Experience with the TESLA Test Facility

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DESY -MPY-

SRF 2005

11.7.2005

- Overview on the TESLA Test Facility (TTF)
- Operation of the superconducting linac
  - Properties of the accelerator modules
- R&D on superconducting cavities
  - EP on multi-cells
  - Single-cell program
- TTF Program 2005

Thank you…

- ... to B. Faatz, J. Iversen, H. Weise, B. Petersen, D. Reschke, A. Matheisen, Jacek Sekutowicz for some of the viewgraphs.
- … the many people having worked on TTF.
  - These are results of work over many years!

TESLA Test Facility (TTF 1, 1995-2002)

TTF 2

experimental hall

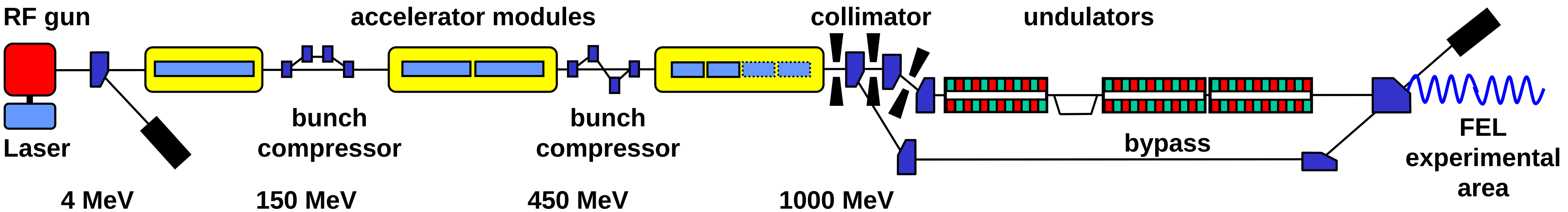
Commissioning: 2004/5

User experiments: 2005

TTF Mission

- TTF serves two purposes
  - R&D for a superconducting Linear Collider
    - E.g. Cavity preparation
    - Integration towards full accelerator modules
      - E.g. HOM couplers, power couplers, tuner
  - R&D for free-electron lasers
    - VUV-FEL user facility
    - Preparation for the European XFEL project
      - Industrial studies based on TTF experiences

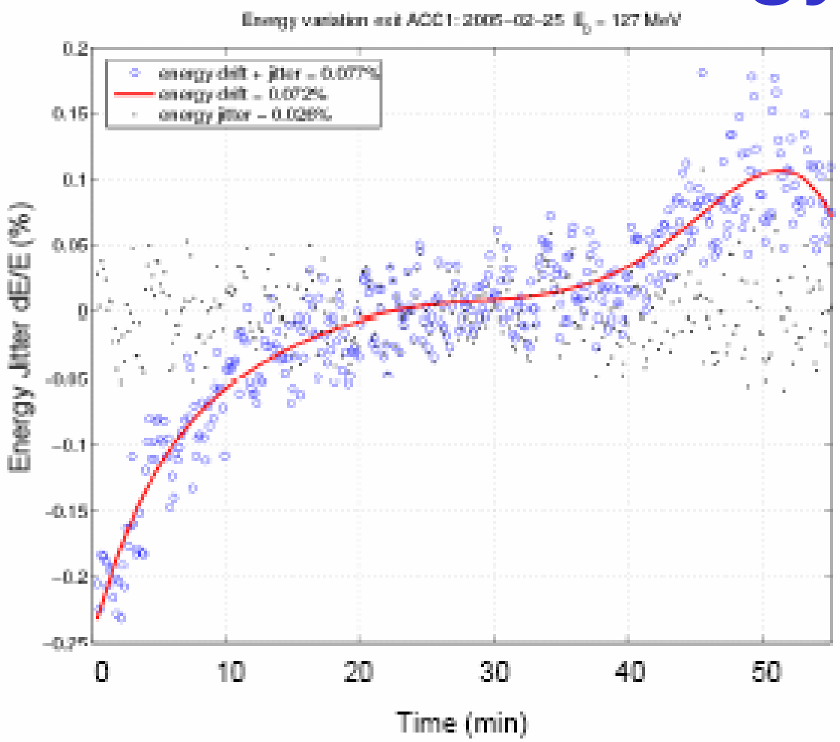
TESLA Test Facility Linac
FEL User Facility in the nm Wavelength Range (VUV)

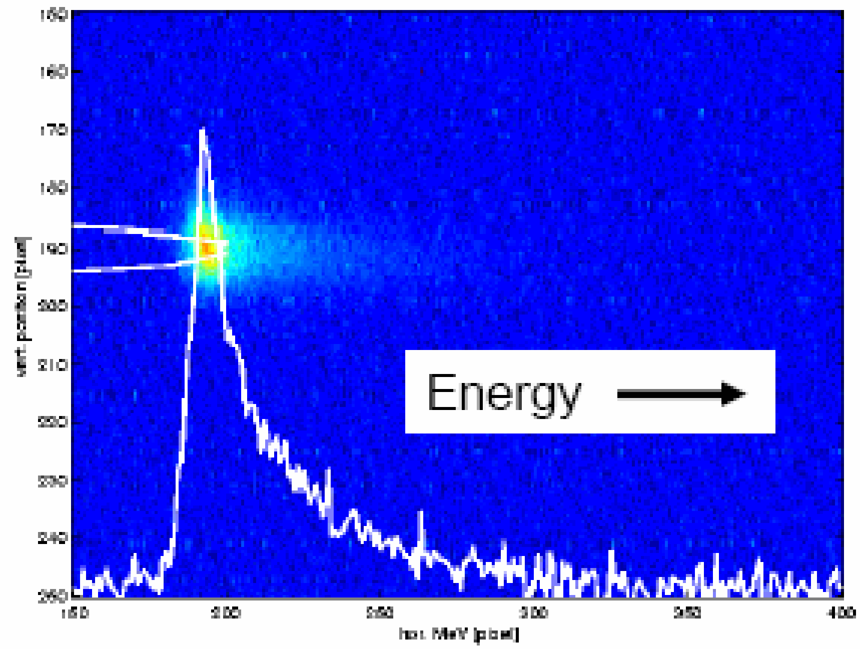


Beam and FEL Properties

- Show some of the more recent measurements with the TTF facility
  - Energy Spread
  - Emittance
  - FEL radiation power

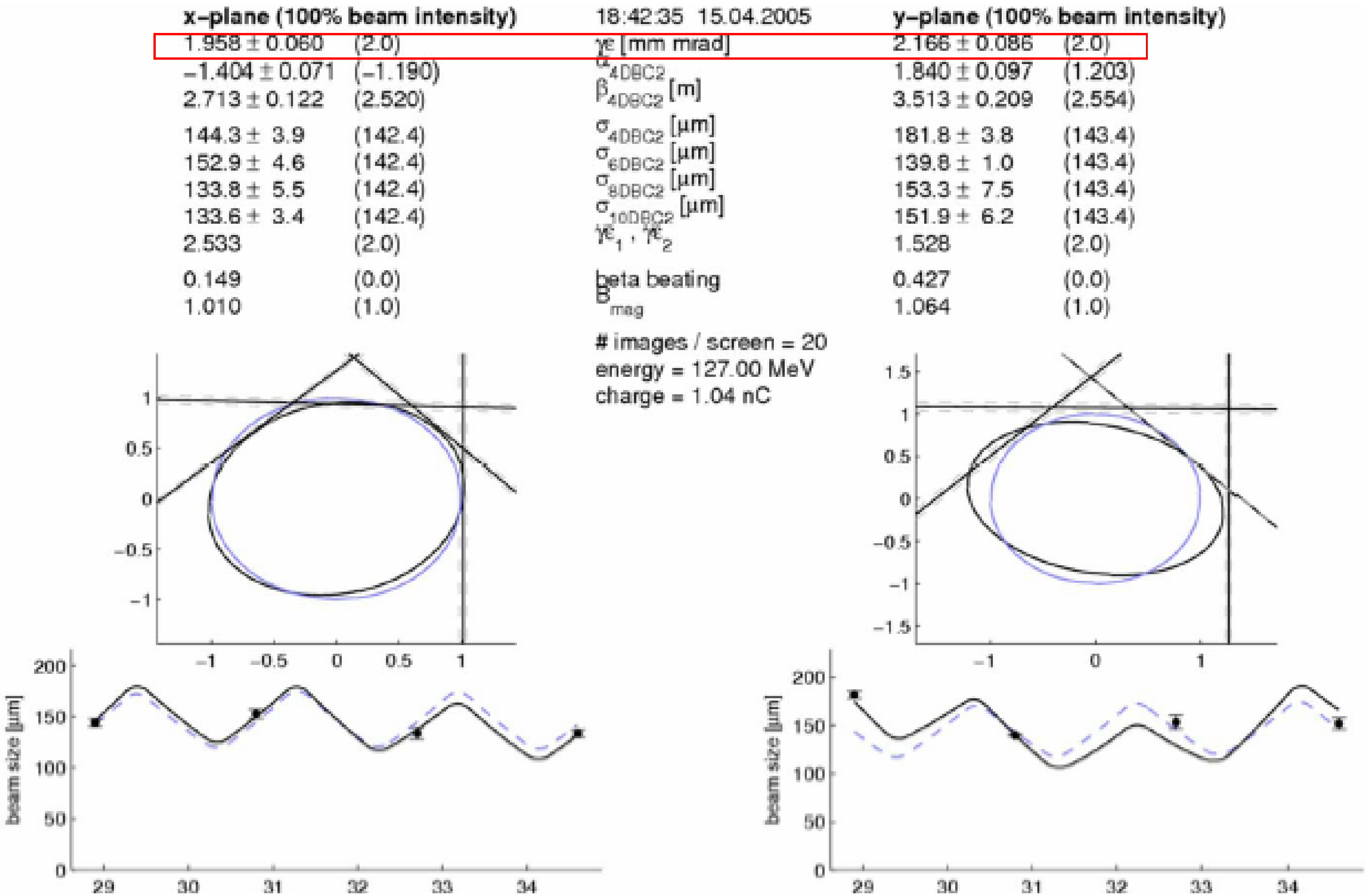
Energy Spread



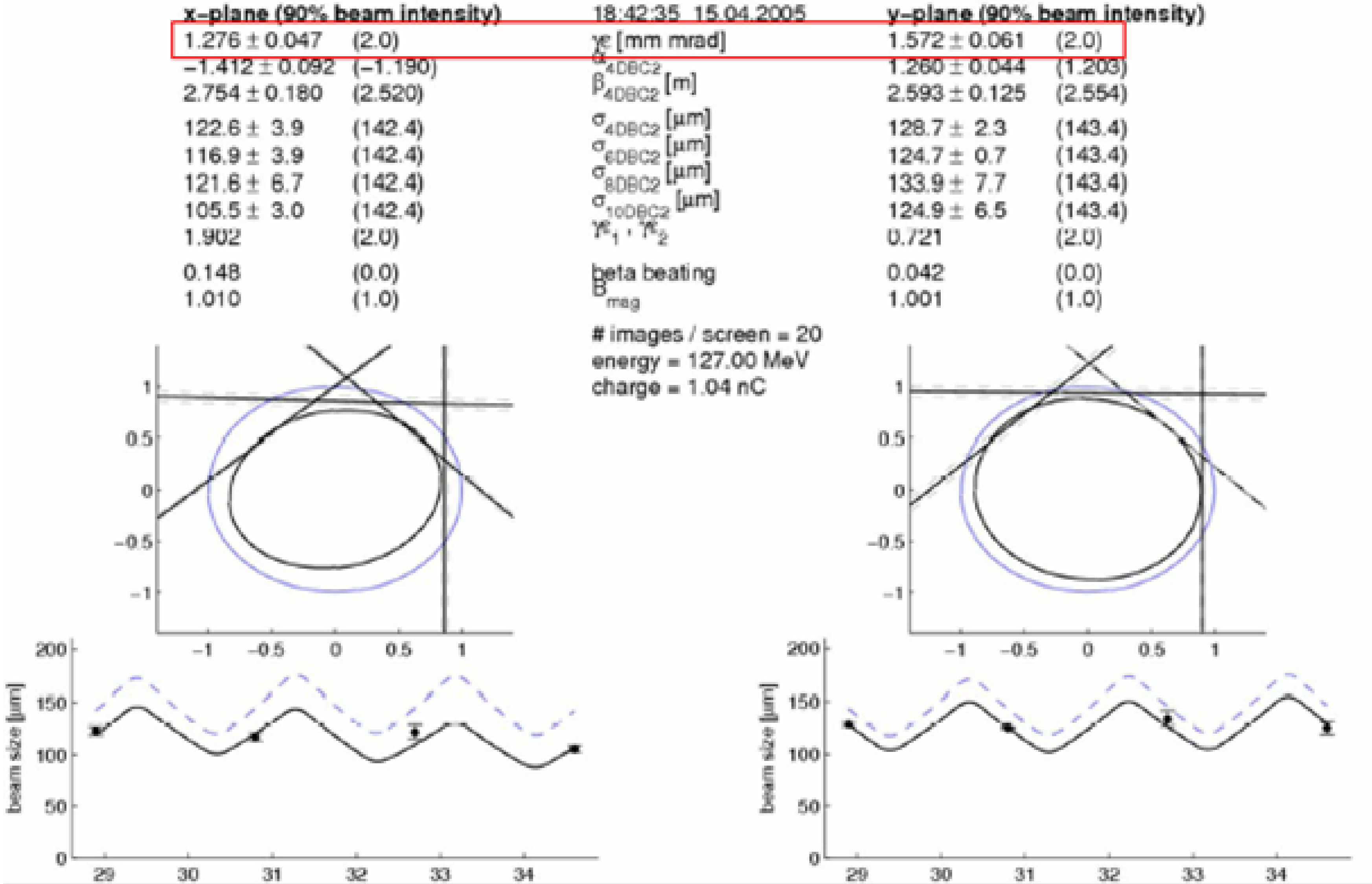


- Energy measured using the OTR screen in the dispersive section of the first bunch compressor
- Energy jitter w/o drift dE/E = $2.6 \cdot 10^{-4}$ at 127 MeV
- Including the drift yields $7 \cdot 10^{-4}$
- Uncorrelated energy spread < 25 keV (resolution limited)

Emittance for 1nC (100 %): 2 mm mrad

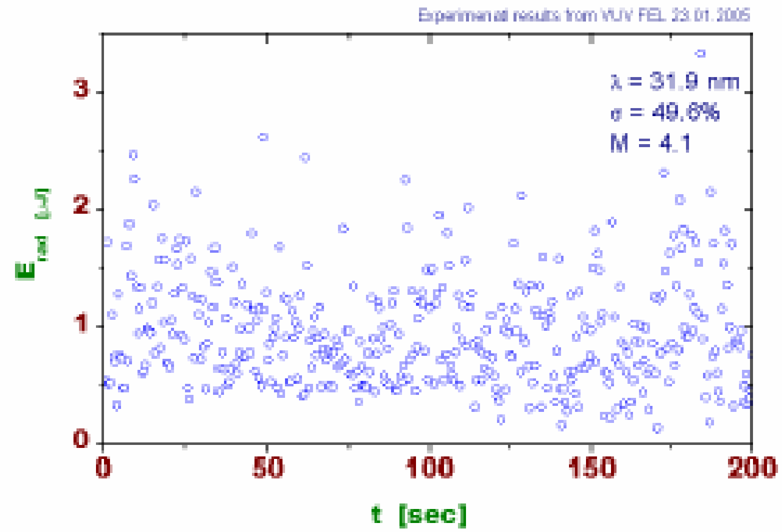


Emittance for 1nC (90 %): 1.4 mm mrad



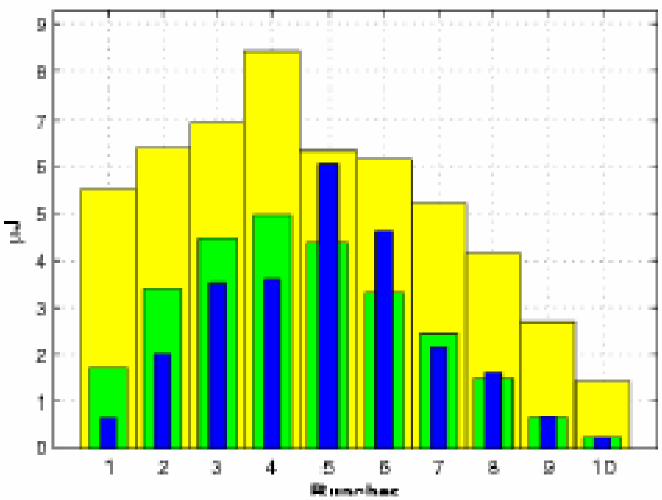
FEL Radiation: Results of January, 2005

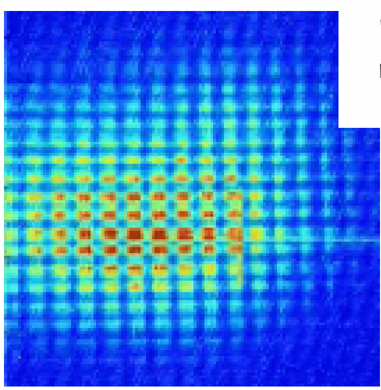
Wavelength	31.9 nm
Average energy per pulse	5 µJ
Maximum energy per pulse	10 µJ
Peak power	0.5 GW
Radiation pulse duration	20 fs
Spectrum width (FWHM)	0.7-1%
Angular divergence (FWHM)	150 µrad



Multibunch SASE signal (uJ) recorded with MCP Detector

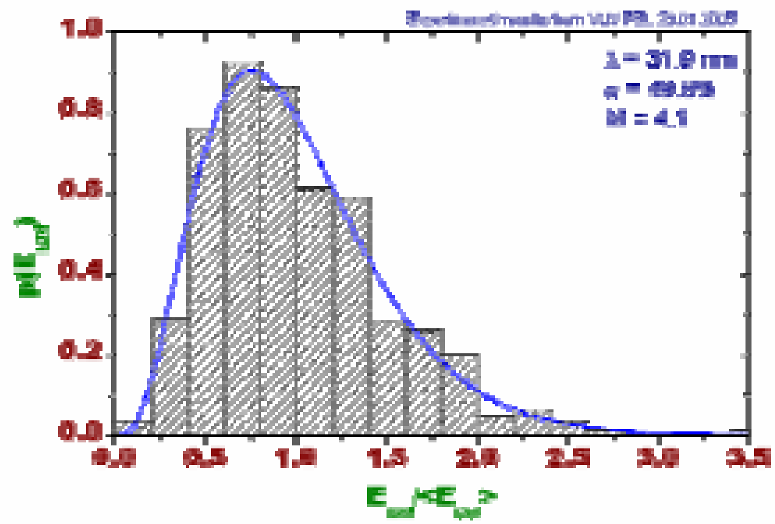
max
average
single

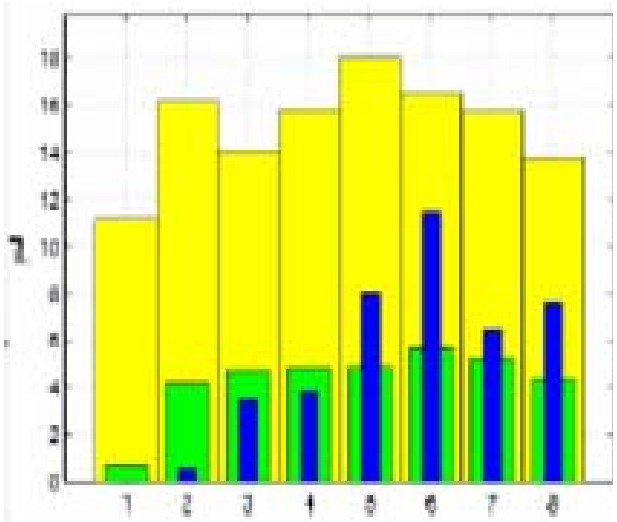




3 mm spot size (FWHM) @ 20 m

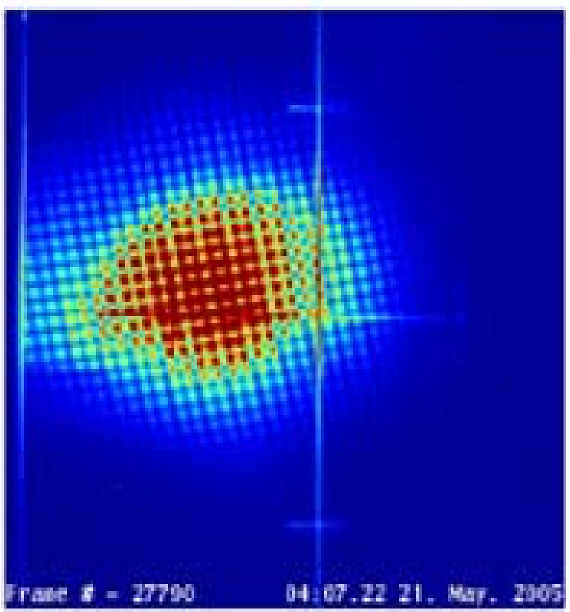
A gold mesh (0.25 mm pitch) in front of the screen is used as intensity monitor.

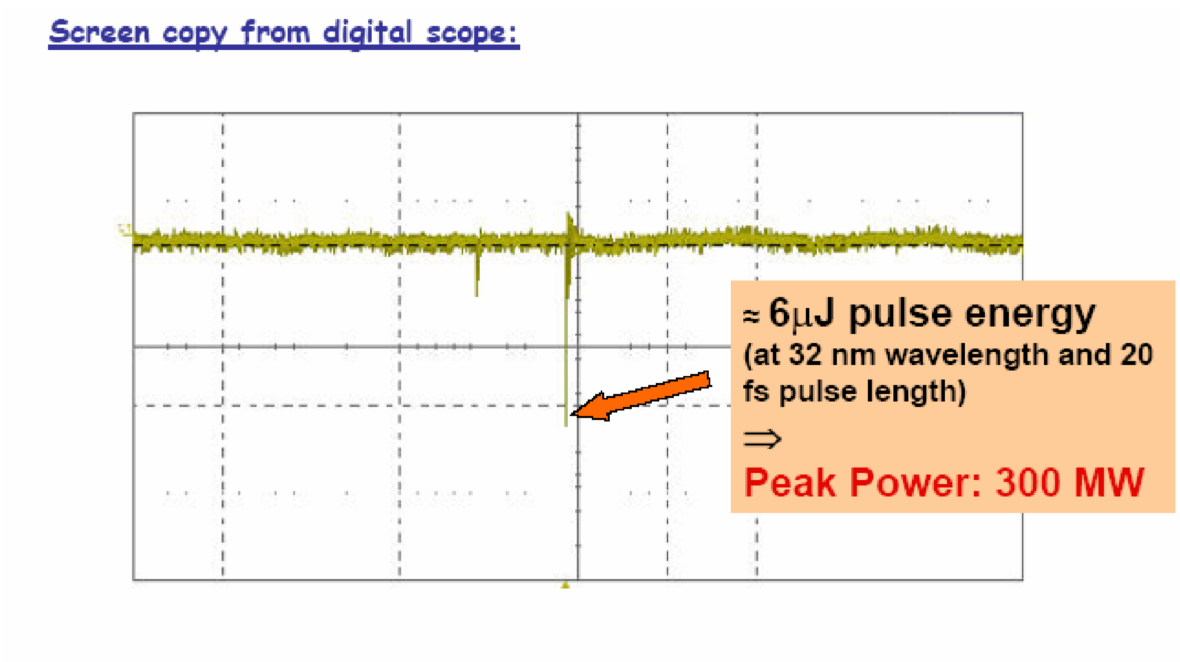




FEL Radiation: Results of May, 2005

- Intensity measurements from gas ionisation monitor





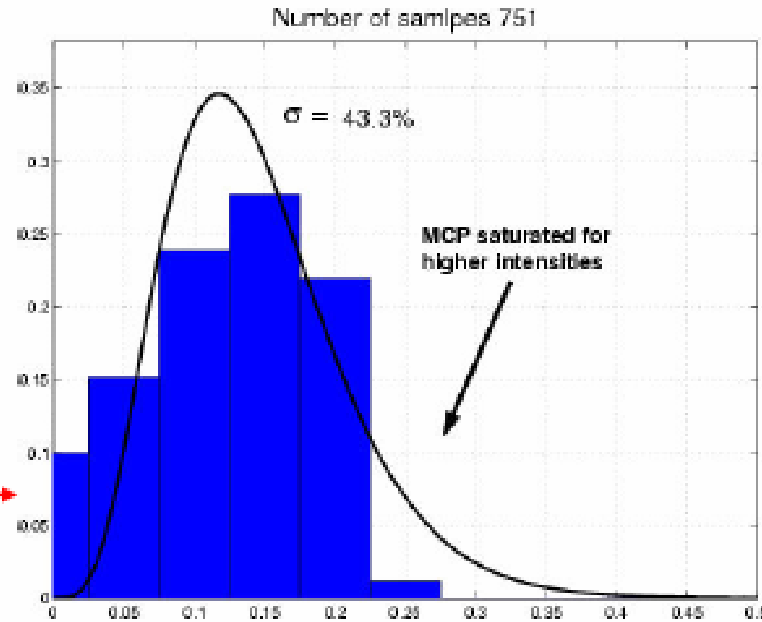
Shift Summary of May 2005

shift summary week 20 16-May-2005 to 22-May-2005

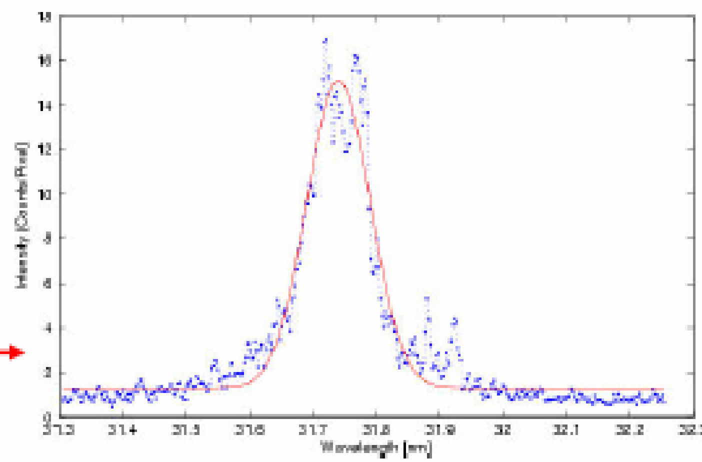
level first half of the week: 3 μJ max, 0.5 μJ av

level end of week: 15 to 20 μJ max, 5 μJ av.

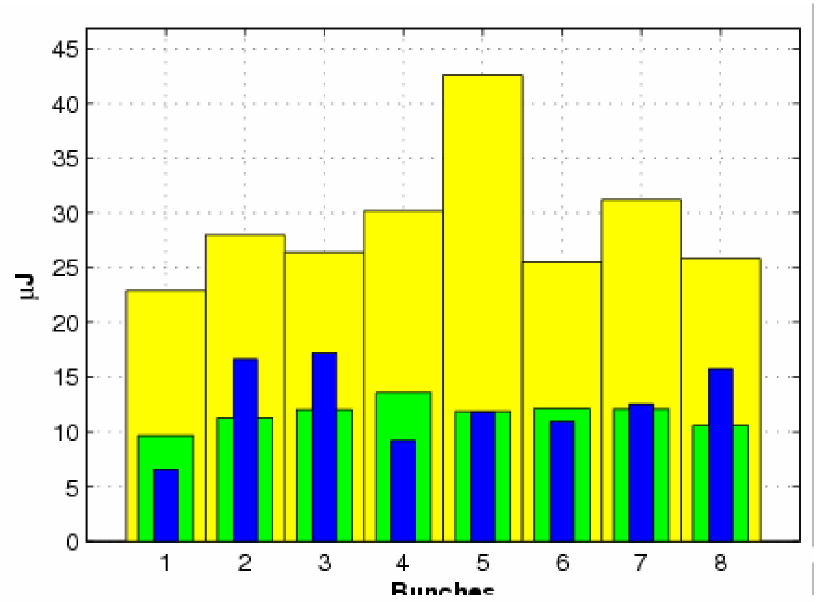
- *tuning SASE on orbit mainly, scanning steerers in front of undulator*
- *Up to Thursday: 3 to 4 μJ max, <0.5 μJ average. After extensive scanning of the orbit high SASE signal, which presumably saturated the MCP 8 to 9 μJ peak, 3 to 5 μJ average, stable over several shifts*
- *Gas detector commissoned: first hint of a much higher SASE energy of 20 μJ*
- *Confirmation of SASE pulse energy by an independent method: MCP1 saturates, MCP3 and MCP4 have been calibrated against MCP1 with spontaneous radiation. After this, MCP1/MCP3/MCP4 show similar SASE around 8 μJ max, 2-3 μJ av.,*
- *Up to 20 μJ peak and 5 μJ average on MCP recorded*

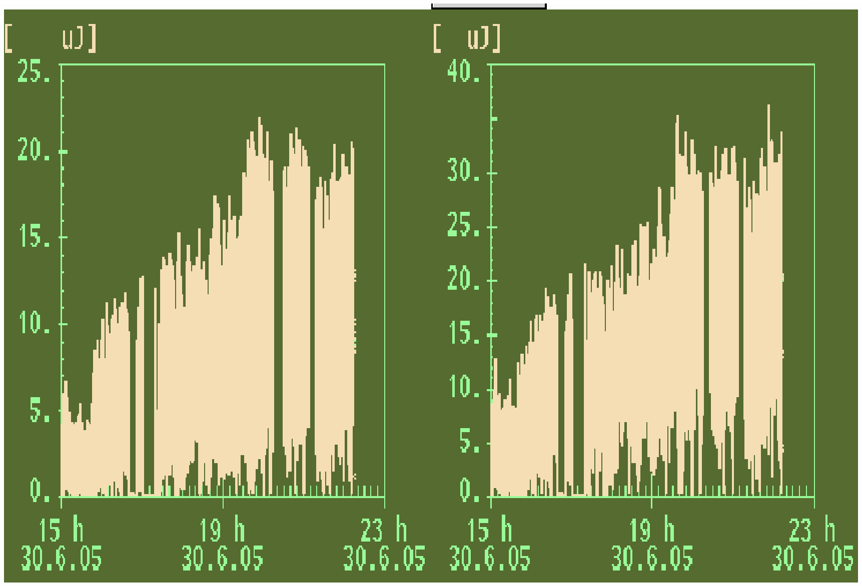


This SASE spectrum is about 10 times more intense than before and exhibits only a width of 0.05nm



TTF in the last user week: 30.06.2005

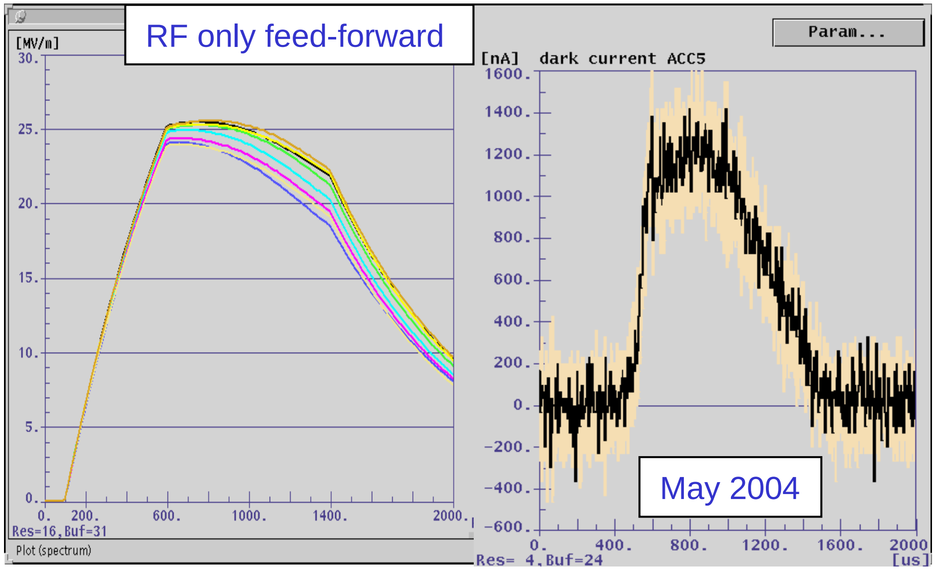


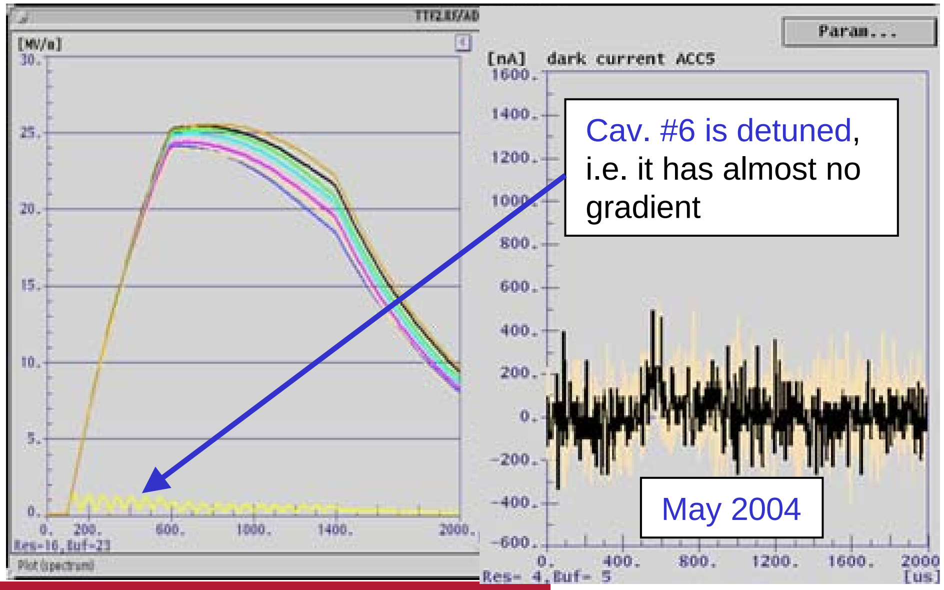


- Further improvement of SASE pulse energy:
  - Up to : 42 µJ
- Now:
  - Module ACC5 performance measurements
  - Then go back to user operation

Dark Current (d.c.) Measurements

- The on-axis d.c. was measured for ACC4 / ACC5.
  - setup incompatible with accelerator operations
- Only one cavity in module ACC5 produced a mentionable dark current.
  - Captured dark current measured only at exit ACC5
  - No d.c. observable from this cavity at entrance ACC4
- The ***d.c. decreased as a function of time***
  - after module commissioning in August 2003
    - 100 nA at 16 MV/m
    - increasing by a factor 10 for each 4.4 MV/m gradient step
    - i.e. approx. 10 µA at 25 MV/m
  - May 2004
    - 100 nA at 20 MV/m
    - increasing by a factor 10 for each 3.7 MV/m gradient step,
    - i.e. 1.2 µA at 25 MV/m
    - Detuning of cavity no. 6 left over an integrated dark current of the order of 20 to 25 nA at 25 MV/m average gradient
  - September 2004 (extended operation at 20-25 MV/m)
    - 250 nA at 25 MV/m
  - July 2005
    - No d.c. measurement, but cavity improved further
- ***Reminder:***
  - 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).





Performance of Accelerator Module 5

A State-of-the-art module

• cryogenic type III

• latest coupler generation

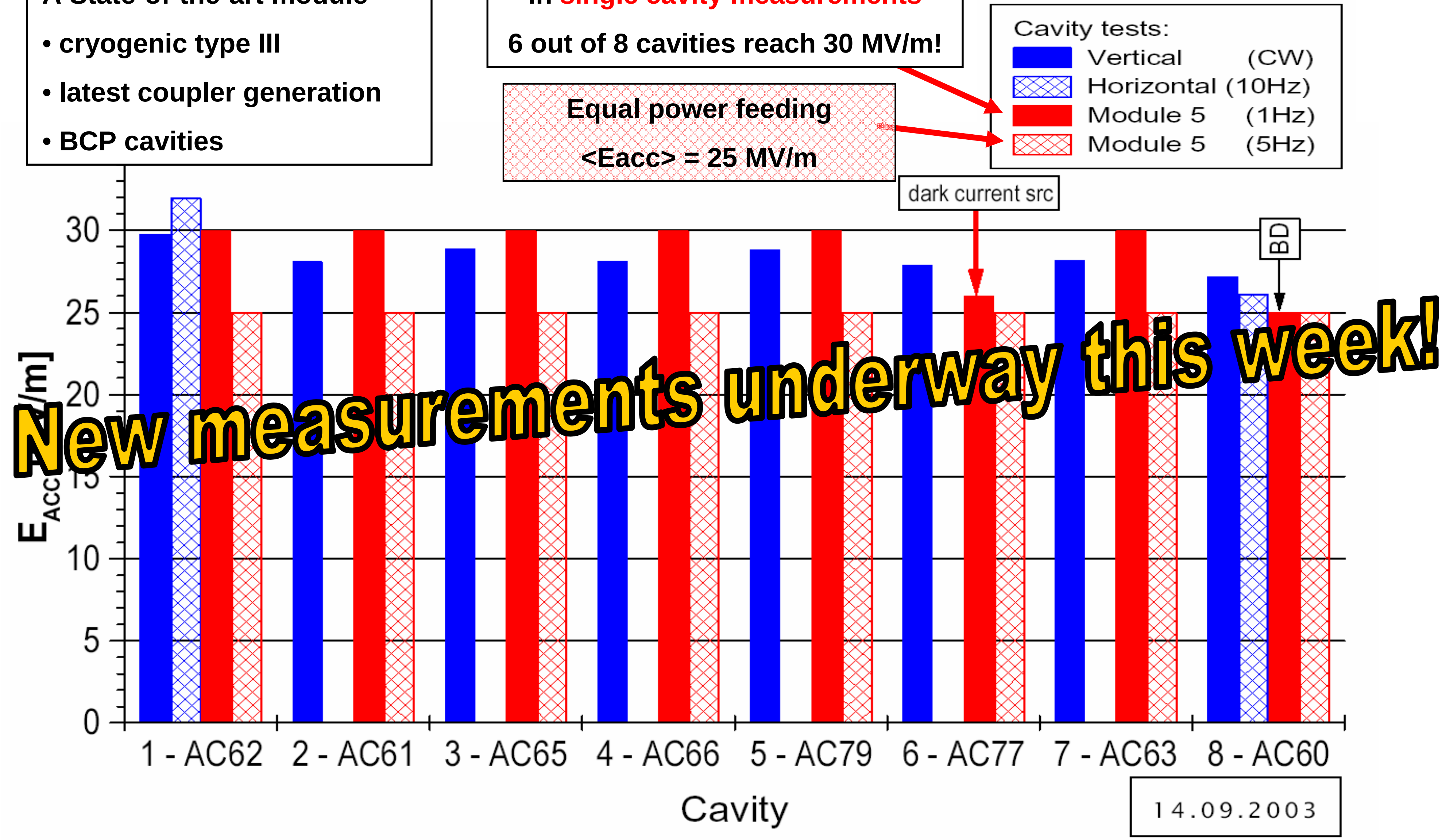
• BCP cavities

In single cavity measurements

6 out of 8 cavities reach 30 MV/m!

Equal power feeding

<Eacc> = 25 MV/m



Experience with Accelerator Modules

- 10 modules have been built
- Experience with several thermal cycles as well as long time operation were studied
- Latest cryostat design (Type III) has shown good performance for etched cavities
  - the assembly problems occurred are understood
    - i.e. no problems with power coupler alignment
  - Dark current measurements show acceptable performance
    - Dark current has been reduced with operational time
      - Not fully understood
    - Further detailed tests cavity / module performance (valuable for ILC and XFEL) in summer this year -> Now!
- Detailed assembly procedures available
  - Study on assembly together with industry ongoing
- Minor modifications will be introduced for the XFEL (120 modules)

Cleanroom String Assembly

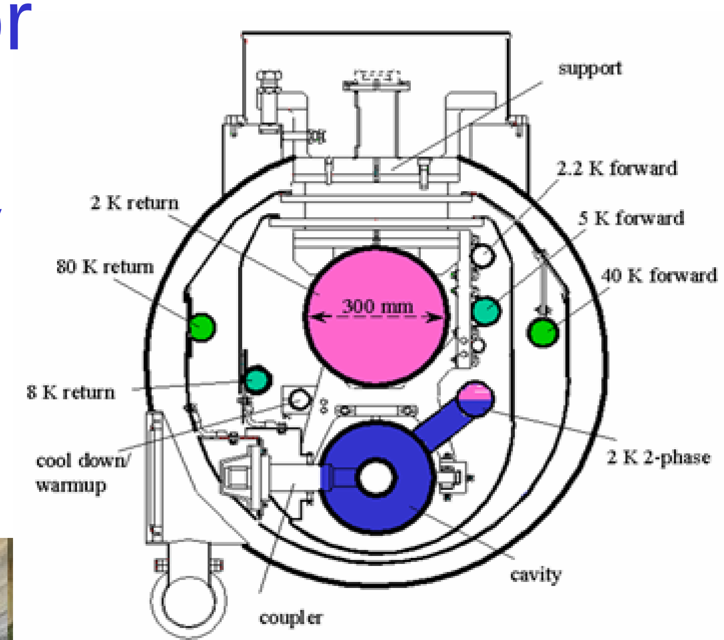
See Posters: ThP05, ThP08, ThP13, ThP14:
N. Steinhau-Kühl, A. Matheisen et al.

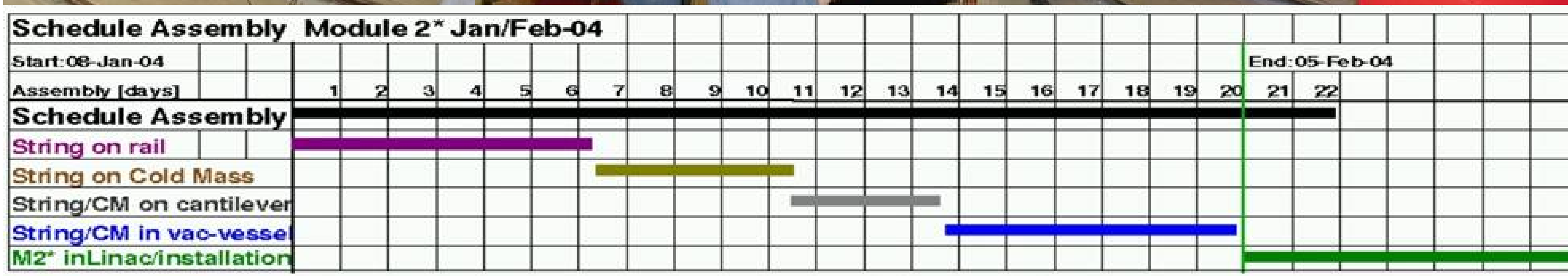
The assembly of an 8 cavity string has been continuously improved

- quality control measures introduced (e.g. particle counts, monitoring of water quality)
- documentation with a cavity test database and an Engineering Data Management System
- was the basis for two industrial studies (for TESLA)
- Ongoing now: Introduction of Electropolishing as a standard process (industrial study in preparation)

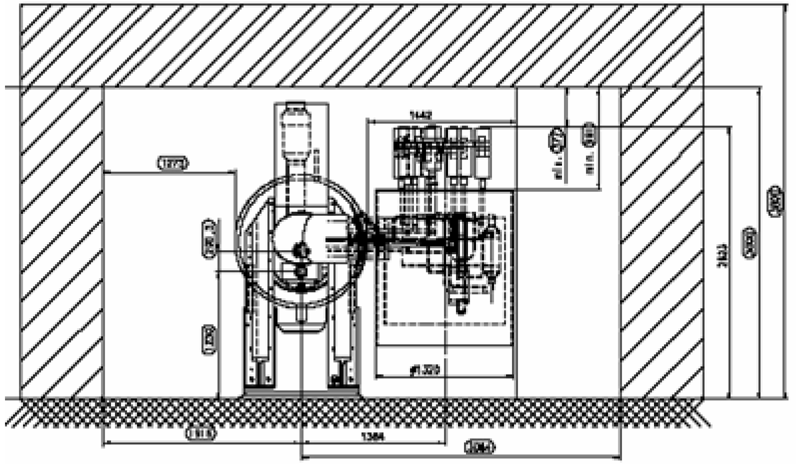
The inter-cavity connection is done in class 10 cleanrooms

Accelerator Module Assembly

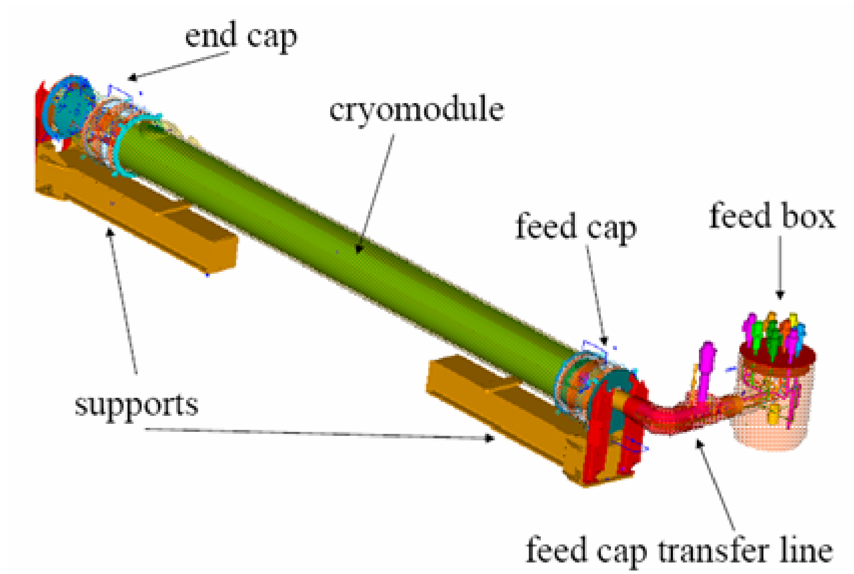


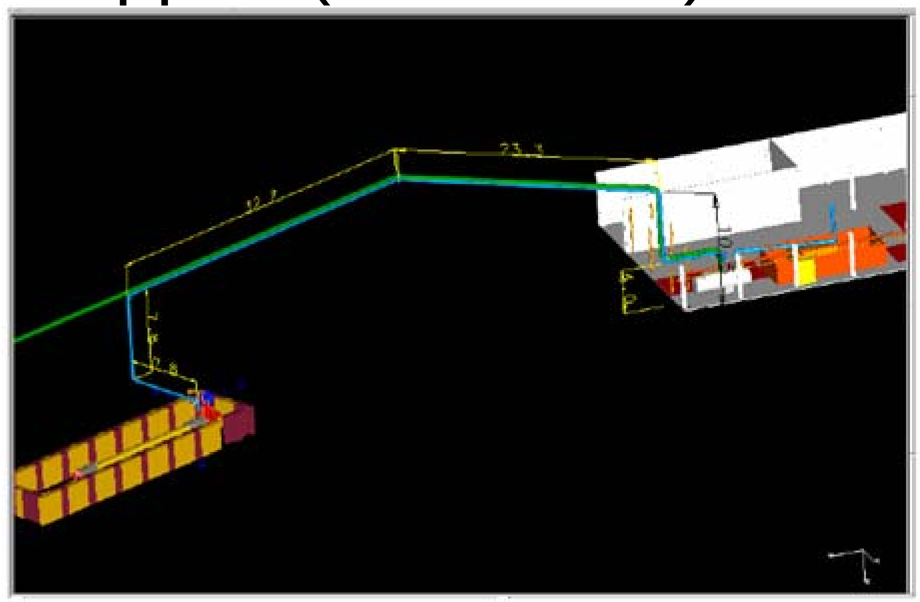


Module Test Stand



- Allows cryogenic tests and RF measurements independent from the LINAC
  - No beam tests
  - Dark current measurements will be integrated
- EU support (EUROFEL)





R&D on Cavity Preparation

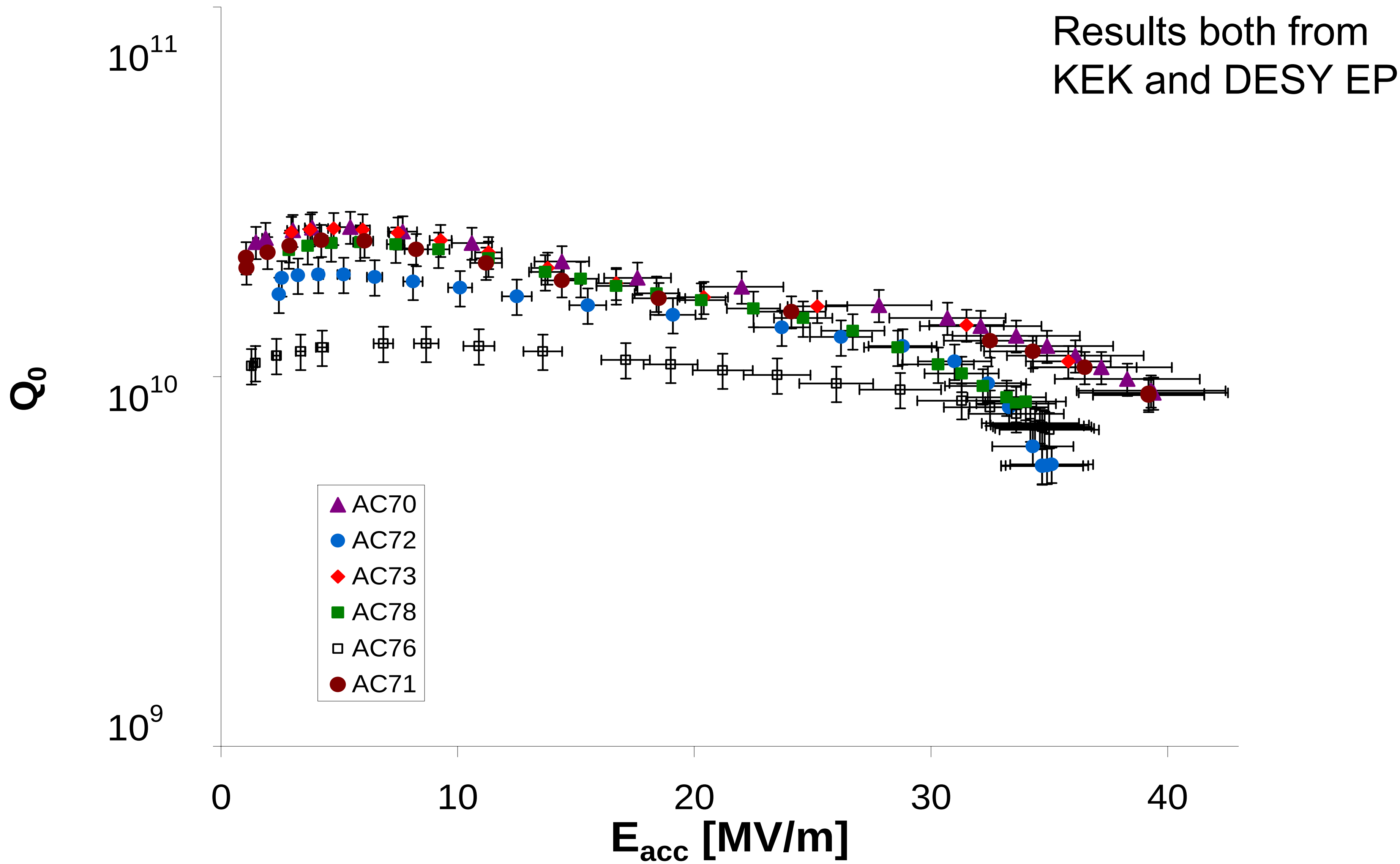
- Electropolishing is the most promising surface preparation technique for superconducting cavities
  - Is baseline also for the XFEL
    - Try to avoid 1400°C furnace treatment for postpurification
  - DESY EP setup accumulated a lot of operational experience
    - Important for a new industrial study on cavity preparation
      - For TESLA cost etimates have been based on etching (+1400°C furnace) treatment
    - Recently problems with field emission
      - Investigations are ongoing to improve quality control
- Part of this work is supported by the EU (CARE Programme)

See Posters: ThP05, ThP08, ThP13, ThP14:
N. Steinhau-Kühl, A. Matheisen et al.

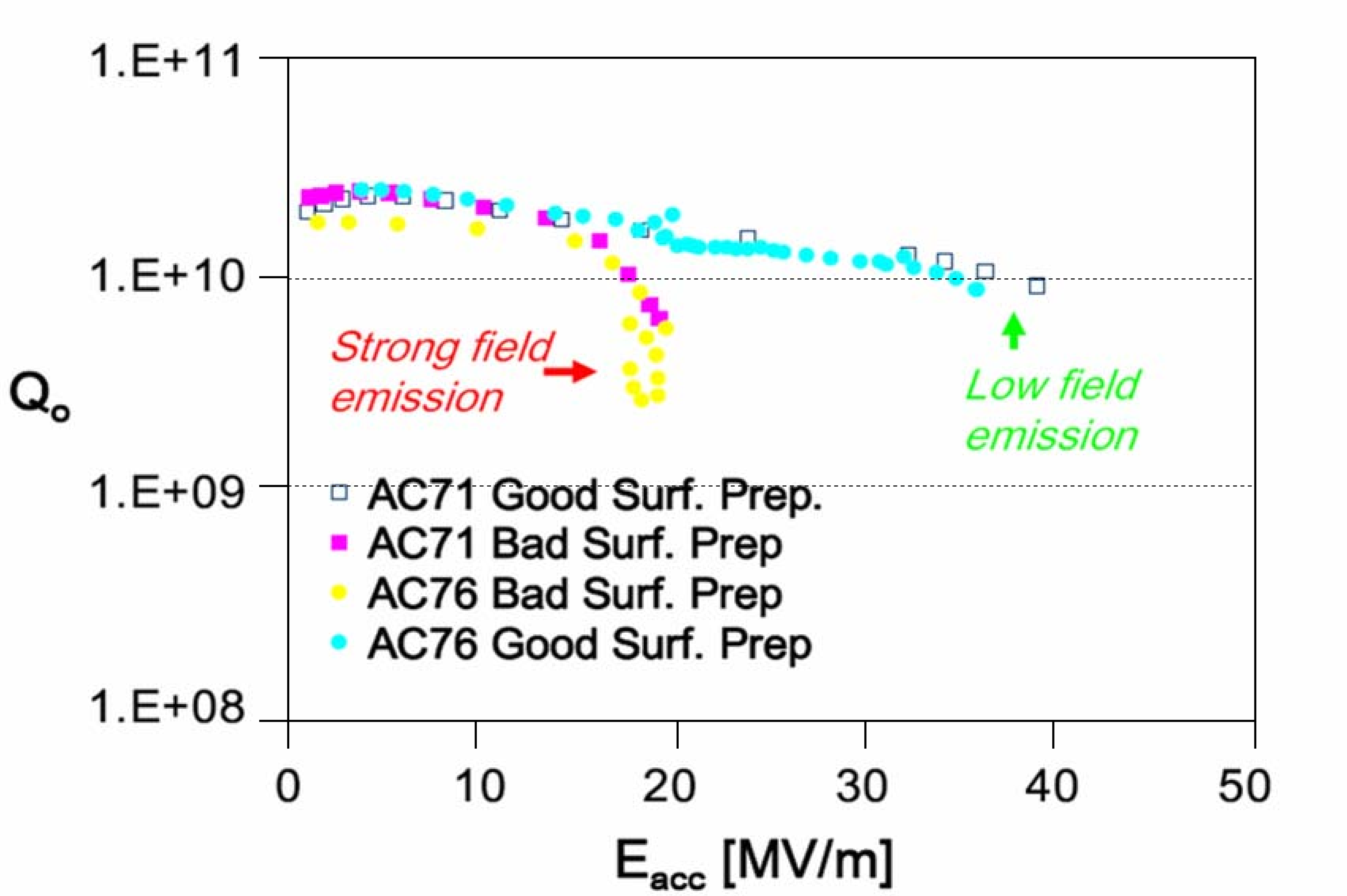
Electropolishing setup at DESY

- First 9-cell cavities were successfully treated.
- Facility runs continuously
- Next steps: improved quality control to achieve more reproducible performance

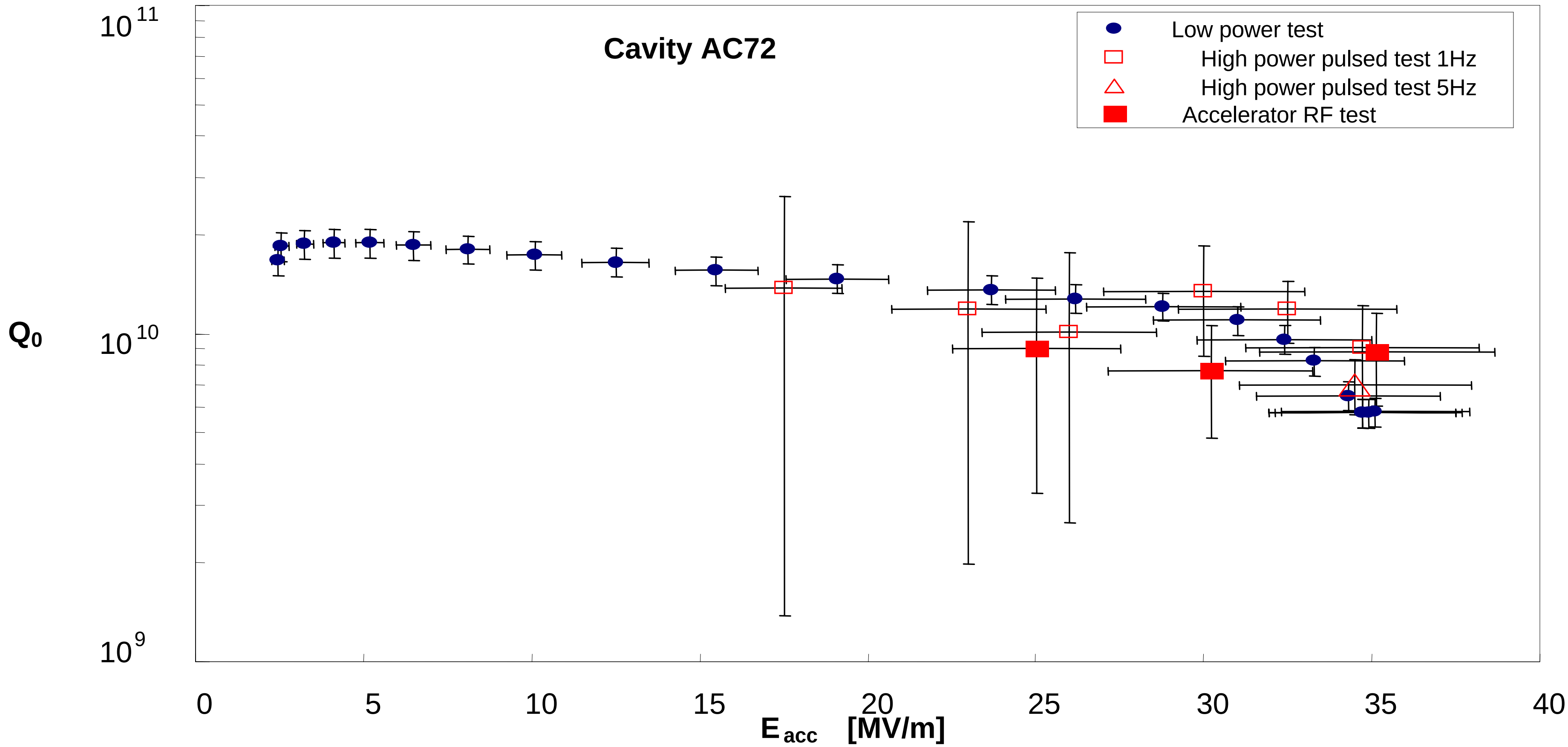
Electropolishing: Test Results



Problems: Reproducibility in the EP Process



Cavity Test Inside a Module (ctd.)

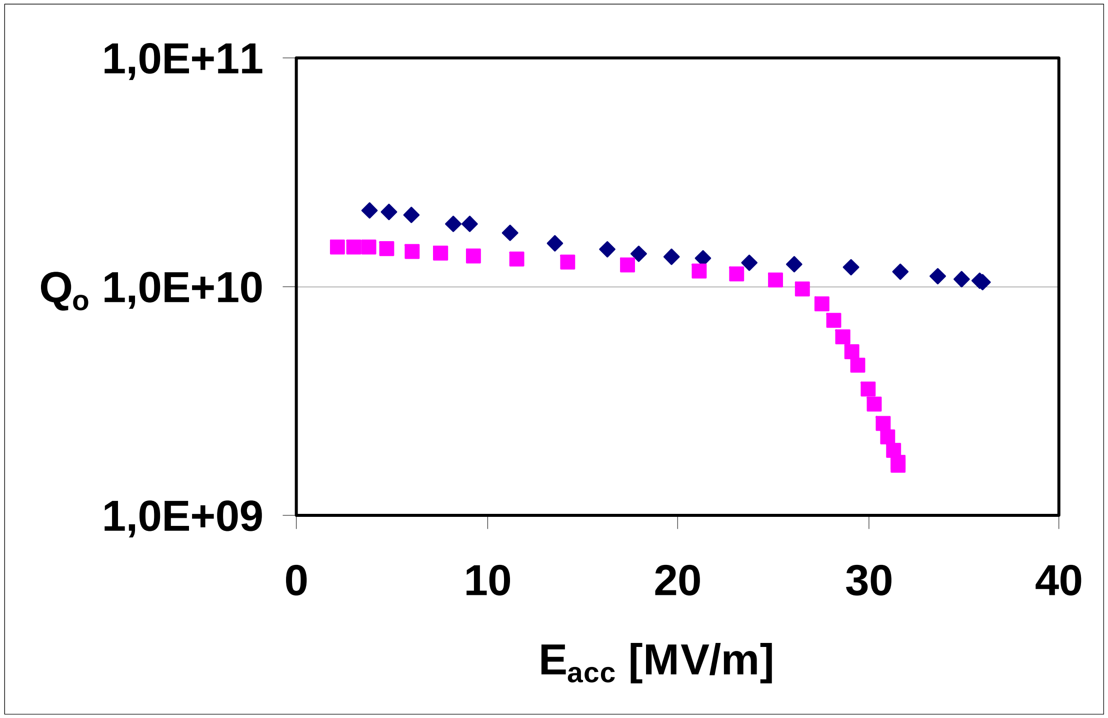


- One of the electropolished cavities (AC72) was installed into an accelerating module for the VUV-FEL
- Very low cryogenic losses as in high power tests
- Standard X-ray radiation measurement indicates no radiation up to 35 MV/m

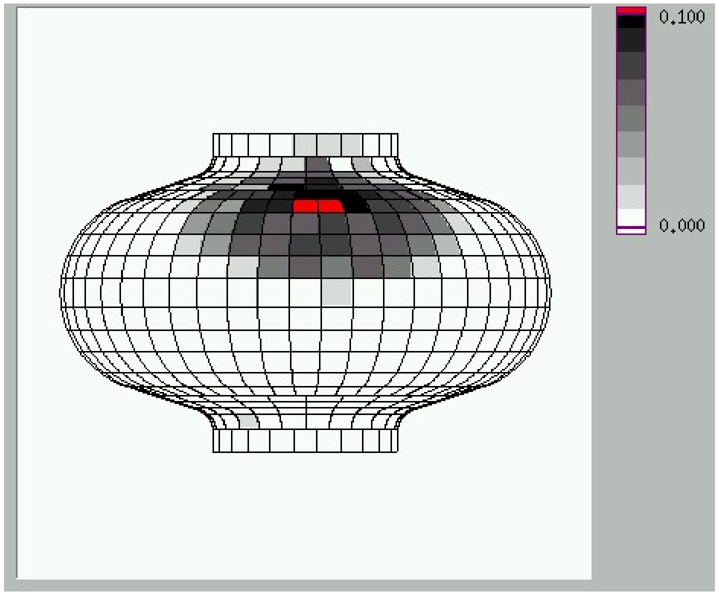
Single Cell Cavity Program for the XFEL

- Main objectives
  - Qualifying of new Nb suppliers
    - Cabot (USA)
    - GIREDMET (Russia)
    - Plansee (Austria)
    - Ningxia Orient Tantalum Industry Co. (China)
  - Rework the specification for fabrication of 9- cell cavity
    - Check the eight hours rule etc.
  - Rework the Nb specification:
    - Nb with high thermal conductivity (RRR 700-900)
    - Check the Ta content
  - Cavity from ingot with very large grain
- First step: qualification of the DESY EB welding device

See Posters: ThP27: *J. Iversen et al.*

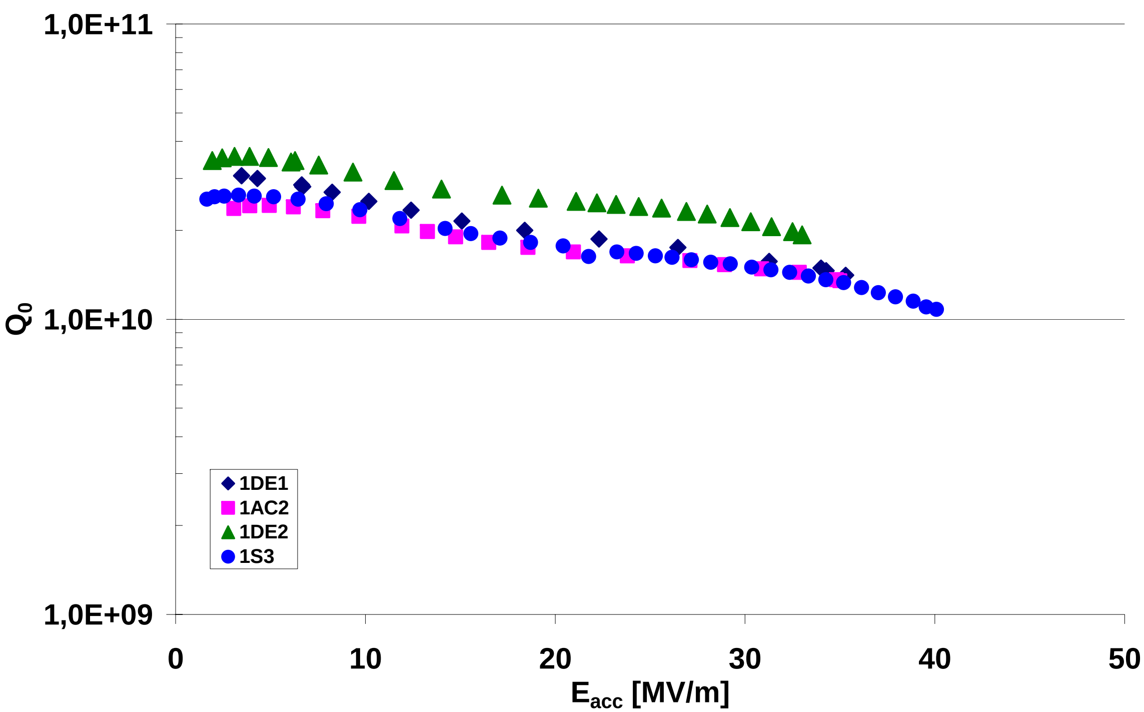


First Single-cell welded at DESY



- Detailed preparation
  - Cavity made of niobium sheets (production 1999)
  - Deep drawing of cups at a company
  - Complete machining, electron beam welding at DESY
  - 150µm EP@Henkel,
  - 800 °C
  - 130µm EP@Henkel,
  - HPR + bake
  - add. HPR (after bake necessary due to field emission)

Electropolishing at Henkel



- Electropolishing at Henkel can produce very high gradient (up to 40 MV/m), high Q0 cavities
- Improved quality control measures at DESY and Henkel
  - Electrolyte-Management
  - Improved parameter-control
- Further cavities will be treated
- 1.3 GHz three-cell cavities can also be treated

See Posters: ThP06: *C. Hartmann et al.*

TTF Program 2005

- TTF accelerator studies
  - 12 weeks accelerator studies
    - E.g. Module measurements in Summer 2005
    - LLRF operation close to cavity limits
  - 13 weeks FEL studies (most of that underway)
  - 19 weeks user operation
  - Maintenance (1day/week + additional weeks for large components e.g. modulators, klystrons)
- Build up module test stand (end 2005)
- Future
  - Installations in Summer 2006 towards 1GeV energy
    - M6 (aimed at 35 MV/m)
    - M5 repair
    - M3* exchange
    - Third harmonic 3.9 GHz RF system
- Cavity R&D

Summary

- TTF offers
  - an opportunity to learn about the superconducting RF technology from a single cavity to a full accelerator module
  - an accelerator environment for extensive testing and development towards reliable operation of a superconducting electron linear accelerator
- This is of importance for the future linear accelerator projects like the XFEL and the ILC

Backup

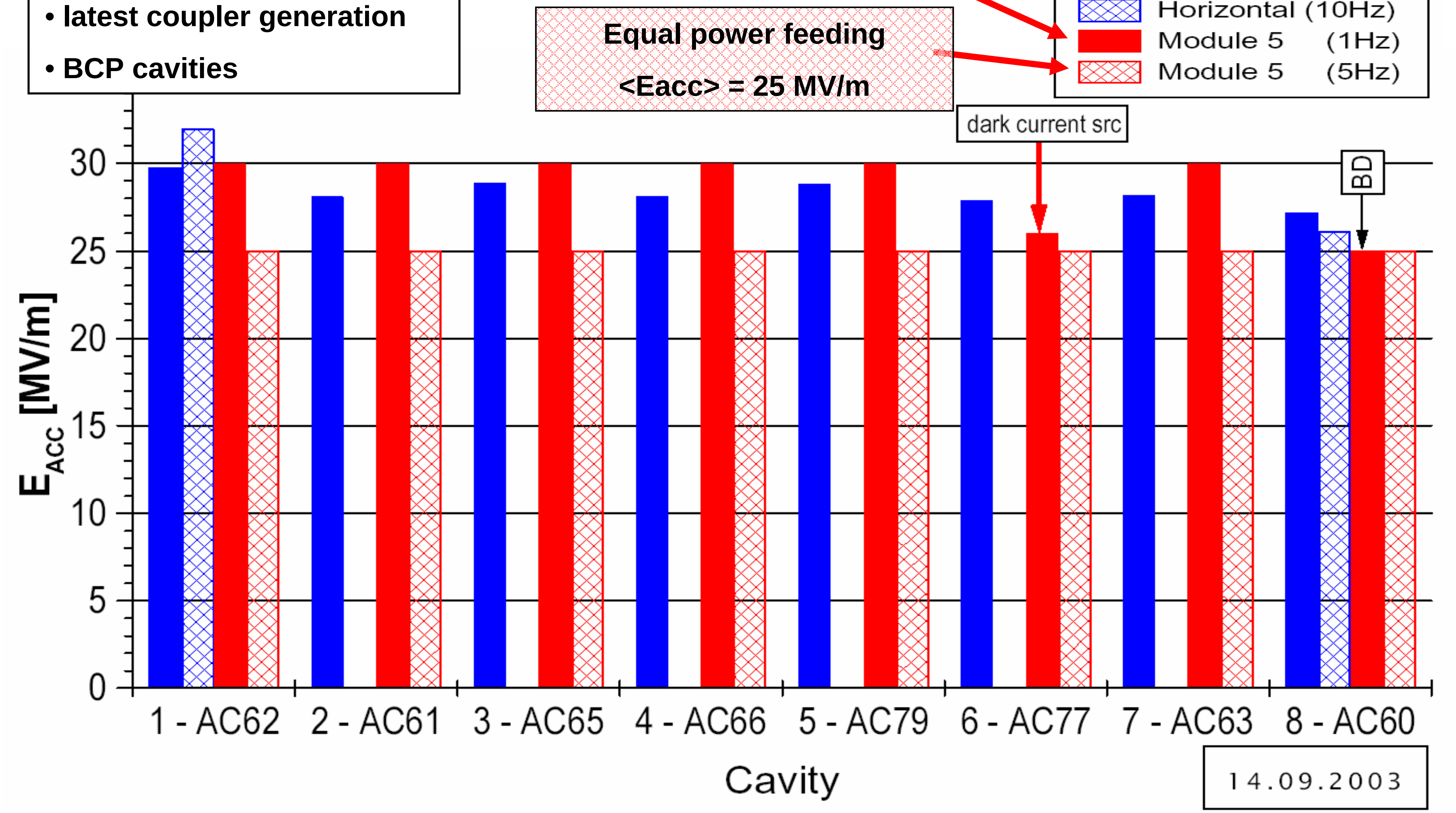
Performance of Accelerator Module 5

A State-of-the-art module

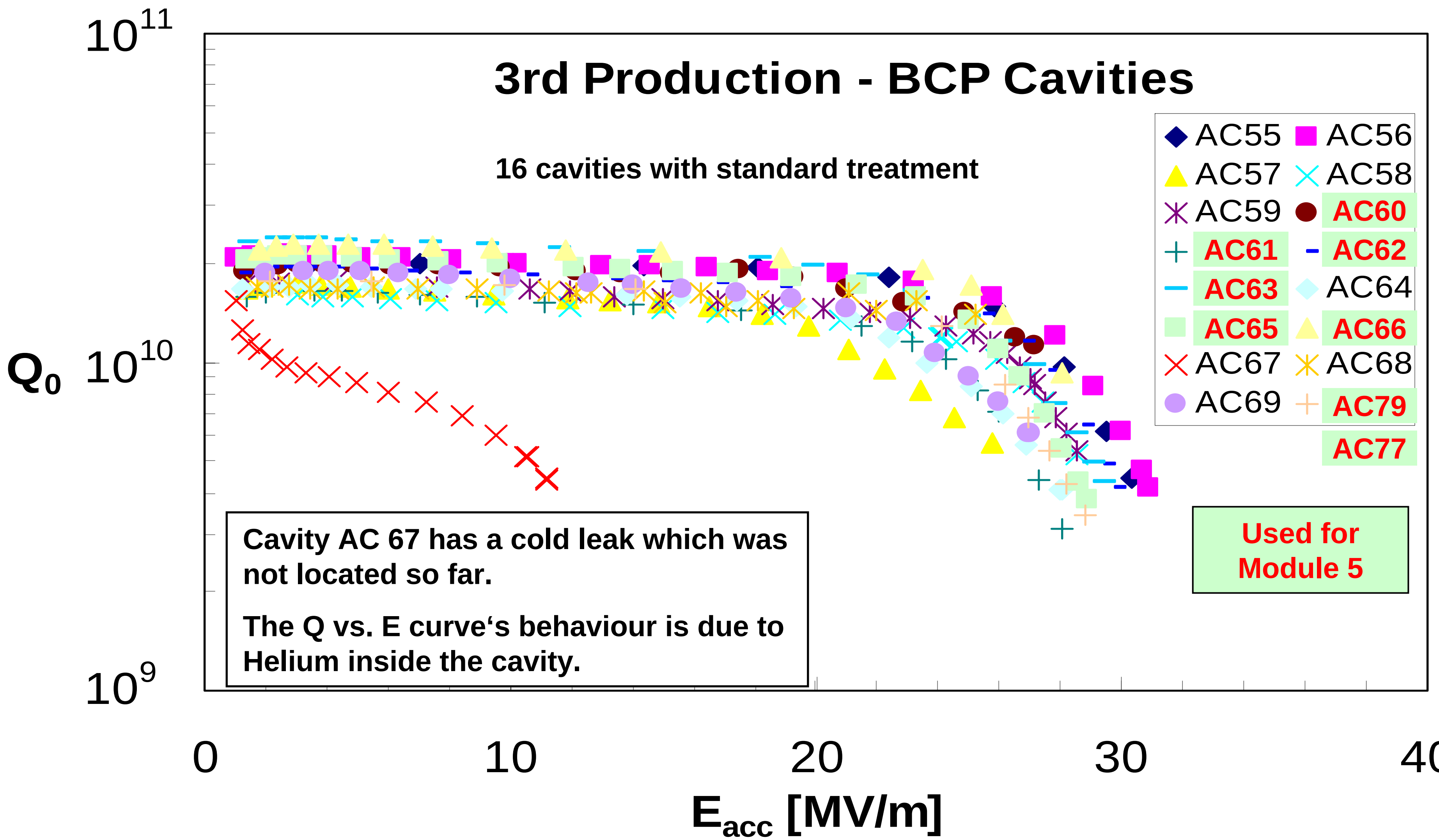
- cryogenic type III
- latest coupler generation
- BCP cavities

In single cavity measurements

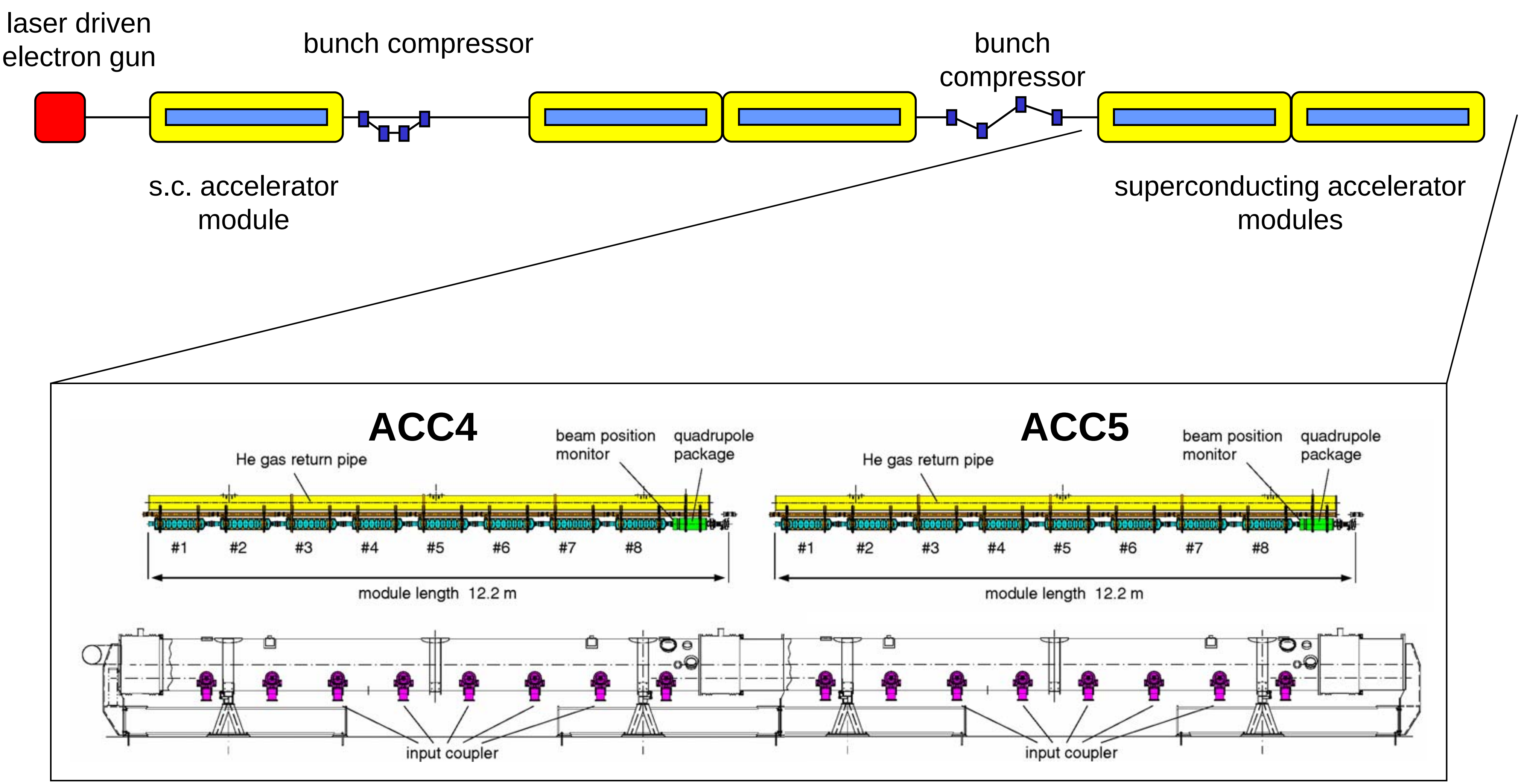
6 out of 8 cavities reach 30 MV/m!



High Gradient Performance (Etched Cavities)



The TTF Linac Installation



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- The ***d.c. decreased as a function of time***
  - after module commissioning in August 2003
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- ***Reminder:***
  - The TESLA limit is defined by additional cryogenic losses:
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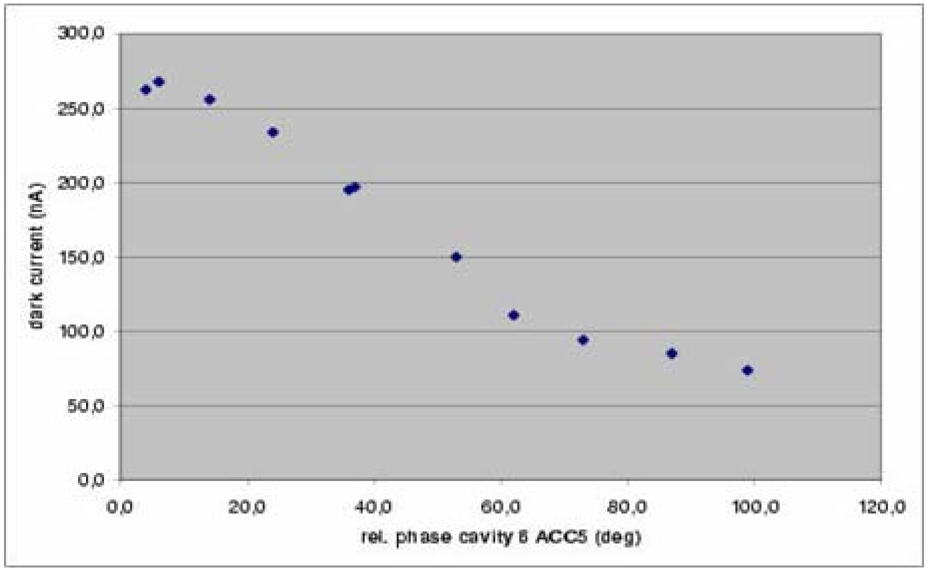
Dark Current vs. RF phase with respect to neighbouring cavities is just as expected

(max → min) over pi/2



ILC R&D - But also XFEL

a must:

- HPP of cavities to cure field emission

- long term operation of M5 at high gradients
  in steps from 20 MV/m to 25+MV/m:

    - what are the typical problems?

    - any change in dark current?

    - how close can we go to the gradient limit?

- processing behaviour after shut down

important:

- repeat test of all cavities
  detuning of individual cavities
  compare rf calibration with beam

- cryo losses vs. operation time

-check cavity alignment with beam

nice to have:

- Lorentz-force detuning of individual cavities at high gradient

- long beam pulse in ACC1/C5 at 35 MV/m

- optimized piezo compensation ACC1/C5

- RF-distribution optimized with respect to maximum gradient

in general

- many LLRF operational aspects as well as feedback issues

ILC R&D - But also XFEL

in general

- develop robust algorithm for Lorentz force compensation / piezo tuners at M6 and M1/C5.
- failure recogination and exception handling, esp.close to performance limit
- measurement and optimization of amplitude and phase stability (within bunch train, from train to train, long time)
- automated operation (FSM) of LLRF
- test next generation of LLRF (developed for XFEL: increased ampl. and phase stability)
- beam based feedback algorithms (energy, phase, bunch length)

More specific... (with beam)

- o measure field stability with beam
- o adaptive feedforward (RF only and for beam energy)
- o exception handling (quench, operation close to the limit)
- o calibration of gradien and phase
- o single bunch transient detection
- o phase drift betwenn RF and beam
- o beam phase with respect to RF phases
- o study EMI/EMC (down converter) / reduce noise
- o crosstalk between RF systems
- o test new FPGA based feedback at the RF Gun.
- o test new FPGA based Feedback at ACC1
- o develop new control algorithms
- o test LLRF FSM with beam

More specific... (without beam)

- o LO optimization for downconverter
- o check M.O. level and frequency distribution
- o measure phase stability of frequency distribution system
- o upgrade of downconverter
- o remote control of attenuators (probe, forward / reflected power cables)