An approach to setting up PDV with a predicable amplitude on all channels:

a collection of requirements, constraints, and feasibility studies to develop input to a set of target and diagnostics plans

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Requirements

Measure shock breakout times and initial particle velocities with high precision and accuracy
i.e., obtain fast rise times and high timing accuracy (better than 100 ps).

Return high quality data from all channels
i.e., we are not allowed to have blank channels,
all channels must be on scale, no channels off scale

Constraints

Target constraints:

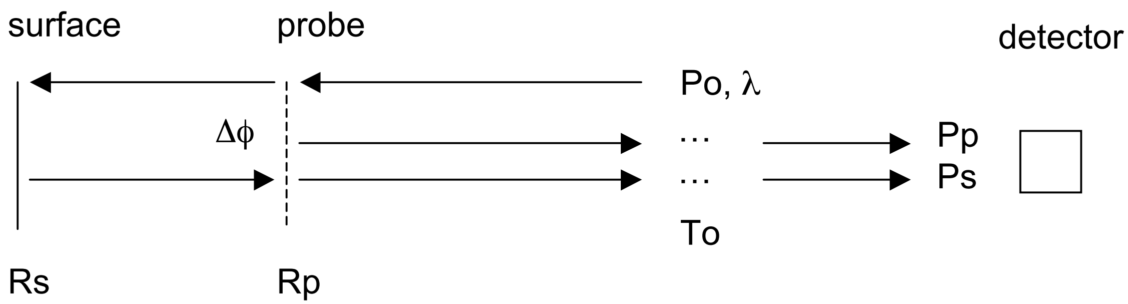
- Target is built in Livermore
- Must survive shaking during shipment to Nevada Test Site (moving parts within the target are discouraged – a rigid structure is the goal)
- Target cannot be seen except by sending light in and out of target single mode probe fibers
- Shelf life of target may need to be weeks to months
- 13 channels
- After a target is built, we cannot adjust target parameters

Facility constraints:

- Three containment feed throughs
- Seven fiber connectors
- One set of connectors that will be re-used on every shot will be in a sooty environment
- The first surrogate shot is a confirmatory shot

A momentary digression into theoretical musings…

Interference Picture:
The two optical paths that return from the probe and surface interfere at the detector (probe and surface form a weak Etalon):



The total power at the detector depends on diagnostic parameters {Po and To}, and target parameters [Rp, Rs, and $\Delta\varphi$]:

$$P_{total} = \left[P_p + P_s + 2\sqrt{P_p P_s}\cos(\Delta\varphi) \right] = \{P_o T_o\}\left[R_p + R_s + 2\sqrt{R_p R_s}\cos(\Delta\varphi) \right]$$

The phase difference $\Delta\varphi$ Is the number of wavelengths between the probe and surface,

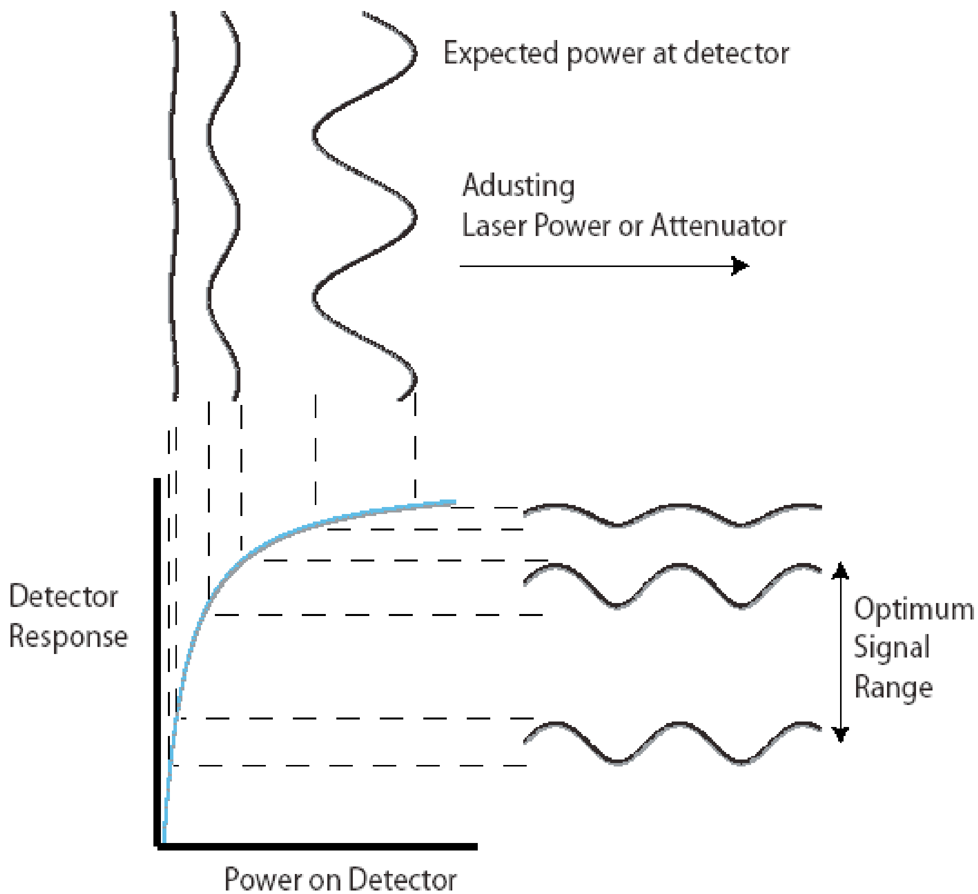
$$\Delta\varphi = 2\pi(2d/\lambda)$$

Equivalence of the Heterodyne Beats and Interferometry

The rate of phase advance in the interferometer picture

$$f_b = \frac{1}{2\pi}\frac{d[\Delta\varphi(t)]}{dt} = -2f_0\frac{V(t')}{c}\frac{dt'}{dt}, \quad \frac{dt'}{dt} = \frac{1}{1-\dfrac{V(t')}{c}} \cong 1\; for\, V << c$$

is the same as the beat frequency expected from a Doppler-shifted signal beam.



Question:
How do we set Po and To?

Answer:
We adjust Po and To so that the power read on the power monitor is near an optimum value on the detector response curve.

Hypotheses:

The power-interference fringe amplitude obtained when the phase difference changes slowly is closely related to the beat amplitude that will be obtained when the surface moves at high velocity.

The interference fringe amplitude can be used to assess the target parameters, and can be used to set the diagnostics parameters.

Questions:

Can we know the size of the fringe amplitude

$2\sqrt{R_p R_s}$ relative to $R_p + R_s$ before the shot?

Can we optimize the size of

$2\sqrt{R_p R_s}$ relative to $R_p + R_s$ as we build the target?

Can we change $\Delta\varphi$ before the shot to see $2\sqrt{R_p R_s}$

and verify that the Rs and Rp are satisfactory?

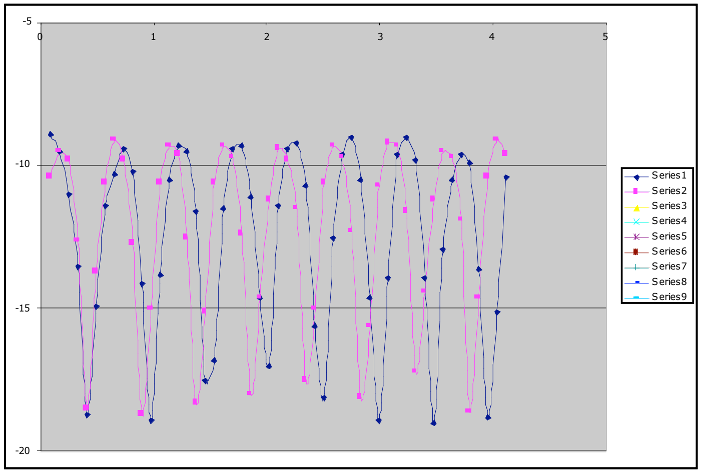
Answers:

When exposed to the wind and sun the amplitude slowly creeps up and down

Interpretation: d changes on the micron scale and the amplitude seen is indicative of the shot amplitude one can expect.

In a gun tank, the interference intensities can be rock solid (d may not change spontaneously).

Do we really observe interference fringes as we change the distance d slowly?

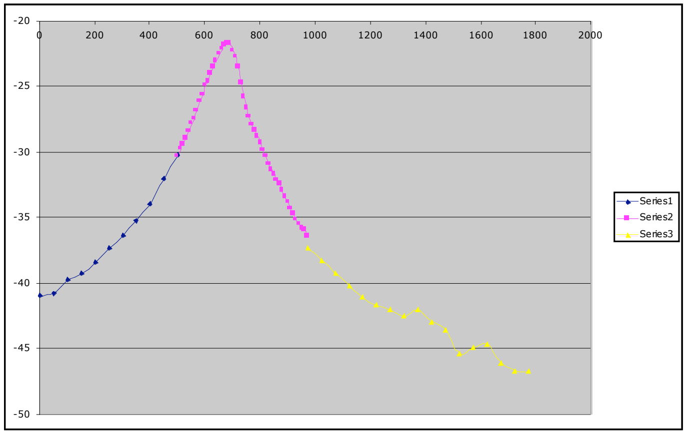


Fringes from a -15 dB probe and surface

(axes: dB return vs displacement in microns)

Interference Fringes are observed when we move slowly

Note: a tight focus and low surface roughness are expected to produce a fast rise time. We selected a probe geometry with
30 micron focus, 10 mm working distance, 4 mm diameter



Return reflection for a -40 dB probe
(axes: dB return vs displacement in microns)

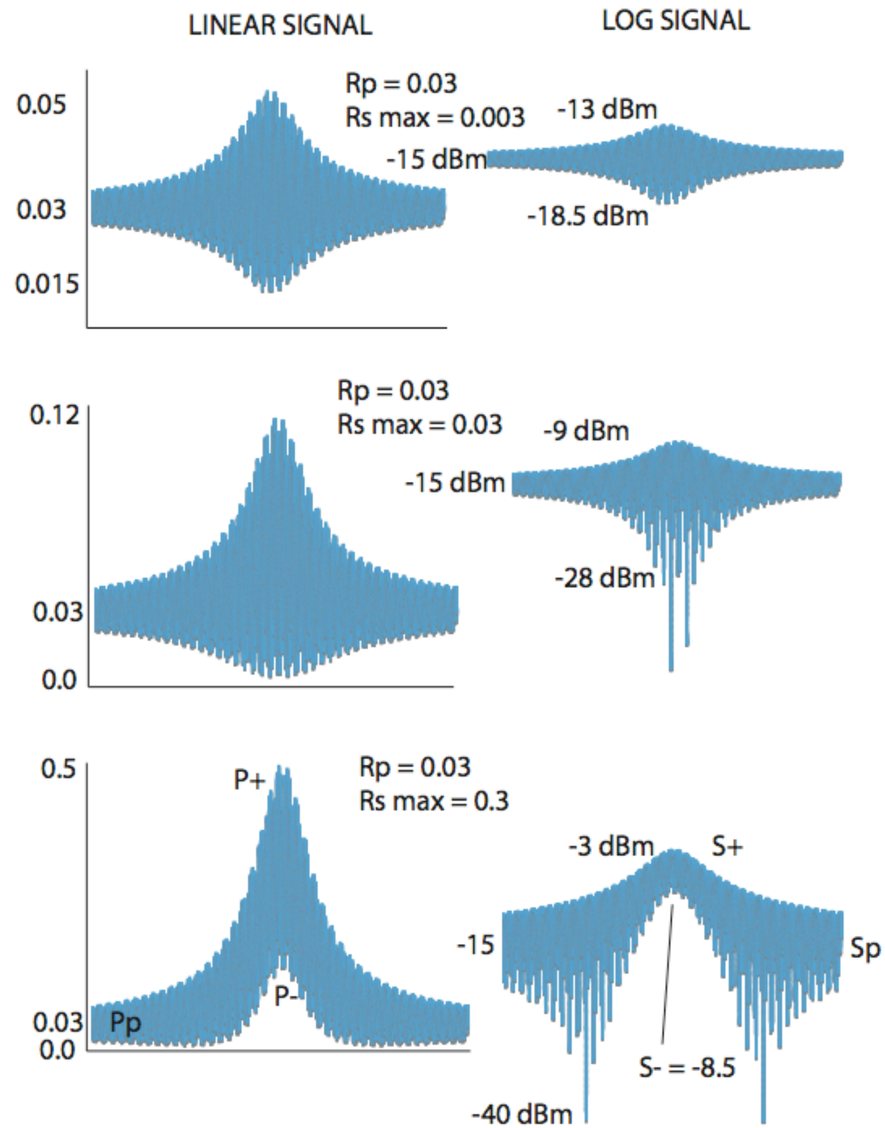
The surface return Rs is peaked because of overlap of the image "blur circle" and the fiber mode.

Simulated interference fringe envelope for various values of the surface return and probe return.

What do we expect to observe as the surface reflectance Rs=Rs(d) varies with distance d over a large distance?

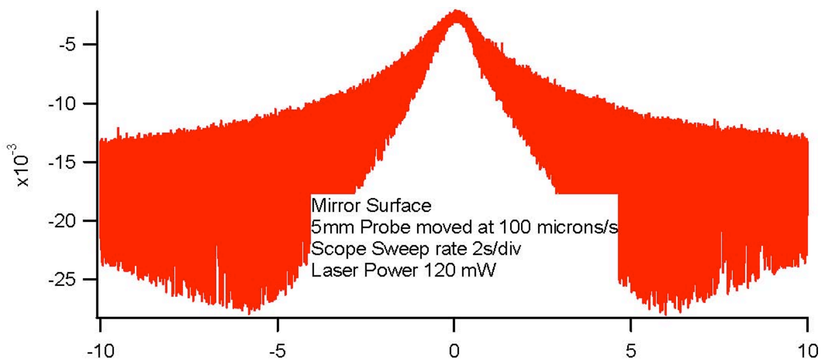
Probe geometry and surface roughness determine Rs.

To select a value for Rp requires a short foray into investigating the effects of surface roughness on signal return.

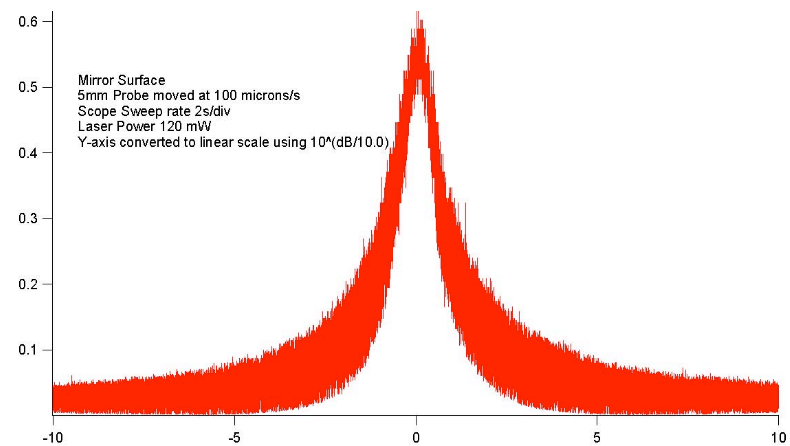


Fringe amplitude envelope measured as we move a mirror (0.1 mm / sec)

Power-monitor output data recorded in dBm.



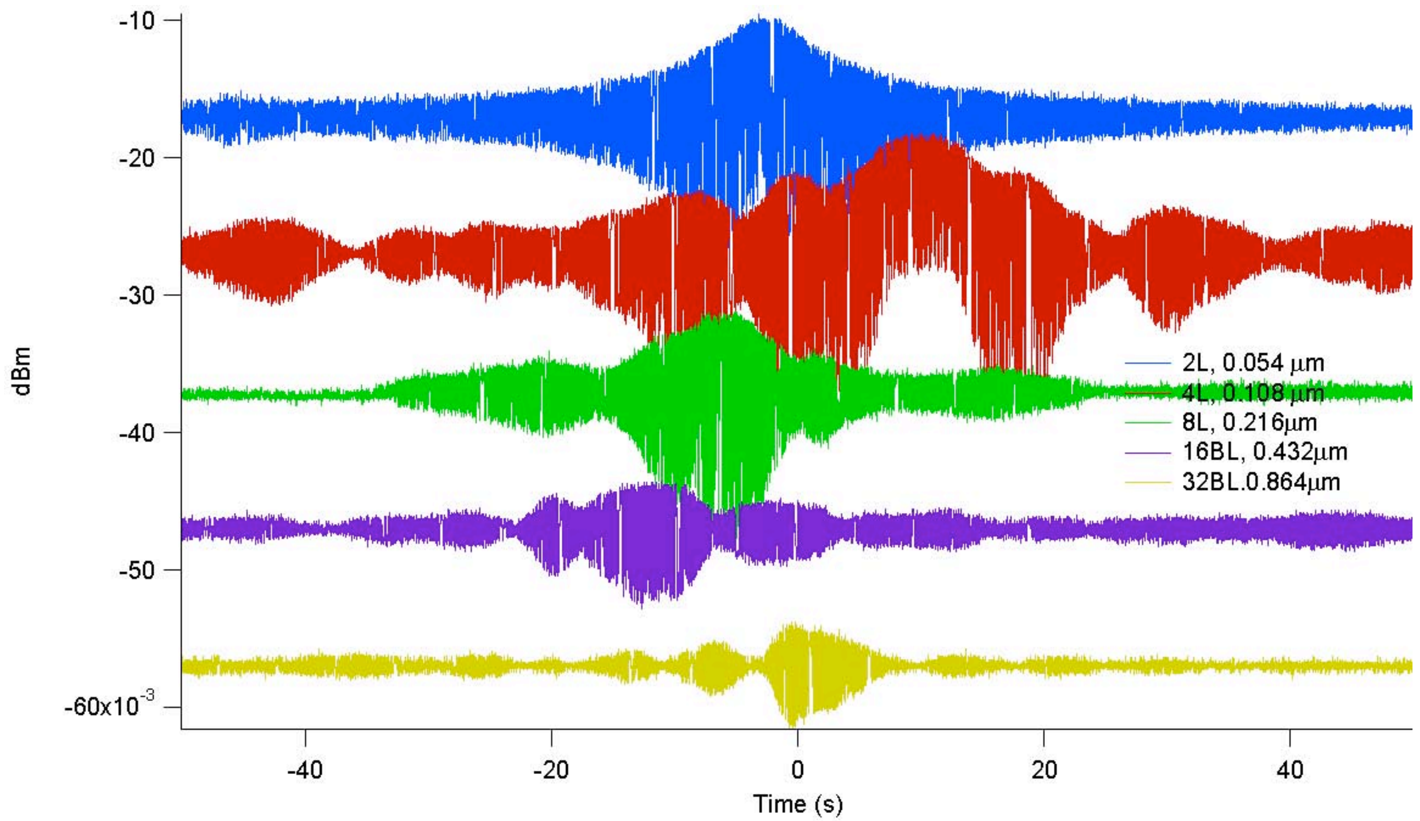
Same data converted to a linear scale



Interference amplitudes tend to decrease with increasing surface roughness

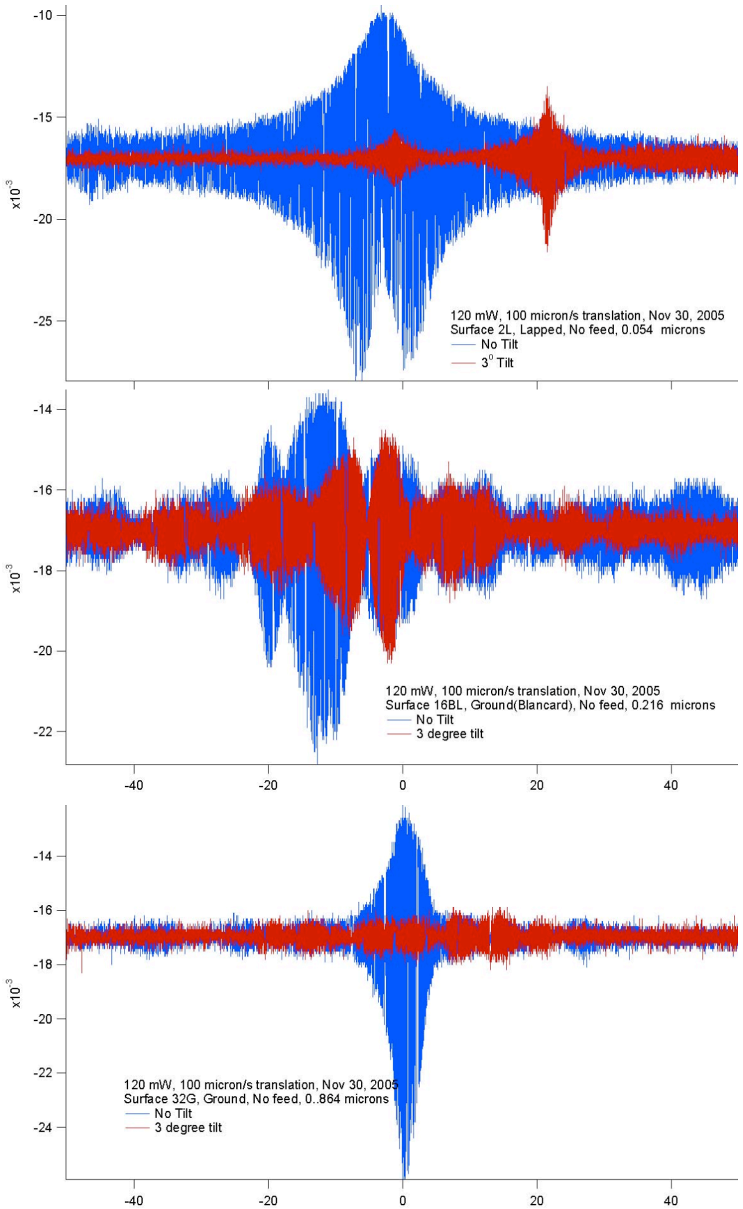
Surface: ISO 9002 certified S-22 machining microfinish comparator

Results measured while moving at 0.1 mm / sec:



Irregular features are repeatable (not shown)

Competing effect: Signal size sensitivity to tilt depends on roughness.



Interpretation: The irregular portion of the beat envelope has a contribution from varying interference paths due to surface roughness.

Usefulness: There is an optimum roughness for a given probe geometry and collection efficiency.

For a 10 mm working distance probe with 4 mm diameter and -15 dB return, a reasonable combination of tilt insensitivity and fringe amplitude is obtained for ¼ micron roughness.

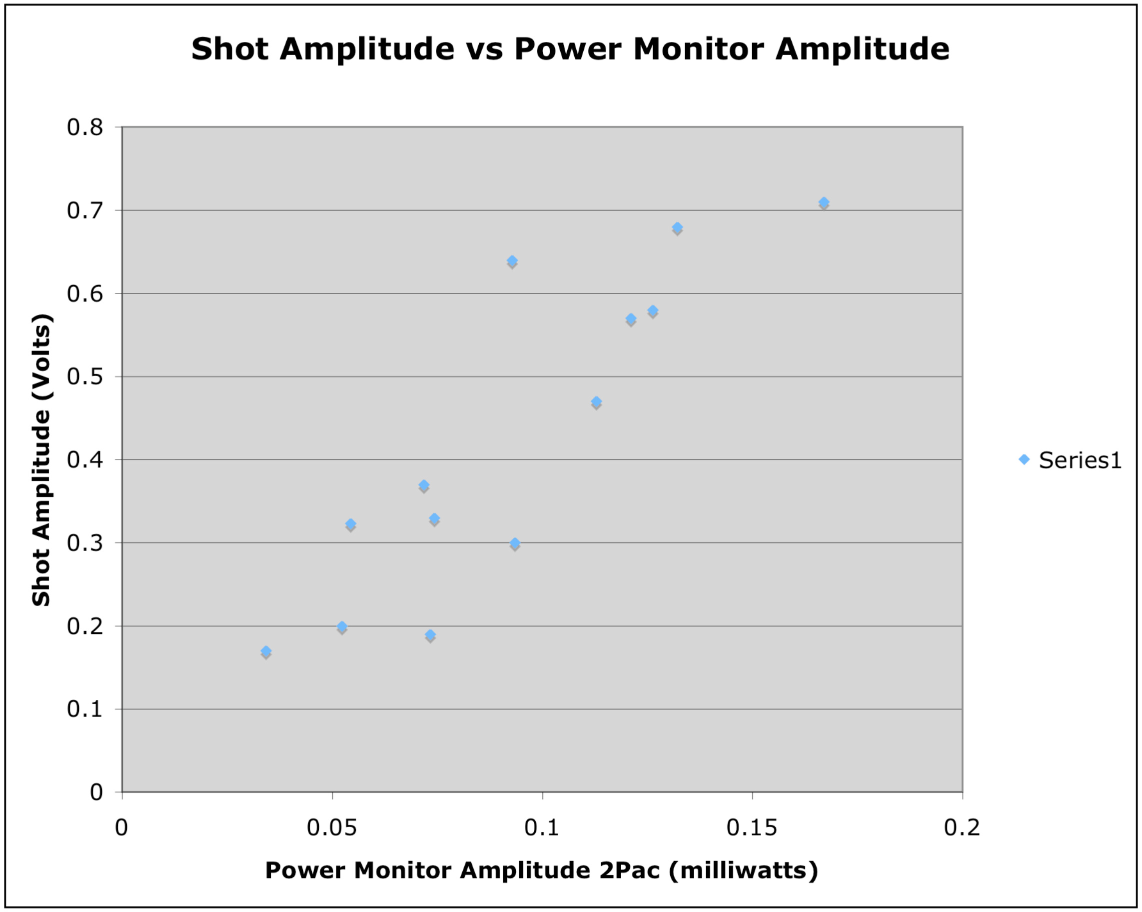
Based on these studies and several other target geometry constraints, a combination of probe geometry and optical parameters were selected.

Fast rise times at breakout and high signal amplitudes for a few mm of displacement are expected for:

10 mm working distance
4 mm diameter probe body
30 microns spot size
¼ micron surface roughness
-15 dB return from probe
(surface return also expected to be -15 dB near maximum)

The fringe amplitude observed while slowly changing d can be correlated to the shock breakout amplitude

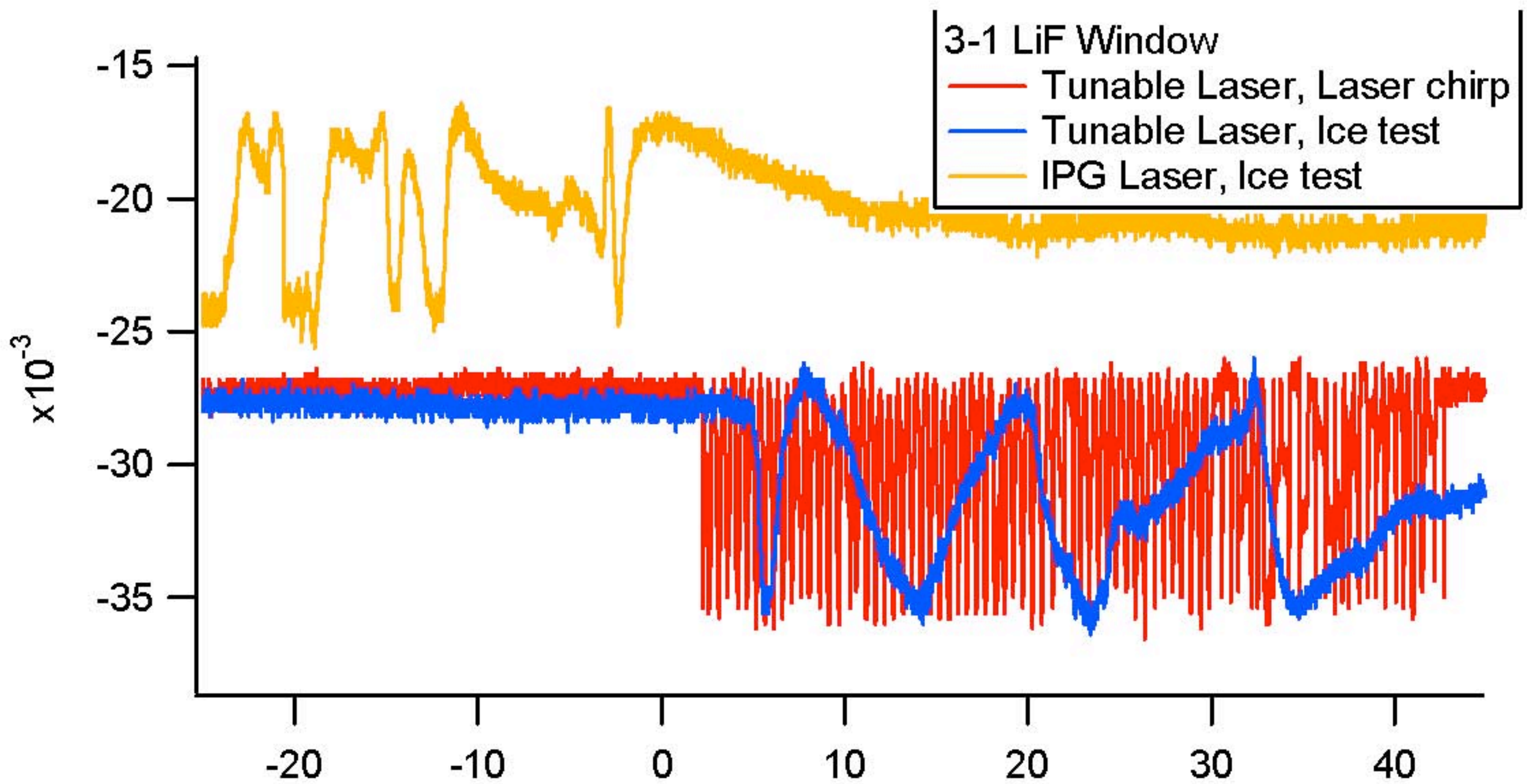
The distance d can be changed slowly by changing the temperature (e.g., placing ice on the target).



Results from shot 1475 at a building 341 gas gun show a correlation between interference and shock breakout amplitudes

Suppose for reasons of being able to maintain confidence in target metrology that we do not allow d to change.
What happens if we change the wavelength instead in

$$\Delta\varphi = 2\pi(2d/\lambda) \quad ?$$



We obtain the same fringe amplitude when we ice the target or when we tune the laser wavelength

Summary:

We have elected to hold d fixed due to :

- target constraints
- feasibility studies demonstrating that slow speed and high speed amplitudes can be the same
- feasibility studies demonstrating that wavelength tuning and displacement amplitudes are the same

Instead, we will use wavelength tuning to:

- check the target parameters at various times during experiment build up, and
- to allow us to set up the product PoTo to optimize the shot amplitude.