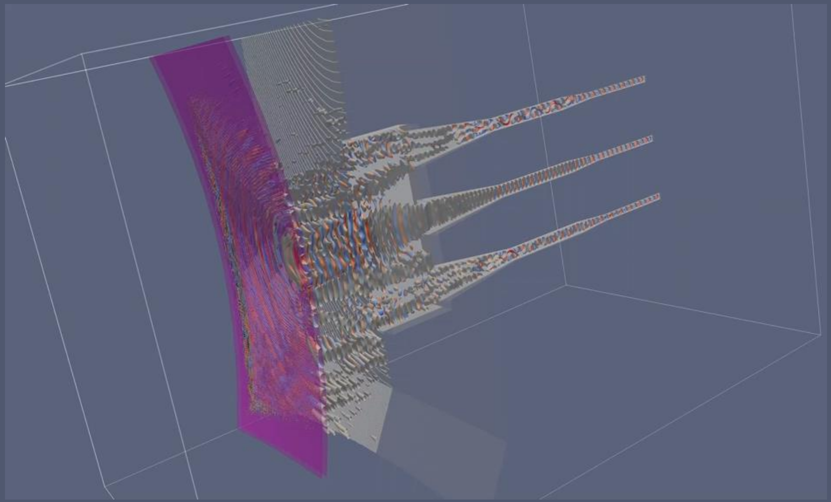
Overview of the studies towards a Plasma Position Reflectometry System for Divertor Test Tokamak (DTT)



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EUROfusion

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Our work (hi)story…

- **Reflectometry foreseen in next generation machines (e.g. ITER & DEMO)**

- **DTT as a possible testbed for DEMO solutions, including reflectometry**

- **Reflectometry can be a useful asset for DTT**
  - *As in all fusion machines there will be a need for diagnostics to gather **knowledge** about the **physical processes** occurring in the plasma, for **engineering needs and control***

This talk will focus/summarize:

- **Assesment study of 3 line-of-sight LFS PPR**
  - *Integrated in EUROfusion PEX DTT Topic2 IST 02/T006*

- **DTT reflectometry efforts included in EUROfusion Enabling Research Project *Advances in real-time reflectometry plasma tracking for next generation machines: Application to DEMO-ENR-TEC.01.IST***
  - *Incorporation of former LFS PPR studies and further development*
  - *During EnR, the possibility of having a PPR at the HFS become tangible*
  - *Concept needed ASAP changed EnR efforts from LFS to HFS*

Main efforts for the HFS PPR during EnR

- **Application of an integrated design workflow for a PPR diagnostic system.**
  - *Uses common CAD models of antenna and first wall components.*
  - *Incorporates 3D target plasma scenarios obtained from equilibria simulations.*
  - *Design of custom-made antennas.*
  - *Laser metal printed prototypes of the antennas.*
  - *Laboratorial tests of these antennas using* ***EnR developed compact reflectometer****
  - *Thermal analysis of plasma facing components*
  - *3D full wave FDTD simulations both in vacuum and with plasma assessed the performance.*

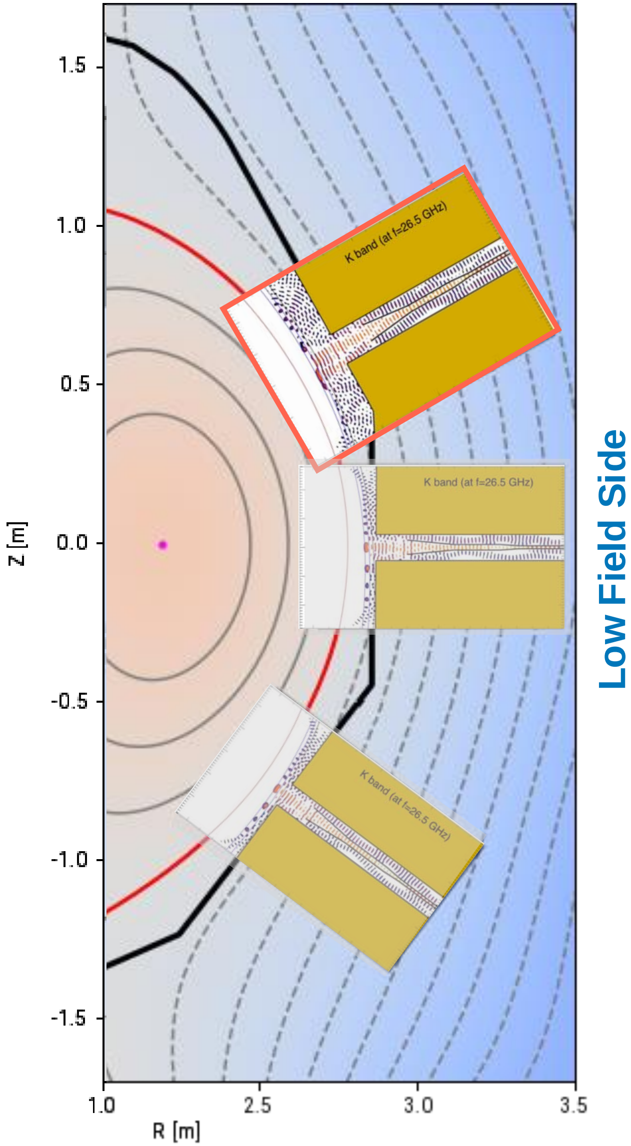
This effort integrates many of the modules that have been worked or developed in this EnR project:

1. *Strong ameliorations in synthetic diagnostics and simulation codes;*
2. *Accurate description of the target machine layout and operating scenario;*
3. *Advances in hardware;*
4. *Use of the enhanced signal processing techniques;*
5. *Advances in numerical simulation codes;*

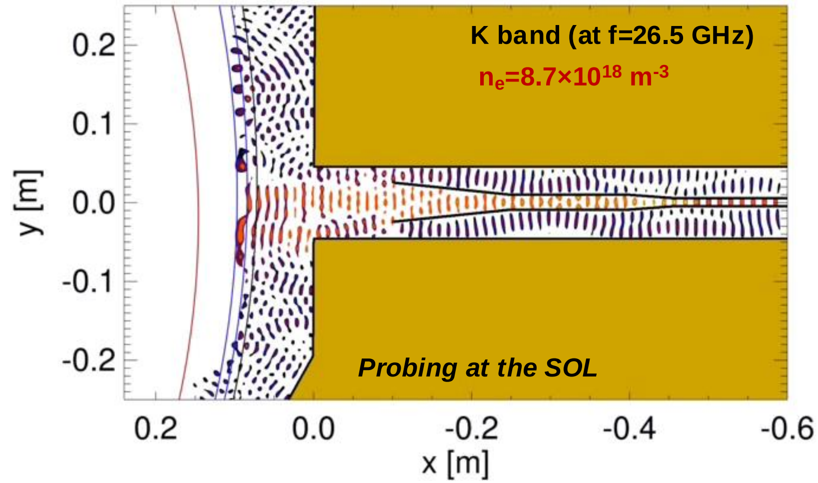
* ***Note:*** **Compact, Reconfigurable Millimeter-Wave Back-End for Next-Generation Fusion Reactors, António Silva et al.** ***at this conference Poster Session B 22 Oct 2024, 18:05***

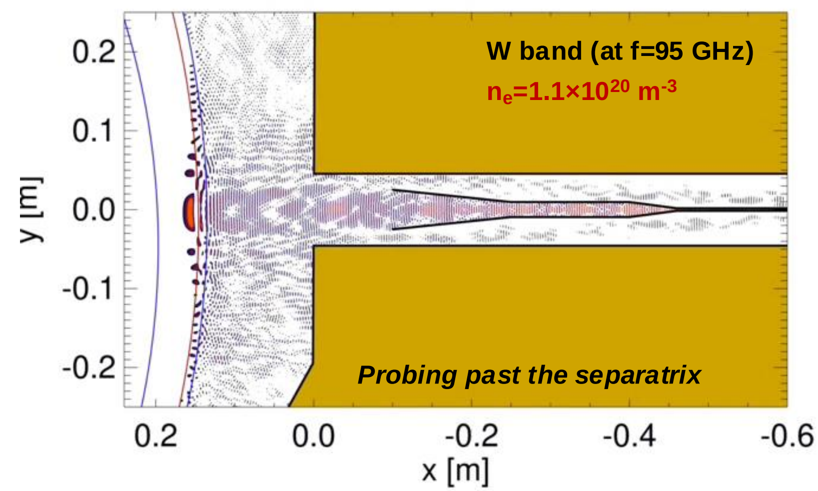
Full System for Gap 45° SN scenario probing

Single Null Scenario



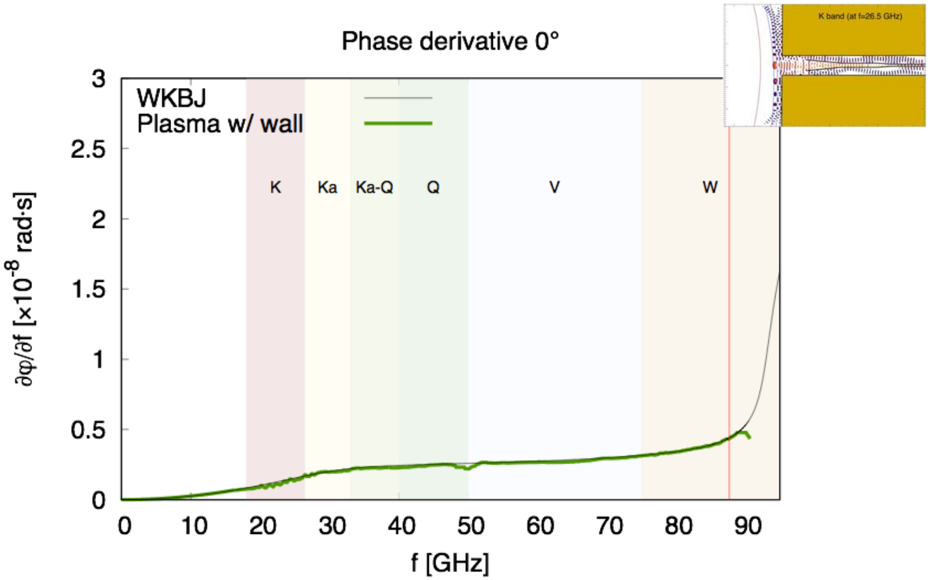
Simulated with REFMULF code

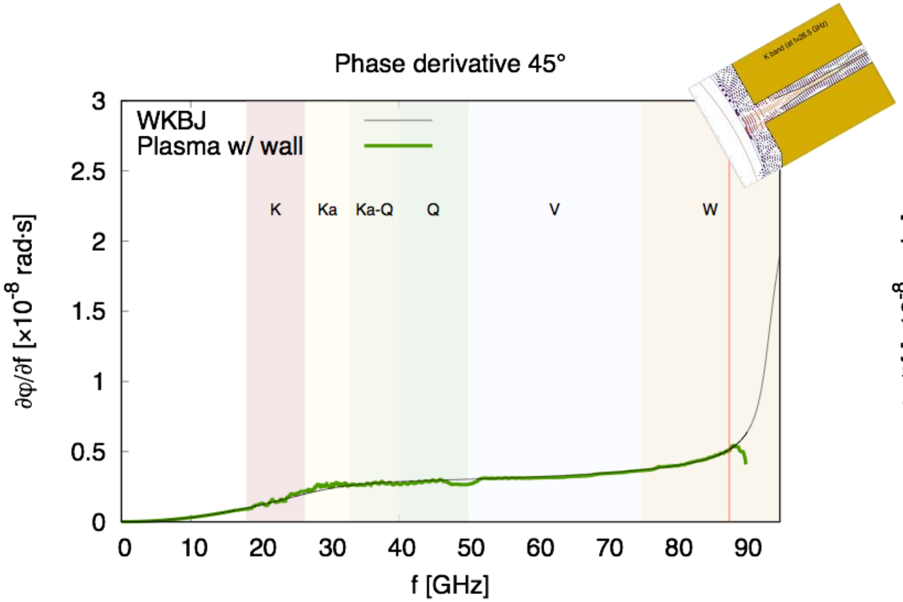


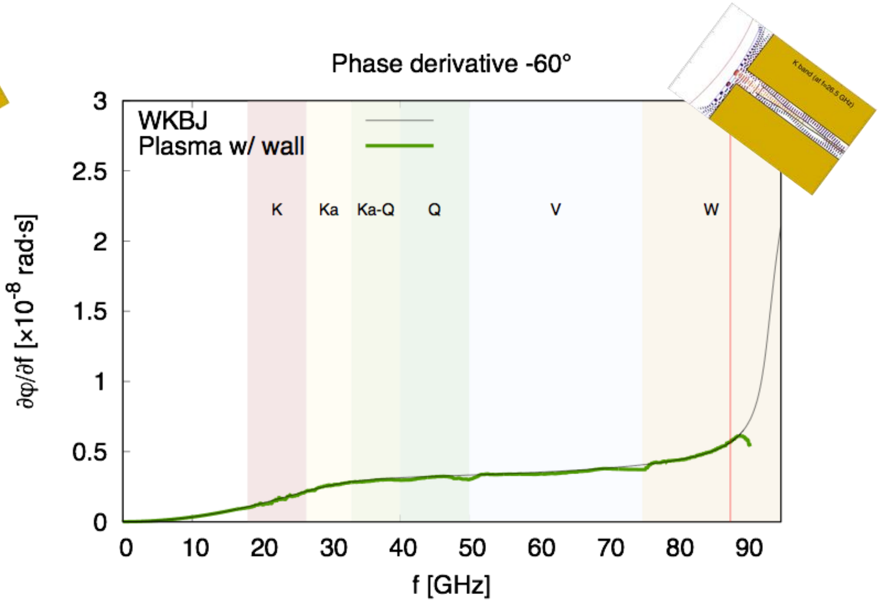


Phase derivative

The **phase derivatives** evaluated from simulation data (SN plasma scenario) represented against the **theoretical WKBJ** (known from input data).
The vertical red line marks the **separatrix frequency**. The vertical shaded areas denote the frequency ranges of the different bands.





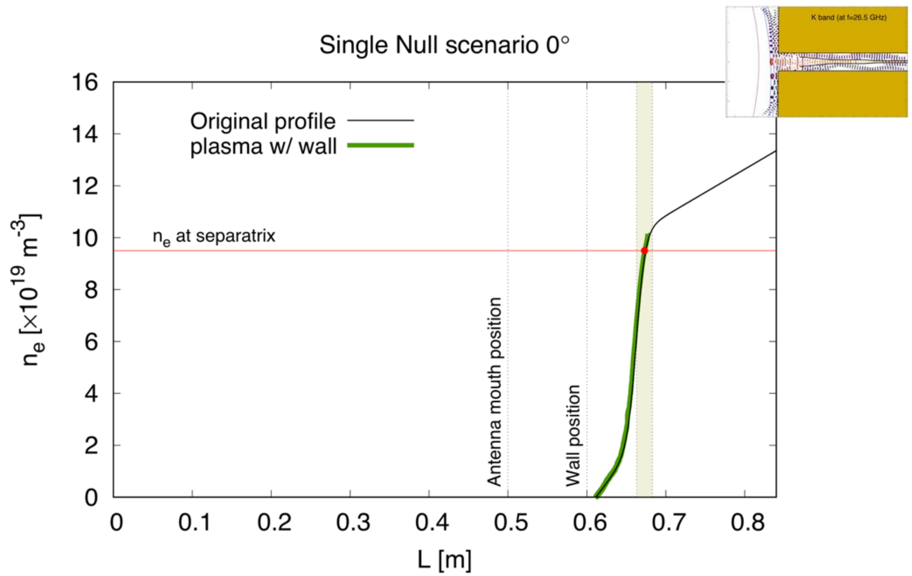


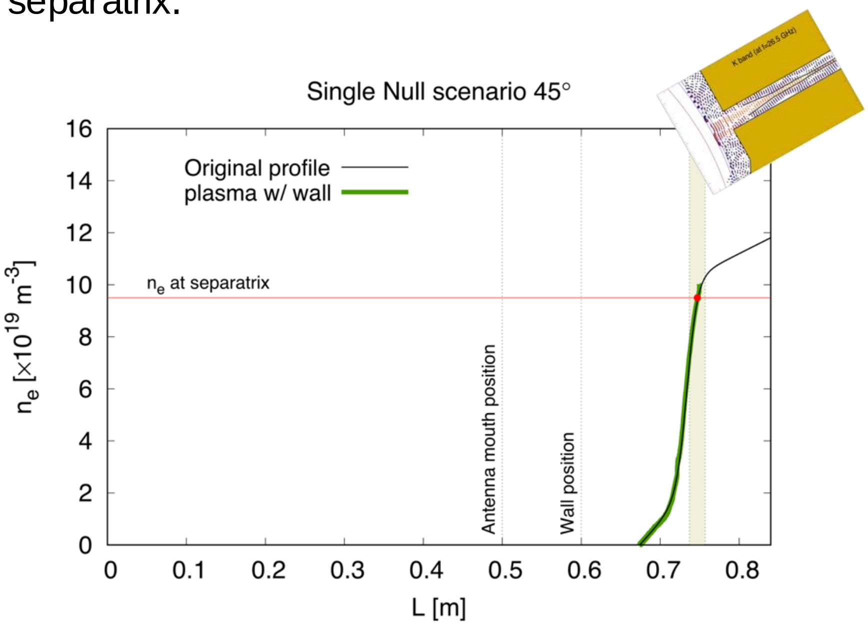
Profile reconstruction

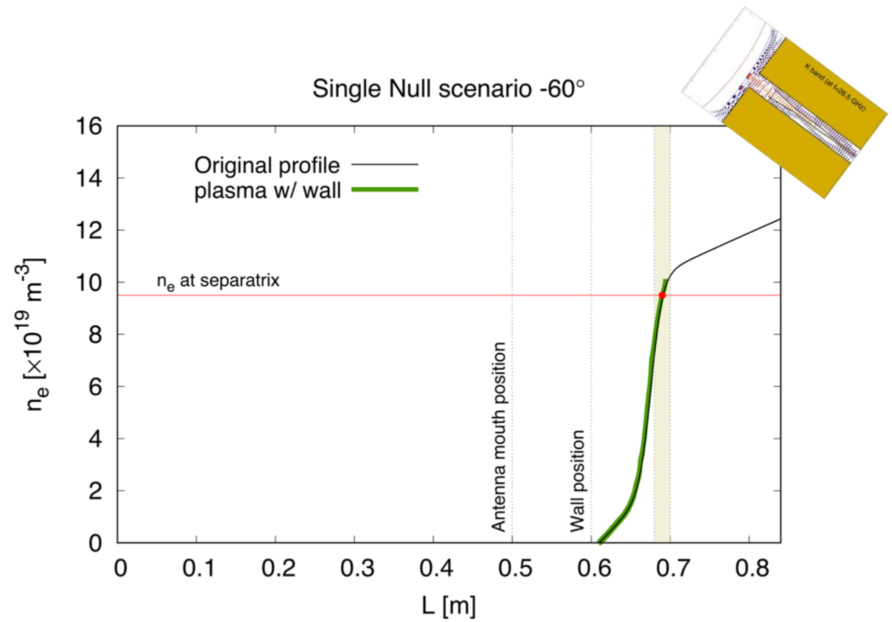
The phase derivative allows us to calculate the position of a given reflecting layer ***r(nₑ)*** and recover the electronic density profile using

$$r(F) = \frac{c}{2\pi^2}\int_0^F \frac{\partial\varphi}{\partial F}\frac{\mathrm{d}f}{\sqrt{F^2 - f^2}}$$

The **profiles reconstructed** from the phase derivatives, for the SN plasma scenario. The horizontal red line marks the separatrix density. The vertical shaded band shows the error tolerance of **1cm** in the position of the separatrix.





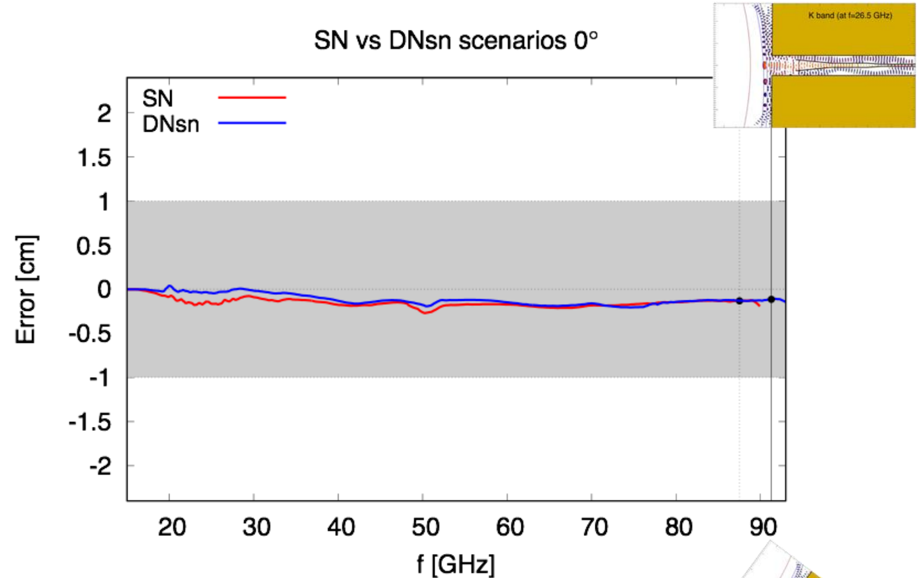


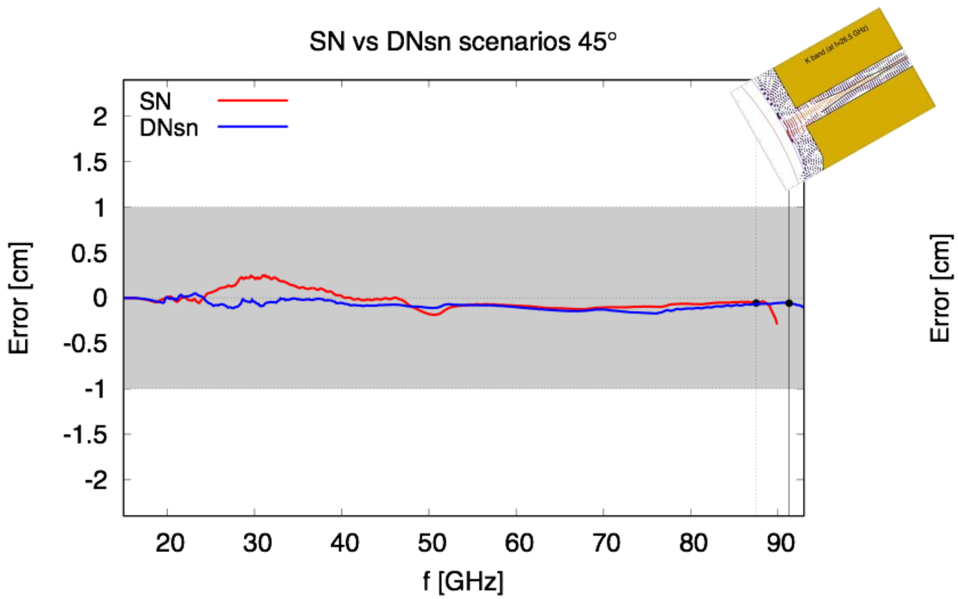
Position error at the separatrix

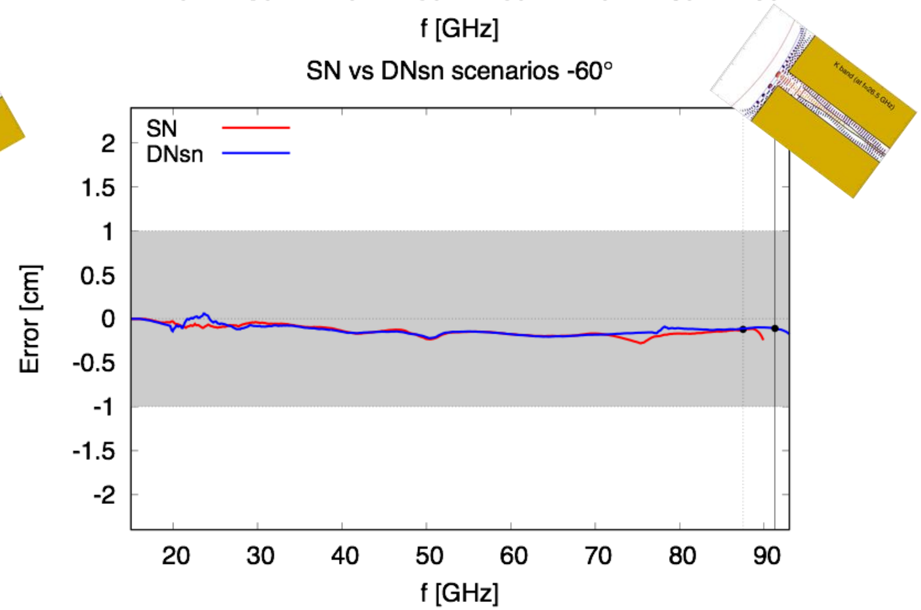
The error in the reflectometry measurement of a given position in the plasma can be evaluated as:

$$\mathrm{Error}(F) = \frac{c}{2\pi^2}\int_0^F \left(\frac{\partial\varphi}{\partial F} - \frac{\partial\varphi_0}{\partial F}\right)\frac{\mathrm{d}f}{\sqrt{F^2 - f^2}}$$

where $\partial\varphi/\partial F$ is the phase derivative of the measurement and $\partial\varphi_0/\partial F$ is the phase derivative of the reference measurement. Evaluating at the cut-off frequency corresponding to the electronic density at the separatrix, the error at the separatrix is obtained $\mathrm{Error}_{sep} = \mathrm{Error}[F(n_e)]$





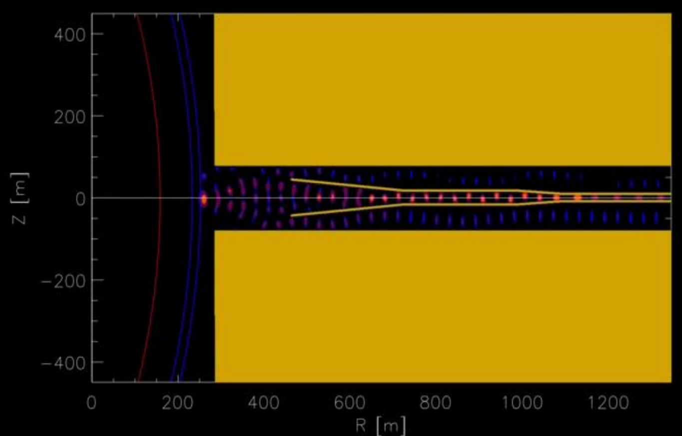


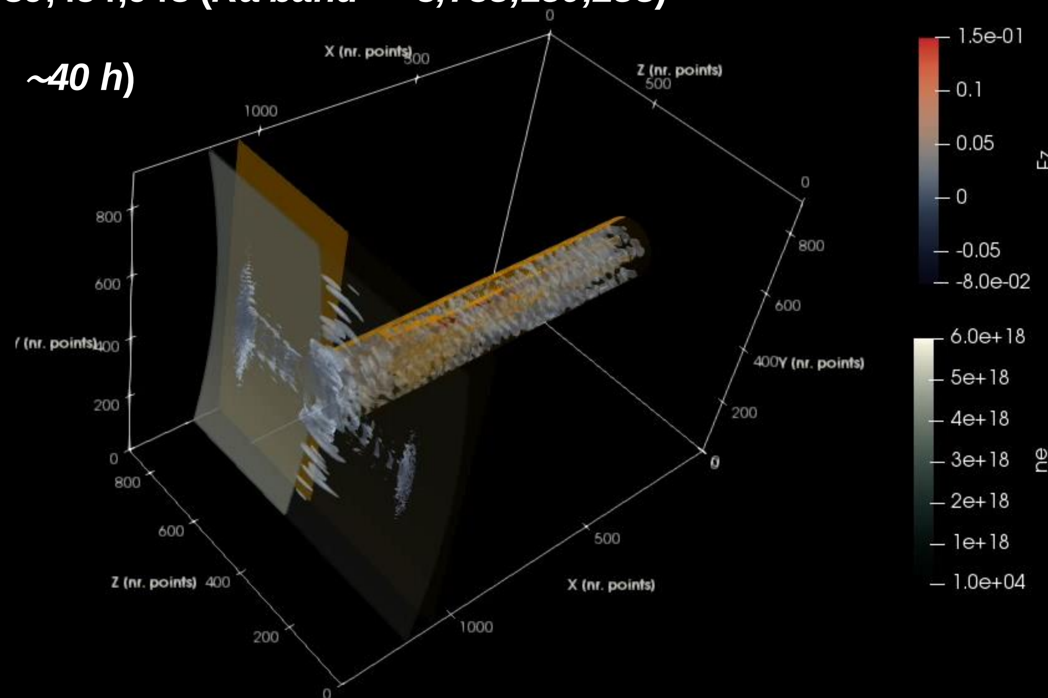
Gap 0° LFS K (&Ka) band(s)

3D

Grid size: K band — 1348×899x899 (*Ka band — 2033×1356×1356*) **Nr. of iterations: 120,000**
Total nr. Grid points: K band —1,089,454,948 (*Ka band — 3,738,150,288*)
Nr. of iterations: 120,000
Wallclock: K band ~ 7h (*Ka band: ~40 h*)

Ran on Marconi Skylake
Nr. Nodes: 64 nodes (3,072 cores)
Nr. Tasks/node (MPI tasks/node): 4
Total nr. MPI tasks: 256
Nr. OpenMP threads/task: 12





Simulated with REFMULF (2D) & REFMUL3 (3D) codes

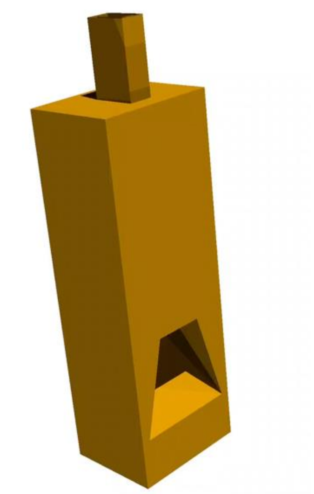
2D

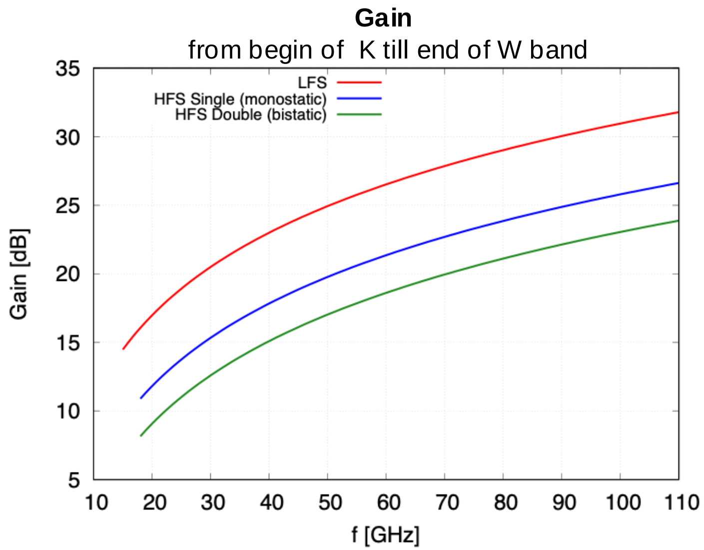
Grid size: K band — 1348×899 (*Ka band — 2033×1356*) **Nr. of iterations: 120,000**
Total nr. Grid points: K band —1,211,852 (*Ka band — 2,756,748*)
Nr. of iterations: 120,000
Wallclock: K band ~ 7min (*Ka band: ~18min*)

Ran on Marconi Skylake
Nr. Nodes: 1 node (48 cores)
Nr. OpenMP threads/task: 48

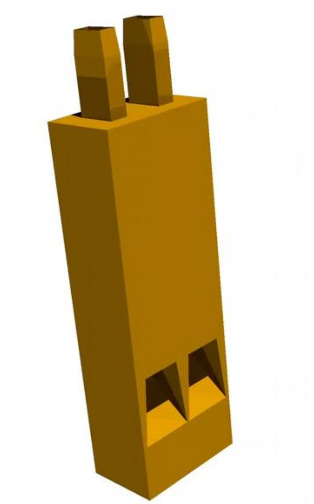
Design of antennas for HFS PPR implementation

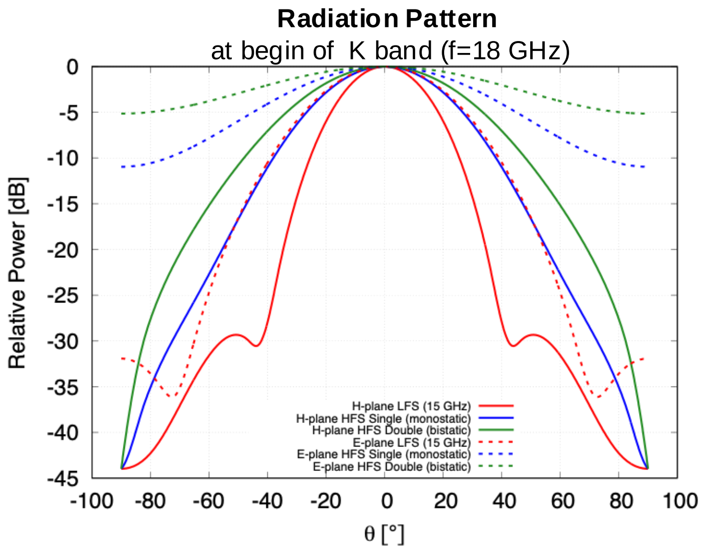
Newly designed
HFS antenna (single)

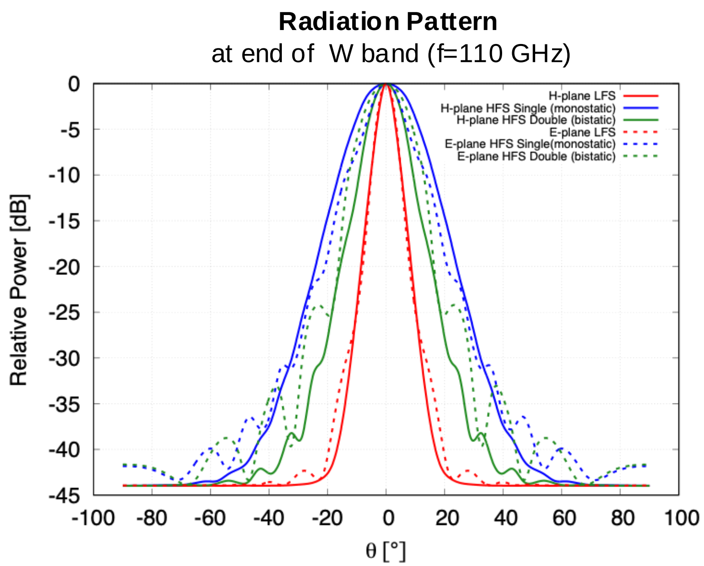




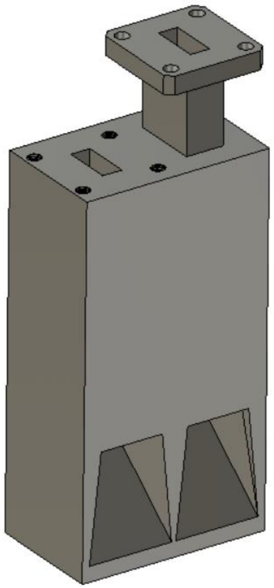
Newly designed
HFS antenna (double)

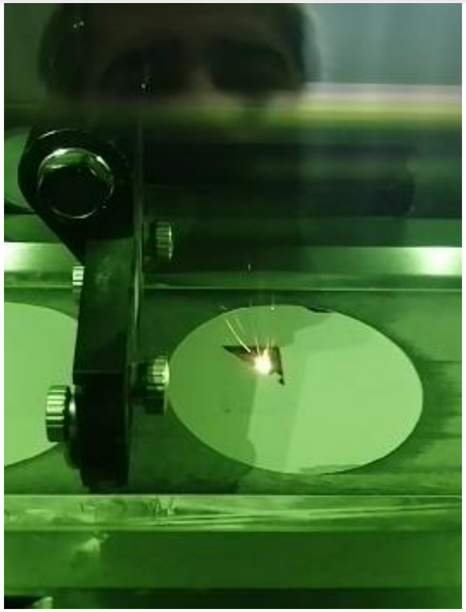




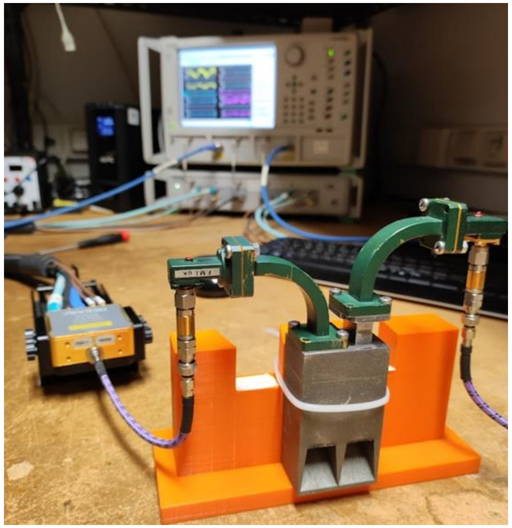


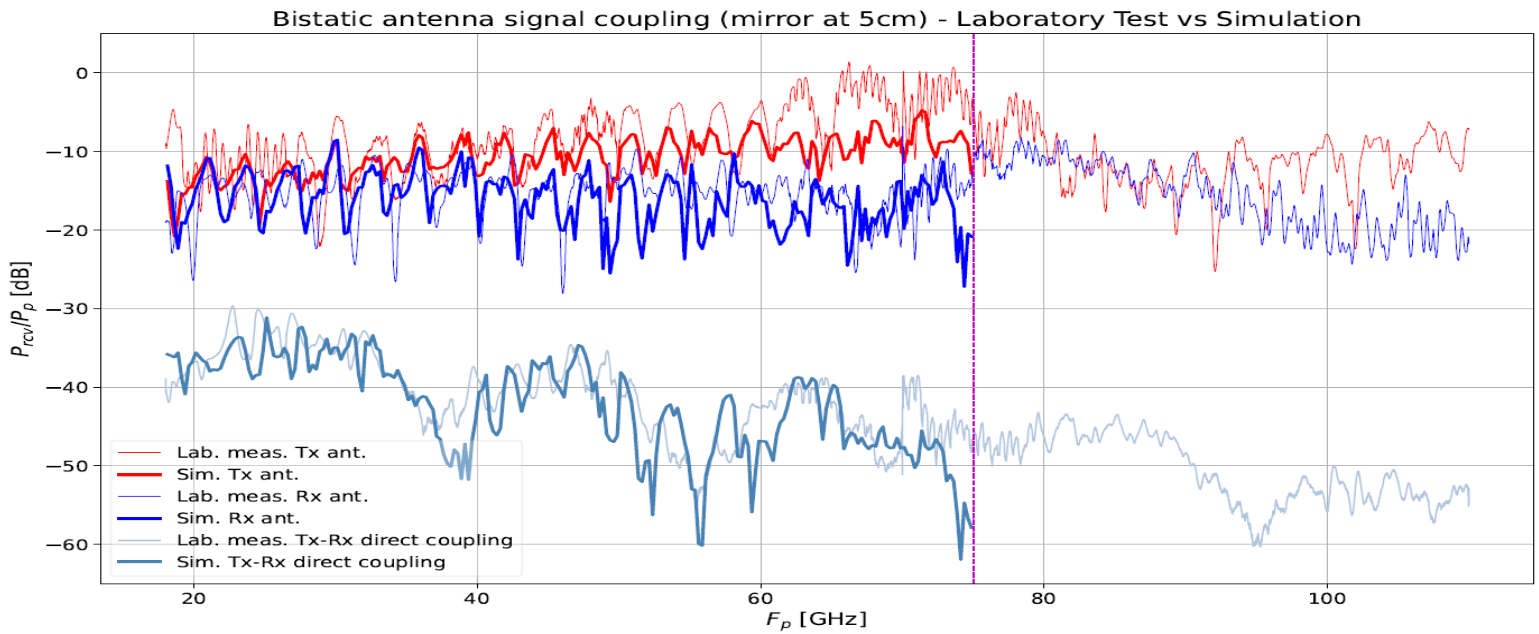
Laboratory measurements of 3D printed metal





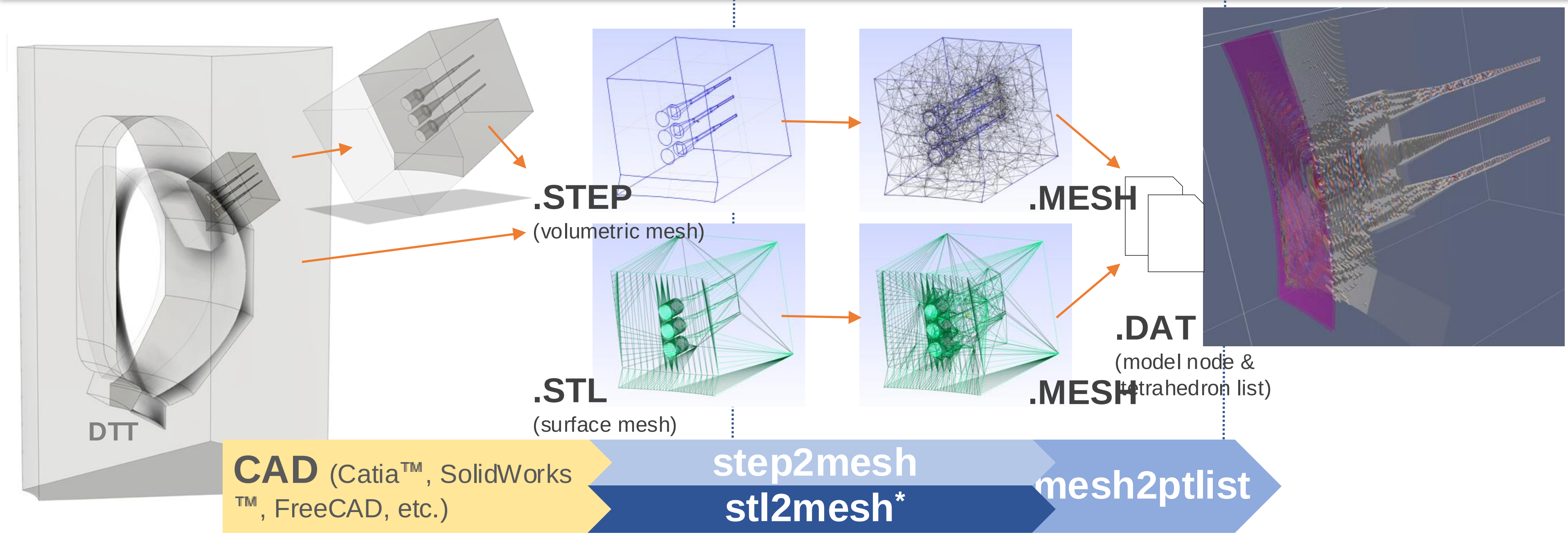
Bistatic antenna mockup





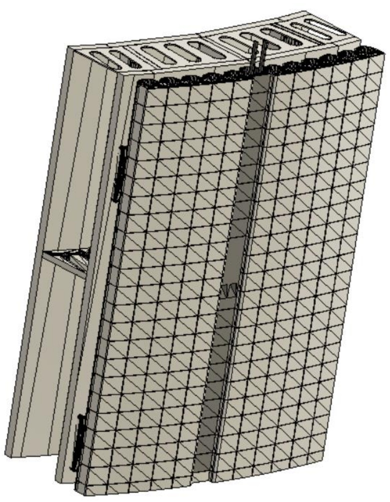
Excellent match to simulation results

CAD import pipeline



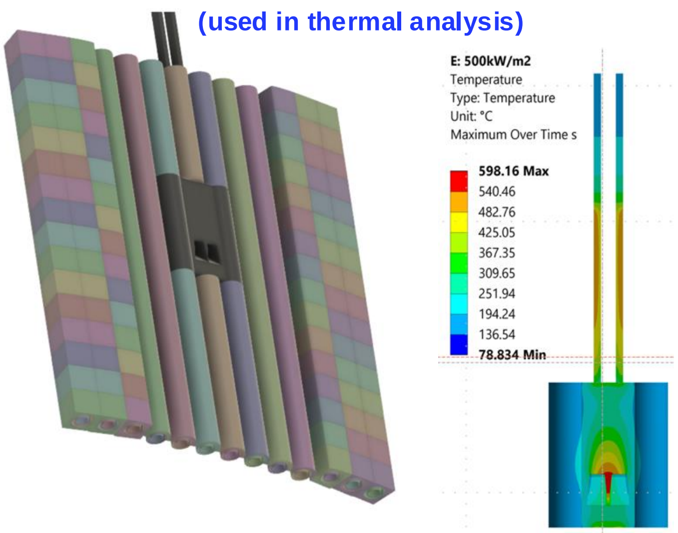
First design concept

Used on EnR bulk studies



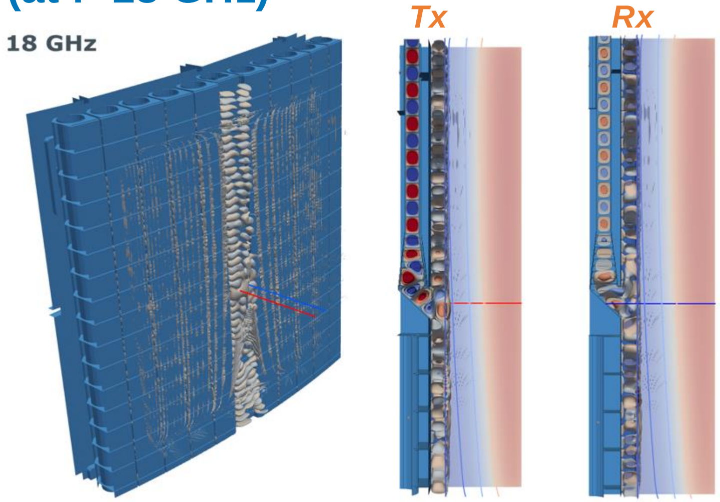
DTT current wall design

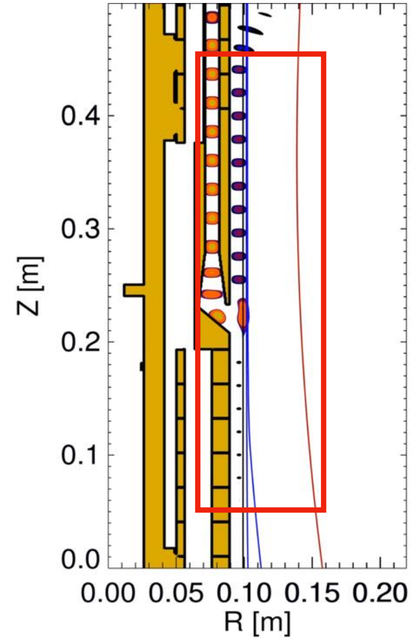
(used in thermal analysis)



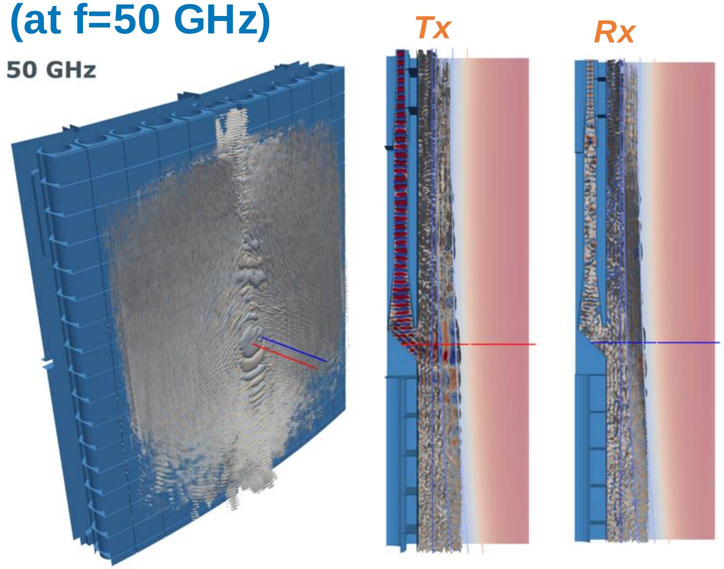
HFS 3D vs 2D qualitative comparison w/ plasma

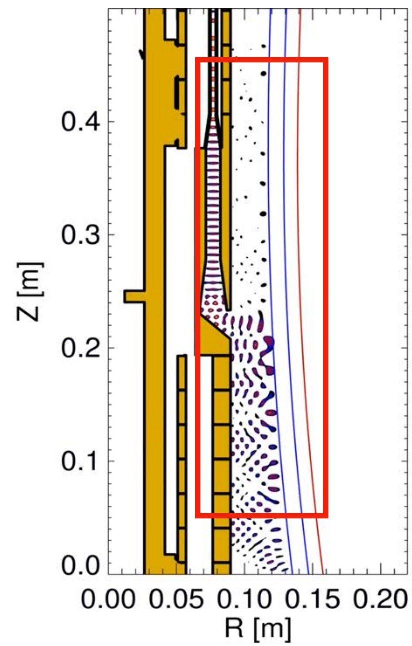
K band (at f=18 GHz)





V band (at f=50 GHz)



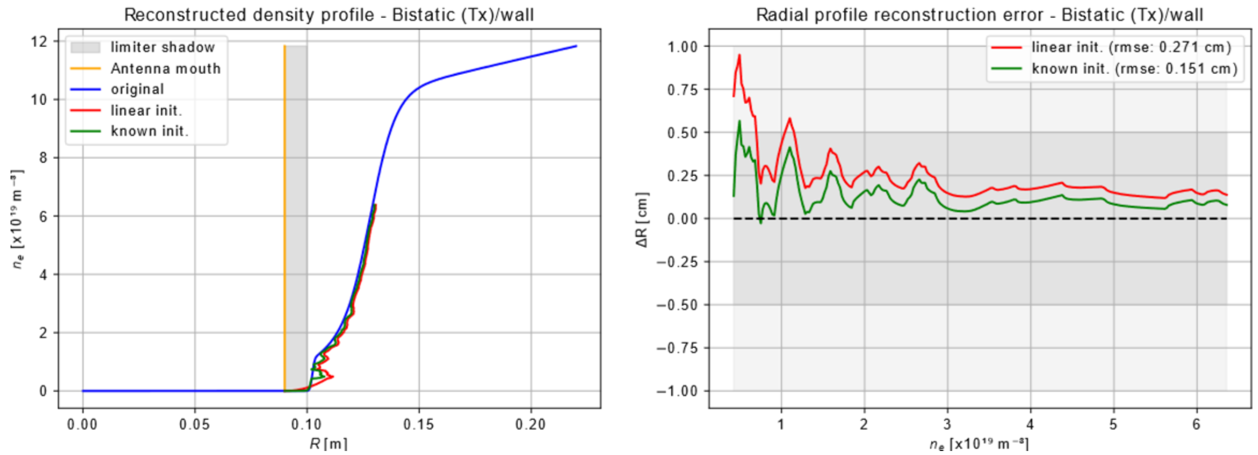


Simulated with REFMUL3(3D) & REFMULF (2D) codes

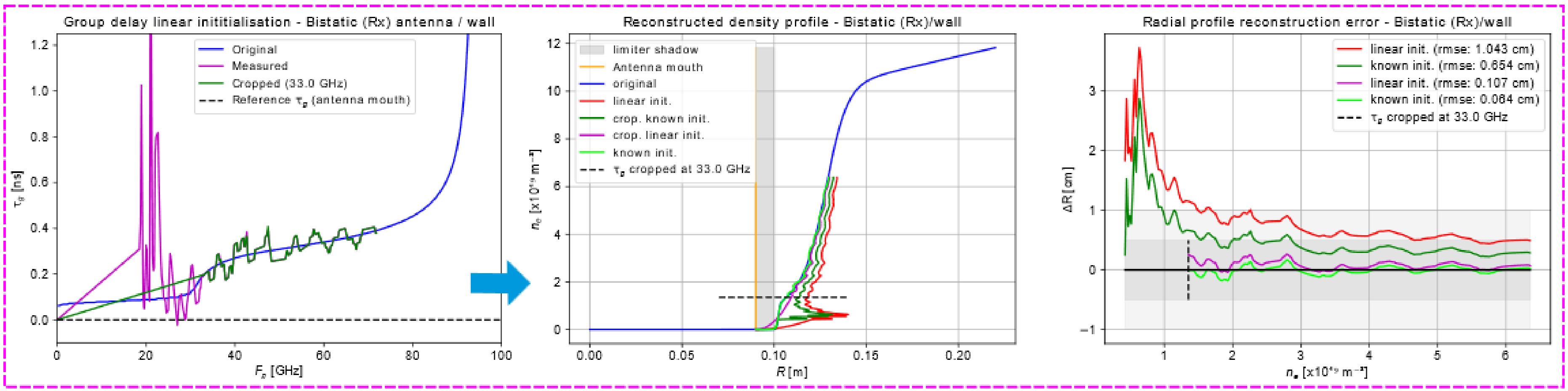
3D fullwave simulations: Bistatic antenna / Std. Single Null plasma

Δ R << 1 cm for n_e > ≈ 1.5x10^{19} m^{-3}

Bistatic antenna - T**x LOS**



Bistatic antenna - **Rx LOS**



Final points…

Important points of the work done on a comprehensive solution for DTT PPR system

- **Plasma Position Reflectometry assessment for the LFS**
  - ***Advocate for the develop and installation of a system in DTT***
  - ***An integrated design workflow for a LFS PPR should follow***

- **The integrated design workflow for a HFS PPR diagnostic system.**
  - ***Puts forward*** **one** ***solution for the HFS PPR***
  - ***A very promising working solution from the EM point of view***
  - ***We consider it a good blueprint to start a work of implementation***

- **Other designs/variations are under study**

Note **Numerical studies and design of the DTT HFS Plasma Position Reflectometer, Frederico Ruffini et al.** ***at this conference Poster Session B 22 Oct 2024, 18:05***

- **With the end of Enabling Research we are looking for a new framework of cooperation for the continuation of the work**

Thank you