Abstract

Internal magnetic field fluctuations and equilibrium poloidal magnetic field have been measured in the MST reversal field pinch by a 11 chord far-infrared polarimeter-interferometer system with frequency response up to 1 MHz. Fast time resolution and low phase noise of the polarimeter enable us to resolve m=1 resistive tearing modes as a precursor to the sawtooth crash. Turbulent magnetic field fluctuations up to 100 kHz have also been observed. The chord-averaged radial magnetic field fluctuation level is about 33 G or 1%. A broad power spectrum peaks at 10-20 kHz and is dominated by m=1 magnetic field fluctuations. By computing the coherence between two toroidally-displaced chords, one can determine the toroidal mode number and rotation speed. The phase of radial magnetic field fluctuations lags poloidal magnetic field fluctuations by 90 degrees which is in agreement with MHD computation for MST. Magnetic field fluctuations are reduced by a factor of four during a high confinement PPCD discharges, consistent with energy confinement improvement.

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Polarimetry Technique

- **Two counter-rotating circularly polarized FIR beams are launched into plasma. The phase difference between two beams is proportional to Faraday rotation angle .**

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

- **Faraday rotation angle is proportional to the product of electron density and magnetic field along the beam direction.**
- **Interferometer gives electron density by measuring the average phase of two probe-LO mixing products .**

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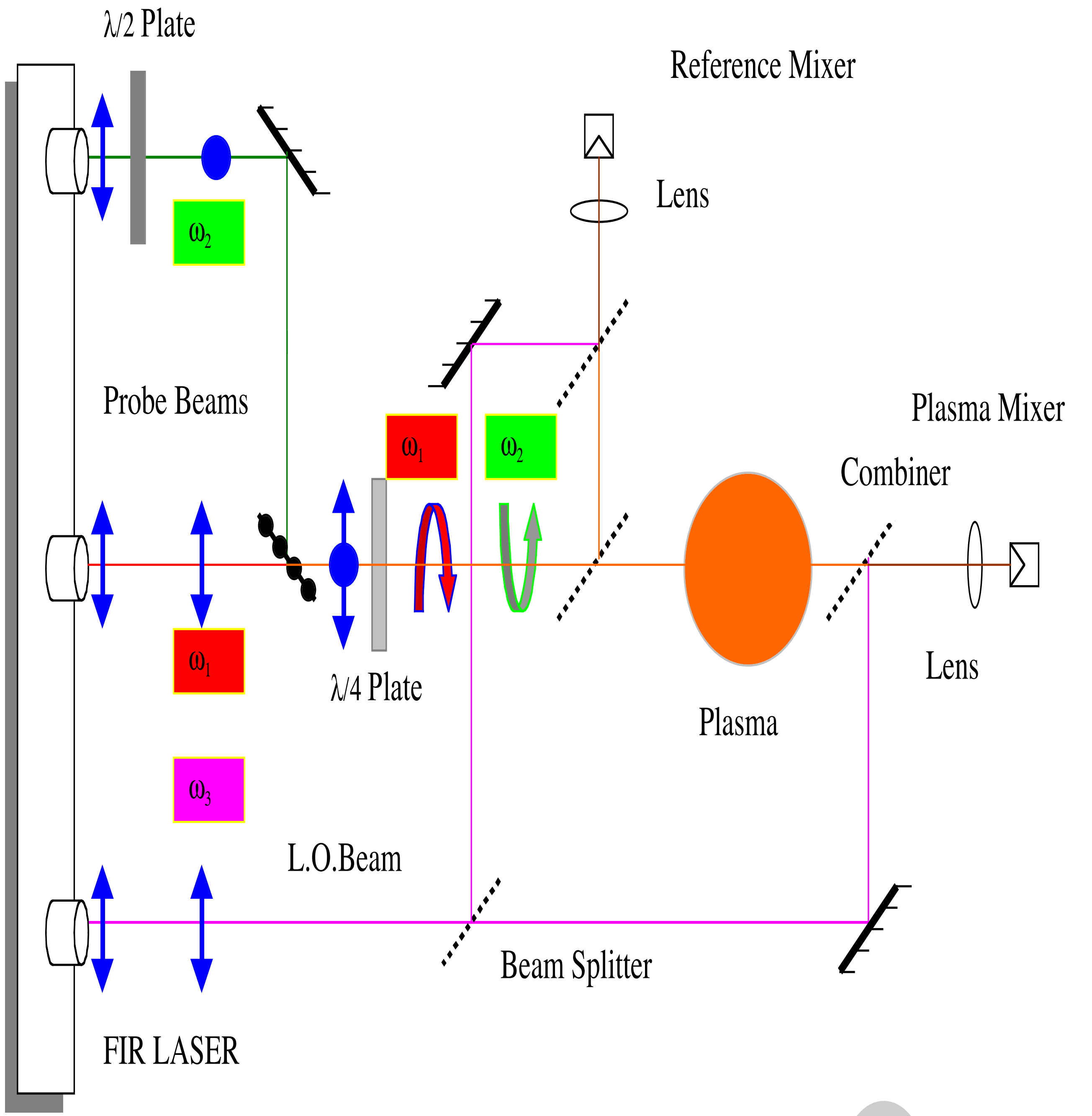
3-Wave Laser Polarimetry



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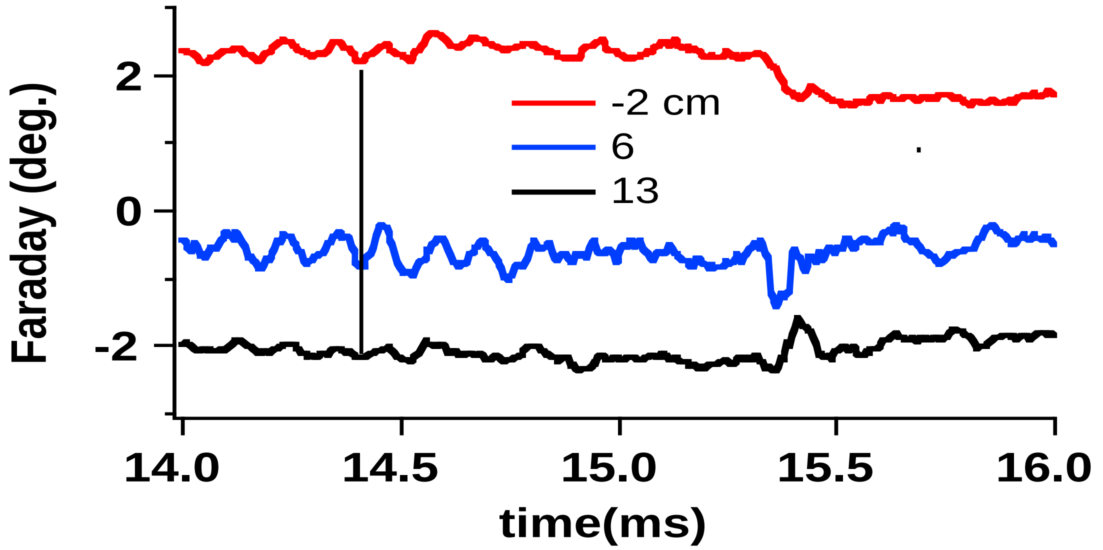
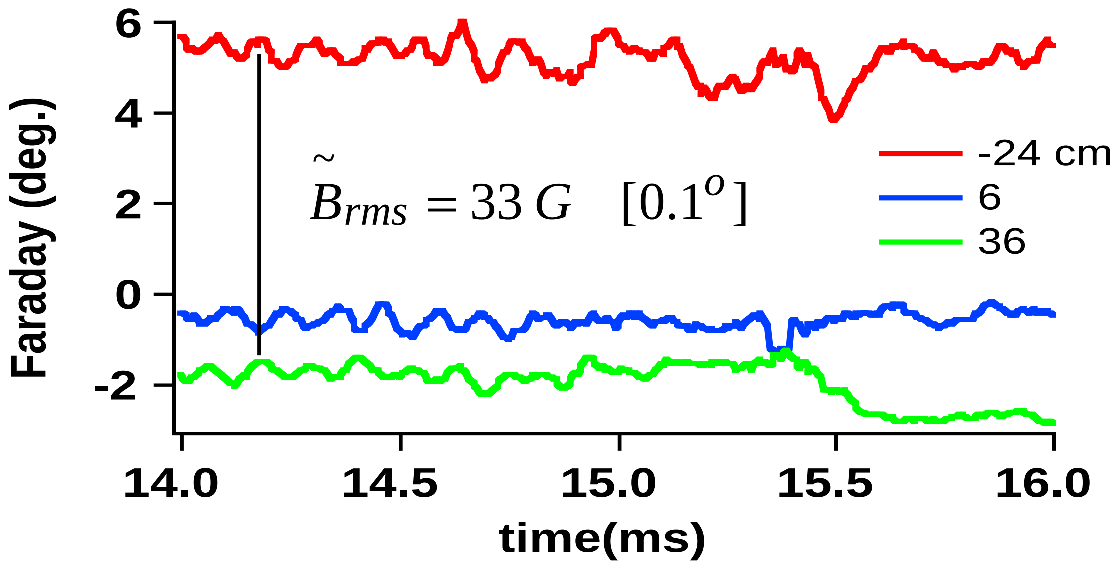
Faraday Rotation Fluctuation

m=1 activity, fluctuating amplitude 0.1-0.2 degree
in phase between x=-2 and 13



out of phase between central chord and edge chords
in phase between two edge chords (x=-24,36)



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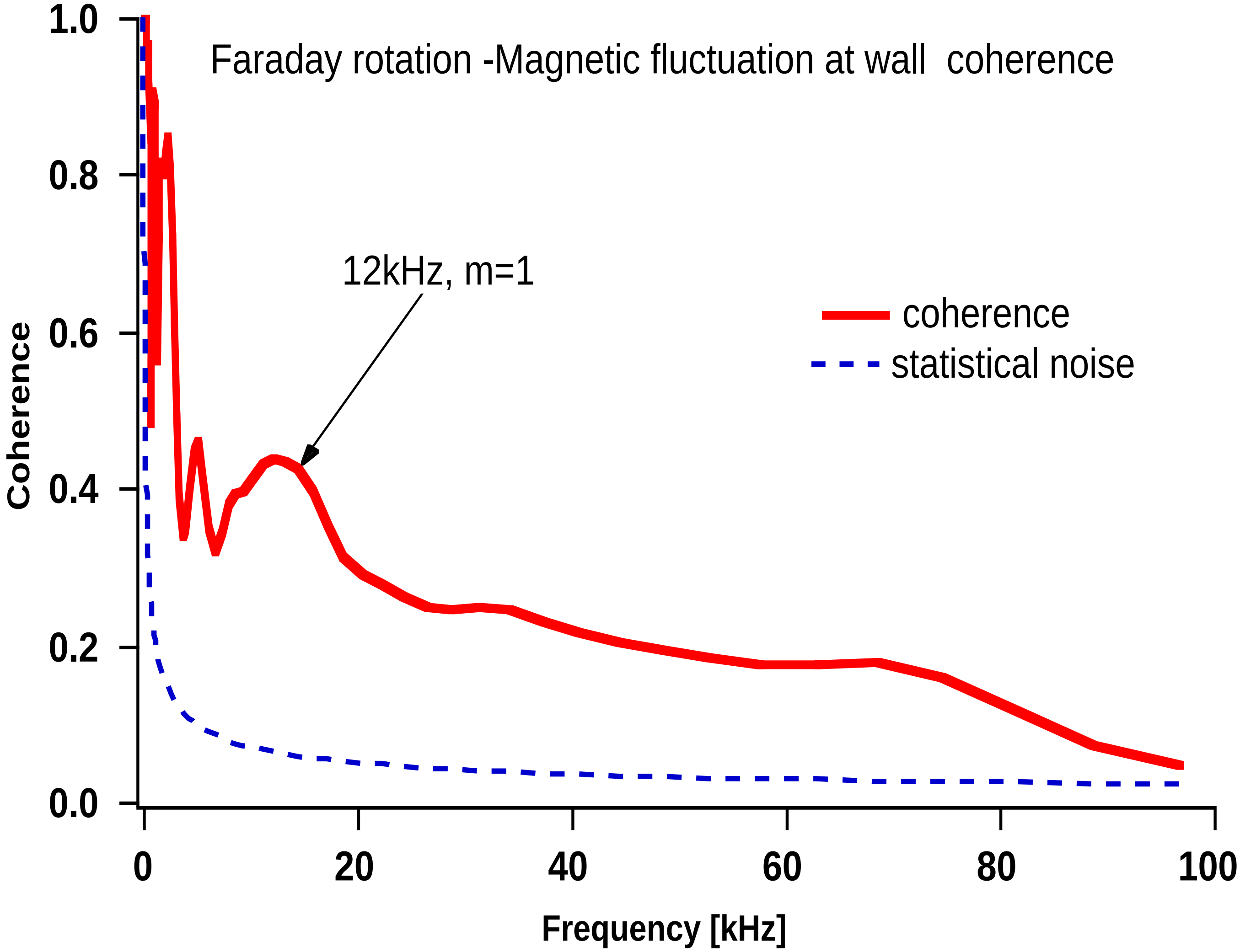
Fast Polarimeter Correlation with Magnetic Coil



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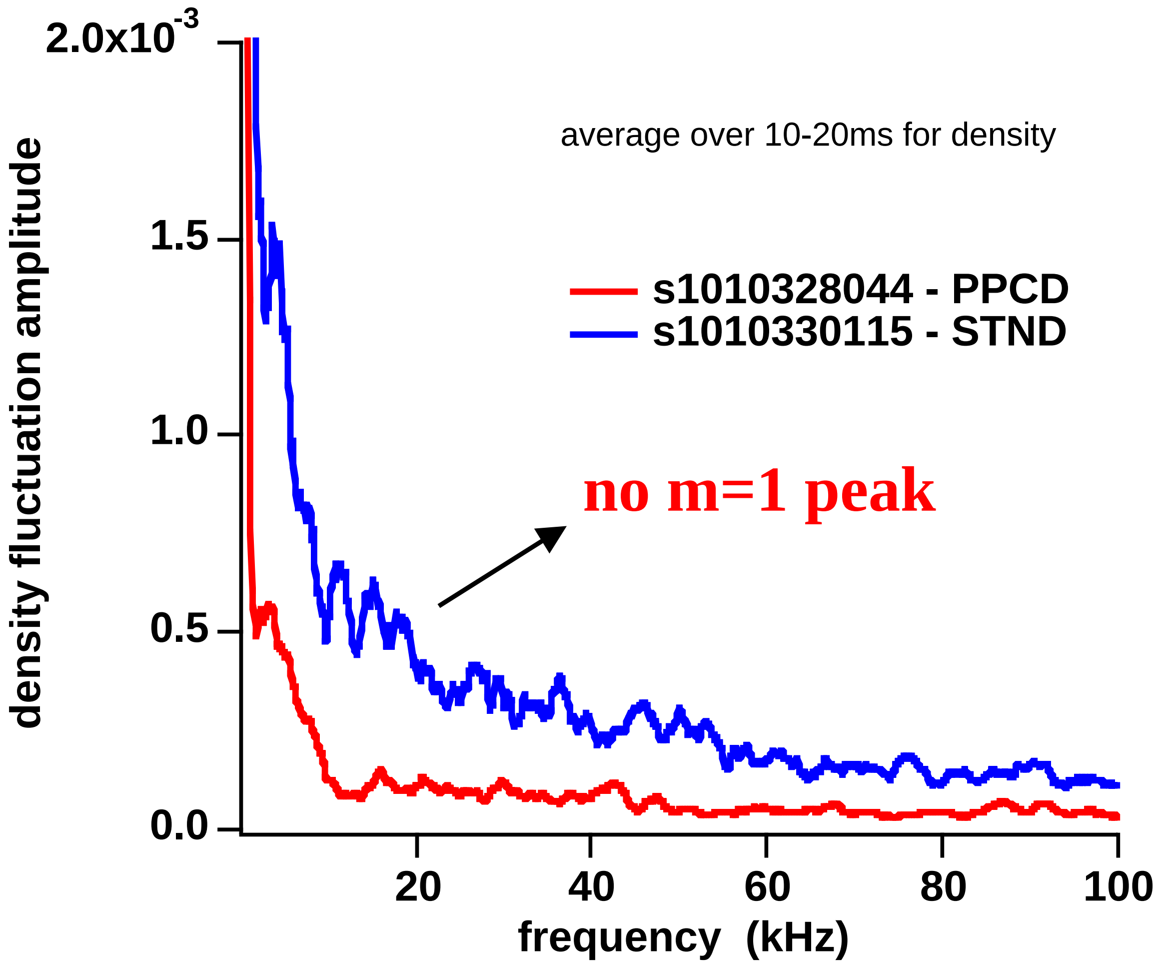
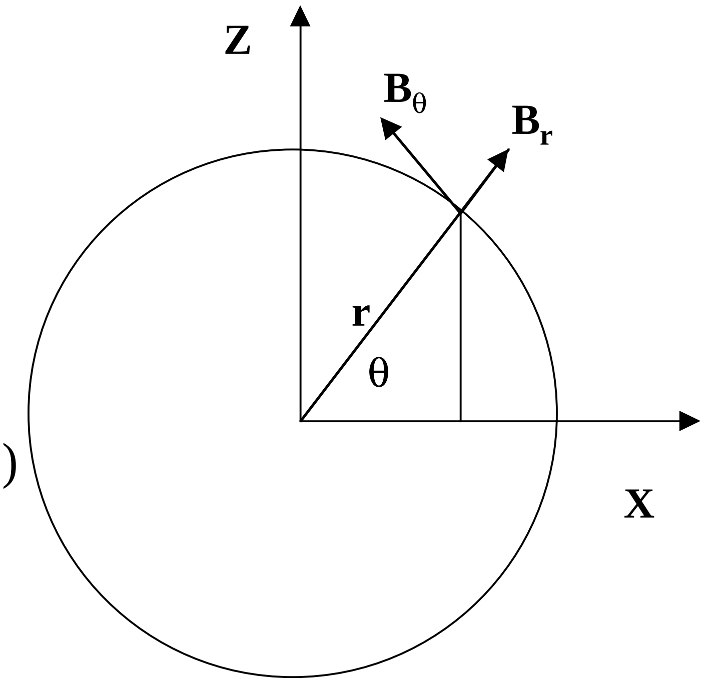
Central Chord Density Fluctuations

P06 interferometer chord



Magnetic Fluctuation Signal Analysis



Faraday Rotation

$$\Psi(x,t) = c_F \int n(r,t) B_z(r,x,t)\,dz$$

linearize the equation using

$$\Psi(\mathrm{x},\mathrm{t}) = \Psi_0(x) + \tilde{\Psi}_1(x,t)$$

$$n(r,t) = n_0(r) + \tilde{n}_1(r,t)$$

$$B_z(r,x,t) = B_{z0}(r,x,t) + \tilde{B}_{z1}(r,x,t)$$

$$\Psi_0 = c_F \int n_0 B_{z0}\,dz,$$

$$\tilde{\Psi}_1 = c_F \left[\int \tilde{n}_1 B_{z0}\,dz + \int \tilde{B}_{z1} n_0\,dz \right]$$

$$x \to 0,\ B_{z0} = B_\theta \cos\theta = B_\theta \frac{x}{r},\ 2\pi r B_\theta = \mu_0 J(0) \pi r^2,$$

$$c_F \int \tilde{n}_1 B_{zo}\,dz = 0.5 c_F \mu_0 J(0) x \int \tilde{n}_1 dz \le 0.02^0 \text{ at x = 7 cm}$$

$$\left(J(0) = 2.0 \times 10^6 A/m^2, \int \tilde{n}_1 dz = 10^{17} m^{-2} \right)$$

For m = 1 mode, $\int \tilde{n}_1 dz \approx 0$. For central chords, $\cos\theta \approx 0, \sin\theta \approx 1$,

we have

$$\tilde{\Psi}_1 \approx c_F \left[\int \tilde{B}_{z1} n_0\,dz \right] = c_F \int \left(\tilde{B}_r \sin\theta + \tilde{B}_\theta \cos\theta \right) n_0\,dz = c_F \int \tilde{B}_r(r,t) n_0(r)\,dz$$

For these edge chords, $B_{z0} = B_\theta \frac{x}{r} = \frac{\mu_0 I_d}{2\pi} \frac{x}{r^2}$

$$c_F \int \tilde{n}_1 B_{z0} dz = \frac{\mu_0 I_d}{2\pi} \int \tilde{n}_1 \frac{x}{r^2} dz \geq \frac{\mu_0 I_d}{2\pi} \tilde{n}_{\min}(\xi) \int_{-29}^{29} \frac{x}{r^2} dz = 0.2^0 \text{ at x = 43 cm}$$

$$(I_d = 400kA, \tilde{n}_{\min} = 2 \times 10^{17} m^{-3}, -29 \leq \xi \leq 29)$$

The measured fluctuation amplitude for edge chords are about 0.2^0.

It means that density fluctuation contributes the most of Faraday rotation fluctuation signals in edge chords.

- **Fast polarimetry measures magnetic fluctuation in central chords. A line averaged magnetic fluctuation amplitude can be obtained.**
- **Fast polarimetry measures density fluctuation in edge chords with better phase resolution;**
- **Toroidal mode number can be determined by the correlation between two toroidally displaced two chords;**

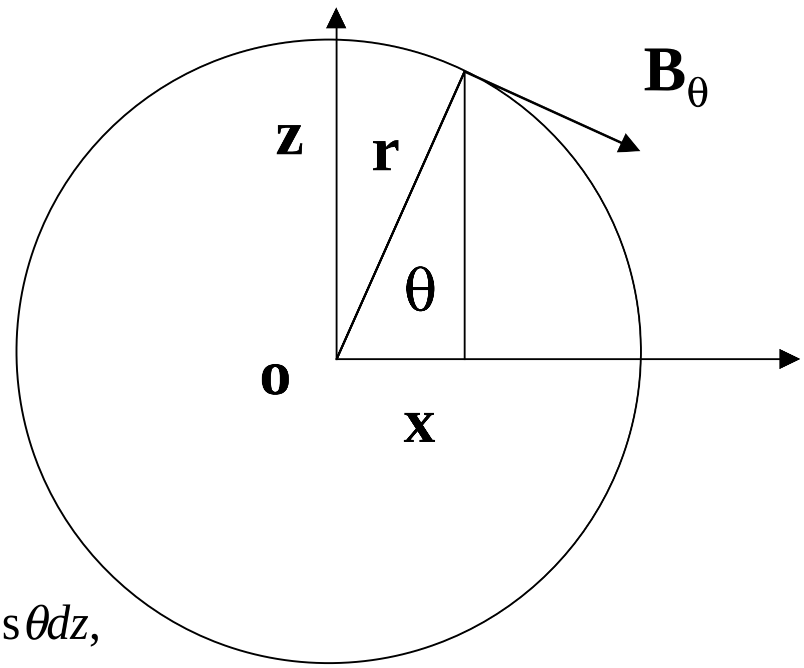
Fluctuation Signals Analysis

- Radial Magnetic fluctuations dominate Faraday rotation fluctuations in central chords (x=-2,6,13 cm) because density fluctuations are small and probing beam is nearly perpendicular to equilibrium field.

- Density fluctuations dominate Faraday rotation fluctuations for edge chords (x=-32,-24,36,43 cm) where density fluctuations are large due to advection.

J(0) measurement

Cylindrical-Slope Model



$$\Psi(x) = c_F \int n_e(r) B_\theta(r) \cos\theta dz,$$

$$x = r\cos\theta = R - R_0, \quad z = r\sin\theta,$$

$$x \to 0, r \to 0, \quad B_\theta \bullet 2\pi r = \mu_0 J(r) \bullet \pi r^2, \frac{\Psi}{x} = \frac{d\Psi}{dx}$$

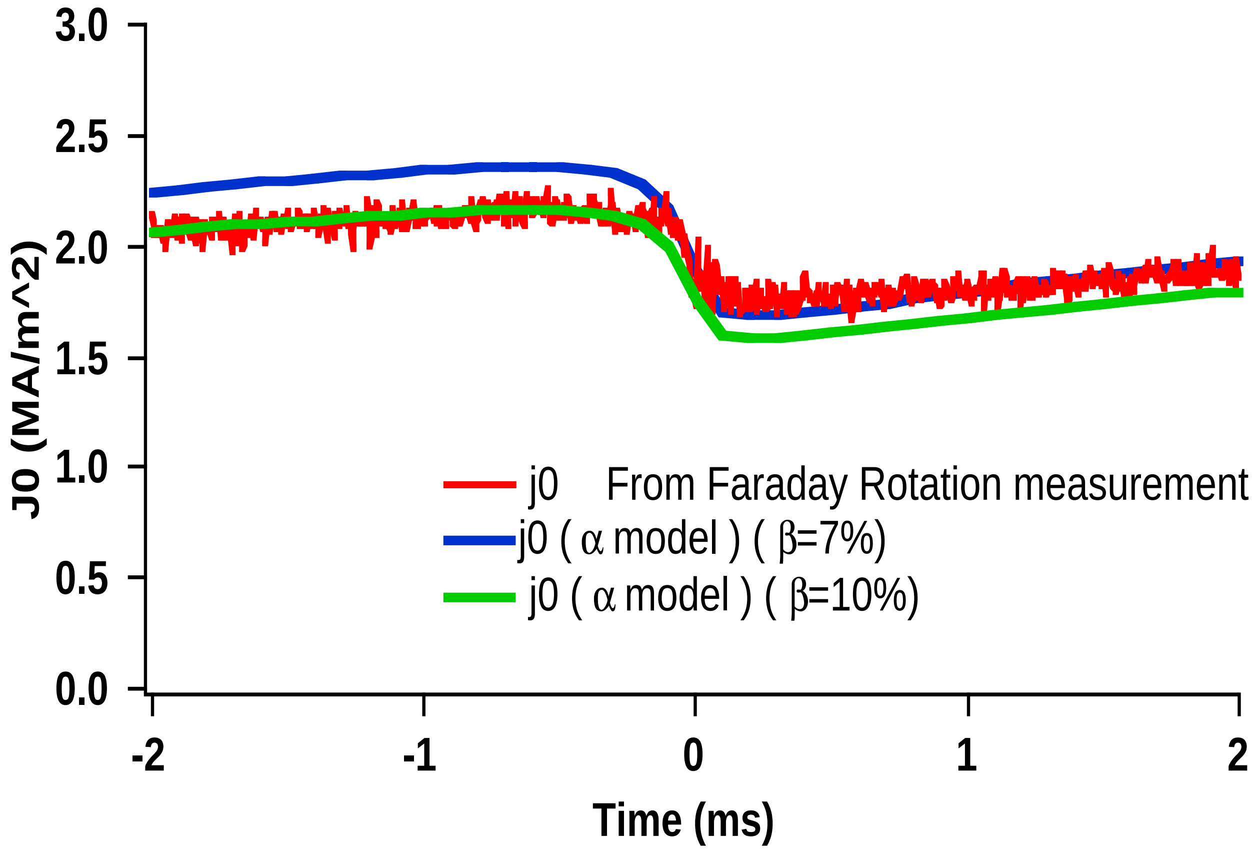
$$\Psi = c_F \int n_e \frac{B_\theta(r)}{r} x dz = 0.5 c_F \mu_0 J(0) x \int n_e(r) f(r) dz$$

where $J(r) = J_0 f(r)$ and assuming $f(r) = (1 - (r/a)^2)^\beta$

$I_d = \int J(r) dS = J(0) \int 2\pi r f(r,\beta) dr$ is total discharge current..

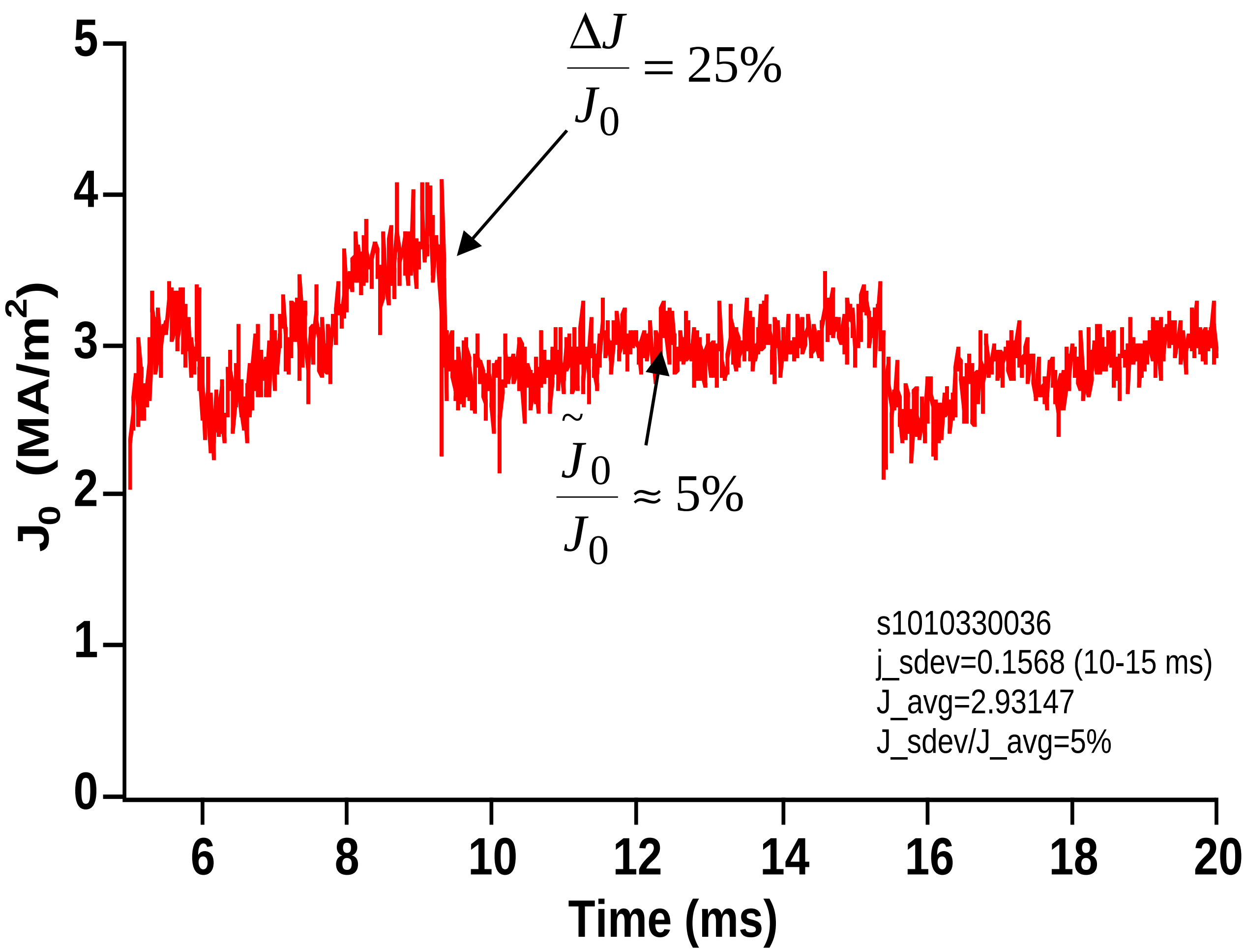
$$J(0) = \frac{2}{\mu_0 c_F} \frac{d\Psi}{dx} \frac{1}{\int n_e(r) f(r,\beta) dz}$$

Comparison of J(0) Estimate with α Model



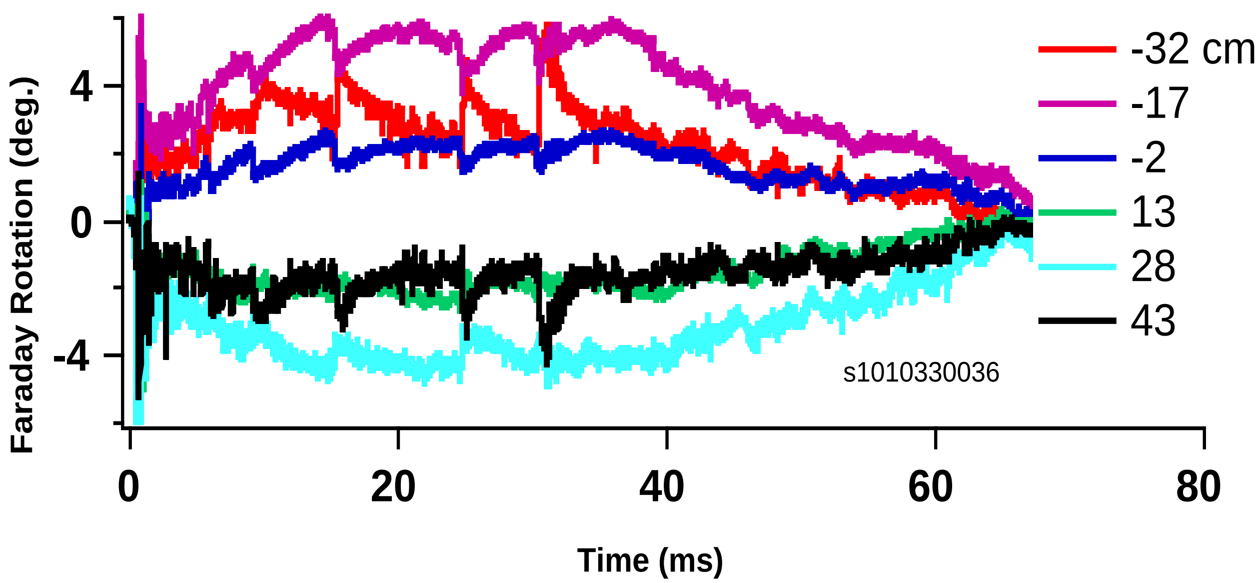
$$J(0) = \frac{2}{\mu_0 c_F} \frac{d\Psi}{dx} \frac{1}{\int n_e(r) f(r,\beta) dz}$$

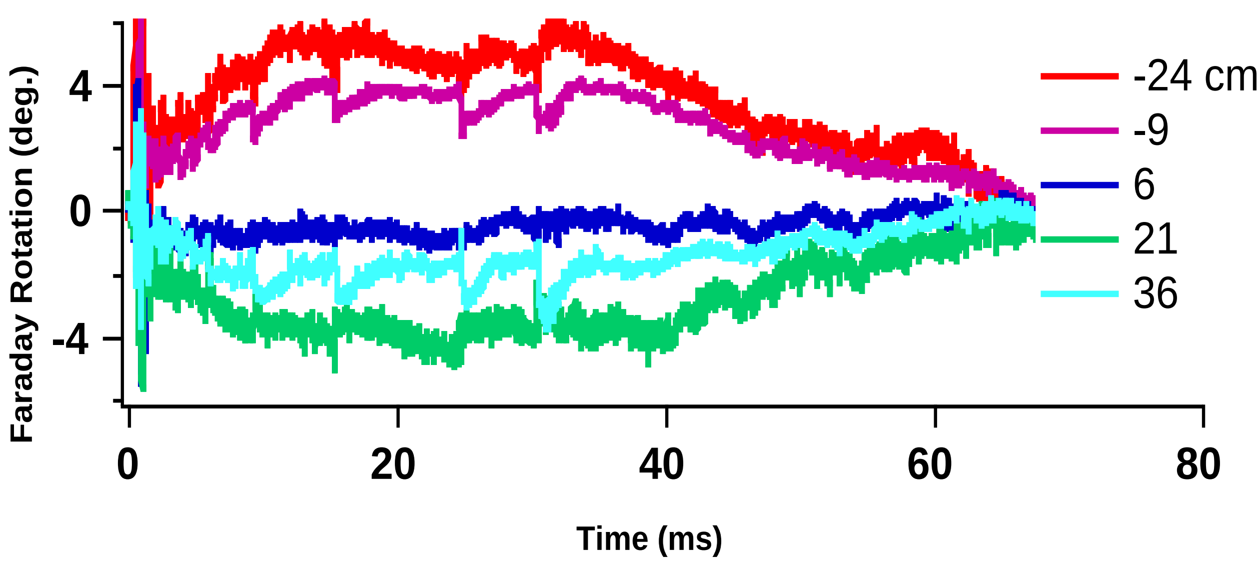
Current Density Fluctuations



Time Evolution of Faraday Rotation Angle

F =-0.2, I_p = 400 kA, 11 channel data, 101033036





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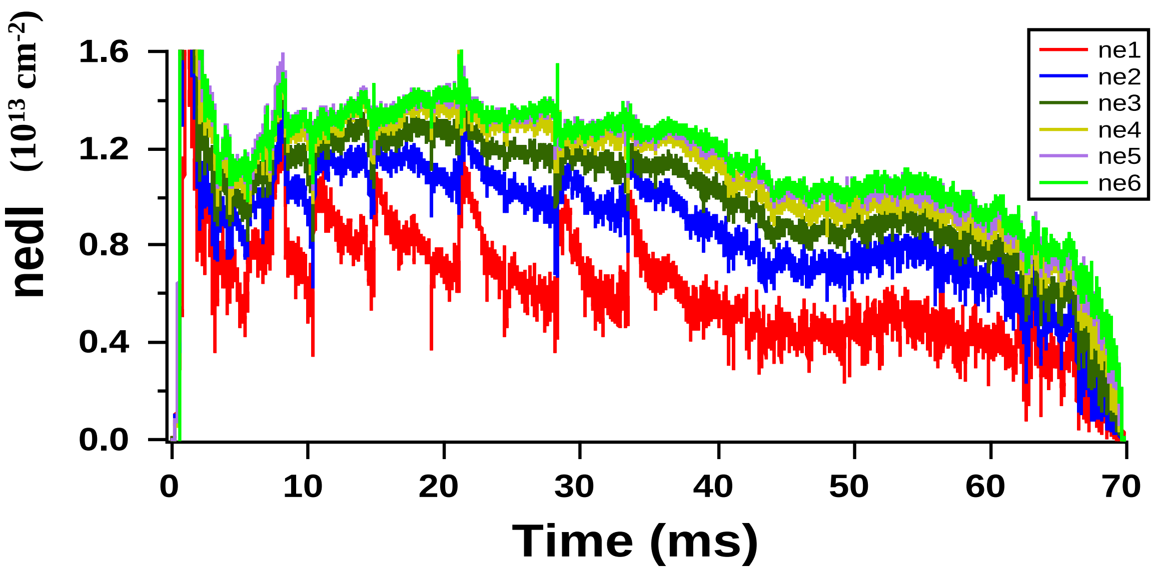
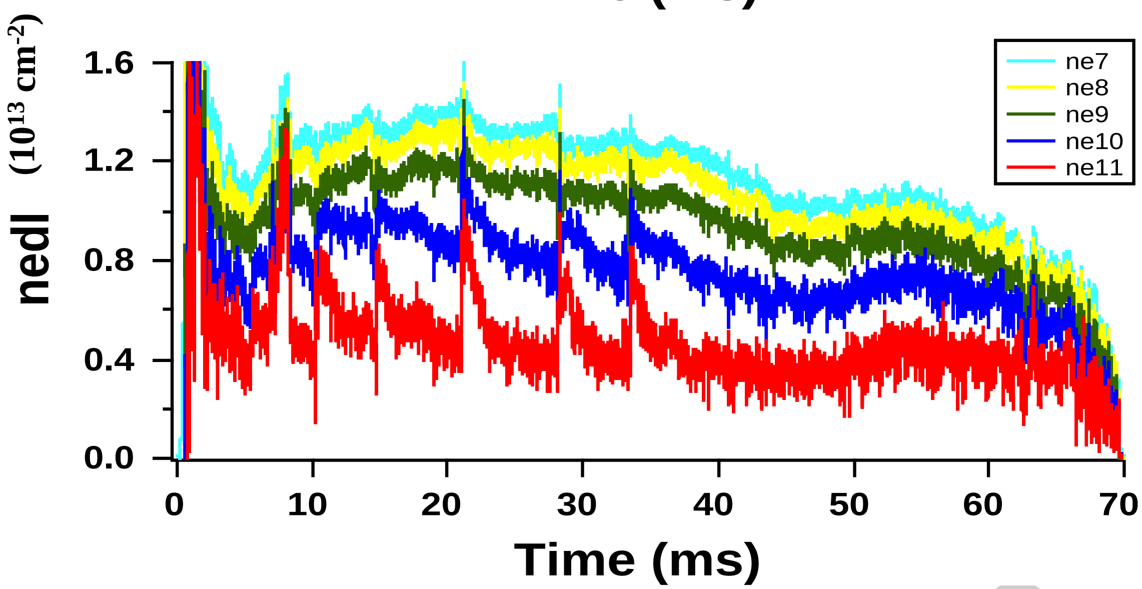
Time Evolution of Electron Density

F =-0.2, I_p = 387 kA, 11 channel data,1010330115





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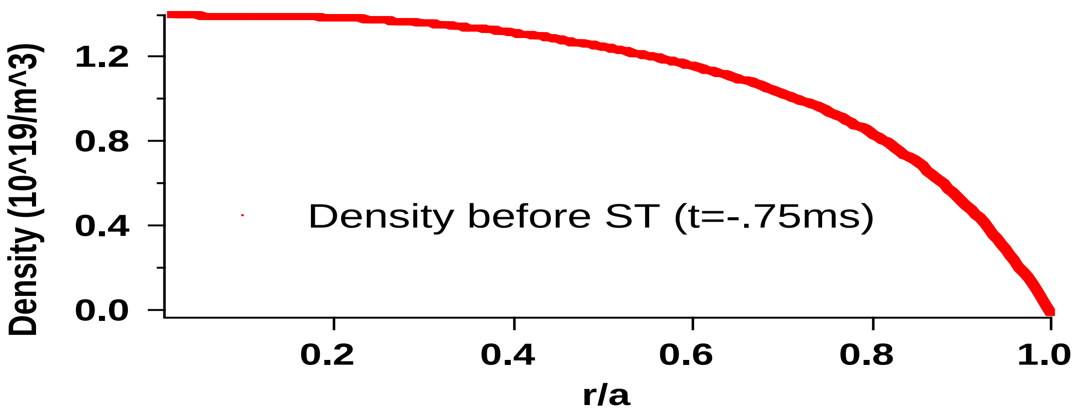
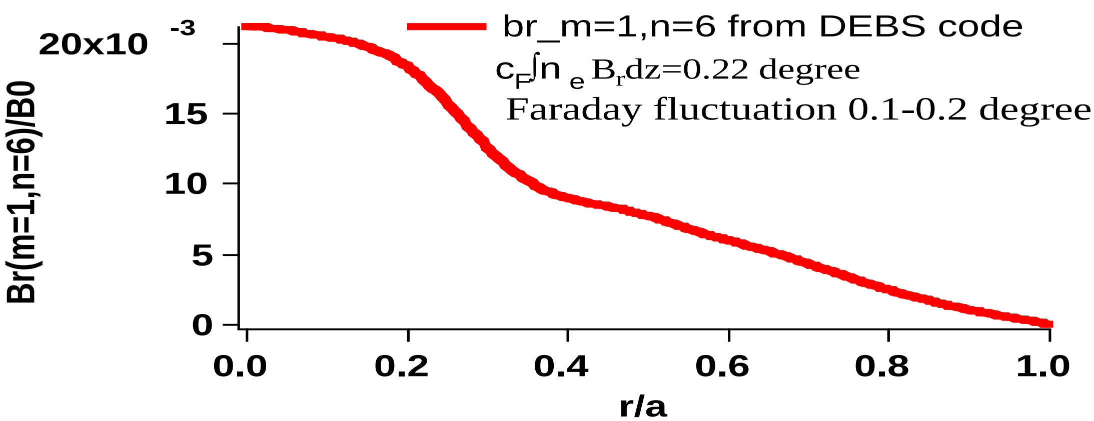
Magnetic Fluctuation B_r Amplitude and Comparison with MHD code

Measured Faraday rotation fluctuation $\sqrt{\overline{\tilde{\Psi}_1^{\,2}}} = 0.1^0$,

$\bar{n}_0 = 1.1\times10^{19} m^{-3}, L = 1.04m,\ c_F = 4.88\times10^{-20}(m^2/T)$

Line average $\bar{\tilde{B}}_r = 33G$





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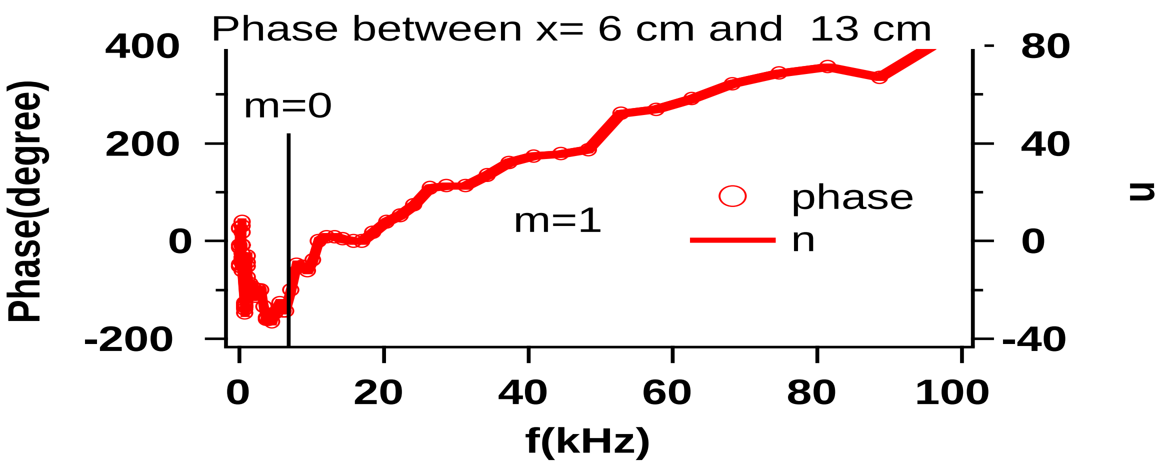
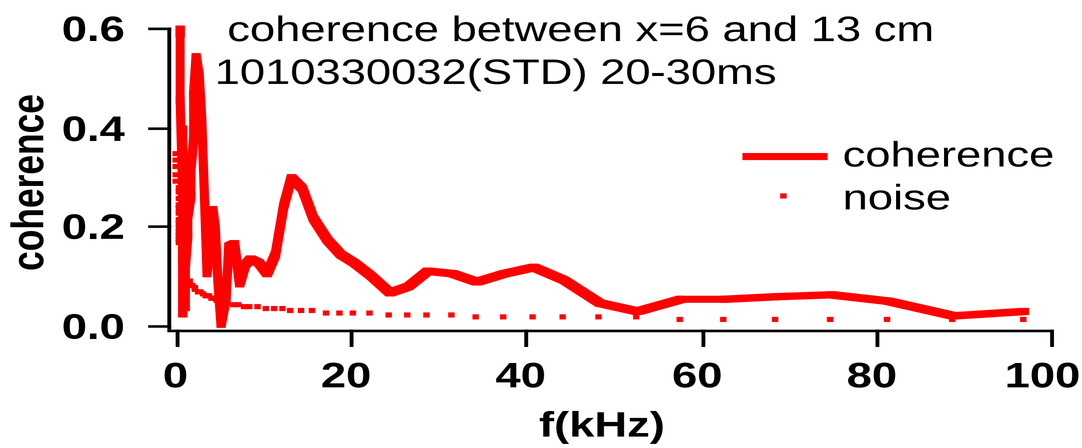
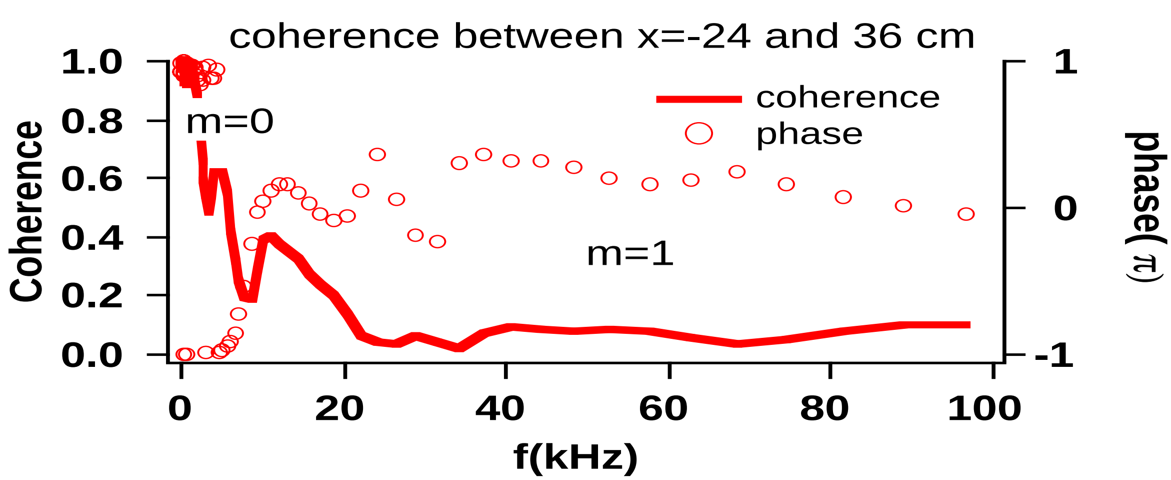
Spatial Correlation of Magnetic Fluctuation B_r







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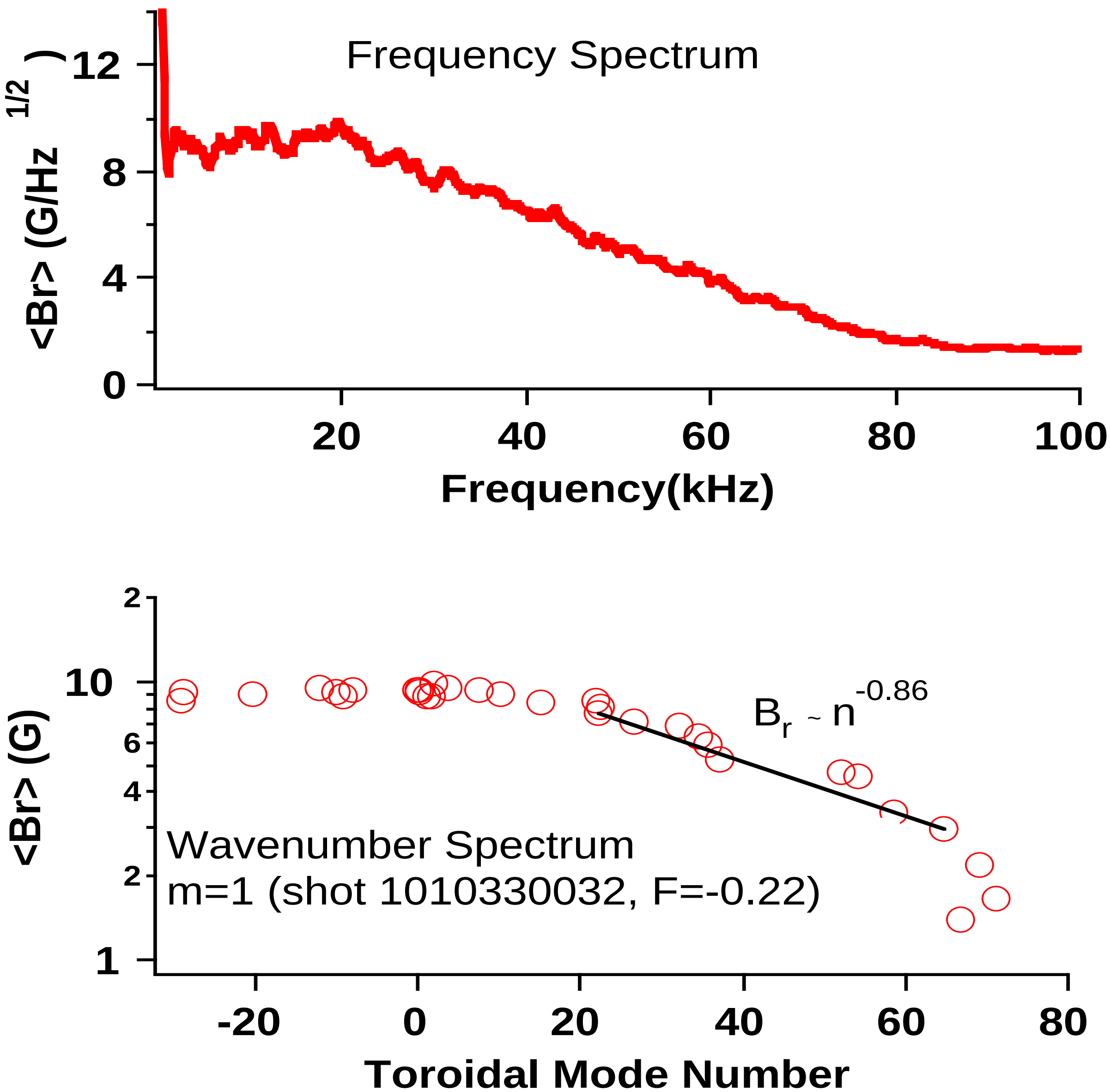
B_r Wavenumber Spectrum



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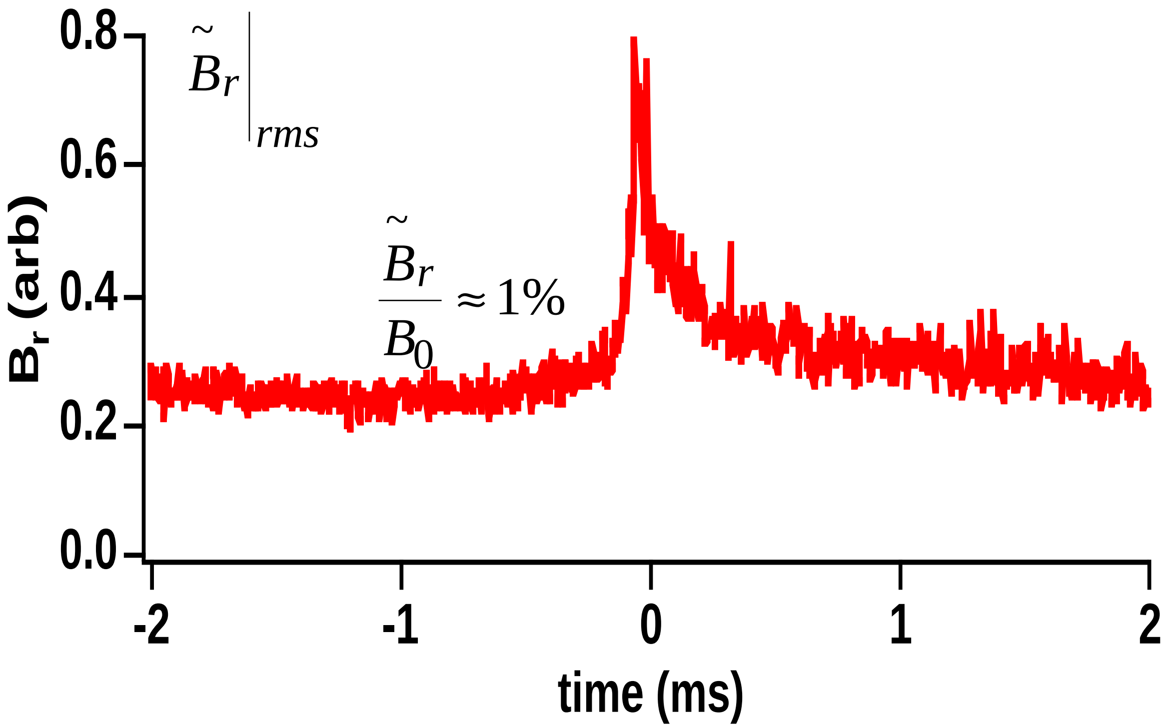
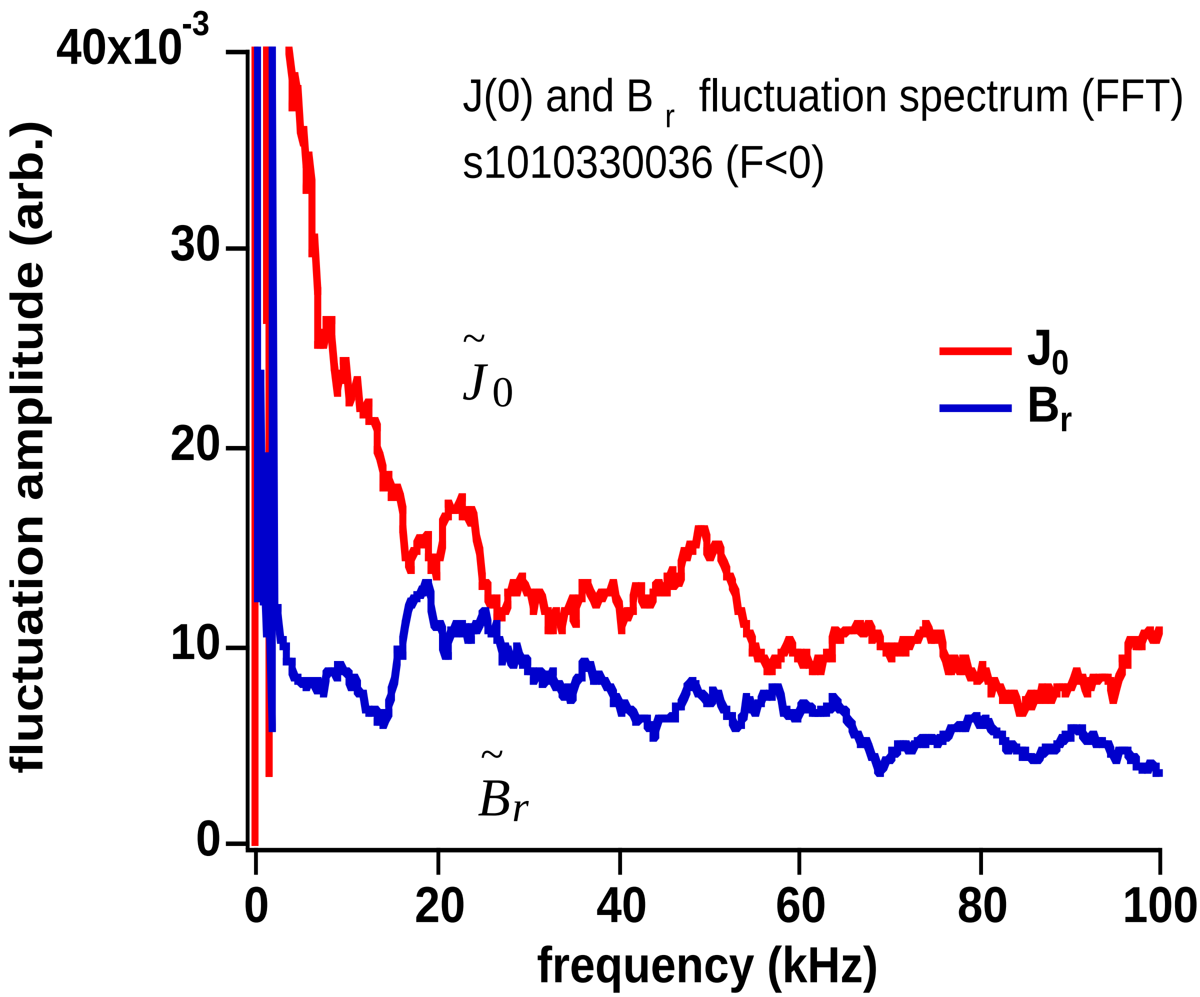
Magnetic Fluctuation change during Sawtooth Cycle



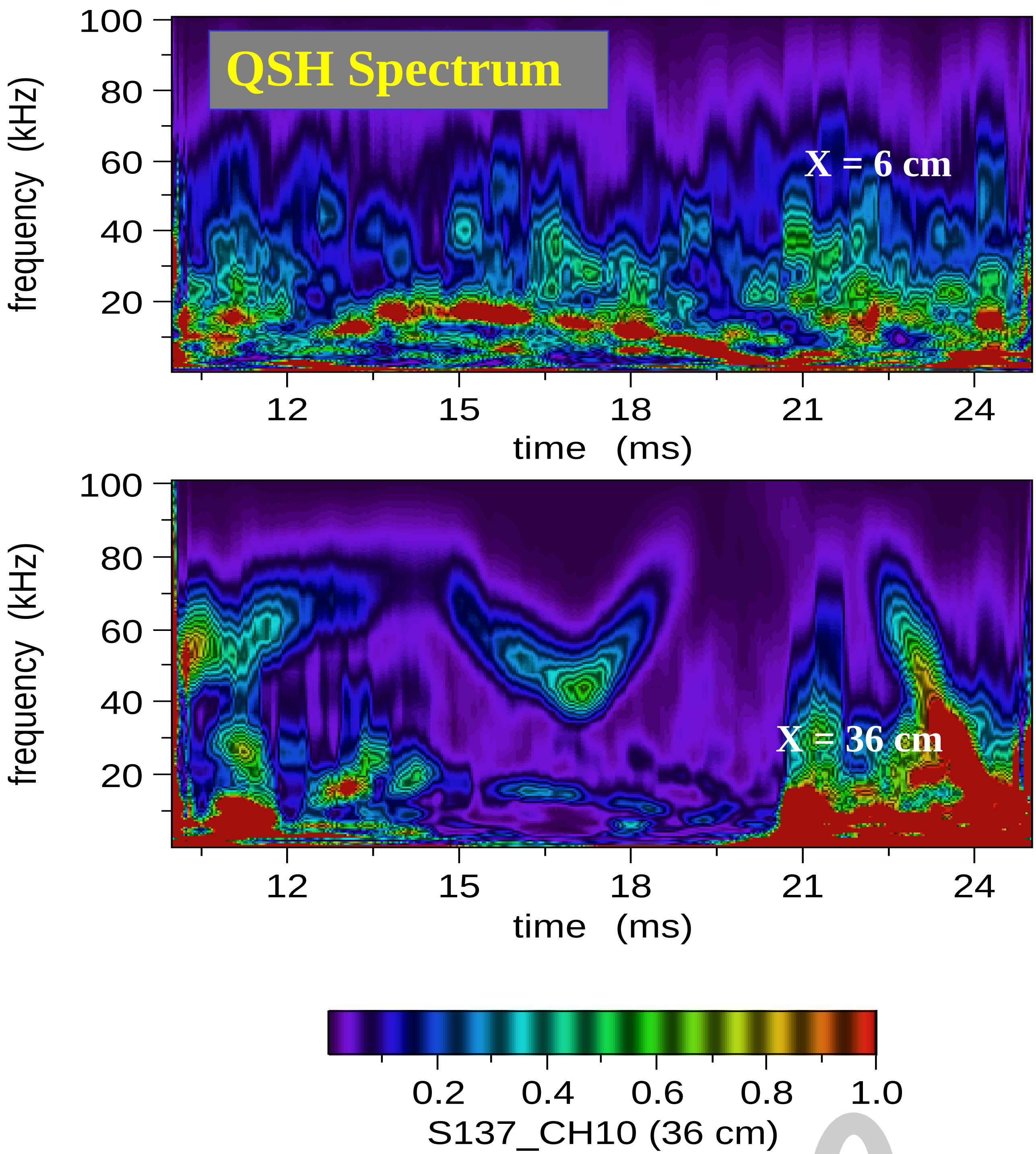
→ **Amplitude approximately 1% before crash**

→ **Fluctuations increase at crash by x3**

Current Density and Magnetic Fluctuations



Quasi Single Helicity in PPCD



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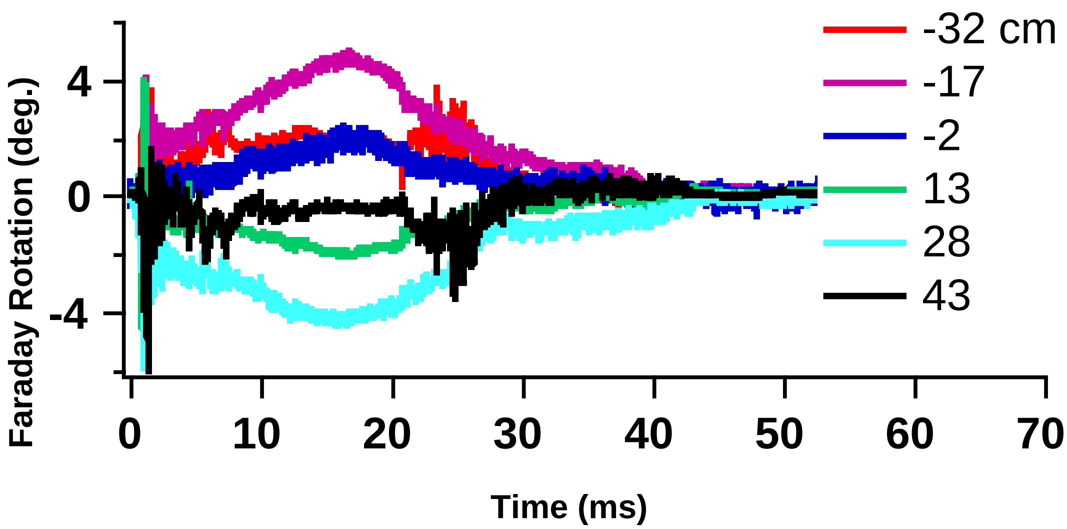
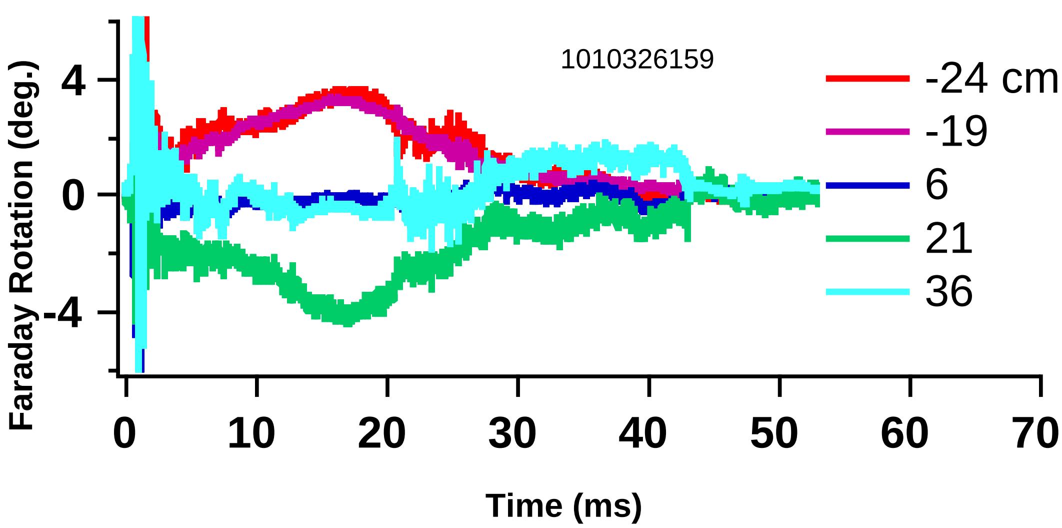
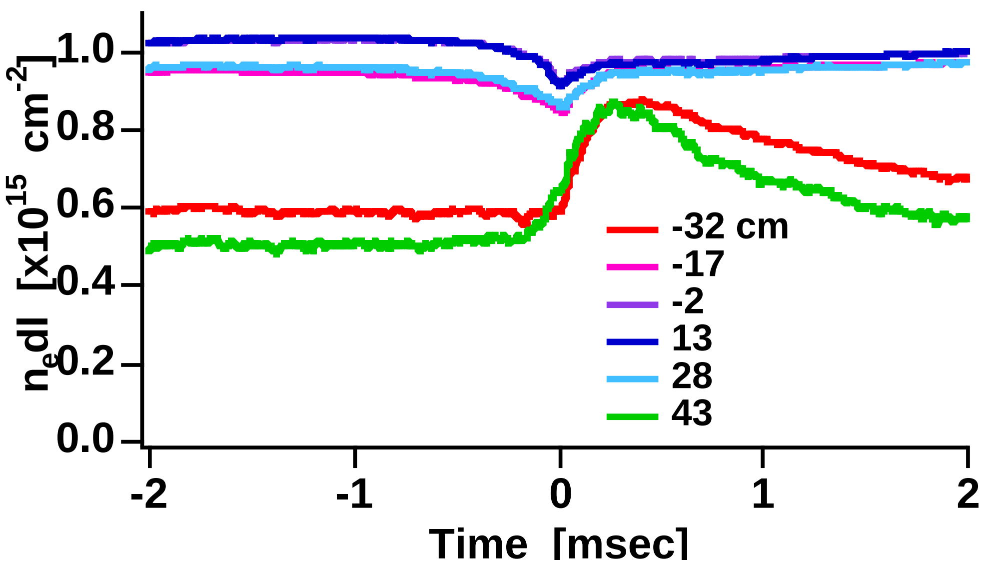
Fast Polarimetry during PPCD

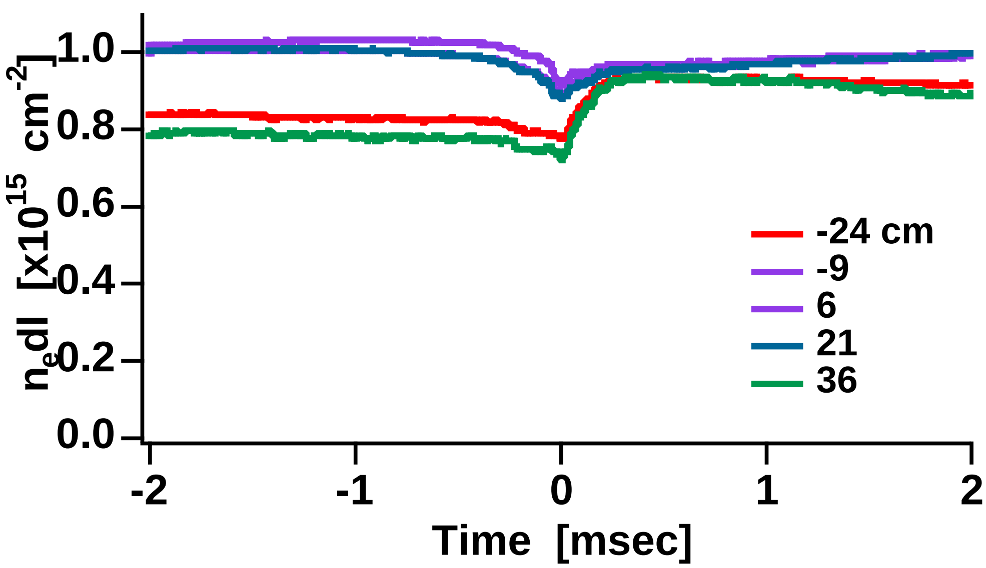
I_p=400kA, 11 channel data





Sawteeth Ensembled Density Dataset





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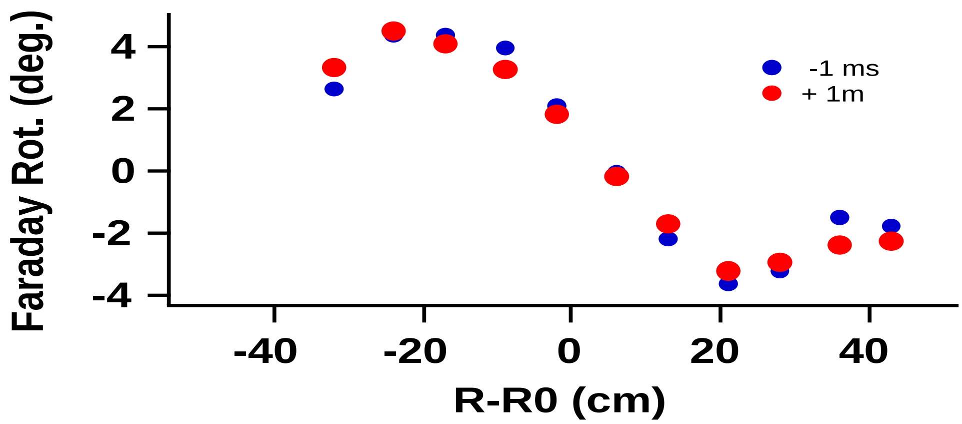
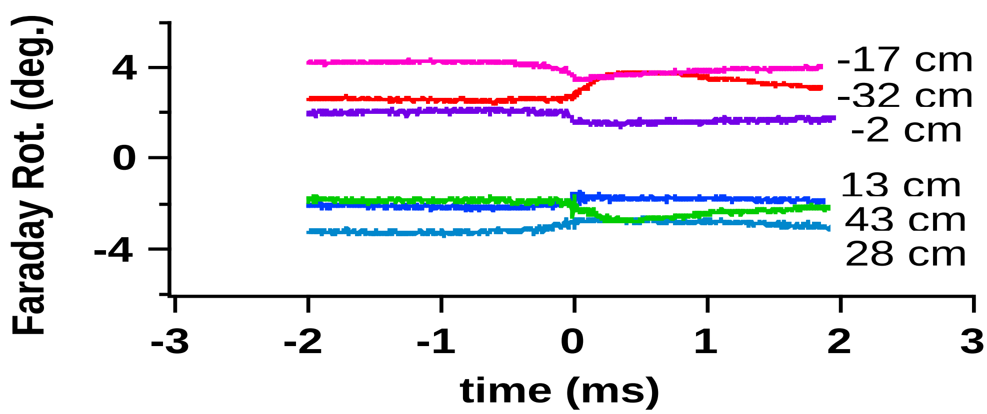
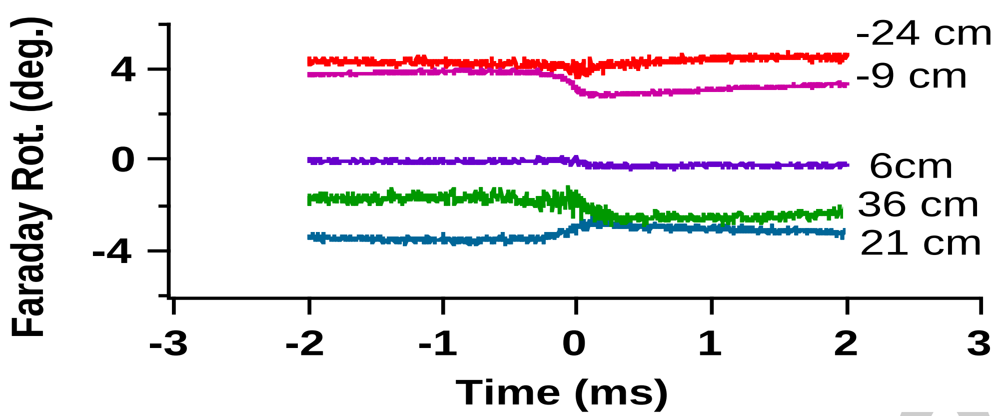
Ensembled Faraday Dataset







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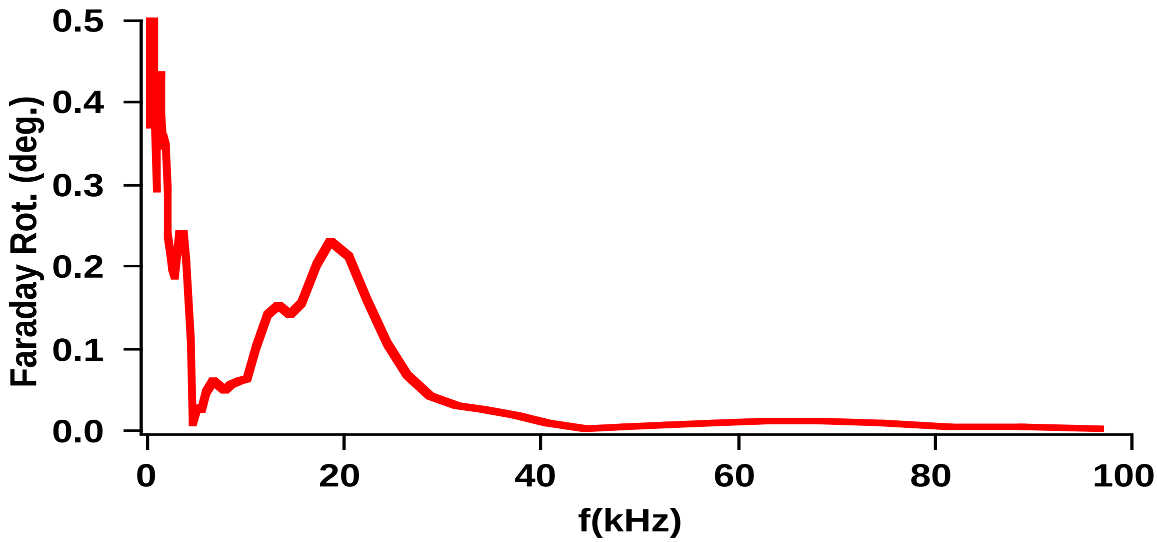
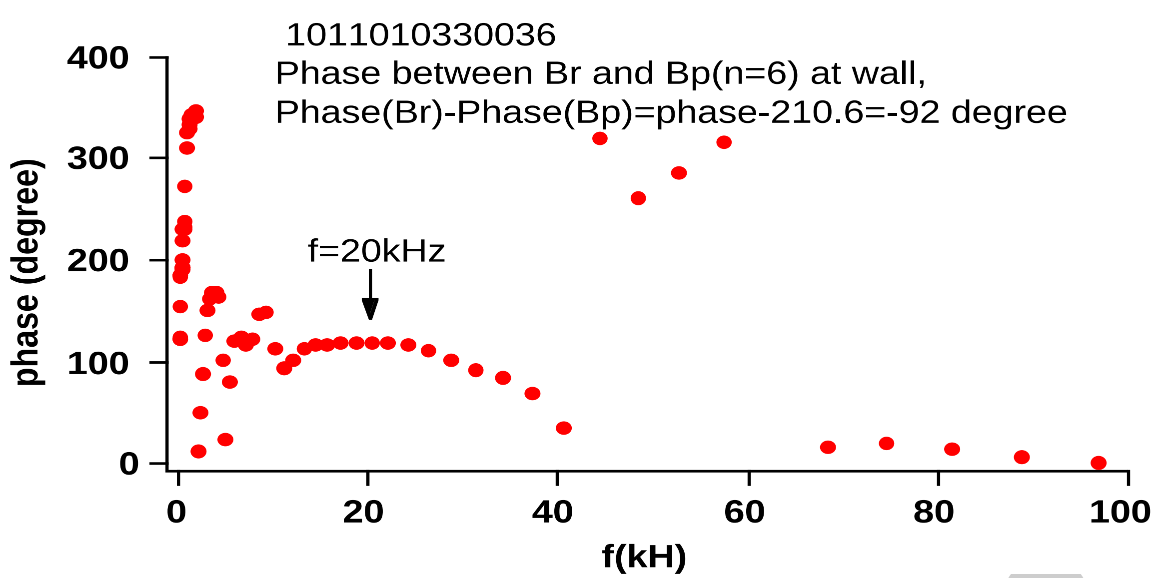
Magnetic Fluctuation B_r Phase

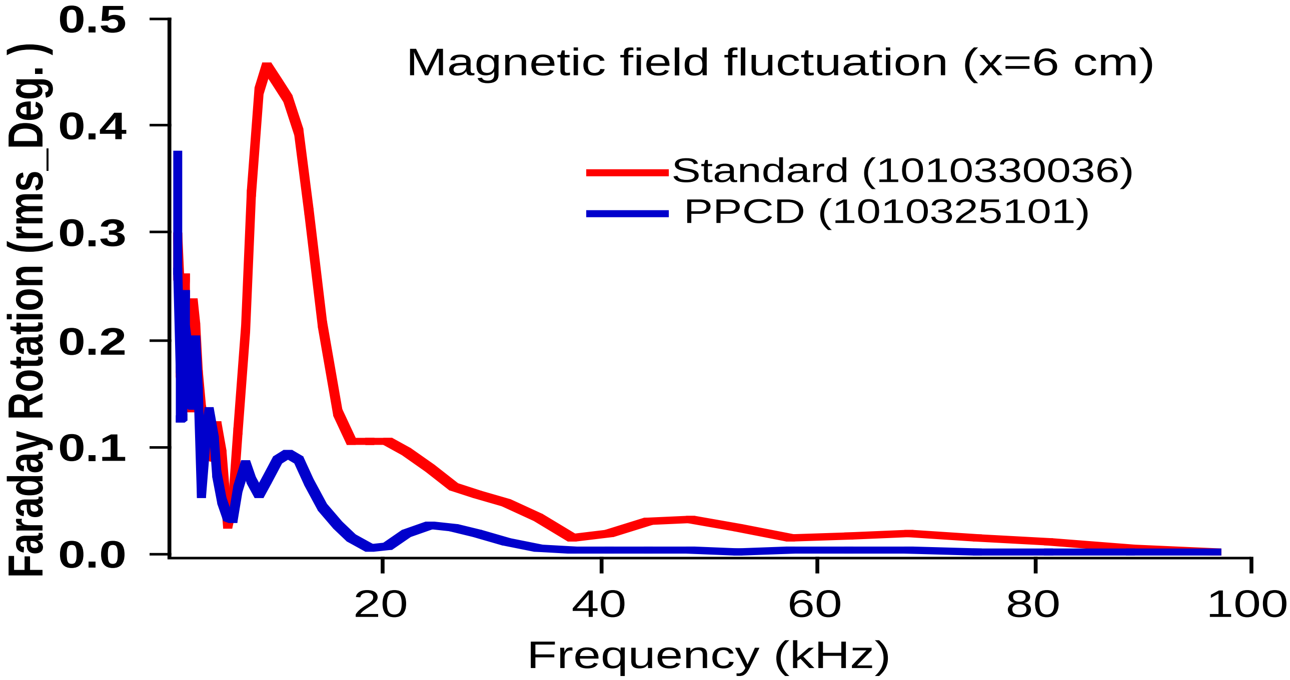
B_r lags B_θ 90 degree

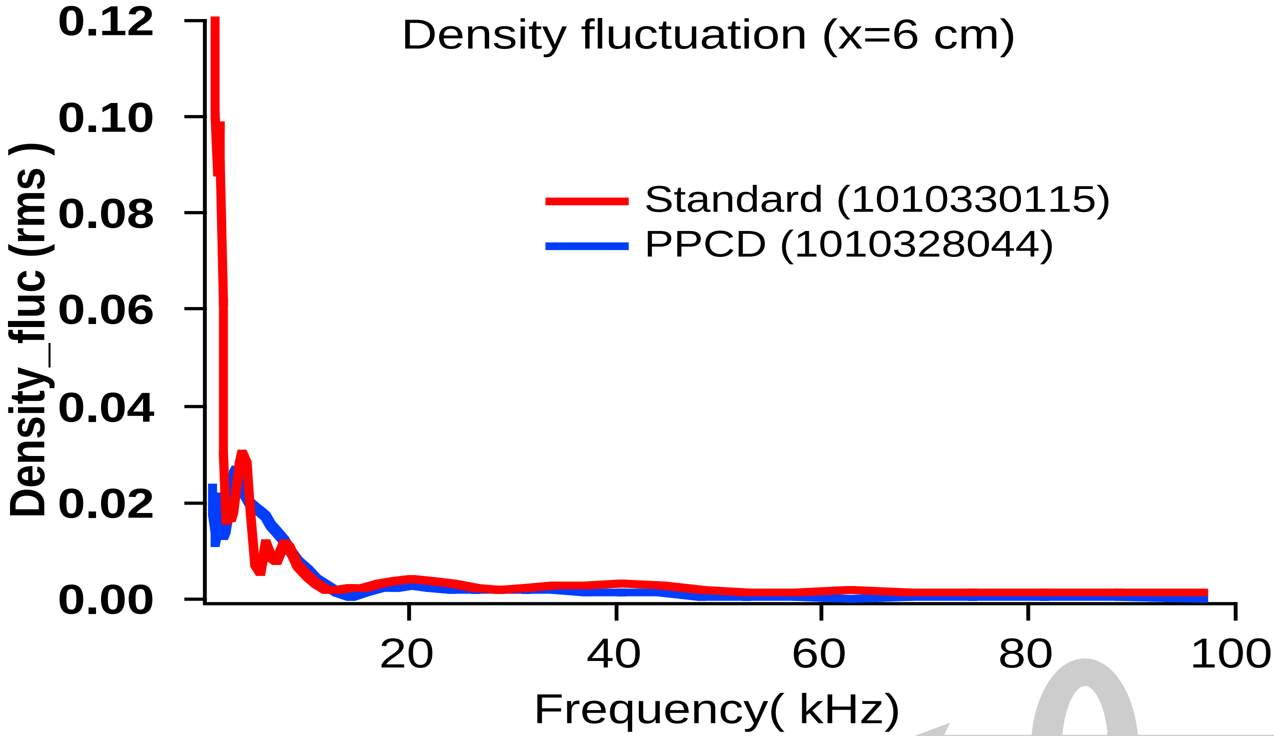
$$\sqrt{\tilde{\Psi}_1^{\,2}} = \frac{\langle \Psi_1 \bullet B_{p,n=6} \rangle}{\sqrt{B^2_{\ p,n=6}}}$$





Magnetic Fluctuation Reduction during PPCD





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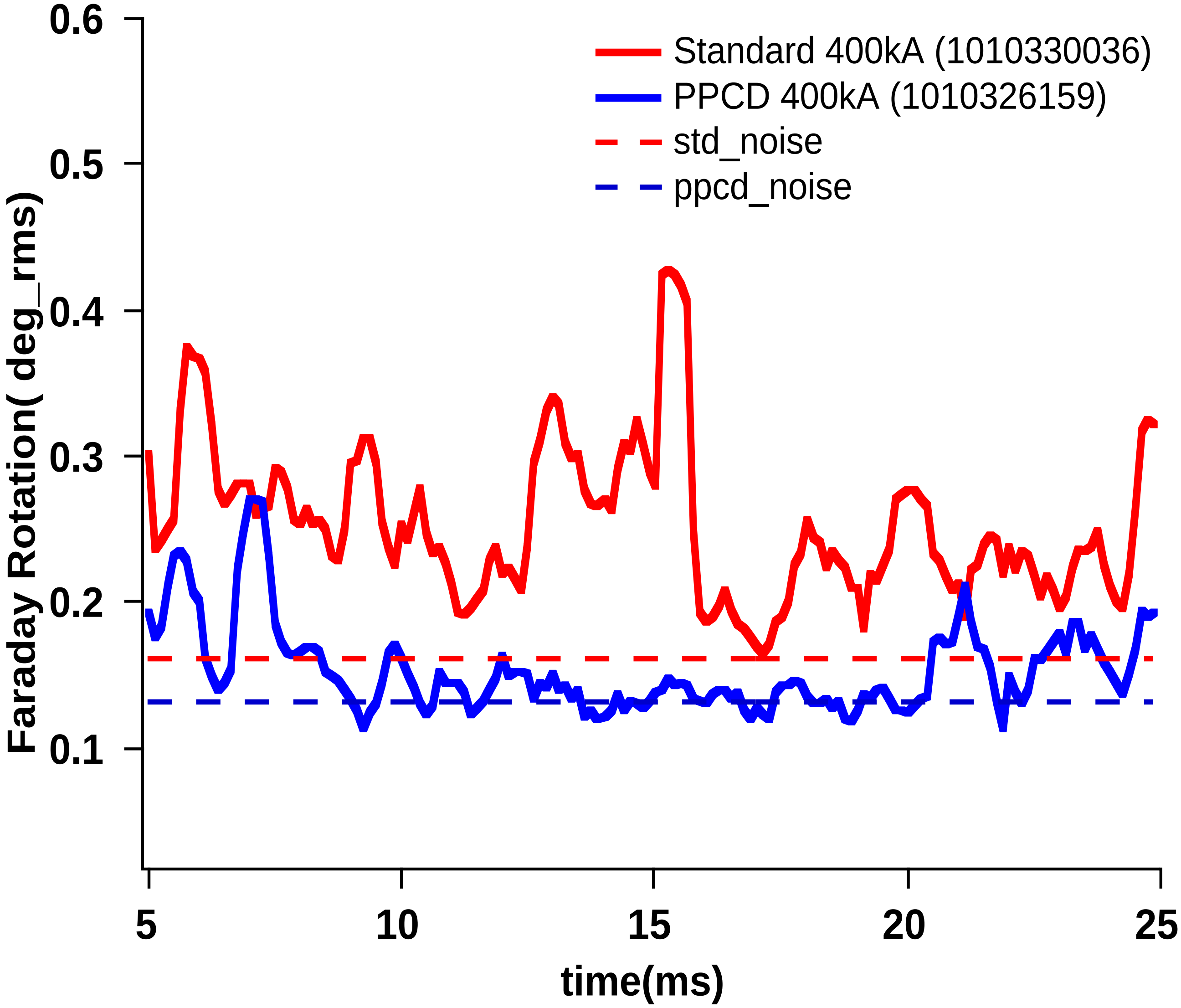
Br fluctuations vs time



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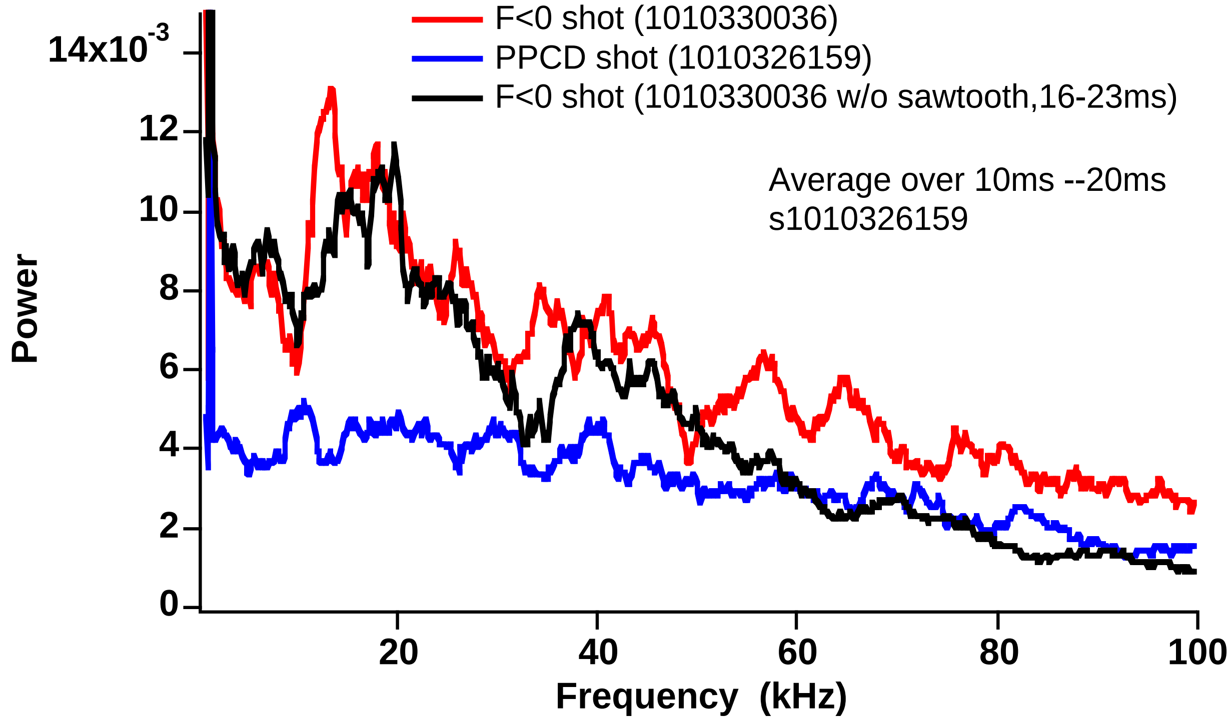
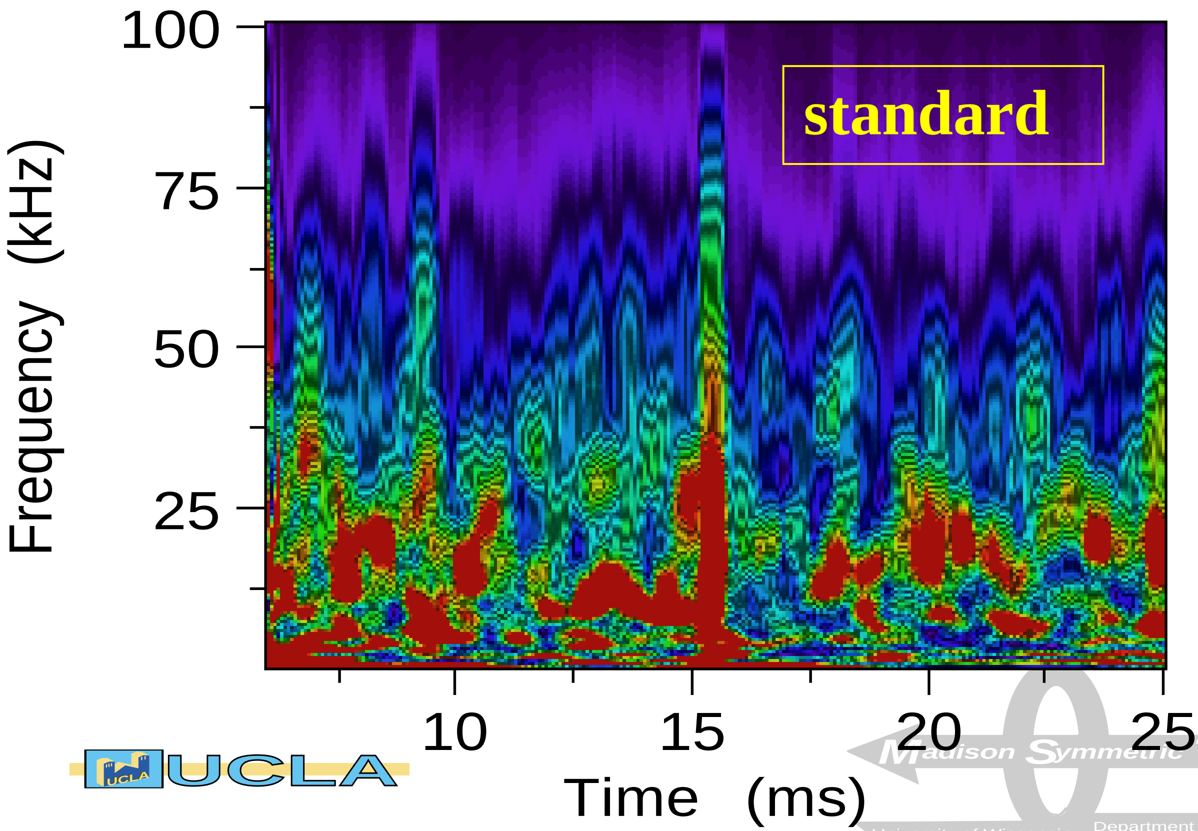
Magnetic Fluctuation B_r Spectrum





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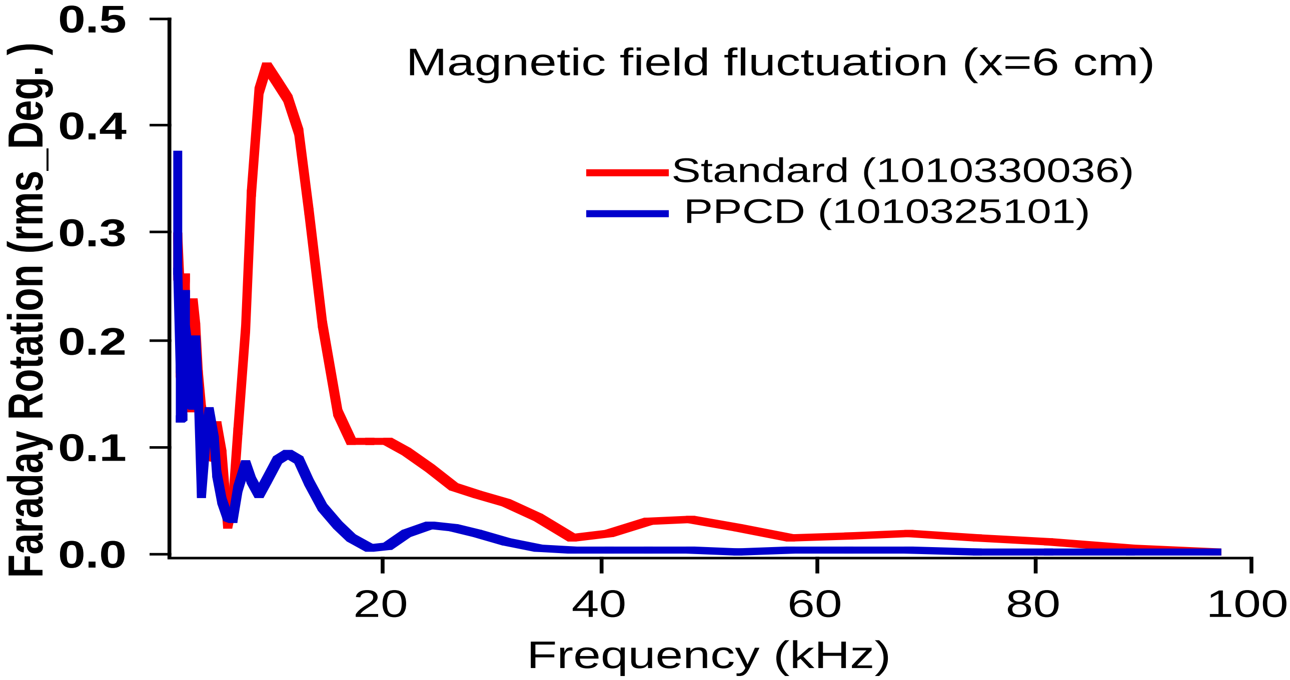
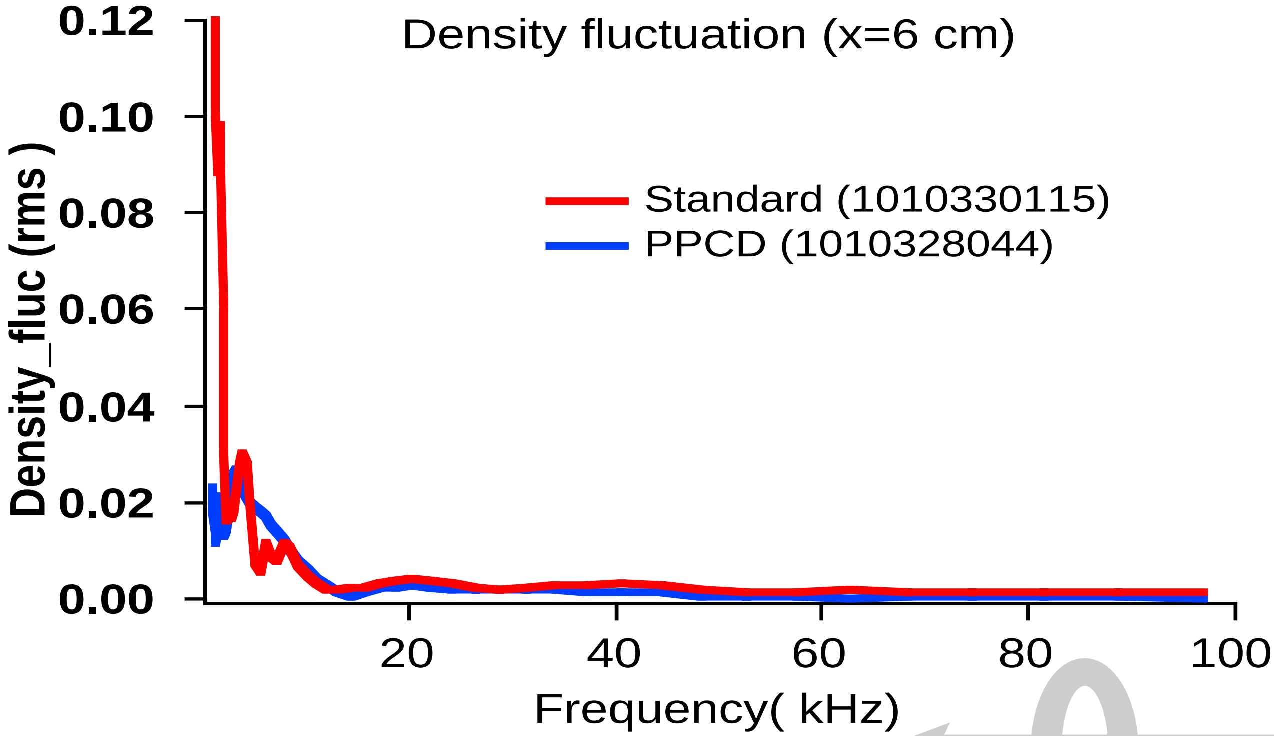
Magnetic Fluctuation Reduction during PPCD





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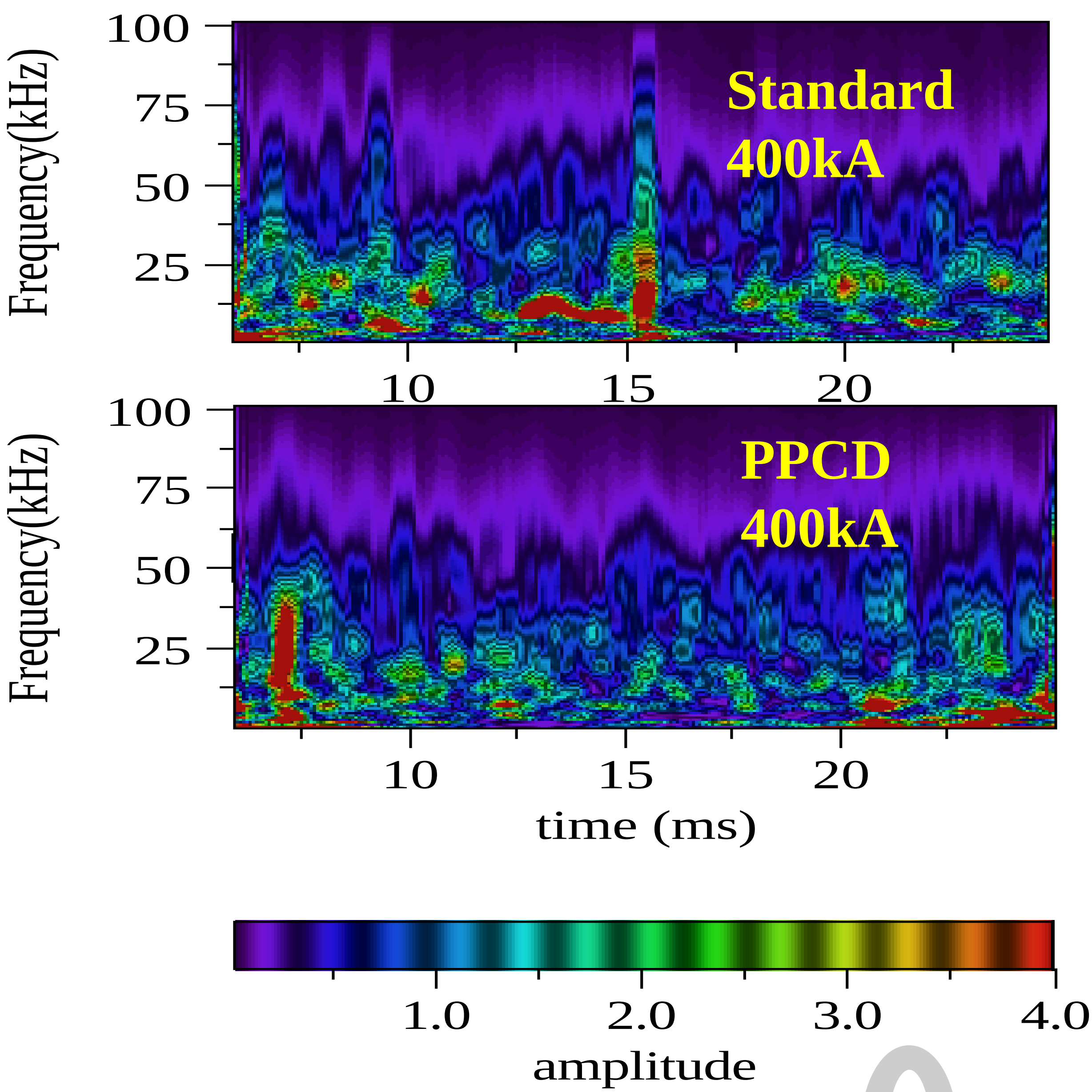
Magnetic Fluctuation Spectra



Summary

- **Fast-polarimeter has 4 μs time response and 0.05° phase resolution.**

- **Internal radial magnetic field fluctuations are measured.**

$$\frac{\tilde{B}_r}{B_0} = 1\% \left(\tilde{B}_r = 33\ G, rms \right)$$

- **Internal magnetic field fluctuations are significantly reduced during a high confinement PPCD plasmas.**

$$\tilde{B}_r \downarrow 75\%$$

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Future Work

- **Measurement of dynamics of current density profile J(r,t) in MST with Sawteeth, PPCD, OFCD, pellets, etc.**

- **MHD stability studies:** $J(r,t) \Rightarrow \tilde{B}$

- **Extract** $\tilde{B}$ **information from all chords**
- **Core transport** $\langle \tilde{n}\tilde{B}_r \rangle, \langle \tilde{J}_\parallel \tilde{B}_r \rangle$
- **Core dynamo studies:**

$$\langle \tilde{v}_\theta \tilde{B}_r \rangle \Rightarrow toroidal \ \ electric \ \ field$$

$$\langle \tilde{v}_\phi \tilde{B}_r \rangle \Rightarrow poloidal \ \ electric \ \ field$$