Supported by

Diagnostic Upgrade Plans

David Johnson
PPPL

For the NSTX National Team

Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
SNL
UC Davis
UC Irvine
UCLA
UCSD
U Maryland
U New Mexico
U Rochester
U Washington
U Wisconsin
Culham Sci Ctr
Hiroshima U
HIST
Kyushu Tokai U
Niigata U
Tsukuba U
U Tokyo
Ioffe Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

DOE Review of
NSTX Five-Year Research Program Proposal
June 30 – July 2, 2003

NSTX diagnostics for start of FY04 run

Confinement Studies

- Magnetics for equilibrium reconstruction
- Diamagnetic flux measurement
- Thomson scattering (20 ch., 60Hz)
- 1 mm interferometer [UCLA]
- FIReTIP 119μm tang. interf/polar. (4 ch) [UCD]
- Imaging X-ray crystal spectrum. ($T_i(0)$, $T_e(0)$)
- CHERS (T_i & v_f)(51 ch)

MHD/Fluctuations

- Locked mode coils
- RWM/error field sensors
- High-n and high-frequency Mirnov arrays
- Soft x-ray arrays (5) [JHU]
- Electron Bernstein wave radiometer
- MSE/CIF polarimeter [NOVA]
- Edge reflectometer [UCLA]
- Edge fluctuation imaging [LANL,PSI]
- MPGD tangential x-ray camera [ENEA,JHU]
- Ultra-fast tangential x-ray camera[PSI]

Plasma Monitoring

- Fast visible cameras [LANL]
- VIPS-1, VIPS-2:Visible spectrometers
- VB detector (single chord)
- SPRED: UV spectrometer (CCD)
- Trans. grating imaging spect. [JHU]
- 1-D CCD H_a cameras [ORNL]
- Visible filterscopes (H_a, OII, CII) [ORNL]
- Midplane tangential bolometer array
- IR cameras

Fast Particles

- Fission chamber neutron measurement
- Fast neutron measurement
- Scanning neutral particle analyzer
- Scintillator fast lost ion probe

Edge/Divertor

- Fast scanning edge probe [UCSD]
- Edge Doppler spectroscopy: (T_i & v_f,v_q)
- Divertor fast camera [Hiroshima]
- Divertor bolometer
- Fast pressure gauges [UWash]
- Target Langmuir probes [ORNL]
- Scrape-off layer reflectometer [ORNL]

Diagnostic upgrades are phased to support planned research

Upgrade	Research Areas of Interest							Development/Deployment				
	MHD	Transport	HHFW	EBW	CHI	Boundary	Integr'n	FY03	FY04	FY05	FY06	FY07
Additional magnetics	√		√		√	√	√	■	■	■	■	■
CHERS upgrade	√	√	√	√	√	√	√	■				
Imaging x-ray crystal		√						■				
EBW antenna with local limiter				√				■				
Fast lost-ion probe	√	√						■				
MSE/CIF (10ch / 19ch)	√	√	√	√	√		√	■	■			
Additional x-ray cameras	√				√		√	■	■			
FIReTIP upgrades	√	√	√	√	√	√	√	■	■			
Line-filtered cameras		√				√		■		■		
Tangential microwave scattering		√						▒	■			
MPTS (30ch / 90Hz / 40ch)	√	√	√	√	√	√	√		■	■	■	
Fast reciprocating probe	√	√	√	√		√			■			
Horiz. divertor bolometer						√	√		■			
Microwave backscattering	√	√							■			
Edge Doppler upgrade	√	√	√	√	√	√	√		■			
Deposition monitors						√			■			■
Poloidal CHERS	√	√					√		▒	■		
MSE/LIF	√	√	√	√	√		√		▒	■		
Planar LIF visualization	√	√				√			▒	■		
Neutron collimator		√							▒	■		
Langmuir probe upgrades						√			▒	■	■	
Divertor visible spectrometer						√				■		
Fast IR camera					√	√				■		
Vertical divertor bolometer						√	√			■		
Imaging reflectometer	√	√								▒	■	
Helium-jet spectroscopy						√	√			▒	■	
Divertor reciprocating probe						√				▒	■	
Charged fusion product det'r	√	√									■	
Divertor Thomson scattering						√	√				▒	■
Divertor UV spectrometer						√						■
Energy extract analyzer						√						■

Highlighted diagnostic upgrades

MHD

- Soft x-ray arrays [JHU]
- Ultra-fast tangential x-ray camera [PSI]
- MSE/CIF polarimeter [NOVA]
- MSE/LIF polarimeter [NOVA]

Turbulence

- Microwave backscattering [UCLA]
- Tangential microwave scattering
- Imaging reflectometry [UC Davis]
- Edge fluctuation imaging [NOVA, PSI]

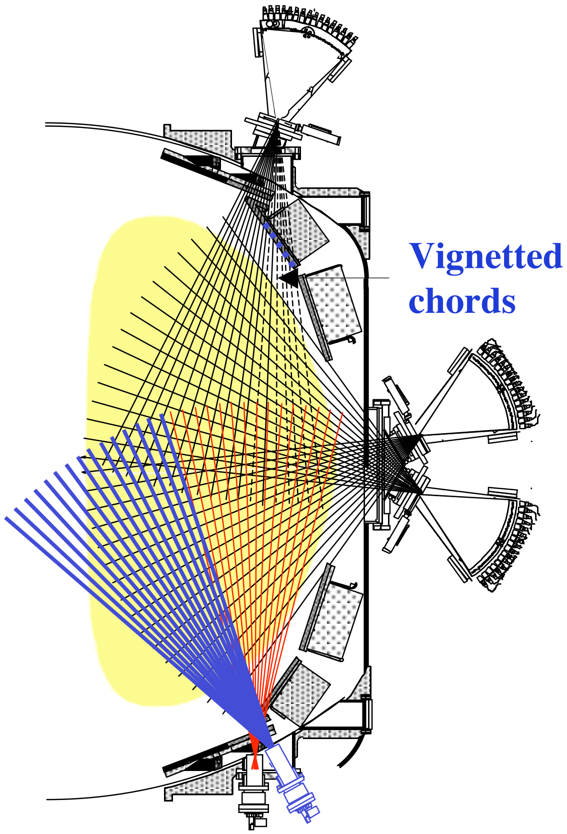
Transport

- CHERS
- Thomson scattering

Edge and Divertor

- Fast scanning edge probe [UCSD]
- Edge Doppler spectroscopy
- Divertor Thomson scattering

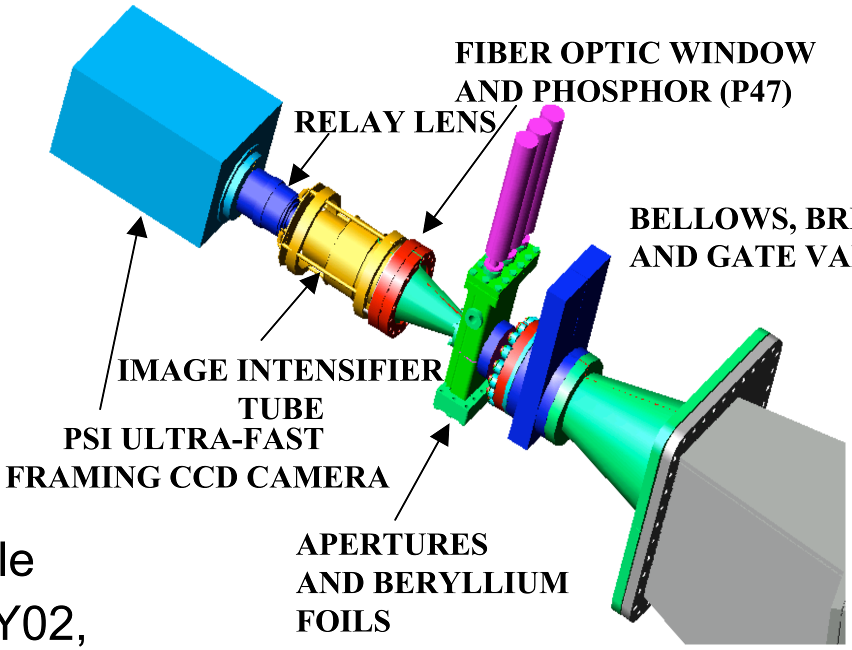
Additional SXR arrays will improve tomographic capability for understanding of internal MHD



- Recently the large SXR arrays were supplemented by a compact re-entrant array that eliminated vignetting in the vertical views.
- A top-view large array has been added at a second toroidal position, which will be useful in studying the toroidal mode structure of RWM modes in FY04 run.
- The data acquisition is being upgraded from 200 600 kHz to better resolve fast-ion induced MHD.
- In FY04, a second compact array will be added to give m=2 tomography capability.
- In FY05-FY06, plan to install additional compact arrays to provide tomography for m ≤ 3.

D. Stutman, M. Finkenthal, K. Tritz, L. Delgado-Aparacio

Tangential 2-D X-ray cameras will provide fast visualization of MHD and constraints on EFIT

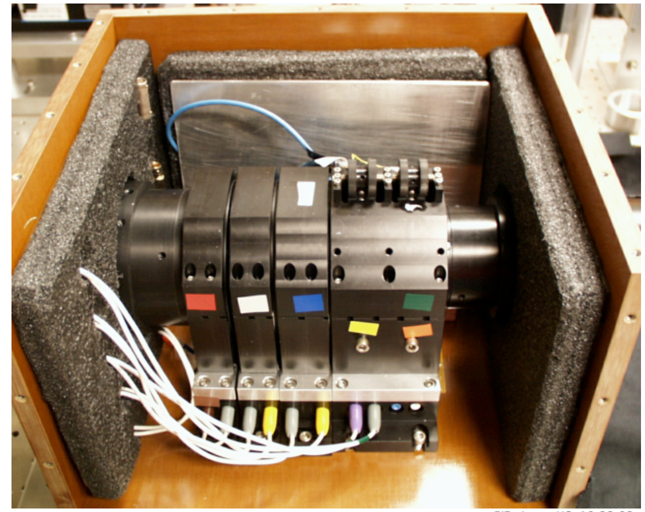


- Resolve higher-m structures on inboard periphery of plasma.
  - sightlines || to B
- PSI-V CCD camera
  - 64x64 pixels
  - 300 frames at up to 500 kHz
- Scheduled for operation in FY04 run.
  - being calibrated in lab.
- A second wide-angle tangential pinhole camera has been operational since FY02, and is based on a 12x12 pixel Micro-Pattern Gas Multiplier.
  - continuous frame rates up to 100 kHz
  - selectable energy sensitivity
  - zoom/pan capability recently added.
- Development of larger 32x32 MPGM arrays is planned.
- Time-integrated images from these cameras will also provide constraints the on equilibrium reconstruction.

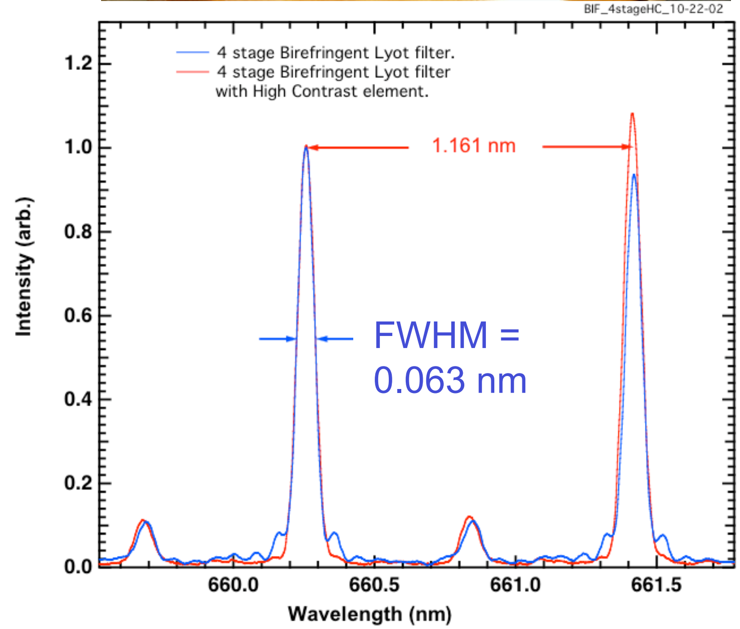
S. vonGoeler, B. Stratton, D. Pacella, K. Tritz

Difficult MSE polarimetry adaptations will be tested in FY04 run

- MSE pitch angle measurements will provide a critical constraint on EFIT, and the resulting J profile evolution can be compared to simulations to guide our path to high □, high NICD fraction.
- Extensive development has succeeded in producing the narrow-bandpass, high throughput filter needed to isolate a single Stark component at low field.
- A collection system viewing the heating beam has been installed with 10x the optical throughput of the TFTR system.
- Implementation plan:
  - 4 spatial channels at beginning of FY04 run
  - 10 channels mid FY04 run
  - 19 channels for start of FY05 run

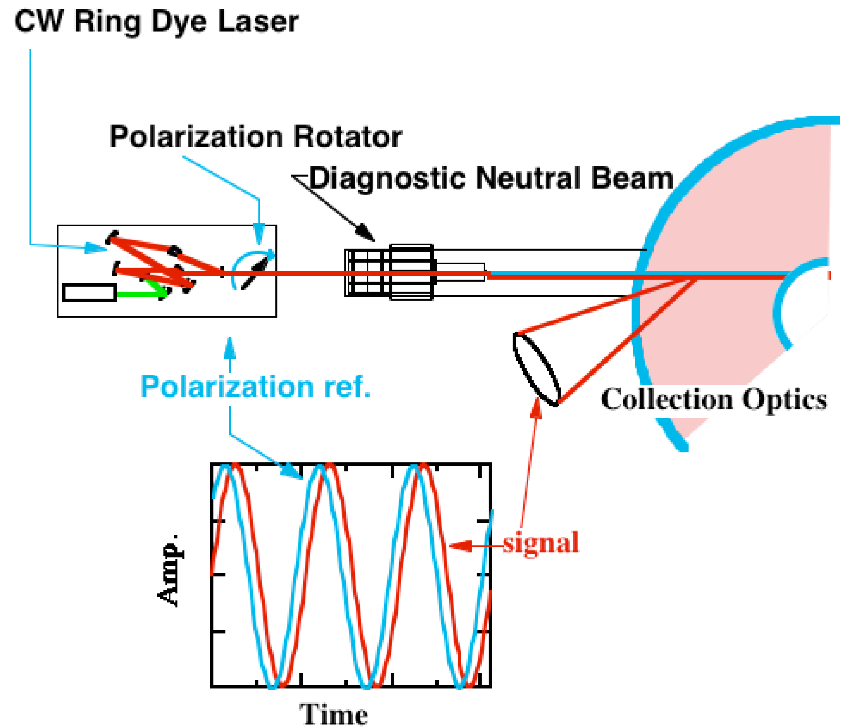


BIF_4stageHC_10-22-02



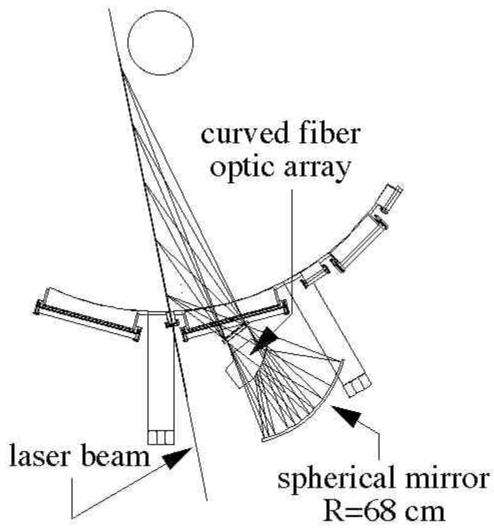
LIF-enhanced MSE will measure pitch angle without E_r effects

- A laser coaxial with an H^0 beam is used to optically pump the beam atoms.
- Linear polarization of the laser is rotated and phase between laser polarization & fluorescence ➡ measure pitch angle.
- Low cost, compact CW DNB operates at 40keV, 30mA, 1.2cm dia.
- By dithering □$_{laser}$ or V_{beam}, can measure Stark shift and therefore |**B**|, diamagnetic effect ➡ pressure profile.
- On NSTX, DNB and laser would be injected radially to eliminate E_r effects.
- Using both MSE systems, permits separation of j and E_r.
- Progress to date has been hindered by poor DNB species mix and large □$v_{||}$.



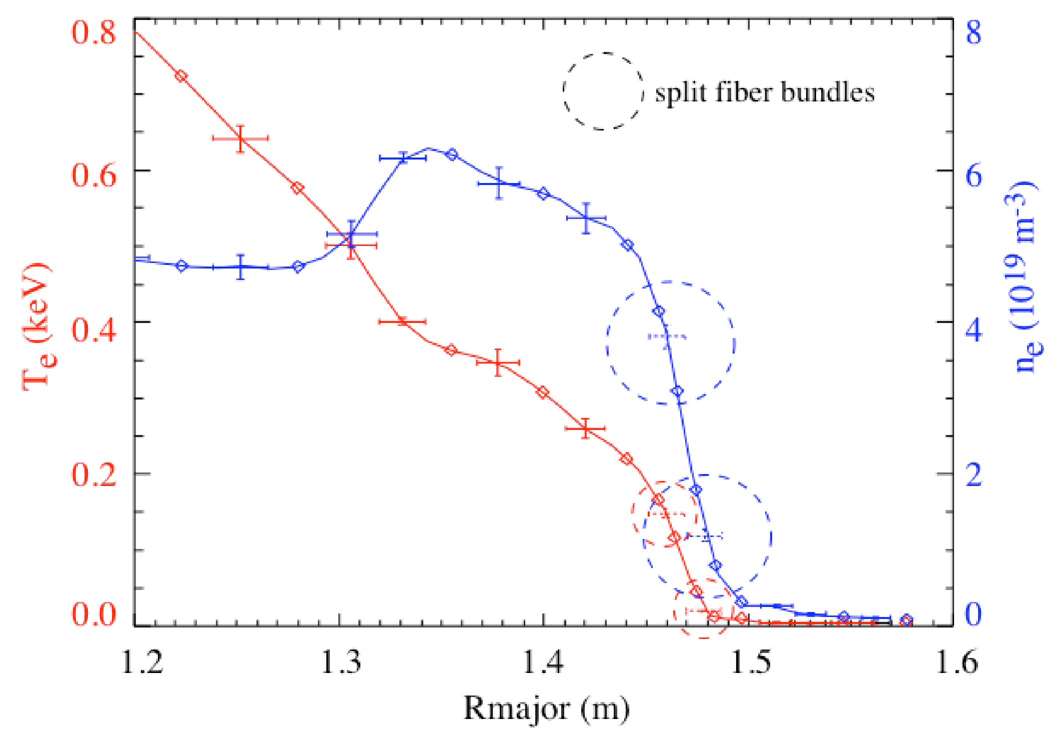
- A new source, developed by Berkeley, and new low-ripple HV supply is being installed on helicon plasma. Will make beam in August.
- Install on NSTX in late FY04 - FY05.

Full implementation of Thomson system would benefit many studies



- Currently 20 spatial channels instrumented, and two 30 Hz Nd:YAG lasers are used.
- System is designed to accommodate ~40 channels and 3 lasers, and much of the hardware to support the full system is in place.

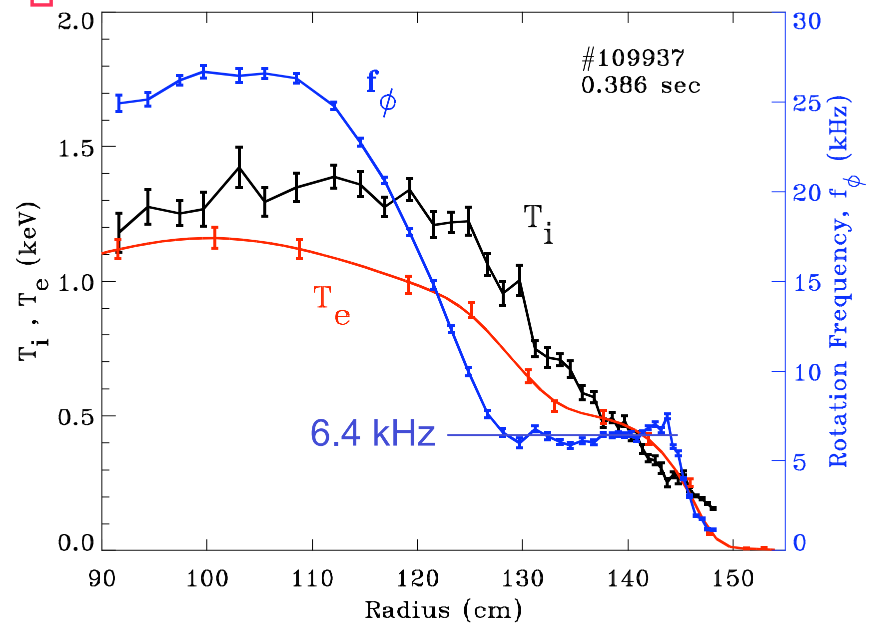
- Small uncertainties permit full use of optical resolution in determining gradients.
- Full implementation is staged in FY04-06

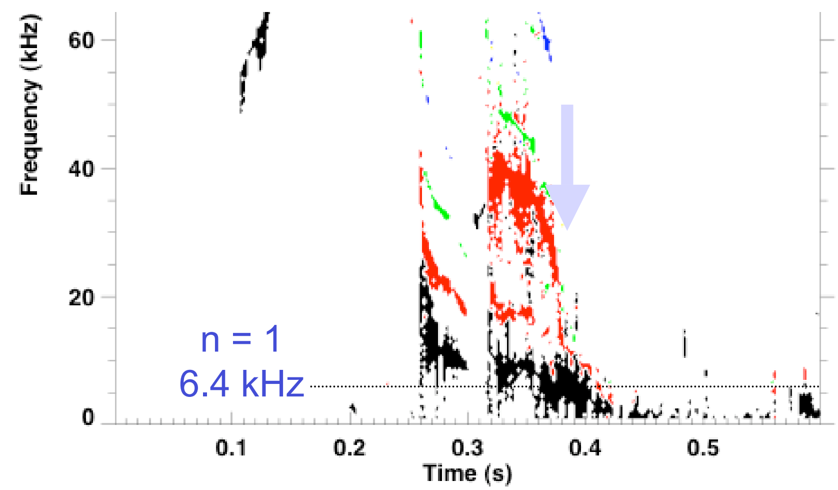


B. LeBlanc, R. Bell, D. Johnson

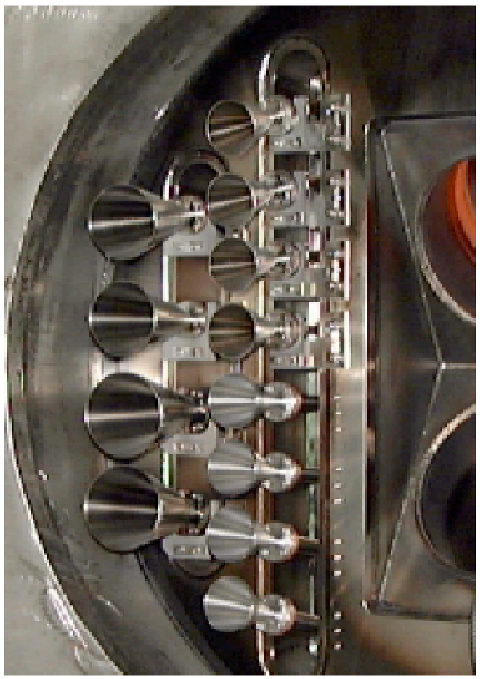
Upgraded toroidal CHERS diagnostic provides detailed T_i and v_{ϕ} profile data

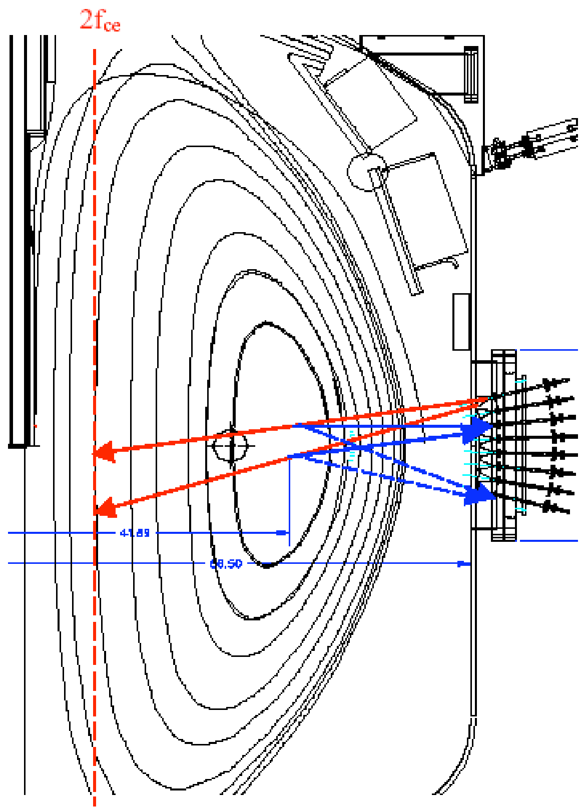
- Recently upgraded from 16 to 51 channels and obtained preliminary hi-resolution data during FY03 run.
- Optimized view of beam provides 3.0 cm core and 0.6 cm edge resolution.
- Dedicated background system is used to properly subtract cold edge component.
- Can also derive N_{carbon} (R)
- Use of parallelized cluster should permit between-shots analysis.
- Currently designing poloidal CHERS diagnostic for installation in late FY04.
  - Atomic physics corrections to $\mathbf{v}_{\phi}$ simpler at low field on ST





Microwave backscattering will probe for existence of high-k turbulence

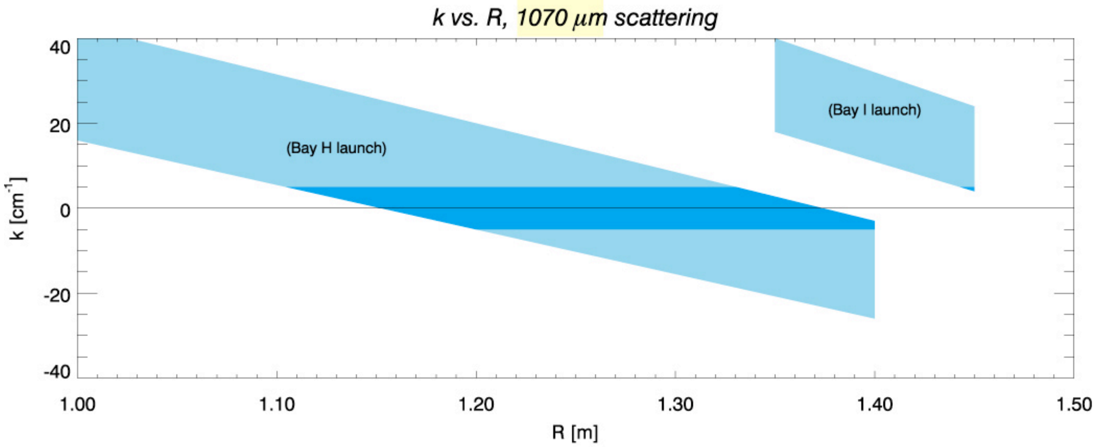


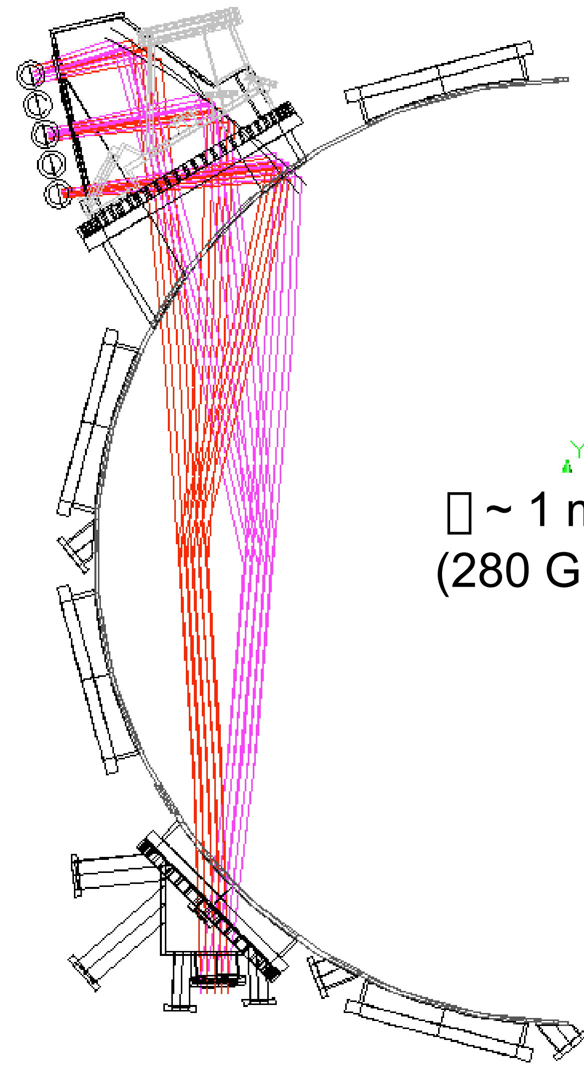


- NSTX provides a unique opportunity to probe for ETG turbulence in a device where low-k turbulence is suppressed and electron transport is dominant.
- To investigate existence of high-k turbulence on NSTX, microwave backscattering using existing reflectometer horn array is planned.
- Plan to use 100 GHz source for probing $k_r \sim 40\ cm^{-1}$.
- Plan to make initial measurements in FY04.

Tangential microwave scattering will measure high-k turbulence with spatial and spectral resolution

- To investigate high-k turbulence on NSTX in FY05, detailed design is underway for a tangential microwave scattering system.
- Using 5 detectors this system would simultaneously sample a relevant range of k_r $k_{\perp}\rho_e$ ~ 0.1 - 0.3, and at r/a ~ 0.4 - 0.8, where ETG turbulence is expected.
- Scattering occurs in a region with a radial extent of ~ 4 cm near the tangency point, and Δk_r ~ 2 cm^{-1}.
- A steerable collection mirror provides flexibility in the choice of R and k_r.





λ ~ 1 mm (280 GHz)

E. Mazzucato, H. Park, N. Luhmann, T. Munsat

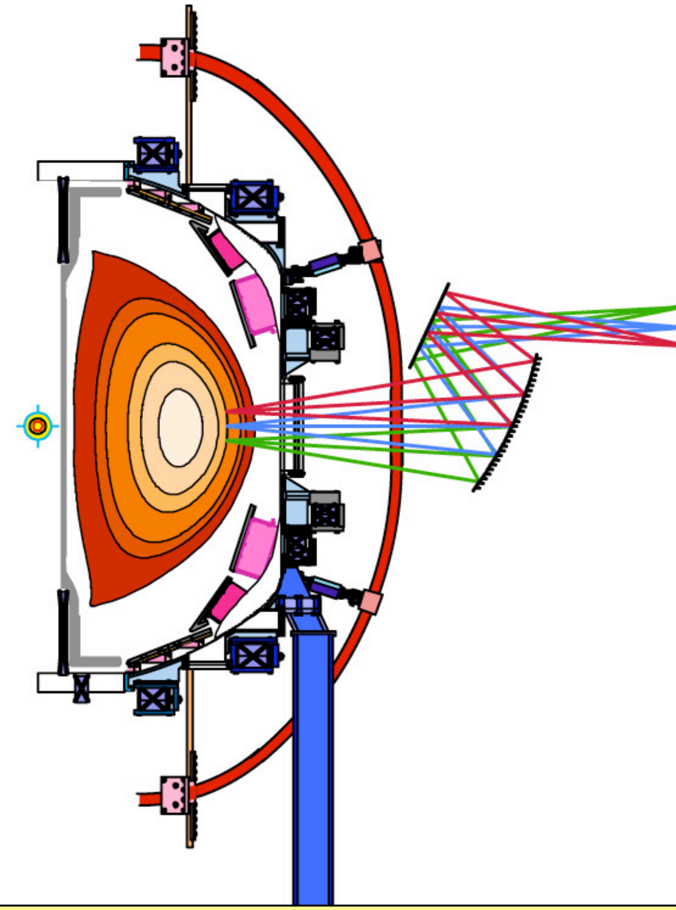
NSTX

Imaging reflectometry is planned as a sensitive probe for low-k turbulence

- Has promise to extend range of measurable fluctuation levels and wave-numbers over conventional reflectometry techniques.
  - extensive laboratory characterization
- Technique is being tested on TEXTOR, supporting development and enabling comparisons at different aspect ratio.
- Provides image of turbulence over poloidal range on NSTX:

  ~ 12 cm (full angular coverage)

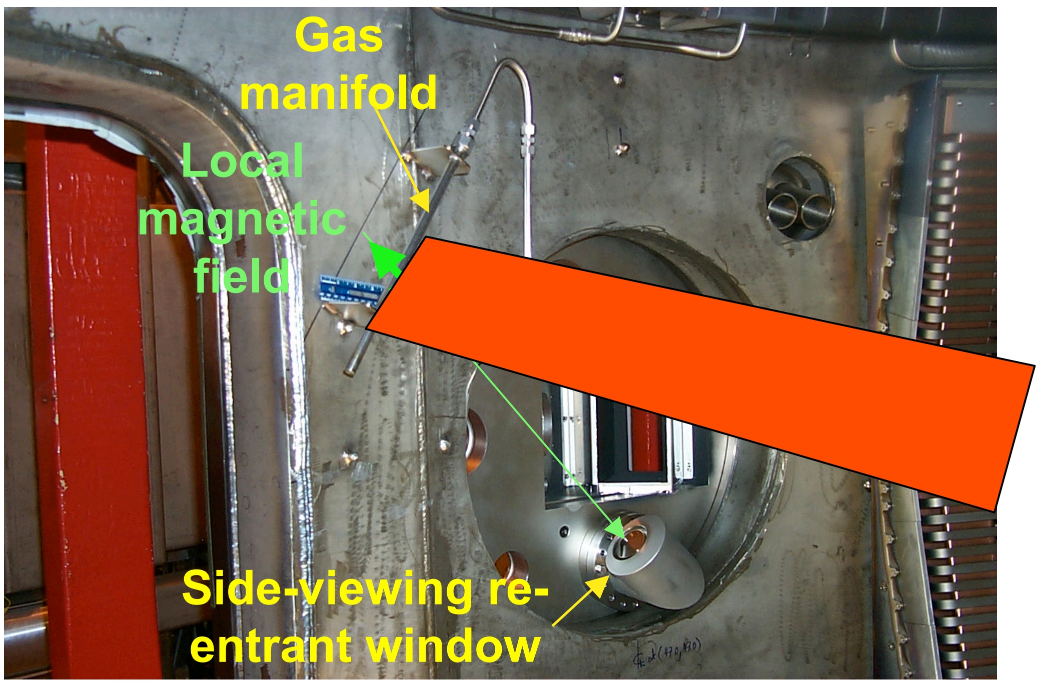
  ~ 20 cm (reduced angular coverage)
- Spatial resolution: ~ 1 cm
- $k_{\square}$ resolution: ~ 0.3-3 cm^{-1}
- Planned for installation on NSTX in FY06.

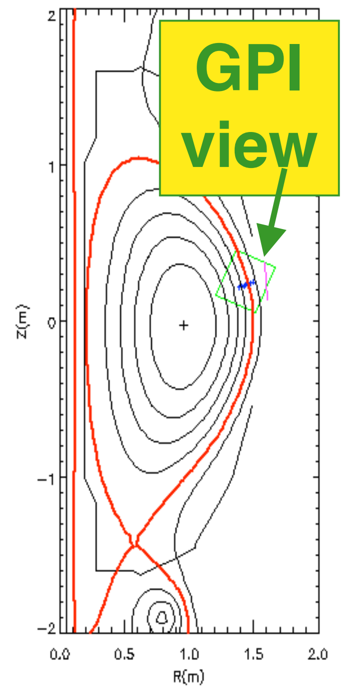


NSTX has favorable access with window close to fluctuating plasma

Gas puff imaging and planar LIF will probe edge turbulence with finer detail

- Turbulent structures are illuminated by puffing gas through a linear manifold and are viewed end-on with an ultra-fast camera.
- Recently optical throughput was increased x10. Added S/N should help to resolve smaller structures, and improve comparisons with theory at high k.
- Planar laser-induced fluorescence (PLIF) is also planned using a burst 100 kHz laser in a planar geometry to edge field to induce LIF with puffed Ar.

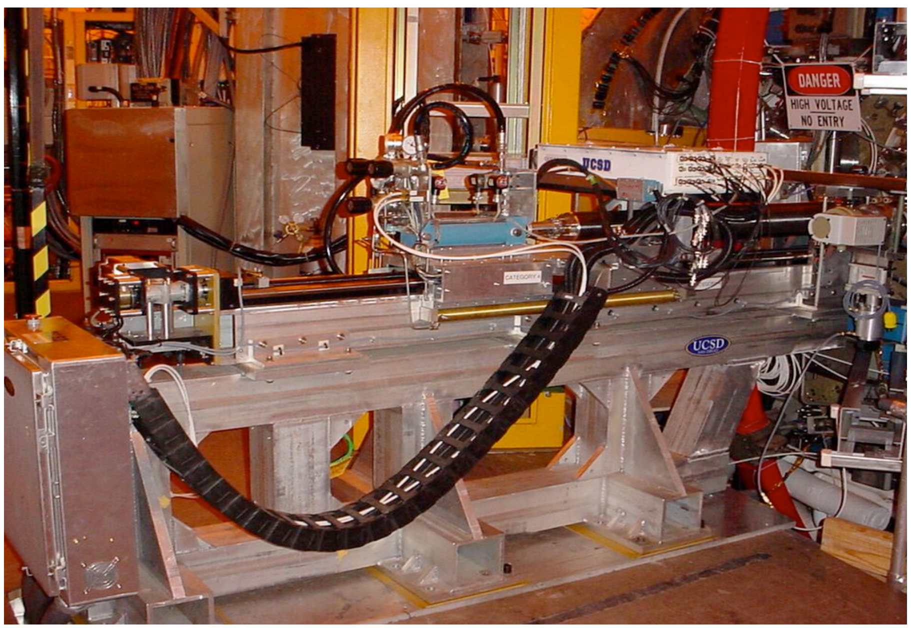


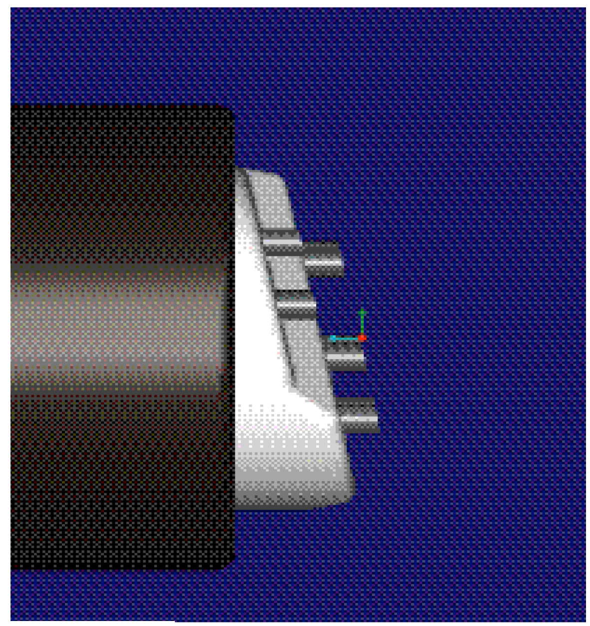


S. Zweben, R. Maqueda, F. Levinton

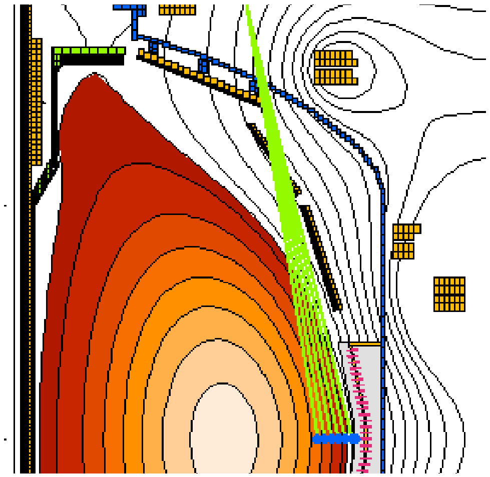
Fast reciprocating probe will measure edge and SOL profiles and turbulence

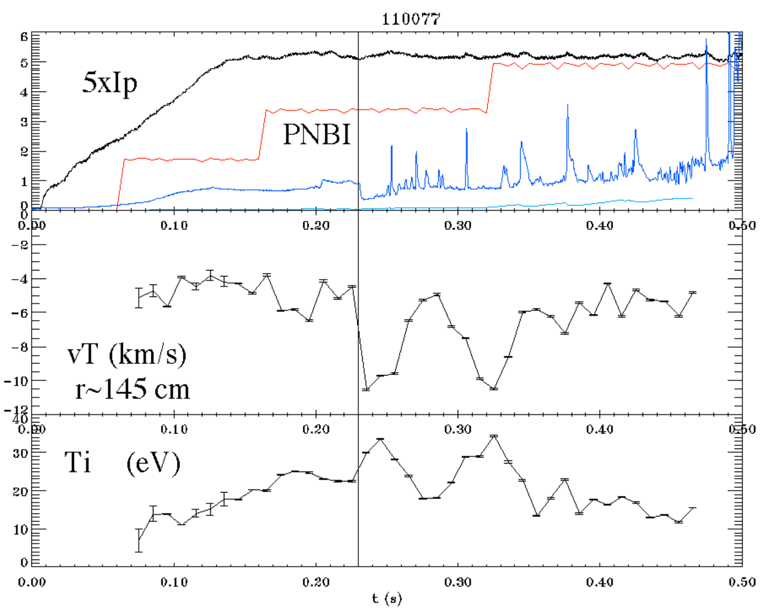
- Will be upgraded in FY 04 with probe head featuring 10 tips positioned on a contour matching the flux surface geometry 17 cm below the midplane.
- Two tips will be used as a double probe to measure T_e and n_e profiles.
- Other tips will be used to measure E_r and E_{pol} and fluctuations.
- Additional upgrades being planned for this system include an interchangeable probe head with fast pickup coils to measure fluctuating magnetic fields, and electronics for extracting T_e fluctuations.





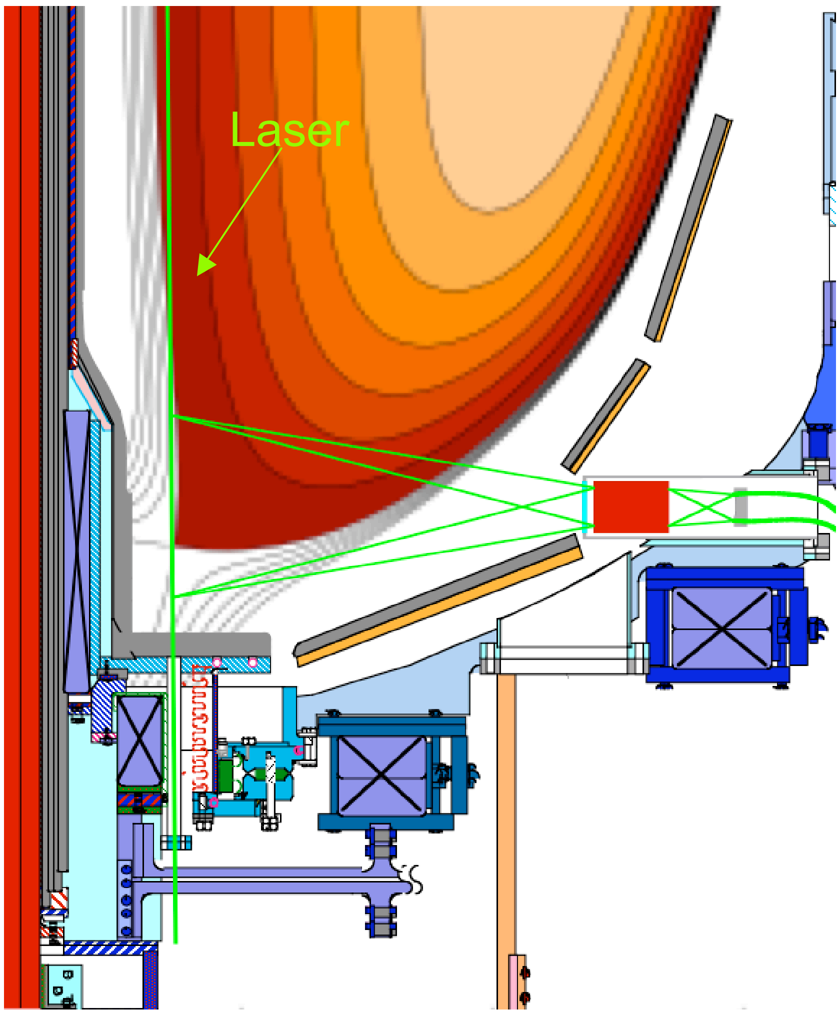
NSTX edge Doppler spectroscopy upgrade will measure carbon ion temperatures and flows near separatrix





- Recently installed system features 7 toroidal and 6 poloidal chords from 140 to 158 cm and 10 ms time resolution.
- Uses intrinsic lines (no beam needed):
  - CIII triplet (48eV) near separatrix
  - CIV doublet (64 eV) farther inside
  - HeII (54 eV) with puffing
- Measures T_i, $v_{\square}$, and $v_{\square}$.
- Currently system is stopped down, throwing away 97% of light available.
- Planning for more spatial channels (x3) and faster CCD detector (~ 1 ms frame time) for FY05 run.
- Localization is possible using spatial inversions with EFIT equilibria. Possible to derive local edge $E_r = (v \times B)_r - \square p/eZn$.

Divertor TS concept uses existing vessel ports



- Horizontal dome port provides opportunity for f/8 collection optics through slot in passive plate.
- Lens would image beam onto 21 fiber bundles with 1.5 cm resolution along laser beam.
- Laser input and output windows on existing ports that are part of center stack assembly.
- Real-time beam position control would be needed.
- Detection will be multiplexed x3 to save cost.
- Concept is compatible with high triangularity equilibria.
- Design must be integrated with redesign of secondary passive plates and/or cryopump.

Summary

- Significant new capability will enable the planned research on NSTX.
  - Research emphasis on ST confinement and stability at high beta is shaping NSTX diagnostic priorities.
- NSTX is benefiting from the efforts of a national team of diagnostic experts.
- Much of this effort is in response to challenges and opportunities specific to the ST configuration. (Examples: MSE development, EBW radiometry, search for ETG turbulence)
  - Just as ST program seeks to broaden toroidal physics database, some of the new diagnostic techniques developed for NSTX may also have broader application for other ICC's and for tokamaks.