Progress on the ORNL HHFW Edge Reflectometer

John Wilgen, Greg Hanson, David Swain

Oak Ridge National Laboratory, Oak Ridge, TN, USA

NSTX Results Review

PPPL

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Significant progress has been made in the last year

Outline

- System description
  - Recent improvements
- Data analysis progress
  - More flexible profile reconstructions (less assumptions)
  - Working toward limited automation
- Fluctuation measurements
  - Setup for arbitrary sweep waveforms
  - Initial fluctuation measurement
- Future plans and some possible options
  - Improved analysis throughput - automation
  - Faster data acquisition to improve reliability
  - Fluctuation measurements
  - Look at 30-MHz component of reflectometer signal when doing 30-MHz rf heating

HHFW Broadband Microwave Reflectometer - Description

- **Purpose:** Measure the edge density profile directly in front of the HHFW antenna, i.e. primarily in the scrape-off layer in the gap between the outermost flux surface and the antenna

- Launcher access located between current straps #1 & #2 of HHFW antenna
  - Transmit/receive antennas recessed 1" behind the Faraday screen
  - Antennas are fed by broadband dual-ridged coax-to-waveguide adapter
  - Polarization is easily changed by rotation of these adapters
  - Connect to reflectometer using 40 GHz low loss cables

- Status Prior to this run period (May - July)
  - Sweep time: 200 μsec
  - Frequency range: 5.7 to 30 GHz
  - X-mode polarization, sweep start with $f<f_{ce}$ (for B>0.3 T)
  - Density range: 0.05 to 6.0 x 10^{12} cm^{-3}
  - Factor of 10X reduction in starting density eliminated $\lambda/2$ ambiguity in starting location

Recent Reflectometer Improvements (July 2001)

- Sweep time reduced from 200 to 100 μsec
  - reduced effects of density fluctuations

- Analog sweep driver replaced by arbitrary waveform generator
  - Improved stability eliminates drift in the phase calibration
  - Allows remote switching between profile measurement and fluctuation measurement
  - Enables linearization of frequency sweep (not yet attempted)

- Replaced Sin(ϕ) detector with a broadband quadrature phase detector
  - Improved phase accuracy and fringe tracking
  - Frequency range limited to 27 GHz maximum

- Utilized remote operation of arbitrary waveform generator to obtain fluctuation data in frequency stepping mode for a limited number of shots

Progress in data analysis

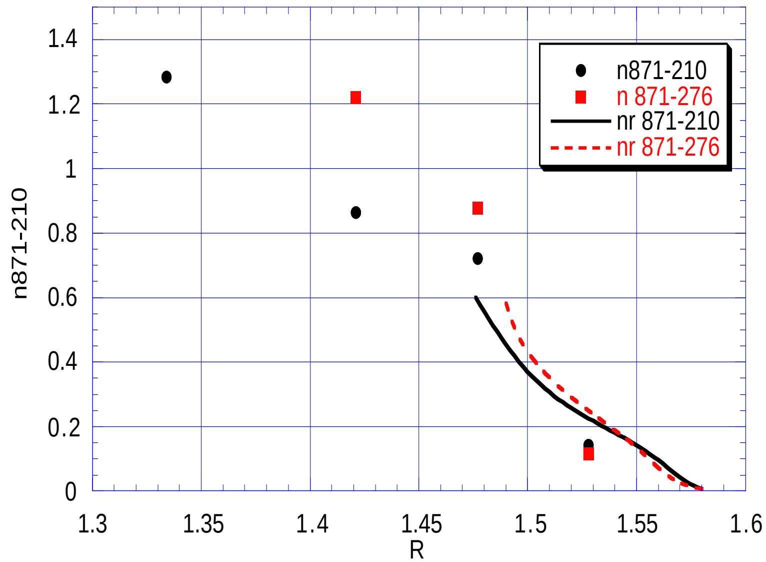
- Began providing time-averaged density profiles by averaging together the phase data from multiple sweeps (to date, have produced 15 profiles for 12 shots)
  - Antenna coupling depends on the an average edge-density profile, spatially-averaged over the entire surface of the HHFW antenna
  - The reflectometer provides a highly localized measurement at single point
  - Time averaging of the locally measured profile (as the density fluctuations drift past the reflectometer) provides a better indication of the average density profile

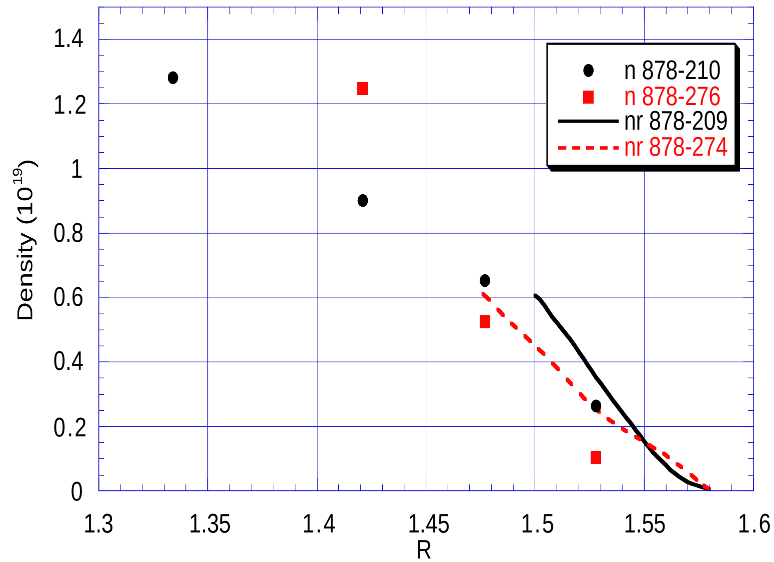
- Replace polynomial fitting of phase data with simple smoothing
  - Initially used polynomial fit to smooth out effects of density fluctuations.
  - Smoothed phase data more closely follows the raw data
  - Data is no longer artificially distorted by the fit

- Now using EFIT mod-B data to determine frequency range of X-mode data

- Using semi-automated display of extracted amplitude and phase data for multiple sweeps (30) to assist in the selection of data and ascertain trends in the time evolution

Phase-Averaged HHFW Reflectometer Edge-Density Profiles

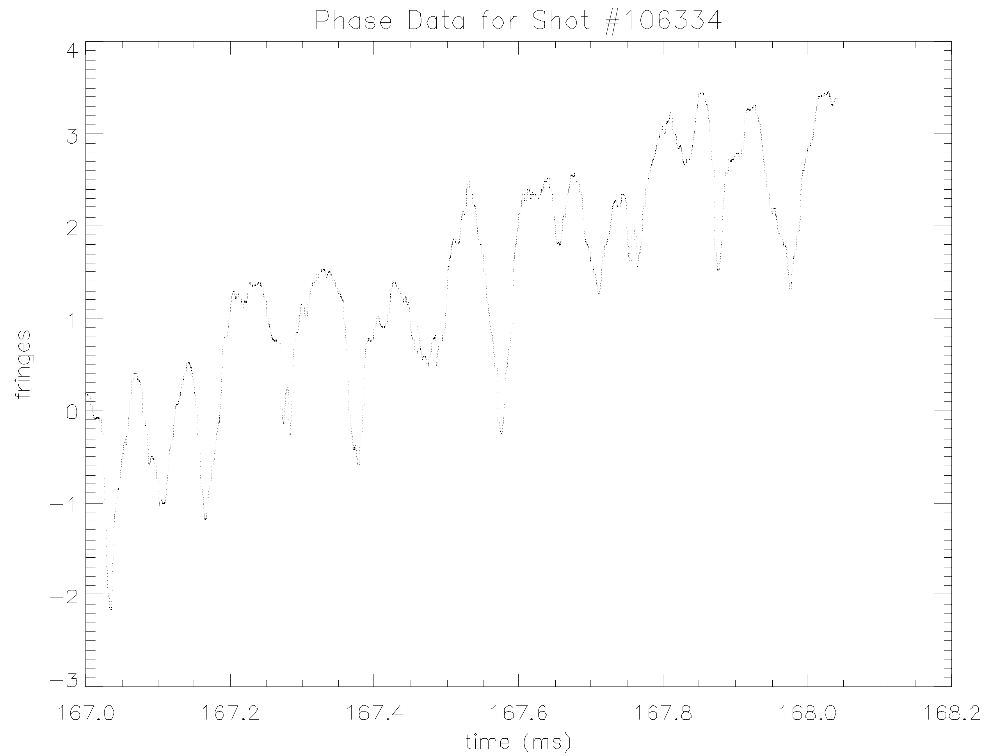




- Comparison of phase-averaged reflectometer profiles with TS data
  - Average phase data from 5-7 sweeps within a 2 msec interval
  - Compare with TS data at 210 msec (blk) and at 276 msec (red)
  - Shots 105871 & 105878 from RF heating experiment on June 13th show reasonable agreement between reflectometer & TS
  - For other low current shots (300 kA), TS is half the reflectometer density

Initial results from fluctuation measurements

f=14.2 GHz
n_e=1.3x10^{12} cm^{-3}
t = 167-168 ms
Shot # 106334



- Phase fluctuations (in fringes) measured at a probing frequency of 14.2 GHz
  - Amplitude of phase fluctuation is about 2-3 fringes peak-to-peak
  - Largest phase excursions are low frequency, about 10-20 kHz

Initial results from fluctuation measurements (con't)

NSTX

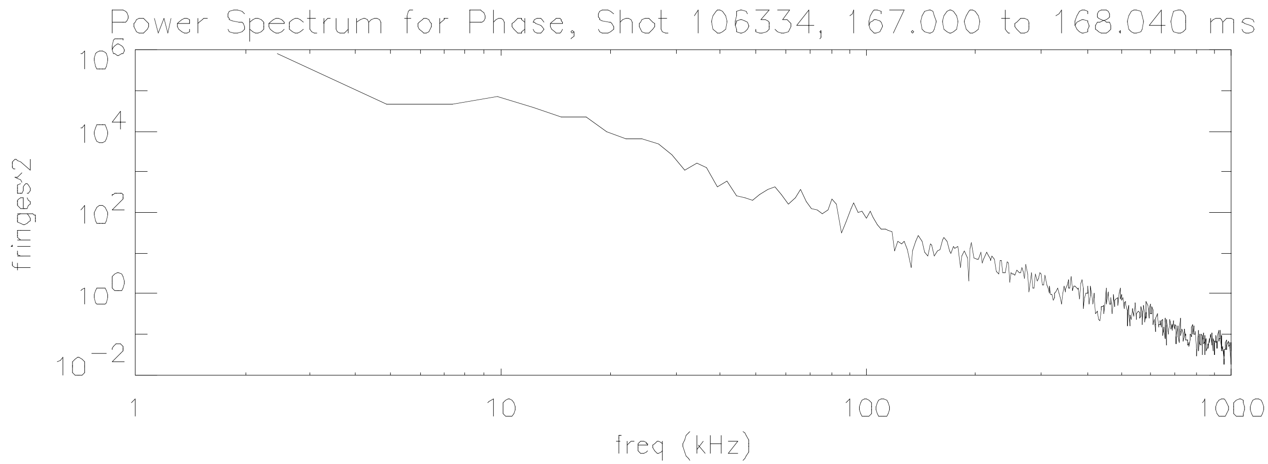
f=14.2 GHz

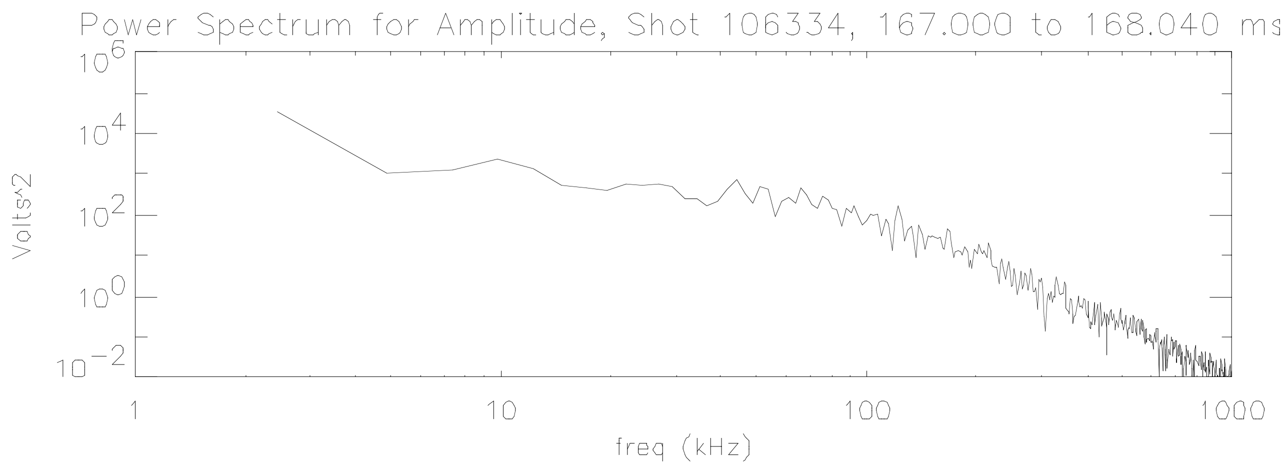
n_e=1.3x10^{12} cm^{-3}

t = 167-168 ms

Shot # 106334

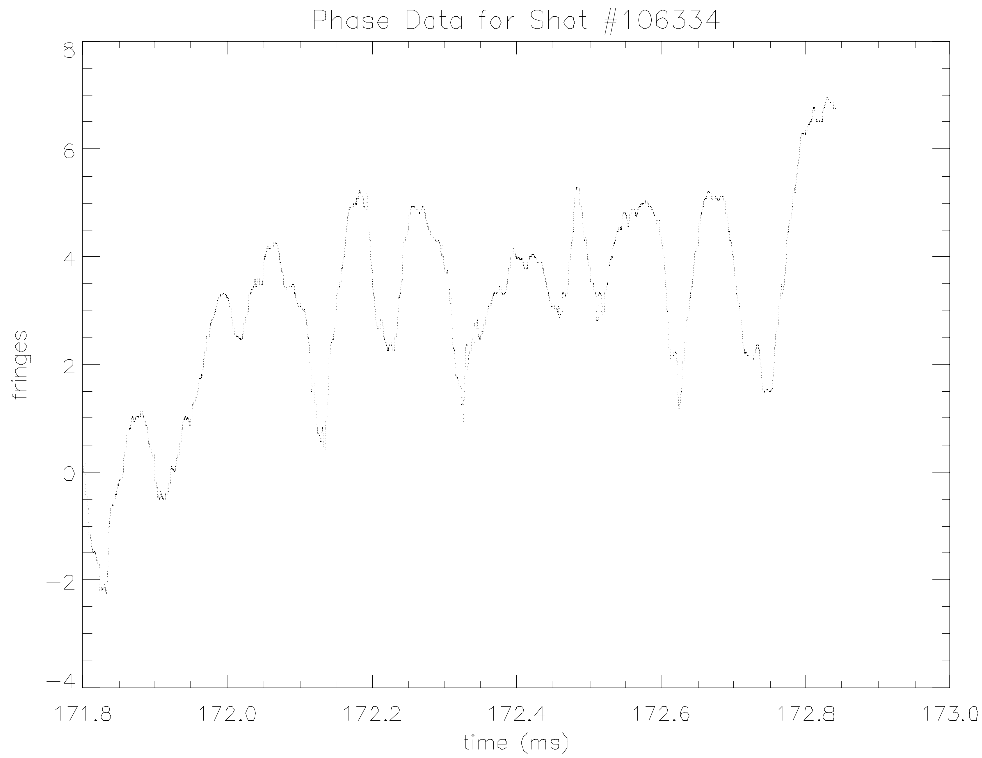
- Power spectrum of phase and amplitude fluctuations measured at 14.2 GHz for this same time interval
  - Phase spectrum peaks at 10 kHz, then falls as $1/f^2$
  - Amplitude spectrum is flatter





Initial results from fluctuation measurements (con't)

f=20.4 GHz
n_e=3.5x10^{12} cm^{-3}
t = 172-173 ms
Shot # 106334



- Phase fluctuations (in fringes) measured at 20.4 GHz for the same condition
  - Magnitude is about 4-5 fringes peak-to-peak
  - Large amplitude component predominantly low frequency, about 10-20 kHz

Initial results from fluctuation measurements (con't)

f=20.4 GHz
n_e=3.5x10^{12} cm^{-3}
t = 172-173 ms
Shot # 106334

- Power spectrum of phase and amplitude fluctuations measured at 20.4 GHz for this same time interval
  - Phase spectrum peaks at 10 kHz, then falls as 1/f^2
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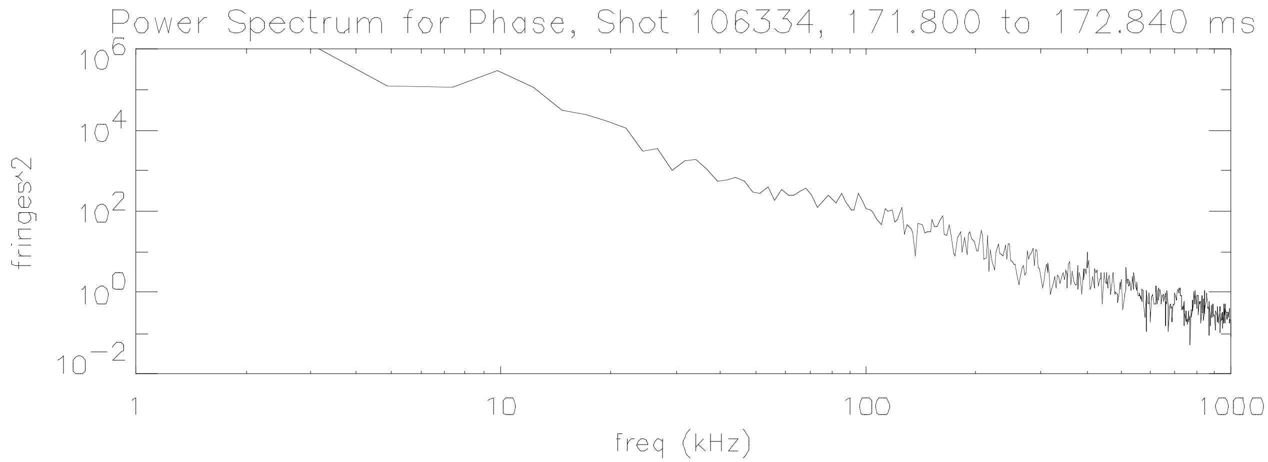
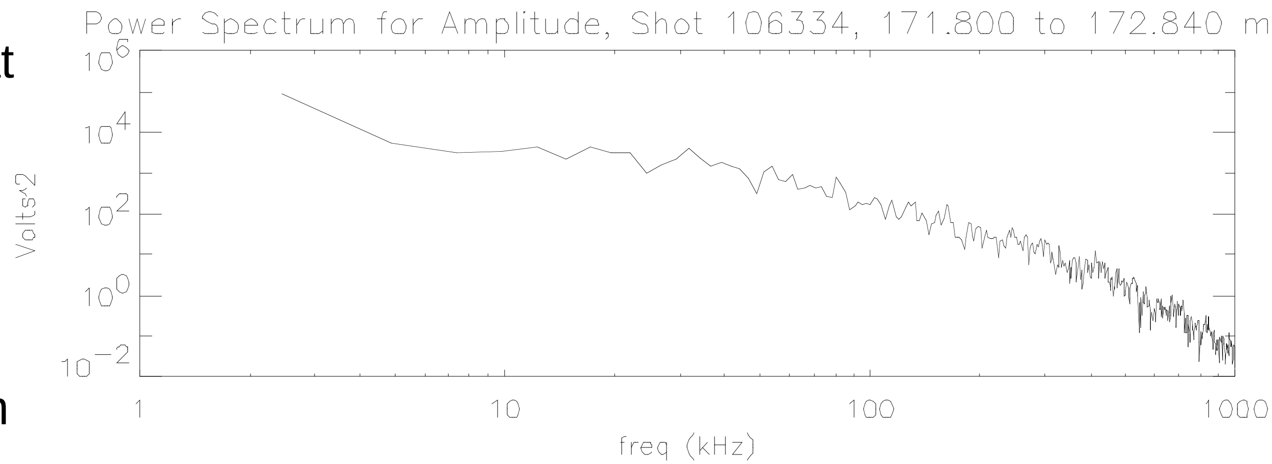




Initial results from fluctuation measurements (con't)

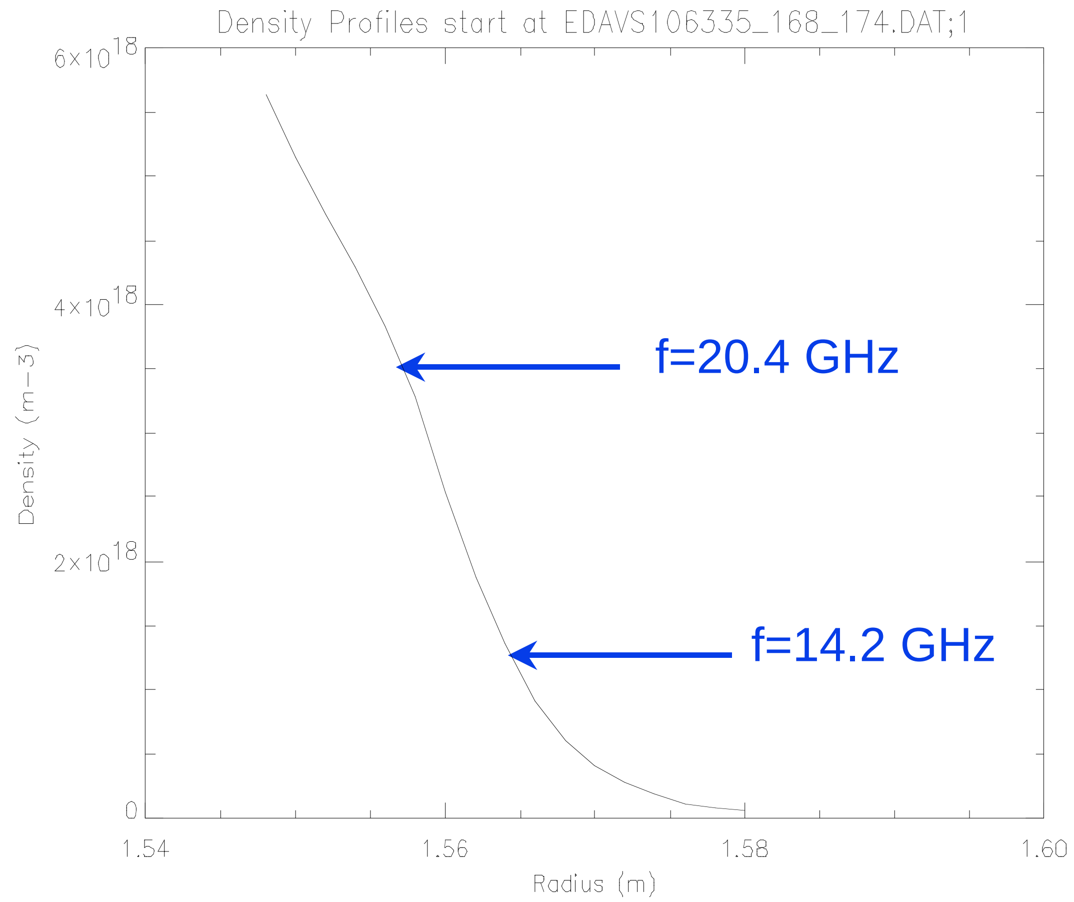
Shot # 106335
t = 168-174 ms

- Phase-averaged density profile obtained by averaging phase data from 16 sweeps

- Using the density scale length, L_n, from this average profile, we can estimate the density fluctuation level:

  $$\delta n/n \cong \delta\phi * \lambda/(2L_n)$$

- Based on the phase fluctuation levels observed at both 14.2 and 20.4 GHz (for shot 106334) $\delta n/n \cong 200\%$



New fluctuation data is ripe for comparison with theory

Future plans, options,….

Definitely in the works –

- Improve viability of HHFW reflectometer for measuring edge density fluctuations
  - Need isolating amplifier between I/Q detector and receiving antenna to eliminate problem caused by LO leakage
  - Increase signal amplitude relative to the offset voltages of the I/Q detector
  - Improve S/N for both profile measurements and fluctuations

- Improved fluctuation analysis
  - Goal is to develop good characterization of edge fluctuations (frequency spectrum, radial profile, …)
  - Needs more modeling to determine what the data means, how we can interpret what we measure.

Hope to have most of this done in time for the start of the next run in Spring ‘02.

Dreams

Would like to do if funding permits –

- Improve data acquisition from present 5 MHz digitizers to ~ 25 MHz
  - Allows sweep time to be reduced to 50 μsec, or less, reducing effects of density fluctuations
  - Will improve reliability of analysis
  - Not easy, will take considerable manpower and money.
  - Consult with PPPL and others on best way to proceed?
- Automate the data analysis (phase-averaged density profile)
- Look at 30-MHz component of HHFW reflectometer signal while doing rf heating
  - Measurement (somewhat) of ñ due to rf wave
  - Need to analyze and figure out how to interpret phase changes, see what we could determine from this measurement.

Can't do everything, but will look seriously at these possibilities.

Are there other things we should consider?

What are program priorities?

Summary

- Reflectometer upgrades have greatly improved the data:
  - Sweep time reduced to 100 μsec
  - Replaced analog driver with arbitrary waveform generator
    - resolved calibration stability issues
    - enabled fluctuation measurements

- Have made steady progress on data analysis:
  - Have started providing phase-averaged density profiles covering the density range from 5×10^{10} to 6×10^{12} cm^{-3}.
  - Quality of phase data is improved - no longer constrained by fit

- Initial look at fluctuation data at 14 & 20 GHz:
  - Phase fluctuations levels are typically 2-4 fringes p-p, mostly in 10-20 kHz range
  - Using L_n taken from phase-averaged density profile, this corresponds roughly to a 200% density fluctuation level

- Additional upgrades/development are needed, both instrumentation hardware and data analysis software