



# High-Gradient R&D at NLCTA

- Structures recently tested in NLCTA  
SW20a375 ,FXB-004,H60vg3S18,C30vg4-Mo,  
H60vg3R17,FXB-006,FXB007,H60vg4S17
- 8-Pack
- R&D-Plans for 2004
- Conclusions and Schedule



## SLAC/NLC

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K. Jobe, R. Jones, F. Le Pimpec, Z. Li, G. Loew, D. McCormick,  
R. Miller, C. Nantista, J. Nelson, C.K. Ng, M. Ross, R. Ruth,  
T. Smith, S. Tantawi, J. Wang and P. Wilson

## FNAL/NLC

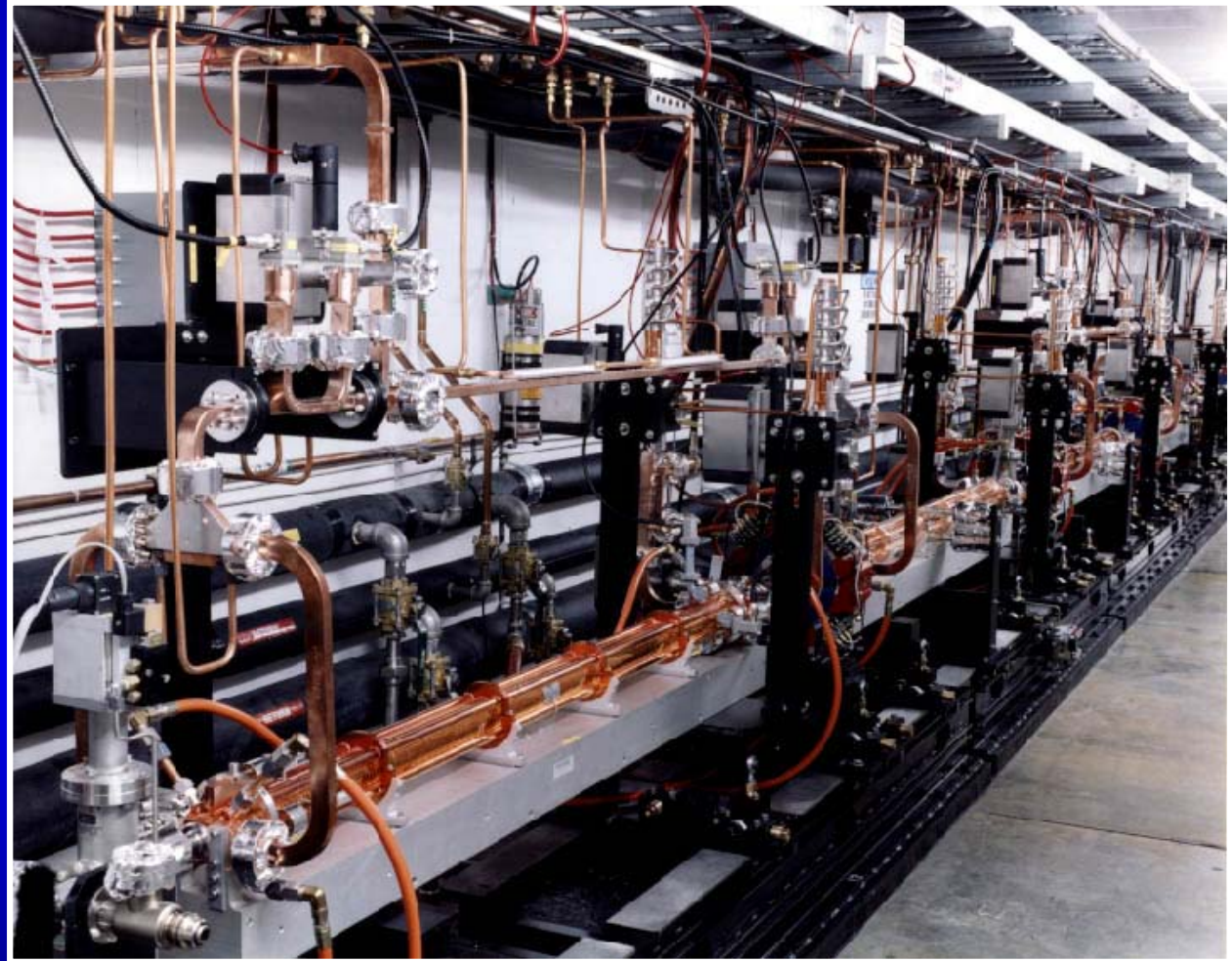
T. Arkan, C. Boffo, H. Carter, D. Finley, I. Gonin,  
T. Khabiboulline, G. Romanov, N. Solyak

## KEK/GLC

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- 2 Test Stations with:
  - 2x50 MW Klystrons into a SLED system
  - 2 testing slots each 150 MW per structure at 240 ns
- 60 MeV electron beam for energy and phase measurements
- 8-Pack:
  - 500 MW, 400ns



## Fire in Modulator #1



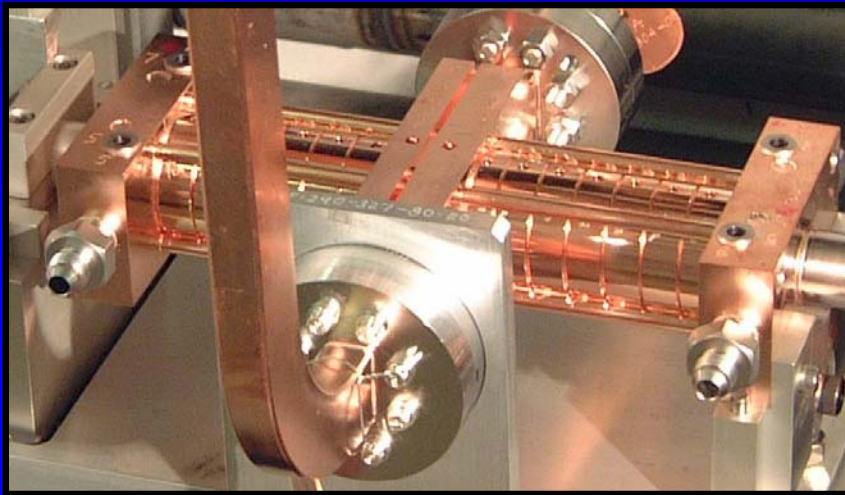
July 8<sup>th</sup>



Power from station 0 (45 MW) was routed into station 1 SLED enabling CERN-Mo structure test up to 240 ns

Dec 1<sup>th</sup>





### Standing wave structures

Length: 2x20 cm

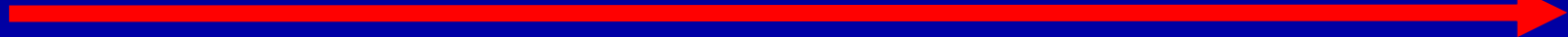
Phase advance: 180 deg

$E_s/E_{acc}$ : 2.05

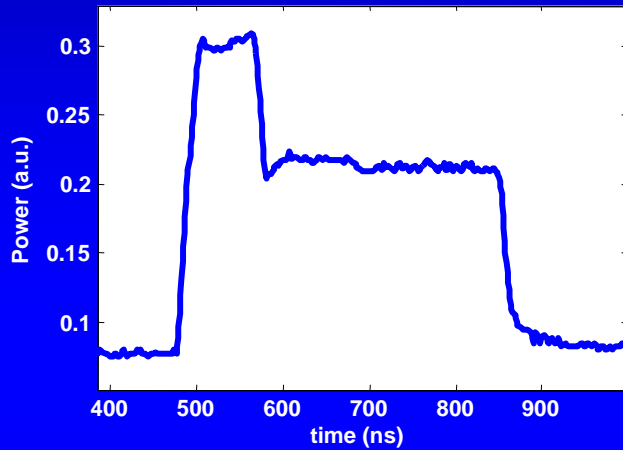
$P_{in}$  (55 MV/m): 9 MW

Coupler: rounded

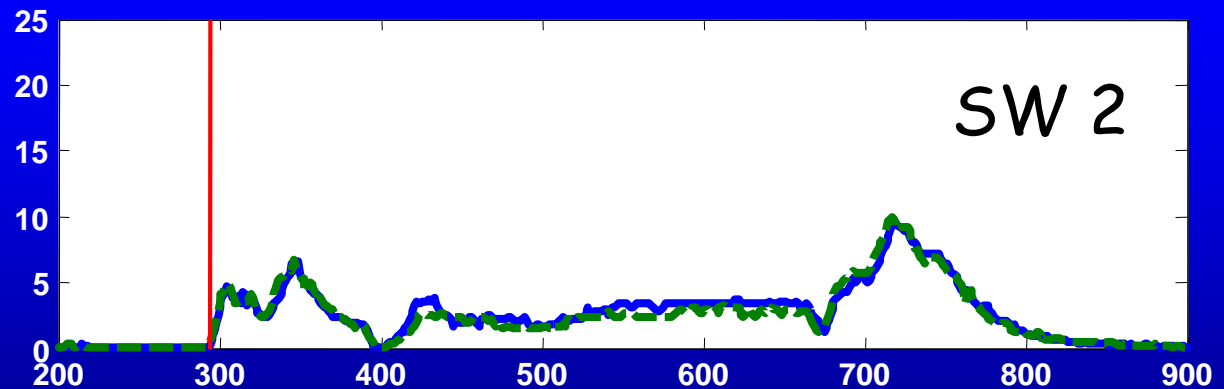
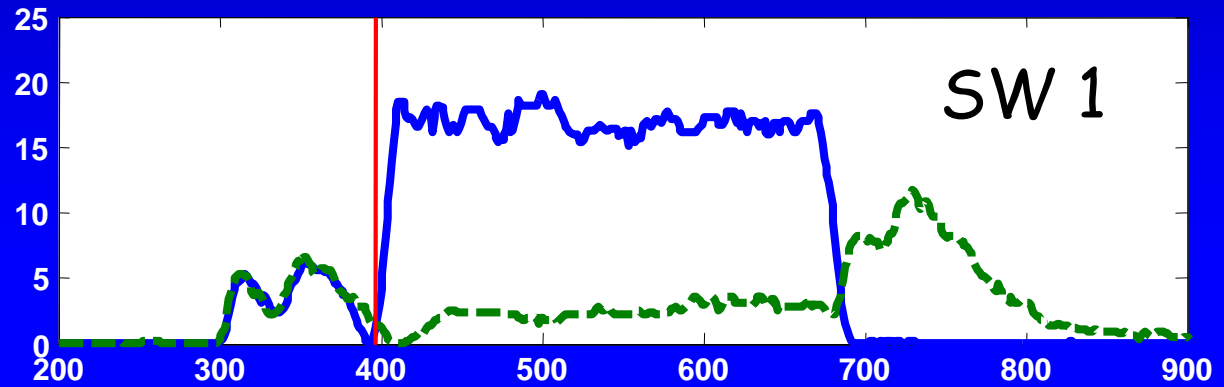
Preparation:  $H_2$ -bonding/brazing  
Vacuum bake



### Input RF pulse

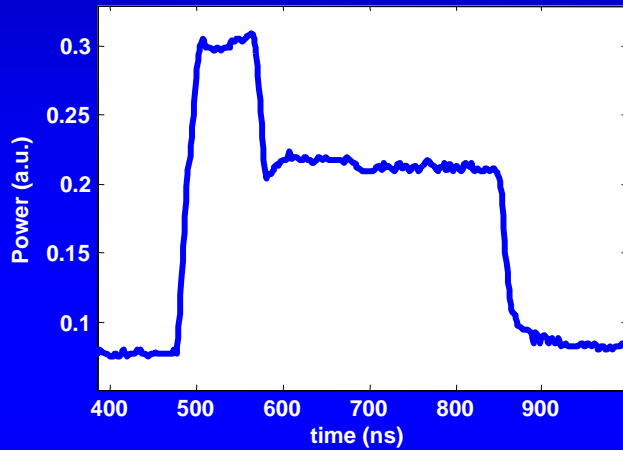


### Reflected Signals



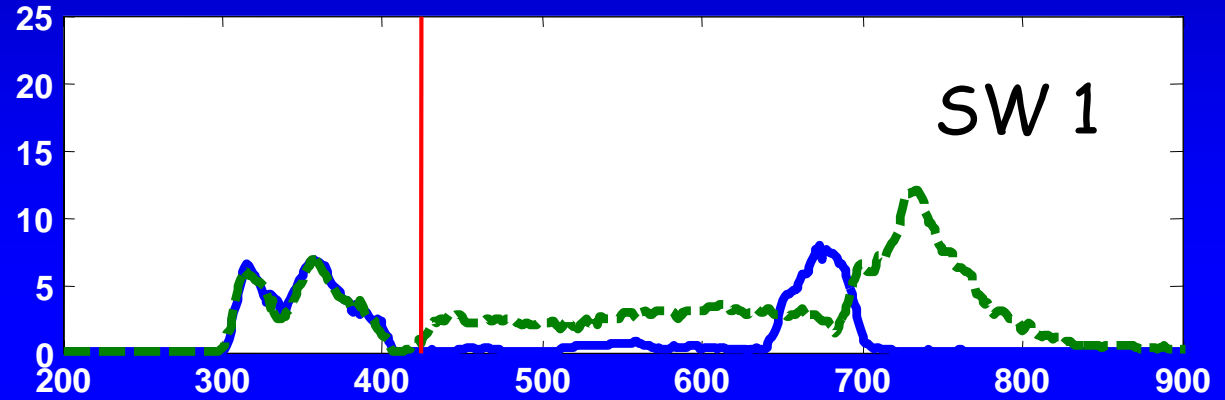


Input RF pulse

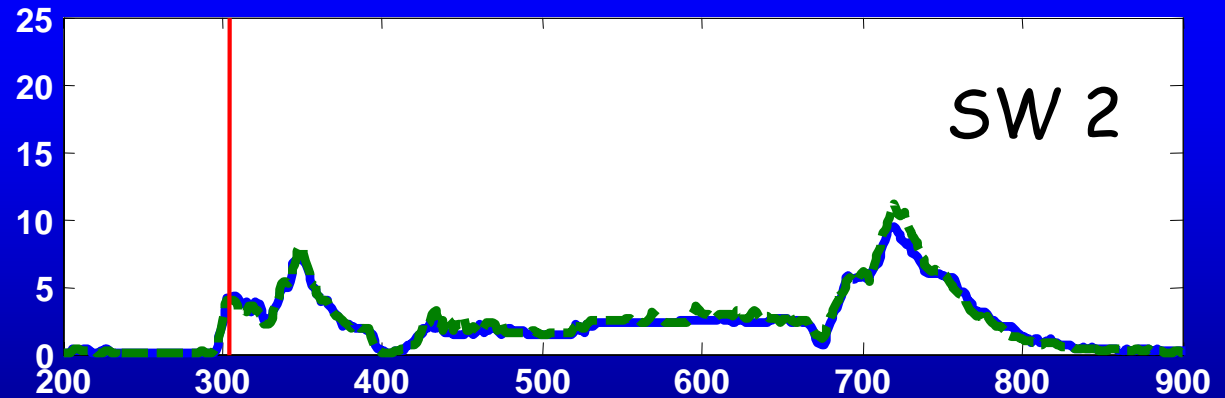


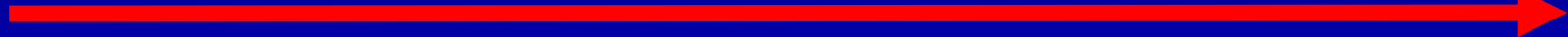
Reflected Signals

FME = 0.94 DS = 0 DP = 142 DT = 0 EV = 12

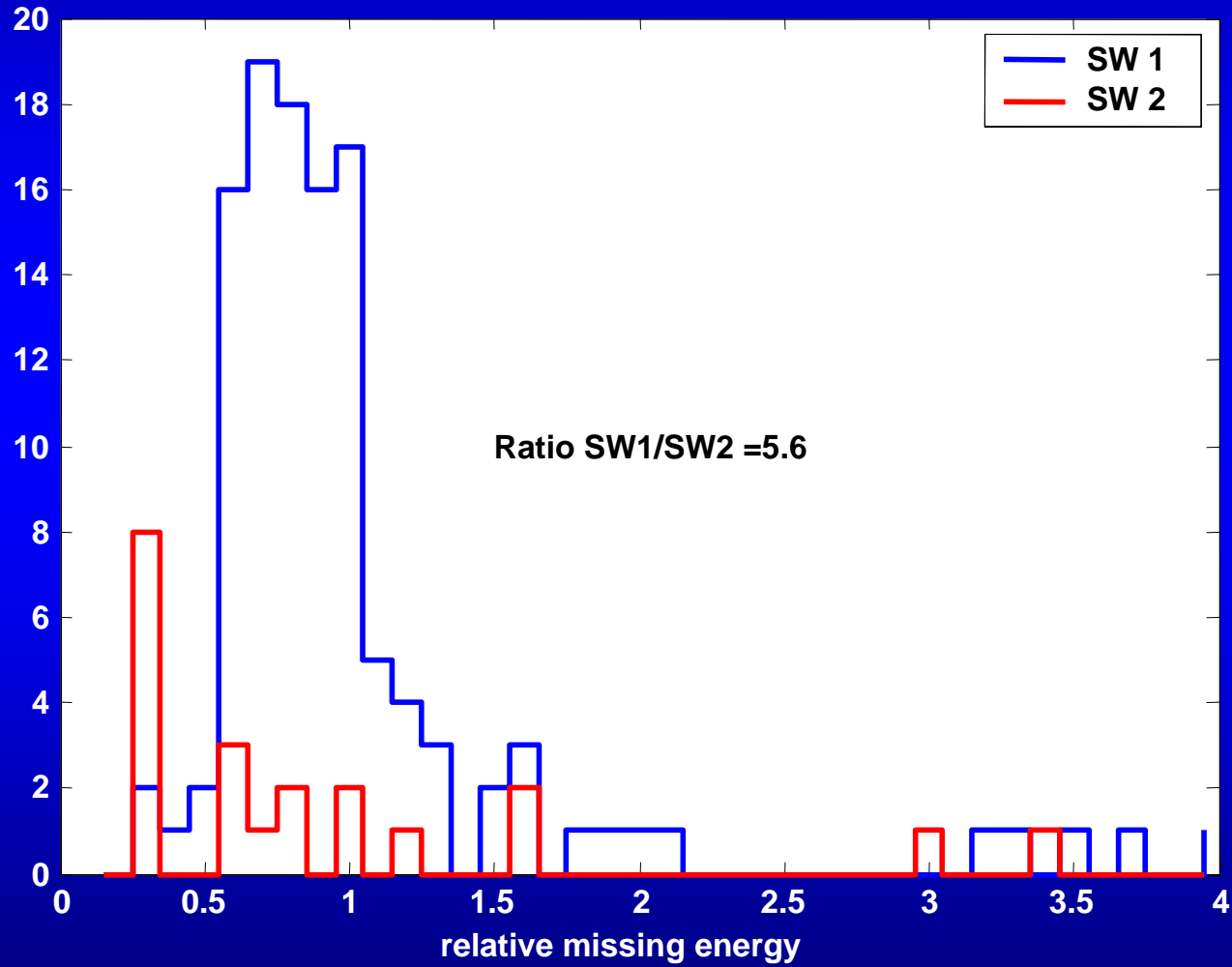


PF1 = 1.01 PF2 = 0.00 PFAC = 1.01 DTC = 125





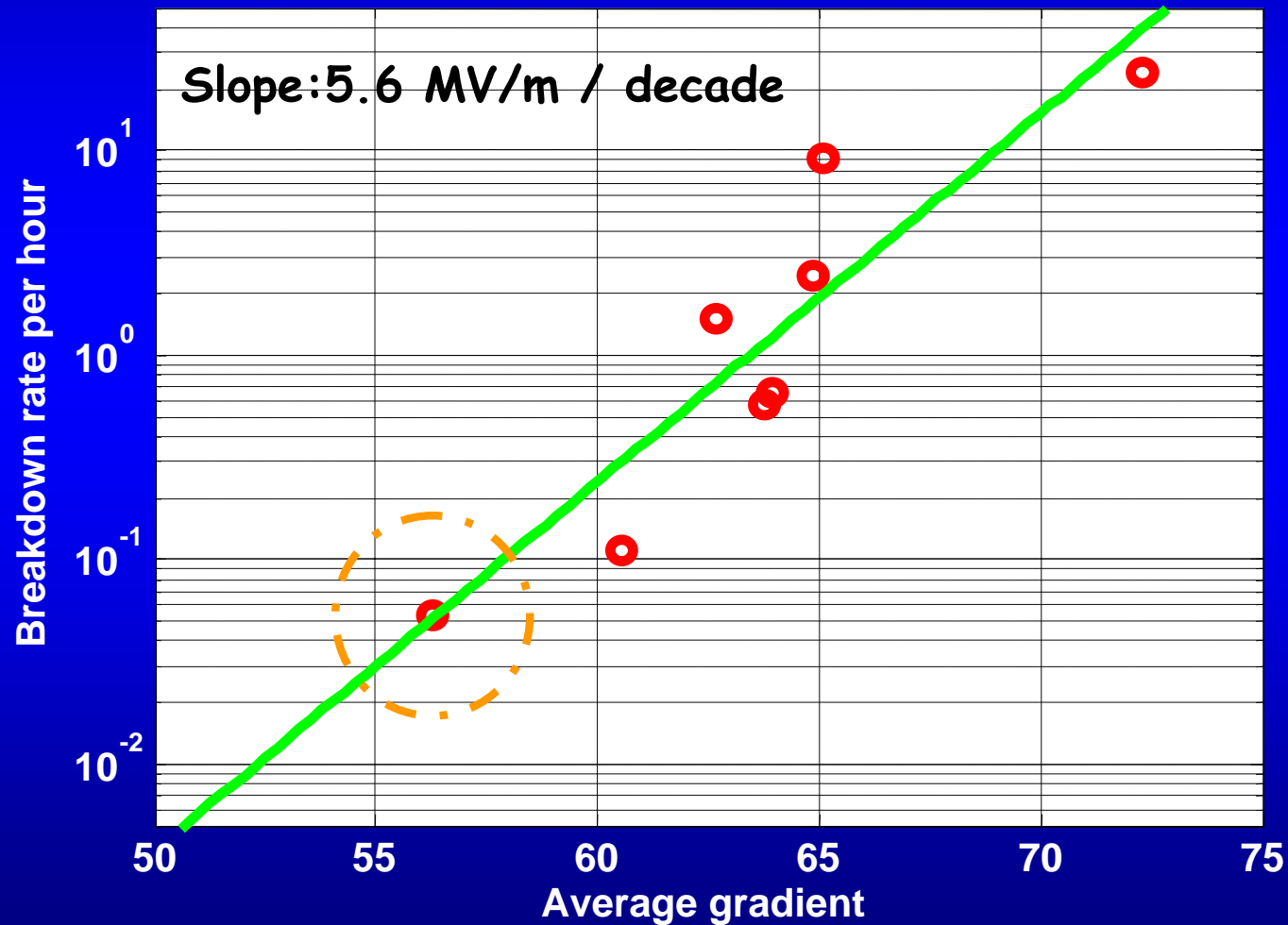
Processing, 270 ns, ~ 70 MV/m







NLC-goal achieved at 55 MV/m !





## First fully slotted structure

Length:	60 cm
Phase advance:	150 deg
Group velocity:	3 %
Es/Eacc:	2.1 elliptical
$P_{in}$ (65 MV/m):	69 MW
Coupler:	mode launcher
Preparation:	H <sub>2</sub> -bonding/brazing

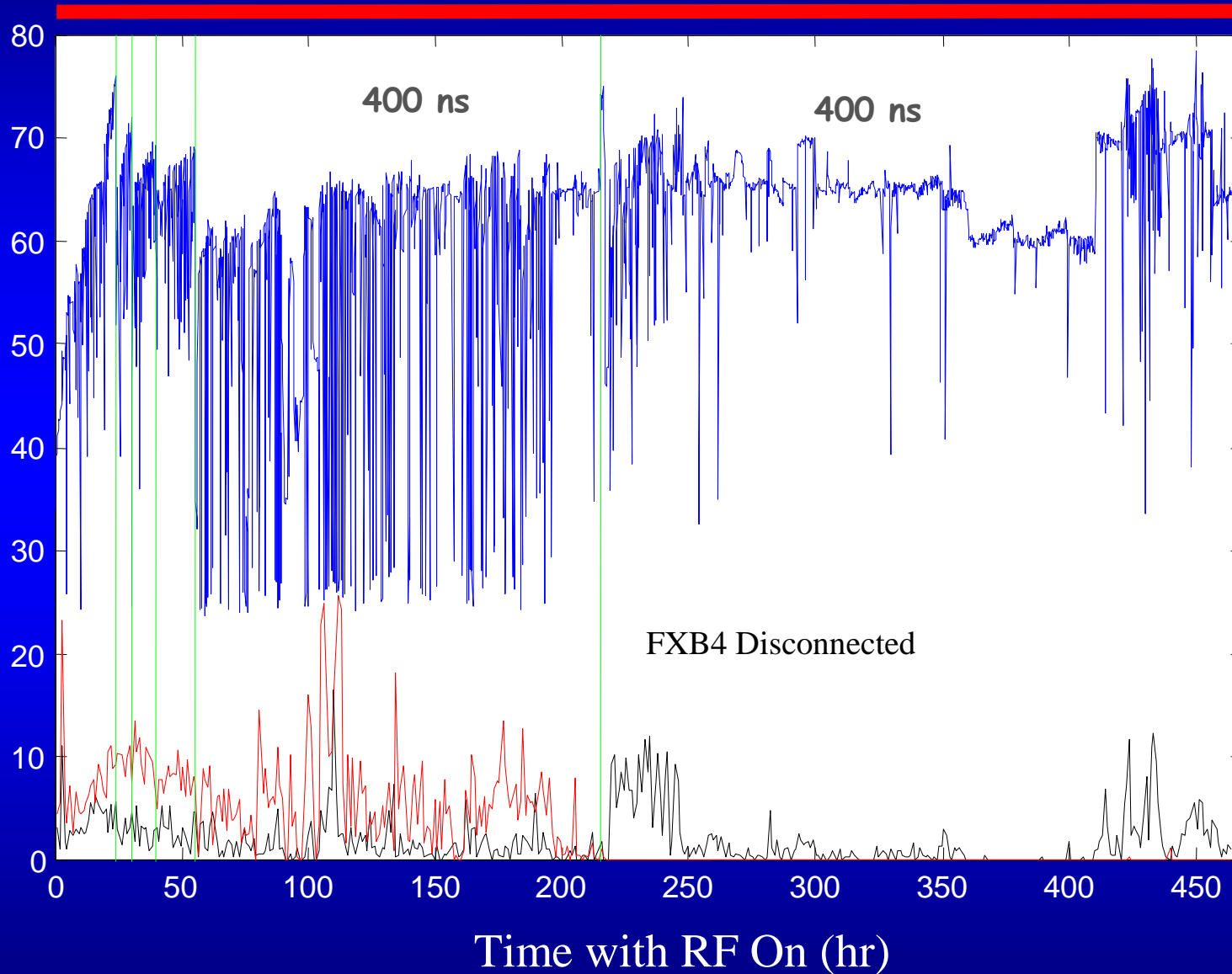
## Structure without Hydrogen

Length:	60 cm
Phase advance:	150 deg
Group velocity:	3 %
Es/Eacc:	2.2
$P_{in}$ (65 MV/m):	63 MW
Coupler:	waveguide coupler
Preparation:	Ar-brazing

## H60vg3S18/FXB004-History

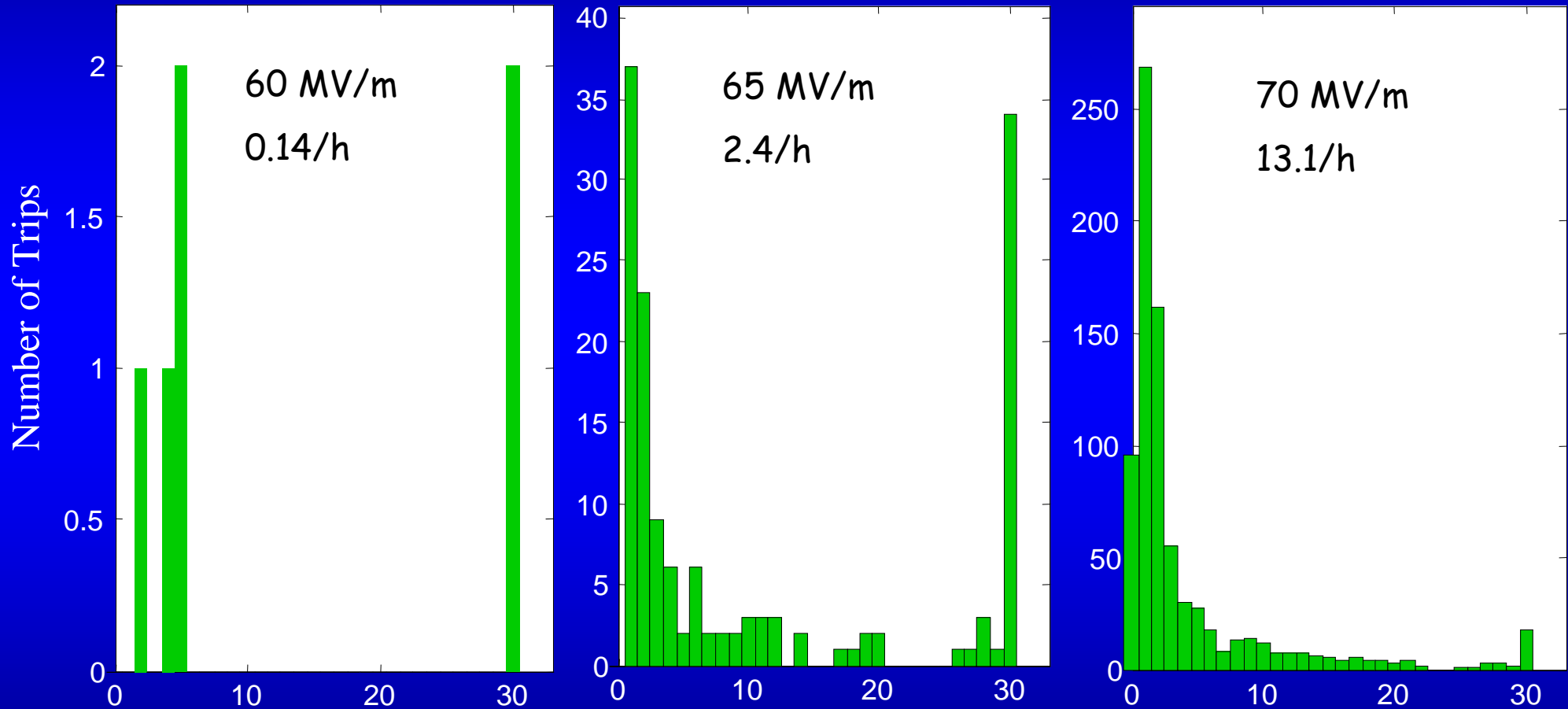


Structure Gradient (MV/m) and Trip Rate/5 (#/hr)  
(S18 = Black, FXB4 = Red)





- Processing stopped because of time constraints
- Reached 65 MV/m, 400 ns, ~ 10 BD/h
- Slightly higher gradient than H60vg3S18
- New Fermilab waveguide coupler showed no problems now baseline design for NLC
- No conclusion about performance at this point

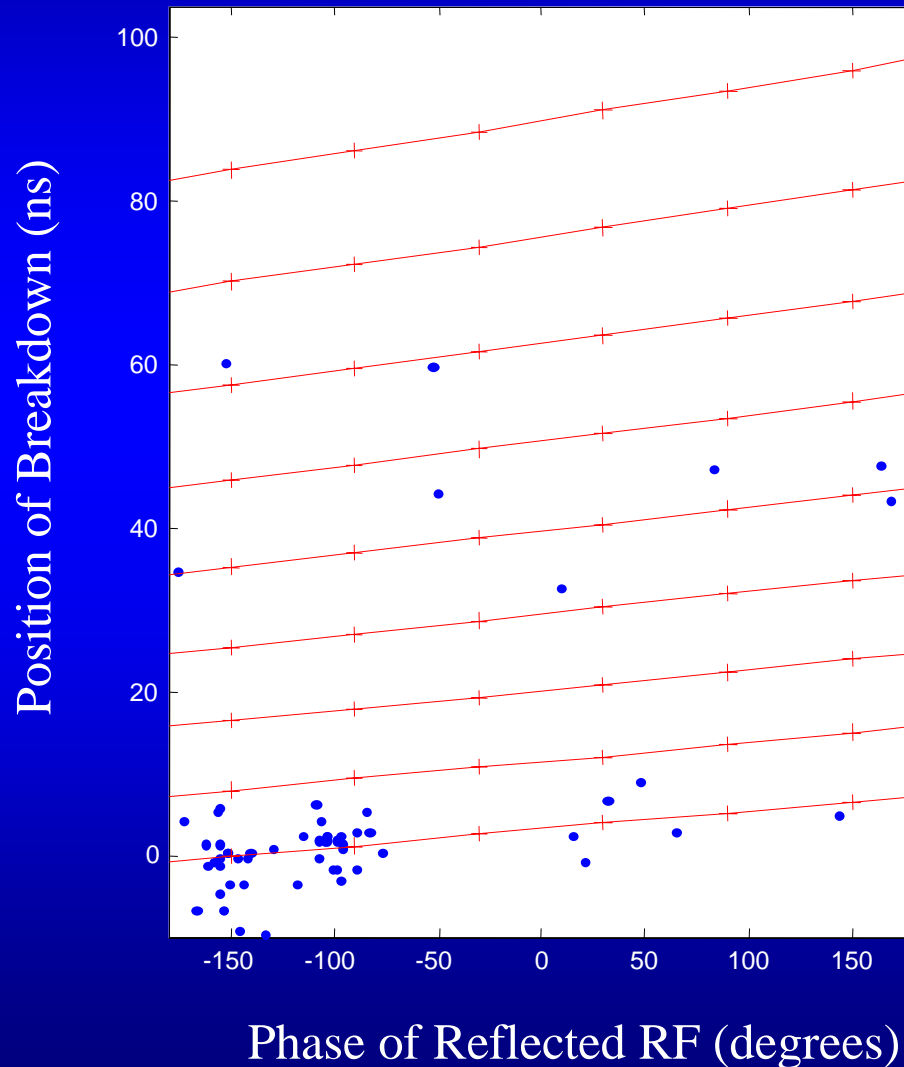


Time Between Trips (Minutes) (Times > 30 Plotted at 30)

# BD-Location - H60vg3S18



All Events at 65 MV/m



Almost all events are in the first two cells these are **soft** events

Boroscope inspection showed discoloration but no clear cause

Input waveguides were found to be out of phase by 20 degrees

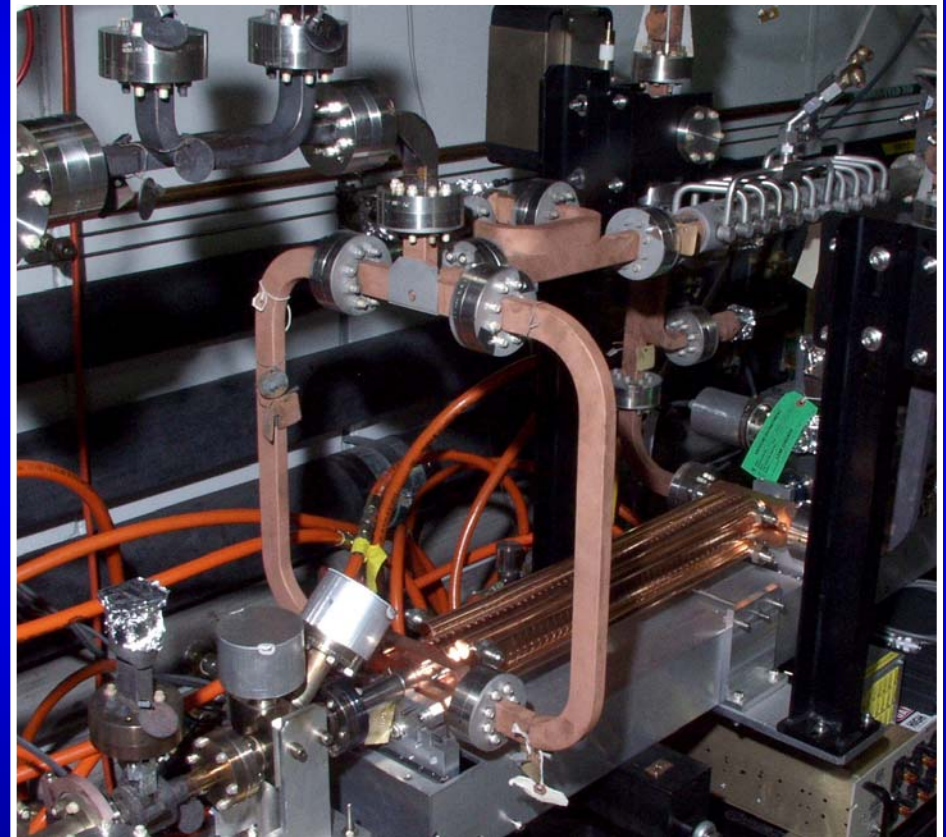
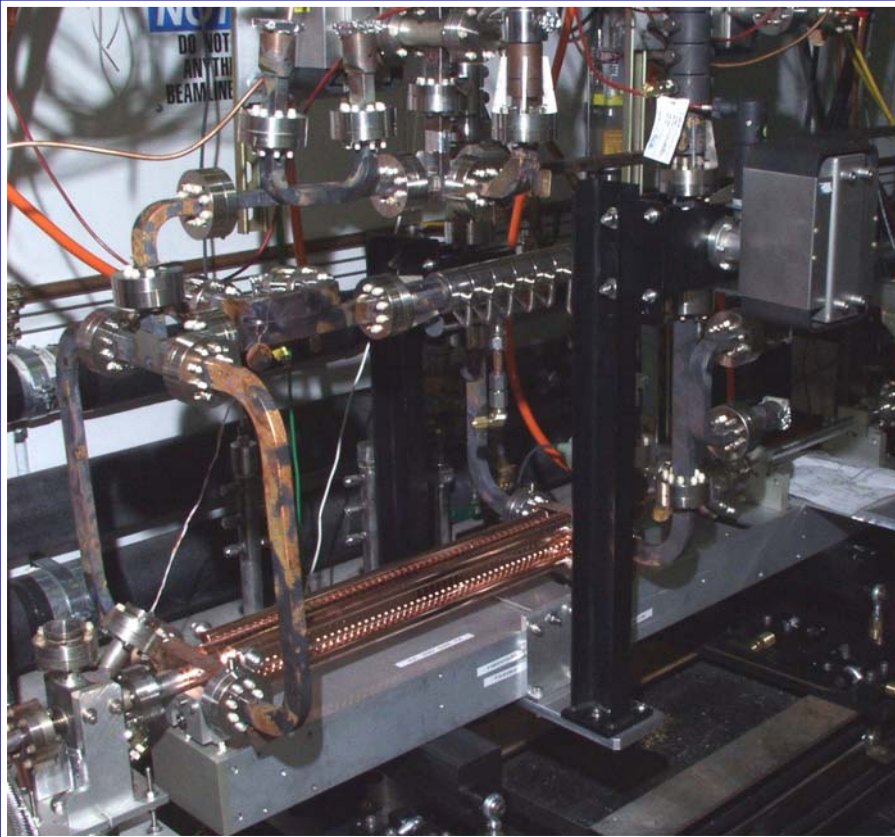
Simulations show only slight field enhancement

Retesting with matched arms being considered

# NLCTA

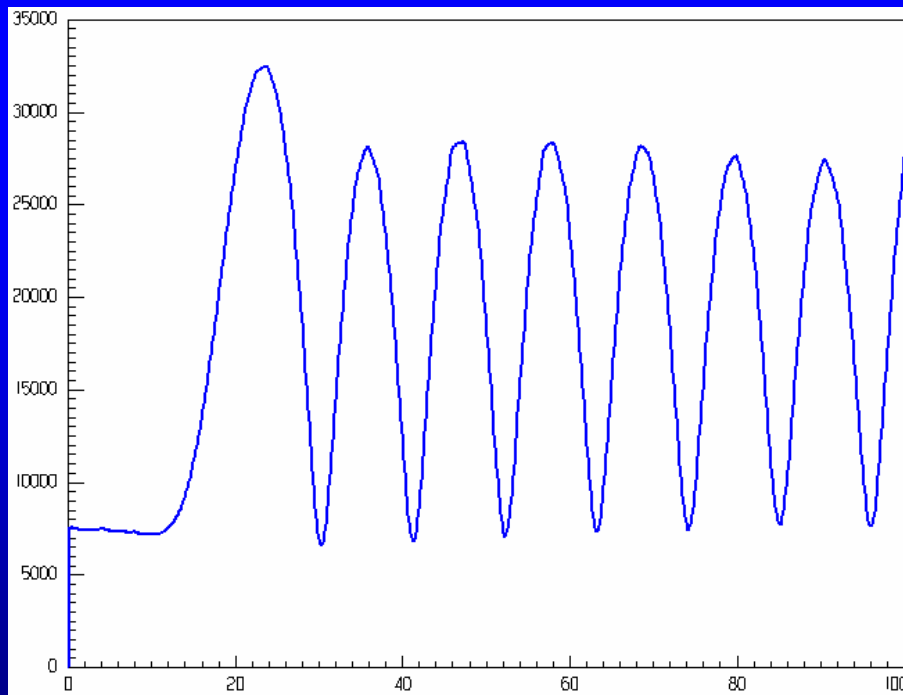
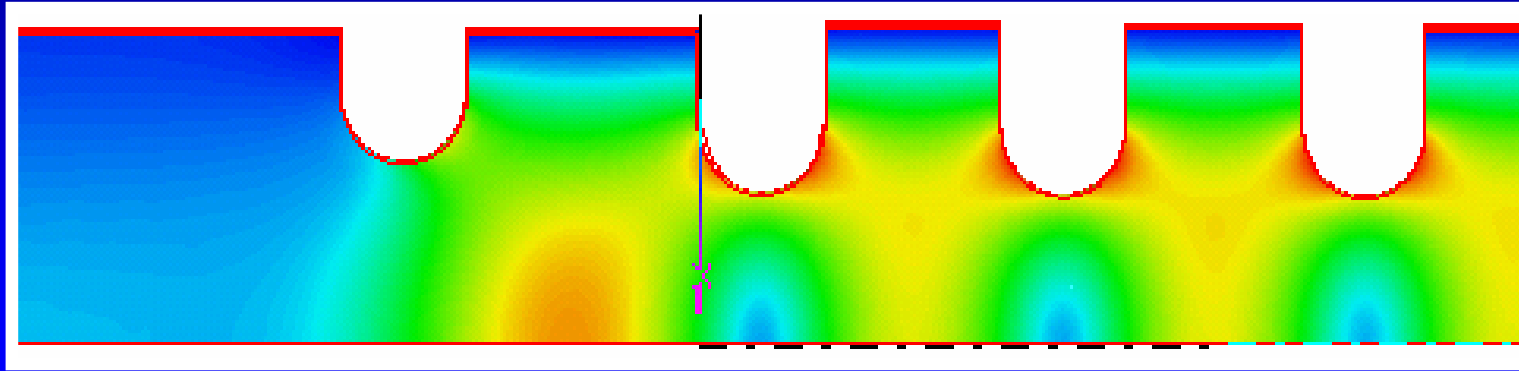
Next Linear Collider  
Test Accelerator

## H60vg3S18/FXB004

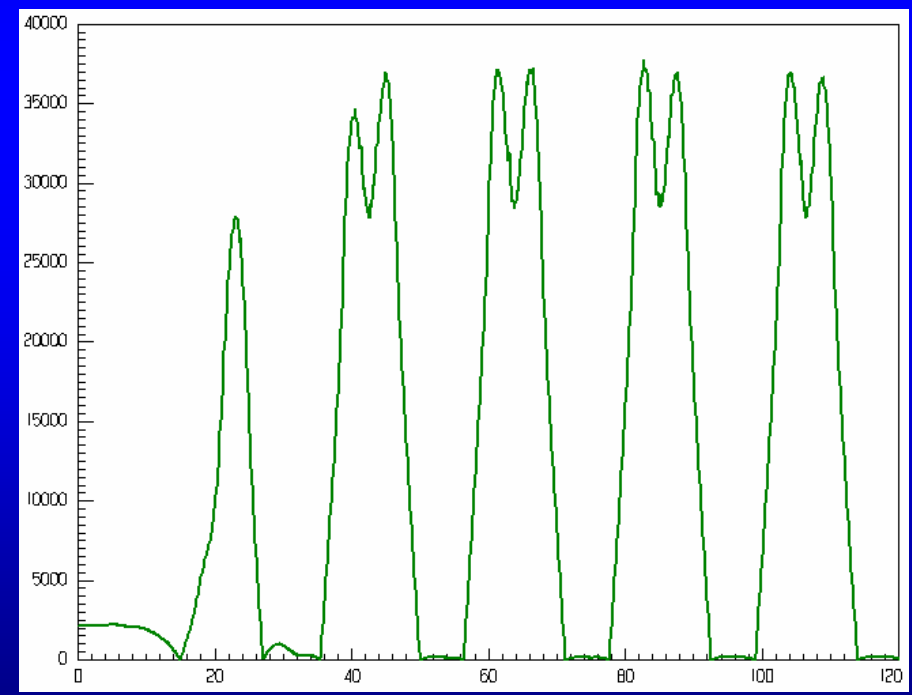


Steffen Döbert, SLAC/NLC

# ML coupler - H60vg3S18



axis



surface





## Clamped constant impedance structure with Mo-irises

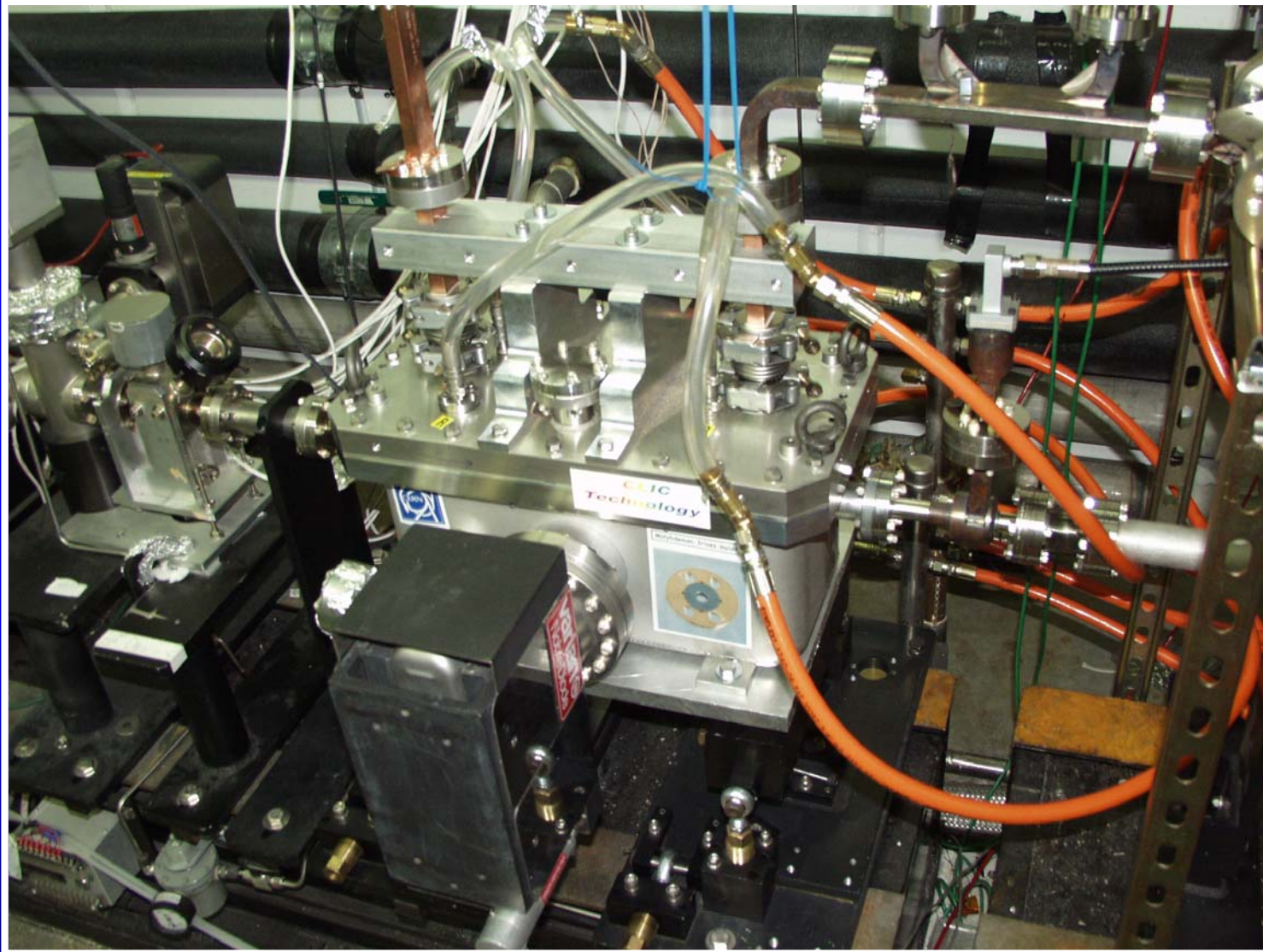
Length:	30 cm
Phase advance:	120 deg
Group velocity:	4.65 %
Es/Eacc:	2.2
$P_{in}$ (65 MV/m):	90 MW
Coupler:	mode launcher
Preparation:	Clamping, no bake



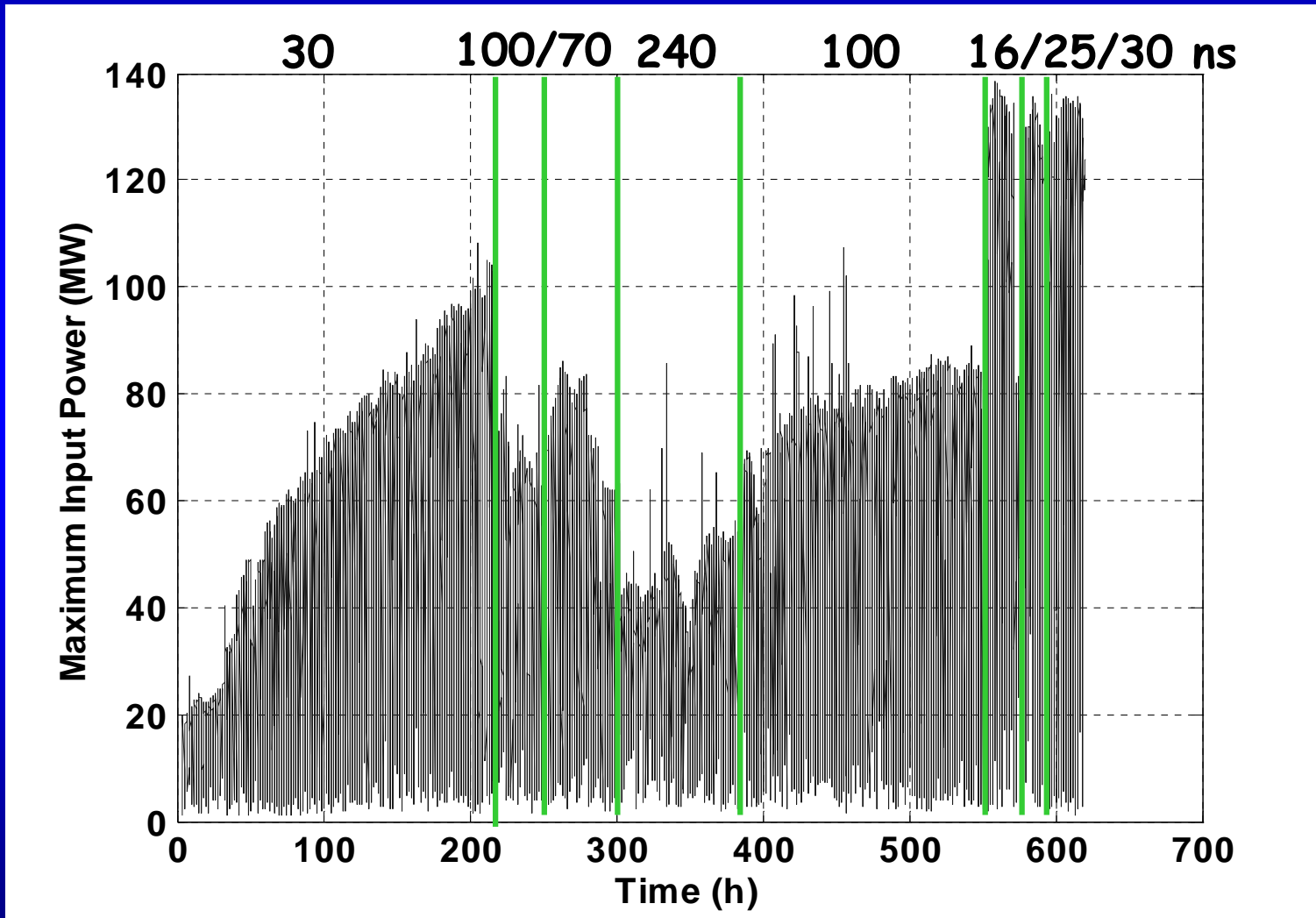
# NLCTA

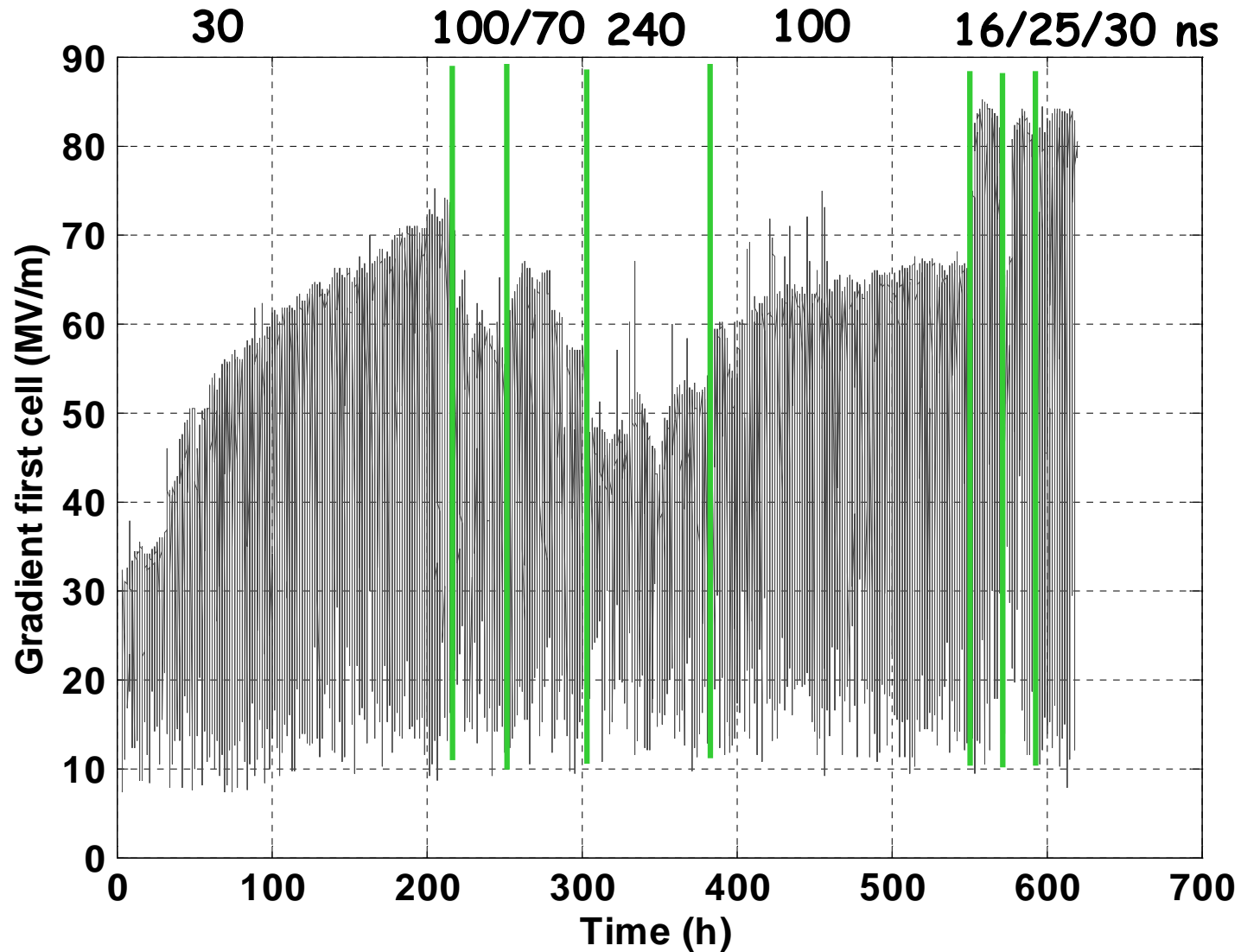
Next Linear Collider  
Test Accelerator

## CERN-Mo-structure in NLCTA



Steffen Döbert, SLAC/NLC





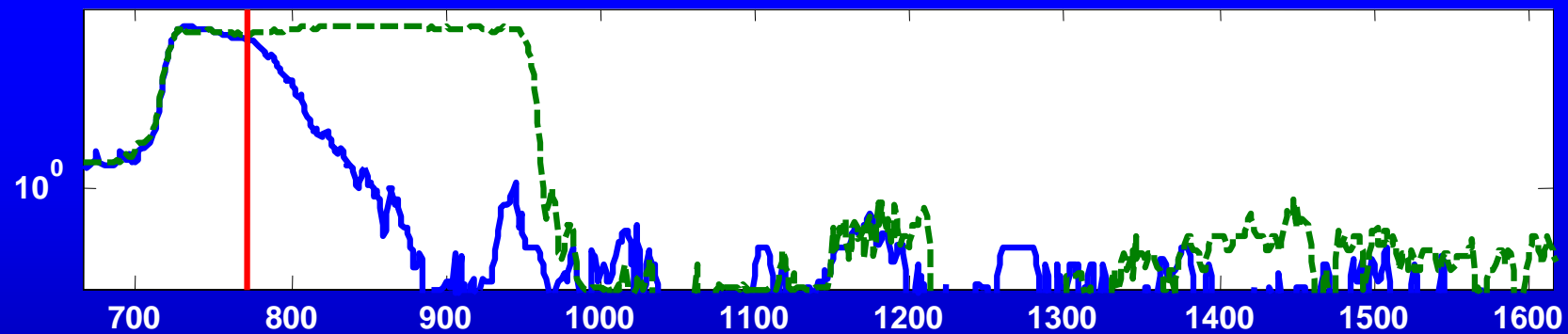
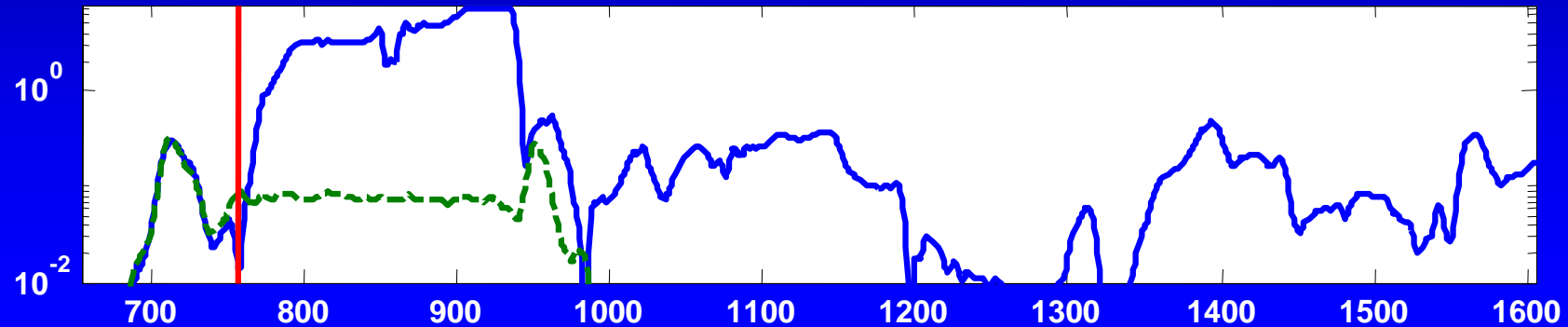


- Vacuum can arrived vented
- Rep Rate change from 60 to 10 had no influence
- For short pulse (30 ns) power limit of 140 MW was reached
- Gas activity went down towards the end of conditioning
- Dark current was reduced and beta higher (14 to 30)
- No evidence for damage from RF-data
- Breakdown counter stopped at 28500  
but may be a factor 4 more
- Total run time: 700 h

## Pulse Example - C30vg4 - Mo



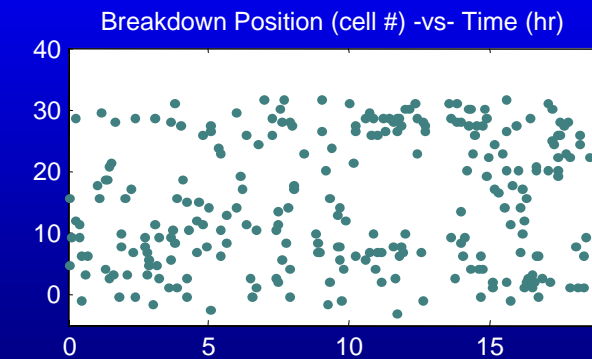
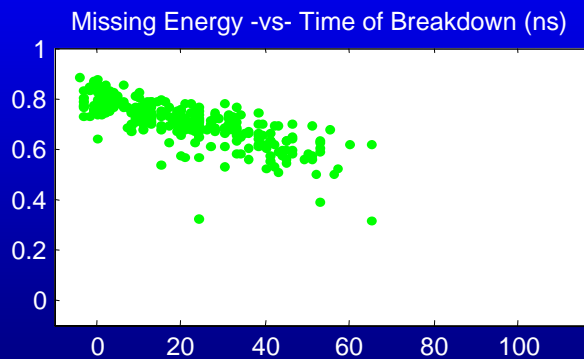
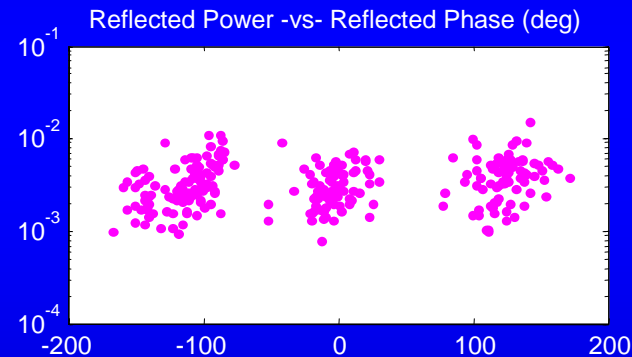
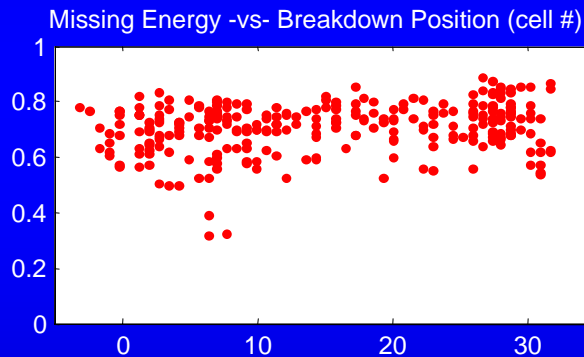
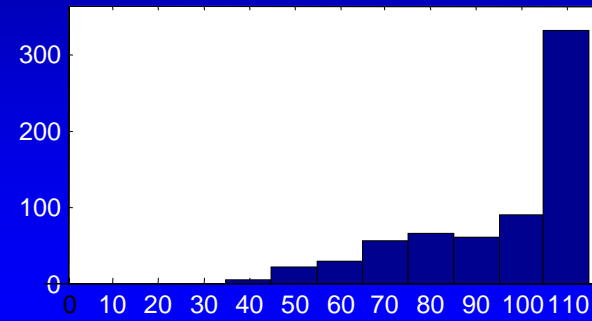
FME = 0.75 DS = 3 DP = 41 DT = -6 EV = 2

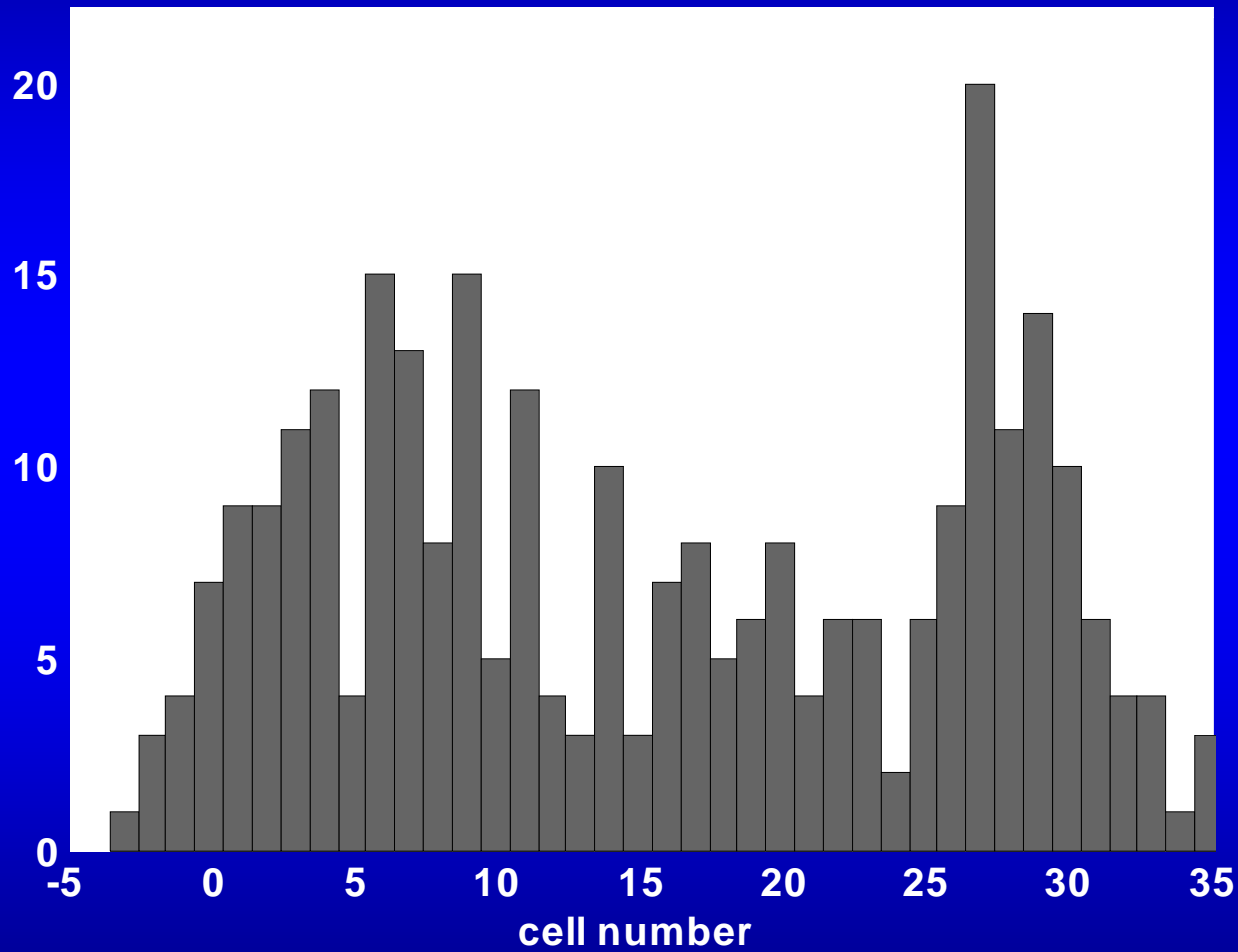




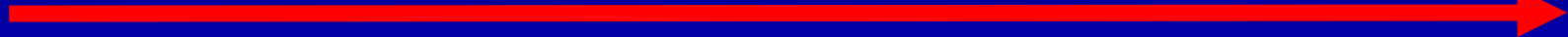
100 ns; 60-65 MV/m

24-27 C30vg4-Mo: Pulse Width (ns): 276 / 366 / 266

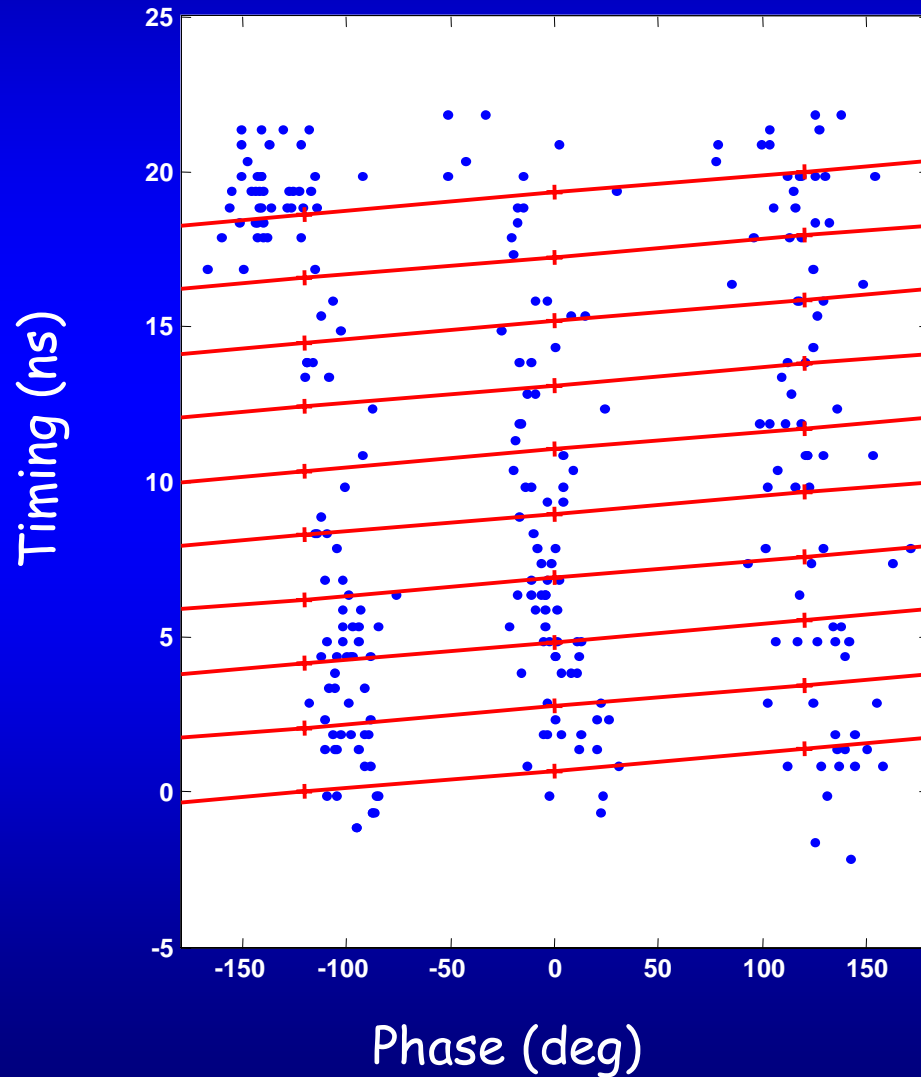




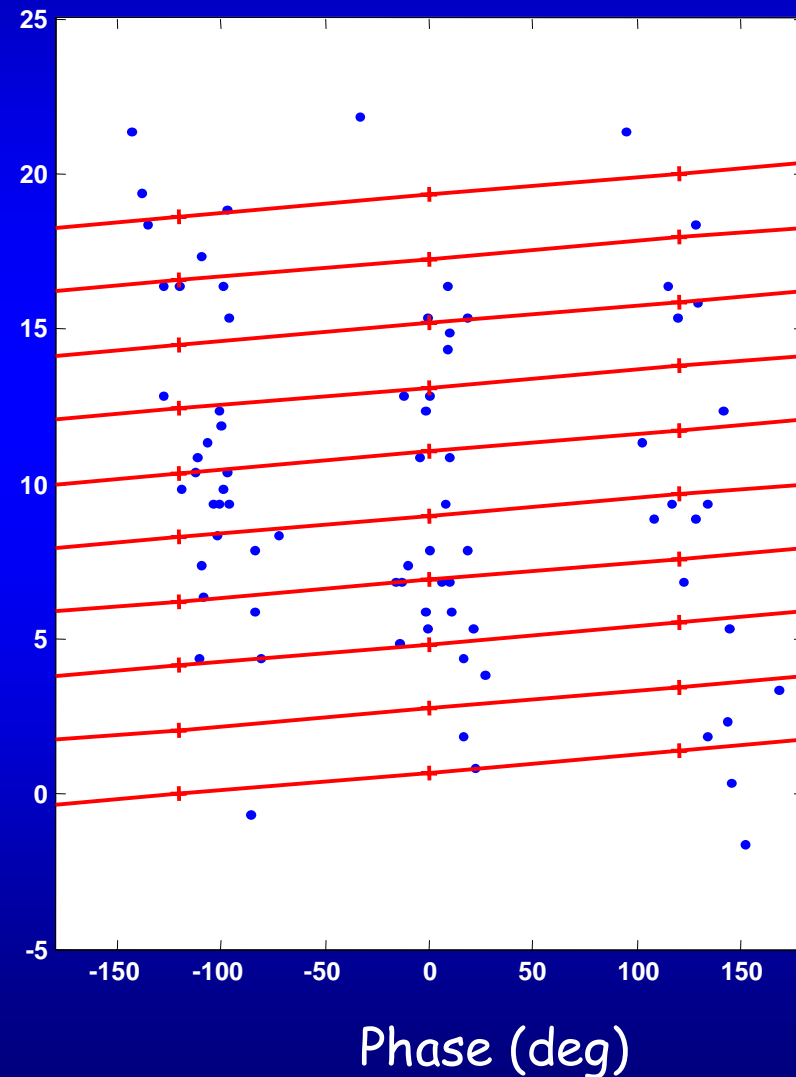




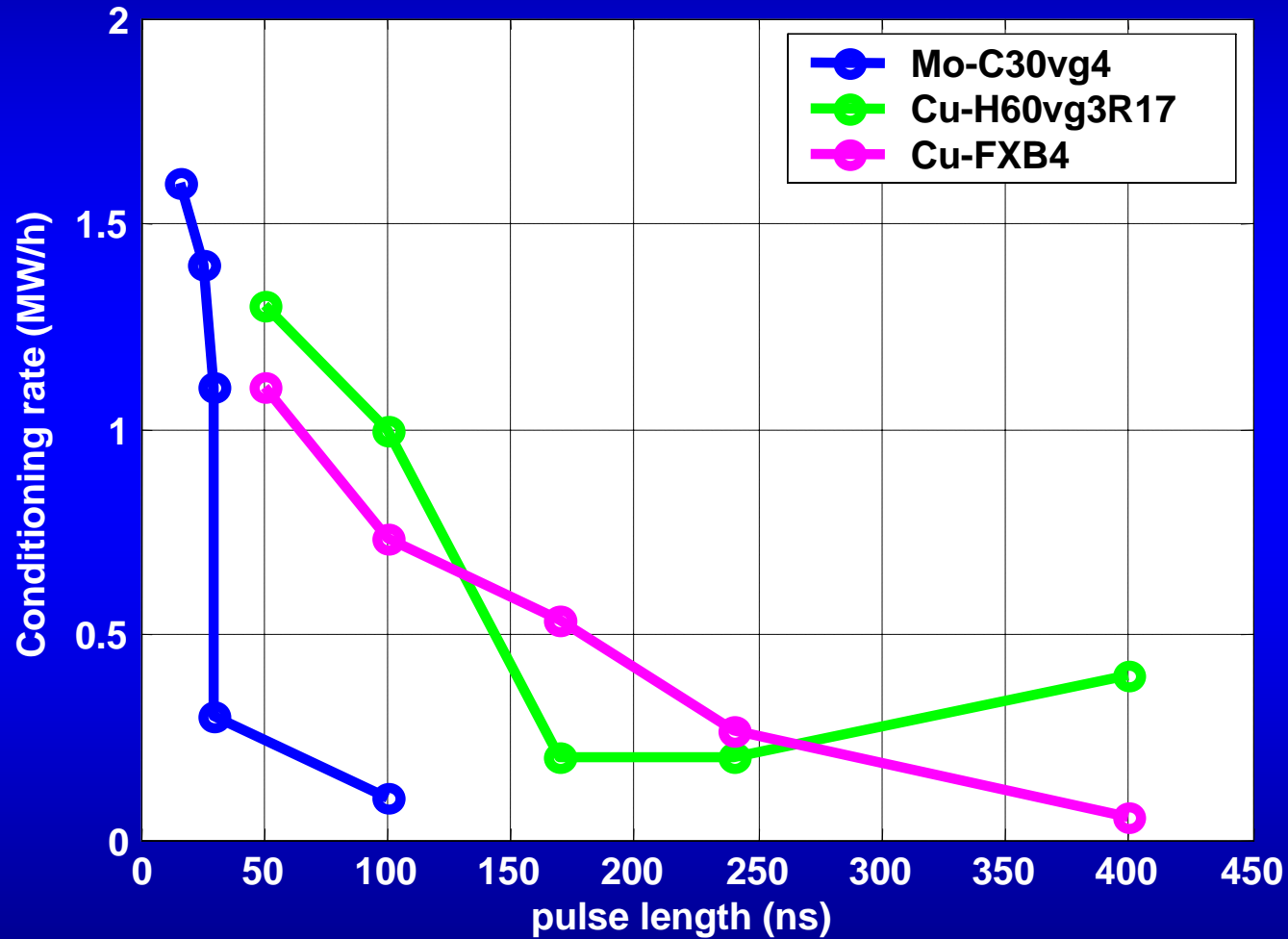
First 100 ns run



Last 100 ns run

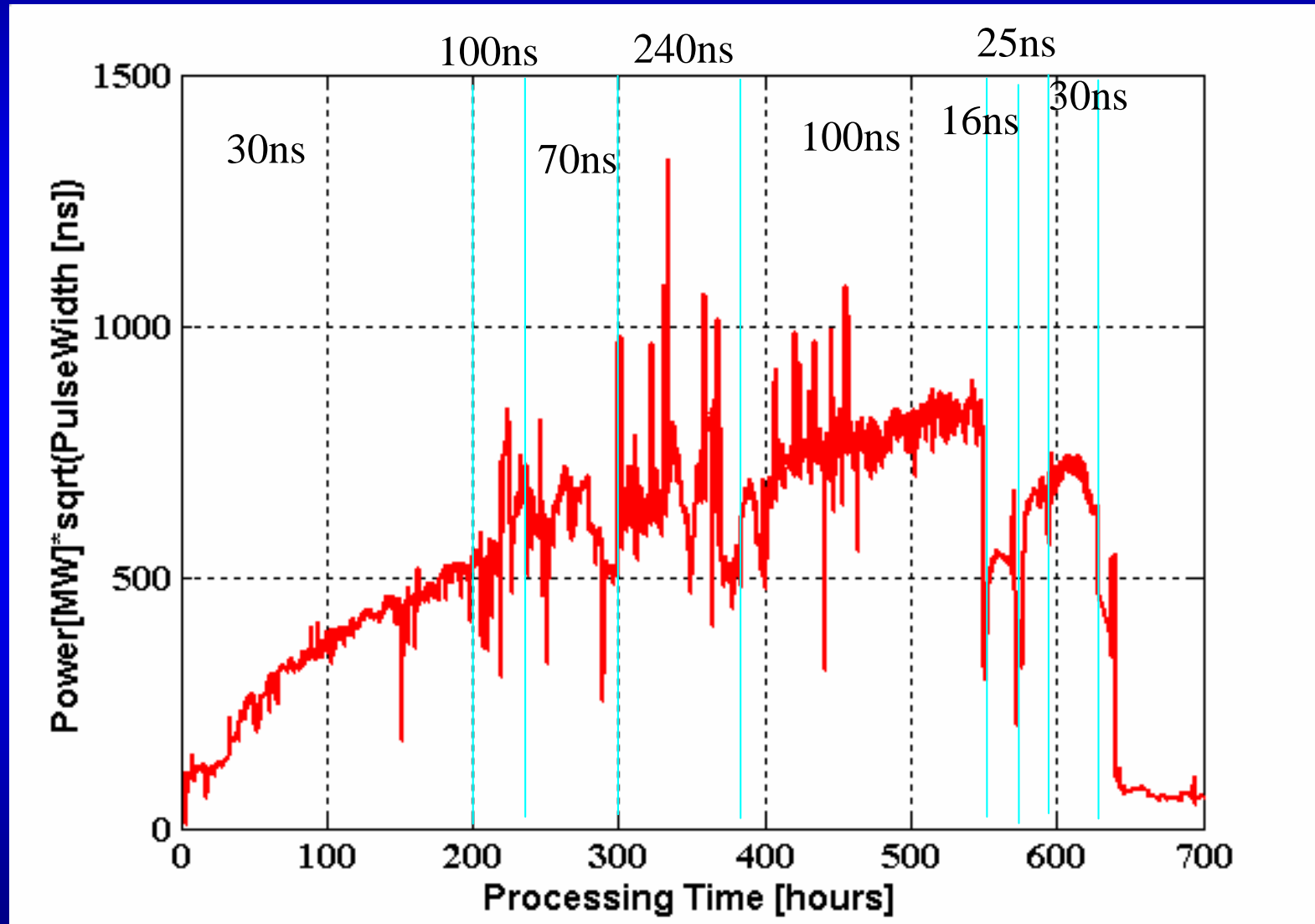


# Conditioning rates - C30vg4-Mo





## Conditioning - C30vg4-Mo



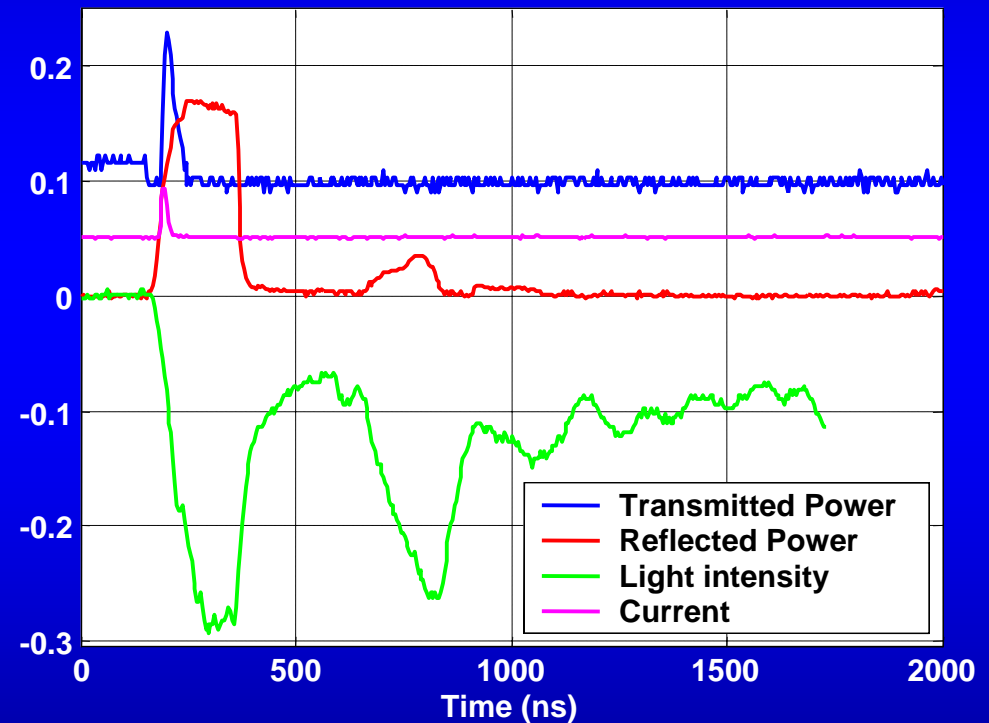
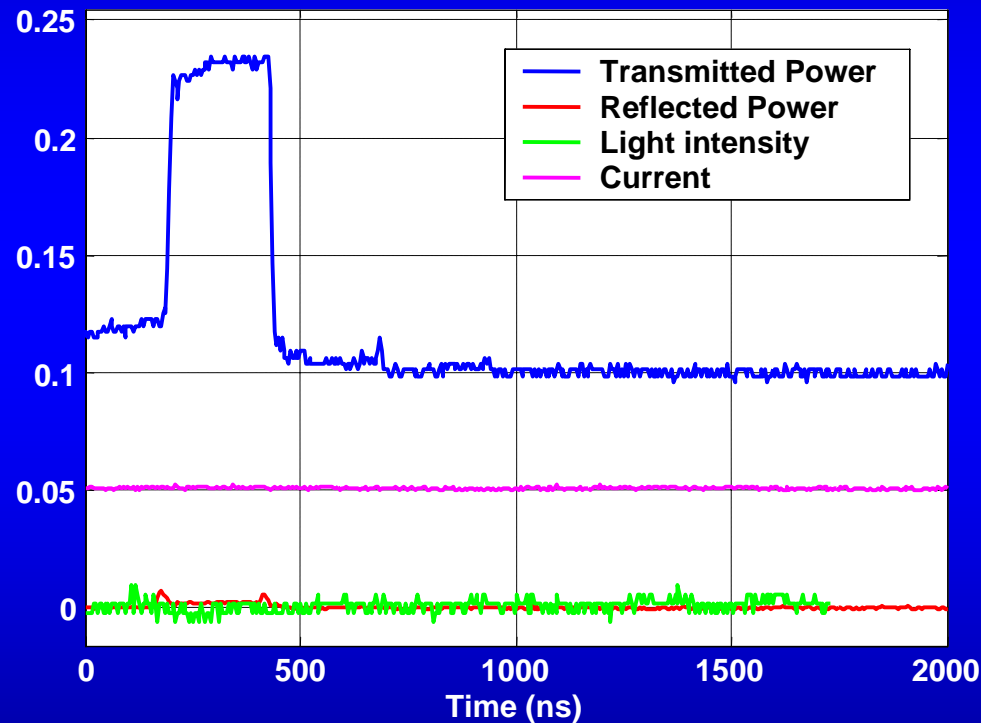
## Light emission - C30vg4-Mo



No breakdown

240 ns pulse width

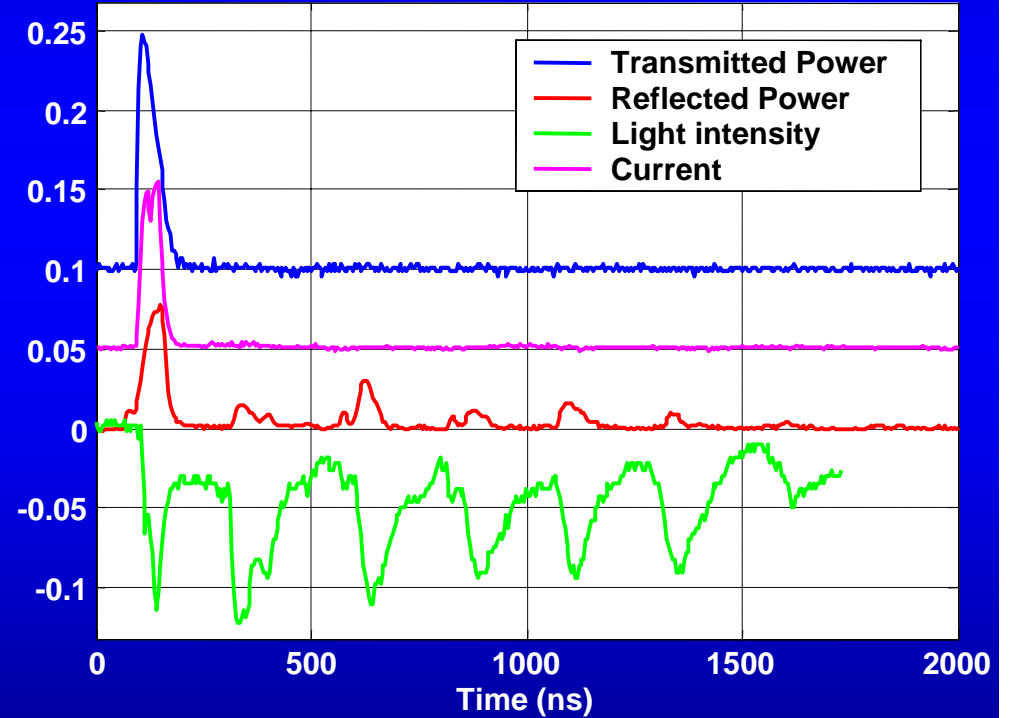
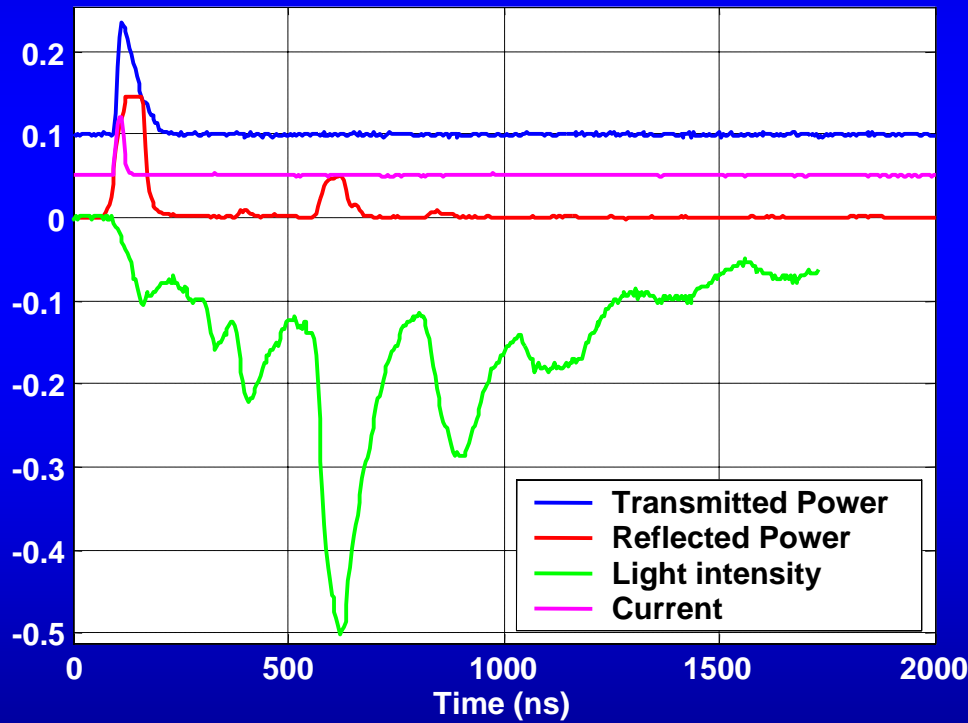
breakdown

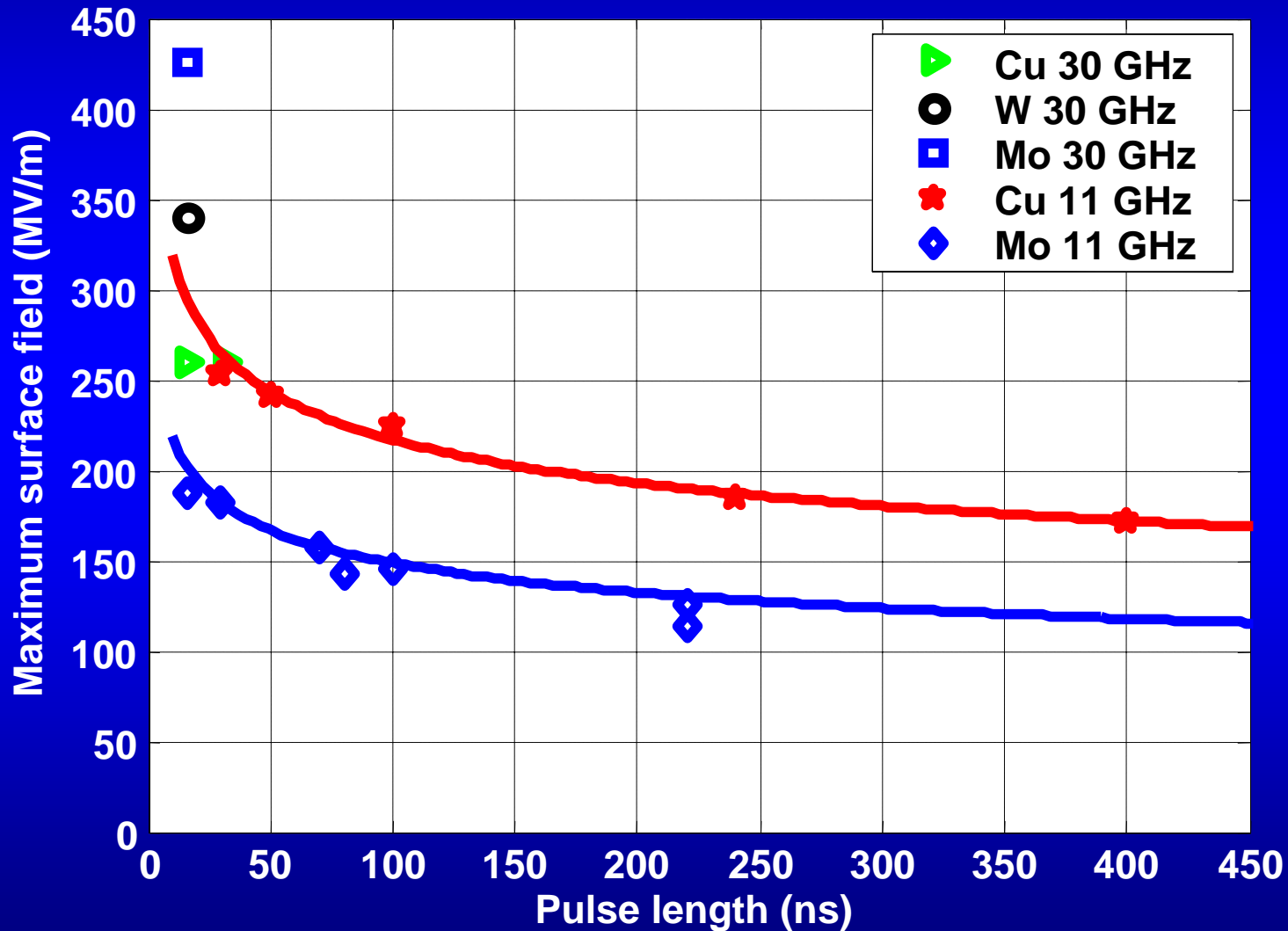


# Light emission - C30vg4-Mo

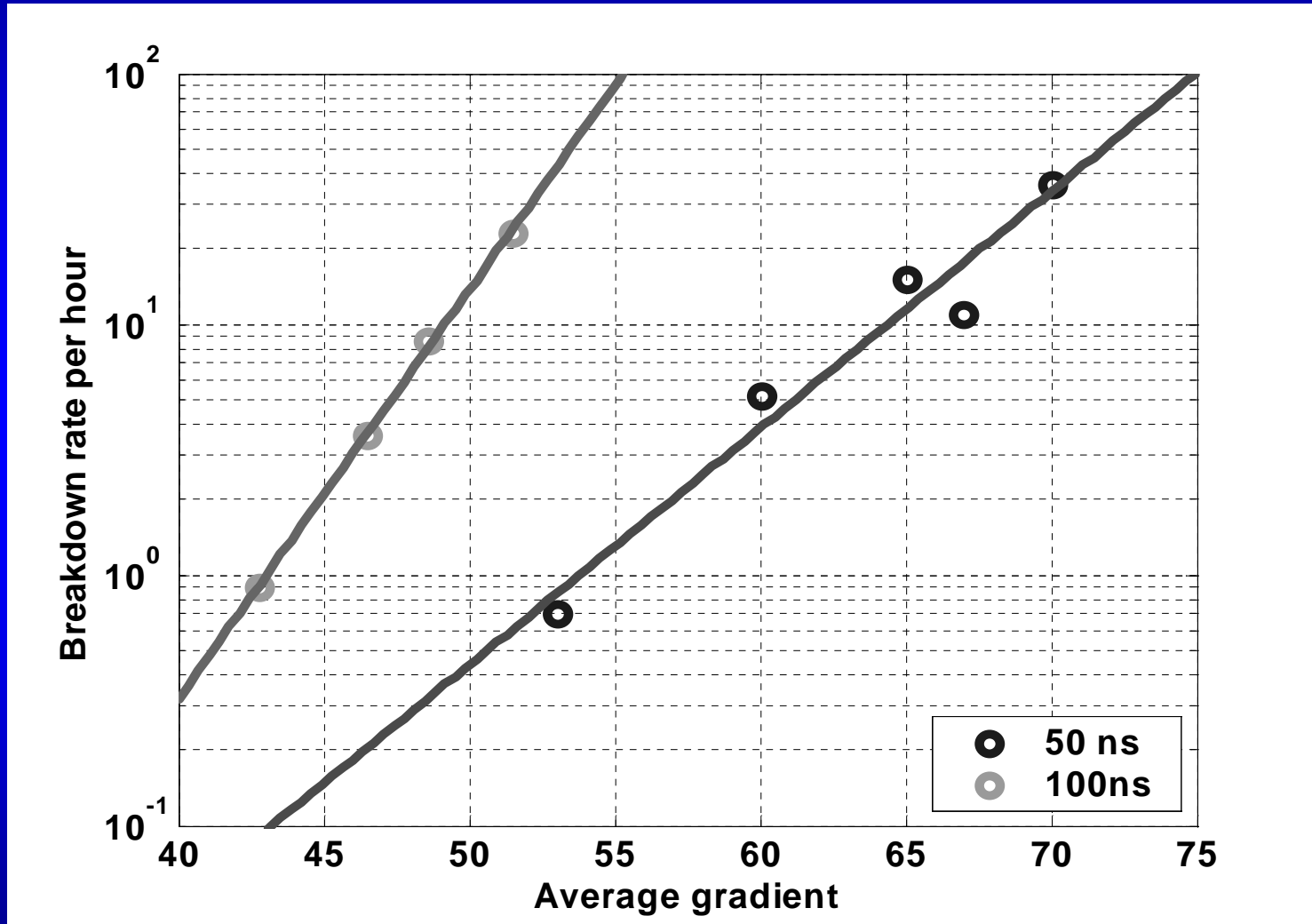


Breakdowns at 100 ns pulse width





# BD-rates C30vg4-Mo



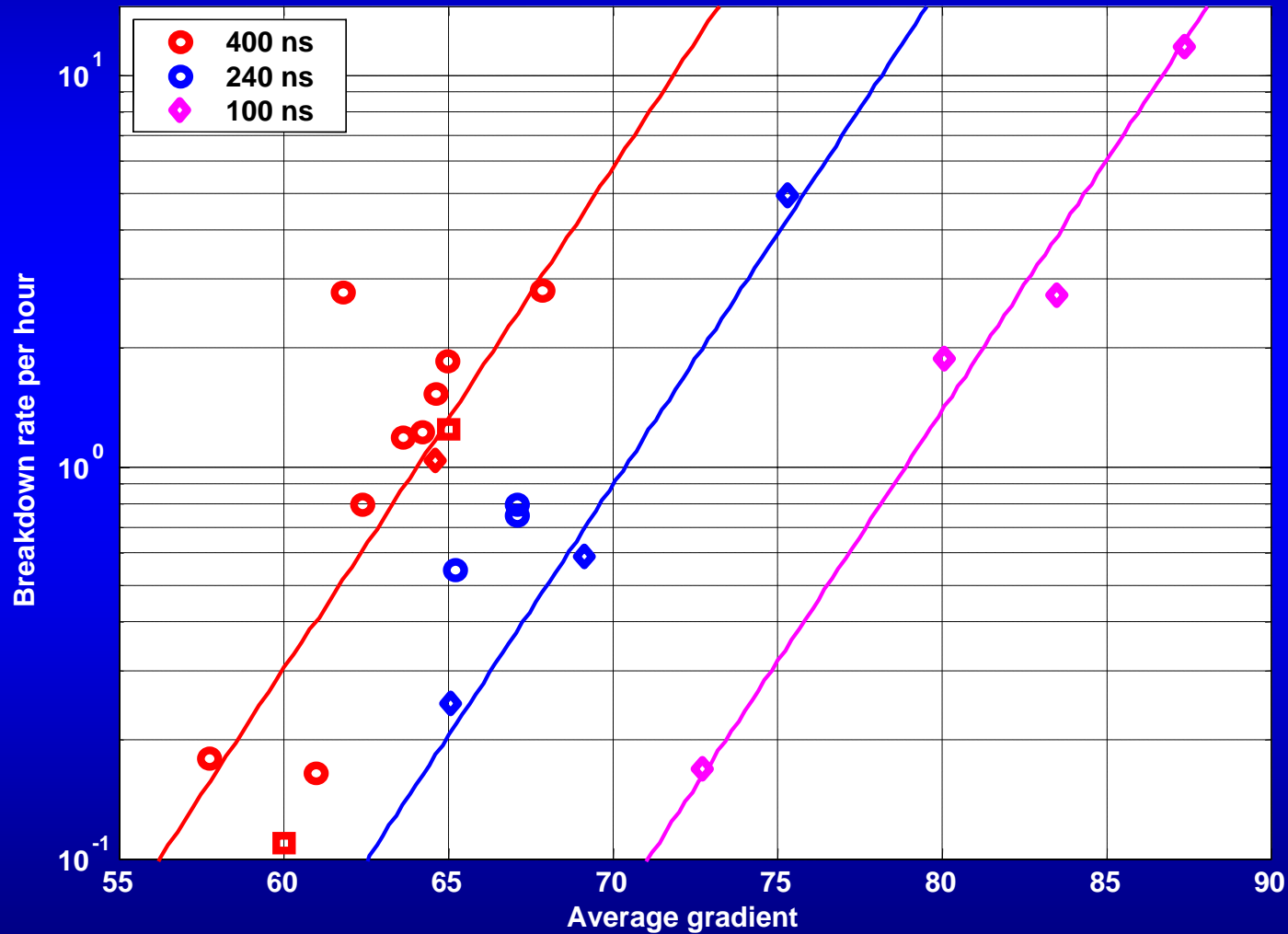
Slopes:

100 ns; 6.1

50 ns; 10.6

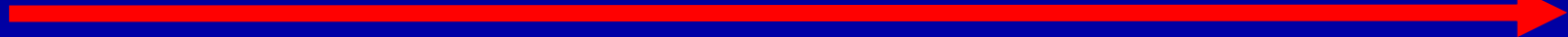


## Breakdown-rates vs pulse length

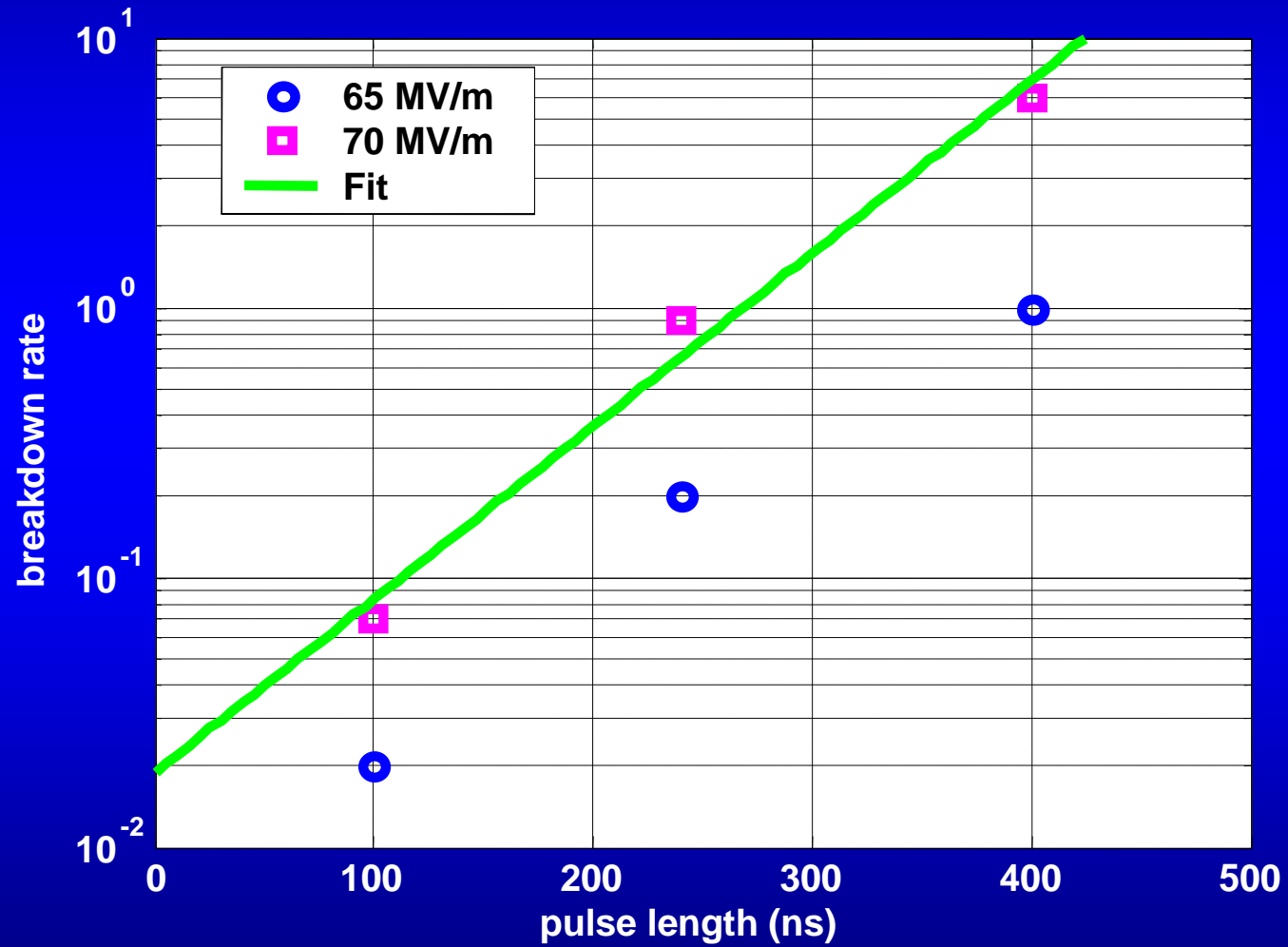


Slope:  
8 MV/m  
per decade





## Breakdown-rates vs pulse length





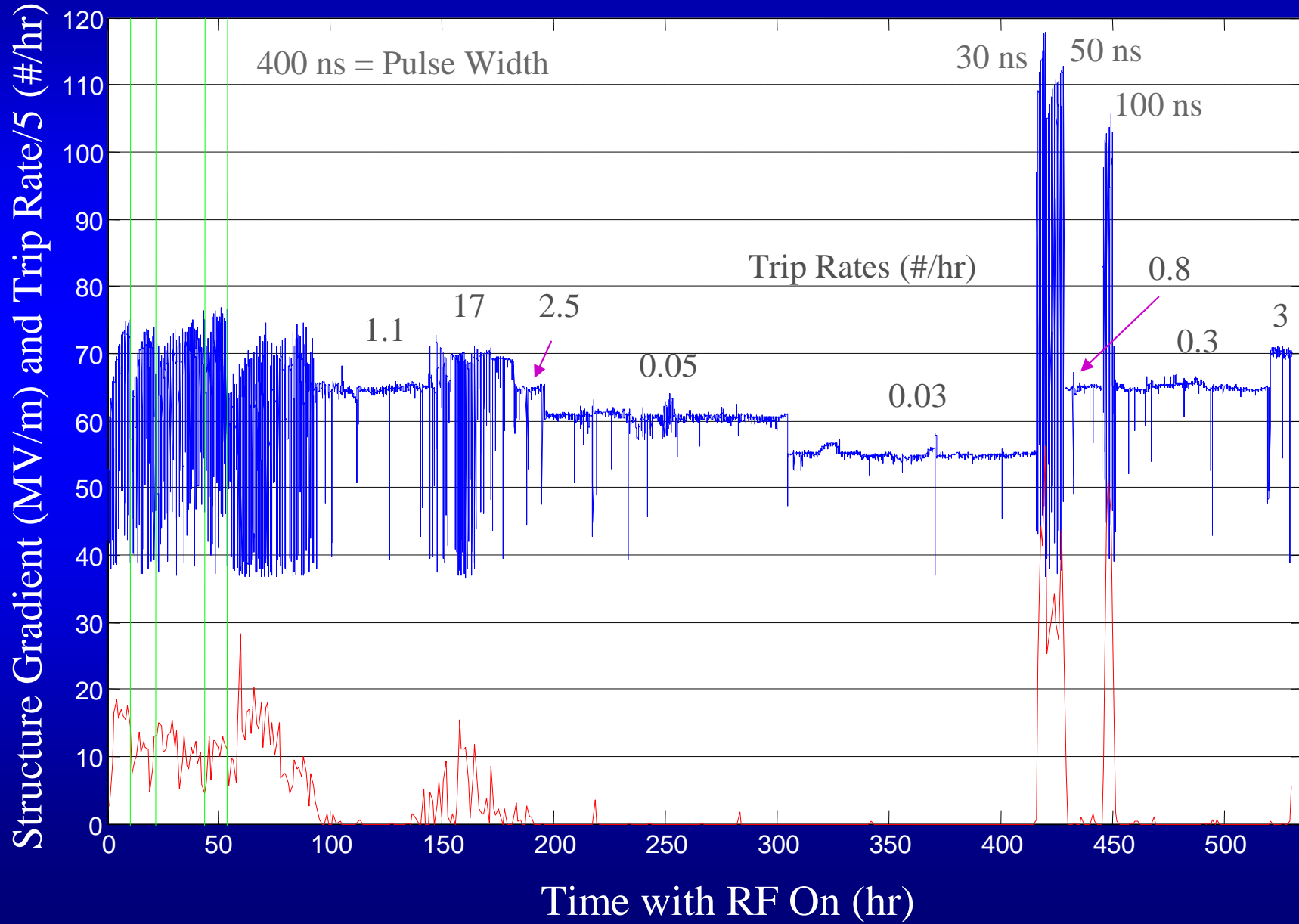
- Performance was worse than expected
- Very slow processing rate
- No effect on average heating
- No indication of damage so far
- Indication that the processing was not finished yet
- Similar pulse length dependence as Copper
- Didn't connect to CERN 30 GHz data at short pulses
- Basically no surface preparation was done
- KEK/SLAC single cell tests will be important

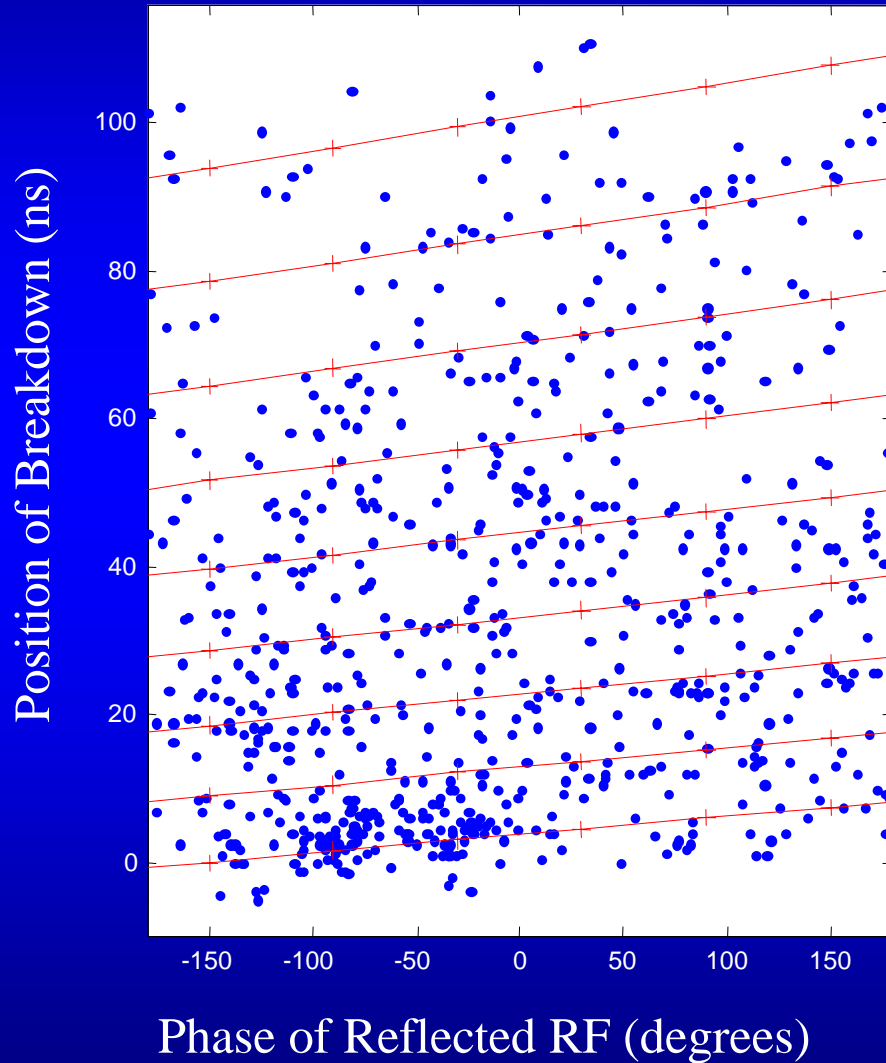
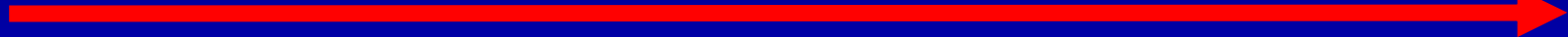


## Non sloted $a/\lambda = 0.17$ prototyp

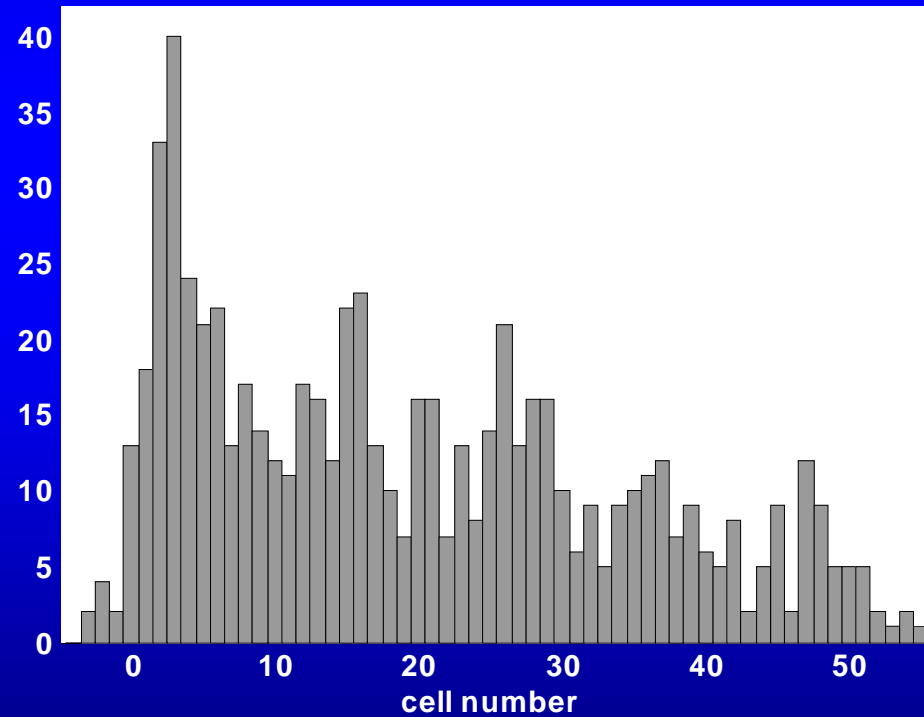
Length:	60 cm
Phase advance:	150 deg
Group velocity:	3 %
Es/Eacc:	2.1 elliptical
$P_{in}$ (65 MV/m):	57 MW
Coupler:	mode launcher coupler
Preparation:	SLAC

Leak problems during insitu bake



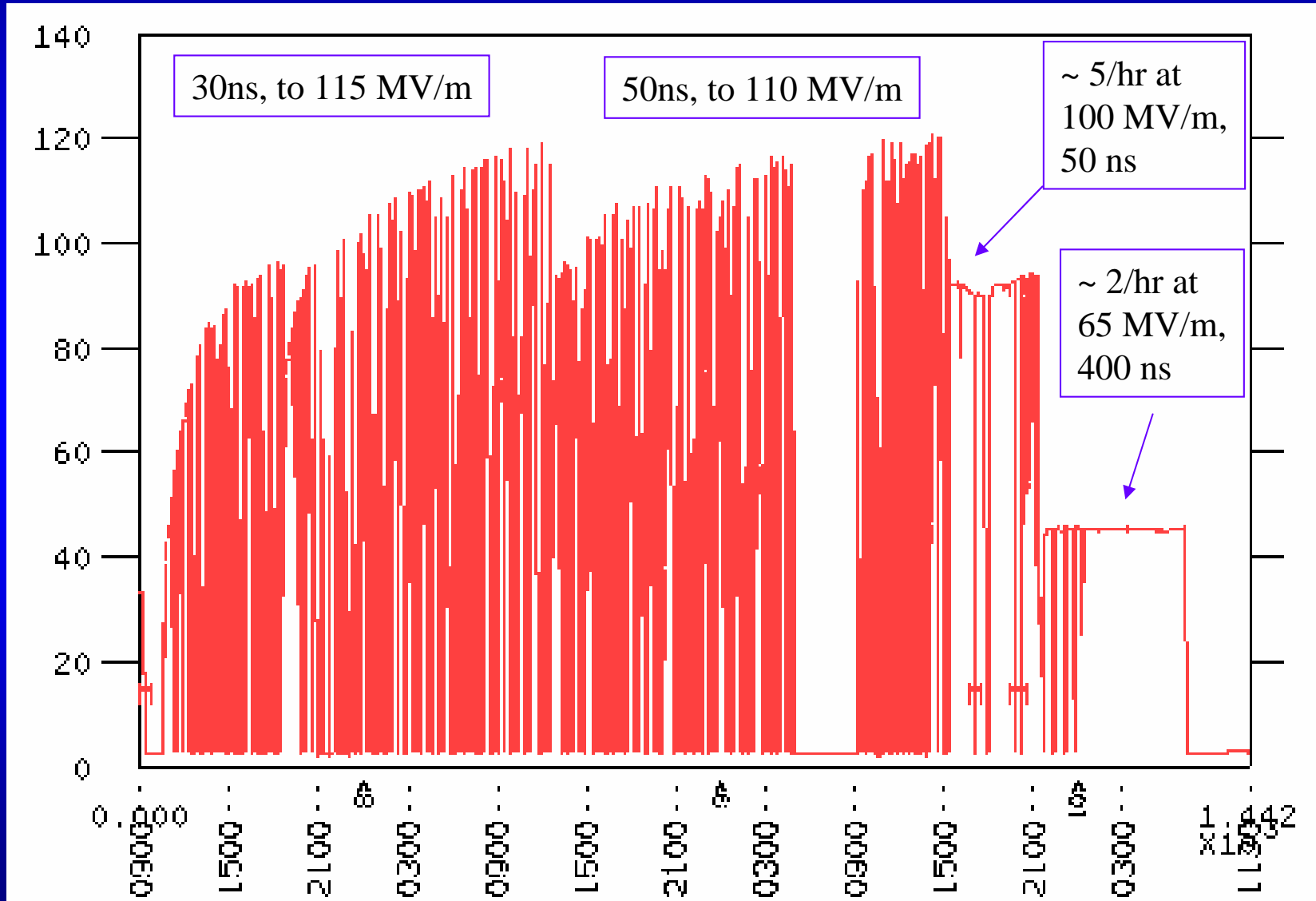


**Breakdown Statistics at 60-74 MV/m,  
400 ns Pulse Width**  
**Breakdown rate at 65 MV/m and 400 ns:  
1-2/ hour**

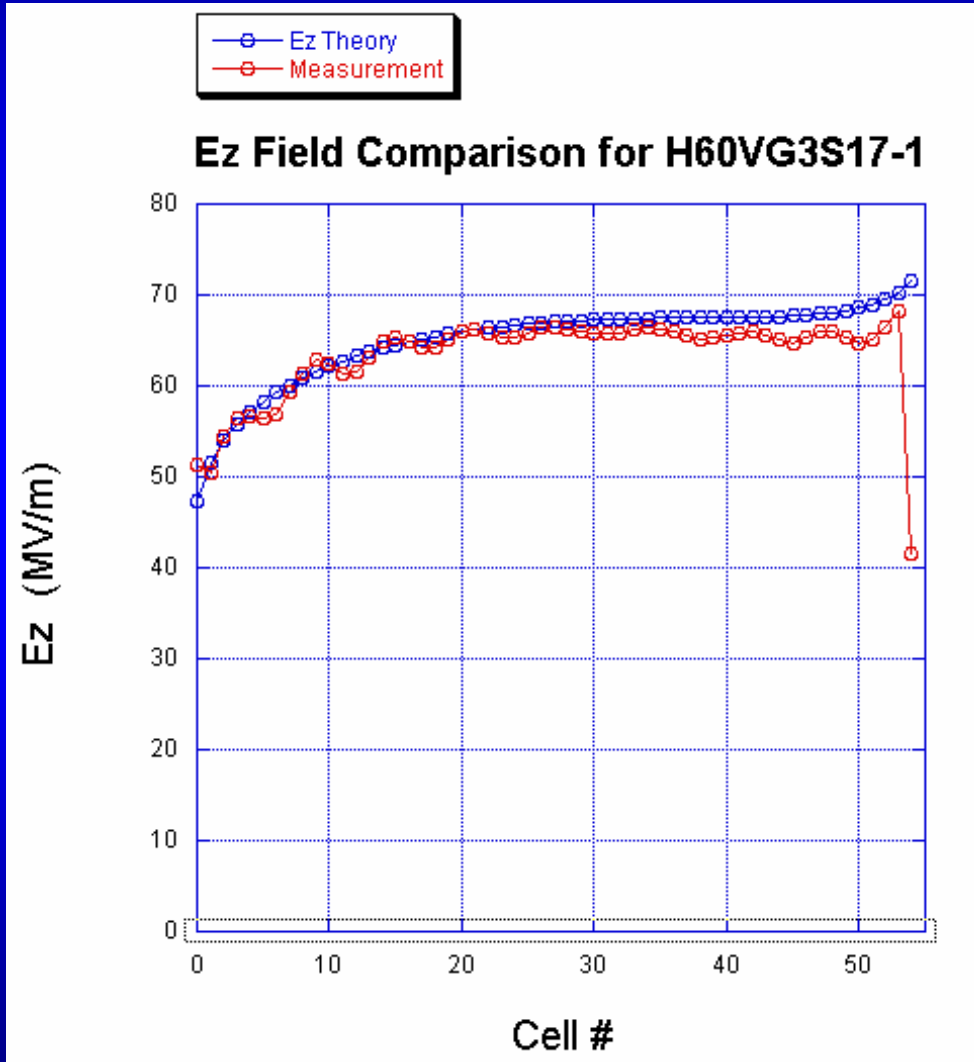




SLED Power (au)

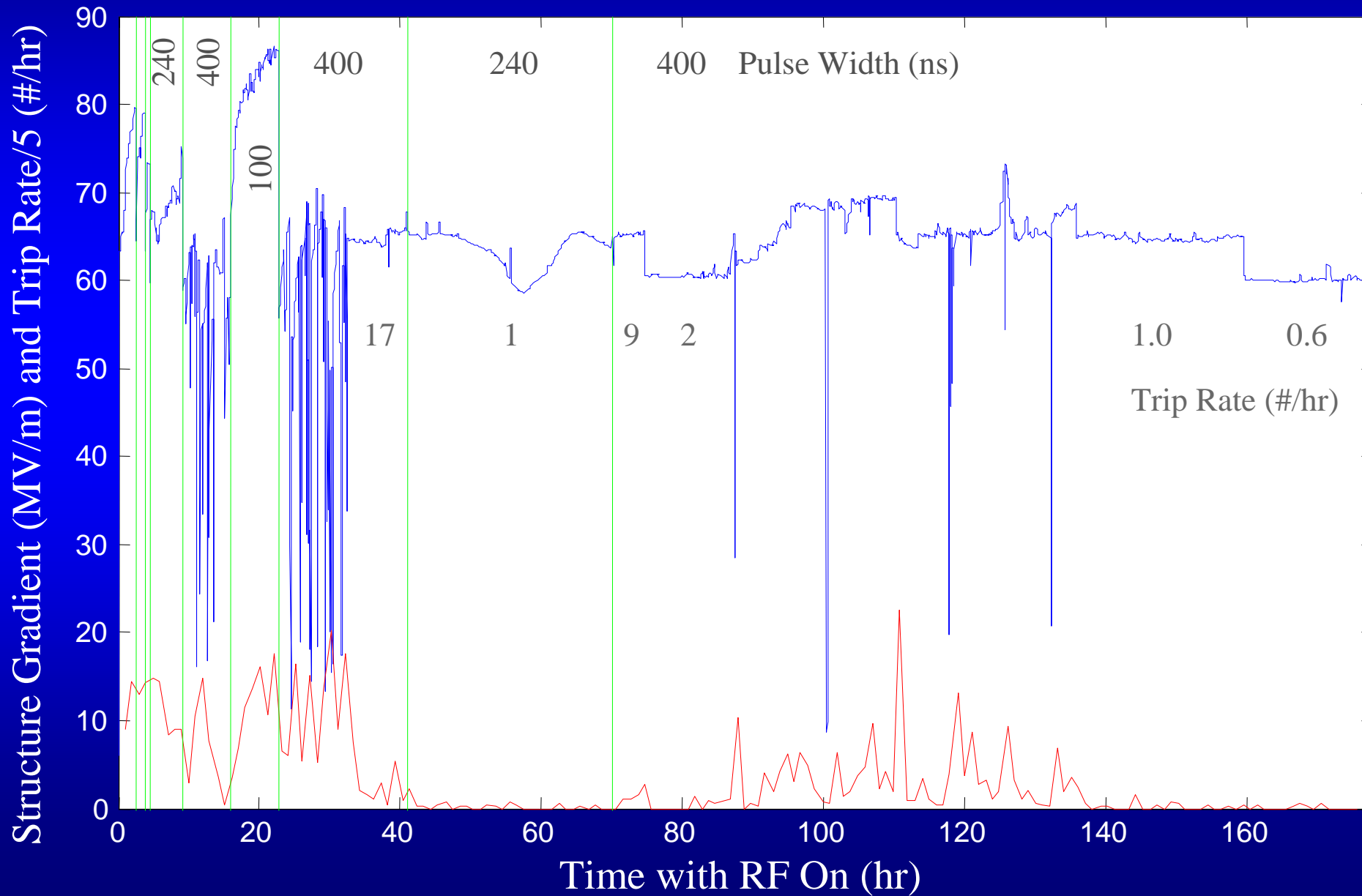
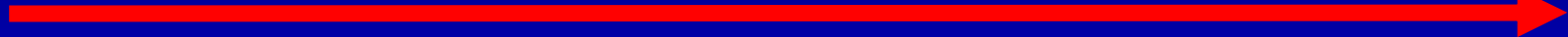


# Field profile - H60vg4S17-1

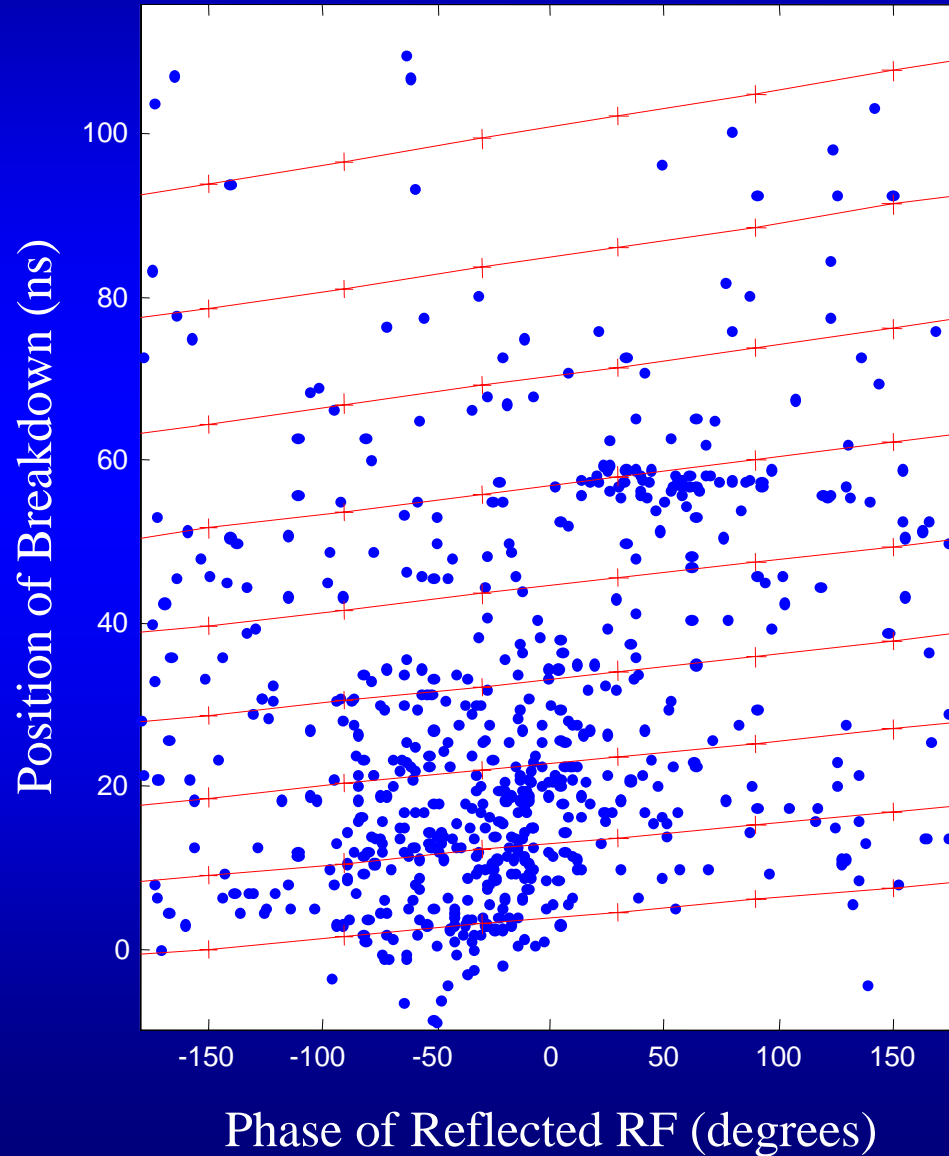
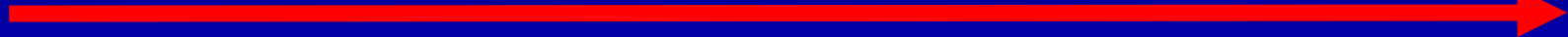


Extra losses due to possibly small gaps at OD

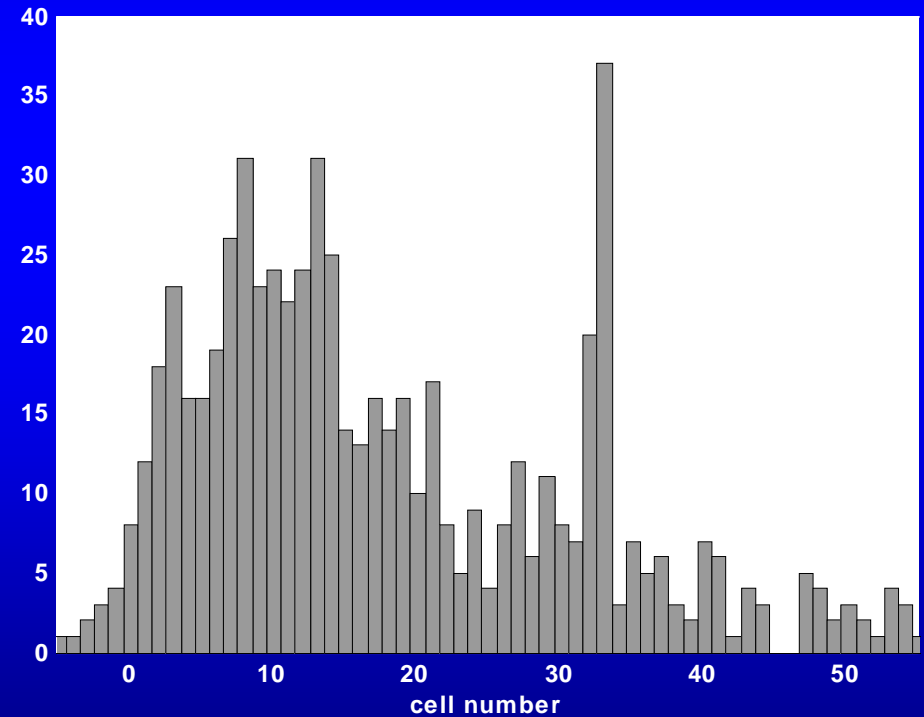
Relevance for performance unclear



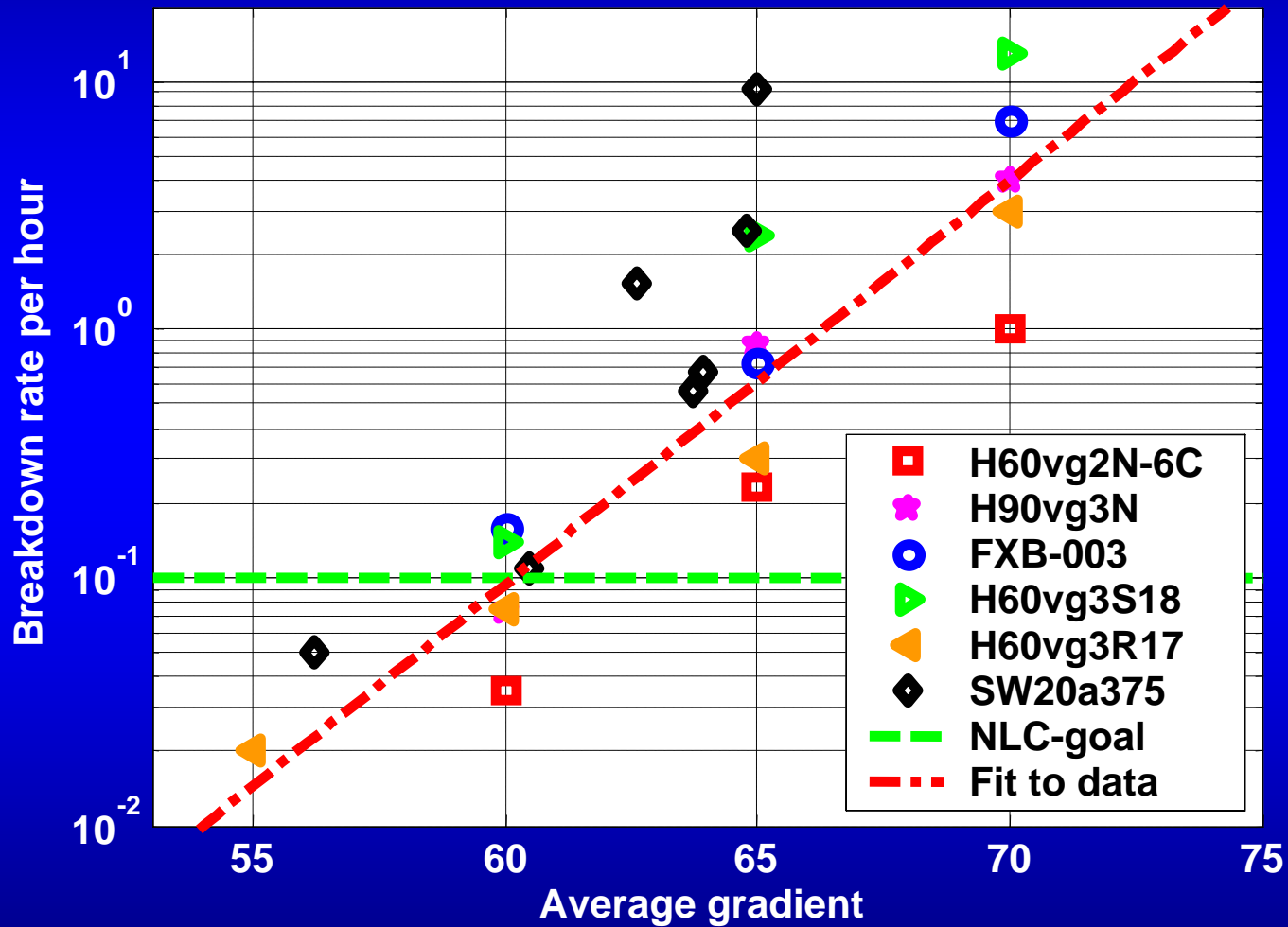


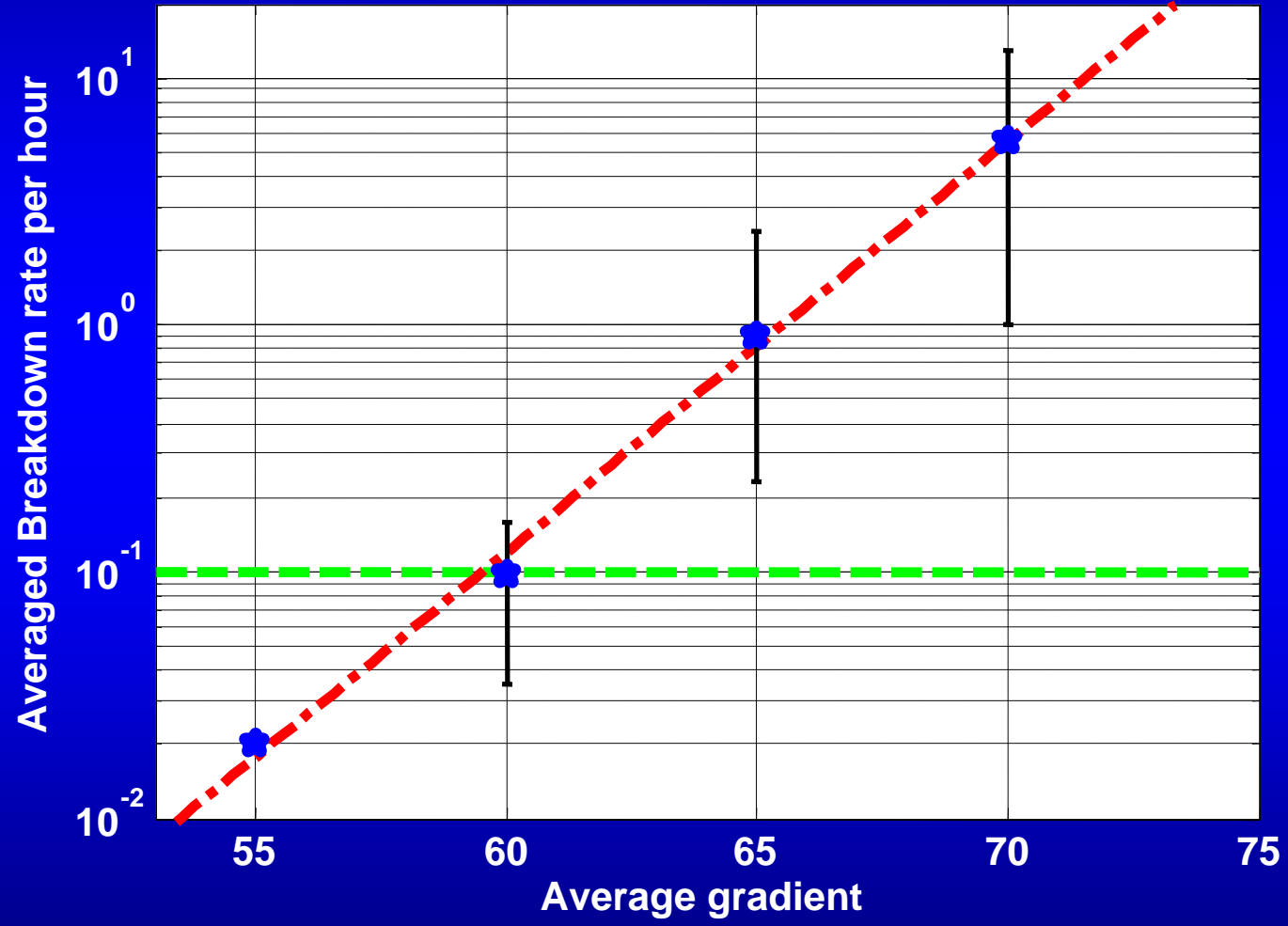


During Processing from  
60-70 MV/m



# H-type-performance BD-rate

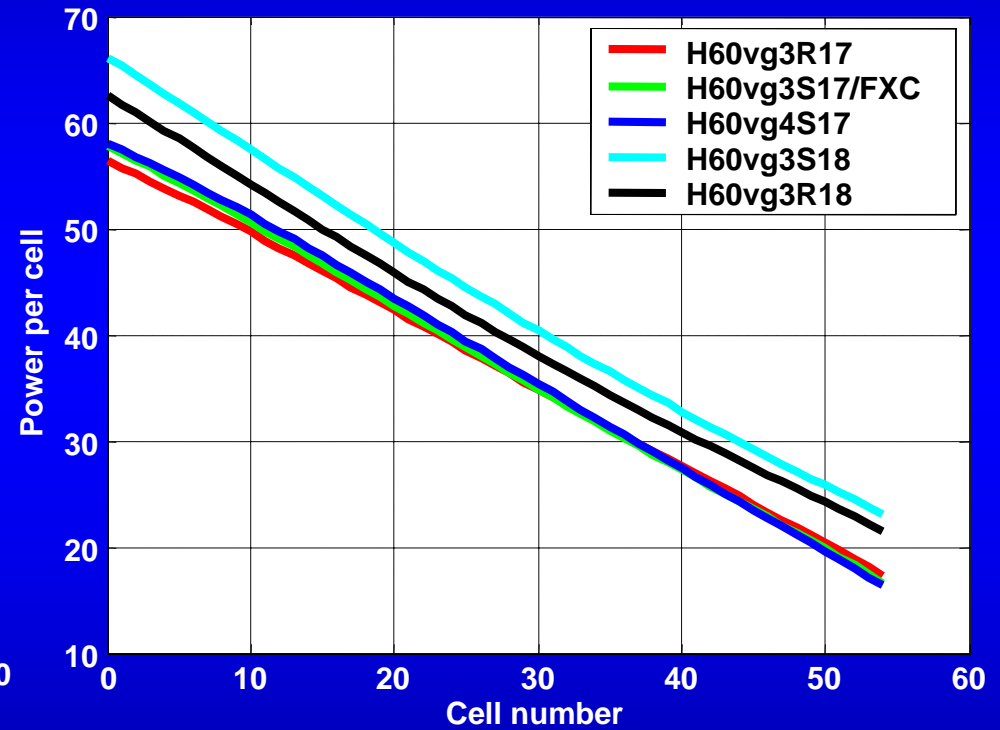
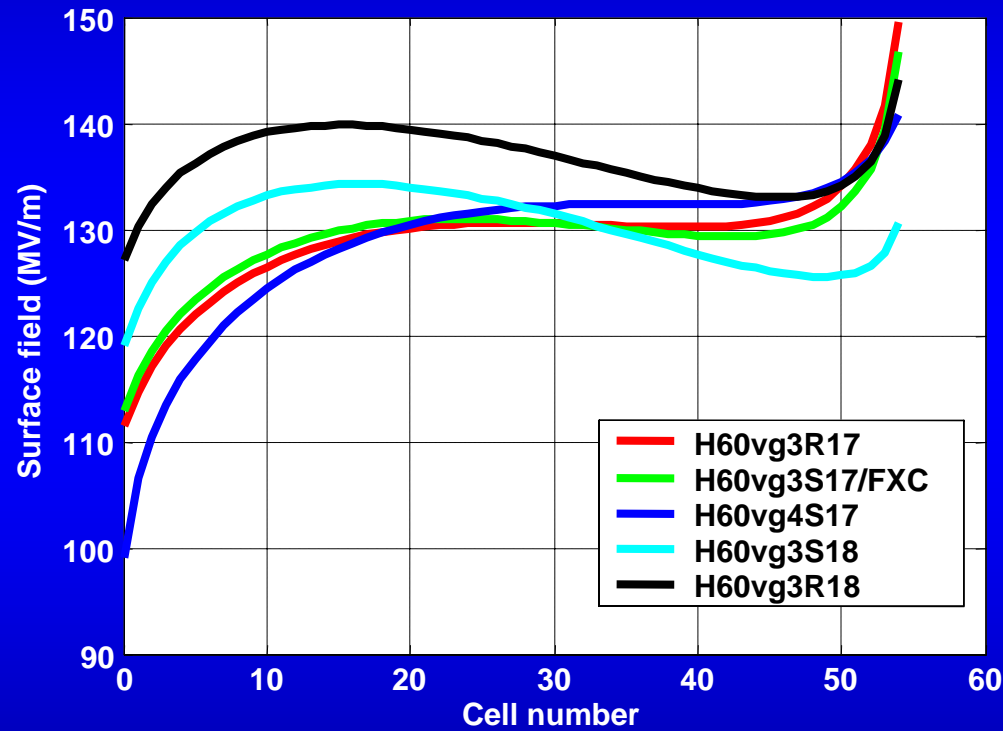




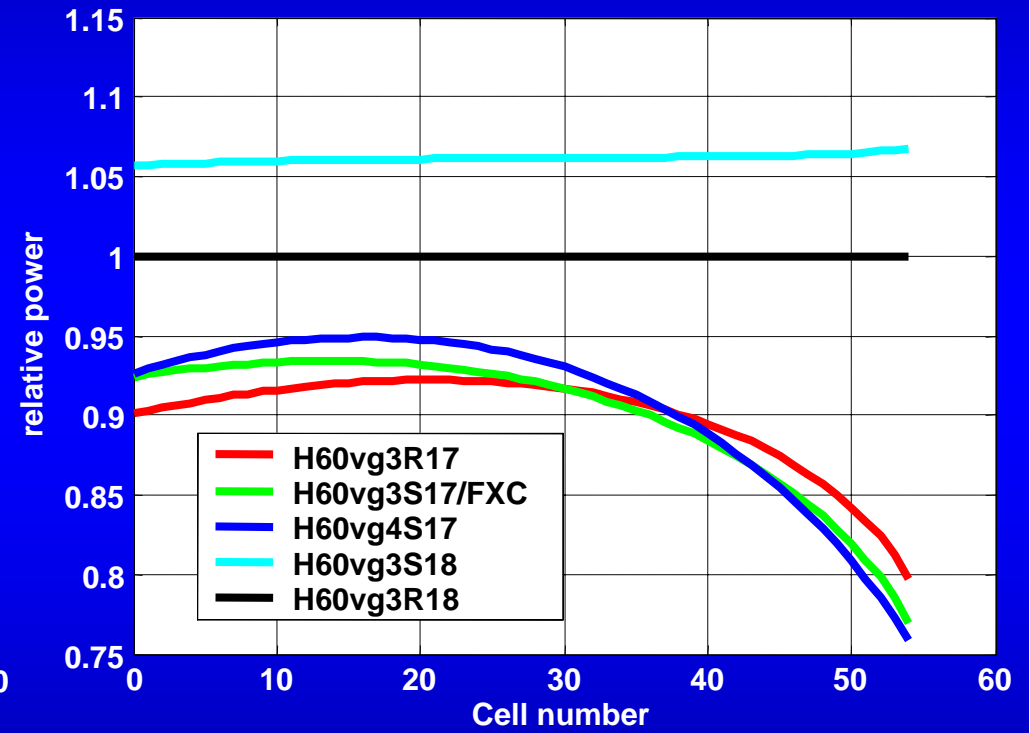
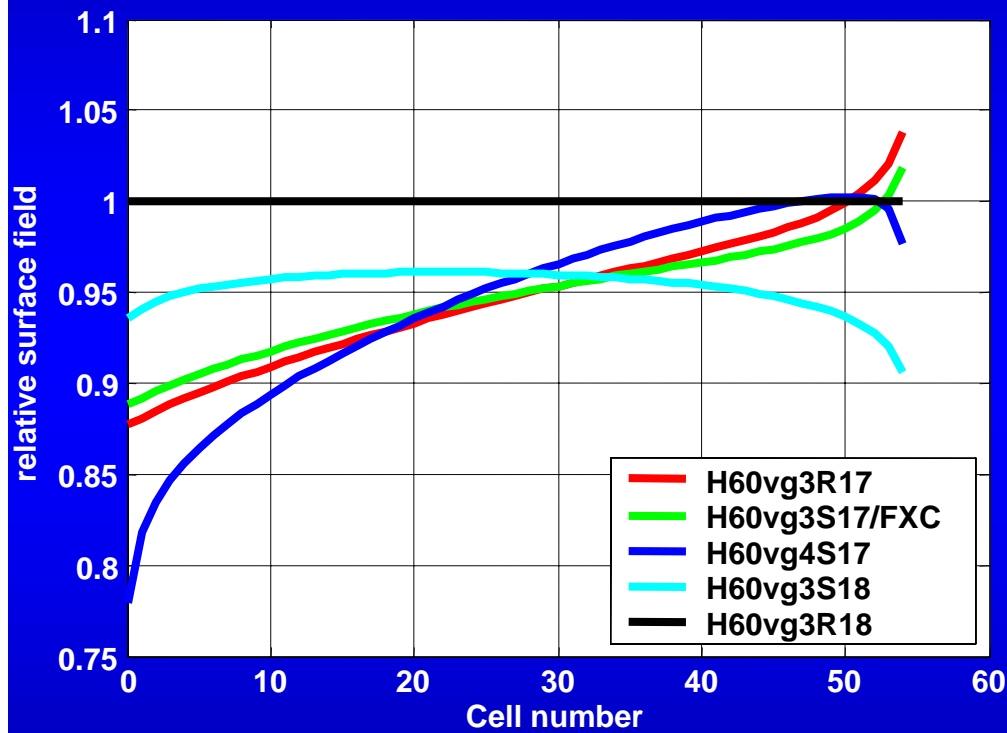


- This SW structures behaved very similar to TW
- CERN-Mo structure shows no superior performance
- Performance of new designs H60vg3R17/H60vg4S17 didn't met the expectations. Recently each structure had it's individual bucks/features  
General philosophy may be still right direction
- Structure preparation vs performance still a mystery
- Fermilab-WG-coupler is our new baseline design  
Dipole modes need more work
- 60 MV/m meets specifications, 65 MV/m not yet
- No frequency dependence found for Copper
- Potensial in shorter pulses ?

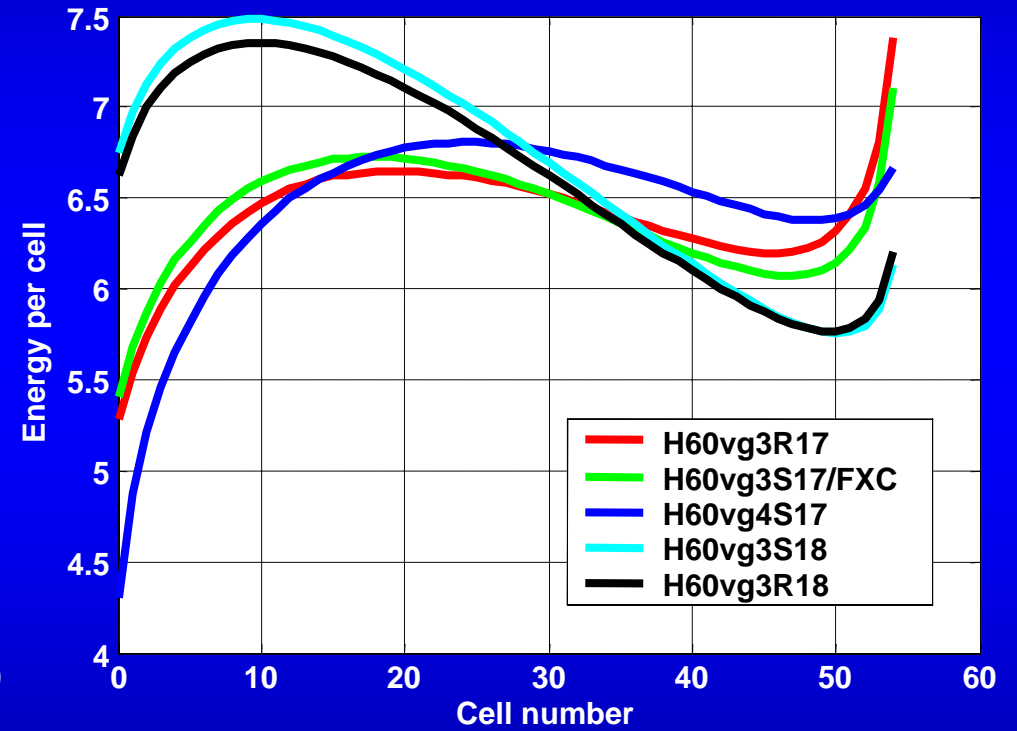
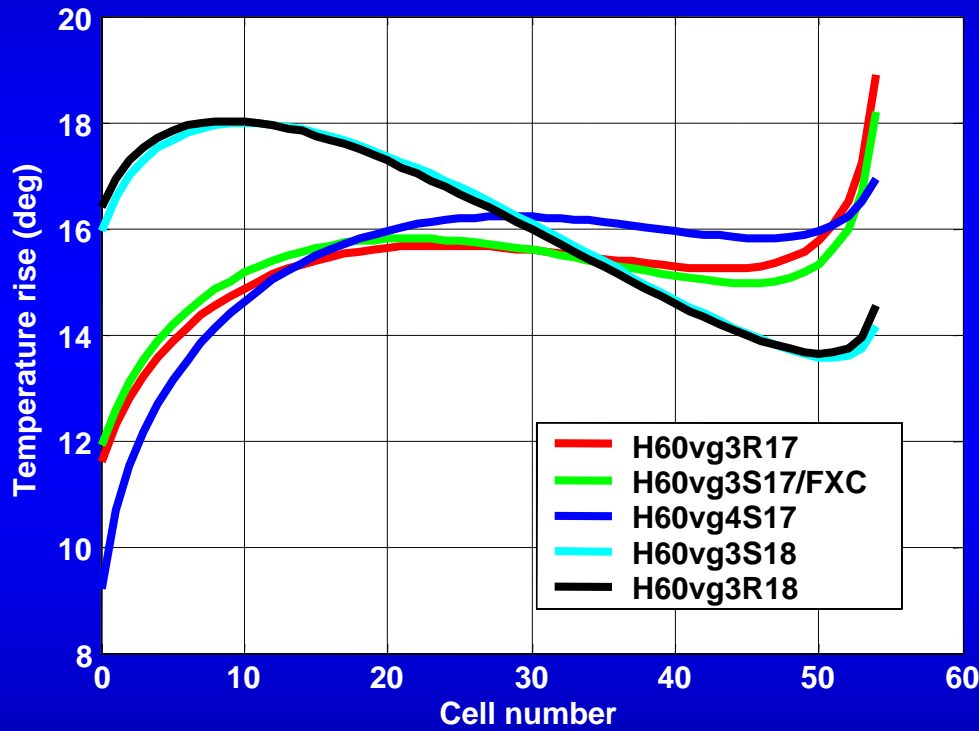
## Recent structure parameters

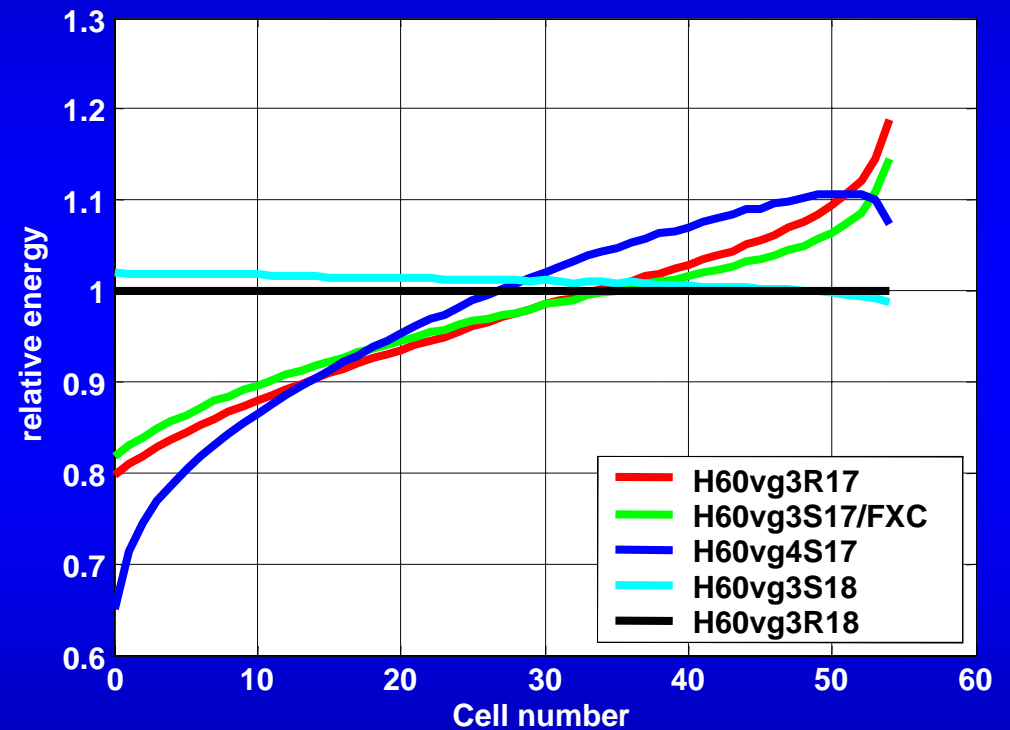
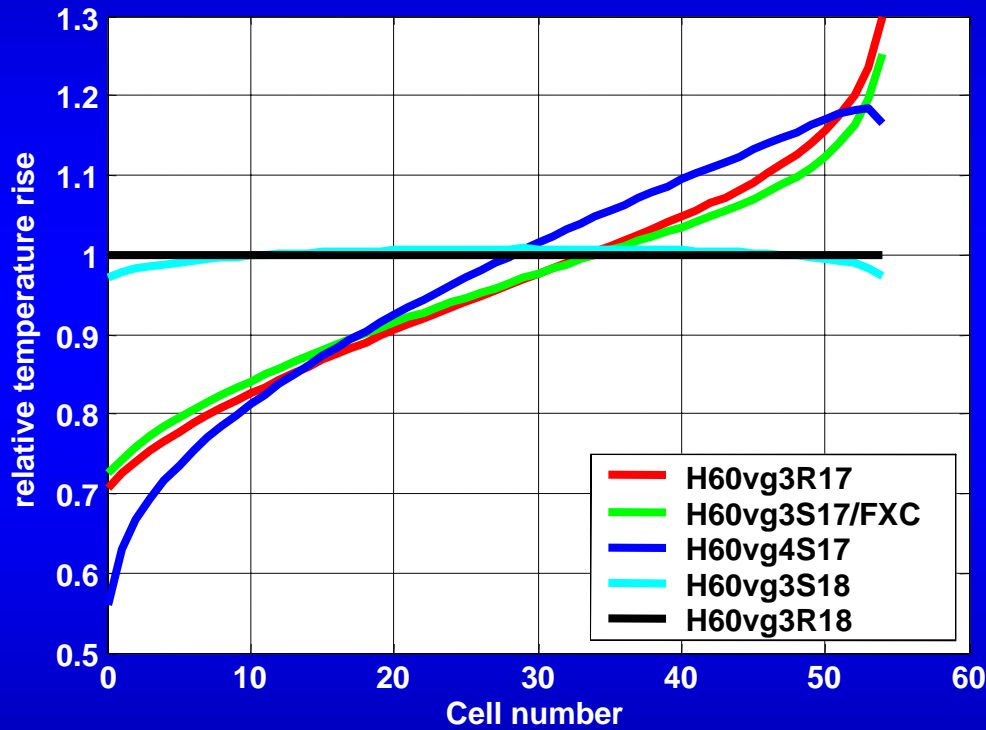
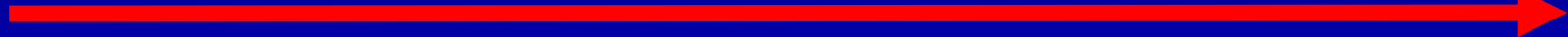


## Relative structure parameters



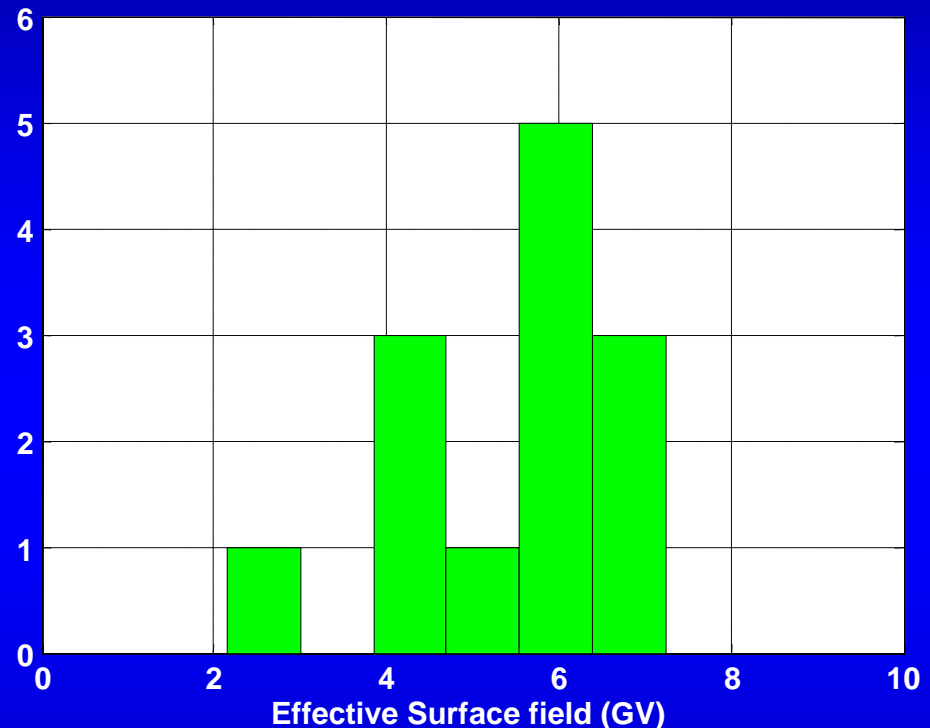
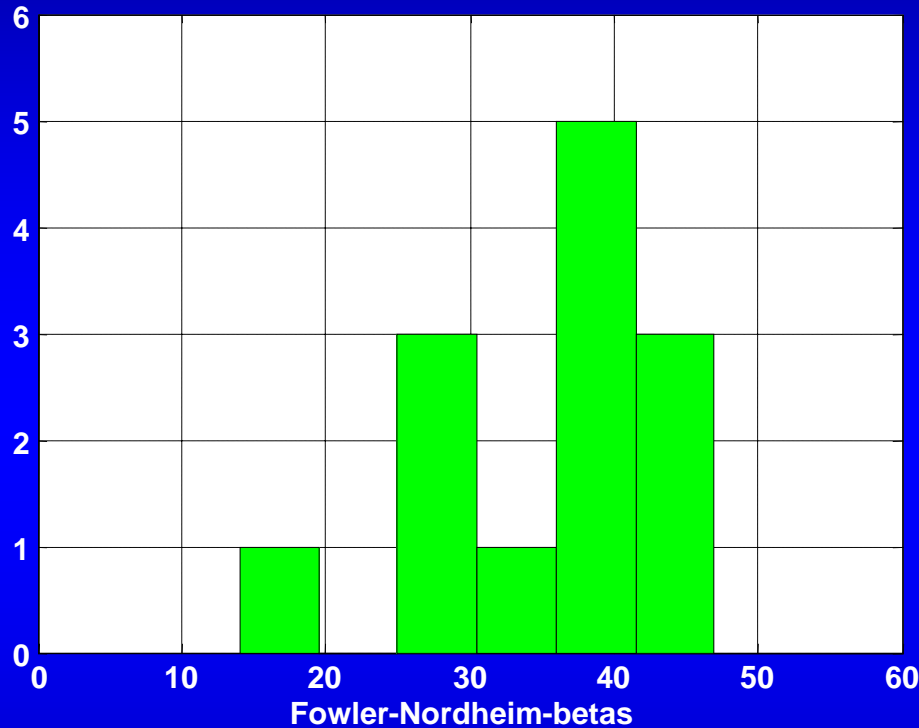
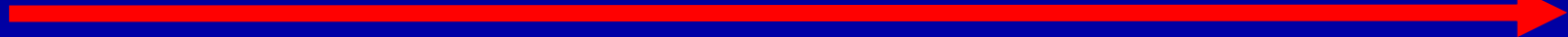
## Recent structure parameters







# Do we understand field enhancement factors ?



S. Yamaguchi: S-Band:  $E_{eff}$ : 6 GV/m

S. Tantawi: X-Band Waveguides:  $E_{eff}$  ~4-8 GV/m (pulse length, material)

S. Doebert: Ka-band:  $E_{eff}$ : 7 GV/m



**Definition: Sudden energy dissipation with damage potential**

**What we do know !**

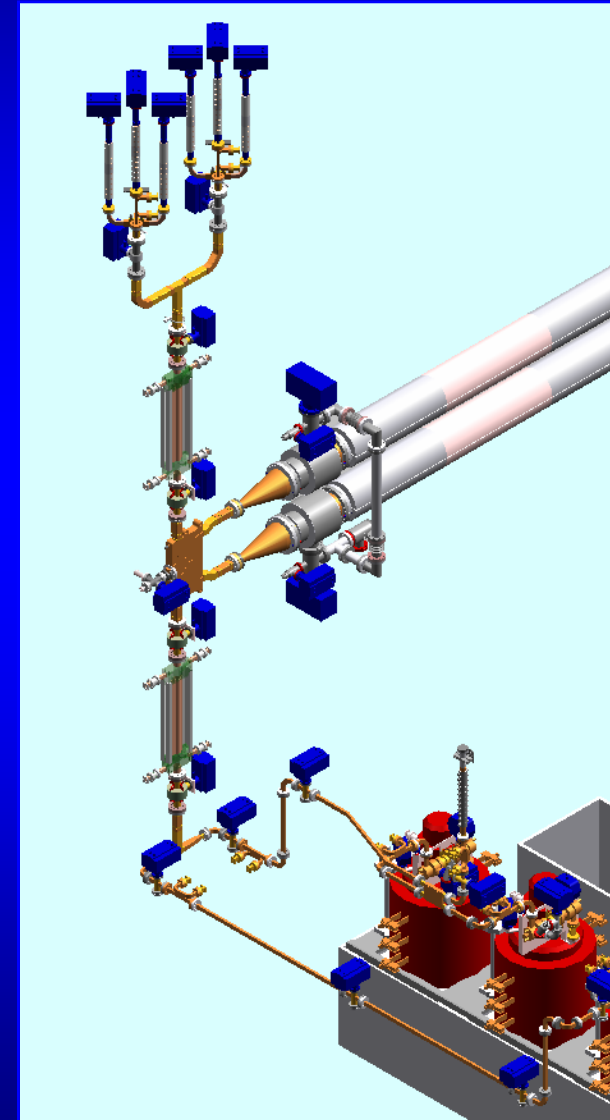
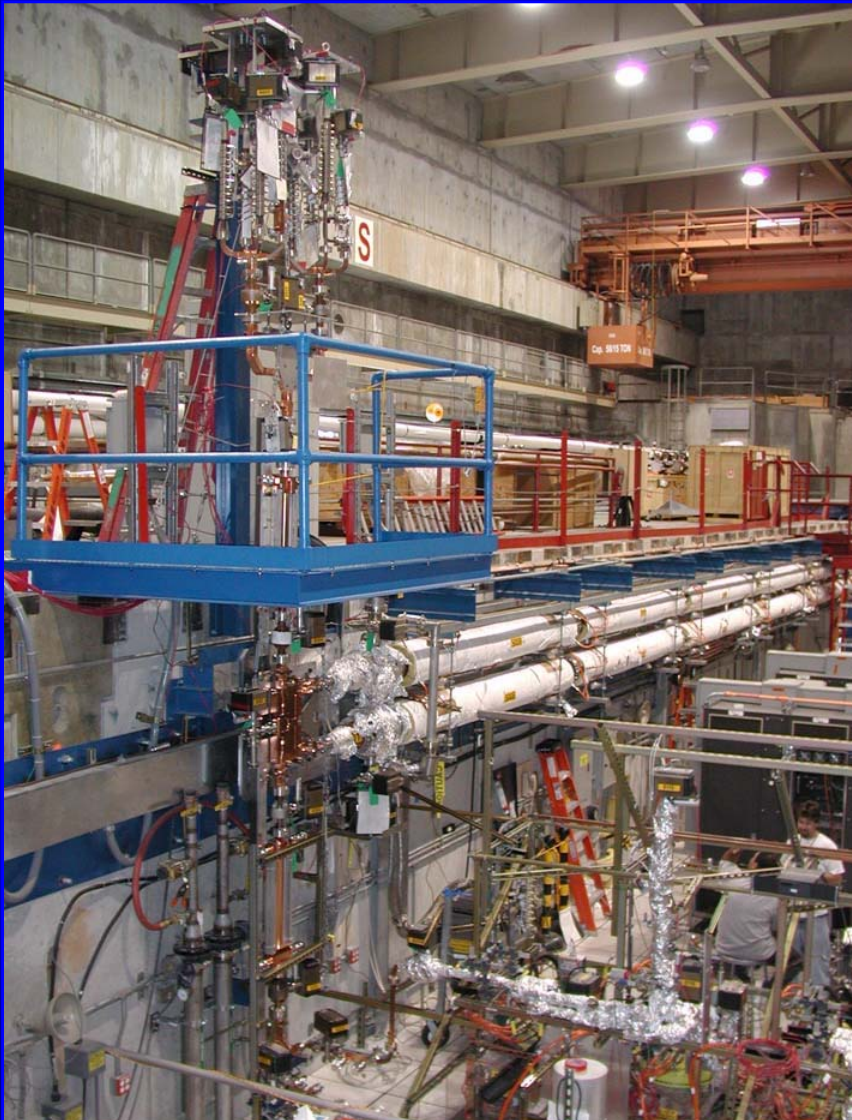
- ✓ Missing energy is absorbed electrons and metal ions
- ✓ Damage consist of molten areas and explosions
- ✓ Initial trigger most likely field emission
- ✓ Threshold depends on pulse length (cubic or square root)
- ✓ No big frequency dependence above 10 GHz
- ✓  $E_s \cdot \beta = \text{const}$  ( $\sim 6$  GV/m)
- ✓ Material dependence of threshold



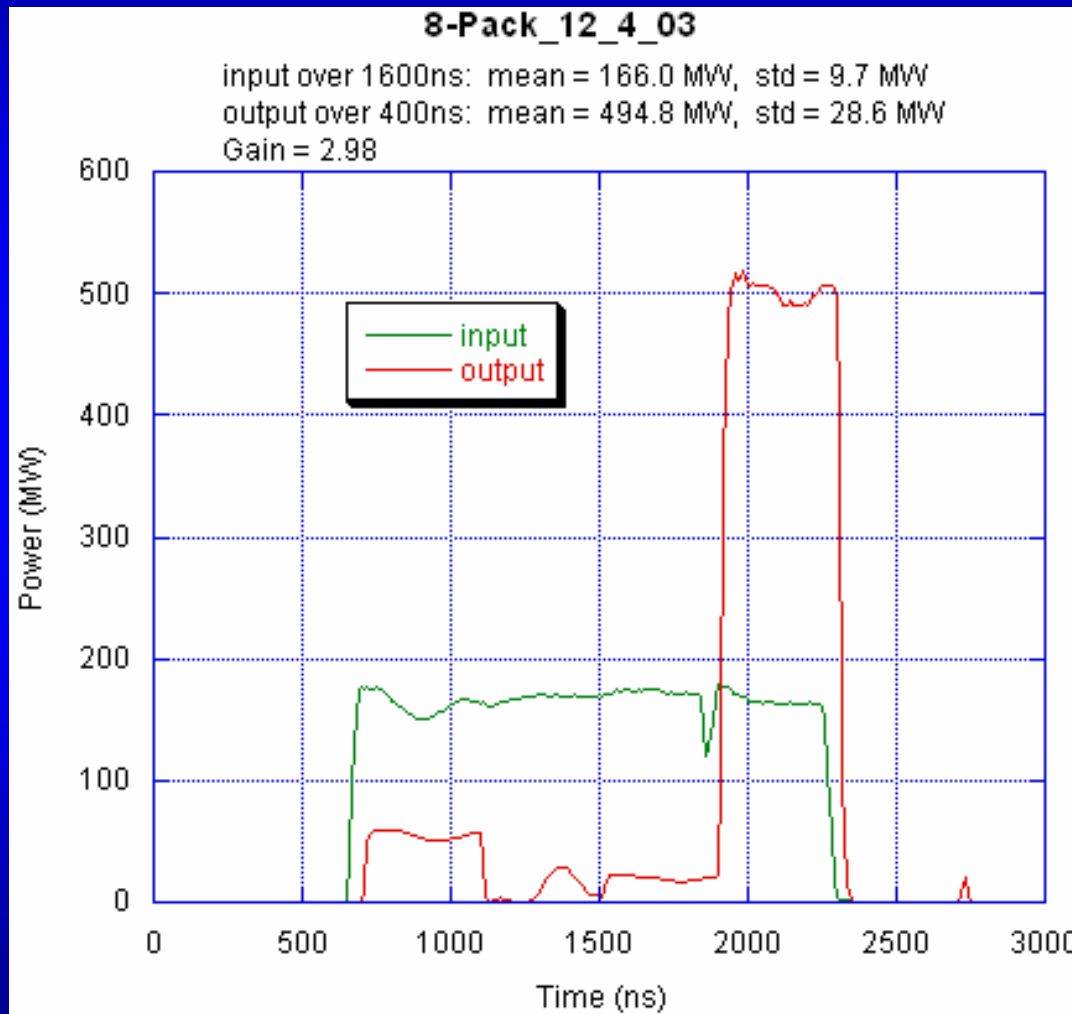
## What we don't know ?

- ✓ Threshold seems to depend on:  $E_s$ ,  $H_s$ ,  $P$ ,  $E_s \times H_s$
- ✓ How is the melting and the metal vapor produced
- ✓ Role of gas from surface or bulk as catalyst
- ✓ What is really described by  $\beta$
- ✓ Which material parameter determines threshold
- ✓ Role of particle contamination
- ✓ Processing strategy which minimizes damage

## 8-Pack , Phase 1



# Recently Power source R1 met



December 4<sup>th</sup>:

494 MW, 400ns

Gain 2.98

Max. Power  
reached:

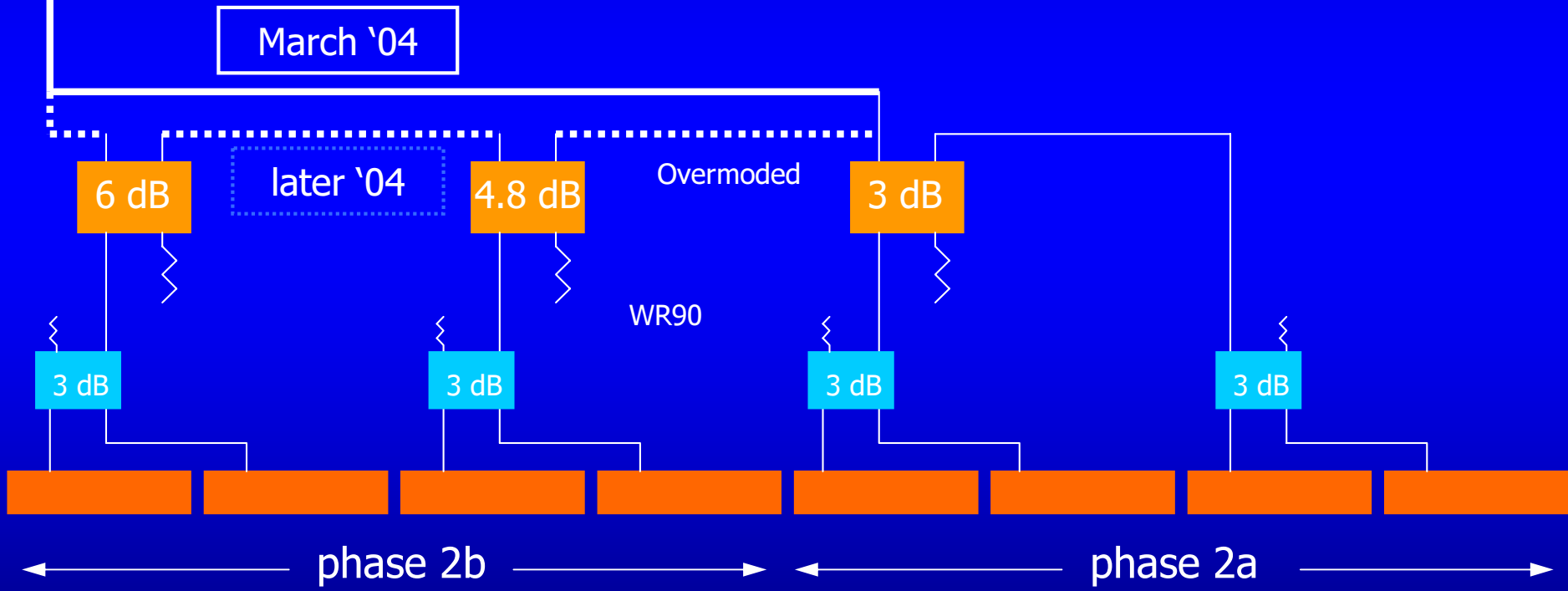
580 MW, 400 ns

# 8-Pack, Phase 2a/b

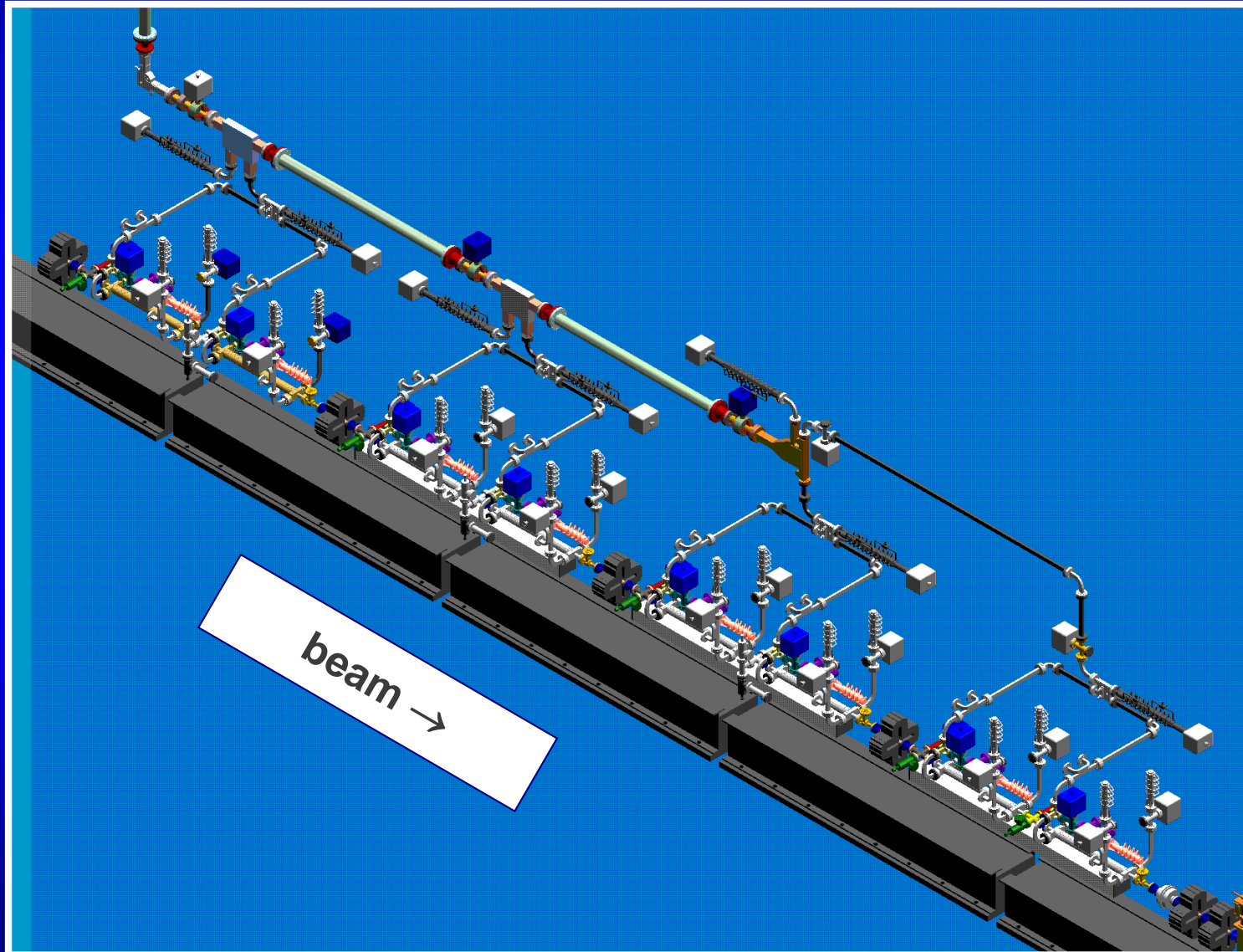


From SLED

By March '04; power to 4 structures,  
 and hardware (not installed) for the rest.



## 8-Pack, Phase 2a/b



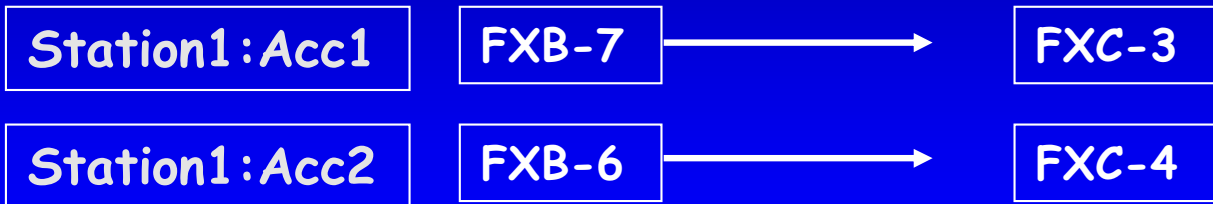


Next Linear Collider  
Test Accelerator

# Structure testing with 8-Pack A scenario



Dec	Jan	Feb	Mar	Apr	May
-----	-----	-----	-----	-----	-----



- |        |  |
|--------|--|
| 8-Pack | FXB-3, 63 MW, Fermilab vented                        |
|        | H60vg3-6C, 63 MW, Klystron vented                    |
|        | H60vg3S18, 69 MW, Endstation B sealed N <sub>2</sub> |
|        | H60vg3R17, 57 MW, Endstation B sealed N <sub>2</sub> |

H60vg4S17-3	H60vg4R17a
H60vg4S17-4	H60vg4R17b





## Technology shoot out, politics

- Run at least one structure at 60-65 MV/m and 400ns with less than one breakdown in 10 hours
- Run eight of these for 2000 hours at 60 Hz
- Demonstrate HOM-damping with a pair of interleaved structures (ASSET test)

## General R&D

- R&D to reduce cost, increase yield and efficiency of production (precision machining, baking, H<sub>2</sub> vs Ag, etching, HPWR, EP, RF-processing tests)
- Very high gradient R&D, going beyond 65 MV/m (materials, geometry: single cells (KEK/SLAC), CERN-W, cold machining, frequency dependence, small  $a/\lambda$ )

## Understand resources

Stainless  
Steel  
'Mushroom'  
Found on  
the Outer  
Wall of  
Cell 35 in  
H90VG3



# Preliminary Results on Particles (< 10 μm) Found in H90VG3 Cells

