Low and high k turbulence measurements in NSTX

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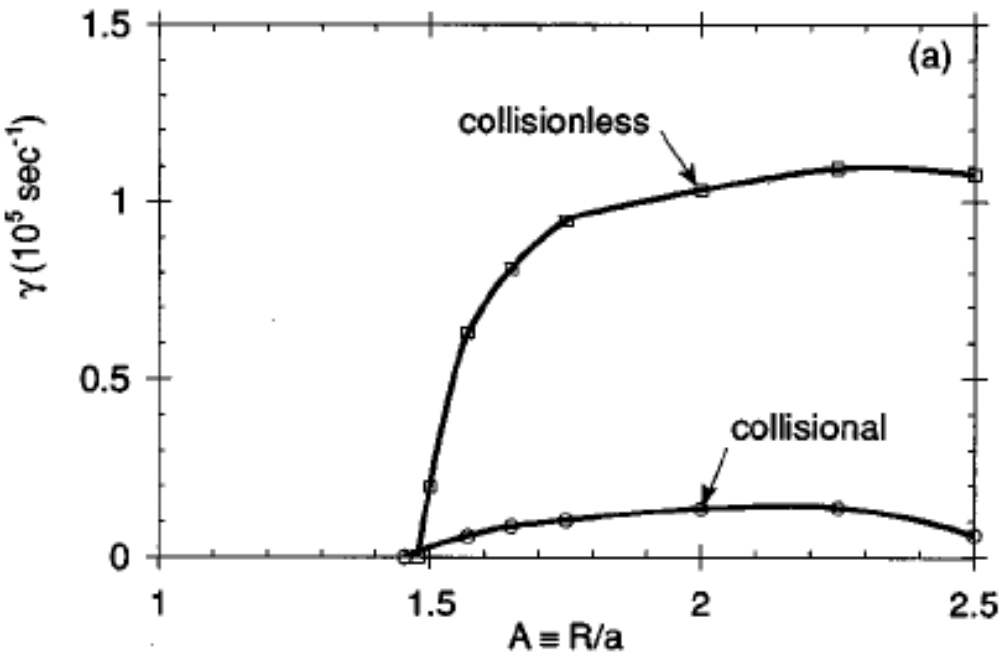
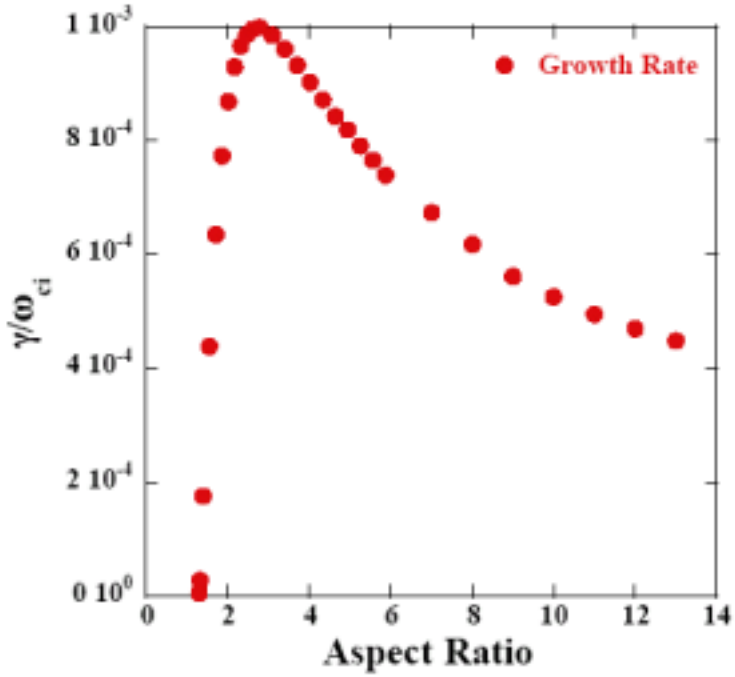
Role of long-wavelength turbulence in NSTX

- In NSTX reduction of "bad" magnetic curvature through low aspect ratio is expected to strongly stabilize ITG modes
- In addition, large sheared ExB flows are also expected to suppress longer wavelength modes
  - Expect short wavelength turbulence to dominate in NSTX

Rewoldt et al, PoP 1996



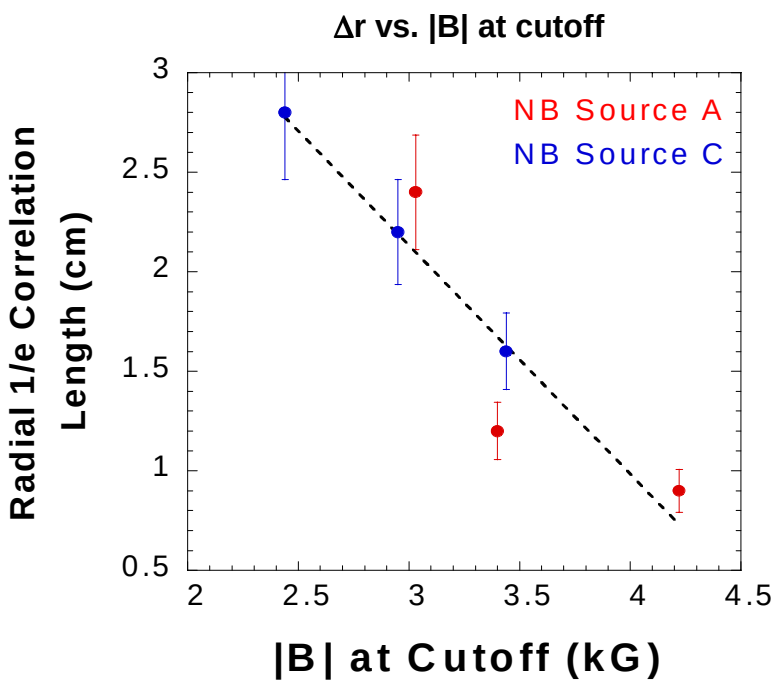
LeBoeuf et al – fluid ITG calculation

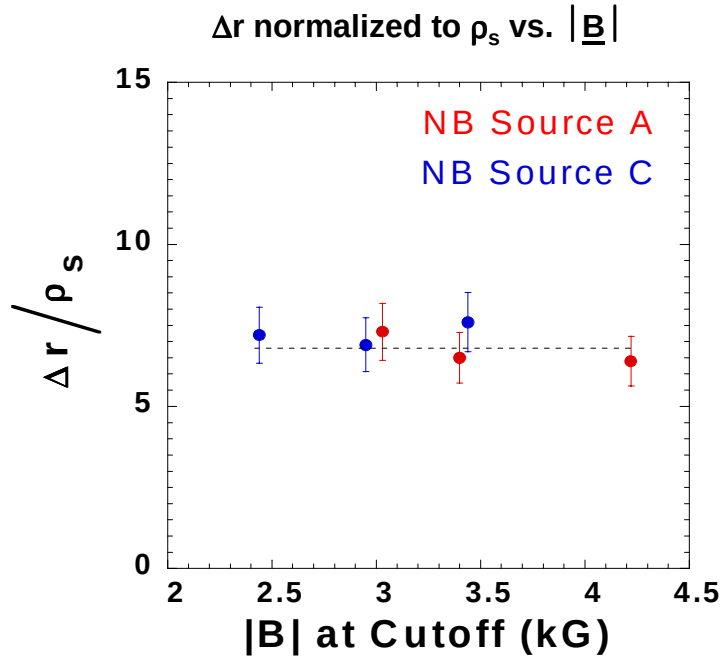


Previous correlation length measurements on NSTX

- Mark Gilmore (now at UNM) performed correlation length measurements of long wavelength modes in NSTX – but only in edge plasma at R/a ~0.9

I_p/B_T ~ constant q scan





Clearly long wavelength turbulent modes exist in the edge plasma of NSTX (reflectometry, probes, GPI) with long correlation lengths.

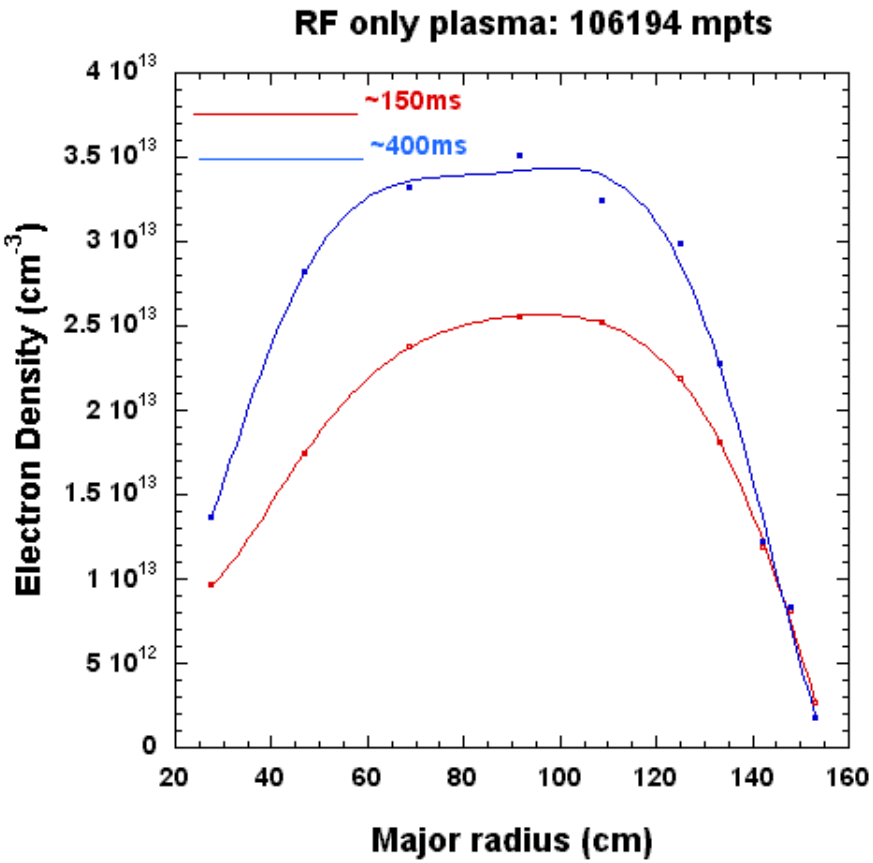
Comparison with gyrokinetic codes in this edge region not currently possible?

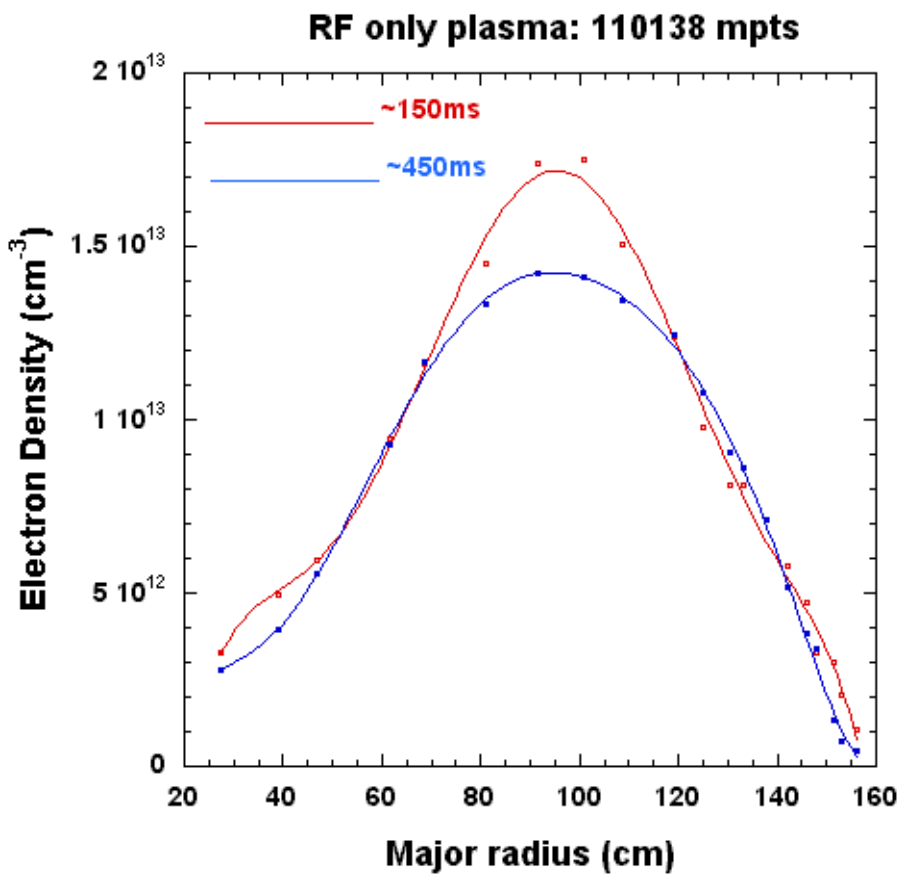
What happens as we move into the core plasma on NSTX ?

Study low k turbulence in lower-density RF & beam plasmas

- Propose to study lower density plasmas where measurements can penetrate deeper into the core plasma
  - RF-only plasmas can provide low density peaked profiles
    - Ideal for above studies
  - Low power neutral beam plasmas more difficult ?
    - Still there are possibilities
- Available turbulence diagnostic systems
  - Correlation reflectometry (densities < $2 \times 10^{13} cm^{-3}$)
  - Fixed frequency O-mode reflectometers at cutoff densities of 5×10^{12}, 1×10^{13}, 3×10^{13} and $5 \times 10^{13} cm^{-3}$.
    - Reflectometers are all quadrature measuring phase fluctuations.
  - 288GHz radial viewing interferometer
    - Can monitor line-integrated, density fluctuation levels – a measure of fluctuation content of plasma at long wavelength. Includes high field plasma region.

RF-only current-drive low-density plasmas



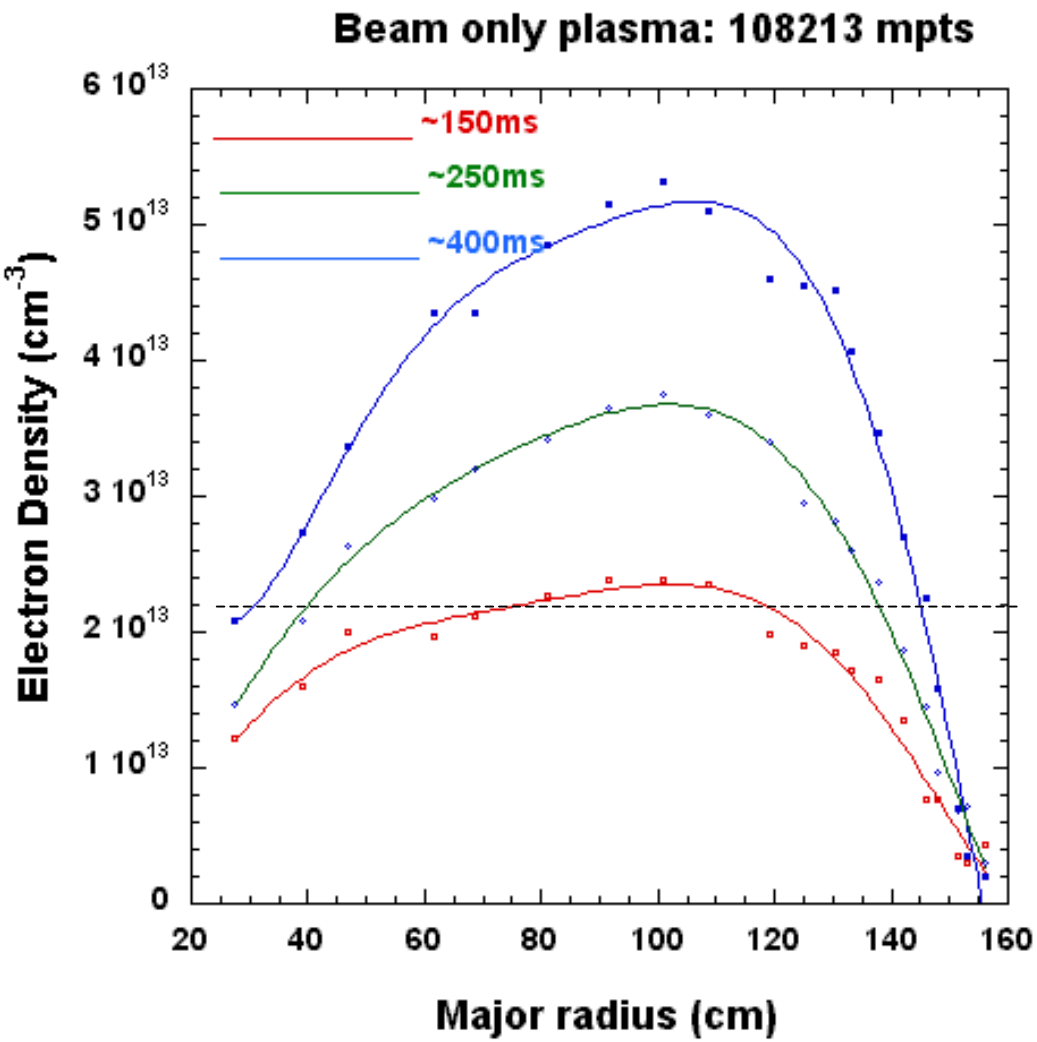


Correlation length measurements : deep into the core for these plasmas

Compare with beam-driven plasmas – can we obtain suitable profiles?

RF-only plasmas should produce lots of interesting data

Neutral beam fueled plasmas



These plasmas were utilized for previous correlation length measurements.

Note that for densities up to $1 \times 10^{13} cm^{-3}$ measurements were located in edge plasma.

UCLA is upgrading the CR system to access densities up to 2×10^{13} cm^{-3} - will allow measurements deeper into the core plasma.

It would be better if lower density plasmas with more constant density could be obtained. i.e. flat top density.

Proposal: start of next run period - study RF plasmas

- Vary peak electron densities
  - Start with peak densities of ~4×10^{13} down to $1.5 \times 10^{13} cm^{-3}$.
- Measure correlation lengths from edge to core
- Measure reflectometer phase-fluctuations at various density cutoff layers: estimate local density fluctuation levels
- Monitor line-integrated fluctuation levels via interferometry
- Vary magnetic field strength and plasma current
  - Keep edge q constant
  - B_T constant: vary plasma current
  - I_p constant: vary toroidal field
- Correlate/compare with transport properties and any available code predictions.

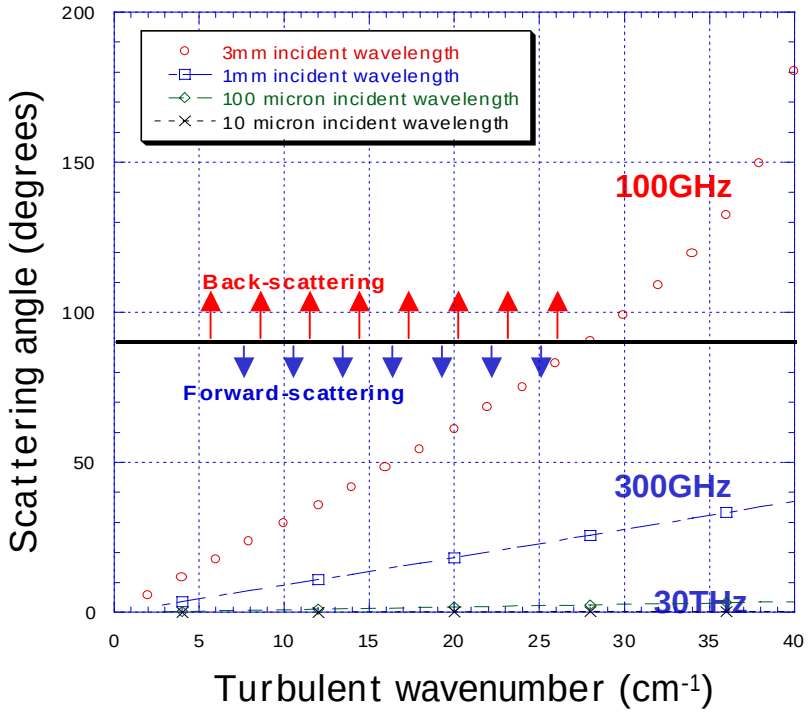
Above would lead to improved understanding of core and edge turbulence in STs: currently little or no information available from MAST/NSTX. Opportunity for NSTX to lead.

High k turbulence– study via microwave back scattering

In collective scattering probed turbulent wavelength given by Bragg equation:

$$k_w = 2k_i . \mathrm{Sin}(\theta_s/2)$$

where k_w is probed wave-number, k_i incident wave number and θ_s scattering angle



- The *infrared & FIR* spectral regions require *forward* scattering for *all* turbulent wavenumbers.

- In the *mm-wave spectral region* high k turbulence can only be probed via *back-scattering.*

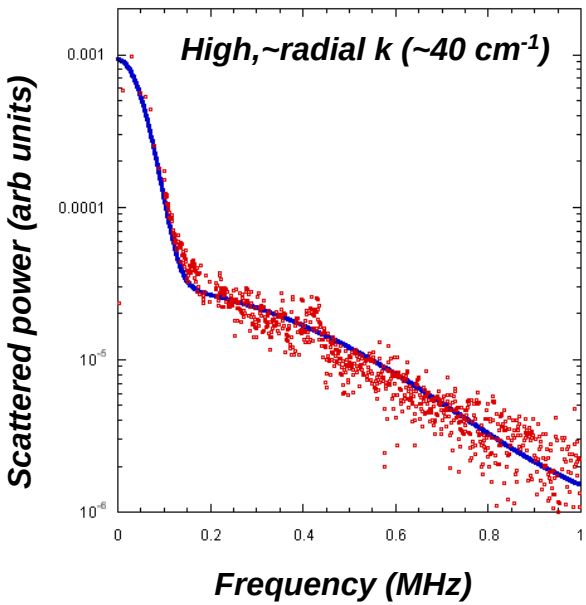
- Scattered radiation from *large amplitude, long wavelength turbulence* is *forward scattered* and thereby more easily distinguished.

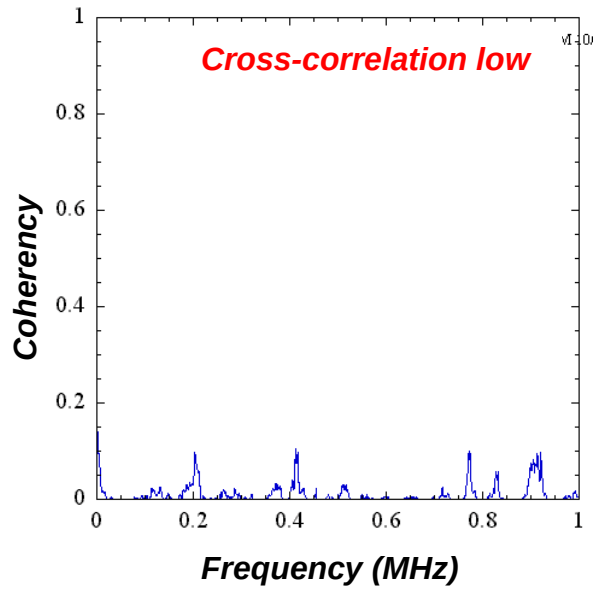
- At high field 2fce resonance can be used as effective *"beam-dump" –> 4.5kG on NSTX*

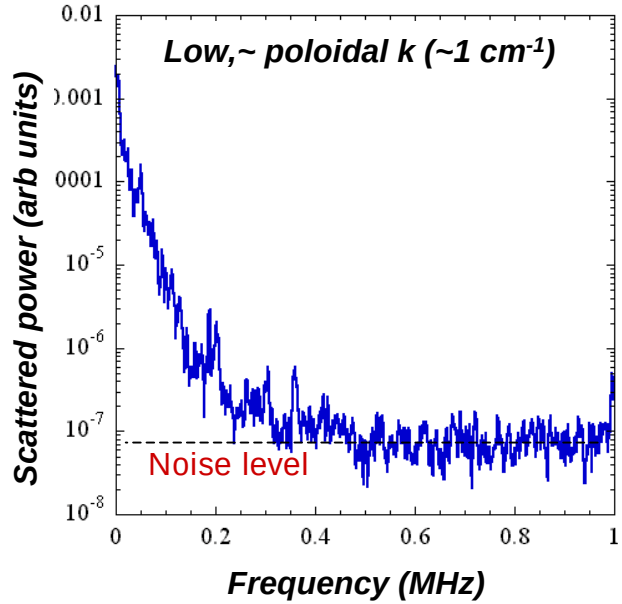
- The use of longer incident wavelengths *enhances scattered power* and also *makes available increased incident power (50W).*

Backscattering diagnostic is operational on DIII-D

Preliminary data





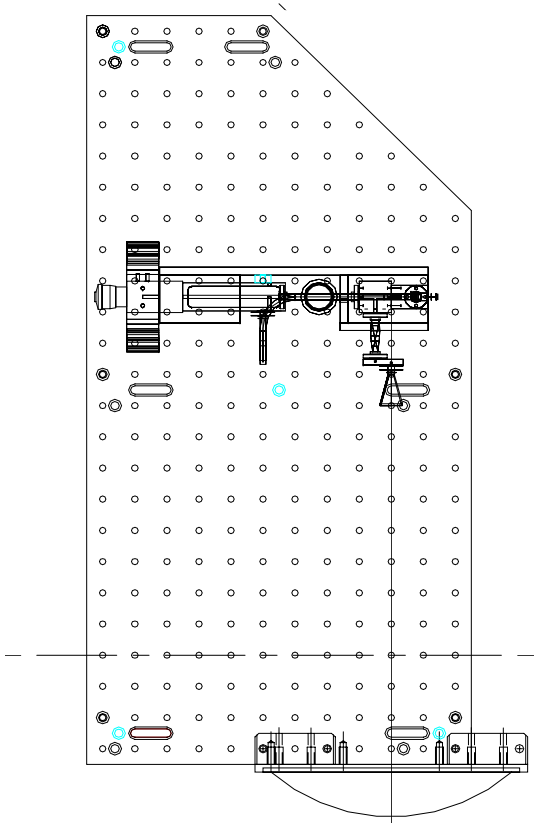


- No indication of high frequency component in low-k spectrum
- High frequency component ⇨ high k (~40 cm^{-1}) turbulence
- No cross correlation observed between low & high k data
- Low-frequency component in high k scattering *might* be residual O-mode scattering from poloidal k.
- However, could still be high k – further checks necessary.

High k measurements on NSTX

- There are two options for back-scattering on NSTX to probe high k
- Utilize Port G (mm-wave interferometer location) and employ similar quasi-optical approach as on DIII-D
  - This would be possible this year- provides a radial view
  - Background ECE should be lower than DIII-D
  - Concern re reflections from inner wall – need $B_T > 4.5$kG for $2f_{ce}$
- Utilize reflectometer horn array on Port J
  - This has advantage of improved localization and ability to probe two or more high k wavenumbers simultaneously
  - Residual reflection from inner wall significantly reduced
  - Disadvantage: ideally requires modification of launch/receive antenna
    - Not possible this year unless we attempt with non-ideal antenna pattern
- Both systems probe high end of expected ETG spectrum
  - Theory predicts growth rates to peak at $k_\theta \rho_i$ ~30-60 for NSTX

Port G quasi-optical measurement

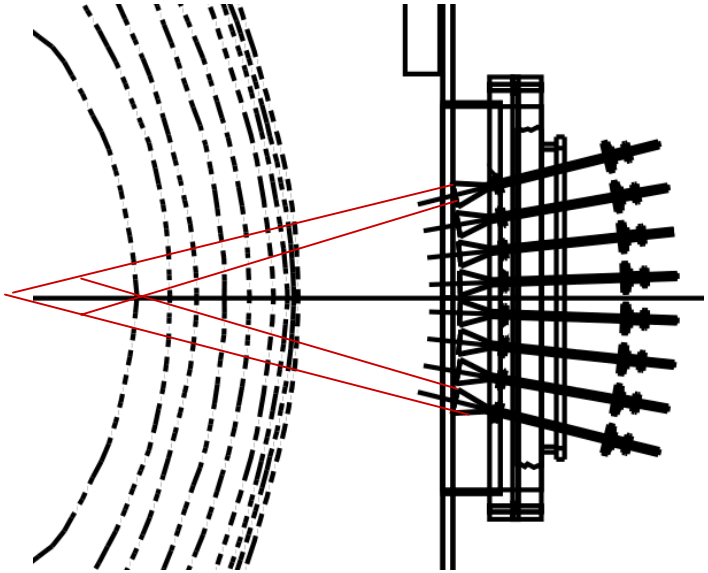


Quasi-optical 288GHz interferometer currently occupies a portion of Port G: views plasma radially at the midplane

This can easily be replaced with quasi-optical back-scattering system

Operate in the range from 75 to 100GHz – could probe wave numbers from ~ 30cm^{-1} (ω_i =75 GHz) to 40cm^{-1} (ω_i =100 GHz) Pure back-scattering.

Port J back-scattering on NSTX



Note that horn configuration is also well suited for *poloidal* correlation reflectometry measurement of turbulent ExB flow, etc

Collaboration with Kramer/Nazikian on DIII-D underway.

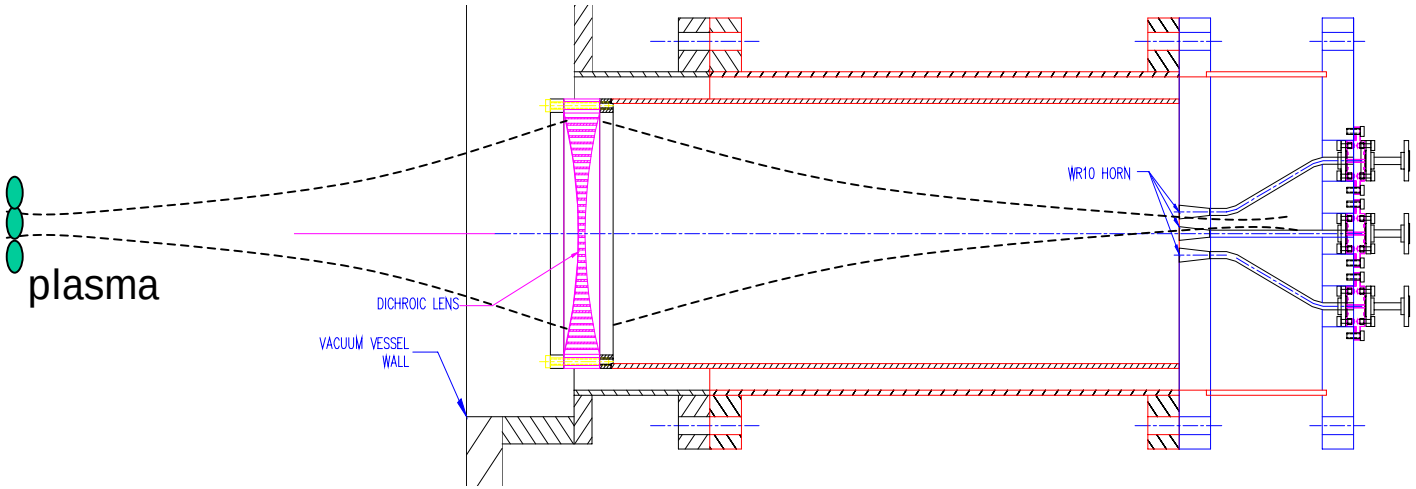
UCLA also has plans for "poor man's" reflectometric imaging on DIII-D and NSTX.

- Reflectometry *horn-array exists* on NSTX
  - Can use to perform back-scattering.
- 2fce "beam dump" exists only at higher fields (> 4.5 kG)
- Launch with one antenna: receive with one or more antennae.
- Provides spatial localization & variation in k. e.g. can probe 26, 28, 30 cm^{-1} simultaneously using a 75 GHz launch
- Horns are not optimized for higher frequencies & do not contain collimating optics.
- Upgrade necessary: vent needed.
- Could attempt with non-optimized antenna – probably will - to assess ECE background etc.

Summary

- Next run
  - UCLA has upgraded turbulent correlation length measurement to perform measurements in core of lower-density RF and NBI plasmas
  - New fixed frequency quadrature (phase) reflectometer systems will also be available to monitor fluctuations at up to four radial locations
  - A new mm-wave interferometer will be fully operational and will provide a monitor of the fluctuation content of NSTX plasmas at long turbulent wavelengths
- Future
  - Back-scattering at microwave frequencies is planned to probe the very high k end of the fluctuation spectrum. Preliminary data obtained on DIII-D
  - A simple reflectometry imaging system is planned for DIII-D and is under investigation for NSTX.

“Poor man’s” reflectometry imaging



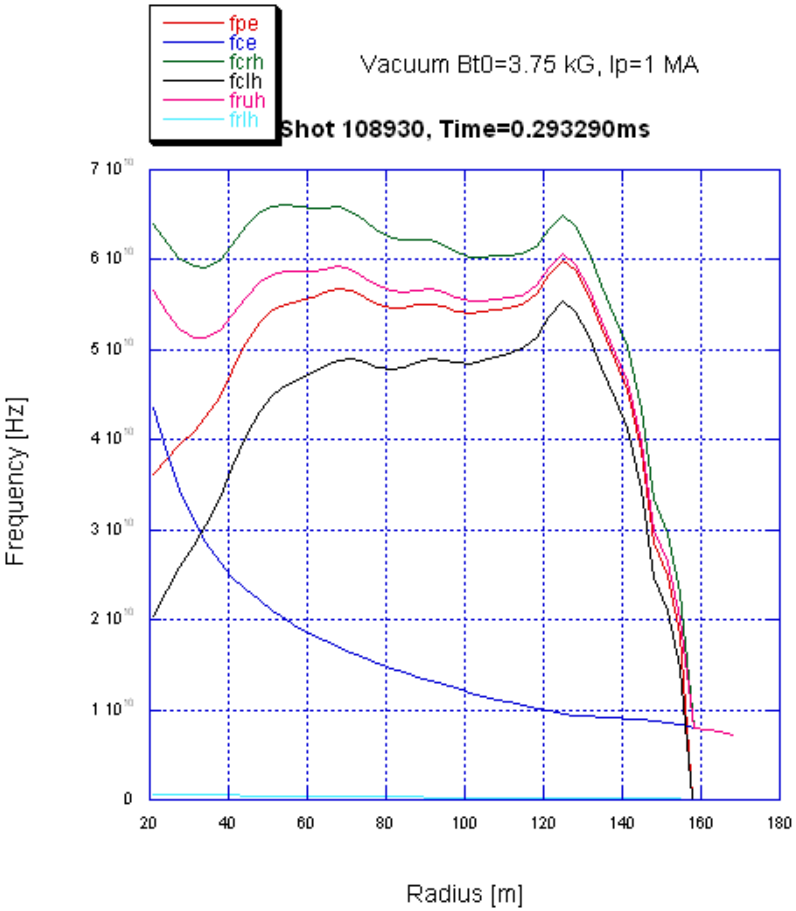
Launch 50.01 GHz

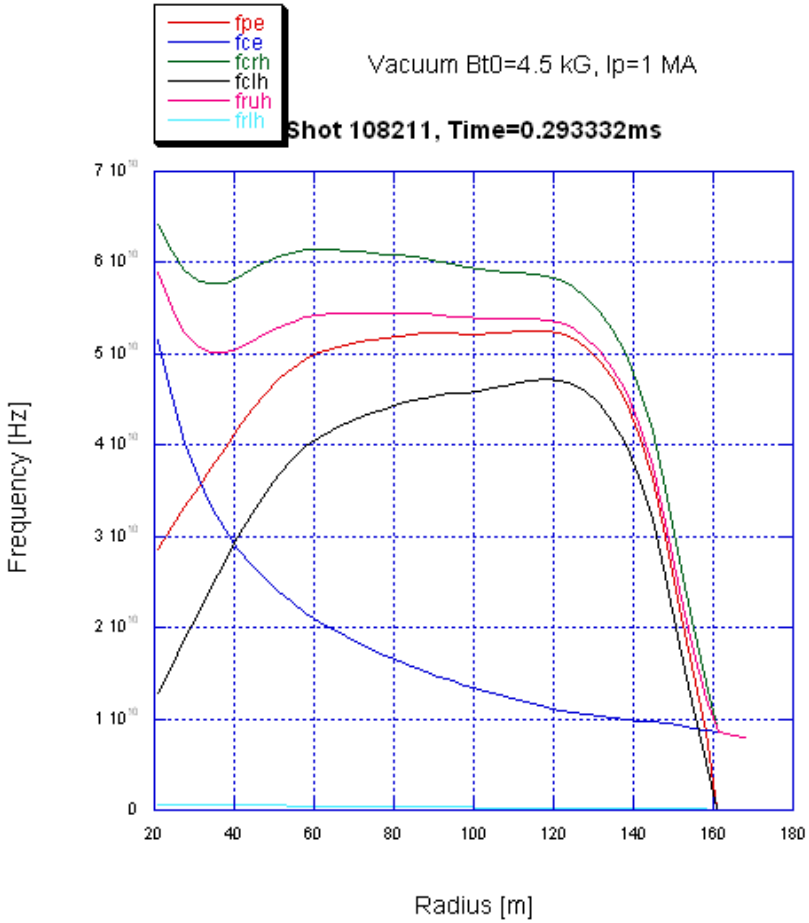
Launch 50.004 GHz

Launch 50 GHz

- Launch different frequencies (e.g. w=50GHz, + 4MHz,-10MHz) from adjacent horns.
  - Dichroic metallic lens would focus different frequencies at different radii
  - Vacuum compatible: locate very close to plasma: improves imaging properties. 8 inch conflat (or larger!) on the midplane
- Radiation emerging from these horns will be “imaged” at adjacent poloidal locations.
  - Since launch and receive identical and horns very close to each other “images” track each other
- When the cutoff layer coincides with the image location the reflected radiation should return to the original horn.
  - The “imaging” properties of the system can therefore easily checked.
- Detection at distinct IF frequencies allows quadrature detection, unambiguous identification of image location, determination of phase. Ideal for measurement of ExB flow, k_θ, Er, etc.

Characteristic cutoff/resonance frequencies





It appears that back-scattering at 75GHz would be appropriate. At B_T =4.5 kG on axis this would allow absorption at $2f_{ce}$ on the high field side while also permitting operation well above cutoff. The probed wave number would be $30cm^{-1}$.

Important to match magnetic field pitch angle

In order to take full advantage of the natural beam dump provided by the $2f_{ce}$ resonance layer it is important to launch a “pure” X-mode wave.

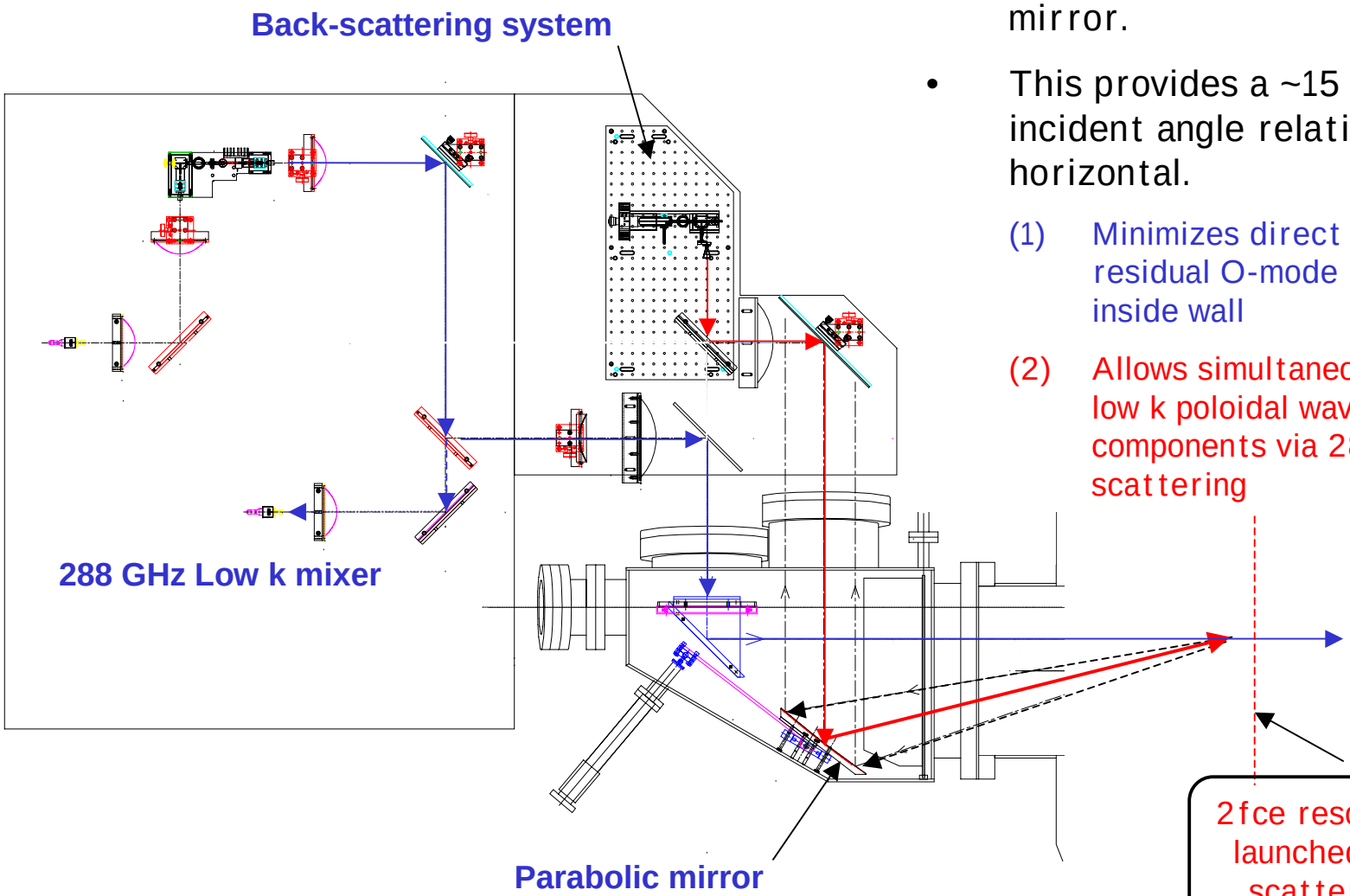
This requires the launch polarization to be matched to the edge magnetic field pitch angle. On NSTX this varies significantly in time.

Can launch a slowly (a few ms) rotating plane polarized beam (easy to create). Ensures that O and X-mode radiation launched every rotation cycle.

Would also allow edge magnetic field pitch angle to be determined !

Back-up Slides

Back-scattering system installed on DIII-D to investigate high k



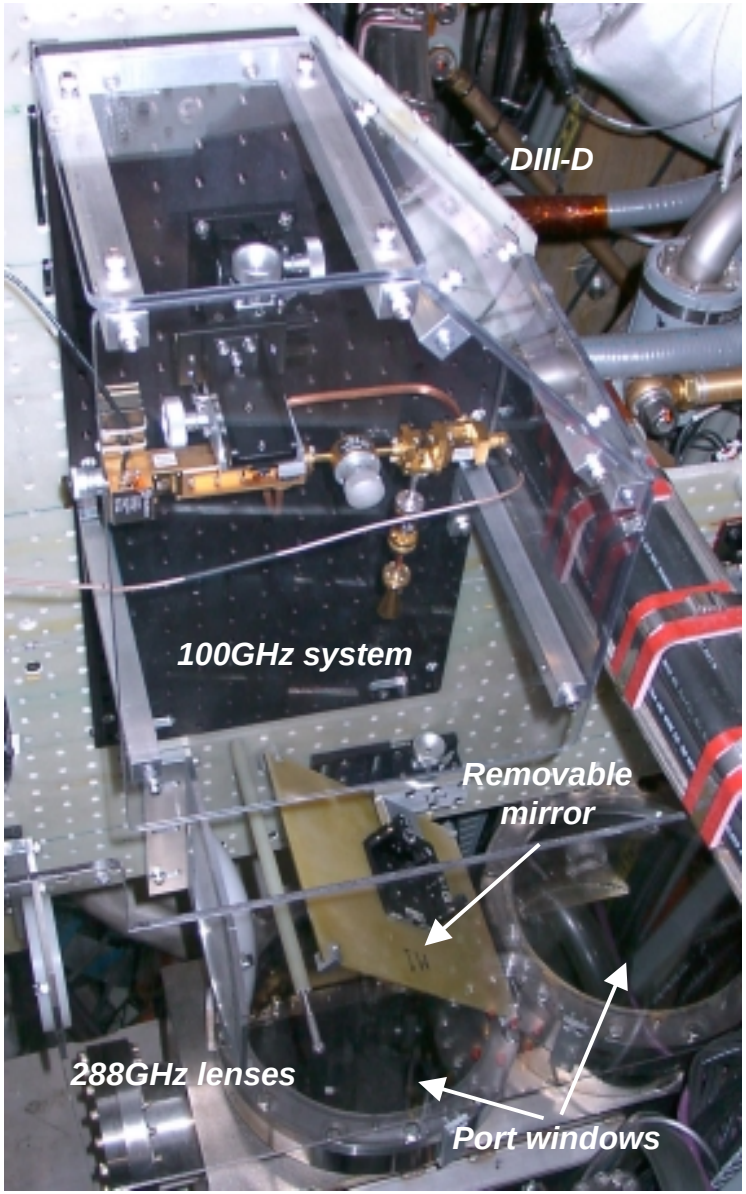
- Mirror and lens arranged to couple into plasma via parabolic *focusing* mirror.
- This provides a ~15 degree incident angle relative to horizontal.

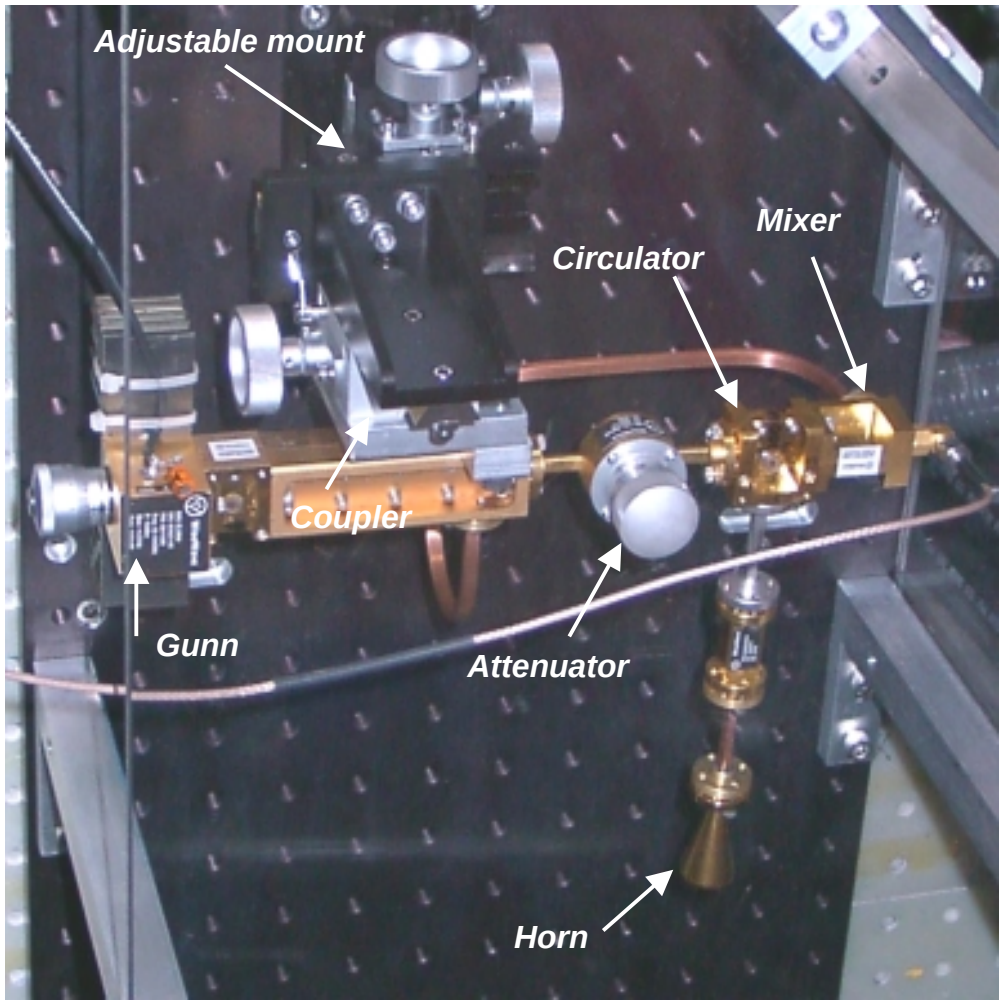
(1) Minimizes direct reflection of any residual O-mode launch from inside wall

(2) Allows simultaneous probing of low k poloidal wavenumber components via 288 GHz forward scattering

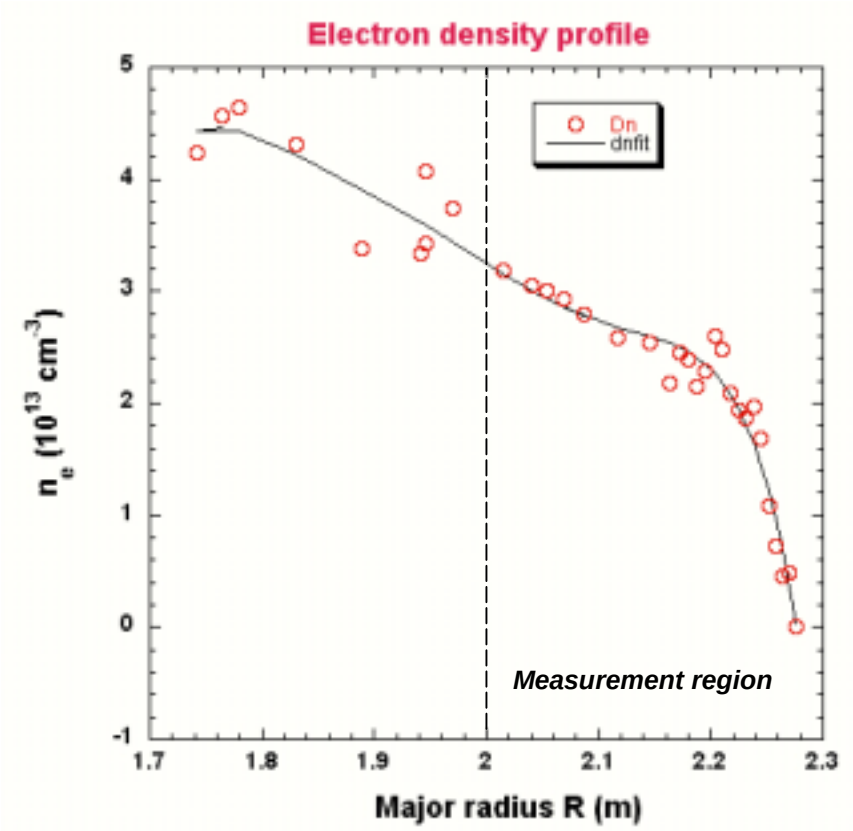
2fce resonance absorbs launched and forward scattered radiation

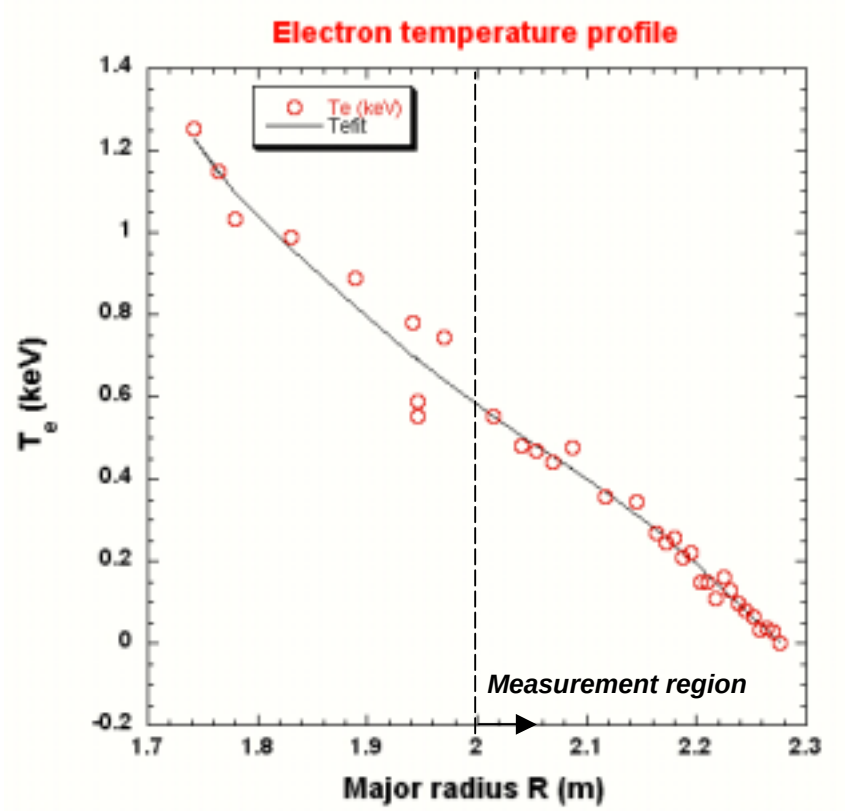
Back-scattering hardware





Density and temperature profiles

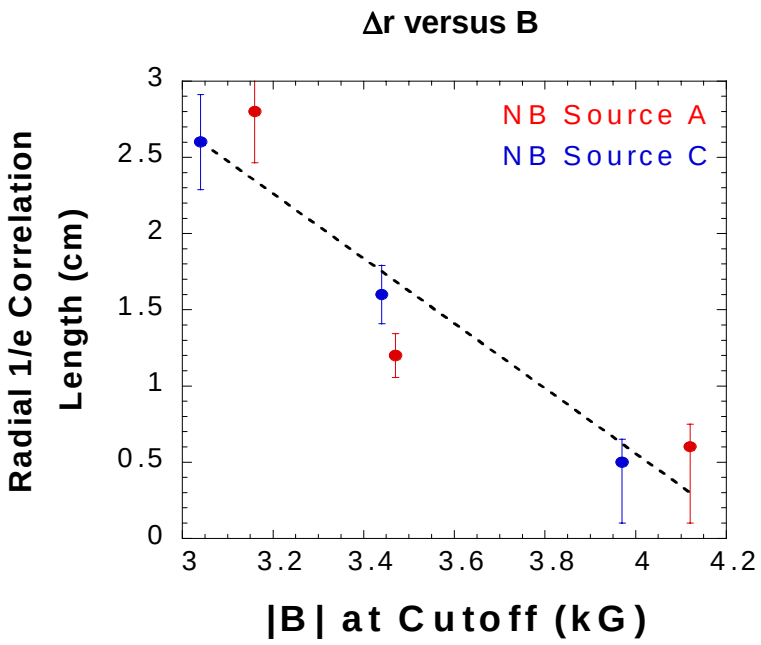




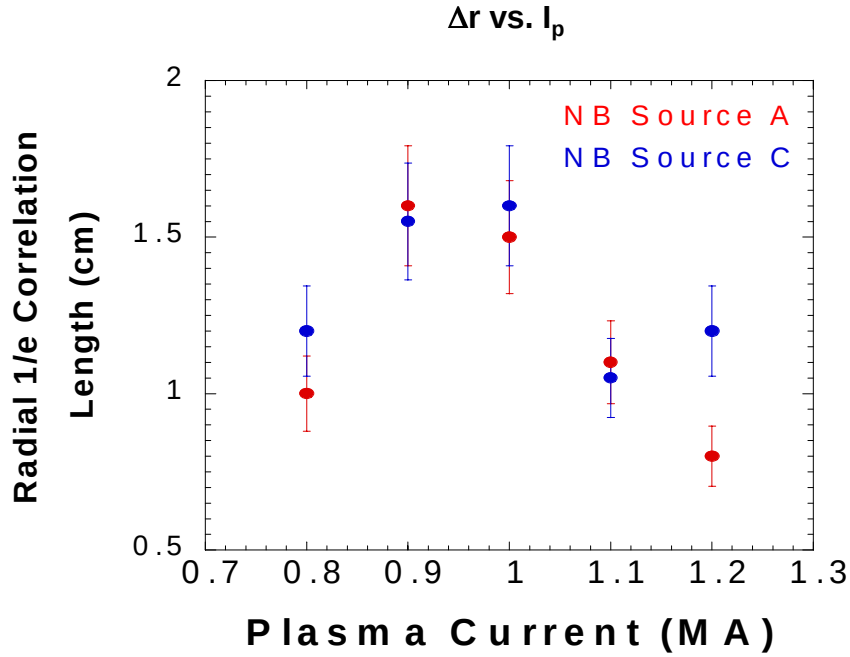
Density and temperature profiles at 1100 ms. Note that the $2f_{ce}$ resonance is located at R = 2m and so backscattering is possible only in the region from 2 to 2.3m.

Additional correlation data from previous run

I_p ~ constant: B_T scan



B_T ~ constant: I_p scan



I_p constant/B_T scan again indicates correlation length very sensitive to local magnetic field strength – factor of ~5 increase as field is reduced. Even after normalization to gyro radius still reduces significantly at higher fields.

In contrast, keeping toroidal field constant and varying plasma current appeared to produce modest changes in correlation length.

Trends are generally consistent with confinement properties for these discharges