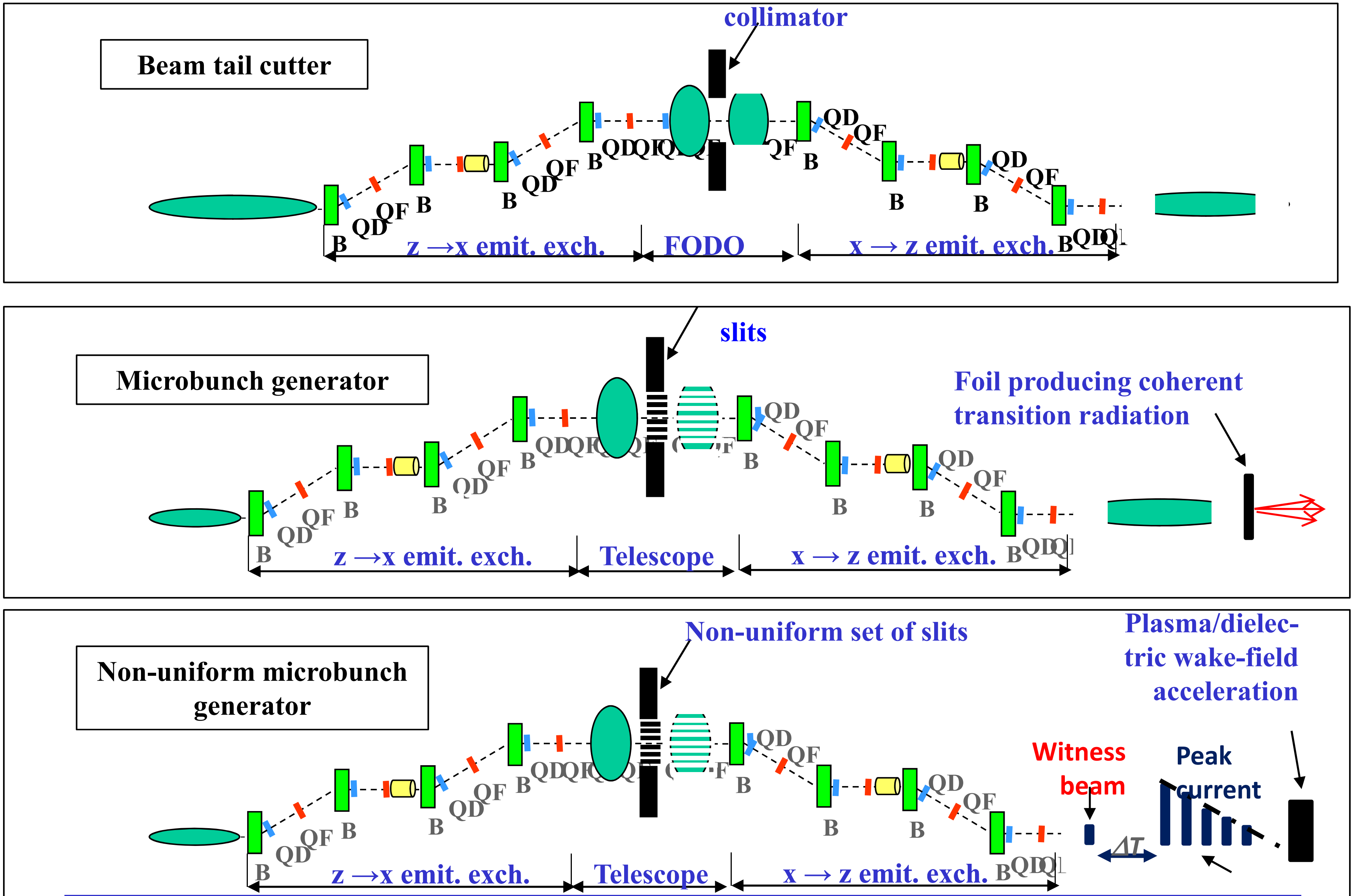


Production of High Intensity X-rays from Channeling (P. Piot, et al.)



- Experiment to be installed in the 40 MeV beamline
- Requires high intensity electron pulse
- NIU/Vanderbilt/FNAL collaboration
- Addresses a DOD challenge for high intensity x-ray beam
  - 10^{12} photons/sec/mm^2/mrad^2/0.1% BW

Double Emittance Exchange (A. Zholents, ANL DWA Workshop)



Future Plans

- **Start beam commissioning with a single cryomodule: late 2012**
- **Some beam experiments possible: 2013**
- **Cryomodules 3,4 delivered and installed at NML: 2013 - 2014**
- **Start ILC RF string test with 3 full cryomodules and new refrigeration plant: 2014**