Numerical studies on the spectral resolution influence in velocity shear layer measurements by Doppler reflectometry

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Outline

• Introduction

• Velocity shear layer measurements in TJ-II
  • Experimental results
  • Numerical simulations: data validation and interpretation
    • Role of spectral resolution in measurements
    • Velocity profile measurement and shear layer localization
    • Role of the shear layer width
  • Extended numerical simulations: parameters scan
    • Turbulence level
    • Radial correlation length

• Conclusions
Introduction: Doppler reflectometry

- Well-established technique to measure:
  - Perpendicular velocity of density fluctuations (Doppler peak shift)
  - Wave-number spectrum (Doppler peak amplitude + tilt angle scan)
  - Changes in turbulence level (scattered power)
Introduction: Doppler reflectometry

- Well-established technique to measure:
  - **Perpendicular velocity of density fluctuations (Doppler peak shift)**
  - Wave-number spectrum (Doppler peak amplitude + tilt angle scan)
  - Changes in turbulence level (scattered power)
Introduction: Doppler reflectometry

- Doppler shift depends on:
  - Perpendicular velocity
  - Tilt angle
  - Probing frequency

- Doppler peak width is affected by:
  - Intrinsic spectral resolution of the system:
    - *beam waist* and beam curvature
  - External factors out of control
    - Plasma curvature
    - *Turbulence level, and radial correlation length*
    - Velocity fluctuations
    - Probing path length
    - etc...

\[
f_d = \frac{u_\perp k_\perp}{2\pi} = \frac{2k_0 \sin \theta }{k_\perp} \text{(plasma slab)}
\]
Optimization parameters:

- Beam size
- Beam curvature
- Plasma curvature
- Alignment perpendicular to $\sqrt{B}$

CLOSE TO OPTIMUM SPECTRAL RESOLUTION

M. Hirsch et. al. PPCF 43, 1641 (2001)

TJ-II Optimized Doppler reflectometer

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Velocity shear layer measurements TJ-II

- **L-mode**: Velocity profile rather flat (5 – 7 km/s)
- **H-mode**: Strong velocity shear layer (5 – 15 km/s)

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Velocity shear layer measurements TJ-II

- Close to the shear two Doppler peaks are observed
- Both peaks have similar amplitudes at that position
- Interpretation: backscattering contains information from low and high velocity regions

Velocity shear layer measurements TJ-II

Relative peak amplitudes

Numerical Simulations

- Plasma slab
- Experimental density profile
- Shear layer 3 cm from edge

- Probing freq. 35 - 50 GHz
- Flat k-spectrum

![Graph showing Density and Velocity profiles](image-url)
Simulations vs. Measurements

- Simulations confirm that signal comes from low and high velocity regions
Role of spectral resolution (beam waist scan)

 Peaks cannot be separated if spectral resolution is not enough and the perpendicular velocity value is error-prone !!!
Spectral resolution: Errors estimation

Similar peaks amplitudes at shear layer position

Radial localization better than $\lambda_0$

Mixing of the two peaks if spectral resolution is poor

Accurate velocity values with optimized systems
Role of the shear layer width

- **Abrupt shear** \( \Delta x = 0 \) (step velocity profile)
- **Shear width** \( \Delta x \approx \lambda_0/2 \) (linear velocity profile)

- Simulations confirm that the shear width is smaller than \( \lambda_0/2 \)
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Extended Numerical Simulations

- Density profile scaled by a constant factor
- Shear layer at 3 cm as before
- Probing frequency (70 – 100 GHz), B = 2 Tesla
- Turbulence level: 2 – 15 % homogeneous $\frac{\delta n_{rms}}{n_{shear}} = C$
- Radial correlation length: 0 (uncorrelated) – 3$\lambda_0$
- Abrupt velocity profile change at shear layer position

\[ L_n = \frac{n_e}{V_n} \text{ (cm)} \]
Scan in turbulence level and correlation

**UNCORRELATED**

- **rms = 2 %**
- **rms = 10 %**
- **rms = 15 %**

**CORRELATED**

- **$L_r = 3 \lambda_n$**

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Spectral width and turbulence level

\[ \frac{\Delta k}{k_{\perp}} = 2\sqrt{2} (k_0 \cdot w_{cutoff})^{-1} \]

but remains almost unchanged regardless the turbulence level and/or correlation length -> discrepancy between theory and simulations

Theory:
\[ \frac{\Delta f_{\text{nonlinear}}}{\Delta f_{\text{linear}}} \approx \gamma \equiv k_0^2 \cdot n^2 \cdot x_c \cdot L_r \ln \left( \frac{x_c}{L_r} \right) \approx 20 \]

\( L_r = 3 \lambda_0 \)

M. Hirsch et. al. PPCF 43, 1641 (2001)

E. Z. Gusakov et. al. PPCF 47, 959 (2005)
Accurate shear layer localization in simulations (approx. $\lambda_0$) regardless the turbulence level and radial correlation length.
Shear Layer Localization

Accurate shear layer localization in simulations (approx. $\lambda_0$) regardless the turbulence level and radial correlation length $L_r = 3\lambda_0$. 

**UNCORRELATED & CORRELATED** 

![Graph showing shear layer localization](image)
• Very accurate velocity profiles (most of them within 5%)
Conclusions:

- Doppler measurements close to strong velocity shear layer can be affected by different velocities giving rise to several peaks in the spectra.
- Optimized Doppler reflectometers are mandatory to separate the peaks. Poor spectral resolution may lead to errors in the velocity profile values.
- The radial localization of the shear can be obtained with a radial resolution smaller than the probing wavelength.
- External factors like turbulence level and radial correlation length do not affect the detection of the two peaks in optimized systems. The spectral width is mainly determined by the intrinsic spectral resolution of the system (beam waist and probing frequency).