Neutron Collimator

SPG

- Beam current drive studies will be a key aspect of the initial NSTX-U program.
- Pending confinement and profile assumptions:
  - Fully non-inductive: $0.7<f_{GW}<1.0$, 900 kA < I_P <1100 kA
  - Highest sustained β_T: $0.7<f_{GW}<1.0$, 1000 kA < I_P <1300 kA
- These conditions would prove difficult for the present FIDA system.
  - Cases with NBCD most interesting for scenario physics might be poorly diagnosed w/ regard to fast ion dynamics?
- Desire a diagnostic that i) can provide useful data over a range of higher current and f_{GW} conditions, and iii) be easily compared to the outputs of codes like TRANSP + NUBEAM.
- Neutron collimator can be easily compared to NUBEAM calculations..
- Nice to have 3-4 chords, 5-20 msec time resolution is good enough for quiescent scenarios.
  - Should be faster the τ_E or τ_{CR}.
  - Faster time resolution would be nice for mode-induced loss dynamics, but may suffer for S/N.
- Should take representative Upgrade Scenarios and calculate the expected signals for various scenarios.
  - Determine if a "realistic" collimator design can discriminate against D_{FI}, different source tangency radii, various outer gaps.
  - Compare simulations to those of other fast ion diagnostics to determine the best tool for these scenarios.
  - If there are better solutions than a collimator, then great.
- Industry vs. University vs. PPPL: Any of the above.

Fusion source profile measurement via charged DD fusion products (Boeglin(FIU), Darrow, Roquemore)

- Goal: Measure DD fusion rate profile to determine radial profile of full energy neutral beam ions
  - 3 MeV p, 1 MeV T & 0.8 MeV ^{3}He from DD fusion unconfined in NSTX-U
  - measure flux of these over fan of collimated detectors at wall & invert fluxes to get emission profile $Y_{DD}(R)$
  - Fusion rate nearly all due to beam-plasma reactions, so compute beam ion density $n_{NBI}(R) = k\, Y_{DD}(R)/n_i(R)$
  - Strongly weighted to full energy beam ions by fusion cross section
- Resolution: 5-10 cm & 1-5 ms
- Supports NSTX-U research on:
  - Redistribution of NB-driven current
  - Fast ion redistribution & loss by Alfvénic & MHD modes
- Suitable for university collaboration: FIU now building prototype

FIDA (& BES) Imaging

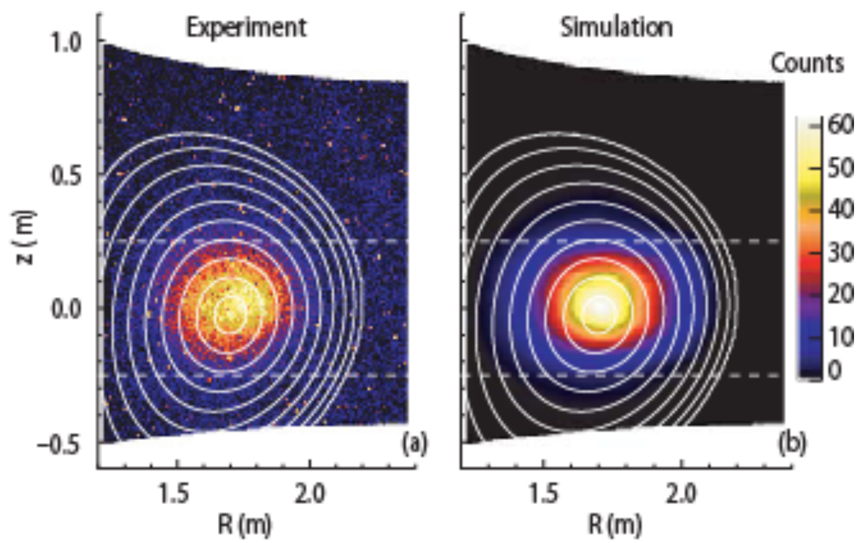
Physics: Vertical & Radial profile of co-tangential fast ions (and of injected neutrals)

Measured Quantity: Blue-shifted FIDA light (red-shifted BES light) obtained using bandpass filters & an imaging camera

Resolution: ~1 cm; ~ 5 ms; poor energy

Upgrade Goals: NBCD & Energetic Particles

Collaborator?: Yes

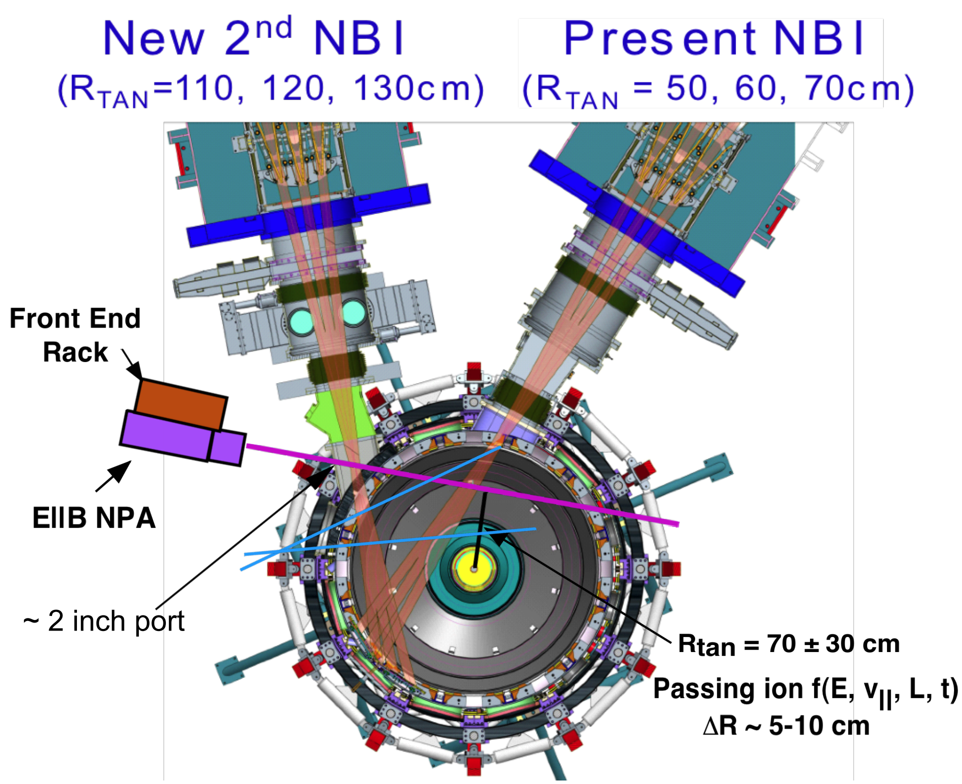


PPCF 51 (2009) 055001

NSTX-U diagnostic proposal: upgrade of ssNPA (M. Podestà, D. Darrow, W. Heidbrink, A. Bortolon)

- Goal: measure radial profile of escaping fast neutrals with improved spatial resolution
  - Complement NPA, FIDA, neutrons, sFLIP, …
  - Good localization in pitch, energy-resolved spectra
    - TBD: focus on trapped or passing fraction -> viewing geometry ?
- Use *arrays* of diodes; combine both current and pulse-count modes for time + energy resolved measurements
  - Spatial resolution: 8 - 16 radial channels -> 10 - 5 cm
  - Time resolution: ~1 MHz (current mode), ≥ 100 Hz (pulse-height mode)
  - Energy resolution: ~10 keV (pulse-height mode @ 100Hz acq. rate)
- Supports NSTX-U research on
  - Redistribution of NB-driven current
  - Fast ion loss/redistribution by Alfvénic modes
  - RF interaction with fast ions
- Project is OK for external collaborations

Installation of the E||B Neutral Particle Analyzer (NPA) with a Fixed Sightline on NSTX-U



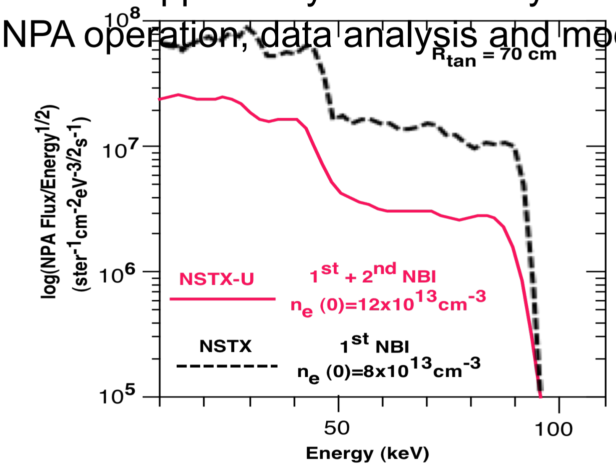
- E_{max}/E_{min} = 30 with 35 energy channels simultaneously for both H and D.

- Energetic ion spectrum, $f(E, v_{||}, L, t)$, is core-localized to sightline intersection with 1st NBI.

- E_D = 1–300 keV, E_H = 1-600 keV, $\Delta E/E \sim$ 2-5%, $v_{||}/v \sim 0.8 \pm 0.1$, $\Delta L \sim$ 20 cm, $\Delta t \sim$ 0.1 ms.

- High resolution $f(E, v_{||}, L, t)$ for NBI-driven I_p scenarios including MHD/*AE effects thereon.

- Prime opportunity for university collaboration on NPA operation, data analysis and modeling.



TRANSP E||B NPA Simulation

- NSTX-U E||B NPA key redeployment elements:
  1) Remove massive scanning mechanism and install NPA on a small fixed pedestal.
  2) Reuse all existing support equipment (CAMAC, electronics, cabling, pumps, etc.).

FIReTIP-II for NSTX Up-grade

► Rearrange of FIR lasers and beam paths : launching (Bay-K ⇨ Bay-L & K),

► Improve signal level and resolution by (a) humidity control (40% ⇨ < 5% for up-grade, ~20% achieved in 2011), (b) two color system (edge channel), (c) new detector technology

Provide real-time electron density data for feedback control
Absolute measurement of density for Thomson scattering calibration
Density fluctuation measurement for T&T /MHD(*AE, EPH-mode, ELM etc) studies
Accurate edge density by two-color system for boundary/SOL study

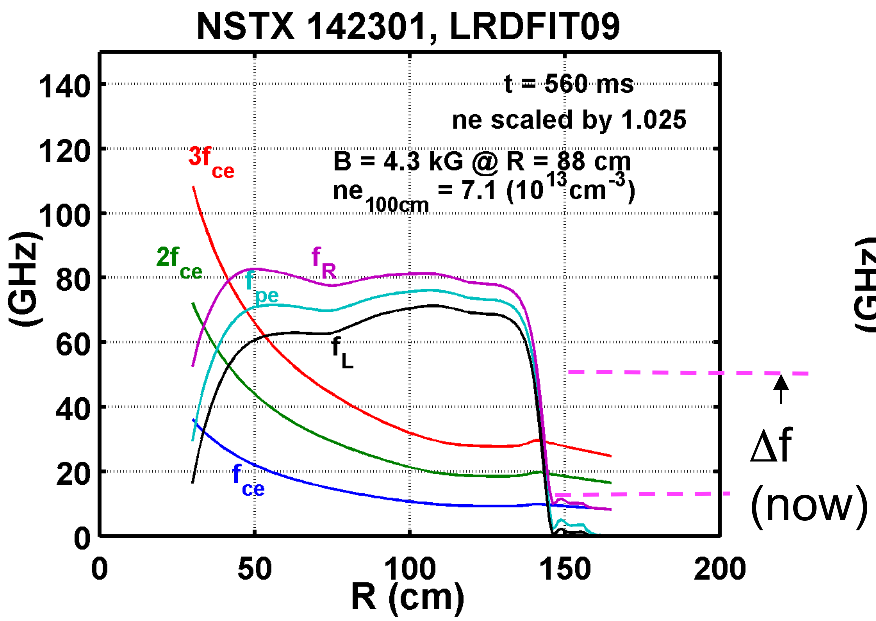
► Focusing one inboard channel (R_T ~50 cm), one outboard channel (R_T ~120 cm), one edge channel (R_T ~145 cm) with 4 MHz bandwidth will support many NSTX Upgrade research plans;

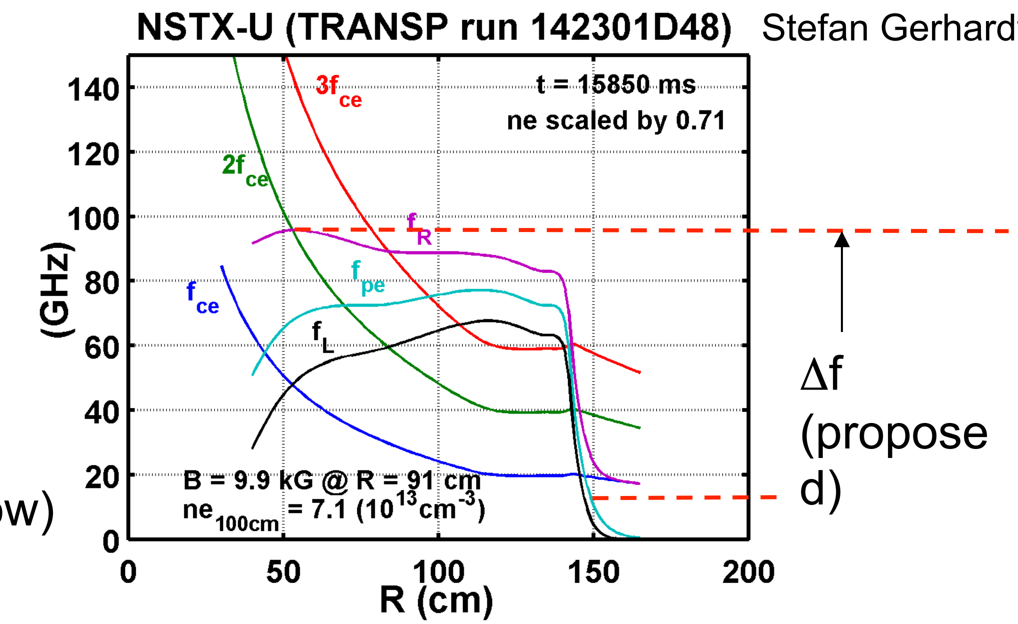
- density feedback control for current ramp-up and flat-top (scenario-2014)
- turbulence understanding and ST confinement trends (T&T-2018)
- pedestal structure understanding (boundary-2011)
- measure *AE activity by 2nd NBI-compare to existing NBI (energetic particle-2015)
- comparing diverter gas injection to mid-plane gas injection/assess density assimilation (ITER-2012)

-accurate density measurement (especially for edge) is critical for pedestal transport and ELM mitigation, can be incorporated for ITER and ST-FNSF

► FIReTIP-II will be collaboration with plasma diagnostics group of UC Davis

Profile reflectometry: Increased magnetic field combined with frequency upgrade provides access to new physics in NSTX-U





Stefan Gerhardt

See: http://w3.pppl.gov/~sgerhard/NSTXU_FBT_Res0.pdf

- **New physics:**
  - detailed particle transport studies via gas modulation – includes SOL/edge/outer core
  - the effect of stochastic fields on the edge/SOL profile
  - investigation of the role of lithium, snowflake divertor, cryo-pumping, etc. in governing particle transport and density control in edge/SOL of NSTX-U
  - investigation of simultaneous O & X-mode data provides an additional constraint on EFIT
  - study of the spatial extent and effect of the EHO on edge density profile
  - high temporal (~5μs) measurement of edge density profile evolution during L-H transition/ELMS

NSTX-U diagnostic proposal: upgrade of ERD (M. Podestà, R. E. Bell)

- Goal: upgrade Edge Rotation Diagnostic to improve spatial and temporal resolution
  - Complement CHERS/pCHERS with passive measurements
    - Measured lines: C III and He II
  - Keep basic configuration: toroidal + poloidal views
- Modify existing fiber holders; add 210μm fibers
  - Spatial resolution: ~20 radial channels, ≤1 cm resolution
  - Measurements in the range 135 cm < R < 155 cm
  - Time resolution: ~1 kHz (x10 with respect to present system)
  - Need new CCD camera
- Supports NSTX-U research on
  - Routine measurement of edge features, electric field
  - RF ion heating at the edge
- Project is more suitable for PPPL
  - Fiber holders for CHERS/pCHERS/RTV/FIDA must be re-designed
  - Analysis software already exists

Edge Reflectometer at the HHFW Antenna

- The present reflectometer measures the plasma density profile and localized density fluctuations in the edge region around the HHFW array.
- Needed for RF/plasma coupling studies, power losses to PDI, and antenna modification assessments.
- Reflectometer system ~13 years old and in need of refurbishing
- New |B| requires change in frequency sweep
  - Presently sweeping 5.7–26.8 GHz
    - First cutoff for 0.28 T is ~5.7 GHz
    - At 1 T, first cutoff will be at ~19 GHz
  - Will need 10–40 GHz to cover 0.5–1 T plasmas
- Existing instrument can be upgraded to cover 10–40 GHz
  - Need new phase detector, amplifiers and local oscillator
  - Maintain capability for edge-density profiles, PDI, and density fluctuations
- Existing waveguide horns do not perform well above 30 GHz
  - Existing launchers were optimized for the 6-26 GHz frequency range
  - Need to reduce diameter of launchers from 1.5” to 0.75” OD
  - Coaxial feed cables are rated to 40 GHz

Visible bremsstrahlung imaging of Alfvén eigenmode spatial structure (Darrow, Fredrickson, …)

- Goal: Obtain 2D images of AE structures to constrain fits of measured mode numbers and amplitudes to NOVA eigenmode calculations
- Method: Capture a tangential view of plasma, preferably at midplane, with widest possible rectangle in R & Z; view at VB wavelength with high speed 12-16 bit video camera
  - AE identification & modeling presently use Mirnovs for freq & n number, plus microwave reflectometer array for absolute ñ to match NOVA eigenmodes
  - Camera data would aid in selection between nearly degenerate modes
- Resolution: ~1 cm & ~20 μs
- Supports NSTX-U research on:
  - Redistribution of NB-driven current
  - Fast ion redistribution & loss by Alfvén modes
- Suitable for university collaboration

Outboard Langmuir Probe Array (OLPA) and ion-sensitive particle diagnostics

- Existing HDLP array likely to be removed in upgrade
- Propose: new OLPA to retain existing capabilities and cover larger extent of divertor floor for med. and low triangularity (Ne, Te, Vf, Vp, EEDF)
- Propose: *tile-mounted* ion-sensitive diagnostics to measure Ti (IEDF) and Vp at divertor floor
  - Basic system with similar spatial distribution as OLPA (order 1cm spacing)
  - Development to make *tile-mounted* plasma ion mass spectrometers (PIMS)
- Physics topics: heat transmission and sputtering i.e. *what* physical mechanisms reduce heat flux and impurity gen. at the target plate and *how much*
- Expansion: Prototype for *Inboard* LPA (ILPA)
- Collaboration? In-vessel hardware should probably be PPPL led

Heat flux to a biased PFC MAJ

$$V_f \neq 0$$

$$q_{surface}(V) \equiv \gamma(V) k T_e \Gamma$$

$$\gamma(V) = -\frac{eV}{T_e} + 2.5\frac{T_i}{T_e} + \cdots$$

$$\cdots 2\left[\left(1+\frac{T_i}{T_e}\right)\left(\frac{2\pi m_e}{m_i}\right)\right]^{-1/2} \exp\left(\frac{eV}{kT_e}\right)$$

Physical sputtering Yield

$$Y_{sputt.} = Y(M_{tar.}, M_{inc.}, E_0, \text{matl.prop.})$$

$$E_0 = V_p + E_i \approx \underbrace{3kT_e + 2kT_i}_{?} \approx \underbrace{5kT_e}_{???}$$

Why guess when you can measure?

BES: Expansion and Increased Resolution

D. Smith, R. Fonck, G. McKee, I. Uzun-Kaymak, *University of Wisconsin*

- **BES provides low-k ñ fluctuation measurements (0.1<r/a<1) for:**
  - Turbulence and transport investigations
  - Energetic particle-driven mode/GAE studies
  - Pedestal structure and instabilities
- **Increase number of channels from 32 to 64 (32 new detection channels)**
  - Simultaneously sample wide region of plasma
  - Extended poloidal capability (L_C~10 cm)
- **Implement wide-field 2D (~8x8) capability (new fiber bundles/mount)**
  - Turbulence imaging; direct shear flow measurement; nonlinear analysis
  - 2D correlation, wavenumber spectra, velocimetry
- **Increase spatial resolution (smaller viewing spots)**
  - Currently ΔX~2.5 cm; decrease to ΔX~1.5-2 cm (access higher-k)
  - Pedestal studies can especially benefit
- **Measure toroidal mode # of pedestal instab. (PB/KBM), zonal flows, xAEs**
  - Exploit new neutral beam injection system
  - Add toroidally-displaced viewing channels; also, measure background signal

BES Passive FIDA Reference View

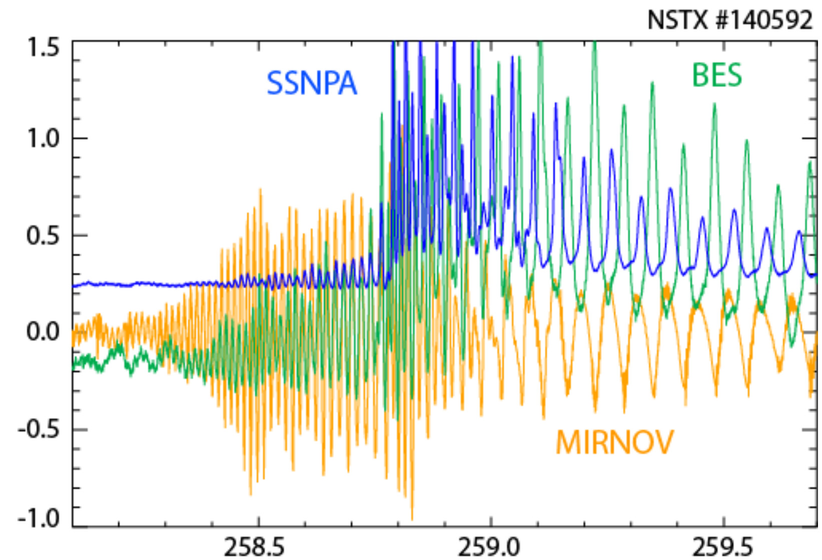
Physics: Validate BES eigenfunction measurements for modes that expel fast ions

Measured Quantity: Bandpass filtered light from a reference view that does not intersect a neutral beam

Resolution: Same as BES (run fiber to BES electronics)

Upgrade Goals: Energetic Particles

Collaborator?: Yes



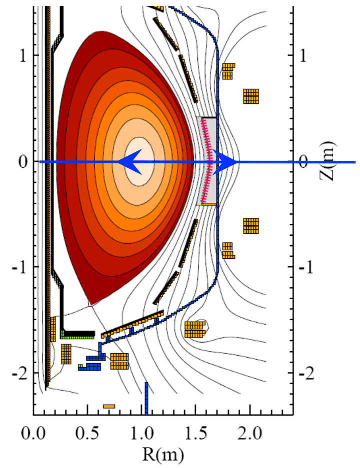
PPCF 53 (2011) 085007

Radial polarimetry: Direct measurement of magnetic field fluctuations: constraint on central q; can operate as radial view “simple” interferometer

Radial view is insensitive to density fluctuations as long as measurement close to mid-plane - where the equilibrium $B_{||}$ is small

Use simulated magnetic and density fluctuations associated with micro-tearing modes (Walter Guttenfelder) as input to calculate expected polarimetry signal

Results indicate that internal direct measurement of magnetic fluctuations is possible in NSTX

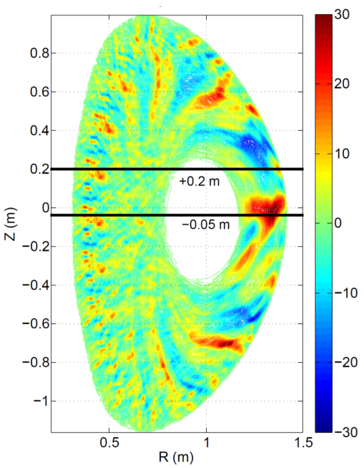


- Radial-view, retroreflects from center-stack tile
- Prototype single channel system to be installed in early August

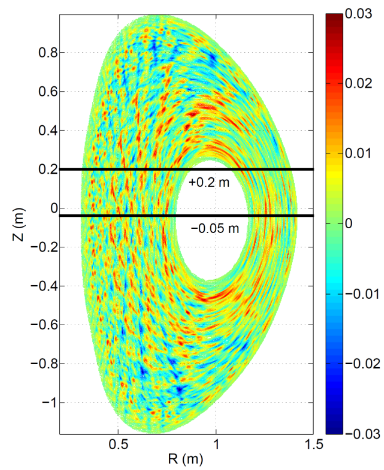
$$\Psi = 2.62\times10^{-13}\lambda^2\int B_{||}(z)n(z)dz$$

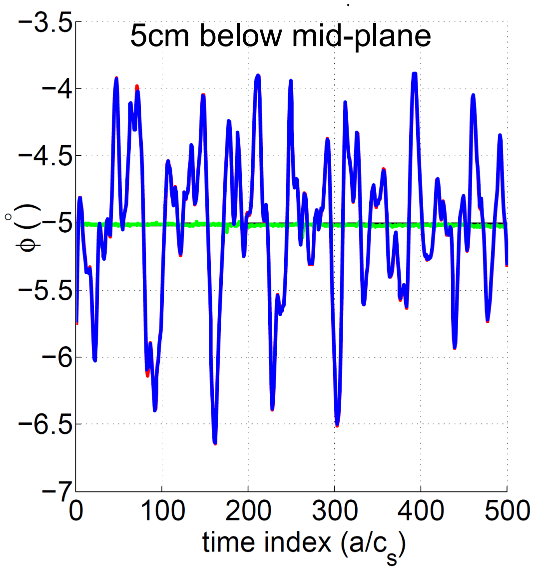
$$\tilde{\Psi} = 2.62\times10^{-13}\lambda^2\int\left[\tilde{B}_{||}(z)n_0(z)+B_{||,0}(z)\tilde{n}(z)\right]dz$$

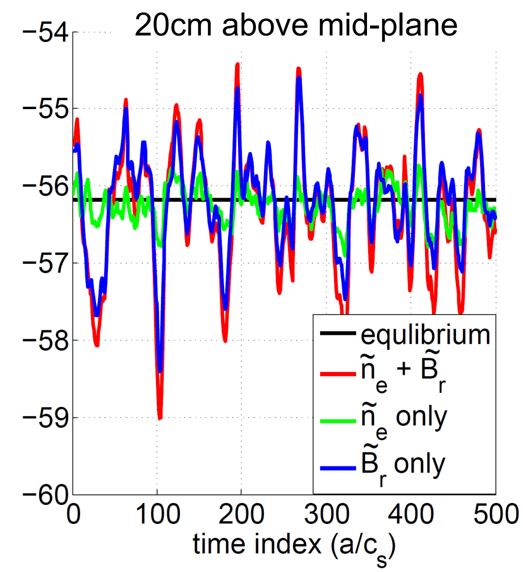
$\tilde{B}$



$\tilde{n}$

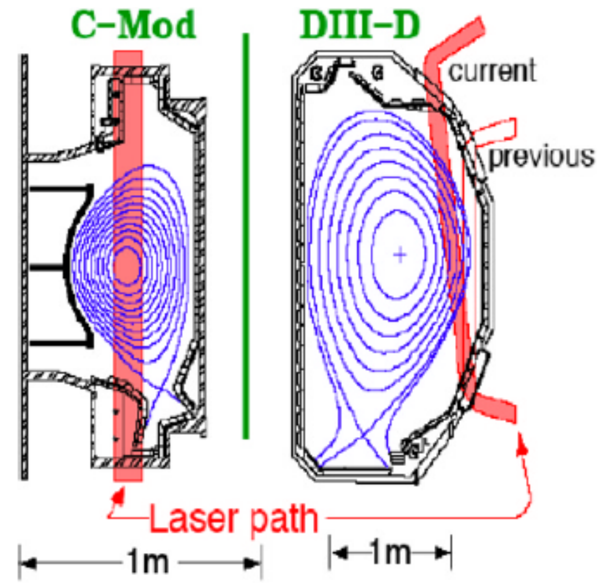


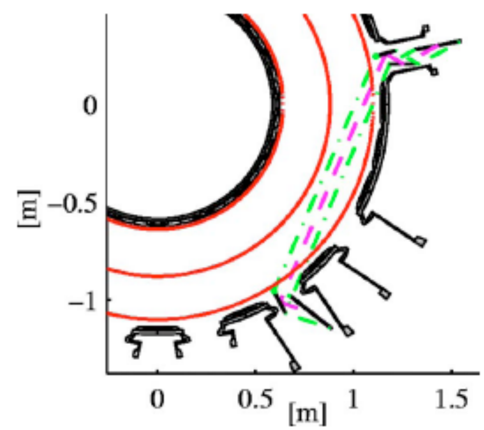




Phase Contrast Imaging (PCI) for NSTX-U

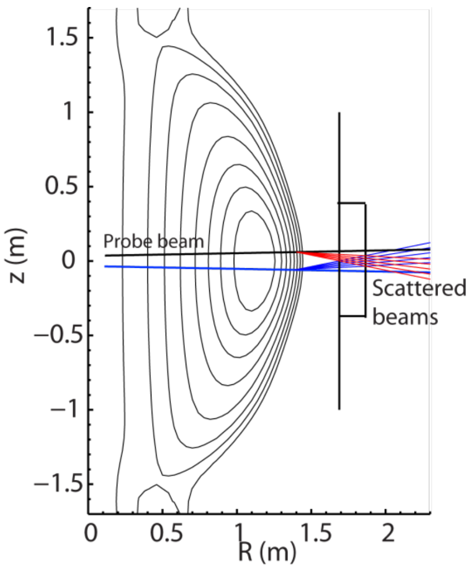
- Idea: Phase Contrast Imaging (PCI) to measure density fluctuations over a broad wavenumber range that could *fill the gap between, and overlap with,* BES ($k_\perp$<1.5 cm^{-1}) and high-k scattering ($k_\perp \geq$10 cm^{-1})
- Physics motivation: May expect to see changes in this presently unmeasured range of k-space as mode dominance varies between low-k (ITG/TEM/microtearing) and high-k (ETG) instabilities
- Resolution: $k_\perp$~0.5-30 cm^{-1}, >1 MHz
- Requires CO2 laser, ZnSe phase plate, 1D (or 2D) array of LN_2 cooled HgCdTe photoconductors
- Vertical (DIII-D, C-Mod, LHD) or tangential (CDX-U, TCV) views plausible, ~10-20 cm beam width
- Localization possible due to strong local **B** shear and $k_\perp$>>$k_{||}$
- Synthetic diagnostics developed for comparison with GK codes (Rost et al.; Ernst et al.) – could try out on NSTX sims for feasibility study
- Supports 5 year plan to "*measure low-k and high-k turbulence, compare with transport trends, validate with gyrokinetics, inform confinement projections to FNSF/Pilot*"
- Well suited for university collaboration [e.g. MIT; K. Tanaka (NIFS) *et al.* is ready and willing to support design study]

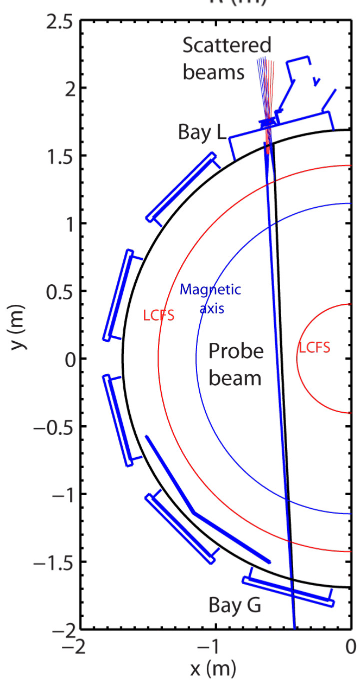




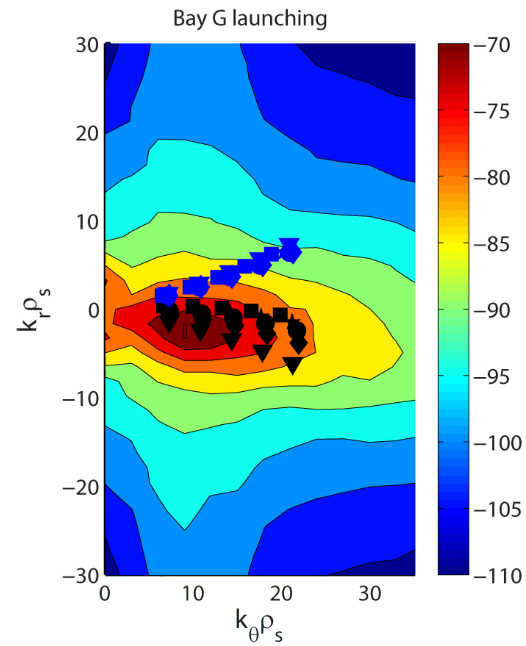
r online) Top view of the TCV tokamak showin

2D Wavenumber Spectra Measurement via High-k Scattering



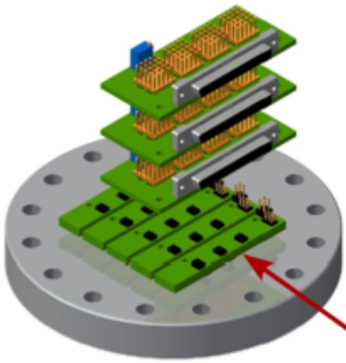


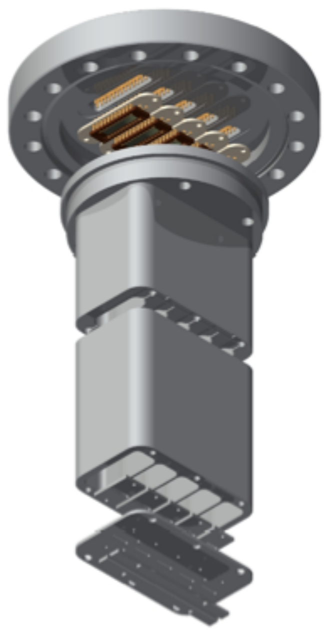
- 600 GHz FIR laser is launched from Bay G as the probe beam
  - ~100 mW input power and ~3 cm beam radius
- Scattered beams are collected through a vacuum window at Bay L
- 2D wavenumber spectra measured with two scattering schemes:
  - Downward scattering scheme captures k_θ's predicted to have dominant power in ETG turbulence
  - Upward scattering scheme measures spectra with different k_θ/k_r
- Target scattering system performance:
  - **5-8 channels of heterodyne receiver: Wave propagation direction resolved**
  - **k resolution and *range*: 2-5 cm^{-1} and 10-30 cm^{-1}**
  - **Radial resolution: 2-6 cm**
  - **Radial range: R>=110 cm**
  - **Minimal detectable density fluctuation: similar to the present high-k scattering system**



Toroidally Displaced In-vessel ME-SXR arrays

K. Tritz for the JHU Plasma Spectroscopy Group





- **We propose a system of two toroidally displaced, tangential edge/core multi-energy SXR (ME-SXR) arrays**

- **Each array contains:**
  - edge sub-array (130<R<150) ~1cm resolution, 5 diode arrays @ 20ch. ea.
  - core sub-array (40<R<140) ~3cm resolution, 3 diode arrays @ 32ch ea.
  - time resolution 10-100kHz

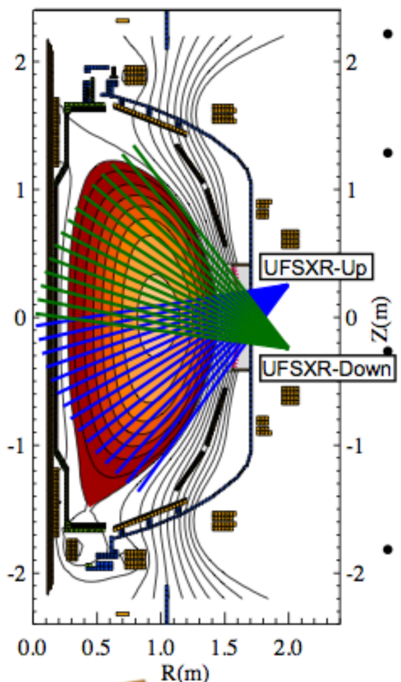
- **In-vessel design reduces port crowding, increases placement flexibility**
  - design 1: electronics in re-entrant can @ atmosphere with air cooling
  - design 2: vacuum compatible first stage electronics on detector PCB
  - potential to incorporate A/D, (fiber?) serial output for reduced wire count

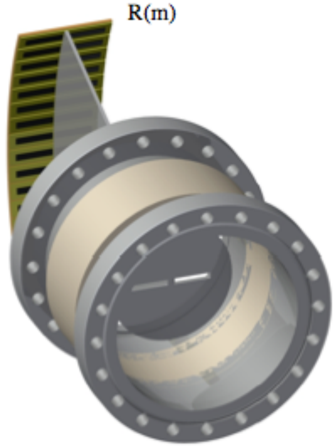
- **Projected physics capabilities for NSTX-U:**
  - impurity/electron perturbative transport measurements from the edge to the core using gas puff and repetitive laser blow-off
  - fast, high resolution edge T_e, n_e, and n_z profiles for ELM studies and code validation; edge stability analysis
  - fast, toroidally resolved edge T_e, n_e, and n_z profiles for RWM/RFA studies
  - fast, toroidally resolved core T_e, n_e, and n_z profiles for disruption studies
  - real-time T_e measurements for stability prediction and feedback control development
  - enhanced, non-magnetic MHD mode identification

- **Supports NSTX-U research priorities:**
  - I-1-4: macrostability research of RWMs, NTMs, effect of 3D fields, disruptions
  - II-3: impurity transport research (also pert. electron transport measurements)
  - III-3: measure response of edge plasma to applied 3D fields
  - VI-1,2: real-time T_e for stability feedback control, detection of instability precursors

Dual-energy Ultra-Fast SXR arrays

K. Tritz for the JHU Plasma Spectroscopy Group





- **The JHU Group is proposing to build and implement on NSTX-U a system of two poloidal, dual-energy UltraFast SXR (UFSXR) arrays**

- **Each array contains:**
  - 2x16 channels viewing poloidally through two different filters ~2-3cm resolution
  - at least 1 set of 16 channels will have a variable filter setting
  - time resolution ~4MHz

- **Upgraded system would replace current H-Up, H-Down USXR arrays**
  - maintain spatial resolution
  - significantly increase temporal resolution
  - dual-energy capability provides temperature/density discrimination $\Delta Te/Te \geq 0.5\%$

- **Projected physics capabilities for NSTX-U:**
  - Maintain/improve physics capabilities of present USXR system
  - Measure high-frequency *AE modes, including poloidal structure
  - Provide T_e/n_e discrimination and phase measurement to distinguish CAE/GAE
  - Provide validation data for fast MHD simulations with good time/spatial resolution
  - *AE measurements in conjunction with transport measurements for χ_e studies

- **Supports NSTX-U research priorities:**
  - II-1: investigate *AE effects on electron thermal transport
  - IV-2: measure *AE modes for simulation validation, projection to FSNF
  - IV-3: investigate effects of *AE on RF heating of plasma using T_e discrimination
  - VI-2: identification of high-frequency precursors to disruptions for mitigation/control

- **Suitable as joint JHU/NSTX collaboration**