MIT PSFC Plasma Science and Fusion Center

National Spherical Torus eXperiment Upgrade

Study of High Harmonic Fast Wave (HHFW) Interaction with the Scrape-Off-Layer Plasmas in NSTX-U

Seung-Gyou Baek, Paul Bonoli, Raymond Diab (MIT PSFC)

NSTX-U / Magnetic Fusion Science Meeting

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Project Overview

- The principal goal of this project, “Study of High Harmonic Fast Wave (HHFW) Interaction with the Scrape-Off-Layer Plasmas in NSTX-U,” is to optimize HHFW heating and current drive with direct measurements of HHFW power using the RF probes at the divertor and antenna.

- Objective 1: Extend core confinement and stability
  - 1.2.d: “understanding and minimization of HHFW SOL power loss…”
  - Answer critical questions of how RF losses can be mitigated (experimental and modeling investigations)

- Objective 2: Develop non-inductive scenario
  - 2.3.c: “reduction of V-s consumption of ramp-up”
  - Contribute to establish optimized operation of HHFW power coupling

- Objective 3: Evaluate power handling and PMI
  - 3.2.a: “Characterize heat loads in plasmas…”
  - Characterize RF-edge interaction and RF-induced heat flux to the divertor

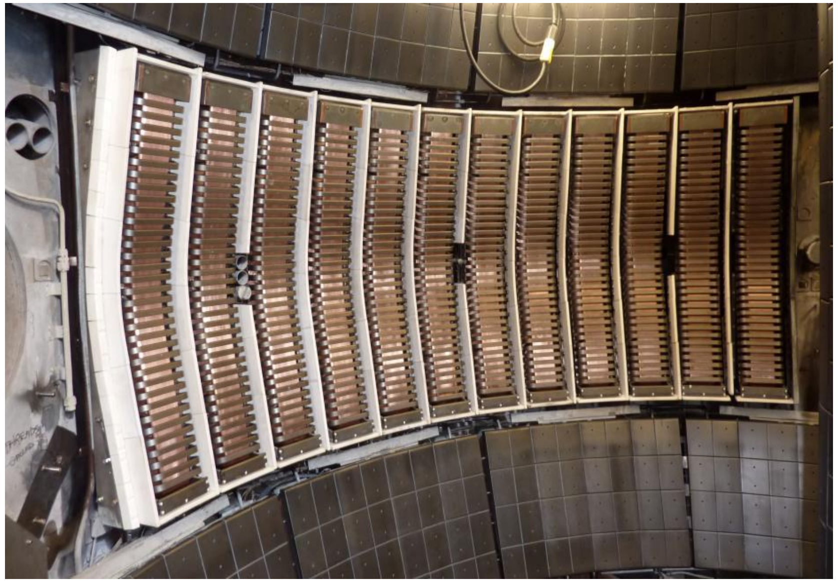
Personnel and Key needs

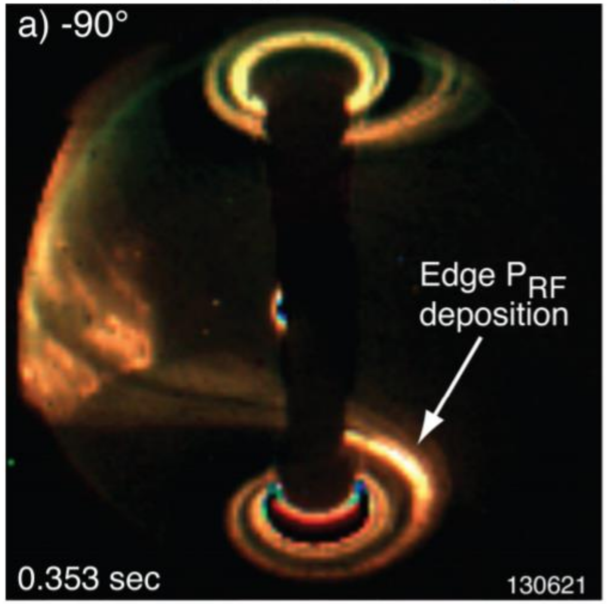
- MIT Participants
  - PI: Seung Gyou Baek
    - hardware development and experimental analysis (0.2 FTE)
  - Key Personnel: Paul Bonoli
    - data interpretation with modeling assist (0.05 FTE)
  - Graduate Research Assistant: Raymond Diab
    - Joined the project this year (PhD project)
    - Hardware development, experimental analysis, and modeling (1.0 FTE)
    - Will be on-site after finishing the coursework at MIT
- Primary PPPL contacts
  - Nicola Bertelli, Masa Ono, Syun'ichi Shiraiwa

- Key needs: Support for hardware installation on the NSTX-U torus hall and system shakedown

Background: High harmonics fast wave system and parasitic RF power flow in the SOL

- 12-strap antenna located on the outboard midplane
- Heat and current drive actuator
- Wave frequency = 30 MHz, up to P_{RF} = 6 MW
- $|k_\phi|$ = 3, 8, and 13 m^{-1} when $\Delta\phi$ = 30º, 90º, and 150º





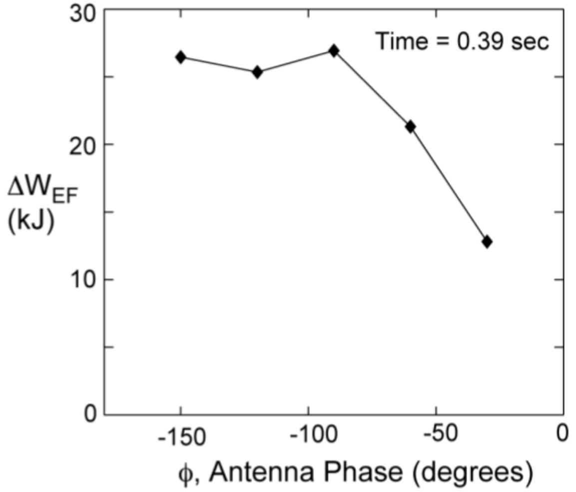
- In NSTX, up to 60% of the injected HHFW power could be lost in the SOL on the first pass, preventing efficient RF power coupling.
- Visible camera images clearly show a bright spiral along the SOL field line to the top and bottom divertors, evidencing RF power deposition at the plasma boundary.

Figure from Perkins et al., PRL **109**, 045001 (2012)

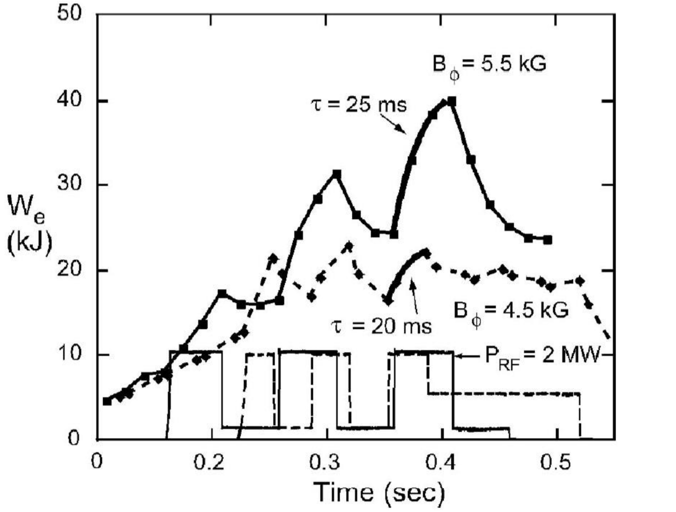
Observed loss in heating efficiency is correlated to the onset density of fast wave propagation in the SOL.

- Parameter dependence is also identified in recent modeling ($n_{onset} \propto \frac{B\,k_{\parallel}^2}{\omega}$)
- Expanded operating space of NSTX-U will provide an unique environment
    - Low phasing operation at a higher magnetic field
    - Plasma current and wall conditioning (boronization and lithiation) → SOL density and turbulence

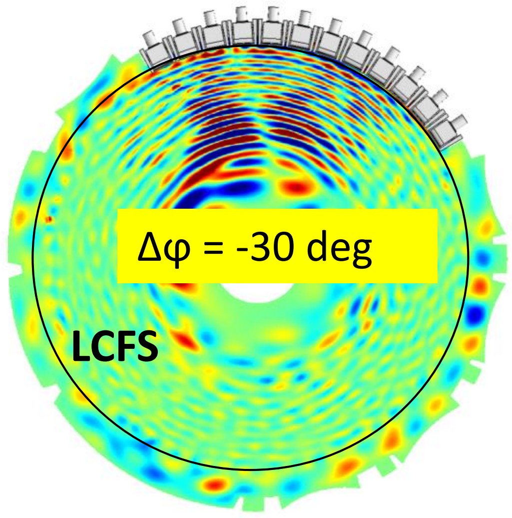
Stored Energy vs. Phasing



Stored Energy vs. Magnetic Field



Model RF Electric Field

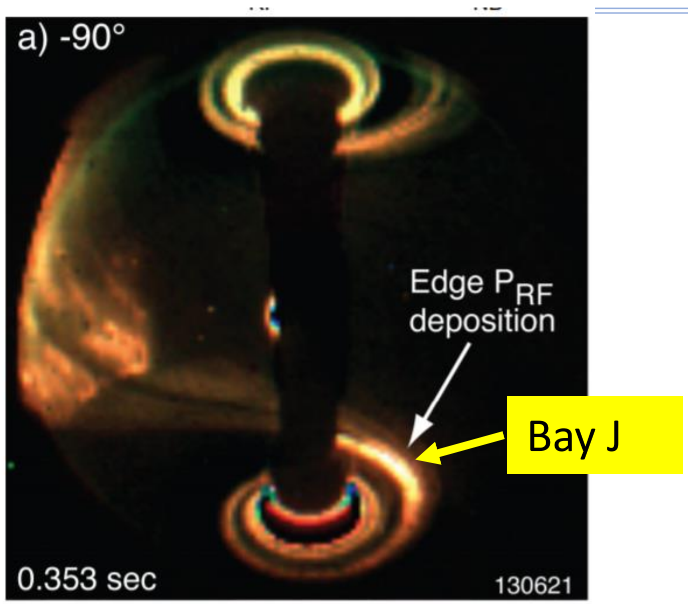


Figures from Hosea et al. PoP **15**, 056104 (2008)

Figure from Bertelli et al. APS (2020)

Research Task (Year 1 and Year 2): design/develop the RF power measurement system

- Characterize the RF probes installed on NSTX-U
  - RF Langmuir probes at Bay J are installed as a part of the NSTX-U Recovery Project
    - 4 RF/Langmuir probes and 2 high flux rail probes
  - EM modeling of a probe response



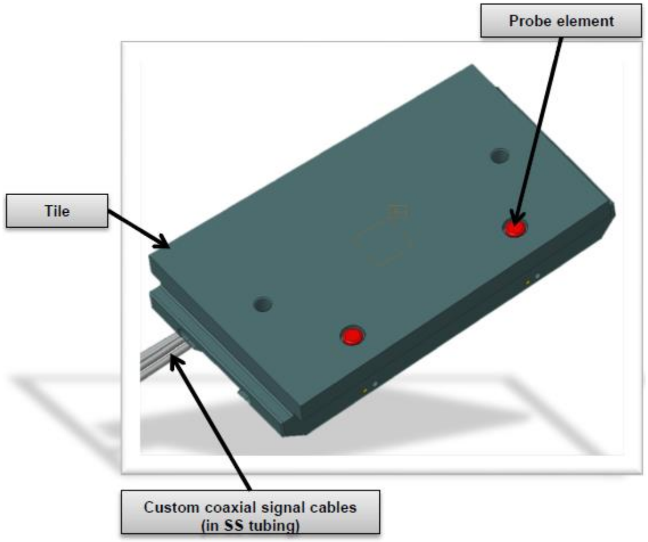


Figure from PFC design review

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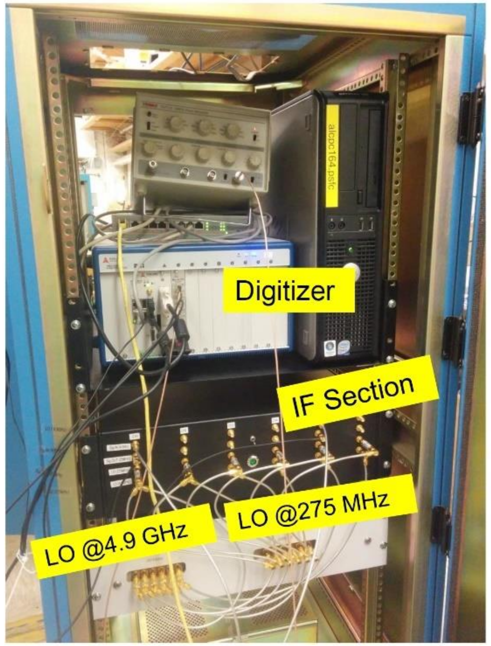
- Design and fabricate the RF power detection system
  - A MIT-owned eight-channel ADLINK digitizer will be utilized.
    - 100 mega-samples/second
  - New RF circuit to amplify and filter the HHFW signal will be developed.
  - All the hardware will be mounted on a 19-inch rack.
  - Installation of a RF diagnostic rack on the torus hall and its interface with the NSTX-U infrastructure



4.6 GHz power detection system at MIT

Research Task (Years 3-5): Characterize and mitigate HHFW power loss in the SOL

- Characterize the relationship between RF core and edge absorptions
  - RF modulation experiment with a systematic scan of magnetic field, current, wall conditioning, and phasing
  - Understand how RF power flow is dissipated in the SOL.
  - RF probes will provide RF power flow (or RF voltage) in the divertor and RF frequency spectra

Research Task (Years 3-5): Characterize and mitigate HHFW power loss in the SOL

- Characterize the RF core and edge absorption
- Investigate RF rectification at the divertor
  - NSTX: probes under the spiral exhibit a negative shift in the floating potential → deduce RF voltage and RF-induced heat flux
  - Measure RF voltage with RF probes where the spiral is the most intense
  - Compare to Langmuir probe and IR thermography measurements
  - What is the relative contribution of RF rectification to the total RF power loss?

Probe I-V Characteristic Curve

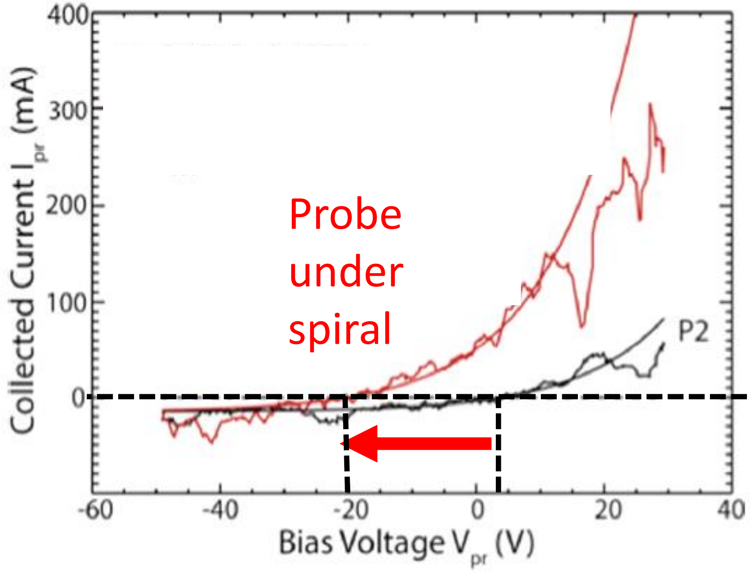


Figure from Perkins et al., PoP **22**, 042506 (2015).

Research Task (Years 3-5): Characterize and mitigate HHFW power loss in the SOL

- Characterize the RF core and edge absorption
- Investigate RF rectification at the divertor
- Investigate non-linear parametric decay instabilities
  - Power threshold and decay types
  - Can we evaluate the RF power loss from decay instabilities?

HHFW Frequency Spectrum

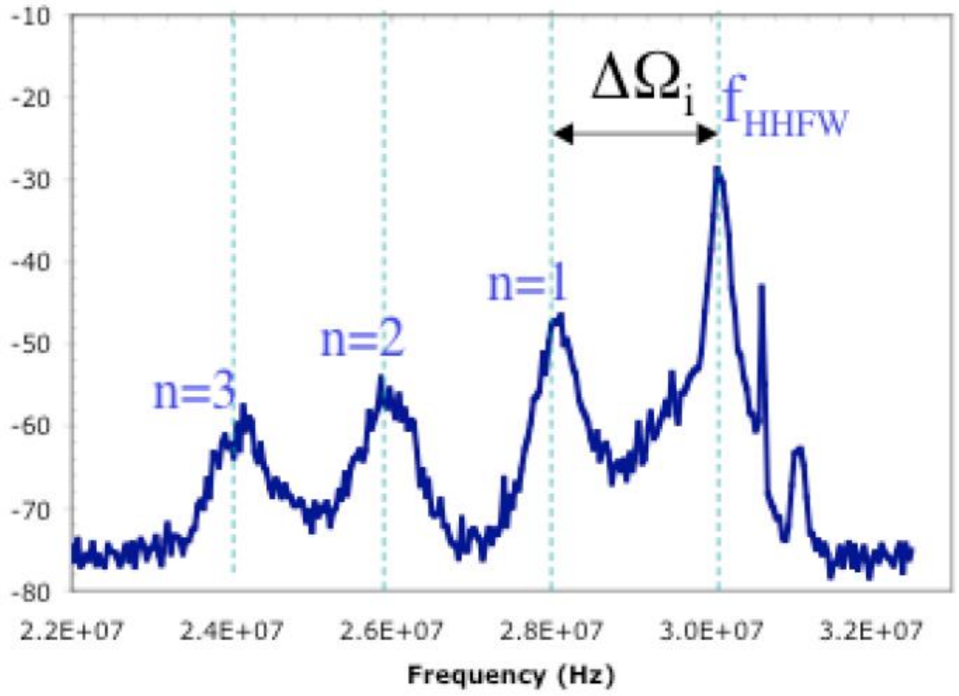


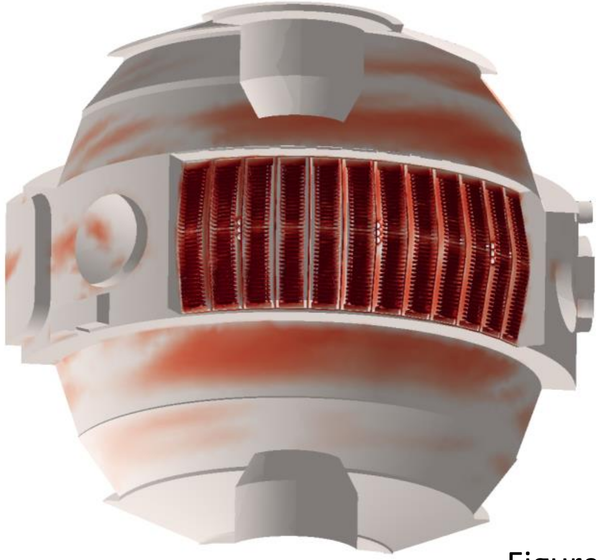
Figure from Wilson et al., AIP Conf. Proc. **787**, 66 (2005)

Research Task (Years 3-5): Characterize and mitigate HHFW power loss in the SOL

- Characterize the RF core and edge absorption
- Investigate RF rectification at the divertor
- Investigate non-linear parametric decay instabilities
- Comparison of experimental RF power with modeling using realistic geometry and plasma parameters
    - Evaluation of RF power in the spiral

|E| on the wall surface

Antenna phasing = 30º



Antenna phasing = 150º

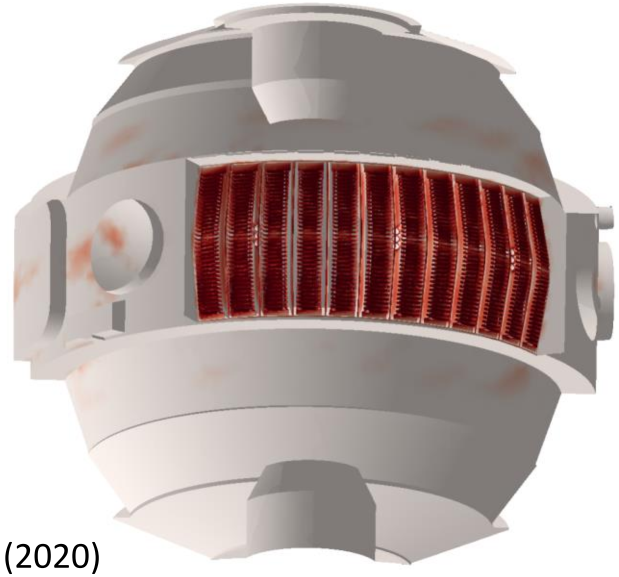
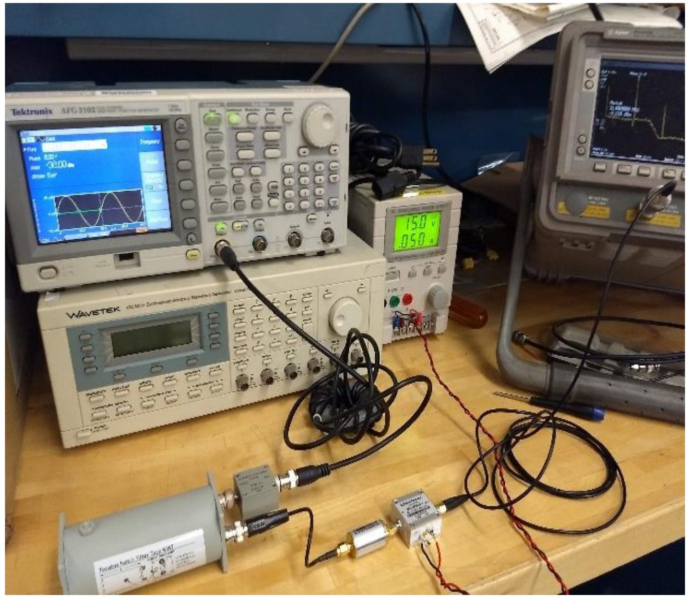
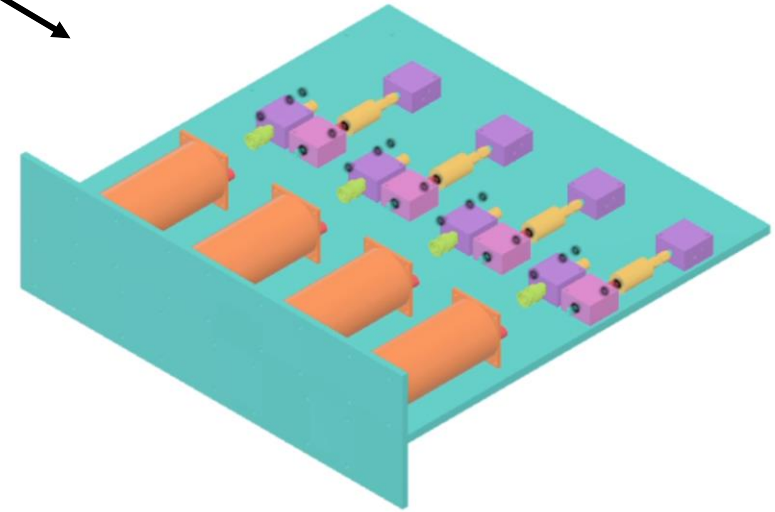


Figure from Bertelli et al. APS (2020)

On-going work

- Regular meetings with the RF group every 2~3 weeks since Sept. 2020
- Identified the RF circuitry
  - no frequency conversion, direct digitization
  - Initial test of RF components (cavity filters, amplifiers)
  - Design of the RF chassis
- A probe tip is being modeled in PETRA-M for EM response.





Estimated schedule of activities / milestone

- Year 2: Carry out Design Review activities
- Year 2: Diagnostics installation

} Diagnostic Development

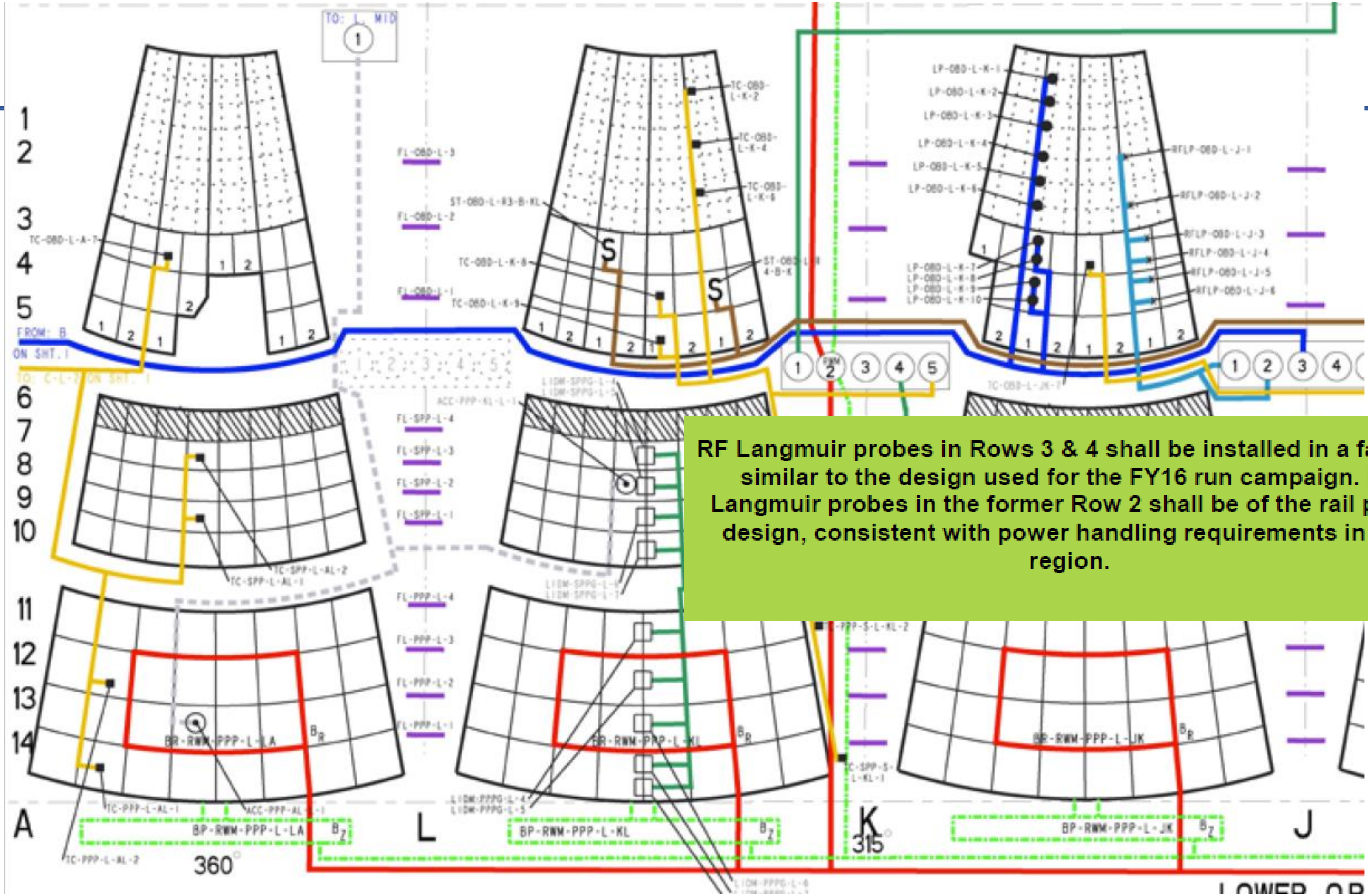
- Years 3&4: experiments and data interpretation
- Years 4&5: experiments, data analysis and model comparison
- Year 5: Identify optimal HHFW operation scenarios

} Physics Research

Summary

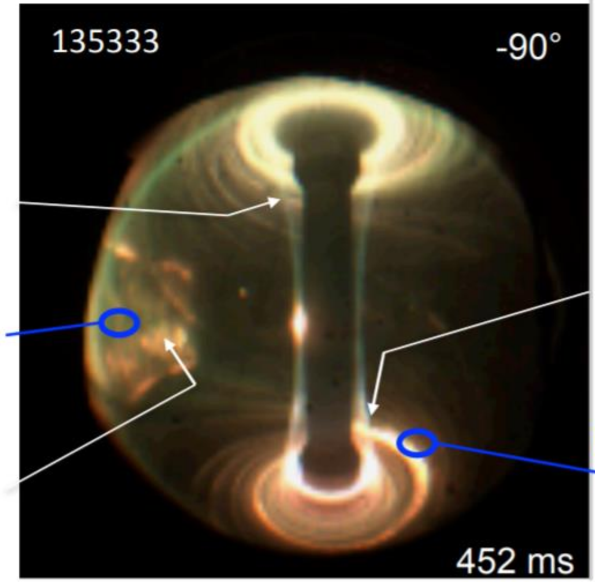
- The project will carry out RF physics investigation to support the NSTX-U research objectives.
- 3 personnel (S.-G. Baek, P. Bonoli, R. Diab) from MIT will work closely as the NSTX-U team
  - Primary contacts at PPPL: N. Bertelli, M. Ono, S. Shiraiwa
- The project aims to characterize and optimize HHFW operation by understanding and mitigating RF parasitic coupling to the SOL.
  - RF rectification and parametric decay instabilities
- Careful documentation of HHFW performance in a wide range of NSTX-U operating parameter space.
  - RF power detection system: relatively simple, yet provides important information of RF power at the divertor
    - Will be a part of a larger suite of diagnostics on NSTX-U
  - Advances in modeling now allows a direct comparison

Extra

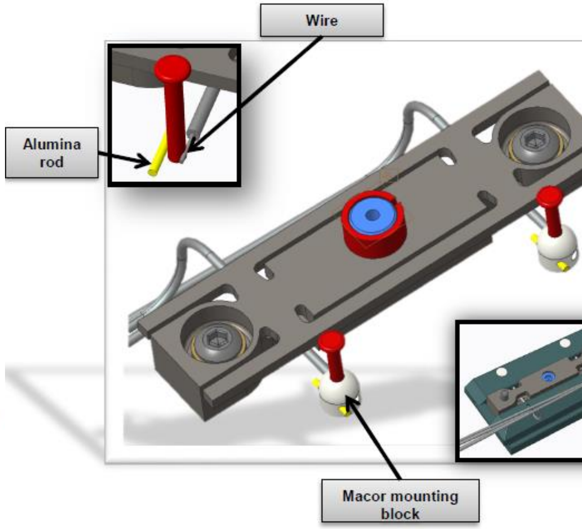


RF Langmuir probes in Rows 3 & 4 shall be installed in a fashion similar to the design used for the FY16 run campaign. RF Langmuir probes in the former Row 2 shall be of the rail probe design, consistent with power handling requirements in that region.

IR camera and probe upgrade: critical for documenting RF edge heating



B_T = 4.5 kG, I_P = 0.8 MA



- Diagnostics configured: to "see" hot HHFW streak over wide range of field pitch
- IR views: at bottom, top and antenna
- Probes for measuring IV characteristics and RF fields: Coaxial Langmuir and RF probe