CTU

CZECH TECHNICAL UNIVERSITY IN PRAGUE

Density measurements by microwave interferometry

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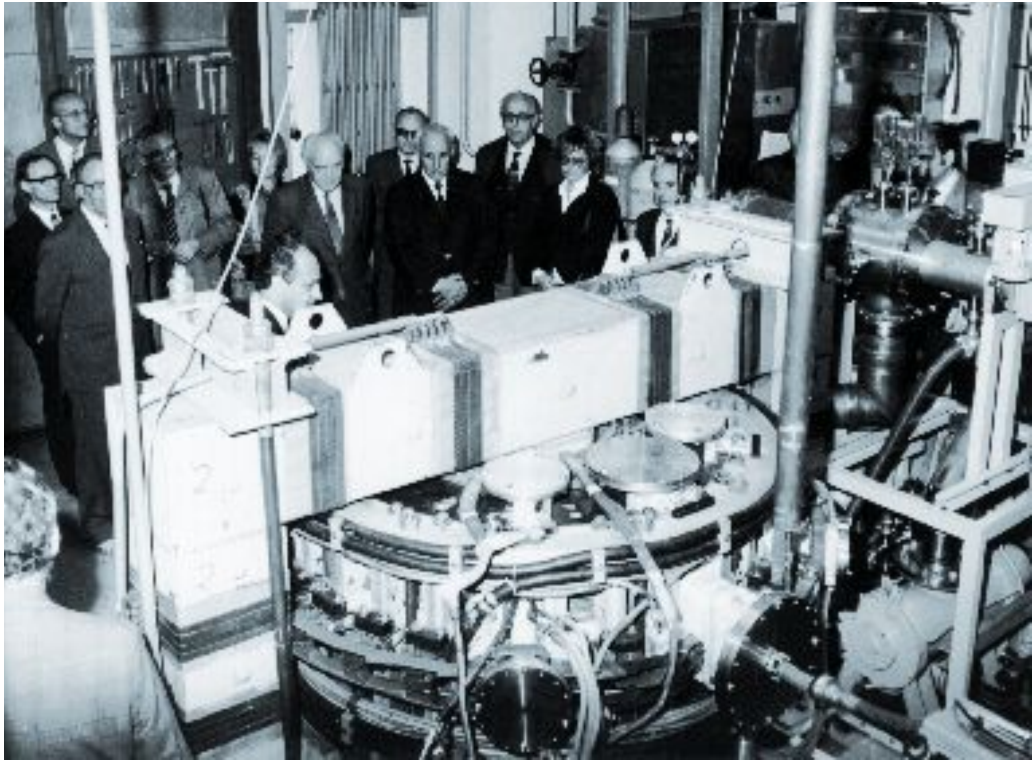
Introduction



Toroidal magnetic field	**<0.8 T**
Plasma current	**<8 kA**
Central electron Temperature	**80 eV**
Safety factor of plasma edge	**15**
Working gas pressure	**0-100 mPa**
Work gas	**H2 (He)**

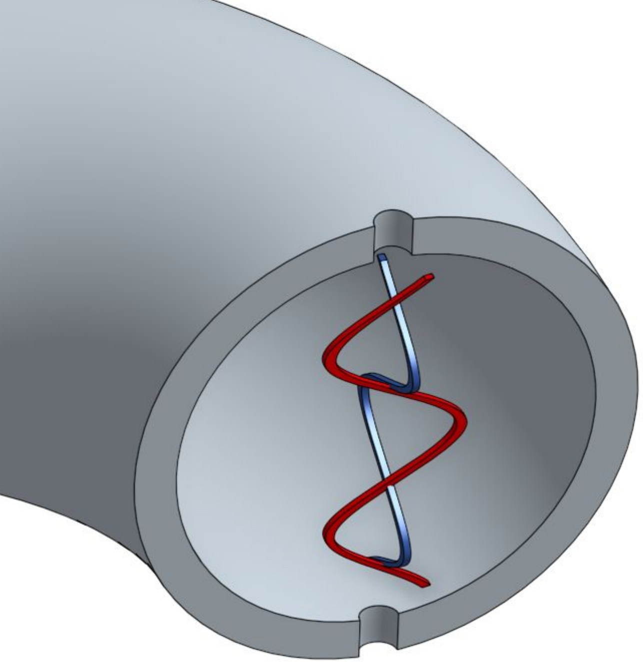
Main features of the Interferometry on GOLEM tokamak

- The real-time line-average electron density measurement
- The precise frequency filtering
- Tunable bandwidth of the digital filters
- Multi-chord measurement

Tasks

- Dependency of the plasma density on toroidal magnetic field and electric field.
- Reconstruction of the plasma density profile evolution from LFS (low field side) to HFS (high field side) by multi-chord measurement.

Basic Concepts



- Ordinary waves (O waves) $\vec{k} \perp \vec{B}_0, \ \vec{E}_1 \| \vec{B}_0$

$$N_O = \sqrt{1 - \frac{{\omega_p}^2}{\omega^2}} \approx 1 - \frac{ne^2}{2\varepsilon_0 m \omega^2} \qquad \omega_p^2 = \frac{ne^2}{\varepsilon_0 m}$$

- One wave goes through the plasma
- Another goes through air

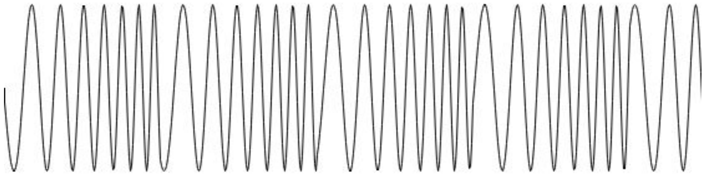
$\propto$

- We can deduce the density from the phase difference between the two!

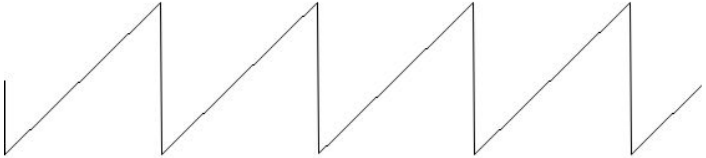
refr. index $\propto$ density $\Longrightarrow$ phase shift $\propto$ density :)

Basic Concepts

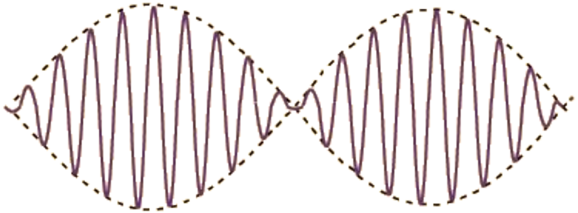
- Waves need to have a high frequency (71 GHz) to overcome the cut-off



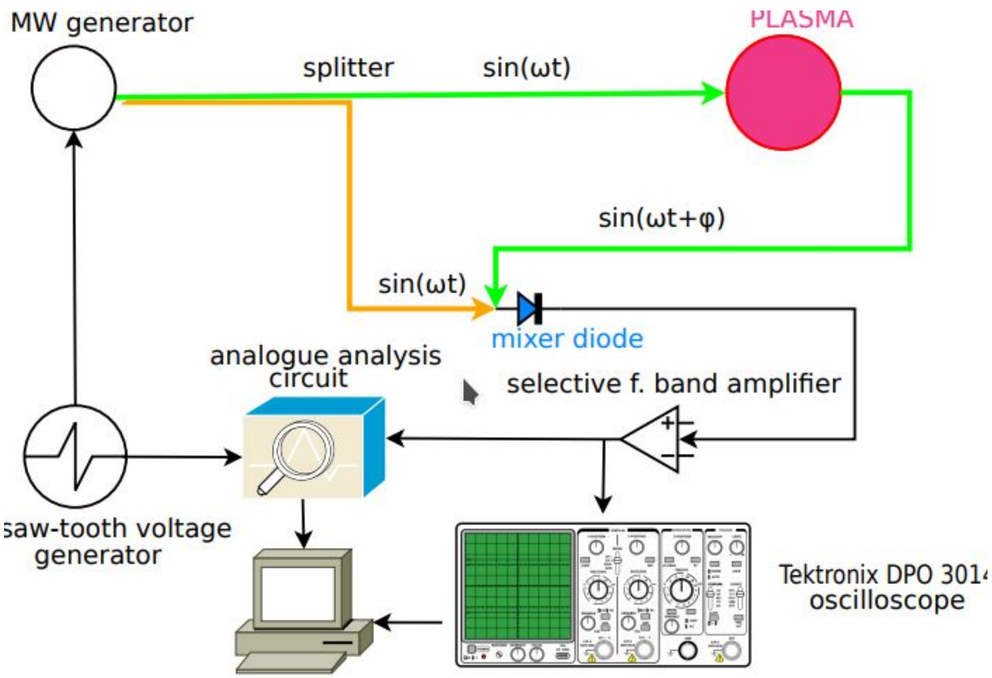
- We modulate the wave in frequency with a sawtooth signal

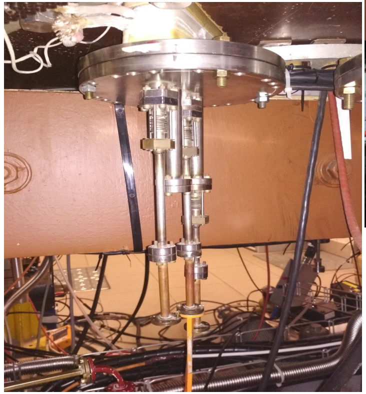


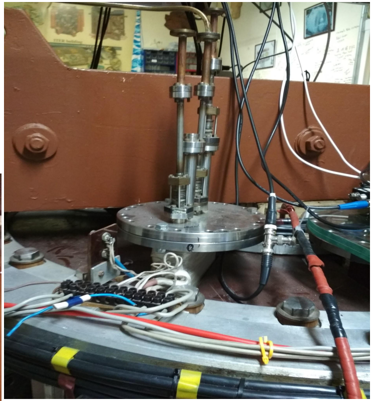
Reference wave: $cos(wt)$ + Probing wave: $cos((w + \Delta w)t + \Delta\phi)$

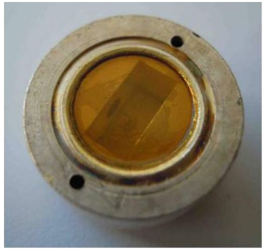


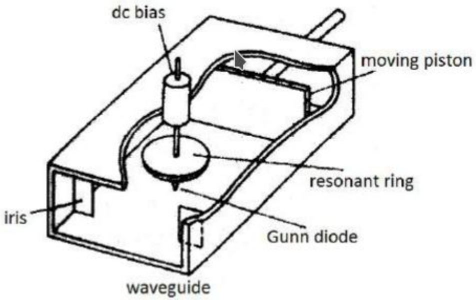
$$(\text{high freq. component}) \times cos\left(\frac{\Delta wt + \Delta\phi}{2}\right)$$







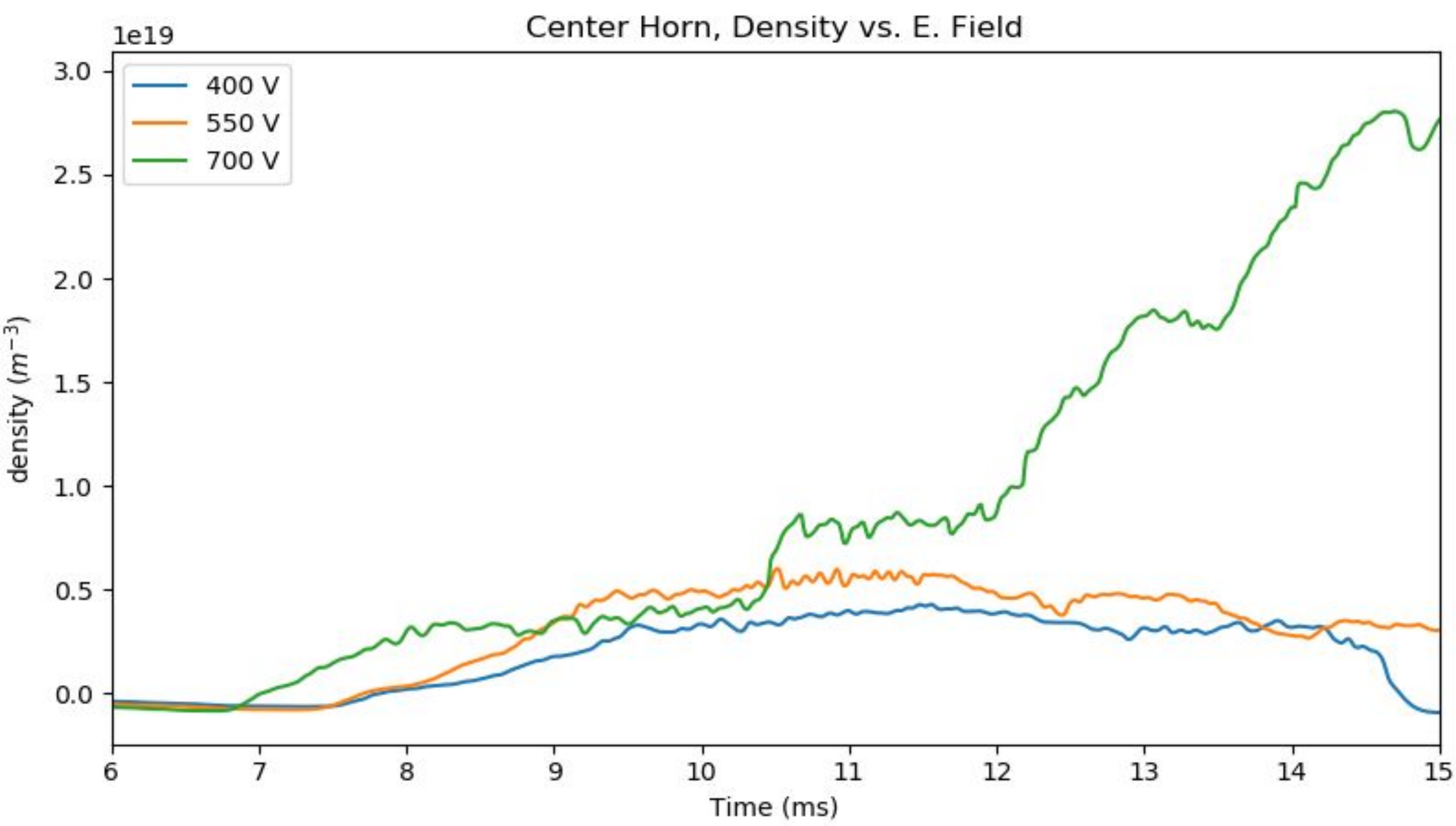




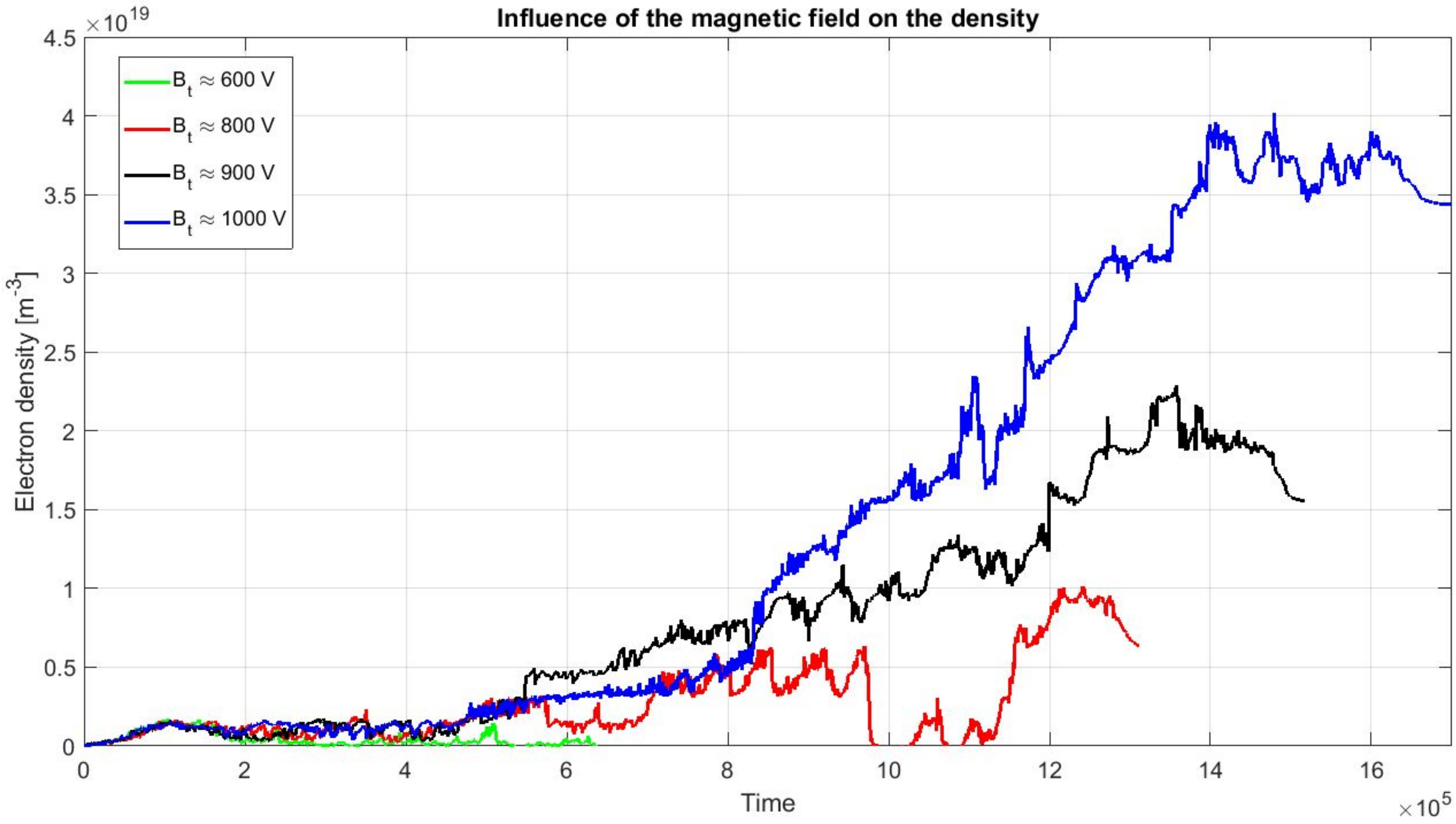
Gunn oscillator frequency:	71 GHz
Sawtooth frequency:	500 kHz
Frequency sweep:	30 MHz
Waveguide path difference:	10 m

Goals

- Dependency of the plasma density on the electric field.
- Dependency of the plasma density on toroidal magnetic field.
- Reconstruction of the plasma density profile evolution from LFS (low field side) to HFS (high field side) by multi-chord measurement.

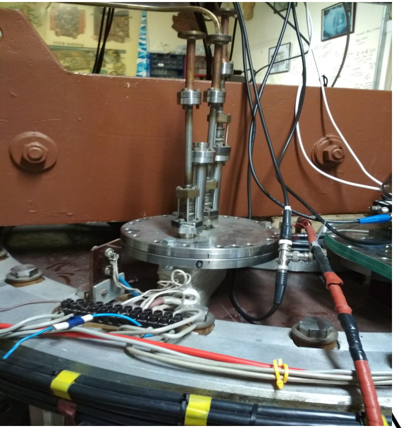


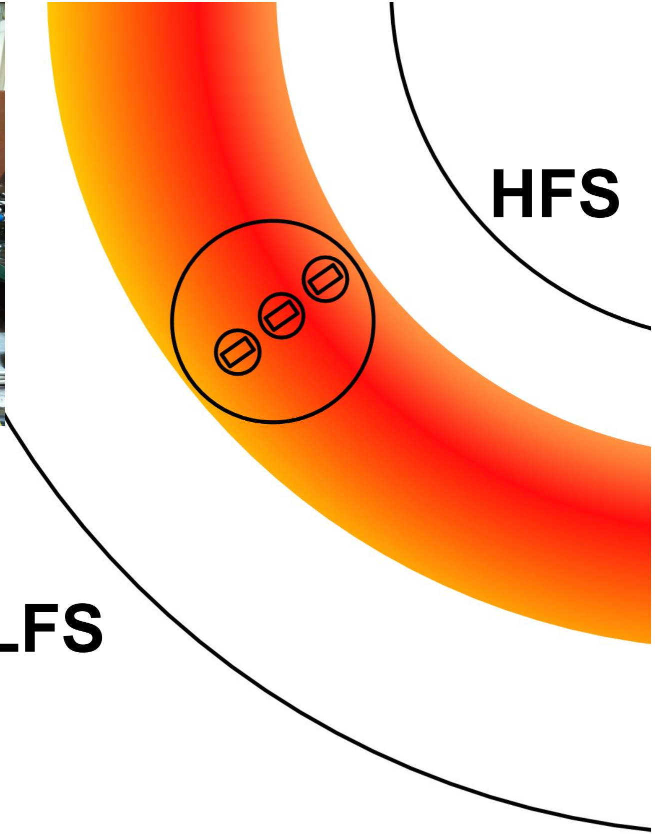
Center Horn, Density vs. E. Field
1e19
400 V
550 V
700 V
3.0
2.5
2.0
1.5
1.0
0.5
0.0
density (m^{-3})
6
7
8
9
10
11
12
13
14
15
Time (ms)



Influence of the magnetic field on the density
×10^19
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Electron density [m^-3]
B_t ≈ 600 V
B_t ≈ 800 V
B_t ≈ 900 V
B_t ≈ 1000 V
0
2
4
6
8
10
12
14
16
Time
×10^5

Density profile measurements

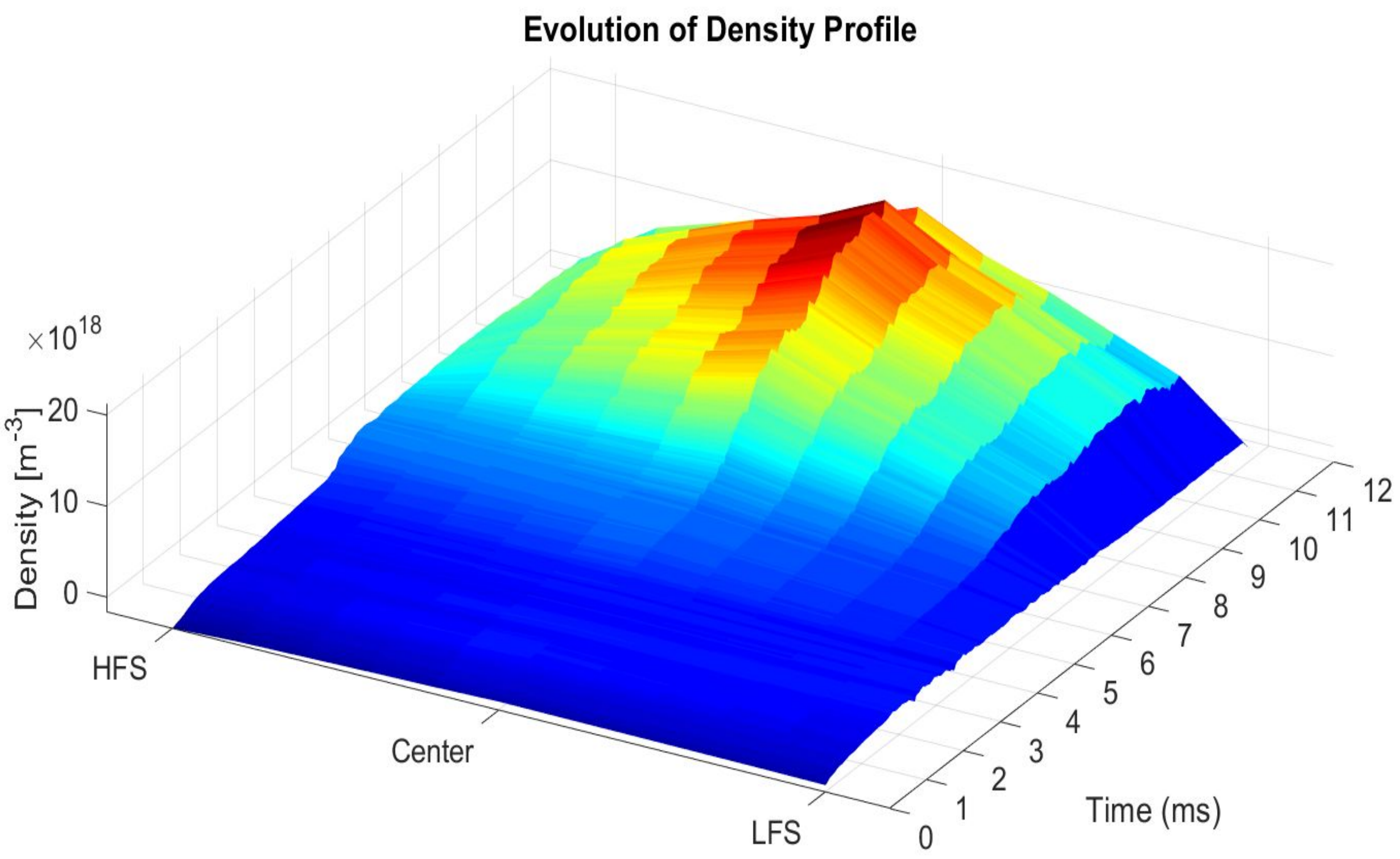




Three chords for the line-average electron density measurement:

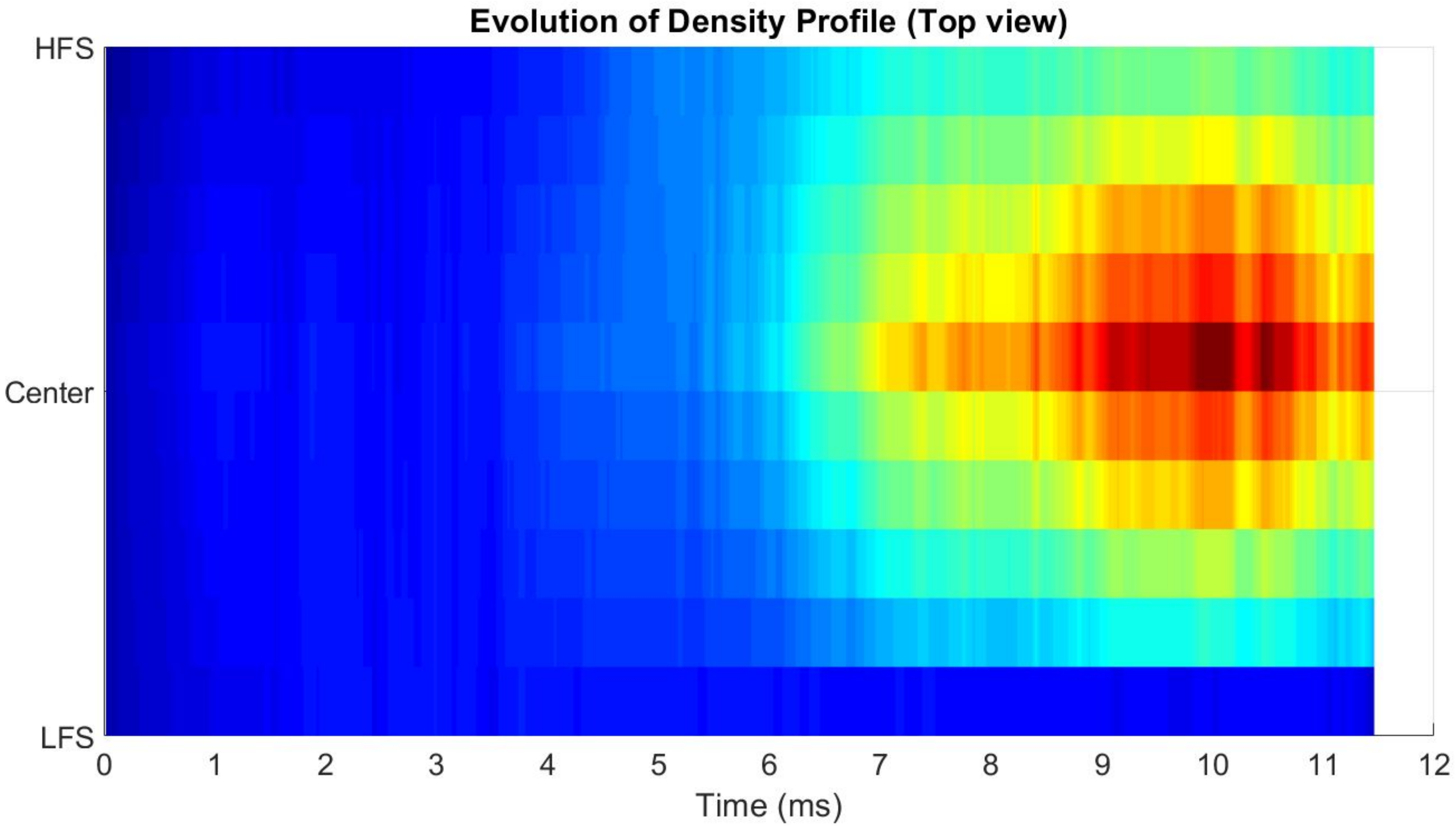
- LFS
- Center
- HFS

Only one interferometer



Evolution of Density Profile
×10^18
Density [m^-3]
20
10
0
HFS
Center
LFS
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (ms)

A glimpse of the future...



Conclusion

- Density versus Electrical Field
- Density versus Magnetic Field
- Density profile evolution
- Horizontal position of plasma

Basic equations

$$\omega_p^2 = \frac{ne^2}{\varepsilon_0 m}$$ [1]

$$N_O = \sqrt{1 - \frac{{\omega_p}^2}{\omega^2}} \approx 1 - \frac{ne^2}{2\varepsilon_0 m \omega^2}$$ [2]

$$n_c = \frac{\varepsilon_0 m}{e^2}\omega^2$$ [3]

Basic algorithms for data processing

$$s(t) = A\cos(\omega t + \theta) = A\frac{1}{2}\left(e^{i(\omega t+\theta)} + e^{-i(\omega t+\theta)}\right)$$

Phase shift

$$n_e \propto (\omega t + \theta(t)) - (\omega t + \varphi_{ref}) = \theta(t) - \varphi_{ref}$$

Complex representation

$$s_a(t) = A \cdot e^{i(\omega t+\theta(t))}$$

Polar representation

$$\omega t + \theta = \arg[s_a(t)]$$
$$A = |s_a(t)|$$

$$f_{ref}(t) = \text{sawtooth}(\omega t + \varphi_{ref})$$

1. Fourier transformation via FFT.
2. Finding the carrier frequency.
3. The complex exponential signale creation.
4. The analytic representation is created
5. This filter). representation This smoothing is smoothed averages out in time the oscillating by a convolution component with a of Gaussian s a (t) constructed window (essentially in the previous a low-pass
 step.
6. The phase and amplitude are obtained from the polar representation of s a (t).