Sensitivity Analysis of Radiation Distribution in W7X

P. Hacker[1], F. Reimold[1], R. Burhenn[1], D. Zhang[1]

[1]Max Planck Institute for Plasmaphysics, Wendelsteinstraße 1, 17491 Greifswald, DE

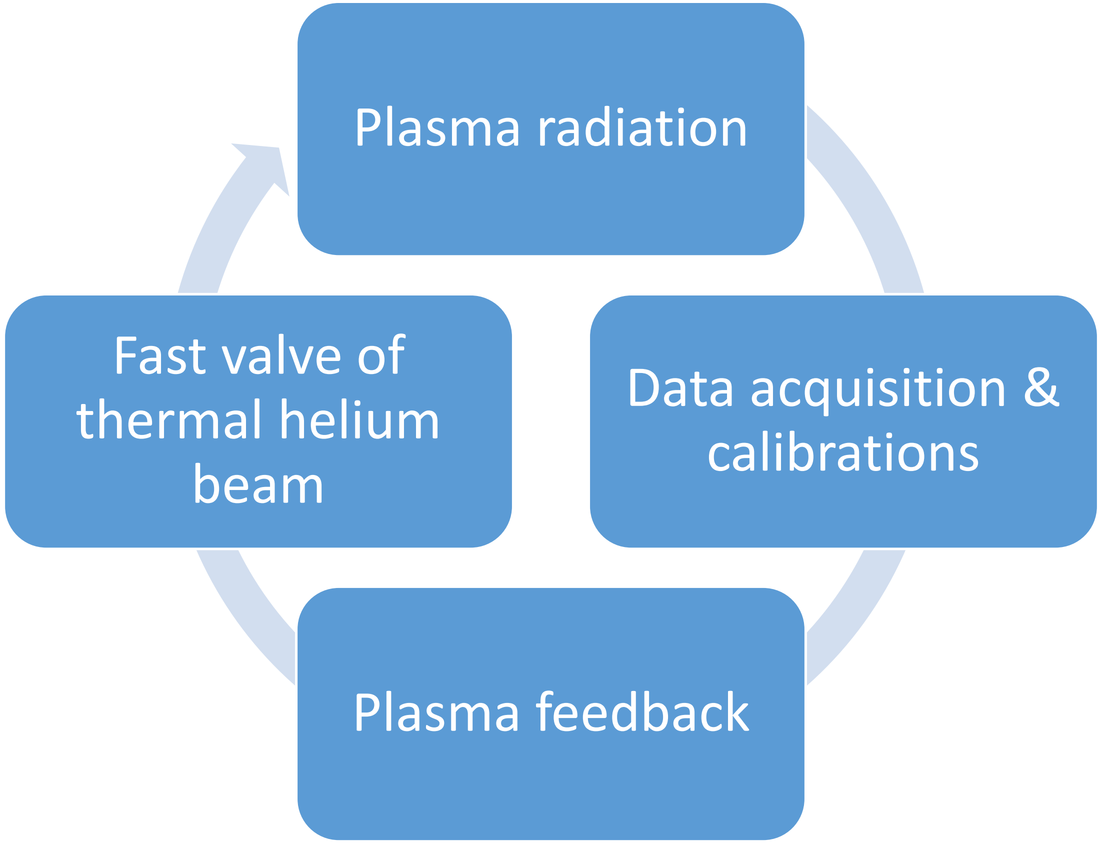
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European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

Background & Motivation

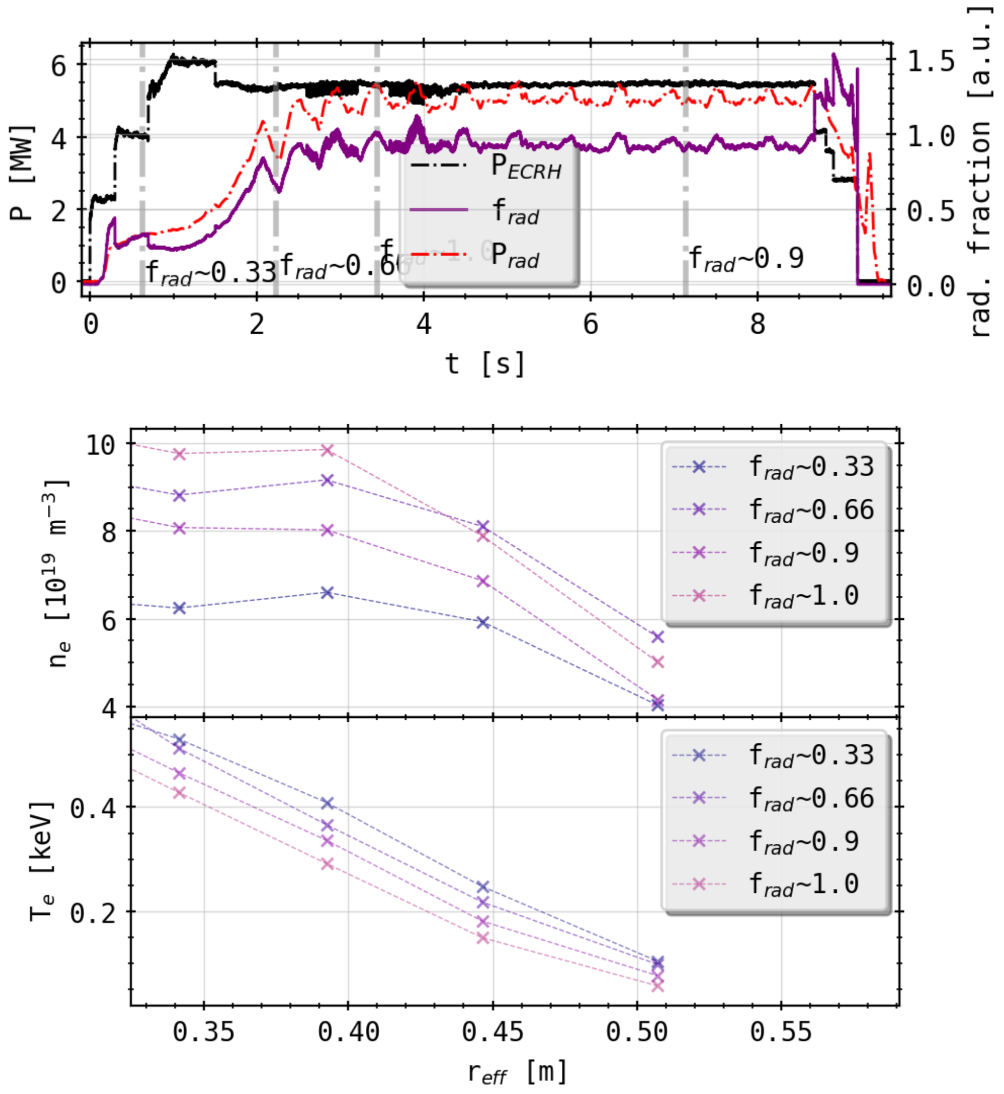
We try to use the Bolometer to control the plasma based off of information on the radiation distribution.

1) adjust heat loads, investigate radiation regimes, improved detachment

2) investigate radiation (scaling), i.e. importance of intrinsic/extrinsic impurities



Background & Motivation



- electron temperature decreases with greater radiation fraction and increasing density

➢ plasma irradiates more energy, lowering the temperature while maintaining/increasing the density

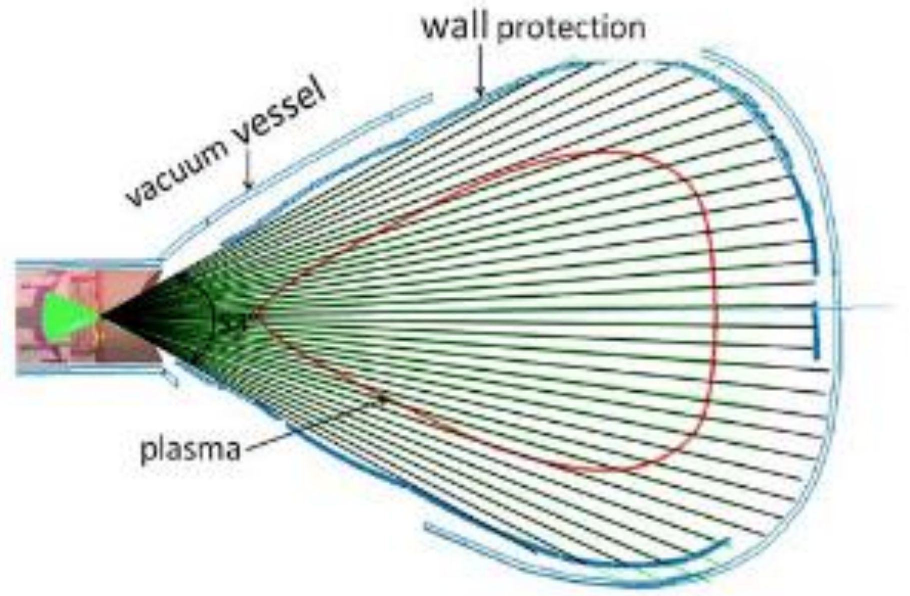
Feedback Evaluation

- limited set of lines of sight possible for fast feedback calculations (e.g. 3-5 channels)

➢ Which channel yields most (important) information on plasma radiation?

- Create measurement tools to decide on ‘best’ possible detector combination for estimation of P_{rad} during experiment

HBCm



AEU30
horizotal bolomter camera (HBC)

Feedback Evaluation

Example:

$$P_{prediction}(t) = \frac{V_{P,tor}}{V_S} \cdot \sum_{ch}^{S} \frac{V_{ch}}{K_{ch}} \cdot \frac{P_{ch}}{53\%}$$

$$d_{diff}(t) = \|P_{rad}(t) - P_{prediction}(t)\|$$

$$\varepsilon(t) = \left\{ \begin{array}{ll} 1 - \frac{d_{diff}(t)}{P_{rad}(t)} & , d_{diff} < P_{rad} \\ 0 & , \text{else} \end{array} \right\}$$

$$\vartheta = \overline{\varepsilon(t)}$$

- done for >10^4 combinations of cameras and channels
- + 8 different sensitivity metrics (e.g. self correlation, coherence, convolutional)
- + multiple experiments

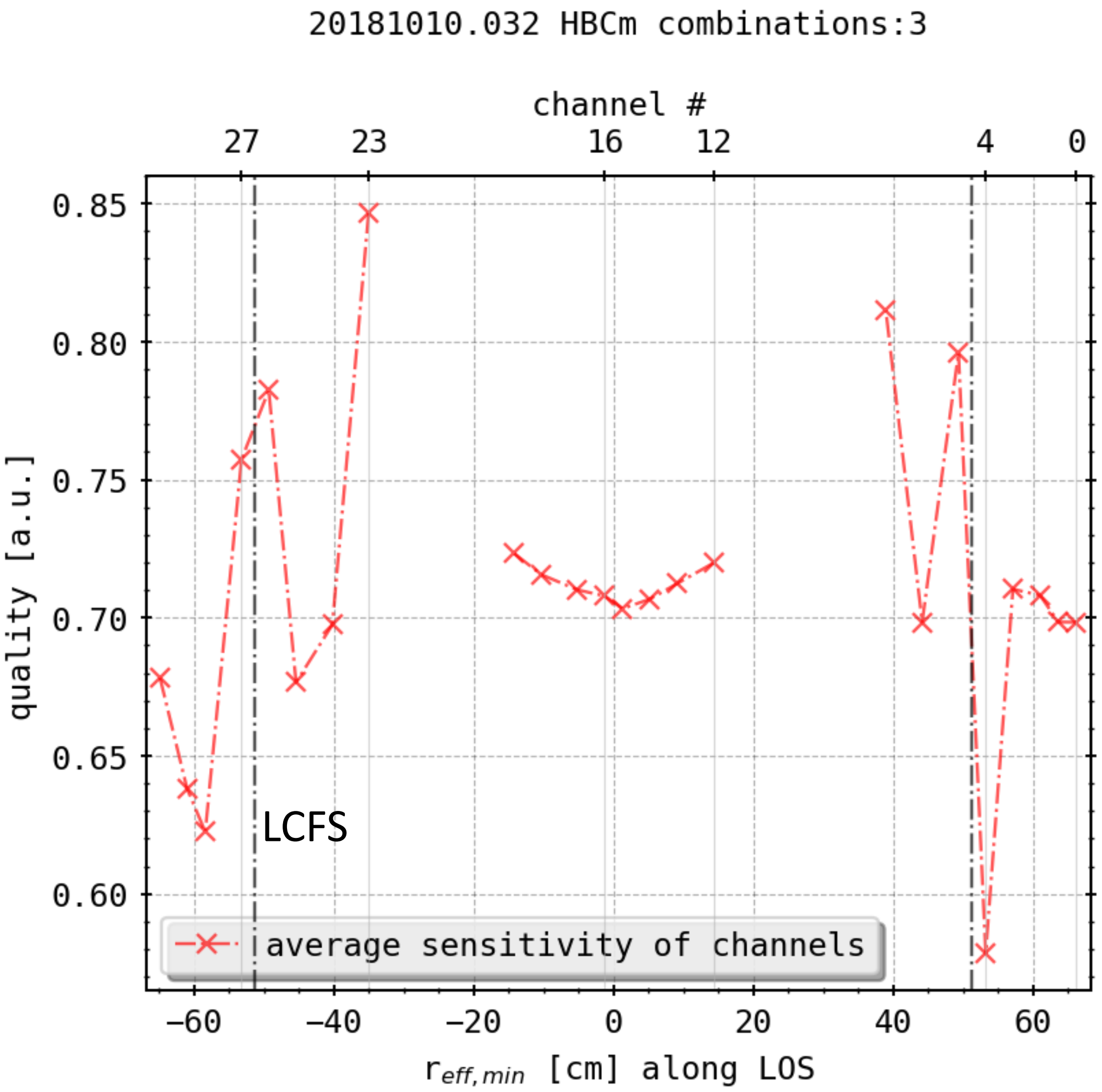
Feedback Evaluation

- all evaluation methods and camera/subset combinations show same behavior:

➢ detectors viewing tangential to LCFS are capable of representing >60% of the plasma radiation

➢ LOS along LCFS & slightly inwards are most sensitive to changes in the plasma radiation

➢ a subset of 5 detectors can reflect the total radiation with up to 90% accuracy (!)



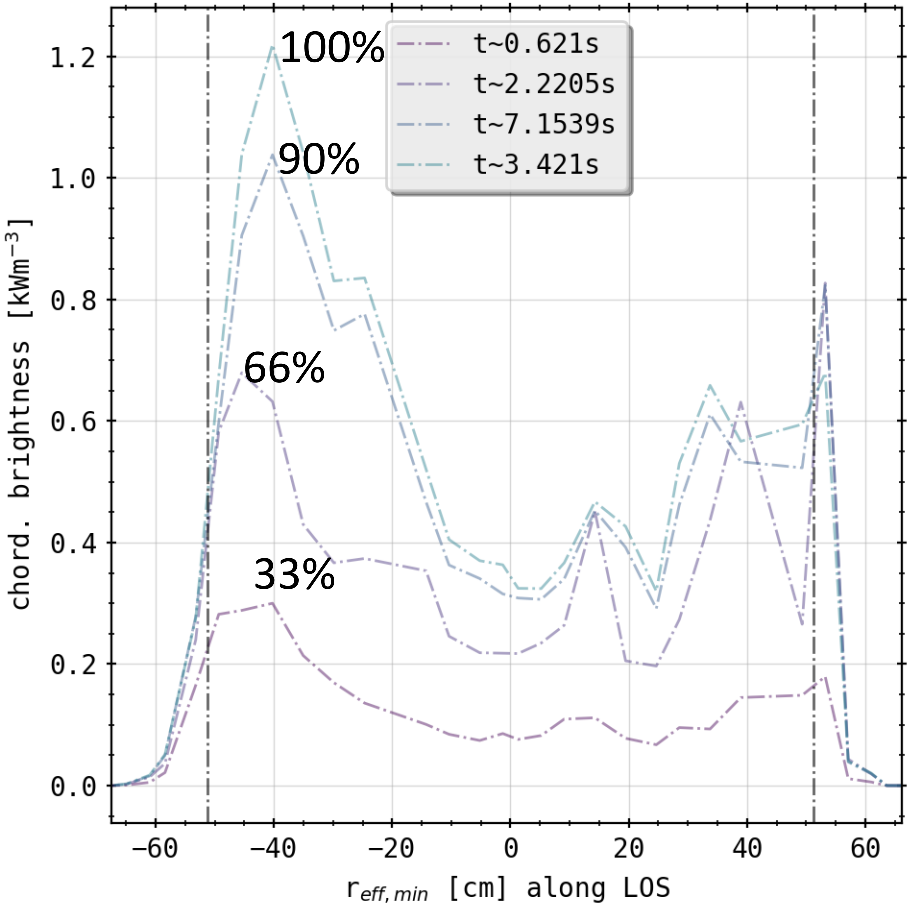
Feedback Evaluation

- majority of radiation comes from edge region or close to SOL

- with increasing radiation fraction chordal brightness shifts inwards away from LCFS

➢ What is the radiation source responsible for this shift given the previous plasma profiles?

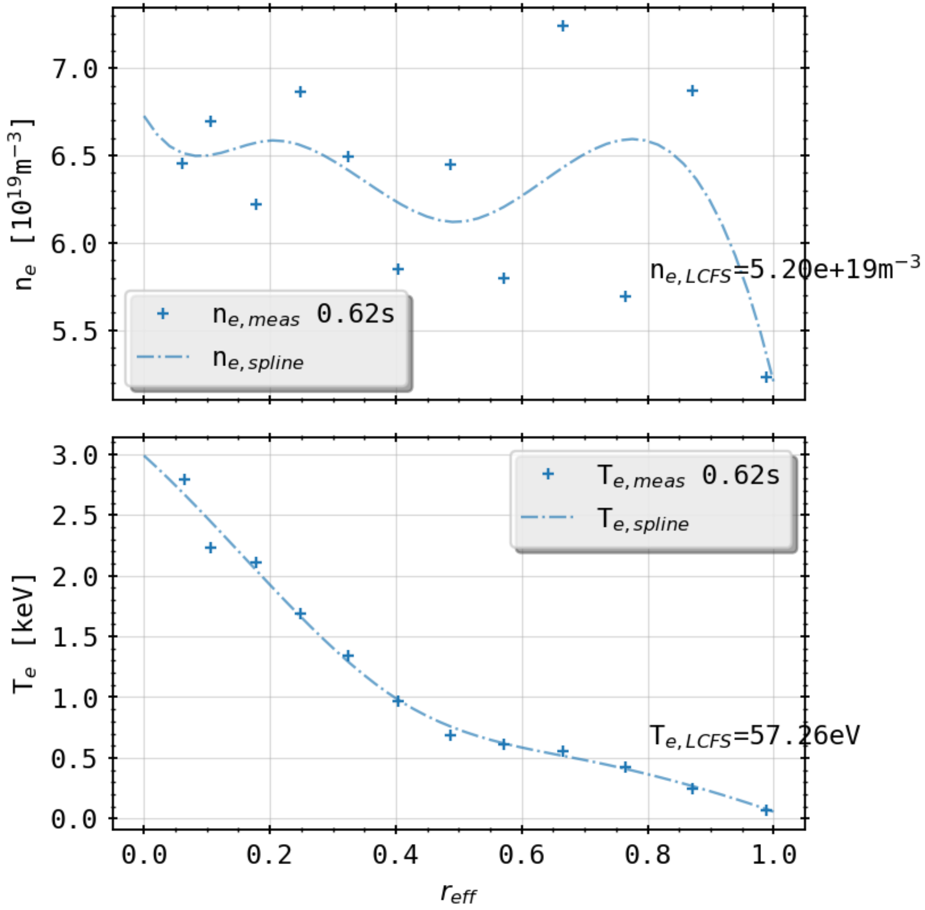
(decreasing T_e, intrinsic impurities …)



chordial profiles of the previously discussed f_{rad}

STRAHL Simulations of Carbon Radiation

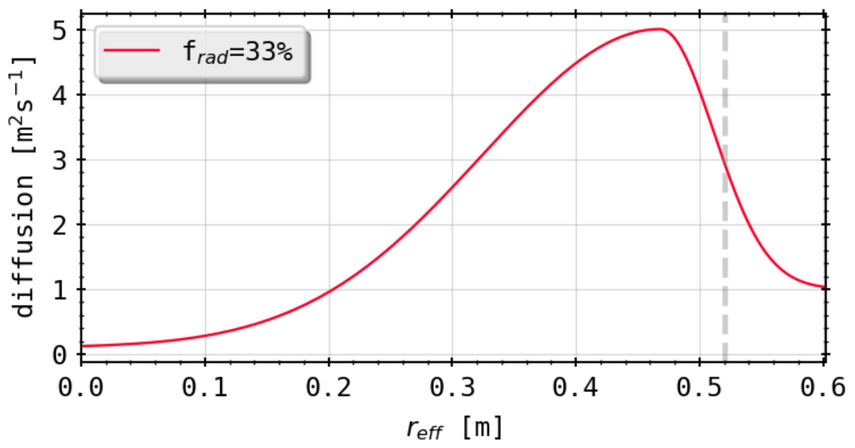
- assuming 1D radiation distribution given the chordal profiles, i.e. coming from inside the LCFS
- investigating main intrinsic impurity carbon (i.e. lines measured also by HEXOS)
- Thomson Scattering profiles from radiation feedback controlled plasma



TS profiles (+) and STRAHL profiles for $f_{rad} = 0.33$

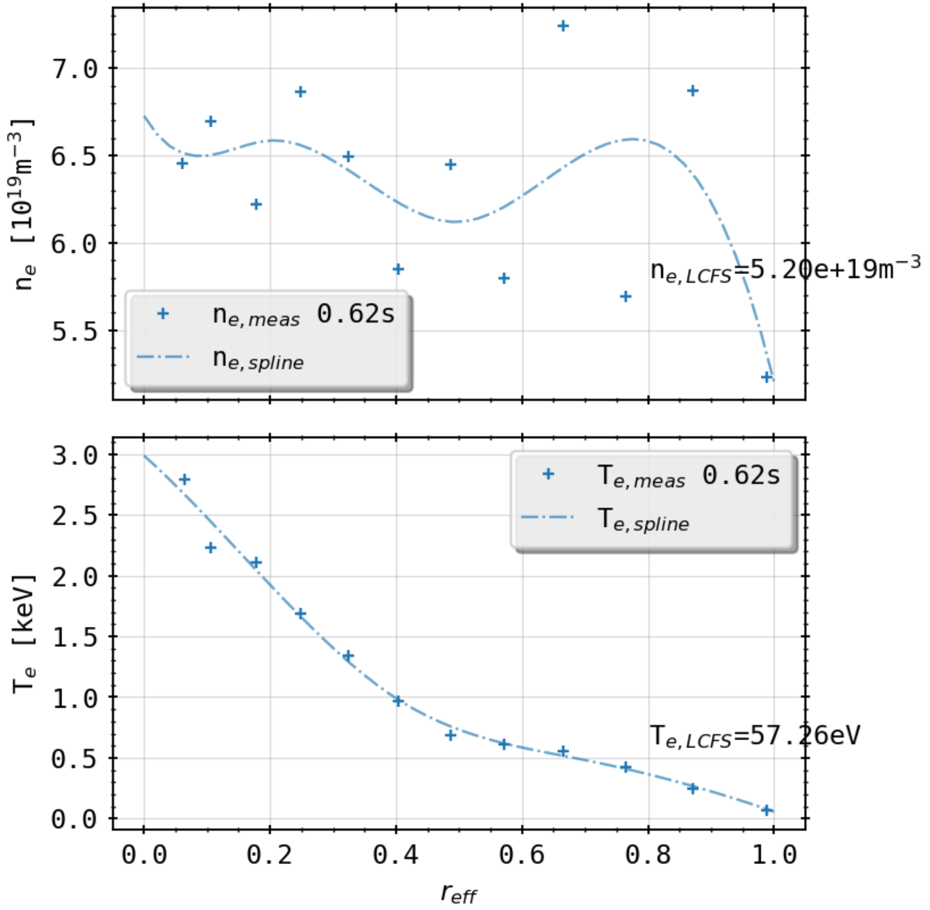
STRAHL Simulations of Carbon Radiation

- transport:



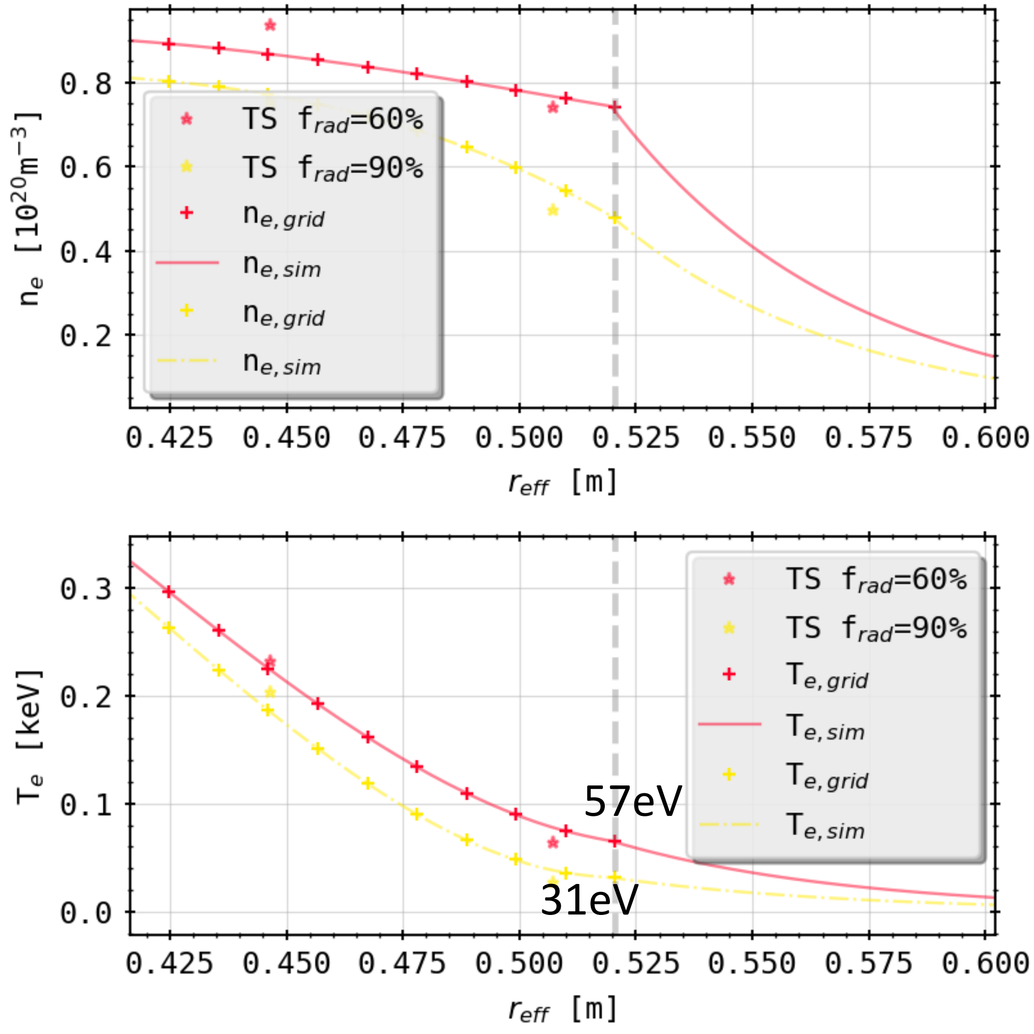
- decay length $\lambda = 5cm$, mimicking island chain regions

- source of carbon at the +7.5cm outside LCFS with $10^{21}s^{-1}$

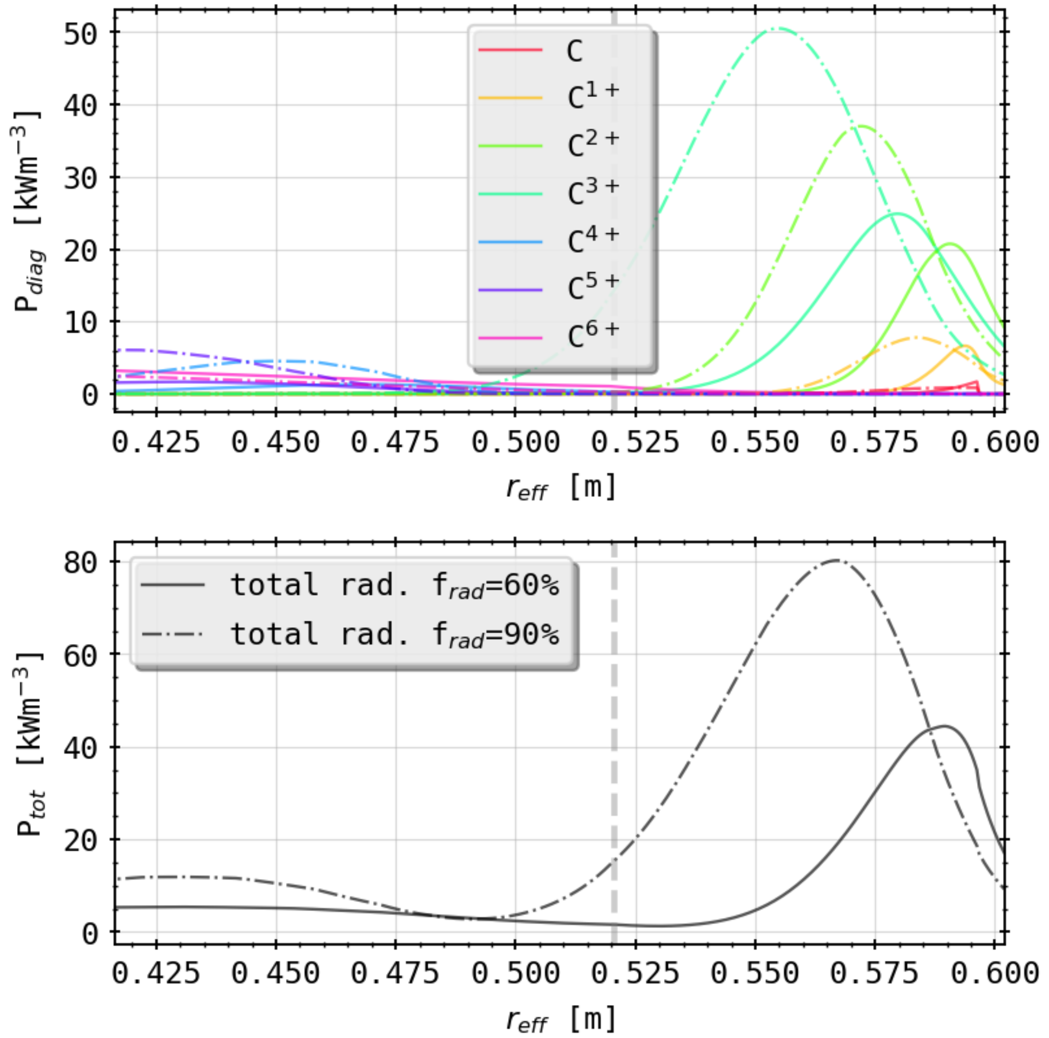


TS profiles (+) and STRAHL profiles for $f_{rad} = 0.33$

STRAHL Simulations: 60% v 90%



TS profiles (*) and STRAHL profiles for $f_{rad} = 0.6, 0.9$

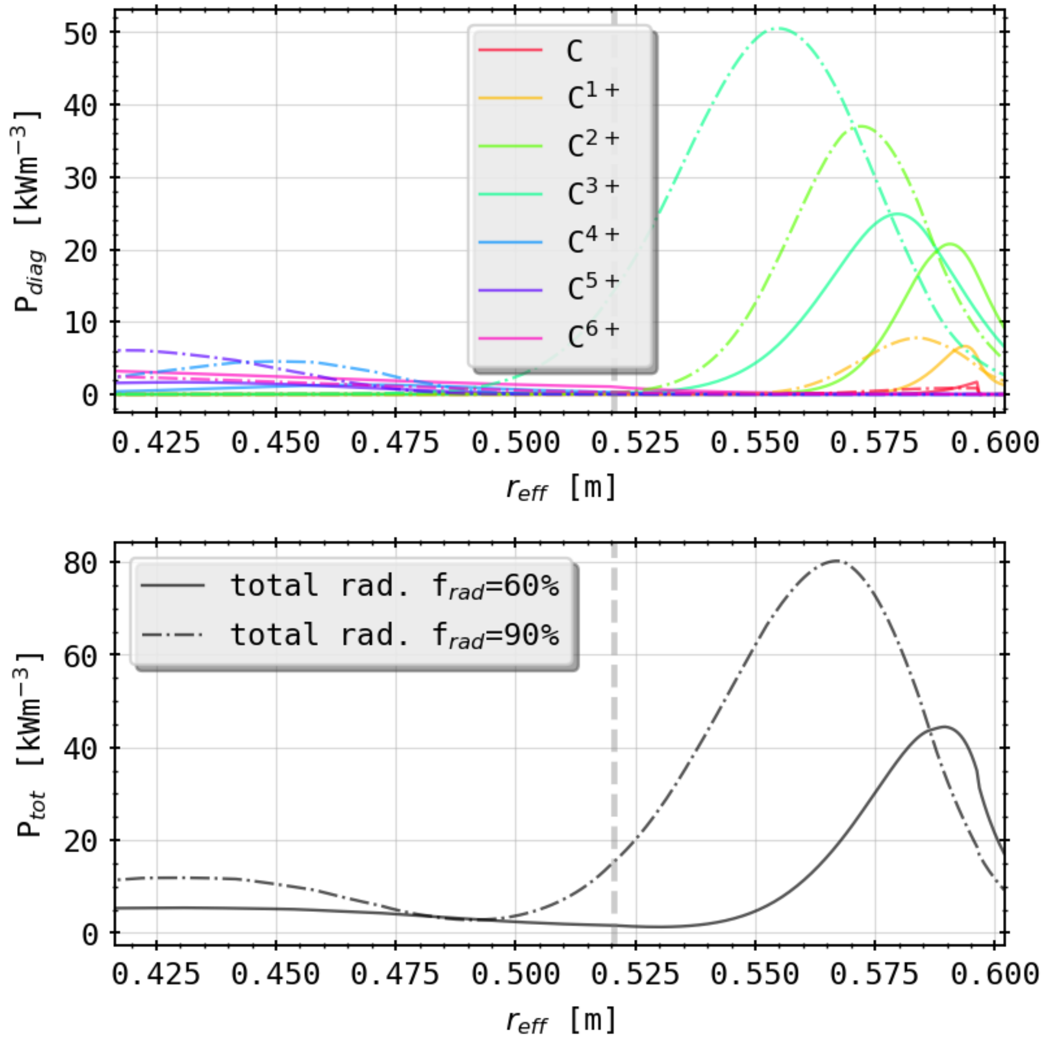


coronal equilib. line radiation profiles for $f_{rad} = 0.6, 0.9$

STRAHL Simulations: 60% v 90%

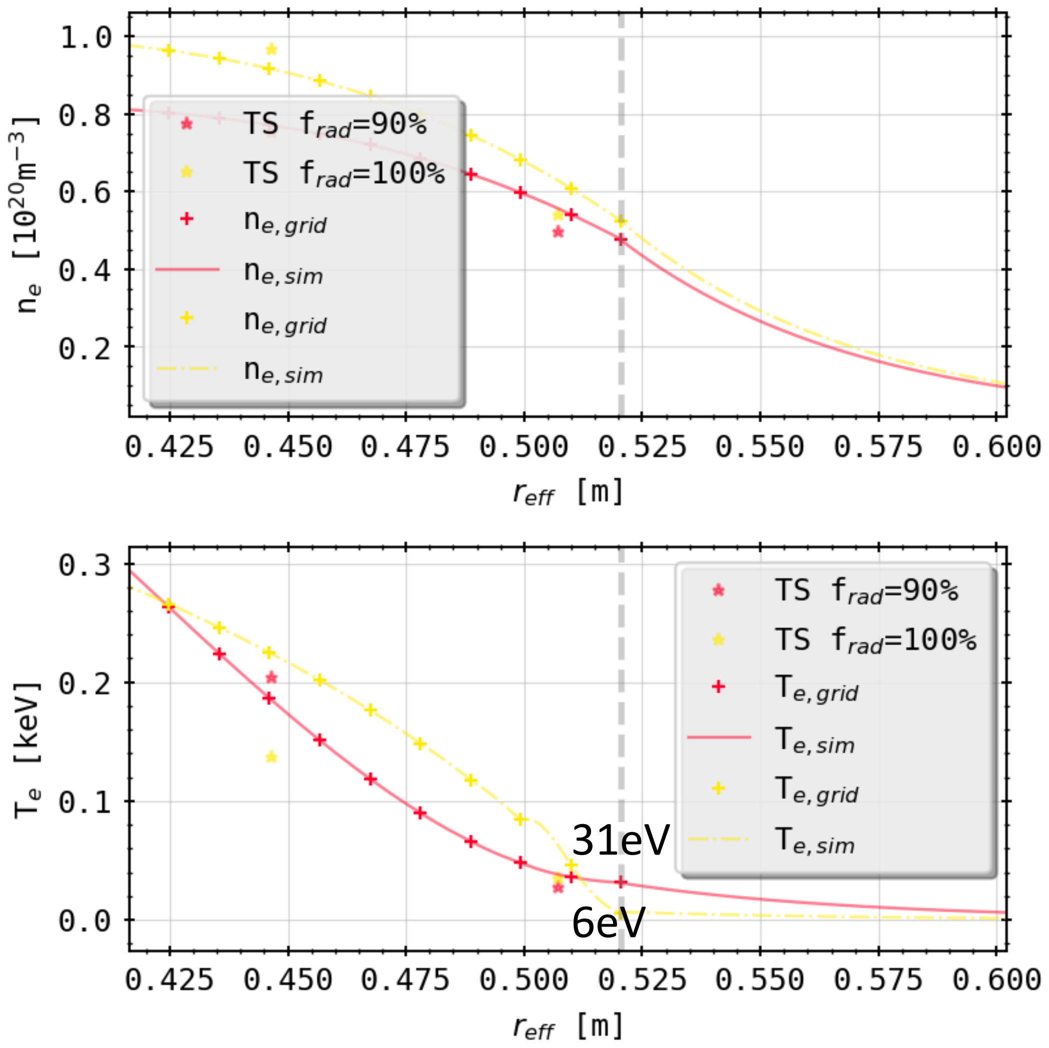
- inward shift of all stages
- inconclusive for Bolometer: spatial resolution 5cm on-axis inside LCFS

➢ radiation peak outside LCFS

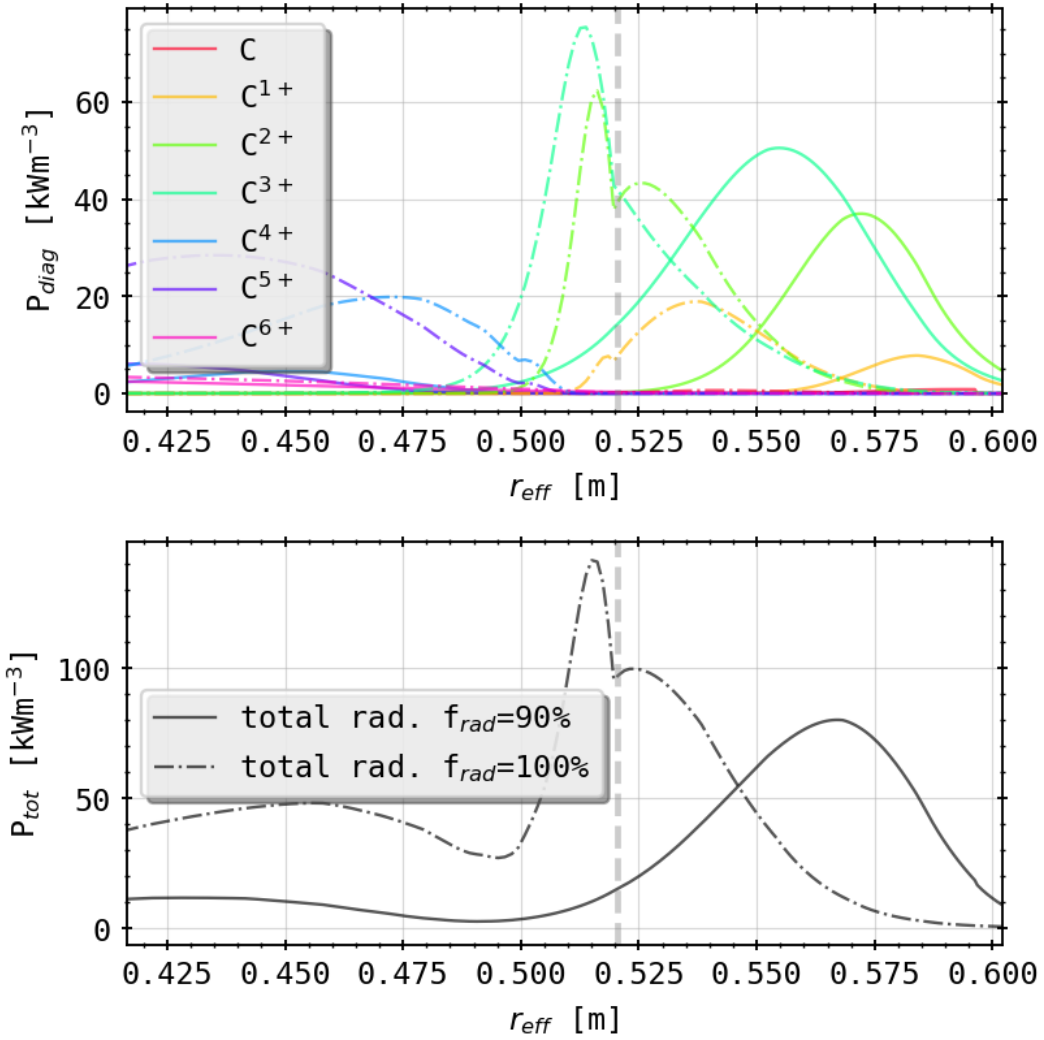


coronal equilib. line radiation profiles for $f_{rad} = 0.6, 0.9$

STRAHL Simulations: 90% v 100%



TS profiles (+) and STRAHL profiles for $f_{rad} = 0.9, 1.0$

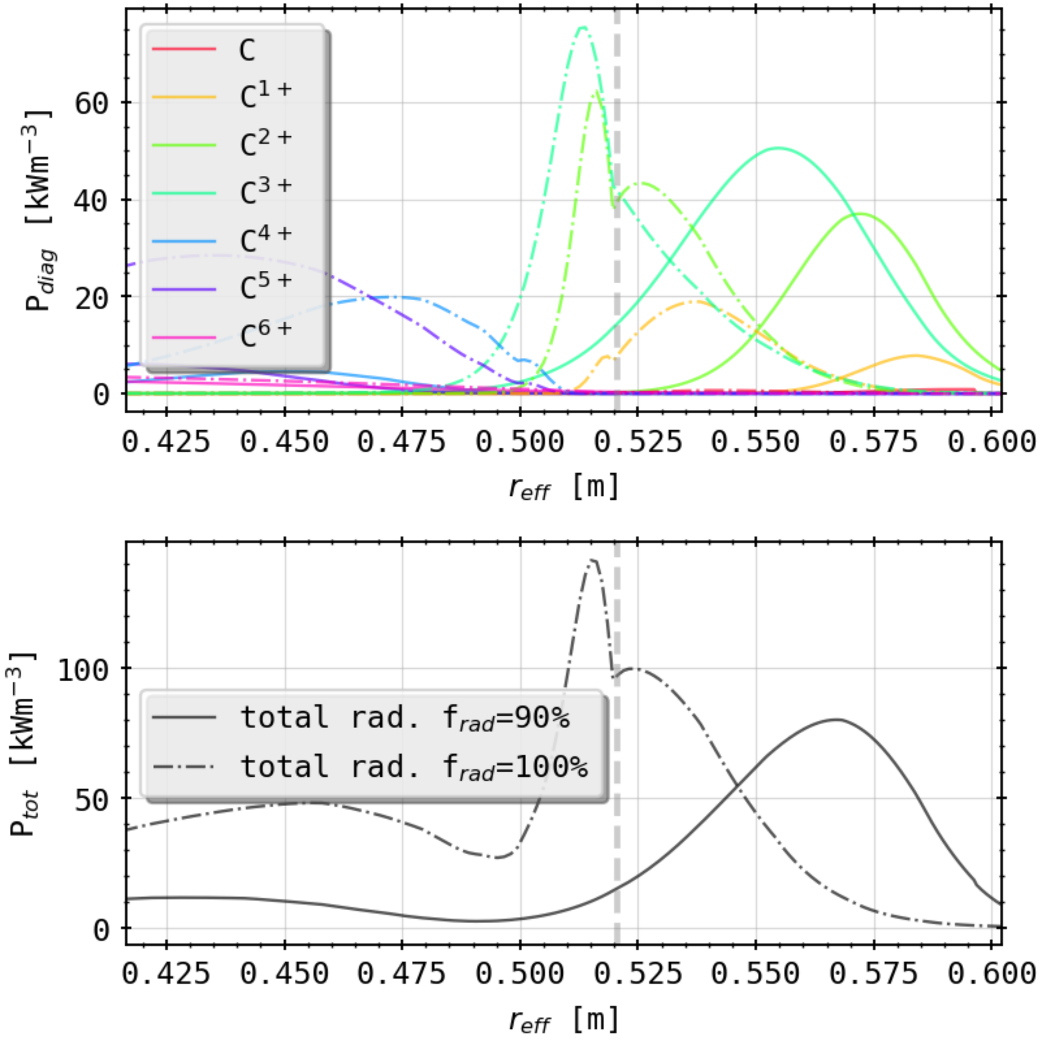


coronal equilib. line radiation profiles for $f_{rad} = 0.9, 1.0$

STRAHL Simulations: 90% v 100%

- peak impurity radiation now inside the confined region > core radiating carbon population

- volume integrated radiation around experimental level

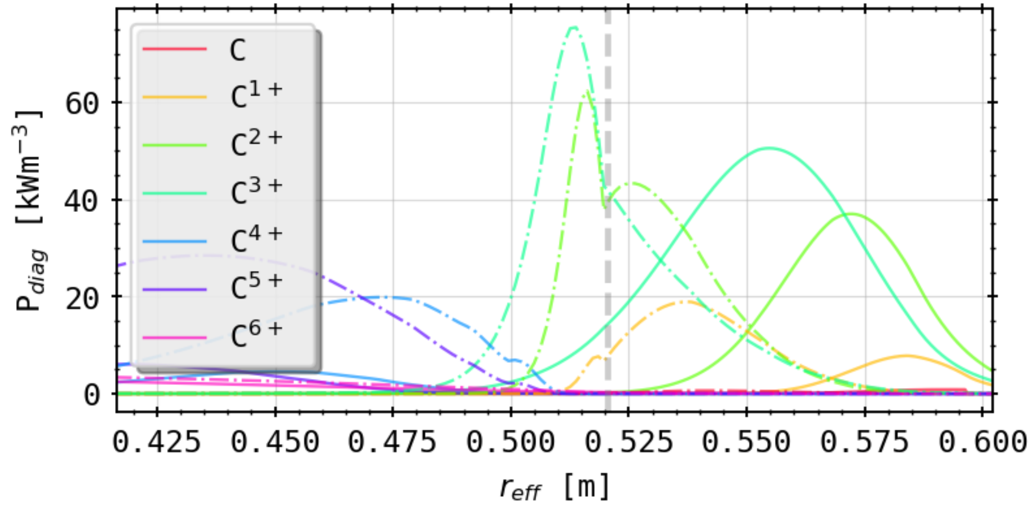


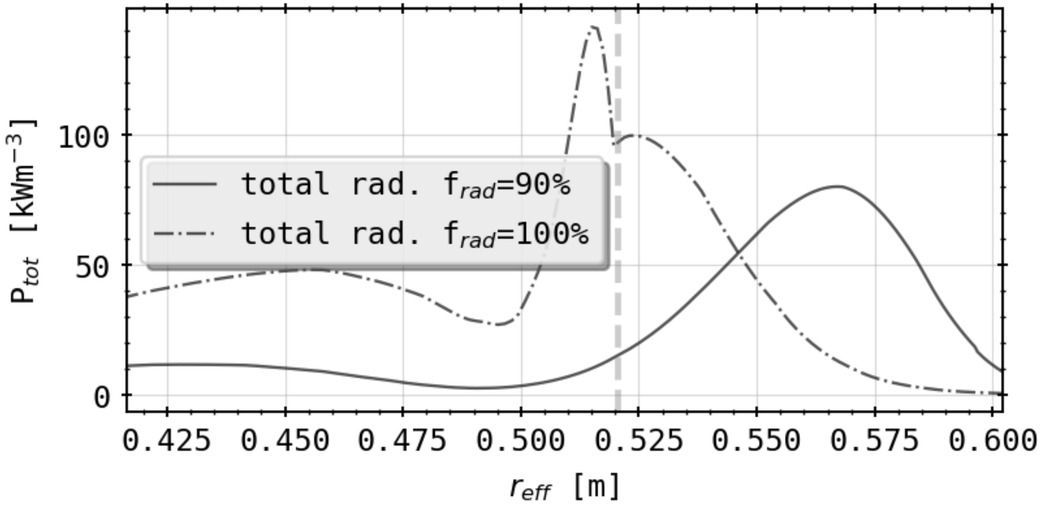
coronal equilib. line radiation profiles for $f_{rad} = 0.9, 1.0$

STRAHL Simulations: 90% v 100%

- great radial shift, especially now in Be- and Li-like ions
- transition from bright to dark SOL from 90% to 100% of radiation power loss

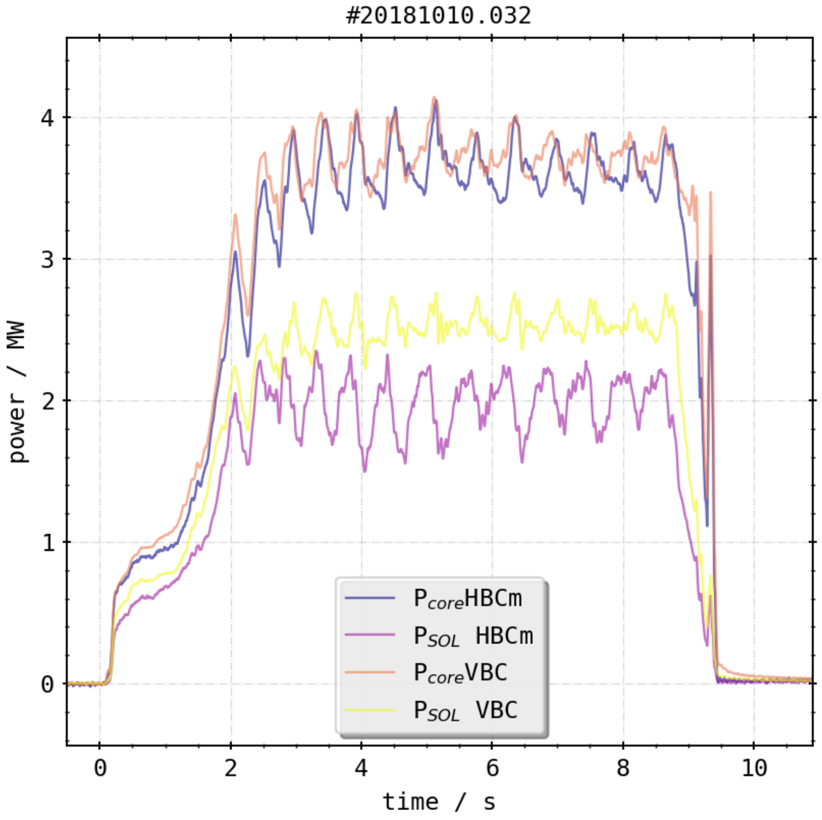
- possible indicator for radiation regimes in detachment
- intrinsic impurity C main radiation source for those scenarios

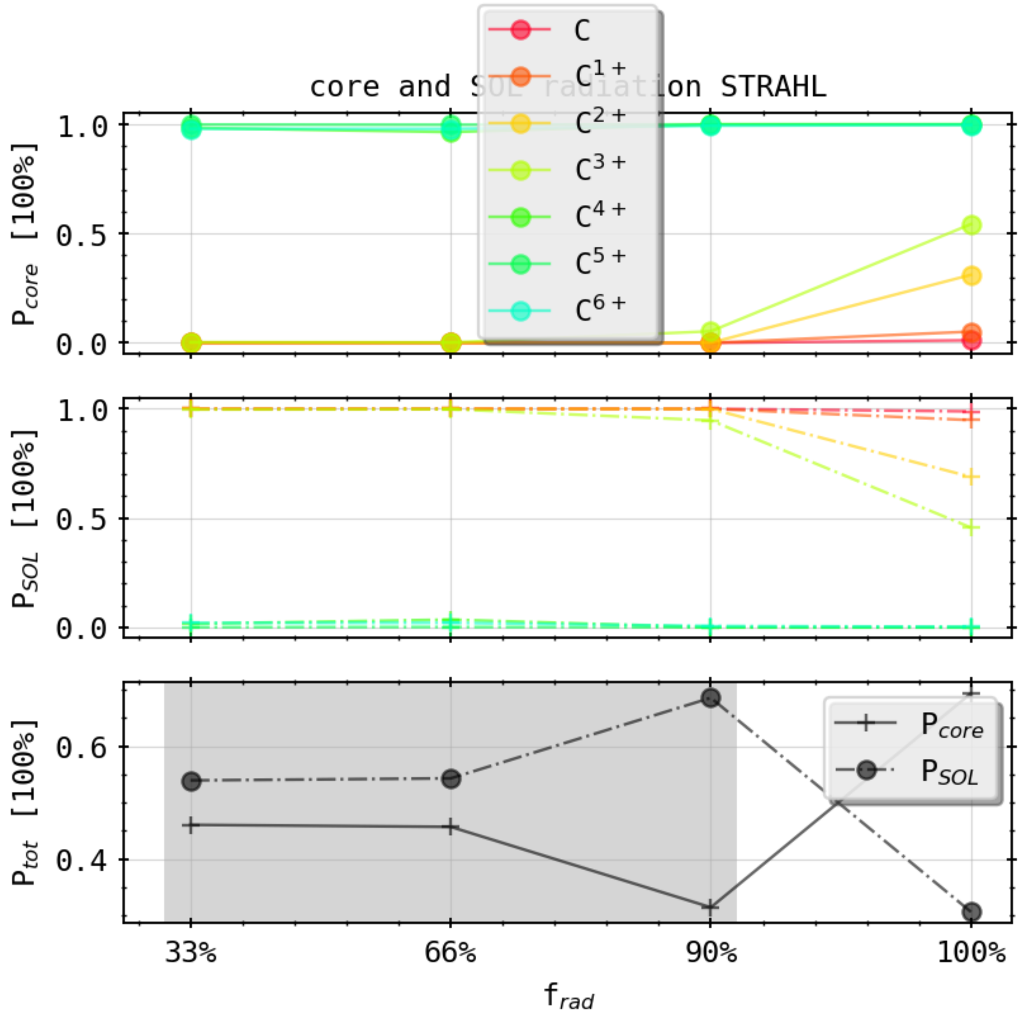




coronal equilib. line radiation profiles for $f_{rad} = 0.9, 1.0$

STRAHL Simulations: Core vs. SOL Radiation

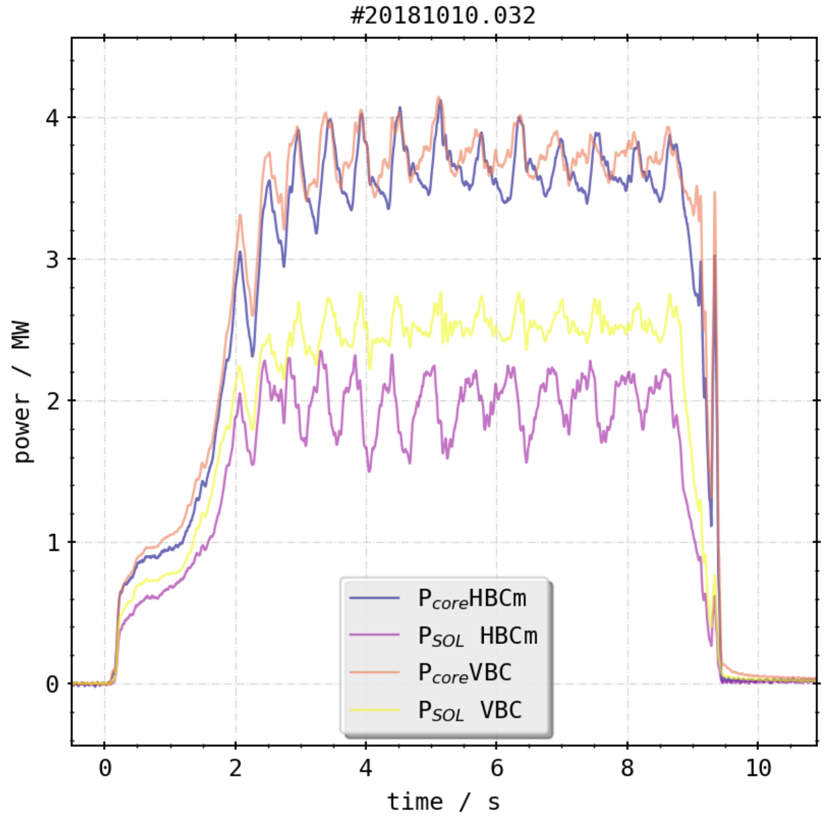




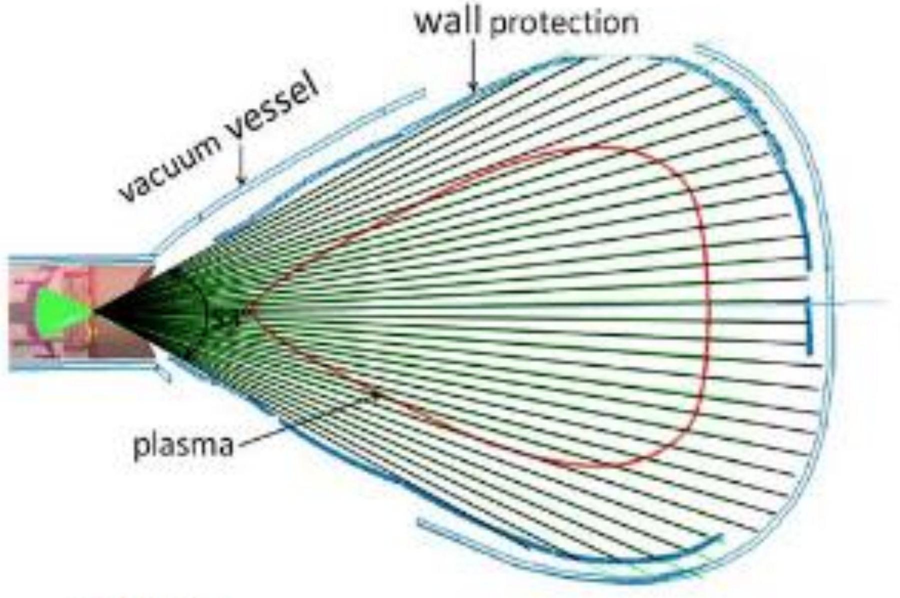
- ➢ anticyclical changes in experiments core/SOL radiation
- ➢ absolute ratio different due to LOS geometry

Core and SOL radiation ratios $f_{rad} = 0.3 \ldots 1.0$

STRAHL Simulations: Core vs. SOL Radiation



- reminder:



AEU30
horizotal bolomter camera (HBC)

➢ anticyclical changes in experiments core/SOL radiation

➢ absolute ratio different because LOS geometry

Summary & Outlook

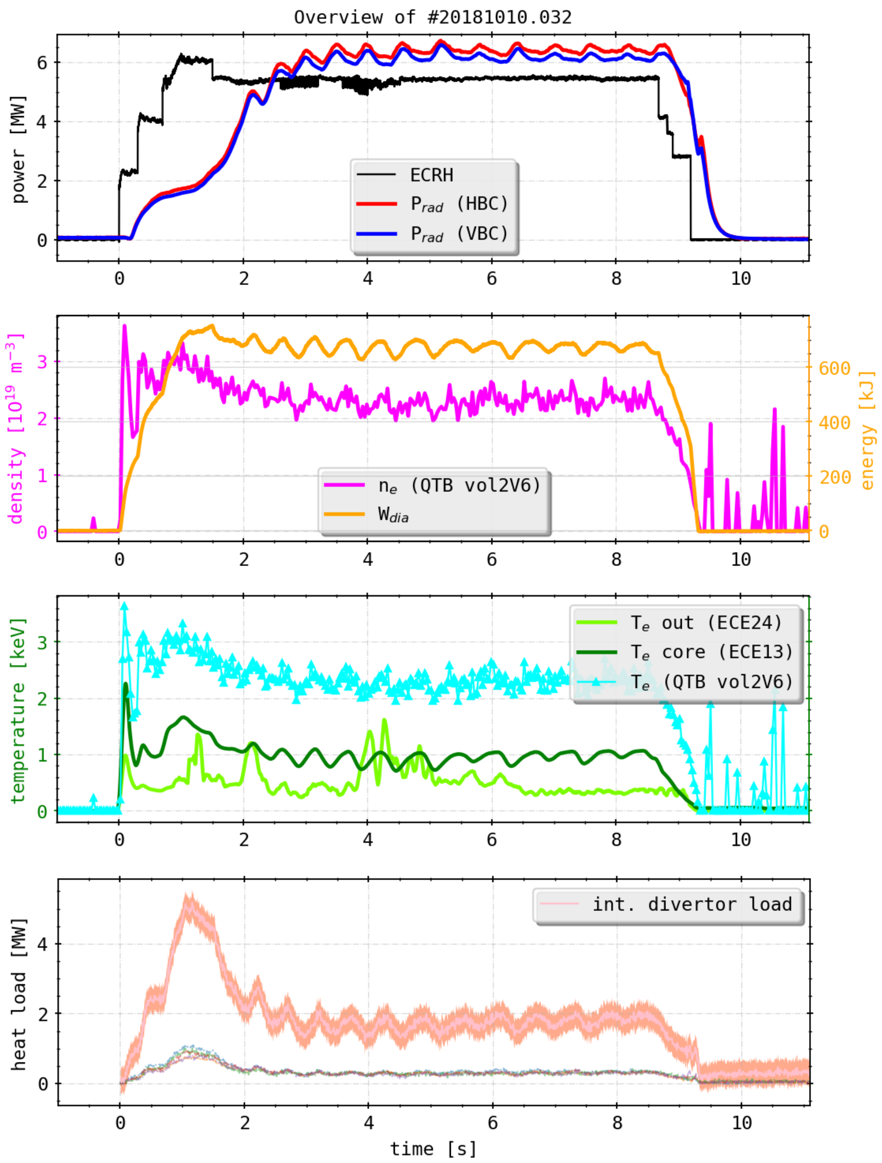
- STRAHL shows strong radial dependence of intrinsic impurity radiation
- Bolometer (feedback) most sensitive to changes along the separatrix and SOL
- indication of intrinsic impurity C making inward shift of distribution from experiment

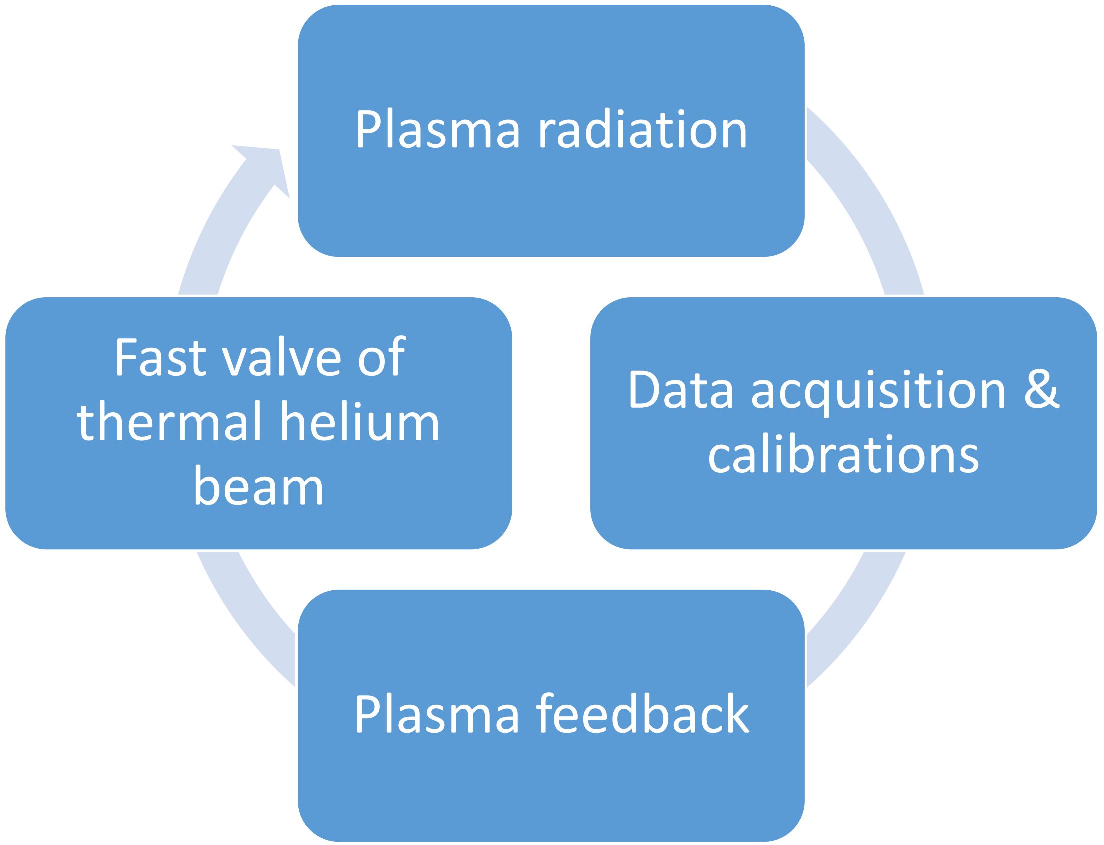
- LOS geometry prohibits further arguments towards any 2D profiles
- directly compare line integrated STRAHL results for lines of sight geometry with chordal profiles
- extending simulation space to 2D with MFR (Minimum Fisher Regularization) **NECESSARY**

(STRAHL technically only valid in highest f_{rad} case)

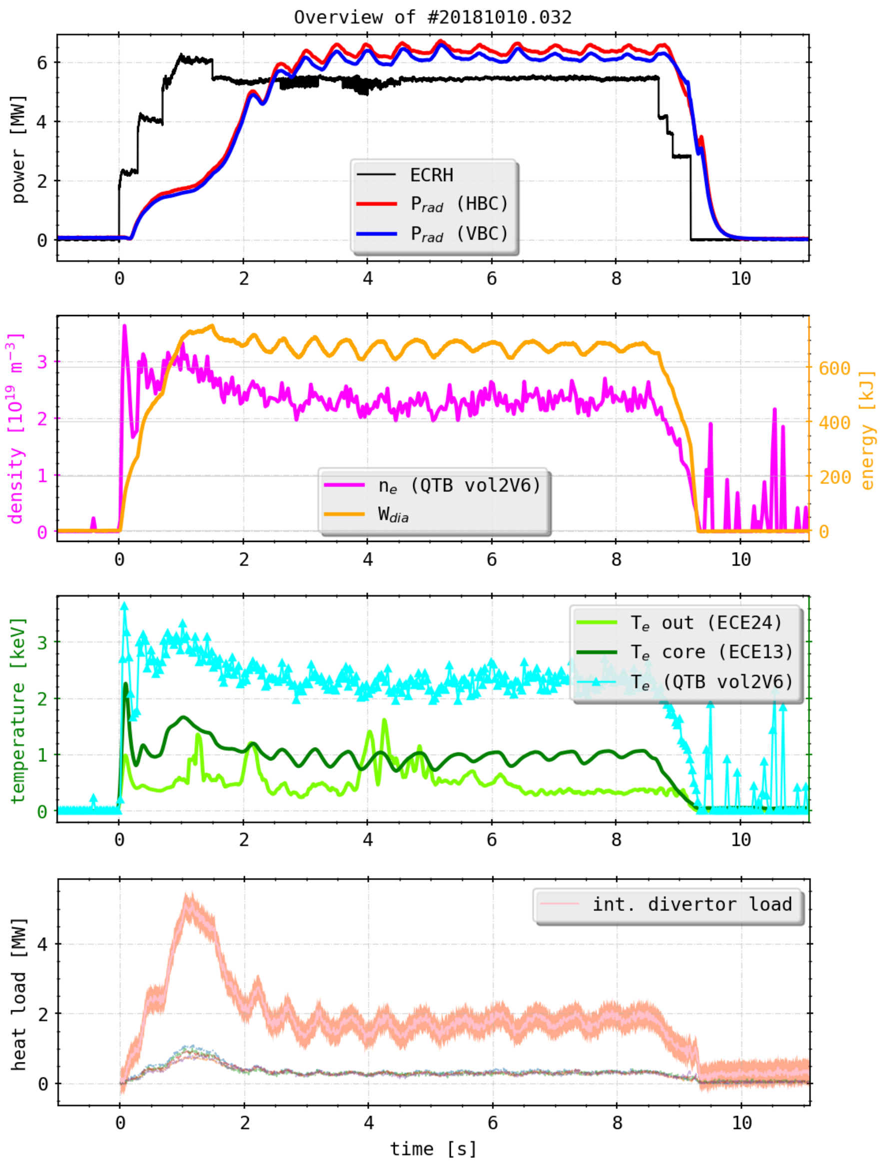
Appendix

Background & Motivation



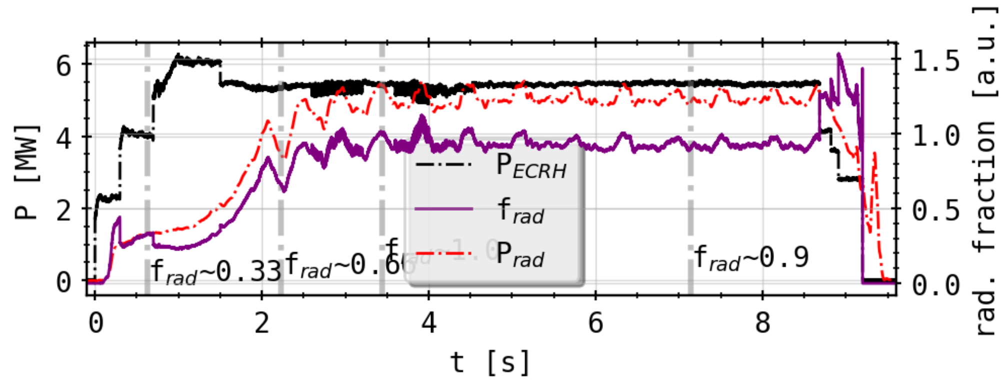


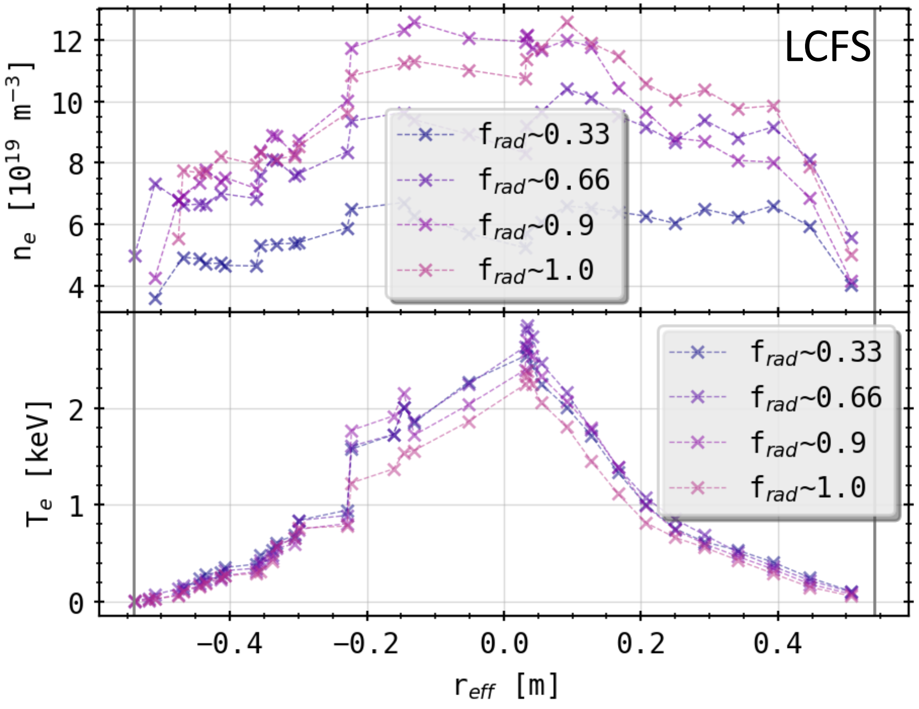
Background & Motivation



- increasing power loss fraction (f_{rad}) through evaluation of the radiation distribution, i.e. $P_{rad} = f(T, n)$ as an actuator
- initial ramping phase by gas puffing from thermal helium beam until target f_{rad} ***or*** P_{rad}
- fast valve is opened & closed according to feedback aiming for radiation loss equal to input power

Background & Motivation

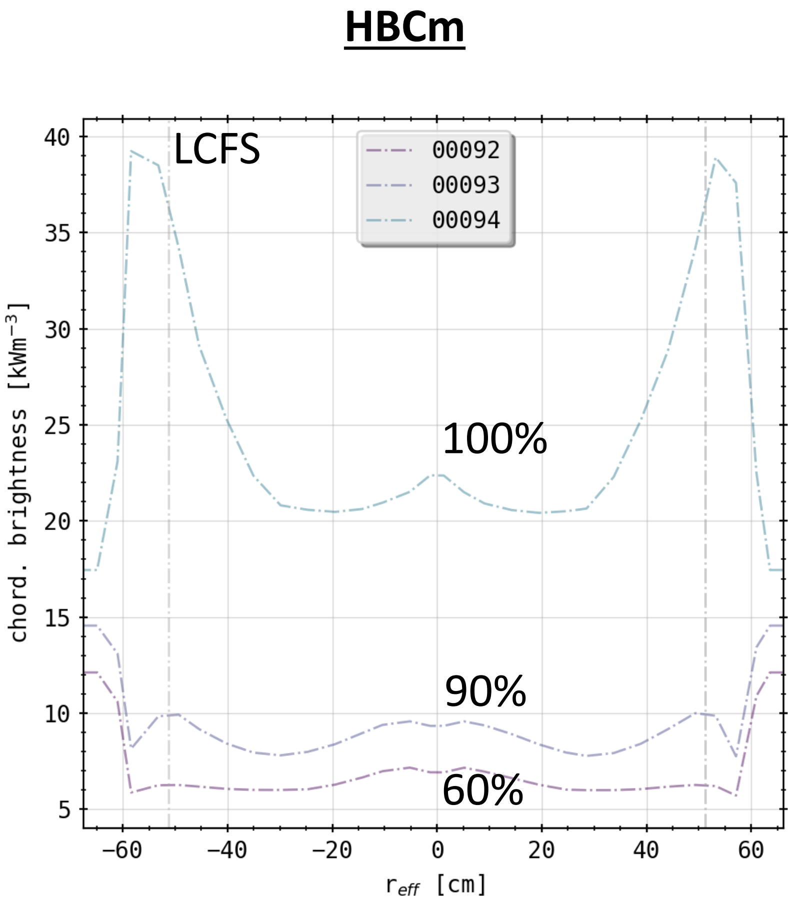


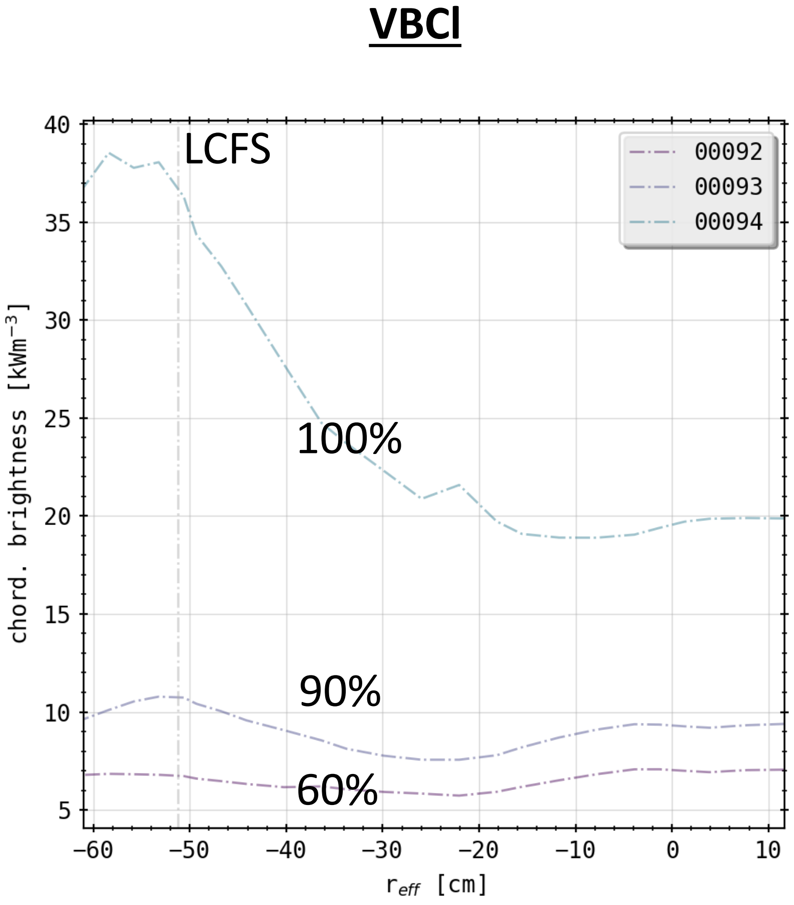


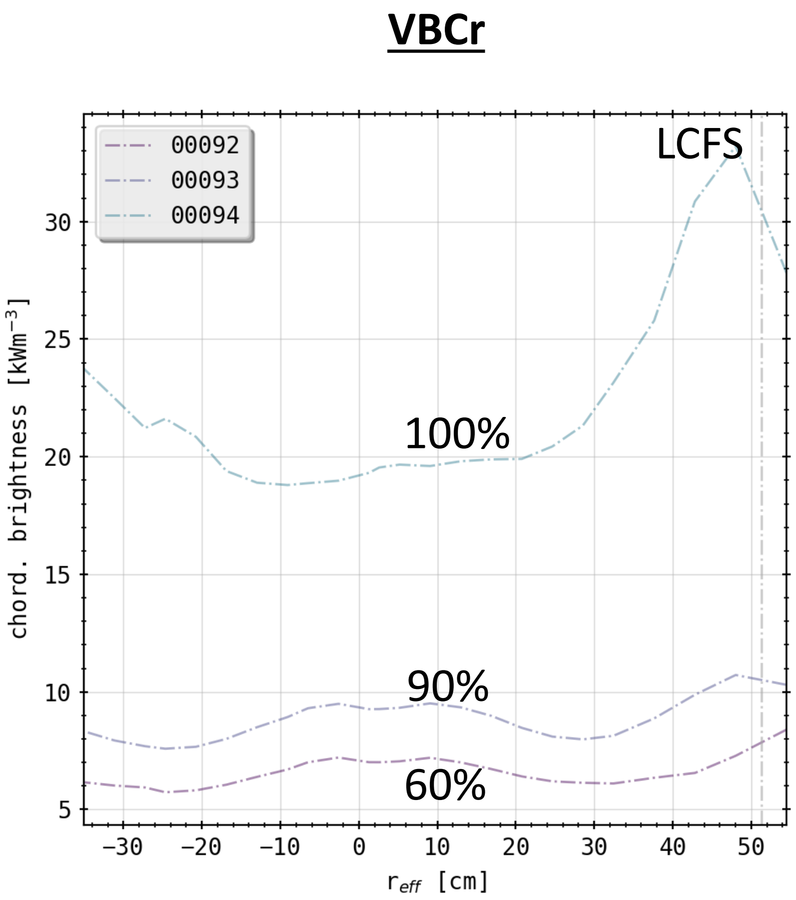
- electron temperature decreases with greater radiation fraction and increasing density

➢ plasma irradiates more energy, lowering the temperature while maintaining/increasing the density

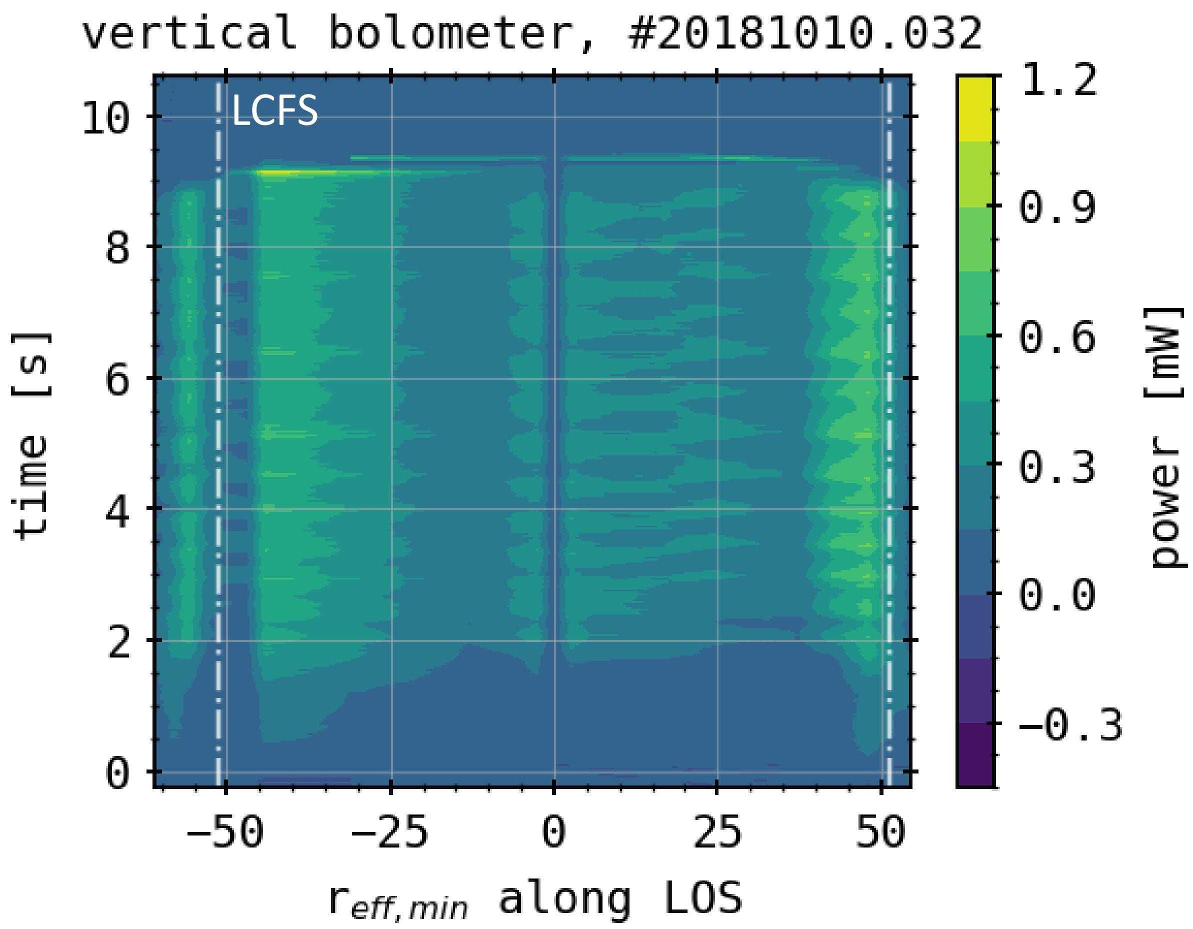
Appendix: Forward Integration with LOS

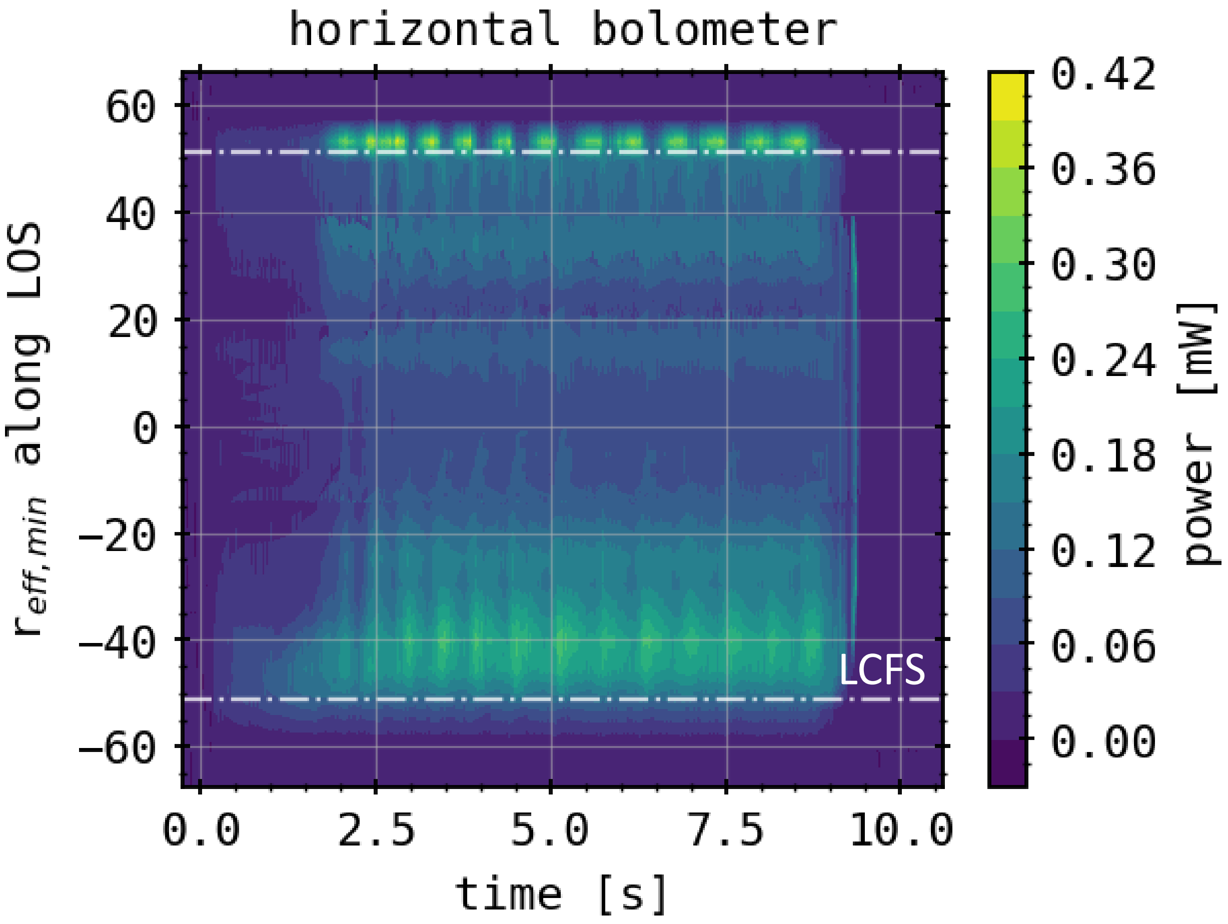




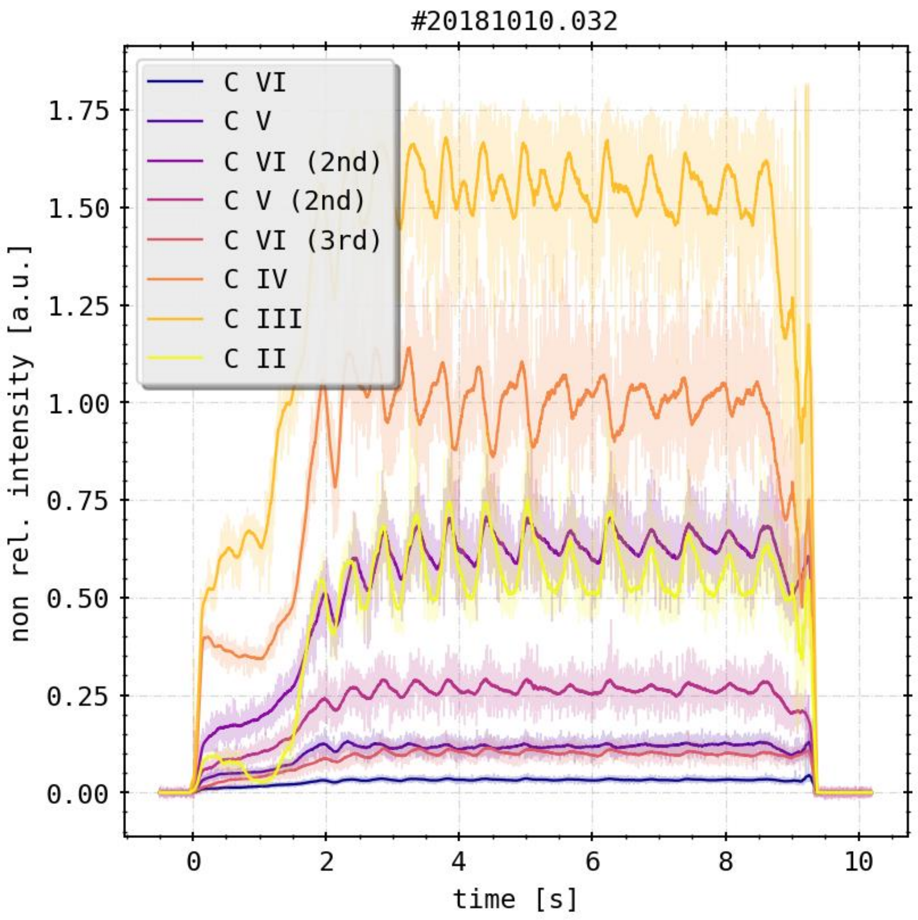


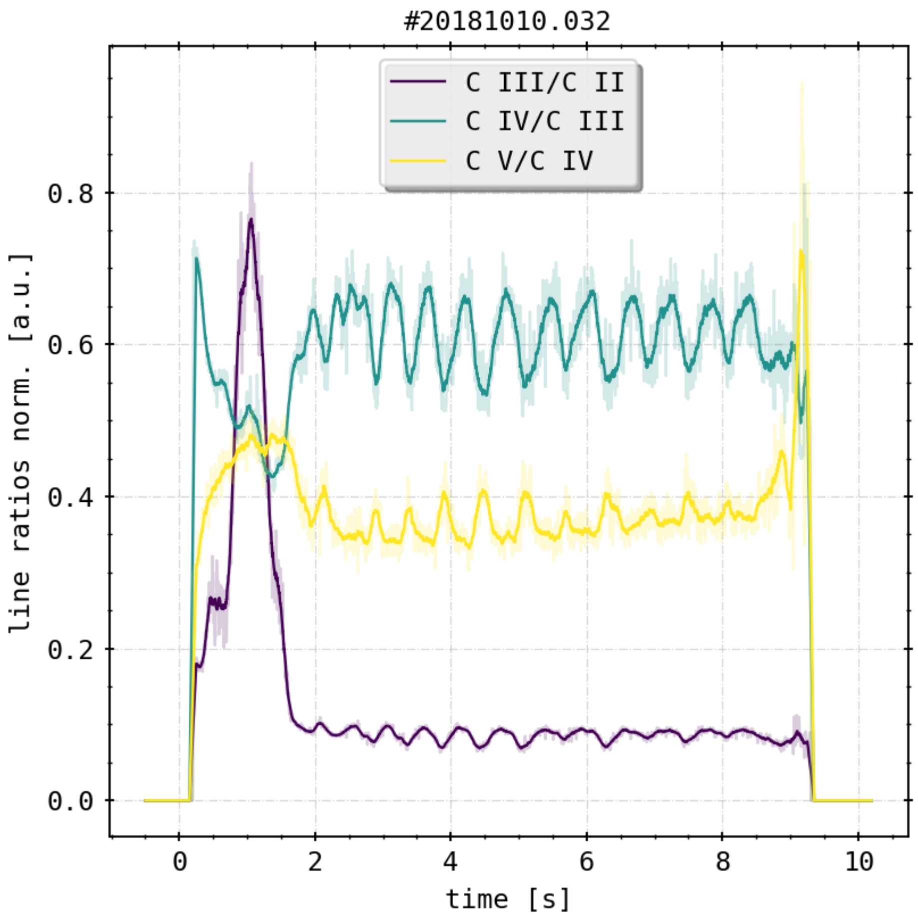
Appendix: Chordal Profiles



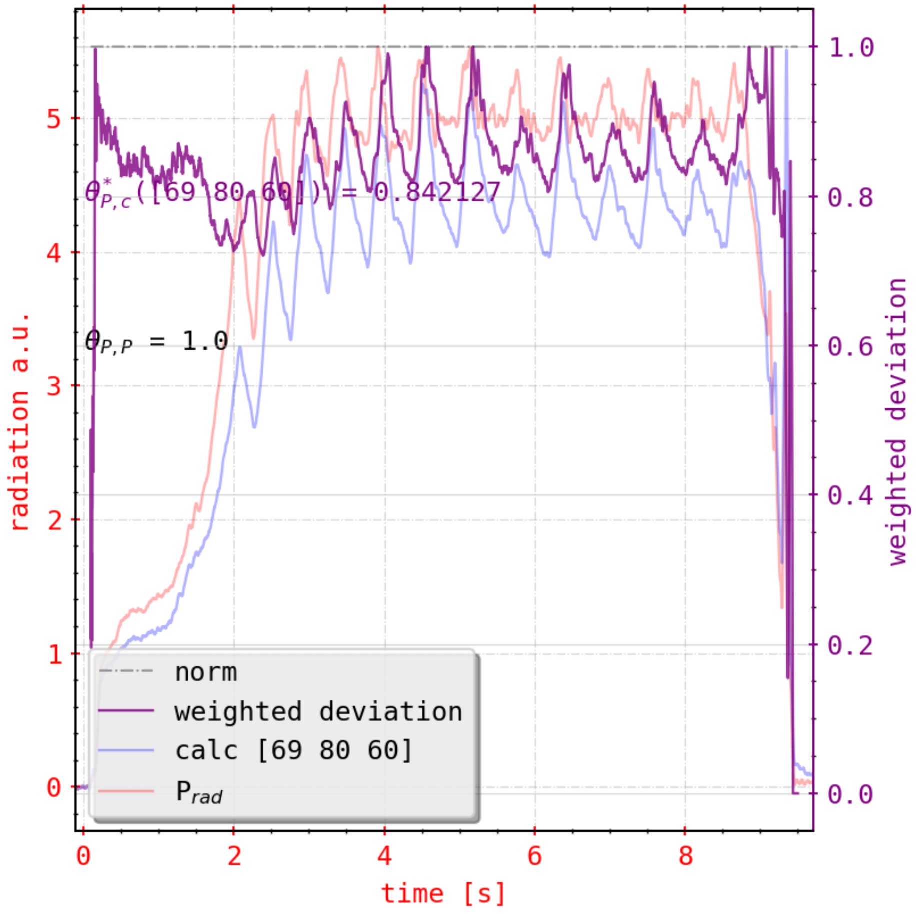


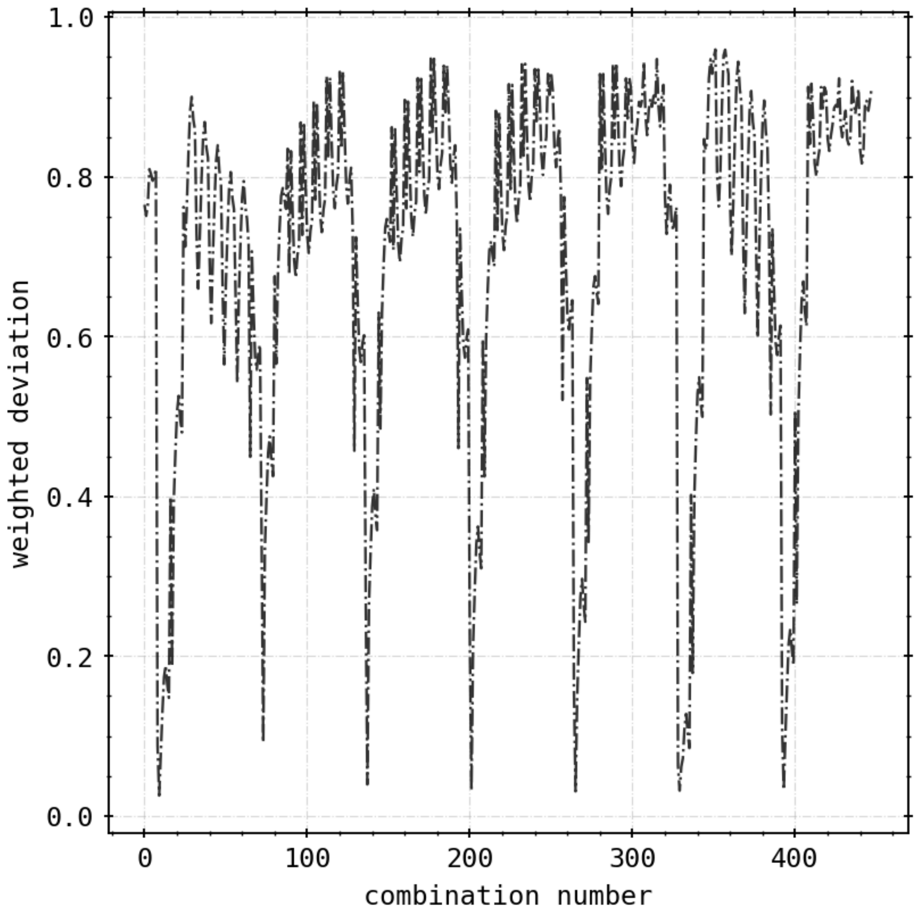
Appendix: HEXOS Lines



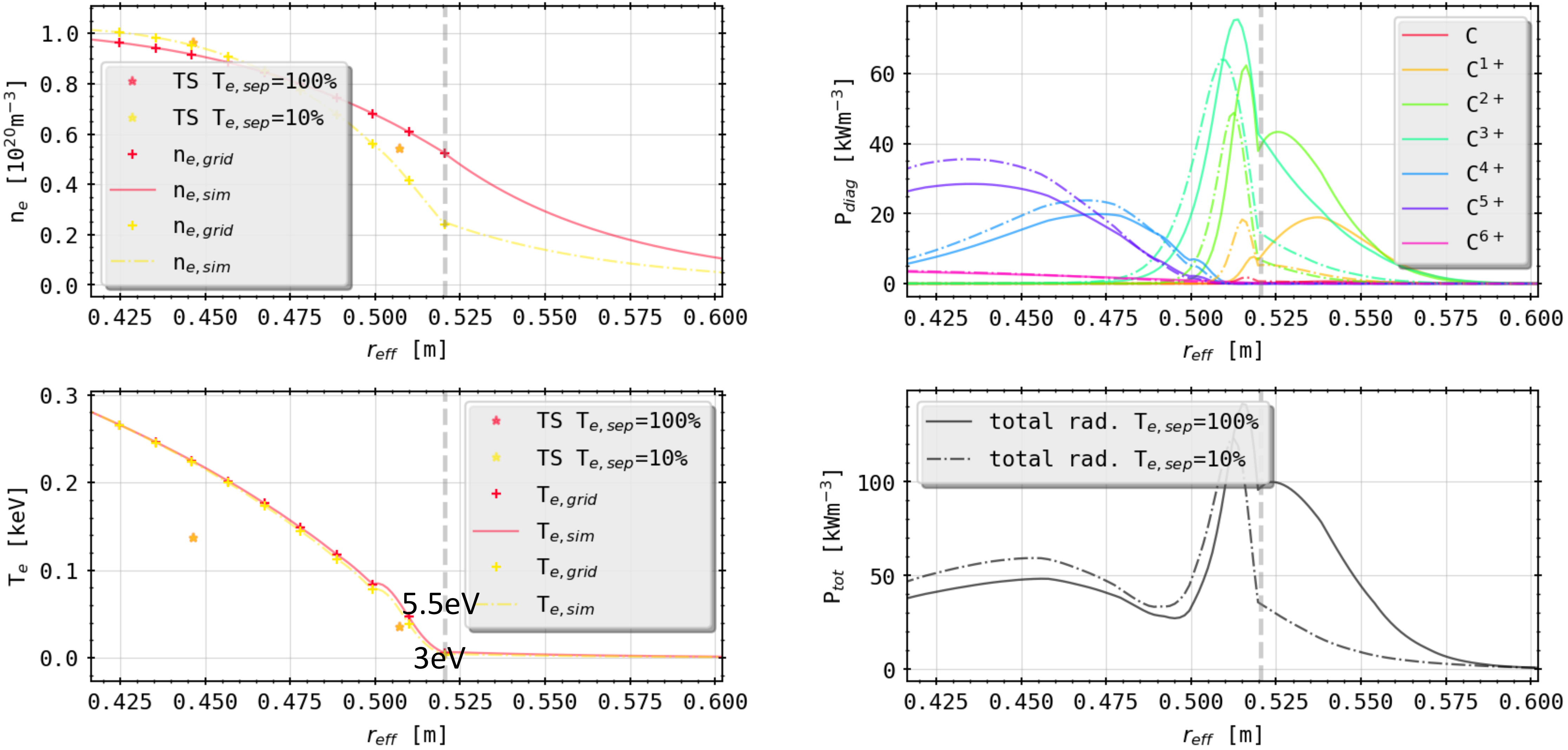


Appendix: Sensitivity Analysis





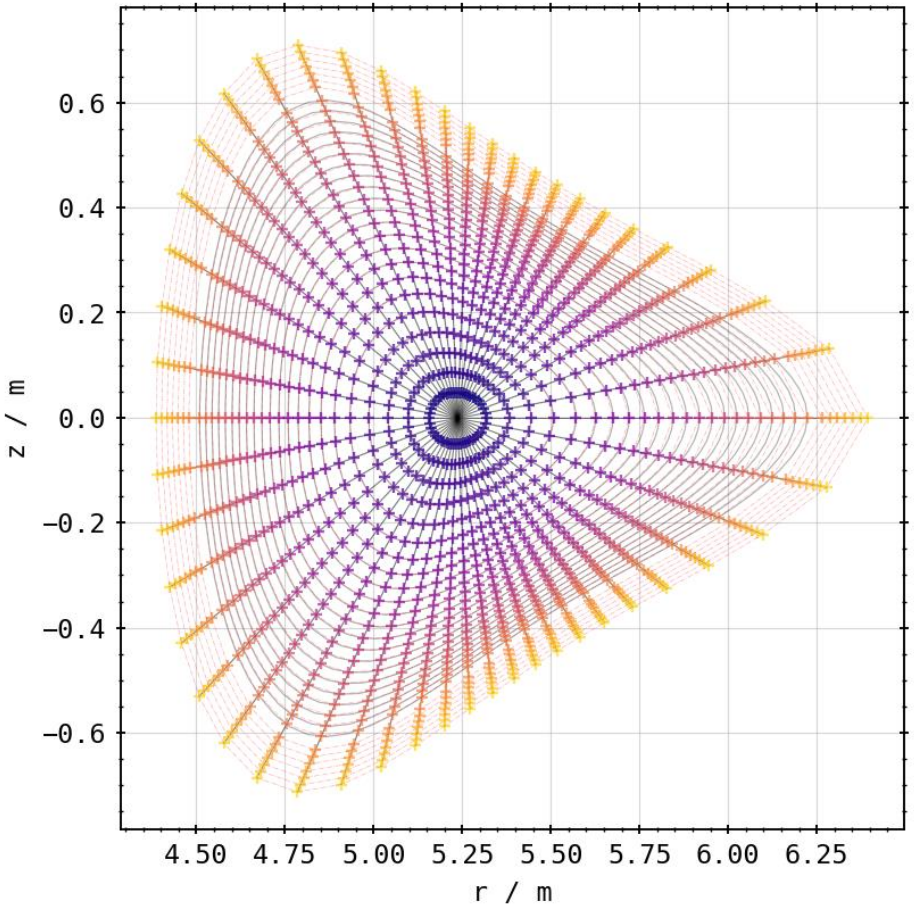
Appendix: 100% - 100% v 10% LCFS n/T



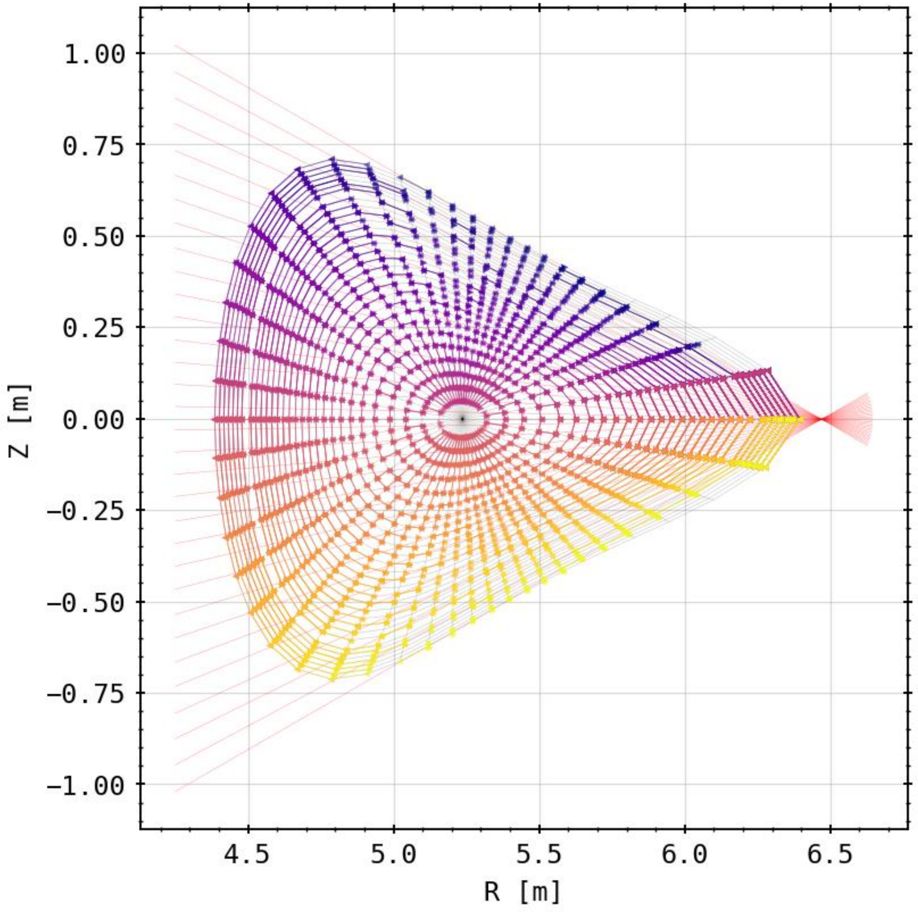
TS profiles last point scaled down, spline fit for continuity

Appendix: Emissivity Factors

mesh from EIM VMEC equilibrium flusxurfaces with extended shells

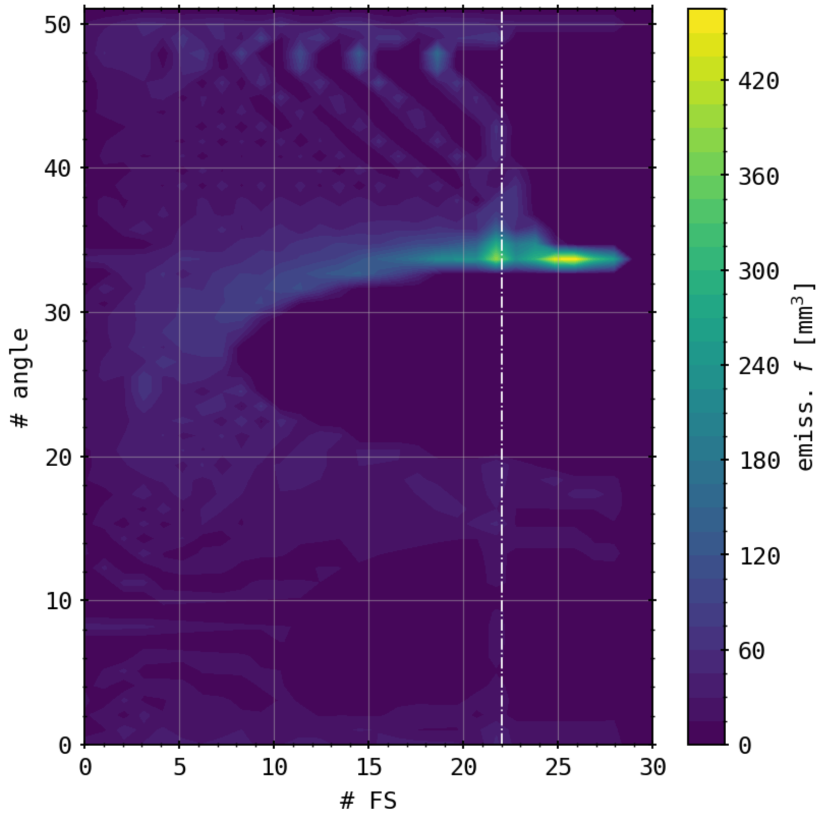


line of sight cuts through mesh cells (HBCm)

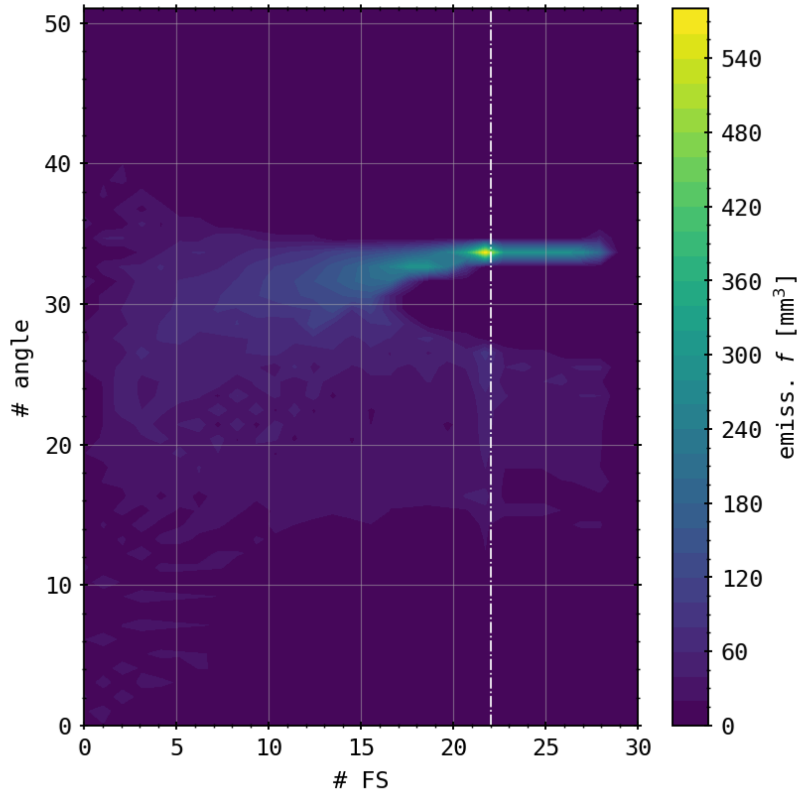


Appendix: Emissivity Factors

VBCr



VBCl



HBCm