ILC Cryomodule Industrialization in the U.S.

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ILC Schedule

- What are the next steps beyond the RDR ?
- During the TDR phase the focus will be:
  - Detailed engineering for site specific machine designs
  - Demonstration to funding agencies that the design and technology is ready for a multi-billion dollar project
  - Validation of cost estimates
- We need a schedule that charts the course from the current design and R&D phase through industrialization to construction
- A credible long range schedule is crucial for both project approval and for long term strategic planning in our field

ILC Schedule

- Cavity, cryomodule infrastructure, RF power sources and, civil design should all be focal points in developing this schedule because:
  - Extensive industrialization and infrastructure will be required
  - They are cost drivers
  - Cost & Risk mitigation are crucial elements for project approval
  - Verification of the technology, industrial capability, & cost will be required by funding agencies
- Because cryomodules represent such a large cost and require extensive industrialization and infrastructure
  - Need to develop a plan for how to ramp up production in industry prior to project approval
  - Need a plan to stage the required CM fabrication and test infrastructure so it is ready when needed
- Also need a plan to develop and demonstrate the performance and reliability of RF power source

SCRF Infrastructure

- The ILC requires extensive infrastructure for:
- Bare cavity production
  - Fabrication facilities (e.g. Electron beam welders)
  - Buffered Chemical Polish 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 facility (RF pulsed power)
- String Assembly Facilities
  - Large class-100 clean rooms, Large fixtures
  - Class-10 enclosures for cavity inner connects
- Cryo-module test facilities
  - Cryogenics, pulsed RF power, LLRF, controls, shielding, etc.
  - Beam tests ➔ electron source & instrumentation

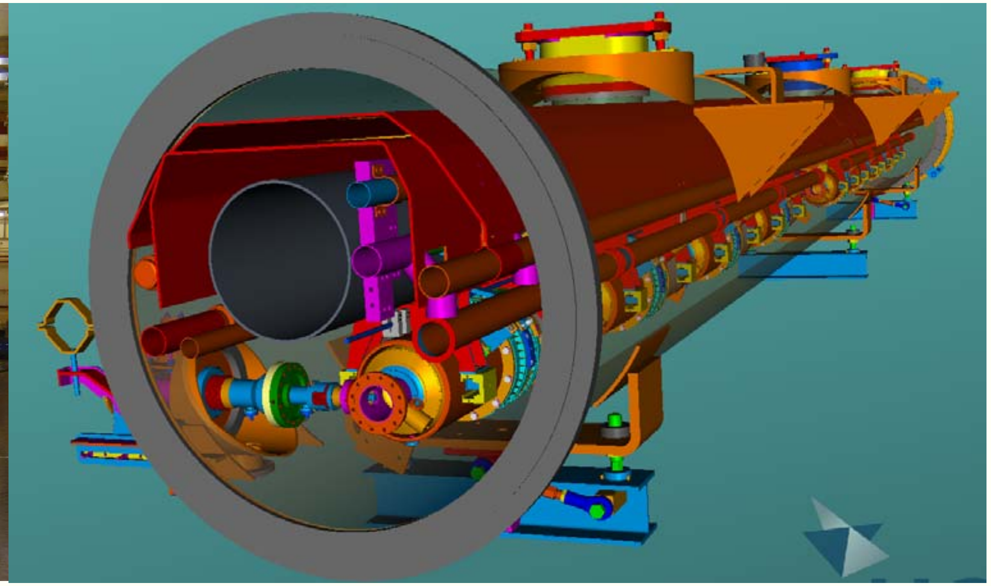
CM Infrastructure vs ILC Schedule

- We do not yet know the final process steps for ILC cavities ➔ some infrastructure must wait for critical R&D to be finished (e.g. EP vs BCP & large grain Nb)
- There is a big delay from the time infrastructure is ordered until it can be used to assemble cryomodules
- To build the ILC on the GDE schedule ➔at least PART of the infrastructure be in place before project approval (more on this later)
- Since in the U.S. industrial contracts cannot be bid prior to project approval ➔ a fast ILC start means that the initial infrastructure to build cryomodules is likely to be at labs.
- Also, it seems likely that cavity and cryomodule test areas will never be in U.S. industry ➔ need at labs also
  - Tests➔ Big cryo & RF systems, rad safety issues, $$$, etc
  - Facilities must be in place well in advance of project approval
  - Not useful to industry afterwards ➔ you pay full cost recovery
  - Europe, will not try this for XFEL. Asia ? Maybe…

Infrastructure Time Scales

- **Schedule: Purchase Order to operational item**
  - **Electron Beam welder: ~2.0 yrs**
  - **Large Class 10/100 clean room: ~ 1.5 yrs**
  - **Assembly tooling: ~ 0.5 yr**
  - **Large BCP or EP facility: ~ 1.5 yrs**
  - **Large Cryogenic plant: ~ 2.0 yrs**
  - **Vertical test facility: ~ 1.0 yrs**
  - **Horizontal test facility: ~ 1.0 yrs**
  - **Klystron + modulator: ~ 1.5 yrs**
  - **Build an industrial building: ~ 2.0 yrs**
- **Need also to add the time required to train the required technical staff**

Cryomodule



- ILC cryomodules are complex objects
- TTF cryomodules (type III) need to evolve for ILC
- FNAL is collaborating with DESY, INFN, KEK, CERN, JLAB, SLAC, and U.S. Industry on the design of the next generation ILC cryomodule (Type IV)
- Labs need to learn to built these, then pass that knowledge to industry… ➔need to build CM's in Industry !

Cryomodule ramp up

- **World experience:**
  - **DESY infrastructure has built 6 cryomodules (10 with rebuilds ?) for TTF. The rate was ~ 1-2 cryomodules/yr**
  - **TJNL successfully built 2 cryomodules/month for SNS**
- **Plans:**
  - **DESY XFEL plans 116 cryomodules in 5 yrs ➔ average of ~20 cryomodules/yr (peak = 50) in industry**
  - **ILC: For a 7 yr const schedule (funding approval to finish) we have about 5 yrs for the actual CM production ➔**
  - **Average rate of 400 CM/yr (peak ~ 600 CM/yr)**
- **My assertion: The cost of CM and associated infrastructure is such that it is extremely unlikely that this will be done in any one region (also regions want technology development)**
- **If I assume that a region builds 1/3 of the ILC CM on the RDR timeline ➔ average of 133 cryomodules/yr (peak =200)**
- **One cannot just switch on this huge industrial capability… it must ramp up over time so it is ready when we need it**

Model Assumptions

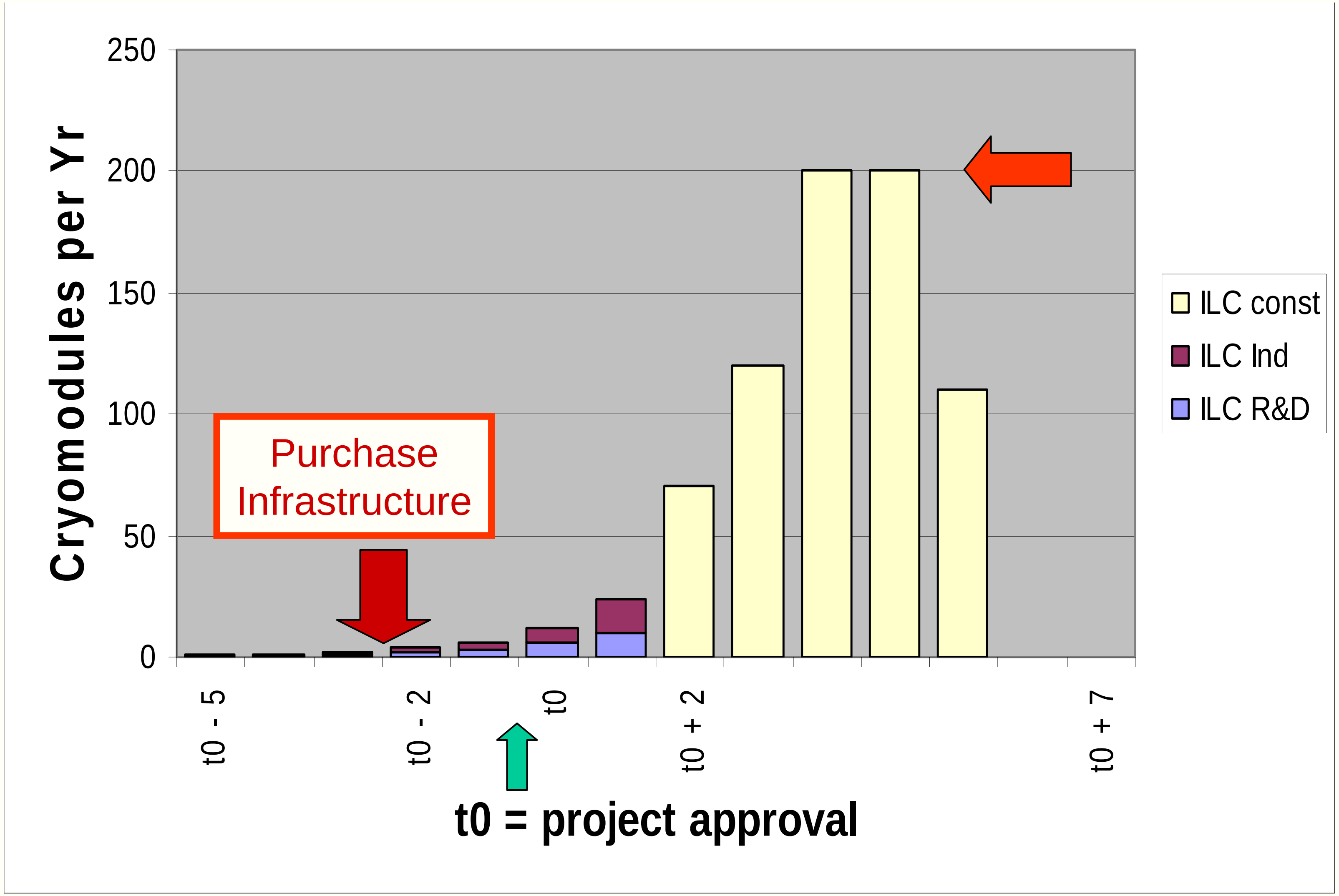
ILC Construction	7	yrs
Cryomodule construction	5	yrs
Cryomodules/linac	960	
Total ML cryomodules	1920	
RTML cryomodules	120	
1/3 = U.S. share	680	
Initial spares = 3%	20	
Total U.S. Plan	700	
Klystrons=cryomodules/3	233	
U.S. klystron hrs	39144	/ILC wk
Assumed lifetime	30000	hrs
Maintenance production	68	/yr

- **Note: Assumed peak cryomodule or klystron production rates set the cost of the required industrial infrastructure**
- I assume we want RF power sources for all CM produced

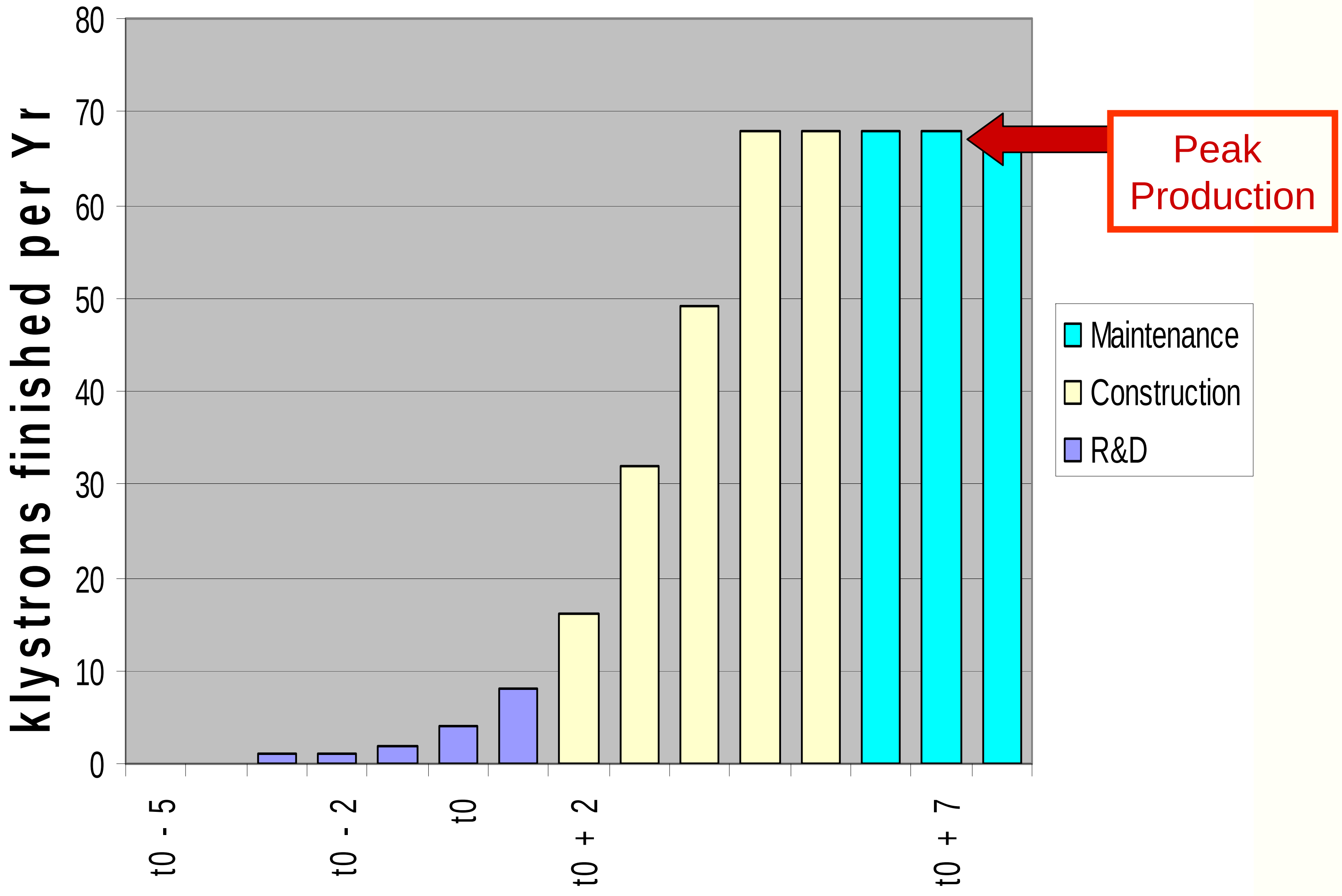
ILC
Americas

U.S. Cryomodules

Fermilab



U.S. Klystrons



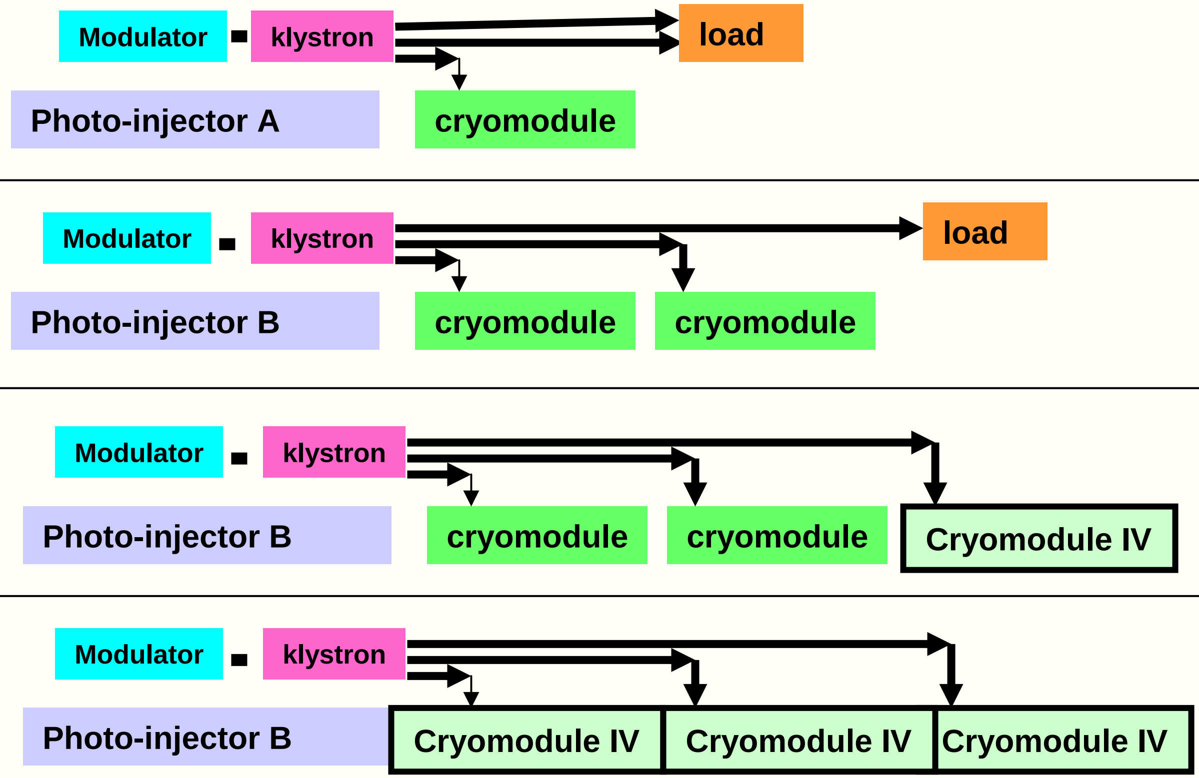
Spread sheet model

- Model required U.S. CM Infrastructure vs time
- Resource table (with Hasan)
  - Infrastructure system (eg. EP system, HPR, oven, etc)
  - Estimated throughput for that system (CM/yr)
  - Estimated Cost of infrastructure system
  - Delay from purchase order to operational system
- Assume that the overall U.S. capacity is set by the bottle necks in infrastructure
- Arrange "just in time" delivery of infrastructure so that infrastructure capacity always exceeds
- Assume CM parts and labor are $ 1.5 M (~ XFEL)
- See what this leads to in terms of when funds must be spent to meet schedule and overall costs
- Can vary assumptions to explore other options

What do you learn ?

- To achieve the GDE proposed ILC schedule:
  - We have to complete the R&D program to reliably achieve the ILC gradients with high yields (35 MV/m or lower it) in about 2 years
  - To develop the industrial capability required by the ILC schedule, we need to buy:
    - ~ $ 85 M (M&S) of "production" infrastructure
    - ~ $ 70 M of industrially produced Cryomodules
    - ~ $ 25 M industrially produced RF equipment
    - Or about $ 180 M prior to project approval (CD2 in DOE)
    - Over ~ 4yrs in present GDE plan
  - Infrastructure is assumed to be at labs so this estimate does not count buildings, etc.
  - These costs do not include the costs to design the machine itself, nor the rest of the ILC R&D program
  - More on this estimate in a minute

Current CM test Plan (ILCTA_NM)



Year	Cryomodule Number
07	1
08	2
09	3
10	4-5

By FY10, One RF unit= basic building block of ILC ML

By FY11, Two RF units

ILC RF unit = three ILC Type IV cryomodules, modulator, 10 MW klystron

Type IV design will not exist until FY07

~ 2 years before a module is delivered

Large Scale System Demonstration

- The current plan to build 1-2 RF units at ILCTA_NM is a useful first step (eg R1, R2 demonstration) but is not a sufficient technology demonstration to launch a multi-billion dollar project
  – XFEL plans 16 preproduction cryomodules in 3 batches (>10%) before series production
  – e.g. CERN LHC pre-series was 10% of full set of 1200 cryo-magnets (over 2.5 years)
  – U.S. needs a plan to develop its industrial capability (working with labs)
- Proposal: Make 8 more ILC RF units, 24 modules, 240 cavities (80% yield)
- Approximate Cost :
  – 1.5 M$ per module ~ 36 M$
  – Infrastructure to produce & test ~ 21 CM/year ~48 M$
  Total ~84 M$
- Install 7 units in a twin tunnel and build a 5 GeV linac (1.0% system test)
- Approximate Cost :
  – 7 RF sources (klystron, modulator, (via SLAC) ~ 25 M$
  – Cryogenics (use FNAL CHL) ~10 M$
  – Civil 300 m of ILC twin tunnel (near surface) + infrastructure ~31 M$
  Total ~66 M$
- ~150 M$ total but $ 109 M overlaps with industrialization costs on previous slides

ILC
Americas

Infrastructure to build ~ 7 RF units/yr

Fermilab

- Size infrastructure at 10% = 21 CM/yr (scale x 10 to build ILC)

• 2 e-beam welders	$ 4 M
• Processing (BCP + Clean room)	$ 3 M
• EP systems (2)	$ 3 M
• VTS (1 cavity/wk/system => 4 systems)	$ 3 M
• HTS (1 cavity/2 wks ➔ 8 systems)	$ 12 M
• Module assembly (MP9 Clean room + fixtures)	$ 2 M
• Module test (1/month➔ 2 + 1 stands)	$ 13 M
CM Total	$ 40 M

- Need another $ 8 M for klystron test stands and coupler processing facility @ SLAC ➔ total is about $ 48 M

Processing: 3 total: Fermilab/Argonne, Jlab and one at Los Alamos/MSU/Cornell
- A lot of infrastructure already exists at these places

Install EP facility at Fermilab/Argonne, Cornell/MSU, : total $ 2 M
- Basic chemistry facilities exist, need to add EP

VTS systems = Cornell, TJNL, MSU, FNAL ILCTA_IB1, IARC (1→4)
HTS systems = ILCTA_MDB, ILCTA_IB1(2), TJNL, IARC(4-6)
Module test = IARC (3 stands)

Large Scale System Demonstration

- **How long will it take to execute this plan ?**
  - I'm not sure… we need to work that out
  - First priority is to build and install cryomodule infrastructure at U.S. labs and contract fabrication work out to industry
  - Industry and labs should work closely together
  - Build CM in groups paying careful attention to cost. Review cost after each ~5 CM and then adjust the fabrication and assembly procedures, to get a new cost point for the next 5
  - By the time you are finished (3-5 yrs) the cost curve from U.S. industry and extrapolation will be believable.
  - Lots of overlap with current plans to build infrastructure
  - Cavity and cryomodule test facility for 2 modules per month can be in new 35 M$ State of Illinois (IARC) building at FNAL
  - There is lots to do in developing a sensible ILC schedule

Conclusions: Next steps

- We need to develop a plan to ramp up industrial production of Cryomodules in each region.
- Need to make substantial investment in the required CM infrastructure prior to project approval.
- In the U.S. it seems likely that much of this infrastructure will need to be at national labs… other regions may have different models but must achieve the same outcome
- We need to make an ILC construction schedule with realistic time estimates, achievable milestones, and which includes resources and time to create the required infrastructure
- We need to agree on what large scale technology demonstrations are needed to show that we are ready to build this large project and how this might fit into the overall ILC project timeline.

XFEL Next Modules 2005-2008

Order at Zanon
Sep-05

M8

M9

Goal:
Modify for Type3+
Must:compatible with
Type3(spare TTF)
Learn specification

Order at A, B, C
3x2 cryostats
Sep-06

M A1

M B1

M C1

Goal:
3 producers
improved design
Type 3++

2007

M A2

M B2

M C3

Goal:
3 producers for
XFEL prototype
best solution

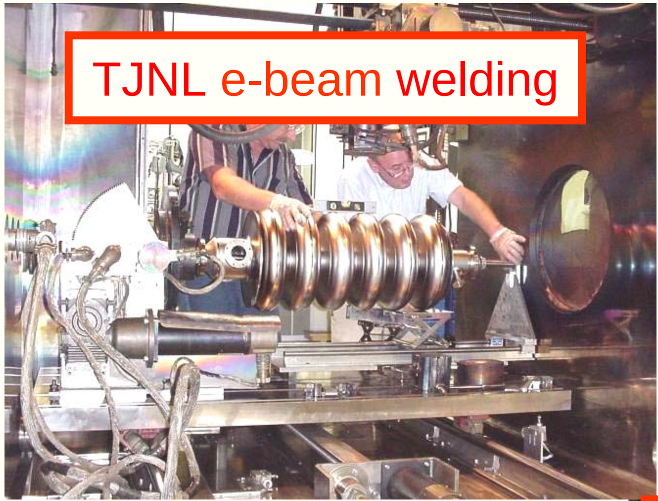
Order at ?
5 cryostats
2008

Goal:
Production and
Test of 5 XFEL
preseries
modules

ILC Americas

Examples: SCRF infrastructure

Fermilab


TJNL e-beam welding


Chemistry

Horizontal Test of Dressed Cavity @ DESY


TJNL Electro polish

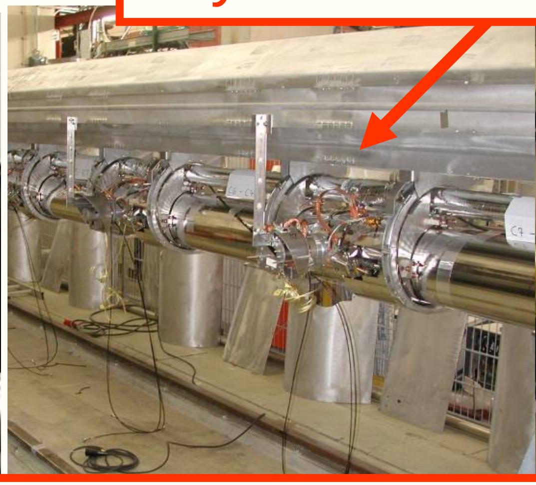
Cryomodule Test at DESY TTF

Examples: Cryomodule Assembly

Assembly of a cavity string in a Class-100 clean room at DESY

The inter-cavity connection is done in class-10 cleanroom

Cryomodule Assemby at DESY

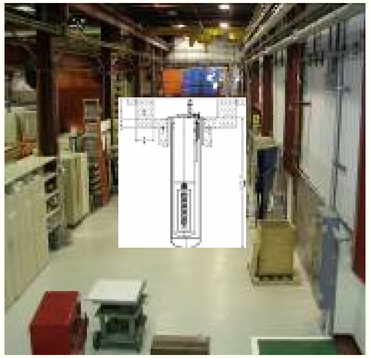


Lots of new specialized SCRF infrastructure needed for ILC!

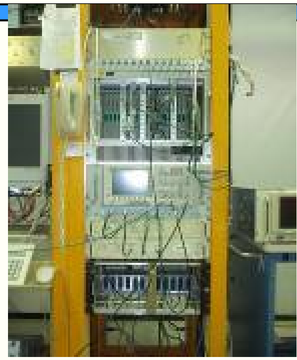
Fermilab ILC Infrastructure

Eddy Current Scanner

Cavity Vertical Test Stand

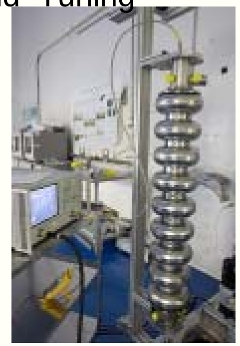


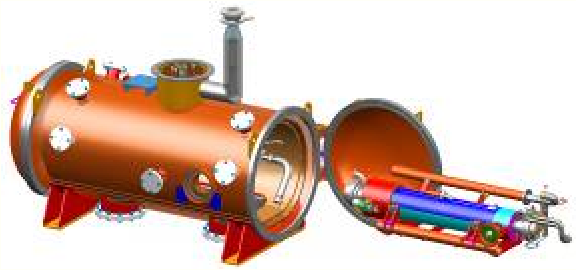
LLRF



Cavity String Assembly Clean Room Class 10/100

RF Measurement and Tuning





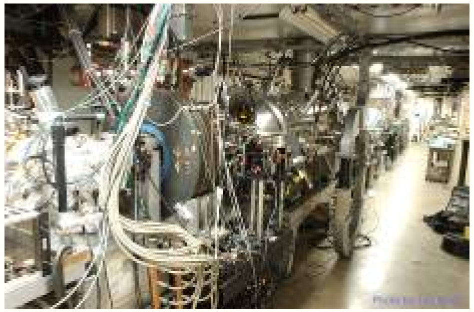
1.3 GHz Cavity at 2 K

Cryomodule Assembly @ MP9

BCP Facility at ANL

Horizontal Test Stand

Fermilab Photo-injector



ILCTA @ Fermilab