Overview of Regional Infrastructures for SCRF Development

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Introduction

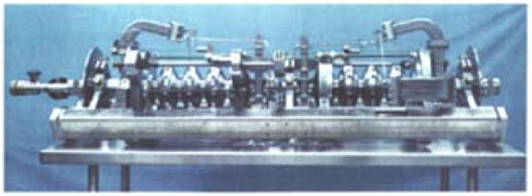
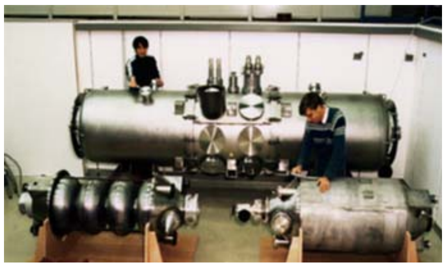
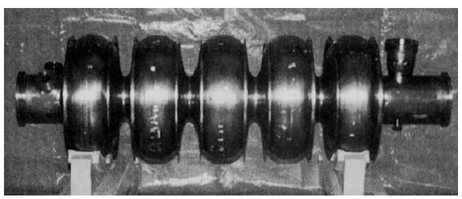
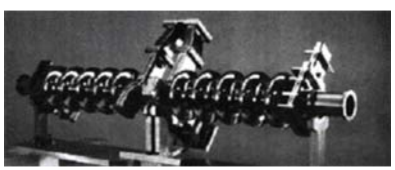
- Superconducting RF has been developed to efficiently transmit energy to a variety of particle beams
- For the first few decades the maximum usable accelerating field has been limited by the allowable technology in term of material production, cavity treatments and handling
- The construction and operation of hundreds of SRF cavities at JLab for **CEBAF** and at CERN for **LEP II** set the basis for a new level in quality control and industrialization
- Deeper understanding of the limiting factors pushed the technology to be compatible with the new challenging demands
- The **TESLA** challenge to use SRF as the basic technology for the future TeV e^+e^- Linear Collider impressed the momentum to move SRF Technology to a new frontier, opening a new era
  - ***Accelerating fields exceeding 35 MV/m***
  - ***Quality factor higher then 10^{10}***

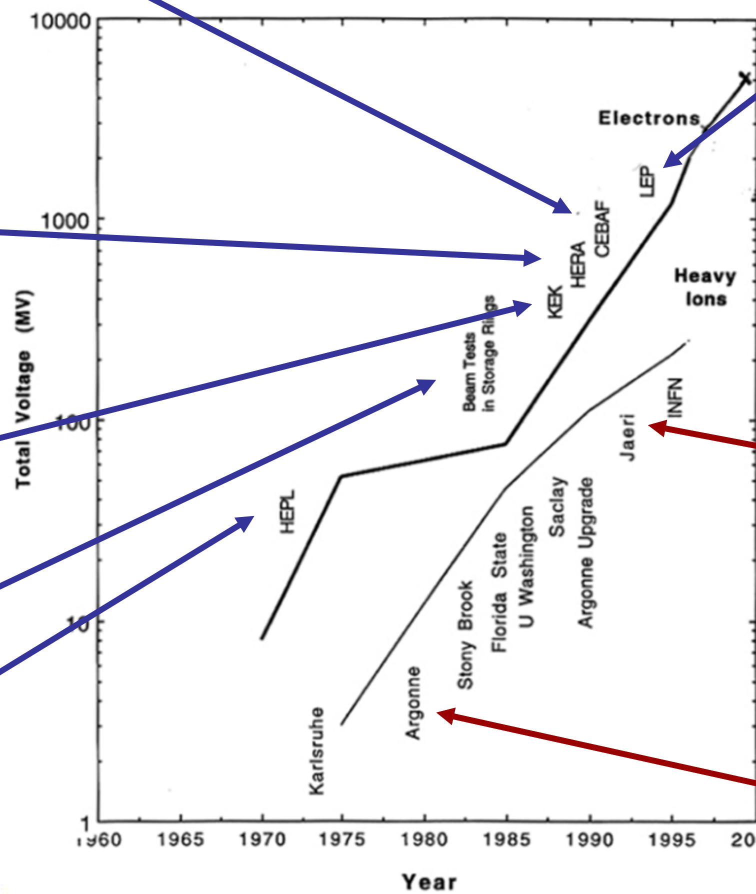
All major steps based on new large infrastructures

SRF before 2000

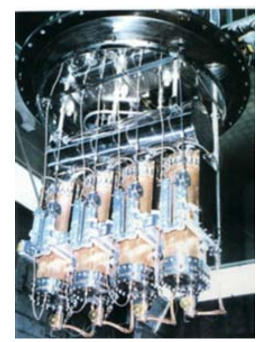
"Livingston Plot" from Hasan Padamnee

Total Installation > 1000 m
Provided > 5 GV








ILC is a Demanding Project

- 16,000 cavities have to be produced with performances close to the limit demonstrated so far
- Each cavity is integrated in a cavity package that includes power coupler, HOM couplers and slow and fast tuners
- All cavity packages have to be integrated into cryomodules maintaining their performances
- To respect the required reliability and availability goals for ILC, each cavity package must have a MTBF (mean time between failure) of the order of 1 million hours.
- Cavity to be accepted have to pass a vertical test with the following minimal performances in term of Field a Quality factor: Eacc = 35 MV/m, $Q = 8 \cdot 10^9$
- ILC is designed and costed on the basis of the following average cavity performances: Eacc = 31.5 MV/m, $Q = 10^{10}$

Early Age Limiting Problems

Poor material properties

- Moderate Nb purity (Niobium from the Tantalum production)
- Low Residual Resistance Ratio, RRR → Low thermal conductivity
- Normal Conducting inclusions → Quench at moderate field

Poor cavity treatments and cleanness

- Cavity preparation procedure at the R&D stage
- Poor rinsing and clean room assembly not yet introduced

Microphonics

- Mechanical vibrations in low beta structures → Higher RF power

Multipactoring

- Major limit for HEPL and electron linacs to 1984
- Poor codes and surface status

Quenches/Thermal breakdown

- Low RRR and NC inclusions

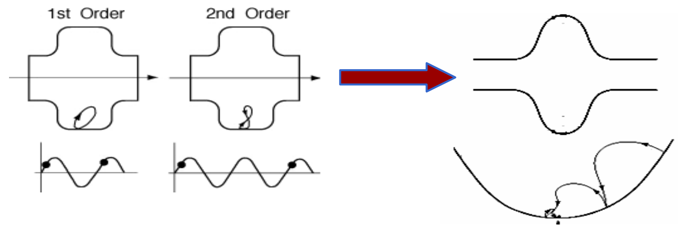
Field Emission

- General limit at those time because of poor cleaning and material defects

R&D waiting for big projects

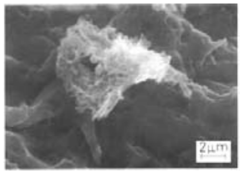
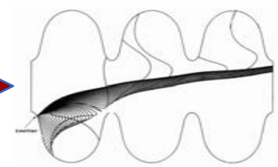
Multipactoring

- A few computer codes developed
- Spherical shape realized at Genova and qualified at Cornell & Wuppertal



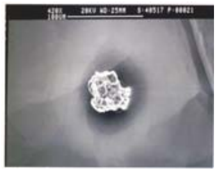
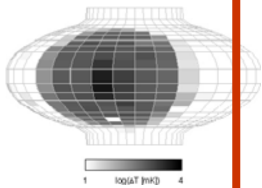
Field Emission

- Emitters were localized and analyzed
- Improved treatments and cleanness

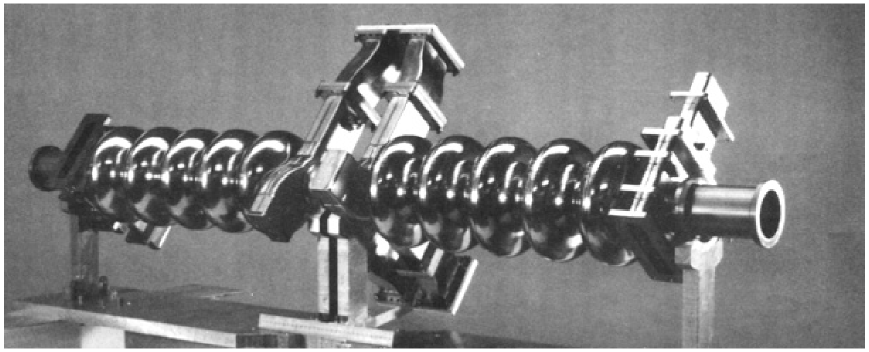



Quenches/Thermal Breakdown

- Higher RRR Nb

E_{acc} > 5 MV/m



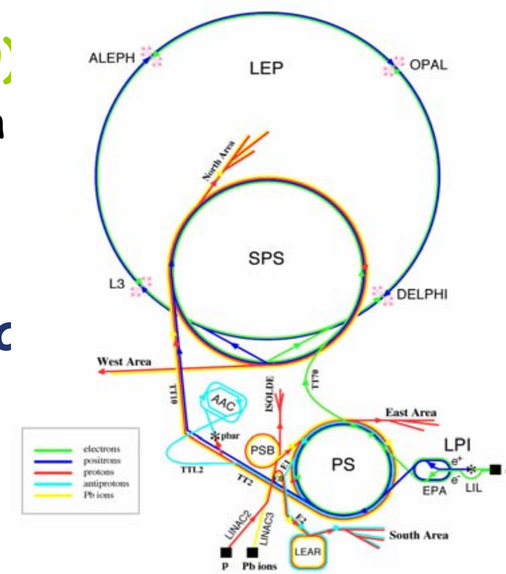
1984/85: First great success

- A pair of 1.5 GHz cavities developed and tested (in CESR) at Cornell
- Chosen for CEBAF at TJNAF for a nominal E_{acc} = 5 MV/m

Impressive grow from middle ‘80

Multi-cell, β = 1, cavities for large storage rings

- KEK/TRISTAN – (from 1987 to 1989)
  - 200 MV peak RF voltage to the beam per revolution
  - 32 x 5-cell cavities @ 508 MHz
- DESY/HERA – (from 1991 to 1993)
  - 75/30 MV peak RF voltage to the electron beam
  - One string of 16 x 4-cell cavities @ 500 MHz
- CERN/LEP II – (SC upgrade from 1996 to 2000)
  - > 3.65 GV peak RF voltage to the beam per revolution
  - 288 x 4-cell cavities @ 352.2 MHz (256 Sputtered)



Multi-cell, β = 1, cavities for recirculating linac

- TJNAF/CEBAF – (from 1995 to 1999)
  - 600 MV RF voltage to beam per linac pass
  - 338 x 5-cell cavities @ 1497 MHz RF

Large project impact on SCRF

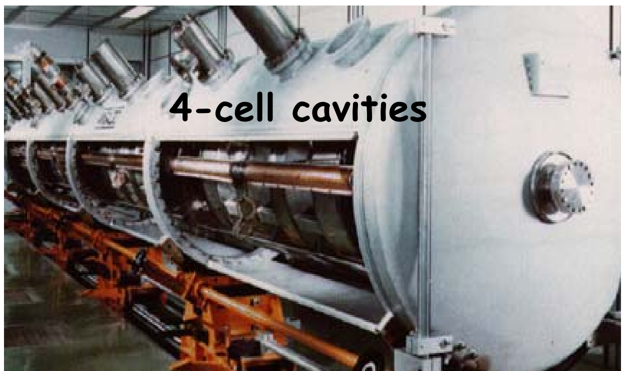
- The decision of applying this unusual technology in the largest HEP and NP accelerators forced the labs to invest in Research & Development, infrastructures and quality control
- The experience of industry in high quality productions has been taken as a guideline by the committed labs
- At that time TJNAF and CERN played the major role in SRF development, mainly because of the project size
- The need of building hundreds of cavities pushed the labs to transfer to Industry a large part of the production
- The large installations driven by HEP and NP produced a jump in the field
- R&D and basic research on SRF had also a jump thanks to the work of many groups distributed worldwide

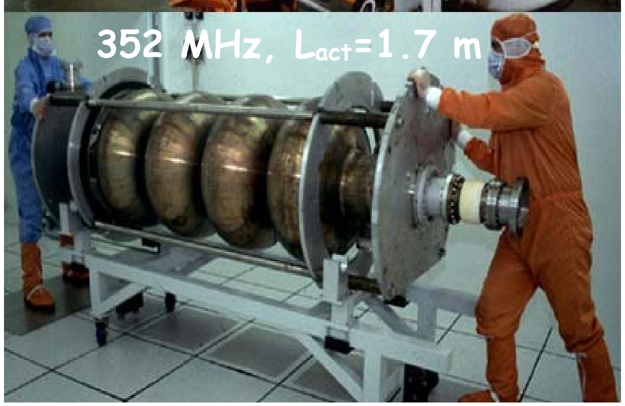
CEBAF and LEP II

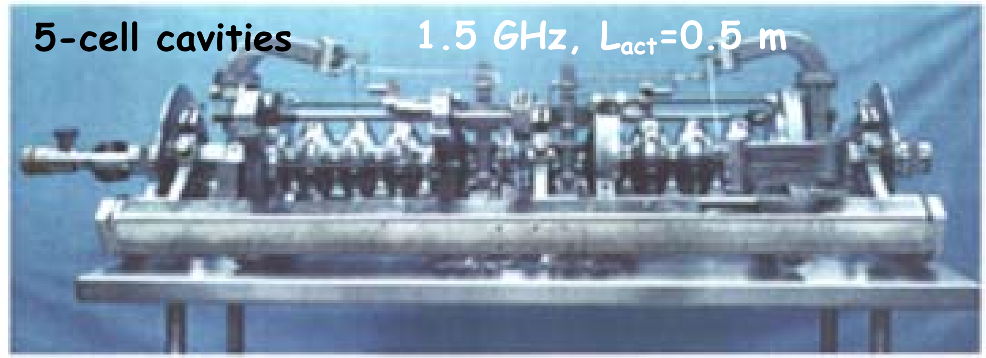
CEBAF

338 bulk niobium cavities

- Produced by industry
- Processed at TJNAF in a dedicated infrastructure







LEP II & CERN

32 bulk niobium cavities

- Limited to 5 MV/m
- Poor material and inclusions

256 sputtered cavities

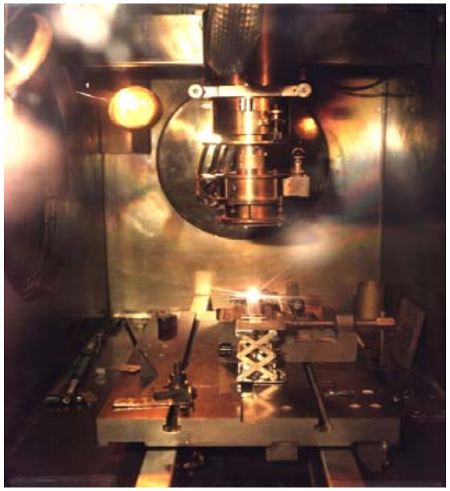
- Magnetron-sputtering of Nb on Cu
- Completely done by industry
- Field improved with time
  $\langle E_{acc} \rangle$ = 7.8 MV/m (Cryo-limited)

Important technological steps

- Use of the best niobium (and copper) allowable in the market at the time
- Industrial fabrication of cavity components with high level quality control
- Assembly of cavity components by Industry via Electron Beam welding in clean vacuum
- Use of ultra pure water for all intermediate cleaning
- Use of close loop chemistry with all parameters specified and controlled
- Cavity completion in Class 100 Clean Room
  - **Final cleaning and drying** (UV for bacteria and on line resistivity control)
  - **Integration of cavity ancillaries**

That is

New level on Quality Control



Electron Beam Welding

Clean Room Assembling

A great success for CEBAF

Processing and conditioning improve cavity performances, when not limited by material defects (hard quench)

- Field emission moves to higher field
- Accelerating Field improves with time

2 K operation very reliable and well understood

All ancillaries perform quite well

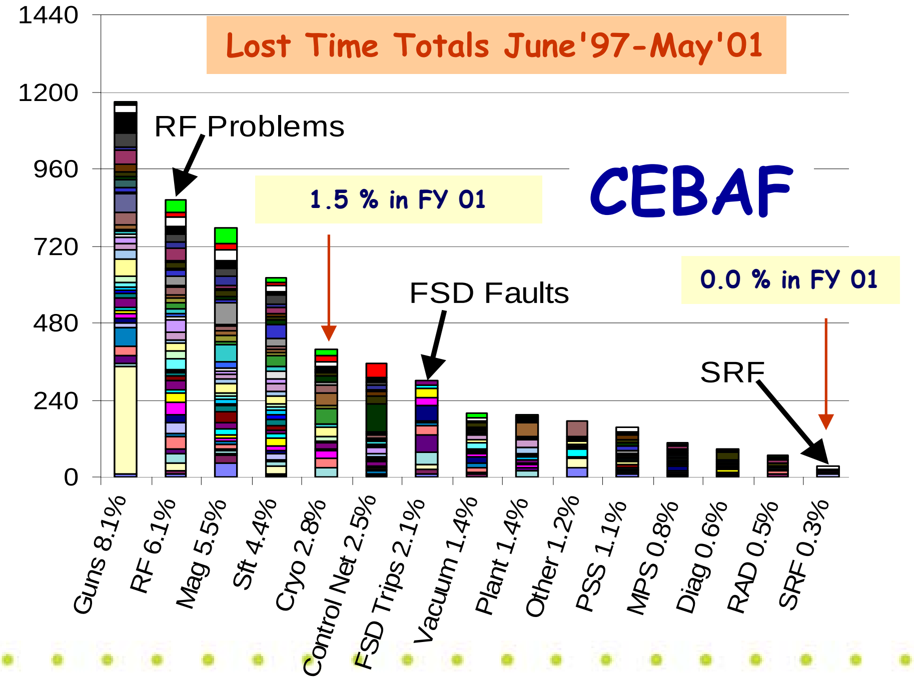
Maximum energy and beam current above the design values

CEBAF performances finally limited by the installed cryo-power and RF-power

Excellent reliability of SRF technology

High availability for physics

The only warm-up for
Isabelle Hurricane

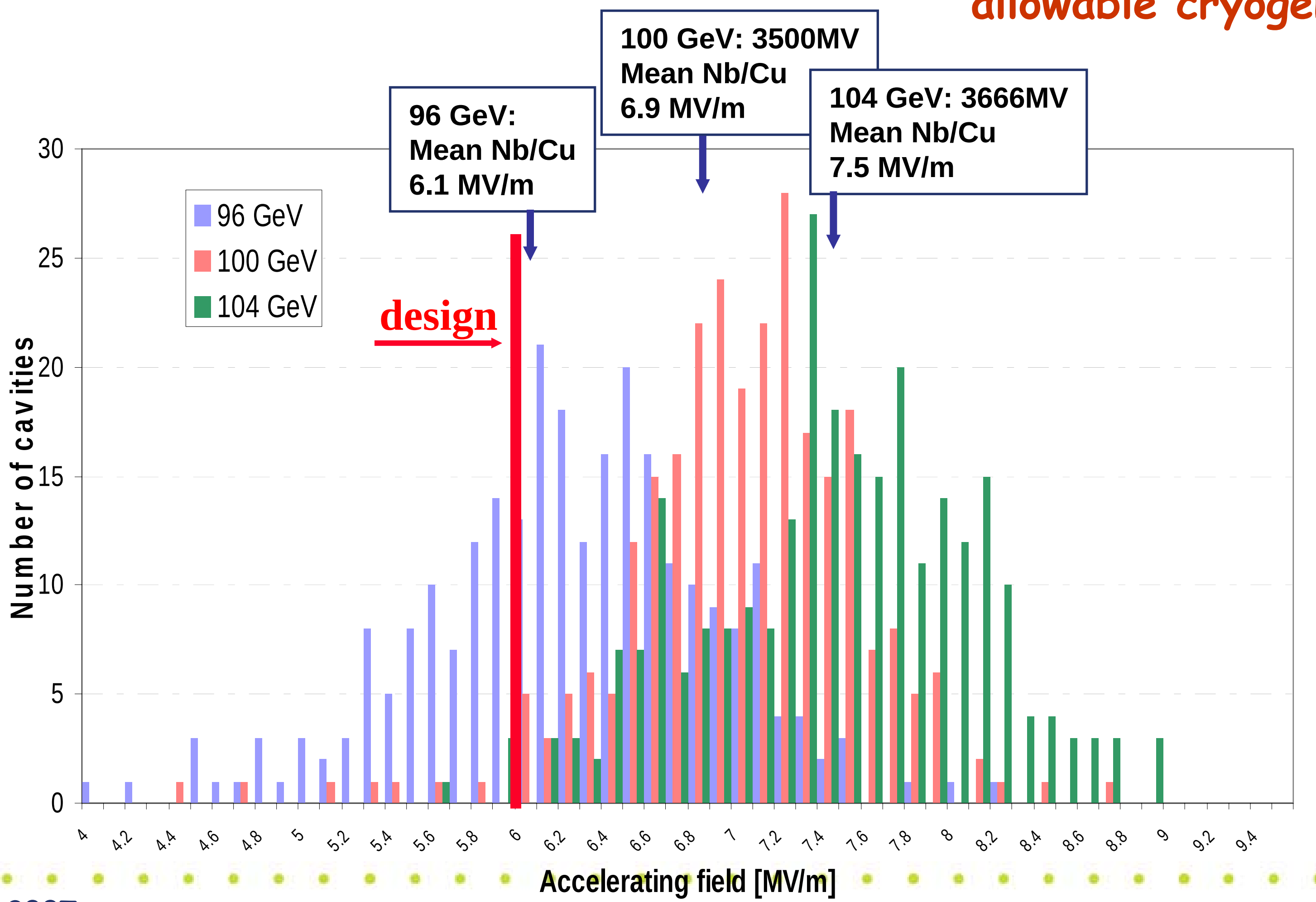


A great success for LEP II

Accelerating Field Evolution with time

from G. Geschonke's Poster for the ITRP visit to DESY

Final energy reach
limited by
allowable cryogenic power



Same lessons learned

- **Bulk Niobium** is preferred to push **for gradient** and **quality factor**
- Magnetron sputtering looks better at lo frequency (LHC) when beam current is more important than accelerating field
- **Cryogenics** systems are **highly reliable** and produced by industry
- SRF ancillaries can be designed to be as reliable as the one required by the Normal Conducting RF technology
  - **SRF quality controls end to be a plus**
- For high gradient, $\mathbf{E_{acc}}$, and high quality factor, **Q**, **Niobium quality** has to be pushed to the possible limit
- **Quality control** during cavity production and surface processing has to be further improved. High Pressure Rinsing can make the difference
- **Basic R&D** and technological solutions must move together
- When fabrication procedures are fully understood and documented, **Industry** can do as well and possibly better

The TESLA Mission

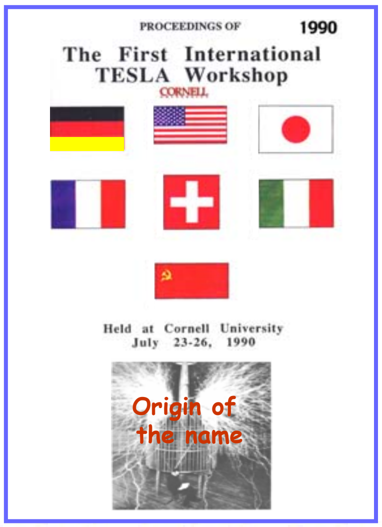
Develop SRF for the future TeV Linear Collider

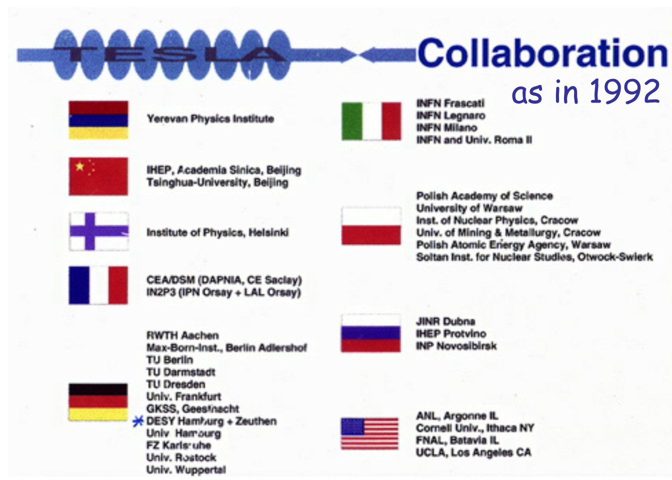
Basic goals:

- **Increase gradient by a factor of 5** (Physical limit for Nb at ~ 50 MV/m)
- **Reduce cost per MV by a factor 20** (New cryomodule concept and Industrialization)
- **Make possible pulsed operation** (Combine SRF and mechanical engineering)

Major advantages vs NC Technology

- **Higher conversion efficiency**: more beam power for less plug power consumption
- **Lower RF frequency**: relaxed tolerances and smaller emittance dilution

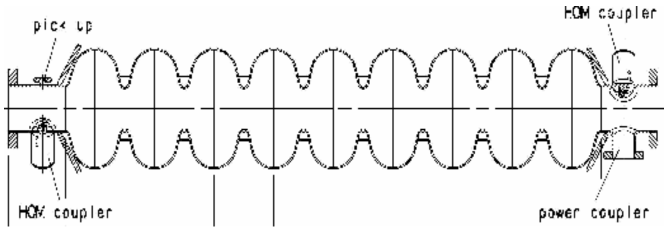


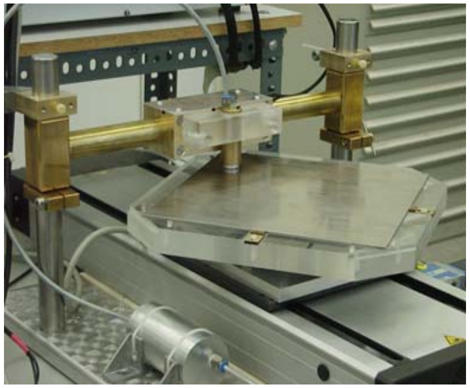


TESLA cavity design and rules

Major contributions from: CERN, Cornell, DESY, CEA-Saclay & LASA

- 9-cell, 1.3 GHz





Eddy-current scanning system for niobium sheets

Cleanroom handling of niobium cavities

TESLA cavity parameters

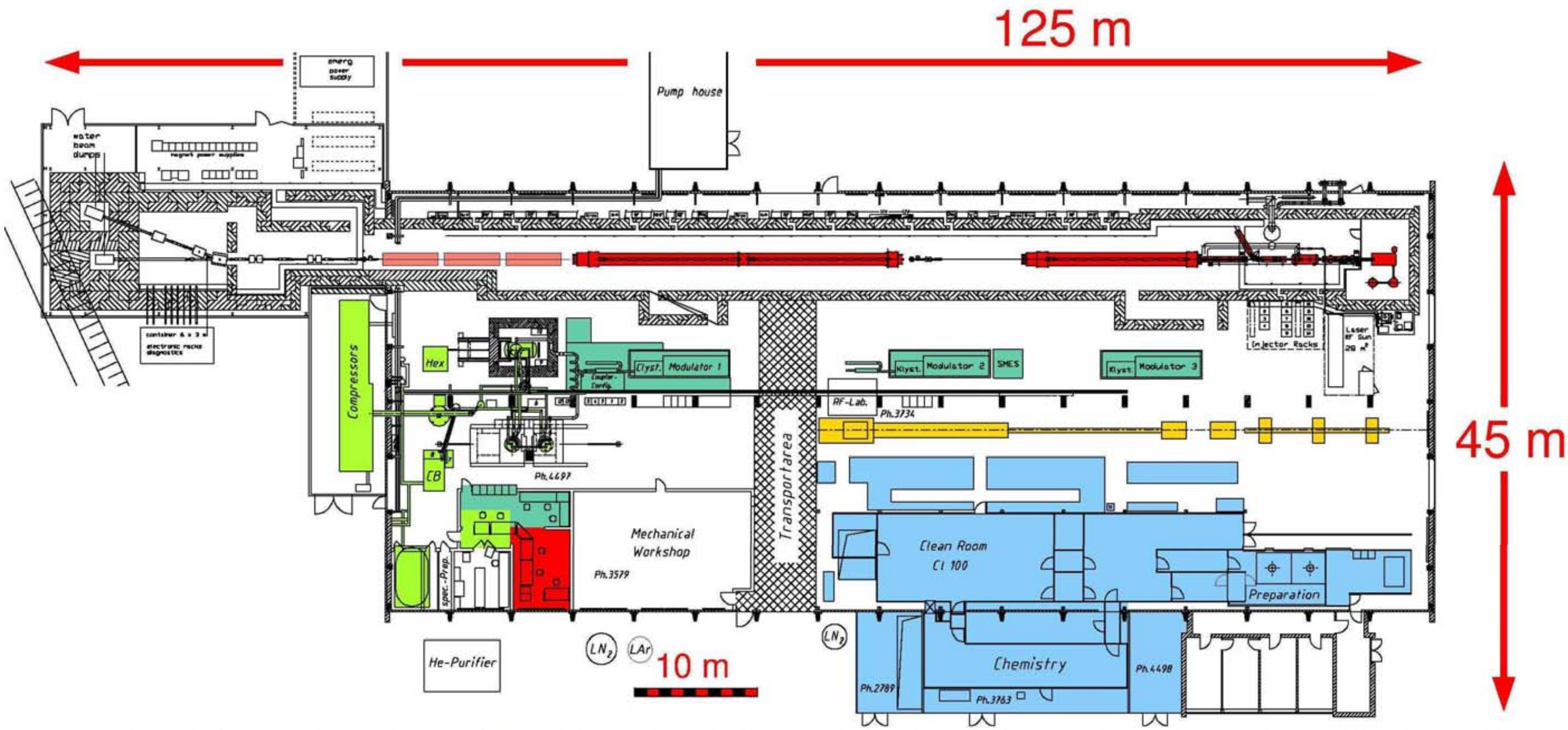
R/Q	1036	Ω
E_{peak}/E_{acc}	2.0	
B_{peak}/E_{acc}	4.26	mT/(MV/m)
Δf/Δl	315	kHz/mm
$K_{Lorentz}$	≈ -1	$Hz/(MV/m)^2$

Preparation Sequence

- Niobium sheets (RRR=300) are scanned by eddy-currents to detect avoid foreign material inclusions like tantalum and iron
- Industrial production of full nine-cell cavities:
  - Deep-drawing of subunits (half-cells, etc.) from niobium sheets
  - Chemical preparation for welding, cleanroom preparation
  - Electron-beam welding according to detailed specification
- 800 °C high temperature heat treatment to stress anneal the Nb and to remove hydrogen from the Nb
- 1400 °C high temperature heat treatment with titanium getter layer to increase the thermal conductivity (RRR=500)
- Cleanroom handling:
  - Chemical etching to remove damage layer and titanium getter layer
  - High pressure water rinsing as final treatment to avoid particle contamination

New dedicated infrastructure at DESY

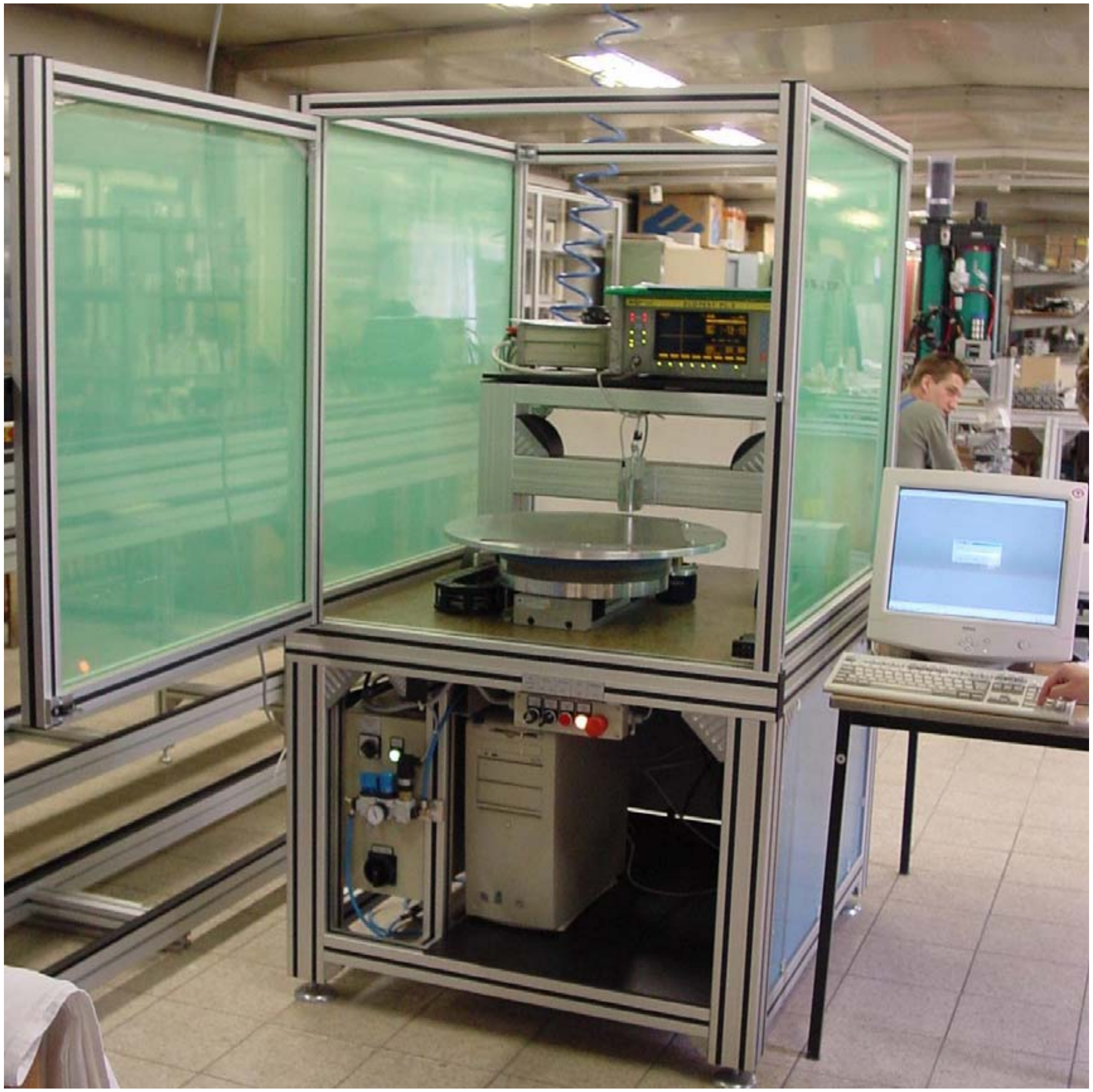
- Scanning niobium material for inclusion
- Clean closed loop chemistry (Buffer Chemical Polishing – BCP)
- High Pressure Rinsing, HPR, and clean room drying
- Clean Room handling and assembling (Class 10 and 100)



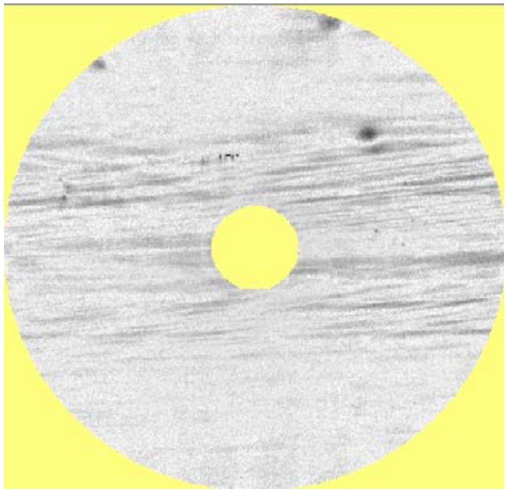
Large Infrastructure Role

- Cavity production with industrial style
  - Parameter control along all the process
  - Quality control on material and components
  - Quality assurance for reproducibility
- Cavity test with high throughput all all possible diagnostics
  - Highly professional testing set up
  - Vertical test of naked cavity
  - Horizontal test of cavity package
  - Cavity instrumentation to identify the limits
  - R&D to link problems to production steps
- Ancillary qualification and integration into the cavity package
- Cavity integration into a performing cryomodule
- From a cavity cryomodule to a complete accelerator
- Beam test of the Linac prototype

Eddy Current Scanner for Nb Sheets



Scanning results

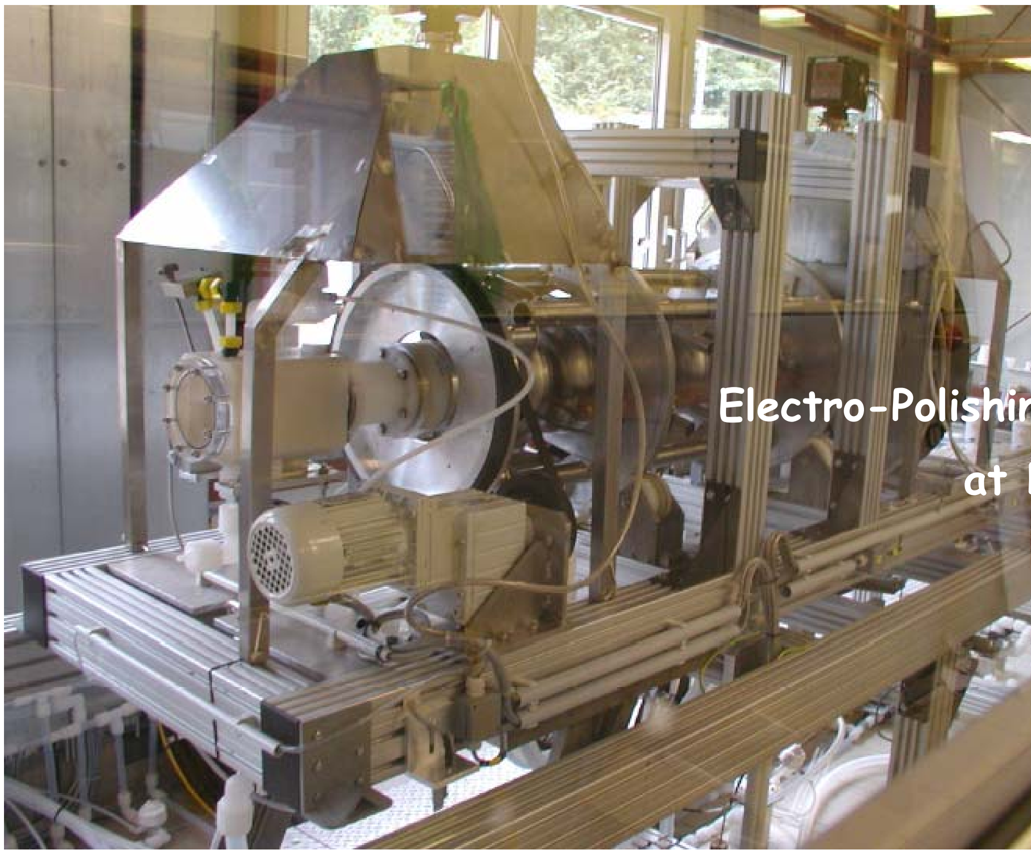


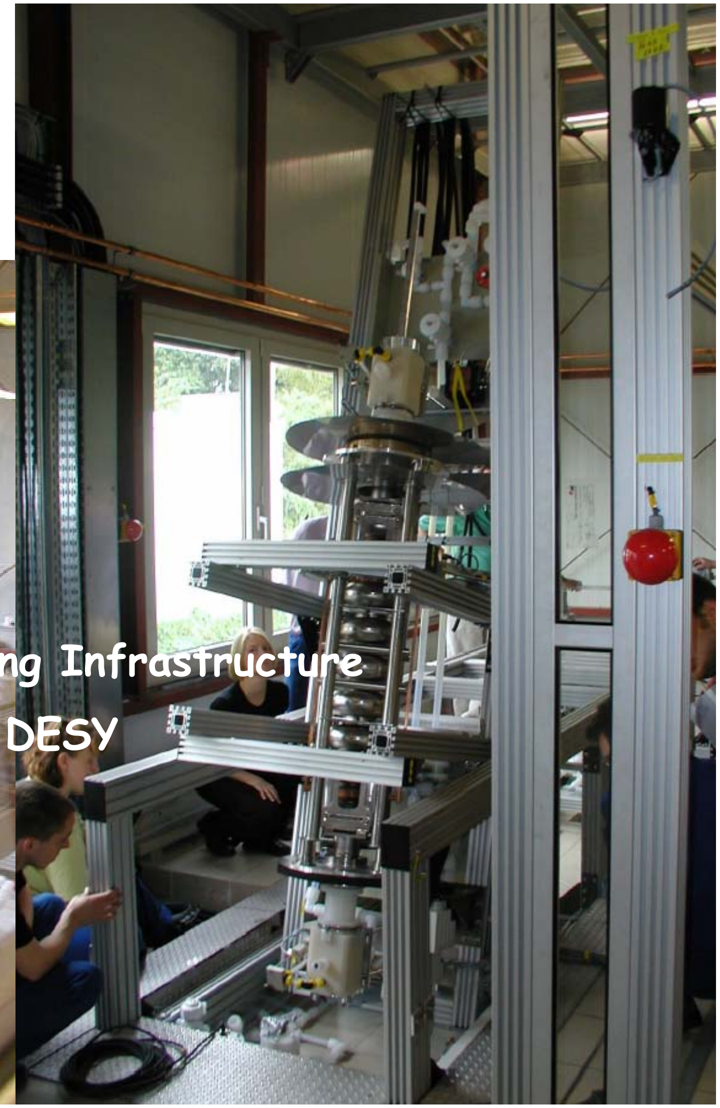
- Rolling marks and defects are visible on a niobium disk to be used to print a cavity half-cell.
- Surface analysis is then required to identify the inclusions

Chemistry, HPR and String Assembly

Electro-Polishing set up at DESY

- Electro-Polishing preferred for high performances
- Parameter control more demanding





String Assembly

The assembly of a string of 8 cavities

- is now a standard procedure
- is done by technicians from the TESLA Collaboration
- is well documented using the cavity database as well as an Engineering Data Management System
- was the basis for two industrial studies.

Technology transfer of the complete established procedure to industry ready for the EU X-FEL.

The inter-cavity connection is done in class 10 cleanrooms

Module Assembly

The module assembly is a well defined and standard procedure.

- experience of 10 modules exists
- the latest generation (type III) will be used for series production (XFEL requires 120 modules)
- several cryogenic cycles as well as long time operation were studied
- the assembly problems occurred are well understood and cured

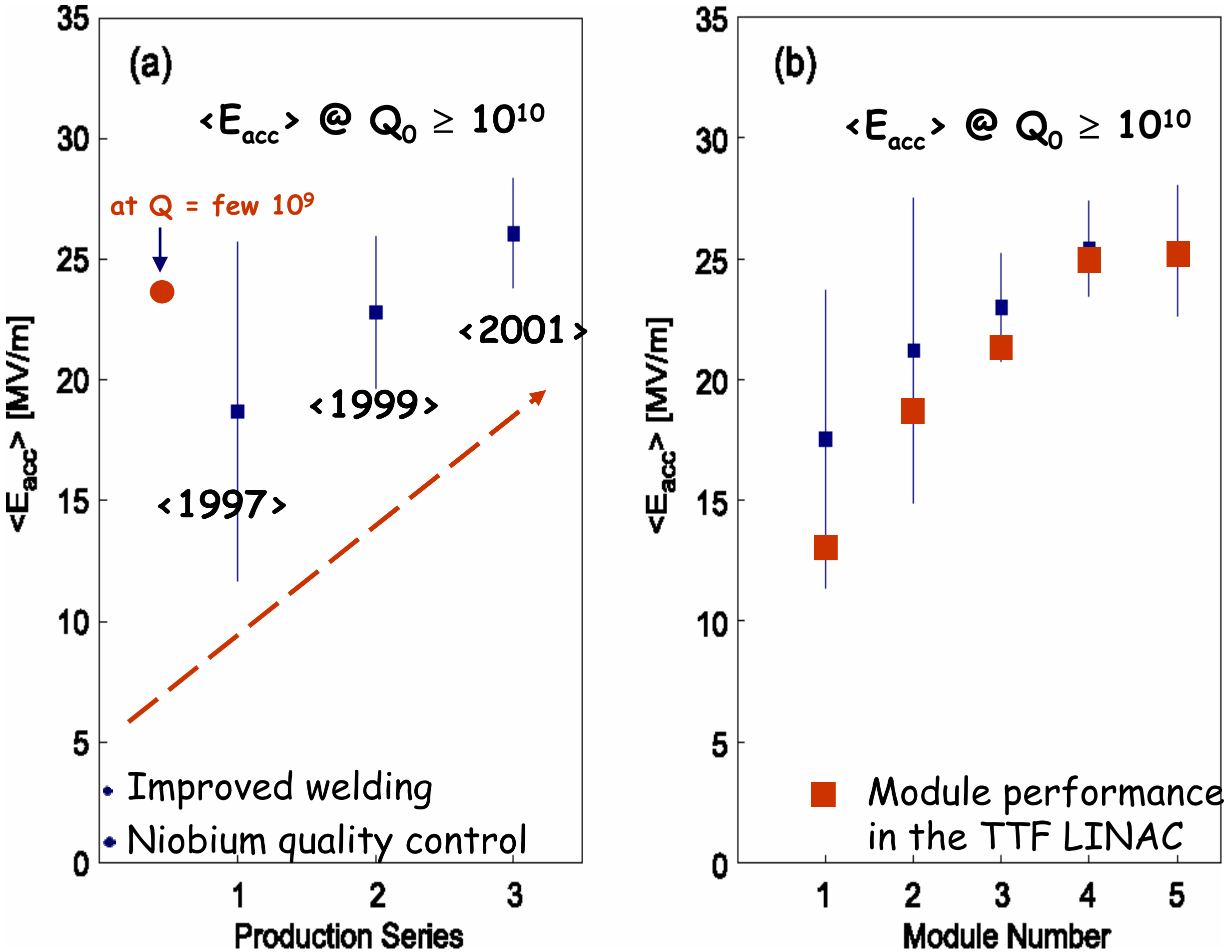
Learning curve with BCP

BCP = Buffered Chemical Polishing

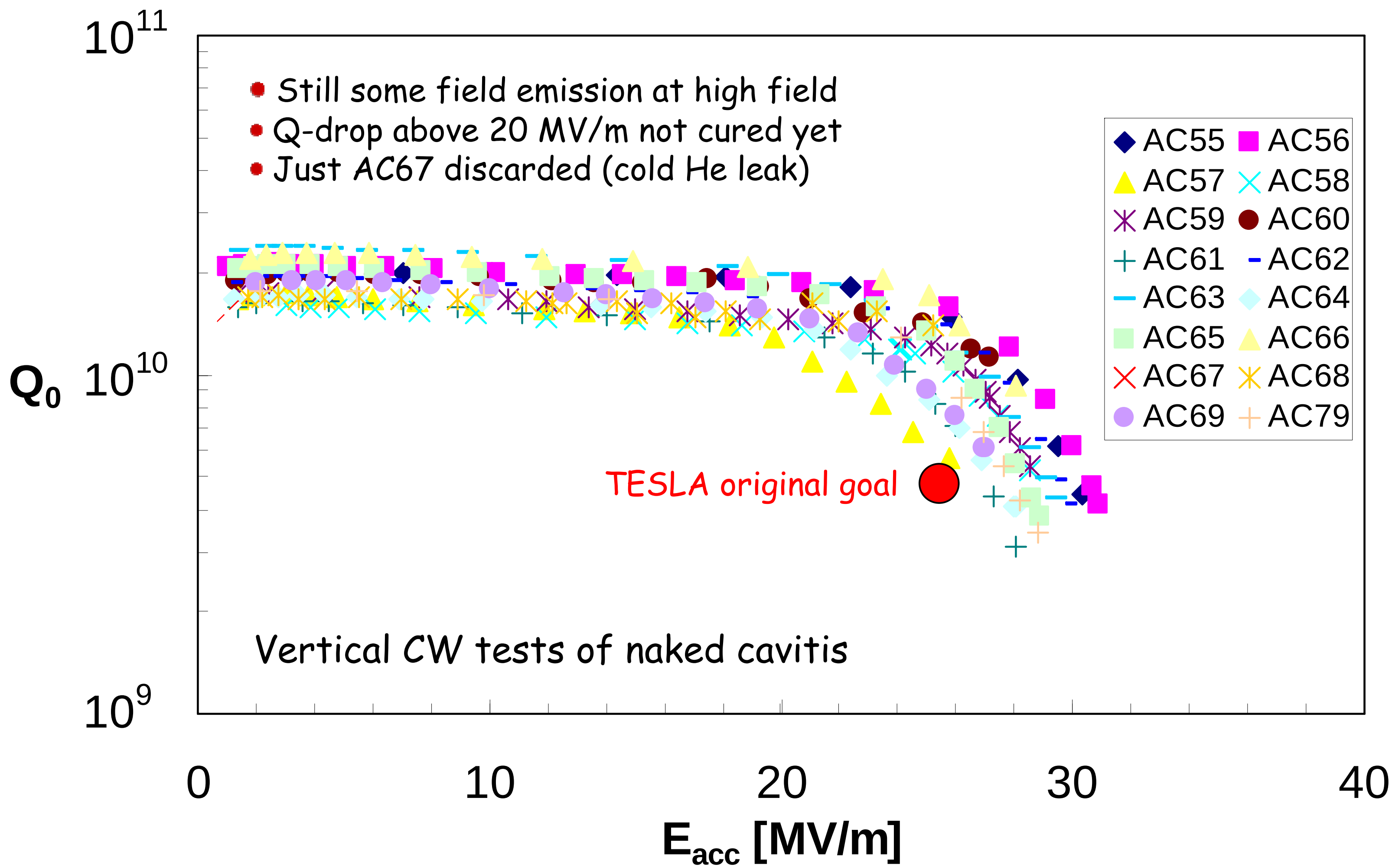
3 cavity productions from 4 European industries: Accel, Cerca, Dornier, Zanon

Cornell 1995

5-cell



3^{rd} cavity production with BCP



Two major contributions for high field

In-Situ Baking (110-140 °C) from CEA-Saclay

Cures Q-drop at High Field

- Formation of a uniform Nb_2O_5, dielectric, layer on the surface
  - Reduction of the normal conducting dissipation from NbO and NbO_2
- Diffusion of the oxygen from the superconducting layer
- Some effect at the grain boundaries?

Electro-polishing (EP) from KEK

Improves field emission onset and maximum field

- Much smoother surface, less local field enhancement
- Better cleaning with high pressure water rinsing
  - Foreign particles better removed
  - High temperature (1400 °C) heat treatment possibly avoidable

EP & Baking for 35 MV/m

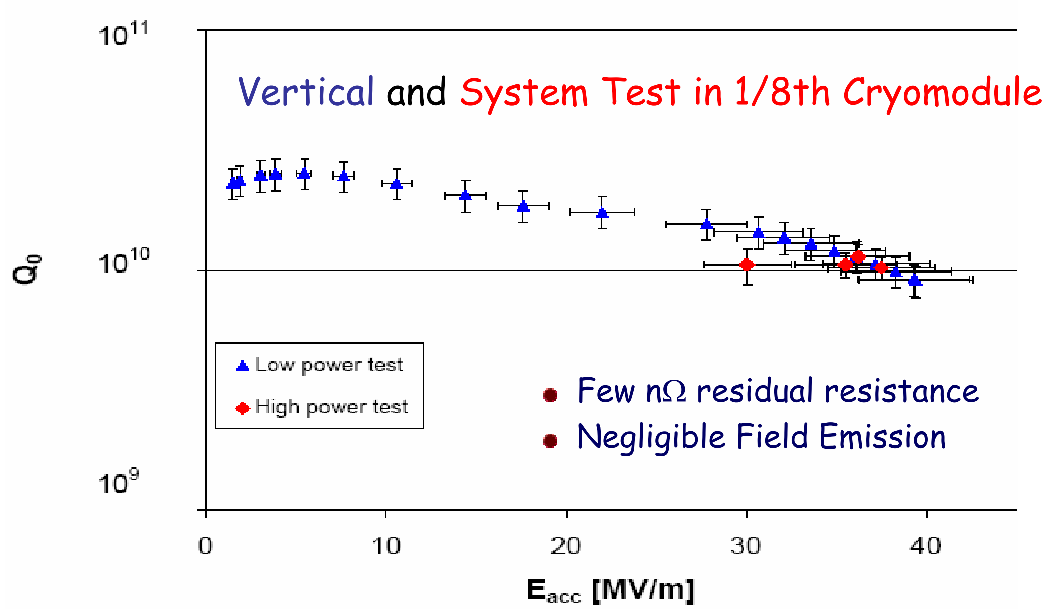
The AC 70 example

EP at the DESY plant
- **Low Field Emission**

800°C annealing

120°C, 24 h, Baking
- high field Q drop cured

High Pressure Water Rinsing



Electro-Polishing (EP)

instead of

Buffered Chemical Polishing (BCP)
- less local field enhancement
- High Pressure Rinsing more effective
- Field Emission onset at higher field

In Situ Baking

@ 120-140 ° C for 24-48 hours

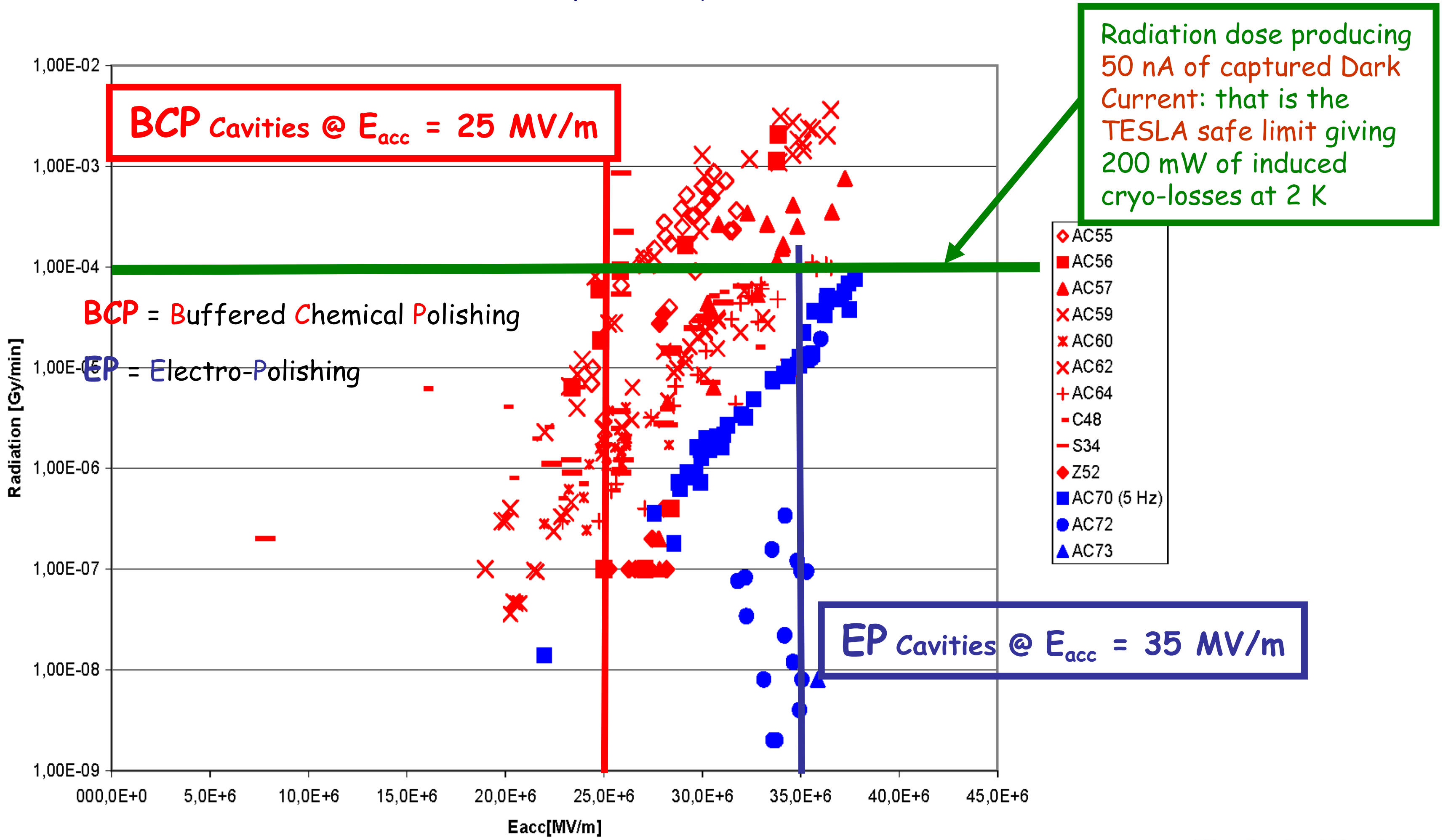
- to re-distribute oxygen at the surface
- cures Q drop at high field

Field Emission pushed to higher field

BCP Cavities used in Modules 4 & 5 are in red, EP cavities in blue

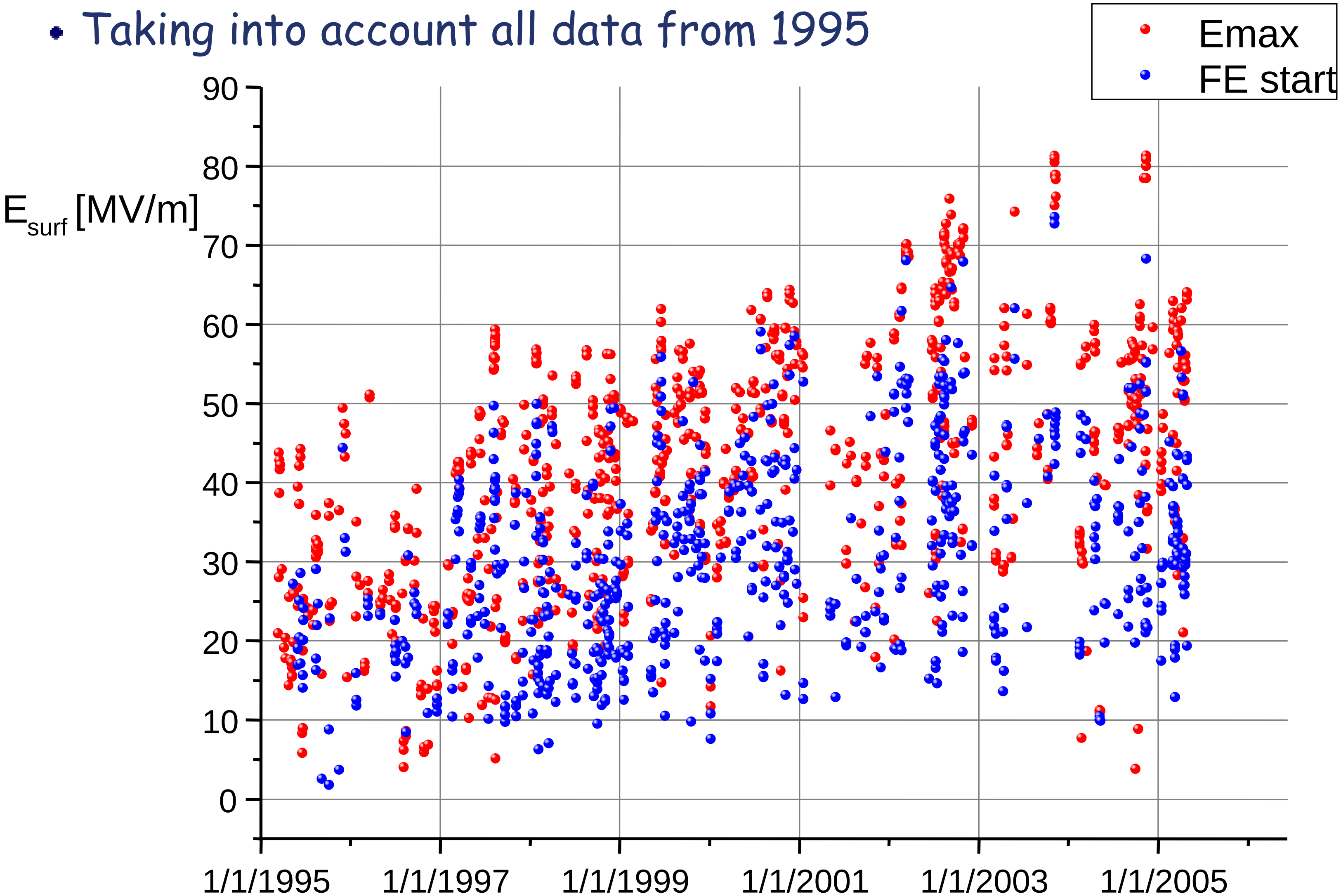
Radiation Dose from the fully equipped cavities **while High Power Tested** in "Chechia"

"Chechia" is the horizontal cryostat equivalent to 1/8 of a TTF Module



TESLA Cavities: all tests to June '05

- Taking into account all data from 1995



Regional Infrastructures for ILC

- **TESLA Test Facility (TTF) @ DESY**
  currently unique in the world
  FLASH as VUV-FEL user facility
  test-bed for both XFEL & ILC
  CMTB for independent cryomodule test

- **SMTF @ FNAL**
  Supported by: Cornell, JLab, ANL, FNAL, LBNL, LANL, MIT, MSU, SNS, UPenn, NIU, BNL, SLAC + DESY, INFN & KEK
  Test Facility for ILC and other projects

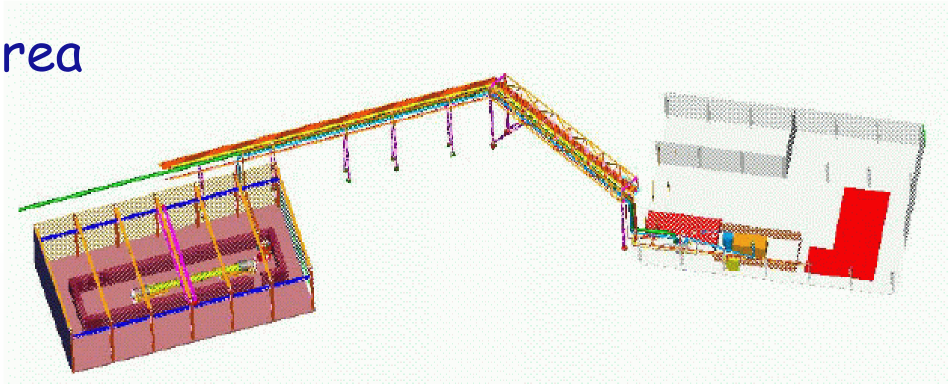
- **STF @ KEK**
  To set up the ILC technology in Japan and Asia

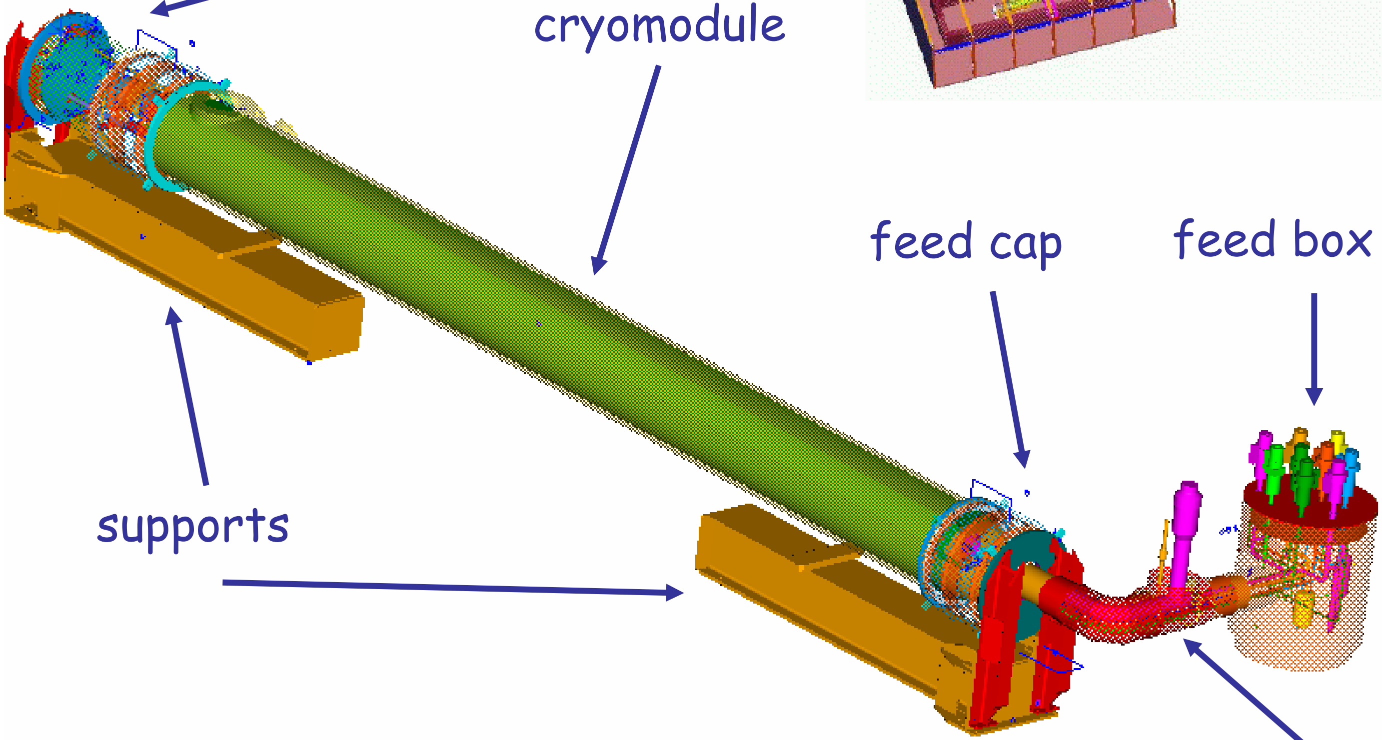
- **Others: JLab, CERN ?, R&D Infrastructures**

CMTB @ DESY

Built at DESY close to TTF area

Commissioned end 2006



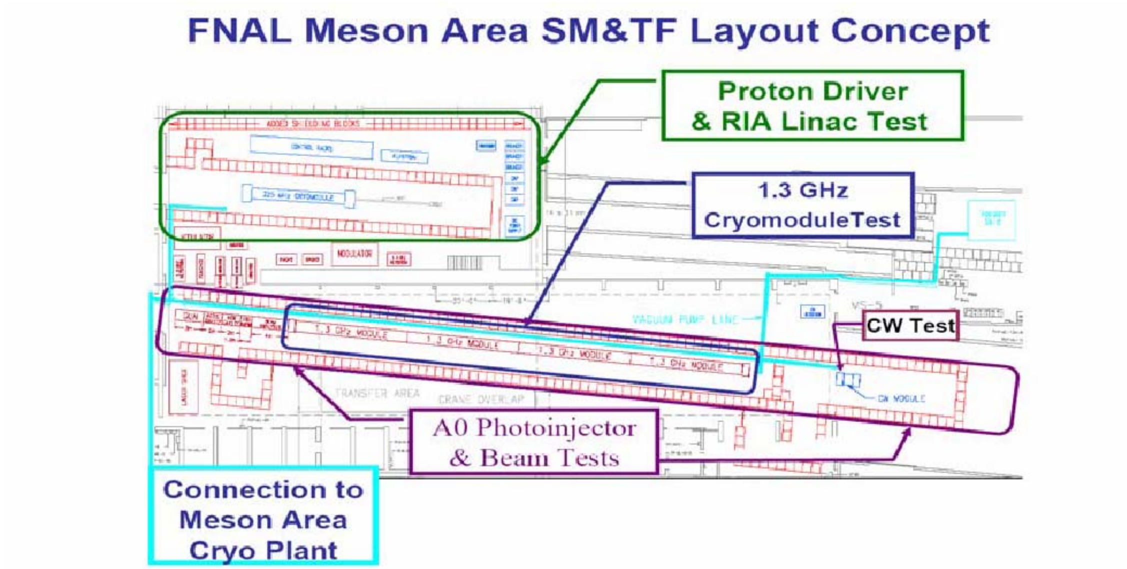


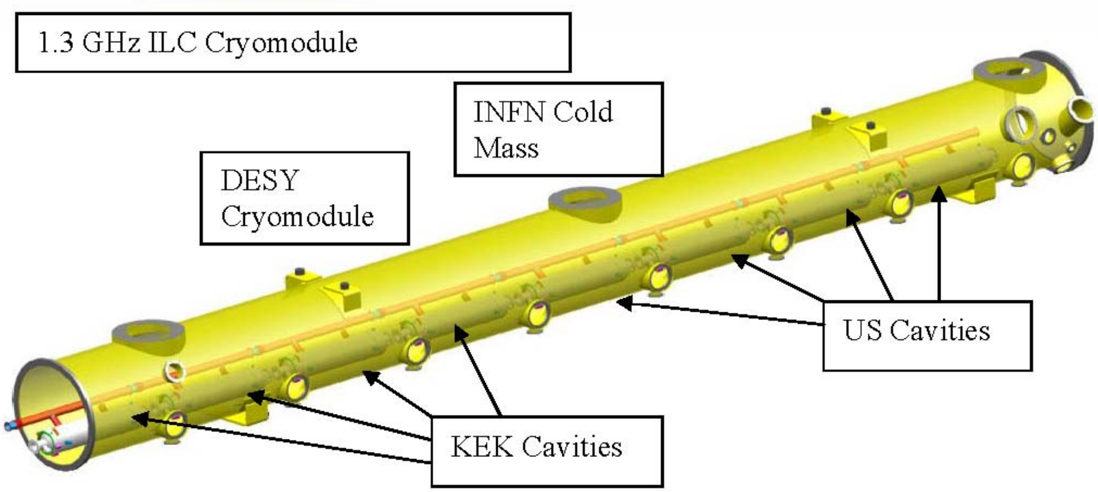
CMTB in fall 2006

Test of module 6 started end October 2006

6 cool-down warm-up cycles successfully performed

SMTF @ FNAL as presented to DOE





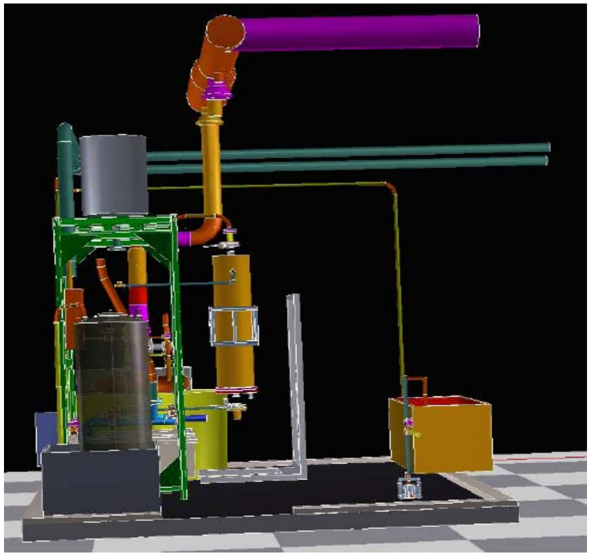
"The **SMTF proposal is to develop U.S. Capabilities** in high gradient and high Q superconducting accelerating structures

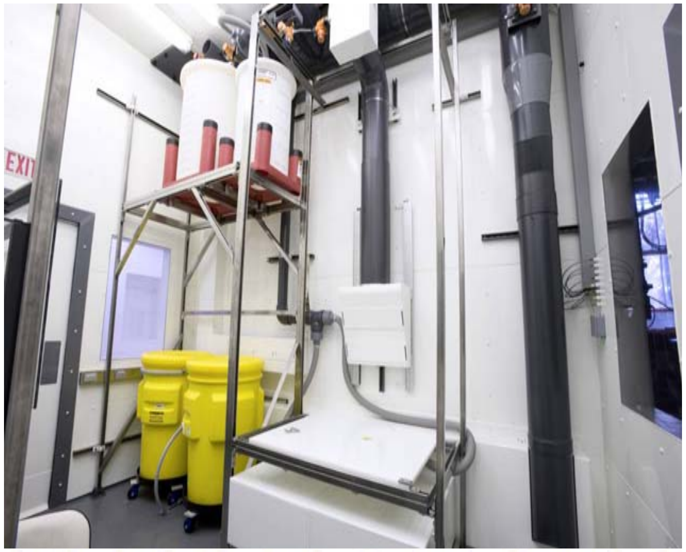
in support of

International Linear Collider
Proton Driver
RIA
4th Generation Light Sources
Electron coolers
lepton-heavy ion collider
and other accelerator projects of interest to U.S and the world physics community."

Surface Processing at ANL/FNAL

- Fermilab and Argonne are jointly building a surface processing facility for ILC Cavity R&D.
- The facility will have capability to perform BCP, EP and HPR.
- The BCP Facility is under final phase of construction and will be safety reviewed by Spring of 07.
- Design of the EP facility is progressing with plans to be commission with 9 Cell 1.3 GHz Cavities by the end of FY07.



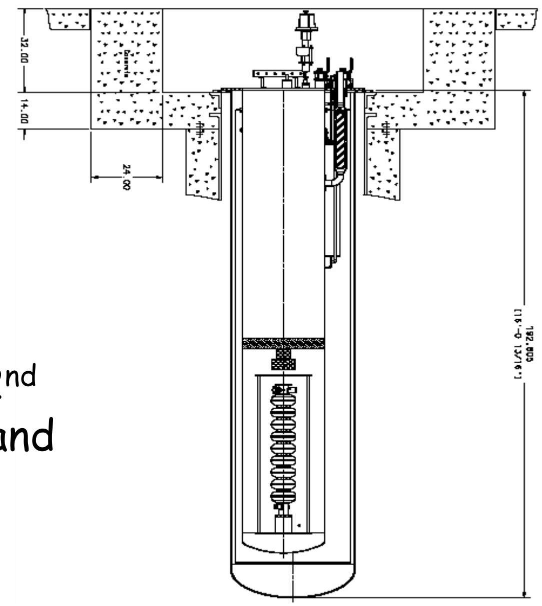


HPR and Vertical Test at Fermilab

- Fermilab in collaboration with MSU is developing a new HPR system.
- FNAL Vertical Test Stand to be commissioned Summer 07.
  - Civil Construction finishes Aug. 06
  - Cryostat has been ordered
  - Changes to cryogenics in IB1 building soon
  - RF and controls being developed in collaboration with Jlab.

Civil Construction 8/06

- Present cryostat top plate can hold two ILC Cavities.
- Plan underway to put 2nd pit. This will share RF and controls.



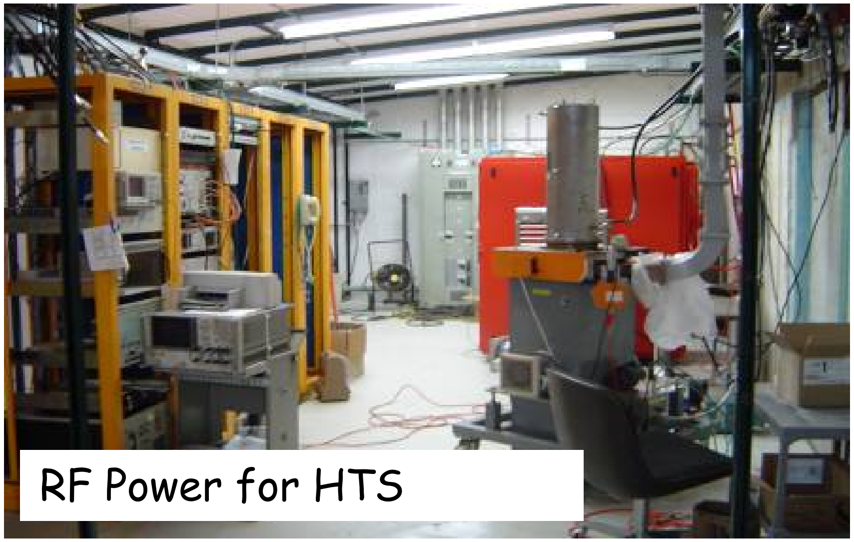
Horizontal Test Stand

- Fermilab is in progress of building a Horizontal Test Stand for 1.3 and 3.9 GHz cavities.
- All the hardware needed have been delivered and the system in being put together.
- The cryogenic, RF Power, Controls have been debugged using CC-II.
- HTS is being commissioned using a Dressed Cavity from DESY

LLRF
International Collaboration

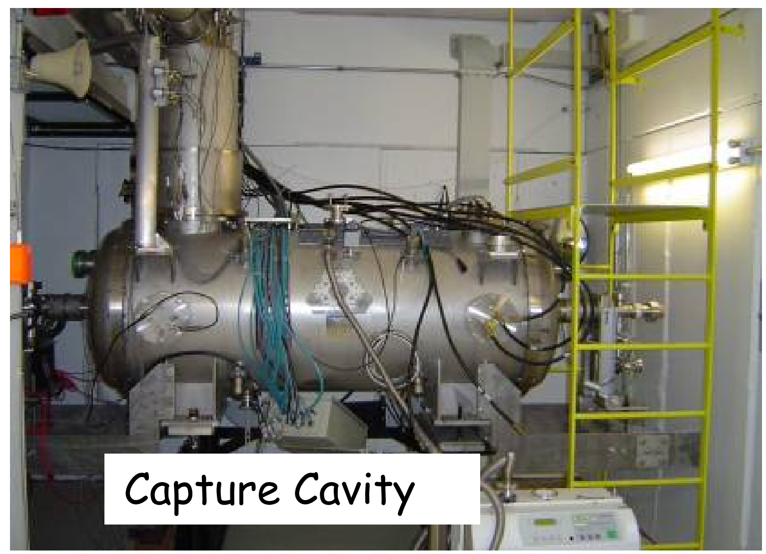
DESY
KEK
Poland
Fermilab
SNS
Cornell
U Penn

Horizontal Test Stand details


RF Power for HTS

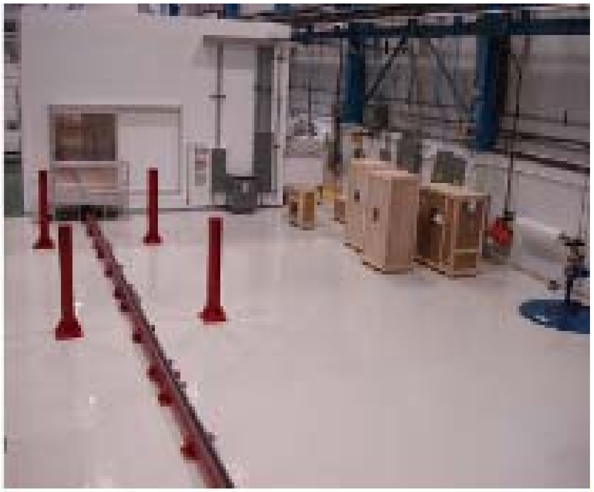

Cryogenics for HTS ready at 2 K


Cryogenics for HTS getting ready for 2 K

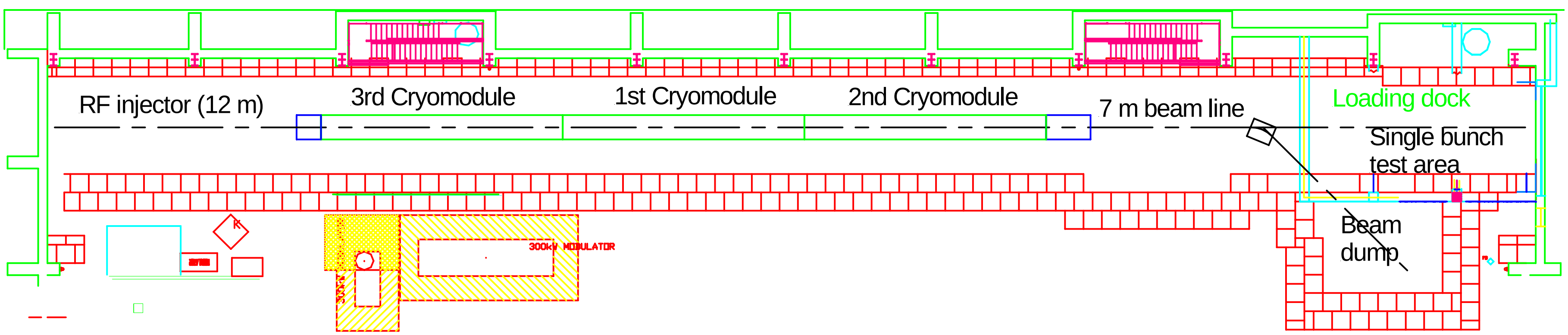

Capture Cavity

Cavity Dressing and Cryomodule Assembly

- Fermilab has finished the construction of the Cavity Dressing and Cryomodule Assembly Facility.
  - The design is based on input and recommendations from DESY.
- Detailed development and check out of the tooling is in progress.
  - DESY is sending two dressed cavities to debug this facility.
- FNAL is awaiting the delivery of Cryomodule Kit from DESY (INFN Cry 3 design)

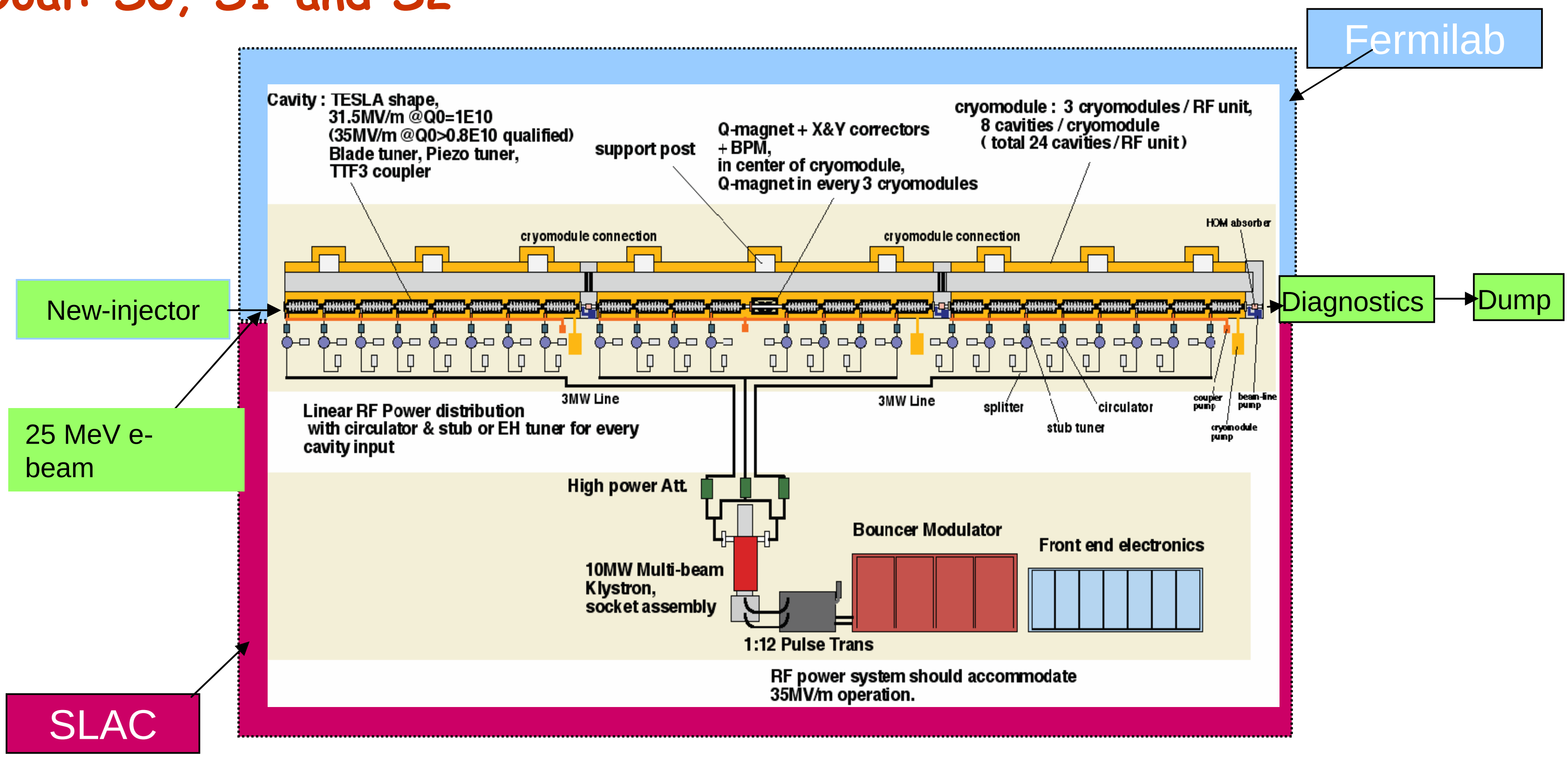

Three cryomodules (fits into NML)



- Mid 2009 - 3 CM's, 750 MeV, 40 kW beam power

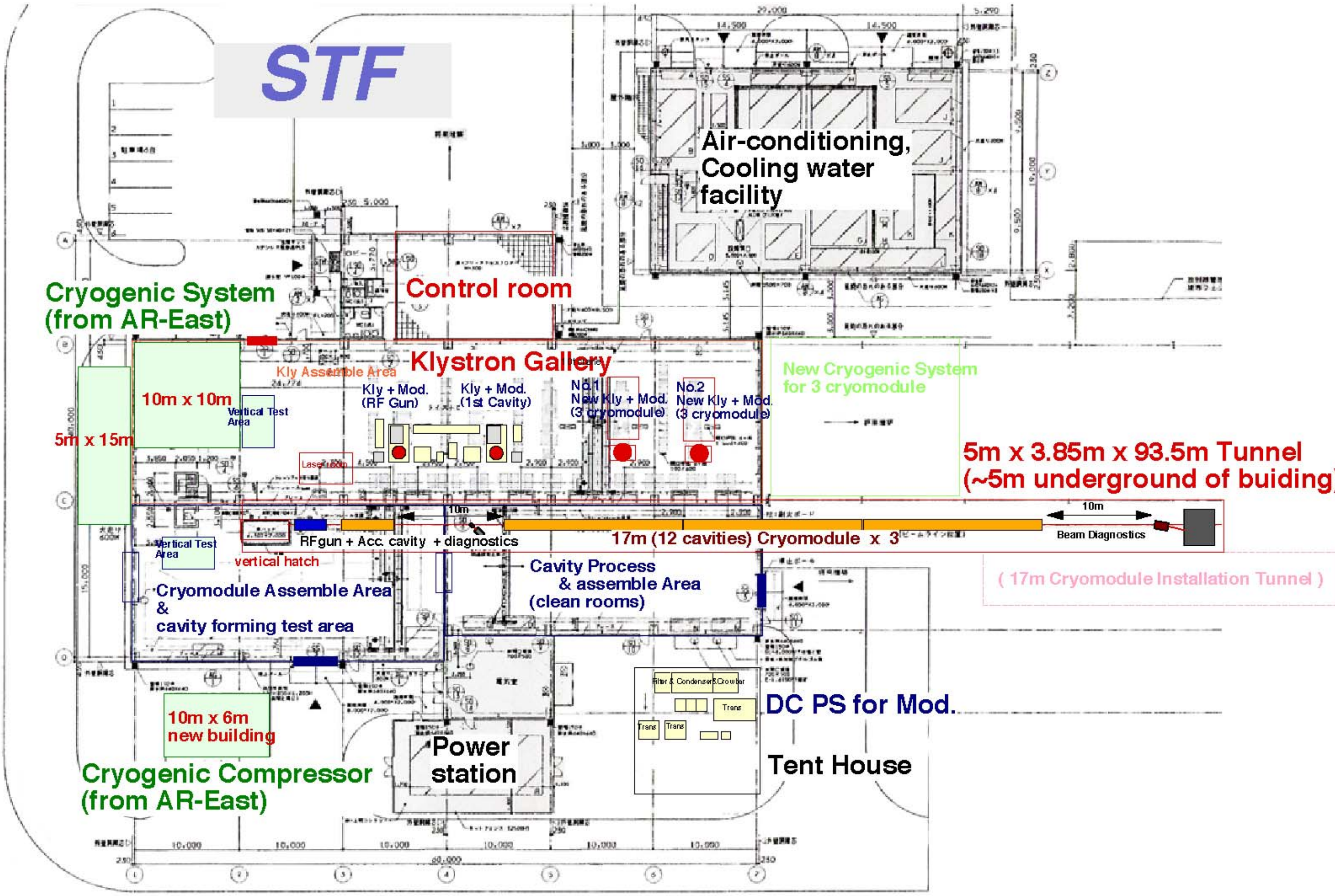
ILCTA Phase 1: 1 RF Unit

Goal: S0, S1 and S2



Components provided by US and International Collaborators

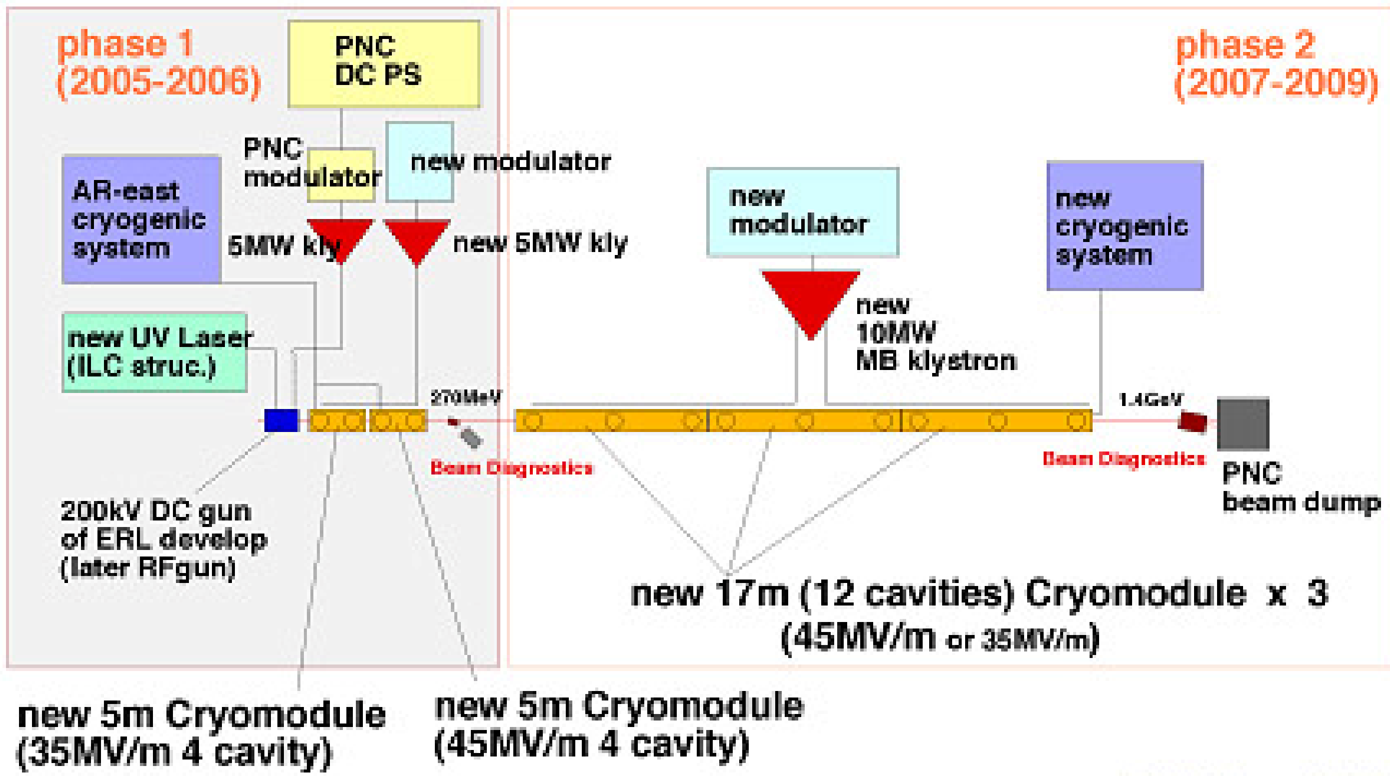
STF @ KEK



Plan of Superconducting Cavity Test Facility (STF)

V2.1 Hitoshi Hayano, 11/03/2004

Plan of Superconducting RF Test Facility (STF)



V1.2 Hitoshi Hayano, 2/20/2005

KEK STF development plan update

Phase 1 (2005 -2007),

for quick startup of ILC SCRF, infrastructure development

subdivided to

Phase 0.5 : 1 cavity in each short cryostat (cool-down in Mar.2007)
Phase 1.0 : 4 cavities in each short cryostat (Jul.2007)
Phase 1.5 : replacement of 4 cavities by improved ones (Apr.2008)

Phase 2 (2007 - 2009),

develop ILC Main Linac RF unit

start design Apr. 2007
fabrication in 2008 and 2009 (2 years for 24 cavities)
completion middle to end of 2009

* S0 Task Force activities will be done in parallel.

KEK STF Highlights

clean room for cavity assembly

5MW power source
and coupler test stand

5m cryomodule vacuum vessels

TESLA-like cavities

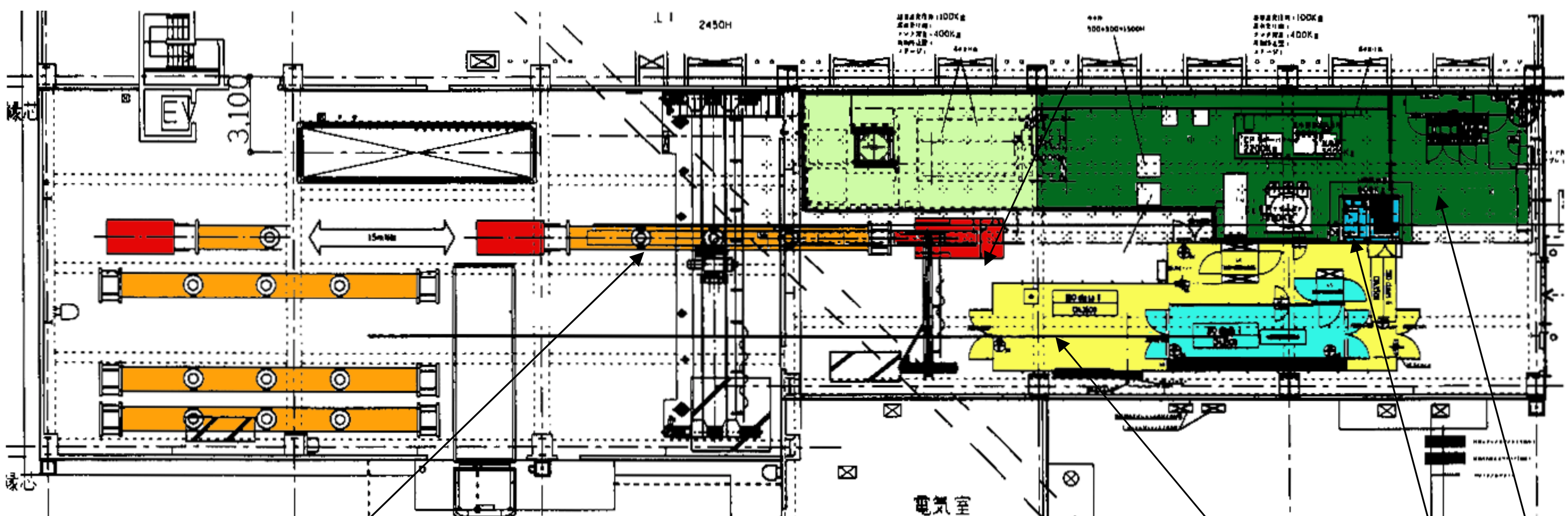
Disk Input Coupler

LL shape cavities

Capacitive Couplers

STF SC Infrastructure

EP: under construction. will be completed in Mar. 2007
HPR: under construction. will be completed in Dec. 2006
Clean room: under use of short cryomodule assembly.



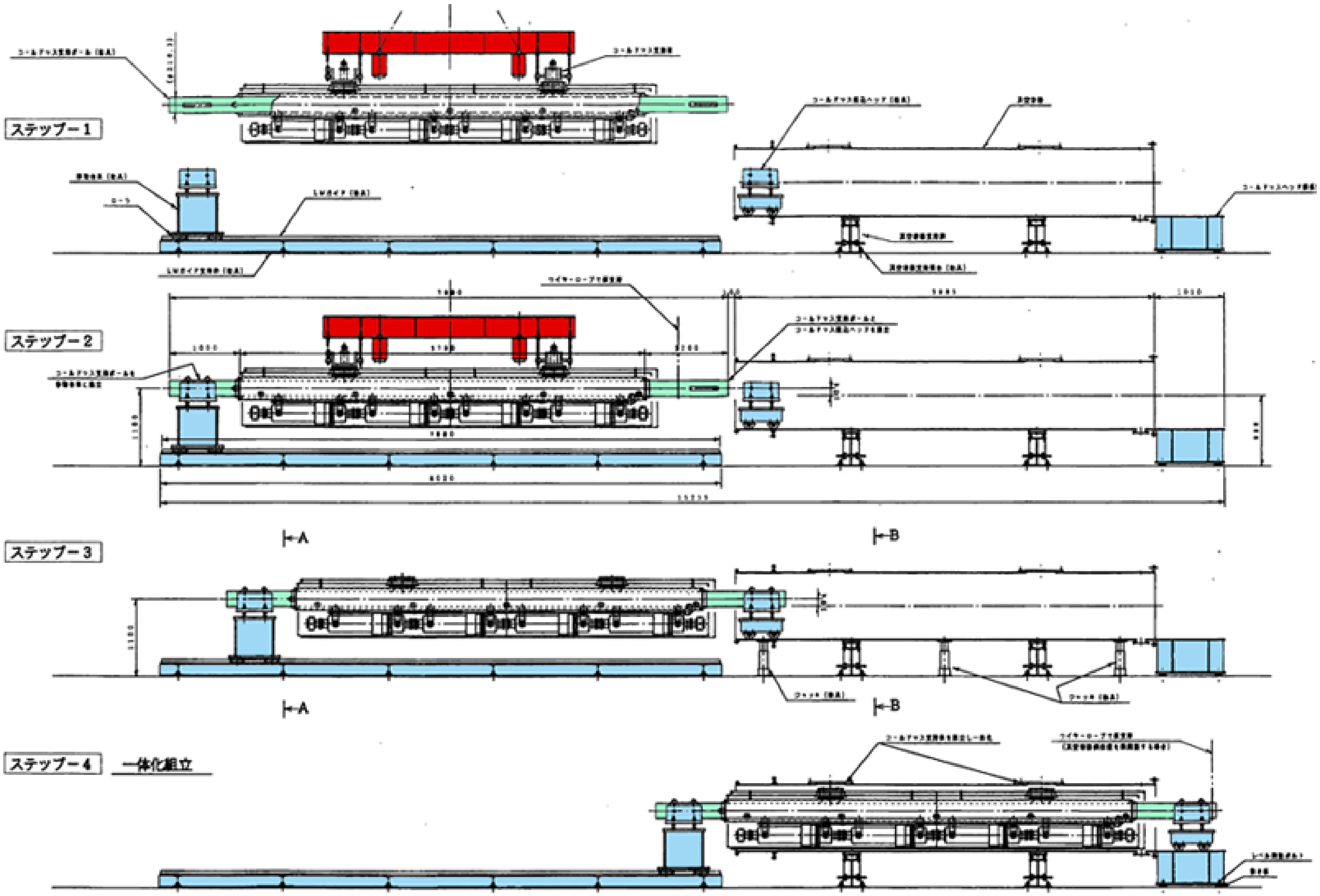
Cryomodule Assembly

EP

HPR

Clean room

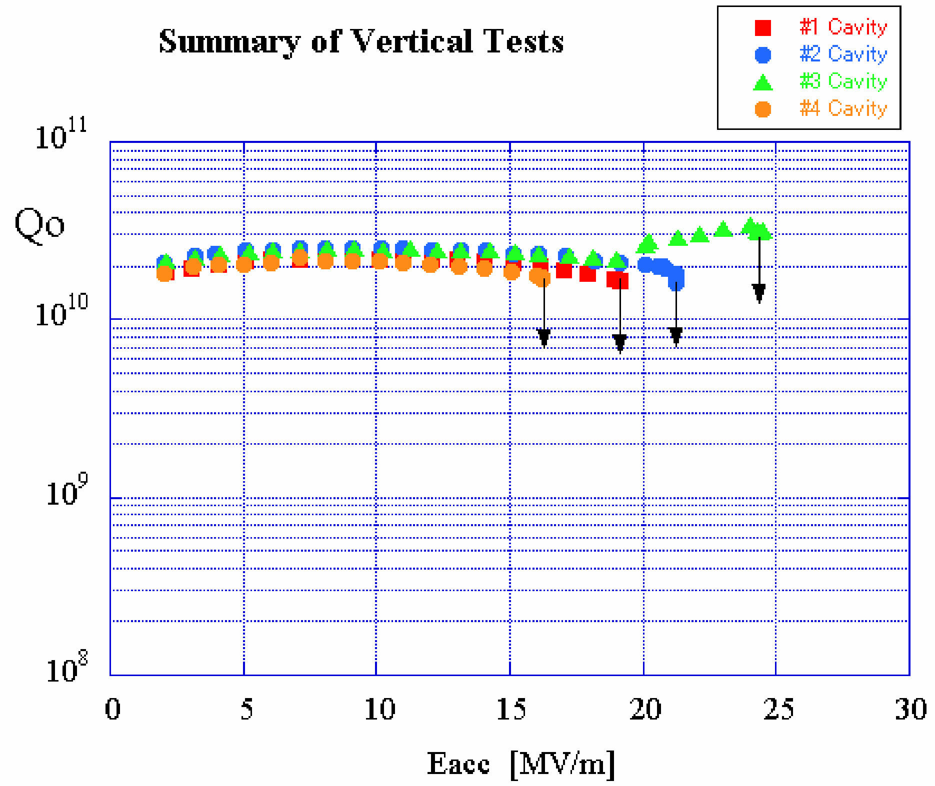
Plan of cryomodule assembly



Vertical Tests of Standard Cavities

Up to now, 9 tests for 4 cavities.

#1 cavity : 3 tests (max 19.2MV/m)
#2 cavity : 2 tests (max 20.3MV/m)
#3 cavity : 3 tests (max 24.5MV/m)
#4 cavity : 1 test (max 17.1MV/m)



As in October 2006

STF at KEK in these days

assembly of the two short Cryomodules: from part to the linac

The Dream Infrastructure at CERN ?

Original Proposal: EGDE Meeting, Oxford, Nov. 2005

- Use the CERN Cryogenic infrastructure
- Use the CERN expertise from LHC and LEPII

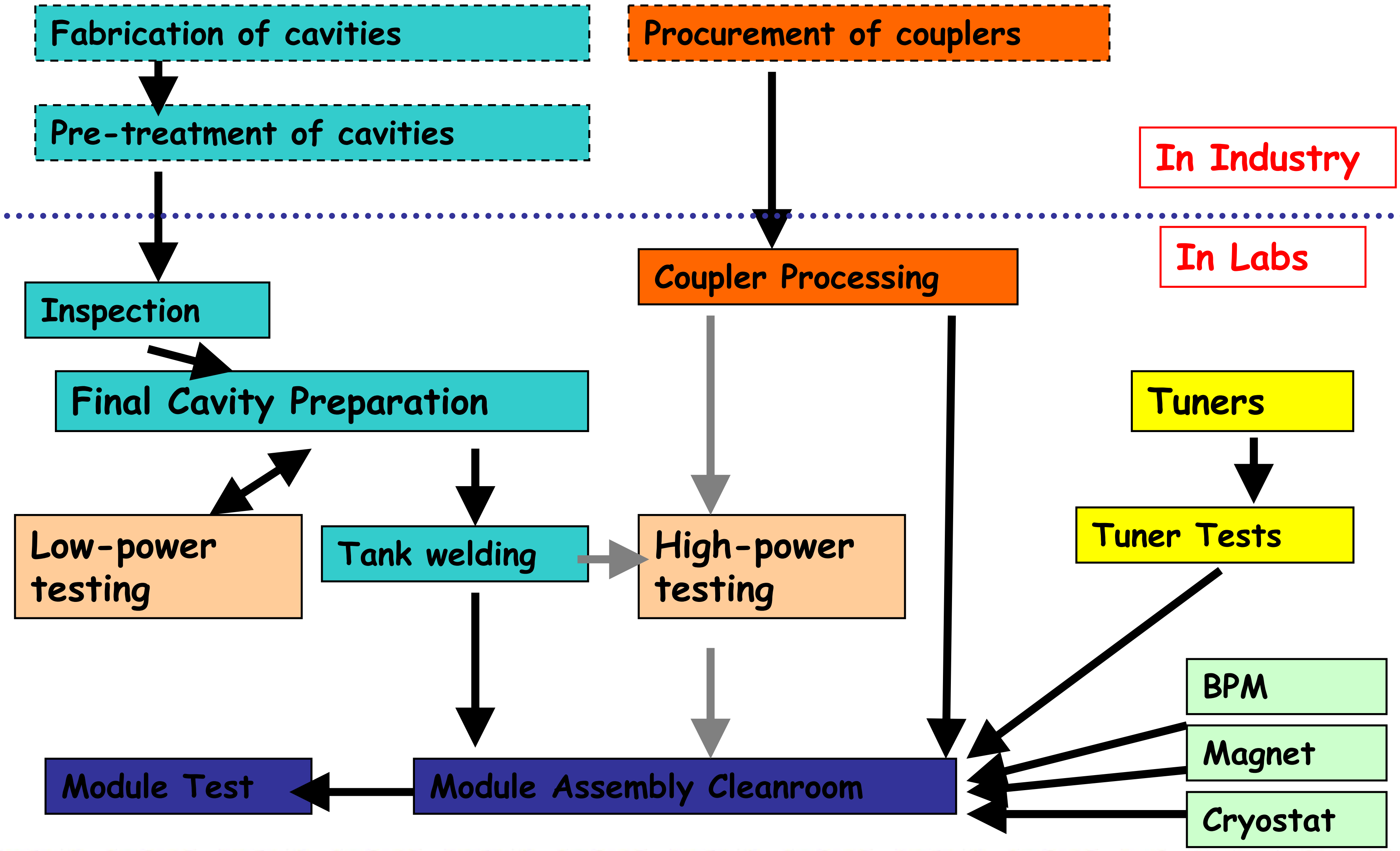
Create an European new infrastructure dedicated to High Field and high Q SCRF to maintain European momentum and expertise.

Integrate the TESLA Collaboration experience into a new infrastructure designed for parameter control and industrialization.

Size the infrastructure with these throughput goals:

- 24-30 new cavities per year produced
- 100 Cavities per year processed and tested
- 3 cryomodule per year assembled and tested

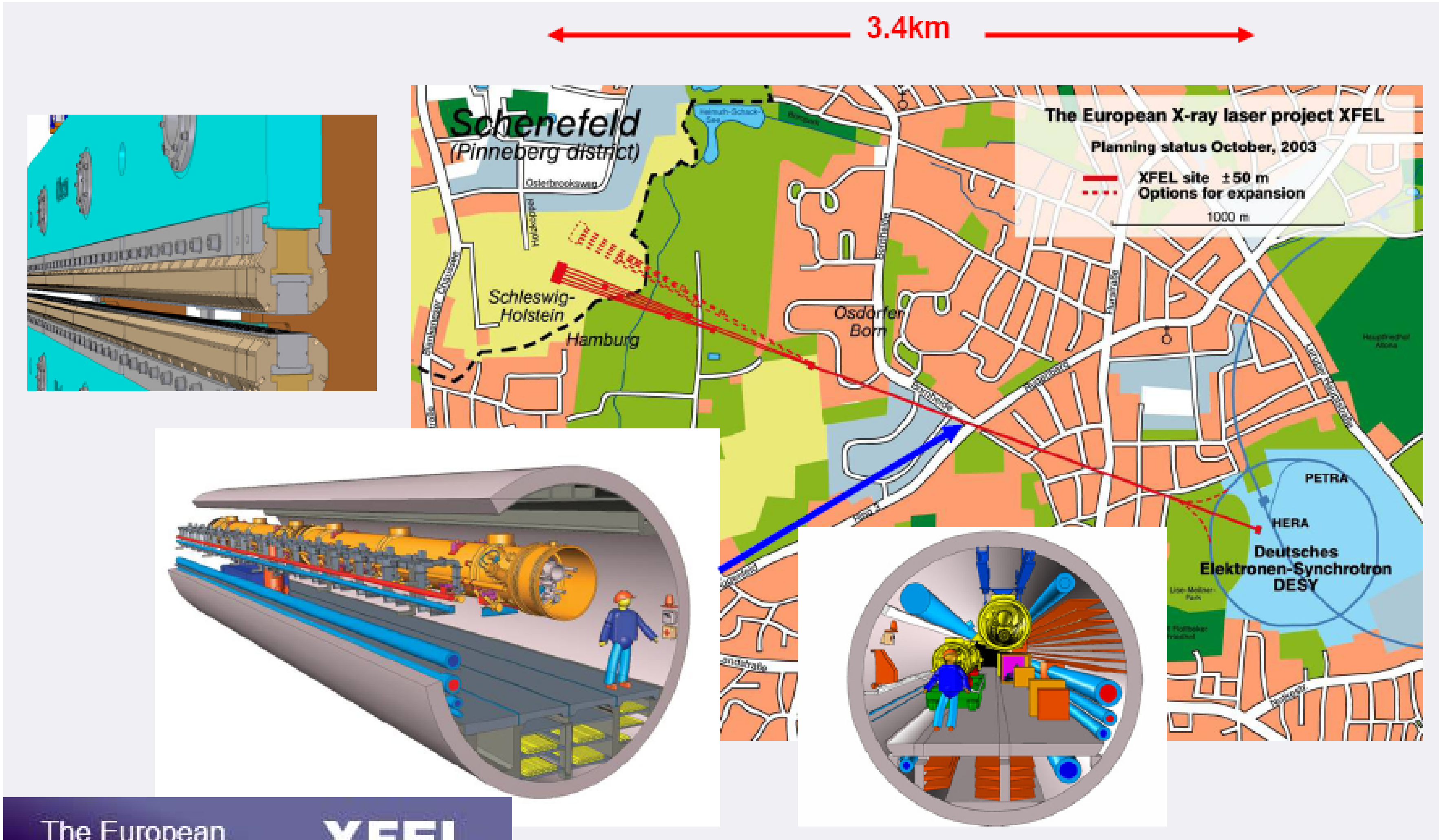
Scheme of Cryomodule Production



Final Thoughts

- To transform the impressive results on prototypes into a stable, fully controlled, Industrial production of SCRF:
  - Large investments in infrastructure are required
  - Industry and industrial stile have to be integrated for an higher level of Quality Control and Quality Assurance
- This effort, mandatory for ILC, is needed for the extended application of SCRF foreseen
- The European XFEL could be the required infrastructure.
  - XFEL needs to transfer to industry the reliable production, at a moderate and controlled cost, of:
    - 120 Cryomodules
    - 1000 Cavities at 28 MV/m on average
    - All cavity ancillaries
    - Few tens of 10MW klystron and modulators
    - Etc.
- **XFEL would be** a very effective 6% prototype for ILC and possibly **the best SCRF large infrastructure for ILC**

European XFEL Layout and Site



The European X-Ray Laser Project XFEL X-Ray Free-Electron Laser