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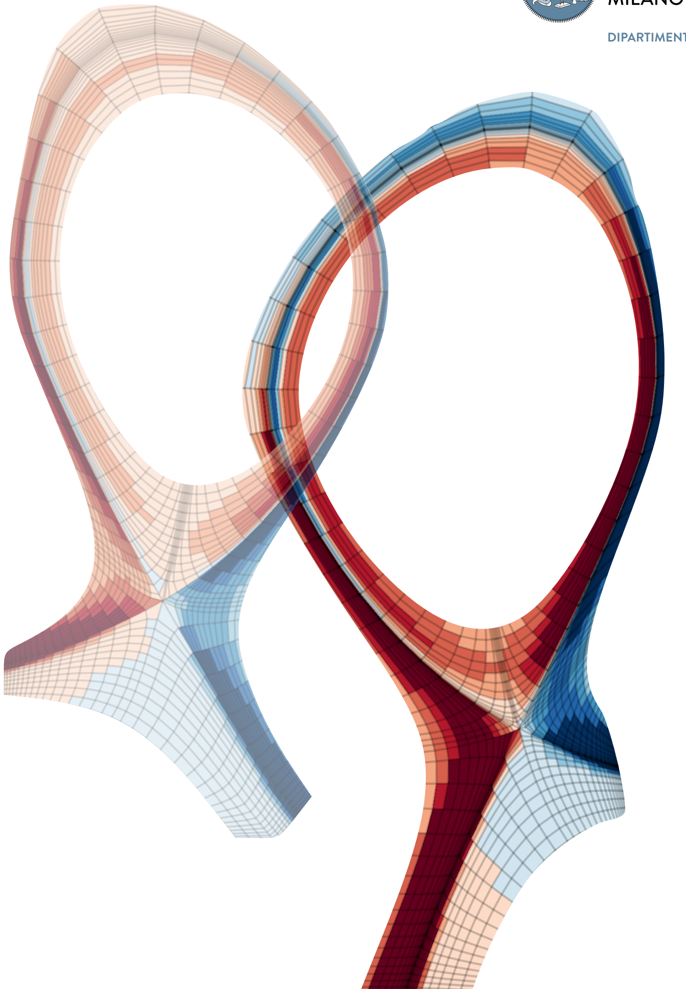

# Analysis of positive and negative triangularity L-mode plasmas by SOLPS-ITER modelling

Elena Tonello

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# Outlook

- **Motivation**: L-mode detachment experiments in TCV - PT vs. NT
- **The SOLPS-ITER code**
  - Physics, equations and geometry
  - Simulation setup and strategy
- **Results**
  - Reference simulation: attached condition and benchmark with experiments
  - Density ramp trends
- **Conclusions and perspectives**



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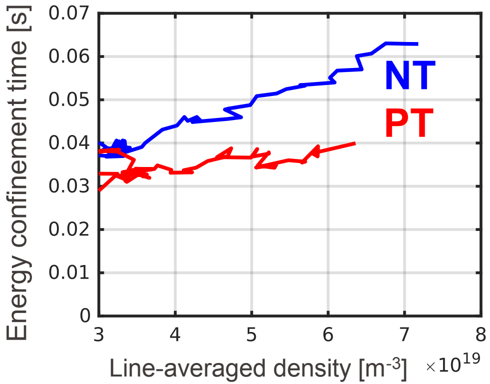
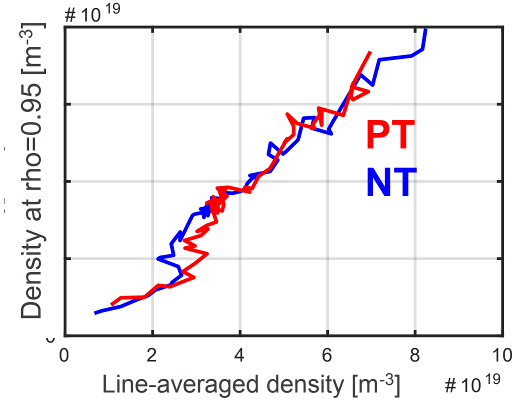
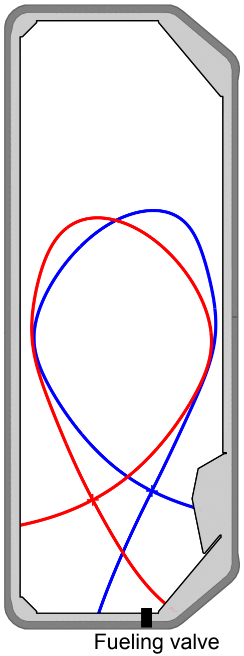
# L-mode experiments in TCV



- L-Mode, $I_P$ = 220kA, Ohmic heating only
- Configuration mirrored around $R_0$=0.88 m:
  - Negative triangularity (**NT**): $\delta_{top} = -0.30$ and $\delta_{bot} = -0.27$
  - Positive triangularity (**PT**): $\delta_{top} = 0.27$ and $\delta_{bot} = 0.29$
- In core density rumps, *for the same feeling rate,* $\langle n_e \rangle_{NT} > \langle n_e \rangle_{PT}$ while $n_{e,sep,NT} \simeq n_{e,sep,PT}$

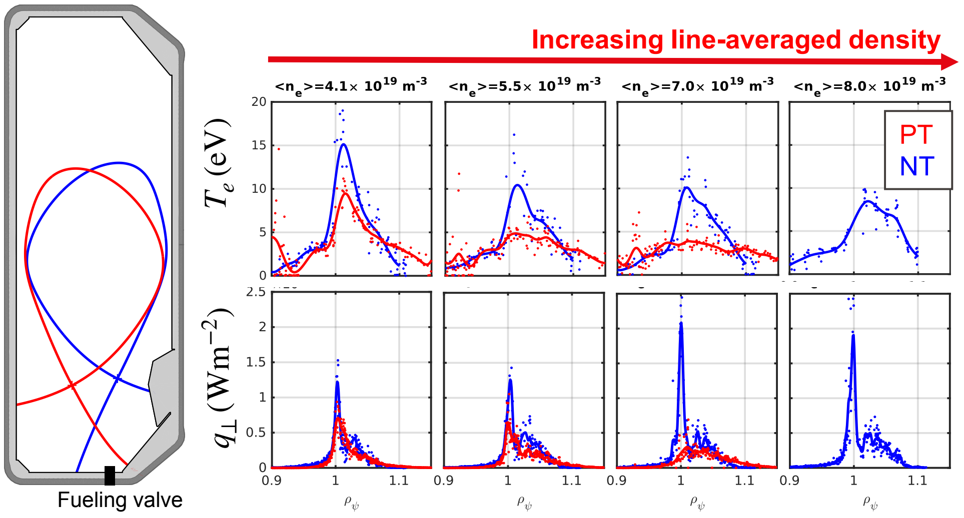



[O. Février, Invited EPS 2023]

# L-mode experiments in TCV




- **Reduction** of the OSP $T_e$ and heat flux **in PT**, but **not in NT**
- Indication of **reduced OSP detachment in NT** with respect to PT

[O. Février, Invited EPS 2023]

The aim of the simulations is to **interpret** these results **in light of SOLPS-ITER modelling**

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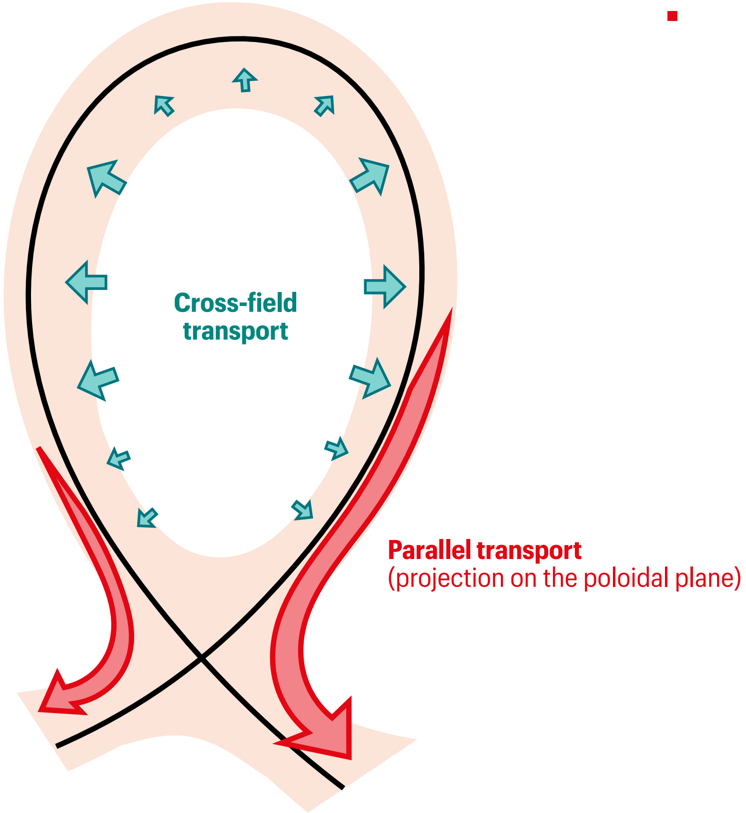
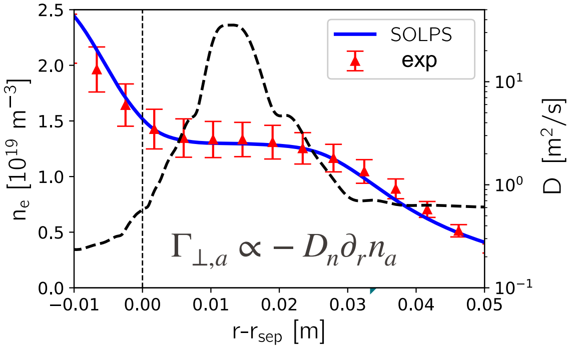
# The SOLPS-ITER code

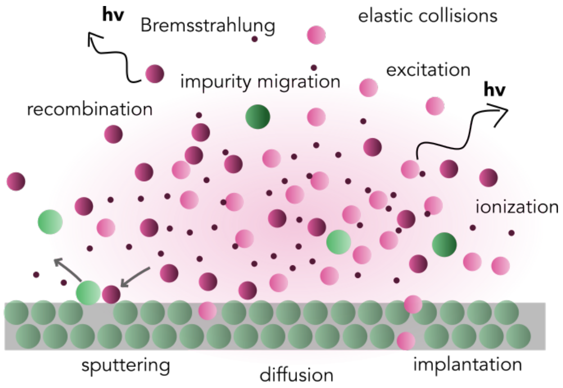



- Model the **main mechanisms controlling power exhaust** in tokamaks and quantitatively **estimate fluxes** on the PFCs
  - time scale ~1s
  - full size device up to DEMO scale

# The SOLPS-ITER code

[P. Mantz et al. Phys. Plasmas 27, 022506 (2020)]




- Model the **main mechanisms controlling power exhaust** in tokamaks and quantitatively **estimate fluxes** on the PFCs
  - time scale ~1s
  - full size device up to DEMO scale

- **Cross-field transport:**
  - Poloidal and cross field contributions due to drifts may also be included
  - The average effect of turbulence as diffusive process controlled by $D_n, \chi_{e,i}$

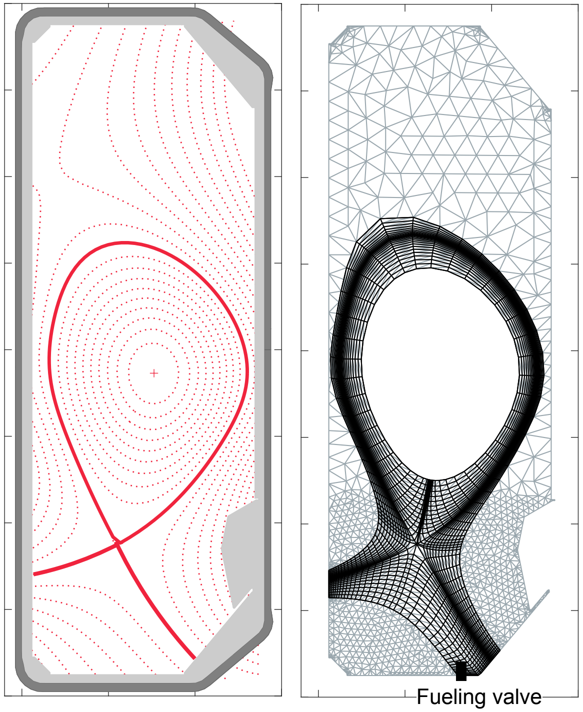
- **Plasma-neutral interaction and plasma-wall interaction:**
  - Poloidal and cross field contributions due to drifts may also be included

# The SOLPS-ITER code: the geometry



- 2D model: computational domain in the **poloidal plane** (2.5D if drifts are on: it includes effects of $B_\phi$)

- **Field-aligned** plasma mesh:
  - Generated on the experimental magnetic equilibrium reconstruction
  - Extend up to the first open flux-surface touching the wall



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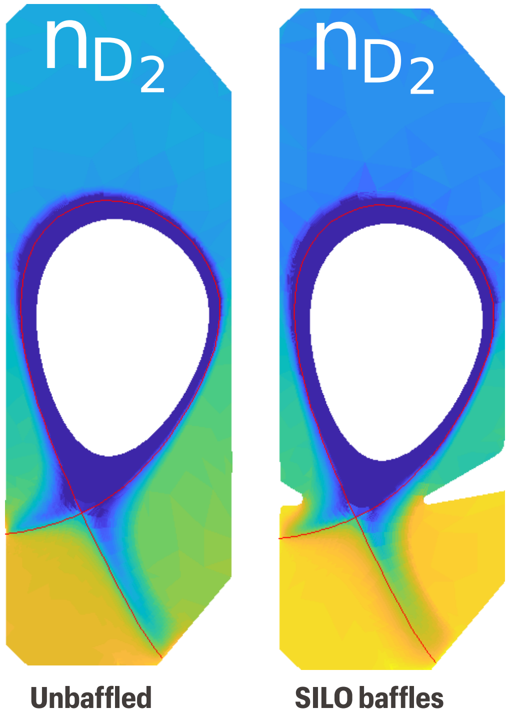
- Flexibility of **Monte Carlo geometry**: neutral injection, recycling and sputtering, divertor closure




[M. Wensing PhD thesis, 2021]

# The SOLPS-ITER code: the geometry



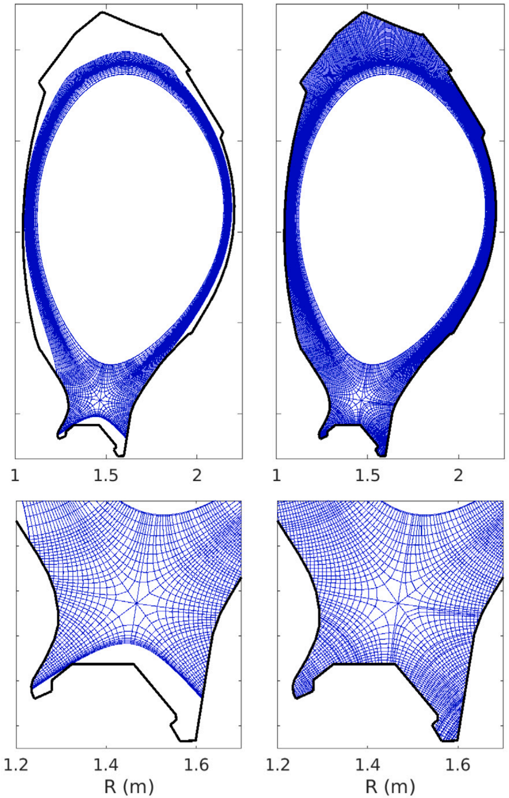
- 2D model: computational domain in the **poloidal plane** (2.5D if drifts are on: it includes effects of $B_{\phi}$)

- **Field-aligned** plasma mesh:
  - Generated on the experimental magnetic equilibrium reconstruction
  - Extend up to the first open flux-surface touching the wall

- Flexibility of **Monte Carlo geometry**: neutral injection, recycling and sputtering, divertor closure

- Now possible to **extend plasma grid** all over the vessel (not used in this work)

[W. Dekeyser et al, NME 2021]



# Simulation setup and strategy

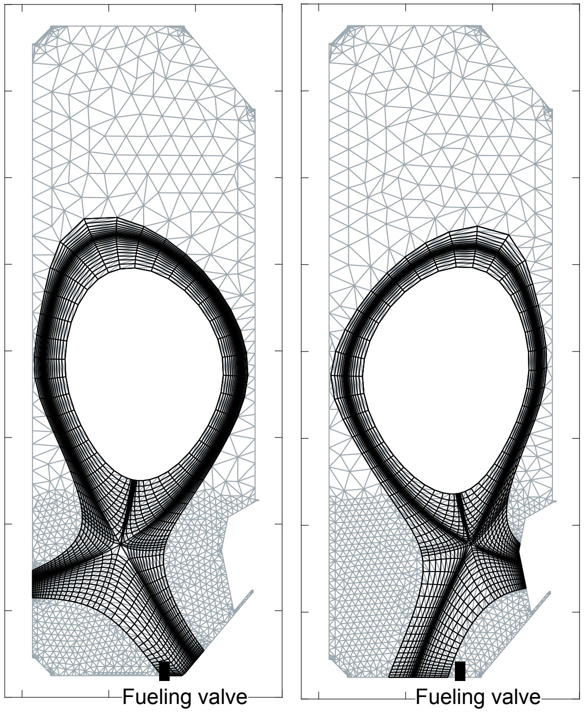


- Computational meshed built on PT and NT experimental equilibria: **same poloidal** and **radial resolution**.

- NT and PT simulations are performed at **fixed input parameters**: assess the effect of different plasma meshes
  - $P_{\mathrm{in,e}} = P_{\mathrm{in,i}} = 0.5 \times (P_{\mathrm{Ohm}} - P_{\mathrm{rad,core}}) \simeq 100\,\mathrm{kW}$
  - Upstream density: $n_{e,\mathrm{sep}} = 1.0 \times 10^{19}\,\mathrm{m}^{-3}$

- No drifts, D only (neglect C impurities)

**PT** (#67476) **NT** (#67465)



# Outlook



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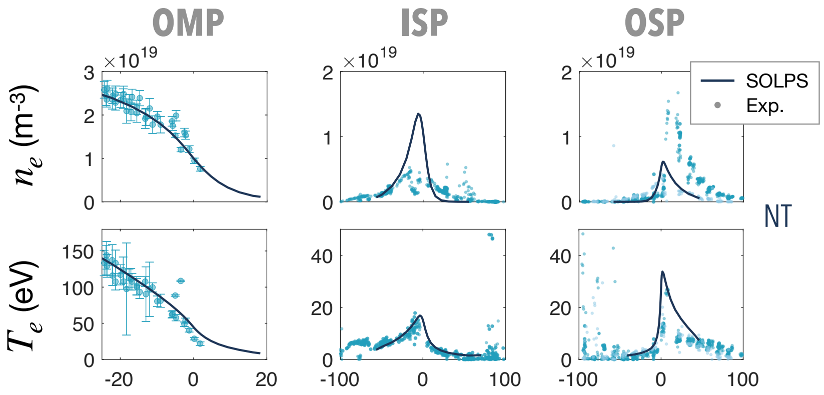
# Reference simulation: validation against TCV data

- $D_n$ and $\chi_{e,i}$ optimised for NT and kept fixed switching to PT
  - $D_n = 0.2\,\mathrm{m^2s^{-1}}, \chi_{e,i} = 1.0\,\mathrm{m^2s^{-1}}$



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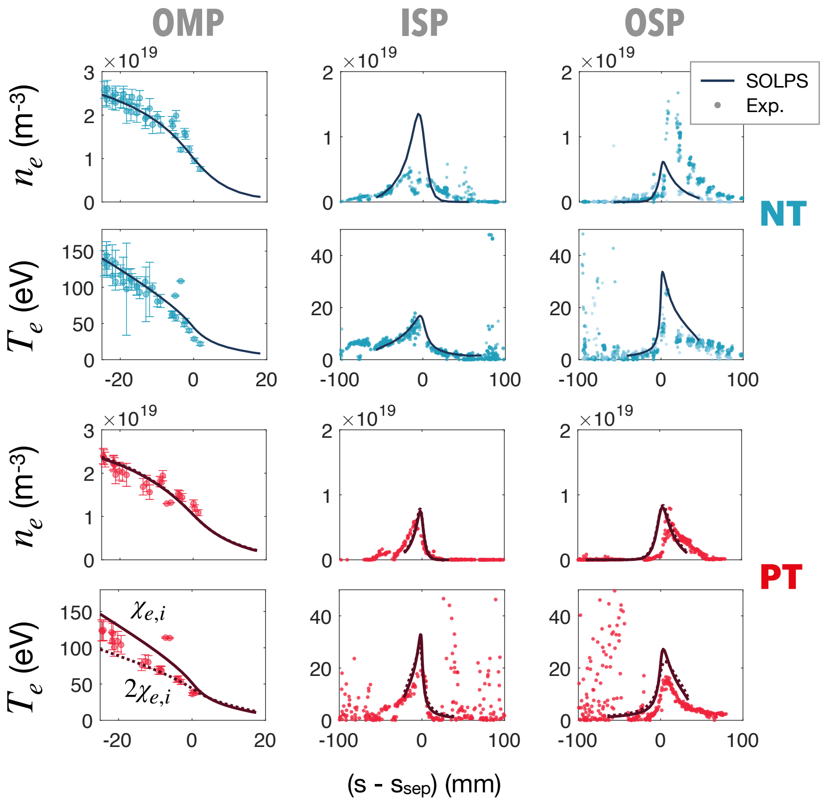
# **Reference simulation**: validation against TCV data



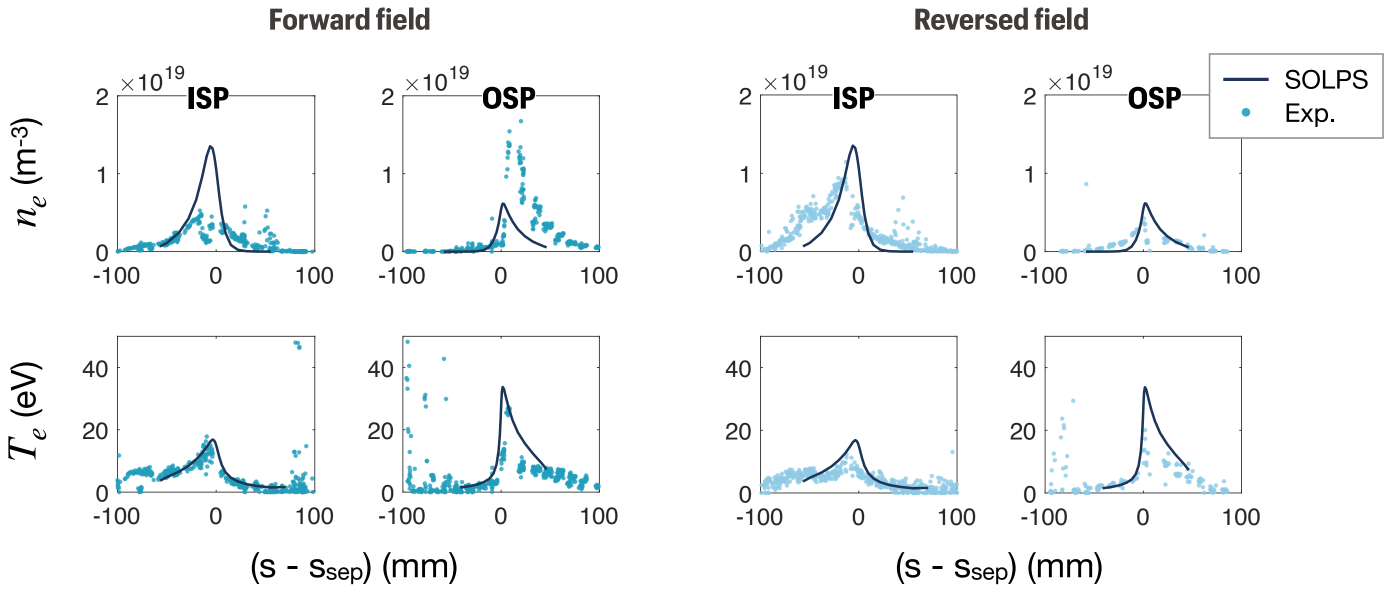
- $D_n$ and $\chi_{e,i}$ optimised for NT and kept fixed switching to PT
  - $D_n = 0.2\,\mathrm{m^2s^{-1}}, \chi_{e,i} = 1.0\,\mathrm{m^2s^{-1}}$
- In **agreement** with experiments:
  - Overall agreement, both for NT and PT
  - $T_{e,\max@OSP} > T_{e,\max@ISP}$ in NT and $T_{e,\max@OSP} \simeq T_{e,\max@ISP}$ in PT (…effect of connection length?)
- **Discrepancies**:
  - $n_e$ profiles at the target in NT (…drifts?)
  - Overestimation of upstream $T_e$ profile if PT , agreement improves if $\chi_{e,\mathrm{NT}} > \chi_{e,\mathrm{PT}}$ (lower energy confinement..?)



# Field reversal: effect on OSP density profiles



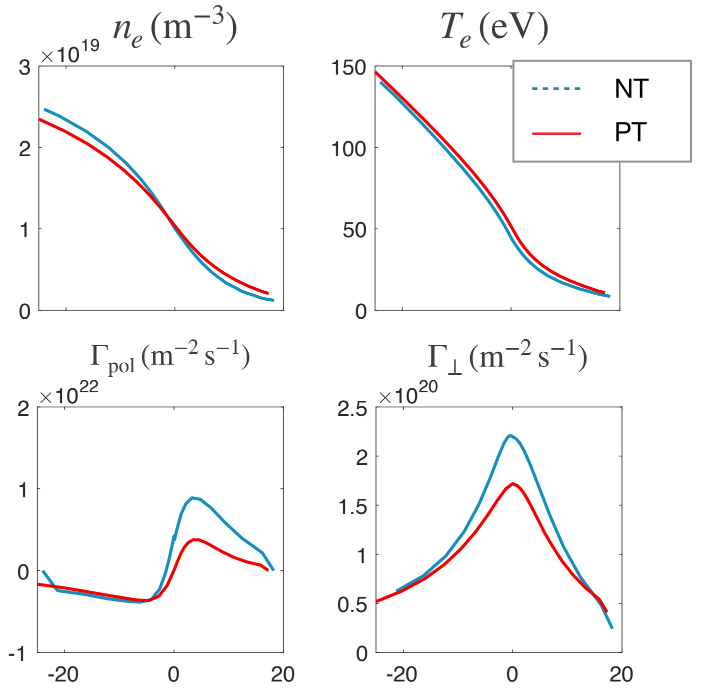
- Field reversal has significant effect on the target $n_e$ profiles, while $T_e$ is almost unaffected
- To analyse the effect of field reversal with SOLPS-ITER drifts need to be included



# Fluxes and sources (preliminary analysis)

**Steady state density equation:** $\nabla \cdot (\vec{\Gamma}) = S_n$

- **OMP** profiles:
  - for the same $n_{e,\text{sep}}$, $|\partial_r n_e| >$ in NT than PT
  - since $D_n = 0.2\,\text{m}^{-2}\text{s}^{-1}$ (same for both), $\Gamma_\perp >$ in NT than PT
  - $\Gamma_{\text{pol}} >$ in NT than PT



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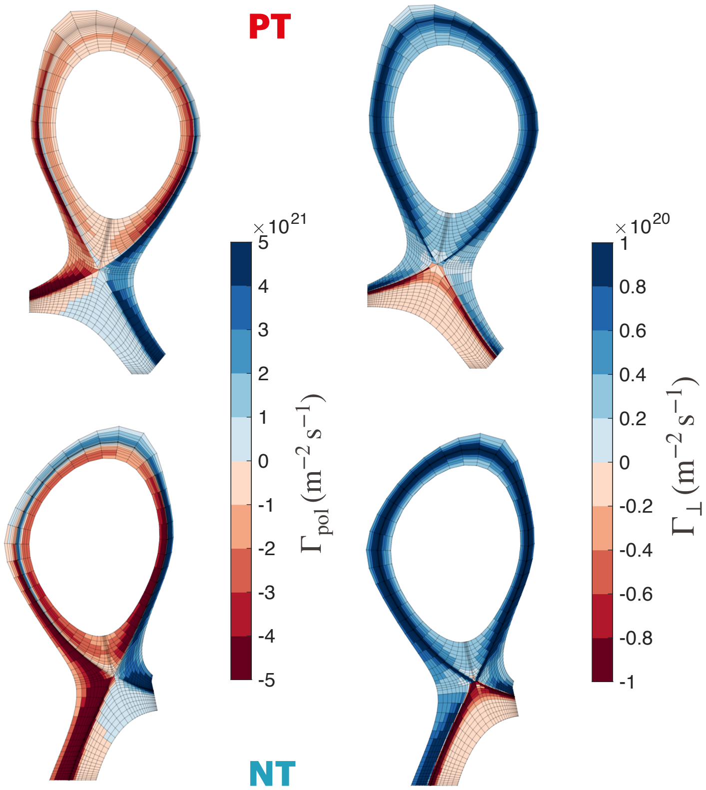
  - $\Gamma_{\mathrm{pol}} >$ in NT than PT
  - positive $\Gamma_{\mathrm{pol}}$ (clockwise in the poloidal plane) to higher field region in NT



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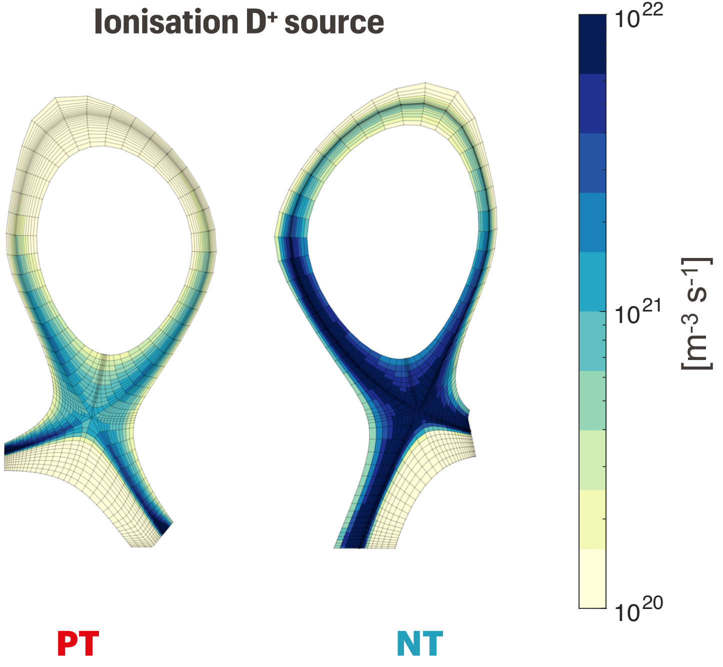
  - $\Gamma_{\mathrm{pol}} >$ in NT than PT
  - positive $\Gamma_{\mathrm{pol}}$ (clockwise in the poloidal plane) to higher field region in NT
- **Ionisation distribution** is also different in NT and PT: ~factor 5 higher in NT!

**Ionisation D⁺ source**

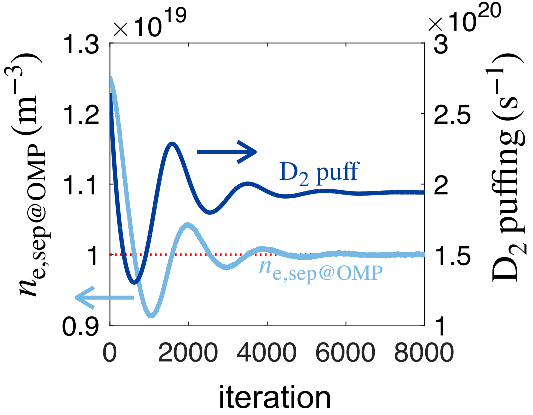


# Feedback density ramp

- Density ramp as a $n_{e,\mathrm{sep}}$ scan in SOLPS-ITER
- SOLPS-ITER density scan using the **density feedback scheme**: $D_2$ influx is adjusted iteratively to match specified $n_{e,\mathrm{sep}}$
- Six simulations, repeated for PT and NT:

$$n_{\mathrm{e,sep}} = \{ 0.75 - 1.00 - 1.25 - 1.50 - 1.75 - 2.0 \} \times 10^{19}\ \mathrm{m}^{-3}$$

- Fixed anomalous transport and input power



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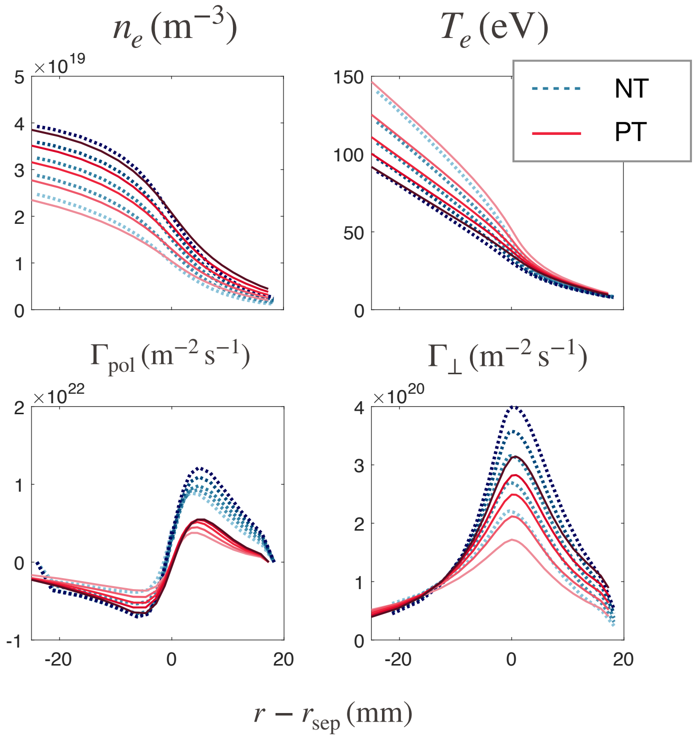
# Feedback density ramp: upstream profiles and $\partial_r$

- Density ramp, i.e. increase of $n_e$ at the core boundary, obtained by reducing $D_n$
- Stronger effect on $\Gamma_\perp$, for increasing $n_{e,\mathrm{core}}$
  - increasing $n_{e,\mathrm{sep}}$, $\Gamma_\perp$ increases
  - decreasing $D_n$, $\Gamma_\perp \propto D_n$ decreases



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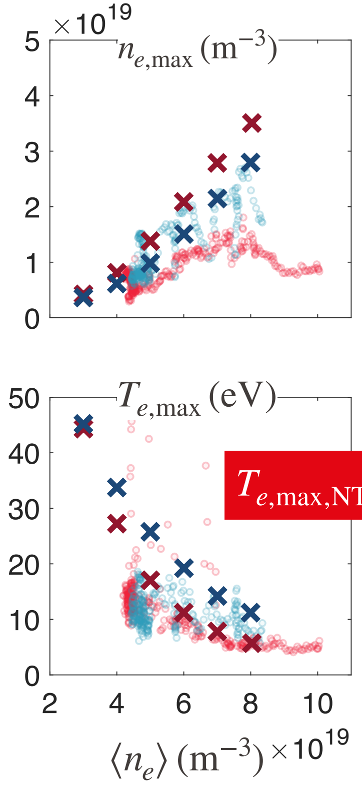
# Feedback density ramp: OSP trends



- Density ramp, i.e. increase of $n_e$ at the core boundary, obtained by reducing $D_n$
- Stronger effect on $\Gamma_\perp$, for increasing $n_{e,\mathrm{core}}$
  - increasing $n_{e,\mathrm{sep}}$, $\Gamma_\perp$ increases
  - decreasing $D_n$, $\Gamma_\perp \propto D_n$ decreases
- Simulations **predicts the experimental trend** of higher OSP $T_e$ in NT compared to PT
- Flux roll-over in PT is not observed in simulations




$T_{e,\max,\mathrm{NT}} > T_{e,\max,\mathrm{PT}}$

# Density ramp: $n_{e,sep}$ scan vs. $D_n$ scan



- Density ramp, i.e. increase of $n_e$ at the core boundary, obtained by reducing $D_n$
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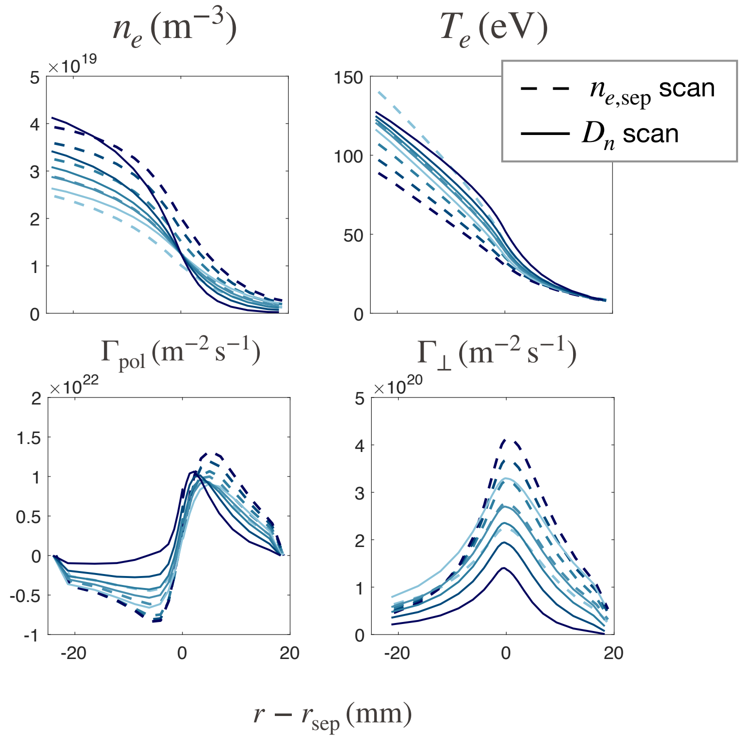
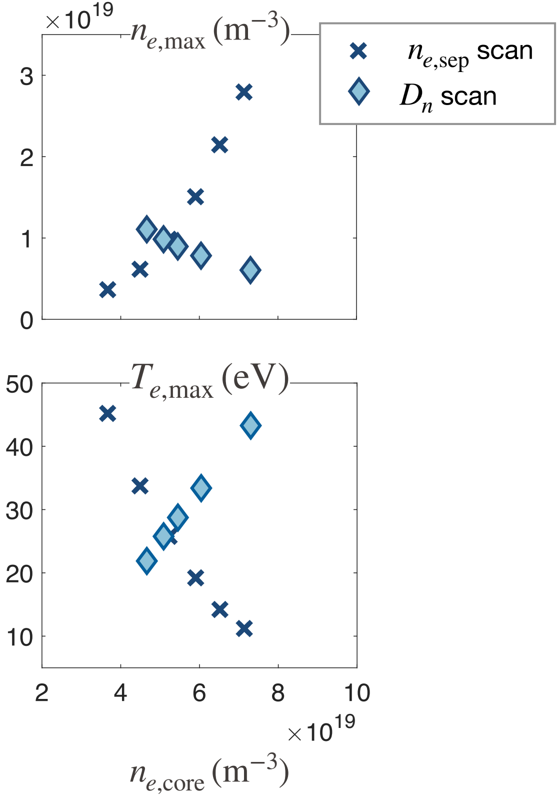


# Density ramp: $n_{e,\mathrm{sep}}$ scan vs. $D_n$ scan

- Density ramp, i.e. increase of $n_e$ at the core boundary, obtained by reducing $D_n$
- Stronger effect on $\Gamma_\perp$, for increasing $n_{e,\mathrm{core}}$
  - increasing $n_{e,\mathrm{sep}}$, $\Gamma_\perp$ increases
  - decreasing $D_n$, $\Gamma_\perp \propto D_n$ decreases
- Effects at the **OSP:**
  - increasing $n_{e,\mathrm{sep}}$, $T_{e,\max}$ decreases and $n_{e,\max}$ increases
  - decreasing $D_n$, $T_{e,\max}$ increases and $n_{e,\max}$ decreases

**OSP trends**



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# Conclusions



- Comparison of PT and NT TCV L-mode shots by SOLPS-ITER modelling

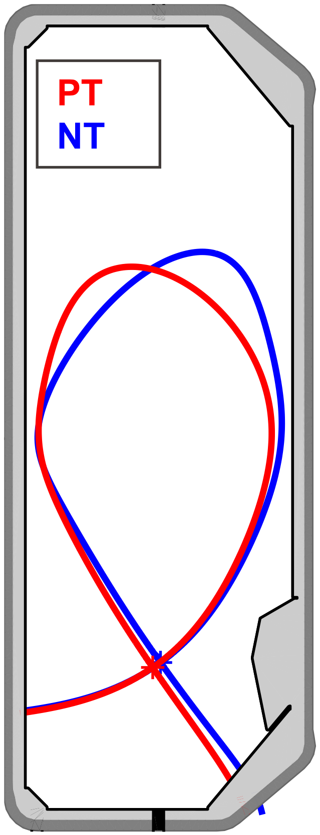
- **Validation** of the simulation in attached condition for NT:
  - Keeping the same input parameters (including radial transport), good agreement also with PT profile
  - Differences in radial and poloidal fluxes and partile sources although same input parameters

- Trends during **density ramp**:
  - Simulations predict higher OSP $T_e$ in NT compared to PT
  - ~constant OSP $T_e$ observed experimentally in NT, may be connected to a reduction of radial transport

# Perspectives



- **Priority**: isolate the effect of connection length ($L_{||}$) by modelling NT and PT with the same diverter geometry
  - include drifts..
  - include C impurities…



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# Backup slides

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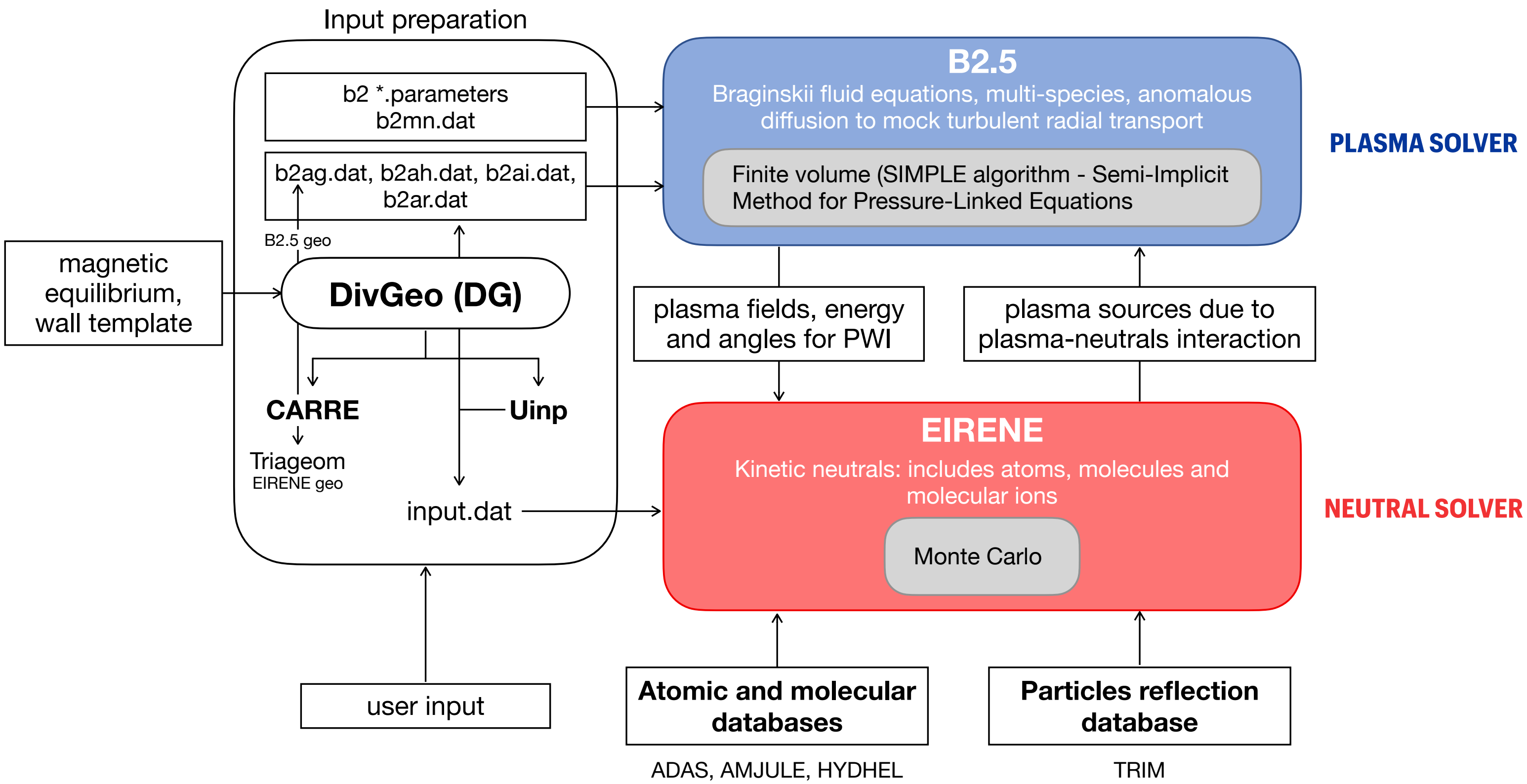
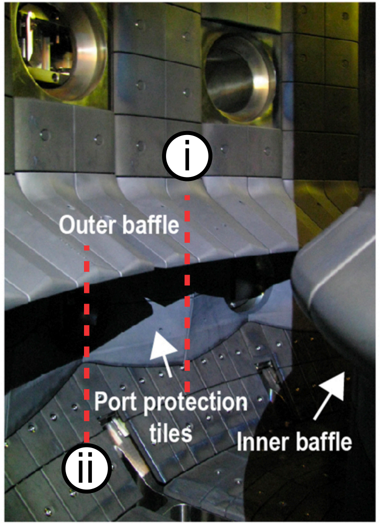
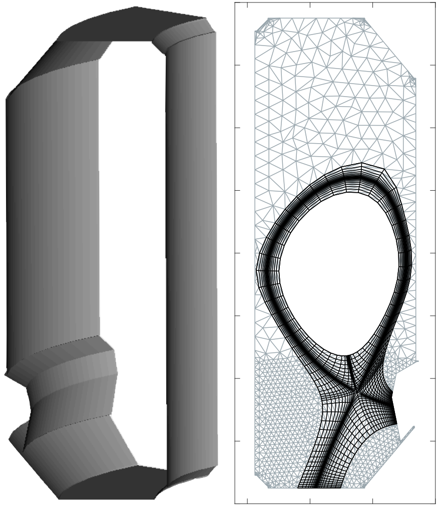
# The SOLPS-ITER code

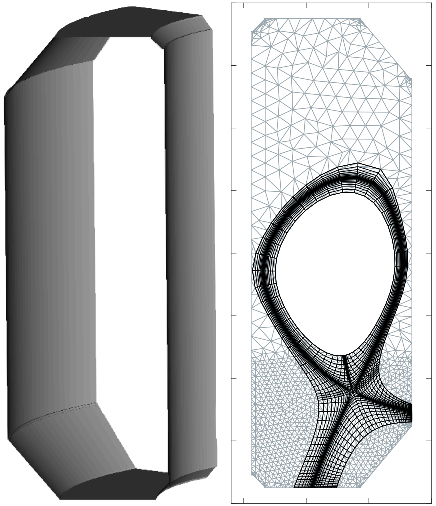


# **Toroidal effects:** non toroidal port-protection tiles

[H. Reimerdes *et al* 2021 *Nucl. Fusion* 61 024002]





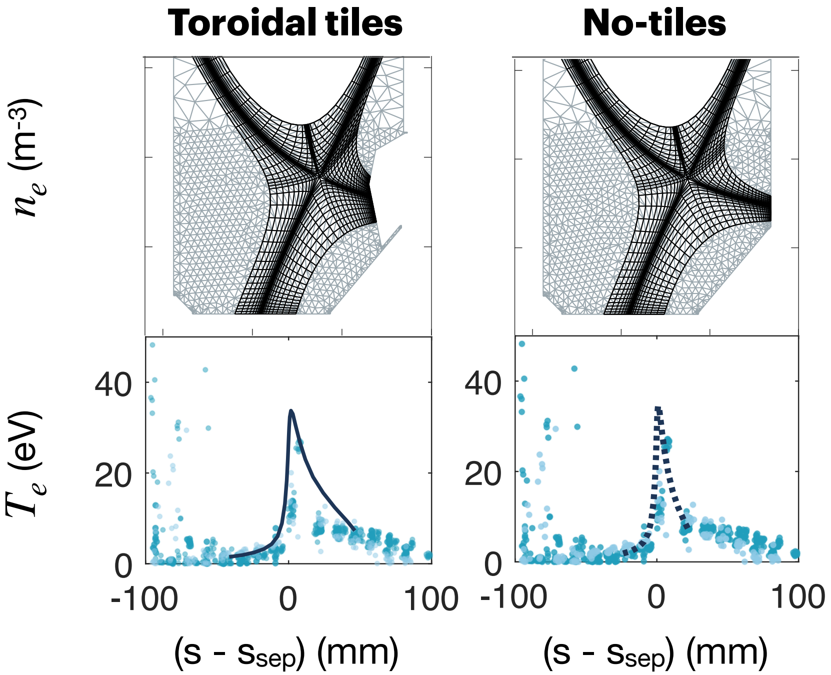
(i) Toroidal symmetric port protection tiles

(ii) No port protection tiles

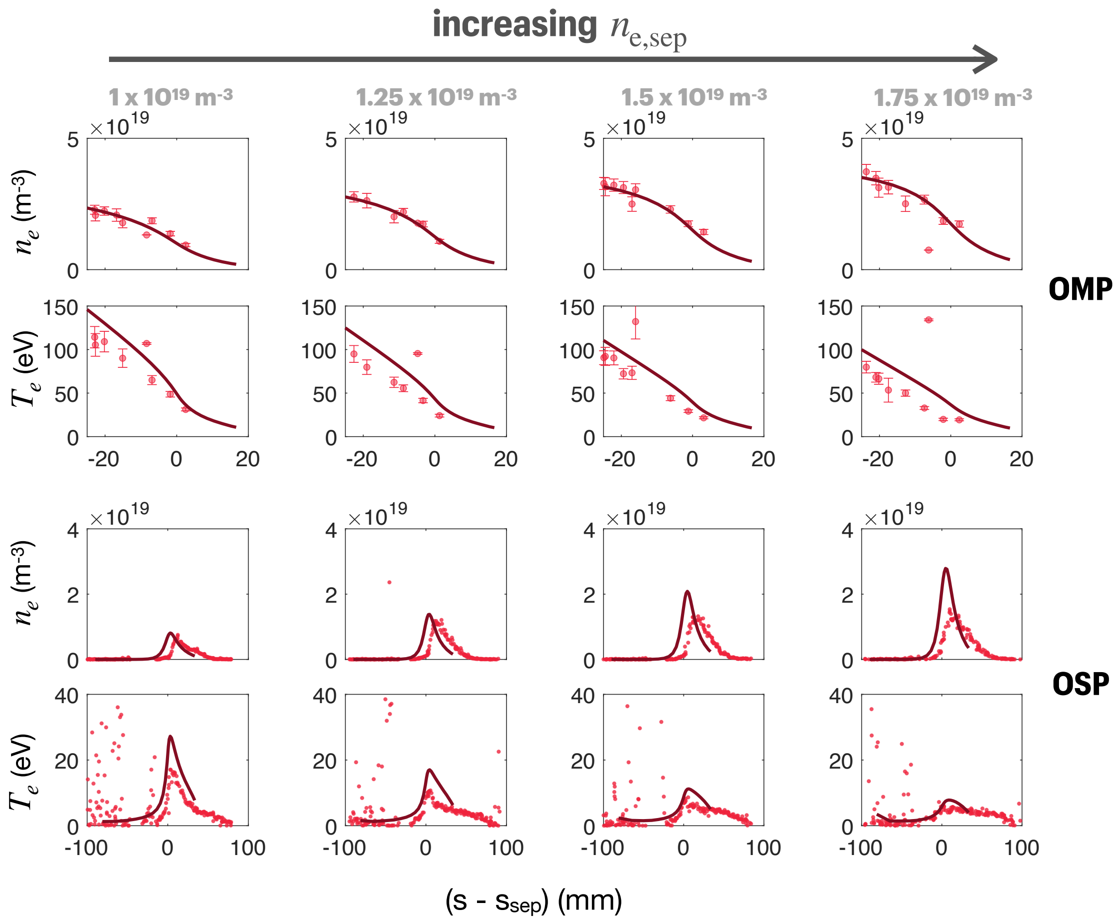
# **Toroidal effects**: non toroidal port-protection tiles



- Narrower $T_e$ profiles at the OSP, no differences in $T_{e,\max}$

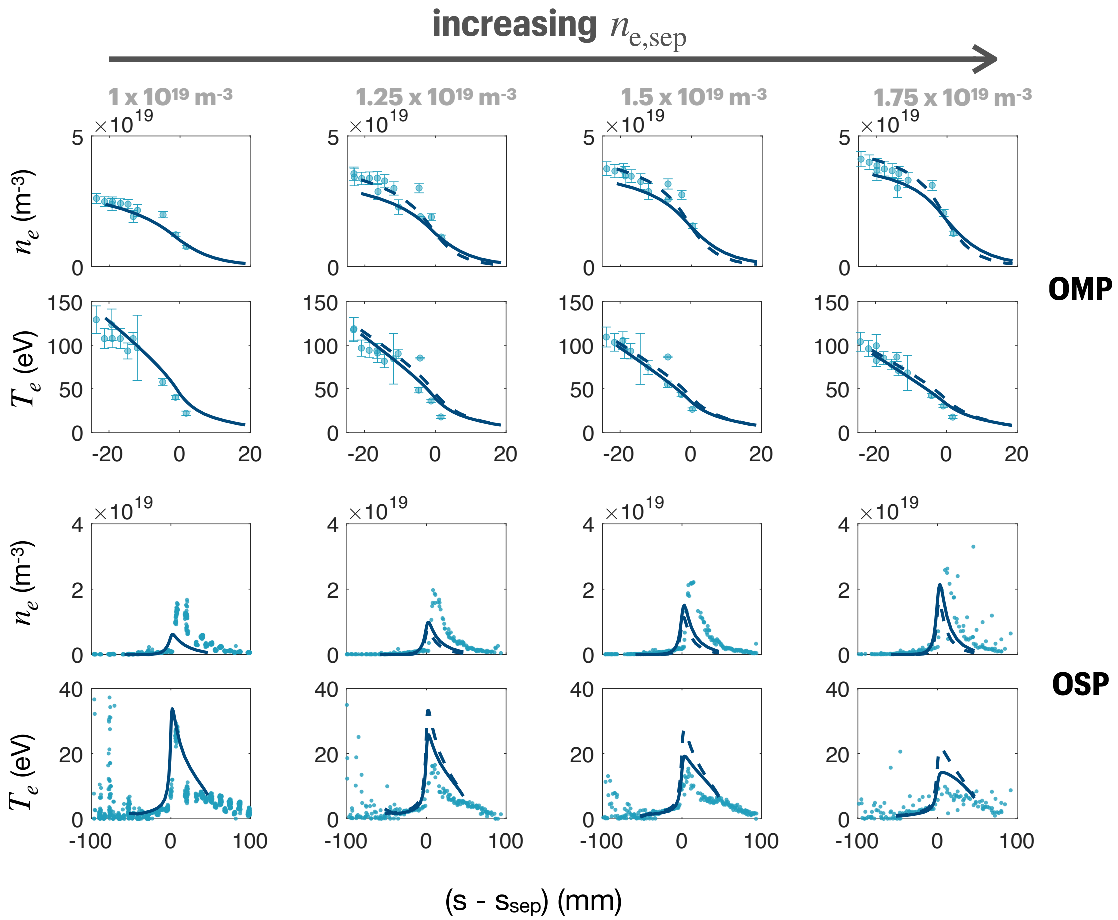


# PT profiles



increasing $n_{e,sep}$
1 x 10¹⁹ m⁻³
1.25 x 10¹⁹ m⁻³
1.5 x 10¹⁹ m⁻³
1.75 x 10¹⁹ m⁻³
×10¹⁹
$n_e$ (m⁻³)
$T_e$ (eV)
OMP
OSP
(s - s_sep) (mm)

# NT profiles

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