The CLIC accelerating structure development program

MeChanICs Kick Off Meeting
6 September 2010
W. Wuensch

Outline

- Introduction
- Coupled rf design and linac optimization
- High-power test program
- Manufacturing
- Transverse wakefield suppression
- Fundamental breakdown and pulsed-surface-heating studies

Introduction:

The main challenges for accelerating structures for CLIC:

100 MV/m accelerating gradient with a breakdown rate of the order of 10^{-7}/pulse/m, pulse length of 250 ns. Performance is mainly limited by vacuum breakdown and pulsed surface heating. Need strong coupling to the beam to remain efficient which in turn gives,

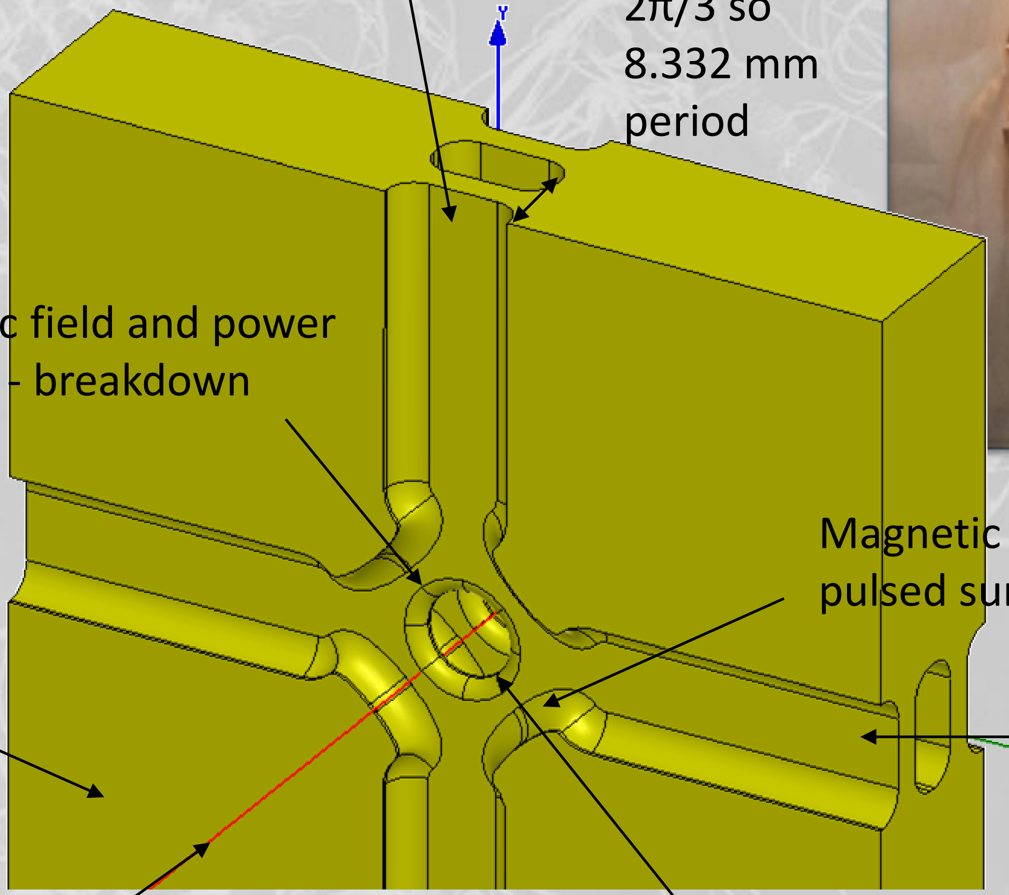
Demanding beam dynamics requirements - low short-range transverse wakefields and strong long-range wakefield suppression. Both complicate getting a high gradient. Requires micron assembly and alignment tolerances.

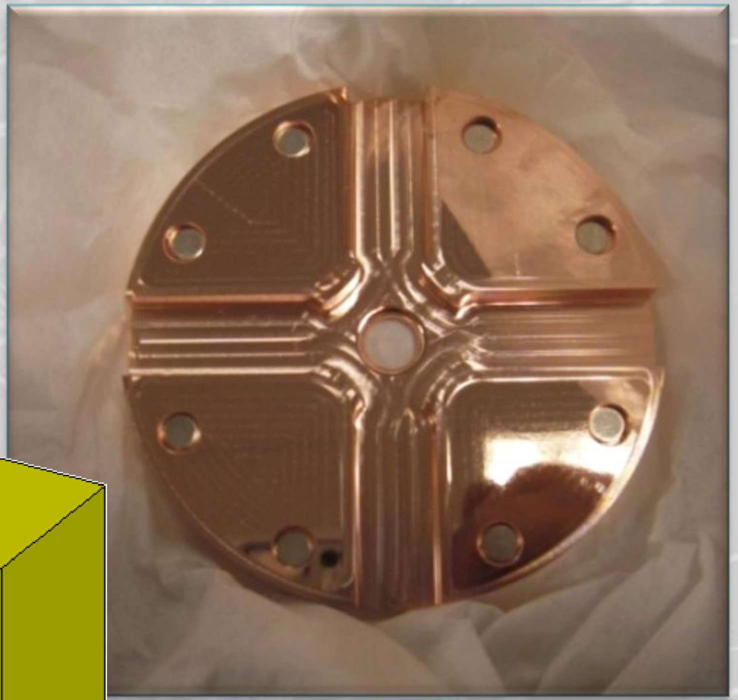
I will not cover our PETS, decelerating structure, program today.

Coupled rf design and linac optimization

Baseline accelerating structure features

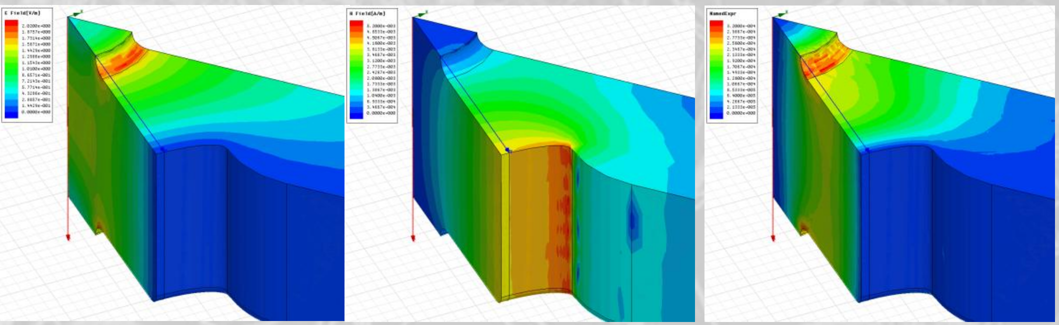
11.994 GHz,
2π/3 so
8.332 mm
period



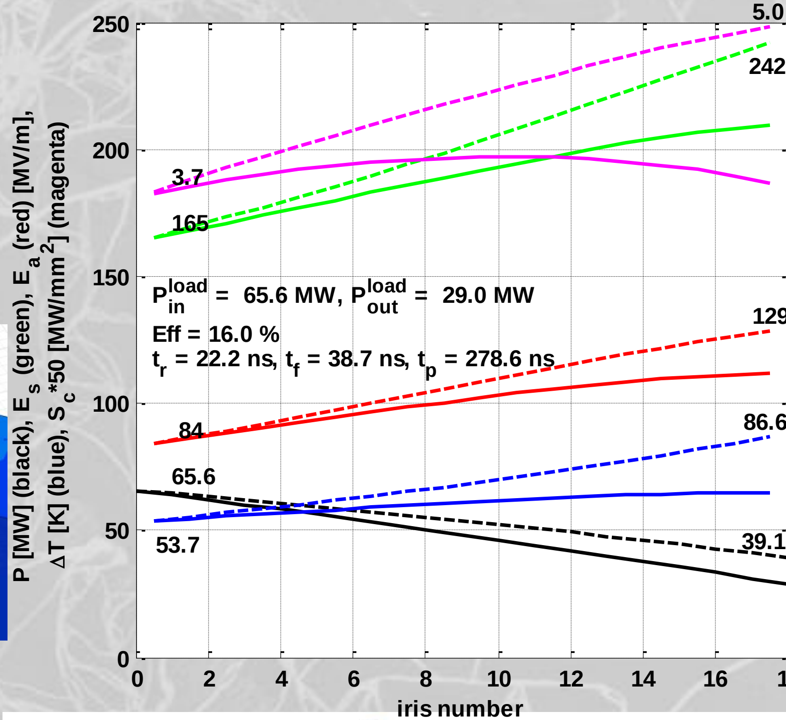


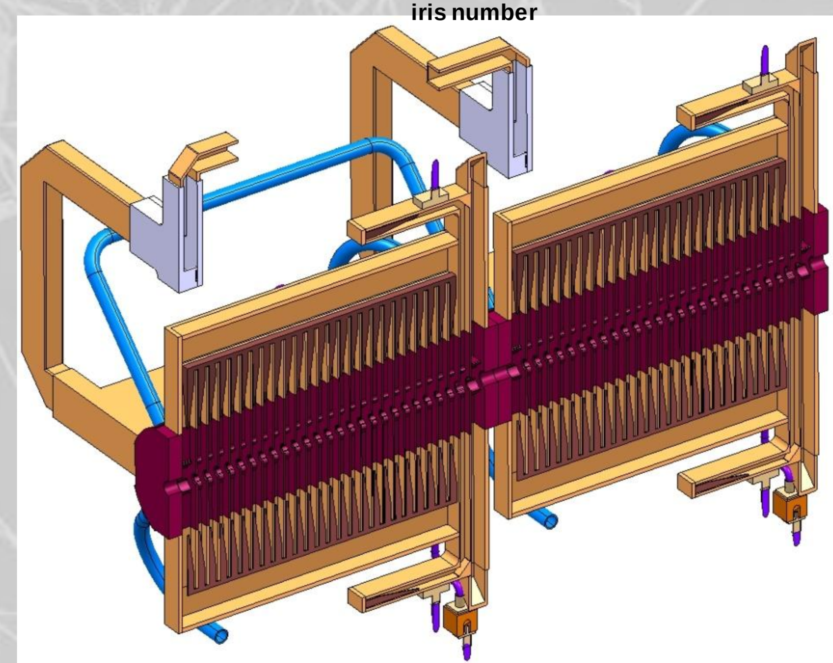
Accelerating structure features

E_s/E_a H_s/E_a S_c/E_a^2

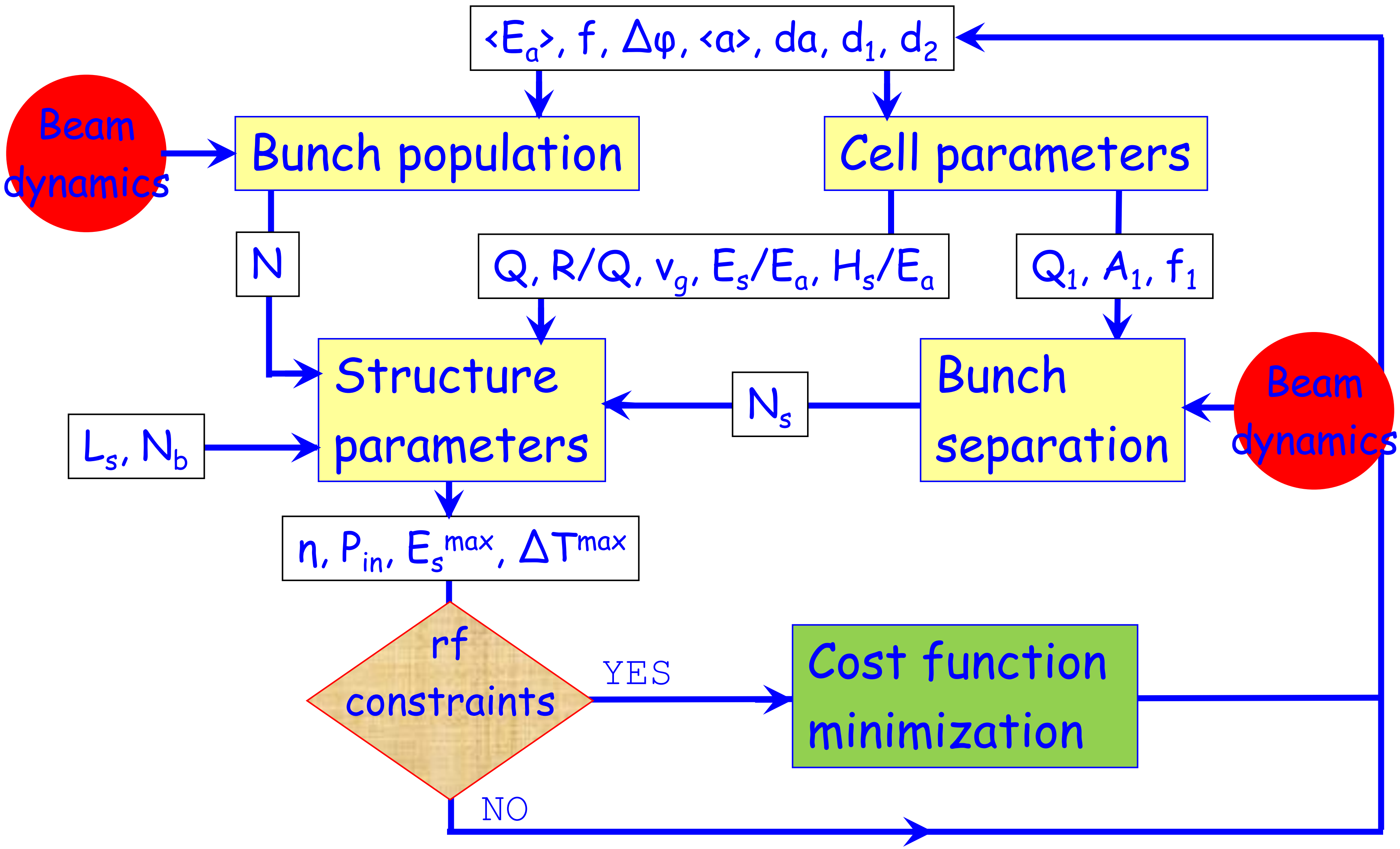


TD18





Optimization procedure



Beam dynamics input

$FoM = L_{bx}/N \cdot \eta$

BD → L_{bx}/N

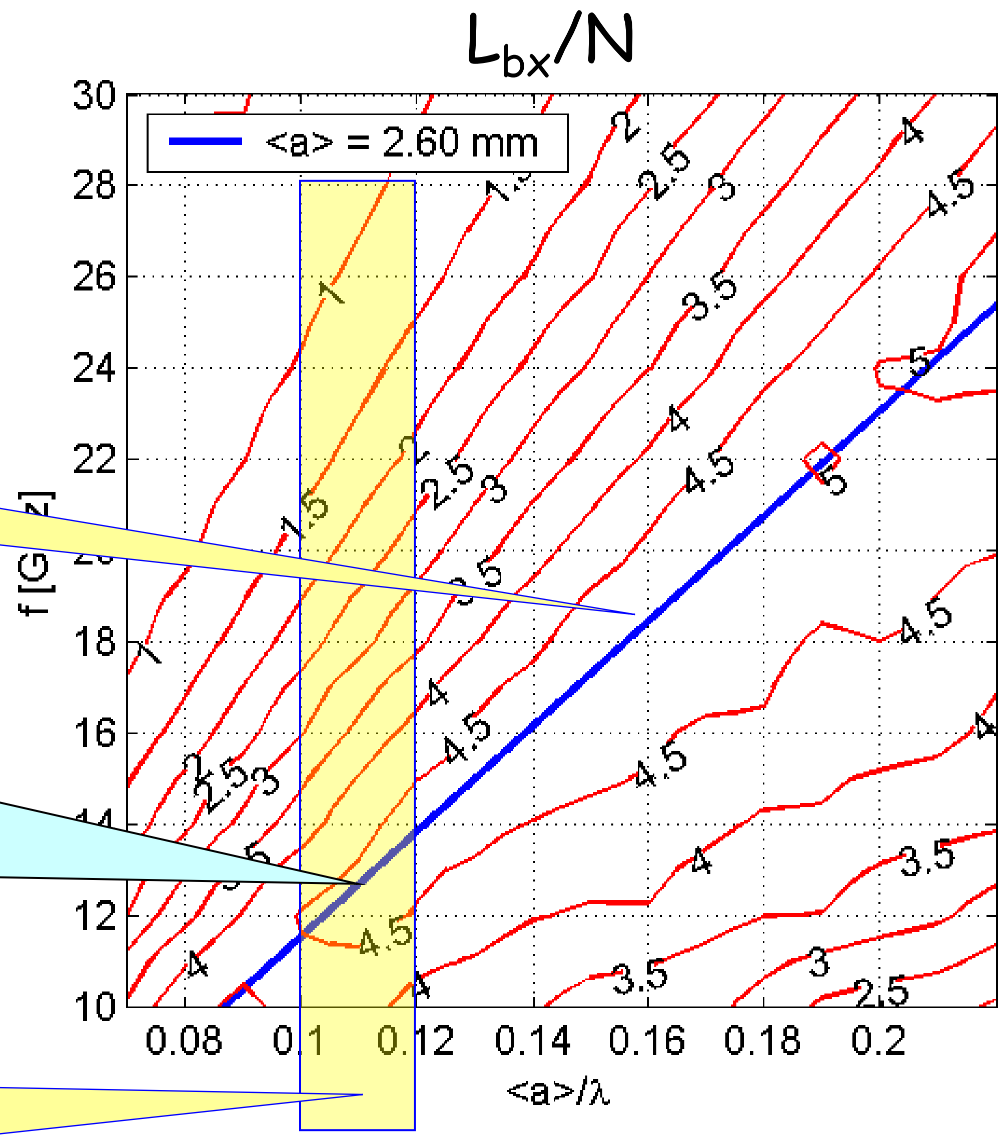
RF → η

BD optimum aperture:
<a> = 2.6 mm

Why X-band ?

Crossing gives optimum frequency

High-power RF optimum aperture: <a>/λ = 0.1 ÷ 0.12

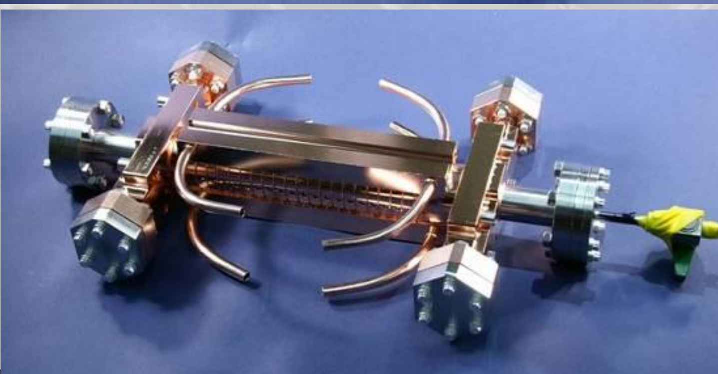


High-power test program

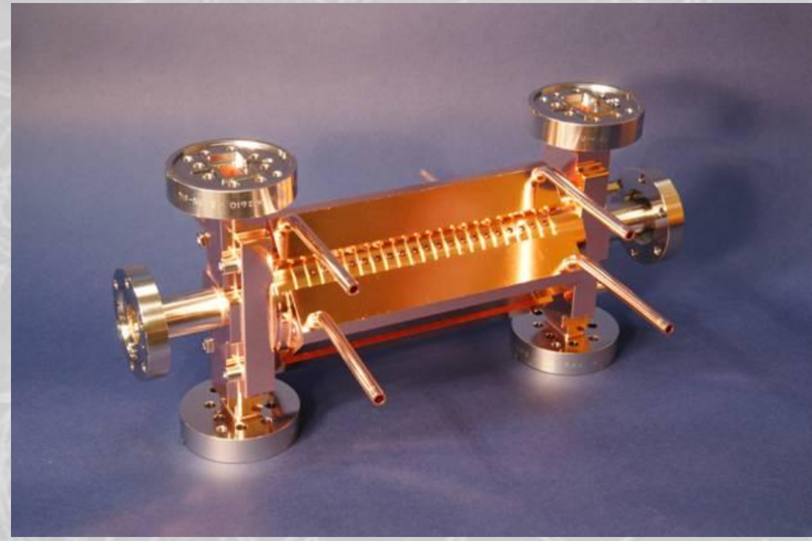
CERN/KEK/SLAC high-power test structures

T18 - undamped

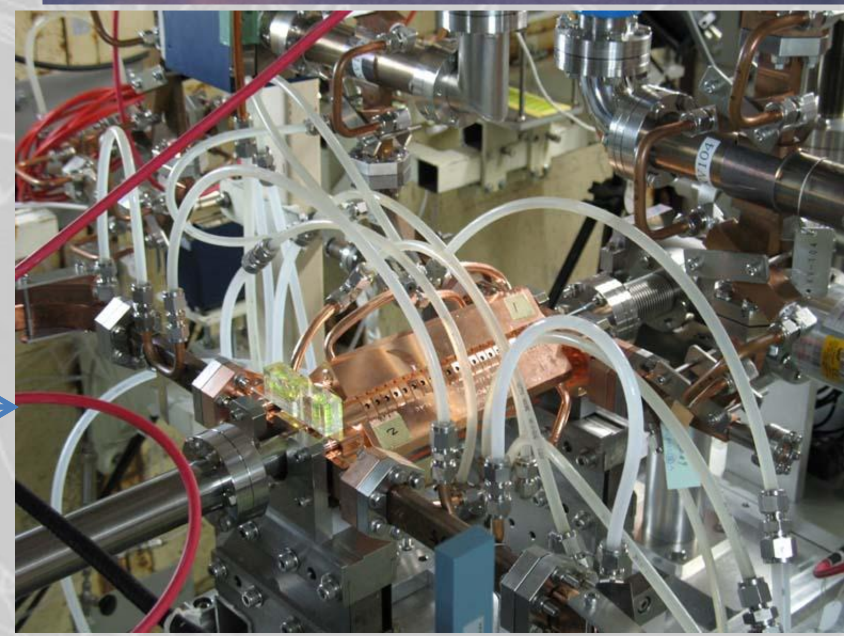
TD18 - damped



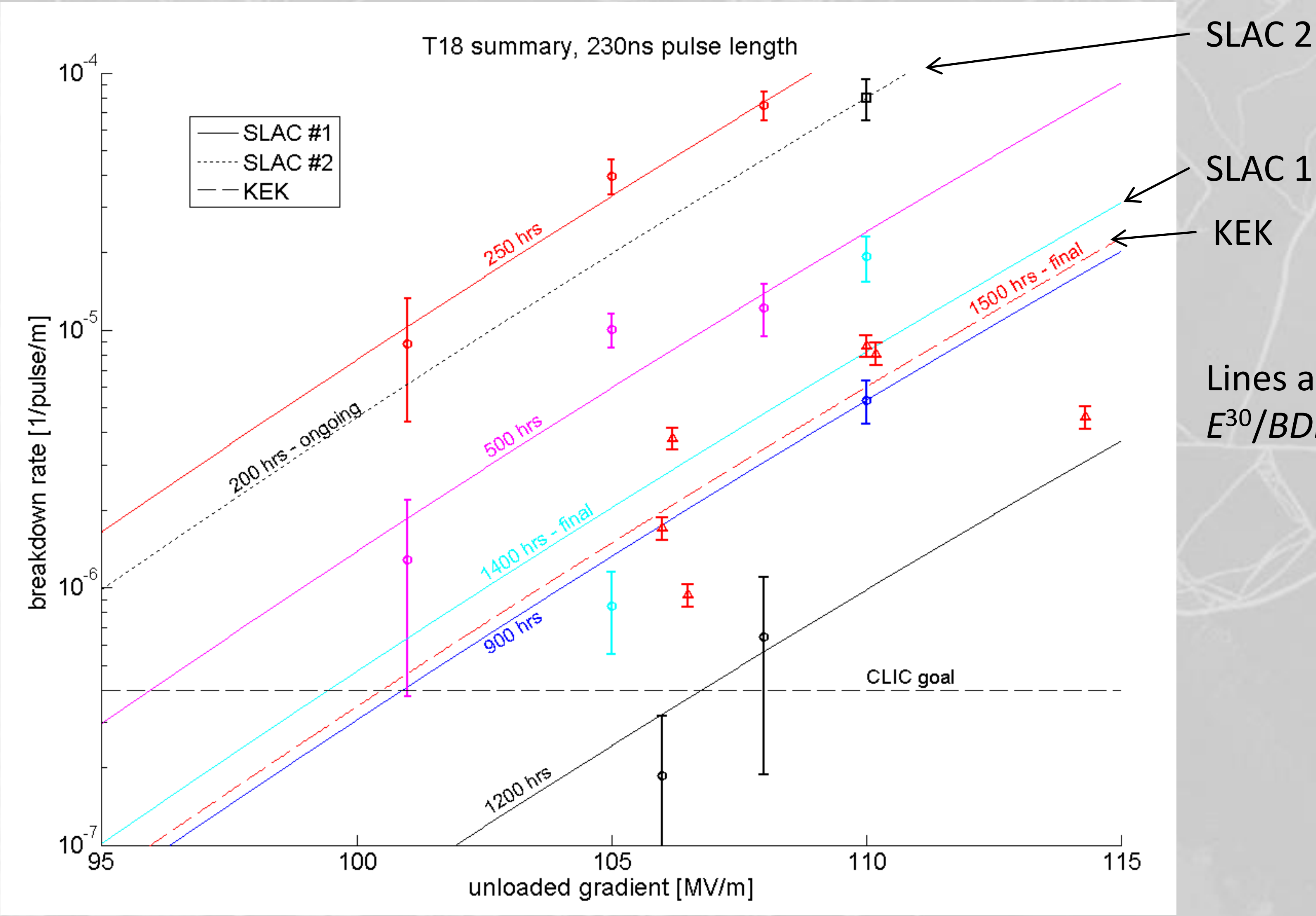
Done



Under test

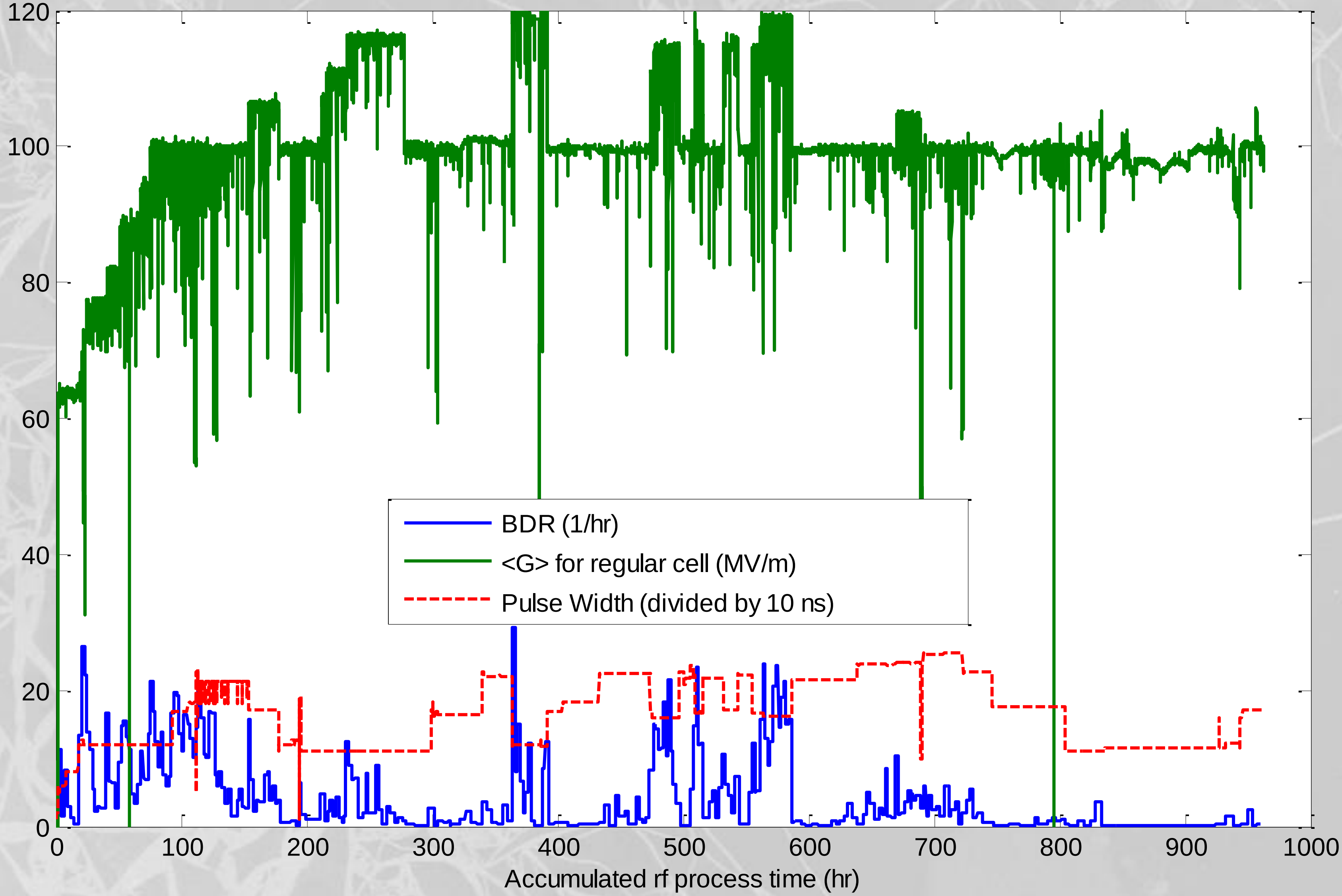


CERN/KEK/SLAC T18 structure tests



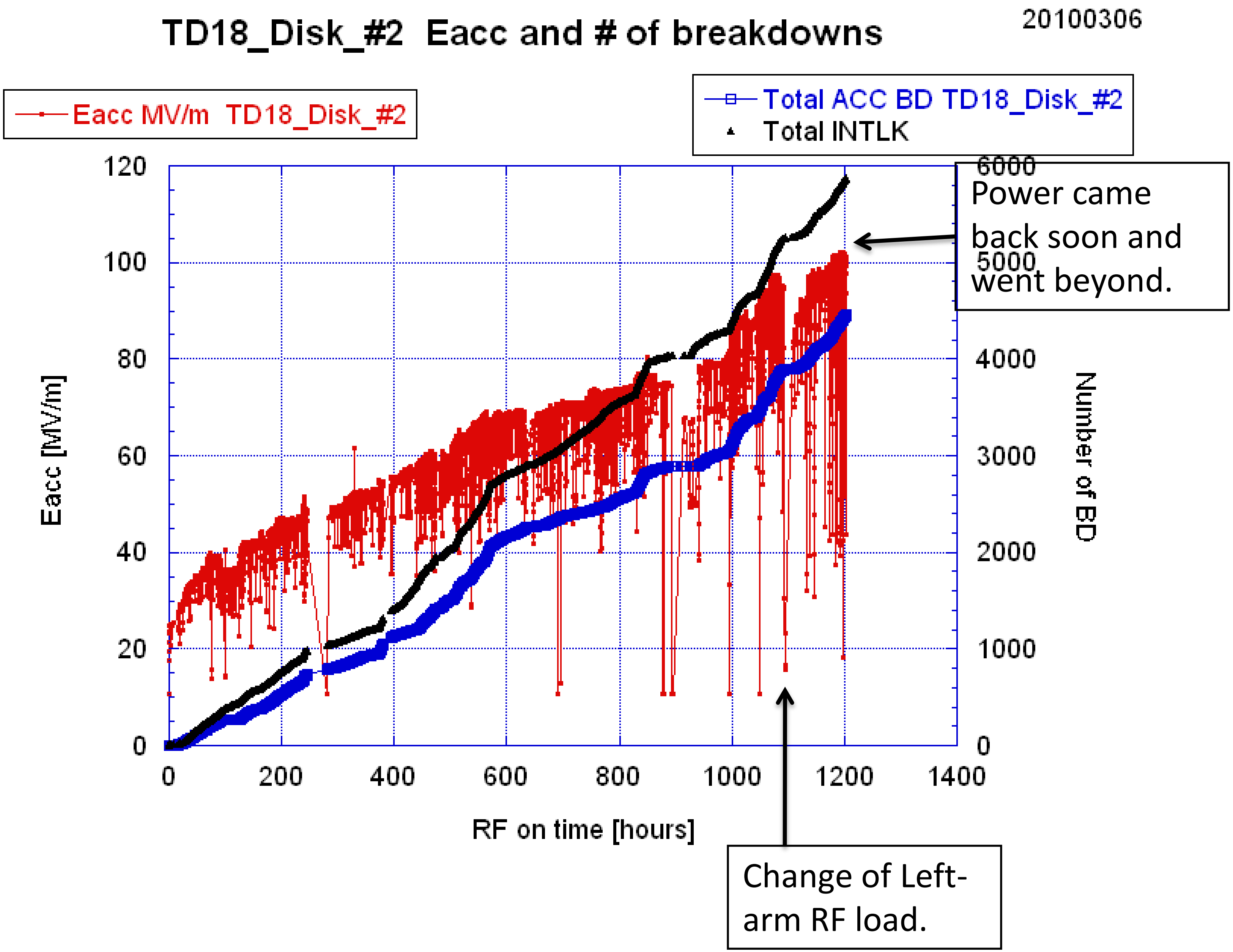
Lines are
E^{30}/*BDR=const*

High Power Test begin at 12/03/2009 15:00



TD-18

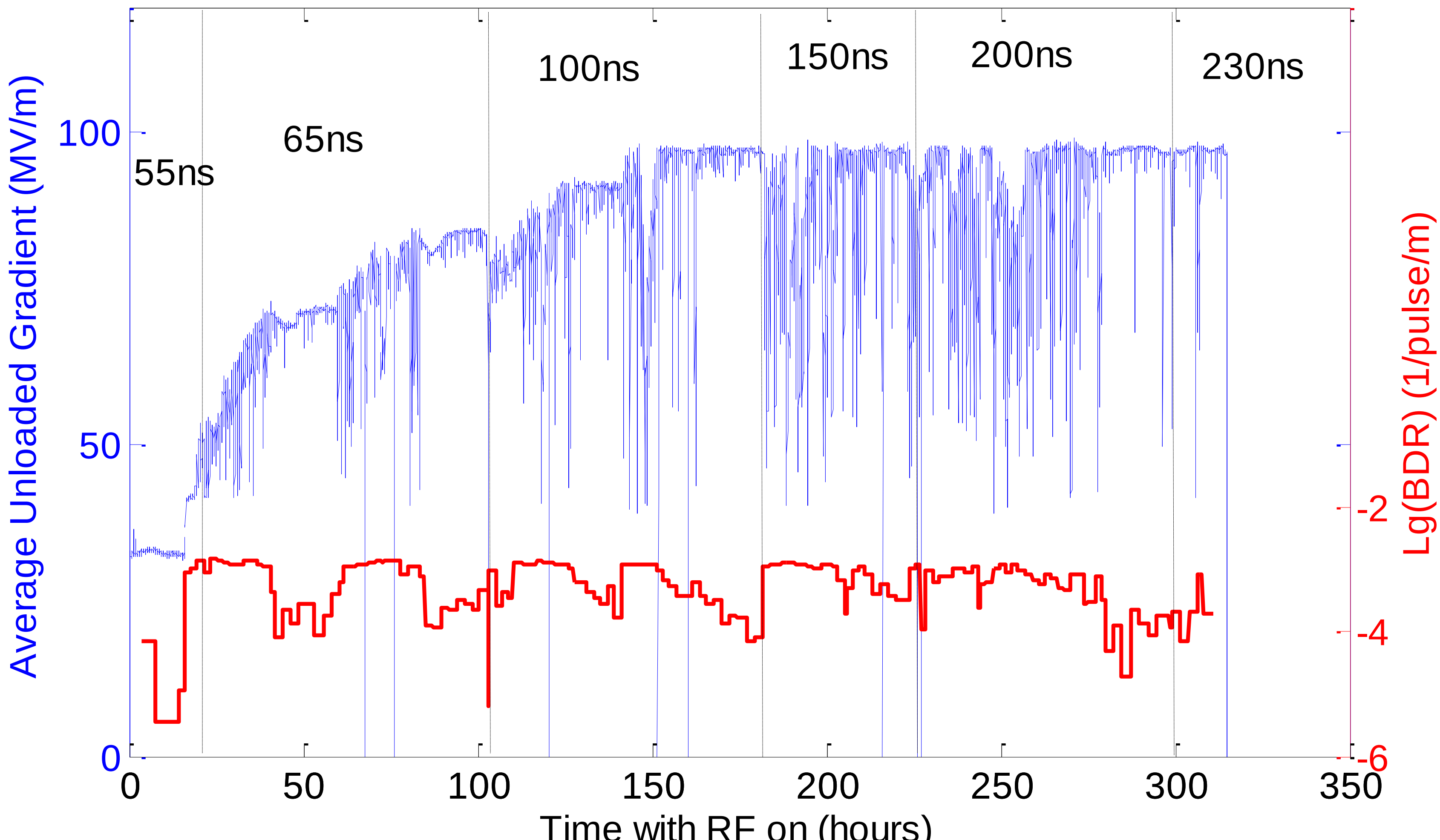
Faya Wang, SLAC



TD18_Disk_#2 Eacc and # of breakdowns
20100306
Eacc MV/m TD18_Disk_#2
Total ACC BD TD18_Disk_#2
Total INTLK
Eacc [MV/m]
Number of BD
RF on time [hours]
0
20
40
60
80
100
120
0
1000
2000
3000
4000
5000
6000
0
200
400
600
800
1000
1200
1400
Power came back soon and went beyond.
Change of Left-arm RF load.

RF Process Results T18_Disk_2 Made by CERN

Started at Aug/02/2010   1e-3(1/pulse/m) = 34.6/hour at 60 Hz for 0.16 m



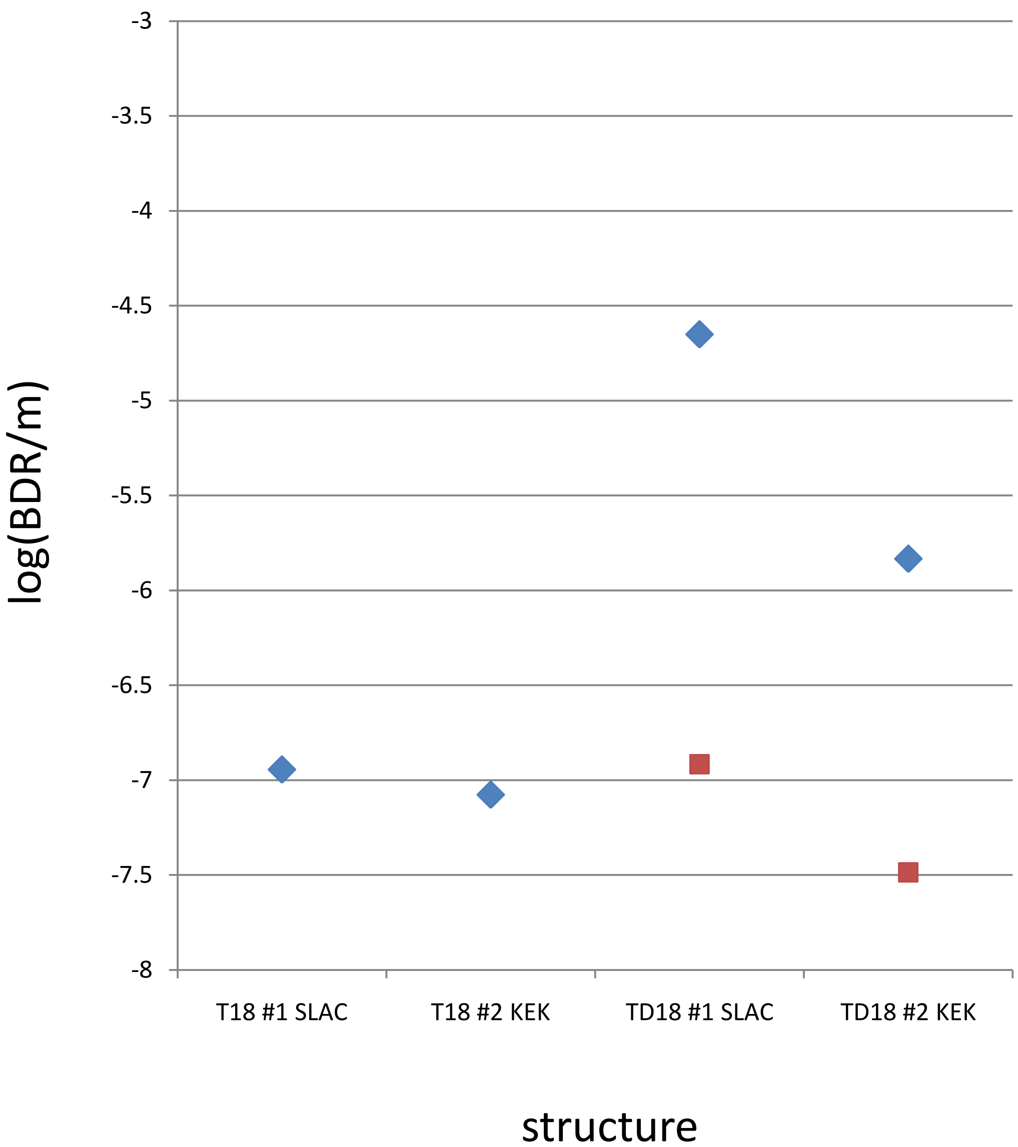
Current BDR = 1.7e-4/pulse/m ~ (6/hour)

Faya Wang

Summary of completed CLIC structure test results through June 2010 - measured data

Structure name	Unloaded gradient [MV/m]	Flat top pulse length [ns]	Breakdown rate [1/pulse/meter]
T18 #1 SLAC	105	230	1.6×10^{-6}
T18 #2 KEK	102	252	8×10^{-7}
TD18 #1 SLAC	85	230	2.4×10^{-6}
	100	230	7.6×10^{-5}
TD18 #2 KEK	87	252	2×10^{-6}
	102	252	1.4×10^{-5}

The effect of damping waveguides in T/TD18



All data scaled to a flat top pulse length of 180 ns using $E^6\tau$=const

Blue points – 100 MV/m-range data scaled to 100 MV/m using E^{29}BDR=const

Red points – 85 MV/m-range data scaled to 80 MV/m using E^{29}BDR=const

Conclusion – Waveguides in T/TD18 cost a bit less than a factor 100 in BDR or alternatively 20% in gradient.

Accelerating structure development core program

Adopt NLC/JLC technology

Structure for 100 MV/m using high-power scaling laws – T18

Two successful tests, third underway, have shown that **100 MV/m, 240 ns, 10^{-6} to 10^{-7} range is feasible.**

Add damping features – TD18

Successful start of one test already shows damping features do not significantly affect performance. **Damped structures at 100 MV/m are feasible.**

CLIC nominal structure with better rf design for higher efficiency – TD24 (and T24 to be systematic)

Predicted equivalent performance from high-power limits but more efficient. Needs verification, tests in spring.

Verification of features such as SiC loads, compact coupler, wakefield monitor

Mechanical design underway (tricky).

Fine tuning of design, optimization of process, medium series production and testing

Accelerating structure critical issues and programs 2

Long range wakefield damping of the order of two orders of magnitude in six fundamental cycles.

- Simulations using a number of different techniques and programs
- Experimental program including a test in ASSET and indirect wakefield monitor tests.
- Baseline heavy damping. Alternatives are slotted quadrants, DDS (Manchester) and Choke mode (Tsinghua)

From CLIC advisory committee meeting of 2-2-2010

Micron precision manufacture, assembly and integration

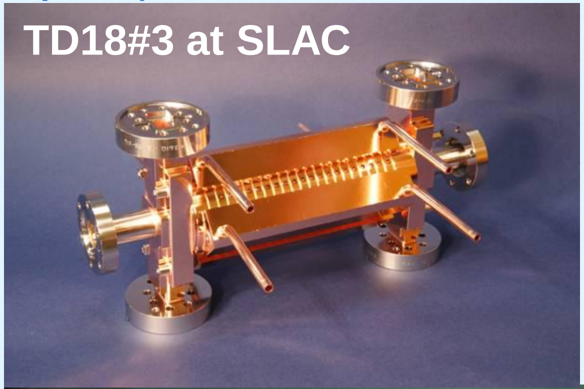
- Dedicated manufacturing study
- Subsystem (cooling, vacuum, support) design
- Wakefield monitor development
- Dedicated cost studies are underway
- Other X-band and high gradient applications like TERA, X-FEL to gain experience and spread expertise.

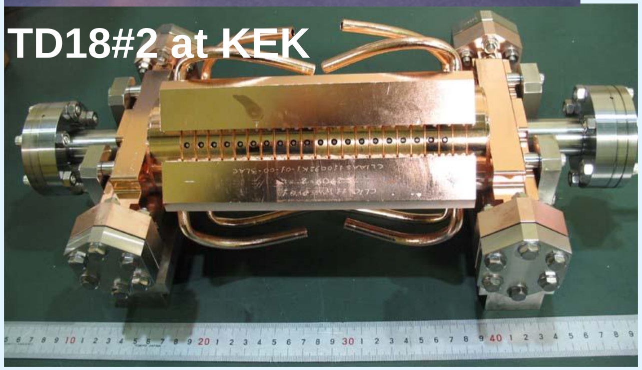
Dynamic Vacuum

- Work program is now being established. Goal is direct measurement, we will likely need a combination of measurement and simulation.

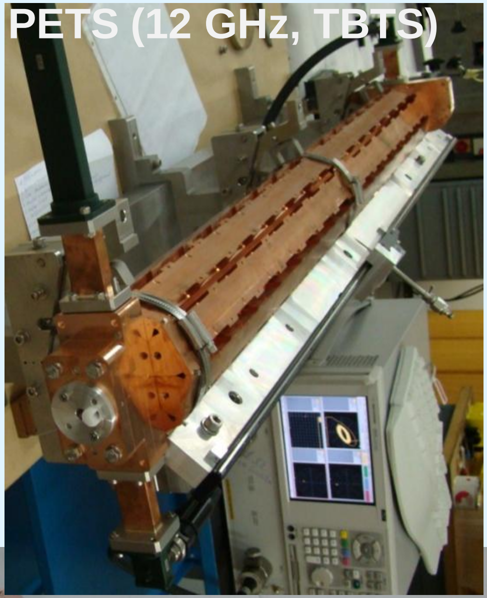
Manufacturing

Introduction


TD18#3 at SLAC

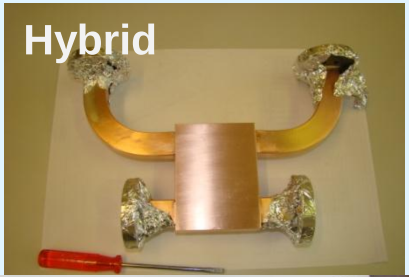

TD18#2 at KEK

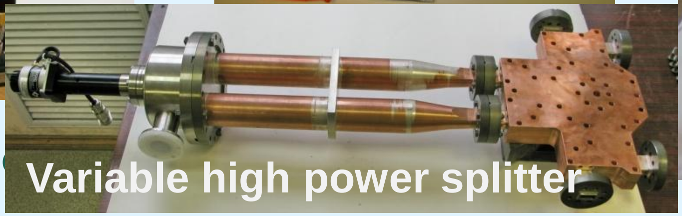

TD24#2 at CERN (12 GHz)


PETS (12 GHz, TBTS)


PETS (11.4 GHz, test at SLAC)


High-power dry load


Hybrid


Variable high power splitter

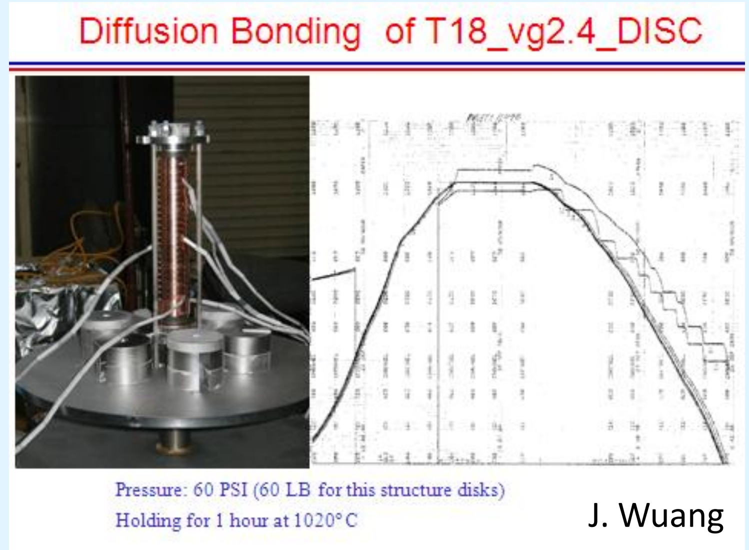
Baseline procedure

Diamond machining (sealed structures)

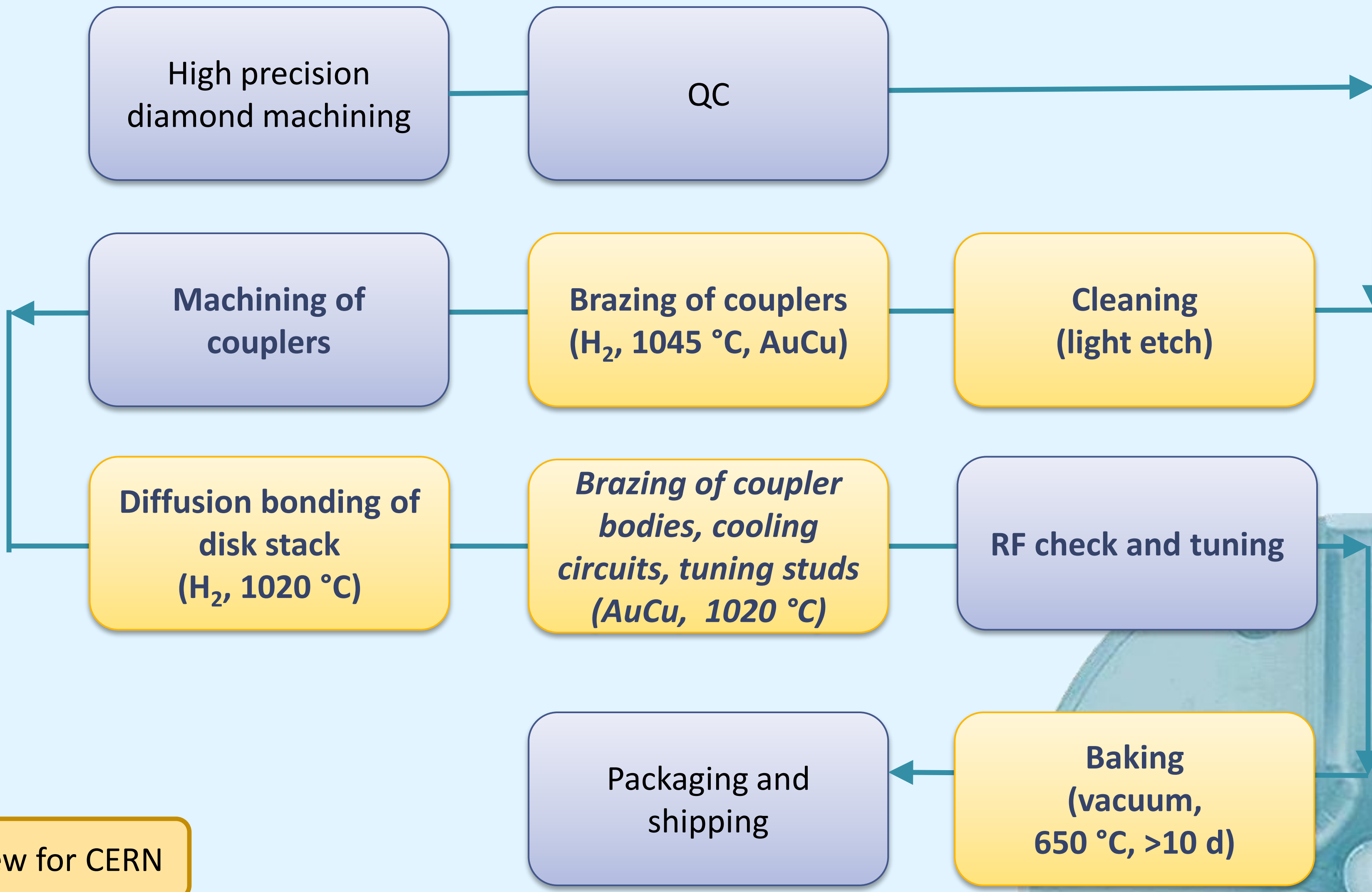
Cleaning with light etch

H2 diffusion bonding/brazing at ~ 1000 ˚C

Vacuum baking 650 ˚C > 10 days

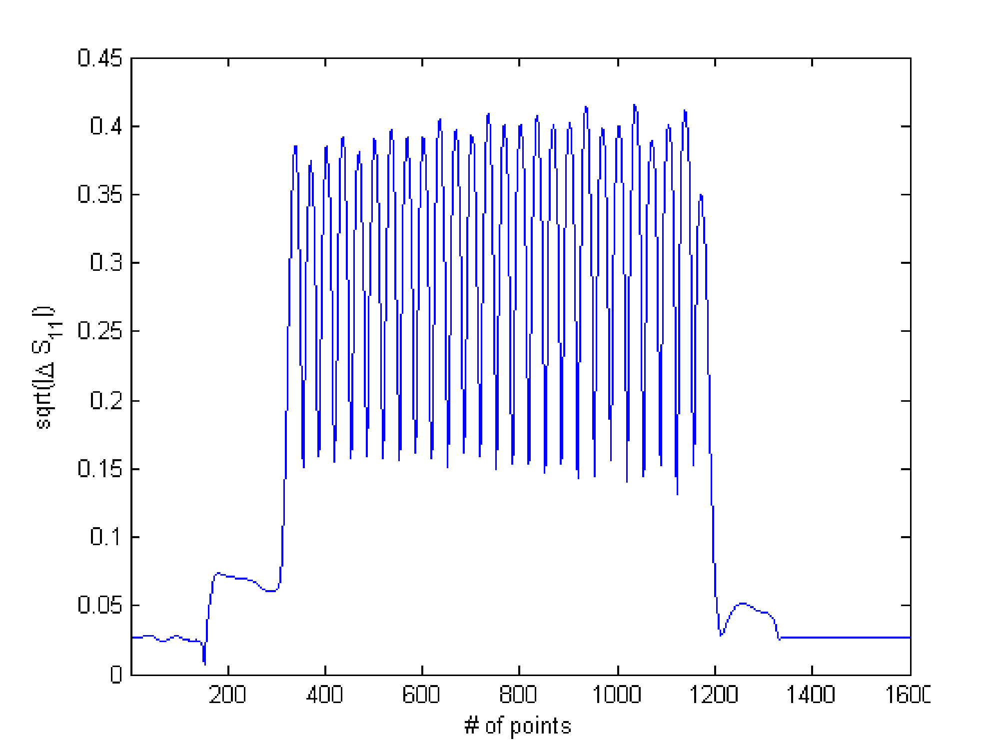


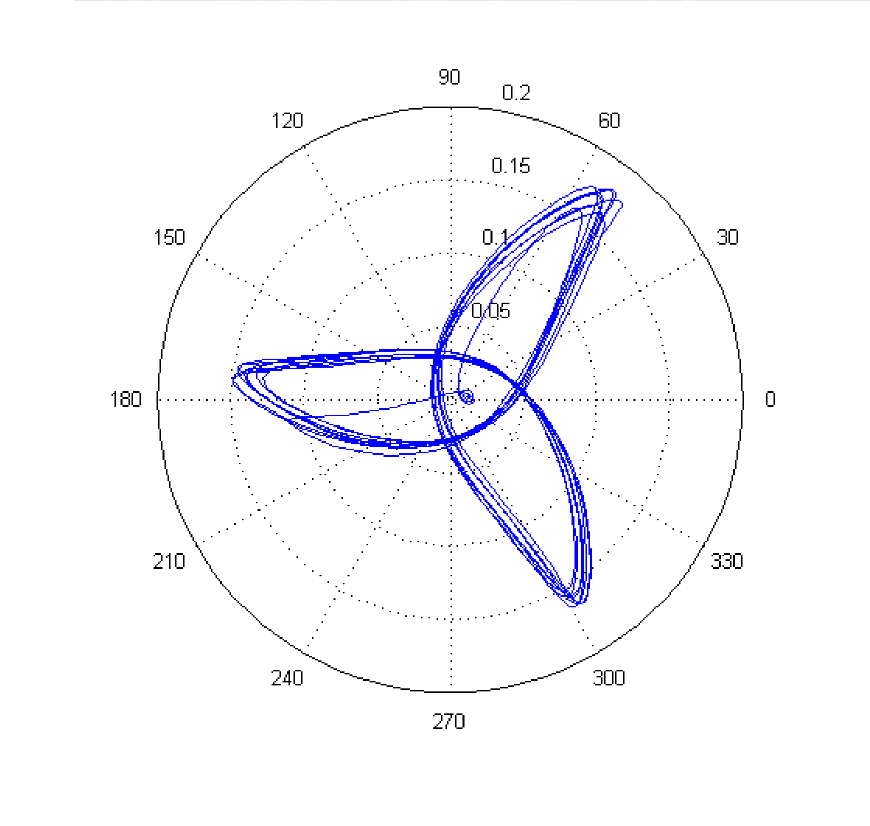
Baseline manufacturing flow



New for CERN

rf tuning TD24

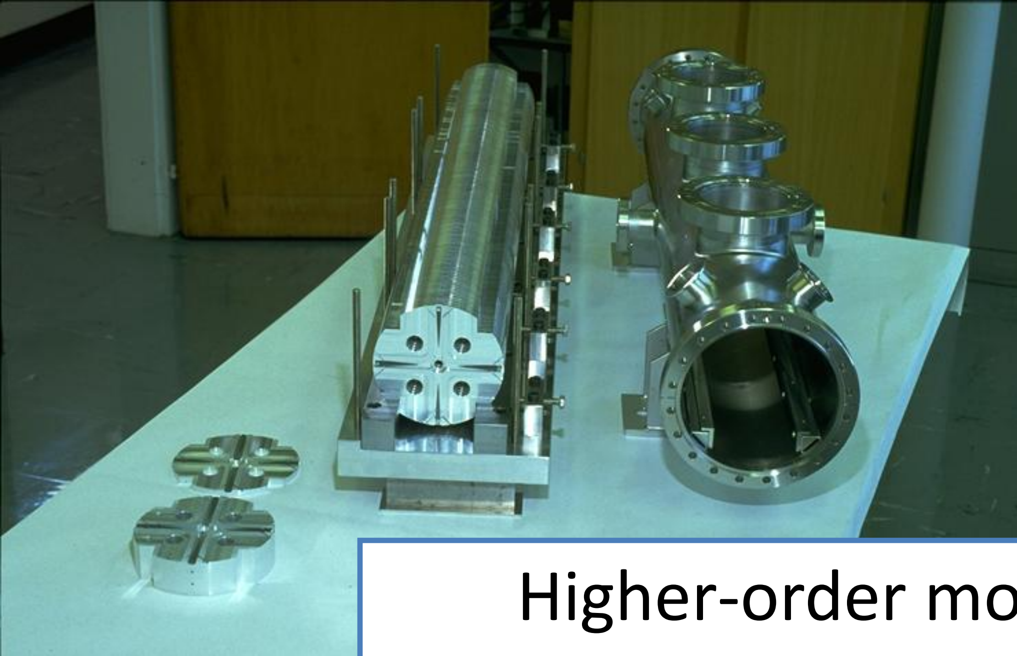


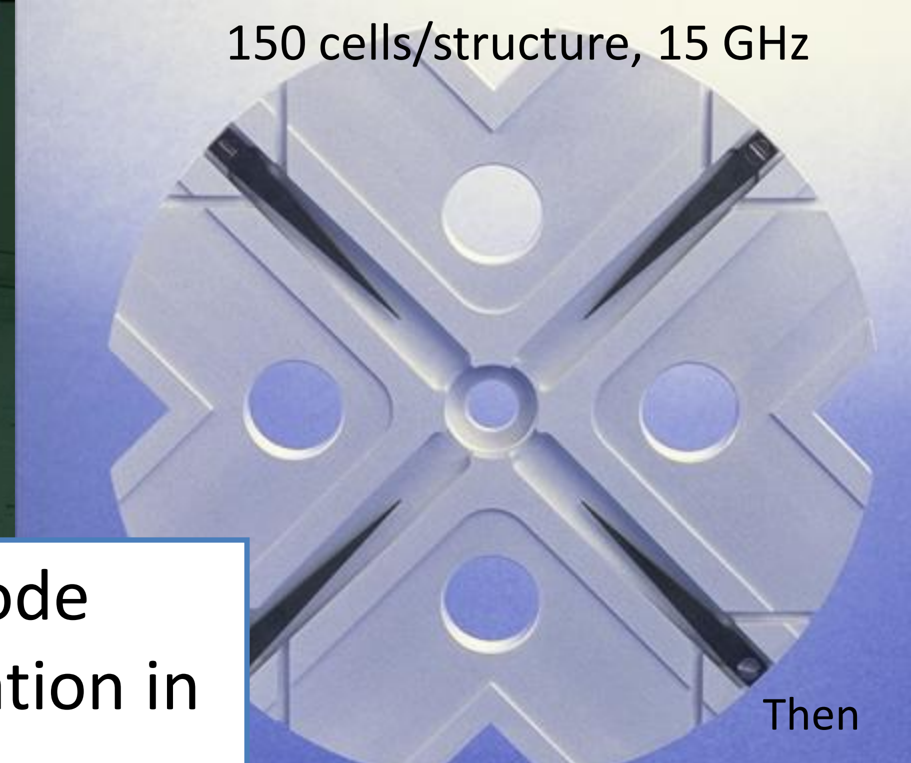


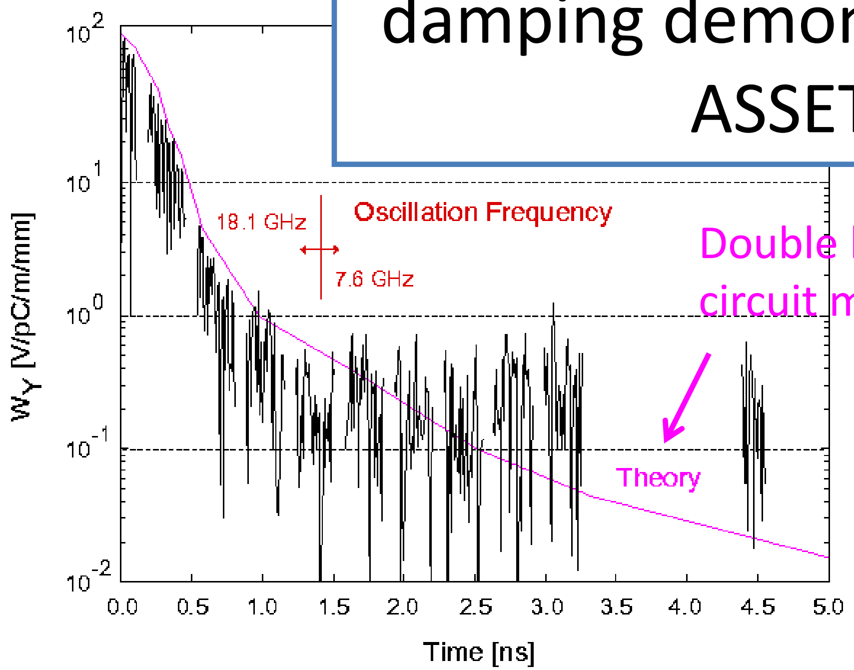
Jiaru Shi

Transverse wakefield suppression

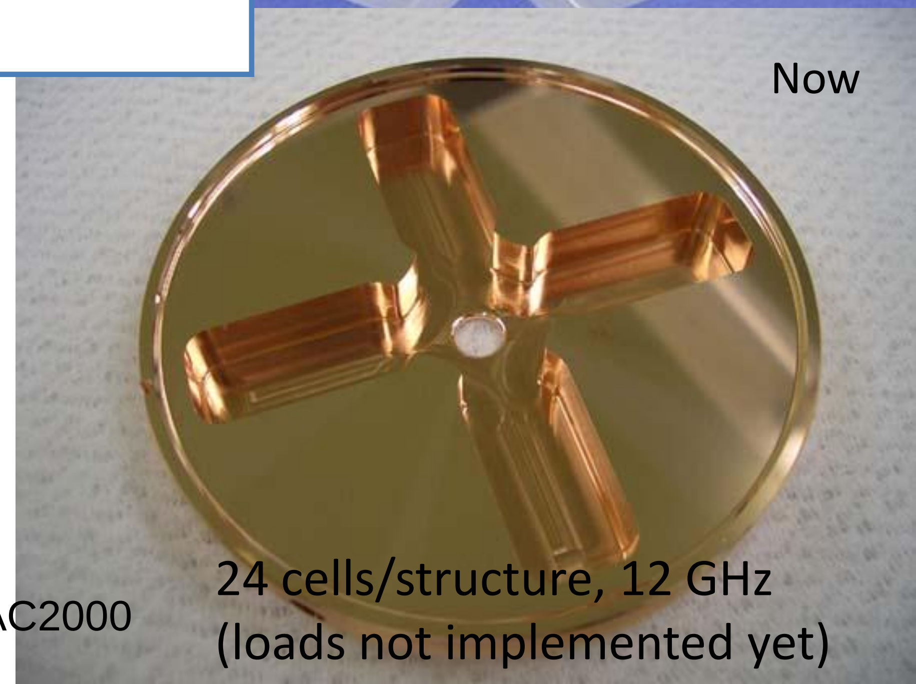
Higher-order mode damping demonstration in ASSET



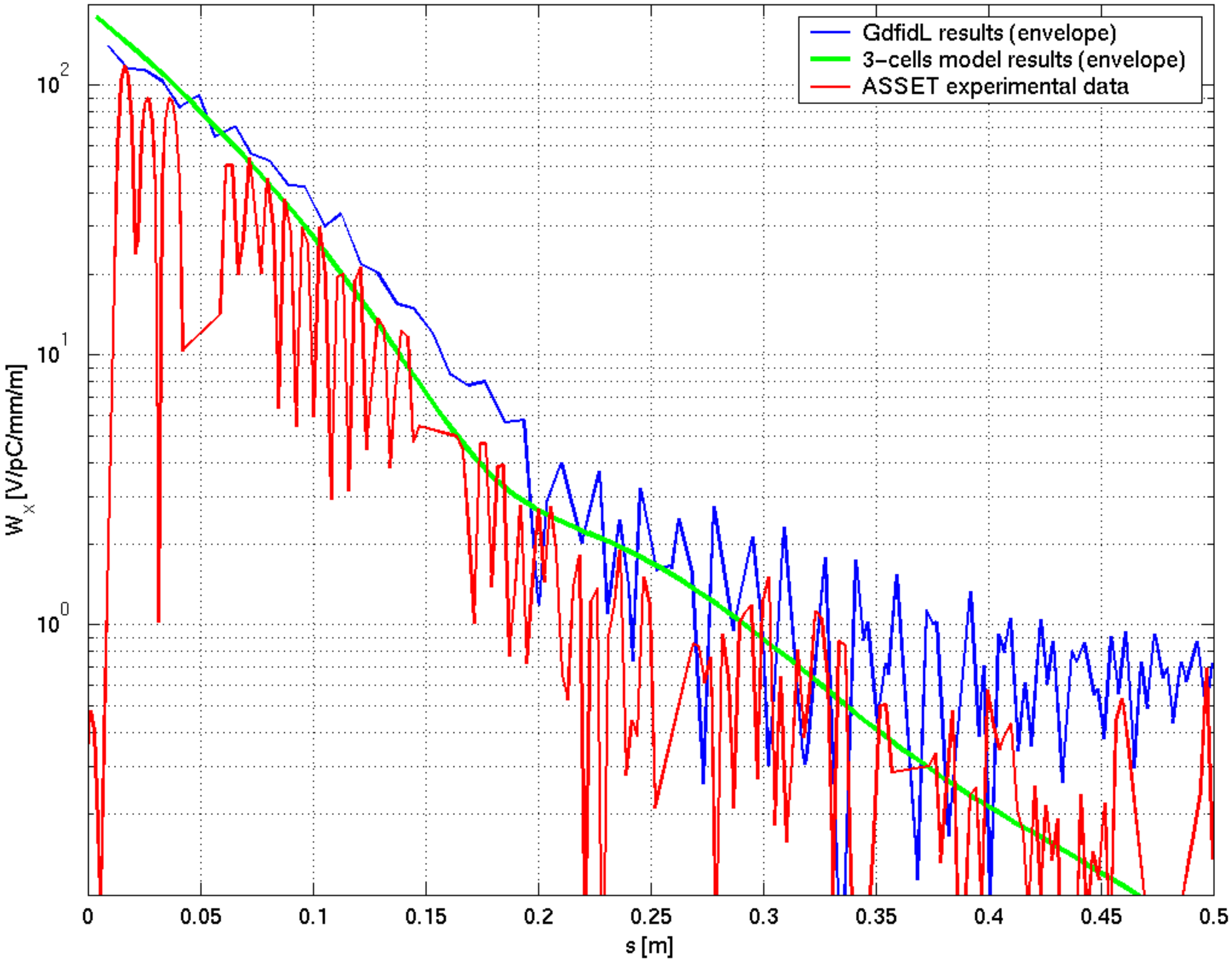




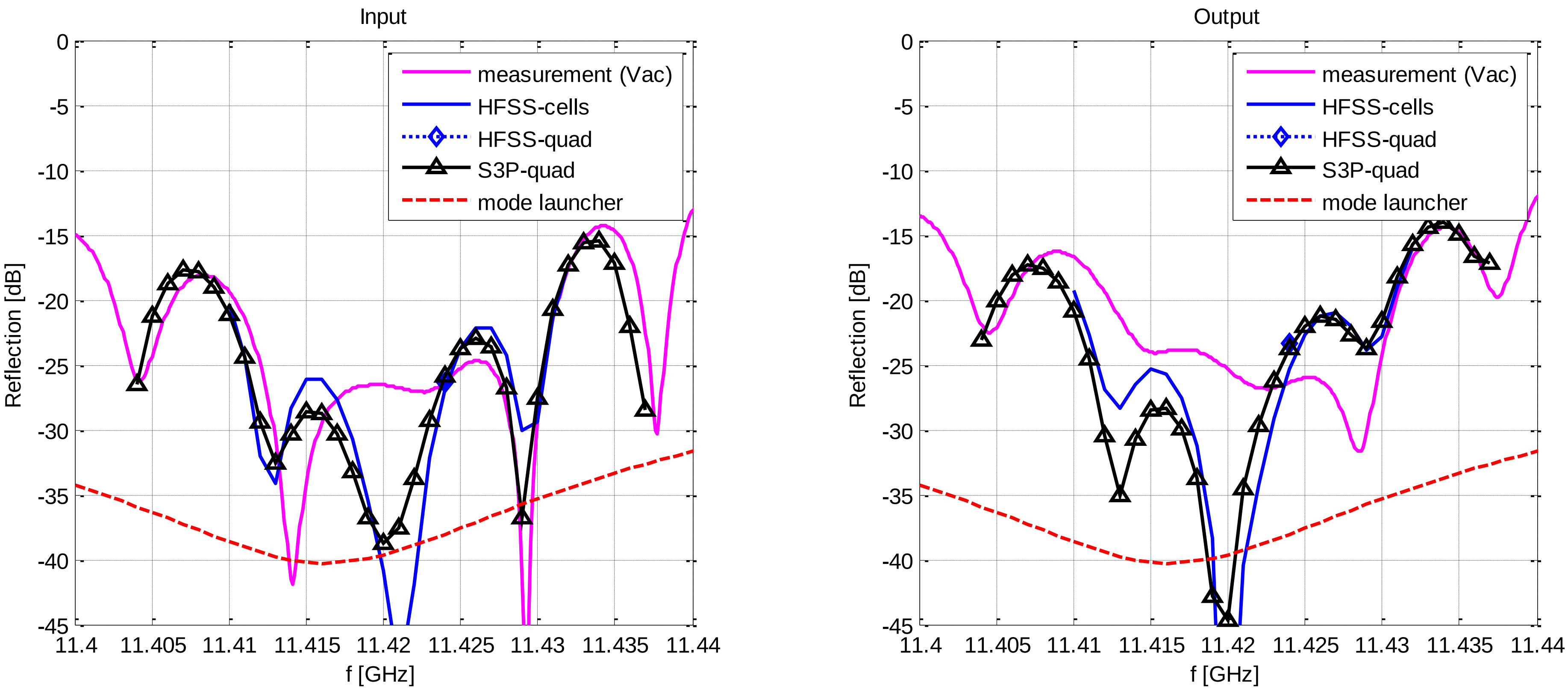
An Asset Test of the CLIC Accelerating Structure, PAC2000



Full length TDS results comparison



Reflection: comparison



There is very small (~1MHz) or no difference in frequency between simulations and the air corrected measurements

Our computational capability is constantly being refined and benchmarked.

Fundamental breakdown and pulsed surface heating studies

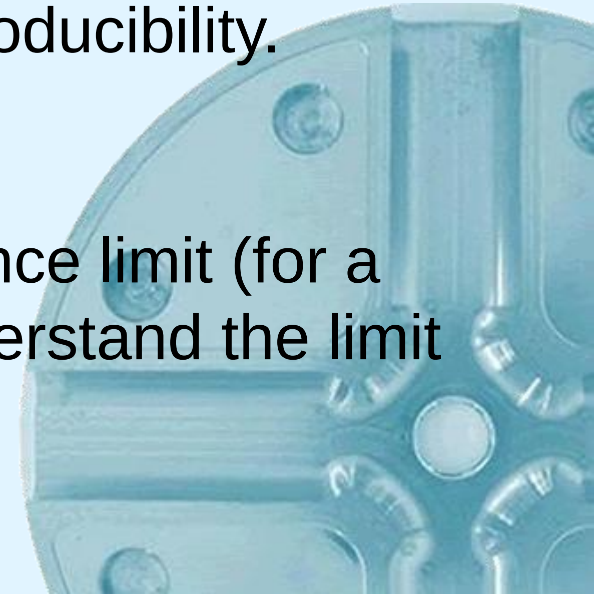
High-power rf theory and simulation effort

Over the past couple of decades computational tools have developed to the point that we can now accurately design complex, 3-D and even multi-moded rf structures.

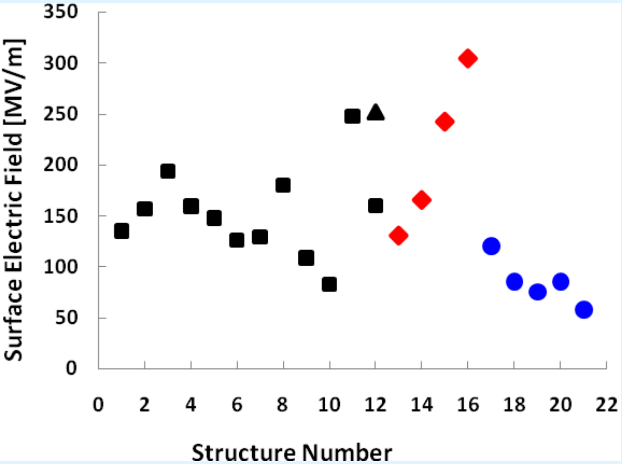
The ability to predict high-power performance has lagged behind:

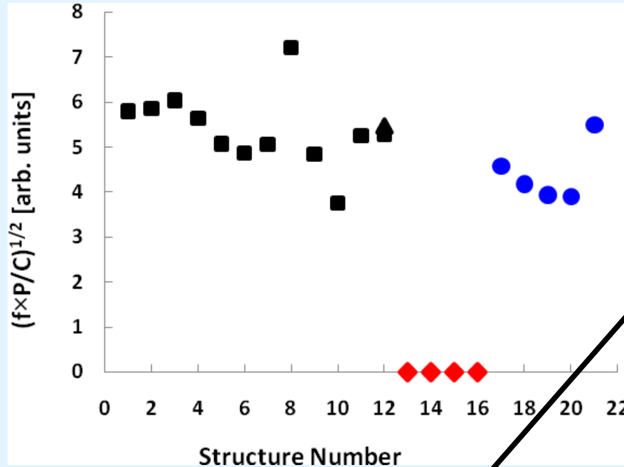
- A lot depends on preparation. But NLC/JLC made enormous progress in improving performance and reproducibility.
- The phenomena are extremely complex.

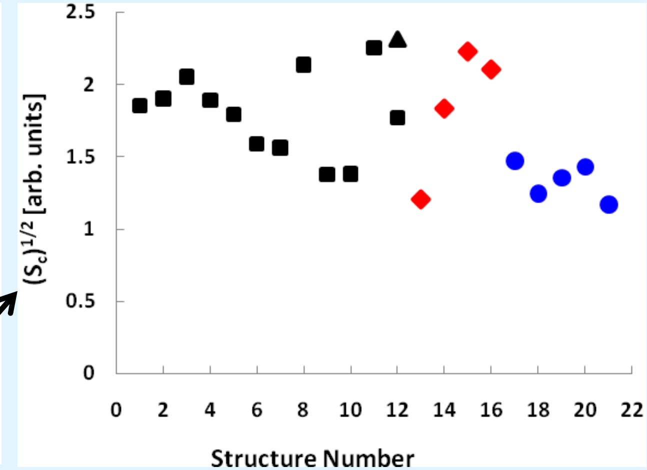
CLIC aims to run very close to the performance limit (for a given breakdown rate) so we had better understand the limit pretty well.



S_c: high-power design parameter



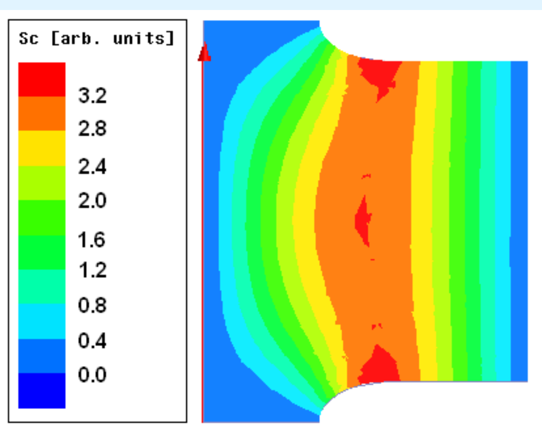




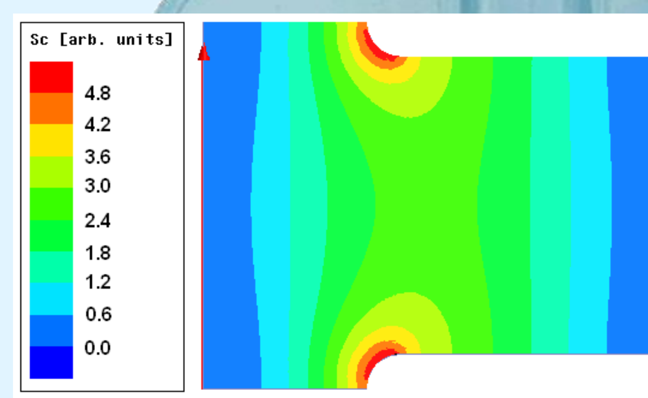
X-band and 30 GHz, pulses of the order of 100 ns.
Travelling and standing wave

Related to the complex Poynting vector:

$$S_c = \Re\{\bar{S}\} + g_c \cdot \Im\{\bar{S}\}$$

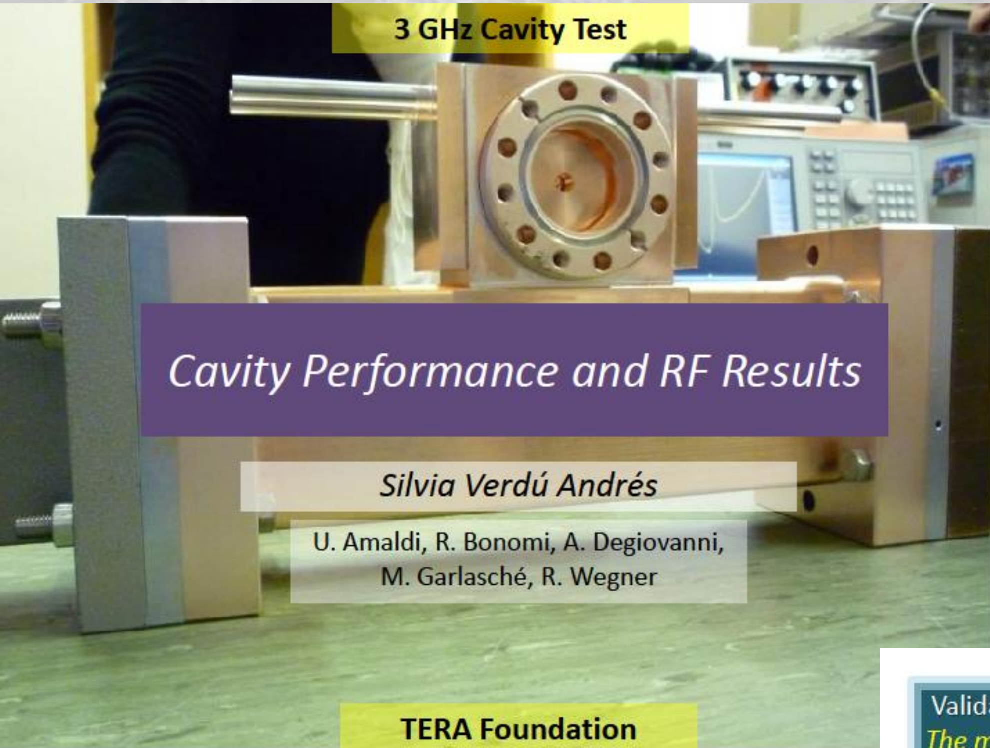


Travelling wave



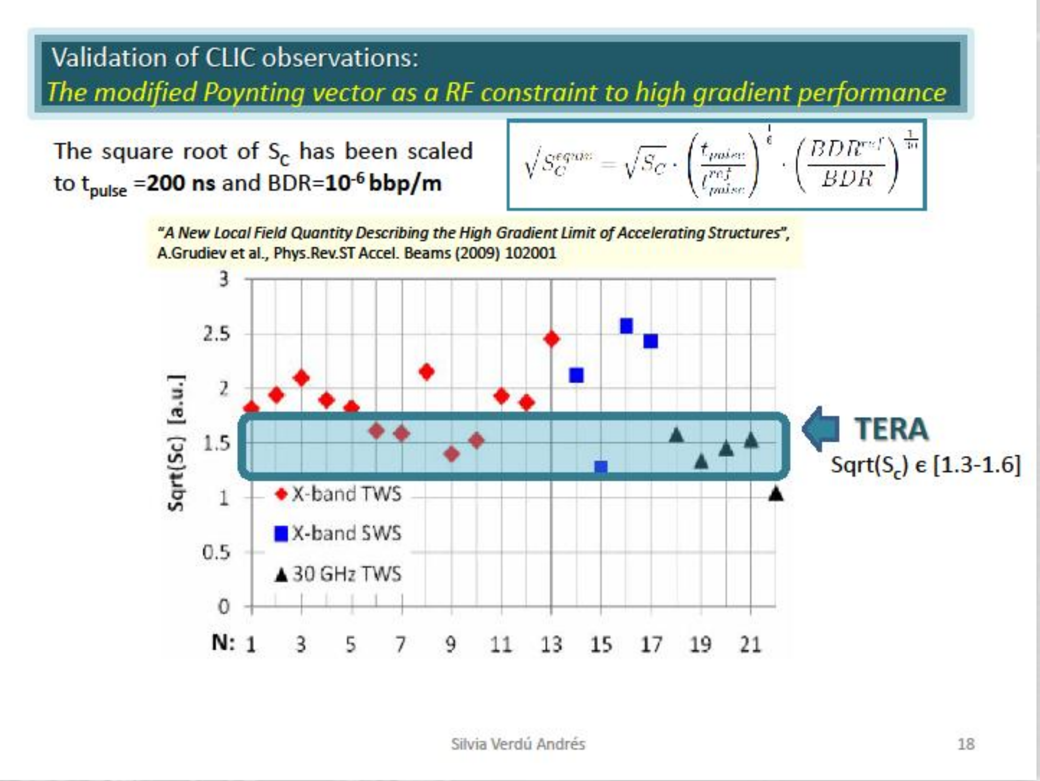
Standing wave

W. Wuensch

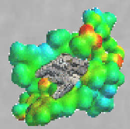


Do our high-gradient limits extend all the way down to S-band and microsecond pulses?

PRELIMINARY RESULTS!



Electrical Breakdown in multiscale modeling approach

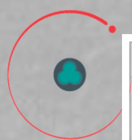


Stage 0: Onset of tip growth; Dislocation mechanism
Method: MD, Molecular Statics…

~ sec/min

Stage 1: Charge distribution @ surface
Method: DFT with external electric field

~few fs



Stage 2: Atomic motion & evaporation
Method: Hybrid ED&MD model

Classical MD+Electron Dynamics: Joule heating, screening effect

Solution of Laplace equation

~few ns

Stage 3: Evolution of surface morphology due to the given charge distribution
Method: Kinetic Monte Carlo

~ sec/hours

=> Electron & ion & cluster emission ions

Stage 4: Plasma evolution, burning of arc
Method: Particle-in-Cell (PIC)

~10s ns

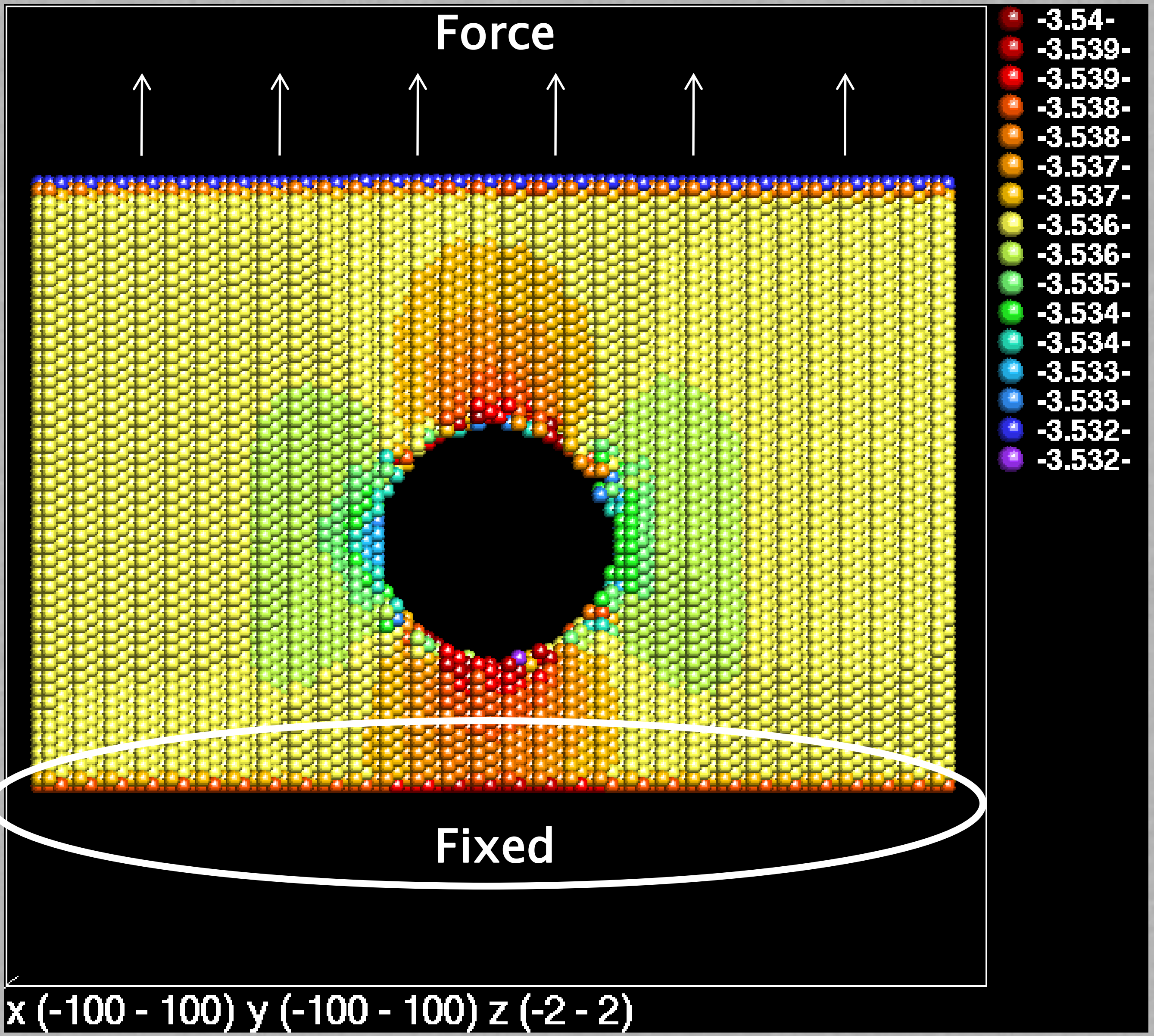
=> Energy & flux of bombarding ions

Stage 5: Surface damage due to the intense ion bombardment from plasma
Metod: Arc MD

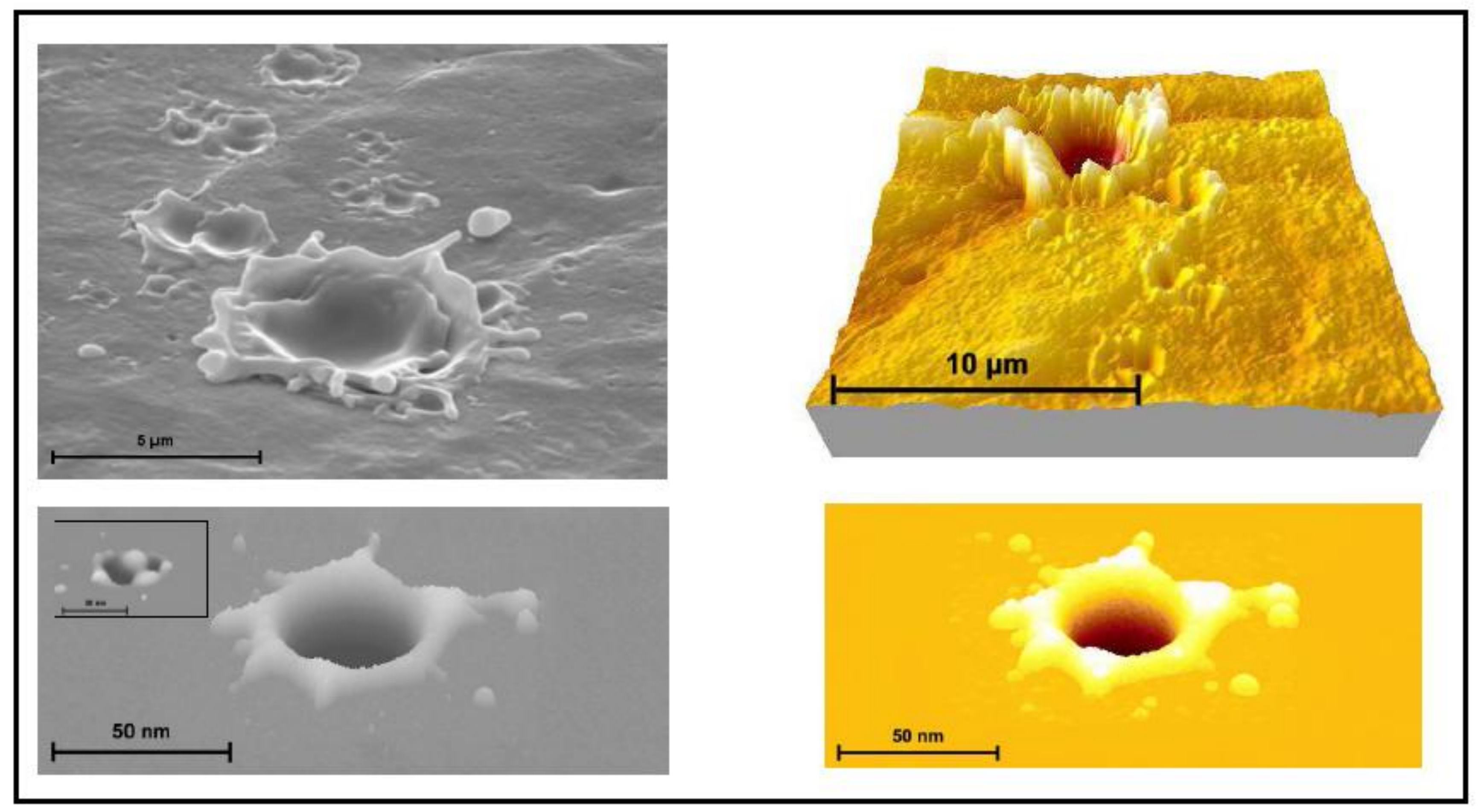
~100s ns

PLASMA ONSET

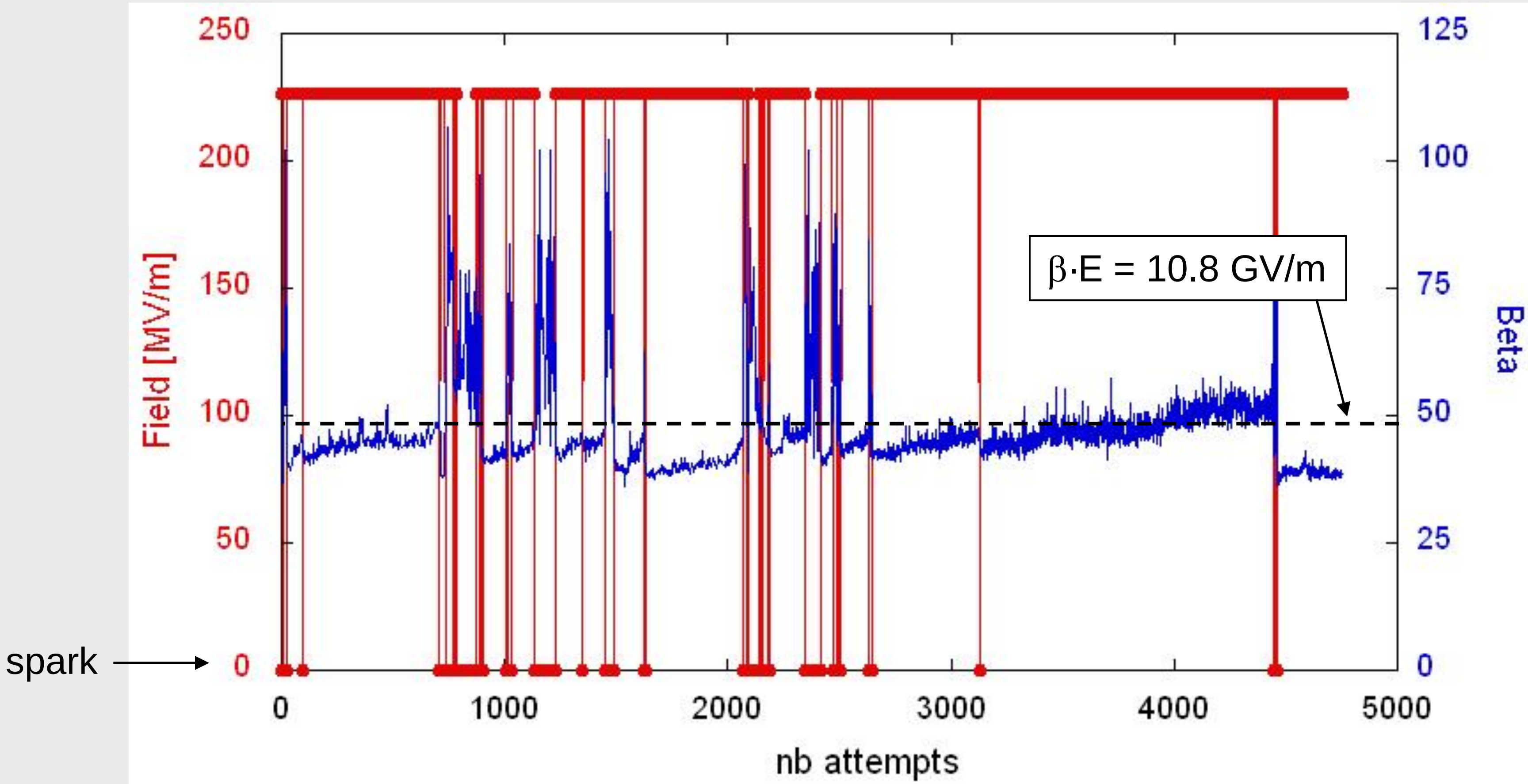
Voids as dislocation sources



Plasma-surface interaction.
Crater formation.



Evolution of β during BDR measurements (Cu)

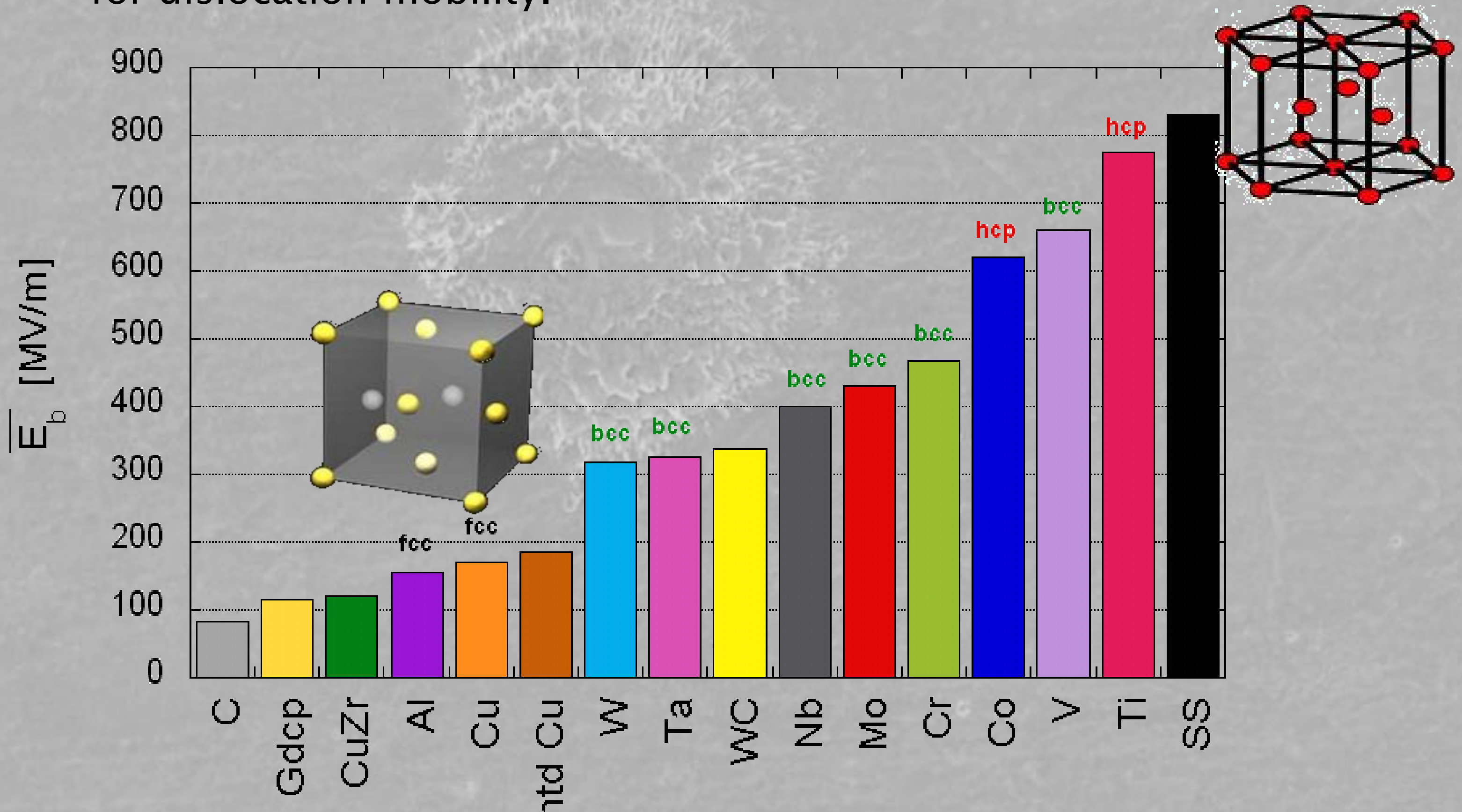


- breakdown as soon as $\beta > 48$ (↔ $\beta \cdot 225$ MV/m > 10.8 GV/m)
- consecutive breakdowns as long as $\beta > \beta_{threshold}$

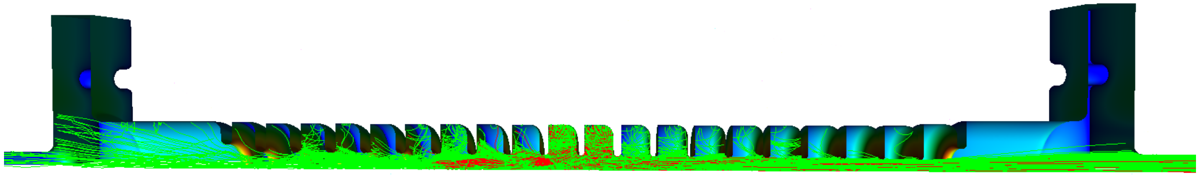
→ length and occurence of breakdown clusters ↔ evolution of β

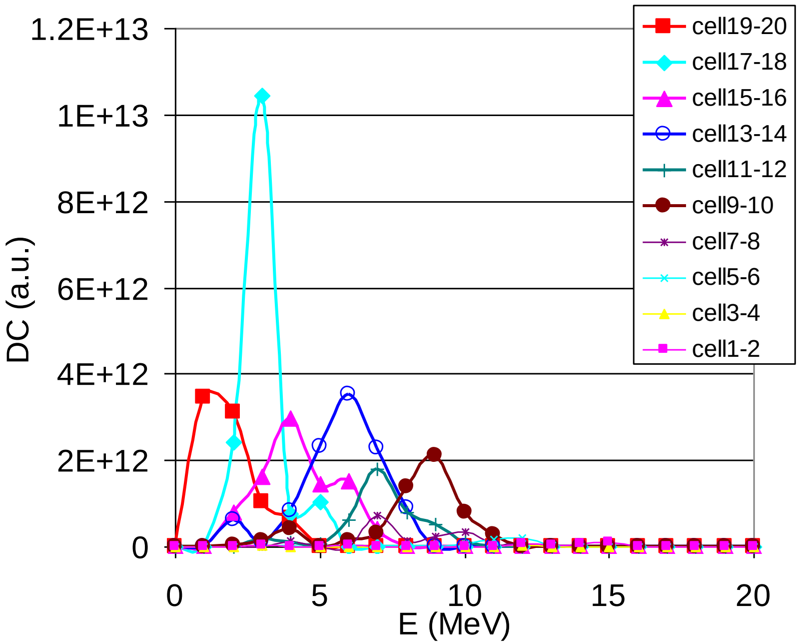
Recent experiment at CERN: CLIC-note

- The dislocation motion is strongly bound to the atomic structure of metals. In FCC (face-centered cubic) the dislocation are the most mobile and HCP (hexagonal close-packed) are the hardest for dislocation mobility.



Energy of Captured Dark Current vs Location





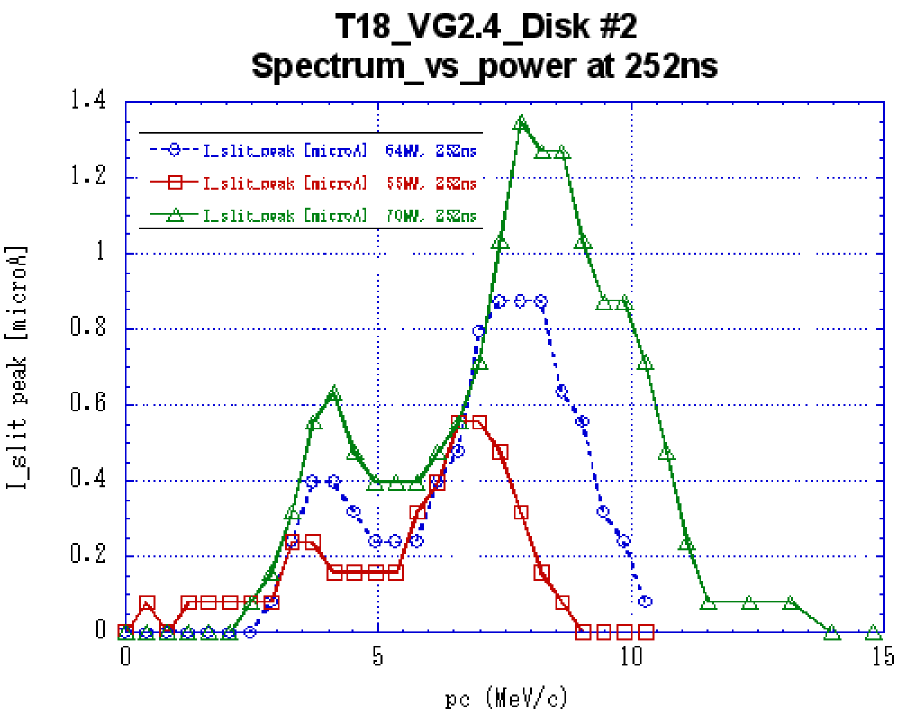
Simulation

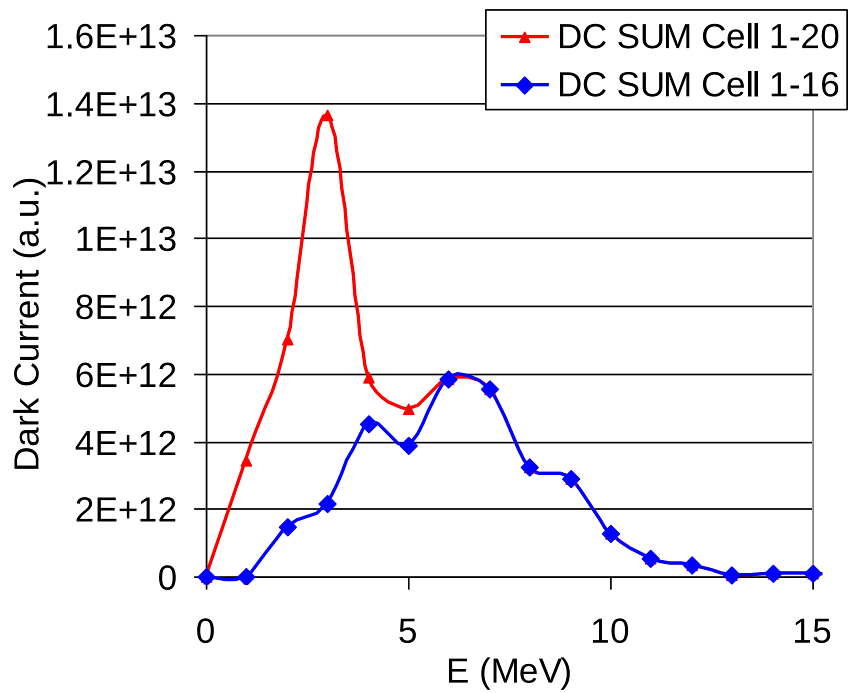
Electron energy as function of emission location.

- Eacc=97MV/m.
- Higher cell number indicates downstream location

Electrons emitted upstream are accelerated to higher energy (monitored at output end).

Dark Current Spectrum Comparison





Measured dark current energy spectrum at downstream (need to scale by 1/(pc)

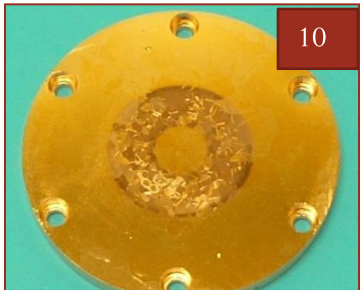
Spectrum from Track3P simulation, 97MV/m gradient.

"Certain" collimation of beampipe on dark current is considered in simulation data. More detailed analysis Needed.

Hardness Test Value

Lisa Laurent, SLAC

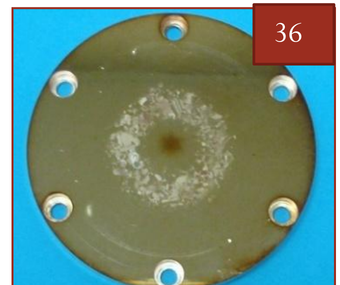
Pulse Heating Samples (CLIC09)



Cu101 (SLAC)

KEK3 (KEK)

HIP2 (KEK)



HIP1 (KEK)

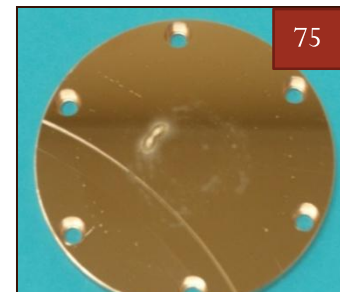
CuZr2-2 (CERN)

CuCr101 (SLAC)

Single Crys Cu (KEK)

E-Dep. Cu (KEK)

AgPCu (KEK)

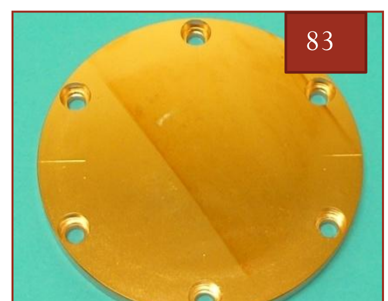


Glidcop4-2 (CERN)

CuZr3-2 (CERN)

CuAg5 (SLAC)

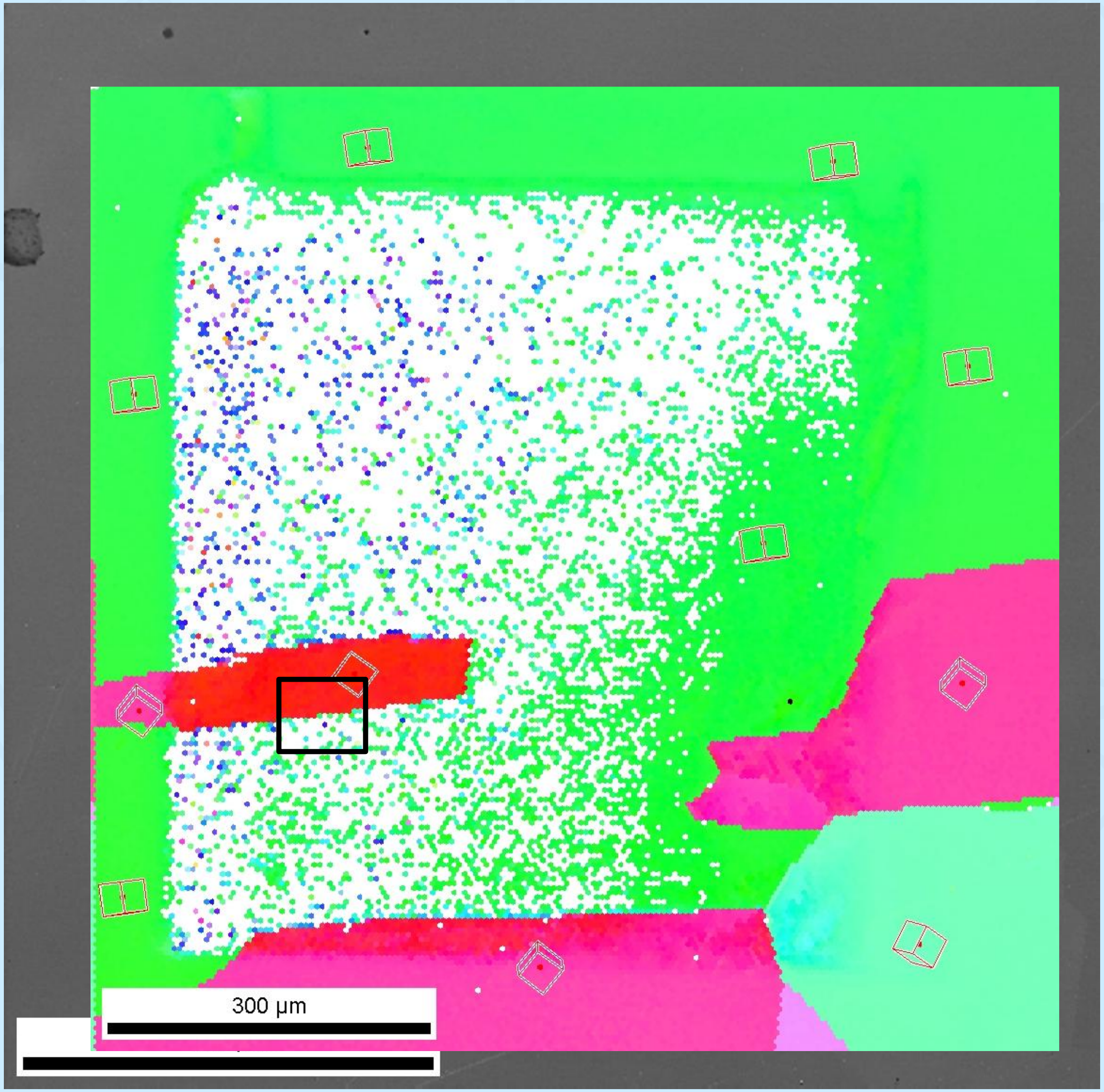
CuAg1 (KEK)

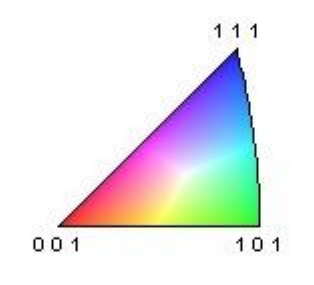


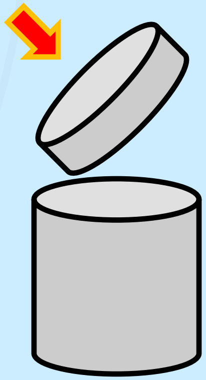
CuCr102 (SLAC)

Glidcop4-1 (CERN)

C10100_2h@1000_EP_45°Probe3_C1







C10100_2h@1000_EP_45°Probe3_C1