Development of a 2-D Ion Velocity Diagnostic on NSTX using the SWIFT Camera

S. F. Paul, R.E. Bell, Robert Kaita, A. Lane Roquemore
Princeton Plasma Physics Laboratory, Princeton University

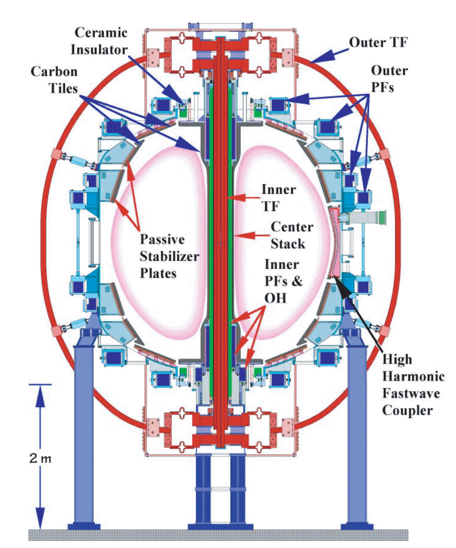
Nobuhiro Nishino
Hiroshima University, Hiroshima, Japan

Abstract

Using a beam-splitter and interference filter diagnostic, the development of a 2-D ion flow measurement of toroidal ion flows is being developed on NSTX. A high frame-rate, 12-bit Photron-USA Ltd. monochrome digital camera is used to view He II line emission at 468.6 nm on the inboard side of the plasma in NSTX. The image is split and imaged onto two distinct 64 x 64 pixel sections of the camera's 1024 x 1024 pixel detector. A mirror and the beam-splitter are adjusted so that each of the two sections view the same 30 cm x 30 cm region in the plasma. Each section is made to view through separate interference filters located in the near field. The filters are custom designed and have opposite but linear sloping passbands. In this way the Doppler shift causes the ratio of the light incident on each section of the detector to vary with toroidal velocity. A calibration of the relative gain and linearity of the detector and a wavelength calibration the shape of the passband of the filter, the ion velocity is calculated from the ratio of the intensities from the two images. The light level in helium discharges in NSTX is found to be adequate to make measurements from 250 to 2000 fps. Because the camera was found to be sensitive to magnetic fields, the discharges were taken at a 3 kG field strength, quite low for NSTX. Nevertheless, these helium discharges lasted up to 0.5 sec and 4 MW of neutral beam heating was injected. Adequate light was obtained for time resolution as short as 0.5 ms and about 500 images were recorded per discharge.

Examining radially localized, poloidal ExB flows

- Self-generated, $k_\theta \approx 0$ poloidal flows thought to play an important role in suppressing turbulence
- Expected poloidal flows: $v_\theta \approx v_{ExB} \leq 0.01 \times v_{thi}$
- For edge parameters, $v_{thi} \approx 3\times10^7$ cm/sec, need to measure small fraction of $v_{ExB} \approx 3\times10^5$ cm/sec
- Fluctuation autocorrelation frequency for flows of interest is $\Delta\omega^{ZF} \approx 5$ kHz, considerably faster than CXRS diagnostic data acquisition rate
- Radial localization of modes is $k_r\rho_i \approx 0.1$, so radial resolution must be finer than 40-60ρ_i or 1-2 cm

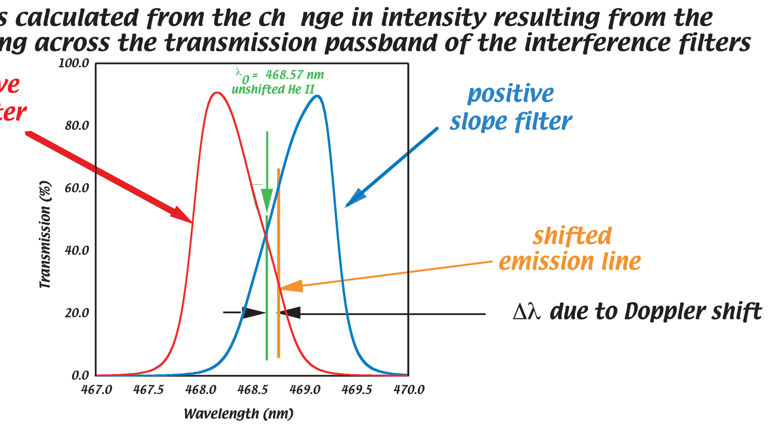


Good diagnostic access to NSTX, a spherical tokamak

- Open divertor configuration
- Allows viewing from midplane and between plate structures
- This diagnostic has a mid-plane horizontal view of the center stack with a 20 cm field of view.

Principle of Measurement with Crossed Filter Method

The Doppler shift is calculated from the ch nge in intensity resulting from the emission line moving across the transmission passband of the interference filters



- One detector views through a filter with a positive slope, the other has a negative slope. The Doppler shift is a function of the only the measured signal ratio. Parameters include the two filter slopes and the relative gain.
- The relative calibration of the channels to each other means that terms which are constants (the fiber, window and lens transmission, detector sensitivity, amplifier gain, and phaseshift etc.) do not need to be known absolutely
- Data analysis assumes that slope of filter in the region of the Doppler shift is perfectly linear
- There are no impurity or working gas emission lines that are comparable in intensity to the He II, as long as helium concentration is greater than a few percent

Derivation of Doppler Shift in Rev. Sci. Instrum. paper from previous HTDP conference

Measuring ρ and knowing the unshifted wavelength, $\langle\lambda\rangle$, the Doppler shift, $\Delta\lambda$, can be calculated from the filtered intensity.

$$\Delta\lambda - \langle\lambda\rangle = \frac{\rho\left(\frac{b_-}{a_-}\right) - R_G\left(\frac{b_+}{a_+}\right)\left(\frac{a_+}{a_-}\right)}{R_G\left(\frac{a_+}{a_-}\right) - \rho}$$

where:

- $R_G = G_+/G_-$ is the relative gain between the two channels with both filters
- a_+, a_-, b_+, b_- are filter characteristics and of the respective positively and negatively sloped filters
- the ratio of the two signals is $\rho = I_+^{fil}/I_-^{fil}$
- $\langle\lambda\rangle$ is a constant, i.e., the unshifted "center of mass" of the line

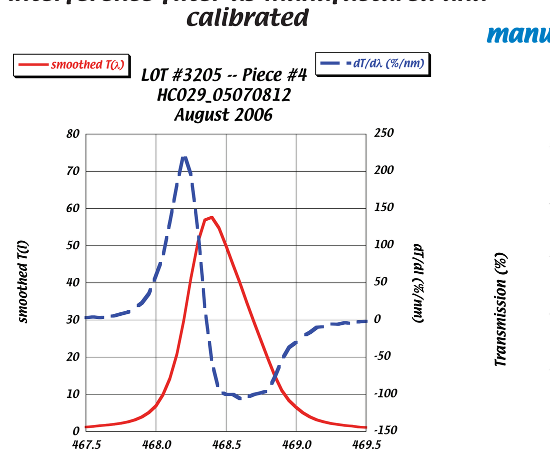
$\langle\lambda\rangle$ is provided by:

- Knowing at some point in time that the plasma ions are stationary or
- Calibrating by transferring the detector system to a view perpendicular to the ion flow so that no Doppler shift is present.

Real-time determination of velocity because only the signal ratio need be known

Calibration of Filter Characteristics:

Transmission passband of the negative slope interference filter as manufactured and calibrated

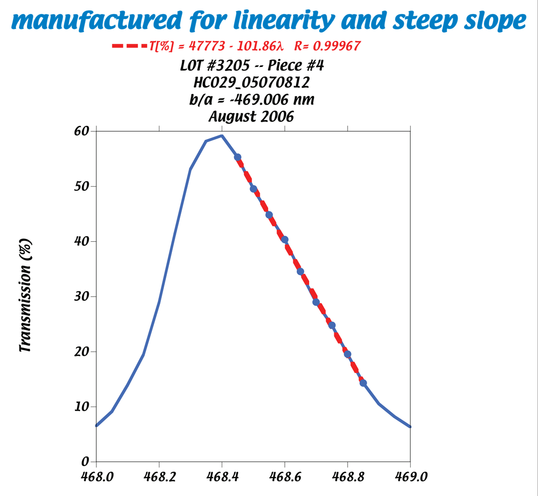


Required filter characteristics. Filter should have:

- Linear slope centered at 468.6 nm and extending for 0.3-0.4 nm to cover the Doppler broadening of the line
- Steep transmission function for good sensitivity
- 0.5 nm passband or narrower to reject CIII light

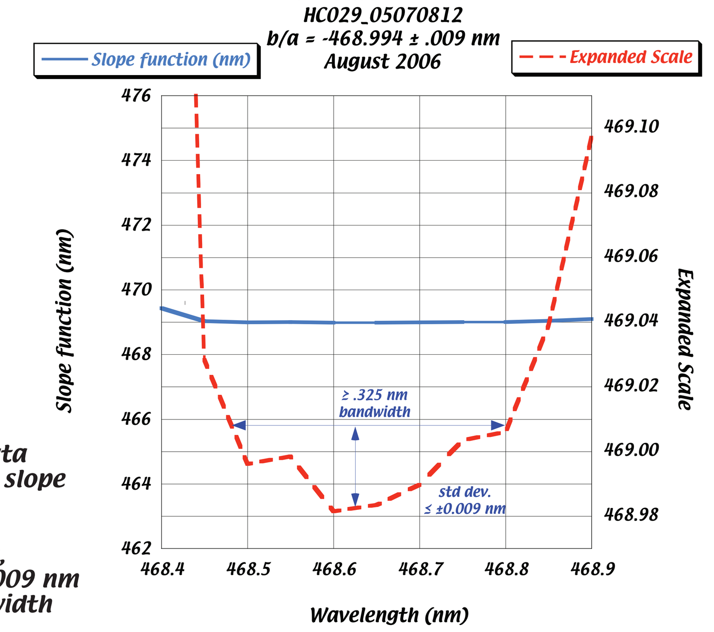
Measurement of achieved linearity and slope of filter

manufactured for linearity and steep slope



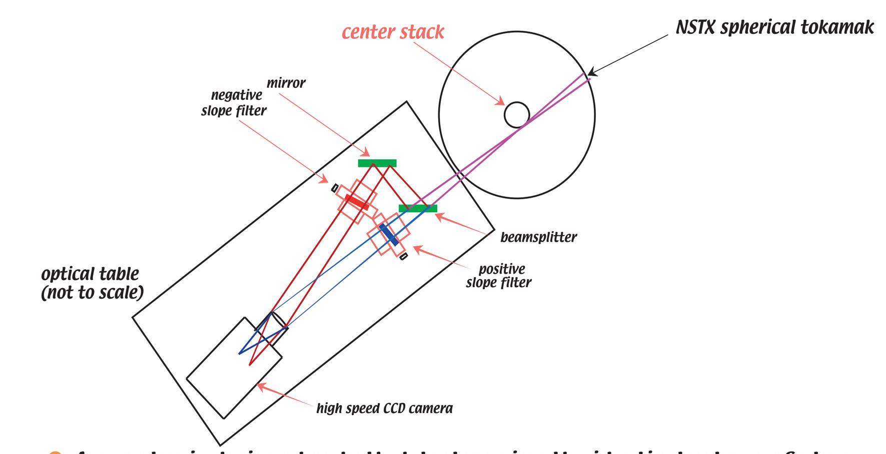
- Deviation from linearity is less than .03% over 0.4 nm (R > .9997)

How good is the linearity quantitatively?

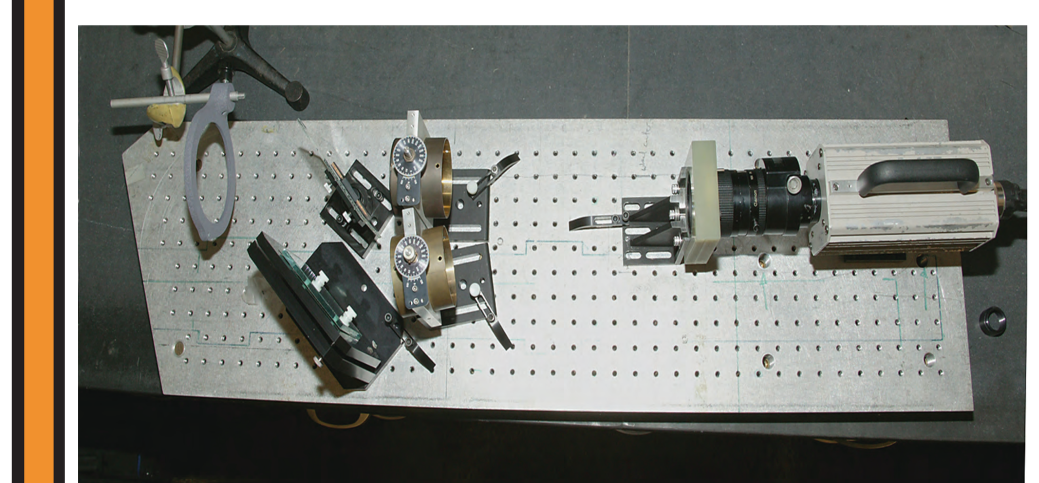


- The transmission data shows linearity in the slope over at least 0.3 nm.
- Figure of merit, b/a, varies by less than ±.009 nm over a .325 nm bandwidth

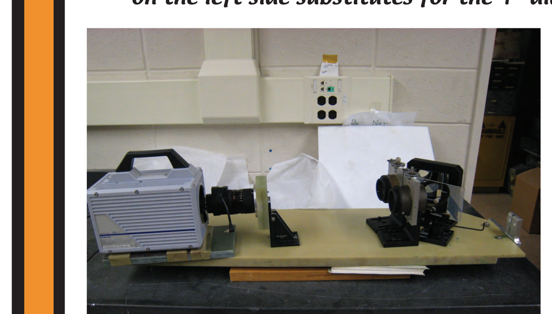
Experimental Setup on NSTX



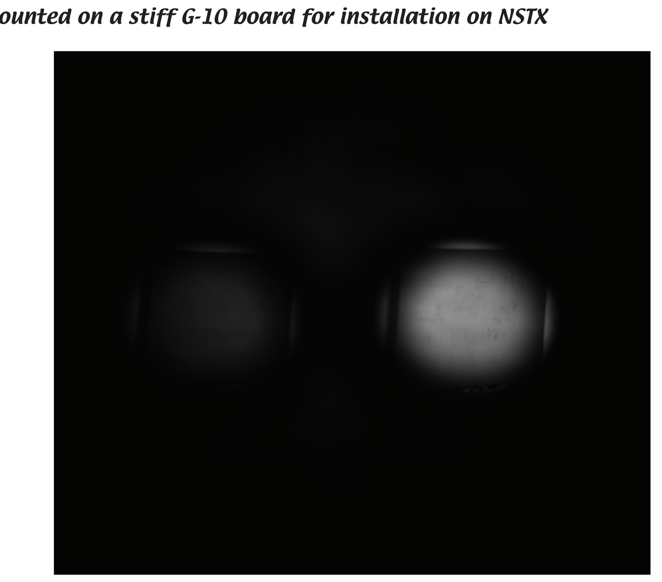
- Apparatus is designed so both detectors view the identical volume of plasma
- Filters are tilt-adjusted to isolate the region of flattest slope of transmission band
- Effect of changing plasma intensity is removed
- Filters are temperature stabilized with a controller that maintains T within 0.1°C



- Prototype apparatus as designed and tested on an optical bench. The grey ring on the left side substitutes for the 4" diameter vacuum window on NSTX



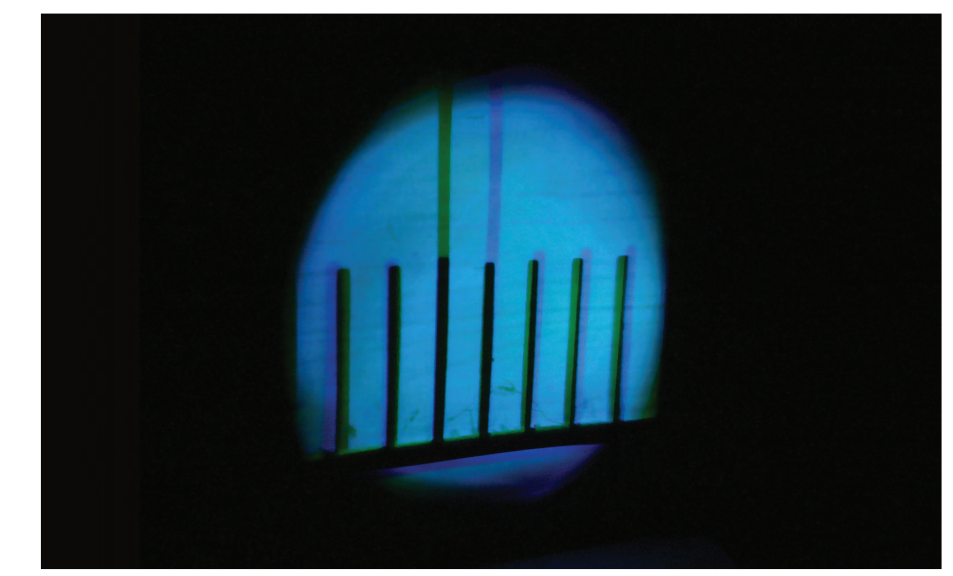
- As mounted on a stiff G-10 board for installation on NSTX



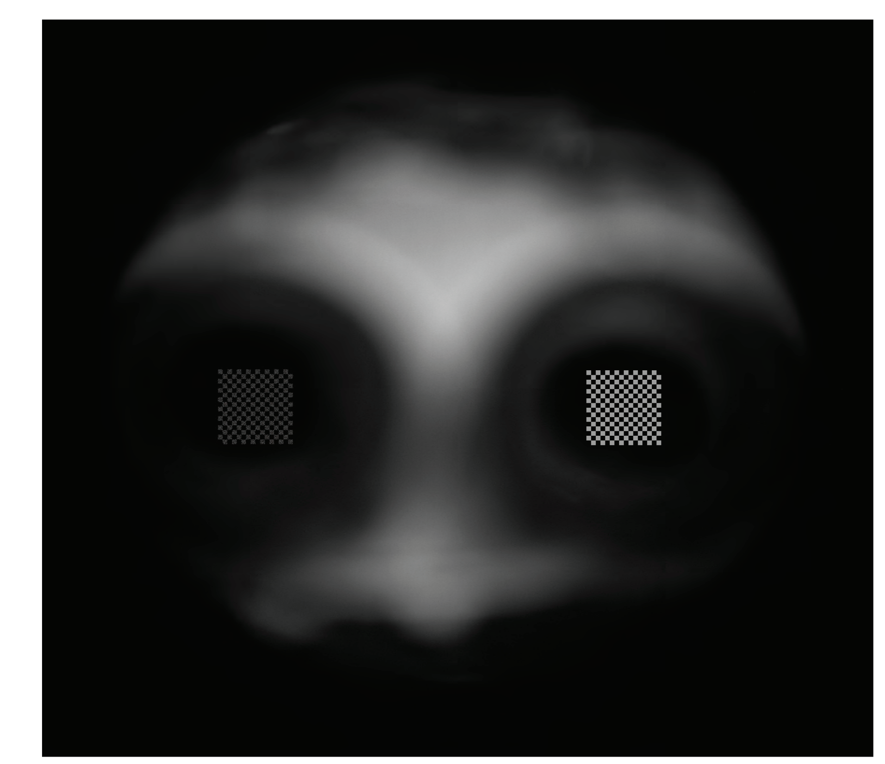
- White place calibration with out filters to obtain a relataive calibration of the optical system and the camera.
- The beamsplitter is a 127mm X 90 mm, 40R/60T, plate-type beam splitter, but the relative intensity was observed to be far from a 60/40 ratio.

Backlighting fibers show the uniformity achieved

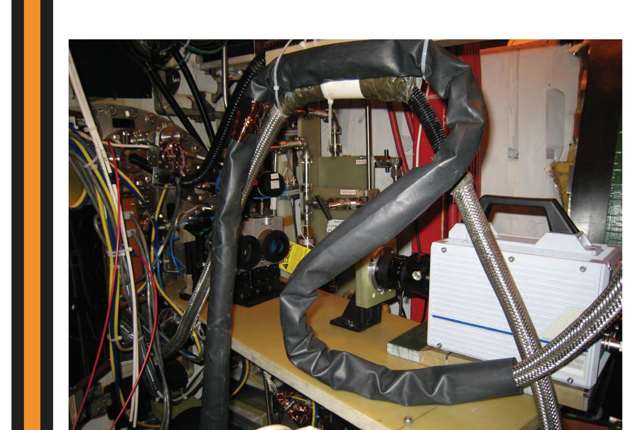
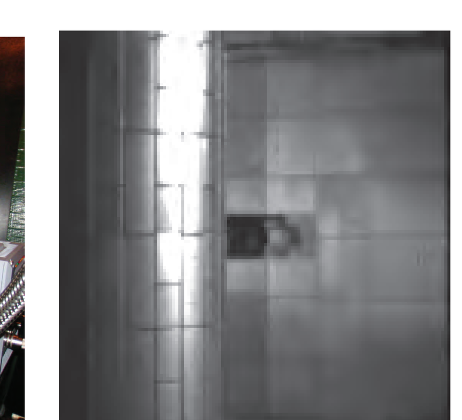
- One branch is backlit with a green LED, the other with as blue LED
- Color is uniform as seen by eye



- When combined, the cyan image appears
- The uniformity of the color shows that the branches view the plasma similarly
- Note the slight variation in the magnification. The "green side" is about 4% larger because of the longer object distance due to the mirror and beamsplitter. The correction is so small, it would require a lens with a focal length of over 11 meters.

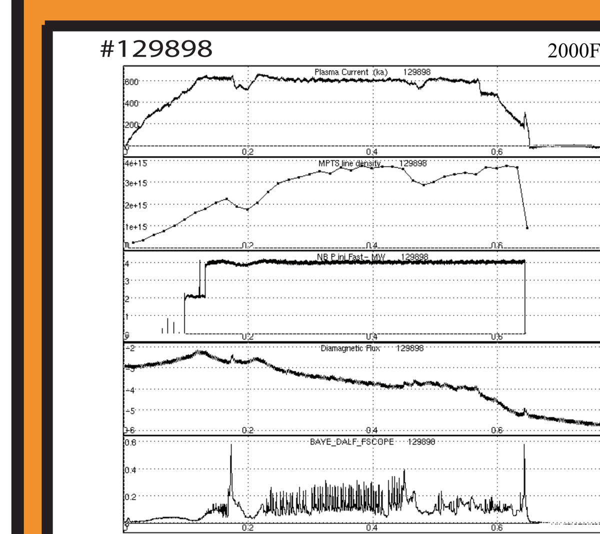


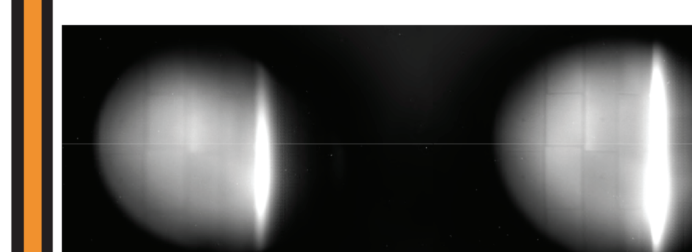
- Though slightly out of focus, the spatial calibration on in the diagnostic lab was good to < 1 pixel.

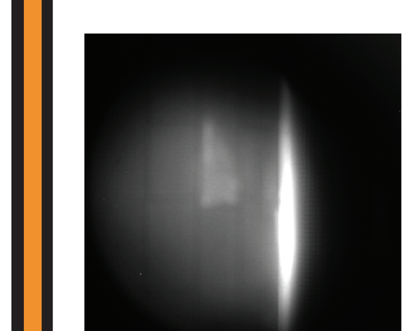
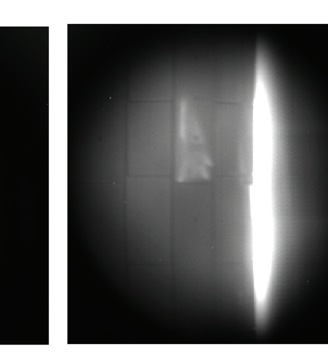
- As installed on NSTX. Red vertical on right side is the TF coil.
- Filaments lluminating NSTX center stack with Nova Photonics' Phantom camera

Preliminary data taken to observe light levels in an NSTX discharge (4 MW NBI) with helium gas puffing





- Example of frame taken at 200 fps. The right side is well in focus, but too bright. A spatial correspondence leading to a calculation of velocity could not be performed.
- The right image is in focus and each tile on the center stack can be distinguished, however, the left image is slightly out of focus, because the optical path of left image is longer than that of right image.

- The smearing of left image is about 1 pixel and the smearing on the right side is about ~3x3pixels.
- Example of frame taken at 2000 fps. The camera does not saturated. More work needs to be done with the beam splitter and focus to get quantitative data.
- The calibation will be redone using a new 14-bit, high-speed Phantom camera

Sign up for more information when the calibation is redone and the data is analyzed: