Gradient Limitations for High-Frequency Accelerators

- Introduction
  Sources of breakdown
- Reliability, Processing
- Dependence on pulse length, frequency and materials
- Conclusions

NLCTA

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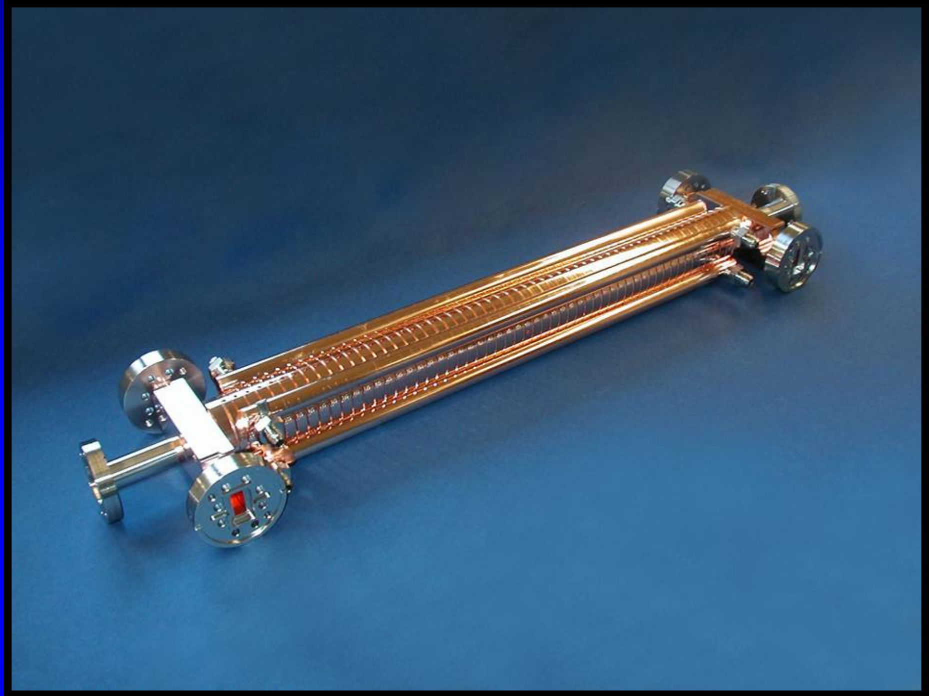
Hardware

NLC/GLC, SLAC/KEK
11 GHz
65 MV/m, 400 ns



CLIC, CERN
30 GHz
170 MV/m
60 ns

What happens in an RF breakdown ?

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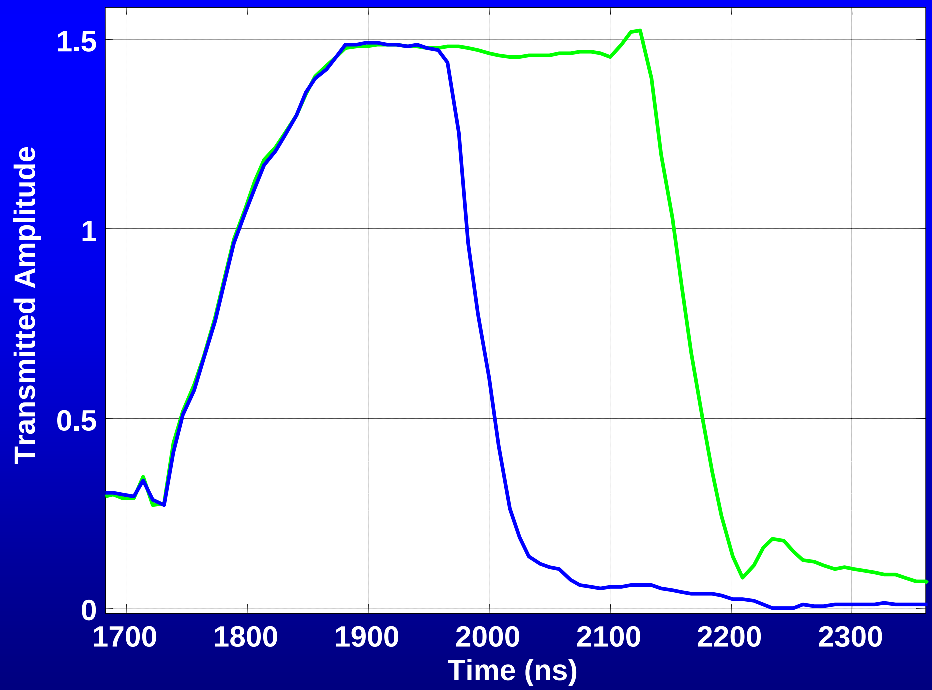
'Hard'

Large missing energy,

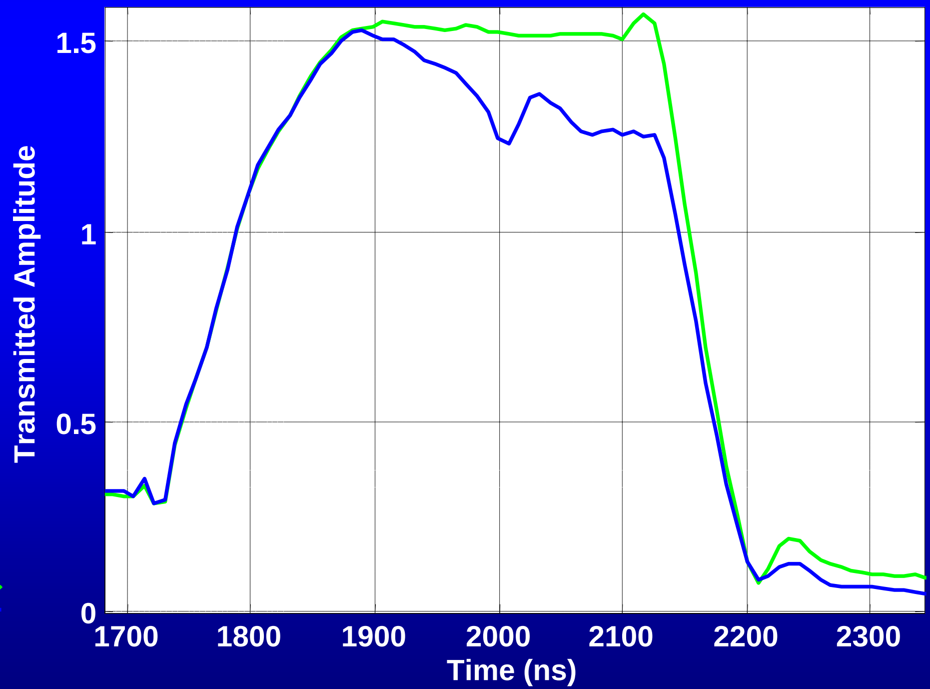
fast cut off



'Soft'

Little missing energy,

slow cut off



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What happens in an RF breakdown ?

'Hard' | Breakdown Trigger | 'Soft'

Field emission: $E_s * \beta$

Es high | β, Hs high

Local heating, ion creation

Ohmic heating, particle bombardment, gas desorption and ionization
melting and vaporization
resonant secondary emission

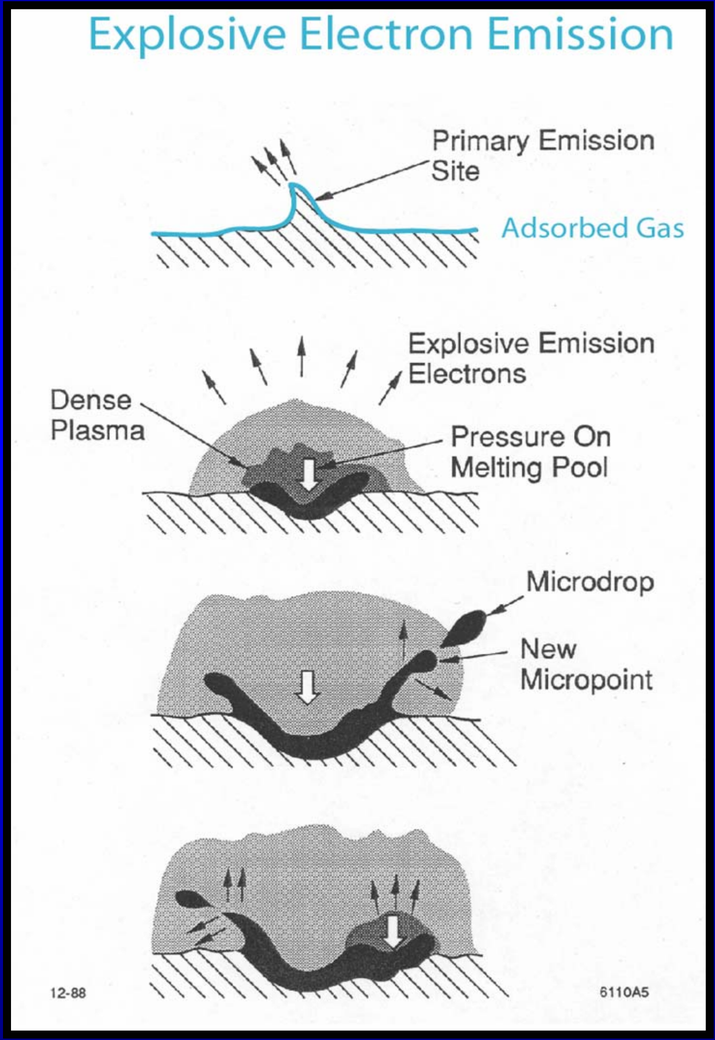
Plasma phase, energy absorption, run-away condition

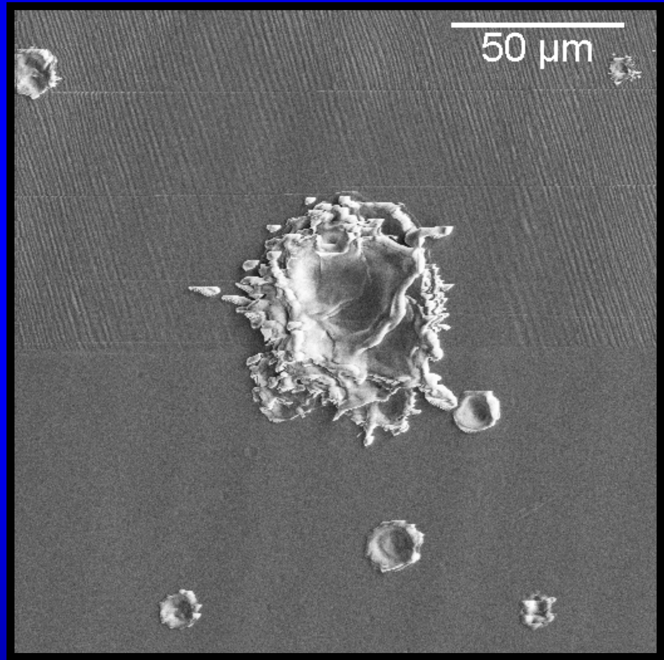
High density Plasma builds and absorbs most energy

RF fields driven:
high electrical surface fields

Defect driven:
Particles, voids, oxides

High electric surface fields





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Large Particles in high magnetic field areas

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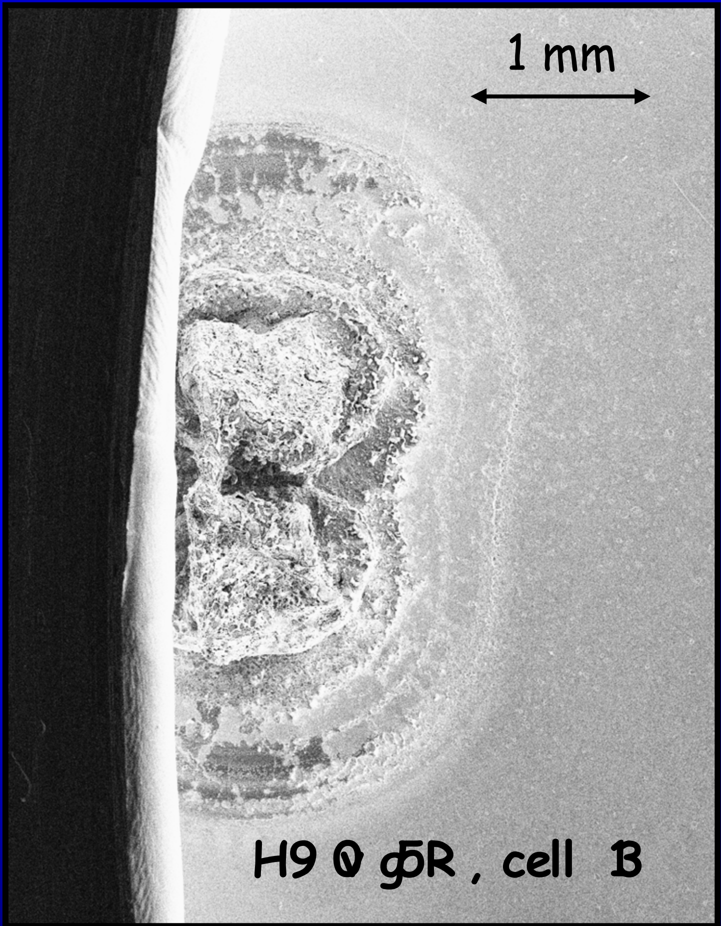
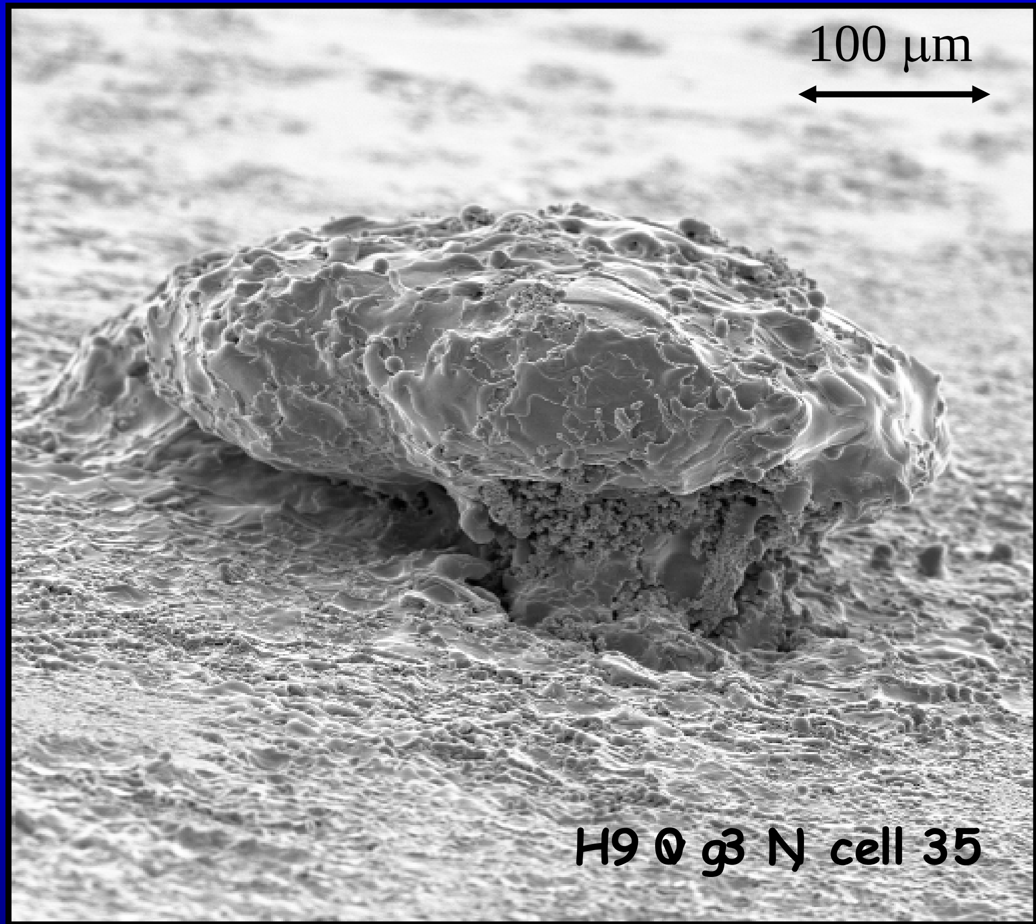
Aluminum



Stainless steel



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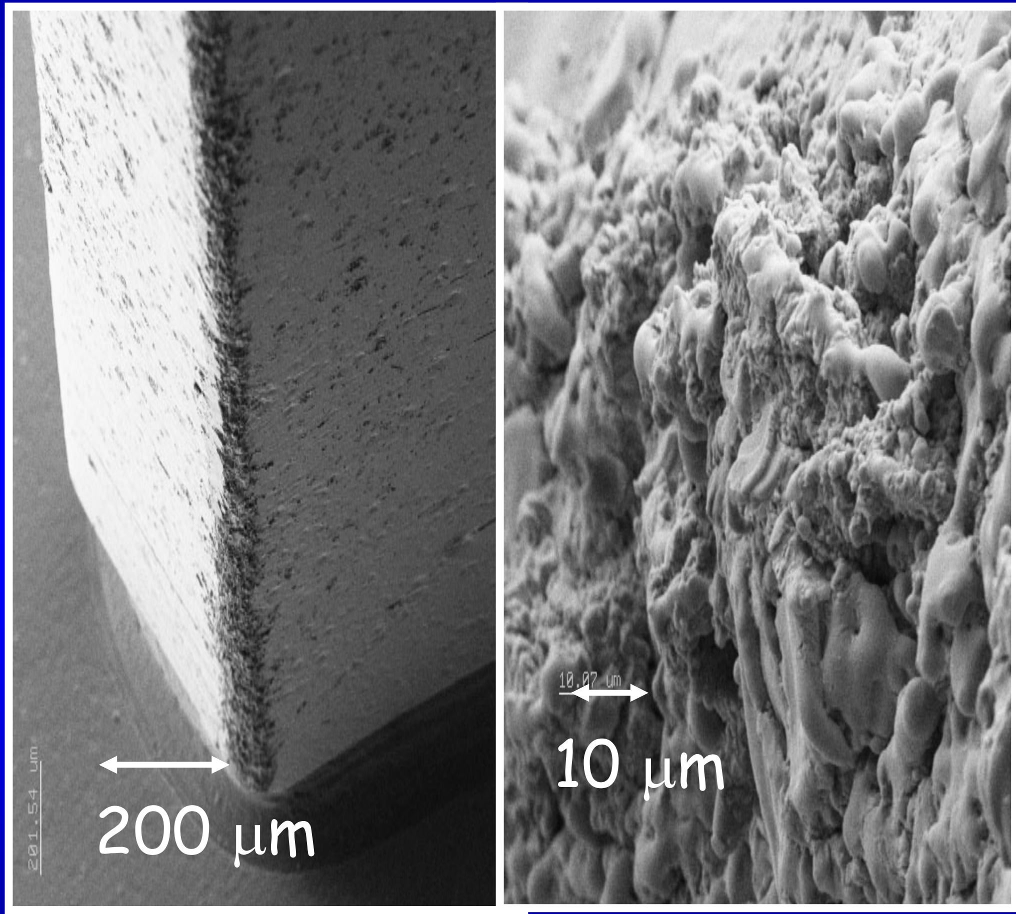
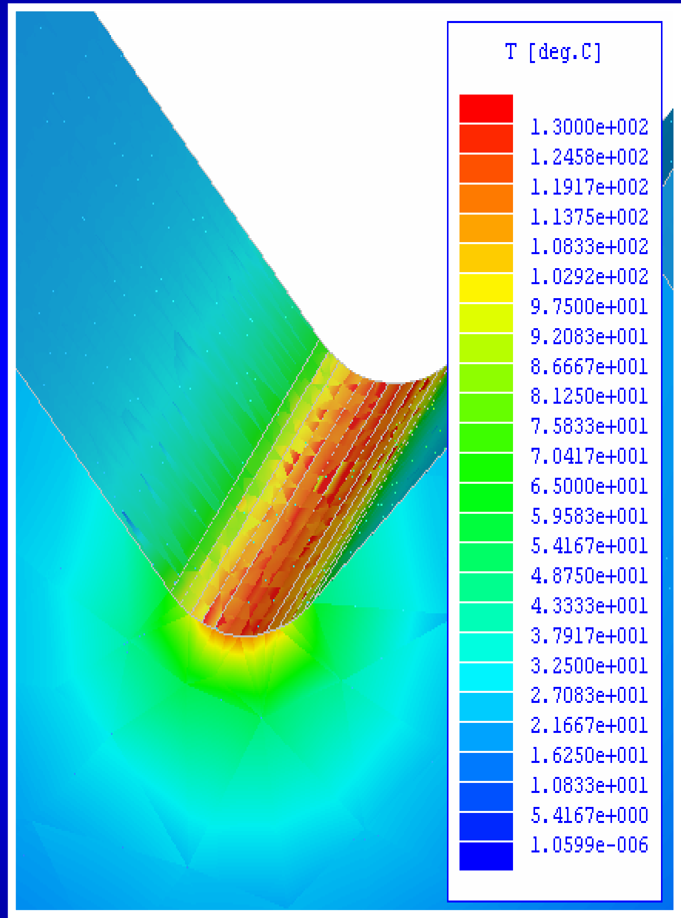
High magnetic surface fields





130 K pulse heating at 400 ns pulse length

Rule of thumb: < 50 k pulse heating is safe

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Reliability – Trip rates

NLC a example of a large scale accelerator (30 km)

18000 structures , 2% operational overhead,
10 s trip recovery, 100% availability

→ trip rate > 0.1/h at 60 Hz

(5 s, 99% availability → trip rate 0.4/h)

Still a trip every second !

Assumption that breakdown kicks reduce luminosity on the pulse but wouldn't hit the collimators

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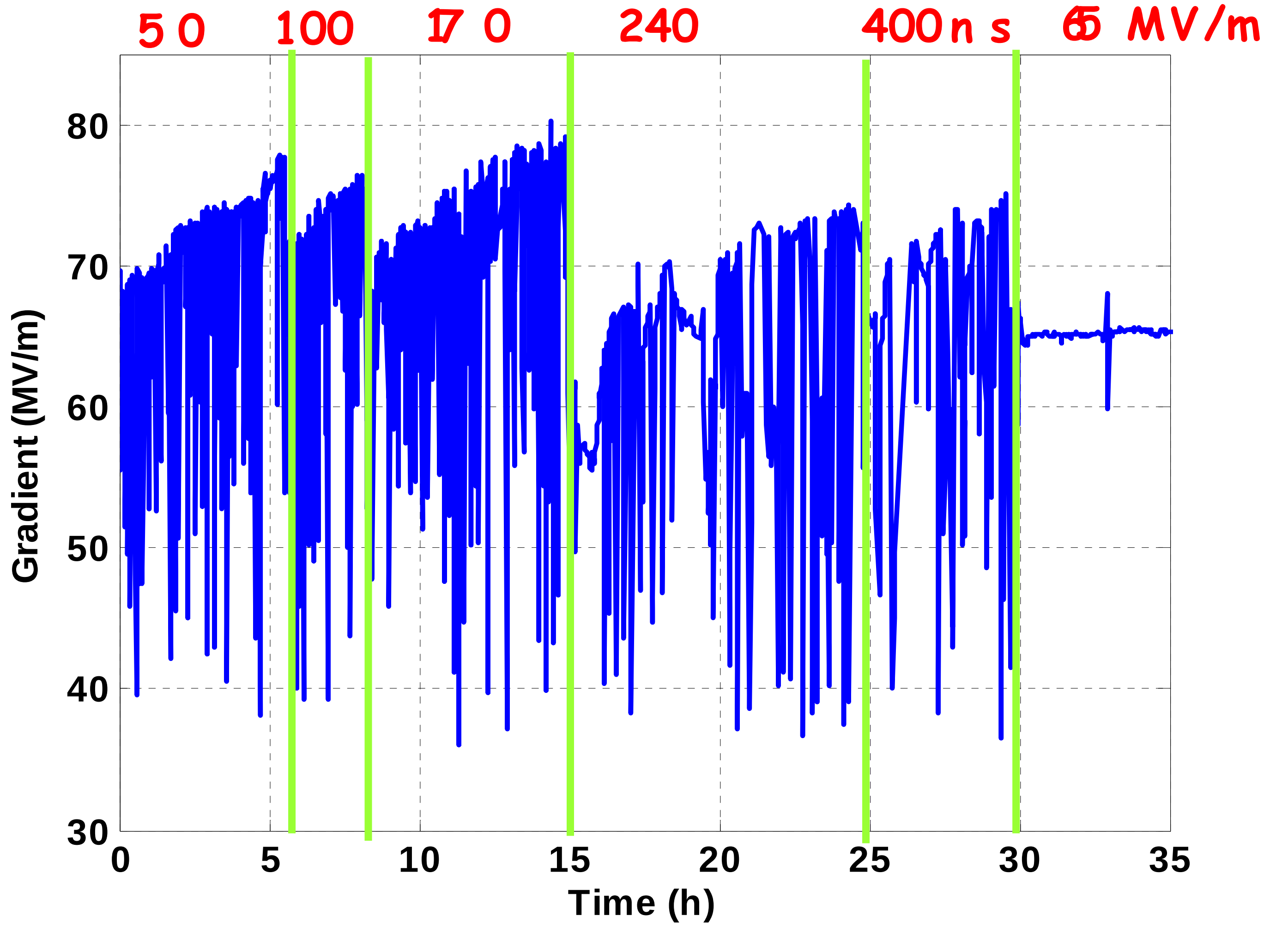
Typical structure processing history



NLC working point: 65 MV/m, 400 ns, 1 trip in 10 hours

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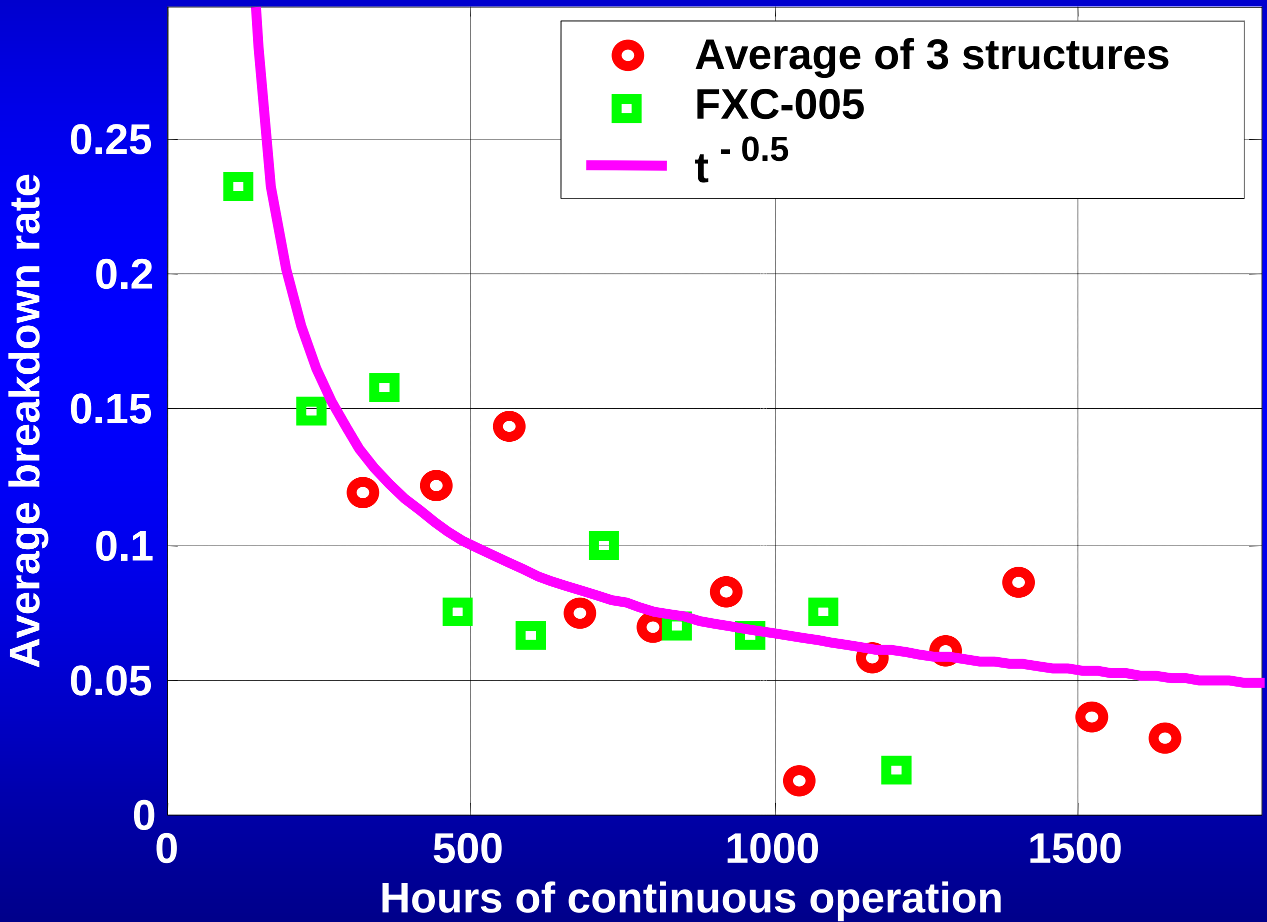
Long term operation

Performance improvement over time



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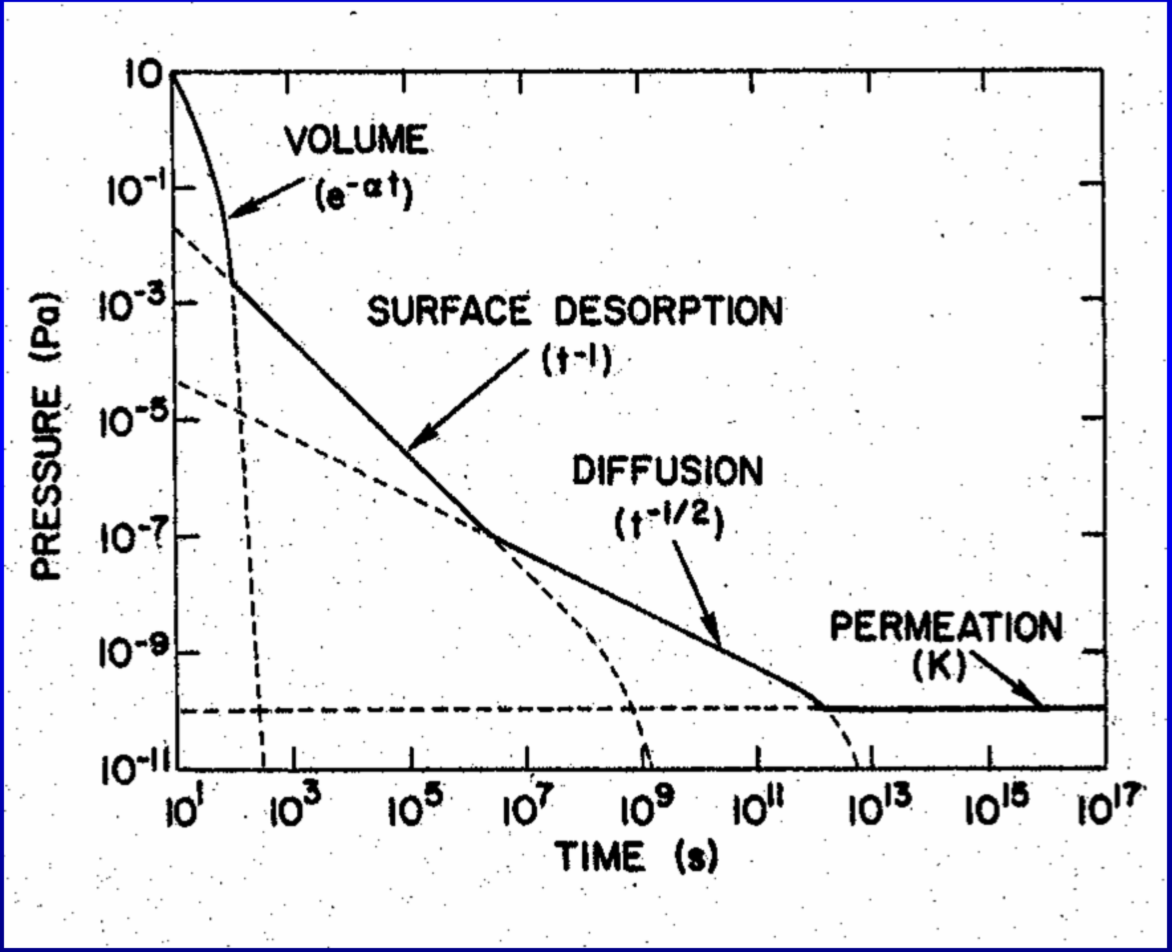
Long term operation

Long term monitoring of a vacuum system



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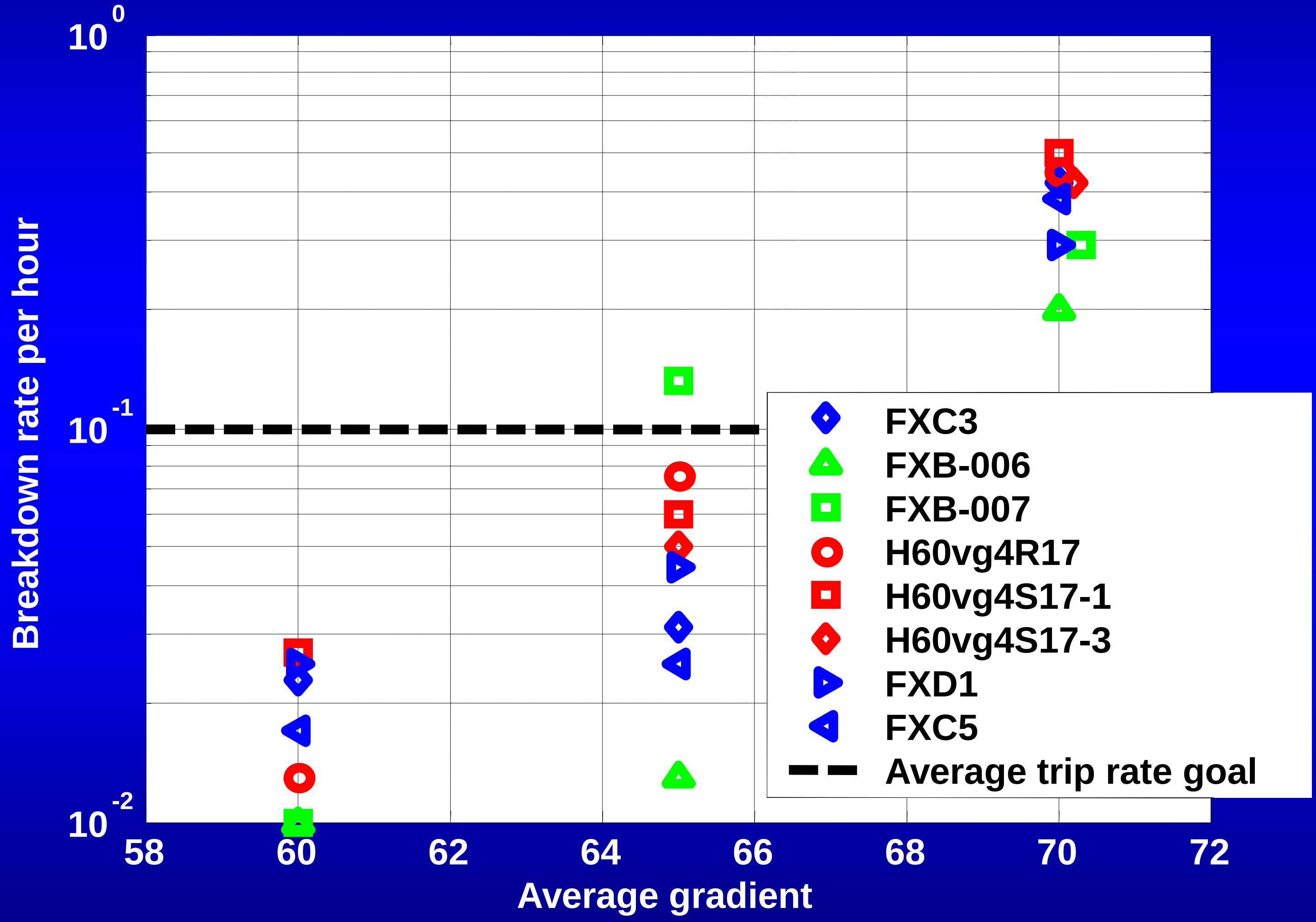
Performance of latest structures



Details about structure designs see poster. J.W. Wang THP33

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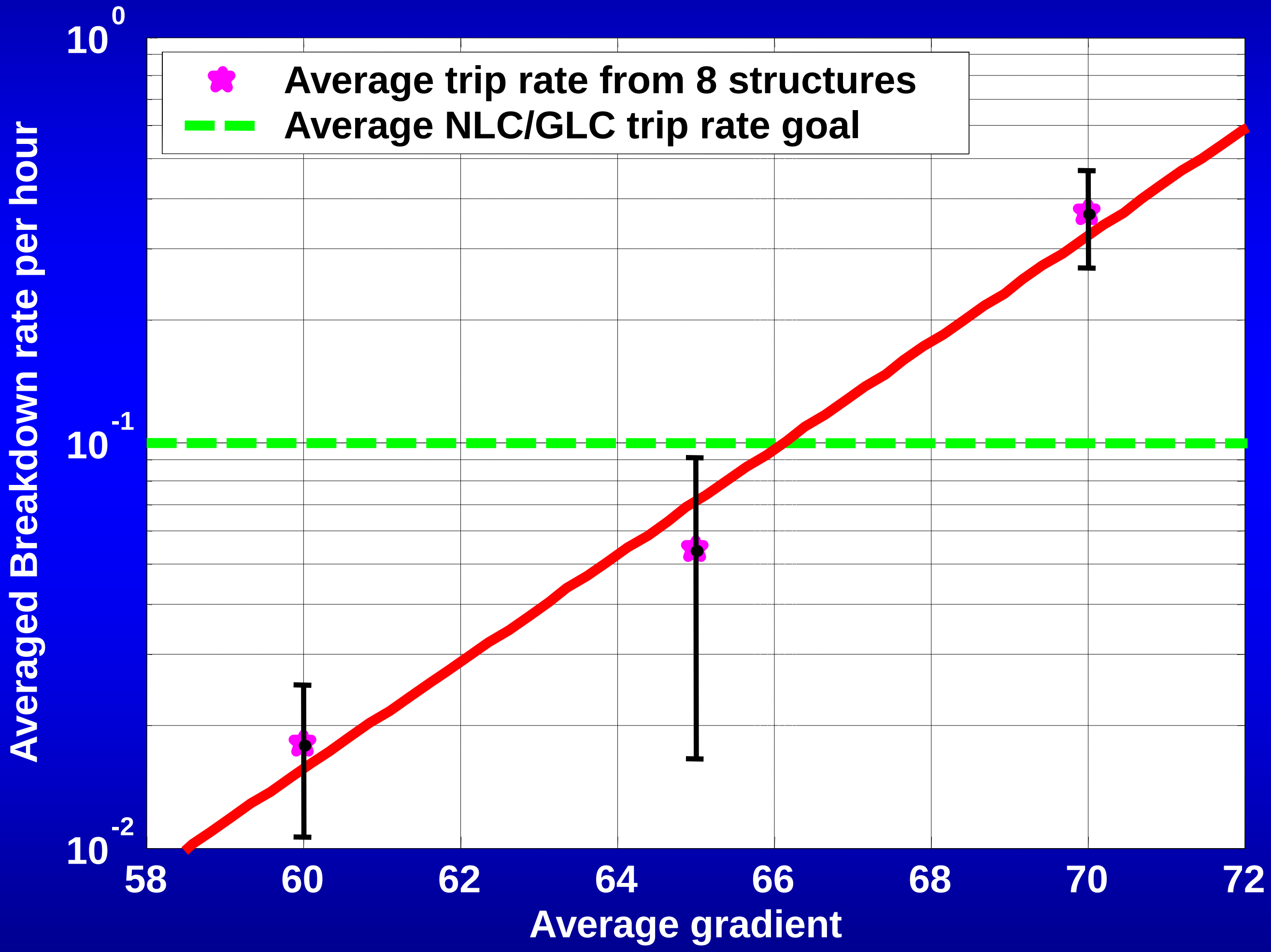
Averaged performance of 8 structures



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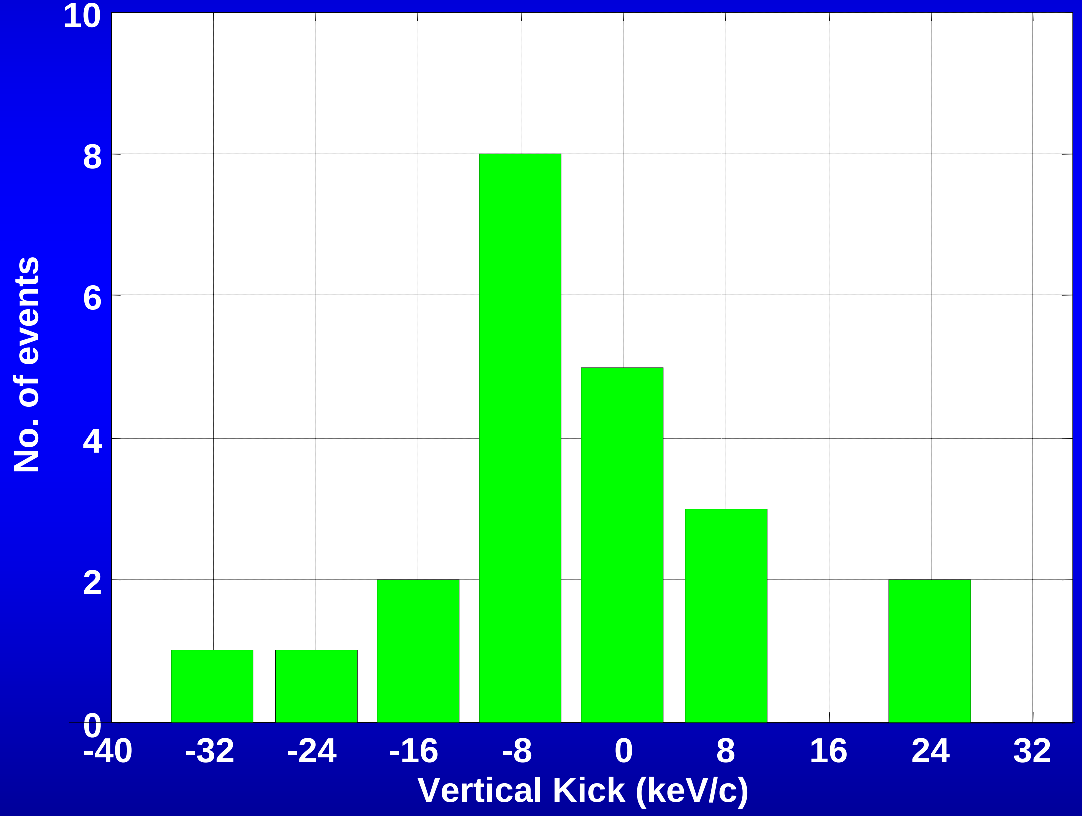
Breakdown Kicks to the Beam

Measured Kick Distribution from breakdowns at 90 MeV



NLC kick limits:

- 200 – 1000 keV/c to hit collimator

(1 σ beam size 10 – 100 keV/c)

Kick simulations see poster: V. Dolgashev: TUP56

Pulse length dependence

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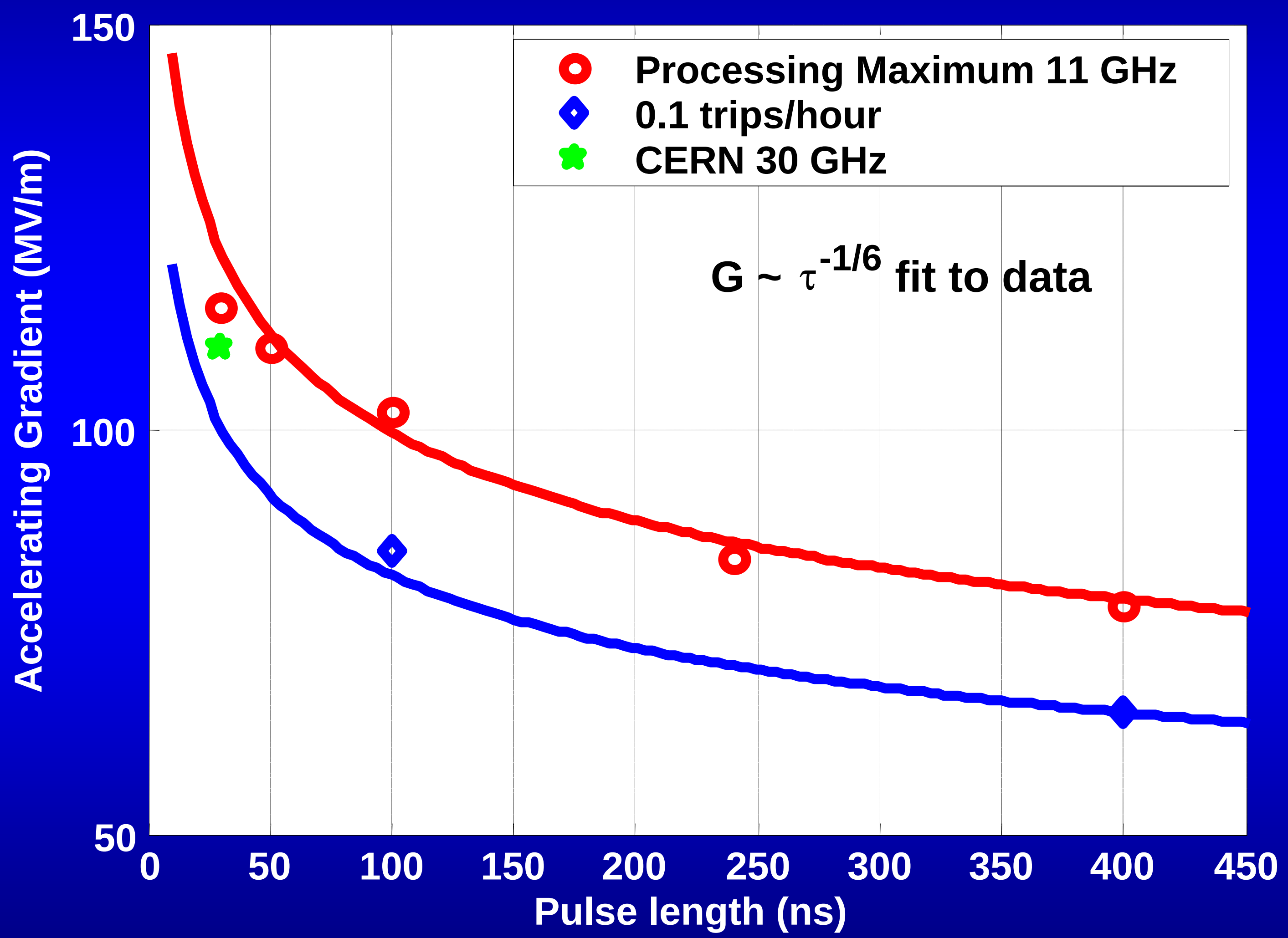

Steffen Döbert, SLAC/NLC, 2004

Breakdown-rates vs pulse length

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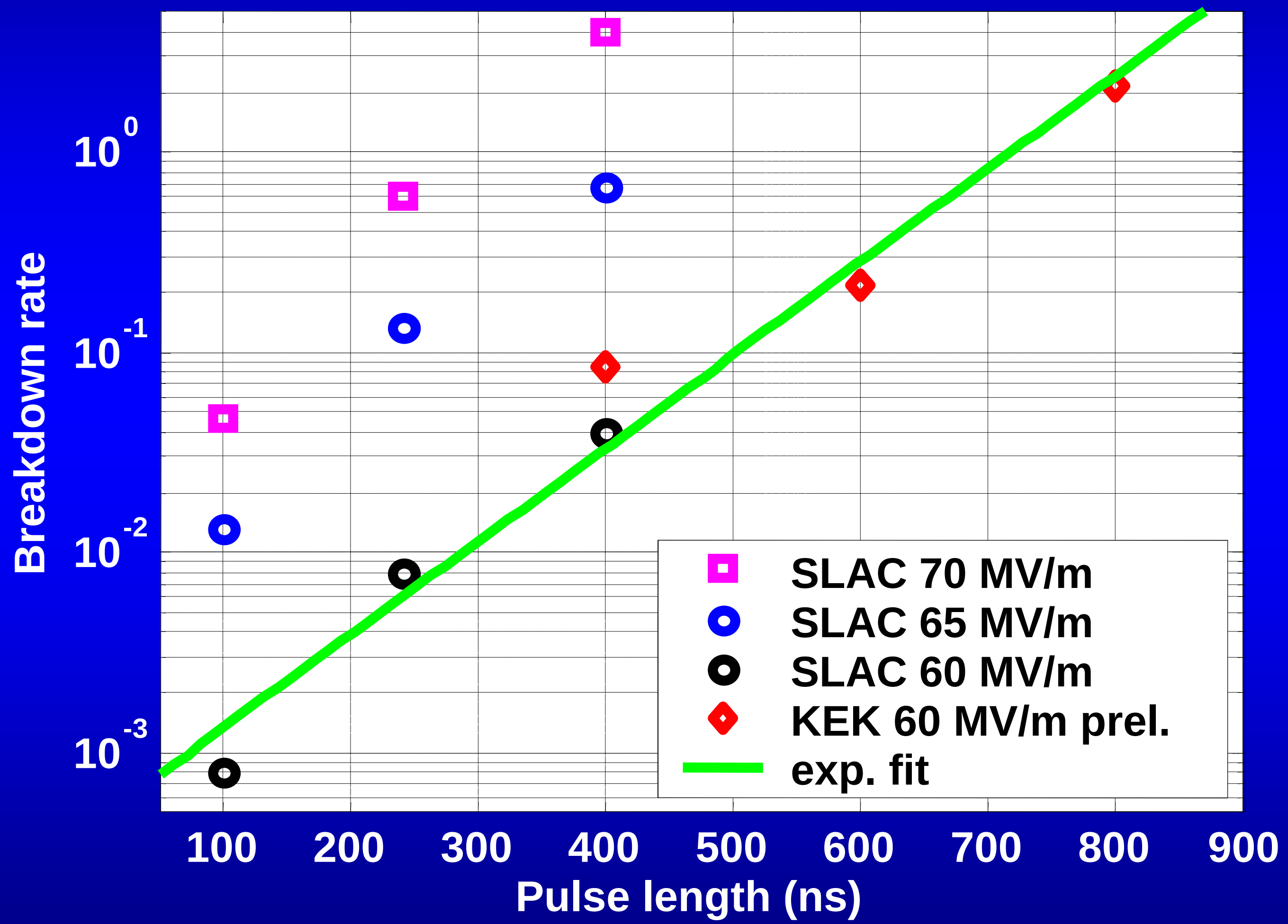

Poster, P. Wilson: MOP72

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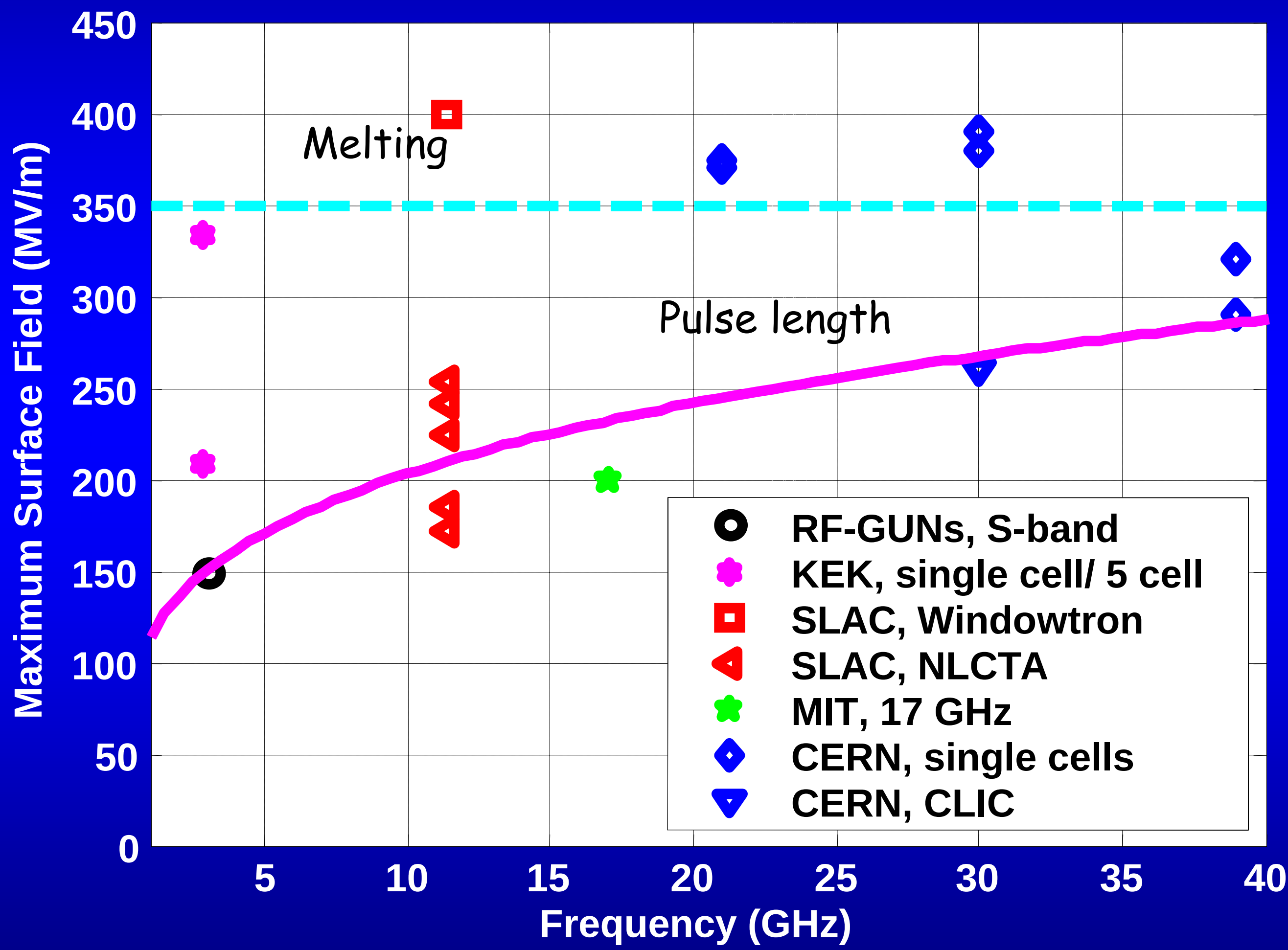
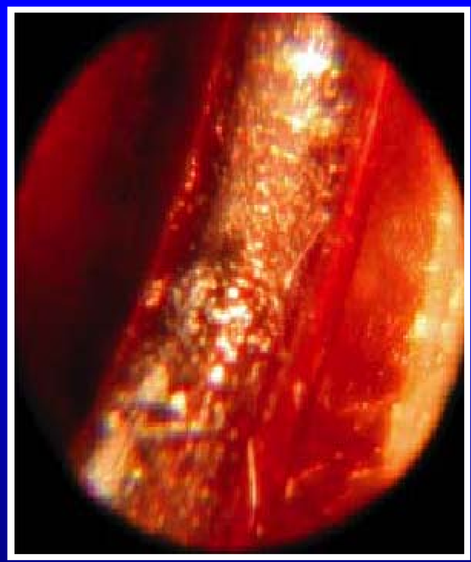
Frequency dependence



Realistic structures:

Filling time ~ $f^{-3/2}$
$E_s \sim t_p^{-1/6}$
$E_s \sim f^{1/4}$



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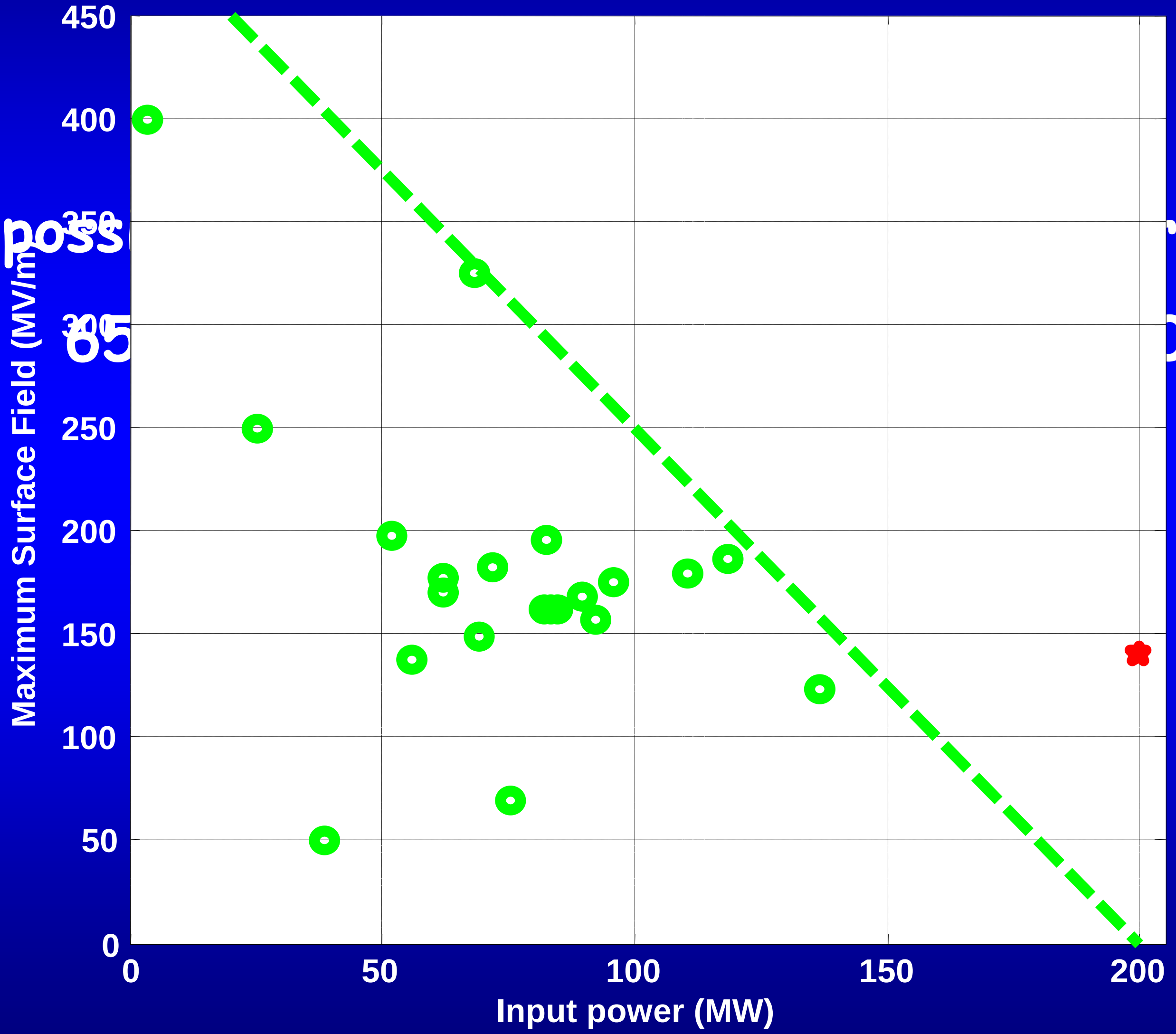
RF Power limit (group velocity)

Is it poss… …re with:

65… …0 hours



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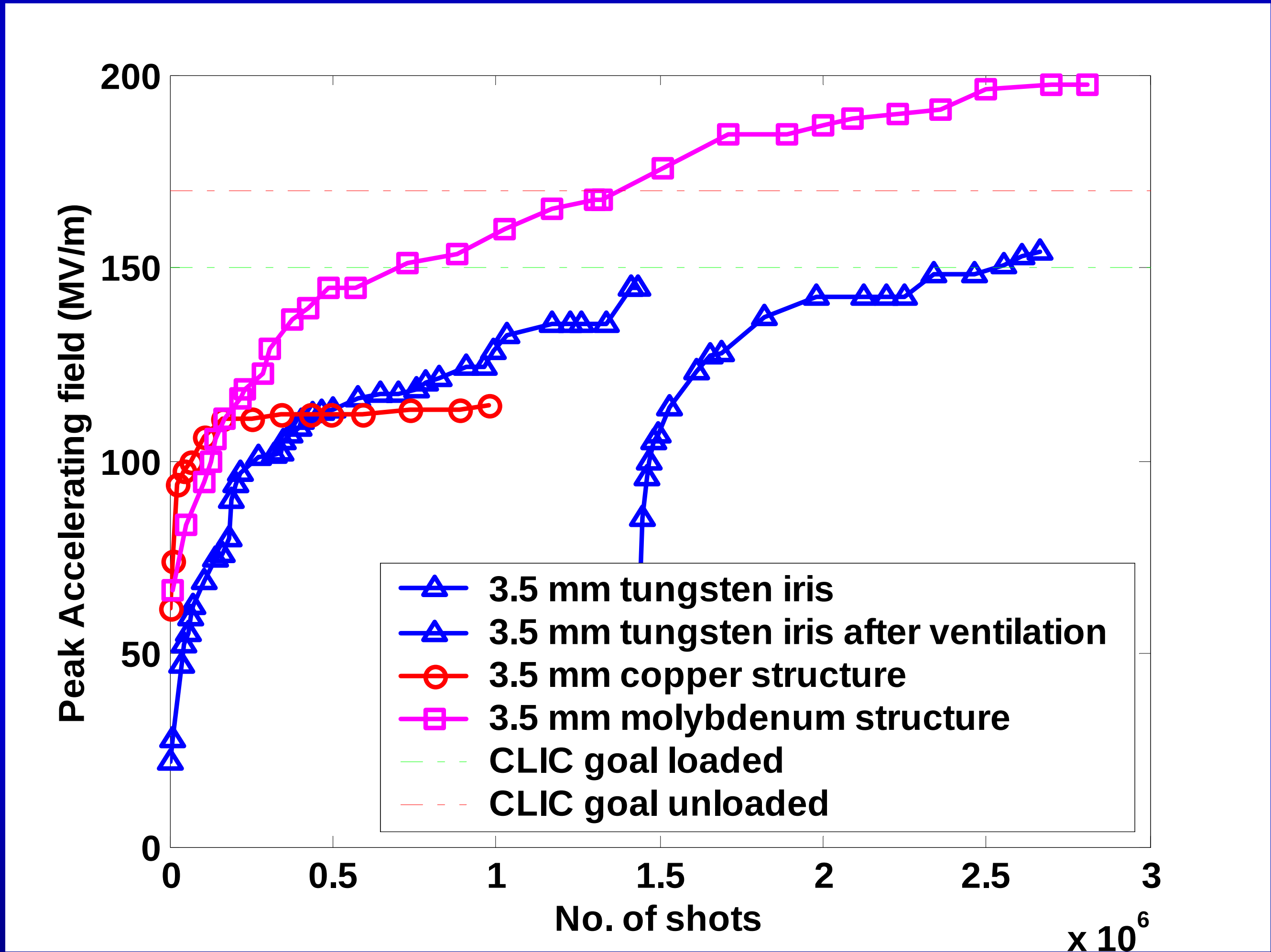
Different Materials at 30 GHz



30 GHz
16 ns pulses

Molybdenum-iris X-band structure

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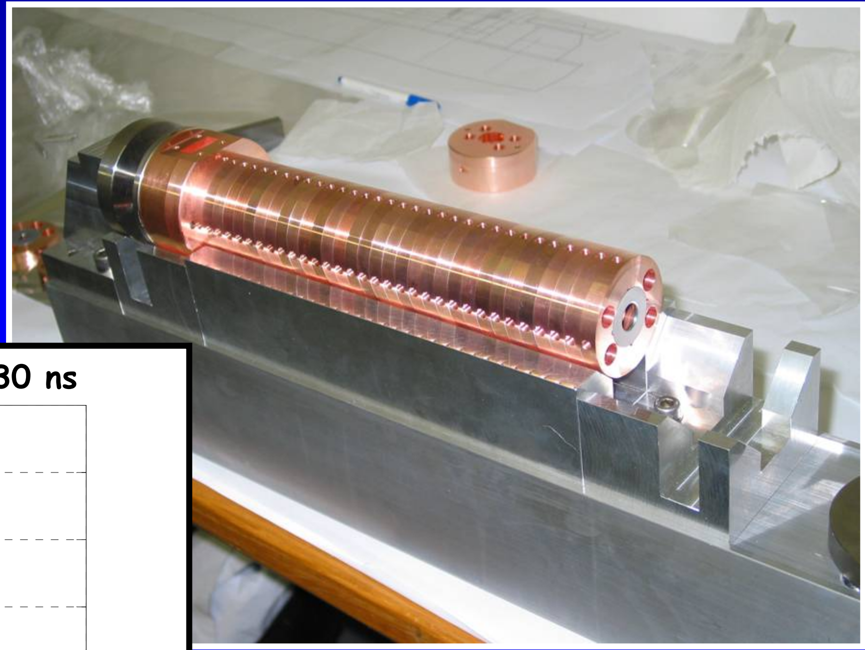
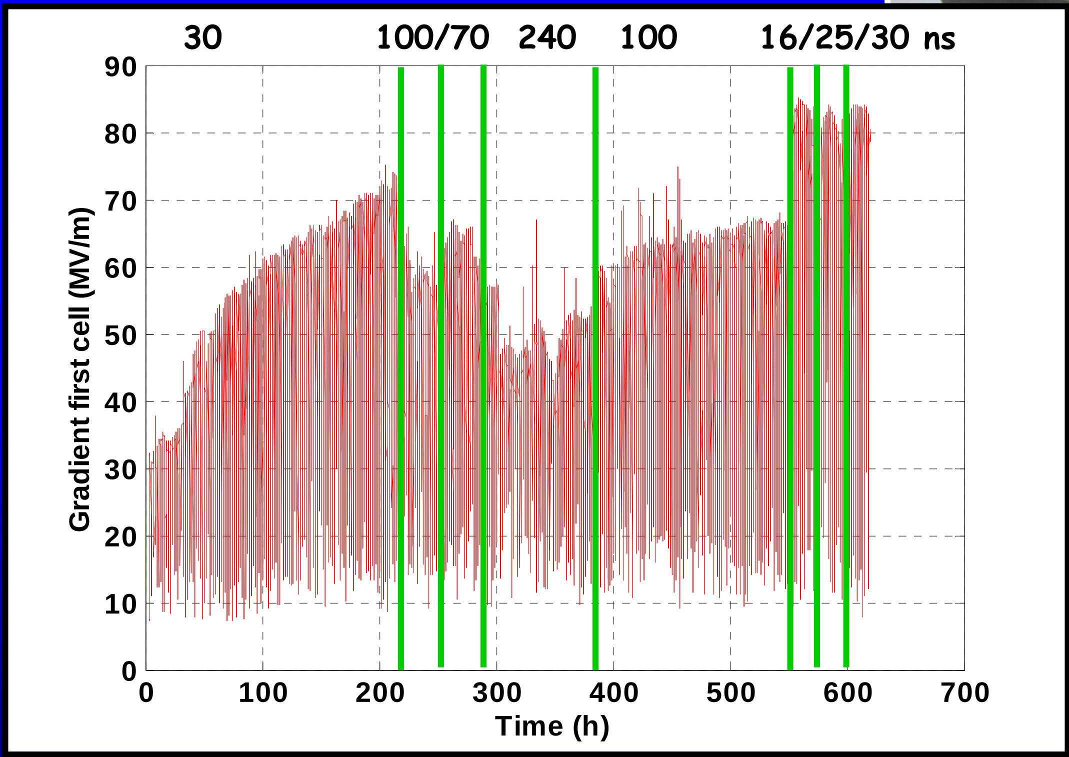
High-power tested in NLCTA at SLAC





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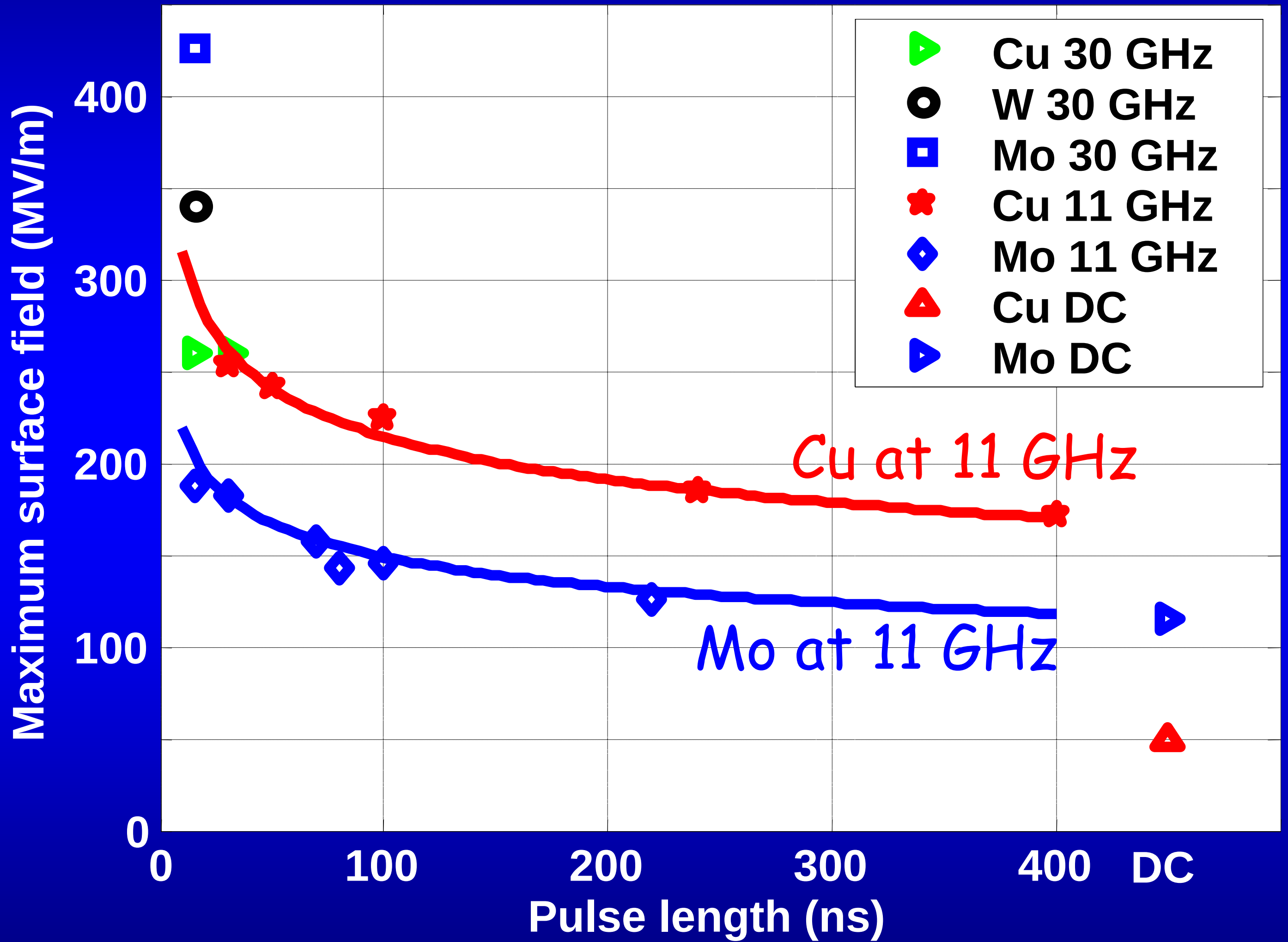
Pulse length dependence - Materials



CERN-data: W. Wuensch et al; see poster:THP34

DC-data: T. Nakanishi et al., see Poster:THP23

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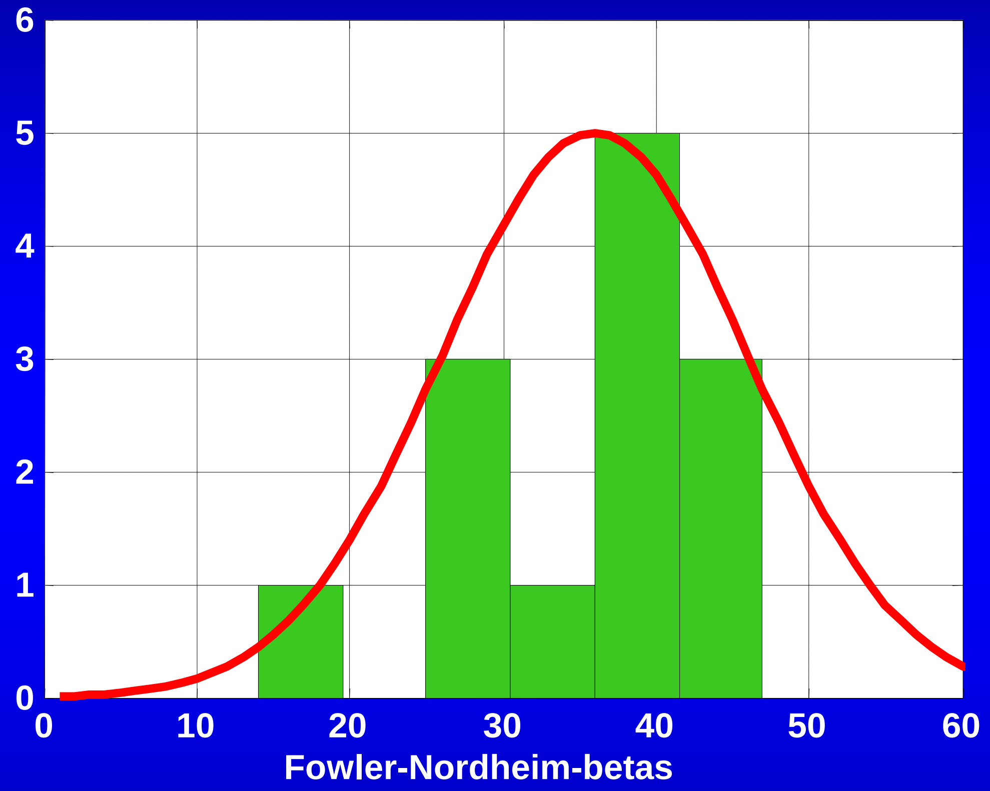
Do we understand field enhancement factors ?



Breakdown limit observed

Es β ~ 6-7 GV/m

- Field emission threshold
- Independent from frequency
- Independent form material

S. Yamaguchi (KEK): S-Band: Eeff: 6-7 GV/m

S. Tantawi (SLAC): X-Band Waveguides: Eeff ~7 GV/m (material)

S. Doebert (CERN): Ka-band: Eeff: 7 GV/m

Conclusions

- NLC/GLC-collaboration achieved important milestone for future high energy physics
  - demonstrated 65 MV/m at 400 ns and less than 1 trip in 10 hours
- Frequency dependence of breakdown voltage is fairly weak above X-band,
  pulse length dependence seems to dominate
- New materials could provide a path for future very high gradient (>100 MV/m) applications as shown by the CLIC-study
- Still missing consistent breakdown theory

Future Research, Remaining questions

- What are the relevant local parameter Es, Hs, P, Es x Hs
- Local melting by ohmic losses or bombardment ?
- Importance of gas from surface or bulk as catalyst
- What is really determined by β
- Which material parameter determines threshold
- What is the optimal surface processing
- Physical model of pulse length dependence
- Breakdown statistics (1 breakdown in two million pulses)

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NLC Structure development

SLAC/NLC

C. Adolphsen, G. Bowden, D. Burke, J. Chan, J. Cornuelle, S. Döbert, V. Dolgashev, J. Frisch, K. Jobe, R. Jones, R. Kirby, F. Le Pimpec, J. Lewandowski, Z. Li, D. McCormick, R. Miller, C. Nantista, J. Nelson, C.K. Ng,C. Pearson, K. Ratcliffe, M. Ross, R. Ruth, D. Schultz, T. Smith, S. Tantawi, J. Wang and P. Wilson

FNAL/NLC

T. Arkan, C. Boffo, H. Carter, I. Gonin, T. Khabiboulline, S. Mishra, G. Romanov, N. Solyak

KEK/GLC

Y. Funahashi, H. Hayano, N. Higashi, Y. Higashi, T. Higo, H. Kawamata, T. Kume,Y. Morozumi, K. Takata, T. Takatomi, N. Toge, K. Ueno, Y. Watanabe

End of the talk

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Gas exposure and installation

1. Venting with nitrogen and leave backfilled for 24 h
   Structures came back to full performance after 8 h of pumping and 1 breakdown to reach 65 MV/m, 400 ns
2. Venting and purging through a structure with nitrogen
   24 h of pumping, 3 breakdowns,
   one structure 2x higher trip rate in the first 24 h
3. Venting with nitrogen and purging with filtered air through a structure
   48 h of pumping, 14 breakdowns, trip rates ~ 10x higher in first 24 h, still 4 times higher after 100 h in one structure

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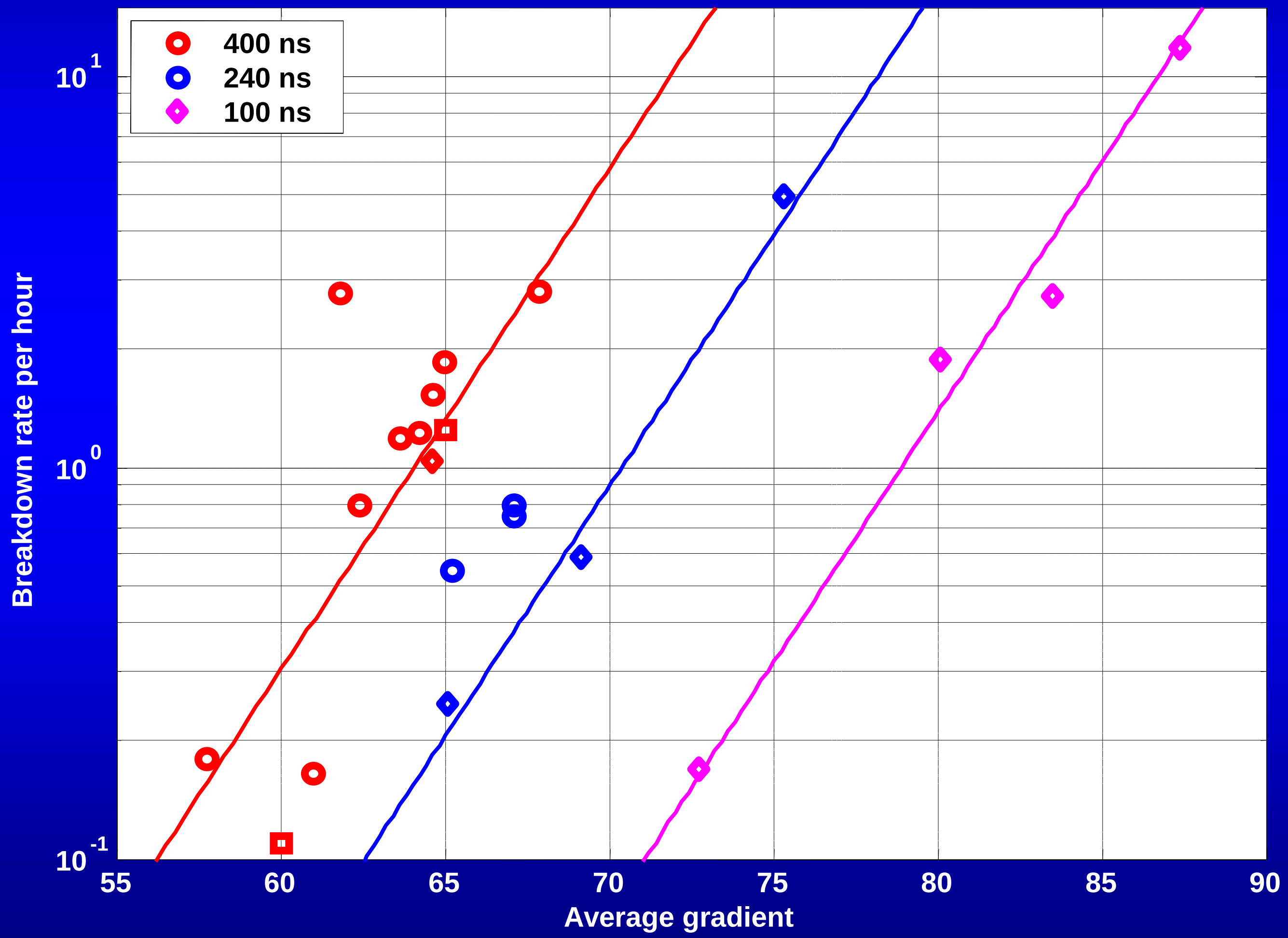
Breakdown-rates vs pulse length

H90vg3N



Slope

8 MV/m

per decade

Steffen Döbert, SLAC/NLC, 2004

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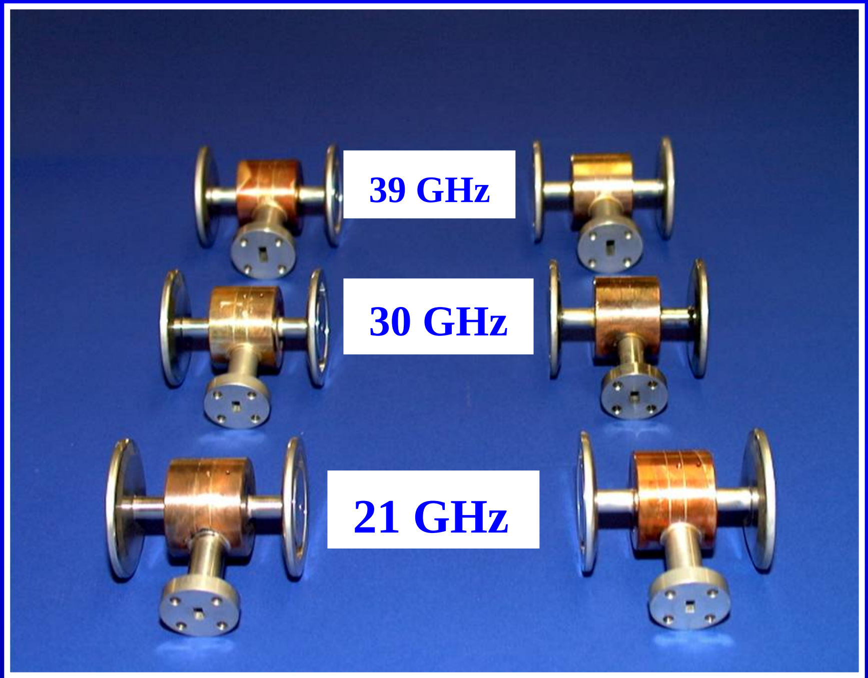
CERN- Mo/W - structures

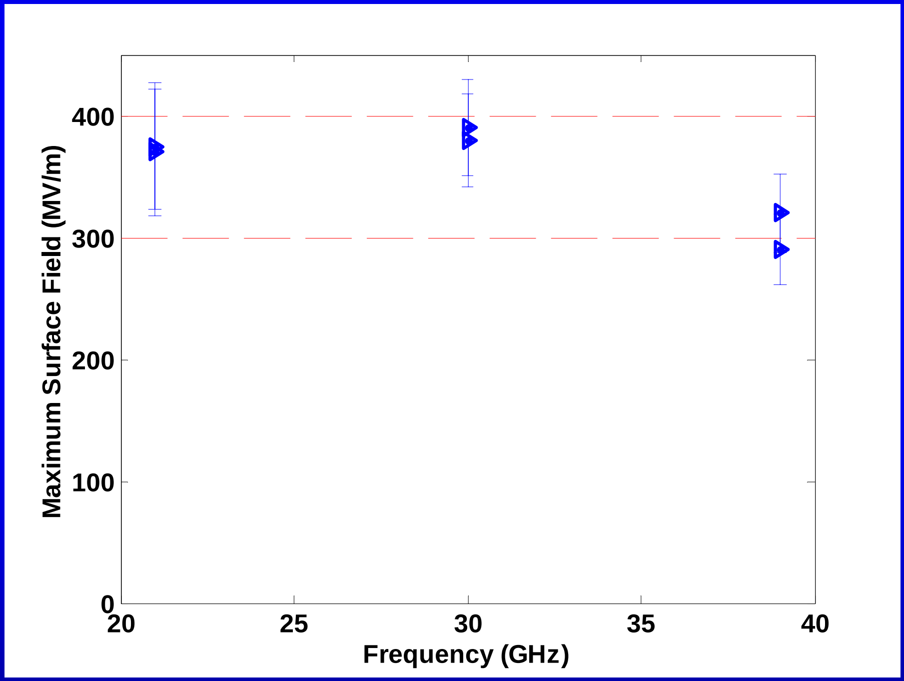
Clamped constant impedance structure with Mo-irises

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

Frequency dependence

High Gradient Single cells, CERN





PRL, 2003, Vol. 90, No 22, 224801