High Temporal Resolution Polarimetry on the MST Reversed Field Pinch

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Abstract

The 11 channel far-infrared polarimeter on MST is being modified to reduce the time response from 100 to 10 μsec in order to permit high time resolution measurement of the poloidal magnetic field and toroidal current density profiles. Changes in the Faraday rotation profile associated with fast events like the sawtooth crash can then be temporally resolved. Initial polarimetry measurements indicate a broadening of the current density profile and increase in q_o after the sawtooth crash. In addition, direct measurement of magnetic fluctuations associated with global tearing modes [5-30 kHz] will also be possible. The effect of these modes on the plasma density is already clearly resolved and provides insight into the dynamics of these structures. Improved time response is achieved by replacing the mechanical spindle bearing[1 kHz] which rotates the laser polarization with an added laser beam. High speed polarization rotation is realized by combining two circularly-polarized, orthogonal far-infrared laser beams with intermediate frequency of 250 kHz. This change will improve the system signal levels, reduce phase noise [on the interferometer and polarimeter], as well as increase time response. The phase between the probing beams is recovered by use of a digital complex phase demodulation algorithm. System calibration and first experimental results will be presented.

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Introduction

- **MST is a toroidal reversed-field pinch [R=1.5 m, a=0.52m, Ip=200-600 kA].**

- **Improvement of MST energy confinement is achieved by the current density profile control to suppress global tearing modes.**

- **Measurement of current density profile by polarimetry will play an important role in further improving MST plasma confinement through understanding stability and transport.**

Polarimeter Upgrade

- **Replace mechanical λ/2-plate rotator with 3- λ laser**
- **Requires adding a 3rd FIR laser cavity**
- **Detection scheme remains unchanged**
- **Benefits**

  - polarimeter and interferometer phase noise reduced

  - polarimeter time response reduced from 1000 to 10 μsec,

  can measure

  *** tearing modes [5-30 kHz]**

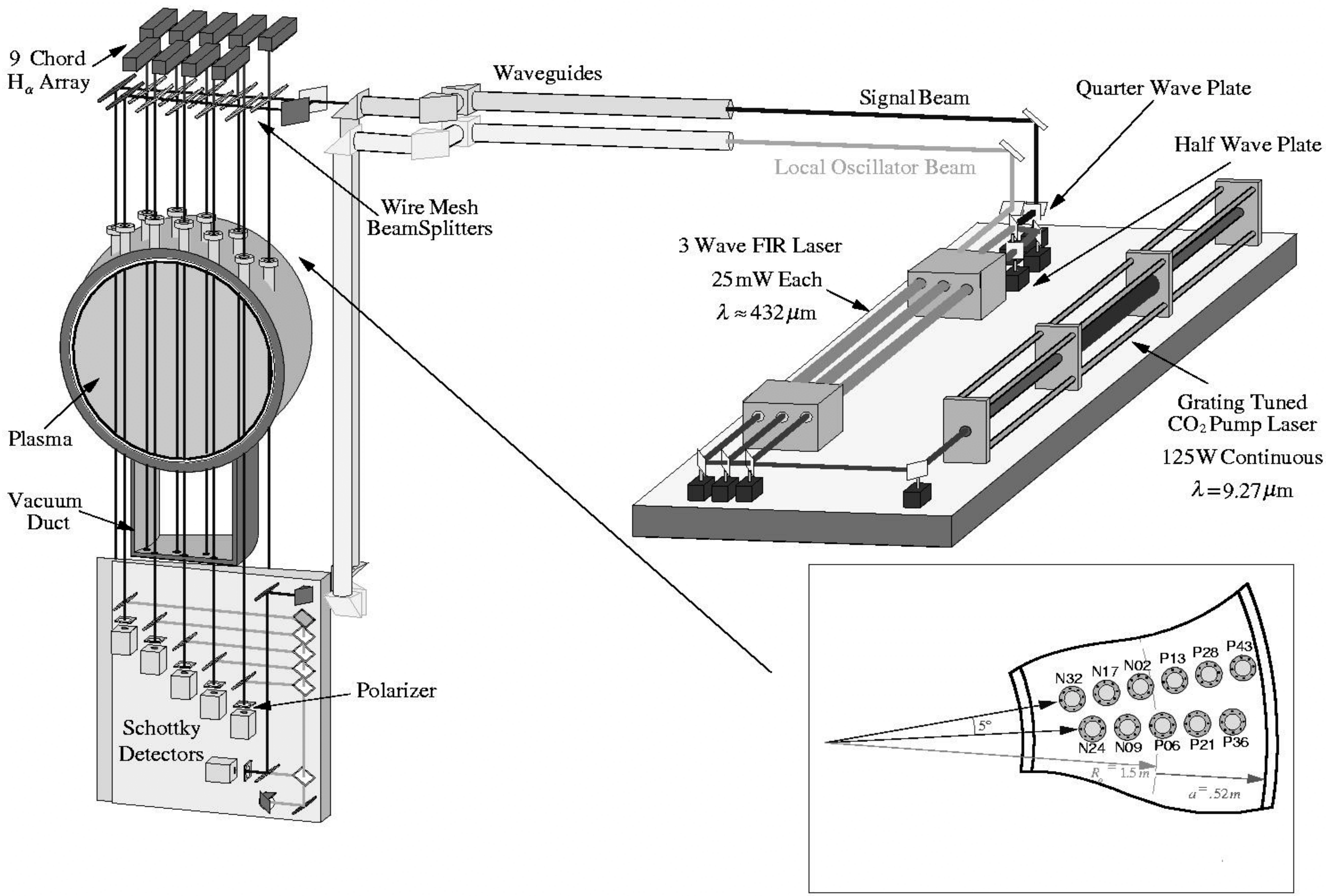
  *** current profile changes during dynamo**

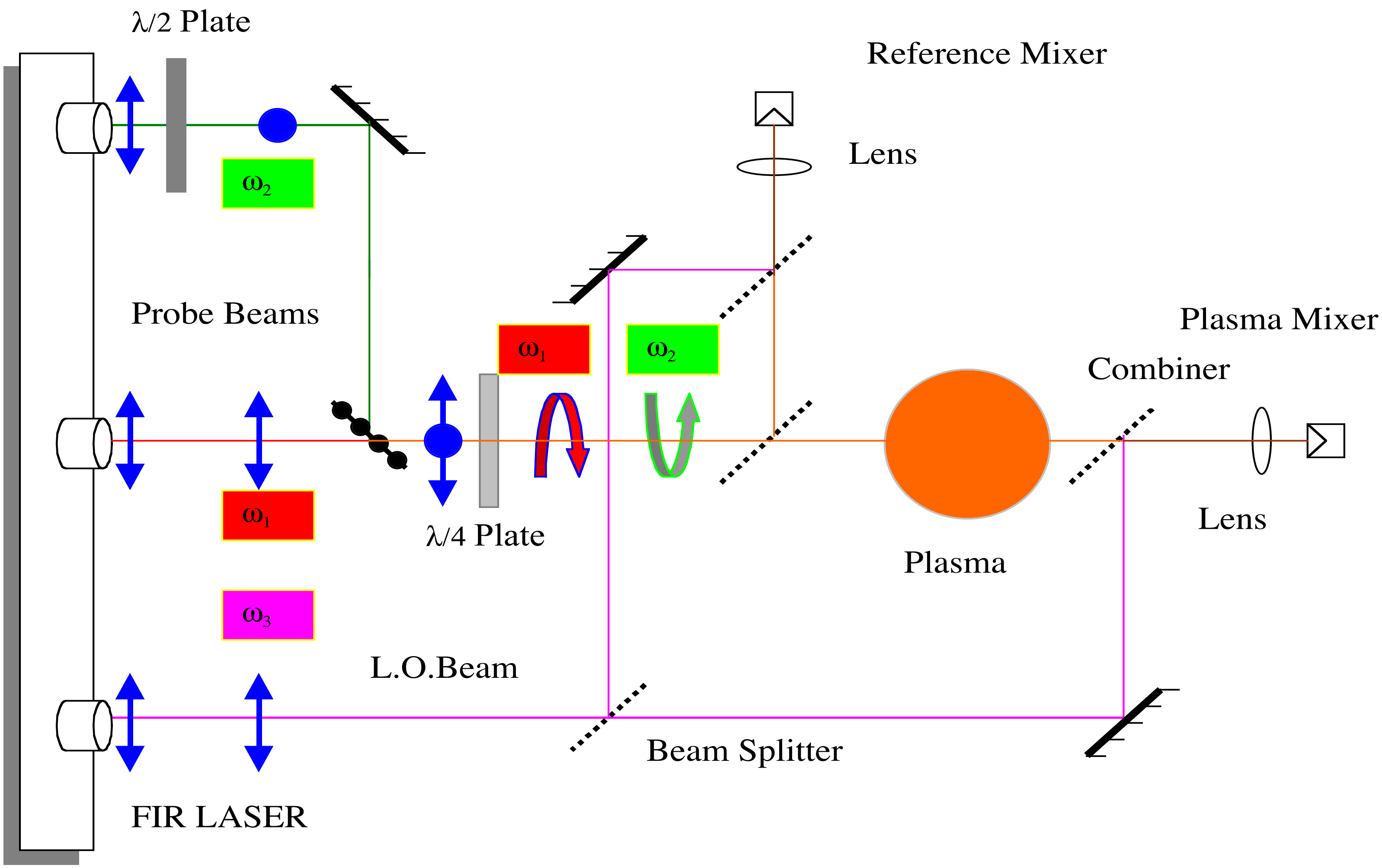
  - increased signal levels due to removal of 'lossy' mechanical rotator

3-λ Laser Technique

- 3 FIR lasers with fixed frequency offsets
- Mixing products
  - probe 1 with LO beam
  - probe 2 with LO beam
  - probe 1 and probe 2
- Phase difference between probe 1 and 2 is directly proportional to the Faraday rotation angle
- Faraday rotation can also be determined from the difference between the probe-LO mixing products
- Interferometer phase is the average of the two probe-LO mixing products

MST Far-Infrared Polarimeter-Interferometer System



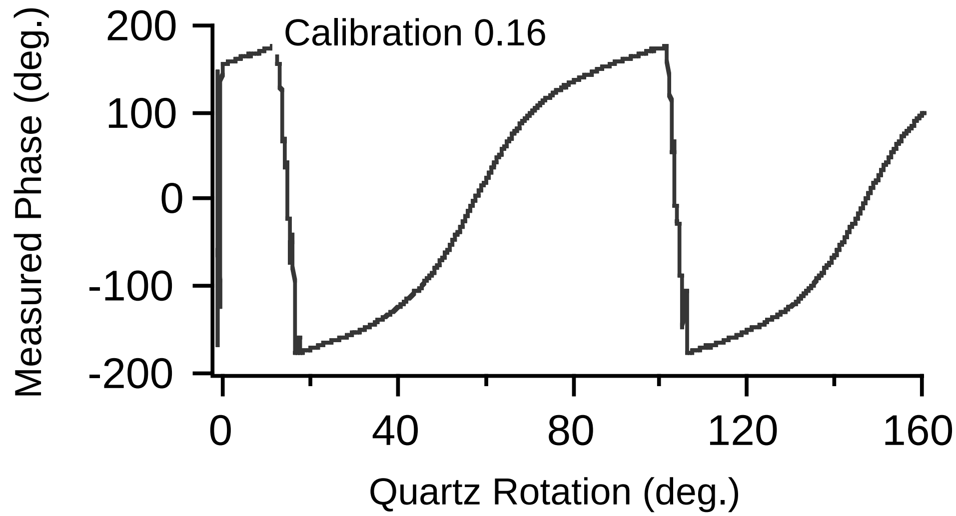


λ/2 Plate
Reference Mixer
Lens
ω2
Probe Beams
ω1
ω2
Plasma Mixer
Combiner
λ/4 Plate
ω1
Plasma
Lens
ω3
L.O.Beam
Beam Splitter
FIR LASER

Polarimetry Calibration

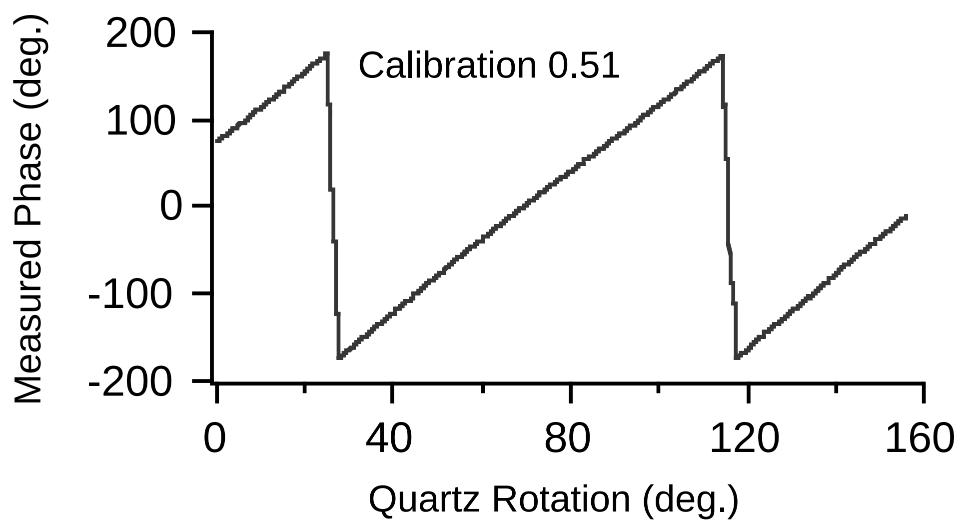
- Beamsplitter polarization sensitive reflection and transmission properties requires calibration
- Polarimetry calibration is done by placing a rotating half wave plate in the probe beam path.
- Phase difference between probing beam and reference beam is calculated by digital phase comparator (DPC)
- Calibration factors result from fitting experimental curves for different channels.

Polarimeter Calibration

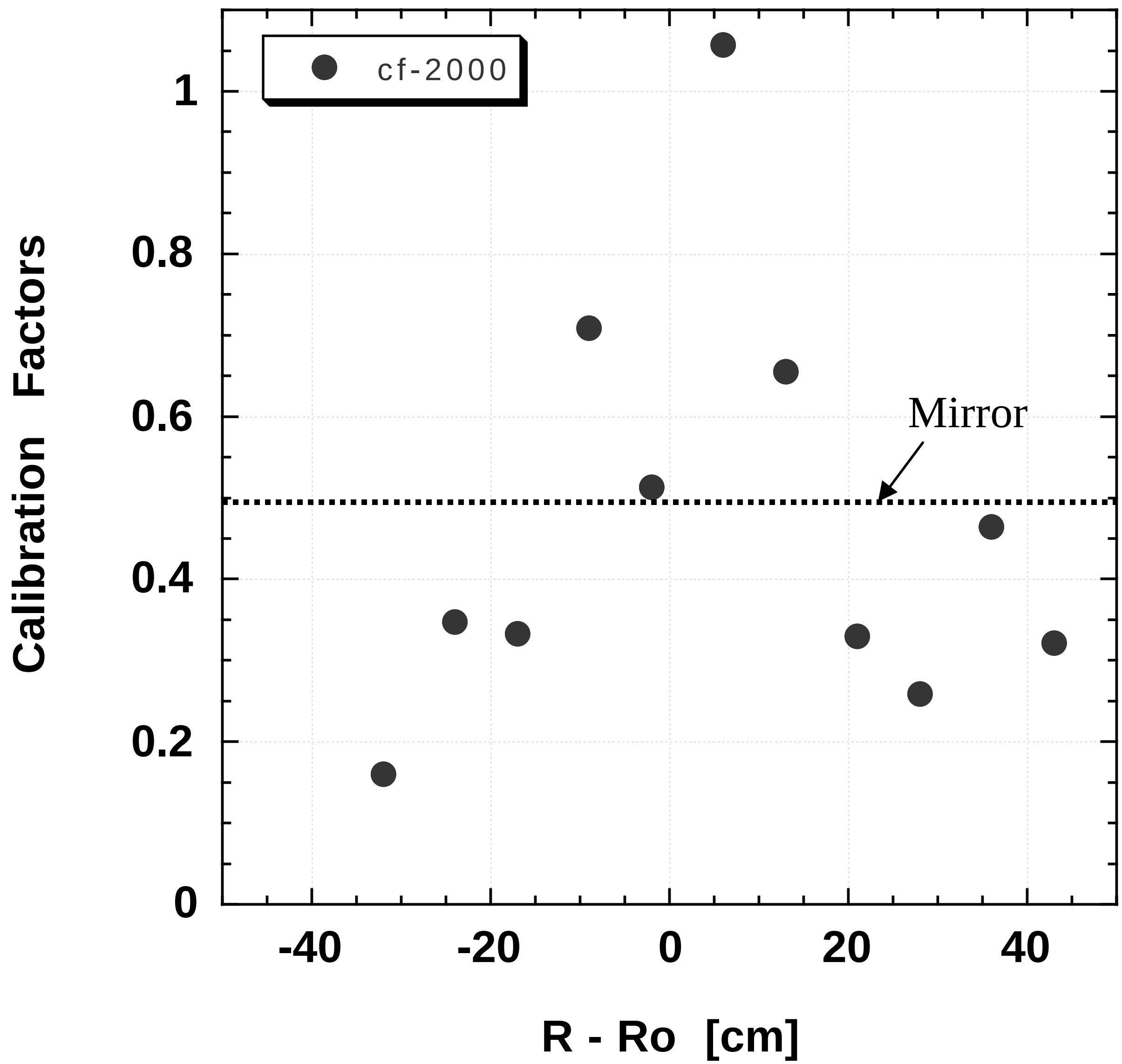


R-Ro = -32 cm

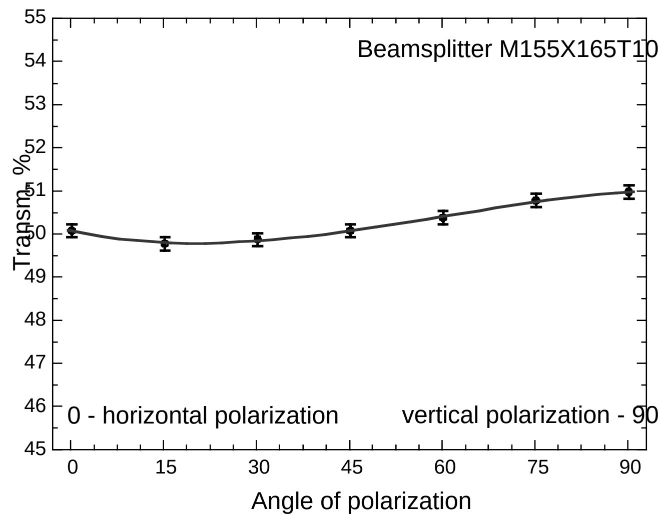
R-Ro = -2 cm



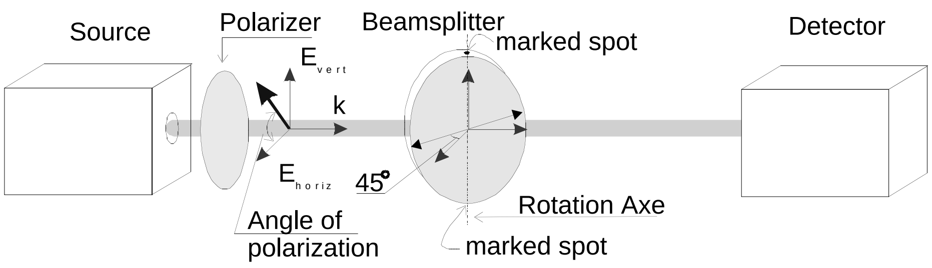
Calibration Factors



Beamsplitter f=639.4 GHz (λ=0.4325mm)



Dependence of transmissivity vs. Angle of polarization.



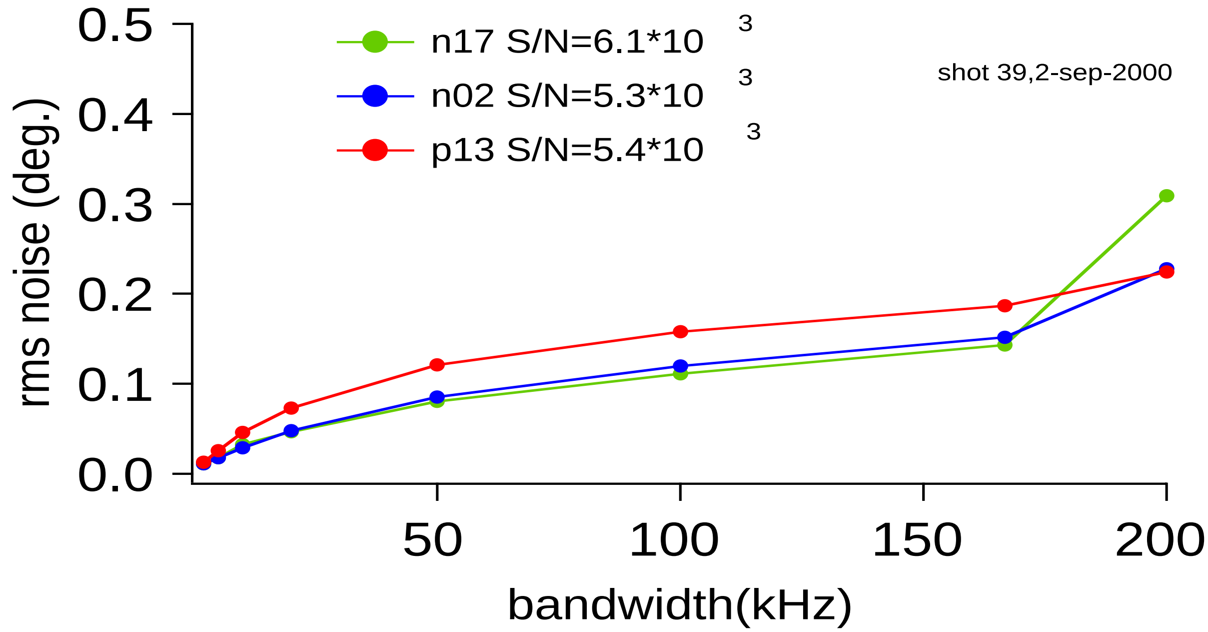
Scheme of measurement

The instruction of the beamsplitter (BS) appliance:
In order to get 50% transmittance it is necessary to install the BS-plane in the optical path with the angle 45° relatively the incidence beam. The 45° rotation of the BS must be done around the rotation axe marked out on the two opposite sides of the BS ring by two marked spots.

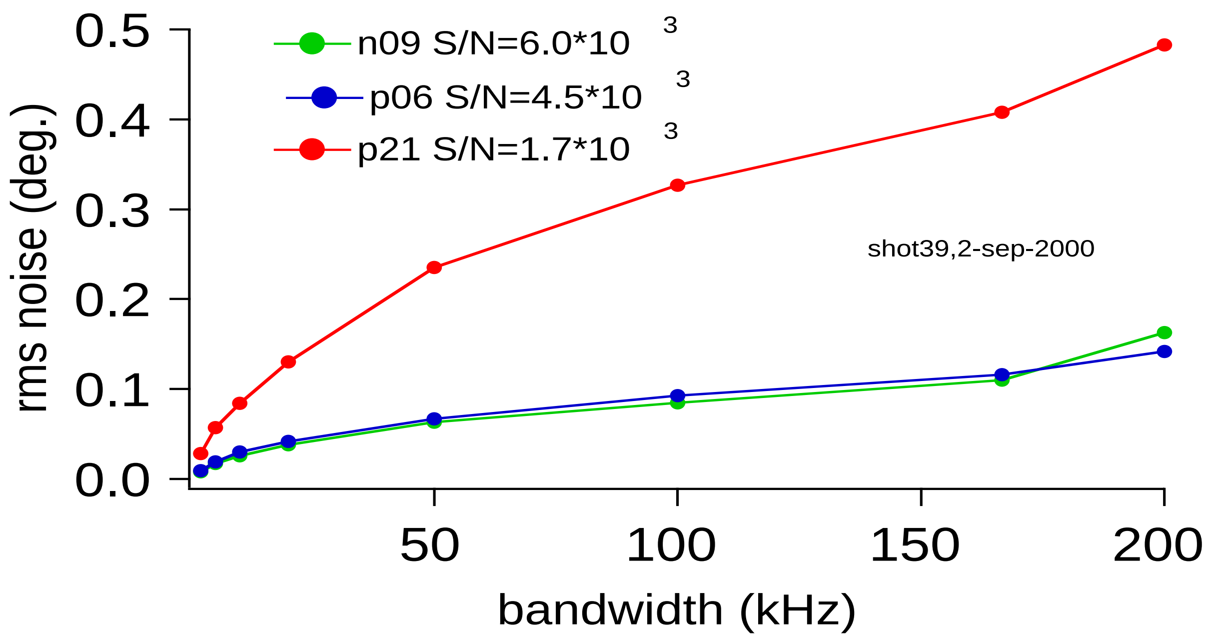
Polarimetry Phase Noise

- Fast polarimetry phase noise (rms noise) depends on system signal-noise ratio (S/N) and bandwidth.

- For bandwidth 2 kHz, phase noise is less than 0.05^0 compared to $0.18^{\,0}$ for slow polarimetry

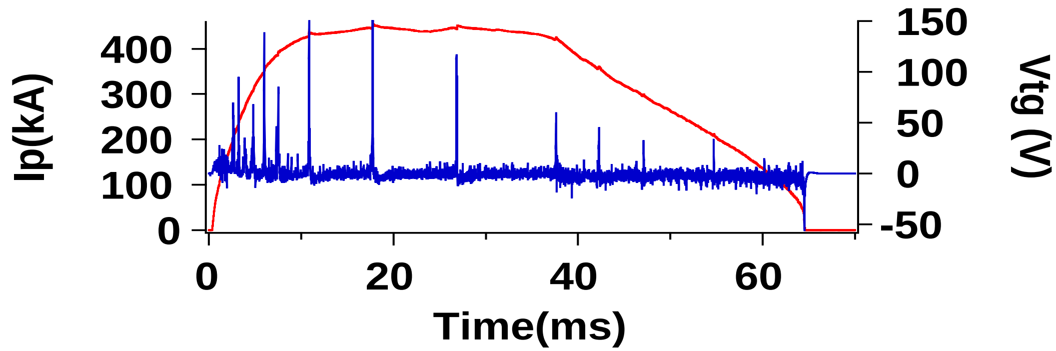


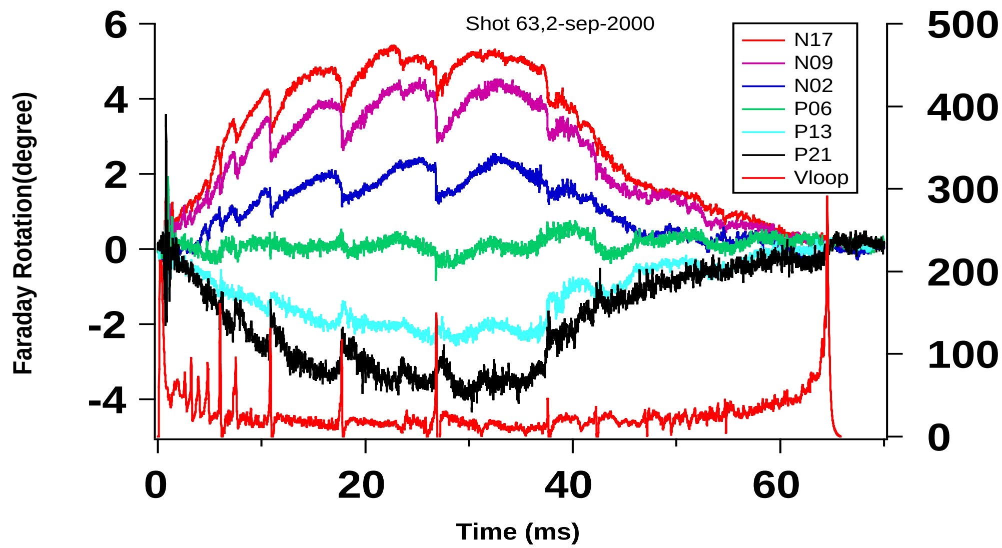
0.5
0.4
0.3
0.2
0.1
0.0
rms noise (deg.)
n17 S/N=6.1*10 3
n02 S/N=5.3*10 3
p13 S/N=5.4*10 3
shot 39,2-sep-2000
50
100
150
200
bandwidth(kHz)



0.5
0.4
0.3
0.2
0.1
0.0
rms noise (deg.)
n09 S/N=6.0*10 3
p06 S/N=4.5*10 3
p21 S/N=1.7*10 3
shot39,2-sep-2000
50
100
150
200
bandwidth (kHz)

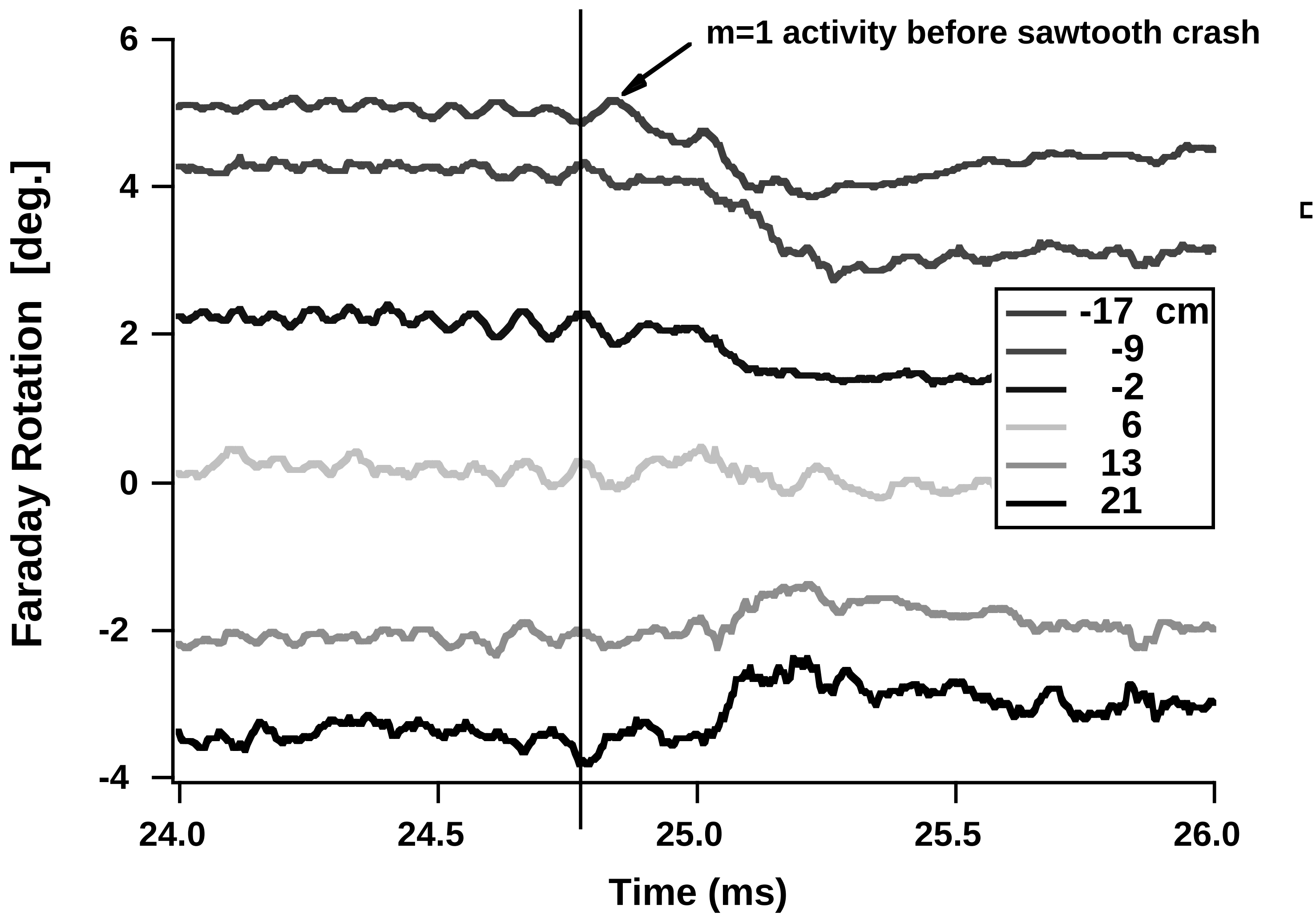
Change with Dynamo: Fast Polarimeter



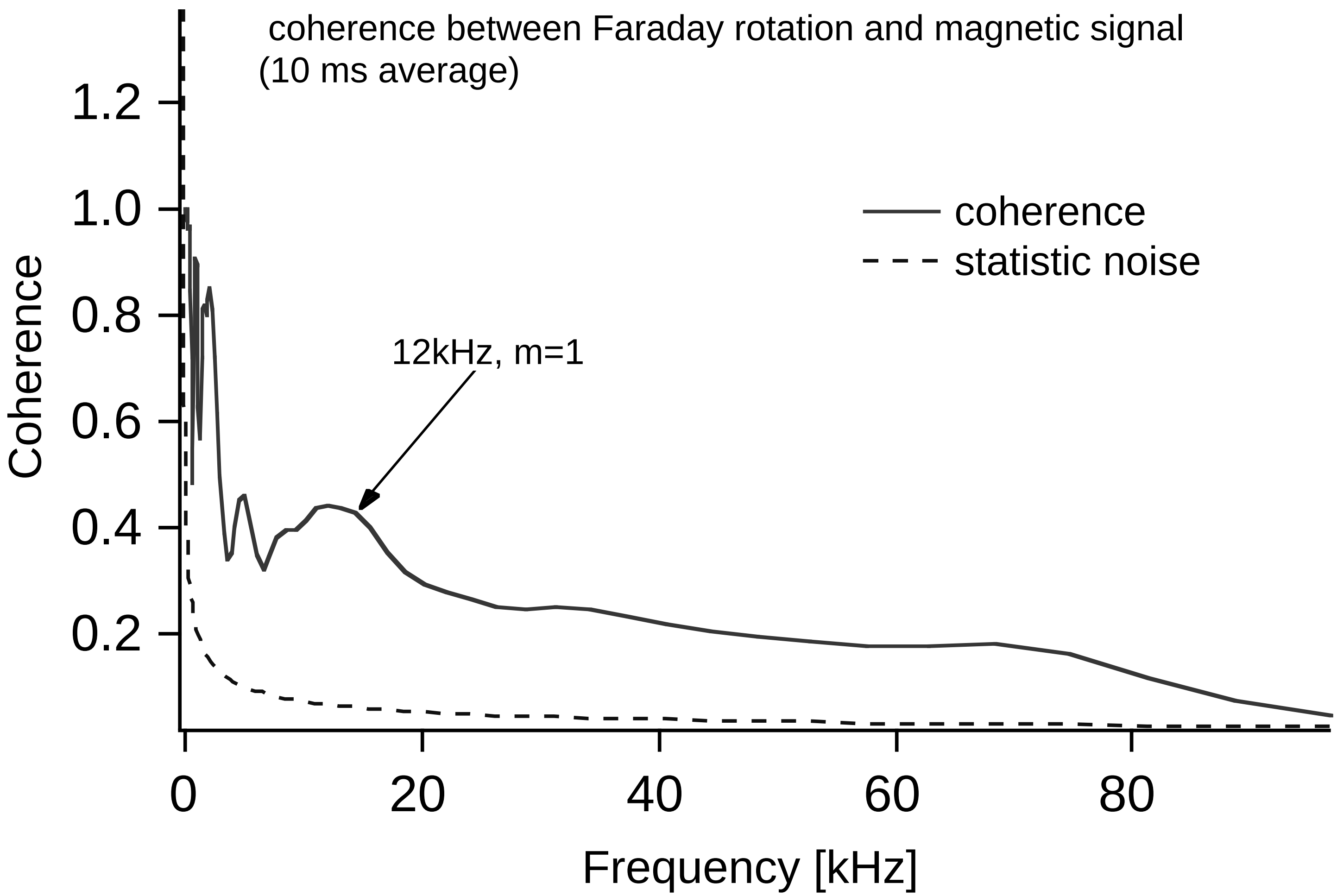


Fluctuation of Faraday rotation is well correlated to sawteeth activity

MHD Activity Observed by Fast Polarimeter



Polarimeter Correlation with Magnetics



Equilibrium ALPHA Model

- The equilibrium $\nabla\times\mathbf{B}=\lambda(r)\mathbf{B}+(\beta/2B^2)\mathbf{B}\times\nabla p$ is calculated approximately by choosing $\lambda=\lambda_0(1-r^\alpha)$ and adjusting the parameters to agree with the measured toroidal plasma current, flux and field at the plasma surface.

- Central current density $\mathbf{J}_0=\lambda_0/\mu_0\mathbf{B}_0$ can be deduced from this model (also called α-Model) .

Current Change during Dynamo from ALPHA Model and [Slow] Polarimeter

$$J(0) = (2/\mu_o a c_p)\,[1/n_e(0)]\; d\Psi/dx$$

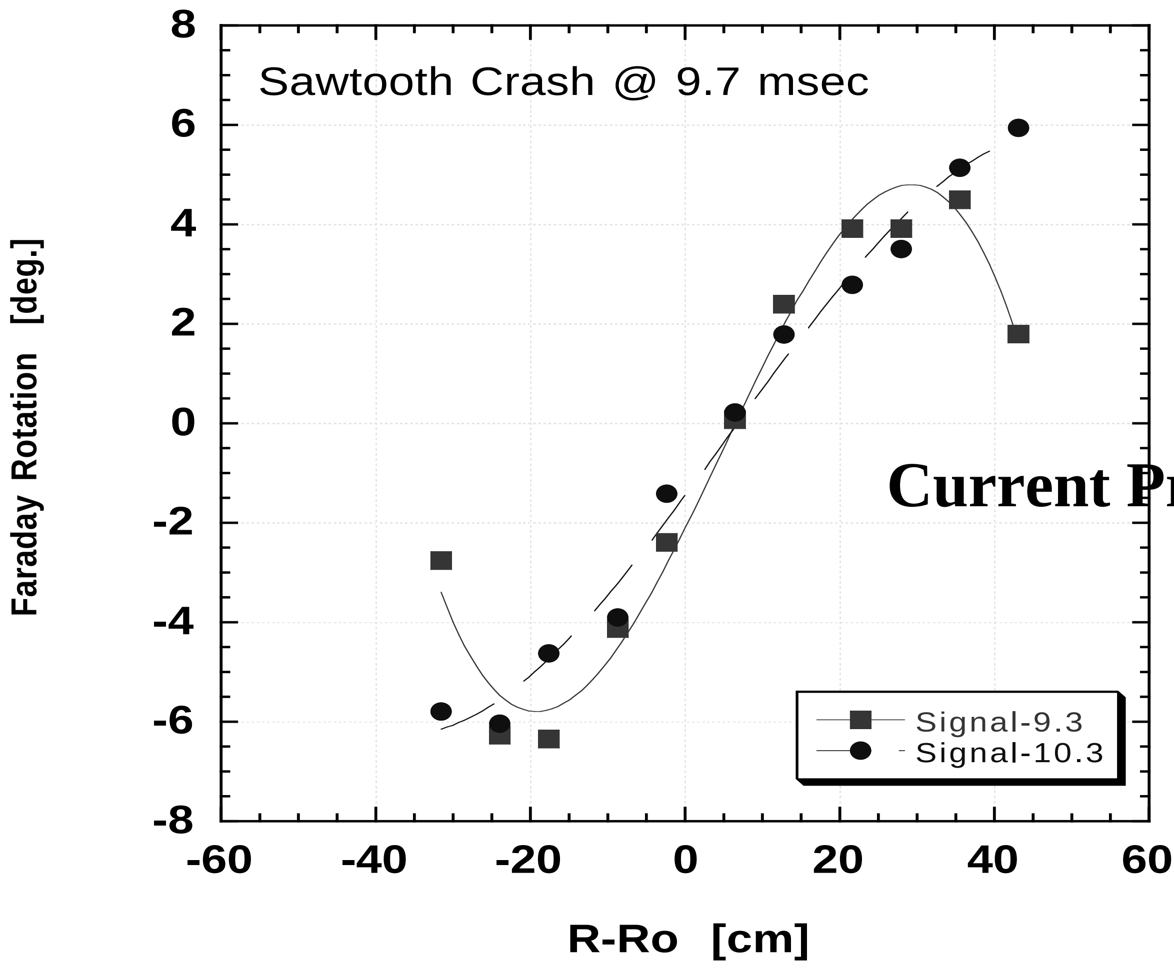
where c_p is a constant

I_p = 430 kA	Before Crash [9.3 msec]	After Crash [10.3 msec]
$n_e(0)$	1.4 (10^{13} cm^{-3})	1.2 (10^{13} cm^{-3})
$d\Psi/dx$	0.31 (deg/cm)	0.21 (deg/cm)
J(0) : meas.	2.5 (MA/m^2)	1.9 (MA/m^2)
J(0) : model	2.6 (MA/m^2)	1.85 (MA/m^2)

When comparing before/after the sawtooth crash:

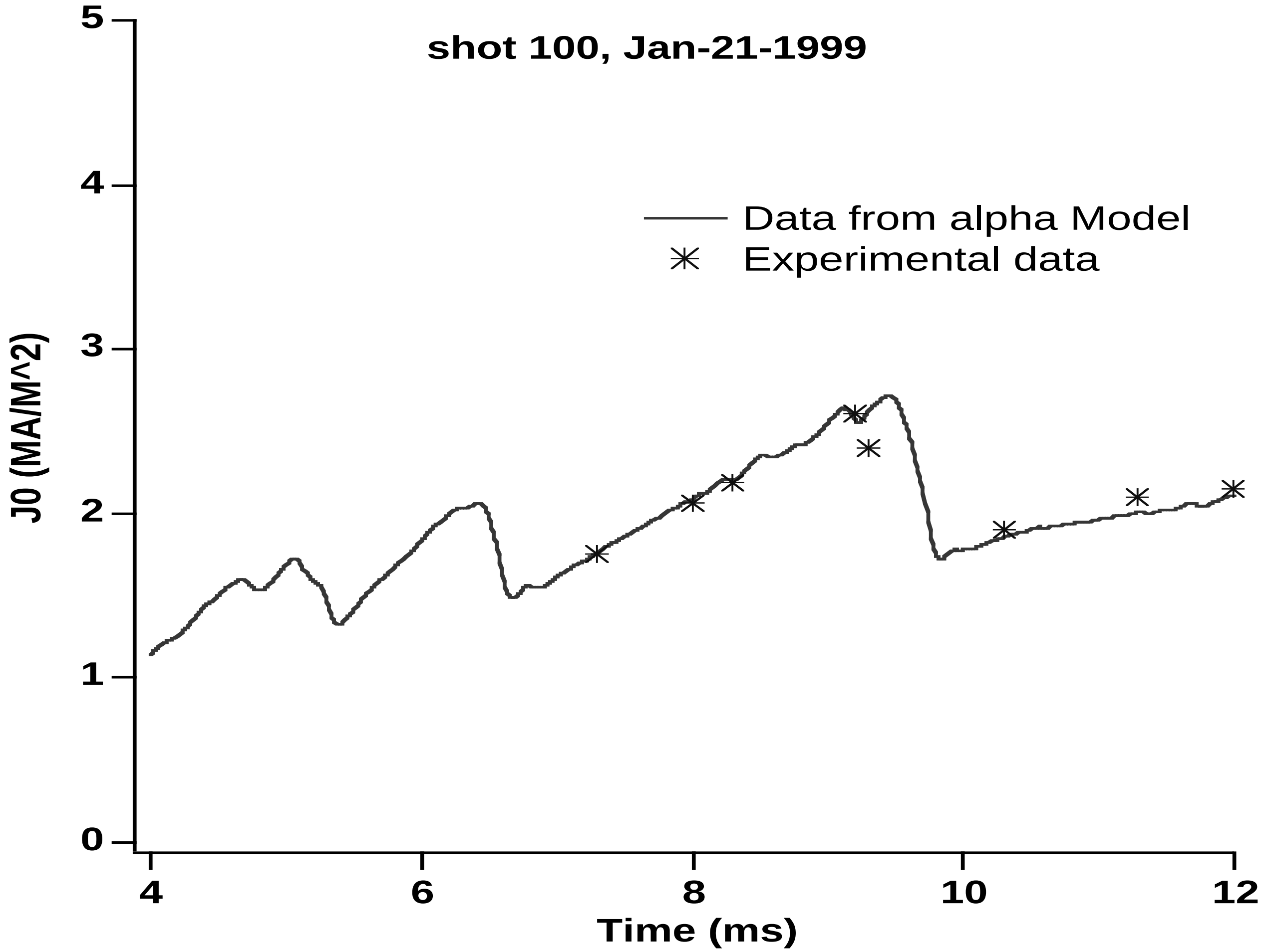
Measurement and ALPHA Model are in agreement

Faraday Rotation Change with Dynamo

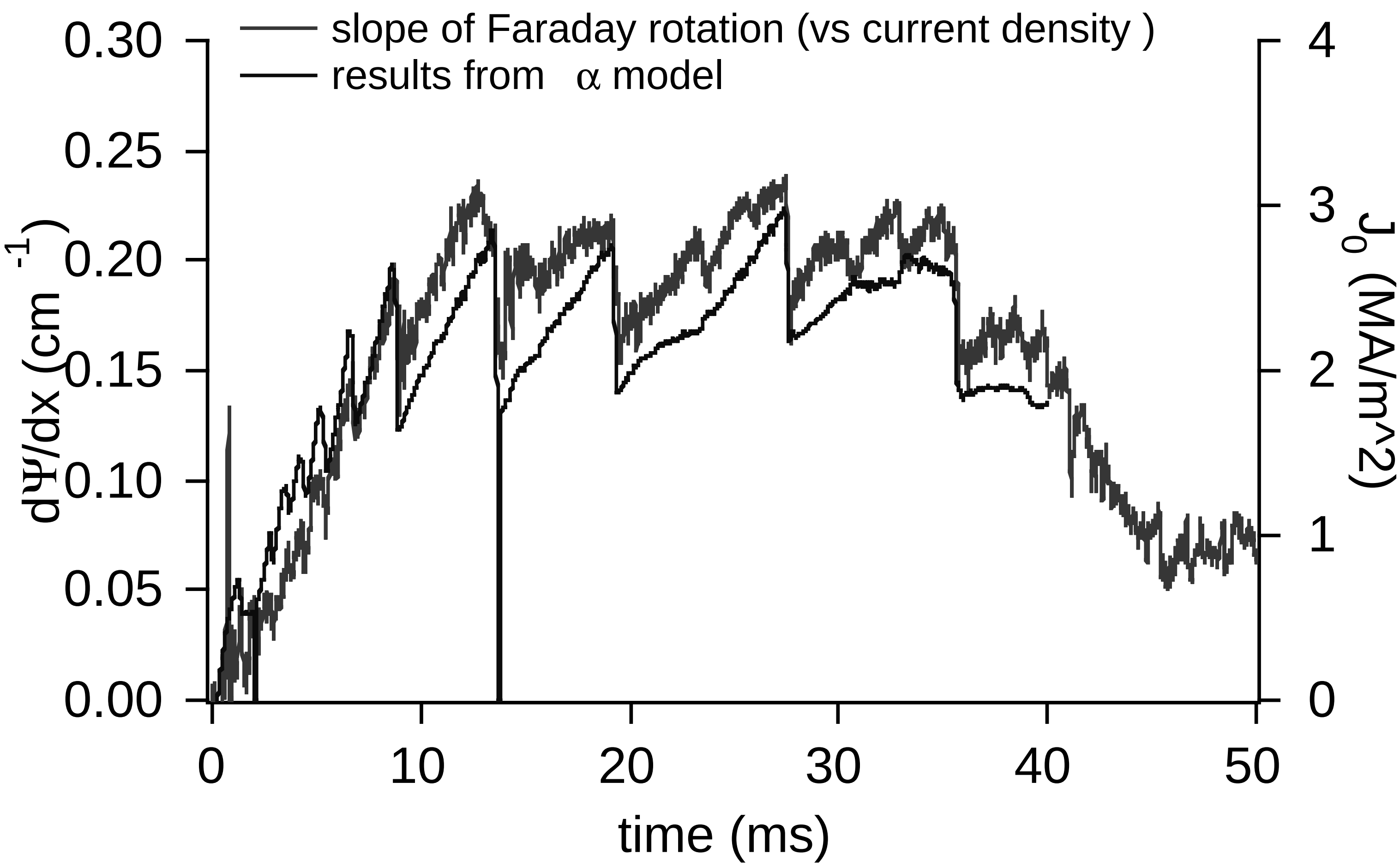


Current Profile Broadens

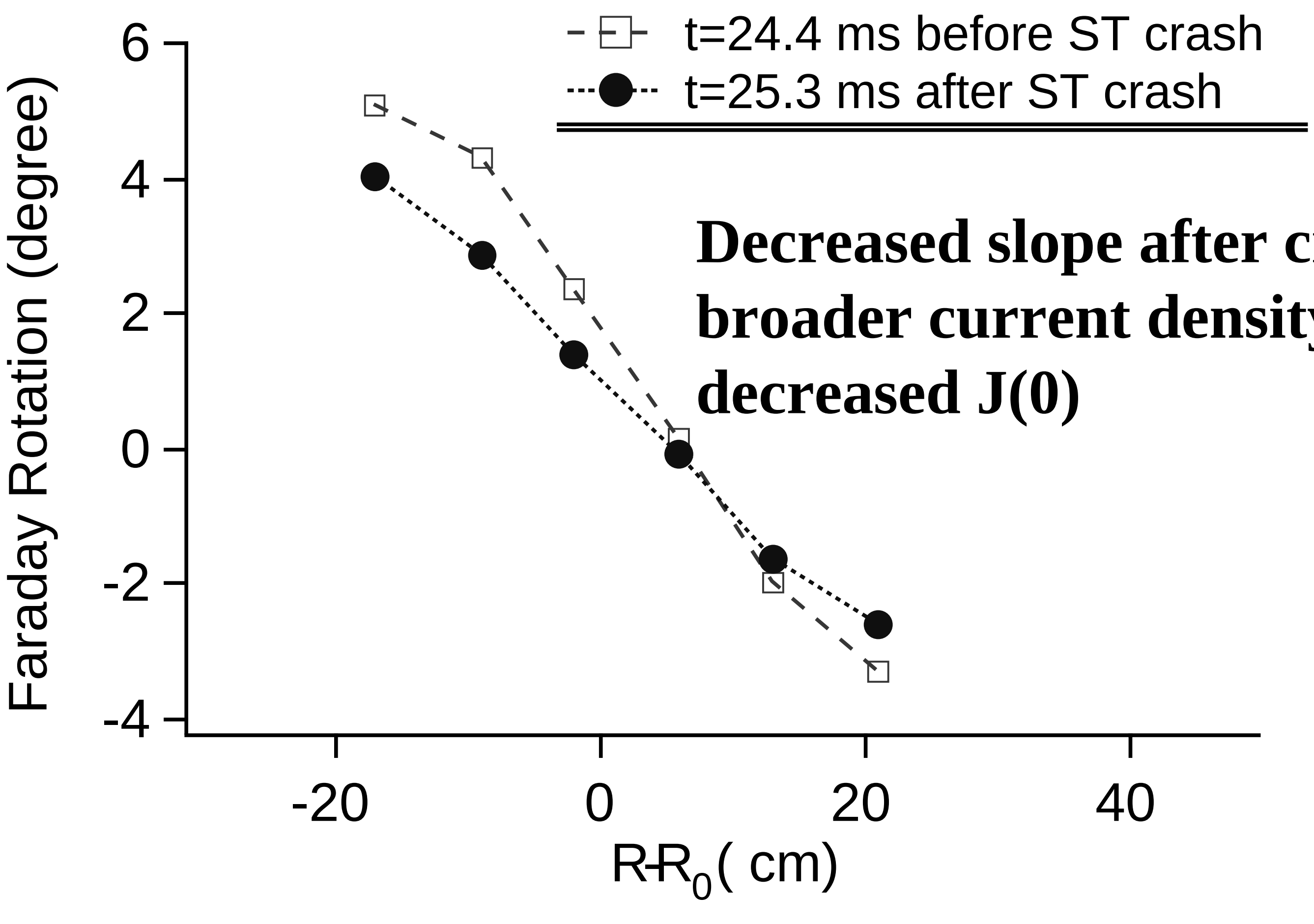
Comparison of Alpha Model with (Slow) Polarimeter Measurments



Fast Polarimetry



Profile Change with Sawtooth



Decreased slope after crash implies broader current density profile and decreased J(0)

Summary

- A high temporal resolution polarimetry system is available on MST. Time response of 10 μs has been demonstrated
- Phase noise of Faraday rotation measurement is less than 0.1 degree with bandwidth 50 kHz.
- The dominant magnetic tearing modes in MST have been observed. Polarimeter correlation with magnetics shows coherence up to 100 kHz.
- Axial current density J_0 measurement is consistent with MST α model calculation.

Future Work

- Expand present 6 channel polarimeter system to 11 channels.
- Install third laser beam as a LO beam so that electron density can be measured simultaneously.0
- Measurement of dynamics of current density profile J(r,t) in MST .