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## Embedded reflectometry into additional heating launchers of WEST

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► **To cite this version:**

F Clairet, C Bottereau, A Jamann, C Jammes, L. Vermare. Embedded reflectometry into additional heating launchers of WEST. IRW16 - 16th International Reflectometry Workshop, May 2024, Greiswald, Germany. cea-04706584

**HAL Id: cea-04706584**

**<https://cea.hal.science/cea-04706584v1>**

Submitted on 23 Sep 2024

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## Embedded reflectometry into additional heating launchers of WEST

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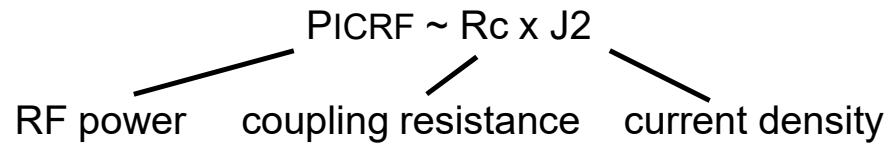
## **outline**

- **Coupling issue of LH and ICRH heating systems.**
- **Embedded reflectometry in LH launcher.**
- **Embedded reflectometry in ICRH launcher.**
- **Sectoral waveguide horn antennas.**
- **Magnetic ripple and Doppler shift issues.**



# Coupling issue of RF heatings LH and ICRH

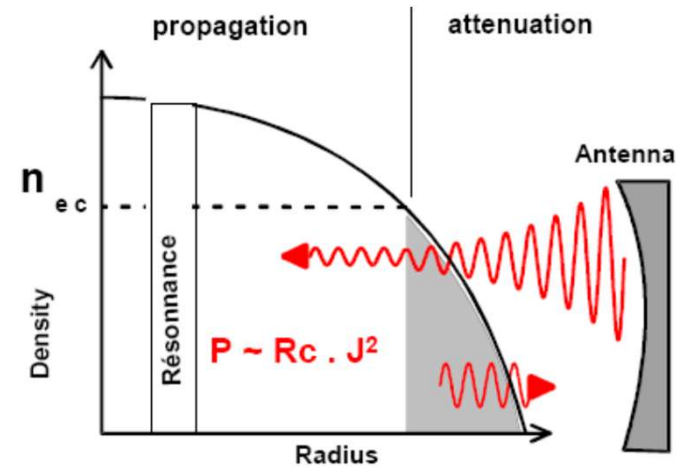
**Coupling** is related to antenna matching



**Cut-off densities :**

LH  $\sim 10^{18} \text{ m}^{-3}$

ICRH  $\sim 10^{19} \text{ m}^{-3}$



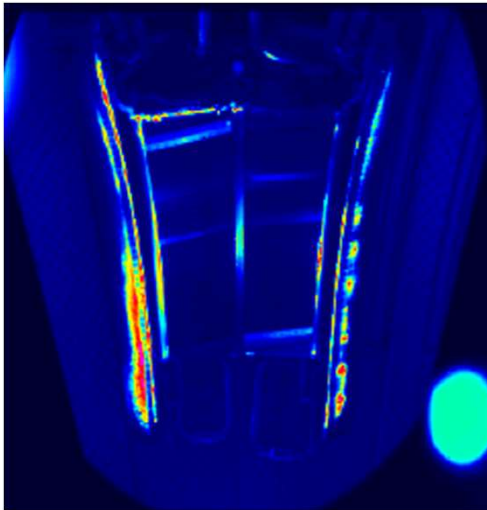
**RF coupling depends on the distance between the RF launcher and the plasma**

*Clairet PPCF 2004)*



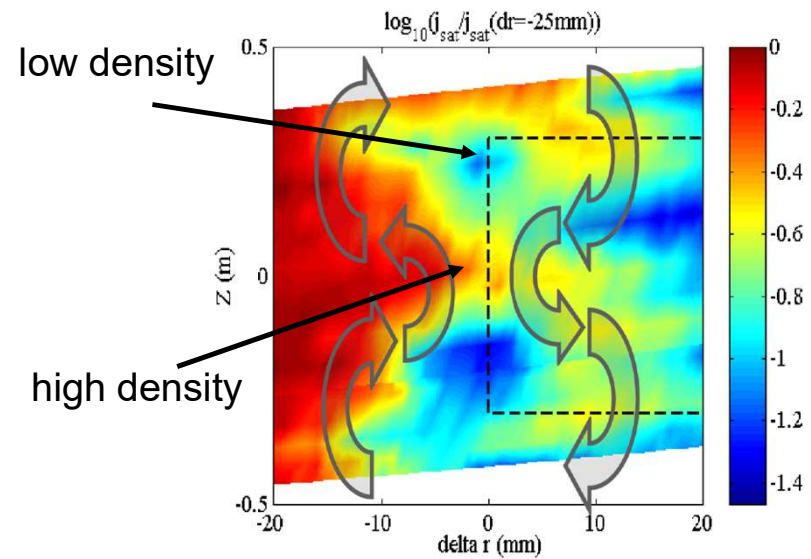
# Density variations in front of the antenna

Density inhomogeneities related to local overheatings of a ICRH antenna



L. Colas et al. *Nuclear Fusion*, vol. 46, p. S500 (2006)

Density turns around cells



L. Colas, J.P. Gunn et al. *JNM*, vol. 363-365, p. 555 (2007)



# Waveguides embedded in the LH Antenna

(Clairet IRW 2009 & RSI 2011)



3.4 m of WR-28 waveguides (26-40 GHz) between the 2 modules of the LH antenna.

+ 68 cm of WR-15 waveguides (50-75 GHz) to avoid water cooling pipes.

- 10 cm of linear taper welded by electron beam.
- Differential thermal expansion module/waveguides : 5mm max.
- Estimated losses in waveguide ~ 5dB.



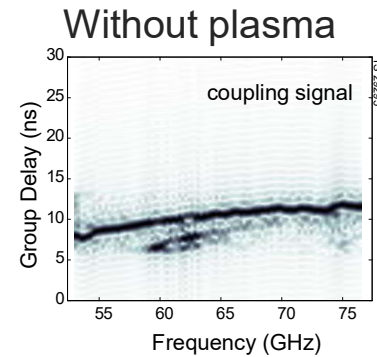
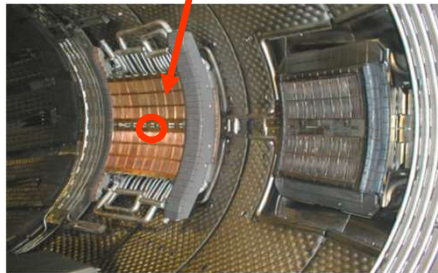
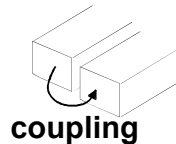
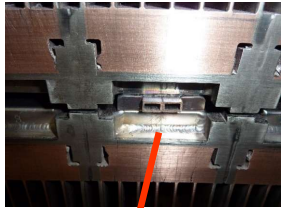
**Rather complex integration required...**



# Edge density measurements

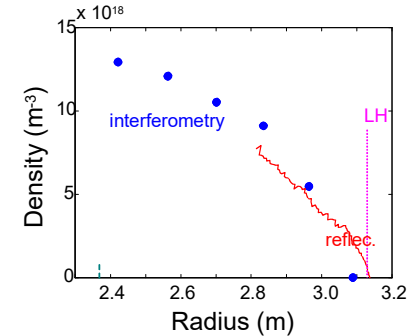
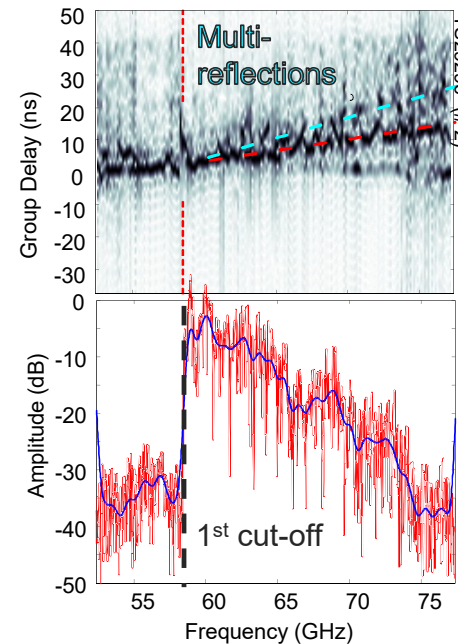
Tore Supra : Designed and operated in V-band X-mode

open WR-28 waveguides antennas



→ Reference signal

With plasma



- Installation constrains by limited place.
- Antennas with poor directivity.
- Convenient coupling for reference.

- First cut-off clearly identified.
- Signal losses due to low directivity.
- Multi-reflections issue.

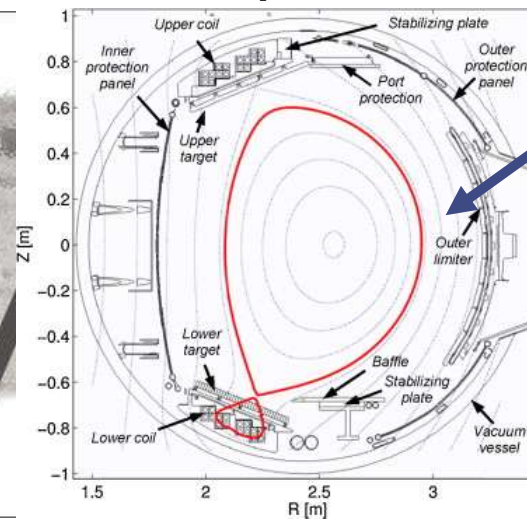


# From Tore Supra to WEST

**Circular shape  
carbon limiter**



**D-shape & X-point  
W - open divertor**



**Same B field  
but plasma  
further away.**

**Reflectometers  
evolution :**

**V-band X-mode (edge)  
W-band X-mode (core)  
D-band X-mode (center)**



**V-band O-mode (core)  
W-band X-mode (edge)  
D-band X-mode (center)**





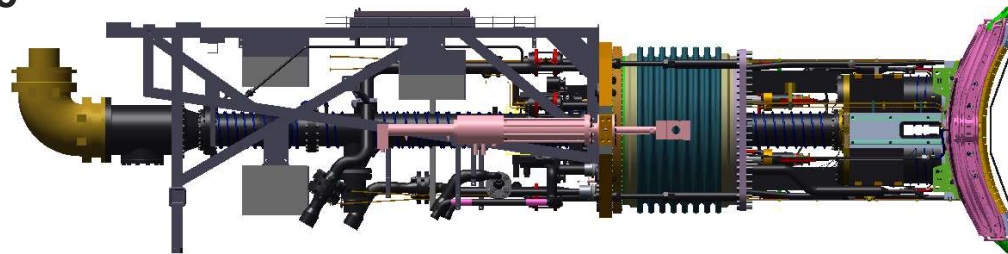
ASIPP



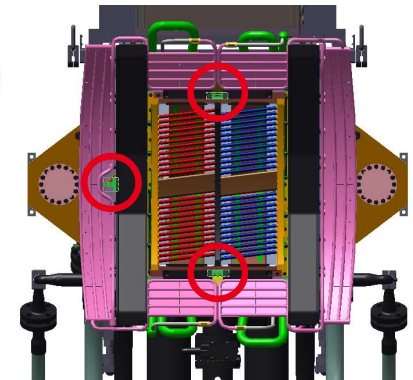
# Waveguides embedded in the ICRH Antenna

(SIFFER : Sino-French Fusion Energy center)

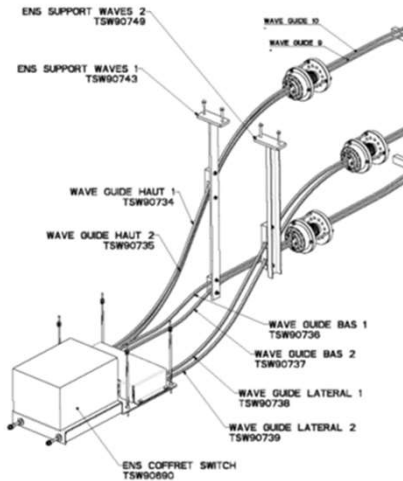
WEST : Embedded X-mode  
W-band reflectometer.



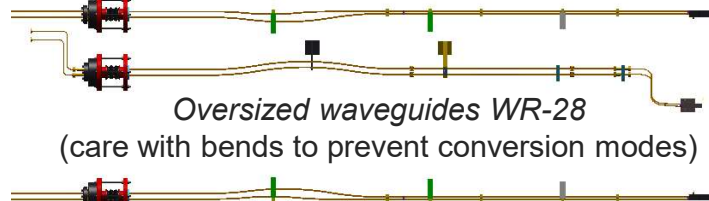
3 pairs of waveguides



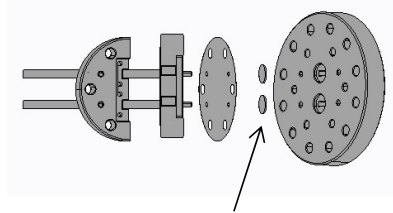
Top, bottom and lateral  
Measurements.



All the waveguides can be  
connected to one reflectometer



Oversized waveguides WR-28  
(care with bends to prevent conversion modes)



quartz windows for vacuum insulation

Provide "simultaneous"  
measurements at all three locations.

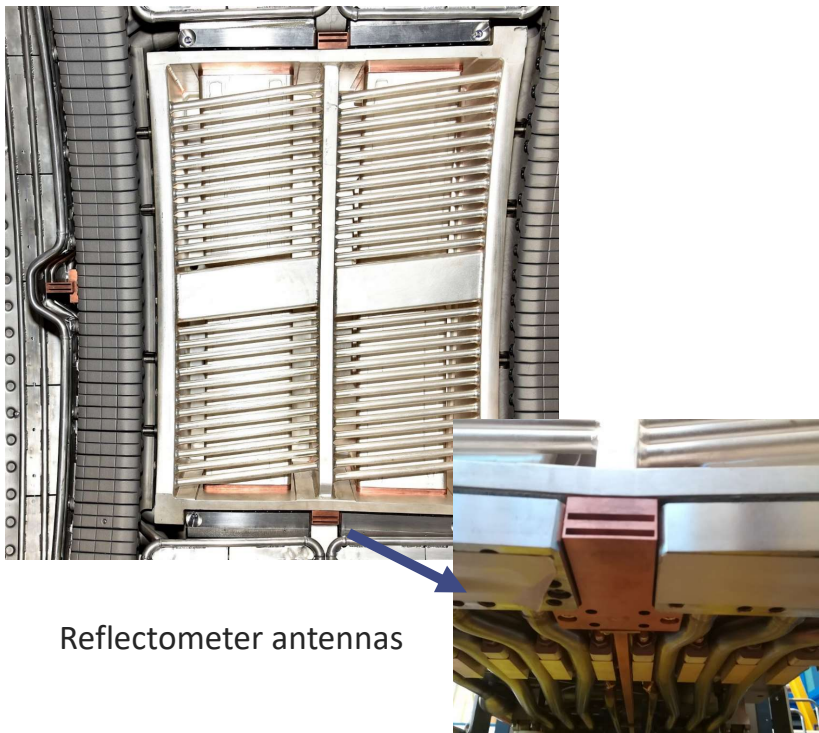


# Sectoral waveguide antennas

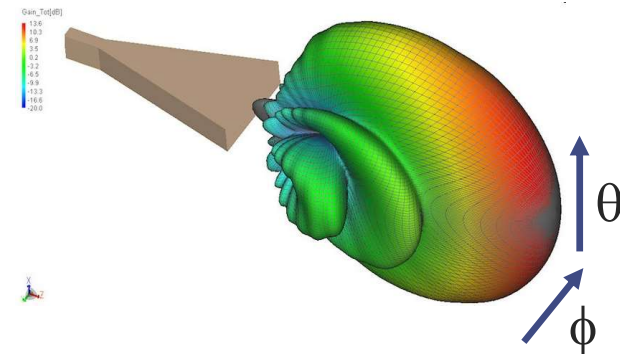
Provide comparable coupling signal with higher reflected signal amplitude

*(designed and proposed for ITER-ICRH - Claret IRW11 2013)*

ICRH launcher



Radiation pattern



## Sectoral antennas

- **Manage limited occupation.**
- **Better toroidal directivity.**
- **Still provide coupling reference.**

*Improved reflected signal by 20 dB  
Reflected / coupling signals ~ 30 dB*



# Experimental results

## Advertisement

- **ICRH reflectometry operates since 2024.**
- **“Normal” reflectometry had acquisition issue, available only at end of campaign.**
- **Present results are still in progress and will need further assessments.**

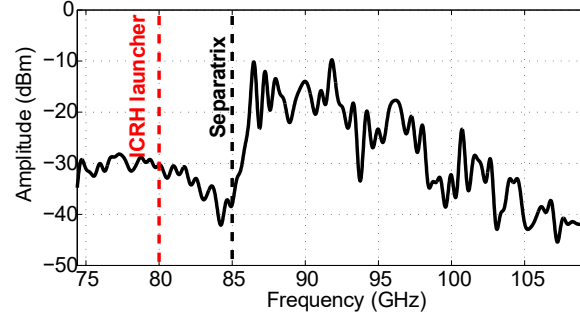
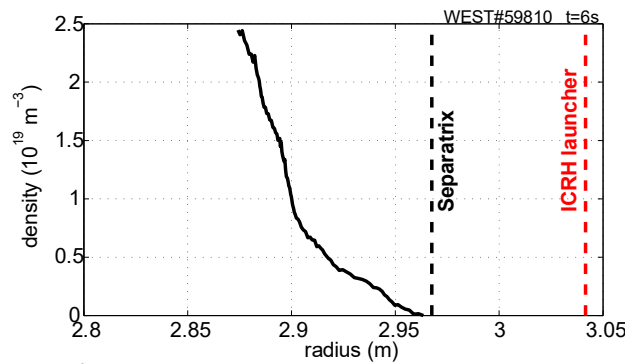


# ICRH - Lateral antennas

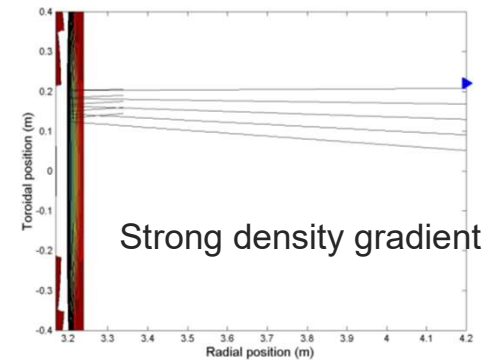
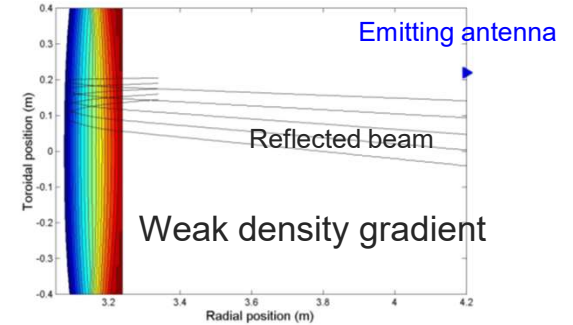


Angle to compensate for ripple

No plasma in the SOL !  
→ profile initialization issue



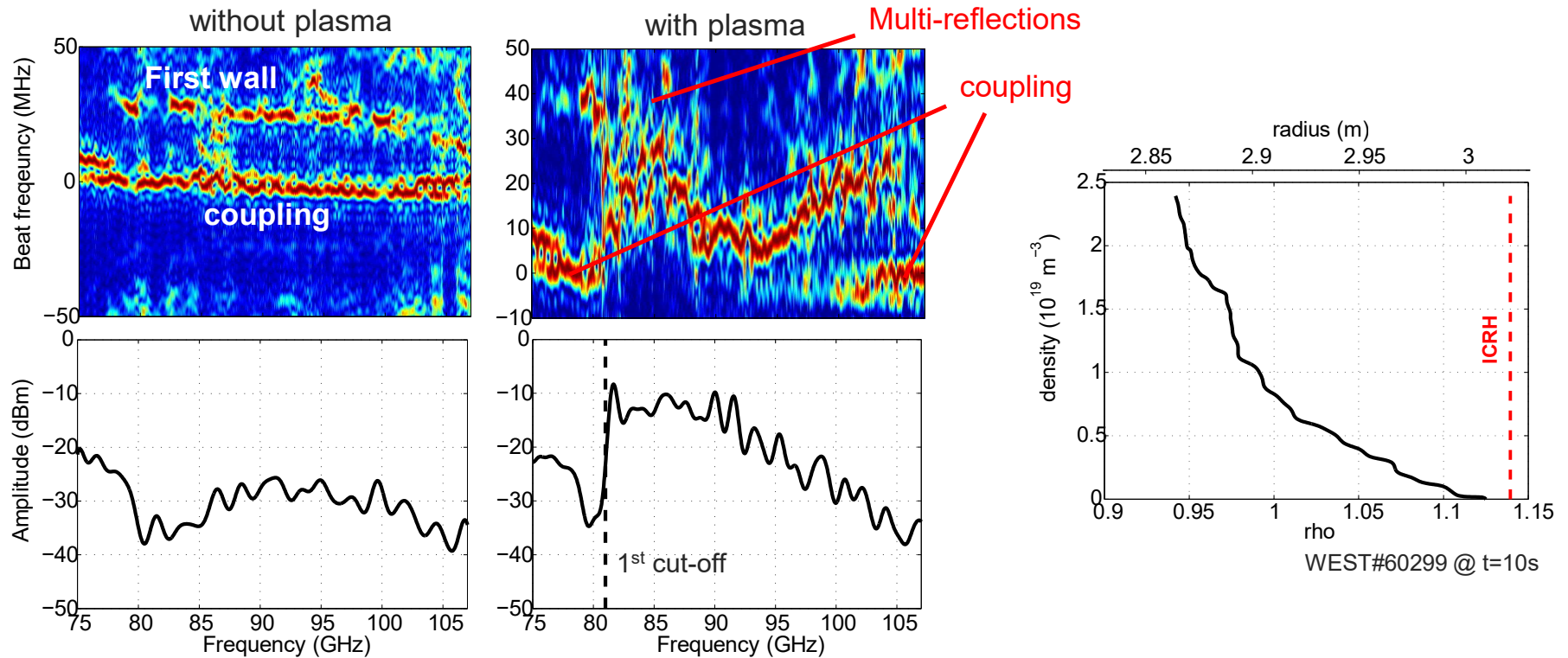
## Simulations



**Despite the corrected angle, the measurements still suffer amplitude losses due to the magnetic ripple (~ 6% on WEST) accentuated by the low density gradient in the SOL.**



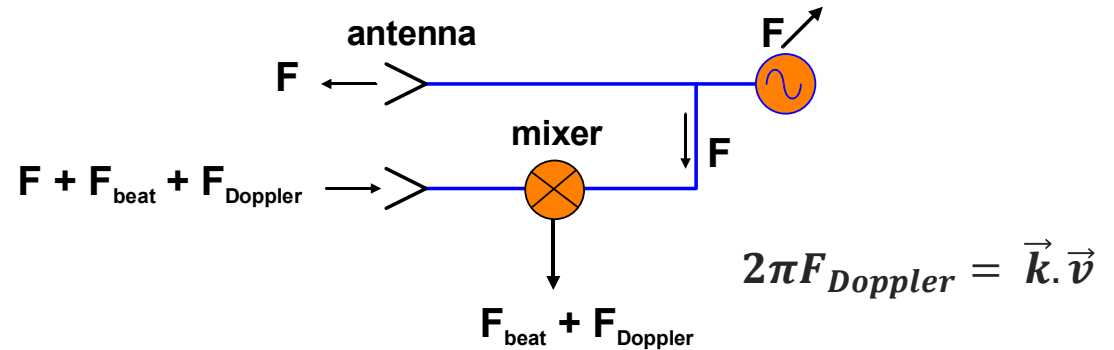
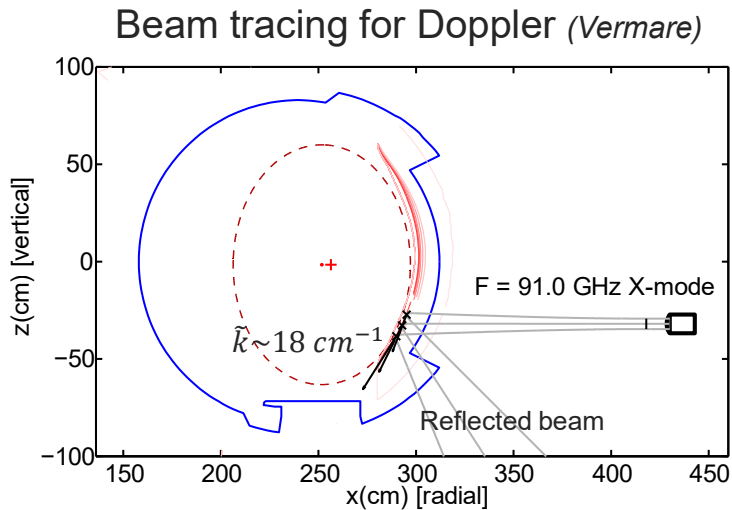
# ICRH - Lower antennas



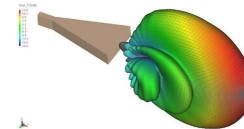
**Good radial coverage of the density profile for ICRH coupling studies.  
Still issues with multi-reflections but manageable with adequate signal processing...**



# Beam tracing & Doppler shift



Low poloidal directivity



$k \sim ?$  (but likely low  $k$  at the cut-off)

$v \sim$  up to tens km/s, positive & negative & radial dependent...

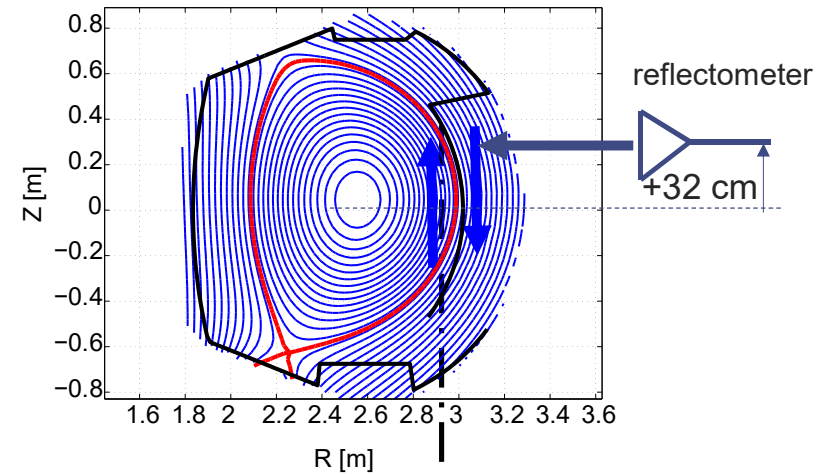
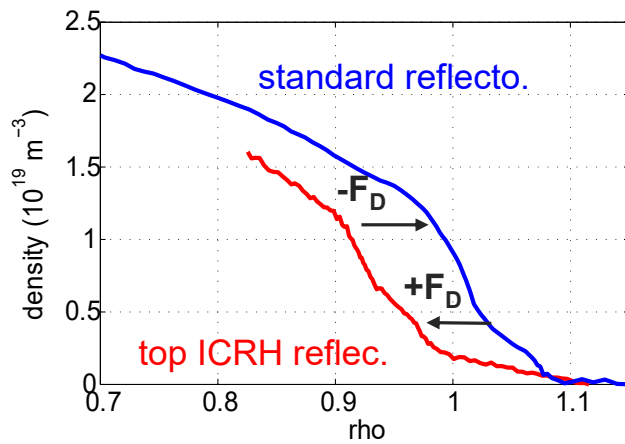
→ difficult estimation of  $F_{\text{Doppler}}$

**Thanks to the low antenna directivity, the reflected signal can still be detected.  
But difficulty to figure out precisely where it is reflected...**



# But likely affected by the poloidal rotation...

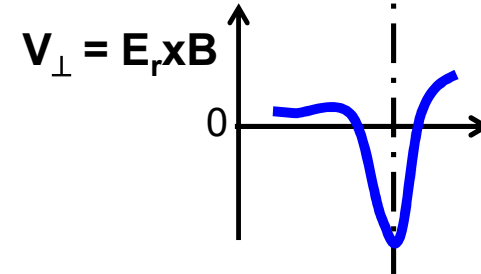
Profile exhibits radial shift compared with "standard" reflectometry



**Doppler effect due to poloidal rotation :**

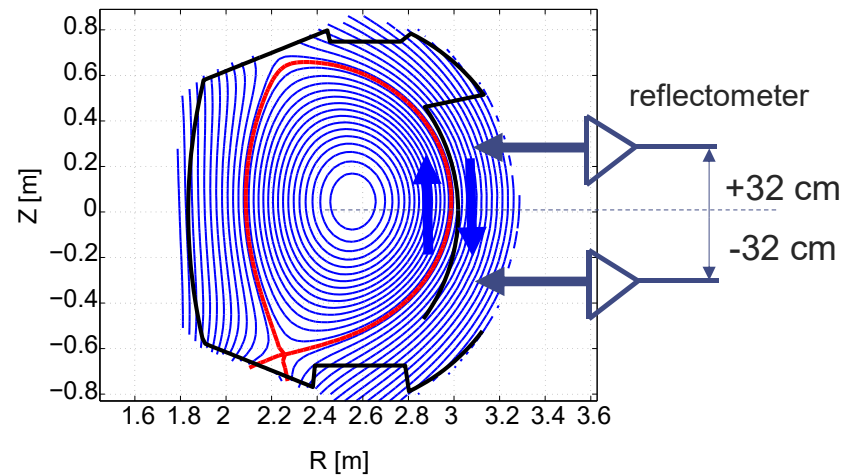
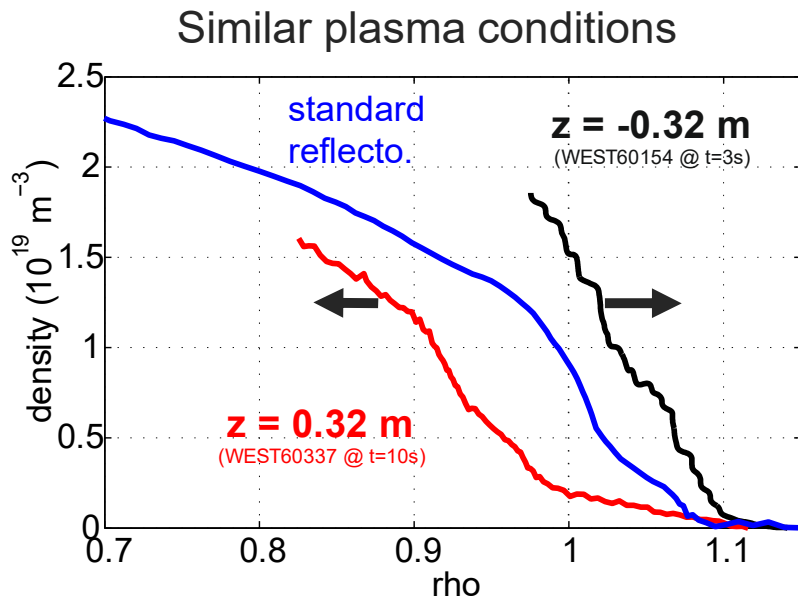
Fb ↗ in the SOL → distance increased

Fb ↘ in the Er well → distance decreased





# Comparison between up and down ICRH reflectometry



Depending on reflectometer positions the Doppler effect shifts the profiles inward or outward (as one would expect...)



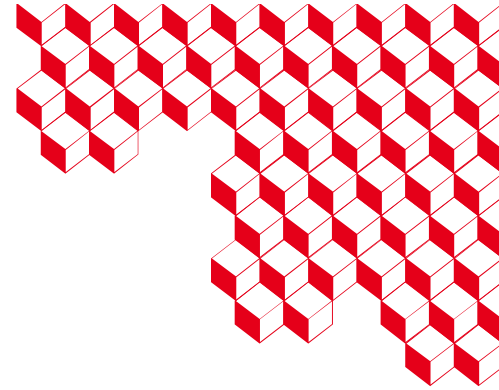


## Summary

- Sector antennas provide interesting reference coupling as well as plasma reflected signals.
- Lateral ICRH antenna system appears to be ineffective due to ripple and power losses...
- Use ultra-fast sweep capabilities to neglect the Doppler shift relative to the beat frequency.
- Perform consecutive frequency sweeps, ramping up ( $F_b + F_D$ ) then ramping down ( $-F_b + F_D$ ), to compensate the Doppler shift and to measure it by post-processing.
- Use it as a simple Doppler reflectometer.



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**Thank you for your attention**