Beam Test Facility at NML and Cryomodule Test Stand

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What is this talk about?

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Infrastructure	M&S		SWF		Total with Indirect	
Cavity Fabrication Infrastructure	$	3,000	$	675	$	4,380
Cavity Processing Facilities	$	11,100	$	4,590	$	18,945
Vertical Test Stand (VTS 2 & 3)	$	2,625	$	1,845	$	5,475
Horizontal Test Stand (HTS 2)	$	1,220	$	1,057	$	2,805
Cavity/Cryomodule Assembly Facilties (CAF_MP9 & ICB)	$	690	$	270	$	1,158
NML Facility (ILCTA_NML)	$	18,270	$	23,220	$	51,700
Cryogenics for Test Facilities	$	10,690	$	950	$	13,692
Cryomodule Test Stand	$	5,400	$	2,970	$	10,180
Material R&D	$	870	$	722	$	1,960
Illinois Accelerator Research Institute	$	20,000	$	4,050	$	28,605
Grand Total	**$**	**73,865**	**$**	**40,349**	**$**	**138,900**

Goals for SRF Infrastructure

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- To perfect U.S. fabrication & processing of SRF cavities and modules and to demonstrate performance with a full range of testing (including beam)
  - Deploy ILC design / processing / assembly techniques
  - Establish process controls to reliably achieve high gradient cavity operation and module performance
  - Test cavities and modules at the component level and in a systems test to demonstrate yield, reproducibility and beam performance
- To facilitate commercial production of SRF components and modules
  - Train and transfer SRF technology to the US industry
  - Allow industrial participation and input to the process
    - Similar to SC cable and magnet technology transfer
- To participate in SRF Research and Development
  - Develop expertise in SRF technology and provide training base for construction and operation of future accelerators
  - Our attempt to fit into the world's SRF community

All of this work will be carried out with US/international collaboration

Our overall strategic goal: bring the ILC to the Fermilab site

- **Need to create state-of-the-art SCRF technology base at Fermilab**
  - **Tight-loop cryomodule manufacturing and testing process**
- **Need to train personnel to be experts in linac construction, commissioning and operation**
  - **This can only be accomplished by "building" a large enough facility to create a critical mass of people on site**
- **Focus on international collaborations to conduct critical R&D and tests.**
- **Need to educate students who will be building and operating the ILC in the future.**

How does our plan address these goals ?

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- The facility we are proposing will be the primary facility in the world to build and test new ILC CM's for the near future.
- Several important changes to the Tesla CM design are being planned for the ILC CM. These include a higher gradient, relocation of the quad, shortening of the cavity end-group, and a new tuner design. Also under discussion are different modulators, klystrons, cavity shapes, and other things.
  - Need to test all critical components in realistic operating conditions, prior to design freeze. The "realistic conditions" to include the following four: rf power, mechanical, thermal cycles, and radiation.

ILC S2 recommendation

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- ILC S2 task force (string test) recommends: the minimum size system test needed to confirm the performance of a new design is a single RF unit with ILC like beam.
  - ILC RF unit is 3 CMs powered by a 10 MW MBK
- Many tests are statistical in nature, a longer string test with several RF units would be better.

Why beam tests?

- Cryomodule gradient calibration with beam energy spectrometer; there could easily be a 10% uncertainty in rf calibrations.
  - Need energy spectrometer upstream and downstream of CMs.
- Many tests can be done at the Horizontal Test Stand. What is missing:
  - Beam loading effects;
  - HOM excitations;
  - Cavity alignment;
  - Check static and dynamic heat loads
- Allows to train Fermilab personnel by "doing" it.
  - Needs to be intellectually stimulating
  - Exercises all support departments: controls, instrumentation, utilities, cryo, EE, RF, safety, operations, mechanical

Total Cost - NML Test Facility

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Expenditure Description	M&S	SWF	Total Including Indirect
NML Conventional Facilities	$ 720.00	$ 445.50	$ 1,422.32
NML Cryogenic System	$ 2,400.00	$ 3,334.50	$ 7,163.53
NML RF Power System	$ 2,900.00	$ 1,849.50	$ 5,800.98
NML Auxillary Systems	$ 530.00	$ 472.50	$ 1,236.33
NML Operations	$ 400.00	$ 1,080.00	$ 1,880.58
NML LLRF	$ 710.00	$ 3,294.00	$ 5,141.63
NML Controls	$ 940.00	$ 4,711.50	$ 7,266.22
NML Instrumentation	$ 1,510.00	$ 2,875.50	$ 5,525.48
NML Injector/Laser	$ 1,230.00	$ 1,323.00	$ 3,165.82
NML Accelerator	$ 250.00	$ 796.50	$ 1,334.51
NML Test Beamlines	$ 990.00	$ 999.00	$ 2,461.84
NML Support Equipment/Systems	$ 2,340.00	$ 1,431.00	$ 4,600.42
NML Building Extension	$ 3,350.00	$ 607.50	$ 4,698.45
Total NML Infrastructure	$ 18,270.00	$ 23,220.00	$ 51,698.11

- **Includes FY07 - FY09**
- **Assumes FY07 M&S funding of ~ $4M**
- **Cost given in FY07 dollars**
- **Does not include escalation or contingency**

NML cost drivers

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- Cryogenics (J. Theilacker's talk): $7.2M – The temporary 1.8K system is needed to start the program. A new cryo plant is needed by FY09.
- RF power (M. Champion's talk): $5.8M – Not included in our request is the SLAC contribution, which is essential for making the system test.
- LLRF and controls (B. Chase' talk): $12.4M -- Very labor-intensive. Switching to a new controls system.
- Instrumentation (M. Wendt's talk): $5.5M -- Substantial development effort required.
- Injector and test beam lines: $6.9M – Much already exists at A0, but a lot more is needed.
- Building extension ($4.7M) is needed to fit the system test.
- Support systems ($4.6M): safety, alignment, vacuum, cable pulls etc.

NML

- **NML is a facility to be located in the existing building at Fermilab (New Muon Lab)**
  - The New Muon Lab building is not large enough to accommodate 3 cryomodules and need to be extended by FY09
- **New Muon Lab building is part of Fermilab's ILC Test Areas (ILCTA_NM)**
  - Other areas are: MDB (horizontal SCRF cavity test stand), IB1 (vertical test stand) etc.
- **The first NML users will be the ILC program.**
  - The cryomodule tests are also essential to HINS (β=1)
  - The Accelerator R&D (AARD) portion will first piggy-back on these programs; its share will increase with time

Location

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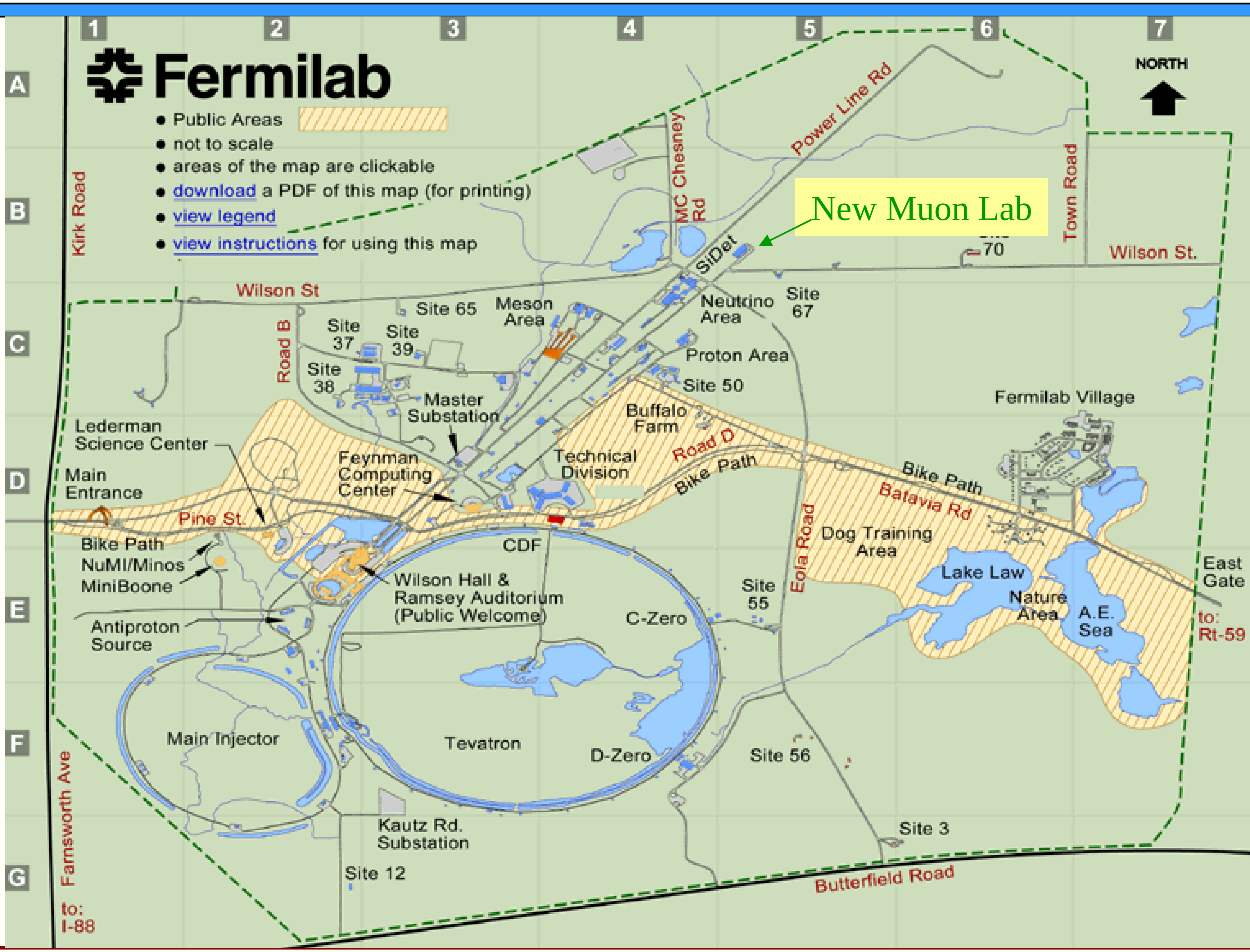

New Muon Lab building

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NML inside (before)

NML inside (now)

NML: north side

Outline of our plans

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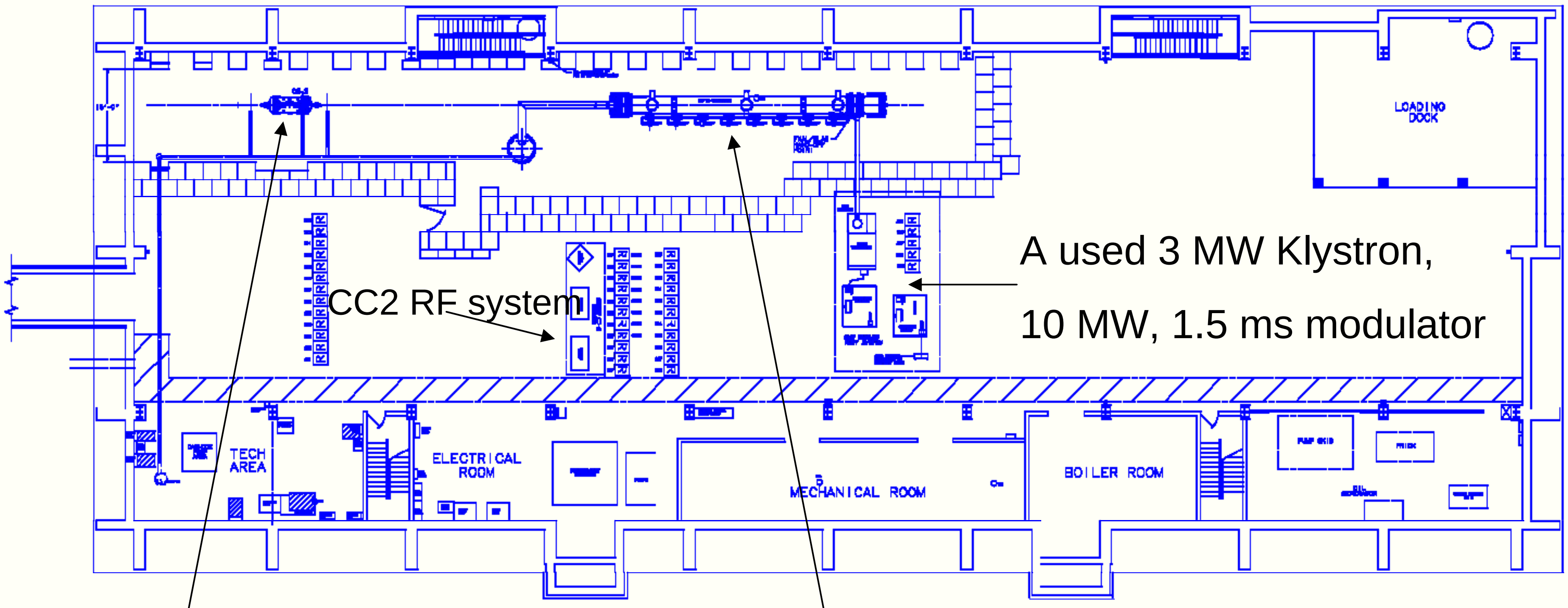
- Cryomodule delivery
  - 1st (Type 3+) cryomodule is planned to be delivered in fall, 2007
  - 2nd (Type 3+) CM – summer 2008
  - 3rd (ILC Type 4) CM – Mid FY09
  - Replace all three CMs with ILC Type 4+ in FY2010
- The NML facility will start as a Cryomodule Test Stand in FY07-08
- FY08: add beam; start civil construction of the building extension
- Convert to an ILC RF Unit beam test facility in FY10
- Construct a separate Cryomodule Test Stand (no beam) in FY10. Location TBD.

Stage 1: 1st CM (end of CY07)



CC2 RF system

A used 3 MW Klystron,

10 MW, 1.5 ms modulator

Capture cavity 2 in its final location for the injector

Type 3+ cryomodule

ILC-like beam?

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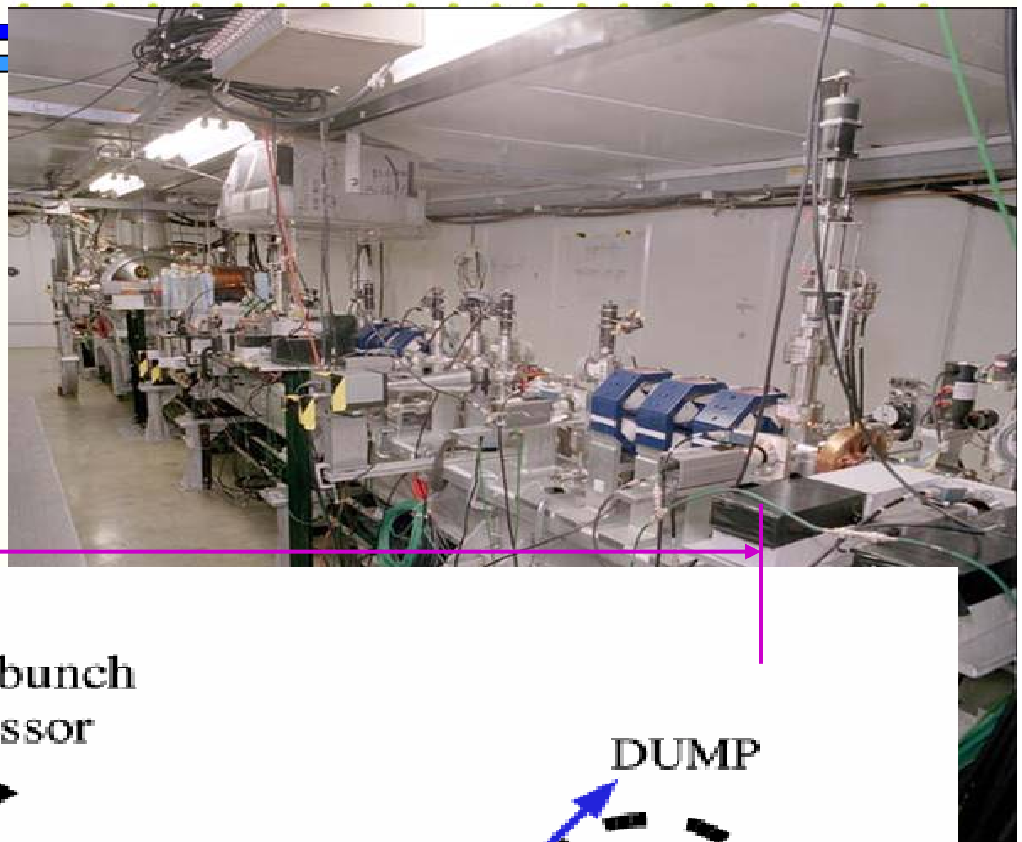
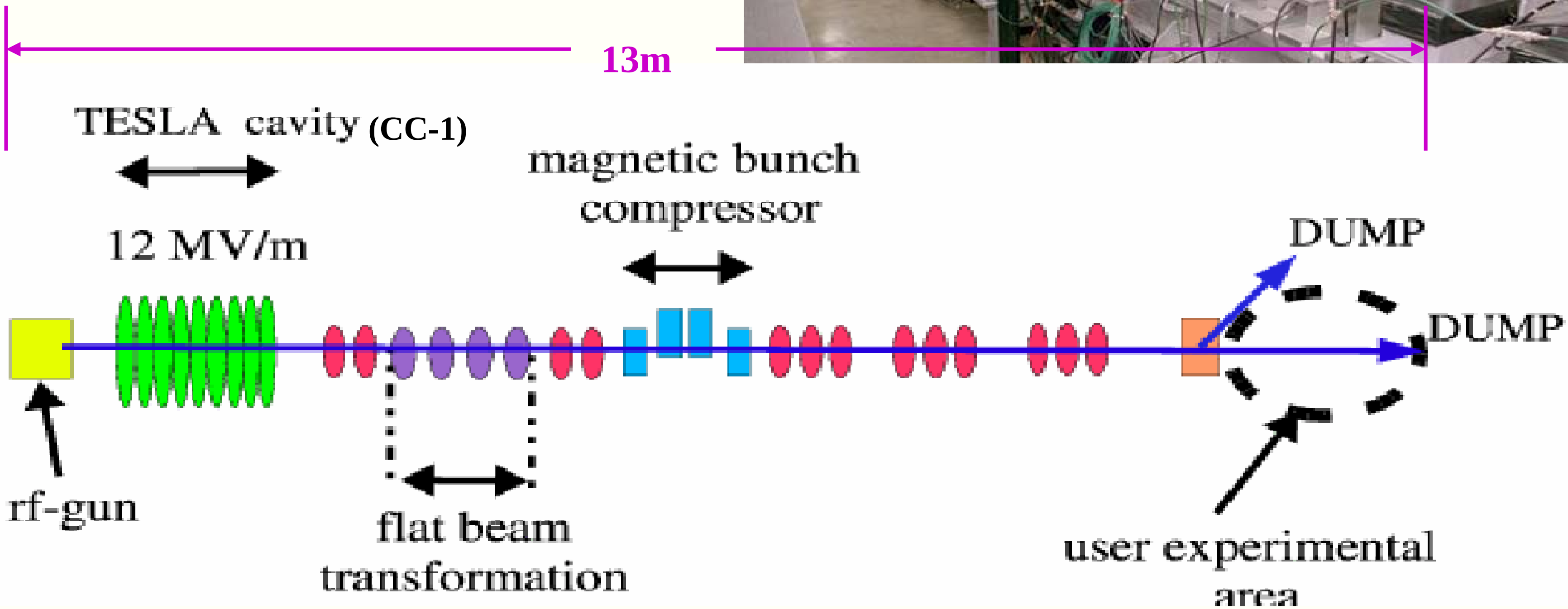
- 3.2 nC/bunch @3 MHz, up to 3000 bunches @ 5Hz
- Bunch length: 300-μm rms
- Transverse emittance: not important (~5 μm)
- Energy: 30-40 MeV (to avoid overfocusing in the CM operating at 31 MV/m)
- Need "known and frozen" beam parameters at the cryomodule entrance
- The AARD program requires more flexibility, mostly in terms of peak current.

Current Photoinjector Layout at A0





Proposed NML Injector Layout

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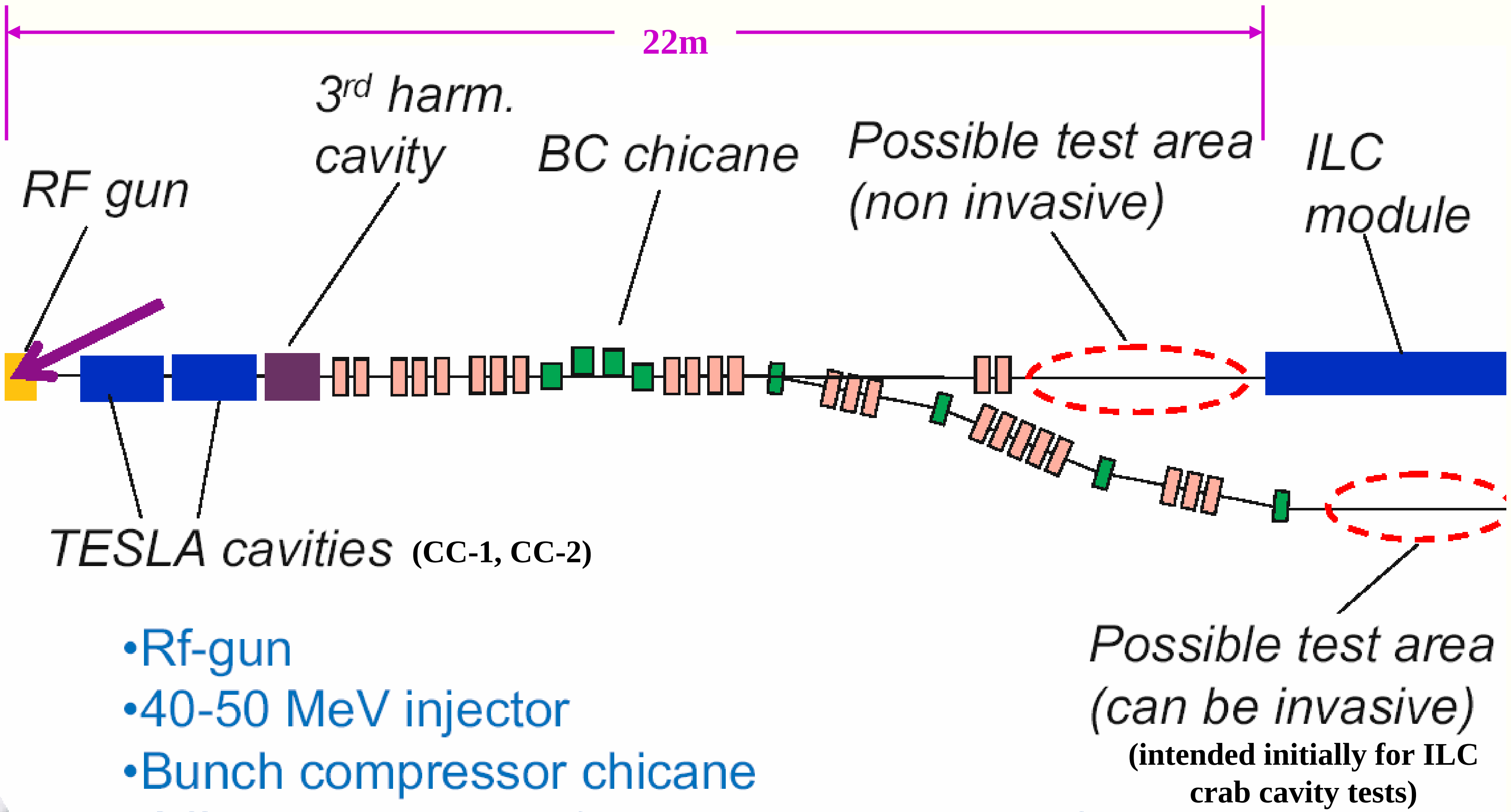

- Rf-gun
- 40-50 MeV injector
- Bunch compressor chicane
- Off-axis beam line (dogleg w tunable R56)

P. Piot

Photoinjector Upgrades for NML

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- **Laser** - no additional major upgrades for NML
- **Egun** – entirely new – similar to DESY(PITZ) egun design; capable of ILC beam parameters
- **Egun modulator** – upgrade: 1 Hz → 5 Hz; 300 msec → 1 msec
- **Beamline** – higher energy → decreased space-charge
- **3rd harmonic cavity** – shorter bunch length; higher peak current
- **Instrumentation** – upgrade
- **Off-axis beamline** – addition of a 4-dipole dogleg will provide an off-axis beamline for testing ILC crab cavities, emittance exchange experiment, and other tests
- **Better integrated controls system**

Other beamline elements needed

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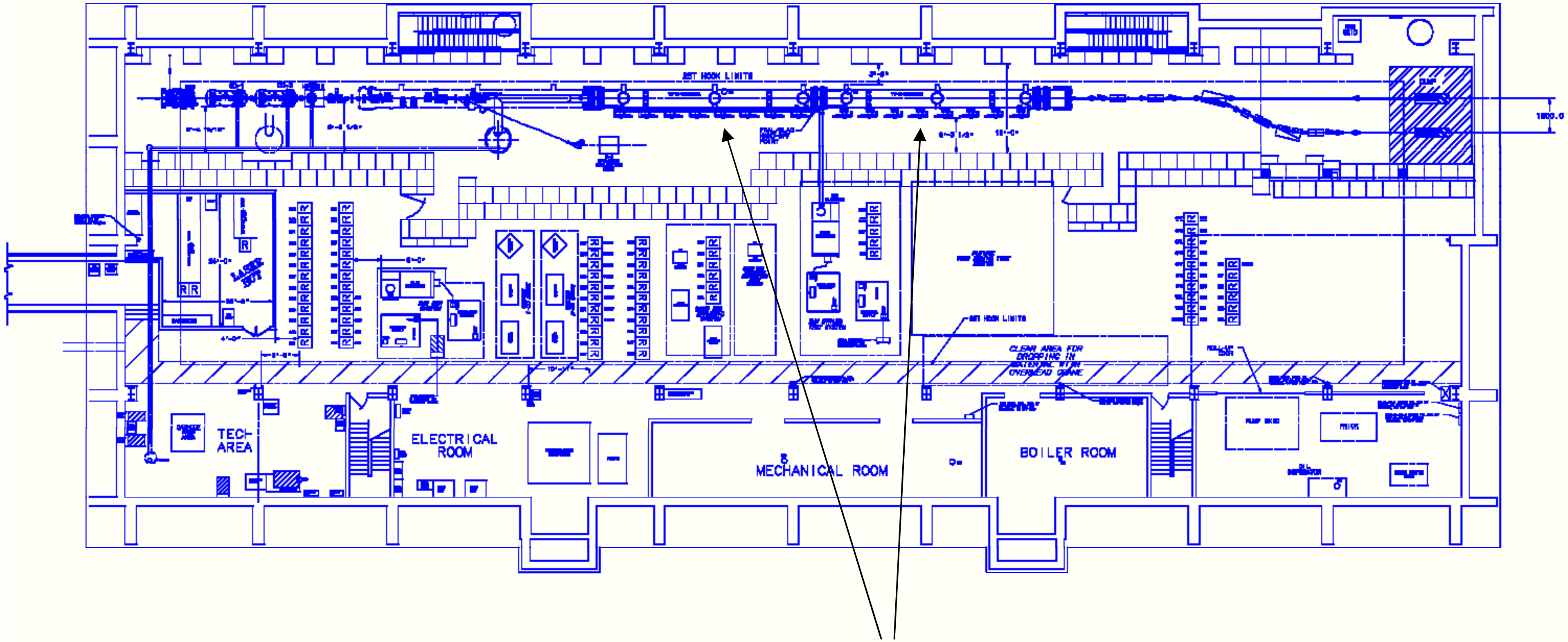
- High-energy beamline elements (downstream of CMs)
- A beam dump (50 kW at final stage)
- A spectrometer magnet(s)
- Cryomodule instrumentation (and other devices)
- New beam instrumentation
- Machine protection system

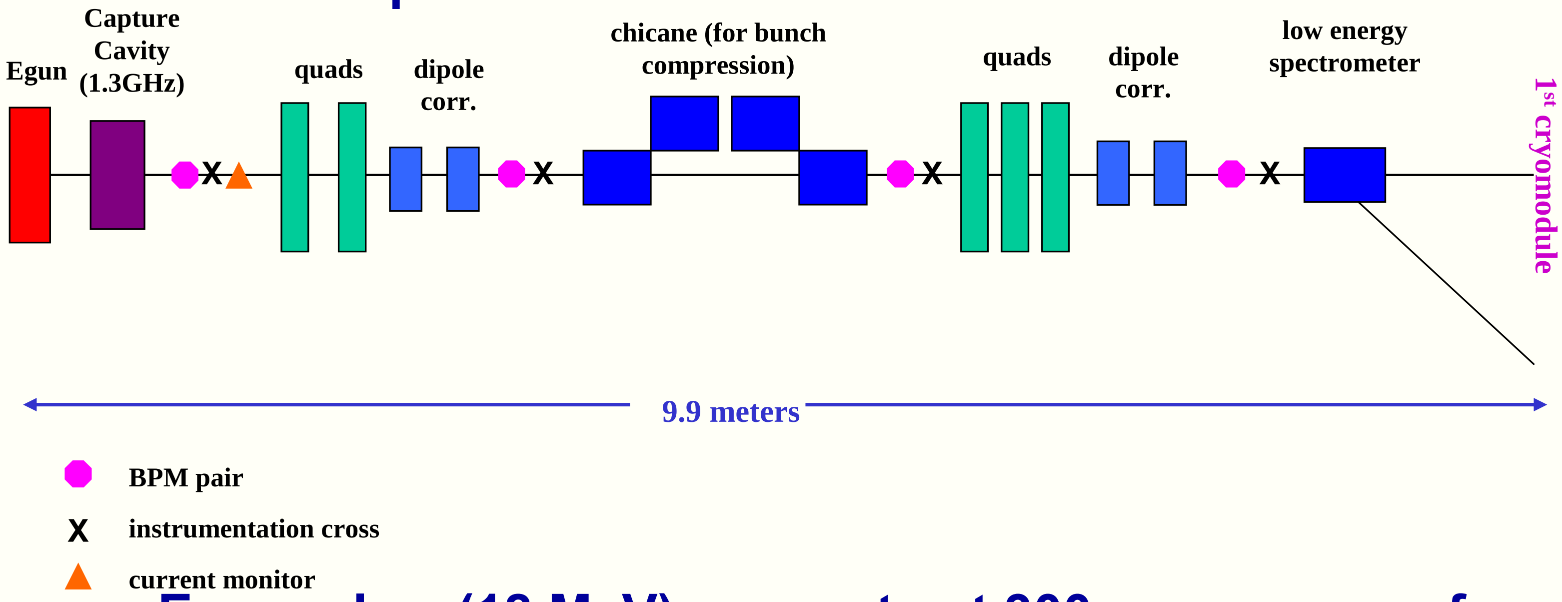
Two CMs with beam



The existing building is perfect for testing two cryomodules with ILC-like beam. The building can be extended to fit 3 cryomodules.

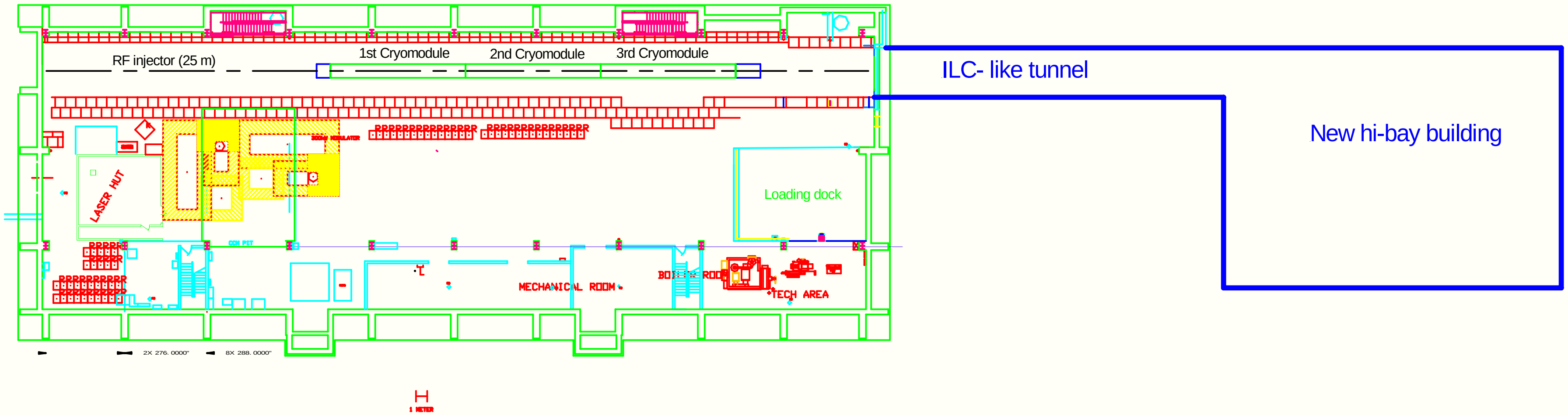
Can we fit 3 CMs?

- **With 3 CMs, the space available for the injector is ≤ 10 m.**
  - **Possible, but injector is compromised;**
  - **Many ILC studies impossible;**
  - **AARD impossible.**



  - **Energy low (18 MeV), can not get 300-um, no room for instrumentation**

Building extension



- Construct a new building ~50m away from NML. Connect by a tunnel when schedule allows. Move loading dock.
- ILC-like tunnel, space for 3 more cryomodules
- Room for a new cryoplant (see Jay's talk)

New Cryo Plant

- **Temporary cryo system (being installed now):**

NML Stage		# of Tev Satellite refrigerators	
		1	**2**
1	PI + Single ILC Cryomodule	1 Hz	5 Hz
2	PI + Two ILC Cryomodules	n/a	5 Hz
3	PI + Single ILC RF Unit	n/a	< 2 Hz

- **New Cryo plant**
  - Must be flexible to allow a wide range of heat loads, including 5-Hz operation
  - Must meet specifics of the ILC operating temperature levels of 2.0 K, 5 K, and 40-80 K
  - Long lead time
- **Requires a 15m x 25m building; the plan is to combine it with the NML extension.**
- **Engineering studies complete, have a quotation.**
  - See Jay's talk

ILC plans at NML

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1. Demonstrate stable long-term high-gradient beam operation at ILC-like bunch parameters.
2. While operating at high gradient and ILC-like beam currents, demonstrate a LLRF controls system such that the beam energy and beam phase stability meet the ILC specs.
3. Evaluate effects of cavity gradient spreads, dark current, cryogenic load, radiation levels with beam operation.
4. Measure beam kicks due to couplers, cavity tilt, quad rotations + tilt errors characterize focusing properties of SCRF cavities.
5. Measure vibrations of cavities and quads.
6. Test beam diagnostics.
7. Test ILC crab cavities.
8. Test the ILC installation procedure and tunnel layout.
9. May evolve into a near-final system integration test.

A facility to test ILC baseline and alternative designs

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- **Many groups in the US and world-wide are looking for a place to test their ILC-related designs.**
  - **Need beam at 200-800 MeV, need space to set up tests**
- **Baseline design:**
  - **“Keep alive” positron source (ANL)**
  - **SC undulator (Cornell)**
  - **Crab-cavity (SLAC, Cockcroft Inst)**
- **Alternative designs:**
  - **New HOM coupler design (MIT)**

AARD plans

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- The existence of the NML facility provides the opportunity to conduct an AARD program
  - Had a workshop in Nov 2006
- Fermilab wants to establish an AARD program at NML.
  - In this proposal, we are not asking to fund the AARD program at NML.
- Flexible beam injector needed to support various beam parameters (emittance, bunch charge, bunch length)
- Unique beam parameters anticipated:
  - Record high peak current of 14kA possible
  - ~30 um beam spot size (FWHM)
  - Beam energy up to 800 MeV
  - Structure: 3000 bunches or a witness bunch 300 um behind

AARD plans

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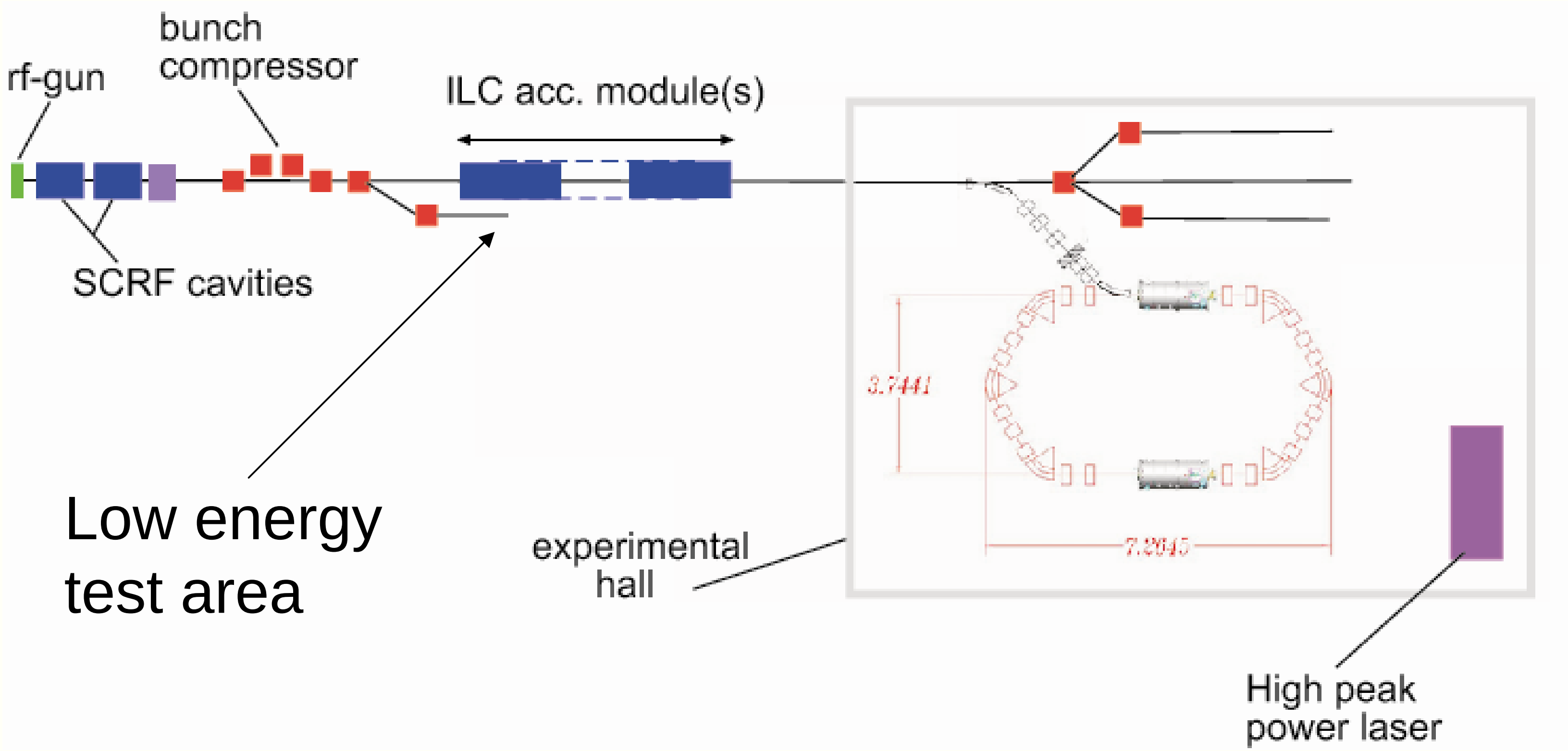
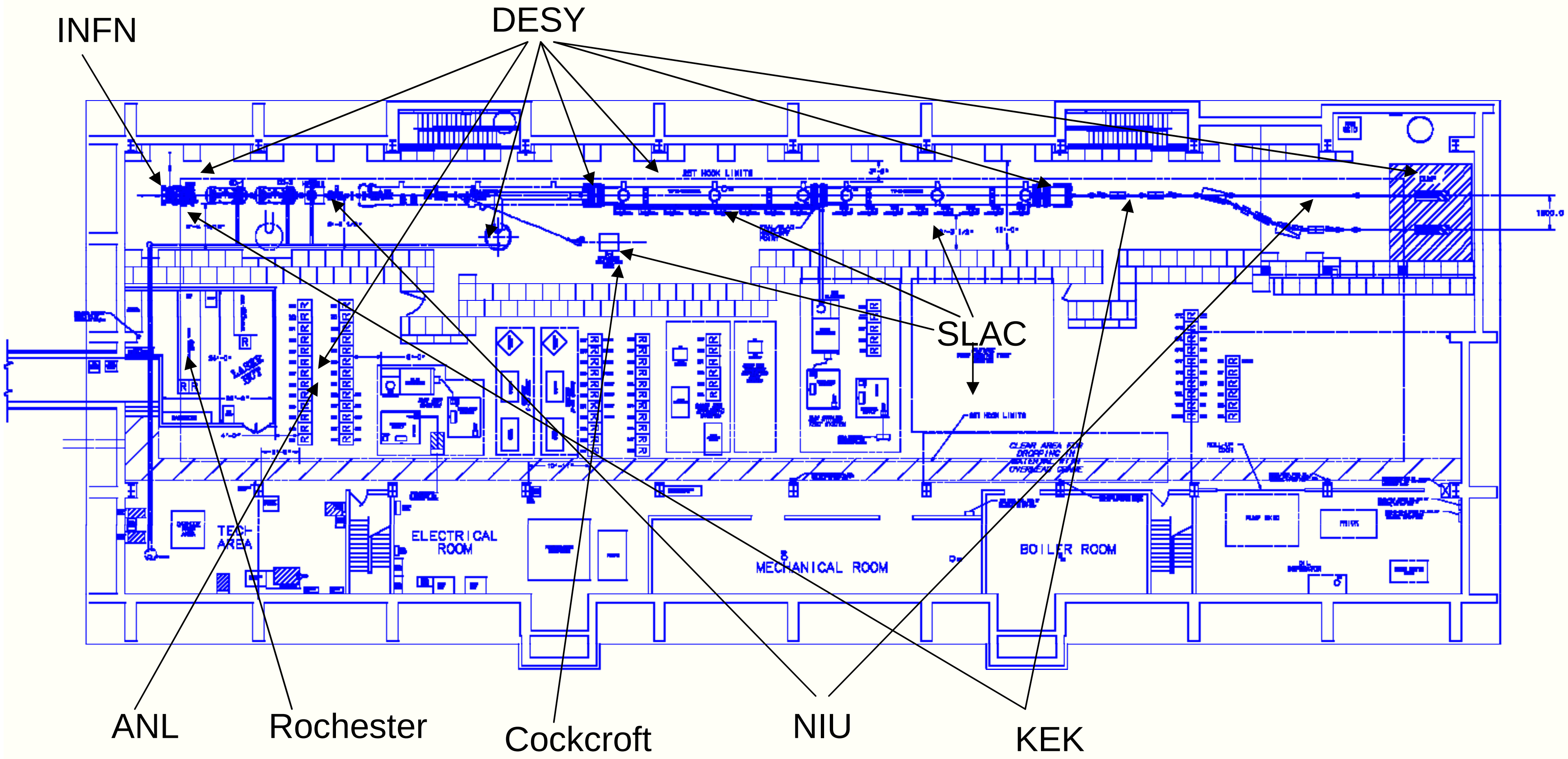
- **Number of AARD experiments possible in NML itself:**
  - **one at low energy (50MeV), one-two at full energy (space!)**
- **Building extension needed to provide area for 4-7 more**



Collaborations



NML collaborations

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- SLAC: RF power dist system, 10 MW Klystron; crab cavities;
- DESY: too many topics to list;
- KEK: rf gun, diagnostics;
- ANL: controls, AARD;
- INFN: photo cathode;
- Rochester: laser;
- NIU: AARD, injector;
- Cockcroft Inst.: crab cavities

Cryomodule Test Stand

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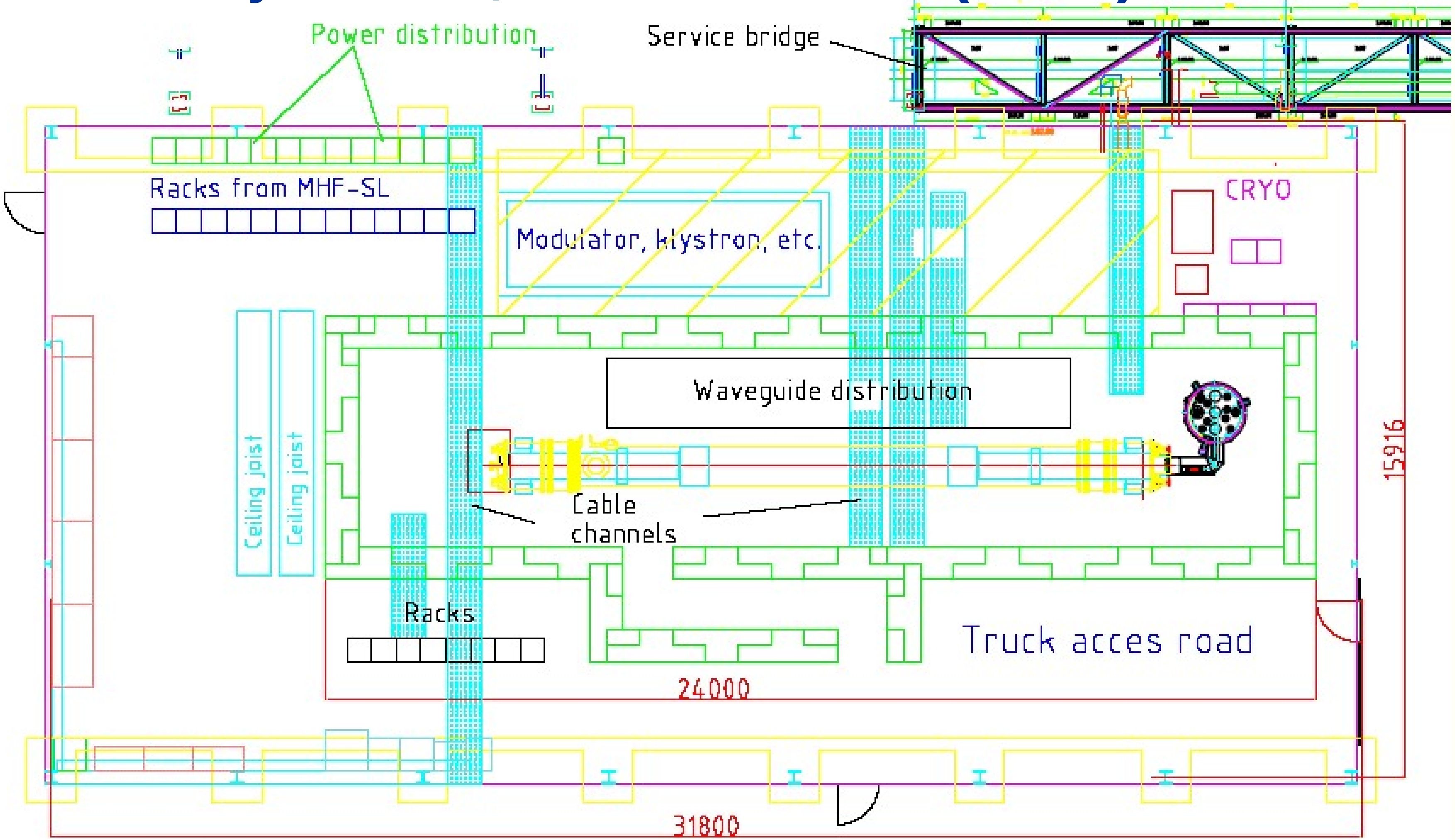
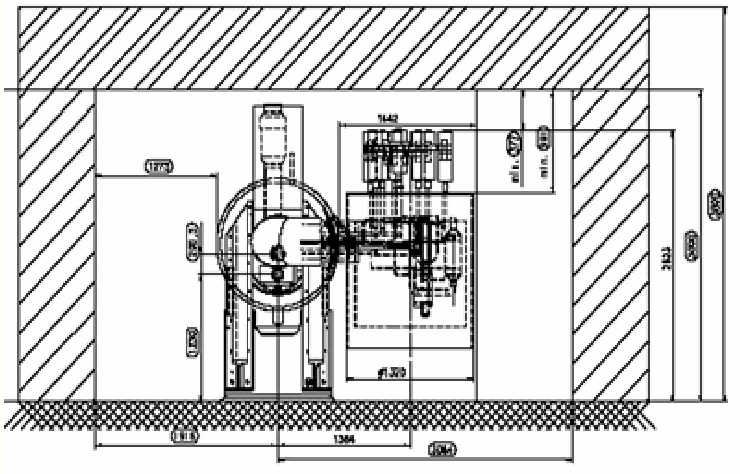
- We know we will need it eventually. …Need by FY2010-11
- Location yet undetermined
- A 500 sq meters, 32m x 16m, building required. Includes some utility and access space
- Much larger than a typical Fermilab magnet test stand due to the shielding cave
- Comparable in scope to Stage-1 of NML
- Motivations for cryomodule tests
  - Mechanical checks
  - Alignment of tubes, flanges, etc.
  - Leak checks of all volumes
  - Conditioning of main RF-couplers
  - Cryo load measurement, Q and Eacc
  - SC magnet power test
  - Dark current measurements

XFEL Module R&D Test Stand

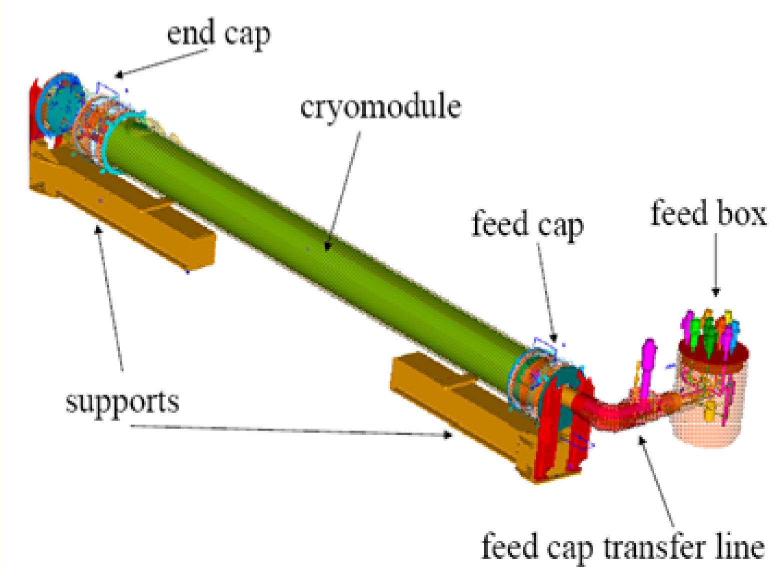
From Yury Bozkho, Bernd Petersen (DESY)



Module Test Stand (Lutz Lilje, DESY)



- Allows cryogenic tests and RF measurements independent from the LINAC
  - No beam tests
  - Dark current measurements



Summary

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- **Fermilab plans to create the NML facility to test the ILC RF unit (3 CMs) with beam at ILC-like parameters by FY10.**
  - Planning and engineering designs underway
  - Building extension and new cryo plant are needed to meet demands of users (ILC, AARD).
- **Plans to use the NML for accelerator research and training; develop partnerships with NIU and other local universities. Collaborations with SLAC, KEK, DESY and ANL.**
  - Building extension required to make it a users facility with competitive and flexible beam parameters.
- **Plan to construct a new Cryomodule Test Stand by FY10-11.**