Sub-micron Glue Thickness Measurement and Uncertainty Determination for Dynamic Material Experiments on NIF

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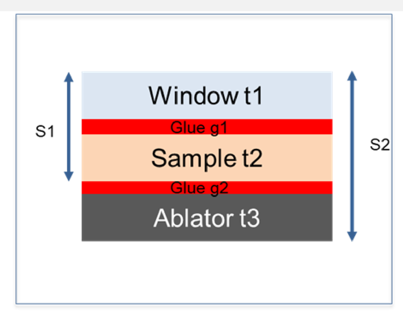
Abstract

Dynamic materials experiments at the National Ignition Facility require targets which include precision planar components in the so-called physics package. The physics package contains the sample material of interest usually sandwiched between the ablator or the pusher, and the window. These components are glued together at ~<500-1000 nm tolerance in thickness and uniformity to allow such experiments to that drive the sample on the intended trajectory in the density/pressure phase space, providing invaluable information for the stockpile stewardship program. Failure to produce samples with such small glue gaps, or samples that do not meet stringent, sub-micron, tolerances, can have a detrimental impact on the experiment. Such thin glue layers and dimensional tolerances need to be verified by precision measurements with uncertainty, much better than the allowed <500-1000 nm for each glue gap or dimensional tolerance. In this paper, we review the double-sided interferometric technique developed for measuring the form of individual parts as well as glue layers between such opaque stacked samples, and then discuss in detail the effort to quantify and validate the uncertainty in the measurement which is in general~ 100 nm dependent on the details of the sample stack.

Why does this matter? Dynamic Materials experiments provide key SSP data and require precision part fabrication and *measurements*

Dynamic Materials (Diffraction, EOS, etc.) physics packages involve planar parts stacked using glue between layers

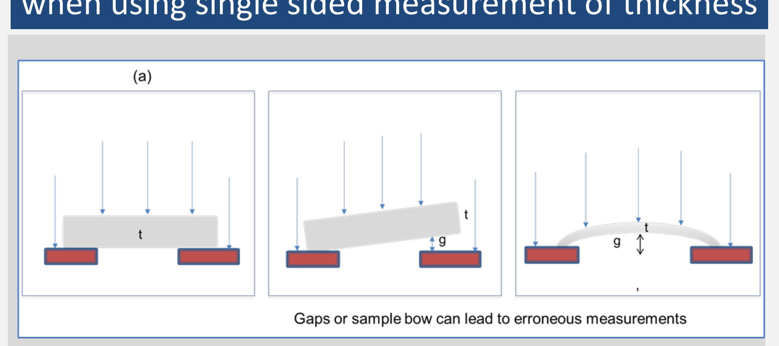
- Dynamic Materials (Diffraction, EOS, etc.) physics packages involve planar parts stacked using glue between layers
- Glue layers need to be <~1um, measured to ~<500 nm ideally ~ 100 nm
- Glue measured by subtraction, hence parts also need such accurate measurements
- Large glue layers and/or inaccurate measurements can lead to sample being in undesired state during NIF shot and adversely affect or nullify experiment goals



~ few um < t_i < few hundred um

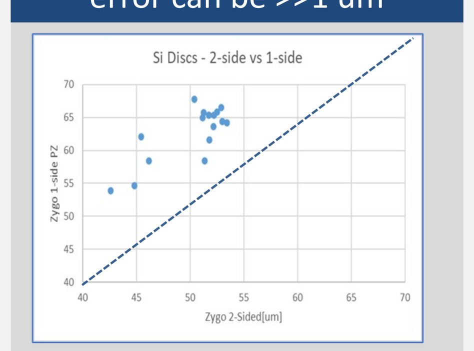
Single sided thickness measurements are insufficient for part and glue thickness determination

Part bow, debris or other gaps introduces errors when using single sided measurement of thickness



Single sided measurement can over (and under) estimate part thickness

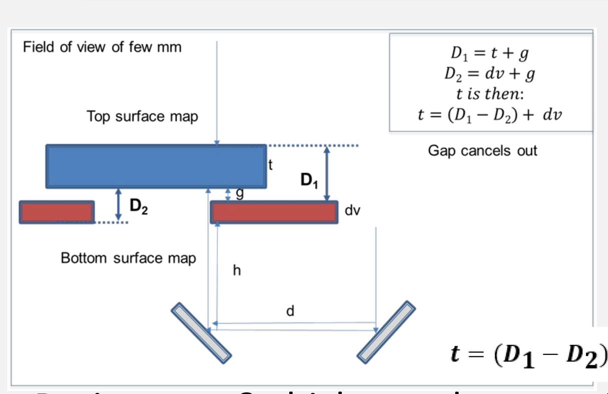
Single side measurement error can be >>1 um



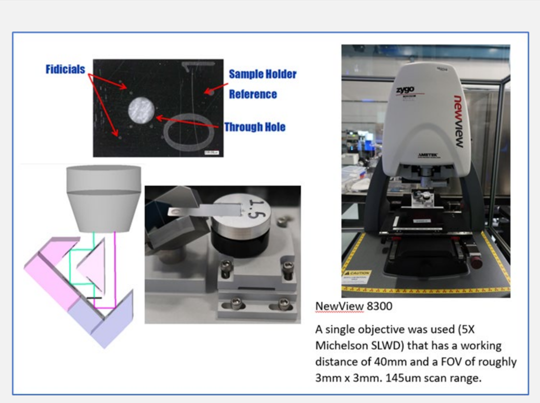
Single vs. double sided measurement of Si flats

While double sided measurements have been used for such measurements for year, the accuracy of such measurements needed improvement

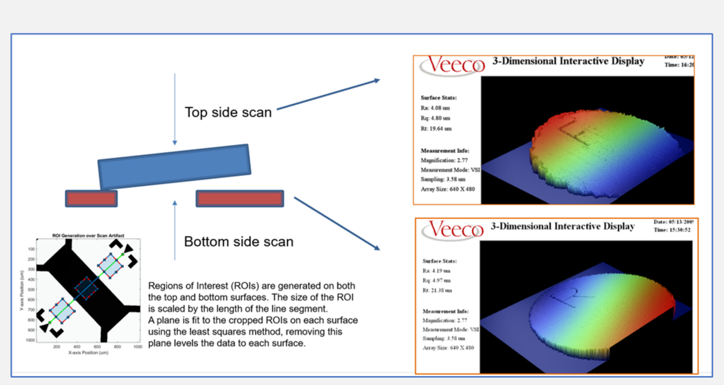
Double sided measurement details



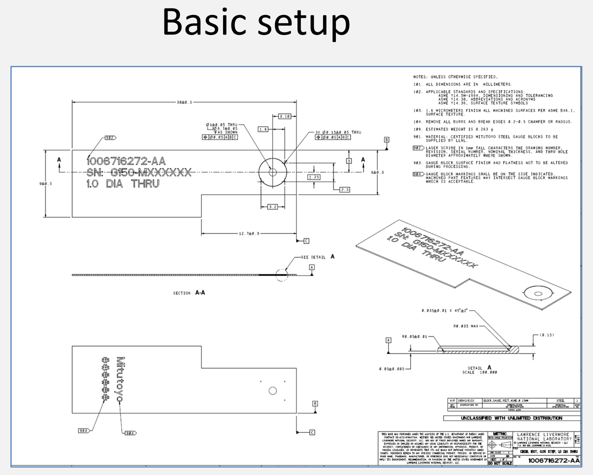
Basic setup & thickness degermation



Basic setup



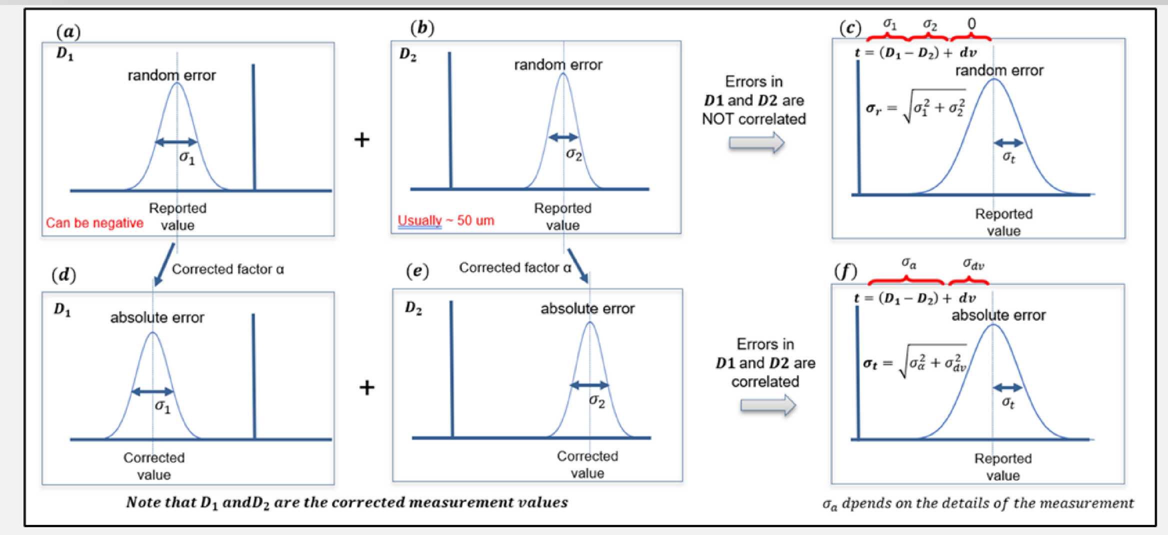
Measurements of top & bottom concurrently



"Cantilever" part holder

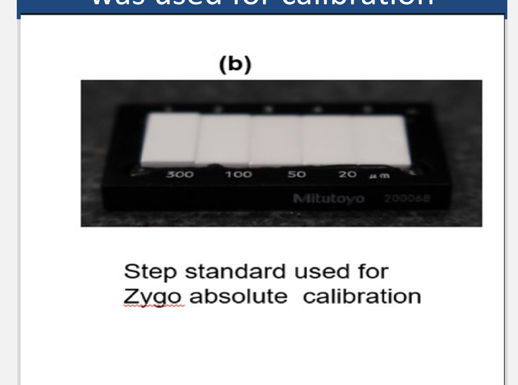
Random and Absolute errors determination

Total error is a combination of random and absolute errors which need to be convoluted



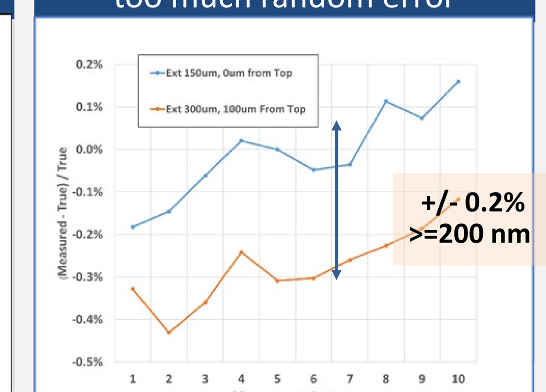
Piezo mode had ~10 nm 1-sigma random error and chosen versus stepper motor with >200 nm random error

A certified set of precision steps was used for calibration



Certified steps from Mitutoyo

Using stepper motor scan led to too much random error



Error will be too large for typical 100 um or larger parts

Using stepper motor, we often got **negative** glue thicknesses and as much **1 um**

Piezo scan mode had ~<10 nm random error

Histogram of repeated step measurements on a certified ~20 um step

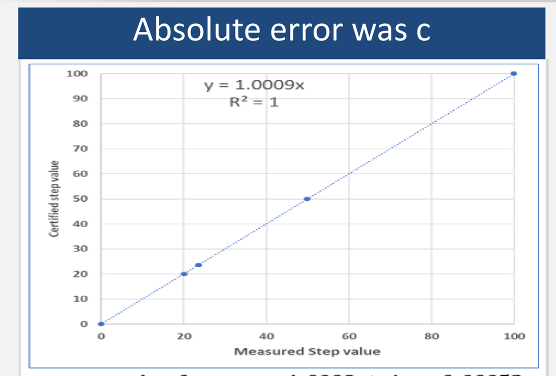
Histogram of measurements on 20 um step (~ 5 nm RMS)

~<10 nm

Nominal Length (um)	Certified Length (um)	Mean Measured Length (um)	Std Dev (nm)
20	19.99	20.033	4.93
24	23.625	23.669	8.38
50	49.53	49.523	12.48
50	49.9	49.829	6.14
100	100	99.923	5.27

Absolute error determined vs certified values from vendor (including its respective errors)

Absolute error was c

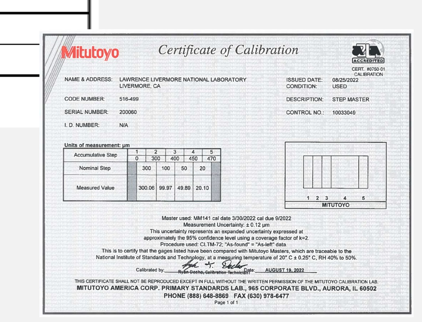


correction factor, α = 1.0009 ± Δα = 0.00052

Absolute calibration curve using supplier certificates

Measured	Certified	Certficate 1σ Uncertainty
0.000	0.000	0.000
20.087	20.100	0.060
23.669	23.625	0.070
49.890	49.890	0.060
99.844	99.970	0.060

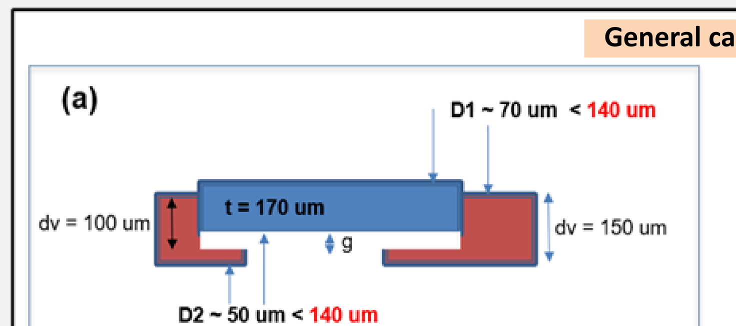
All values in um



Since piezo scans are limited 140 um the cantilever needs to have a counterbore for thicker samples and taken into account in design of measurements

Error bar determination for a single part accounting for both random and absolute errors

General case



Max sample thickness = (100+140) um= 240 um

Random error, 1σ **(b)**

$$\partial t = \partial(D1 - D2) + \partial dv$$

since $\partial dv = 0$

$$\partial t = \sqrt{\partial D1^2 + \partial D2^2}$$

$$^{*}\partial t_{max} <\approx \sqrt{12^2 + 12^2} = 16.9\ nm,\ \mathbf{1\sigma}$$

* See table1

Absolute error, 1σ **(c)**

$$\Delta t = \sqrt{\Delta t_D{}^2 + \Delta dv_i{}^2}$$

$\Delta t_D = t^{+/-} - t = \Delta\alpha^{\pm}\Delta d_i$

with $\Delta d = (D_1 - D_2)$ and

and $\alpha \sim 1.0009 \pm \Delta\alpha^{\pm} = 0.0005$

being absolute correction factor $\pm 1\sigma$

$\boxed{\Delta t_{D\_max} \approx 0.00052 * 140\ um \approx 73\ nm}$

$\boxed{\text{and with } \Delta dv_{i\_max} \approx 60\ nm \text{ and}}$

$$\Delta t_{max} = \sqrt{73^2 + 30^2} \approx 79\ nm$$

~<80 nm

(d) *Example case:*

170 um sample measured using 150 um Tardis diving board **110367** (see table 2)

$$D1 = t + g$$
$$D2 = dv + g$$
$$\text{Assume } g = 1\ \mu m$$
$$t \text{ is then:}$$
$$t = (71 - 51) + 150 = 170\mu m$$
$$^{*}\partial D1 \approx 5nm,\ \partial D2 \approx 12nm$$
$$\partial t \approx \sqrt{12^2 + 5^2} \approx \mathbf{13.4nm, 1\sigma}$$

* See table1

$\Delta t_D \approx 0.0005 * 20\ um \approx 10\ nm$

with $\Delta dv_{110367} \approx 30\ nm$ and

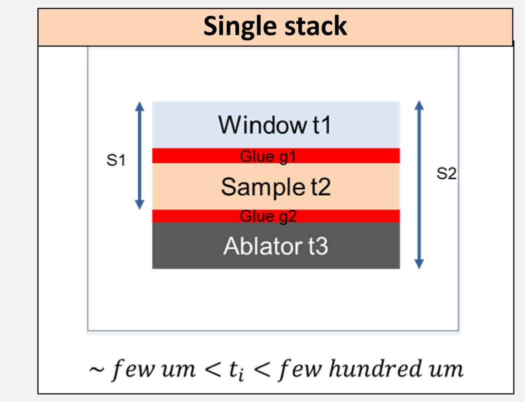
$$\Delta t_{max} = \sqrt{10^2 + 30^2} \approx 32\ nm$$

Error from part measurements propagate into glue thickness measurement and error

Full application of error bar determination for use on NIF targets

Error in glue layer is determined by propagating the errors from each layer and the stack

Single stack



~ few um < t_i < few hundred um

Single stack glue thickness and error calculation

$$\left.\begin{aligned} T_{1,2} &= t_1 + t_2 \\ T_{1,2} &= \alpha(\Delta d_1 + \Delta d_2) + (dv_1 + dv_2) \end{aligned}\right\} \textit{stack component sum}$$

$$t_3 = \alpha\Delta d_3 + dv_3 = T_{1,2} + G \quad \textit{stack with glue gap } G$$

Given above:

$$\alpha\Delta d_3 + dv_3 = \alpha(\Delta d_1 + \Delta d_2) + (dv_1 + dv_2) + G$$

$$\boldsymbol{\Delta d_3 = (\Delta d_1 + \Delta d_2) + \frac{dv_s + G}{\alpha}} \qquad \boldsymbol{with\ dv_s = dv_1 + dv_2 - dv_3}$$

$$since\ t_i^{+/-} = \alpha^{+/-}\Delta d_i + dv_i \qquad using\ x\ above\ and\ substituting\ for\ \Delta d_3$$

$$t_3^{+/-} = T_{1,2} + G = \alpha^{+/-}(\Delta d_1 - \Delta d_2) + \alpha^{+/-}\frac{dv_s + G}{\alpha} + dv_3$$

and hence,

$$G^{+/-} = t_3^{+/-} - t_1^{+/-} - t_2^{+/-} \Rightarrow \boldsymbol{G_s^{+/-} = (\frac{\alpha^{+/-}}{\alpha} - 1)dv_s + G\frac{\alpha^{+/-}}{\alpha}}$$

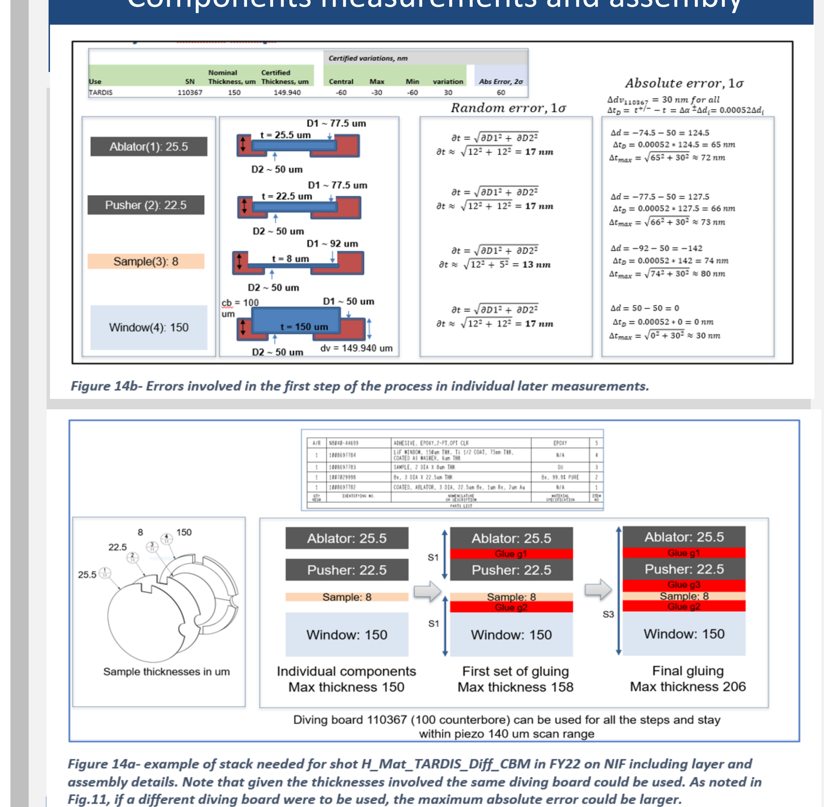
$$\Delta G_s = G^{+/-} - G$$

$$\boldsymbol{\Delta G_s^{+/-} = (\frac{\alpha^{+/-}}{\alpha} - 1)(dv_s + G)} \quad \textbf{(3)} \qquad \Delta G_s^{+/-} = \pm 1\sigma\ error\ of\ glue$$

The process is then applied as each layer is added

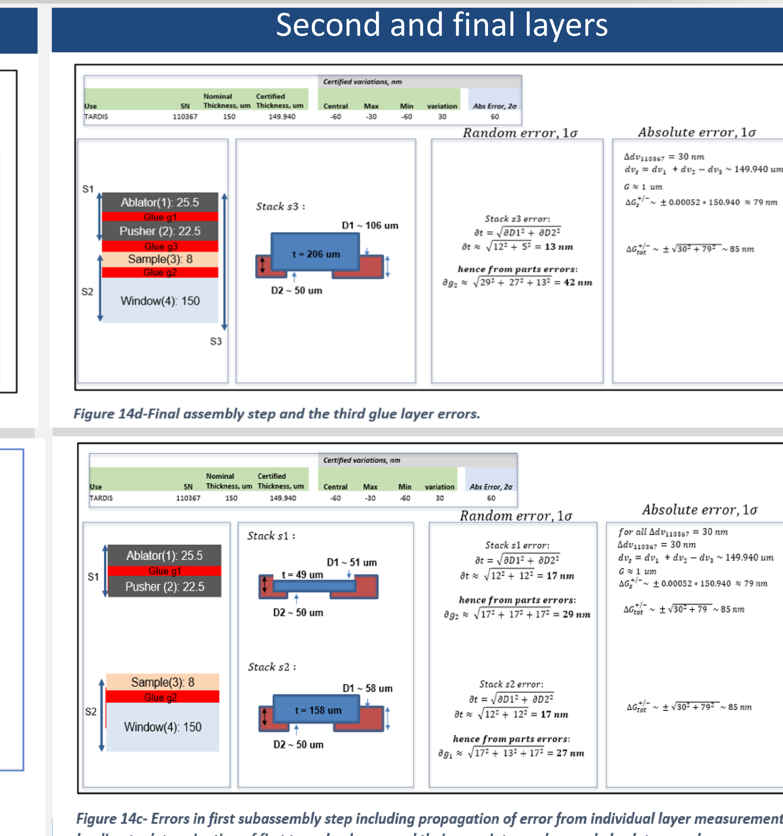
Step by step assembly and measurement and error propagation for an example package used in a shot

Components measurements and assembly



All part errors are <100 nm 1σ

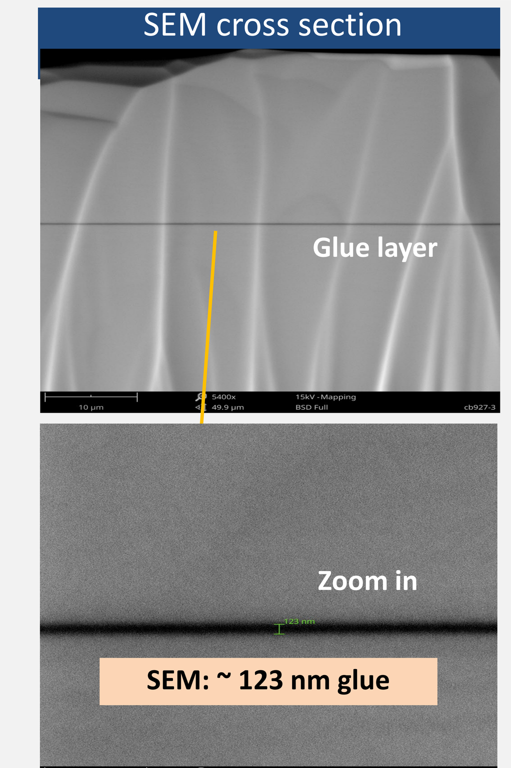
Second and final layers



All glue errors are <100 nm 1σ

Process was verified using cross sectional checks on parts as well as by trends in occurrence of measured negative glue gaps

SEM cross section



Double-sided (avg) ~ 80 nm

Example of a series of glue error measurements for parts used on NIF shots

Measured Glue	Tota Abs Error	Abs (D1-D2)	Abs (dv)	Min Glue	Diving Board factor
-0.046	0.084	0.078	0.03	-0.084	149.939
0.052	0.083	0.078	0.03	-0.031	149.939
0.287	0.060	0.052	0.03	0.227	-100.142
0.321	0.060	0.052	0.03	0.261	-100.142
0.389	0.060	0.052	0.03	0.329	-100.142
0.410	0.084	0.078	0.03	0.326	149.939
0.551	0.083	0.078	0.03	0.468	149.939
0.644	0.084	0.078	0.03	0.560	149.939
0.678	0.084	0.078	0.03	0.594	149.939
0.801	0.084	0.078	0.03	0.717	149.939
0.984	0.084	0.079	0.03	0.900	149.939
0.995	0.084	0.079	0.03	0.911	149.939
1.053	0.084	0.079	0.03	0.969	149.939
1.189	0.060	0.051	0.03	1.129	-100.142

All part errors are <100 nm 1σ

Using the new process, the glue measurements are now typically 90% of time non-negative and all within 100 nm of zero value

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