NLC - The Next Linear Collider Project

Breakdown Studies
NLCTA

- Coupler breakdowns in low field region
  - Role of pulse heating
- Copper surface processing – what we can learn from LHC

Marc Ross

Operational Questions:

There are two main ideas about the dependence of damage on cell breakdown:

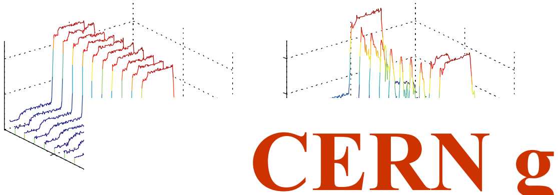
1) The damaging mechanism represents a constant, very low impedance. The match to this impedance is better in the higher group velocity structures. Lower group velocity should show less tendency to damage.

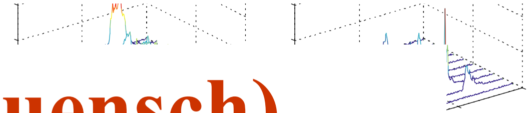
OR

2) Currents that are absorbing the RF power are responsible for the damage. Since there is more than enough missing energy in breakdowns to produce the observed damage, *the key issue is the extent to which the breakdown currents are localized.*

Walter Wuensch
CERN/CTF
EPAC 2002 CLIC-note 516

A striking feature of breakdown is the tremendous power it is capable of absorbing with little reflection.
→ currents of kilo-amps.

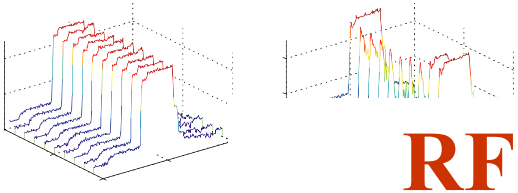


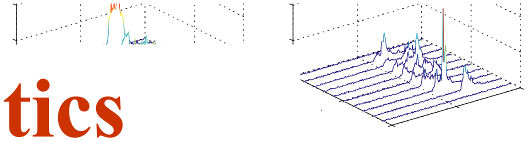


CERN group hypothesis (Wuensch)

- Group velocity is not a big part of the picture
  - iris diameter is (cell geometry…)
  - 150 degree structure coming soon…
    - (it has large irises and low group velocity)
- Breakdown arc impedance is similar to a ‘cold cathode’ gas arc (fluorescent tube) and very well understood
  - Impedance matches source impedance – not a fixed impedance

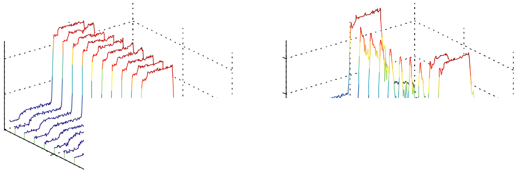
- Damage comes about by the way the electron current is captured in the structure
  - 100 MW = 100 KV *1 KAmp
  - Single cell tests ineffective
  - Should be able to test with acoustic emission

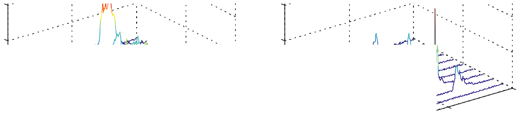




RF Breakdown Diagnostics

- Goals:
  - Location within mm → *location of what?*
  - Quantify energy deposition
    - Comprehensive recording
- Provide feedback to manufacturing & fabrication process
  - Acoustic sensors gave first indication of coupler ‘horn’ breakdowns
  - Showed where to look in SEM
    - Easy to pinpoint once you know what to look for…
- Observations:
  - Breakdowns in the coupler easily localized
  - Structure body results similar
    - Too few sensors (taken for coupler studies)





Acoustic sensors

- Excellent success with coupler
  - Can use timing & amplitude to differentiate between horns
- Structure symmetry makes interpretation more difficult
- New sensors ~ 3 – 20 MHz
  - ~ mm resolution

- Need to identify location(s) of heating inside the structure
  - <u>First real potential for understanding breakdown</u>

    (many decades)
- 80 sensors will be used on the next structures…

Fritz Caspers (CERN)/Joe Frisch

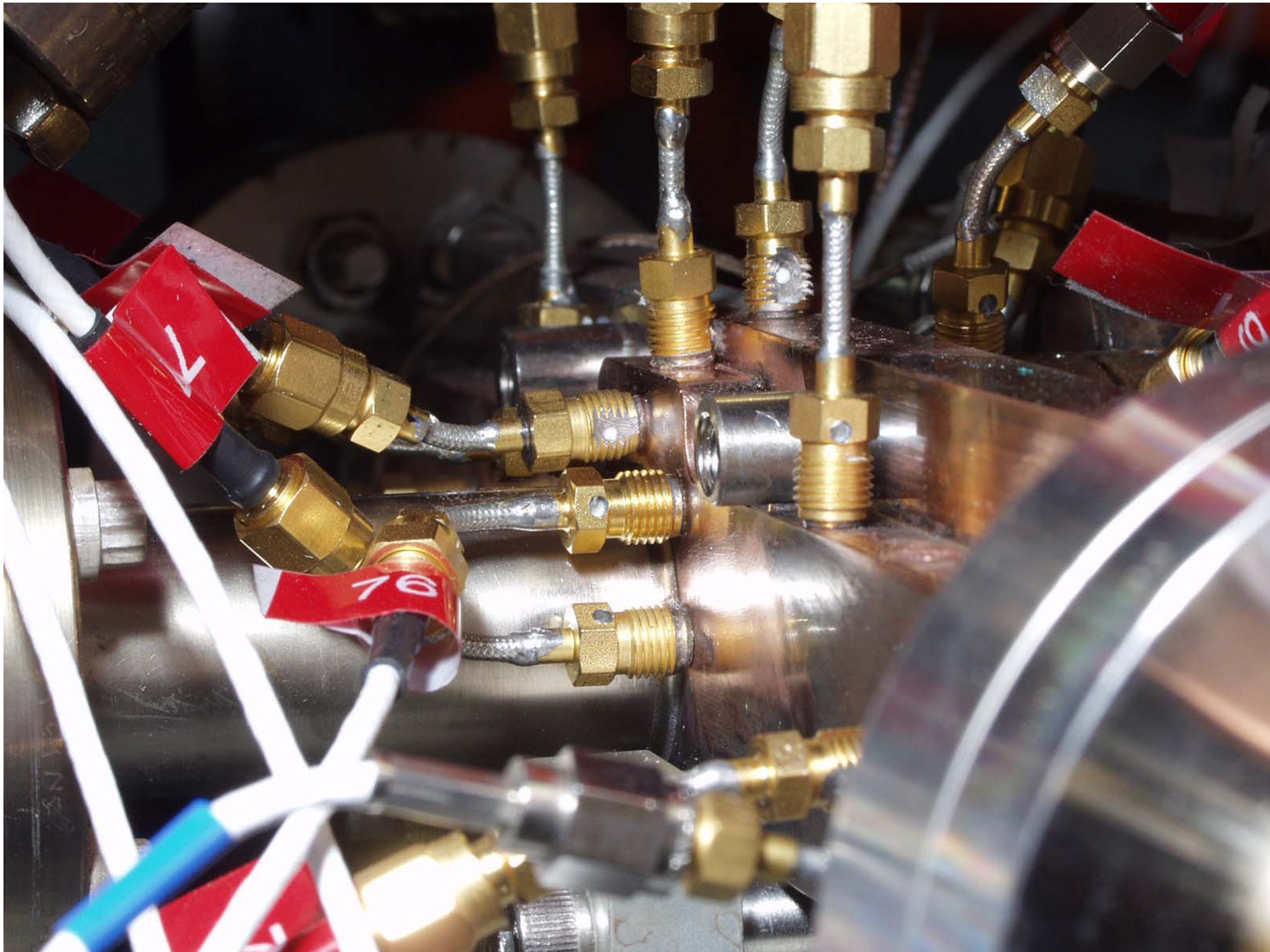
Warm equivalent of SRF thermal map→ thermal pulse microphones → Acoustic Emission (AE)

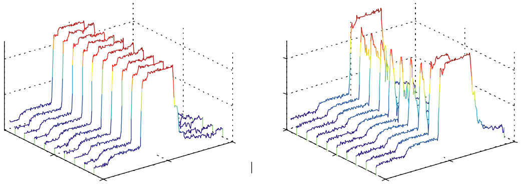
Easy for L band structures – TTF

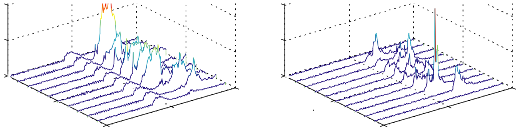
AE used for industrial structure monitoring (e.g. planes, bridges)

Completely different from “macrosopic microwave” diagnostics

10 mm

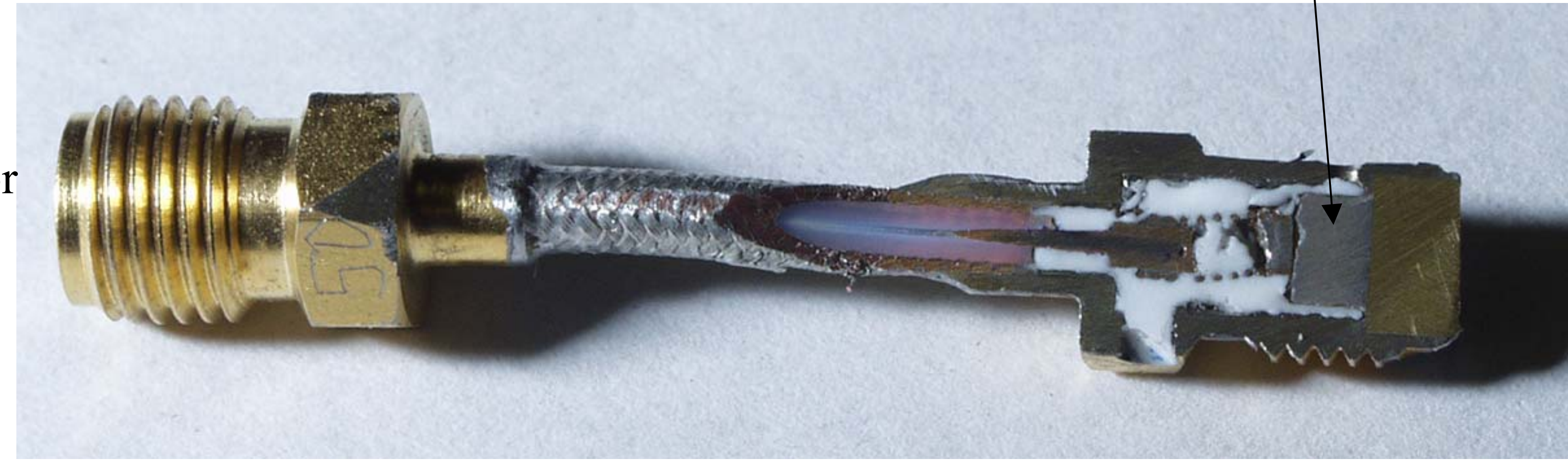






Acoustic Emission Sensor:

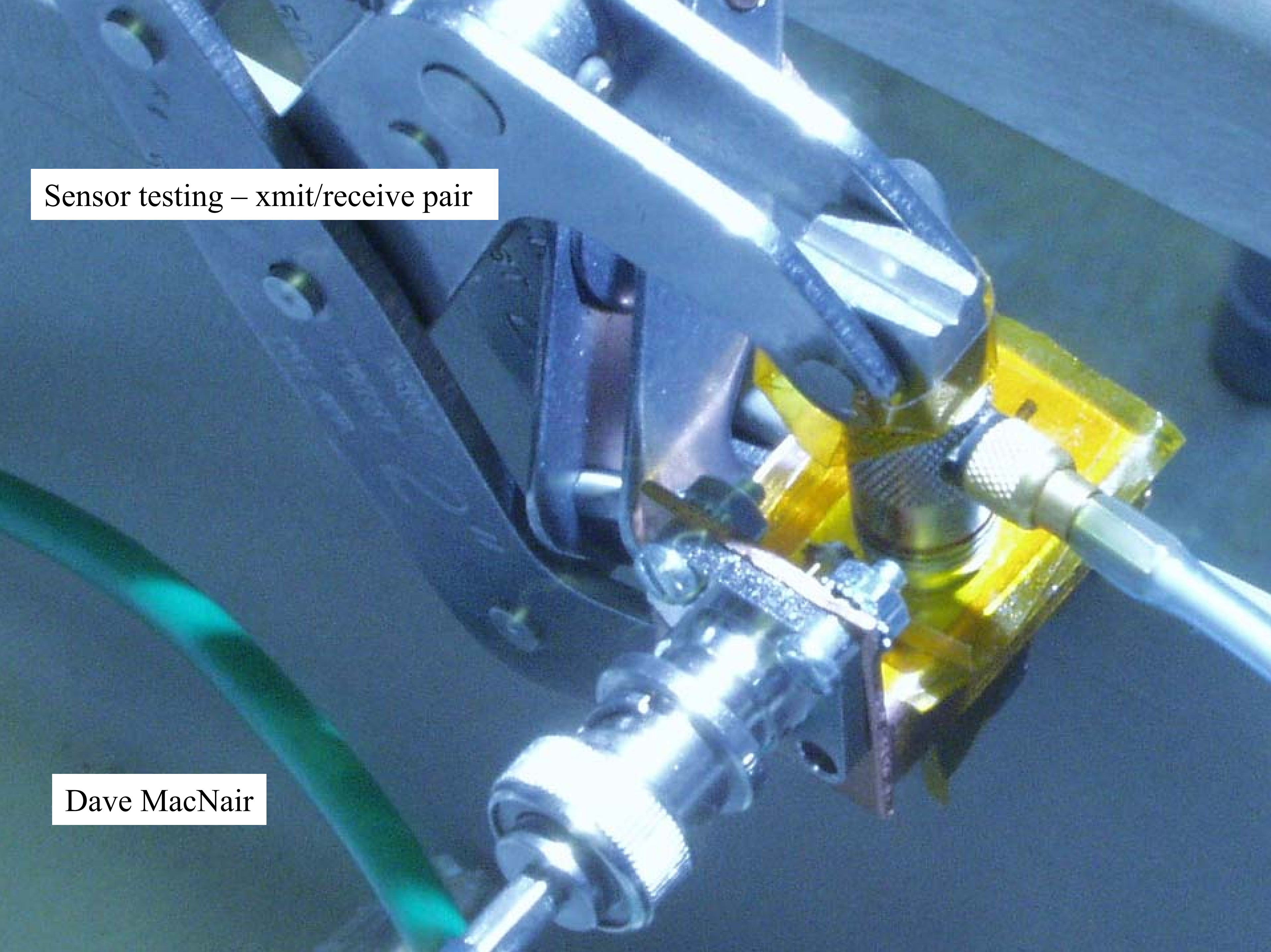
100 KHz – 1 MHz (speed is 3 mm/us)
Non-directional



SLAC-built
PZT piezo

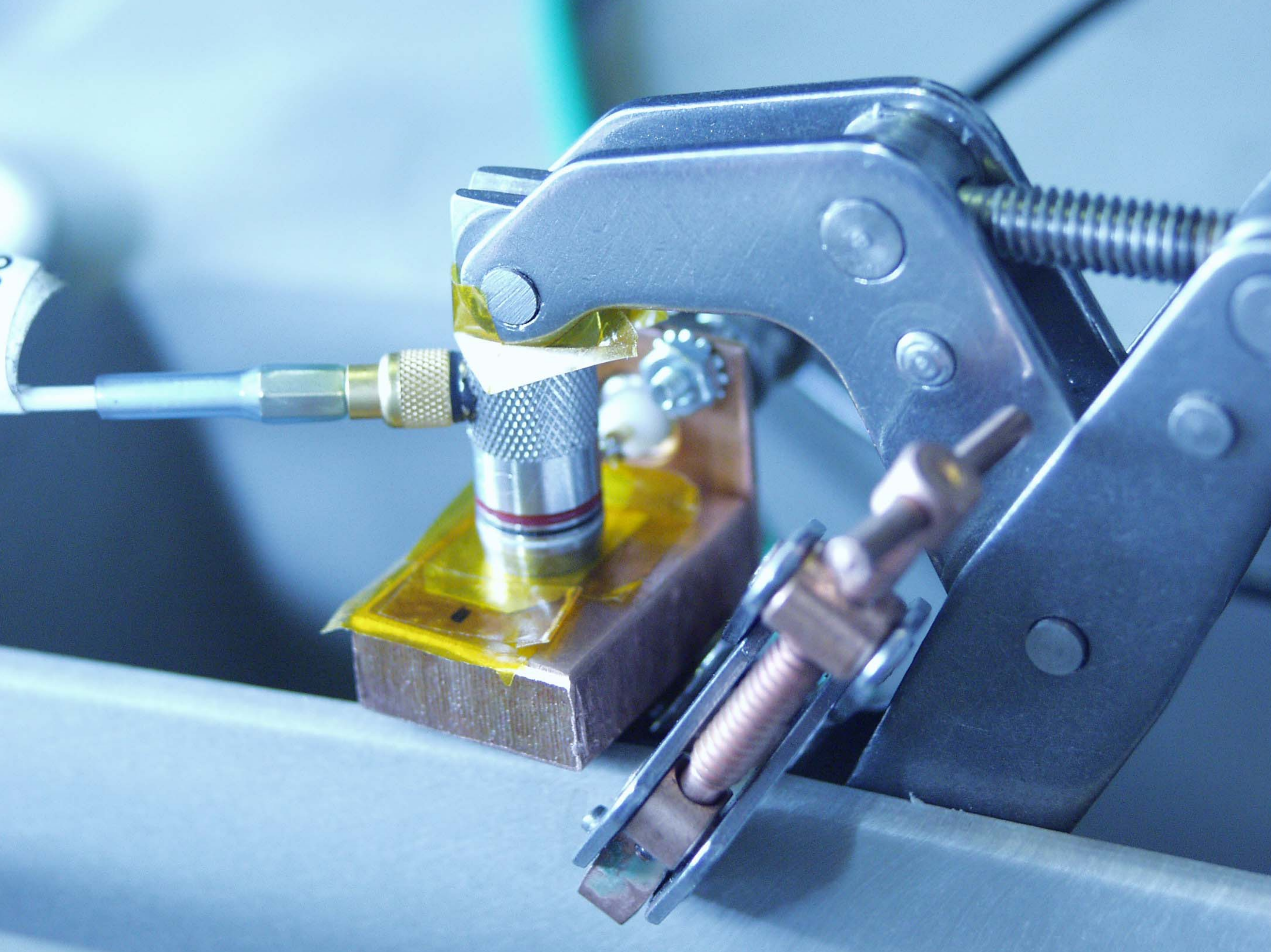
SMA connector

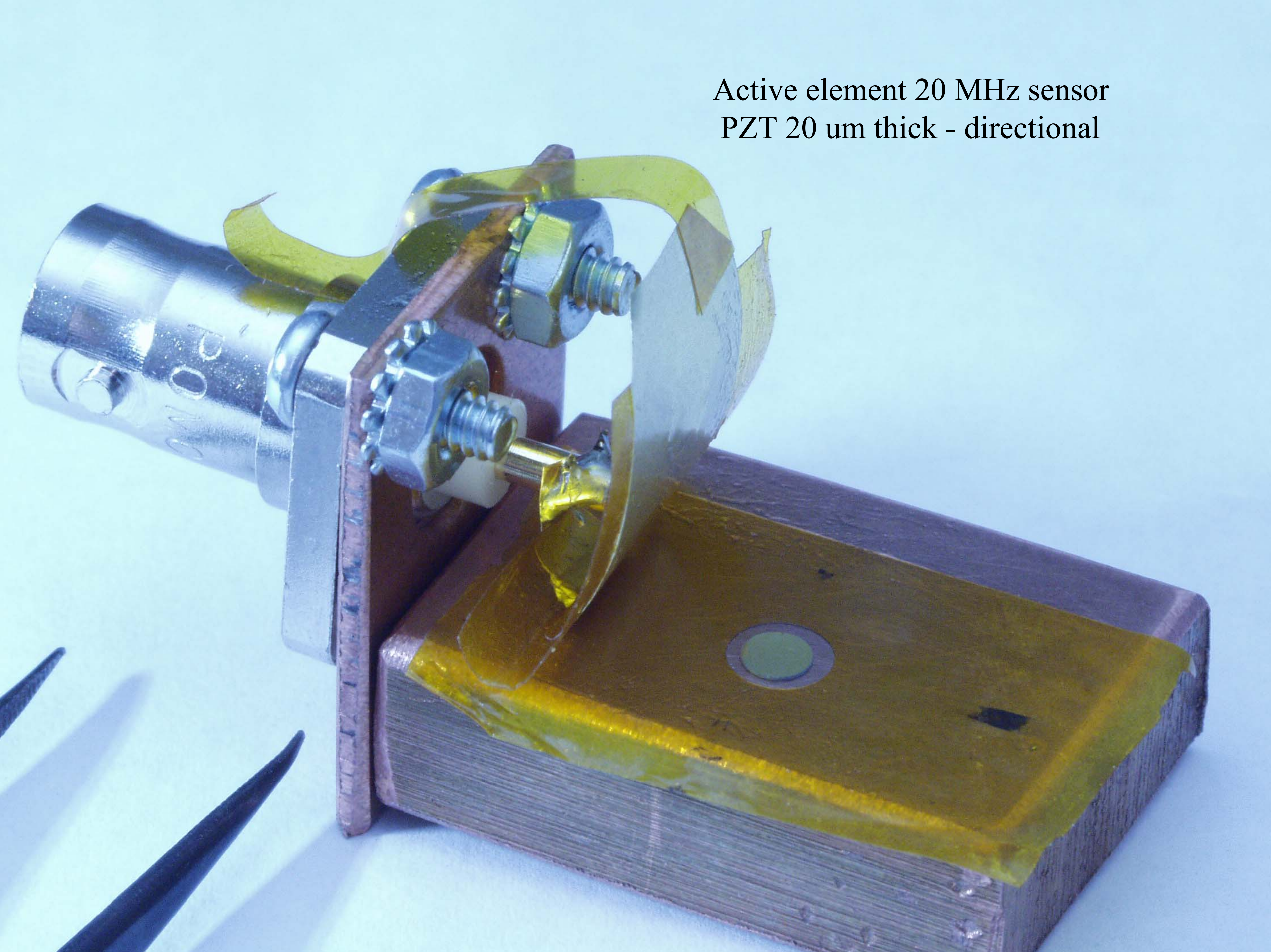
Doug McCormick



Sensor testing – xmit/receive pair

Dave MacNair

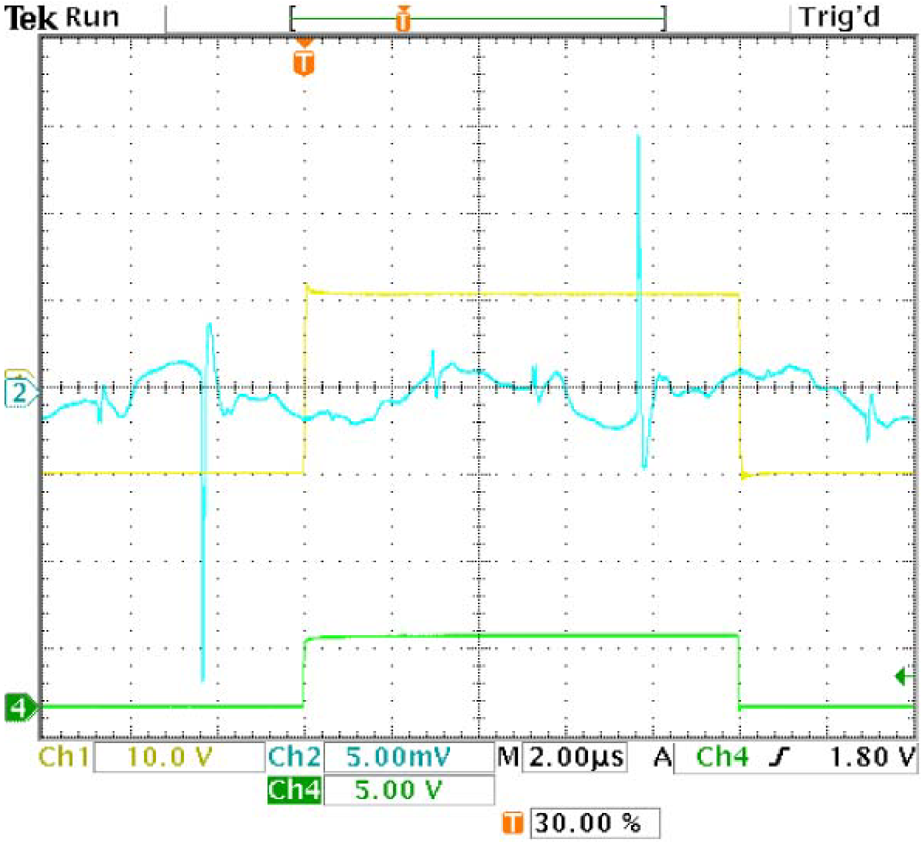




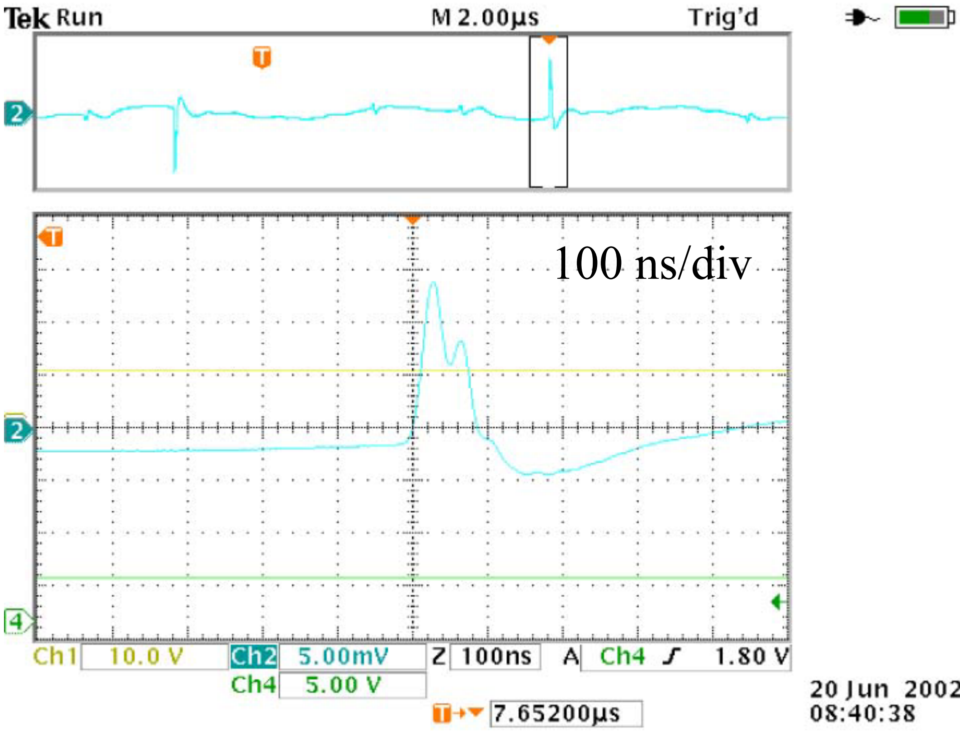
Active element 20 MHz sensor
PZT 20 um thick - directional

Xmit / receive AE sensor pair tests

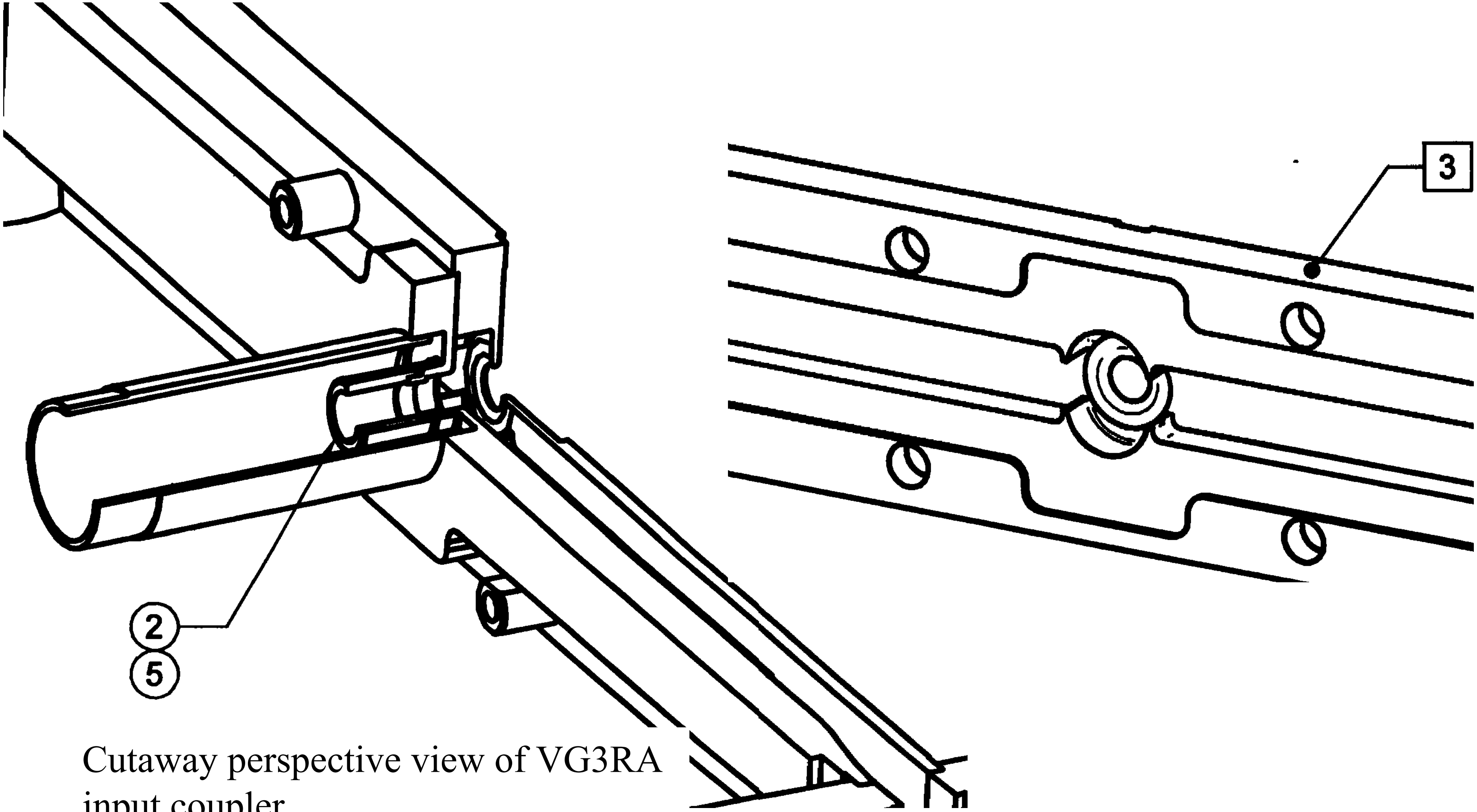
50 % duty cycle square wave drive,
showing delayed response and
suppressed low frequencies



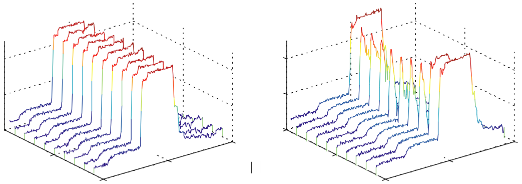
Xmit / receive tests:
showing high band, noise-free response

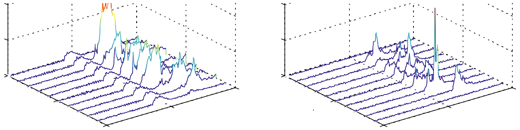

100 ns/div

SLAC-built input coupler → exactly where are breakdown events?

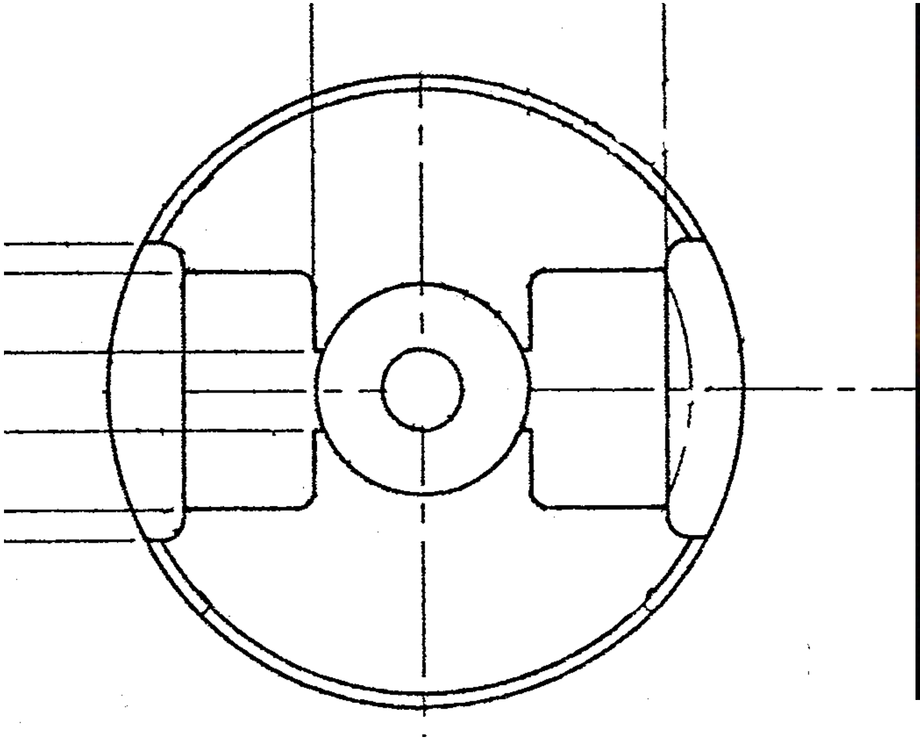


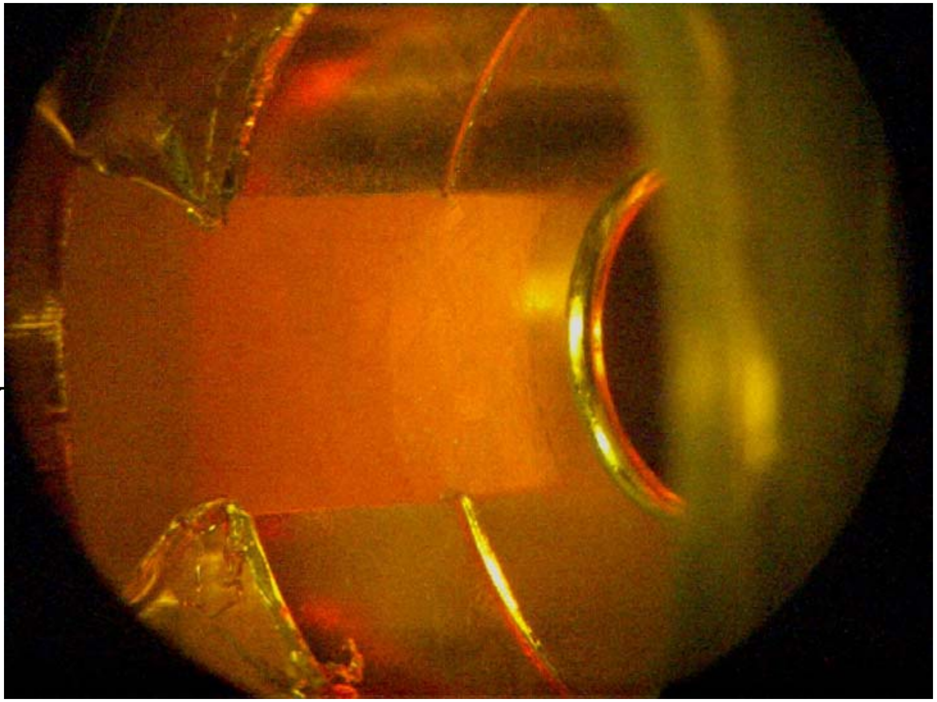
Cutaway perspective view of VG3RA input coupler





Input Couplers



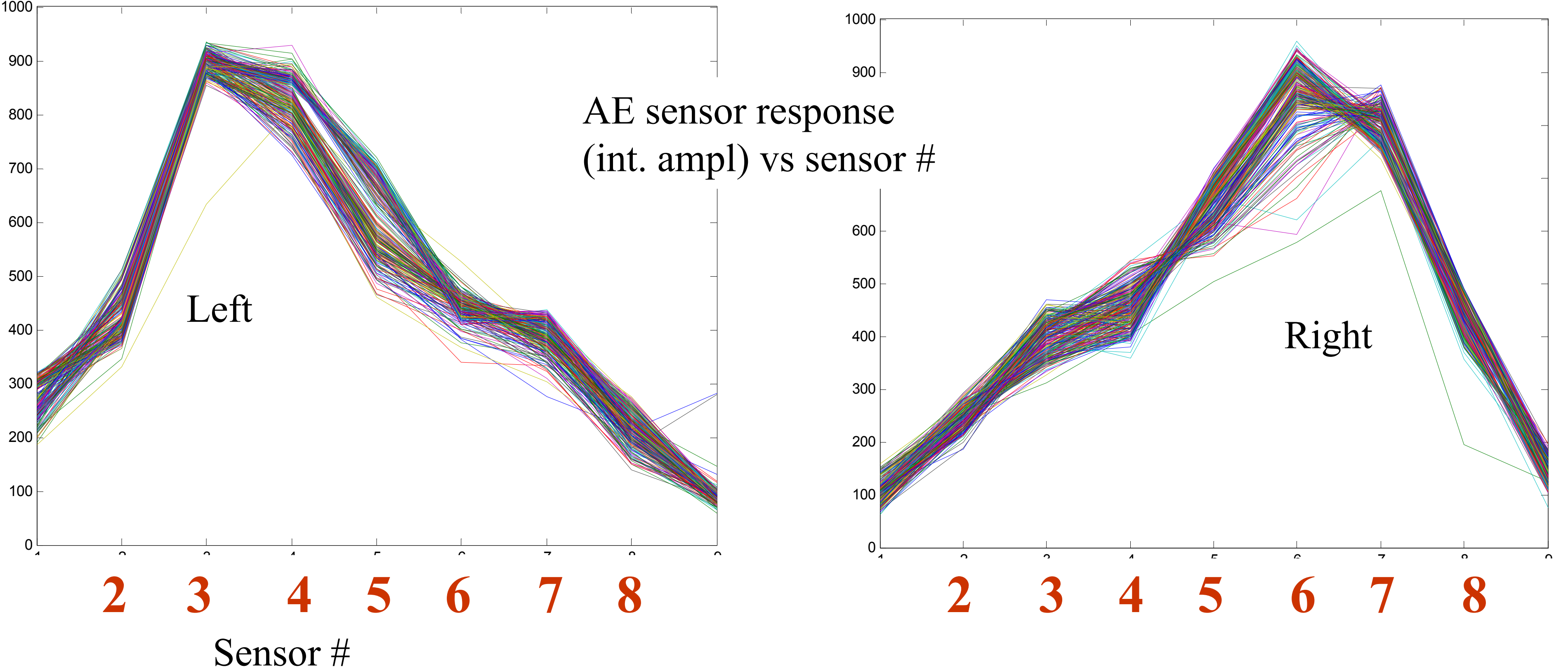


SLAC – VG3R removed 10/01

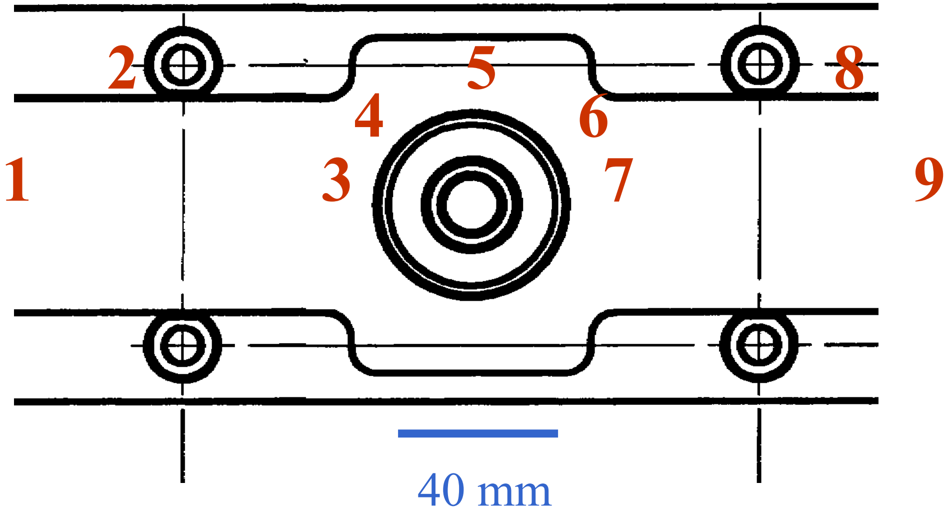
KEK – ‘F’ structure removed 4/02

Sensor signals from ~ 600 coupler breakdowns

AE sensor response
(int. ampl) vs sensor #



All coupler
breakdowns
come from one
side or the other

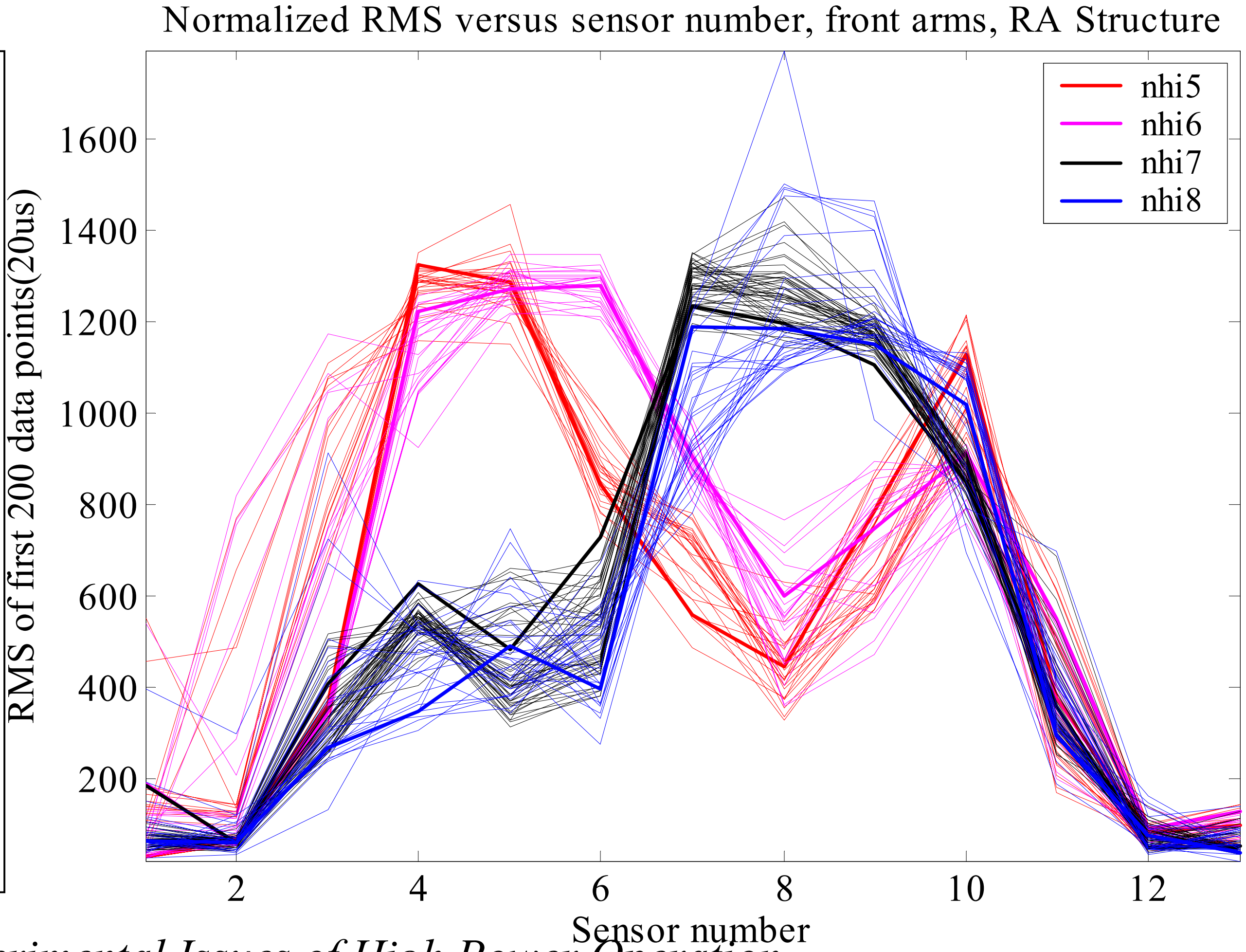


Data: 1/24-1/30
830 bkdns
289 R 259 L
270 F
(30 bulk RA)

Coupler cell surrounded by a ring of sensors

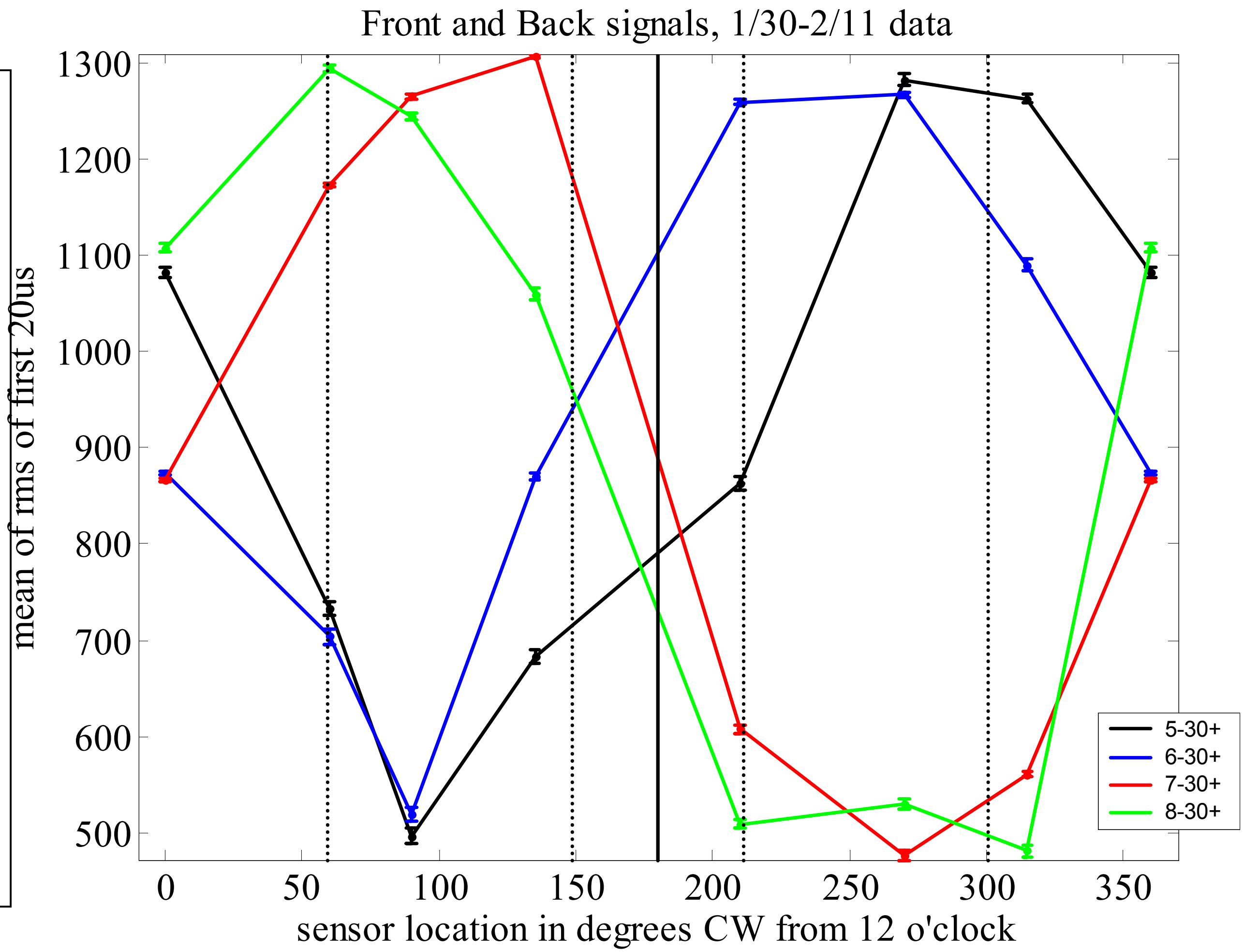
Janice Nelson

- Signals of a certain event-type are normalized such that all RMS_{1024} for a certain channel are equal.



Average of RMS_{200n} versus azimuth angle

- Dashed vertical lines are azimuthal locations of the input waveguide iris points (horns)
- Solid vertical line is the symmetry point (180 degrees)

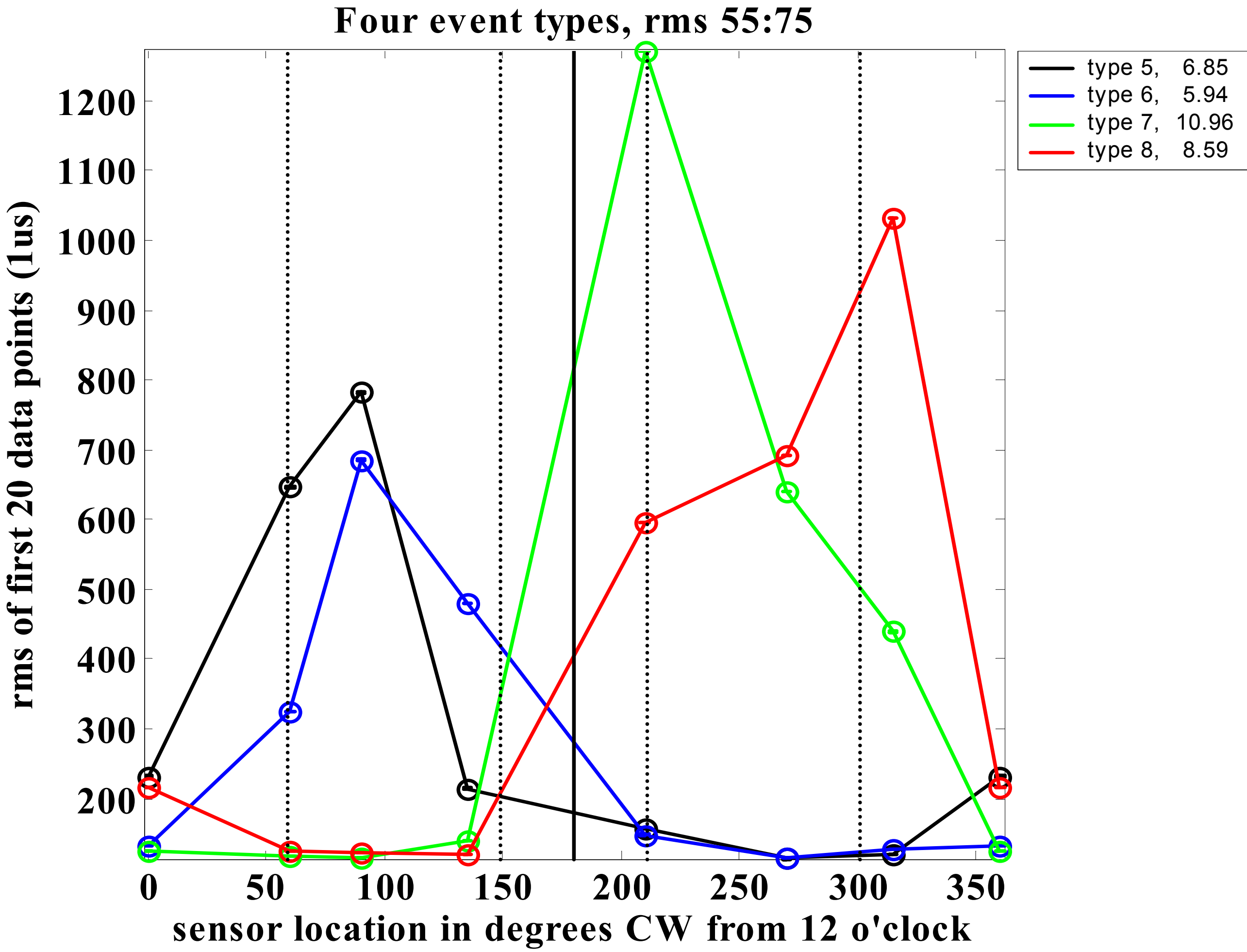


Prompt acoustic signal

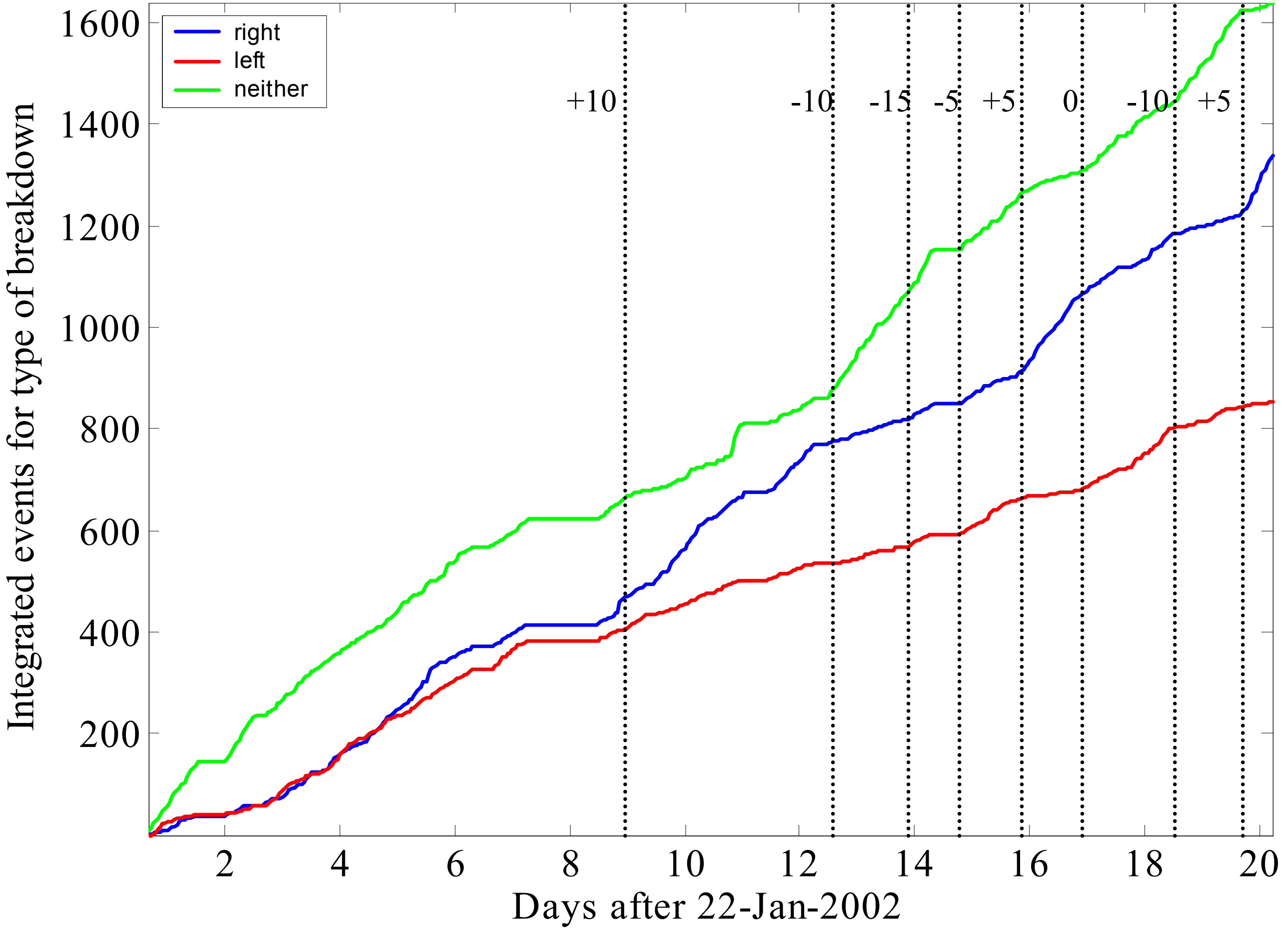
Showing breakdown signals from the 4 horns

First 10 us of the waveform
(10 us ~ 30 mm)

Signal imbalance much larger than 3:1



Asymmetry between left / right side of RA structure input coupler



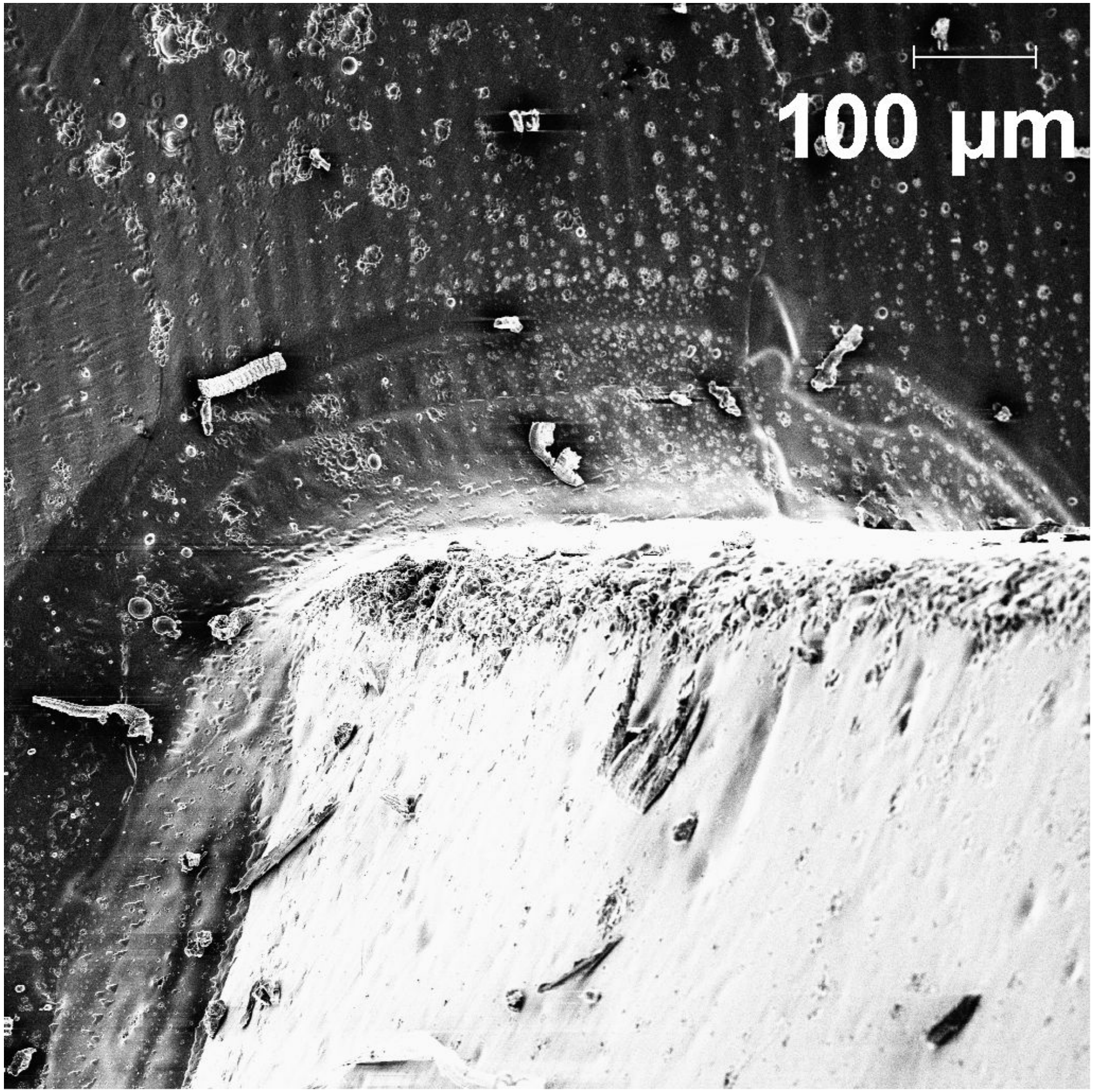
Vertical lines represent frequency changes, MHz from nominal

Secondary emission microscope – looking down the horn

Horn edge very rough and perforated – appears very shiny

The number of craters away from the horn is small compared to the number of breakdowns

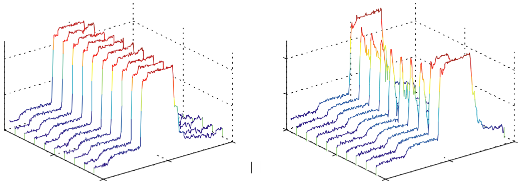
F. Le Pimpec / R. Kirby

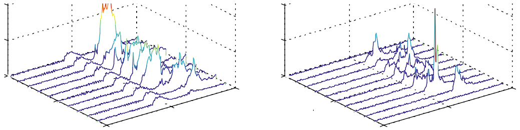


What about the rest of the structure?

- breakdown simulations do a poor job of predicting Energy deposition
  - contrast to SRF predictions for dark I
- should be able to pinpoint cell and azimuth with thermal shock/acoustic sensors
  - much more powerful than RF measurements
    - … but many channels are needed to monitor an entire structure

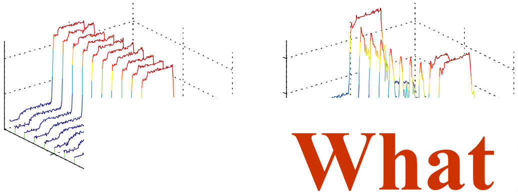
- How does E_{dep} vary with iris diameter?
  - missing RF energy? pulse length?

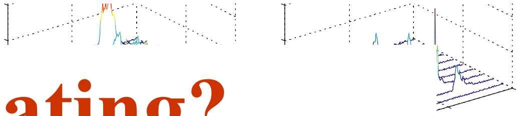




NLCTA plan:

- use sensors to catalog and sort all breakdowns during the entire life of a structure
- use the catalog to compare with the autopsy
  - the craters themselves are not the source of the thermal shock (energy too small)
  - What is?
  - Can this help us to understand structure damage?



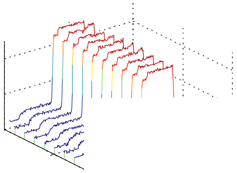


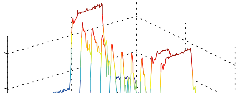
What is the role of pulse heating?

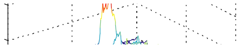
The coupler breakdowns provide a critical lesson

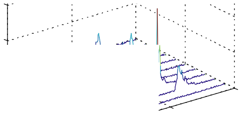
- <u>Suppose</u> that copper surface micro-fractures appear following many, many nominal pulses
  - Must look at the rest of the cell (esp. where the pulse heating is largest) with the SEM!
  - Iris pits involve an extremely small fraction of the RF energy
  - Begin to explain the statistical nature of breakdown events
- Acoustic sensors are most often used for micro-fracture/crack location
  - Pressure vessel & crane boom certification
- Renewed search for precursors…

Beware of the damping manifold slots!





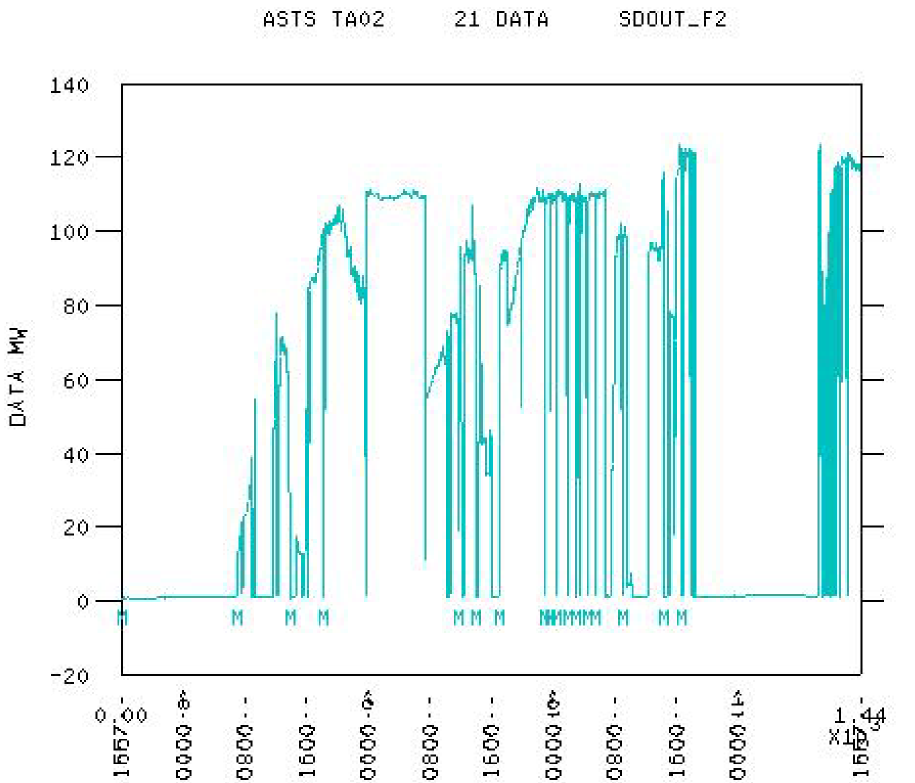




Copper surfaces – recent progress

- What does conditioning/processing do to the copper?
- Important experiment done in March 2002
  - Clean (but very close) vent, followed by a bake
  - Bake was good but…
  - Re-processing was very slow
  - (in contradiction with earlier claims DDS2 etc @ ~ 40MeV/m)
- Why?
- Look at studies done by CERN (Grobner) to prepare the LHC vacuum chamber internal copper liner
  - Secondary emission coeff. Processing ← what does this have to do with processing?
  - Gas monolayer processing

2 vents – 2 bakes – 2 recoveries



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                            SIGMA: 48.90501             MAX: 123.581
LAST DATA POINT:11-AUG-2001 15:54:41                MAX-MIN: 123.235
                                                3-MAY-02 16:07:01
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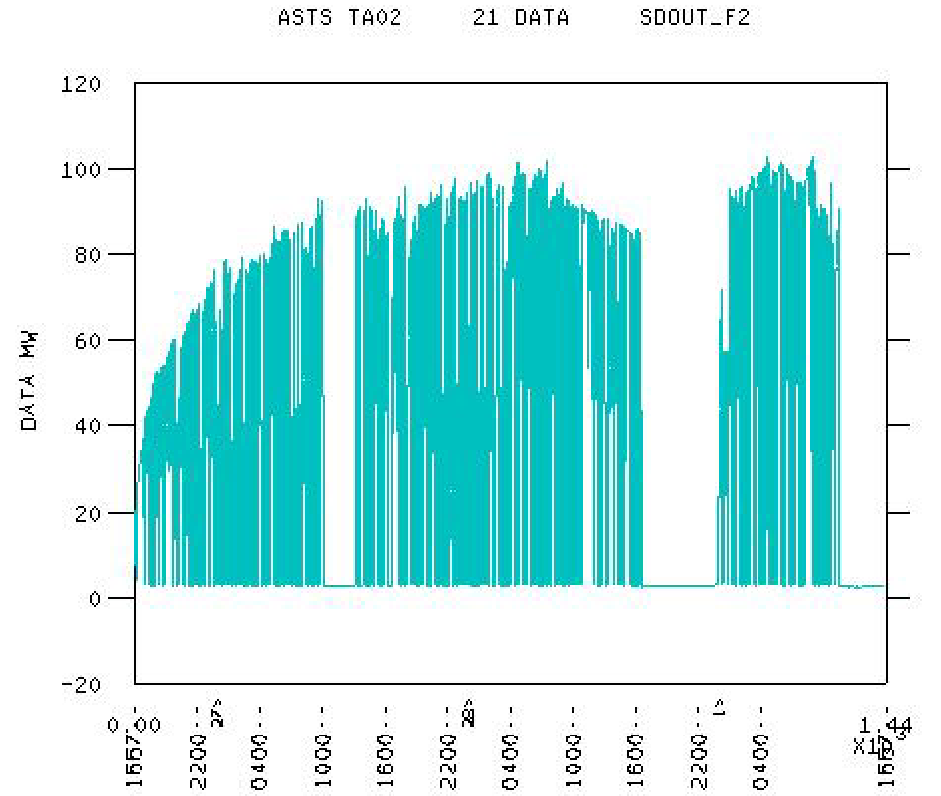

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                            SIGMA: 39.96728             MAX: 102.828
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                                                3-MAY-02 16:05:25
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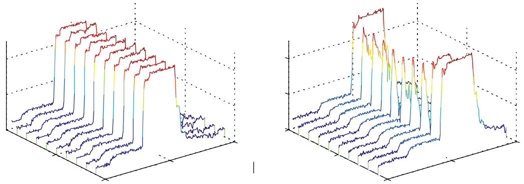
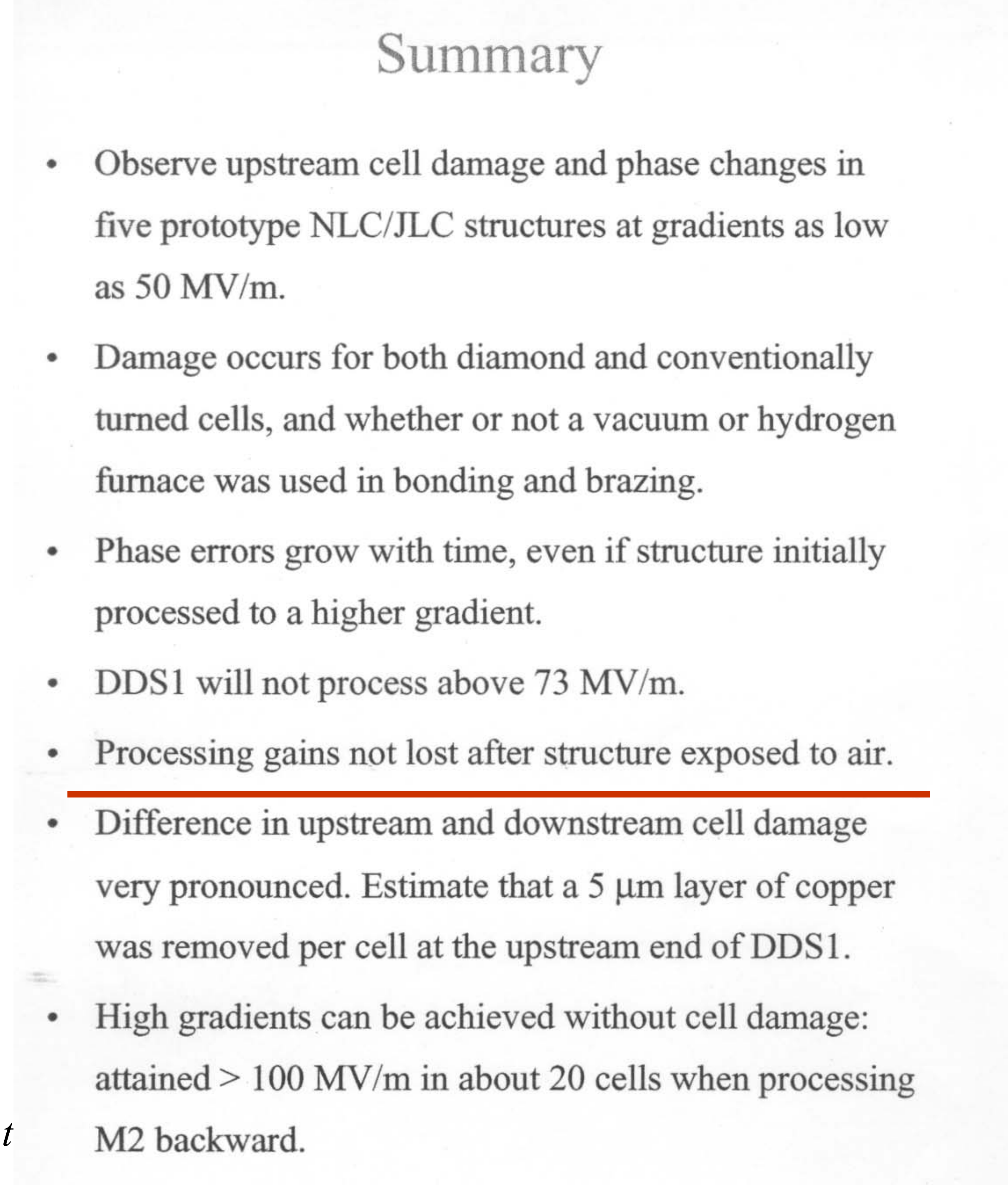


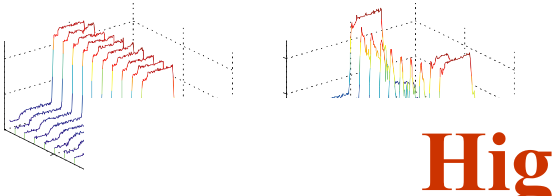
8/2000 workshop –

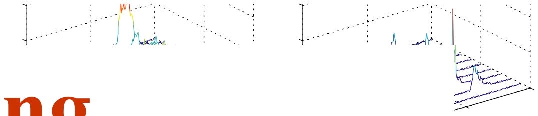
Now have a different viewpoint



Summary

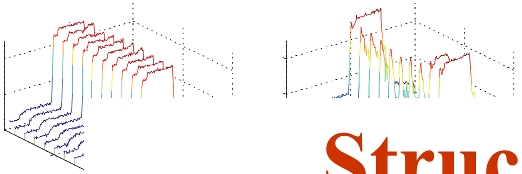
- Observe upstream cell damage and phase changes in five prototype NLC/JLC structures at gradients as low as 50 MV/m.
- Damage occurs for both diamond and conventionally turned cells, and whether or not a vacuum or hydrogen furnace was used in bonding and brazing.
- Phase errors grow with time, even if structure initially processed to a higher gradient.
- DDS1 will not process above 73 MV/m.
- Processing gains not lost after structure exposed to air.
- Difference in upstream and downstream cell damage very pronounced. Estimate that a 5 μm layer of copper was removed per cell at the upstream end of DDS1.
- High gradients can be achieved without cell damage: attained > 100 MV/m in about 20 cells when processing M2 backward.

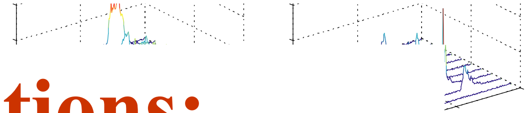




High Power Conditioning

- Does the aggressive vacuum processing help?
- Why does the coupler breakdown where the field is low (even if there is substantial ΔT)?
- Many original structures had ‘slots’ – similar to the coupler edge
  - Is this why their gradient was limited?
- *Vacuum processing clearly reduces the duration of high power processing*
  - *damages during long pulse operation*





Structure Operation Questions:

1) What evidence is there for the group velocity dependence?
2) What evidence is there for length dependence?
3) What is the overall consistency between damage and breakdown events? What are the energetics of breakdown and damage?
4) What is the role of the SPITFEST in our understanding of breakdown?
5) Are the number of pits consistent with anything (breakdowns or detuning)?
6) What is the role of the external circuit - input loop, coupler and output loads?
7) What is the difference between 250 and 400ns?
8) What is the most definitive statement that can be made about the surface/vacuum treatment?
9) Initial comments and efforts concerning the coupler problem have proven wrong – why?
10) What can dark current tell us?
11) What about the 'real' gradient, as measured by the beam?
12) What is the role of the recently identified ‘contaminants’? (MnS…)

Suggestion from Roger:

- We have structures that can run at 70 MV/m if we fix the couplers, i.e. T53VG5 and T53VG3. The only thing wrong with them is a/lambda, which to some extent we can fix with more aggressive BNS damping. Since with large a/lambda, large phase advance, and thick disks we give up significant shunt impedance, we can afford heavier BNS damping with small a/lambda. Perhaps we should reopen the issue of a/lambda. We might even reduce the gradient and increase a/lambda at the output end of the linacs where the BNS energy spread has to be removed.

Xverse tolerances 25% tighter – but the structure works…