National Spherical Torus eXperiment Upgrade

High-k Poloidal Scattering Diagnostic for NSTX-U

DE-FG02-99ER54518

FIReTIP Diagnostic for NSTX-U

DE-SC0021353

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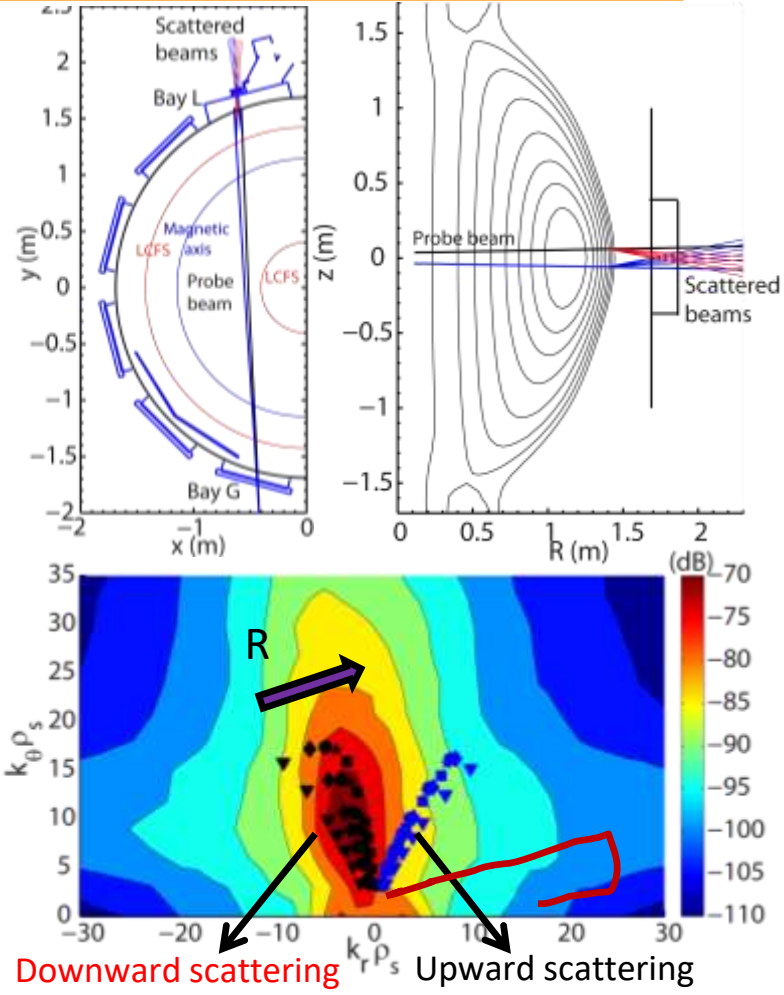
PPPL PRINCETON PLASMA PHYSICS LABORATORY

BRIDGE 12

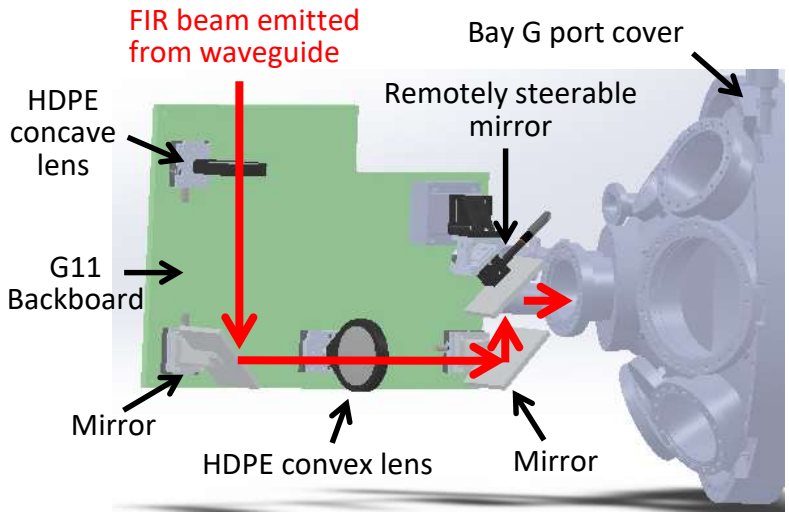
UCDAVIS UNIVERSITY OF CALIFORNIA

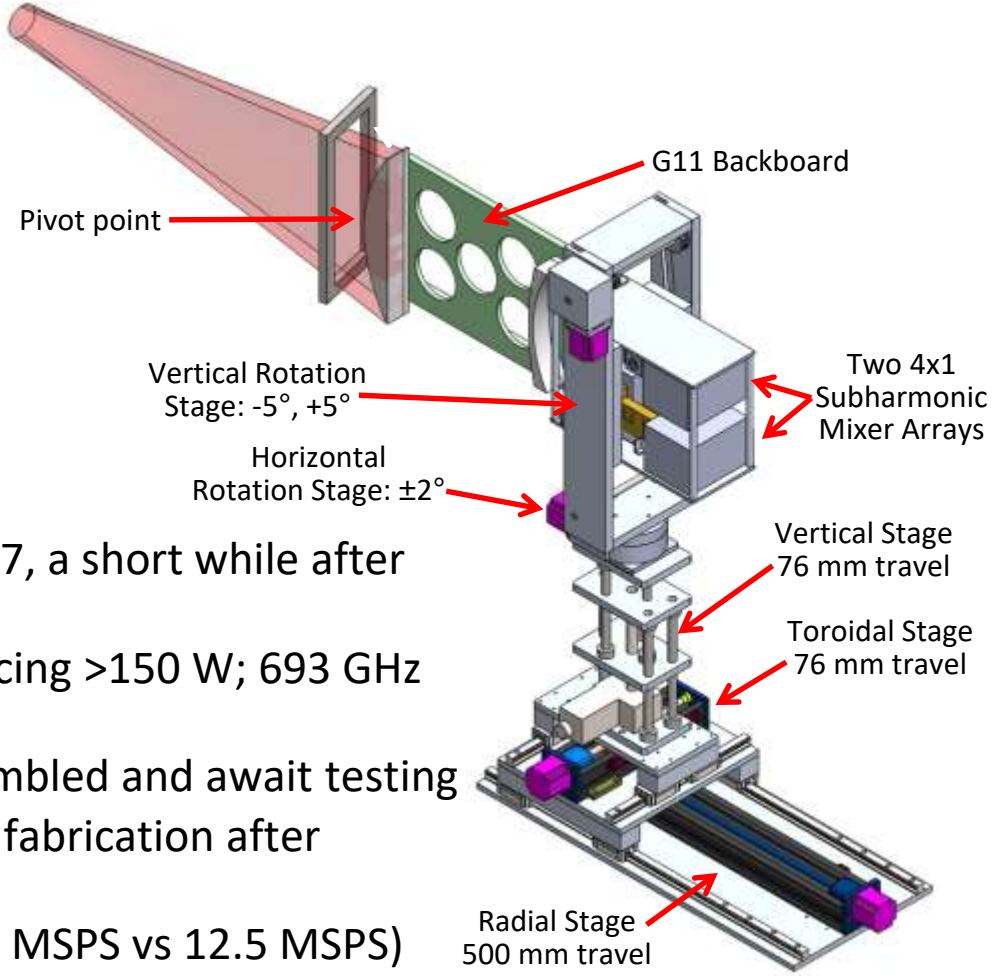
High-k_θ Scattering

- Density fluctuations scatter the FIR launch beam (enters from Bay G) into ω- and k-matched beams
- Scattered beams (8 in total) exit on Bay L, with each beam corresponding to a distinct k_θ
- Scattering regions extending radially from plasma edge to the core, and up to ±15 cm vertically
- Two scattering directions (upwards and downwards) possible at the same flux surface
- Poloidal geometry and reduced probe wavelength extends k_θ coverage up to ~40 cm^{-1} and predicted ETG peak
- NSTX-U Mission Objective Support:
  - Thrust 1-1: Characterize and understand H-mode performance at lower collisionality using increased B_T, I_p, P_{NBI}
  - Thrust 1-2: Identify transport and stability mechanisms that determine core and pedestal profiles and overall performance
  - Thrust 1-3: Develop reduced stability and transport models required to run and validate integrated predictive simulations



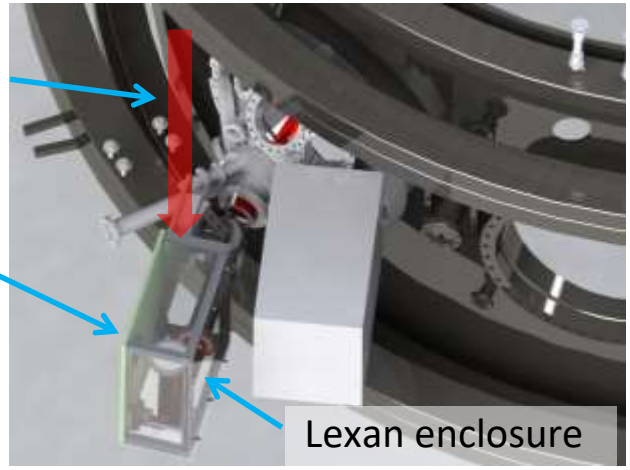
High-k_θ Scattering: Status as of March 2021

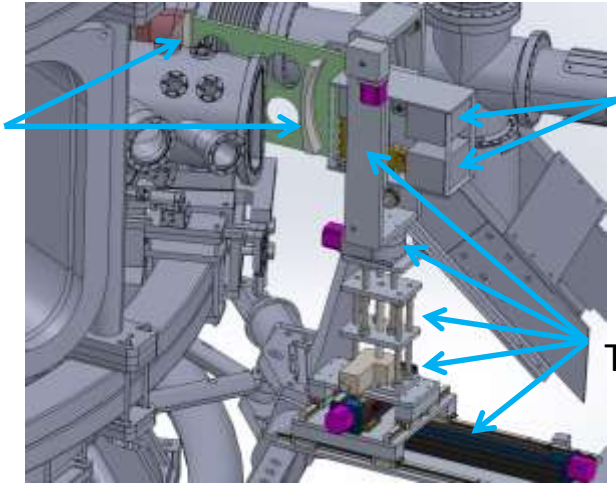




- Final Design Review (FDR) held in May 2017, a short while after the NSTX-U shutdown
- High power CO_2 laser realigned and producing >150 W; 693 GHz FIR laser is currently being overhauled
- High-k launch optics (see above, left) assembled and await testing
- High-k receiver optics (see right) ready for fabrication after NSTX-U support issues have been cleared
- New higher speed digitizers purchased (50 MSPS vs 12.5 MSPS)

High-k_θ Scattering: 5 Year Plan





Year 1

- Lasers, power supplies, launch and receive optics,etc. shipped to NSTX-U in Fall 2021
- 1 research scientist (Yilun Zhu, shared with FIReTIP) and 1 post-doc to be sited at NSTX-U beginning in Fall 2021

Year 2

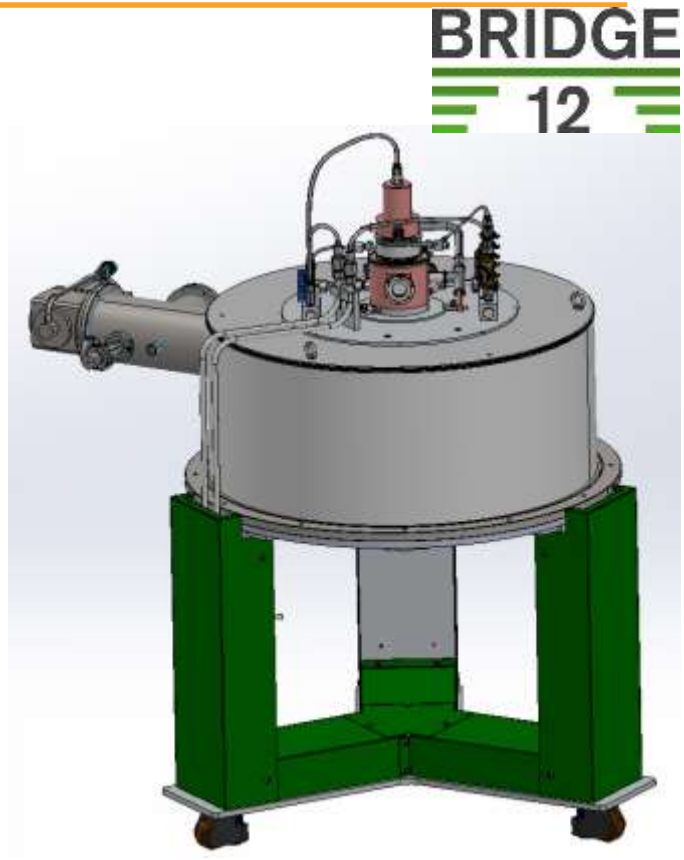
- Install system on NSTX-U (launch on Bay G, receiver on Bay L), and commission
- On-site team to be augmented by 1 graduate student also sited at NSTX-U

Years 3-5

- Operate the high-k scattering system and work with PPPL researchers to analyze data

High-k_θ Scattering: Potential Gyrotron Upgrade

- Our collaborator, Dr. Jagadishwar Sirigiri (founder and President and CEO of Bridge12 Technologies, Inc.), is funded under a DOE SBIR activity to develop a 5W, 693 GHz gyrotron to replace the ~50 mW optically-pumped FIR laser
- Two different designs are under development: a second harmonic system (with a 13 T magnet) and a third harmonic system (with a 8.6 T magnet)
- Turn-key system with a fully autonomous control system and remote user interface
- TEM_{00} output mode to couple to corrugated waveguide
- He has offered to make it available to NSTX-U for the duration of the NSTX-U high-k program, with a target date of 2022 for NSTX-U deployment
- Existing CO2 and FIR lasers would be repurposed to serve as on-hand spares for FIReTIP



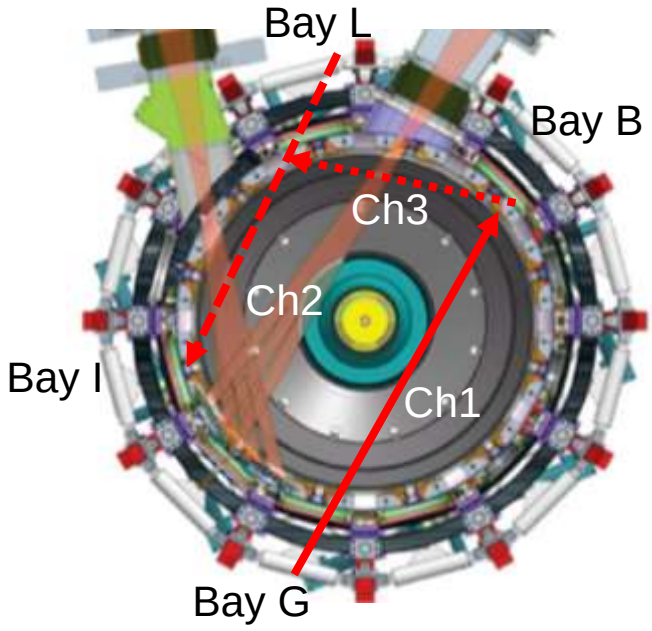
2 m^3 total volume

Far Infrared Tangential Interferometer/Polarimeter (FIReTIP)

- Far Infrared Tangential Interferometer/Polarimeter (FIReTIP) system performs simultaneous interferometry and polarimetry at 118.8 μm

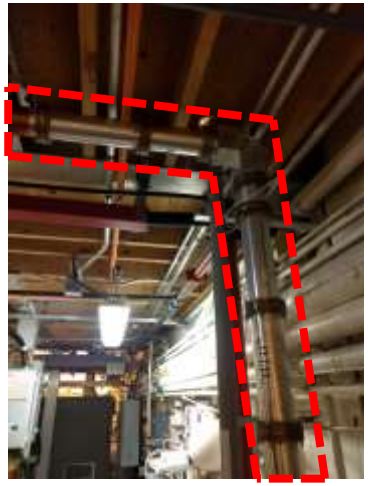
$$\phi(x) = 2.8 \times 10^{-15} \lambda \int_o^x n(x')dx'$$

$$\Psi(x) = 2.6 \times 10^{-13} \lambda^2 \int_o^x n(x')B_T(x')dx'$$



- Three separate chords are planned but only Ch1 approved at this time
- FIReTIP Ch1 launches from Bay G, reflects from Bay B, and outputs to Real Time Control Program (RTCP)
- NSTX-U Mission Objective Support:
  - Thrust 1-1: Characterize and understand H-mode performance at lower collisionality using increased B_T, I_p, P_{NBI}
  - Thrust 1-2: Identify transport and stability mechanisms that determine core and pedestal profiles and overall performance
  - Thrust 2-2: Demonstrate high-β, low-l_i discharges at low disruptivity
  - Thrust 2-3: Establish and optimize high non-inductive fraction operations

FIReTIP: Status as of Feb. 2021

- Final Design Review (FDR) held in Dec. 2015, a short while before NSTX-U shutdown
- CO2 and FIR lasers installed in area outside of the NSTX-U test cell (above, left); waveguides between this area and the NTC partially installed (above, middle) prior to NSTX-U shutdown
- FIReTIP launch optics completed (above, right) and await installation on Bay G
- FIReTIP mixer and co-aligned HeNe visible light interferometer completed and await installation below Bay G
- Software for the FPGA addition to the FIReTIP electronics (for use in real-time control) has been received; software programming is now underway

FIReTIP: 5 Year Plan

Year 1

- New high power (>150 W) CO2 laser will replace the existing ~100 W laser for increased FIR power and enhanced reliability
- 1 research scientist (Yilun Zhu, shared with High-k Scattering) to be sited at NSTX-U beginning in Fall 2021

Year 2

- Install the system on NSTX-U, and commission
- Connect FPGA density feedback control signals to Real Time Control Program (RTCP)
- On-site team to be augmented by 1 graduate student also sited at NSTX-U

Years 3-5

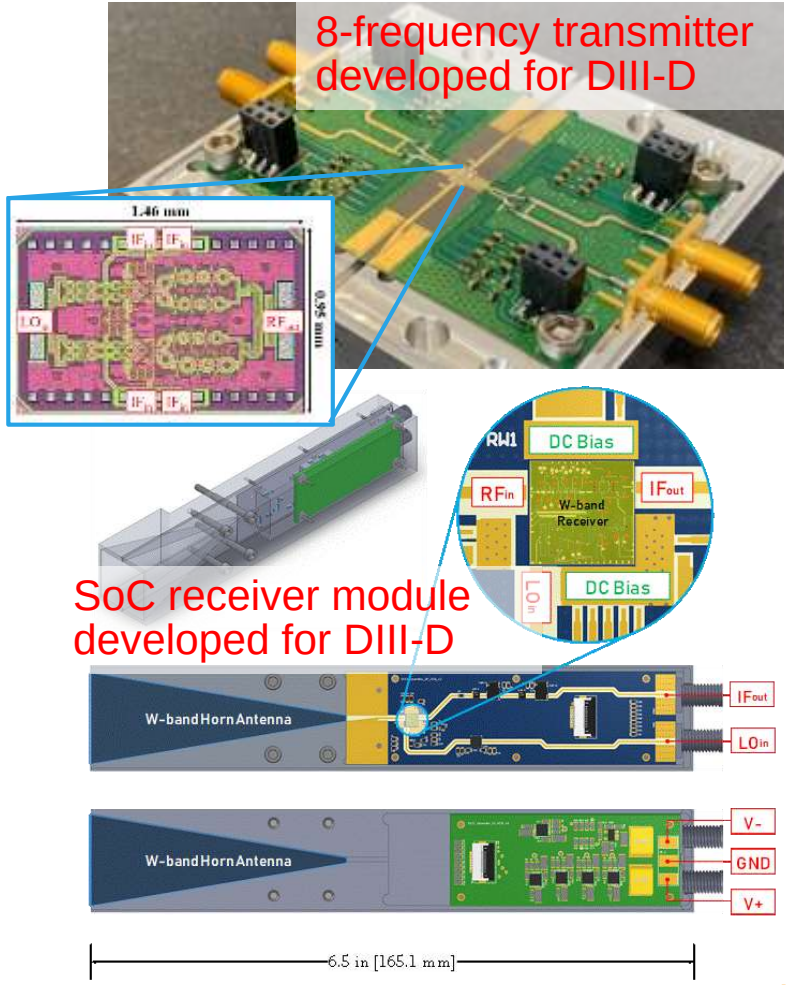
- Operate the FIReTIP system and work with PPPL researchers to analyze data

Key Needs for PPPL Support

- Install FIReTIP launch optics and mixer table in NTC, and complete the FIReTIP waveguide run down to the mixer table
- Complete all safety measures for CO2 laser operation for both High-k and FIReTIP systems (laser exhaust vent, emergency stop, internet/network access, etc.)
- Install High-k window shutters on Bay L and failsafe waveguide shutter blocks (FIReTIP and High-k) in laser cage area
- Install High-k launch optics on Bay G and receiver on Bay L

Future MIR System Upgrade

- Design and development of a 50-75 GHz Microwave Imaging Reflectometer (MIR) system funded under previous NSTX-U grant for imaging low-k density fluctuations
- System-on-chip (SoC) technology development carried out under Innovative Diagnostics Program for DIII-D and NSTX-U
- MIR not funded under current NSTX-U grant
- MIR can be installed later, to co-exist with high-k_θ scattering on Bay L:
  - High-k scattering optics pulled slightly out from Bay L port to allow large aperture polarizer to be placed next to window (high-k_θ and MIR are polarized perpendicular)
  - Sufficient space above Bay L window to house MIR transmitter and receiver



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