ILC Cavity and Cryomodule Development Plan

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Outline

- Strategic Plan and SRF Goals
- Needed Infrastructure
- FY06-08 Technical Accomplishments
- FY08 Omnibus
- FY09 and 5 yr SRF plan
  - Technical elements of the plan
  - Time line
- Conclusion

HEP Strategic Plan

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- The HEPAP and FNAL long range plans envision that FNAL remains the US center for accelerator-based High Energy Physics (P5 report soon)
- The major Program Elements are
  - Energy Frontier Physics
  - Neutrino Physics
- ILC is the primary long term Energy Frontier goal
  - in parallel with a strong participation in LHC
- The next priority is a world-leading neutrino program
  - New multi MW SRF linac based proton source is a key
- Plans for both the energy frontier (ILC) and the intensity frontier revolve around SRF based linacs
- To be a viable host for ILC or Project X FNAL must have SRF expertise and infrastructure

Key SRF R&D Goals

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- To perfect U.S. fabrication & processing of SRF cavities and cryomodules and to demonstrate performance
  - Establish process controls to reliably achieve high cavity gradient
  - Develop ILC/Project X Cryomodule design & assembly techniques
  - Test cavities and cryomodules at the component level
  - Systems test of RF an RF unit (basic building block of ILC or PX)
  - Project X: Develop the infrastructure to produce 1 CM/month by 2013
- Develop lab base to transfer SRF technology to US industry
  - To facilitate commercial production of SRF components
  - To reduce construction costs for SRF based linacs
- To participate in SRF Research and Development
  - To prepare FNAL as a viable host site for the ILC or Project X
  - Carry out this work within national and international collaborations to develop the relationships needed for either ILC or Project X

The Scope of SRF Facilities Required

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- Cryomodules are a major cost driver of ILC/Project X
- The best cavity fabrication & surface processing can yield outstanding cavity performance (> 40 MV/m Eacc)
  - But the process yield is low for 9 cell cavities (cost !!!)
  - Evidence points to one or more uncontrolled variables
  - Improving the yield is a major goal of ILC R&D (S0 Goal)
  - Yield depends on the design of infrastructure !
  - Cavity performance often degrades when cavities assembled into cryomodules ➔ need to improve how we do this
- Need adequate lab infrastructure to:
  - Process, and test bare cavities to track down variability
  - Dress and test cavities
  - Build & test Cryomodules
  - Build and test complete RF units
- Typical lead times for this infrastructure is ~ 2 yrs

Cavity/CM process and Testing

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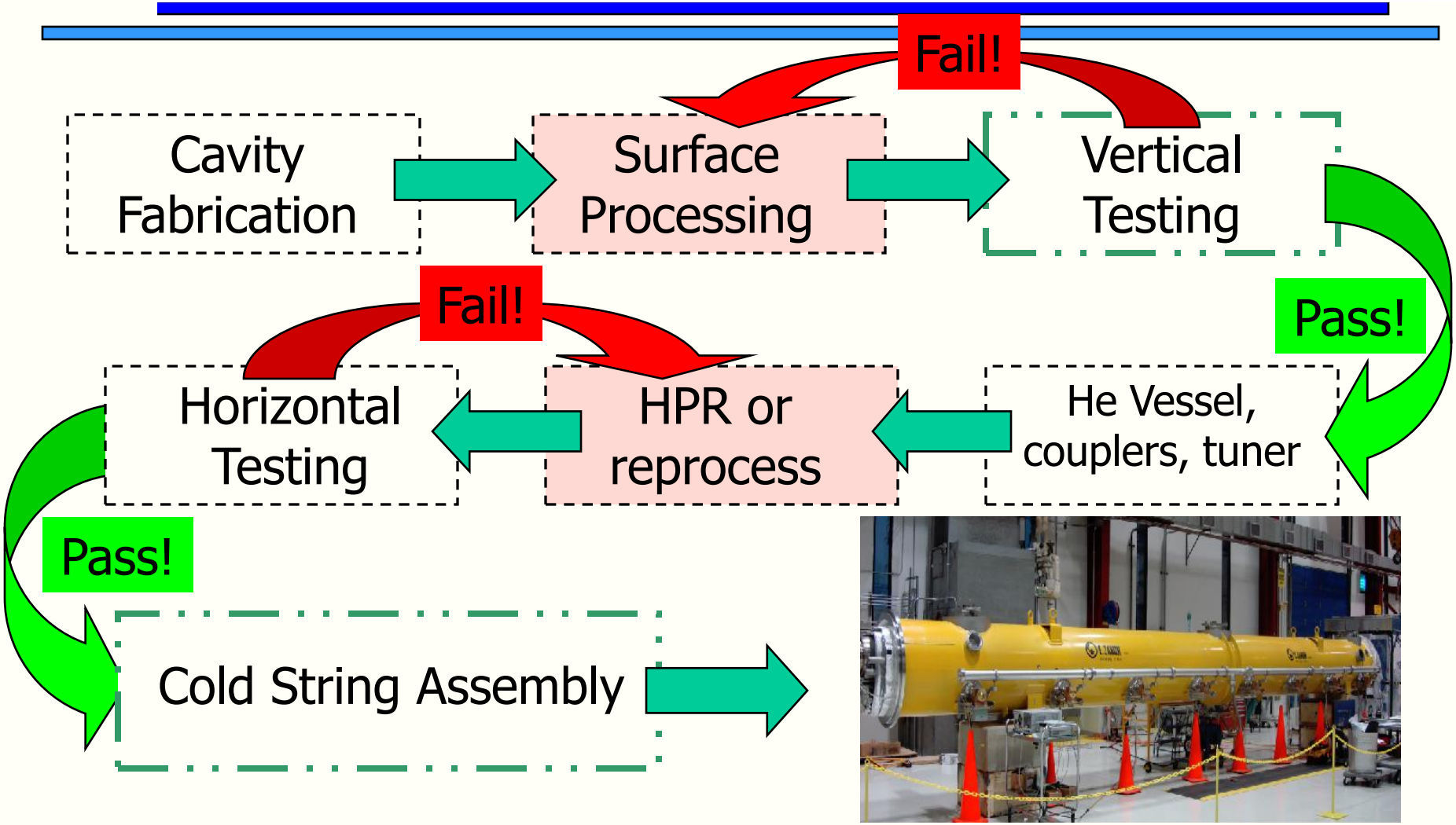

Plan… Develop in labs then transfer technology to industry

SCRF Infrastructure

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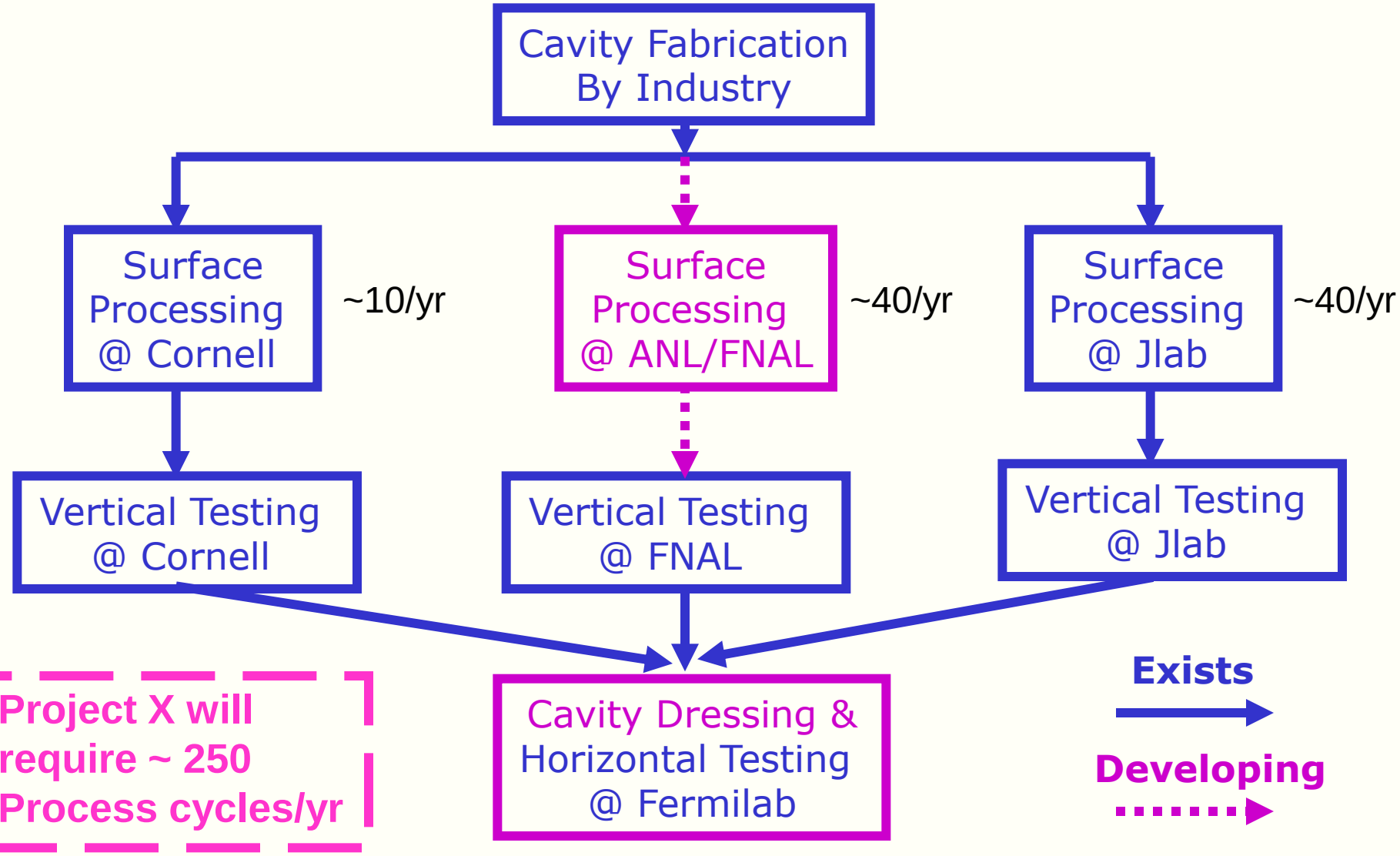
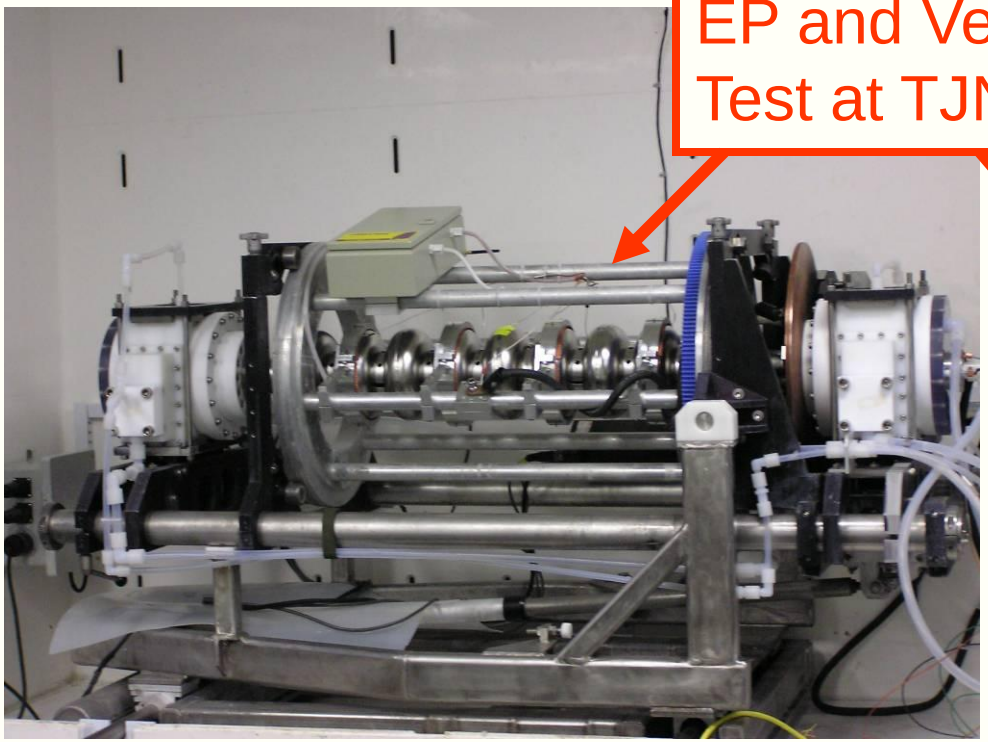
- **This process requires extensive infrastructure**
- **Bare cavities**
  - Fabrication facilities (Industry: Electron beam welder, QC, etc)
  - Surface treatment facilities BCP & Electro-polish facilities (EP)
  - Ultra clean H_20 & High Pressure Rinse systems
  - Vertical Test facilities (Cryogenics + low power RF)
- **Cavity Dressing Facilities (cryostat, tuner, coupler)**
  - Class 100 clean room
  - Horizontal cavity & Coupler test facilities (RF pulsed power)
- **String Assembly Facilities**
  - Large class 10/100 clean rooms, Large fixtures
- **Cryo-module test facilities**
  - Cryogenics, pulsed RF power, LLRF, controls, shielding, etc.
  - Beam tests ➔ electron source (RF unit test facility at NML)

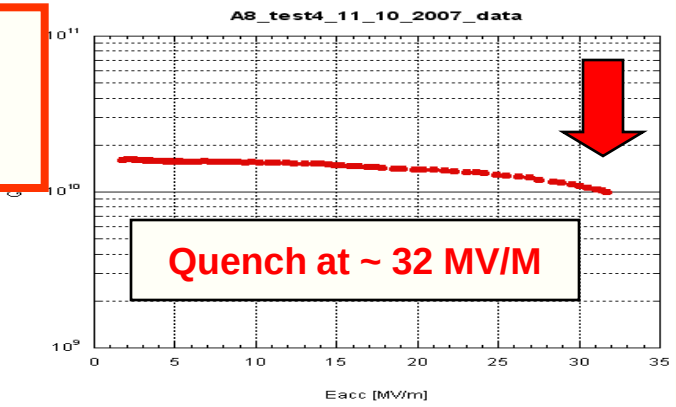
U.S. Cavity Processing & Test

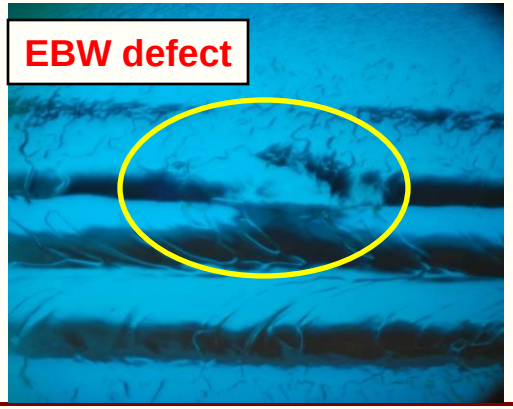


EP and Vertical Test @ Jlab

- FNAL collaborates closely with Jlab on cavity processing
- Jlab modified existing infrastructure for Electropolish, High Pressure Rinse, and Vertical Test of ILC cavities
  - Capable of > 40 process and test cycles/yr
  - Completed 32 in FY07, learning a lot about what limits cavities







EP & Vertical Test: Cornell

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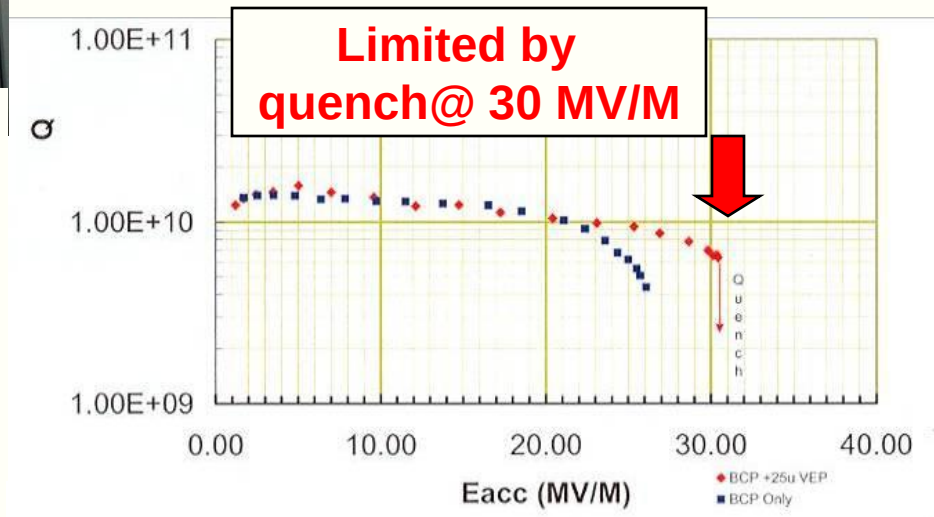
Vertical EP Infrastructure

HPR (High Pressure Rinse)

Vertical test

ACCEL cavity EP Processed & tested at Cornell



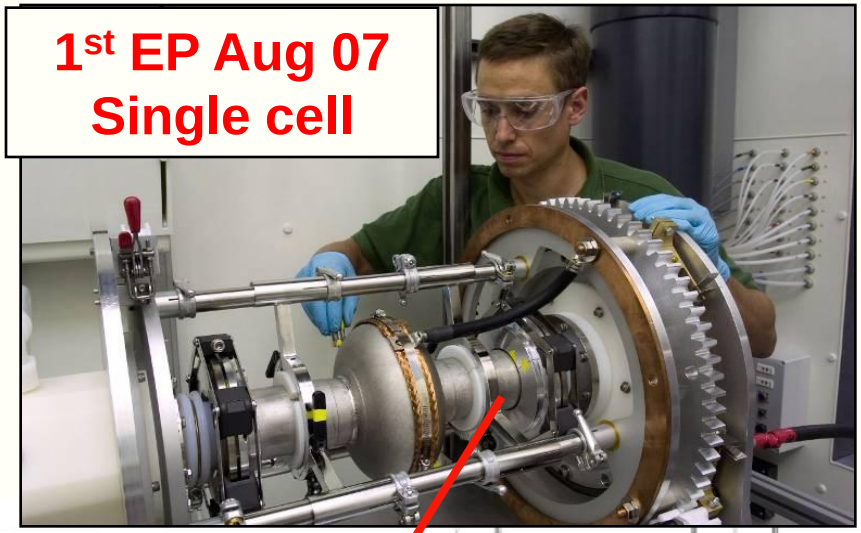
- New vertical EP R&D infrastructure
- HPR & Vertical Test of ILC cavities
- 3 ACCEL cavities processed # 5, 8, 9
- 8 process and test cycles in FY07
- Gradients achieved 24-30 MV/M
- Limited by quench

New ANL-FNAL Processing Facility

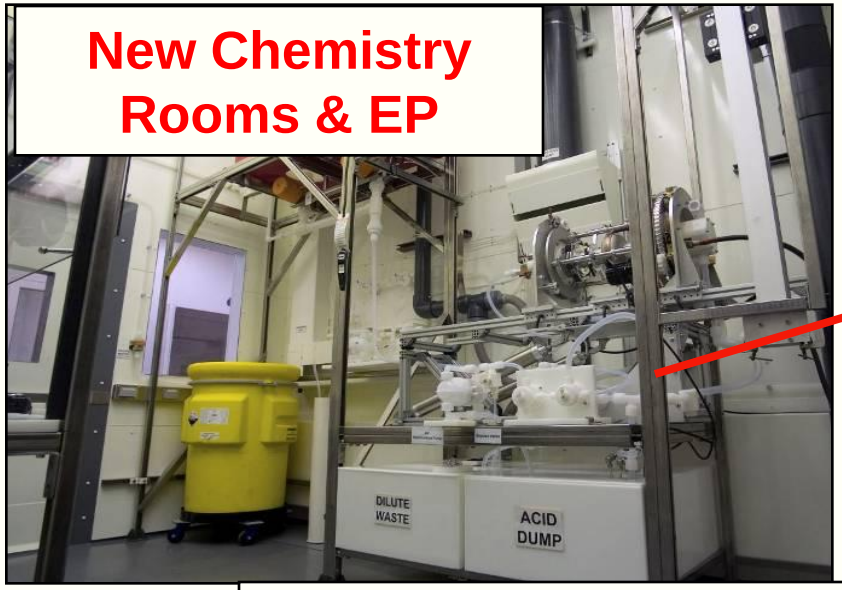
Chemistry, Clean rooms, BCP,HPR & state-of-the-art EP @ANL

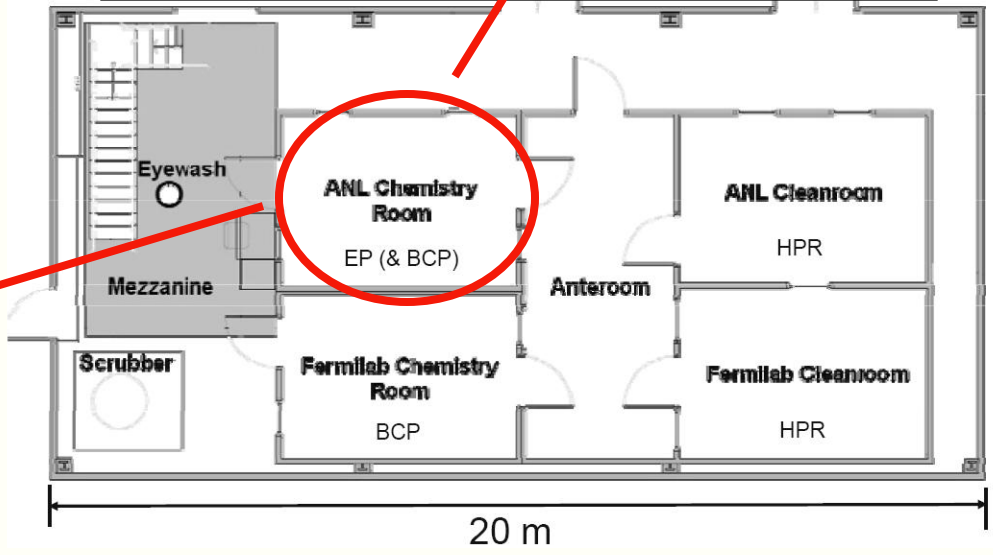
New Clean Rooms

1st EP Aug 07 Single cell



New Chemistry Rooms & EP

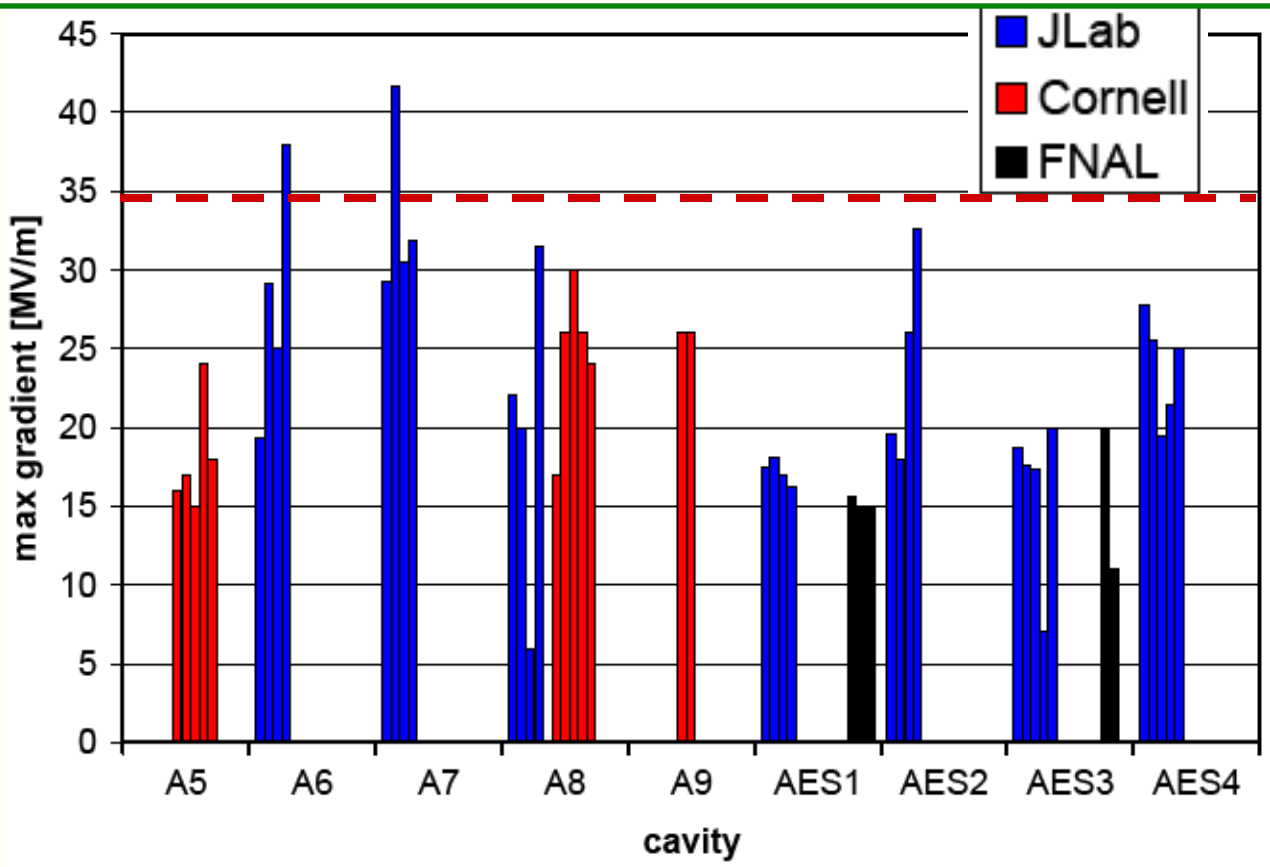




1st single cell in Dec, 9 cell in Jun 08 ~ 40 EP cycles/yr

9-cell Test Results

- >45 tests at JLab, Cornell and Fermilab
- Highest gradient in a test was 42 MV/m - A7, 2nd test of 4
- Progress on FE, more often Quench is the limit
- Significant variability remains, sources unknown



ILC Goal

FY06-08 Accomplishments

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- **ILC Design:**
  - FNAL made a large contribution to ILC RDR machine design and cost estimate
- **DESY 3.9 GHz Collaboration**
  - Fabricated, processed, & tested first 3.9 GHz cavities
  - Successful HTS test of dressed cavity
  - Cryomodule design, fab parts, construction in progress
- **Capture Cavity II**
  - Installed DESY supplied cavity in cryostat for NML
  - Extensive modifications the MDB cryogenic system were completed and demonstrated 1.8 K operations
  - 300 KW klystron, LLRF, etc installed/commissioned
  - Successfully operated the cavity at 31.5 MV/M

FY06-08 Accomplishments

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- **Cavities:**
  - **Purchased & received 18 ILC cavities**
    - 4 ACCEL, Europe
    - 4 AES, U.S
    - 2 TJNL
    - 8 ACCEL (recent)
  - **18 additional cavities are on order**
    - 12 ACCEL
    - 6 AES
  - **Using experienced European cavity vendor as a bench mark**
  - **36 cavities total ordered… 18 in our hands…**

  - **Before FY08 Omnibus:**
    - Ordered single cells from AES/Roark/Niowave
    - Working to develop new U.S. cavity vendors

FY06-08 Accomplishments

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Cavity Processing:

- **Cornell: in collaboration**
  - Developed vertical EP system; FNAL personnel @ Cornell
  - 10 process and vertical test cycles in FY07 (29 MV/M)
  - 5 single cells processed and tested
- **TJNL:**
  - Upgraded TJNL facilities to EP process and test TESLA cavities; FNAL personnel @ TJNL
  - 32 process and test cycles (40 MV/ M)
- **ANL:**
  - Collaboration to process 3.9 GHz cavities.
  - Completed a joint EP/BCP processing facility @ ANL
  - Collaborative design of EP system for 1.3 GHz cavities @ANL
  - New EP facility being commissioned when omnibus passed
- **Strong collaborations with experienced SRF institutions**

SRF Collaborations

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- Our plan is built to leverage existing SRF assets at other labs and universities (18 MOU's)

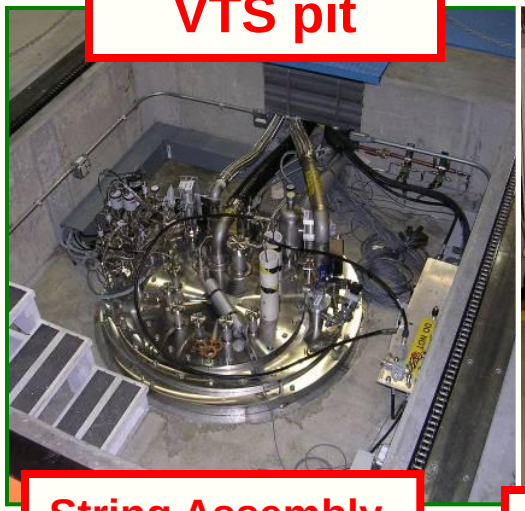
- ANL: EP development and cavity processing
- Cornell: Cavity processing & test, materials R&D
- DESY: 3.9 GHz, cryomodule kit, TTF
- KEK: Cavity R&D, ATF II
- MSU: HPR, Cavity vendor development and cost
- TJNL: EP cavity processing and test
- INFN: tuners, HTS, NML gun cathodes
- Penn/Triumf: cavity development and tuners
- SLAC: RF power, klystrons, couplers
- CERN, DESY, KEK, INFN, etc: Type IV CM design
- India: CM design, couplers, cavities, etc
- NW,UW/NHMFL, Cornell, DESY, KEK: Materials etc…

FY06-08 Accomplishments

Completed key elements of SRF infrastructure !

- Vertical Test System (1st of 3 planned for IB1)
  - Tests bare 1.3 GHz cavities
  - Operational Summer 07
- Horizontal Test System (MDB)
  - Operational Summer 07
  - Being used for tests for 3.9 GHz cryomodule in FY08
- Cryomodule Assembly Facility (MP9 and ICB)
  - Clean room procured and installed
  - Extensive fixtures designed and installed
  - Used facility to assemble 1st U.S. built ILC cryomodule from DESY kit of parts in Fall 07

VTS pit



VTS RF & Control

HTS

String Assembly

MP9 Clean Room

VTS

Final Assembly

1st U.S. built ILC/PX Cryomodule

NML Facility

FY06-08 Accomplishments

RF unit test facility

- A facility to test an RF unit, the basic building block of either ILC or Project X, is under construction at FNAL
- RF unit test facility (ILCTA_NM)
  - Extensive Facility Design work nearing completion
    - Electron source design
    - Building Layout, Dump and shielding design
    - RF systems, instrumentation, controls, etc
- Cleaned out New Muon Lab, including removal of 2500 Ton CCM magnet and began building refurbishment
- Shielding Block Cave installed
- Electrical and cryogenic infrastructure being installed
- 1st of two Satellite refrigerators installed and tested
- Control Room installed
- Large vacuum pumps for 1.8 K operation installed

ML basic building block

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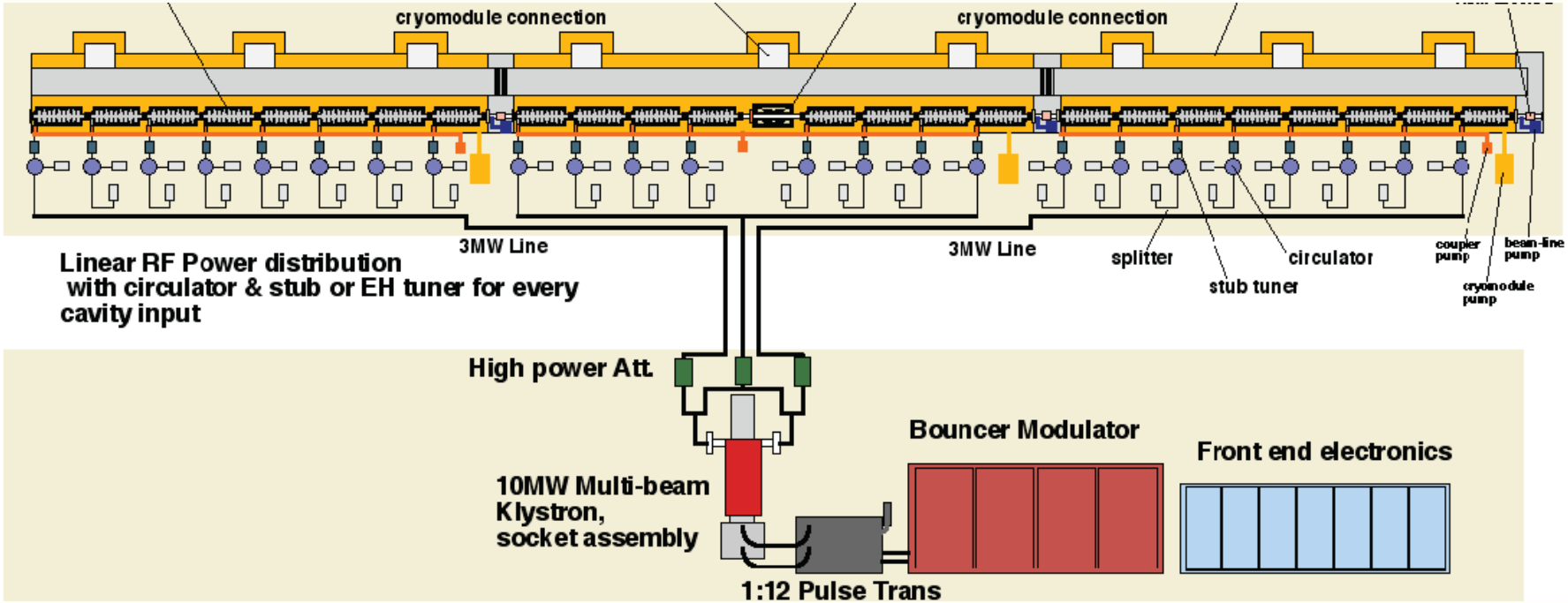
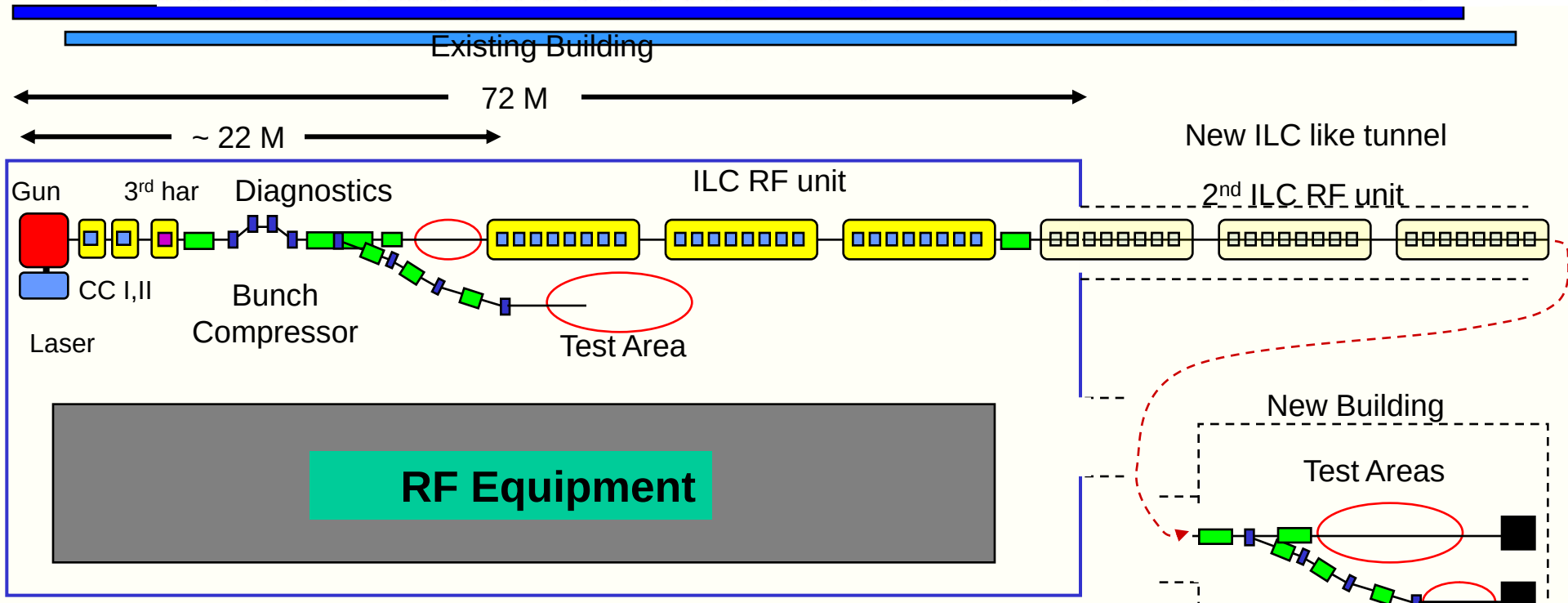
ILC RF Unit: 3 CM, klystron, modulator, LLRF



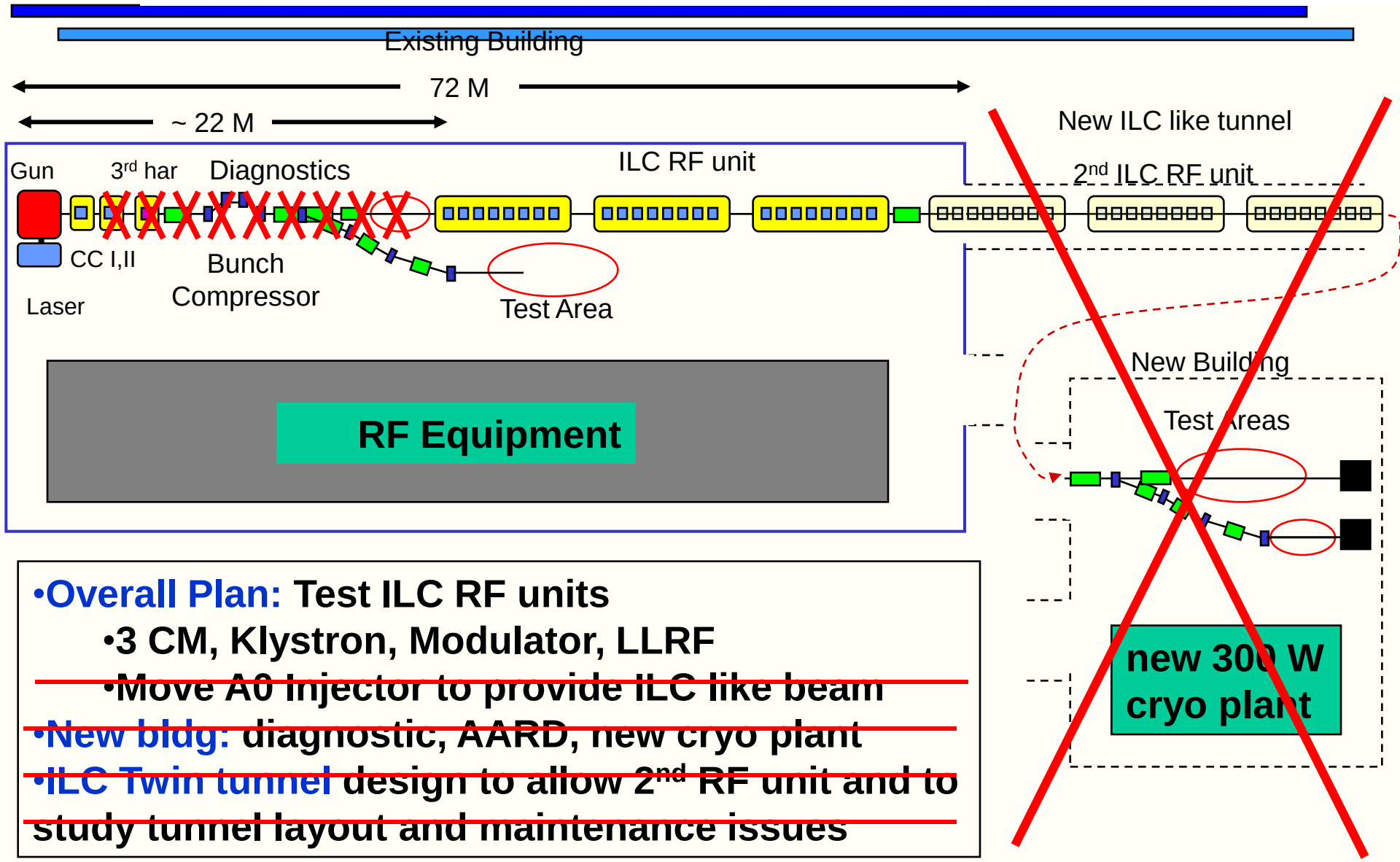
Baseline design now has 2 CM with 9 cavities, 1 CM with 8 cavities + quad

FY08 Plan: RF Unit Test Facility



- **Overall Plan:** Test ILC RF units
  - 3 CM, Klystron, Modulator, LLRF
  - Move A0 Injector to provide ILC like beam
- **New bldg:** diagnostic, AARD, new cryo plant
- **ILC Twin tunnel** design to allow 2nd RF unit and to study tunnel layout and maintenance issues

RF Unit Test Facility (Staged)



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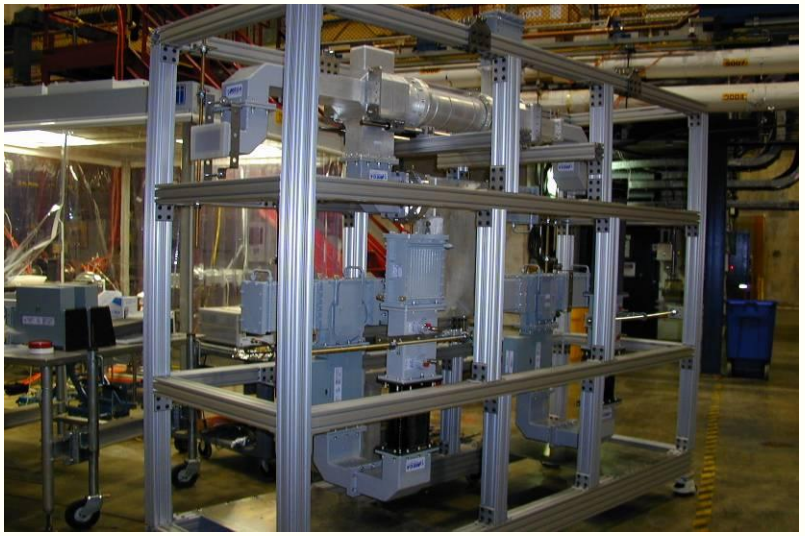
Pictures of NML Facility



FY08 Omnibus Bill (Dec 07)

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- $ 52 M cut in lab's budget (huge!)… 25% thru FY08
- National funding for ILC R&D was cut from FY08 PBR level of $ 60 M to $ 15 M (25%)
- The B&R supporting FNAL's SRF infrastructure work was cut from $ 23.4 M to $ 5.4 M (23%)
- OHEP was required to assess nationally whether the ILC and SRF infrastructure funds had already been obligated… ie whether any funds remained
  - Dec 20, 2007 OHEP issued a "Stop Work" order for all ILC and SRF work funded from the B&R codes that were cut
  - Severe lab financial crisis➔ Rolling furloughs, RIF of 10% of workers, extreme shortage of M&S funds, etc.
  - This continues….

What Stopped and What Didn't

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- **Stopped: All ILC R&D work, most SRF activities**
  - **All 1.3 GHz cavity purchases, processing, and test**
  - **Design and parts procurement for: Tuners, He vessels, CM's**
  - **Construction of most infrastructure and test facilities**
  - **ILC Civil Design, ILC accelerator simulation, global systems design, GDE meetings, travel, etc.**

- **Continued (other B&R… but with very limited M&S)**
  - **3.9 GHz DESY cryomodule work (international commitment)**
  - **ILC Detector R&D: (generic & funded via separate B&R line)**
  - **Generic SRF materials and surface studies**
  - **RF unit test facility at NML**
    - **not just ILC, also Project X and AARD**
    - **But now slowed and with reduced goals**

FY08 Status

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- ~Half of FNAL's SRF & ILC funds supported salaries. ~ 150 FTE's
  - These people had to be moved to other tasks
  - ~ 25% moved to complete the 3.9 GHz module (good since it was under-staffed and on a very tight schedule)
  - The rest moved to other non-SRF tasks around the lab
- Determined that all the SRF funds had been expended
  - except for $0.355 M contingency released in Apr for NML work
- Nationally a small amount of ILC funds remain:
  - Enough to support the GDE Common Fund & Project Managers from the U.S.
  - $ 1.4 M of ILC funding remain at FNAL, mostly because we had not yet placed large orders for SRF cavities
  - ~ $ 0.5 M of FNAL ILC funds remain at JLab, Cornell, and ANL
- Stop work order lifted in March … but…
- Resources for the rest of FY08 at less than 10% of our plan

Recovery Plan for FY08

- Much reduced program: Workforce: ~ 40 FTE
  - Mostly working on 3.9 GHz for DESY, 3.4 FTE on ILC
  - ~ 2.4 FTE on ILC cavities
  - ~1 FTE so a few of us can attend GDE meetings
- Priorities:
  - Complete 3.9 GHz module
  - Interact with Global ILC effort (e.g. Sendei, Dubna GDE meetings)
  - Process bare cavities in hand with remaining funds
    - JLAB: ~ 4 process and test cycles
    - Cornell: ~ 3 process and test cycles
    - ANL/FNAL: ~ 4 process and test cycles
  - Dress and test one 1.3 GHz cavity in HTS
  - Work towards making first CM cold in NML
- Clearly trying to survive a crippling blow…

Plans for FY09 and Beyond

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- Clearly FY08 was devastating to our plans
  - Future of ILC in U.S. ? At best… unclear
- FY09 ILC Guidance assuming PBR
  - ILC is at $ 35 M nationally
  - FNAL ILC: will be ~ $ 11 M (1/2 of FY08 Plan)
  - Reduced U.S. goals: e.g. drop focus on gradient (~ $ 3M on S0)
  - Focus on cryomodule development and test
    - Align with Project X
- FY09 SRF funds assuming PBR
  - ~$ 25 M/yr, and more flexibility in spending
- Working with OHEP to make a new 5 yr plan

5 yr FNAL SRF Plan

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- **Goals:**
  - Prepare for 2013 Project X start (CM production within 1 year)

  Or…
  - Prepare for participation in an off shore ILC by ~ 2015-16

- **OHEP funding guidance (March 08):**
  - ILC (cryomodules) ~ $ 6.5 M/yr + SLAC RF work
  - SRF (infrastructure) ~ $ 25 M/yr
  - Project X (to be determined)

Elements of the 5 yr plan

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- **Participate in Global ILC effort**
  - ILC machine design and GDE activity during TDP
  - Civil Design, cost reduction
- **Work towards ILC SRF Goals:**
  - ILC S0: bare cavity gradient > 35 MV/ meter with good yield
  - ILC S1: Full ILC CM at average gradient of 31.5 MV/M
  - ILC S2: Test ILC RF unit
- **Prepare for Project X:**
  - Infrastructure to produce 1 CM/month by 2013
- **Develop SRF expertise and infrastructure at FNAL**
  - Both for ILC and Project X

Elements of the 5 yr plan

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- **U.S. Cavity Purchases**
  - Develop U.S. cavity vendors
- **Cavity Processing**
  - Upgrade JLAB and Cornell cavity processing capabilities
  - Operate new ANL/FNAL joint processing facility
  - R&D program to understand cavity performance limitations
- **Vertical Test Systems (tests bare cavities)**
  - Operate VTS1
  - IB1 infrastructure upgrades (cryogenics, RF power, control)
  - Build VTS 2 and 3 (capacity for ILC and Project X)
- **Horizontal Test System (tests dressed cavities)**
  - Operate HTS1 to support cryomodule construction
  - Upgrade cryogenics, RF power, control
  - Build 2nd HTS and RF/cryo upgrades to increase capacity

Elements of the 5 yr plan

- **Cryomodules:**
  - Finish Cryomodule Assembly infrastructure
  - Build Cryomodules in support of both ILC and Project X
  - Build Stand alone CM test stand

- **Descoped: RF Unit Test Facility (3 CM, modulator, klystron, LLRF)**
  - NML building infrastructure
    - AC power, LCW, shield blocks, Control room, etc.
  - Cryogenics, LLRF, RF power, and distribution for 1 CM
  - Cryogenics and RF upgrades (for full RF unit)
  - Electron gun, capture cavity, magnets, instrumentation, beam dump, etc.

- **Goal: by 2012 Complete and test a full RF unit (of ILC or Project X)**

Timeline

1.3 GHz Cryomodules

U.S. Fiscal Year	2008	2009	2010	2011	2012	2013
CM1 (Type III+)						
Assembly	in FY07	install				
Test		CM1 test@NML				
CM2 (Type III+)						
Cav Processing + VTS						
Dressing & HTS						
Assembly			install			
Test			S1 Demo@NML			
CM3 (Type IV)						
Design & Order Cav & CM Parts		Design	Order Cav & CM parts			
Cav Processing + VTS						
Dressing HTS						
Assembly				install		
Test					S1 Demo@NML	
CM4 (Type V) => Pattern Repeats (Goal = 1 CM/month capability)						
Design & Order Cav & CM Parts		Design	Order Cav & CM parts			
Cav Processing + VTS						
Dressing HTS						
Assembly					install	
Test						Replace Type III+
NML Beam			Beam (avg ILC current)			ILC Beam?
10 MW RF unit test					S2 RF unit test	
Px β=0.8 CM *(Project X R&D Plan)*						
Design & Order Cav & CM Parts		Design (Px Collab Effort)	Order Cav & CM parts			
Cav Processing + VTS						
Dressing HTS						
Assembly						install
Test						test
S1 Global (2 Cav - Funding source not yet determined)						
Cav Processing + VTS						
Dressing & HTS?						

New SRF Infrastructure Construction (funding limited)

U.S. Fiscal Year	2008	2009	2010	2011	2012	2013
Nb Scan/Cavity Fab Upgrade		Design / Procure & Install				
Add CM Ass'y Capacity					Design	Procure & Install
VTS 2 & 3 Upgrade		Design / Procure, Install & Commission				
HTS 2 Upgrade				Design	Procure, Install & Commission	
NML Facility		Procure, Install & Commission	*Beam Available*			
CM Test Stand			Design	Procure, Install & Commission		
Add Cavity Proc Capacity				Design	Procure, Install & Commission	

Conclusions

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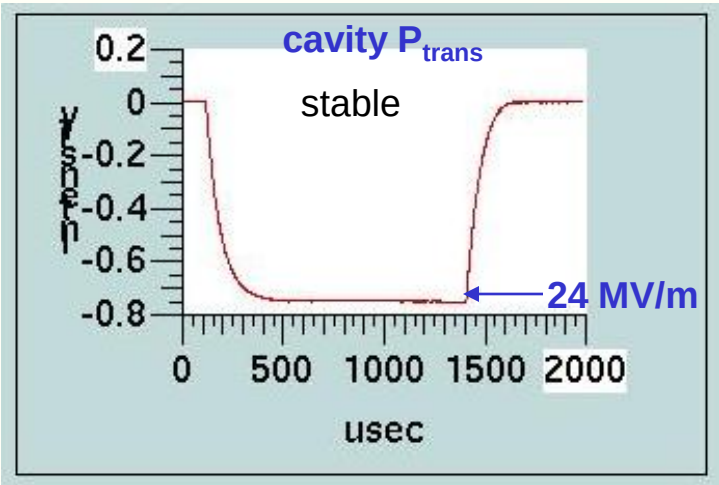
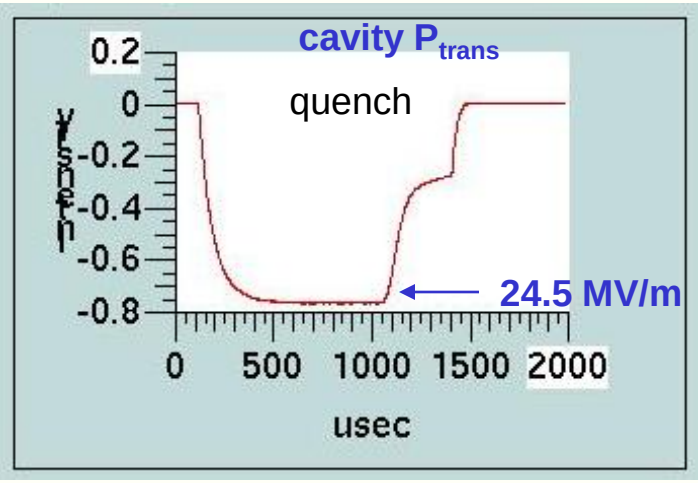
- **Creating a new 5 yr plan that is coordinated with the needs of ILC and Project X and that leverages existing U.S. expertise and infrastructure**
- **If successful, this plan accomplishes:**
  - **ILC S1 goal in Mid 2010**
  - **ILC S2 goal in mid 2012**
  - **Ready for Project X construction in ~2013**
  - **leads to U.S. participation in ILC construction ~ 2015-16**

3.9 GHz Cavity #5 Horizontal Test





- **C5 reaches 24.5 MV/m before quenching**
  - **1.3 ms RF pulse, 5 Hz rep rate**
- **Q_0 @ 18 MV/m = (5.6 ± 3.4) x 10^9**