Microwave-Based High-Gradient Structures and Linacs

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SLAC

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  - V. Dolgashev, L. Laurent, F. Wang, J. Wang, C. Adolphsen, D. Yeremian, J. Lewandowski, C. Nantista, J. Eichner, C. Yoneda, C. Pearson, A. Hayes, D. Martin, R. Ruth, S. Pei, Z. Li
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  - T. Higo and Y. Higashi, et. al., KEK
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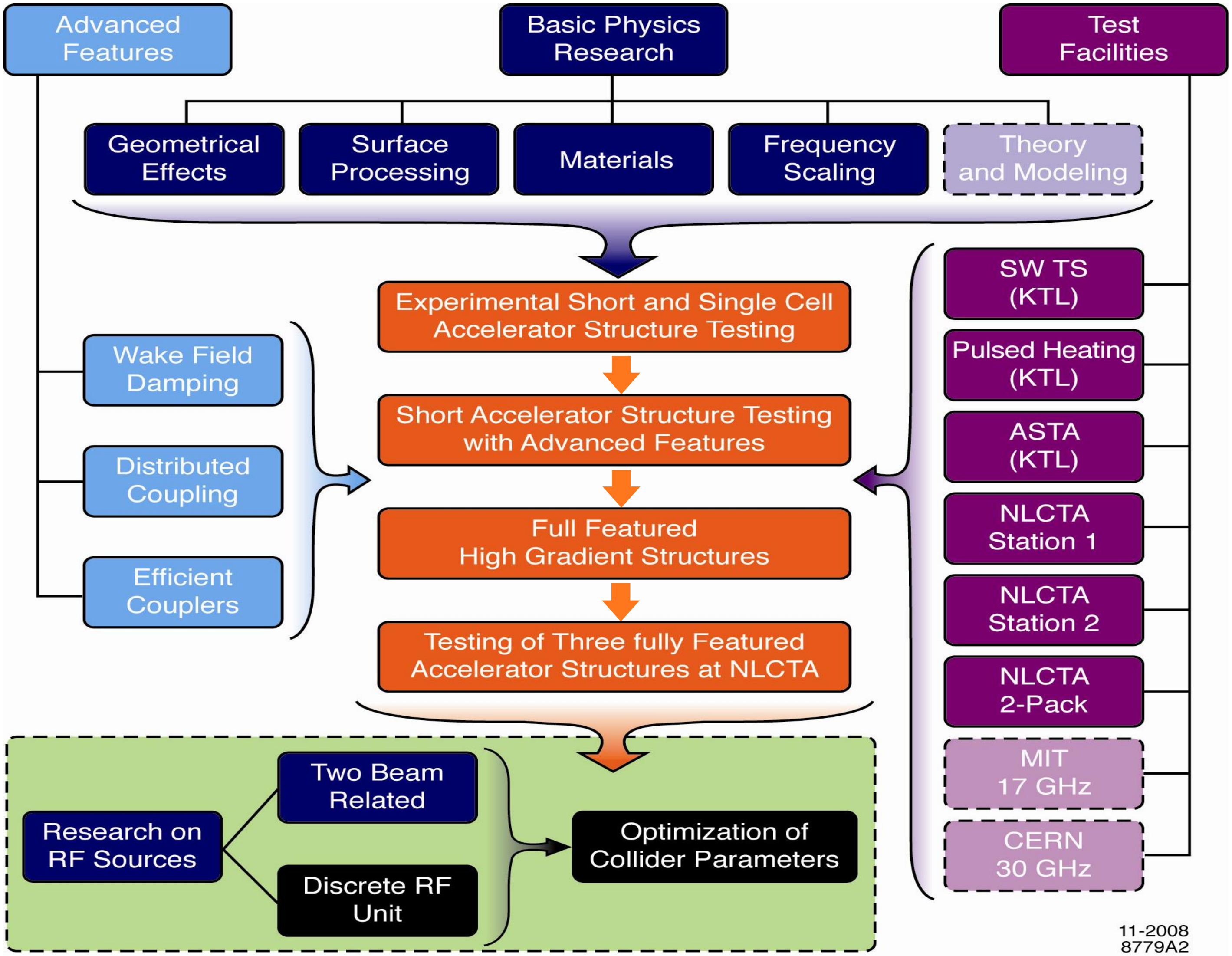
Overview

- Review of experimental data on high gradient structure
- Efficiency and standing wave accelerator structure designs
- A 1 TeV collider
  - Improved efficiency
  - Possible parameter set

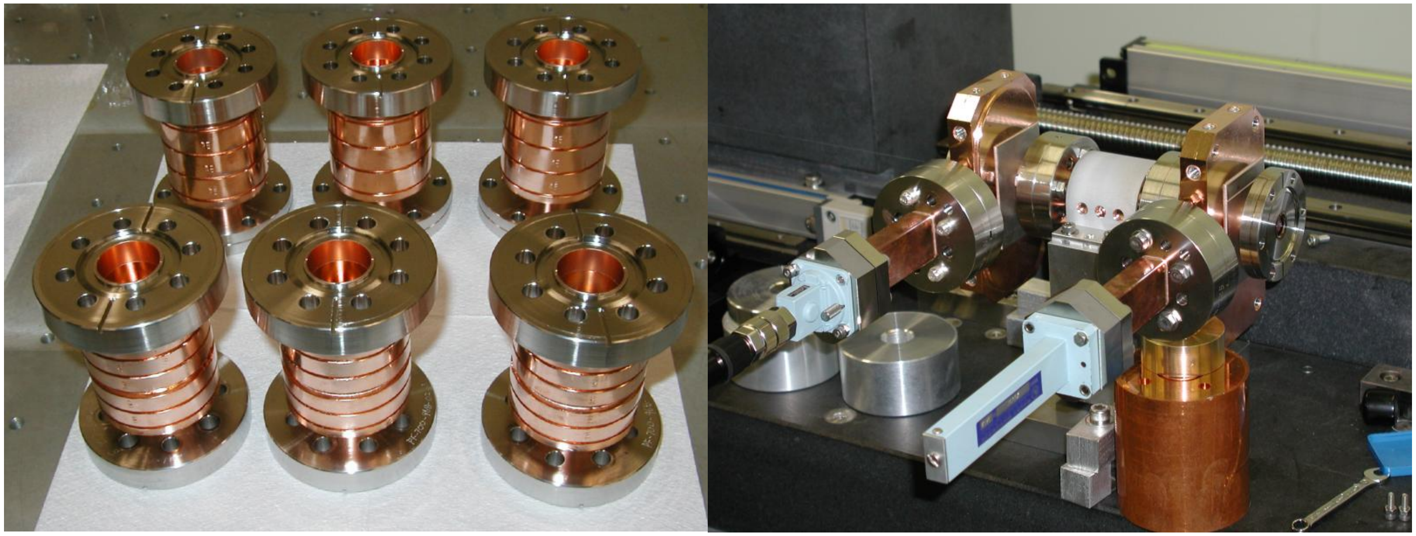
Research and Development Plan



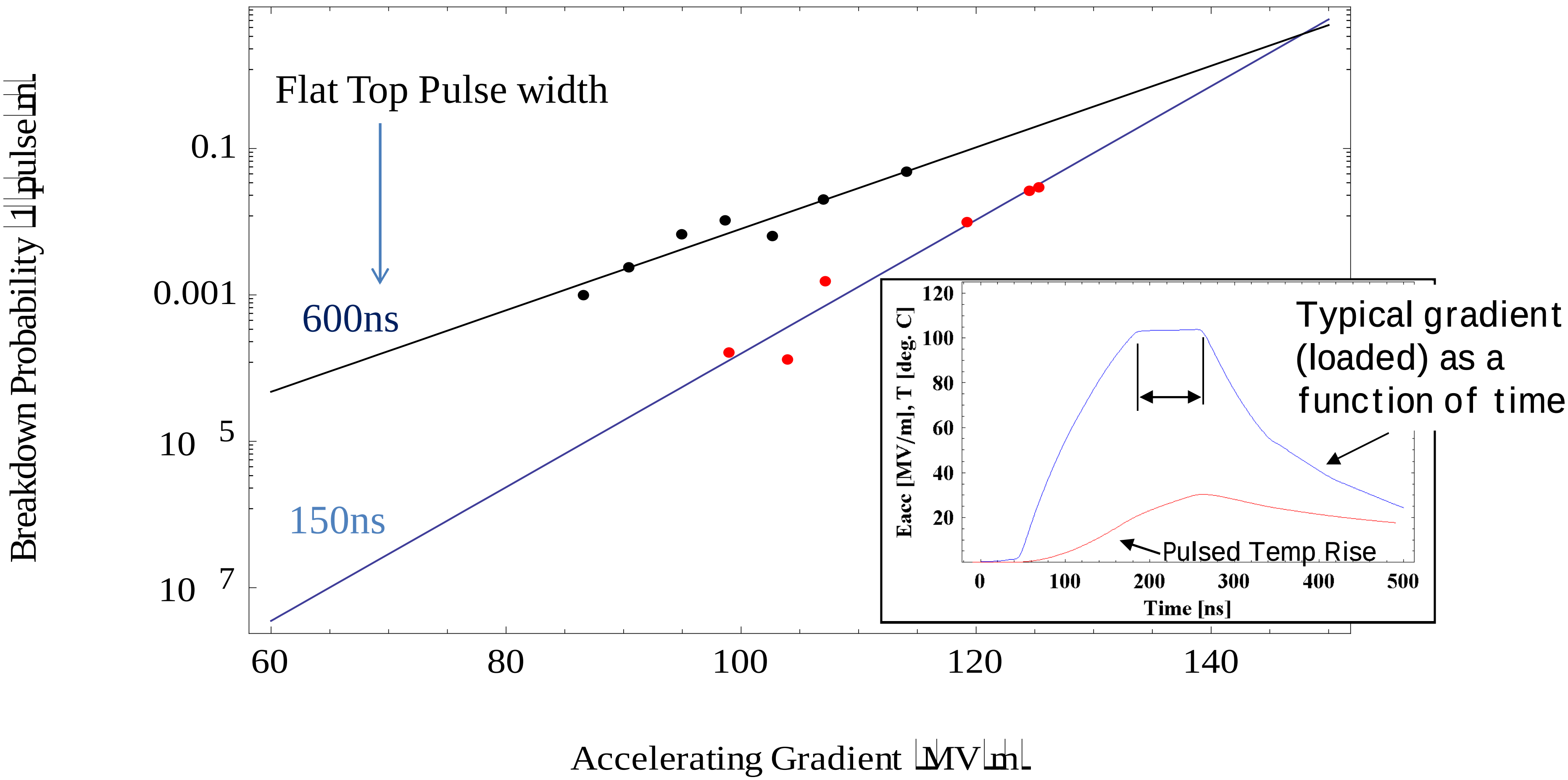
Experimental Studies

- Basic Physics Experimental Studies
  - Single and Multiple Cell Accelerator Structures (with major KEK and CERN contributions)
    - single cell traveling-wave accelerator structures (Needs ASTA)
    - single-cell standing-wave accelerator structures (Performed at Klystron Test Lab)
  - Waveguide structures (Needs ASTA)
  - Pulsed heating experiments (Performed at the Klystron Test Lab, also with major KEK and CERN contributions)
- Full Accelerator Structure Testing (Performed at NLCTA, with CERN contributions)

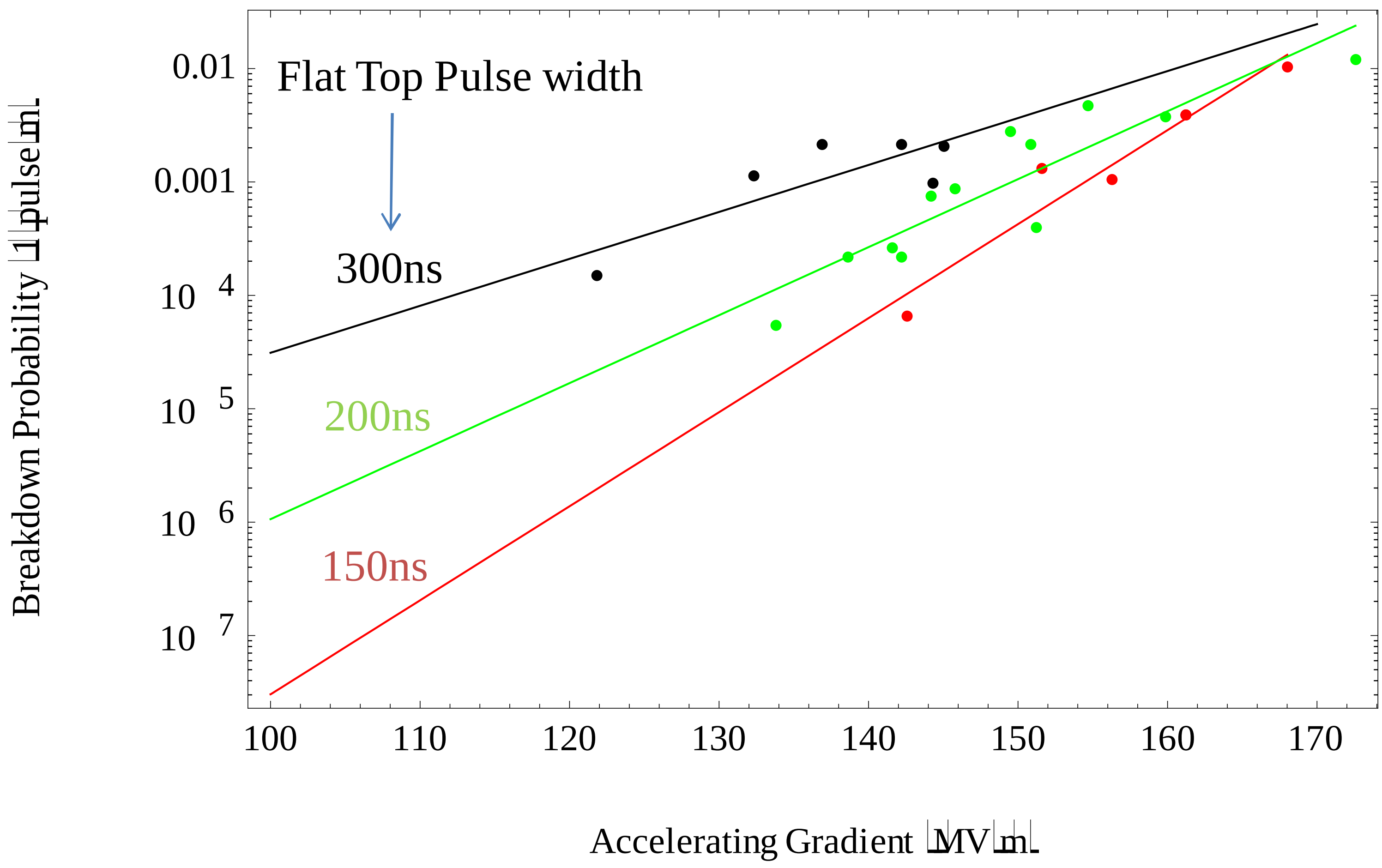
  Can only be done at NLCTA at SLAC



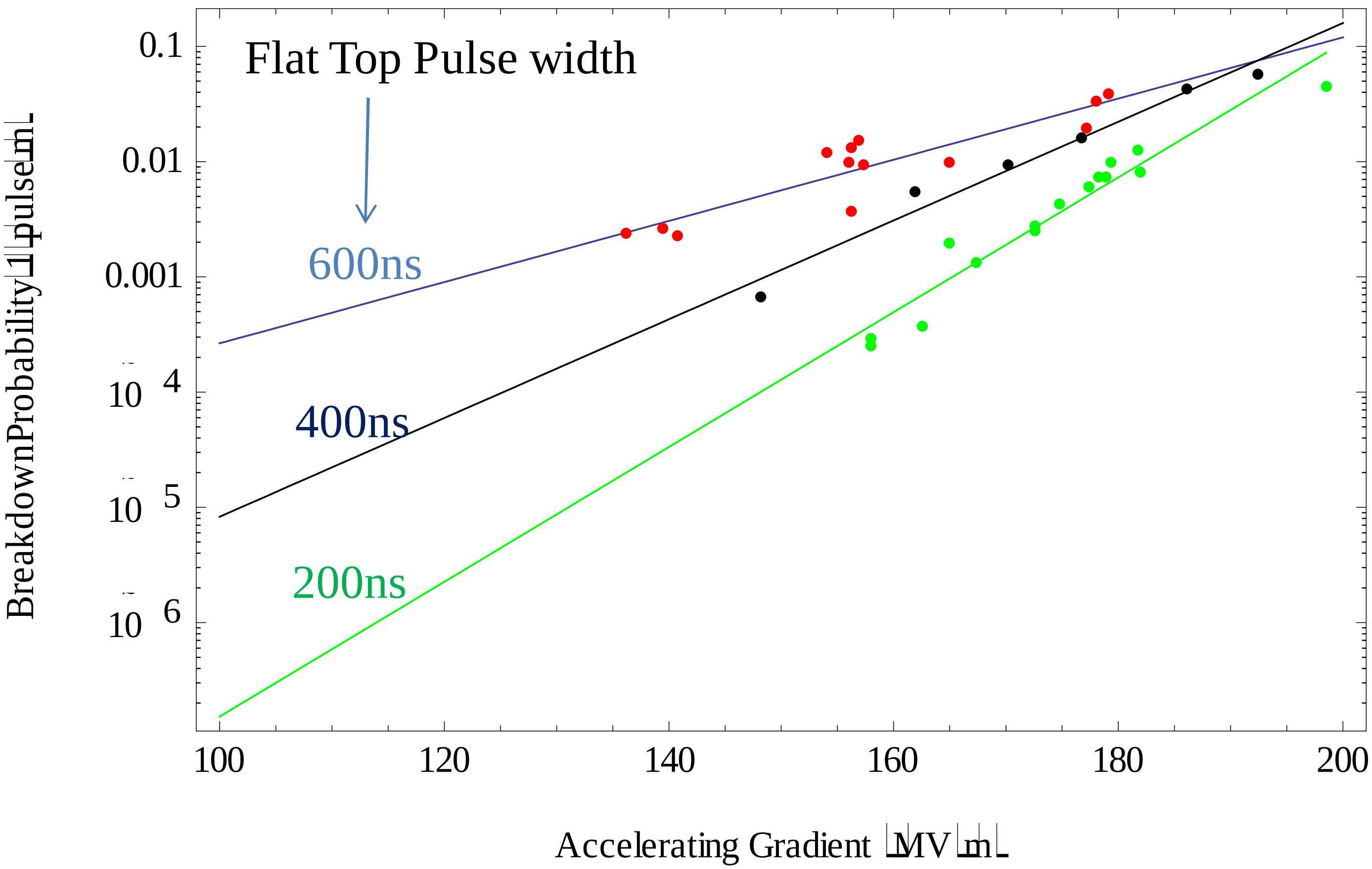
Breakdown Probability for a Standing Wave Accelerator Structure with a/λ=0.22



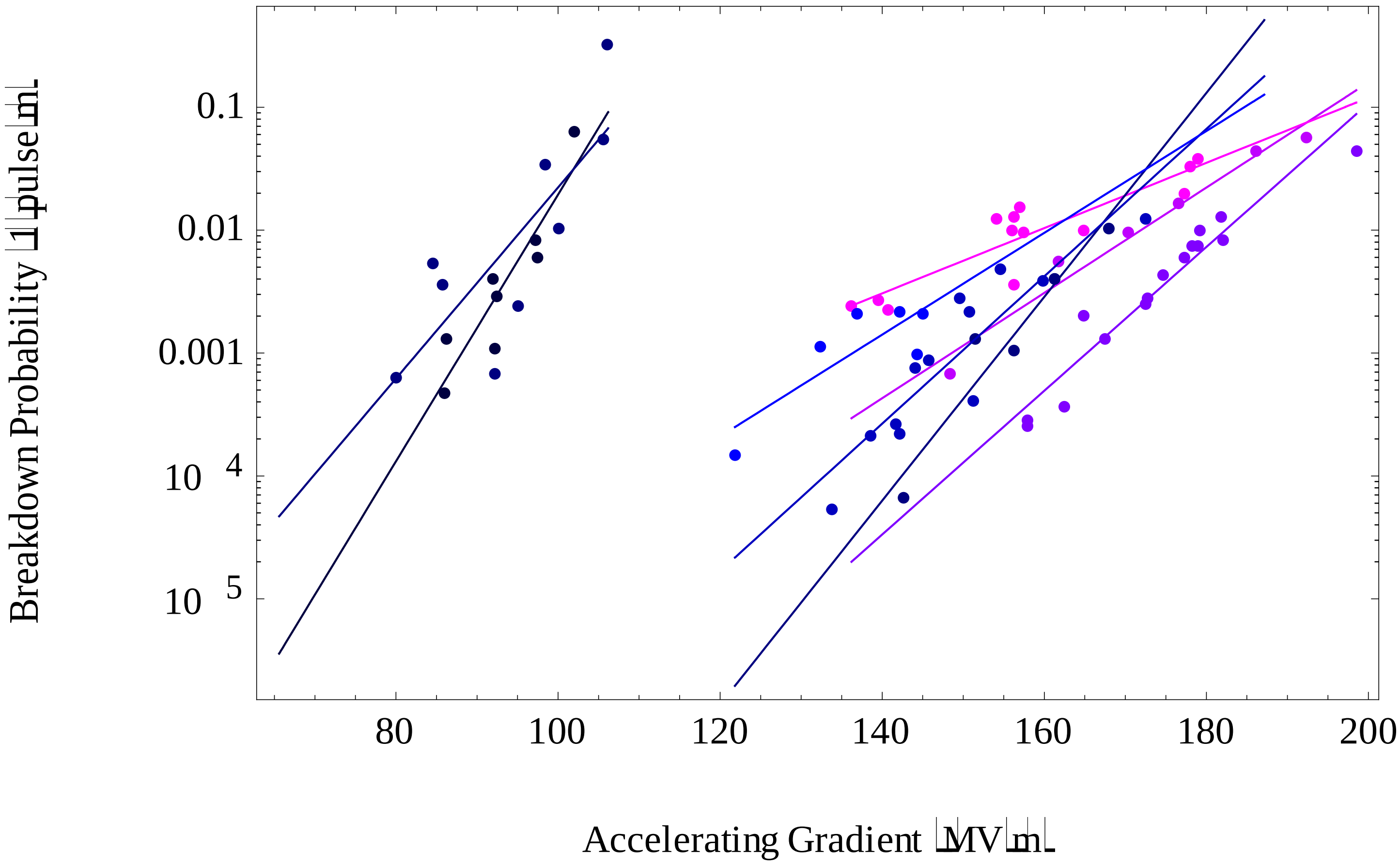
Breakdown Probability for a Standing Wave Accelerator Structure with a/λ=0.14



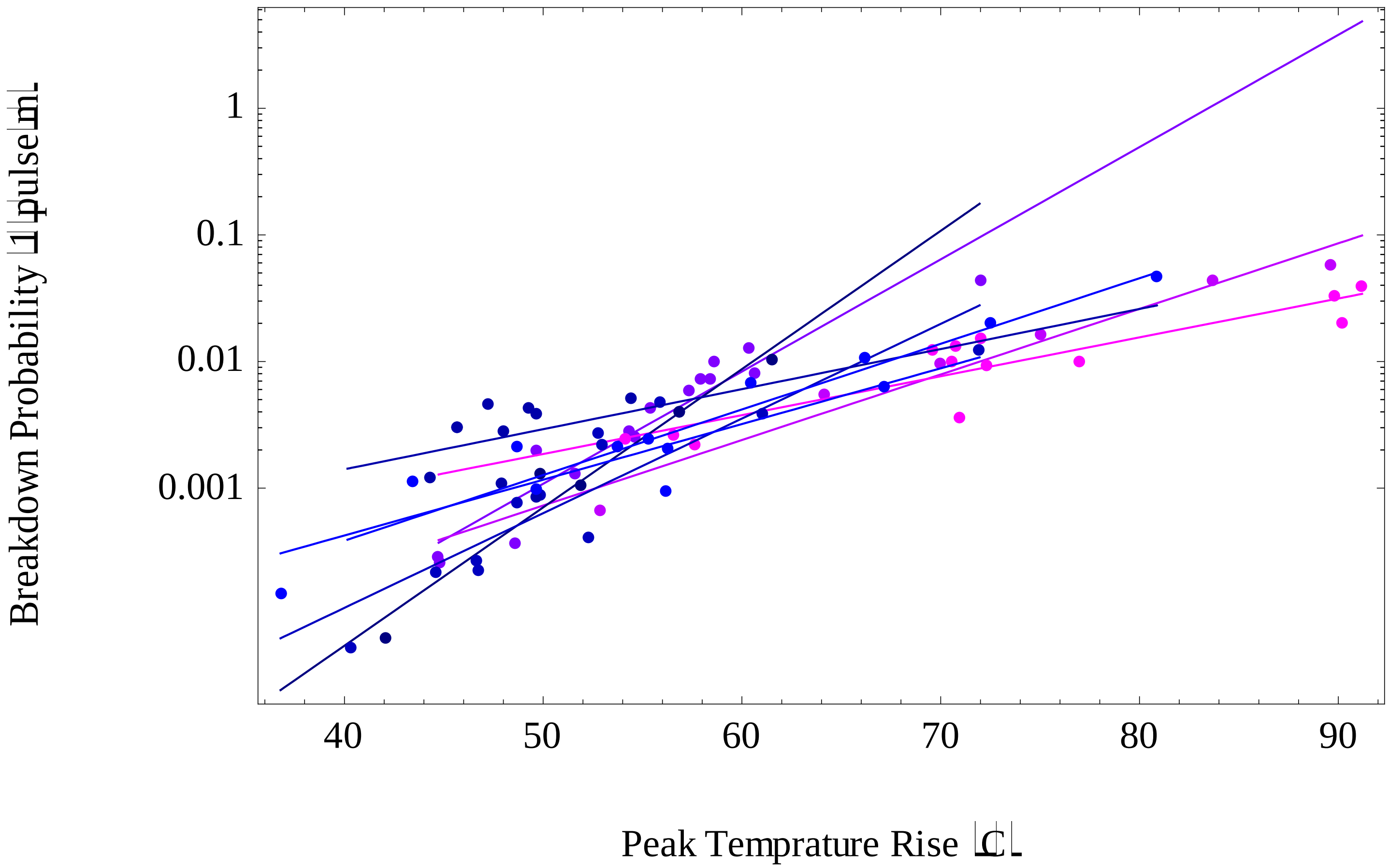
Breakdown Probability for a Standing Wave Accelerator Structure with a/λ=0.1



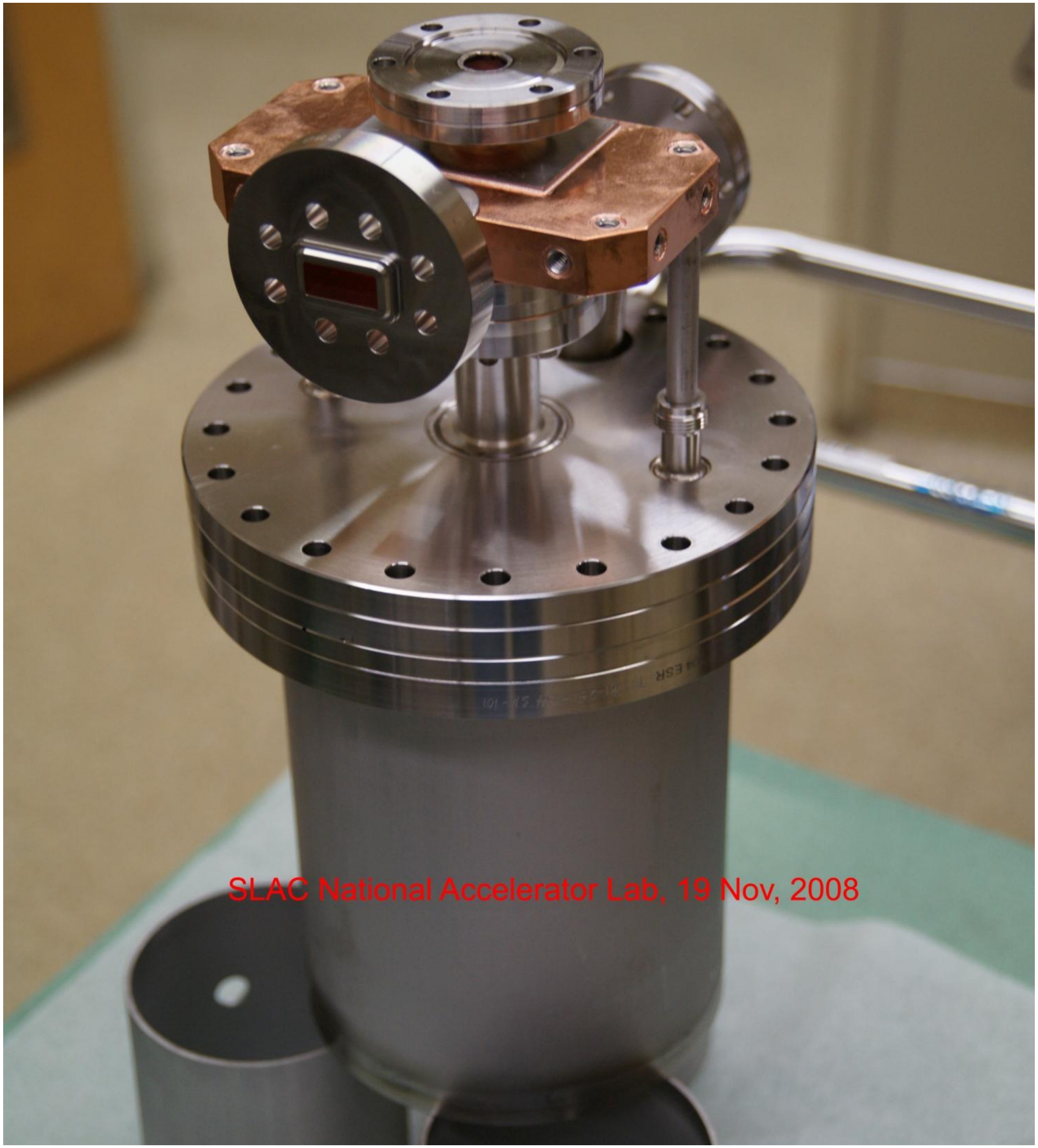
Breakdown Probability for a Standing Wave Accelerator Structure with different a/λ=0.21



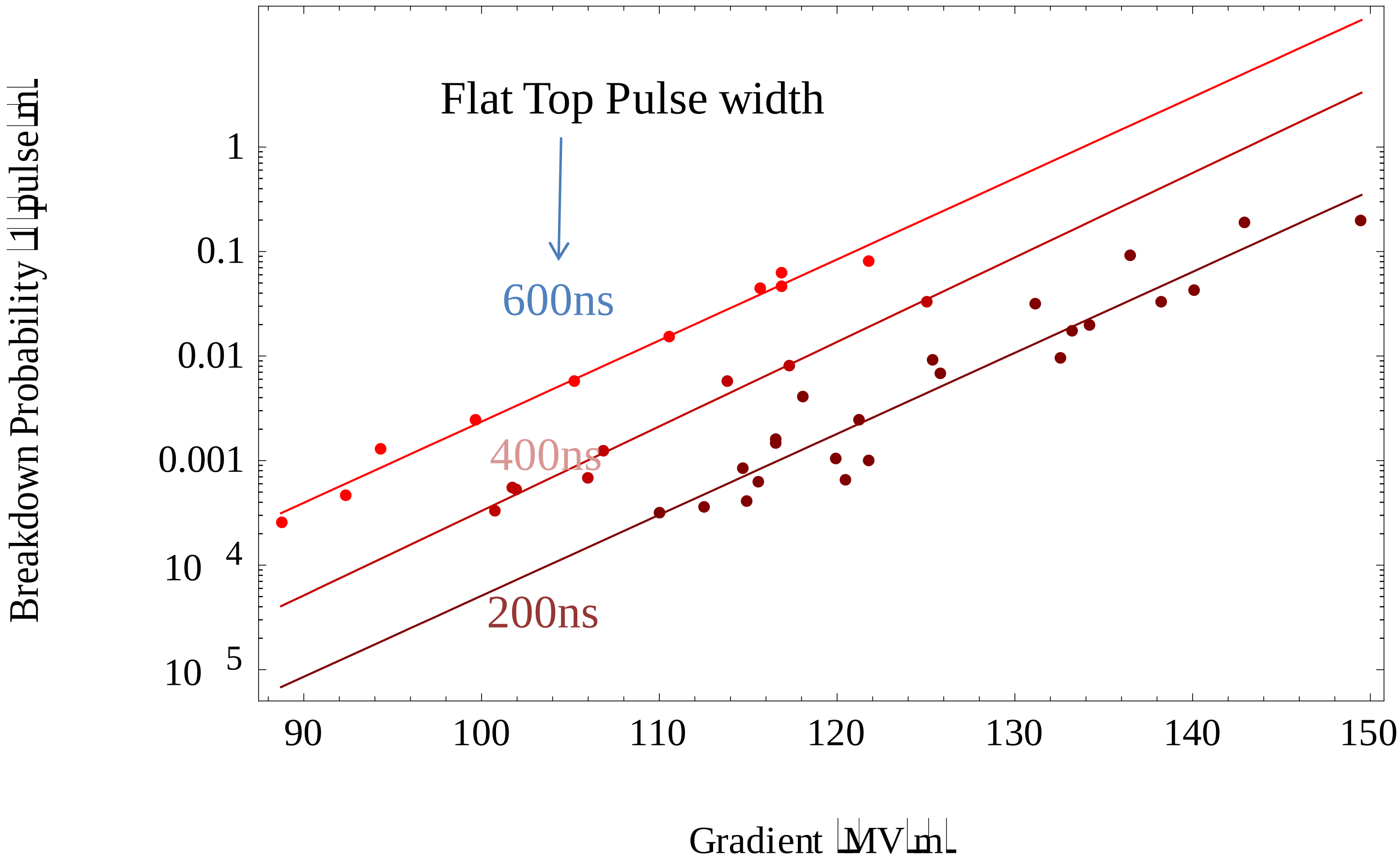
Breakdown Probability for a Standing Wave Accelerator Structure with different a/λ



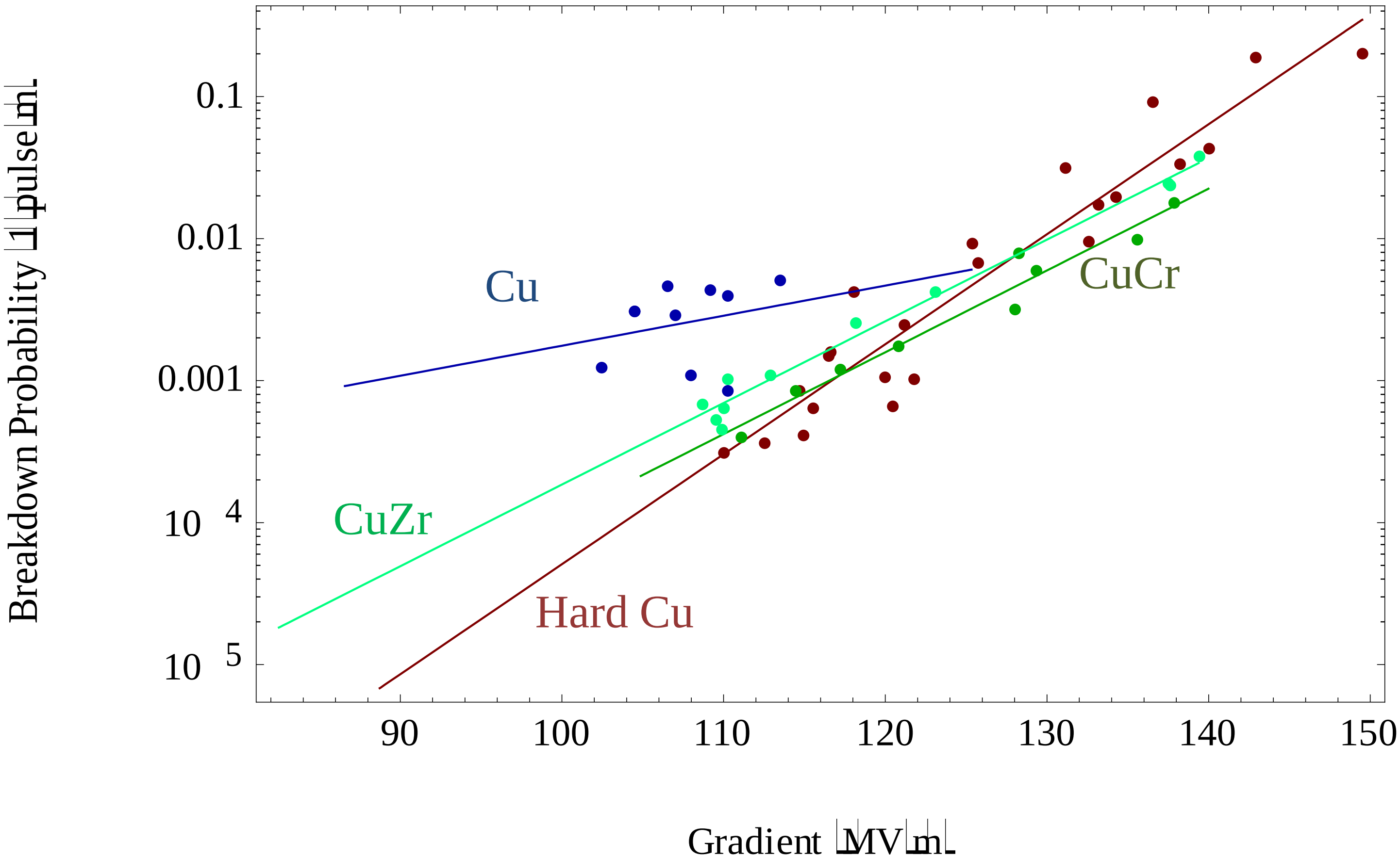

SLAC National Accelerator Lab, 19 Nov, 2008


SLAC National Accelerator Lab, 19 Nov, 2008

Breakdown Probability for a Standing Wave Accelerator Structure with a/λ=0.22



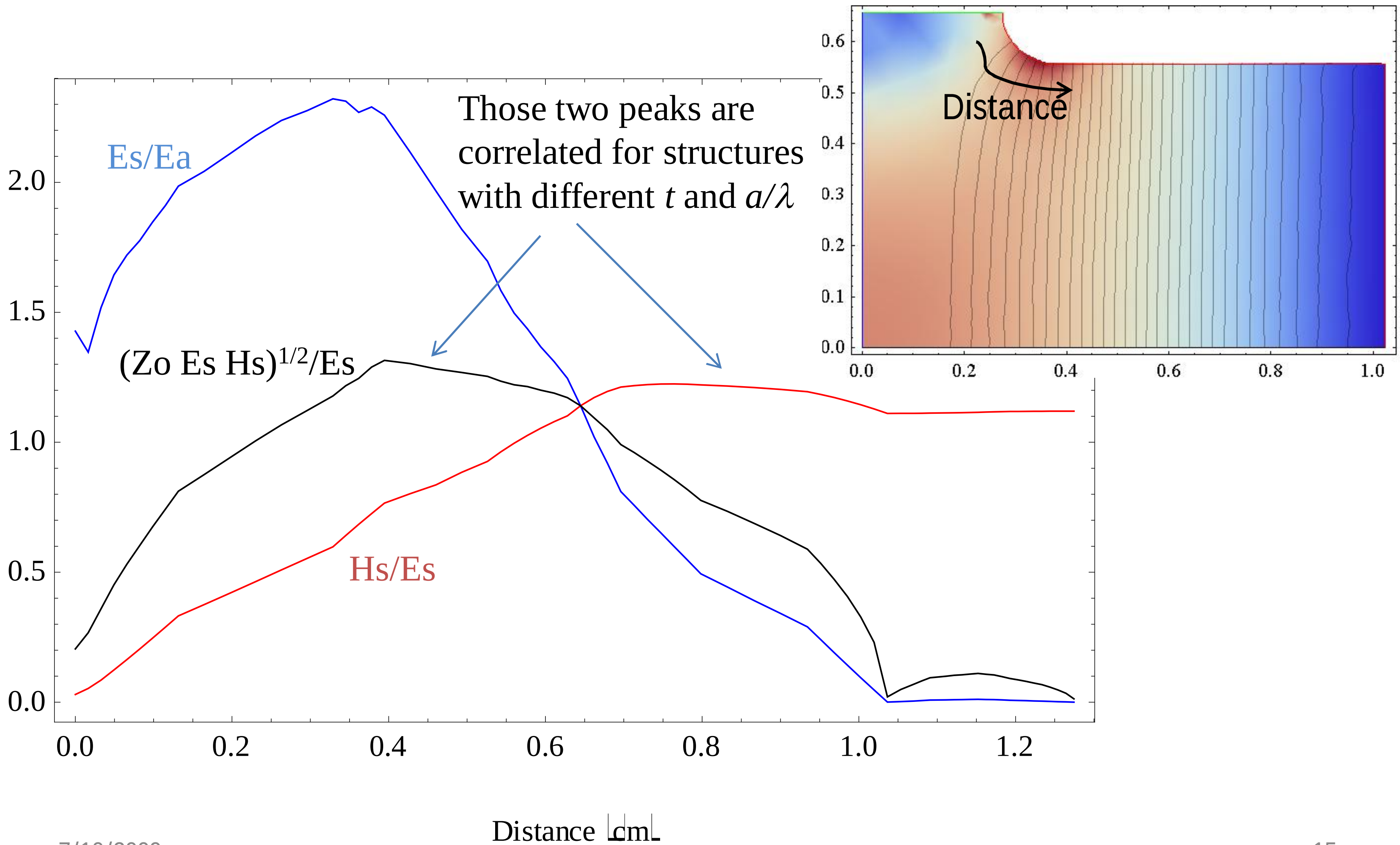
Breakdown Probability for a Standing Wave Accelerator Structure with a/λ=0.22, Pulse length=200ns



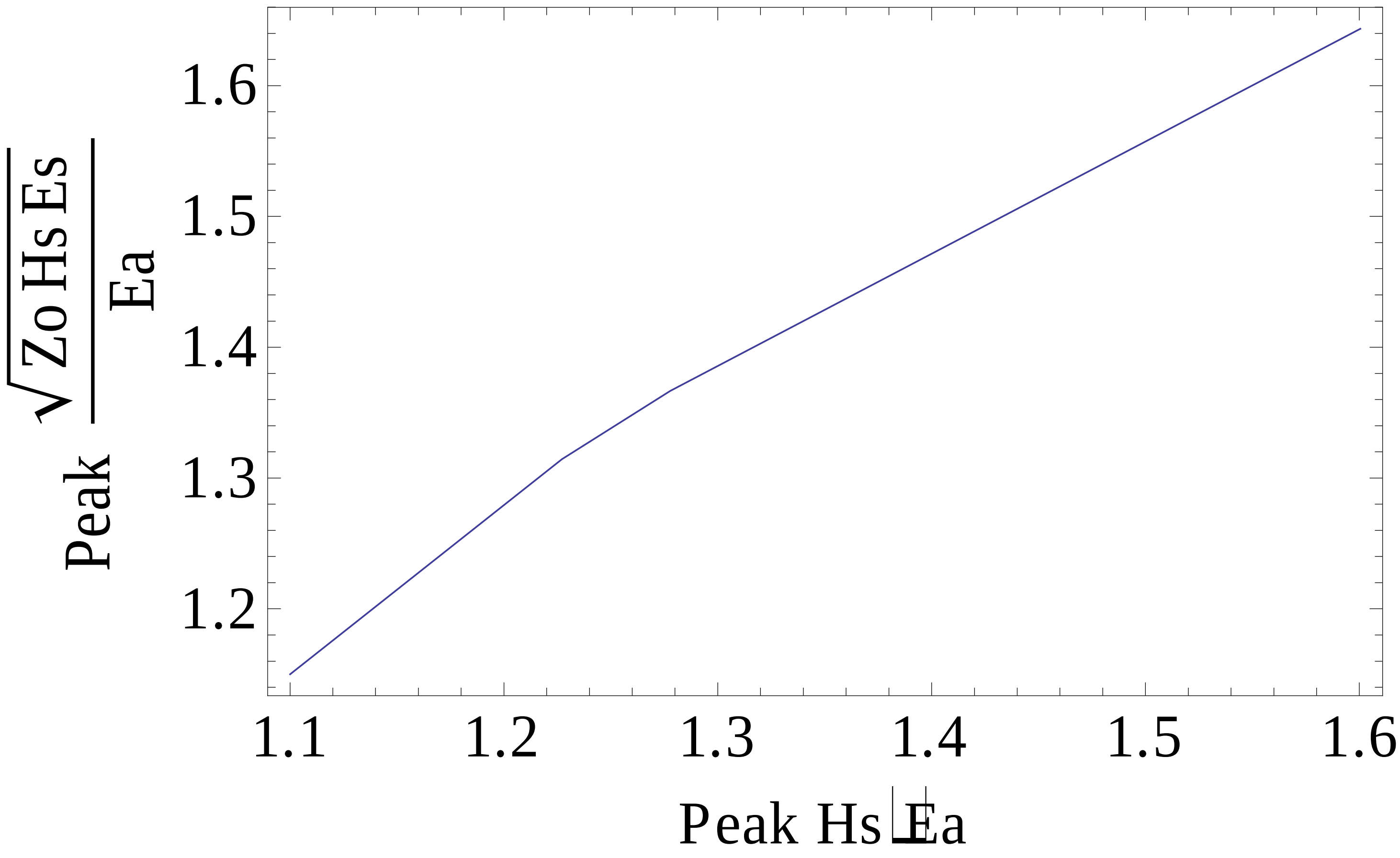
We have not tested yet structure with small apertures and different material

"Stay Tuned" This is coming very soon

Field Profile over the Iris



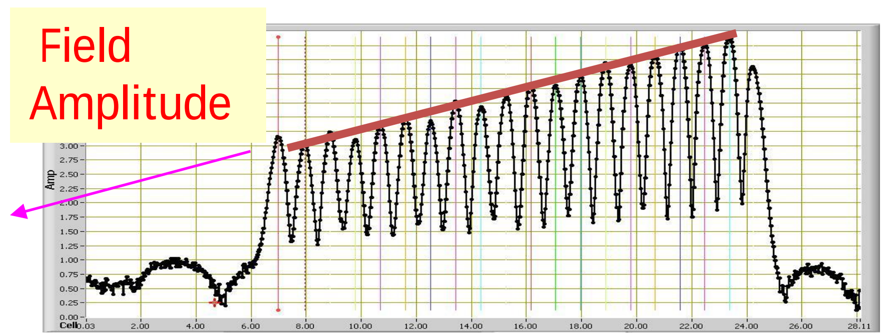
Peak H and Peak ExH



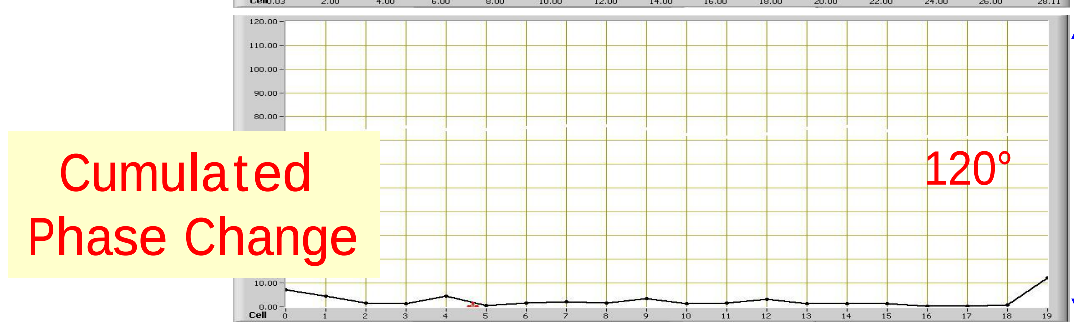
Full Accelerator structure testing (the T18 structure)

Frequency.	11.424GHz
Cells	18+input+output
Filling Time	36ns
a_in/a_out	4.06/2.66 mm
vg_in/vg_out	2.61/1.02 (%c)
S11	0.035
S21	0.8
Phase	120Deg
Average Unloaded Gradient over the full structure	55.5MW→100MV/m

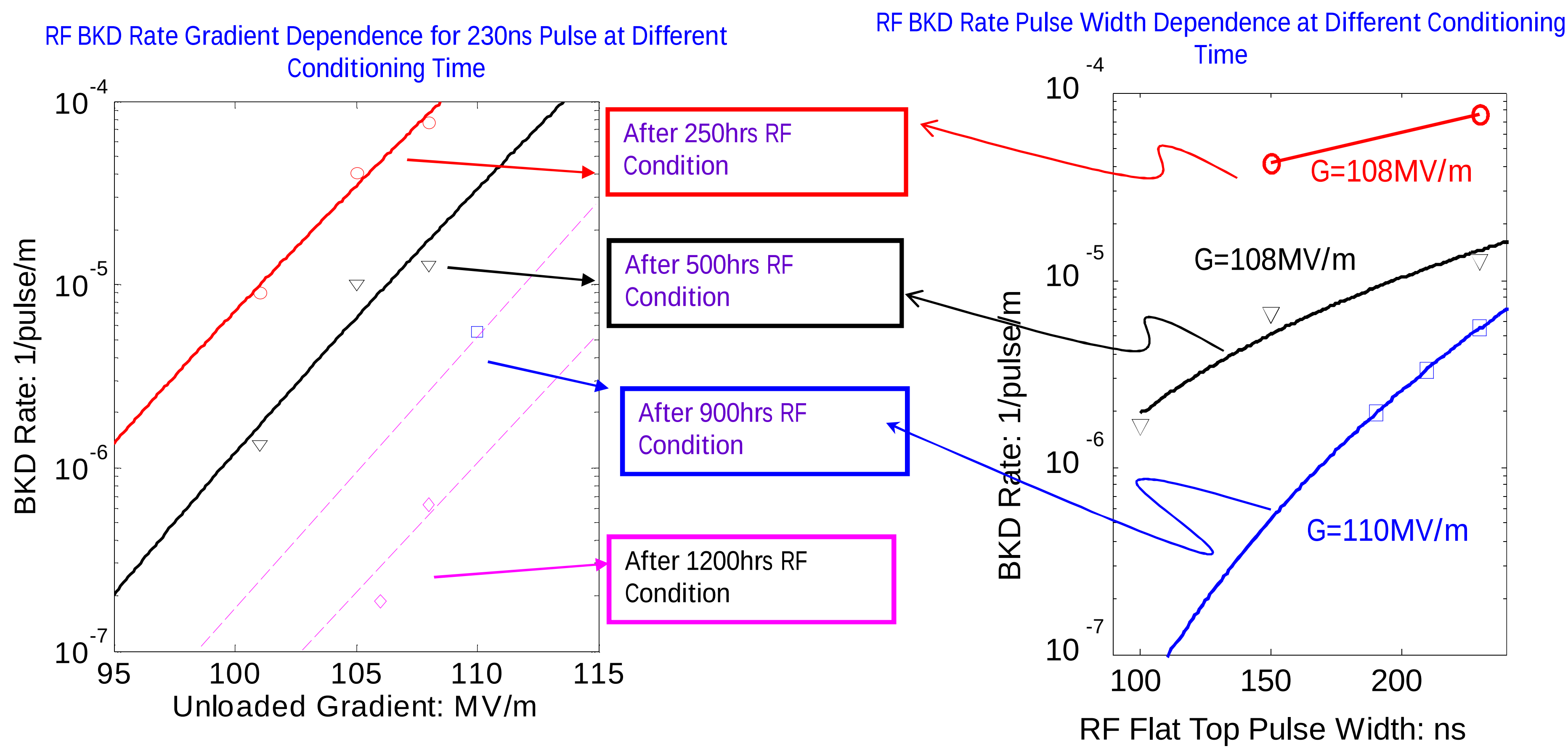
$$E_{acc\_out} / E_{acc\_in} \sim 1.5$$



- Structure designed by CERN based on all empirical laws developed experimentally through our previous work
- Cells Built at KEK
- Structure was bonded and processed at SLAC
- Structure was also tested at SLAC



RF Processing of the T18 Structure



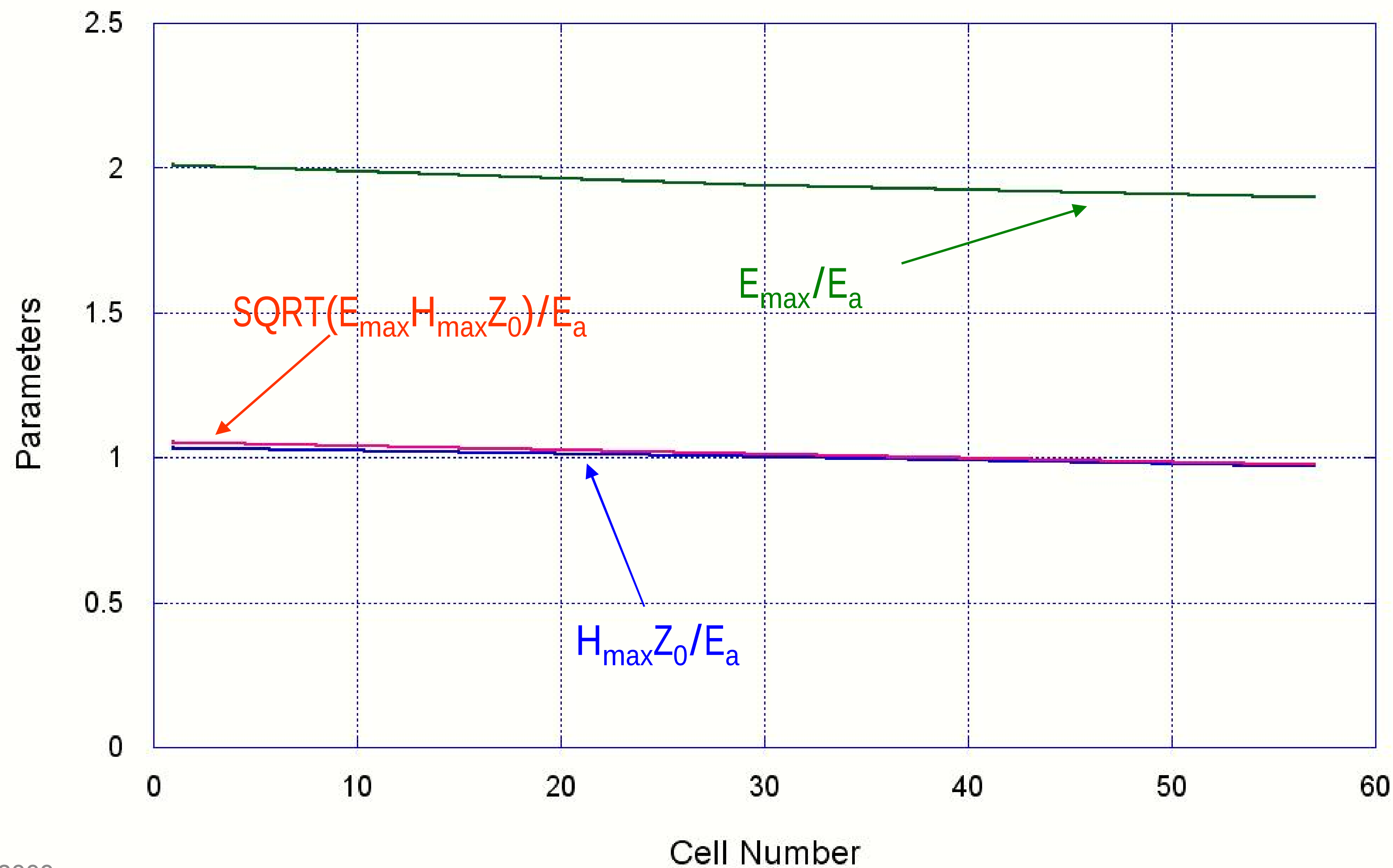
This performance *may be* good enough for 100MV/m structure for a warm collider, however, it does not yet contain all necessary features such as wakefield damping. Future traveling wave structure designs will also have better efficiency

2007-09 CERN/CLIC Design Structures Tested at NLCTA

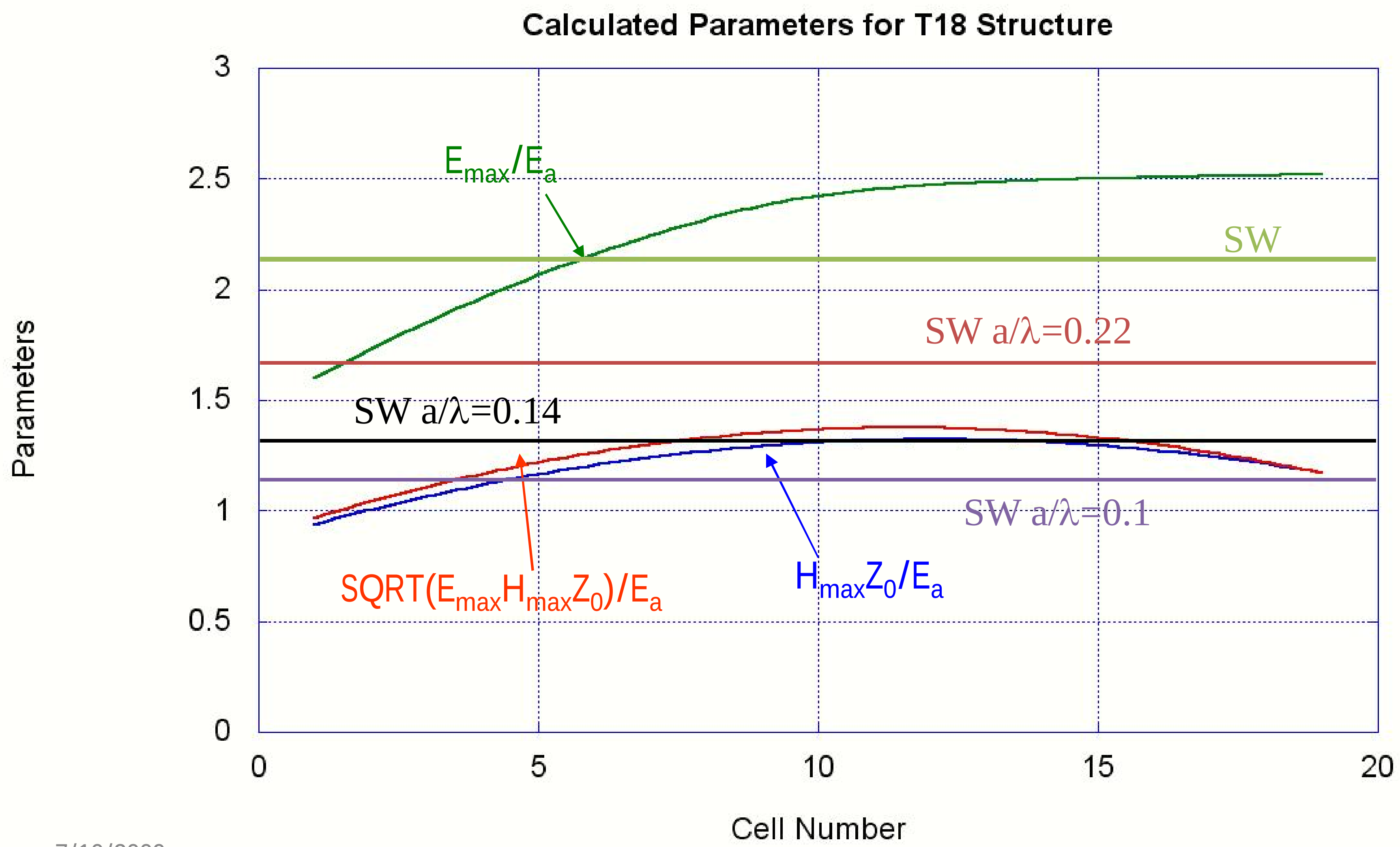
(Yellow = Quad Cell Geometry, Green = Disk Cell Geometry)

In Beamline	Structure	Note	Performance
11/06 – 2/07	C11vg5Q16	First X-band Quad - Irises Slotted	Poor: 57 MV/m, 150 ns, 2e-5 BDR – grew whiskers on cell walls
2/08 - 4/08	C11vg5Q16 Redux	Refurbished	Initially good (105 MV/m, 50 ns,1e-5 BDR) but one cell degraded
4/07 – 10/07	C11vg5Q16-Mo	Molybdenum Version of Above	Poor: 60 MV/m, 70 ns, 1e-6 BDR
10/08 – 12/08	TD18vg2.6_Quad	No Iris Slots but WG Damping	Very Poor: would not process above 50 MV/m, 90ns – gas spike after BD
4/08 – 7/08	T18vg2.6-Disk	Cells by KEK, Assembled at SLAC	Good: 105 MV/m, 230 ns at LC BDR spec of 5e-7/pulse/m but hot cell developed
7/08 – 10/08	T18vg2.6-Disk	Powered from Downstream End	Good: 163 MV/m, 80 ns, 2e-5 BDR in last cell, consistent with forward operation
12/08 – 2/09	T18vg2.6-Disk CERN	CERN Built, Operate in Vac Can	Very Poor: very gassy with soft breakdowns at 60 MV/m, 70 ns

Calculated Parameters for T53VG3 Structure



T18 Surface Field Parameters in Comparison with SW Structures



So, What does all this imply for a 1 TeV collider parameters?

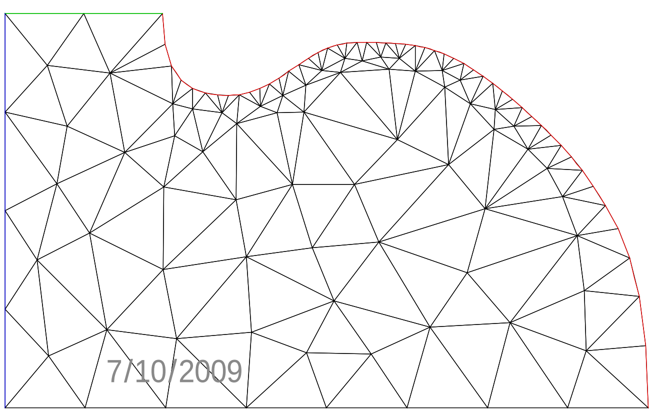
- High gradient requires high power density/unit length, quadratic with gradient. Hence the two beam choice for the CLIC design
- However, since one also accelerates in shorter length the total required RF power increases linearly with gradient.
- High gradient also implies reduced efficiency; $\eta \sim \frac{x}{1+x}; x = R_s I_0 / E_a$
- However, one can compensate by increasing the efficiency the *accelerator structure* and *RF sources*.
  - Increasing the efficiency of the accelerator structure would reduce the power/unit length, and it might allow for the use of a conventional RF unit
  - At the moment the best (published) design that respects high gradient constraints imply an RF to beam efficiency of about 28%
  - Higher efficiency RF source and accelerator efficiency imply lower RF system cost

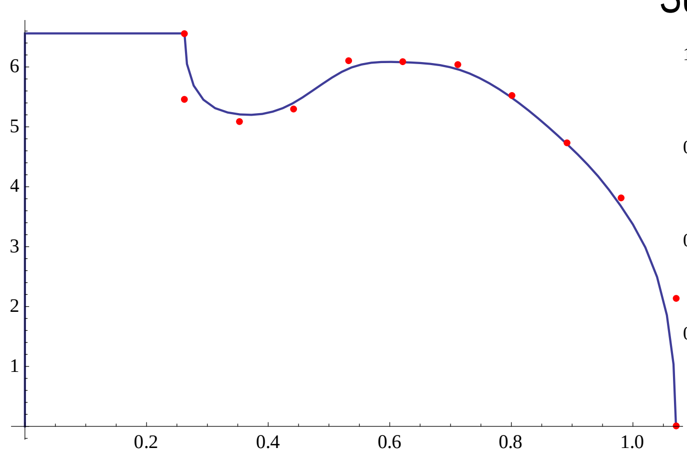
Yet another Finite Element Code

Motivated by the desire

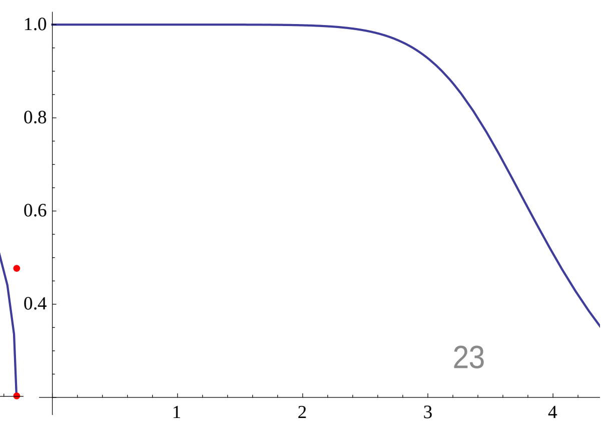
- to design codes to perform *Large Signal Analysis* for microwave tubes (realistic analysis with short computational time for optimization)
- study surface fields for accelerators
- the need of a simple interface so that one could “play”

- A finite element code written completely in Mathematica was realized.
- To my surprise, it is running much faster than SuperFish or Superlance
- The code was used with a Genetic Global Optimization routine to optimize the cavity shape under surface field constraints

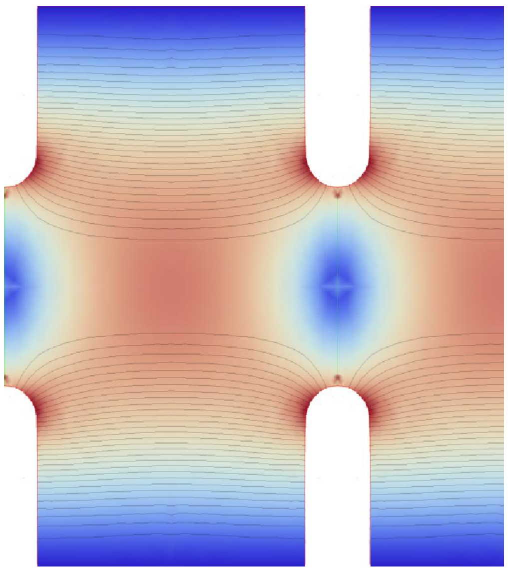


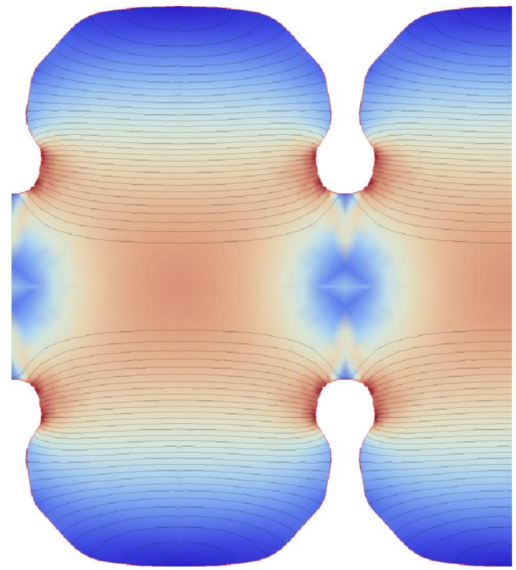


Surface field penalty function



Iris shaping for a structure with $a/\lambda=0.14$



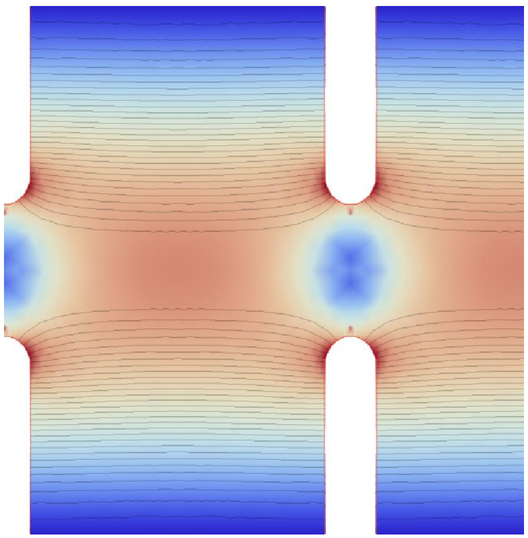


Shunt Impedance	83 MΩ/m
Quality Factor	8561
Peak E_s/E_a	2.33
Peak Z_0H_s/E_a	1.23

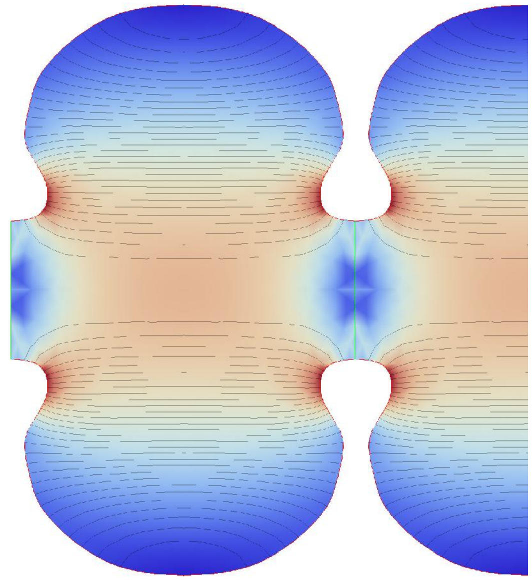
Shunt Impedance	104 MΩ/m
Quality Factor	9778
Peak E_s/E_a	2.41
Peak Z_0H_s/E_a	1.12

- With 1 nC/bunch and bunch separation of 6 rf cycles the RF to beam efficiency~70%
- The power required/m~287 MW

Iris shaping for a structure with $a/\lambda=0.1$



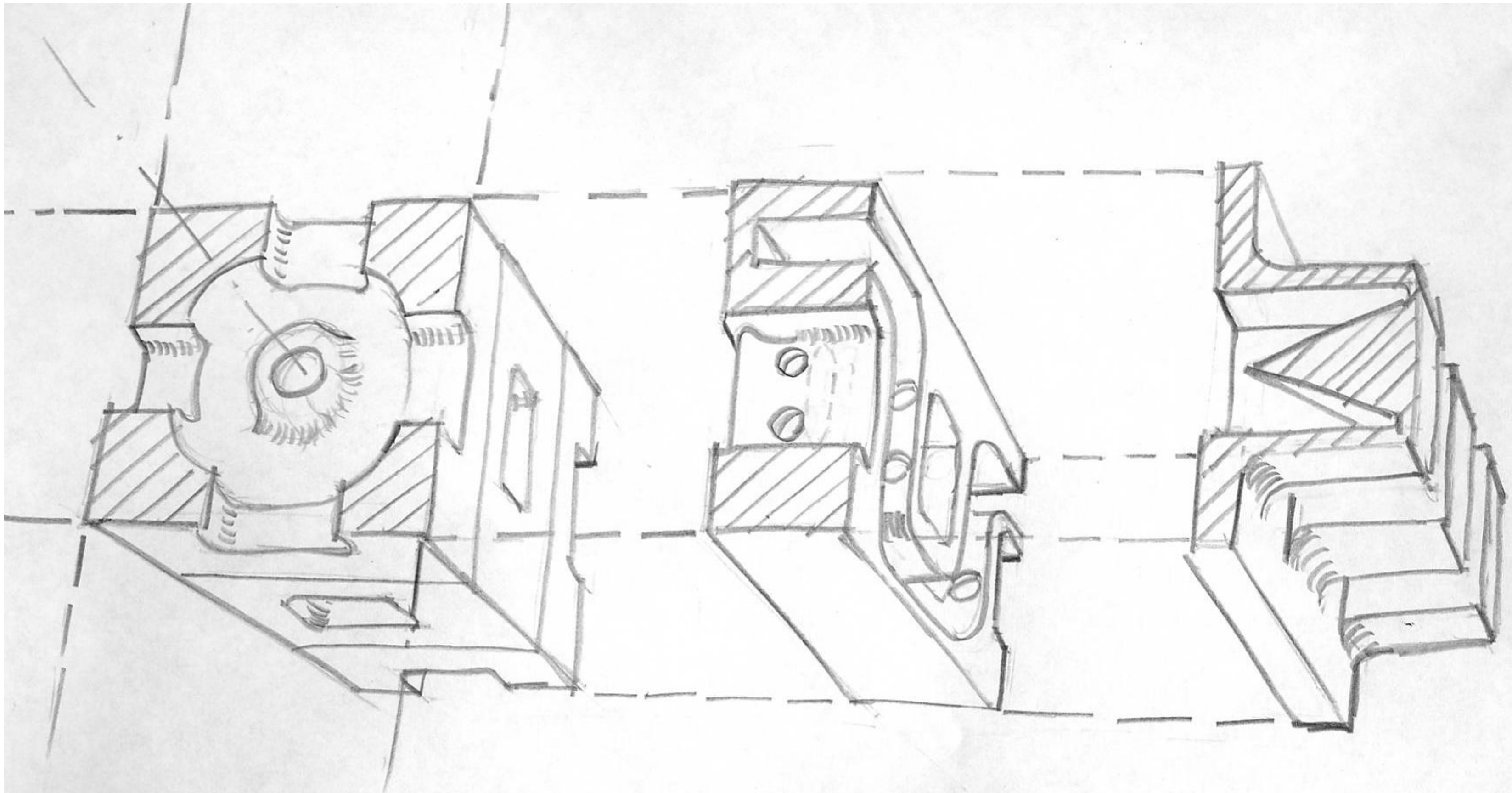
Shunt Impedance 102 MΩ/m
Quality Factor 8645
Peak E_s/E_a 2.3
Peak Z_0H_s/E_a 1.09



Shunt Impedance 128 MΩ/m
Quality Factor 9655
Peak E_s/E_a 2.5
Peak Z_0H_s/E_a 1.04

- With 0.5 nC/bunch, bunch separation of 6 rf cycles, and loaded gradient of 100 MV/m the RF to beam efficiency~53%
- The power required/m~173 MW

Feeding and Wakefield damping of a set of π-mode structures



- Each cell is fed through a directional coupler.
- The feeding port serve as the damping port
- The system has a four-fold symmetry, only one section is shown

Parameter Options for a 1 TeV machine, $2\ 10^{34}\ cm^{-2}\ s^{-1}$

	Option-1	Option-2	Option-3
Frequency (GHz)		11.424	
Gradient (MV/m)	100	100	80
Power/meter (MW)	287	173	126
Charge/bunch (nC)	1	0.5	0.5
Bunch separation (RF cycles)		6	
Number of bunches	300	600	600
<a/λ>	0.14	0.1	0.1
RF source	Two beam	Two Beam/Conventional Unit	Conventional Unit
RF/Beam Efficiency(%)	73	53	60
Beam duration Pulse length (ns)	158	315	315
Repetition Rate (Hz)	60	60	60

Conclusion

- With recent advances on high gradient accelerator structures, it is possible to think of an “efficient” room temperature collider
- Reduced power levels/unit length may permit designs based on conventional RF unit.