ILC Cavity and Cryomodule Overview

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Fermilab

Outline

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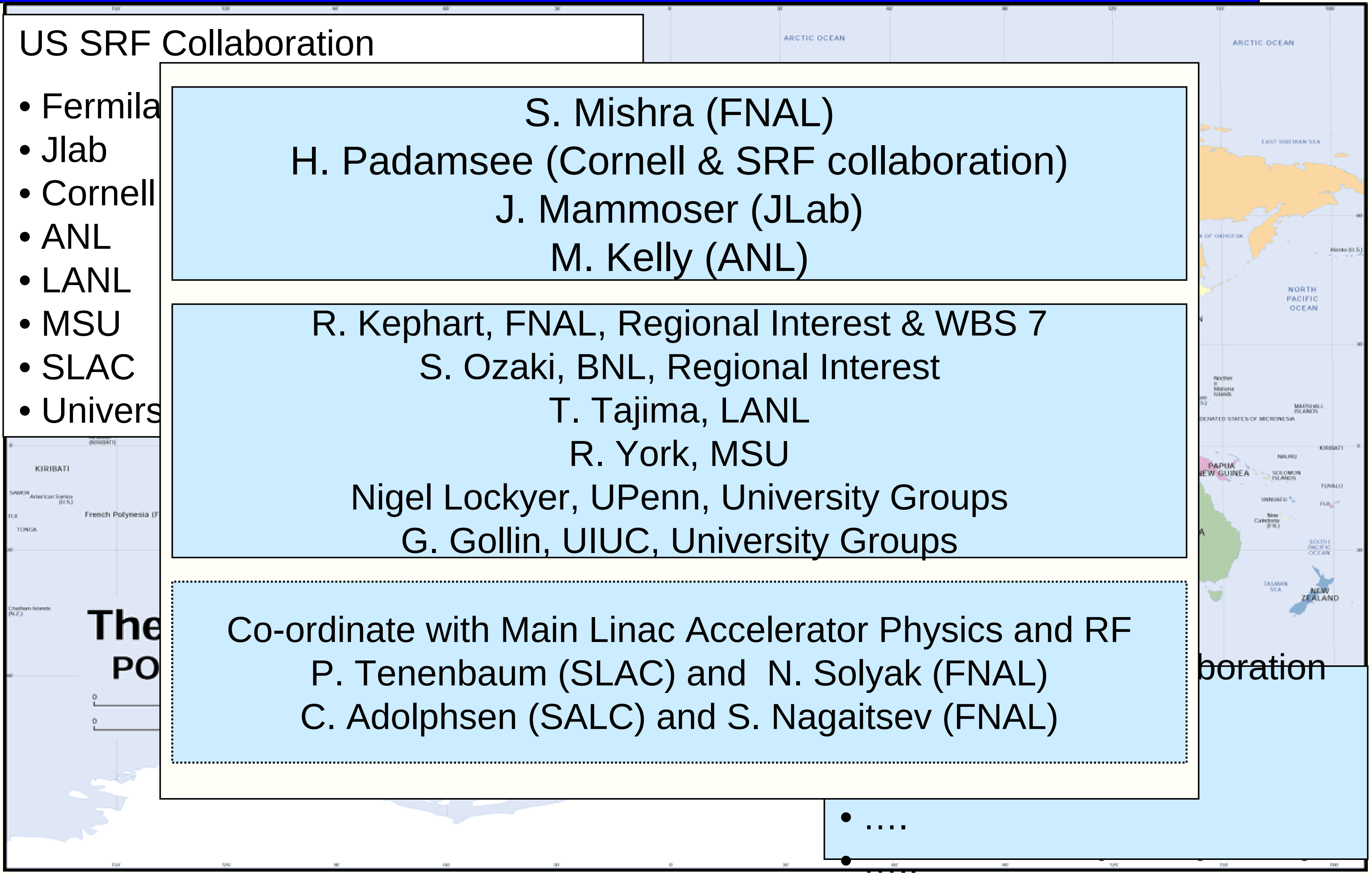
- Motivation and Goals
- Infrastructure for Cavity Fabrication, Processing and Testing
- Infrastructure for Cryomodule Fabrication
- Proposed Scope of the facility
- Present and Developing US SRF Infrastructure
- Future SRF Infrastructure @ FNAL
- Summary

Focus on Charge 2 and 3

Generic infrastructure is needed, ILC sets the scale

International SRF Collaboration



US SRF Collaboration

- Fermila
- Jlab
- Cornell
- ANL
- LANL
- MSU
- SLAC
- Univers

The
PO

S. Mishra (FNAL)
H. Padamsee (Cornell & SRF collaboration)
J. Mammoser (JLab)
M. Kelly (ANL)

R. Kephart, FNAL, Regional Interest & WBS 7
S. Ozaki, BNL, Regional Interest
T. Tajima, LANL
R. York, MSU
Nigel Lockyer, UPenn, University Groups
G. Gollin, UIUC, University Groups

Co-ordinate with Main Linac Accelerator Physics and RF
P. Tenenbaum (SLAC) and N. Solyak (FNAL)
C. Adolphsen (SALC) and S. Nagaitsev (FNAL)

boration

- ….
- ….

Technical Goals

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- **Demonstrate the basic ILC Main Linac technology**
  - **Develop cavity processing parameters for a reproducible cavity gradient of 35 MV/m; improve the yield of 9-cell cavities for gradient of 35 MV/m in vertical tests (S0.1).**
  - **Carry out parallel/coupled R&D on cavity material, fabrication, and processing to identify paths to success (S0.2).**
  - **Assemble and test several cryomodules with average gradient > 31.5 MV/m (S1).**
  - **Build and test one or more ILC rf units at ILC beam parameters, high gradient, and full pulse rep rate (S2.1).**
  - **Carry out Key Alternate Design R&D item**
    - **GDE wants a "forward looking" approach**
    - **Improve ILC performance, reduce cost**
- **Install Sufficient Infrastructure to support these activities**

Goals for SRF Infrastructure

- To perfect U.S. fabrication & processing of SRF cavities and modules and to demonstrate performance with a full range of testing
  - Deploy ILC design / processing / assembly techniques
  - Establish process controls to reliably achieve high gradient cavity operation and module performance
  - Test cavities and cryomodules at the component level and in a systems test to demonstrate yield, reproducibility and beam performance
- 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
- 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
- US and Fermilab to be a
  - “Credible” and “Qualified Host” of ILC

Infrastructure for Cavity and Cryomodule Fabrication, Testing

- **Bare cavity production**
  - Niobium QC
  - Fabrication facilities (e.g. Electron beam welders)
  - Buffered Chemical Polish facilities (BCP) for cavity parts pre-welding
- **Pre-Production Cavity Processing**
  - Tuning for field flatness
  - Surface Processing (Tumbling, BCP and Electro Polishing)
  - Ultra clean H_20 & High Pressure Rinse systems
  - Furnace for 600 – 800 C bake (removal of H)
- **Vertical Test facilities (Cryogenics + low power RF)**
- **Cavity Dressing Facilities (cryostat, tuner, coupler)**
  - Class-10/100 clean room
- **Horizontal cavity test & Coupler test facilities (RF pulsed power)**
- **String Assembly Facilities**
  - Large class-100 clean rooms, Large module assembly fixtures
  - Class-10 enclosures for cavity inner connects

Cavity and Cryomodule

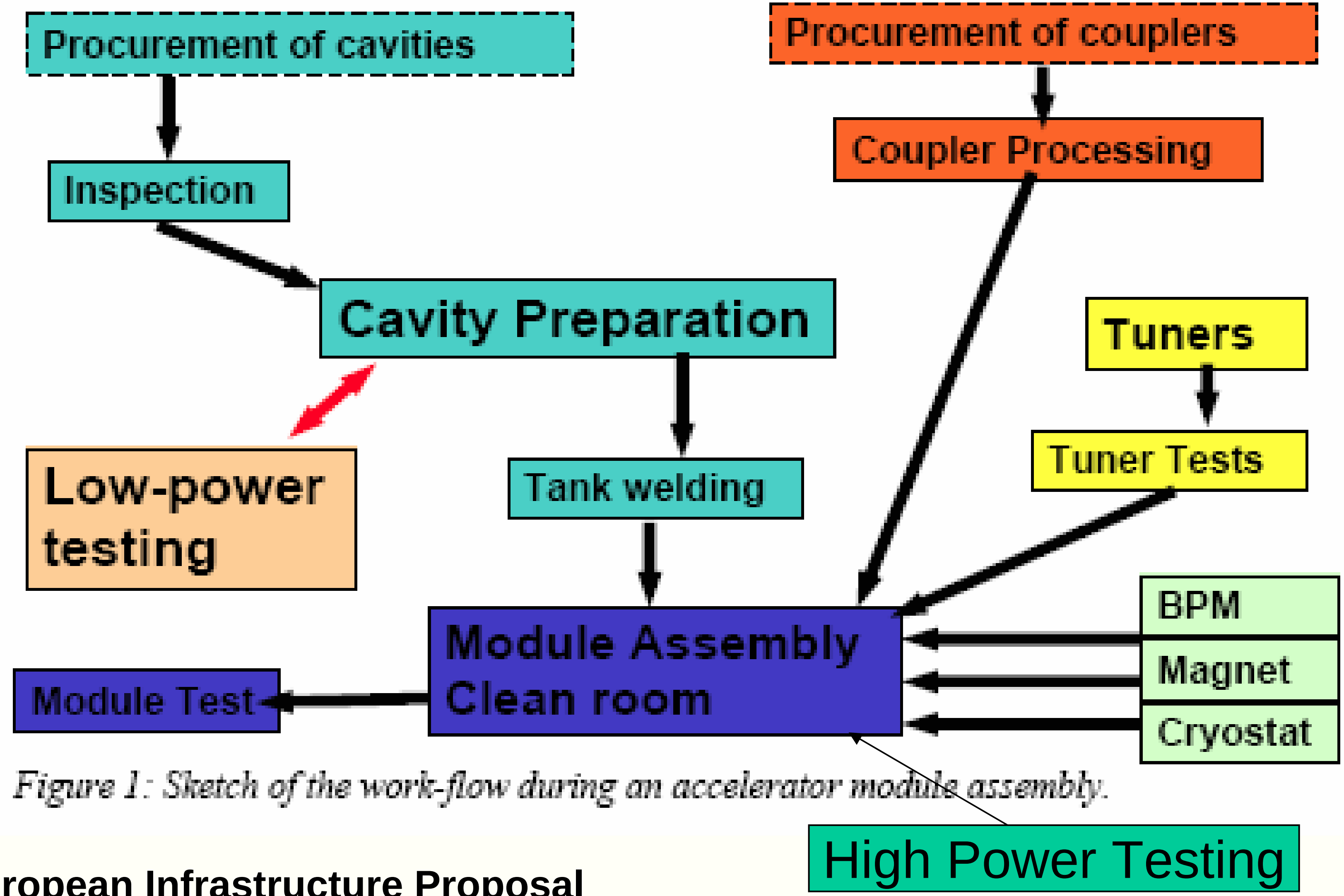

Figure 1: Sketch of the work-flow during an accelerator module assembly.

European Infrastructure Proposal

Proposed Scope : ILC-ART Program

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Focus on Crucial R&D

- **Cavity R&D (S0 goals)**
  - Cavity (24 FY07, 64 (08), 64 (09))
    - Material QC, Fabrication, Tuning
  - Cavity Processing (x 3 number of cavities)
  - Cavity Vertical (Low Power) Testing
  - Cavity Horizontal (High Power) Testing
  - Cavity failure analysis (Improve yield)
  - ACD Shapes and Material
- **Cryomodule R&D (S1 and S2 goals)**
  - Design and Fabrication (2 (FY07), 4 (08), 4 (09))
- **Infrastructure**
  - Cavity Tuning
  - Pre-Production Cavity Processing Facility at Fermilab
  - RF Unit Test Infrastructure at Fermilab (With Beam)
  - Cryomodule Test Stand

ILC Cryomodule Production (RDR)

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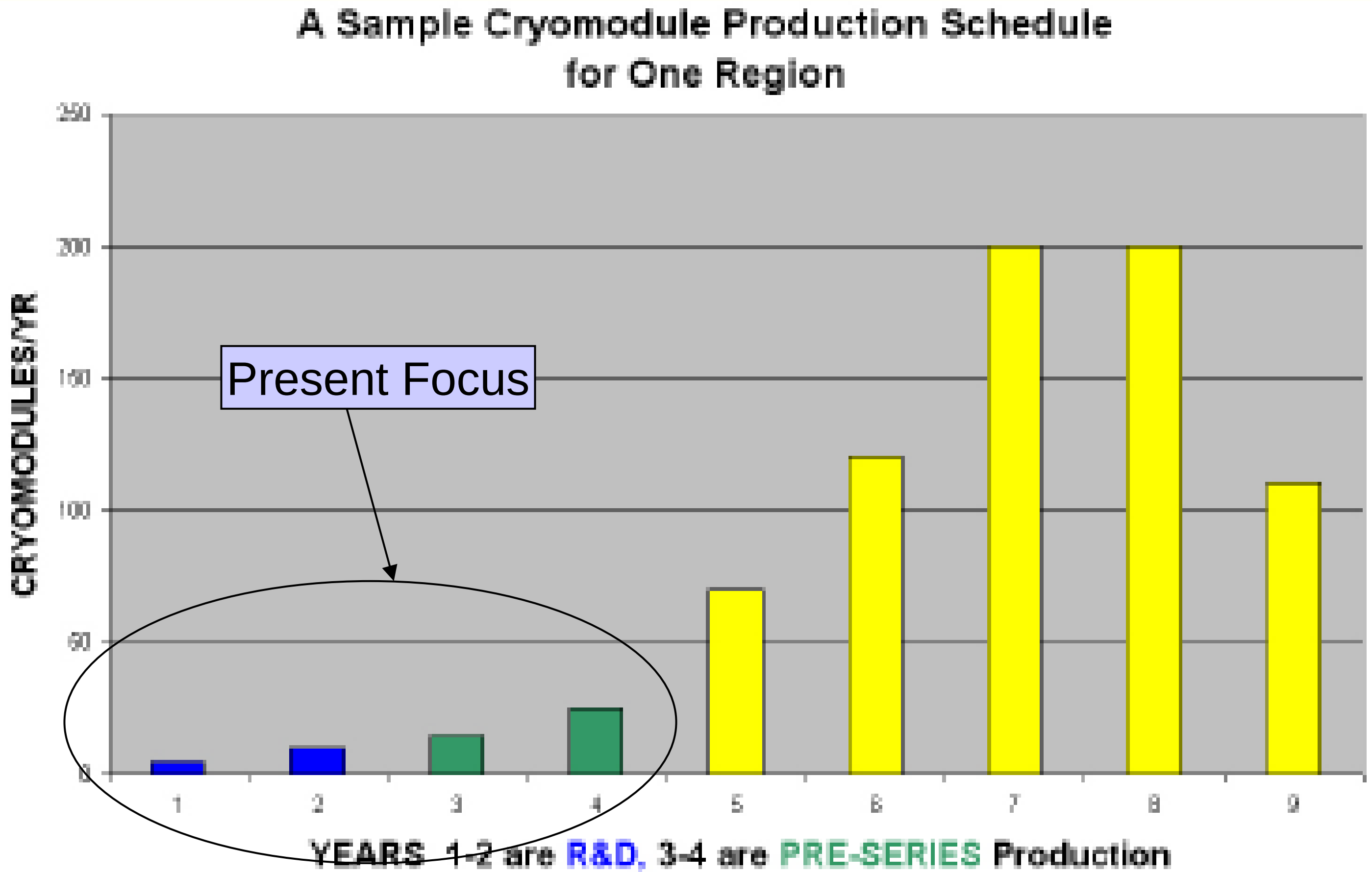

YEARS 1-2 are R&D, 3-4 are PRE-SERIES Production

Construction Funding is assumed to begin around year 3 or 4

FIGURE 6.3-3. A possible model schedule for cryomodule production shows 1/3 of the required ILC cryomodules produced in one of three regions. R&D and pre-series devices lead to 5 years of series production (yellow). The position and magnitude of the peak of series production will vary with changes to the available construction and test infrastructure.

Proposed Scope: Ozaki Panel Report

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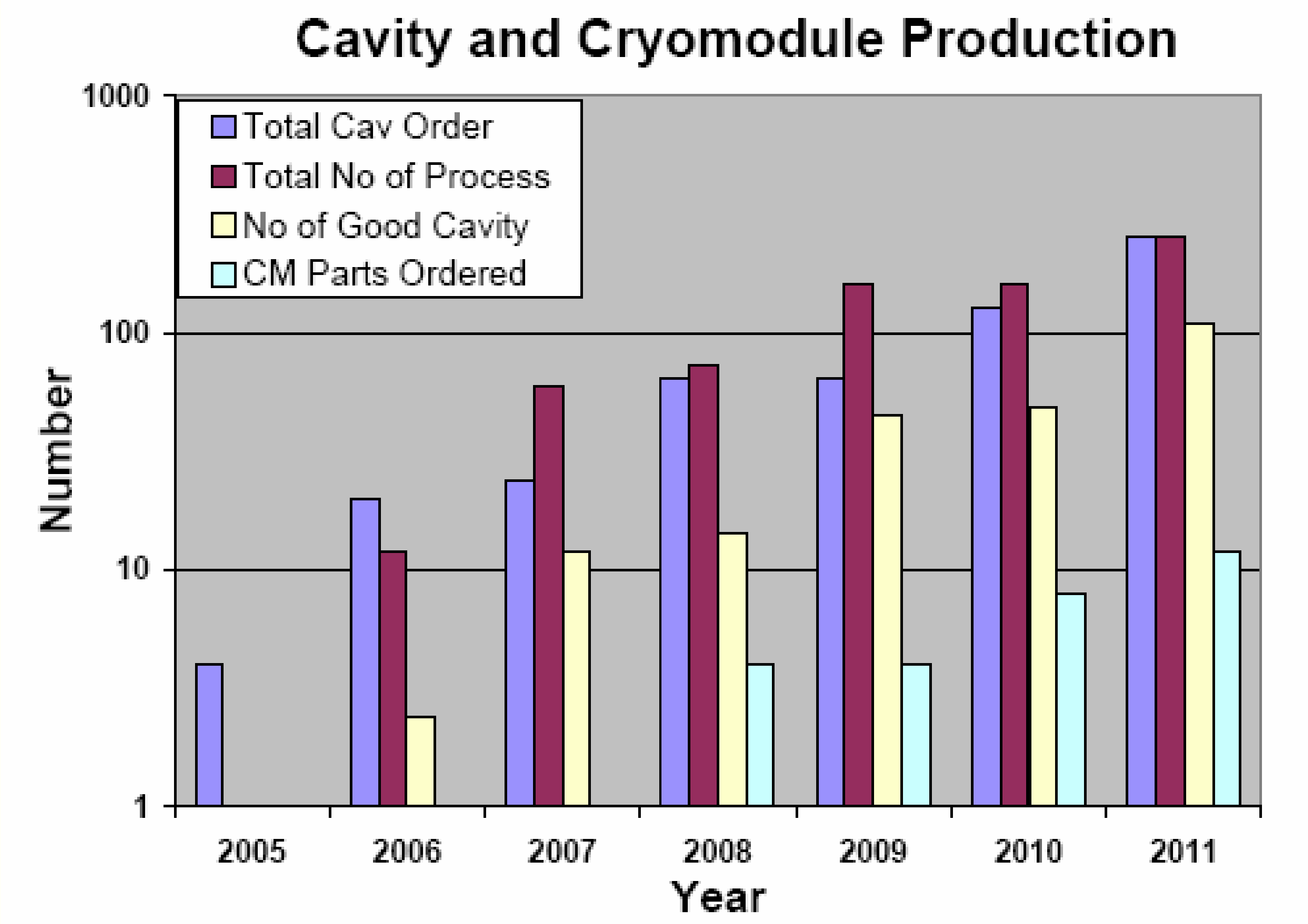
Develop US Capability

- Cavity R&D (S0-S1-S2)
  - US Industrial Development (49 (FY07), 125 (08), 219 (09))
- Cryomodule R&D (S1-S2)
  - Industrial Development (3 (FY07),12(08),12(09))
- Development of SRF Infrastructure
  - Cavity Tuning
  - Pre-Production Cavity Processing Facility at Fermilab
  - RF Unit Test Infrastructure at Fermilab (With Beam)
  - Cryomodule Test Stand
  - Cavity Fabrication (Electron Beam Welder, etc)
  - Cryomodule Fabrication (Industry Technology Transfer)
  - Vertical and Horizontal Test Stand
  - Cryogenic to support the test stand

US Program (ILC-ART & OPR)



Present: US SRF Infrastructure

- Limited cavity fabrication capability in US industry
  - One US company (AES) fabricating SRF cavity
  - Developing two new companies (Niowave and Roark)
    - European Industry much advanced in ILC cavity fabrication
- Cavity Processing and Vertical Testing R&D Facility
  - Jlab (~30 FY07, ~40 FY08, ~50 FY09) cycles/yr
  - ANL/FNAL (~50 FY08, ~60 FY09) cycles/yr
  - Cornell ~12 cycles/yr
  - VTS @FNAL ~50 cycles/yr (late FY07)
  - Significant fraction of this capacity is used to support R&D Program
    - Process development
    - Single cell Processing
- Horizontal Test Stand
  - FNAL ~24 cavities/yr
- Cavity Dressing and Cryomodule Assembly
  - FNAL 2-4/yr (FY07)

Scope: US Laboratories Capacity

Program	FY07	FY08	FY09	FY10	Capacity Needed/yr by FY10
Cavity Processing (EP, HPR, Bake) Cycles/yr	Jlab-30 Cornell-10	Jlab-40 Cornell-10 ANL-40	Jlab-40 Cornell-10 ANL-40 Fermilab-20	Jlab-40 Cornell-10 ANL-40 Fermilab-100	200
Vertical Testing	Jlab-30 Cornell-10 Fermilab-20	Jlab-40 Cornell-10 Fermilab-75	Jlab-40 Cornell-10 Fermilab-75	Jlab-40 Cornell-10 Fermilab-200	200
Horizontal Testing	Fermilab-6	Fermilab-24	Fermilab-24	Fermilab-72	72
Cryomodule Assembly	Fermilab-1	Fermilab-4	Fermilab-8	Fermilab-12	12
Cryomodule Test	Fermilab: ILCTA_NML	Fermilab: ILCTA_NML	Fermilab: ILCTA_NML	Fermilab: ILCTA_NML CMTS	12

Proposed: US Laboratories Capacity

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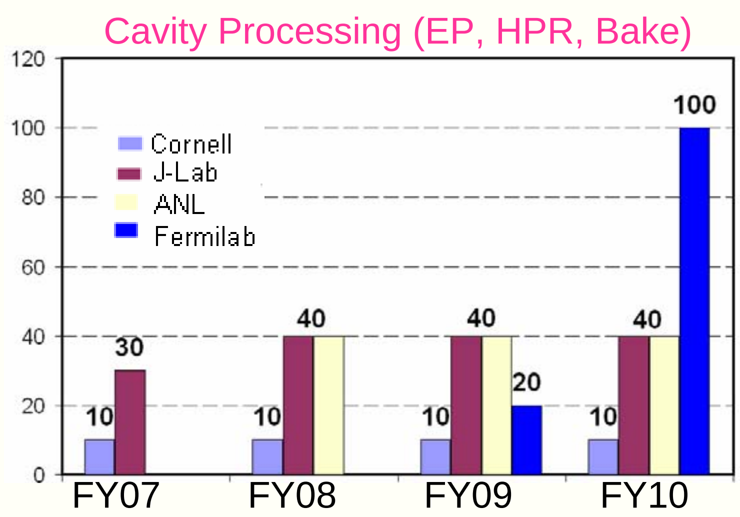

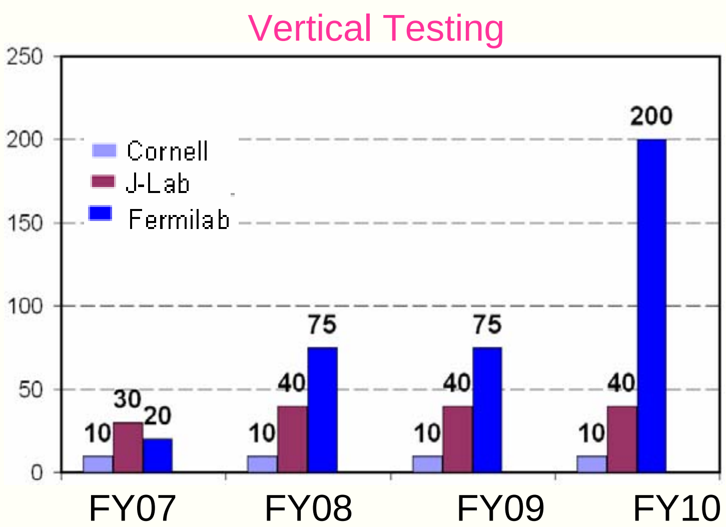

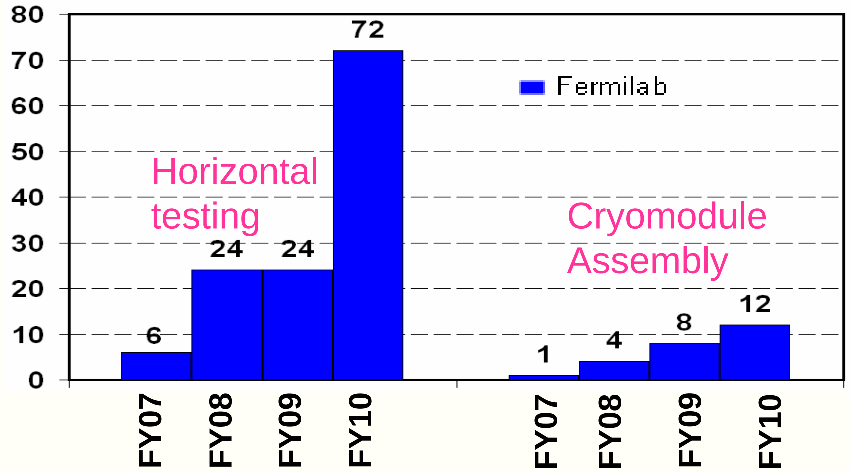

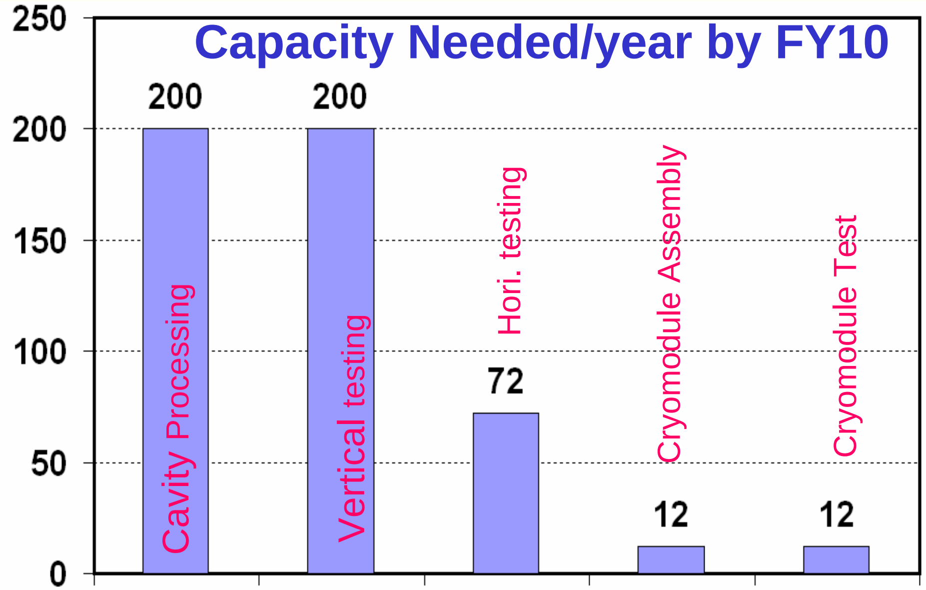

Scope: Fermilab SRF Infrastructure

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- Cavity Fabrication
  - Increased cavity fabrication R&D and training US industry
    - Electron Beam Welder
    - Eddy Current Scanner
  - Automated Cavity Tuning
    - 100+ Cavity/yr (by FY09)
- Cavity Processing Facility (Pre-Production Facility, existing technology with industry, modular and redundancy)
  - 100+ Cycles/yr (by FY09)
- Vertical Testing
  - Additional 100+ Cavity/yr (by FY09)
- Horizontal Test Stand
  - Additional 48 Test/yr (Maximum US Capacity needed)
- Cryomodule Assembly
  - 1 per month
- Material R&D

Breakout Session I - Cavity/CM

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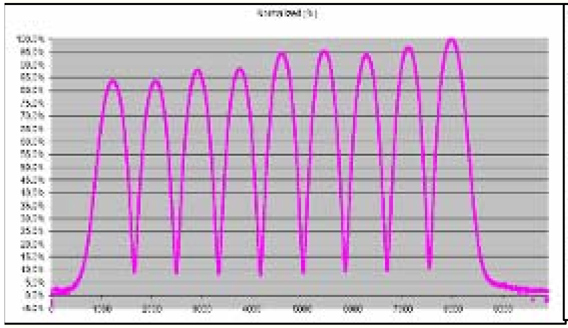
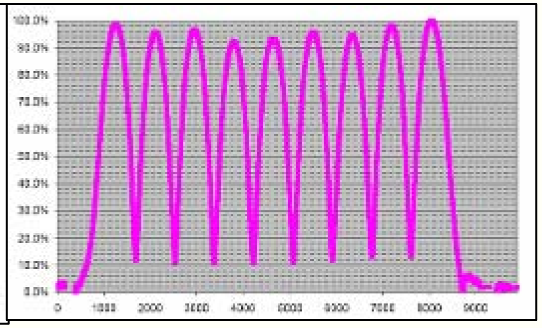
- Elliptical Cavities - M. Foley
- Cavity Processing, Current Facilities, Plans for Future Facility, H. Carter
- IB1 Infra - Vertical Test Facility and Future Upgrades - C. Ginsburg
- CCII Results and Horizontal Test Facilities - A. Hocker
- Cryomodule Assembly Facility - T. Arkan
- SCRF Materials Program - C. Antoine

Cavity Fabrication

- **Present US Cavity production is through**
  - **Niobium QC at Fermilab, Jlab**
  - **Advanced Energy System, ACCEL, Zanon**
  - **Jlab (Cavity and Material R&D)**





Fermilab does not have the infrastructure to

- Train and develop a new vendor
- Carry out cavity R&D.
- Auto Tune Cavities

Proposed: Cavity Fabrication Infrastructure

- **The following infrastructure are proposed for the Cavity R&D and Technology Transfer**
  - **Electron Beam Welder**
    - **Prototype Cavity development**
    - **Cavity fabrication R&D**
    - **Industry Development**
  - **Eddy Current Scanner (2nd to increase throughput)**

Cavity Fabrication Infrastructure: $4.38M

Cavity Gradient: 35 MV/m

- **At present, there is good proof-of-principle that 9-cell cavities reach gradients of 35 – 40 MV/m after applying the best preparation procedures**
  - **Electro-polishing (EP),**
  - **High Pressure Rinsing (HPR)**
  - **Baking at 120 C.**
- **DESY has tested (~5-10) cavities with gradients of ~35 MV/m,**
  - **Yield is less than 0.5,**
  - **Gradient spread is large (±25%)**
  - **Average number of preparations and test cycles per cavity is three.**
- **Cavity fabrication and processing R&D is needed to achieve an overall yield > 80% in the first test of cavities and 95% ultimate in two tests for cavities**
  - **Limited by preparation and processing.**

Yield Improvement: 35 MV/m

- The yield improvements would come in a few stages
  - Input from R&D activities becomes incorporated into the 9-cell preparation
  - Testing batches for each stage.
- Dramatic improvement in yield and spread will require coupled R&D programs in parallel to large scale testing of 9-cell cavities.
  - Basic R&D on the preparation recipes
  - Materials R&D
  - Diagnostics on EP, HPR, VTS systems
  - Multi-cell tests with full diagnostics
  - Single cells preparation/tests
- Present Limiting Factors:
  - Field emission
  - Quench
  - Hydrogen initiated Q-disease.
- Existing Procedure needs optimization and we need to explore any promising procedures that reduces these effects. Some examples are:
  - Improved methods of final rinsing
  - New final rinsing agents
  - Stringent control of cleanliness during assembly
  - Processing field emission with high pulsed power RF.

Cavity Processing and Testing

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- The present US cavity R&D is using
  - Distributed Cavity Processing and testing infrastructure
  - This is an ideal way to get started with very limited resources to make significant progress towards the ILC R&D goals.
- The production of high-performance SRF cavities will require state-of-the-art surface preparation.
- We are proposing build additional facility at Fermilab, We already have
  - Existing infrastructure and significant engineering resources
  - Low and High Power Cavity Test Facilities
  - Cryomodule Assembly Facility
  - Cryomodule Test Facility With and Without Beam
- An integrated facility will be needed
  - For significant improvement of the current preparation
  - Steps towards an industrial production-like level
  - A large enough throughput (~100 cavities/yr)

Cavity Preparation Infrastructure

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- The proposed infrastructure will improve over the existing infrastructures
  - Present infrastructures are single-line processing R&D infrastructure
    - Failure in one process chain leads to unacceptable delay in schedule
  - New Infrastructure will have
    - All cavity processing under one clean environment
    - Redundancy in layout
    - Modularized for maintainability and flexibility
    - Flexibility: Implementing change in the overall production scheme
    - Quality Assurance and control process
    - Available for use for other projects

Model: Processing and Testing Infrastructure

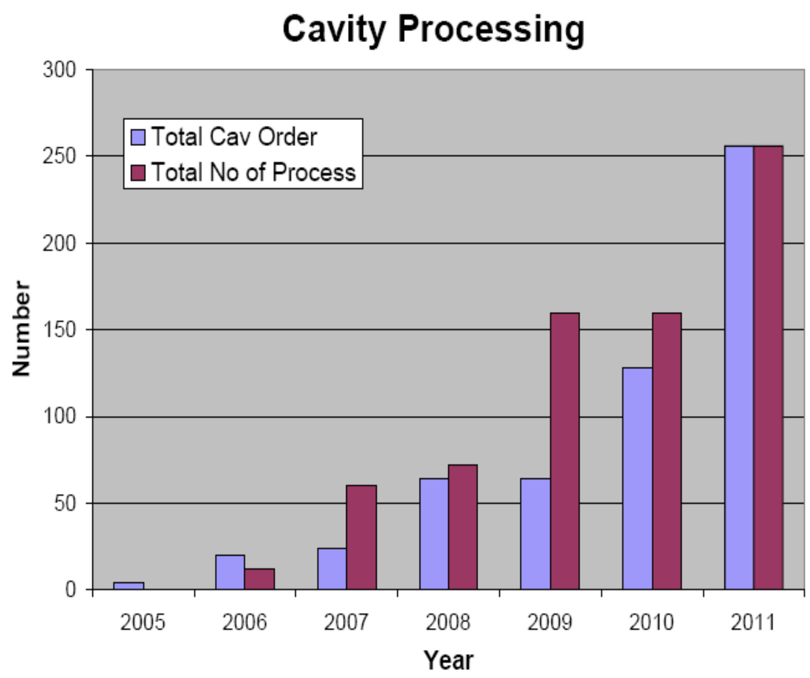
- Degrease & EP 80 um (3 days)
- HPR 1 day
- Drying 1 day
- H-removal, 600 – 800 C (3 days)
- Tune field flat (1 day)
- EP 10 um (1 day)
- HPR (1 day)
- dry (1 day)
- First stage assembly & HPR (1 day)
- Dry 1 day
- Final assembly to bake stand, evacuation (1 day)
- 120 C on bake stand (2 days)
- Assembly to test stand (1 day)
- Cold test, warm up (3 days)

Total 21 days (4 weeks)

Test set-up has maximum 4-day, rate limiting time

- Assume one set-up each per facility
- Max cycles = 5 per month (20 days) = 60 per year
- Down time and maintenance time may reduce this
- Calculation Estimates: 50 per year max
- Jlab estimates : 40/year

A R&D Model



As defined by ILC-ART & OPR

Schematic of Cavity Processing Facility

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Each EP, HPR .. System can do ~40 cy/yr

EP Systems: 2 (1 Spare)

HPR Systems: 2 (1 Spare)

BCP Systems: 1 (1 S)

Vacuum Furnaces: 2

Low Temp Furnaces: 2

Cavity Tuning: 1

Tumbling: 1

Clean Rooms

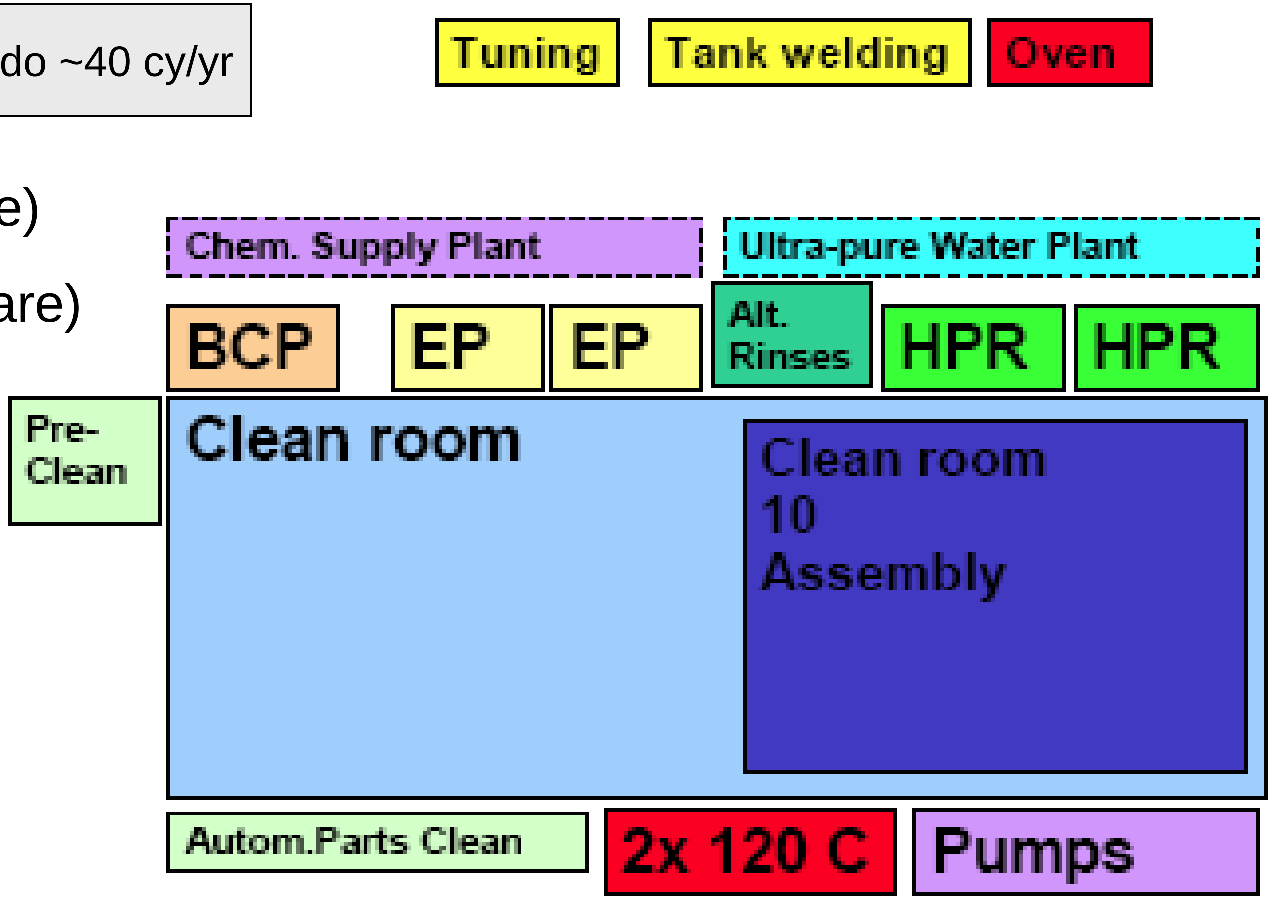


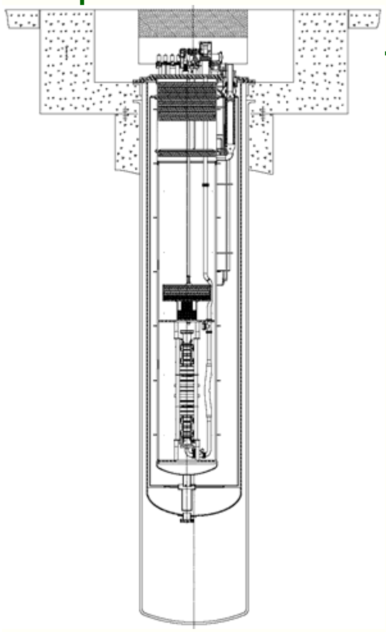
Figure 2: Sketch of the cavity preparation infrastructure.

European Infrastructure Proposal

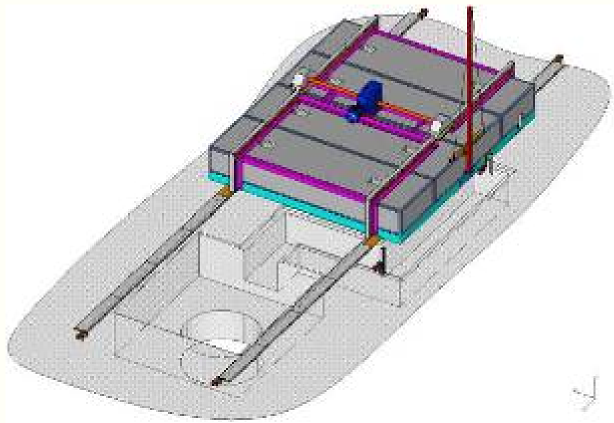
Cavity Processing Facility $18.9M

Present: Vertical Test Facility-1

- A Vertical Test Stand is under Construction at Fermilab (IB1)
  - Existing Cryogenic plant in IB1 has the capacity of 125 W at 2 K (250 W available for intermittent test)
  - Test Stand will be capable of testing ~50 Cavities/yr
  - Commissioning late summer 07

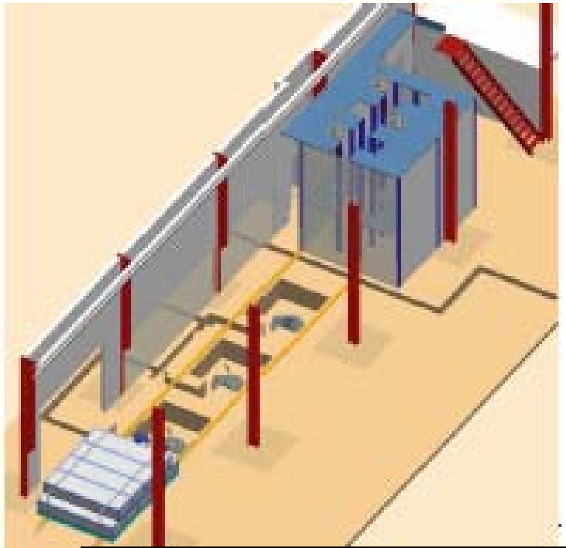


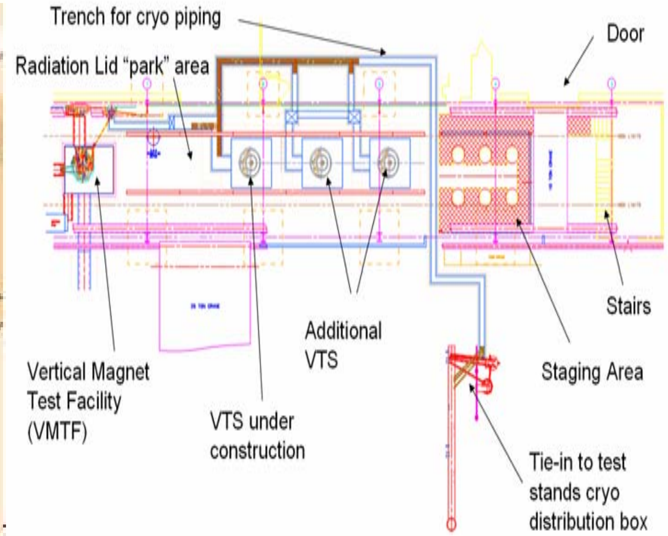
Cryostat at PHPK

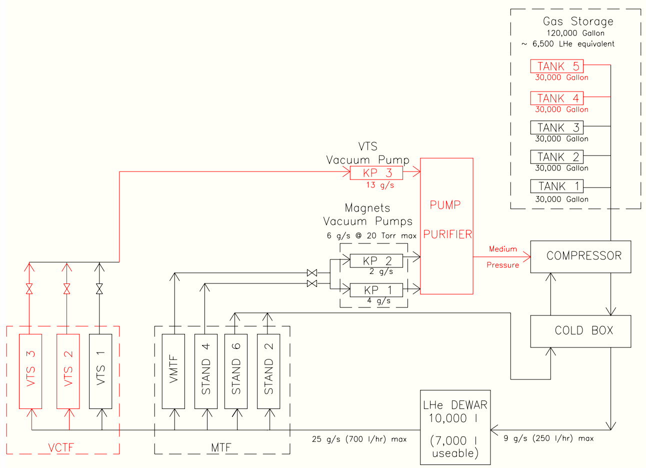


Proposed: Vertical Test Stand 2 & 3

- **To increase the capacity of the VTS**
  - **Upgrade the VTS-1 for 2 cavity operation (~75 cy/yr)**
  - **Add 2 more VTS pits (VTS-2 and VTS-3) (~200 cy/yr)**
  - **Upgrade the cryogenic infrastructure (decouple from superconducting Magnet test)**
  - **Upgrade the cavity staging area**
- **To support cavity R&D: Field emission studies and Quench Location**





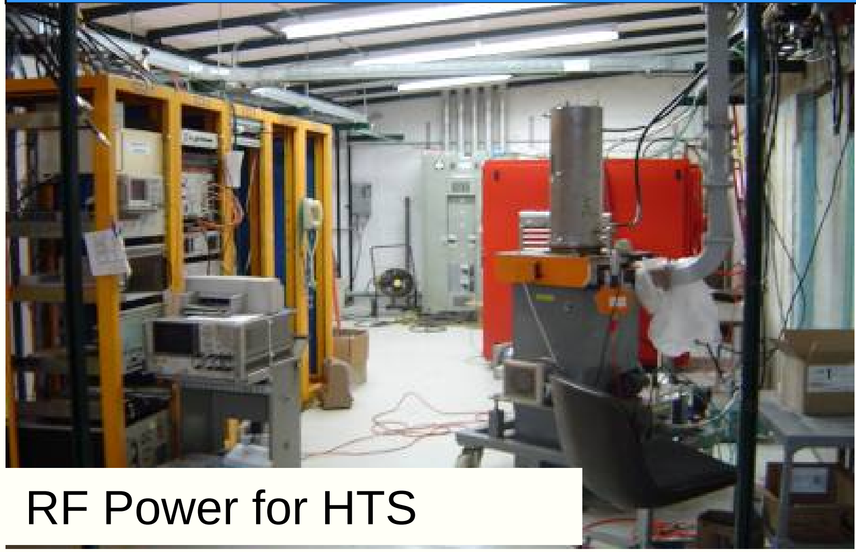


Vertical Test Stand 2 & 3: $5.5M

Present: Horizontal Test Stand - 1

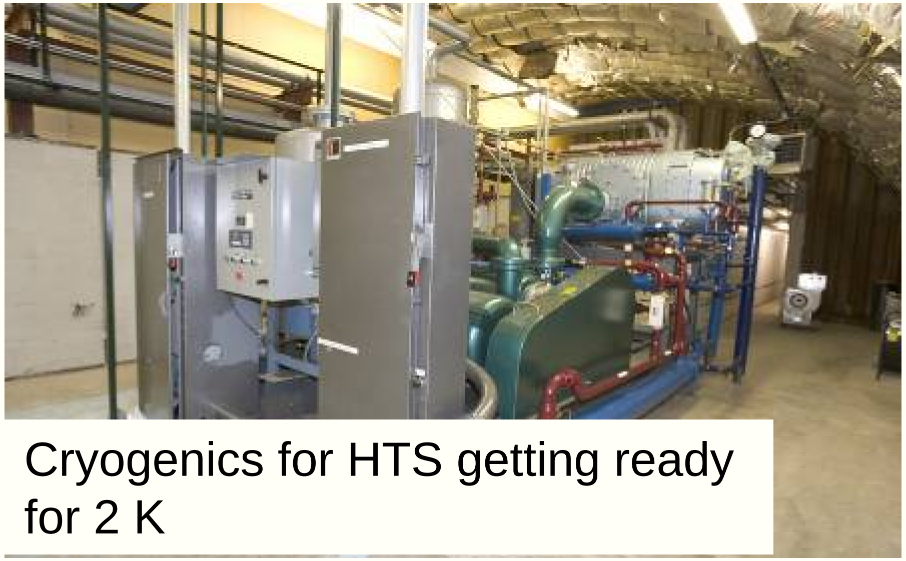
- Horizontal Test Stand -1 is getting ready for commissioning at Meson.
  - The maximum capacity of this test stand is ~24 cavities/yr
- It will be debugged with a cavity from DESY in early spring.
  - This cavity is getting prepared by Jlab.
- The commissioning of the HTS will happen with AC7 (9-cell, 41 MV/m) cavity.
  - Coupler from DESY
  - Tuner and He Vessel from INFN to Penn, Getting commissioned at Penn
  - Will be dressed at Jlab

Cavity Testing Infrastructure

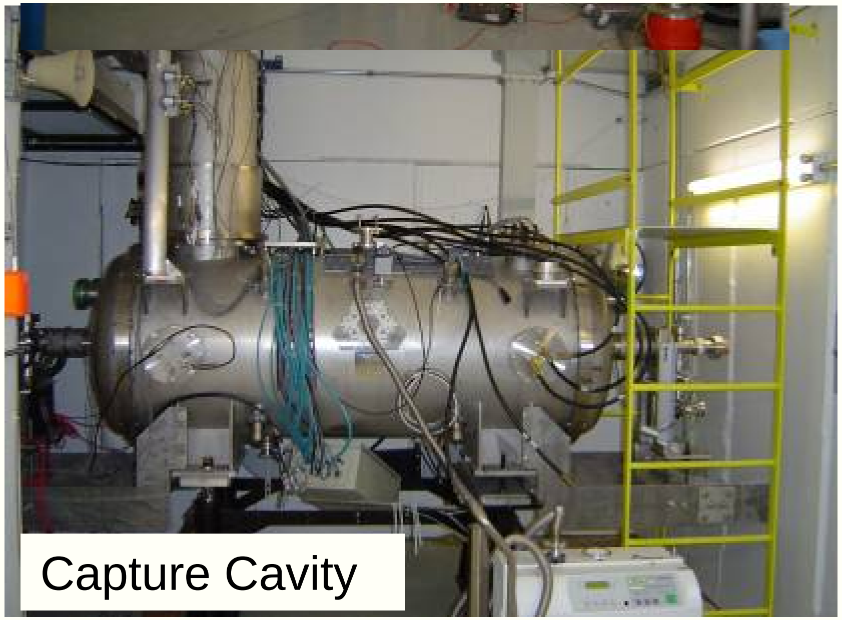


RF Power for HTS

Cryogenics for HTS ready at 2 K



Cryogenics for HTS getting ready for 2 K



Capture Cavity

Proposed: Horizontal Test Stand - 2

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- **We proposed to build a second Horizontal Test Stand at Fermilab and install it next to HTS-1.**
- **The HTS-2 to will have the capability to cool down and test 2 9-Cell cavities at a time.**
  - **This will enable us to increase the throughput to 72 cavities/yr**
  - **It will also allow development of RF controls using multiple cavities.**

Horizontal Test Stand 2: $2.8M

Present: Cryomodule Assembly Facility MP9 and ICB

CAF infrastructure:

- Clean Rooms (10,100,1000)
- String Assembly Fixtures
- Vacuum / Ultra Pure Gas Flow Equipment/ Hardware
- Ultrasonic Cleaner
- Ultra pure DI water
- Cavity Handling Cart / Fixture
- Cold Mass Assembly Fixture

Proposed: CAF (MP9 and ICB) Upgrade

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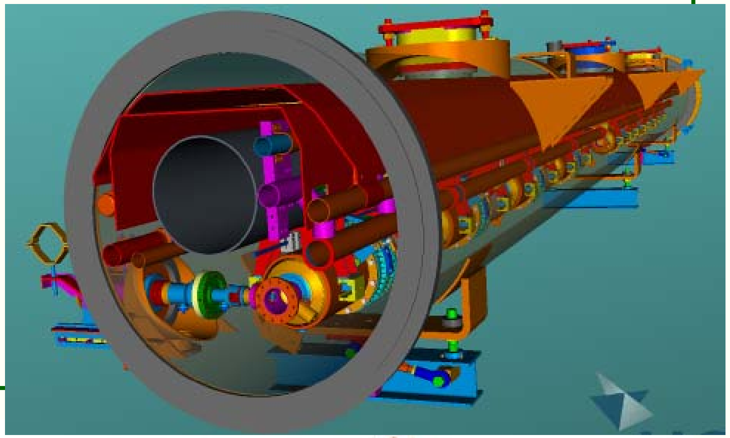
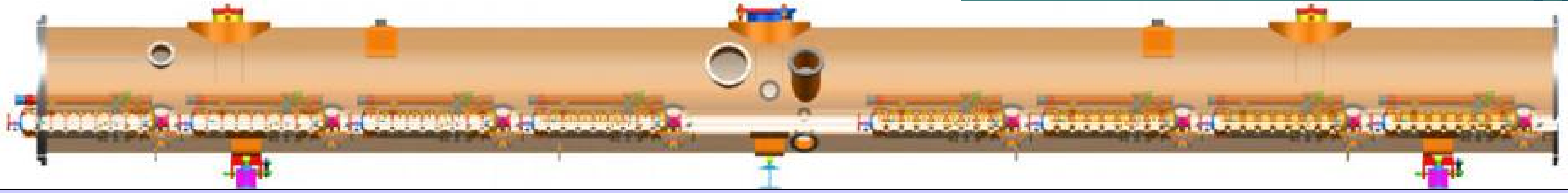
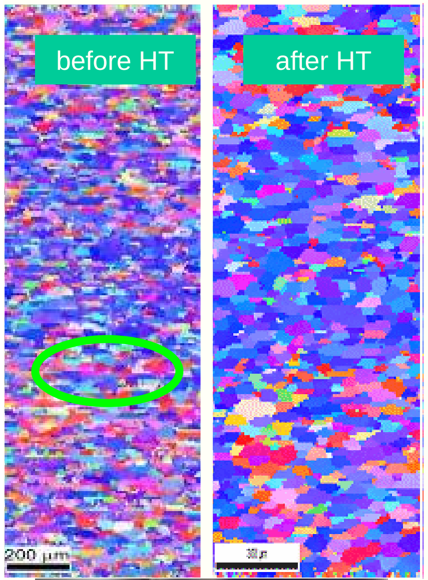
- **CAF can be used for small scale mass production assembly area for cryomodules. With the fixtures / tooling procured & installed in FY07.**
  - **ILC R&D quantity Cryomodules can be assembled at CAF.**
- **To increase the assembly capacity to 1 cryomodules per month, get industry involved, additional infrastructure will be needed for CAF, especially for CAF-ICB.**
  - **Cold Mass Assembly Fixture**
  - **Vacuum Vessel Assembly Fixture**
  - **Rail System for Cavity Support**
  - **Tooling**





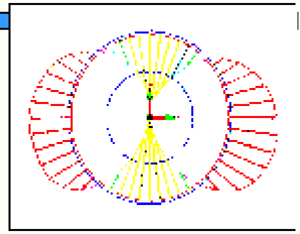
Cryomodule Assembly Facility (MP9 & ICB): $1.2M

Material R&D



Forming Problems at AES:

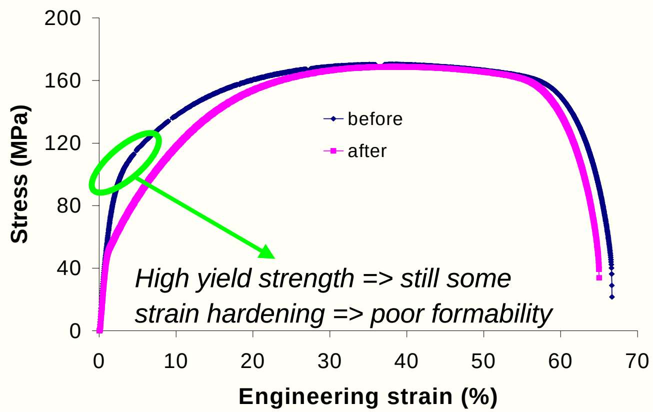
Nb too hard, spring back, 6 passes vs 1, ovalization…

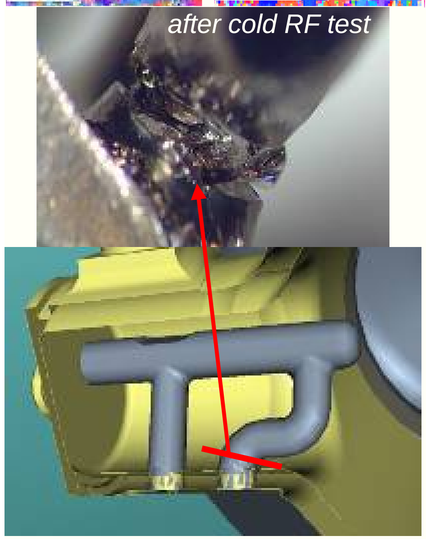


Deviation from circular shape

Microstructure & Mechanical Properties studied (MSU):

- ***Diagnostic: non fully recrystallized material***
- ***Recommendations***
  - *Re-annealing of the batch (~ 200 sheets)*
  - *QA : delivered material should meet tightly specifications*
  - *We must work with the suppliers to help them to meet specification*





Antenna breaking in HOM coupler

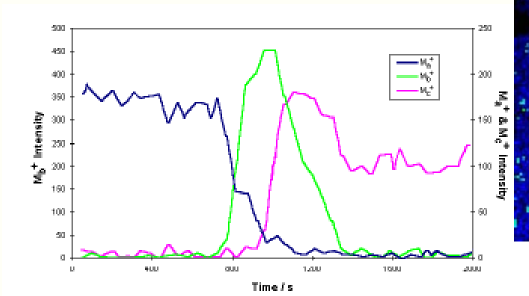
- ***Diagnostic: brittle fracture, but precursor cracks during processing ?***
- ***Recommendation***
  - *We need to know better cold and room temperature mechanical properties of Nb*

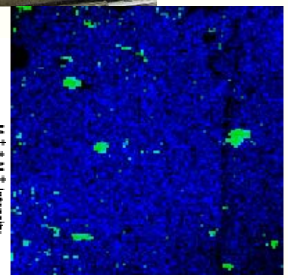
Material Characterization : Mechanical, surface chemistry

Systematic testing of new batches (QA) + Failure analysis

- **RT and Cold mechanical properties**
  - **data for modeling (forming, mechanical resistance , RF behavior…)**
  - **Recrystallization study (post doc student) => improving specifications for Nb**
  - **Crystal orientation/texture effects…**
- **Rapid SIMS characterization**
  - **High detection sensitivity (metal or non-metal)**
  - **Spatial resolution 10 μm (horizontal) and 1 nm (depth)**
  - **Large size sample (100 mm round)**
  - **Very robust/reproducible analysis conditions => allows to gather statistics**
- **Additional benefit**
  - **Hydrogen, oxygen embrittlement at low temperature**
  - **Effect of welding (mechanical, chemical)**
  - **Grain boundary strength, composition**
  - **Oxide layer study**
  - **Weaker layer study/Coating study**

Saclay Setup





Material R&D: $1.96M

Required Funding

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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 & ICE	$	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 Center	$	20,000	$	4,050	$	28,605
Grand Total ($k)	**$**	**73,865**	**$**	**40,349**	**$**	**138,900**

Cavity and Cryomodule Fabrication and Testing Infrastructure ~$34.7 M

Summary

- **The Main Linac Cavity and Cryomodule R&D program and Infrastructure development as presented would**
  - **Impact and contribute toward the critical ILC R&D as proposed by ILC Task Forces**
  - **Build a minimal facility at Fermilab**
  - **Train people in SRF at Fermilab**
- **Get the US industry involved from the initial phases**
- **Position US and Fermilab to be a "Credible" and "qualified host" of ILC**

We request a strong support for the full program