NSTX Diagnostic Ideas

July 21 and July 26, 2011

Introduction/Organization

- One slide/five minutes per idea with brief discussion
- Agenda and presentations in DragNDrop Area:

  http://nstx.pppl.gov/DragNDrop/Five_Year_Plans/2014_2018/diagnostic_brainstorming/meetings/2011_July/Day1_07_21_2011/

  – Overview by J. Menard
  – Idea presentations in one Powerpoint document
- Summarize at the end of presentations on both days

July 21, 2011

Current Density/ q Profile Measurements

Real-Time MSE (rtMSE)

- Hardware/software upgrade to MSE-CIF system to provide magnetic field pitch angles in real time.
- Spatial(1-3 cm) and time(5 ms) resolution the same as the present MSE-CIF system.
- Combined with real time equilibrium reconstruction to provide q-profiles for current profile control using NBI.

Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF)

- Installation for first operation in upcoming run.
- Diagnostic neutral beam and laser.
- Measurements of magnetic field magnitude and pitch angle.
- Can operate during startup and for RF studies.
- |B| can be used to reconstruct the total plasma pressure, use for MHD studies, and for fast ion pressure.
- With MSE-CIF system, determine radial electric fields of interest for transport.
- Time resolution ~5 ms, spatial resolution 1–3 cm, 38 channels planned (fibers for 10 channels presently installed)

NOVA PHOTONICS

Internal Magnetic Fluctuation Profile Measurement

- Utilizes MSE-CIF system. Coherent magnetic pitch angle fluctuation measurement has 5–10 ms time interval with ~100 kHz frequency bandwidth, same 18 spatial channels as MSE.
- Capability presently installed - completed filter upgrade in 2010 - initial analysis underway.
- Simultaneously measure density fluctuation profile, and phase angle between density and magnetic field fluctuations.
- Can identify magnetic island locations, provide information for stability control.
- MHD studies, including seeking internal magnetic field fluctuation precursors to disruptions.

NOVA PHOTONICS

Lithium Beam Zeeman Polarimetry on NSTX

A. Diallo

- Knowledge of the edge current density is crucial for the understanding of the local MHD and pedestal physics.

- Lithium beam polarimetry in combination with EFIT could provide such measurement. Characterization of the Zeeman triplet components of Lithium emission at 670 nm.

- Inline with the assessment of pedestal at up to 2.0 MA.

- Suited for industry/university.

Coherent Imaging of the Magnetic Pitch Angle in the Edge Region

A. Diallo

- Knowledge of the edge current during the inter-ELM phase in the pedestal region is important for local MHD stability and pedestal physics.
- Measurement of the pitch from polarization characteristics of D_α components of Stark splitting in the edge region.
- Target an imaging polarization interferometer approach for greater spatial resolution and throughput. The temporal resolution can be 5 ms.
- 2D imaging scheme will supplement the magnetic equilibrium solver, EFIT, for equilibrium reconstructions in the pedestal region.
- Will provide 2D snapshot of the pitch angle, which could be synchronized with ELM events for enhanced temporal resolution in the pedestal.
- Suited for industry/university.

Fusion Products/ Fast Ions

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

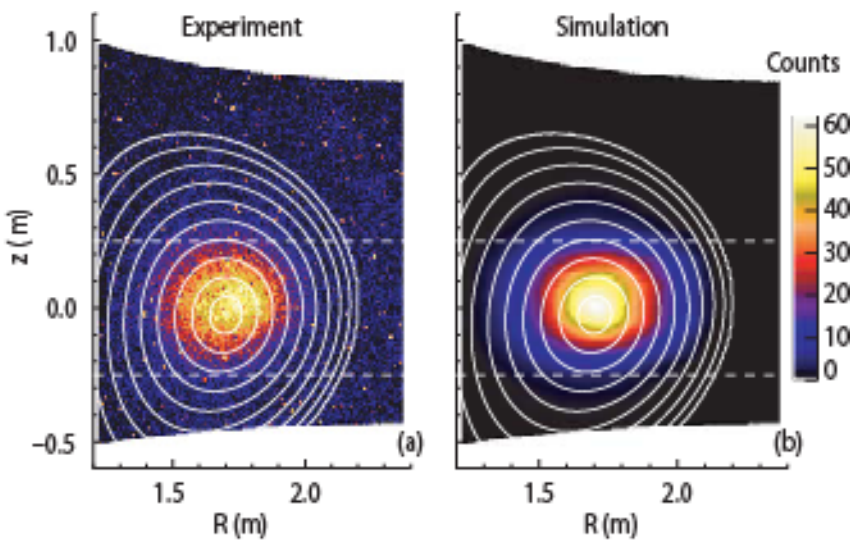
Physics: Vertical & Radial profile of co-tangential fast ions (and of injected neutrals)

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

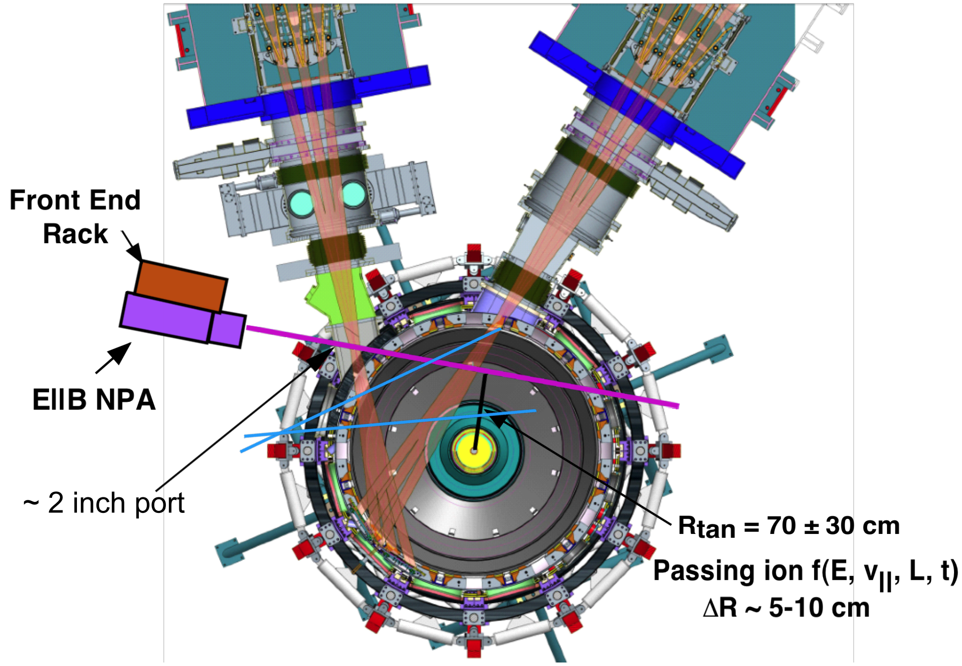


PPCF 51 (2009) 055001

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

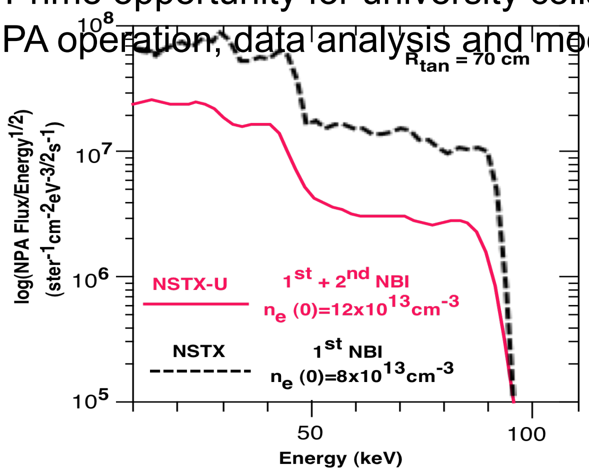
- Goal: measure radial profile of escaping fast neutrals with improved spatial resolution
  - Complement NPA, FIDA, neutrons, sFLIP, …
  - Good localization in pitch, energy-resolved spectra
    - TBD: focus on trapped or passing fraction -> viewing geometry ?
- Use *arrays* of diodes; combine both current 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, ΔE/E ~ 2-5%, $v_{||}/v$ ~ 0.8 ± 0.1, ΔL ~ 20 cm, Δt ~ 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.).

Thomson Scattering
(not incl. divertor TS)

rtMPTS

B.P. LeBlanc after discussion with S.P. Gerhardt and S.A. Sabbagh

- rtEFIT does not have internal constraints at present
  - Only magnetics…magnetic flux and fields, loop voltages
- rtMPTS can provide internal constrains
  - p_e isobaric (à la EFIT02) or T_e isotherm (à la LRDFIT04, EFITXX)
  - Constrain magnetic axis location
  - Can help constrain outer gap
  - Useful to estimate resistivity for current profile control
- Resolution:
  - 2 Nd:YAG lasers → 16.7msec; 11ms with a 3rd laser
  - 10 to 20 radial channels distributed on both sides of magnetic axis
- Scheme and latency
  - Use existing buffered outputs, do initial-guess T_e and n_e calculations
    - Iterative fit steps might be possible
  - 0.4ms intrinsic latency, plus computation time → 1ms after laser pulse

Innocent bystanders: A. Diallo. J. Dong, and H. Schneider

Edge Thomson Scattering System

A. Diallo

- Dedicated edge system at the region of near optimal flux expansion (20 cm below midplane)
- Increasing spatial resolution in the pedestal region (sub-mm). Further constraining the EFIT equilibrium reconstruction.
- Support the pedestal physics studies and turbulence codes.
- Suited for industry/university.

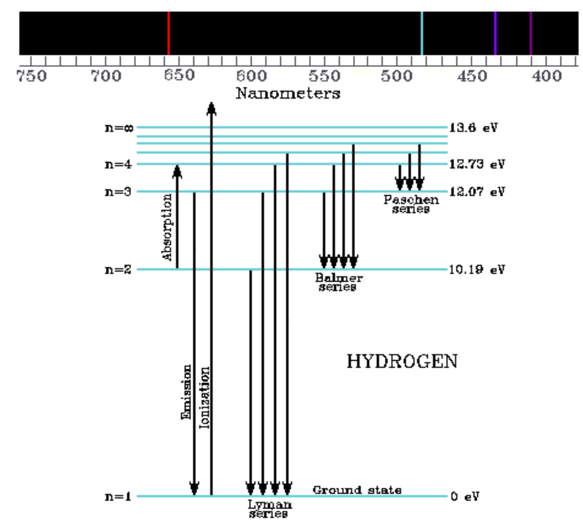
Neutral Density Measurements

Neutral density measurements for H-mode, ion power balance, fueling, particle balance, lithium studies

Laser-induced ionization (LII) diagnostic for 1D core, pedestal and edge neutral profiles

- Developed at Ioffe Institute in the 90-s (Nuclear Fusion 35, 1385 (1995)
- Feasibility study for NSTX by Dr. S. Tolstyakov in 2001
    - Collaboration with Globus-M
- Based on spectroscopic measurements of upper level population depletion using laser photoionization (P_{laser} ~ MW/cm^2)
  $E = A_{ij}\, n_j\, n_0$
- May be possible to use for pilot measurements
    - present MPTS system
    - proposed divertor Thomson system

Electron Energy Levels in Hydrogen



Sensitivity $n_0 > 10^{14}$ m^{-3}

Measurements of n_D using a Two-Photon Laser-Induced Fluorescence in the Edge Plasma

A. Diallo

- Measure the radial profile of the neutral density n_D near the separatrix.

- Possibly determine the core fueling rate.

- Doppler-free two-photon excitation in Lymanβ and observation of the fluorescence of Balmer α. [Voslamber and Seidel RSI 1999].
  - Requires two counter-propagating laser beams to eliminate the linear Doppler broadening.
  - Scheme is being implemented at DIIID [Brooks APS 2010]

- Support the pedestal physics studies by providing information on the effects of neutral.

- Suited for industry/university.

Electron Density Measurements

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

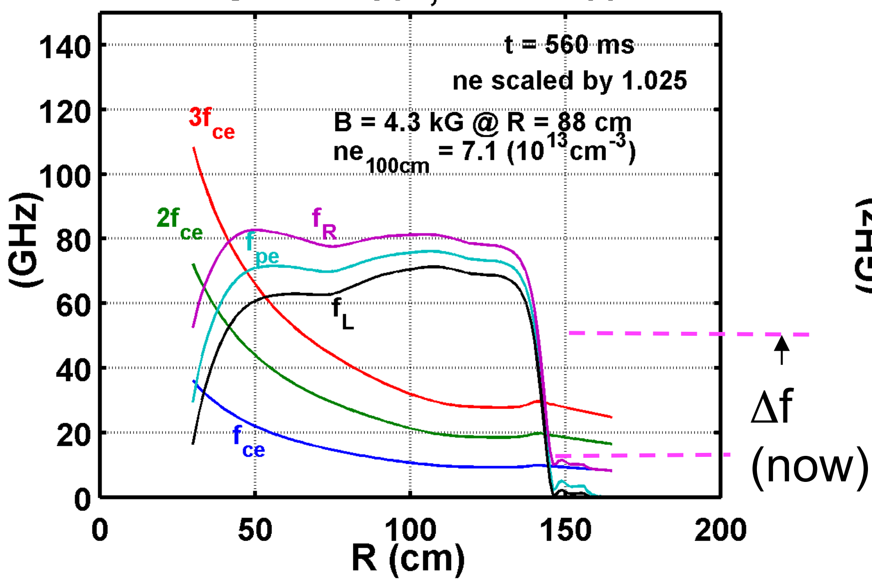
► FIReTIP-II will be collaboration with plasma diagnostics group of UC Davis

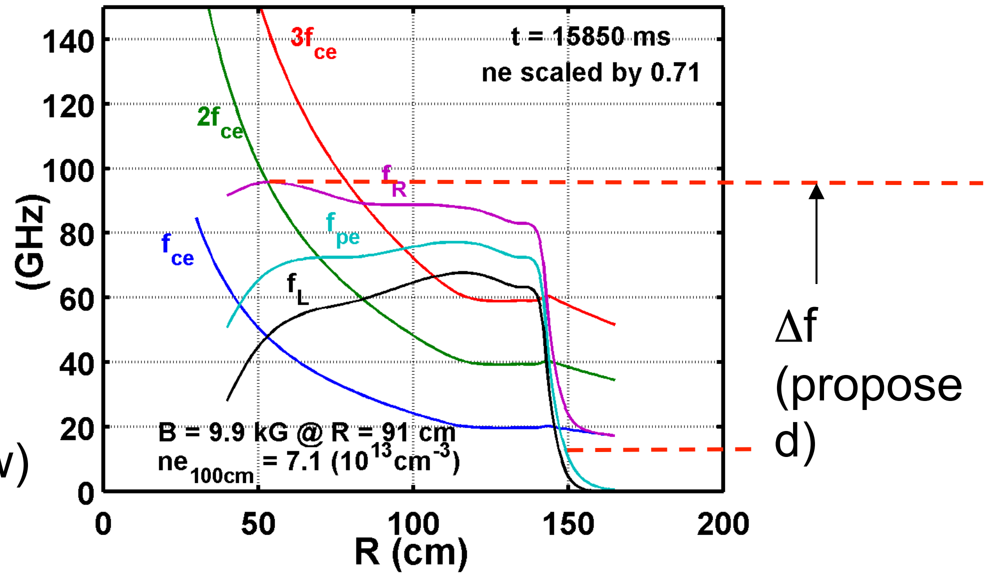
"Simple" Interferometer For Operations and Density Feedback Control

- A highly reliable single chord interferometer could be useful for:
  - Physics operations: Provide basic information when MPTS is unavailable (deliberately or not), to facilitate basic operations.
  - Plasma control: Provide basic density feedback at the beginning of each discharge, to improve the pulse-to-pulse reliability.
    - Help avoid dangerously underdense plasmas.
  - Physics analysis:
    - Provide an ever-present check on the MPTS density calibration.
    - If in vertical view, could complement the horizontal MPTS view. For very downward shifted plasmas.
- Use of present interferometers for this purpose is constantly in planning…
- System requirements could be modest: 1-10 kHz, single chord.
- PPPL/Industry/University?: Many institutions in the U.S. have the capability to construct and run such an instrument.
  - But would any be interested in taking on such scope?
  - Operations support may be less relevant than physics data for collaborator proposals?

SPG

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

Ion Temperature/Rotation Velocity Measurements

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

Measurement of bulk plasma flows with an interferometric technique

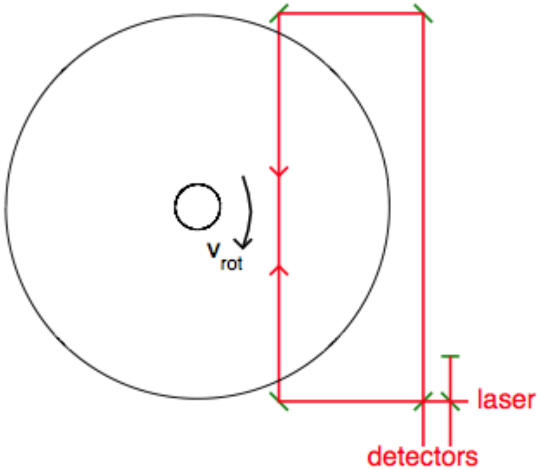
Gerrit J. Kramer

- The speed of light in a medium depends on the velocity of the medium:

$$v_{light} = 1/R\ (c +/- v_{medium}\ (R^2-1)\ /\ R) \qquad \text{(R: index of refraction)}$$

experimentally verified by: H. Fitzeau, Ann. de Chim. et de Phys. 57 (1859) p. 885
P. Zeeman KNAW, Proceedings, 17 I, 1914, Amsterdam, (1914) p. 445

- We can use this effect to measure the plasma rotation in NSTX



- Let light (or microwaves) pass through the plasma at the same line of sight in both co– and counter to the rotation and measure the phase difference between the signals
- This will give a measure of the line–integrated plasma velocity projected on the sight line but it is weighted to the tangency radius
- The (line integrated) density should also be measured to get index of refraction
- With this technique rotation measurements can be made that are independent from (diagnostic) NBI injection
- This project is suitable for university collaboration

2D Flow imaging in the Divertor

A. Diallo

- Large parallel flows have been predicted using UEDGE simulation.
  A.Y Pigarov, Memo 2005

- LiII (548.6nm) and CIII (465 nm) are targeted for Doppler spectroscopy measurements in the divertor enabling larger radial coverage.

- Target a polarization interferometer scheme for greater spatial resolution and superior throughput. The temporal resolution can be 5 ms.

- 2D imaging scheme will generate a map of the "hurricane" type flows in the divertor, which can be compared to theory/simulation.

- Suited for industry/university.

July 26, 2011

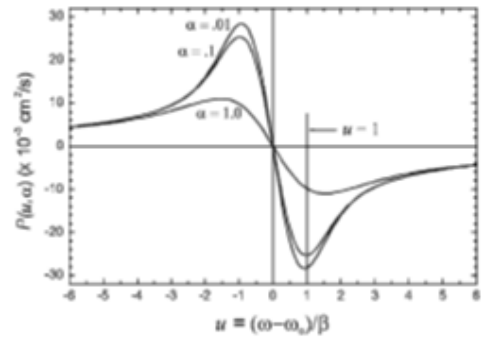
Edge Reflectometer at the HHFW Antenna

- 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

Neutral density measurements using spectral line interferometry



- Resonant enhancement of refractive index for wavelengths near a transition

$$\Delta\phi(\omega) = \Delta\phi_{n_e} + \Delta\phi_V + \frac{\overline{n}_H f}{\beta} P(u,\alpha)$$

- Two lasers: one tunable laser to scan around transition (~ kHz sweep), one a few angstroms away from transition
  - Subtract phase shifts to get resonant enhancement part
  - Analysis essentially provides transition linewidth and height
    - No absolute calibration needed and a fast measurement
    - Similar to fluorescence → does not rely on upper state density

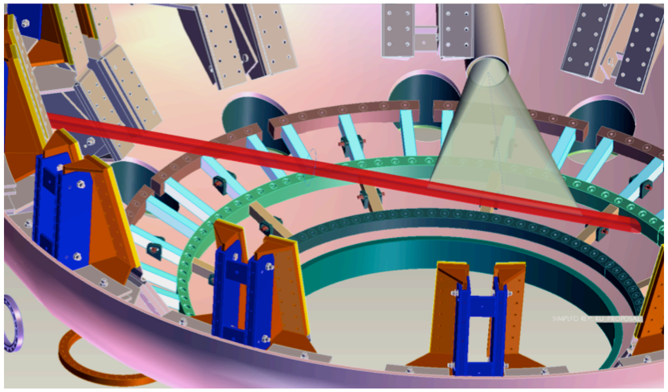
- Single chord heterodyne system: Hy-tech industry (RSI 2006)
  - 10^{17} m^{-3} n=2 H state in 10 eV, 10^{21} m^{-3} plasma (2 mm spatial resolution)

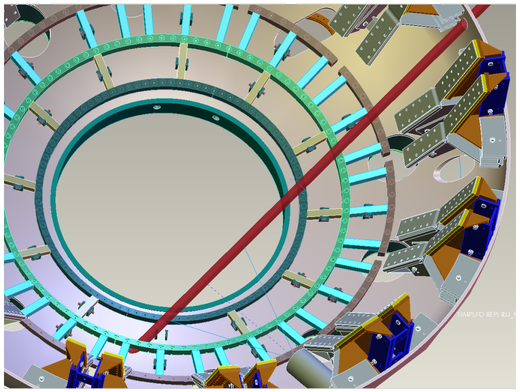
- Suitable for university / industry

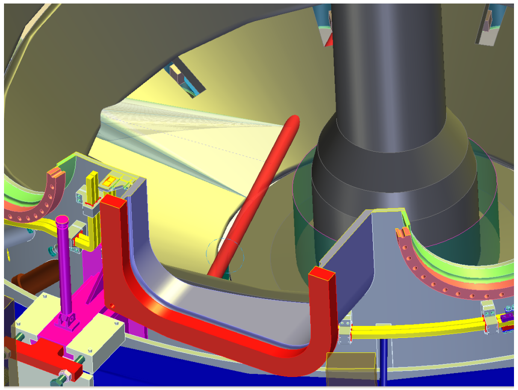
Divertor Measurements

Divertor Thomson Scattering system for divertor and lithium studies in NSTX-U

- Unique ("true") divertor T_e and n_e measurements
  - DTS systems available only on DIII-D and TCV
- Progress in NSTX-U DTS (Conceptual proposal by LLNL in 2008)
  - Identified implementation issues on NSTX
  - Planned NIR spectral survey for FY2011-2012
  - Determined possible geometries of laser beam and collection optics
  - Determined scope and division of work
    - LLNL designs and installs DTS system (laser, collection optics, detectors, DAQ)
    - PPPL develops and builds NSTX machine interface
    - LLNL operates and maintains DTS system







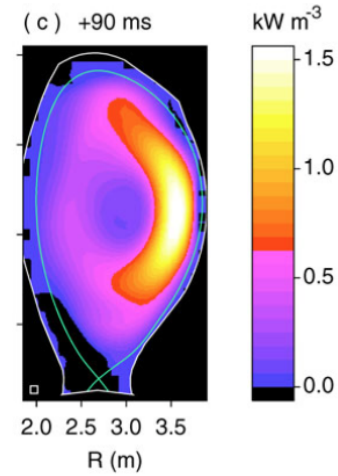
Divertor diagnostics for real-time control of radiative (partially detached) divertor

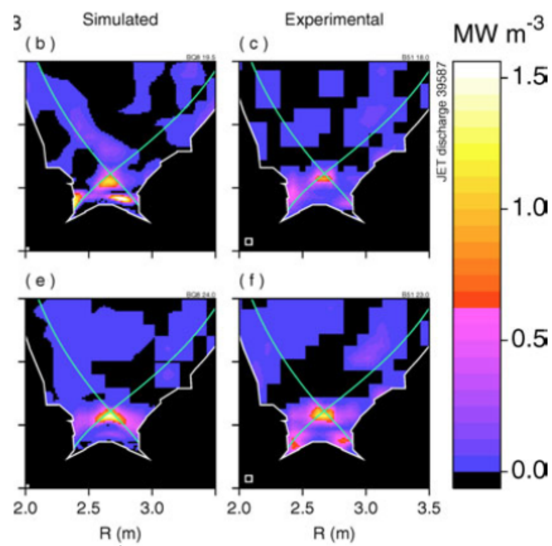
- Proposed and partially funded as part of DoE ECRP Award in 2010
- Use diagnostic signal indicative of divertor detachment / reduced heat flux as actuator and pass it on to PCS for fast gas valve control for divertor impurity seeding control
- Conceptual study and prototype development will be performed
  - PFC temperature / heat flux monitoring (e.g., fast IR diodes)
  - Divertor ion current (e.g., Langmuir probes)
  - P_{rad} (e.g., fast bolometers or RADA)
  - Recombination rate (D Balmer, Paschen lines)
  - D or Impurity pressure (e.g., Optical Penning gauge)
- Plan for FY2011-2012 was to evaluate diagnostic options
  - NIR spectroscopy
  - Optical Penning Gauge (installed on Bay H divertor port for FY2011-2012 measurements)

NSTX optical Penning Gauge

Radiation tomography system for full cross-section radiation profile

- In NSTX-U experiments, increased emphasis on power balance in core and divertor
  - Radiative divertor and Radiative mantle
  - Disruption and Disruption mitigation studies
  - Double-null divertor studies
  - Core/Edge poloidal asymmetry studies
  - 3D physics, ELM studies
- 5-10 AXUV diode arrays needed for full coverage
- Ample NSTX experience (e.g. JHU arrays, LADA / RADA)
- Complementary to existing divertor bolometers
- Possibility for SXR filtering





Figures of JET results from Ingesson et al.
TOMOGRAPHY DIAGNOSTICS: BOLOMETRY AND SOFT X-RAY, FUSION SCIENCE AND TECHNOLOGY VOL. 53 FEB. 2008

Fast ion gauges used in DIII-D pumping and radiative divertor studies; propose to use in NSTX-Upgrade

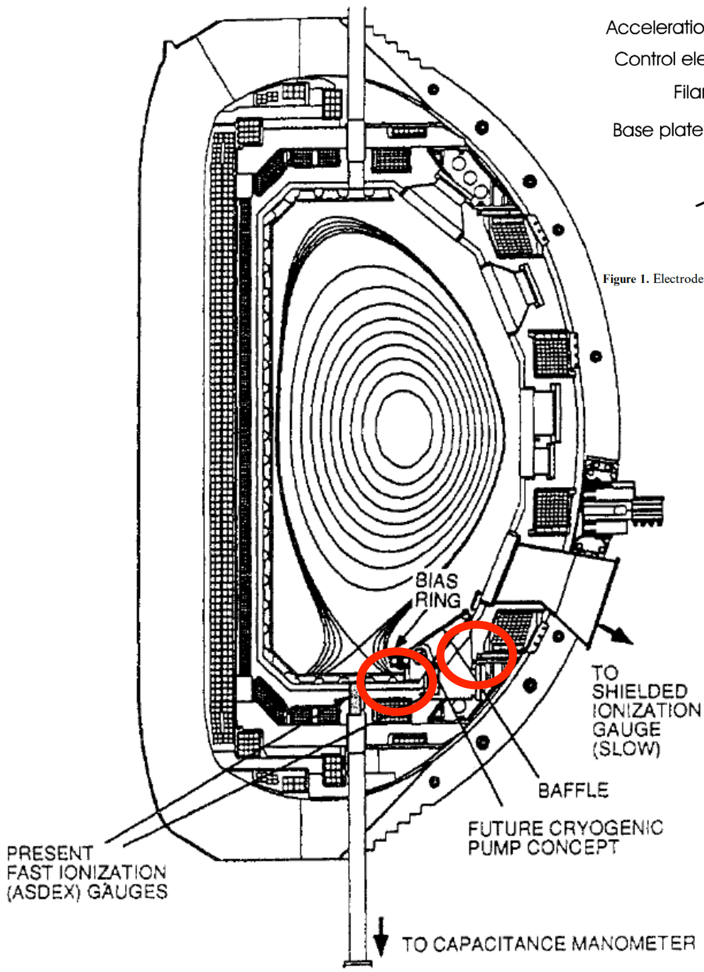


FIG. 1. A lower single null divertor configuration in DIII-D, with the outer divertor intercept near the bias ring, which forms the throat of the baffle region. Also shown are the locations of the fast ionization gauges.

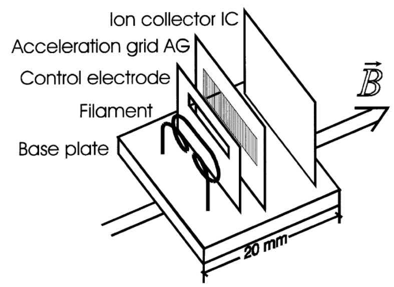


Figure 1. Electrode arrangement of the ASDEX gauge.

Fast ionization gauges developed in 1980's that work with the magnetic field because of a rapid background subtraction

Can be placed very close to the plasma with time response $\geq$ 1 msec

Limited conductance: measures flux density, otherwise neutral density

Fast pressure gauges inserted in the private flux region and lower pump plenum in DIII-D, as well as the dome structure in the upper divertor

The private flux region can gauge can be used to control PFR gas puffing , and thus detachment onset and MARFEs, as PFR pressure a key control in MARFE formation (Ghendrih, JNM 1995)

Klepper, NF 1993
Maingi, NF 1996
Petrie, NF 1997

Fast thermography and thermocouples for feedback

A. McLean, R. Maingi, J-W. Ahn, T.K. Gray

- Potential for transition to very high q operation in NSTX-U
  - Destructive to PFCs, detrimental impact on plasma performance
- Processing of dual-band IR camera data too intensive for use in real-time operations response
- 10-16 additional 'eroding' thermocouples for high speed (~1 ms response time) $T_{surface}$, q measurements in NSTX-U
  - Coverage throughout lower divertor, higher radial spatial resolution at targets (5-10 cm)
  - Customizable to ATJ, Mo, W PFCs
  - Added to existing DAC system with analog output for feedback in PCS (~1 ms latency)
    - Would be first-of-it's kind in a Tokamak
- 1-D IR diodes for high speed band-integrated measurements
  - 10-15 chord array, commercial MWIR PbS/PbSe diodes, 10 kHz operation
- Additional application of dual-band IR imaging in NSTX-U
  - Tangential wide-angle system for observation of the center stack and wall
- Enhancement of dual-band technique to simultaneous multi-band
  - Improved accuracy, immunity to Li window coatings and other losses

Real time surface emissivity measurement in NSTX-U

A. McLean, R. Maingi, J-W. Ahn, T.K. Gray

- Emissivity in the IR contains useful information about surface composition and structure
- Commercial Optitherm/Pyrolaser system provides single chord pulsed laser-based emissivity measurement for rapidly varying surfaces
  - Would be first application to a Tokamak
  - Currently limited to NIR/SWIR, 1 ms response time
- Extension of technique to MWIR and LWIR pulsed laser systems
  - First-of-its kind development
- Collaboration for test-stand measurements of emissivity for prepared surfaces potentially relevant to NSTX-U PFCs
  - LiD, Li_2C_2, Li_2O, Li_2CO_3, Li_2MoO_4
  - Measurement/application of Hagen-Rubens relation for spectral emissivity vs. λ
- Ideal for university, PPPL involvement/collaboration

Due to high heat fluxes expected in NSTX-U, operation in a Double Null discharge shape will be needed

- We need better diagnostic coverage in the upper divertor for DND discharges
- Power balance (IR and radiation)
- Measure in the Upper Divertor:
  - PFC surface temperature via fast eroding thermocouples and Dual-band IRTV
    - Fast TC's: 1 kHz and a few cm resolution
    - DB-IRTV: 30 Hz+ and 4-6 mm spatial resolution
  - Radial bolometer array to measure upper divertor radiation
    - XUV photodiode array: ≤ ms and ~1 cm spatial resolution
  - Tangential Divertor Imaging
    - Fast CMOS camera: 10-100 kHz frame rate
- These diagnostic upgrades should be capable for a university/industrial collaborator.
  - Would require close collaboration with PPPL for tile TC's

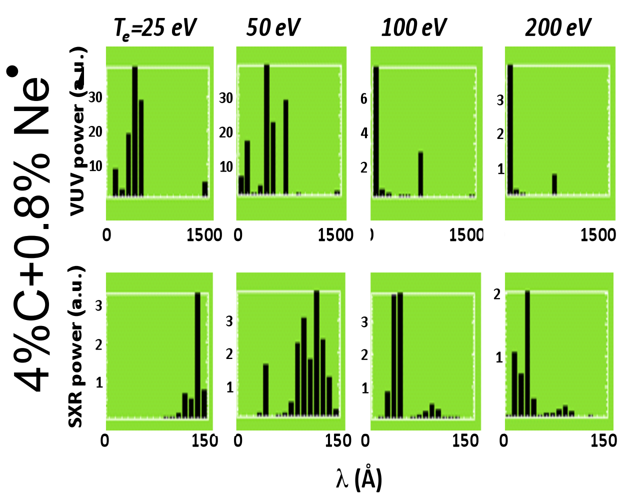
Currently, the inner strike point is only diagnosed in low δ discharges

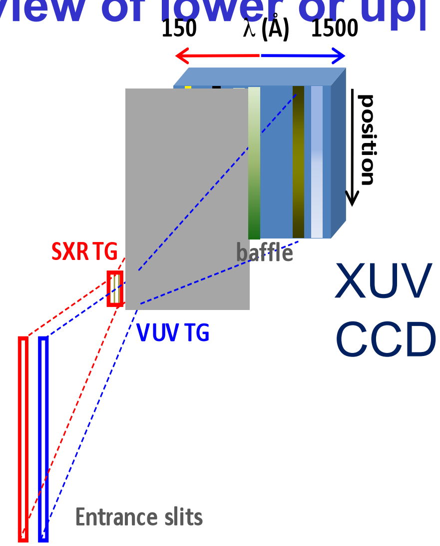
- Measure visible and IR emission from the vertical part of the center stack (first lower then upper divertor)
- Full divertor coverage with IR and visible in high δ discharges
  - Power Balance, SOL energy and particle transport
  - 5 year plan priorities in Boundary Physics
- Measure IR and visible radiation from a radial divertor port
  - IR: 30 Hz+ and 4-6 mm spatial resolution
  - Visible: Up to 100 kHz, < 1 mm spatial resolution
    - Possible multi-color 1D CCD array with interchangeable filters
- Well suited to a University/Industrial Collaboration

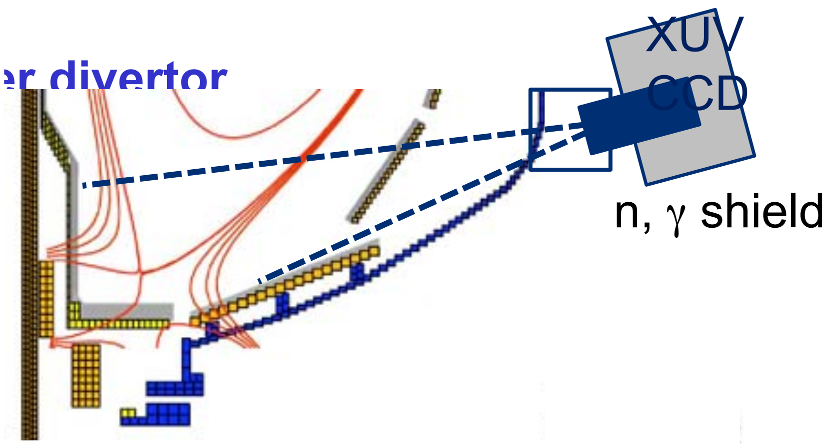
SXR/VUV Imaging Radiometer for NSTX-U divertor

D. Stutman for the Johns Hopkins Group

- **Space/time resolved radiated power in $\lambda/\Delta\lambda \sim 1/20$ spectral bins covering the 0-150 Å ('SXR') and 0-1500 Å ('VUV) ranges**
  - **$P_{rad}(\lambda)$, impurity type, charge state distribution for enhanced constraints on divertor modeling (M. Jaworski)**
  - **Approximate line-of-sight T_e (with e.g., Neon seeding)**
- **Parameters:**
  - **Dual transmission grating + absolute XUV CCD for $P_{rad}(\lambda)$**
  - **≥2 cm/5-10ms space/time resolution, strike to above X-point coverage**
  - **Poloidal view of lower or upper divertor**

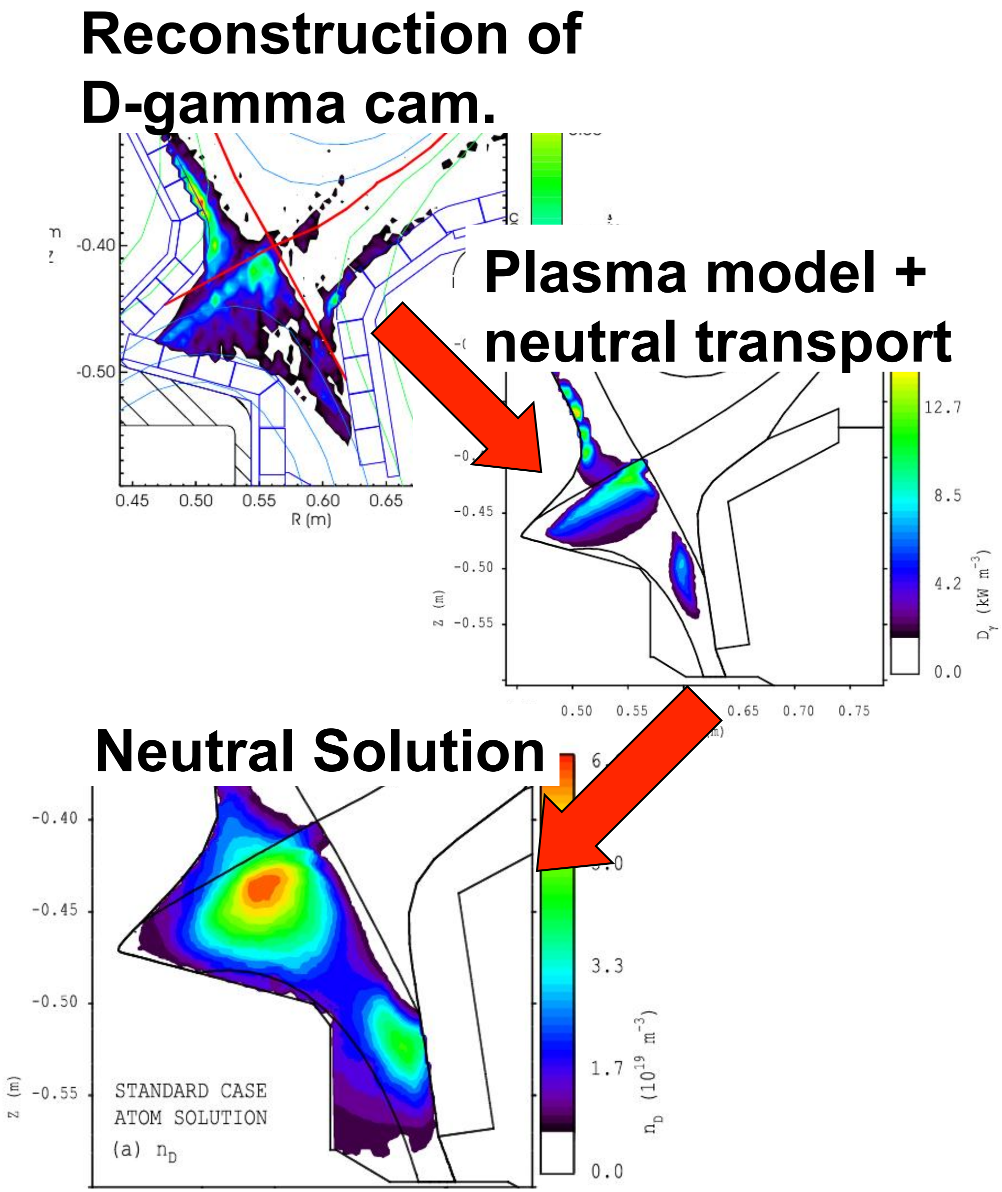






Radiating Volume Reconstruction

- Motivation: tomographic reconstruction a powerful tool for constraining codes and diagnosing regions with high spatial variation (i.e. divertor)
- Propose: Set of filtered camera systems capable of producing inversions of upper and lower divertors on relevant wavelengths
- Physics topics: poloidal structure in inner divertor and *private flux zone*
  - Poorly understood/ diagnosed
  - Thought to play large role in neutral dynamics and impurity transport
  - With constrained background plasma and neutral solution, impurity transport studies become viable
- Collaboration? Great for University/ Industry



S. Lisgo, Ph.D. Thesis, U-Toronto (2003).

Tangential imaging of divertor
Absolutely calibrated

R. Maqueda

- Divertor physics and development of power handling techniques essential for NSTX-U:
  snowflake divertor, divertor detachment and performance, divertor radiation, 3D fields effects, impurity source/puffing and transport (moly?)
- Results obtained from imaging used to guide divertor models.
- Use fast framing digital cameras, coherent imaging bundles, interference filters in remotely operated filter wheels.
  Need: absolute calibration (each filter) and monitoring of window transmission!
- In NSTX-U, inner strike point will automatically be in field of view of current system.
- Depending of spectral line, up to several 10s of kHz and few mm resolution.
- Possibly reinstate 2-color viewing system (simultaneous images).

Tangential divertor SXR camera

- Do external 3D fields open up magnetic islands in the plasma edge? What is the plasma response to these fields?
  – If islands exist: large-m & largest spatial extent near X-point
  – Islands would be locked to 3D field structure and inside the pedestal

- Use tangential imaging of X-point to resolve 3D structure
  – SXR wavelengths to get good SNR in region of interest
  – Requires sophisticated inversion of 2D images to get 3D data
  – Sub-cm resolution, long (few ms) integration

- Support other NSTX-U goals as well
  – Run faster, with less resolution for divertor T_e, n_e, Z constraint
  – May be able to push into the >100 kHz range with new technology

- May be suitable for university / industry

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

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

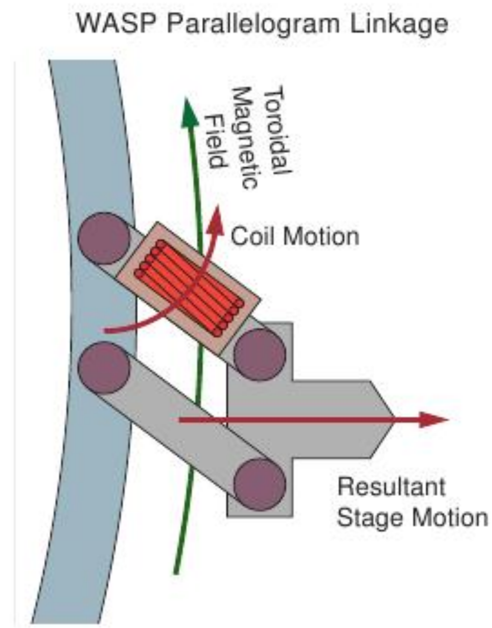
$$E_0 = V_p + E_i \approx \underbrace{3kT_e + 2kT_i}_{?} \approx \underbrace{5kT_e}_{???}$$

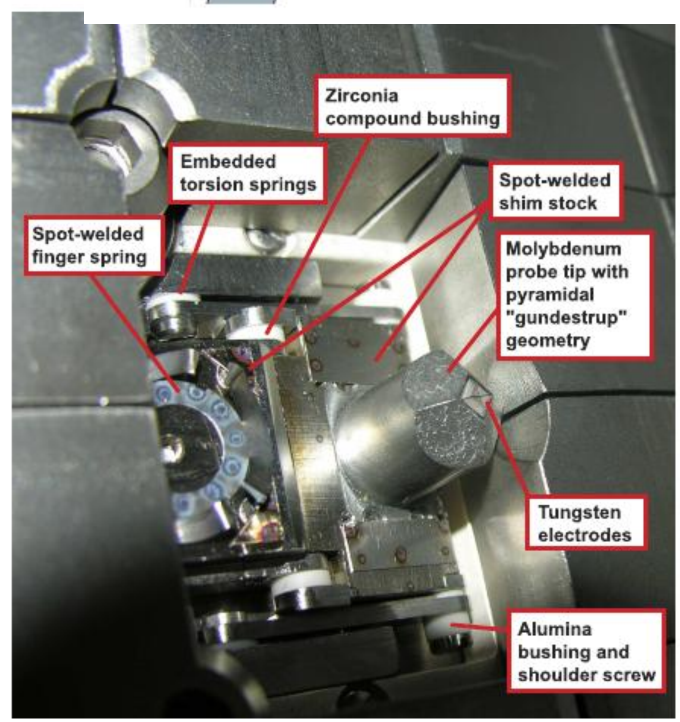
Why guess when you can measure?

MAJ

Popup/Swing probes

- Motivation: upstream measurements of the plasma to complement divertor target system
- Propose: popup/swing probes with the following capabilities:
  - Standard Langmuir probe, Ne, Te, Vf
  - Mach probe for flow measurement, M
  - RFA or ion-sensitive probe for Ti and Vp
- Physics topics:
  - diagnose inboard divertor structures,
  - SOL flows,
  - poloidal potential structures,
  - poloidal Pe and Pi
- Collaboration? In-vessel hardware should probably be PPPL led





N. Smick, Ph.D. Thesis, MIT, 2009.

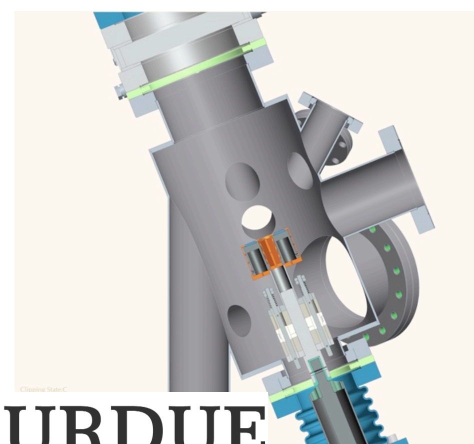
PMI Measurements

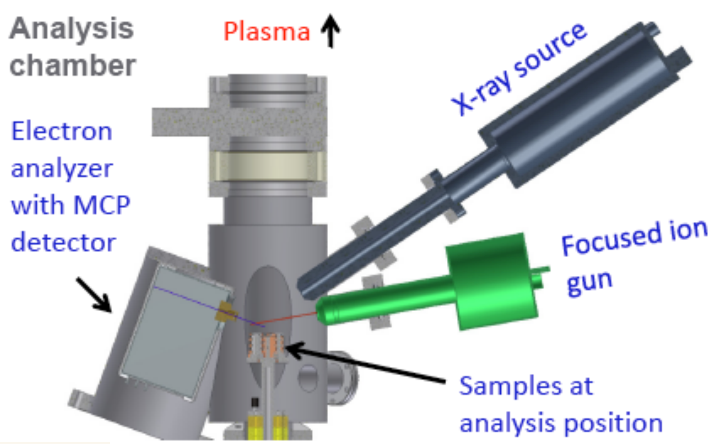
Prompt surface analysis using a Materials Analysis Particle Probe (MAPP) to measure and analyze lithium-based surfaces and correlate their behavior to plasma behavior (Priority III-2 under Lithium Research)

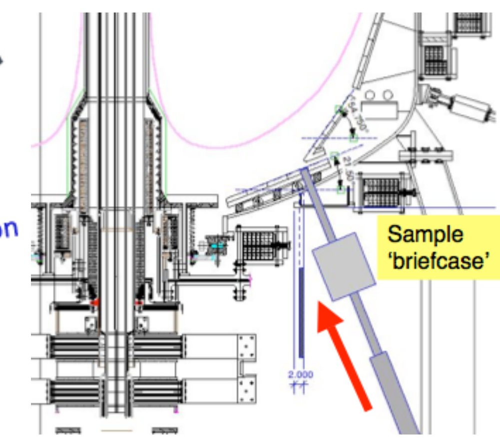
Allain and Skinner

- Critical diagnostic capability: MAPP is the first in-vacuo surface-sensitive inter-shot diagnostic capable of correlating surface chemistry evolution[1] with plasma response to PMI (plasma-material interface) conditioning[2,3].
- MAPP will include: TDS, XPS, and DRS, four-sample probe head, heating
- Upgrade capabilities:
  - Move MAPP closer to center stack in the NSTX-U configuration
  - Upgraded "smart diagnostic" including: in-situ measurement of erosion, hydrogen sensor for deuterium concentration measurement, high Z materials probes (e.g. a backscattering LEISS).
  - Local optical emission spectroscopy (collaboration with Vlad Soukhanovskii) to attain mm-level spatial resolution of MAPP probe head correlating surface chemistry data to plasma behavior. In principle simultaneous measurement of D-alpha, lithium and carbon emission profiles in the MAPP region would be possible.

[1]C.N. Taylor et al. J. Appl. Phys. 109 (2011) 053306
[2]C.H. Skinner, J.P. Allain et al. JNM in press 2011
[3]B. Heim, IEEE-Trans. Plasma Sci. 2011

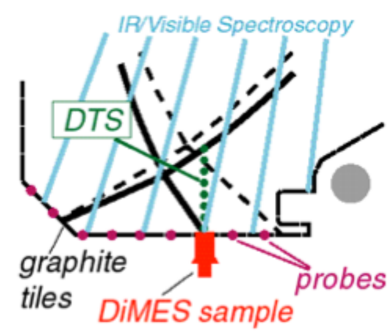


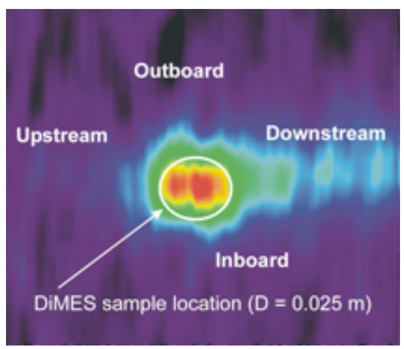


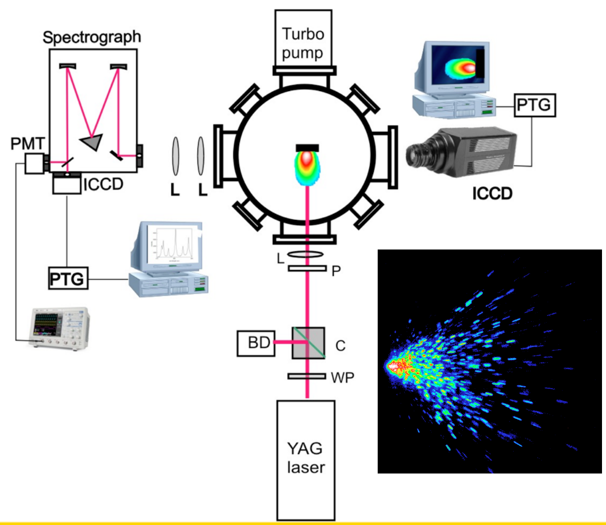


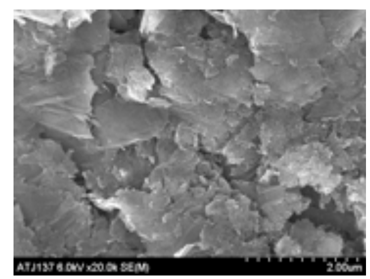
Laser-induced break-down and abrasion spectroscopy (LIBS/LABS) as an in-situ measurement of lithium-based surfaces to correlate their behavior to plasma behavior (Priority III-2 under Lithium Research)

- Critical diagnostic capability: LIBS/LABS will allow *in-situ* and real-time characterization of surface impurities and concentrations in-between shots and in some cases during shots
- Ablated material can be diagnosed with OES locally with simultaneous measurement of D-alpha, lithium and carbon emission profiles
- Can address limitation of MAPP (fixed toroidal position) and assess surface concentration over large area radially and toroidally (depends on port access and surface conditions)
- May also provide for a complementary technique to MAPP for addressing challenging plasma-induced driven morphology
- Requirements: Laser: 1.06 μm radiation from a Nd:YAG laser (6 ns FWHM) is used.









10-shot NSTX exposure

PURDUE UNIVERSITY

PURDUE ENGINEERING

Fluctuation Measurements

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

Ion Temperature and Velocity Fluctuation Measurement

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

- **T_i fluctuation measurements can provide crucial data for:**
  - Basic turbulence characterization
  - Turbulence mode identification
  - Testing & validation of nonlinear simulations
  - Turbulent transport (correlated with $\tilde{n}$ & $\tilde{v}$)
  - Fast T_i/rotation changes at L-H transition, pedestal and ITB development
- **Very fast, high throughput CHERS-style diagnostic**
  - Observe CVI (n=8-7) at 528-530 nm
  - Utilize high-throughput BES optics
  - Exploit new high-efficiency transmission grating spectrometers
    - *~80% grating efficiency*
    - *Large-area Prism-coupled gratings provide sufficient dispersion*
  - Cooled-APD detectors
    - *Custom-designed low-noise preamplifier circuits*
- **Currently developing and testing prototype UF-CHERS at DIII-D**

BES Passive FIDA Reference View

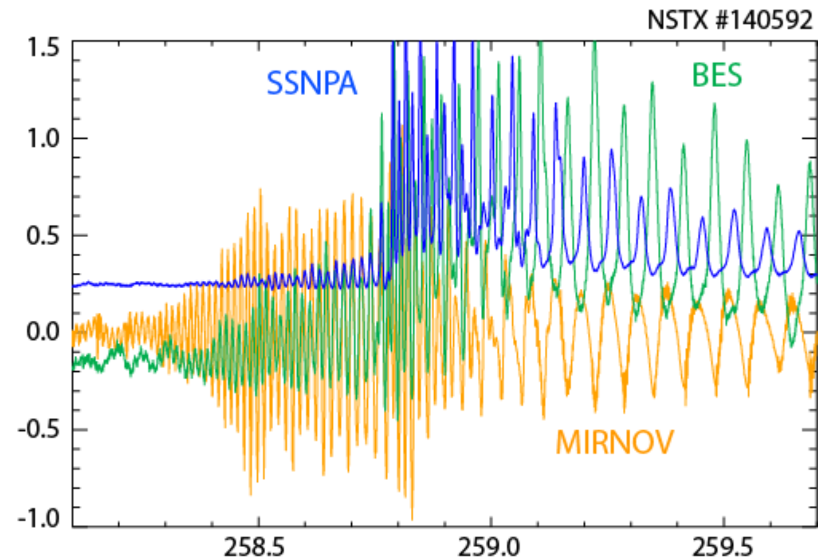
Physics: Validate BES eigenfunction measurements for modes that expel fast ions

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

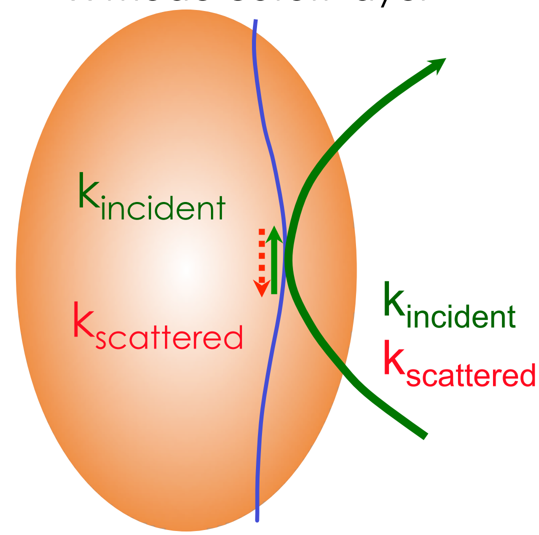


PPCF 53 (2011) 085007

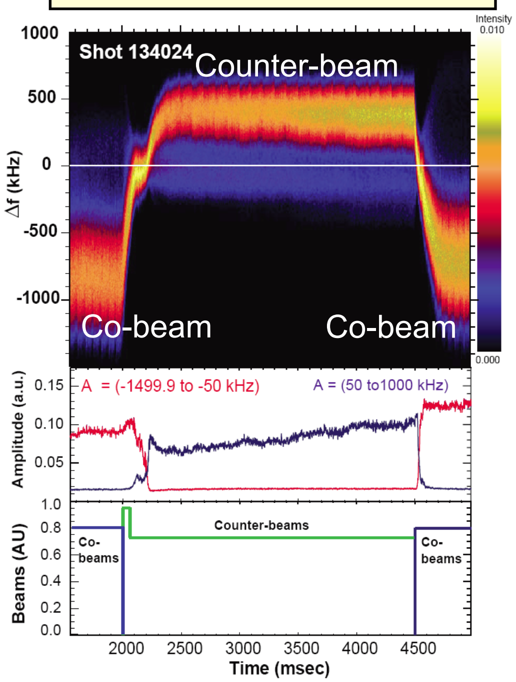
Doppler backscattering (DBS): Determine E_r, GAMs, zonal flows via Doppler shift of scattered data: Scattered power gives fluctuation levels

- DBS locally measures scattering from intermediate scale turbulence
  - Doppler shift provides information on turbulent flow ($\sim E_r$), GAMs, etc.
  - Scattered power provides info on turbulent fluctuation levels at intermediate-scale wavenumbers

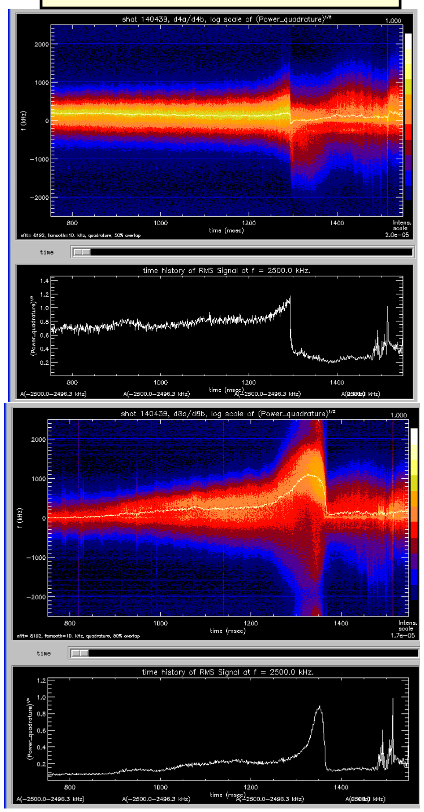
DBS on NSTX requires a flexible antenna arrangement to probe in plane perpendicular to magnetic field.



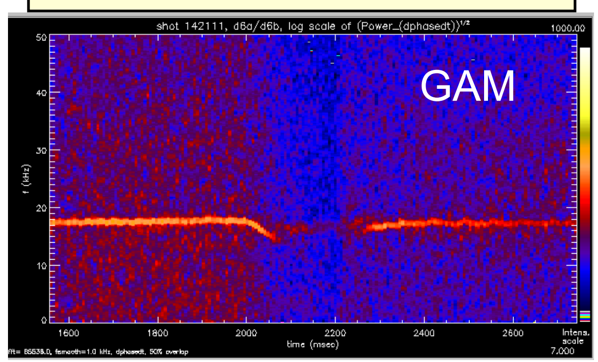
Quadrature data for co- and counter beams



Quadrature data for L-H transition



Phase analysis of DBS data reveals the GAM

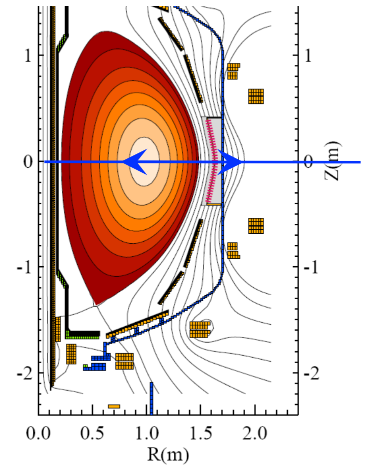


Radial polarimetry: Direct measurement of magnetic field fluctuations: constraint on central q; can operate as radial view "simple" interferometer

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

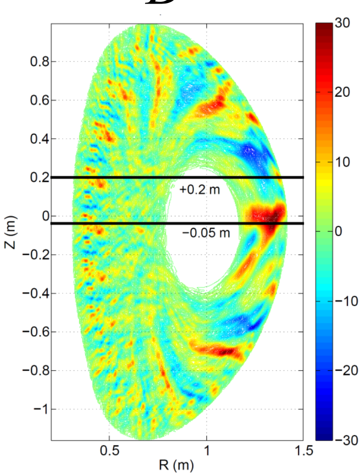


- Radial-view, retroreflects from center-stack tile
- Prototype single channel system to be installed in early August

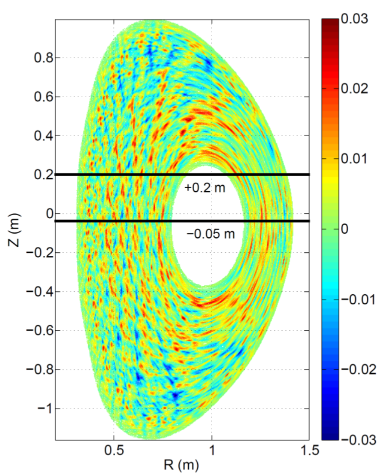
$$\Psi = 2.62\times10^{-13}\lambda^2\int B_{||}(z)n(z)dz$$

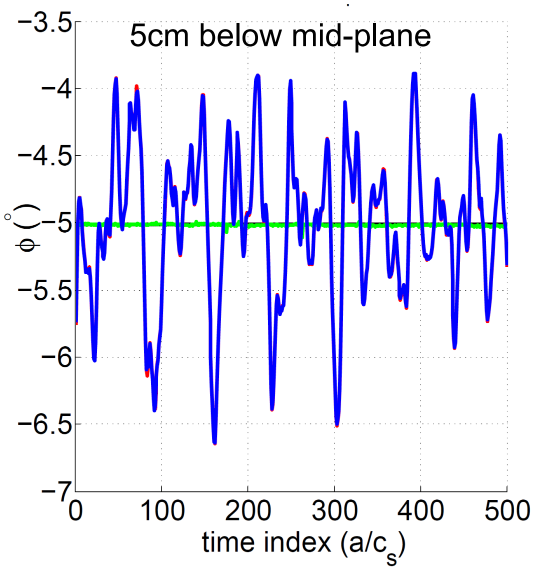
$$\tilde{\Psi} = 2.62\times10^{-13}\lambda^2\int\left[\tilde{B}_{||}(z)n_0(z)+B_{||,0}(z)\tilde{n}(z)\right]dz$$

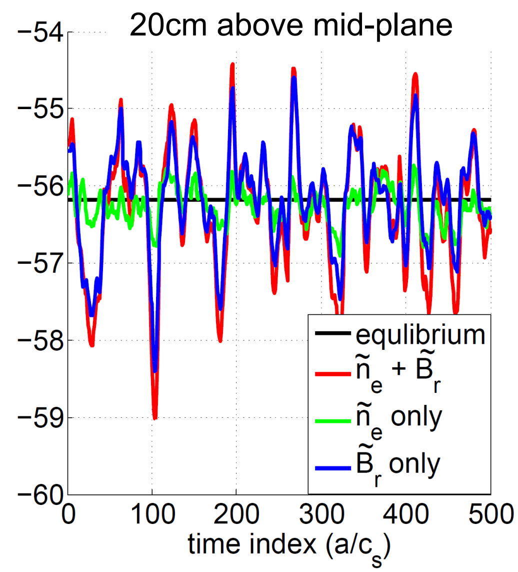
$\tilde{B}$



$\tilde{n}$







Cross polarization scattering for B fluctuations

D. Smith – UW-Madison

- Magnetic fluctuations ($B_\perp$) scatter EM waves and change the wave polarization
  - $B_\perp$ fluctuations induce O→X or X→O mode conversion
  - Density fluctuations preserve polarization
  - Cut-off layers can reduce/eliminate contamination from density fluctuation scattering
  - Vahala, Vahala, and Bretz, PoFB 4, 619 (1992)
    Zou et al, PRL 75, 1090 (1995)
    Mase et al, RSI 68, 454 (1997)

Phase Contrast Imaging (PCI) for NSTX-U

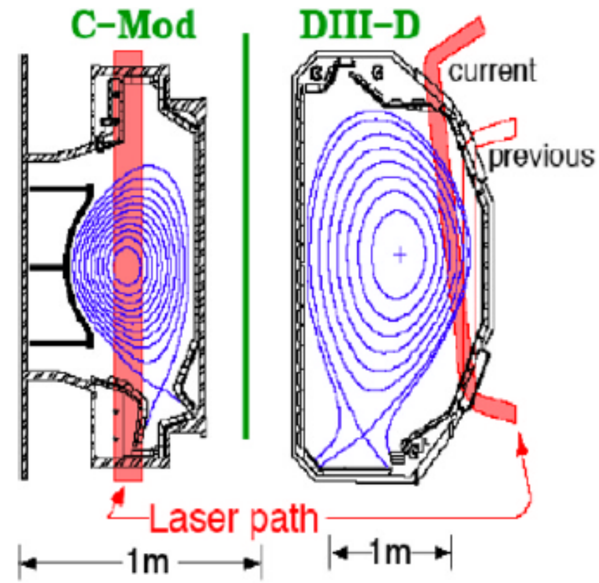
- Idea: Phase Contrast Imaging (PCI) to measure density fluctuations over a broad wavenumber range that could *fill the gap between, and overlap with,* BES ($k_\perp$<1.5 cm^{-1}) and high-k scattering ($k_\perp$≥10 cm^{-1})

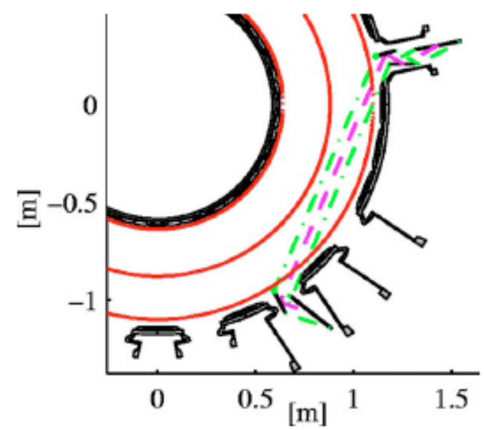
- Physics motivation: May expect to see changes in this presently unmeasured range of k-space as mode dominance varies between low-k (ITG/TEM/microtearing) and high-k (ETG) instabilities

- 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]



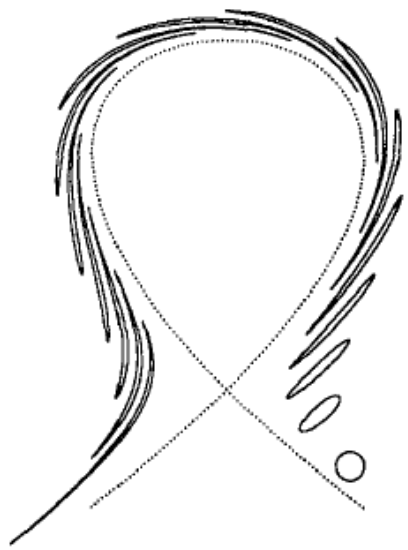


r online) Top view of the TCV tokamak showin

3-D Gas Puff Imaging Diagnostic

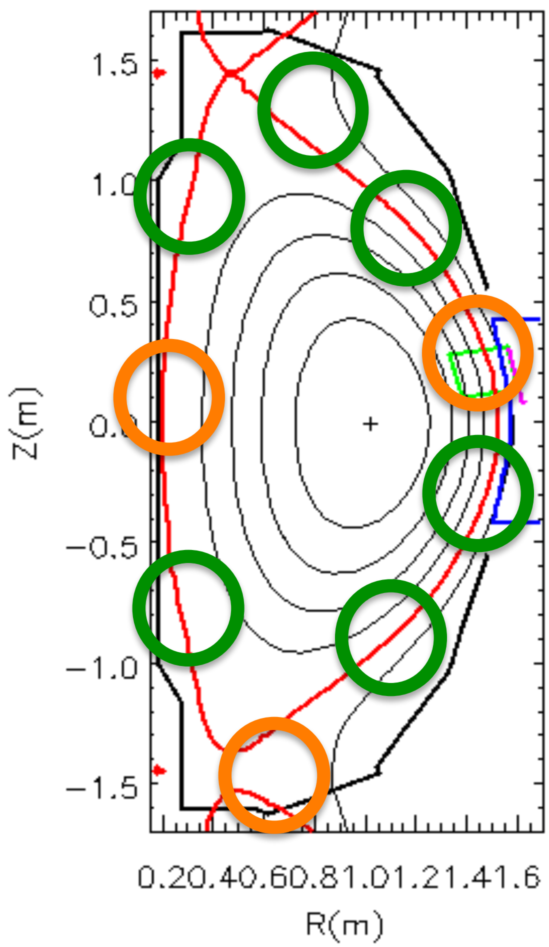
S.J. Zweben, R.J. Maqueda, T. Munsat, L. Roquemore, D.P. Stotler, J.L. Terry

Flux tube map in 3-D – is this the 3-D structure o edge turbulence ?



Farina, Pozzoli, Ryutov
NF 1993

GPI views to follow 3-D structure of B



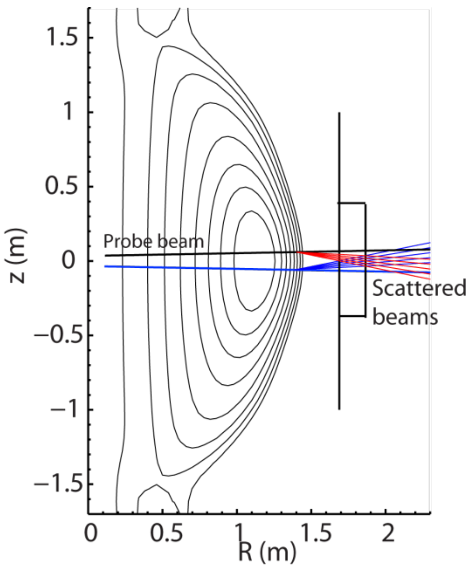
Should help to understand:

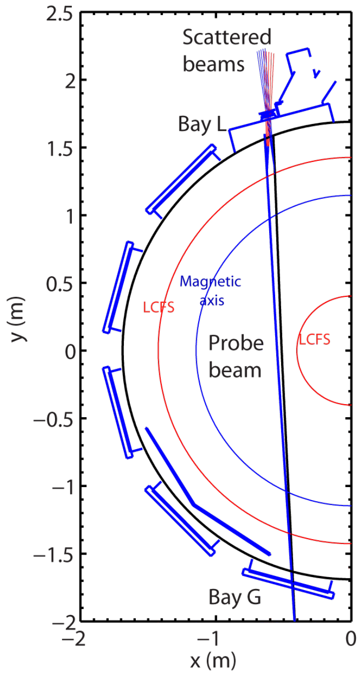
- edge zonal flows
- ELM transport
- L-H transition
- lithium effects
- momentum flow
- density limit
- impurity transport
- RF coupling

New technology:

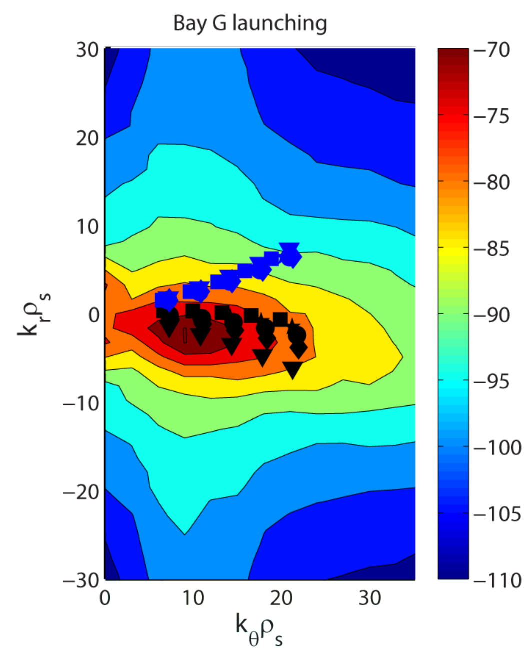
- in-vessel fiber bundles
- collimated gas puffs
- super-fast cameras
- parallel photodiodes
- 3-D visualization
- *3-D turbulence codes*

2D Wavenumber Spectra Measurement via High-k Scattering





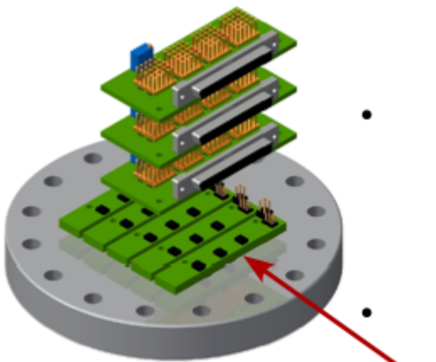
- 600 GHz FIR laser is launched from Bay G as the probe beam
  - ~100 mW input power and ~3 cm beam radius
- Scattered beams are collected through a vacuum window at Bay L
- 2D wavenumber spectra measured with two scattering schemes:
  - Downward scattering scheme captures k_θ's predicted to have dominant 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**

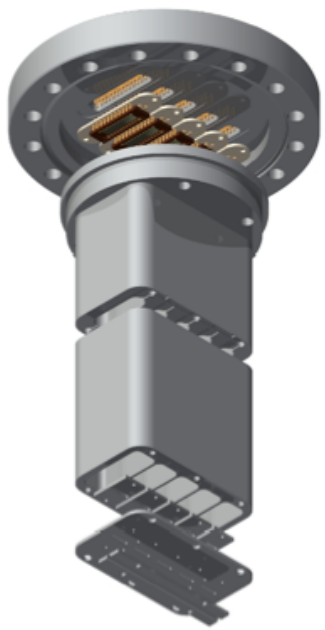


Soft X-Ray Measurements

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

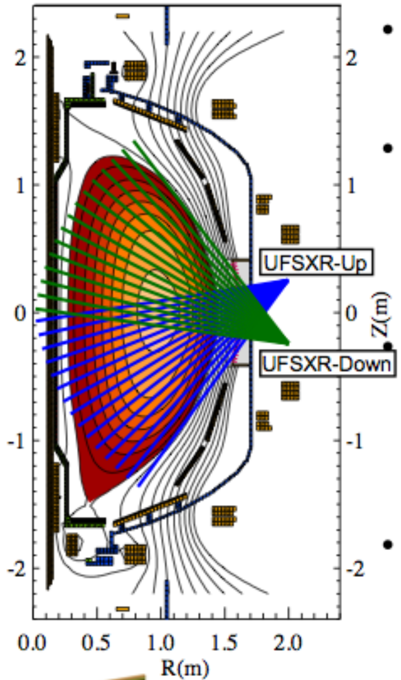
- **In-vessel design reduces port crowding, increases placement flexibility**
  - design 1: electronics in re-entrant can @ atmosphere with air cooling
  - design 2: vacuum compatible first stage electronics on detector PCB
  - potential to incorporate A/D, (fiber?) serial output for reduced wire count

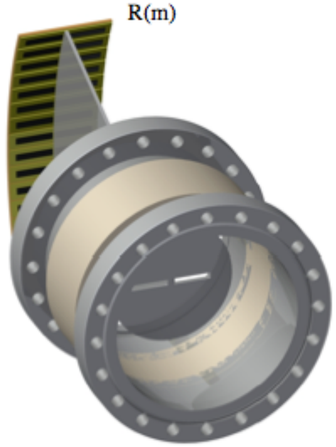
- **Projected physics capabilities for NSTX-U:**
  - impurity/electron perturbative transport measurements from the edge to the core using gas puff and repetitive laser blow-off
  - fast, high resolution edge T_e, n_e, and n_z profiles for ELM studies and code validation; edge stability analysis
  - 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**

SXR/VUV Spectroscopy

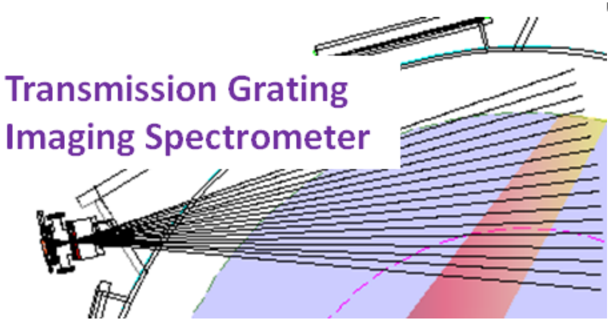
Fast Transmission Grating Imaging Spectrometer (TGIS) for NSTX-U

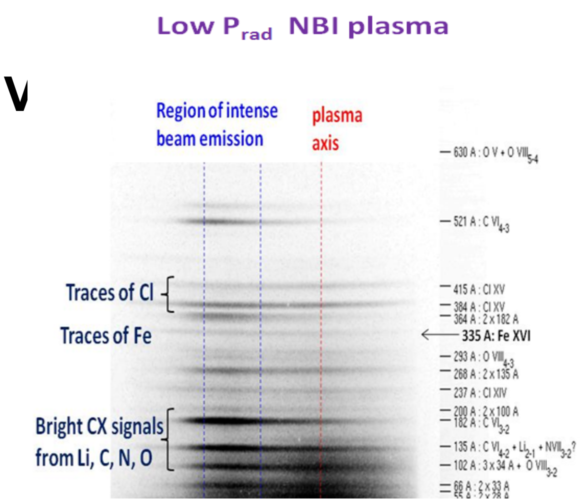
D. Stutman for the Johns Hopkins Group

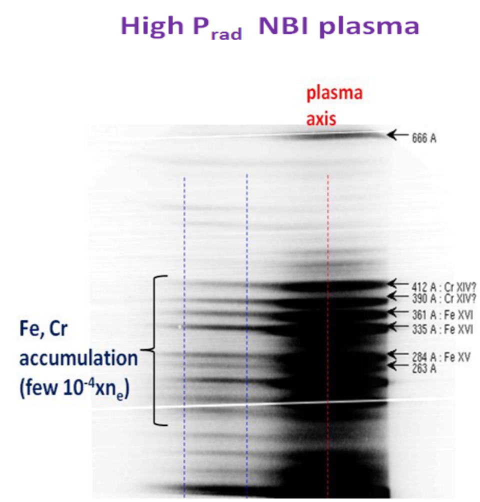
- **Fast tangential TGIS for space-resolved XUV (50-800 Å) impurity spectra:**
  - **Space/time resolved impurity fractions for improved ME-SXR modeling**
  - **Low to high-Z impurity monitoring for start-up to non-inductive sustainment**
  - **Stand-alone' impurity transport (V pinch)**

- **Parameters:**
  - **≥2 cm/5-10 ms space/time resolution, 90 ≤R ≤ 150 cm**
  - **Beam view for low-Z /CX , high-Z /electron-excited spectra**
  - **Enhanced Mo detection capability**

- **Addresses II.3, III.3, V.1.2, V**





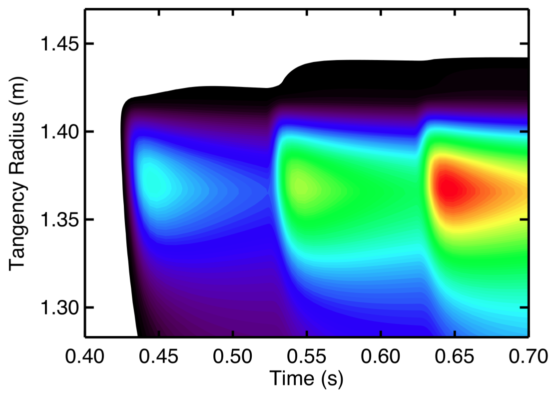


Repetitive Laser Blow-off Impurity Injection System

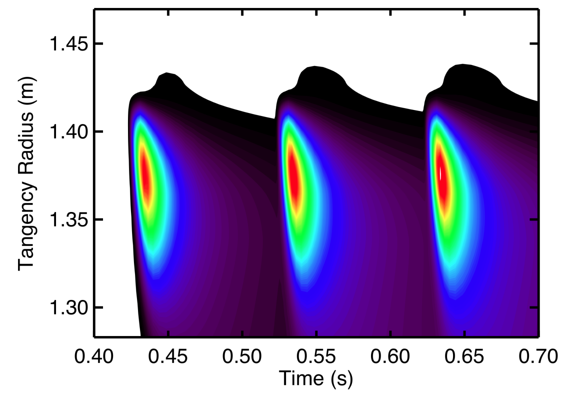
D. Clayton for the JHU Plasma Spectroscopy Group

- We propose a repetitive laser blow-off impurity injection system for transport measurements of non-recycling impurities
  - Laser with ≥ 10 Hz rep rate, 100's of mJ per pulse, scans target throughout discharge
  - Based on C-Mod system, cost within scope of a university collaboration
  - Impurity transport measurements will be made with JHU's proposed in-vessel ME-SXR arrays and fast TGIS diagnostics
  - Other possible uses include T_e transport measurements via cold pulse propagation
- Benefits of laser ablation of non-recycling impurities include:
  - More NSTX-relevant impurities (Li, C, Mo, etc.)
  - Better-constrained impurity source term for transport modeling
  - Multiple transport measurements per discharge (less impurity accumulation)
- Reflex discharge plasma will be used to characterize impurity injection
  - Simulate SOL conditions to determine source term and test STRAHL SOL model

ME-SXR Model: Recycling Impurity



ME-SXR Model: Non-Recycling Impurity



Magnetics

Proposals for
Magnetic Diagnostics on NSTX-U

1. Internal Tri-axial Magnetic Probe Arrays for Determining Scrape-Off-Layer Current (SOLC) Distributions in NSTX-U (*)

2. Tile Current Sensor Arrays for Measuring SOLC Distributions in NSTX-U (*)

3. Electrode Array for Exciting ELMs and Probing SOLC Structures in NSTX-U

4. External Tri-axial Magnetic Probe Arrays for Determining Structural Error Field in NSTX-U

5. High-reliability, High-resolution, Fast, Internal Diamagnetic Loop for NSTX-U

(*) The first two viewgraphs describe the first two proposals together.

H. Takahashi

Princeton Fusion Research LLC

Presented at

NSTX-U Innovative Measurements of ST Brainstorming

Tuesday, July 21, and Thursday, July 26, 2011

Determine SOLC Distributions by Magnetic Probe Arrays and Tile (Halo) Current Sensor Arrays (with Stefan Gerhardt)

• SOLC, acting as a *transforming agent* of external error field, could be a game changer in assessment of max tolerable error field in ITER.

An *unstated assumption,* underlying a stringent symmetry requirement (5 x 10^-5) for ITER based on a device-size scaling law, is that a (small) applied error field *directly* caused observed adverse plasma response (rotation slow-down/stoppage followed by a disruption).

An external error field, intrinsic or applied, may cause SOLC to flow, which in turn generates an error field of its own that is, not only greater in magnitude but also more destructive in nature, than the external field.

A much more relaxed symmetry requirement could emerge, if adverse plasma response was a consequence of this transformed error field, provided SOLC can be controlled or eliminated.

• Study and control of SOLC, as a source of dynamically-generated error field, will broadly impact NSTX-U research, as achieving *low-collisionality regimes* through eliminating rotation slow-down/stoppage, is central in demonstrating the relevance of NSTX-U program to future STs, ITER, and beyond.

• Study roles played by SOLC in ELM physics.

• Study post-disruption halo current (Gerhardt).

Determine SOLC Distribution by Magnetic Probe Arrays and Tile (Halo) Current Sensor Arrays (with Stefan Gerhardt) – cont.

• Determine a spatio-temporal structure of SOLC, which generates both axisymmetric and non-axisymmetric fields.

Solve an *inverse problem* using an SVD method, i.e., calculating a SOLC distribution from a measured SOLC-generated field distribution. Tile current, measured only at discrete locations, will serve as constraints on the solutions.

• Develop algorithm for taking advantage of *tri-axial field measurements,* which can define a field vector at the measurement point completely, both in magnitude and direction. Three field components should exhibit correlated features that are characteristic of the nature of the field source.

• Use a toroidal magnetic sensor array on the center stack as a "pseudo-Rogowski coil" to measure post-disruption halo current (Gerhardt).

• Transfer sensors, integrators, and digitizers from the structural error field measurement project.

Electrodes for SOLC Tracing and MHD Control

Broad impact on the NSTX-U program: the capability for triggering ELMs on demand in lithiated ELM-free discharges to control radiation loss and for helping to improve the vertical stability at a high-aspect-ratio.

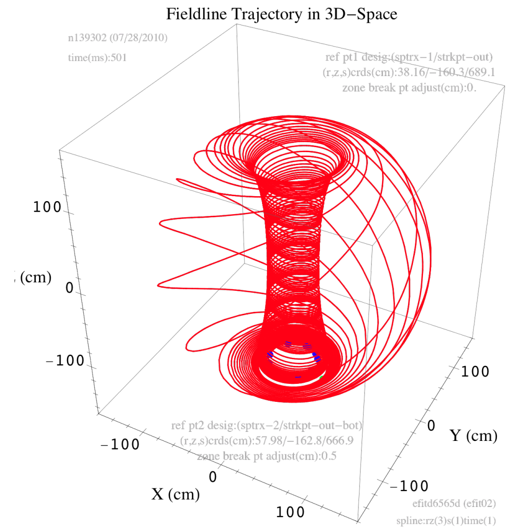
• Field lines ("wide-band") in most part of the SOL, suffering strong toroidal angular dispersion ("phase mixing"), tend to smooth out non-axisymmetry in SOLC, with resulting axisymmetric field positively or adversely affecting the n = 0 stability.

• Field lines ("narrow-band") around the "sweet spot," midway between primary and secondary separatrices, tend to stay bundled together, and SOLC along these field lines generates non-axisymmetric field that may adversely affect the n > 0 stability.

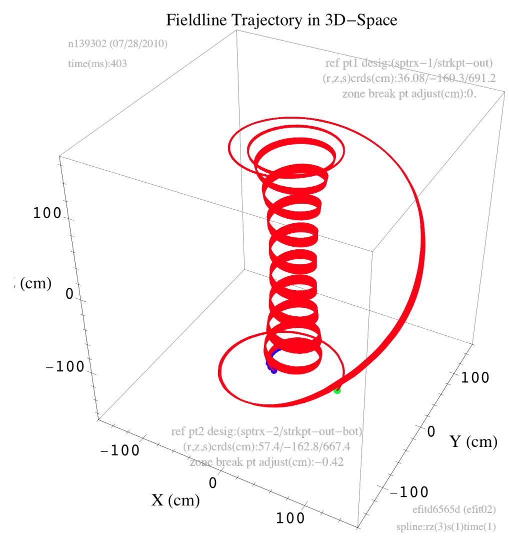
• Field lines ("interrupted"), between top and bottom divertors in far SOL well outside secondary separatrix, may play a role in triggering ELMs.

• A partial toroidal array of metal electrodes, spanning several tiles, for actively driving SOLC will give NSTX-U the capability for probing field line structures and MHD control.

Wide Band



Narrow Band



PPPL PRINCETON PLASMA PHYSICS LABORATORY

Error Field Measurement by External Sensing Coils

• Immediate and broad impact on NSTX-U (attain *low-collisionality* by reducing rotation slow-down/stoppage)

• Develop a novel error field detection method for ITER (free from intractable *sensor motion* issues)

•Magnetic sensors move, if mounted on vacuum vessel under atmospheric and electromagnetic stress, but have no sensor motion issues, if mounted on (temporary) external structures independent from vessel.

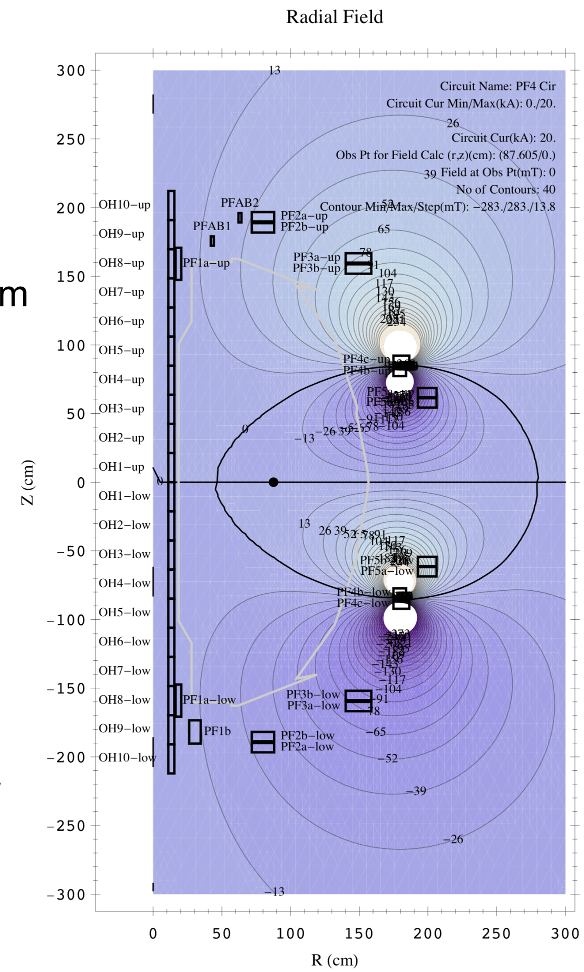
• No need to accurately *install* sensors, but need only to accurately *measure* sensor locations using *cascading levels of reference points.*

  • Primary reference points on wall/ceiling/floor (laser tracker)
  • Secondary reference points on sensor frames (photogrammetry)
  • Sensor locations referred to secondary references (measuring arm)
  • Assess cumulative errors

• Develop algorithm to take advantage of *tri-axial field measurements,* which exhibit deviations from ideal response that are correlated and characteristic of the type of deviations present.

• Upon completion of external field measurement, transfer sensors, integrators, and digitizers to the internal field measurement project.

PF4 Circuit



PPPL
PRINCETON PLASMA PHYSICS LABORATORY

High-Reliability/Resolution, Fast, Internal Diamagnetic Loop

- A fast-response (< 10 μs) energy diagnostic will be a unique addition to the NSTX-U diagnostic suite.
    - Establishing a causality relationship based on onset times of two phenomena – e.g., an abrupt rise of SOLC and edge thermal collapse.
    - Measuring energy change due to fast ion losses.
- Equilibrium Reconstruction
    - Diamagnetic flux provide a powerful constraint on equilibrium reconstruction process.

      With a correct diamagnetic flux, reconstruction rapidly converge to a correct equilibrium. With an incorrect diamagnetic flux, reconstruction rapidly converge to a very wrong equilibrium.
    - Tracking equilibrium changes on a fast time scale.
- Build a diamagnetic loop based on the same “philosophy” as the PBX loop.

LFS Magnetics Refurbishments

- Many flux loops and Mirnovs on the outer vessel have been damaged, but not (fully) repaired, over the years.
  - Largely masked to the research team by redundancy in that system.
  - For instance, all the lower passive plate flux loops should probably be reinstalled with guide tubes (as in the upper passive plates).
- Outage period will likely require many sensors to be displaced, and will probably break some that stay put.
  - The cutting of new ports will displace many of the vessel-mounted flux loops, high frequency Mirnov arrays.
  - Plate upgrades (?) will impact all the S/P PP flux loops and the plate-back & gap Mirnov sensors.
- Need to start the upgrade with a complete set of sensors.
  - Good enough to simply mimic the physical distribution of the present sensors.
  - Need to incorporate these needs in the outage scope.
- Also need better digitizers for the magnetics (LFS and HFS).
  - Cannot digitize the longer pulses at 5 kHz, and anything slower is getting kinda silly.
  - Efforts to test DTAQ solutions in the magnetics rack environment during the present run are in question.

SPG