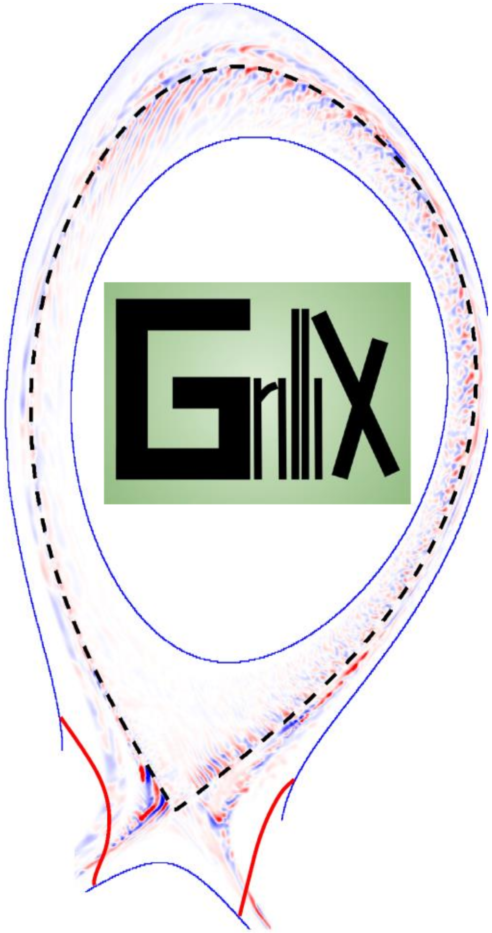

# The role of neutral gas in validated global edge turbulence simulations

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

MAX PLANCK GESELLSCHAFT

EUROfusion

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# Global drift-reduced Braginskii with diffusive neutrals

plasma density

$$\frac{d}{dt}n = nC(\varphi) - C(p_e) + \nabla\cdot\left[\left(j_\parallel - nu_\parallel\right)\mathbf{b}\right] + \mathscr{D}_n(n) + k_{iz}nN + S_n,$$

quasineutrality / vorticity

$$\nabla\cdot\left[\frac{n}{B^2}\left(\frac{\partial}{\partial t} + \delta_0\left(\frac{\mathbf{B}}{B^2}\times\nabla_\perp\varphi\right)\cdot\nabla_\perp + Nk_{iz} + Nk_{cx} + u_\parallel\nabla_\parallel\right)\left(\nabla_\perp\varphi + \zeta\frac{\nabla_\perp p_i}{n}\right)\right] =$$
$$-C(p_e+\zeta p_i) + \nabla\cdot(j_\parallel\mathbf{b}) - \frac{\zeta}{6}C(G) + \mathscr{D}_\Omega(\Omega),$$

momentum

$$\left(\frac{d}{dt} + u_\parallel\nabla_\parallel\right)u_\parallel = -\frac{\nabla_\parallel(p_e+\zeta p_i)}{n} + \zeta T_i C(u_\parallel) - \frac{2}{3}\zeta\frac{B^{3/2}}{n}\nabla_\parallel\frac{G}{B^{3/2}} + \mathscr{D}_u(u_\parallel),$$

Ohm & Ampère

$$\beta_0\frac{\partial}{\partial t}A_\parallel + \mu\left(\frac{d}{dt} + v_\parallel\nabla_\parallel\right)\frac{j_\parallel}{n} = -\left(\frac{\eta_{\parallel 0}}{T_e^{3/2}}\right)j_\parallel - \nabla_\parallel\varphi + \frac{\nabla_\parallel p_e}{n} + 0.71\nabla_\parallel T_e + \mathscr{D}_\Psi(\Psi_m), \qquad \nabla_\perp^2 A_\parallel = -j_\parallel,$$

electron heat

$$\frac{3}{2}\left(\frac{d}{dt} + v_\parallel\nabla_\parallel\right)T_e = T_eC(\varphi) - \frac{T_e}{n}C(p_e) - \frac{5}{2}T_eC(T_e) - T_e\nabla\cdot(v_\parallel\mathbf{b}) + 0.71\frac{T_e}{n}\nabla\cdot(j_\parallel\mathbf{b})$$
$$+\frac{1}{n}\nabla\cdot\left[\left(\chi_{\parallel e0}T_e^{5/2}\right)\mathbf{b}\nabla_\parallel T_e\right] - 2\nu_{e0}\mu\left(\frac{n}{T_e^{3/2}}\right)(T_e - \zeta T_i) + \left(\frac{\eta_{\parallel 0}}{T_e^{3/2}}\right)\frac{j_\parallel^2}{n} + \frac{3}{2}\left(\mathscr{D}_{T_e}(T_e) + S_{T_e}\right),$$
$$S_{T_e} = -\frac{2}{3}\left(W_{iz}N + W_{rec}n\right) - \left(k_{iz}N - k_{rec}n\right)T_e$$

ion heat

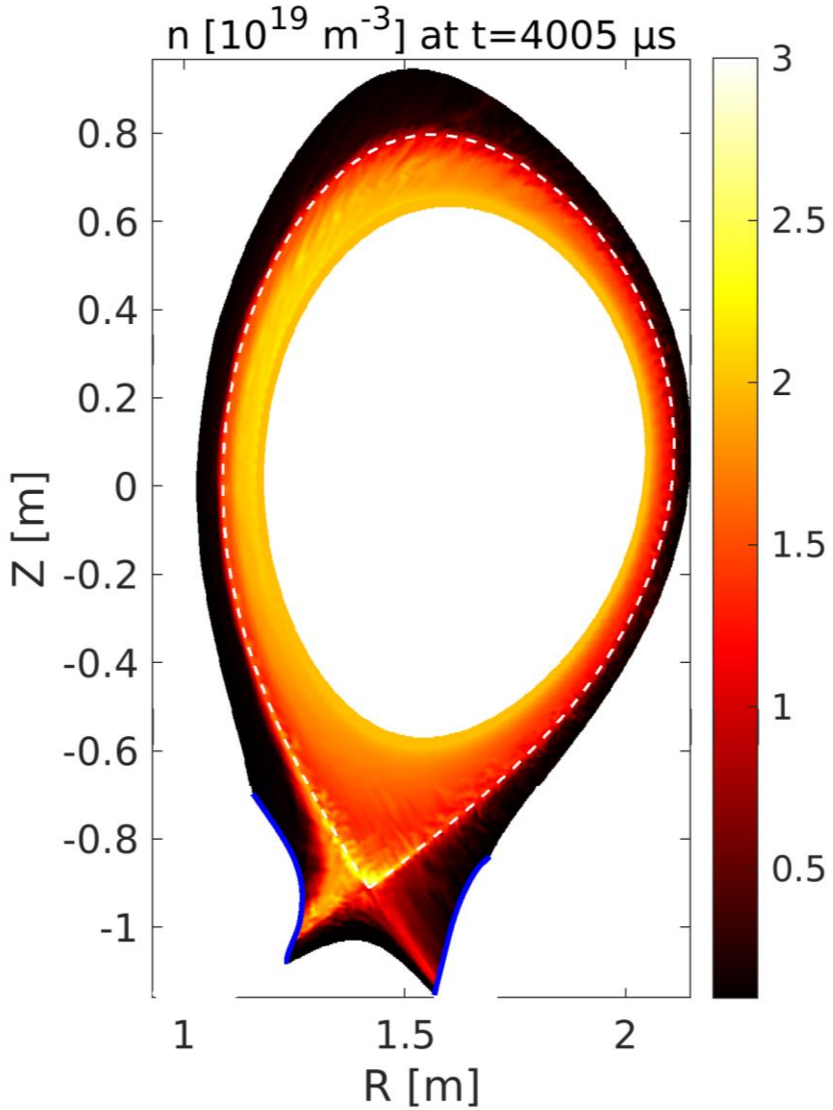
$$\frac{3}{2}\left(\frac{d}{dt} + u_\parallel\nabla_\parallel\right)T_i = T_iC(\varphi) - \frac{T_i}{n}C(p_e) + \frac{5}{2}\zeta T_iC(T_i) - T_i\nabla\cdot(u_\parallel\mathbf{b}) + \frac{T_i}{n}\nabla\cdot(j_\parallel\mathbf{b})$$
$$+\frac{1}{n}\nabla\cdot\left[\left(\chi_{\parallel i0}T_i^{5/2}\right)\mathbf{b}\nabla_\parallel T_i\right] + 2\nu_{e0}\mu\left(\frac{n}{T_e^{3/2}}\right)\left(\frac{1}{\zeta}T_e - T_i\right) + \frac{2w_{GTi}}{9\eta_{i0}}\frac{G^2}{nT_i^{5/2}} + \frac{3}{2}\left(\mathscr{D}_{T_i}(T_i) + S_{T_i}\right),$$

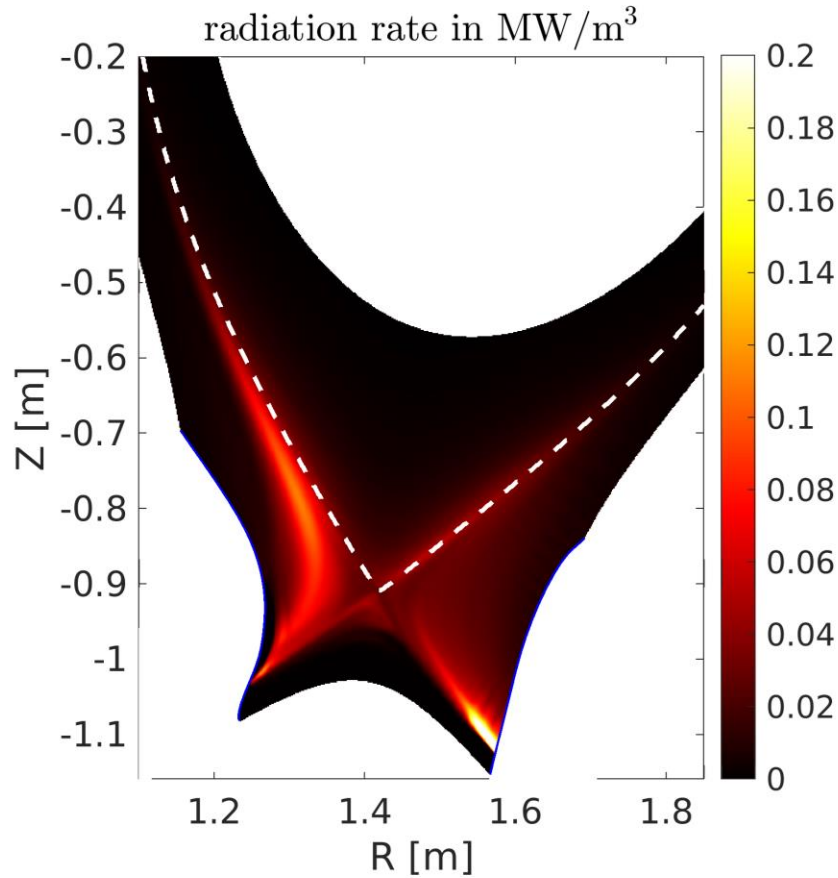
neutral particles

$$\frac{\partial}{\partial t}N = \nabla\cdot\frac{\zeta\nabla NT_i}{nk_{cx}} - k_{iz}nN,$$

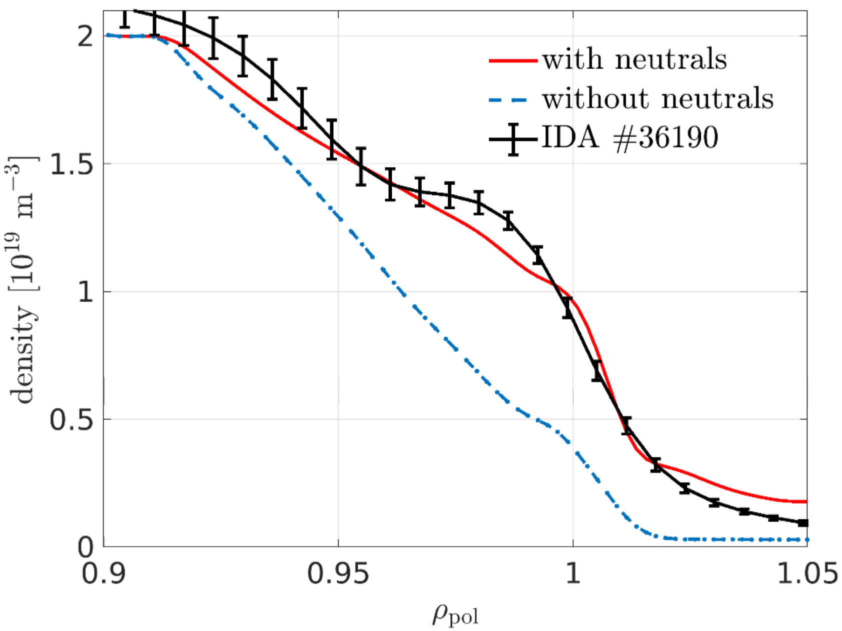
$N$ fixed at the divertor.

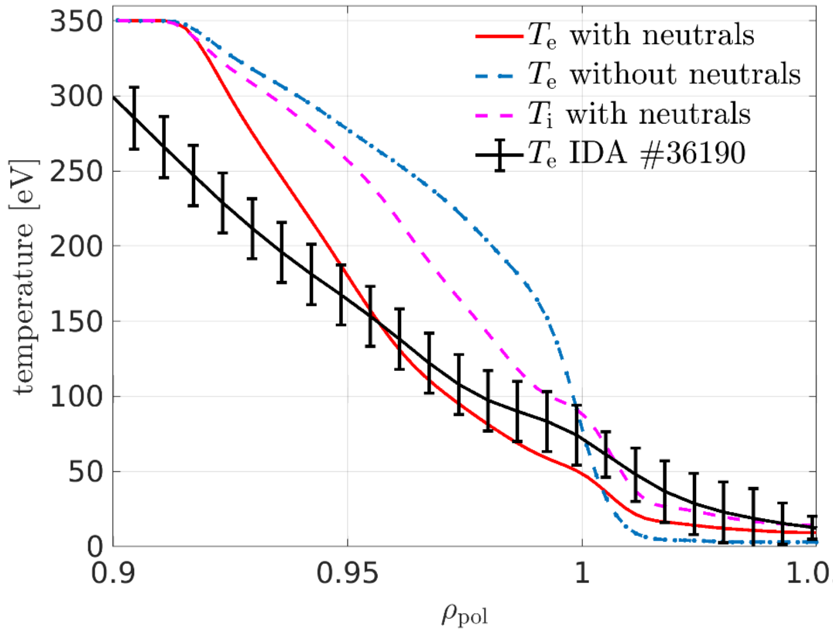
# Ionization source and poloidal asymmetry



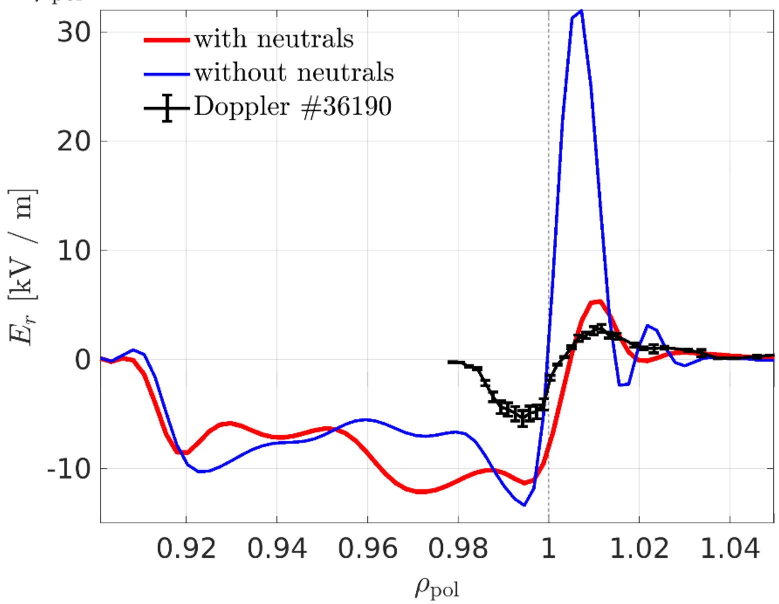



# Validation against attached AUG L-mode (#36190)




**outboard mid-plane profiles**

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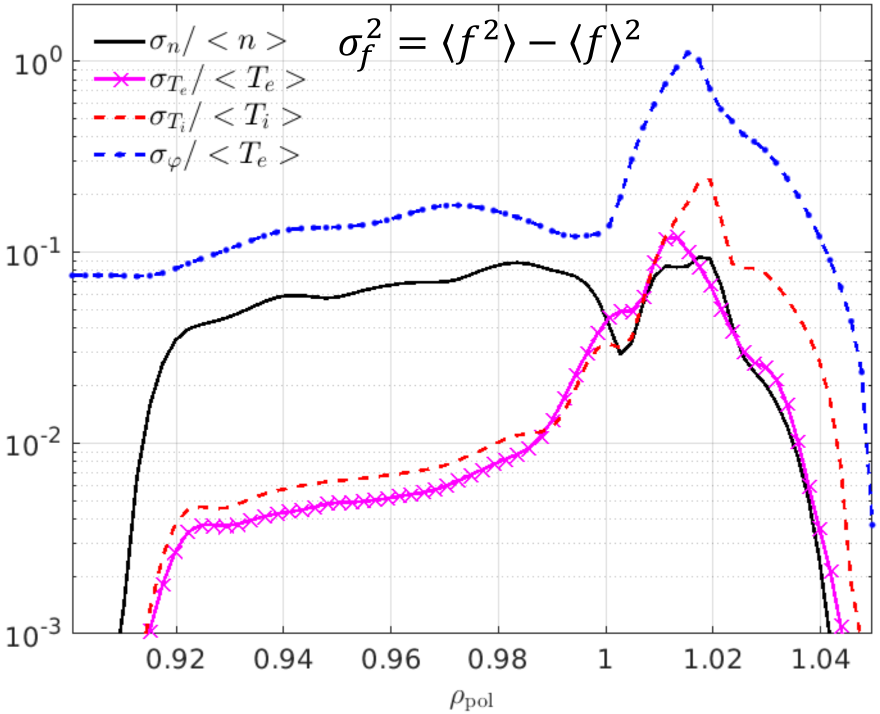
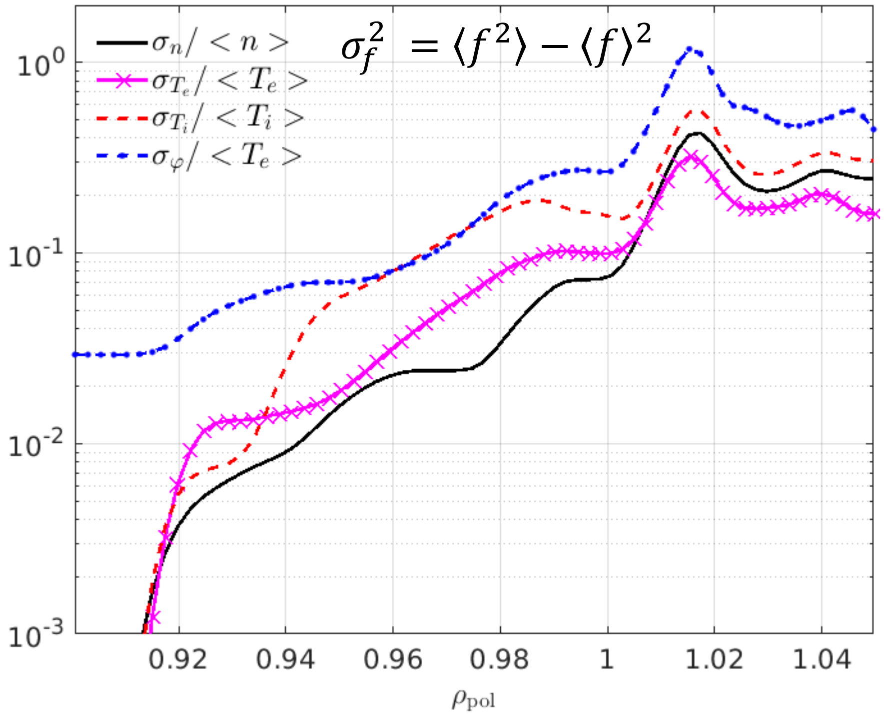
# Turbulence characterisation

## without neutrals (core source)




## with neutrals (edge source)




$\frac{\sigma_\varphi}{\langle T_\mathrm{e} \rangle} > 2 \frac{\sigma_n}{\langle n \rangle} \gg \frac{\sigma_T}{\langle T \rangle} \implies$ ballooning

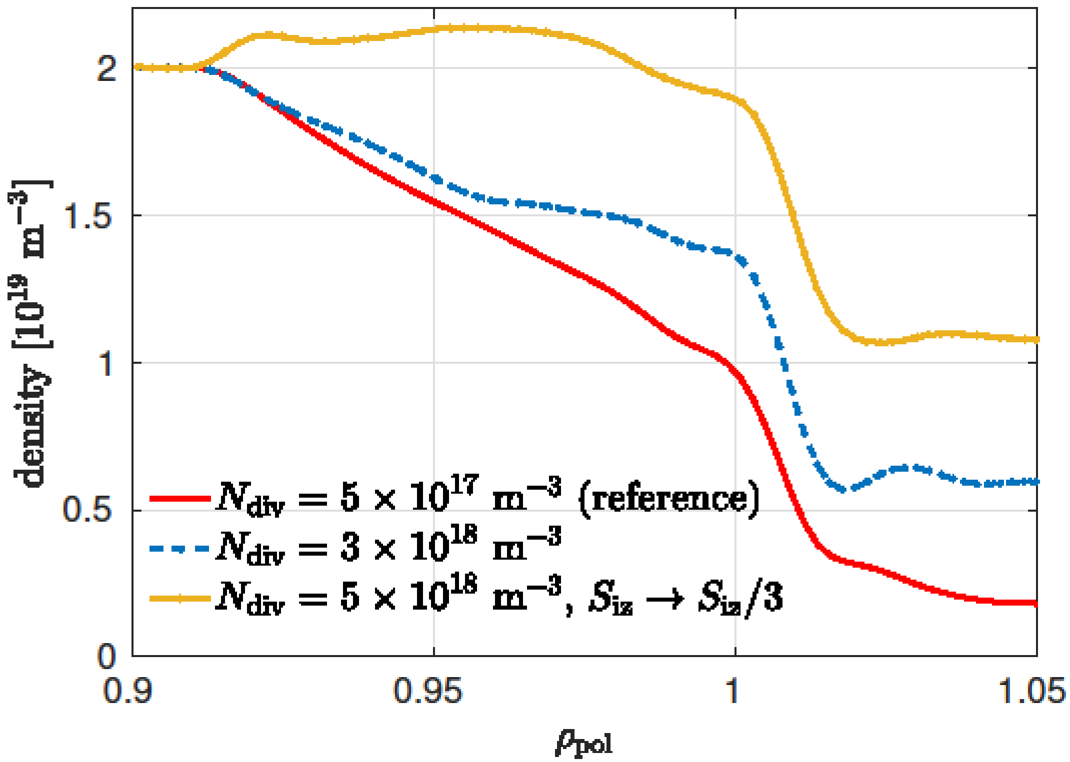
$\frac{\sigma_\varphi}{\langle T_\mathrm{e} \rangle} \geq \frac{\sigma_{T_\mathrm{i}}}{\langle T_\mathrm{i} \rangle} > \frac{\sigma_{T_\mathrm{e}}}{\langle T_\mathrm{e} \rangle} > \frac{\sigma_n}{\langle n \rangle} \implies$ **ITG**

$\chi_\perp^\mathrm{e} = 2/3 D_\perp$

$\langle D_\perp \rangle \approx 0$

# Towards high-recycling conditions

## outboard mid-plane plasma density as a function of divertor neutrals density

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- **Even the simple diffusive neutral gas model makes simulations much more realistic!**
- **Will take advantage of in upcoming modelling efforts**
- **Extensions naturally remain of high interest!**