Application of Stark Tuned FIR Laser for Interferometry/Polarimetry on NSTX

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Introduction

- Objective
  - High modulation frequency in laser interferometry/polarimetry
  - First application of the Stark tuned FIR laser
- Principle and frequency modulation technique
  - Principle of interferometry and role of modulation frequency
  - Frequency modulation techniques
  - Stark tuned FIR laser
- Optical configuration and simulation
  - Choice of probe beam wavelength
  - Simulation study
- Status of FIReTIP system on NSTX
  - Experimental results
  - Upgrade plan

Plasma interferometry/polarimetry

- Principle of plasma interferometry/polarimetry

$$\phi(x) = 2.8 \times 10^{-15} \lambda \int_o^x n(x')\,dx'$$

$$\Psi(x) = 2.6 \times 10^{-13} \lambda^2 \int_o^x n(x') B_\Gamma(x')\,dx'$$

- Role of frequency modulation
  - Phase change between [$\cos(\omega_{if}t)$ and $\cos(\omega_{if}t+\phi(t))$], where ω_{if} is the modulation frequency and $\phi(t)$ is proportional to the plasma density

$$\frac{d\phi(t)}{dt} << \omega_{if}$$

  - Long term stability (wide frequency range)

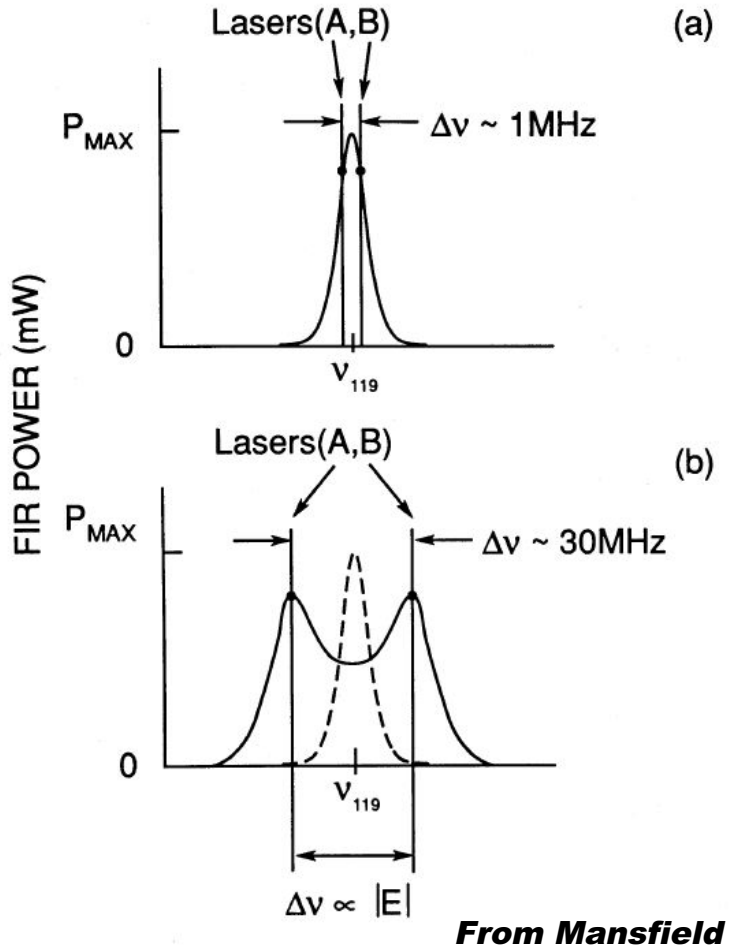
Frequency modulation techniques

- Rotating grating
  - Frequency modulation range
    - 10 kHz ~ 100 kHz
  - Limited by mechanical speed
- Twin lasers
  - Frequency modulation range
    - < 2 MHz
    - Limited by intrinsic narrow laser gain bandwidth (FWHM ~ 5MHz)
- Stark tuned laser
  - Frequency modulation range
    - Up to 30 MHz
  - Modulation frequency is proportional to the applied electric field

Stark effect on CH_3OH laser

- Splitting of gain curves
  - Gain medium is immersed in a uniform electric field
    - Low pumping power: Bionducci, et al., Infrared Phys., ***9***, 297 (1979)
    - High pumping power: Mansfield et al., Applied Optics, ***31***, 503, (1992)
  - Splitting of the Stark components is a function of applied electric field

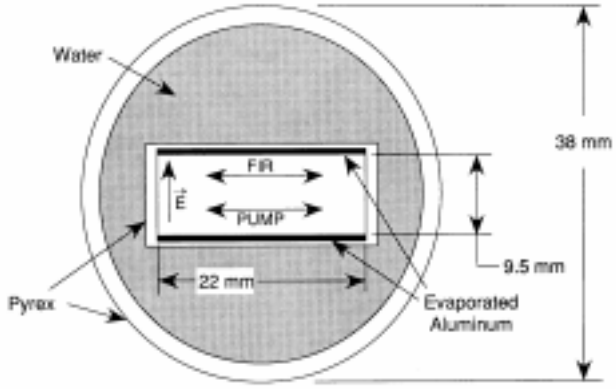
$$\Delta\omega \propto \mu E f(M, J, K)$$

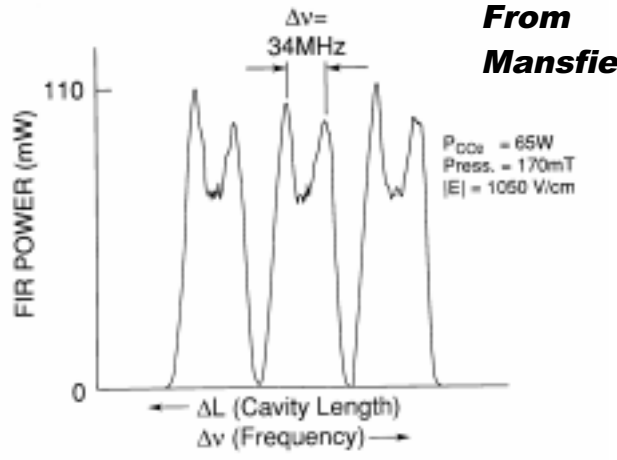


From Mansfield et al.

Stark laser system

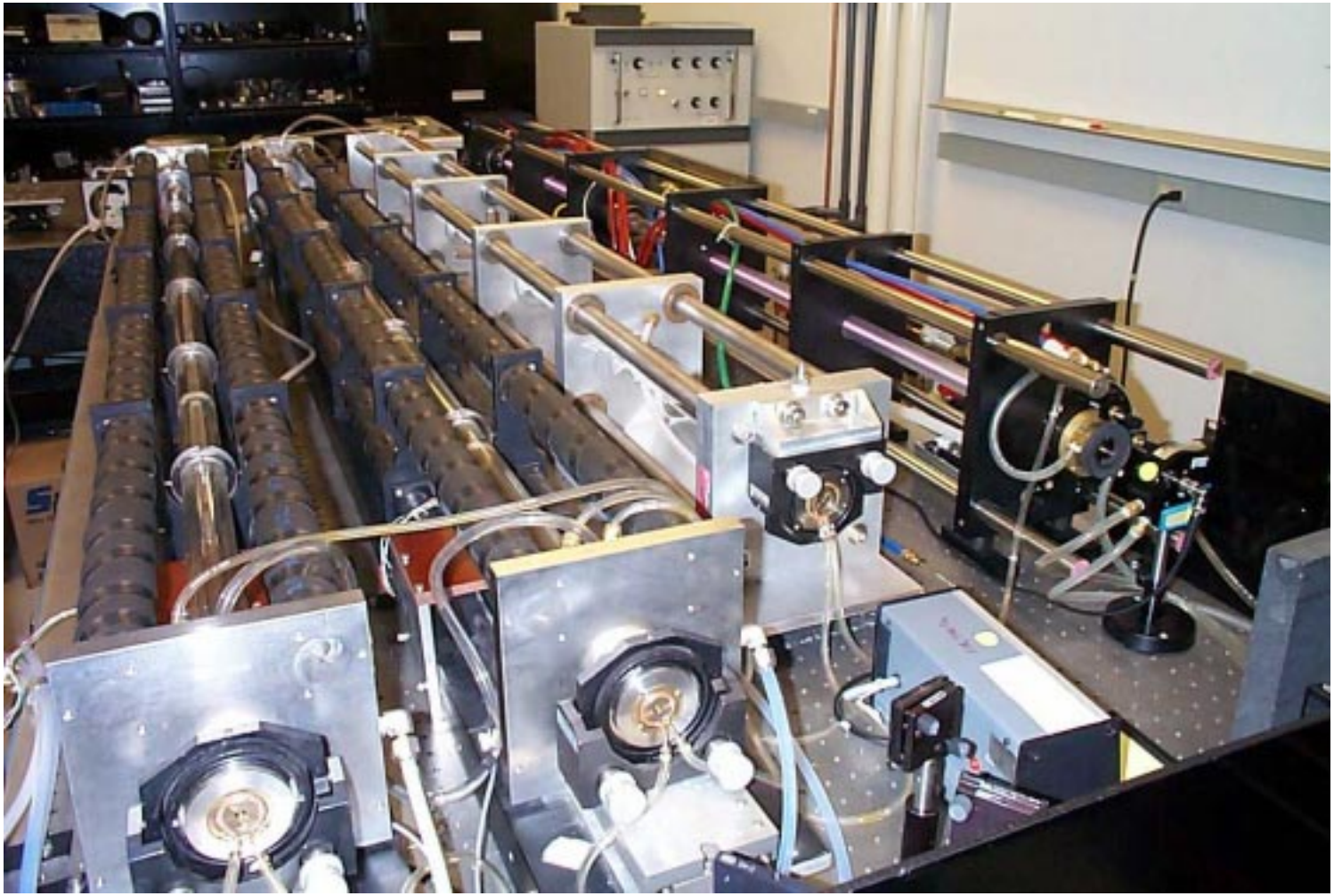
- Input/output characterisitcs
  - CO_2 P36: 20 W
  - Pressure : 50 mT
  - Output power: ~20 mW
- Cavity characteristics
  - Applied voltage: ~400 V
  - Cavity length: ~ 2 m
  - Gap distance: 1 cm
  - Offset frequency : ~7 MHz
- Used as a local oscillator





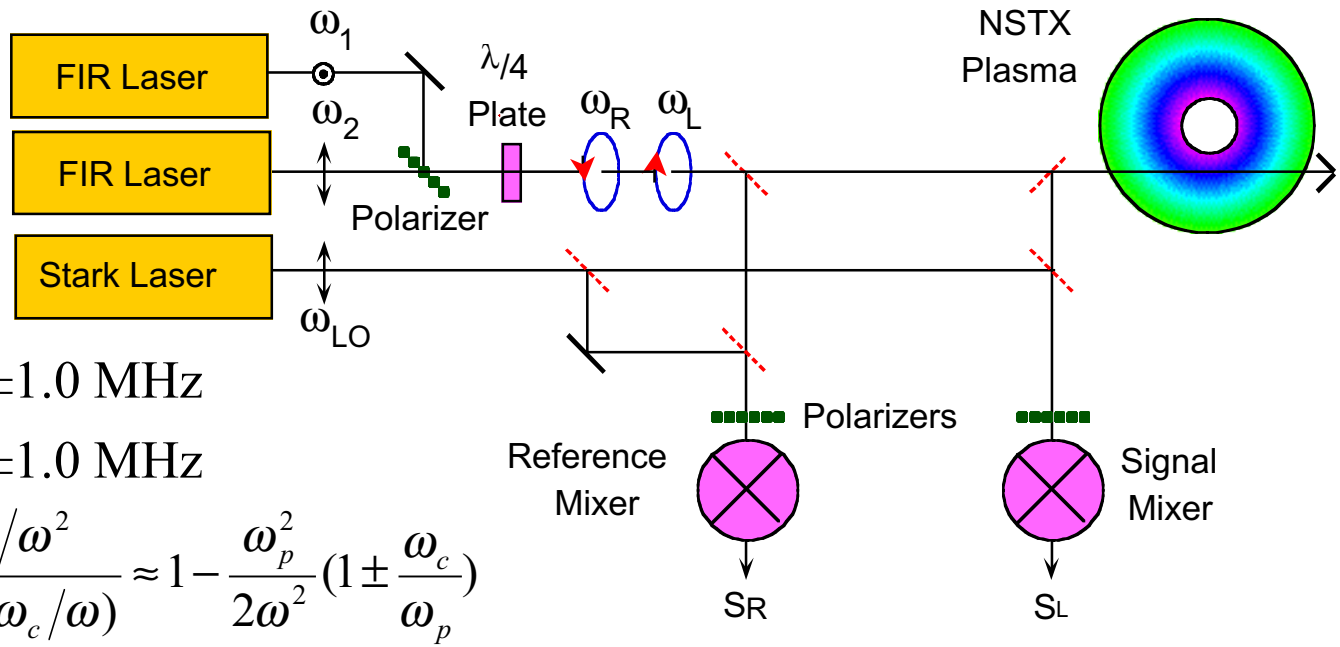
From Mansfield et al.

Three laser system



Schematic for detection system

- The phase difference between the eigen states is twice of the Faraday rotation angle, while the average of the plasma induced phases is the interferometric phase
- Time resolution will be 0.5 MHz (limitation in analog system)



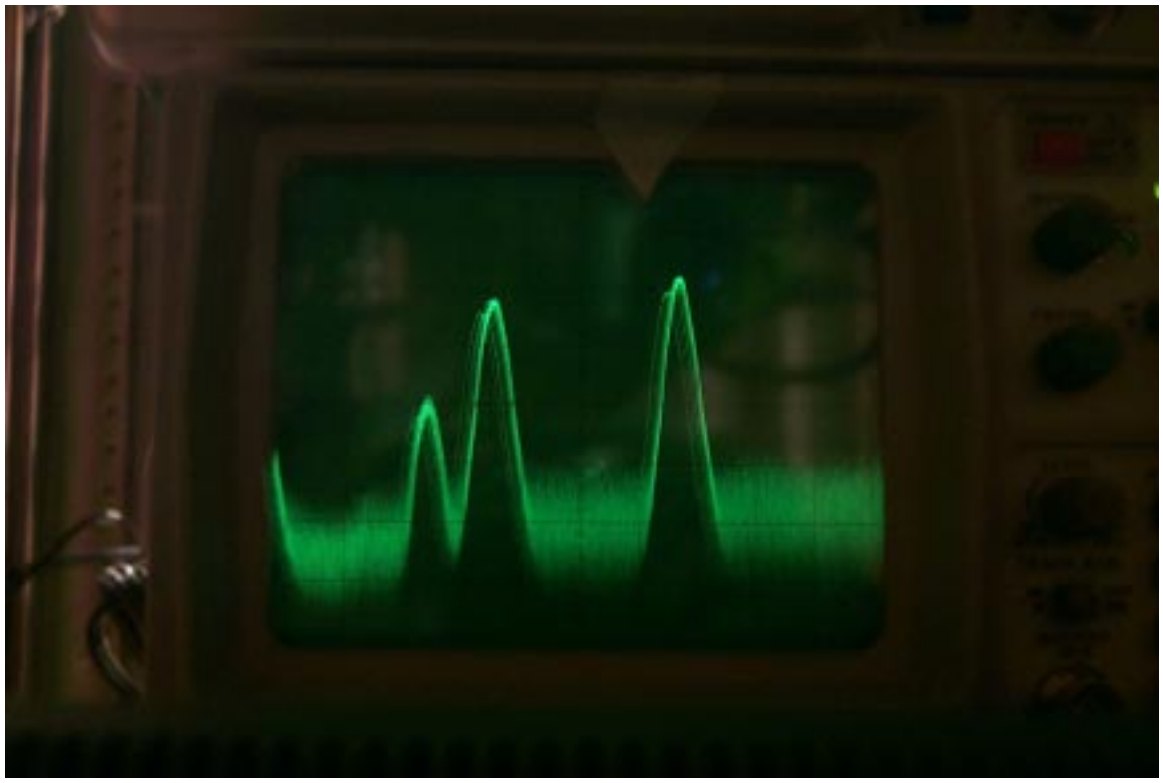
$$\omega_{LO} - \omega_1 = 4.0 \pm 1.0 \text{ MHz}$$

$$\omega_{LO} - \omega_2 = 6.0 \pm 1.0 \text{ MHz}$$

$$N_{R,L} \approx 1 - \frac{\omega_p^2/\omega^2}{2(1 \mp \omega_c/\omega)} \approx 1 - \frac{\omega_p^2}{2\omega^2}\left(1 \pm \frac{\omega_c}{\omega_p}\right)$$

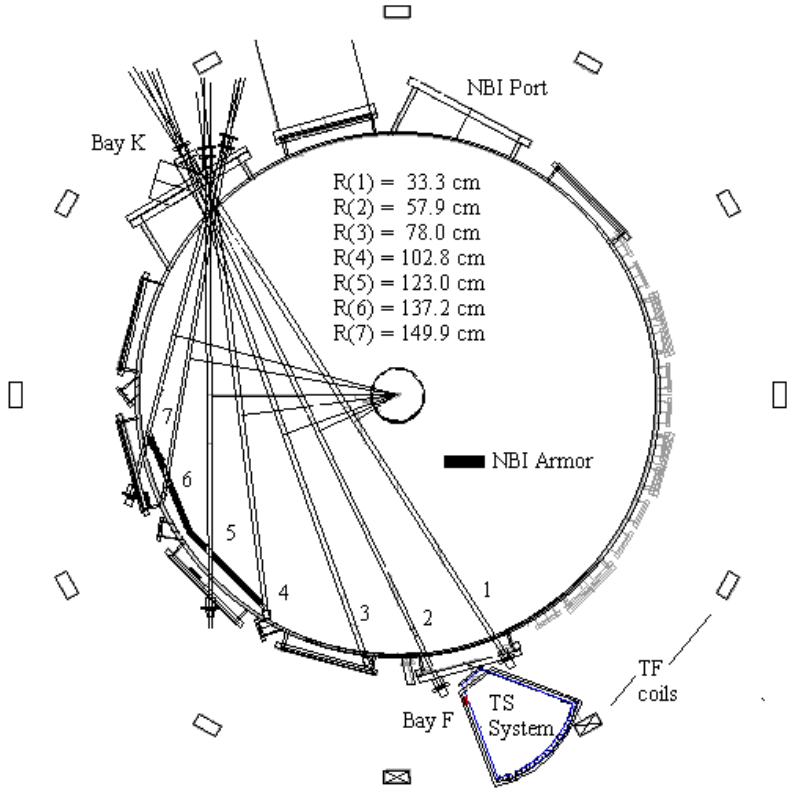
Example of modulation frequencies

- Spectrum analyzer shows the operating laser frequencies
  - Operating frequencies are 7 MHz and 4 MHz



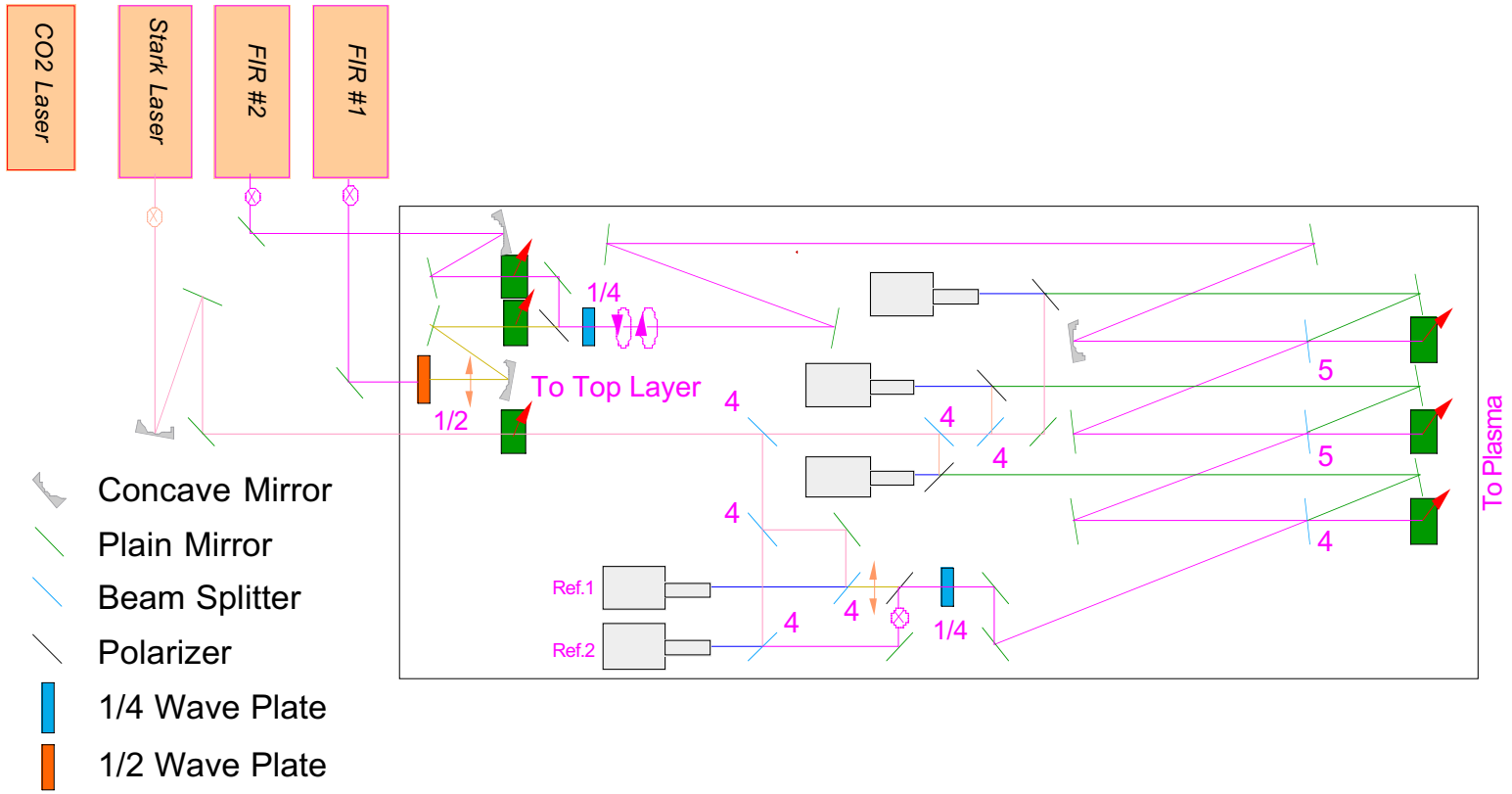
FIReTIP System Configuration

- Seven chords configured as a fan beam Michelson system
- Initial operation was at tangency of 66 cm close to the channel #2
- Retro-reflectors
  - 4 external : real time control signal:
- Windows: crystal quartz (etalon for 119 μm)



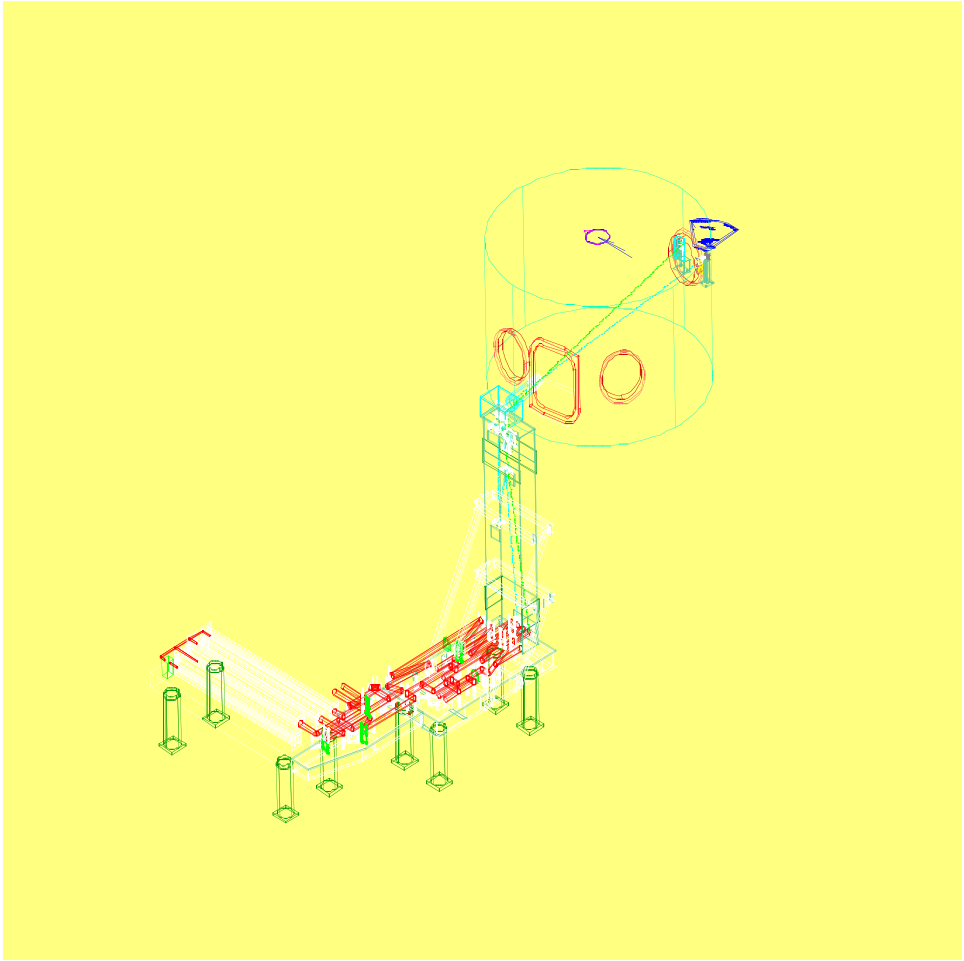
Optical Layout of the FIReTIP System (1)

- Schematic for the first three channel system (Phase 1).



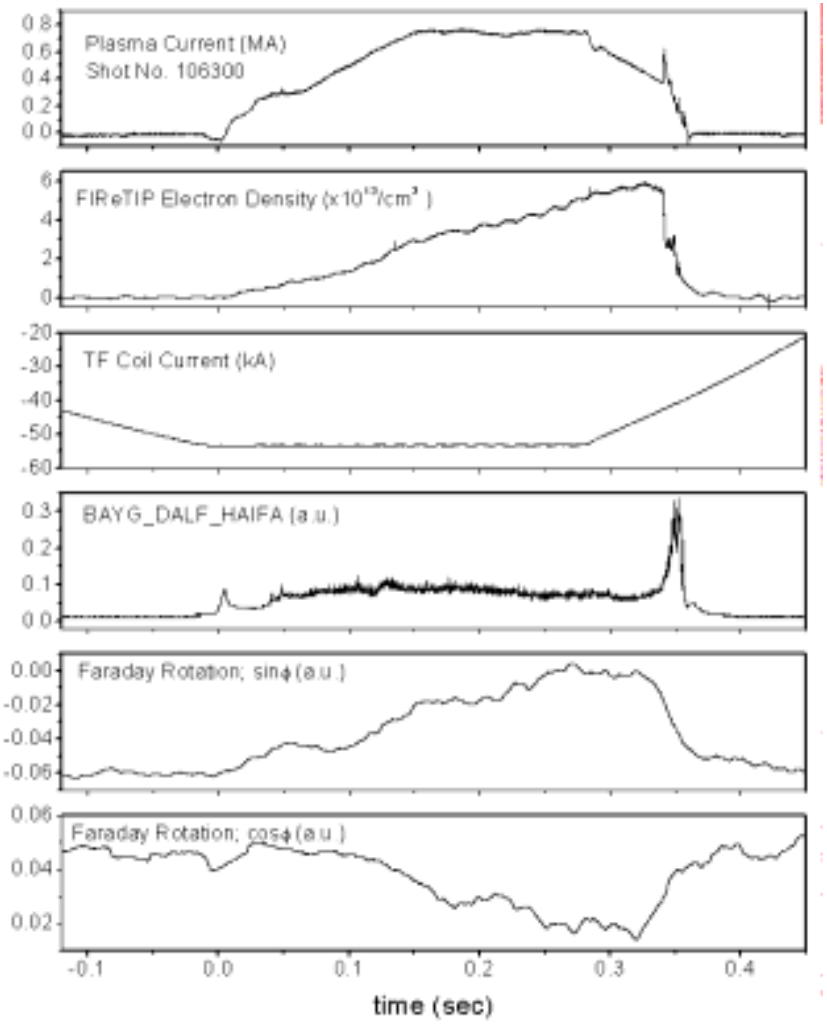
3-D CAD design and Installation

- Full system is designed using 3-D CAD.
- All optical elements and detector assemblies are installed and aligned with visible laser
  - Beam splitters, polarizers and retro-reflectors
- CO2 laser is operation and testing magnetic field effect. FIR laser will be ready



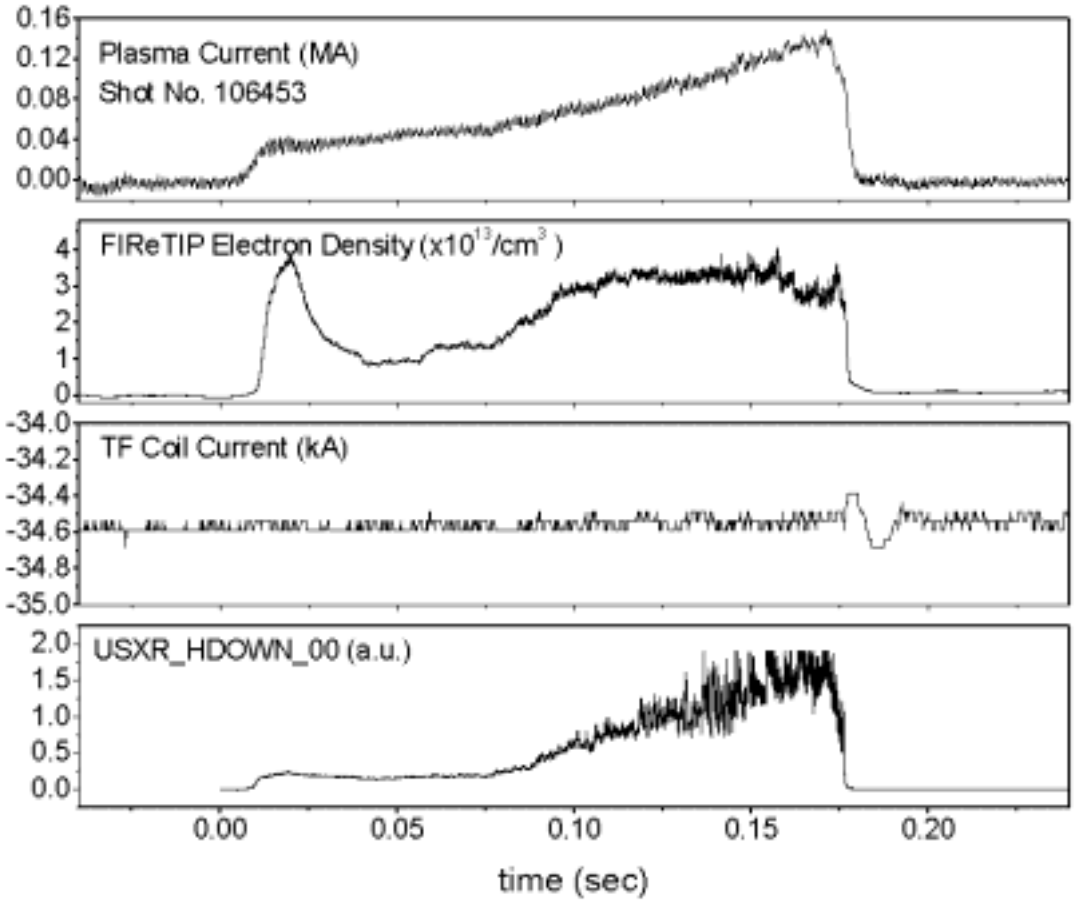
Test results from 2001 campaign

- Main objective was Interferometry system test
  - Successful operation single channel line density measurement at tangency of 66 cm.
    - Isolation of floor vibration
    - Magnetic isolation
  - Small level of vibration from the floor (induced by OH force)
    - Need a full isolation
  - Test of Faraday rotation measurement
    - Quadrature output
    - New fringe counter will be installed in the next run



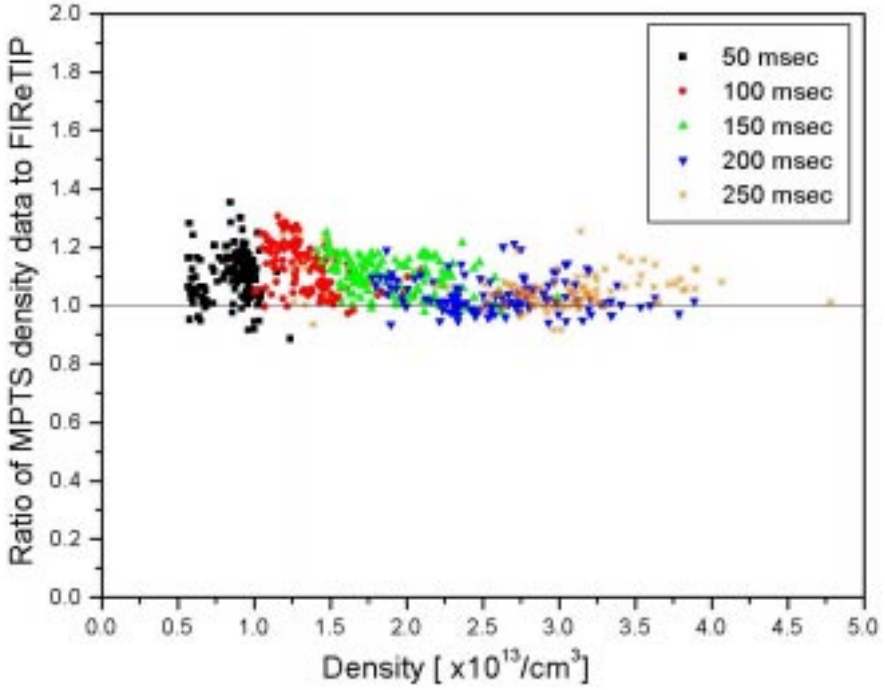
Continue

- Example of density evolution during CHI (notable fluctuation level)



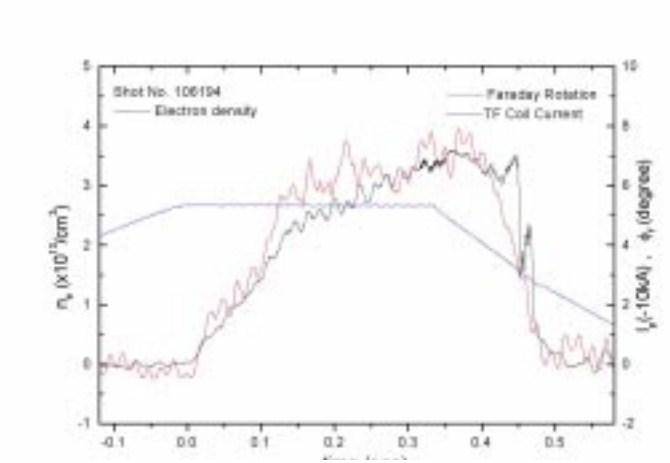
Comparison study with TS measurement

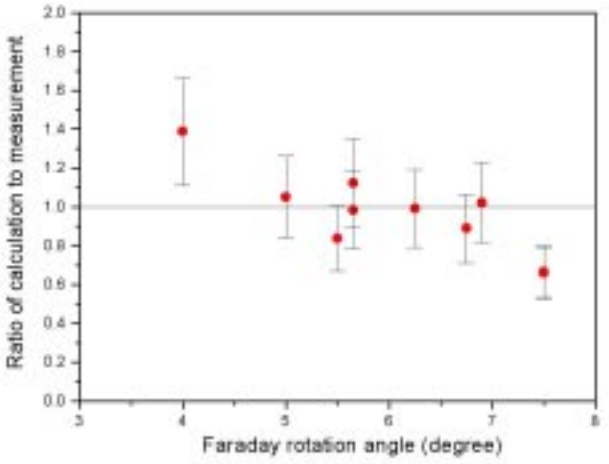
- Time period
  - May-June-July, 2001
- Density profiles measured by TS was used to integrate along our beam path
- Results
  - Ratio is at about 1.1
  - Scatter at a lower density may be due to premature density profile ?
    - Hollow in early stage
  - No clear variation in time (May, June and July)



Test result from Polarimetry

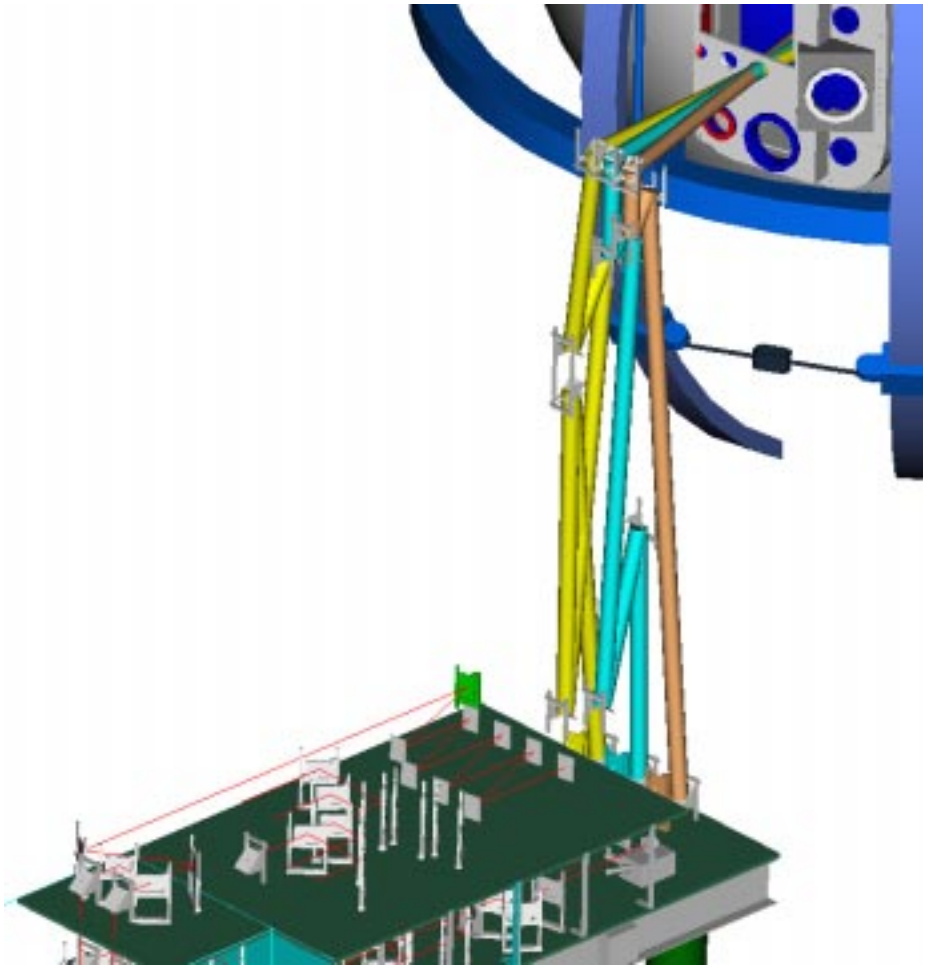
- Qualitative agreement was obtained based on quadrature measurement
  - Time history of Faraday rotation is reasonable
  - Data points are in a reasonable agreement with the predicted values
- Improvement will be made
  - Optical table isolation will reduce noise level
  - Fringe counting system will be implemented in the next run





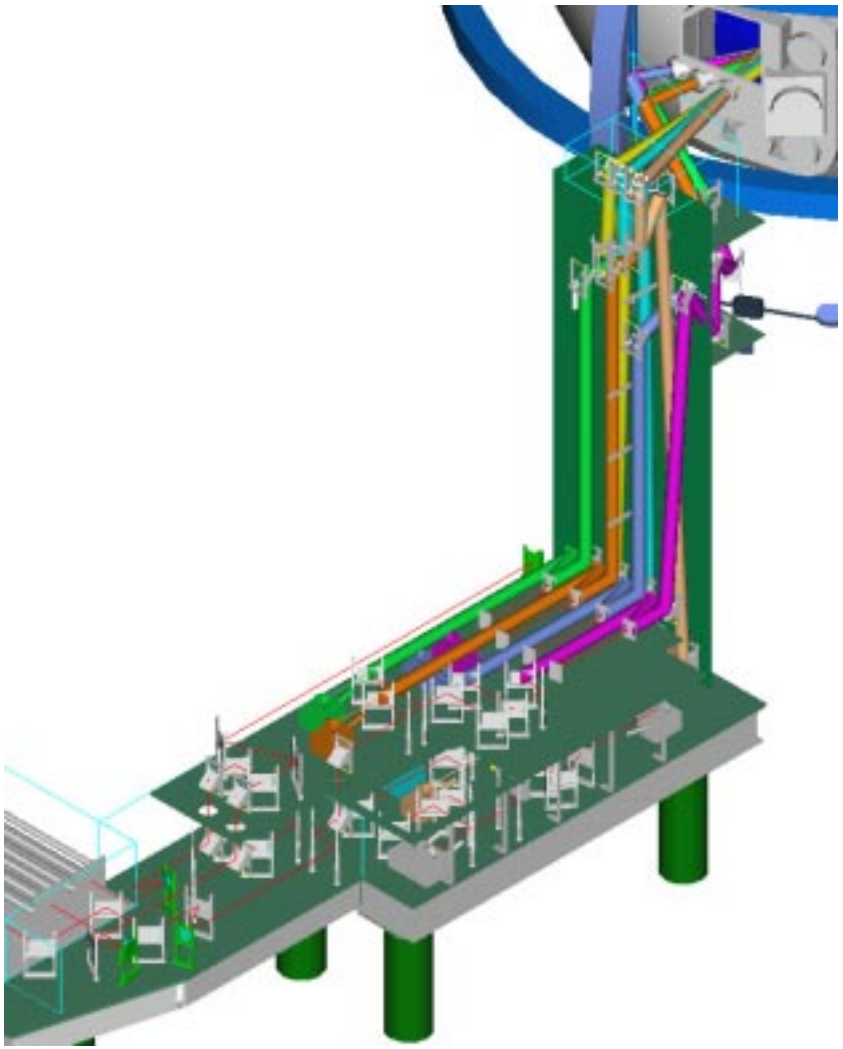
Upgrade plan during this opening

- Operation of three/four channels (2001)
  - Bay K windows & new optical tower will be installed
  - Completion of first floor (three channel) during this opening
    - One edge channel at the tangency of 150 cm
  - Two optical tables will be isolated from the floor
    - Test of air cushion system is in progress
  - Focus on polarimetry



Next year plan

- Extension to the second floor (2002)
  - Second floor by the end of next year
    - Add 4 more channels
  - Laser system will be upgraded
    - CO_2 laser will be upgraded to a higher power level (~100 W)



Summary

- First application of Stark tuned laser for plasma interferometry/polarimetry
  - Objective: measurement of toroidal field and 2-D density profile
  - Channel number: seven chords with three FIR lasers at 119 μm
- Operation of a single channel was successful
  - 3-D CAD design of the system
  - Installation of the system and alignment
  - Preparation for upgrade to three channel operation
- Schedule
  - Three channel/four operation in next campaign
  - The full system will be completed by late 2002