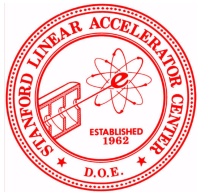


Standing wave structure design

Valery A. Dolgashev

SLAC, Stanford, CA

ISG meeting, SLAC, 25 June 02

Contributors (list is not complete)

Ronald Ruth
David Burke
Juwen Wang
Chris Adolphsen
Roger Jones
Zenghai Li
Roger Miller
Sami Tantawi
Christopher Nantista
Gordon Bowden
Chokuen Ng
Chris Pearson

Outline

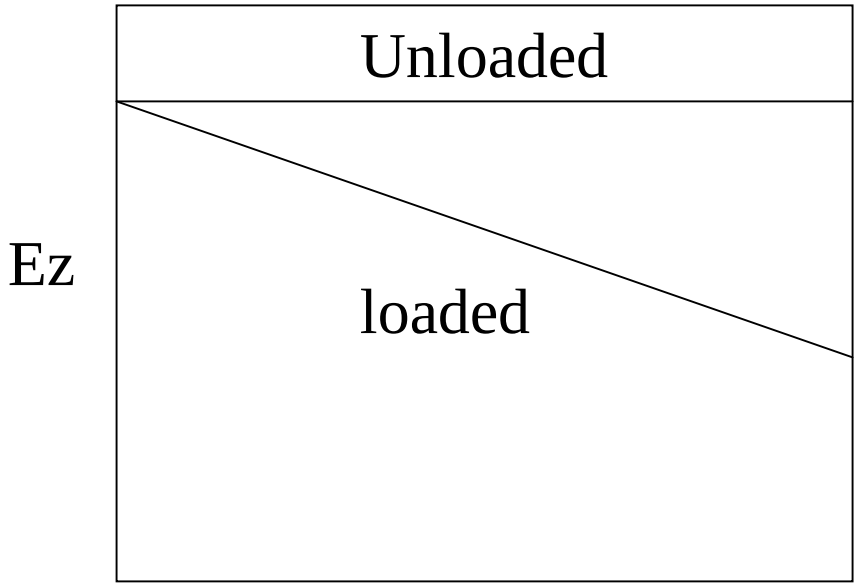
- Motivation
- Design consideration
- NLC standing wave structure
- Breakdown performance
- Feeding
- HOM
- Damping
- Detuning

Motivation for Standing Wave Studies

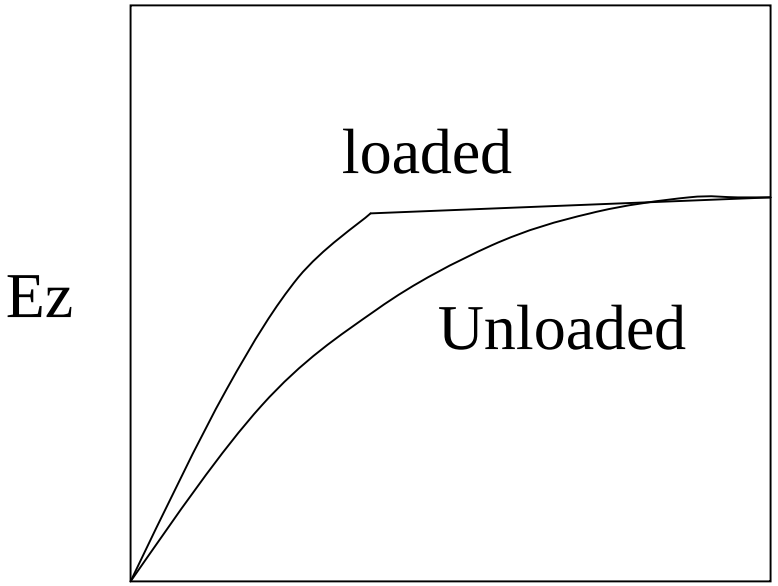
- Loaded gradient = unloaded gradient
- Less power into the structure, less energy in the structure – less damage: 60 cm traveling wave structure ~20 J incident energy, 20 cm standing wave structure ~2 J stored energy.
- In most cases, when breakdown started the field collapses in a few nanosecond and the power is reflected from the input waveguide iris.

Beam Loading

Traveling Wave



Standing Wave



Parameter Comparison

Parameter	**Traveling Wave**	**Standing Wave**
Current	1.0 A	1.0 A
Power	120 MW/m	120 MW/m
Loaded Ez	65 MV/m	66 MV/m
Unloaded Ez	**83 MV/m**	**66 (75 MW/m)**
E surf/Ez	~ 2.3	~2.3
Beam on time	103 nsec	108 nsec, β=2.8
Beam/RF eff.	~ 38%	~38%

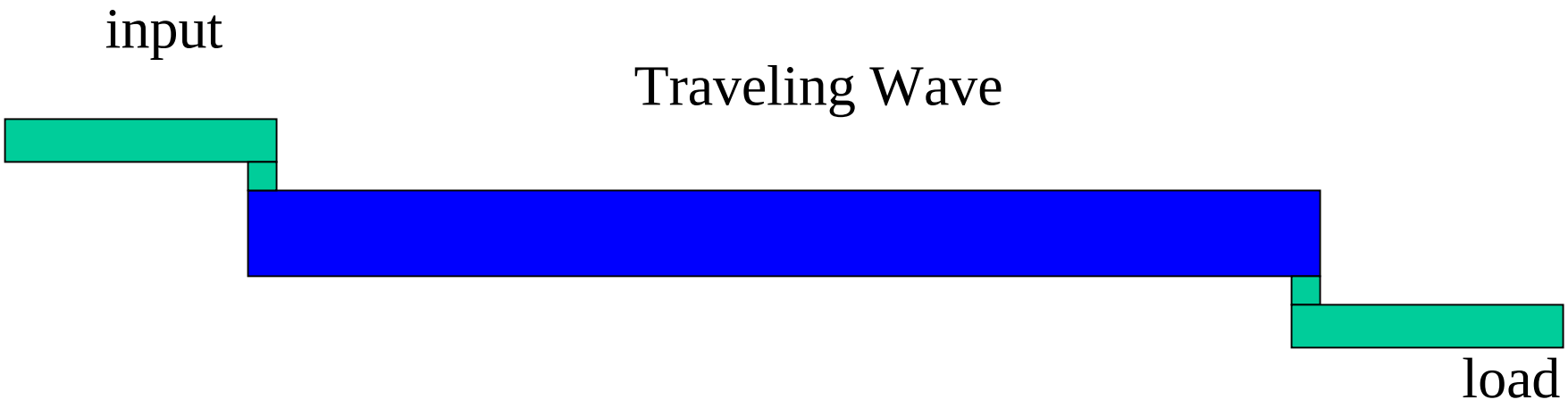
Design considerations

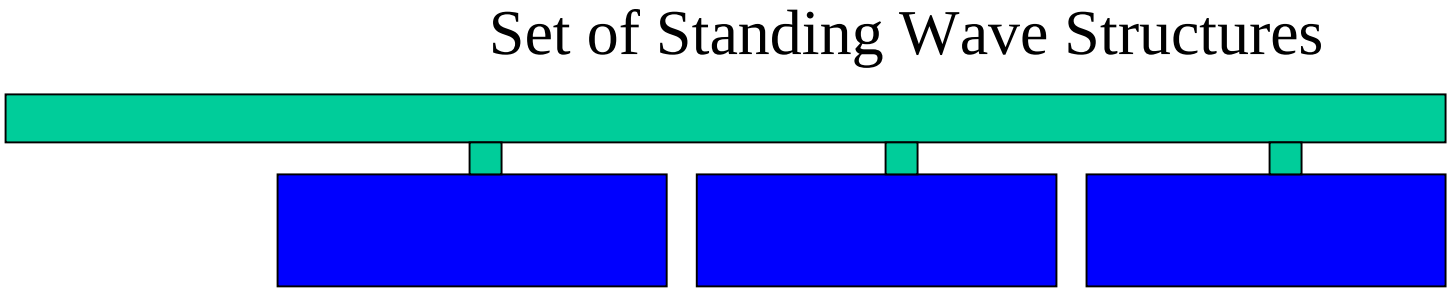
- High power performance
  - Breakdown threshold
  - Damage
  - Beam loading
- Efficiency
- Wake field performance
  - Detuning
  - Damping
- Manufacturability
  - Feeding with RF
  - Wake field damping with 2D choke cavities

NLC standing wave structure

- Superstructure made of 3 or 4 short (15 cell) standing wave structures
- 2D all, but couplers
- Local damping with choke cells: 1 damping cell per ~4 regular cells.
- Power distribution: compact 2D planar circuit
- **High gradient** version with iris tips made of stainless steel or molybdenum.

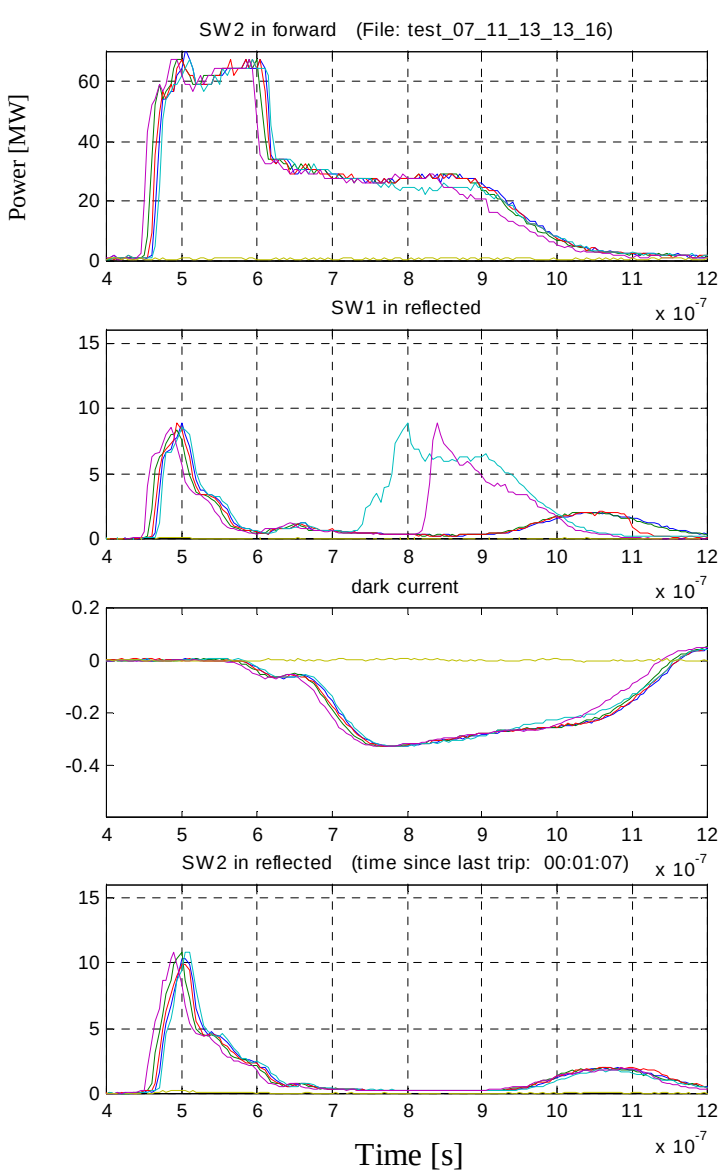
Sets of Standing Wave Structures

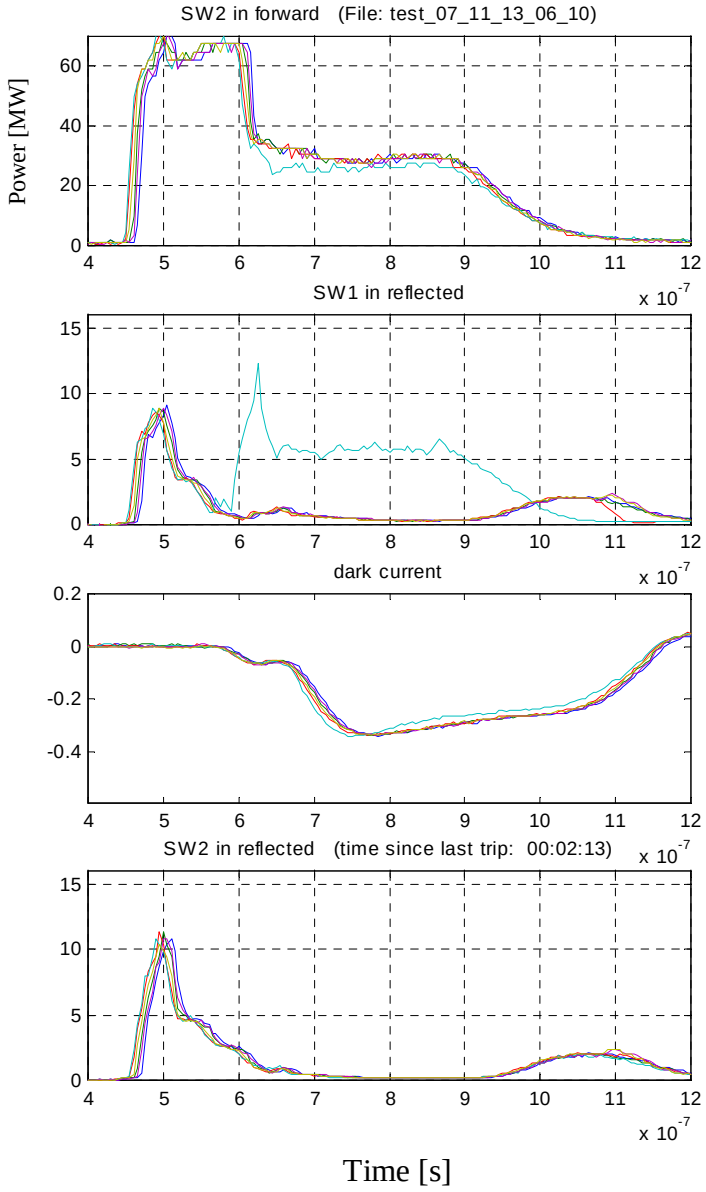




- Each standing wave structure of a **super**structure is short and relatively simple. We can simulate and optimize it "full 3D".

Breakdown in standing wave accelerating structures





Breakdown in 15-cell π mode cavity, gradient 70 MV/m during 300 ns, *NLCTA, SLAC*, 11 July 2001

V.A.Dolgashev, 25 June 02.

Breakdown in standing wave accelerating structures

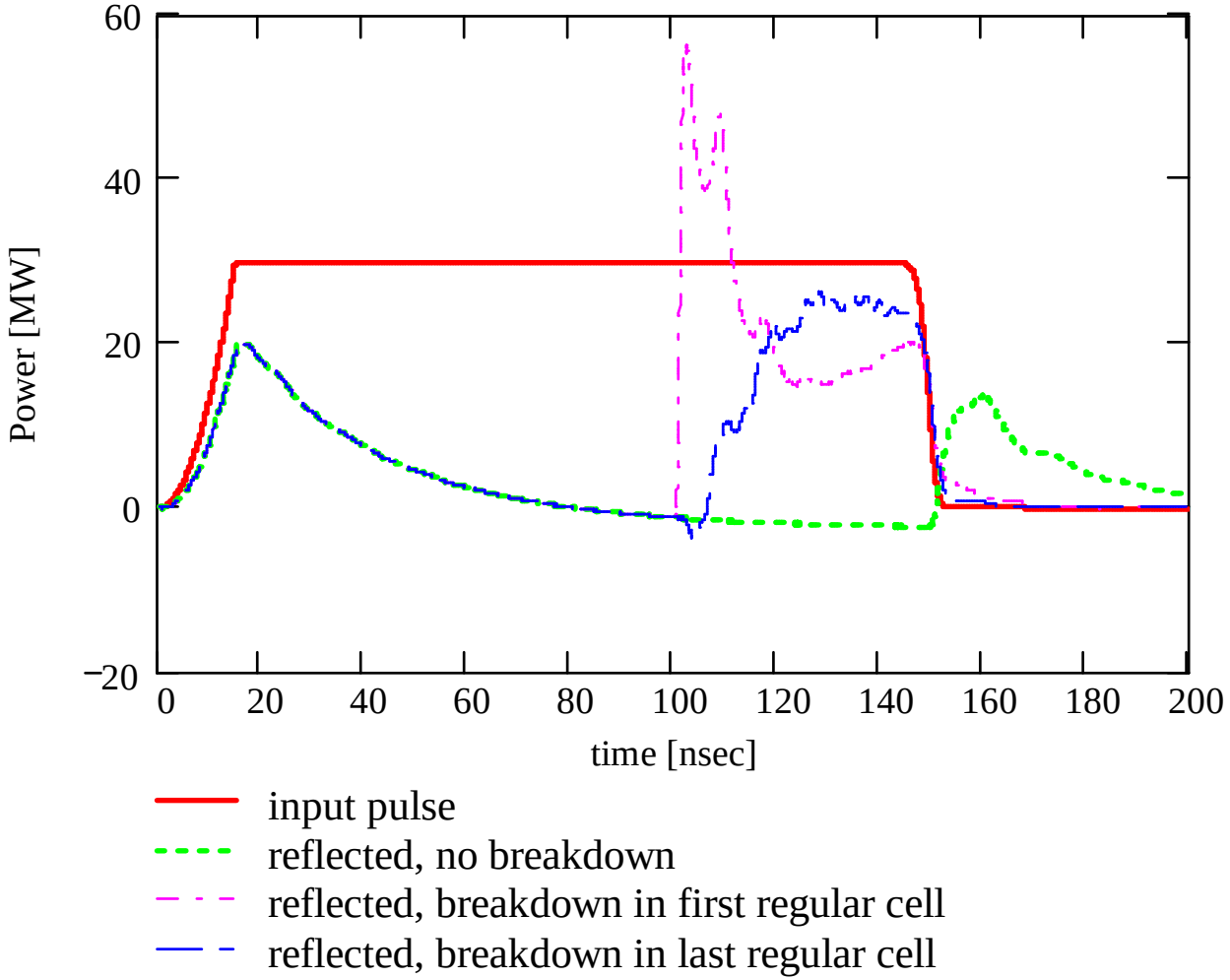
Features of RF breakdown in SW structure

- Major part of input power reflected
- Reflected energy increases during ~**10 ns**
- Pulse length of current passed through beam pipe is ~10ns

Simulation model

- 2D model
- Space charge limited emission of electrons

Breakdown in standing wave accelerating structures



Input RF pulse and reflection from the standing wave structure without breakdown, and with breakdown in the first and last regular cells *vs*. time

V.A.Dolgashev, 25 June 02.

Breakdown in standing wave accelerating structures

Result

- Electromagnetic fields in the structure collapse just after emission starts. Currents pass across whole cavity and absorb major part of stored rf energy in a few nanoseconds while filling time of the structure is ~100 ns.

- The currents detune the whole structure, hence the π resonance is shifted from the working frequency. This shift causes rf energy to reflect from input iris of the structure.

Summary of high power processing

1. We have tested 7 standing wave structures of 4 different types. Breakdown behavior of **all** structures is very **similar**.
2. **3 tested structures of 2 types (*couplers included*) satisfy NLC criteria for breakdown rates and short-range wakefields.**
3. Effective conditioning regime (start with short (50-100 ns) pulse, high power and gradually increase pulse width) let us with 1000-2000 breakdowns reach breakdown **limit** (with breakdown rate 20/hour it will take **less than 4 days**). Further processing has **weak** effect on this limit.
4. We **do not** have evidence that variation in **pre-processing** (backing, etching *etc*.) effects breakdown **limit**.
5. Breakdown limit as well as breakdown rate at certain gradient correlated well with primitive model of **pulsed heating.**
6. Structures with **less then 40 deg. C** pulse heating have very low breakdown rates.
7. Breakdown limit due to surface electric field is **masked** by breakdowns due to high magnetic field. **Highest** surface **electric field** at **low breakdown rate**, NLC gradient, and NLC pulse width was **150MV/m.**
8. Damage is roughly proportional to number of breakdowns (**no breakdowns – no damage**).
9. Breakdowns in vicinity of **couplers** produce damage equivalent to one cell frequency shift of **~1 kHz/breakdown**.

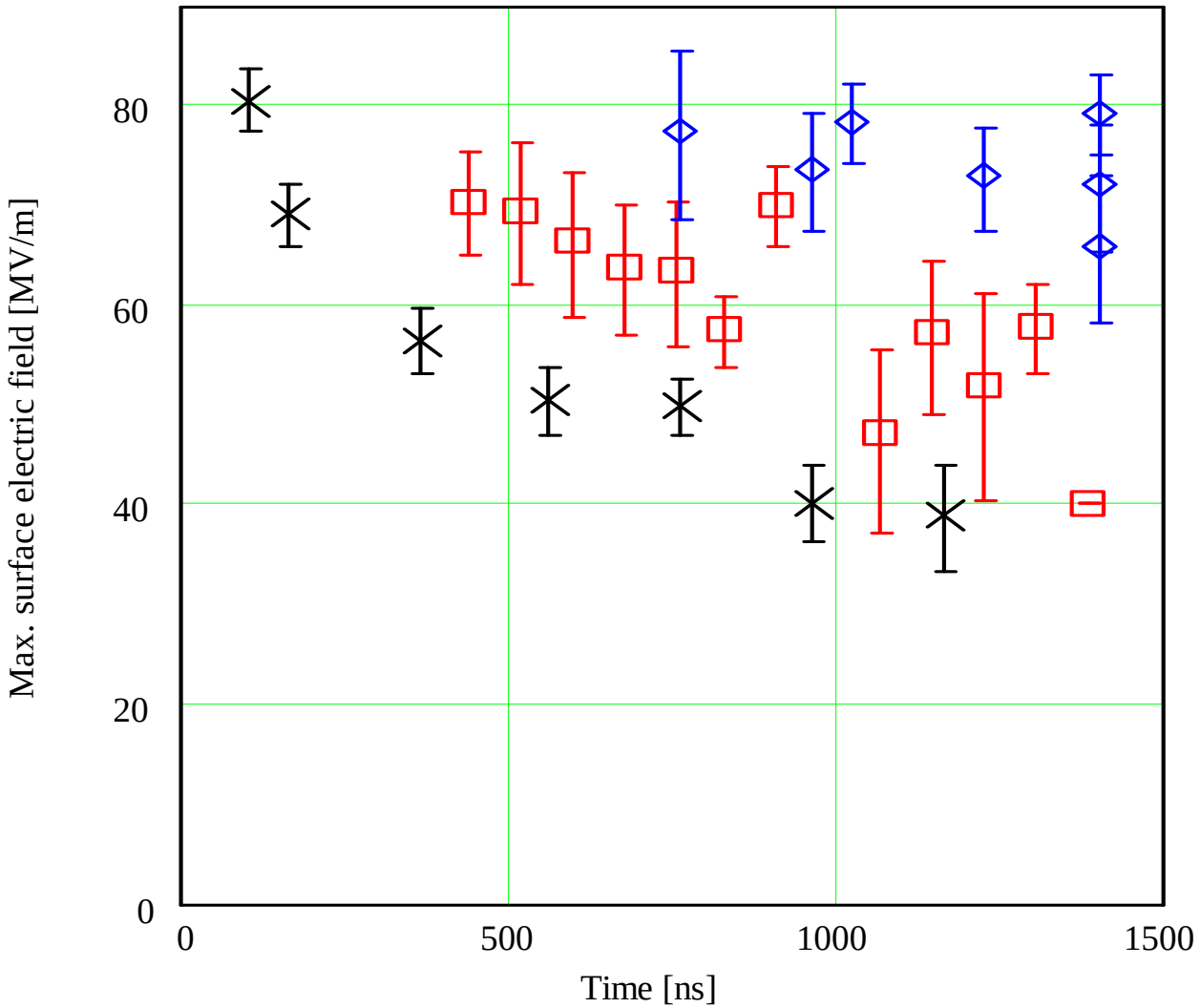
V.A.Dolgashev, 22 June 02.

New design for couplers to avoid pulsed heating

- Rounding of the waveguide iris
- Radial coupler (Ron Ruth)
- Choke in rectangular waveguide (Sami Tantawi)
- No waveguide irises (Chris Nantista)

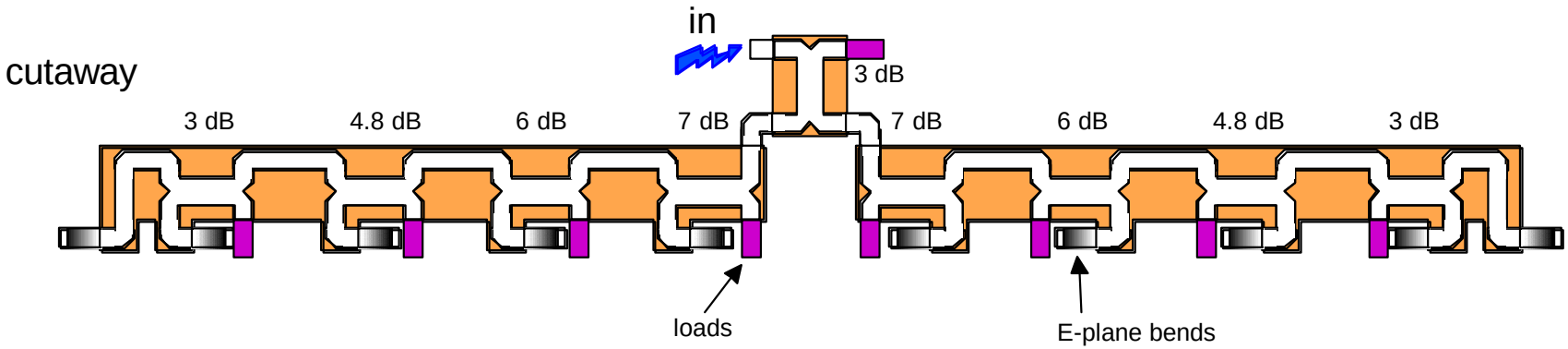
Breakdown threshold measurements for low-magnetic-field waveguides with different materials

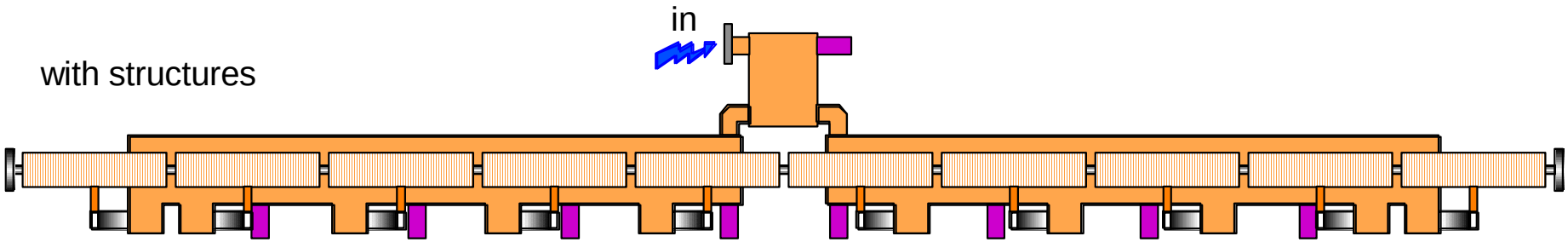
boxes – copper, **x** - gold plated, diamonds – stainless steel waveguides
data with ± standard deviation



V.A.Dolgashev, S.G.Tantawi, 25 June 02.

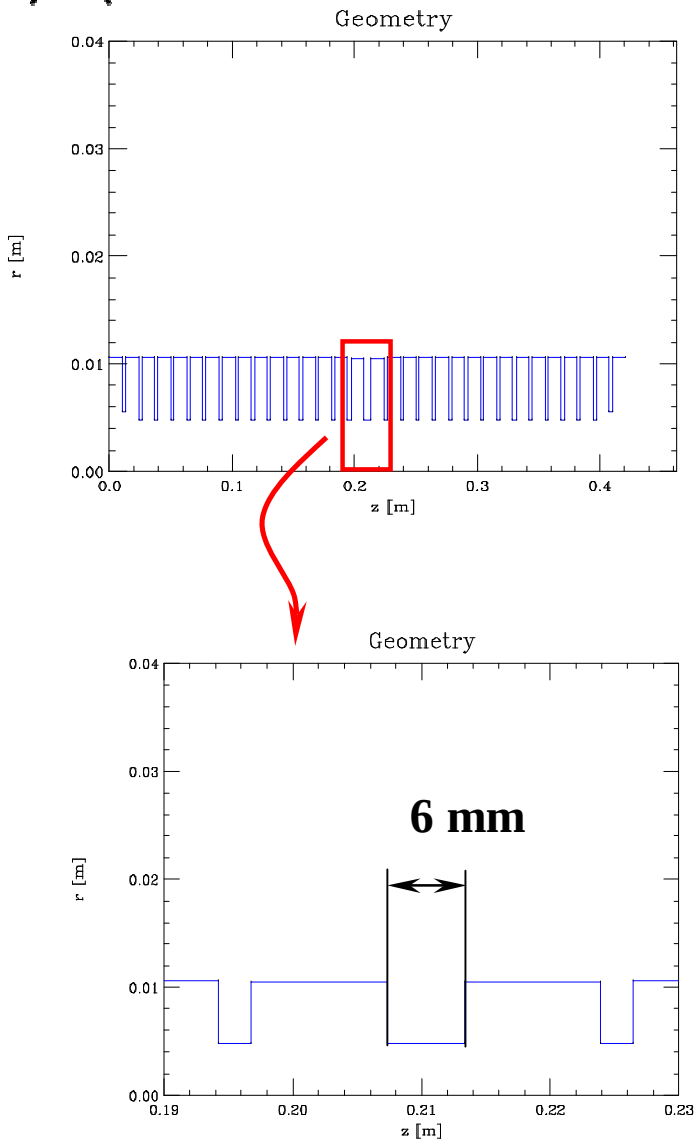
A Power Distribution Circuit for Filling Ten Structures from One Feed



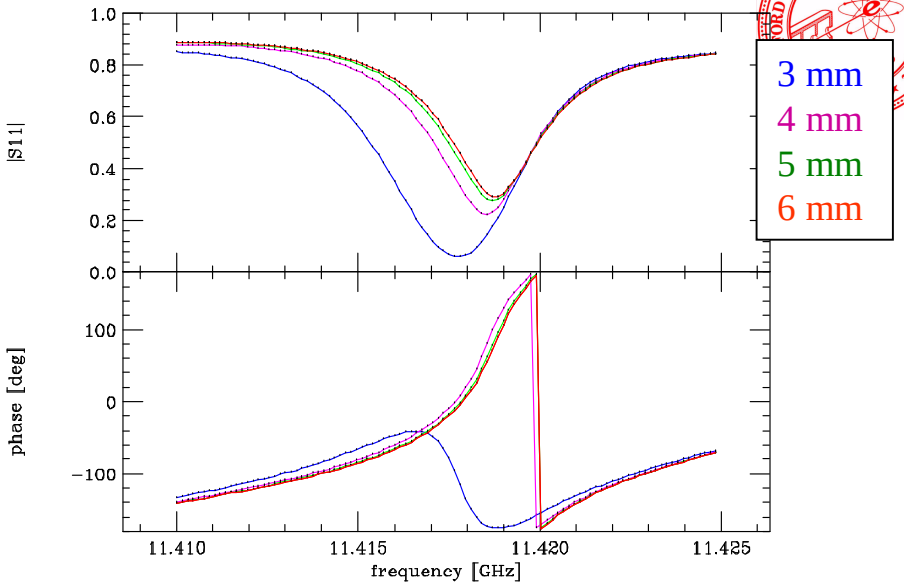


Sami Tantawi

Characteristics of SW structure *vs.* thickness of cut-off iris



Geometry of two 15 cell 2D SW structures connected by an iris with thickness 6 mm, a = 4.75 mm



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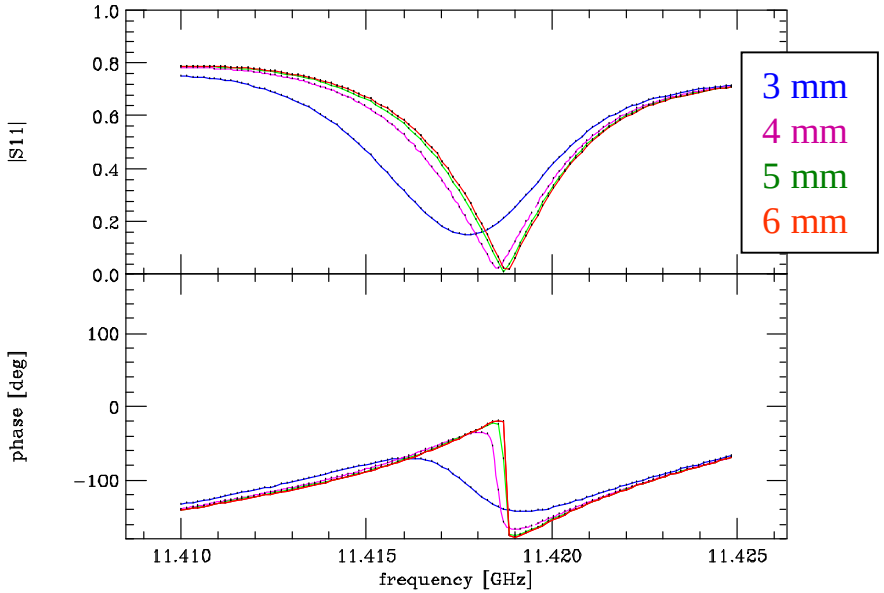


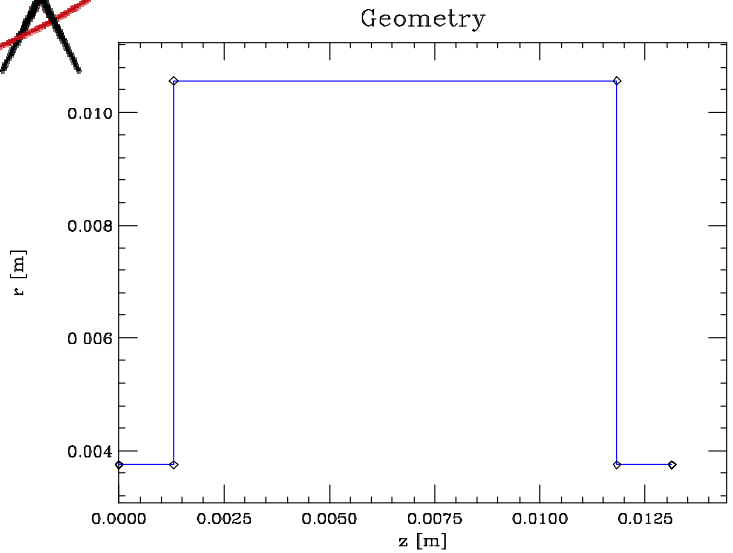
Loaded

V. A. Dolgashev, Structure meeting 28 Mar 02

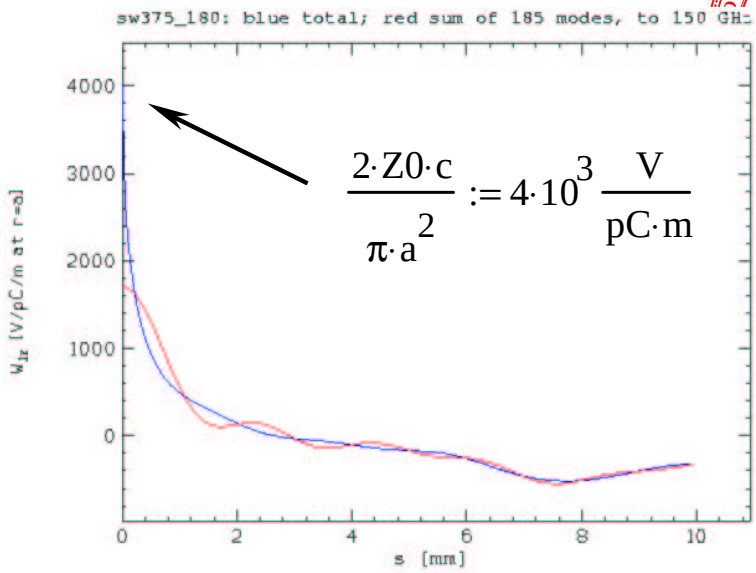
Higher Order Modes (HOM)

- **How many modes are important?**
- **Uncoupled model of higher HOM.**
- **Wakefield partitioning *vs.* detuning and change in phase advance?**

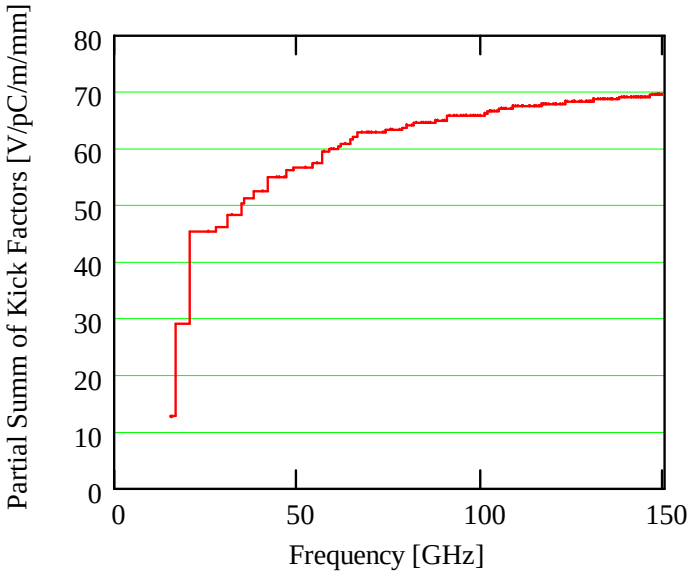
Short range dipole wake for standing wave structure, a = 4.23



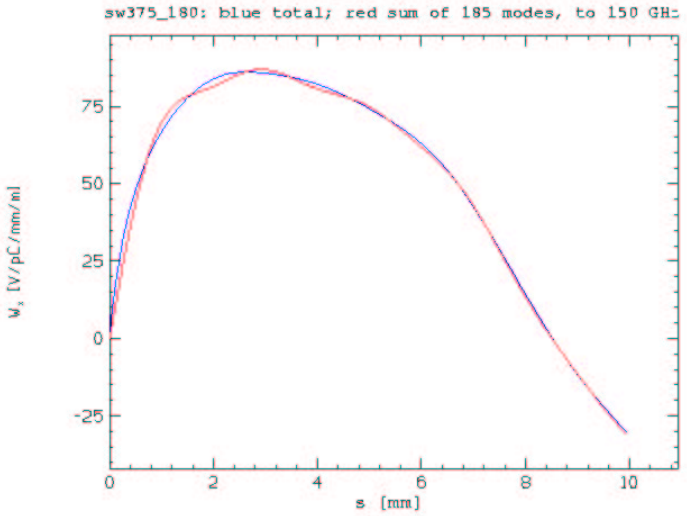
One period



Longitudinal dipole wake



Partial sum of kick factors

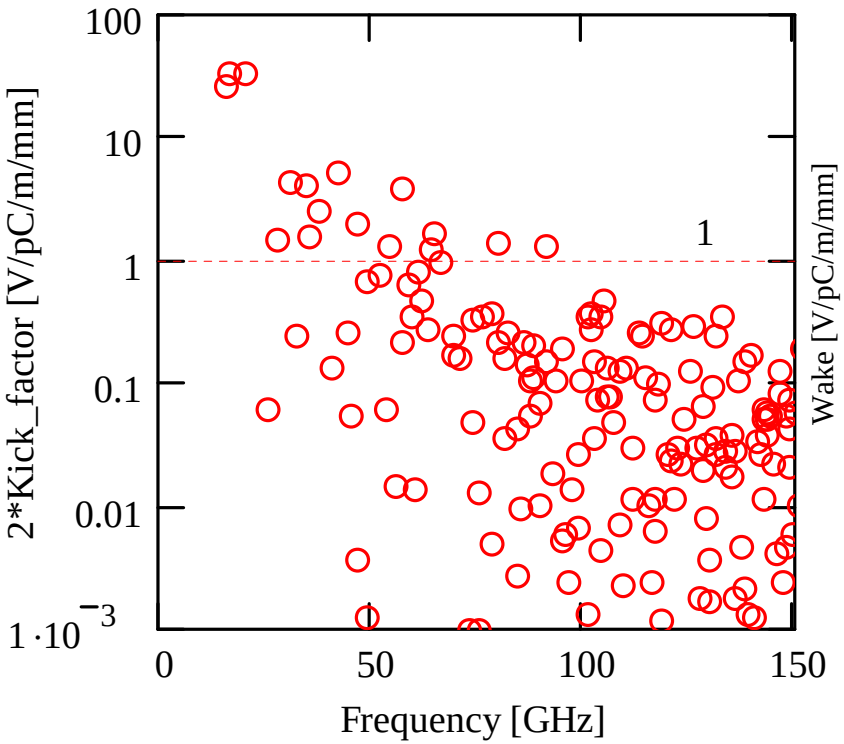


Transverse dipole wake

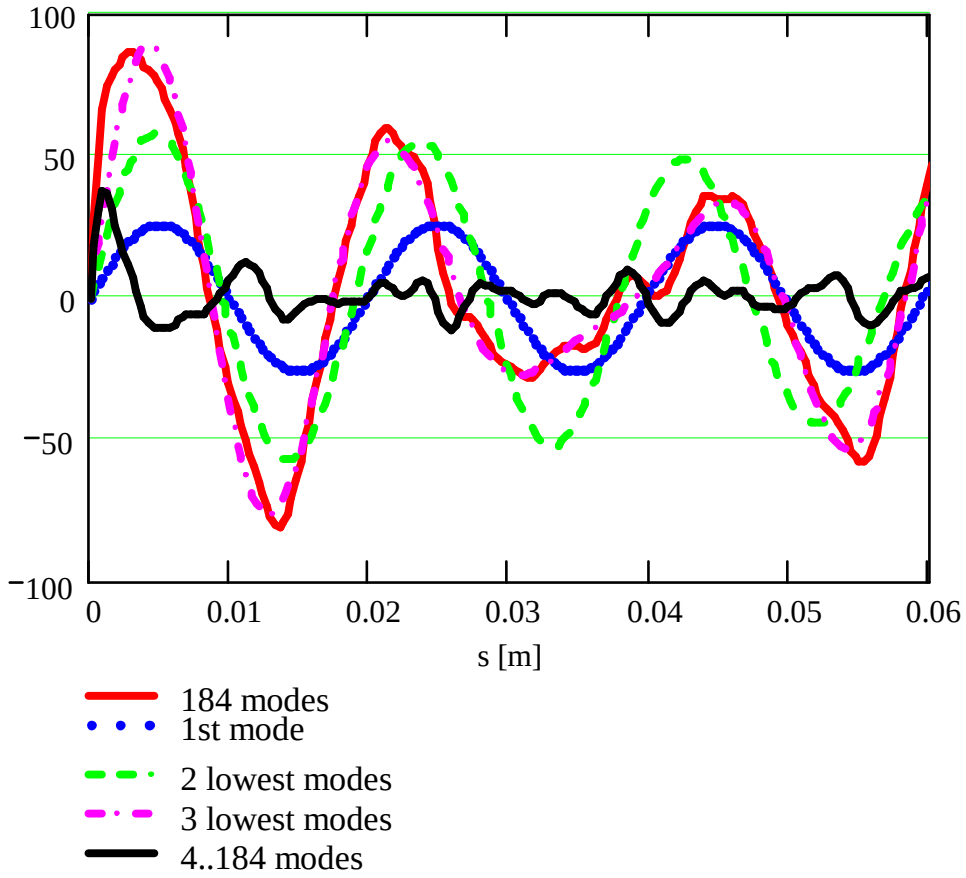
V. Dolgashev,K. Bane, March 2002

Wakefield performance

Higher order modes, uncoupled model



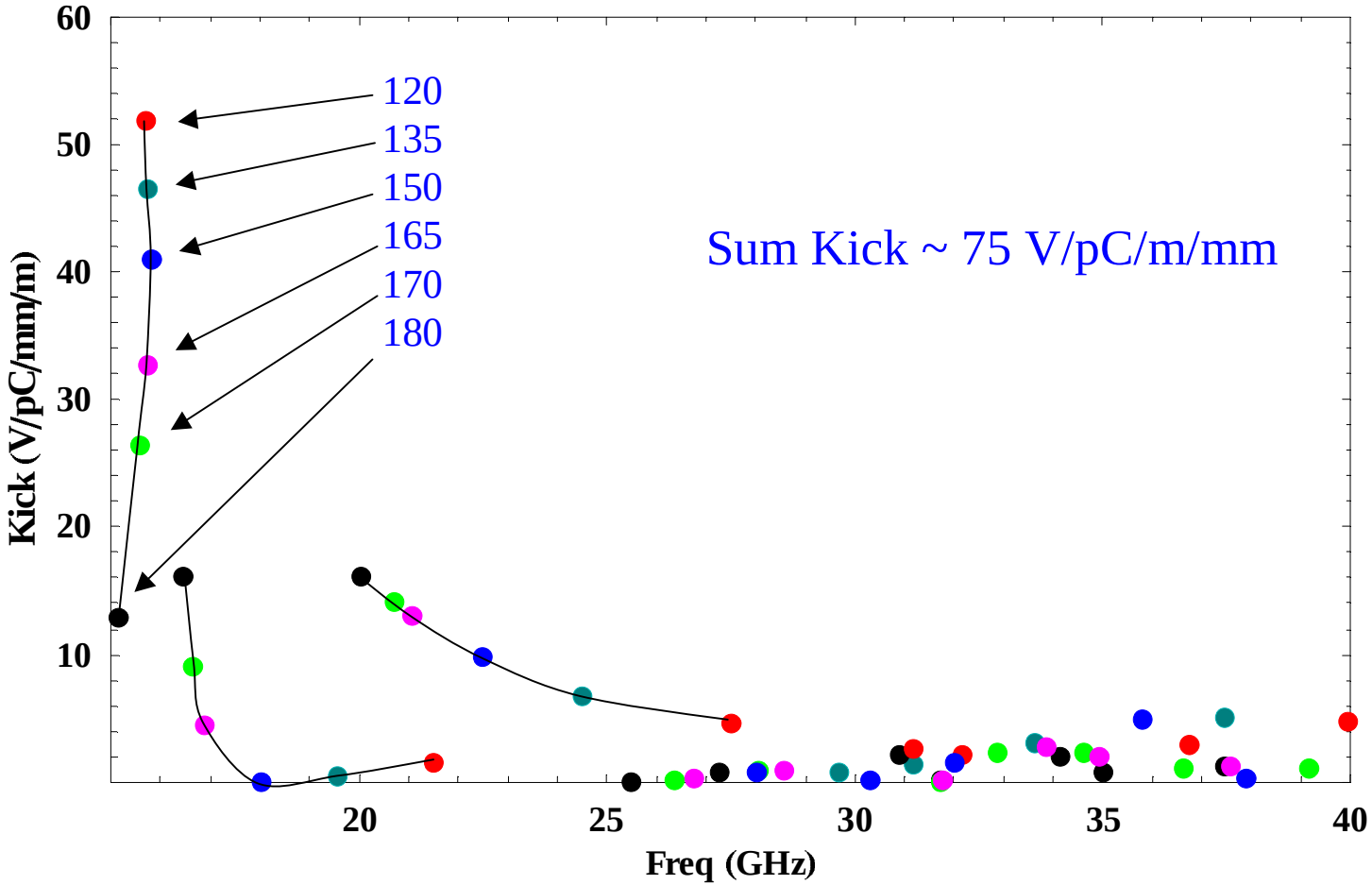
Kick factors of dipole modes vs. frequency for SW375



Transverse wake for SW375

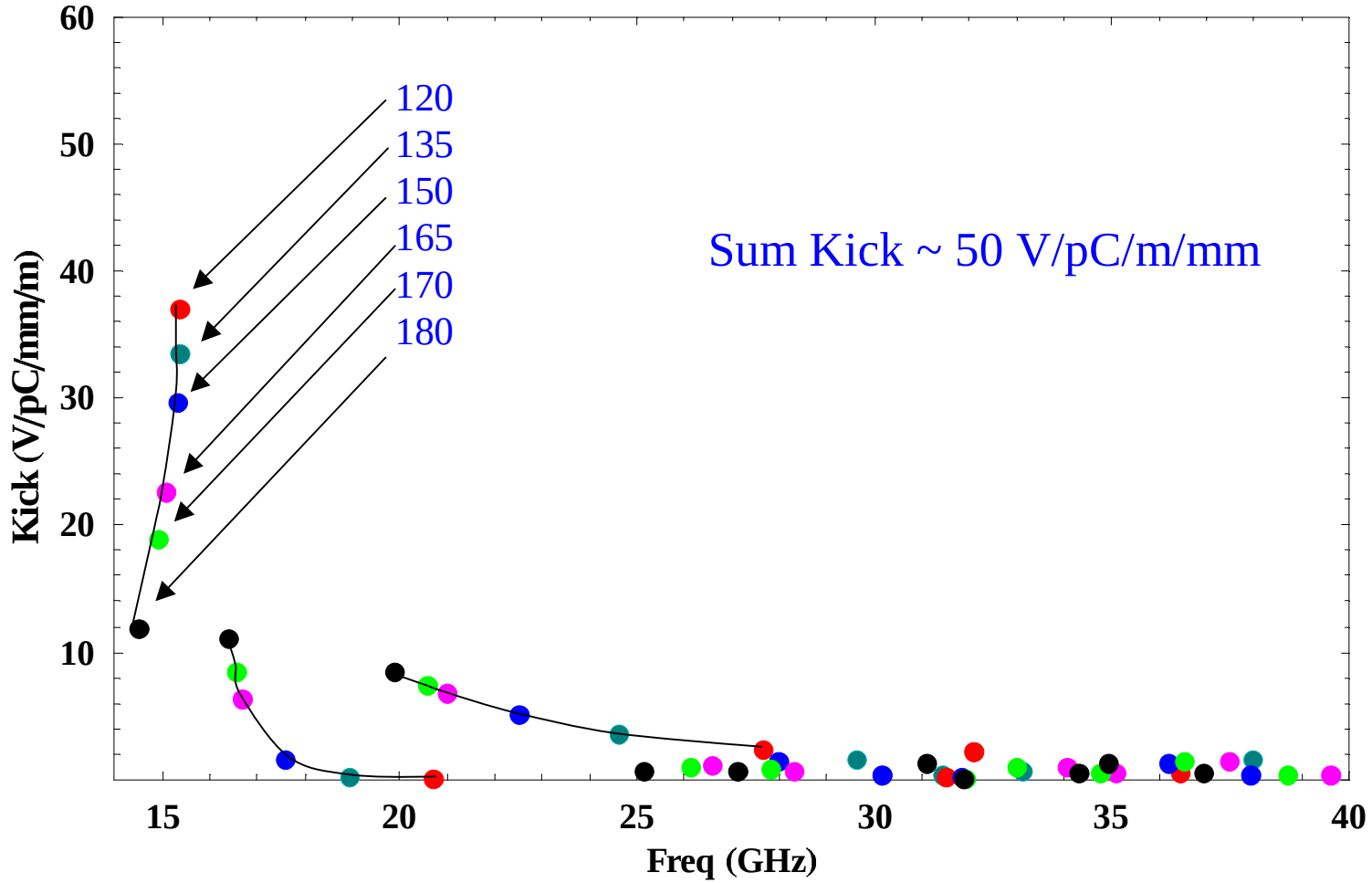
V.A.Dolgashev, 25 June 02.

Kick Factor *vs.* Synchronous Freq. For Different Cell Lengths
(Determined by Phase Advance Per Cell). a = 4.23 mm, a/lambda = 0.161



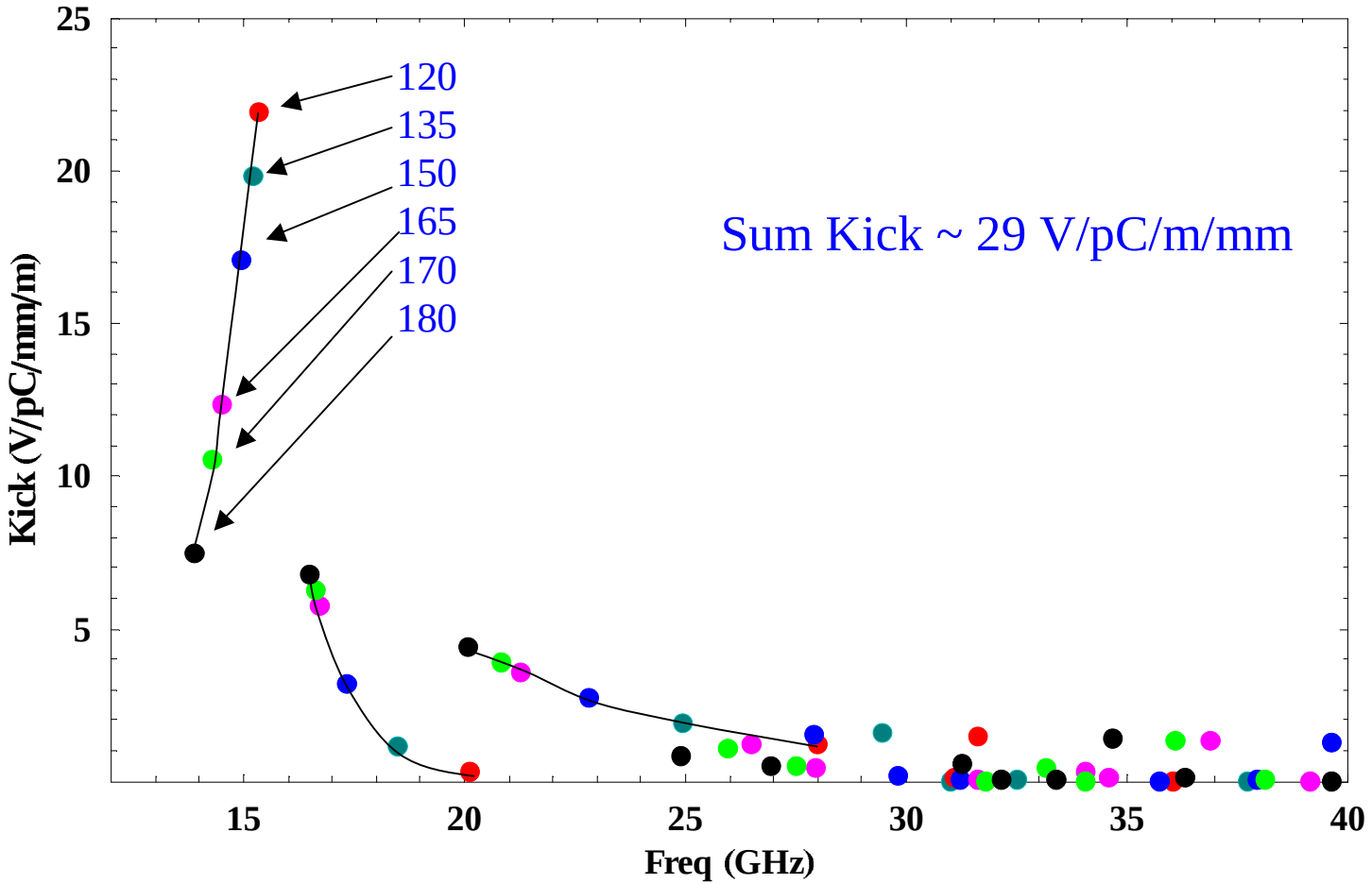
V.A. Dolgashev,R.M. Jones, Structure meeting 4 Apr. 02

Kick Factor *vs.* Synchronous Freq. For Different Cell Lengths
(Determined by Phase Advance Per Cell). a = 5 mm, a/lambda = 0.19



V.A. Dolgashev,R.M. Jones, Structure meeting 4 Apr. 02

Kick Factor vs Synchronous Freq. For Different Cell Lengths (Determined by Phase Advance Per Cell). a = 6 mm, a/lambda = 0.229

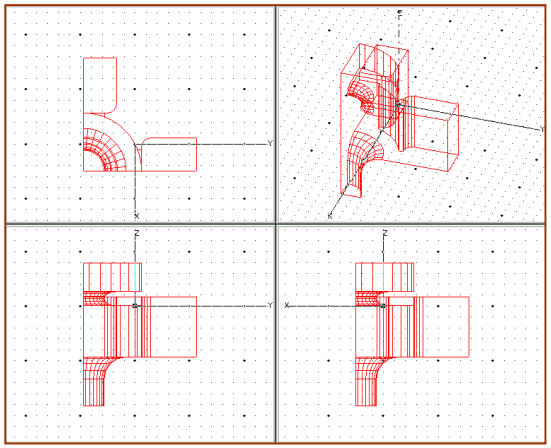


V.A. Dolgashev,R.M. Jones, Structure meeting, 4 Apr. 02

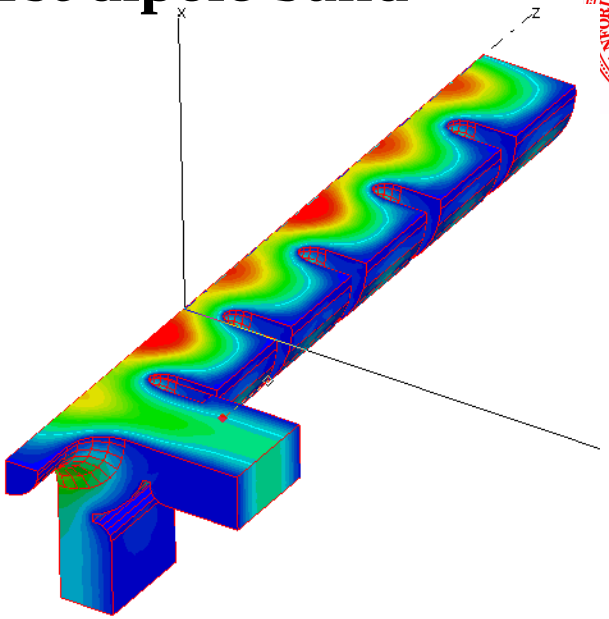
Wakefield damping

- **Feasibility study: ultimate one-cell damping**
- **Practical two-cell damping**
- **Pulsed heating of damping cells**
- **Choke cell - no pulsed heating**

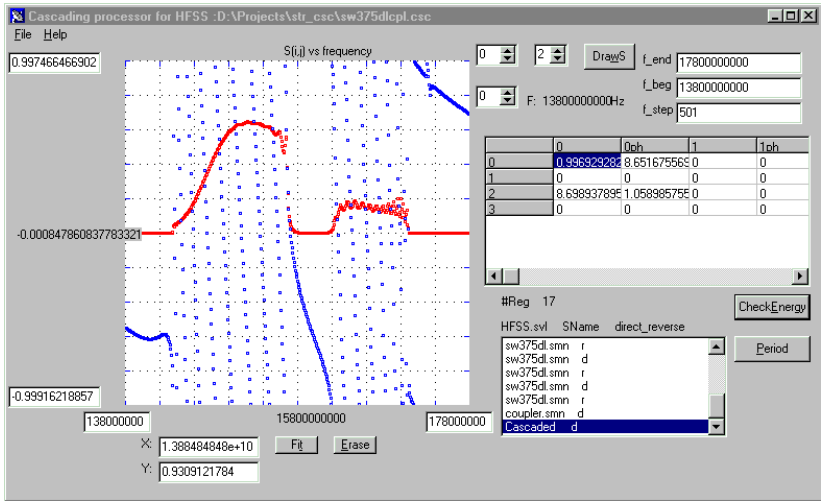
Damping cell for SW375, first dipole band



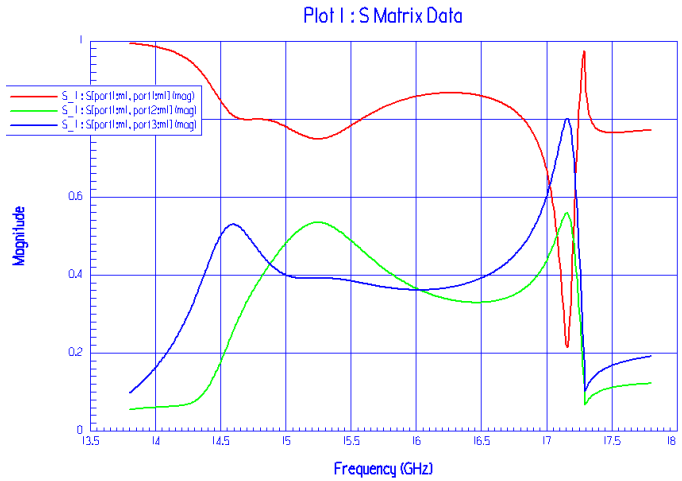
Geometry



f = 14.8 GHz, S11 = 0.08, iris_w = 7.8,
h_wgd = 11, d_cpl = 11.95, iris_h= 9.35



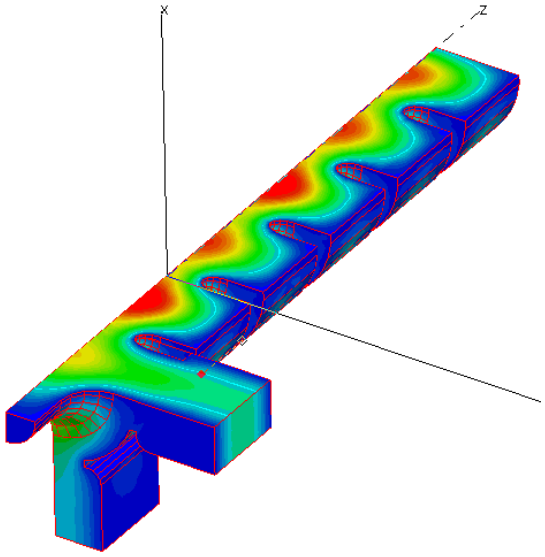
S12: Damping-waveguide to damping-waveguide transmission, 15 cells SW357, matching frequency 14.8GHz. Cascading of S-matrices for 3D geometry, 500 frequency points, calc. time ~35 min.



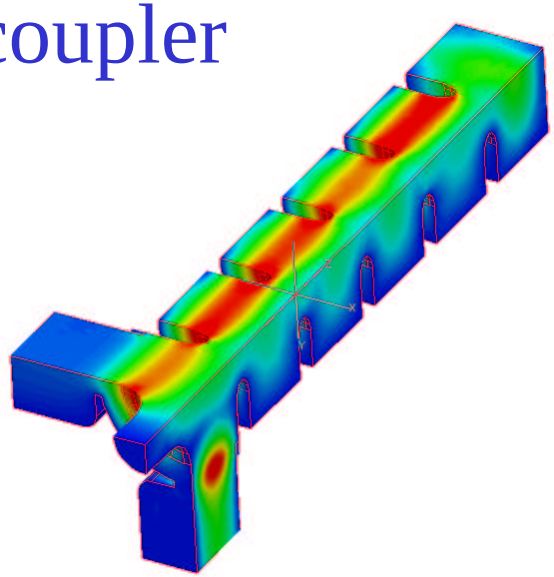
V. Dolgashev, March 2002

SW damping 3D model

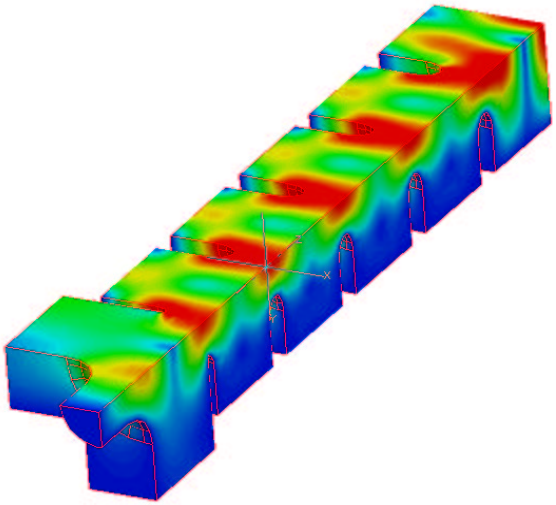
Matched coupler



f = 14.8 GHz, S11 = 0.08, Q = 150



f = 16.72GHz, S11 = 0.16, Q = 265



f = 21GHz, S11 = 0.01, Q = 170

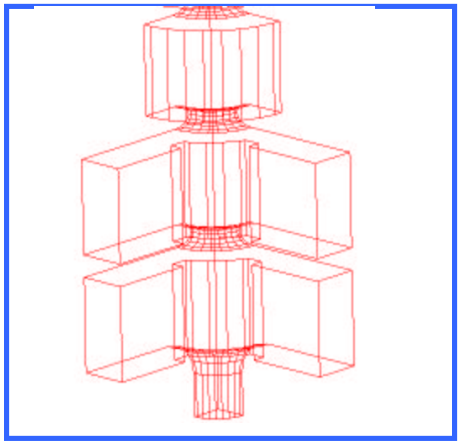
V.A.Dolgashev, 25 June 02.

Coupler for SW structure wake field damping

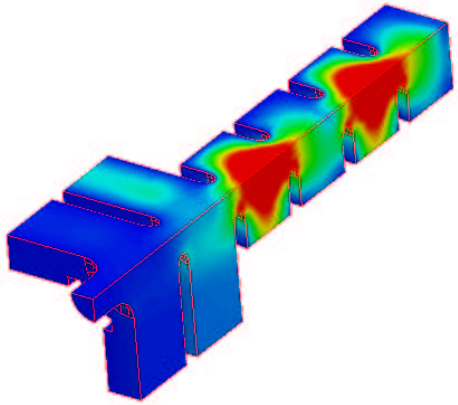
Dipole mode characteristics of two-cell damper cavity,

Bold – two cells low-damping accelerating cells

Italic – one-cell

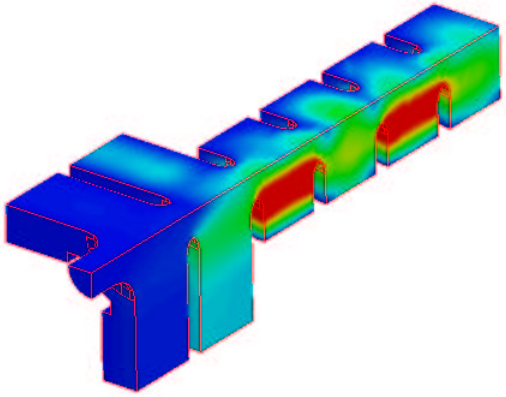


Geometry of two-cell low-damping cavity



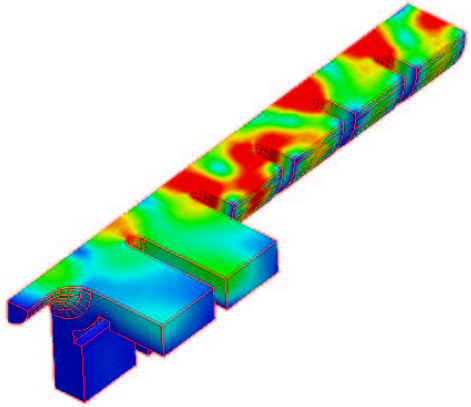
f=14.8 GHz, S11=0.77, Q=430

f=14.8 GHz, S11=0.71,Q=433



f=16.71GHz, S11=0.4,Q=230

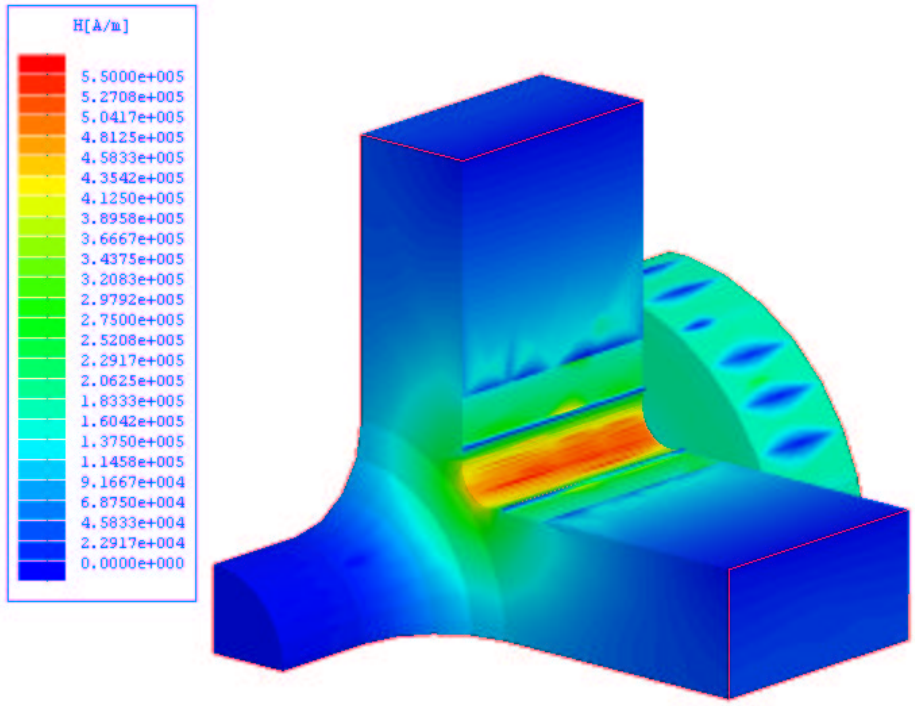
f=16.71GHz, S11=0.7, Q=610



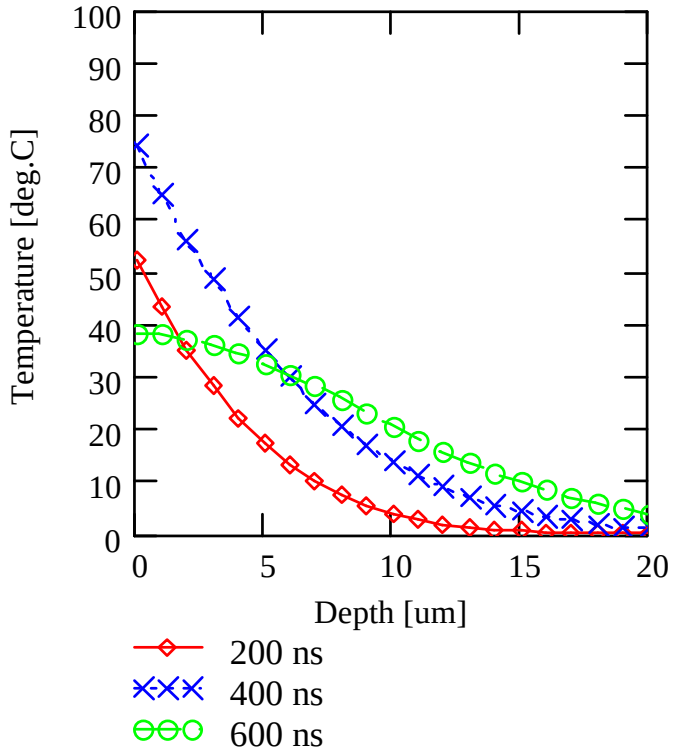
f=21GHz, *S11= 0.44*, **Q=205**

f=21GHz, S11= 0.28, Q=193

Coupler for SW structure wake field damping, rounded coupling iris, radius 1.55 mm
Monopole mode characteristics



Distribution of the surface magnetic field, max. magnetic field 0.55 MA/m



Temperature *vs*. depth for 55 MV/m loaded gradient, 400 ns filling time

V.A.Dolgashev, 25 June 02.

Choke cell damping

- Shunt impedance reduction
- Maximum electric fields
- End-cell design for SW365
- Silicon loads:
  - "knife" loads
  - "ladder" loads
- Possible load configurations for SW365

BINP
March 1992

Third International Workshop
on Linear Colliders

LC91

SEPTEMBER 17—27, 1991
BINP, PROTVINO, USSR

Volume 3: *CONTRIBUTED TALKS*

Issue 2: *High Energy Beam RF Power Systems*

Edited by
V. BALAKIN
S. LEPSHOKOV
N. SOLYAK

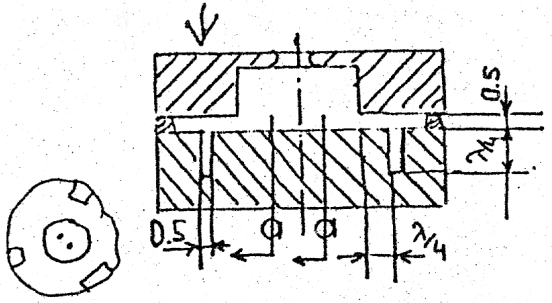
BRANCH OF INSTITUTE
OF NUCLEAR PHYSICS

Fast control of cells for VLEPP structure.

V. Balakin, V. Dolgashev,
V. Fominykh, E. Pohlebenin,
V. Vogel.

1991, Protvino.

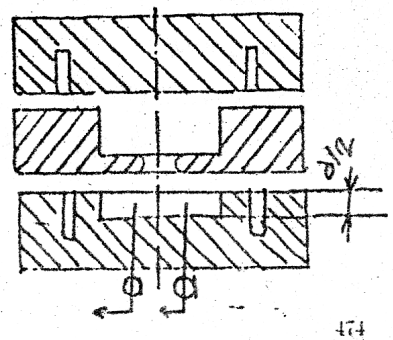
Resonant stand:



$\sim \pi/2$

disadvantage:

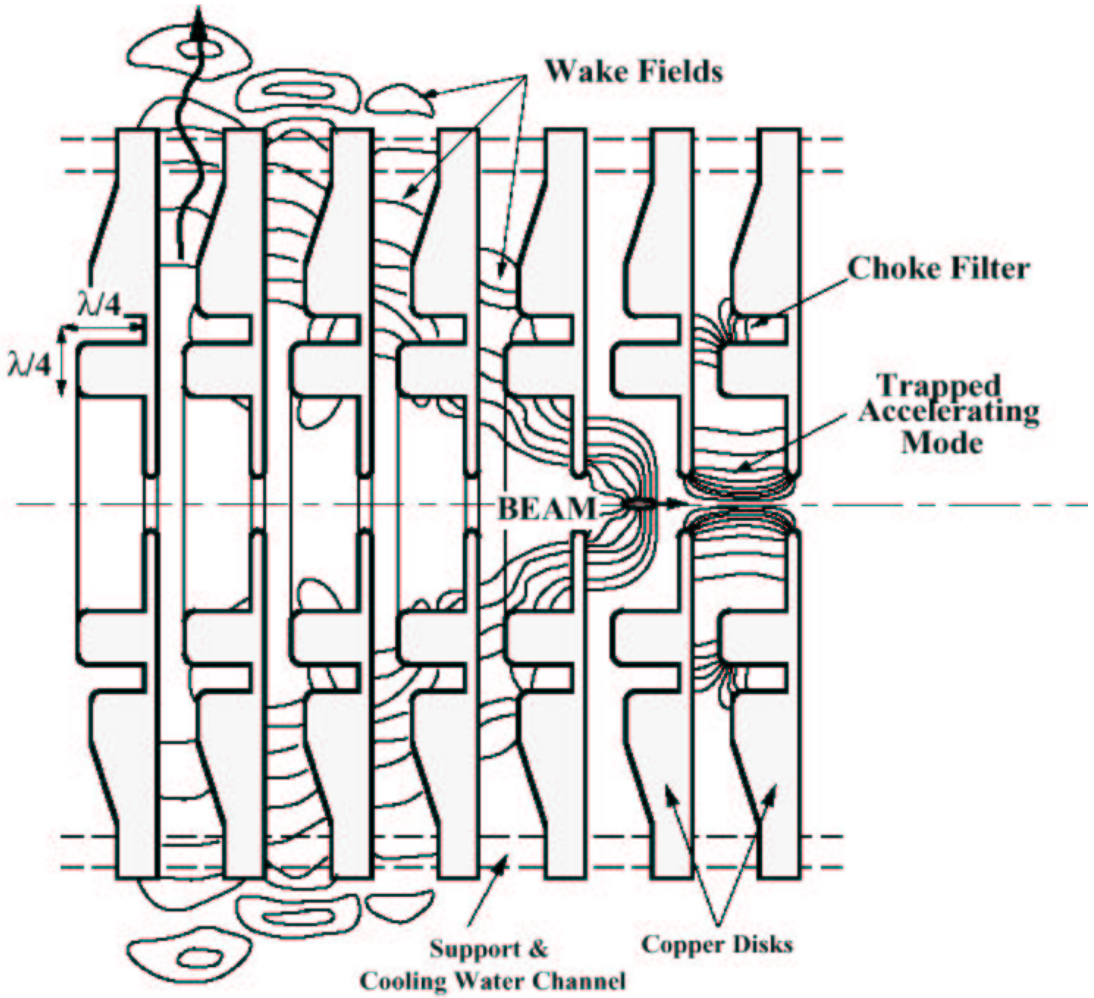
1. $\frac{\partial f}{\partial 2a} = 0.036 \frac{MHz}{MKM}$
2. dust



$0, 2\pi/3.$

474

V.A.Dolgashev, 25 June 02.



T. Shintake, "The Choke Mode Cavity", Jpn. J. Appl. Phys. Vol. 31 (1992) pp.L1567-L1570, Part 2, No. 11A. 1 Nov. 1992

SW375 structure, no choke

SLANS NUMBER OF MODE 2; ACCURACY 6.075E-07

CAVITY RADIUS 1.0557 CM, LENGTH 1.3116 CM

FREQUENCY ..... 1.1423E+04 MHZ

LENGTH OF WAVE ..... 2.62435 CM

WAVE VALUE 2.3941848 1/CM

QUALITY FACTOR ..... 8.5584E+03

STORED ENERGY ..... 1.8946E-01 J

TRANSIT TIME FACTOR .... .5247E+06

EFFECTIVE IMPEDANCE .... 9.651E+00 KOHM/M

SHUNT IMPEDANCE ..... 82.59778 MOHM/M

MAXIMUM MAG. FIELD ..... 3.249E+05 A/M

NEAR POINT R= .853 CM , Z= .130 CM

MAXIMUM ELEC.FIELD ..... 2.030E+02 MV/M

NEAR POINT R= .420 CM , Z= .079 CM

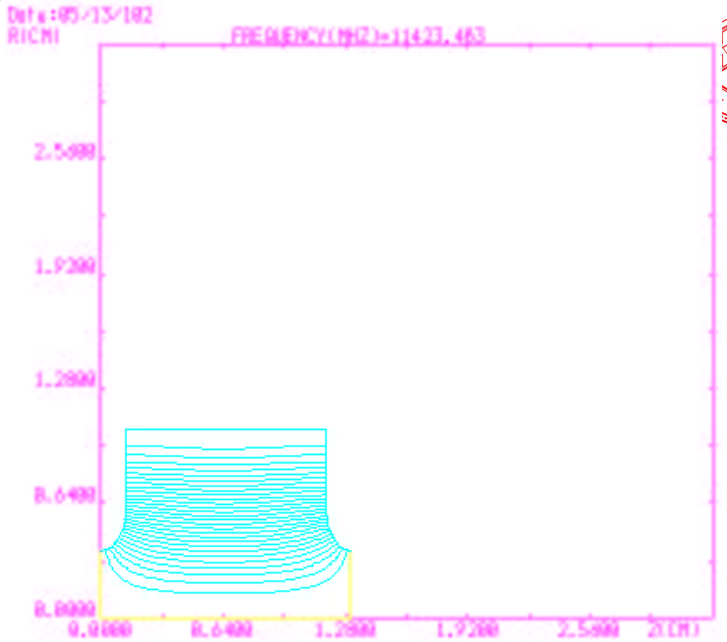
ACCELERATION ..... 1.312E+00 MEV

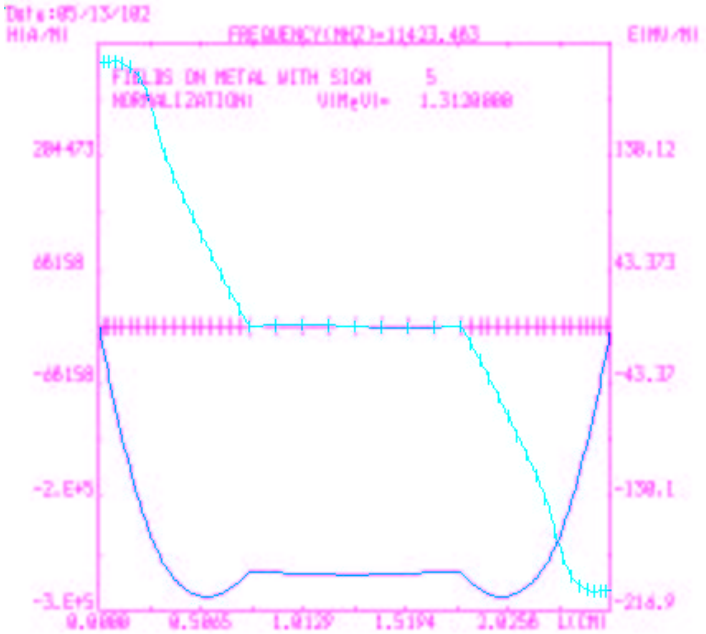
ACCELERATION RATE ..... 1.000E+02 MEV/M

AVERAGE E.FIELD ON AXIS 1.906E-04 MV/M

KM (Emax/Accel.rate).... 2.02912

KH (Hmax*Z0/Accel.rate). 1.22373





Gap 1 mm

V.A.Dolgashev, 13 May 02.

Choke mode SW365 structure, rounded choke

SLANS NUMBER OF MODE 6; ACCURACY 1.273E-07

CAVITY RADIUS 3.0447 CM, LENGTH 1.3116 CM

FREQUENCY ..... 1.1424E+04 MHZ

LENGTH OF WAVE ..... 2.62419 CM

WAVE VALUE 2.3943307 1/CM

QUALITY FACTOR ..... 7.6925E+03

STORED ENERGY ..... 2.0697E-01 J

TRANSIT TIME FACTOR .... .3607E+10

EFFECTIVE IMPEDANCE .... 8.834E+00 KOHM/M

SHUNT IMPEDANCE ..... 67.95618 MOHM/M

MAXIMUM MAG. FIELD ..... 3.251E+05 A/M

NEAR POINT R= .853 CM , Z= 1.182 CM

MAXIMUM ELEC.FIELD ..... 2.036E+02 MV/M

NEAR POINT R= .421 CM , Z= 1.232 CM

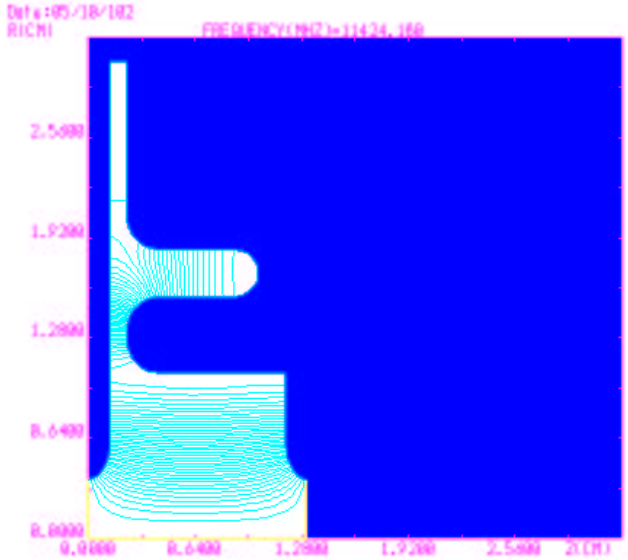
ACCELERATION ..... 1.312E+00 MEV

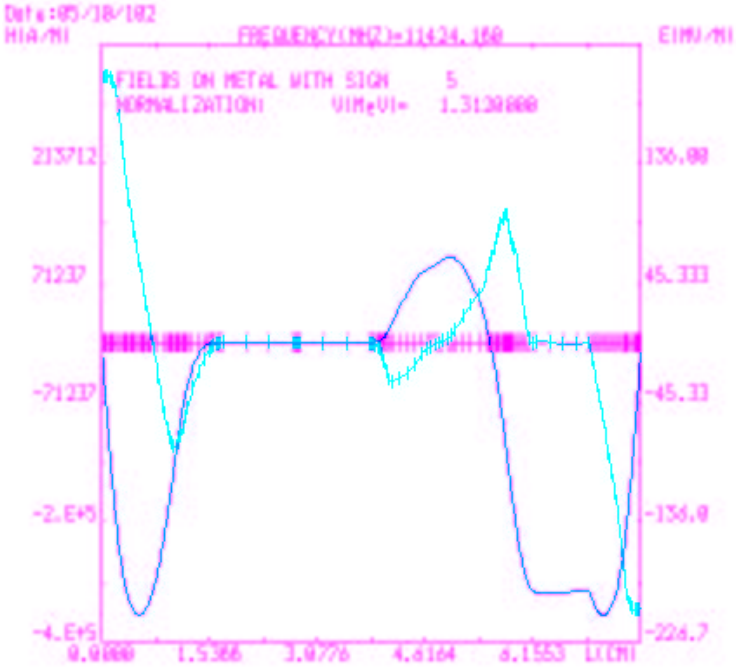
ACCELERATION RATE ..... 1.000E+02 MEV/M

AVERAGE E.FIELD ON AXIS 2.773E-08 MV/M

KM (Emax/Accel.rate).... 2.03519

KH (Hmax*Z0/Accel.rate). 1.22420





Gap 1 mm, rounding 2 mm

V.A.Dolgashev, 10 May 02.

SW365 structure, choke in last two cells

SLANS NUMBER OF MODE 4; ACCURACY 2.175E-06

CAVITY RADIUS 3.0427 CM, LENGTH 3.3232 CM

FREQUENCY ..... 1.1424E+04 MHZ

LENGTH OF WAVE ..... 2.62424 CM

WAVE VALUE 2.3942878 1/CM

QUALITY FACTOR ..... 7.7151E+03

STORED ENERGY ..... 4.1393E-01 J

TRANSIT TIME FACTOR .... .8221E+01

EFFECTIVE IMPEDANCE .... 1.159E+02 OHM

SHUNT IMPEDANCE ..... .89396 MOHM

MAXIMUM MAG. FIELD ..... 3.255E+05 A/M

NEAR POINT R= .853 CM , Z= 3.193 CM

MAXIMUM ELEC.FIELD ..... 2.040E+02 MV/M

NEAR POINT R= .422 CM , Z= 3.243 CM

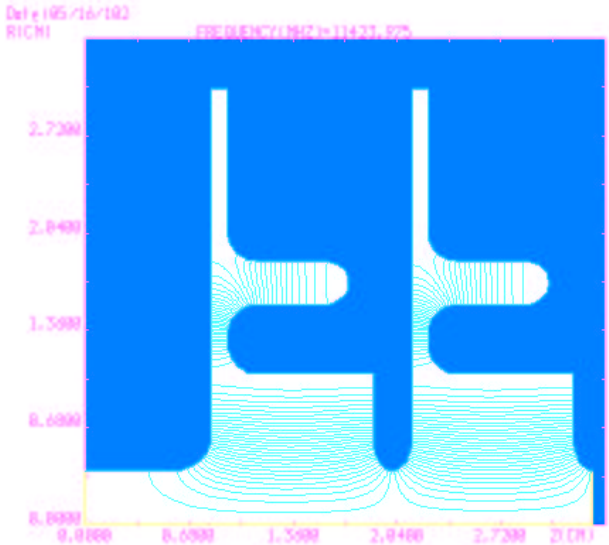
ACCELERATION ..... 2.624E+00 MEV

ACCELERATION RATE ..... 7.896E+01 MEV/M

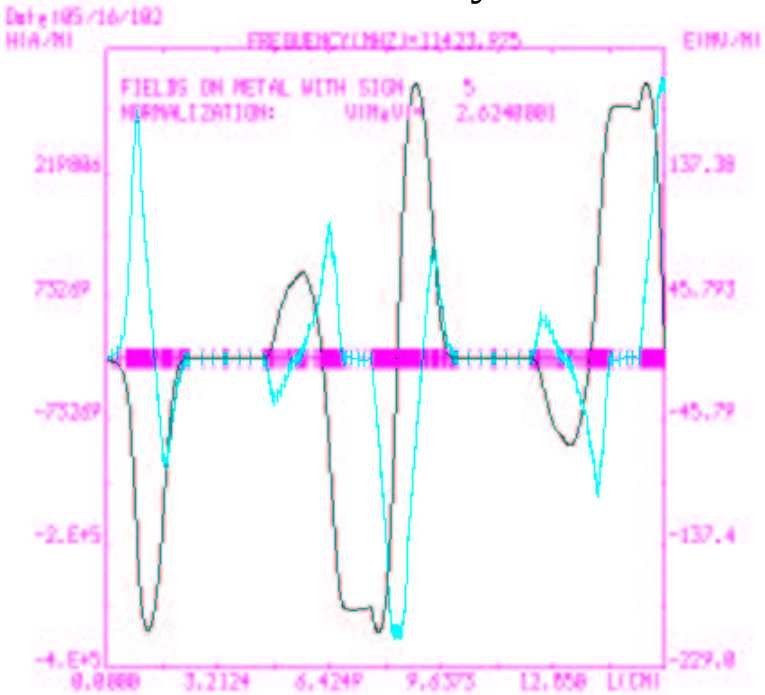
AVERAGE E.FIELD ON AXIS 9.605E+00 MV/M

KM (Emax/Accel.rate).... 2.58320

KH (Hmax*Z0/Accel.rate). 1.55287



Geometry

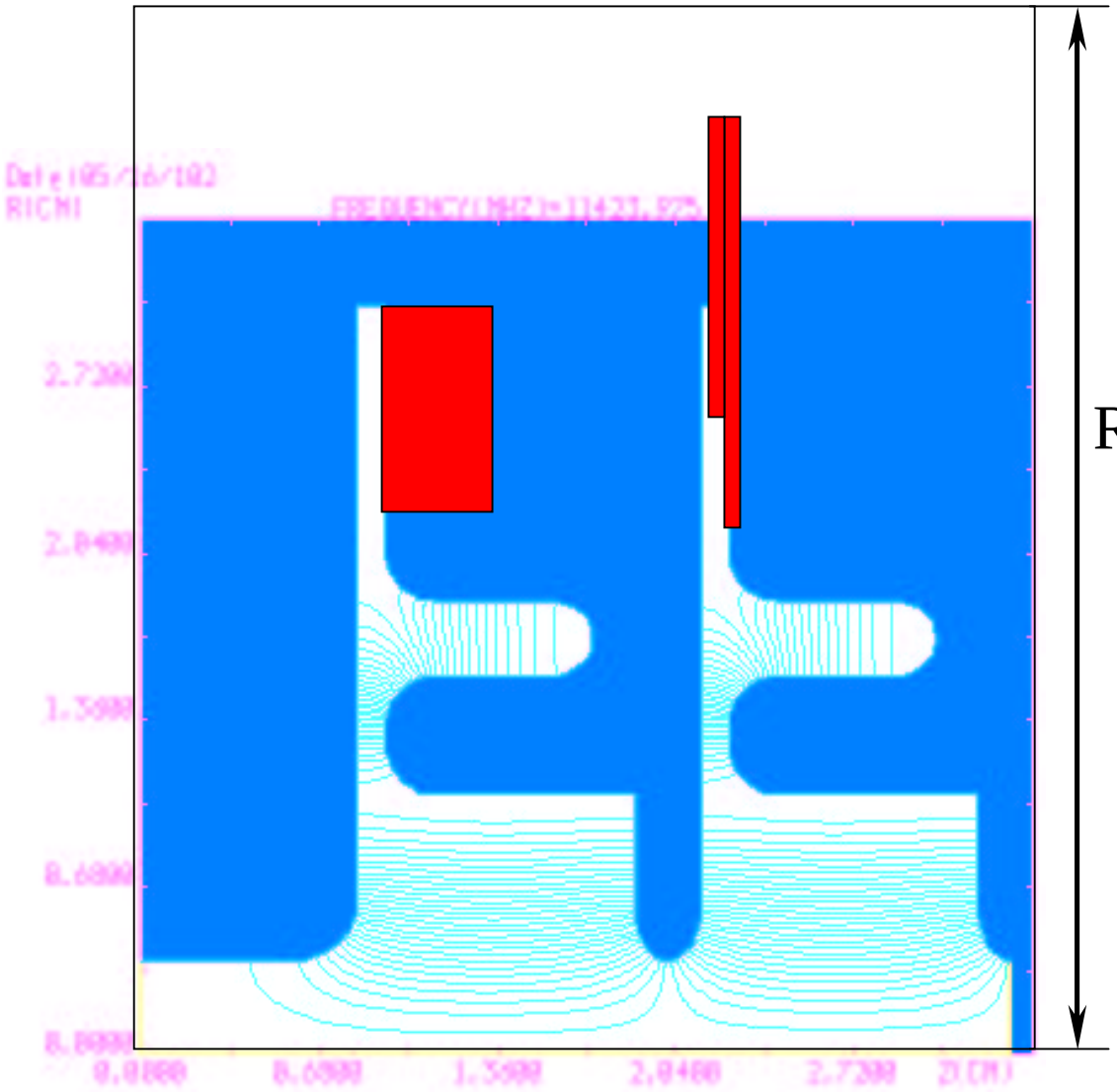


Surface fields

Gap 1 mm, rounding 2 mm, rounded choke

V.A.Dolgashev, 16 May 02.

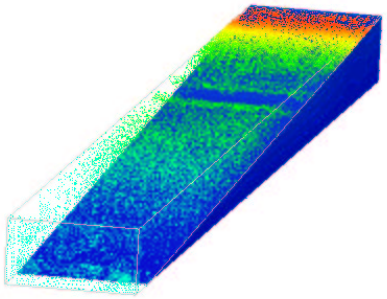
SW365 structure, choke in the last two cells



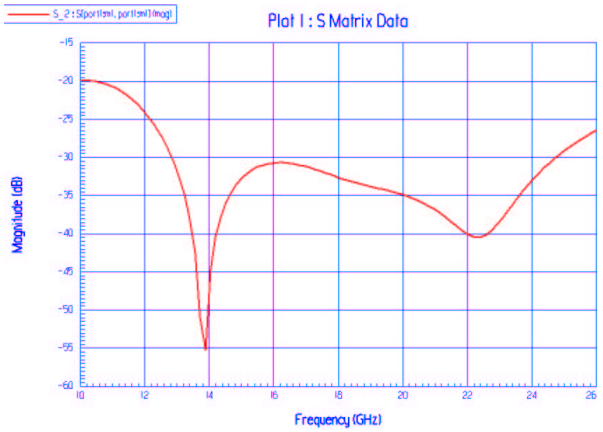
Dimension

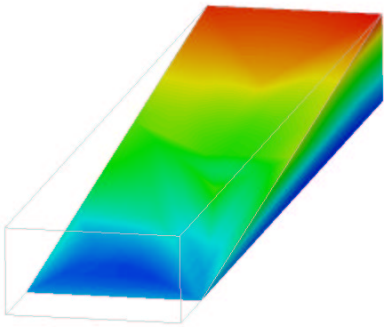
Possible load configurations

Silicon load for the choke cell

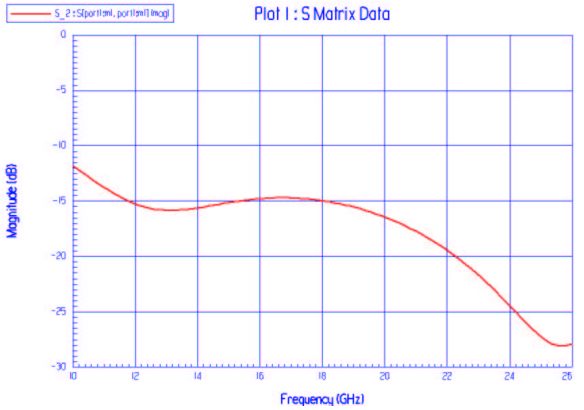


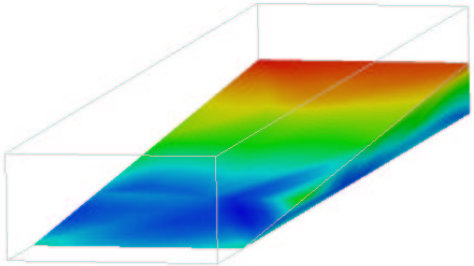
length **20** mm, gap 1 mm, σ = 32 Ohm/m



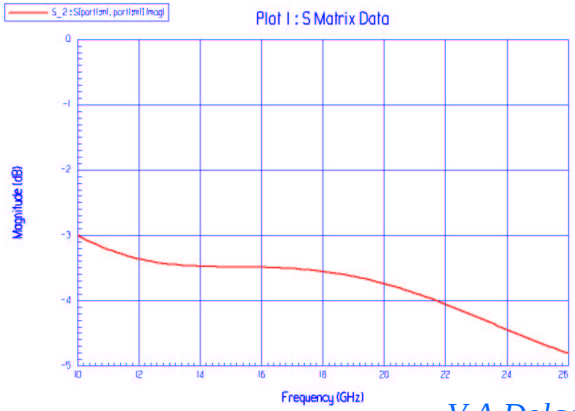


length **10** mm, gap 1 mm, σ = 128 Ohm/m



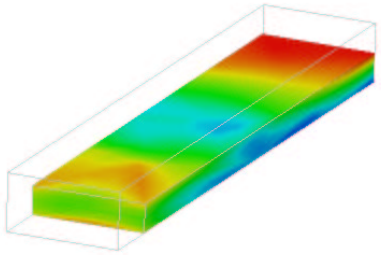


length **10** mm, gap 1 mm, σ = 256 Ohm/m

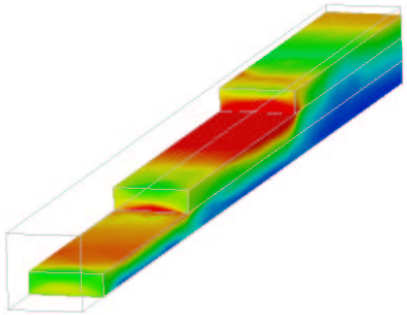


V.A.Dolgashev, 14 May 02.

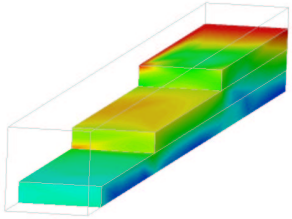
Silicon loads for the choke cell



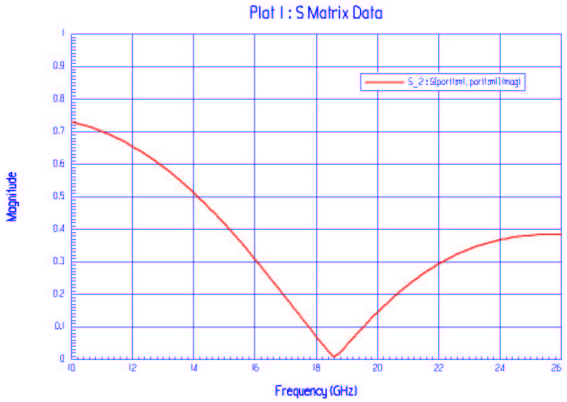
length 10 mm, gap 1 mm, σ = 64 Ohm/m,
0.5 mm layer thickness

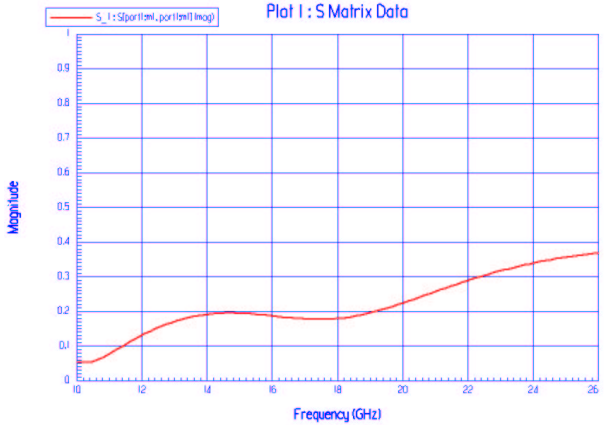


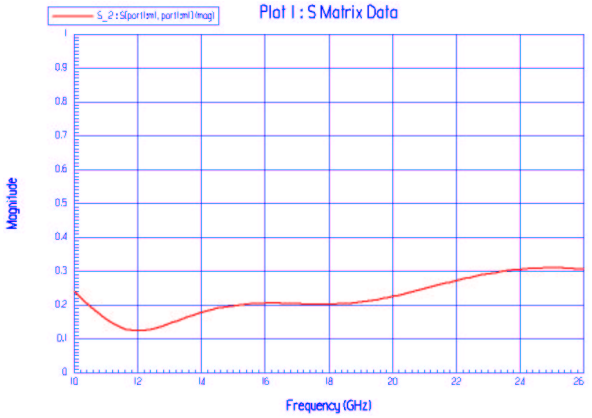
length 15 mm, gap 1 mm, σ = 128 Ohm/m,
0.33 mm layer thickness



length 15 mm, gap 1 mm, σ = 64 Ohm/m,
0.25 mm layer thickness





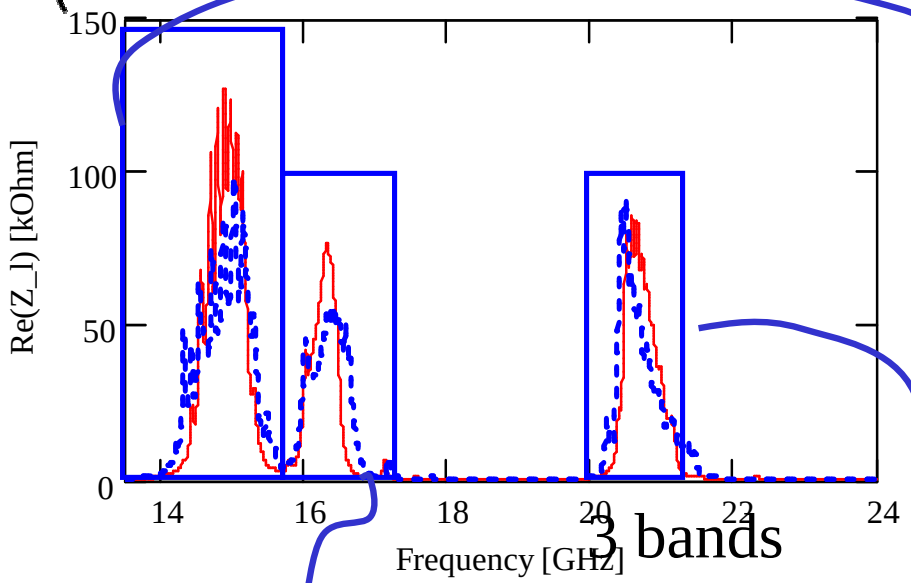


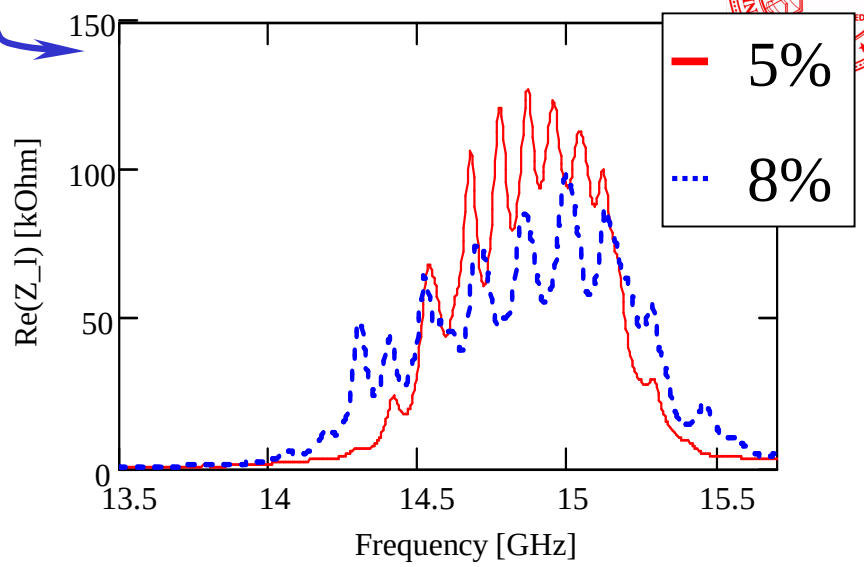
V.A.Dolgashev, 14 May 02.

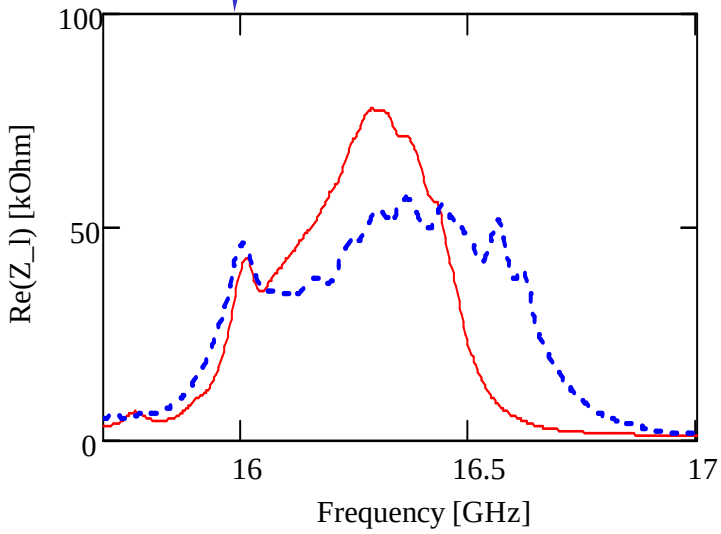
Detuning

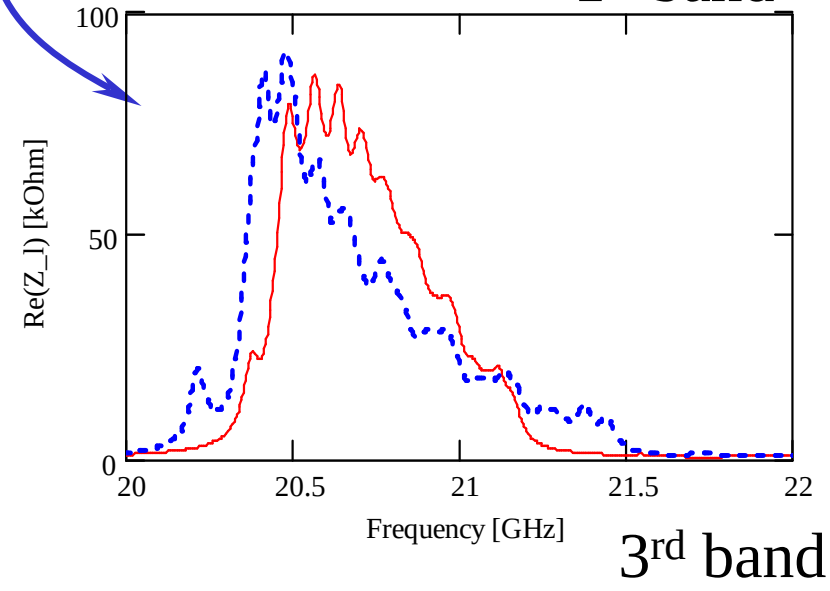
- Detuning sigma 5%, Q ~300
- Detuning sigma 8% Q ~300
- Dependence of wakefields from number of cells in sub-structure

Detuning of standing wave structures, dipole longitudinal impedance,
taper-over- **super**structure, detuning bandwidth 5% and 8%



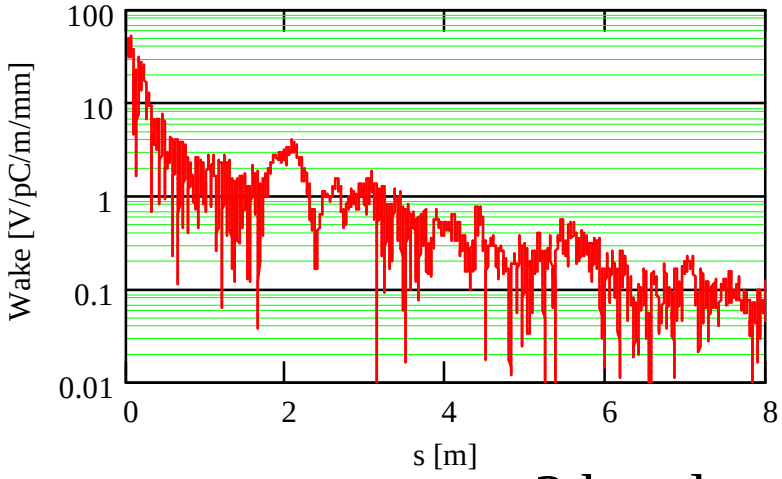




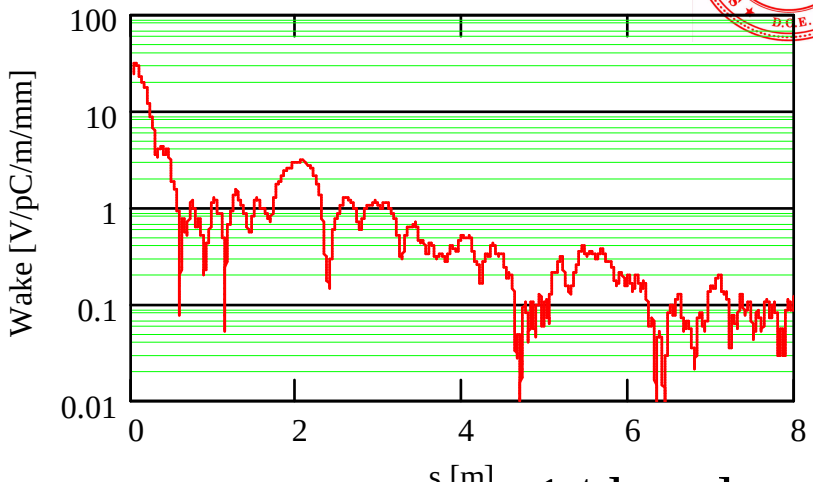


V.A.Dolgashev, Z. Li, structure meeting ,11 April 02

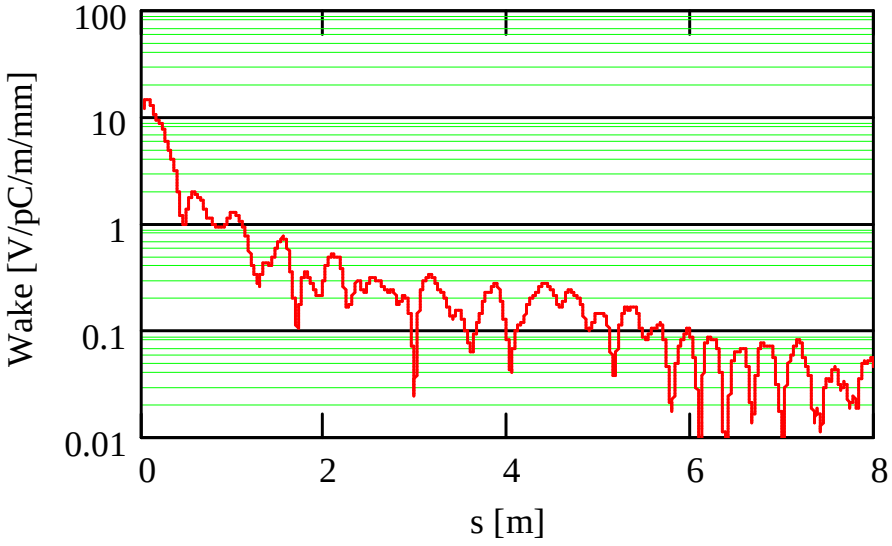
Detuning of standing wave structures, taper-over-**super**structure, 3rd band detuned, transverse wake, detuning sigma 8%, Q ~300



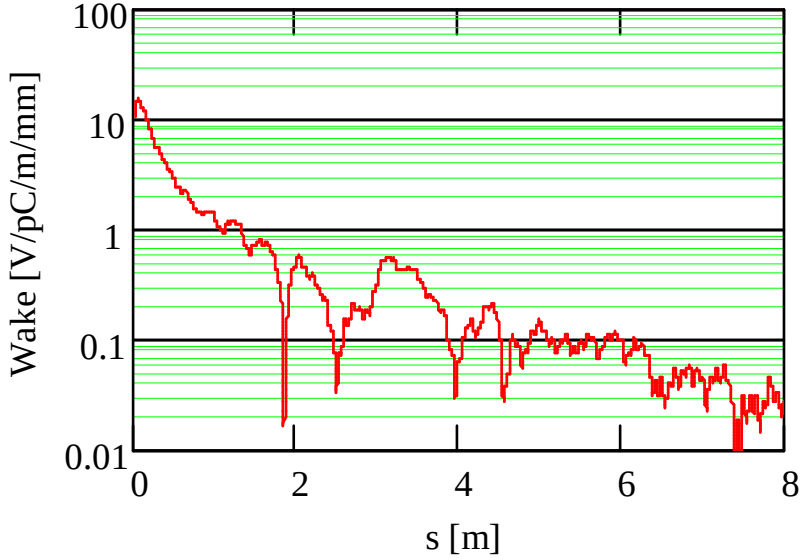
3 bands



1st band



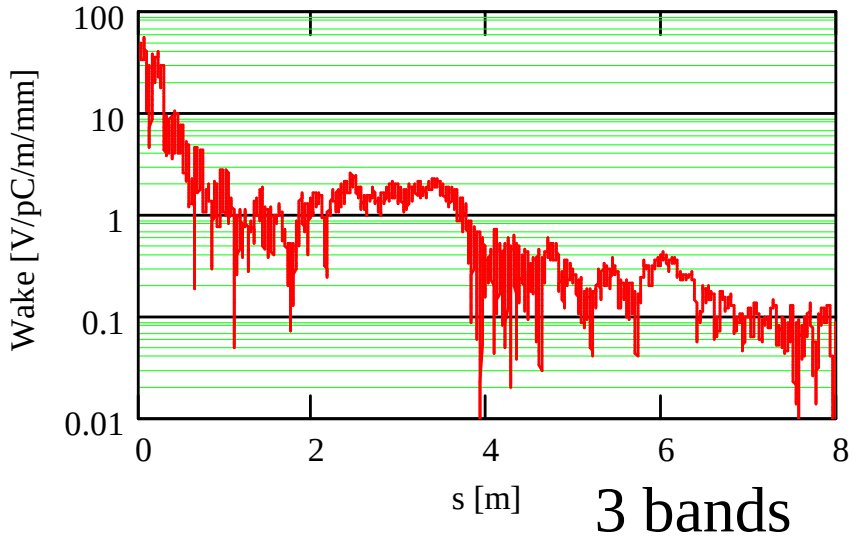
2nd band



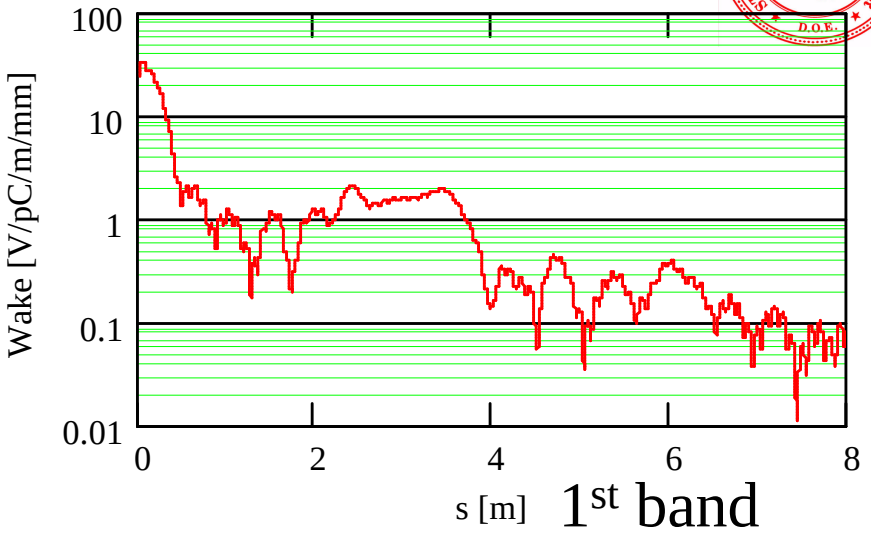
3rd band

V.A.Dolgashev, structure meeting ,11 April 02

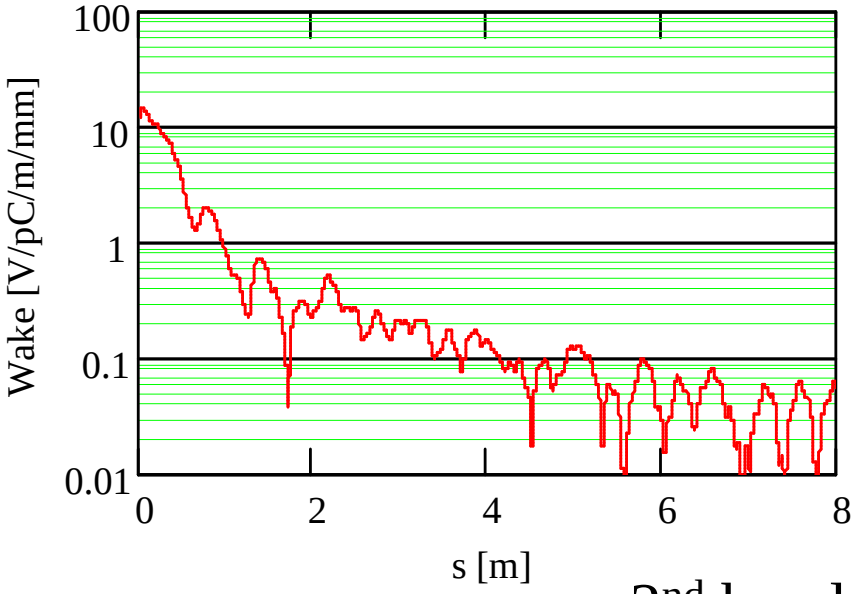
Detuning of standing wave structures, taper-over-**super**structure, 3rd band detuned, transverse wake, detuning banwidth 5%, Q ~300



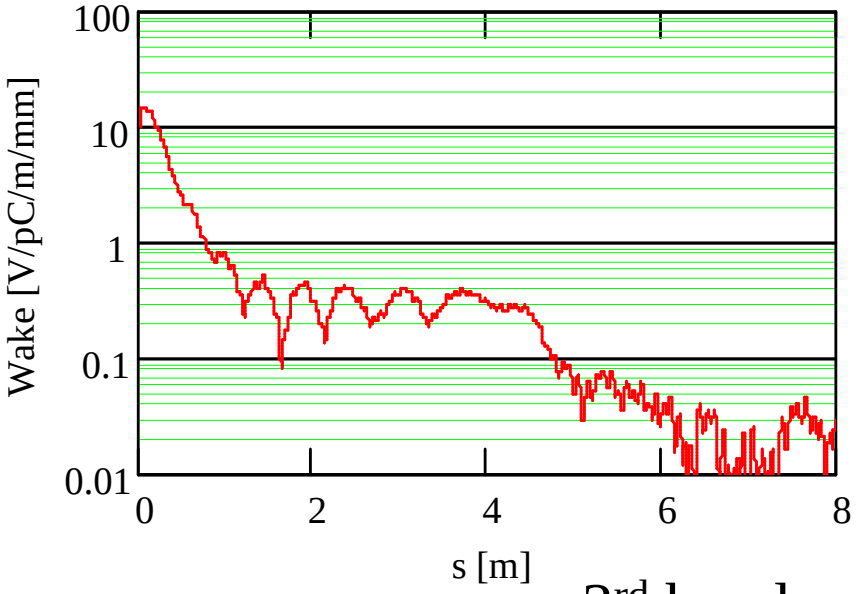
3 bands



1st band



2nd band

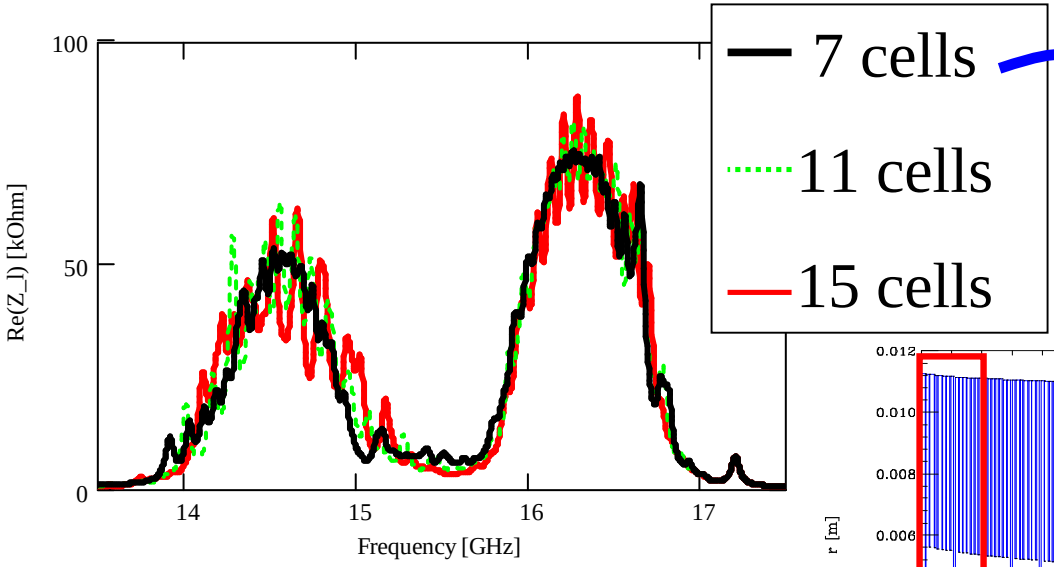


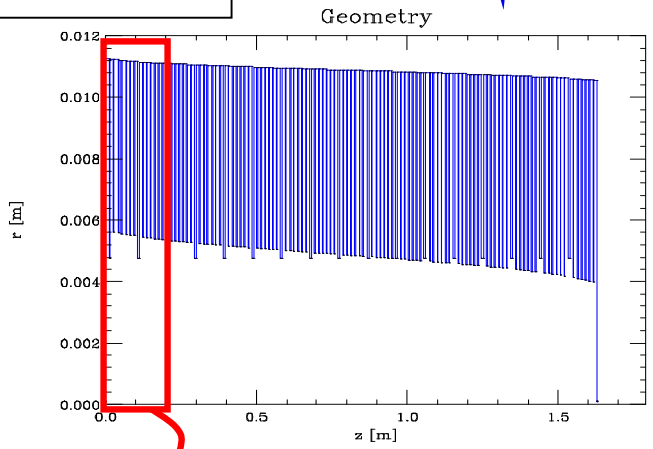
3rd band

V.A.Dolgashev, structure meeting ,11 April 02

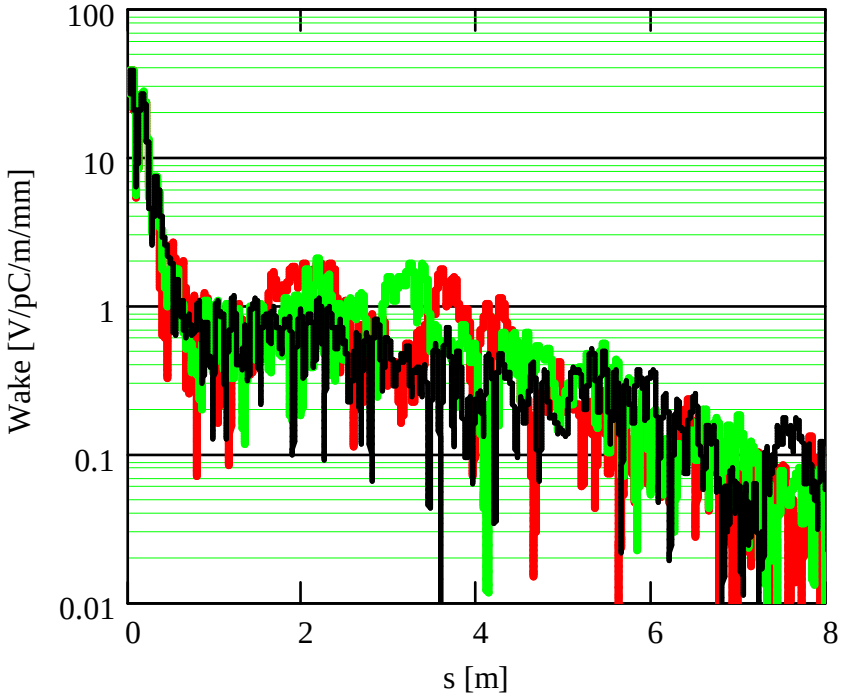
Detuning of standing wave structures, taper over superstructure, different **number of cells** in **sub**-structure, 2 lowest modes

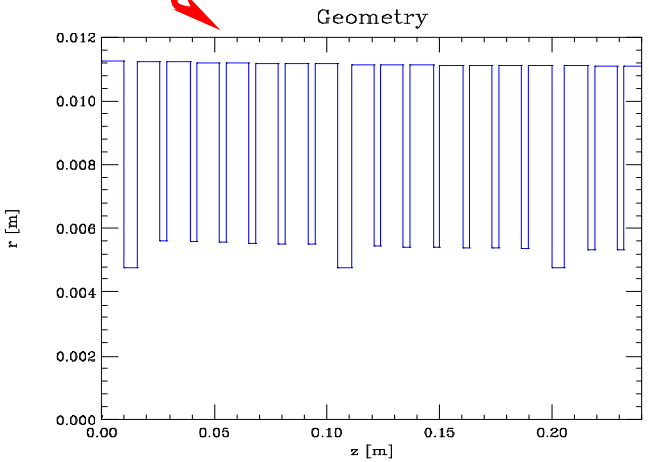
Dipole longitudinal impedance





Transverse wake

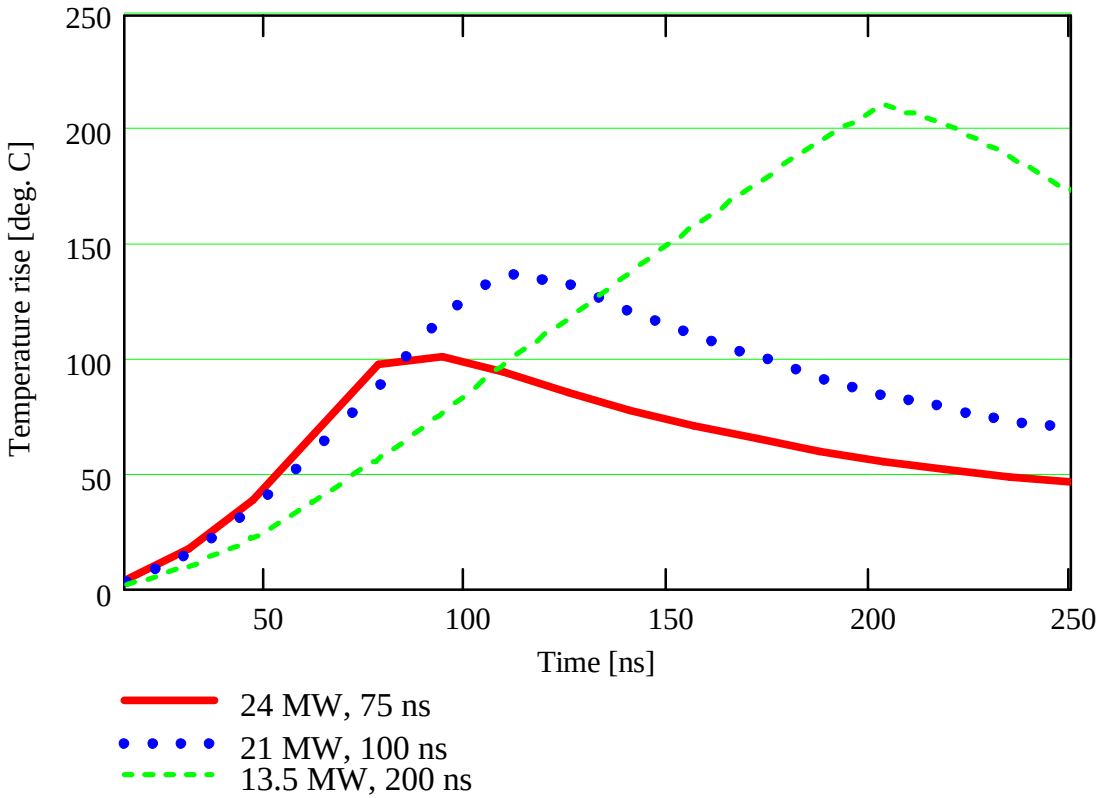




V.A.Dolgashev, structure meeting ,11 April 02

Summary

- **Pulsed heating in coupler – solution straightforward.**
- **Breakdown performance very promising, especially with use of stainless steel.**
- **Local damping with 2D radial choke looks very attractive.**
- **Detuning: very close to solution, but need some work on optimization.**
- **Power distribution: solution exist, could be optimized**


250
200
150
100
50
0
Temperature rise [deg. C]
50
100
150
200
250
Time [ns]
24 MW, 75 ns
21 MW, 100 ns
13.5 MW, 200 ns