

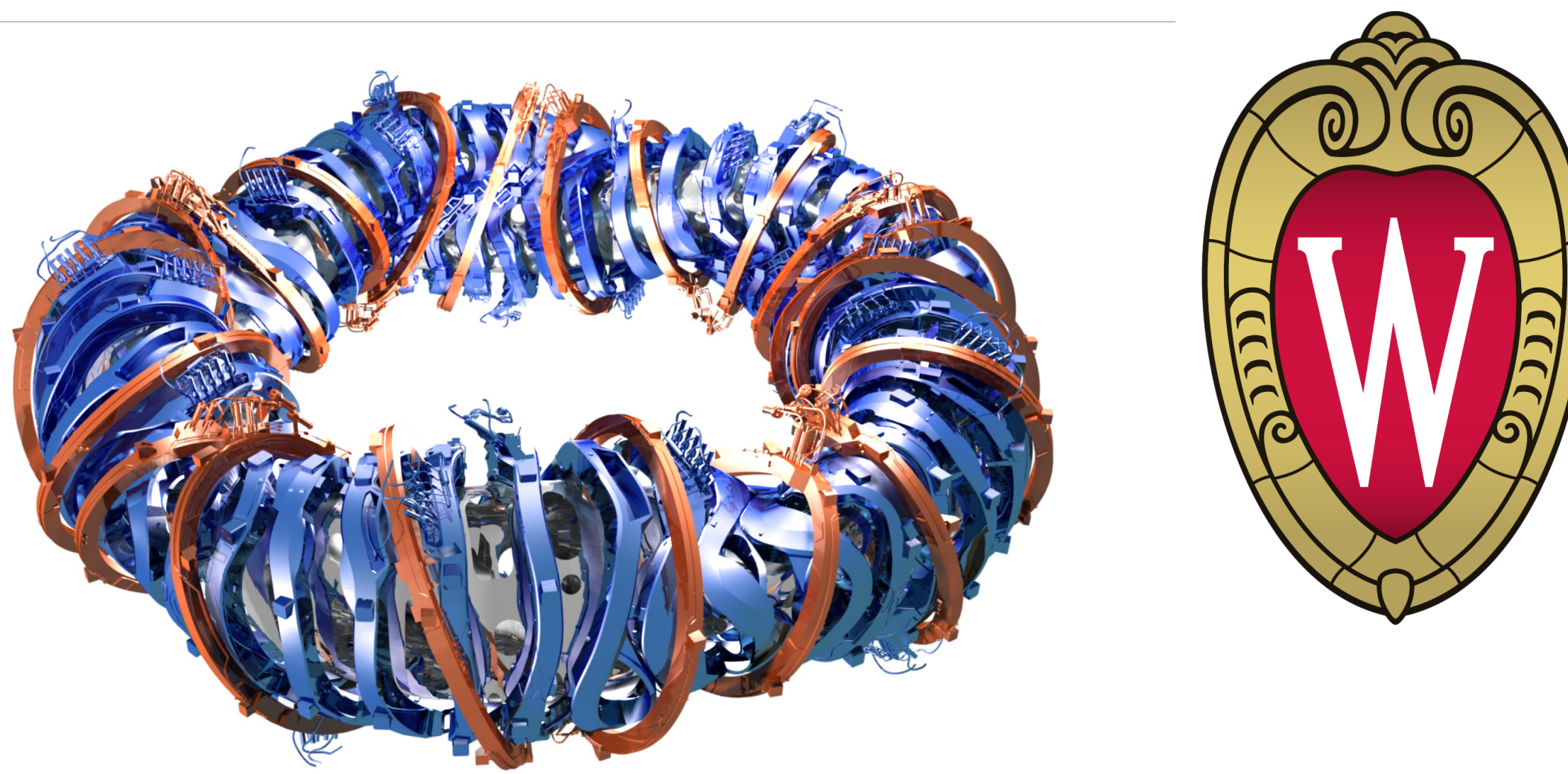
Investigation of impact of radiation cooling on startup plasmas at Wendelstein 7-X with EMC3-Eirene simulations

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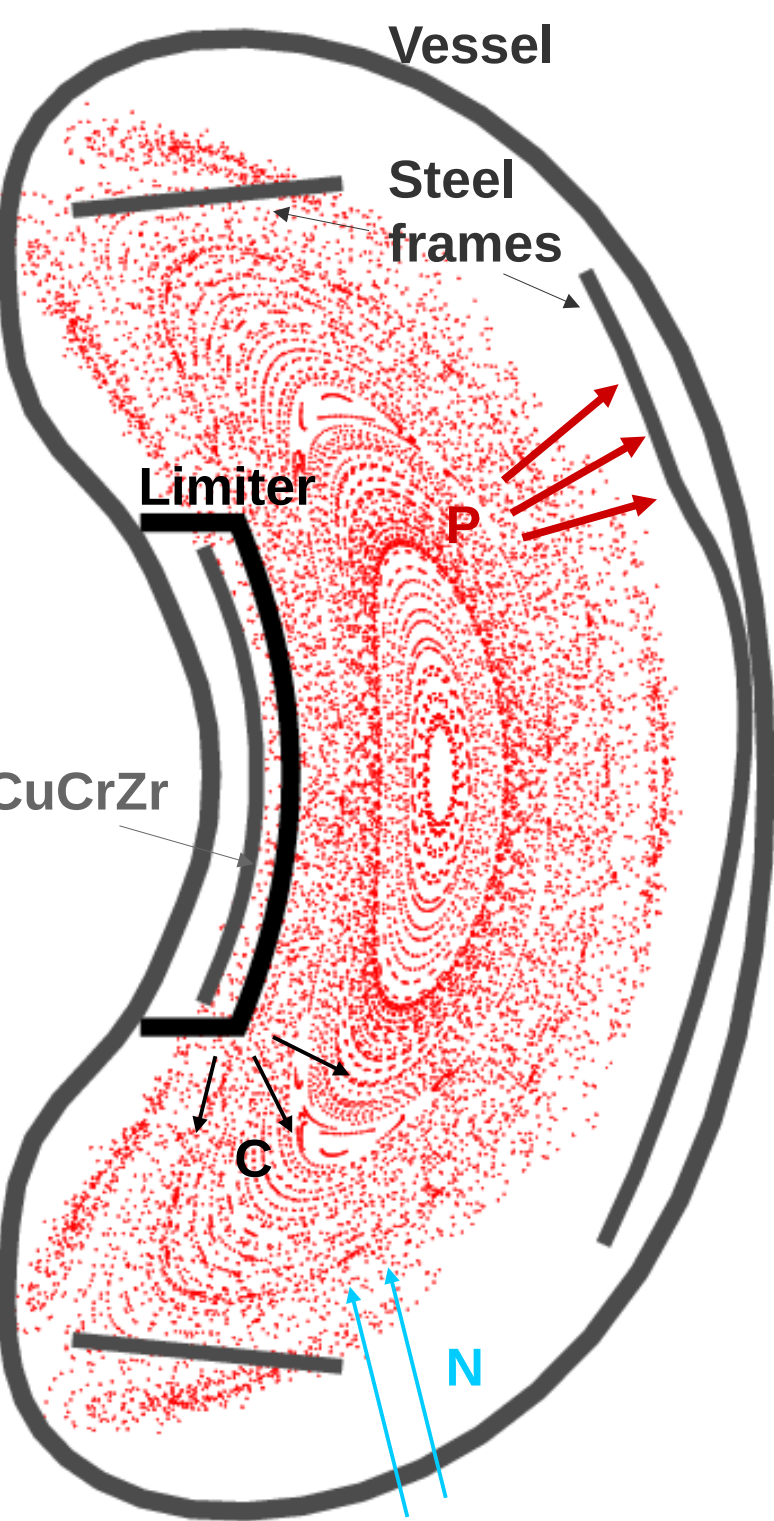
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Motivation: for limiter startup configuration of the optimized stellarator Wendelstein 7-X heat load reduction is crucial



Initial operation (OP1.1):

- 5 graphite limiters at bean shaped symmetry planes ($\varphi = 0^\circ$, tor. width: 0.1m, height: 0.85m)
- avoid damaging heat fluxes onto unprotected steel frames and CuCrZr structures (divertor targets and graphite shields not yet installed!)
- limiter is strong recycling and C impurity source
- n_e up to $9 \times 10^{19} \text{m}^{-3}$ @ $P_{\text{Heat}} = 0.5\text{--}2\text{MW}$ (possibly 4MW)

Goal: investigate impurity transport and radiation cooling feasibility of versatile gas inlet to guaranty safety and performance of first experiments

EMC3-Eirene: reliable tool to model plasma edge transport and plasma wall interaction

→ 3D plasma edge transport Monte-Carlo Code

→ Fluid model for electrons and ions (EMC3)

→ Kinetic model for neutrals (EIRENE)

→ Trace impurity model (energy balance)

$$S_e^{(\text{cool})} = \sum_{n=0}^{Z_{\text{max}}} P_{\text{rad},n} + \sum_{n=0}^{Z_{\text{max}}-1} E_n R_{n \rightarrow n+1}^{(\text{ion})}$$

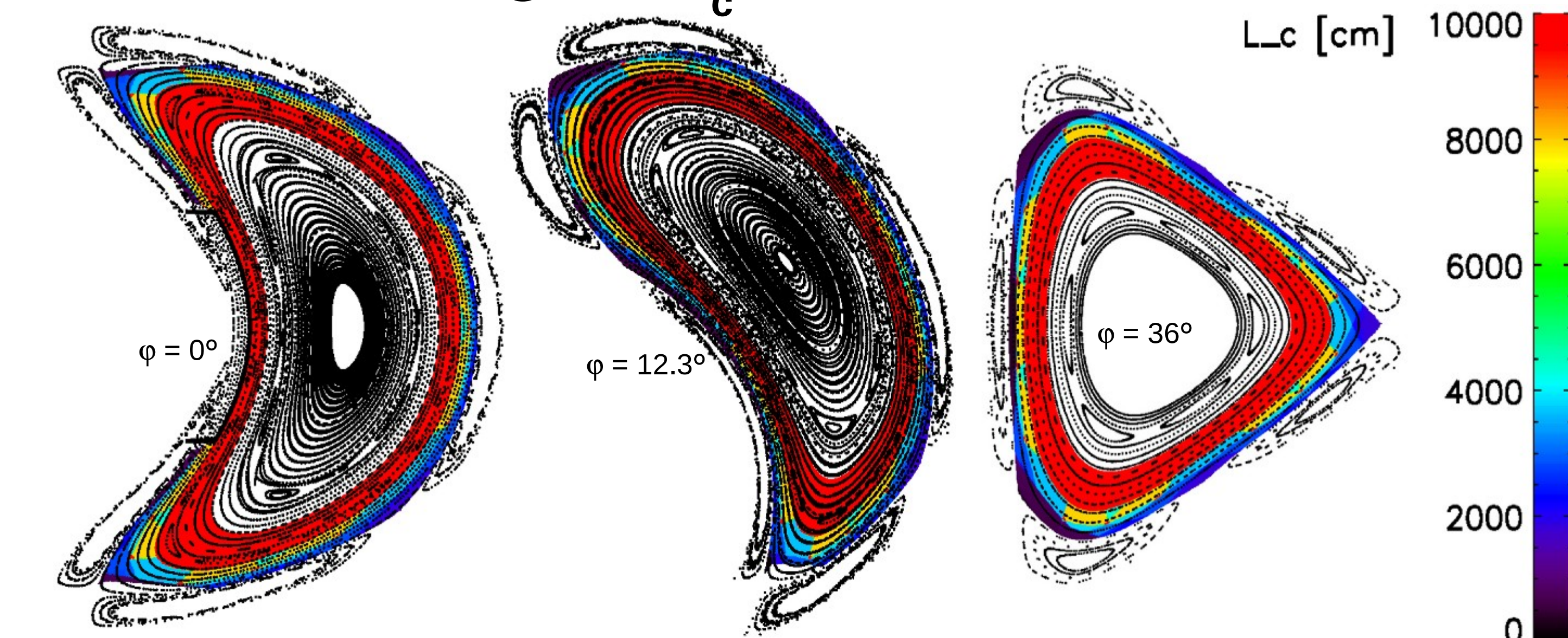
Main input parameter:

- Anomalous cross-field diffusion coefficient $D_{\perp}$
- Anomalous cross-field heat conductivity $\chi_{\perp,e,i}$
- Density @ inner boundary n_{in}
- heating power P_{heat}
- Chemical sputtering coefficient C_{sput}
- Gas injection current $I_{\text{impurities}}$

Main output:

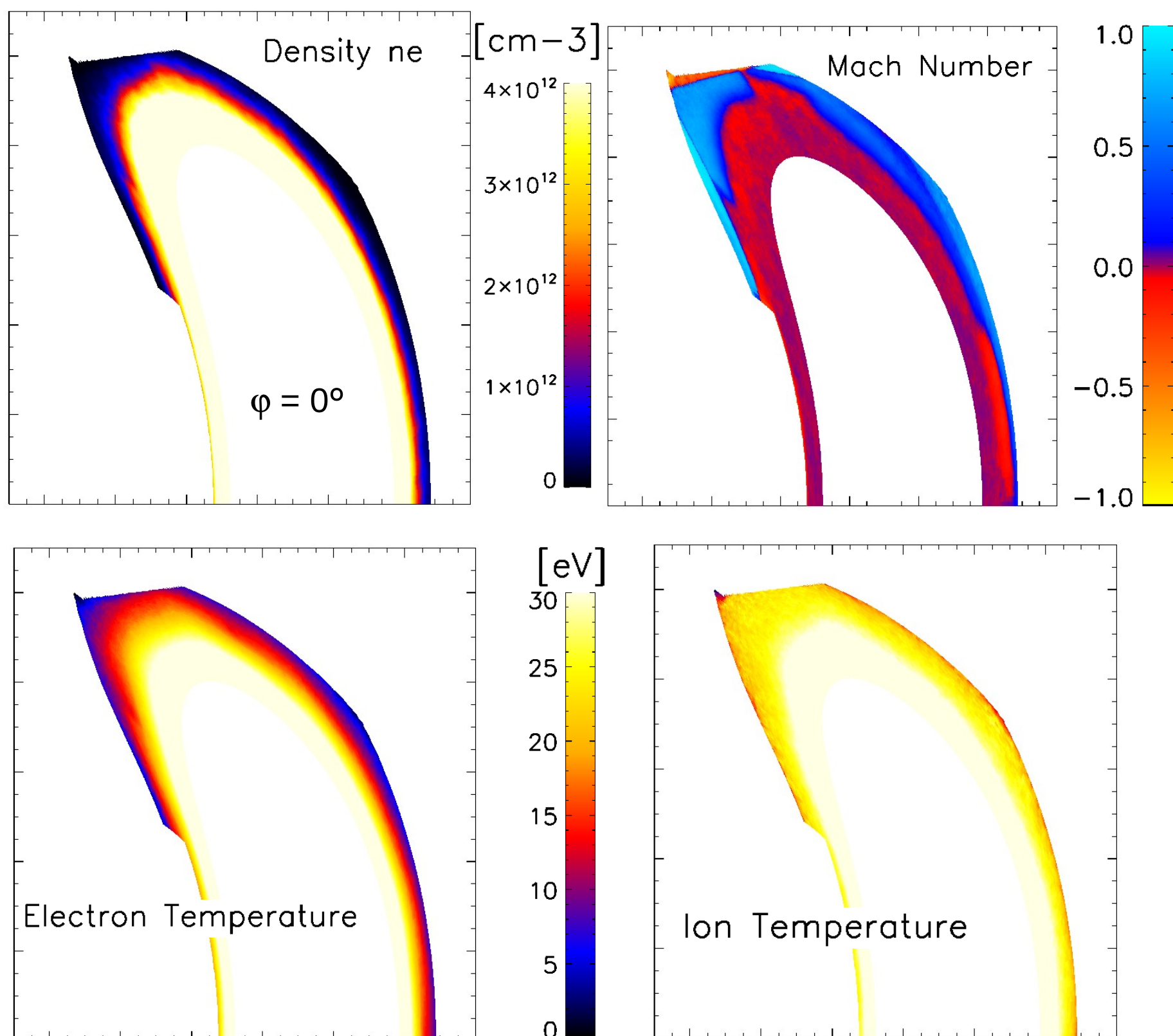
- Temperatures T_e, T_i
- Densities $n_e, n_{\text{imp}}, n_H, n_{H_2}$
- Velocity u_i
- Radiated power P_{imp}

Magnetic field configuration analysis shows non-isotropic edge topology with poloidally alternating connection lengths L_c



Poloidal modulation of target-to-target L_c by a factor of 2 (sharp switch between ~40m, 80m) corresponding to one and two toroidal revolutions (limiter screens only half of the edge per turn)

Plasma edge transport simulations with EMC3-Eirene: field topology causes poloidal alternating plasma profiles



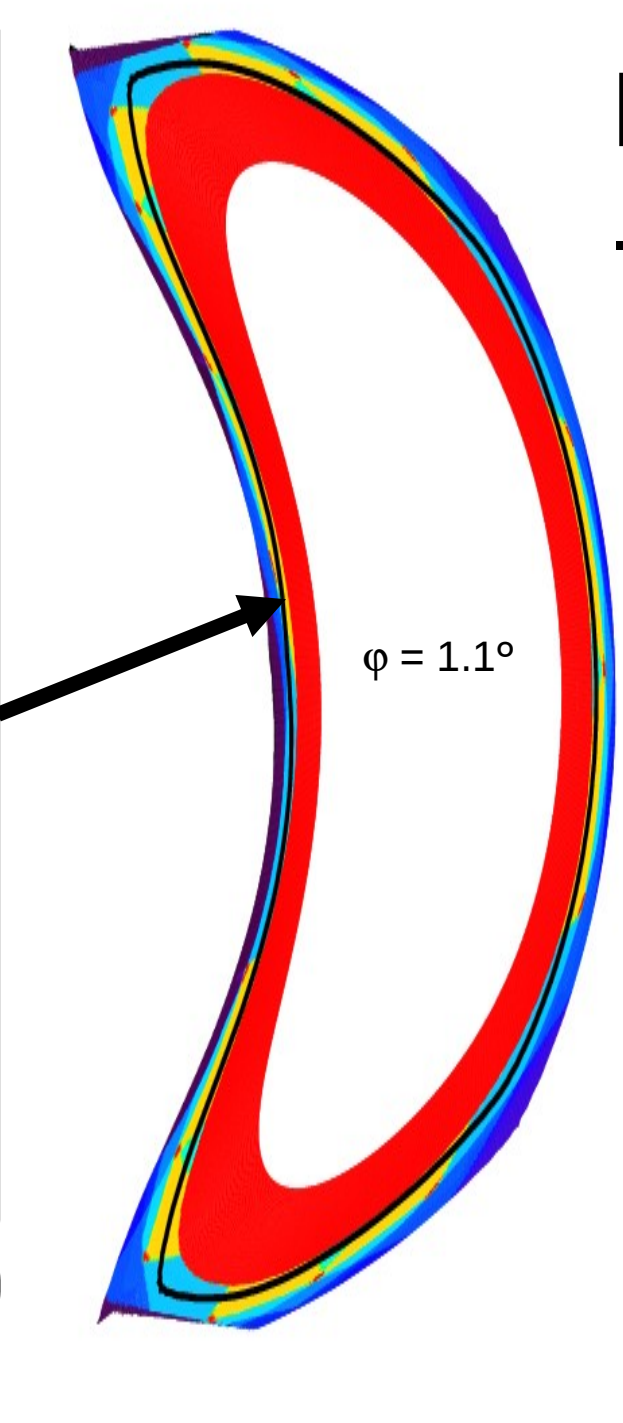
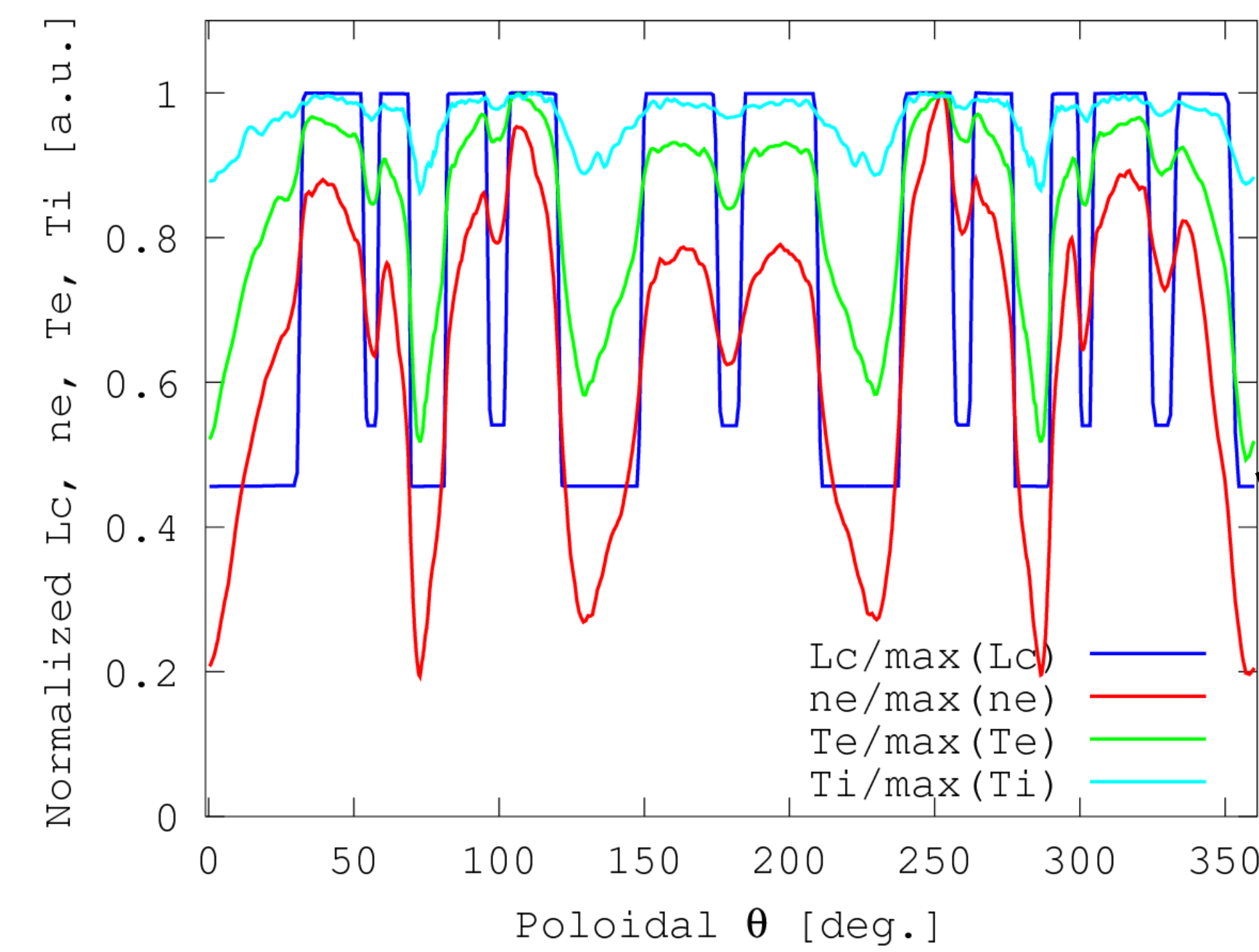
Modeling conditions:

- starting with low densities and heating Power: $3.6 \times 10^{18} \text{m}^{-3}$ @ $P_H = 0.5 \text{MW}$
- $D_{\perp} = 1 \text{m}^2/\text{s}$ and $\chi_{\perp,e,i} = 3 \text{m}^2/\text{s}$

Result:

- field topology strongly affects the plasma edge transport: density, temperature and flow profile show correspondent non-isotropic structure

Poloidal scan along vacuum SF in SOL shows modulation of plasma parameter with L_c



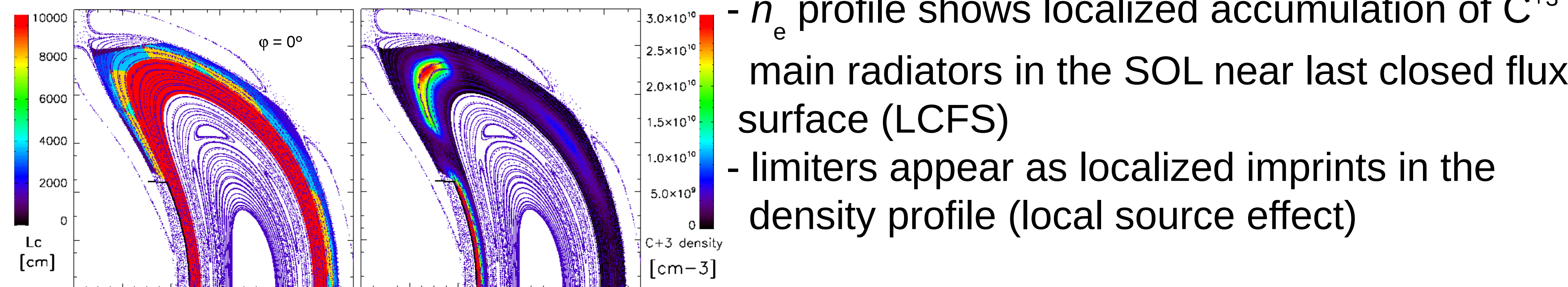
Result:

- a poloidal scan next to the limiter at $\varphi = 1.1^\circ$ along a flux surface through the scrape off layer shows modulation of plasma parameter with connection length L_c

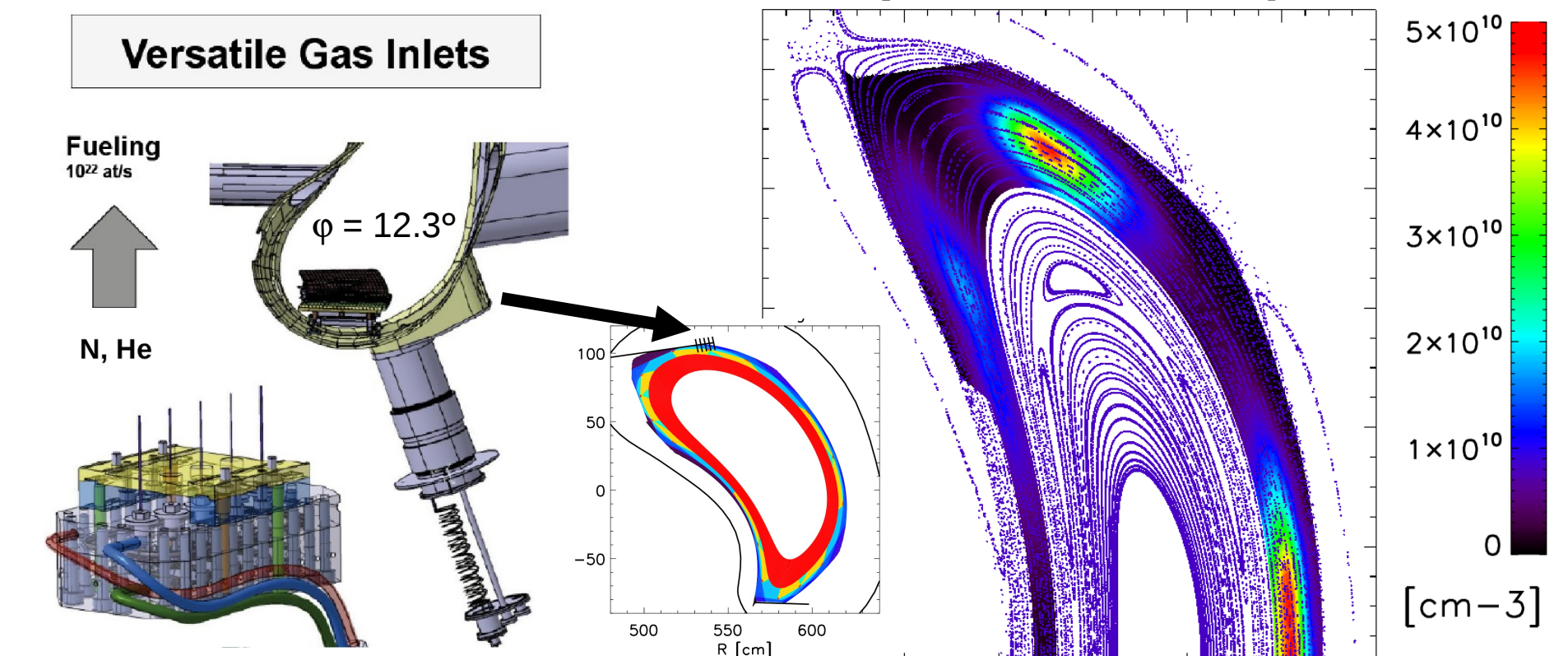
- SOL separated in helical flux channels with different parallel flow profiles
- modulation is a result of parallel losses due to fast parallel transport along field lines connecting to wall/target on different length scales

Impurity transport modeling: radiation cooling by N seeding more flexible and effective than intrinsic C

Carbon: modeled as intrinsic impurities from sputtering Yield $Y = 2\%$ of recycling flux Γ_{rec} with kinetic energy of 0.05eV

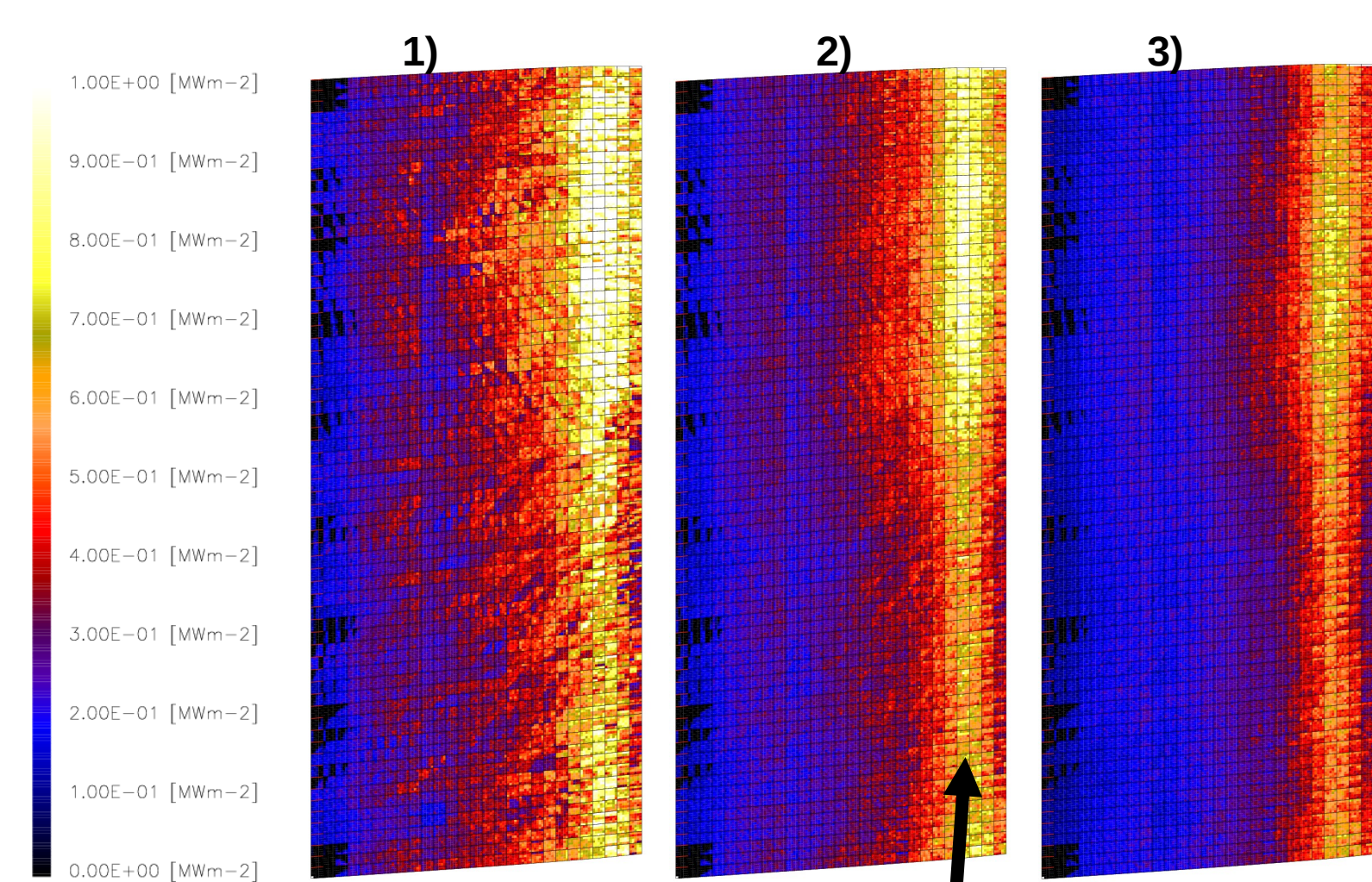


Nitrogen: modeled as local gas sources with particle fluxes of $I_N = 1\text{A}$ and kinetic energy of 0.05eV at 10 toroidal positions (each 5 inlet tubes at $\varphi = 12.3^\circ$)



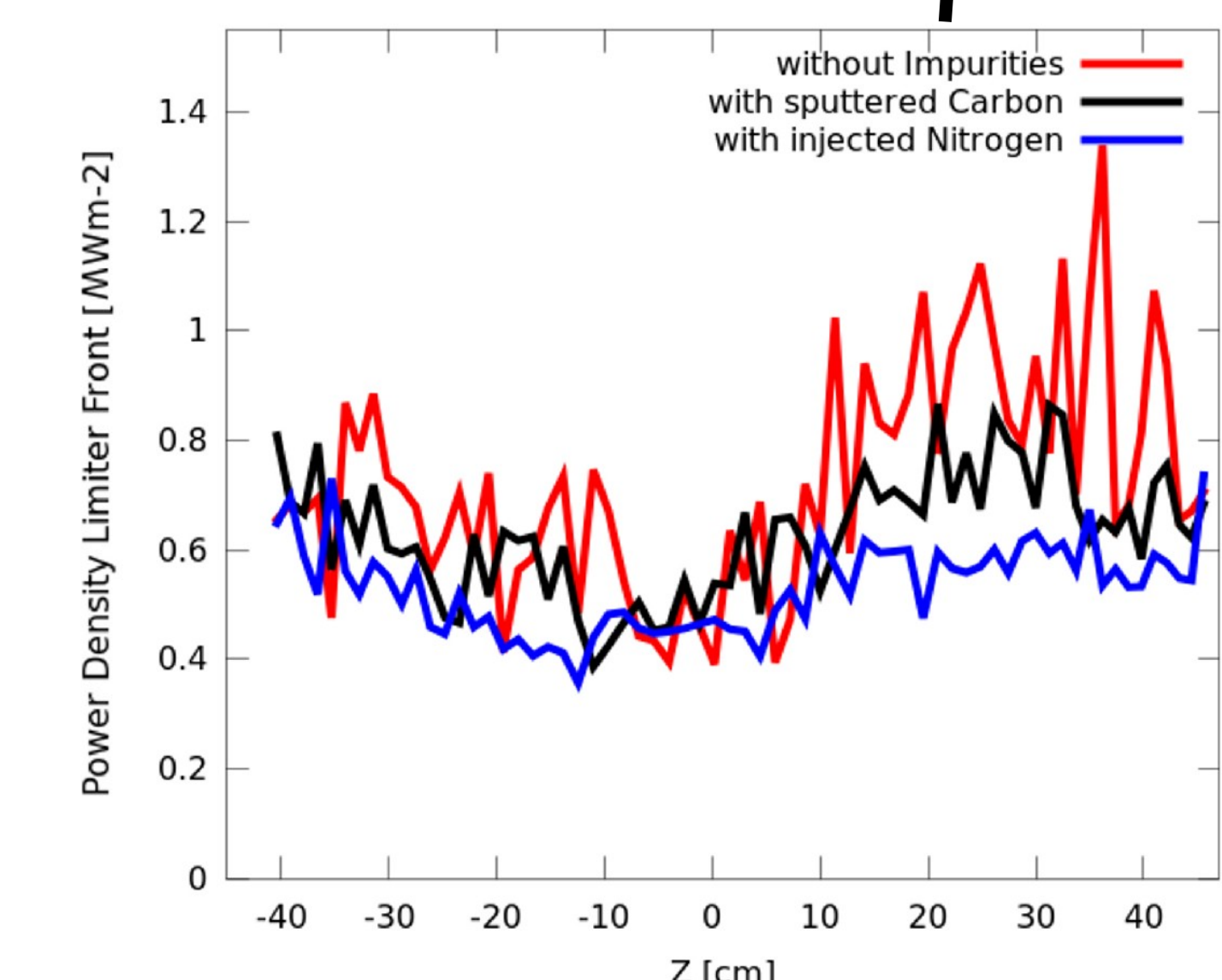
- neutral N injected into helical flux bundles
- localization of N^{+3} main radiators in the SOL near LCFS
- n_N and resulting radiation can set several times higher than in case of intrinsic impurities

Power load on limiter front reduced by 13% due to intrinsic C and 30% due to seeded N



Results:

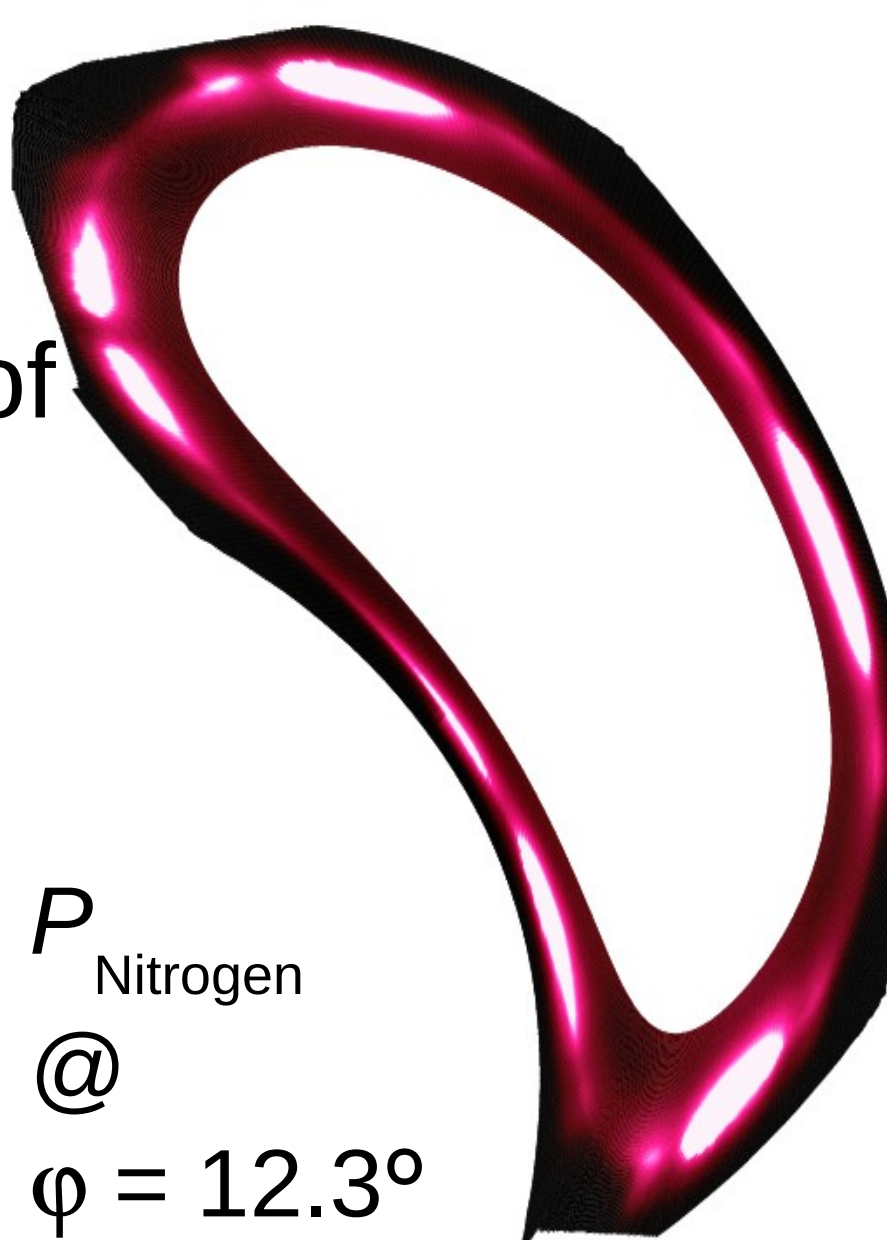
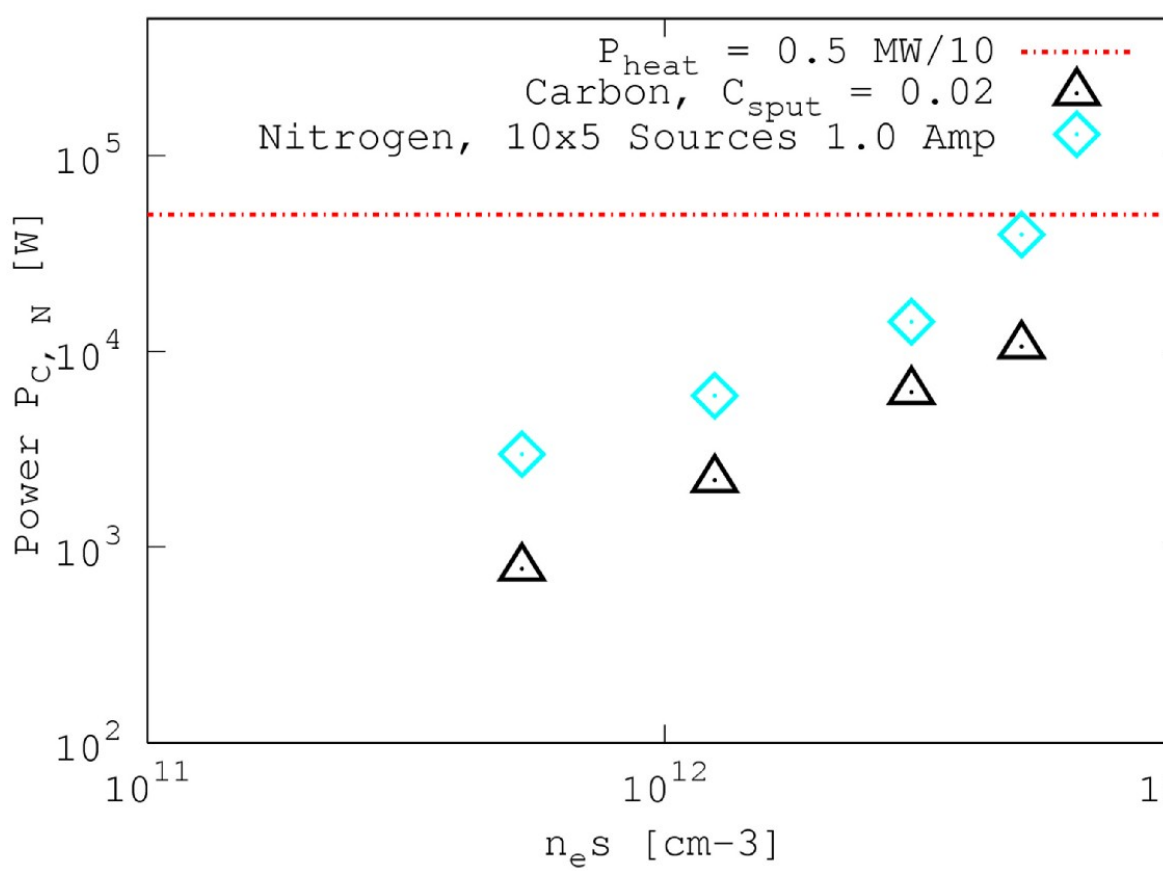
- power deposition onto $\frac{1}{2}$ limiter calculated with EMC3-Eirene for cases: **1)** clean plasma, **2)** intrinsic C and **3)** active injected N
- resulting deposition patterns on $\frac{1}{2}$ limiter reflect poloidal alternating structure (higher concentration in upper right corner)
- intrinsic C reduces the total power load by 13%, moderate N seeding allows for ~3x higher reduction



Scan in low density range predicts linear increasing of total impurity radiation

Results:

- integrated C and N radiation increases with rising density
- spots and localization of total N impurity radiation may need careful alignment of gas sources to obtain homogenous edge cooling and protect certain in-vessel components



Conclusion: power load reduction possible, but strong impact of helical flux bundle structure and localization of impurity radiation

- EMC3-Eirene results contribute to OP1.1 design of limiter scenario (and first physics program)
- homogenous egde cooling challenging due to field topology

- first tests show principle feasibility of power load reduction by impurity seeding

Next steps: ongoing simulations for redesigned field configuration and limiter

- investigate impurity transport and power load for density scans for up to 4MW
- consider and compare impurity transport and radiation cooling also for island divertor, test divertor (TDU) phase in OP1.2

