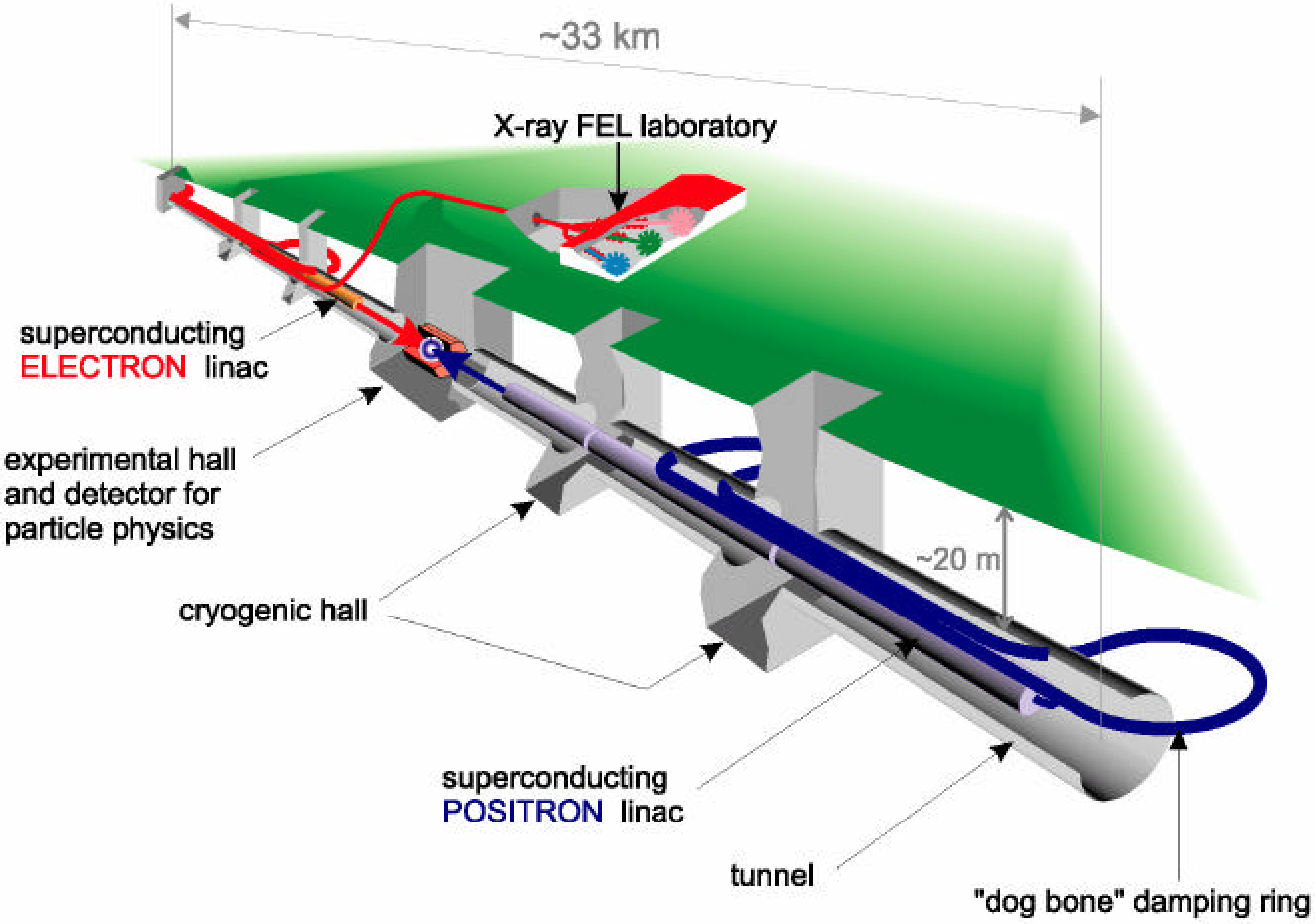
# TESLA Design &
# Accelerator R&D Opportunities

## H. Padamsee, Cornell University

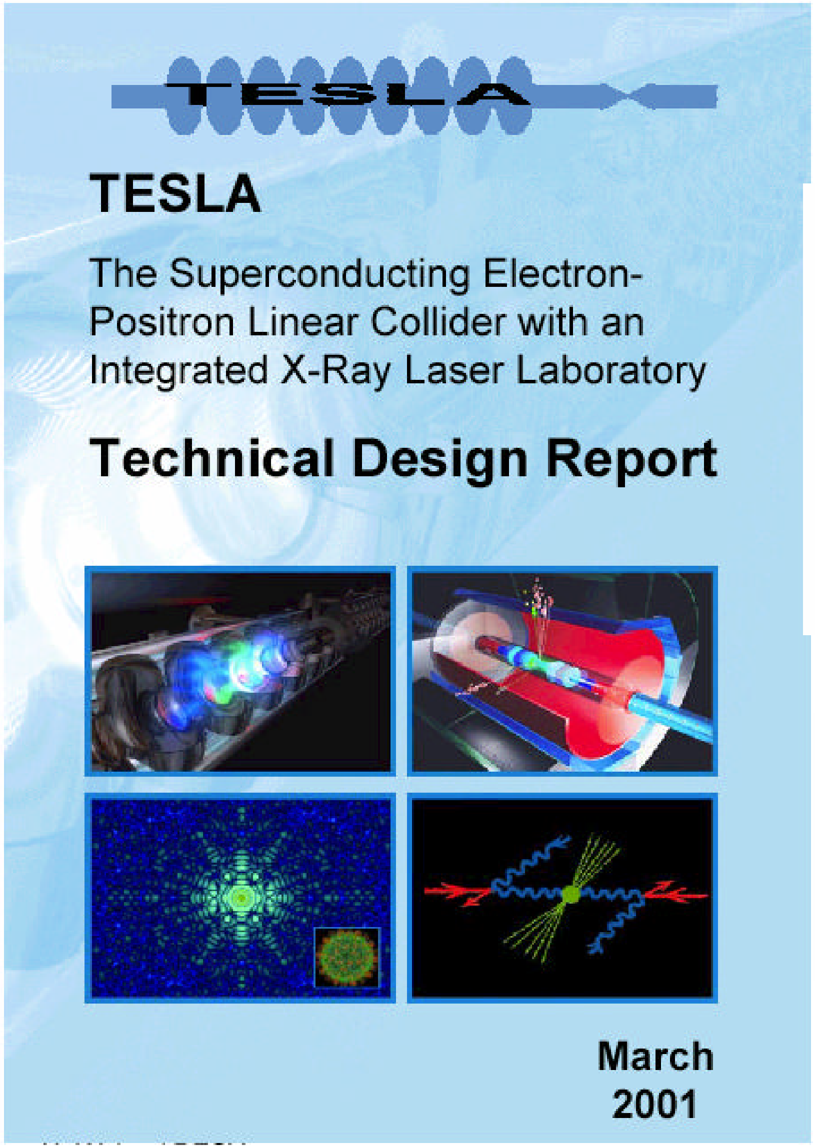


TeV
Energy
Superconducting
Linear
Accelerator

500 GeV
Needs 24 MV/m

800 GeV needs
35 MV/m

# Sources



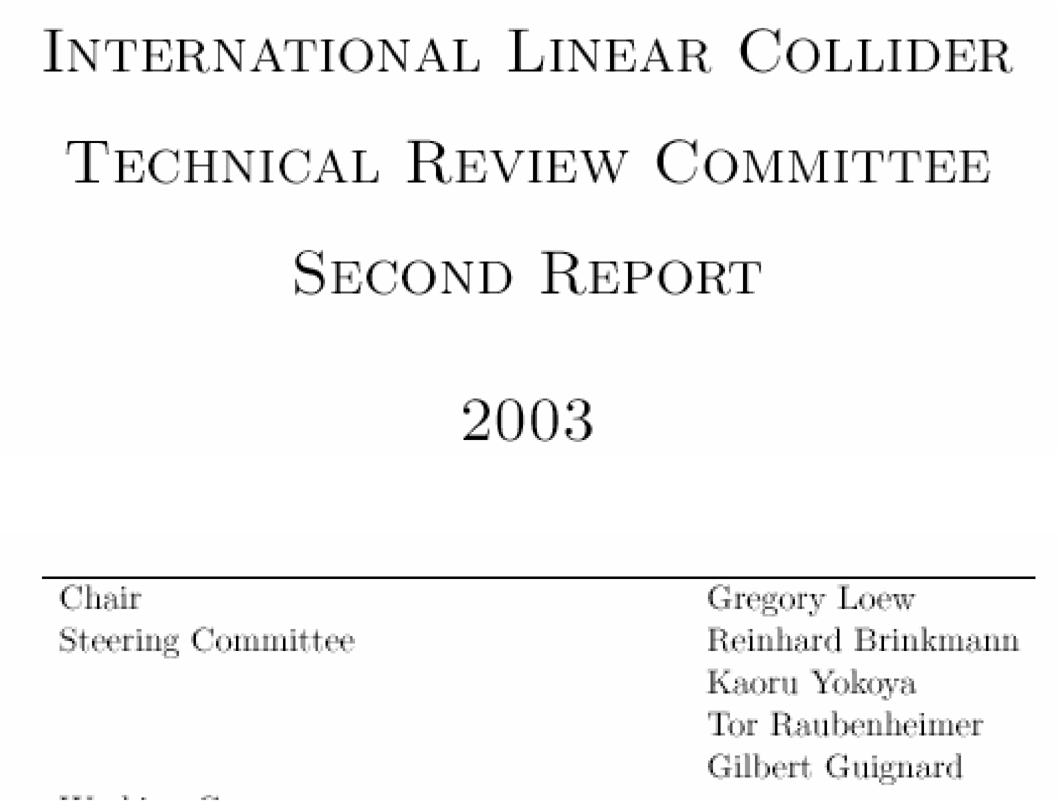
TESLA

**TESLA**

The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory

**Technical Design Report**

**March 2001**



INTERNATIONAL LINEAR COLLIDER

TECHNICAL REVIEW COMMITTEE

SECOND REPORT

2003

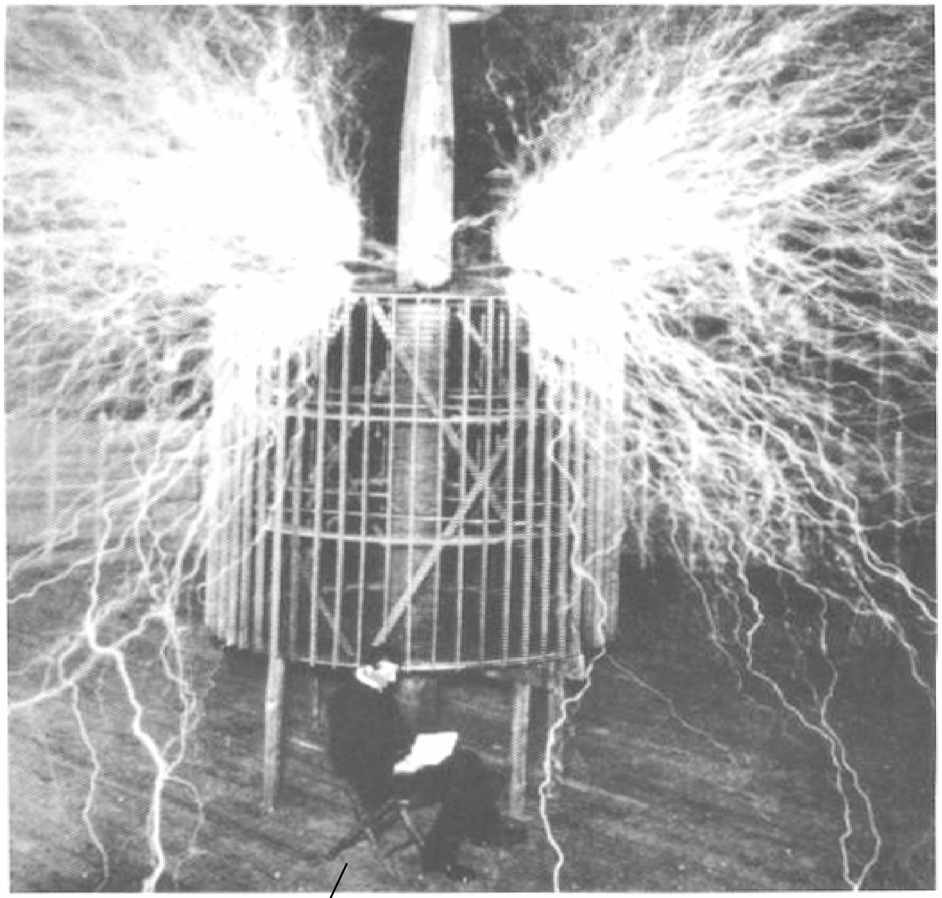
| | |
|---|---|
| Chair | Gregory Loew |
| Steering Committee | Reinhard Brinkmann<br>Kaoru Yokoya<br>Tor Raubenheimer<br>Gilbert Guignard |

PROCEEDINGS OF 1990

The First International
TESLA Workshop

CORNELL
UNIVERSITY

Held at Cornell University
July 23-26, 1990



# 50 Labs, 12 Countries

Barcelona
Spain

**Yerevan Physics Institute**

**DSM/DAPNIA, Saclay**
**IN2P3/IPN, Orsay**
**IN2P3/LAL, Orsay**

**INFN, Frascati**
**INFN, Legnaro**
**INFN, Milano**
**Univ.Roma II**

**BINP, Novosibirsk**
**BINP, Protvino**
**IHEP, Protvino**
**INR, Troitsk**
**JINR Dubna**
**MEPhI, Moscow**
**ITEP, Moscow**

**Paul Scherrer Institut, Villingen**

**IHEP, BeijingTsinghua University**

**BESSY, Berlin**
**DESY, Hamburg**
**Frankfurt University**
**FZ Karlsruhe**
**GKSS Research Centre**
**Hahn-Meitner-Institut Berlin**
**Hamburg University**
**Max Born Institute, Berlin**
**Rostock University**
**RWTH, Aachen**
**TU, Berlin**
**TU, Darmstadt**
**TU, Dresden**
**Wuppertal University**

**APS/Argonne, Chicago, IL**
**Cornell University, Ithaca, NY**
**Fermilab, Batavia, IL**
**Thomas Jefferson National Laboratory, Newport News, VA**
**UCLA Dep.of Physics, Los Angeles, LA**

**Institute of Physics, Helsinki**

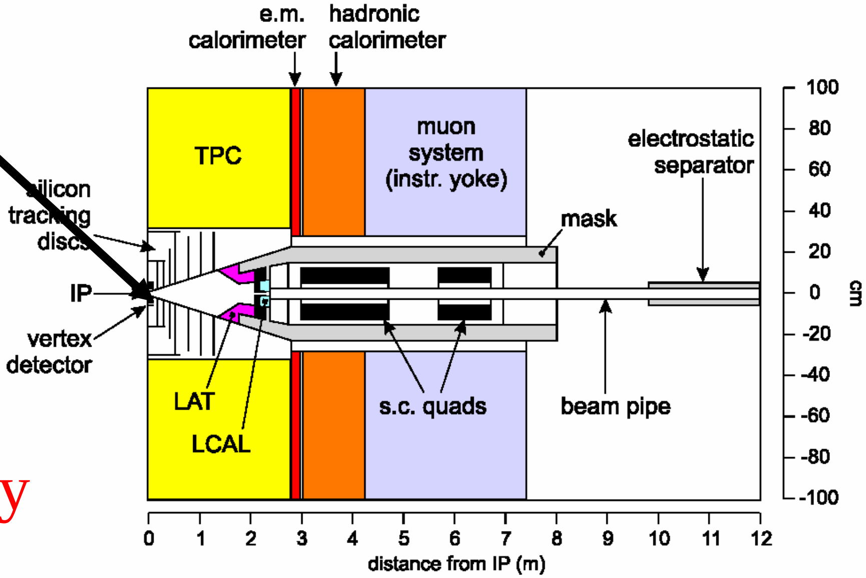
**CCLRC, Daresbury & Rutherford Appleton**

**DMCS Technical University, Lodz Faculty of Physics Warsaw University**
**High Pressure Reaserch Center "UNIPRESS" PAS, Warsaw**
**Inst. of Nuclear Physics, Cracow**
**Inst. of Physics Polish Acad. of Science, Warsaw**
**ISE Technical University, Warsaw**
**Polish Atomic Energy Agency, Warsaw**
**Soltan Inst. for Nuclear Studies, Otwock-Swierk**
**Univ. of Mining & Metallurgy, Cracow**

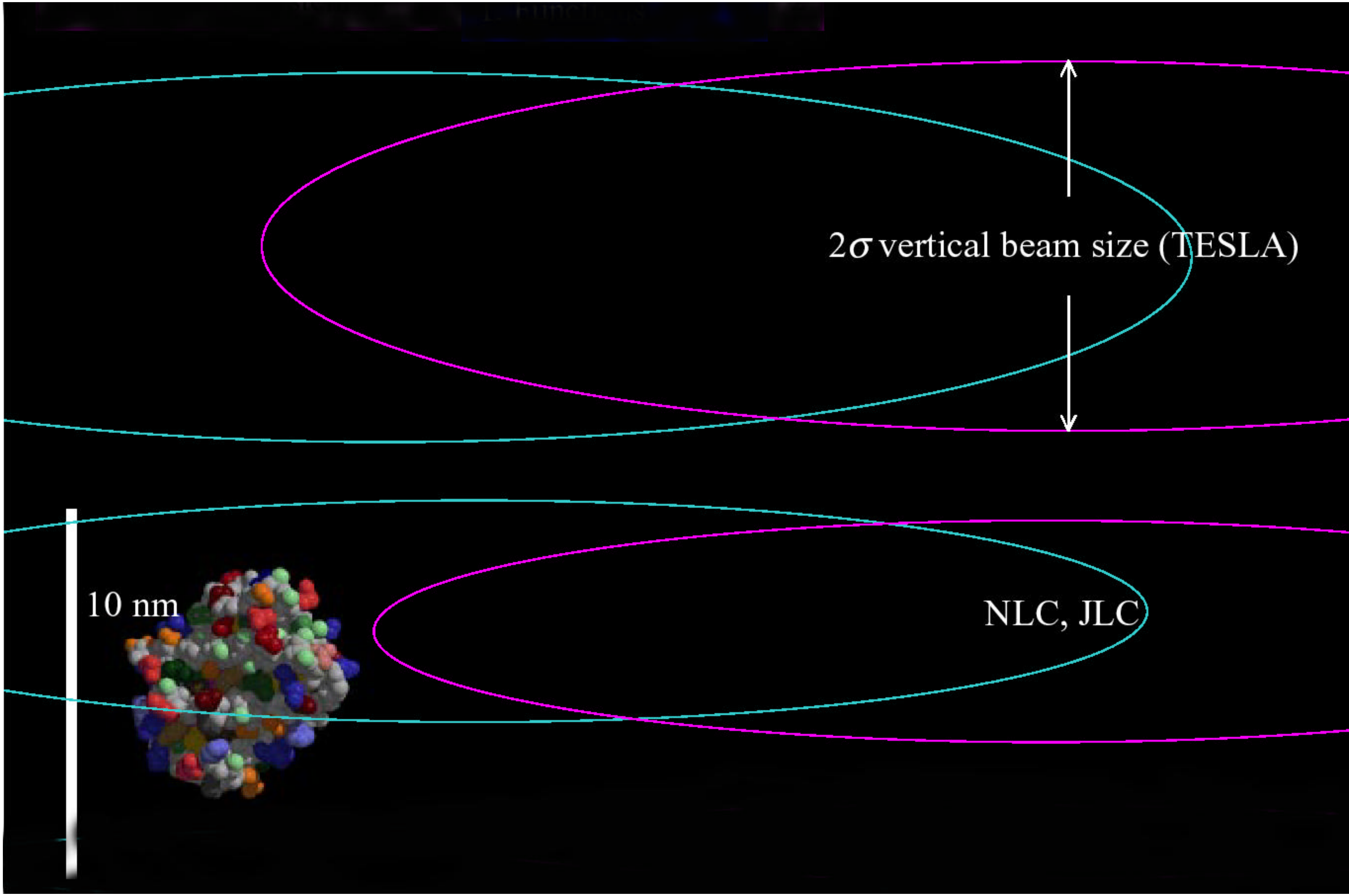
# Linear collider luminosity parameters

$$L\left[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\right] \approx 121\left(N_g H_D\right)\frac{P_b[\mathrm{MW}]}{E_b[\mathrm{GeV}]}\,\frac{1}{s_y[\mathrm{nm}]}$$

| Parameter | SLC | TESLA |
|---|---|---|
| Beam energy [GeV] | 46 | 250 |
| Beam power/beam [MW] | 0.035 | 11.3 |
| Vertical rms beam size at IP [nm] | 650 | 5 |
| Beamstralung photons/electron $N_g$ | 1.1 | 1.6 |
| Disruption enhancement $H_D$ | 2.1 | 2.1 |
| Luminosity [$10^{33}$ cm$^{-2}$ s$^{-1}$] | 0.003 | 34 |

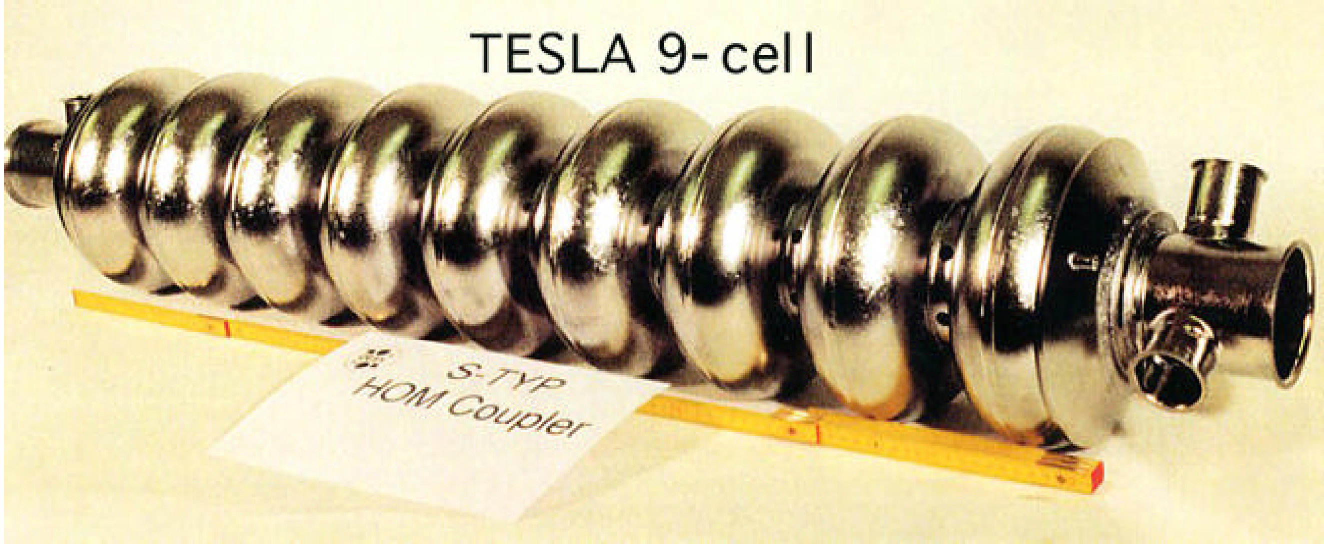


One Major Challenge for Luminosity


2σ vertical beam size (TESLA)
NLC, JLC
10 nm

# The dominant challenge to reach the desired energy is the main linac technology

- RF power and accelerating structures
- Superconducting standing-wave cavities, operating at 1.3 GHz, developed by the TESLA collaboration



# TESLA acceleration system: principal features (500 GeV c.m.)

| Feature | TESLA<br>1.3 GHz |
|---|---|
| Structure length (cm) | 104 |
| (loaded) accelerating gradient [MV/m] | 24 (35*) |
| Number of structures | 20592 |
| Two-Linac length [km] | 30 |
| RF pulse length [µs] | 1370 |
| Cycle rate [Hz] | 5 |
| RF power/structure [MW] - all for beam | 0.25 |
| Efficiency (Beam power/AC Power [%]) | 23.8 |

## Main Reasons for SC

•1 Fill slowly =>
Big Reduction of Peak RF Power

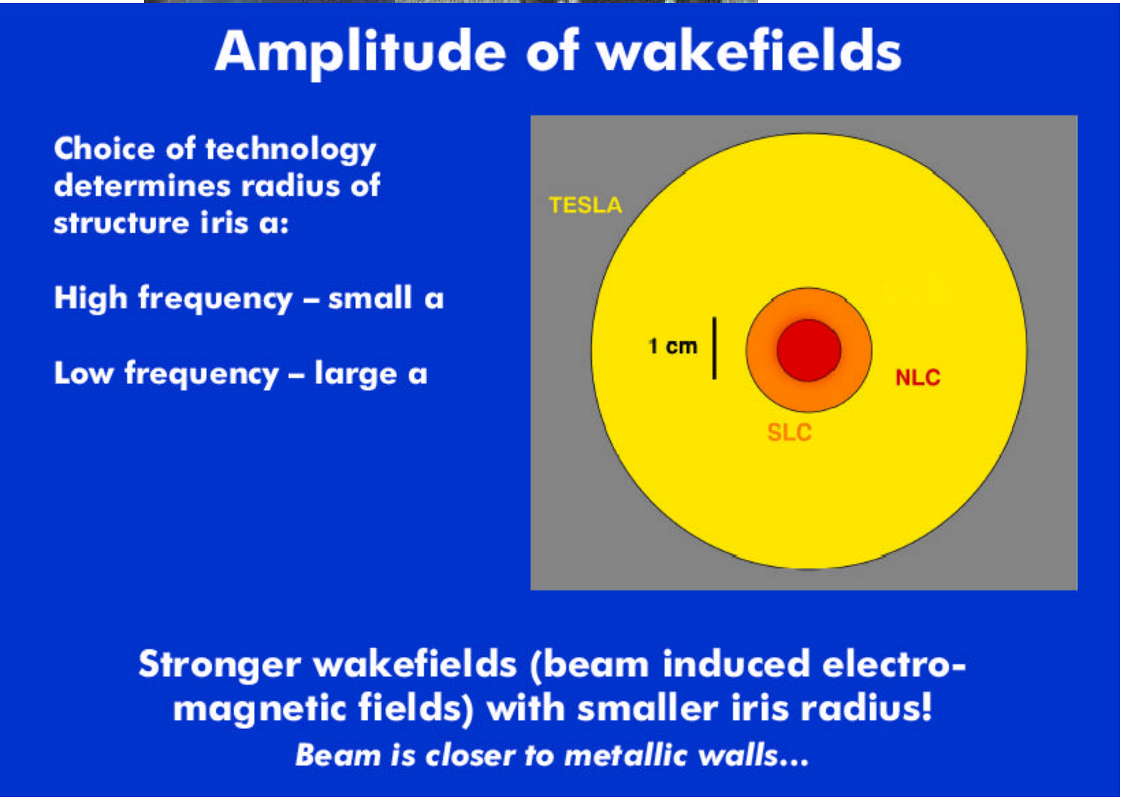
•2 High overall efficiency of
AC power to beam power

*Required for energy upgrade

# 3. Wakefields

Low Frequency, large apertures Affordable =>

Low Wake fields to disrupt beam



## Amplitude of wakefields

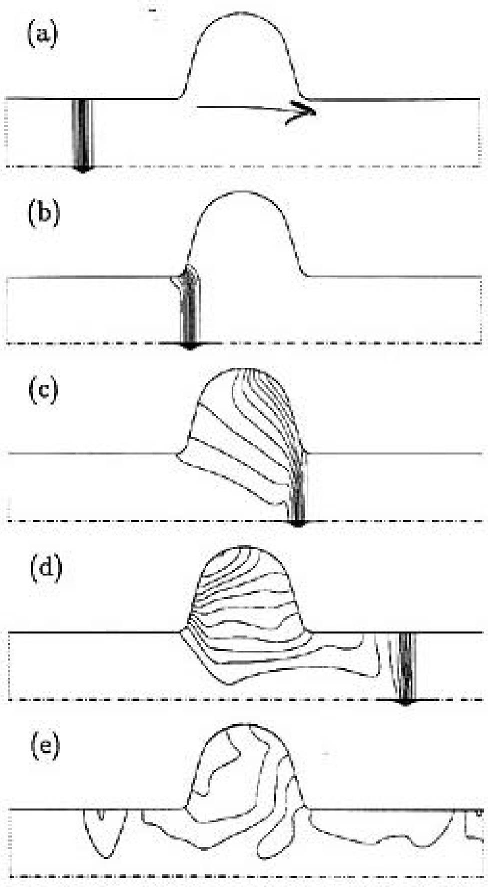
**Choice of technology determines radius of structure iris a:**

**High frequency – small a**

**Low frequency – large a**

**Stronger wakefields (beam induced electro-magnetic fields) with smaller iris radius!**

***Beam is closer to metallic walls...***



# Key Challenges

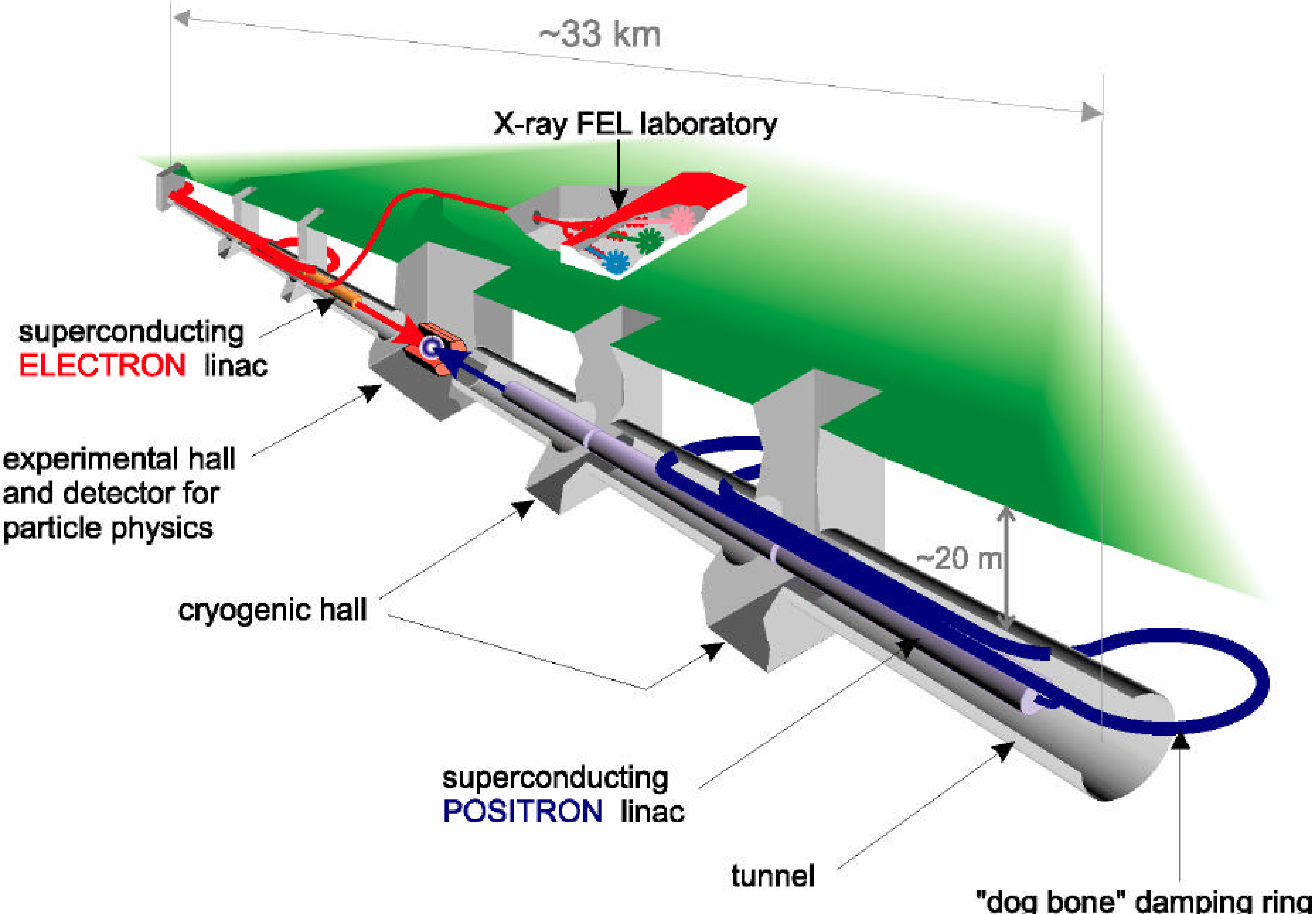
- Operate 500 GeV at Eacc ˜ 24 MV/m
- 35 MV/m for upgrade, needed at first installation
- Extensive R&D at DESY, KEK, JLAB and Cornell over the past decade, in
  - cavity design (to reduce peak surface electric and magnetic fields),
  - Nb material quality,
  - cavity fabrication, cleaning and processing techniques

=> Production of > 50 structures with gradients > 24 MV/m.

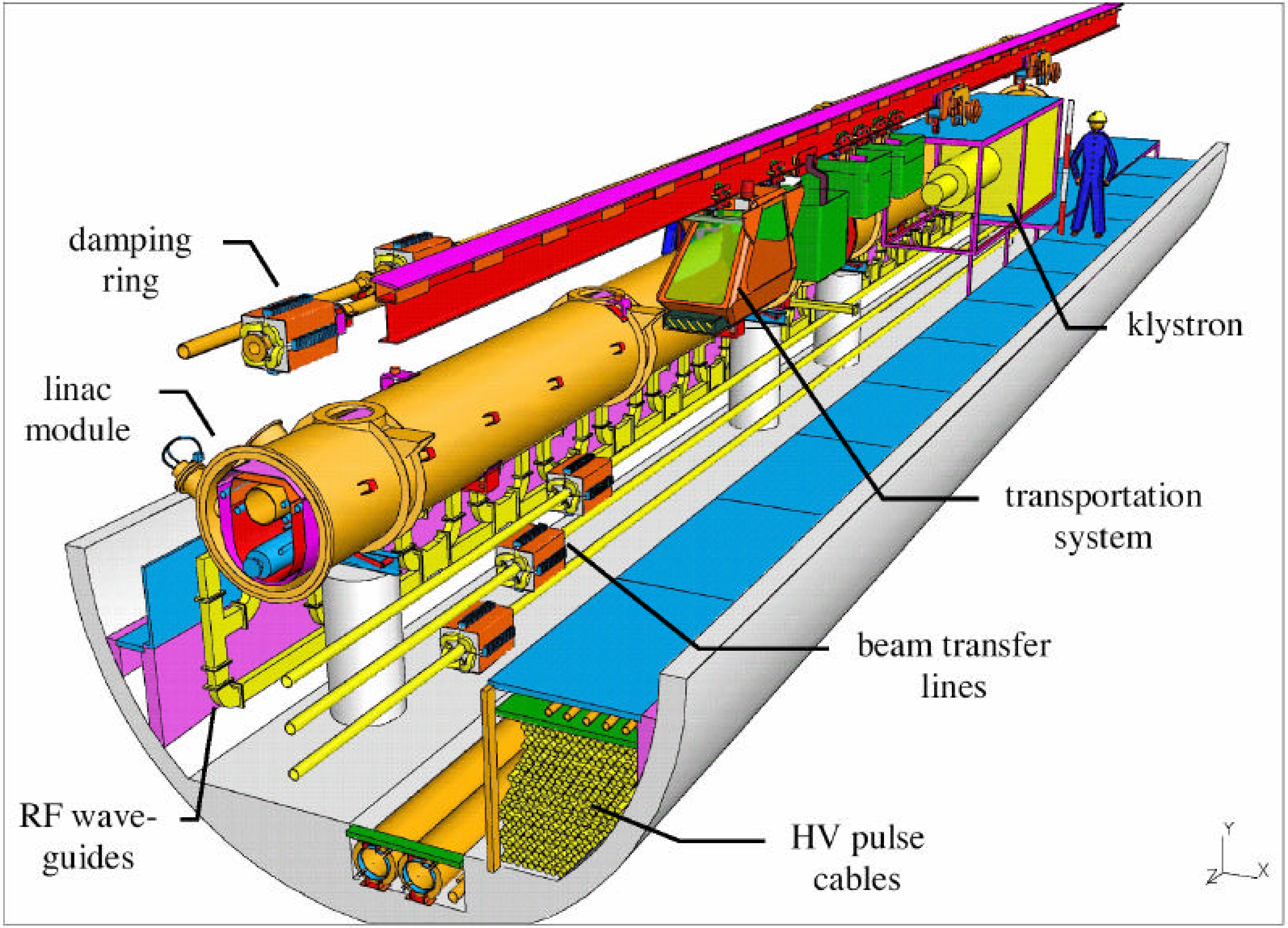
- The latest development in cavity processing (electropolishing) has yielded two “fully-dressed” 9-cell cavities capable of 35 MV/m

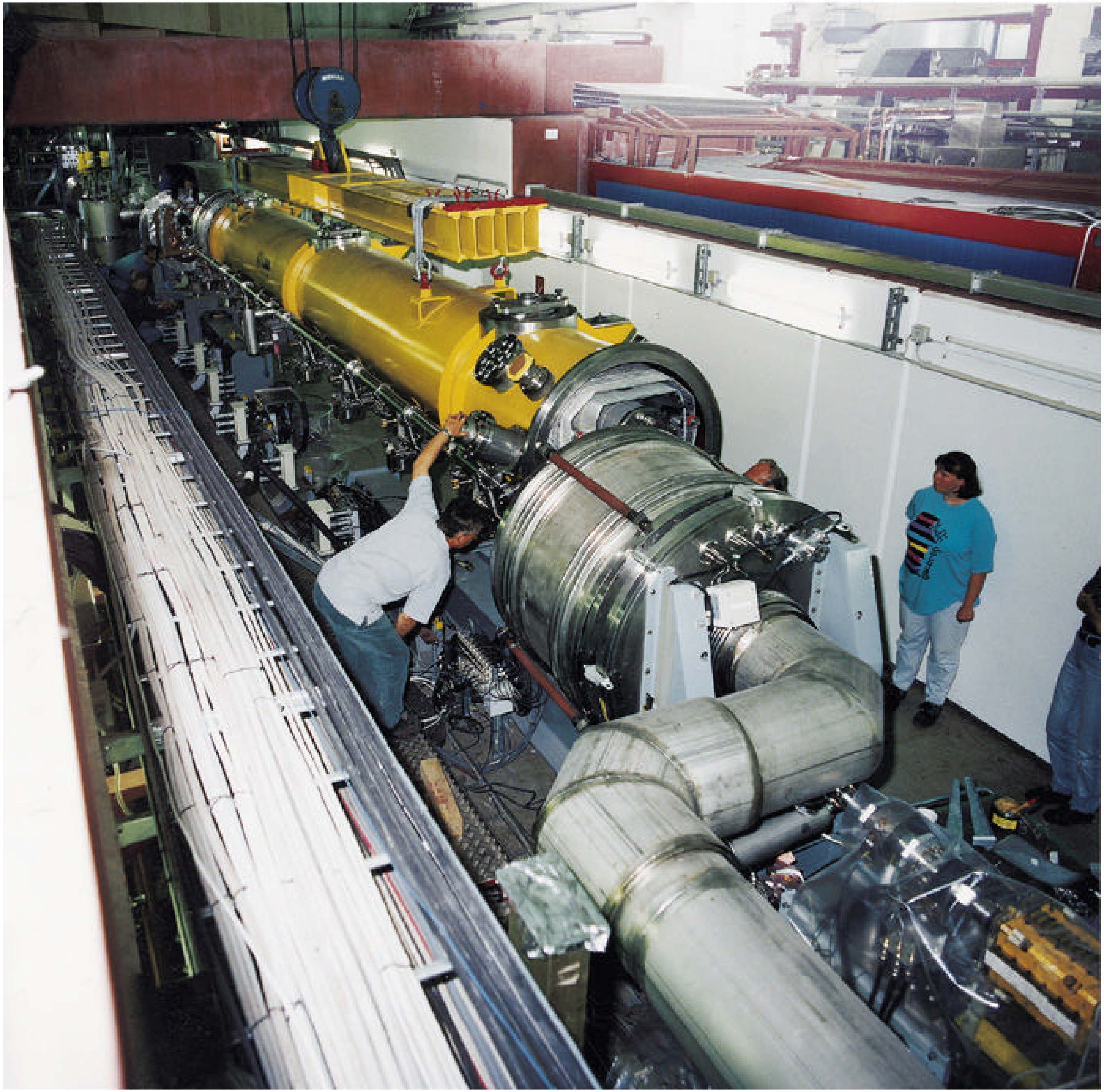
- More 35 MV/m cavities need to be made, to demonstrate the reproducibility of the process, and tested for dark current.

# Zooming in on TESLA

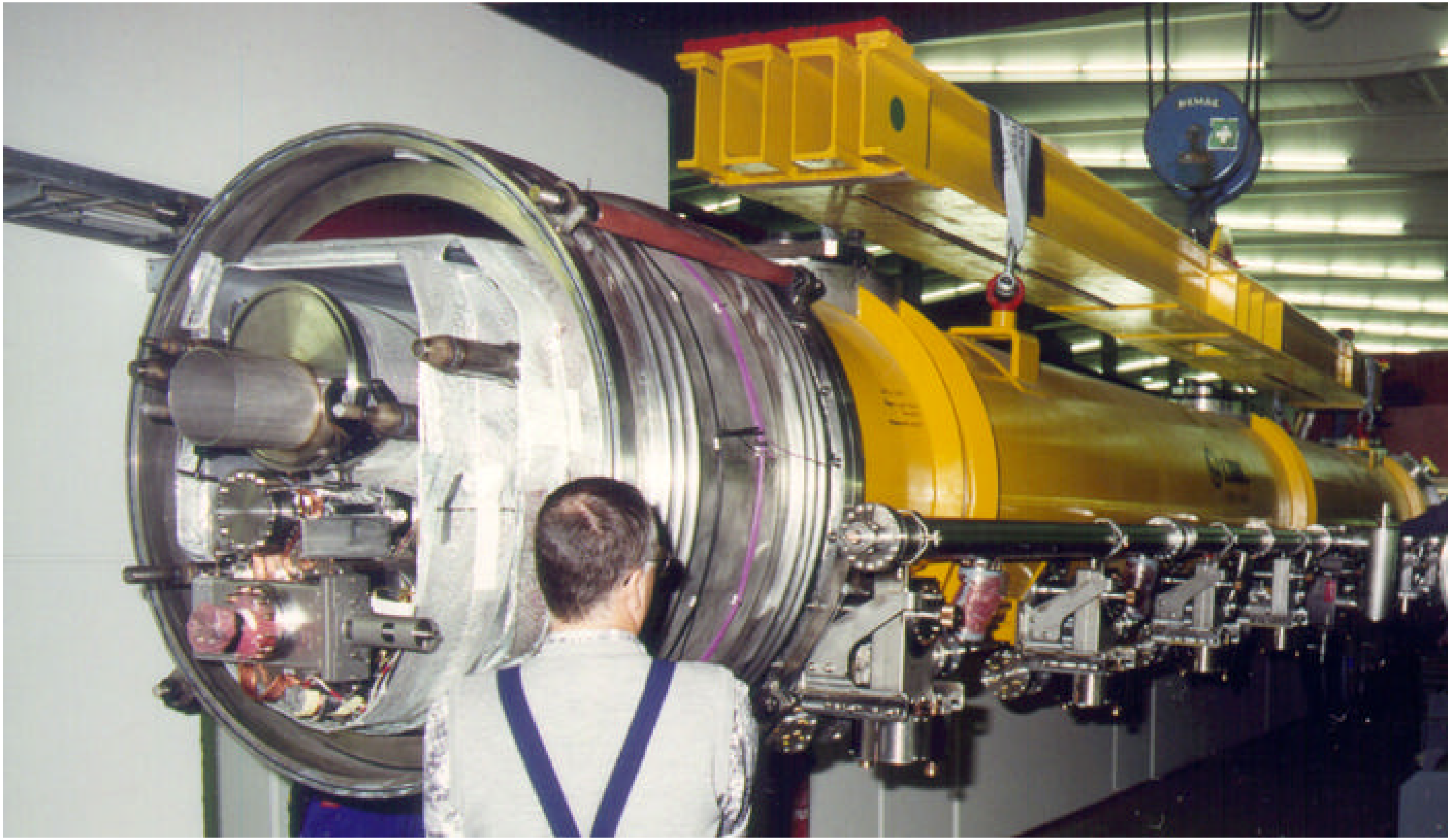


# TESLA Tunnel



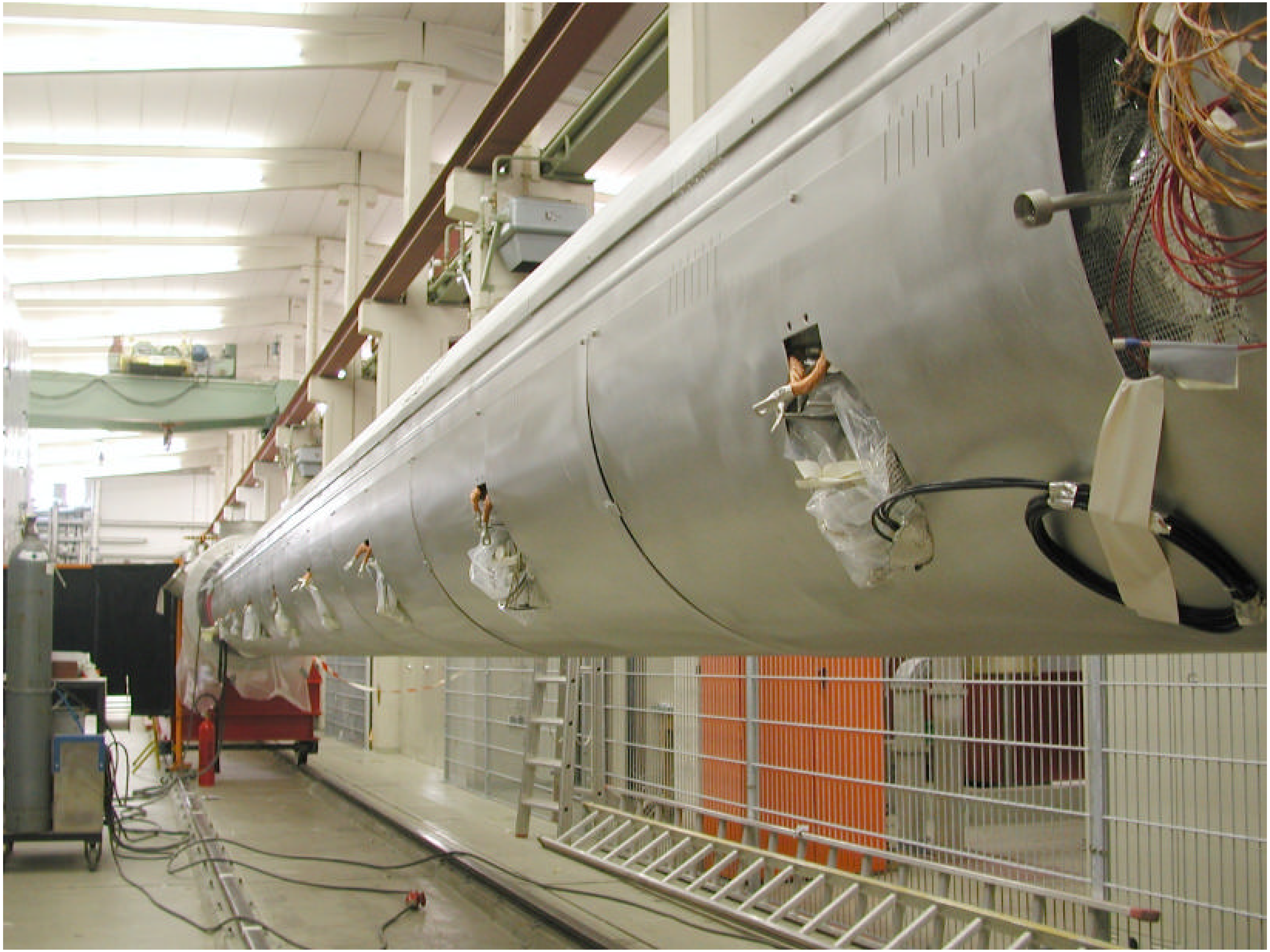


1700 Cryomodules


DEMAG

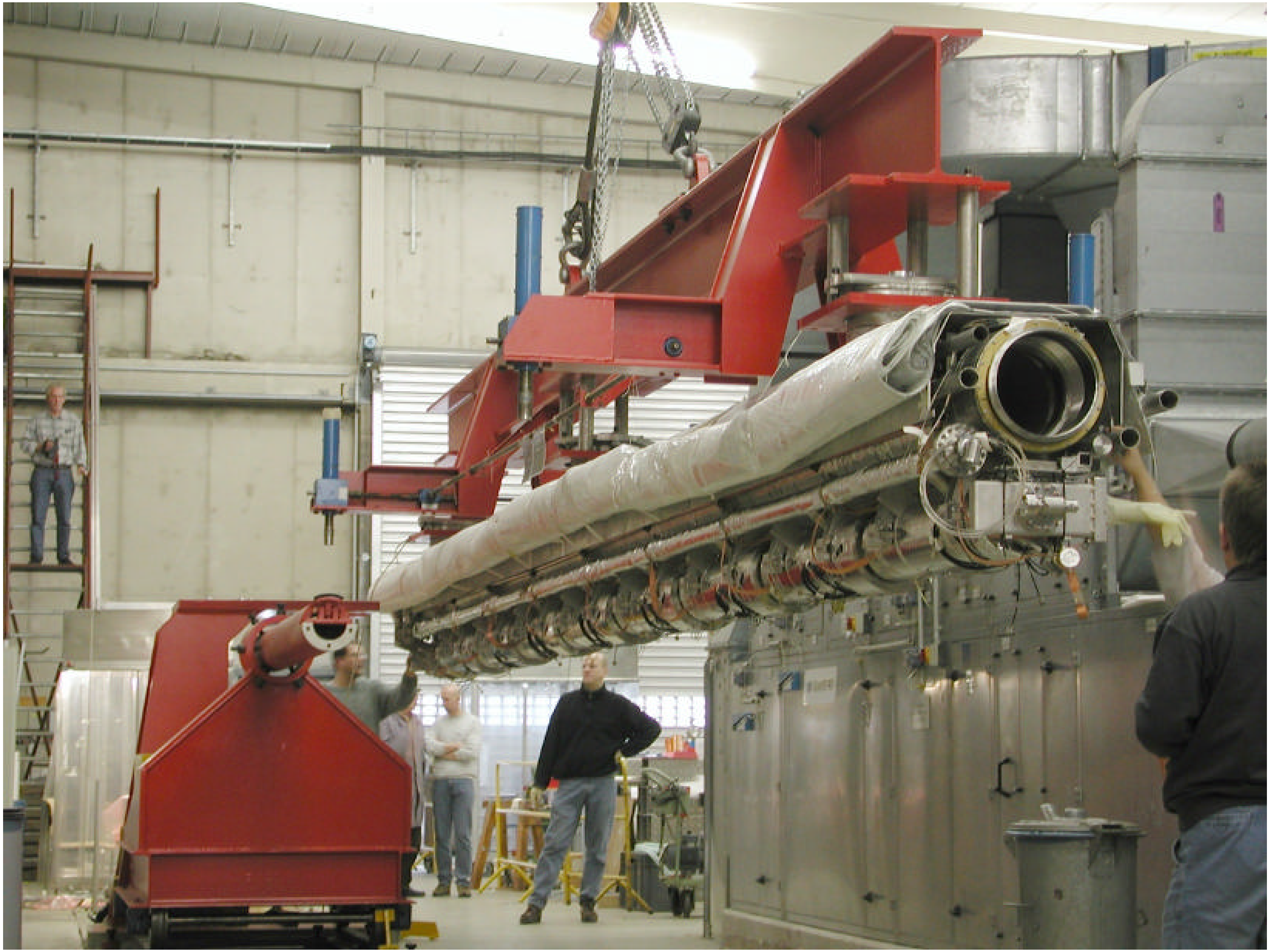
# 70 K ML Isolation (30 Layers)

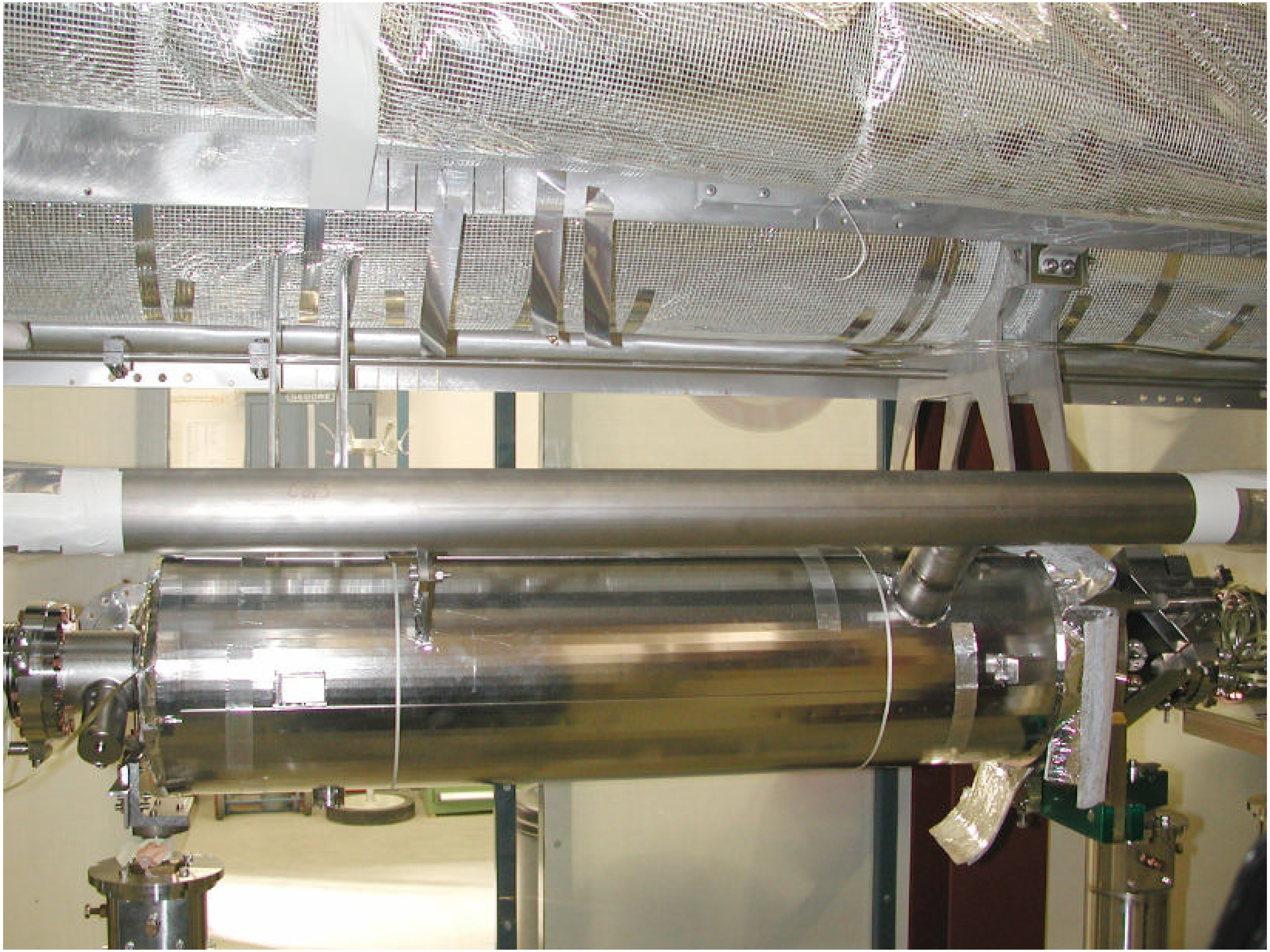
# 70 K Shield before Welding



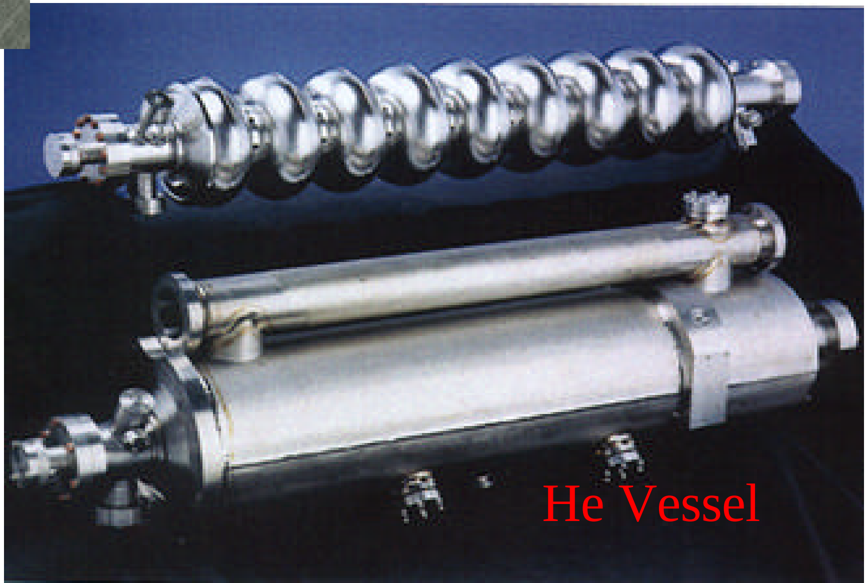
# 4 K Shield

# Cavity String mounted on 300 mm He Gas Return Pipe





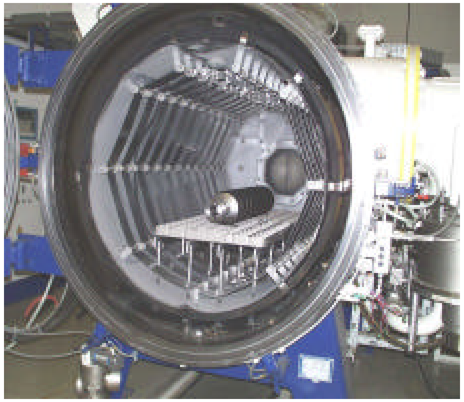
# Preparation of TESLA Cavity String

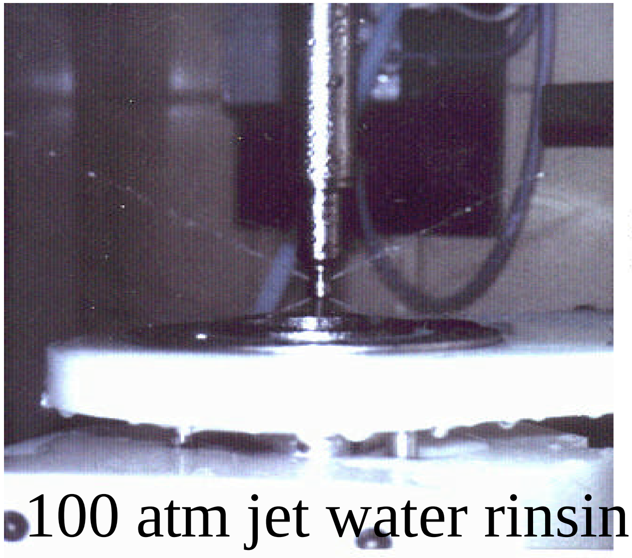

He Vessel

# Cavities and Cavity Parts

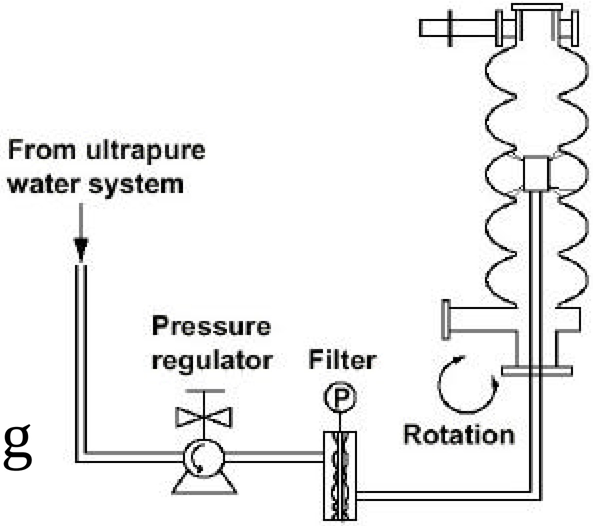
# Preparation of TESLA Cavities

Furnace treatment





100 atm jet water rinsing

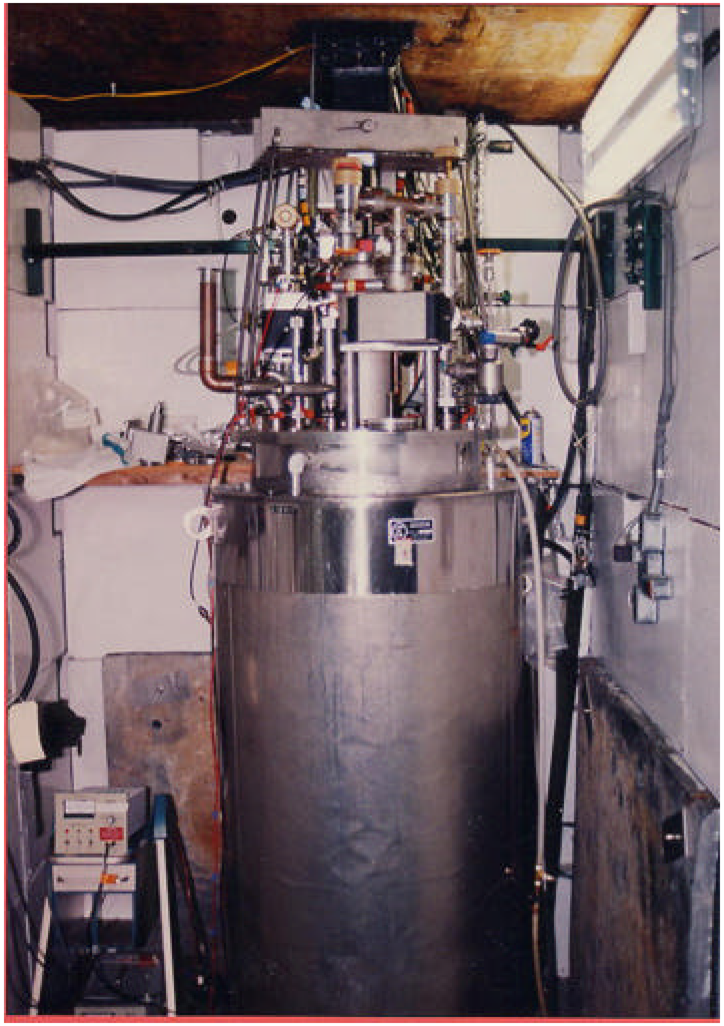


Chemical Treatment

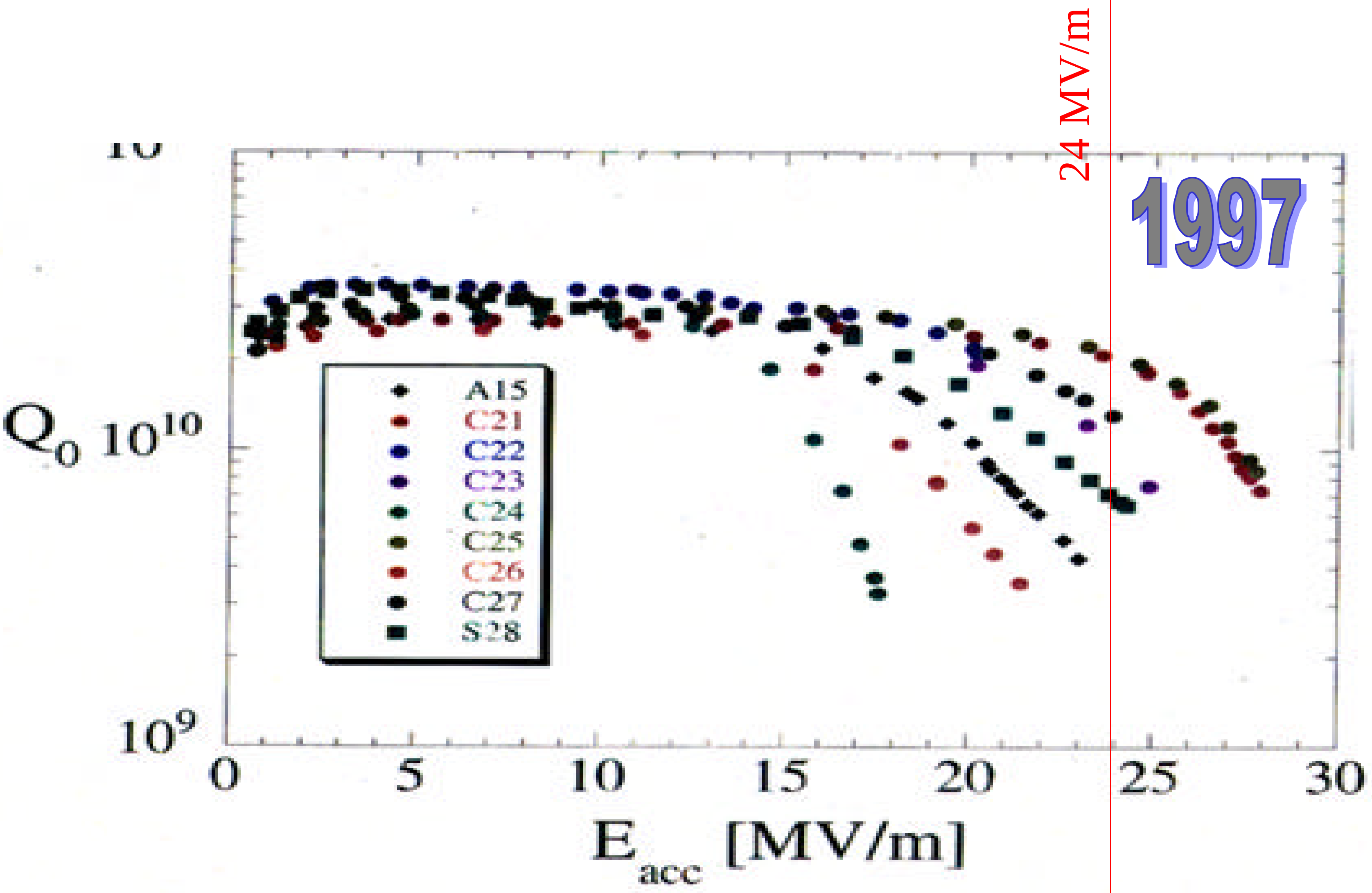
Class 100 Dust Free Clean Room Assembly

# Cavity Vertical Test

- The naked cavity is immersed in a super-fluid He bath (2 K).
- RF test are performed in CW with a moderate power(< 300W)

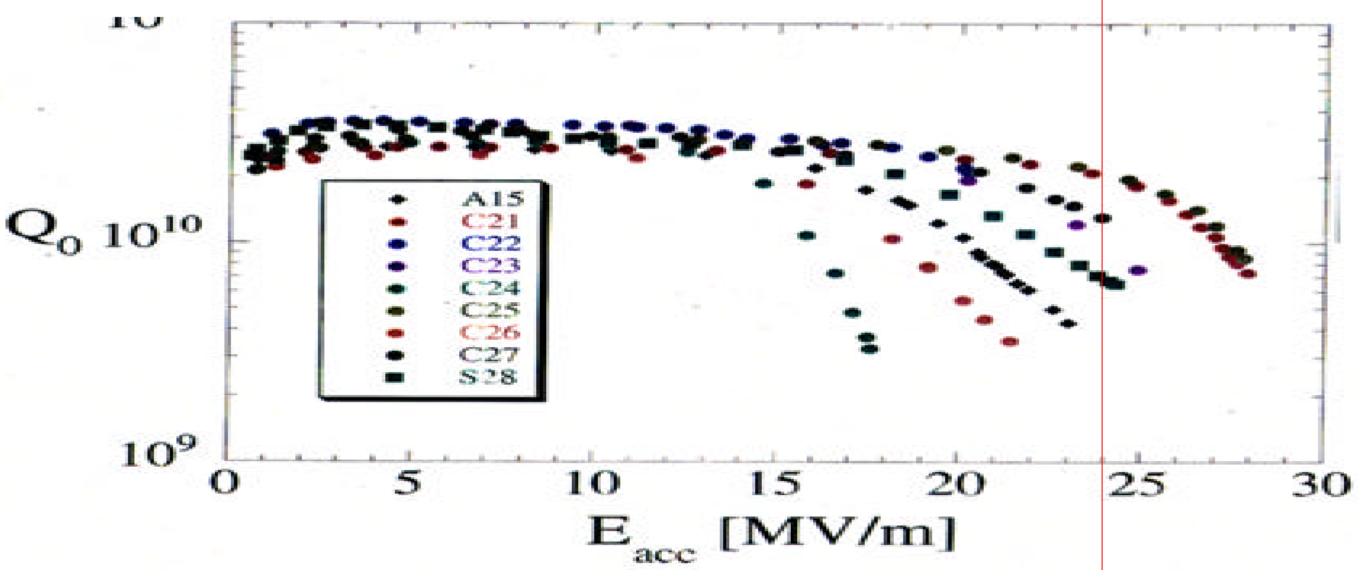


# Steady Improvement in Cavity Gradients and Q’s



average gradient at $Q_0 > 3\ 10^9 = 23.9$ MV/m

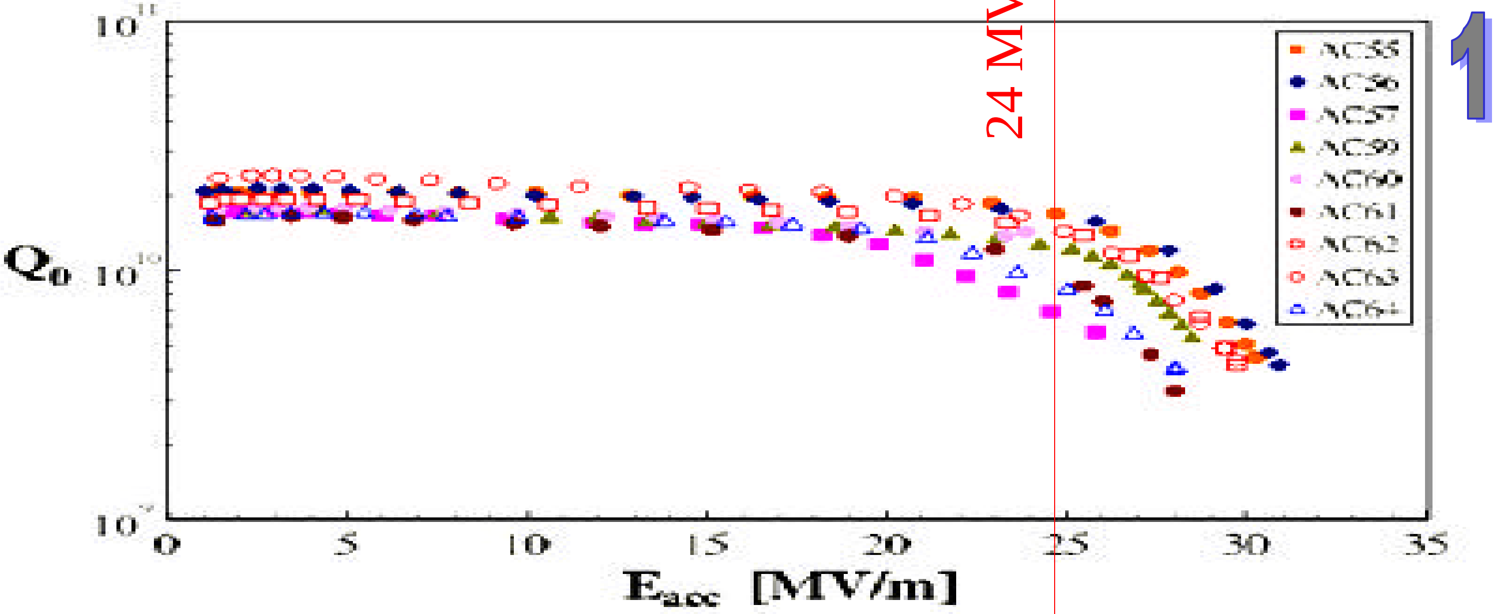
# Steady Improvement in Cavity Gradients and Q's



average gradient at $Q_0 > 3\ 10^9$ = 23.9 MV/m

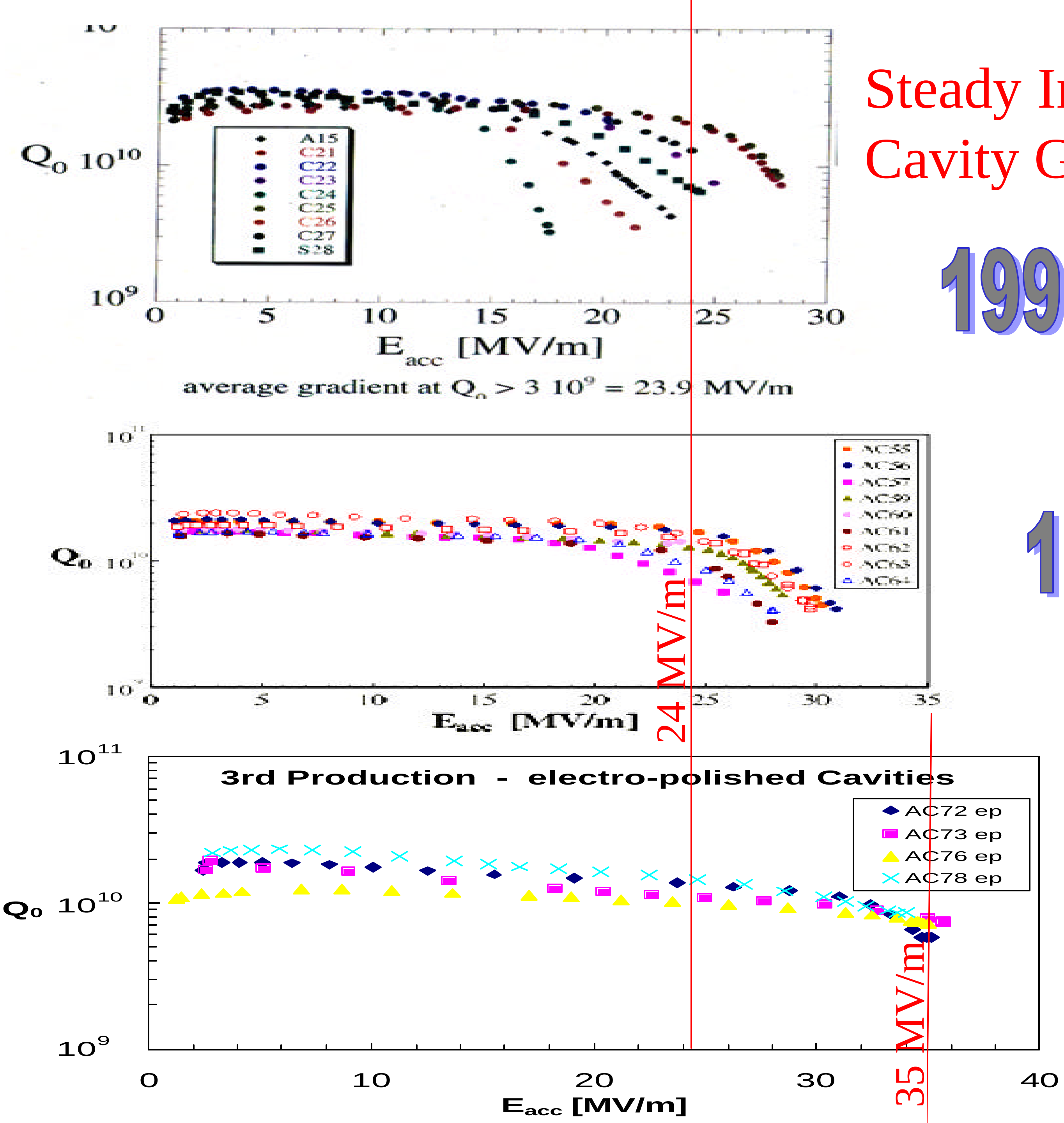
**1997**

24 MV/m



**1999**

# Steady Improvement in Cavity Gradients and Q's



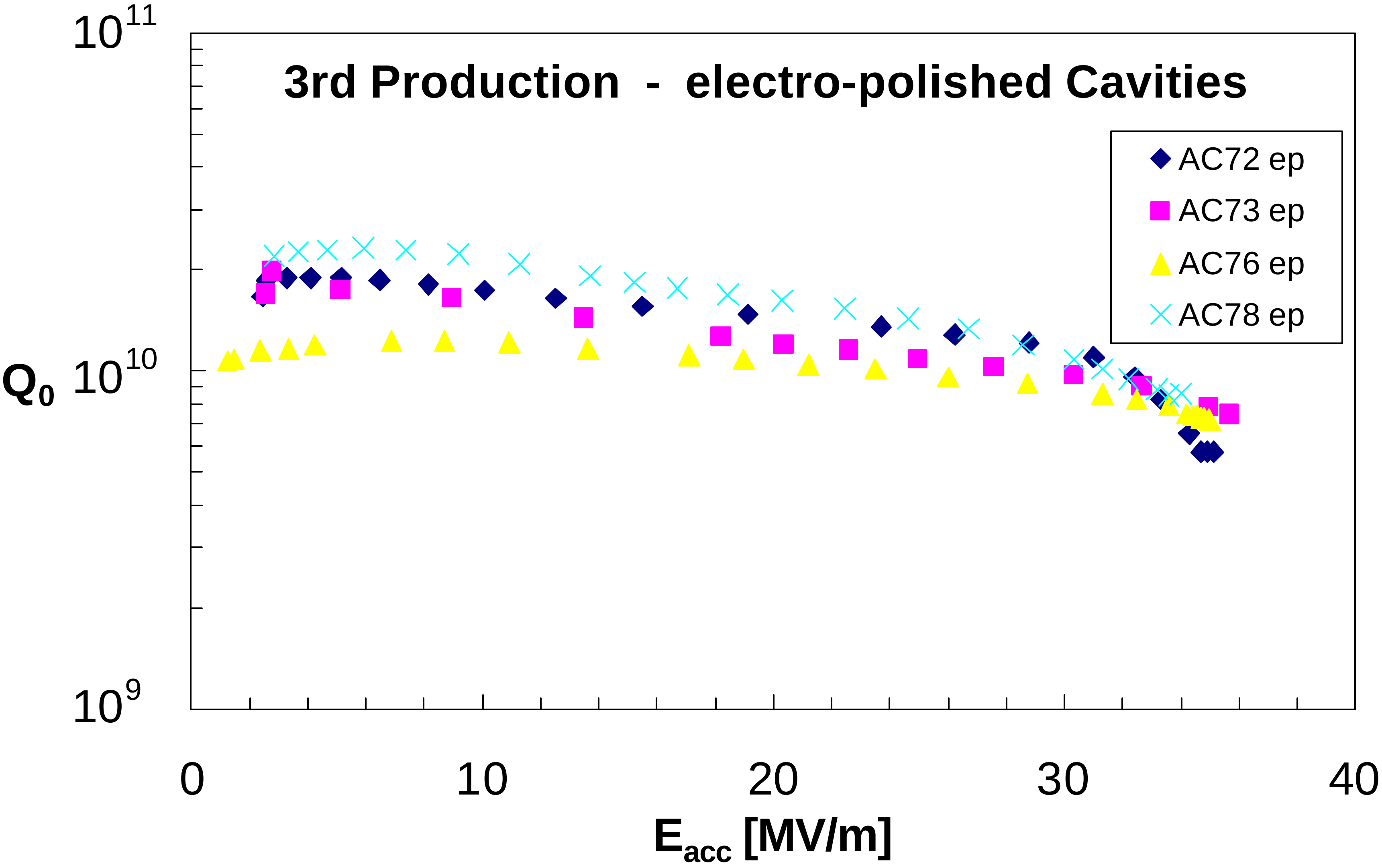
average gradient at $Q_0 > 3\ 10^9 = 23.9$ MV/m

1997

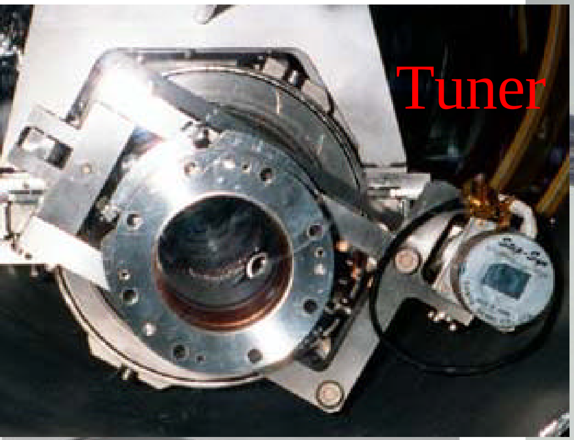
1999

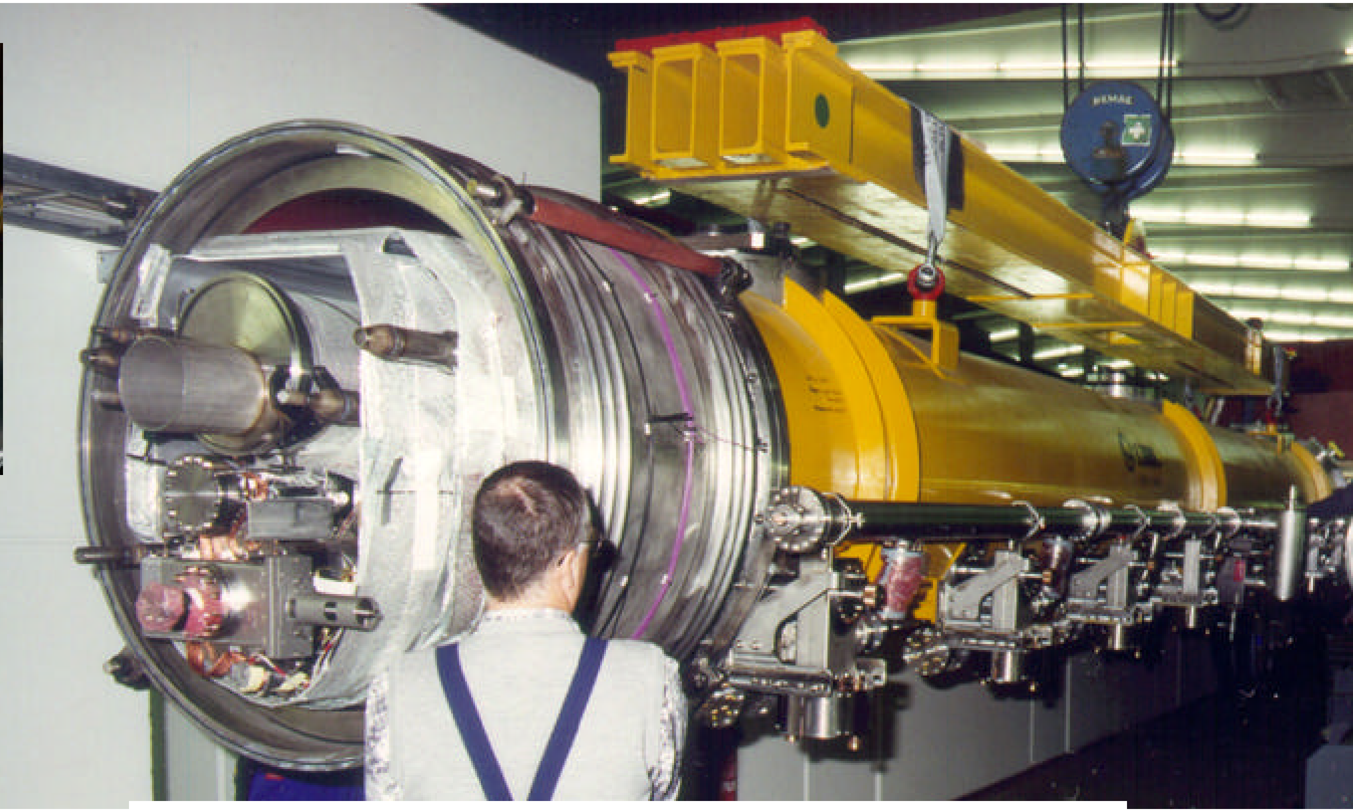
2002

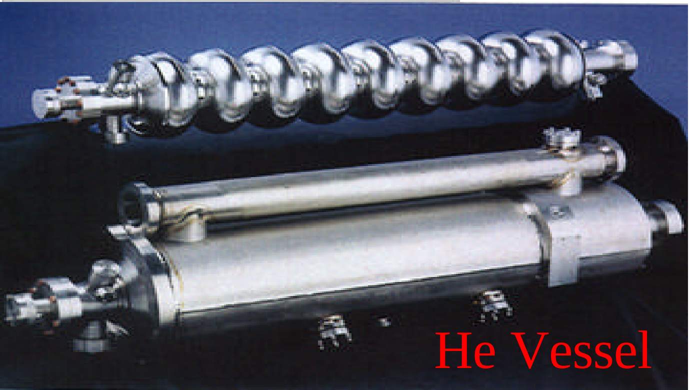
# Highest Gradient Performance

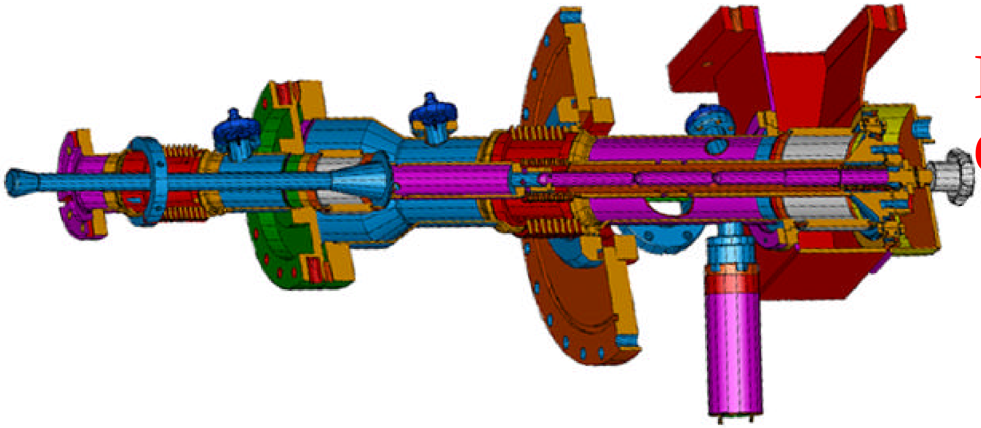


# In Cryomodules

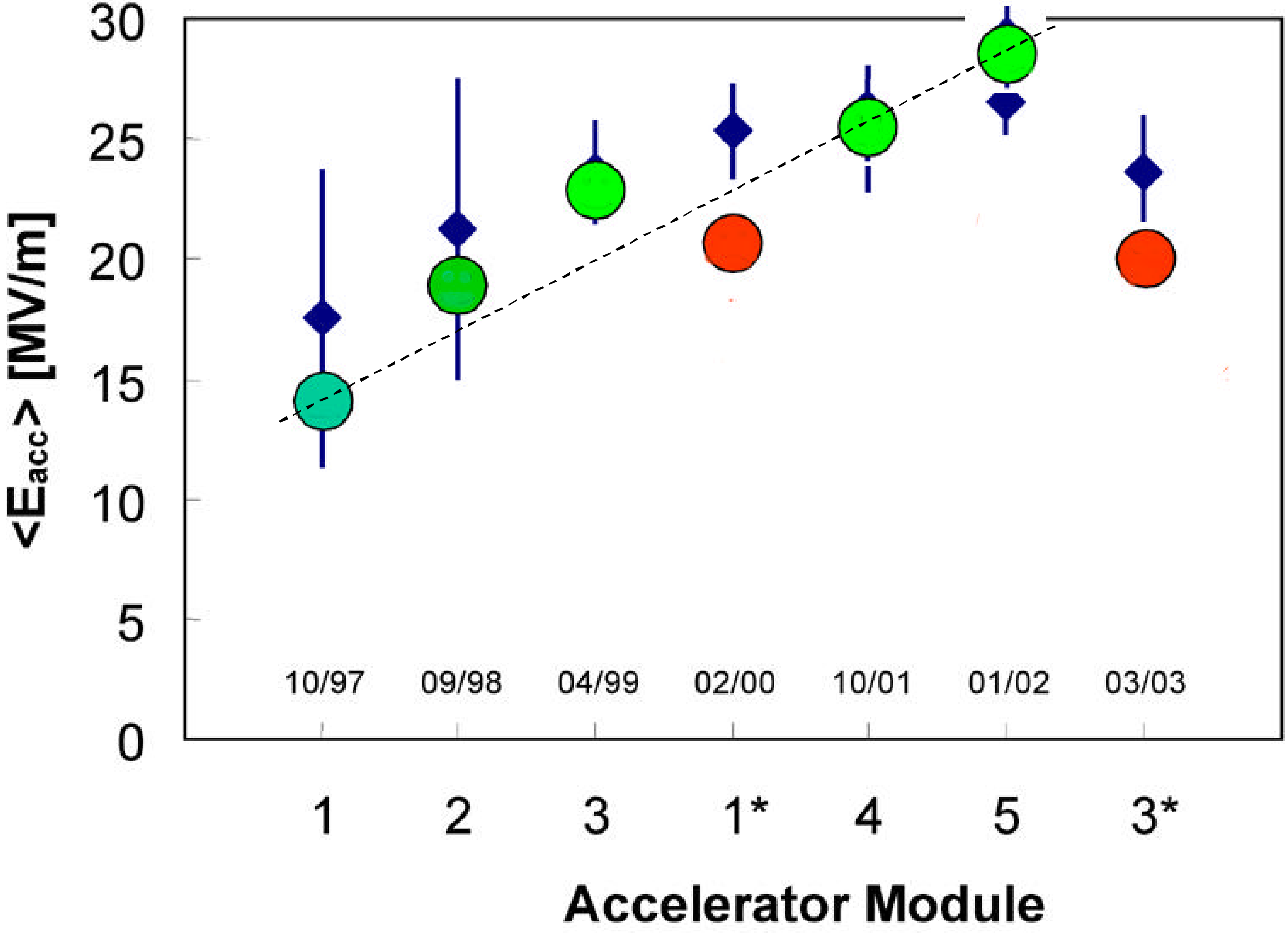




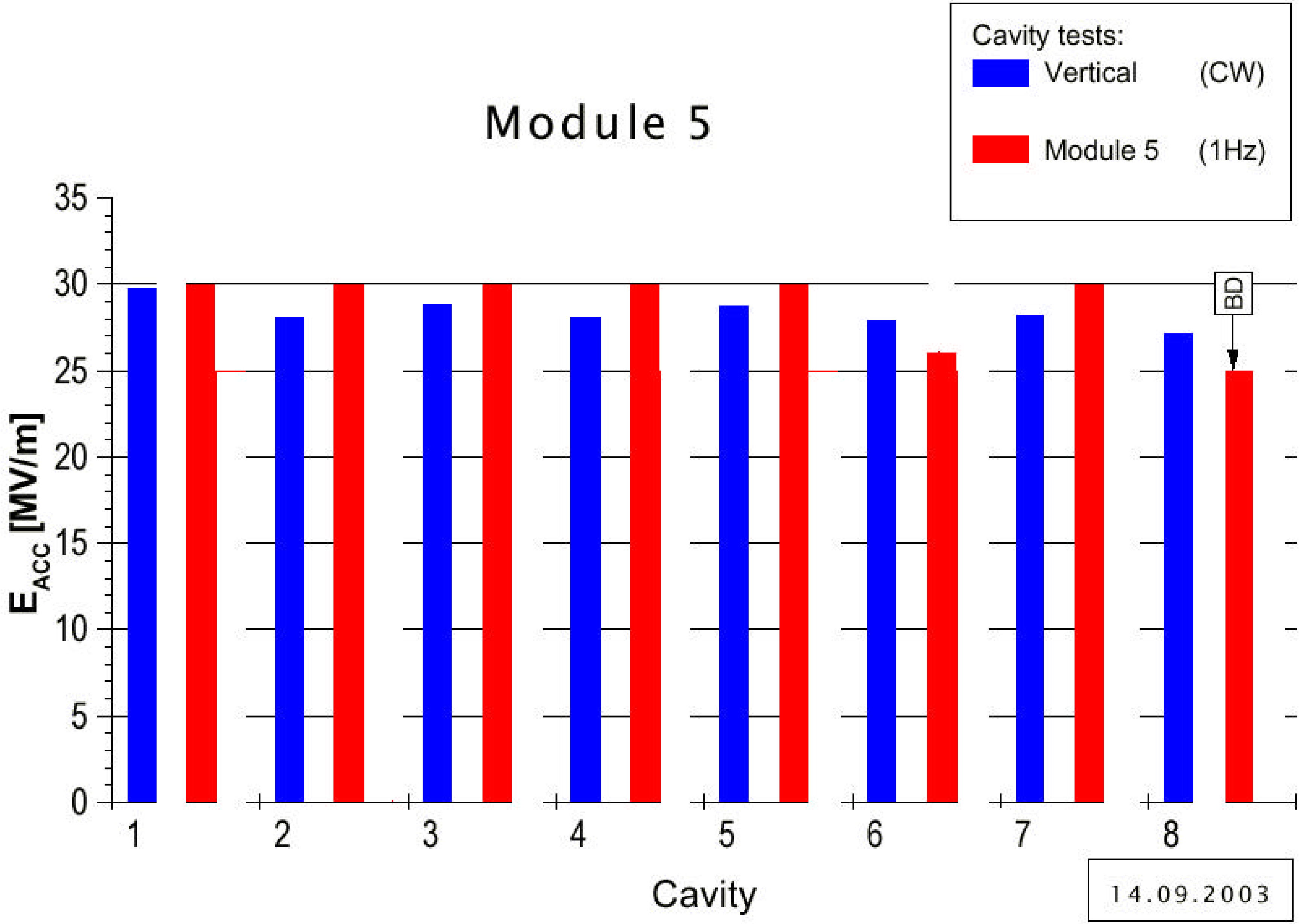




# Gradient of Accelerator Modules

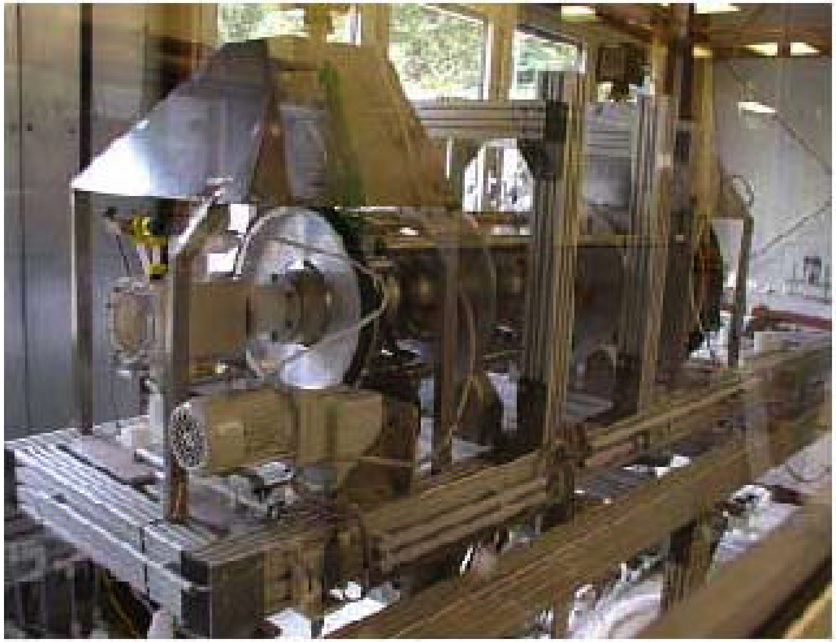


# Module 5



14.09.2003

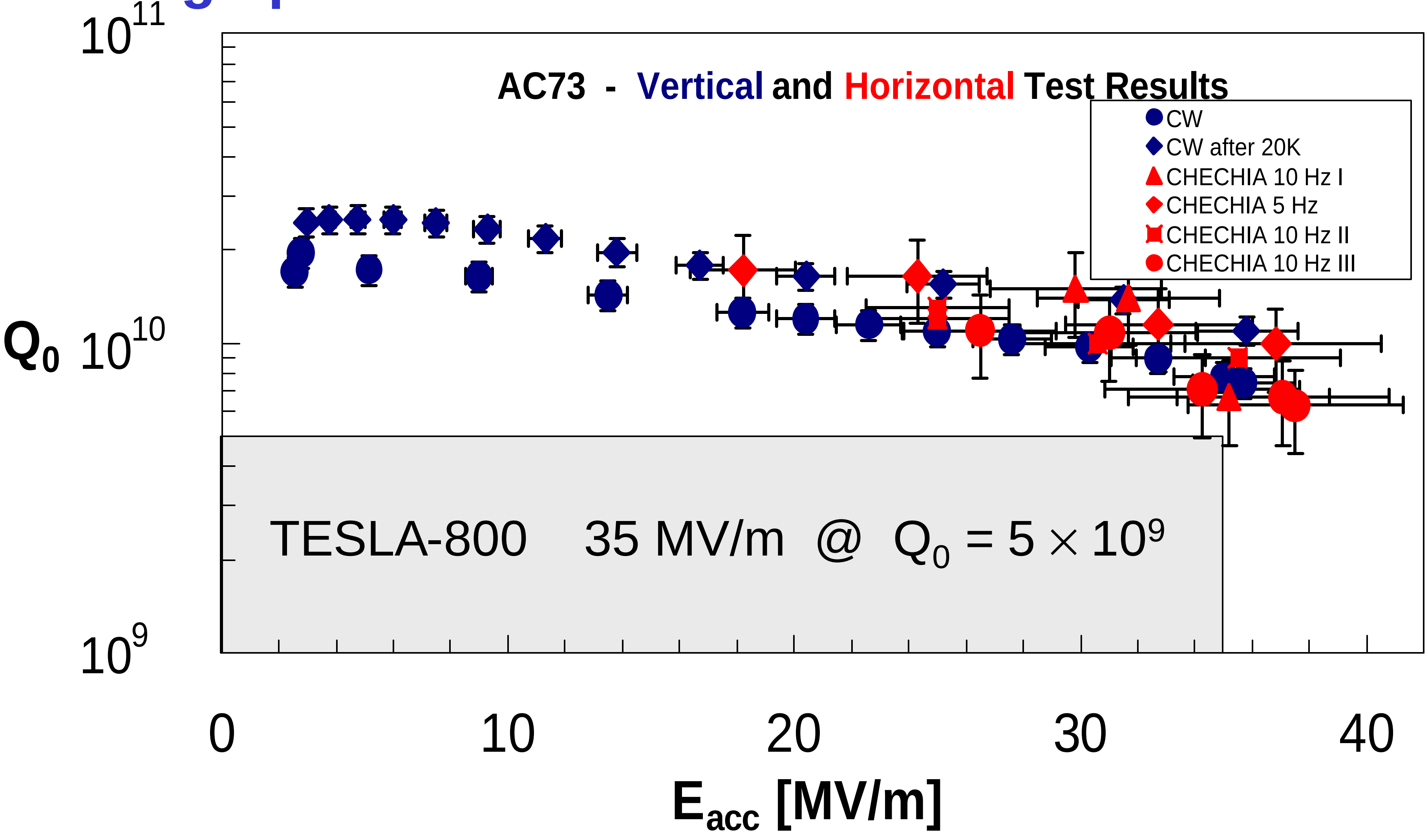
# EP 9-cell Cavities - Cryomodule "Chechia"



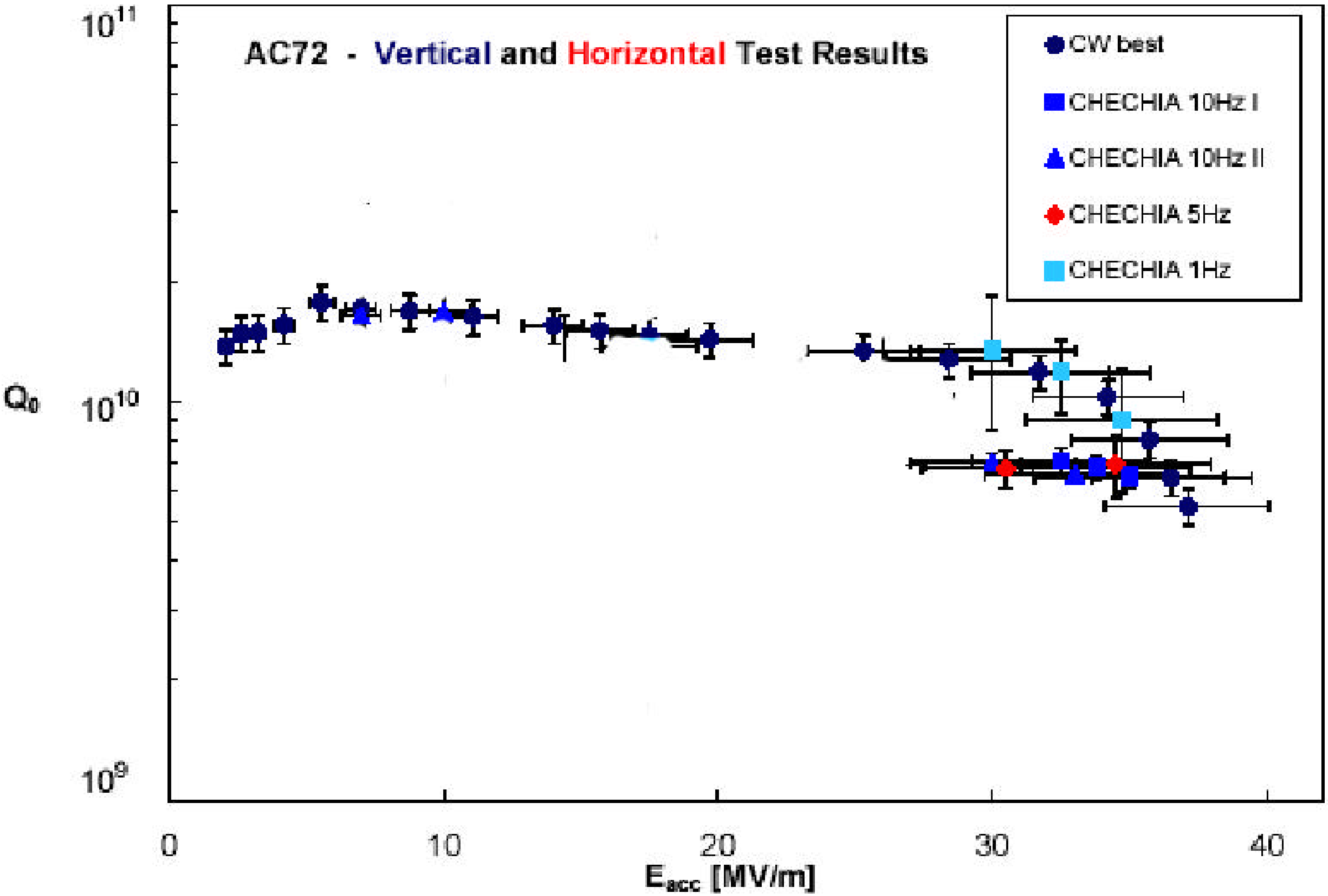
- Cavity is fully assembled
- It includes all the ancillaries:
  - Power Coupler
  - Helium vessel
  - Tuner (…and piezo)
- RF Power is fed by a Klystron through the main coupler
- Pulsed RF operation using the same pulse shape foreseen for TESLA

# Cavity AC 73: 35 MV/m in CHECHIA

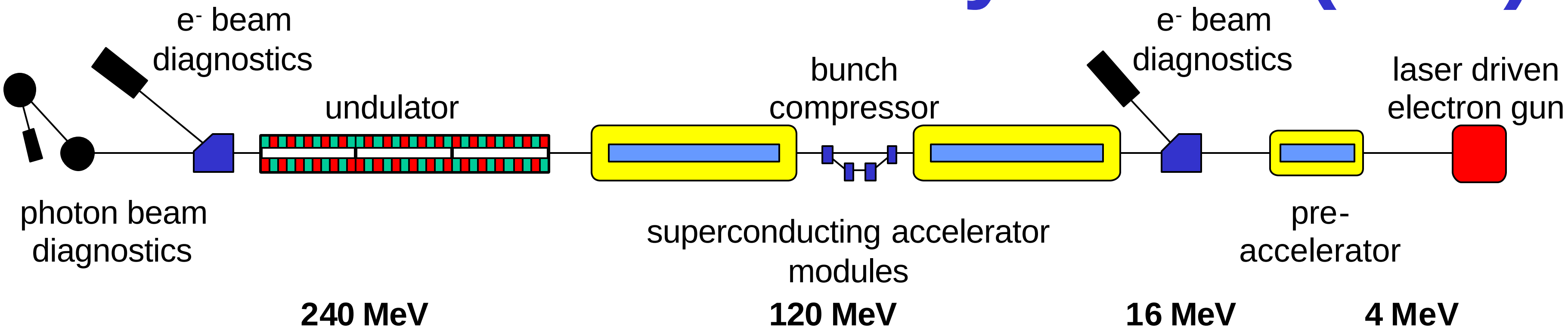
## i.e. high power test and 1/8th of a TTF Linac module



# AC 72 also reached 35 MV/m in CHECHIA



# TESLA Test Facility Linac (TTF)



photon beam diagnostics

e$^-$ beam diagnostics

undulator

superconducting accelerator modules

bunch compressor

e$^-$ beam diagnostics

pre-accelerator

laser driven electron gun

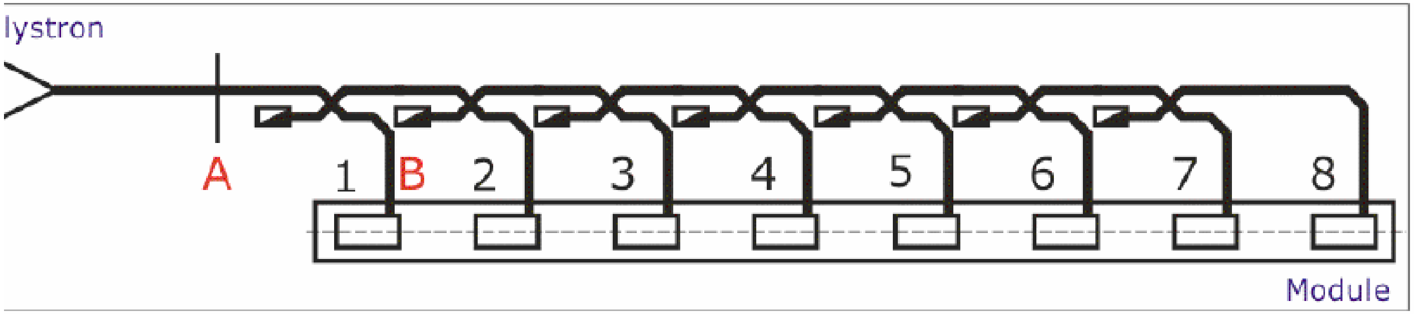
**240 MeV**

**120 MeV**

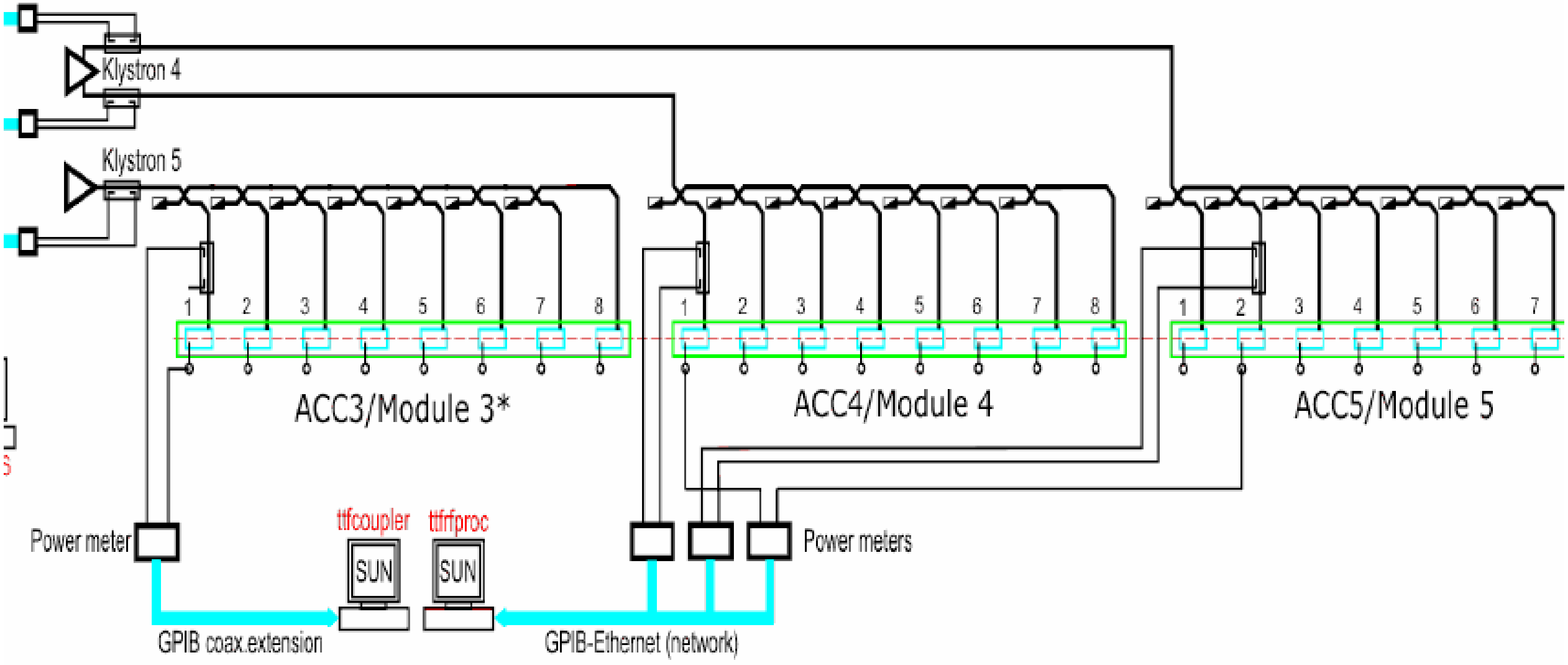
**16 MeV**

**4 MeV**

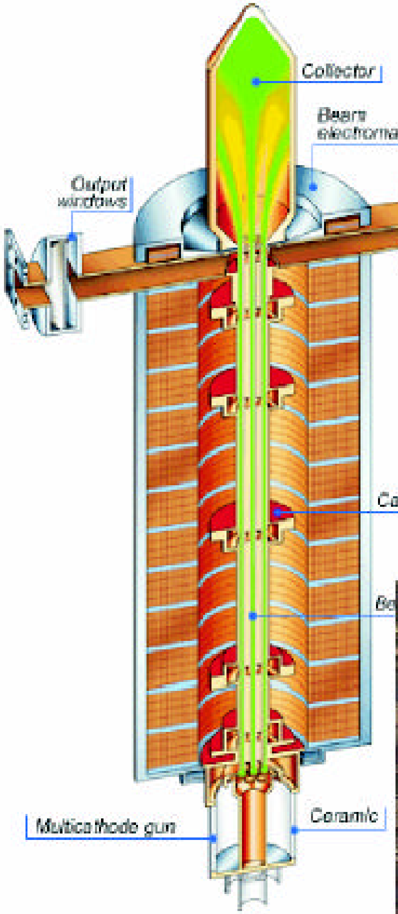
# RF Systems Assembled and Tested in TTF



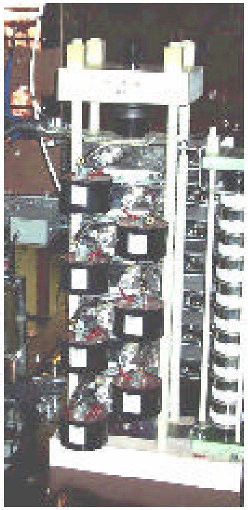
F II RF test: Power distribution/measurement diagram



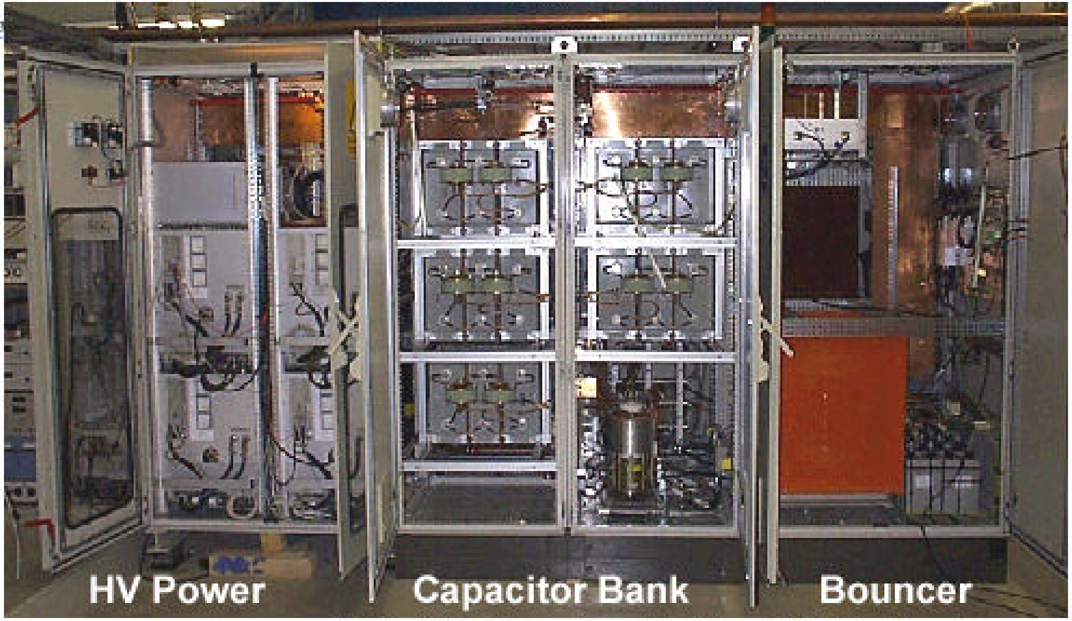
# TTF High Power RF



TH1801
Multi-Beam
Klystron

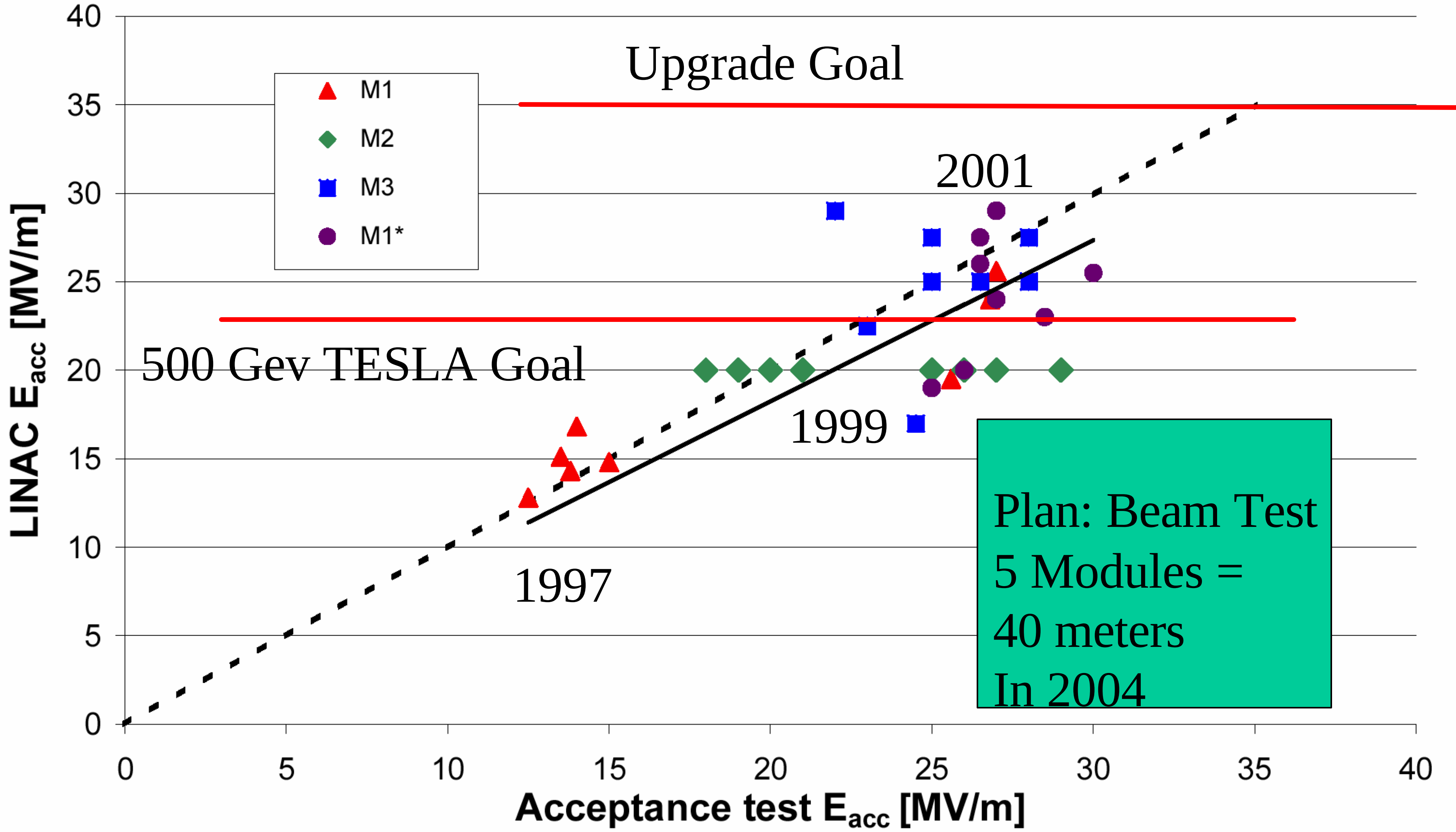


IGCT Stack



# In Beam

## LINAC vs. Vertical



Plan: Beam Test
5 Modules =
40 meters
In 2004

13, 000 hours of beam time

TTF - I Complete

TTF-II under construction
In Model Tunnel

Experimental Hall for
UV FEL Facility

# Model for TESLA Tunnel

# TESLA Test Facility Linac – Phase II

Six accelerator modules to reach 1 GeV beam energy.

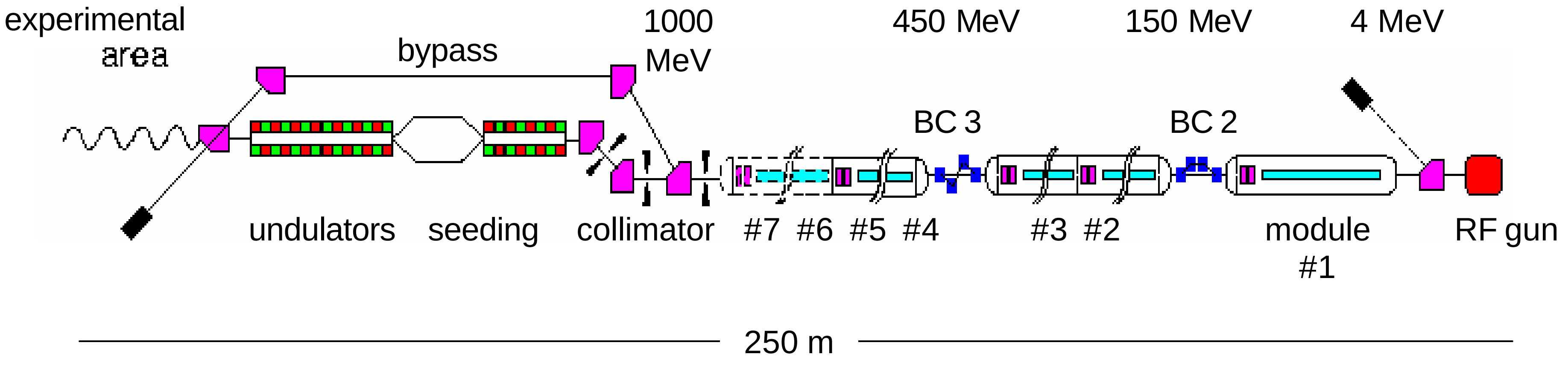
Module #6 will contain 8 electro-polished cavities.

Engineering with respect to TESLA needs.

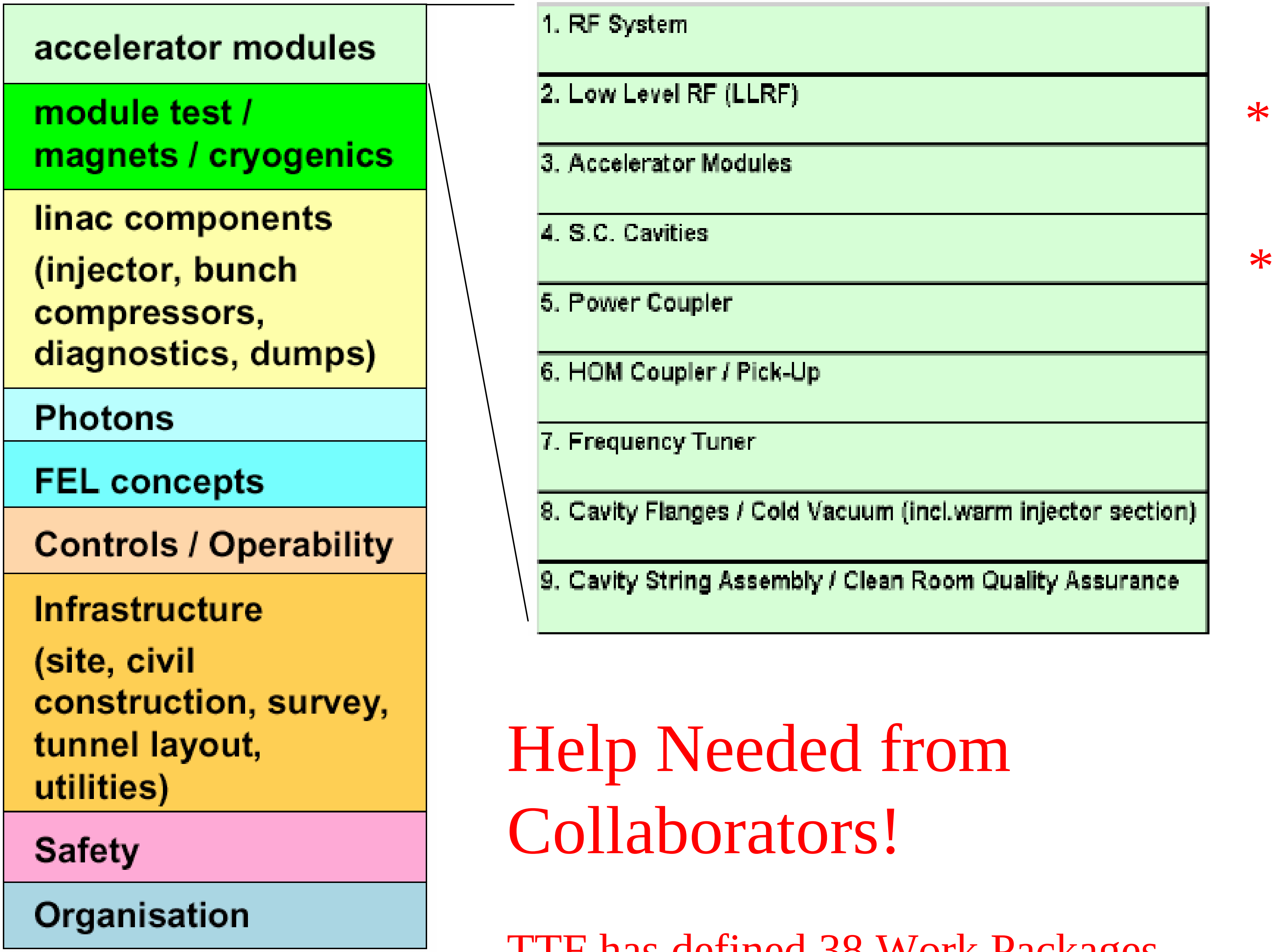
Klystrons and modulators built in industry.

High gradient operation of accelerator modules.

Space for module #7 (12 cavity TESLA module).



**FEL User Facility in the nm Wavelength Range**



**accelerator modules**

**module test / magnets / cryogenics**

**linac components**

**(injector, bunch compressors, diagnostics, dumps)**

**Photons**

**FEL concepts**

**Controls / Operability**

**Infrastructure**

**(site, civil construction, survey, tunnel layout, utilities)**

**Safety**

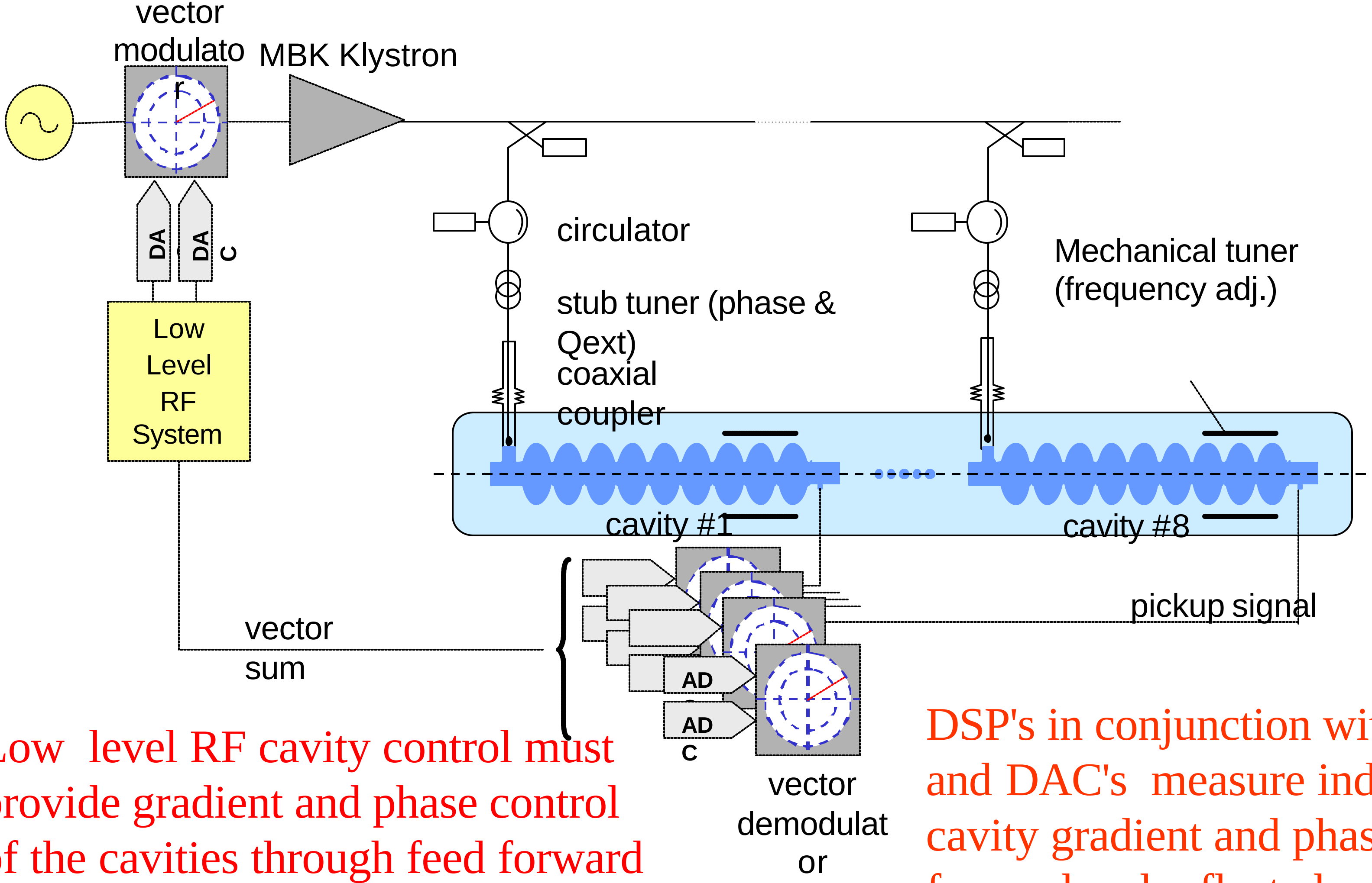
**Organisation**

1. RF System
2. Low Level RF (LLRF) *
3. Accelerator Modules
4. S.C. Cavities *
5. Power Coupler
6. HOM Coupler / Pick-Up
7. Frequency Tuner
8. Cavity Flanges / Cold Vacuum (incl.warm injector section)
9. Cavity String Assembly / Clean Room Quality Assurance

Help Needed from Collaborators!

TTF has defined 38 Work Packages

# RF Unit 1 klystron for 36 nine-cell cavities each



Low level RF cavity control must provide gradient and phase control of the cavities through feed forward and feedback systems, detect the relative beam to rf phase, detect developing cavity problems and faults, and provide exception handling.

DSP's in conjunction with ADC's and DAC's measure individual cavity gradient and phase, and forward and reflected power.

<u>Example for further hardware advance : use of digital receivers.</u>

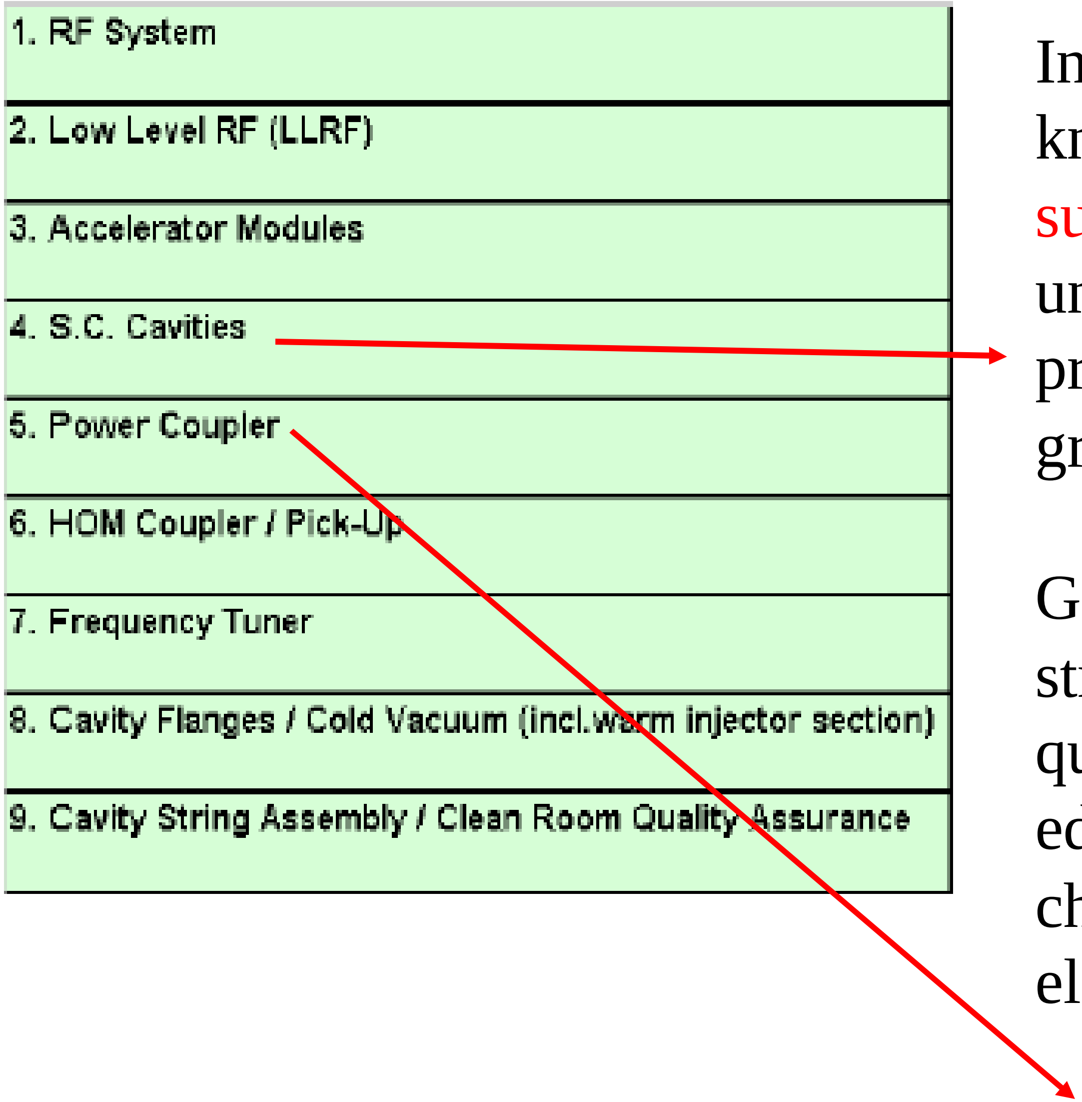
# LLRF Continued

The DSP's get their parameters from the DSP server. The server software handles: generation of set point(SP) and feedforward (FF) tables from basic settings, matrices information for each cavity, loop phase constant, startup configuration files, and exception handler control parameters. Server software and interface to the DSP's and control system needs detailed specification and code generation.

Development needed: connect DSP systems of different klystrons together through an optical giga Hz link. Such a system would allow for very fast compensation by adjacent systems if one system experienced a fault.

Definition of system architecture and concepts, as well as code, need to be developed.

Low level RF simulation programs are being developed to check feedback and feed forward algorithms, response to cavity quench, or beam current variations, and non linear gain behavior of the klystron. Effort is needed to develop, test and apply these simulators to RF control.



1. RF System
2. Low Level RF (LLRF)
3. Accelerator Modules
4. S.C. Cavities
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8. Cavity Flanges / Cold Vacuum (incl.warm injector section)
9. Cavity String Assembly / Clean Room Quality Assurance

Invites scientists knowledgeable in material and surface physics into understanding important properties related to high gradient and Q.

Grain size, hardness, tensile strength, RRR, workability, quality control of inclusions, eddy current scanning, chemical treatment, electropolishing parameters….

Copper plating, TiN plating for input couplers

**accelerator modules**

**module test / magnets / cryogenics**

**linac components**

**(injector, bunch compressors, diagnostics, dumps)**

**Photons**

**FEL concepts**

**Controls / Operability**

**Infrastructure**

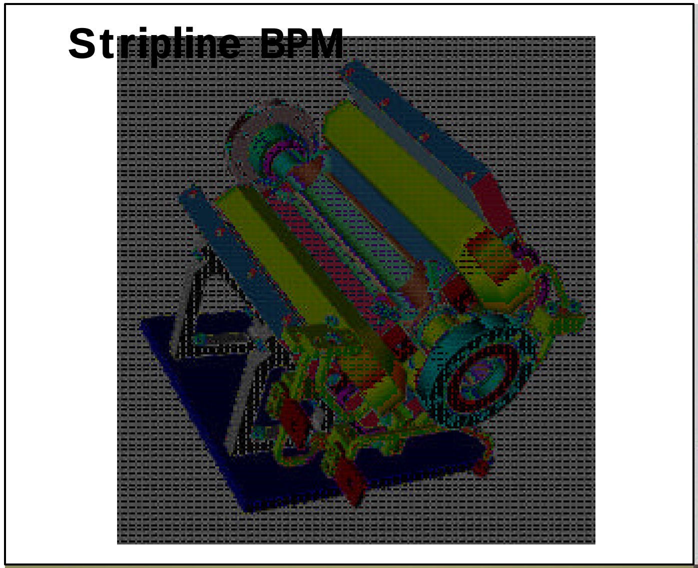
**(site, civil construction, survey, tunnel layout, utilities)**

**Safety**

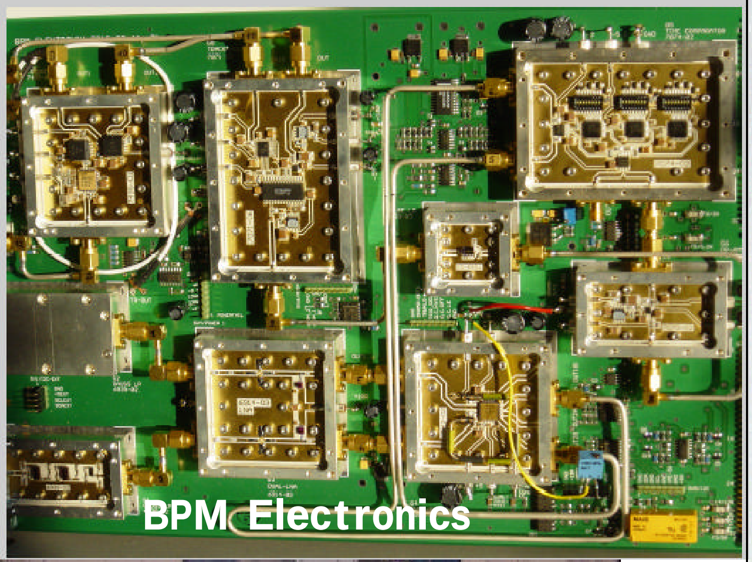
**Organisation**

14. Injector
15. Bunch Compression and Start-to-End Simulation
16. Lattice Design and Beam Optics/Dynamics
17. Standard Beam Diagnostics *
18. Special Beam Diagnostics *
19. Vacuum system (warm)
20. Beam Dumps
21. Undulators

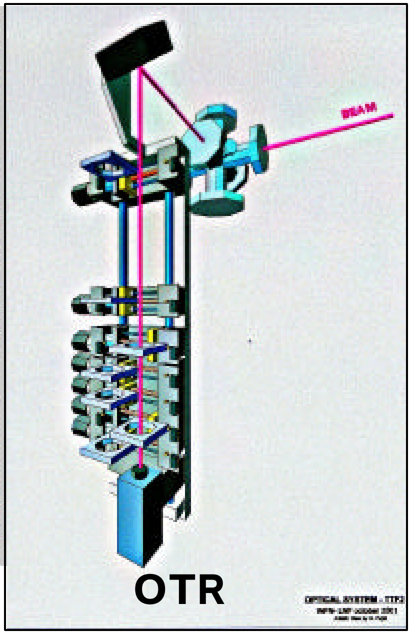
# Beam Diagnostics



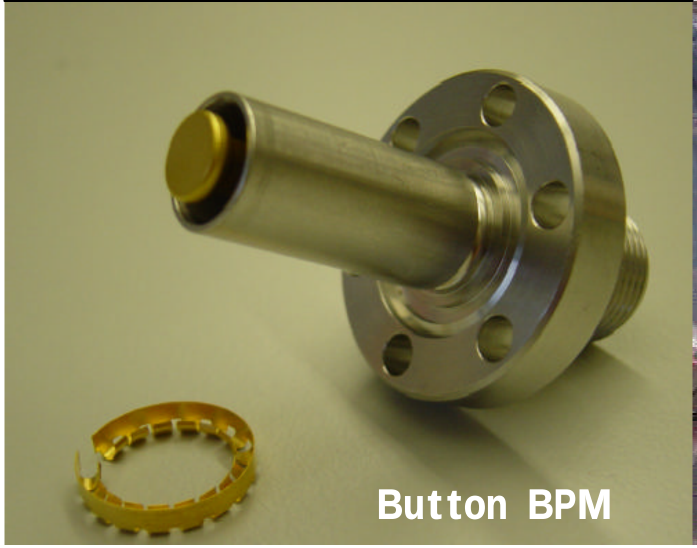
Stripline BPM



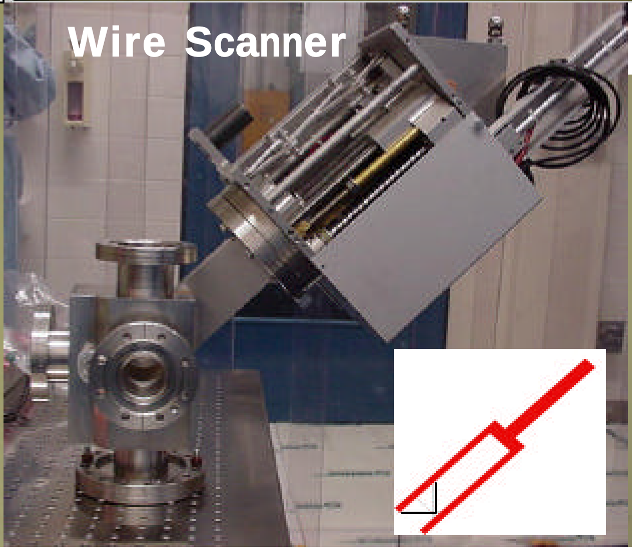
BPM Electronics



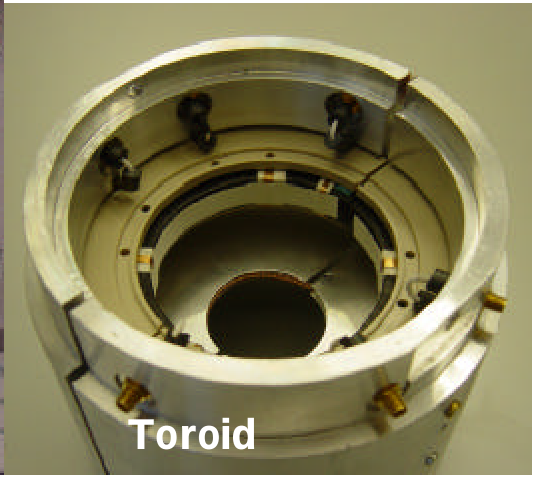
OTR



Button BPM



Wire Scanner



Toroid

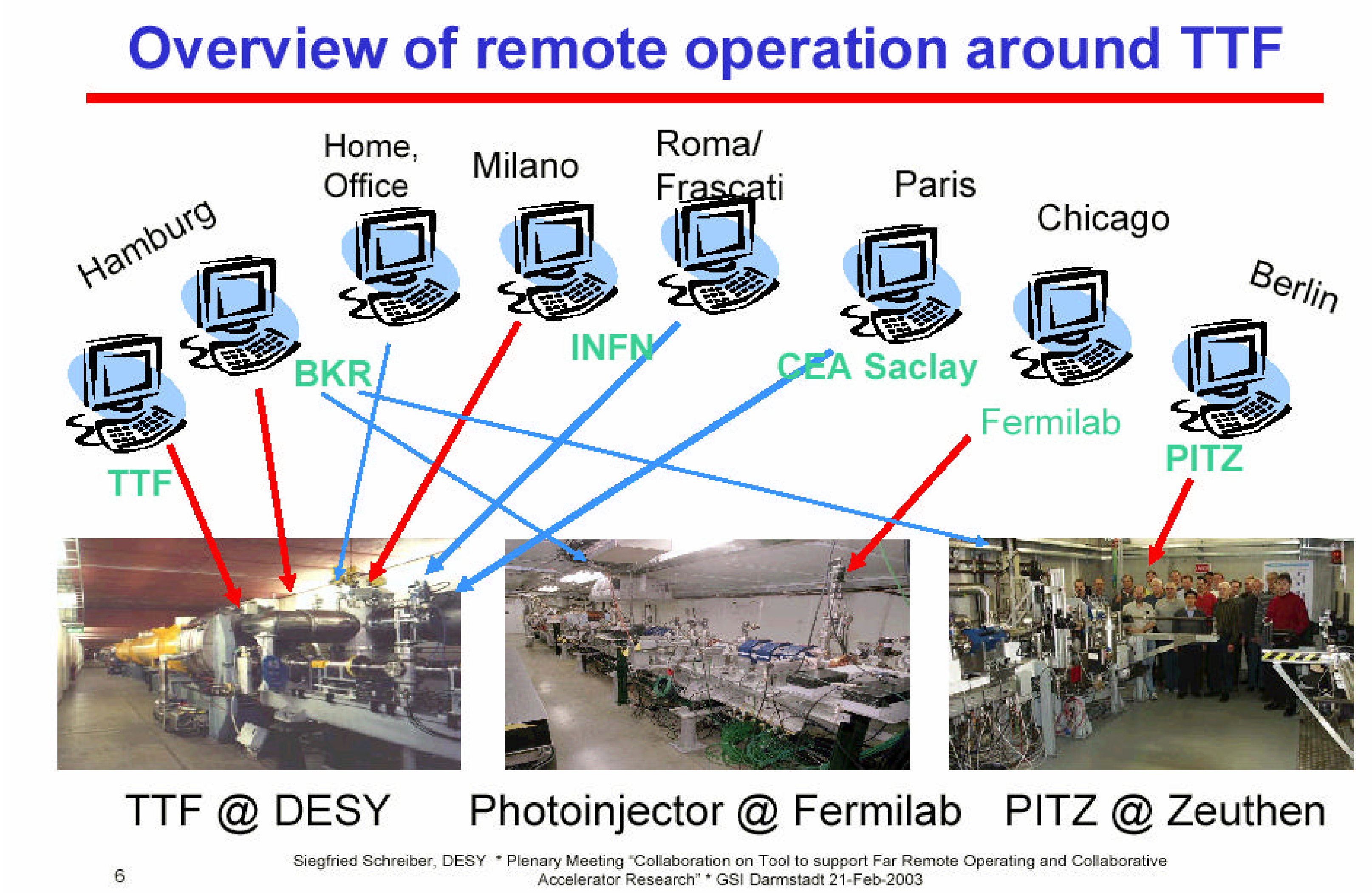
# Remote Involvement

Involvement of collaborators in design, construction, operation, and maintenance of the accelerator or experiment

This includes:

- remote operation
- remote experiments
- remote solving of problems
- remote improvements and developments
- coordination, sharing of information and documentation

Siegfried Schreiber, DESY * Plenary Meeting "Collaboration on Tool to support Far Remote Operating and Collaborative Accelerator Research" * GSI Darmstadt 21-Feb-2003



## Overview of remote operation around TTF

TTF @ DESY Photoinjector @ Fermilab PITZ @ Zeuthen

Siegfried Schreiber, DESY * Plenary Meeting "Collaboration on Tool to support Far Remote Operating and Collaborative Accelerator Research" * GSI Darmstadt 21-Feb-2003

### Proven Examples

- Remote operation and tuning of SC capture cavity from Saclay (Paris)
- Remote access and tuning of beam imaging system from INFN Frascati, Rome
- Remote regular shifts from INFN/LASA Milan
- Remote experiments from DESY at the Fermilab photo-injector test facility

# Possible Global Accelerator Network Activities

Setup remote control station and become familiar with aspects of the linac control and beam analysis.

Plan and carry out beam experiments

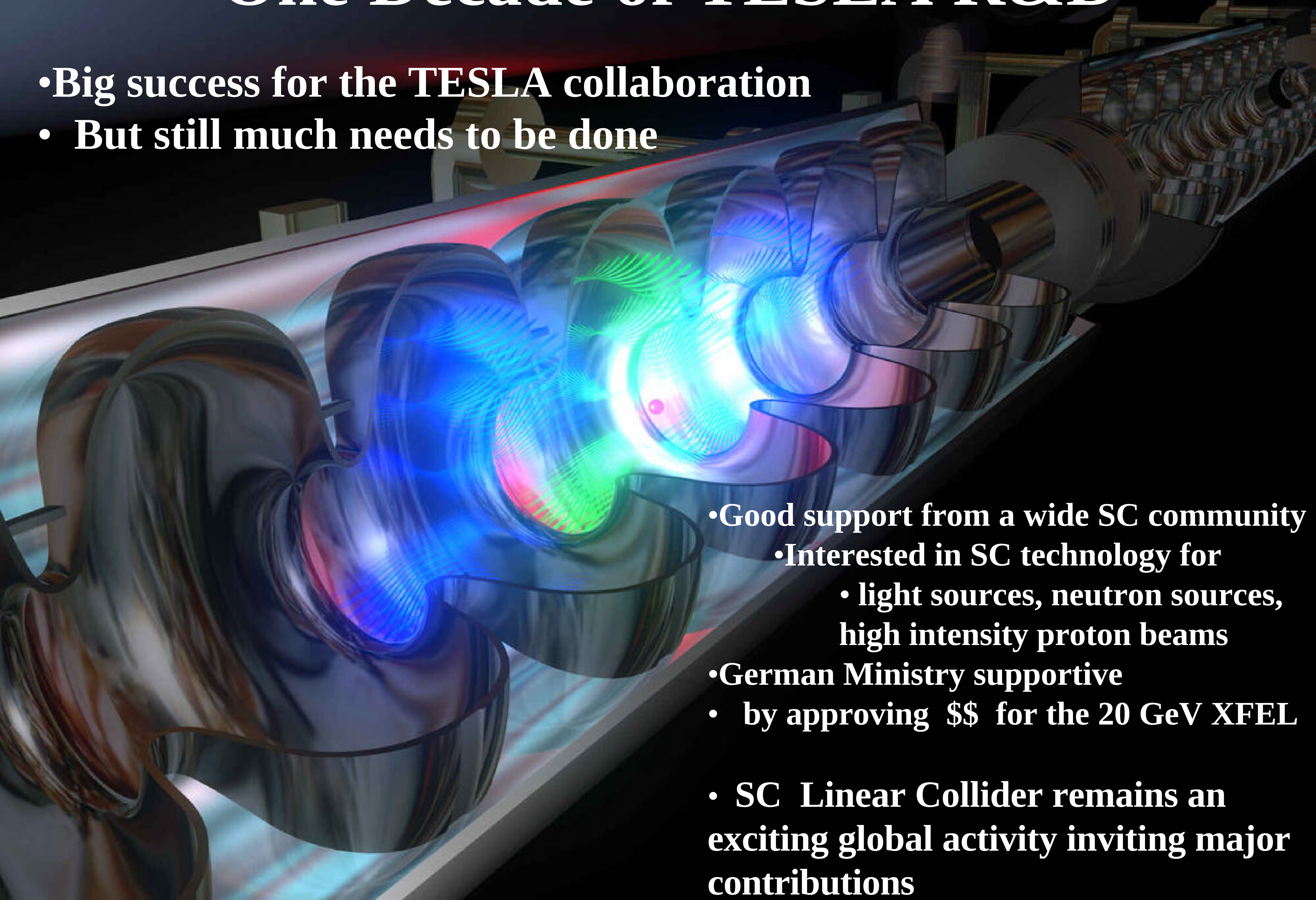
Develop new tests or get involved in ongoing diagnostics and rf control systems, machine protection systems….

Monitor beam-inhibit incidents and causes to determine how to minimize beam recovery time for a LC. Improve reliability of sub-systems

Develop Data Acquisition Systems, DSP Servers, User displays, e-logbooks, and Web based Tools to work towards demands of

True global operation of an international facility

# One Decade of TESLA R&D



- Big success for the TESLA collaboration
- But still much needs to be done

- Good support from a wide SC community
  - Interested in SC technology for
    - light sources, neutron sources, high intensity proton beams
- German Ministry supportive
- by approving $$ for the 20 GeV XFEL

- SC Linear Collider remains an exciting global activity inviting major contributions