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Operational Experience with Optical Streak Cameras used on the National Ignition Facility

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Disclaimer

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Lawrence Livermore National Laboratory • National Ignition Facility & Photon Science

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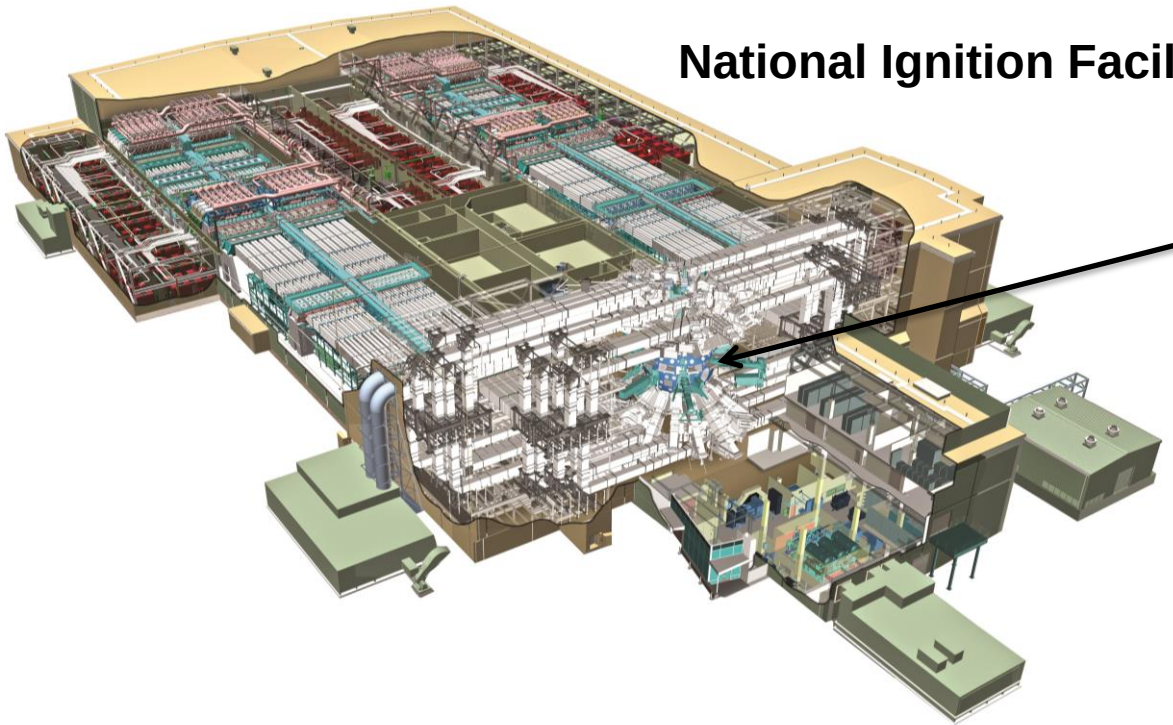
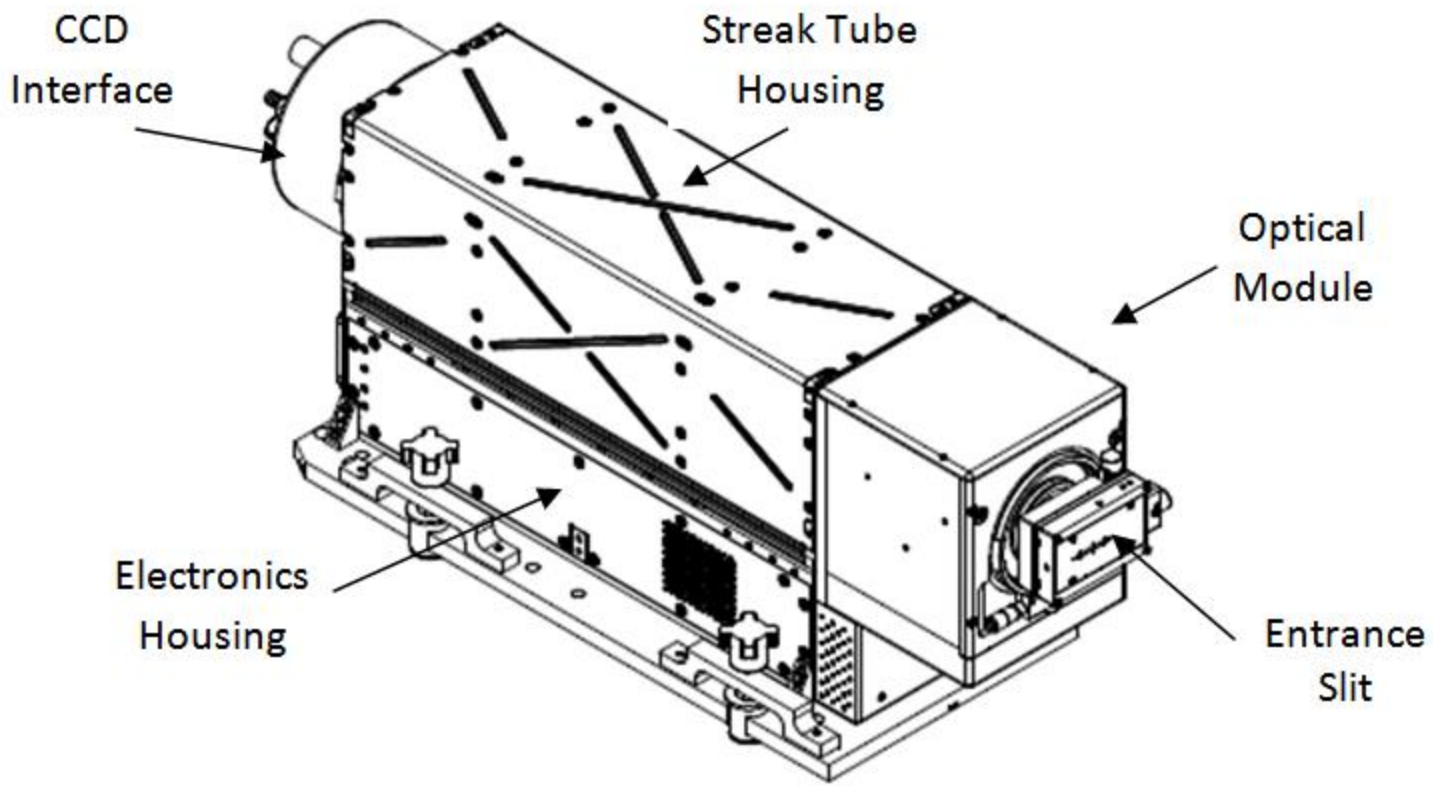
National Ignition Facility (NIF)

- **The National Ignition Facility (NIF) is a 192 beam laser facility designed to support the Inertial Confinement Fusion (ICF) program.**
- **The facility was designed to have the capability of producing a deuterium-tritium (D-T) target shot in excess of 20 MJ of energy or 7.1E18 neutrons at 14 MeV.**
- **Optical streak camera systems reside on all levels of the facility and are typically located 5.5 meters from target chamber center.**



Optical streak camera system used on NIF



NIF uses a single optical streak camera style for all of NIF, the sweep speeds are what is managed differently from diagnostic to diagnostic.

Optical streak camera specifications

Optical Streak Camera Specifications (Typical)		
Wavelength Band	350nm – 1053nm	Covered with two tubes
Time Windows	2 ns – 90 ns	Choice of 4 windows per streak camera
Spatial Aperture	20 mm	
Streak Tube	P510-P43	Photonis with P43 Phosphor
CCD	4096 x 4096	Spectral Instruments
Pixel Size	9 μm	Before binning
Number of Bits	16 Bits	
Binning	3x3	27 μm after binning
Slit Spacing	500 μm	

Streak camera specifications are typical values and the results may vary once the calibration files have been applied.

Optical streak cameras require calibrations

- Optical streak cameras are not inherently linear and require calibration.
- Calibrations increase the measurement accuracy to the 2% level.
- Calibrations are used to generate a warp (2D) correction file that is applied to each sweep speed.
- This warp correction file removes the nonlinear effects in both space and time.
  - For calibration techniques see:
    - "*Reliable and Repeatable Characterization of Optical Streak Cameras*", M. Charest Jr., P. Torres, C. Silbernagel, D. Kalantar, APS Topical Conference on High Temperature Plasma Diagnostics, Albuquerque, NM. May 11, 2008

Measured streak camera calibration performance values

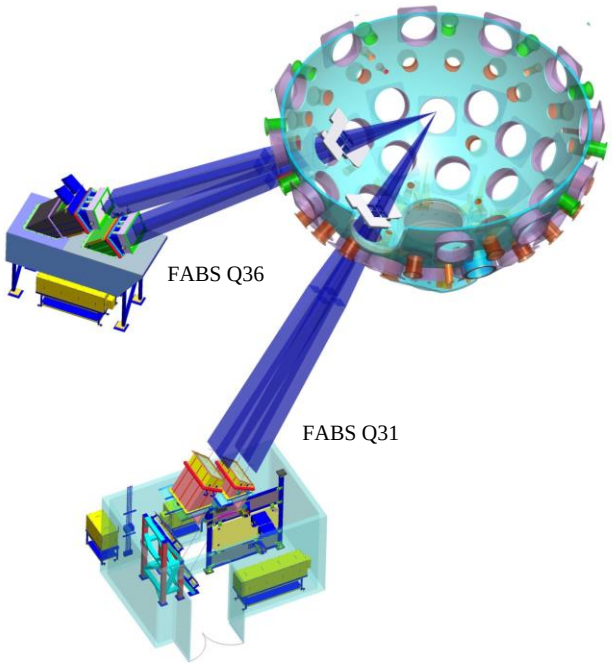
Example Calibration Report Summary: GSCP104, NOV 2012

Specifications	Sweep Speeds			
Sweep Speeds	**3**	**6**	**16**	**40**
Dynamic Range (Temporal)	230:1	41:1	35:1	28:1
Dynamic Range (Spatial)	193:1	139:1	N/S	N/S
Dynamic Spatial Resolution				
Line Spread Function (50% CTF)	3.8	4.0	4.1	4.3
lp/mm (50% CTF)	3.5	3.5	3.4	3.3
Dynamic Temporal Resolution (ps)	19.1	28.46	54.73	159.29

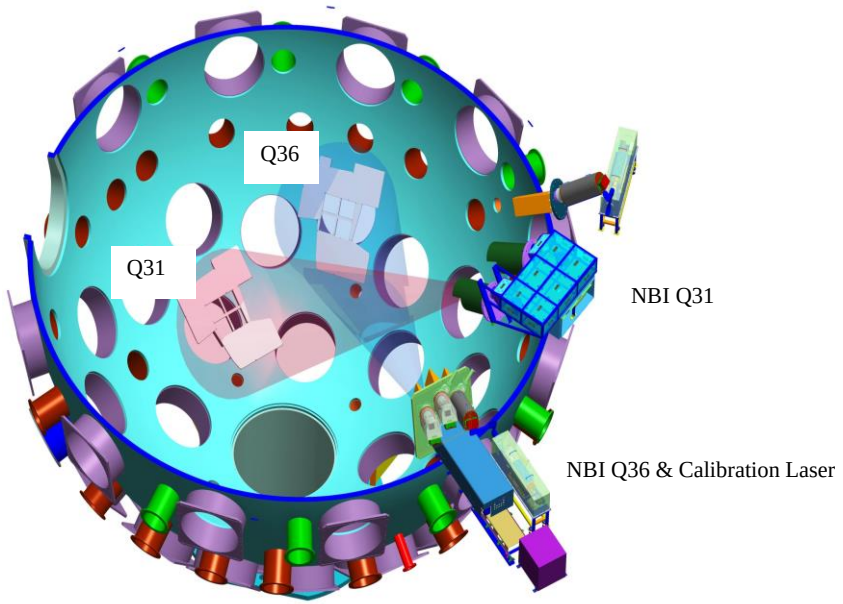
All streak cameras go through an extensive calibration to generate a Dynamic Warp Correction for each sweep speed. The listed values are typical for these sweep speeds. The warp correction removes the nonlinear effects in two dimensions, time and space.

Backscatter implementation of optical streak cameras

Full Aperture Backscatter (FABS)



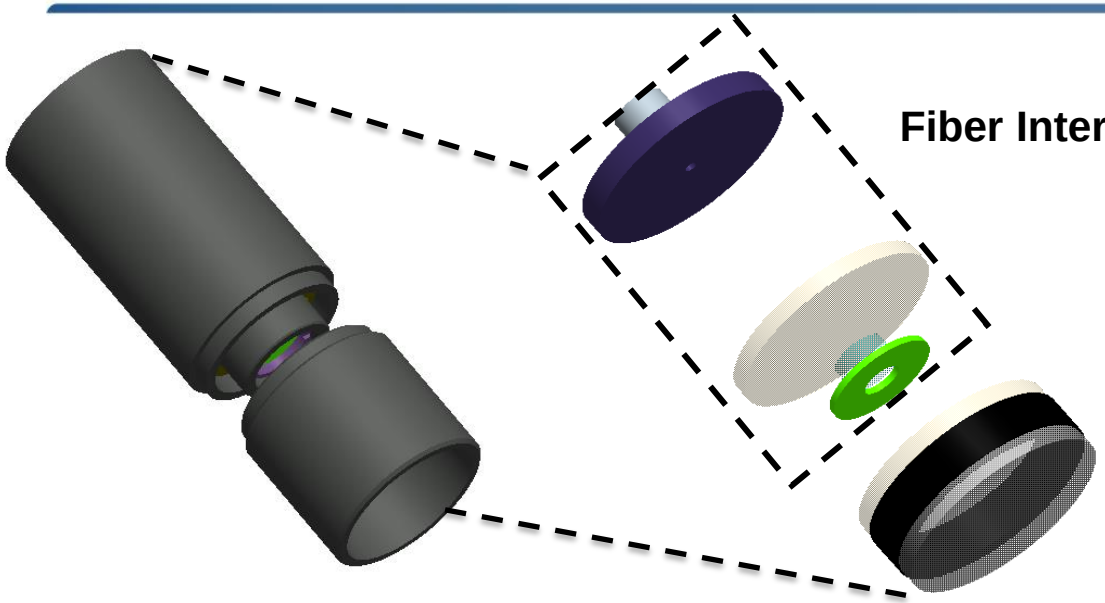
Near Backscatter Imager (NBI)



- **Backscatter measurements on the National Ignition Facility (NIF) are an important part of understanding laser-target coupling**

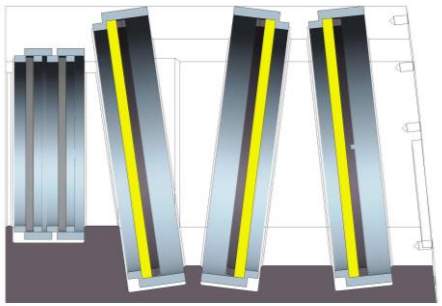
FABS and NBI requires optical streak cameras for the time resolved spectral measurements associated with Stimulated Raman and Stimulated Brilloun scatting. NBI requires the cameras for time resolved Stimulated Raman Scattering measurements off the scatter plate located on the wall of the target chamber.

All backscatter measurements require band-pass filters to select wavelength band a the fiber input



Filter Callout

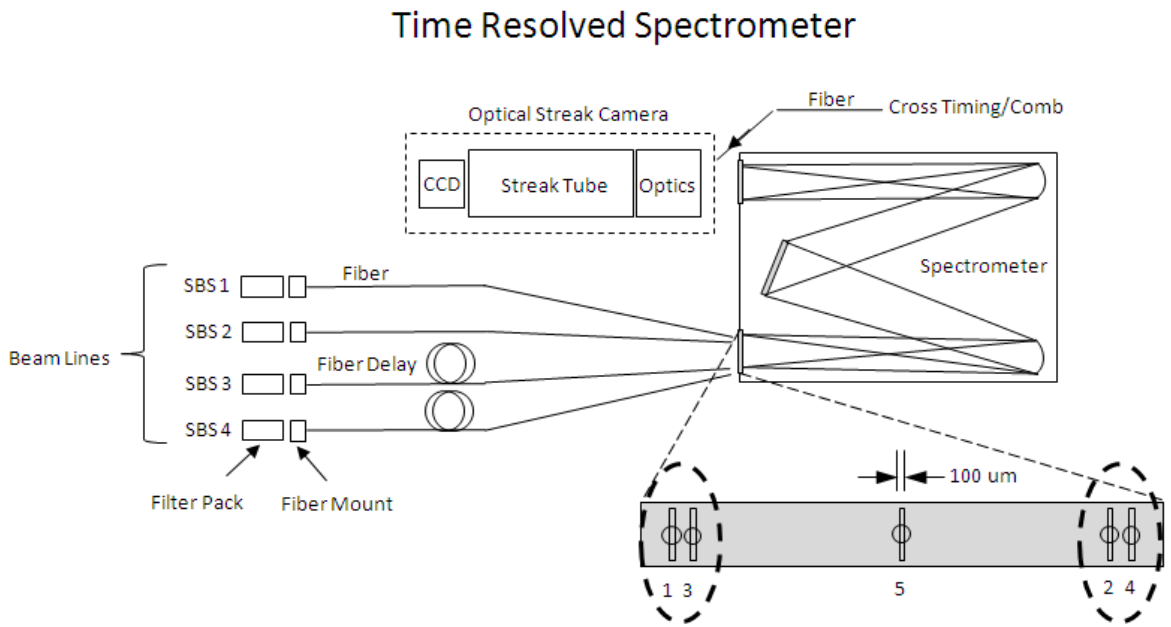
- **Instrument Flatting Filter**
- **Band-pass Filter, selects (SBS or SRS)**
- **ND Filter**



All filters have a tilt to prevent backscatter from effects from front surfaces

All fiber based measurements contain a band-pass filter and an unique instrument response flattening filter.

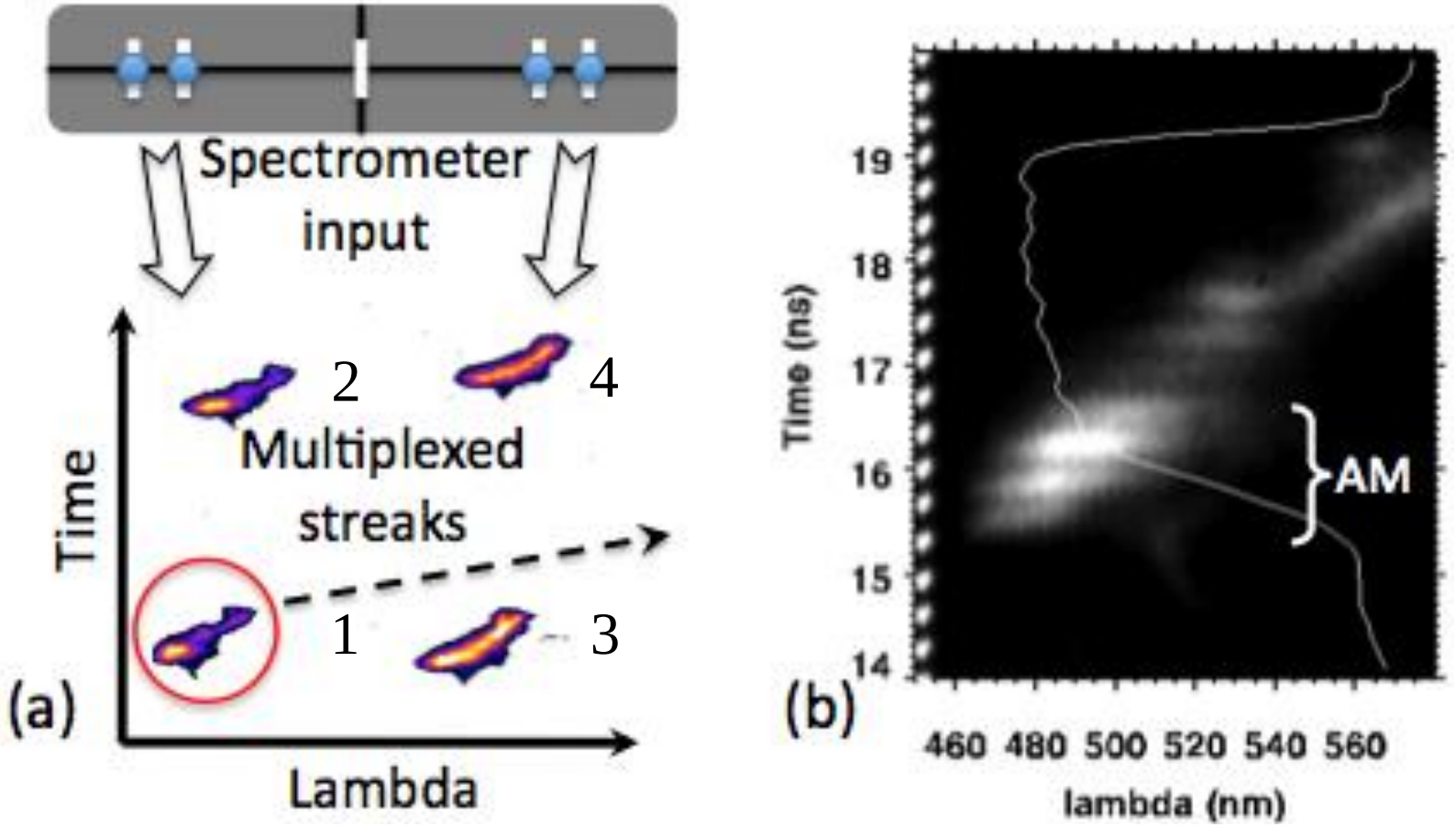
FABS backscatter time resolved configuration



- **Time resolved 1 meter spectrometer fiber delayed multiplexed configuration.**
- **System includes spectrometer, optical streak camera, fiber injection with delay offsets and filter pack.**
- **Sweep window is set to 40 ns, which is optimized for the fiber delay.**

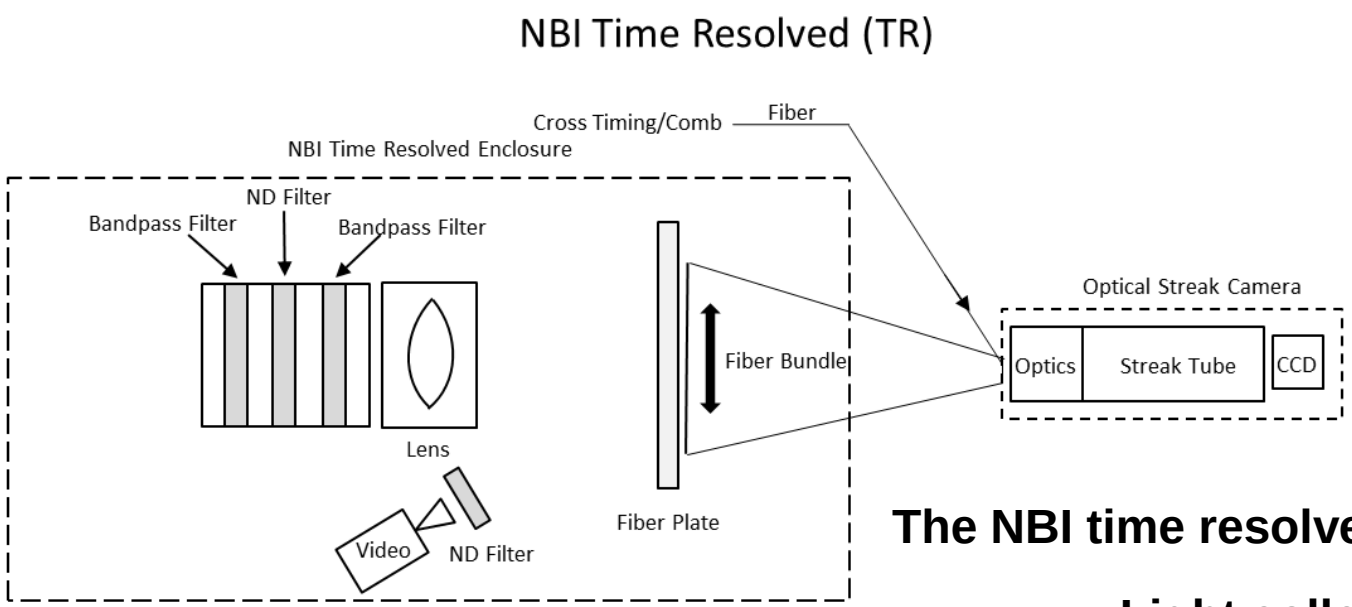
Time resolved spectral measurements are accomplished by a multiplexed fiber arrangement and a sweep window optimized for full coverage of sequential two input measurements on the same window. A 40ns window has ~160ps/pixel resolution.

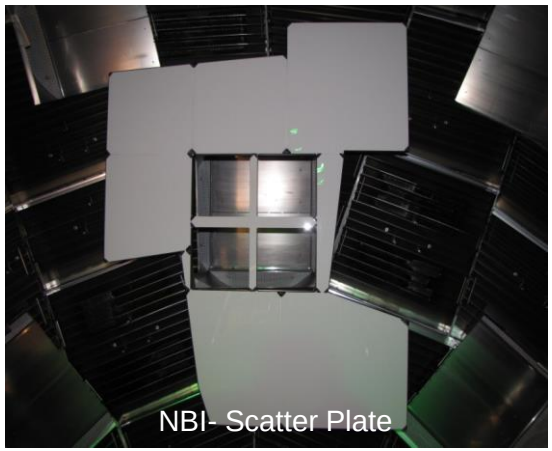
Time resolved spectral measurement results



The Stimulated Raman Scattering output from FABS. Four beams on a quad are measured via a fiber on one sweep record. Spectral calibration and fiber dispersion correcting are required for final analysis.

Time resolved NBI implementation





Projects complete image of scatter plate onto fiber plate

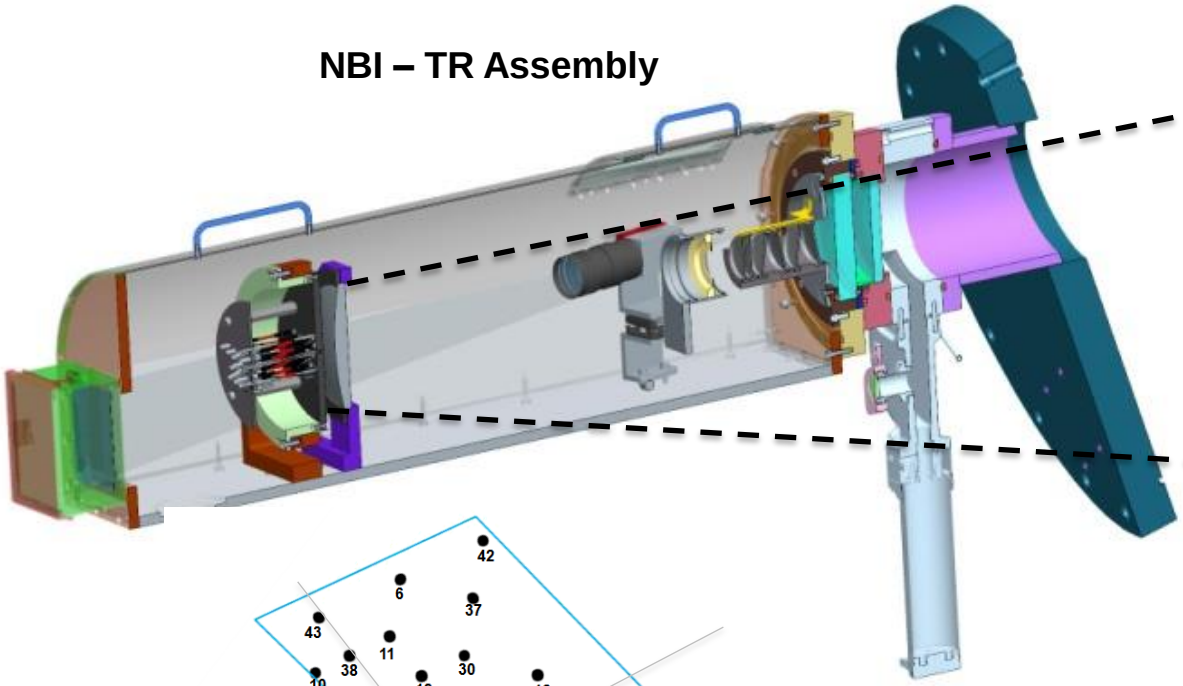
The NBI time resolved system

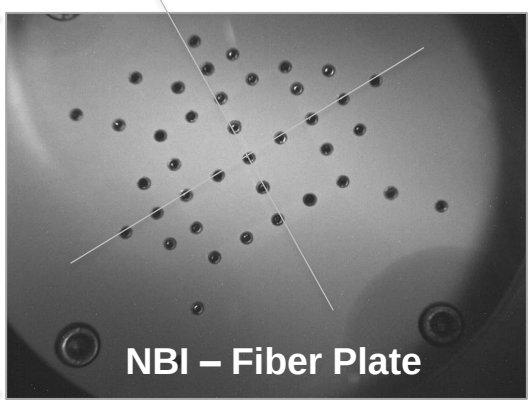
- **Light collection lens**
- **Filter pack**
- **Fiber plate**
- **Optical streak camera**
- **CCD camera**
- **Scatter plate**

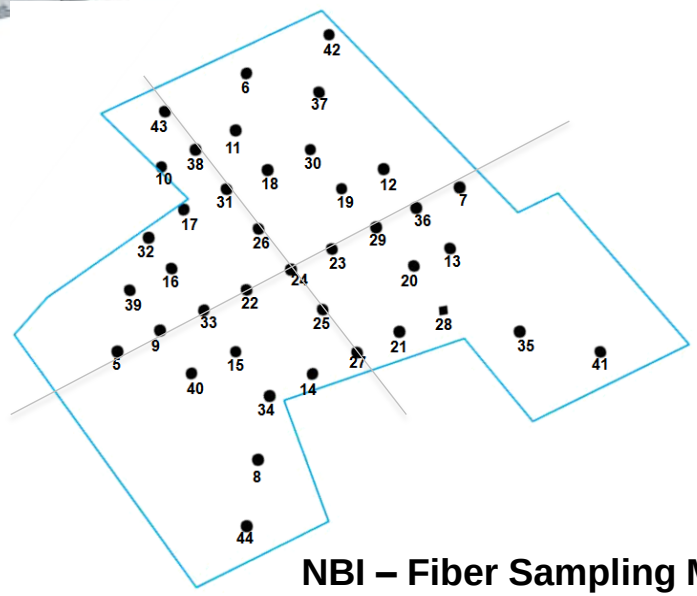
Time resolved backscatter imager spatially samples the NBI scatter plate and measures the time evolution of the backscatter light for the SRS band.

Time resolved backscatter imager fiber map

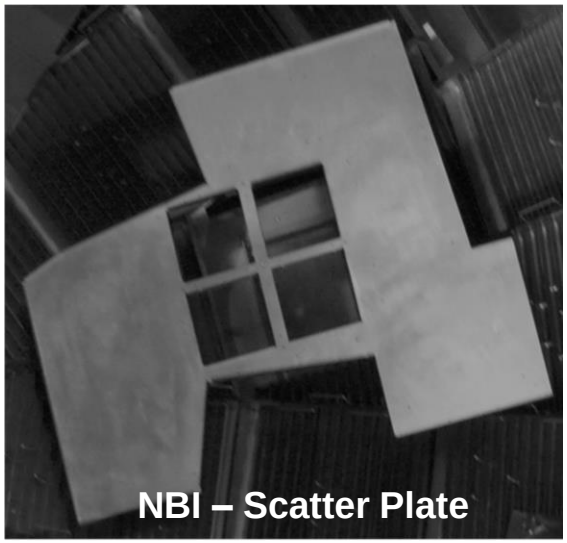
NBI – TR Assembly





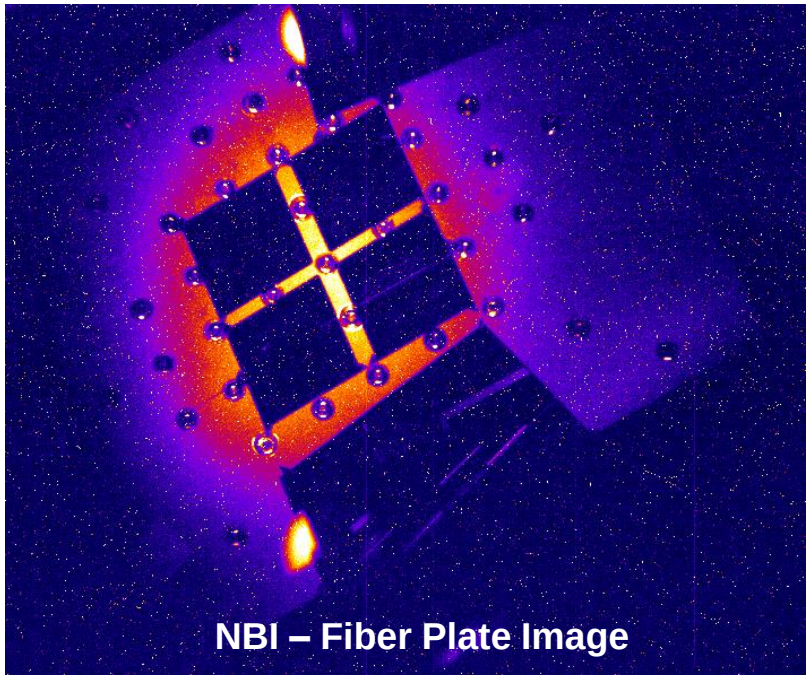


NBI – Fiber Sampling Map

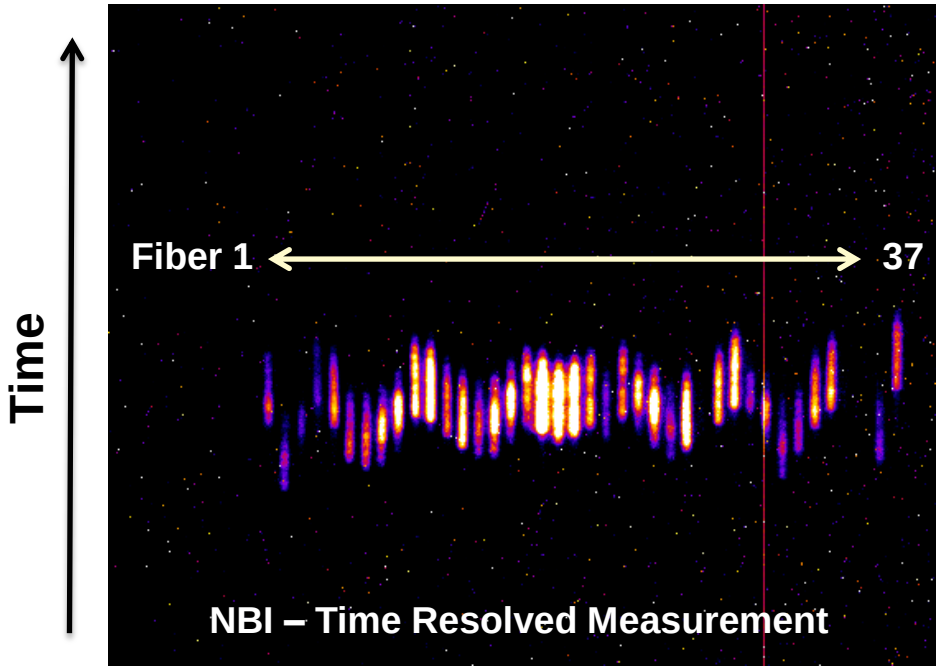


Imager fiber collects backscatter light in a unique 2D spatial pattern and is interface to the streak camera in a linear array across the spatial orientation of the slit.

2D fiber measurement translated to 1D spatial measurement



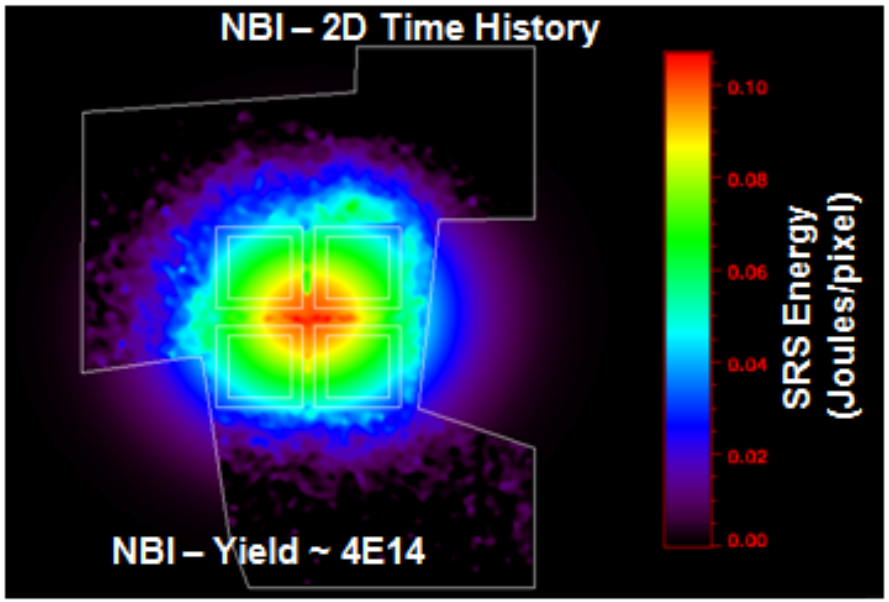
2D spatial image of the NBI scatter plate on the diagnostic fiber plate



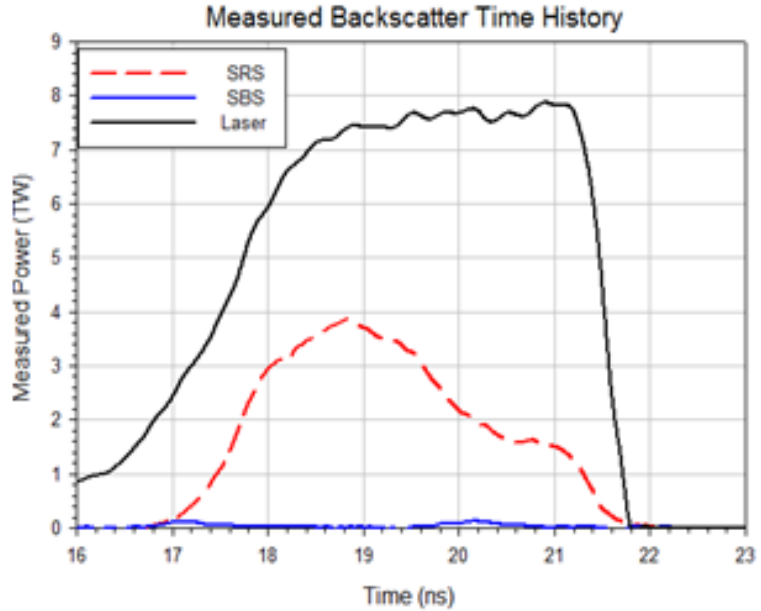
1D spatial fiber recording of the fiber output on the streak camera

Imager fiber collects backscatter light in a unique 2D spatial pattern and is interface to the streak camera in a 1D linear array across the spatial orientation of the slit.

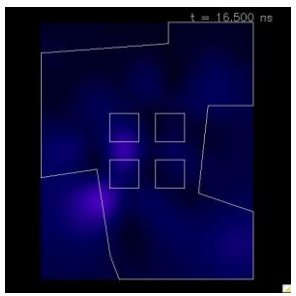
Time resolved SRS backscatter measurement



2D reconstruction of the fiber measurement on the streak camera



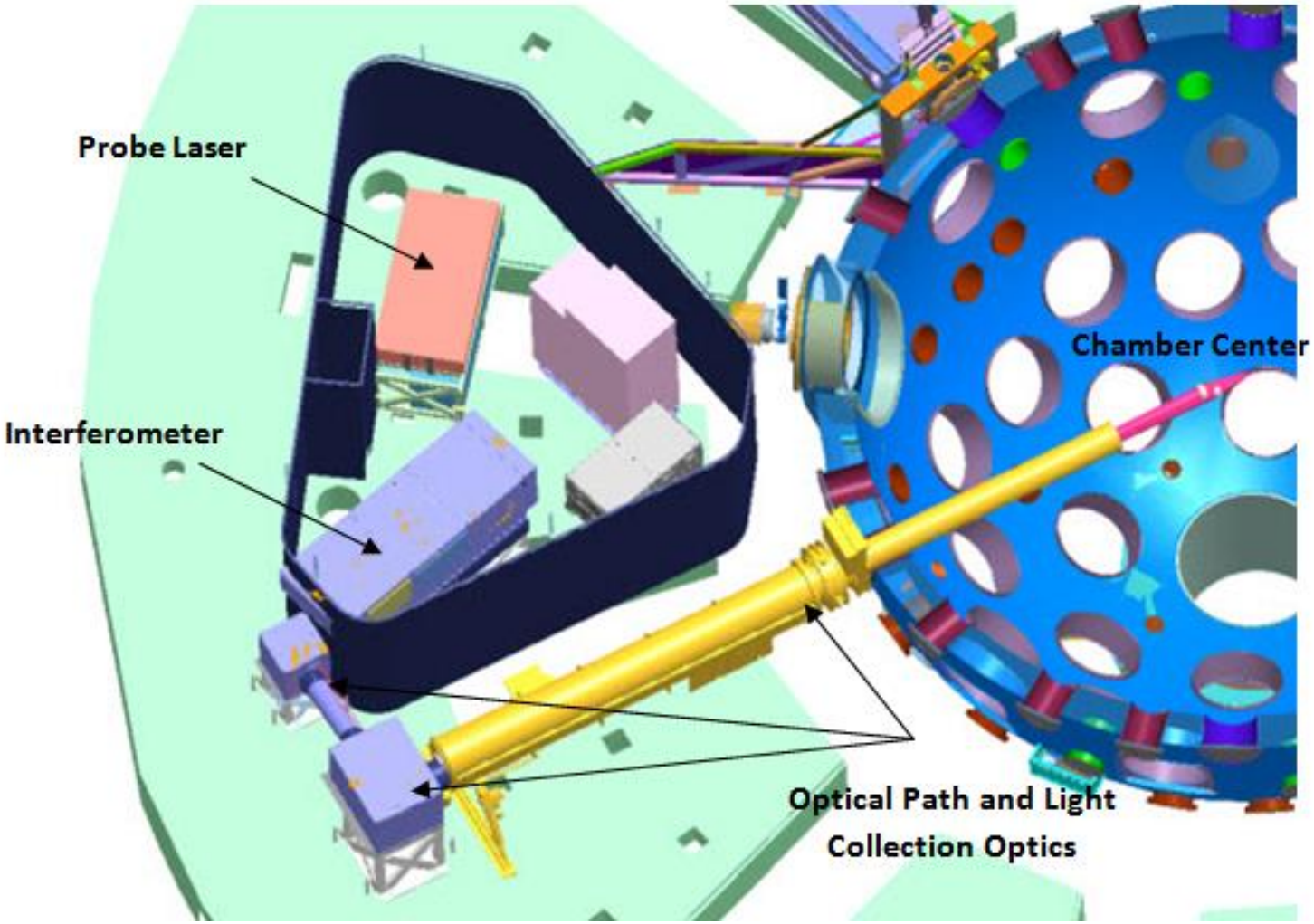
Temporal reconstruction of the backscatter measurement



Play Movie:

The time resolved measurement requires the spatial interpolation of the 2D sampled data and is displayed as a function of time.

Velocity Interferometer for Any Reflector (VISAR)



VISAR is an imaging type "line" VISAR mounted at the equator in the target bay. Collection optics and relay telescope are mounted on a positioner that extends in the target chamber.

VISAR description

•The Velocity Interferometer for Any Reflector (VISAR) functions as a shock timing measurement system that operates with thee optical streak cameras.

•The VISAR measures the Doppler shift of a reflected optical probe beam. The light is reflected from a surface of the target and the surface velocity is inferred from the Doppler shift and knowledge of the target.

•This type of diagnostic is typically used for the measurements of shock breakout events, velocities of ionizing shocks in transparent media, wave profiles at interfaces and free surfaces to name a few.

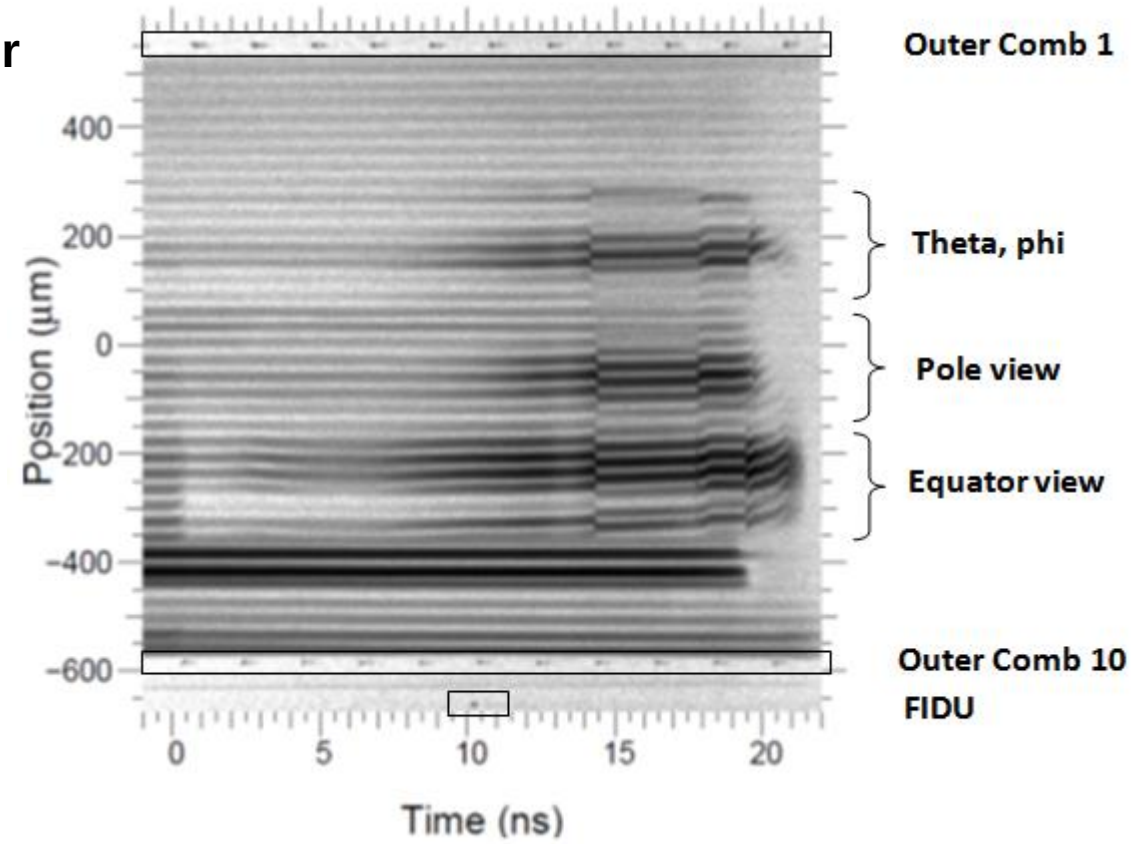
•The system includes a (660 nm) probe laser, light collection beam path that extends to target chamber center, an interferometer table, support electronics and camera alignment systems

Example VISAR data, double mirror shot (N130109)

Example streak from a double mirror shot (N130109).

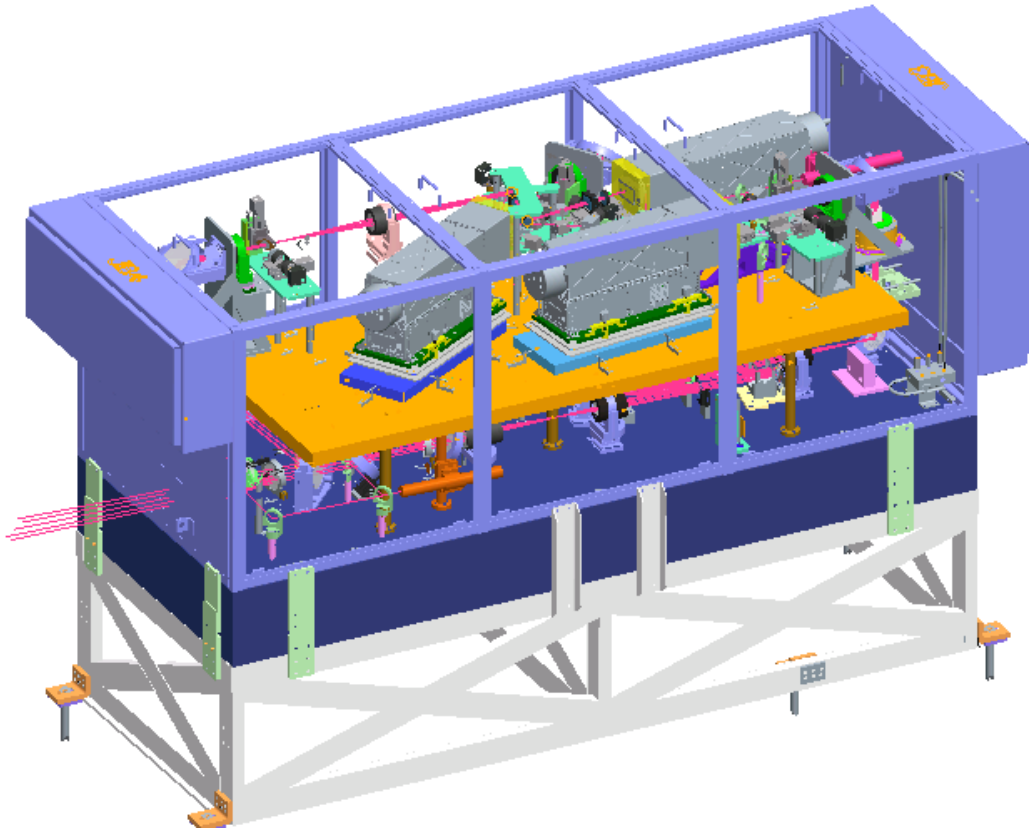
- **logarithmic gray scale over the range 50 and 10000 counts.**
- **3 groups of data**
- **Equatorial view, x = -200,**
- **Polar view, x = –50**
- **Theta, phi=45,135 view, x = +175**

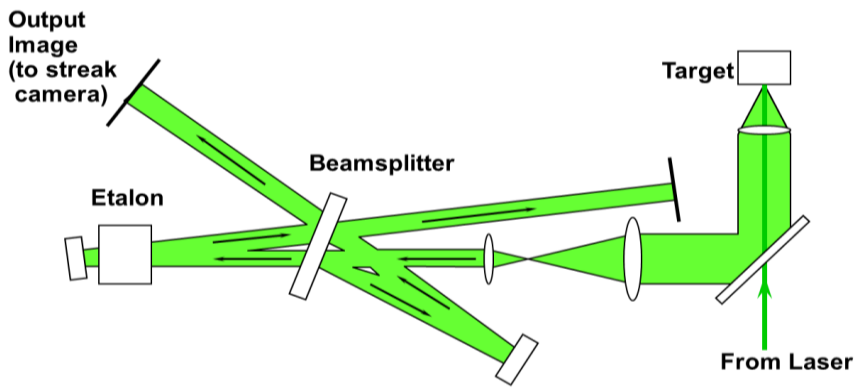
(mirrors are part of the target assembly)



The VISAR example data was collected on a double mirror shot (N130109). The data has been warp corrected and includes the outer combs and fiducial pulse.

VISAR interferometer table assembly





Mach-Zehnder interferometer arrangement

Interferometer table configuration with two interferometers and one streaked optical pyrometer (SOP) . Each interferometer uses one streak camera with different time windows.

The VISAR interferometer table contains three optical streak cameras, two are associated with an interferometer and the third serves as the streak optical pyrometer (SOP) measurement and provides spatial temperature information of the target.

VISAR requires higher accuracy than the standard calibration files can provide

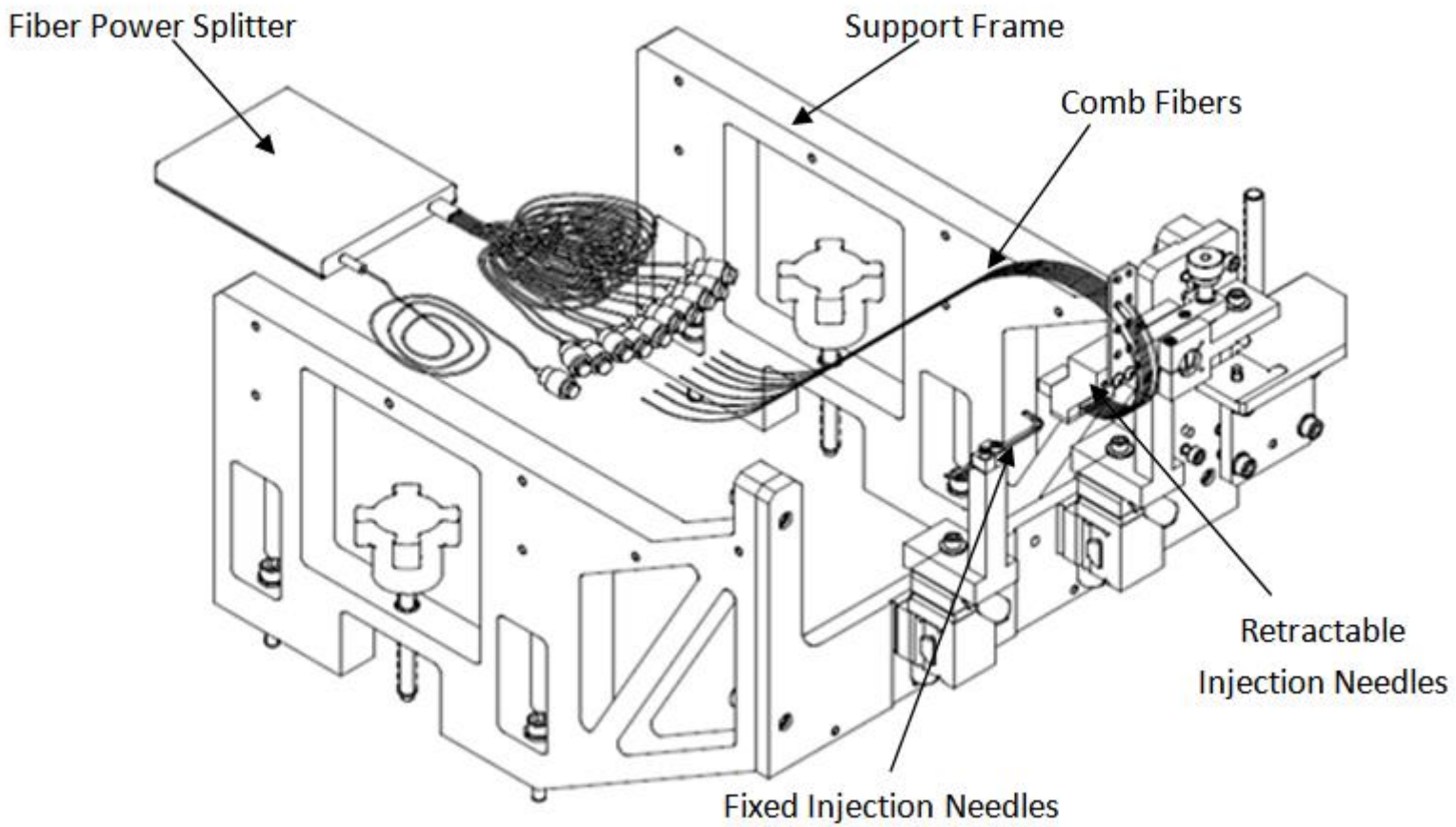
- Additional calibration is required for key VISAR measurements
  - Additional calibrations account for long term drift
  - Sweep window jitter
  - Temperature variations associated with the electronics that vary from shot to shot

Dynamic multi comb calibration increases measurement accuracy

- In situ calibration is accomplished with a multi optical comb injection system mounted on the outside of the streak camera.

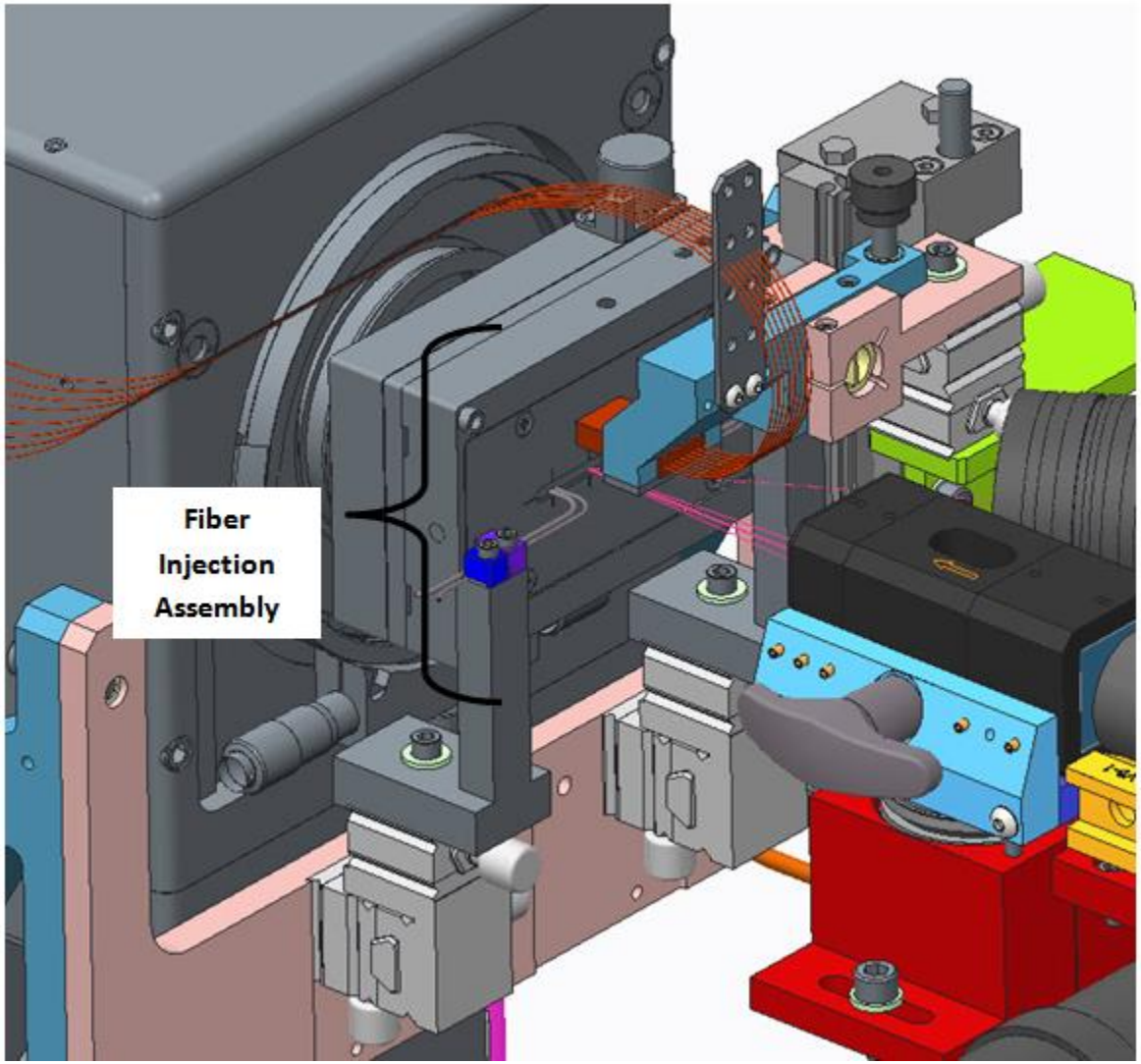
The multi optical comb injection system provides a way to dynamically calibrate the streak camera moments before a shot. Post shot signal processing uses new dynamic calibration data.

Multi optical comb mechanical assembly externally attached to streak camera



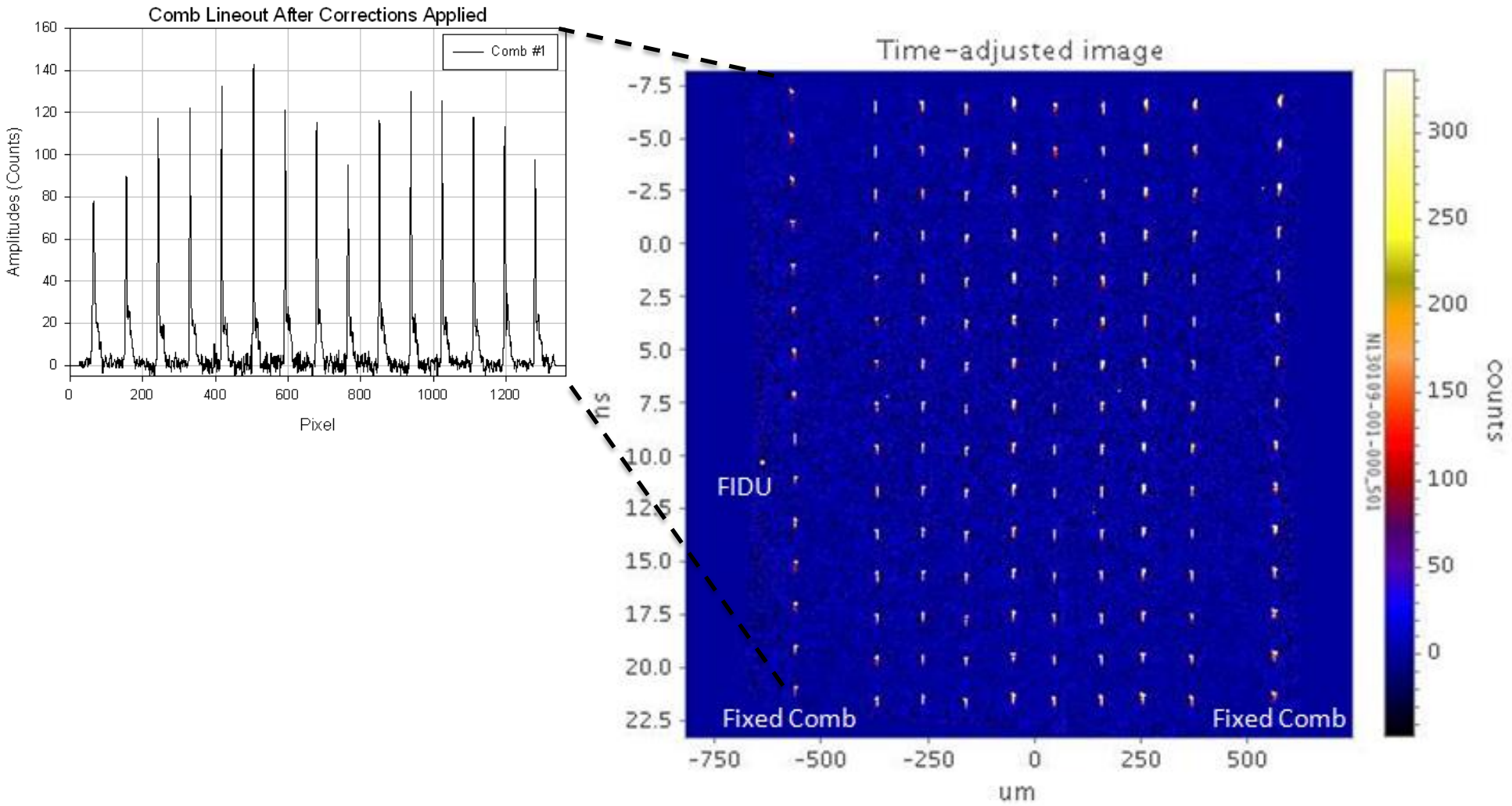
The multi optical comb mechanical assembly is externally attached to the streak camera and allows fiber light to be injected through the slit minutes before a shot.

Multi optical comb implementation



The multi comb hardware implementation where the two outer optical combs are fixed and the 8 multi comb group can be cycled in and out of the beam path.

Multi comb data after initial corrections applied



The multi comb data based on a known frequency is used to generate a second warp correction that increases the measurement accuracy down to (0.5% - 1%).

Summary

- **Optical streak cameras are complex instruments and play an important role on several NIF diagnostics systems requiring sophisticated measurement techniques.**
- **Camera warp correction calibrations are required in order to get reproducible accuracies of 2%.**
- **Fiber based recording systems allow for multi channel acquisition of complex data sets that can reduce the channel cost of the program.**
- **External comb injection capability can extend the camera accuracy for critical measurements . (0.5%-1%)**


NIF