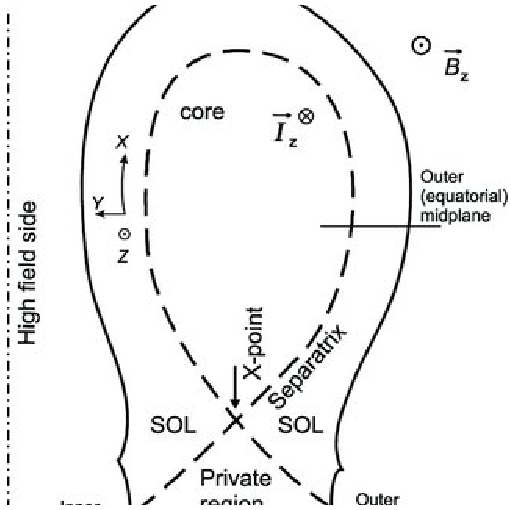
Separatrix Prep

- **Where is separatrix?**
  - LCFS
- **What are we interested in? Why?**
  - Separatrix Density Height, n^{sep}_{height}
    - an increasing n^{sep}_{e} leads sometimes to an outward shift of n^{ped}_{height}, $\rightarrow$ increasing n^{ped}_{pos} and T^{ped}_{pos} $\rightarrow$ affects on pedestal pressure. **We want high pedesetal pressure!** Therefore it is important to determine what pedestal profiles correspond to an increase in pedestal pressure, and thus the main engineering paramaters that lead to this. [2]



    - Connect SOL to pedestal to core.
  - Separatrix Position
    - Identify and predict power width within separatrix (Stangeby)
      - Identifying what leads to an increase in power within the SOL, leads us to know what ultimately increases confinement time ($\tau_E = W/P_{net}$)
    - Identify the general pedestal width, in combination with n^{ped}_{height}
  - Pedestal in general
    - Using pedestal pressure, we can determine the pedestal contribution to the global confinement time τ_E

$$\tau_{e,IPB(y,2)} = 0.0562 I_p^{0.93} B_T^{0.15} n_{line-avg.}^{0.41} P_{loss}^{-0.69} R^{1.97} \kappa^{0.78} \epsilon^{0.58} M_{avg.ion}^{0.19}$$

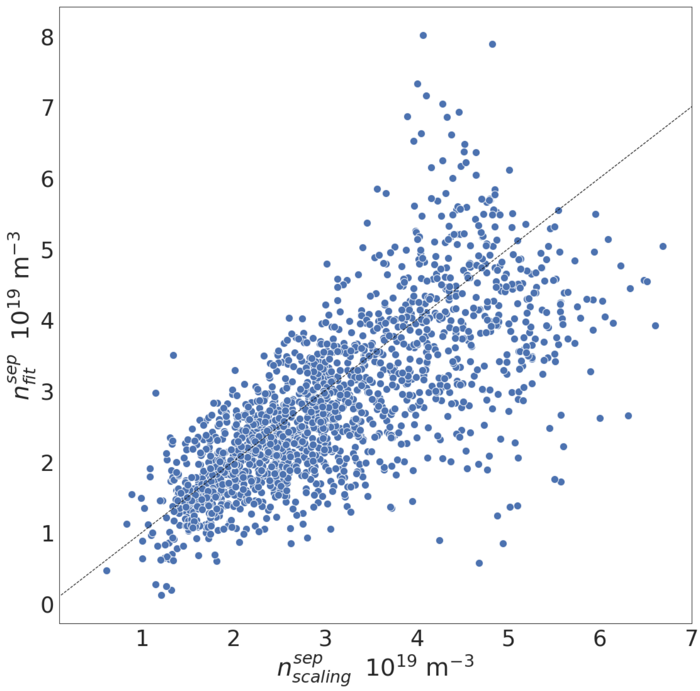
- **What plays a roll in separatrix position and density height?**
  - Categoricals
    - DC
    - Impurities
  - Numericals
    - Fueling
      - As well as neutral bema heating, recyling from walls, and general gas puff (Γ)
    - P_{SD} or neutral pressure
  - Pedestal Profiles

- Heights: T_e^{ped}, n_e^{ped}, p_e^{ped}

- Power [2, 4, 5]

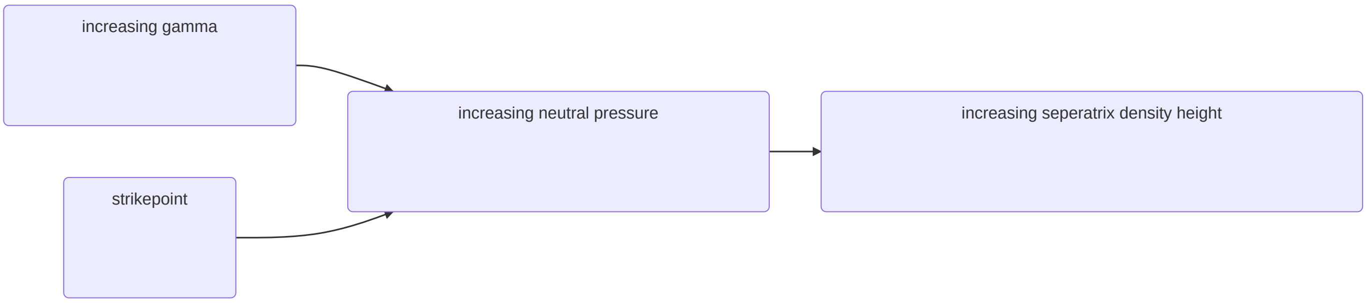
Separatrix Height, n_{height}^{sep}

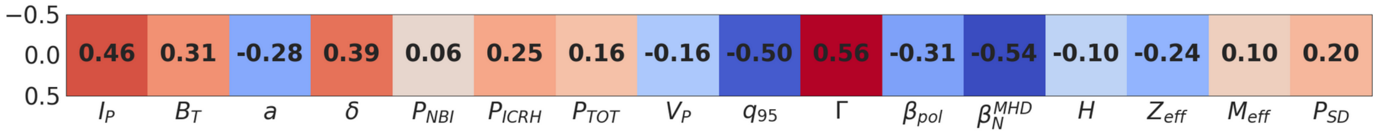
- **Lorenzo Emperical**:
  - $$n_{sep}^{scaling} = (10 \pm 5) I_P^{1.1\pm0.3} P_{TOT}^{-0.4\pm0.2} \delta^{0.8\pm0.03} \Gamma^{0.23\pm0.07} M_{eff}^{0.0\pm0.3}$$
  - Strong depdencies on I_P and δ
  - Pulses with highest power had highest T_{height}^{ped}, and lowest n_{height}^{sep} (Fig 9a.)
  - Positive scaling with Γ (Fig further below)



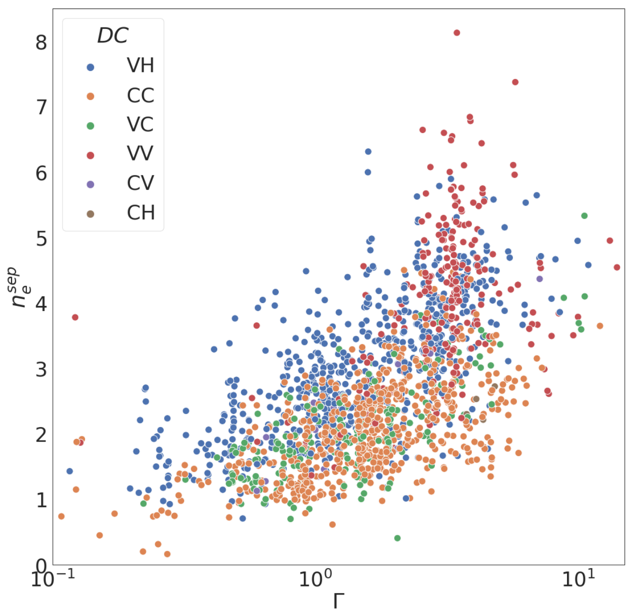
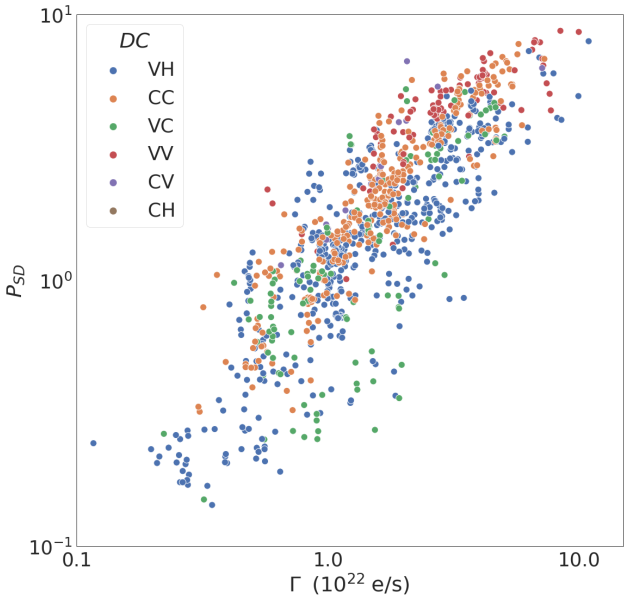
- **Kallenbach scaling** [1]
  - Minimum Separatrix power flux, P_{sep} in the range of 100-200 MW has to be present to sustain H-mode.
  - Radial width of carrying layer is order of milimiter in OMP
  - **What database is used?**
- **negative correlative between n_e^{sep} and pedestal height**
  - Alcator C-mod and AUG show this
  - Pedestal pressure height has opposite correlation with seeding rate
  - Reduction of p^{ped} with increasing n_e^{sep}
- **Correlated with divertor neutral pressure**
  - A proxy for the **neutral pressure**
    - subdivertor pressure
    - Kallenbach says its an engineering param, as it is a large extent determined by the gas puff rate and divertor pumping speed
- Divertor configuration
  - Plasma in the corner tend to have lower n_{height}^{sep} than plasma in horizontal or vertical config (Fig below)

Variable Correlations





- positively correlated with Γ, gas dosing rate
  - Divertor configuration shows the most obvious correlation
  - The hypothesis is that, due to the better pumping efficiency of the corner configuration directing deuterium neutrals (molecules and atoms) into the outer pumping plenum, more fuelling would be necessary to reach the same n_e^{sep} of other configurations. [2]

<table>
<tr><th>n^{sep}_{height} vs. gas dosing rate</th><th>Why P_{SD} is eng. param</th></tr>
<tr><td>
</td><td>
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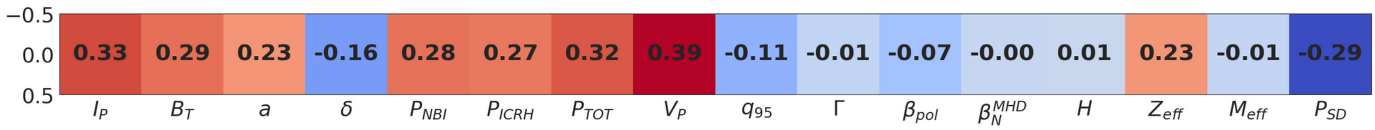
The same correlation is found with P_{SD}

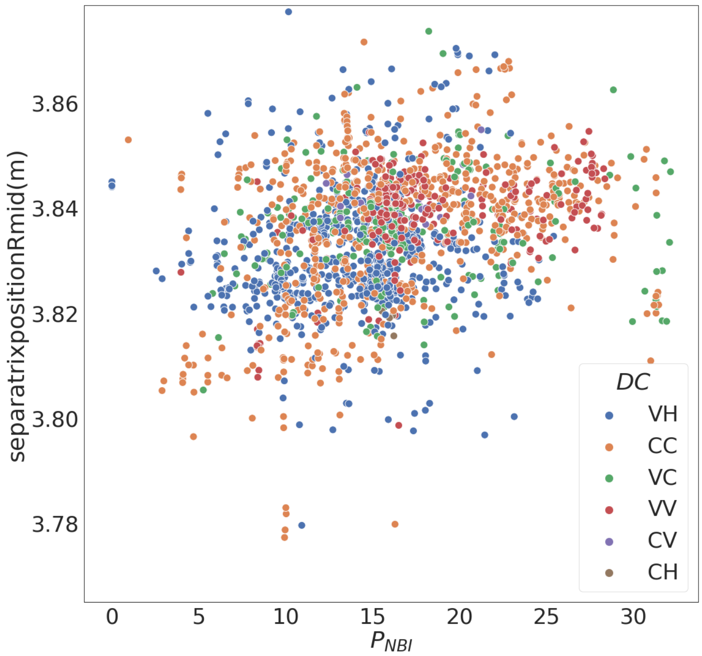
Separatrix Position R_{sep}

Not really sure.
All the pedestal parameters are clearly correlated with the separatrix position.

Variable Correlations



- , Γ and P_{SD} play no role like they did above.
- On the other hand, V_P does.
  - Specific DC lead to lower V_P, for example VV, but achieve a relative constant high position
- Increase in separatrix position with increasing power (all types of power)



PROBLEM: THERE IS NO UNCERT. FOR POSITION, i.e., UQ impossible....
This is also a problem, since this is one of the most precise measurements needed, and many variables are at play here. [3]

Power Accounting

This I am still trying to understand so bear with me.

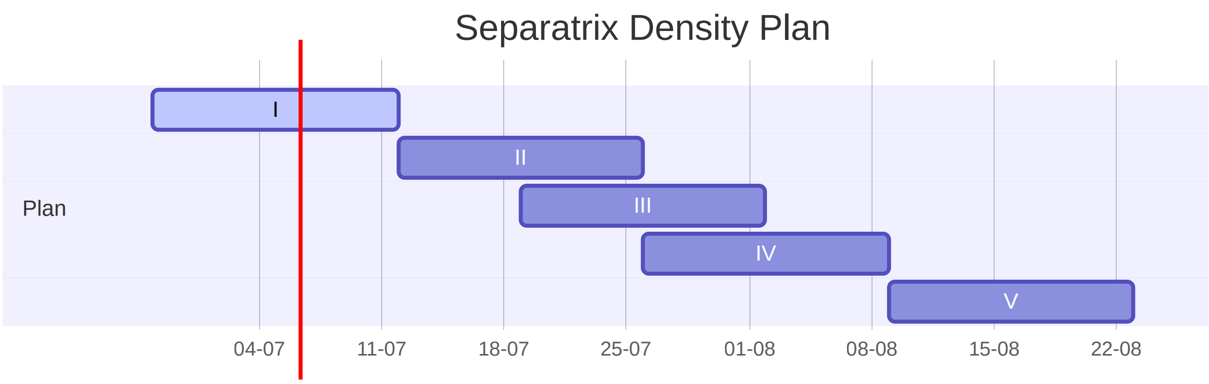
- Using power profiles we can estimate the separatrix position R_{sep} [5]
  - power transport in SOL is dominated by electron Spitzer parallel heat conduction (chapter 4 of [6])
    - SOL weakly collisional near OMP, so using kinetically corrected Spitzer expression for flux-limited-conduction (section 26.2 of [6])
    - Using Thomson profiles of T_e and n_e, can calculate spizter, flux-limited , and kinetically corrected spitzer parallel power flux density profiles $q_{||}^{Sp}$, $q_{||}^{fl}$, $q_{||}^{kcSp}$

            - $q_{||}^{Sp} \approx 2\kappa_0 T_e^{7/2}/7L$
            - $q_{||}^{fl} = \alpha_e n_e \sqrt{eT_e/m_e} eT_e$ (α_e is a constant)
            - $1/q_{||}^{kcSp} \equiv 1/q_{||}^{Sp} + q_{||}^{fl}$
        - $P_{SOL}^{exhaust} \rightarrow$ using $q_{deposited}^{target}$, the measured target power flux density
            - Compare IR measured power profile at outer target (converted to parallel power flux density and mapped back to OMP) with theory based on $q_{||}^{kcSp}$ calculated at OMP from measured thompson profiles, i.e., compare $q_{||0}^{Eich}$ with $q_{||}^{kcSp}$, the power flux densities at separatrix. The peak and the width of the Eich fit are of interest.
            - This method assumes: decoupled SOL, ion power width is greater than the electron power width (4.4 of [6])
        - $P_{SOL}^{input} \rightarrow$ using power *entering* SOL, P_{SOL}^{e}
            - P_{SOL}^{e} is unkown, but calculated from P_{SOL}
        - Weak dependence on effective charge.
- Using safety factor, q, mean power flux across separatrix $q_\perp$ and torodial field B_T (and a shit ton of assumptions) we can find the ratio n_e^{sep}/n_e^{ped} for ASDEX 1999 [4]
    - two point model using upstream temperature $T_S \propto \left(\frac{n_e^{sep}L^2}{\Delta}\right)^{2/7}$ and temperature fall of length $\Delta \propto \frac{n_e^{sep}T_S^2}{q_\perp B_T}$
    - This assumes only Bohm transport.

Lessons Learned from Power Accounting

- The power within the separatrix can be used to determine the location and electron density of separatrix.
- P_{SOL} is generally dependent on the conduction limited SOL, thus is dependent on T_E, m_e, n_e.
- The thomson data on location of separatrix may need to be corrected, as it is in [5]. I see now that there is lots going on at this region, and the Thomson profiles sometimes are not enough.
- I think to emperically predict the separatrix location, some multi-model framework might be necessary, one model that takes main engineering and predicts n_e, T_e at separatrix, then model that uses those predictions + eng. params to give location. Of course we can try just using main eng. params to predict separatrix location.

Plan Going Forward



- **Section I:** Emperical/Theoretical analysis of separatrix
    - Assert which databases are available for predicting separatrix profiles*
    - Produce plots of existing understanding of separatrix profile dependencies using above databases
    - Able to point out variables that contribute to the location and electron density from emperical plots
    - Assert what forms of uncertainty exists in the databases
- **Section II:** Develop ML tools to predict separatrix profiles
    - Using databases found in **I**, develop ML tools to predict the separatrix profiles
    - If tabular data, use existing TABnet, ALIBI, Gaussian Processes, extending work from B.Sc.
    - If raw HRTS data, use GPs with multiplacative kernels, or RNNs, or VAEs
- **Section III:** Evaluate ML tools developed in **II**
    - Evaluate ML models developed
    - Determine what variables drive predictions from each dataset (e.g., using GPs, sensitivity analysis, or with TabNet, masking)
- **Section IV:** UQ/Inverse UQ
    - Develop forms of UQ on the existing databases geared towards predicting separatrix profiles
    - See what this whole inverse-UQ method is all about.
- **Section V** TBD
    - TBD, potentially write something if we learned anything

*Separatrix profiles referes to the location of separatrix and the electron density & temperature of separatrix

Curent next steps

To be discussed on Wednesday 7, July with Aaro.

References

[1] Kallenbach, A. et al “Neutral Pressure and Separatrix Density Related Models for Seed Impurity Divertor Radiation in ASDEX Upgrade.” Nuclear Materials and Energy 18 (January 2019): 166–74. https://doi.org/10.1016/j.nme.2018.12.021.
[2] Lorenzo DB paper
[3] Illerhau, Johannes "Estimation,Validation and Uncertainty of the Position fo the Separatrix Contour at ASDEX Upgrade". PhD Thesis. Universität München. 2019
[4] K. Borrass et al 1999 Nucl. Fusion39 843
[5] P.C. Stangeby et al 2015 Nucl. Fusion 55 093014
[6] Stangeby P.C. 2000The Plasma Boundary of Magnetic FusionDevices(Bristol: Institute of Physics)