Progress of X-Band Accelerating Structures

LINAC10, Tsukuba

17 Sep. 2010

T. Higo (KEK)

Contents

- Evolution in 20 years
- Judgment with breakdown rate
- Supplemental high-gradient studies
- Effort with parameter optimization
  for stable high gradient
- Effort with other HOM damping scheme
- Efforts in fabrication technology
- X-band collaboration

Evolution of LC structures in 20 years

LINAC94 at Tsukuba "Linear Collider Structures" 16 years ago, the beginning

On the other hand, traveling-wave S-band structures were studied at KEK[27]. They obtained the maximum field of 91MV/m in 0.6m-structure. There is no evidence that this is a breakdown limit, though. What should be

A 7-GHz standing-wave structure was high power tested up to 90MV/m for VLEPP in 1978.

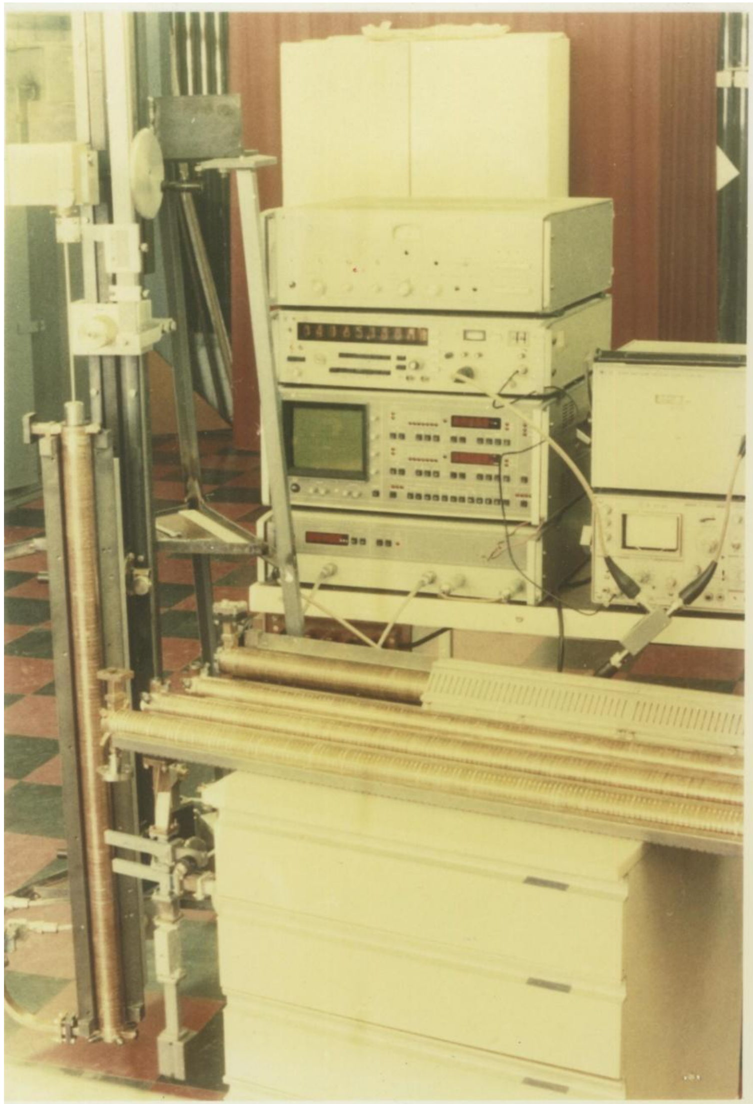
High field test on traveling wave structures at X-band aiming at the feasibility check for the linear collider use have been performed at SLAC[29] and KEK[28]. The typical parameters are summarized in the Table 1. The obtained field levels are not necessarily limited by the structures themselves. It is fairly easy to reach a stable operation at 50MV/m level without measurable dark current. The accelerating field of even 100MV/m can be reached without severe conditioning but with a dark current of the order of mA. The behavior of this dark current in the realistic structures should be performed from now.

TABLE 1
High-Field Experimental Results

Length(m)	0.2	0.26	0.26	0.75	1.8
Type	CI	CI	CI	CI	Detuned
Maker	CERN	CERN	SLAC	SLAC	SLAC
Input (MW)	39	69	116	130	105
Eav (MV/m)	100	125	101	79	55
Pulse (ns)	100	150	60	75	75
Fill Time (ns)	58	74	27	52	100

$\boxed{\text{Discussed 100 MV/m level.}}$

VLEPP based on 100 MV/m in LC91



I. Energy

RF – Power (100÷150 MW) · acc. structure (100 MV/m)

(Gridded klystron, permanent magnetic system)

↓

RF Pulse Compression ×4
(„open" cavity)
$Q = 2.5 \cdot 10^5$
$V \approx 0.3 \times 0.3 \times 0.3\ м^3$

↓

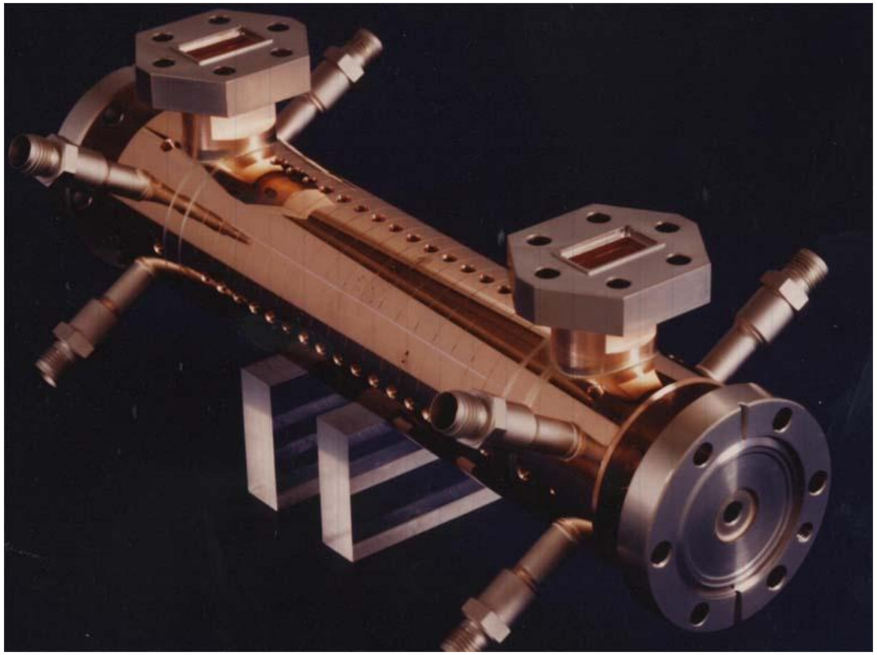
cost, volume
(NO modulator
NO power for focus. sys.)

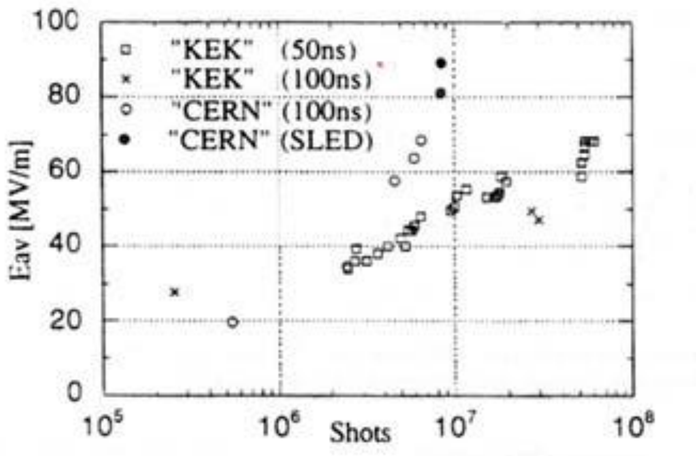
high precision serial production
(1÷2 μm, $1.5 \cdot 10^5$/km)

↓

special machine-tools

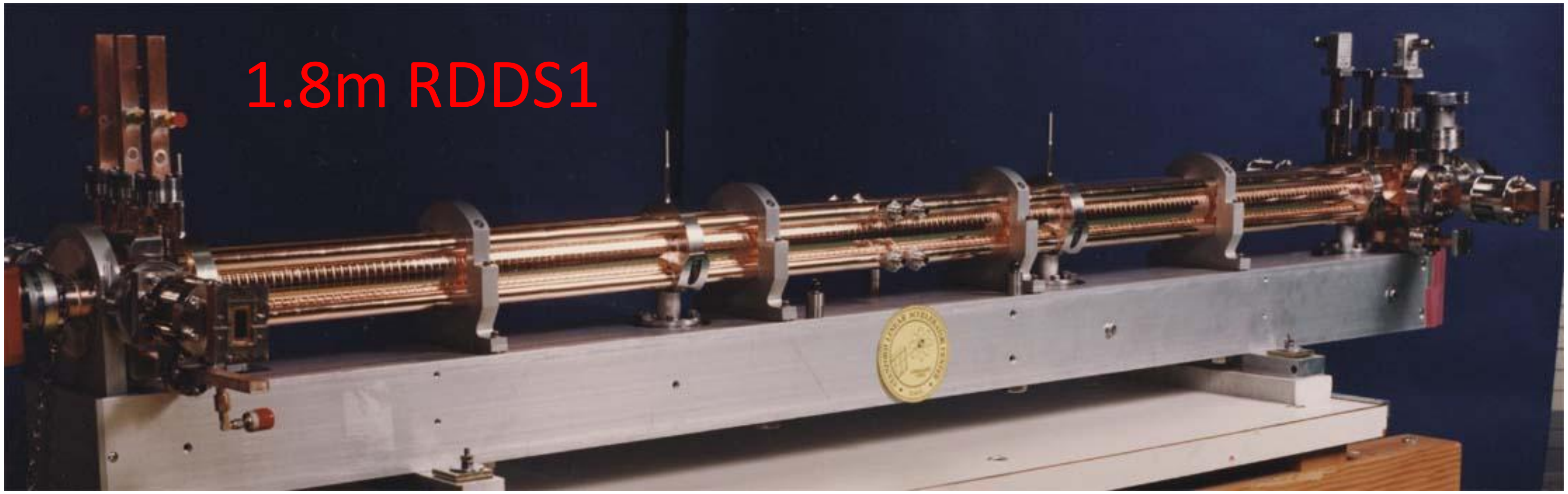
CERN made 20cm vg/c=1% structure tested up to 100 MV/m in early 90's



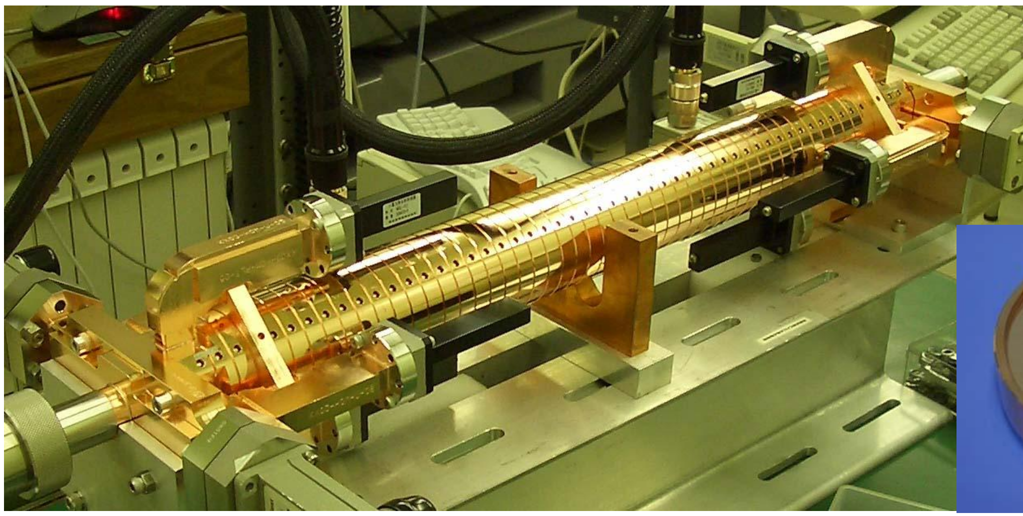


90 MV/m with SLED at KEK
>100 MV/m at SLAC

DDS scheme was confirmed in mid. 90's sharp edges in its cells→ no high gradient test

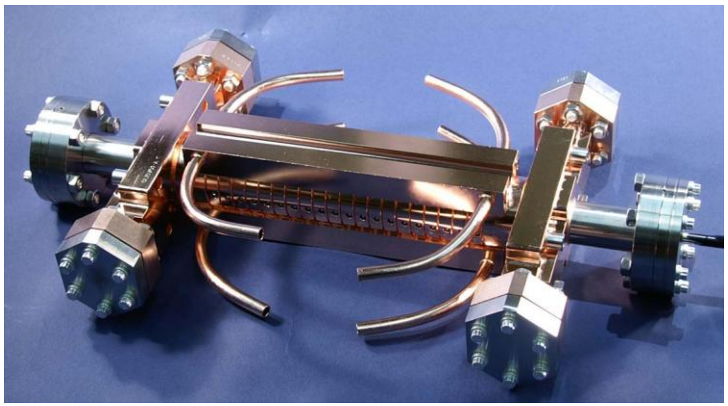


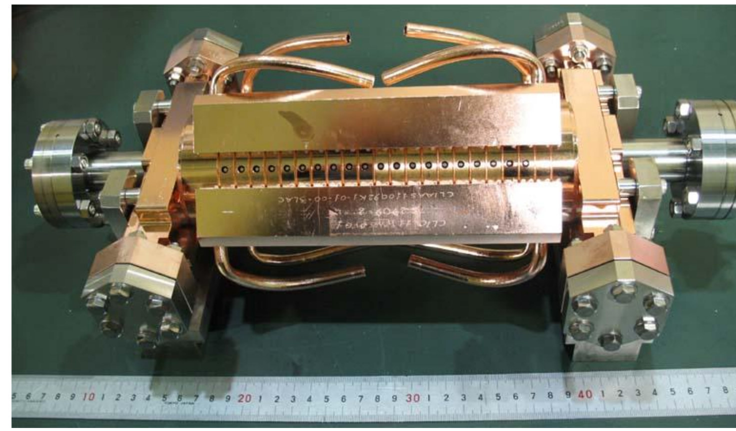
Many of the HDDS 60cm structures were made and tested in collaboration among SLAC, FNAL and KEK in late 90's till 2004

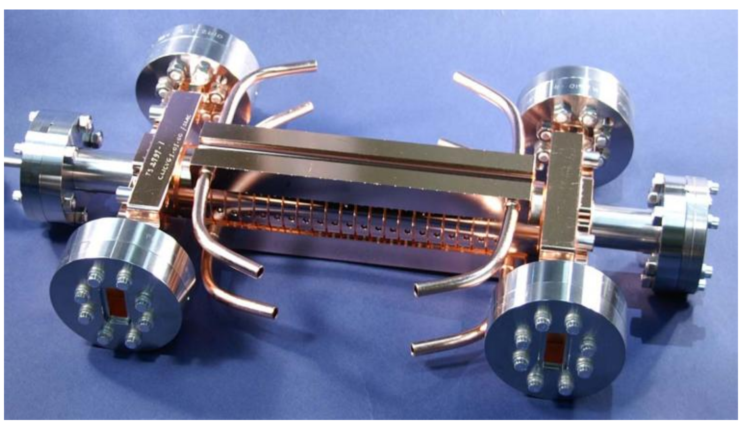


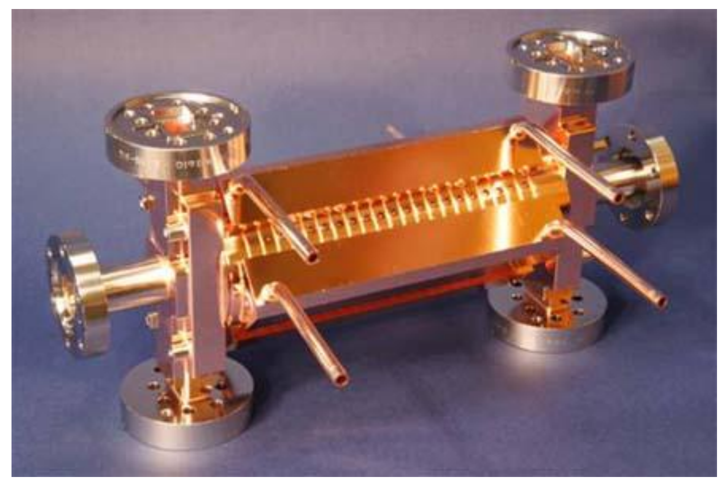
Unloaded 65 MV/m was established in wake-field suppressed structures.
These opened a base which extended to
→ CLIC 100 MV/m design choice
→ medium-gradient applications

Series of CLIC test structures made as twins
Targeting 100 MV/m
In collaboration among CERN, SLAC and KEK

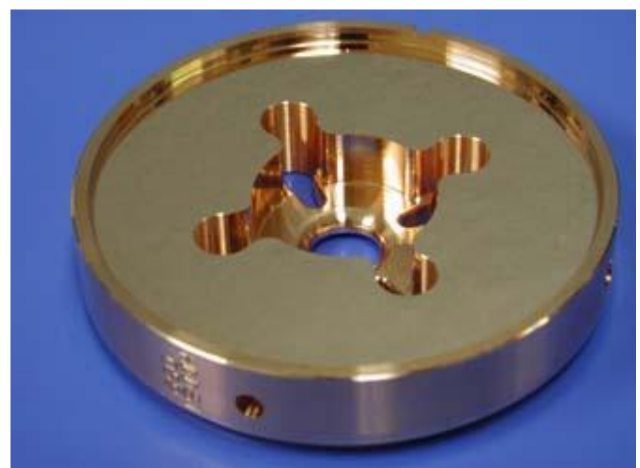




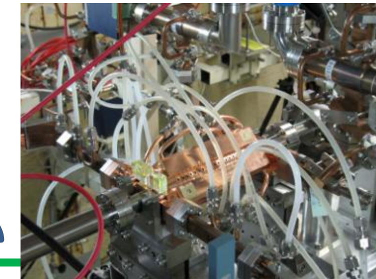




Cell shape evolution

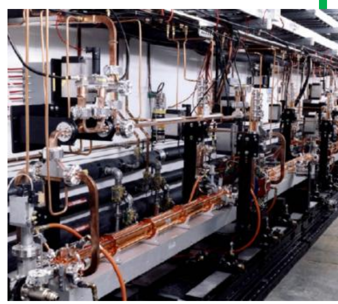


Nominal test procedure



Design for CLIC (CERN)

Fabrication of parts (KEK)



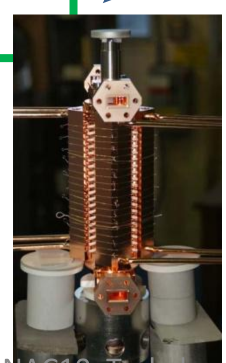
High power test (NLCTA-SLAC)

High power test (Nextef-KEK)

CP (SLAC)

Bonding (SLAC)

VAC bake (SLAC)



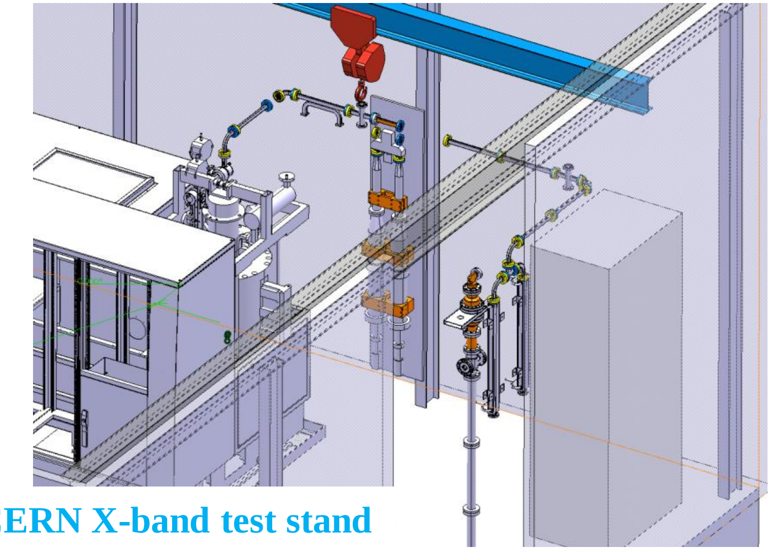
Two structures are made and treated as the twin for the evaluation.

Three existing test facilities and one under construction at CERN

1, 2

NLCTA & ASTA at SLAC

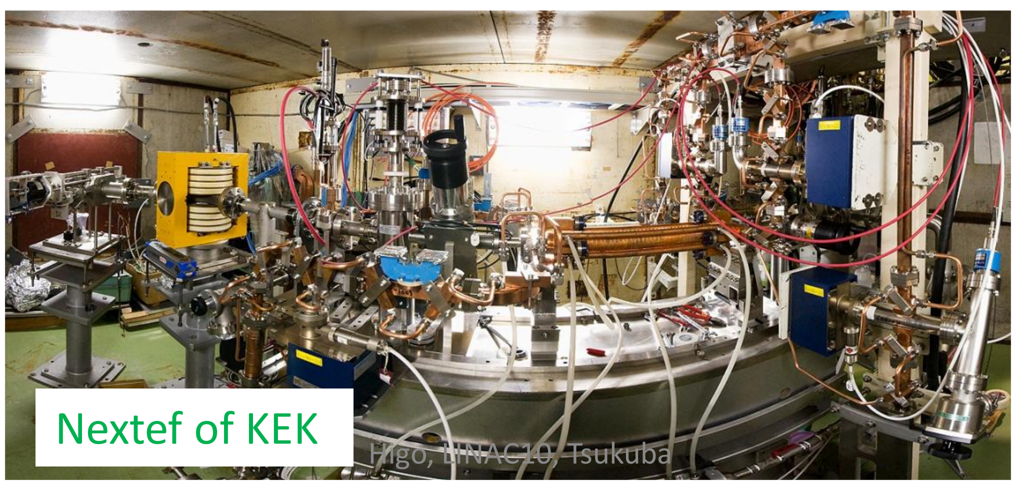
4



CERN X-band test stand
K. Shirm in May 2010

CERN - CEA – PSI – SLAC

3

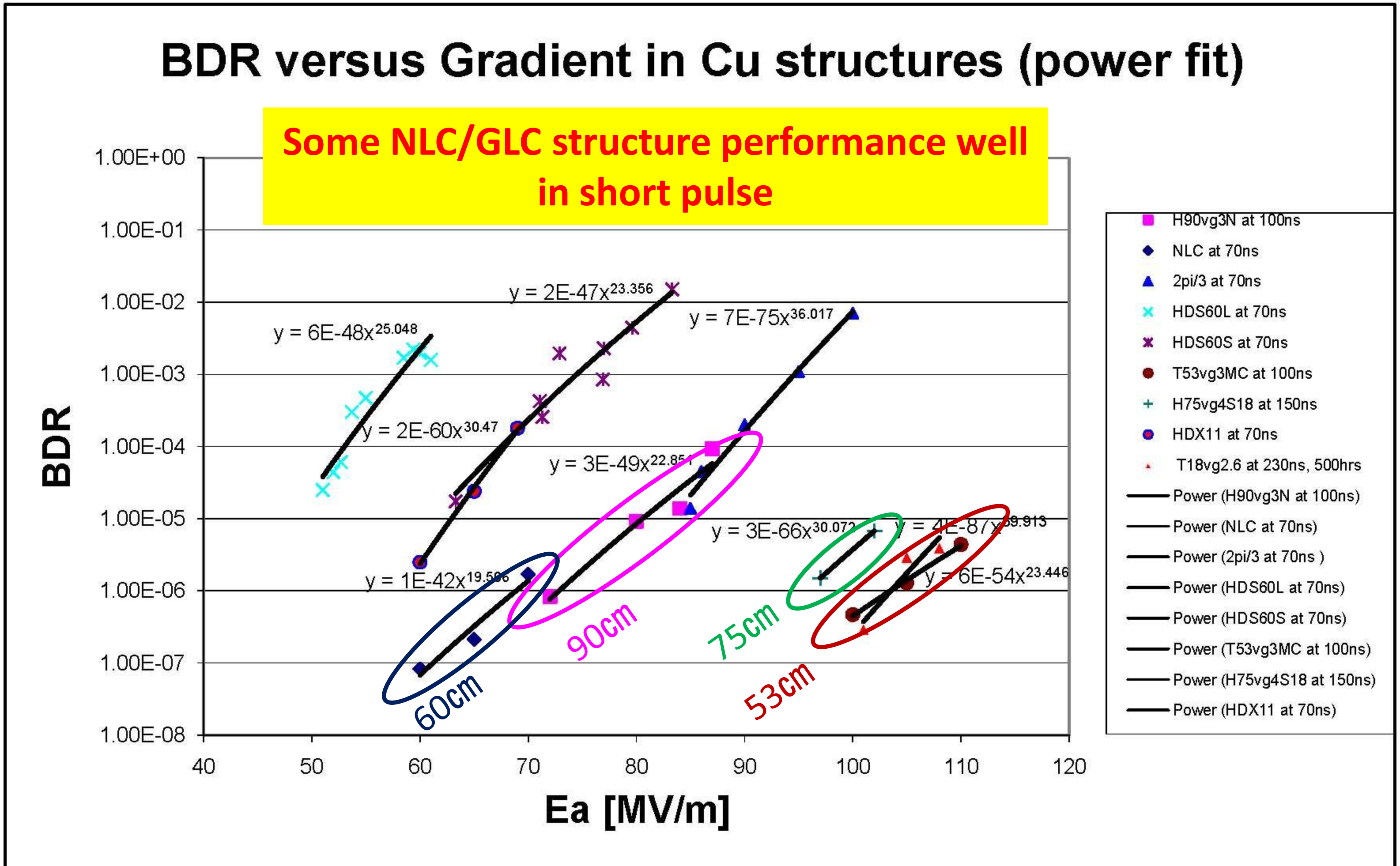


Nextef of KEK

Judgment with breakdown rate

CLIC

BDR versus Gradient scaling

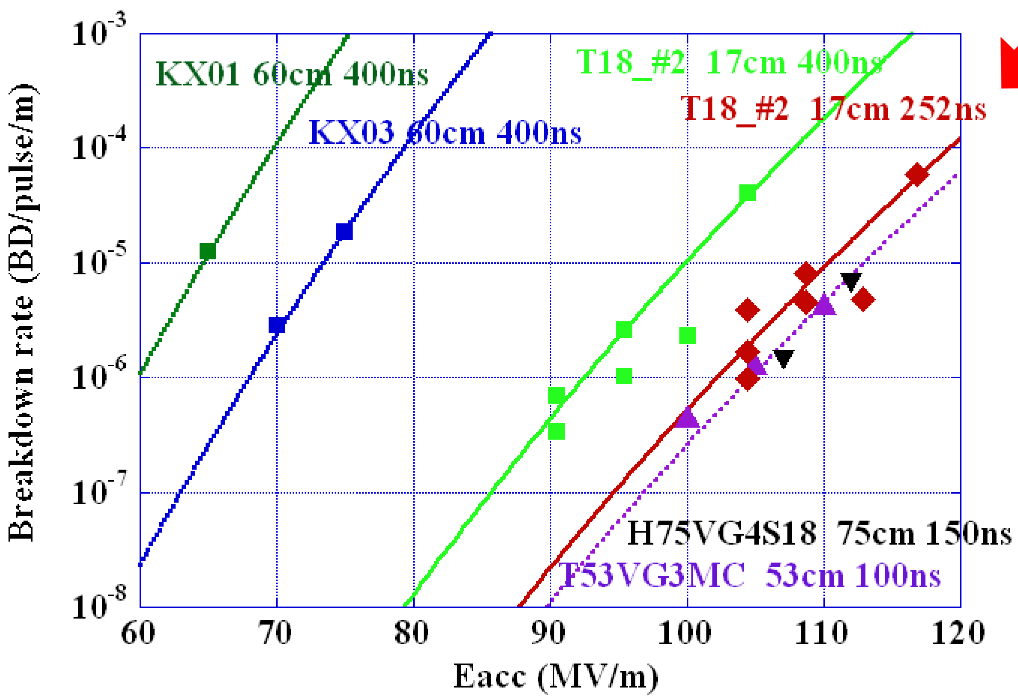


Power fit can be done with the same power for all gradients

Possibility of 65 → 100 MV/m

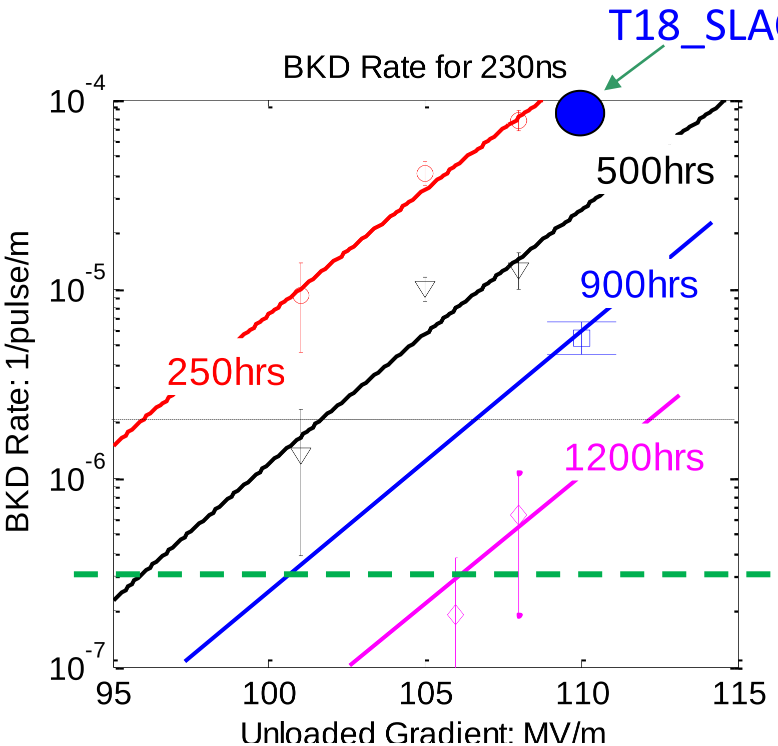
BDR: promising result in CLIC prototype structure

CLIC undamped T18

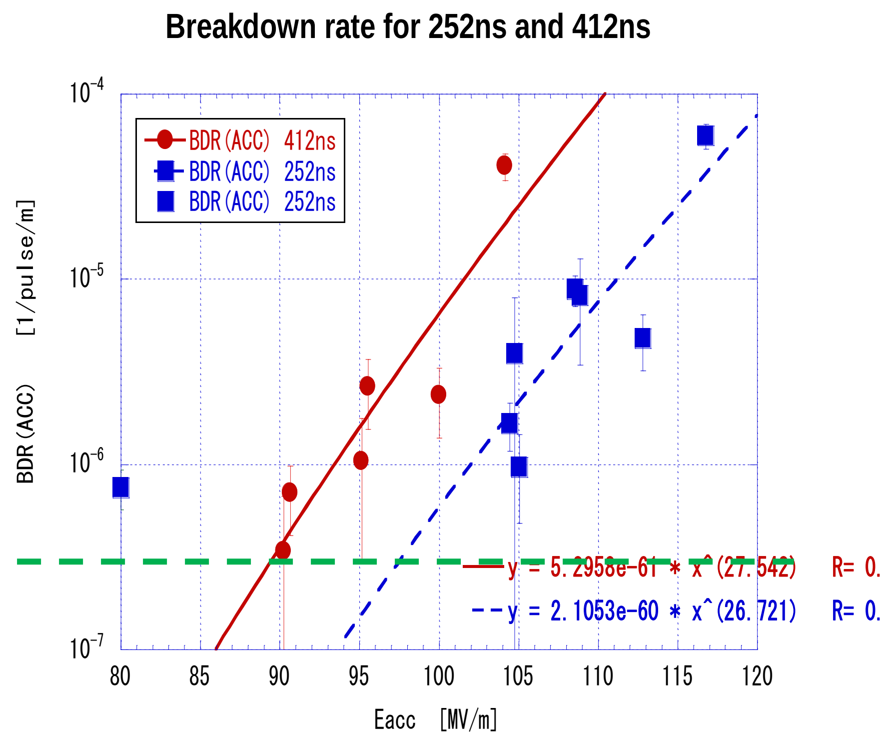


BDR of CLIC prototye but undamped structures

T18 tested at SLAC



T18 tested at KEK



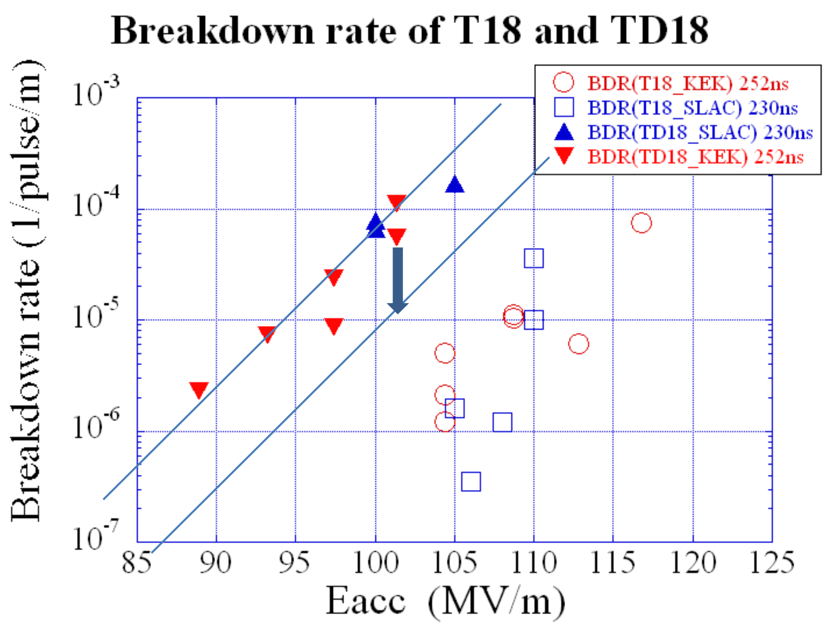
1. A pair of the same structures are tested in different laboratories.
2. Both agrees after nominal processing period.
3. BDR decreases as processing proceeds.
4. Not yet completely stable. Need study more.

BDR: Undamped T18 → Damped TD18

△ ○ T18 vs TD18 ▲ ●

Undamped vs Damped

SLAC vs KEK



Sensitive to Eacc (Es, Hs)

~ X5~10 / 5 (MV/m)

BDR(damped)

~ 100 X BDR (undamped)

To be studied!

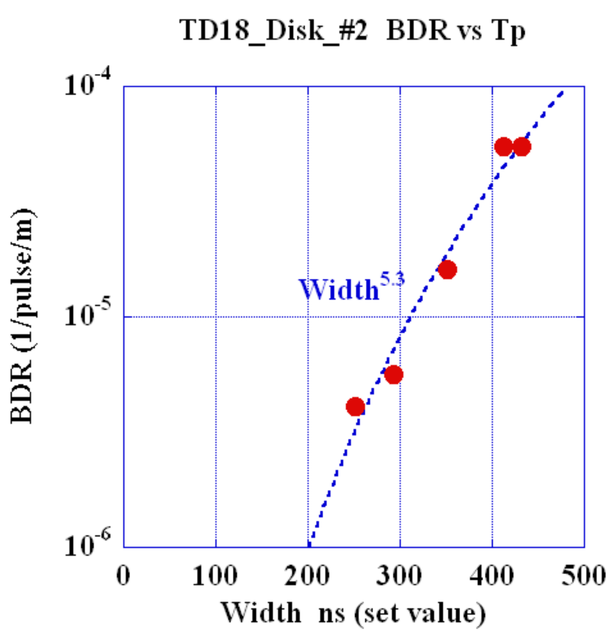
Damped structure:

High ΔT

Any other mechanism?

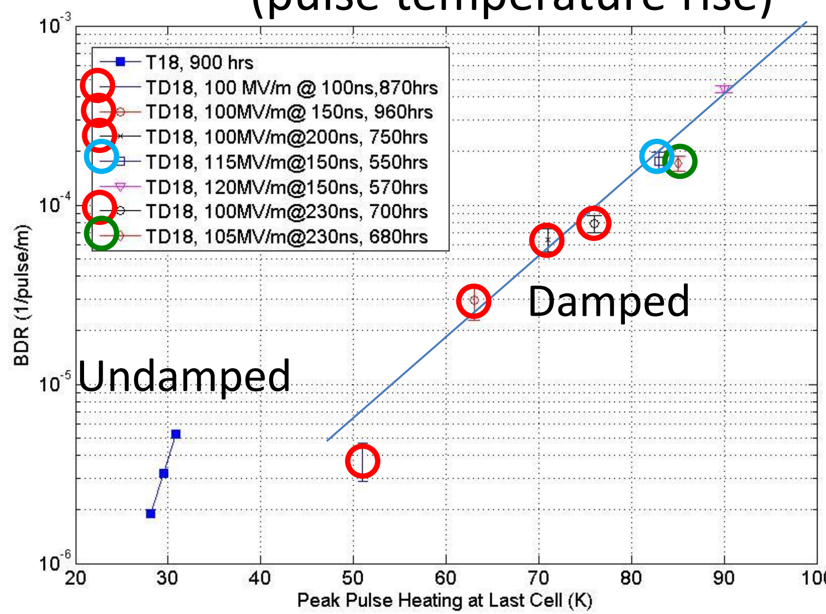
BDR versus RF width or ΔT(pulse heating)

TD18_Disk_#2
BDR versus pulse width



Similar correlation with pulse width.

TD18_Disk_#3
BDR versus ΔT
(pulse temperature rise)



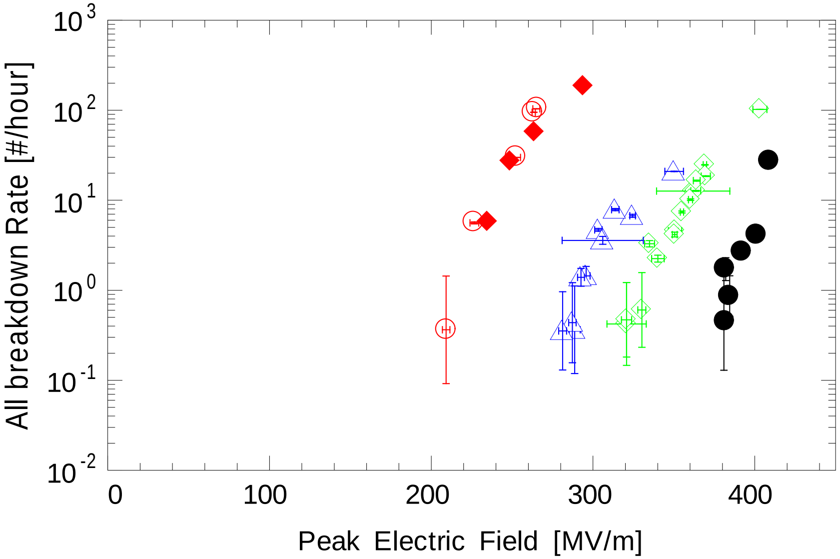
Tight correlation with pulse temperature rise.
Same at 100MV/m but pulse length → ΔT
Same ΔT 83~84 degC but diff. Eacc

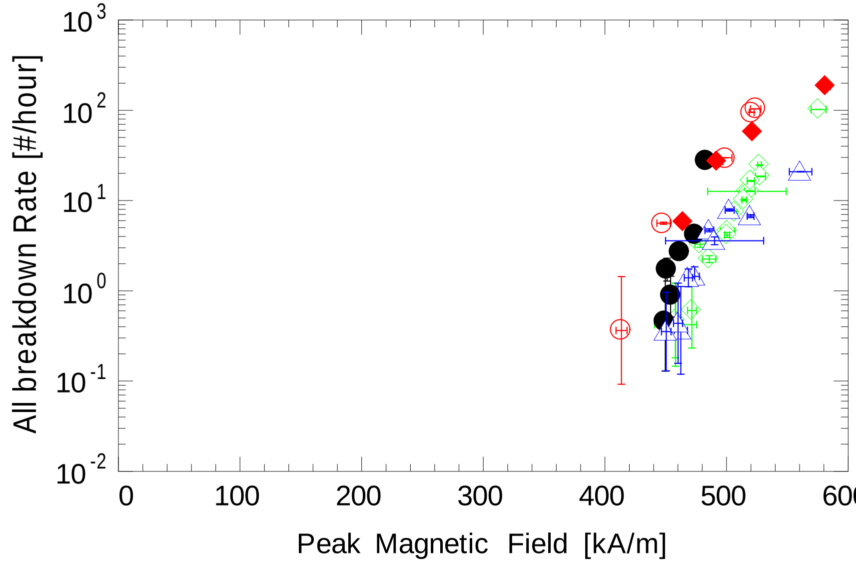
Supplemental high-gradient studies

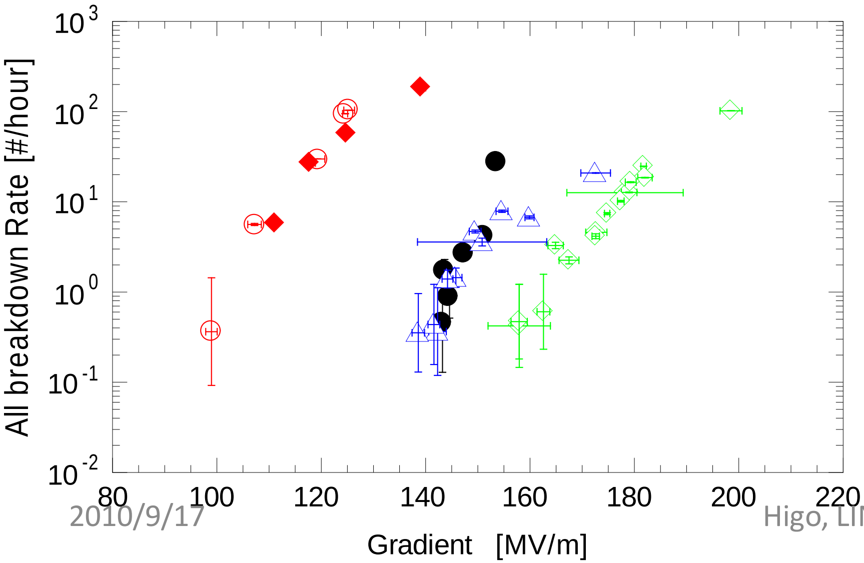
- DC arc at CERN → Calatroni MOP070, Yokoyama MOP075
- Waveguide RF at SLAC and KEK
- Single-cell SW at SLAC → Valery talk FR105
- Pulse heating at SLAC → Laurent MOP076
- CZ 10-cell setup at SLAC

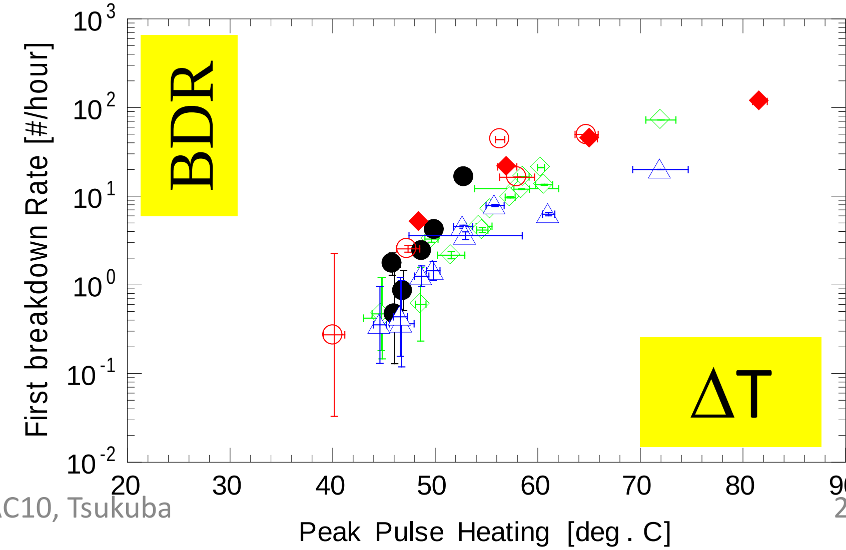
Some of these are presented in the following talk by Valery

Breakdown rate for 5 single cell SW structures
1C-SW-A2.75-T2.0-Cu-SLAC-#1 (green empty diamond), 1C-SW-A3.75-T1.66-Cu-KEK-#1 (black solid circle), 1C-SW-A3.75-T2.6-Cu-SLAC-#1 (blue empty triangle), flat part of the pulse 200 ns, and 1C-SW-A5.65-T4.6-Frascati-#2 (red empty circle), and 1C-SW-A5.65-T4.6-Cu-KEK-#2 (red full diamond)), flat part of the pulse 150 ns









Effort with parameter optimization for stable high gradient

Grudiev, 100621 at FNAL

Compilation

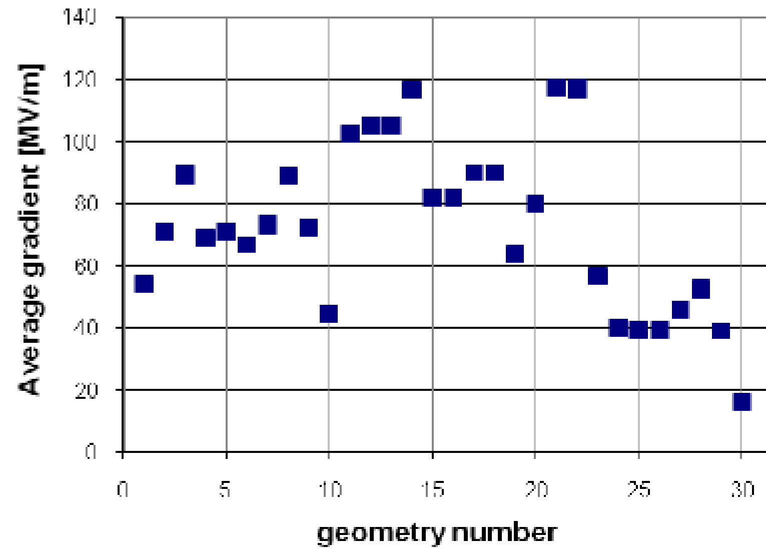
RF constraints: data analysis 1

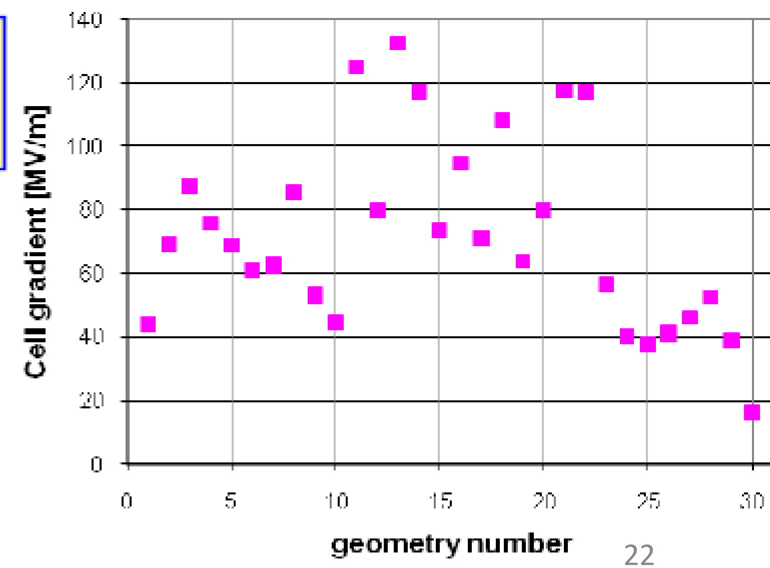
	RF design name	f [GHz]	dphi [deg]	vg1 [%]
1	DDS1	11.424	120	11.7
2	T53VG5R	11.424	120	5
3	T53VG3MC	11.424	120	3.3
4	H90VG3	11.424	150	3
5	H60VG3	11.424	150	2.8
6	H60VG3R18	11.424	150	3.3
7	H60VG3R17	11.424	150	3.6
8	H75VG4R18	11.424	150	4
9	H60VG4R17	11.424	150	4.5
10	HDX11-Cu	11.424	60	5.1
11	CLIC-X-band	11.424	120	1.1
12	T18VG2.6-In	11.424	120	2.6
13	T18VG2.6-Out	11.424	120	1.03
14	T18VG2.6-Rev	11.424	120	1.03
15	T26VG3-In	11.424	120	3.3
16	T26VG3-Out	11.424	120	1.65
17	TD18_KEK_In	11.424	120	2.4
18	TD18_KEK_Out	11.424	120	0.9
19	SW20A3p75	11.424	180	0
20	SW1A5p65T4p6	11.424	180	0
21	SW1A3p75T2p6	11.424	180	0
22	SW1A3p75T1p66	11.424	180	0
23	2pi/3	29.985	120	4.7
24	pi/2	29.985	90	7.4
25	HDS60-In	29.985	60	8
26	HDS60-Out	29.985	60	5.1
27	HDS60-Rev	29.985	60	5.1
28	HDS4Th	29.985	150	2.6
29	HDS4Th	29.985	150	2.6
30	PETS9mm	29.985	120	39.8

High power test results has been scaled to tp=200 ns BDR=1e-6 bpp/m using power scaling lower

$$\frac{E_a^{30} \cdot t_p^5}{BDR} = const$$

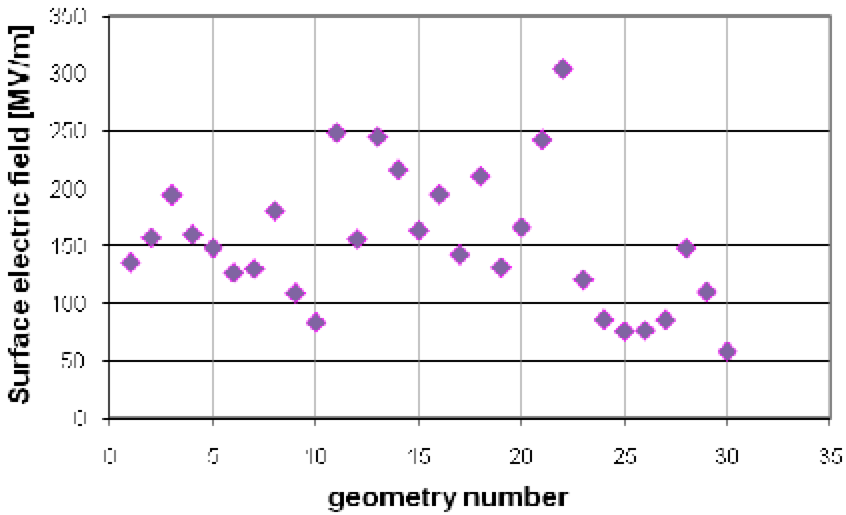
based on the fitting the data

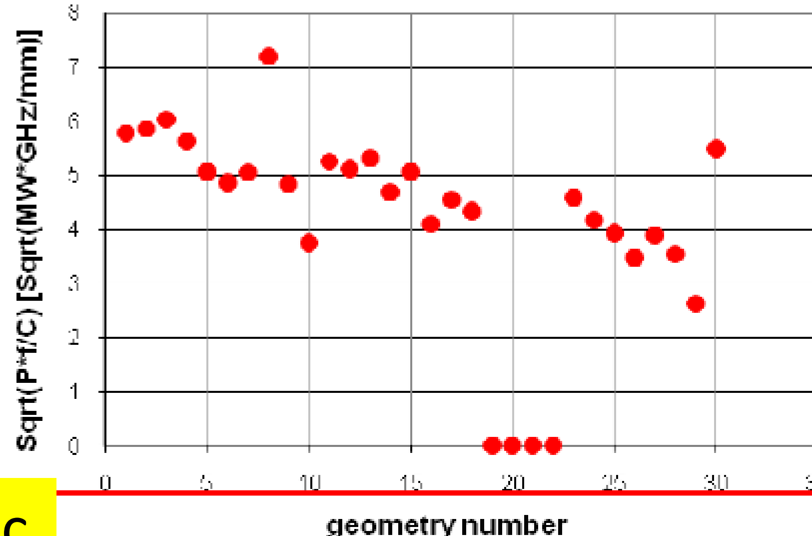


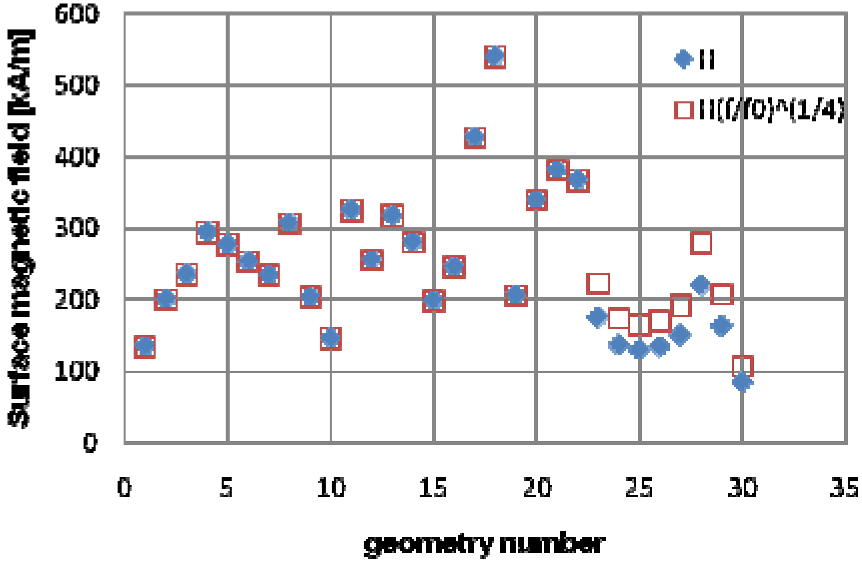


RF constraints: data analysis 2

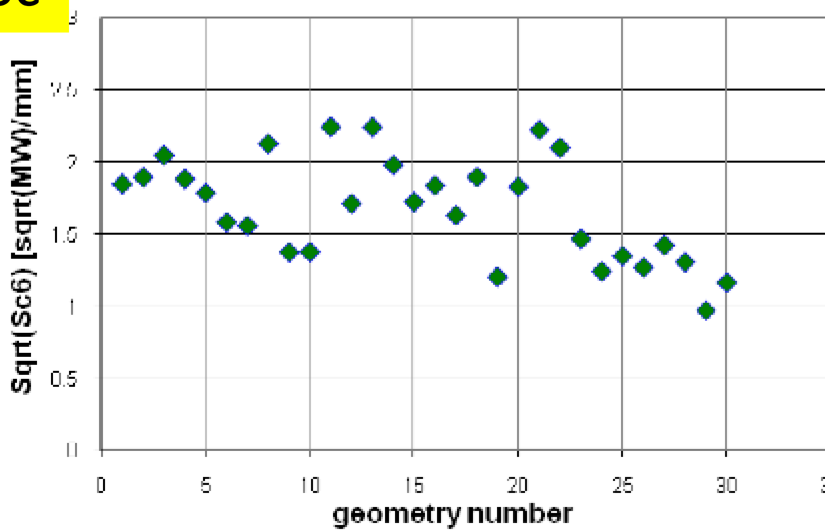
Data has been scaled to tp=200 ns BDR=1e-6 bpp/m







Sc



$$S_c = \mathrm{Re}\{\mathbf{S}\} + \mathrm{Im}\{\mathbf{S}\}/6$$

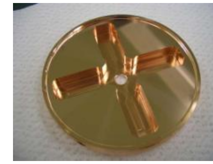
Grudiev, 100621 at FNAL

From Grudiev, May 2010 4th WS at CERN

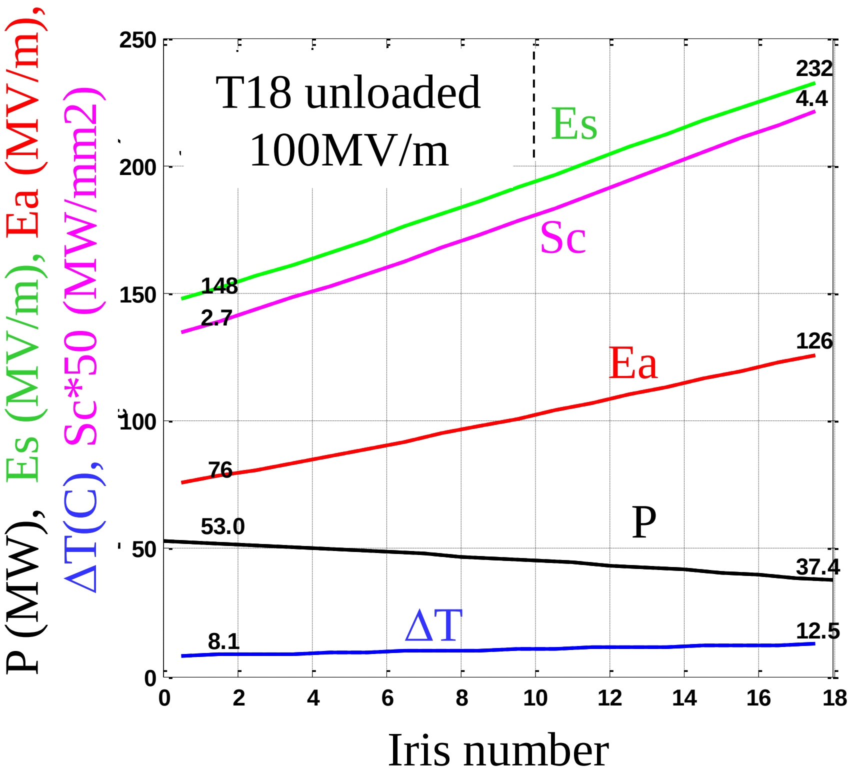
Unloaded 100MV/m

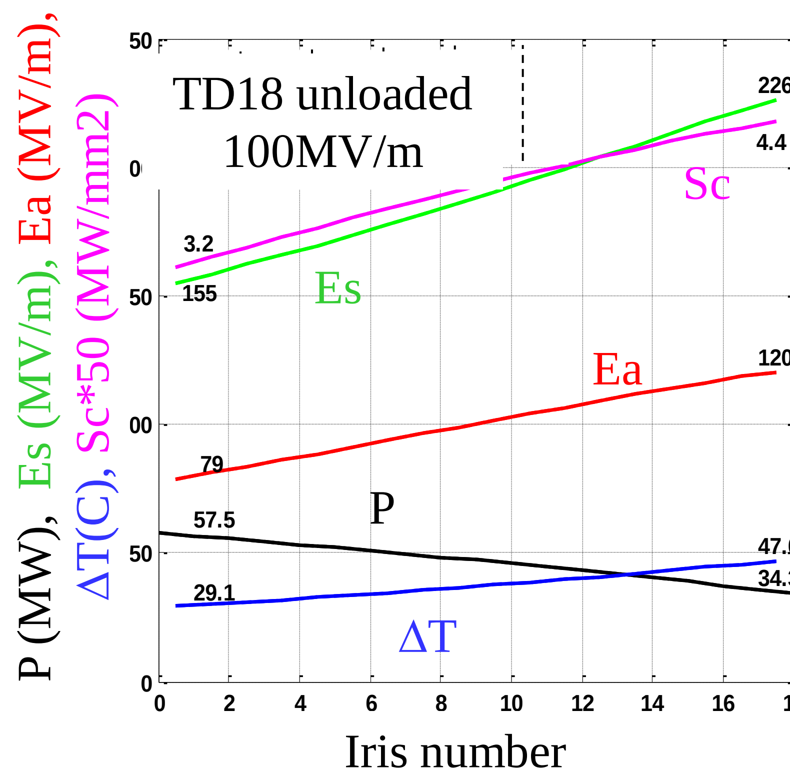
T18

ΔT



TD18

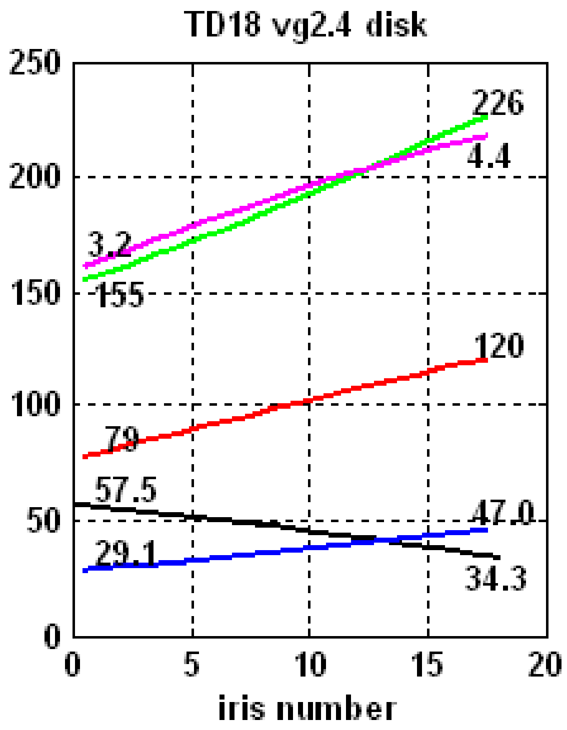




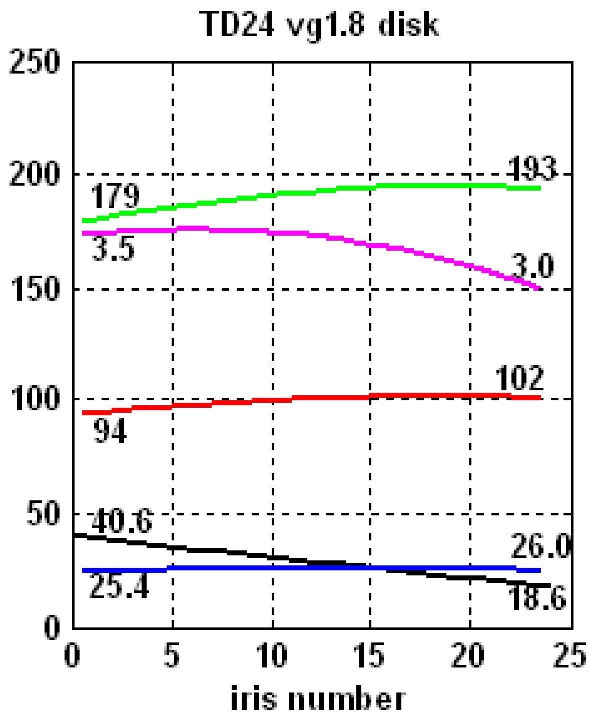
From Grudiev, May 2010 4th WS at CERN

Acc mode parameters TD18 → TD24

Tested



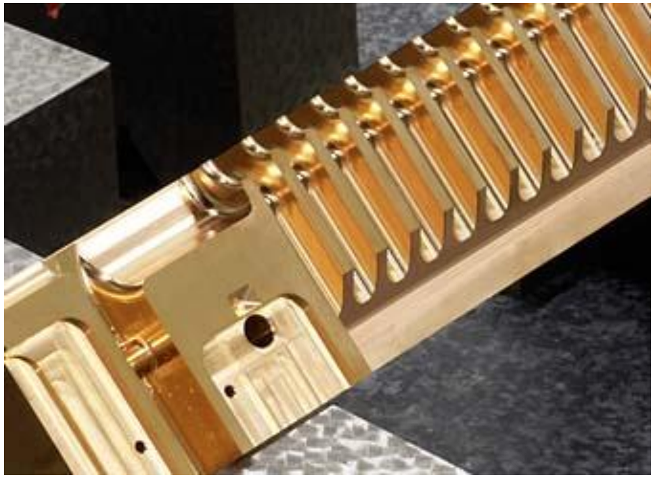
To be tested

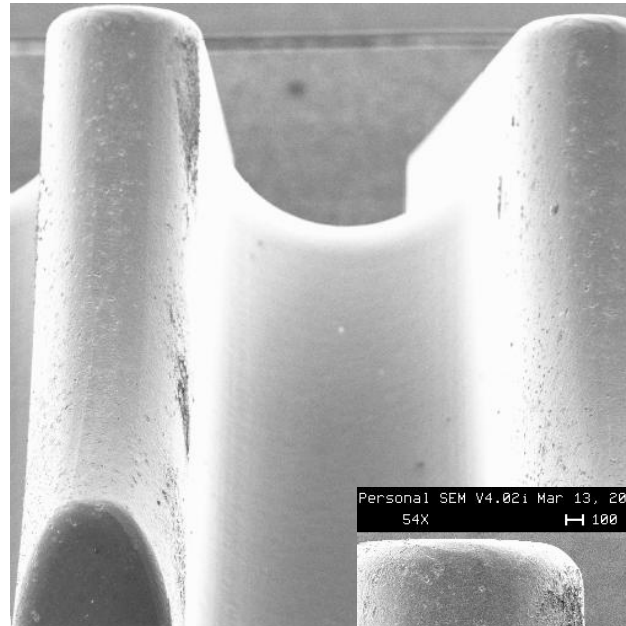


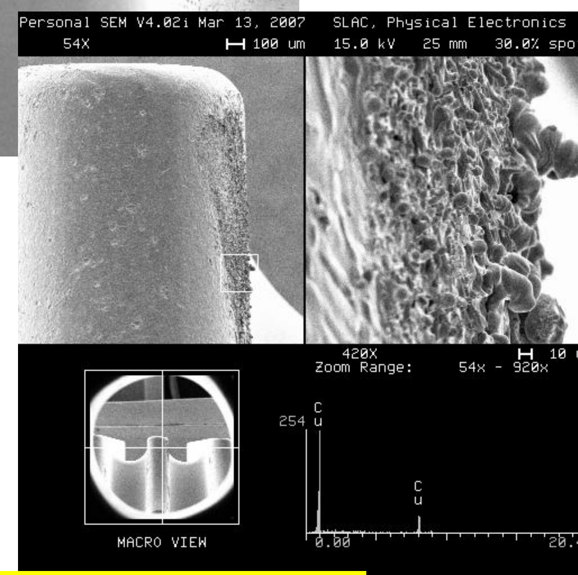
Both Sc and ΔT decreased
by taking cell parameter optimization

Effort with other HOM damping scheme

Consists of rods, quads or halves

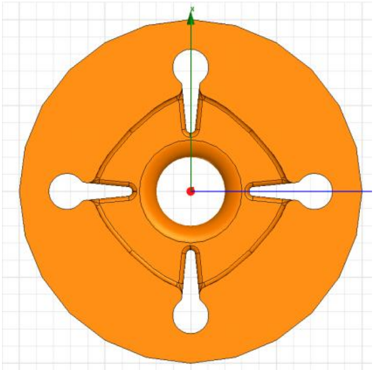




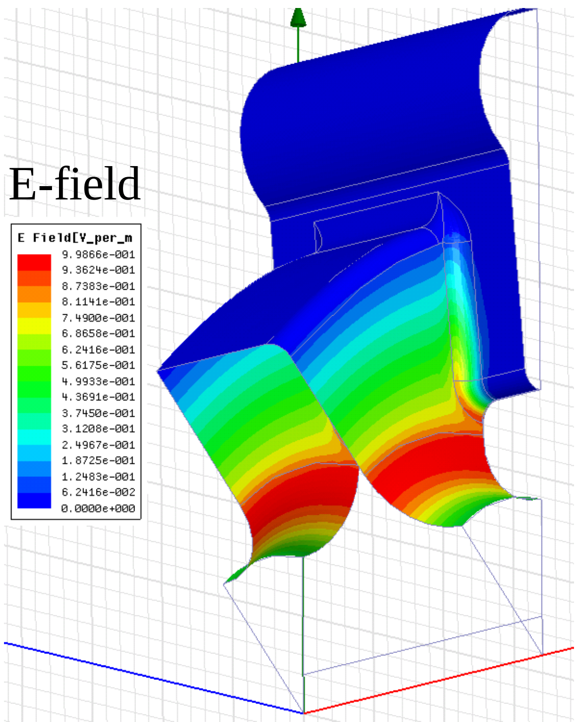


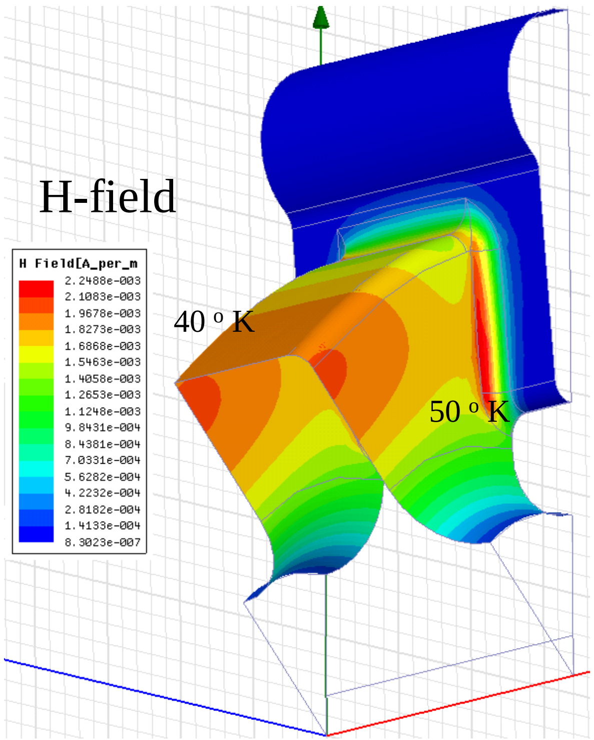
Still poor high gradient performance.

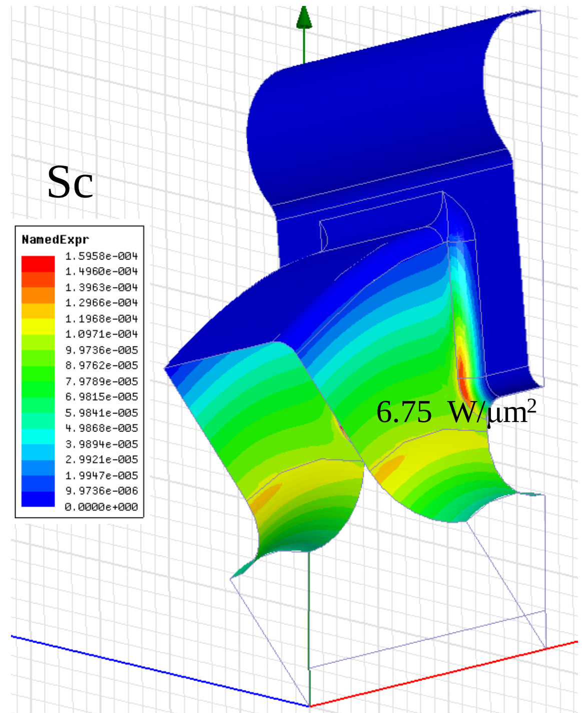
Adolphsen, CLIC09, 2009



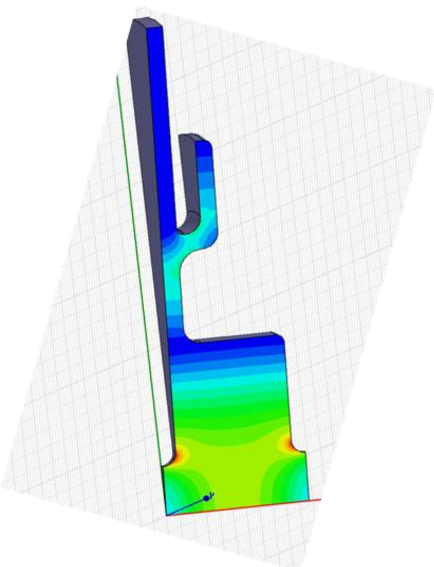
DDS scheme for CLIC
Fabrication test was started.
May evaluate high gradient performance and wake field.



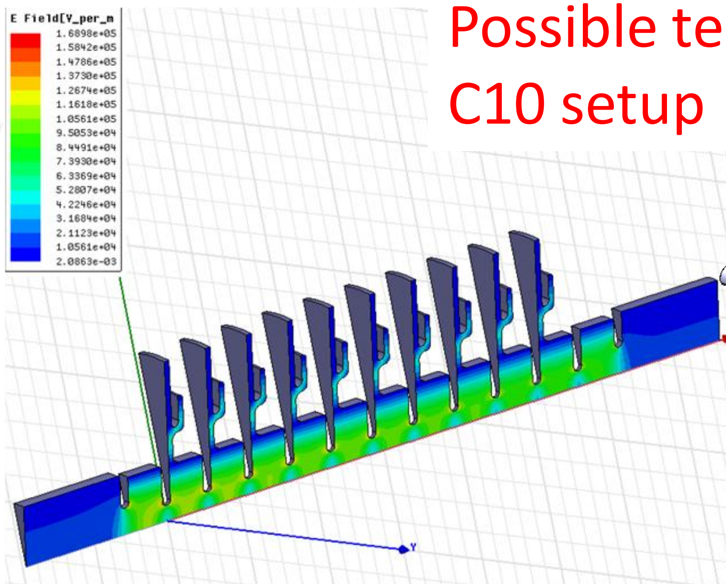




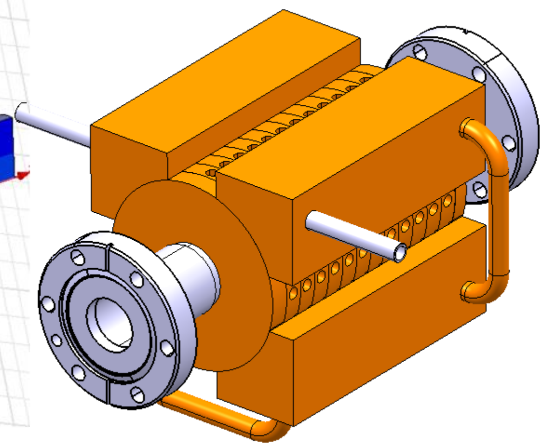
Choke-mode design



Design with
choke mode



Possible test in
C10 setup



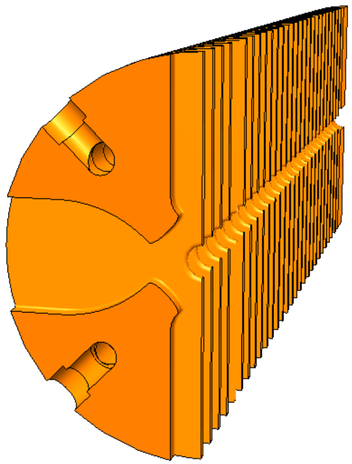
CLIC collaboration with Asia
Design in collaboration with Tsinghua U.
High gradient test at KEK

Efforts in fabrication technology

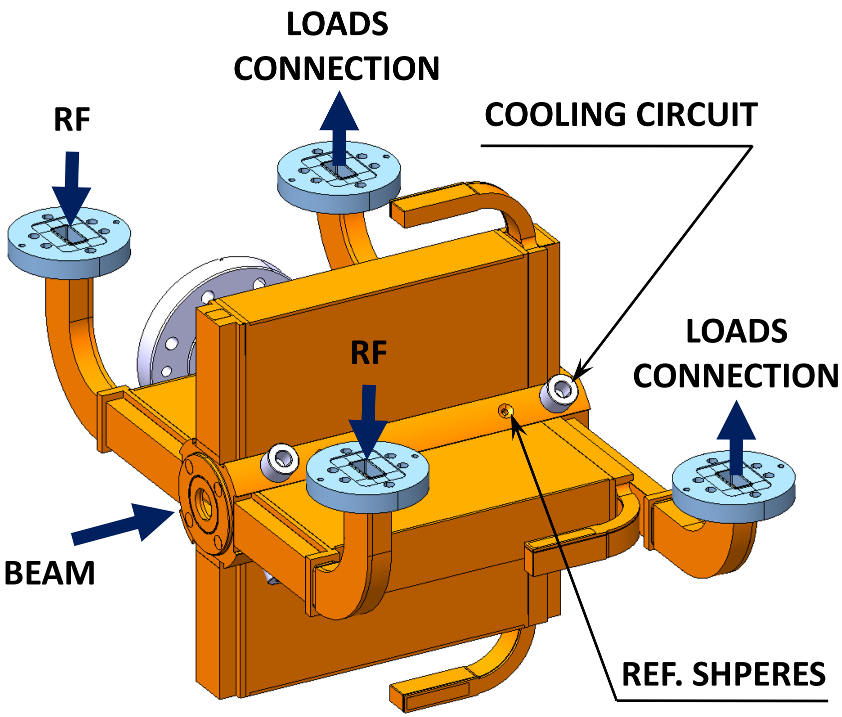
- Before
  - CERN: diamond-tool machining + vacuum brazing
  - SLAC/KEK: technology hydrogen diffusion bonding + vac baking
- Present to future
  - Collaboration among three
  - CERN follows SLAC/KEK to understand
    - CERN-made T18 runs well, $<2\times10^{-7}$ BD/pulse/m (CLIC req.)
  - Technologies are developed which can be realized at multiple places

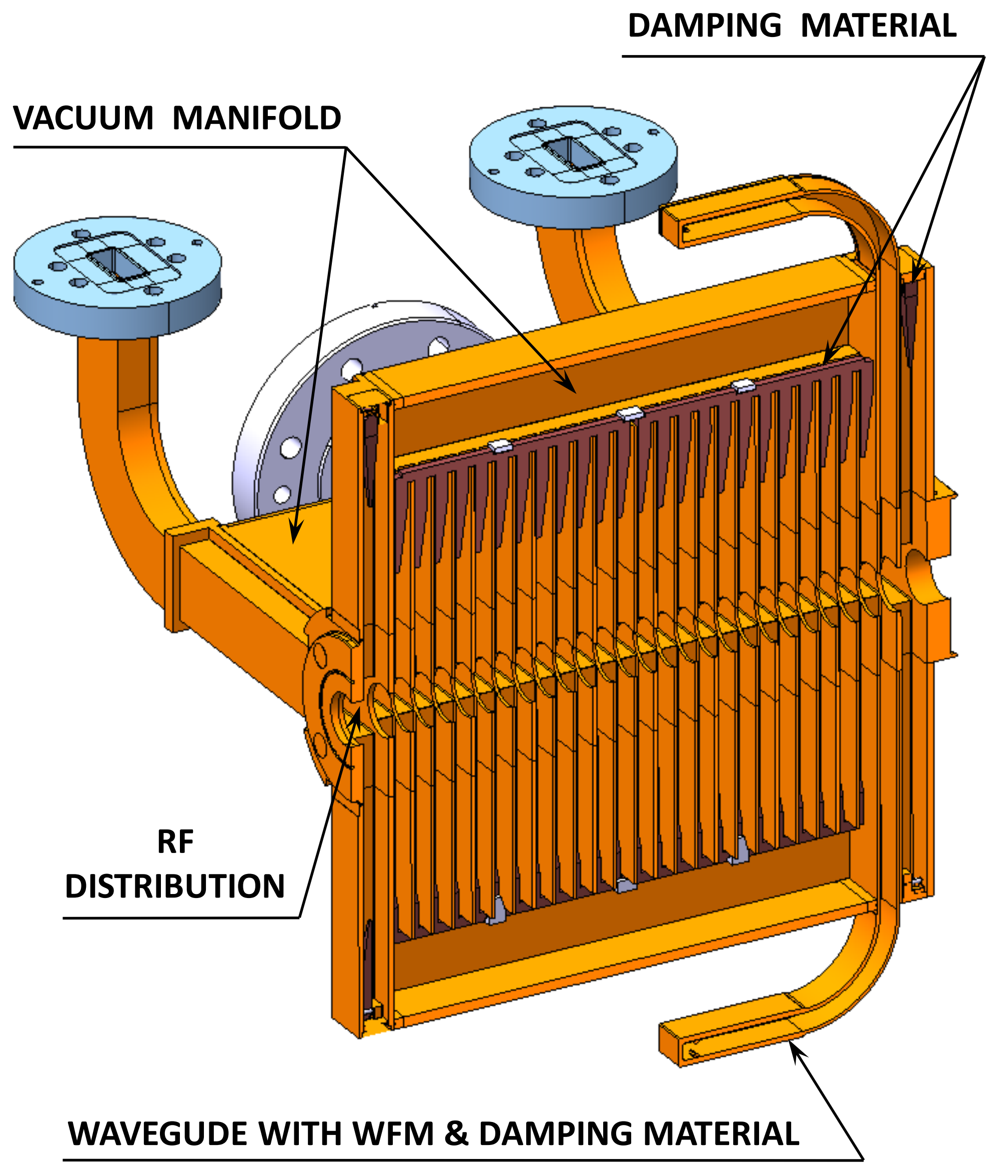
G. Riddone, CERN, 100914

TD 26 (CONCEPTUAL DESIGN)



11.994 GHz, damped structure, 26 cells, asymmetric disk (Ø80 mm), external diameter reference, internal cooling.





Assembly of accelerating structures

G. Riddone, 06/09/2010

CERN strategy

T18 structures tested at SLAC/KEK showed excellent test results

↓

consequent validation of design, machining and **<u>assembly procedure</u>**

↓

NLC/JLC fabrication technology: validated to 100 MV/m (baseline for future CERN X-band accelerating structures)

Baseline procedure

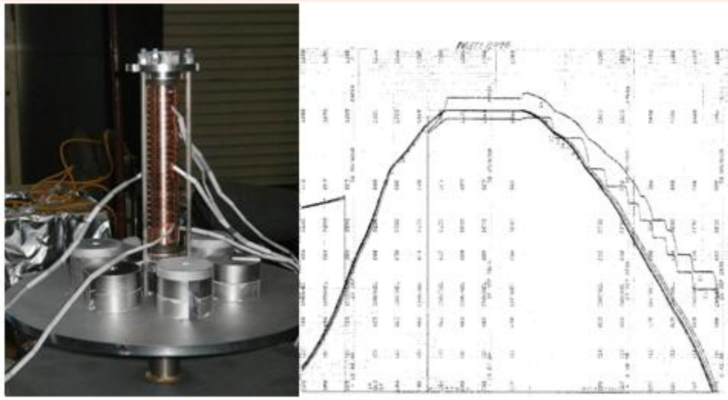
Diamond machining (sealed structures)

Cleaning with light etch

H2 diffusion bonding/brazing at ~ 1000 ˚C

Vacuum baking 650 ˚C > 10 days

Diffusion Bonding of T18_vg2.4_DISC



Pressure: 60 PSI (60 LB for this structure disks)

Holding for 1 hour at 1020° C

J. Wuang

Vacuum Baking of T18_vg2.4_DISC

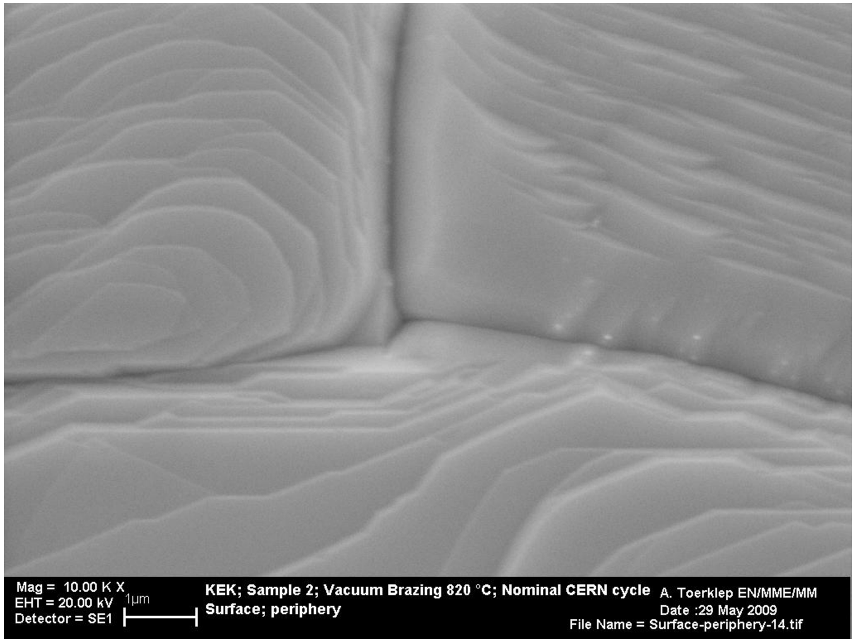
650° C

10 days

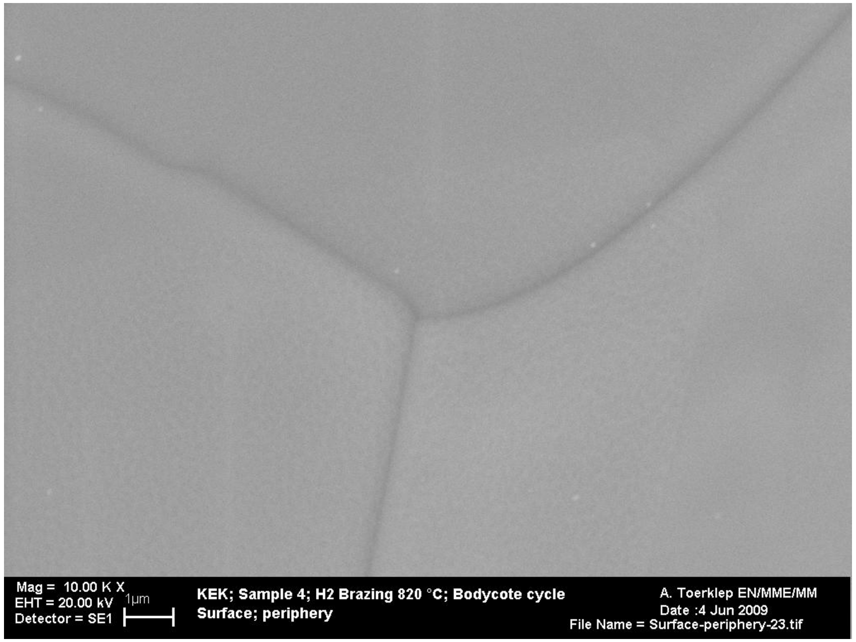
J. Wuang

Vacuum brazing versus hydrogen brazing

Vacuum brazing

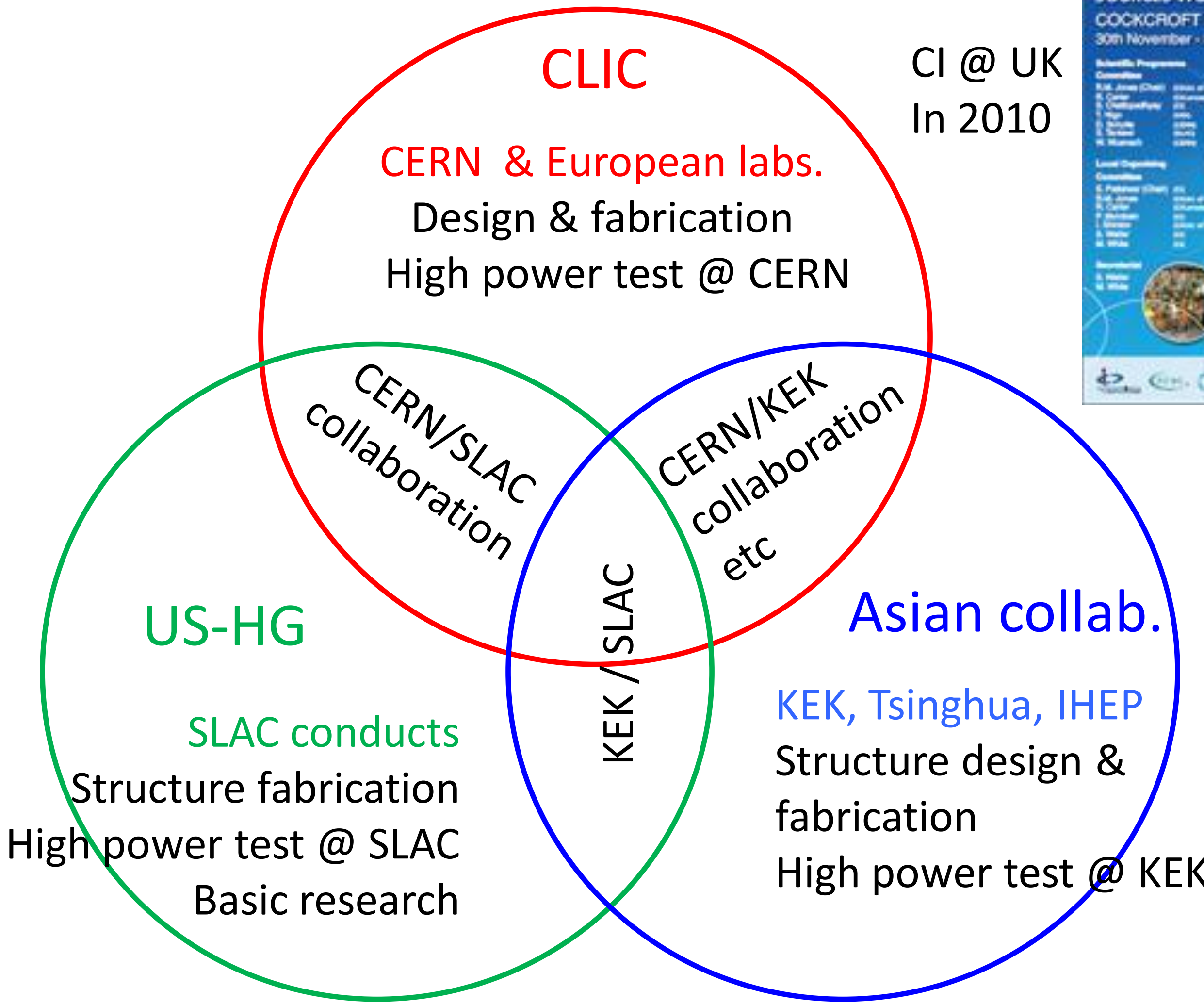


Hydrogen brazing



Extensive program launched to improve our understanding on the influence of different thermal cycles on the copper surface

X-band collaboration



CI @ UK
In 2010

Conclusion

- CLIC BDR requirement
  - CLIC undamped structures T18 meet at 100 MV/m
  - CLIC damped structures TD18 meet at 90 MV/m
  - Need to confirm the long-term stability
- Important parameters were identified
  - Such as Sc and ΔT
  - New designs were made and to be tested in 2010
- Fabrication technology
  - SLAC/KEK scheme is being reproduced by CERN
  - Problems are identified to be improved
- X-band collaboration
  - Worldwide collaboration is expanding centered at CLIC but also in other applications