X-band Structure Tests at NLCTA

(May-Oct 08: T18, T18 back, T26)

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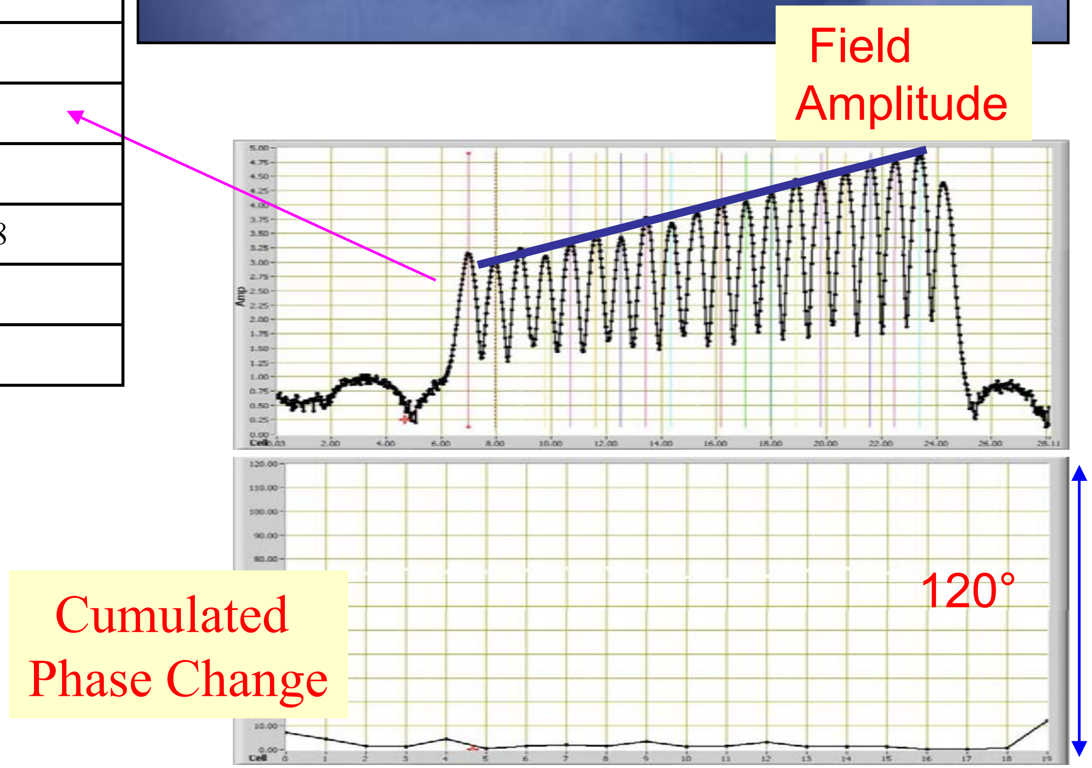
T18 Structure Properties

Freq.: GHz	11.424
Cells	18+input+output
Filling Time: ns	36
Length: cm	29
Iris Dia. a/λ (%)	15.5 ~ 10.1
Group Velocity: v_g/c (%)	2.6 - 1.0
S_{11}/ S_{21}	0.035 / 0.8
Phase Advace Per Cell	2π/3
Power Needed $\langle E_a \rangle$ = 100 MV/m	55.5 MW
Unloaded E_a(out)/E_a(in)	1.55
E_s/E_a	2
Pulse Heating ΔT: K (75.4MW@200ns)	16.9 - 23.8
High Power Test Time: hrs	1400
Total Breakdwon Events	2148



The structure is designed by CERN, built at KEK, assembled and bonded in SLAC and tested at SLAC (NLCTA).

RF Conditioning Statistics

Max average Unloaded Gradient at different pulse width:

120MV/m at 70ns for 6hrs (*152MV/m)

120MV/m at 100ns for 76hrs (*152MV/m)

120MV/m at 140ns for 47hrs (*152MV/m)

110MV/m at 190ns for 41hrs (*140MV/m)

120MV/m at 200ns for 21hrs (*152MV/m)

120MV/m at 210ns for 24hrs (*152MV/m)

110MV/m at 230ns for 78hrs (*140MV/m)

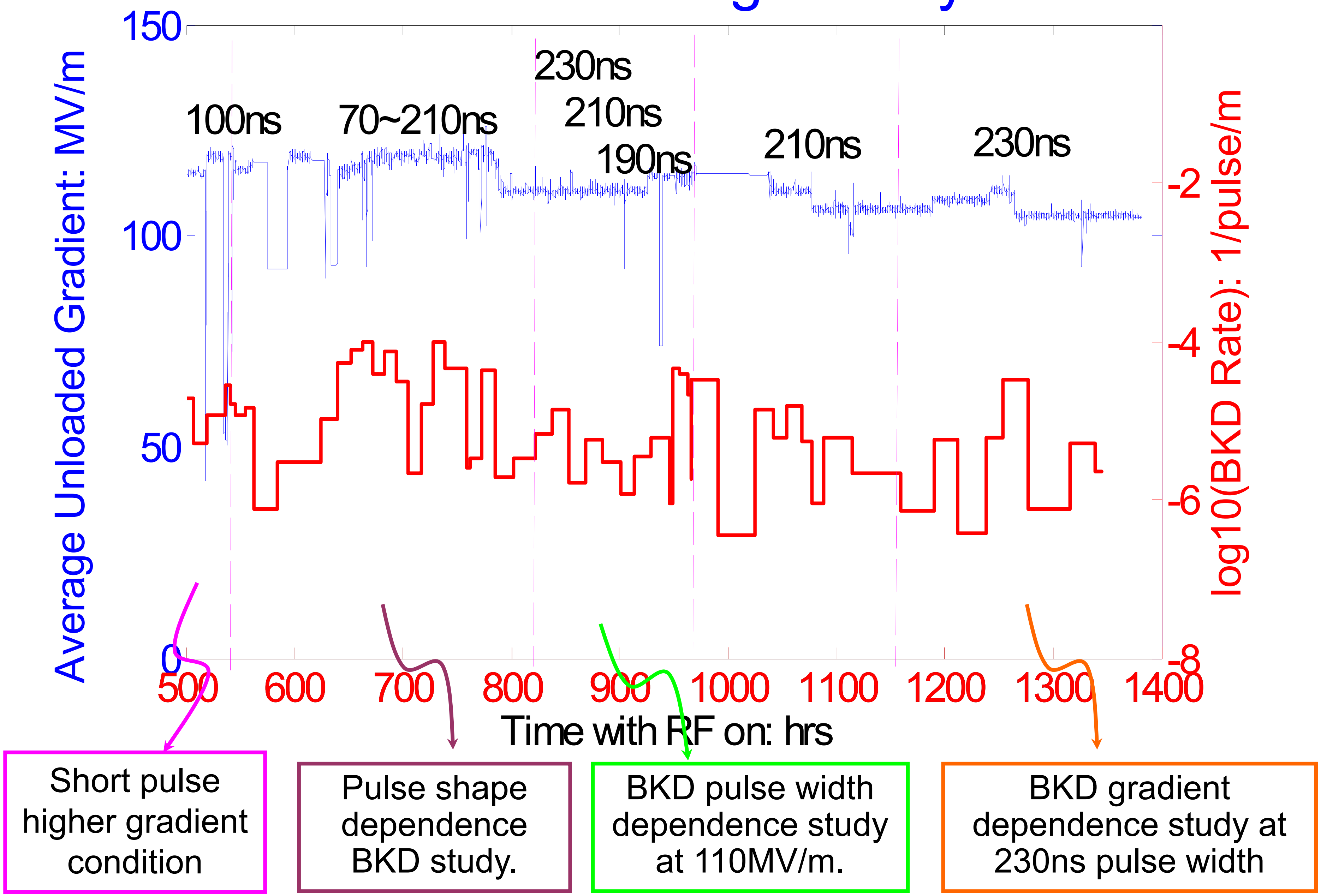
600 → 1400 RF Conditioning Time: hrs

~1400 hours total conditioning from 14 Apr. 2008 to 3-Jul-2008

~2148 breakdowns (average 119 per cell)

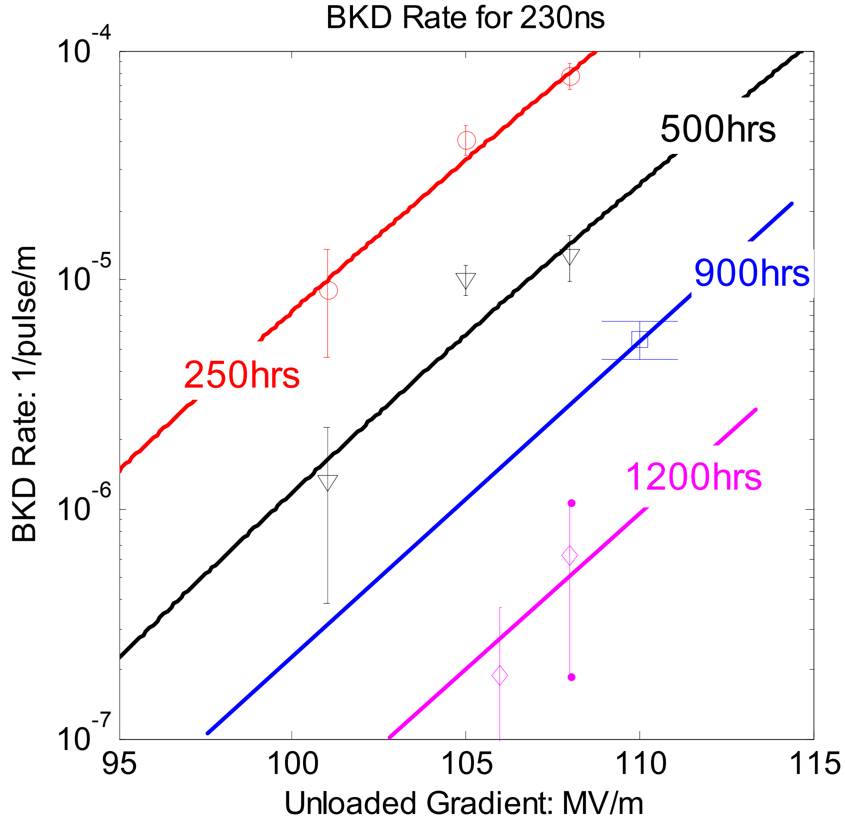
*:Max accelerator gradient in the structure

T18 Processing History

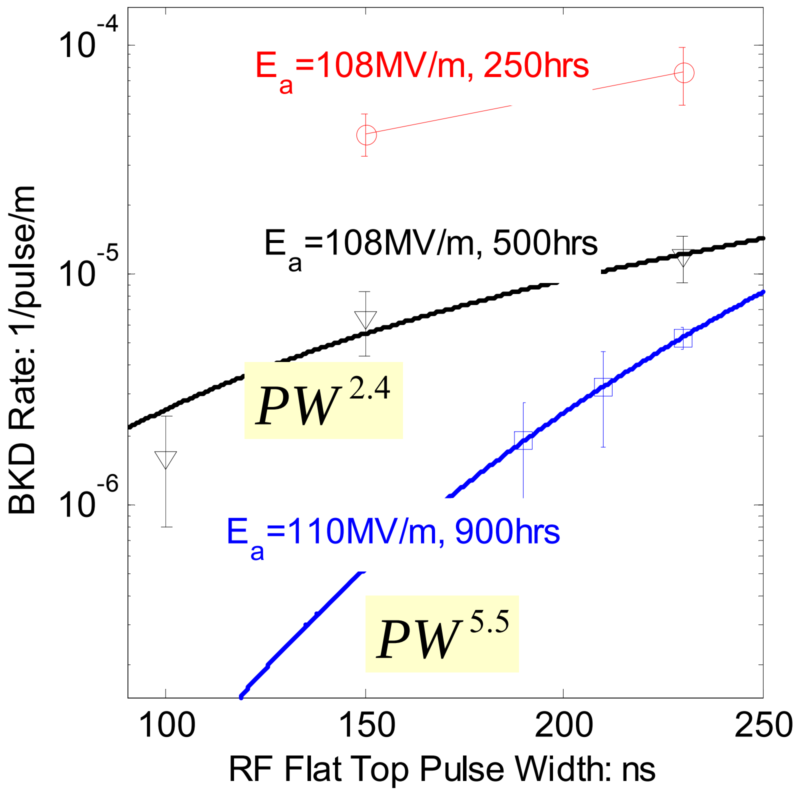


BKD Rate Characteristics at Different Conditioning Times

RF BKD Rate Gradient Dependence for 230ns Pulse at Different Conditioning Time



RF BKD Rate Pulse Width Dependence at Different Conditioning Time

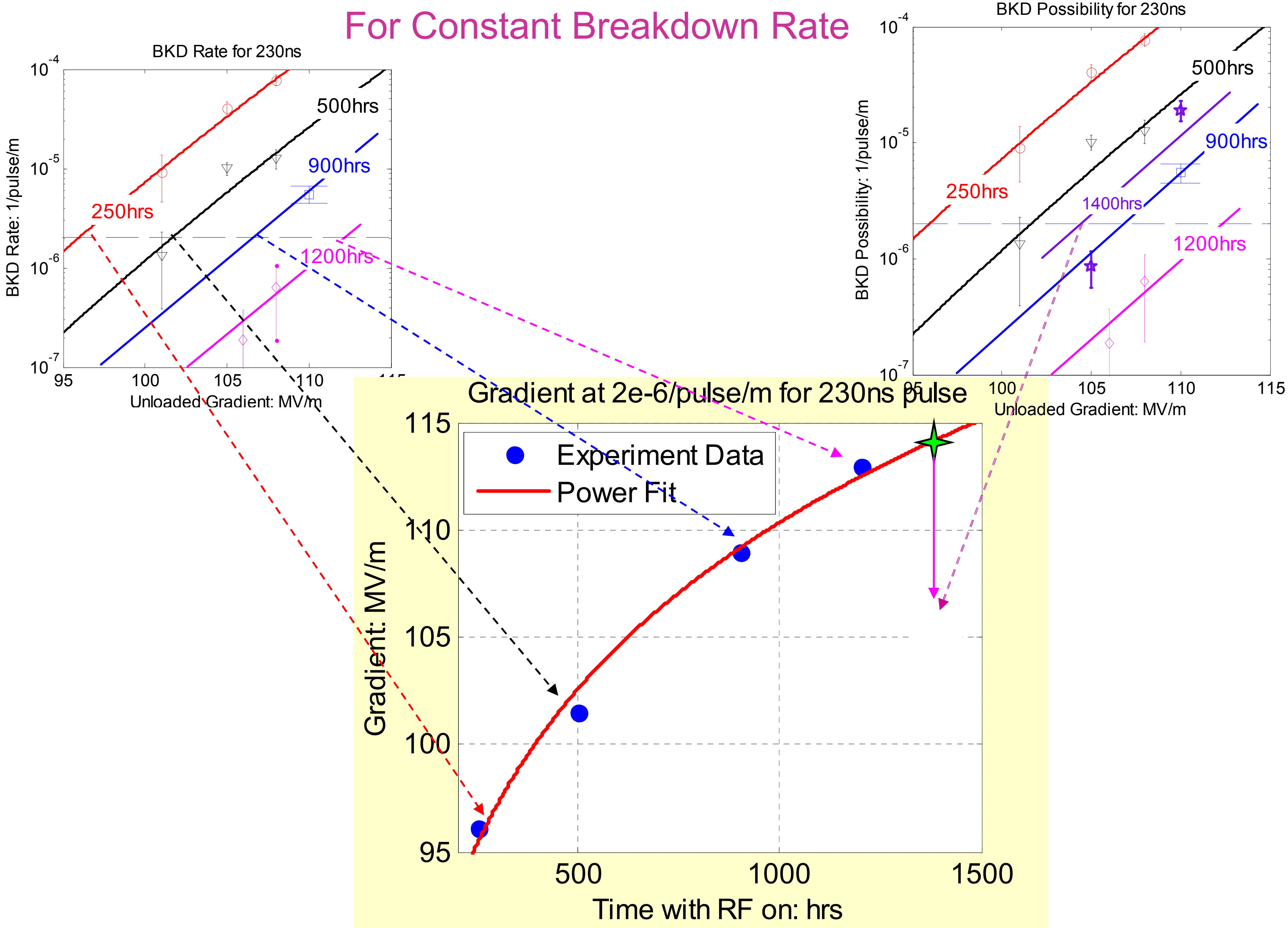


After 900hrs RF condition BKD rate has a gradient dependence ~ G^{32}

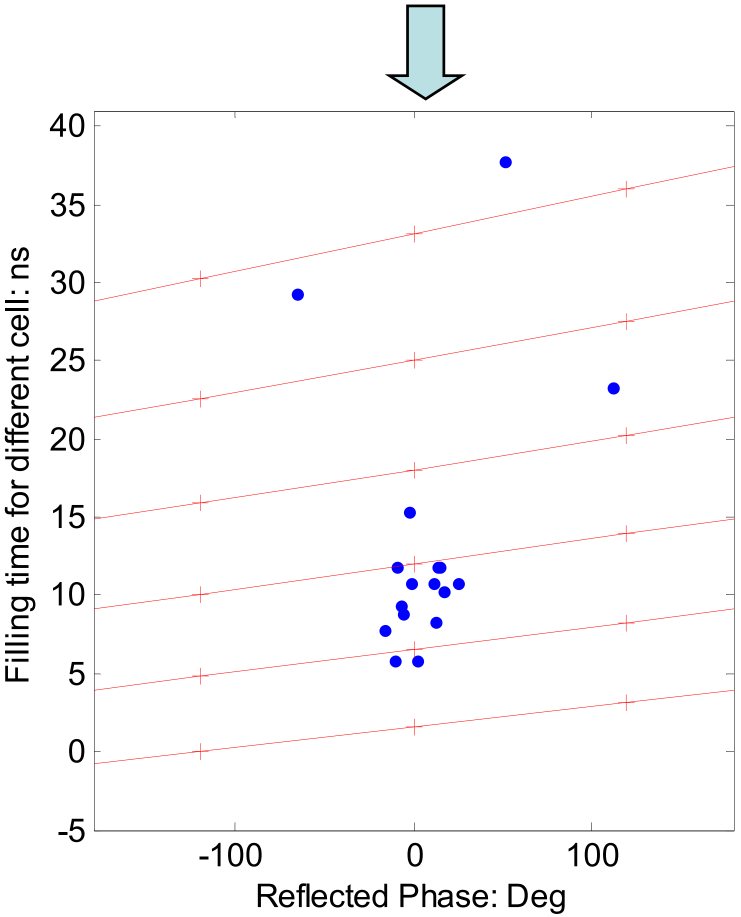
and pulse width dependence ~ $PW^{5.5}$

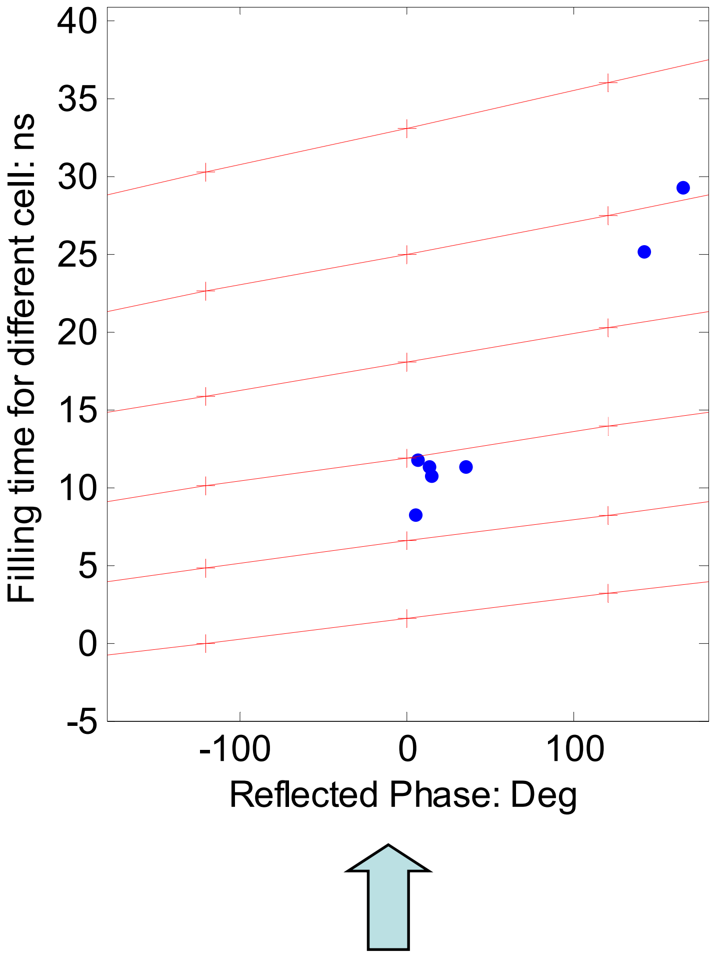
Unloaded Gradient at Different Conditioning Times

For Constant Breakdown Rate



The following test after 1200hrs at 110MV/m@230ns shows BKD rate is very high up to 1.9e-5/pulse/m.



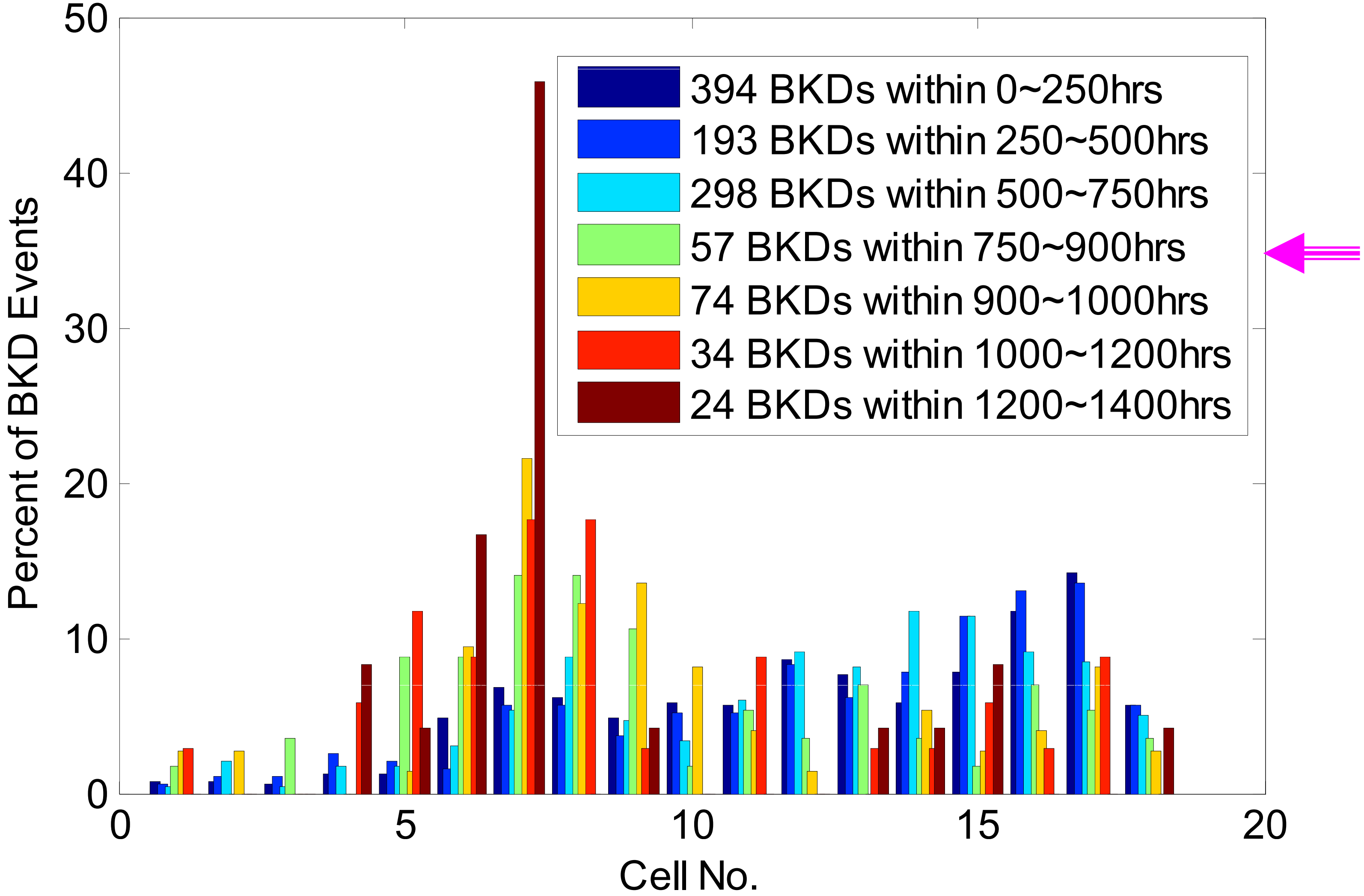


Red cross—cell position

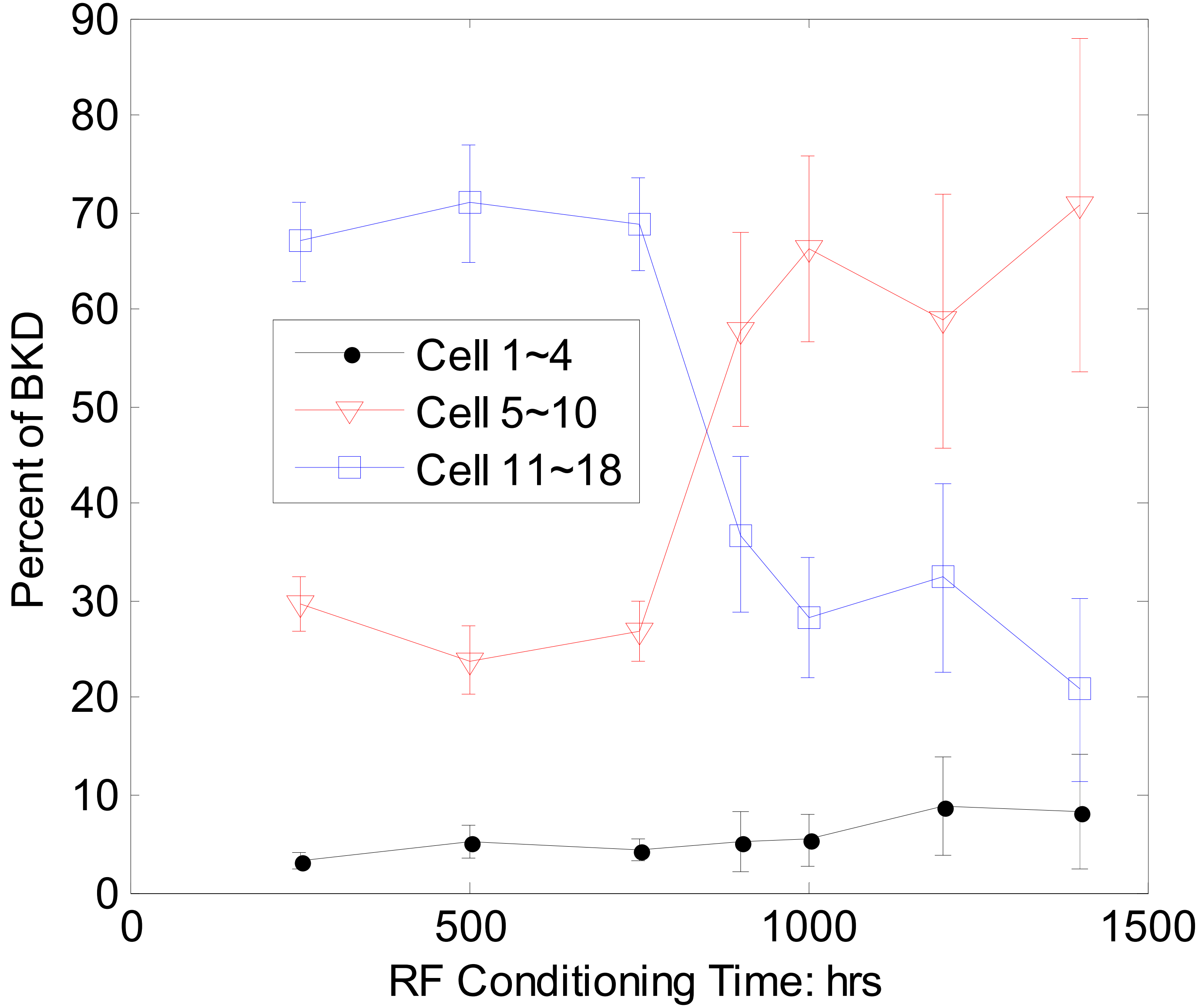
Blue dot - breakdown position

Then, set at 105MV/m@230ns for 140hrs (7 BKD Events)

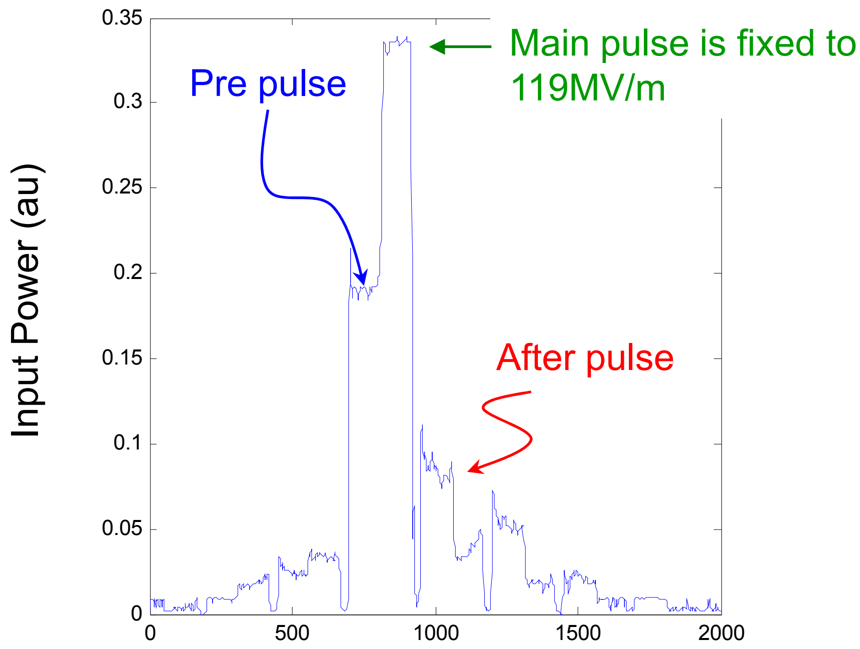
BKD Distribution along Structure at Different Stages of Processing



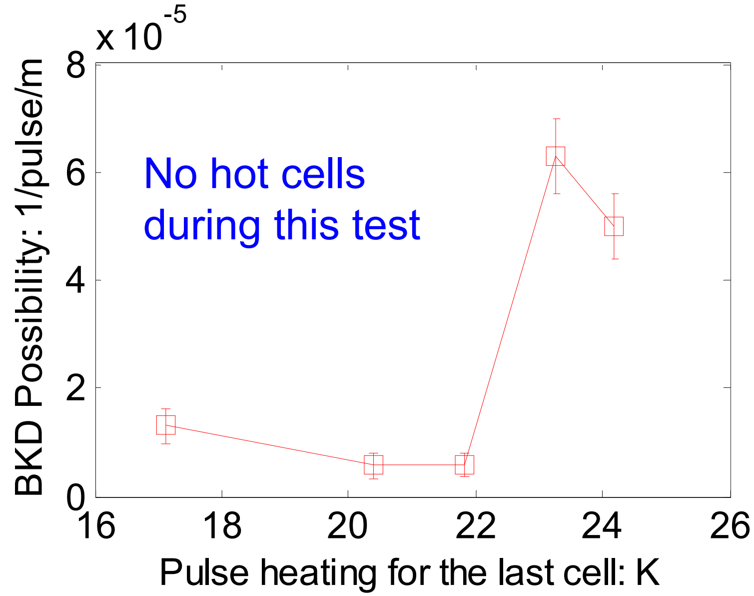
Breakdown Distribution Along the Structure in Cell Groups

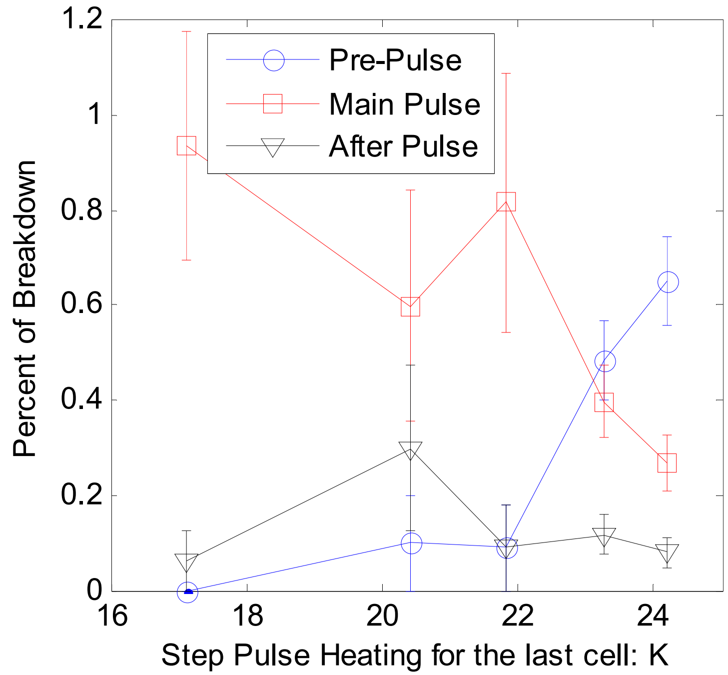


Breakdown Dependence on Pulse Heating



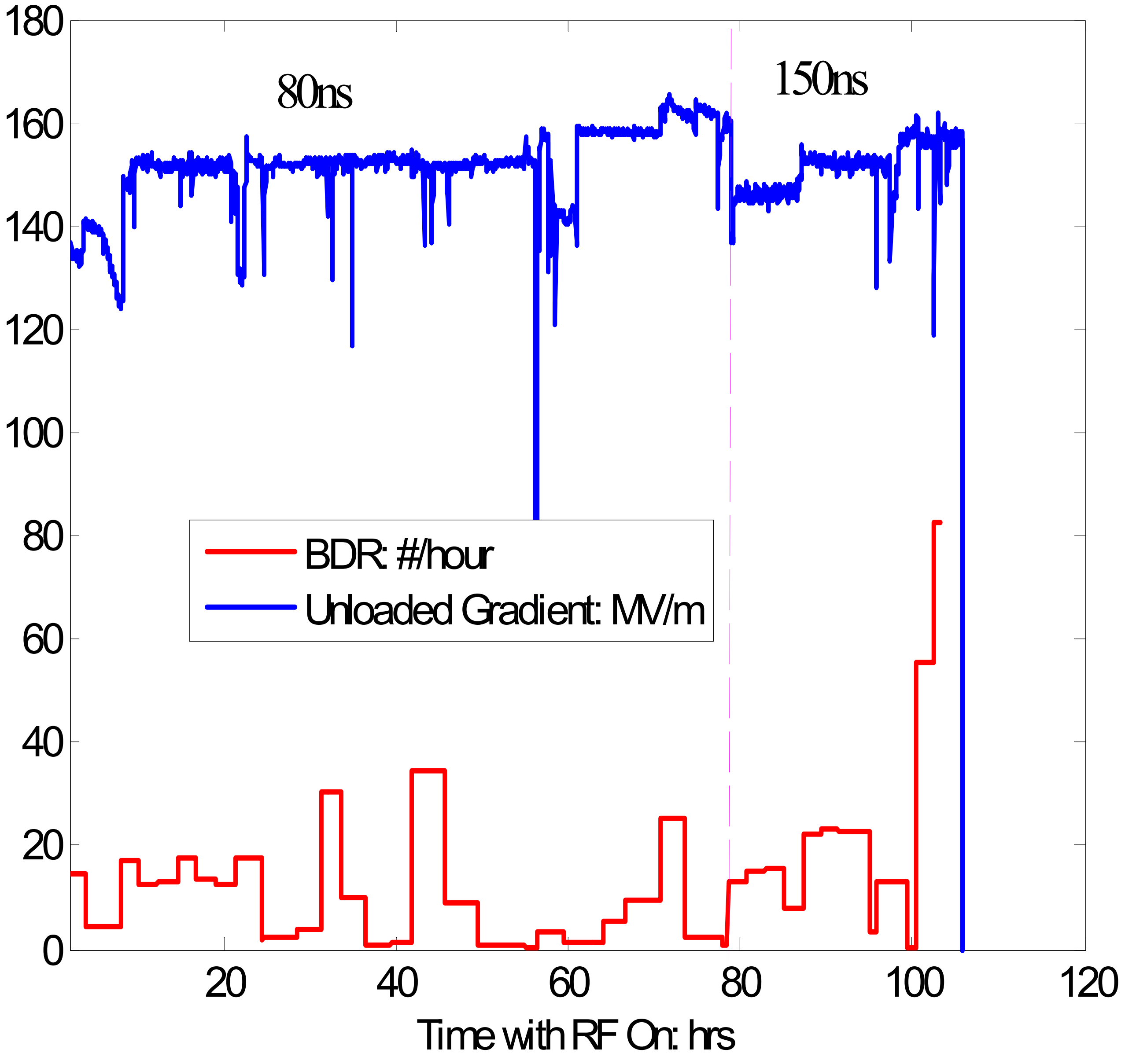
Pre pulse gradient	Time: hr	BKD Events	BKD Rate (1/pulse/m)
Single Pulse	19	16	1.3e-5
81MV/m	16	6	5.8e-6
97MV/m	21	8	5.9e-6
111MV/m	20	81	6.3e-5
119MV/m	21	68	5.0e-5



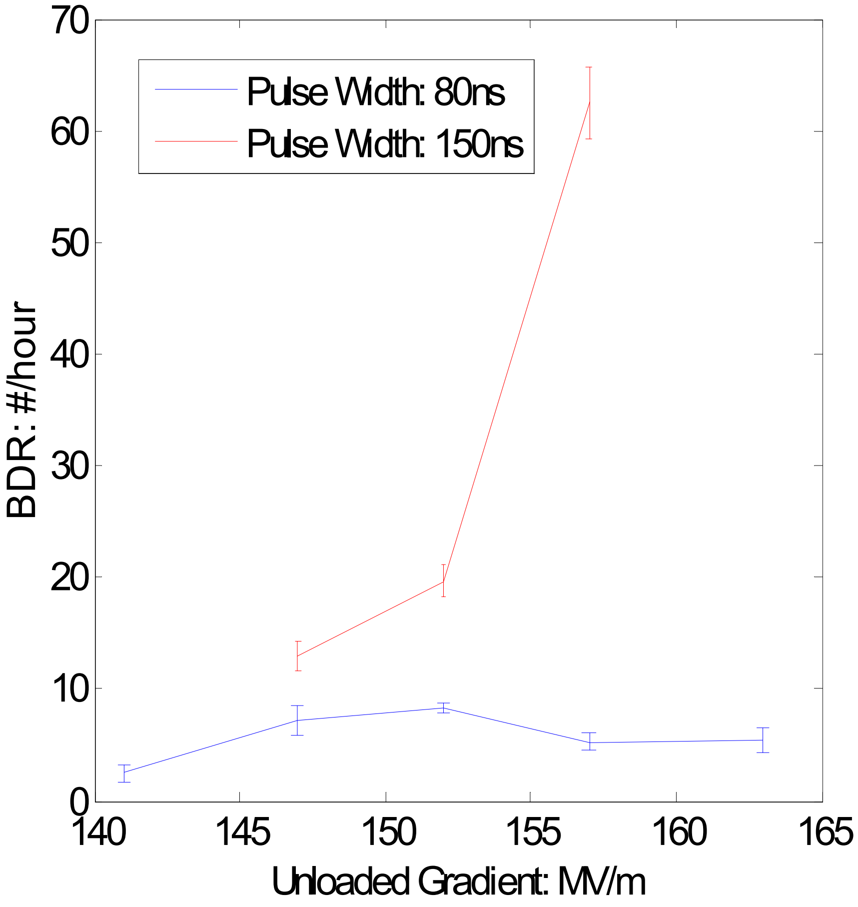


Operation of T18 Backward

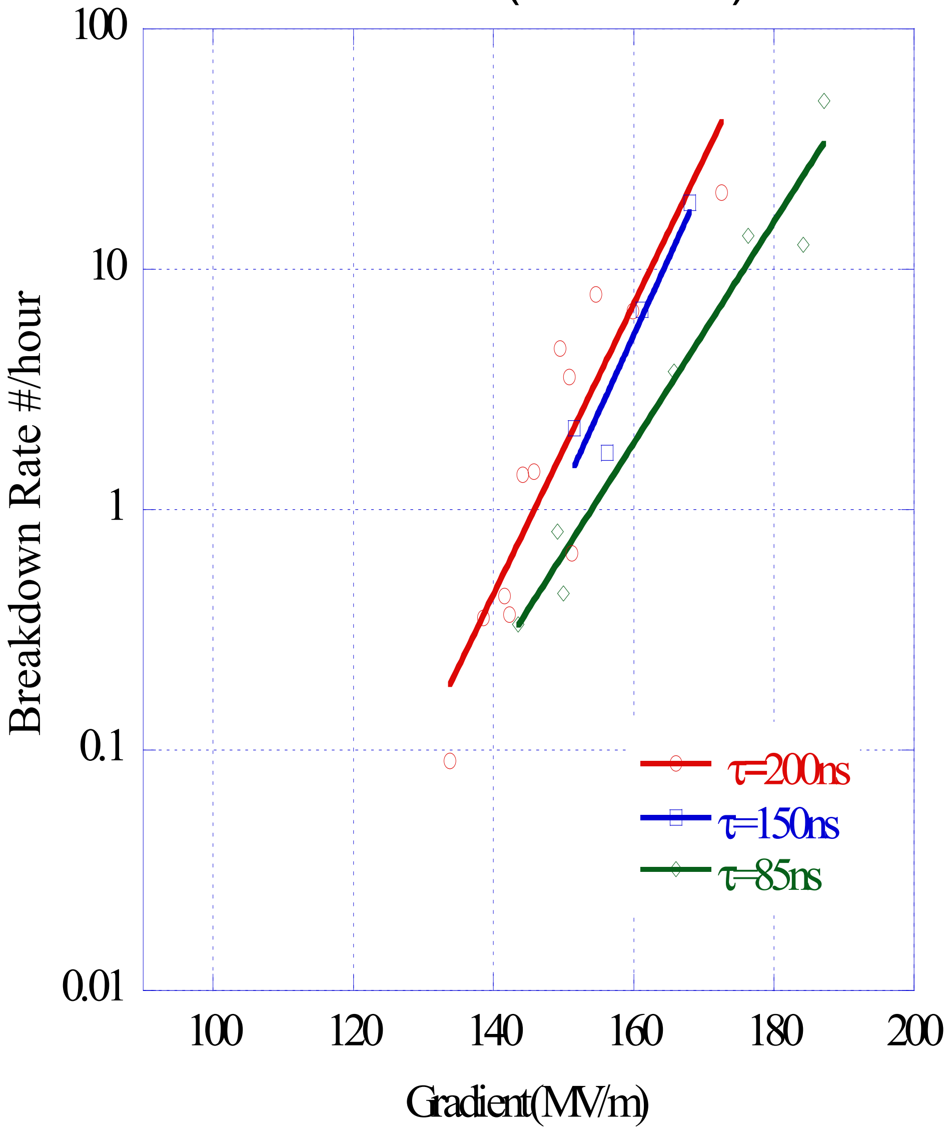
T18 Backward Processing History



RF BDR Gradient Dependence of 1st Cell (a/λ = 0.10)

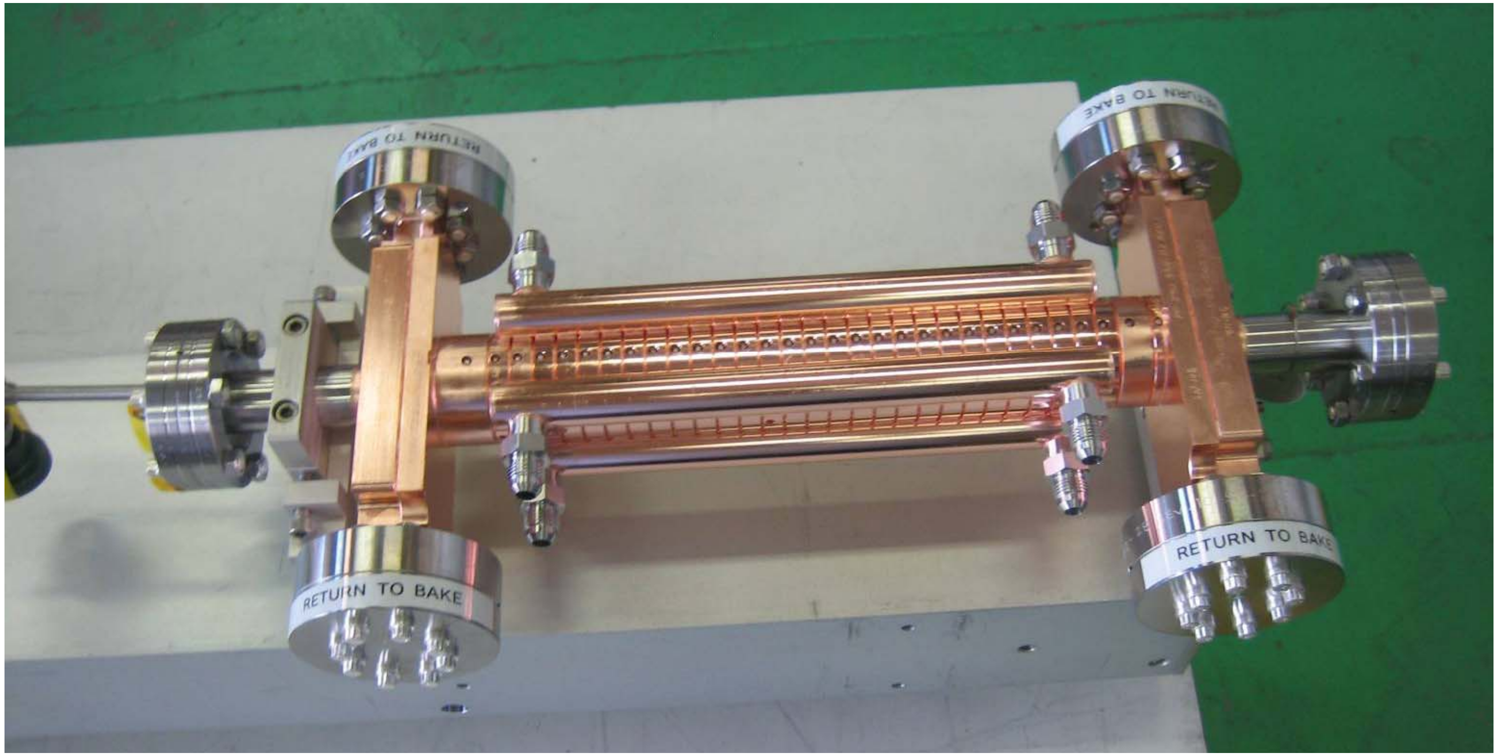


Single Cell Standing-Wave Accelerator Structure Recent Results (a/λ~0.14)



‘T26’ (T28_vg2.9) Structure

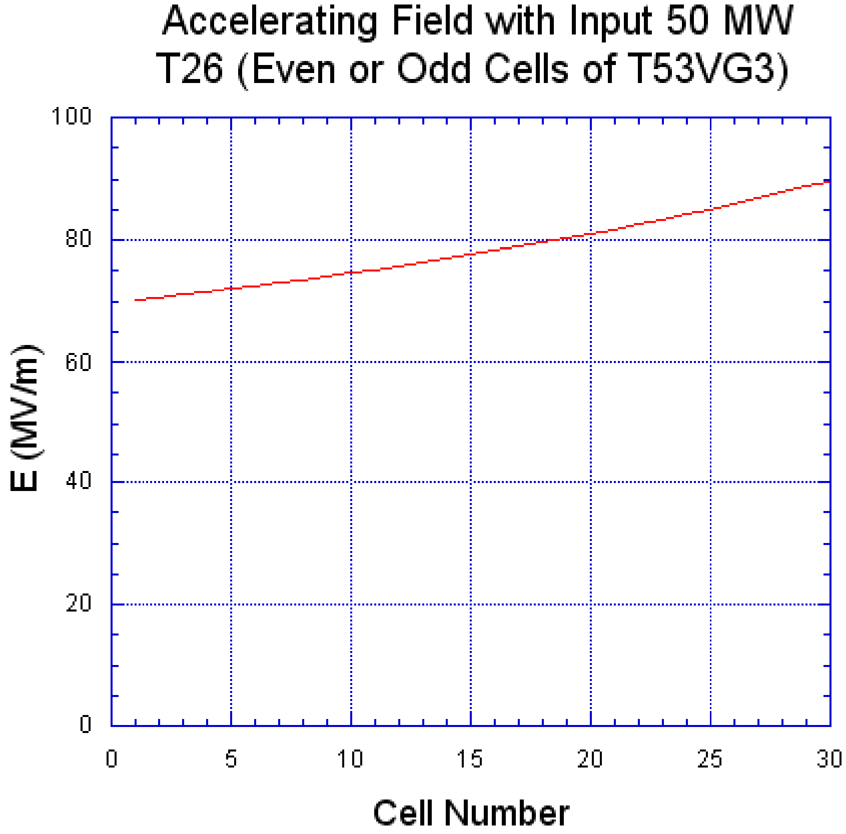
Built at SLAC using cells left over from 2000-2 NLC T-structure study – same as T53 with every other cell omitted



T26 RF Parameters

Structure Type	L (cm)	Total Acc. Cells	v_g % c	a/λ	T mm	r MΩ/m	τ	Q_{ave}	T_f ns
Even Cell Of T53VG3	26	30	3.30-1.62	0.149-0.120	1.66	92-107	0.19	6843	35.8

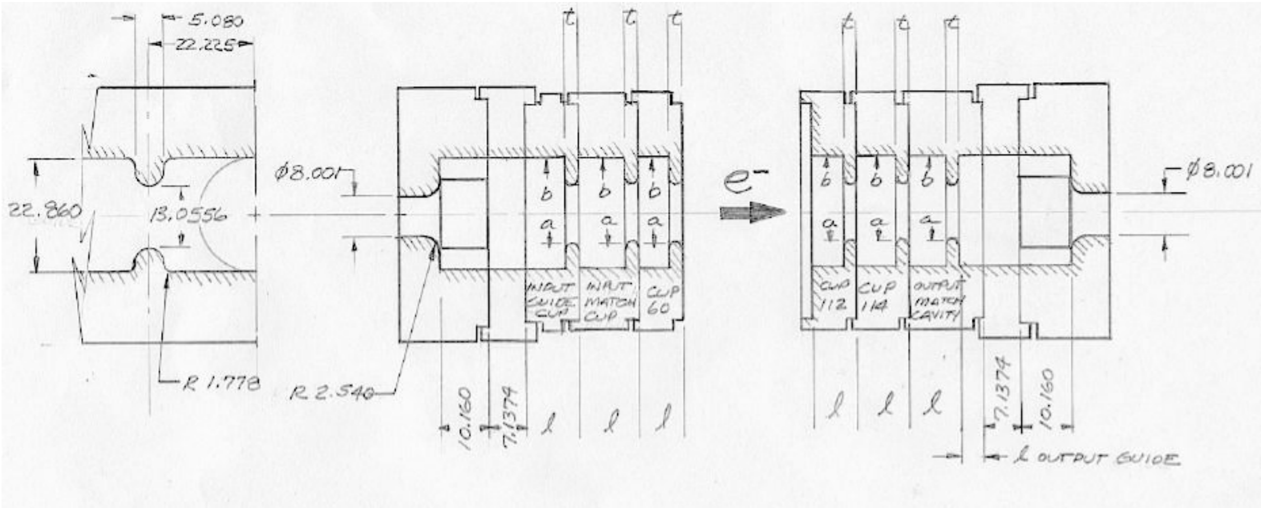
Gradient increases by 30% along structrure



28 Acc. Cell and 2 coupler cells.

Filling Time: cool test 38ns

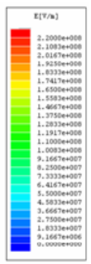
T26 Design

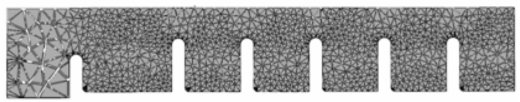


Structure Layout

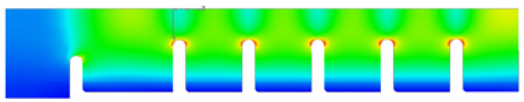
- Input and output to use existing universal coupler assembly.
- Check and small modification of input/output matching.
- Regular cups: 28 even number cups from T53VG3.
- Total 30 accelerating cells in the structure.

Check and small modification of input/output matching

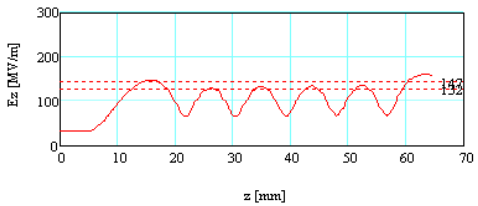


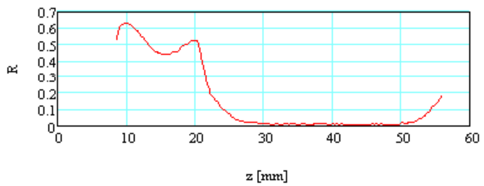


Mesh



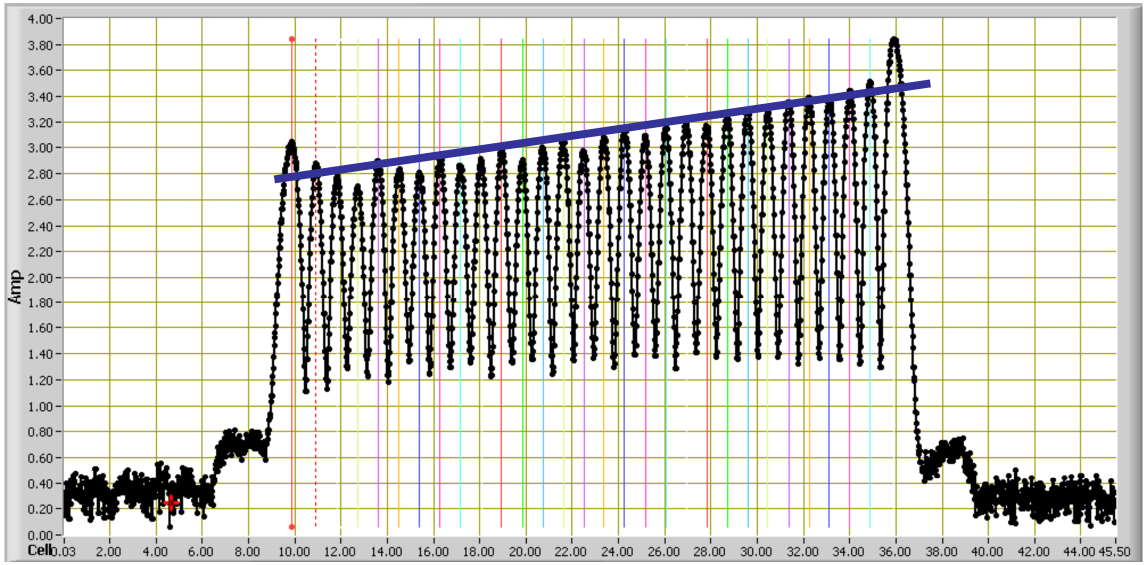
Surface electric field, max. field 220 MV/m



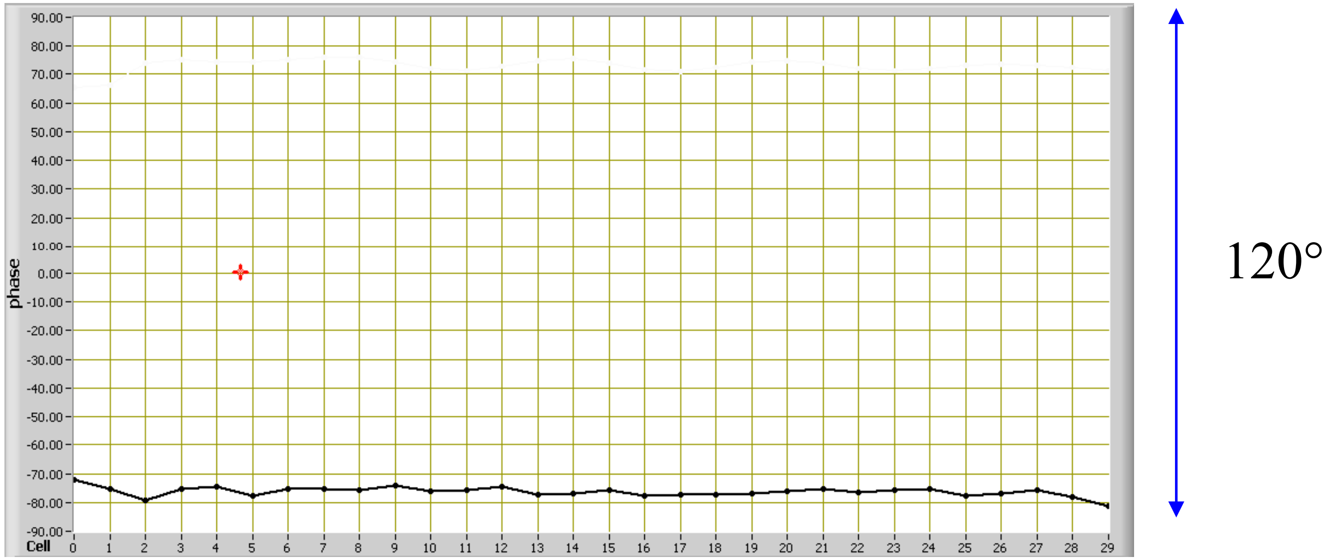


T26 Structure after Tuning

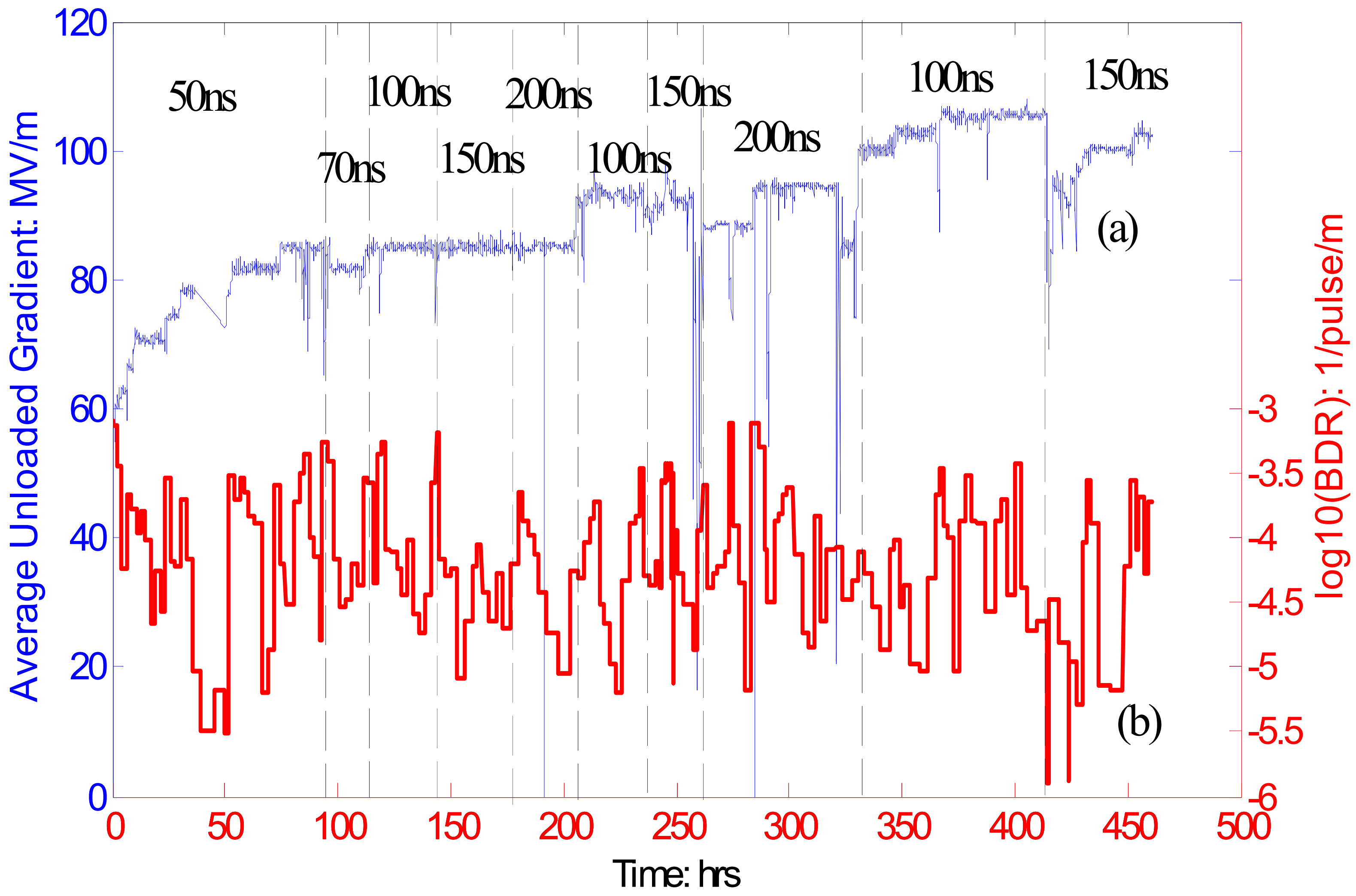
Field Amplitude



Accumulated Phase Change

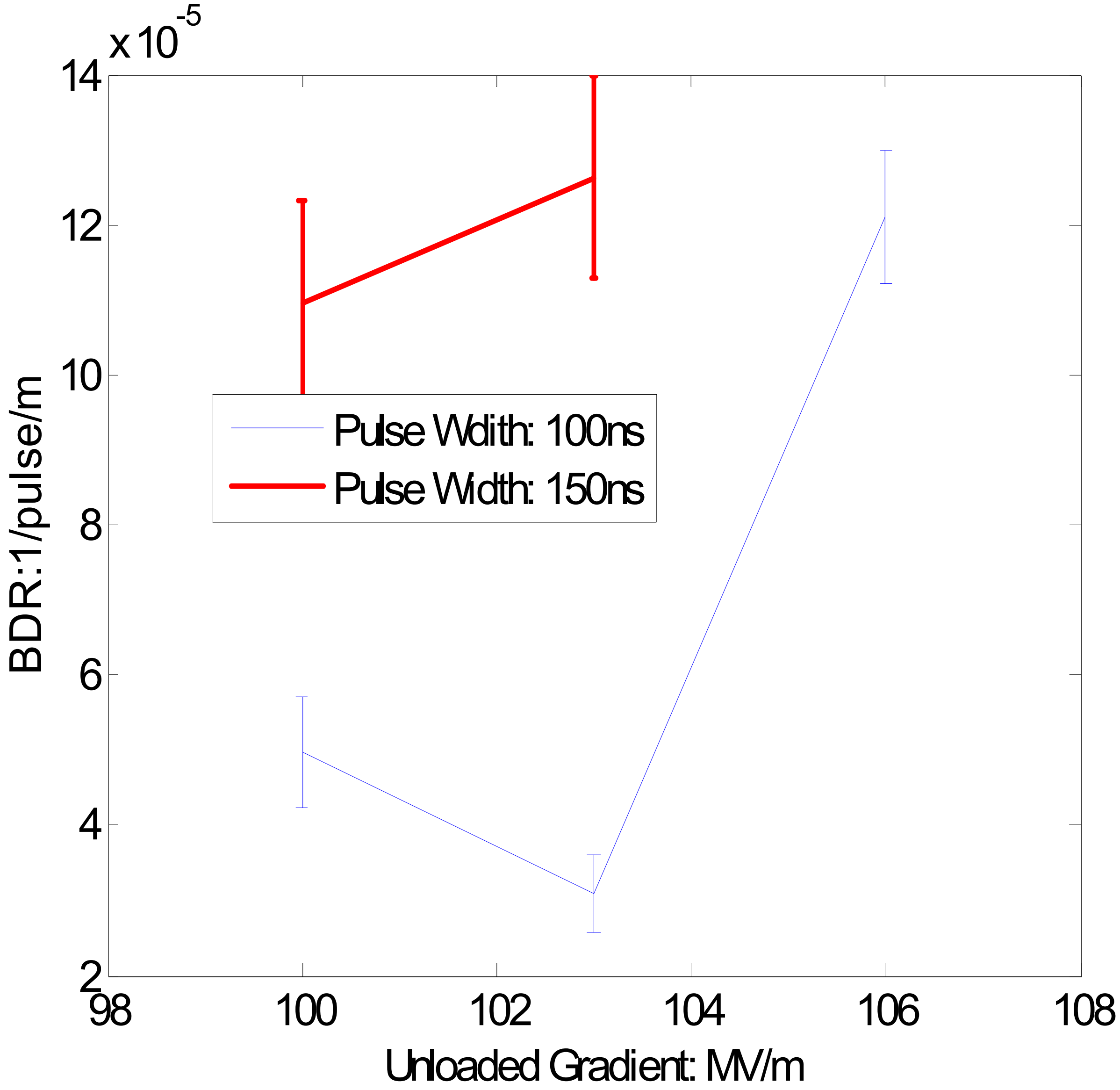


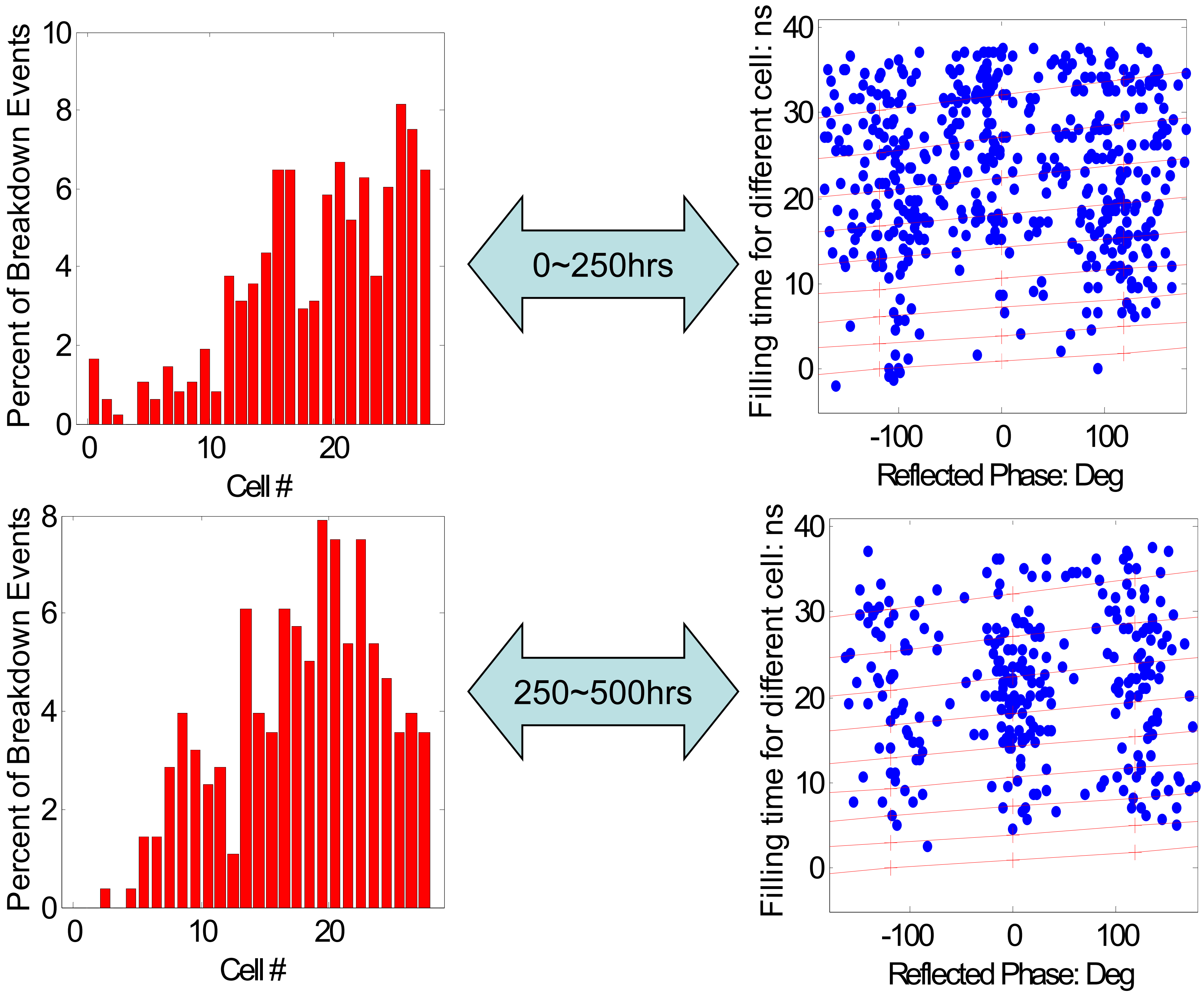
T26 Structure Process History Profile during the First 500hrs



(a) The average unloaded gradient (b) Normalized breakdown rate.

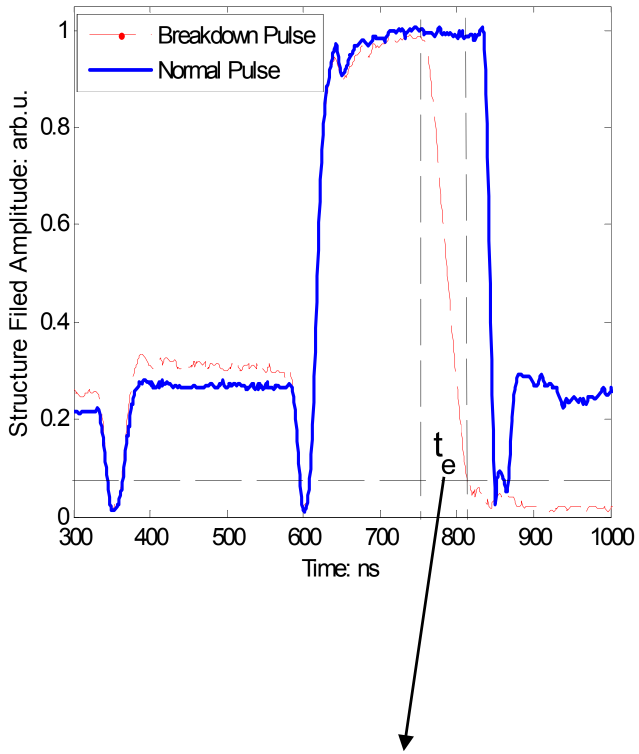
T26 BDR Gradient Dependence



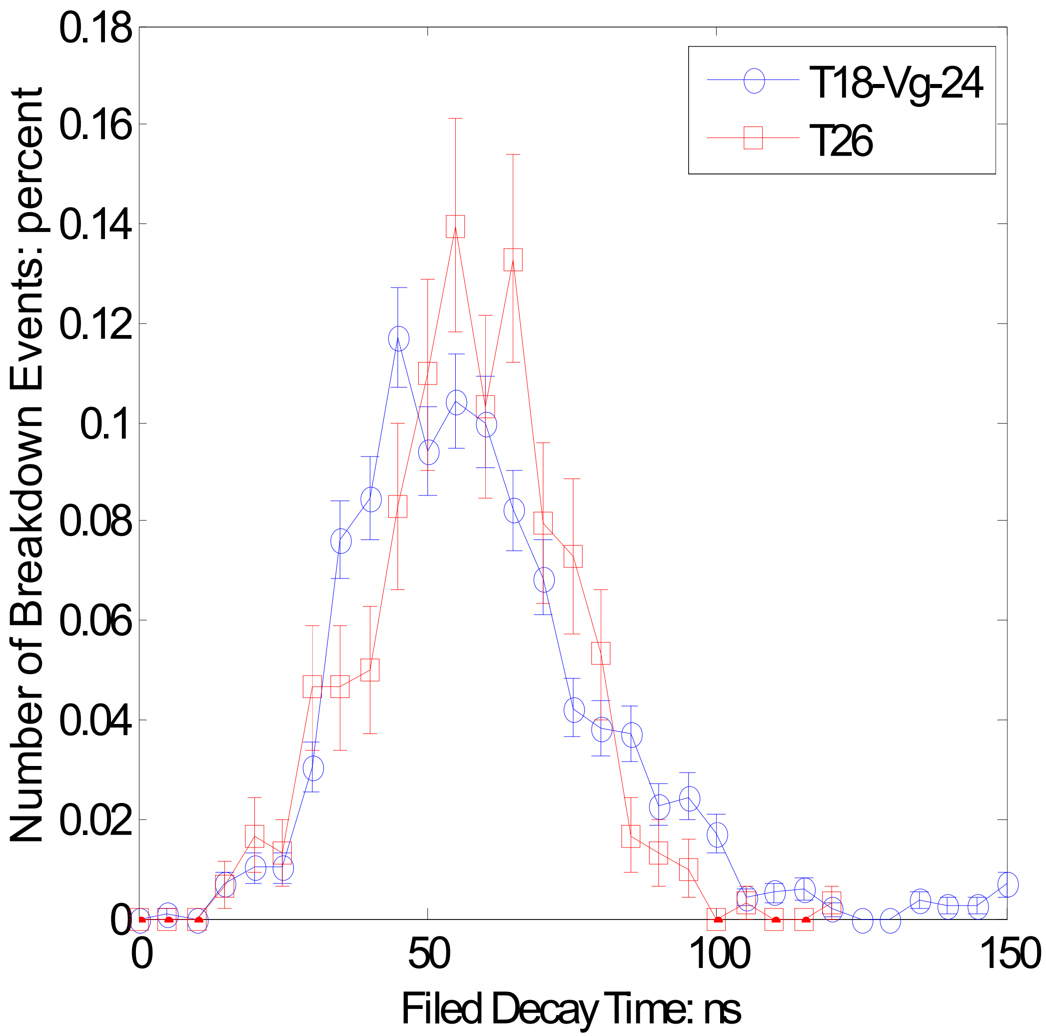


Percent of Breakdown Events
Cell #
0~250hrs
Filling time for different cell: ns
Reflected Phase: Deg
Percent of Breakdown Events
Cell #
250~500hrs
Filling time for different cell: ns
Reflected Phase: Deg

Field Decay Time Distribution



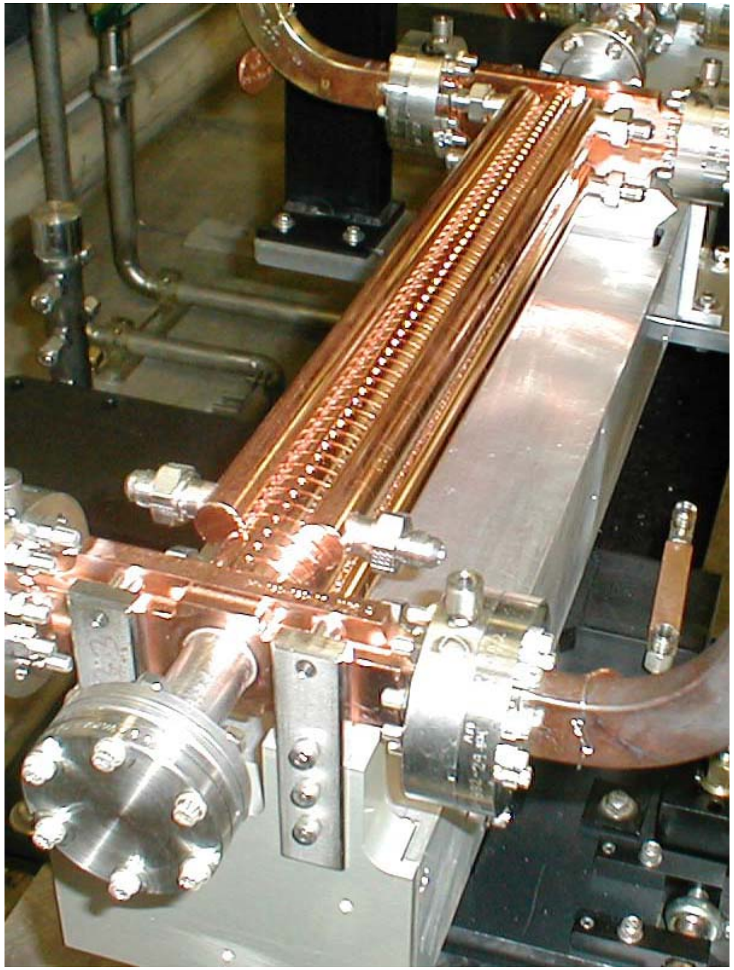
Field Decay time: the time for field collapsed to 5% of normal field level



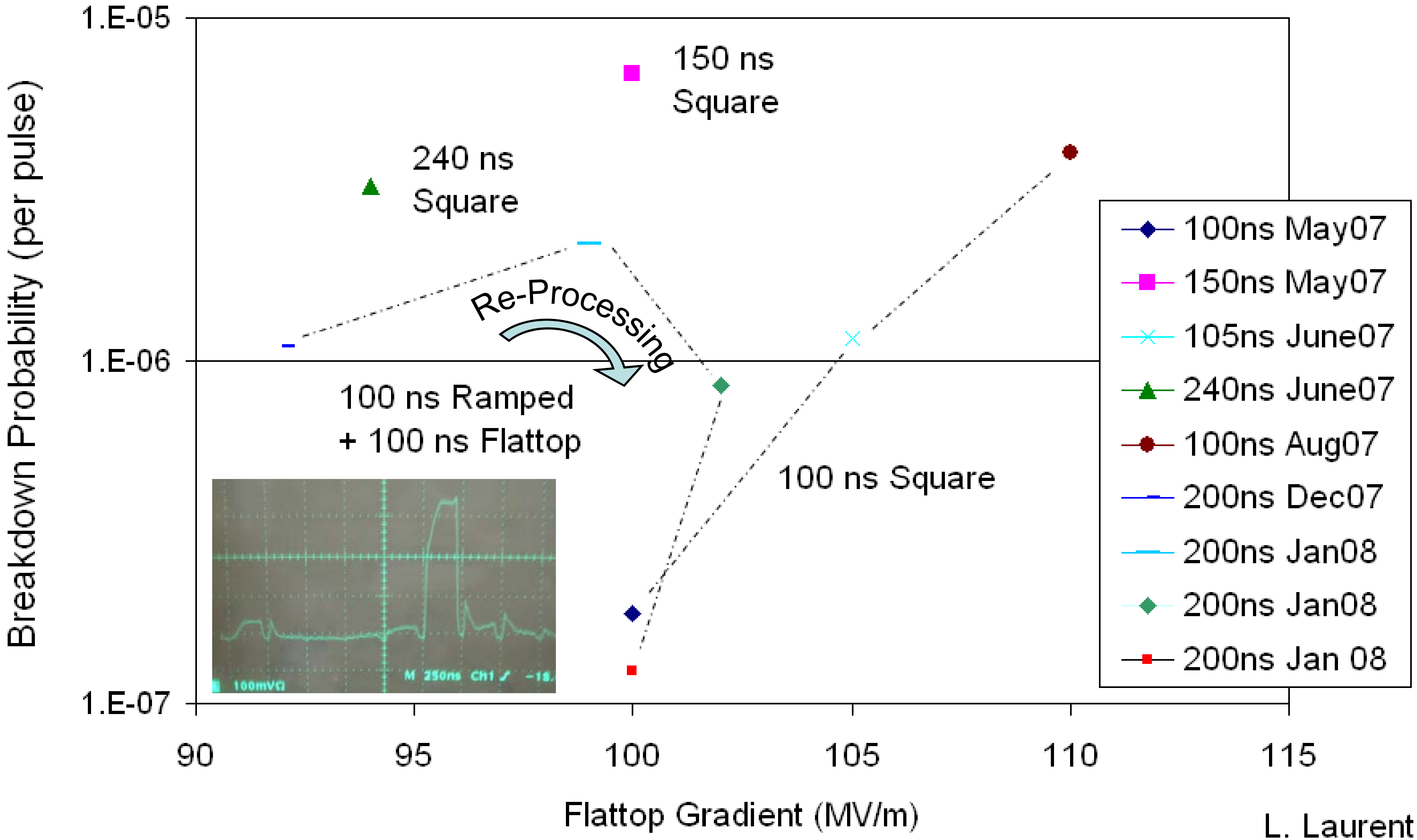
T53VG3MC

First with Mode Converter input coupler – performed exceptionally well in 2002

- 53 cm long, a/λ = 13%, initial vg = 3.3%, requires 98 MW for 100 MV/m operation
- In 2002, breakdown rate < 5e-7 at 90 MV/m with 400 ns square pulses
- Reinstalled in 4/07 and have since run 2300 hours with shorter pulses (includes two vents to SLED system)
- In following plot, most points based on 60 Hz operation for more than 50 hours



Short Pulse Operation of T53VG3MC



L. Laurent

Summary of Structure Parameters

Structure	a/λ	Vg (%c)	Power (MM) for 100 MV/m
T18 Last Cell	0.10	1.0	30
T18	0.16 - 0.10	2.6 - 1.0	56
T26	0.15 - 0.12	3.3 - 1.6	82
T53	0.15 - 0.12	3.3 - 1.6	102

Summary

- T18 ($a/\lambda = 0.13$) has preformed well (bkd rate ~ 1e-6/pulse/m at 106 MV/m with 230 ns pulses after 1400 hours) but hot cell turned on after 800 hrs of processing.
  - T53 ($a/\lambda = 0.13$) had a similar rate at 106 MV/m, but with 100 ns pulses
  - For CLIC, structure efficiency too low and damping needs to be added
- The bkd rate of T18 operated backward ($a/\lambda = 0.10$ for last cell) similar to single $a/\lambda = 0.14$ SW cell.
- T26, which has every other cell as T53, performs poorly relative to T53 (~ 100 times bkd rate at 106 MV/m, 100 ns) for reasons unknown.

Study of X-band Klystron Sections

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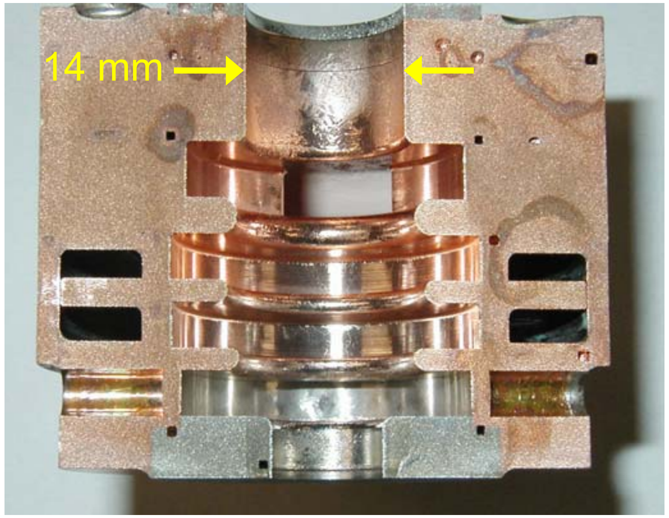
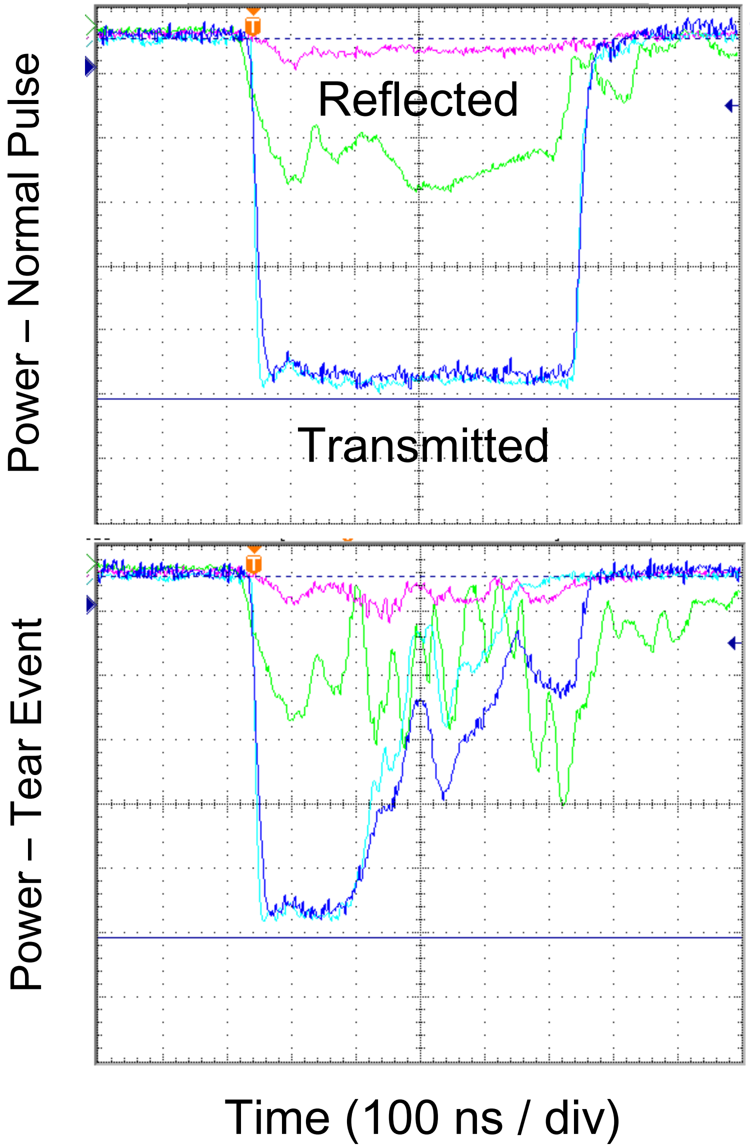
PPM Klystron Tear Events

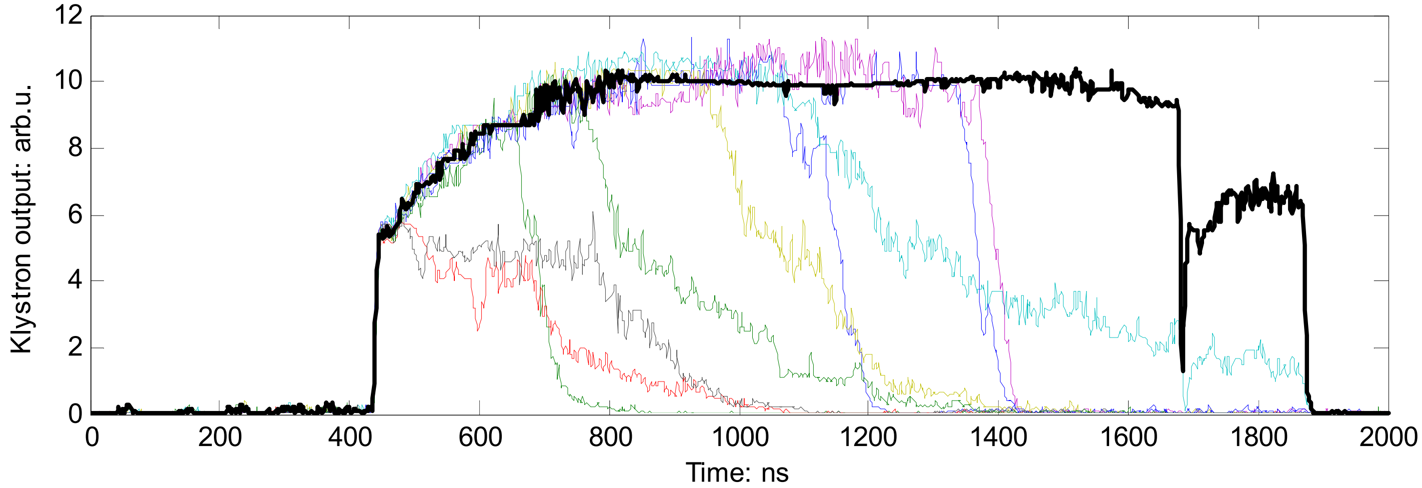
- Character of events suggest they originate in output cavity – visual inspection inconclusive so far.
- At 75 MW, iris surface field ~ 70 MV/m, lower than in 3% v_g structures, but higher than sustainable (~ 50 MV/m) in waveguide with comparable v_g (~ 20%) as the klystron TW output structures.

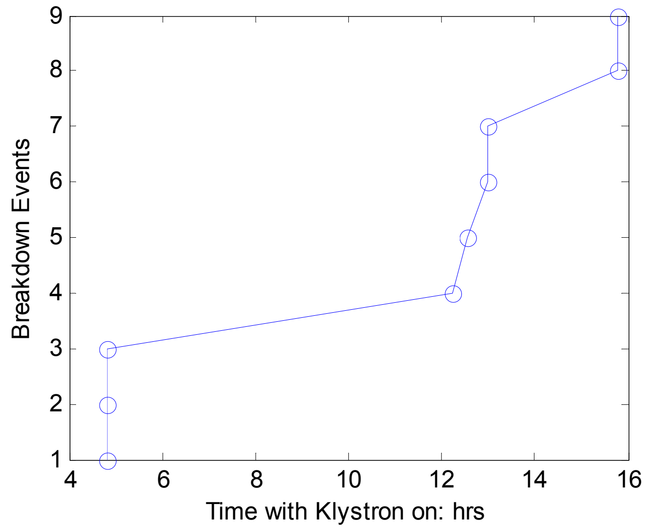


KEK PPM2 Output Structure



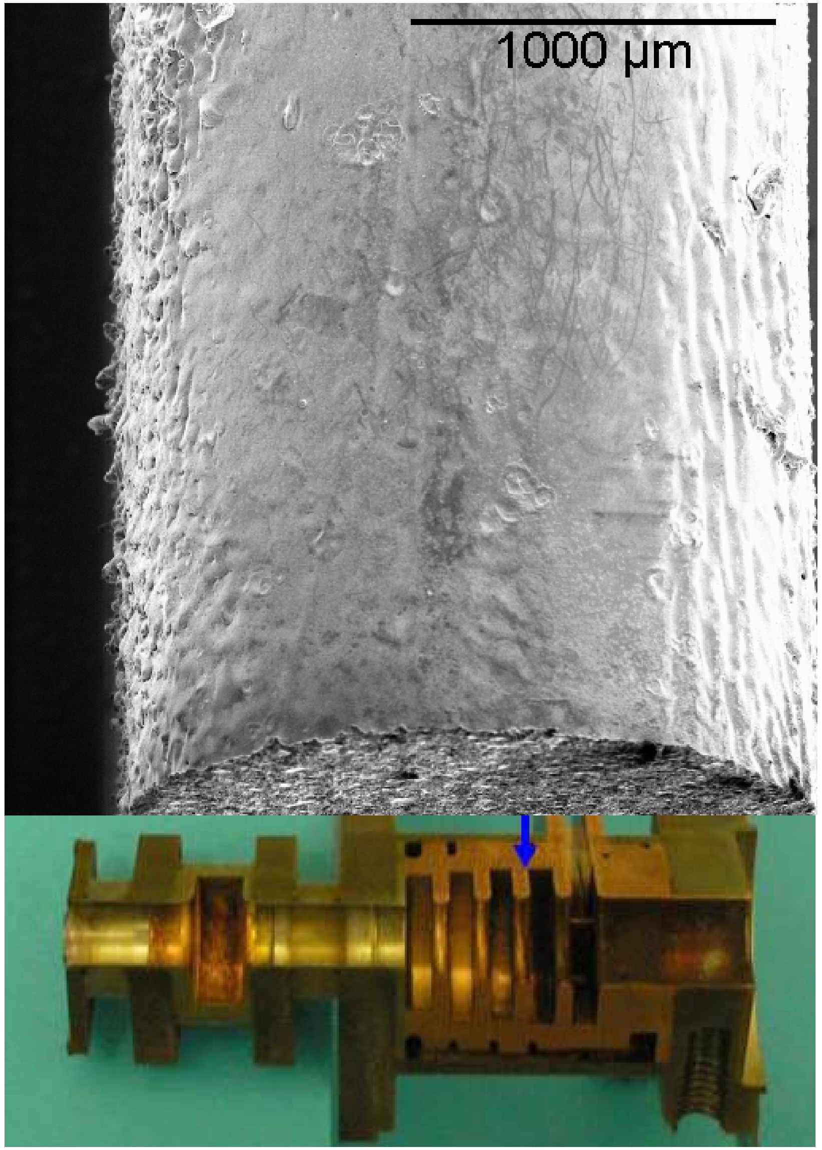
XL4 Klystron Tear Events at 50 MW

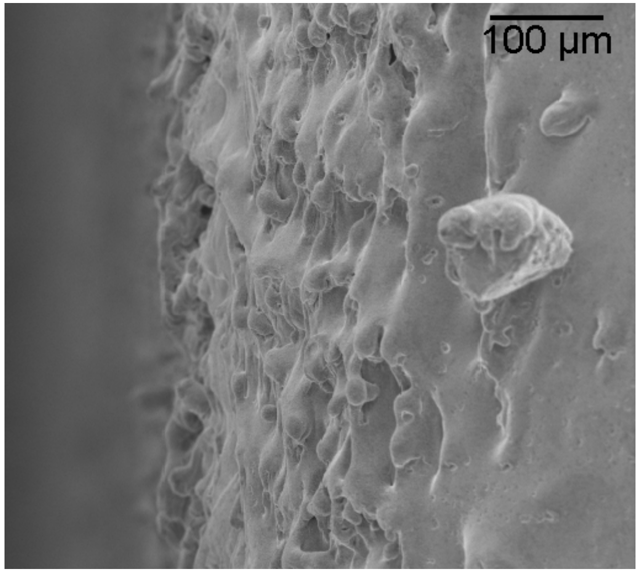


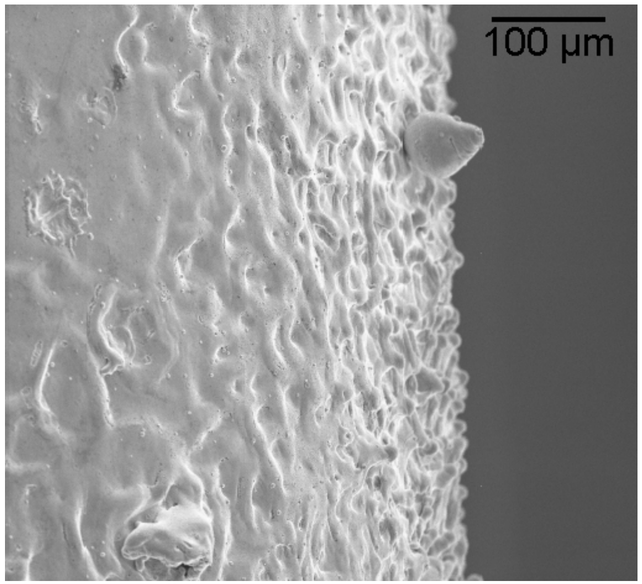


9 events occurred during 17 hrs running at 50 MW with 1.44 us pulse width.

SEM Photos of a 75 MW PPM X-band Klystron Output Section







Experimental Proposal

In the effort to improve on the design of the XL4 for the new X-band klystron, modifications to the output structure will be tried.

RF breakdown/pulse tearing is a limiting phenomenon in klystron performance which, since imperfectly understood, is difficult to overcome by design and simulation alone.

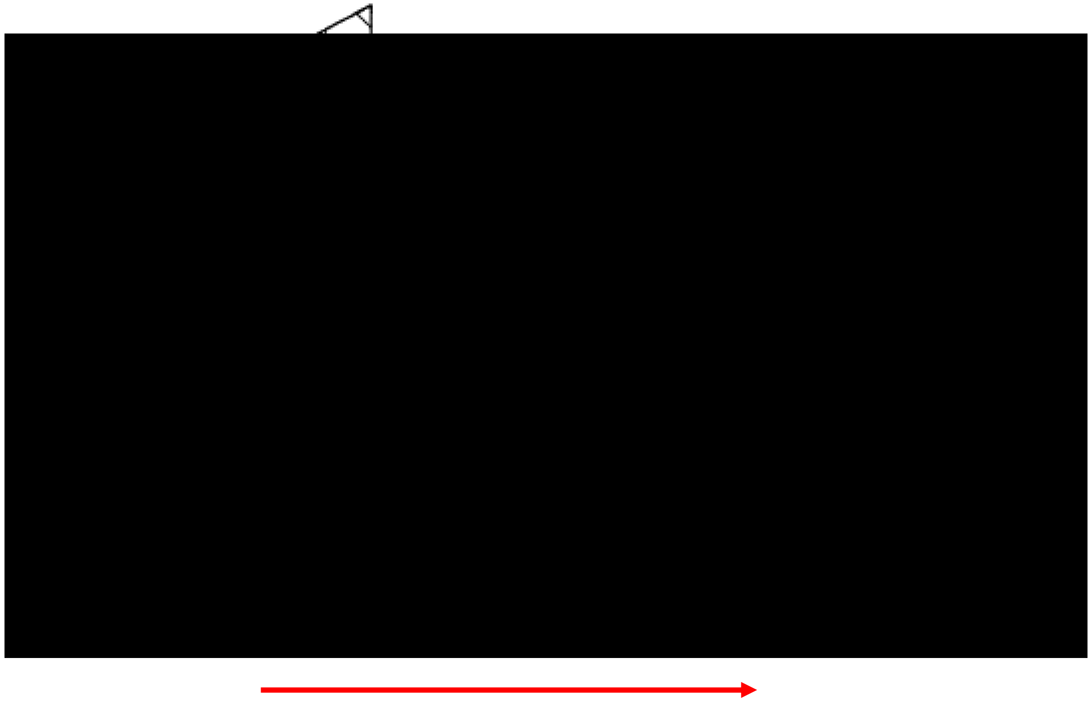
The time and cost of this R&D program might be greatly reduced if we can test new output structures without building a whole tube for each modification.

We have an X-band TM01 mode launcher developed for the "single cell" structure tests in the high-gradient program.

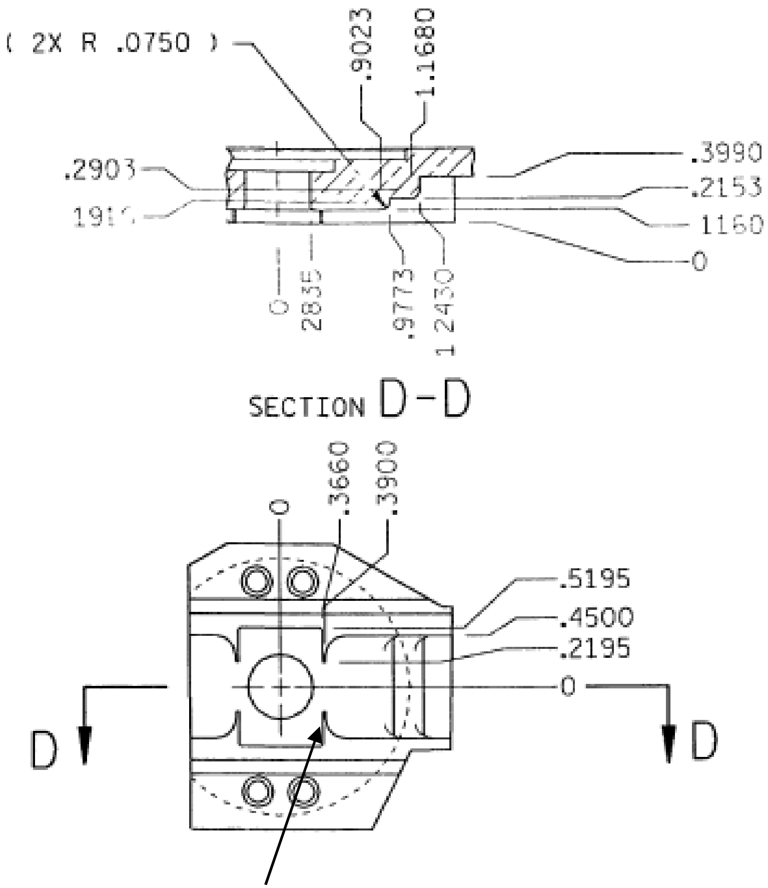
This can be used to power dummy output structures with built-in matching sections.

CAVEAT: The power enters the cavity differently than when deposited by the beam, so the field pattern and and power flow will not be exactly the same as in a klystron. Nevertheless, such experiments should prove useful in comparing different structures.

XL-4 Output Structure

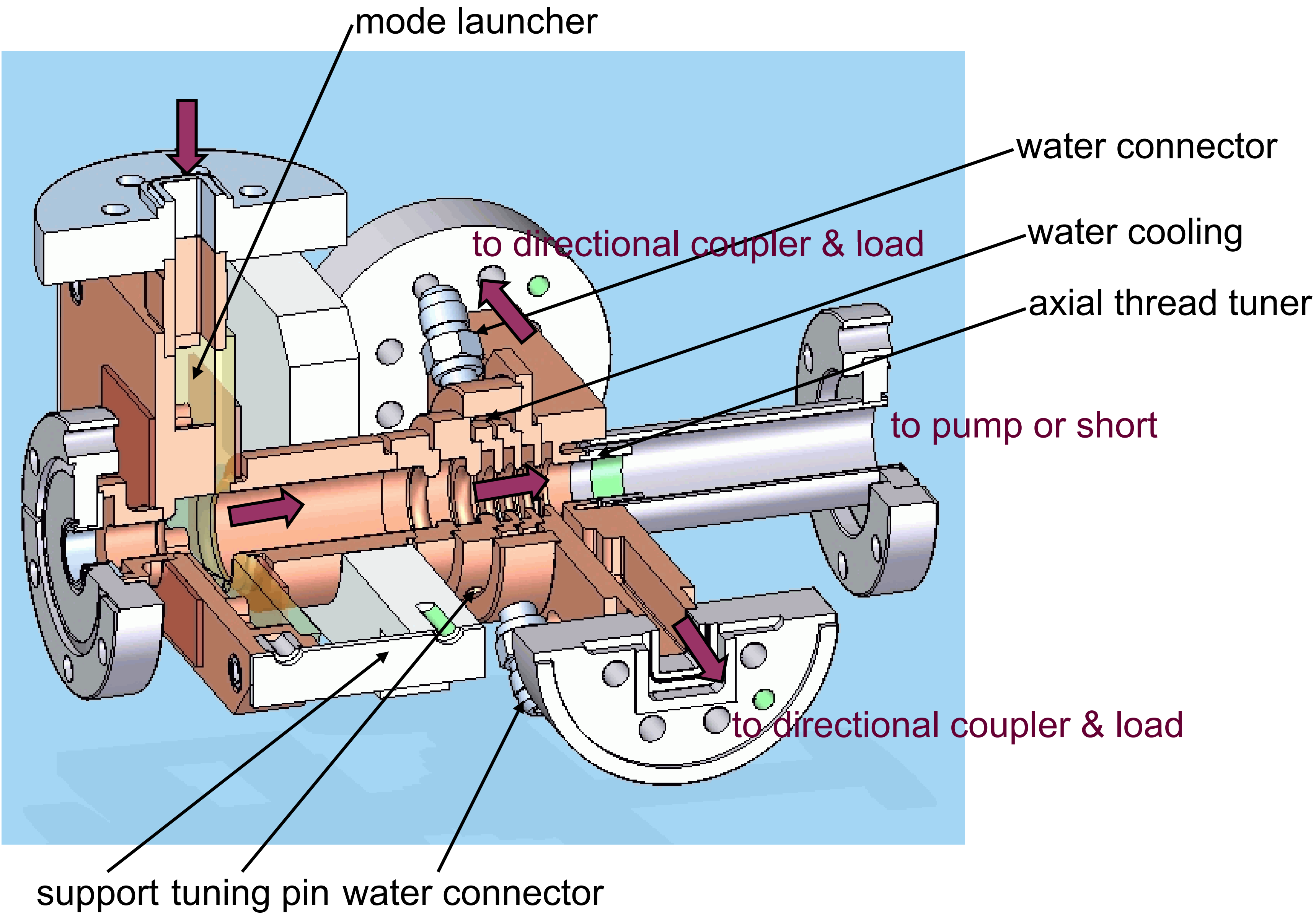


Beam direction



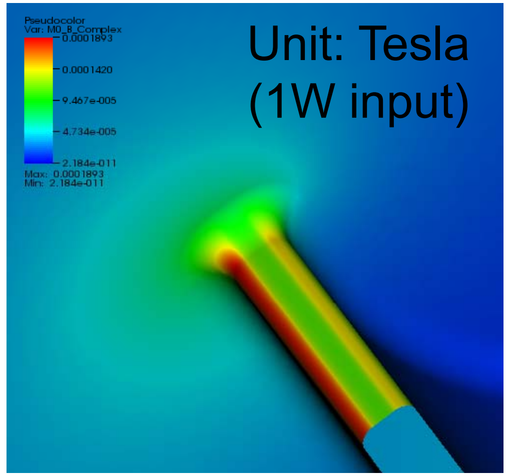
Thin-Lip Coupler

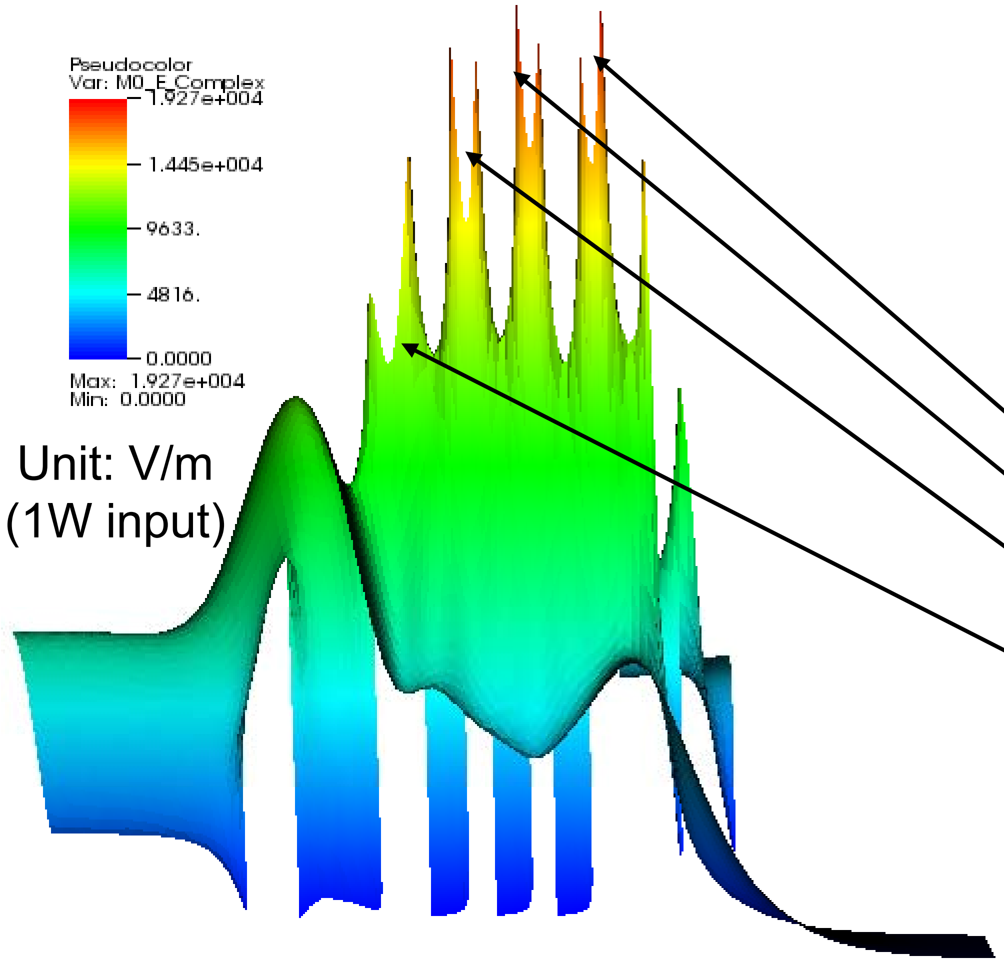
Mechanical Design

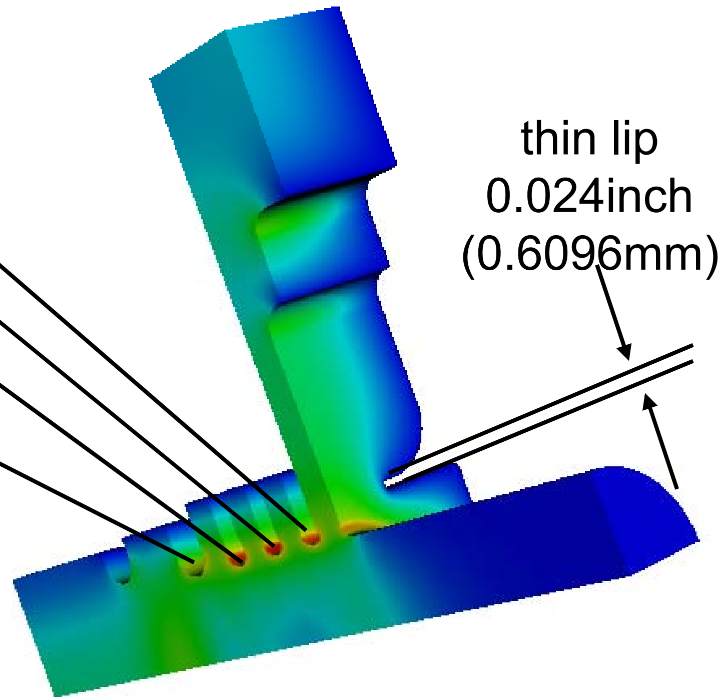


Final Design – Thin Lip

S11@11424MHz = 0.003
S21@11424MHz ≈ 1.000
For 75MW input, Emax=83MV/m, Bmax=0.82Tesla.

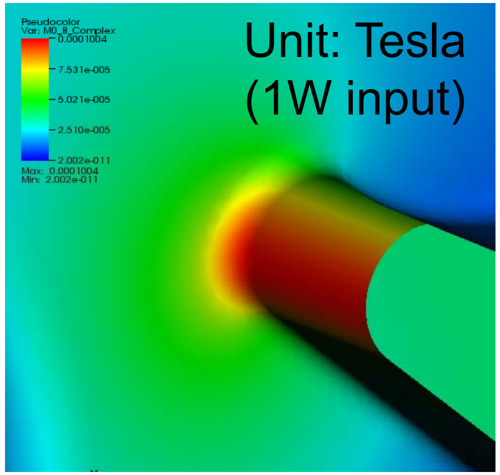


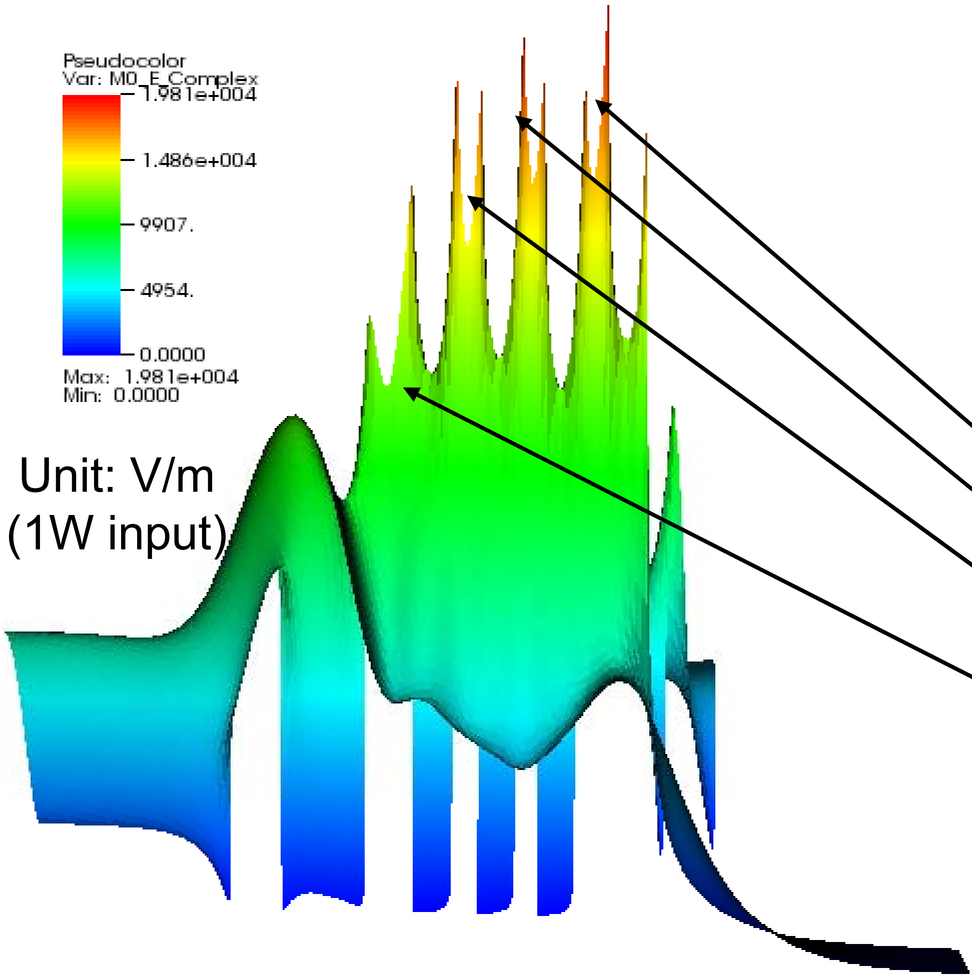


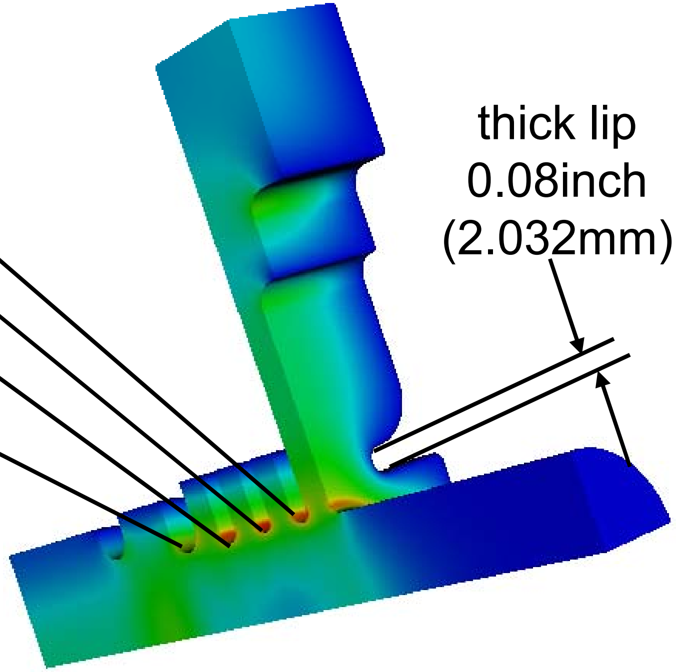


Final Design – Thick Lip

S11@11424MHz = 0.005
S21@11424MHz ≈ 1.000
For 75MW input, Emax=86MV/m, Bmax=0.43Tesla.







Summary

- Will test rf-powered output sections to see if they have similar breakdown characteristics as beam-powered sections
- Continue testing XL4 klystrons to characterize pulse tearing (e.g., measure dependence on pulse width)
- Looking for new ideas for more robust output sections