Sensitivity Analysis of Radiation Distribution in W7X

P. Hacker

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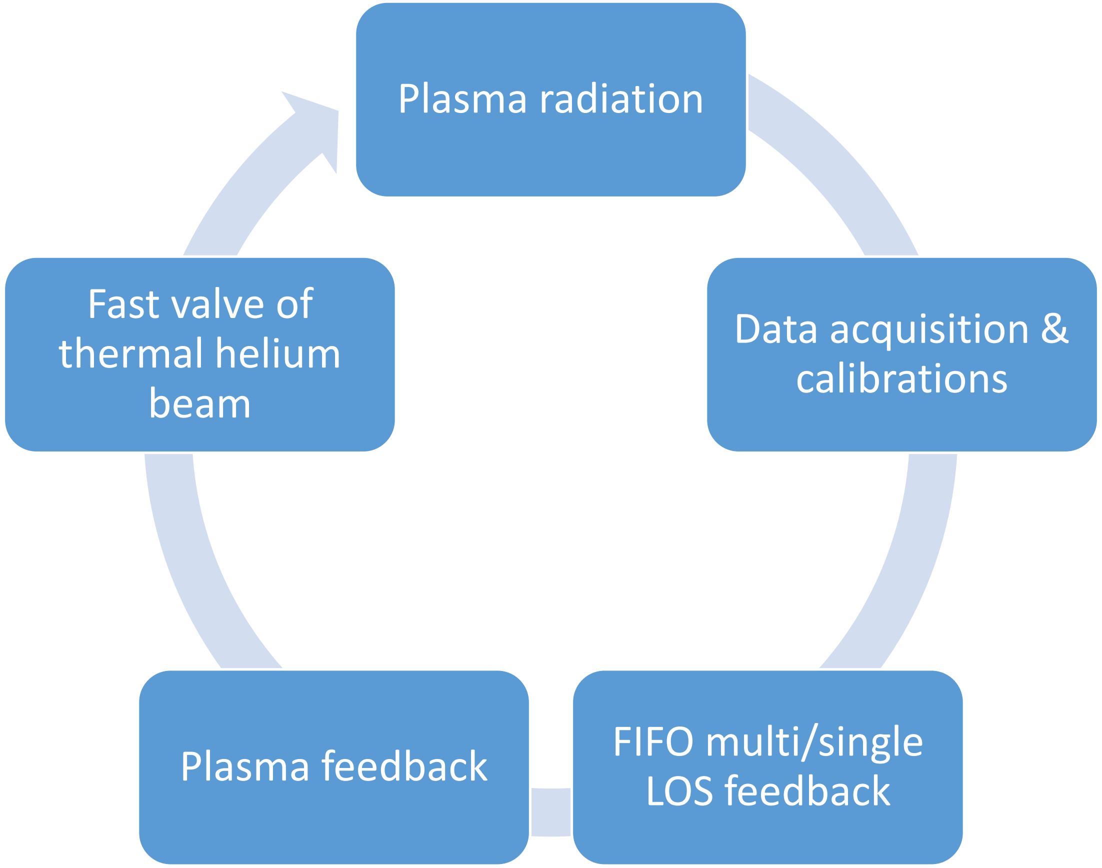
Background & Motivation

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, maybe improved detachment

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



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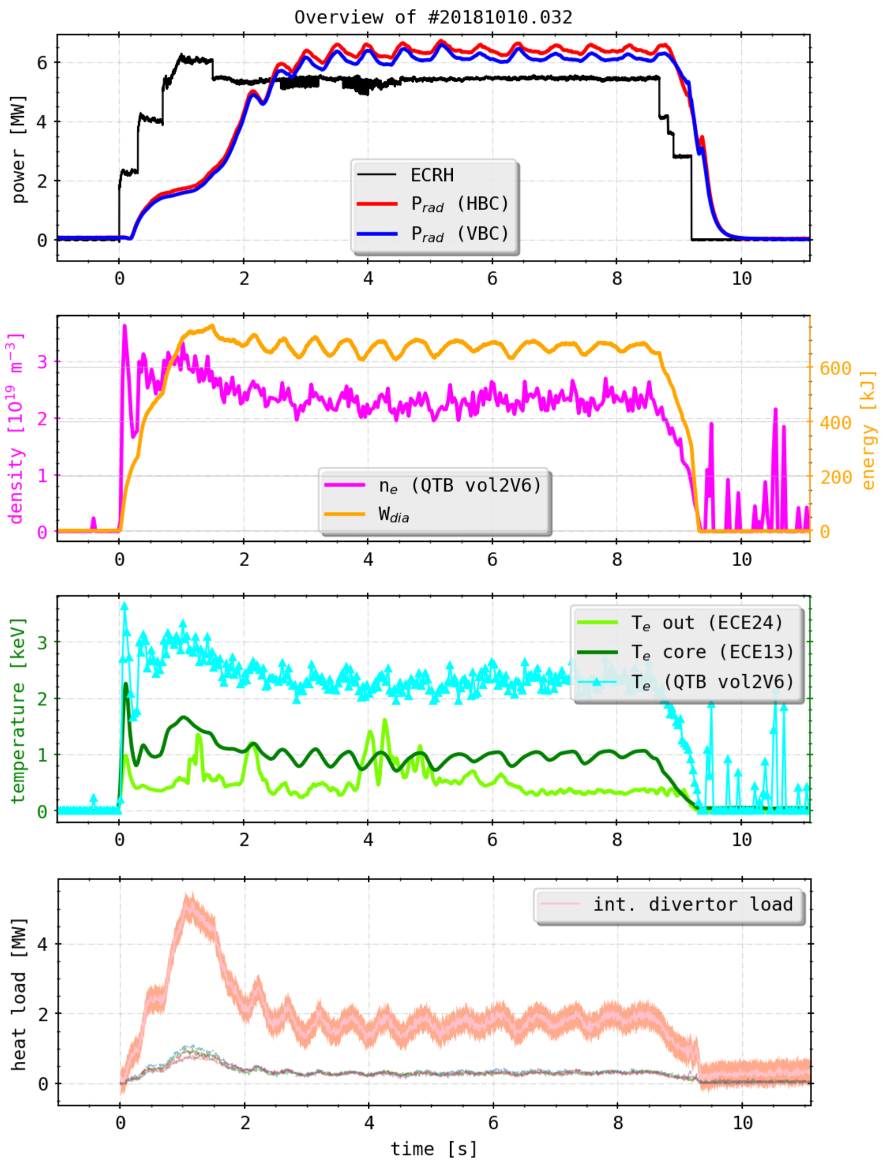

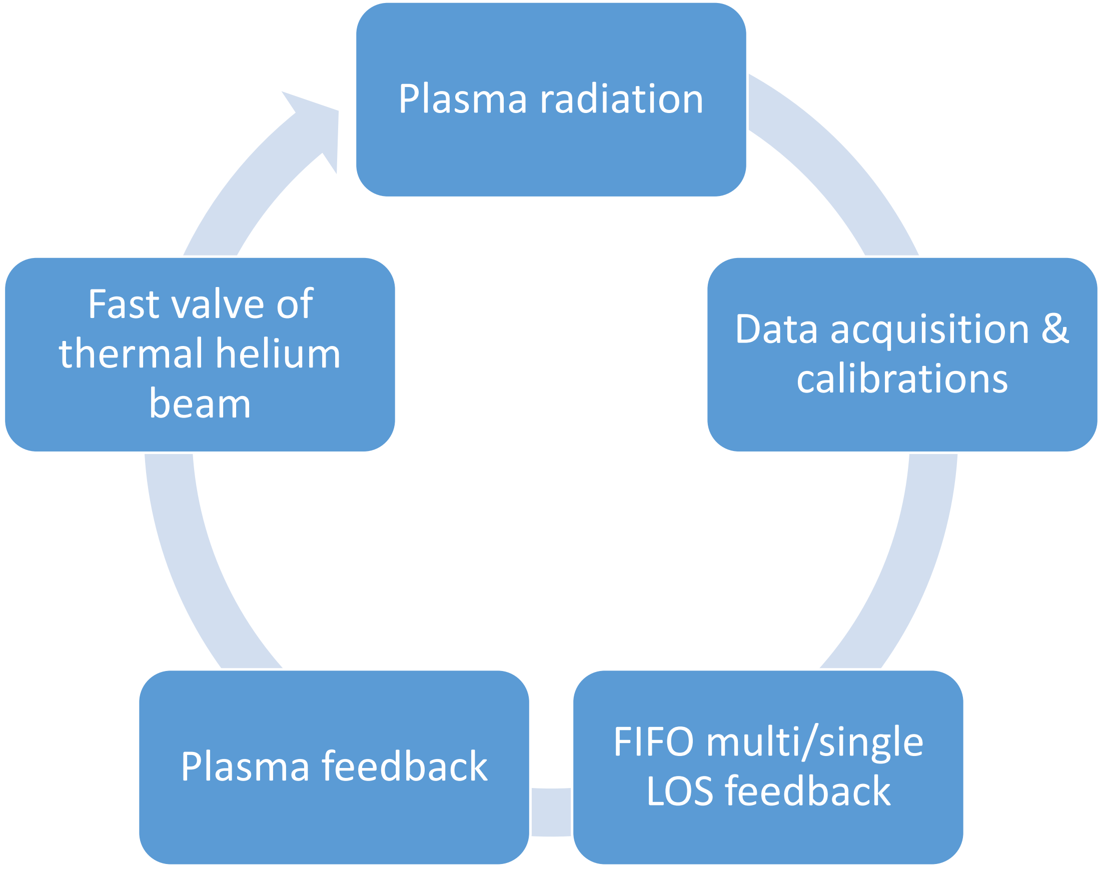

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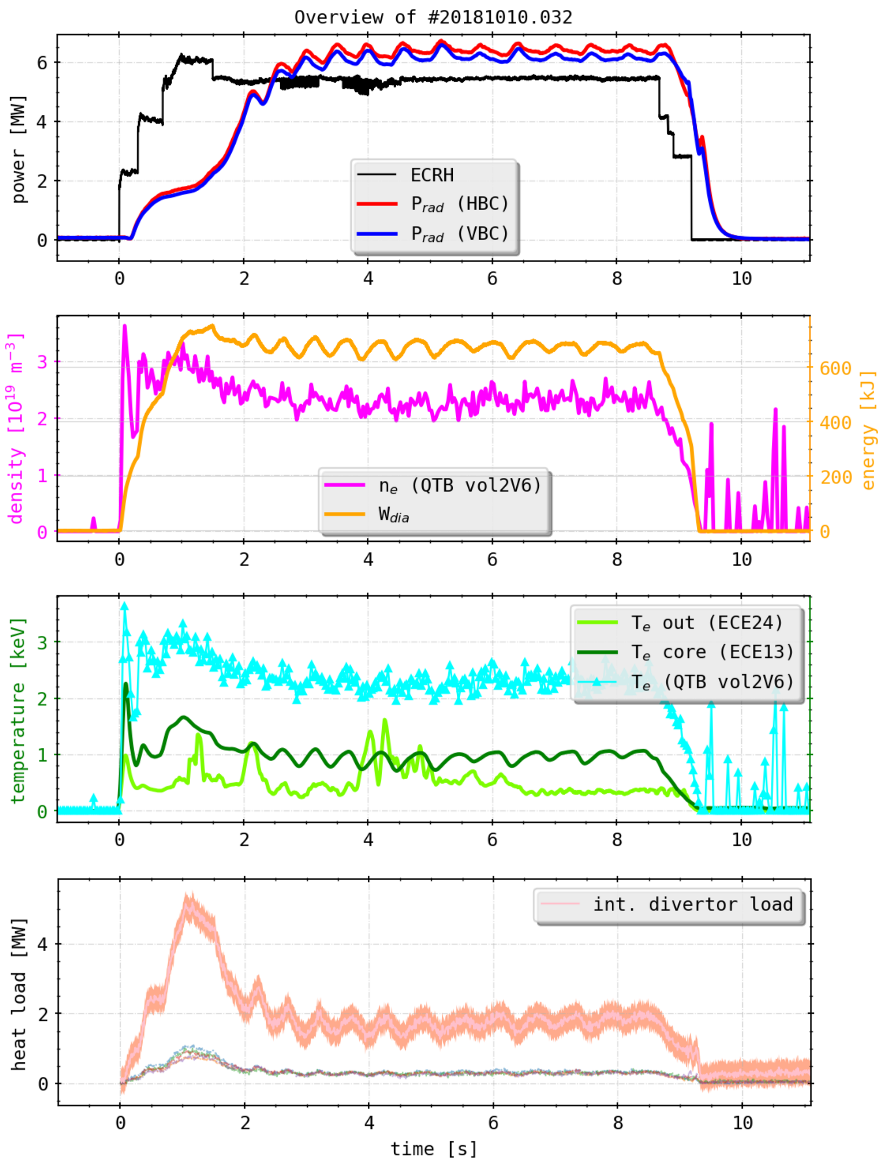
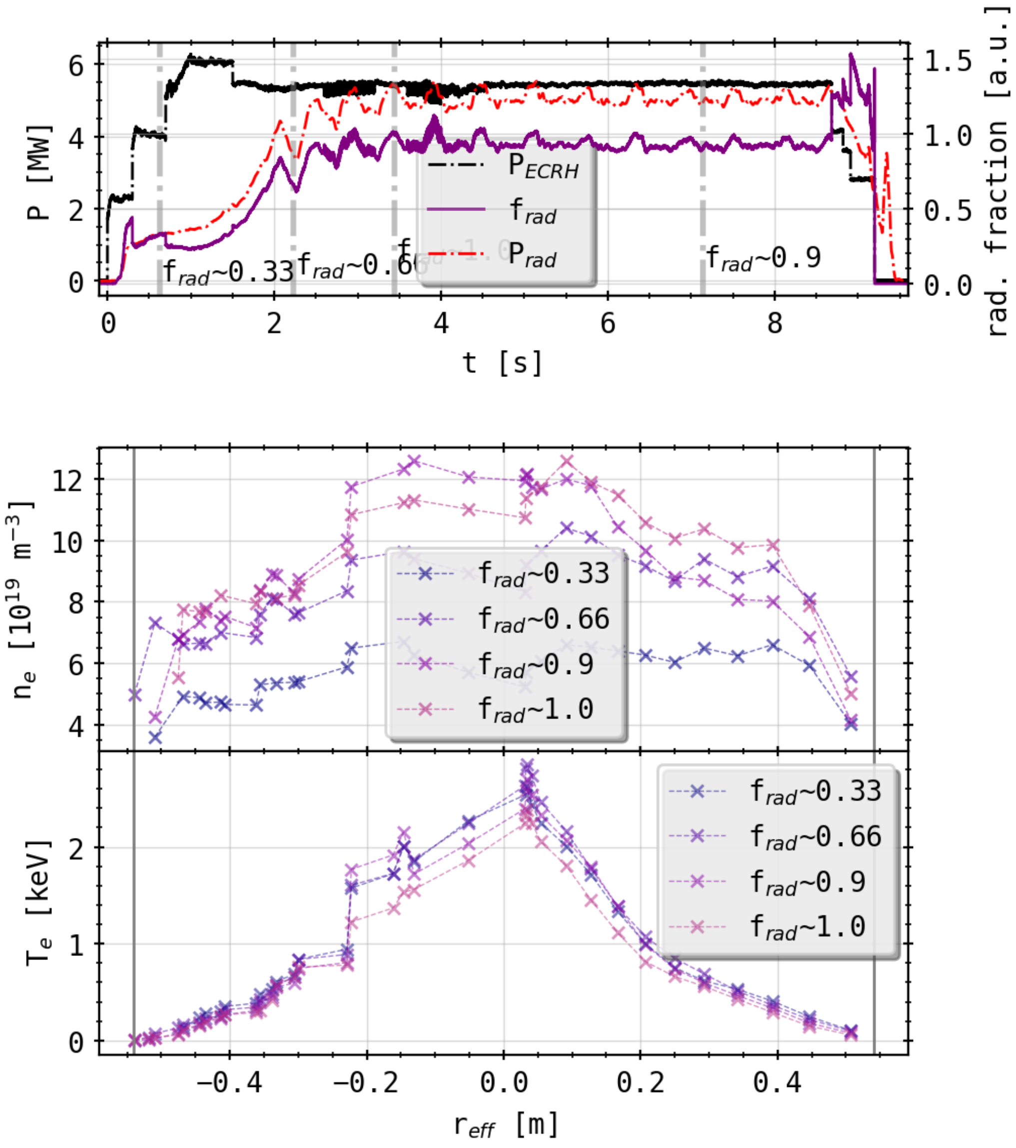


- increasing power loss fraction (f_{rad}) through evaluation of the radiation distribution, i.e. $P_{rad} = f(T, n)$ as an actuator

- 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

- relatively constant W_{dia}, line int. electron temperature/density while target load is greatly decreased and f_{rad}~$0.9 \ldots 1.0$

Background & Motivation



- overall increasing (Thomson scattering) n_e until $f_{rad} = 0.6$
- beyond: smaller changes in absolute value
- electron temperature decreases slightly with greater radiation fraction
- edge profile of T_e close to unchanged

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

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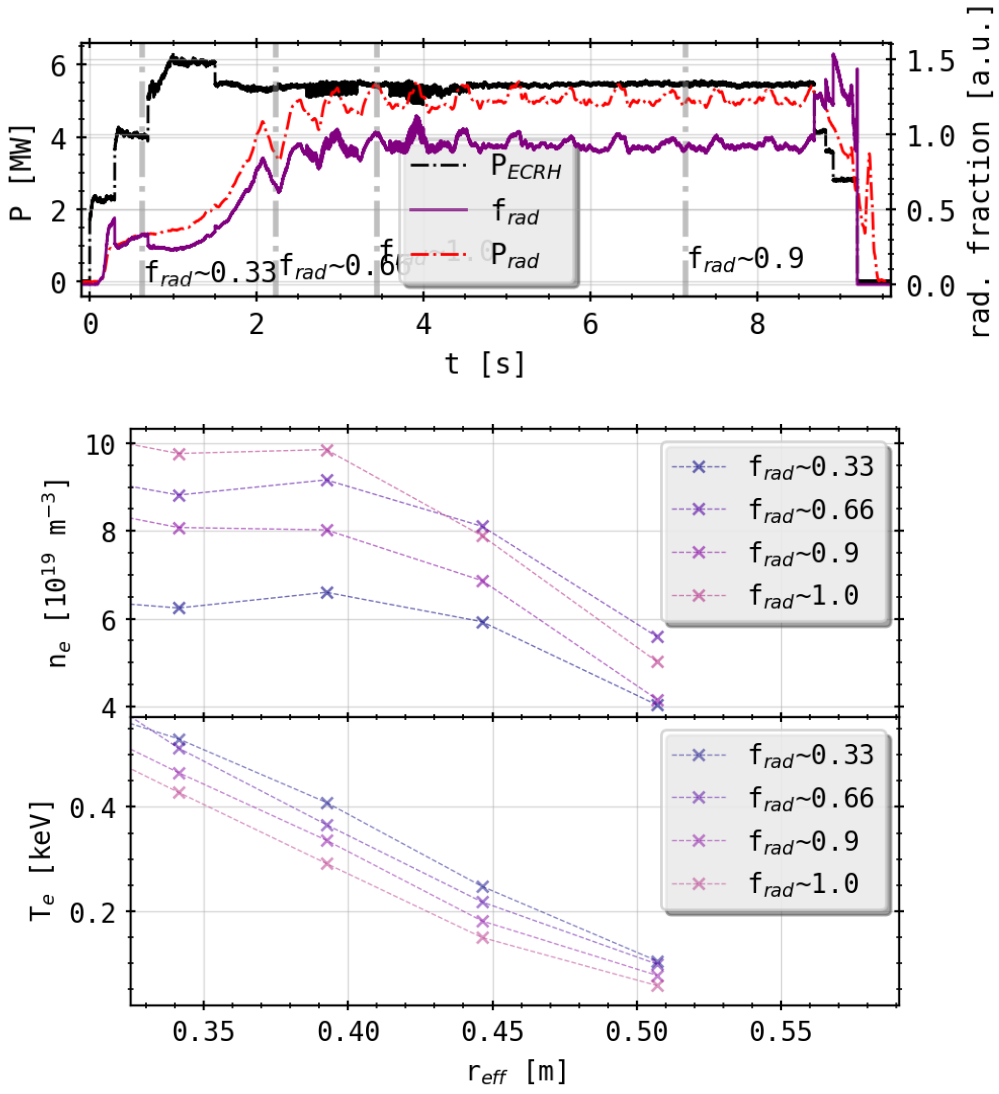

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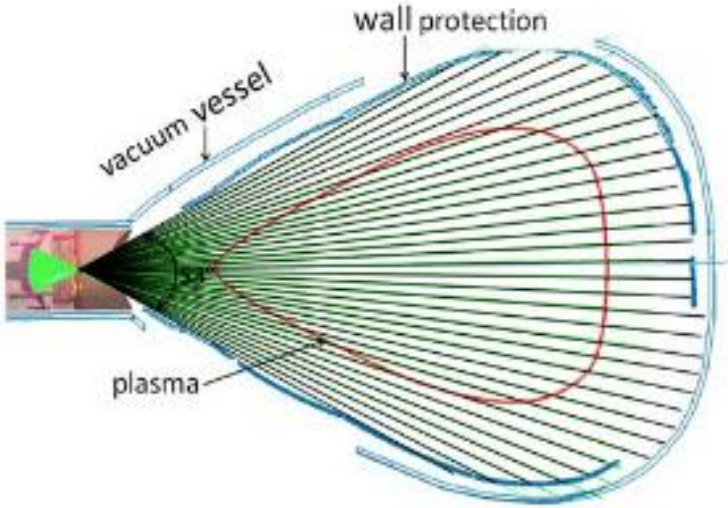
Feedback Evaluation

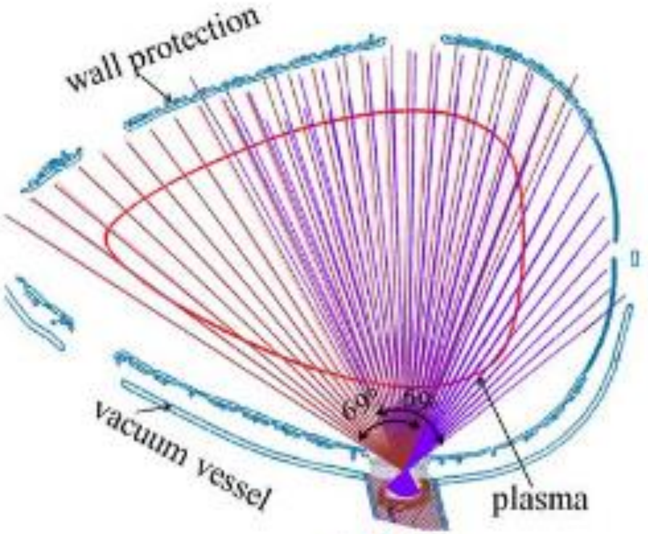
- limited set of lines of sight possible for fast feedback calculations (e.g. 3-5 channels)

➢ 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:



AEU30
horizotal bolomter camera (HBC)



AEV21
vertical bolometer camera (VBC)

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 >1e4 combinations of cameras and channels
- + 8 different sensitivity metrics (e.g. self correlation, coherence, convolutional)
- + multiple experiments

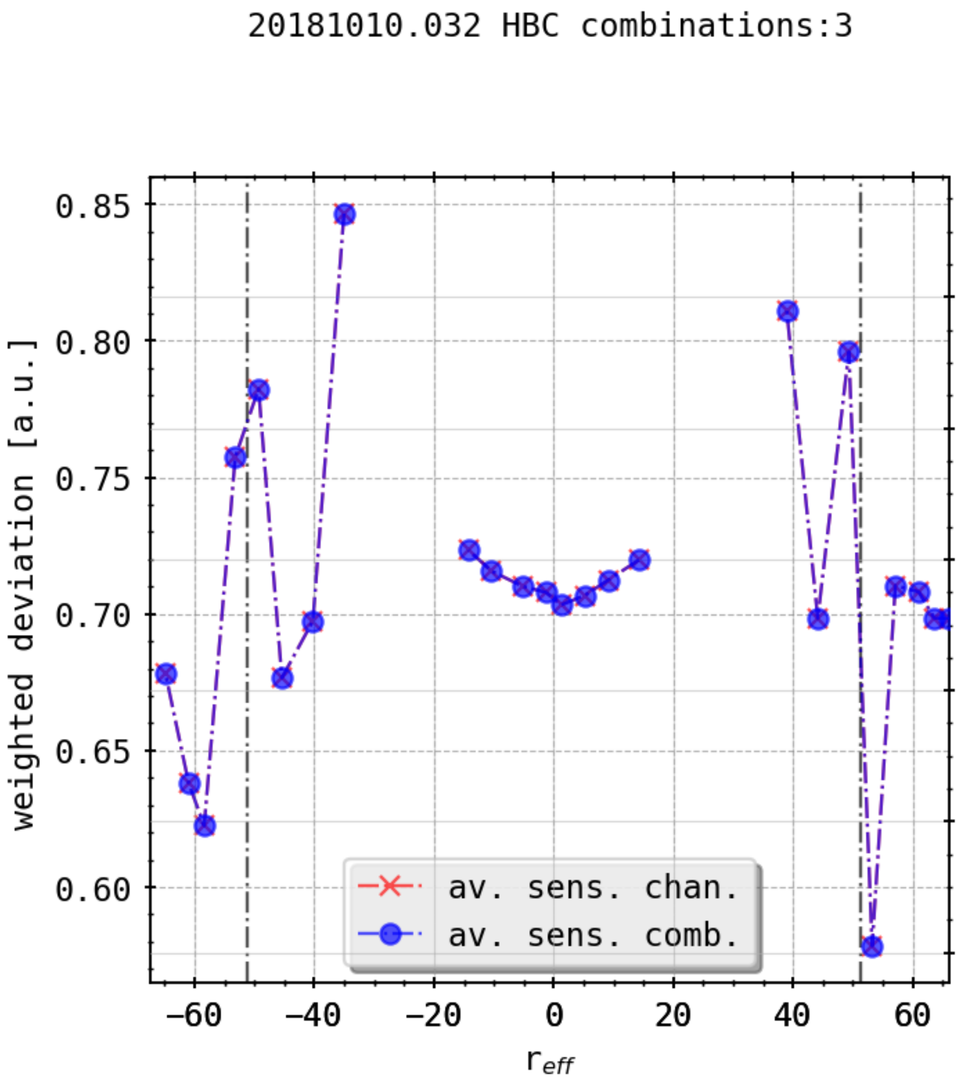
Feedback Evaluation

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

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

➢ lines of sight along the LCFS + slightly inwards are most sensitive to changes in the plasma radiation regime

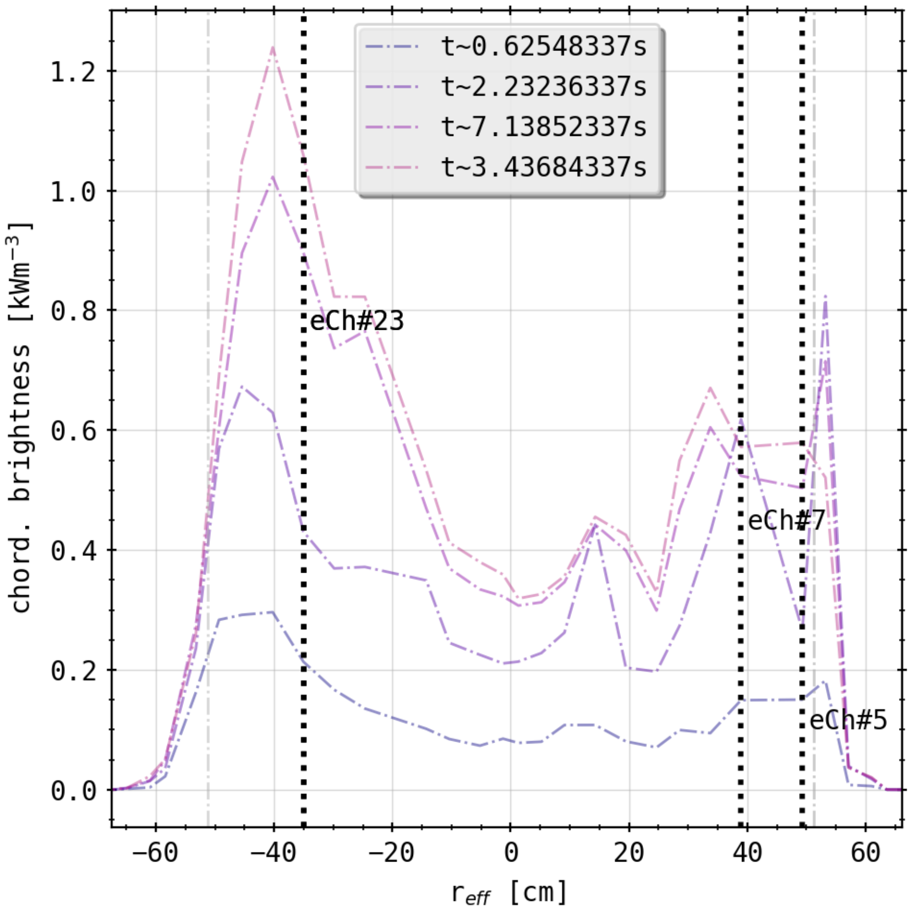
➢ a well picked subset of 5 detectors can reflect the total plasma radiation with up to 90% accuracy (!)



Feedback Evaluation

- majority of radiation comes from edge region or close to SOL
- with increasing radiation fraction chordal brightness shifts inwards away from LCFS

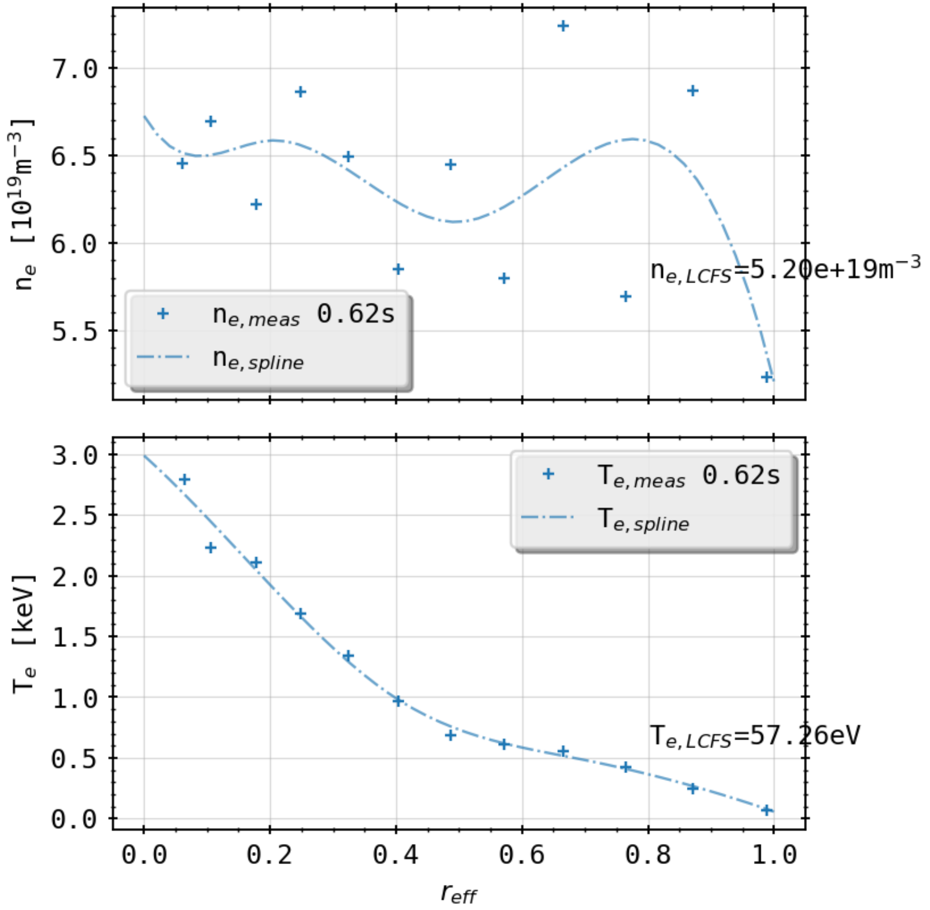
➢ radiation source responsible for shift given the previous plasma profiles? (decreasing T_e, intrinsic impurities …)



chordial profiles of the previously discussed f_{rad}

STRAHL Simulations of Carbon Radiation

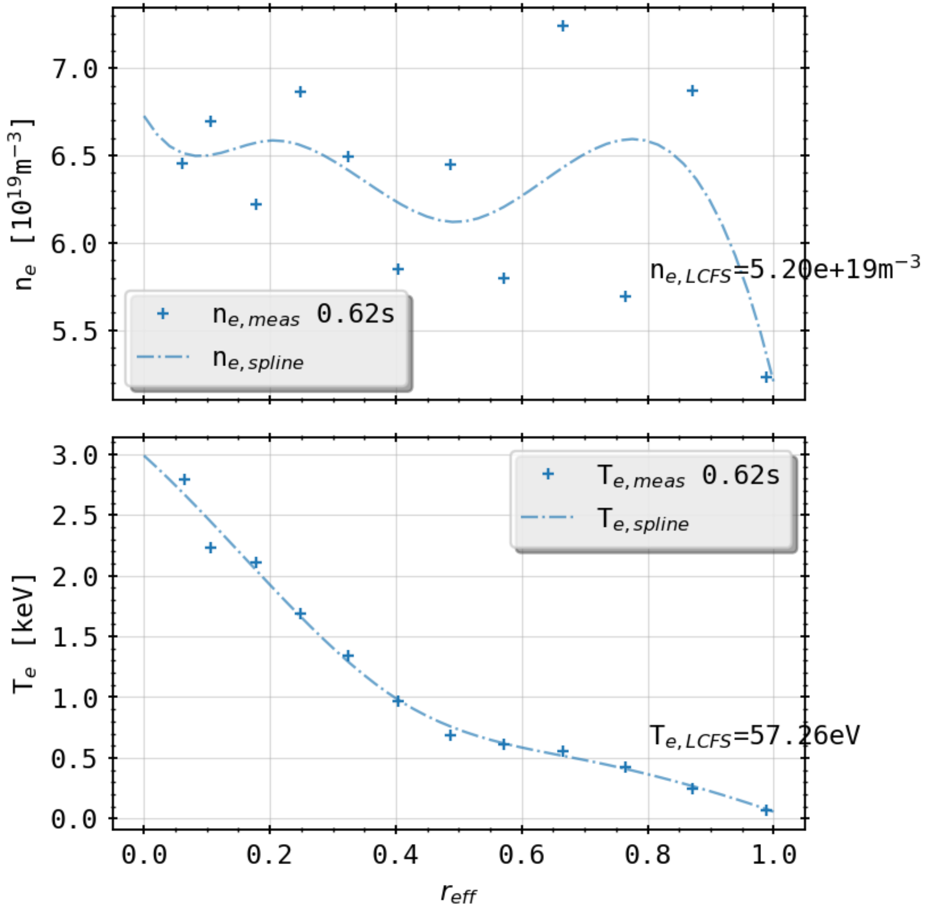
- assuming 1D distribution given the chordal profiles, i.e. radiation coming from inside the LCFS
- investigating main intrinsic impurity carbon (i.e. lines measured also by HEXOS)
- use TS profiles from radiation feedback controlled plasma
- scale values of electron density and temperature at the SOL, i.e. $r_{eff} = 1.0$ since TS is least accurate
- 4th order spline interpolation for smoothness (k=3 leads to rising edge T_e and n_e)



TS profiles (+) and STRAHL profiles for $f_{rad} = 0.3$

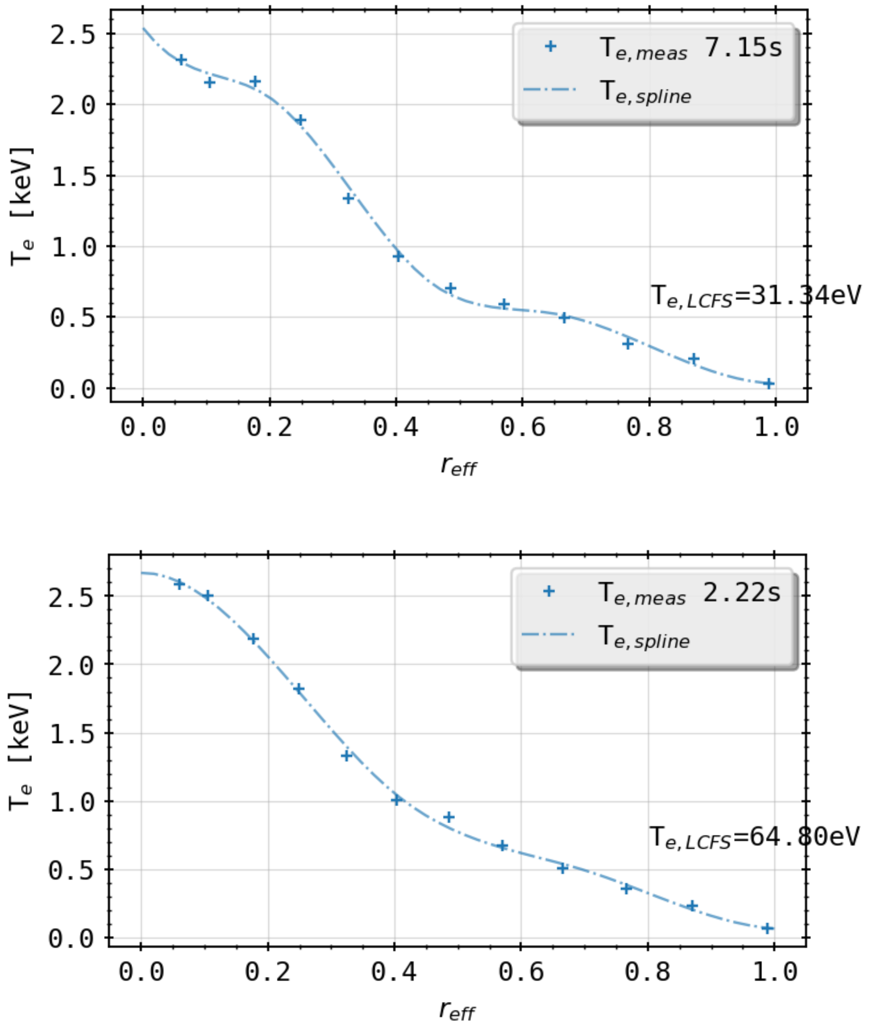
STRAHL Simulations of Carbon Radiation

- transport: $D = 0.1\frac{m^2}{s}$ at the center $5\frac{m^2}{s}$ at $r_{eff} = 0.6$ and $0\frac{m^2}{s}$ at the LCFS
- decay length of temperature and density $\lambda = 5cm$, mimicing island chain regions
- source of carbon at the $r_{eff} = 1.1$ with $10^{21}s^{-1}$
- oxygen calculations show orders of magnitude smaller impact on P_{rad}

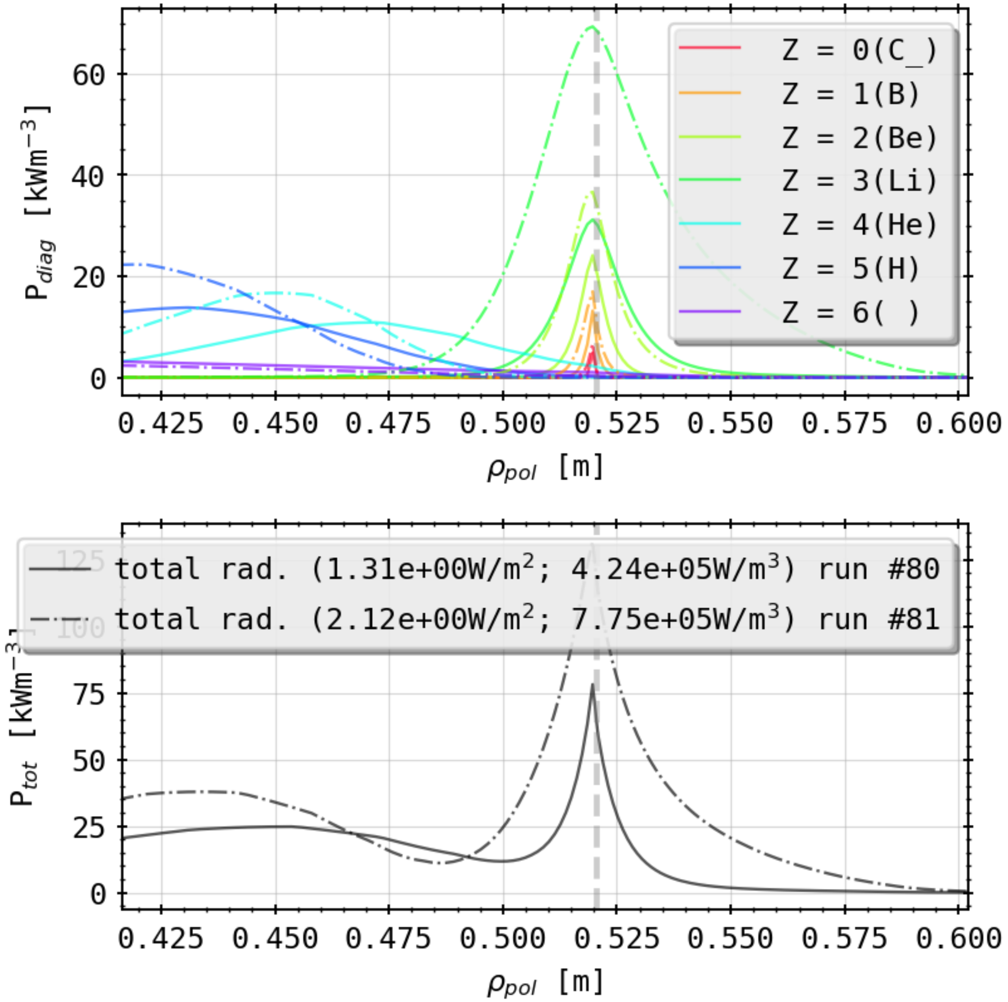


TS profiles (+) and STRAHL profiles for $f_{rad} = 0.3$

STRAHL Simulations: 60% v 90%



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

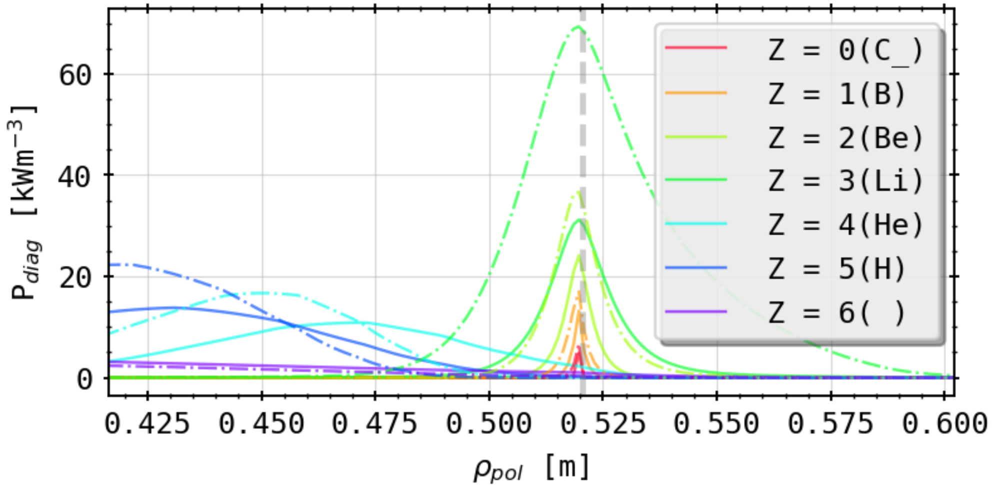


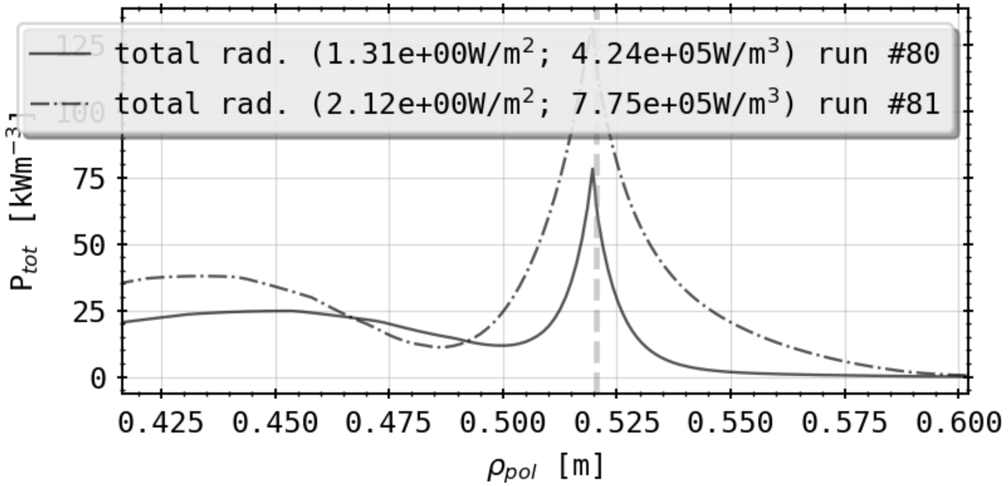
coronal equilib. line radiation profiles for $f_{rad} = 0.6, 0.9$

STRAHL Simulations: 60% v 90%

- minimal inward shift of all higher stages inconclusive for Bolometer, spatial resolution is 5cm
- no visible change of radiation fraction between core and SOL

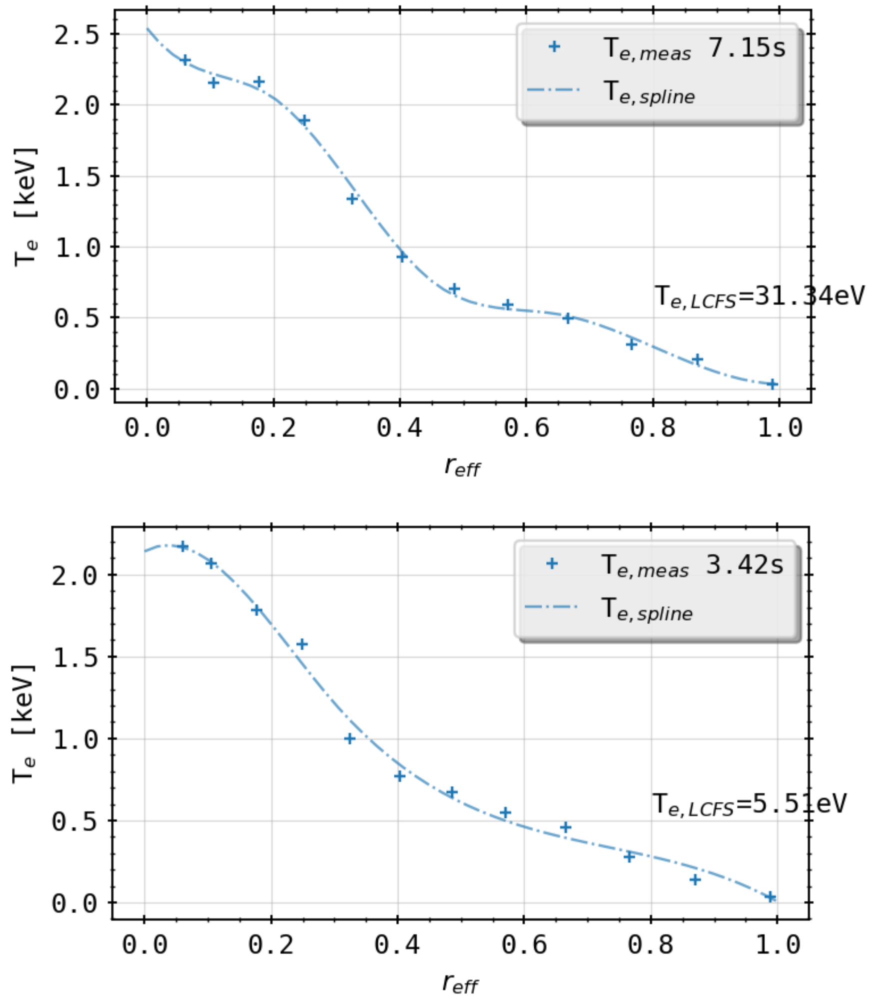
➢ radiation peak inside LCFS



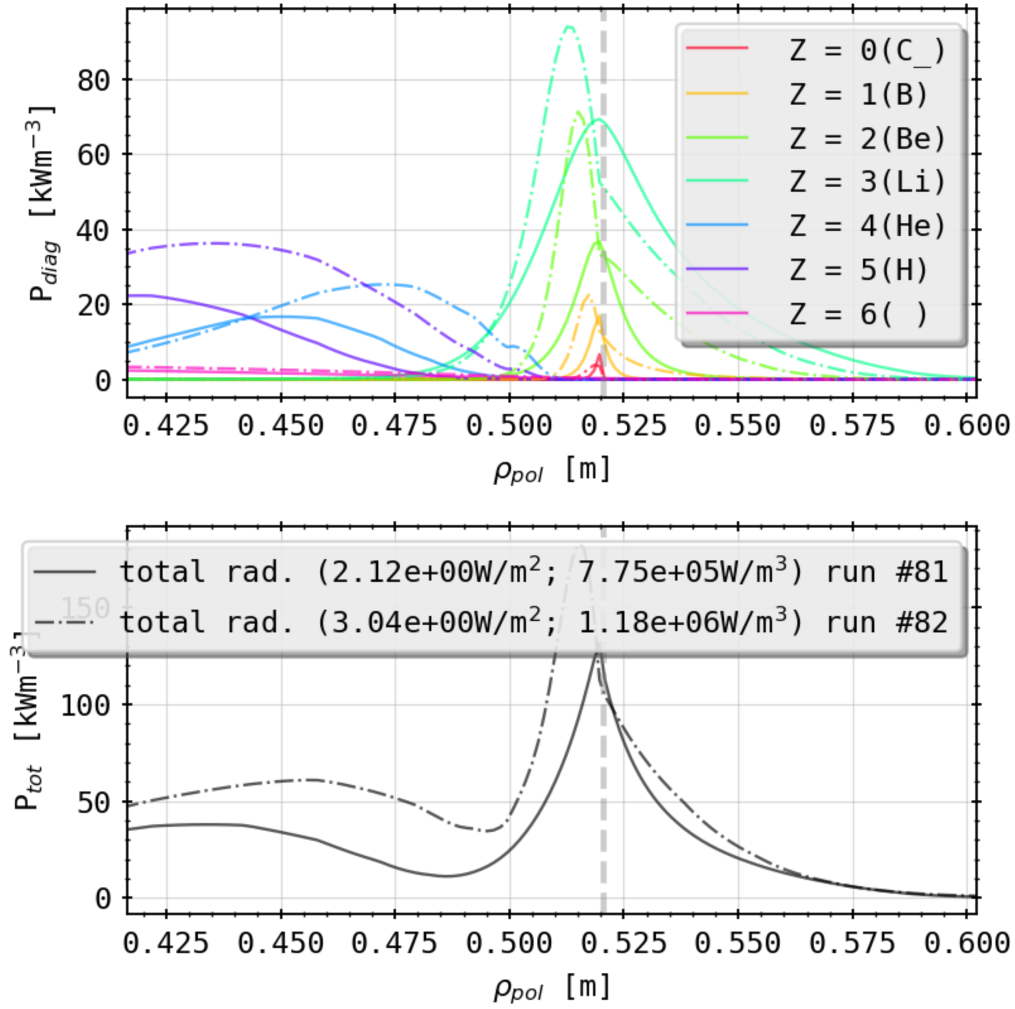


coronal equilib. line radiation profiles for $f_{rad} = 0.6, 0.9$

STRAHL Simulations: 90% v 100%



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



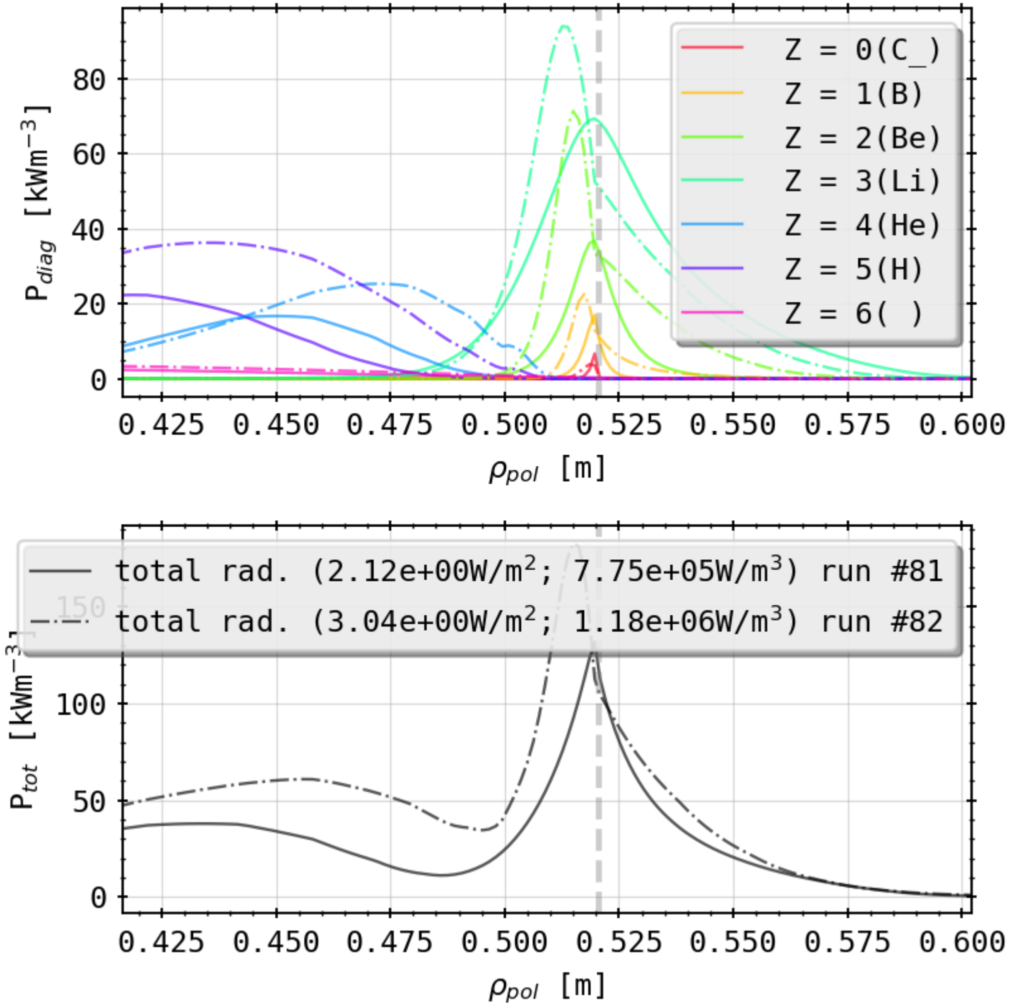
coronal equilib. line radiation profiles for $f_{rad} = 0.9, 1.0$

STRAHL Simulations: 90% v 100%

- very small temperature at LCFS (5eV) for 100% of irradiated power
- shift in position of ionization peaks

➢ trend between SOL and core radiation changes >> strong core radiating carbon population

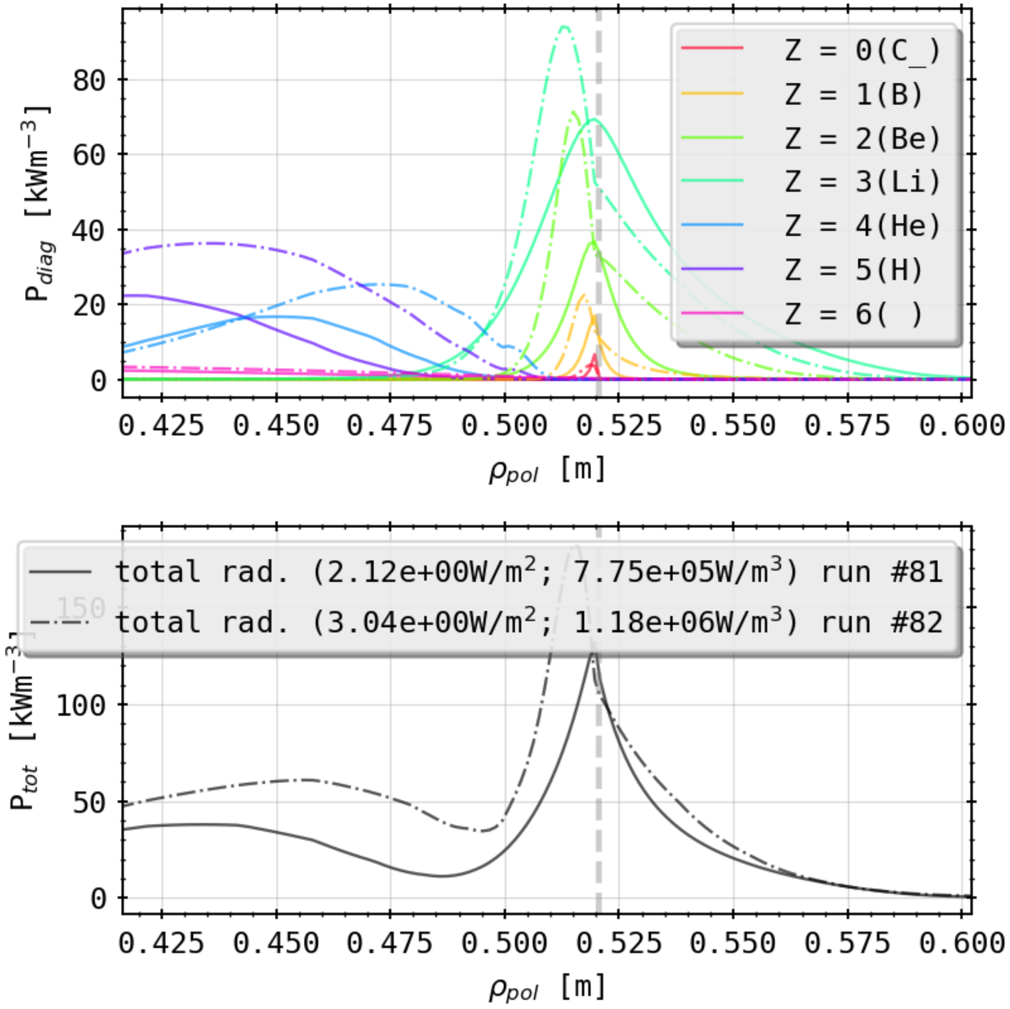
➢ volume integrated radiation (for 30sqm of plasma volume) roughly (OOM) matches experimental level



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

STRAHL Simulations: 90% v 100%

- measurable spatial shift, especially now in Be- and Li-like ion radiation peaks
- transition from bright to dark SOL from 90% to 100% of radiation power loss
- possible means for radiation regimes in detachment
- intrinsic impurity C main radiation source? (oxygen levels much smaller for same scenario)



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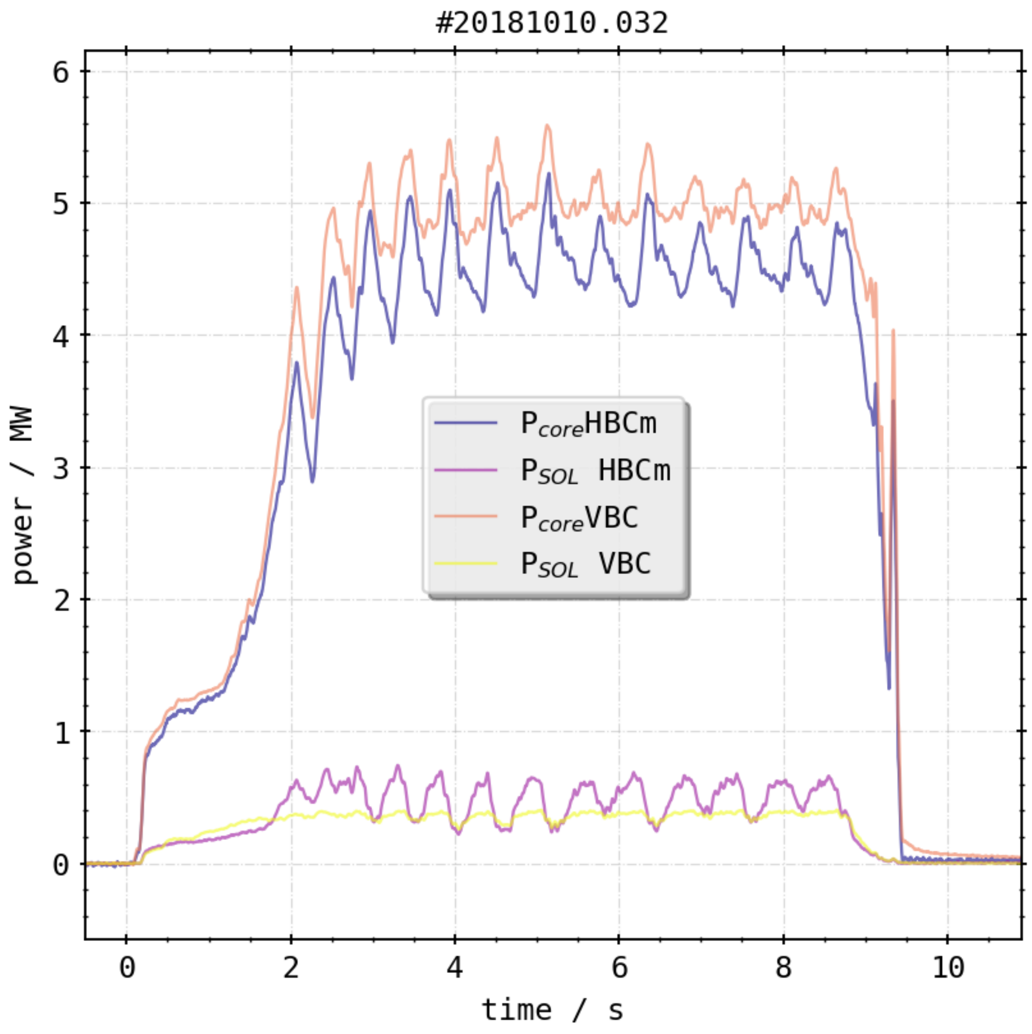
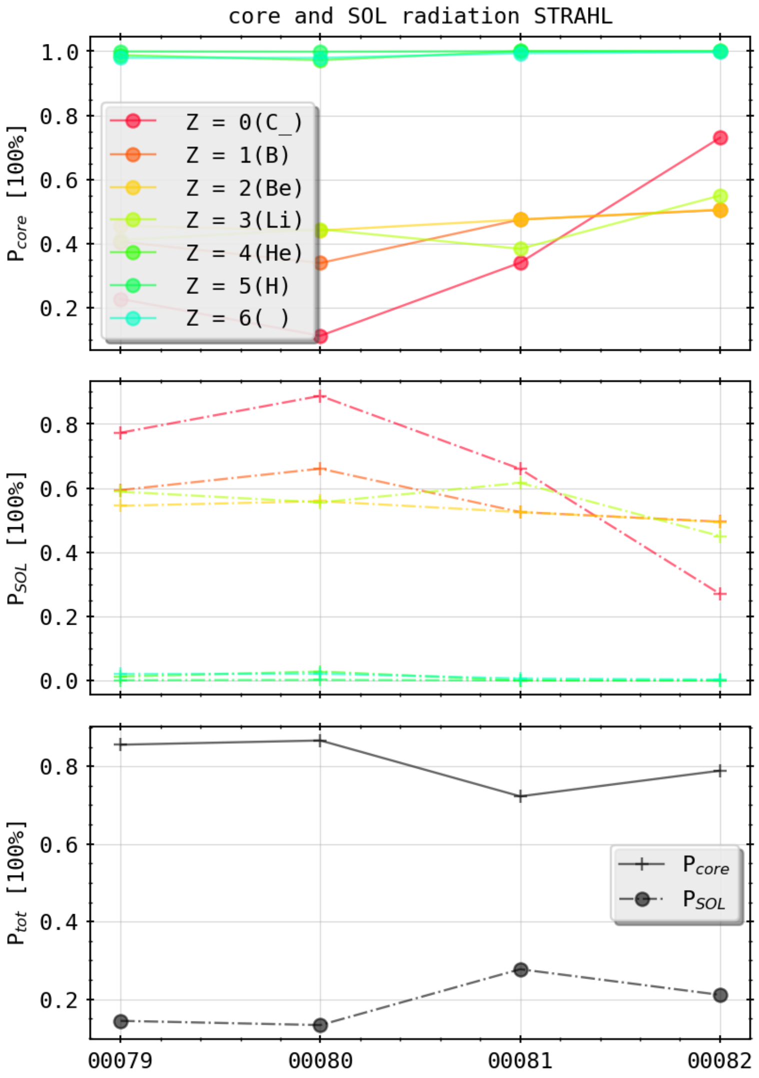
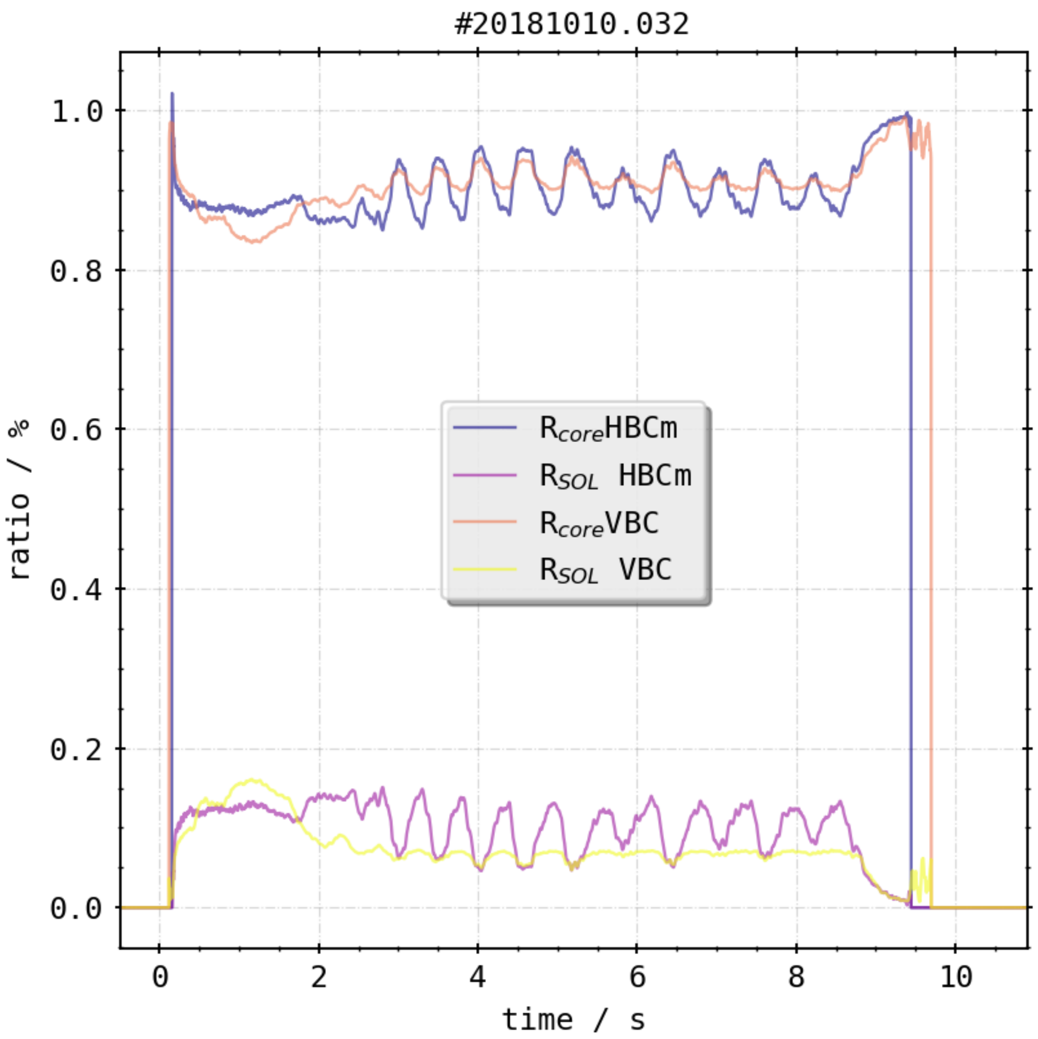
STRAHL Simulations: Core vs. SOL Radiation

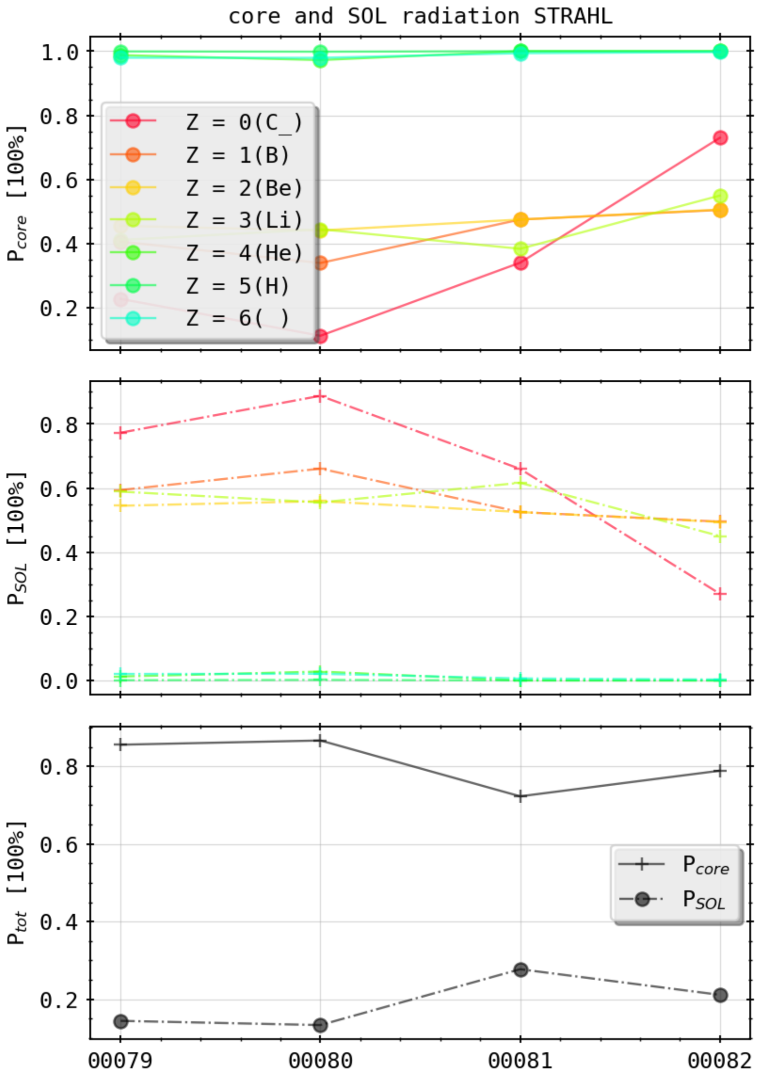




Core and SOL radiation ratios $f_{rad} = 0.3 \ldots 1.0$

STRAHL Simulations: Core vs. SOL Radiation



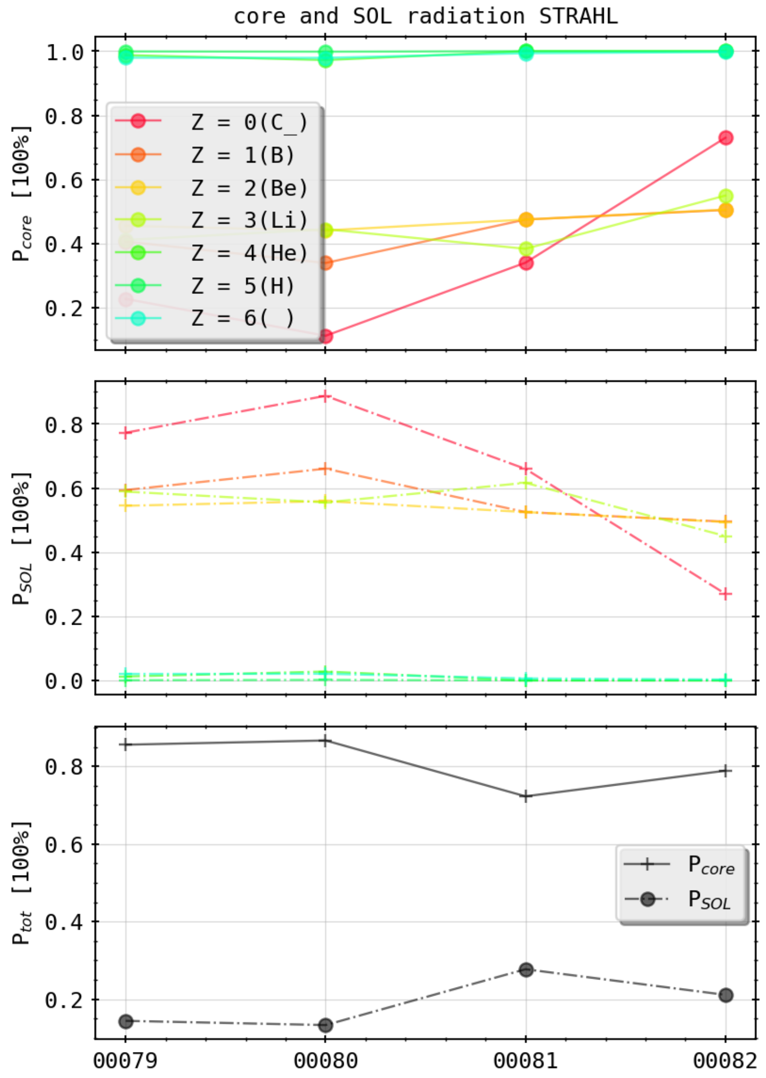


Core and SOL radiation ratios $f_{rad} = 0.3 \ldots 1.0$

STRAHL Simulations: Core vs. SOL Radiation

- ➢ both STRAHL and experimental data represent in estimation the previous claims >> SOL starves of radiation power

- ➢ total radiation level in core v SOL comparison by factor of ~3 too big, scalable by source intensity



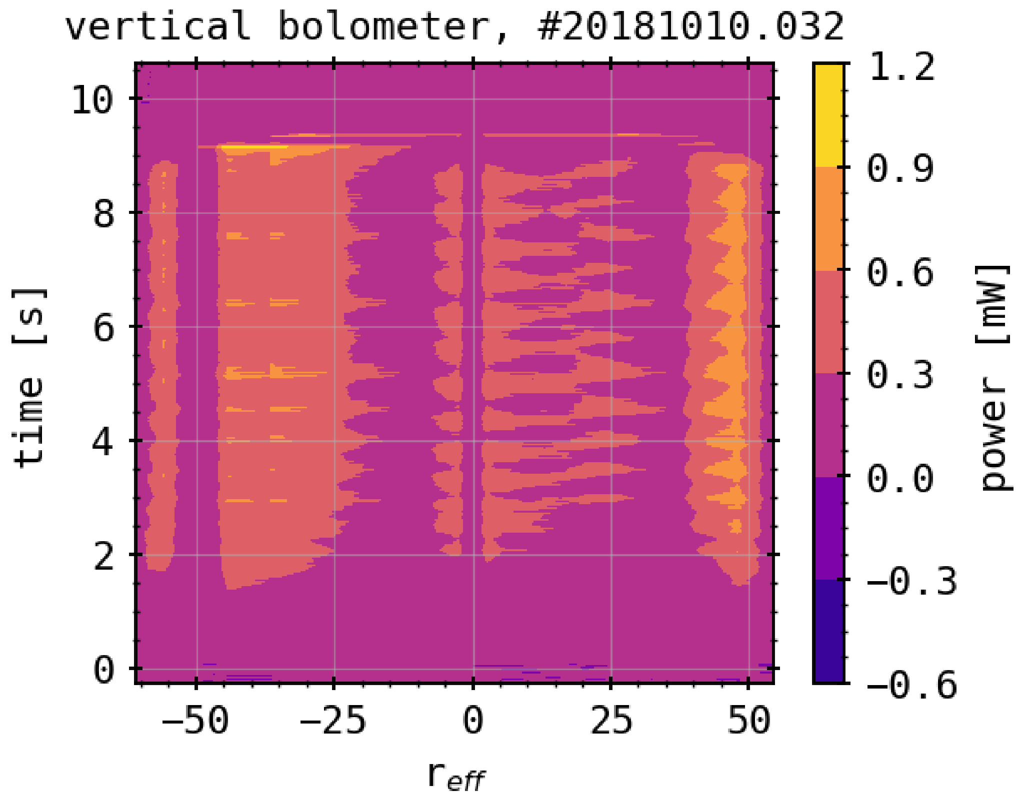
Core and SOL radiation ratios $f_{rad} = 0.3 \ldots 1.0$

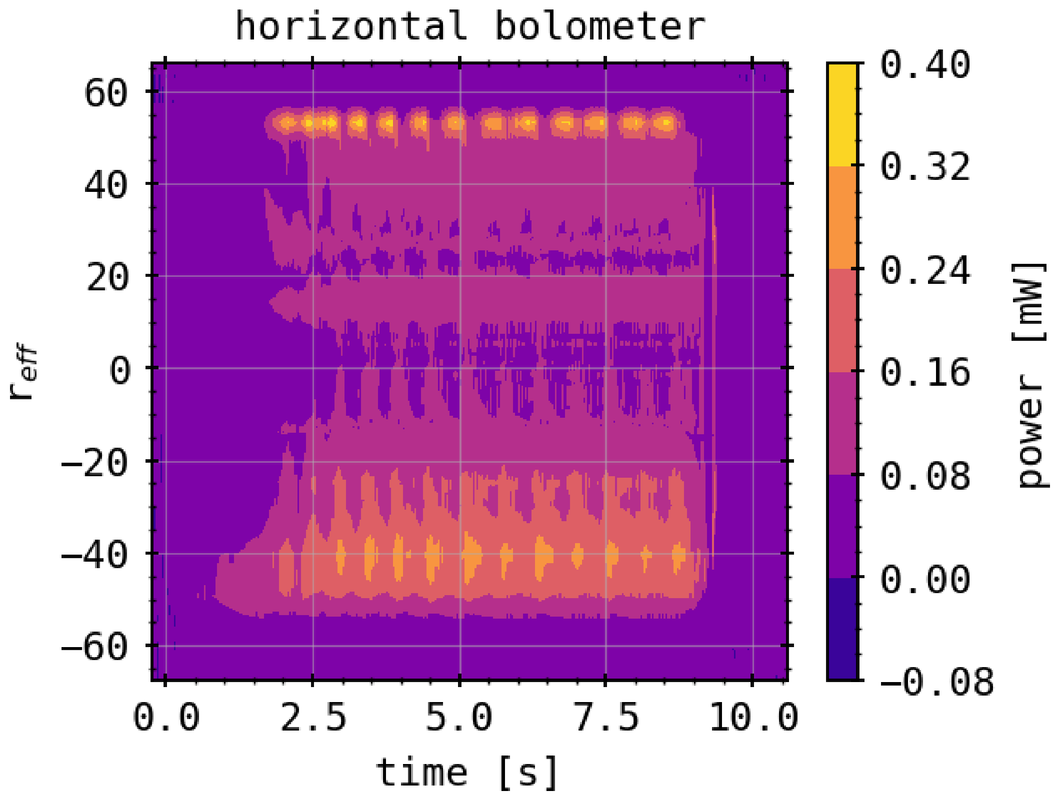
Future Investigation

- directly compare line integrated STRAHL results for lines of sight geometry with chordal profiles
- measure SOL and core radiation in both STRAHL and Bolometer data
- extend simulation space to 2D inversion with MFR (Minimum Fisher Regularization)

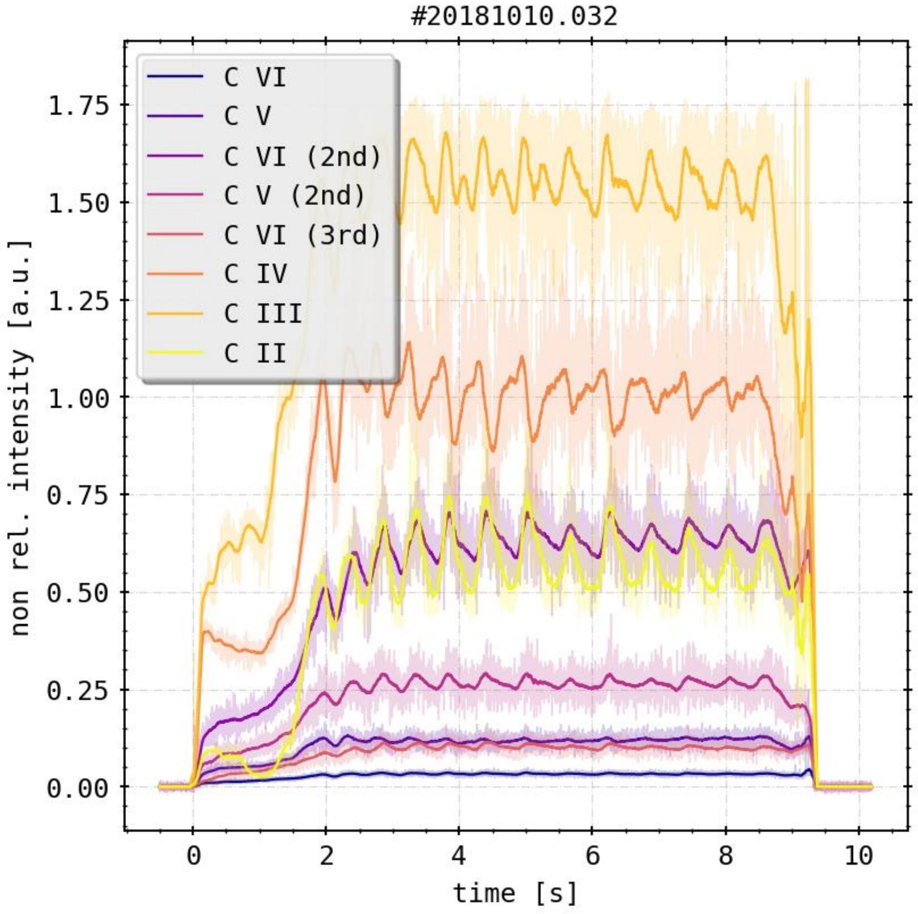
Appendix

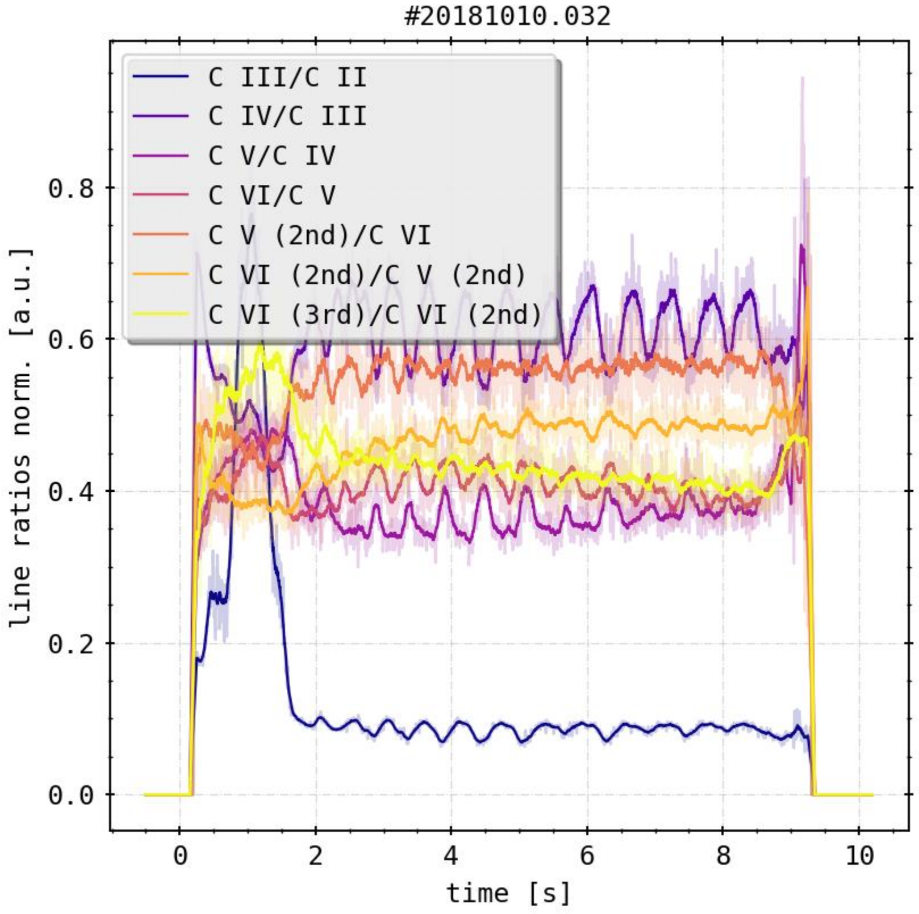
Appendix: Chordal Profiles



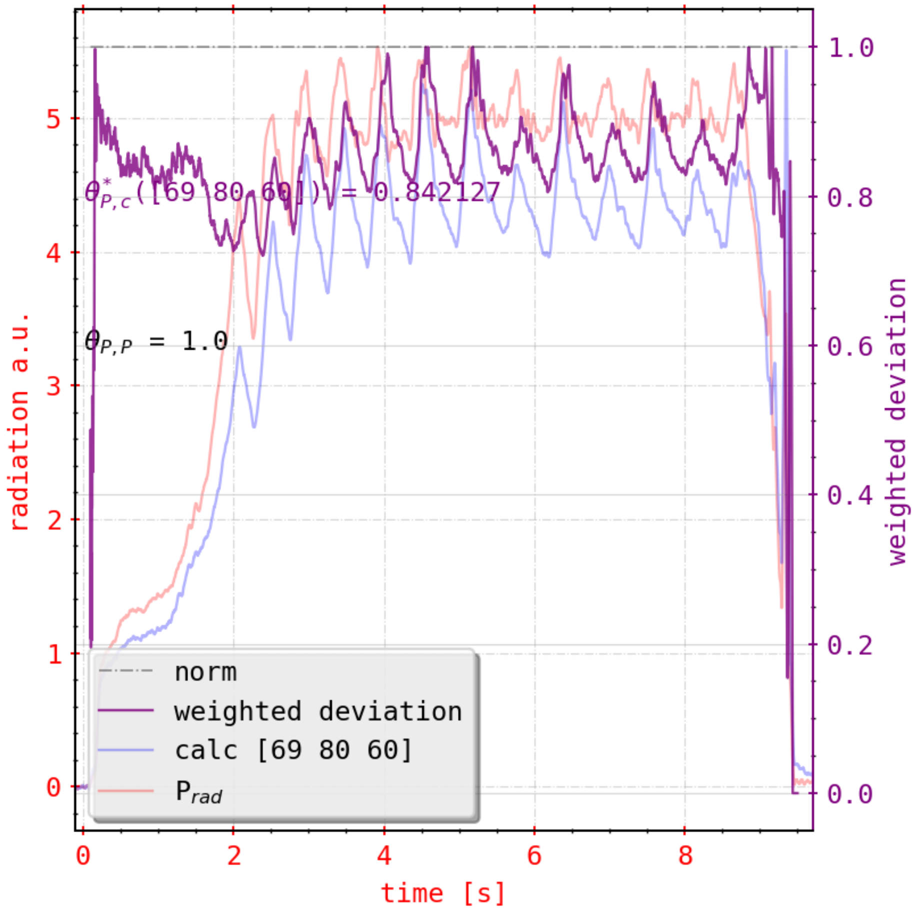


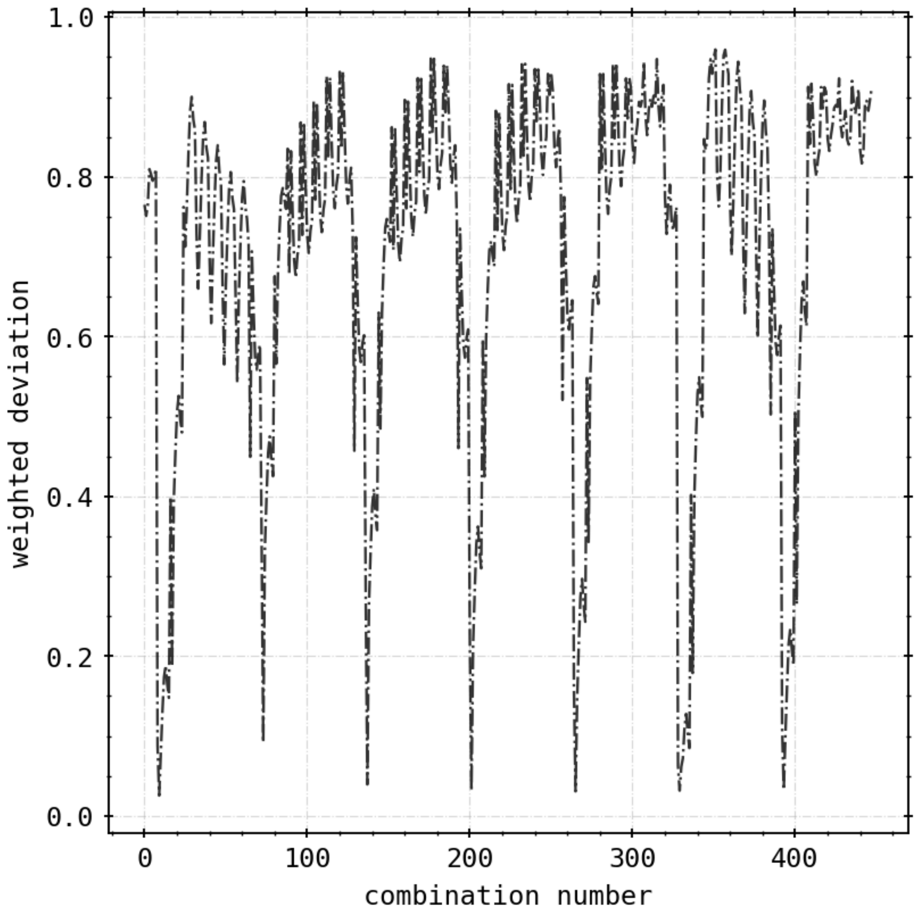
Appendix: HEXOS Lines



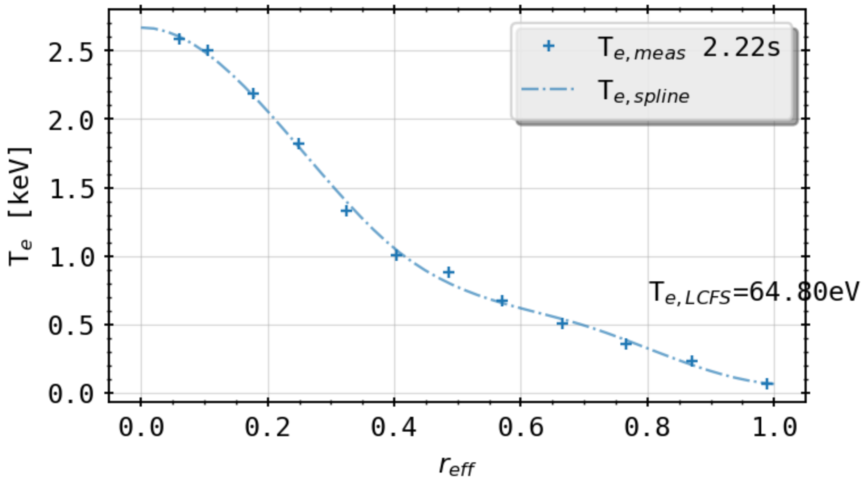


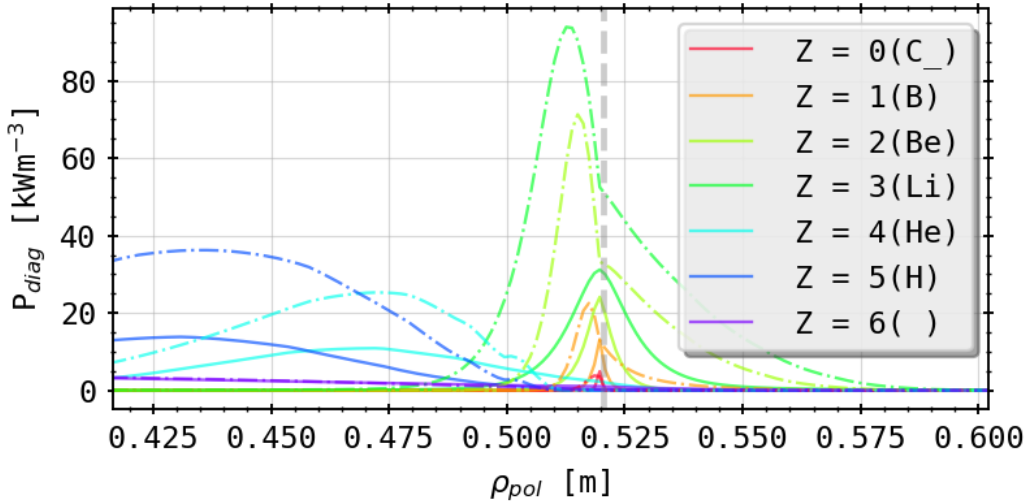
Appendix: Sensitivity Analysis

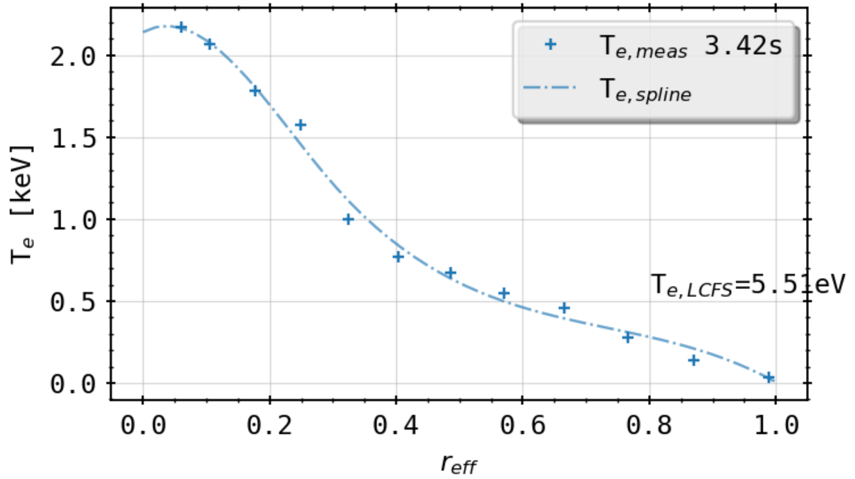


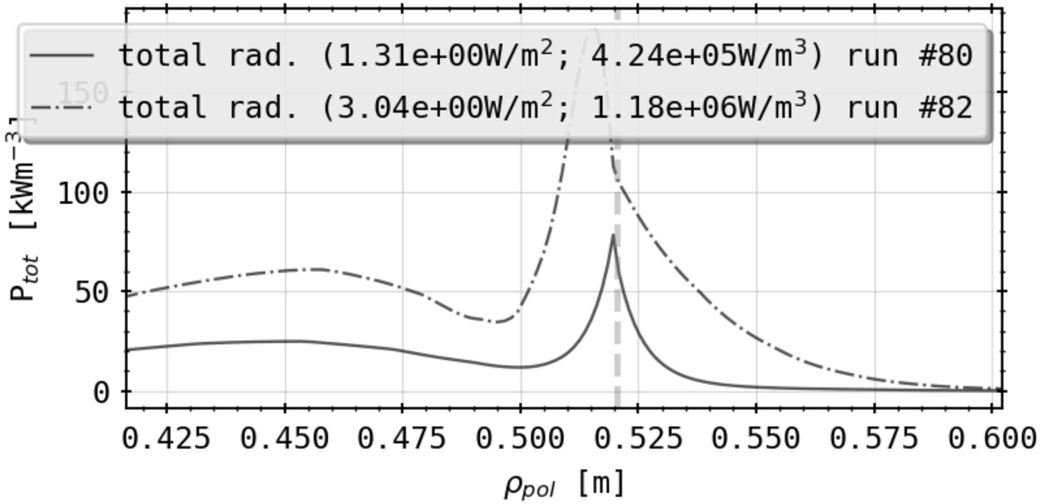


Appendix: 60% v 100%





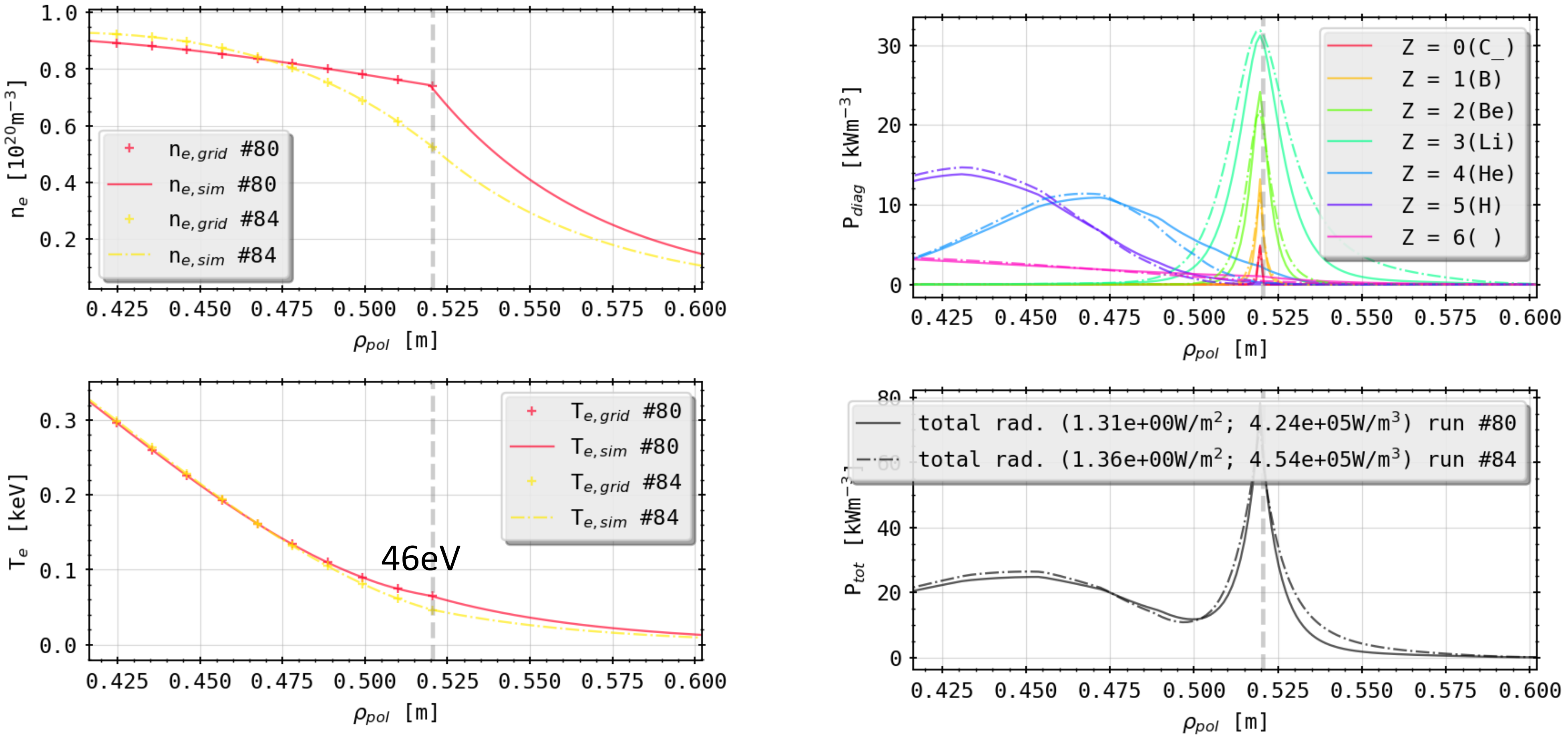




TS profiles (+) and STRAHL profiles for $f_{rad} = 0.6, 1.0$

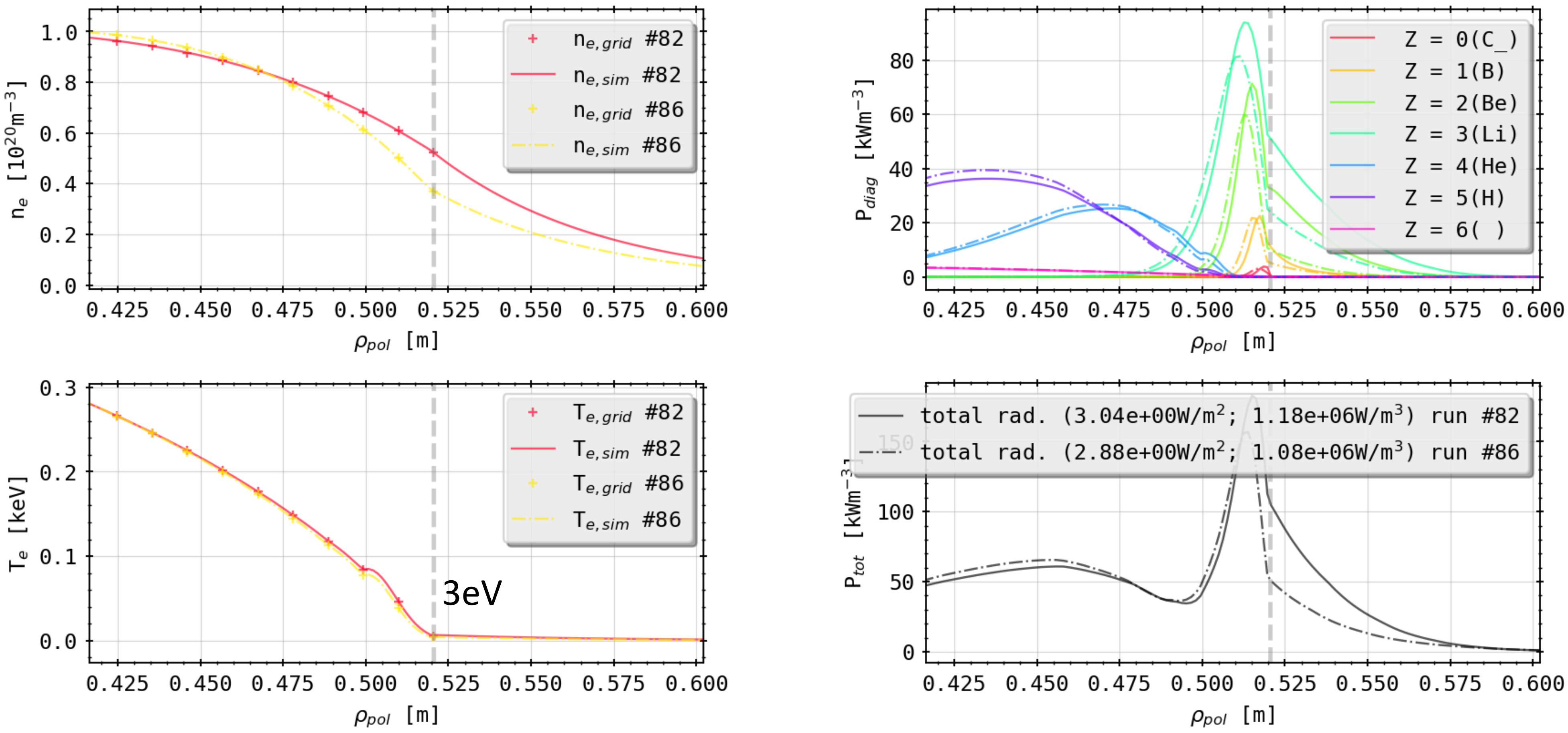
coronal equilib. line radiation profiles for $f_{rad} = 0.6, 1.0$

Appendix: 60% - 100% v 50% LCFS n/T



TS profiles last point scaled down, spline fit for continuity

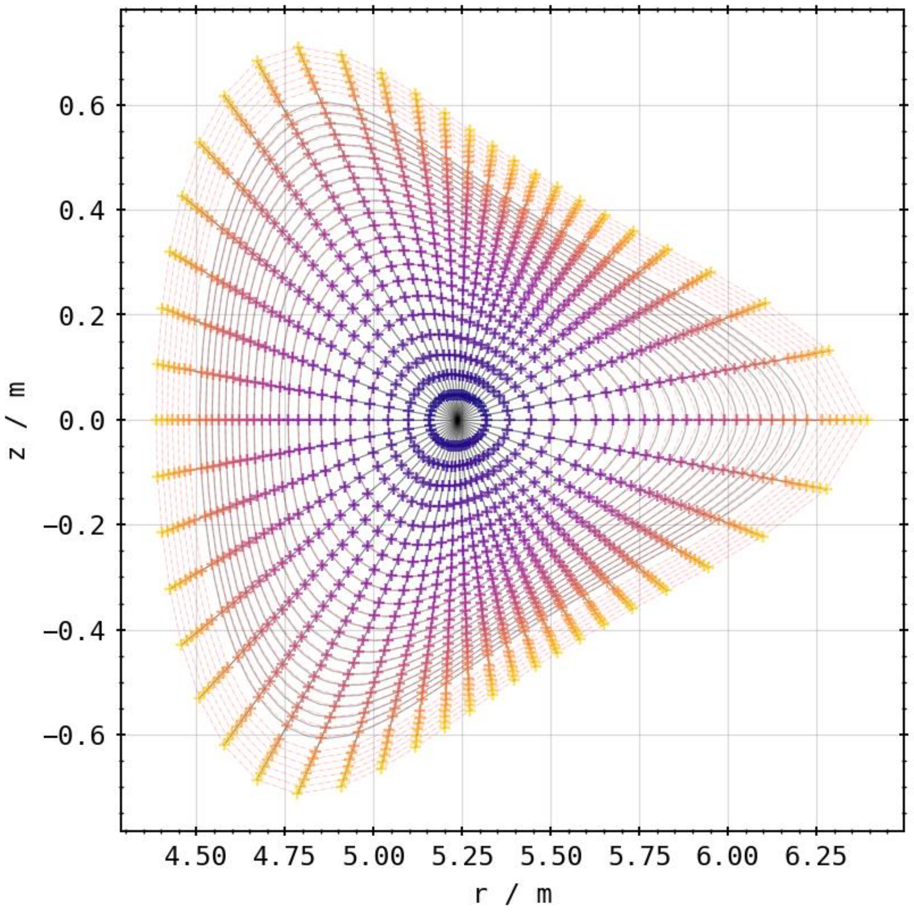
Appendix: 100% - 100% v 10% LCFS n/T



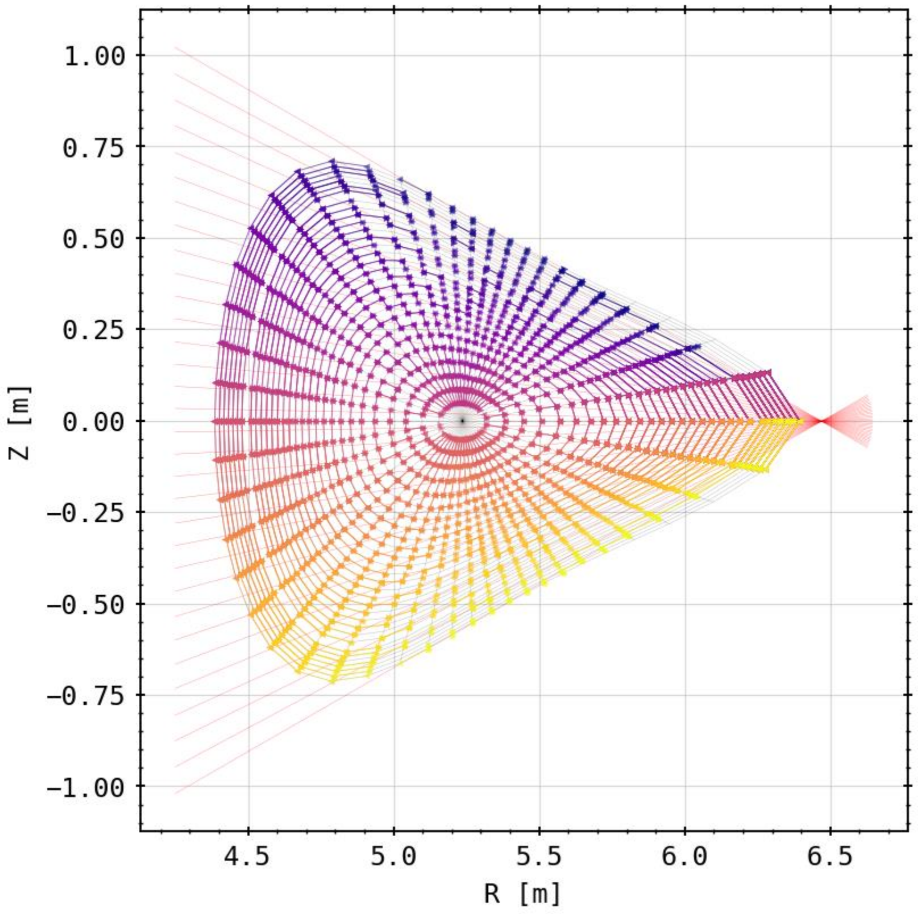
TS profiles last point scaled down, spline fit for continuity

Appendix: Emissivity Factors

mesh from EIM VMEC equilibrium
flusxurfaces with extended shells



line of sight cuts through mesh cells (HBCm)



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