ILC Cavity & Cryomodule Overview

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ILC Program

Fermilab

Outline

- Motivation and Goals
  - ILC-GDE
  - US Regional Team
  - International Collaboration
- Present and Developing SRF Infrastructure at Fermilab and Collaborating Institution
  - VTS
  - HTS
  - CAF
- Future SRF Infrastructure Proposal
- Summary

Charge for the Review

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1. What are the key R&D issues faced by the U.S. accelerator community in the area of SCRF?

2. What is the scope of facilities required at FNAL to address these key issues including those questions key to the success of the ILC?

3. Will the laboratory SCRF infrastructure started in FY06 and planned for FY07 and beyond be adequate to address these key issues, and on what time scale. Are the proposed solutions cost effective?

4. Does the laboratory make effective use of collaboration and existing SCRF assets at other laboratories and universities?

5. Does the SCRF plan for FY08 and beyond make use of and develop U.S. industry at an appropriate level?

6. Is the FNAL SCRF plan configured and prioritized in a such a way that it can be sensibly scaled back should all of the requested funds not be available?

Vision: SRF FY08-10 and Beyond

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- A new approach to managing the ILC R&D and US ILC Program has been proposed by the American Regional Team of the Global Design Effort (ART-ILC-GDE) and US Regional Team (USRT)
  - Develop a national program for ILC
- A consortium of U.S. laboratories and universities already involved in SRF R&D will be the nucleus of this effort.
- The collaboration will, in close communication with the ART- ILC-GDE, ILC R&D Board, USRT and Major Laboratories (Fermilab and SLAC) managements would
  - establish goals
  - develop a technical and resource management plan to reach those goals.
  - The proposed plan has tried to make a balance between the scope and resources.
- "Credible" and "Qualified to be a Host": Invest in significant SRF infrastructure
- Strong international collaboration with DESY, the TESLA Technology collaboration (TTC), INFN, KEK, STF collaborations and others will be important.

International SRF Collaboration

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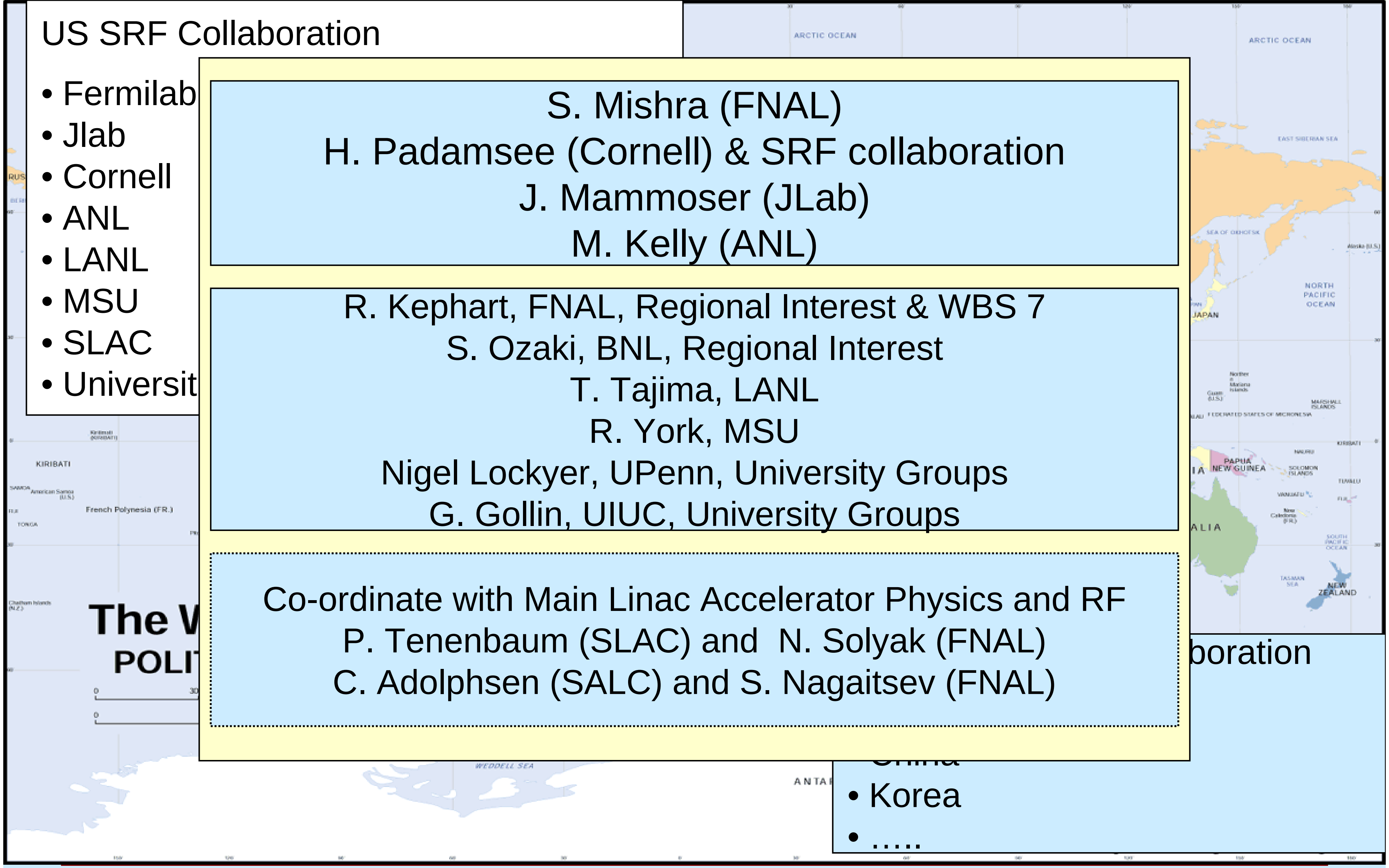

US SRF Collaboration

- Fermilab
- Jlab
- Cornell
- ANL
- LANL
- MSU
- SLAC
- Universit

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

boration

- China
- Korea
- …..

Overview: 3 Major Areas of SRF Work

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- Support S0, S1 and S2 goals (as discussed in GDE Task Forces)
  - Demonstrate ILC technology
  - Work with GDE, work with TTC
  - Install sufficient infra-structure to support activities
- Advance industrial capability for SRF in the US region to improve our readiness for ILC (as discussed in Regional Interest Panel)
  - US labs and industry need to gain command of main linac technology (core competency)
  - Industry and labs work closely together
- Carry out key ACD R&D items (as outlined in the BCD)
  - GDE wants a "forward looking" approach
  - Improve ILC performance, reduce cost

Technical Goals

- The technical goals are consistent with the ILC-GDE priorities as proposed by the S0, S1 and S2 Task Forces and the US Regional priorities (Ozaki Panel).
  - 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 one or more 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).
  - Develop plans for an ILC Main Linac System Test consisting of several rf units (S2.2).
  - Strengthen U.S. SRF technical capabilities and prepare the U.S. with the infrastructure, expertise and industrial capabilities necessary to host the machine.

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 (~10) cavities with gradients of 35 - 40 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 inadequate preparation.

Yield Improvement: 35 MV/m

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- 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.

Gradient R&D: Scope Details

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- S0 has two main parts (with subdivisions)
  - S0.1: Tight loop to improve "final preparation" yield
    - 1a. 9 best cavities globally x 3 tests each, cross calibrate regions (may need to start with 15-20 cavities)
    - 1b. Parallel/coupled R&D to improve yield (1-Cell Program, Study of failed cavity, Materail R&D, etc.)
    - 1a'. Repeat 3 cycles on 9 cavities with improved process
  - S0.2; Production-like activities to determine overall yield for cavity materials, fabrication and full cavity processing
    - 2a. First batch of about 36 cavities globally (12 US Cavities)
    - 2b. Second batch of about 150 cavities globally (50 US Cavities)
- Using an "optimistic model" for increasing production and process yield, USRT is considering the availability of 32, 96 and 96 good cavities during 2008, 2009, and 2010.
  - This will require more cavities to be ordered and processed

Cryomodule and RF Unit R&D: S1 and S2

- S1 Goal:
  - Prepare and test 3 or more ILC cryomodules
  - Demonstrate average gradient > 31.5 MV/m
- S2 Goal:
  - Small scale Test Facilities in all 3 Regions with 1 – 2 RF Units
  - In American Region the proposal is two build 2 RF Units
    - 1 learning RF unit with the goals of engineering development, cost reduction and initial industrial involvement
    - Plus 1 ILC RF unit with 31.5 MV/m operating gradient
  - A String of several RF units (number and models under discussion)
- Ideally S0.2 and S1 should interface with S2
  - Prepare the needed number of cavities in S0.2 for S1 and S2

Production Model: LHC vs. ILC

- The LHC requires 1200 cryomodules (15 m long) as compared to the ILC's 2000 modules (12 m long). (Superconducting Magnet a established Technology)
- After design and modeling work at CERN
  - 3 prototype coils were built in industry and modules assembled and tested at CERN.
- Prior to launching a large "pre-construction series,"
  - 9 modules (3 per vendor) assembled at CERN using facilities installed at CERN.
- Vendors then manufactured
  - Total of ~20 modules (7 per vendor).
  - ~6 of these were fully tested (2 per vendor) before starting the pre-construction series.
- Total of 32 modules were prepared by the CERN/industrial collaboration before launching the pre-series.
- The "pre-construction" series consisting of 90 modules by 3 vendors was successfully finished over a 2 year period.
- Upon completing the pre-series, CERN launched the final construction series of the remaining 1100 modules.

Cryomodule: US Infrastructure Development

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- These combined activities for Cavity and Cryomodule would demonstrate that ILC Main Linac Technology
  – is prepared for a multi-billion dollar project,
  – that regional institutions have gained adequate command of the technology,
  – that the regional industrial capability exists for the large scale, big expense components for ILC
    - cavities, cryomodules, refrigeration, and RF power.
- Industrial involvement would be encouraged in early cryomodule activities for future vendor training and qualification.
- Industrial personnel could assemble cryomodule using the infrastructure set up at the laboratories.
- Building significant number (~28) of cryomodules would better prepare industry to launch construction.
  – The staged approach (laboratory and Industry working together) would qualify industry to build modules, estimate costs, and finally lower costs in larger production stages during construction.

Infrastructure for Cavity and Cryomodule Fabrication, Processing and Testing

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- Bare cavity production (3-4 depending on number of vendors to develop)
  - Fabrication facilities (e.g. Electron beam welders)
  - Buffered Chemical Polish facilities (BCP) for cavity parts pre-welding
- 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-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
- Cryo-module test facilities
  - Cryogenics, pulsed RF power, LLRF, controls, shielding, etc.
  - Beam tests ➔ electron source (to test RF units)

Model: Processing and Testing Infrastructure

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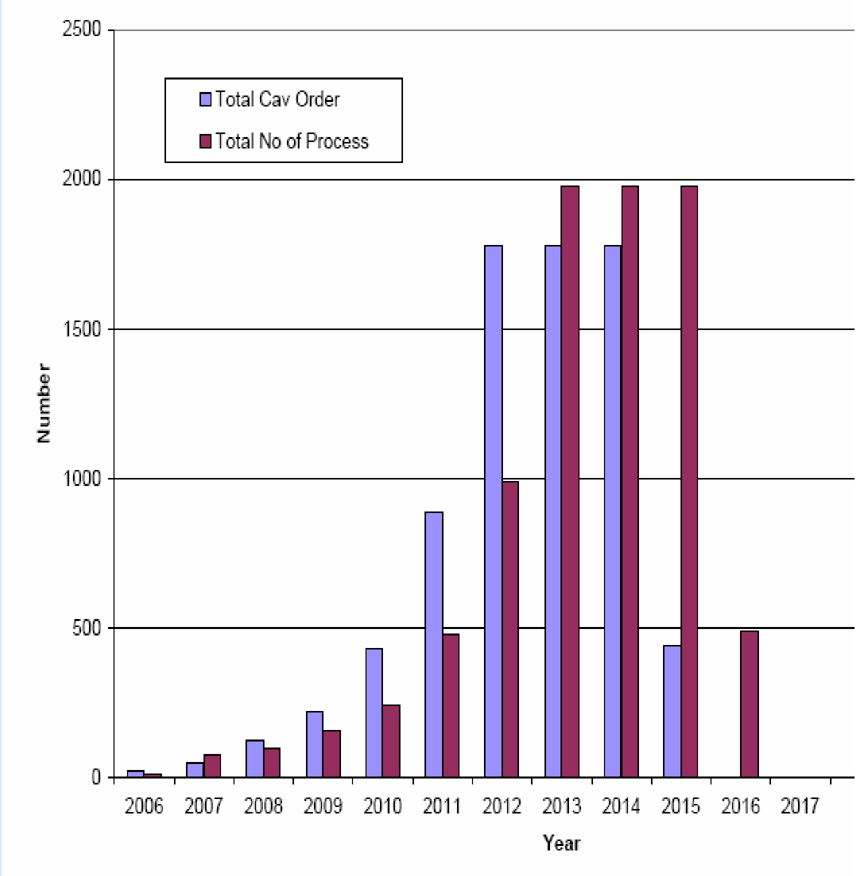
- Degrease & EP 80 um (3 days)
- HPR 1 day
- Drying 1 day
- H-removal, 600 – 800 C (3 days)
- Tune field flat (1 day)
- EP 10 um (1 day)
- HPR (1 day)
- dry (1 day)
- First stage assembly & HPR (1 day)
- Dry 1 day
- Final assembly to bake stand, evacuation (1 day)
- 120 C on bake stand (2 days)
- Assembly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



Present: US SRF Infrastructure Strength

- Limited cavity fabrication capability in US industry
  - One US company (AES) fabricating SRF cavity
  - Two new companies (Niowave and Roark) being developed
  - 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 70 cycles/yr (FY07)
  - Significant capacity will be used by supporting R&D Program
    - Process development
    - Single cell Processing
- Horizontal Test Stand
  - FNAL 24 cavities/yr
- Cavity Dressing and Cryomodule Assembly
  - FNAL 12/yr (FY07)

Scope: US SRF Infrastructure

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- Increased cavity fabrication capability in US industry
  - Electron Beam Welder
- Automated Cavity Tuning
  - 100+ Cavity/yr (by FY09)
- Processing and Vertical Testing (Pre-Production Facility, existing technology with industry redundancy)
  - 100+ Cavity/yr (by FY09)
- Horizontal Test Stand
  - Additional 48 Test/yr (Maximum Capacity needed)
- Cryomodule Test without beam
  - Cryomodule Test Stand (1 by FY10)
- RF Unit Assembly and test without and with beam

Cavity Fabrication Infrastructure

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Cavity Processing and Testing

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- The present US model of using distributed Cavity Processing and testing infrastructure 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.

- An integrated facility will allow significant improvement of the current preparation steps towards an industrial production-like level with a large enough throughput (~100 cavities/yr)
  - We have proposed build such a facility at Fermilab

Cavity and Cryomodule Infrastructure

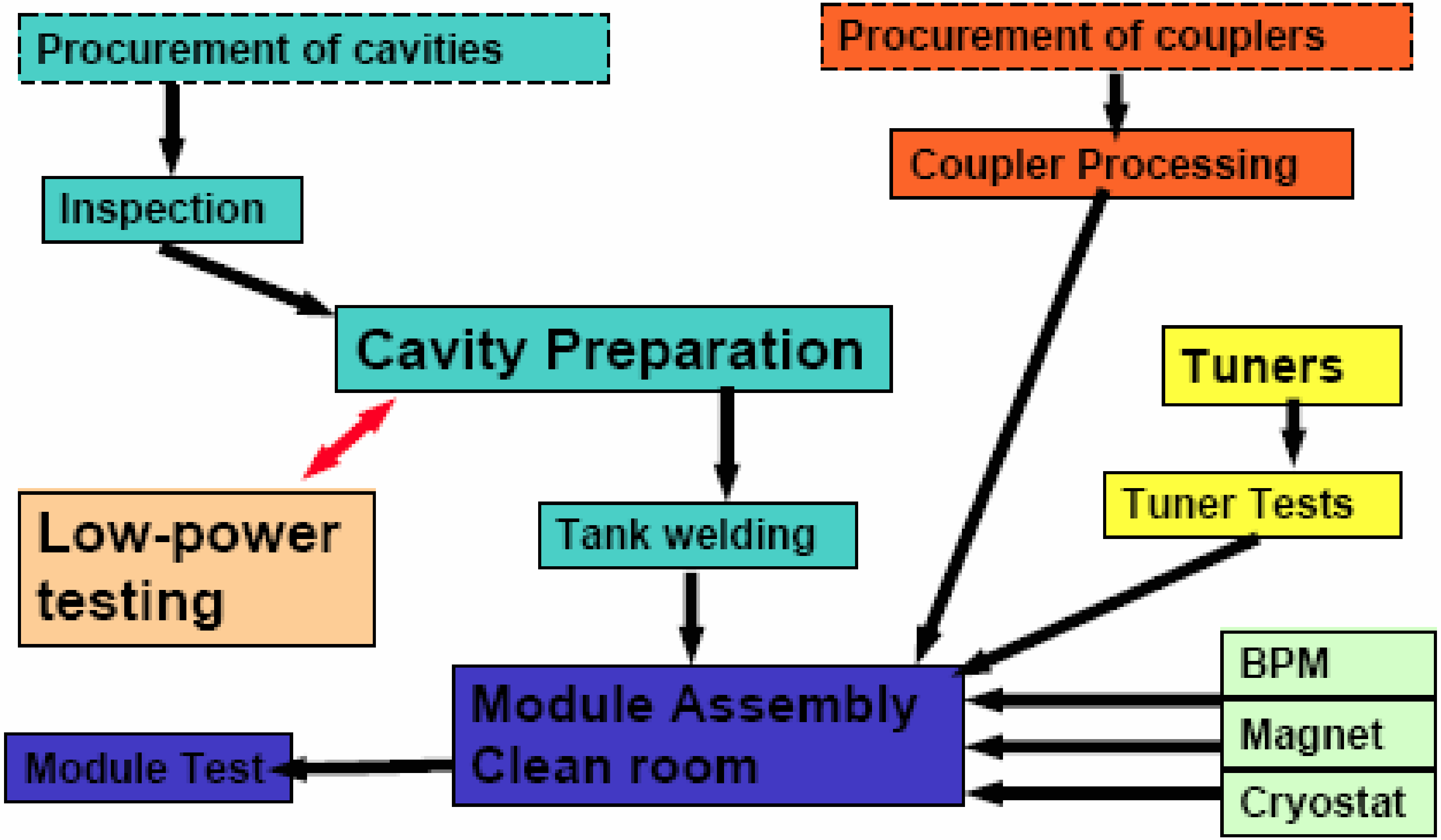

Figure 1: Sketch of the work-flow during an accelerator module assembly.

European Infrastructure Proposal

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

DESY Infrastructure Downtime

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Failure rate of components and infrastructure downtime
[total down time in working days]

year	2000		2001		2002		2003		2004	
	failure	days	failure	days	failure	days	failure	days	failure	days
Cleanroom	3 times	5	5times	14	2times	20	5times	21	5times	35
Chemistry	9times	42	2times	11	2times	25	4times	27	2times	40
Reverse osmosis	2times	2	2times	11	4times	40	5times	34	2times	31
Ultrasonic bath	3times	9	1 time	11	1time	20	4times	28	0	0
HP - rinsing	7times	31	3times	122	2times	37	5times	40	4times	44

Success Oriented Planning: Several months of down time has not been considered.

Cavity Preparation Infrastructure

European Infrastructure Proposal

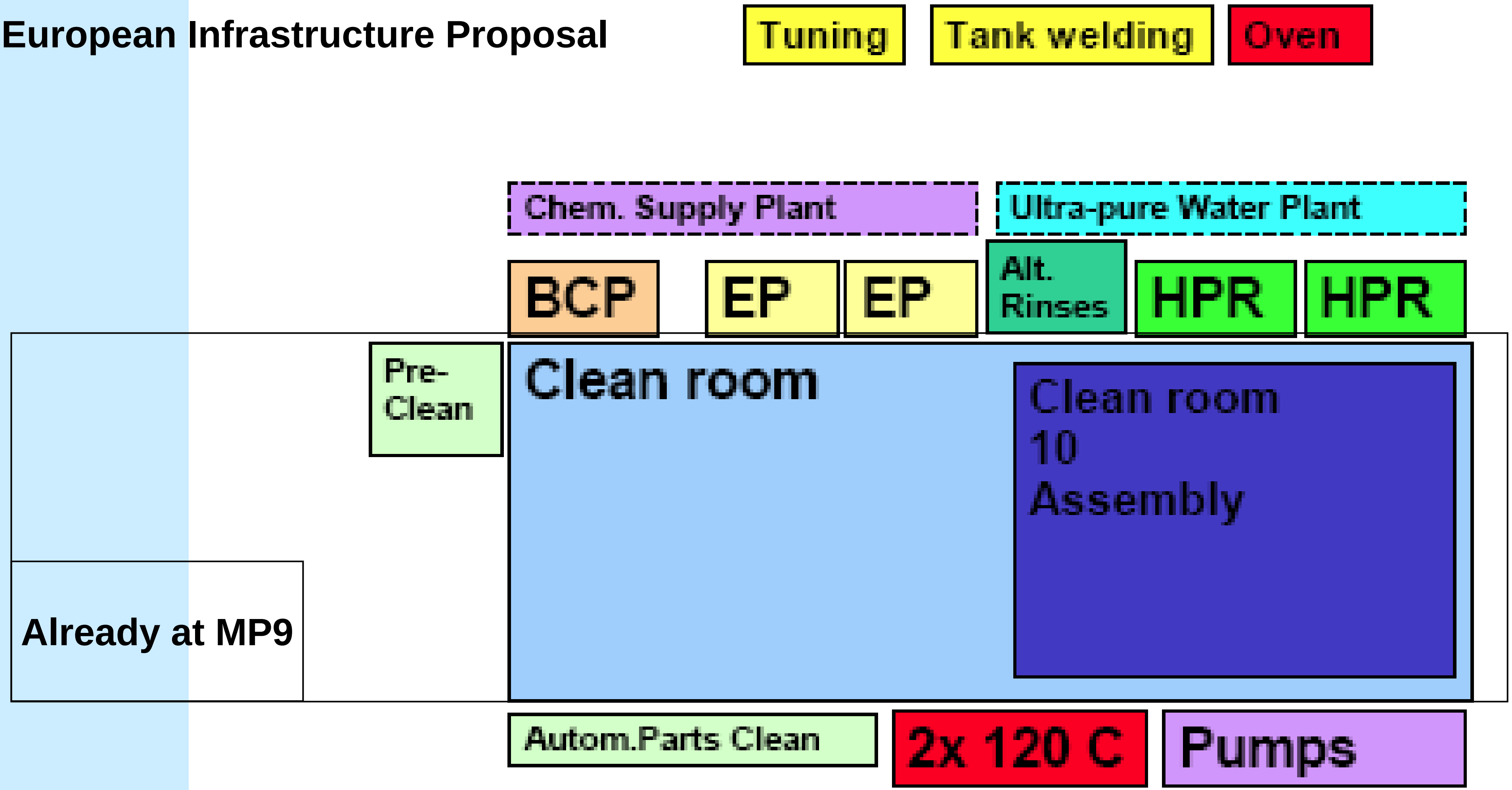

Figure 2: Sketch of the cavity preparation infrastructure.

Vertical Test Stands

Horizontal Test Stands

Cryomodule Design and Assembly

Cryomodule Test Stand

- US ILC R&D proposed to build 10's of cryomodule before production.
- The ILCTA_NML plan is to test first 5 Cryomodule.
- After that it will be dedicated for the RF Unit studies.
- We have proposed to build a Cryomodule test stand at ILCTA_ME next to the Horizontal Test Stand with the goal of having it operation by FY10.
- We need to collaborate with DESY on this project.

DESY's Cryo Module Test Bench

Upgrades to HTS and VTS

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- Fermilab is in process of installing a Horizontal and Vertical Test Stand with the initial capacity of
  - 70 (140) cavity test/yr in Vertical test stand
  - 12-24 cavity test/yr in Horizontal test stand
- Additional Vertical testing capacity will be needed for increased number of cavities beyond FY09.
  - We have proposed to add two more pits to the vertical test stand with shared cryogenics and RF infrastructure
- An additional Horizontal Test Stand with two cavities capability will be need to test a maximum of 5% of the ILC cavities.
  - This could be used for development of other hardware like RF control by having multiple cavities.

Jlab R&D Program

- R&D Program
  - Processing and Vertical Testing of 9 Cell Cavity for S0 program
  - Single Cell R&D to improve the Processing
  - Field Emission studies for tracking the contamination
  - ACD: LL Shape Cavities, Large Grain and Single Crystal
- Jlab Infrastructure Upgrade
  - Jlab has already commissioned a electro-polishing and vertical testing for ILC cavities
  - Development of Field emission studies
  - Incremental upgrade and maintenance of the facility

Cornell R&D Program

- R&D Program
  - Electro-polishing and testing of 9-cell cavities (S0)
  - Explore basic parameters for HPP with 9-cell ILC Cavity
  - Process and test two 9-cell re-entrant cavities (0.5 FTE)
    - Fine grain with EP, large-grain with BCP
- Cornell SRF Infrastructure Upgrade
  - Vertical EP
  - RF power source 300 – 400 Watt
  - Smaller diameter vertical test dewar

ANL R&D Program

- ANL R&D Program
  – Electro-polish ILC cavities for S0
  – Develop and improve processing parameters
  – Optimize existing EP hardware/Interface with U.S. EP vendors/develop and optimize hardware suitable for large-scale EP

- ANL SRF Infrastructure Upgrade:
  – Finish and commission the new EP system
  – Install new HPR system
  – Installation of a PLC-based control system for EP

MSU and LANL R&D Program

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- MSU R&D Program:
  - Cavity Autopsy (Yield Improvement)
  - Single Cell Cavity (R&D)
  - Advanced Cavity and Material Science studies (R&D)
- MSU SRF Infrastructure Upgrade:
  - Upgrade ultra-pure water and high pressure rinse
  - Nine-cell structure vertical test dewar
- LANL R&D Program:
  - Cavity Autopsy (Yield Improvement)
- LANL SRF Infrastructure Upgrade:
  - Re establish cavity testing at LANL
  - 1.3 GHz Power Amplifier
  - Thermometry (provided by Fermilab)

Fermilab SRF Program

- Order Cavity and Cryomodule parts
  - Material QC and R&D
- Vertical test processed cavities at collaborating laboratories
- Dress cavities with Power Coupler, Tuner etc.
- High Power test of dressed cavities
- Assemble and test cryomodule

Fermilab New Infrastructure Development

- Cavity Fabrication Infrastructure
- Design and build Cavity Processing Facility
- Upgrade to VTS and HTS
- Design and Build one Cryomodule Test Stand

SRF Funding

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Infrastructure	M&S		SWF		Total with Indirect	
Total of Cavity Infrastructure	$	3,000.00	$	675.00	$	4,374.86
Cavity Processing Facility	$	11,100.00	$	4,590.00	$	15,690.00
Total of Vertical Test Facilities	$	3,280.00	$	3,165.00	$	8,550.00
Total of Horizontal Test Stand	$	1,220.00	$	1,057.05	$	2,805.82
Cavity Dressing and Cryomodule Assembly Infrastruct	$	230.00	$	690.00	$	1,565.00
Cryomodule Test Stand	$	5,400.00	$	2,970.00	$	10,200.00
Total NML Infrastructure	$	17,600.00	$	20,641.50	$	47,099.83
Total Cryogenics	$	10,690.00	$	945.00	$	13,691.61
Illinois Accelerator Reseach Center Infrastructure	$	20,000.00	$	4,050.00	$	28,604.69
Grand Total	$	72,520.00	$	38,783.55	$	132,581.82

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 initial phase
  - Position US to be a “creditable” and “qualified host”
- We request a strong support for the full program.