Things that go bump in the pipe: understanding acoustic signatures of NLC rf cavity breakdown

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Can we learn more about NLC rf cavity breakdown through acoustic signatures of breakdown events?

1. Who is participating
2. Acoustic properties of heat-annealed Copper
3. Modeling and reconstruction
4. Conclusions

Who is participating at UIUC

Joe Calvey (undergraduate)

Michael Davidsaver (undergraduate)

George Gollin (professor, physics)

Mike Haney (engineer, runs HEP electronics group)

Justin Phillips (undergraduate)

Jeremy Williams (postdoc)

Erik Wright (grad student)

Bill O'Brien (professor, EE)

Haney's PhD is in ultrasound imaging techniques; O'Brien's group pursues a broad range of acoustic sensing/imaging projects in biological, mechanical,… systems

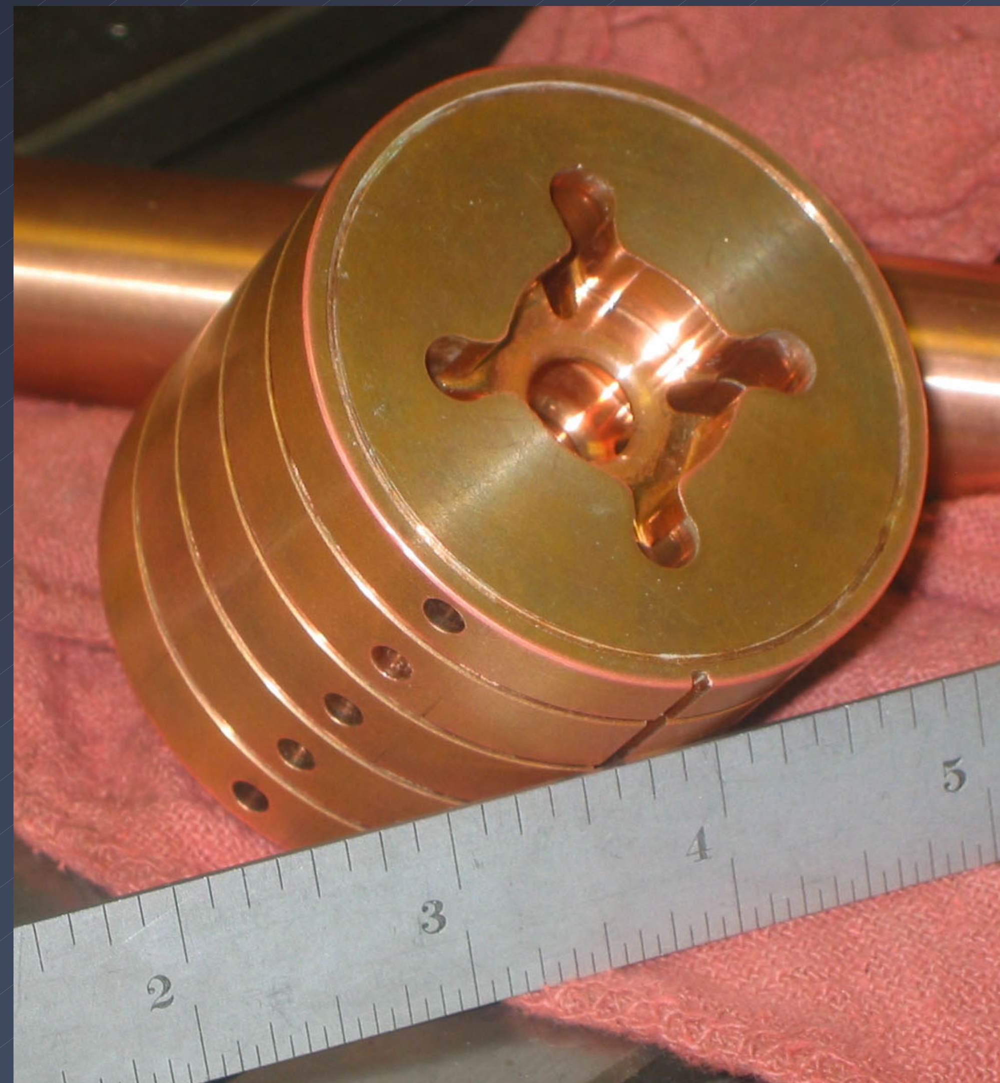
We discuss progress and plans from time to time with Marc Ross at SLAC.

This is what we're studying

Harry Carter sent us a five-cell structure from Fermilab's NLC structure factory.

We need to understand its acoustic properties.

Start by pinging copper dowels with ultrasound transducers in order to learn the basics.



Copper dowels from Fermilab NLC Structure Factory

NLC structures are heat-brazed together; heating creates crystal grains (domains) which modify the acoustic properties of copper.

Harry had previously sent a pair of copper dowels from their structure manufacturing stock: one was heat-treated, one is untreated.

Marc also sent us a (small) single crystal copper dowel.

We cut each dowel into three different lengths.

Speed of sound and grain structure…

Close-up of one of the (heat-treated) dowel #2 sections.

Note the grain patterns visible at the copper's surface.

Grain structure is not visible on the surface of dowel #1.

Speed of sound measurement:

v_s = 4737 m/sec (no grains)

v_s = 4985 m/sec (with grains)

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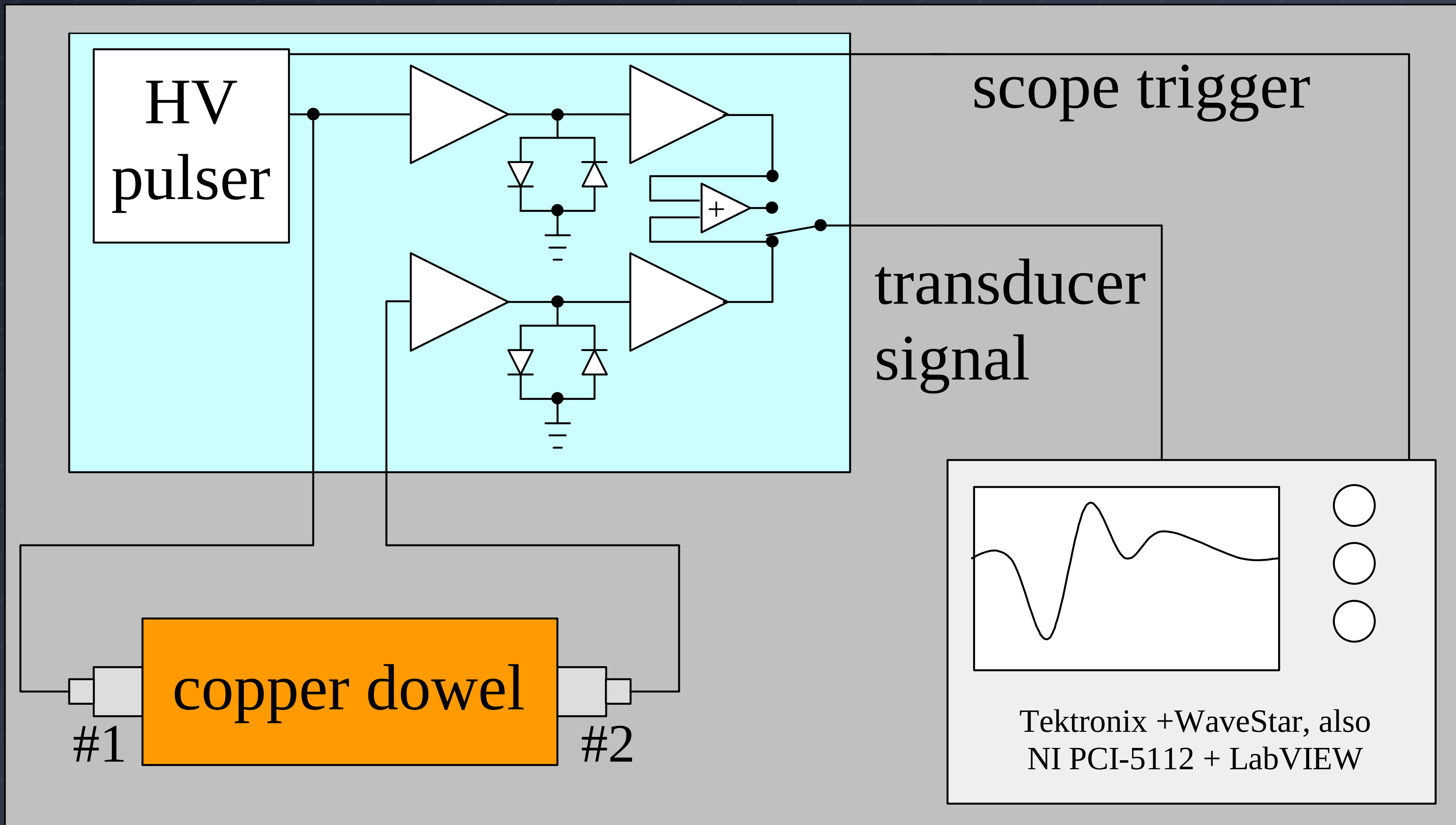
Transducer setup



We can listen for echoes returning to the transducer which fires pings into the copper, or listen to the signal received by a second transducer.

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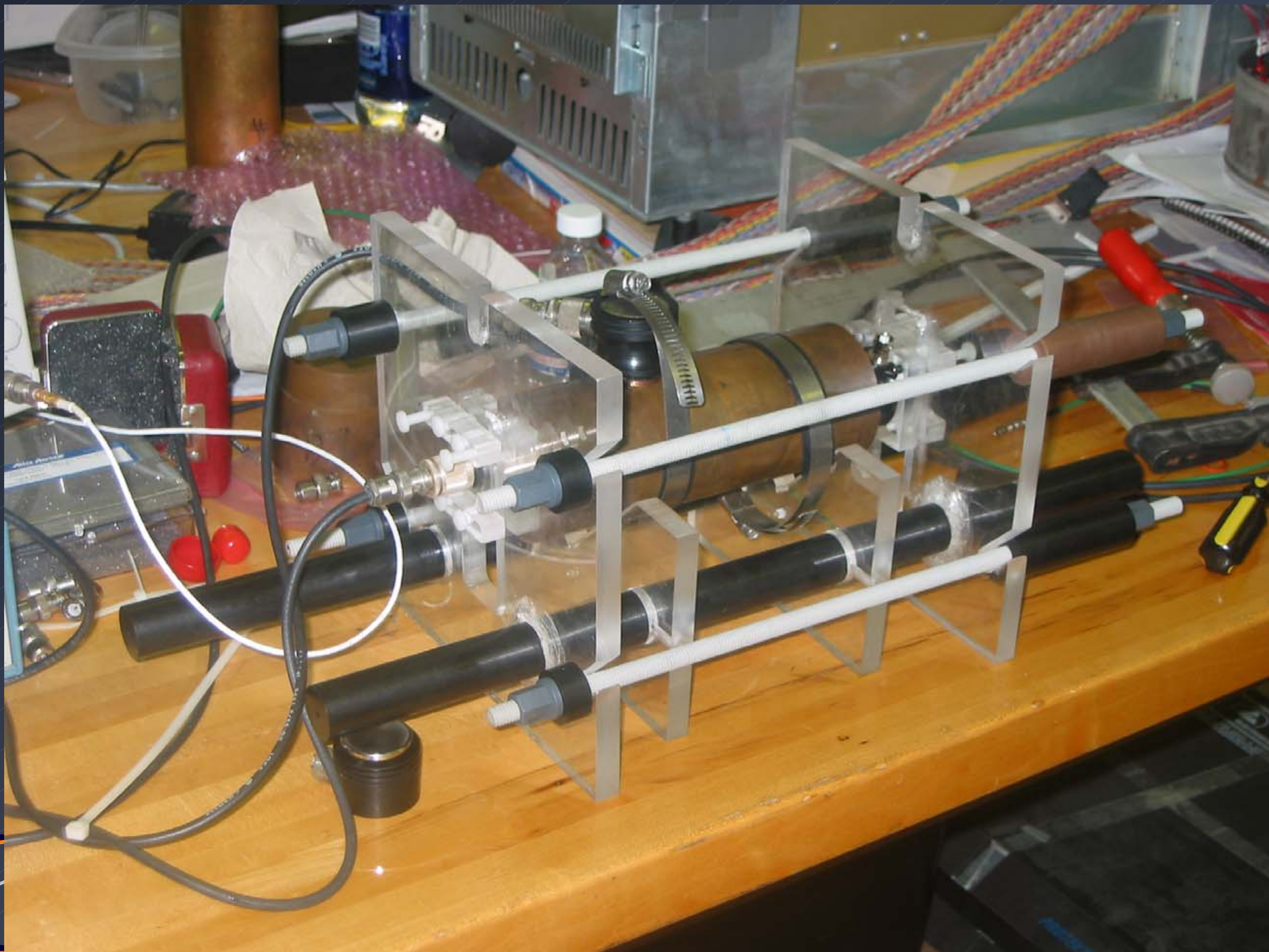
Transducer setup, on the bench

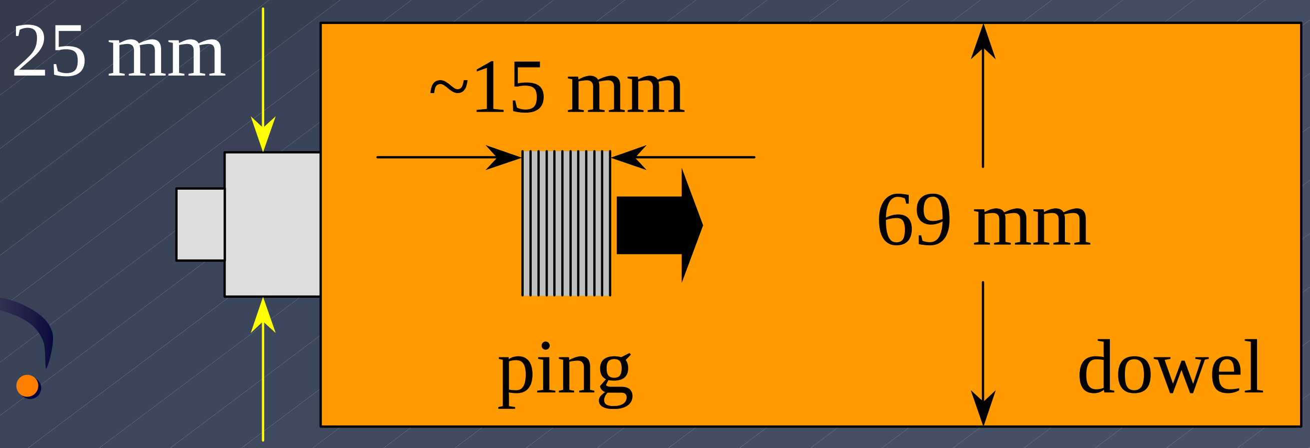


Scattering/attenuation at 1.8 MHz in copper

Piezoelectric transducer behaves like a damped 1.8 MHz oscillator.

A "ping" launched into a copper dowel will bounce back and forth, losing energy through

- absorption in the transducer
- scattering of acoustic energy out of the ping
- absorption of acoustic energy by the copper.



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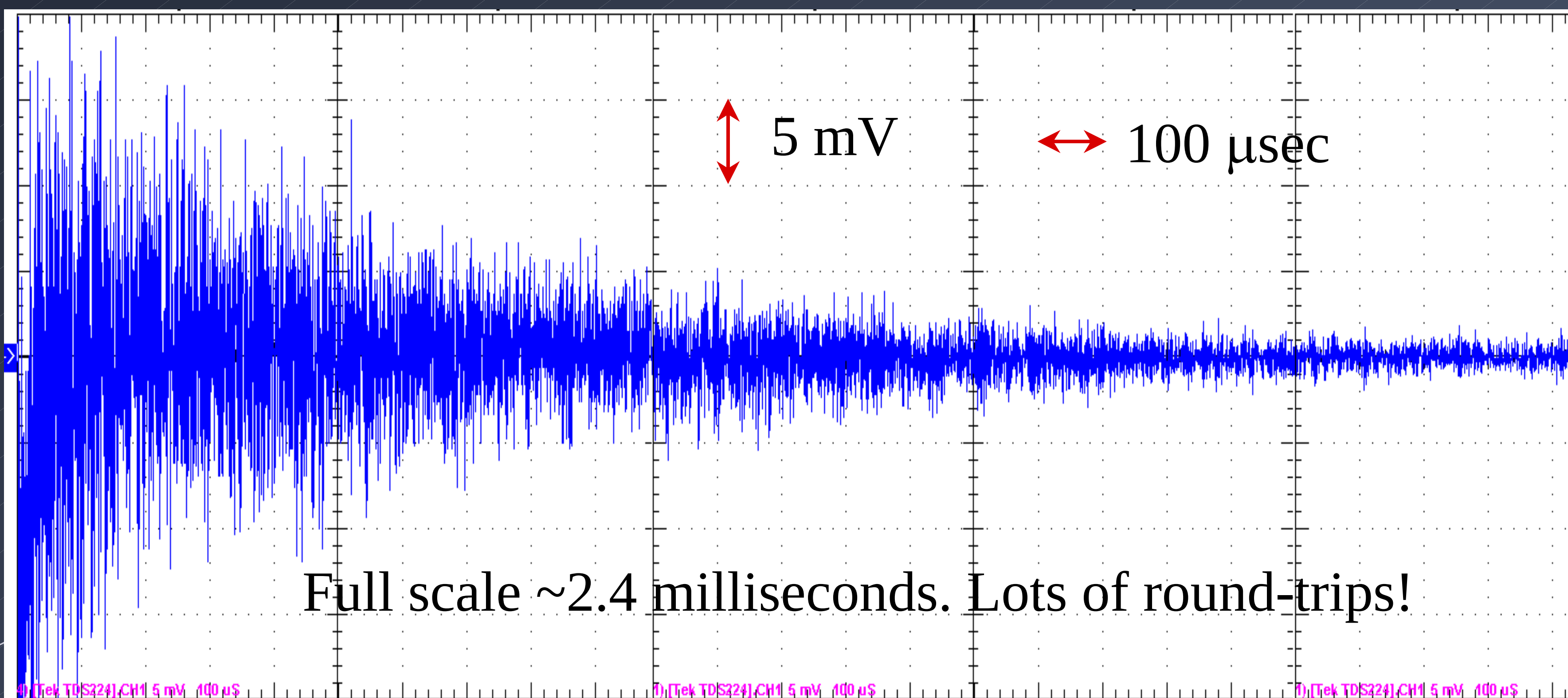
Scattering is much more important than attenuation

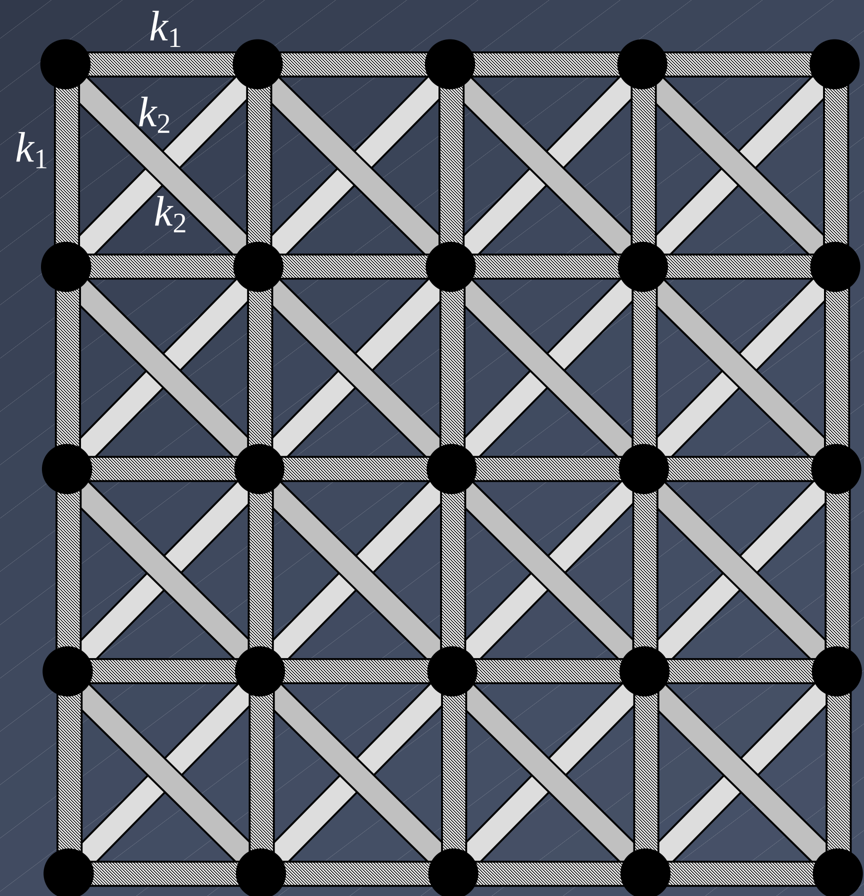
Single transducer: ping, then listen to baseline "noise" as pulse travels in copper, pumping energy into acoustic baseline "glow."

At ~5 mm per μsec, full scale corresponds to 12 m acoustic path inside the heat-treated (grainy) dowel. The "glow" lasts a long time.



Condensed matter, as done by folks in HEP

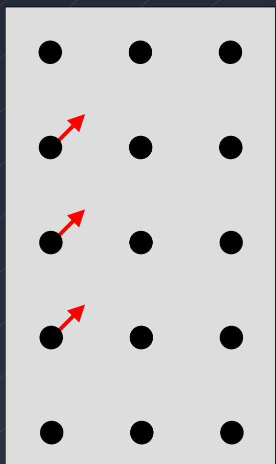
Our model: regular (rectangular, 2*D*, 3*D*) grids of mass points connected by springs. Transducer is an array of points driven in unison, with damping.

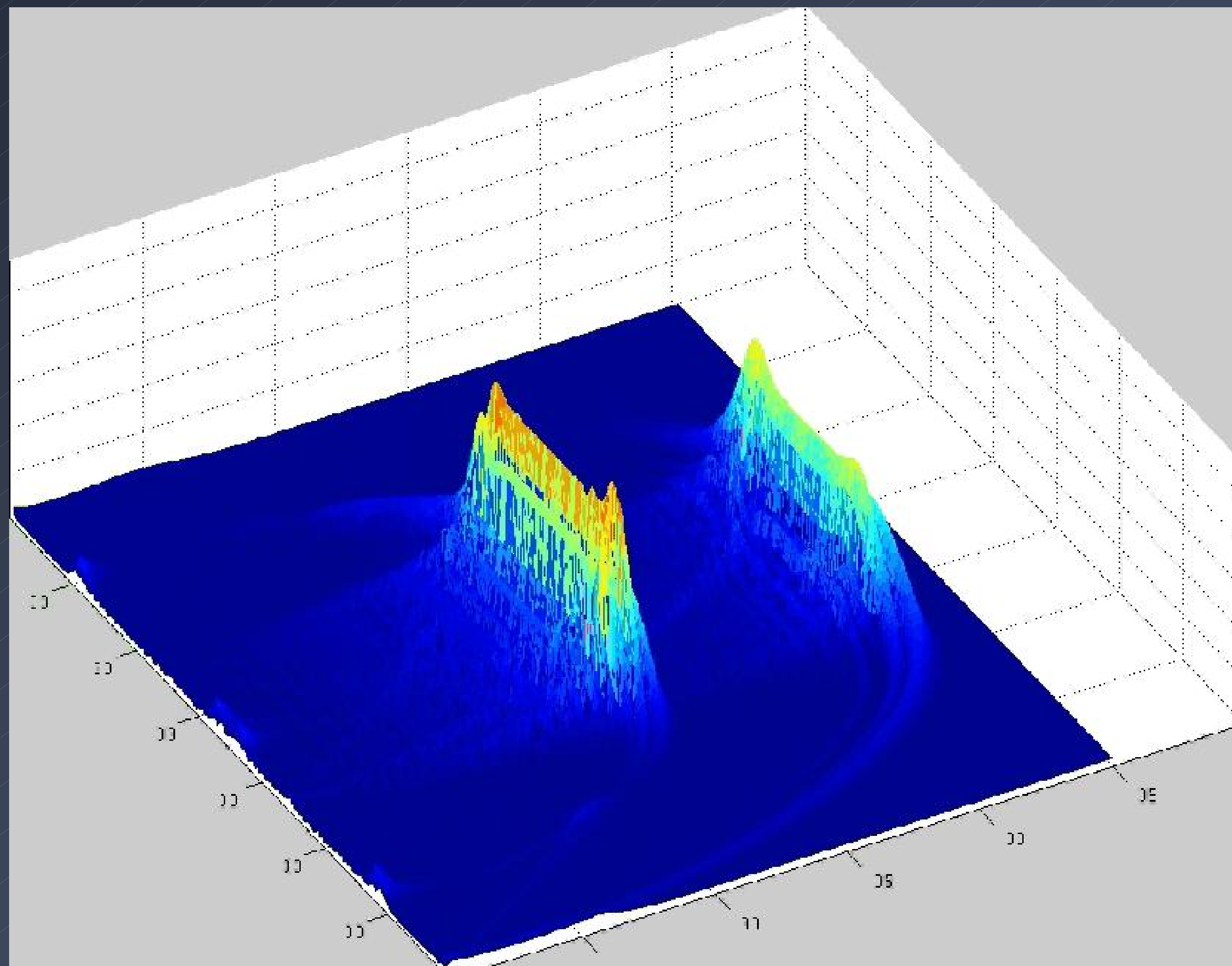


Speeds of propagation for pressure and shear waves are determined by k_1, k_2, and k_1/k_2. We use $k_2 = k_1/2$.

We can vary spring constants arbitrarily in order to introduce dislocations and grains: our grain boundaries have smaller spring constants.

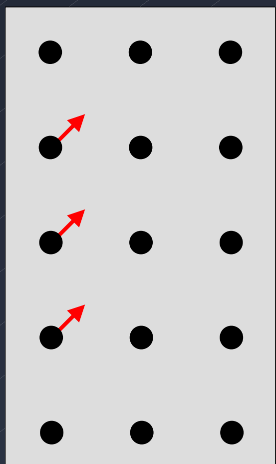
Propagation of a 50% shear, 50% compression wave, copper without grains

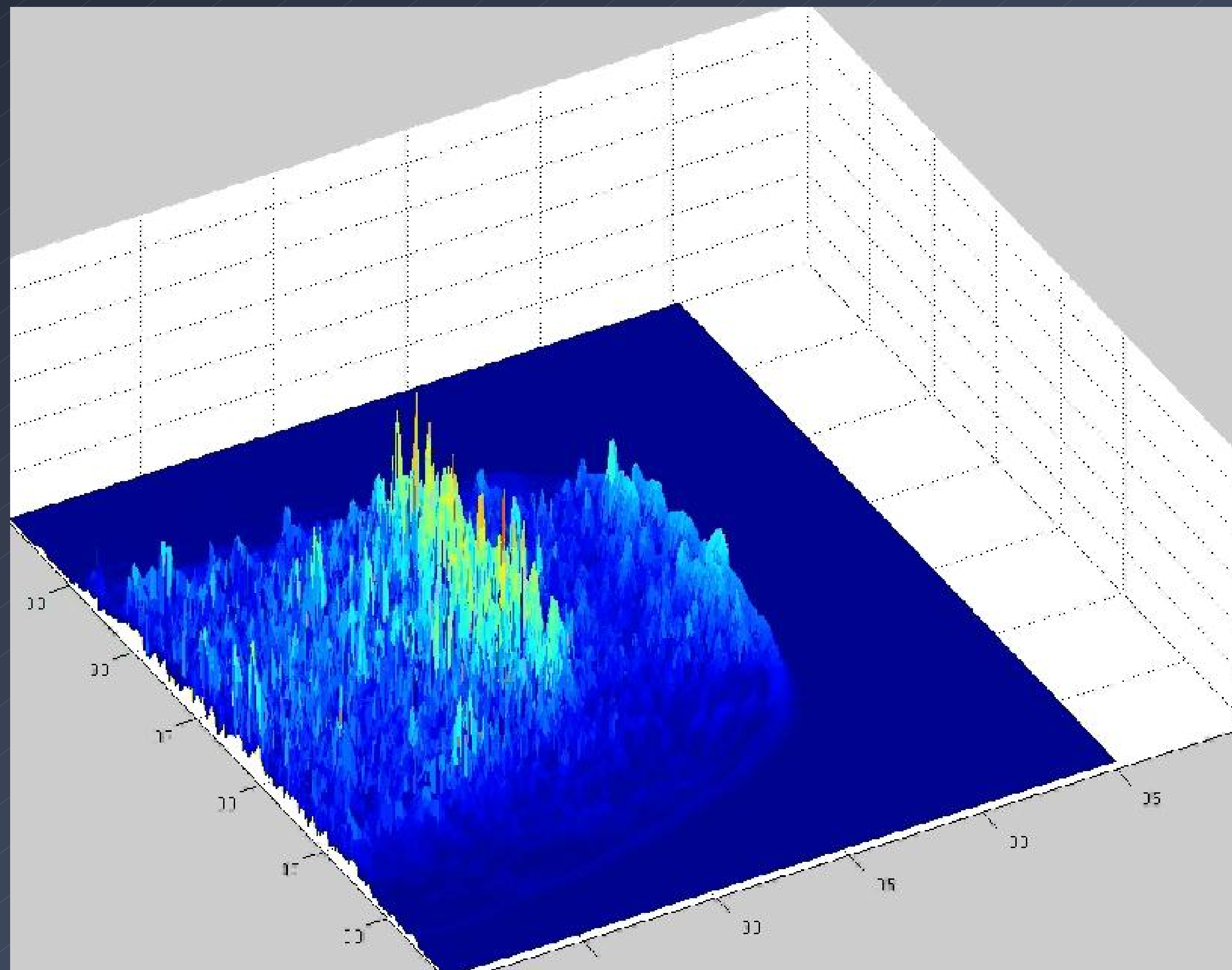




Note the different propagation speeds.

Propagation of a 50% shear, 50% compression wave, copper with grains





Note the disruption of the wave fronts due to scattering!

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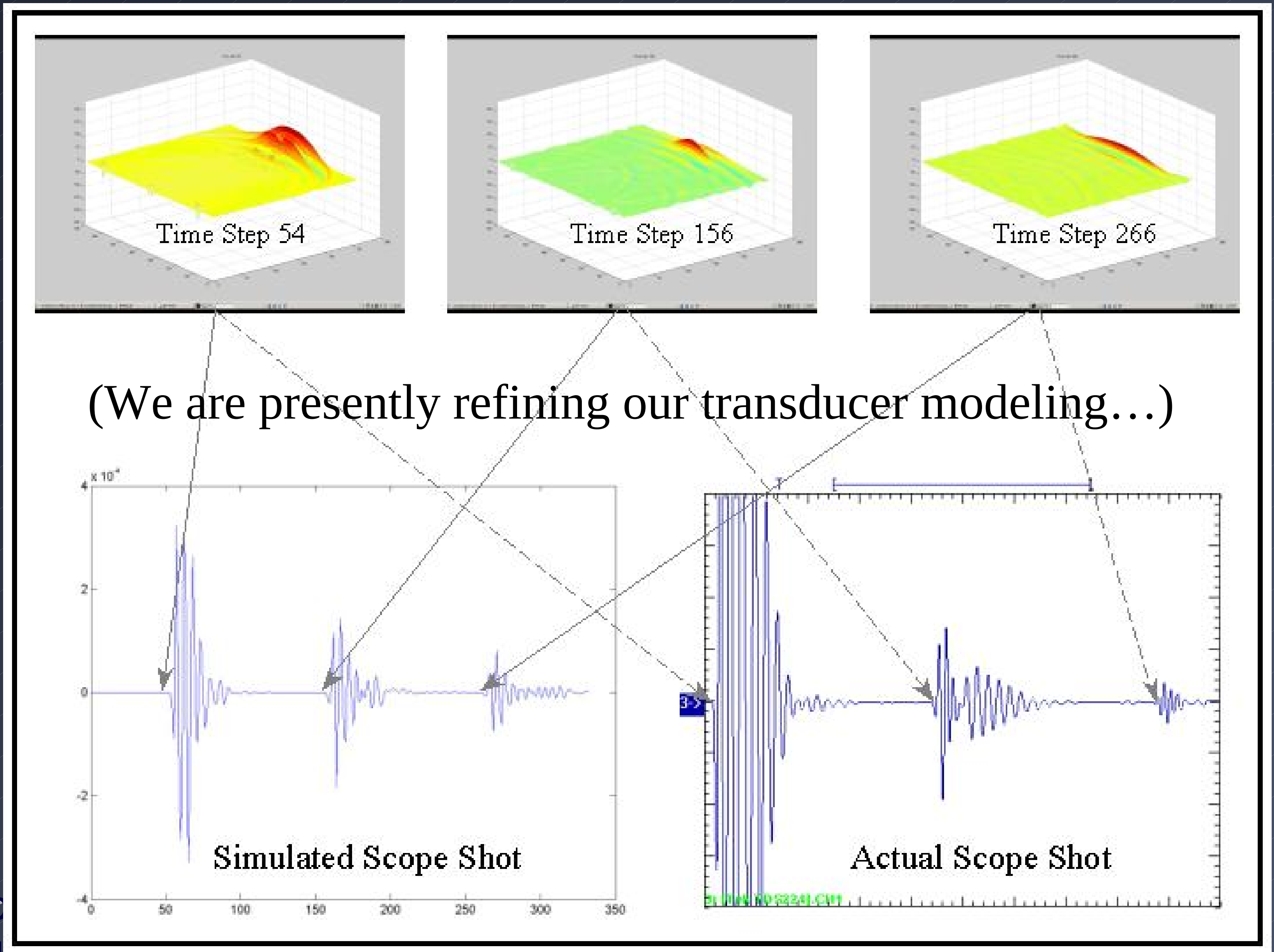
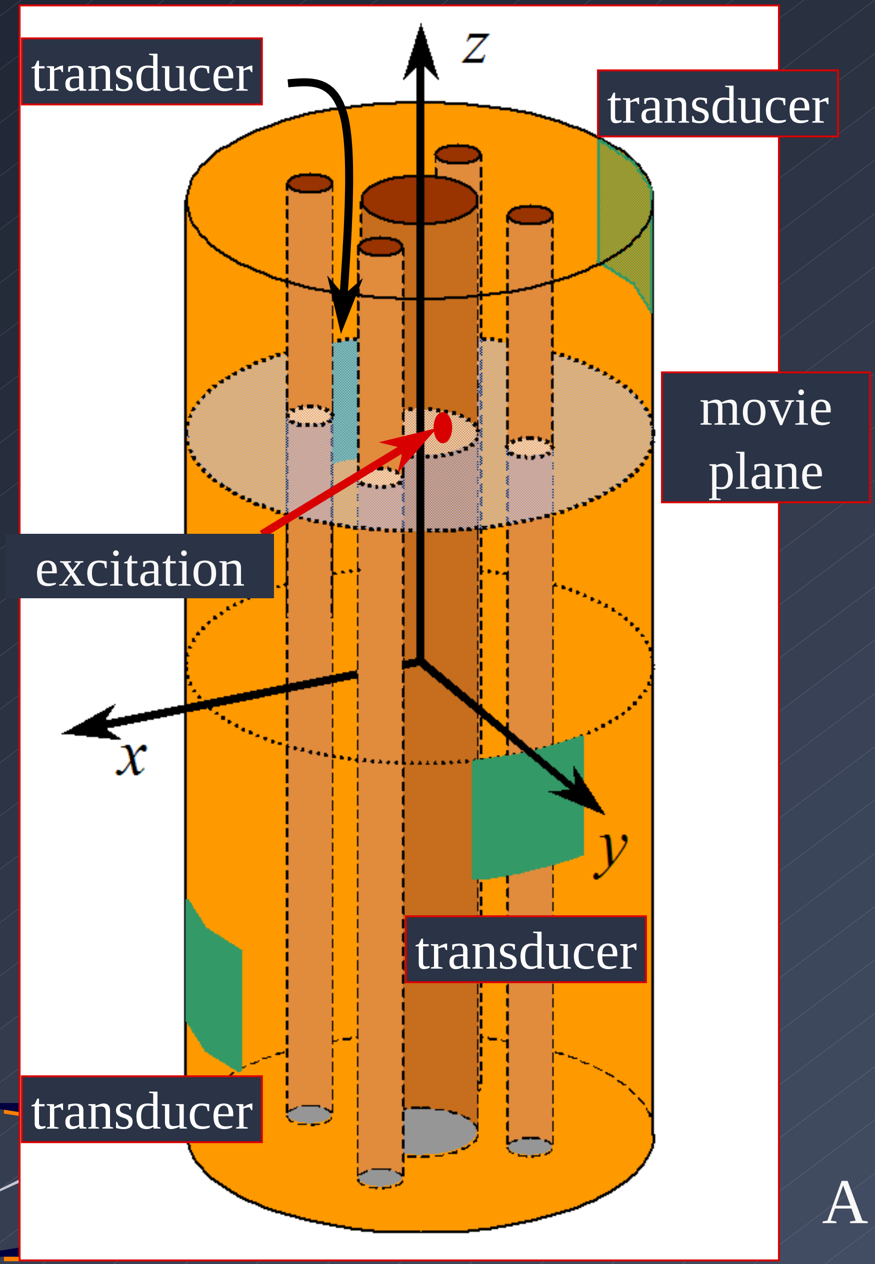
Simulated transducer response, some months ago



3-D model we're working with right now



4 "perfect" transducers, one acoustic excitation spot.

A flaw: transducers are TOO good.

The main difficulty…

Our general approach has been to assume "perfect knowledge" of the behavior of the copper at the transducers:

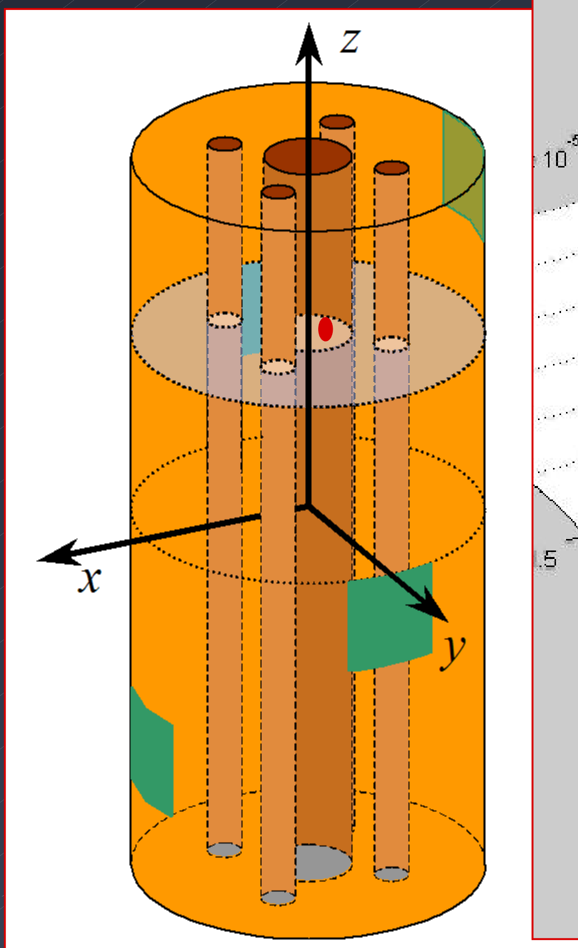
- transducer knows about individual motions of each of the individual mass points it touches (a real transducer returns a signal based on the average of all points)
- transducer returns velocity vector of surface points (ours don't [though this kind exists]: we only measure the component normal to the transducer face

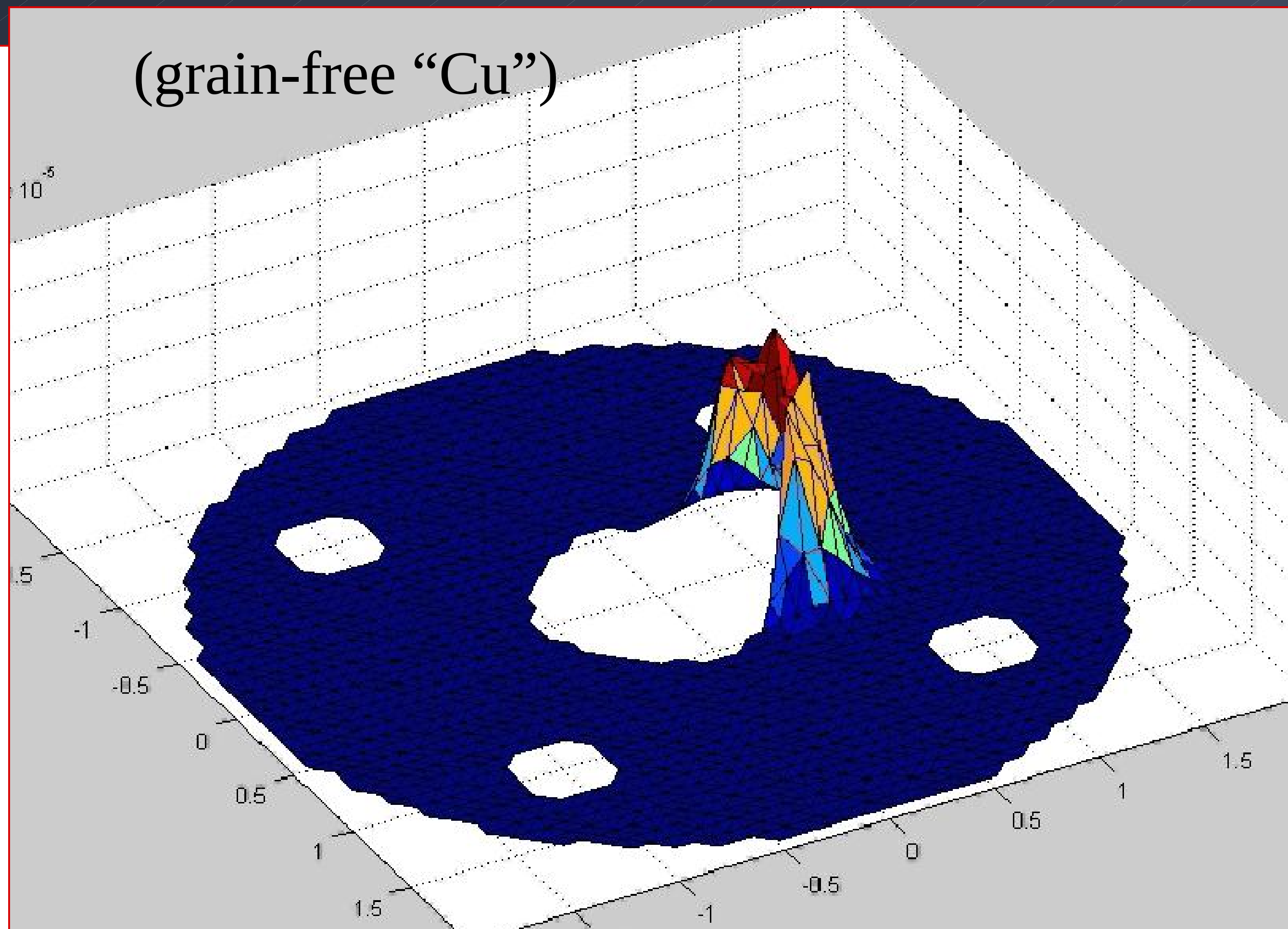
Discarding information degrades our naïve reconstruction algorithm's performance considerably. (This is what we're working on now.)

But here's a look at our naïve approach anyway: it gives an idea of how surprisingly well things work with very limited information.

Acoustic excitation, viewed in one horizontal slice

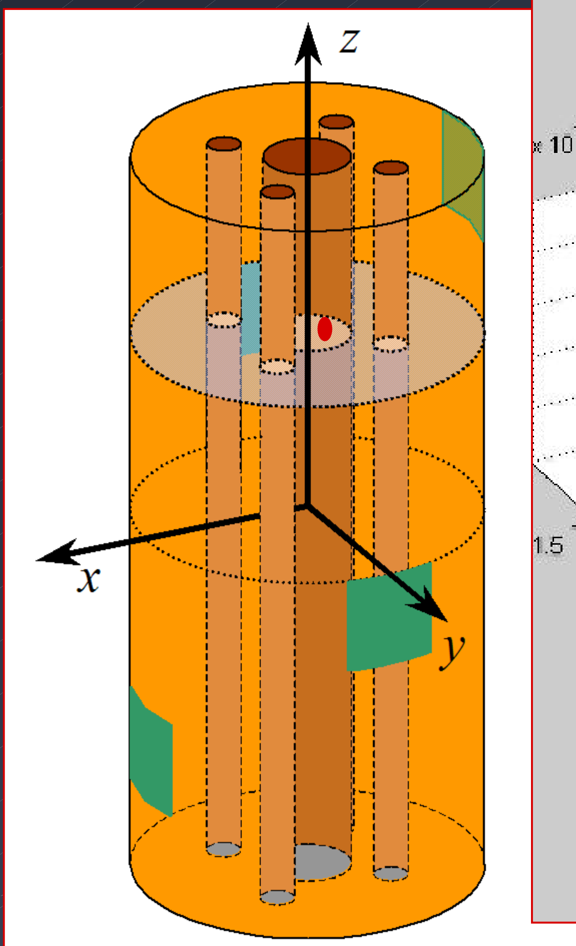
We'll record what the simulated transducers "hear" then try playing it back into the copper to see if we generate a peak in the intensity somewhere which corresponds to the original excitation.

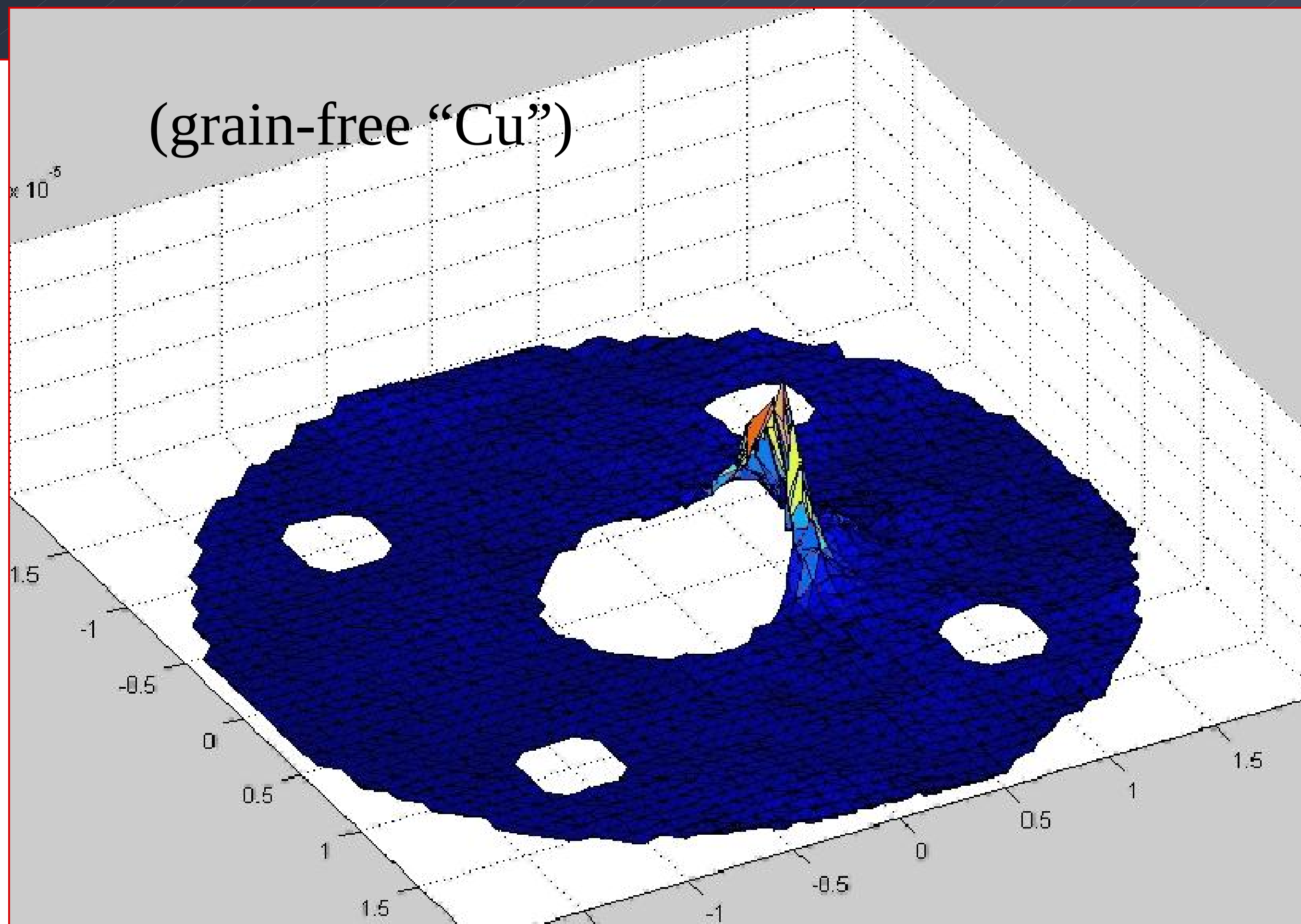




Drive transducer signals back into copper

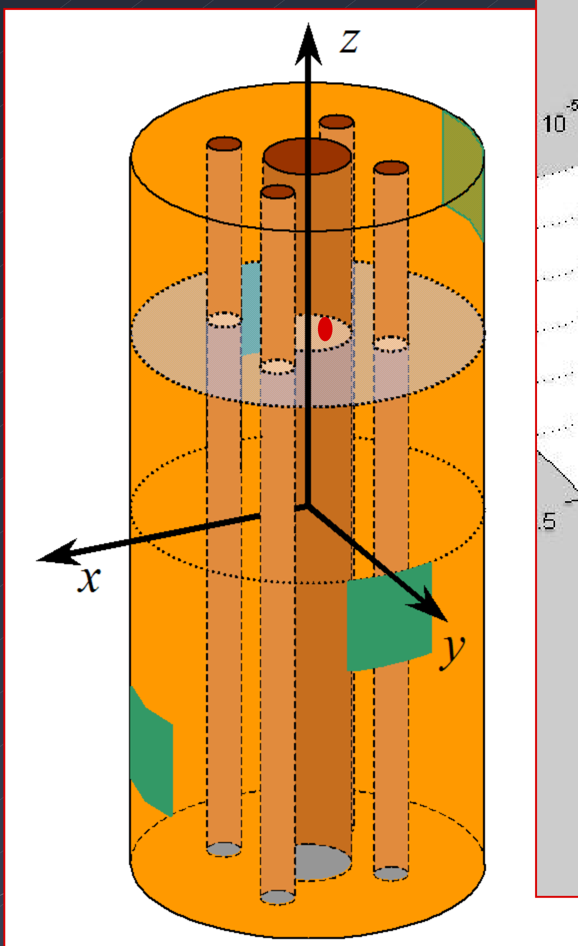
Now use measurements from perfect transducers to drive acoustic signals back into the copper… look for an intensity peak:

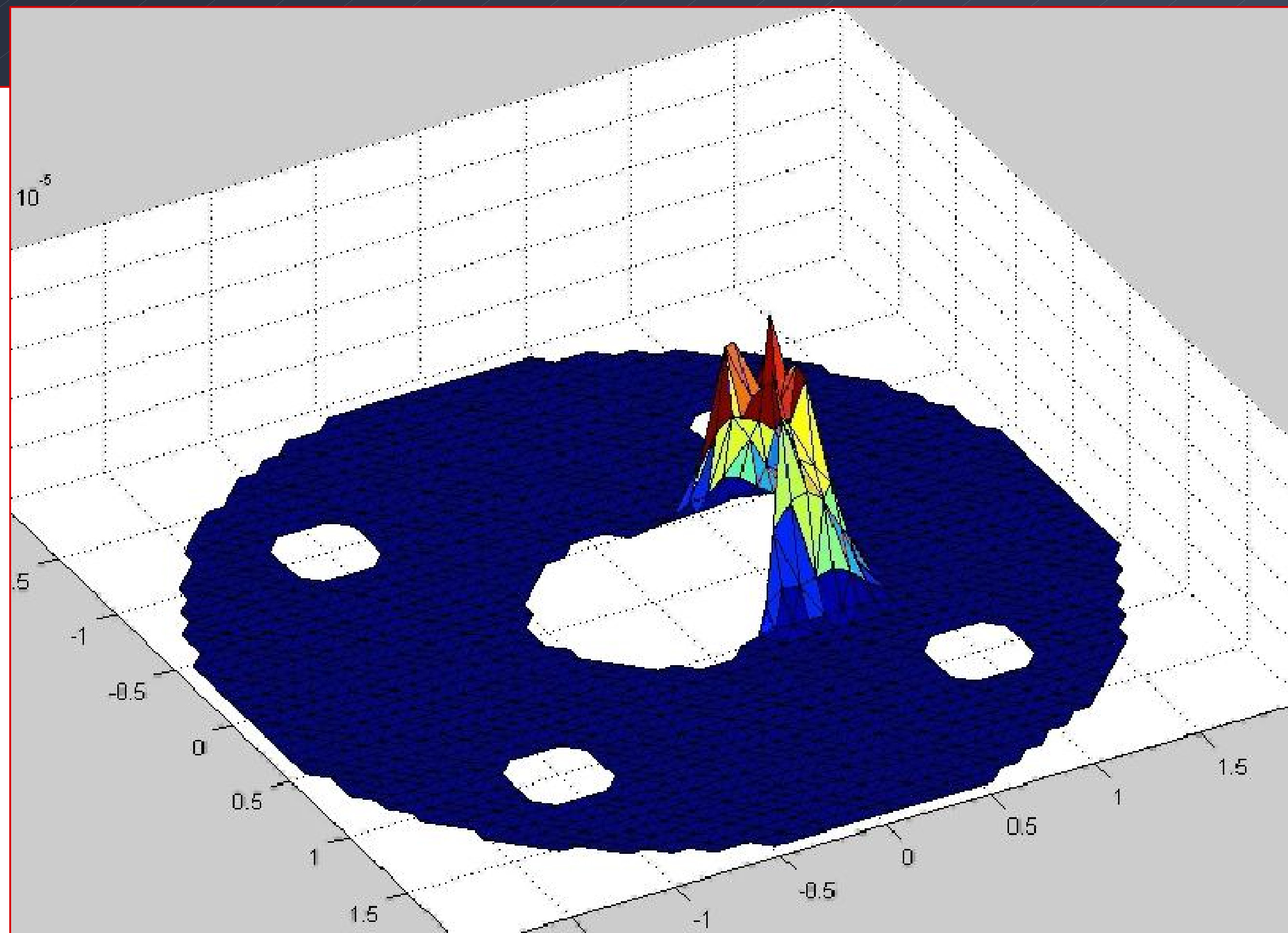




Acoustic excitation, copper with grains

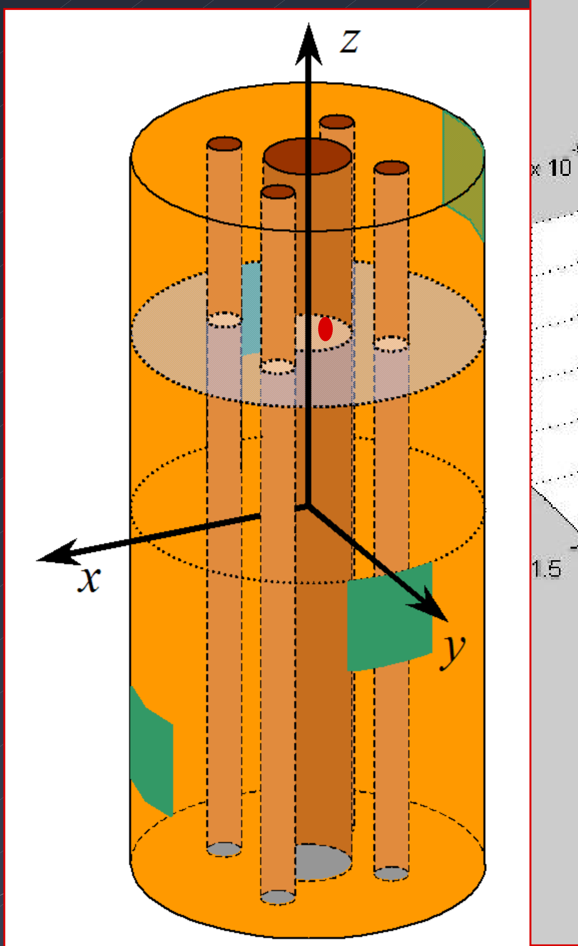
650 grains total; grain size is random, but typically one wavelength

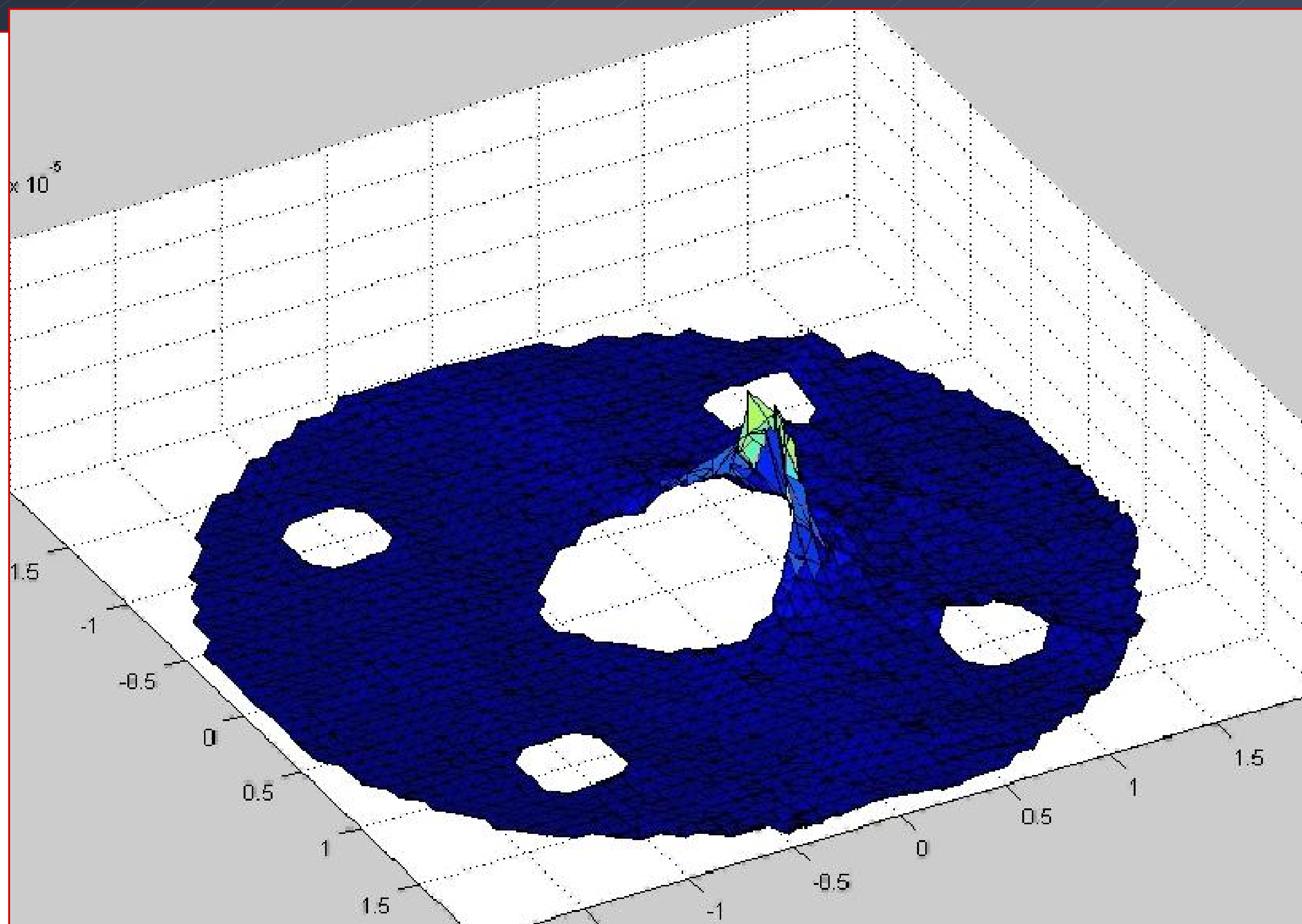




Drive transducer signals back into grainy copper

It still works. BUT these transducers have unrealistic properties: model assumes perfect knowledge of movement of surface everywhere at transducer face. Real transducers don't work this well.





What we are working on

- More realistic modeling of transducer performance

    real transducers are insensitive to shear waves, and only provide sums of amplitudes over entire transducer surface.

- Refinement of reconstruction algorithm. So far we find t_0 and initial position using something like an autofocus algorithm:

    use receiver transducers to “drive” signals backwards in time into copper; find time of maximum rms deviation from constant amplitude.

    a real transducer only reports average amplitude over sensor face: it doesn’t project sound backwards in a realistic manner (it produces a narrow beam)

- Measurements of real NLC structure properties

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DOE support

DOE is funding LCRD 2.15!

- $25k FY04
- $35k FY05
- $35k FY06
- Support goes for a mix of instrumentation (more electronics, transducers,…) and student salaries

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Closing comments

- We are working on understanding the reconstruction limitations imposed by real-world transducers. Most of our modeling to date has assumed our transducers give us perfect information about the Cu surface under the transducer. Reconstruction/resolution is going to be worse with nothing but compression wave sensing, averaged over the entire transducer face.
- We are working at reconciling 3*D* model predictions with real data.
- We are beginning to work with the 5-cell NLC structure on loan from Fermilab.
- How well will this work? Stay tuned!