High-Gradient theory

Misquoting Richard Feynman:

High-gradient researchers don't make predictions, they make excuses.

W. Wuensch
Structure away-day
19-9-2006

My personal view of the main theoretical questions

• How does a breakdown start? Trigger mechanism. Two main ideas – electron emission and tensile strength. J. Norem is active proponent of the latter (and I like it too). Both predict βE limit of material, but β is never derived.

• What are the breakdown dynamics? rf/plasma interaction. P. Wilson has elaborate theory based on plasma spots. Predicts ordering of materials for ultimate gradient and gives pulse length dependence.

•How do structure parameters enter into it? Surface field limits come via trigger mechanism. W. Wuensch has theory based a power flow limit. Predicts gradient relationship between different types of structures made of the same material. V. Dolgashev simulates at this scale, rectangular waveguide done so far.

• What gives the breakdown rate and apparent material dependence? W. Wuensch has theory based on extension of tensile strength trigger mechanism – at lower fields, potential breakdown sites are subject to cyclical tensile stress and fatigue.

• What is conditioning and how best to do it? How does effect of breakdown affect breakdown trigger? Stress relief by annealing?

Most recent analysis of data for power constraint

TABLE 1). 30 GHz copper periodic structure data [12,13, 14,15,16]. The structure labeled NLC is structure number H60VG4S17 and data is quoted for the first cell. 2*a* refers to iris diameter.

	f **[GHz]**	V_g**/c**	E_{acc} **[MeV/m]**	E_{surf} **[MeV/m]**	***P*** **[MW]**	**τ [ns]**	**2*a*** **[mm]**	$\frac{P\tau^{1/3}}{C}$	
CERN X-band	11.424	0.011	153	326	69	150	6	19	
NLC	11.424	0.045	72	152	140	100	11.4	18	
Acceler-ating	30	0.047	116	253	34	70	3.5	13	
CTF2 PETS	30	0.5			240	16	16	12	
CTF3 PETS	30	0.40	30	116	100	50	9	13	

TABLE 1). Copper waveguide data taken from [20]. *a* is the waveguide width.

	f [GHz]	V_g**/c**	E_{surf} **[MeV/m]**	***P*** **[MW]**	**τ [ns]**	***a*** **[mm]**	$\frac{P\tau^{1/3}}{2a}$	
WR-90	11.424	0.82	60	56	750	22.9	11.2	
Reduced width	11.424	0.18	45	32	750	13.3	10.8	

Apparently significant. Perhaps due to f dependence or iris thickness

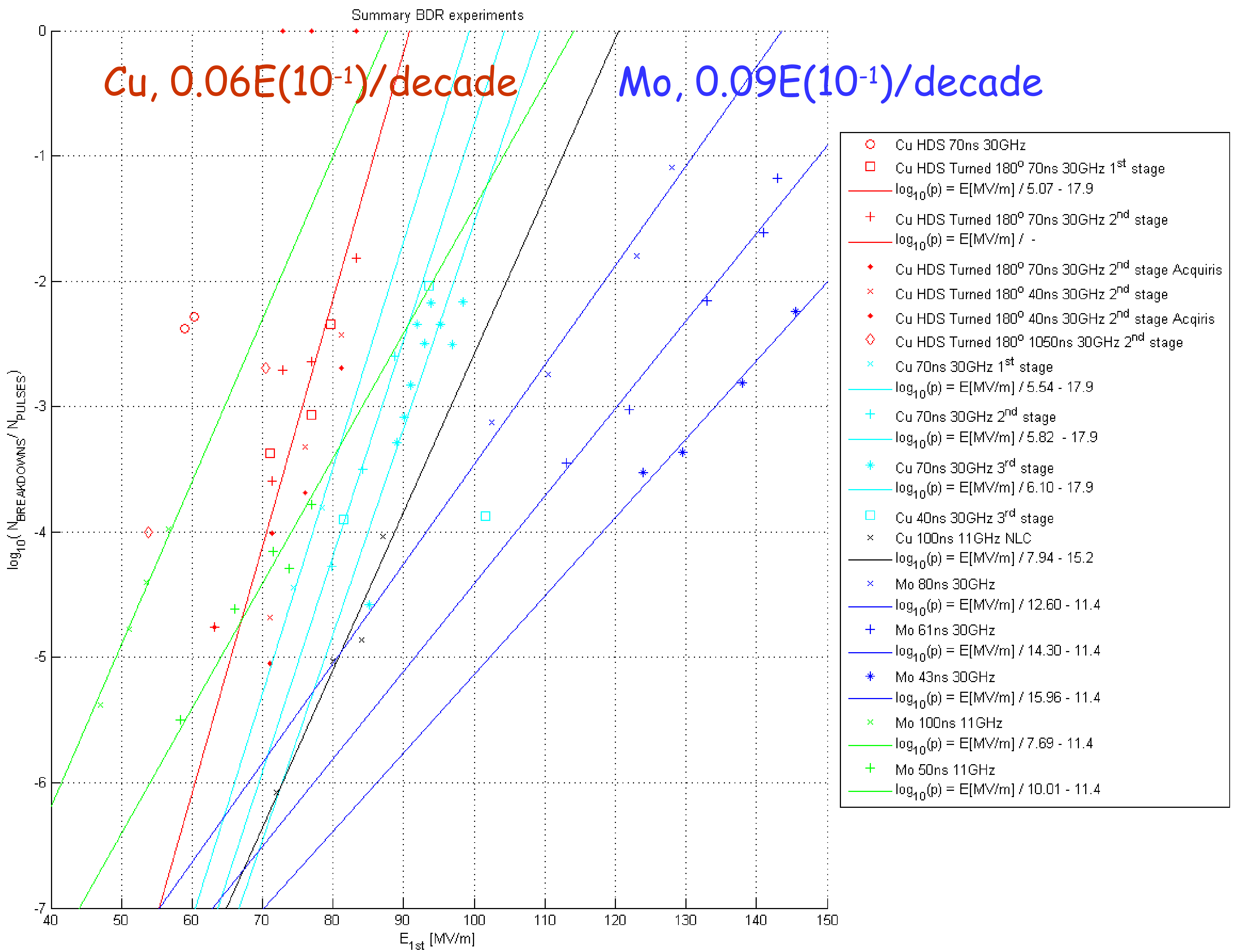
Comparison of circular copper and the two ends of the HDS60 at 10^{-3} and 70 ns

	V_g/c	E_{acc} [MeV/m]	E_{surf} [MeV/m]	P [MW]	$2a$ [mm]	$\frac{P\tau^{1/3}}{C}$
circular	0.047	90.3	198	19.6	3.5	7.3
HDS60	0.08	60.8	108	16.1	3.8	5.6
HDS60 reversed	0.051	74.5	124	13.3	3.2	5.4

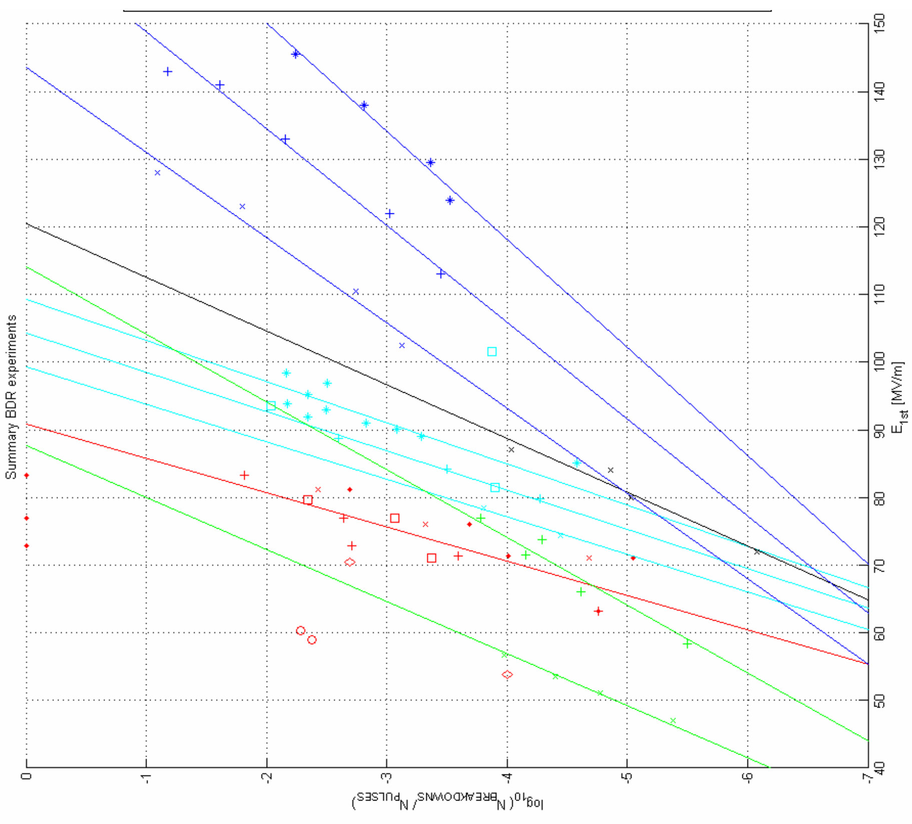
Possible explanations for the difference between circular and HDS:

- power flow concentration in HDS
- other aspect of HDS
- iris thickness (0.85 vs 0.55)
- phase advance

Breakdown probability: observed material dependence of slope

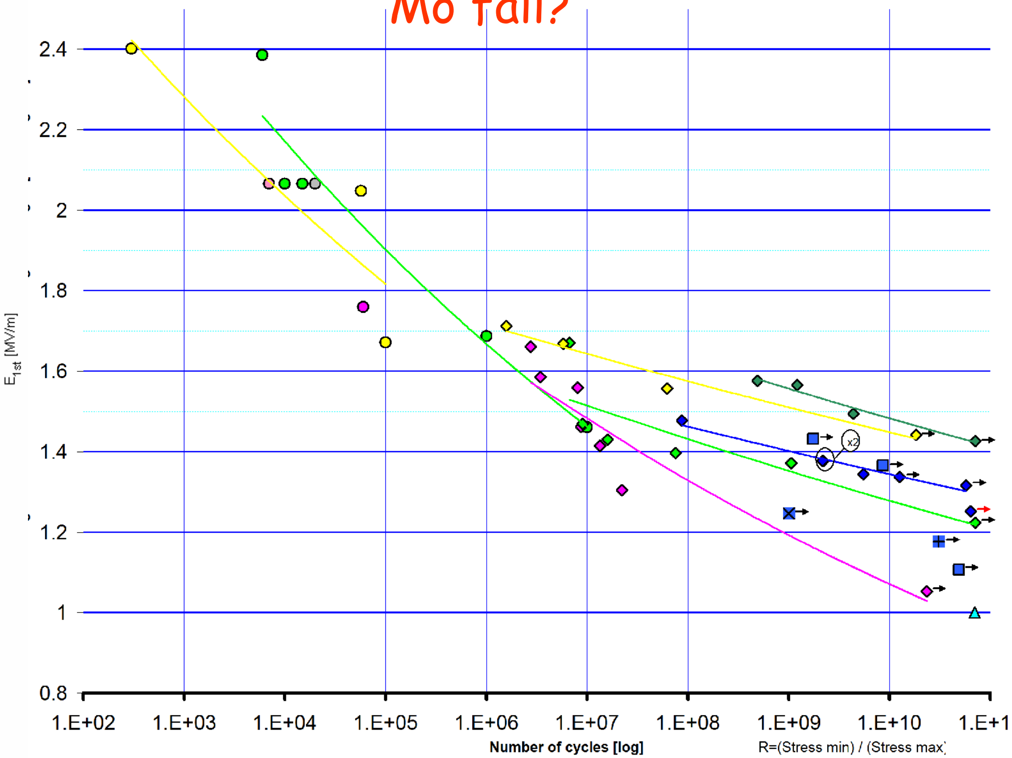


Below tensile strength trigger limit, a standard fatigue process gives breakdown probability and dependence with field (electrostatic force αE^2)
Alloying could then give strong influence, if properties survive effect of breakdown (read melting).
Mo sonotrodes are under test (since last Friday) because we need its fatigue behaviour anyway.



rotated breakdown probability

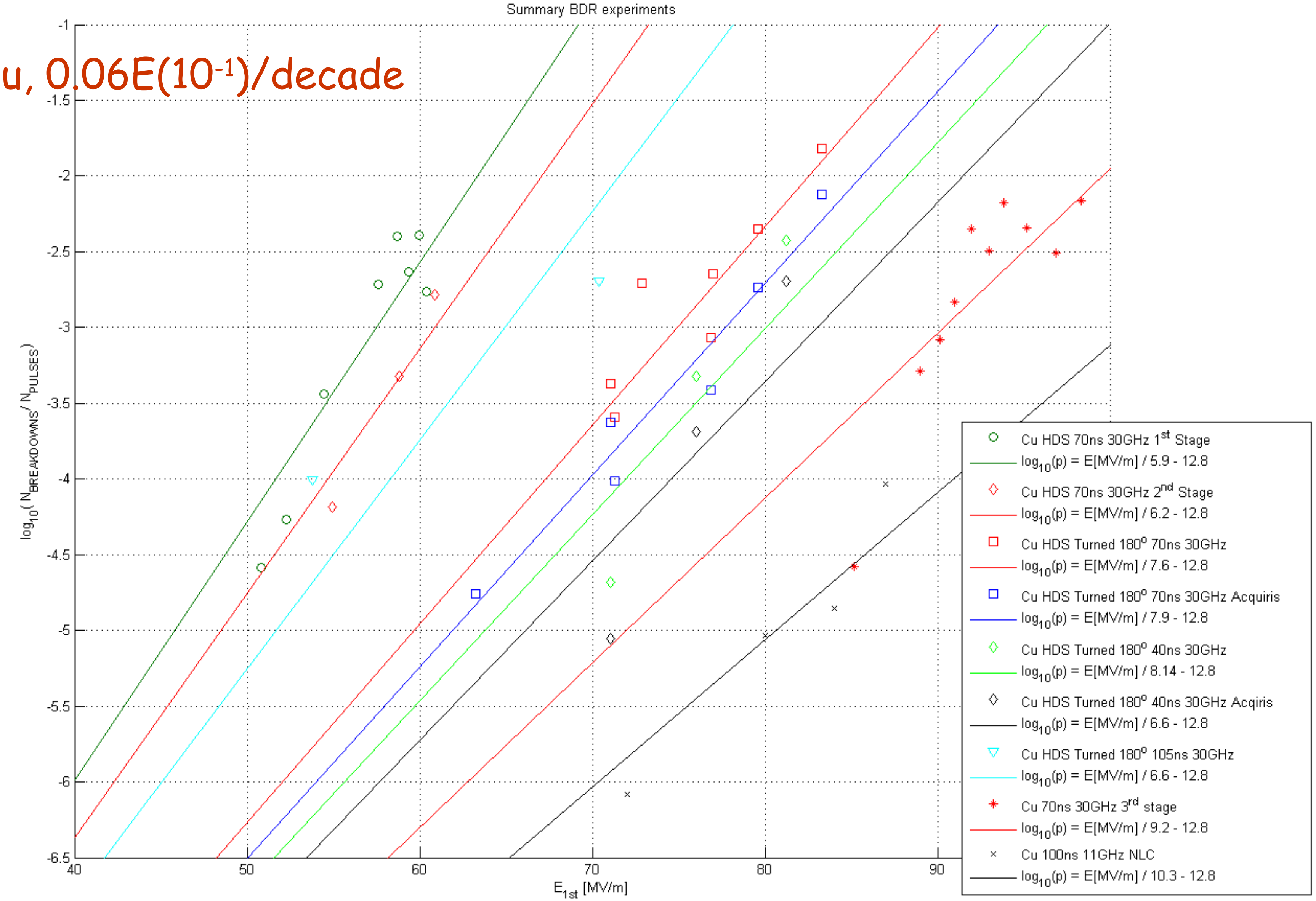
Cu data only, where will Mo fall?



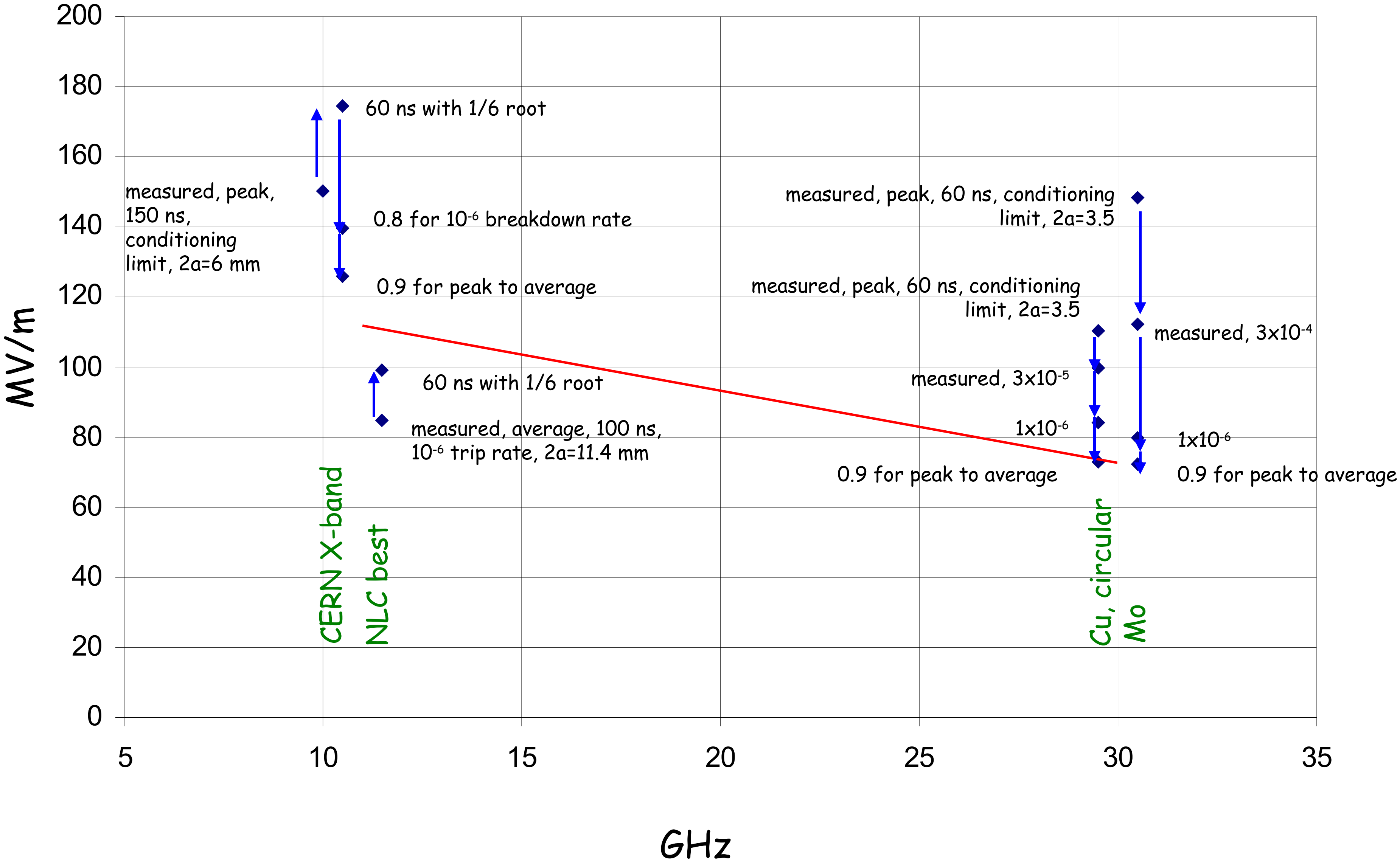
Laser and ultrasonic fatigue data

The case for a global fit parameter for copper

Cu, 0.06E(10^{-1})/decade



Best available data: measured gradients at 60 ns and $1x10^{-6}$
Straight-forward corrections included, major scalings not
Input for constraints



Bending the picture
Full optimization: rf constraints, structure characteristics and beam dynamics