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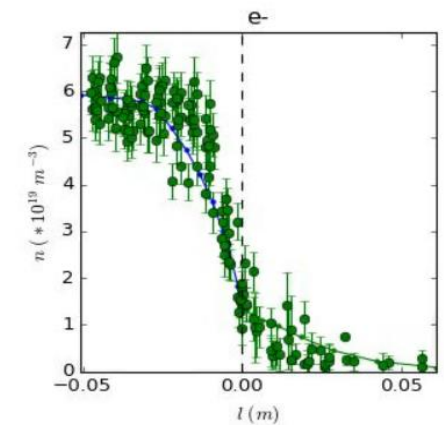
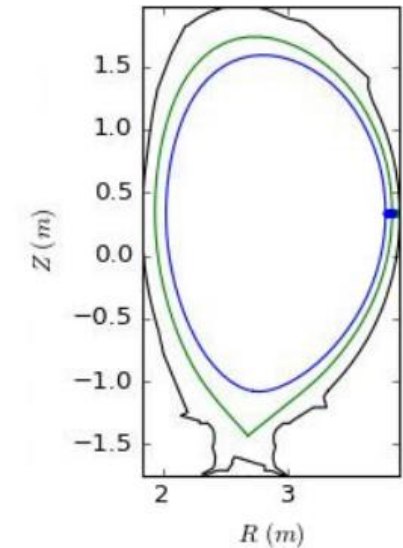
Derivation of a scaling law for $n_{\text{sep}}/n_{\text{ped}}$ as a function of engineering parameters in JET H-mode plasma and impact of divertor geometry

*J Balbin-Arias, J Bucalossi, G Ciraolo,
N Fedorczak, P Innocente, P Muscente
and the JET team*



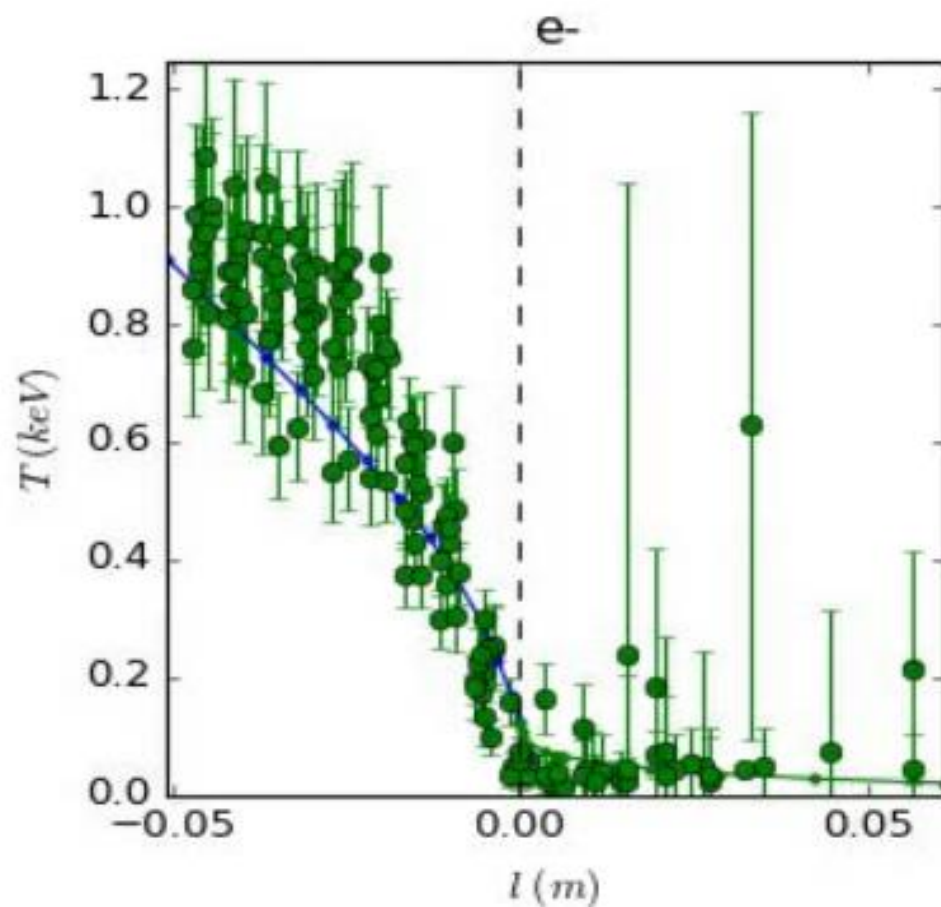
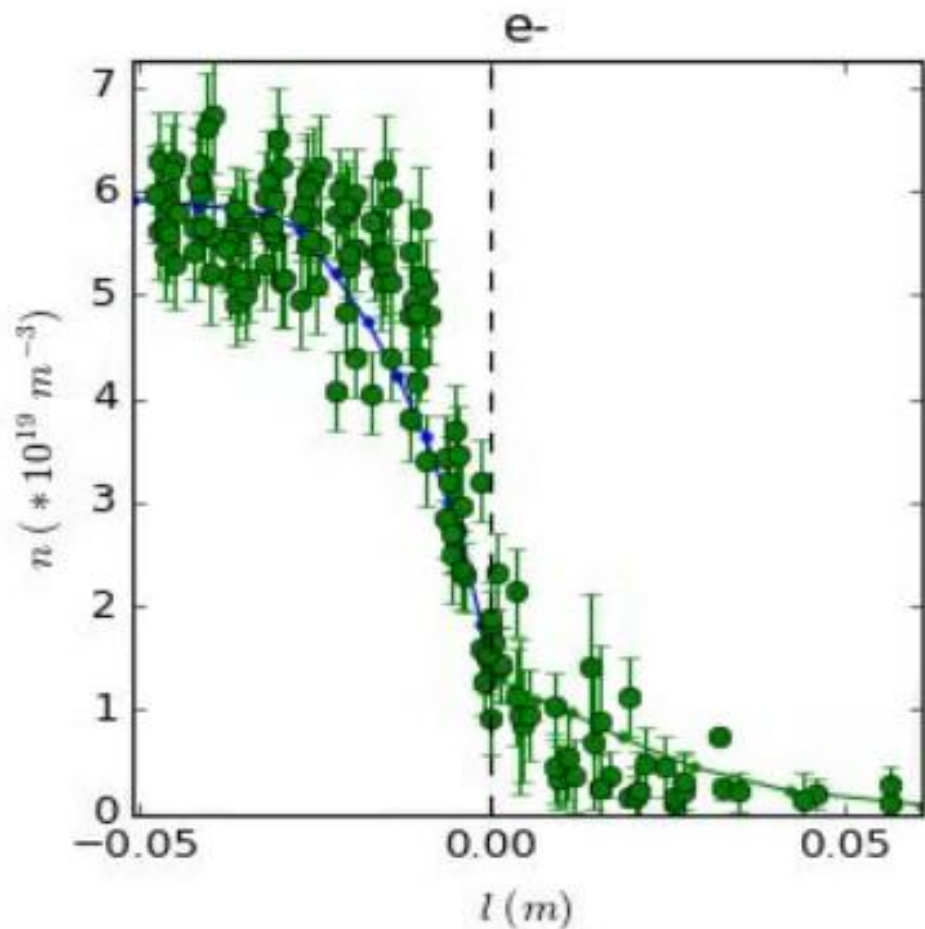
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

- **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
- **RT01: Core-Edge-SOL integrated H-mode scenario compatible with exhaust constraints in support of ITER**
- 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 $n_{\text{sep}}/n_{\text{ped}}$** where
 - n_{sep} is the separatrix density at the outer midplane
 - n_{ped} 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 DIID (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

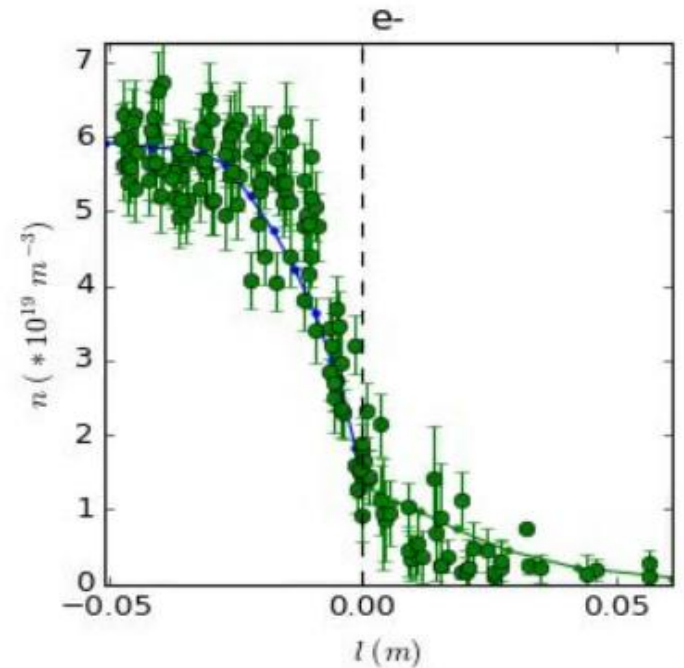
- We consider electron density and electron temperature data from HRTS during flat top conditions



- 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)
 - $P_{sol} = \frac{1}{4}(P_{inj} - P_{rad,bulk})$ 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



- Spitzer-Harm:

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

- Sheath-limited:

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

- Flux-limited:

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

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

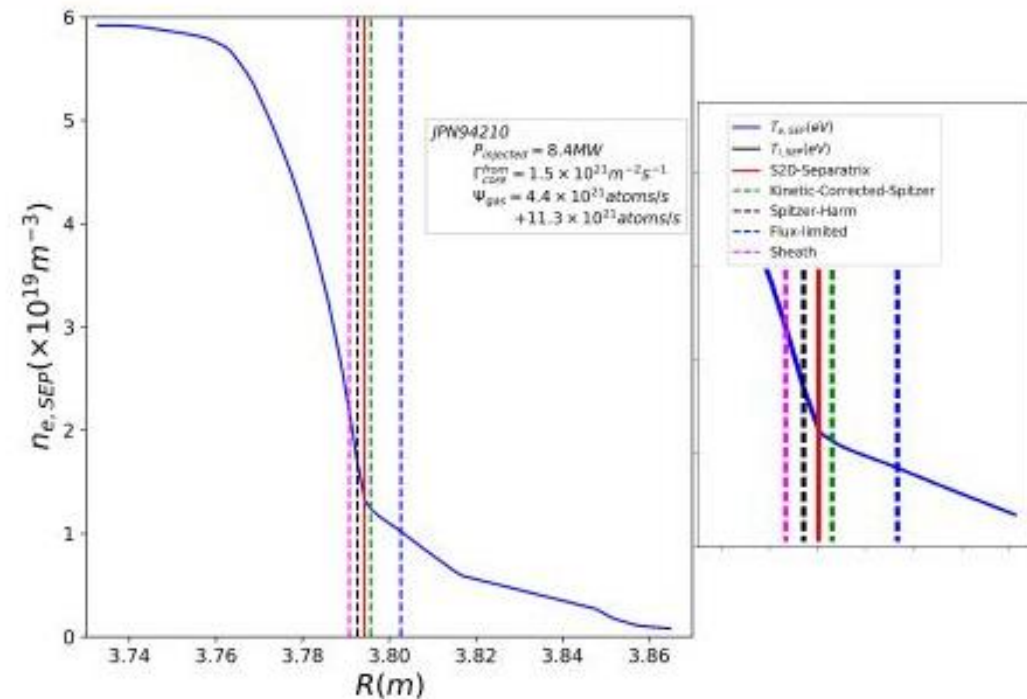
- Kinetically-corrected Spitzer:

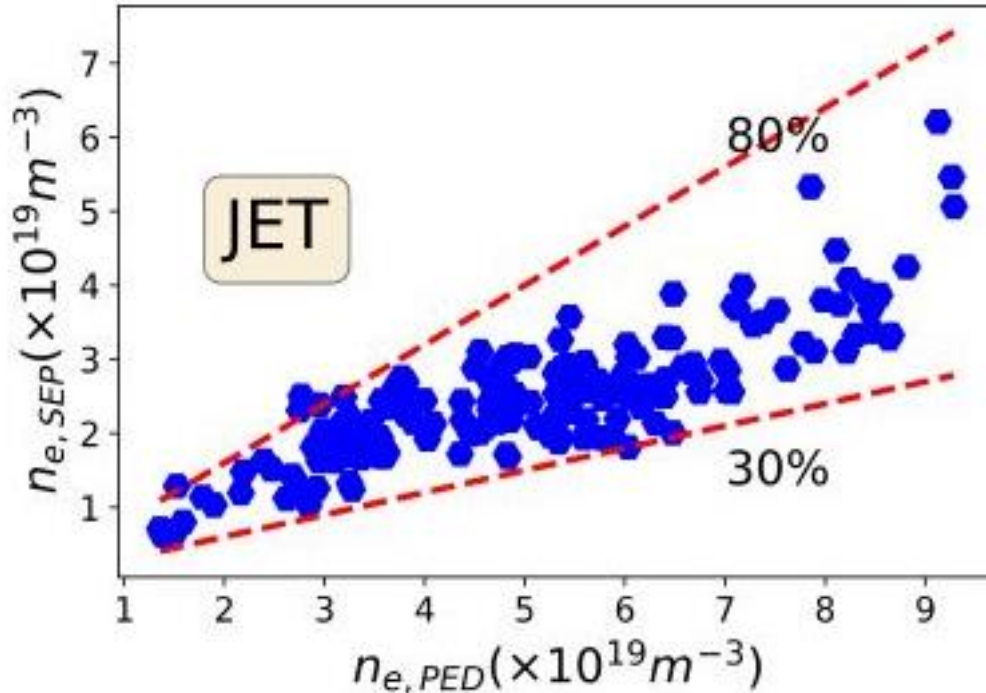
$$q_{||}^{\text{kin-corr-Spitzer}} = \frac{q_{||}^{\text{Spitzer}} q_{||}^{\text{flux-limited}}}{(q_{||}^{\text{Spitzer}} + q_{||}^{\text{flux-limited}})}$$

Selection of $q_{||}$

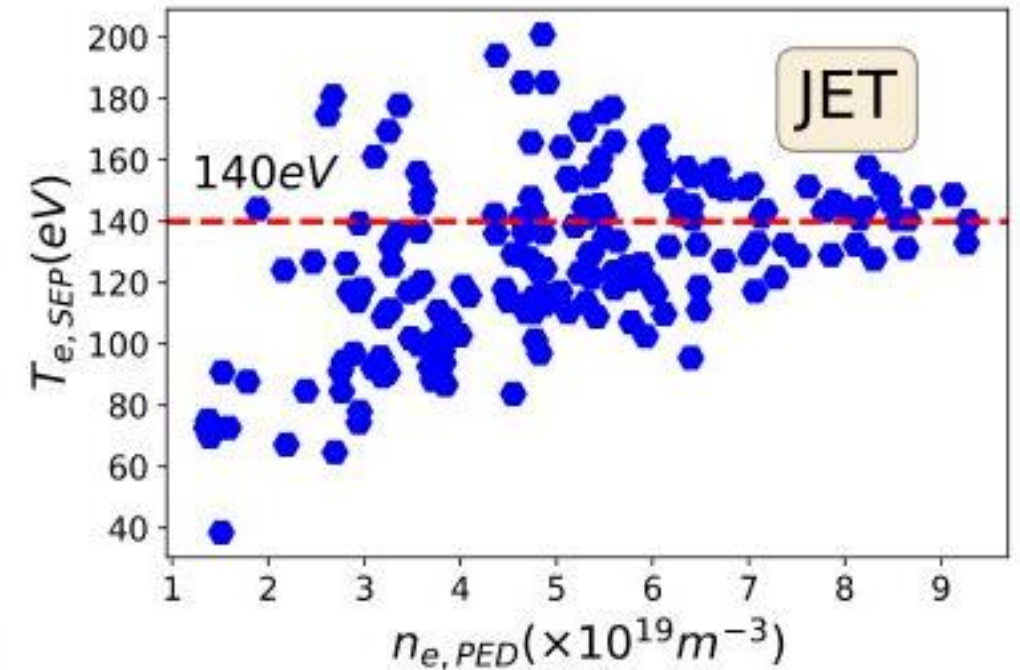
$q_{||}$ is chosen using SOLEDGE2D (S2D) by comparison. The method compares separatrix position for each $q_{||}$ expression with the sep. position imposed by mesh grid.

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

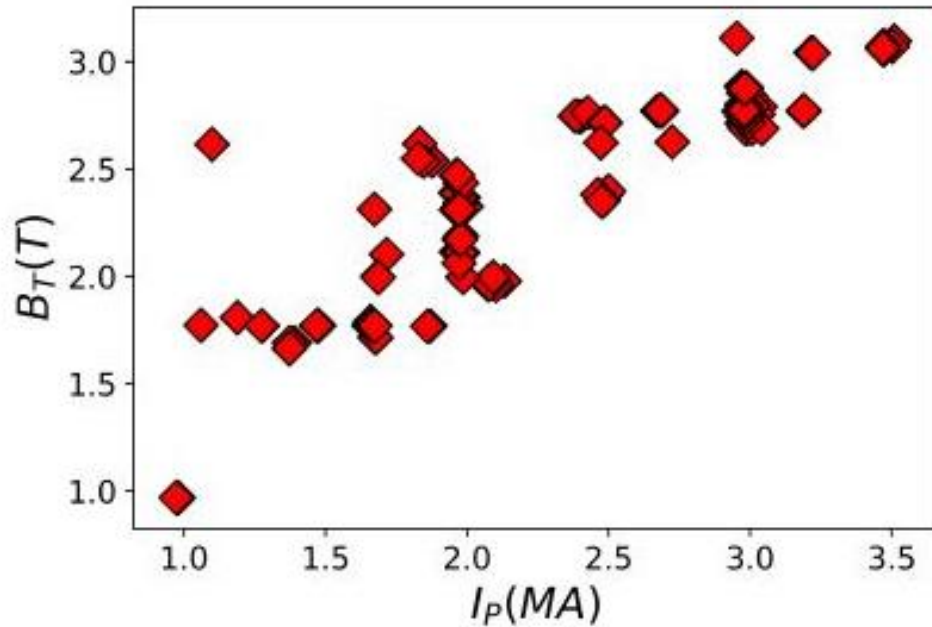




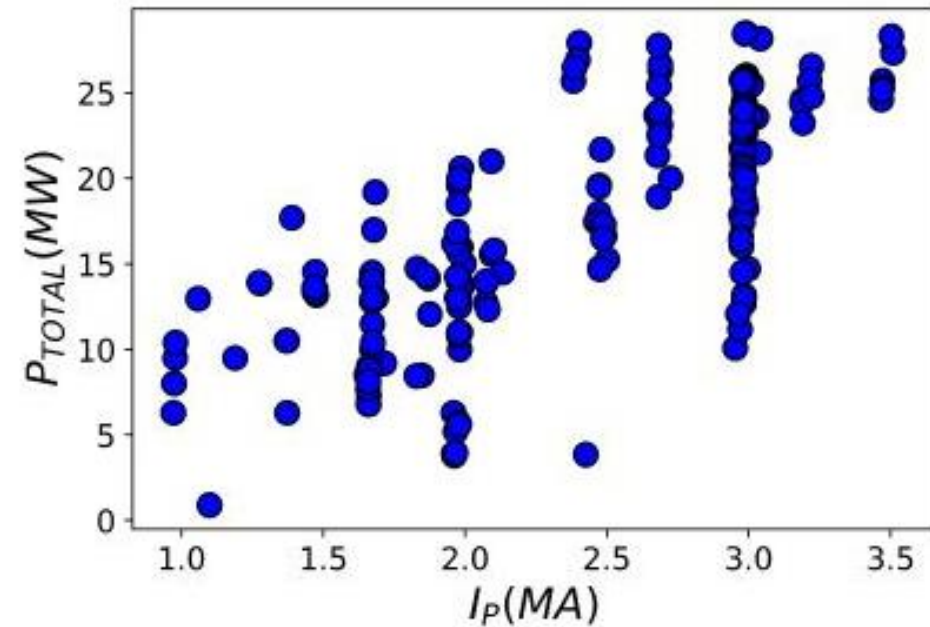
- Large range of values of the ratio between separatrix and pedestal density ($0.3 < N_{sep}/N_{ped} < 0.8$)



- 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

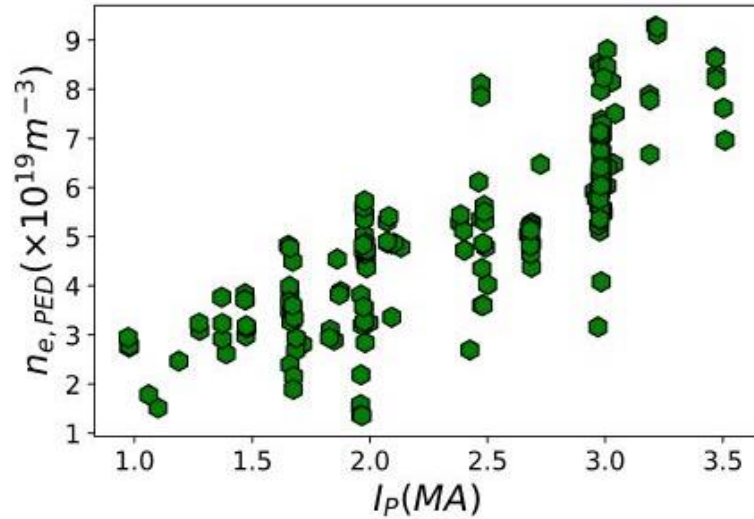


- The $I_p - P_{tot}$ plane is quite well covered from the discharges under consideration

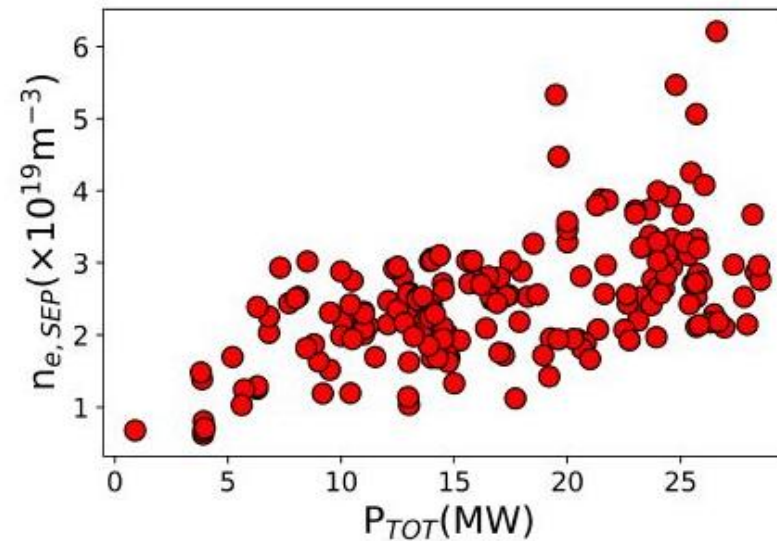
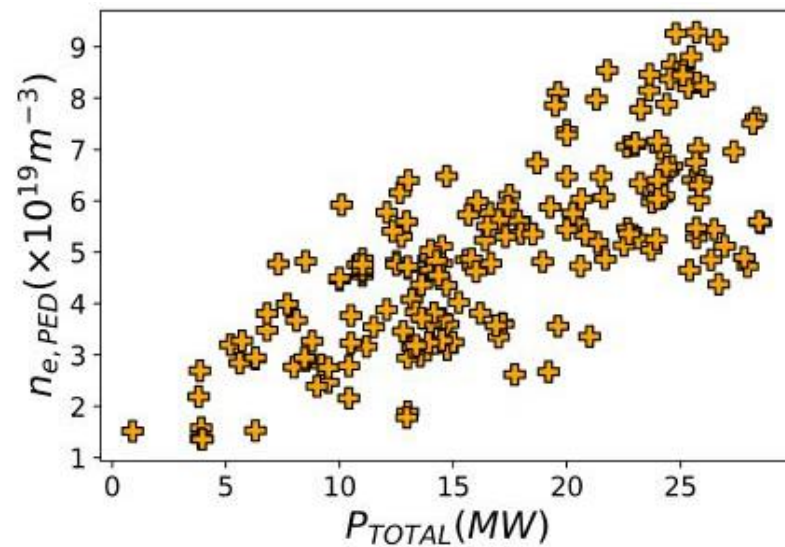
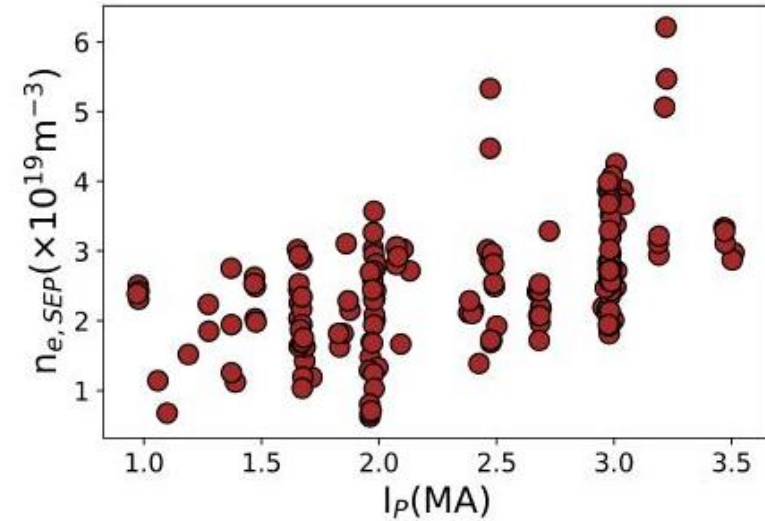


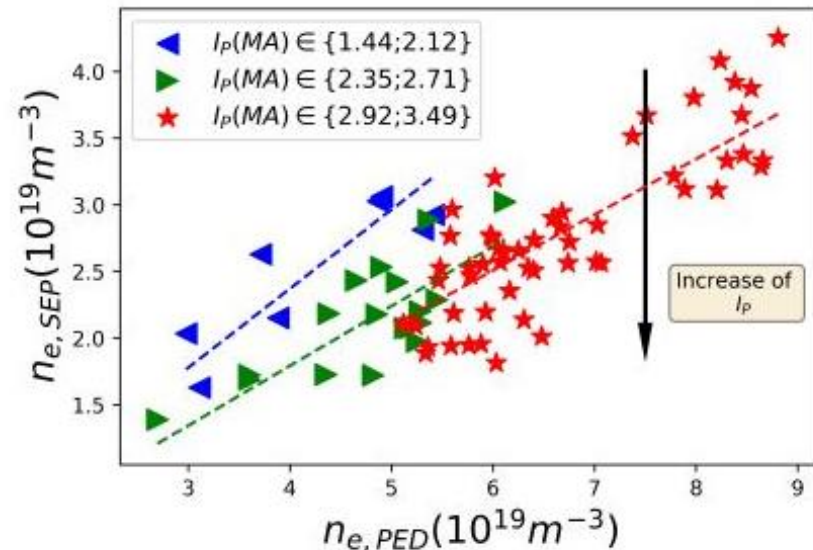
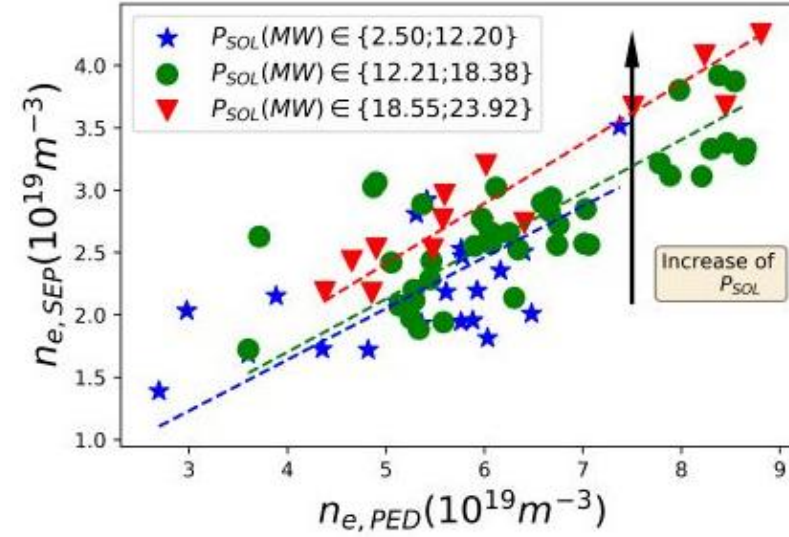
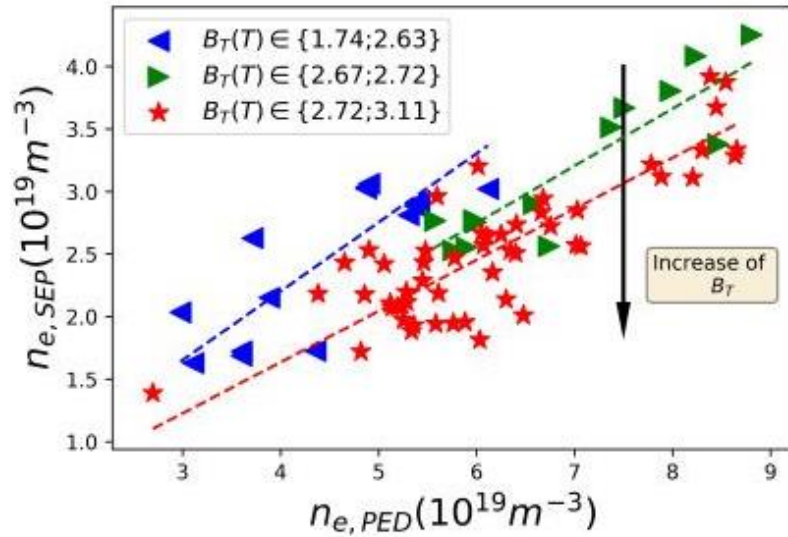
We will consider I_p and P_{tot} as independent engineering parameters for the scaling law

Pedestal density

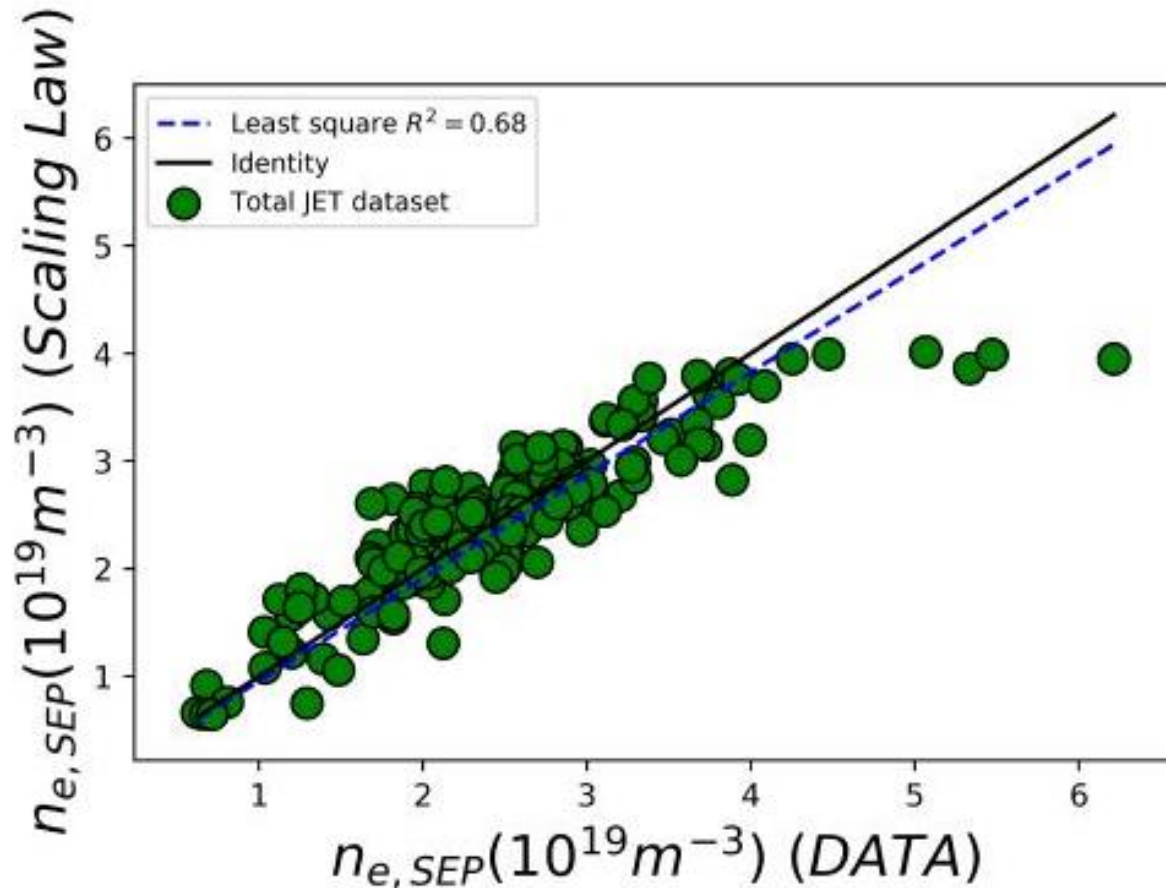


Separatrix density



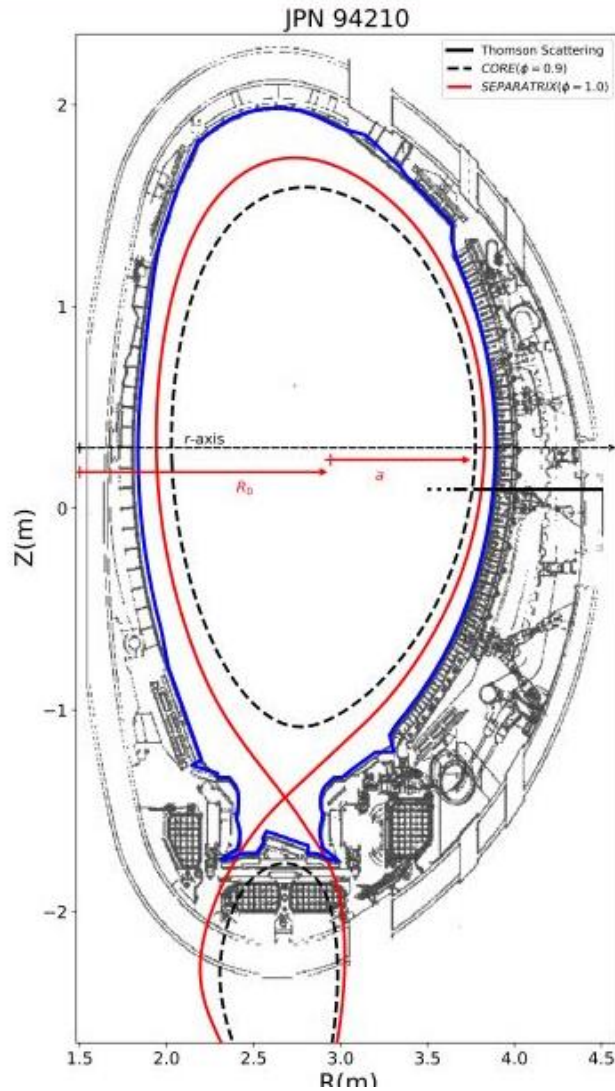


- For fixed pedestal density increasing B_t or I_p the separatrix density decreases
- For fixed pedestal density, increasing the power the separatrix density increases

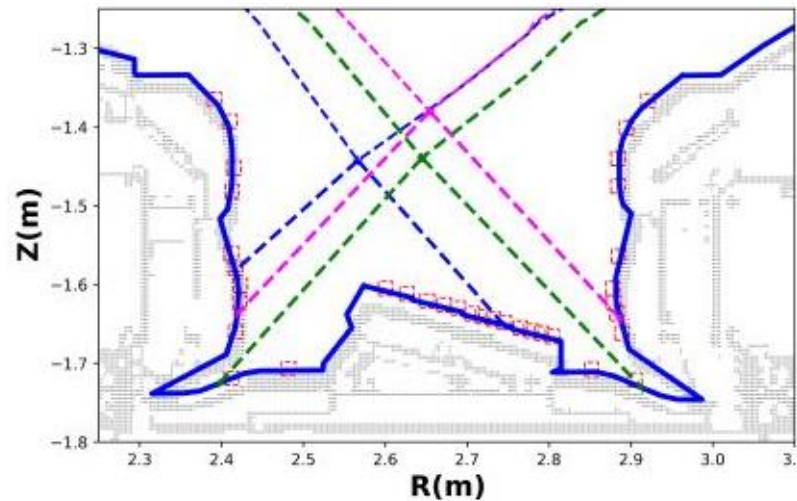


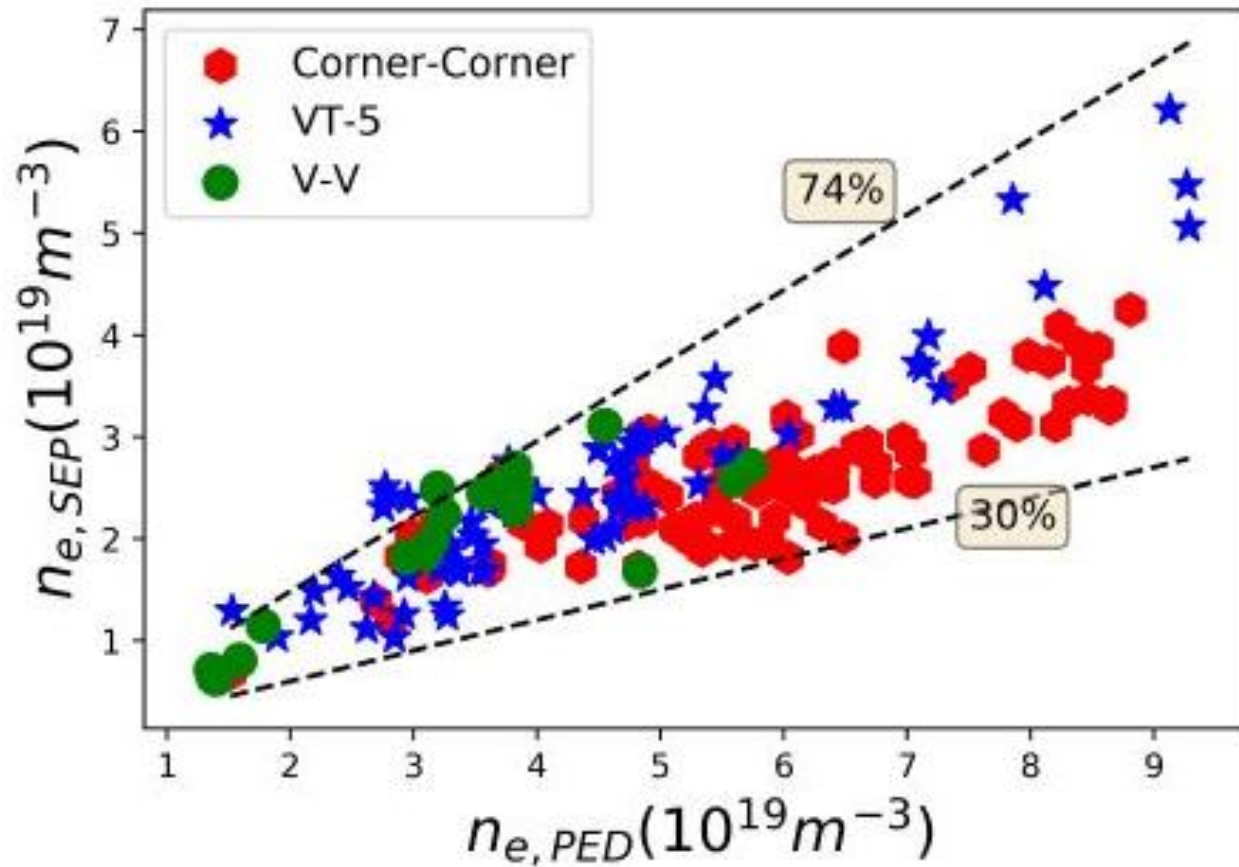
$$n_{e,SEP}/n_{e,PED} \propto P_{TOT}^{0.13} I_P^{-0.59}$$

- Strong dependence on I_P
- Not so strong dependence on P_{tot}
- 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?



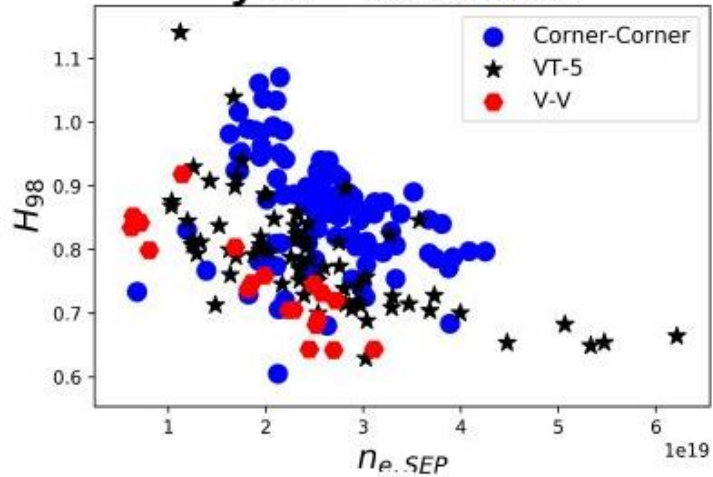
- We will label the data depending on their divertor configuration (CC, VT, VV)
- Does it affect the global behaviour of n_{sep}/n_{ped} ?



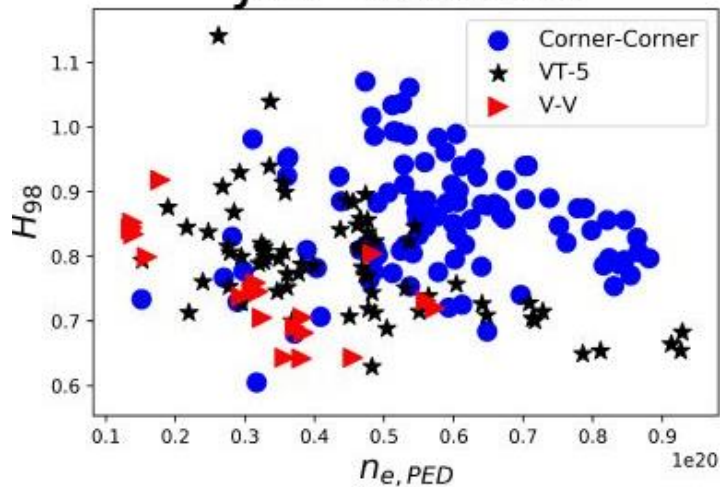


- Corner-corner configuration seems to be associated with a stronger pedestal gradient

JET--dataset

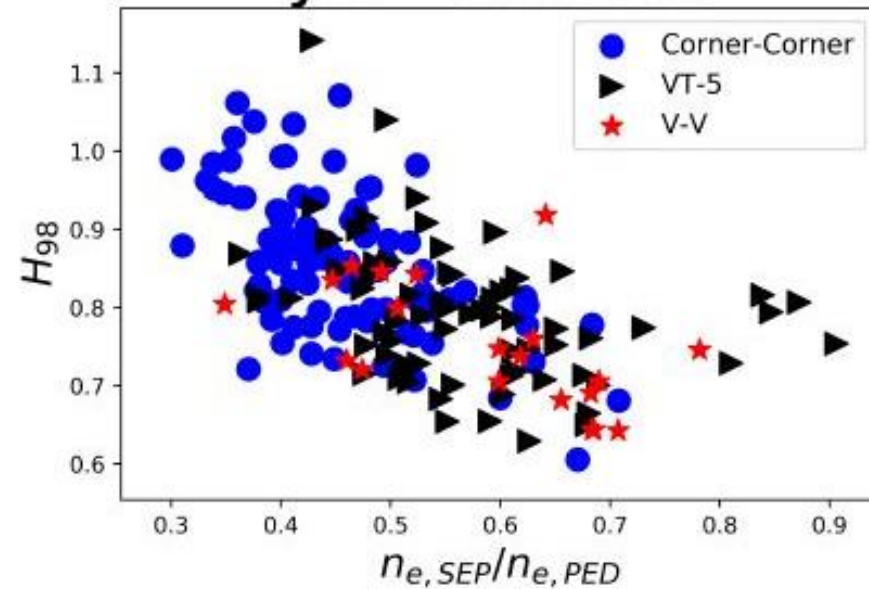


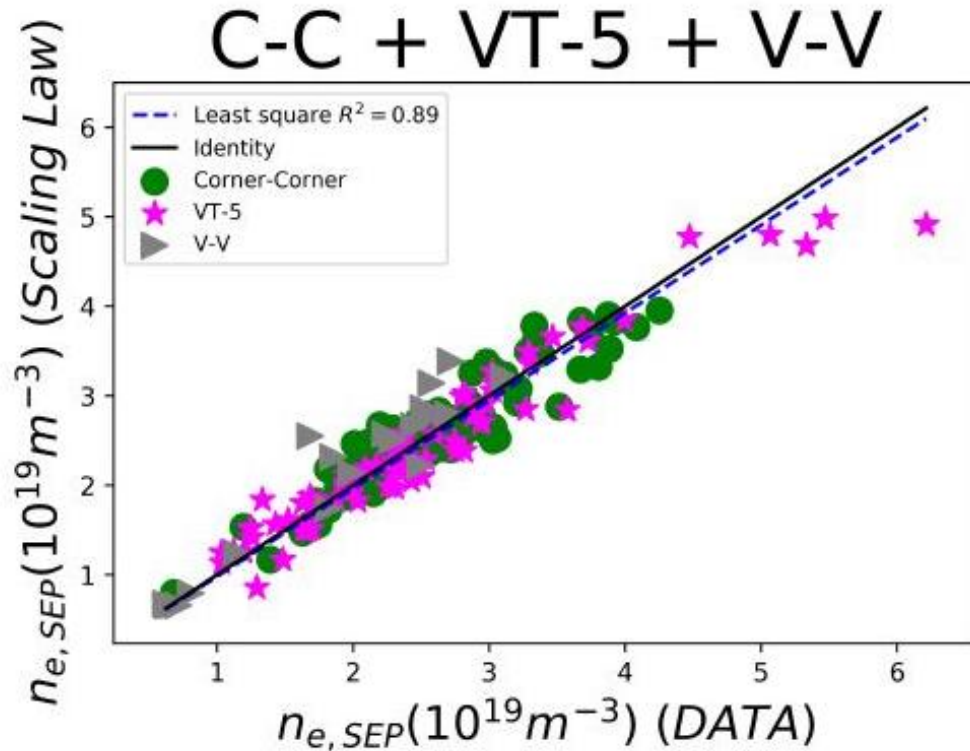
JET--dataset



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

JET--dataset





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

JET Scaling law - H mode

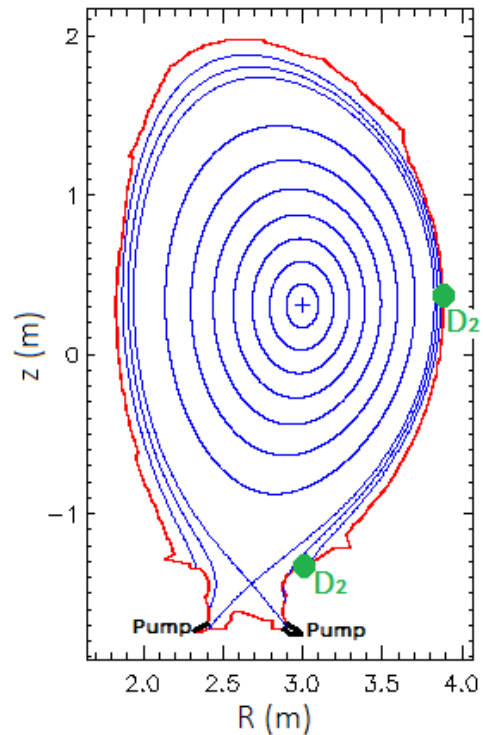
$$n_{e,SEP}/n_{e,PED} \propto P_{TOT}^{0.14} I_P^{-0.53} H_{98}^{-0.98}$$

- Very strong dependence on H98
- Similar dependencies from I_p and P_{tot} as the previous one

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	15.7×10^{21}	1.5×10^{21}
V-V ⁽¹⁾	85262	2.48	2.7	6.9	22.6×10^{21}	1.7×10^{21}
V-V ⁽²⁾	84714	1.97	2.2	8.6	12.6×10^{21}	1.4×10^{21}

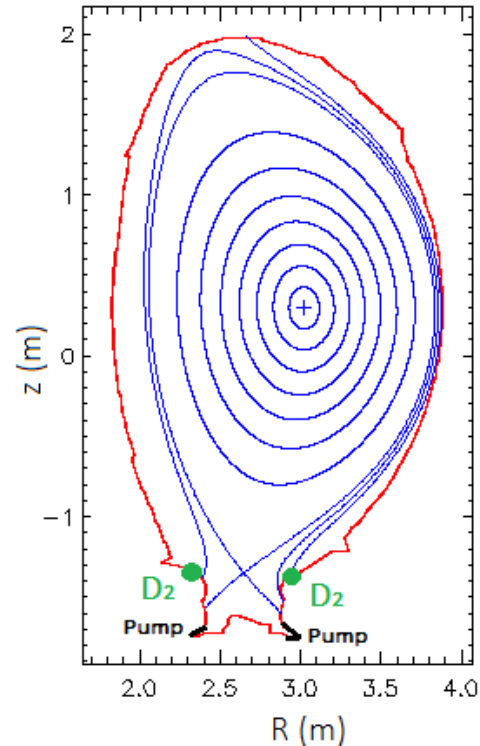
C-C configuration

Equilibrium reconstruction on poloidal section



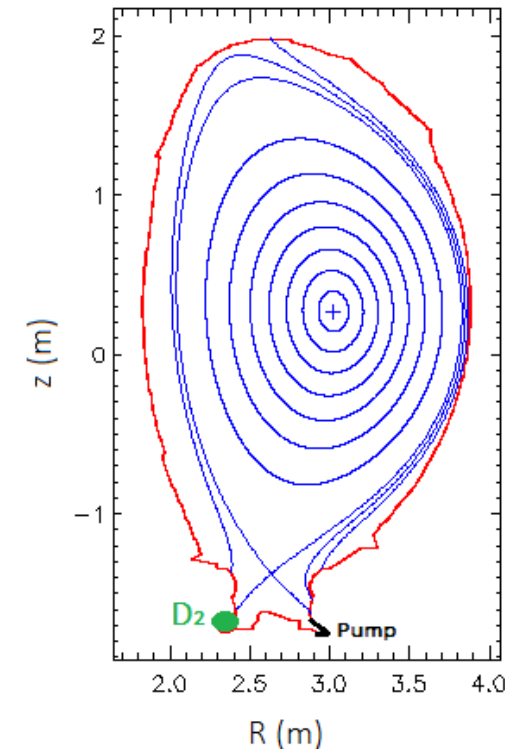
V-V configuration (1)

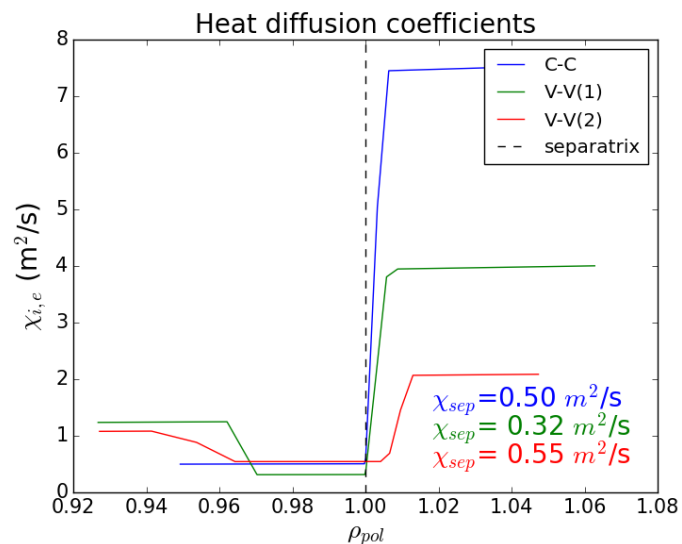
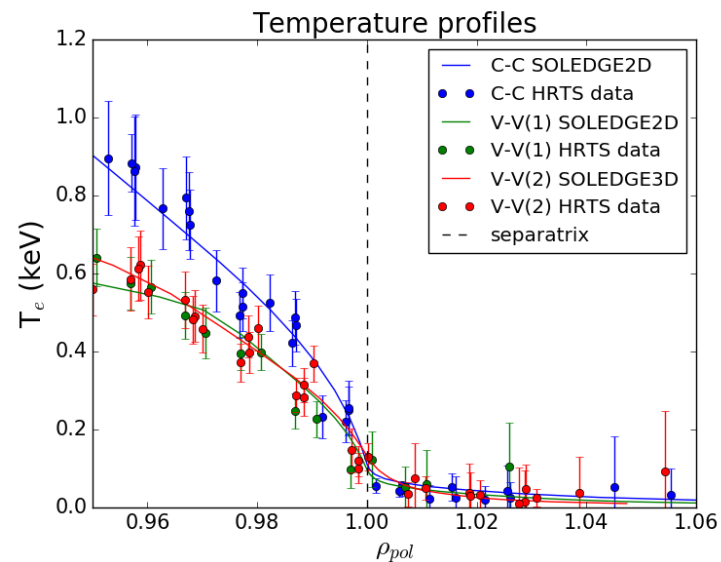
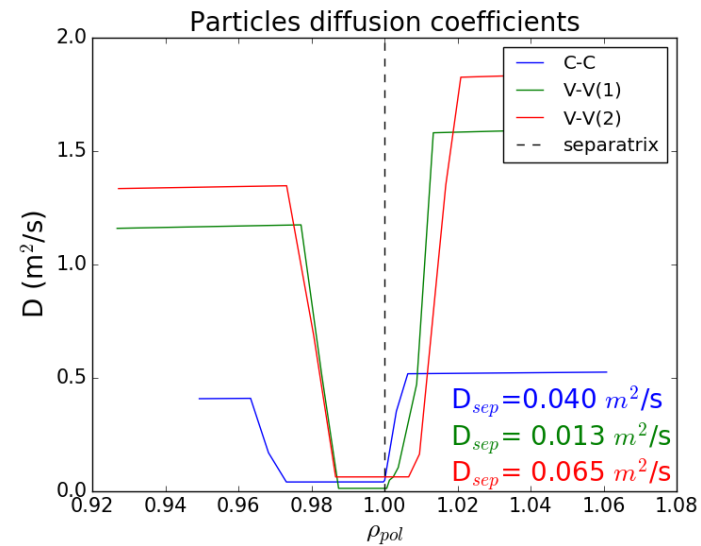
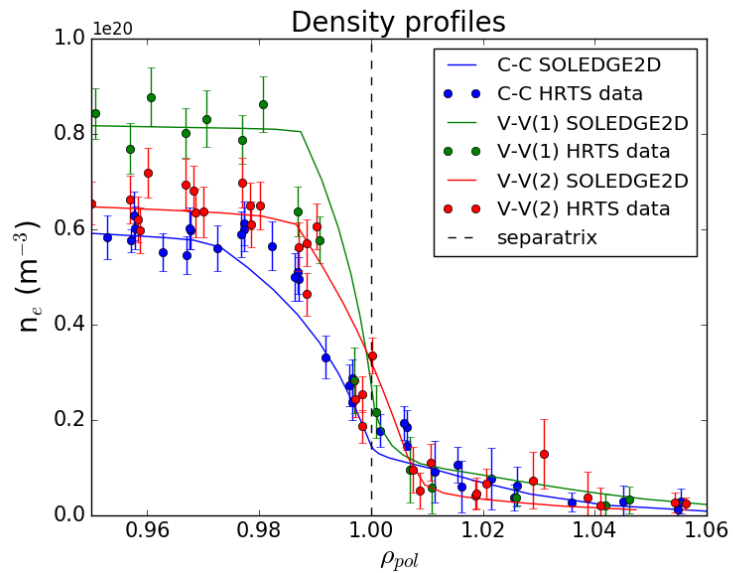
Equilibrium reconstruction on poloidal section



V-V configuration (2)

Equilibrium reconstruction on poloidal section

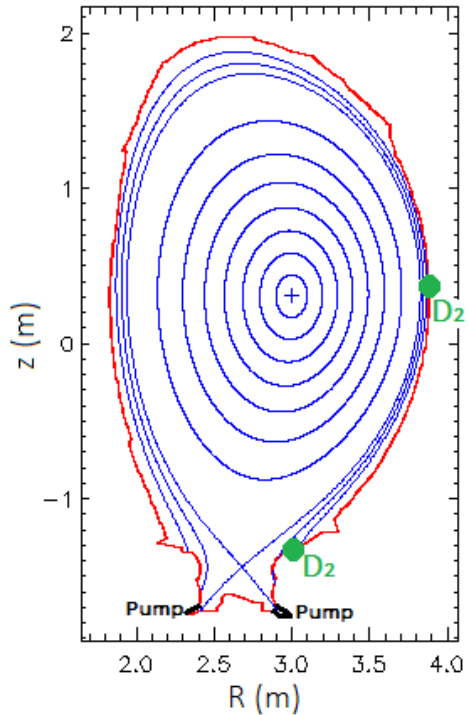




- For the CC configuration the particle diffusivity seems much smaller than for VV configuration
- But the D , χ_i profiles are very sensitive to the fitting of the density and temperature profiles
- sensitivity studies are ongoing

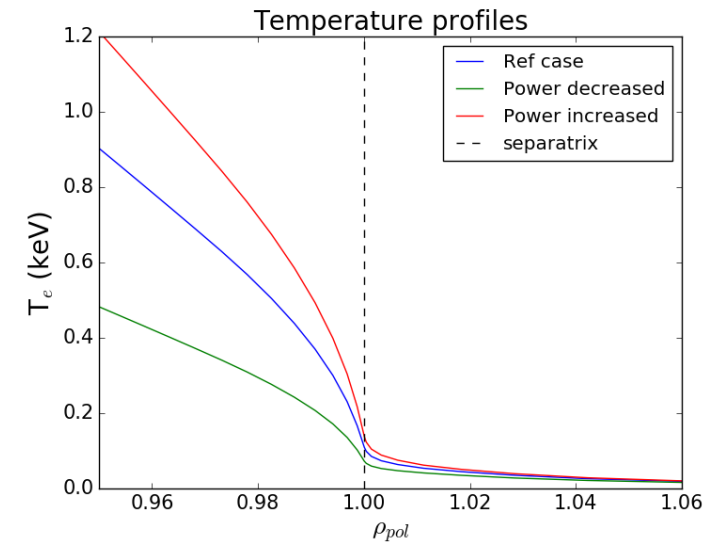
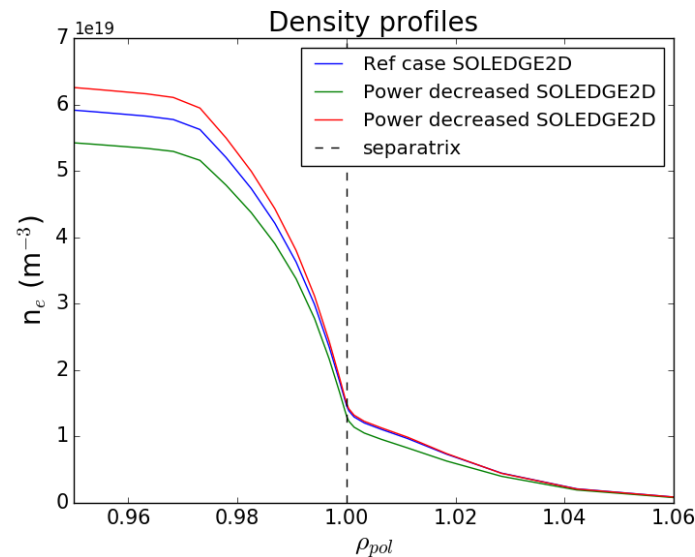
C-C configuration

Equilibrium reconstruction on poloidal section



	P_{SOL} [MW]
<i>Reference case</i>	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 essentially
 - an increase in the temperature
 - A reduced increase in pedestal density
 - Almost no variation in nsep

- We have derived a scaling law for the ratio $n_{\text{sep}}/n_{\text{ped}}$ for a large database of H-mode discharges in JET (for more details J Balbin, PhD manuscript, Aix-Marseille University 2022)
- We are now considering a much larger data base (from about 200 to more than 1000 H-mode discharges from EUROfusion JET pedestal database (L. Frassinetti et al, NF2021);
 - Evaluation of the impact of the method for determining the separatrix position on scaling law
 - Strong dependence on H98 parameter under investigation
 - Other engineering parameters to be considered in the scaling law
 - Including data from other devices (TCV, AUG, DIIIID,...)
 - SOLEDGE simulations ongoing to have a better understanding of the role of the divertor and the radial transport (adding also seeded impurities)
 - What is the best way of doing a power scan with transport codes for preparing scenarios of future machines?