ITRP Visit to DESY, 5th/6th April 2004

Operational Experience with the TESLA Test Facility Linac

cavities

linac

SASE FEL

Hans Weise / DESY

05.04.2004

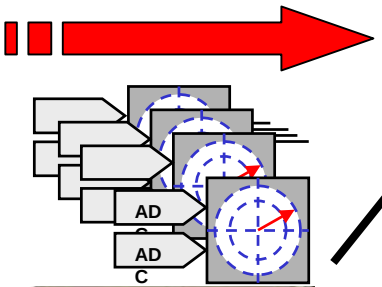
Goals of the TESLA Test Facility Linac

TESLA

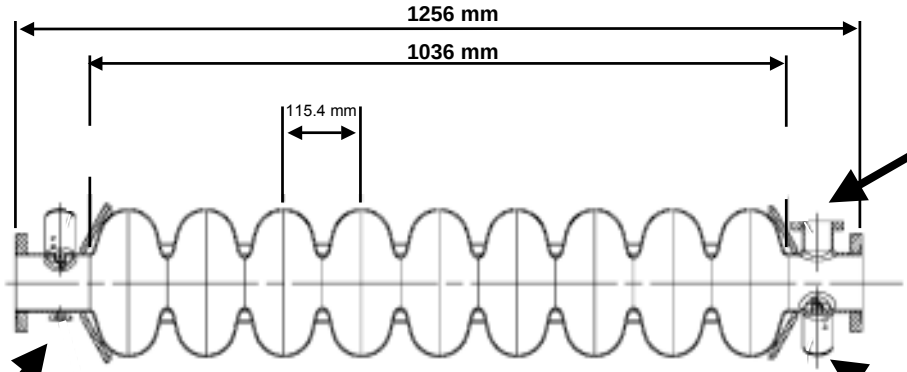
The LC cold option

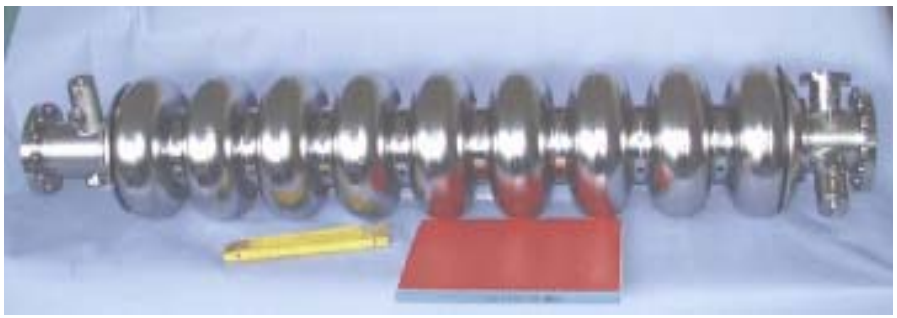
Test all the components in a real linac environment with

e^- - beam



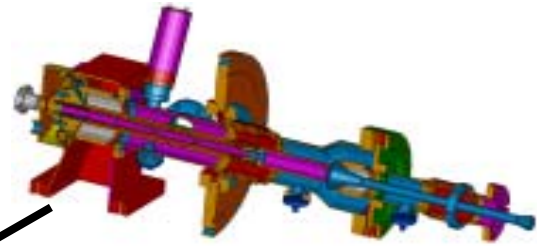
RF pick up & LLRF



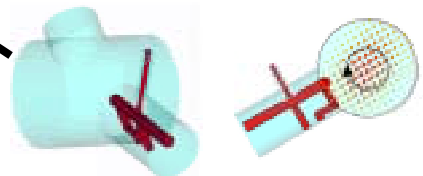


One standard **9-cell TESLA accelerating structure** operated as a π-mode standing-wave cavity.

One 230 kW **rf power coupler**, an **rf pick up** antenna and two **Higher Order Mode antennas** are assembled to each cavity.



RF power coupler



HOM coupler

String Assembly

The assembly of an 8 cavity string

- **is 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.**

We are ready to transfer this well known and complete procedure to industry.

The inter-cavity connection is done in class 10 cleanrooms

Module Assembly

The module assembly is a well defined and standard procedure.

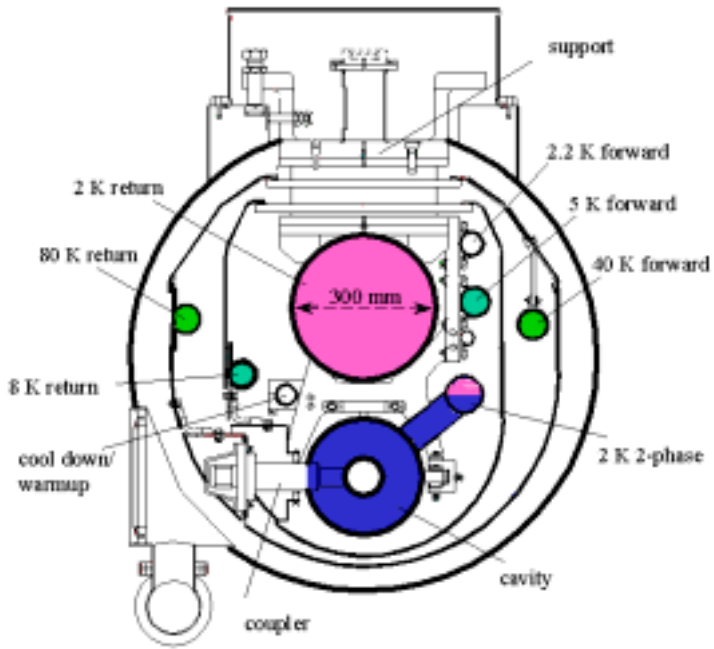
- **experience of 10 modules exists**
- **the latest generation (type III) will be used for series production (XFEL requires 120 modules)**
- **several cryogenic cycles as well as long time operation were studied**
- **the assembly problems occurred are well understood and cured**

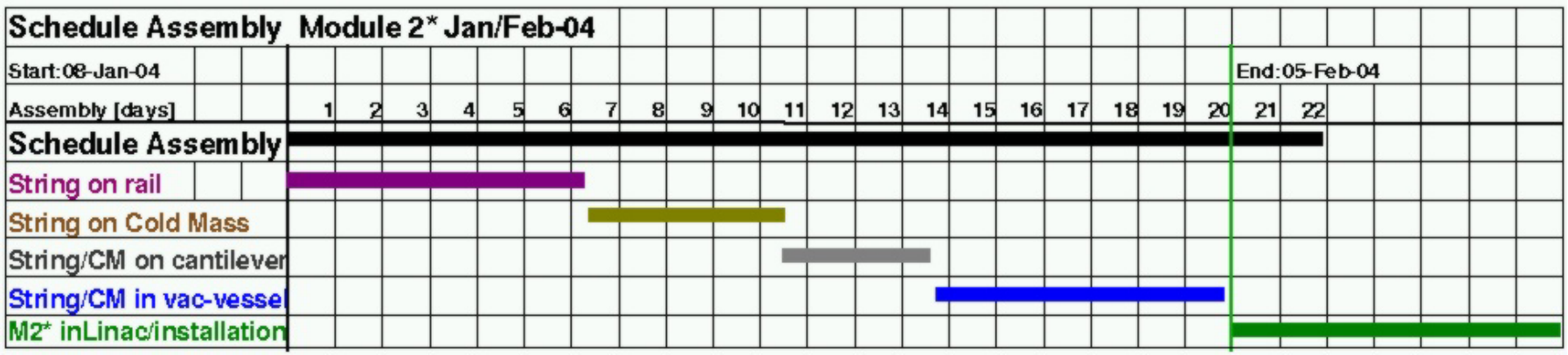
Module Assembly

Preparation and tests of single components:

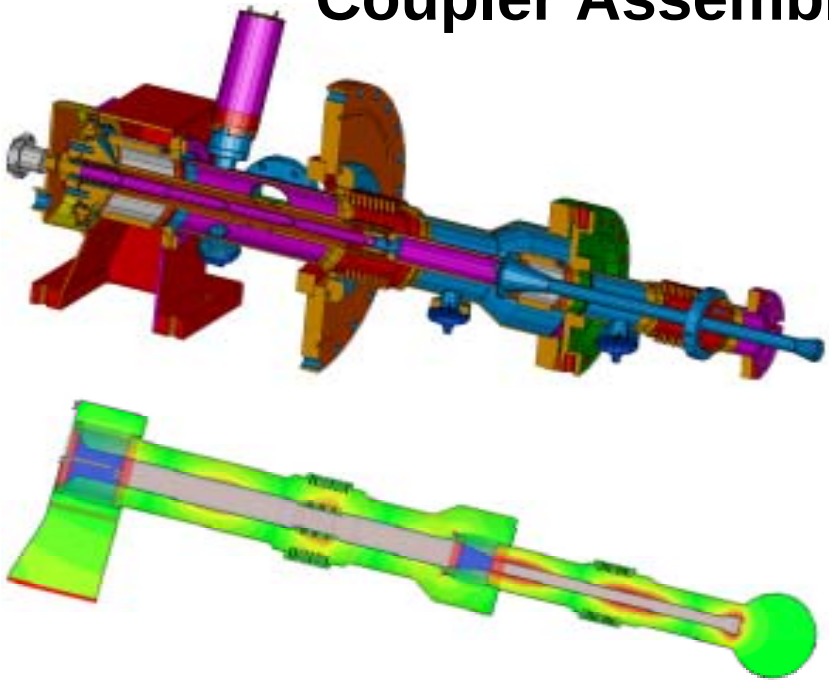
- **demagnetisation of the outer vacuum vessel**
- **warm conditioning of the main couplers**
- **baking of magnetic shieldings**
- **cold tests for cavities, frequency tuners, sc-magnet, current leads, feed throughs, partly couplers**
- **cavity string assembly**

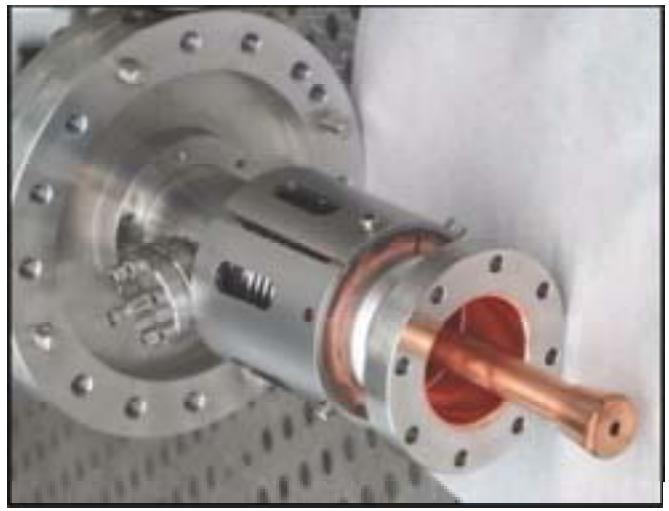
Scheduled Module assembly: 22 days





Coupler Assembly



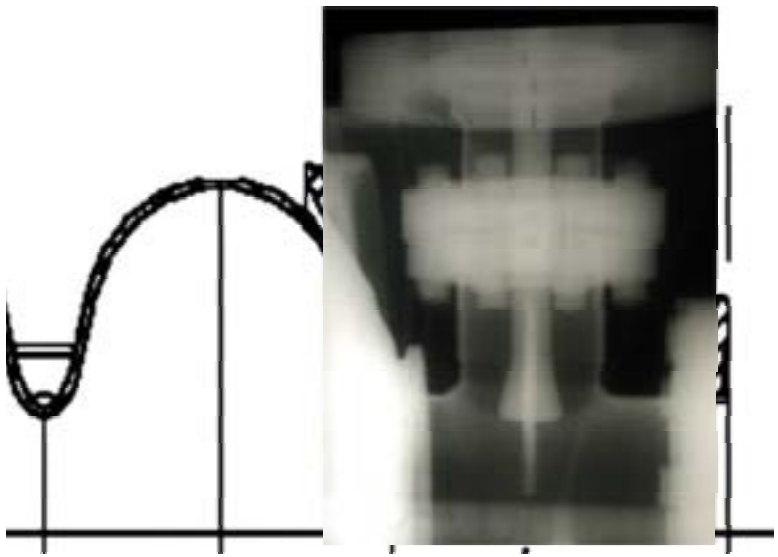


Two types and **three generations of couplers** were used at the TTF Linac.

All couplers were cold conditioned to a power level corresponding to accelerating gradients of at least 25 MV/m **(>200 kW, 1.3 ms, 10 Hz).**

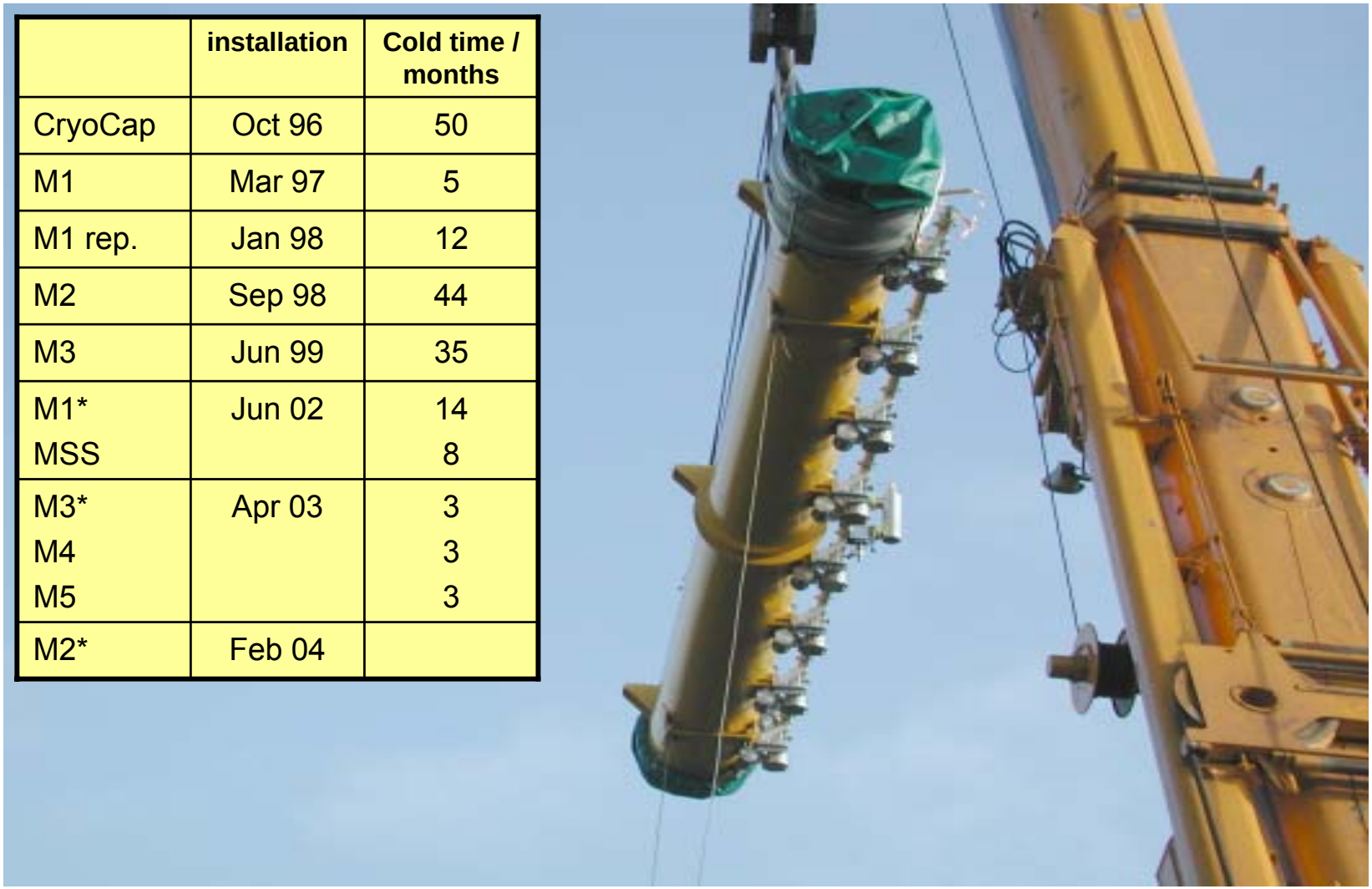
Coupler type III will be the base for the XFEL (≈1000 couplers). **Only minor modifications are expected to allow for large scale production.**

The total operation time exceeds **135,000 hours.**



Module Installation

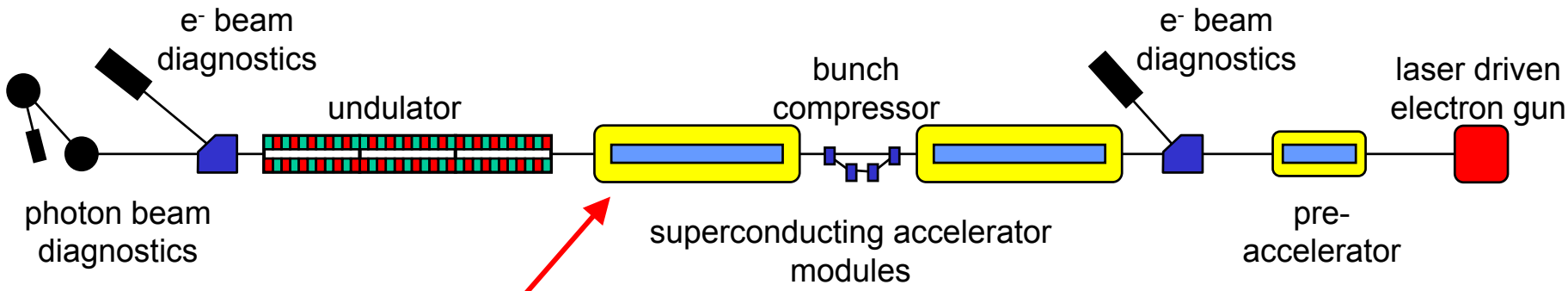
	installation	Cold time / months
CryoCap	Oct 96	50
M1	Mar 97	5
M1 rep.	Jan 98	12
M2	Sep 98	44
M3	Jun 99	35
M1* MSS	Jun 02	14 8
M3* M4 M5	Apr 03	3 3 3
M2*	Feb 04	

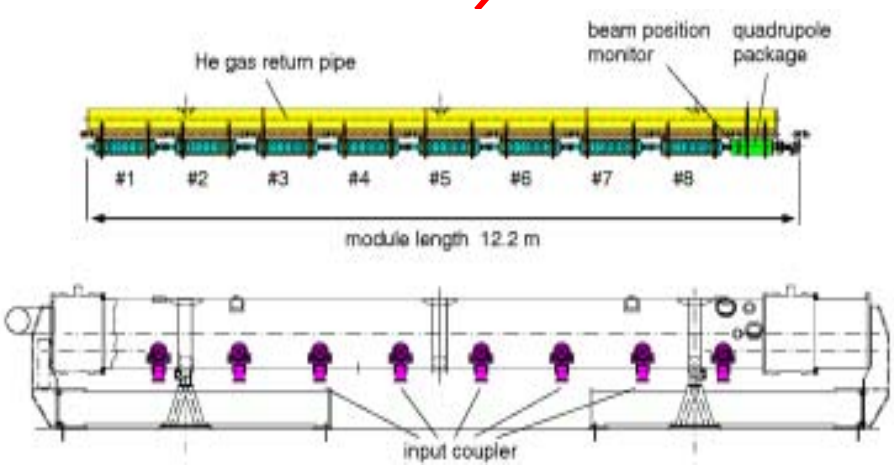


The TTF Linac Installation

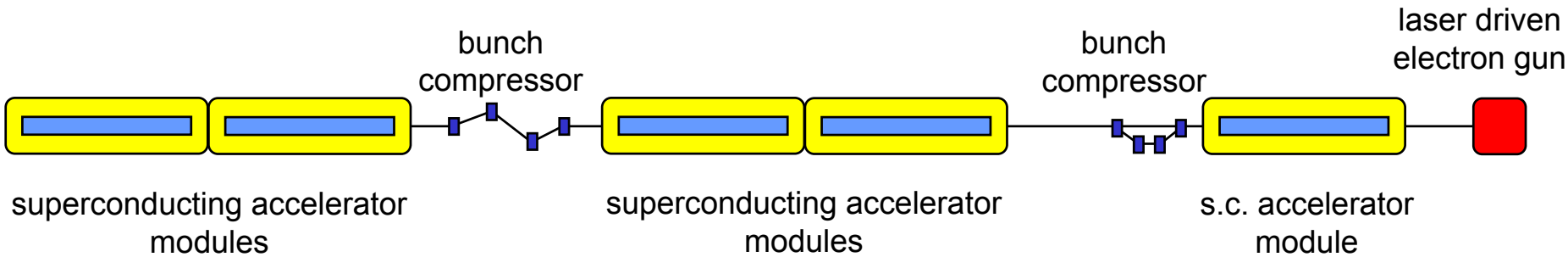
TESLA

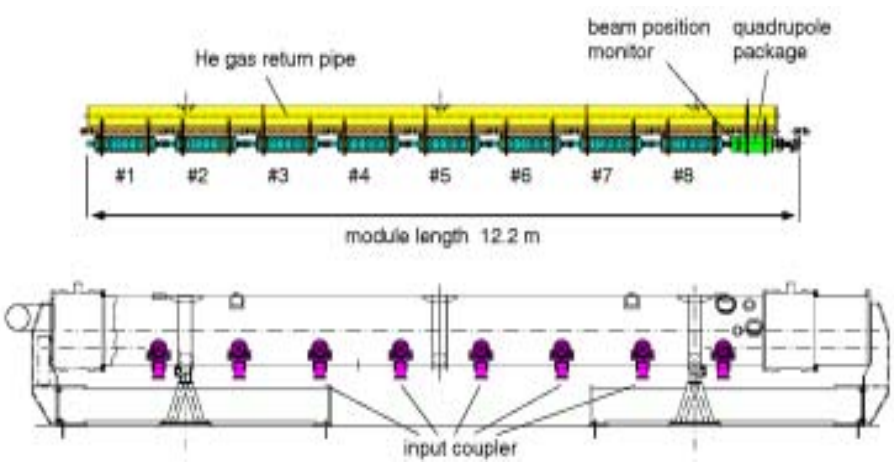
The LC cold option

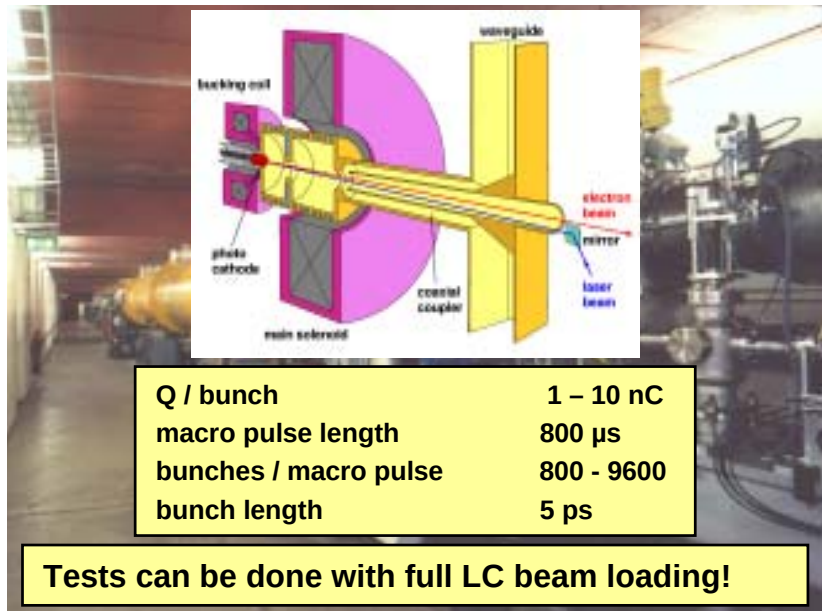




The TTF Linac Installation







Q / bunch	1 – 10 nC
macro pulse length	800 µs
bunches / macro pulse	800 - 9600
bunch length	5 ps

Tests can be done with full LC beam loading!

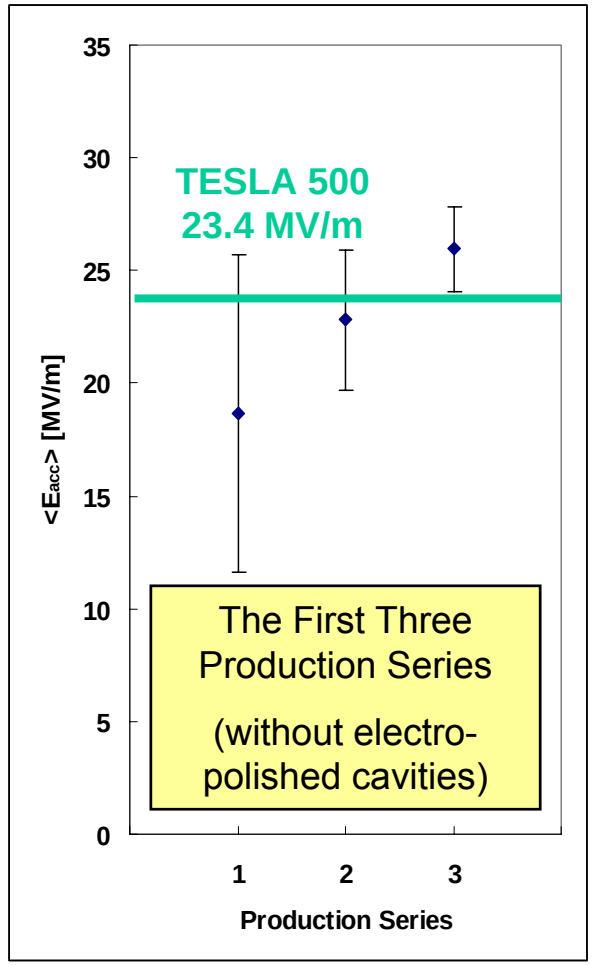
The TTF Linac Installation

Approx. 80 cavities were produced in three production series.
Gradient and gradient spread improved a lot.

Nine accelerator modules with 8 cavities each were assembled.

58 different cavities were used for the module assembly. Some cavities were used for a second assembly.

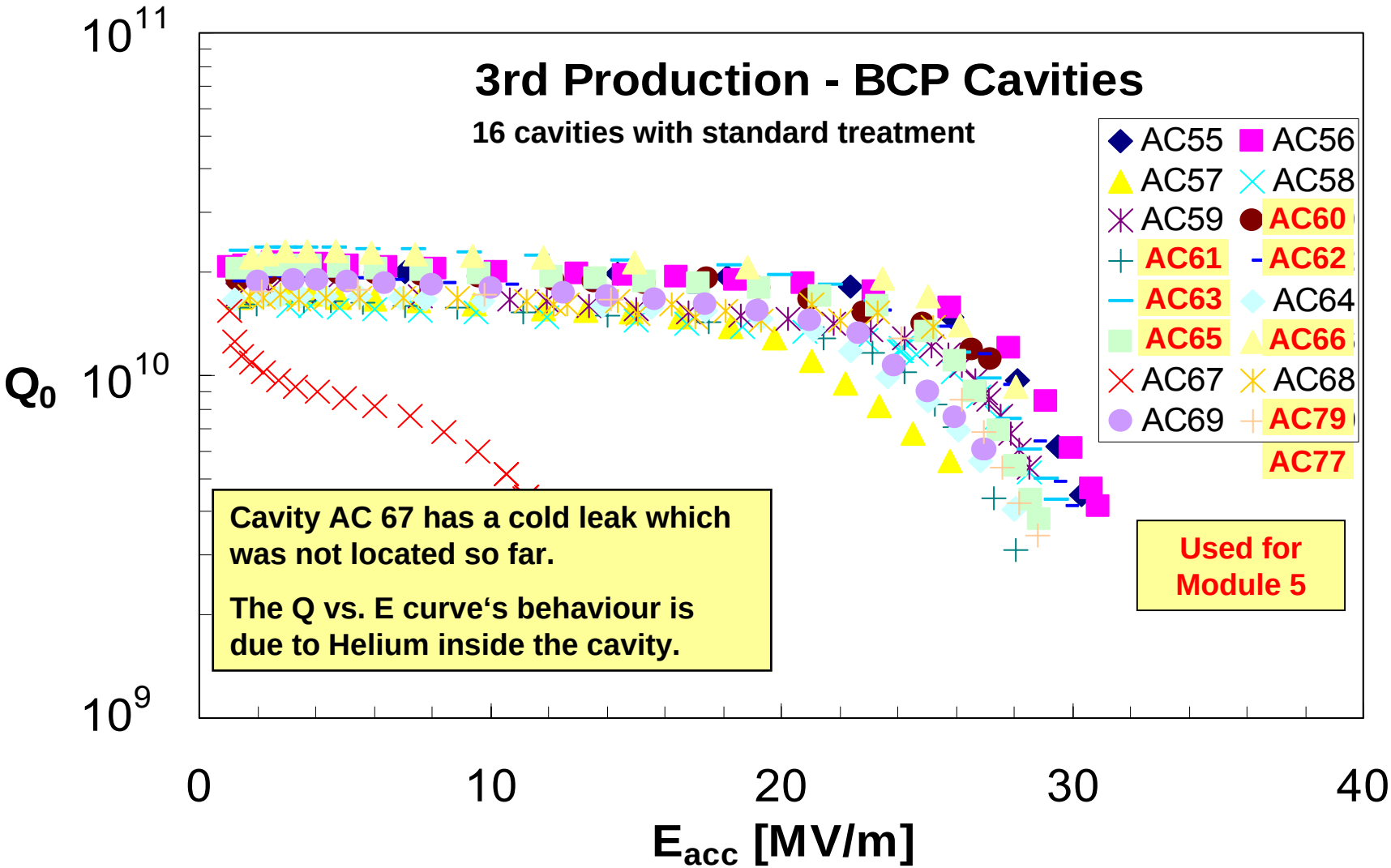
Series 1	**18.7 ± 7.0**
Series 2	**22.8 ± 3.1**
Series 3	**26.0 ± 1.9**



High Gradient Performance

TESLA

The LC cold option



Performance of Accelerator Module 5

TESLA

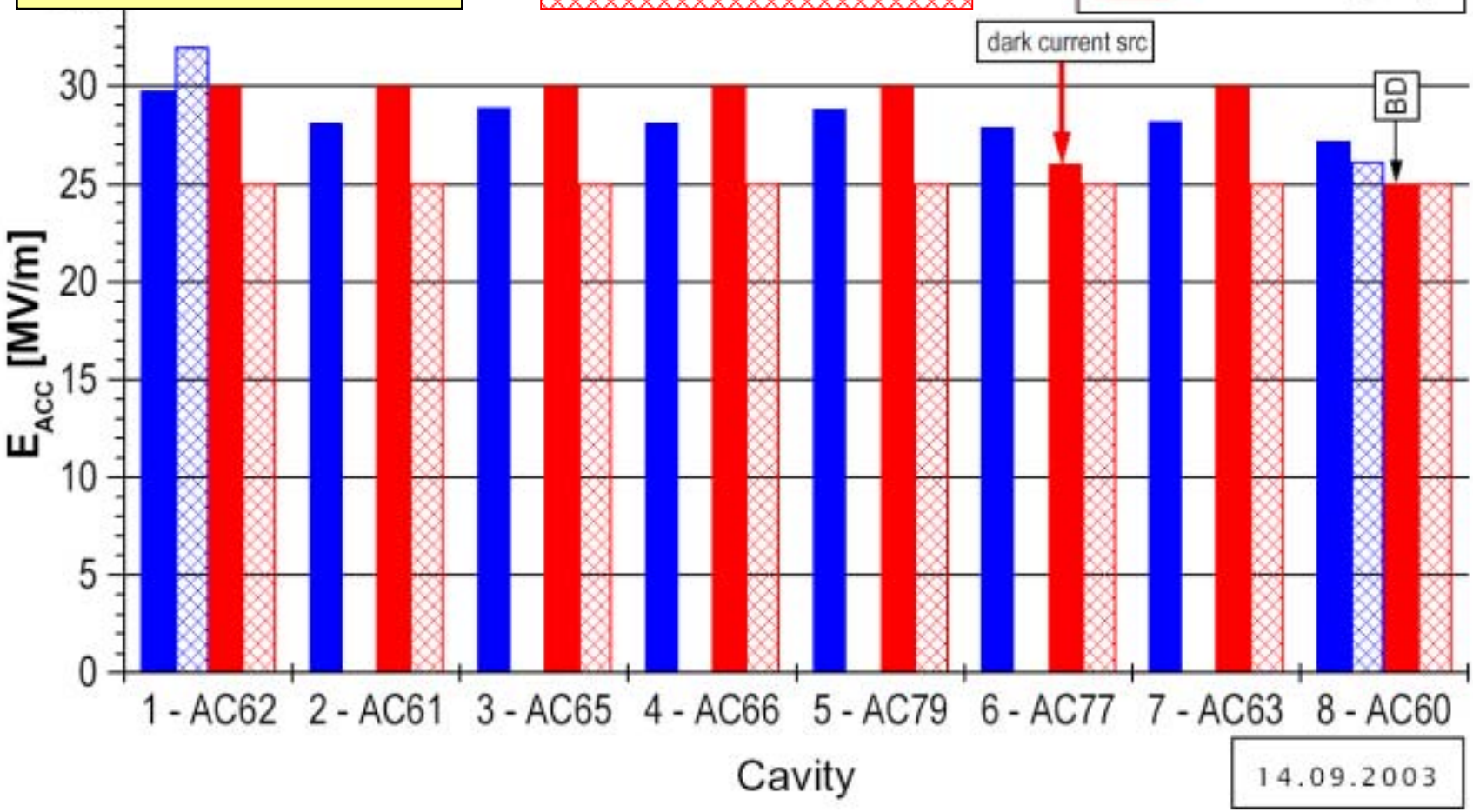
The LC cold option

A State-of-the-art module

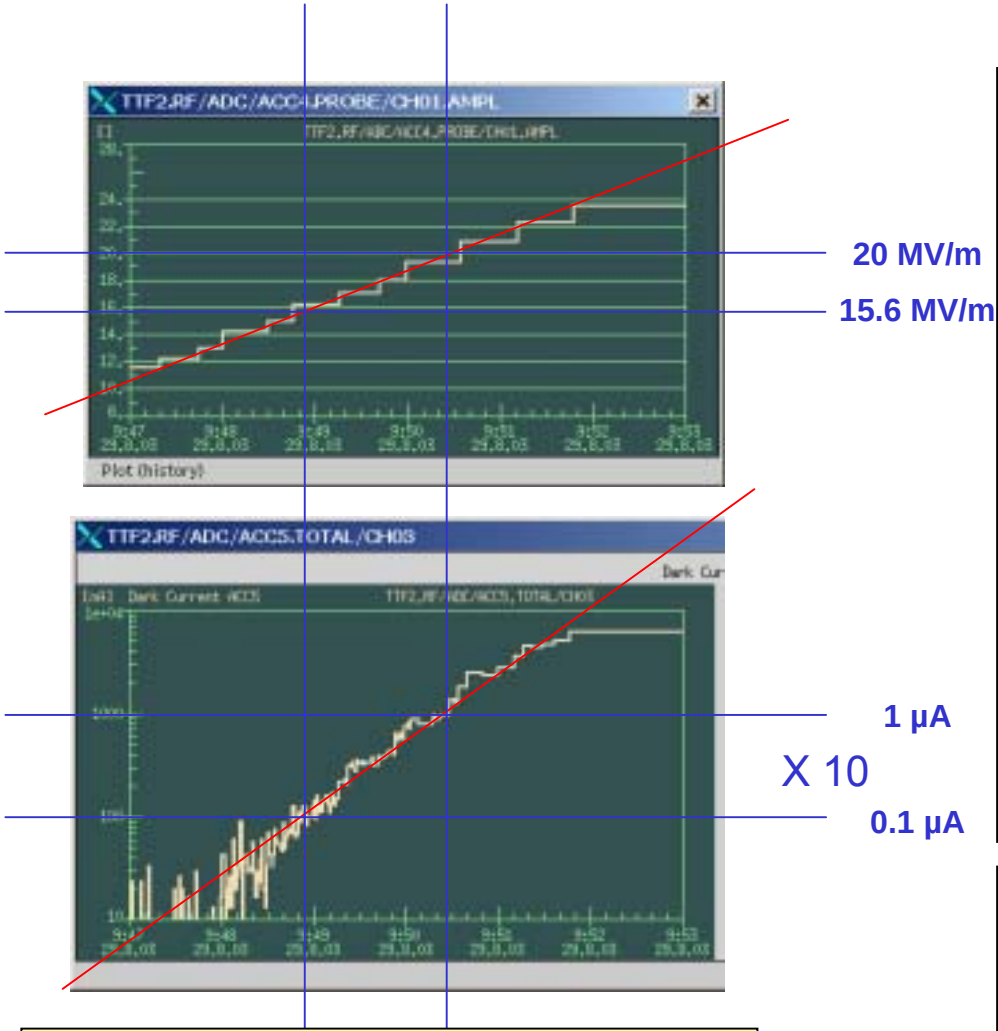
- **cryogenic type III**
- **latest coupler generation**
- **BCP cavities**

In single cavity measurements 6 out of 8 cavities reach 30 MV/m!

Equal power feeding <Eacc> = 25 MV/m



Dark Current Measurement



Total dark current measured at the exit of ACC5. Cavity no. 6 (AC77) in operation.

The on-axis dark current was measured for modules ACC4 / ACC5.

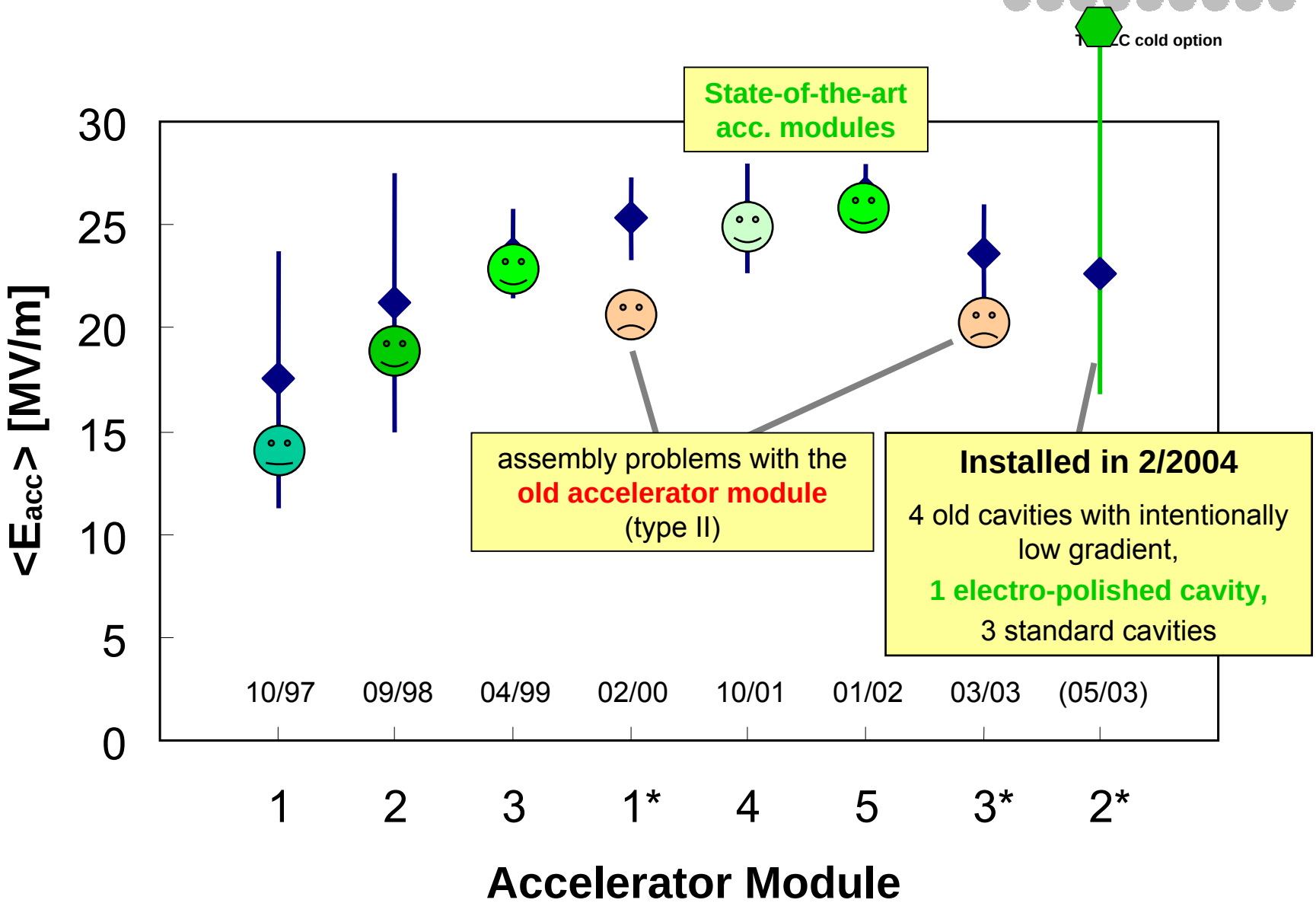
Only one cavity in module ACC5 produced a mentionable dark current.

- **captured dark current could be measured at the exit of ACC5**
- **there was no d.c. from this cavity at the entrance of ACC4**
- **the d.c. increased by a factor 10 for each 4.4 MV/m gradient step, starting with 100 nA at 16 MV/m**
- **detuning of cavity no. 6 left over an integrated dark current of the order of 100 nA at 25 MV/m average gradient**

The TESLA limit is defined by additional cryogenic losses:

The captured d.c. has to stay below 50 nA per cavity. (see TESLA Report 2003-10).

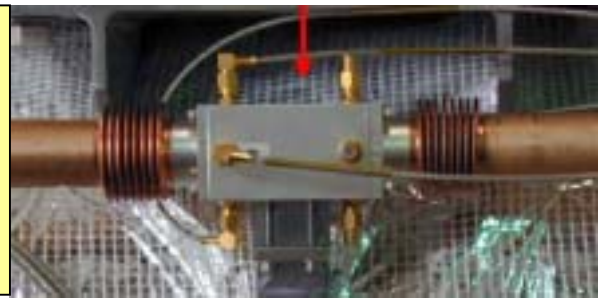
Gradients of Accelerator Modules



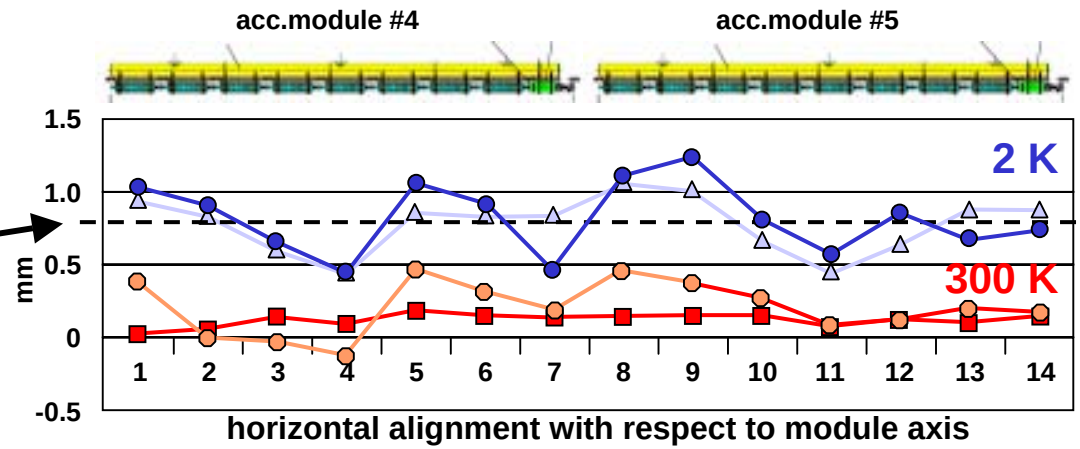
Cavity and Module Alignment

cavity / quad string alignment is measured using a stretched wire system

at warm and at cold temperature



corresponds to a perfectly aligned cavity / quad string



TDR specifications (RMS):

cavities	x/y:	+/- 0.5 mm
	z:	+/- 1 mm
quad/dip	x/y:	+/- 0.3 mm
	z:	+/- 1 mm
	roll:	+/- 0.1 mrad

Results (peak):

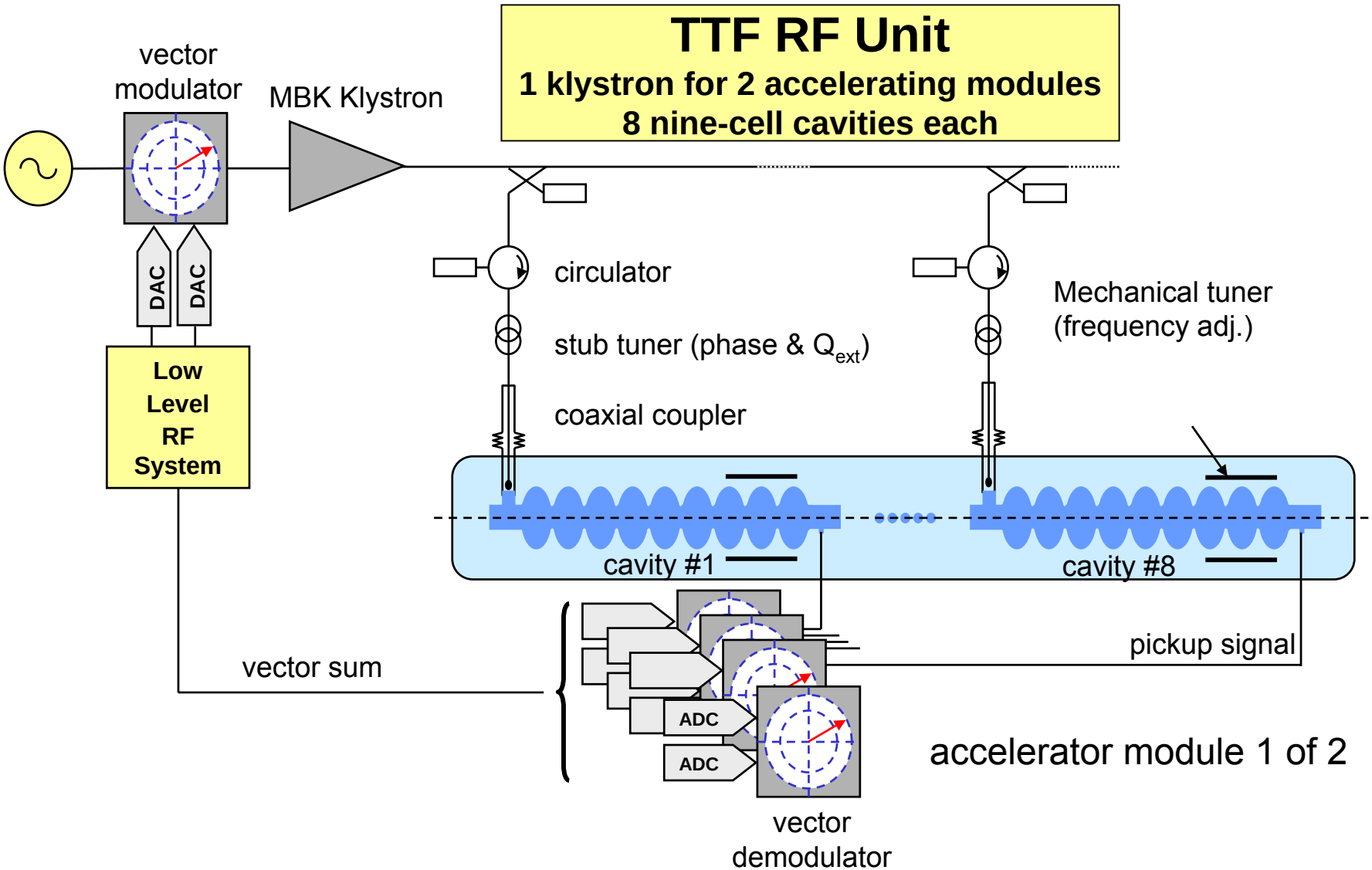
cavities	x:	+/- 0.35 mm
	y:	+/- 0.25 mm
quad/dip	x:	+ 0.1 / - 0.4 mm
	y:	+ 0.2 / - 0.5 mm
overall module tilt		≈ 0.1 mrad

- ■ 20-Jun-03 300 K
- △ 22-Jul-03 2 K
- ○ 06-Oct-03 300 K
- ● 31-Mar-04 2 K

RF Operation of s.c. Cavities

TESLA

The LC cold option

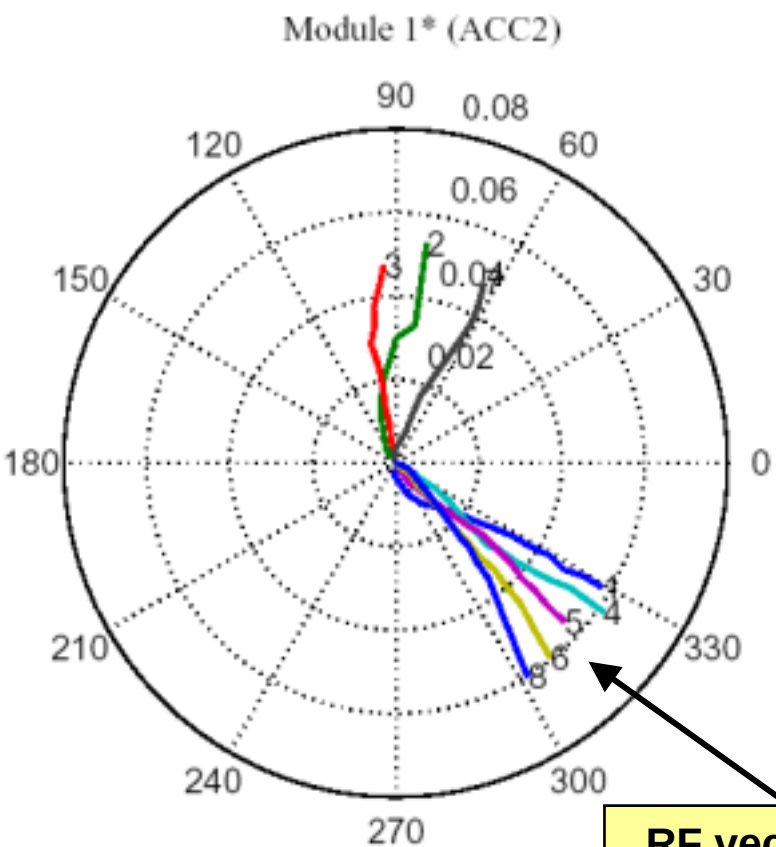


RF Operation of Accelerator Modules
e.g. Phase Adjustment Using Beam Transients

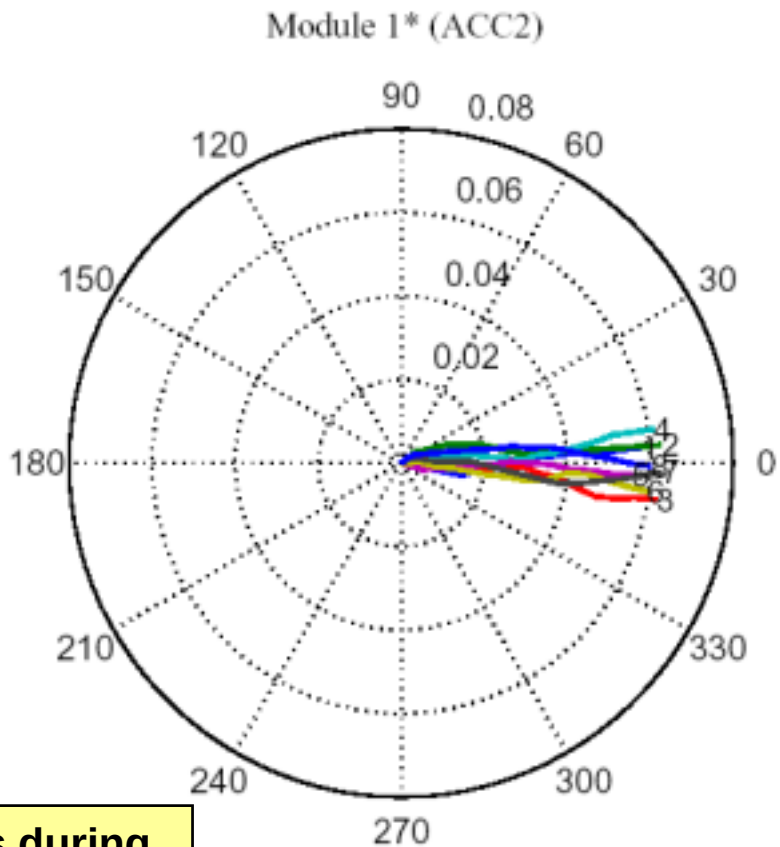
TESLA

The LC cold option

before adjustment



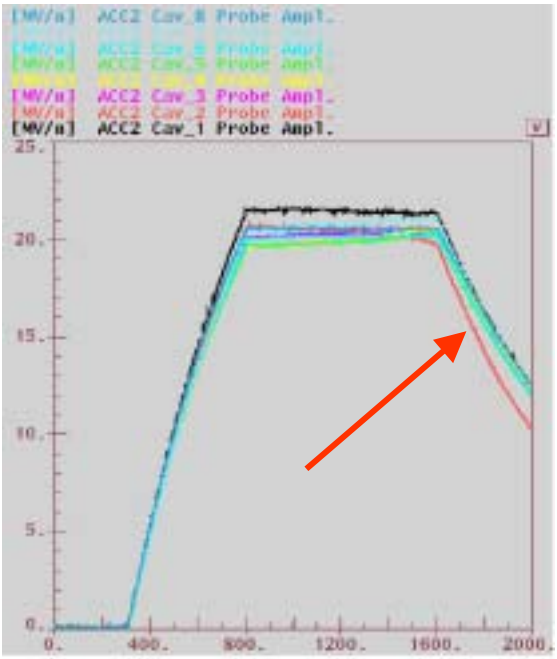
after adjustment

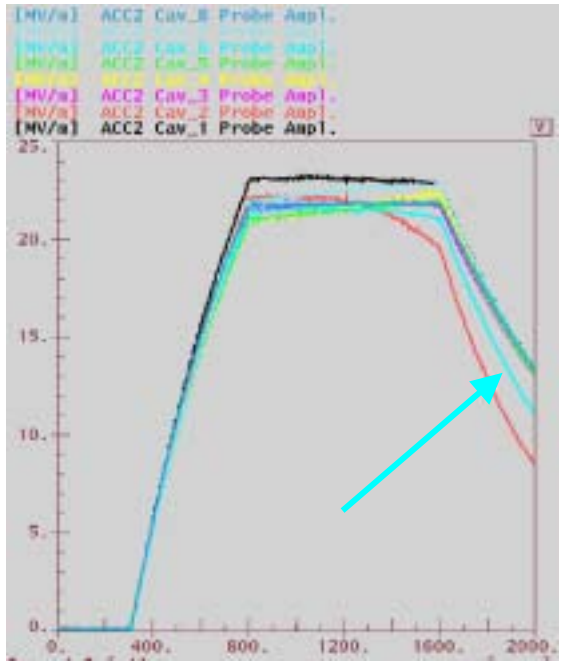


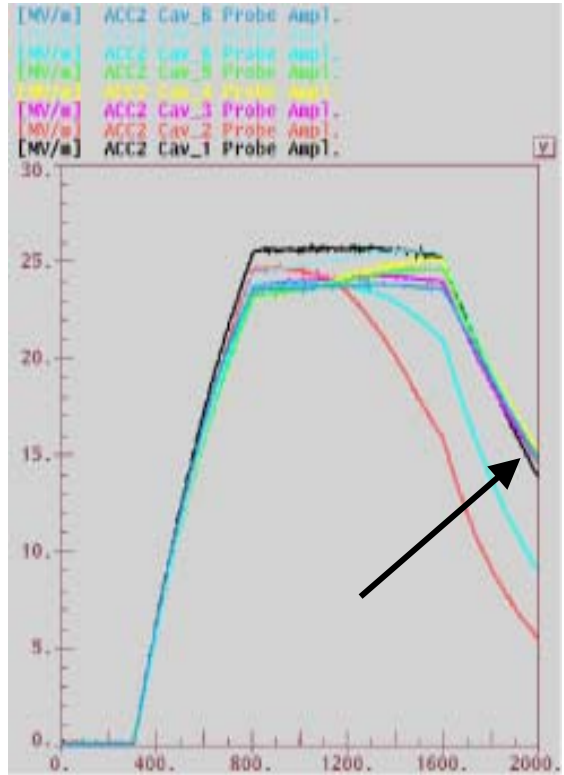
RF vectors during 800 µs flat top

RF Operation of Accelerator Modules Above its Performance Limit (e.g. Module 1*)

Cavity quench detection algorithms and exeption handling procedures analyze the probe signals...





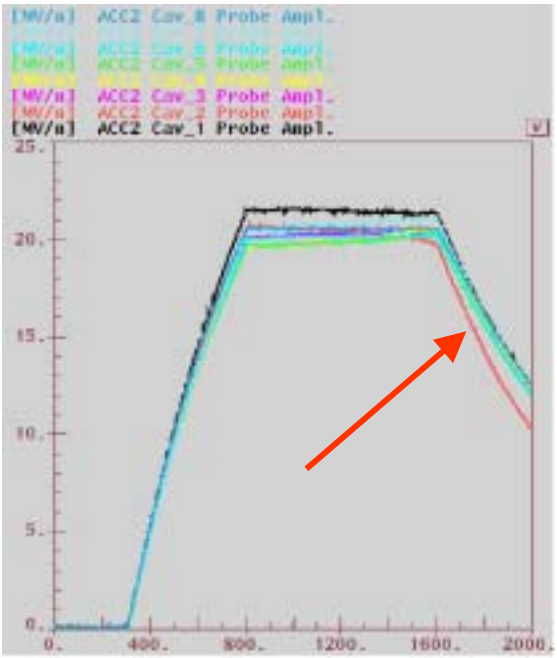


Stable Module #1* operation with slowly but steadily increased gradient

1st quench: **Cavity 2**	2nd quench: **Cavity 6**	3rd quench: **Cavity 1**
E_{acc}=19 MV/m	E_{acc}=21 MV/m	E_{acc}=24 MV/m

RF Operation of Accelerator Modules Above its Performance Limit (e.g. Module 1*)

... so that one can learn from the TTF Linac operation for the TESLA Linear Collider.



The maximum operating gradient of s.c. cavities

- **is set by cavity quench, field emission, or Q-degradation – not by structure breakdown**
- **is not a hard limit**. A too high gradient results in increased cryogenic load, radiation, and dark current
- **does not trip off cavities** in ns but in typ. 100 µs if cavities are operated at the threshold

An **exception handler** as part of the LLRF can avoid quenches.

- **Action can be taken prior to the next pulse.**
- **Consequences for the machine safety are very positive, i.e. correctly injected bunches will not be lost in the linac.**

In a **high gradient long pulse run** in spring 2002, an accelerator module was operated with stable beam (5 mA, 800 µs) **close to its gradient limit.**

The acc. module was operated with a typ. module on-time of 90% at increasing gradients:

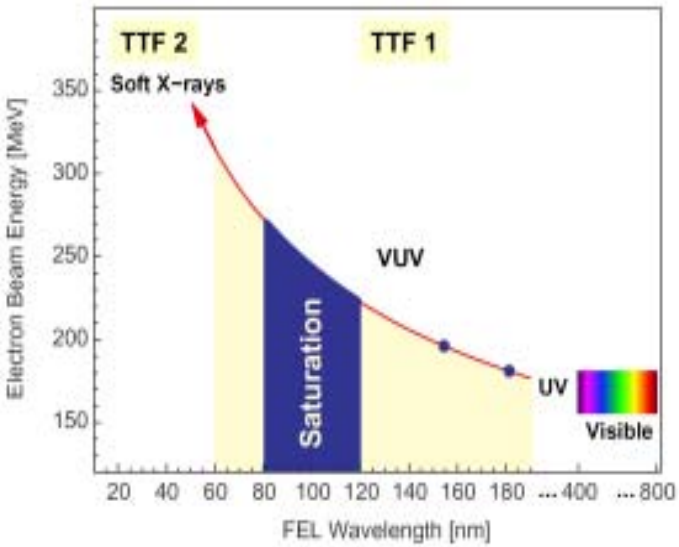
39 days at 19.5 MV/m, 800 µs, 5 Hz
4 days at 20.0 MV/m, 800 µs, 1 Hz
6 days at 21.5 MV/m, 800 µs, 1 Hz

(1 Hz operation due to beam oper. laser + gun were limited)

TTF Linac Operation

TESLA

The LC cold option

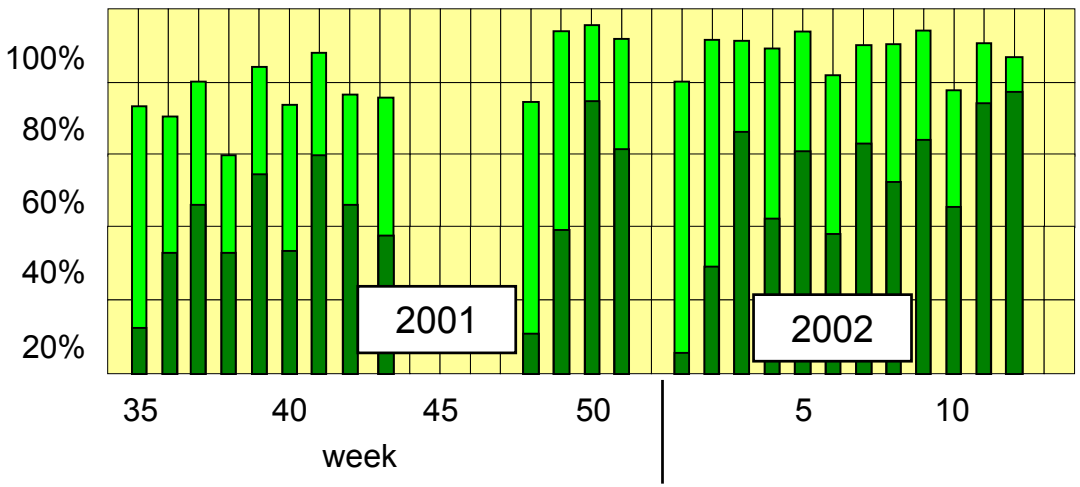


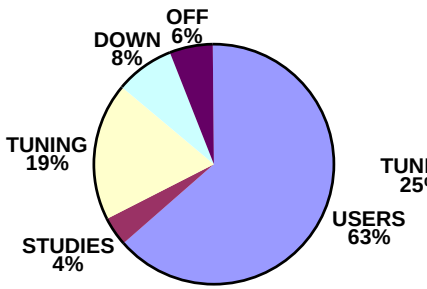
For a long time the TTF Linac was operated **7 days per week, 24 hours**. In its final configuration it is going to be operated as a user facility. Commissioning is scheduled for 2004.

Approx. **50% of the time was allocated to FEL operation** including a large percentage of user time. The FEL requires very stable beam conditions. In its different set-ups, approx. **13,000 hours beamtime** were achieved since 1997.

Based on the TTF experience several FELs /ERLs using superconducting accelerator technology are proposed. The European XFEL is going to be built.

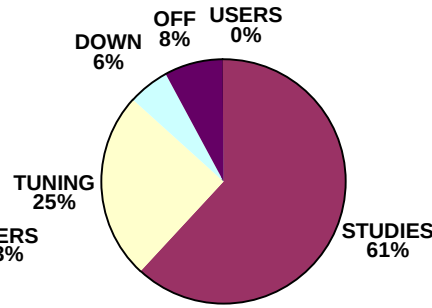
Beam uptime and operational uptime (users or acc.studies)





week 3 / 2002

FEL User Operation



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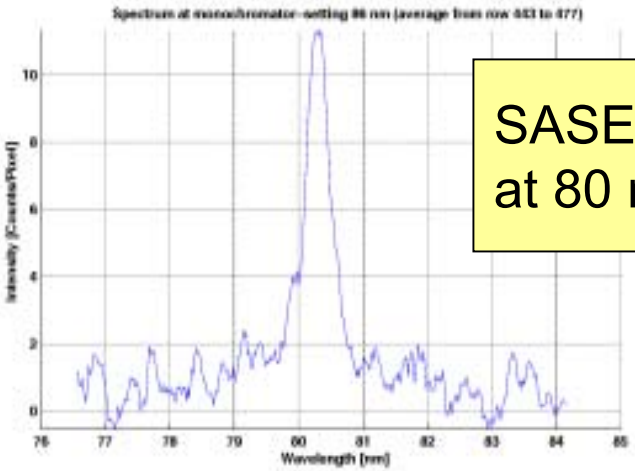
Accelerator Studies

Stable SASE FEL Operation for Users

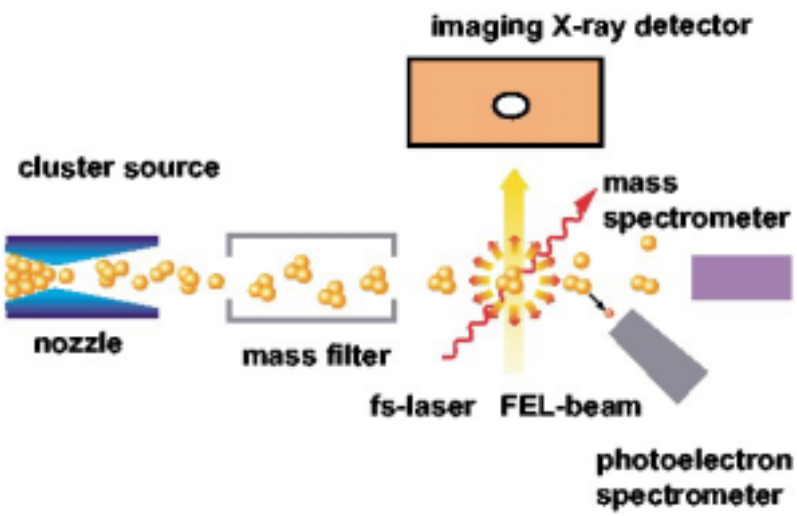


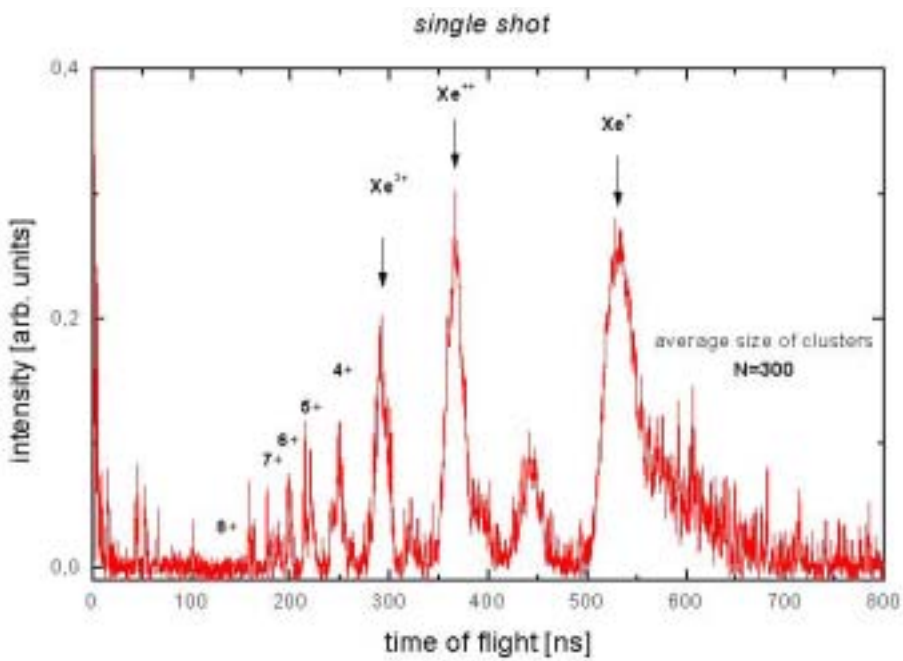
SASE operation at 80 nm

H. Wabnitz et al.

”Multiple ionization of atom clusters by intense soft X-rays from a free-electron laser”

Nature Vol.420, pp 482-485, Dec.2002





TESLA

The LC cold option

TESLA Test Facility Linac – Phase II FEL User Facility in the nm Wavelength Range (VUV)

Six accelerator modules to reach 1 GeV beam energy.

Module #6 will contain **8 electro-polished cavities.**

Klystrons and modulators build in industry.

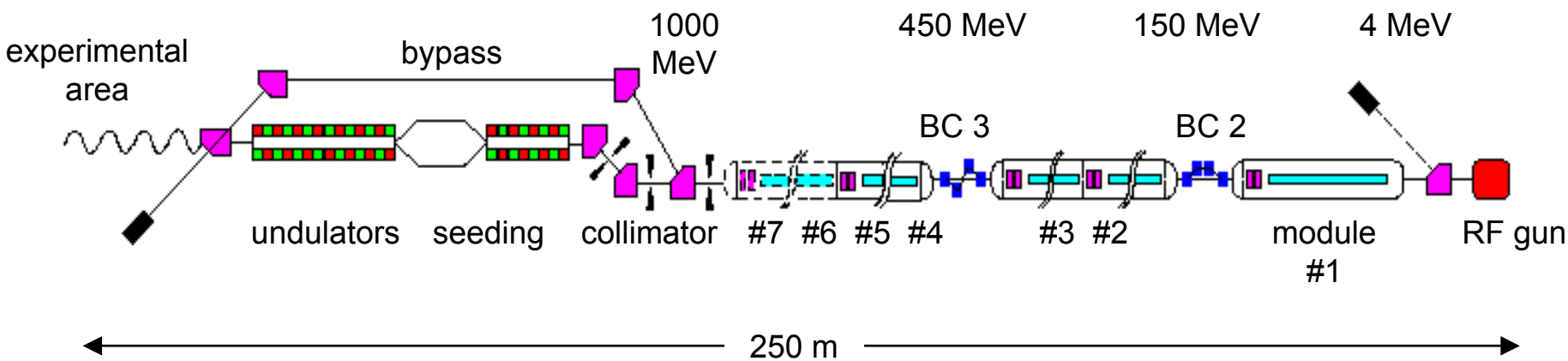
High gradient operation of accelerator modules.

The goals: **Reliable operation**
highest possible availability
24 h / 7 days per week operation

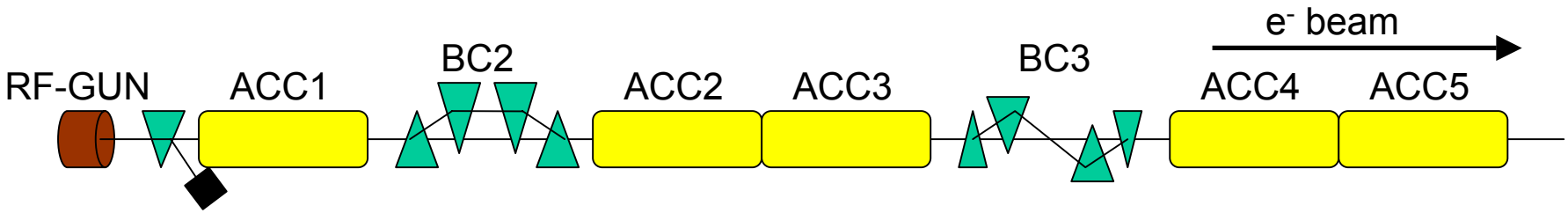
Commissioning

RF in 2003

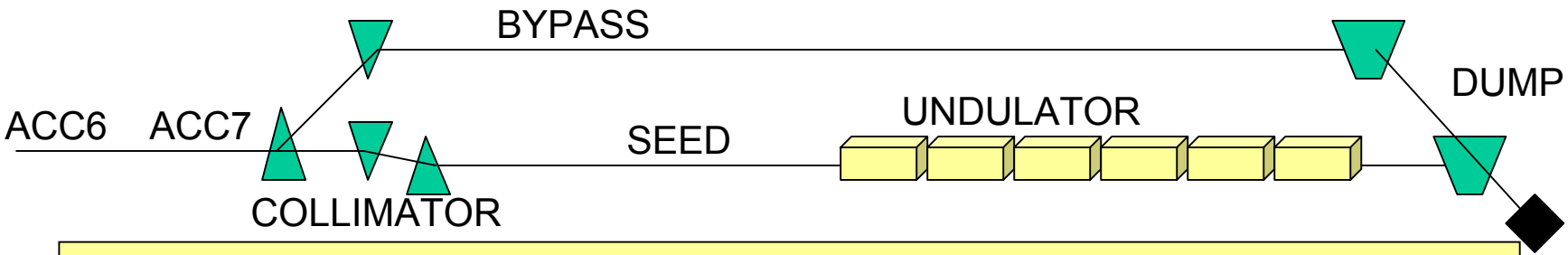
FEL in 2004



The Installations of the Last 12 Months



• a new RF Gun	
• a new injector concept	Injector 3
• five new accelerator modules	ACC1 to ACC5 (2*, 1*, 3*, 4, 5)
• a new bunch compressor	BC3



• new beamlines	more than 150 m
• a new collimator concept	transv. and energy collim.
• a long undulator	6 modules, 30 m
• a long bypass and a spectrometer line	

LC Related R&D in the Next 12 Months (Summary and Outlook)

Long time operation of all 5 acc. Modules.

VUV-FEL Commissioning.

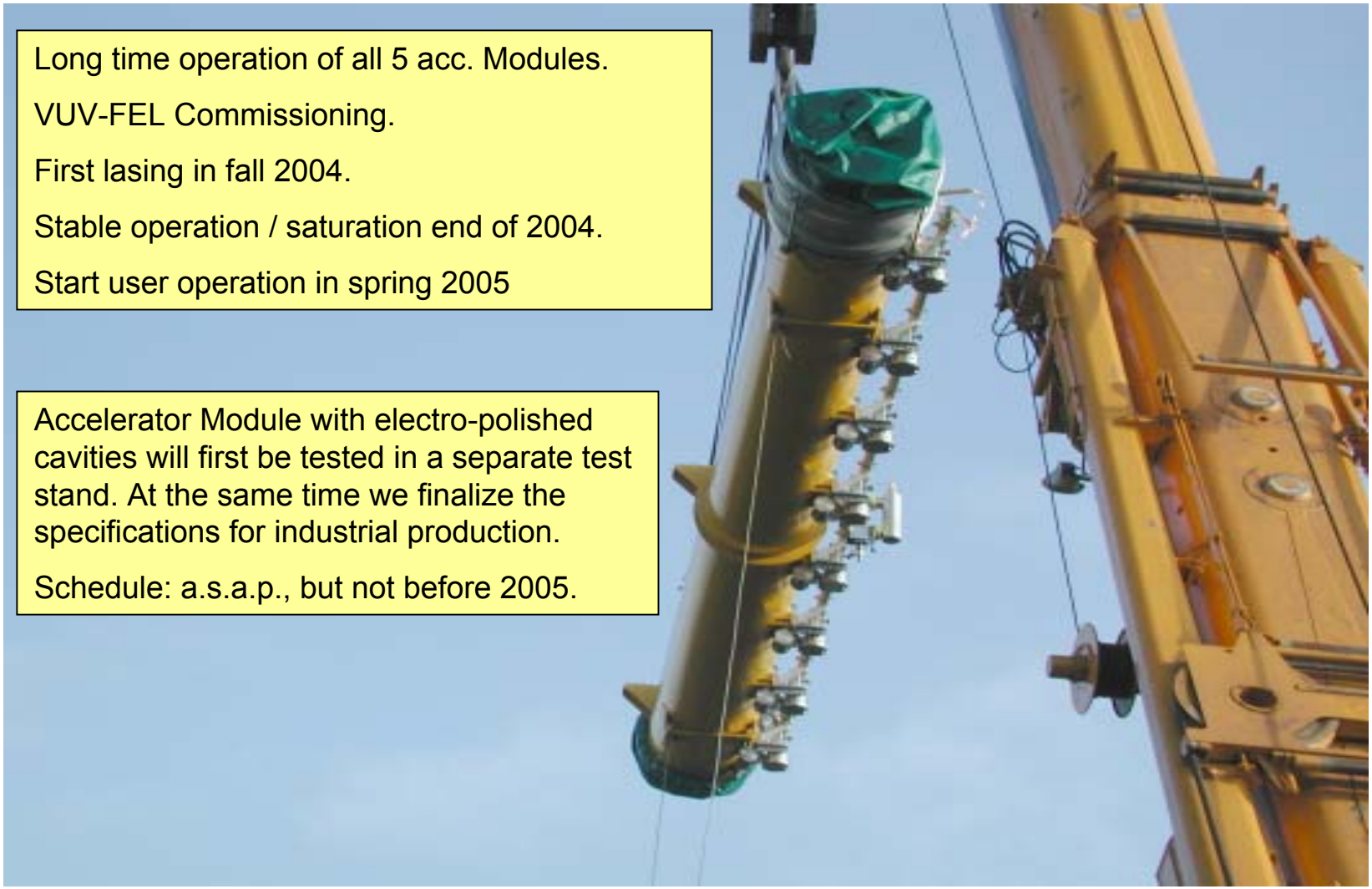
First lasing in fall 2004.

Stable operation / saturation end of 2004.

Start user operation in spring 2005

Accelerator Module with electro-polished cavities will first be tested in a separate test stand. At the same time we finalize the specifications for industrial production.

Schedule: a.s.a.p., but not before 2005.



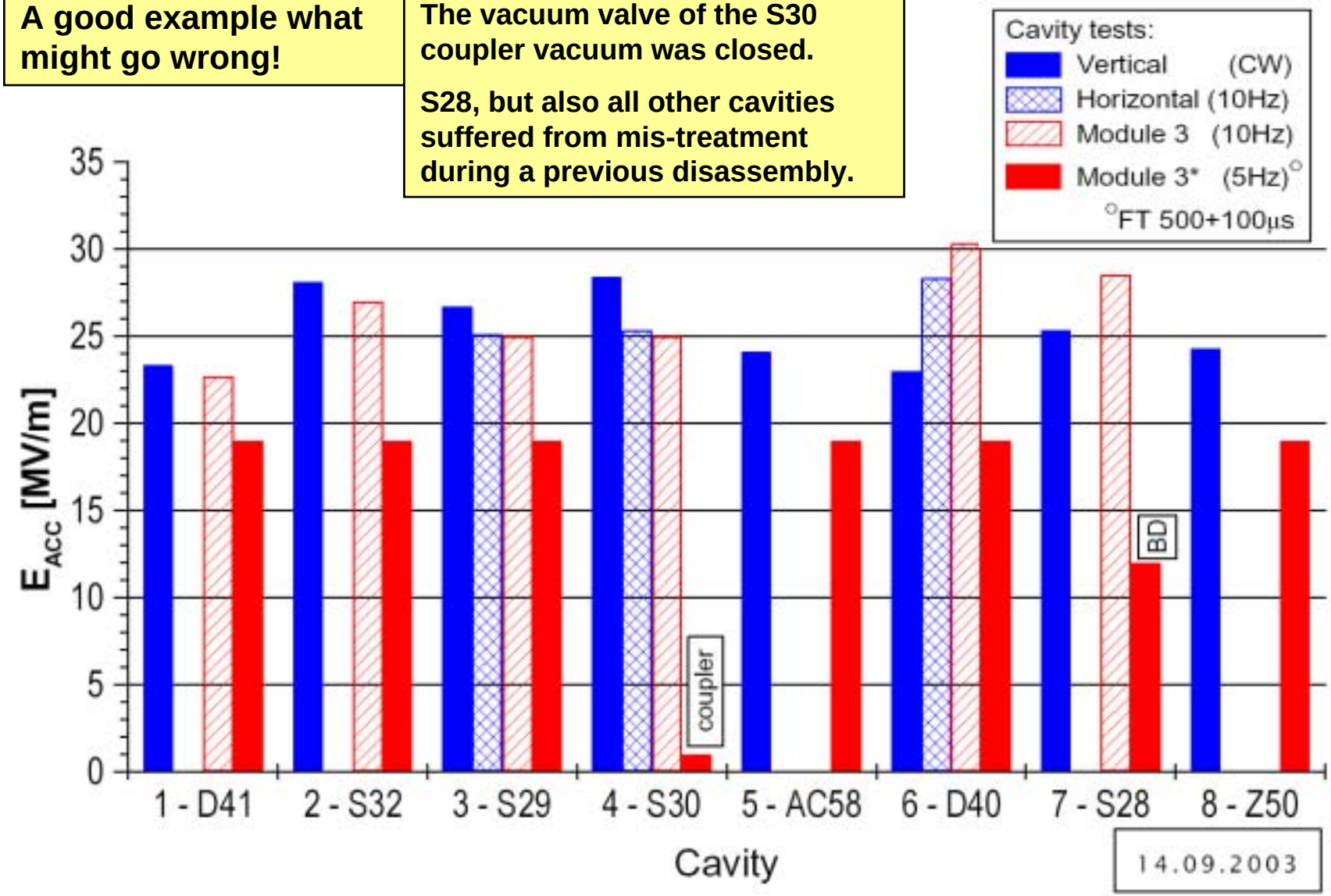
The End

Problems with Accelerator Module 3*

A good example what might go wrong!

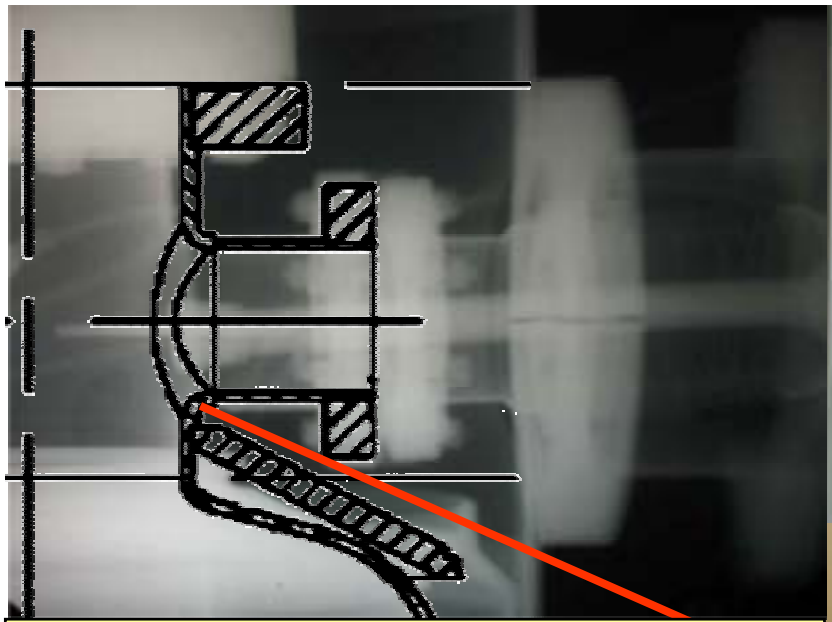
The vacuum valve of the S30 coupler vacuum was closed.

S28, but also all other cavities suffered from mis-treatment during a previous disassembly.



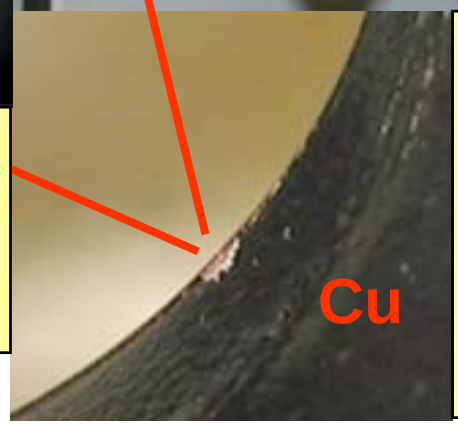
RF Main Power Coupler

Module 3 (cryo type II) – Copper on Niobium



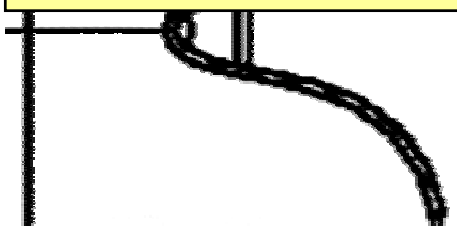
Problems discovered and identified during the disassenbly of **module 3***

Etching with citric acid, short BCP, and HPR obviously only partial successfully.

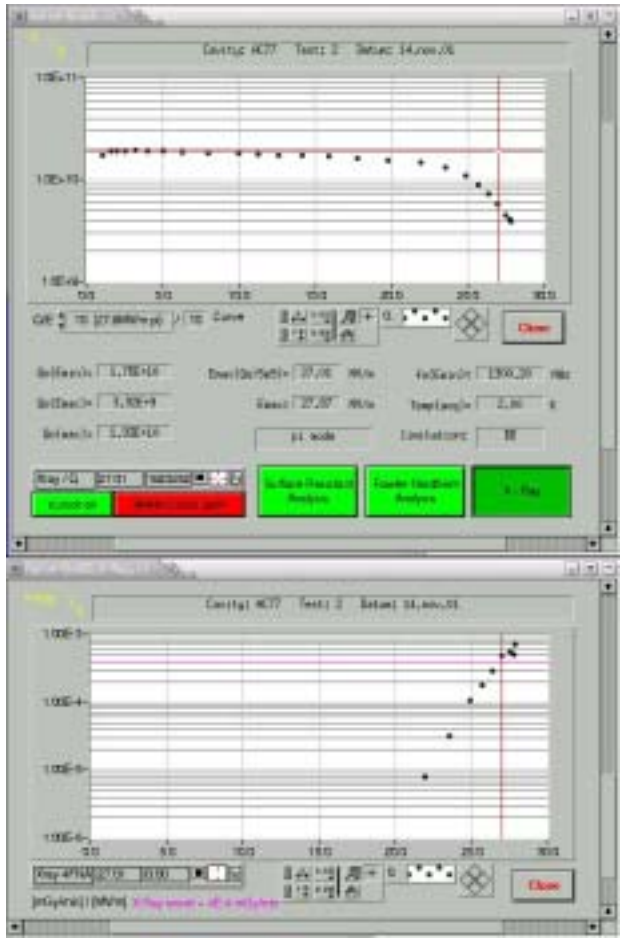


RF Main Coupler

- Inner conductor made from Cu
- Soft due to additional soldering
- bent / misaligned



Cavity AC77 as a Dark Current Source



Q vs. E and radiation measurement in the last vertical test before cavity assembly.

Was there anything special with AC77?

YES!!!

The normal procedure is

1. **Do a vertical test**
2. **Disassembly from vertical insert**
3. **5 min BCP, 1 HPR**
4. **Complete assembly**
5. **2 HPR**
6. **Close beam line flange (class 10)**
7. **Cavity string assembly (class 10)**

During the AC77 assembly a vacuum leak at the ??? flange was detected after step 6. The flange was then re-sealed without repeating step 5.

Why?!?!?!?

None of the other cavities in ACC4 / ACC5 had similar problems. Therefore they have no dark current.