CLIC Accelerating Structure R&D Introduction

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X-band workshop
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Outline

- The three goals of the structure R&D program
- Introduction to CLIC accelerating structures
- Main technical challenges
- Overview of activities
- Specific topic: rf constraints

Goal one

Demonstrate the feasibility of 100 MV/m (equivalent loaded gradient) by 2010.

- with an appropriate pulse length, pulse shape and breakdown rate

- structure with all major features such as full length, higher order mode damping etc.

- would give a reasonable efficiency in CLIC (good rf to beam efficiency, low enough wakes for good beam dynamics)

- design, build, prepare and test lots of structures and test areas

Goal two

Design (and maintain design) of the nominal accelerating structure for the CLIC which,

- provides the basis for the study of the rest of the machine (so must anticipate developments)
- gives an optimized efficiency in CLIC
- should survive 10^{11} pulses (from predicted fatigue behavior based on specialized experiments)
- could be made to required tolerances, microns, in mass production after dedicated development
- would be part of a cost minimized CLIC when fully integrated in the machine

Goal three

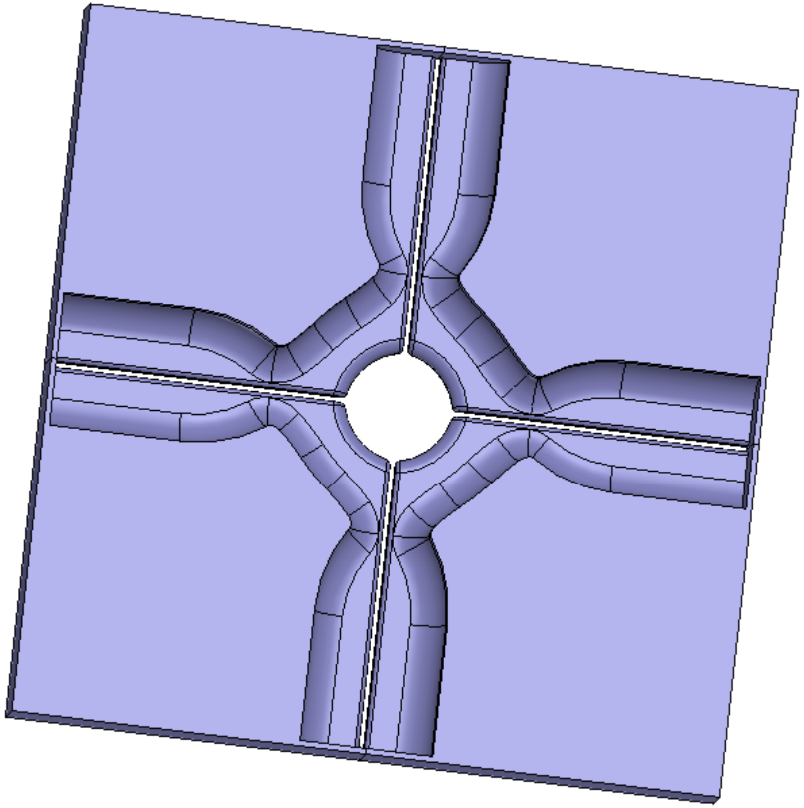
Investigate new ideas and technologies which would give higher performance.

- understand and quantify breakdown
- develop new rf designs (rf parameters, input couplers, damping mechanisms for example) with better high-power performance
- new materials
- new processing/cleaning/preparation
- improve tolerances

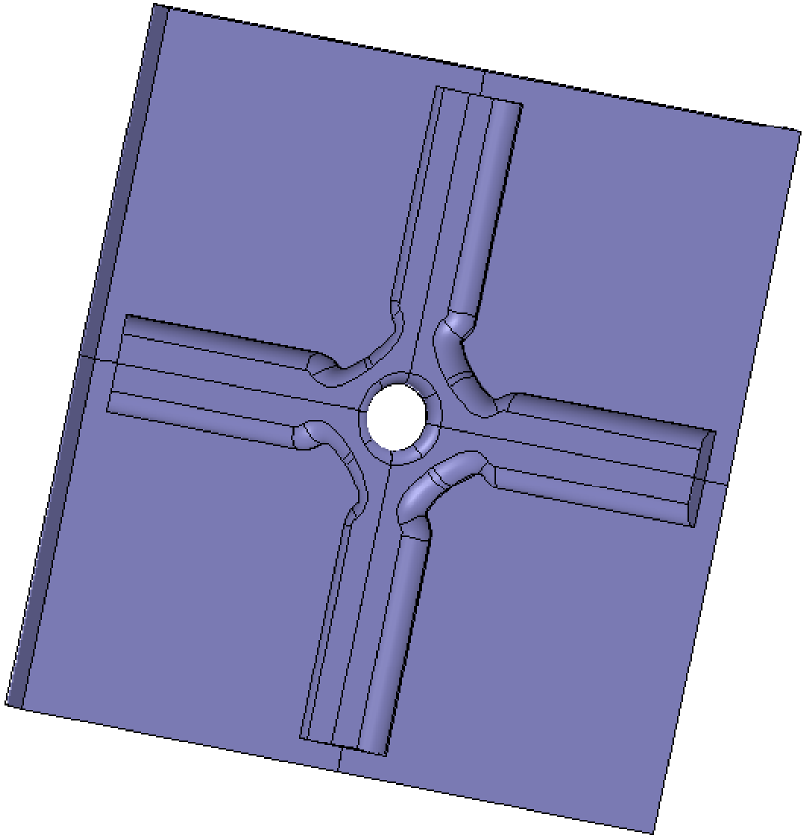
Introduction to CLIC accelerating structures

Traveling wave structure, heavy transverse mode damping, detuning

Two main types under consideration – Hybrid Damped Structure (HDS), Waveguide Damped Structure (WDS). Reevaluation of DDS and choke mode in pipeline.

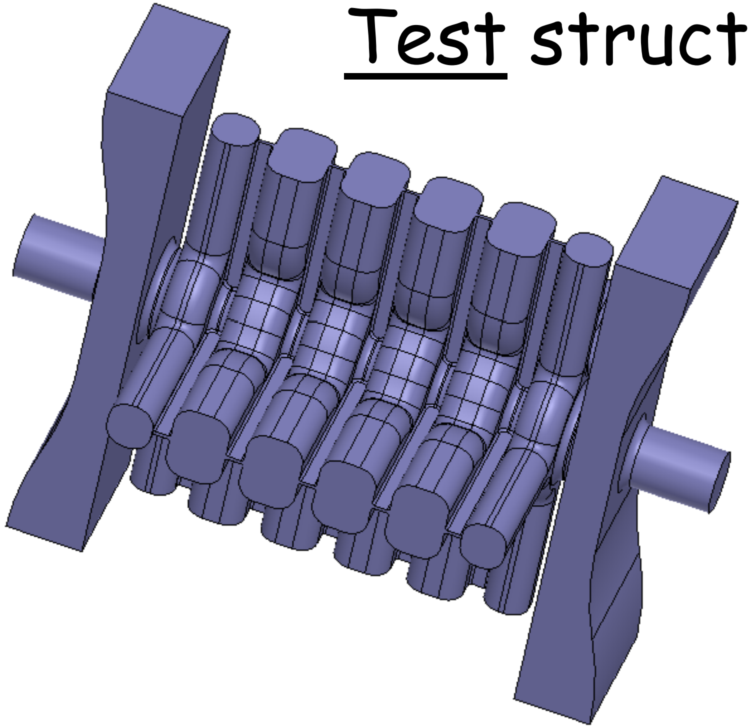


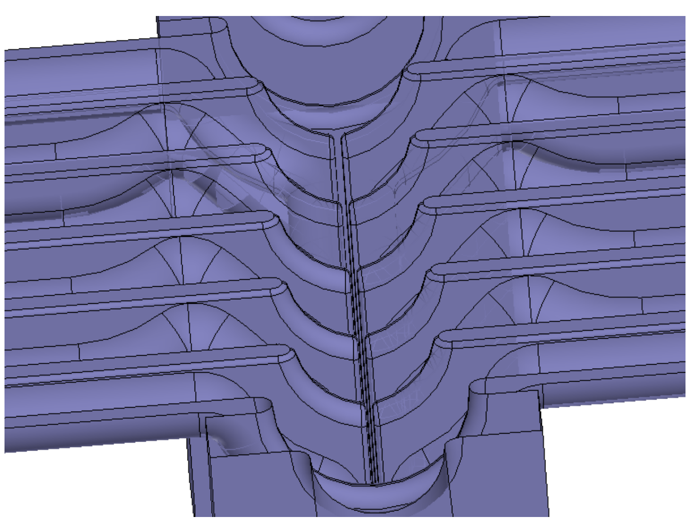
HDS: better for pulsed surface heating, quadrant assembly necessary



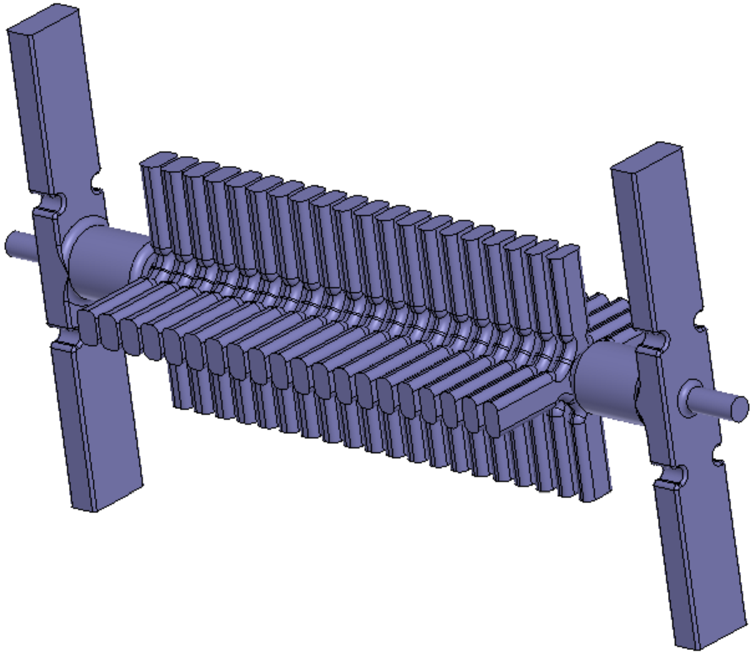
WDS: less risk of enhanced breakdown at iris, disk or quadrant assembly

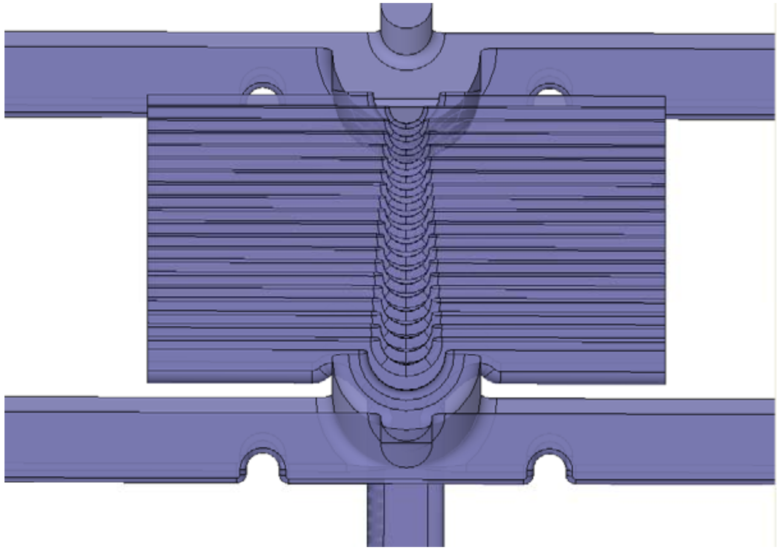
Test structures





HDS



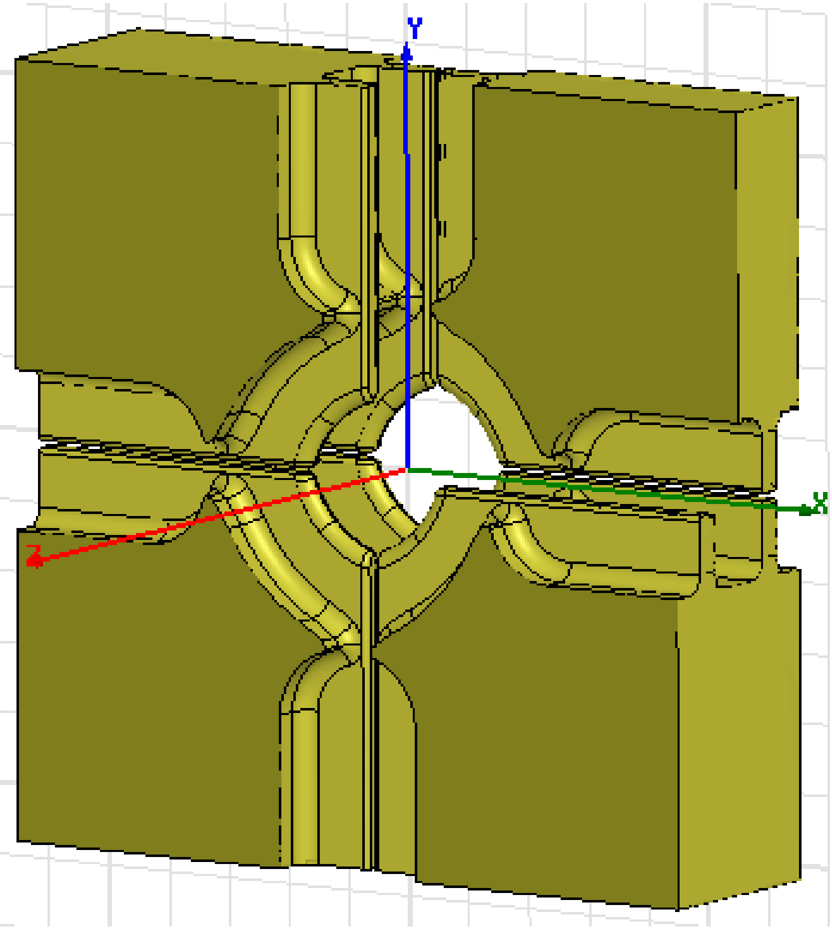


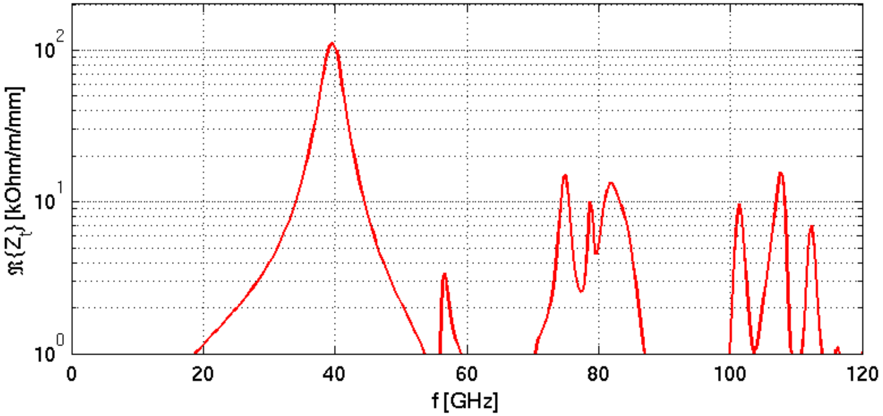
WDS

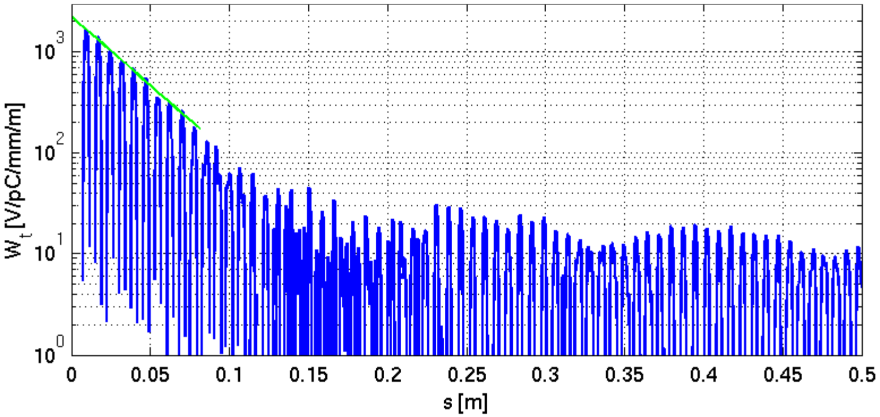
Hybrid Damped Structure (HDS)

Combination of slotted iris and radial waveguide (hybrid) damping

results in low Q-factor of the first dipole mode: ~ **10**

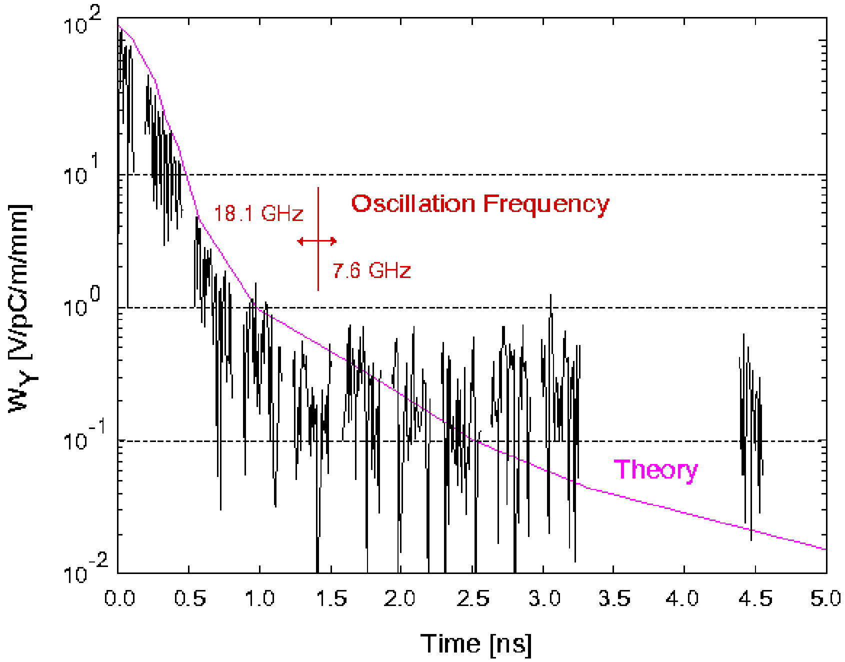


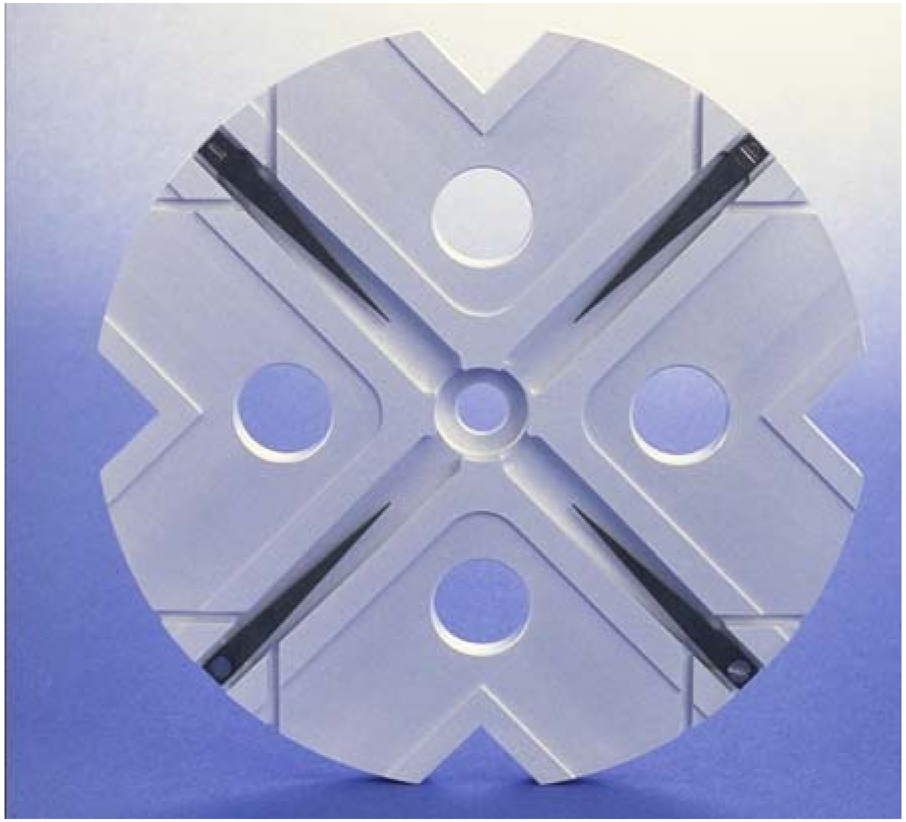




TDS design and modeling

- Strong damping, moderate detuning
- Damping computed via double-band circuit model. Circuit elements determined from MAFIA frequency-domain calculations. Load modeled using HFSS.

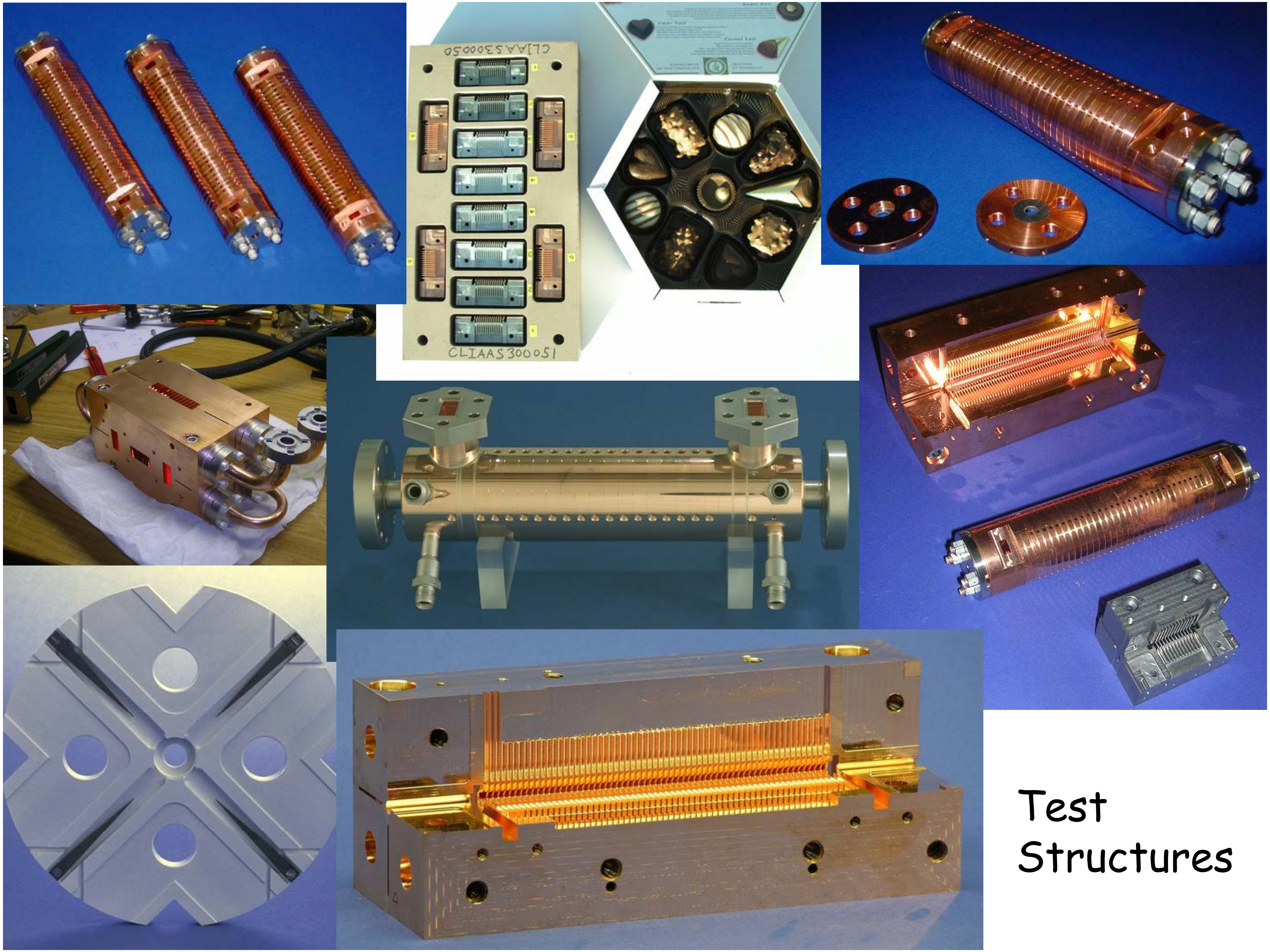




ASSET demonstration of damping

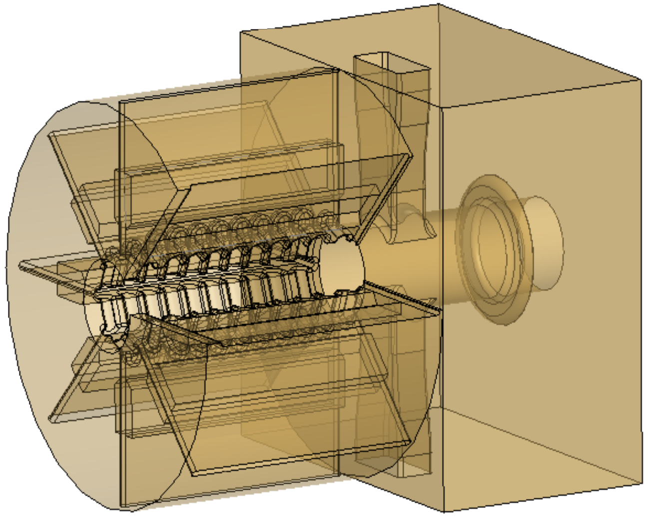
Long range wakefield benchmark

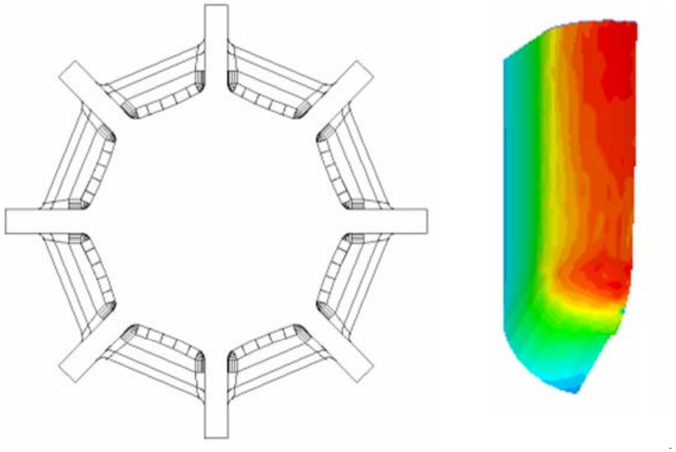
Test Structures



PETS

- The development program for power generating structures, PETS, is made in a close parallel to the accelerating structures.
- Many common rf concepts, computational techniques, fabrication but the over-moded, low gradient, high power high group velocity device has its own set of challenges.
- Many technological ideas used in the PETS are studied on the accelerating structures and will be carried over and will be checked experimentally when the 2BTS is available.
- The PETS as rf objects are not covered in detail in this ACE but Roberto will cover their integration in the drive beam decelerator.





Main technical challenges in accelerating structures

rf breakdown

pulsed surface heating

transverse wakefield damping

tolerances

cost

(dark current capture)

I will only discuss the first two subjects in any detail and make only a preparation for discussion of the other subjects

rf breakdown, short summary

Accelerating gradient is limited by breakdown (arcing, sparking),

- sets ultimate gradient of a structure.

- gives lower practical gradient for an acceptable breakdown rate. CLIC will have around 10^5 structures, spark acts on beam so our working estimate for breakdown rate is 10^{-6}. Breakdown rate is standard measurement in testing. Model for exponential behavior exists (I don't have time…). Kick was measured in NLCTA and will be measured again in the 2BTS.

- damages structure during conditioning when running above the operating (low breakdown rate) power and/or in accumulated breakdowns over lifetime of the machine (10^{-6}x10^{11} is still a lot of breakdowns). Investigation of new materials was initiated by this. Inspection of structures standard procedure.

rf breakdown, numbers

1. Low a/λ=0.12 X-band structure ran at 150 MV/m, 150 ns in 1994 but at high breakdown rate (values were not measured). Aperture was considered to be too small for use in a collider.
2. 30 GHz tests in CTF2 through 2001 showed high gradients (193 MV/m with Mo!) but at short pulse lengths (16 ns), high breakdown rates and with chewed up structures.
3. NLCA structures made 55 MV/m, 400 ns, 10^{-6}.
4. Strong evidence from first full year of full pulse length, correct breakdown rate 30 GHz testing in CTF3 that 150 MV/m is out of range for 2010.
5. Strong evidence from first full year of full pulse length 30 GHz testing in CTF3 that frequency scaling is either weak or flat.

There is more consistency here than first appears, rf constraints…

CLIC fatigue studies

Problem:

The surfaces exposed to high pulsed RF (Radio Frequency) currents are subjected to cyclic thermal stresses possibly resulting in surface break up by fatigue.

Fatigue performance of the cavity material has a direct influence on the achievable gradient of the machine.

Aim:

To find a material for the CLIC accelerating cavities, which can sustain the highest gradient during the 20 years of CLIC operation.

Challenge:

No material data exist in the literature for the CLIC parameter range.
Required number of cycles is 2.33×10^{10}.

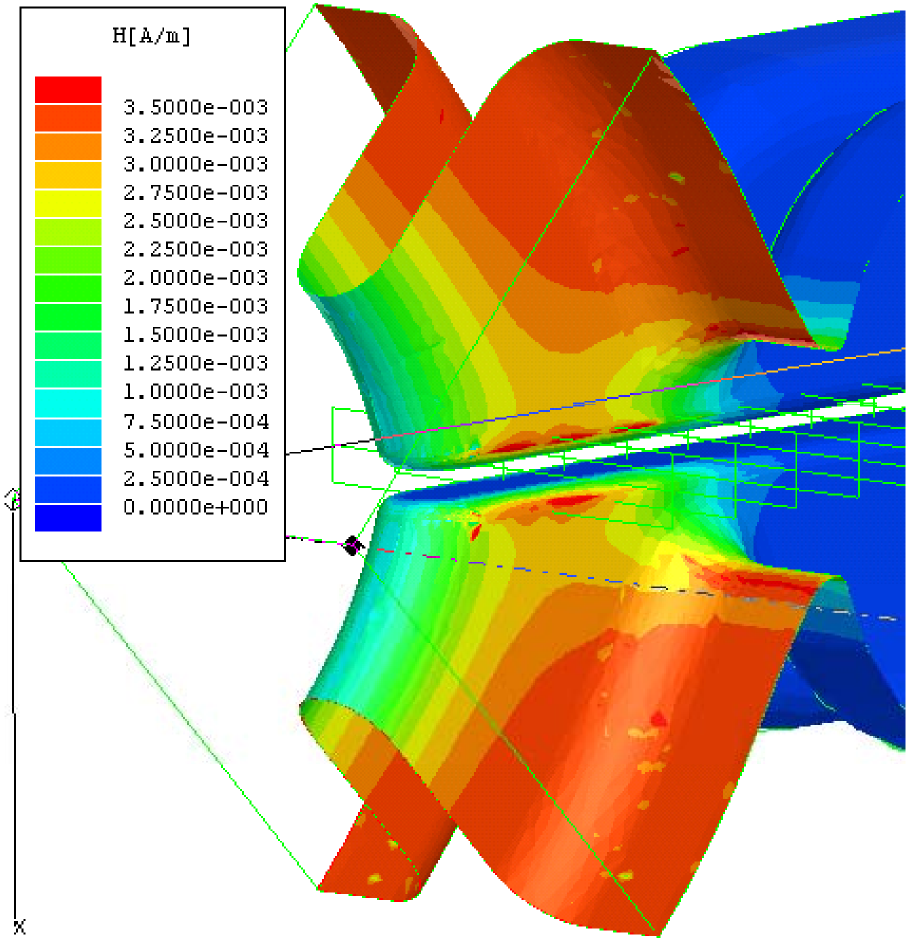
Methods:

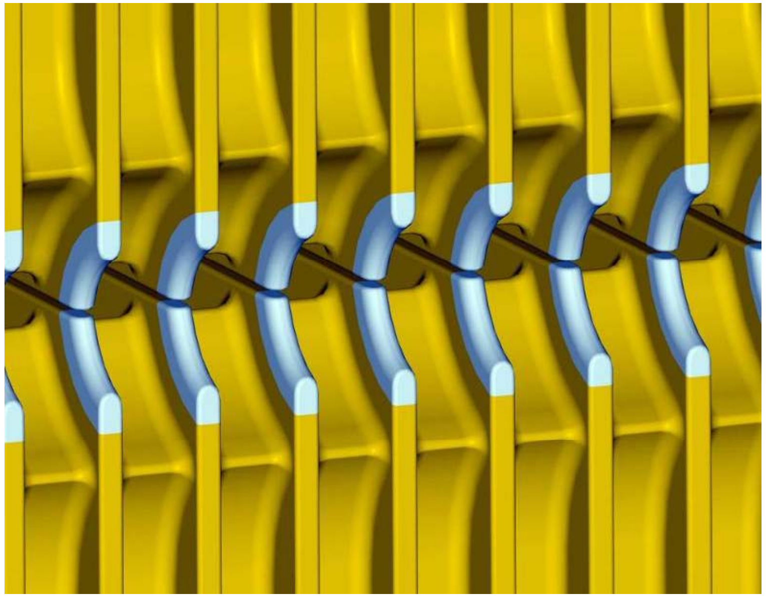
Ultrasonic fatigue test setup is used to study the high cycle fatigue. CLIC lifetime can be achieved in 20 days.

Pulsed laser test setup is used to study the thermal fatigue phenomena at low number of cycles range.

RF fatigue test setup, in collaboration with SLAC, California, is used to make few experiments in real conditions to validate the ultrasound and laser data.

Surface magnetic field causes pulsed surface heating



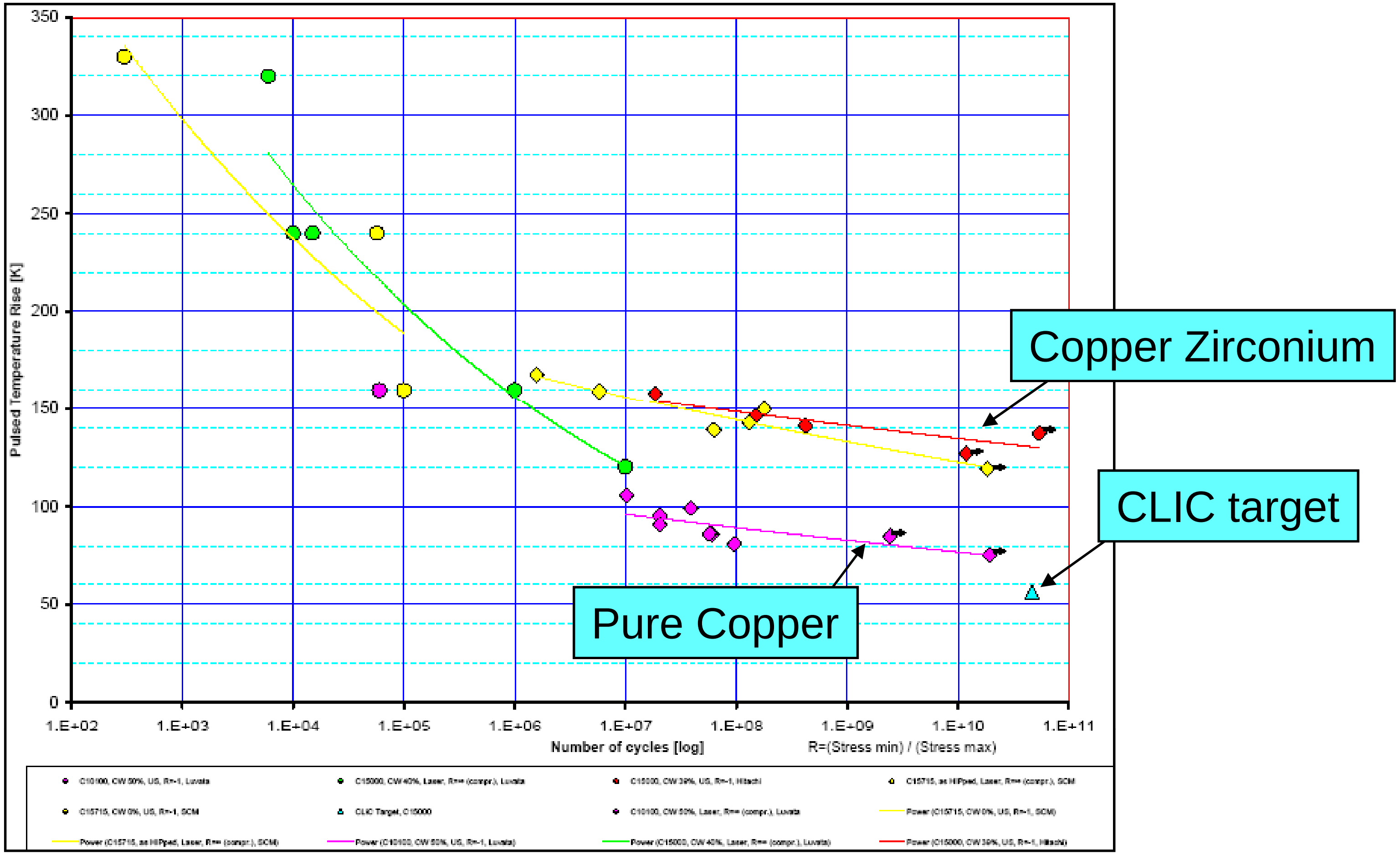


CLIC fatigue studies

Based on Ultrasonic and Laser tests, currently the best candidate is Copper Zirconium (C15000).

Current data suggest, that it will sustain the CLIC target gradient.

RF fatigue experiments at SLAC this summer will validate the data!



Optimization

Optimization procedure was developed to make a search for feasible parameters which takes into account high-power rf constraints, rf design, effect on beam and eventually cost (talks of myself, Alexej, Daniel and Hans).

Personal summary of outcome: 100 MV/m at X-band in copper is reachable assuming reasonable scalings of existing results. Demonstrating (as opposed to defending) this is GOAL 1.

The choice of parameters and the need for efficiency however leaves us with very demanding, few to ten micron, fabrication, alignment and measurement tolerances.

Now a simplified view of the main interplays which dominate our design,

Interplay 1

Geometries which give higher gradients are generally worse for beam dynamics (increased wakes, emittance growth and consequently lowered efficiency).

Directions,

- Quantify the relationship between structure geometry and gradient. Basic data from structures with different parameters analyzed, more data needed.

- Integrated rf design/beam dynamics/cost design loop.

- Improved mechanical tolerances and/or structure BPM performance!

- Better processing, materials etc.

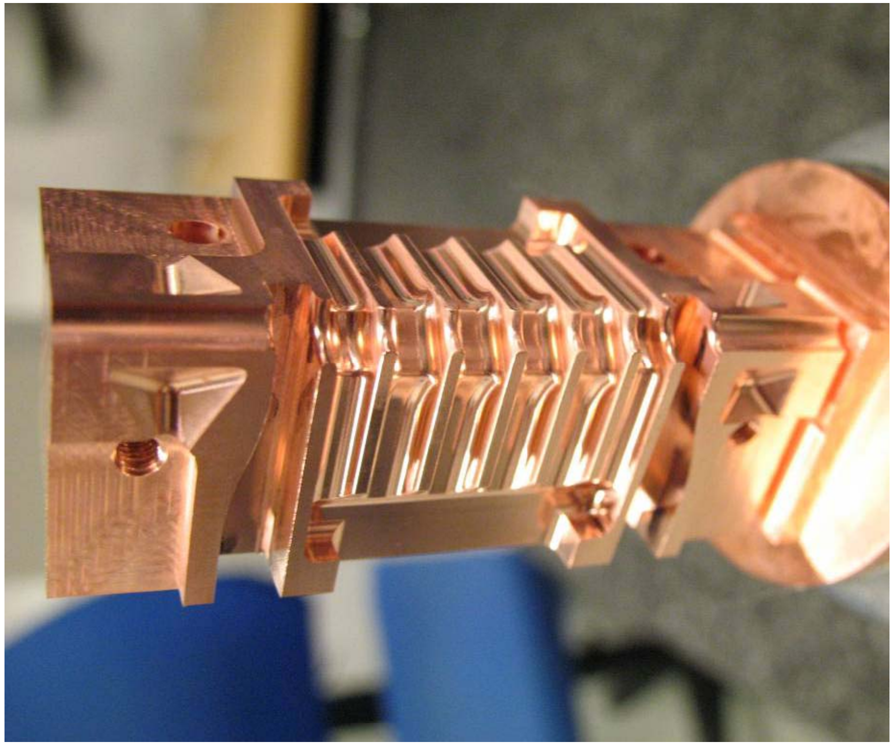
Interplay 2

Features needed for higher order mode damping cause increased pulse surface heating and can give lowered gradient potential from rf breakdown

Directions,

- High power comparison of damping schemes (Slotted iris HDS, waveguide damped WDS, revisit DDS and choke mode)
- Quantify rf breakdown
- Integrated rf design/beam dynamics/cost design loop (I know I am repeating myself)
- Basic data on pulsed surface heating, raise potential through copper alloys, etc.

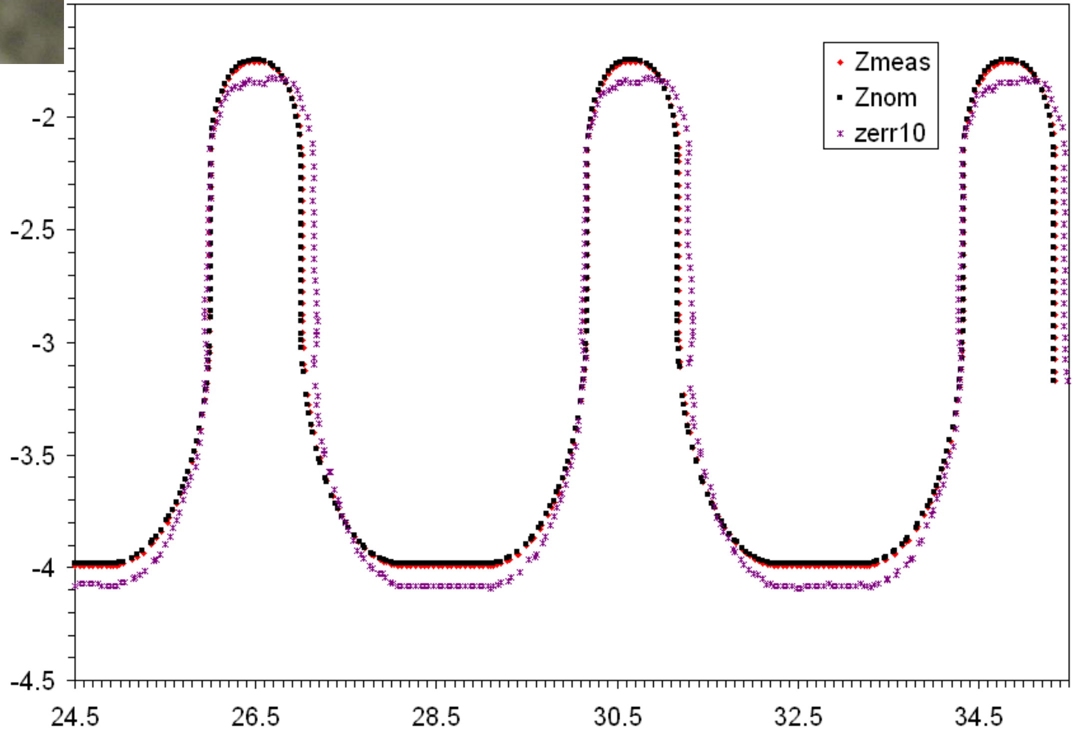
Achieved tolerances in 3-d milling



Result: Machine movement is accurate to better than a couple of μm (probably below measurement error).

Measurement and input of tool diameter into machining file gives dominant error. About 12-15 μm. Cut then fit calibration must be implemented.

error scale expanded by x10



This data is for a 30 GHz structure, expected improvement at X-band from larger tool.

Structure activities overview

- rf design, computation
- rf testing. Ongoing: 30 GHz testing in CTF3 and X-band testing at NLCTA. Future: 2BTS in CTF3, KEK, MYTUBE at CERN
- dc spark testing. Used to quantify preparation procedures and test new materials. Will be used to benchmark breakdown simulation work.
- Preparation technique studies. Heating, etching, rising etc.
- New materials for breakdown (this activity is regrouping after inconsistent results from Mo) and for pulsed surface heating. Bimetallics.
- Precision machining studies

Structure activities overview, continued

- Breakdown theory. Quantifying limits, trigger mechanisms, rf absorption, damage mechanisms.

- ultrasonic, pulsed laser and rf fatigue testing

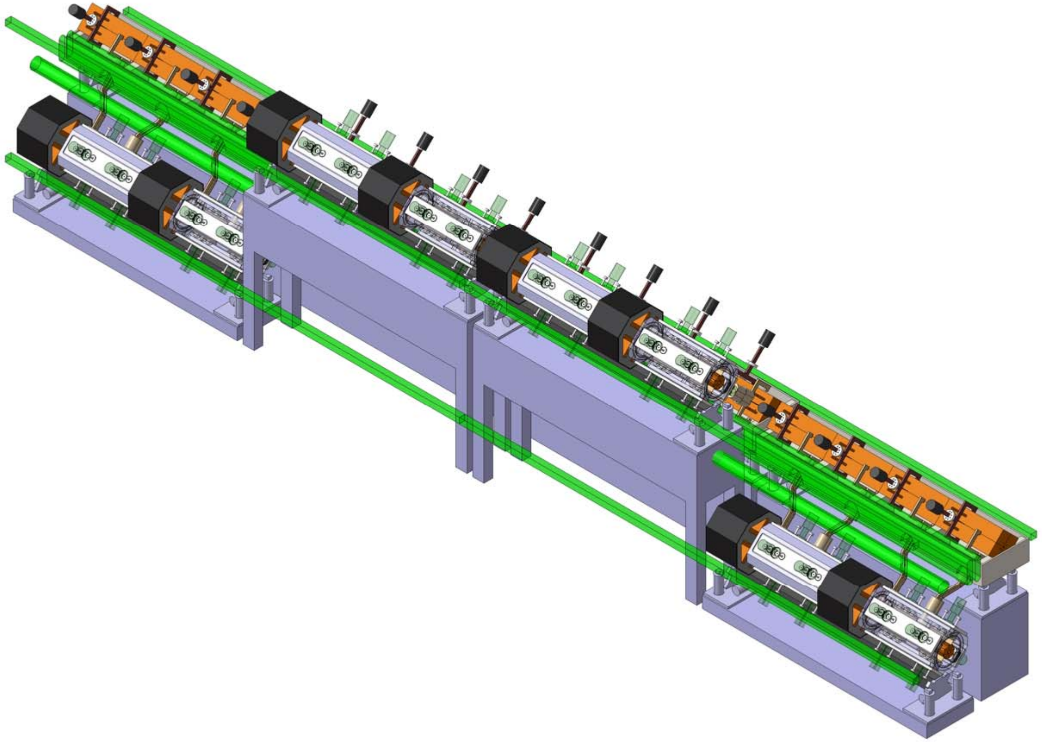
- Collaborations (ongoing and developing): BARC (India), Cockcroft Institute, Dubna, Finnish Industrial network, Frascati, HIP Finland, IAP Ukraine, KEK, Pakistan, Saclay, SLAC, Uppsala

And not to forget,

- rf components

- PETS

- module design



rf constraints