Internal magnetic field measurements in NSTX

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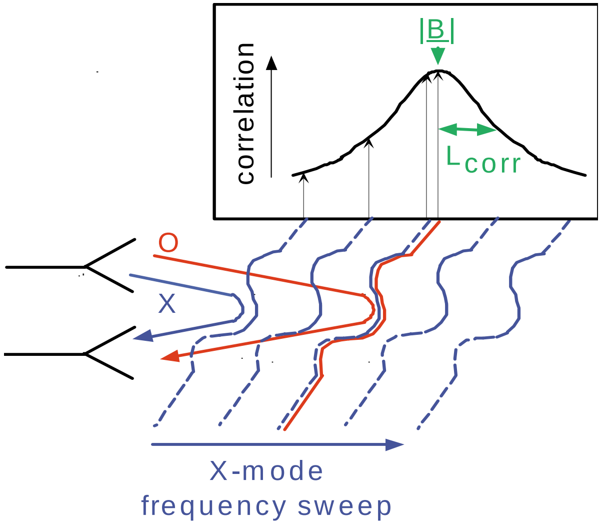
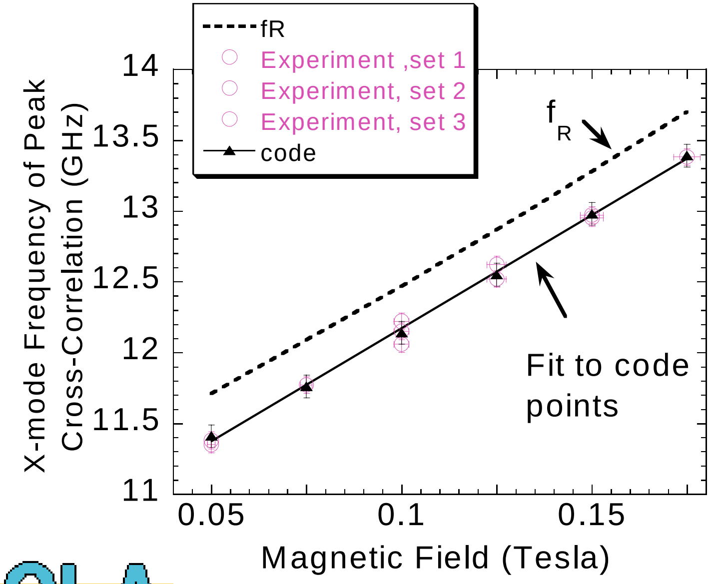
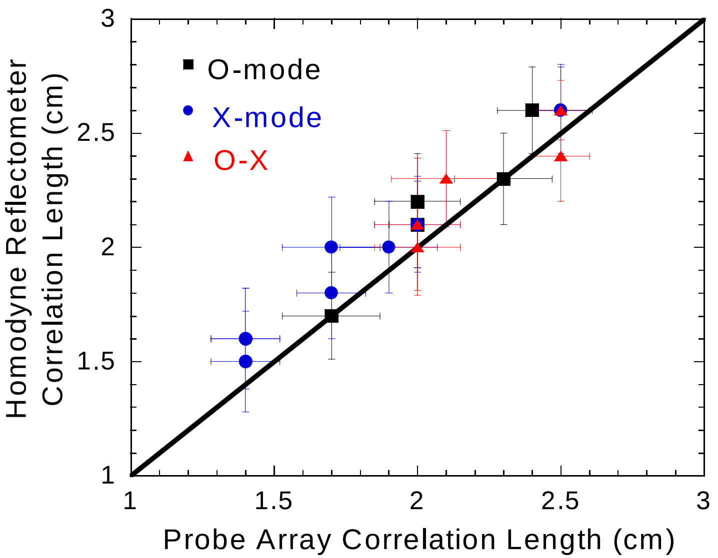
Demonstration of magnetic field strength measurements in NSTX - dual mode correlation reflectometry



- Launch O and X-mode radiation - different frequencies, same antenna.
- After reflection from their separate cutoff layers, fluctuating signals from naturally occurring turbulence are collected and cross-correlated.
- ***Peak*** of correlation provides ***“field strength”*** & ***width*** of correlation provides ***“turbulent correlation length”***

Laboratory LAPD proof-of principle data





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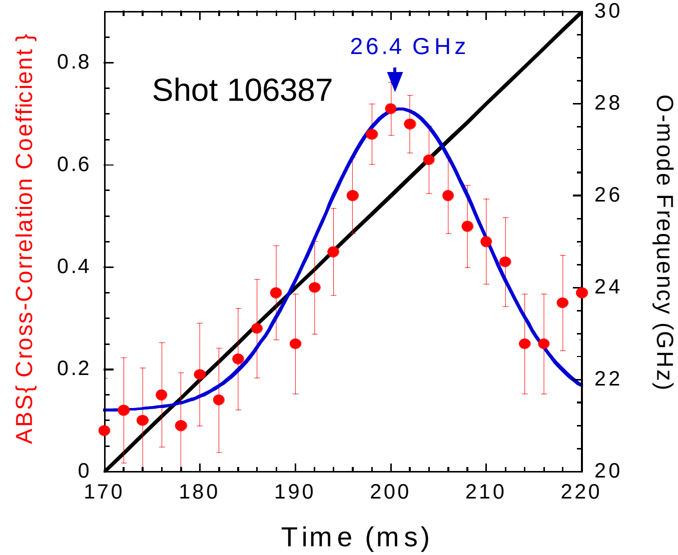
Preliminary demonstration on NSTX

- Last year a 20-30 GHz homodyne correlation reflectometer was modified to operate in a dual mode (O-X) configuration.
- $f_{x\text{-mode}}$ = 30.0 GHz
- $f_{o\text{-mode}}$ swept over 20-30 GHz

- ***Analysis of the data gives B = 2.5 ± 0.015 kG.***
- **EFIT gave $|\underline{B}|$ ≈ 2.4 kG at this radius, R=1.47 m**

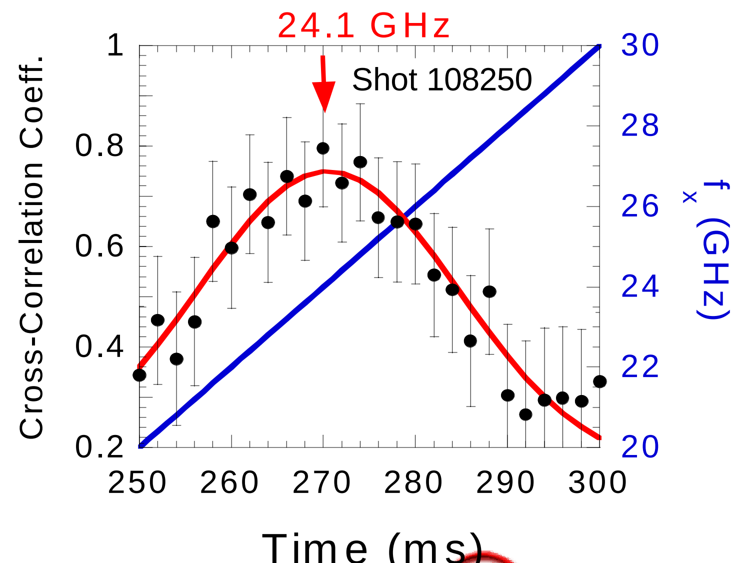


Recently Mark Gilmore completed a run on NSTX – primarily focused on turbulent correlation length measurements. Also took some O-X data. This time

$f_{o\text{-mode}}$ = 20 GHz

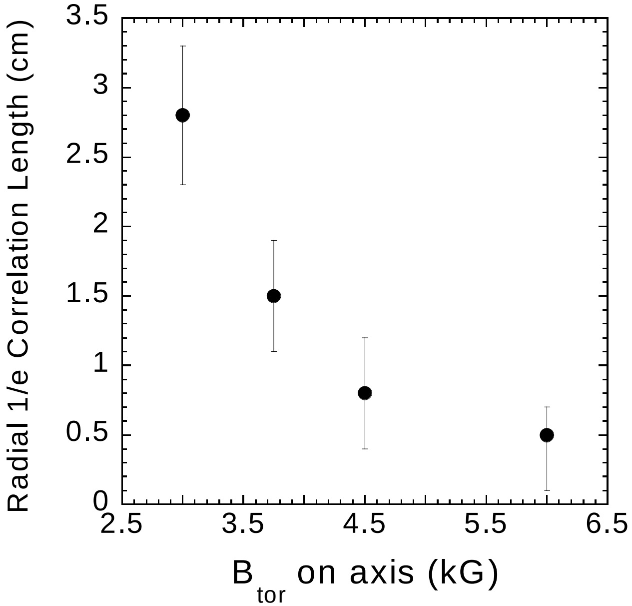
$f_{x\text{-mode}}$ swept from 20 – 30 GHz

- ***Analysis of the data gives B = 3.0 ± 0.014 kG.***
- **EFIT gave $|\underline{B}|$ = 3 kG at this radius, R=1.51 m**
- ***Lcorr ~ 1.8 cm***

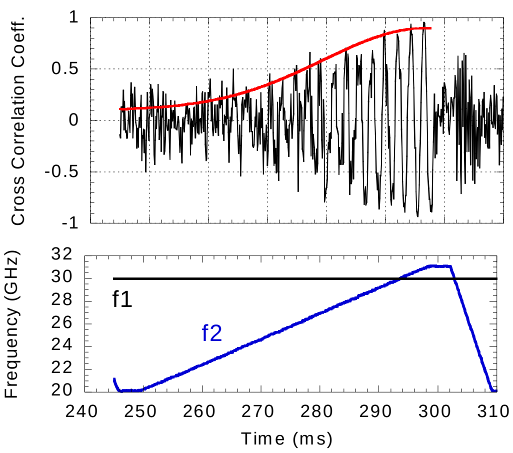


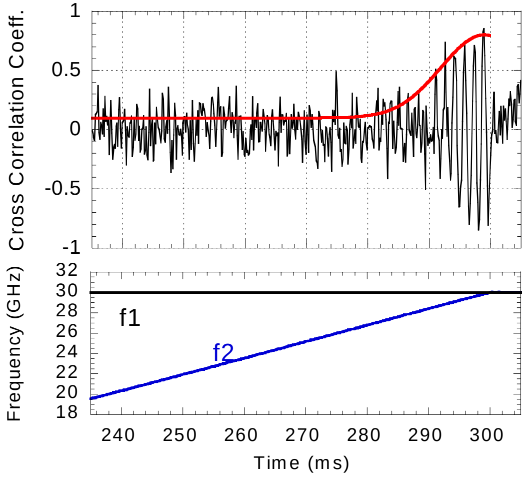
Correlation reflectometer indicates large increase in radial correlation length as B_{tor} decreases

Δr versus B_{tor} on axis



Example Raw Data





1/e Δr ≈ 1.5 cm

1/e Δr ≈ 0.8 cm

B_{tor} = 3.75 kG, Ip = .85 MA
Shot 108223, NB Source A,
L_n≈11 cm

B_{tor} = 4.5 kG, Ip = 1 MA
Shot 108215, NB Source A,
L_n≈11 cm

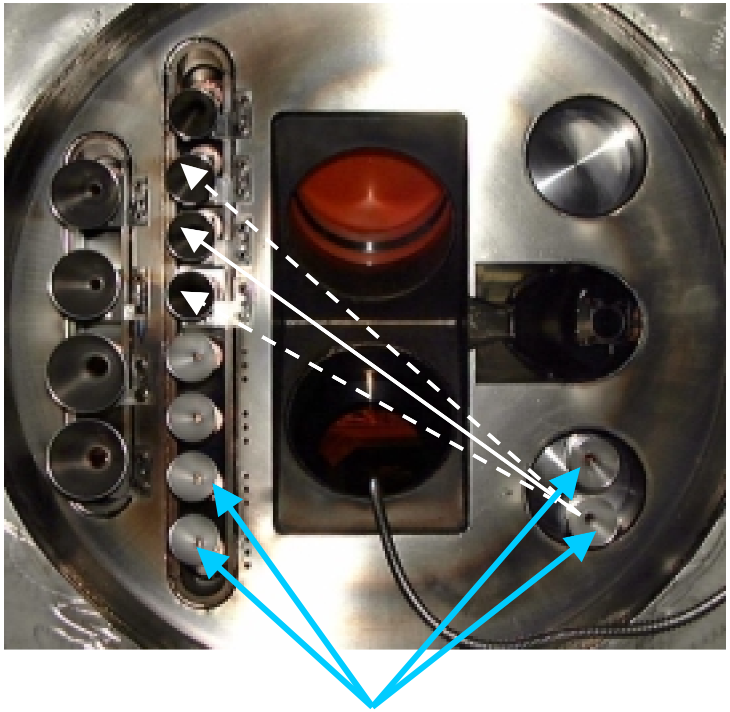
- Reflectometer is 20-30 GHz O-mode homodyne system ($n_{CR} \approx 0.5\text{-}1.0\times10^{13}$ cm^{-3})
- Cutoff layers (30 GHz) 5-7 cm inside LCFS
- L_n varies from ≈ 8 to 16 cm
- Fluctuation frequencies 20 - 500 kHz correlated

Reflectometry measurement of magnetic field pitch angle on NSTX?

- **Experimental evidence and theoretical expectations indicate $k_{II}/k_{perp} << 1$**

– turbulent streamers aligned along magnetic field

- Correlate turbulent reflectometer signals across port (see figure) we can provide picture of ***temporal evolution of pitch angle***.
- By changing launch reflectometry frequency a ***radial scan*** can be achieved.



Microwave horns

Vacuum interface (horns,etc.) already available for test of technique – additional millimeter-wave components necessary to perform a detailed test.

Expected accuracy < 2 degrees - gives immediate view of temporal evolution of pitch angle at various radii.

Complements the MSE, FIRETIP systems.

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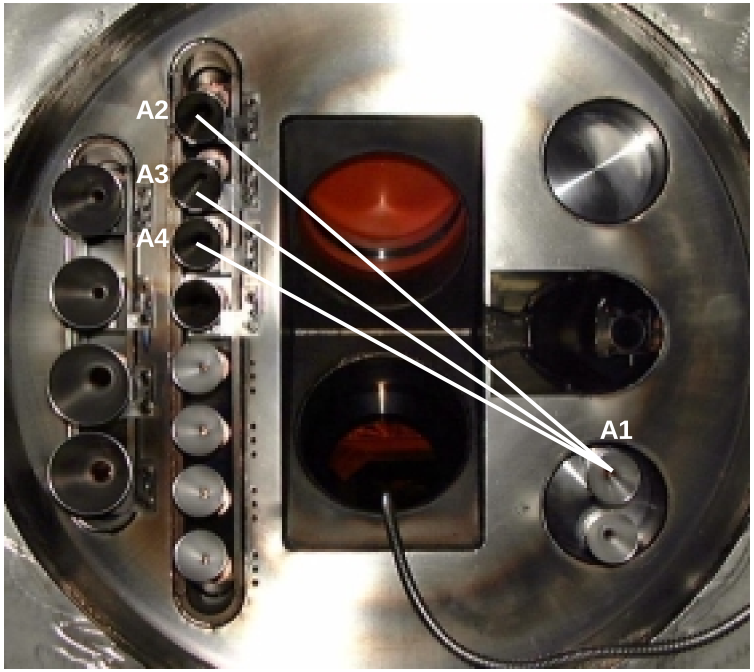
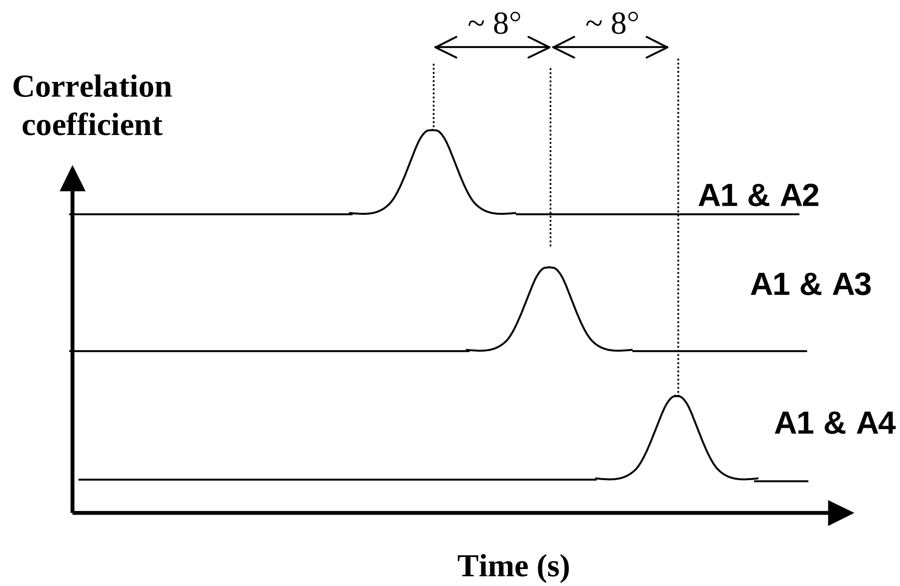
Cross correlation provides evolution of pitch angle



Expected cross correlation during current ramp



- **Accuracy will depend on "purity" of cross correlation data.**

  Anticipate high correlation and an accuracy of < 2 degrees.

- **High correlation is expected based on tests on linear LAPD device at UCLA.**

  Temporal resolution of ~1 ms is anticipated.

- **Frequency scan can provide a radial scan of pitch angle**

  – spatial coverage depends on profile shape

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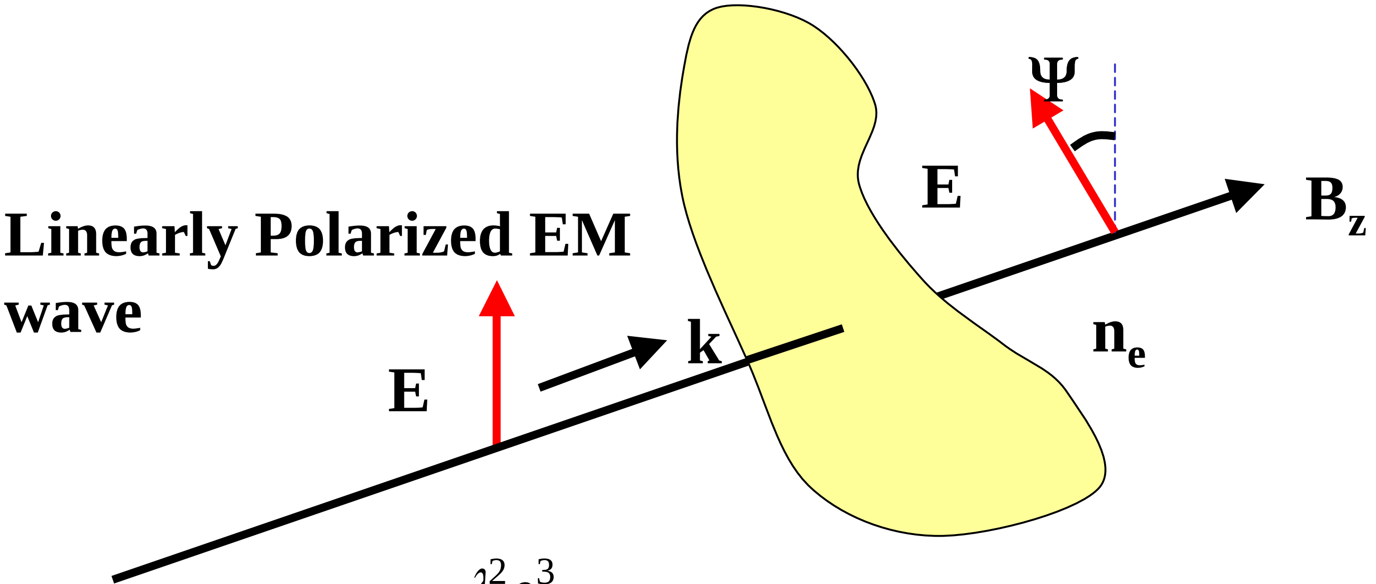
Faraday Rotation



$$\Psi = \frac{\lambda^2 e^3}{8\pi^2 c^3 \varepsilon_0 m_e^2} \int n_e B_z \, dz = 2.62 \times 10^{-13} \lambda^2 \int n_e B_z \, dz$$

$$\Phi = \frac{\lambda e^2}{4\pi \; c^2 \varepsilon_0 m_e} \int n_e dz = 2.82 \times 10^{-15} \lambda \int n_e dz$$

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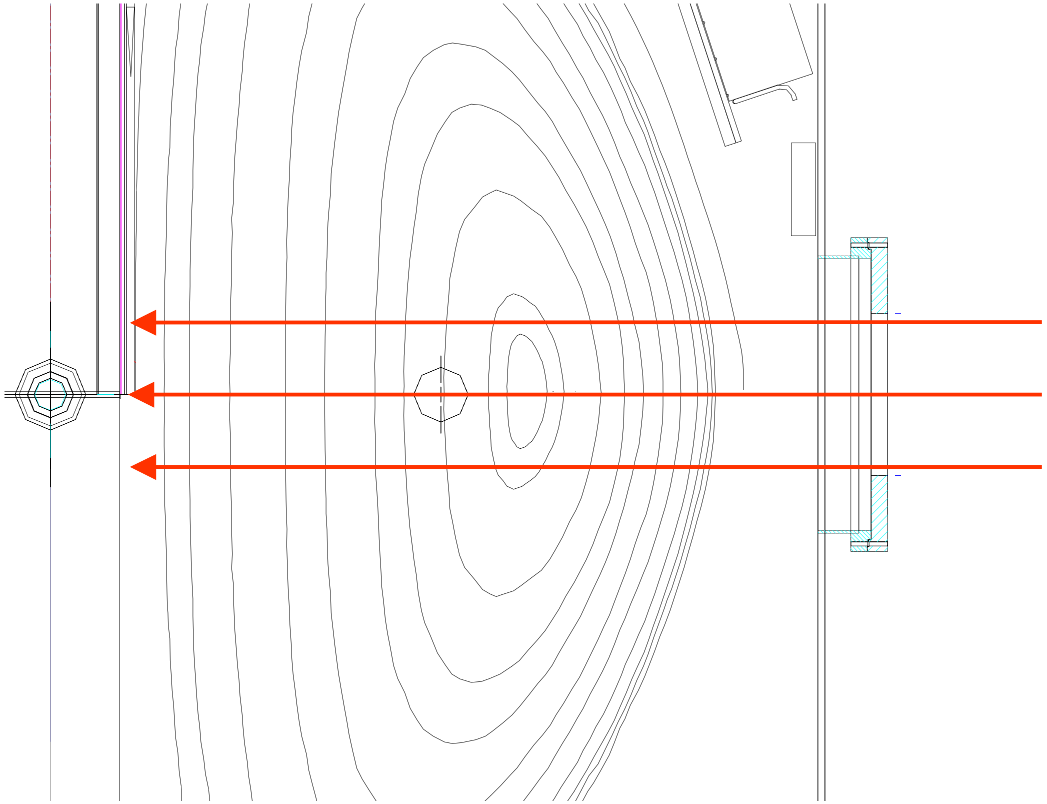
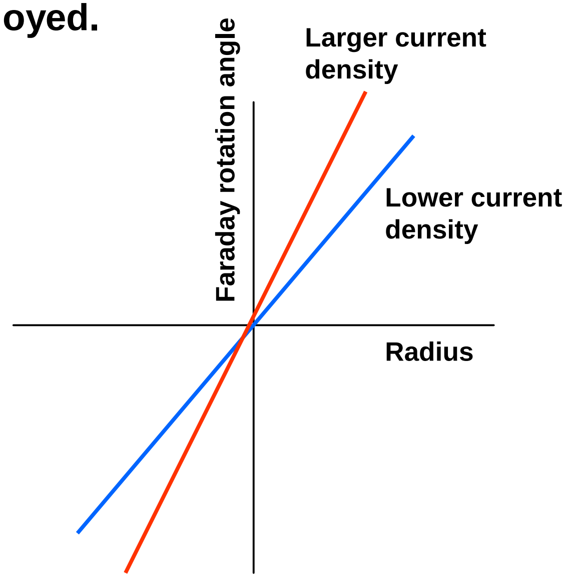
Information on core current density (Jo) via multichannel polarimetry



Reflect an elliptical cross section 0.5 mm(initially 1mm) electromagnetic wave from inside wall carbon tile.

This allows central 12 inch vertical portion of NSTX plasma to be probed. Port access exists. 12 or more Faraday rotation channels can be employed.



- In circular plasma, slope of Faraday rotation signal is proportional to current density on axis
- In NSTX the slope information would be used to significantly constrain EFIT in plasma core.

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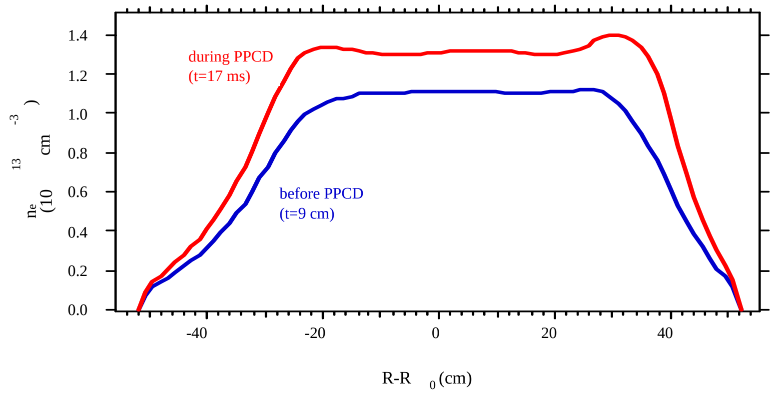
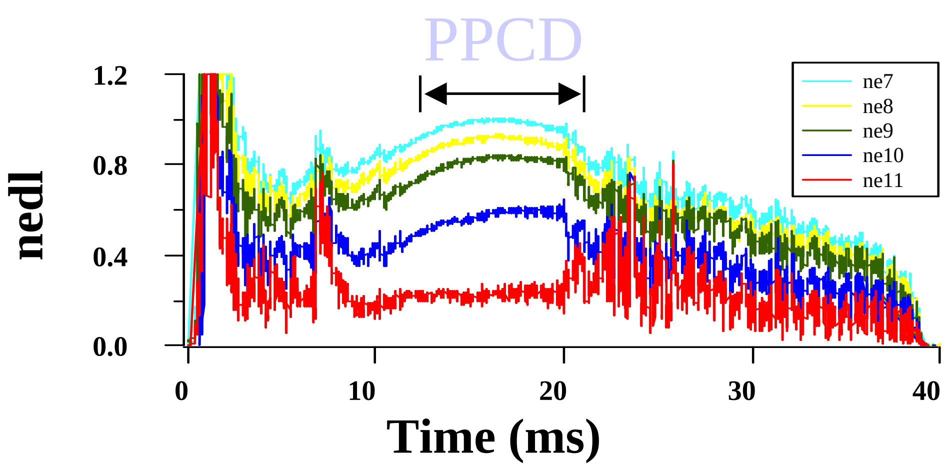
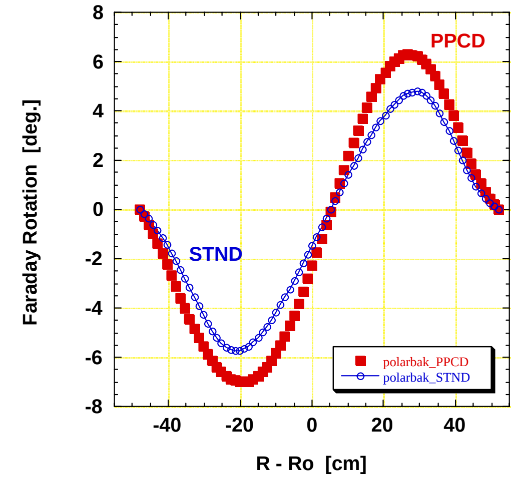
Interferometry & polarimetry data from MST

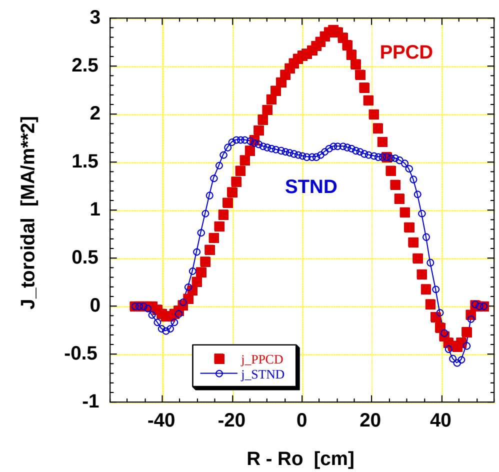
Electron density ***increases*** during PPCD whereas fluctuations ***decrease***





Faraday rotation data/current profiles - ***current peaks during PPCD***





Isolating Magnetic Fluctuations

Faraday Rotation: $\Psi = c_F \int n_e B_{//} dl$

Taking: $\Psi = \Psi_0 + \tilde{\Psi}$ $\quad n_e = n_0 + \tilde{n}$ $\quad B_{//} = B_0 + \tilde{B}$

Rewriting:

$$\Psi_0 + \tilde{\Psi} = \int n_0 B_0 dl + \int \tilde{n} B_0 dl + \int n_0 \tilde{B} dl + \int \tilde{n} \tilde{B} dl$$

$$\Psi_0 = \int n_0 B_0 dl$$

$$\int \tilde{n} \tilde{B} dl \approx 0$$

$$\tilde{\Psi} = \int \tilde{n} B_0 dl + \int n_0 \tilde{B} dl$$

Magnetic axis: $B_0 \Rightarrow 0$, $\tilde{n}_{m=1} \Rightarrow 0$

Leaving:

$$\tilde{\Psi} \approx \int n_0 \tilde{B} dl$$

$$\tilde{B} \Rightarrow \tilde{B}_r$$

For all central chords: $\int \tilde{n} B_0 dl << \textit{rms noise}, \quad \Rightarrow \quad \tilde{\Psi} \approx \int n_0 \tilde{B} dl$

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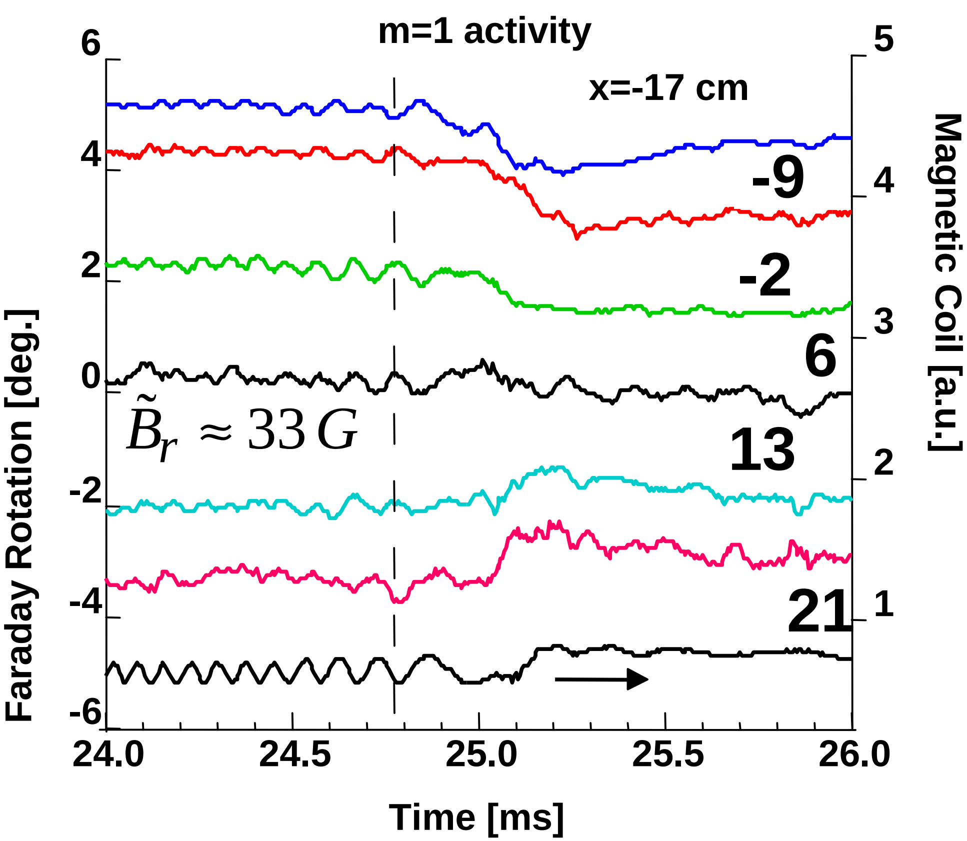
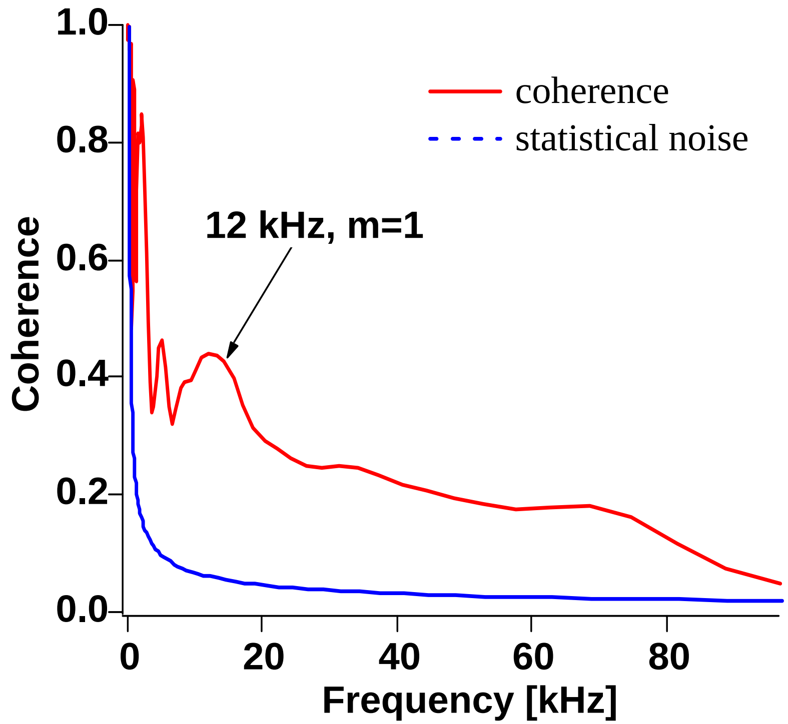
Magnetic Fluctuations





$$\bar{\tilde{B}} \approx \frac{\tilde{\Psi}}{c_F \bar{n}_e \Delta z} \approx 33\ \ G \quad (\sim 1\%)$$

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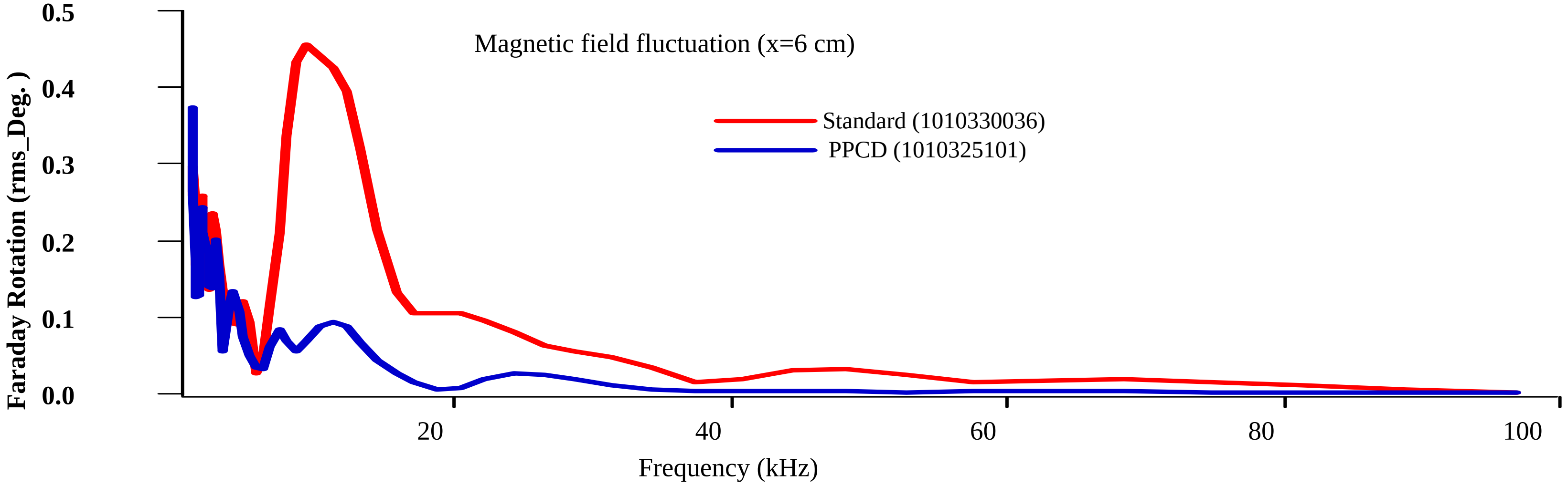
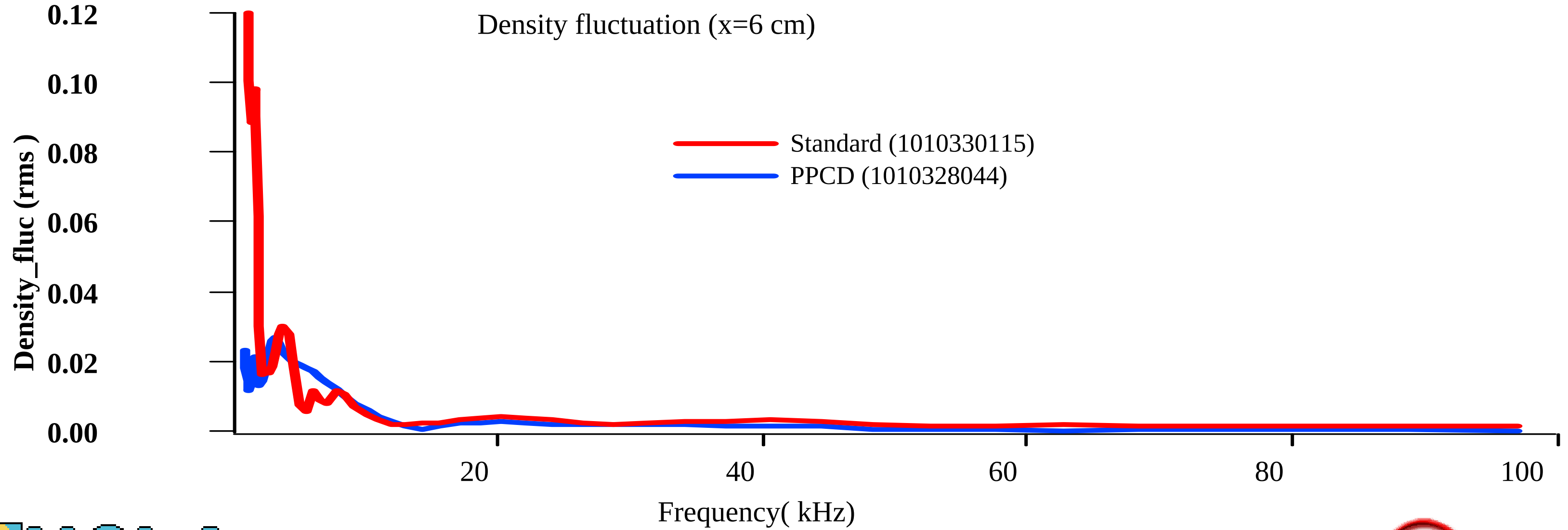
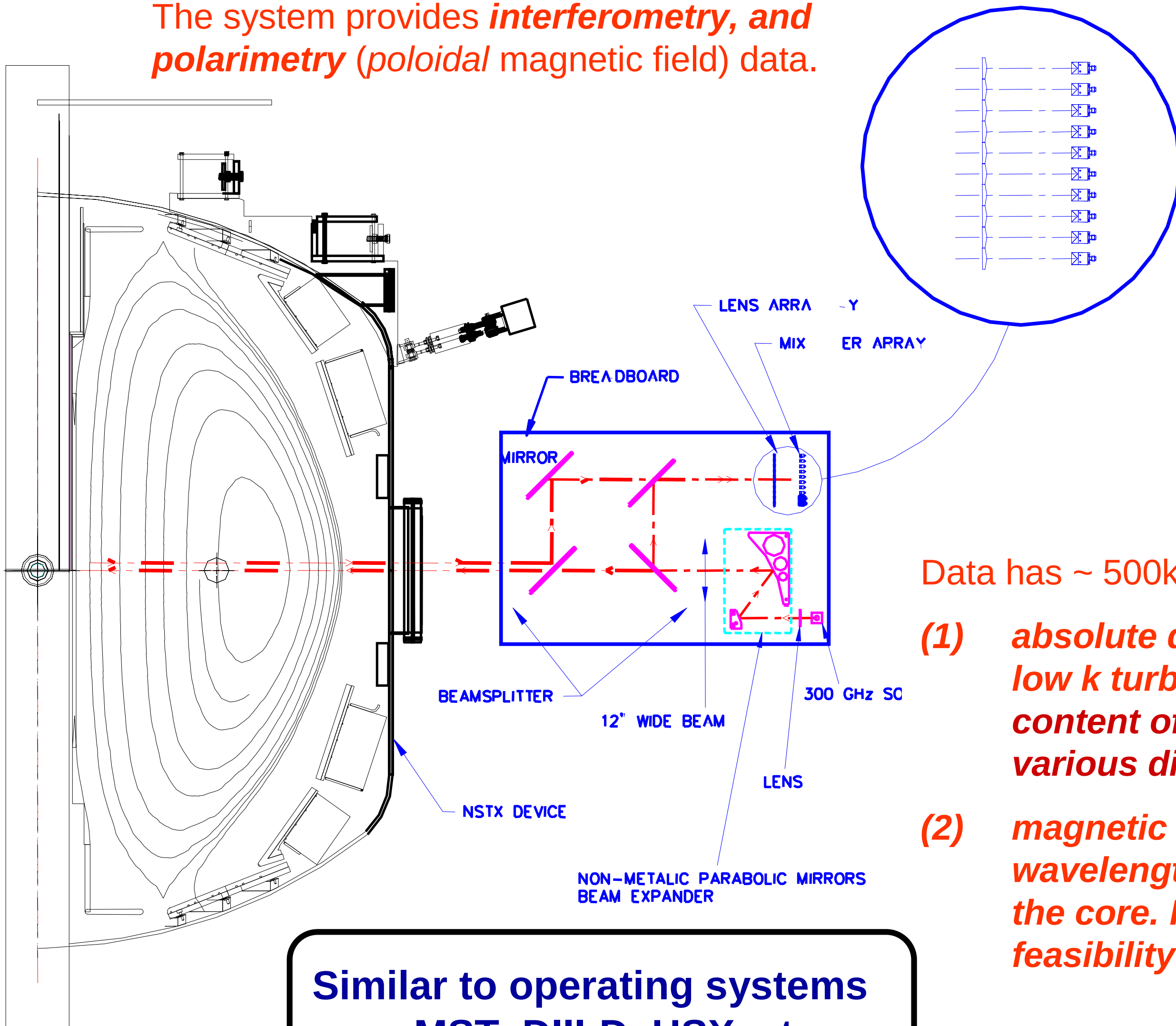
Magnetic Fluctuation Reduction during PPCD

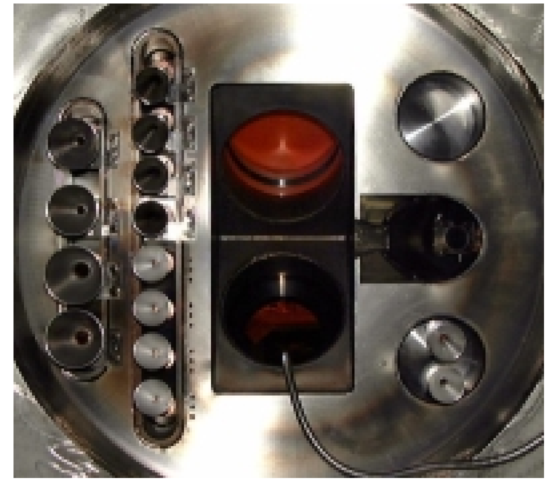




Implementation of multichannel "Fast" interferometry & polarimetry on NSTX

The system provides ***interferometry, and polarimetry*** (*poloidal* magnetic field) data.





Inside view of midplane Port J

Data has ~ 500kHz bandwidth and would provide

(1) ***absolute density fluctuation content of low k turbulence (I.e. total fluctuation content of low k or ITG turbulence in various discharges)***

(2) ***magnetic fluctuation information at long wavelengths – data is weighted towards the core. Recent MST data demonstrates feasibility.***

Similar to operating systems on MST, DIII-D, HSX, etc.

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Current Status

- **UCLA plans to install a single channel mm-wave interferometer/polarimeter during the current vent**
  - this will confirm our confidence that we can reflect off a carbon tile on the inner wall of NSTX.
  - PPPL will install flat 6 inch long carbon tile.

- **We will utilize this single channel to perform line integrated turbulence measurements at low k (ITG) and also test various polarimeter configurations**
  - This will provide a shot-to-shot monitor of the fluctuation content at low k which can be compared with theoretical predictions for ITG turbulence

- **We will generate a DoE proposal to install a multichannel system onto NSTX.**
  - this would provide the equilibrium information necessary to constrain Jo
  - it would also ensure that the channel passing through the current axis will easily be identified
  - this channel would then be utilized to investigate magnetic fluctuations in high beta NSTX plasmas.
  - the existence of flat temperature profiles near the axis cannot be a result of ETG turbulence (no drive) . The most likely culprit is magnetic fluctuations which this diagnostic can address.

Summary

- ***Dual mode reflectometry has been demonstrated on NSTX.***
- ***Full implementation will provide IBI information at various radii with a time resolution of ~10 ms.***
- ***Spatial coverage will be limited by density profile shape - a fundamental limit of reflectometry on the low field devices such as NSTX***

- ***A reflectometry concept has been described to measure the magnetic field tilt angle as a function of radius. Full implementation is limited by funding at this time. Will be included in Grant renewal (August).***

- ***Multichannel interferometry and polarimetry can provide***
  - A significant constraint on the ***current density on axis*** through integration with EFIT
  - A measure of the "***total absolute fluctuation content***" (line integrated $\tilde{n}/n$) at long turbulent wavelengths i.e. ITG modes.
  - A measure of "***magnetic fluctuation content***" at long wavelength ($k_{radial} < 1\ cm^{-1}$) weighted towards higher density i.e. core region. Expect to detect $\tilde{B}/B \sim 10^{-3}$. Turbulence as well as coherent modes will be detectable
  - Current frequency bandwidth is ~500 kHz - can be increased at a cost.