# TURBULENT PARTICLE TRANSPORT DRIVEN BY ION AND ELECTRON MODES

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## Introduction

The topic of this work is turbulent transport of main ions and impurities driven by ion (**ITG**) and electron modes (**TE** and electron scale **ETG**) in tokamaks. Regions relevant to the pedestal of H-mode plasmas (i.e. steep density gradients) are of particular interest. Using the code GENE [1–3], quasilinear (QL) and nonlinear (NL) gyrokinetic simulations are performed. Results are compared with a computationally efficient fluid model [4].

Transport is quantified by the density gradient of zero particle flux, related to the balance of convection and diffusion. This measure of the impurity peaking is calculated for ITG and TE mode turbulence, and conditions for zero main ion flux is investigated for ETG. Further, the quality of He ash removal is studied.

## Particle transport

Particle transport for species $j$ is derived from:

$$\Gamma_{nj} = \langle \delta n_j \boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}} \rangle, \tag{1}$$

where $\langle\cdot\rangle$ means a spatial averaging [5, 6].

This is divided into a **diffusive** and a **convective** part:

$$\Gamma_j = -D_j \nabla n_j + n_j V_j \tag{2}$$

where $\Gamma_j$ is the flux and $n_j$ the density of the species [5].

For the domain studied $\nabla n_j$ and $\nabla T_j$ are constant:

- $-\nabla n_j/n_j = 1/L_{n_j}$,
- $-\nabla T_j/T_j = 1/L_{T_j}$.

The flux can thus be written:

$$\frac{R\Gamma_j}{n_j} = D_j \frac{R}{L_{n_j}} + RV_j, \tag{3}$$

with $R$ the major radius.

In the core region convection (“pinch”) and diffusion balance to give zero flux. The **zero flux peaking factor** quantifies this:

$$0 = D_j \frac{R}{L_{n_j}} + RV_j \Leftrightarrow -\frac{RV_j}{D_j}\bigg|_{\Gamma_j=0} = \frac{R}{L_{n_j}}\bigg|_{\Gamma_j=0} \equiv PF_j \tag{4}$$

Thus $PF_j$ is interpeted as the **gradient of zero flux**.

For **trace impurities** $D_Z$ and $V_Z$ are independent of $\nabla n_Z$. *Eq.* (3) is then linear in $R/L_{n_Z}$, and $PF_Z$ can be found by fitting a straight line to flux data. This is illustrated in *Fig.* 1.

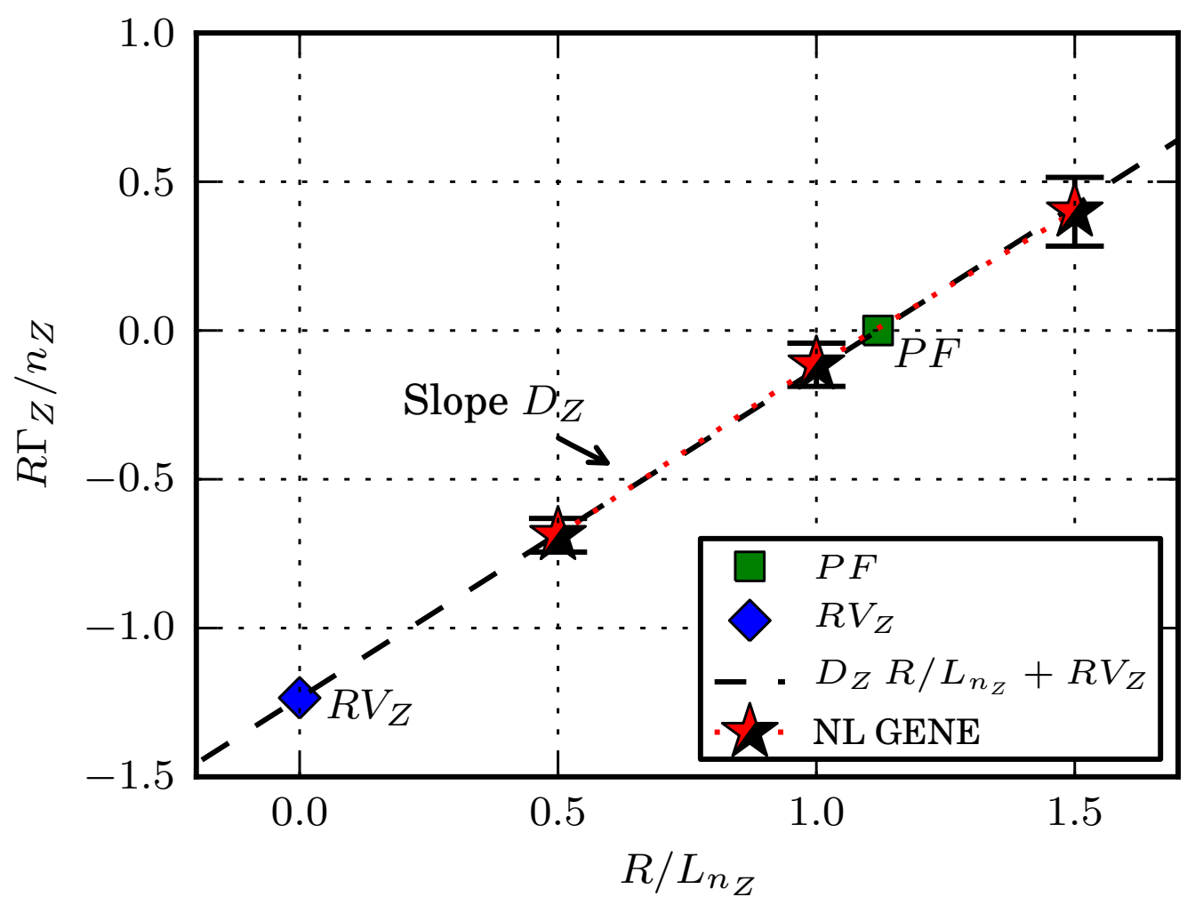

FIGURE 1: The **impurity flux dependence** on $\nabla n_Z$, illustrating $PF_Z$ and the validity of the linearity assumption (3) of *Eq.* (2) for trace impurities, and how the parameters of *Eq.* (3) are estimated. Data from NL GENE simulations.

In general, $D_j$ and $V_j$ may depend on $\nabla n_j$, and $PF_j$ has to be found explicitly from the zero flux condition.

## Results

**EFFECTS OF REALISTIC GEOMETRY ON ITG TURBULENCE:** Simulations of impurity transport using a realistic *JET*-like magnetic equilibrium were compared to s-$\alpha$-geometry for an **ITG** dominated discharge. Parameters were chosen to correspond closely to *JET L-mode discharge #67730*; see [6] for parameters.

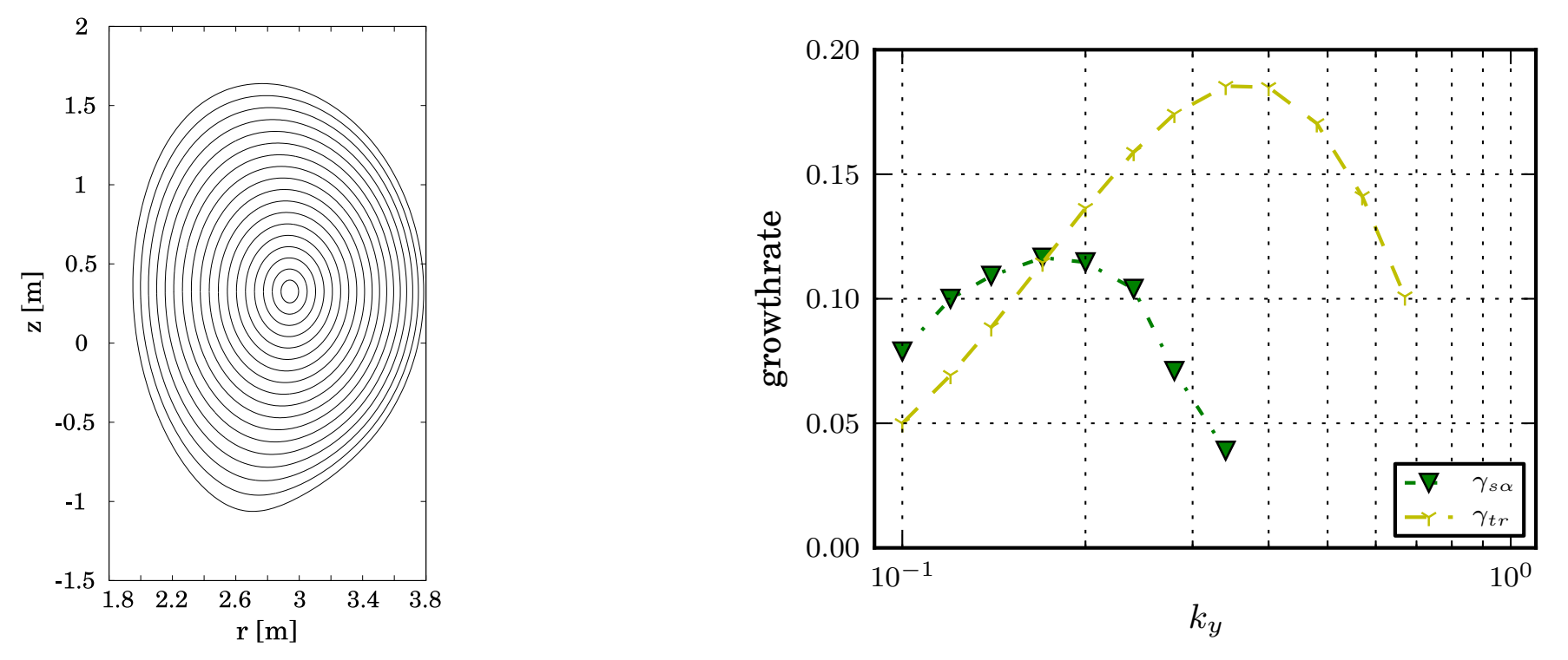

FIGURE 2: Realistic magnetic geometry *(left)* and the growthrate spectra for both geometries *(right)*

- with the realistic geometry the growthrate spectrum:
  - is destabilised
  - shifts to higher $k_\theta\rho_s$
- due to modified curvature and FLR effects
- consistent with fluid results in [7]

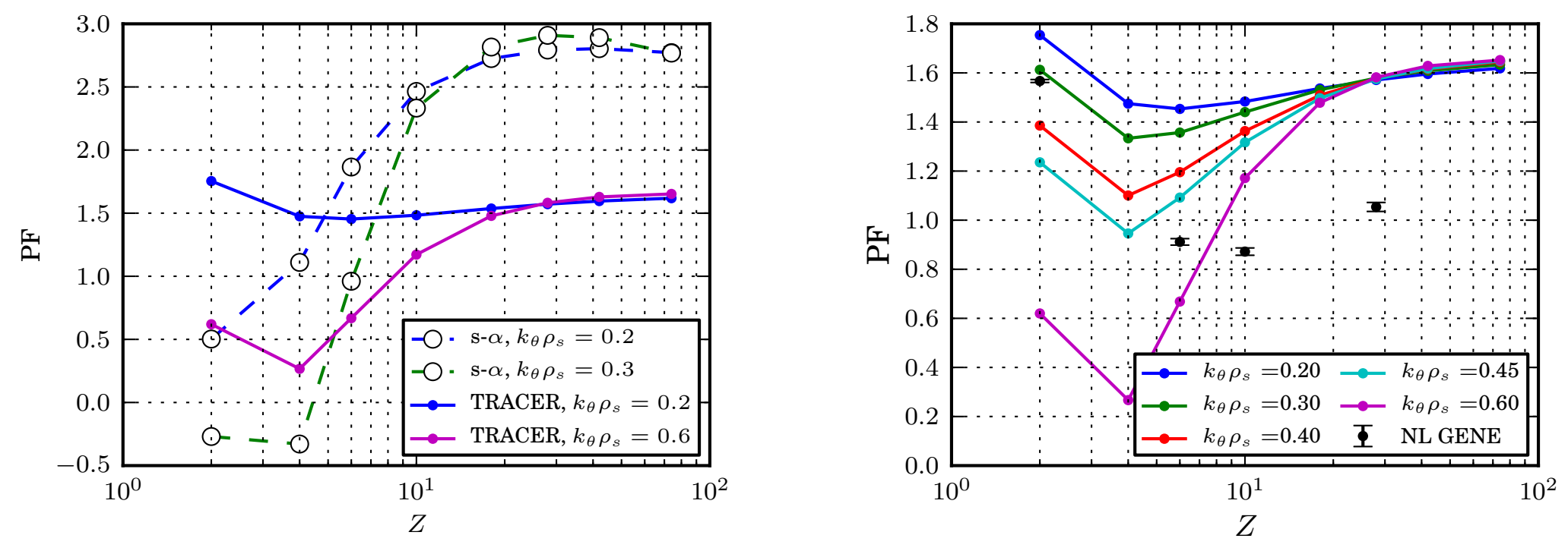

FIGURE 3: Scalings of $PF_Z$ with **impurity charge**, comparing the geometries *(left)*, and QL and NL results *(right)*

- reduction of $PF_Z$ for high $Z$ in realistic case
  - lower levels due to change in **curvature pinch**
- QL results over estimate $PF_Z$ for high $Z$
- change in sign of (outward) thermopinch for low $Z$: $\Rightarrow$ increase in $PF_Z$ for He impurity in realistic case
- NL and QL impurity pinch qualiatively agree with [6, 8]

**STEEP GRADIENTS IN TEM DOMINATED TURBULENCE:** Simulations were performed of steep gradients where **TE** mode turbulence dominates; see [9] for parameters.

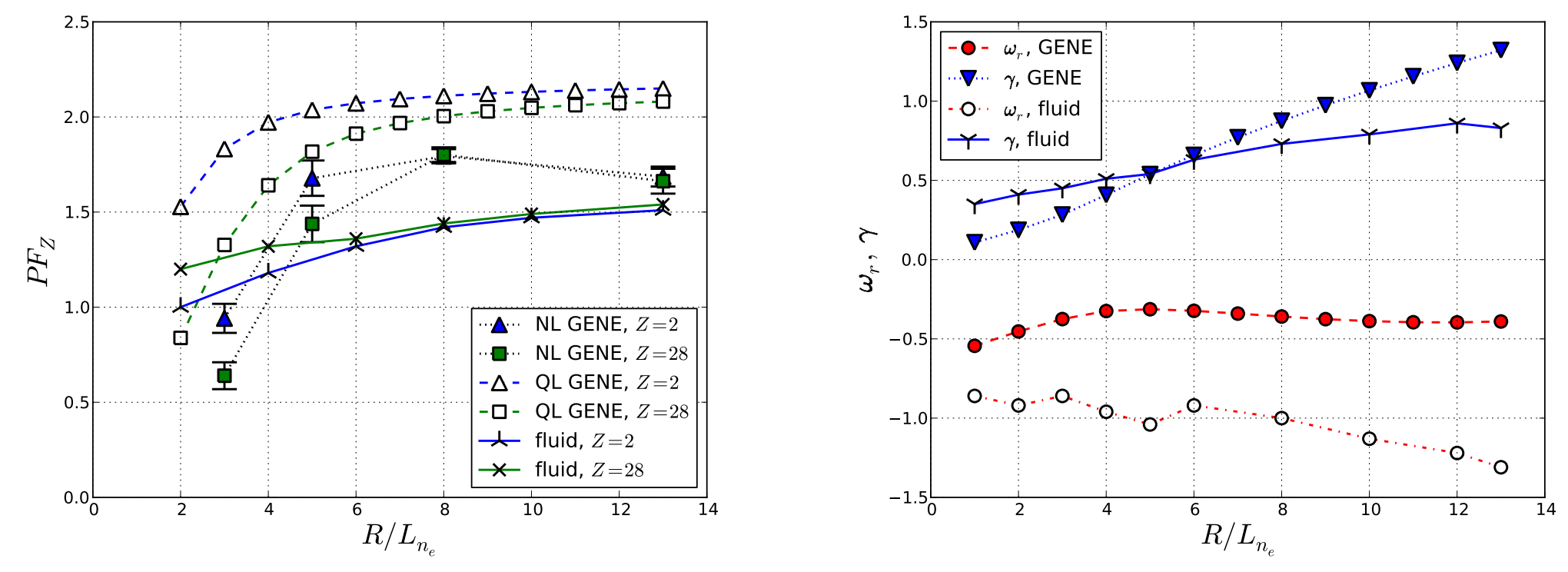

FIGURE 4: Scaling of $PF_Z$ with **electron density gradient** ($R/L_{n_e}$) shows saturation for peaked profiles, despite increased growthrate.

- NL and QL $PF_Z$ saturates at $\sim 2$ for steep gradients $\Rightarrow$ diffusion balanced by pinch
- in contrast, linear growthrate ($\gamma$) increases uniformly
- peaking of impurities is weaker than background gradient for $R/L_{n_e} \gtrsim 2$
- fluid and gyrokinetic results agree well

**HELIUM PUMP OUT:** Efficient removal of the He ash requires $\tau_E/\tau_{He} \geq 0.15$ [10]. This **confinement time ratio** can be estimated by $D_{He,eff}/\chi_{eff}$, where for $T_e = T_i$

$$\chi_{eff} = \frac{\chi_e R/L_{T_e} + \chi_i R/L_{T_i}}{R/L_{T_e} + R/L_{T_i}}. \tag{5}$$

For a simple comparison between ITG and TE cases an estimate of $D_{He}/\chi_{eff}$ is sufficient [8]. Results from NL GENE indicate that TE is at least as efficient as ITG mode turbulence at removing He ash for the parameters studied:

| | $\chi^{\dagger}_{eff}$: | $D^{\dagger}_{He}$: | $D_{He}/\chi_{eff}$: |
|---|---|---|---|
| ITG (s-$\alpha$) [6, 8]: | - | - | 1.0 |
| TE (s-$\alpha$) [8]: | - | - | 1.7 |
| ITG (TRACER): | 4.4 | 9.7 | 2.2 |

$^{\dagger}$: gyrobohm units

**ETG TURBULENCE IN BARRIERS:** For ETG modes focus is on the density gradient leading to zero main ion particle flux, related to the formation and sustainment of the edge pedestal. Parameters are chosen to correspond to barrier like parameters for *ASDEX Upgrade* [11], with

$$R/L_n = \frac{1}{2} R/L_{T_e} = \frac{2}{3} R/L_{T_i} \tag{6}$$

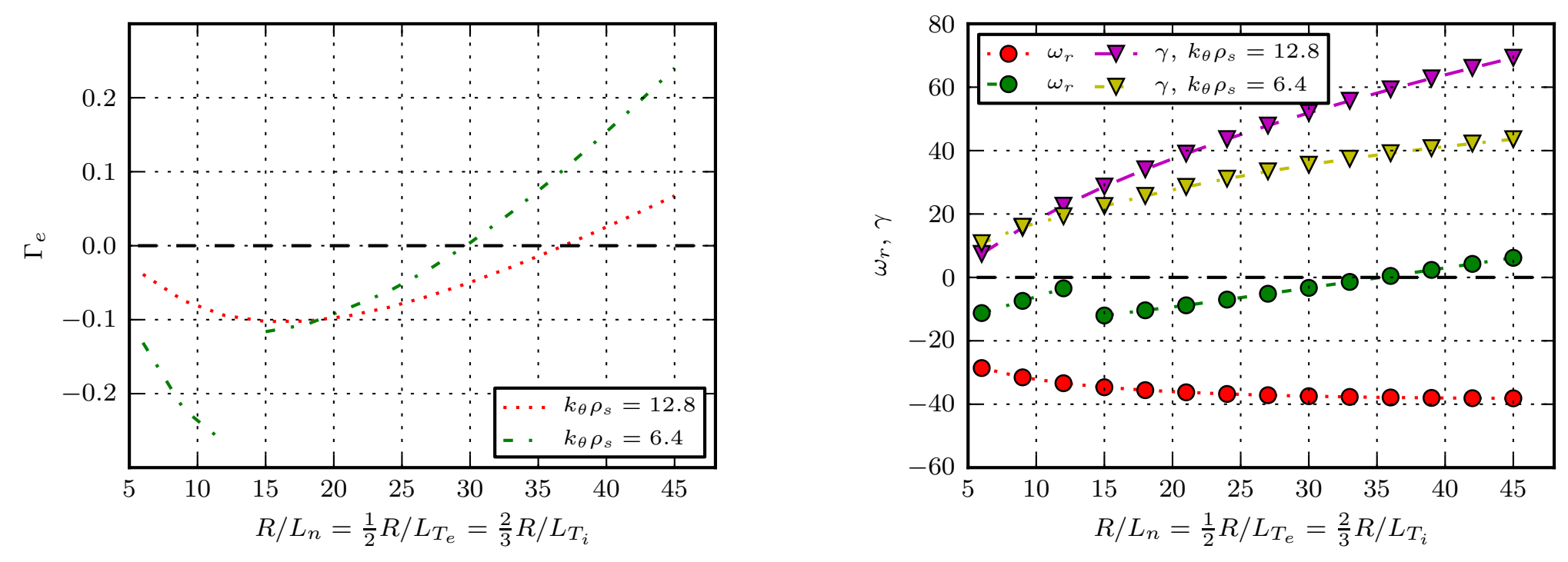

FIGURE 5: Scaling of main ion particle flux *(left)* and linear eigenvalues *(right)* with gradients as in *Eq.* (6)

- zero flux observed at very steep gradients
  - in line with fluid results in **I1.103** *(R. Singh)*
- for ETG fluctuation and transport level estimates see: **P2.061** *(J. Anderson)* and **I1.103** *(R. Singh)*

## References

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The simulations were performed on resources provided on the Lindgren [12] and HPC-FF [13] high performance computers, by the Swedish National Infrastructure for Computing (SNIC) at Paralleldatorcentrum (PDC) and the European Fusion Development Agreement (EFDA), respectively.

this poster kills fascists!

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