ALCW

Cornell, July 13, 2003

TESLA Progress on R1 & R2 issues

Carlo Pagani

Milano & DESY

carlo.pagani@desy.de

TESLA

The TESLA Challenge for LC

Physical limit at 50 MV/m → **> 25 MV/m could be obtained**

→ **Common R&D effort for TESLA**

- Higher conversion efficiency
- Smaller emittance dilution


PROCEEDINGS OF 1990

The First International TESLA Workshop

CORNELL UNIVERSITY

Held at Cornell University July 23-26, 1990

1992

TESLA Collaboration set up at DESY


TESLA Collaboration

Yerevan Physics Institute

IHEP, Academia Sinica, Beijing
Tsinghua-University, Beijing

Institute of Physics, Helsinki

CEA/DSM (DAPNIA, CE Saclay)
IN2P3 (IPN Orsay + LAL Orsay)

RWTH Aachen
Max-Born-Inst., Berlin Adlershof
TU Berlin
TU Darmstadt
TU Dresden
Univ. Frankfurt
GKSS, Geesthacht
DESY Hamburg + Zeuthen
Univ. Hamburg
FZ Karlsruhe
Univ. Rostock
Univ. Wuppertal

INFN Frascati
INFN Legnaro
INFN Milano
INFN and Univ. Roma II

Polish Academy of Science
University of Warsaw
Inst. of Nuclear Physics, Cracow
Univ. of Mining & Metallurgy, Cracow
Polish Atomic Energy Agency, Warsaw
Soltan Inst. for Nuclear Studies, Otwock-Swierk

JINR Dubna
IHEP Protvino
INP Novosibirsk

ANL, Argonne IL
Cornell Univ., Ithaca NY
FNAL, Batavia IL
UCLA, Los Angeles CA

Limiting Problems before TESLA

Poor material properties

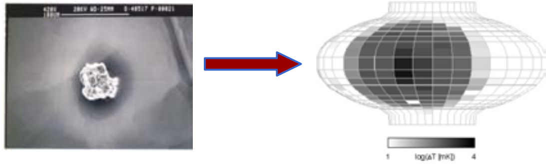
- Moderate Nb purity (Niobium from the Tantalum production)
- Low Residual Resistance Ratio, RRR → Low thermal conductivity
- Normal Conducting inclusions → Quench at moderate field

Poor cavity treatments and cleanness

- Cavity preparation procedure at the R&D stage
- High Pressure rinsing and clean room assembly not yet established

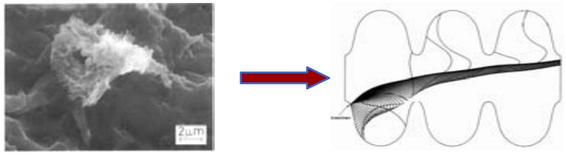
Quenches/Thermal breakdown

- Low RRR and NC inclusions



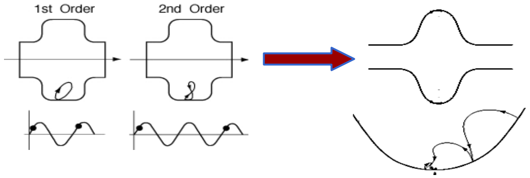
Field Emission

- Poor cleaning procedures and material



Multipactoring

- Simulation codes not sufficiently performing

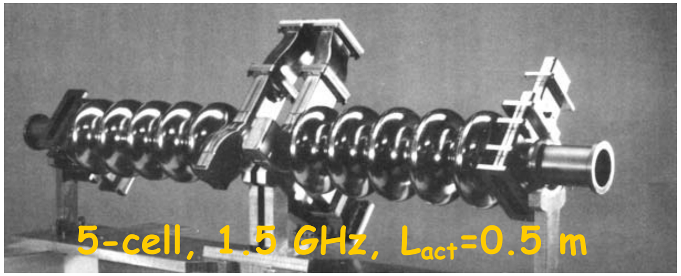


Q-drop at moderate field

Examples: CEBAF, LEPII, HERA

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



32 bulk niobium cavities

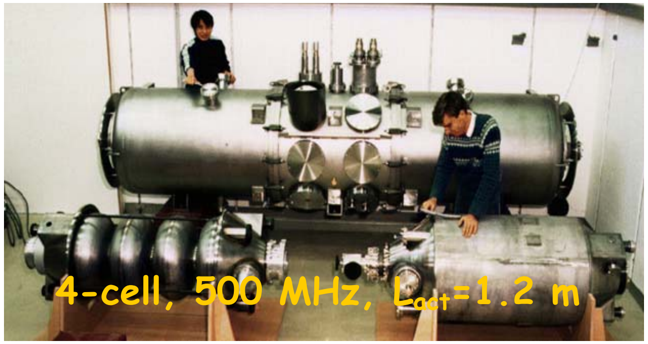
- Limited to 5 MV/m
- Poor material and inclusions

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)

16 bulk niobium cavities

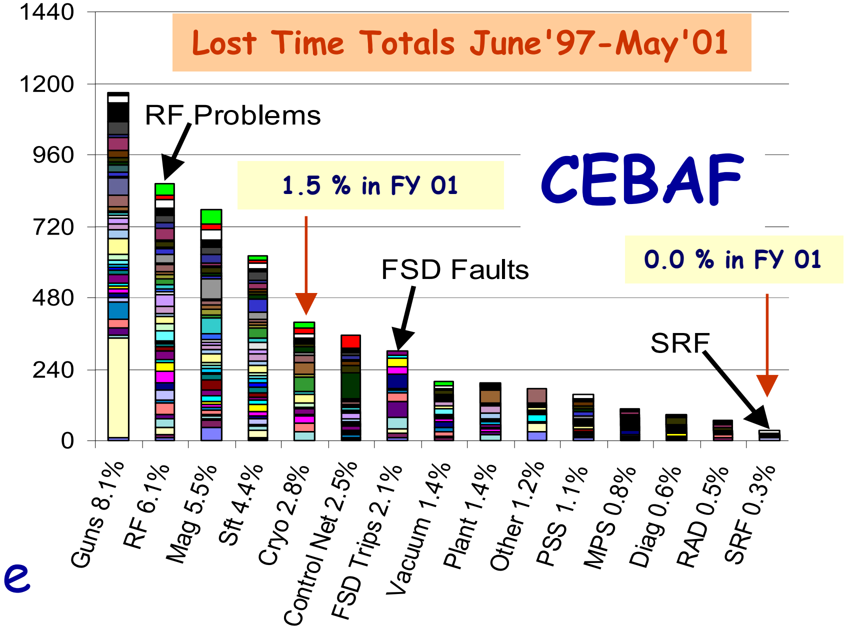
- Limited to 5 MV/m
- Poor material and inclusions
- Q-disease for slow cooldown



Important lessons learned

When not limited by a hard quench (material defect)

Accelerating field improves with time



Large cryo-plants are highly reliable

Negligible lost time for cryo and SRF

Once dark current is set to be negligible

No beam effect on cavity performance

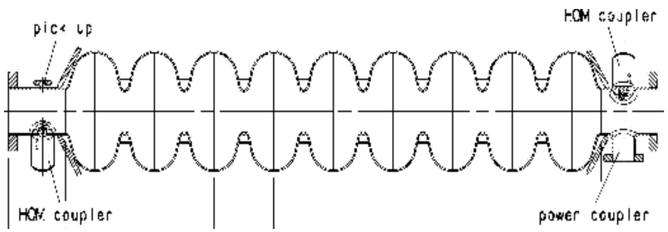
Once procedures are understood and well specified

Industry can produce status of art cavities and cryo-plants

The 9-cell TESLA cavity

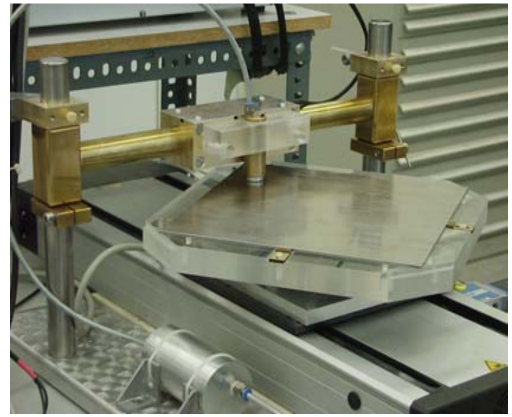
Major Contributors: CERN, Cornell, DESY, Saclay

9-cell, 1.3 GHz, TESLA cavity



TESLA cavity parameters

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



Eddy-current scanning system for niobium sheets

Cleanroom handling of niobium cavities

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

TESLA

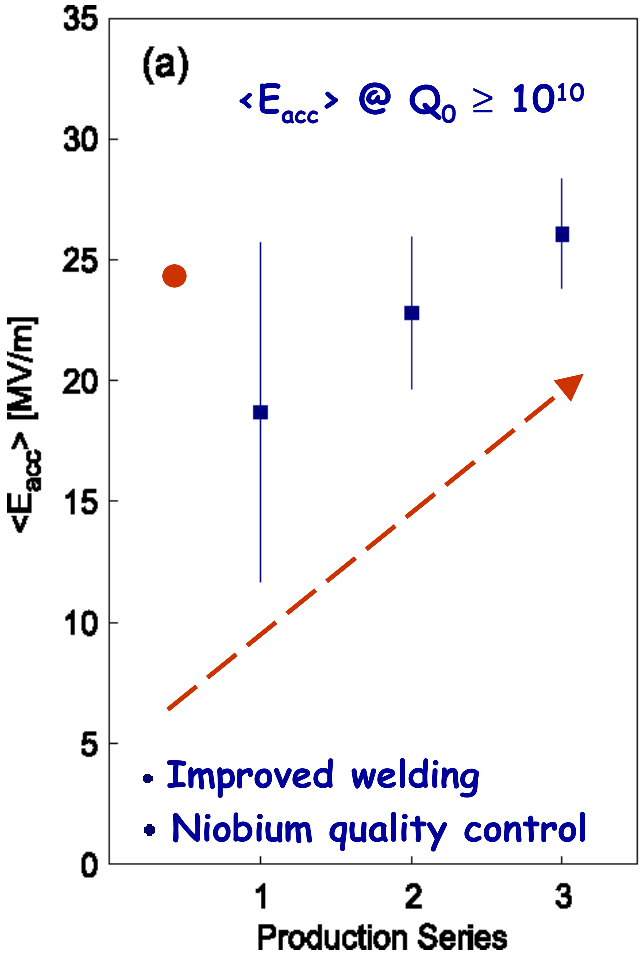
Preparation of TESLA Cavities

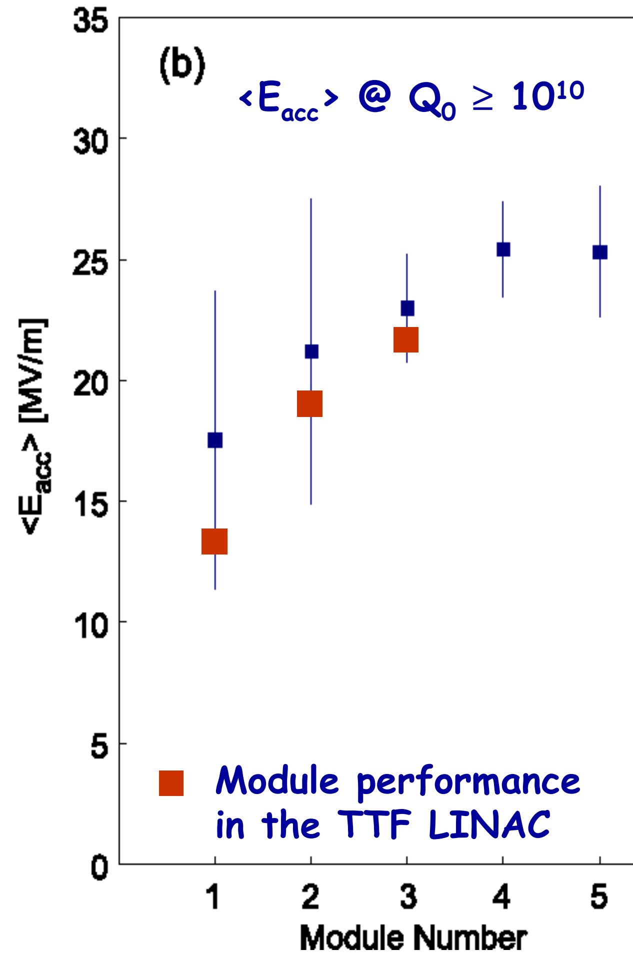
Learning curve till 2000

TESLA 9-cell cavities

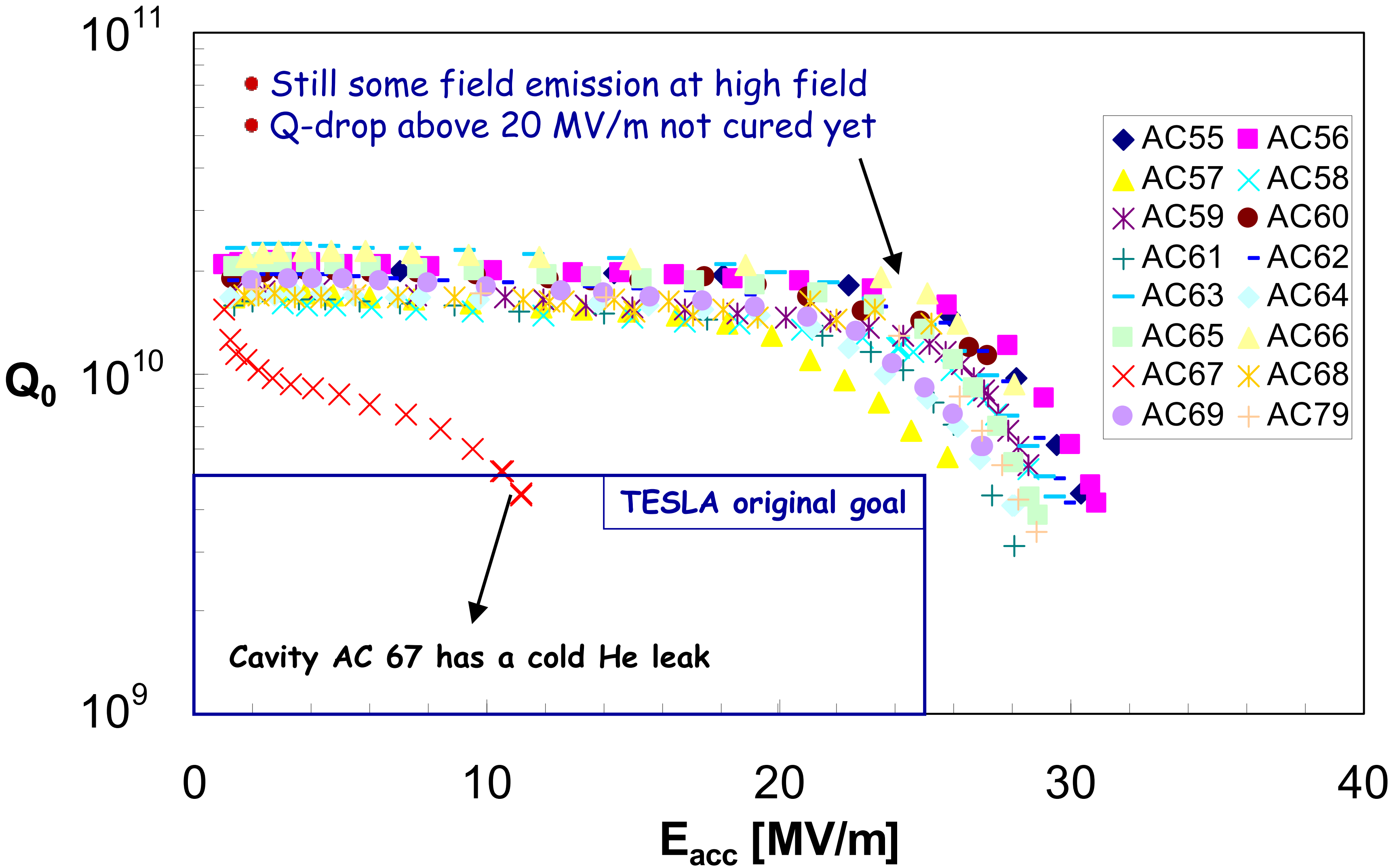
Cornell 1995

5-cell





3^{rd} Cavity Production - BCP

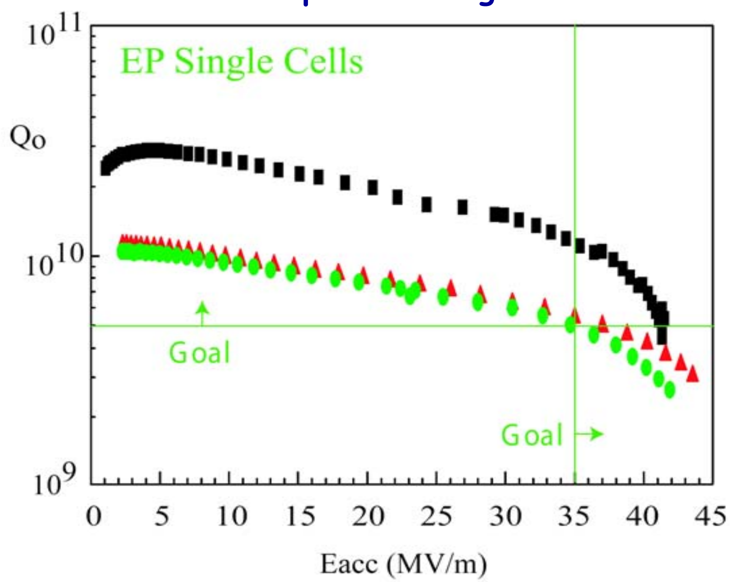


Electropolishing for 35 MV/m

- EP developed at KEK by Kenji Saito (originally by Siemens)
- Coordinated R&D effort: DESY, KEK, CERN and Saclay

BCP Surface
(1μm roughness)

First electro-polished single cell cavities



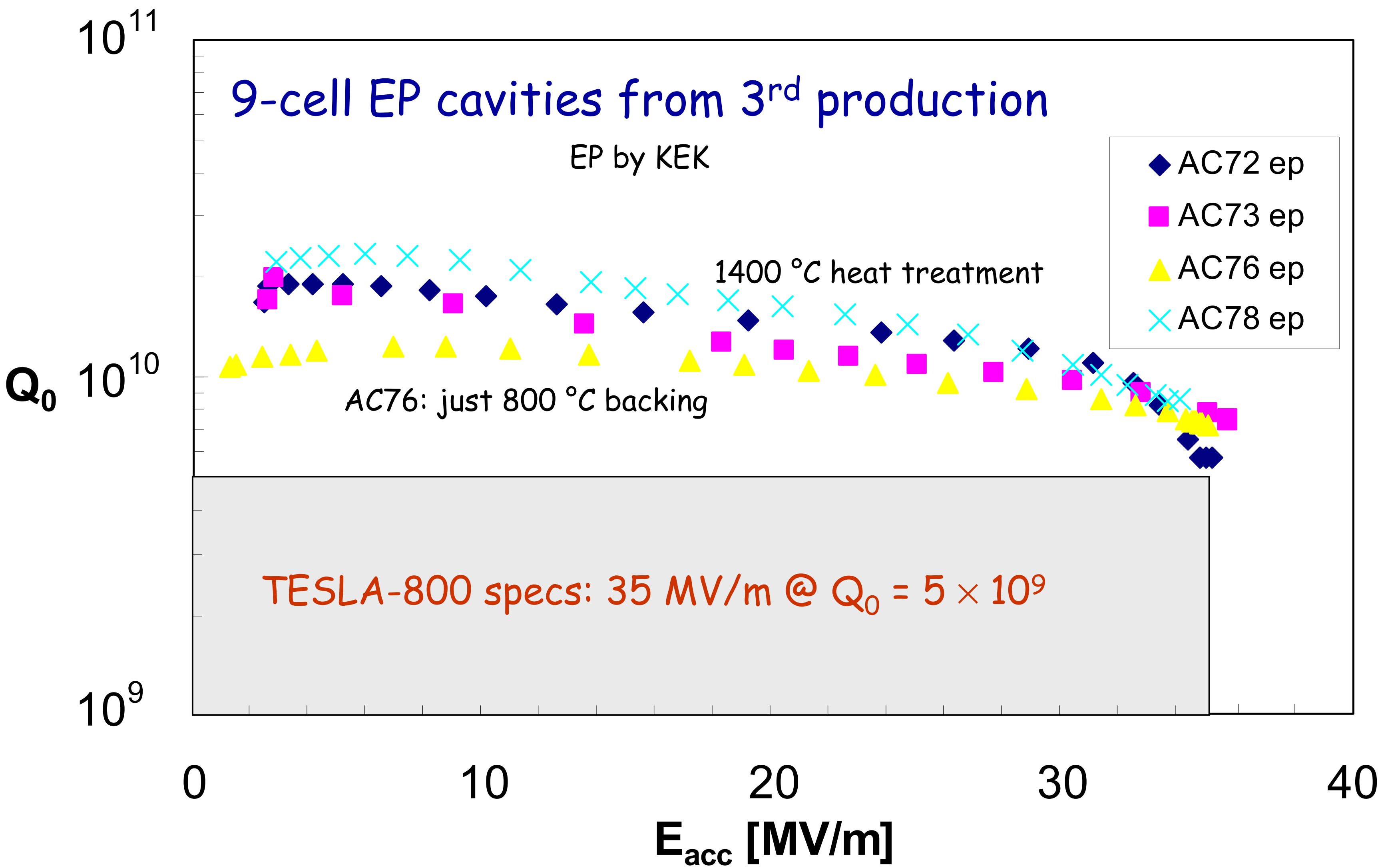
EP Surface
(0.1μm roughness)

Electro-polishing (EP) instead of the standard chemical polishing (BCP) eliminates grain boundary steps → Field enhancement.

Gradients of 40 MV/m at Q values above 10^{10} are now reliably achieved in single cells at KEK, DESY, CERN, Saclay and TJNAF.

TESLA 800 Performances

Vertical Tests

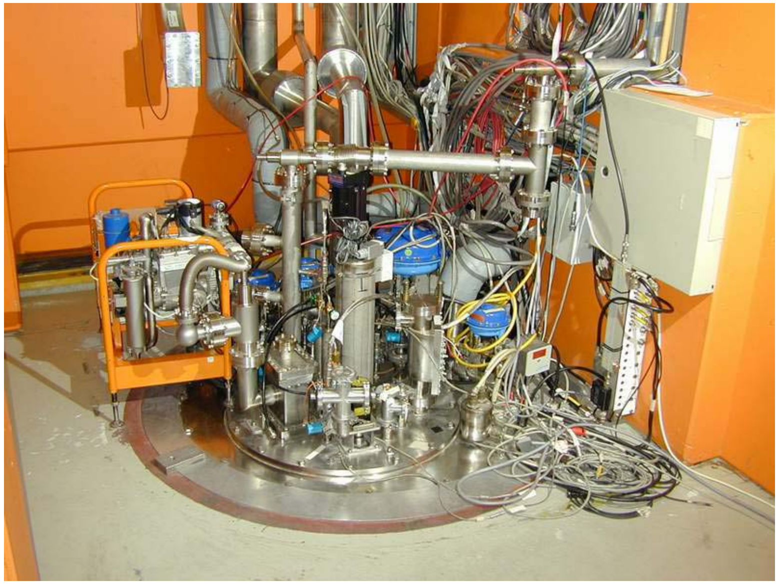


Cavity Vertical Test

The naked cavity is immersed in a super-fluid He bath.

High power coupler, He vessel and tuner are not installed

RF test are performed in CW with a moderate power(< 300W)



Horizontal tests in "Chechia"

Cavity is fully assembled

It includes all the ancillaries:
- Power Coupler
- Helium vessel
- Tuner (…and piezo)

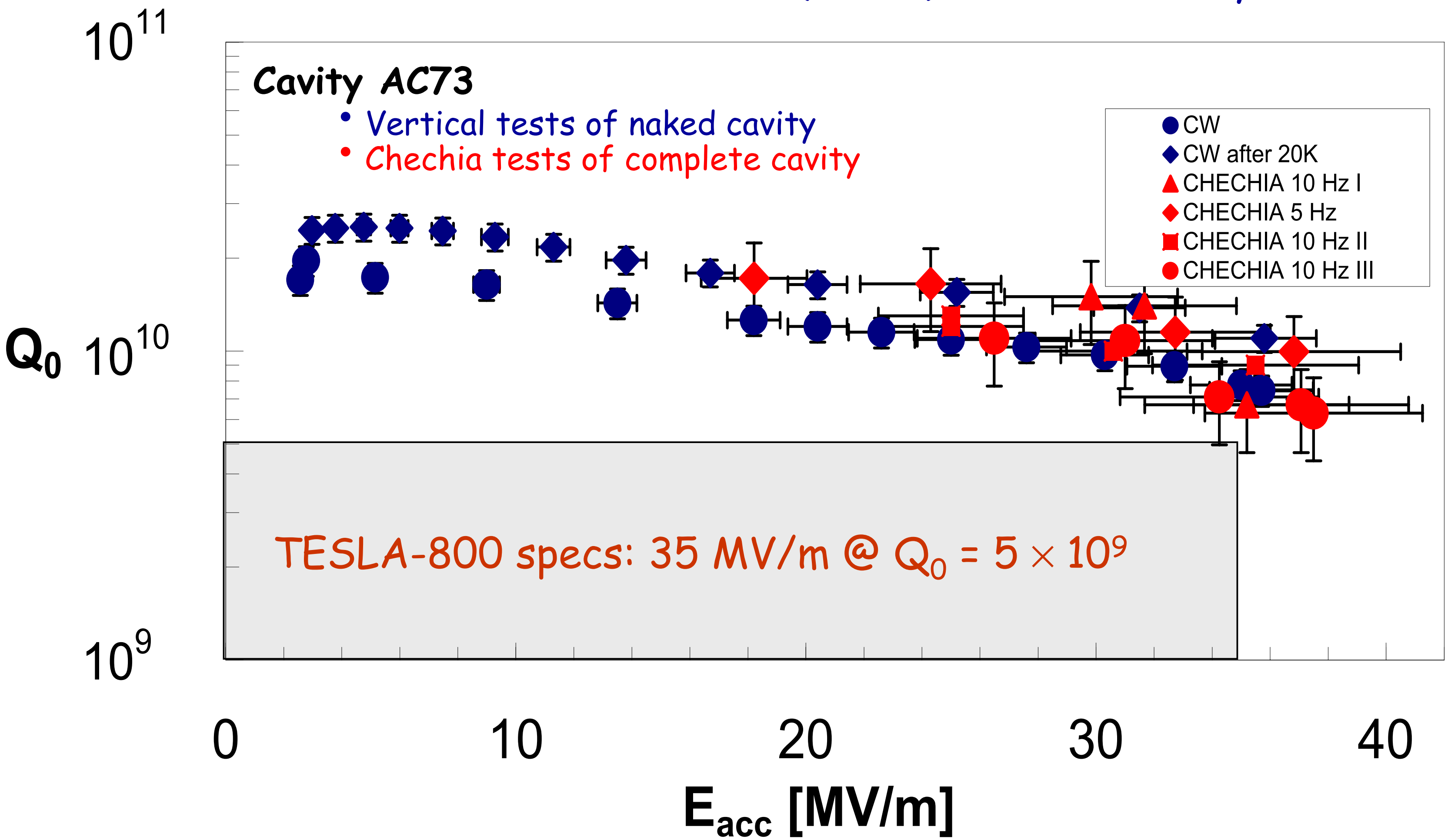
RF Power is fed by a Klystron through the main coupler

Pulsed RF operation using the same pulse shape foreseen for TESLA

TESLA 800 in Chechia

Long Term (> 600 h) Horizontal Tests

- In Chechia the cavity has all its ancillaries
- Chechia behaves as 1/8th (1/12th) of a TESLA cryomodule



TESLA

Important results for TESLA LC

Field Emission and Q-drop cured

Maximum field is still slowly improving

No Field Emission has been so far detected, that is
No dark current is expected at this field level

Cavity can be operated close to its quench limit

Induced quenches are not affecting cavity performances

Some statistics on the test

updated on July 10th

Cavity

Test running since 7 March 2003
- Scheduled cryo shutdown ≈ 600 h
- 5 warm-ups:
  - 2 up to 300 K,
  - 3 up to 100 K

RF operation of the cavity
- 640 hours at around 35 +/-1 MV/m
  - ~110 hours without interruption
  - 30 hours at 36 MV/m +

Cavity did not cause a single event!
- Quenches induced by external facts
  - Klystron/Pre-amp power jumps
  - LLRF problems

Short processing time for max field
- 35 hours for the first test
- < 1 hour after a thermal cycle

Coupler and Cryogenics

Still long conditioning for the coupler
- 130 hours for the first test
- Few hours after a thermal cycle

Coupler did not cause a single event!
- breakdowns induced by external problems
  - Klystron/Pre-amp power jumps
  - LLRF problems

RF operation of the coupler
- cavity off-resonance
- power between 150 – 600 kW
- 950 hours

Many interruptions for cryogenics
- impurities in Helium circuit (HERA plant shutdown)
- TTF LINAC cool-down

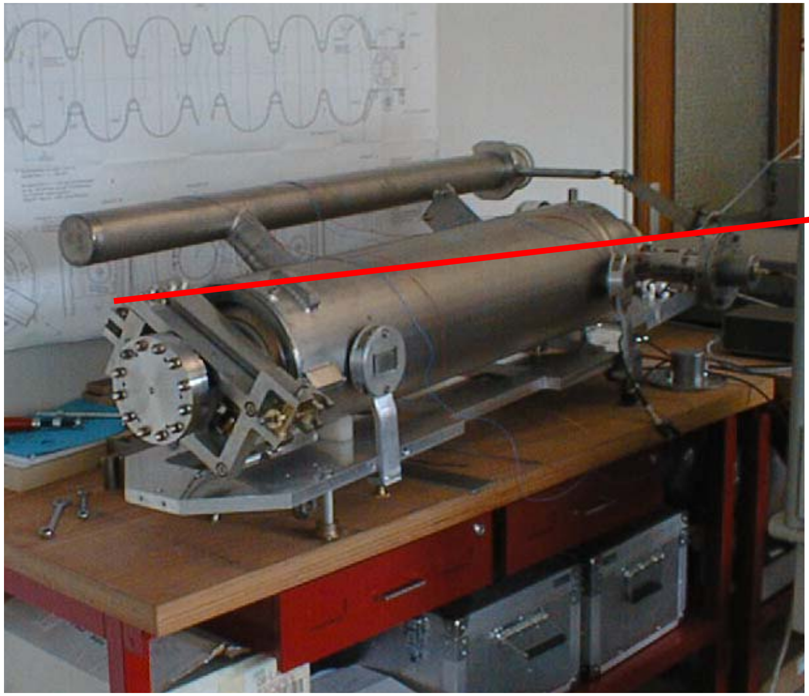
Piezo-assisted Tuner

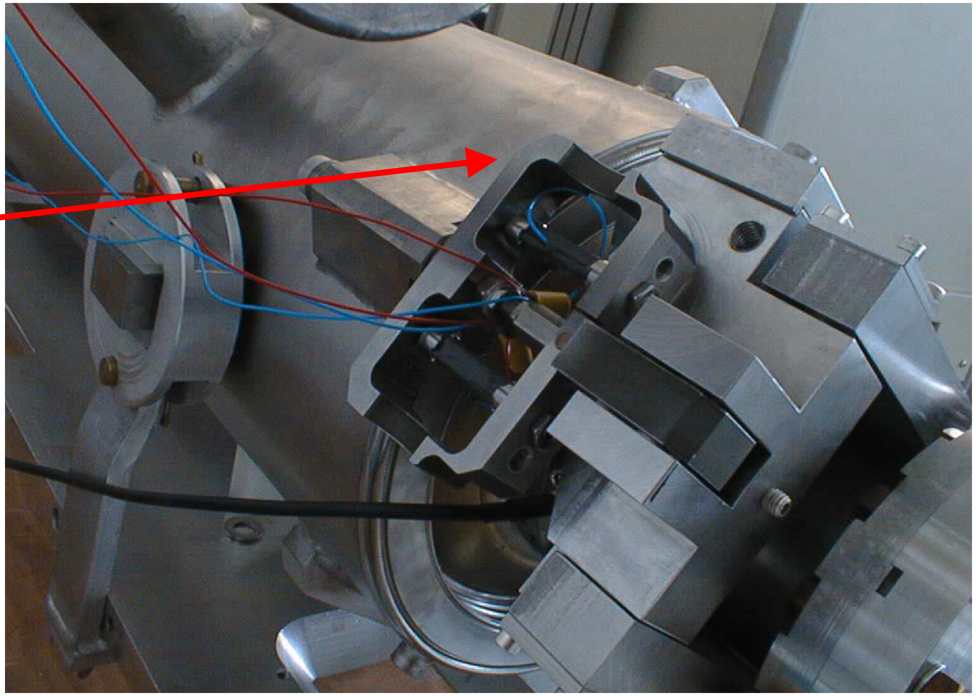
To compensate for Lorentz force detuning during the 1 ms RF pulse

Feed-Forward

To conteract mechanical noise, “michrophonics”

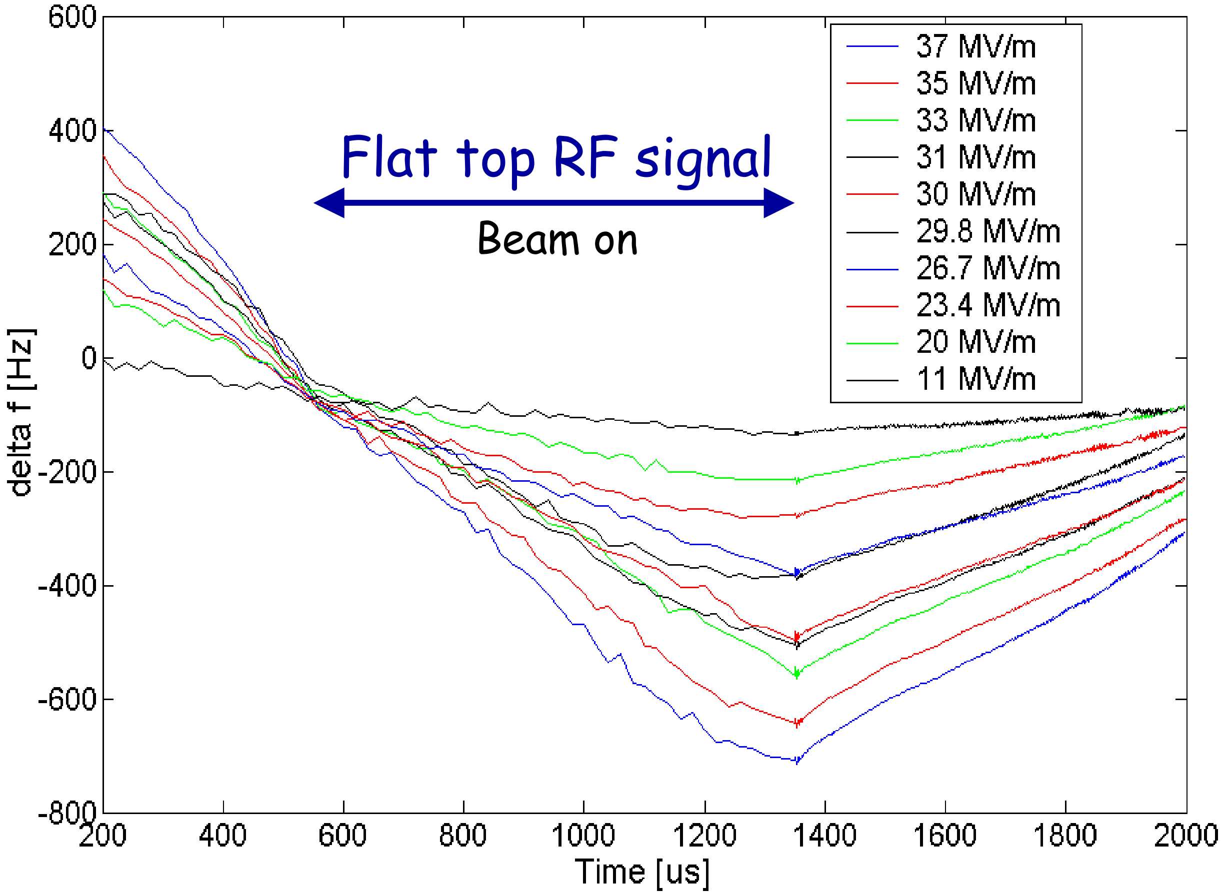
Feed-Back





Frequency detuning during RF pulse

Dynamical Lorentz force detuning, at different field levels, as measured in CHECHIA, AC73



In the static case:

$$\Delta f = K_L \cdot E_{acc}^2$$

TESLA Cavity values:

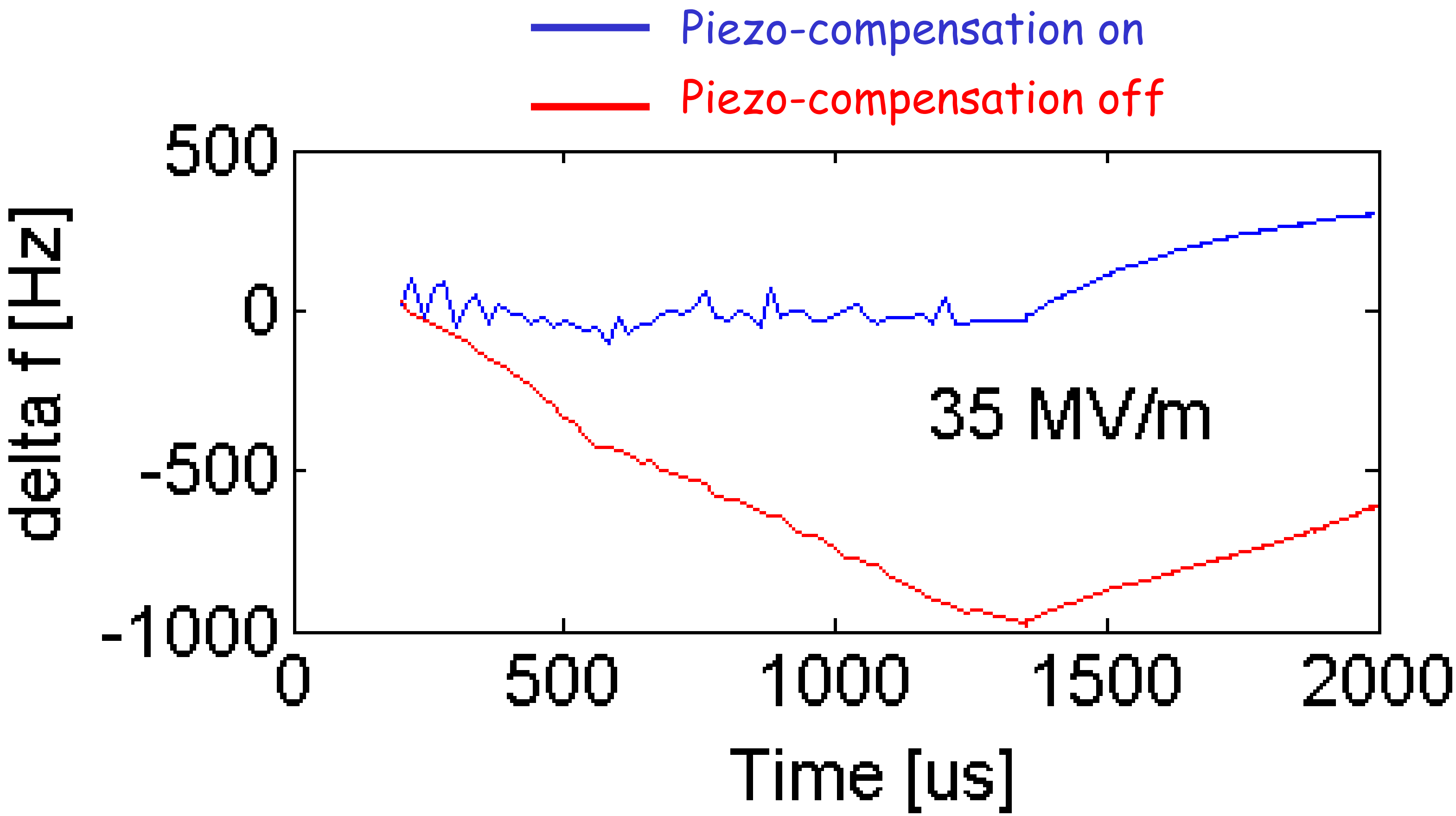
$K_L \approx 1$ [Hz/(MV/m)^2]

Bandwidth ≈ 300 Hz

Successful Compensation
@ 35 MV/m

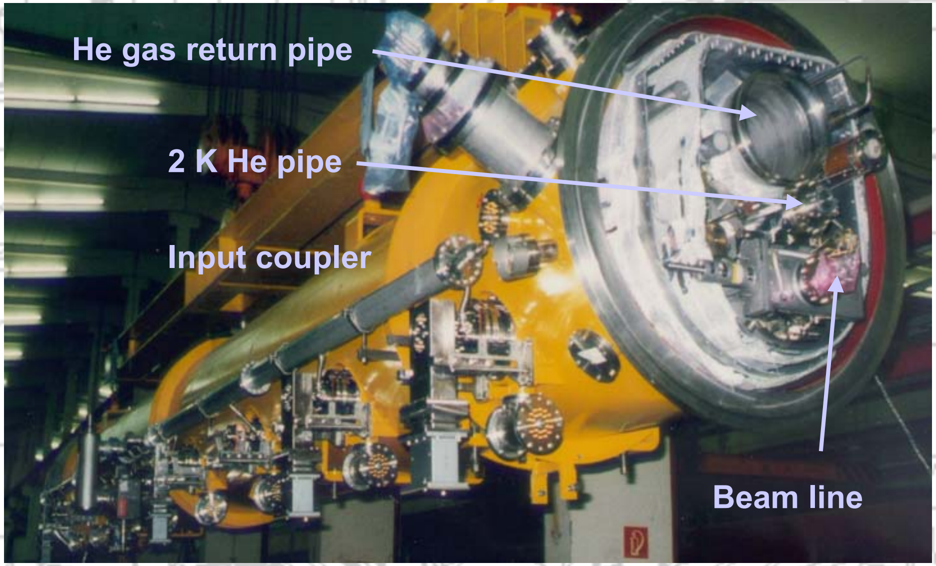
Resonant compensation applied (230 Hz) due to piezo limited stroke

Operation with just feed-forward, feed-back off



Performing Cryomodules

Three generations of the cryomodule design, with improving simplicity and performances, while decreasing costs

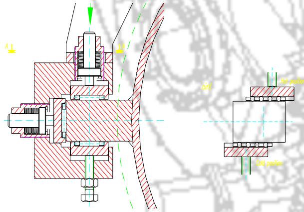


Cryomodule Characteristics

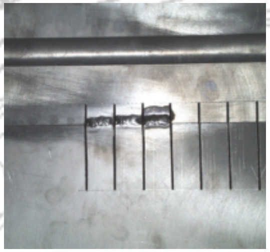
Length		12 m	
# cavities		8	
# doublets		1	
Static Losses	@ 2 K	1.5	W
	@ 5 K	8	W
	@ 50 K	70	W

Required plug power < 6 kW

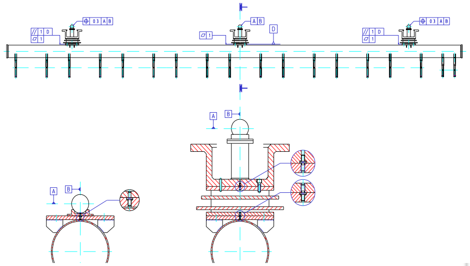
Sliding Fixtures @ 2 K



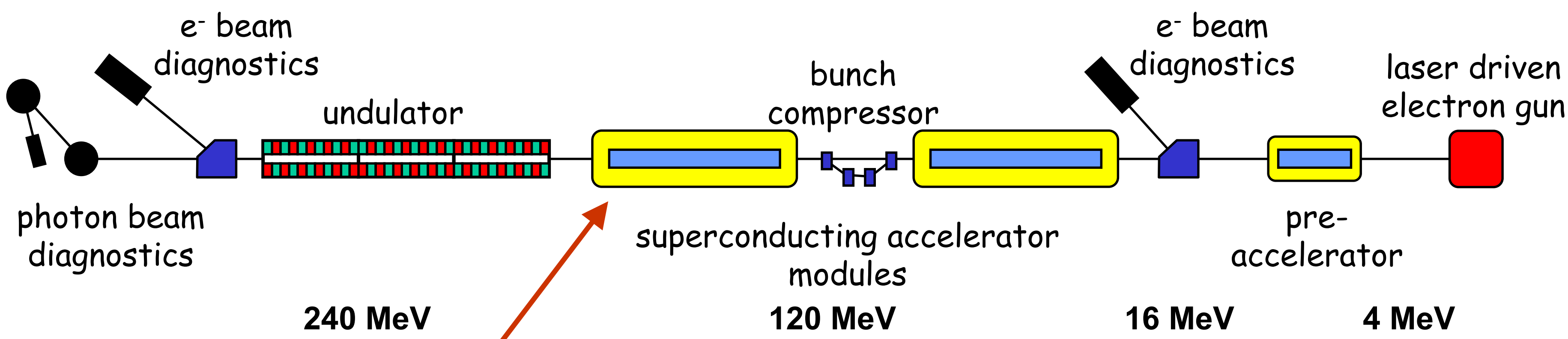
"Finger Welded" Shields

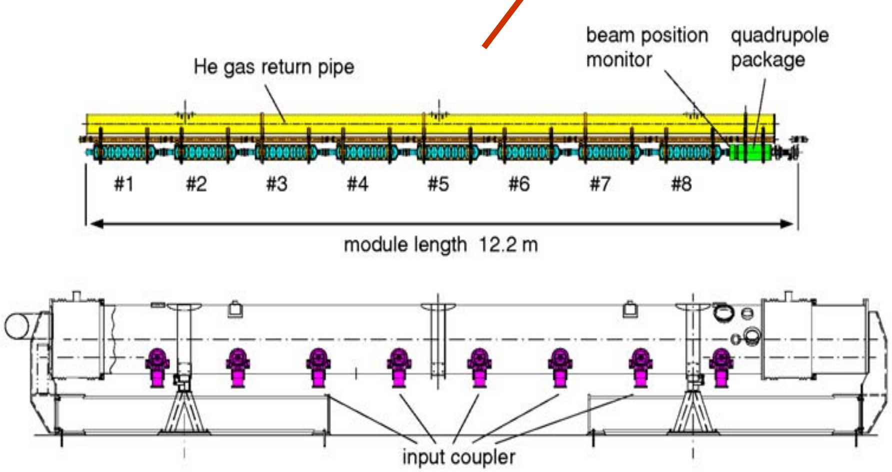


Reliable alignement Strategy



Great experience from TTF I

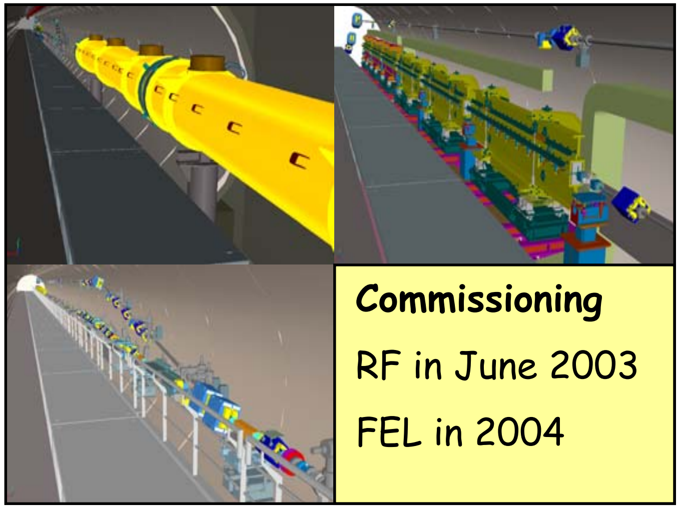




More experience from TTF II

FEL User Facility in the nm Wavelength Range
Unique Test Facility to develop X-FEL and LC

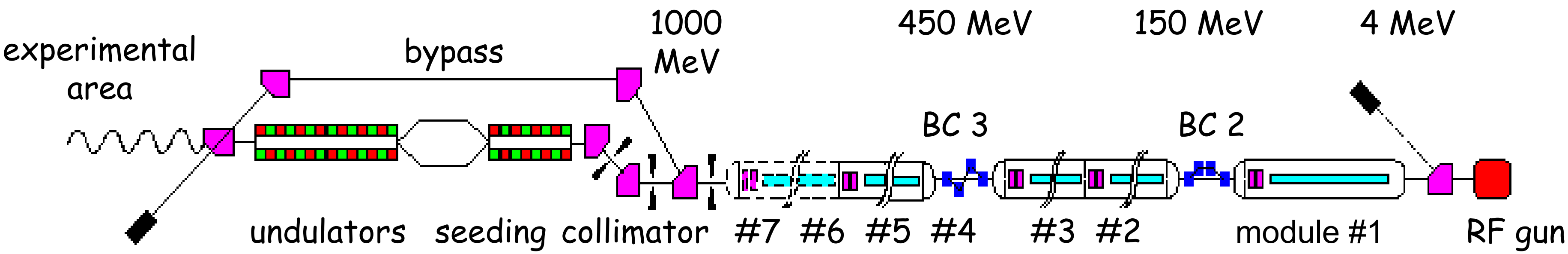
- Six accelerator modules to reach 1 GeV beam energy.
- Module #6 will be installed later and will contain 8 electro-polished cavities.
- Engineering with respect to TESLA needs.
- Klystrons and modulators build in industry.
- High gradient operation of accelerator modules.
- Space for module #7 (12 cavity TESLA module).



Commissioning

RF in June 2003

FEL in 2004



Results from International Technical Review (Feb. 2003)

Quotes:

- If one had to "launch" a project today for 500 GeV, TESLA would be the only one having "essentially" proven performance specs for the main linac RF system
- By the end of 2003, we should hopefully know if TESLA can reach 800 GeV at 35 MV/m (with the addition of RF power and cryogenics)

Ranking 1: R&D needed for feasibility demonstration of the machine

Ranking 2: R&D needed to finalize design choices and ensure reliability of the machine

R1 for TESLA

TESLA Upgrade to 800 GeV c.m.

Energy

The Energy Working Group considers that a feasibility demonstration of the machine requires the proof of existence of the basic building blocks of the linacs. In the case of TESLA at 500 GeV, such demonstration requires in particular that s.c. cavities installed in a cryomodule be running at the design gradient of 23.8 MV/m. This has been practically demonstrated at TTF1 with cavities treated by chemical processing. The other critical elements of a linac unit (multibeam klystron, modulator and power distribution) already exist.

- The feasibility demonstration of the TESLA energy upgrade to about 800 GeV requires that a cryomodule be assembled and tested at the design gradient of 35 MV/m. The test should prove that quench rates and breakdowns, including couplers, are commensurate with the operational expectations. It should also show that dark currents at the design gradient are manageable, which means that several cavities should be assembled together in the cryomodule. Tests with electropolished cavities assembled in a cryomodule are foreseen in 2003.

German Government Decisions

The decisions of the German Ministry for Education and Research concerning TESLA was published on 5 February 2003:

TESLA X-FEL

- DESY in Hamburg will receive the X-FEL
- Germany is prepared to carry half of the 673 MEuro investment cost.
- Discussions on European cooperation will proceed expeditiously, so that in about two years a construction decision can be taken.

TESLA Collider

- Today no German site for the TESLA linear collider will be put forward.
- This decision is connected to plans to operate this project within a world-wide collaboration
- DESY will continue its research work on TESLA in the existing international framework, to facilitate German participation in a future global project

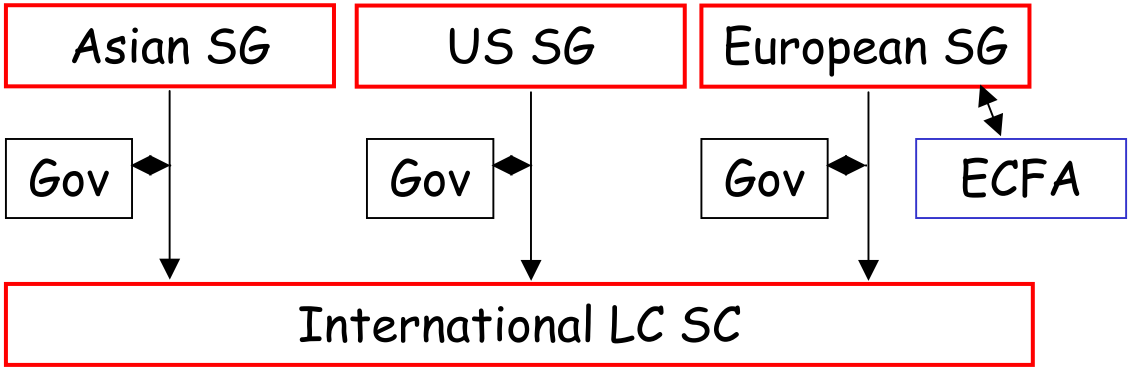
Consequences for the LC

The path chosen by TESLA to move towards approval was recommended by the German Science Council and is generally considered to be the fastest one.

Community will now take the other path used for international projects (e.g. ITER):

- unite first behind one project with all its aspects, including the technology choice, and then
- approach all possible governments in parallel in order to trigger the decision process and site selection.

ICFA initiative for an international co-ordination:



What we planned to do

- The focus of the work: reach the R1 milestone, as defined in the TRC report (test of one module with beam at 35 MV/m). Due to the extremely tight financial situation at DESY in 2003 this goal will not be reachable within one year. It is therefore very important to approach this goal as much as possible until spring 2004:
- Test as many 9-cell cavities as possible, with full power for as long as possible at their highest gradient (35 MV/m). Test with a first 9-cell cavity have shown very promising results.
- 30 new cavities ordered to industry. Delivery will start by fall this year.
- **In addition we are organizing to test one 9-cell EP cavity with beam (at A0-FNAL, with support from Cornell). By mid 2004**
- In order to prepare the construction of the X-FEL, DESY and its partners will soon focus on issues related to the mass production of all components. This will lead within one to two years to further improvements of the technical design and a better cost evaluation.

Beam Test in A0 at FNAL

Proposed by Hasan Padamsee had a wide consensus.

Detailed schedule and cost estimation are in progress

Possible milestones

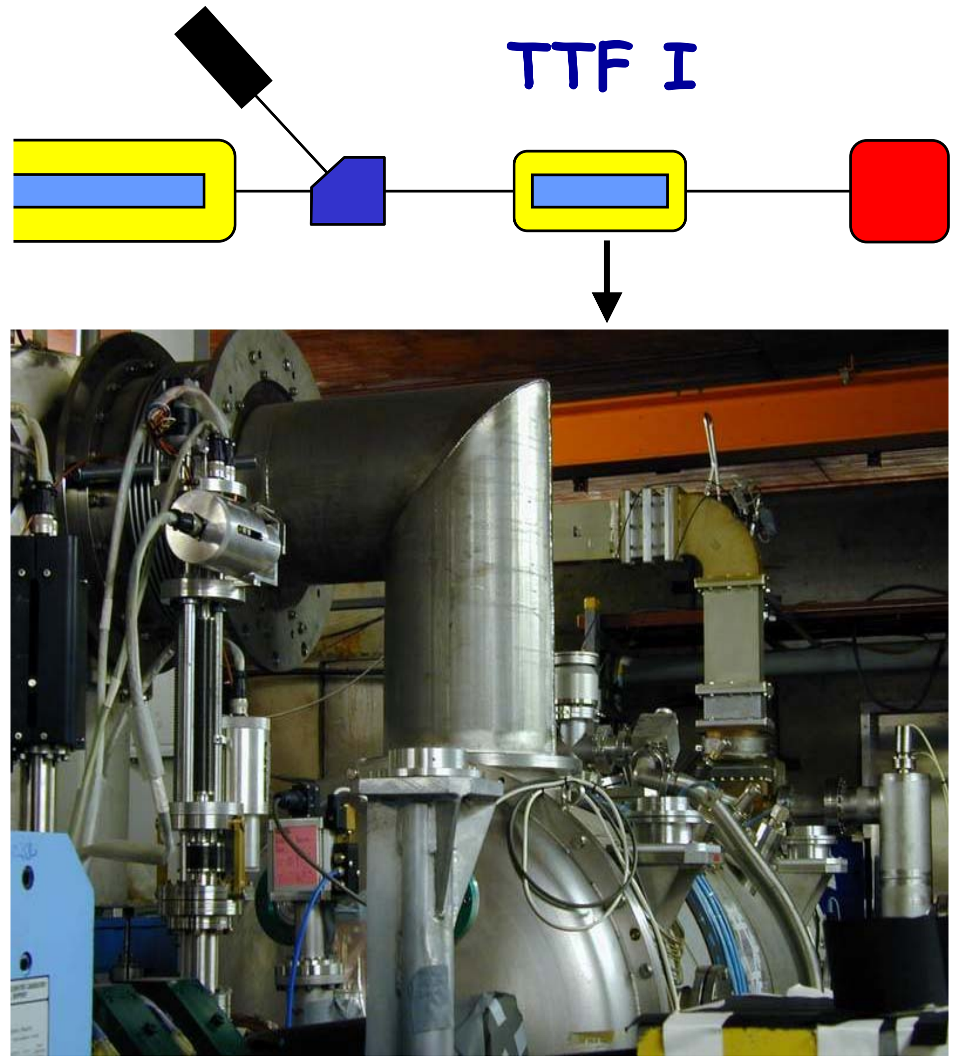
Oct 03 – Booster cavity cryomodule disinstalled and sent to FNAL/Cornell

Mar 04 – Preparation at FNAL of cryogenics, connections, RF and required infrastructures

Mar 04 – Cornell modifies the cryomodule as required

April 04 – Cavity installation

May 04 – Beam tests at A0 start



What is TESLA now

TESLA is at present the combination of: 3 independent Projects:

TESLA LC, **TESLA X-FEL** and **TTF2**

All based on the outstanding SC linac technology

Created by the TESLA Collaboration effort

TESLA LC is one of the two remaining competitors for the next HEP large accelerator facility

TESLA X-FEL is the core of a proposal for an European Laboratory of Excellence for fundamental and applied research with ultra-bright and coherent X-Ray photons

TTF2 will be the first user facility for VUV and soft x-ray coherent light experiments with impressive peak and average brilliance.

It will be also the test facility to further implement the TESLA SC Linac technology in view of the construction of a large and reliable accelerator

Priorities on Linac Technology

In view of the construction of a large scale facility based on TESLA SC Linac Technology, the priorities are:

- Analyze and Improve Accelerator Reliability, that is:
  - Review TTF Linac components for performances and reliability
  - Review the module design to reduce the assembly criticalities
  - Focalize effort on critical items
  - Give precise specifications for all minor ancillaries
  - Complete the development of the 2 K quadrupole
- Reach routinely 35 MV/m on cavities. This is due to:
  - Understand and handle all the fabrication process:
    - Make the X-Ray FEL reliable and more performing
    - Allow for higher c.m. Energies of the TESLA Collider

R2 for TESLA - Energy

Energy

TESLA X-FEL

- To finalize the design choices and evaluate reliability issues it is important to fully test the basic building block of the linac. For TESLA, this means several cryomodules installed in their future machine environment, with all auxiliaries running, like pumps, controls, *etc.* The test should as much as possible simulate realistic machine operating conditions, with the proposed klystron, power distribution system and with beam. The cavities must be equipped with their final HOM couplers, and their relative alignment must be shown to be within requirements. The cryomodules must be run at or above their nominal field for long enough periods to realistically evaluate their quench and breakdown rates. This Ranking 2 R&D requirement also applies to the upgrade. Here, the objectives and time sc … lt.

- The development of a c … ise and fall times is needed.

Luminosity

Damping Rings

- For the TESLA damping ring particle loss simulations, systematic and random multipole errors, and random wiggler errors must be included. Further dynamic aperture optimization of the rings is also needed.
- The energy and luminosity upgrade to 800 GeV will put tighter requirements on damping ring alignment tolerances, and on suppression of electron and ion instabilities in the rings. Further studies of these effects are required.

Machine-Detector Interface

- In the present TESLA design, the beams collide head-on in one of the IRs. The trade-offs between head-on and crossing-angle collisions must be reviewed, especially the implications of the present extraction-line design. Pending the outcome of this review, the possibility of eventually adopting a crossing-angle layout should be retained.

R2 for TESLA - Reliability

Reliability

- The TESLA single tunnel configuration appears to pose a significant reliability and operability risk because of the possible frequency of required linac accesses and the impact of these accesses on other systems, particularly the damping rings. TESLA needs a detailed analysis of the impact on operability resulting from a single tunnel.

Remarks

We have chosen for TESLA:

- head-on collision
- single tunnel layout

These design choices are motivated but they can not affect the technology choice. In fact, once a better solution is demonstrated, in the TESLA case they can both be changed.

US-hosted Linear Collider Options

The Accelerator Subcommittee of the US Linear Collider Steering Group (USLCSG) has been charged by the USLCSG Executive Committee with the preparation of options for the siting of an international linear collider in the US.

Membership of the USLCSG Accelerator Subcommittee:

David Burke (SLAC)
Gerry Dugan (Cornell) (Chairman)
Dave Finley (Fermilab)
Mike Harrison (BNL)
Steve Holmes (Fermilab)
Jay Marx (LBNL)
Hasan Padamsee (Cornell)
Tor Raubenheimer (SLAC)

- Two technology options are to be developed: a warm option, based on the design of the NLC Collaboration, and a cold option, similar to the TESLA design at DESY.
- Both options will meet the physics design requirements specified by the USLCSG Scope document.
- Both options will be developed in concert, using, as much as possible, similar approaches in technical design for similar accelerator systems, and a common approach to cost and schedule estimation methodology, and to risk/reliability assessments.

US Cold option reference design

The major changes to be made to the TESLA design are:

- An increase in the upgrade energy to 1 TeV (c.m.), with a tunnel of sufficient length to accommodate this in the initial baseline.
- Use of the same injector beam parameters for the 1 TeV (c.m.) upgrade as for 500 GeV (c.m.) operation
- The choice of 35 MV/m as the initial main linac design gradient for the 500 GeV (c.m.) machine.
- The use of a two-tunnel architecture for the linac facilities.
- An expansion of the spares allocation in the main linac.
- A re-positioning of the positron source undulator to make use of the 150 GeV electron beam, facilitating operation over a wide range of collision energies from 91 to 500 GeV
- The adoption of an NLC-style beam delivery system with superconducting final focus quadrupoles, which accommodates both a crossing angle and collision energy variation.
- At the subsystem and component level, specification changes to facilitate comparison with the warm LC option.

Extract from a HEPAP Document

High-Energy Physics Facilities Recommended For
The DOE Office of Science Twenty-Year Roadmap - March 2003

Cost and schedule: The linear collider is envisioned as a fully international project. Construction of the collider could begin in 2009 and be completed in six to seven years. …. A firm cost and schedule for completion of construction will be delivered as part of the pre-construction phase of the project, but present estimates … place the total project cost (TPC) for construction in the U.S. at about $6B.

Science Classification and Readiness: The project is *absolutely central* in importance to basic science: it will also be at the frontier of advanced technological development, of international cooperation, and of educational innovation.

It is presently in an *R&D phase*,

- leading to a technology choice in 2004.
- …, pre-construction engineering and design for the collider could begin in 2006 and be completed in about three years, …
- The cost to complete the engineering design and R&D through 2008 is estimated to be $1B, …

Summary

Production of TESLA Cavities with accelerating field exceeding 35 MV/m has been proven.

All the previous limiting factors, including Q-drop and dark current have been understood and cured,

Limited resources are strongly limiting the possible progress in term of large scale demonstration

All the material collected so far, together with the work being performed by the USLCSG Accelerator Subcommittee, should be enough to make a technology choice in one year from now.

Thanks to TESLA achievements
New projects are funded or proposed

High Energy Physics
- TESLA
- Neutrino Factories and Muon Colliders
- Kaon Beam Separation at FNAL
- New TEVATRON Injector

Nuclear Physics
- RIA
- EURISOL
- CEBAF Upgrade

High Power Proton Linacs for Spallation
- SNS, Joint-Project, Korea, ESS
- ADS for Waste Transmutation

New Generation Light Sources
- Recirculating Linacs (Energy Recovery)
- SASE FELs