Impact of divertor geometry on separatrix density in JET H-mode plasmas and derivation of a scaling law as a function of engineering parameters

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MOTIVATION

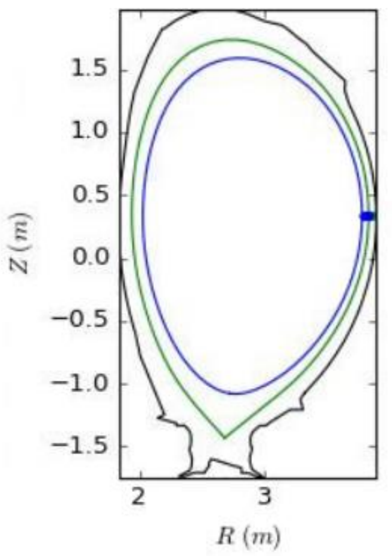
- **A viable magnetic fusion power plant** has to combine very high plasma density and temperature in the core region, in order to maximize fusion reactions, with cold plasma conditions in the peripheral region compatible with long life expectancy of plasma-facing components

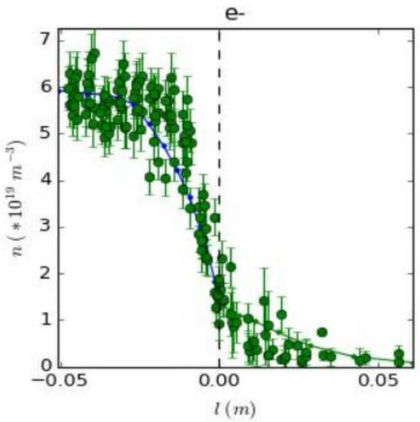
- To investigate **« core-edge » compatibility** we look at the pedestal and SOL regions for a large set of experimental data on **H-mode plasmas** from **JET tokamak** and in particular to the **ratio Nsep/Nped** where
  - Nsep is the separatrix density at the outer midplane
  - Nped is top pedestal density at the outer midplane

- The aim is to derive a **scaling law of this ratio as a function of engineering parameters**

- This work was inspired from what have been done in DIIID (T Leonard et al, NF 2017)

- Many other studies ongoing on JET pedestal properties
  - Pedestal MHD stability and performances (Frassinetti et al, NF 2021 etc…)
  - Divertor conditions and plasma performances (Lomanowski et al, NF 2022)
  - And many others…

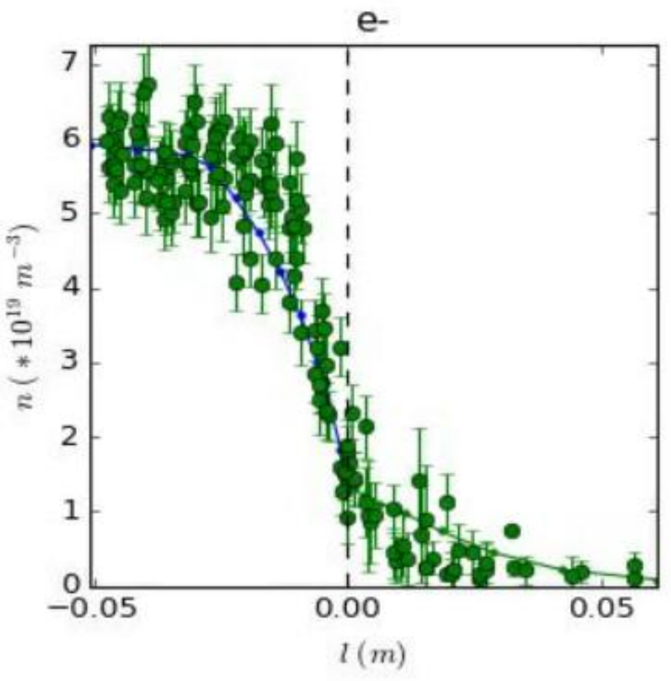


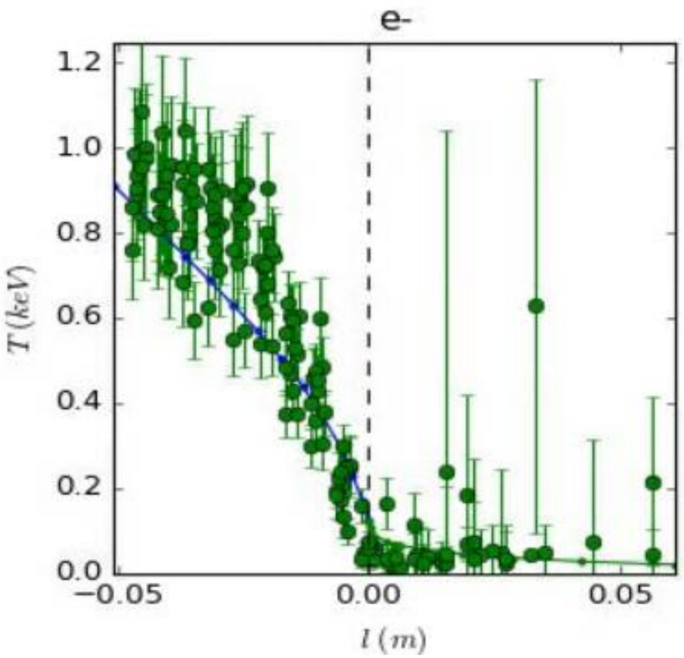


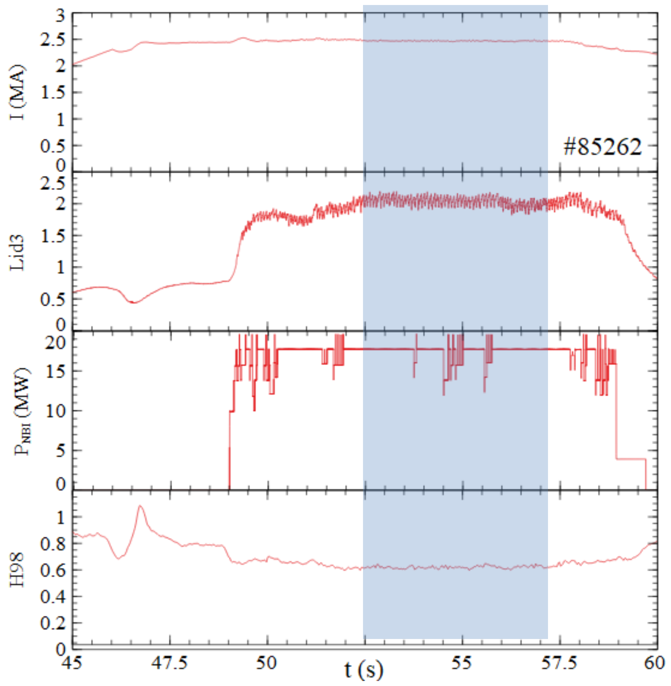
- JET data set and separatrix position determination
- Analysis of N_{sep}/N_{ped} behaviour with respect to engineering parameters
- Investigation of the role of divertor configuration and derivation of a scaling law
- SOLEDGE simulations for few JET cases
- Conclusions

OUTER MIDPLANE PROFILES FROM HRTS DIAGNOSTICS

- We consider electron density and electron temperature data from HRTS during flat top conditions



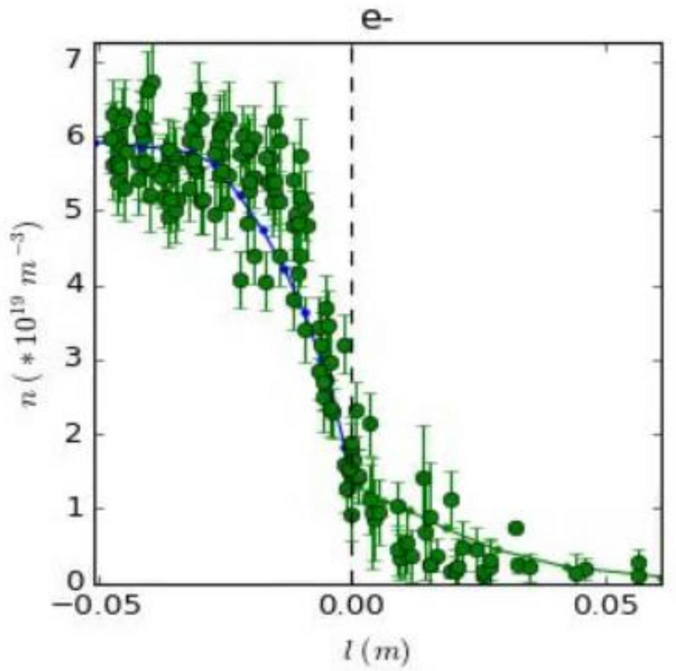




DETERMINATION OF THE SEPARATRIX POSITION USING POWER BALANCE METHOD

EUROfusion

- Electron density and Temperature profiles from HRTS measurements
- Uncertainty on separatrix position
  - Gradient scale length smaller than cm
  - Magnetic equilibrium reconstruction affected by uncertainty on the same scale



- Power balance method (see also Stangeby et al, NF 2015)
  - $P_{sol} = ¼(P_{inj} – P_{rad,bulk})$ from experimental data
  - $P_{pb}(r)$ = $P|_{r \Rightarrow wall} = \int_r^{wall} \frac{B_P}{B_T} q_{||}(r)dr$

- When **P_{pb} (r_{sep}) = P_{sol}** one obtains the separatrix position. The expression used for **parallel heat flux** can have an impact on such position

IMPACT OF HEAT FLUX EXPRESSION ON POWER BALANCE METHOD AND VERIFICATION ON A NUMERICAL CASE

- Spitzer-Harm:

$$q_{||}^{\mathrm{Spitzer}} \approx 2\kappa_0 T_e^{7/2}/7L_{||},$$

- Sheath-limited:

$$q_{||}^{\mathrm{sheath-limited}} \approx \gamma(n_e/2)\sqrt{2eT_e/m_i}eT_e$$

- Flux-limited:

$$q_{||}^{\mathrm{flux-limited}} \approx \alpha_e n_e \sqrt{eT_e/m_e}eT_e$$

optimal $\alpha_e \approx 0.3$ was set by kinetic simulations. [M.Day,CPP 36, 1996]

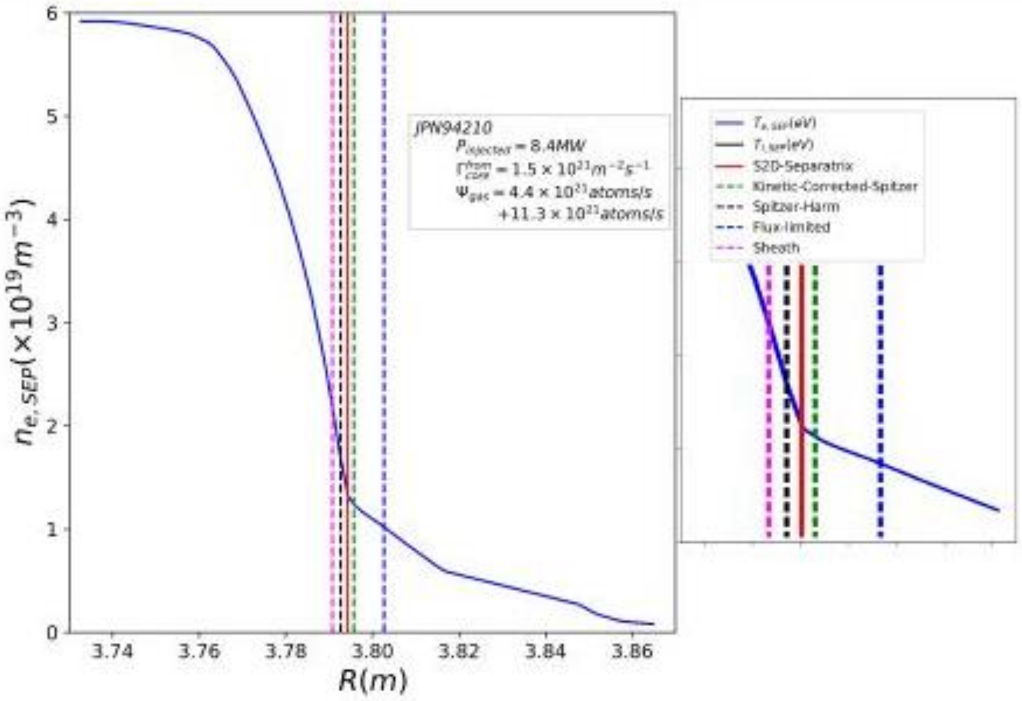
- Kinetically-corrected Spitzer:

$$q_{||}^{\mathrm{kin-corr-Spitzer}} = q_{||}^{\mathrm{Spitzer}} q_{||}^{\mathrm{flux-limited}} / (q_{||}^{\mathrm{Spitzer}} + q_{||}^{\mathrm{flux-limited}})$$

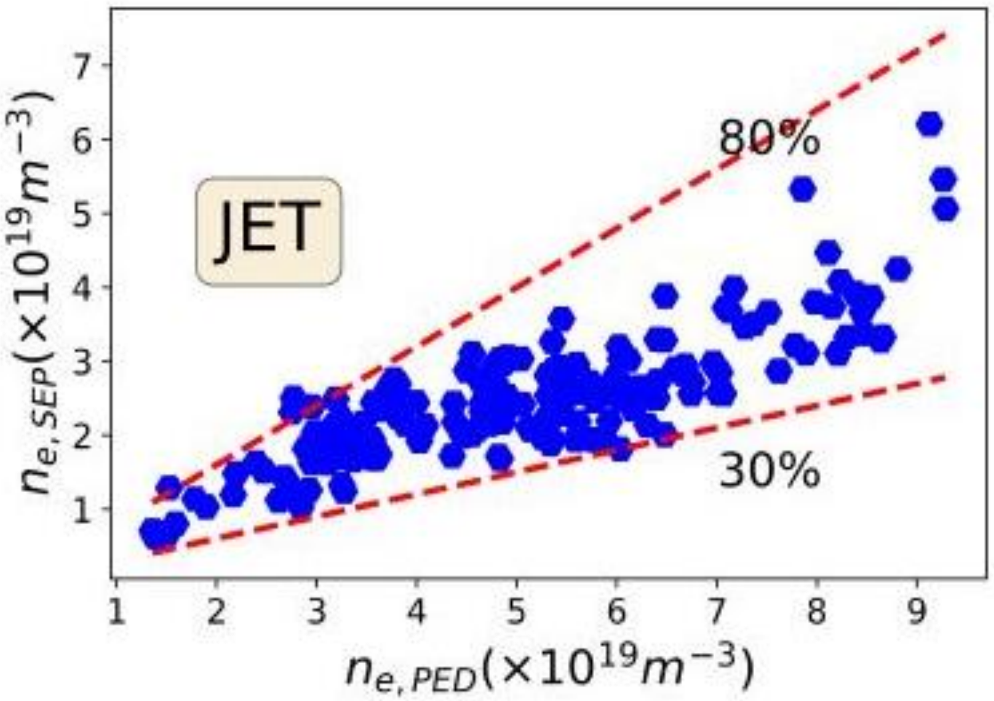
Selection of $q_{||}$

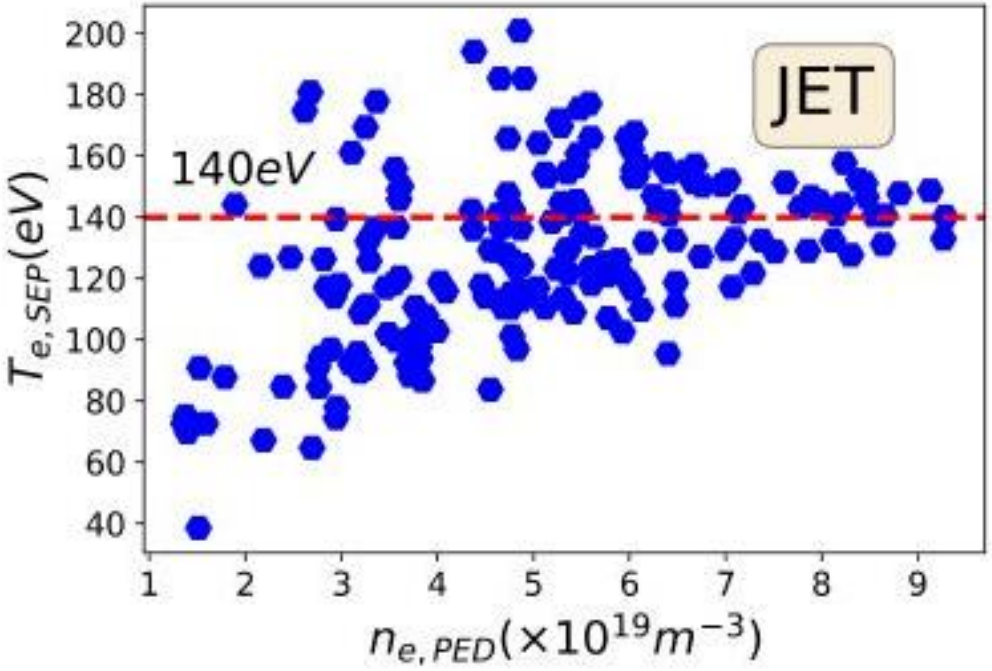
$q_{||}$ is chosen using SOLEDGE2D (S2D) by comparison. The method compares separatrix position for each $q_{||}$ expression with the sep. position imposed by mesh grid.

The kinetic-corrected spitzer $q_{||}$ is chosen.



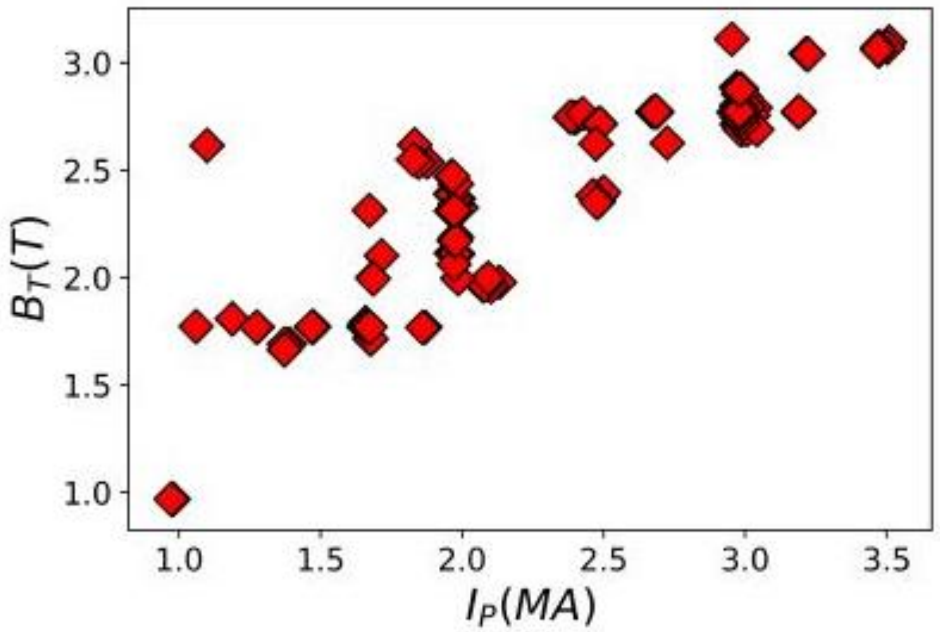
SEPARATRIX ELECTRON DENSITY AND TEMPERATURE AS A FUNCTION OF PEDESTAL DENSITY

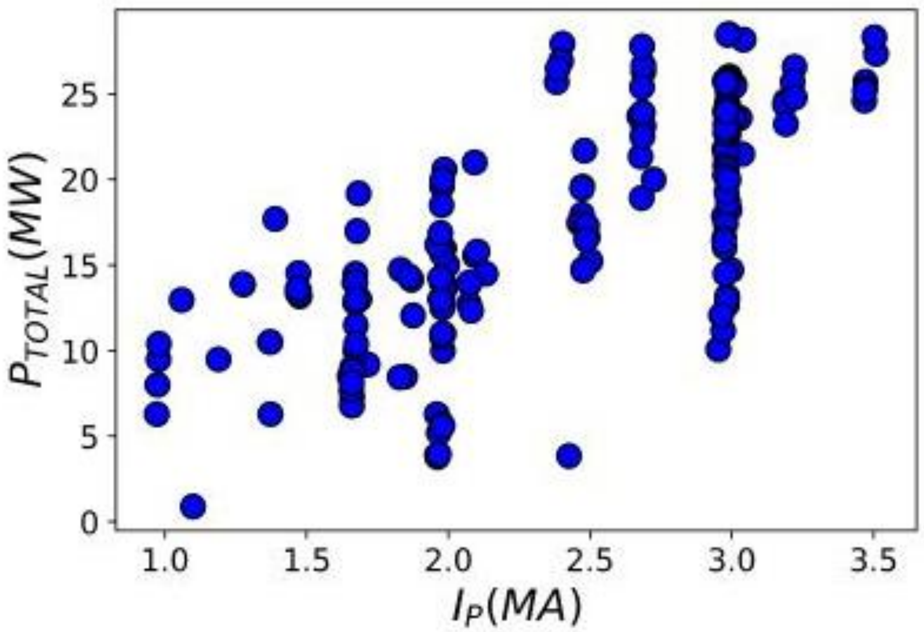




- Large range of values of the ratio between separatrix and pedestal density (0.3 < Nsep/Nped < 0.8)

- Strong variation of separatrix temperature for low pedestal densities, much less at high densities



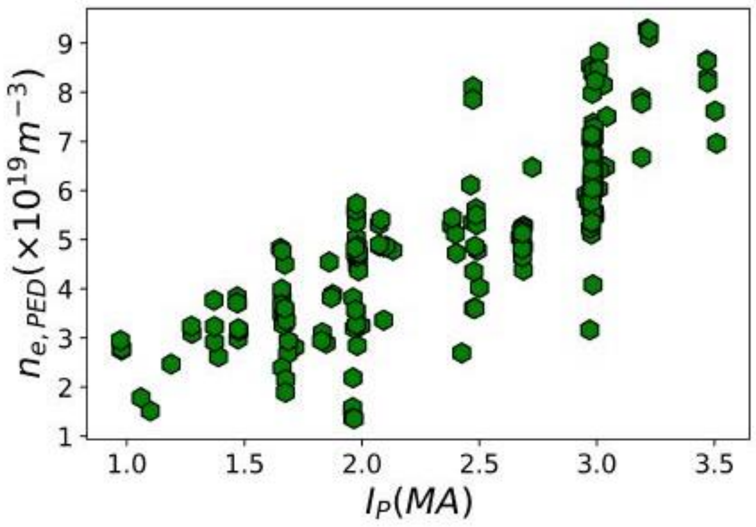


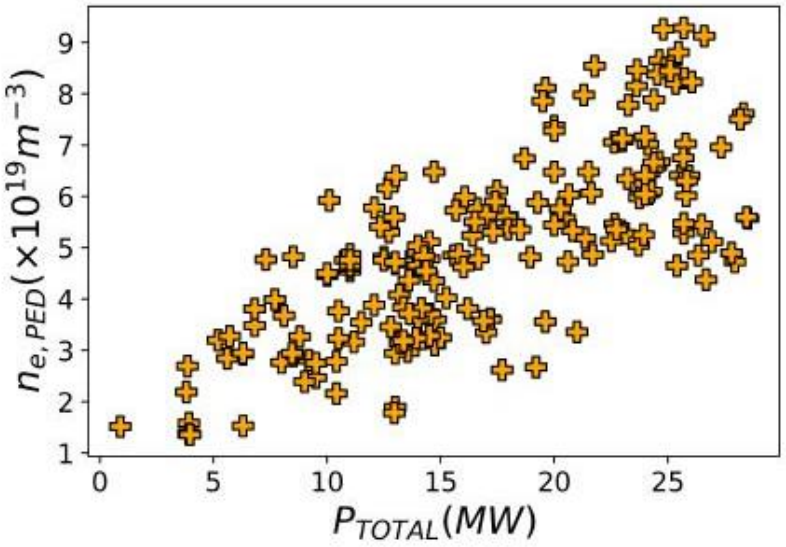
- We remark a linear correlation between I_p and B_t in the discharges under consideration
- The I_p – P_{tot} plane is quite well covered from the discharges under consideration

➡ We will consider I_p and P_{tot} as independent engineering parameters for the scaling law

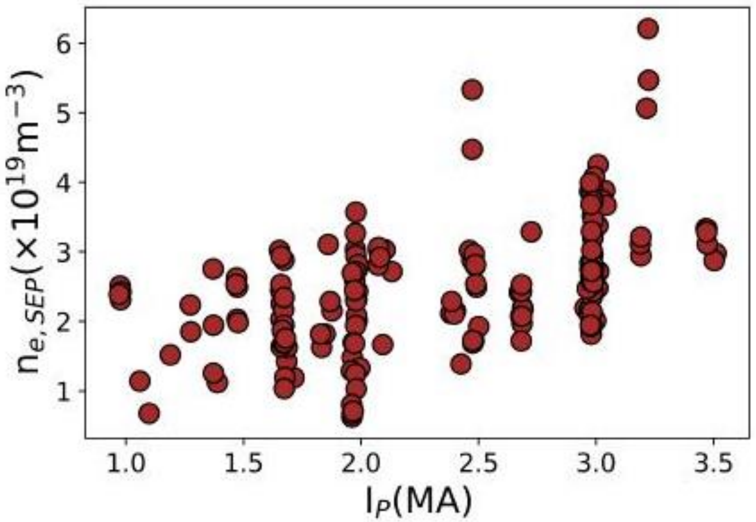
FIRST ANALYSIS OF DEPENDENCE OF DENSITY ON I_P AND P_{TOT}

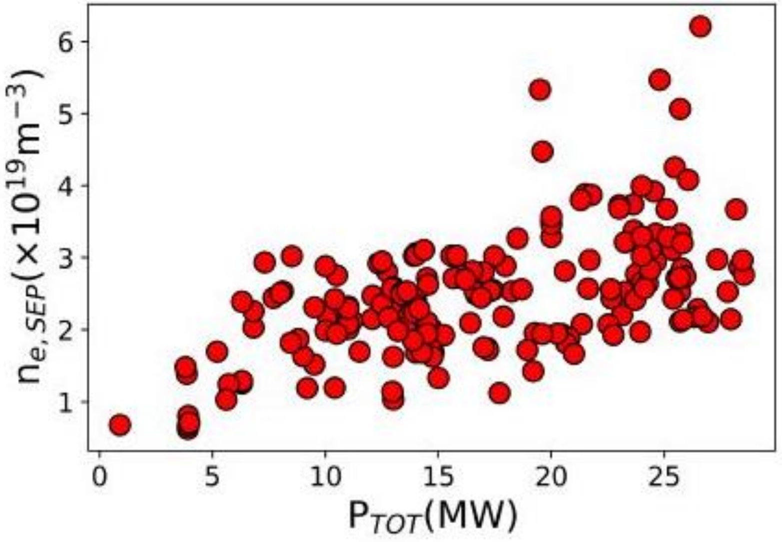
Pedestal density



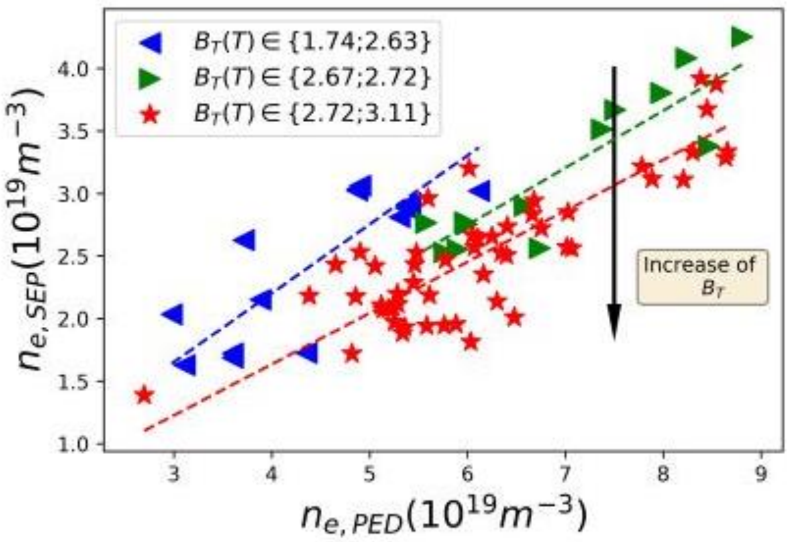


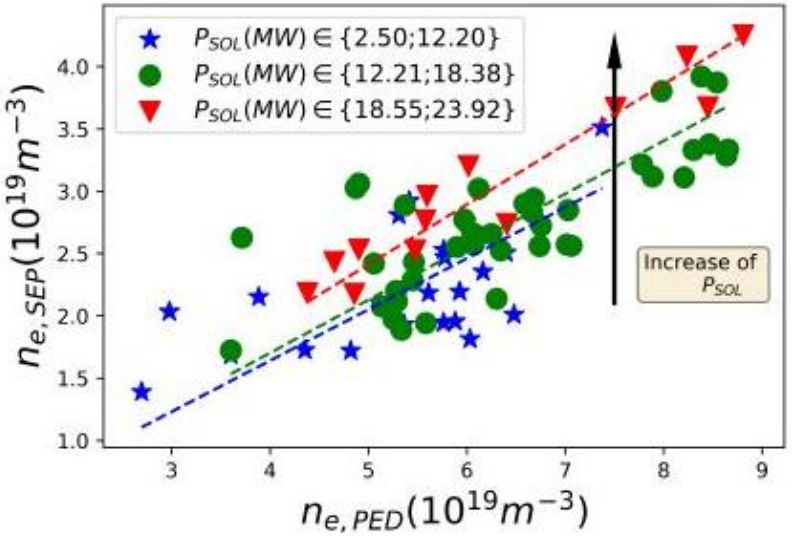
Separatrix density

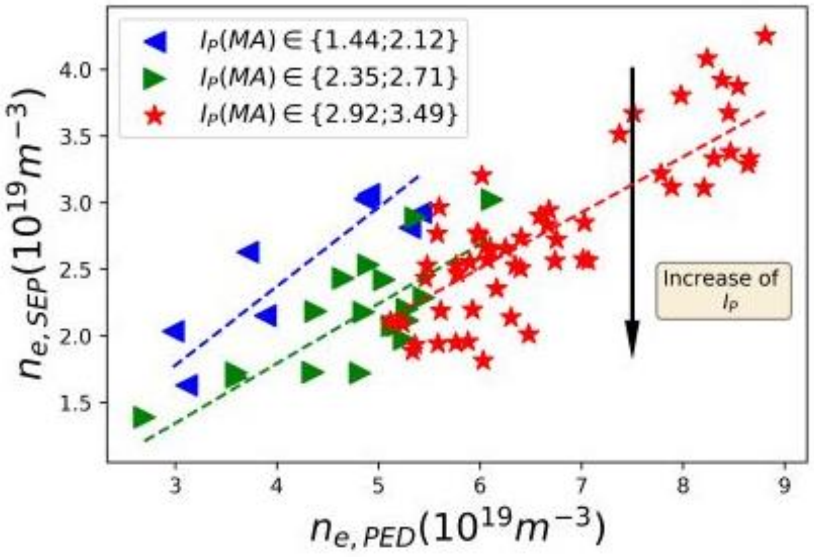




ANALYSIS OF THE DENSITY DEPENDENCE WITH RESPECT TO BT, IP, PTOT

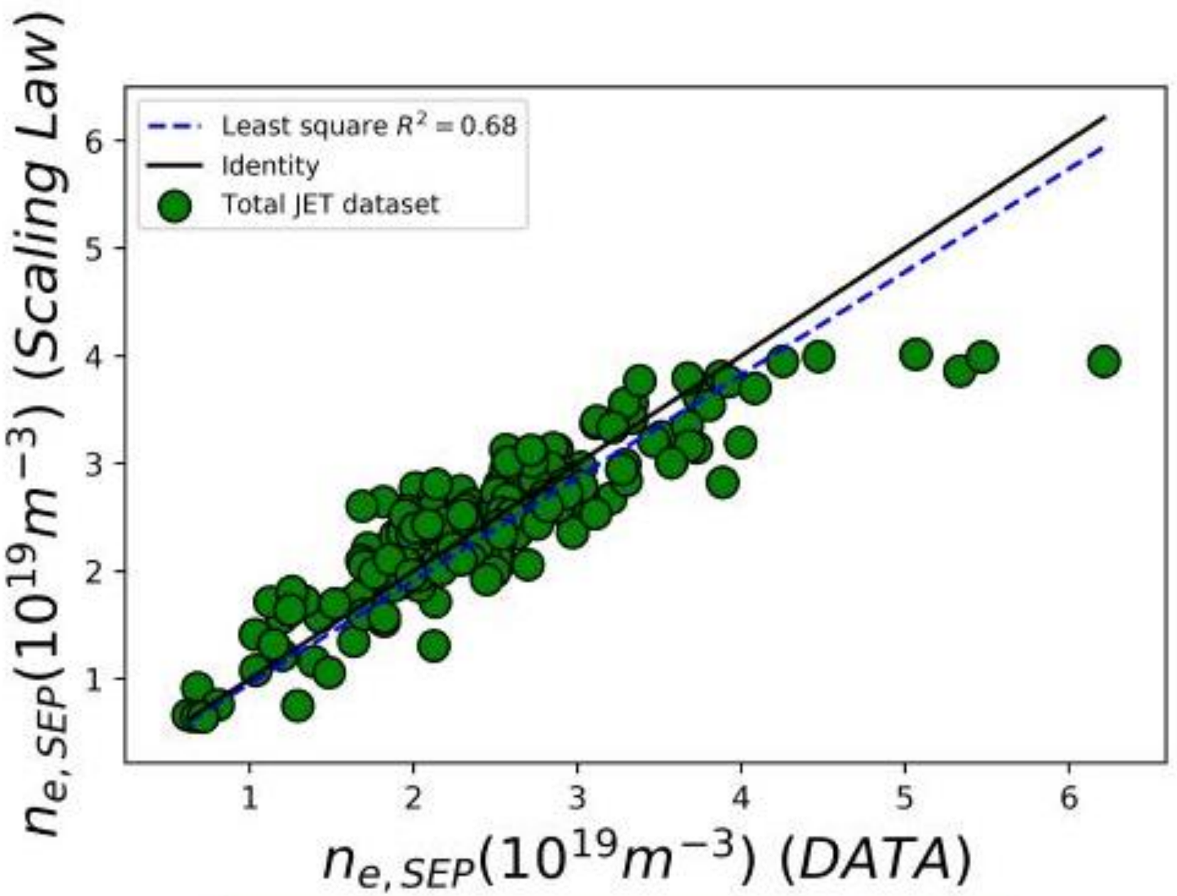






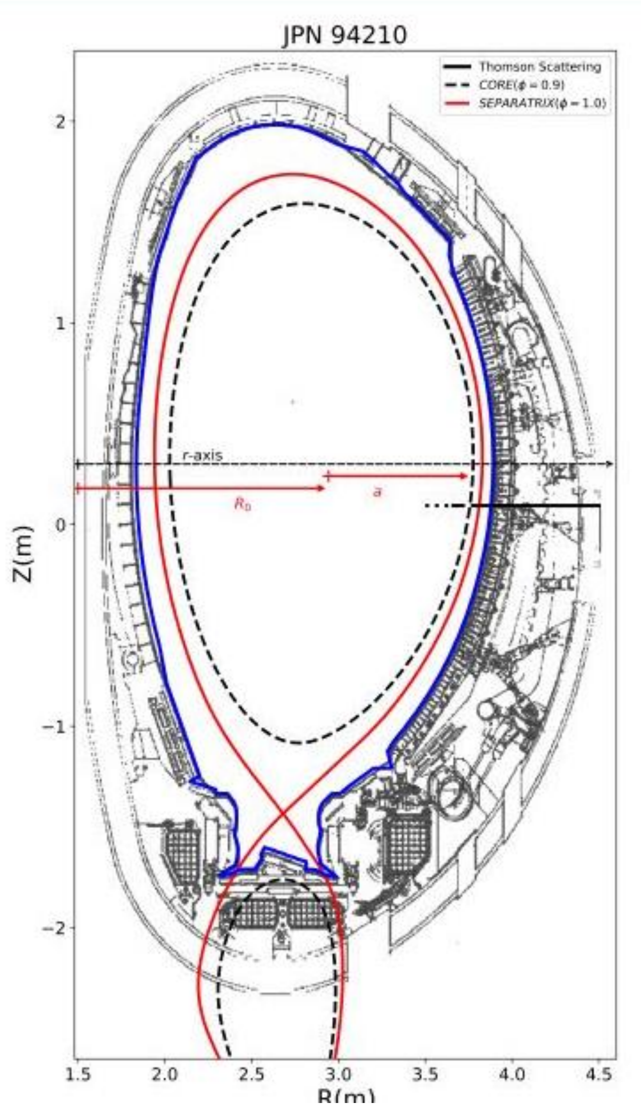
- For fixed pedestal density increasing Bt or Ip the separatrix density decreases
- For fixed pedestal density, increasing the power the separatrix density increases

DERIVATION OF A SCALING LAW FOR NSEP/NPED AS A FUNCTION OF IP AND PTOT

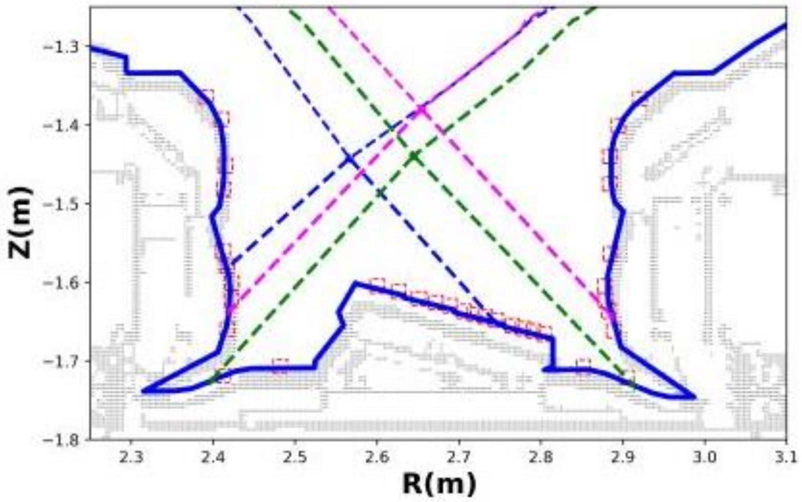


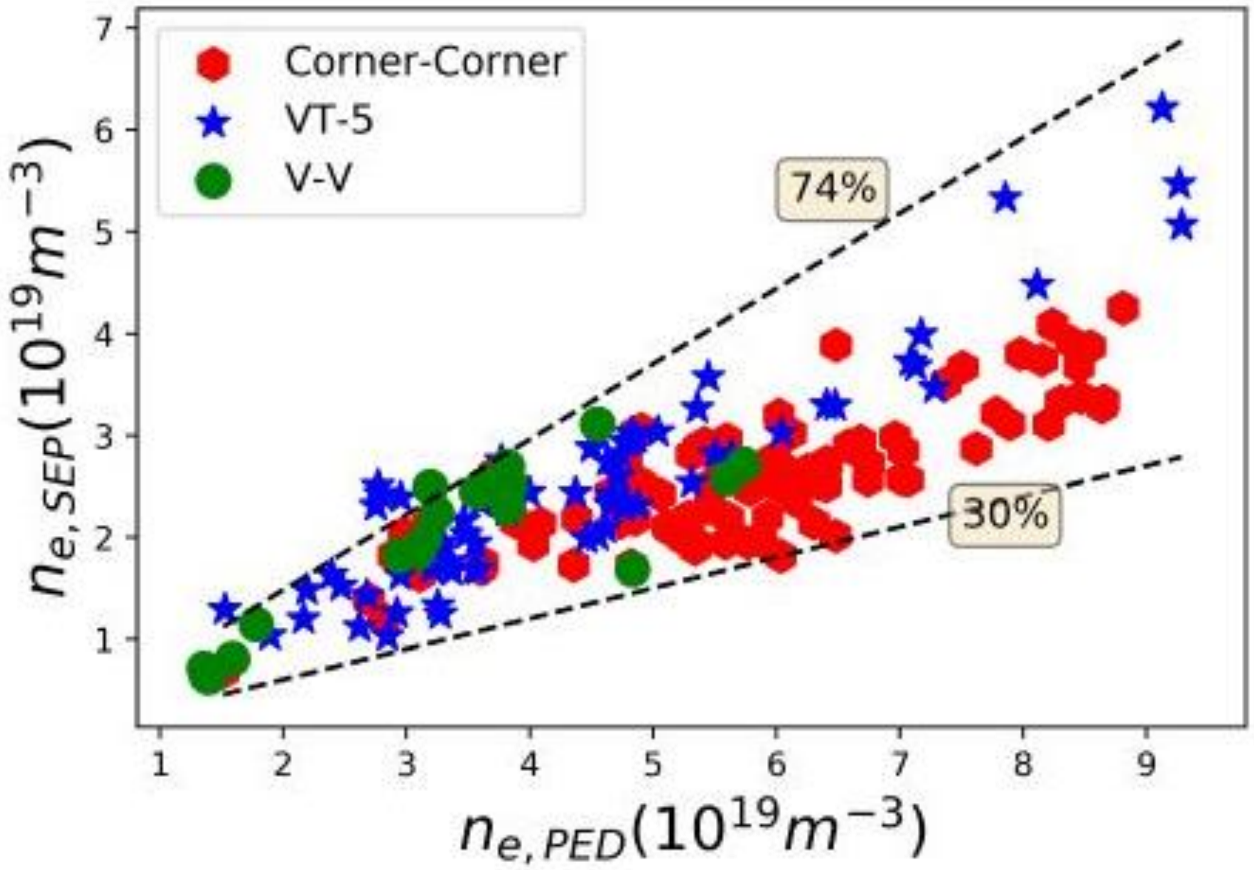
$$n_{e,SEP}/n_{e,PED} \propto P_{TOT}^{0.13} I_P^{-0.59}$$

- Strong dependence on Ip
- Not so strong dependence on Ptot
- Values at high density out of the scaling
- Can we consider another parameter to obtain a better fit at high density?
- Impact of Divertor configuration?



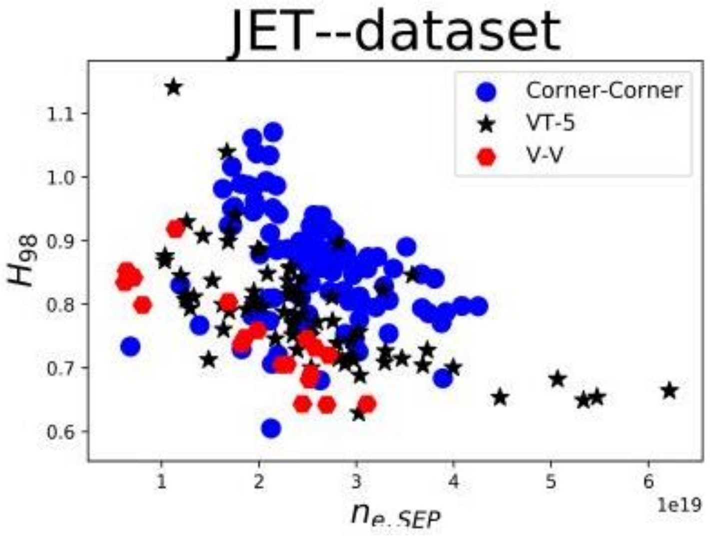
- We will label the data depending on their divertor configuration (CC, VT, VV)
- Does it affect the global behaviour of n_{sep}/n_{ped}?

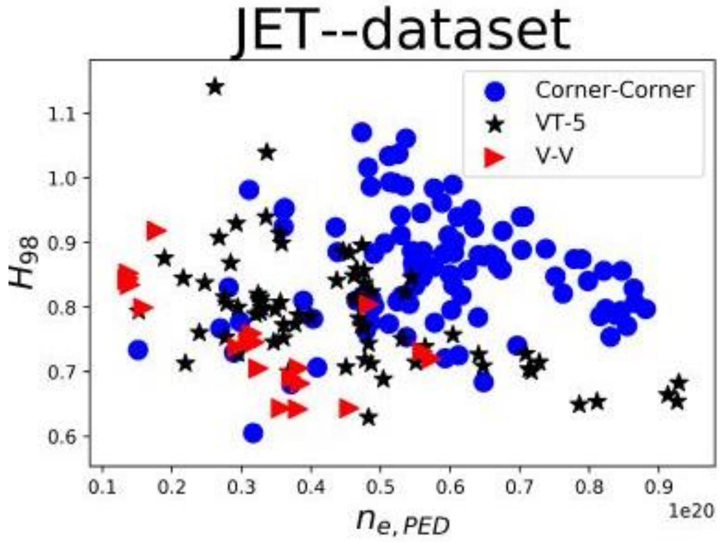




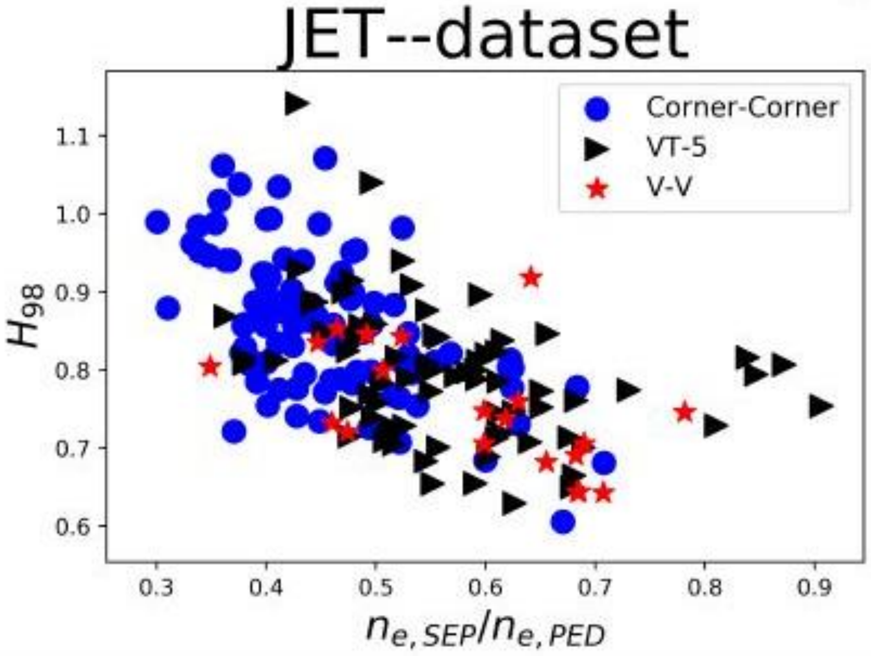
- Corner-corner configuration seems to be associated with a stronger pedestal gradient

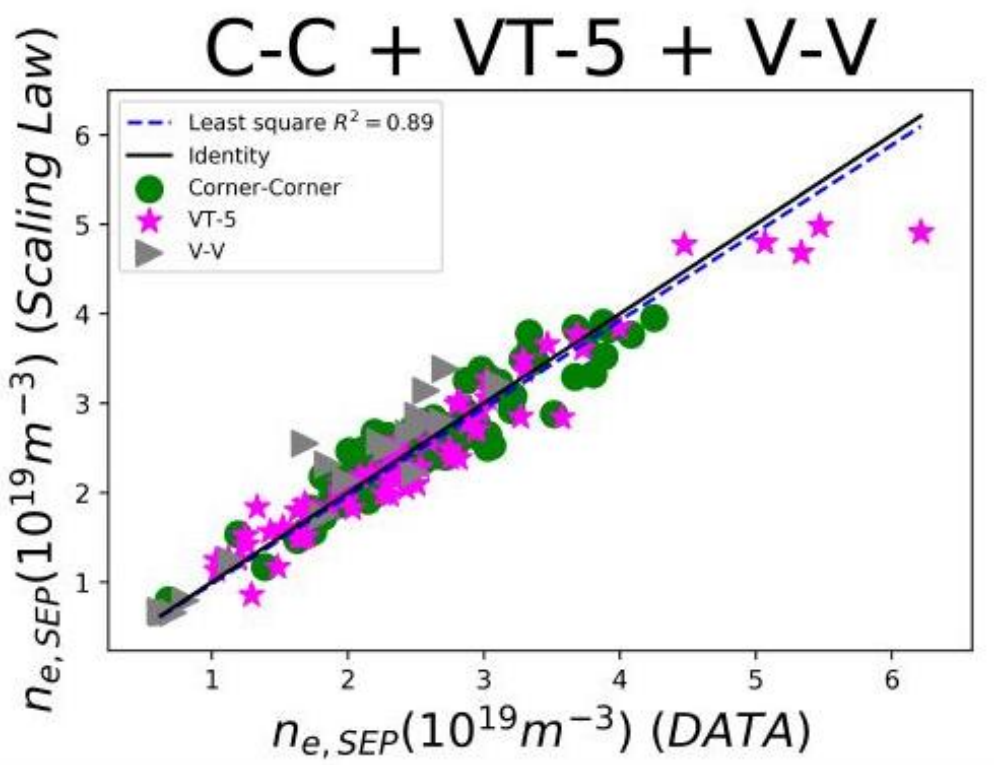
DENSITY BEHAVIOUR CONSIDERING CONFINEMENT PROPERTIES (USING H98) AND DIVERTOR CONFIGURATIONS





- We will label the data depending on their divertor configuration (**CC**, **VT**, **VV**)





- Comparison of experimental $n_{e,SEP}$ (determined using power balance method), and $n_{e,SEP}$ provided by the scaling law. The values for, $n_{e,SEP}$(DATA) $\geq 5 \times 10^{19} \mathrm{m}^{-3}$, now are closed to the scaling law trend.

JET Scaling law - H mode

$$n_{e,SEP}/n_{e,PED} \propto P_{TOT}^{0.14} I_P^{-0.53} H_{98}^{-0.98}$$

- Very strong dependence on H98
- Similar dependencies from Ip and Ptot as the previous one

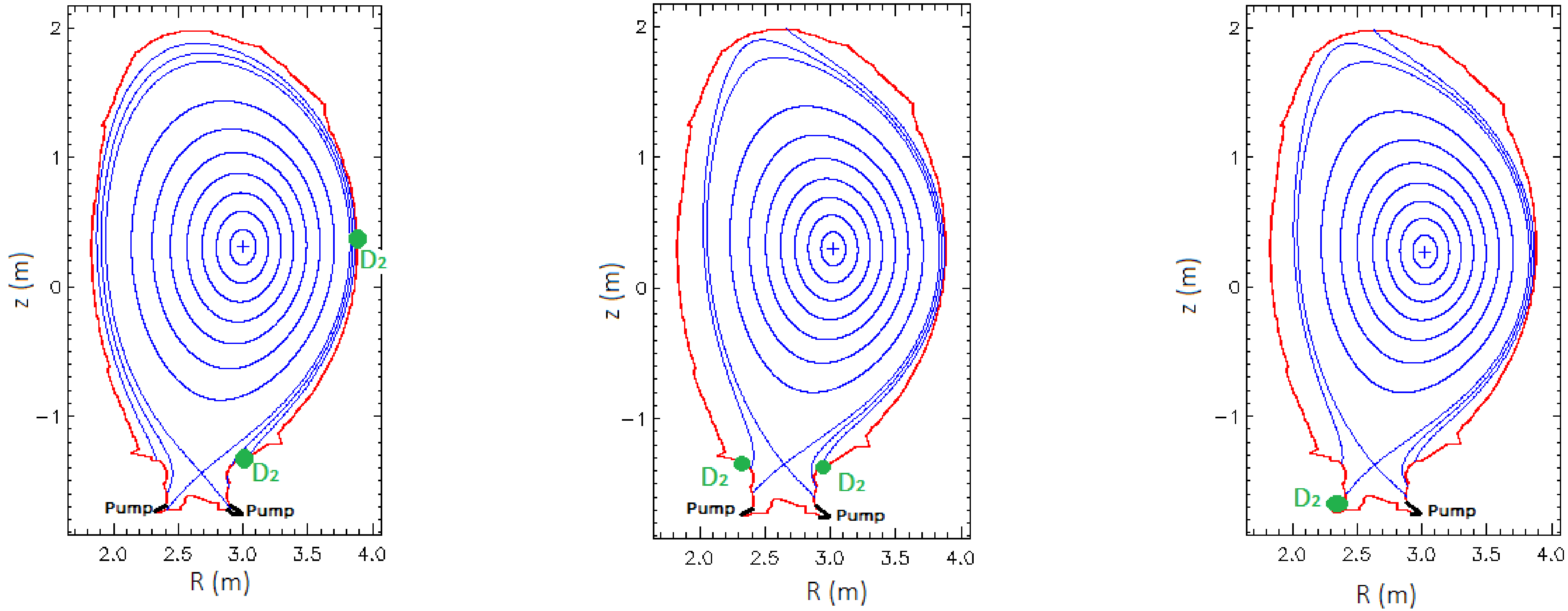
THREE DISCHARGES SIMULATED WITH SOLEDGE2D-EIRENE

Configuration	Pulse number	I_{plasma} (MA)	B_t (T)	P_{SOL} (MW)	D_2 puff (D_2/m^{-3})	NBI (electrons/s)
C-C	94210	2.47	2.8	8.4	$15.7x10^{21}$	$1.5x10^{21}$
V-V (1)	85262	2.48	2.7	6.9	$22.6x10^{21}$	$1.7x10^{21}$
V-V (2)	84714	1.97	2.2	8.6	$12.6x10^{21}$	$1.4x10^{21}$

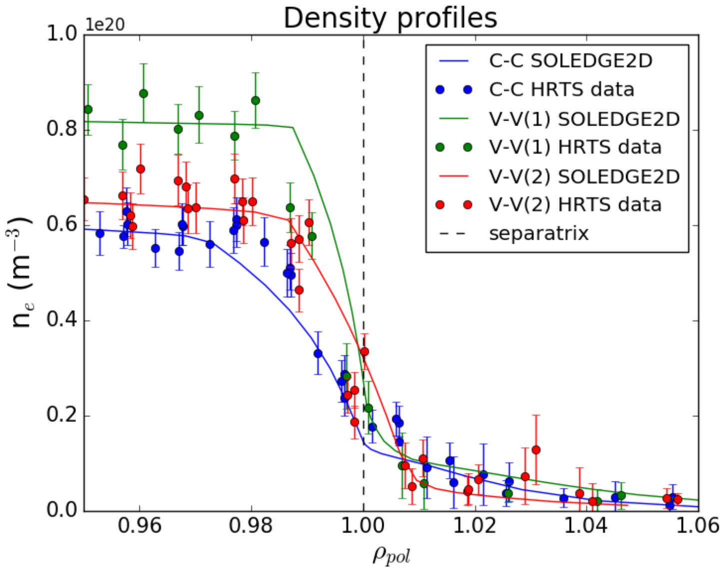
C-C configuration
Equilibrium reconstruction on poloidal section

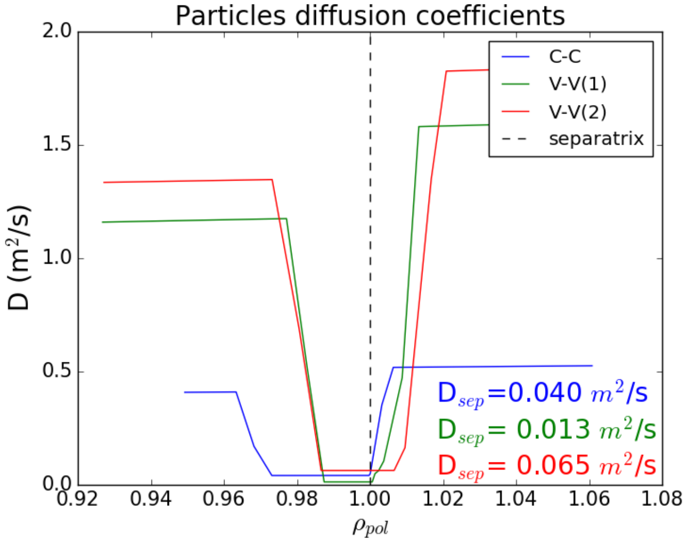
V-V configuration (1)
Equilibrium reconstruction on poloidal section

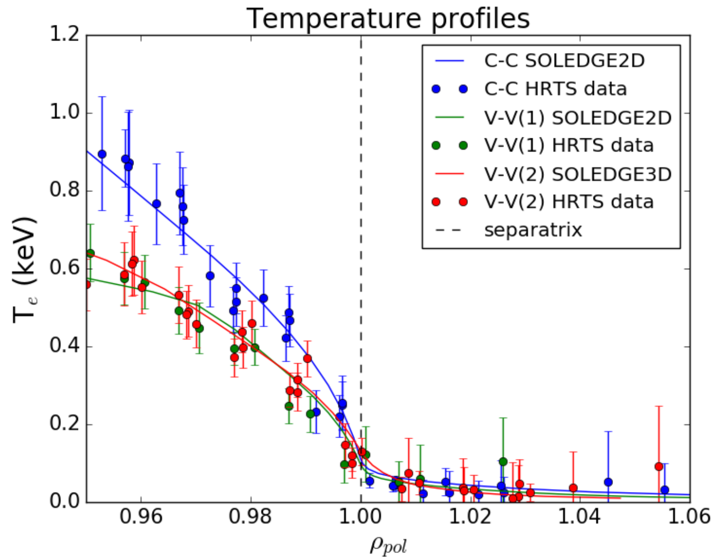
V-V configuration (2)
Equilibrium reconstruction on polidal section

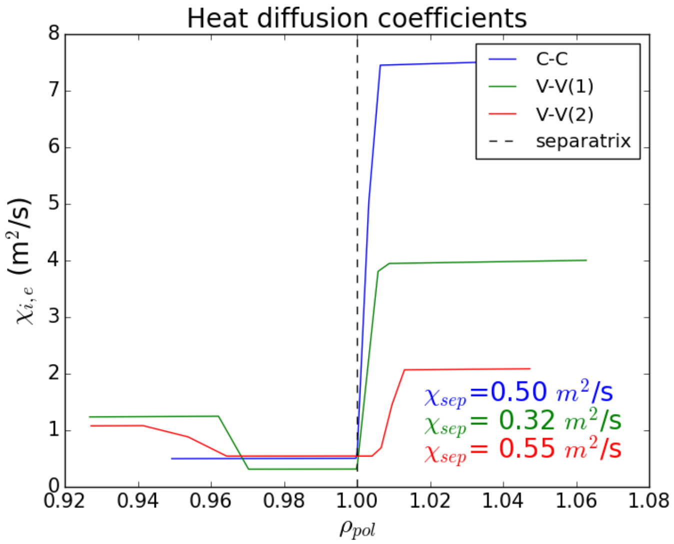


FITTING OUTER MIDPLANE PROFILES AND CORRESPONDING RADIAL TRANSPORT COEFFICIENTS







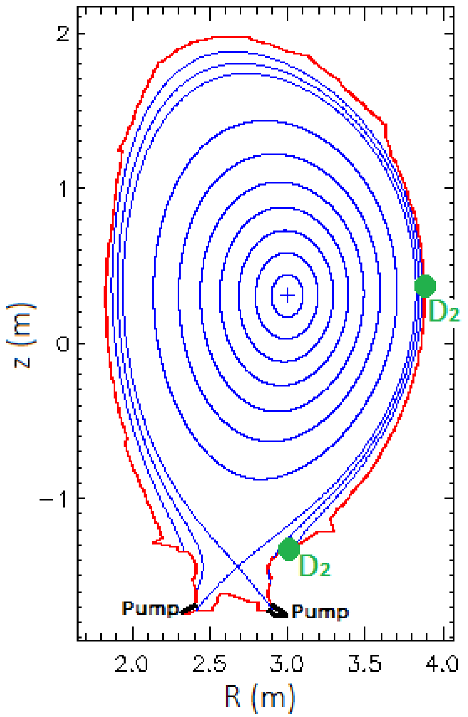


- For the CC configuration the particle diffusivity seems much smaller than for VV configuration
- But the D, Chi profiles are very sensitive to the fitting of the density and temperature profiles,sensitivity studies are ongoing

HOW DOES THE CODE RESPOND INCREASING/DECREASING THE POWER?

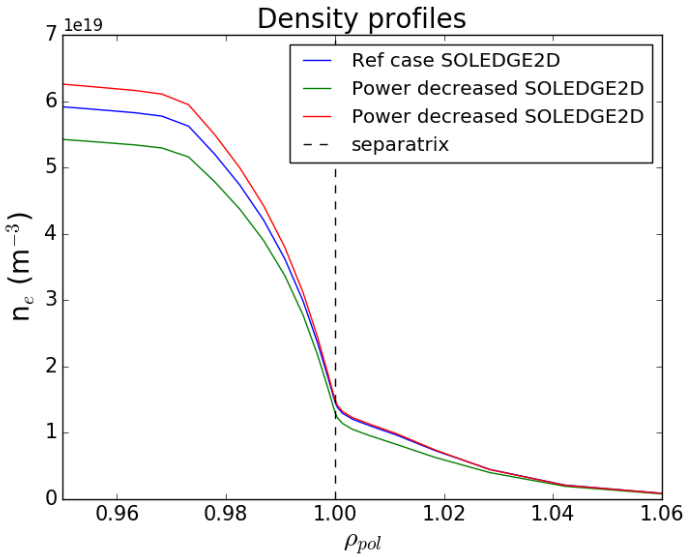
C-C configuration

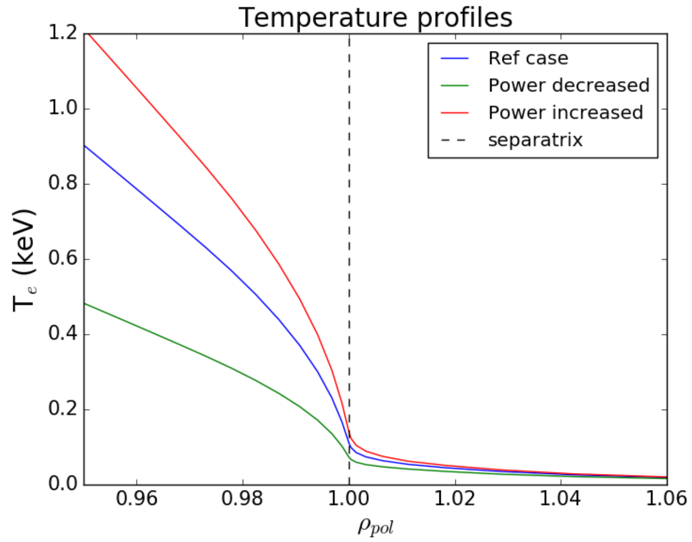
Equilibrium reconstruction on poloidal section



	P_{SOL} [MW]
Reference case	17,65
Increase P	25,2
Decrease P	8,4

- Keeping the same transport coefficient and input parameters apart from input power





- For this simulation, the response to the increase of the power is essentally
  - an increase in the temperature
  - A reduced increase in pedestal density
  - Almost no variation in Nsep

CONCLUSIONS

- We have deriverd a scaling law for the ratio **Nsep/Nped** for a large database of H-mode discharges in JET (for more details J Balbin, PhD manuscript, Aix-Marseille University 2022)

- Strong dependence on H98 parameter under investigation

- Evaluation of the impact of the method for determining the separatrix position on scaling law

- Extension to other discharges in JET and other machines (DIIID, AUG, TCV….)

- SOLEDGE simulations ongoing to have a better undertaning of the role of the divertor and the radial transport.

- What is the best way of doing a power scan with transport codes for preparing scenarios of future machines?