Charge Exchange Recombination Spectroscopy on NSTX

R. E. Bell, D. W. Johnson, R. Feder, T. M. Biewer

Abstract

A high throughput, high spatial resolution charge exchange recombination spectroscopy diagnostic is operating on the National Spherical Torus Experiment. Two f/1.8 fixed-wavelength spectrometers are coupled to thinned back-illuminated CCD detectors. Emission from C VI 5291 Å is measured along 51 sightlines viewing three neutral beam sources with 0.5-3 cm resolution from edge to core every 10 ms. 39 sightlines not viewing the neutral beams measure background emission. Spatial and absolute photometric calibrations are conducted in vessel. Wavelength and instrumental function calibrations are performed using a neon glow. The data analysis consists of fitting and modeling the background emission, fitting the active view, a beam attenuation calculation, Zeeman correction, computation of the effective charge exchange cross section, and correcting for the effects of the energy dependent charge exchange cross section on ion temperature and velocity. Fully automated data acquisition and analysis codes provide between-shot availability of fully corrected profiles of T_i, V_ϕ, N_c, and Z_{eff}.

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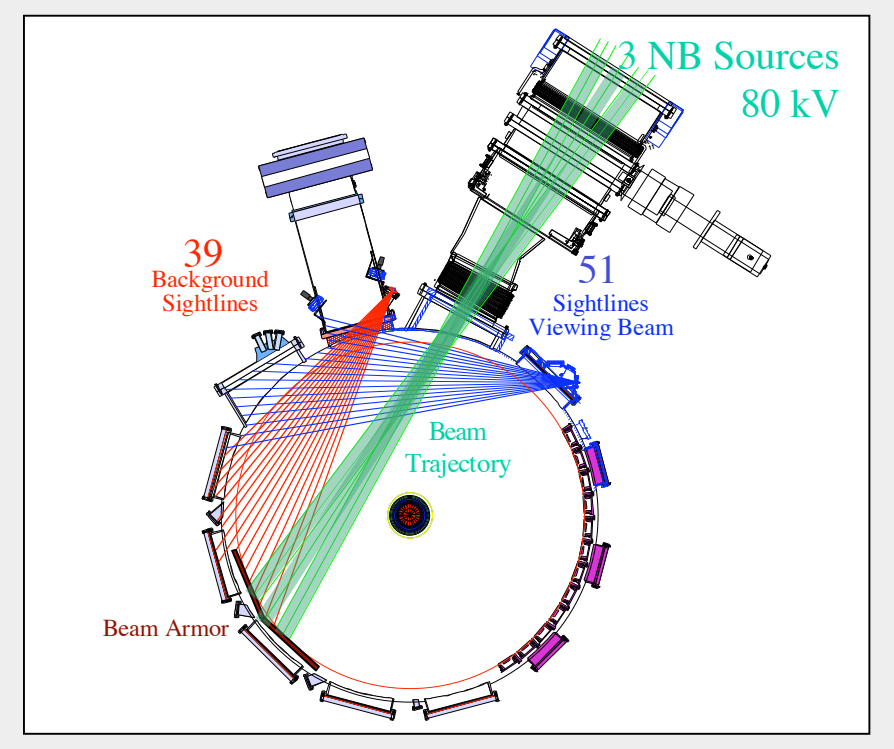
Diagnostic Design

- 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 **T_i, V_ϕ, and N_{carbon}.**
- A **dedicated background view** and a dedicated spectrometer/detector system are used to separately measure the intrinsic emission from the charge exchange emission, allowing dynamic subtraction without beam notches.
- Tangential views are optimized for **high spatial resolution.**
- **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 detector** are used to reduce statistical errors.
- Profiles over outer half of plasma from 3 cm to 0.5 cm resolution
- 10 ms integration time.

Viewing Geometry



Collection Optics

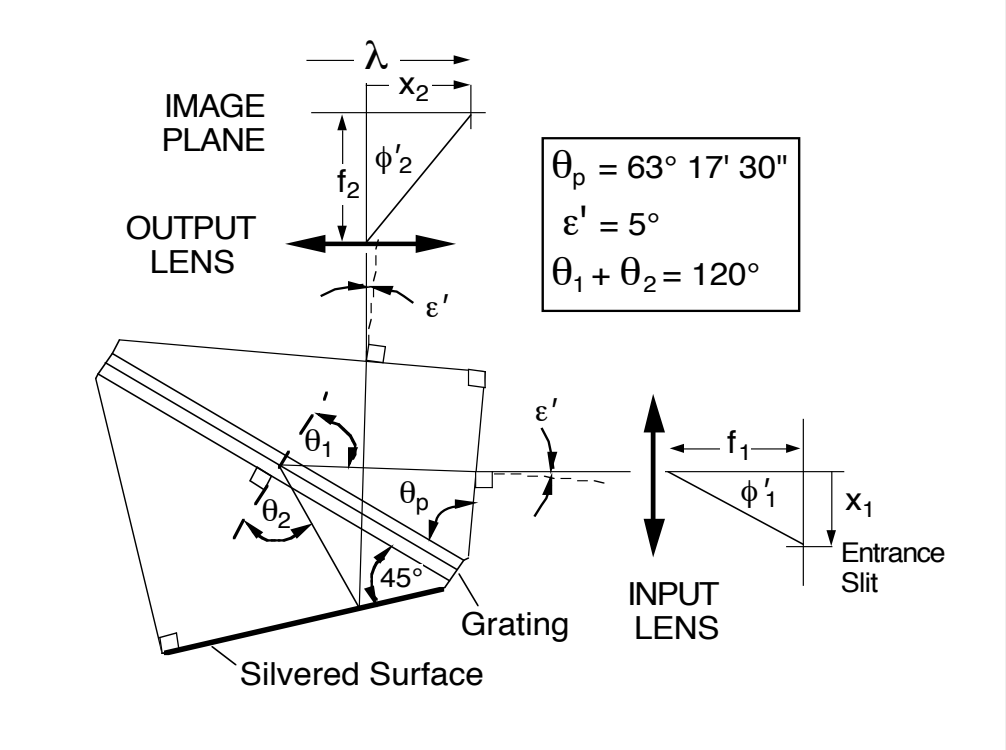
- Optics viewing across the NB are shared with the MSE diagnostic, f/1.2
- The background view uses an 85 mm f/1.8 camera lens identical to the spectrometer input lens for good optical matching.
- 30 meters of fibers optics connect the collection optics to the spectrometers located outside the test cell permitting continuous access.
- Two 210 microns fibers for each of 51 channels are use for the active sightlines.
- 600 microns fibers are used for 39 background channels.

Spectrometer/Detector Description

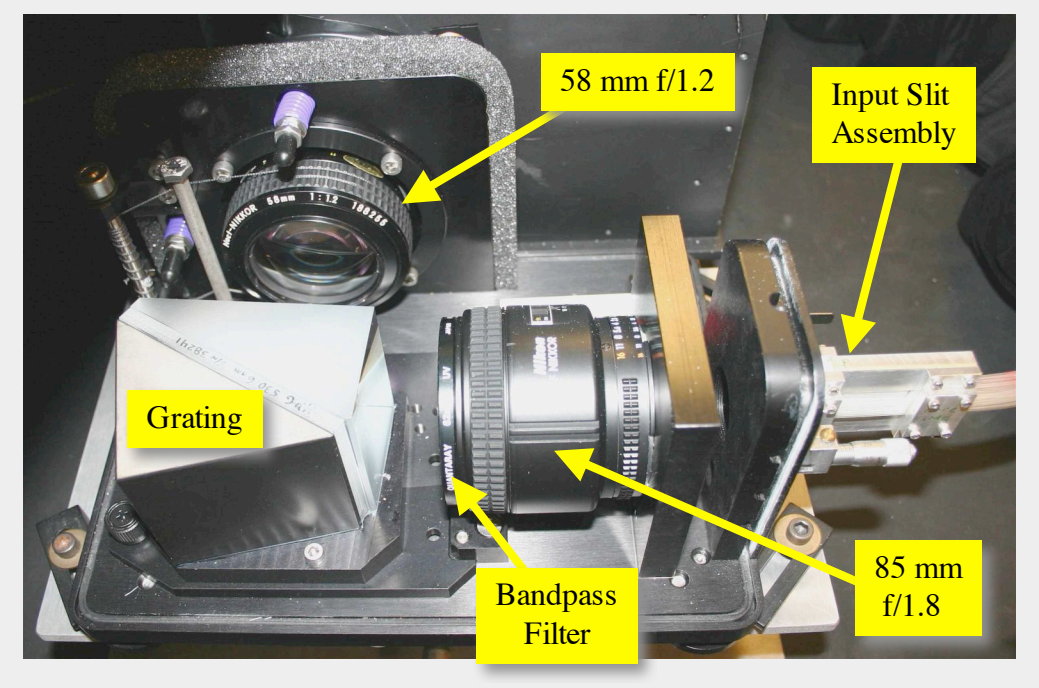
- Two spectrometers are used for **CHERS** (**Ch**arge **E**xchange **R**ecombination **S**pectroscopy)
- In each system, light is dispersed with a f/1.8 **Kaiser Holospec Imaging Spectrometer**, which utilizes a holographic transmission grating. An f/1.2 output lens provides demagnification onto the CCD.
- The detectors are **Princeton Instruments Pentamax Cameras**, utilizing a thinned, cooled, back-illuminated frame-transfer CCD, operating at 5 MHz.
- 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. 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.

HARDWARE

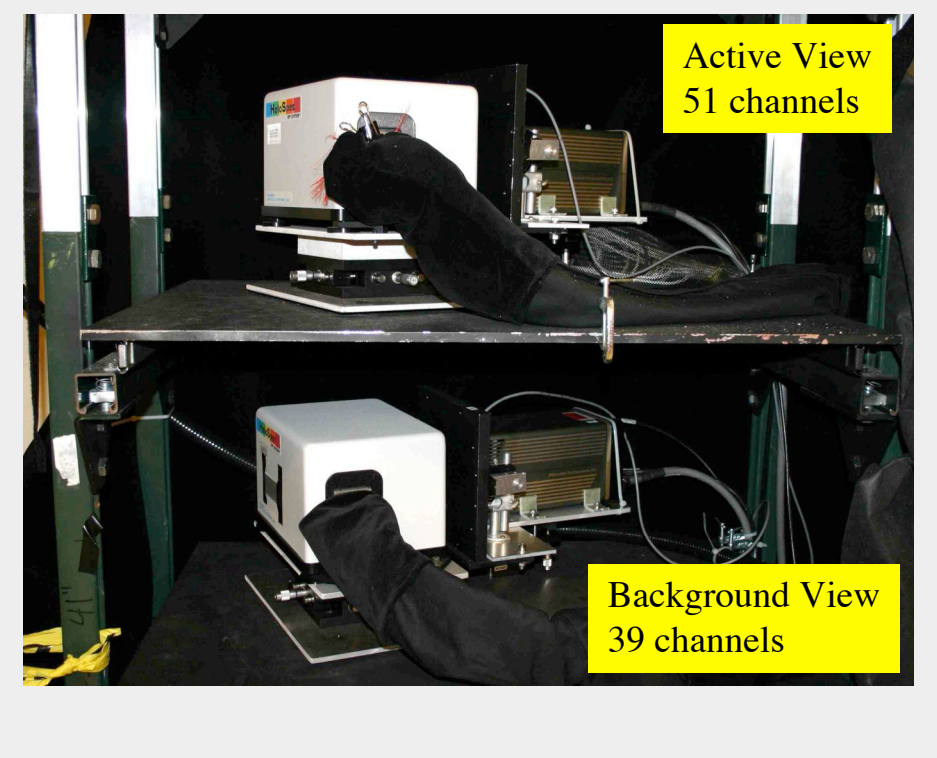
HDG Transmission Grating Spectrometer

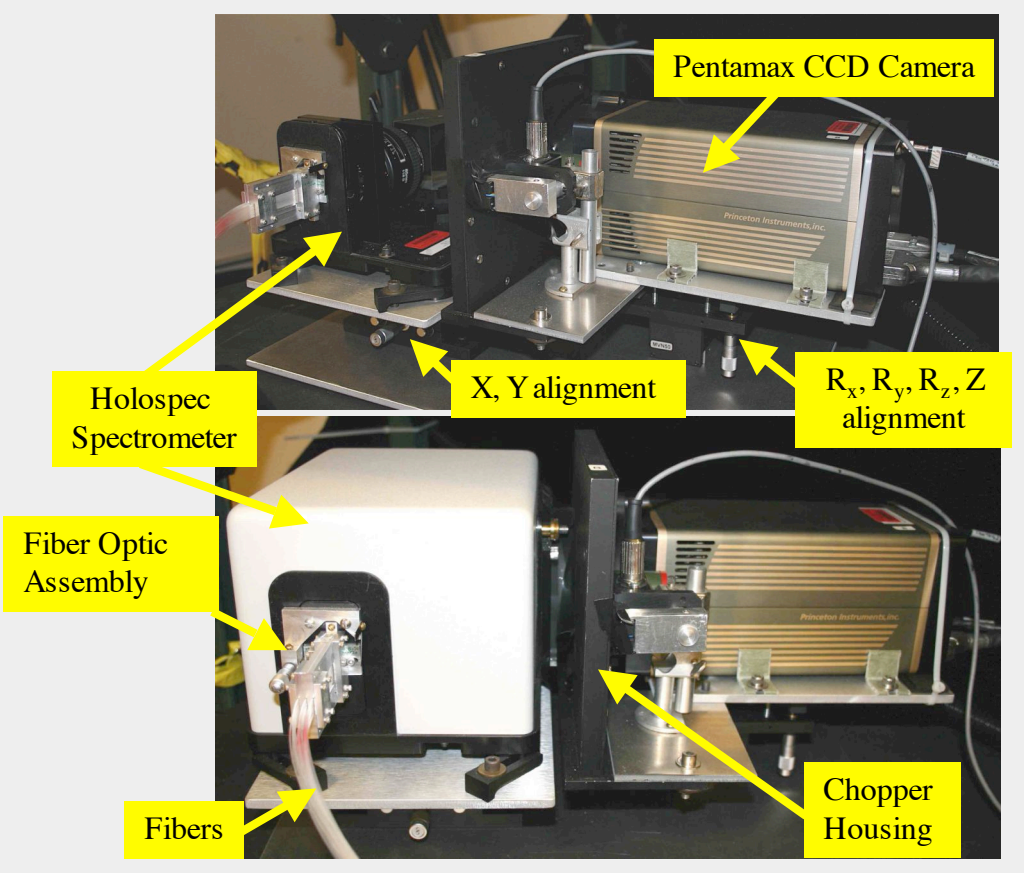


$\theta_p = 63° 17' 30''$
$\varepsilon' = 5°$
$\theta_1 + \theta_2 = 120°$



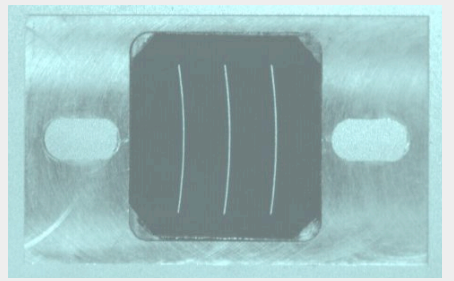
Kaiser Optical Systems Holospec spectrometer with HDG-530.6 grating



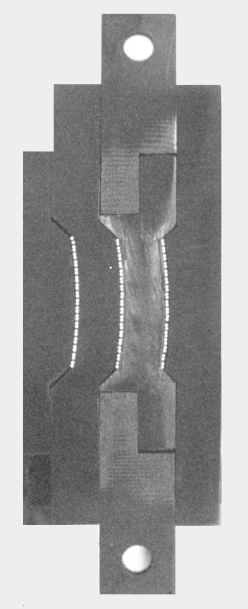


Assembled fibers, slit, spectrometer, chopper, and detector mounted and aligned with adjustable 6-axis mounts

Multiple Slits



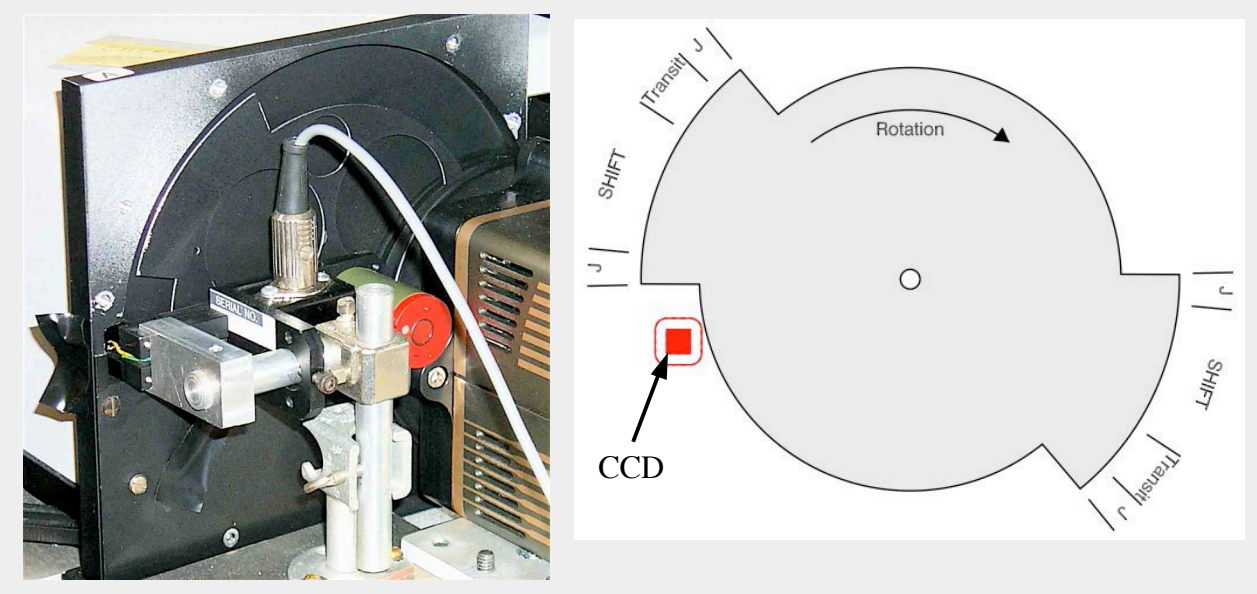
Mounted Laser Cut Air Slits



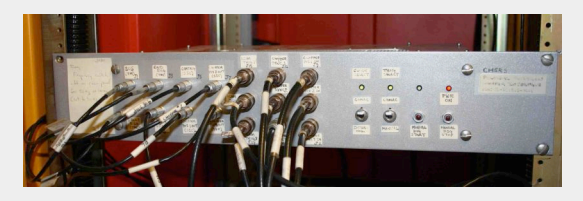
Fiber Optic Assembly:
210 micron core fibers
3 columns × 34 fibers
= 102 fibers

Pentium 266 MHz computers running WinSpec software with MACRO for remote camera control

Chopper Wheel

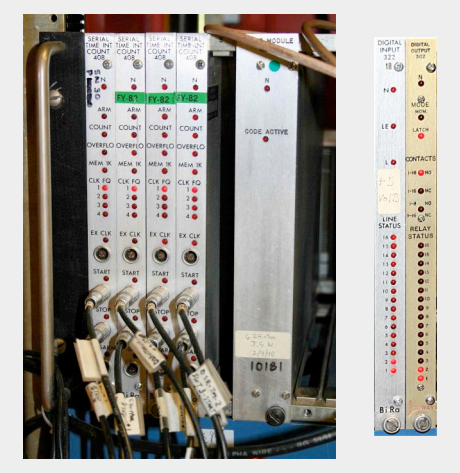


- Chopper wheel with two tabs rotating at 50 Hz.
- Tab width = CCD shift time + transit time + 2 × jitter time= 3.1 ms (out of 10 ms frame time)
- Jitter time (J) is the uncertainty in the feedback control of the chopper position.
- Open square indicates the area that must be shadowed at f/1.2



Chopper/Trigger Interface Electronics

Chopper Controller and Synchronizer

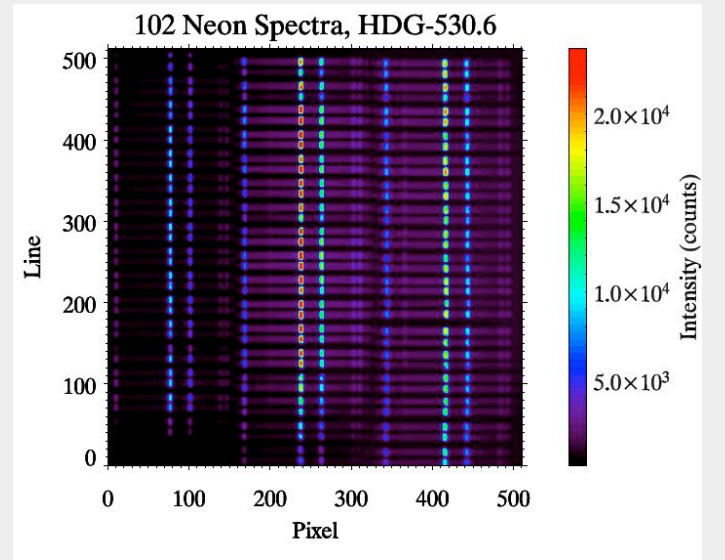


CAMAC modules for timing and AC power to choppers

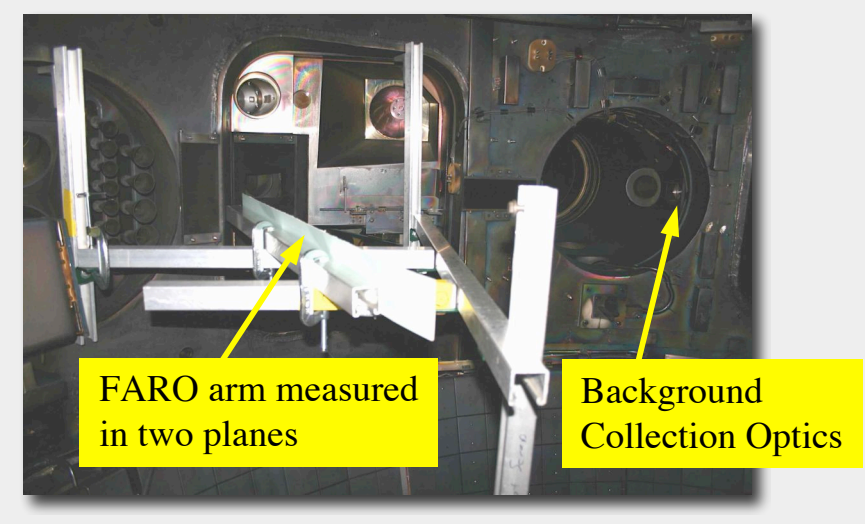
AC controller for remoter chopper control

CALIBRATIONS

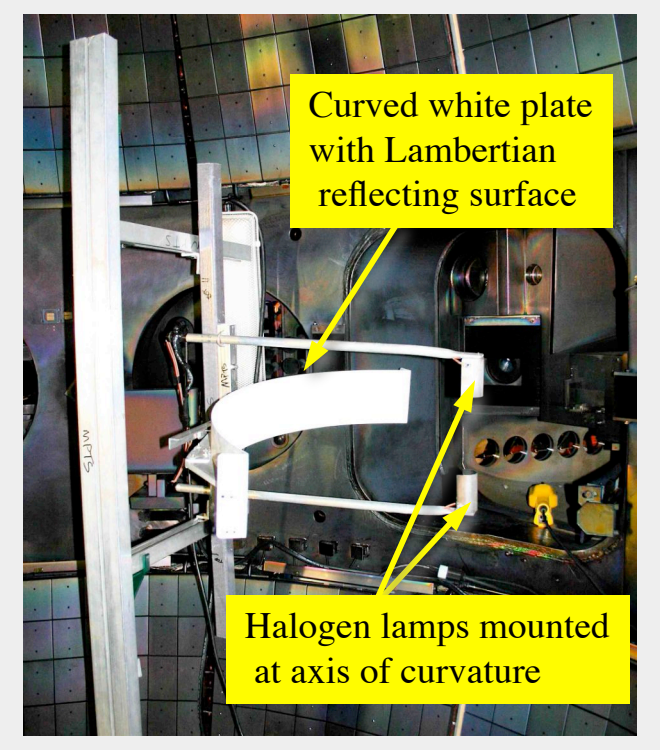
- **Spectrometer alignment** is done using a neon lamp and narrow slits without fibers. Precision optical mounts provide 6 axes of adjustment needed for proper alignment and focus.



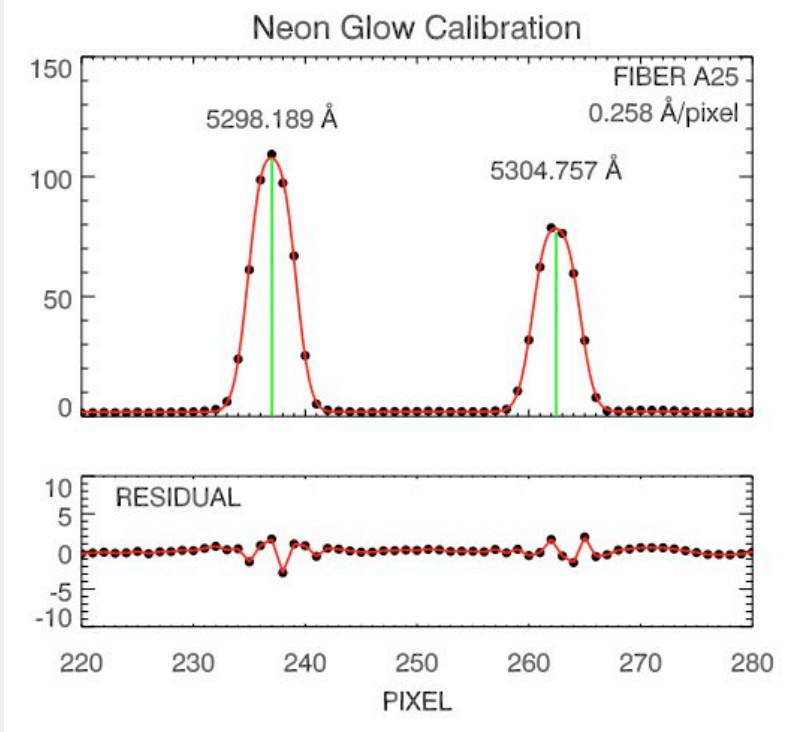
- A **spatial calibration** of collection optics is performed by back-illuminating the fibers. An precision measurement (FARO) arm is used to determine tangency radii.



- 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.

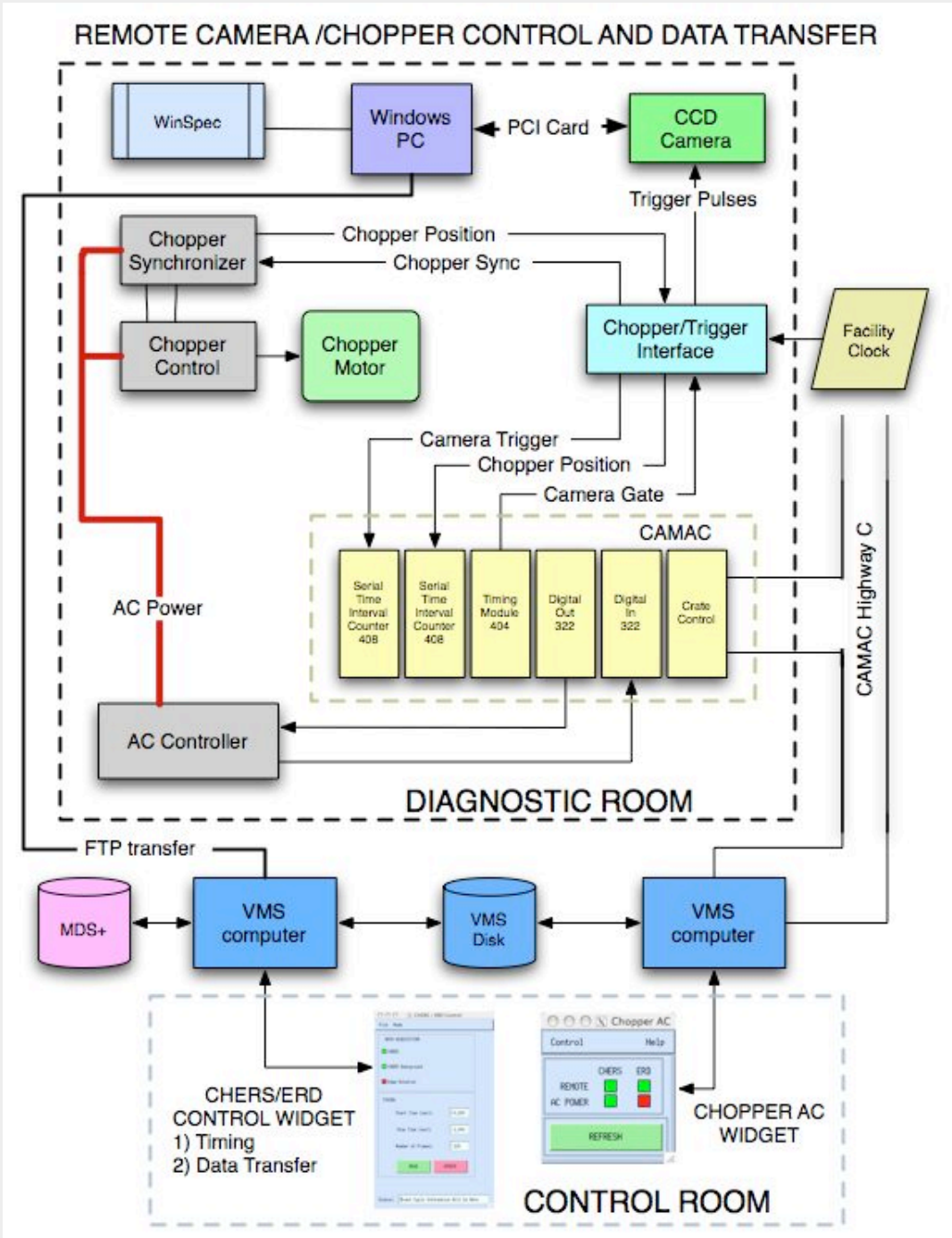


- A **spectral calibration** and **instrumental width calibration** for every channel are obtained using a neon glow discharge inside the NSTX vessel. Multiple neon lines are used to find the instrumental function, dispersion and wavelength calibration.



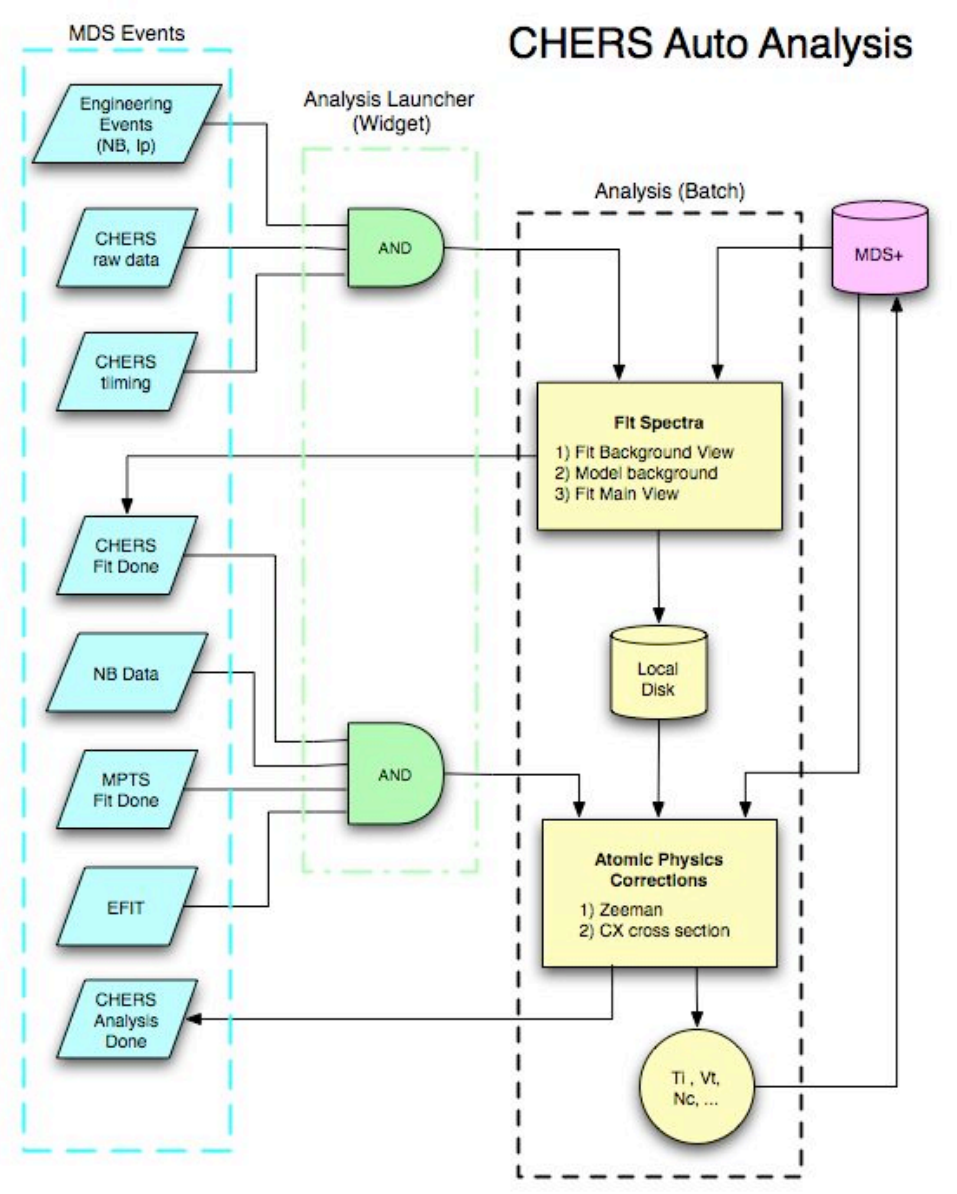
SOFTWARE

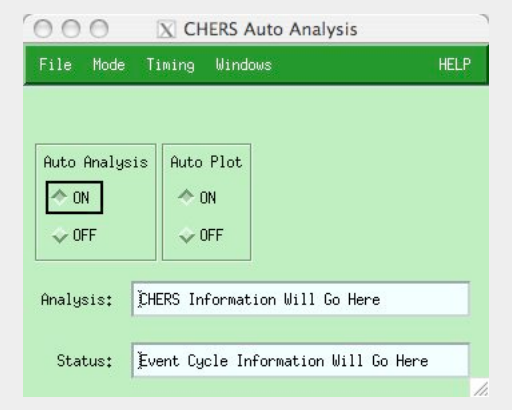
REMOTE CAMERA CONTROL/ DATA ACQUISTION



- **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 Widget.
- A **MACRO** on the camera PC is initiate when file containing shot number and duration appears through FTP transfer.
- **WinSpec software** waits for the camera to be triggered after the T-1 event.
- After the shot the **raw data** is transferred to VMS via FTP and written to the MDSplus tree.

AUTOMATIC ANALYSIS





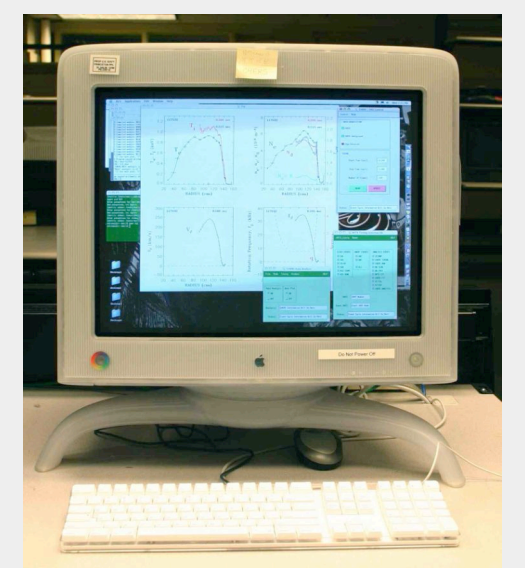
Auto Analysis: ON OFF
Auto Plot: ON OFF
Analysis: CHERS Information Will Go Here
Status: Event Cycle Information Will Go Here

CHERS Auto Analysis Widget

CLOCK EVENTS: ☐ SOC ☐ SOS ☐ T0-60 ☐ SOD ☐ ACQ START ☐ ACQ DONE
ABORT EVENTS: ☐ ABC ☐ ABS ☐ KLC
ANALYSIS EVENTS: ☐ IP/NBP ☐ CHERS TIMING ☐ CHERS RAW ☐ NB SLOW ☐ NB FAST ☐ MPTS FIT ☐ CHERS FIT ☐ EFIT01 ☐ EFIT02 ☐ CHERS ANALYSIS
SHOT: SHOT Number
Event SHOT: Event SHOT Numb
Status: Event Cycle Information Will Go Here

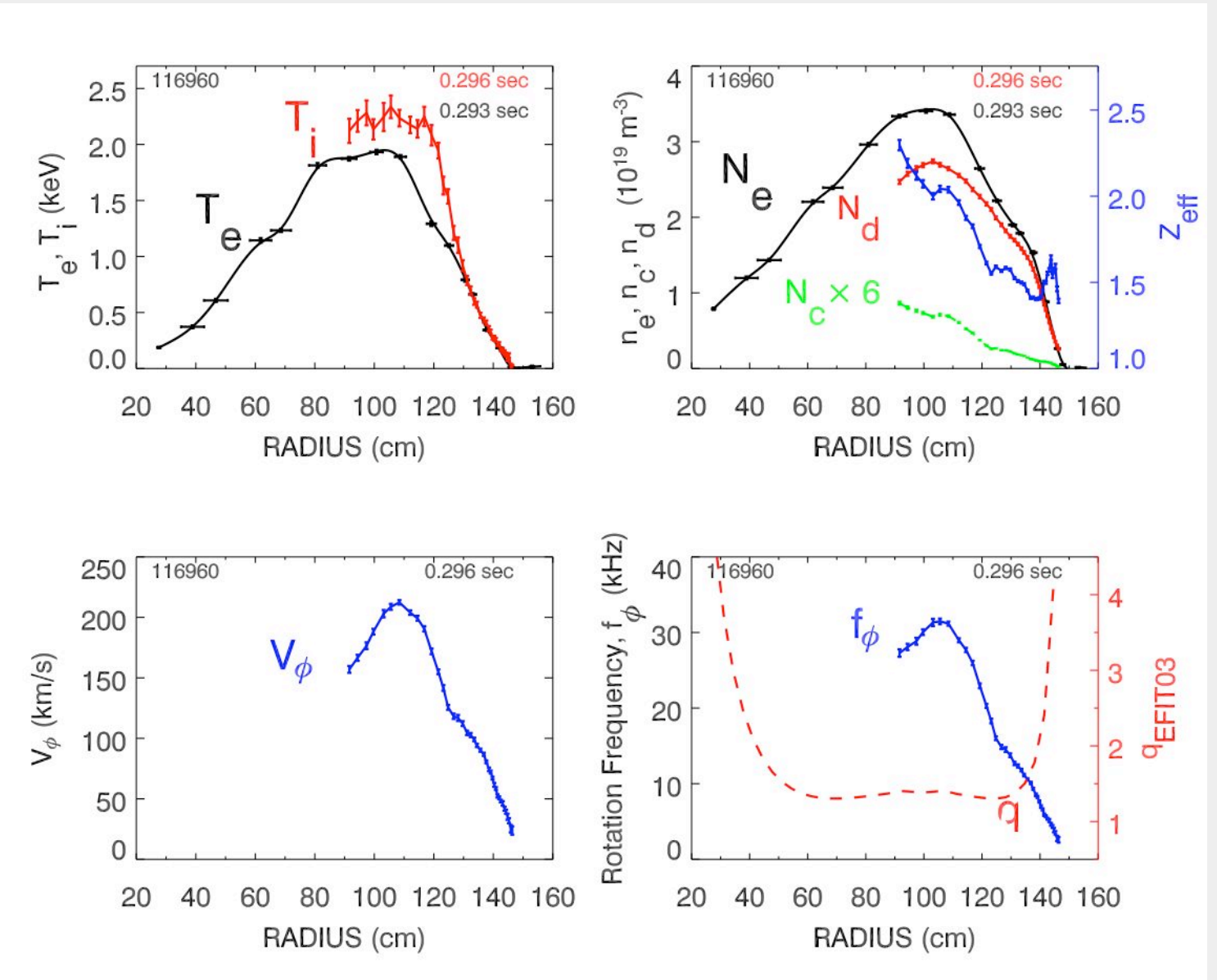
NSTX Timing Widget

- All **Auto-Analysis** software is written in IDL.
- A Macintosh G5 computer running IDL is used for event-driven software and another remote G5 performs the separate fitting and correction tasks.
- **MDS events** are monitored to signal the presence of required raw and analyzed data.
- When the CHERS raw data, Ip and NB timing are available **fitting software** is launched.
- **Background spectra** are fitted, modeled and used to fit **active CX spectra** which are written to a local disk.
- When NB power and voltage data, Thomson (MPTS) analysis, EFIT are ready **correction software** is launched remotely using the intermediate data on the local disk.
- **Atomic physics corrections** for Zeeman splitting, and energy dependent charge exchange cross sections are applied and fully analyzed data for **between shot analysis**, i.e. on the MDSplus tree 3.5 -10 minutes after T0.

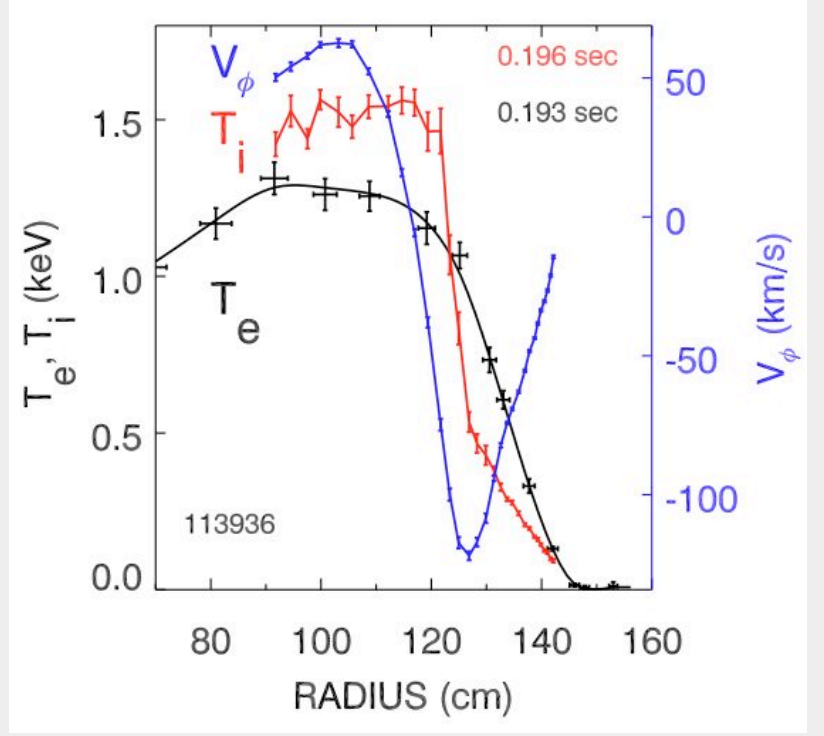


CHERS operation on G5 MAC in control room

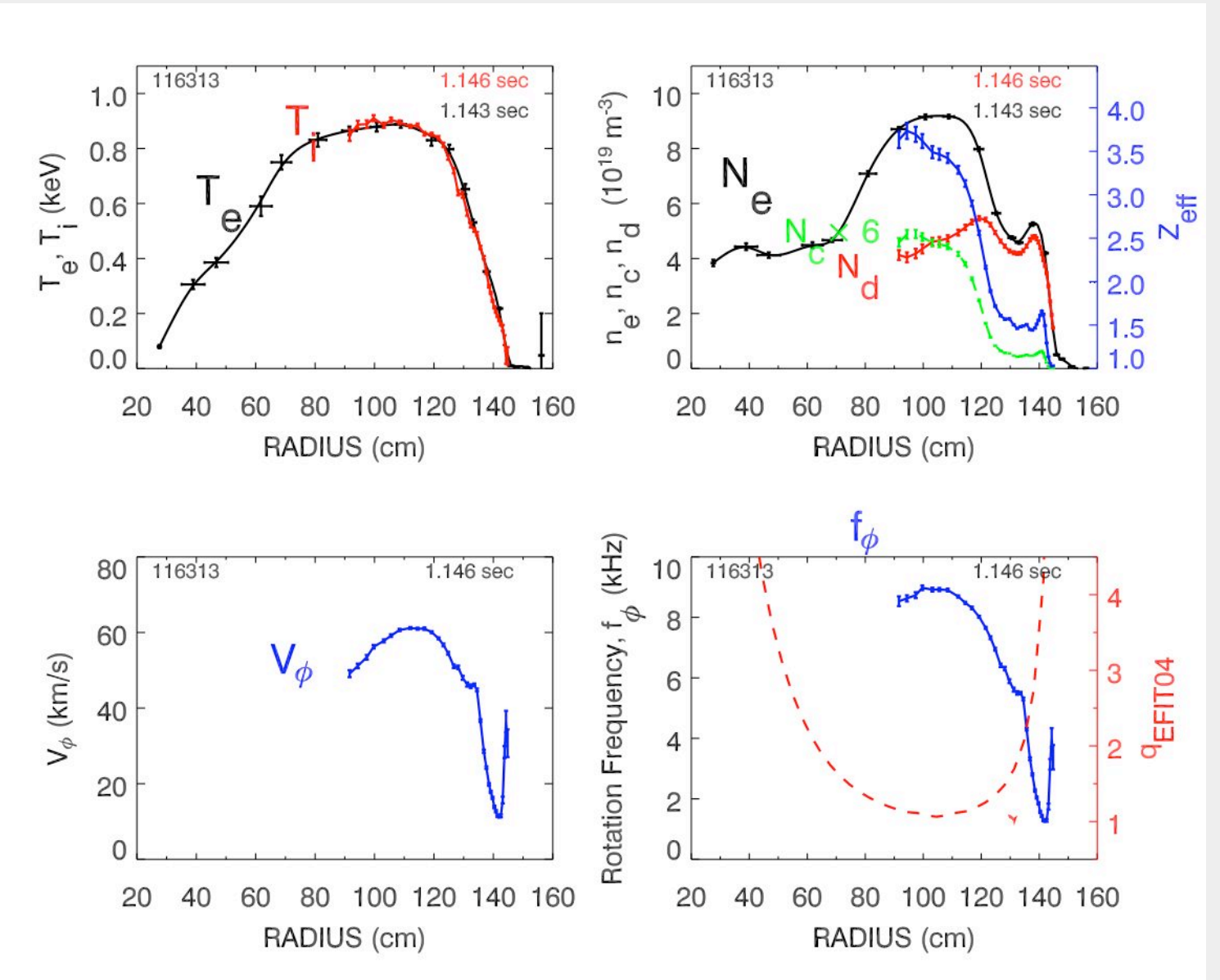
RESULTS



- CHERS analysis for shot 116960, single NB source, $P_{inj} = 2$ MW
- High T_e, T_i>T_e, L mode
- Z_{eff} and N_d are computed assuming C VII is only impurity

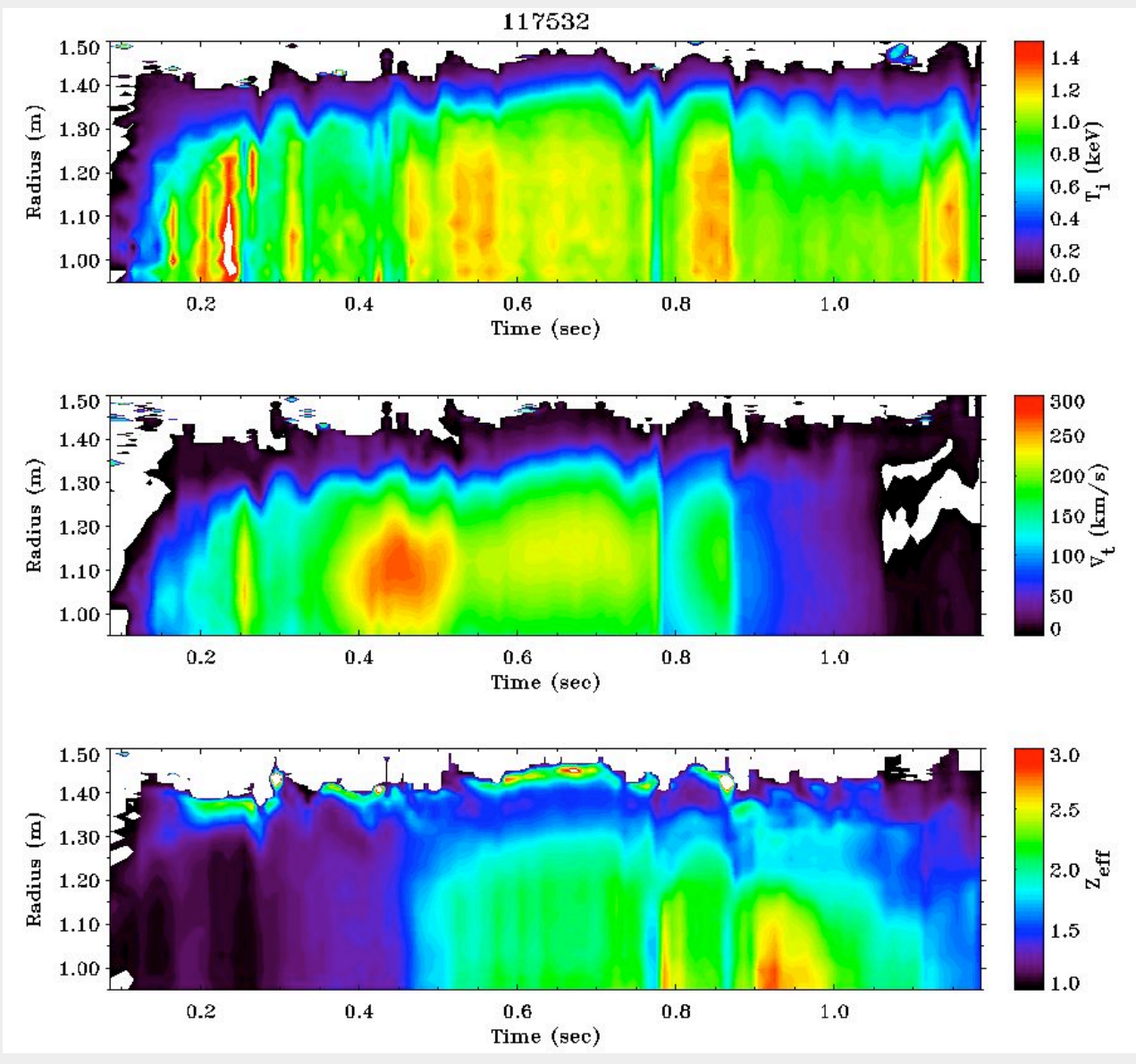


- Shot 113936, $P_{inj} = 4$ MW
- Strong counter rotation early in discharge despite co-NBI

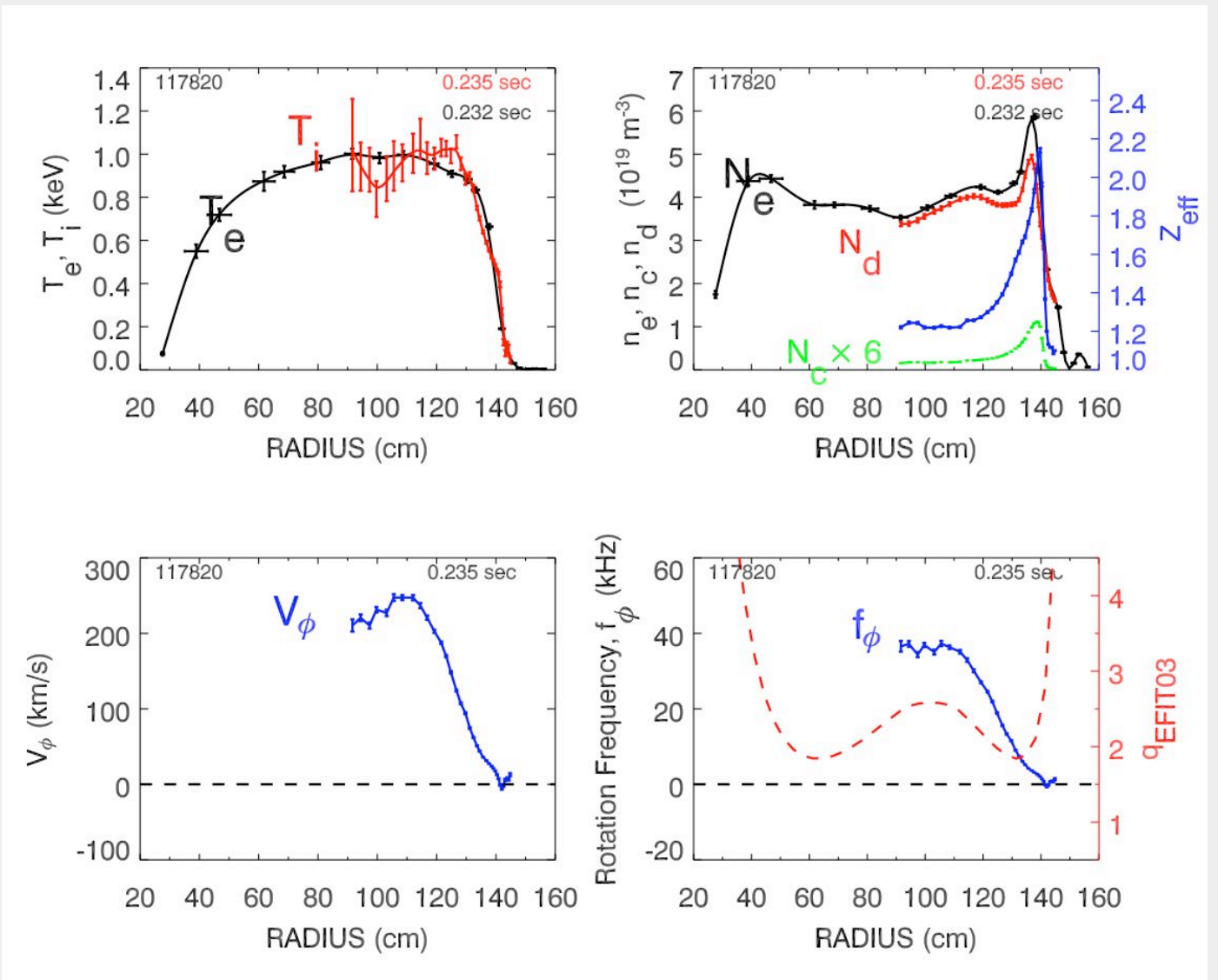


- Long pulse discharge 116313
- Late in discharge with degraded confinement and high density $T_i = T_e$, giving cross-check of calibration of two diagnostics
- Accumulation of carbon in core yield flat N_d profile despite peaked N_e

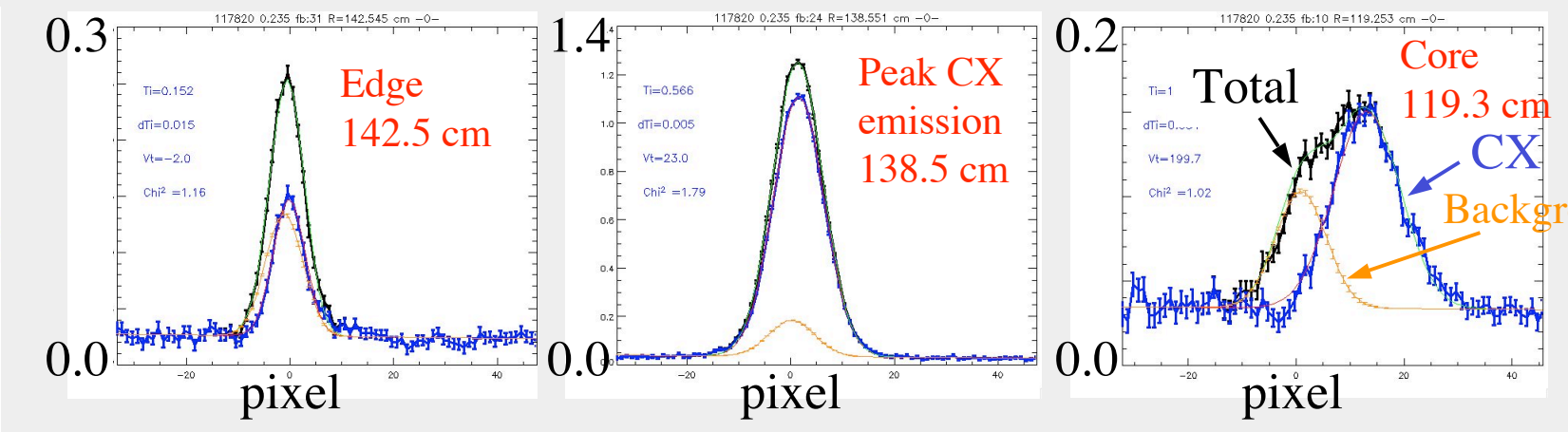
H mode Discharge 117820



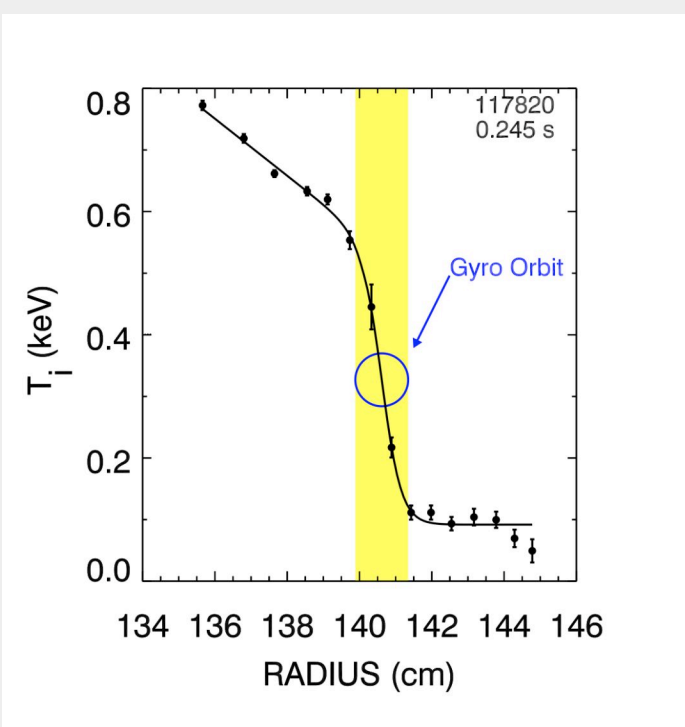
- Dynamics of long-pulse discharge 117532



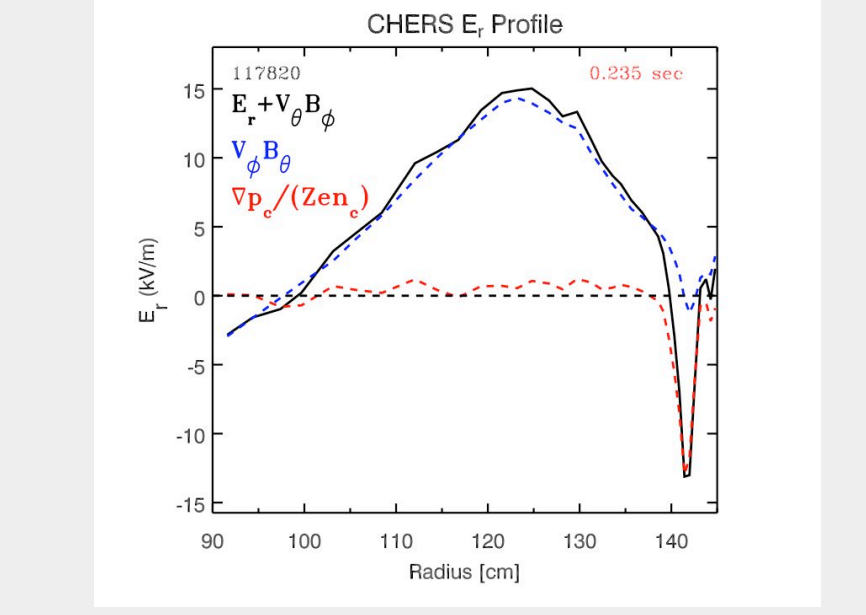
- This is an H mode discharge with strong central reverse shear
- A characteristic build up of carbon is observed near the plasma edge as core N_c decreases
- An uncharacteristically steep edge T_i gradient develops



- Spectral fits showing competition of Background emission with CX emission
- Background spectra is determined from separate background view



- Width of T_i gradient is consistent with gyro orbit diameter



- Toroidal rotation leads to positive E_r in core
- Here an unusually steep pressure gradient leads to a negative E_r at edge.