EUROfusion

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Progress on the analysis and modelling of the long-leg high and low density, L-mode plasmas

D. Mancini

EPFL Swiss Plasma Center

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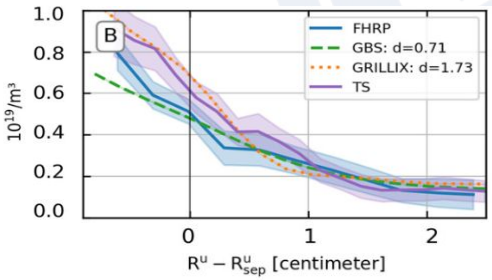
GBS validation in low and high density scenario in TCV-X23 configuration

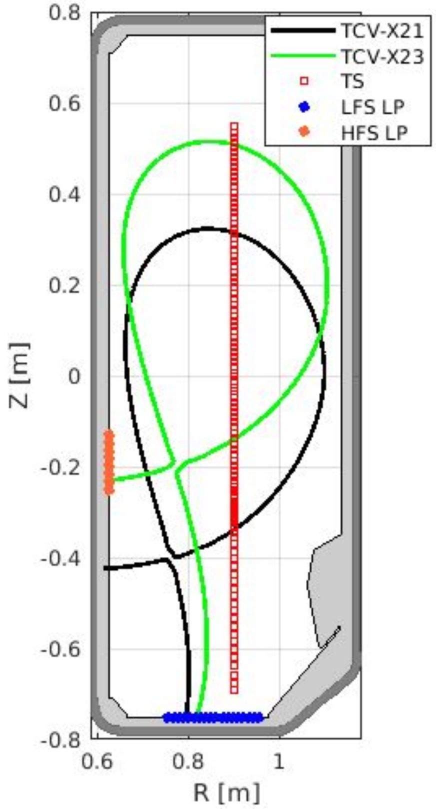
Goal : validate turbulent codes (GBS, SOLEDGE3X, GRILLIX, FELTOR, …) against long-leg case

- Explore power-exhaust capabilities of long leg
- Low B_t → easier to simulate
- Measurements of fluctuations → GPI, RDPA

Validation procedure:

1. Develop and characterize desired scenario
2. Run turbulent simulations with exp. reference (n_{sep} , $T_{e,sep}$, P_{rad})
3. Quantify difference between simulation and measurements with chosen metric

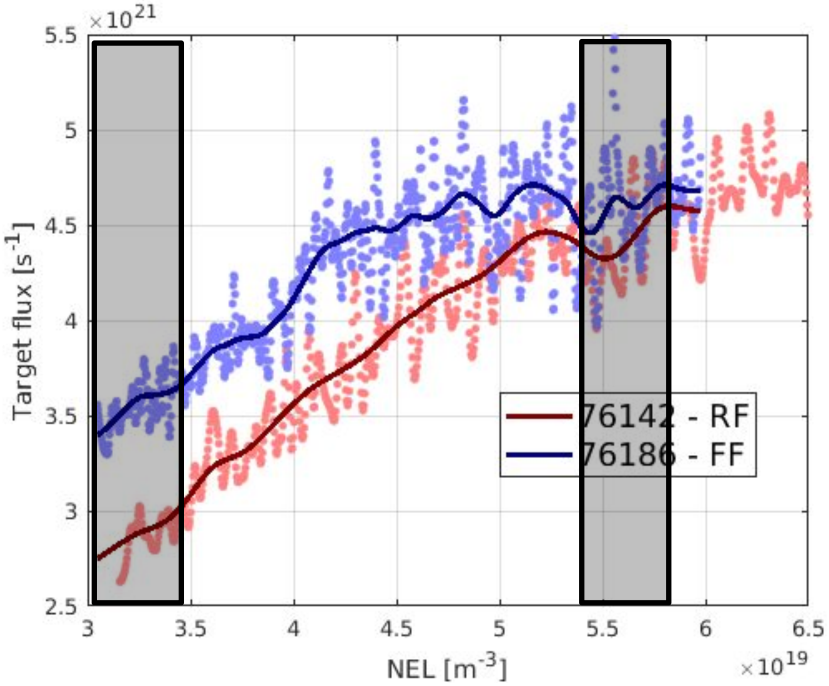


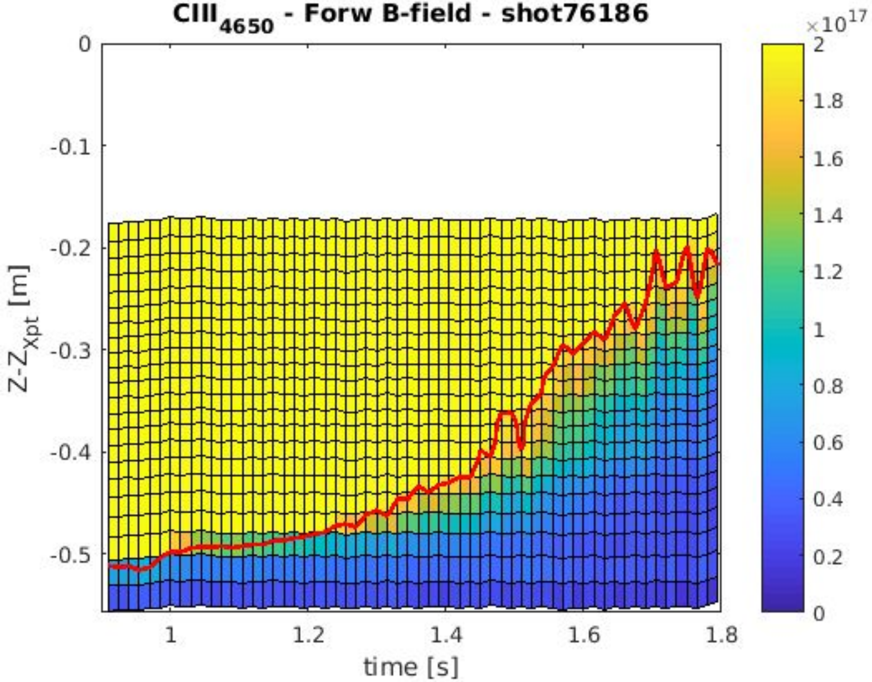


[D.S.Oliveira et al, 2022, Nucl. Fusion 62 096001]

From density ramps (2023) to flat-tops for high quality dataset

- Density ramps up to saturation of ion flux, with CIII front movement from target
- Two density windows chosen for simulations and reference for flat-top shots (2024)



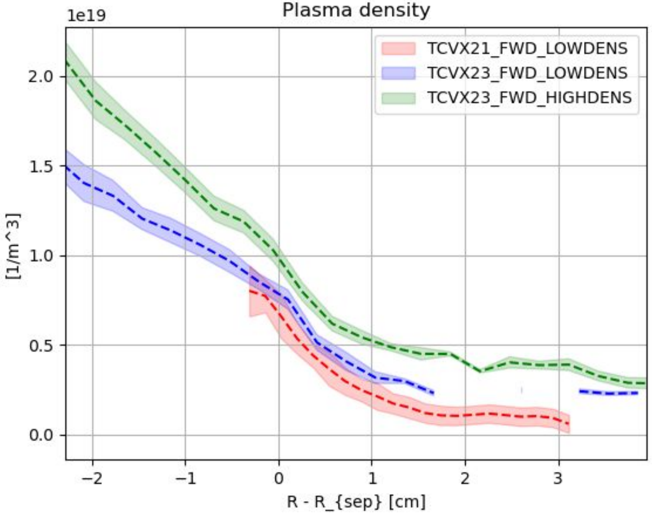


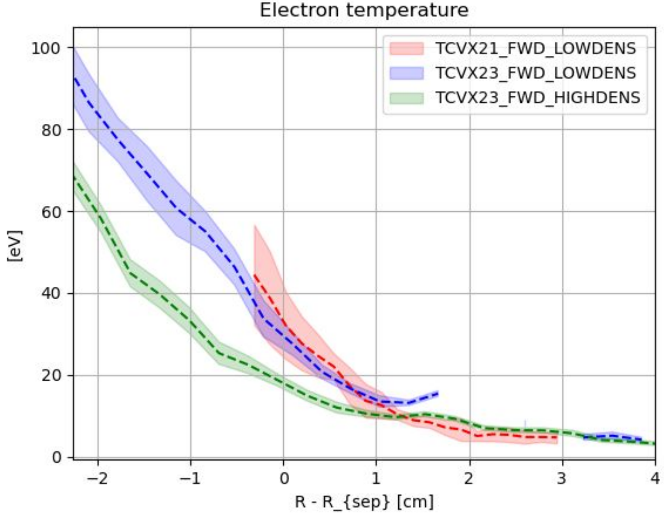
Outline

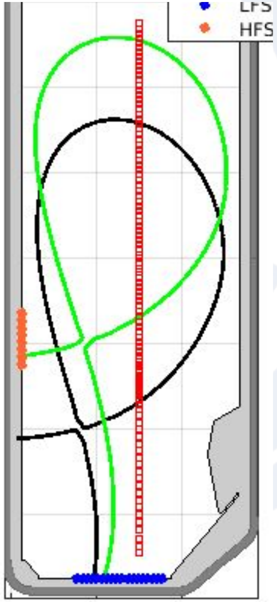
- Introduction on TCV-X23 experiment
- **Analysis performed on new TCVdb.py:**
  - Langmuir Probes measurements, outer and inner target
  - RDPA measurements, divertor profiles
  - Heat flux estimates from IR
- What is next:
  - Radiation profiles: Bolometry, Mantis and DSS
  - Fluctuations analysis: GPI, DBS
- Quick update on simulations
- Conclusions

New database format TCVdb created by D.S. Oliveira

- Easy to read and manipulate database with specific python routines in development
- First comparison of FWD field TCV-X23, with TCV-X21 as reference
- TS measurements show high n and lower T_e in SOL for high density X23, as desired

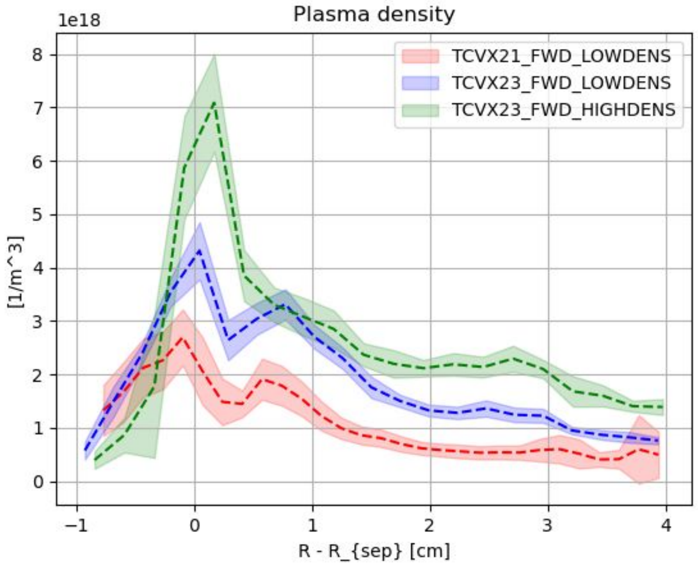


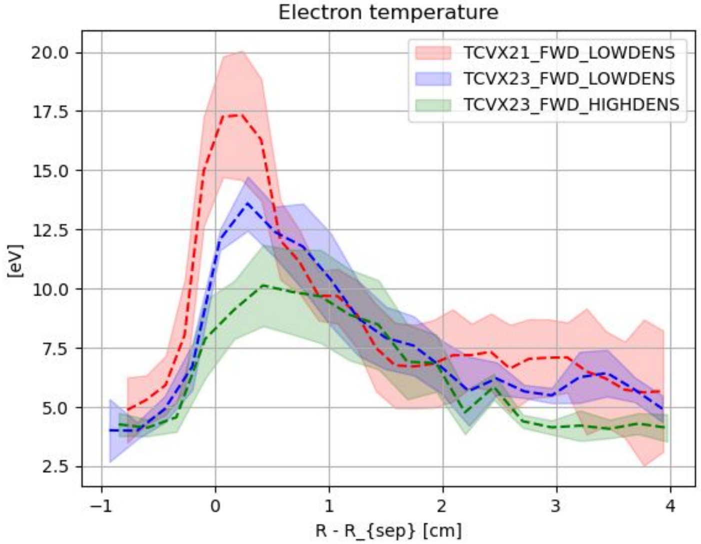


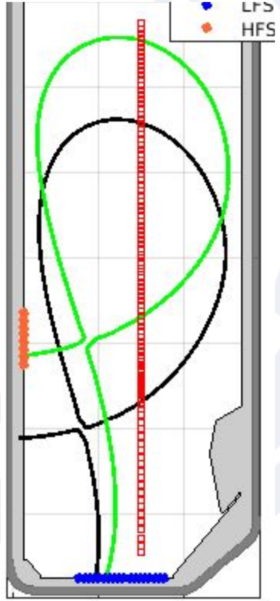


Langmuir probes profiles - Outer target - n, T_e

- Higher target density for X23 high density, in all SOL
- Lower target temperature in X23 high density → ~7 eV at target, broad peak

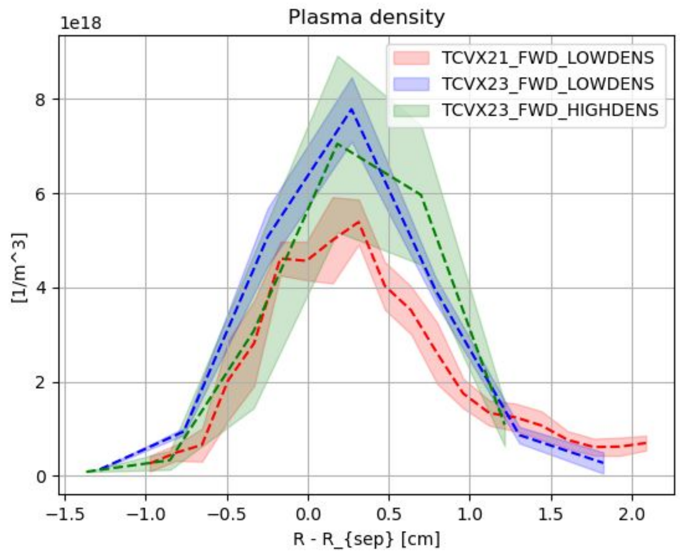


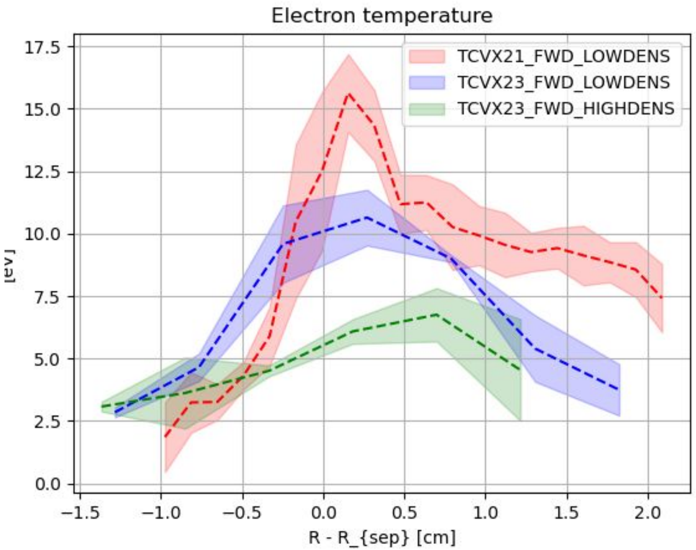


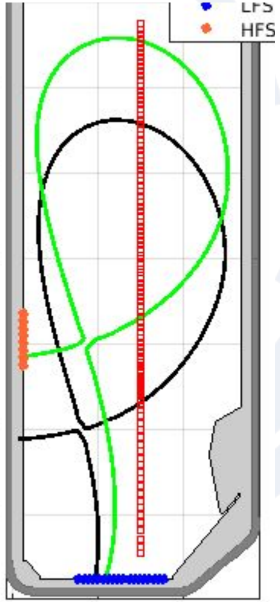


Langmuir probes profiles - Inner target

- More difficult measurements due to probes position →big error bars
- Even lower T_e compared to outer target in high density X23 ~5 eV



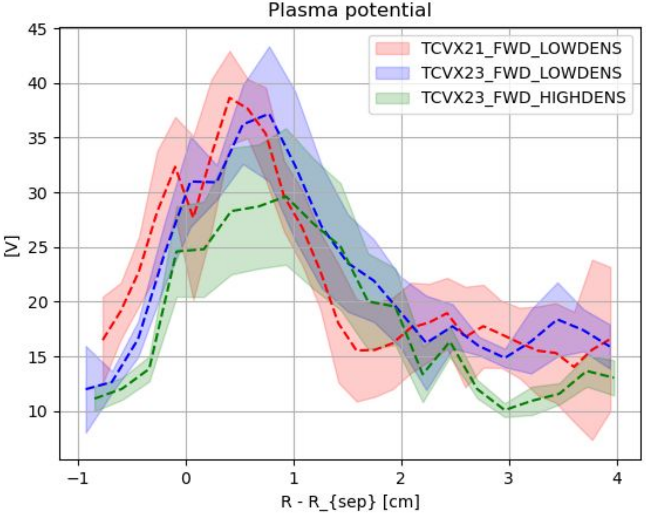




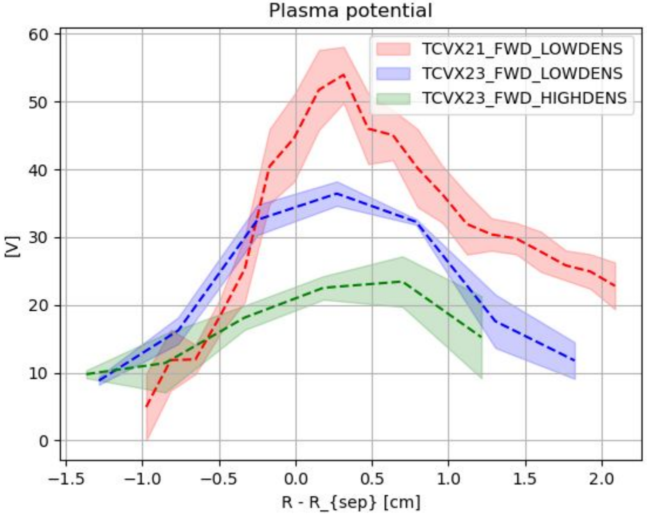
Langmuir probes profiles - Plasma potential

- Plasma potential lowers with T_e $\longrightarrow$ Strong peak decrease at inner target

OT

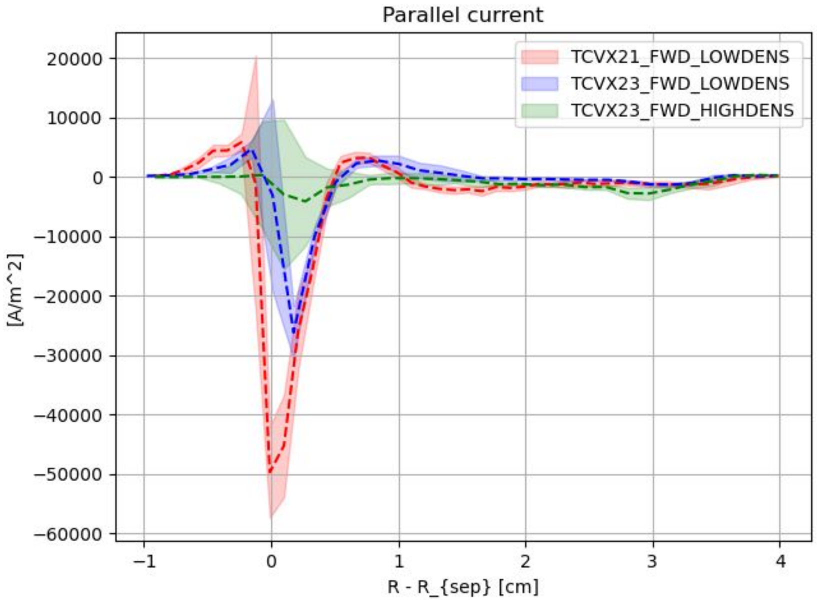


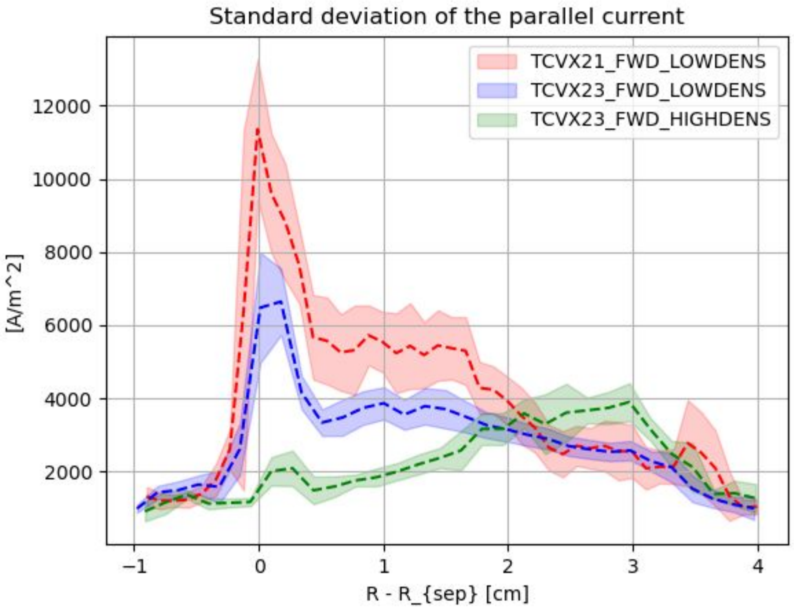
IT



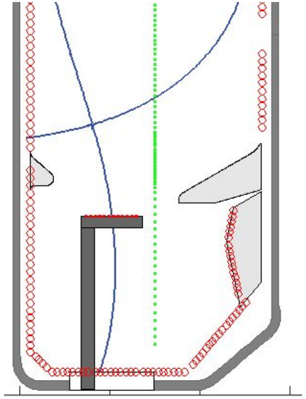
Langmuir probes profiles - Outer target - $j_{||}$, std($j_{||}$)

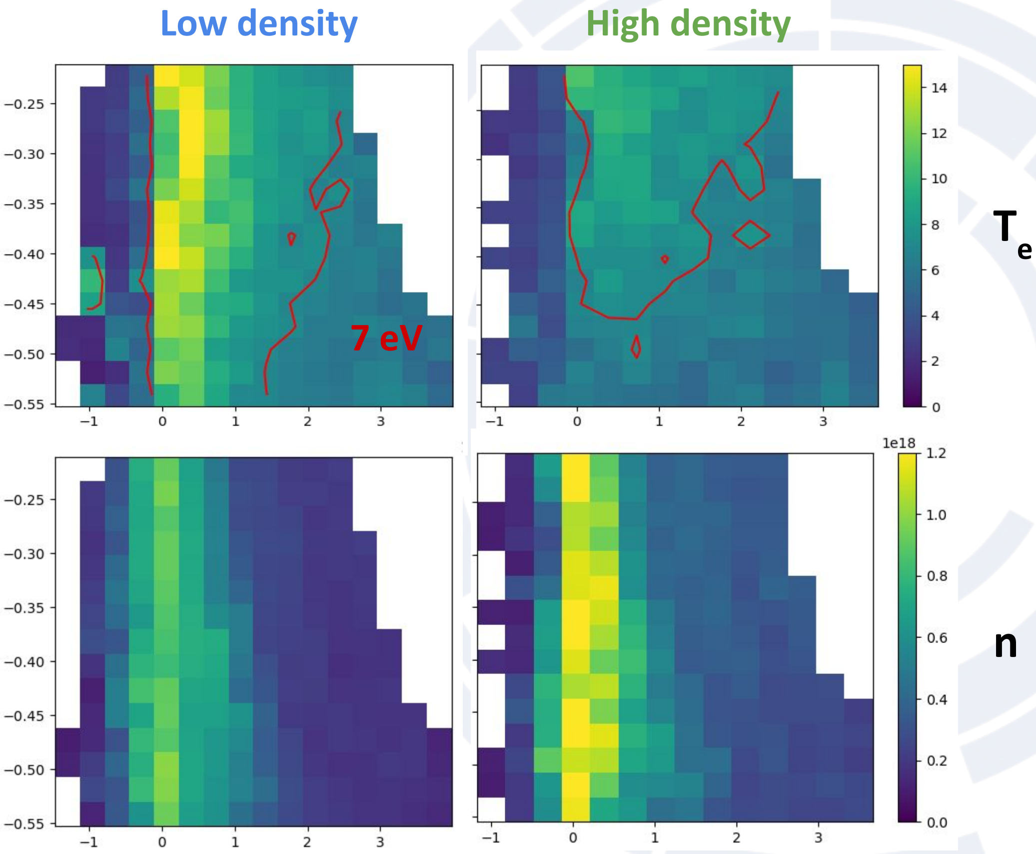
- Ongoing analysis for high density X21
- Smaller peak in X23, broader std → Fluctuations pushed toward far SOL?





RDPA divertor profiles - density and temperature

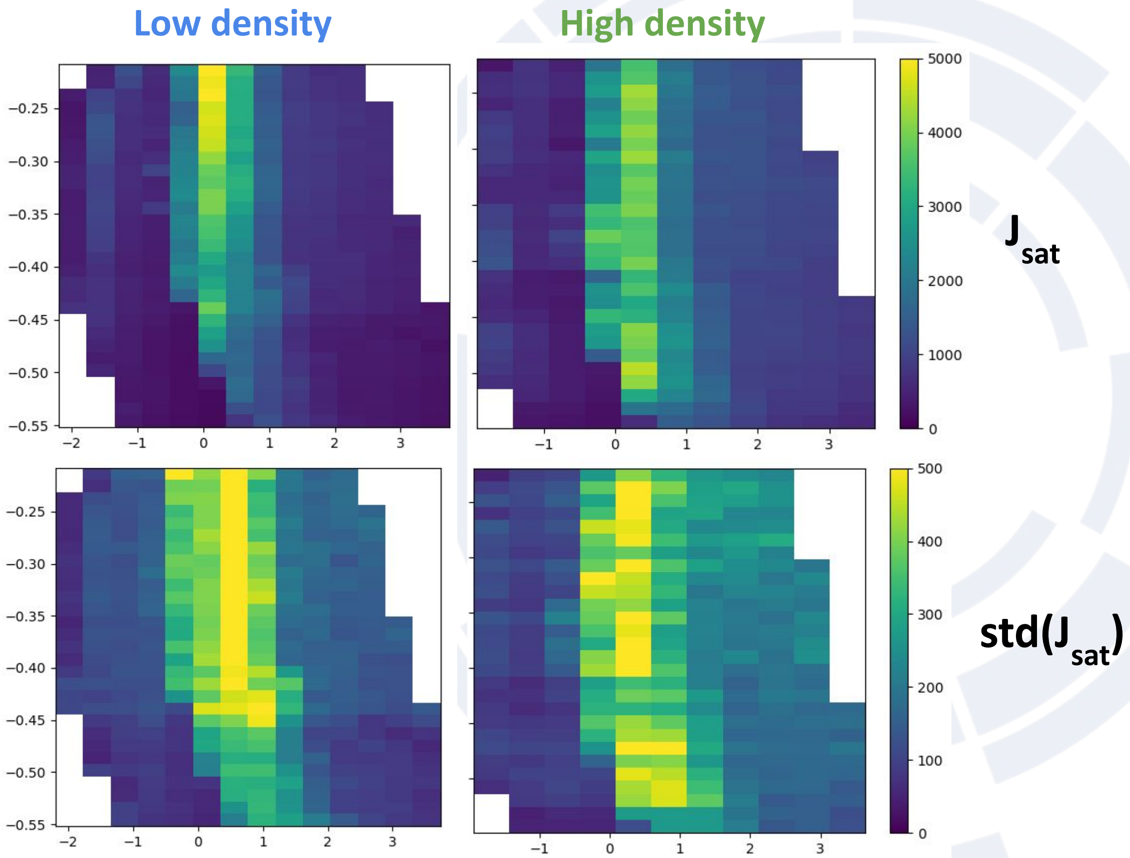




- Strong temperature decrease and density increase for high-density case
- T_e < 7eV at high density target → compatible with CIII front

RDPA divertor profiles - jsat and std(jsat)

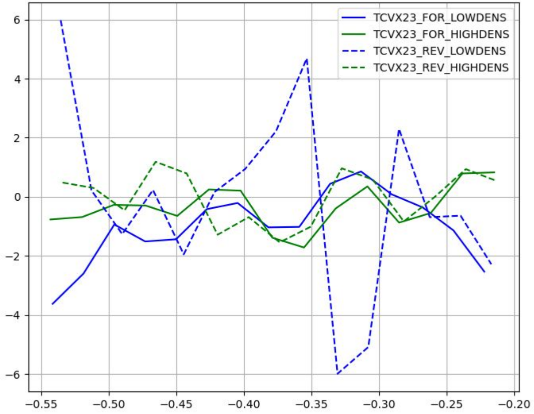
- Lower J_{sat} peak in high density
- Broader fluctuations profile in the far SOL increasing density



RDPA divertor profiles - V_{pl} Forward and Reversed

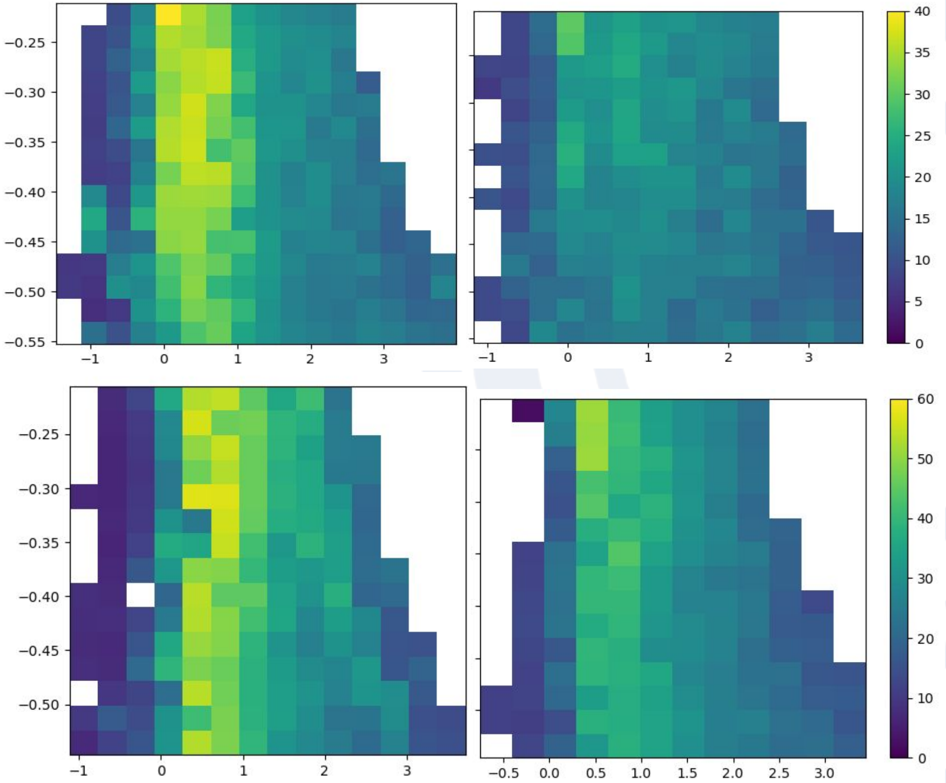
- Lower V_{pl} with high density in both cases
- Opposite vertical electric field at the target for opposite B_{tor}, same direction upstream

E_z



Low density

High density

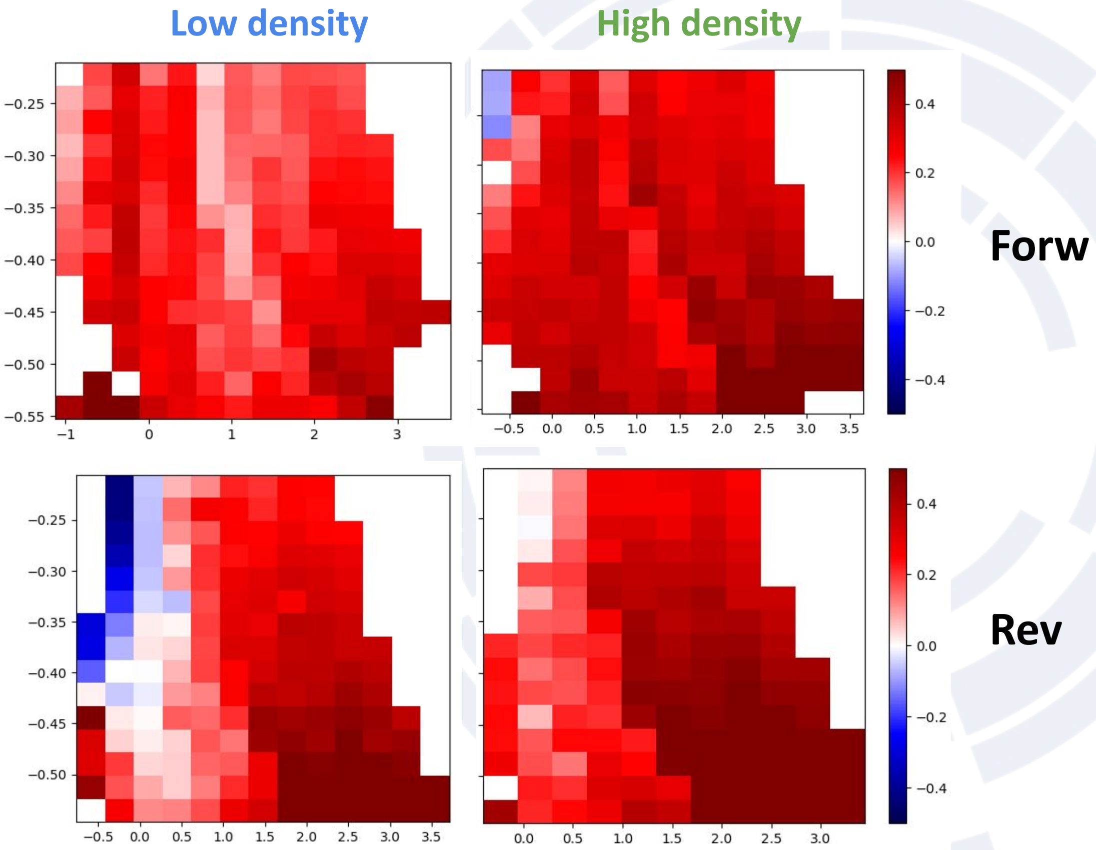


Forw

Rev

RDPA divertor profiles - Mach number

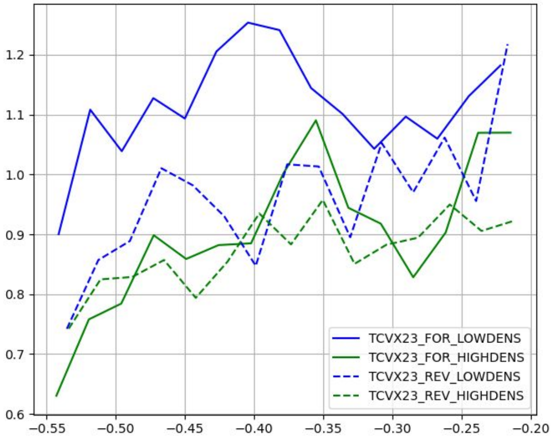
- High M values in far SOL both in low and high density
- Higher M values for higher density
- No reversal of M with field direction close to the target
  $\longrightarrow$ need to be investigated



RDPA divertor profiles - Electron pressure

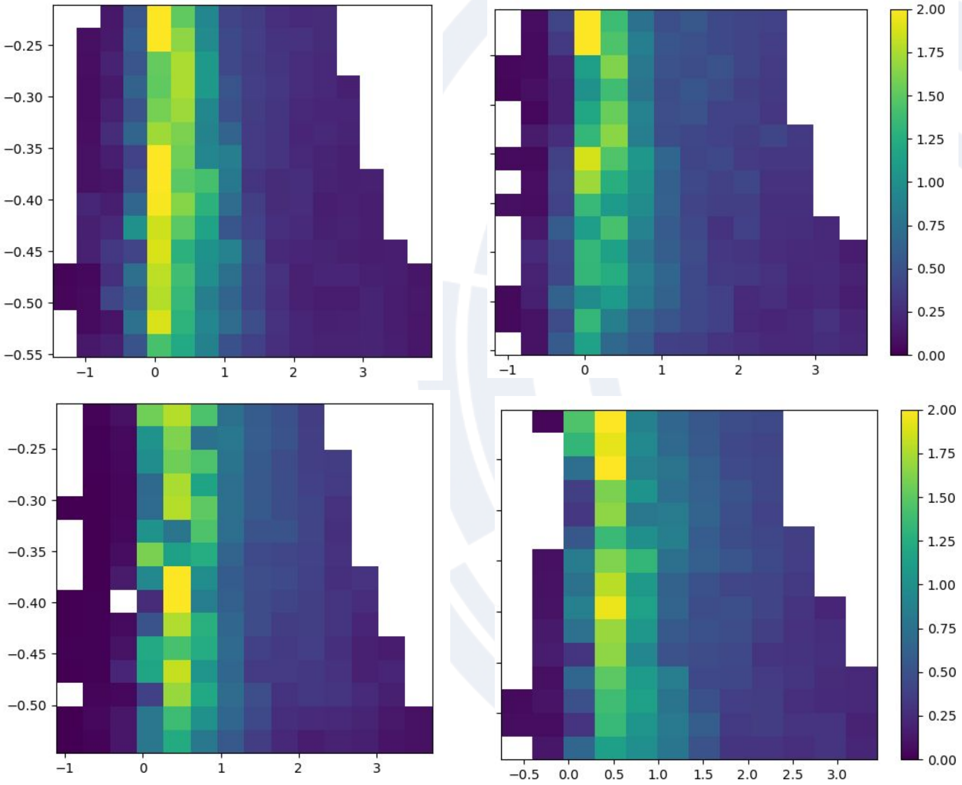
- Pressure loss going to high density along the leg
- Pressure loss stronger in Forward field direction →compatible with heat flux loss

n*T_e



Low density

High density

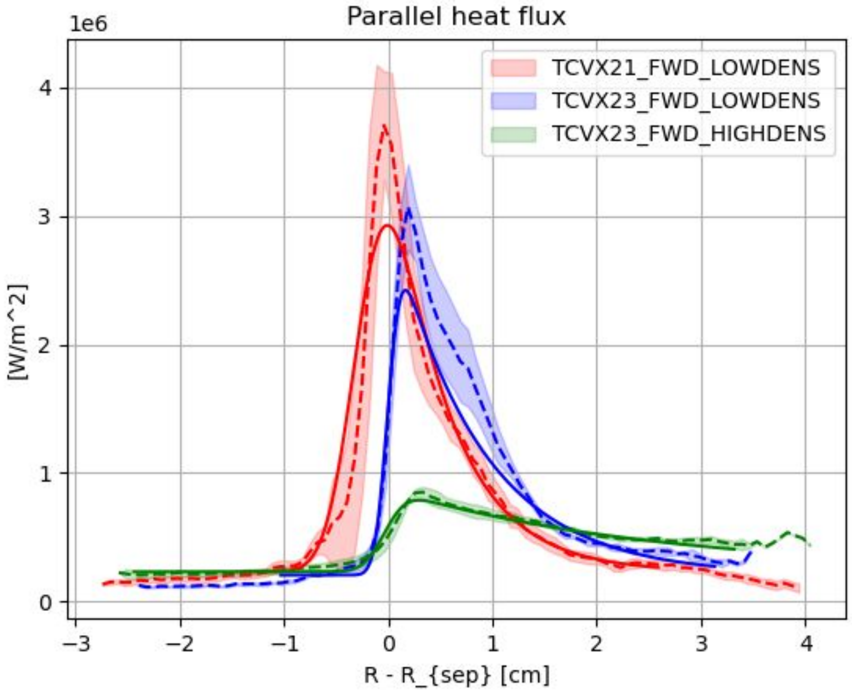


Forw

Rev

Infrared thermography - outer target

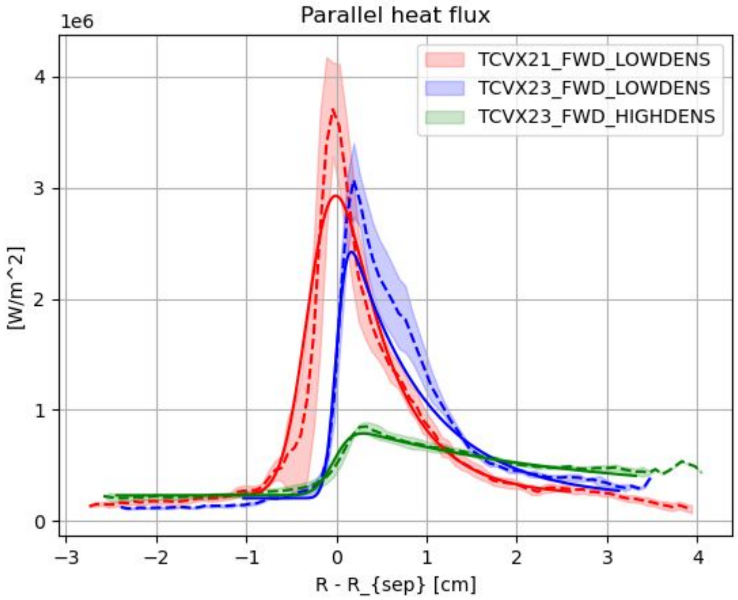
- Strong decrease of heat flux from low to high density X23 → observed in SOLEDGE3X
- Very low heat flux for X23 high density → No good estimate of SOL width?

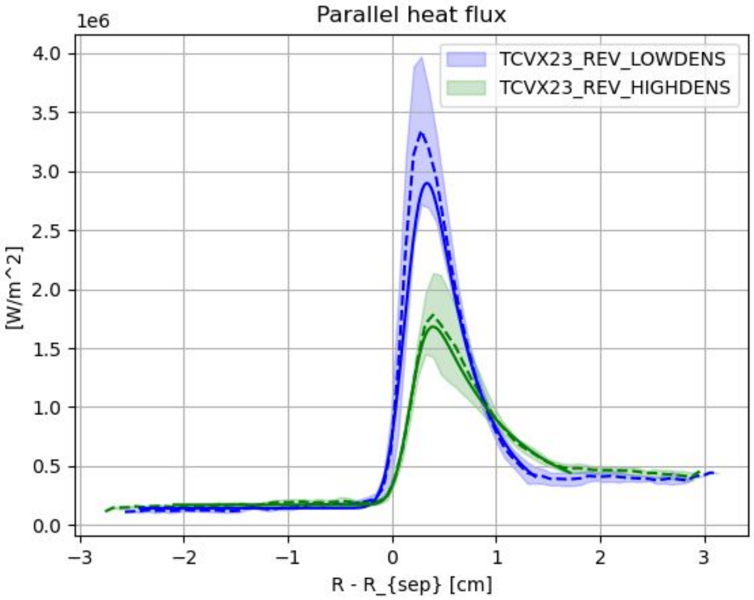


λ_q [mm]	S [mm]
5.5 ± 0.2	3.4 ± 0.3
8.4 ± 0.2	1.4 ± 0.2
20.0 ± 0.8	2.9 ± 0.3

Infrared thermography - outer target

- Weaker heat flux decrease in Rev field direction, still clear
- Already observed in previous similar discharges (D. Galassi et al, in preparation)





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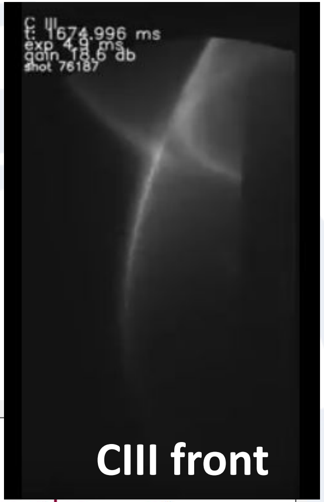
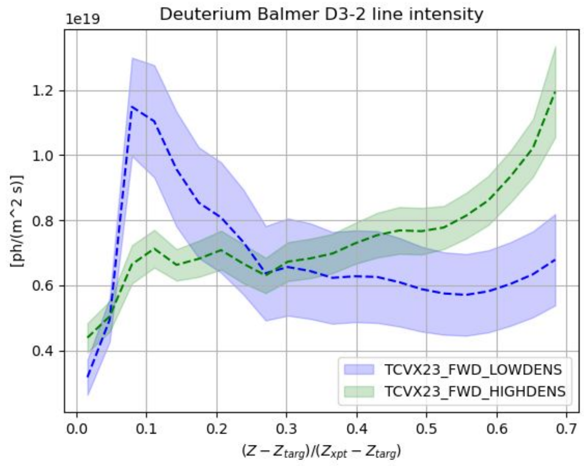
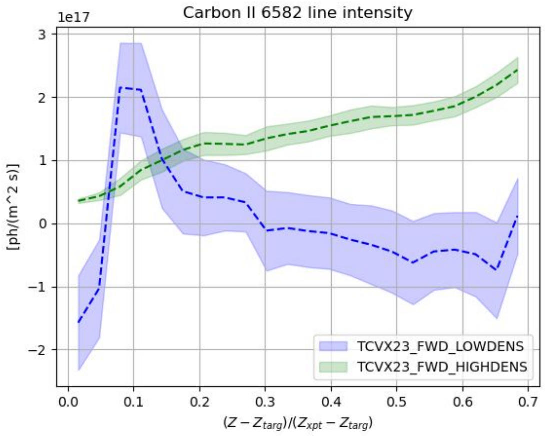
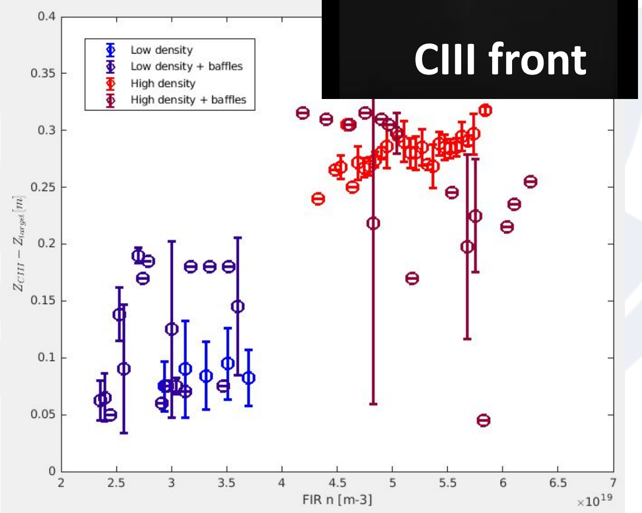
DSS and Mantis emission lines

- Both Mantis and DSS show peak of C emissivity moving away from the target with higher density → expected from low T_e
- DSS gives info about molecular dynamics from D lines ratio → hard to perform analysis, will see where it goes



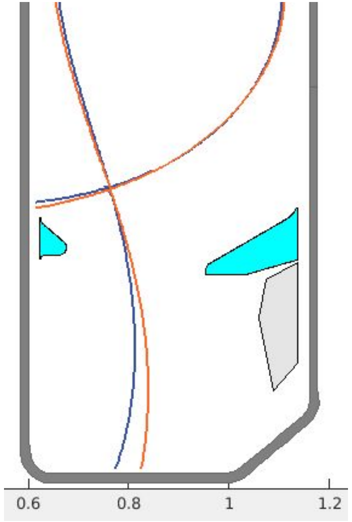


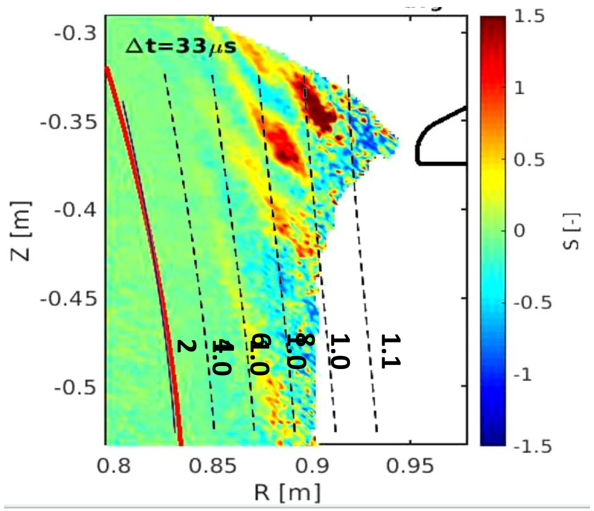


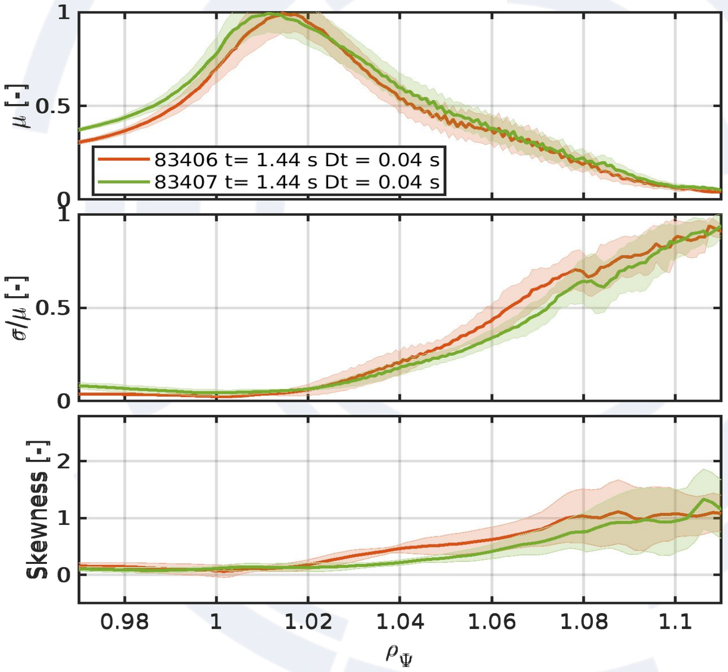


Outer leg Gas Puff Imaging

- On-going characterization of differences compared to un-baffled shots
- Analysis will focus on turbulence velocity profiles





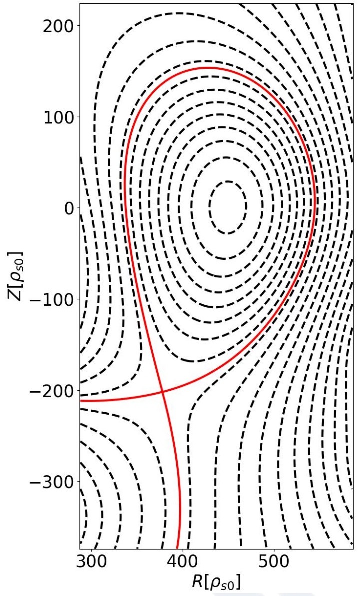


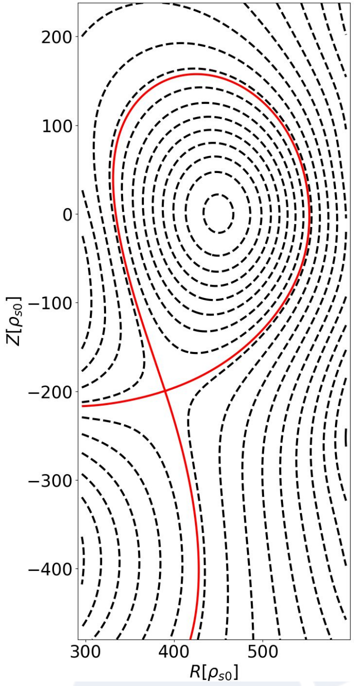
GBS turbulent study for detachment with long leg

For each configuration:

- **Half TCV size** → lost on Marconi
- 2 simulations, low and high density (GP D_2)
- e^-, D^+ and D_2^+ dynamics
  with D and D_2 interactions

Shape	B_t direction
TCV-X21	FF*
TCV-X21	RF**
TCV-X23	**FF**

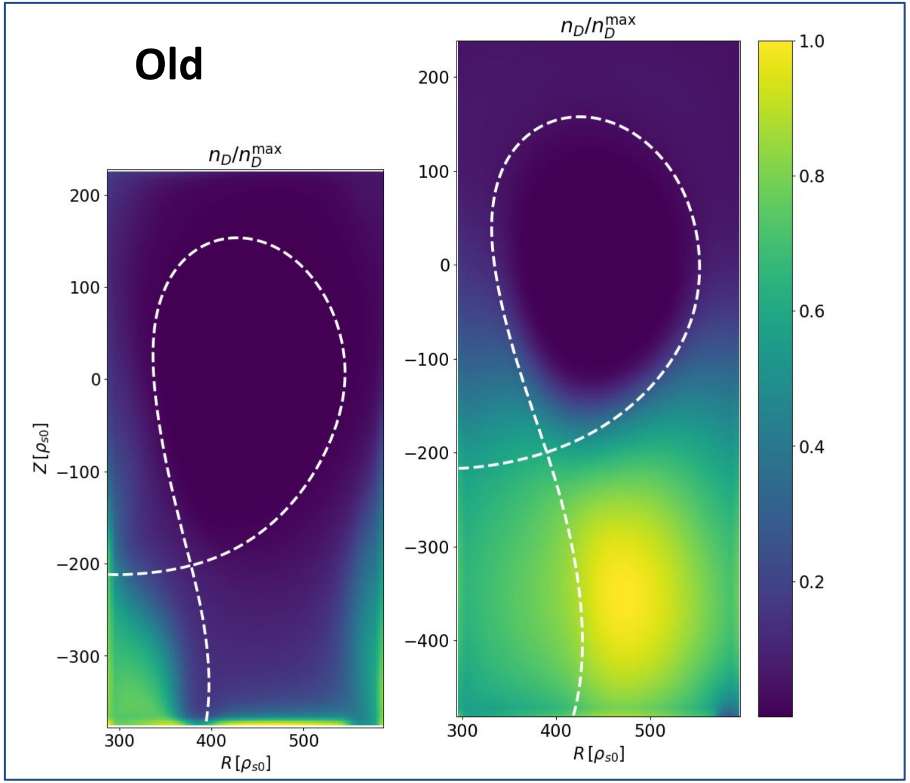


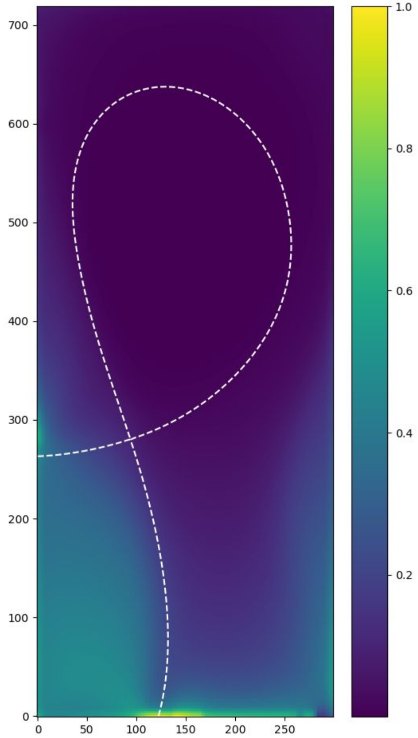


**D. Mancini et al, 2024, Nucl. Fusion 64 016012*
*** D.Mancini et al, 2024, PSI poster*

Recovering neutral profiles

Going in the right direction, waiting for plasma density build up





Conclusions

Structure for new database of TCV-X23 measurements in place, on-going work to clean it and fill it with all diagnostics available

- Present: TS, LPs, RDPA, IR, DSS, Barometer
- Missing: Bolometers, Mantis, GPI, DBS

Analysis of TS, LPs, RDPA and IR shows:

- Obtained scenario at higher density compared to TCV-X21, in both field directions
- Increase in density associated with decrease in target T_e and heat flux, coherent with a decrease of electron pressure in the divertor volume
- Heat flux decrease stronger in Forward field direction
- Decrease of T_e associated with lower V_{pl} and lower electric field close to target $\rightarrow$ sign changes with field direction
- Higher density associated with broader current fluctuations

Conclusions -2

Structure for new database of TCV-X23 measurements in place, on-going work to clean it and fill it with all diagnostics available

- Present: TS, LPs, RDPA, IR, DSS, Barometer
- Missing: Bolometers, Mantis, GPI, DBS

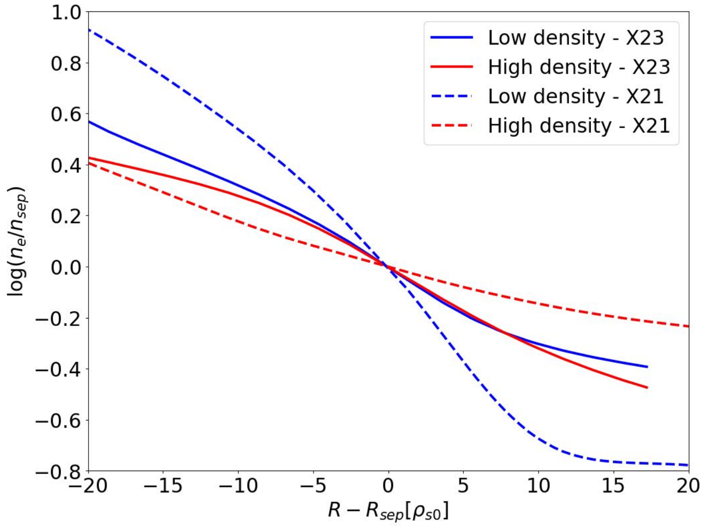
Next:

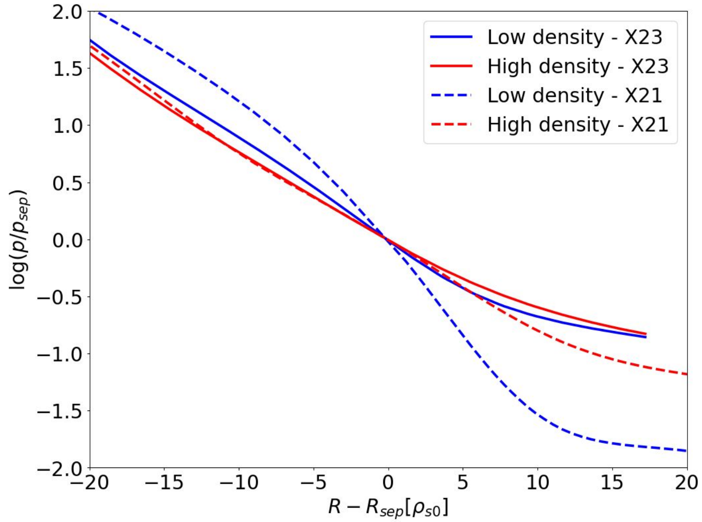
- Include radiated power analysis to account for lower target heat flux
- Include Mantis and DSS analysis to gain knowledge about C and D_2 dynamics
- Characterize differences between baffled and un-baffled experiments
- Analyze GPI measurements to get fluctuation velocity profiles

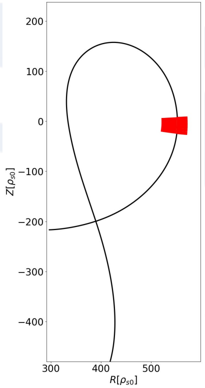
No changes in the OMP profile through puffing

Increased puff simulations show same density profile in low and high density TCV-X23:

- Density shoulder “between” the low and high density TCV-X21
- λ_p higher in TCV-X23

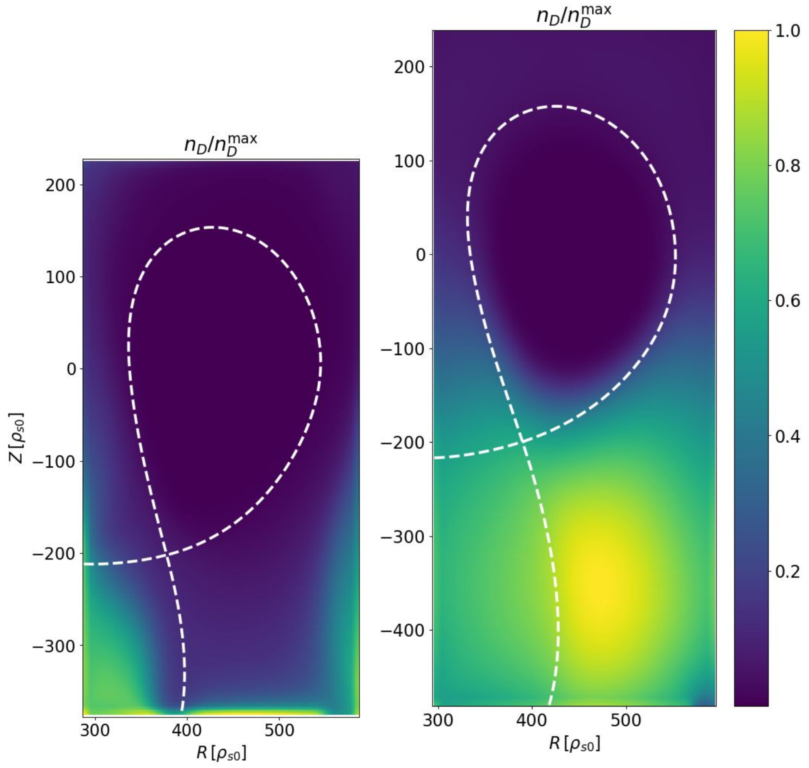


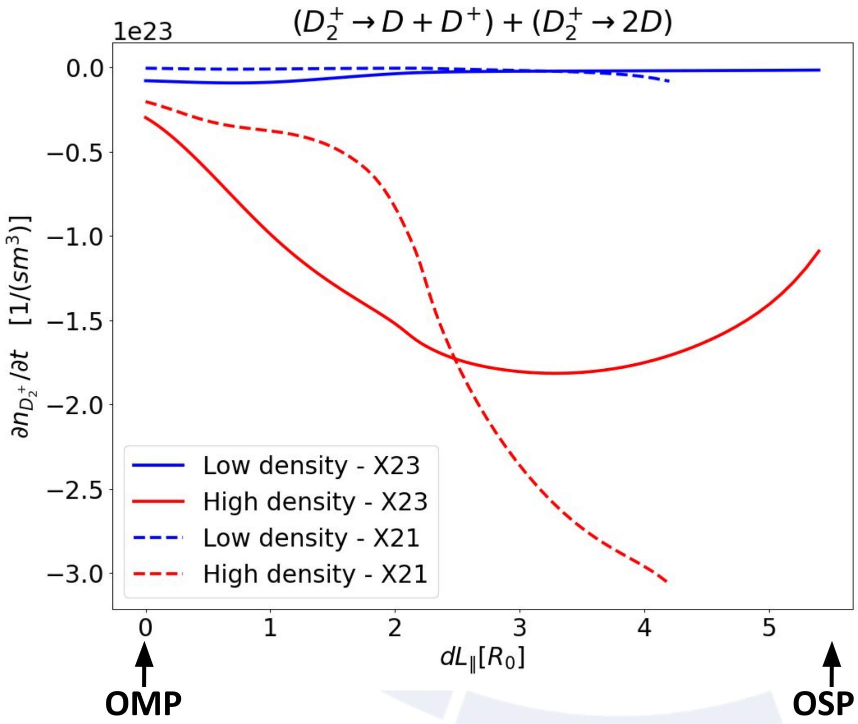




High D_2 density even with lower density

Higher D penetration due to higher D_2 dissociation

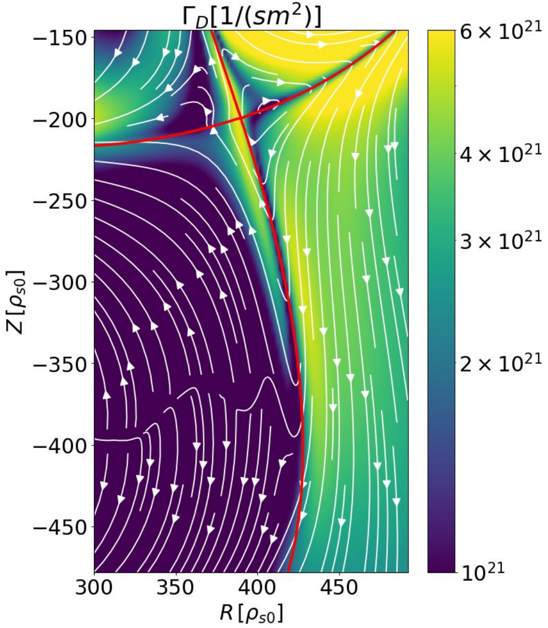




Ion fluxes at both target decreases increasing puffing

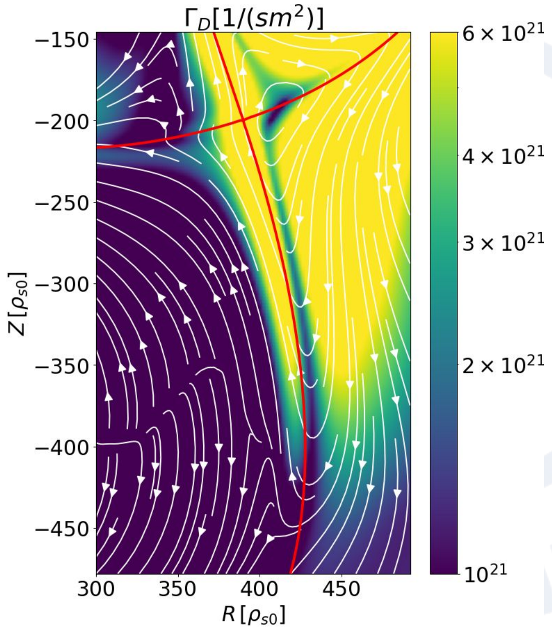
Strong decrease of $\Gamma_{||}$ at outer target $\longrightarrow$ not observed in TCV-X21 simulations

Low density



Flux decrease only close to target

High density

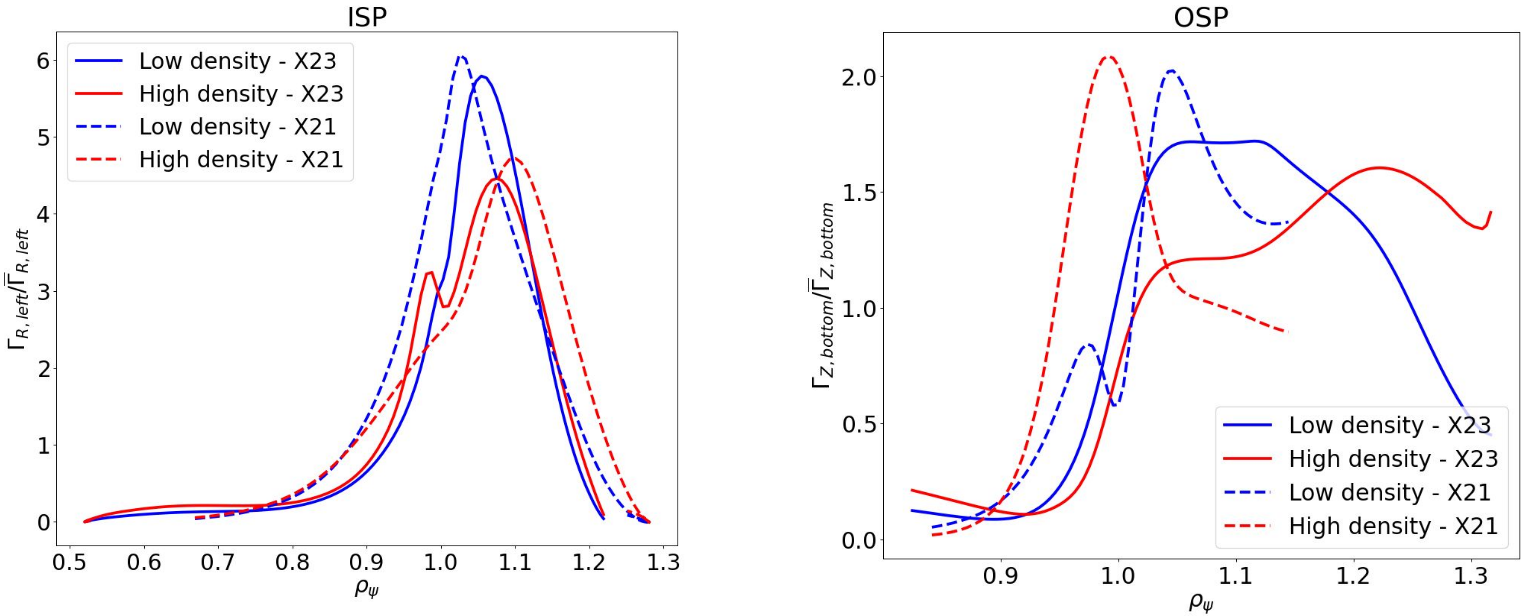


Strong momentum loss

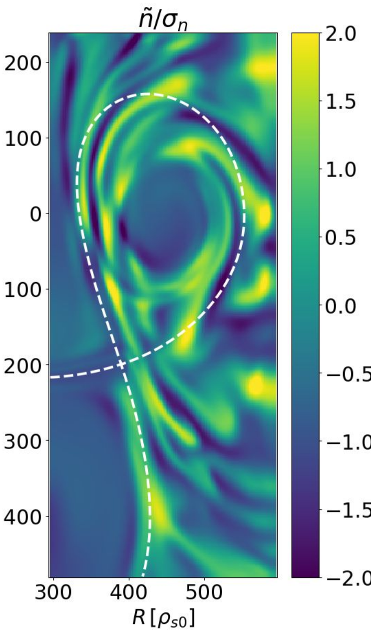
Ion flux profile wider at outer target

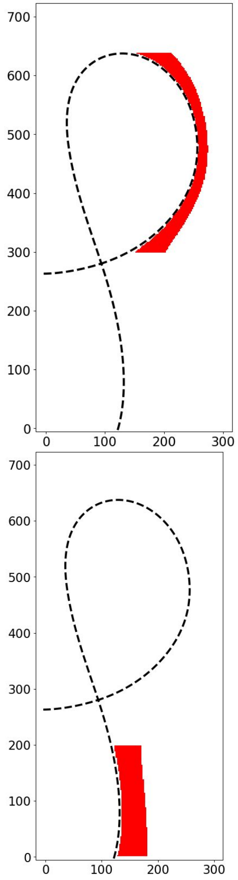
At both targets, ion flux decrease with increasing puffing:

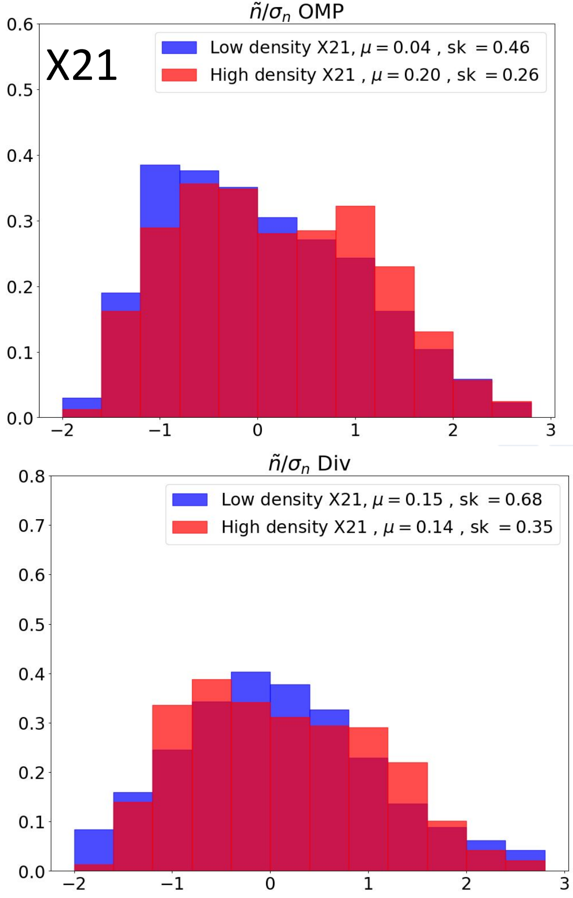
- At ISP same shape for TCV-X21 and TCV-X23 ⟶ detached in similar way
- At OSP broader peak in TCV-X23 even at low density

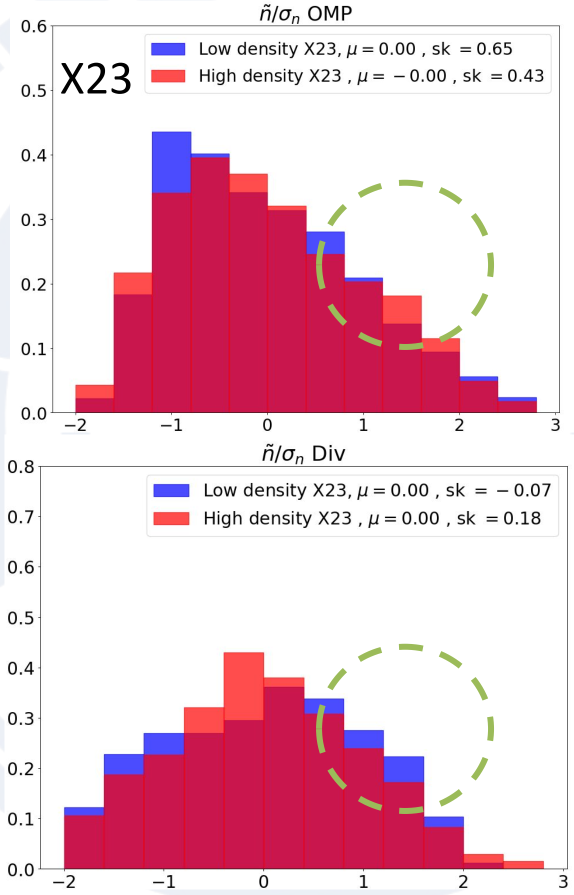


High positive fluctuations killed in X23

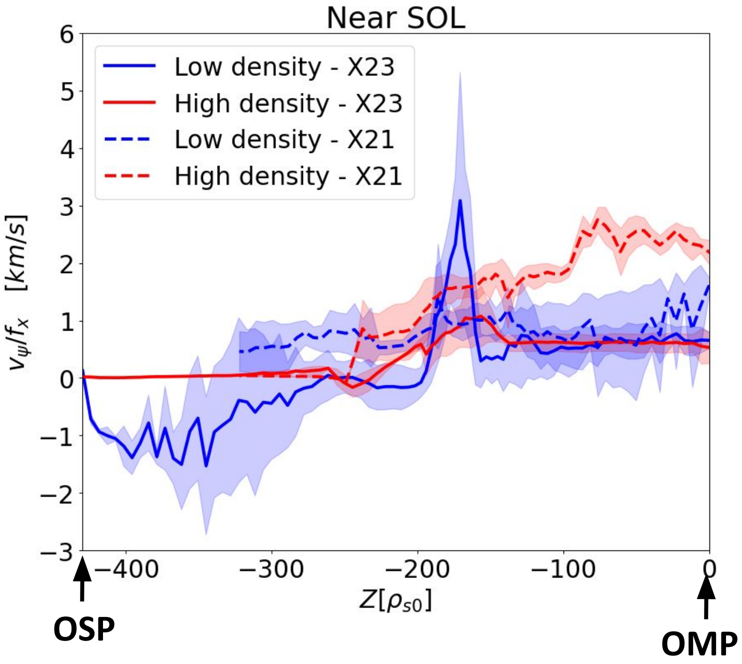


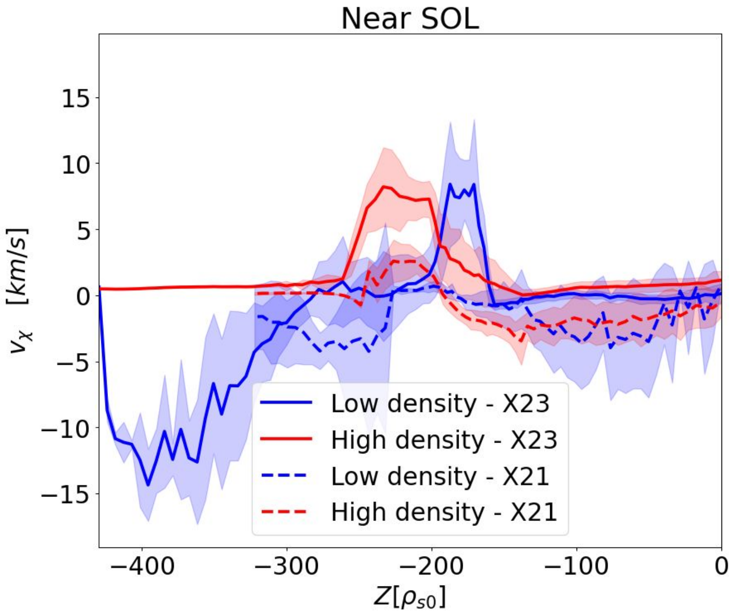






High positive fluctuations slower in TCV-X23



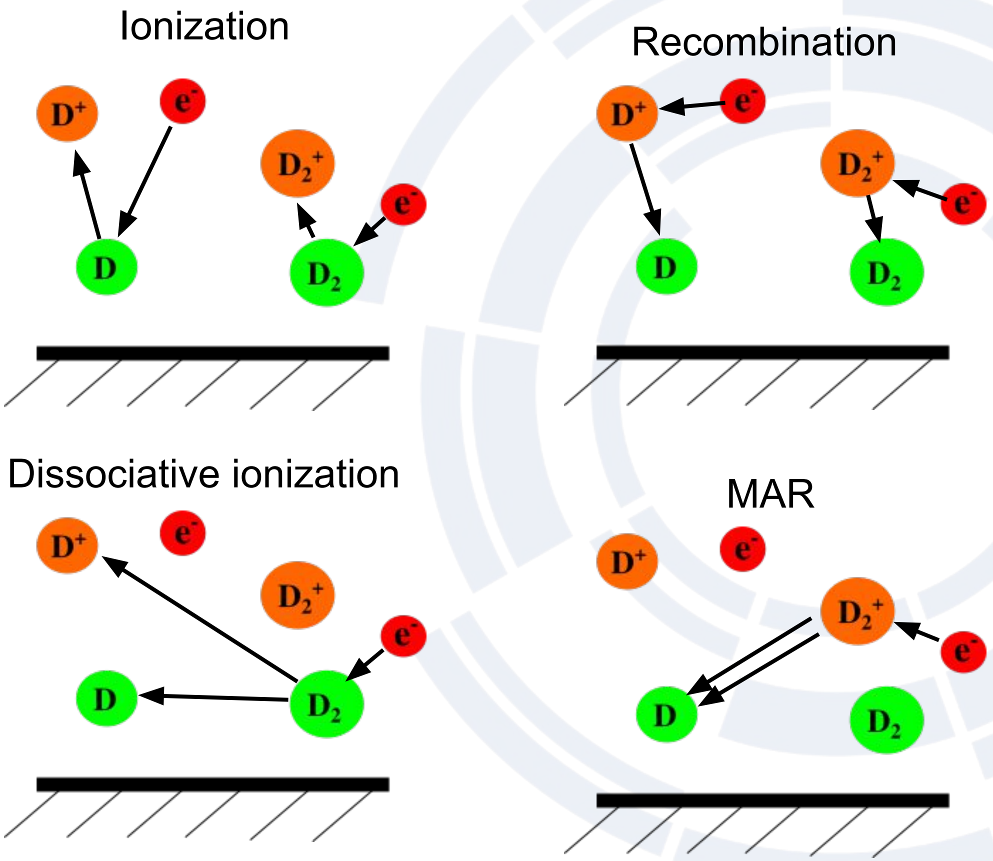


- Slower filaments in X23 from OMP to X-point
- Fast filaments in low density below X-point ($v_r < 0$)
- Very slow filaments for high D_2 density in divertor ⟶ Have to verify detection

Five species (D^+, D_2^+, e^-, D, D_2) and minimal interactions set

Detachment studied through simulations of tokamak plasma and neutrals, modelling:

- Ionization (atomic + MAI)
- Recombination (EIR + MAR)
- Charge exchange
- e-n collisions



Plasma model: drift-reduced Braginskii equations

Plasma described by Braginskii equations with neutrals interactions
We evolve density, parallel velocity and temperatures of all charged species.
Example:

$$\frac{\partial n_e}{\partial t} = \boxed{-\nabla \cdot [n_e(\mathbf{b}v_{\parallel e} + \mathbf{v}_{E\times B} + \mathbf{v}_{de})]} + \boxed{\int (I_{e,D} + I_{e,D_2}) d\mathbf{v}}$$

$$I_{e,D} = n_D \langle v\sigma_{e,D}^{el}\rangle (n_e \Phi_{[\mathbf{v}_D, T_{e,D}^{el}]} - f_e) + n_D \langle v\sigma_{e,D}^{iz}\rangle (2n_e \Phi_{[\mathbf{v}_D, T_D^{iz}]} - f_e) - n_{D^+} \langle v\sigma_{e,D^+}^{rec}\rangle f_e$$

Where : $\Phi_{[\mathbf{v},T]}$ is a Maxwellian centered at velocity **v** , with temperature T , distribution of emitted electrons

With:

- quasi neutrality $n_{D^+} = n_e - n_{D_2^+}$
- Zdhanov closure $\begin{bmatrix} q_{\parallel,\alpha} \\ R_{\parallel,\alpha} \end{bmatrix} = \sum_\beta Z_{\alpha\beta} \begin{bmatrix} \nabla_\parallel T_\beta \\ v_{\parallel,\beta} - v_{\parallel,CM} \end{bmatrix}$ with $n_{D_2^+} << n_{D^+}$
- Pre-sheath boundary conditions

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