

WISSENS WERTE.

Öffentlicher Abendvortrag

Beschleunigertechnologie,
die weltweit Maßstäbe setzt

Hans Weise
DESY, Hamburg



Foto: Manfred Schulze-Alex

WISSENS WERTE.

Öffentlicher Abendvortrag

was / wie / wofür
Entwicklungen bei DESY

FLASH
Free-electron laser FLASH



European
XFEL

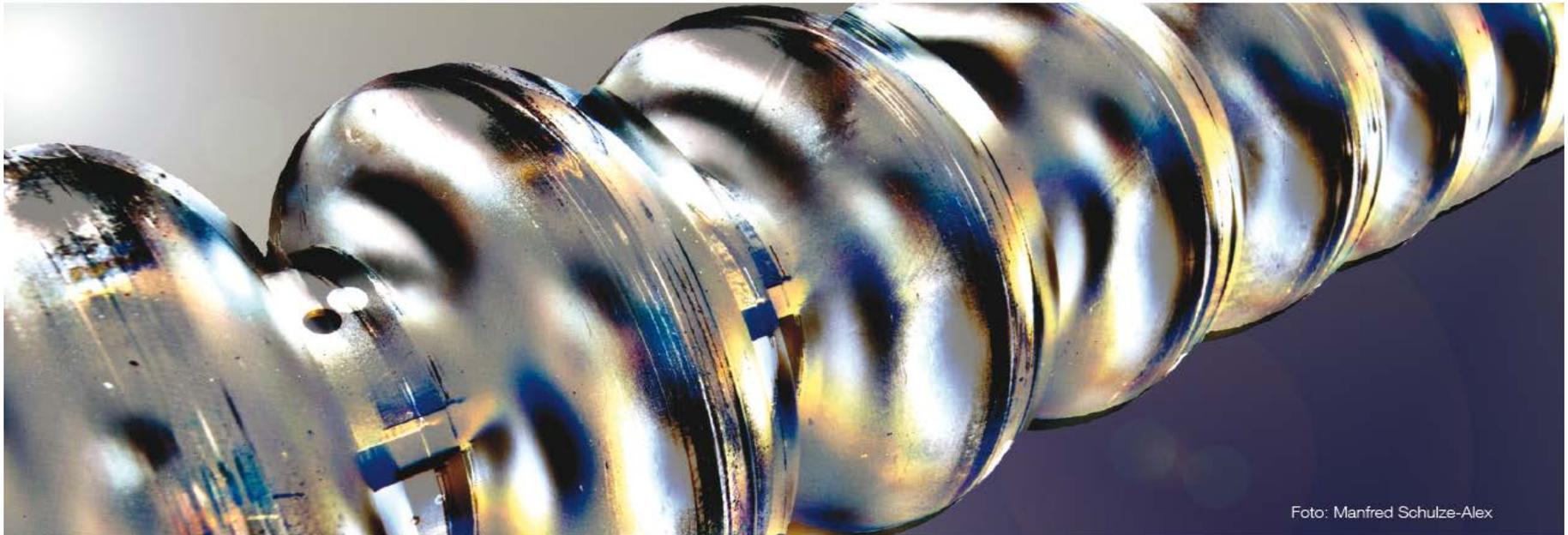


Foto: Manfred Schulze-Alex

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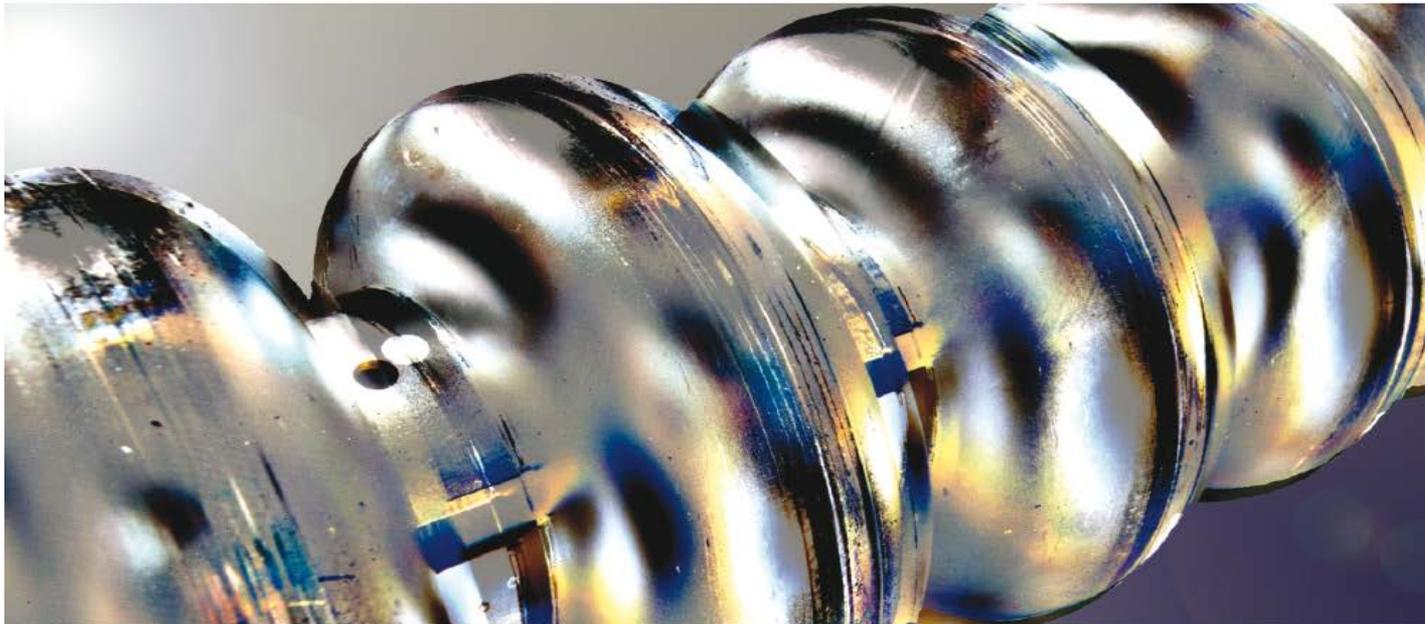
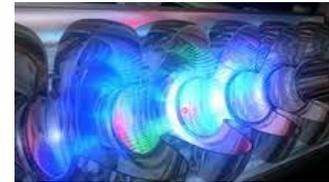
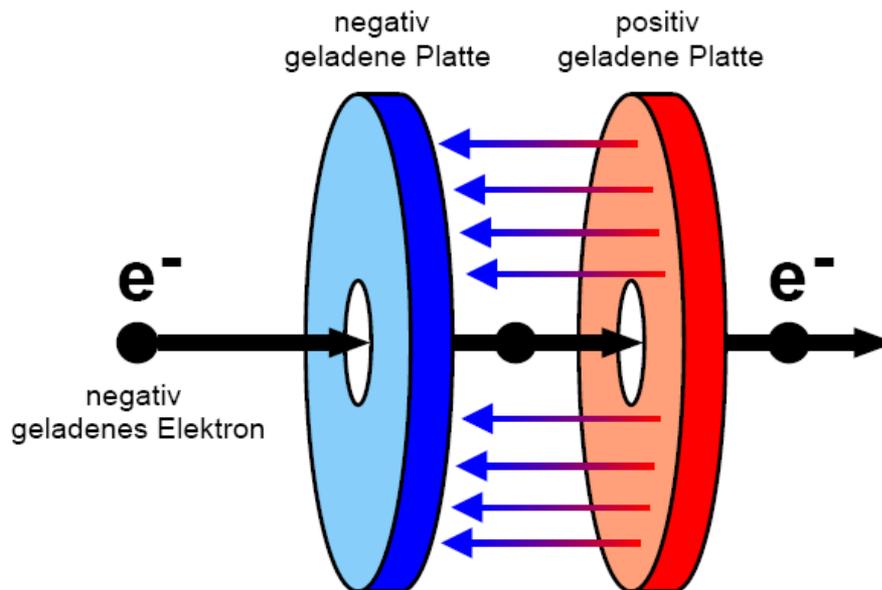


Foto: Dirk Nölle

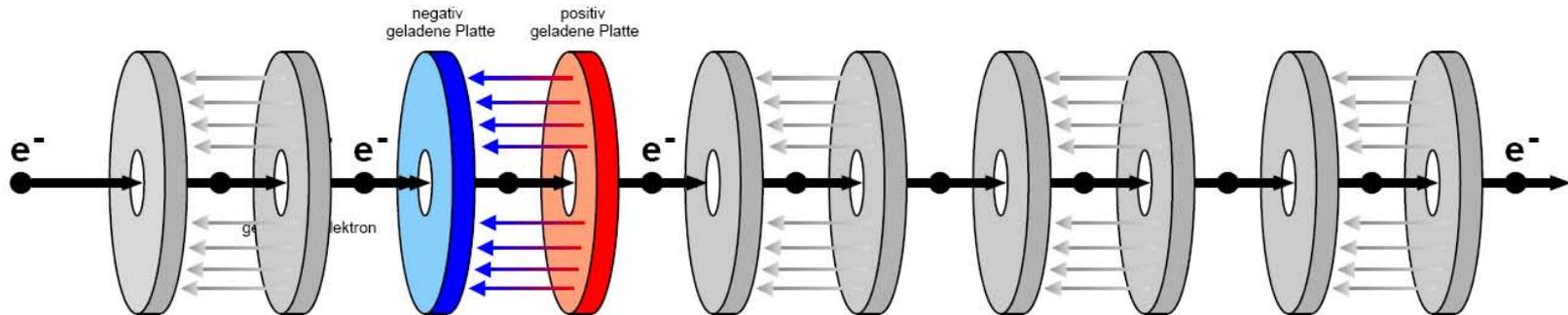
Beschleunigung im elektrischen Feld



Zwischen den beiden Platten liegt **eine Spannung von vielen hundert Volt**. Das **negativ geladene Elektron** wird durch das Loch in der linken Platte in die Anordnung eingeschossen, sieht dann ein elektrisches Feld und **wird zur positiv geladenen Platte hingezogen**.

Dabei wird es beschleunigt, d.h. es gewinnt Energie.

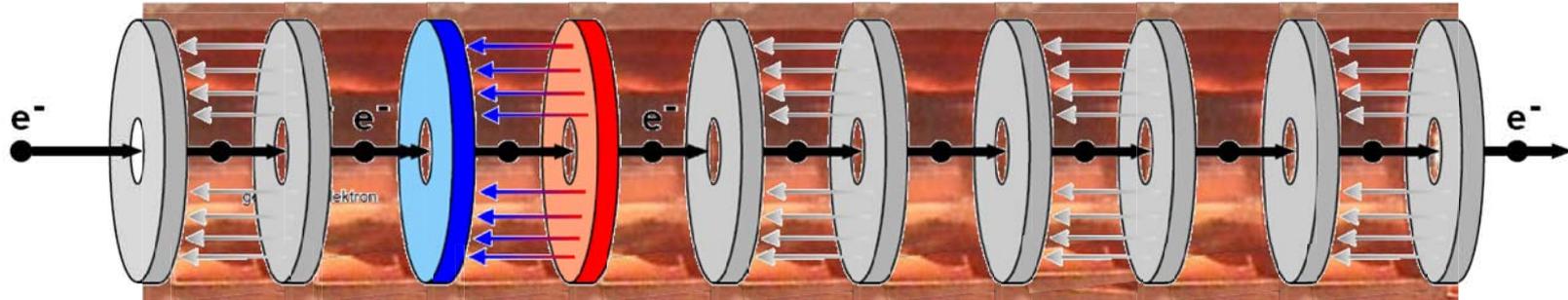
Beschleunigung über längere Strecken



Die Spannung ist durch Überschläge begrenzt. Der Ausweg: man verwendet ein **hochfrequentes Wechselfeld**. Dies entspricht im Prinzip der hier gezeigten Situation: dabei wird das beschleunigende elektrische Feld mit dem Elektron *mit bewegt*, so dass das Elektron während der gesamten Durchflugzeit zur 'positiv geladenen Platte' hingezogen wird. Gleichzeitig kann man so eine **Beschleunigung über längere Strecken** realisieren.

Das nächste Problem – der elektrische Widerstand

Für den Bau von solchen beschleunigenden Strukturen wählt man einen möglichst guten elektrischen Leiter, z.B. Kupfer. So kann man **mehrere Millionen Volt pro Meter** erreichen. Aber....

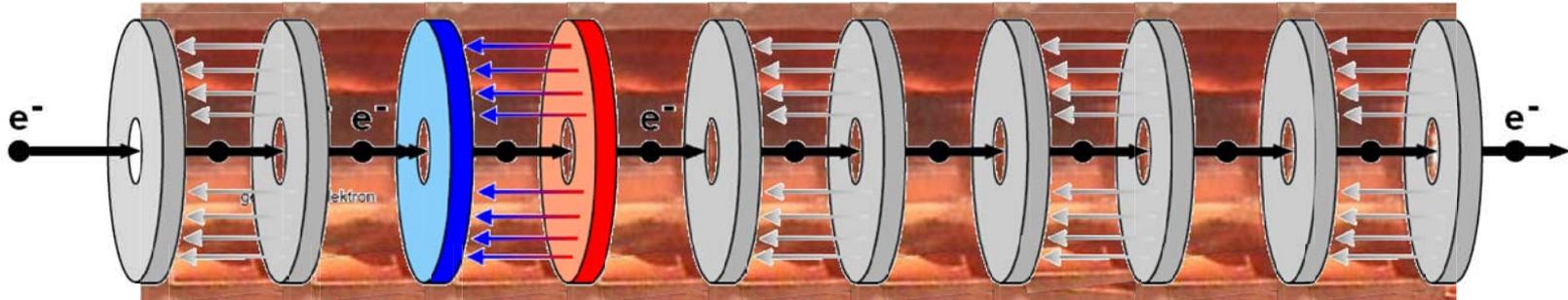


... auch ein guter elektrischer Leiter hat einen Widerstand und wird heiß. Er kann schmelzen!

Mann muss die Spannung immer wieder abschalten.



Der Ausweg ist die Supraleitung



supraleitender 9-Zeller



nahezu ohne elektrische Verluste

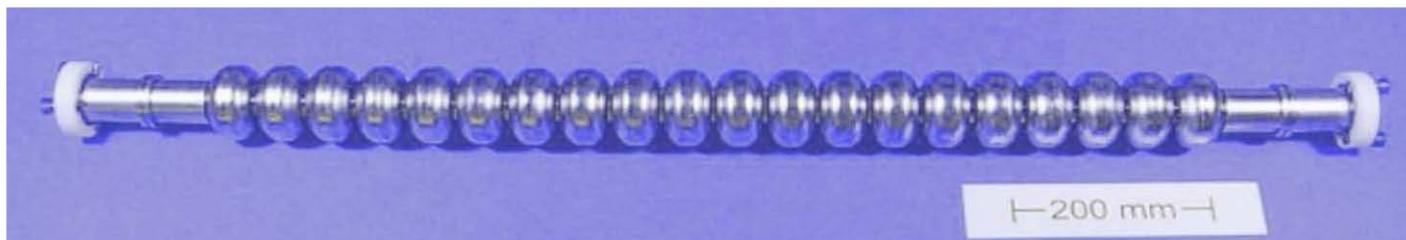
Groß oder klein?



352 MHz
LEP / CERN



1300 MHz
TESLA



3000 MHz
S-DALINAC

Groß! – Nein, ganz groß!



Foto: CERN

Oder doch lieber klein... ?

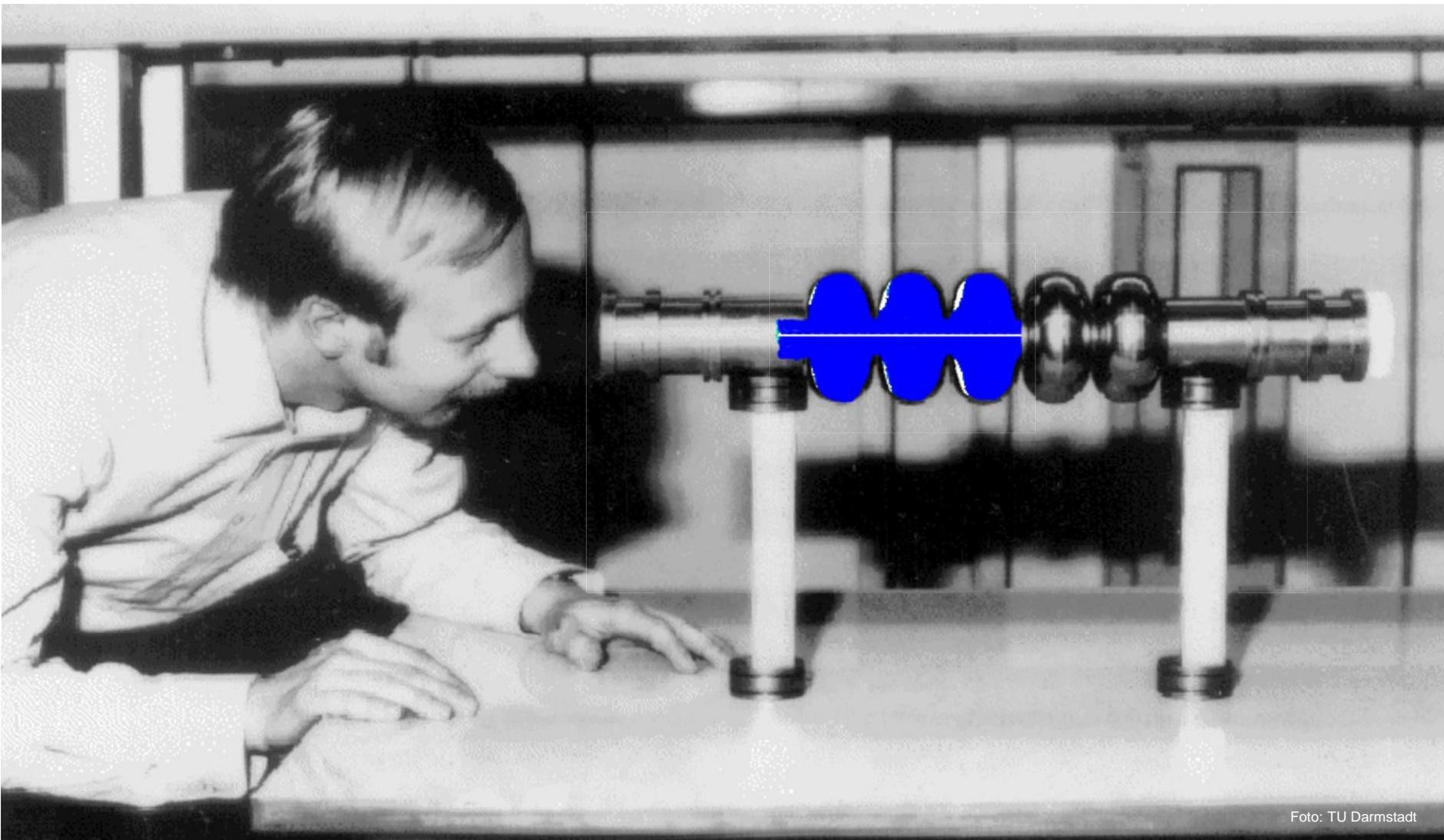
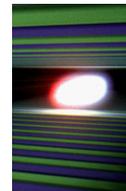
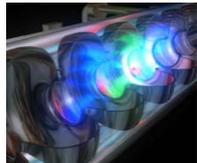
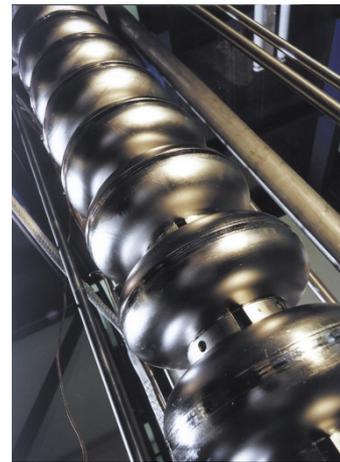
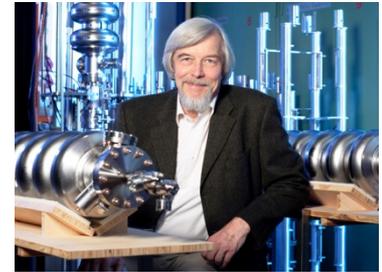
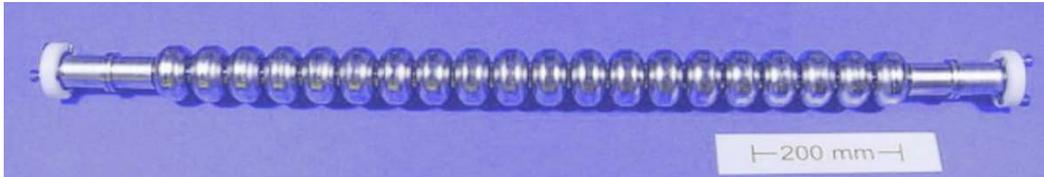
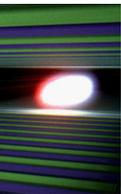
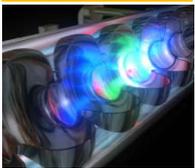
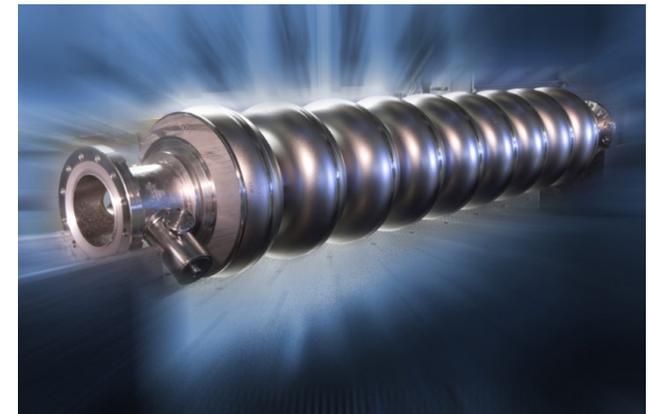


Foto: TU Darmstadt

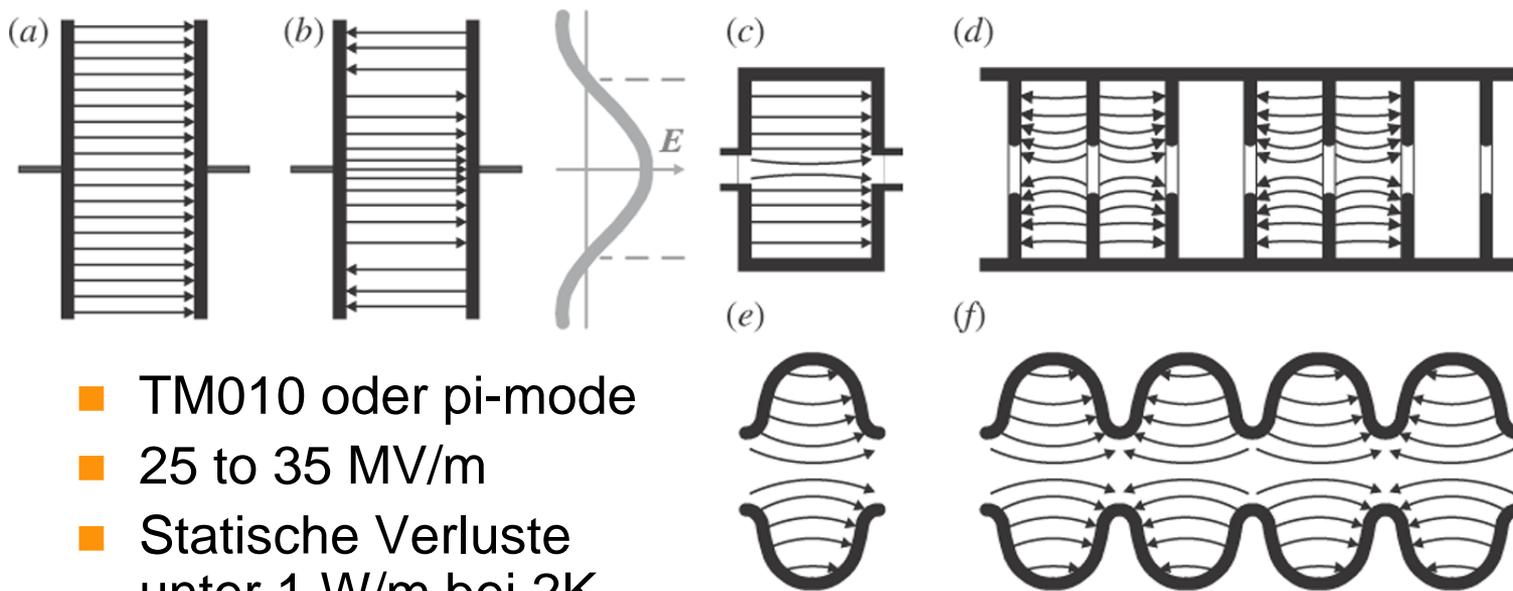
Supraleitende Strukturen für Elektronen



- TESLA
- XFEL
- ILC
- ERLs
- $\beta = 1$



Das Objekt unserer Begierde: die Cavity

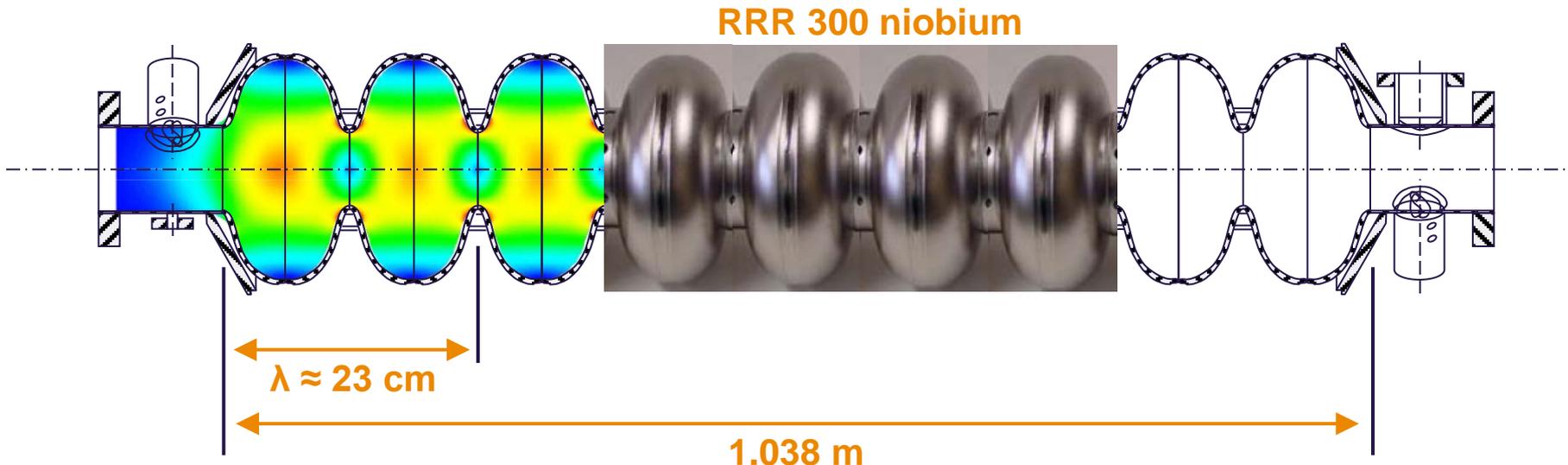


Cavities – Geometry & Betriebsmode

cavity material
 type of accelerating structure
 accelerating mode
 fundamental frequency
 active length
 nominal gradient
 quality factor
 cell-to-cell coupling
 iris diameter

RRR 300 niobium
 standing wave
 TM₀₁₀, π -mode

| | |
|------------------|------------|
| f_{RF} [MHz] | 1,300 |
| L [m] | 1.038 |
| E_{acc} [MV/m] | 23.6 |
| Q_0 | $>10^{10}$ |
| K_{cc} [%] | 1.87 |
| [mm] | 70 |

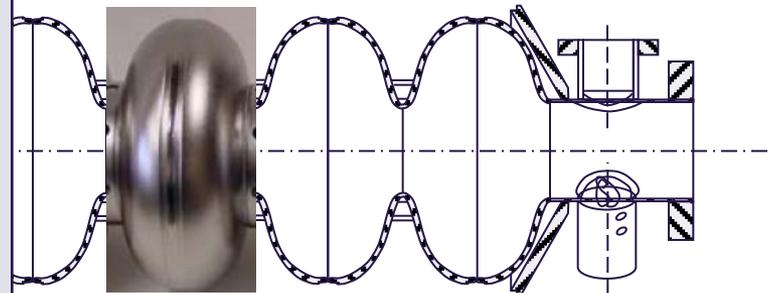
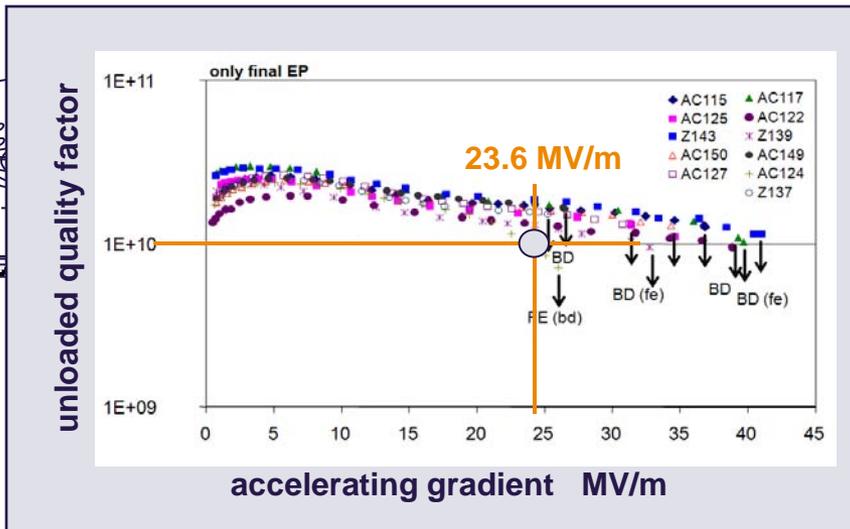


Cavities – Beschleunigungsfeldstärke

cavity material
 type of accelerating structure
 accelerating mode
 fundamental frequency
 active length
nominal gradient
quality factor
 cell-to-cell coupling
 iris diameter

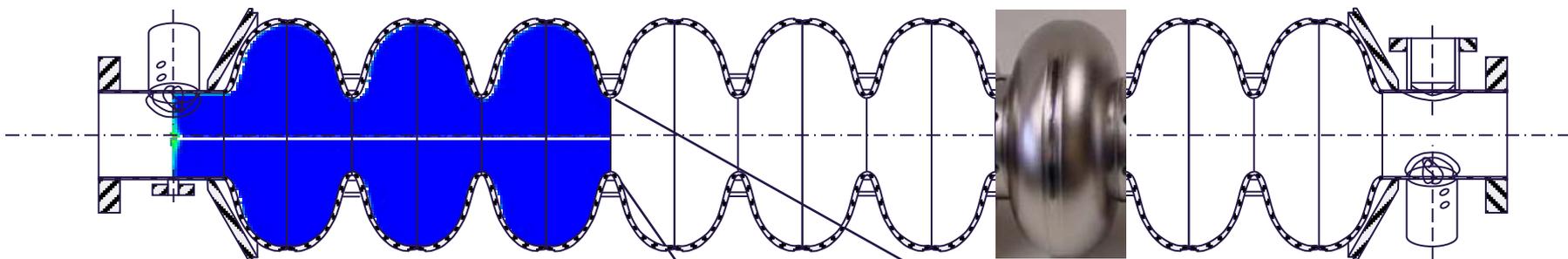
RRR 300 niobium
 standing wave
 TM010, π -mode

| | |
|------------------|---------------------------------|
| f_{RF} [MHz] | 1,300 |
| L [m] | 1.038 |
| E_{acc} [MV/m] | 23.6 |
| Q_0 | $>10^{10}$ |
| K_{CC} [%] | 1.87 |
| [mm] | 70 |



Cavities – Wakefield

| | | |
|--------------------------------|------------------|--------------------|
| cavity material | | RRR 300 niobium |
| type of accelerating structure | | standing wave |
| accelerating mode | | TM010, π -mode |
| fundamental frequency | f_{RF} [MHz] | 1,300 |
| active length | L [m] | 1.038 |
| nominal gradient | E_{acc} [MV/m] | 23.6 |
| quality factor | Q_0 | $>10^{10}$ |
| cell-to-cell coupling | K_{cc} [%] | 1.87 |
| iris diameter | [mm] | 70 |



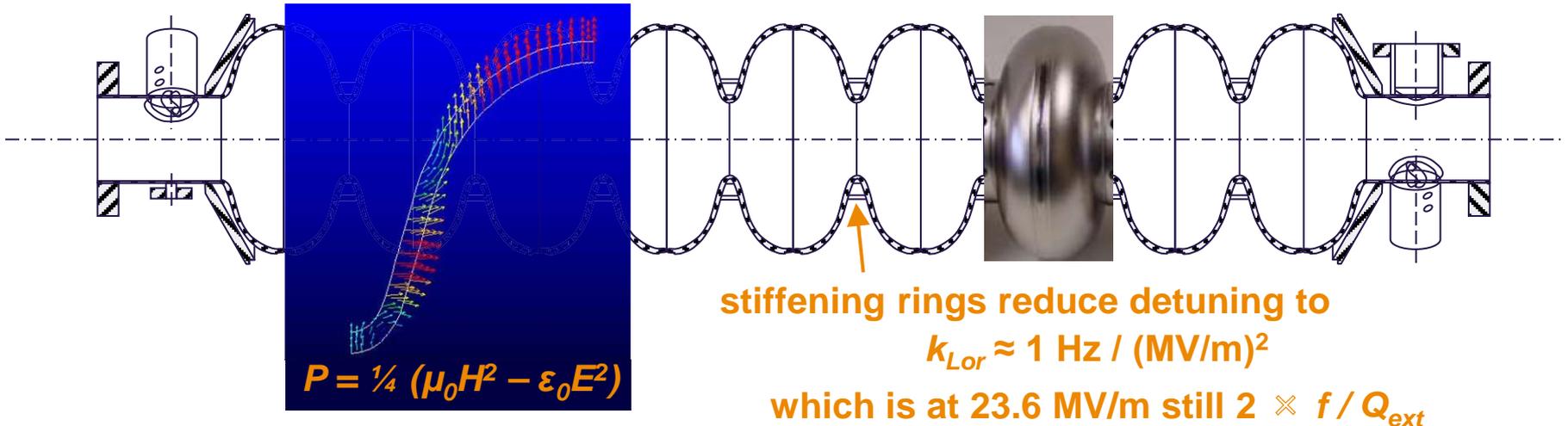
Wakefield excitation is reduced

$$W_{\parallel} \sim f^2 \quad W_{\perp} \sim f^3$$

70 mm

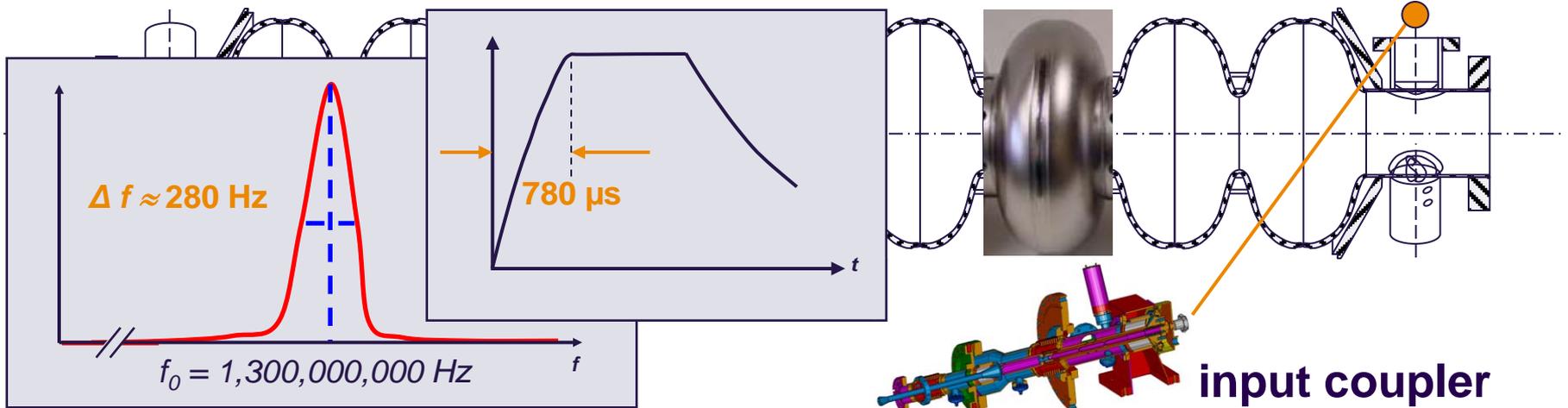
Cavities – Frequenzverhalten

| | | |
|---------------------------------|---------------------------------------|-------------------|
| R/Q | [Ω] | 1,036 |
| E_{peak} / E_{acc} | | 2.0 |
| B_{peak} / E_{acc} | [mT / MV/m] | 4.26 |
| Tuning range | [kHz] | ± 300 |
| $\Delta f / \Delta L$ | [kHz / mm] | 315 |
| Lorentz force detuning constant | K_{Lor} [Hz / (MV/m) ²] | 1 |
| Q_{ext} of input coupler | | 4.6×10^6 |
| cavity bandwidth f / Q_{ext} | [Hz] FWHM | 283 |
| fill time | [ms] | 780 |
| number of HOM couplers | | 2 |



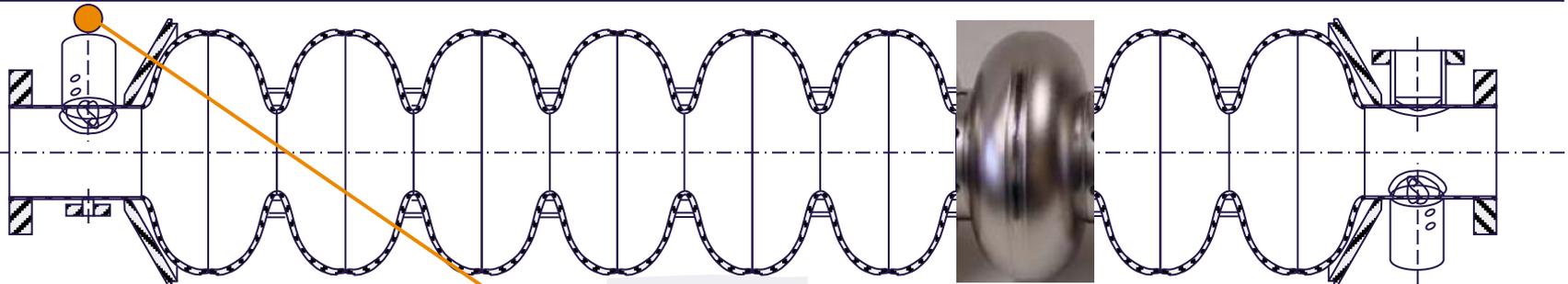
Cavities - Bandbreite

| | | |
|---------------------------------|---------------------------------------|-------------------|
| R/Q | [Ω] | 1,036 |
| E_{peak} / E_{acc} | | 2.0 |
| B_{peak} / E_{acc} | [mT / MV/m] | 4.26 |
| Tuning range | [kHz] | ± 300 |
| $\Delta f / \Delta L$ | [kHz / mm] | 315 |
| Lorentz force detuning constant | K_{Lor} [Hz / (MV/m) ²] | 1 |
| Q_{ext} of input coupler | | 4.6×10^6 |
| cavity bandwidth f / Q_{ext} | [Hz] FWHM | 283 |
| fill time | [ms] | 780 |
| number of HOM couplers | | 2 |

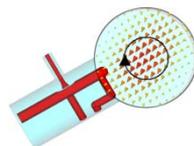
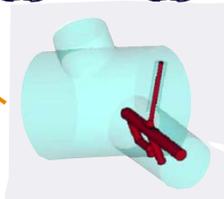


Cavities – Höhere Moden

| | | |
|--|---|-------------------------------------|
| R/Q | [Ω] | 1,036 |
| E_{peak} / E_{acc} | | 2.0 |
| B_{peak} / E_{acc} | [mT / MV/m] | 4.26 |
| Tuning range | [kHz] | ± 300 |
| $\Delta f / \Delta L$ | [kHz / mm] | 315 |
| Lorentz force detuning constant | K_{Lor} [Hz / (MV/m)²] | 1 |
| Q_{ext} of input coupler | | 4.6×10^6 |
| cavity bandwidth f / Q_{ext} | [Hz] FWHM | 283 |
| fill time | [ms] | 780 |
| number of HOM couplers | | 2 |

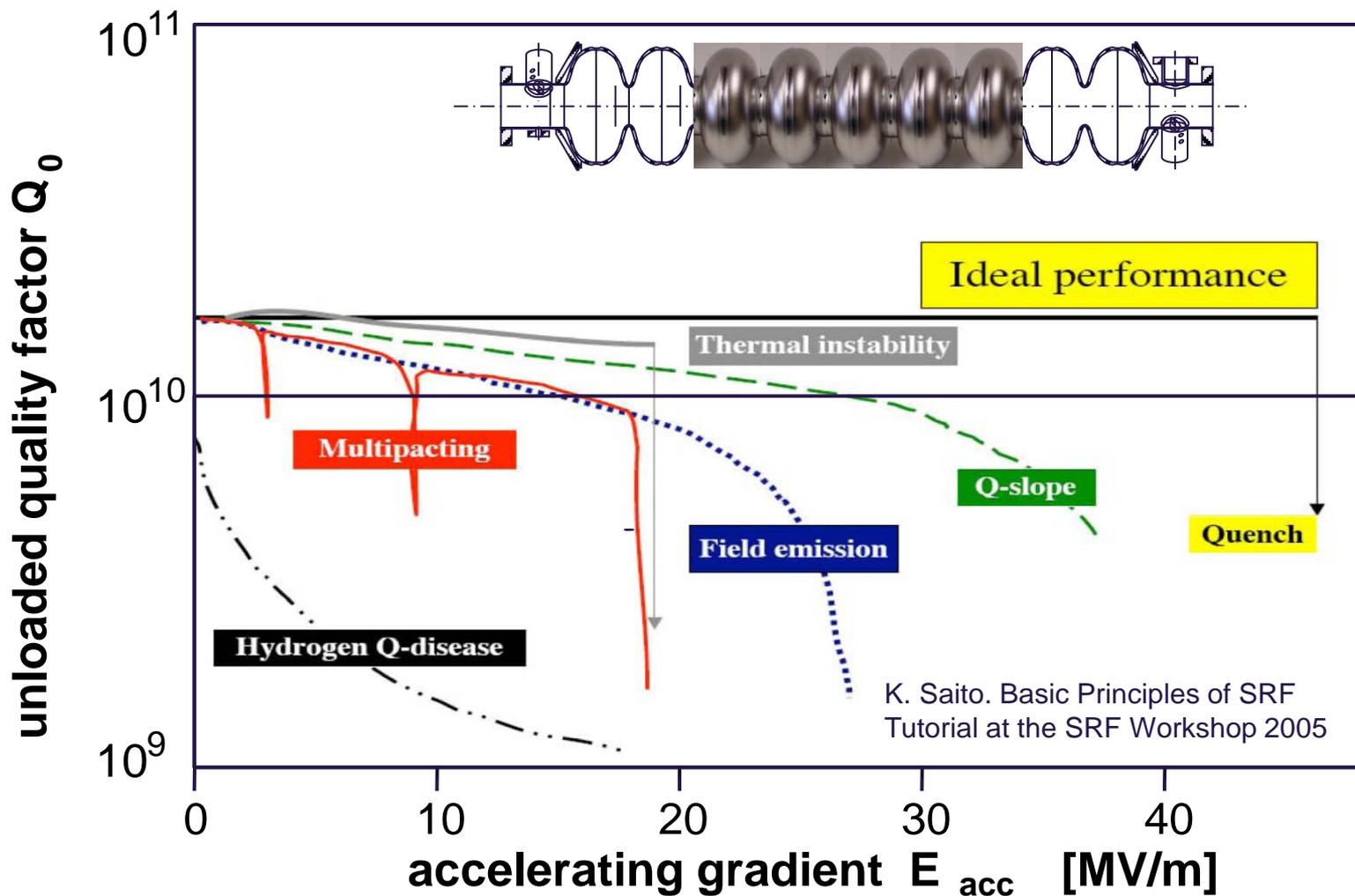


Higher Order Mode excitation has to be avoided.

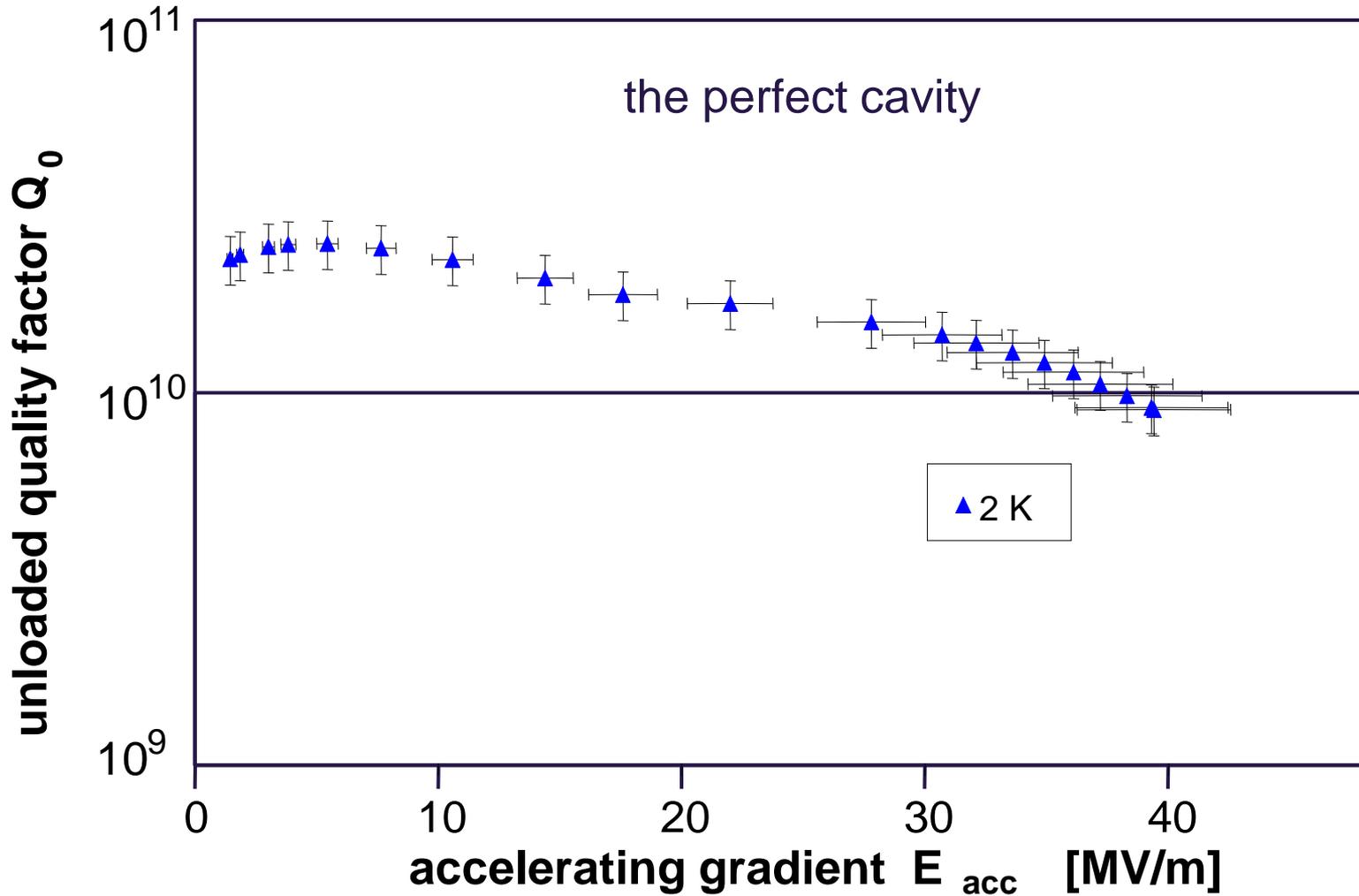


HOM coupler

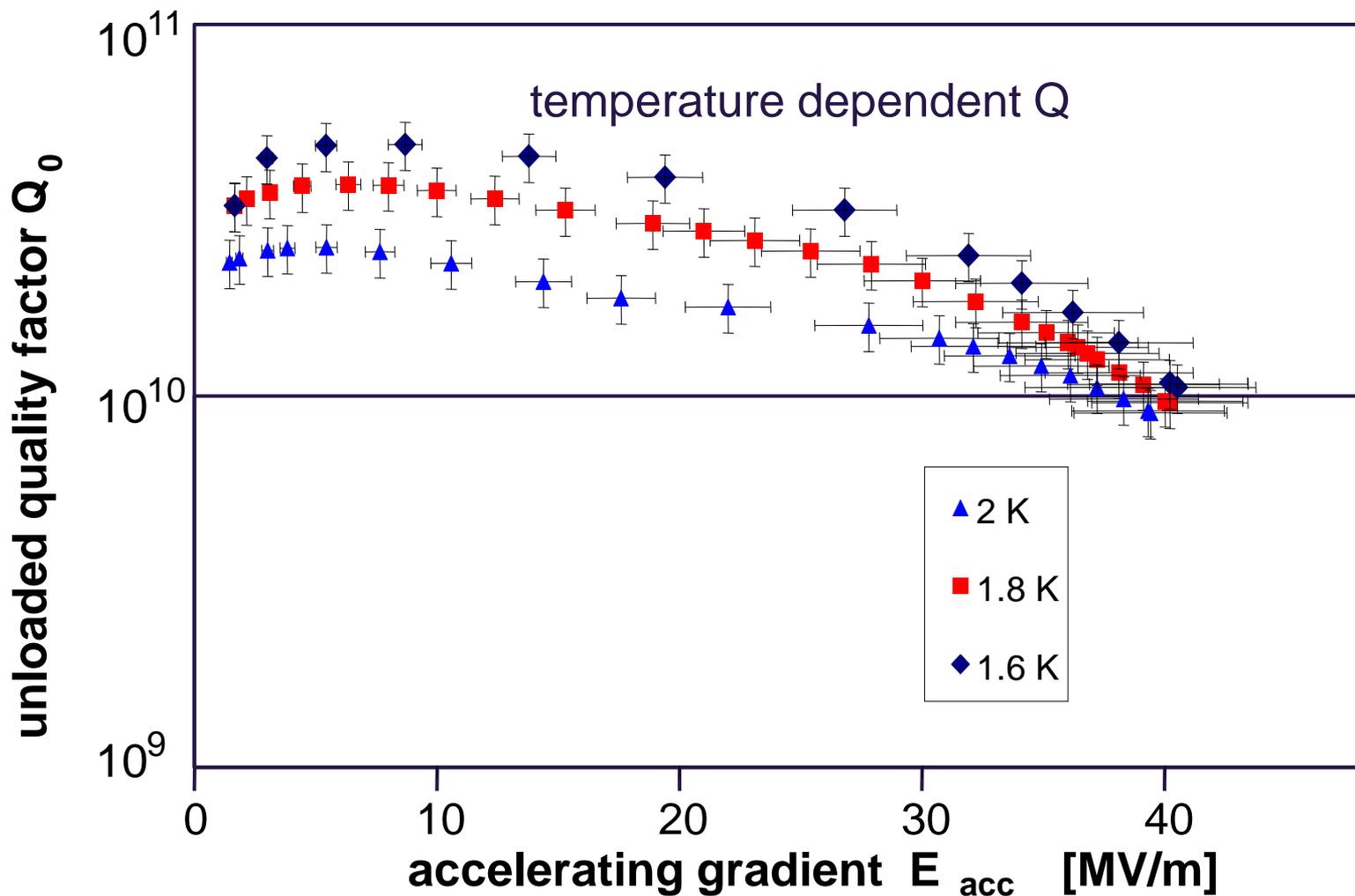
Die berühmte Darstellung von Q vs. E

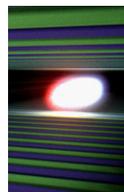
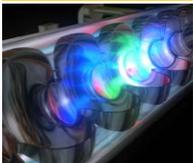


Eine perfekte Beschleunigungsstruktur

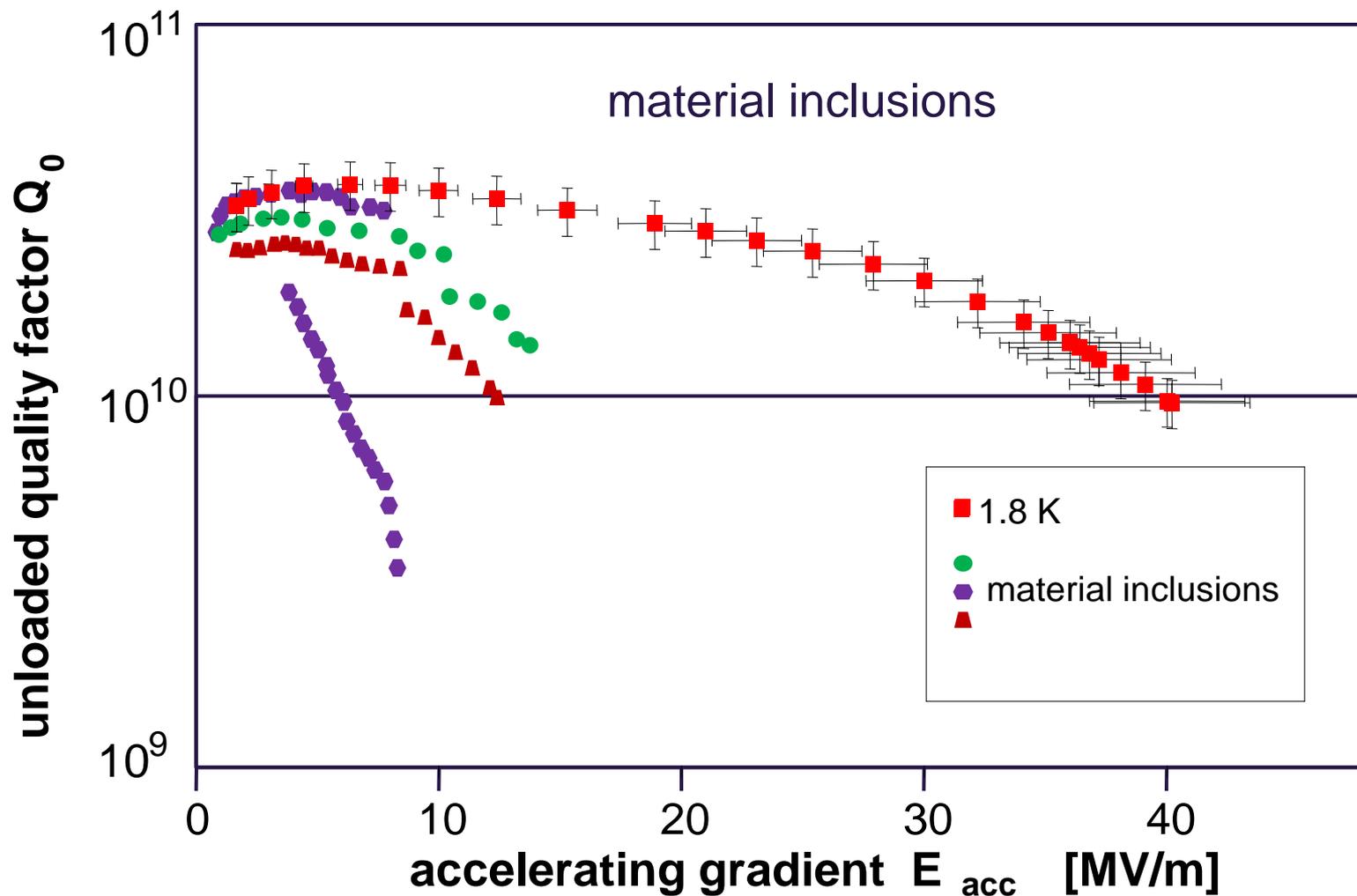


Verschiedene Betriebstemperaturen

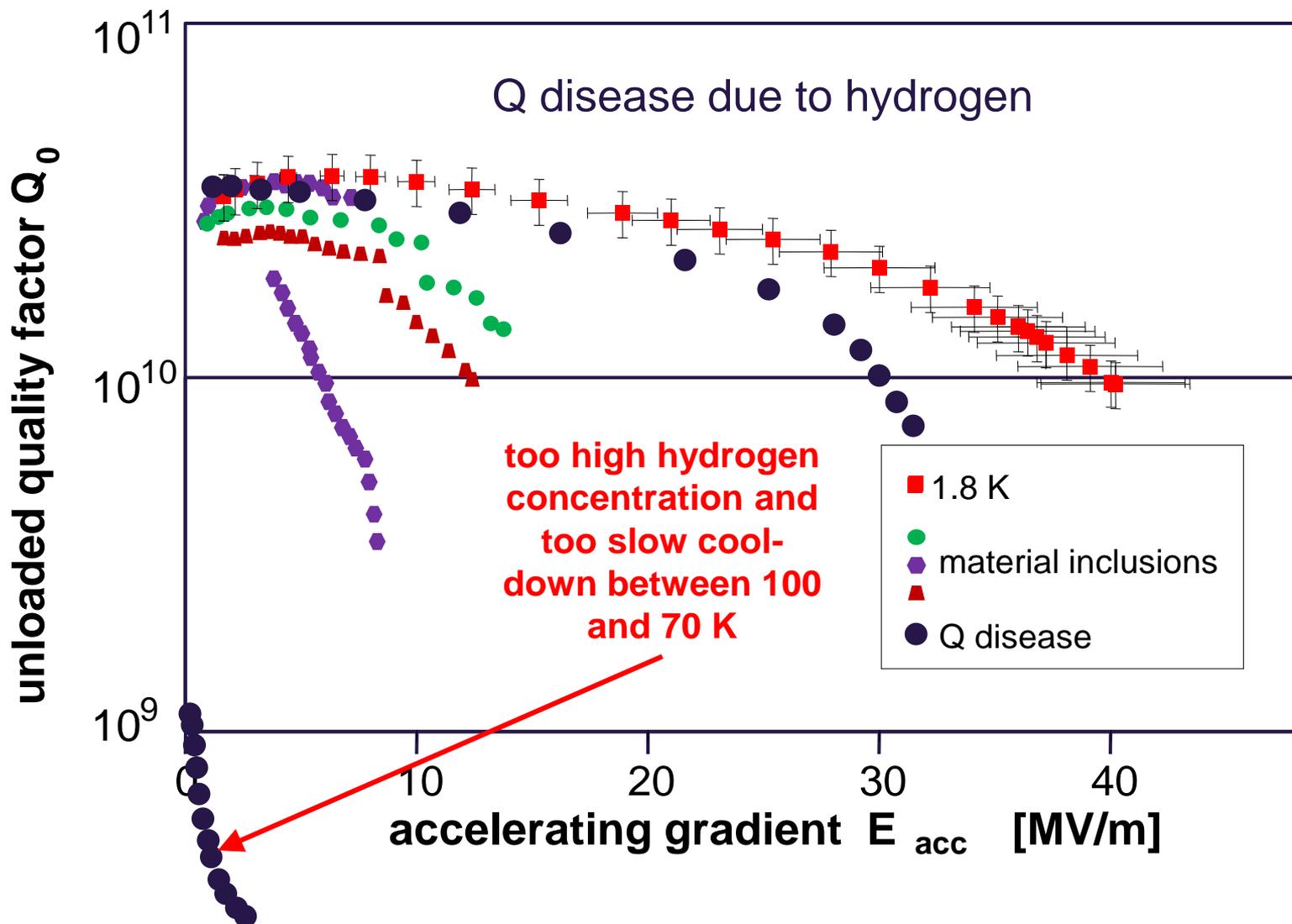




Verunreinigungen im Material



Die Wasserstoffkrankheit *Q-disease*



TESLA Entwicklung in den 90iger Jahren

Ziele der TESLA Kollaboration

- Erhöhung der maximalen Beschleunigungsfeldstärke von 5 to 25 MV/m
- Kostenoptimierung

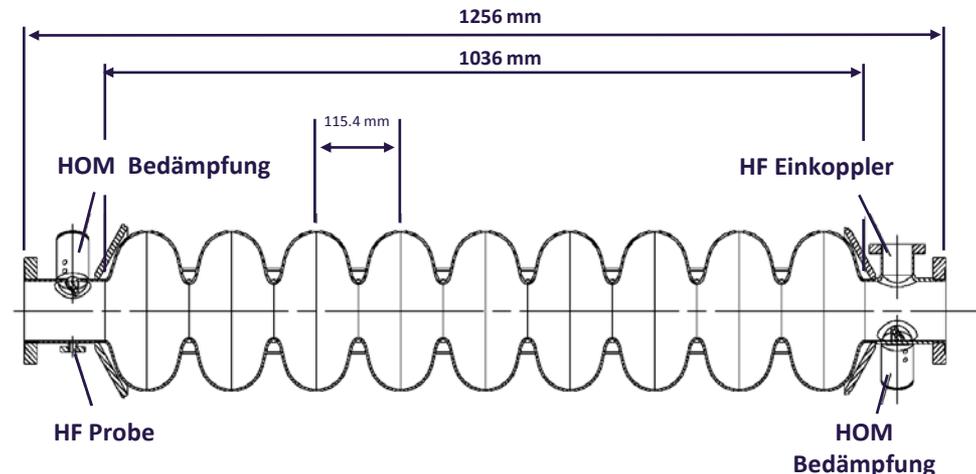
Gemeinsame Herausforderung für alle Labors, die sich mit Hochfrequenz-Supraleitung beschäftigen, z.B.

- (CERN), Cornell, DESY, INFN, (KEK), Saclay, TJNL
- 53 Partner aus 12 Ländern



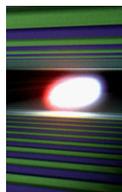
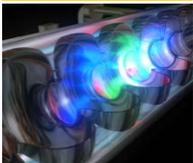
Aufgaben:

- “besseres” Niob-Metall
- Neue Herstellungsverfahren



Die **Standard TESLA Beschleunigungsstruktur** wird als Stehwellenstruktur im π -Mode betrieben. Ein Hochfrequenz-Einkoppler speist bis zu 230 kW Leistung ein, über eine kleine Antenne wird das erzeugte Beschleunigungsfeld gemessen. Weitere Antennen bedämpfen möglicherweise angeregte Felder bei hohen Frequenzen.

Eine alte Idee – der supraleitende *Linear Collider*



IL NUOVO CIMENTO
RIVISTA
ORGANO DELLA SOCIETÀ
SOTTO GLI AUSPICI DEL CONSIGLIO
E DEL COMITATO NAZIONALE

Vol. XXXVII, N. 3 Serie di

A Possible Apparatus for Electron Clashing-Beam Experiments

M. TIGNER
Laboratory of Nuclear Studies, Columbia University

(ricevuto il 21/1/1965)

While the storage ring technique for performing clashing-beam experiments (1) is very elegant in concept it seems worthwhile at the present juncture to investigate other methods which, especially more economic consequence of this particular arrangement. First, by the introduction of superconducting accelerator sections one may avoid the high power necessary to establish the accelerating field. With this technique one might hope to achieve an energy gain of about 11 MeV per meter for a rf power investment of about 12 watt per meter at an operating frequency of about 1000 megacycles per second.

One difference between the two methods is that the two beams made equal velocity at 500 MeV, the electron gun power, the electron current to about one percent even heavy

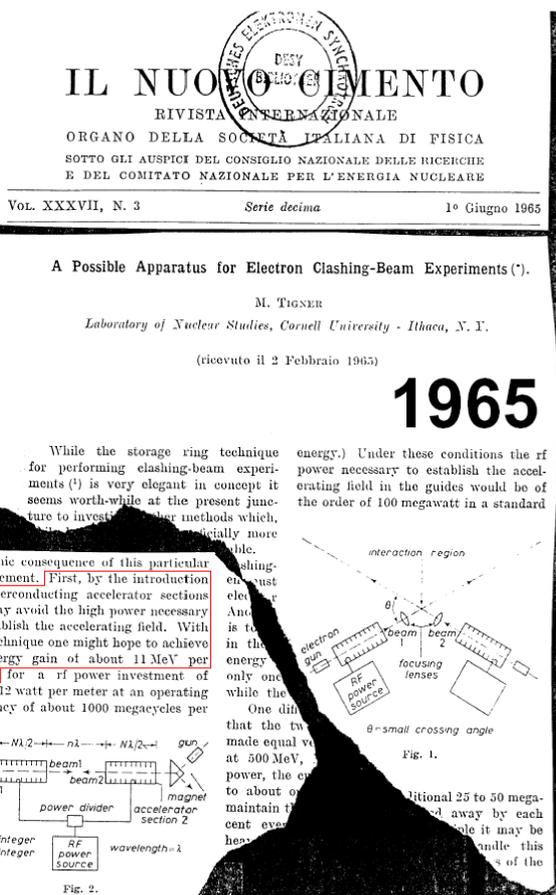
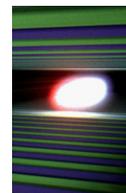
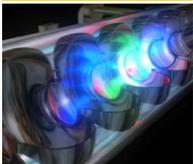
Fig. 2.

1965

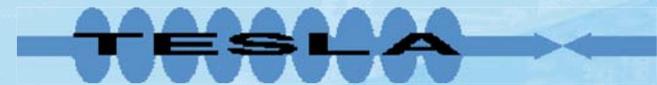
Fig. 1.

M. Tigner, A Possible Apparatus for Electron Clashing-Beam Experiments, *Il Nuovo Cimento* Vol. XXXVII, N. 3, 1965

Der *TESLA Linear Collider* – ein technisches Design



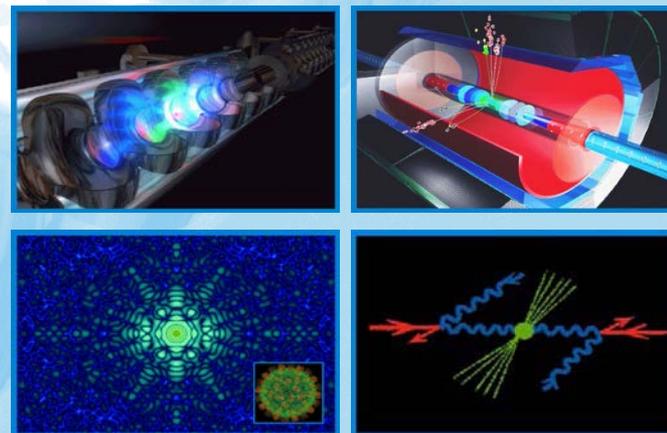
M. Tigner, A Possible Apparatus for Electron Clashing-Beam Experiments *Il Nuovo Cimento* Vol. XXXVII, No.3 (1965)



TESLA

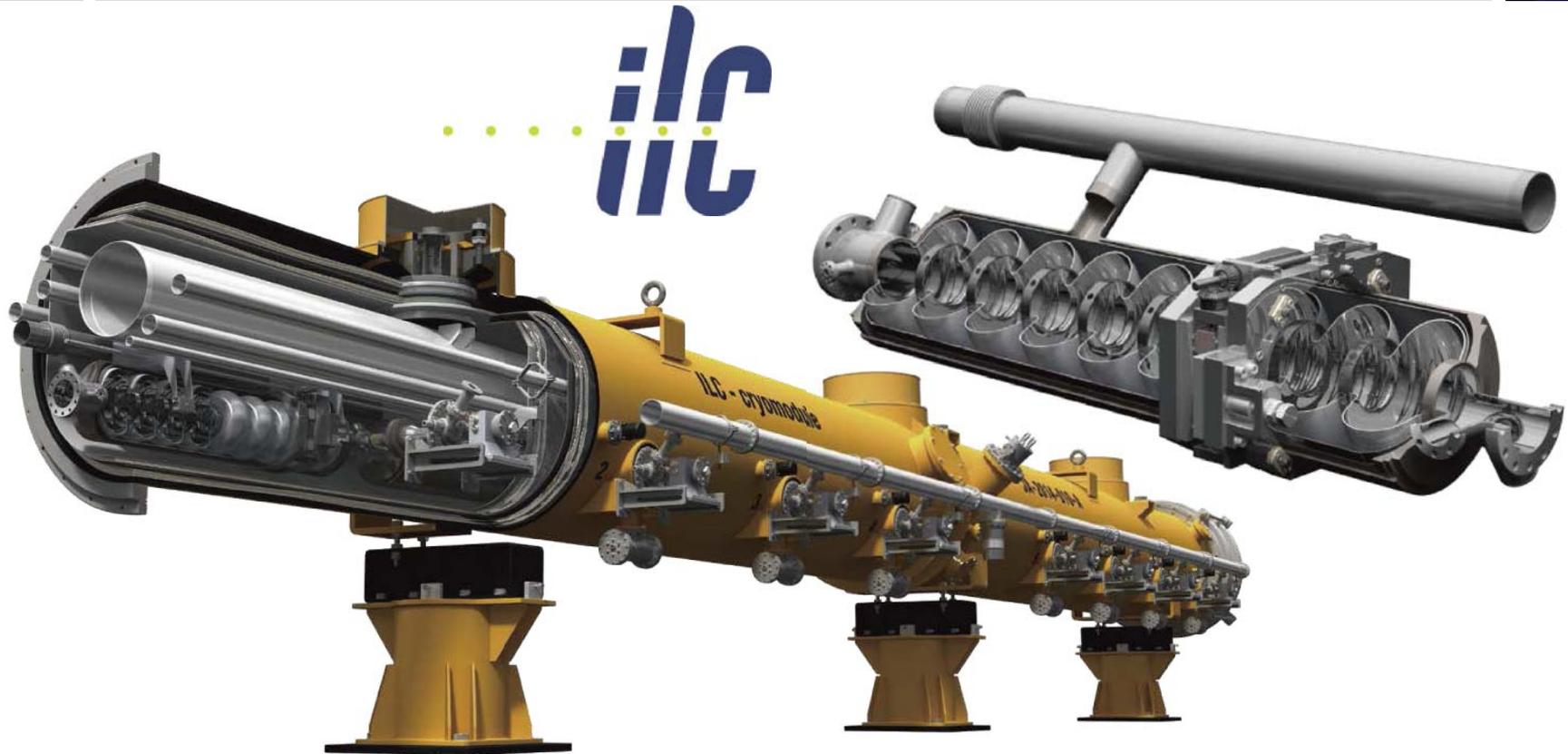
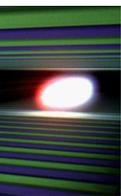
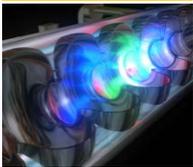
The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory

Technical Design Report



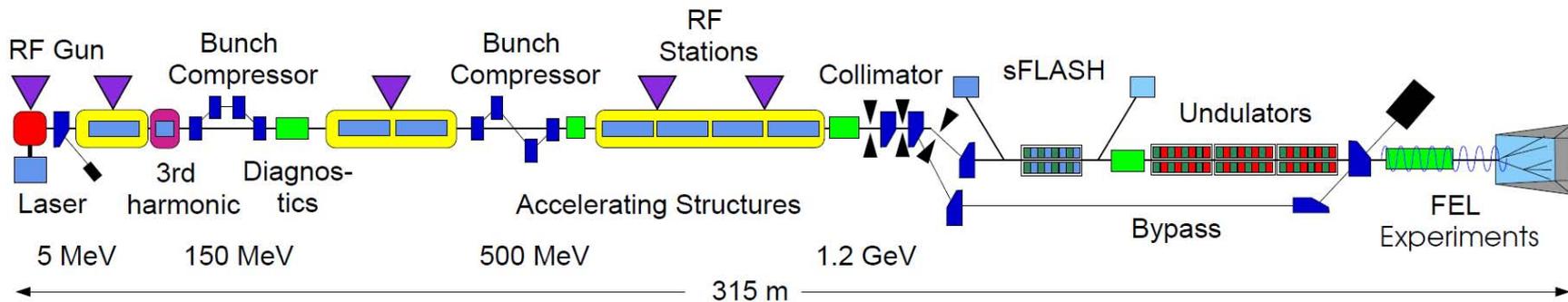
March 2001

TESLA wird in weltweiter Kollaboration weitergeführt



Stärkere Beschleunigungsfelder
Optimierte Technologie
Detaillierte Kostenbetrachtung
Warten auf Ergebnisse von CERN - LHC

FLASH als wirklich aufgebauter Beschleuniger bei DESY

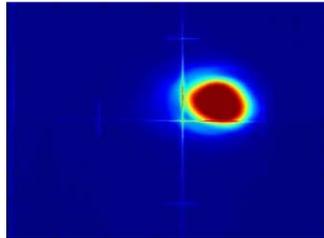


Insgesamt 7 Beschleunigermodule mit 56 einzelnen Strukturen wurden zusammengefügt. Es entstand der Freie-Elektronen Laser FLASH, eine weltweit sehr angesehene Anlage.

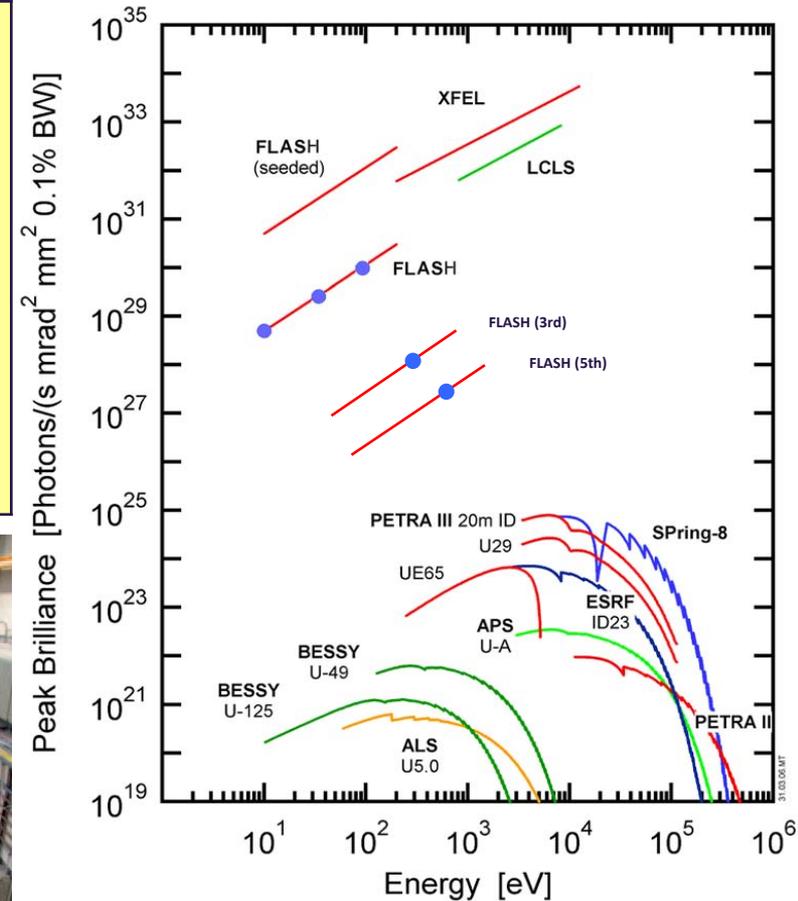
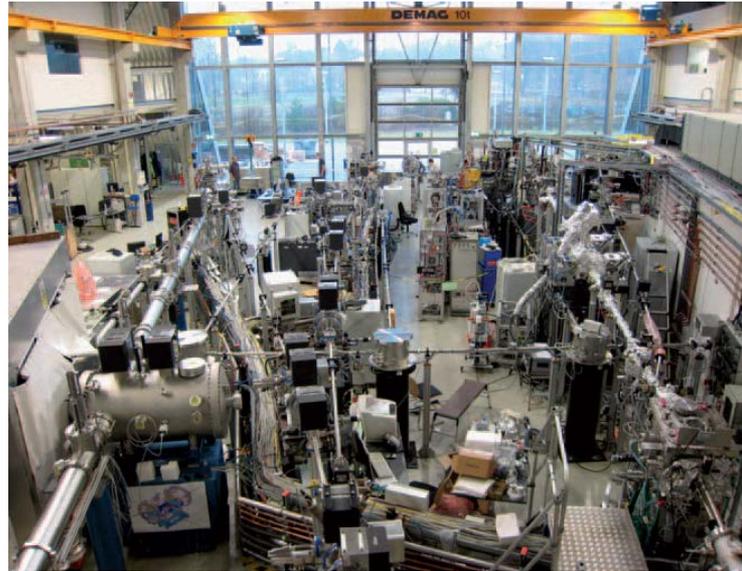
DESY betreibt damit den Prototypen des European XFEL und sammelt gleichzeitig Erfahrung für einen *Linear Collider*.

FLASH bei DESY aus Sicht der Experten

| | |
|--|--|
| Wavelength (fundamental) | 44 – 4.1 nm (tunable!!!) |
| FEL range (harmonics) | → 2.7 nm |
| Average energy per pulse | up to 100 μJ |
| Maximum energy per pulse | 200 μJ |
| Radiation pulse duration | 10 – 70 fs |
| Peak power (calc. from average) | ~ 3 – 4 GW |
| Spectral width (FWHM) | 0.5 – 1 % |
| Angular divergence (FWHM) | 160 μrad |
| Peak brilliance (calc. from max) | $5\text{-}10 \times 10^{29}$ ph/s/mrad²/mm²/ (0.1% bw) |



$\langle E \rangle = 70 \mu\text{J}$



FLASH Informationen für alle und für Experten

FLASH.

The Free-Electron Laser
in Hamburg

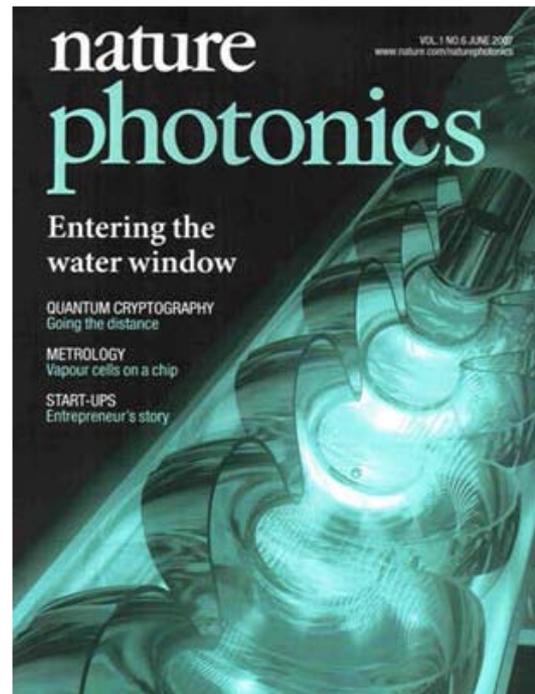


New technologies for new science: Soon X-ray free-electron lasers will enable us to probe ultrafast physical, chemical and biochemical processes at atomic resolution, opening new frontiers for science and technology. At long last we may see, and not just model, how molecular machines really work.

<http://flash.desy.de/>

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
Member of the Helmholtz Association

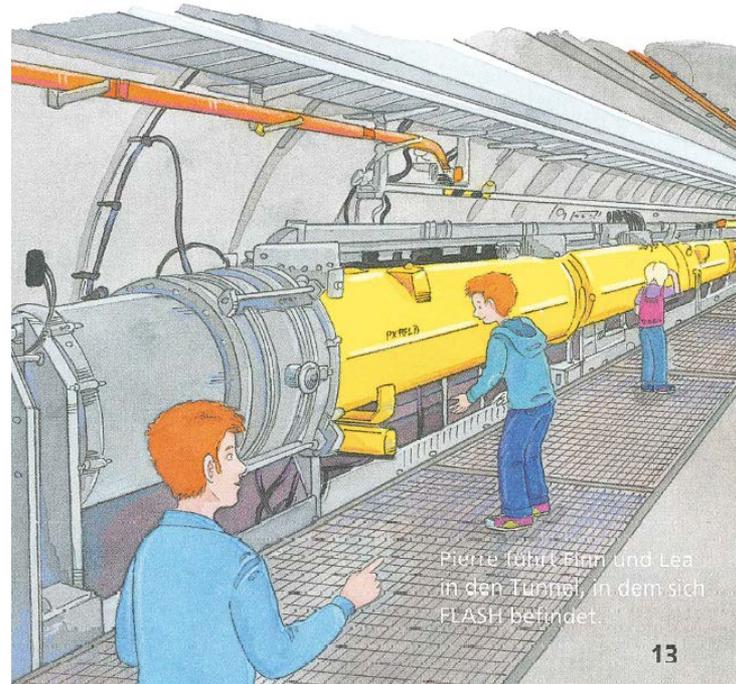


Operation of a free-electron laser
from the extreme ultraviolet to the
water window

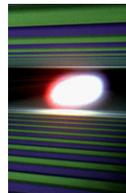
[nature photonics](http://naturephotonics.com) | VOL 1 | JUNE 2007 | www.nature.com/naturephotonics

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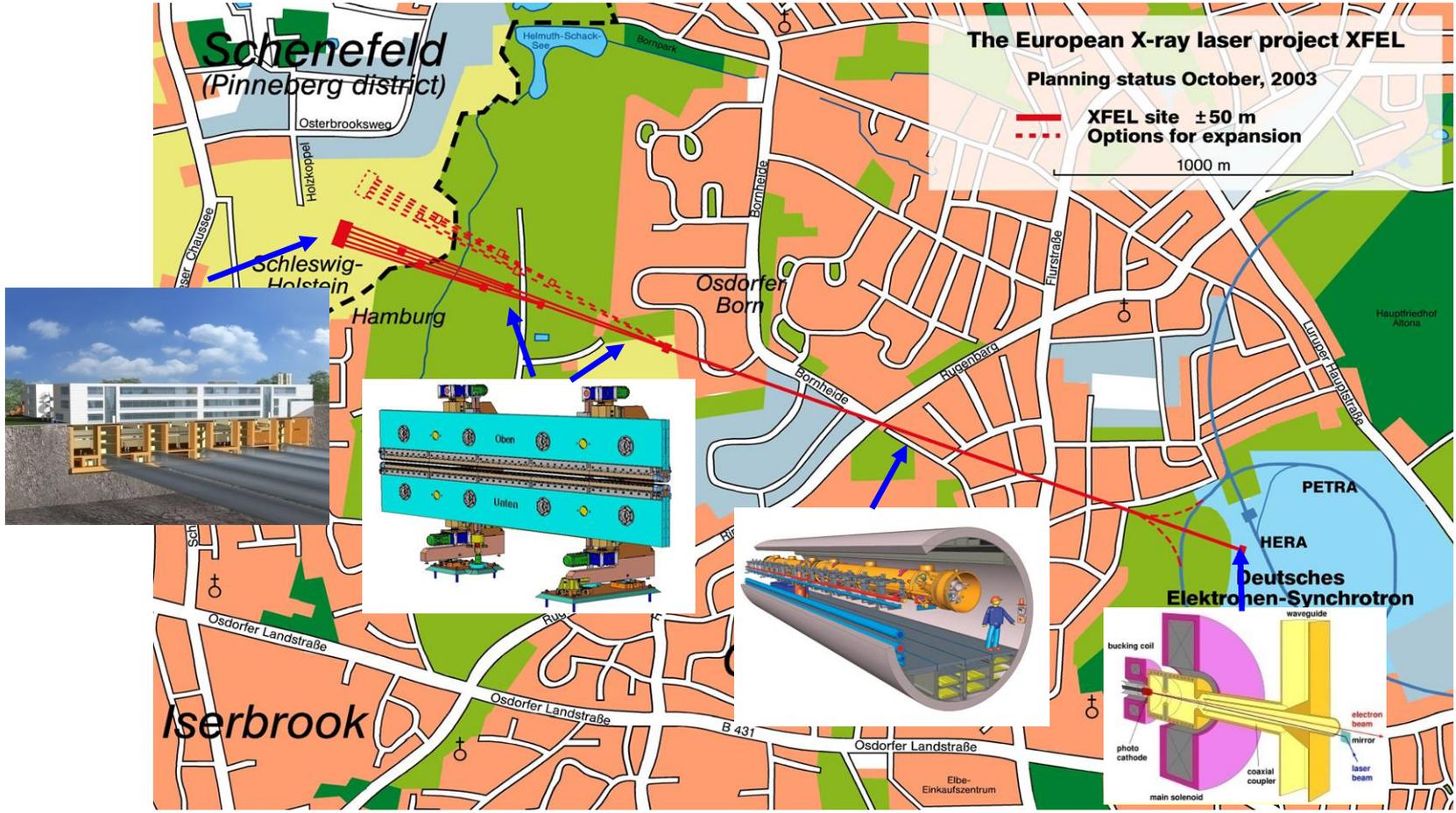
Man kann nie zu früh anfangen...



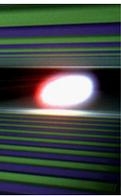
DESY baut mit Partnern den Europäischen XFEL



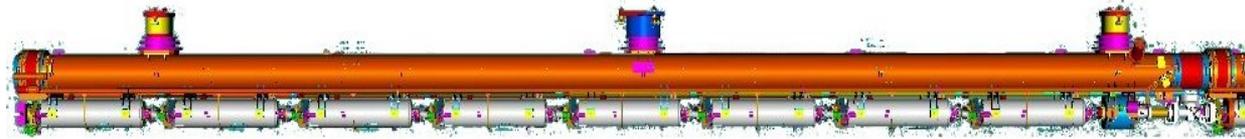
← 3.4km →



Ein Beschleunigerkomplex für 17.5 GeV



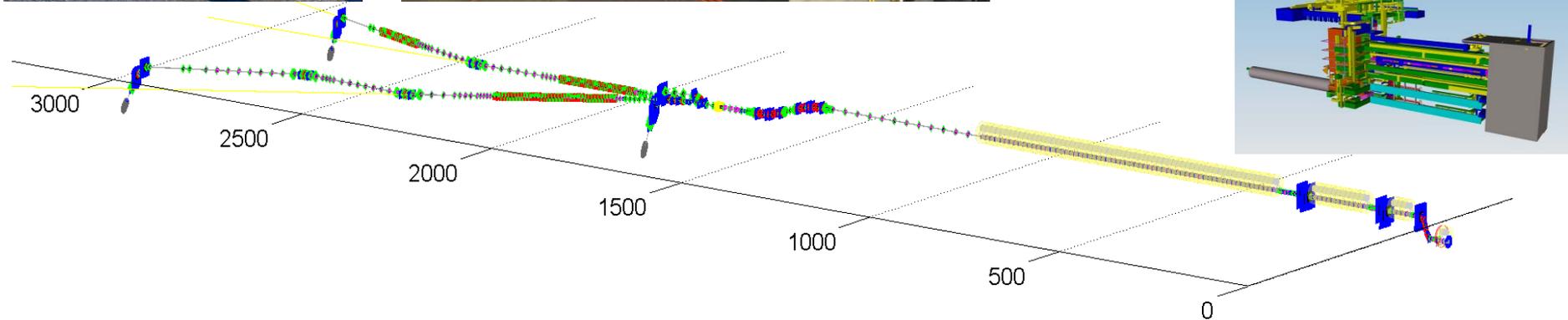
100 accelerator modules



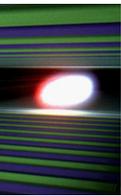
800 accelerating cavities
1.3 GHz / 23.6 MV/m



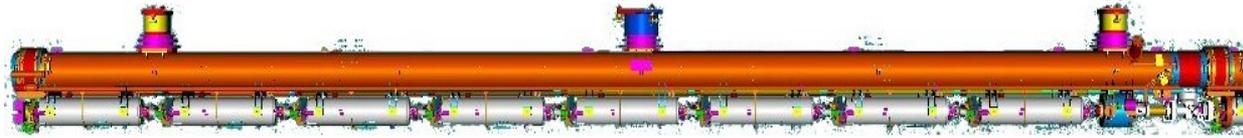
25 RF stations
5.2 MW each



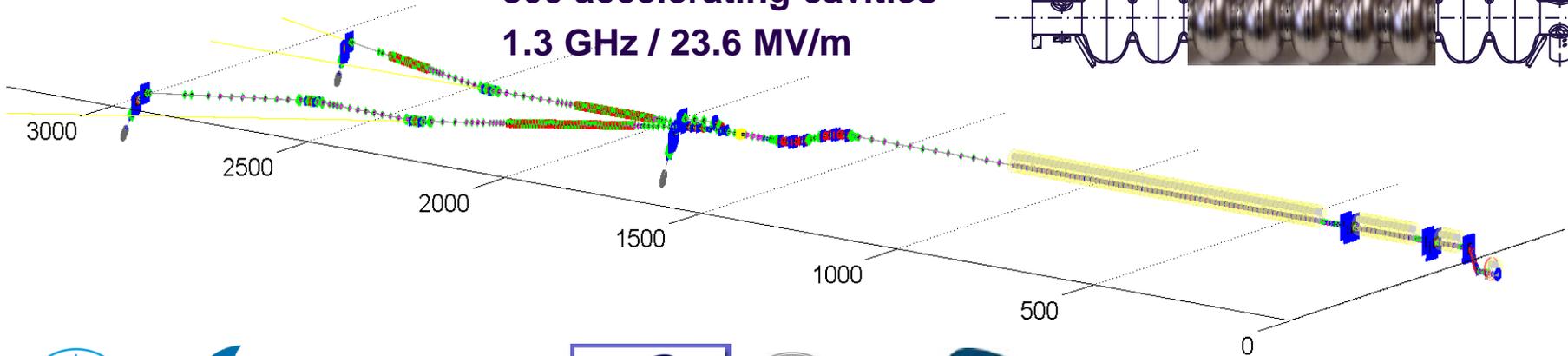
Ein Beschleunigerkomplex für 17.5 GeV



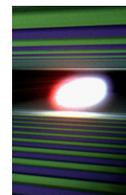
100 accelerator modules



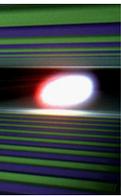
800 accelerating cavities
1.3 GHz / 23.6 MV/m



Reinräume bei DESY und in Frankreich (CEA)

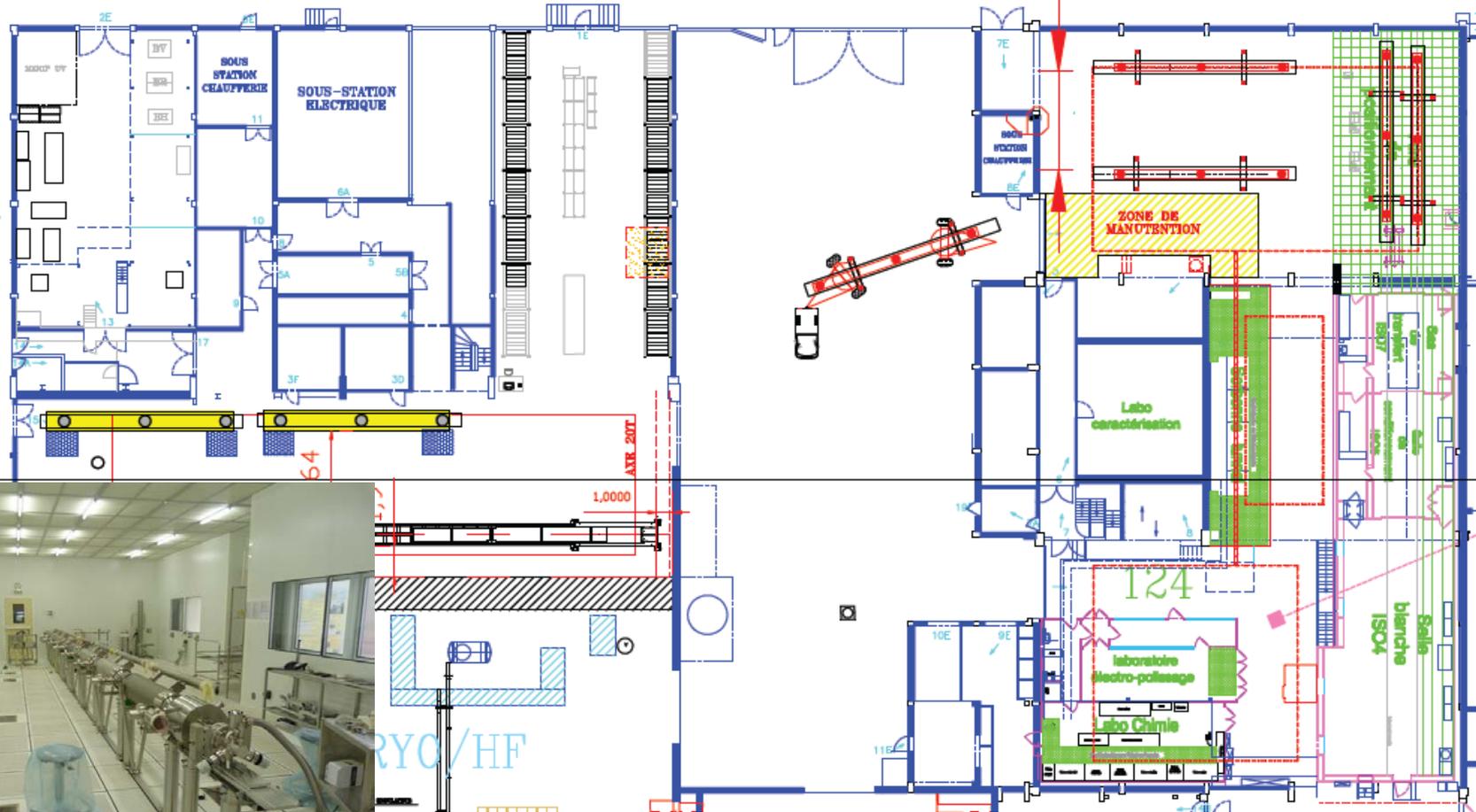


Ein *XFEL Village* für den Zusammenbau der Beschleunigermodule

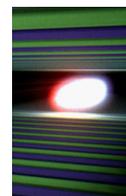


Village XFEL

MONTAGE CRYOSTATING SPIRAL 2

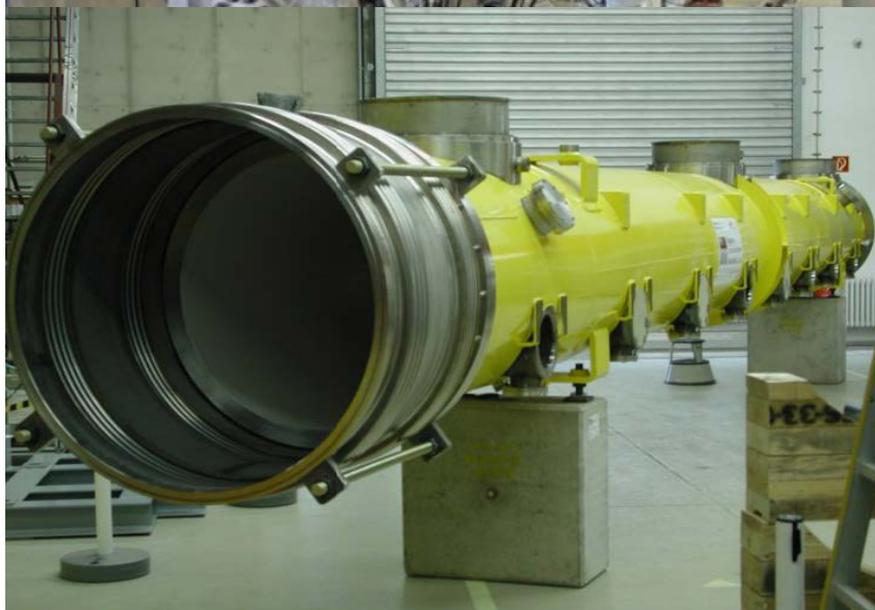
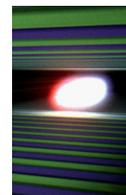


RYCO/HF



Institute of High Energy Physics
Chinese Academy of Sciences



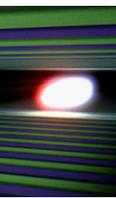


- In einer Prototyp-Phase wurden mehrere Hersteller qualifiziert.
- Insgesamt 103 Kryostate werden benötigt.
- Die Druckgeräteverordnung muss Anwendung finden (*TÜV Nord*).

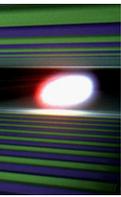


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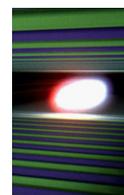
Transporttests: ein Ausflug nach Frankreich und zurück



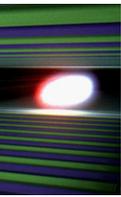
PXFEL1 – Ein echtes XFEL Modul für FLASH



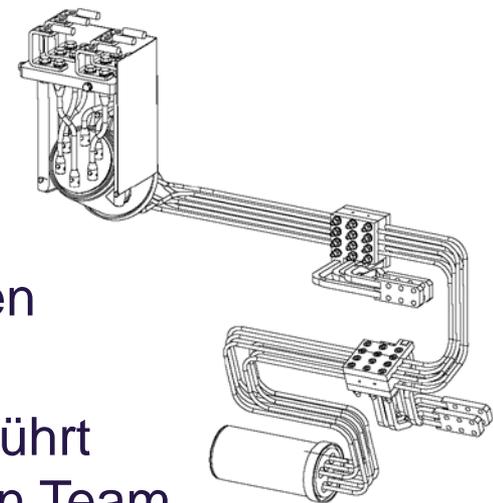
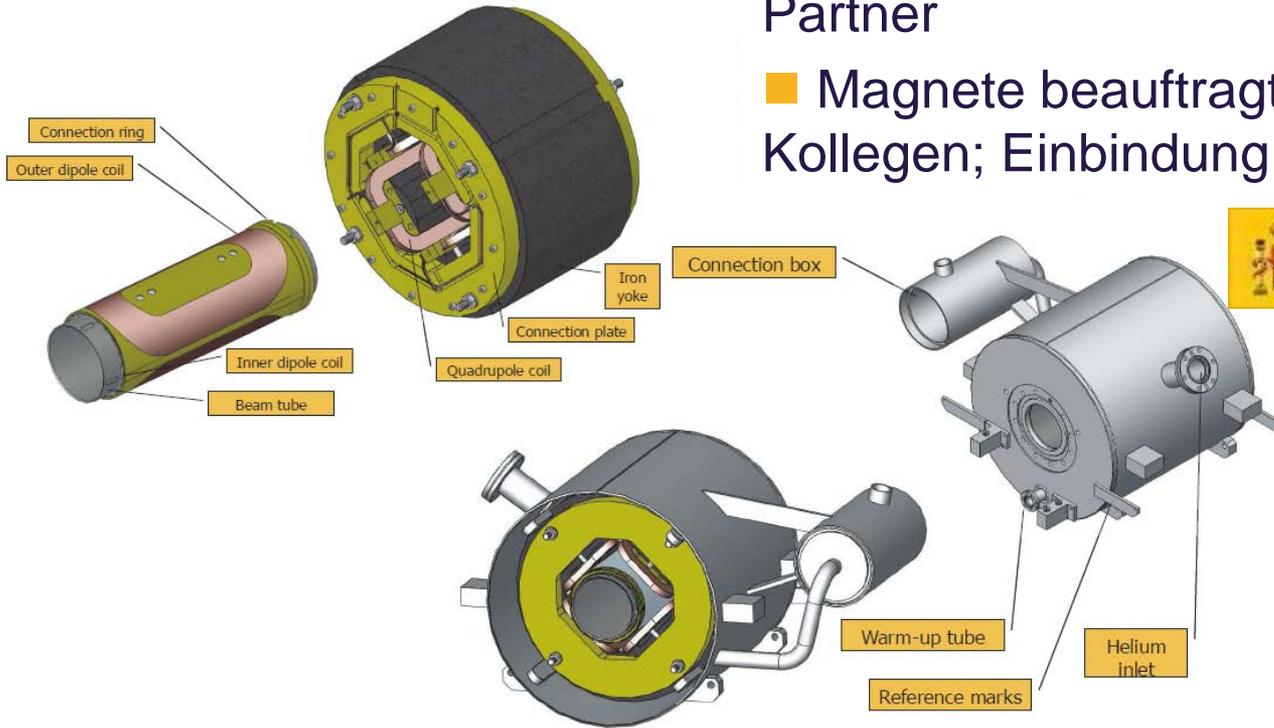
Quasi-Industrieller Zusammenbau



Zusammenarbeit vieler Partner Kalte Strahlführungsmagnete

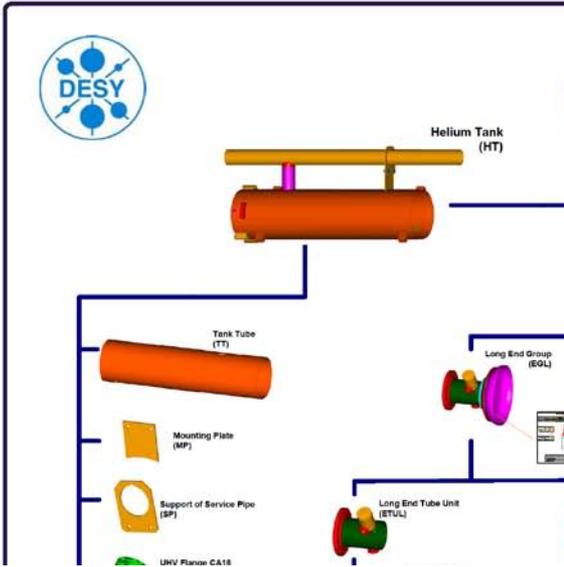
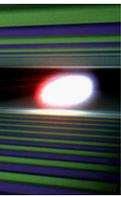


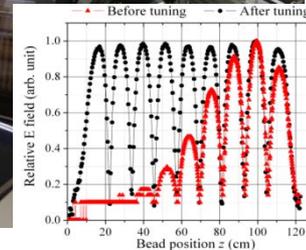
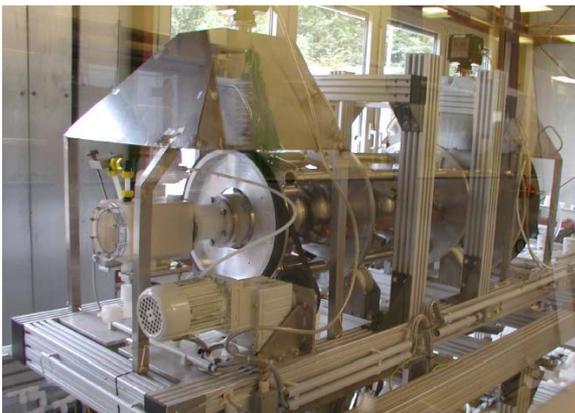
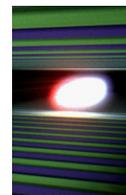
- Formale Fertigungsfreigabe durch alle Partner
- Magnete beauftragt durch spanische Kollegen; Einbindung des TÜV Nord



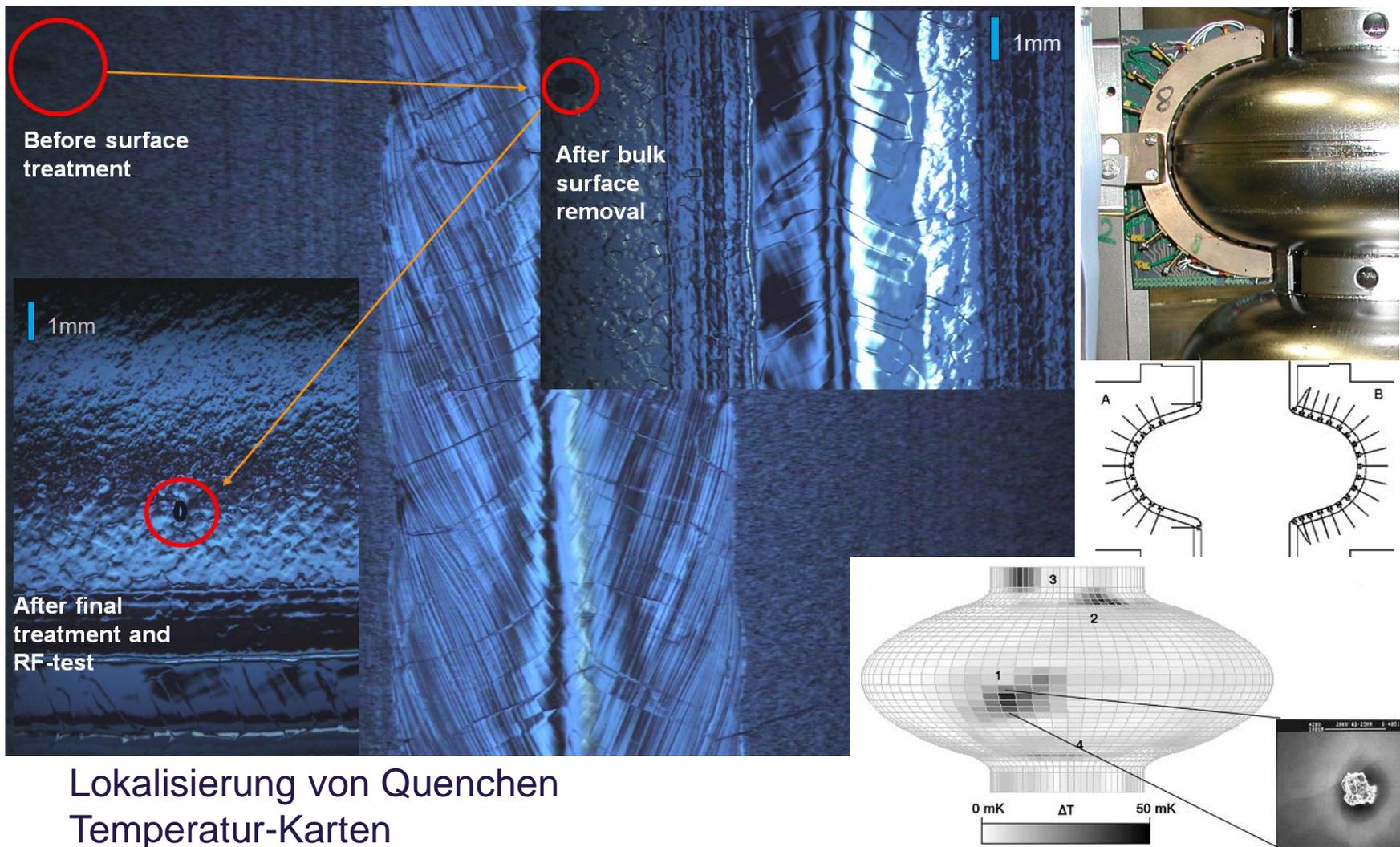
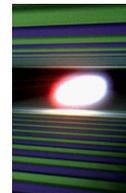
- Verkupferung und Stromzuführungen seitens DESY
- Quadrupol Test bei DESY, durchgeführt von einem speziell trainierten Experten Team

Produktion von 800 Beschleunigungsstrukturen

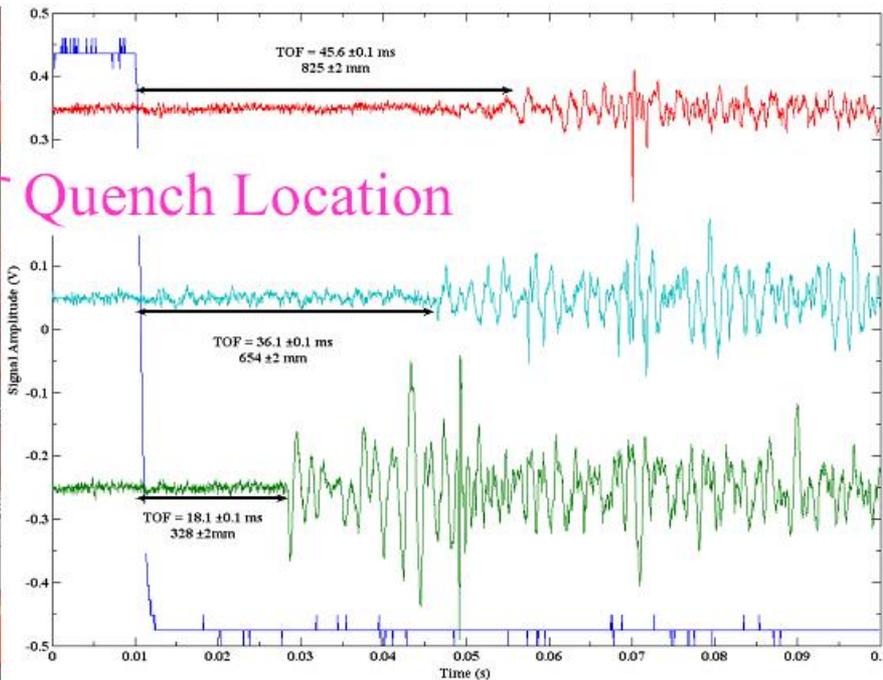




Und doch noch Forschung

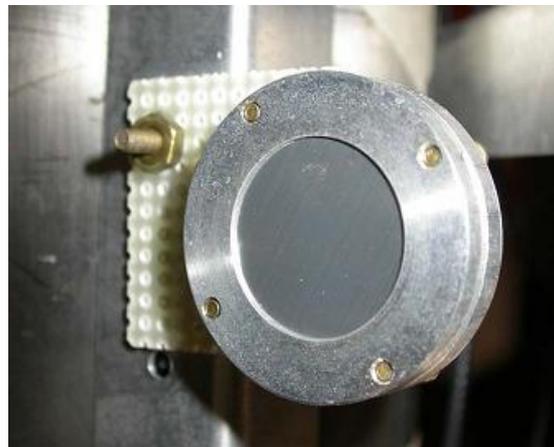


Lokalisierung von Quenchen
Temperatur-Karten
Optische Inspektion

Ein zweites Beispiel: *2nd Sound in liquid Helium*

@ 2K ($v_s = 16.68$ m/s), horizontal scale = 5 ms/Div

Quench Location



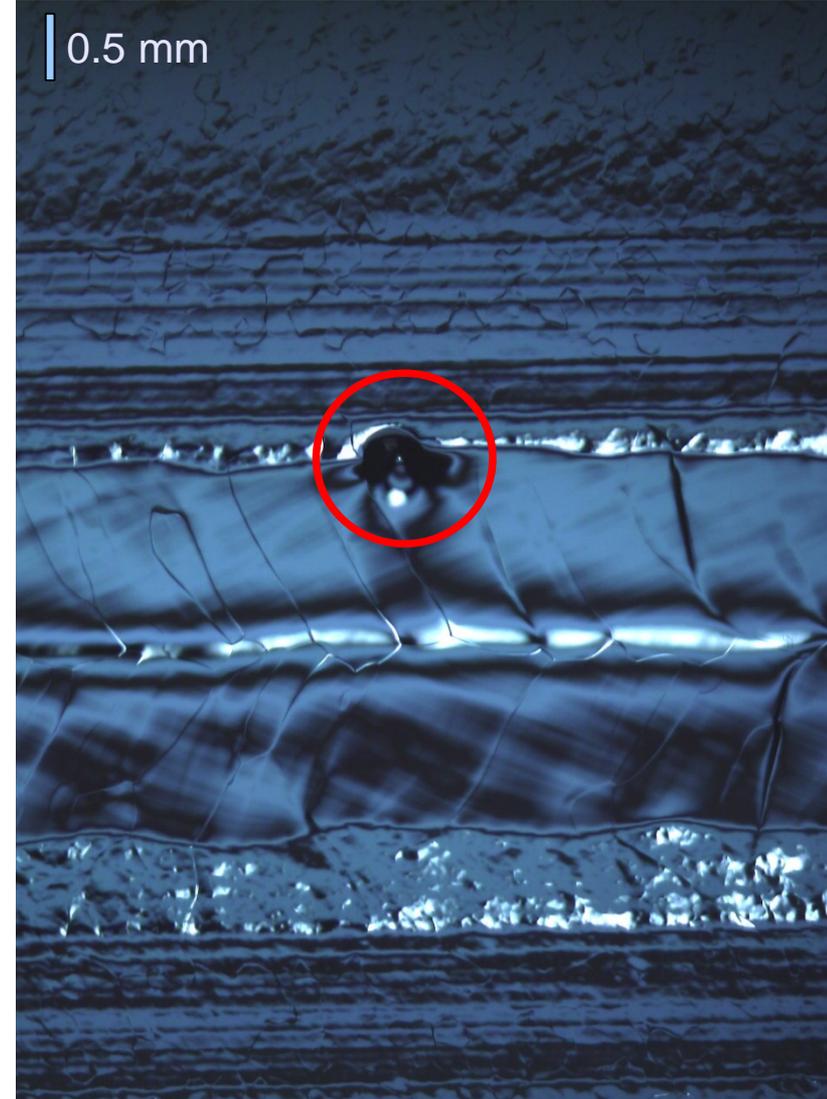
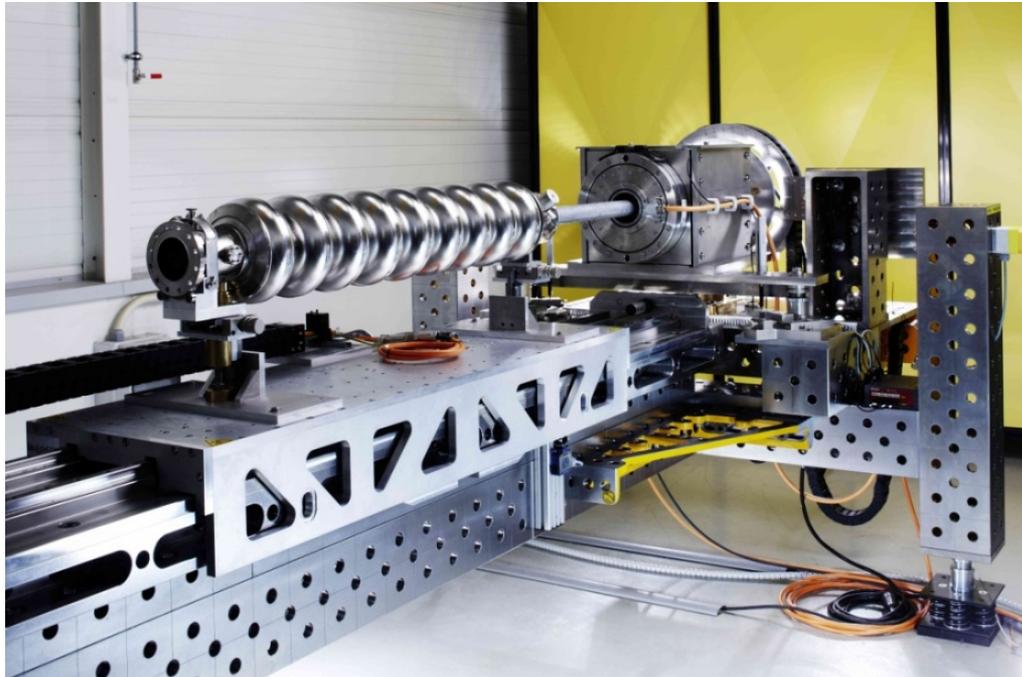
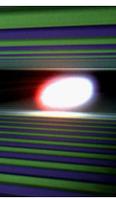
Transducer
(eine Art Mikrophon)

Listen to the sound of the phase transition

Wärme wird hier als Welle übertragen im Unterschied zur Diffusion

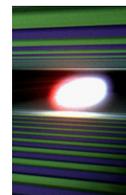
Ein Quench erzeugt einen Temperaturanstieg und einen Phasenübergang im Helium. Die Wärmewelle überträgt sich mit etwa 20 m/s. Das kann man messen! Und auf den Quench-Ort schließen.

Inspektion der inneren Cavity Oberfläche ist wichtig für XFEL und ILC Entwicklung

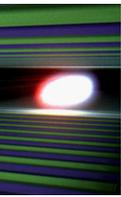


- Kartography der inneren Oberfläche von supraleitenden Beschleunigungsstrukturen
- Einfluß von Oberflächendefekten auf die Begrenzung der Beschleunigungsfeldstärke
- Systematische Analyse mit **OBACHT / DESY**

Ein großes Schneidrad



... für einen langen Tunnel



Hard x-rays

SPB : Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules

- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.

MID : Materials Imaging & Dynamics

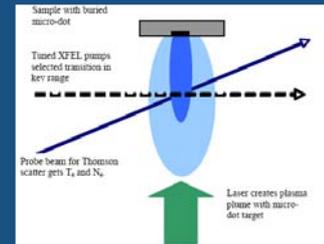
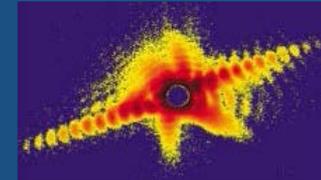
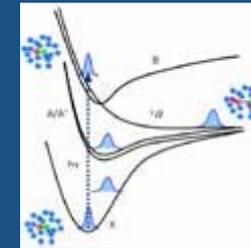
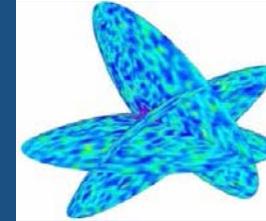
- Structure determination of nano-devices and dynamics at the nano-scale.

FXE : Femtosecond X-ray Experiments

- Time-resolved investigations of the dynamics of solids, liquids, gases

HED : High Energy Density Matter

- Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas



Soft x-rays

SQS : Small Quantum Systems

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

SCS : Soft x-ray Coherent Scattering/Spectroscopy

- Electronic and real structure, dynamics of nano-systems and of non-reproducible biological objects

