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NTOF-4M-BT: A PRIMER AND SHORT HISTORY OF THE DETECTOR (OCTOBER 2013)

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Disclaimer

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NTOF-4M-BT

A primer and short history of the detector (October 2013)

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ABSTRACT

This document describes the NTOF-4M-BT detector and documents its general capabilities and history of use at NIF

General History

NTOF-4M-BT is a detector consisting of three (3) diamonds. The initial deployment utilized one 10mm diameter X 1mm thick diamond (DET1), one 16.5mm diameter X 1mm thick diamond (DET2), and one 5mm diameter X 0.25mm thick diamond (DET3). The detector in its initial deployment is shown in figure 1.

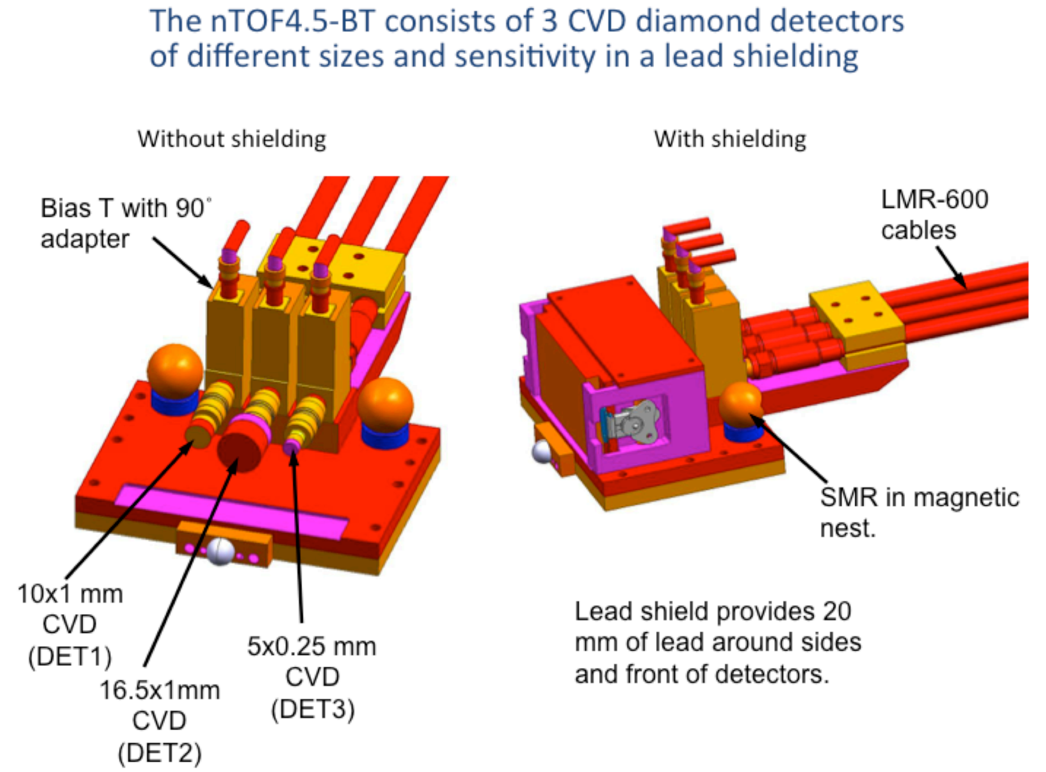


Figure 1. NTOF-4M-BT detector in its initial deployment configuration.

The detector was originally installed in location 64-253 and each detector element had a 24' LMR600-LLPL cable connected to its own Tektronix 70604 digitizer. The digitizers were contained within an EMI enclosure located in the target bay adjacent to the port.

X-ray mode

In addition to the original configuration there are replacement front x-ray shields consisting of either iron or copper/tin shielding that can be used to modify the spectrum of x-rays that reach the detector. Shot participation with these shields is generally referred to as x-ray mode. A rendering of this cover is shown in figure 2.

Use of the detector in x-ray mode was somewhat common during 2010 and 2011 but is considerably more rare presently. This is due to a number of issues including the observation that the lack of collimation results in non-specificity of the source location and that previous analyses have indicated that a significant part of the signal can be generated at the Hohlraum LEH. Additionally, since the installation of the Mach-Zehnder system the sensitivity to x-rays has decreased by about a factor of 8. The decrease in sensitivity makes x-ray measurements of the first shock hot electron generation problematic without the installation of an amplifier (an off-normal setup normally reserved for use on timing shots). Nonetheless there is occasionally a request to run the detector in x-ray mode on Hohlraum shots to observe the rise of the 4th shock and the x-ray extinction at the end of the laser pulse.

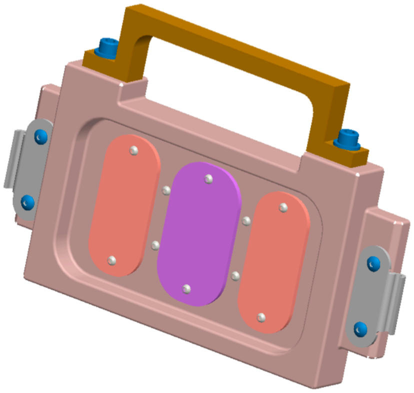


Figure 2. X-ray replacement shield utilizing spectrum modifying filters.

Current configuration (September 2013) and change history

The current configuration utilizes the original 10mm diameter X 1mm thick diamond (DET1), a low sensitivity 5mm diameter X 0.25mm thick diamond (DET2), and the original 5mm diameter X 0.25mm thick diamond (DET3). At various times in the past detector configurations have changed, or parts have been replaced. A summary of theses changes is given in Table 1.

Table 1. Summary of changes in diagnostic since installation

Date	Action/Change
July, 2010	Initial installation
June 2, 2011	moved 5mm diamond to scope 2
June 13, 2011	installed new O/E converter on scope 3
June 14, 2011	installed new splitters on scope 1 (a new, shorter N-SMA adapter was also installed)
June 15, 2011	installed new splitters on DET3 line and a new scope, work order 22902 (a new, shorter N-SMA adapter was also installed)
July 12, 2011	reinstalled 16.5mm diamond onto scope 2 bias tee, moved 5mm diamond back to scope 3 bias tee, work order 23364
October 14, 2011	replaced 16.5mm diamond (scope 2) with new optical grade 5mm diamond from German company, work order 25295

Date	Action/Change
	replaced 5mm diamond on BT2 with 5mm null holder
March 3, 2012	replaced 5mm null holder on BT2 with 5mm diamond (optical grade 5mm diamond from German company)
March 3, 2012	replaced N-SMA adapter on BT3 with same style adapter (short one) - installed one broke
May, 2012	Moved detector to 64, 136 and installed Mach-Zehnder recording system

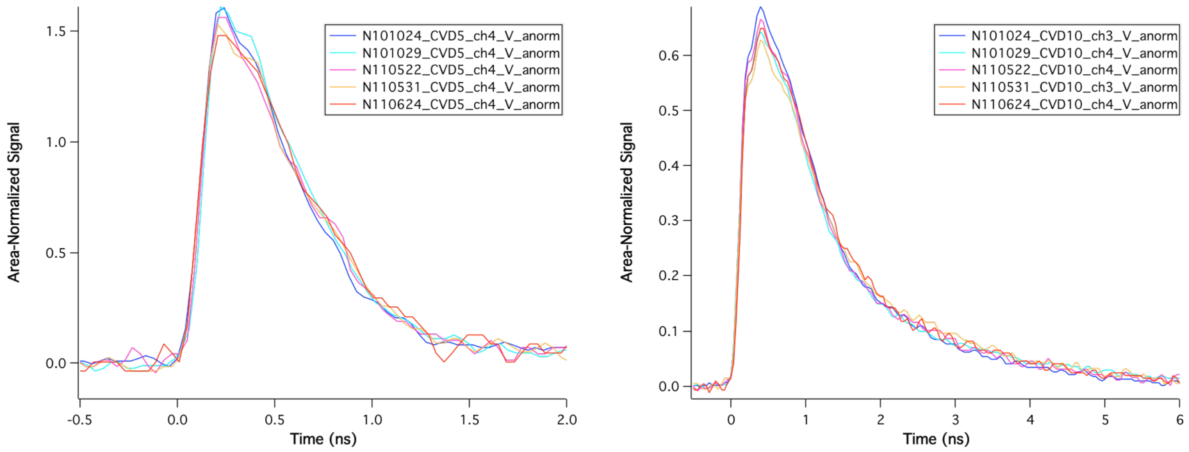
Mach-Zehnder upgrade and detector move

In June of 2012 the recording system was replaced due to concerns about the upset of the digitizers at high yields. The replacement system was based on Mach-Zehnder interferometers with the laser source located in the mezzanine and transmitted to the port via fiber optic cabling. The detector also changed locations and was installed in port 64-136, approximately on the same line of sight as the NTOF SpecA and IgHi detectors. This was done to allow the use of the core velocity measured in the alcove to obtain a neutron-based bangtime from the 4.5BT detector.

Construction of IRF

The construction of the IRF for NTOF-4M-BT utilizes the same general steps as for other NTOF detectors: measurement of an x-ray IRF and convolution with an MCNP simulation of neutron impulse generated signal. A brief discussion follows.

X-ray response has been obtained on NIF timing shots throughout the installed history of the detector. When possible (e.g., no configuration differences) the aggregate x-ray impulse response has been constructed by averaging the individual area-normalized timing shot traces. Variability in the data obtained on timing shots is presented in figure 3. Current x-ray IRFs are shown in figure 4. FWHM values for the 5mm and 10mm CVDDs are 0.61ns and 1.12ns respectively. For Historical purposes the 16.5mm CVDD x-ray IRF is also included.



(a) **(b)**

Figure 3. Area normalized impulse response measured for (a) 5mm CVDD and (b)

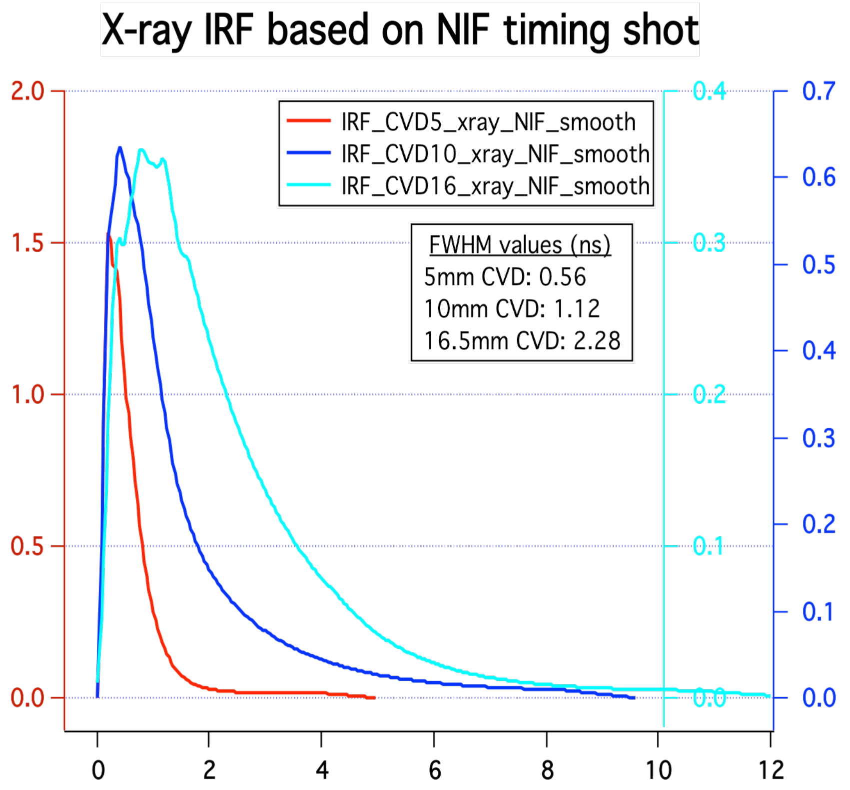
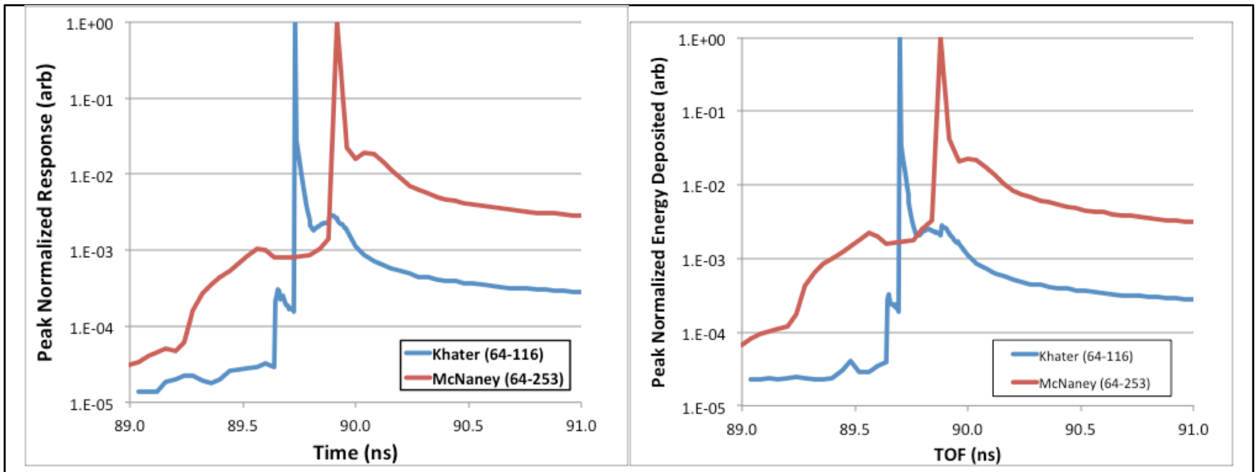


Figure 4. Area normalized x-ray impulse response measured for the 5mm, 10 and 16.5mm CVDD.

Two MCNP models of the detector have been made. One model was constructed by J. McNaney (64, 253 location) while the second model was constructed by Hesham Khater

(64, 116 location). Both have simulated the time-domain response to a 14.03MeV neutron source. The Tally was divided into both energy and time bins for both neutrons and photons. The total energy deposition was based on Tom Phillips' carbon sensitivity calculation for neutrons and Andrew MacPhee's ITS simulations for photons. This method has also been compared to the standard energy deposition tally in MCNP and the differences between these methods have been found to be small for this case. Summary plots of the MCNP si,ulations are shown in figure 5.



(a) **(b)**

Figure 5. MCNP simulated energy absorbed in NTOF4m-BT diamonds for the 2 installation locations. Results for the 5mm and 10mm CVDD are shown in (a) and (b) respectively.

Absolute timing determination

Determination of the absolute timing was carried out through the following fitting methodology:

1. Interpolate scope data onto 1ps time bins (native is 40ps)
2. Construct Gaussian x-ray source function
3. Convolve Gaussian x-ray source with x-ray IRF and adjust temporal position of x-ray source function until the best fit to the data is obtained
4. Obtain the reference time from the temporal positon of the x-ray source function, the position of the scope fiducial, and the temporal position of the laser pulse used to generate the x-ray impulse

Sensitivity of the reference time to the width of the Gaussian source function has been found to be very low for source functions up to 300-400ps. A fixed value of 100ps has been used.

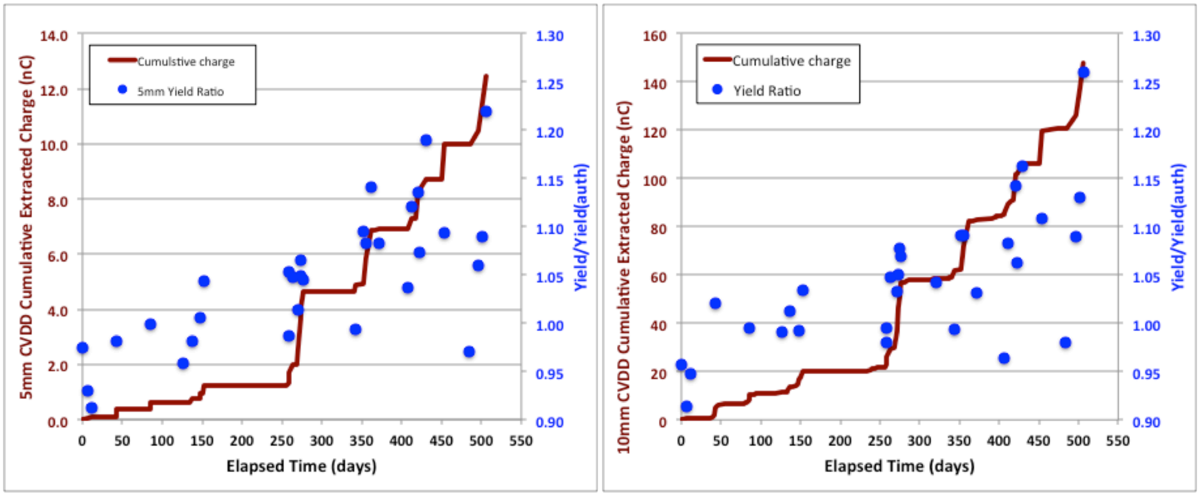
It is recognized that the x-ray source is not an impulse and that this introduces an absolute error in the derived detector x-ray IRF. The error is estimated to be less than 50-60ps in the IRF FWHM value. It terms of analyzed neutron arrival times, this error is very small due to the methodology for determining the reference time (i.e., a slightly wider IRF simply results in an adjustment to the reference time and this adjustment is very close to that needed to account for the slightly wider IRF in analysis of neutron data). The major impact of this IRF error is a systematically higher ion temperature.

Note: see below in "Current thinking on setups" for additional information on timing determination for the current MZ driven system.

Yield calibration and diamond variability

Yield calibration for NTOF-4M-BT follows the same methodology used in other NTOF diagnostics: comparison of the charge associated with the fitted neutron distribution with activation diagnostic results on exploding pusher shots. As there are no changeable components (save attenuators) the process is straightforward. Absolute calibration accuracy is in the 8% range while shot-to-shot variability was shown to be 3% or better based on early shot data analysis that compared results from multiple diamond detectors on single shots.

Subsequent yield variability was observed at levels noticeably above the initial analyses and this variability was shown to be largely dependent on the cumulative neutron exposure but also slightly dependent on time between shots. Figure 6 shows the results of the analysis.



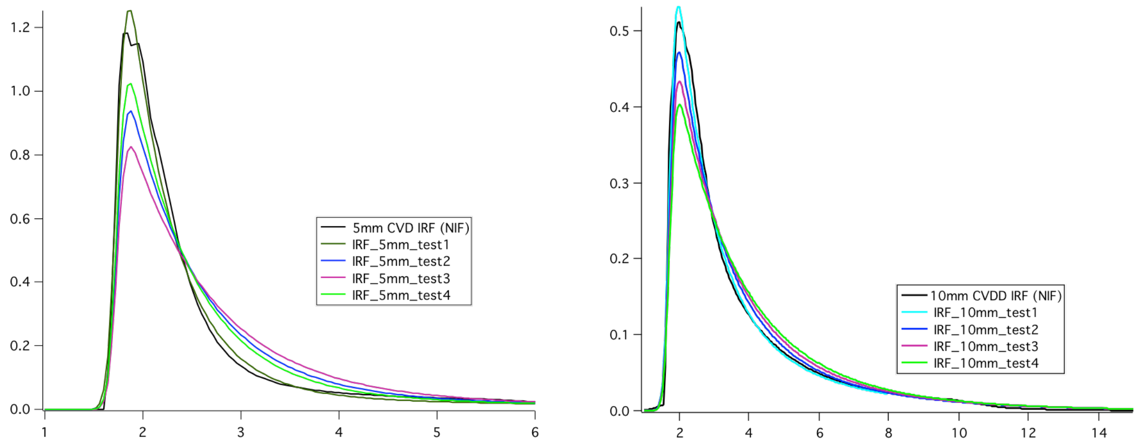
(a) **(b)**

Figure 6. Cumulative neutron charge extracted (left axis) and ratio of derived yield to authorized yield (right axis) versus elapsed time since start of DT shots. Results for 5mm diamond are in (a) while those for the 10mm diamond are in (b).

Timing considerations for IRF changes

Determination of the neutron arrival time account for the observation that the IRF for the BT CVD diamonds is changing over time and has shot-to-shot variability. A methodology has been developed to allow a correction to the arrival time depending on the shot-specific beghavior of the detector. In order to construct such a correction it is useful to recognize that changes to the IRF have a relatively small efeect on the measured yield but a considerable effect on the inferred ion temperature. Using this fact, and the assumption that the ion temperature is relatively insensitive to the LOS, a method was developed using the difference in the authorized ion temperature versus that inferred by a given CVDD detector. The method is descibed in more detail below.

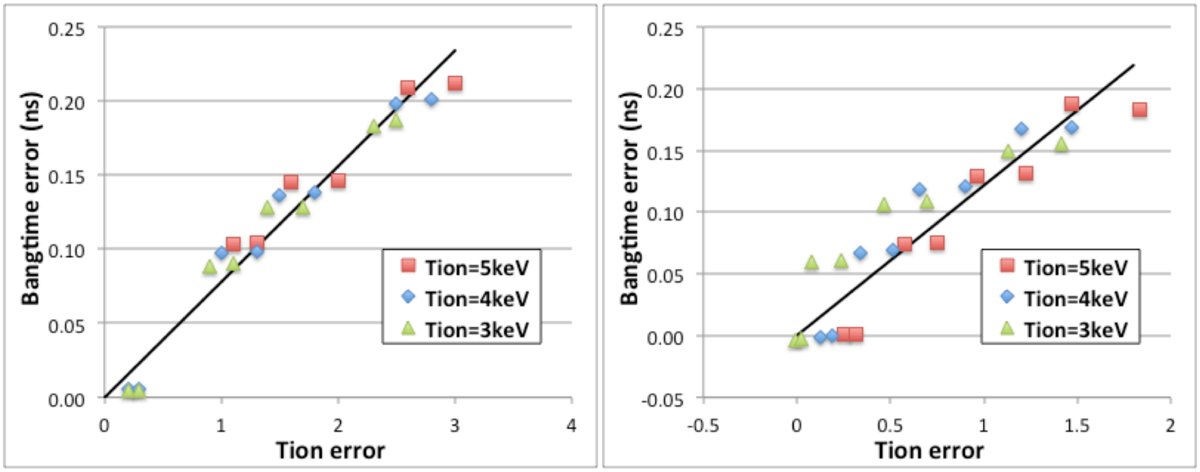
For each CVDD, a series of simulated data set were produced using a reference IRF that was equal to the one in use for that particular CVDD. A second set of IRFs was produced, having a rise time fixed to that of the reference IRF, but with a subsequent shape that was wider to varying degrees. The set of IRFs used is shown in figure 7.



(a) **(b)**

Figure 7. Reference and test case IRFs for determining the functional relationship between the IRF deviation and the change in inferred neutron arrival time. IRFs for the 5mm CVDD are shown in (a) and those for the 10mm CVDD in (b).

In all cases the input neutron spectrum was a Gaussian source (in energy space). The range of ion temperatures considered was 3-5keV. Fits were carrier out for each test IRF case and the error in neutron arrival time versus the error in the inferred ion temperature was obtained. Linear fits to these errors, of the form ΔBT=C*ΔTion, were used to determine the form of the correction factor. The variation in the corrected bangtime versus the inferred, and corrected, arrival time were used as the basis for the associated error. A plot of the



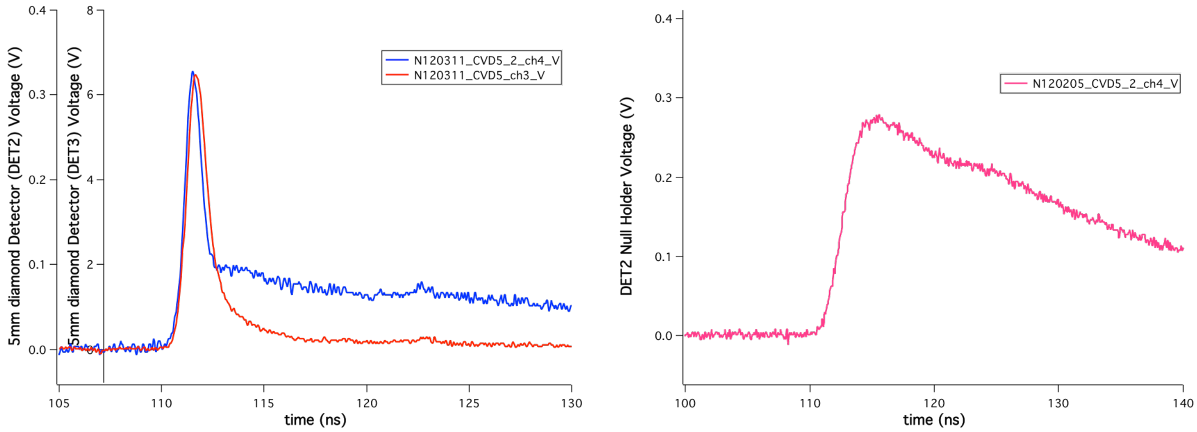
(a) **(b)**

Figure 8. Summary of bangtime error analysis for the (a) 5mm and (b) 10mm CVDD detectors.

results with fit lines are shown in figure 8. The fit coeficient, C, was found to be 0.078 and 0.121 for the 5mm and 10mm CVDD detectors respectively.

Observations for DET2, the lowest sensitivity diamond

As per the notation in Table 1, a second 5mm X 0.25mm CVDD was installed in DET2 in March of 2012. This diamond was expected to have lower sensitivity than the existing 5mm CVDD due to the presence of additional charge traps resulting from the manufacturing methodology. This was found to be the case and it was also evident that additional signal was being generated by other components in the system and that this signal was temporally very sluggish (Figure 9a). The most likey sources of this signal are the bias capacitor in the bias tee and the biased dielectric in the N-N coupler connecting the CVDD holder to the bias tee. Additional testing with an empty CVDD holder generated a background signal that can be used to remove the additional signal if desired (figure 9b).



(a) (b)

Figure 9. (a) Comparison of originally installed (DET3) 5mmx0.25mm CVDD (red curve) and low sensitivity 5mmx0.25mm CVDD (blue curve) on shot N130311. Note that the new diamond (DET2) is about 20x less sensitive, slightly faster, and that there is additional long-time signal. (b) Signal generated from an empty diamond holder in the DET2 position on shot N120205.

Current status of Mach-Zehnder data analysis

The basic structure of the recording system is as follows:

a. There are two MZ units for each CVDD. MZ1 & MZ2 are connected to DET1, MZ3 & MZ4 are connected to DET2, while MZ5 & MZ6 are connected to DET3.
b. The CVDD output is split unequally with 80% of the signal routed toward the first MZ of the pair and 20% routed toward the other. This prevents both from reaching a wrap point at the same time and extends the region where the signal can be assembled entirely from unwrapped data (if desired).
c. Each MZ has a single scope channel to record the signal. The peak-to valley voltage for a single MZ wrap is about 0.8V. As such, the scope full scale is normally set to 1V and the baseline is located in the middle of the range. Note that the baseline is about

-0.3 to -0.4V so that the MZ is located approximately halfway between the maximal and minimal values when there is no input signal.

d. The fidu signal is input optically to the same transducer that receives the MZ light output. It results in a negative going pulse.
e. The MZ system is set so that a positive CVDD output results in an initially negative going signal (so that the fidu and signal are moving in the same direction). This was done to allow an increase in the scope channel sensitivity for cases where the expected CVDD signal is very low. This increased sensitivity requires a change in the baseline offset requested (supported by CMT) and allows optimization of the signal to noise ratio. Note that the 1V scope setting is scope noise dominated. Below 0.4V full scale the signal is mostly dominated by the opto-electric converted.

A schematic of the system showing smart locations is given in figure 10.

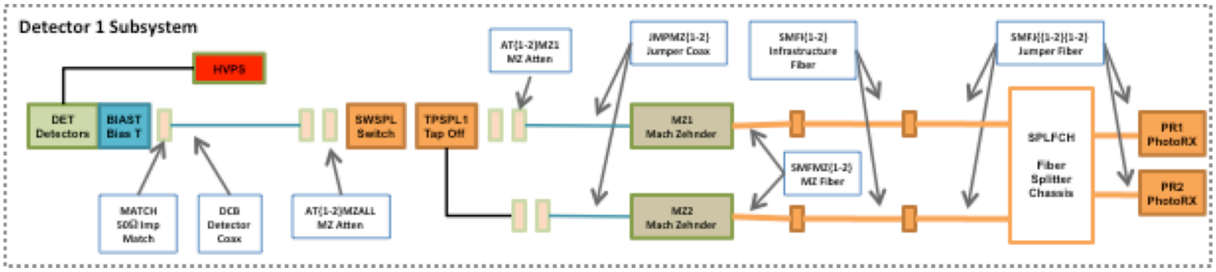


Figure 10. Schematic of MZ system components and smart locations

The use of a Mach-Zehnder based recording system introduces two extra steps in the data retrieval process:

1) Unwrap of the signal to obtain MZ equivalent voltage versus time
2) Deconvolution of the Mach-Zehnder instrument response to obtain the voltage input to the MZ system versus time

Once these two steps have been completed, the standard SAVI analysis can be performed. Care should be taken to compare the voltage versus time traces obtained from steps 1) and 2) to ensure that there is no loss of sensitivity due to the non-linear effects present in the MZ data near the wrap points (if they exist in a particular data set).

Current thinking on setups

Recently the use of NTOF-4M-BT has been limited by usage rules. The current use rules are as follows:

1) Use only on DT shots 5e12<Y<1e16, CMT setup changes only. X-ray use is permitted for DT layered shots when requested by shot RI.
2) Hardware changes by CCB5 request.

Two noteworthy effects of these rules are as follows:

1) Use of the amplifier necessary for running the 5mm CVDD on timing shots required CCB5 approval.

2) Change of the x-ray shield from lead to the preferred Cu/Sn setup used in x-ray mode is permitted without CCB5 approval. Return of diagnostic to neutron mode is also permitted without CCB5 request.
3) Use of the amplifier for very low x-ray signals requires CCB5 approval

Use in x-ray mode

In order to use the detector to measure x-rays it is necessary to remove the usual lead shield. Typically, the lead shield is replaced with a Cu/Sn filter set in order to look at x-ray at high energies ($E_{avg} \approx 200$keV). It can also be run with no shield. There is still filtering from the end of the diagnostic well and the CVDD holder itself and this filtering prevent x-rays below about 20-30keV from reaching the detector in measureable quantities. It is also possible to increase the sensitivity of the measurement by installing an amplifier between the detector bias tee output and the MZ input. This is done for the 5mm CVDD (DET3) on timing shots. Care should be taken if using the amplifier on Hohlraum shots as it can be damaged by excessive input voltage.

There is one template set up for x-ray measurements on Hohlraum shots, named "MZ_high_sensitivity". It uses the Cu/Sn shield. The scope setup is SNR optimized (see i. below) for all MZ channels and there is 2db attenuation on DET1 to prevent LPI generated signals from exceeding the scope setup. The value is based on previously observed signal magnitudes.

Setup for timing shots

Considerable high energy x-ray output is required to time the BT diagnostic due to the inherent aluminum filtering present in the beam line and the relative insensitivity of the diamonds to high energy x-rays. The standard shot employs a plastic coated gold foil and uses a 1ns low intensity pre-pulse to generate a low density plasma for the main laser impulse. This creates enough signal for the 10mm CVDD to record without amplification but neither of the other 5mm CVDDs are capable of sufficient signal without amplification. As such, an amplifier is required to obtain sufficient signal for absolute timing of the DET3 diamond. The setup for this mode of operation is shown in figure 11.

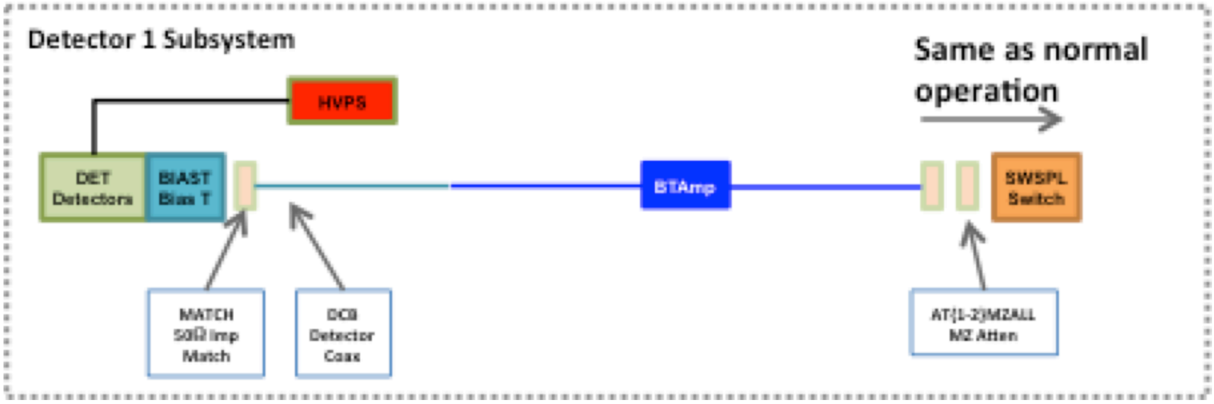


Figure 11. Schematic showing setup during amplifier use on a timing shot. Two 1.44m lengths of HF290 and the amplifier are added to the signal path (shown in dark blue).

To date, only DET3 has used an amplifier for timing determination. This detector is about 10x less sensitive than the 10mm CVDD. The amplifier used is a model 8001 26db linear gain amplifier from Picosecond Pulse Labs. This amplifier has been shown to track the rising edge and the peak of a diamond-like pulse well (figure 12).

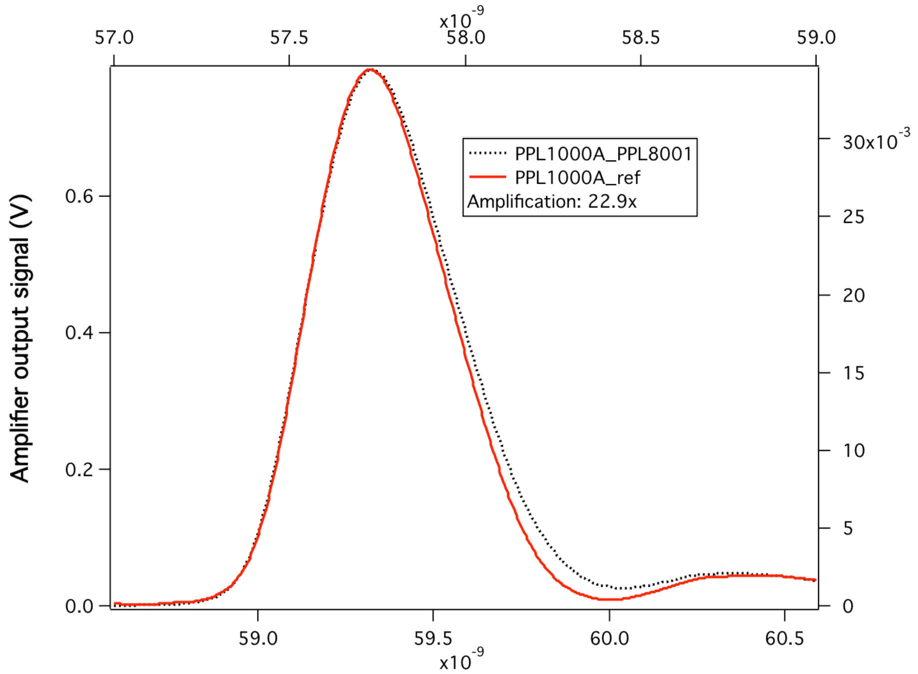


Figure 12. Comparison of test pulse (black dotted curve) and amplified output (red curve) from the Model 8001 amplifier.

Separate measurement of the insertion delay of the amplifier and cabling is required to translate the timing derived from the NIF shot with that necessary for analysis. This was done off-line using the same cabling and amplifier. The additional offset delay was found to be 15.429 ± 0.005ns.

Note that it is unlikely that the remaining 5mm CVDD (DET2) will see sufficient signal even with the amplifier as it is approximately 20x less sensitive than the 5mm CVDD installed in DET3.

One template is available for this setup, named “timing shot Amplifier DET3”. The setup has no shield installed and amplifier on DET3. The scope setup is SNR optimized (see i. below) for DET1 (both MZ channels), DET2 (both MZ channels) and DET3 (second MZ channel only)

<u>Setup for DT shots</u>

Given the restrictions on making physical (e.g., attenuators) changes to the diagnostic for shots a series of templates have been made to cover the entire range of BT operation (5e12<Y<1e16). These are summarized in Table 2 below. The general philosophy is as follows:

i. At the low end of the signal range the MZ system is set to optimize the recording system signal to noise. Recognizing that the signals generated will not result in wrapping, the scope range is decreased from 1V to 0.4V and the baseline is correspondingly offset by -0.3V to move the baseline signal into the scope range. This is designated as the SNR optimized setup.

ii. As the yield increases the scope is reset to the normal MZ operating condition (allowing wrapping of the signal)

iii. At the upper end of the yield range the detector is disabled if the upper bound of the signal generated is large enough to potentially damage the MZ unit. This level is about 250V. Note that analyzing signals above about 100V violates the $V_{max}/V_{bias} <<1$ criterion generally considered necessary for linear system response.

iv. Lead shield is installed

Table 2. Summary of templates available and detector setup for neutron shots.

		DET1 (10x1)		DET2 (5x0.25)		DET3 (5x0.25)	
Yield range	**Template name**	**MZ1**	**MZ2**	**MZ3**	**MZ4**	**MZ5**	**MZ6**
0.5-5e13	New rules 5e12-5e13	stnd	SNR opt	SNR opt	SNR opt	SNR opt	SNR opt
0.2-2e14	New rules 2e13-2e14	stnd	stnd	SNR opt	SNR opt	stnd	SNR opt
0.05-1e15	New rules 5e13-1e15	stnd	stnd	SNR opt	SNR opt	stnd	stnd
0.2-2e15	New rules 2e14-2e15	OFF	OFF	SNR opt	SNR opt	stnd	stnd
0.5-6e15	New rules 5e14-6e15	OFF	OFF	stnd	SNR opt	stnd	stnd
0.1-1e16	New rules 1e15-1e16	OFF	OFF	stnd	stnd	OFF	OFF

SNR opt: SNR optimized setup (see i. above)
Stnd: standard MZ setup – allows wrapping of signals
OFF: detector is not used – upper bound voltage is potentially damaging to MZ unit