X-band standing wave structure

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Contributors (list is not complete)

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Design considerations

- High power performance
  - Breakdown threshold
  - Damage
  - Beam loading
- Efficiency
- Wake field performance
  - Detuning
  - Damping
- Manufacturability
  - Feeding with RF
  - Wake field damping with internal loads

RF breakdown properties

Experimental Observations

- The initiation of ‘conditioning’ begins at higher field with lower group velocity structures.
- In a breakdown event, in many cases a large fraction of the RF energy is dumped in the structure.
- The long high group velocity structures have shown damage sufficient to effect the RF properties.
- Historically the highest gradients obtained have occurred in very short low group velocity structures or standing wave structures.

Some more observations

- In matched traveling wave structures
  - Almost all the transmission of RF is blocked
  - **A large fraction of the RF is typically absorbed by the event**.
  - Evidence of acceleration of electrons (x rays).
  - Evidence of excited copper atoms (light) and CO (RGA).

Some differences between structure types

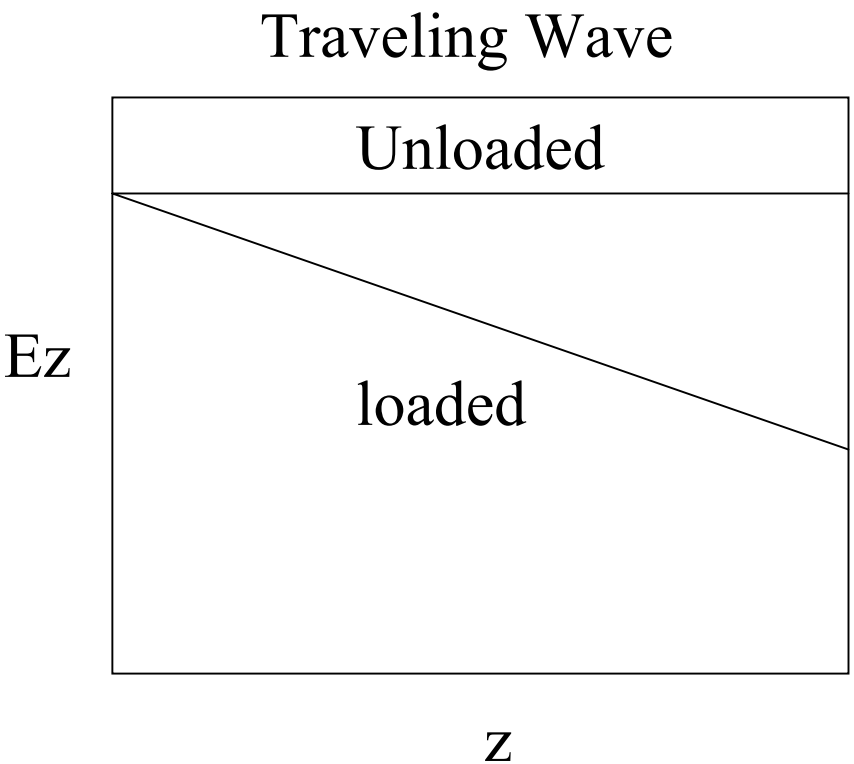
- The **group velocity** and **length** of the structure are linked for good efficiency.
- 1.8 m high vg need about 70 J incident energy.
- 0.9 m with lower vg need about 35 J.
- What is the shortest we can consider?
- Keeping the **irises open for wakes**, we can reduce to about **0.6 m** long.
- Alternatively, consider **short standing wave** structures which store about **2 J** of energy.

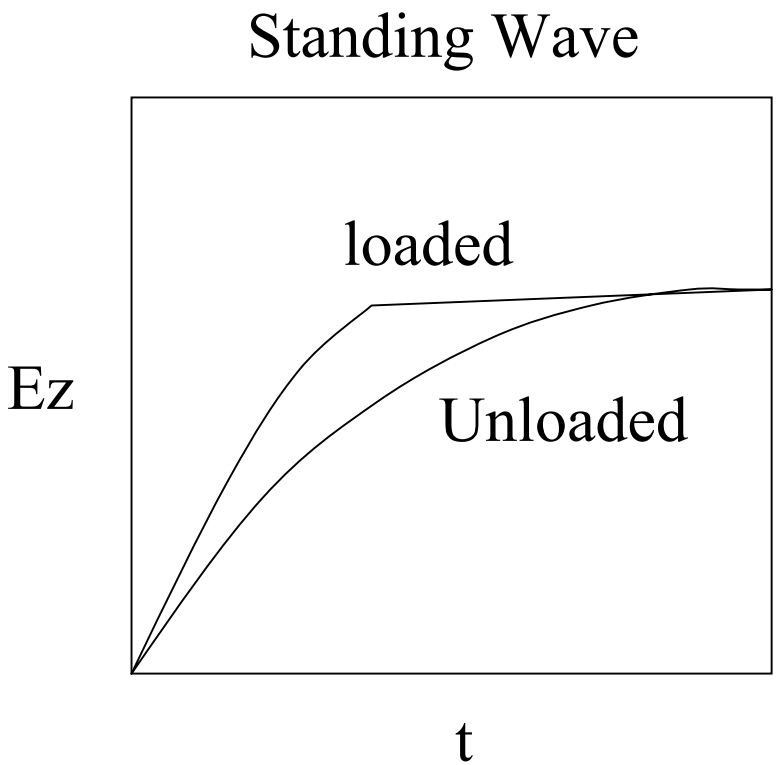
Motivation for Standing Wave Studies

- Breakdown damage depends sensitively on the RF circuit.
- For a given loaded gradient, less overhead is needed.
- There is less energy dumped into the structure during a breakdown event (perhaps an order of magnitude less).
- Everyone ‘knows’ that the field collapses and the power is reflected from the input waveguide iris during breakdown.

R. D. Ruth, SPC meeting, May 2001

Beam Loading



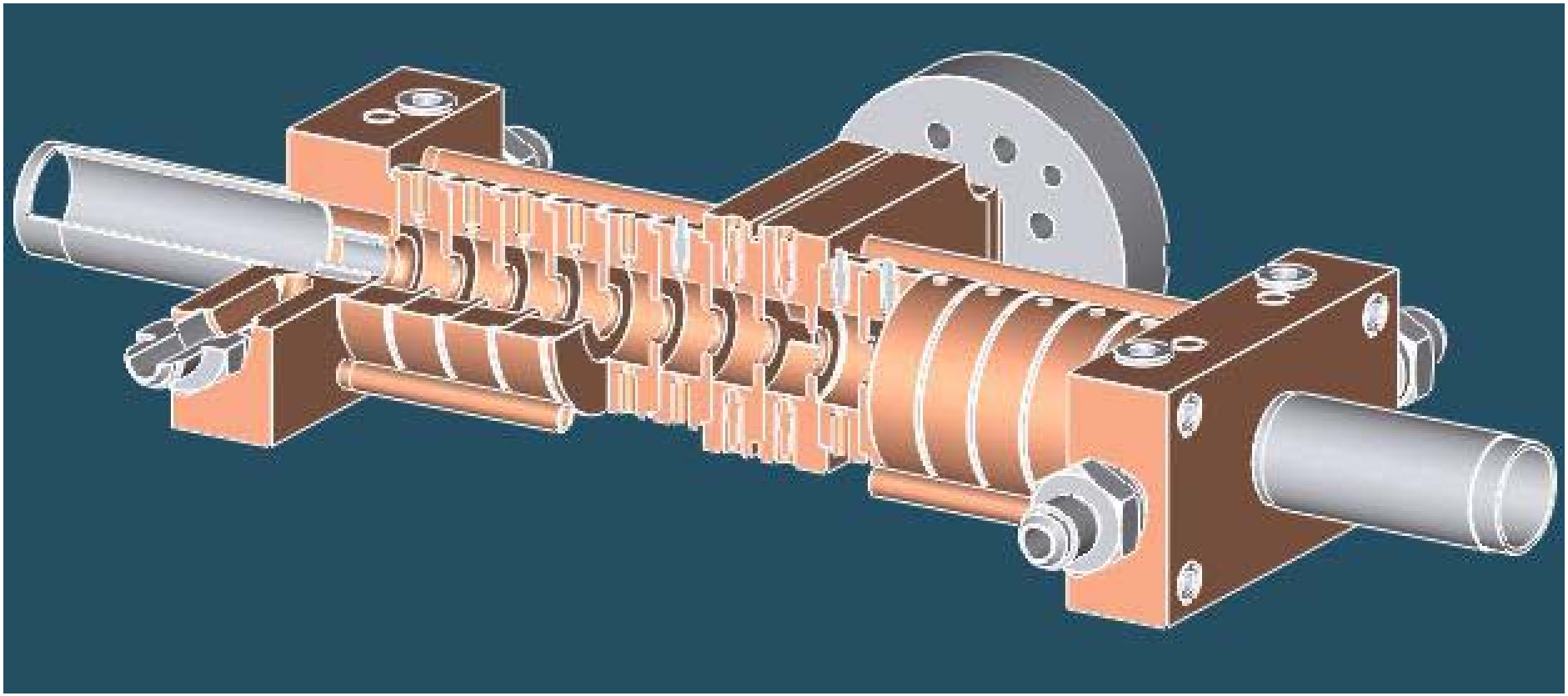


R. D. Ruth, SPC meeting, May 2001

Parameter Comparison

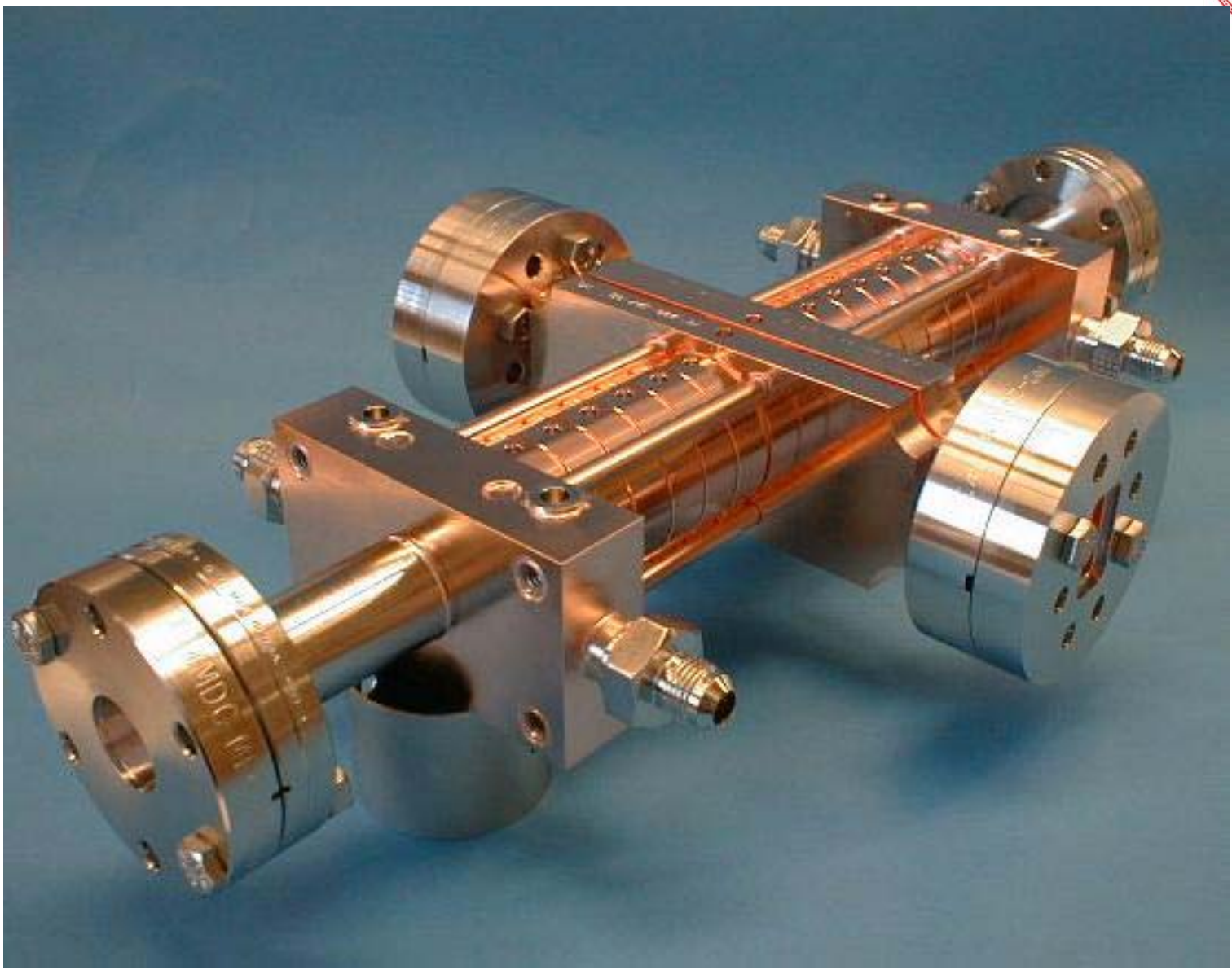
Parameter	**Traveling Wave**	**Standing Wave**
Current	1.0 A	1.0 A
Power	120 MW/m	120 MW/m
Loaded Ez	65 MV/m	66 MV/m
Unloaded Ez	**83 MV/m**	**66 (75 MW/m)**
E surf/Ez	~ 2.3	~2.3
Beam on time	103 nsec	108 nsec, β=2.8
Beam/RF eff.	~ 38%	~38%

Cutaway View of a 20 cm Standing Wave Structure



Juwen Wang, Gordon Bowden

Standing Wave Test Structure



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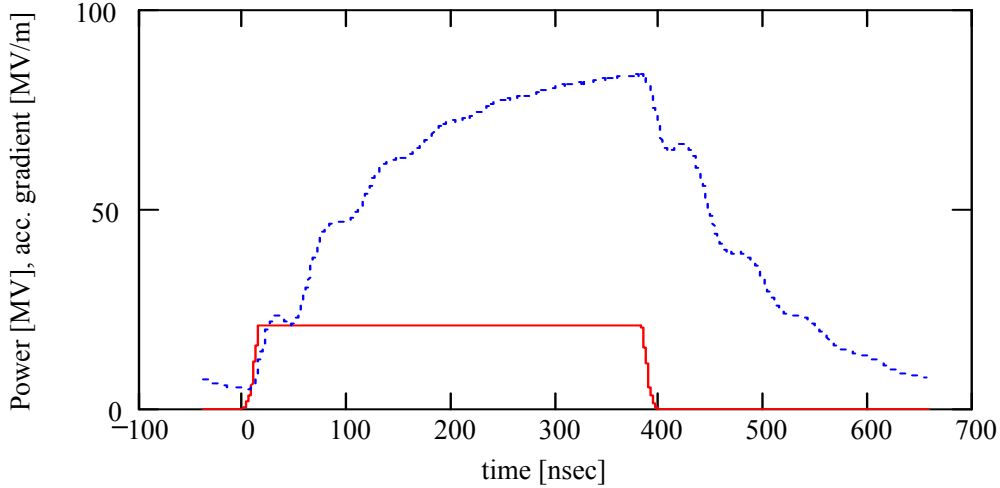
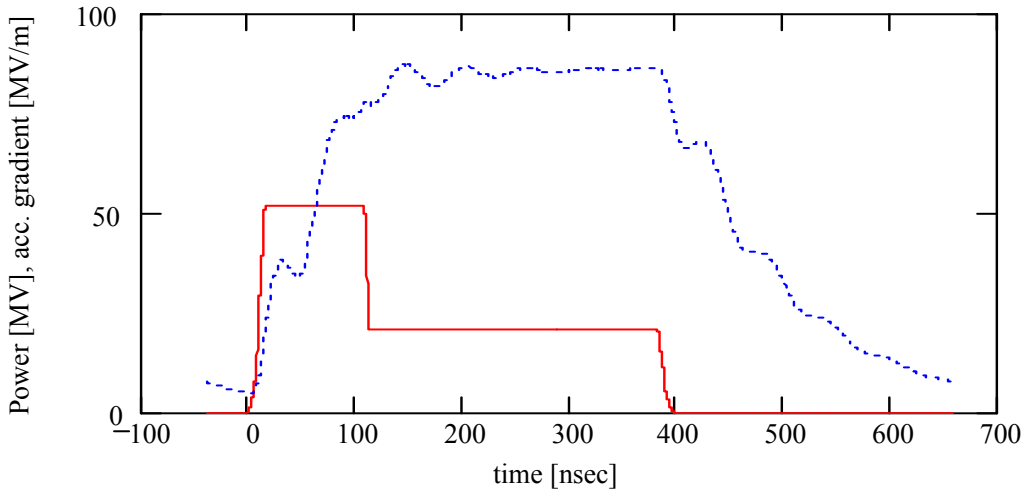
Breakdown performance

Conditioning of standing wave structures

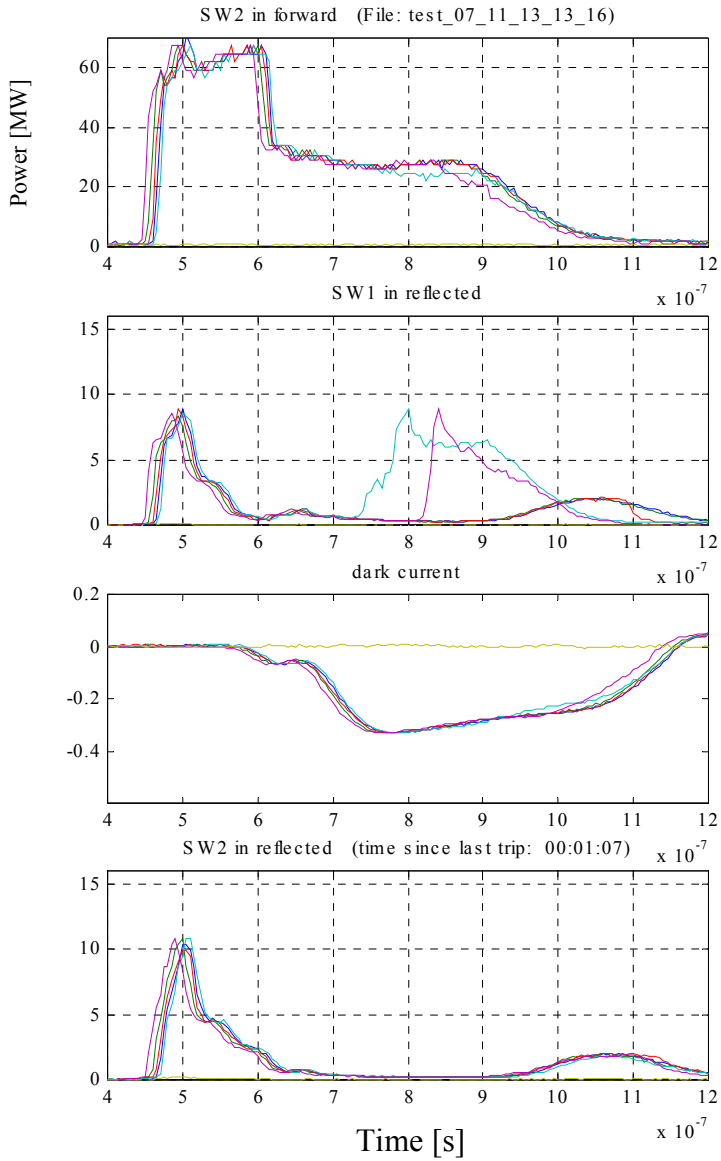


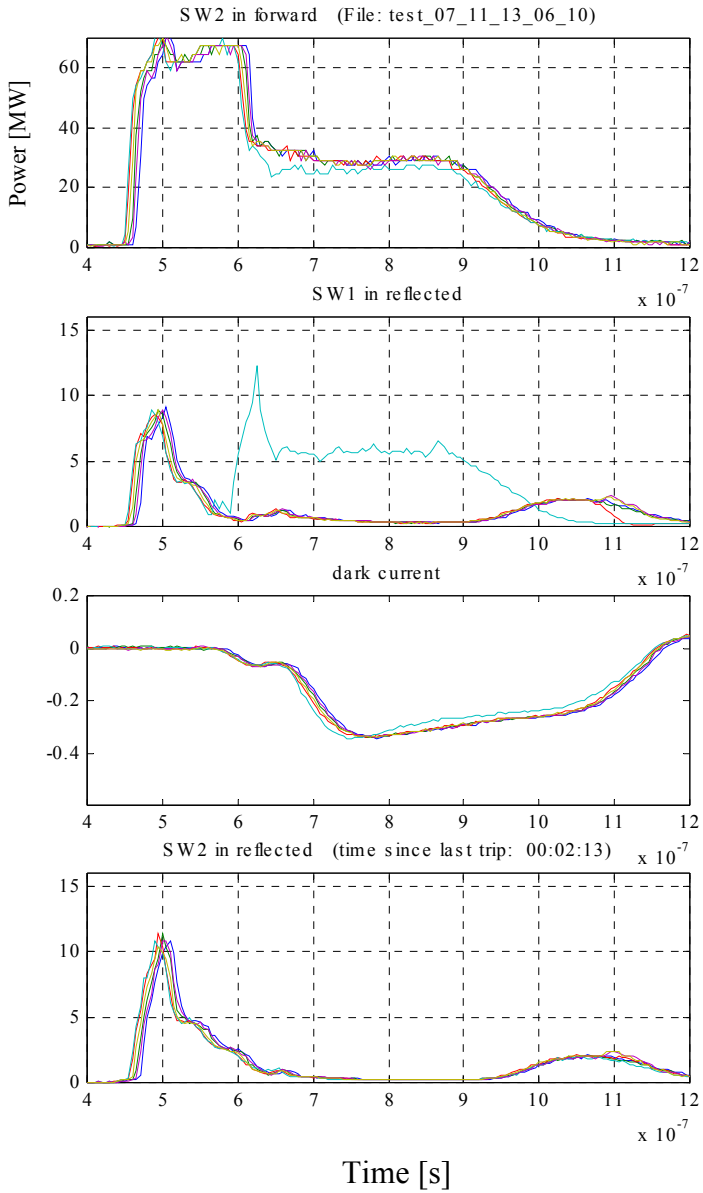
Flat top pulse



Simulation of beam loading

Breakdown in standing wave accelerating structures

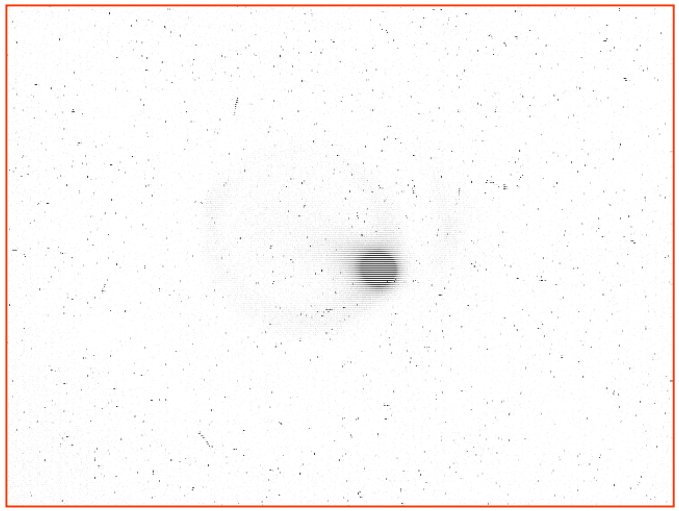




Breakdown in 15-cell π mode cavity, gradient 70 MV/m during 300 ns, *NLCTA, SLAC*, 11 July 2001

Breakdowns in SW1 structure, 2 Aug 01

2001_08_02_10_06_12.bmp



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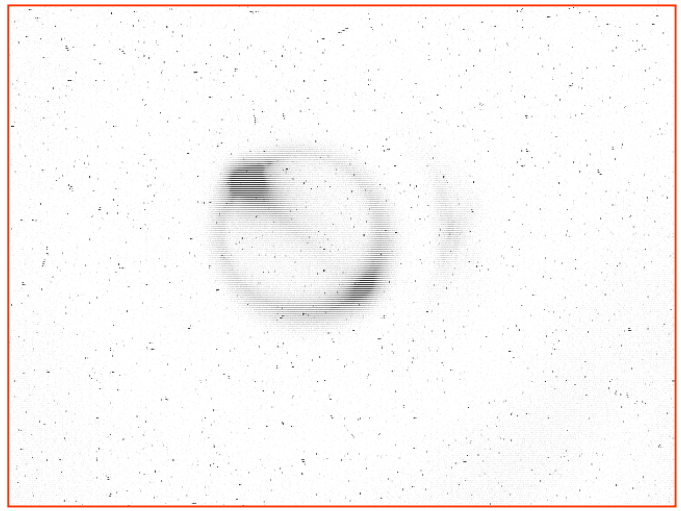

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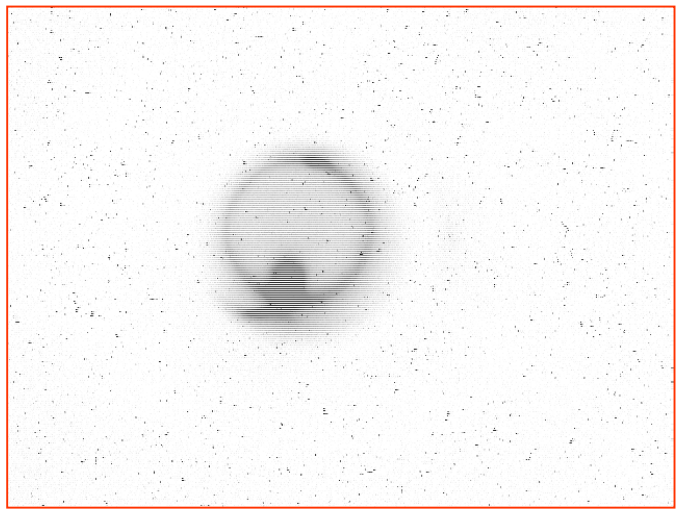
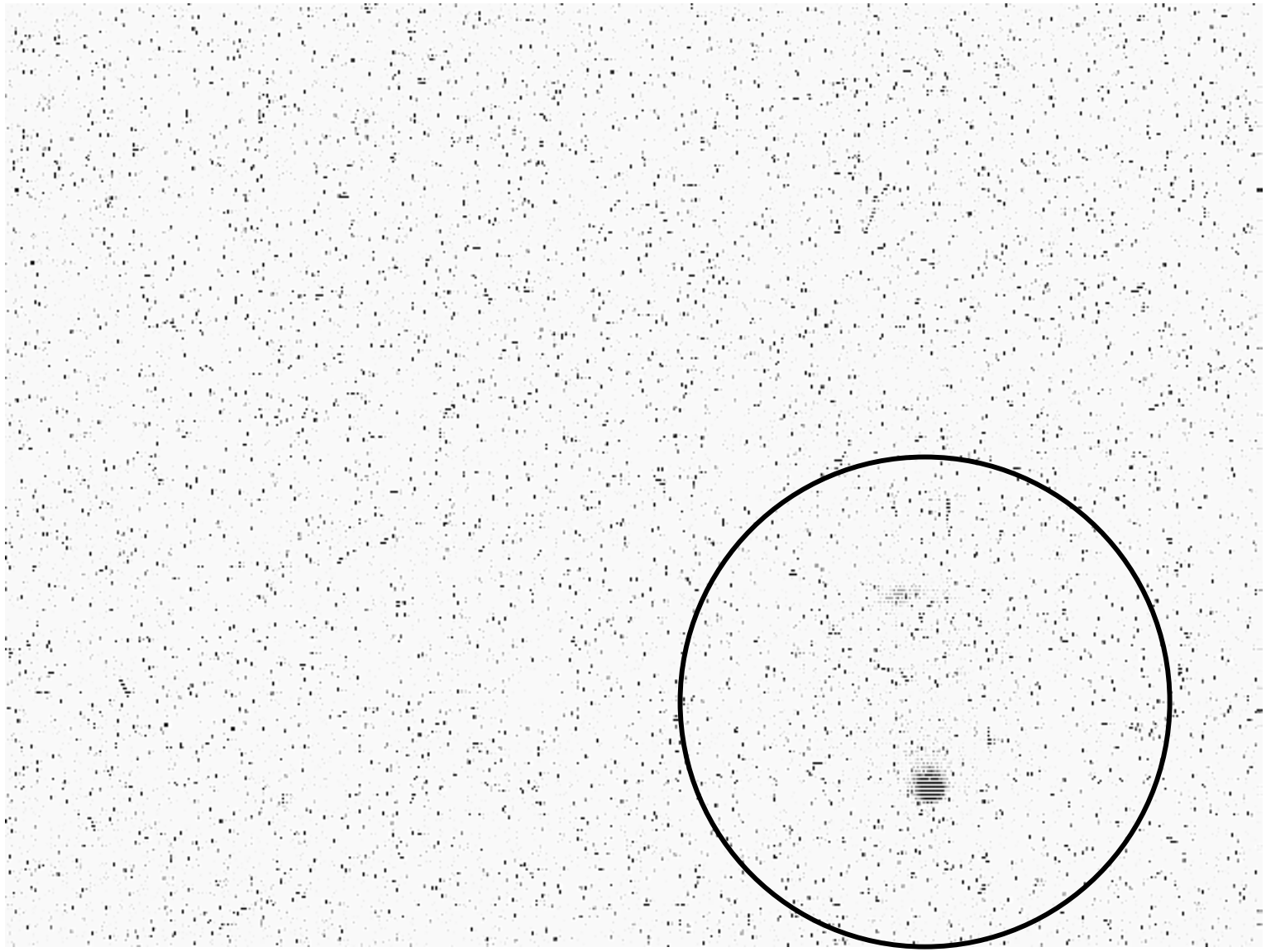


Breakdowns in SW1 structure, 14 Dec 01, 150 ns, ~80 MV/m



Breakdown in standing wave accelerating structures

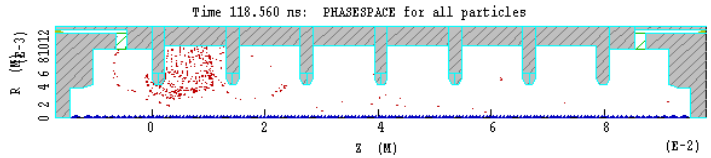
Features of RF breakdown in SW structure

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

Simulation model

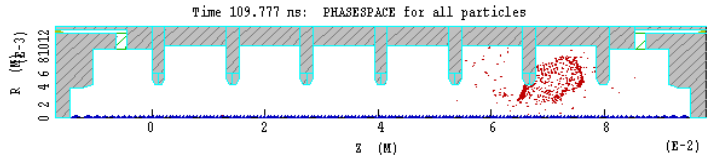
- 2D model
- Space charge limited emission of electrons

Breakdown in standing wave accelerating structures



Remarks: Breakdown Smulations	Device: standing wave struct Run: File: stw29.m2d Author: Valery A Dolgashev Organization: SLAC, Stanford CA
MAGIC2D Version: March 2001 Date: Apr 27,2001	Time: 14:09 Page: 146

Emission spot in first regular cell, projection of phase space on the *z-r* plane

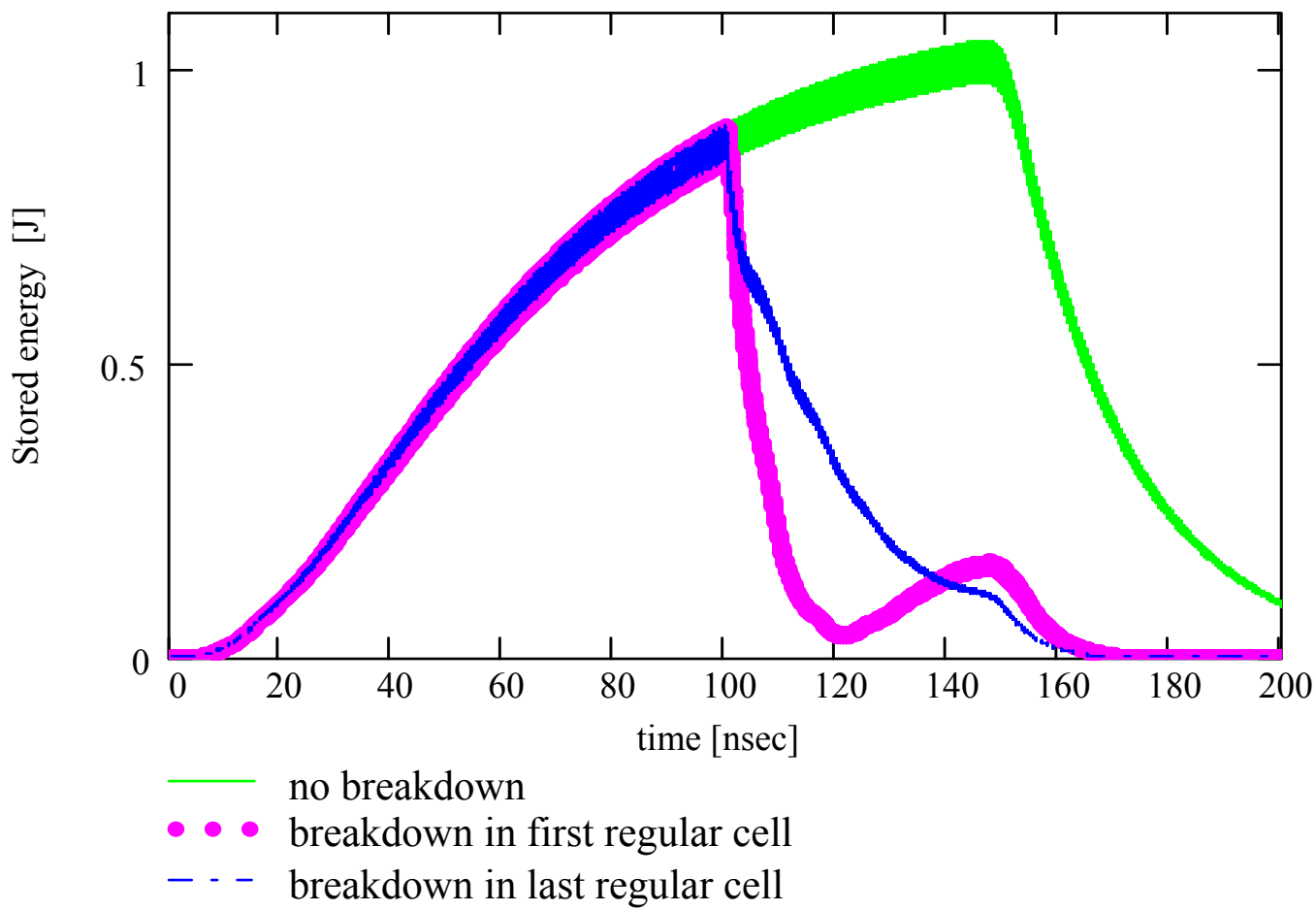


Remarks: Breakdown Smulations	Device: standing wave struct Run: File: stw30.m2d Author: Valery A Dolgashev Organization: SLAC, Stanford CA
MAGIC2D Version: March 2001 Date: Apr 27,2001	Time: 14:10 Page: 78

Emission spot in last regular cell, projection of phase space on the *z-r* plane

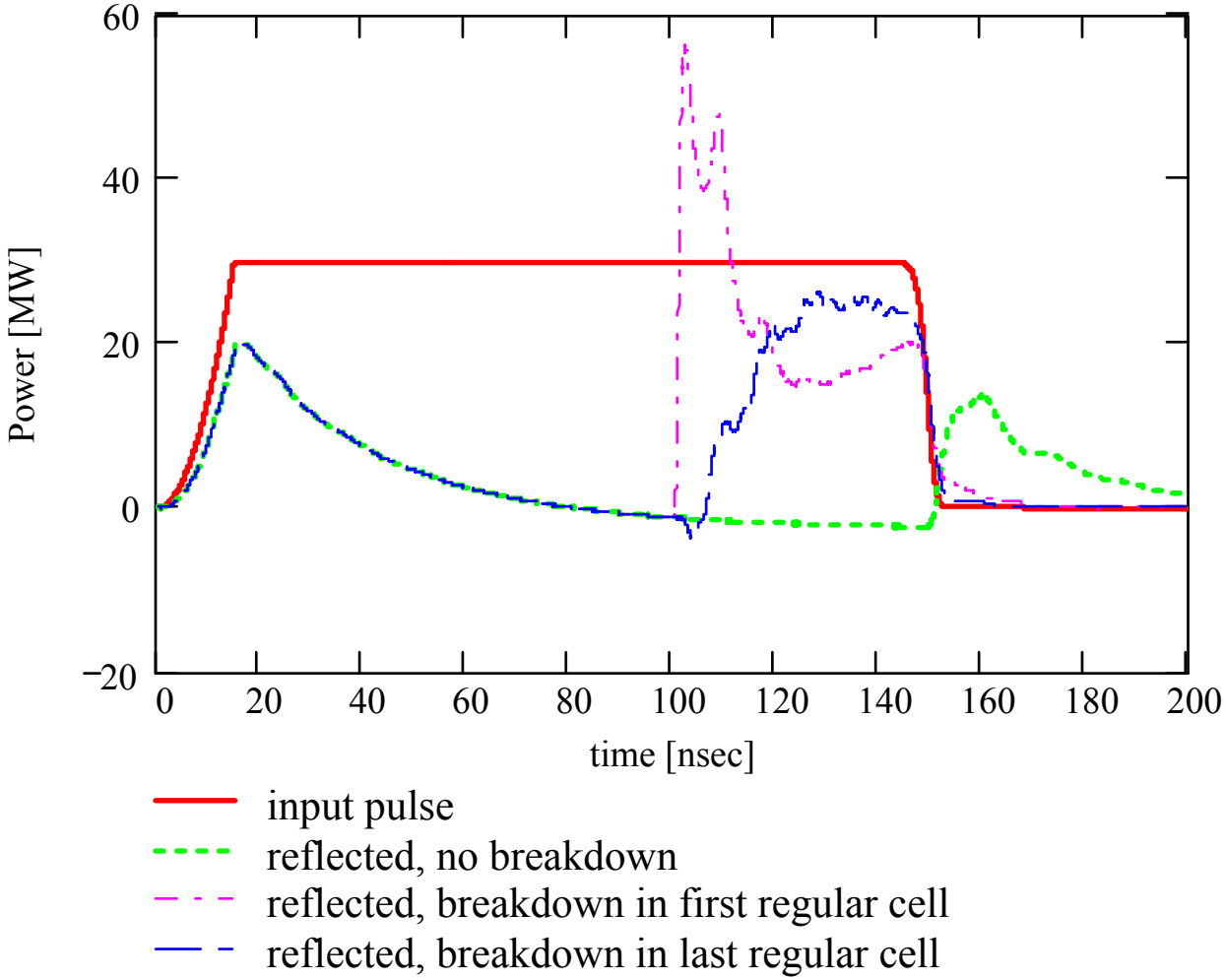
2D geometry

Breakdown in standing wave accelerating structures



Collapse of stored electromagnetic energy in the standing wave structure due to breakdown the first and last regular cells

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

Breakdown in standing wave accelerating structures

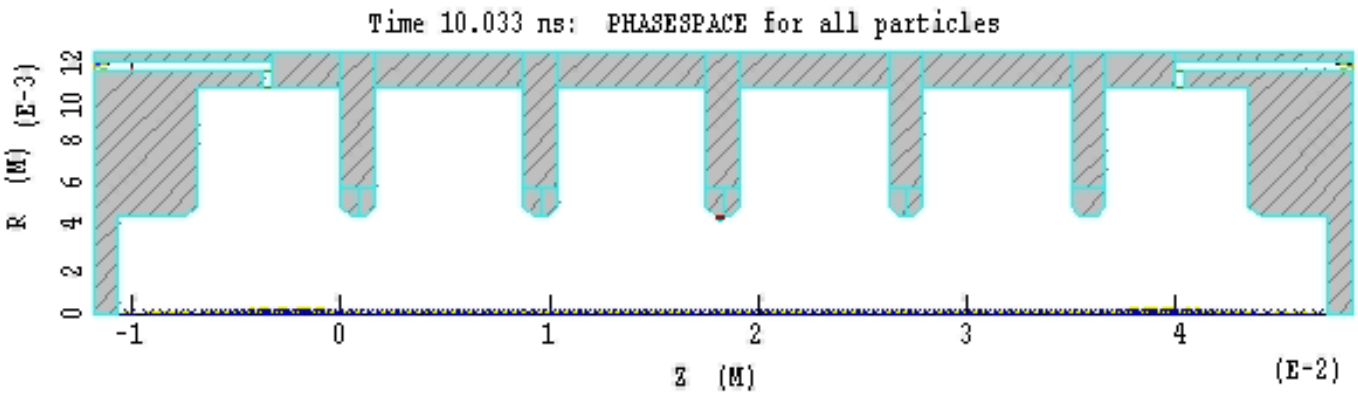
Result

- 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.

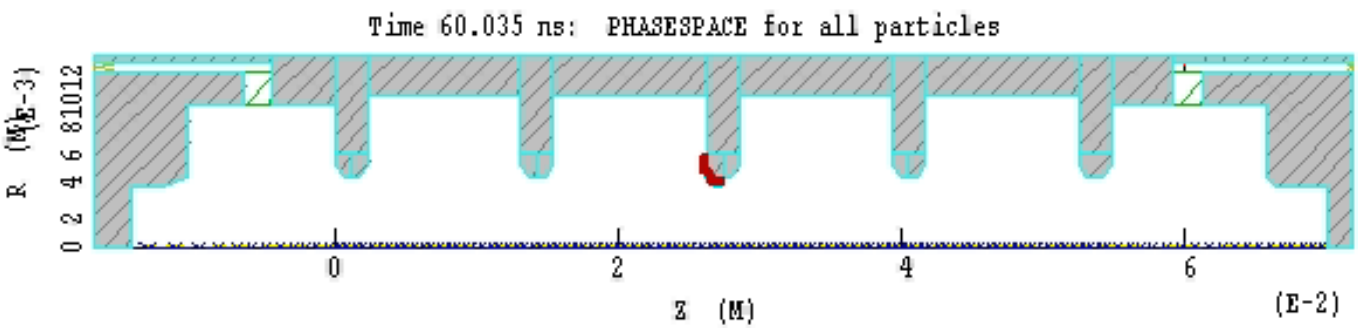
- The currents detune the whole structure, hence the π resonance is shifted from the working frequency. This shift causes rf energy to reflect from input iris of the structure.

Comparison of breakdown in traveling and standing wave structures

TW



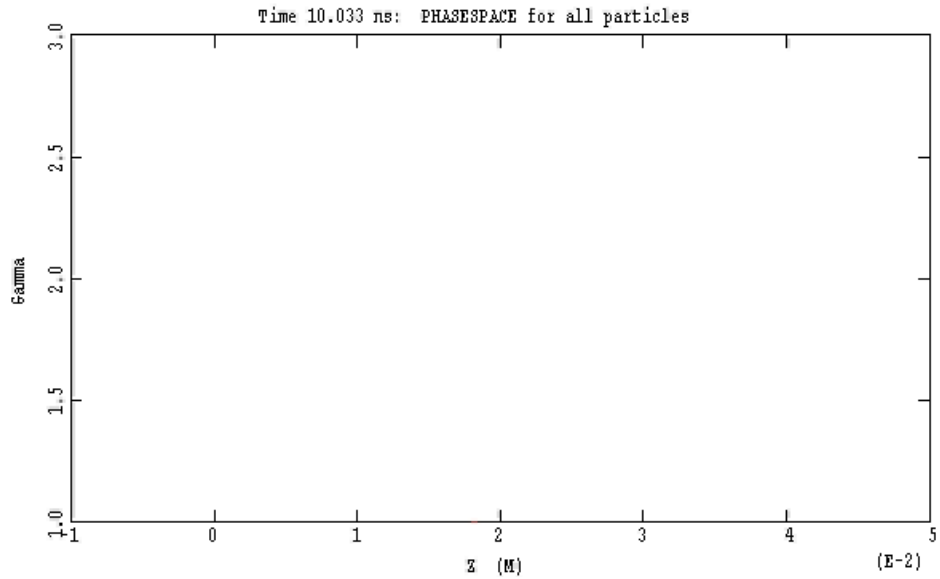
SW



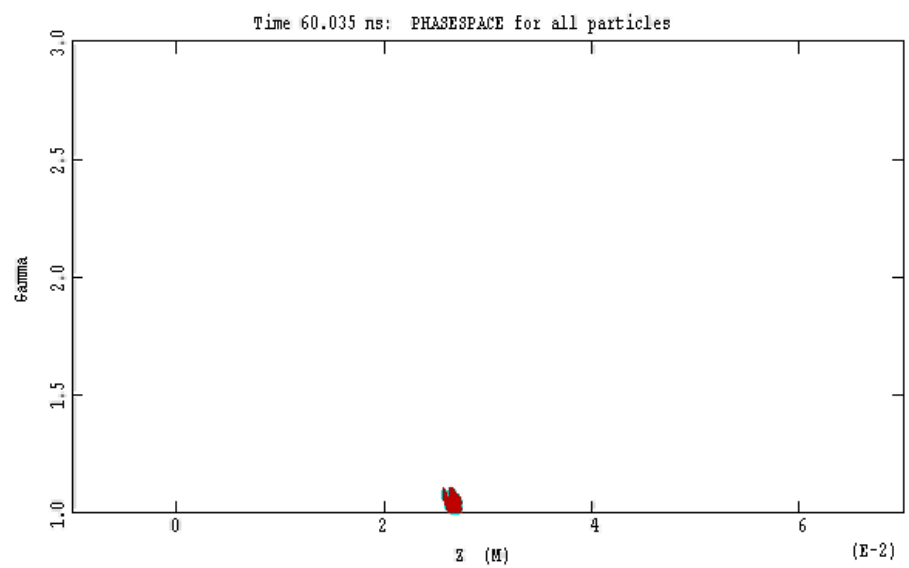
Projection of phase space on the *z-r* plane

Comparison of breakdown in traveling and standing wave structures

TW



SW



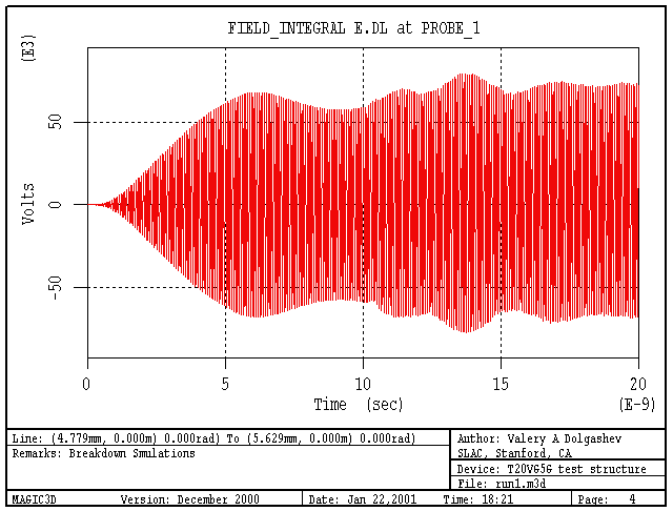
Projection of phase space on the z-γ plane

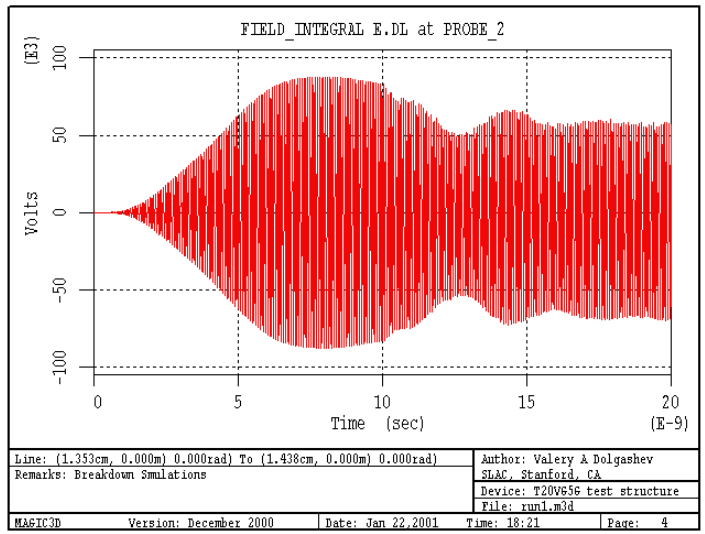
Comparison of breakdown in traveling and standing wave structures

1st cell

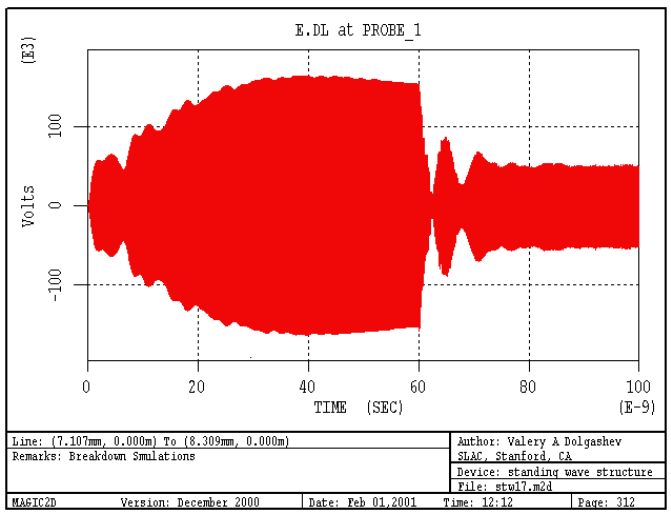
2nd cell

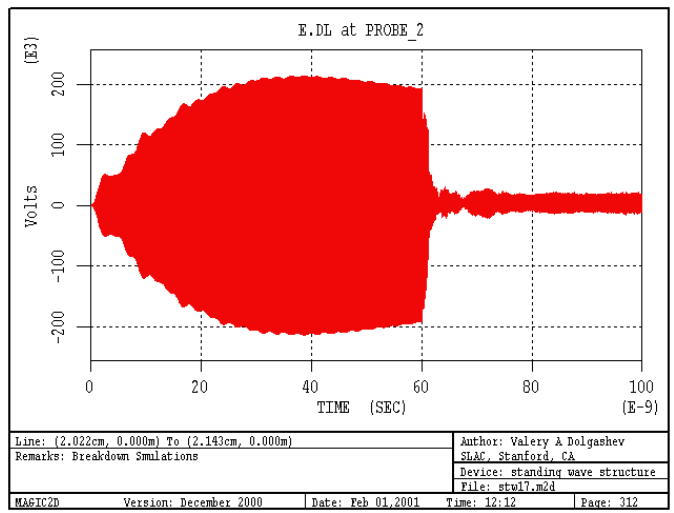
TW





SW



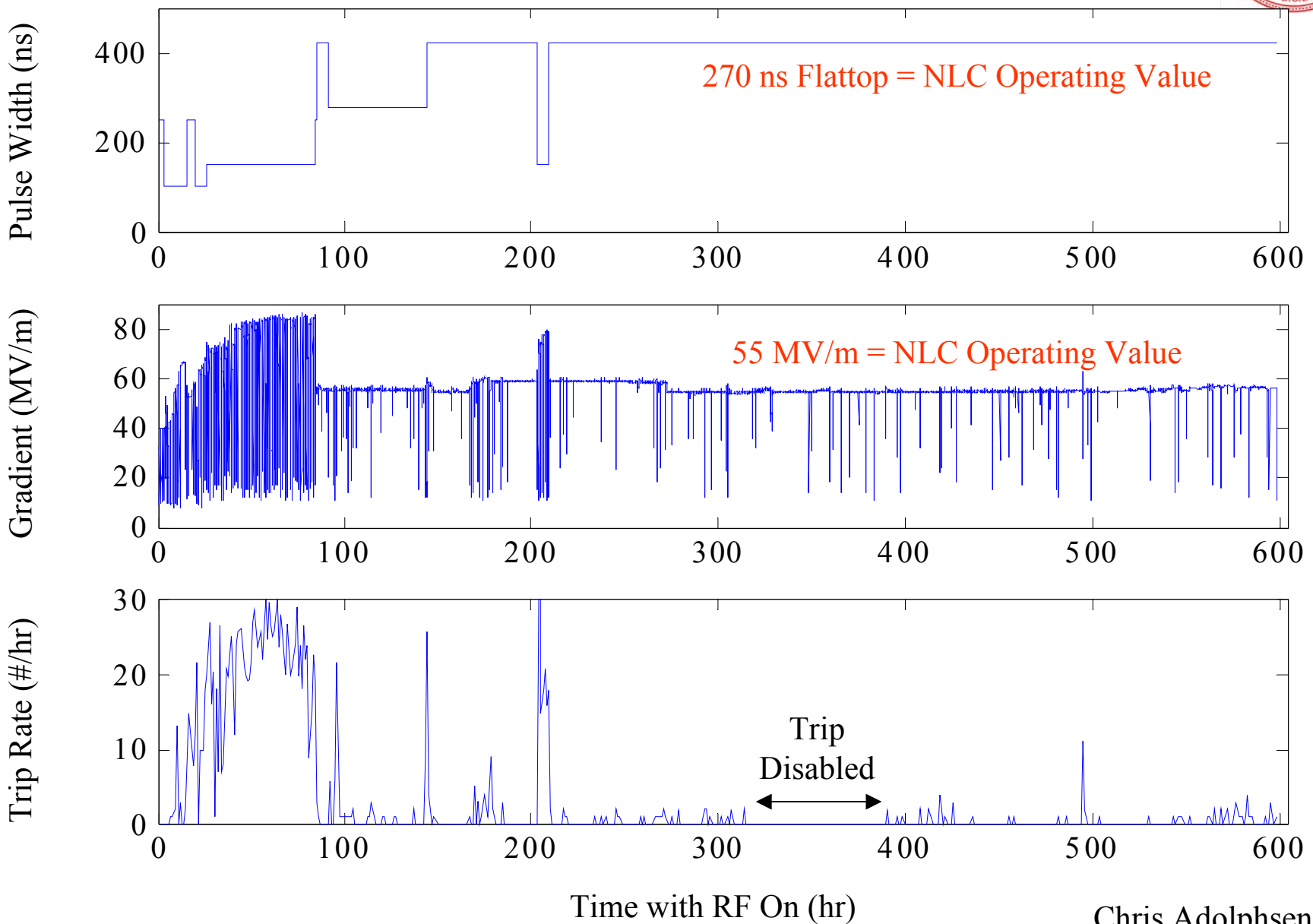


Amplitude of electric field

Result

- In the TW case breakdown currents on the order of 10 A have a negligible effect on transmission and reflection of rf power, but in the SW case the same current shifts the resonant frequency enough to cause reflection of a major part of the incident rf power.
- Increase of electric field in the cells (due to emitted currents) is generally smaller than for the TW structure.

SW20PIL Processing History



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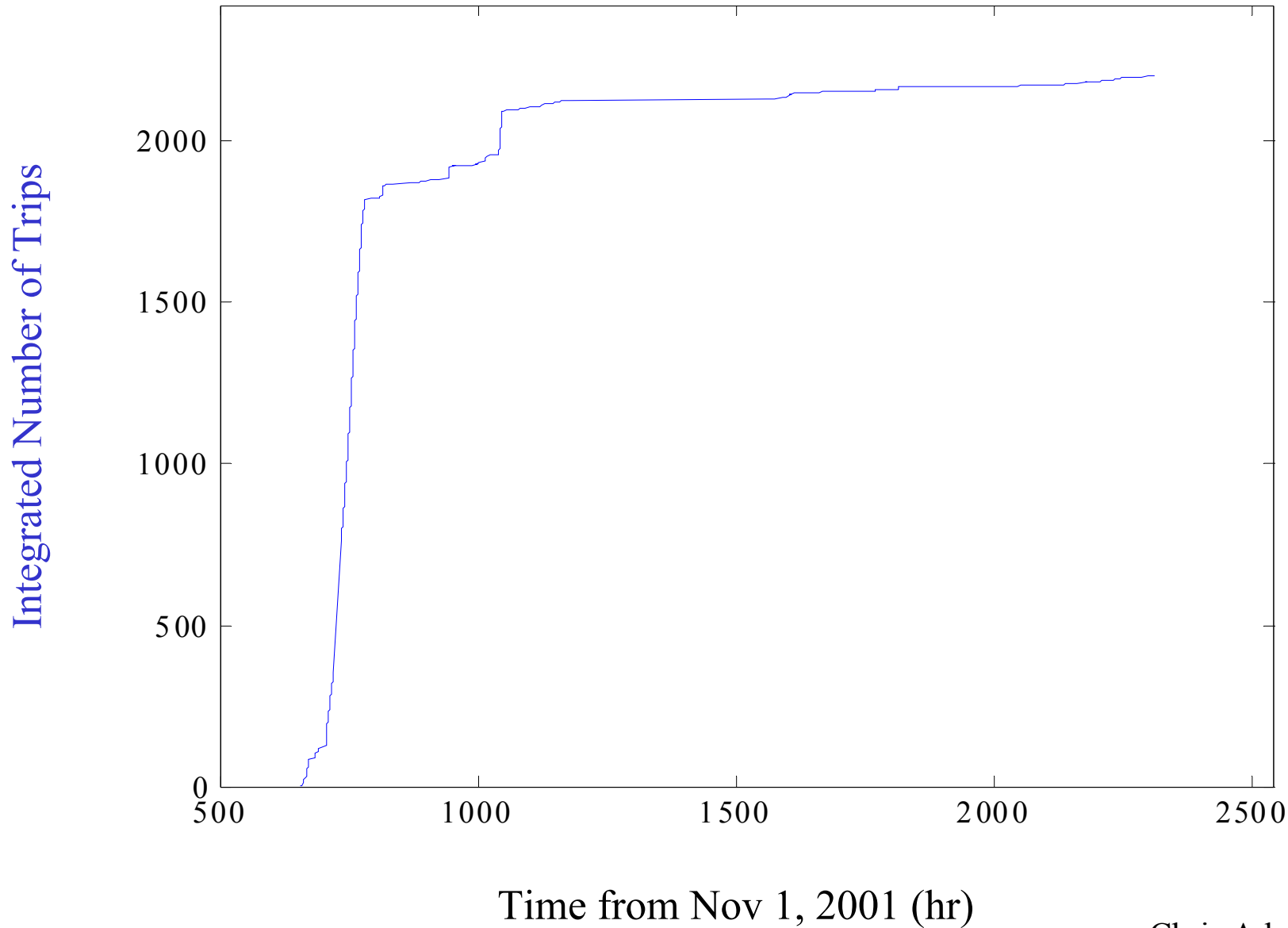
SW20PIL Processing History



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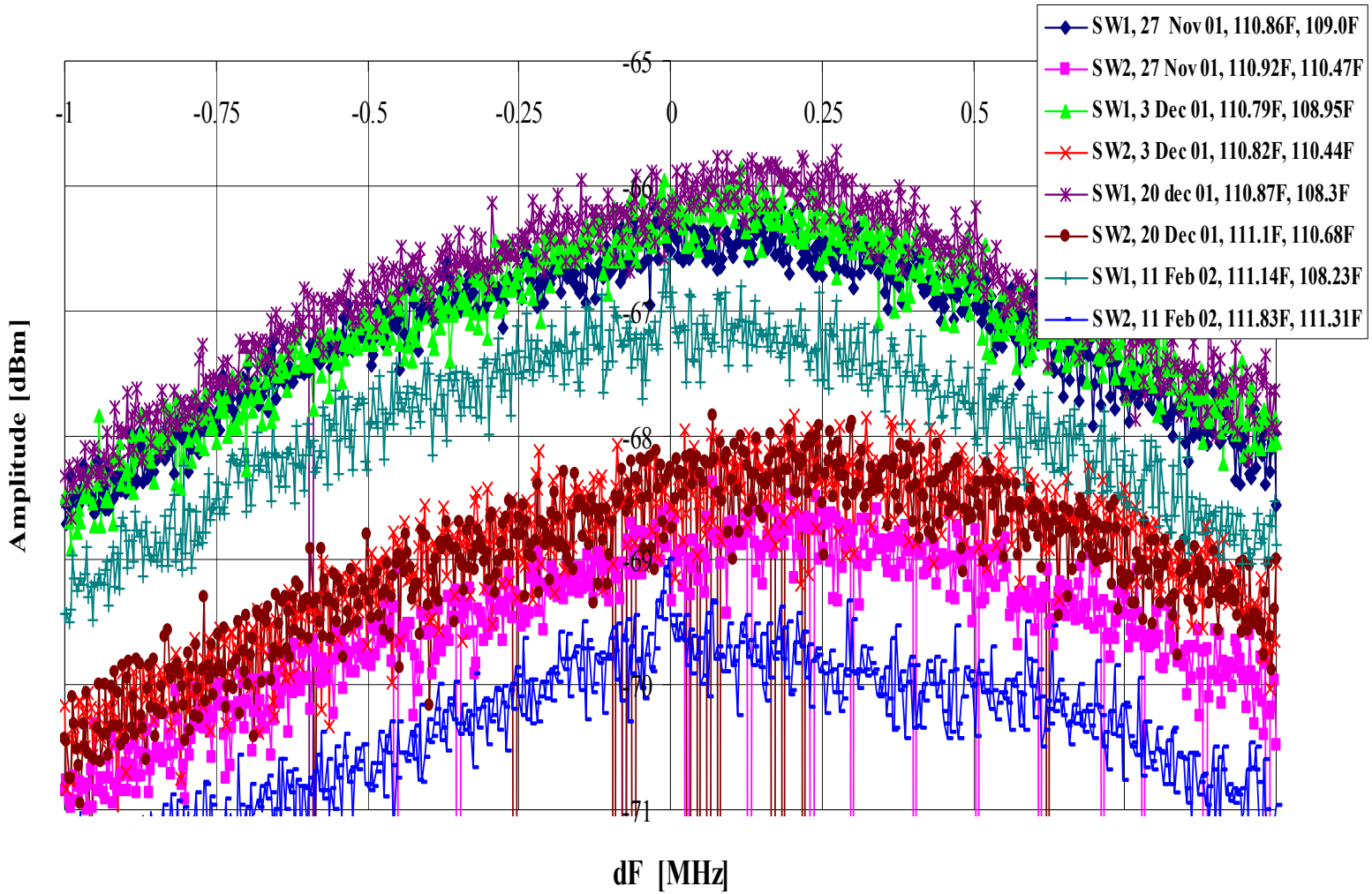
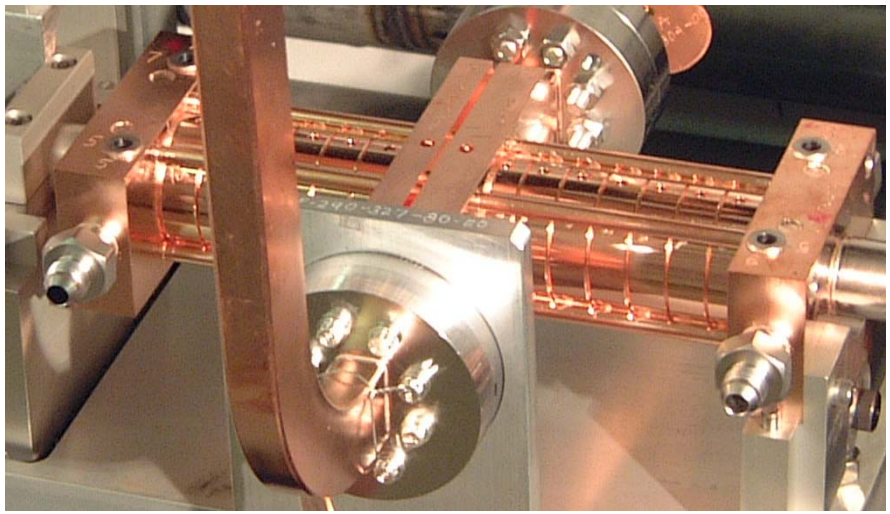
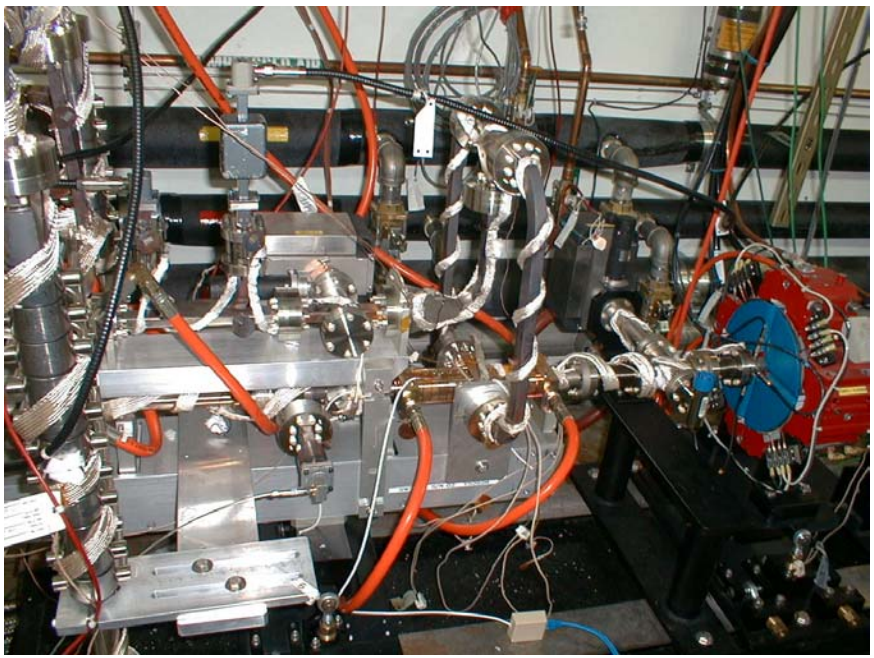
Spectrum excited by beam in standing wave structures before (27 Nov 01) and after processing up to 84 MV/m using 150 ns square rf pulse (3 Dec 01), after running at 270 ns at 55 MV/m acc. gradient ~4 days (20 Dec 01), and two month (11 Feb 02)



Standing-Wave Structures

(15 Cells, 20 cm Long, 124 ns Field Rise Time)





- In NLC, standing-wave structures would operate at the loaded gradient of 55 MV/m.
- In recent tests, breakdown rates of < 1 per 8 million pulses were measured at this gradient and the structures showed no discernable damage ($\Delta f/f < 10^{-5}$) after processing, making this design a candidate for the NLC.
- Next round of structures will have lower surface fields

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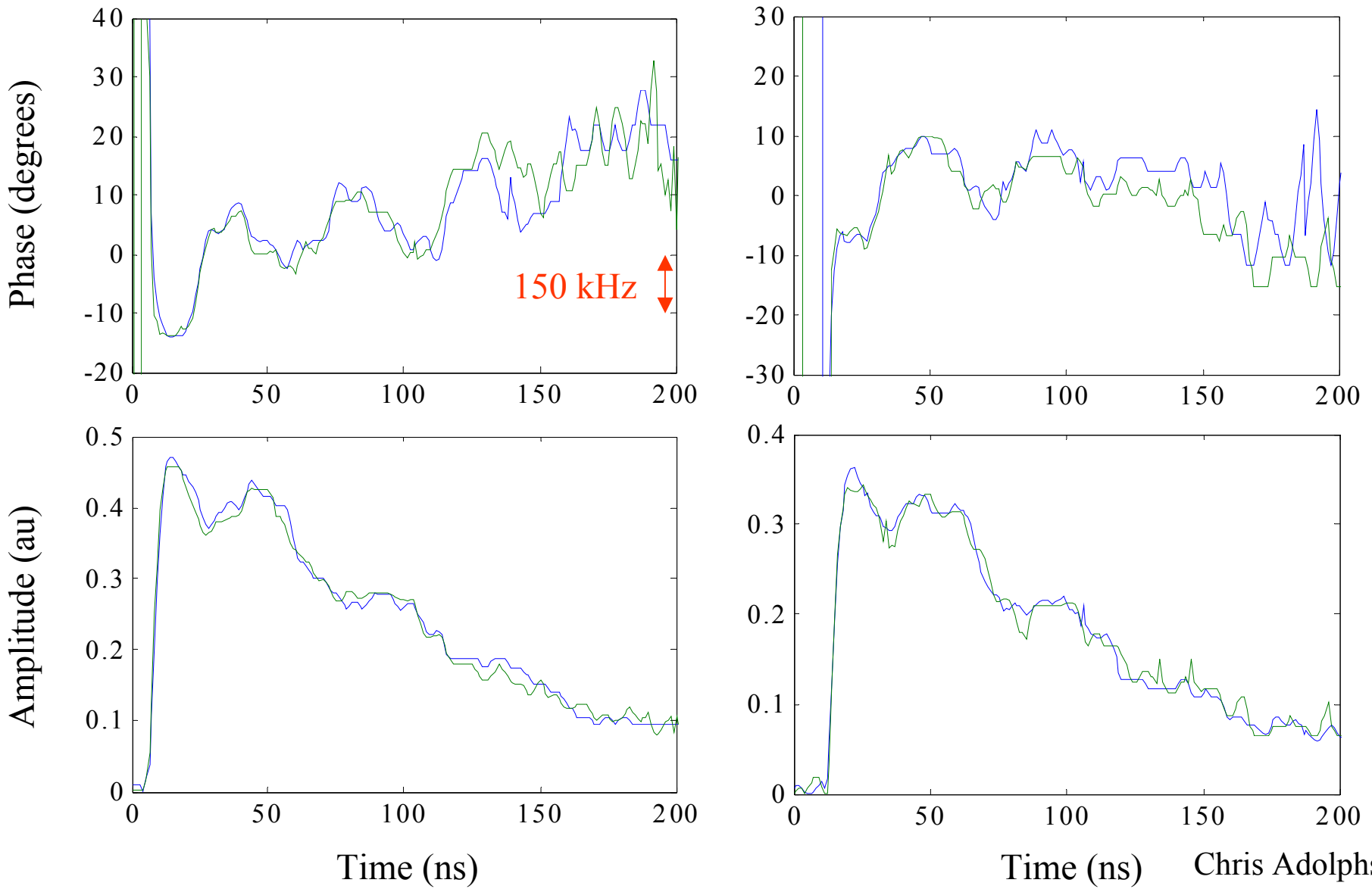
SW20PIL Beam Induced RF Measurements
Before (green) and After (blue) 600 Hours of Operation



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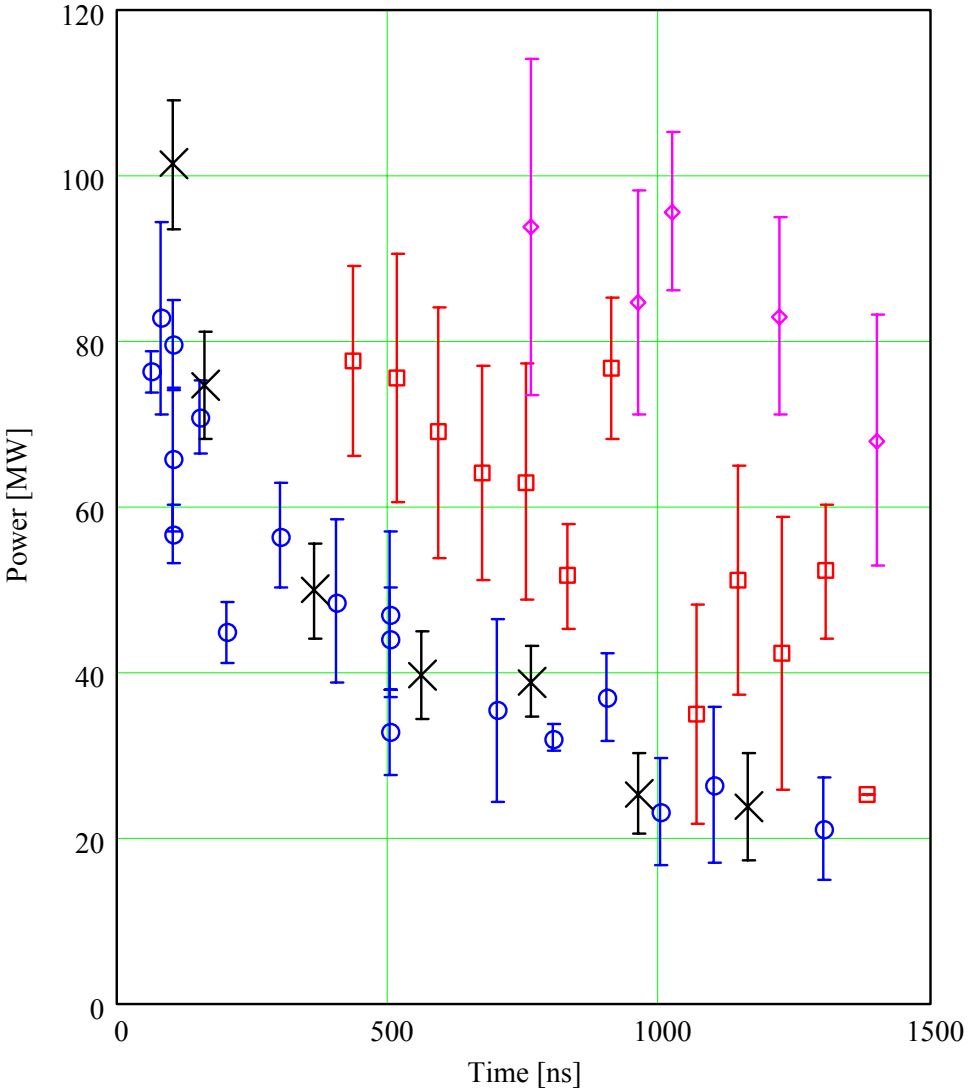
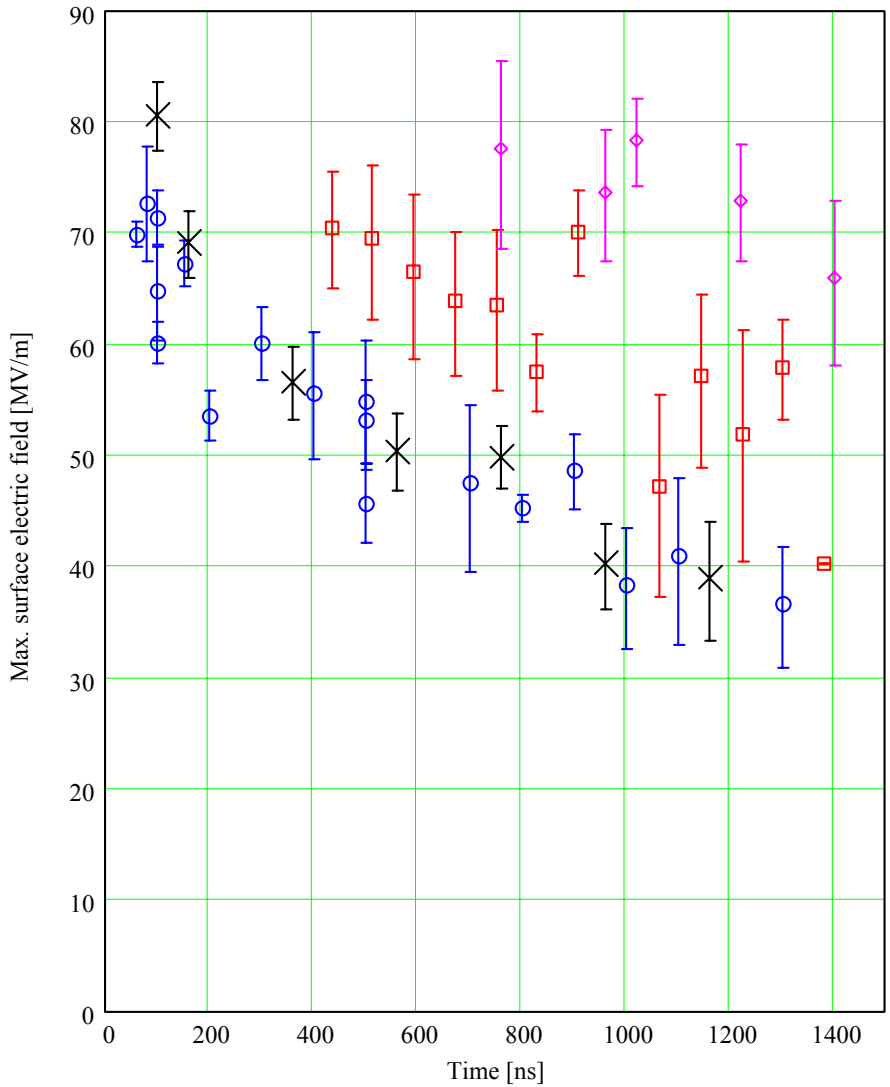
Breakdown threshold measurements for waveguides with different materials

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

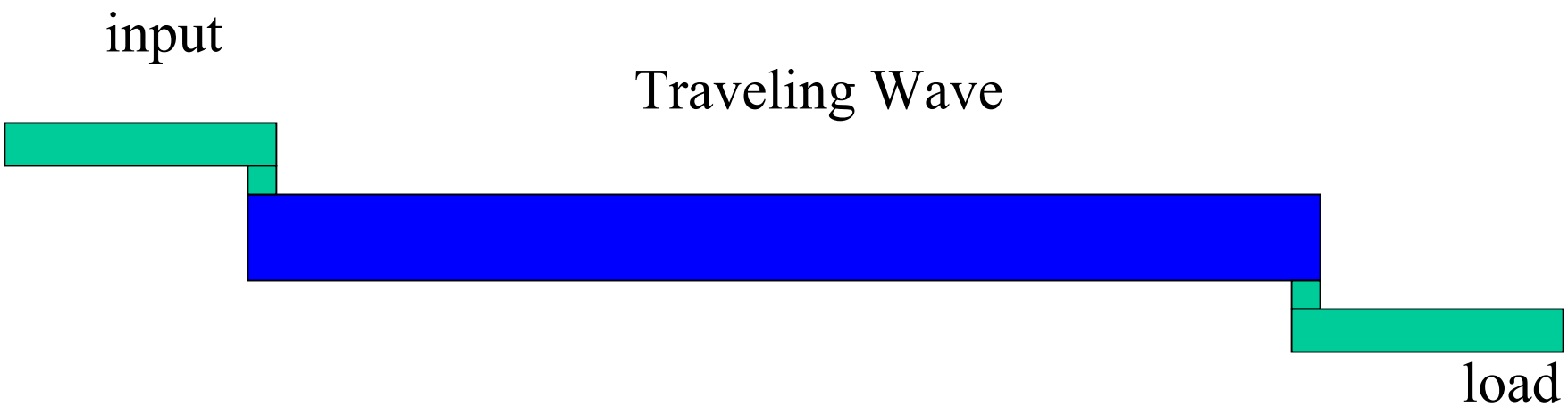


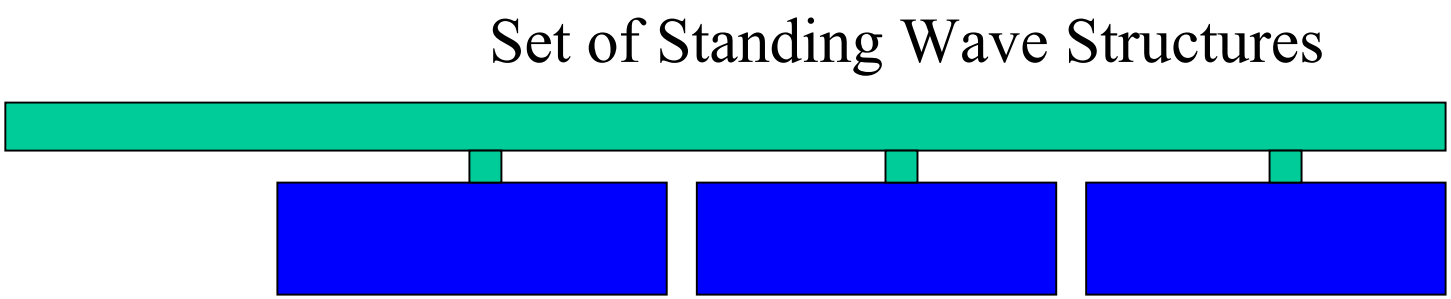


Parameter Comparison

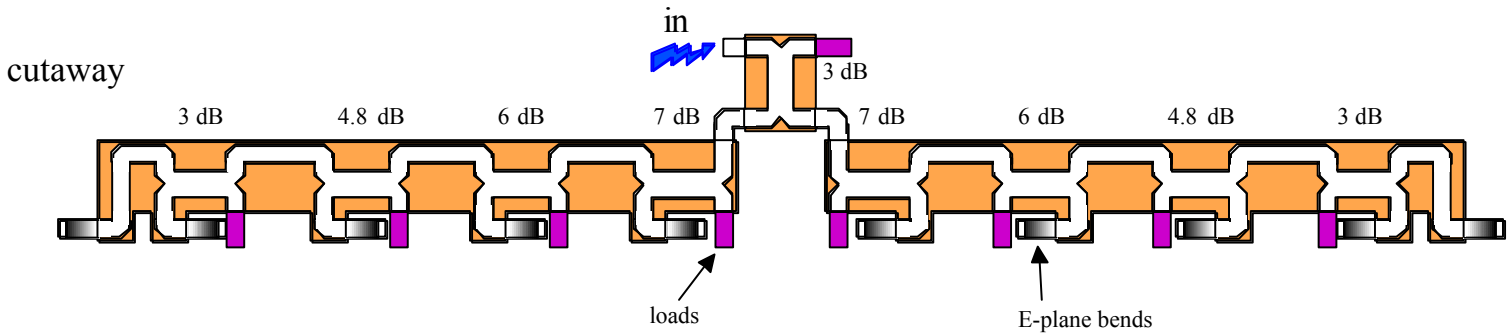
Parameter	**Traveling Wave**	**Standing Wave**
Experimental *Working* surface field	160 MV/m	160 MV/m
Experimental *working* loaded gradient (must be > 55 MV/m for 270 ns)	55 MV/m	55 MV/m
Experimental average iris size (must be > 0.18 a/λ)	0.12 a/λ	**0.18 a/λ**
Next structures loaded gradient for E_surface = 160 MV/m	**57 MV/m**	**70 MV/m**
Stainless steel iris tips ~30%	75 MV/m	91 MV/m

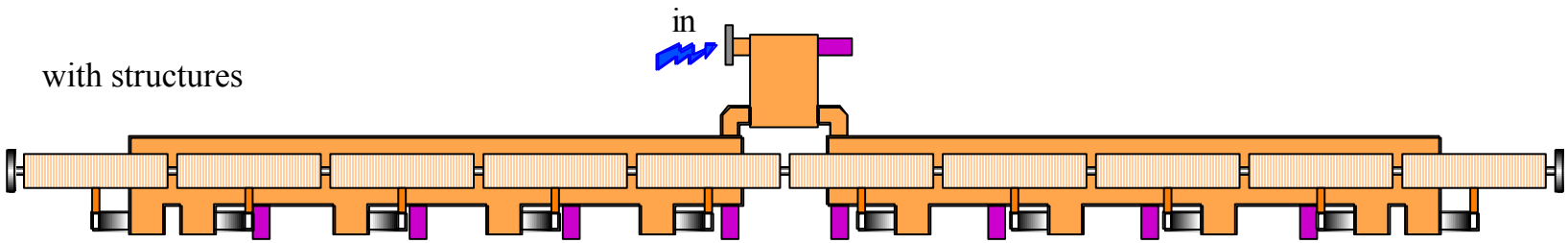
Sets of Standing Wave Structures





A Power Distribution Circuit for Filling Ten Structures from One Feed

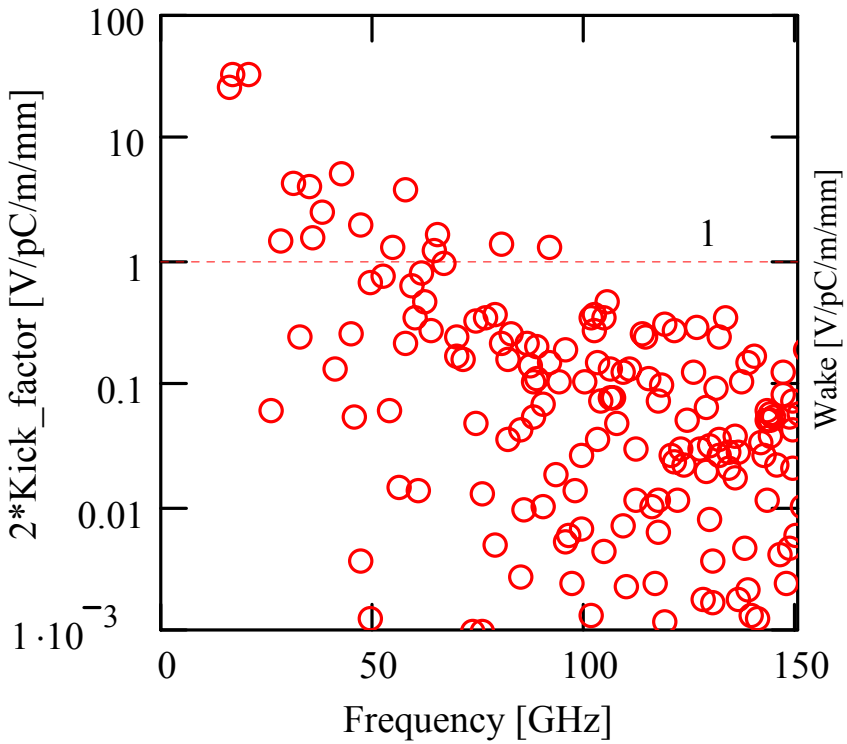


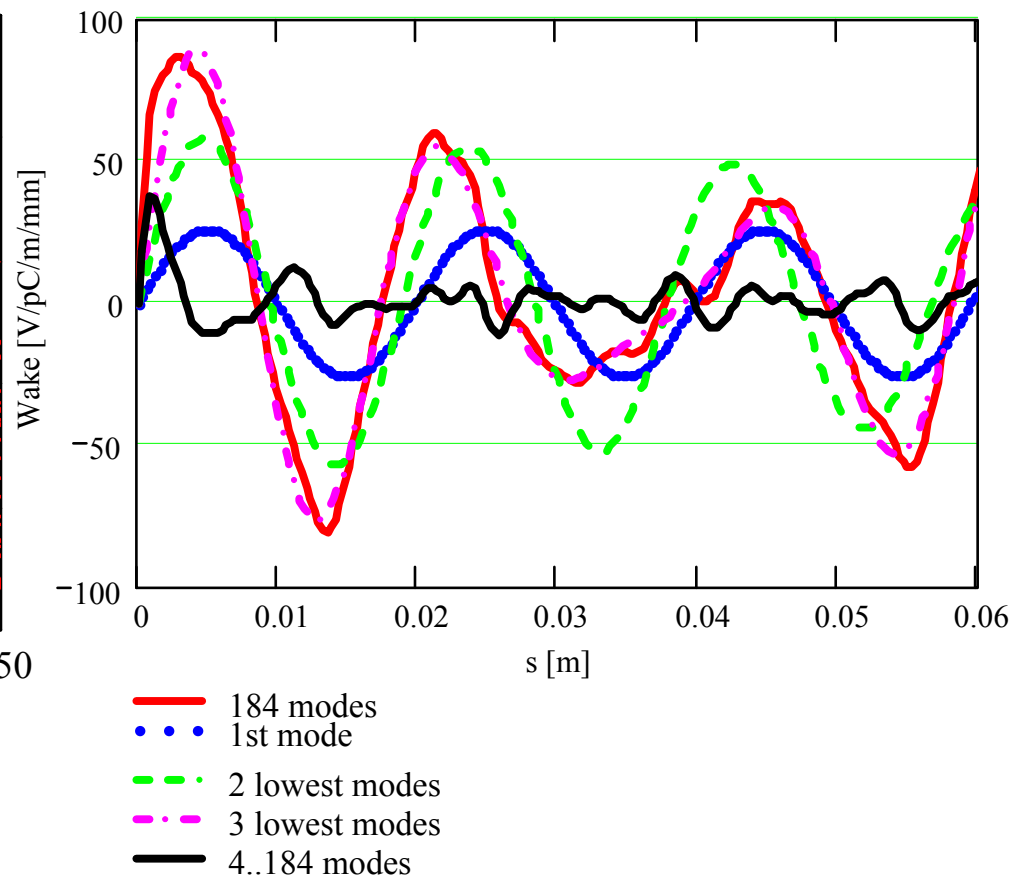


Sami Tantawi

Wakefield performance

Higher order modes, uncoupled model



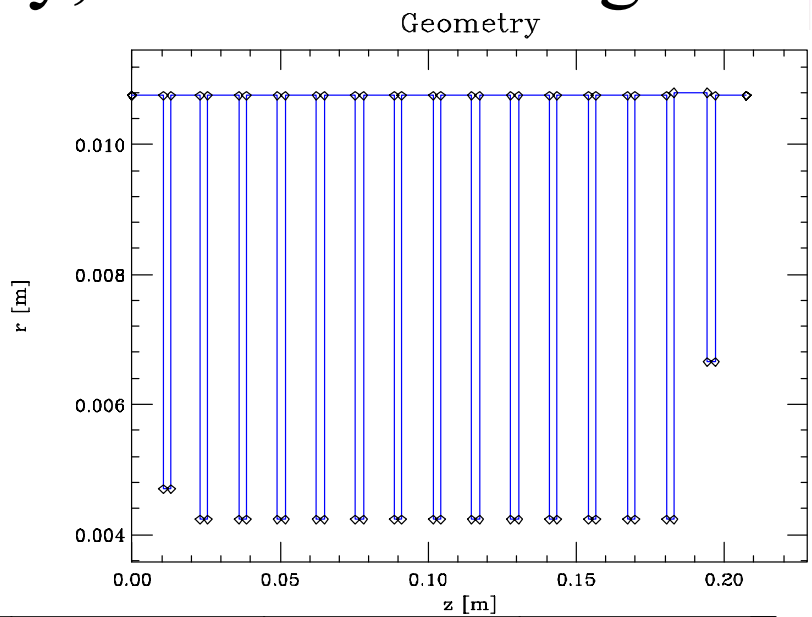


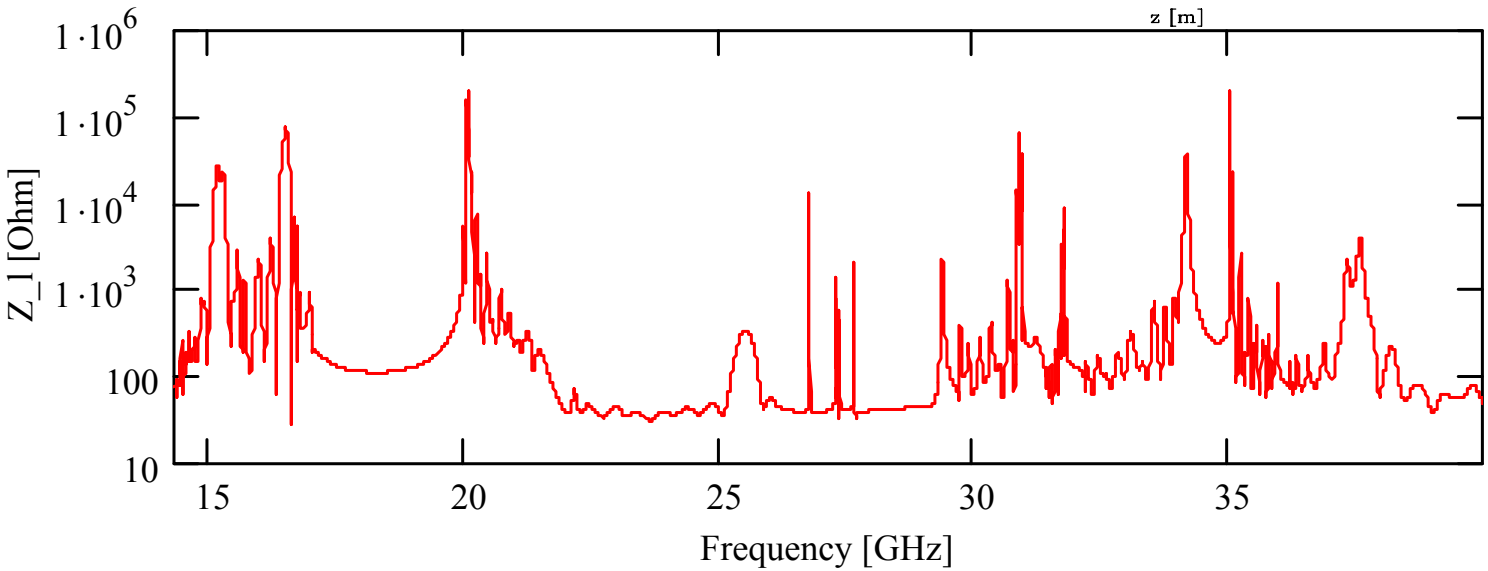
Kick factors of dipole modes vs. frequency for SW375

Transverse wake for SW375

Wake field,
2D 'open' geometry, mode matching

Input: a_c = 4.7 b_c = 10.75 d_c = 9.8
Output: a_c = 6.65 b_c = 10.8 d_c = 11.4

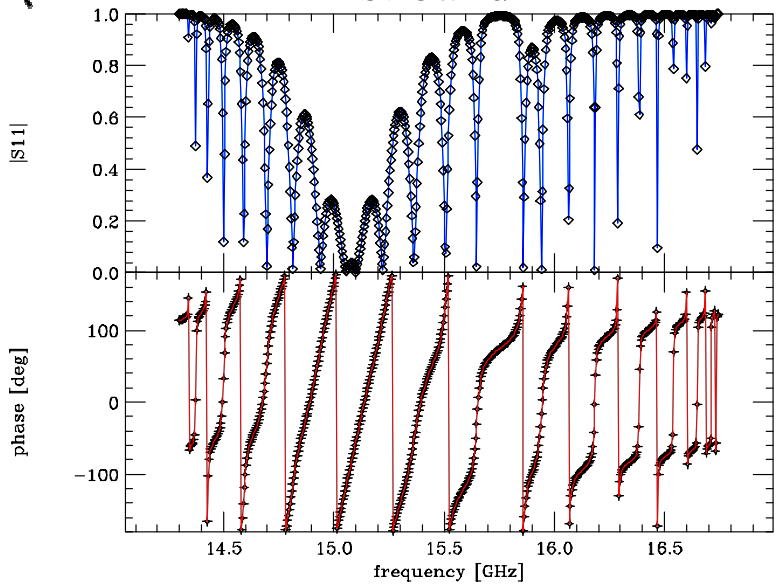




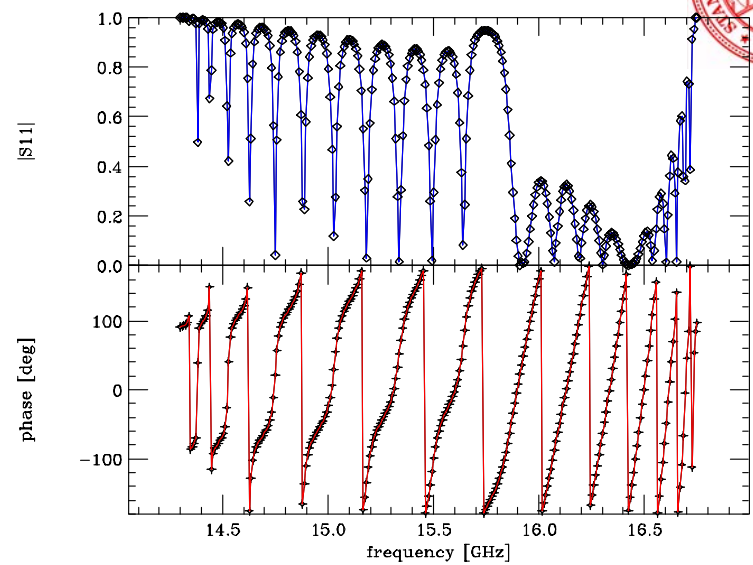
Real part of longitudinal impedance *vs.* frequency

2D simulation of the wakefield damping

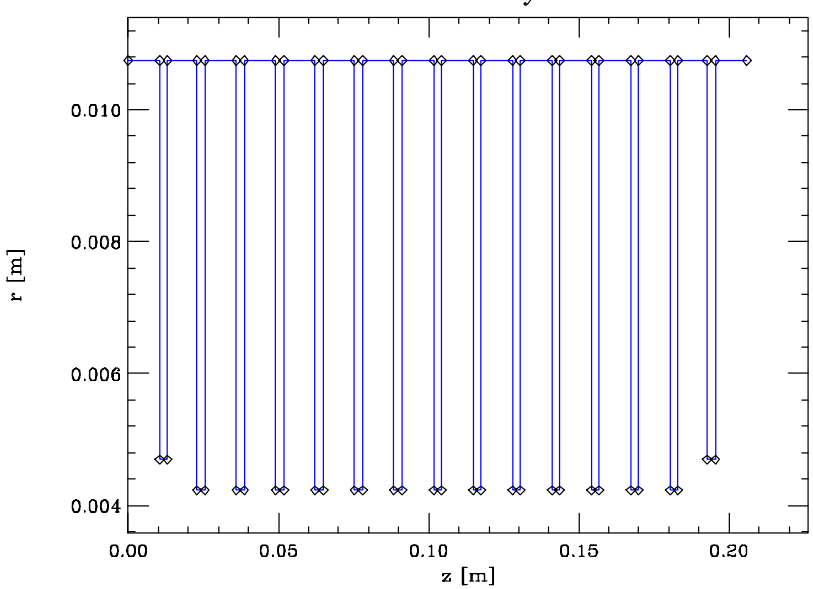
1st band



2nd band

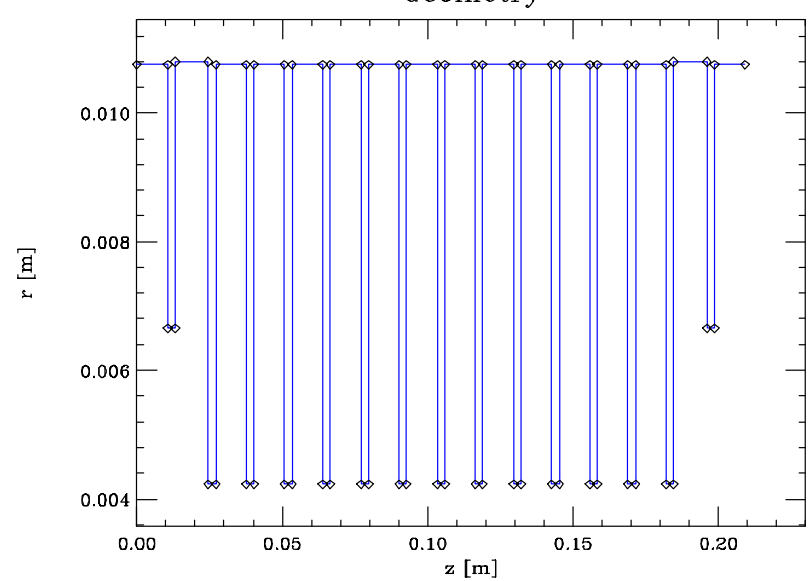


Geometry



a_c = 4.7 b_c = 10.75 d_c = 9.8

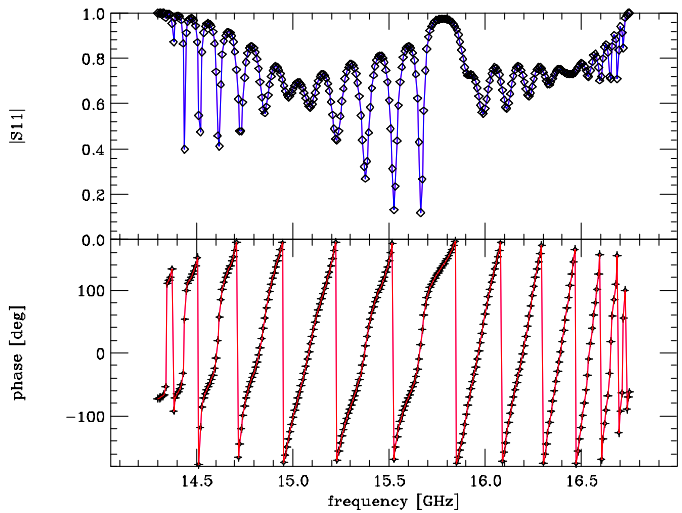
Geometry

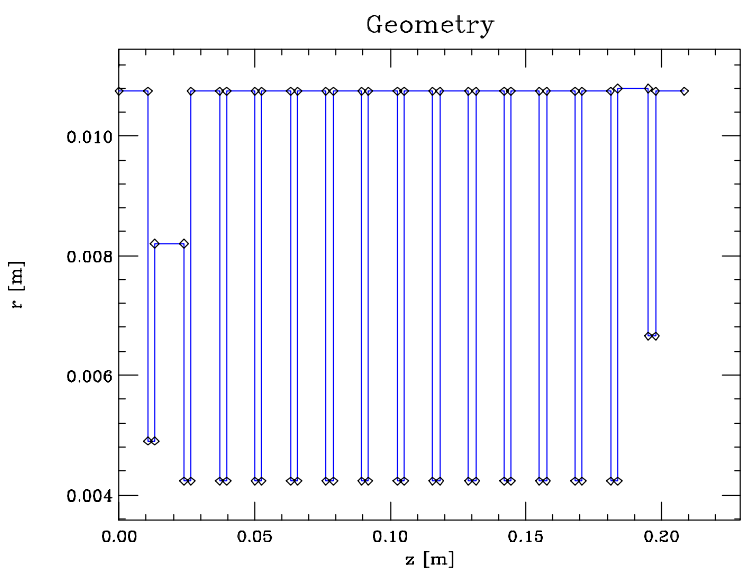


a_c = 6.65 b_c = 10.8 d_c = 11.4

2D simulation of the wakefield damping, 2 lowest modes

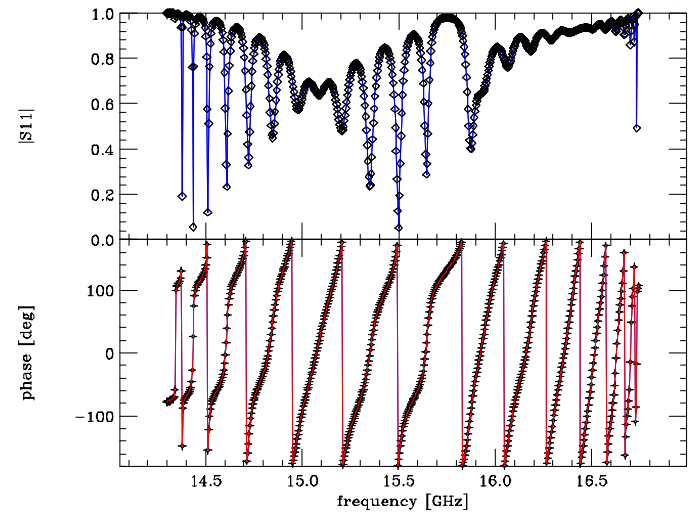
One damping-cell in cut-off iris

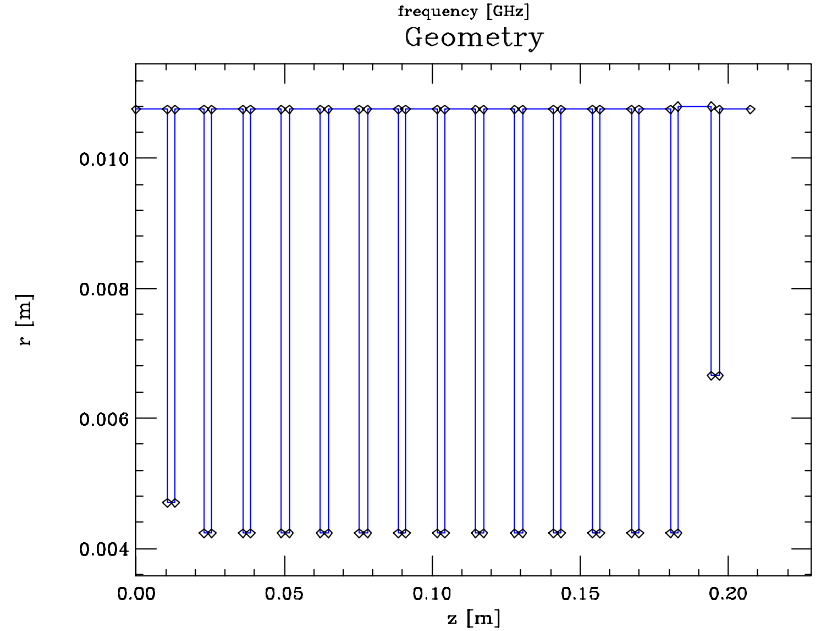




Input a_c = 4.9, b_c = 8.2, d_c = 10.75
Output a_c = 6.65 b_c = 10.8 d_c = 11.4

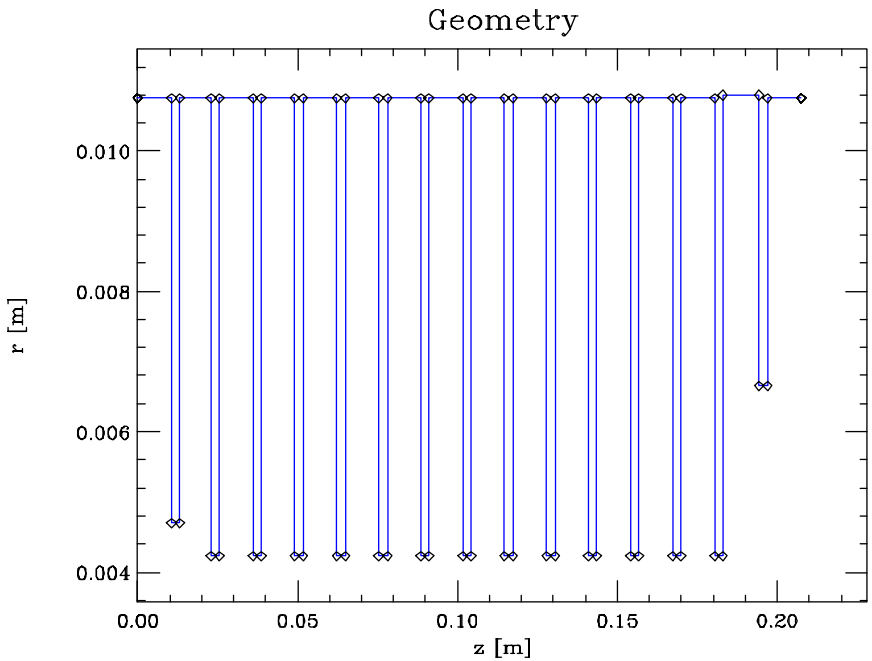
No damping-cell in cut-off iris

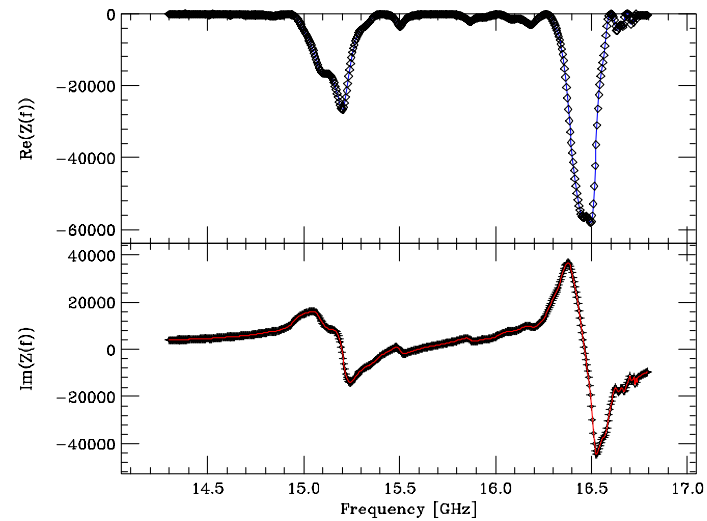


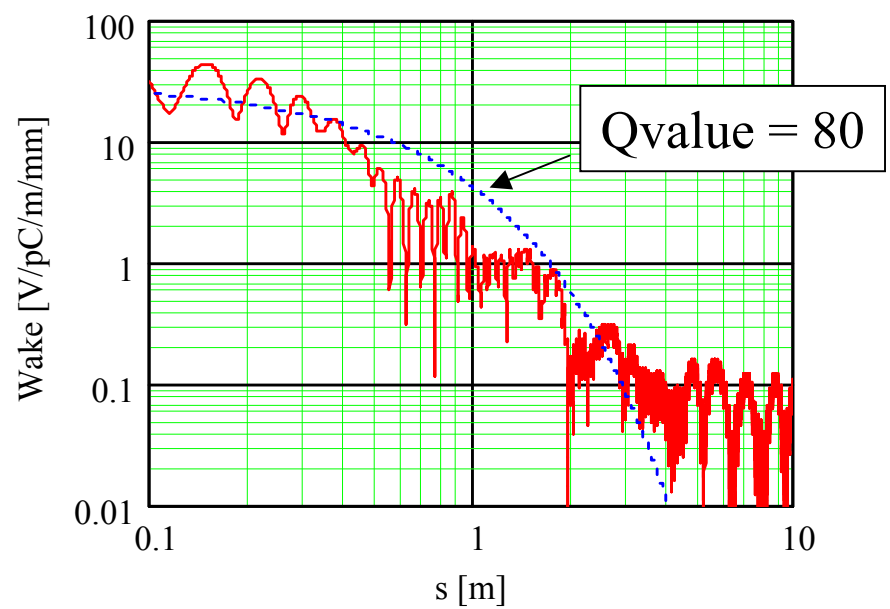


Input: a_c = 4.7 b_c = 10.75 d_c = 9.8
Output: a_c = 6.65 b_c = 10.8 d_c = 11.4

Damping of 2 lowest dipole modes of 14 cell SW structure using two damping cells

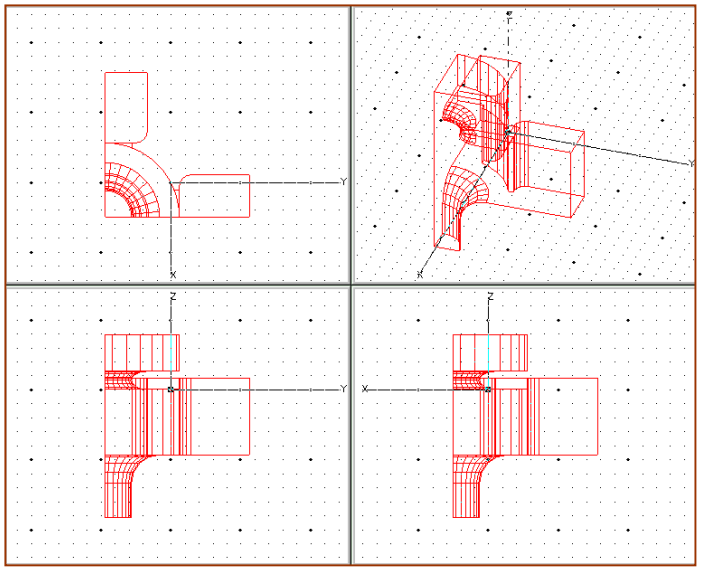




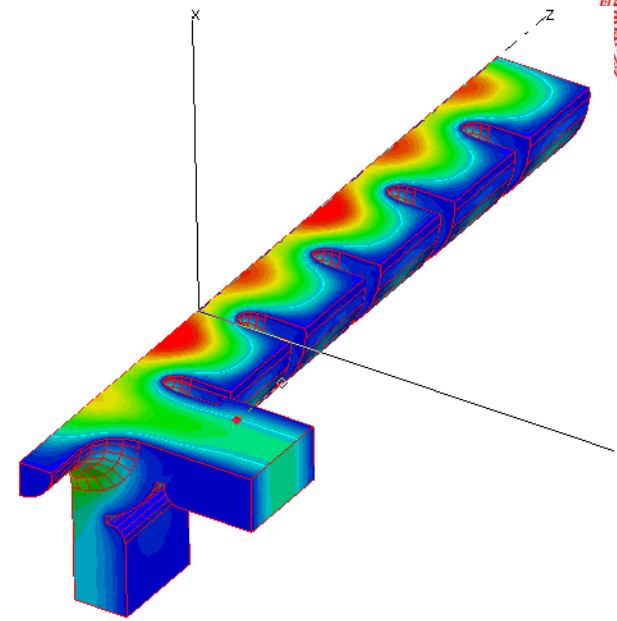


Input: a_c = 4.7 b_c = 10.75 d_c = 9.8
Output: a_c = 6.65 b_c = 10.8 d_c = 11.4

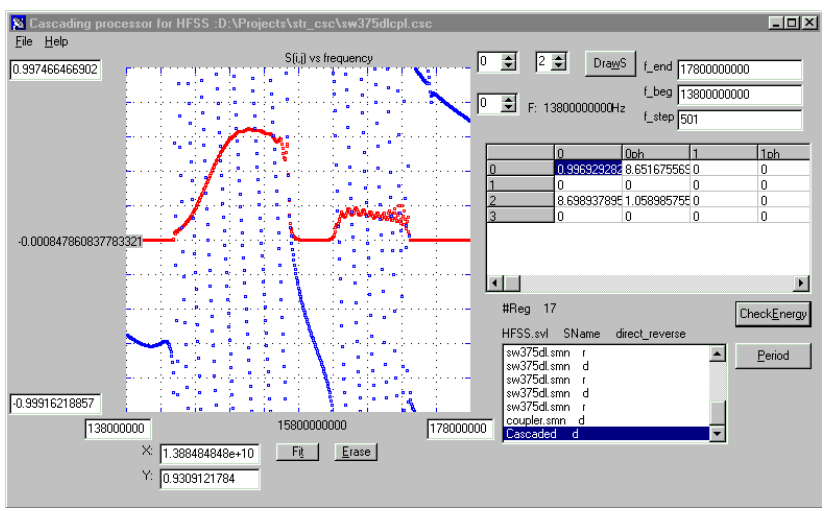
Damping cell for SW375, first dipole band



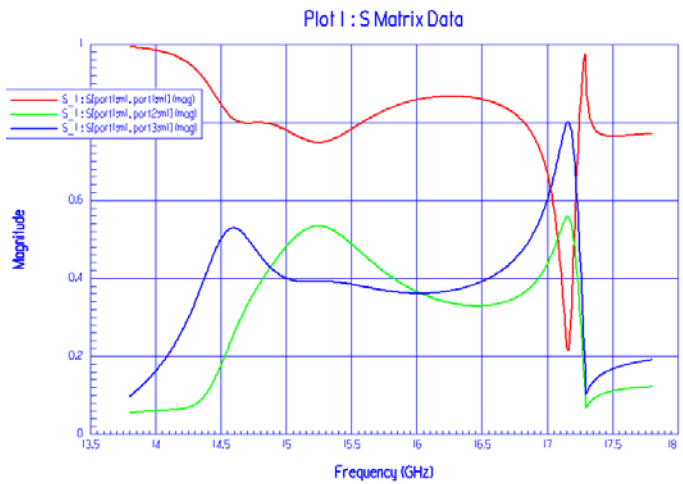
Geometry



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.



Summary

- Standing wave structure is a possible candidate for NLC accelerating structure
- Breakdown performance - OK
- Power distribution: circuit design established
- Wake field performance: detuning OK, damping – under way