

Progress on the DTT Interferometric and Polarimetric Diagnostics

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ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES,
ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT



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DTT interferometric and polarimetric systems

Commissioning diagnostics:

- **2-lines of sight tangential dispersion interferometer**: Line-integrated measurement & control of electron density

Early phase 1 diagnostics:

- **Multi-chord Poloidal interferometer/polarimeter**: The system will allow determining plasma density profiles, it will give valuable information on the internal magnetic field and it will contribute to evaluate the plasma magnetic equilibrium and to the real time estimation of the q-profile

Later-stage diagnostics:

- **Divertor scanning dispersion interferometer**: Detachment condition assessment

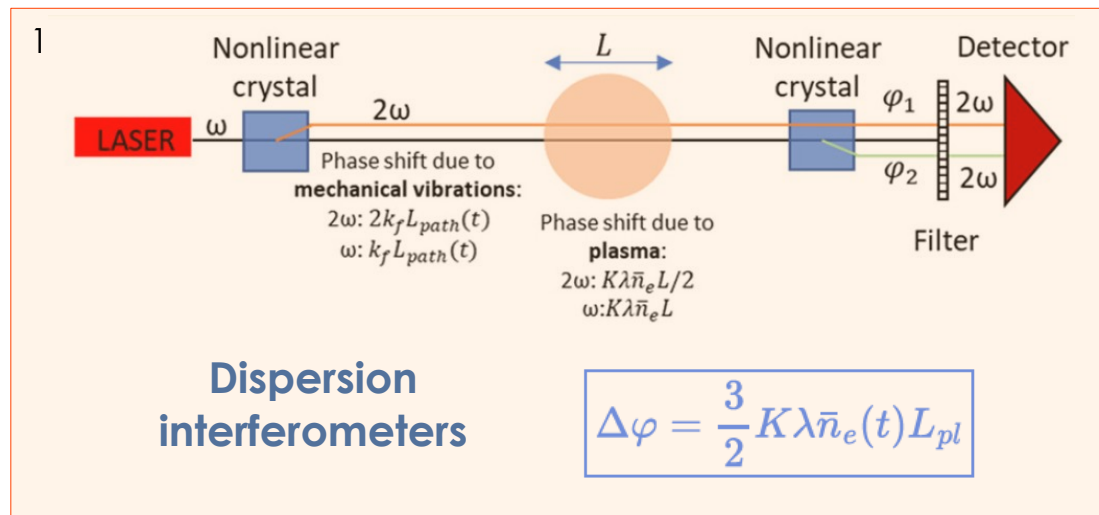
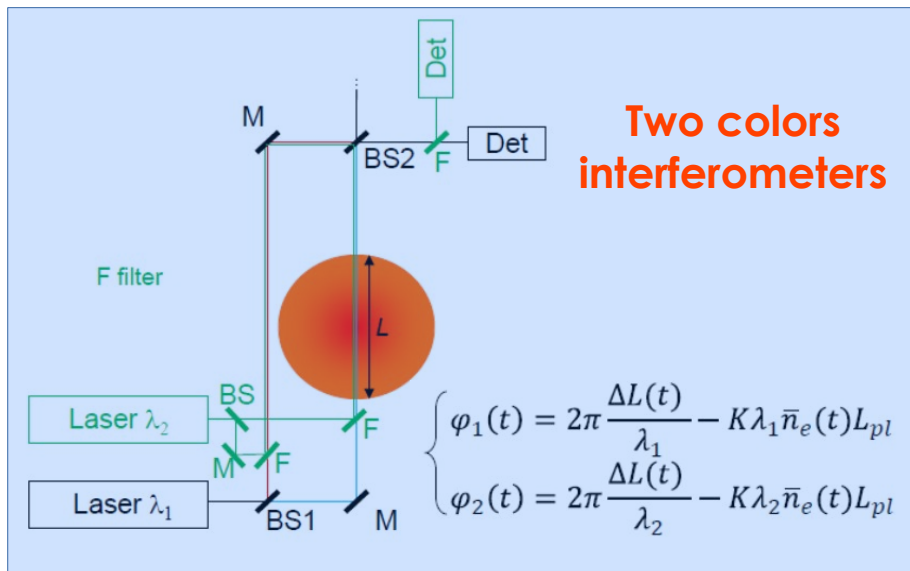


Presentation Outline

- **Dispersion interferometers**
- **DTT tangential dispersion interferometer:**
 - New optical scheme
 - Experimental tests
- **DTT poloidal interferometer/polarimeters:**
 - DTT poloidal interferometer/polarimeter: interferometric phase shift perturbation
 - Code simulation validation through WEST experiment

Dispersion interferometer for fusion experiments

Vibration-induced errors are a major issue in interferometers for fusion experiments. Several methods have been developed to mitigate this problem.

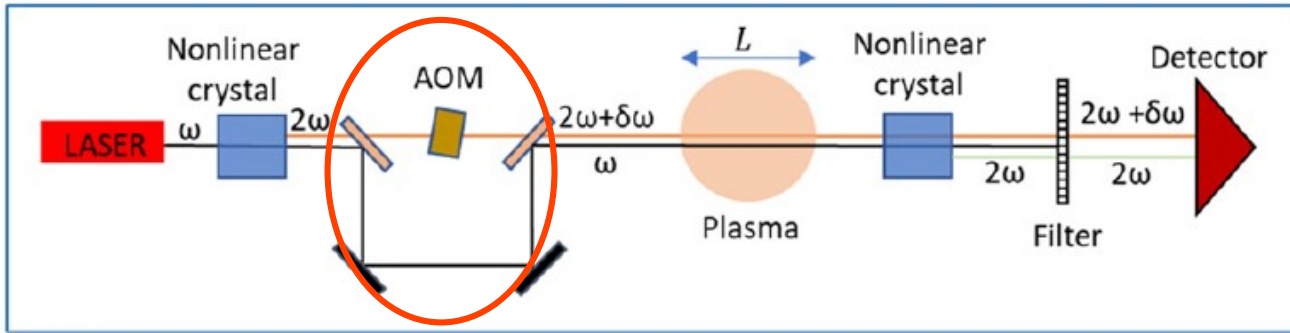


- Inherently insensitive to vibrations
- Simpler optical configuration



Dispersion interferometer: heterodyne configuration

To achieve higher-precision measurements, heterodyne schemes are commonly used, at the cost of **increased system complexity**.

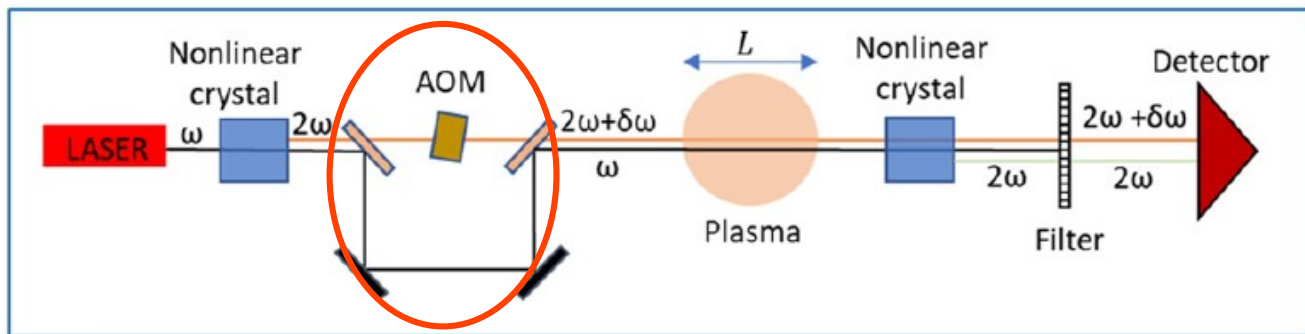


Increase in Vibration-induced errors¹



Dispersion interferometer: heterodyne configuration

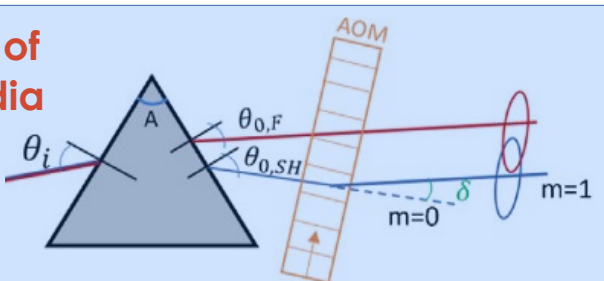
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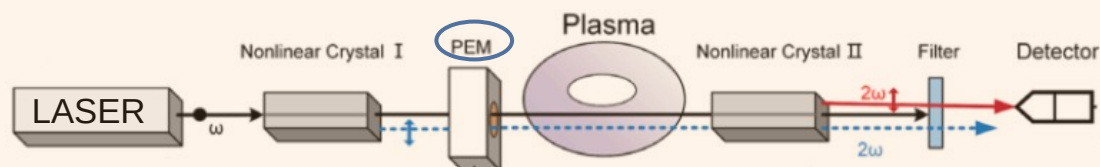
Increase in Vibration-induced errors¹

Possible solutions:

1. Introduction of dispersive media (e.g., prisms)¹



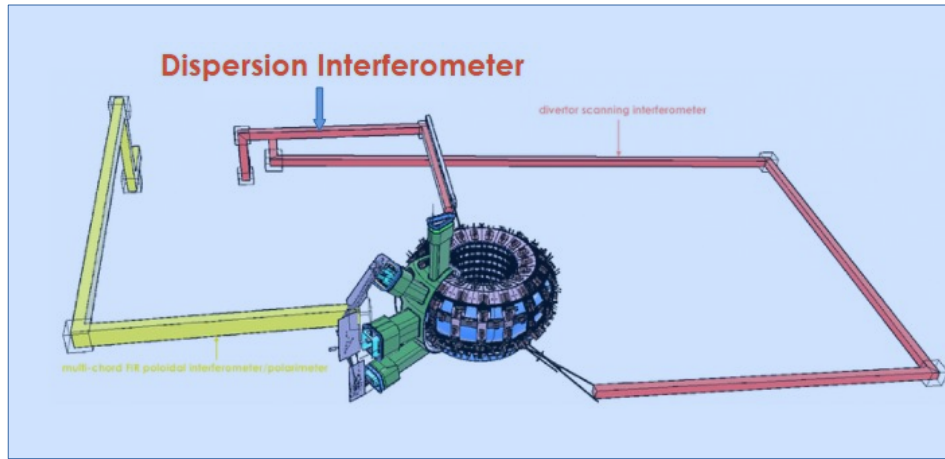
2. Photoelastic modulator $\rightarrow$ no SH/F beam separation²



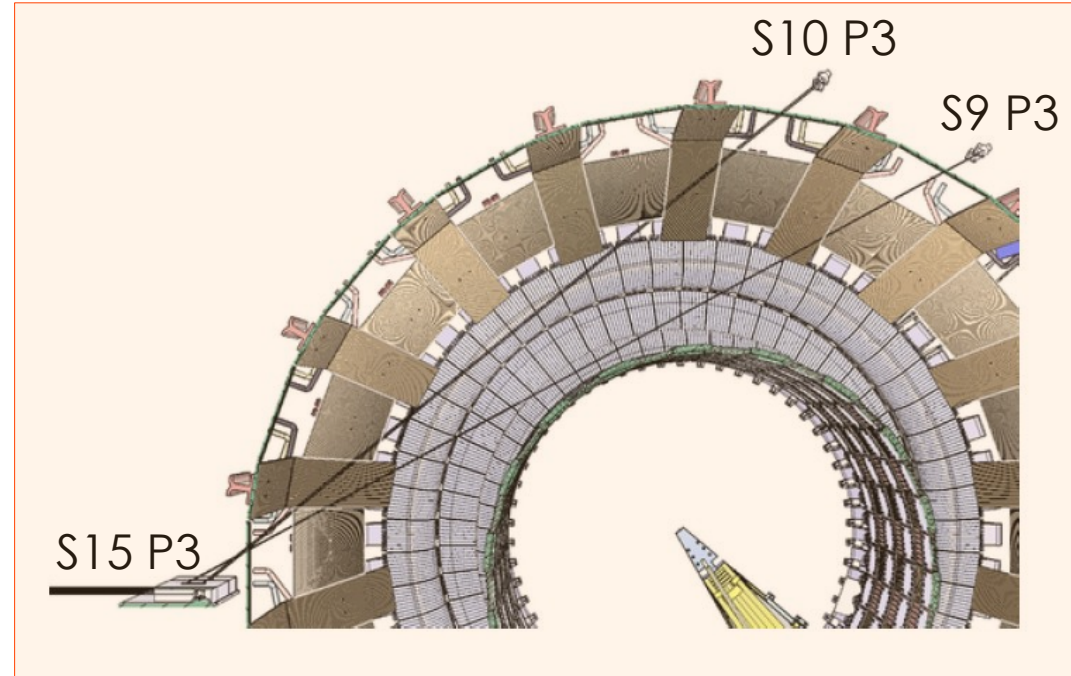


DTT Tangential Dispersion Interferometer

Laser optical path inside the Tokamak hall



Two tangential lines of sight through the tokamak



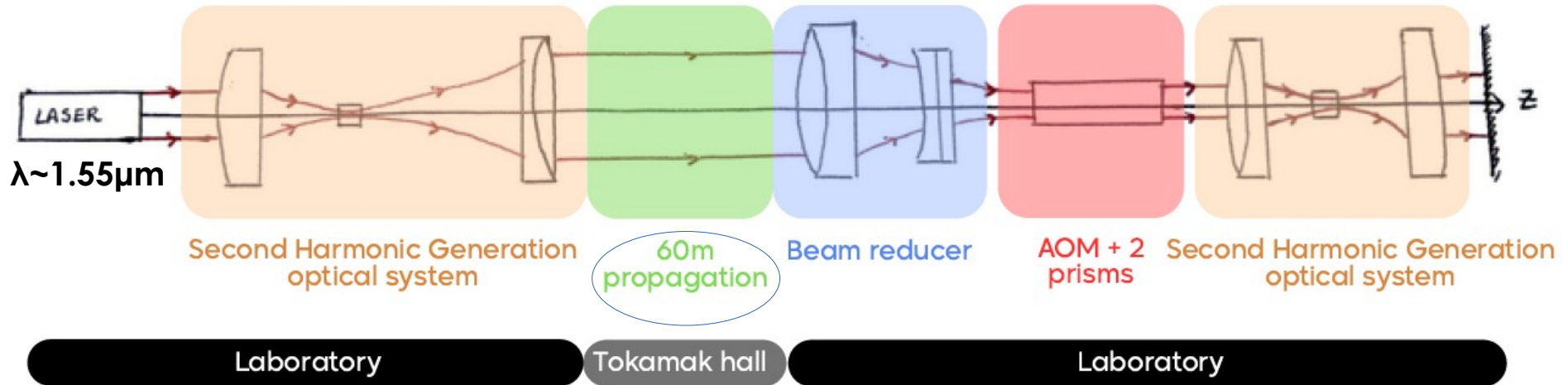


DTT Tangential Dispersion Interferometer

Improvement of the Optical System using Python and Zemax:

- Chromatic aberration correction for the lens-based system
- Evaluation of mirrors as an alternative to lenses

2D schematic of the improved optical layout with lenses





DTT Tangential Dispersion Interferometer

Improvement of the Optical System using Python and Zemax:

- ▶ Chromatic aberration correction for the lens-based system → **good control of the cromatism with acromatic doublets**
- ▶ Evaluation of mirrors as an alternative to lenses → **good control of the astigmatism**

Parameter	Target	Fund. (B1)	Harm. (B2)	Conclusion
f'_{L1}	75 mm	75 mm	/	✓
$\Phi_{laboratory}^{out}$	≈ 2 cm	2.45 cm	1.73cm	✓
$d_{waist-CC}$	≈ 0 mm	8.47cm	8.61cm	$\sim$
Φ_{CC}	≈ 4 mm	2.4 mm	1.7mm	✓
Φ_{AOM}^{in}	≈ 1 mm	1.1 mm	0.8mm	✓
Φ_{prisms}^{out}	≈ 1 mm	0.8 mm	0.5mm	✓
$d_{waist-NLC2}$	≈ 0 mm	0.5 mm	0mm	✓
Φ_{NLC2}	$\Phi_{NLC1} = 0.1$ mm	0.5mm	/	$\sim$



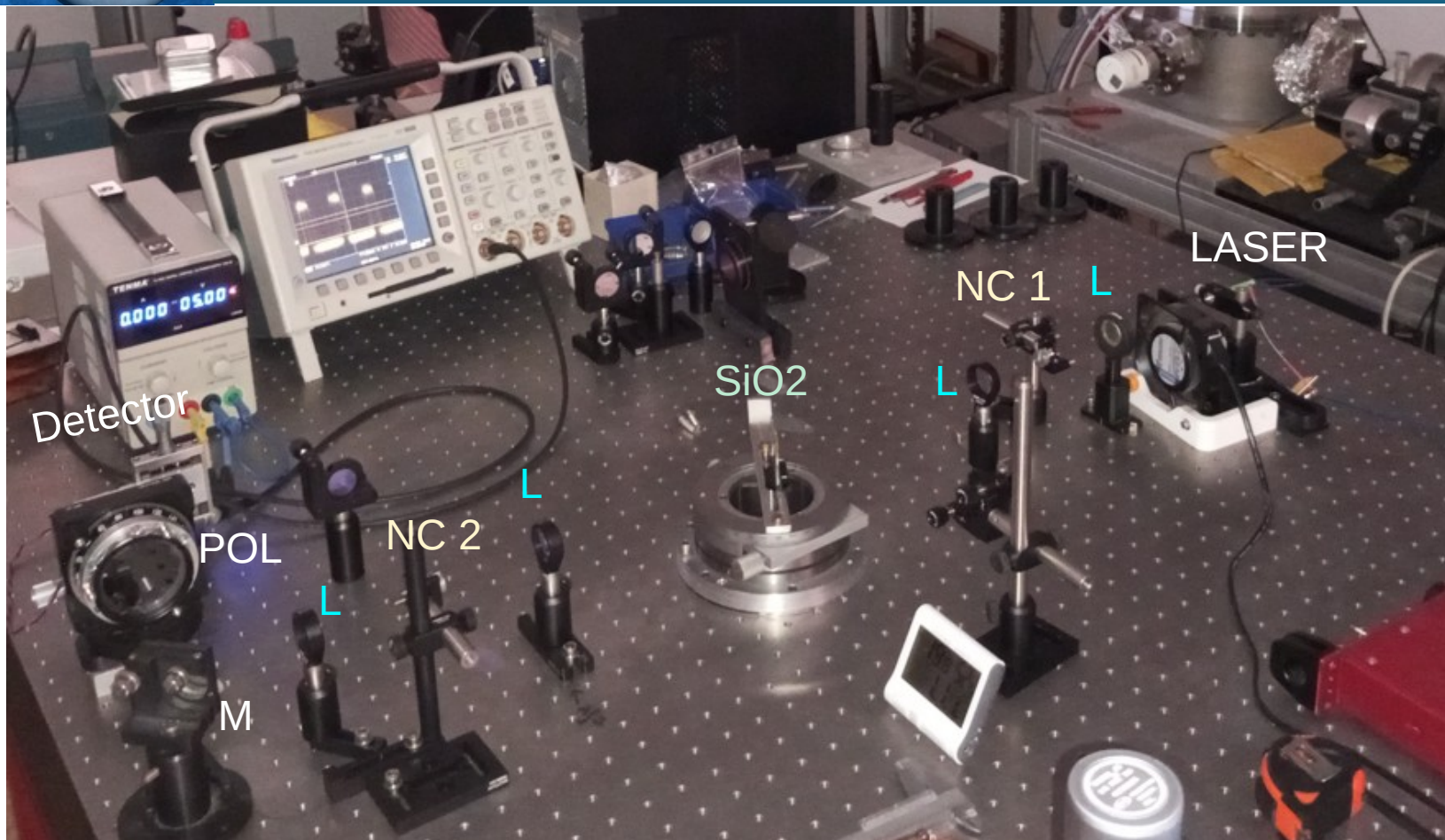
Results for the Lens-Based Configuration

Experimental tests to compare mirror and lens configuration

Courtesy of
E. Amadou



DTT Tangential Dispersion Interferometer



**Tabletop
experiment:**
**lens (L)
configuration**



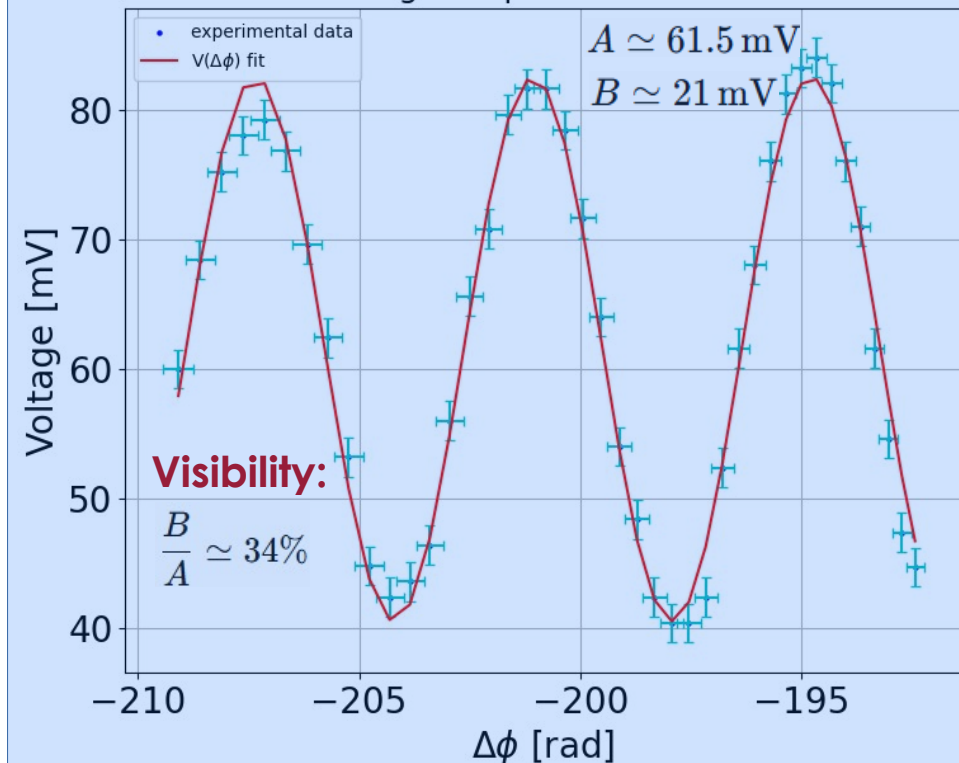
DTT Tangential Dispersion Interferometer

$$V(\theta_r) = A + B \cos [\Delta\phi(\theta_r)]$$

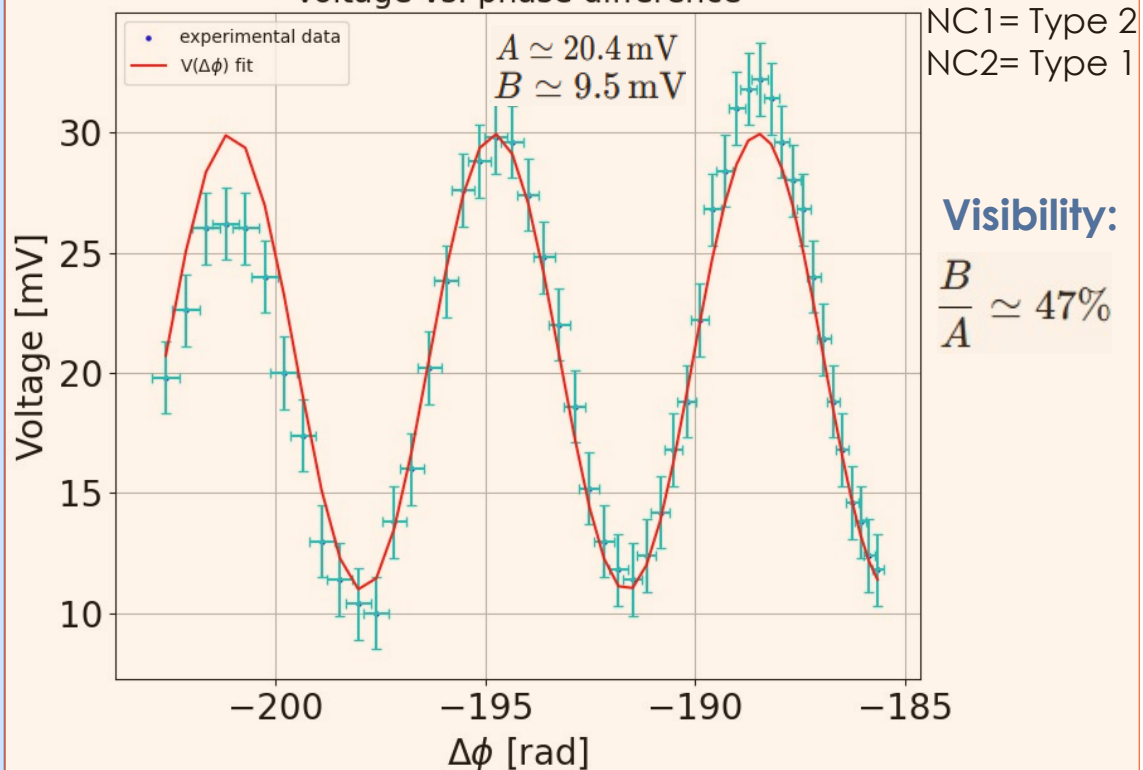
$$\Delta\phi(\theta_r) = \frac{4\pi}{\lambda_f} \frac{(n_{1550} - n_{775}) d}{\cos(\theta_r + c)} \quad \theta_r \rightarrow \text{Average refracted angle}$$

NC1= NC2 = Type 1

Voltage vs. phase difference



Voltage vs. phase difference





DTT Tangential Dispersion Interferometer

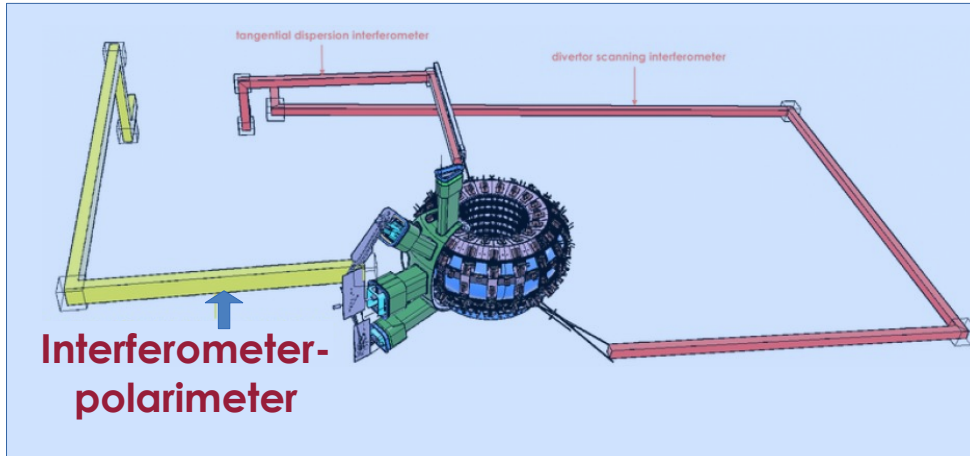
Conclusions and next steps:

- Both lens- and mirror-based configurations can be optimized
- The tabletop experiment indicates that the configuration with NC1 = Type 2 and NC2 = Type 1 is feasible and would offer a simpler implementation.
- Experimentally characterize the mirror configuration and compare its performance with the previously tested lens-based setup.
- Investigate different heterodyne configurations experimentally

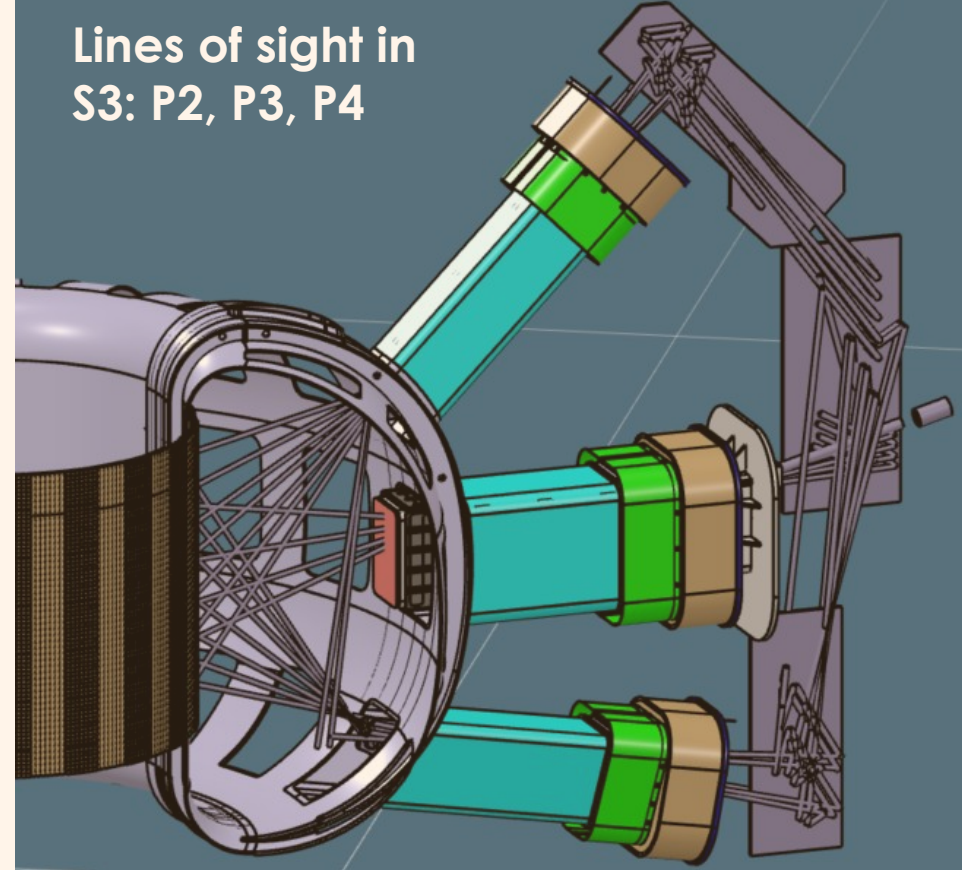


DTT Poloidal Interferometer-Polarimeter

Laser optical path inside the Tokamak hall



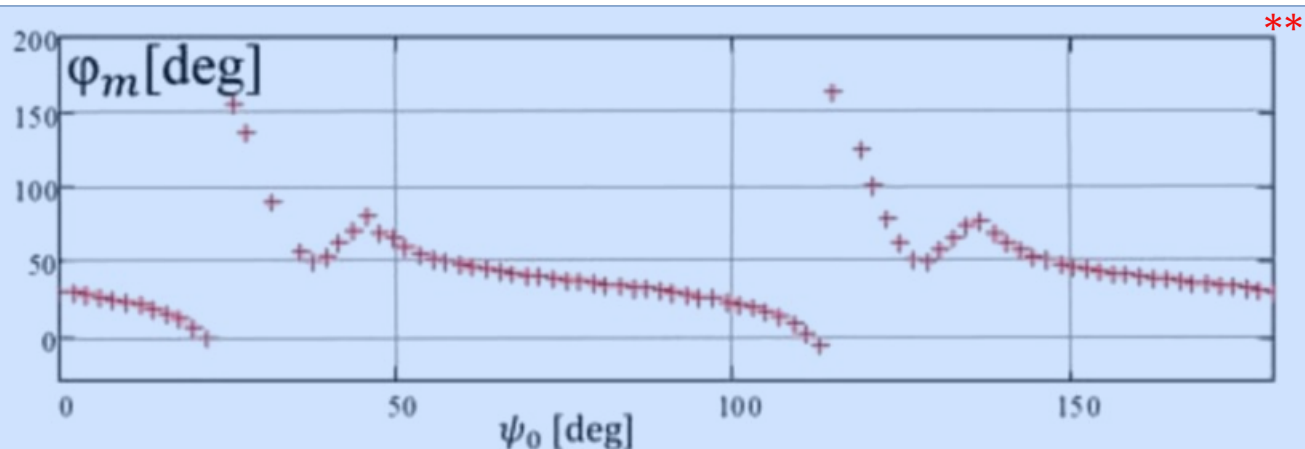
Lines of sight in
S3: P2, P3, P4





DTT Poloidal Interferometer-Polarimeter: phase shift perturbation

- Plasma birefringence can introduce a non-negligible perturbation to the interferometric phase.*
- The perturbation depends on the magnetic field, plasma parameters, propagation geometry, and laser polarization.*
- Its magnitude was characterized for the DTT interferometer/polarimeter configuration ($\lambda \sim 118 \mu\text{m}$) using the **Mueller matrix formalism**, revealing a potentially non-negligible contribution. **



**

$$\Delta\Phi_I = \Delta\Phi + \varphi_m$$

$$\Delta\Phi = 2.82 \times 10^{-15} \lambda \int_{z_1}^{z_2} n_e dz$$

$$\varphi_m = \sum_{i=0}^N \varphi_{m,i}$$

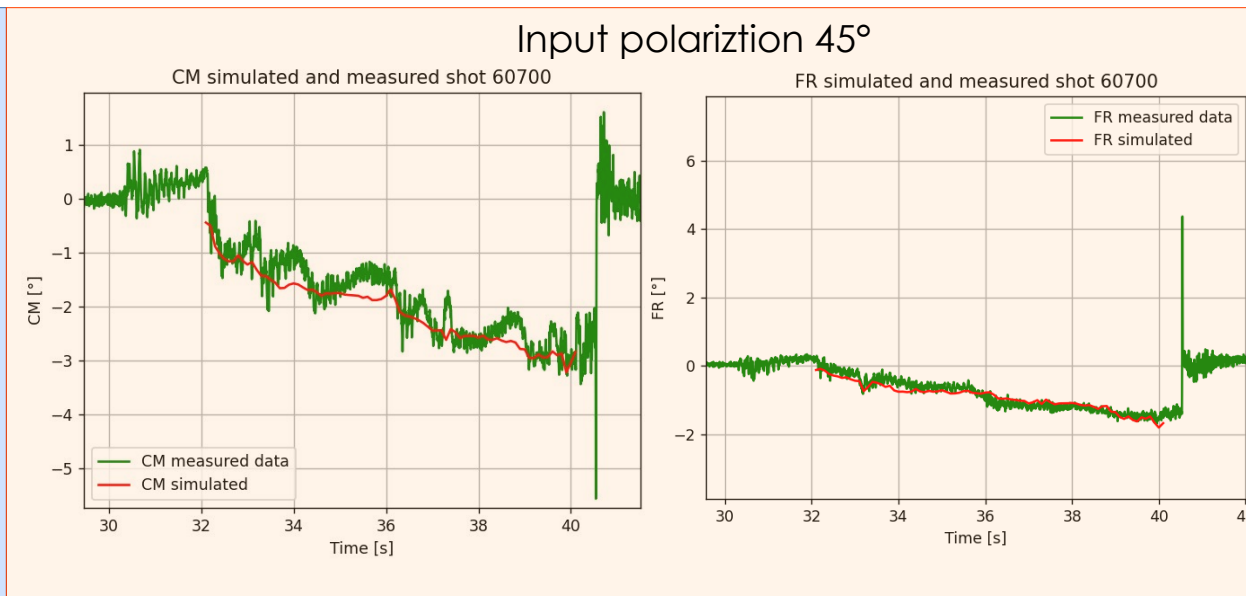
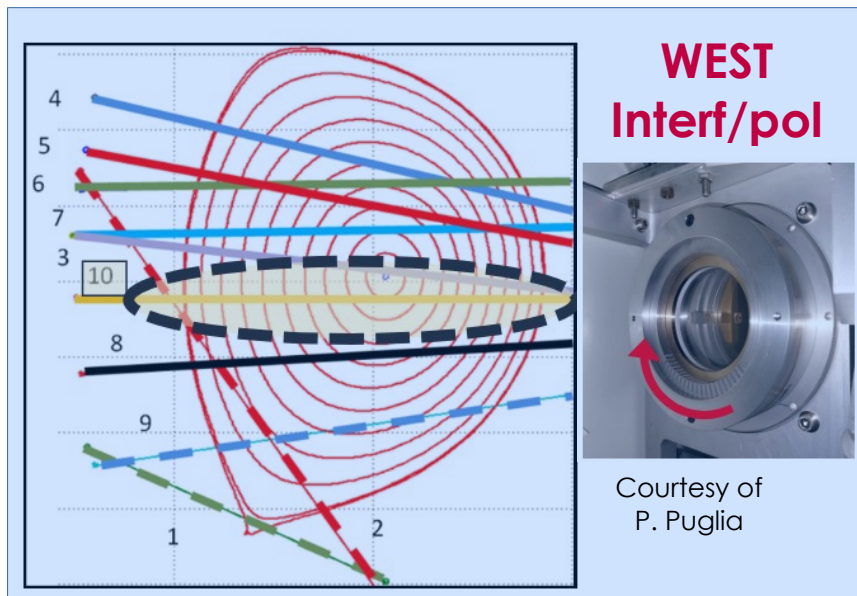
$$\varphi_{m,i} = \tan^{-1} \left(\frac{S_i}{C_i} \right) - \tan^{-1} (\tan \chi_{0,i} \tan \psi_{0,i})$$



DTT Poloidal Interferometer-Polarimeter: phase shift perturbation Tests @ WEST

Validation at WEST of the simulation code used for DTT, described in reference **

- Installation of a half-wave plate in the WEST interferometer/polarimeter to modify the input laser beam polarisation.
- Comparison of measurements and code results





Conclusions and next steps:

- ▶ Initial tests show good agreement between code simulations and experimental measurements. However, only the CM and FR effects were compared for a limited number of shots.
- ▶ Extend the comparison between measurements and simulations to a larger number of shots.
- ▶ Develop experimental tests at WEST to compare the simulated and measured phase-shift perturbations.



Thank you for your attention



Extra slide: Phase Perturbation Formulas

$$\Delta\Phi_I = \Delta\Phi + \varphi_m$$

$$\Delta\Phi = 2.82 \times 10^{-15} \lambda \int_{z_1}^{z_2} n_e dz$$

$$\varphi_m = \sum_{i=0}^N \varphi_{m,i}$$

$$\varphi_{m,i} = \tan^{-1}\left(\frac{S_i}{C_i}\right) - \tan^{-1}(\tan \chi_{0,i} \tan \psi_{0,i})$$

$$\begin{aligned} S_i = & 2 \cos \psi_{2,i} [\cos \delta_i \sin(\psi_{0,i} - \psi_{2,i}) \sin \chi_{0,i} \\ & - \sin \delta_i \cos(\psi_{0,i} - \psi_{2,i}) \cos(\chi_{0,i} - 2\chi_{2,i})] \\ & + 2 \sin \psi_{2,i} [\cos \delta_i \cos(\psi_{0,i} - \psi_{2,i}) \sin \chi_{0,i} \\ & - \sin \delta_i \sin(\psi_{0,i} - \psi_{2,i}) \cos(\chi_{0,i} + 2\chi_{2,i})], \end{aligned}$$

$$\begin{aligned} C_i = & 2 \cos \psi_{2,i} [\cos \delta_i \cos(\psi_{0,i} - \psi_{2,i}) \cos \chi_{0,i} \\ & + \sin \delta_i \sin(\psi_{0,i} - \psi_{2,i}) \sin(\chi_{0,i} + 2\chi_{2,i})] \\ & - 2 \sin \psi_{2,i} [\cos \delta_i \sin(\psi_{0,i} - \psi_{2,i}) \cos \chi_{0,i} \\ & + \sin \delta_i \cos(\psi_{0,i} - \psi_{2,i}) \sin(\chi_{0,i} - 2\chi_{2,i})]. \end{aligned}$$

$$\psi_1 = \psi_2 + \frac{\pi}{2}, \quad \chi_1 = -\chi_2, \quad \sin 2\chi_2 = -\frac{\Omega_3}{\Omega}$$

$$\cos 2\chi_2 = (1 - \sin^2 2\chi_2)^{1/2},$$

$$\sin 2\psi_2 = -\Omega_2 / (\Omega \cos 2\chi_2),$$

$$\cos 2\psi_2 = -\Omega_1 / (\Omega \cos 2\chi_2),$$

$$\Omega = \sqrt{\Omega_1^2 + \Omega_2^2 + \Omega_3^2},$$

$$\Omega \cong \frac{\omega_p^2}{2c\omega^3} \begin{pmatrix} \left(\frac{e}{m_e}\right)^2 (B_x^2 - B_y^2) \\ \left(\frac{e}{m_e}\right)^2 2B_x B_y \\ \left(\frac{2\omega e}{m_e}\right) B_z \end{pmatrix}$$