Ion velocity measurements on NSTX using the SWIFT diagnostic (Shifted Wavelength/Interference Filter Technique)

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

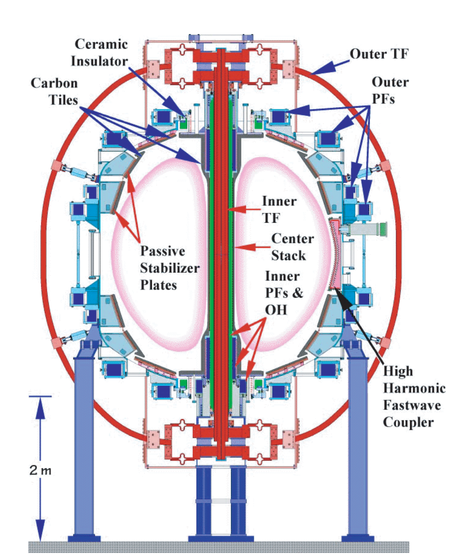
Nobuhiro Nishino
Hiroshima University, Hiroshima, Japan

Abstract

Using a split-image interference filter technique, the measurement of ion flows is being extended from individual analog channels (as implemented on Columbia's HBT-EP tokamak) to a 2-D view on NSTX. A beam-splitter duplicates the image, each of which is then filtered with separate interference filters whose passbands have opposite linear slopes. A high frame-rate Photron Ltd. Ultima SE CMOS digital camera views He II line emission at 468.6 nm at the edge of the center stack. A white-plate calibration of two 64 x 64 pixel regions of the detector in necessary to measure relative gain and linearity of the corresponding pixes. A spectral high-resolution wavelength calibration is done for each pixel-pair, probably requiring the use of a tunable, narrow-band, bright light source such as a dye-laser. But once completed, the ion velocity can be calculated very simply from the ratio of the intensities from the two images. From data taken when viewing through a He II interference filter, the light level in helium discharges in NSTX is adequate to make observations at 1,150 frames per second. A preliminary optical system was bench-tested and the lens used can image a 20 x 20 cm region of the plasma with 3 mm spatial resolution.

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, $v_{thi} \approx 3 \times 10^7$ cm/sec, need to measure small fraction of $v_{ExB} \approx 3 \times 10^5$ 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

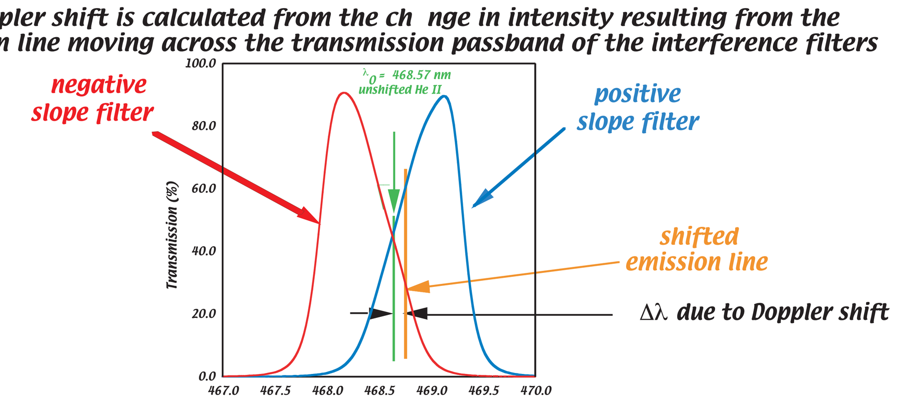


Good diagnostic access to NSTX, a spherical tokamak

- *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:

- $R_G = \frac{G_+}{G_-}$ 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 $\rho = \frac{I_+^{fil}}{I_-^{fil}}$
- $\langle\lambda\rangle$ is a constant, i.e., the unshifted "center of mass" of the line

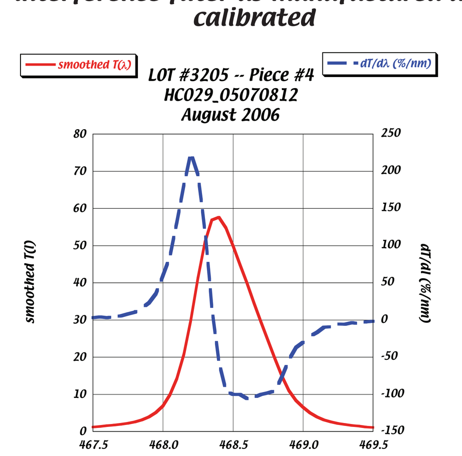
$\langle\lambda\rangle$ is provided by:

- 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

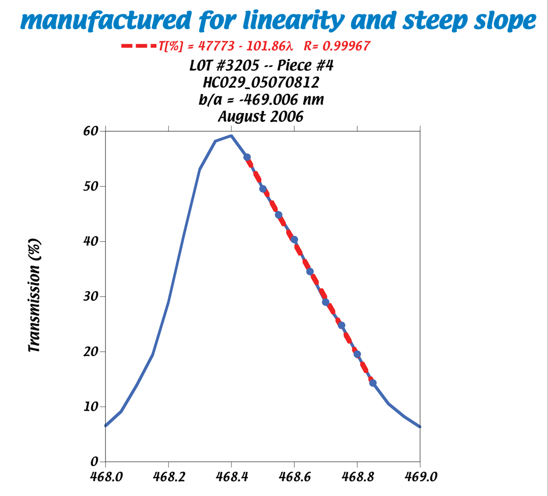


Required filter characteristics. Filter should have:

- 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

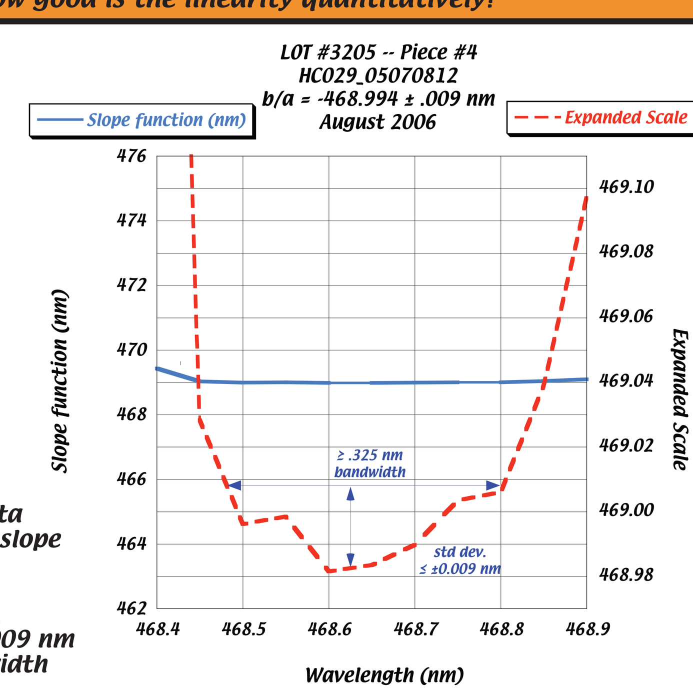
Measurement of achieved linearity and slope of filter

manufactured for linearity and steep slope



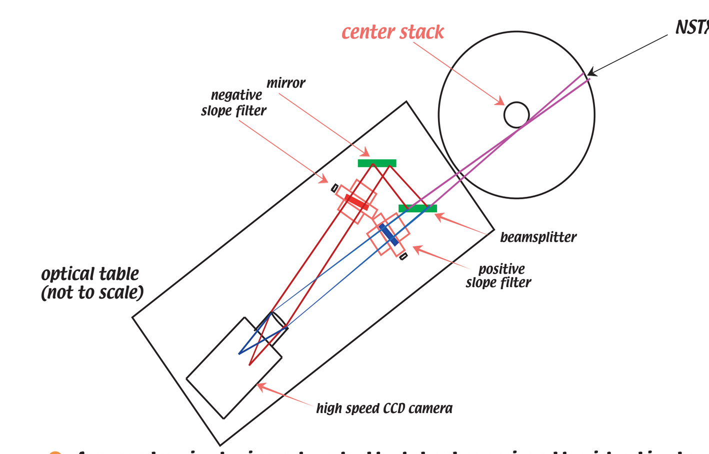
- Deviation from linearity is less than .03% over 0.4 nm (R > .9997)

How good is the linearity quantitatively?

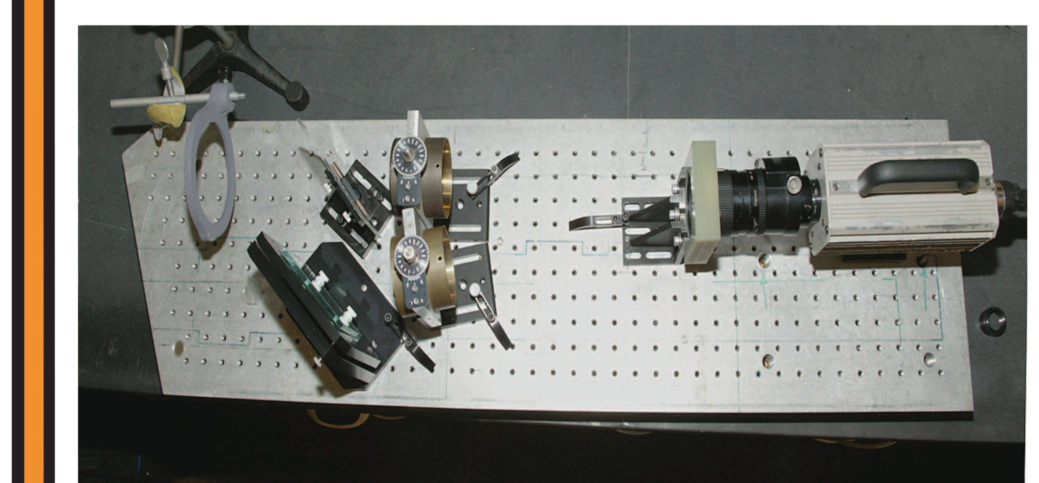


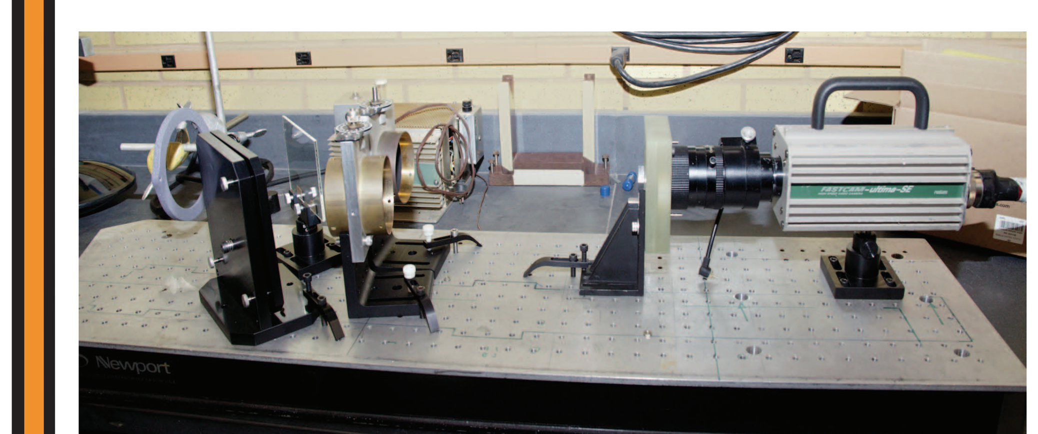
- The transmission data shows linearity in the slope over at least 0.3 nm.
- Figure of merit, b/a, varies by less than ±.009 nm over a .325 nm bandwidth

Experimental Setup on NSTX



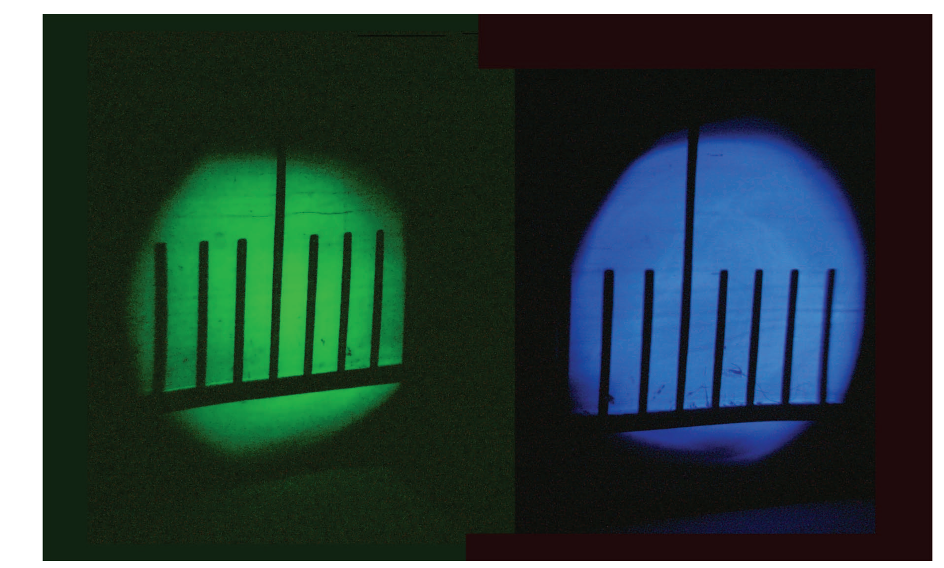
- *Apparatus is designed so both detectors view the identical volume of plasma*
- *Filters are tilt-adjusted to isolate the region of flattest slope of transmission band*
- *Effect of changing plasma intensity is removed*
- *Filters are temperature stabilized with a controller that maintains T within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

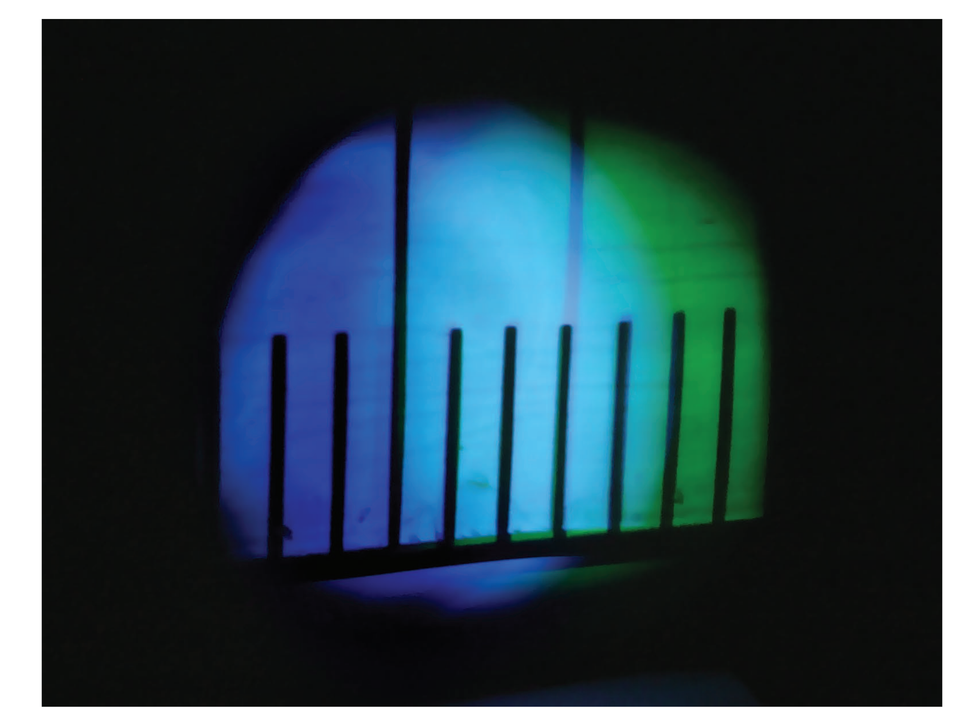


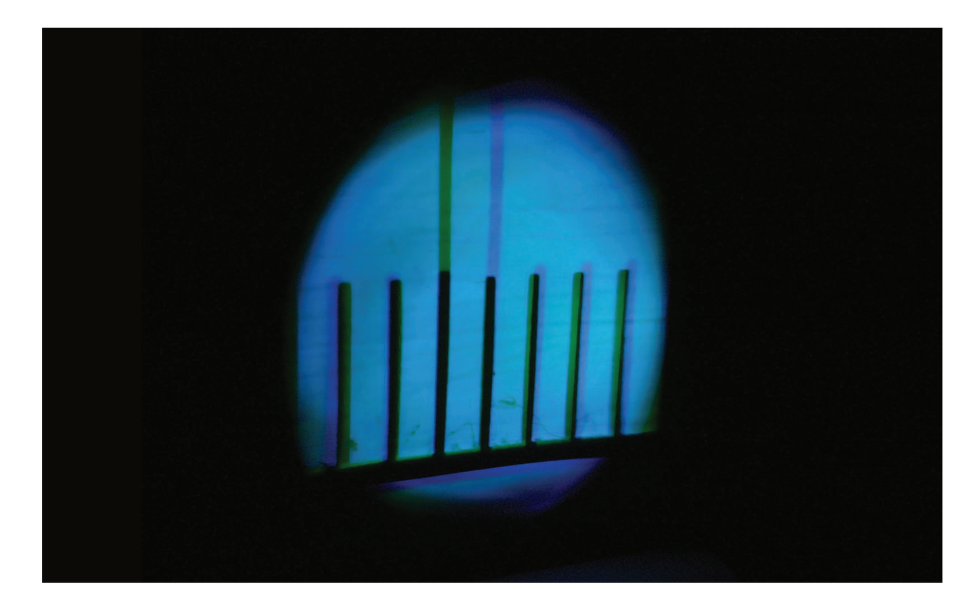


Backlighting fibers show the uniformity achieved

- *One branch is backlit with a green LED, as shown on the left*
- *One branch is backlit with a blue LED, as shown on the right*

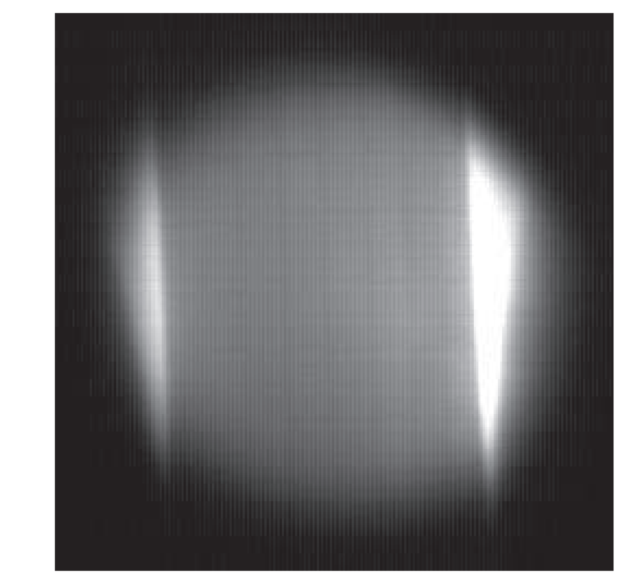


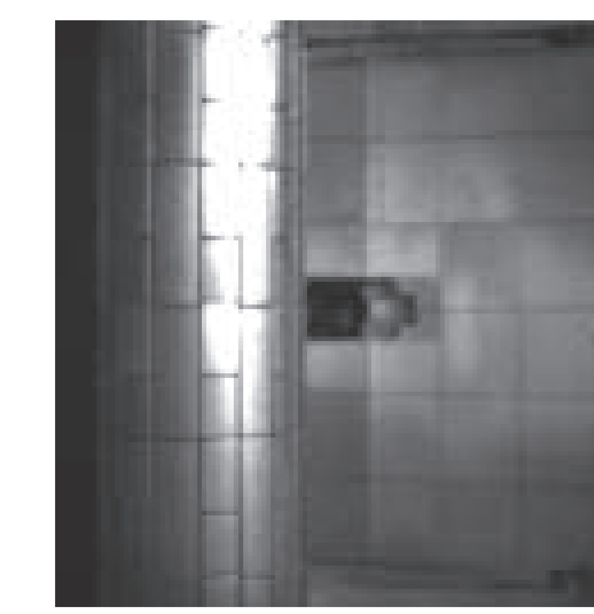


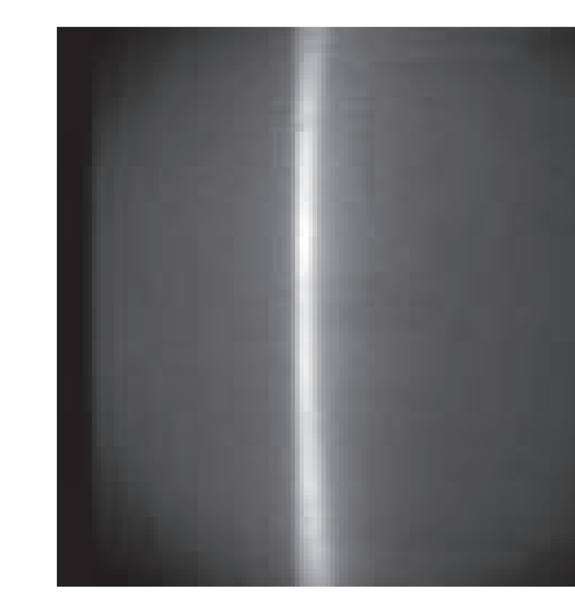


- *When combined, the cyan image appears*
- *The uniformity of the color shows that the branches view the plasma similarly*
- *Note the slight variation in the magnification. The "green side" is about 4% larger because of the longer object distance due to the mirror and beamsplitter. The correction is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

Preliminary data taken to observe light levels in an NSTX discharge (2 MW NBI) with helium gas puffing







- *Top: imaging He II on boths sides of NSTX center stack @ 1,150 fps with Hiroshima U.'s Photron Camera*
- *Middle: filaments lluminating NSTX center stack with Nova Photonics' Phantom camera*
- *Bottom: same view -- imaging of He II at 10,000 fps*