Measurement of Poloidal Velocity on NSTX*

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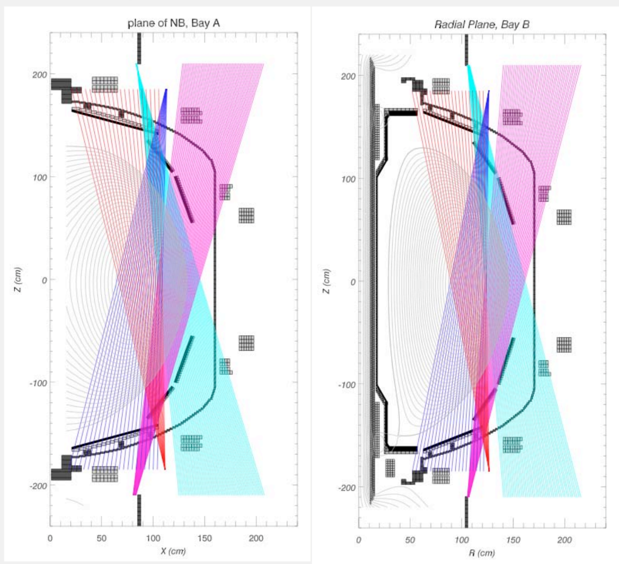
Abstract

A spectroscopic diagnostic to measure impurity ion poloidal velocity profiles using charge exchange recombination spectroscopy has been installed on NSTX. Up-down symmetric viewing chords in the plane of the neutral beam are matched with similar symmetric views off the neutral beam to measure both active and background emission. Eight fast (f/1.8-f/2) camera lenses at four locations make up the collection optics. Six f/1.8 spectrometers measure 276 spectra of C VI ions every 10 ms to obtain 75 active spatial channels and 63 background channels to achieve a spatial resolution of 0.7-1.7 cm after inversion. Inversions are necessary to obtain local values from the chord-averaged measurements. The background emission is fitted and inverted for subtraction from active views. Non-vertical symmetric views and independent toroidal velocity measurements allow the separation of the vertical and horizontal components of velocity induced by the energy-dependent charge-exchange cross section and ion gyromotion, which should eliminate the need for knowledge of atomic physics cross sections, halo neutral densities, level mixing, and excited beam populations when extracting the poloidal velocity.

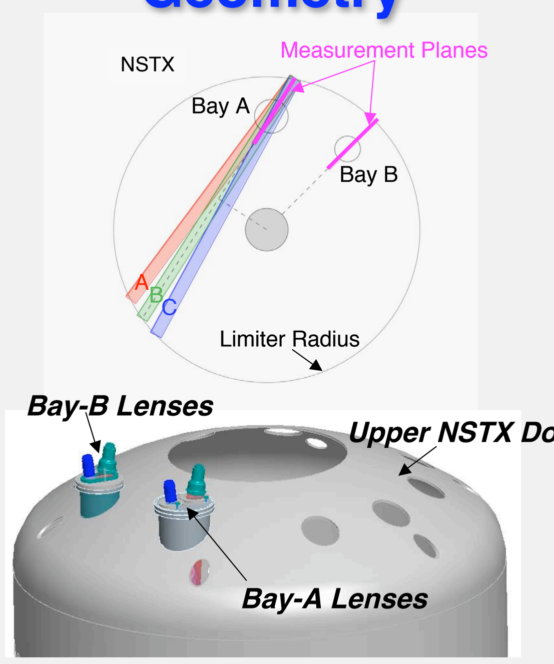
Diagnostic Design

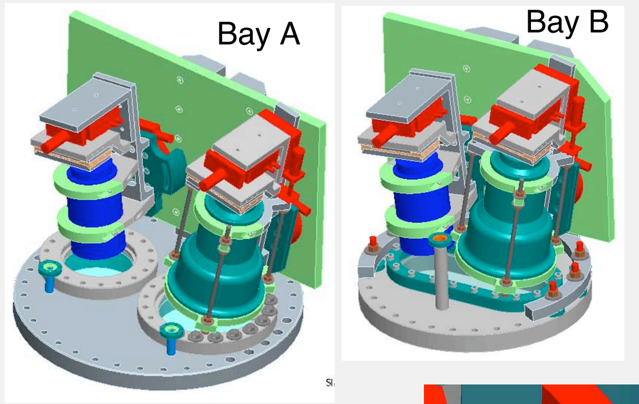
- Emission from **C VI** n = 8-7 line at **5291 Å** are measured.
- Emission from ions produced by charge exchange collisions with injected 80 keV D_0 atoms from the NSTX heating beams are used to obtain **local measurements of V_θ.**
- **Dedicated background views** separately measure the intrinsic emission, allowing dynamic subtraction from the charge exchange emission without beam notches.
- Up-down symmetric poloidal views view on and off the neutral beam.
- 276 spectra yield **75 active channels** and 63 background channels provide **high spatial resolution** 0.7-1.7 cm after inversion (comparable to toroidal CHERS).
- Collection optics use eight f/1.8-f/2.0 commercial lenses in four locations.
- **Multiple slits** are used, permitting a large number of spectra to be simultaneously recorded. A five-cavity **bandpass interference filter** prevents spectral overlap.
- **Curved slits** yield straight images to maintain narrow instrumental width when binning.
- **High optical throughput** and a **high quantum efficiency detectors** are used.
- 10 ms integration time.

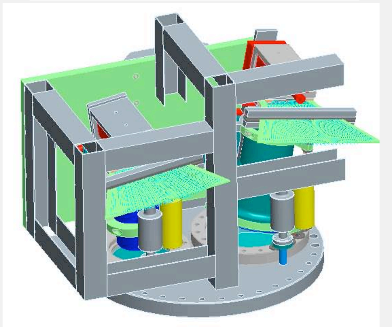
Symmetric Views



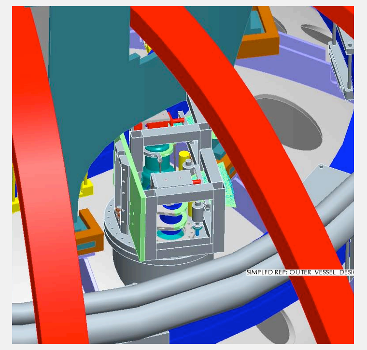
Geometry







Bay A collection optics assembly



Bay A optics in place atop NSTX

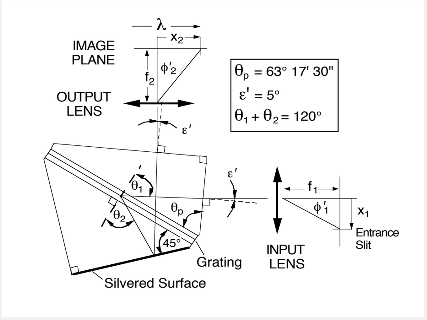
Collection Optics

- Four f/1.8, 200 mm Canon lenses and four f/2.0, 135 mm Nikon lenses
- 400 microns fibers for 108 active spectra for outer sightlines.
- 600 microns fibers for 168 central and background sightlines.
- 35 meters of fibers optics connect the collection optics to the spectrometers located outside the test cell permitting continuous access.

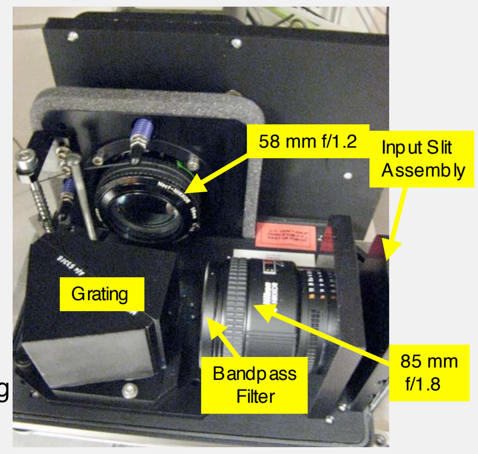
Hardware

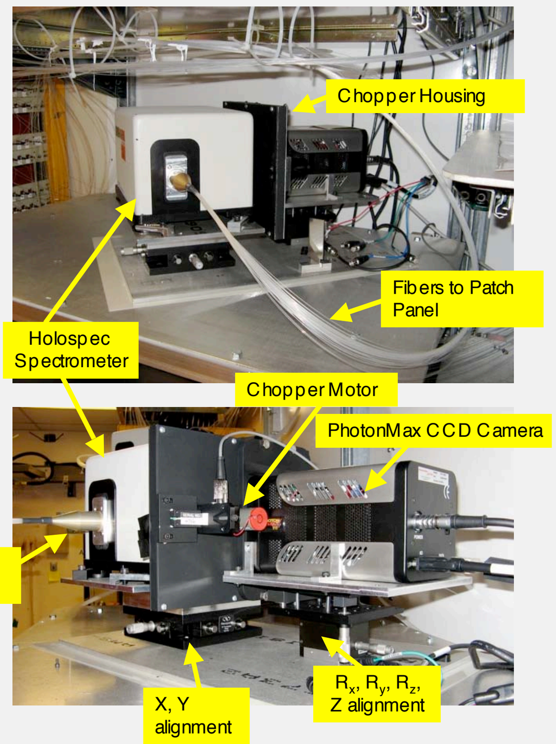
- Six spectrometers and detector systems are used for **pCHERS** (poloidal-viewing **Ch**arge **E**xchange **R**ecombination **S**pectroscopy)
- Each system uses a f/1.8 **Kaiser Holospec Imaging Spectrometer** with a holographic transmission grating. An f/1.2 output lens provides demagnification onto the CCD.
- The detectors are **Princeton Instruments PhotonMax Cameras**, utilizing a thinned, cooled, back- illuminated frame-transfer CCD.
- 54 400 micron fibers or 42 600 micron fibers are coupled to a single spectrometer.
- A **patch panel** using SMA connectors is used to distribute the fiber optics to the spectrometers.
- A **synchronized chopper** is used to blank the CCD during readout to avoid image smearing.
- Custom electronics, controlled by CAMAC, provide signals to the camera and choppers.
- Each camera is controlled from a dedicated PC running Windows XP.
- Trigger timing and chopper phase are recorded by serial time interval counters.
- A **6-axis adjustable mounting system** is used for precise alignment of the spectrometer to the detector.

HDG Transmission Grating Spectrometer



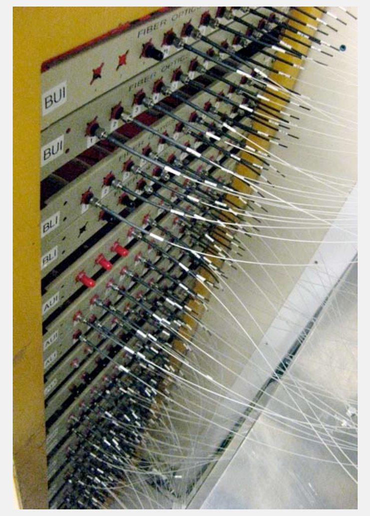
Kaiser Optical Systems Holospec spectrometer with HDG-530.6 grating





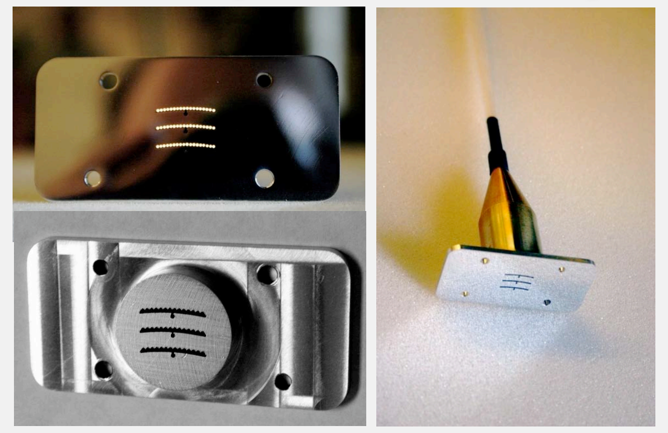
Spectrometers & Chopper Controls

Patch Panel

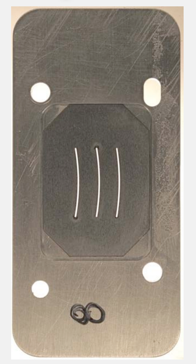


Computers & Monitors for pCHERS, CHERS, ERD

Fiber Optic Assembly



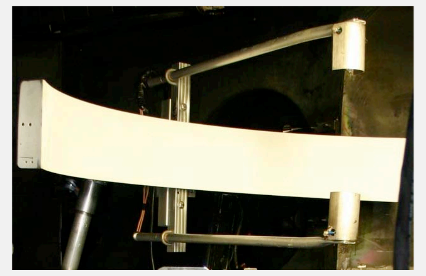
Multiple Slits



Alignments and Calibrations

- **An optical alignment** is performed by adjusting the direction and focus **of the collecting lenses** to match the position of up-down views at the midplane.
- A **spatial calibration** of collection optics is performed by back-illuminating the fibers. An precision measurement (FARO) arm is used to determine sightline paths in 3D using orthogonal distance regression (ODR).
- **Spectrometer alignment** is done using a neon lamp and narrow slits without fibers. Precision optical mounts provide 6 axes of adjustment needed for proper alignment and focus.
- A **white plate calibration** is performed in-vessel using a curved white plate to obtain an accurate fiber-to-fiber and inter-spectrometer calibration. The white plate is cross calibrated with a calibrated integrating sphere (Labsphere) source to obtain an absolute calibration.
- A **spectral calibration** and **instrumental width calibration** for every channel are obtained using a neon glow discharge inside the NSTX vessel. Multiple neon lines are used to find the instrumental function, dispersion and wavelength calibration.

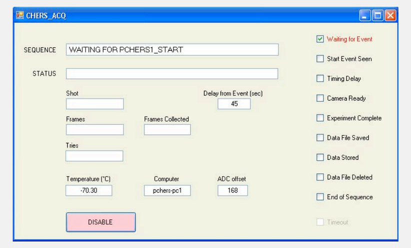
A Plexiglas plate is used to view backlit fibers from upper and lower views at the midplane during optical alignment.



The white plate used is a curved plate with Lambertian reflection properties illuminated by a pair of quartz halogen lamps.

Data Acquistion

- **Data Acquisition and Control** software is written in IDL with a Widget user interface.
- The **timing information** for camera timing is entered and written to MDSplus to autoload before the discharge.
- **Status** of data acquisition is controlled and monitored on the IDL Widget.
- **Camera control** is accomplished through **a Visual Basic GUI**. An MDS event initiates the sequence. The camera waits for a hardware trigger to acquire data. Within seconds after the discharge, raw data is written the MDSplus tree directly from each PC.



Visual Basic GUI controls WinSpec Software operating the camera and writes raw data to the MDSplus tree.

Analysis

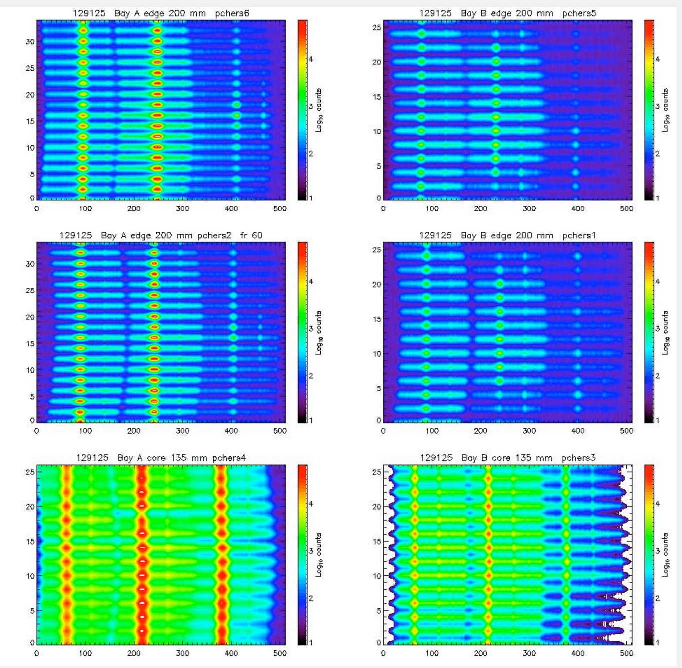
Analysis Steps:

1. Read raw data and calibration data.
2. Apply photometric calibration to each of 276 spectra at each time point.
3. Fit C VI emission lines for each spectrum to determine wavelength shift, amplitude, and width.
4. Using EFIT equilibrium, determine the flux surface where each sightline is tangent at each time point and find midplane radius for this surface.
5. Using EFIT equilibrium, determine the unit vectors of poloidal velocity.
6. Using EFIT equilibrium, determine emission zones for each sightline at each time.
7. Reorder sightlines according to tangency radius
8. Compute inversion matrices for both active and passive planes of measurement:
   a) Length matrix
   b) Velocity weighted Length matrix
9. Compute matrices of CX emissivity in active plane of measurement:
   a) Map T_i, V_ϕ, N_c, T_e, N_e into 2D using CHERS and MPTS data and EFIT equilibrium.
   b) Compute 2D beam neutral density with 2D beam attenuation calculation.
   c) Compute effective charge exchange rate in 2D for all beam sources.
   d) Compute emissivity of CX in 2D- Weight matrix
   e) Compute Emissivity weighted Length Matrix
   f) Compute Velocity and Emissivity weighted Length Matrix
10. Invert matrices.
11. Invert background brightness to get local emissivity of background emission
12. Subtract computed brightness of background emission in active view
13. Invert differential CX signal to get local poloidal velocity

Status of Diagnostic

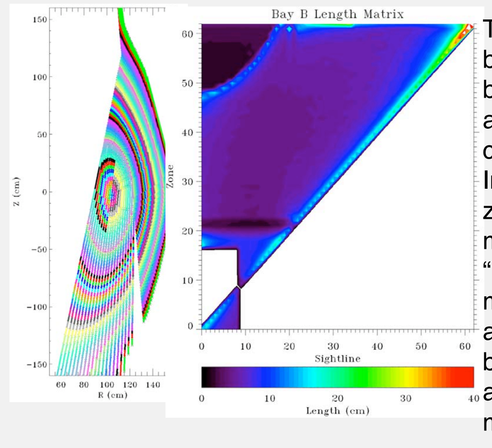
- The PCHERS diagnostic hardware (optics, fibers, spectrometers, detectors) have been installed, aligned and calibrated.
- Data acquisition is automatic and routine.
- Calibration software is complete.
- Fitting software is complete.
- Inversion software is nearing completion, testing is on going.
- Preliminary analysis of a few shots with high signal to background have shown poloidal flow that is quite similar to neo-classical flow (see below).
- Computation time for analysis of a complete shot will be long (> 30 minutes), so analysis will need to be performed on multiple CPUs to achieve between-shot analysis.

Raw Data



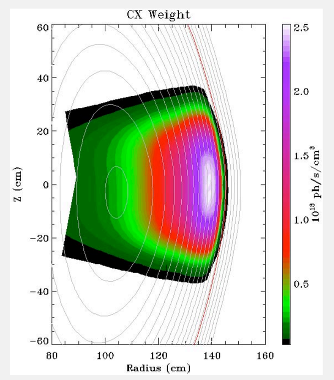
Raw data from 6 detectors for one time point, 276 spectra. Views from upper and lower ports are positioned symmetrically on each detector to improve accuracy of relative wavelength shifts.

Matrices for Inversion

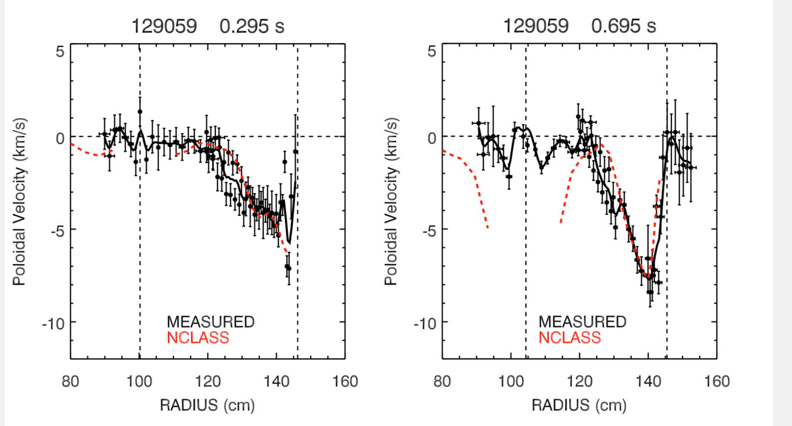


The length matrix for the background view is verified by plotting each segment along the sightlines color-coded by emissivity zone. Independently inverting the zones just inside the magnetic axis leaves a "hole" in the matrix. A similar matrix for the active view allows the transfer of the background emission to the active plane of measurement.

The emissivity (weight) matrix is shown,note the height of the neutral beams . This matrix is used to determine the weighting of the CX emission along the sightline in the inversion process. Data from external diagnostics (MPTS and CHERS) are used to compute this matrix.



Preliminary Results



The figures at left show comparisons of carbon impurity velocity to NCLASS computation of impurity poloidal velocity at two different times. **The measured line-integrated poloidal impurity velocity profile is similar in magnitude and direction to NCLASS values.** NCLASS impurity velocity as computed in TRANSP is shown as dashed red line. A smoothing spline fit to the data points is shown as a solid line. The radial position plotted is the mid-plane radius at which the sightline is tangent to the poloidal magnetic flux surface. The vertical dashed lines show magnetic axis and separatrix locations from EFIT.

This analysis is done without a background subtraction or inversion. The charge exchange emission is quite large compared to background for this discharge. **Inversion to get local velocity from the line-integrated measurement has not been done yet**, though the line integral over the finite height of the neutral beam footprint is heavily weighted to the tangency radius. Positive values of poloidal velocity are downward at the outer midplane.

Gyro Orbit Finite Lifetime Effects

Typically, poloidal velocity measurements are plagued with pseudo velocities due to atomic physics effects, which can be large compared to the true poloidal velocity. A velocity toward the NB due to the energy dependent cross section (V_{cx}) is rotated by the gyro orbit to mimic a poloidal velocity (V_{gfl}).This effect is proportional to both ion temperature and magnetic field (NSTX values are both ~10% of values on TFTR). **On NSTX, the pseudo velocity due to gyro-orbit finite lifetime effect is small** (≤ 0.5 km/s) compared to TFTR (≤ 50 km/s). Computed V_{cx} for the shot above (Te(0) ~ 1.1 keV) is shown on right, $V_{cx} < 10$ km/s. The rotation angle of gyro orbit is shown far right, $\omega\tau < 0.2$ rad/s. The maximum **local** contribution is the product of these two ($V_{gfl} < 0.2$ km/s).