TH/3-3: Assessment of Scrape-off Layer Simulations with Drifts against L-mode Experiments in ASDEX Upgrade and JET

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Outline

- Introduction
- Influence of drifts on a density scan in ASDEX Upgrade
- Influence of drifts on a N-seeding scan in JET
- Underlying physics
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- **Introduction**
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Understanding and predicting divertor exhaust

In ITER and DEMO, divertor exhaust involves **power dissipation by impurities** and **detachment**

⇒A possible bottleneck for reactors

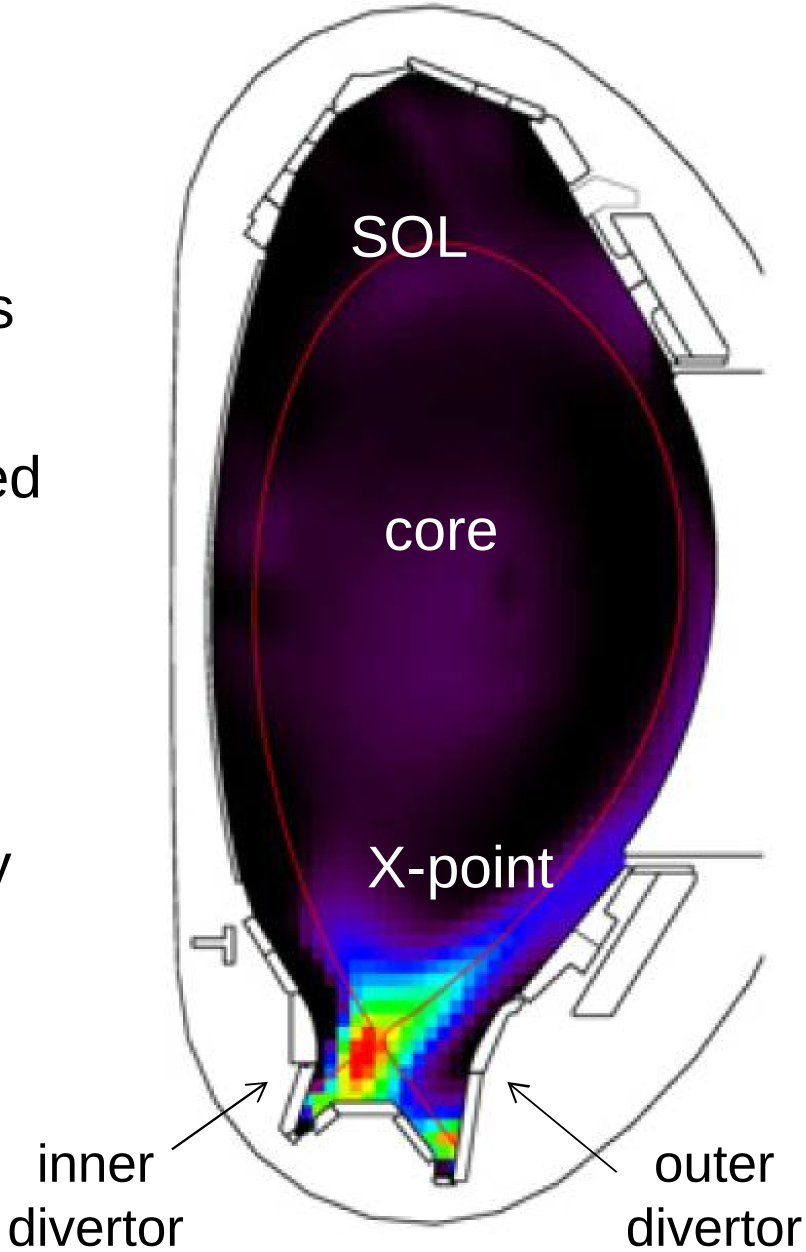
Coupled plasma-neutral simulations required for predicting power and particle exhaust

⇒**plasma fluid / Monte Carlo neutral** code packages

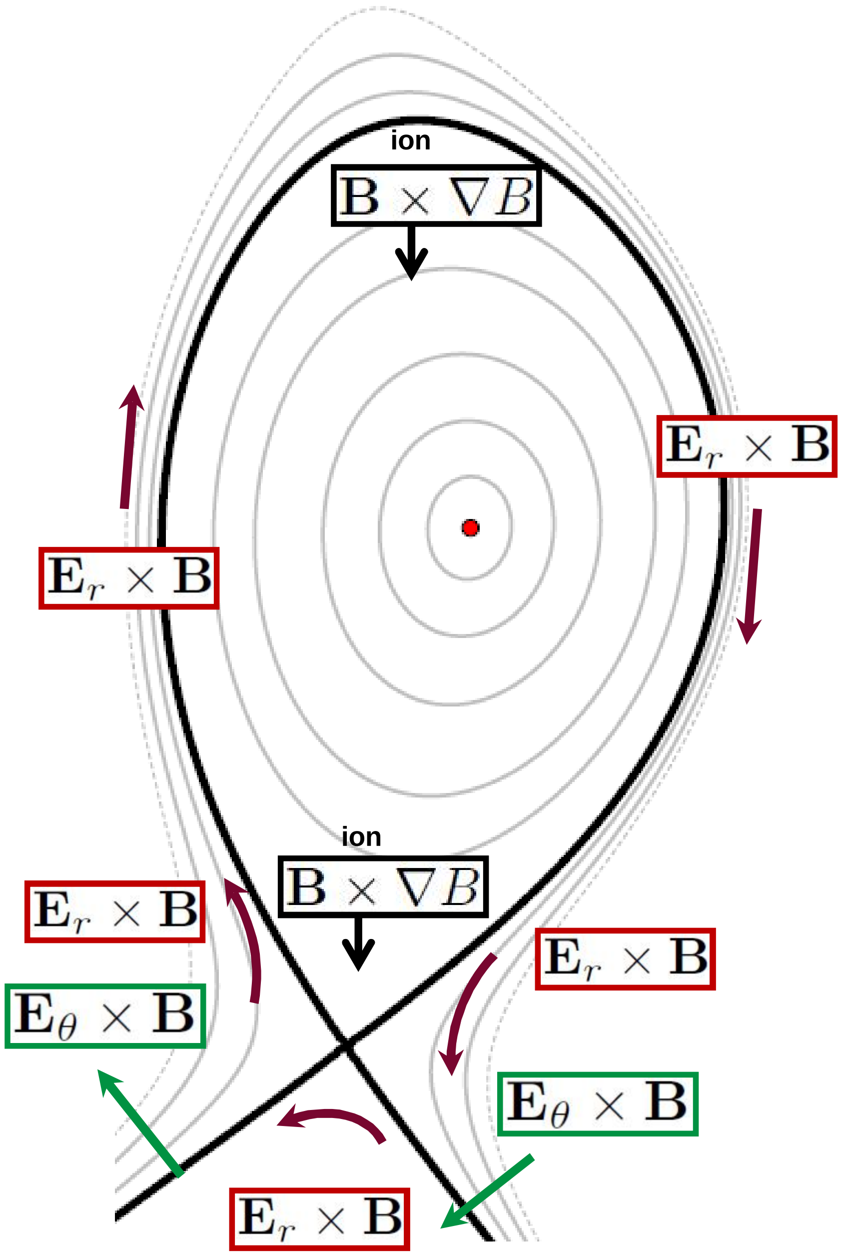
The codes do not reproduce all present-day experimental observations, **predictions uncertain**

⇒detachment

⇒divertor asymmetries



The role of drifts in divertor asymmetries



Experimental studies suggest that **divertor asymmetries are sensitive to cross-field drifts**

e.g. R. Pitts et al, J. Nucl. Mat. 2005

Analytic assessments are not sufficient to verify this, because the ExB drifts are sensitive to **temperature and pressure gradients**

A. Chankin, J. Nucl. Mat. 1997

Activation of drift terms in SOL simulations is computationally challenging and not routinely done

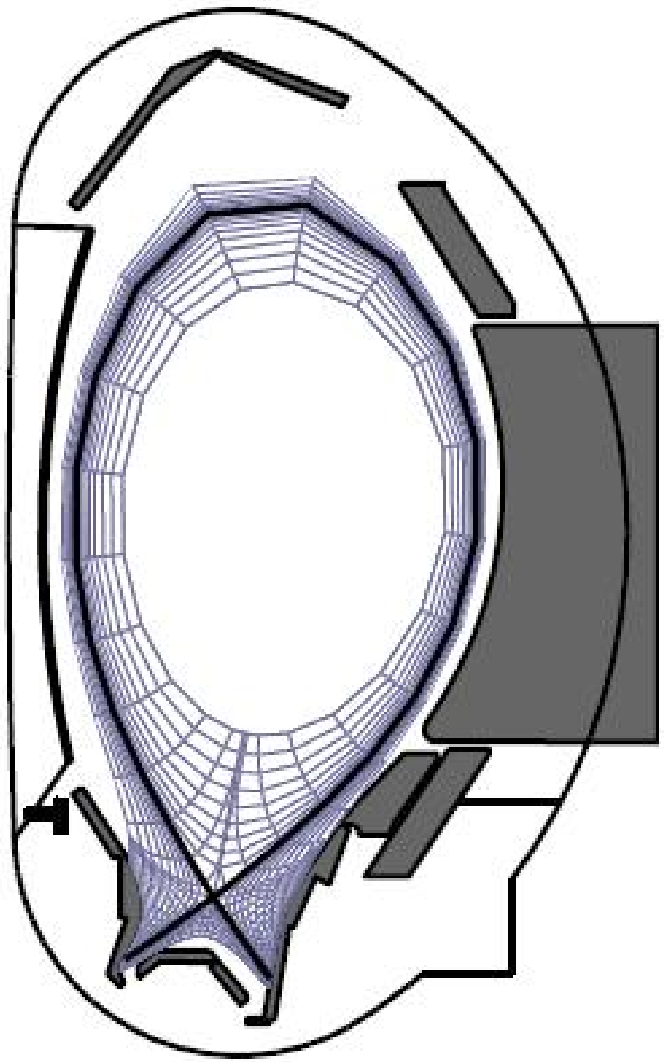
Drift effects modelled using SOLPS5.0

B2.5: 2D plasma fluid code
Eirene: Monte Carlo neutrals code
+ multiple impurities

ExB and **diamagnetic drifts**,
currents

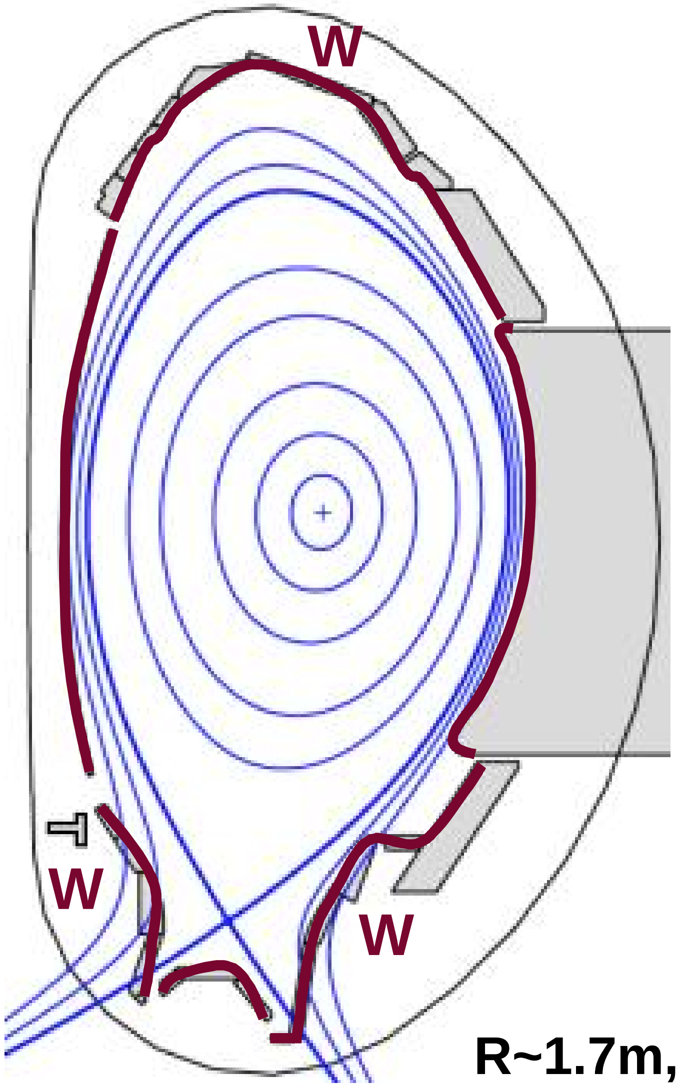
$$
\begin{aligned}
q_{\mathrm{e},x} \quad = \\
&\frac{3}{2}nT_{\mathrm{e}}\left(-\frac{b_z}{Bh_y}\frac{\partial\Phi}{\partial y}+b_xV_{\parallel}-b_xj_{\parallel}/en\right)\\
&+\frac{5}{2}nT_eb_z\left(-\frac{D}{T_{\mathrm{e}}+T_{\mathrm{i}}}\frac{b_z}{h_x}\left(\frac{\partial p}{n\partial x}-\frac{3}{2}\frac{\partial T_{\mathrm{e}}}{\partial x}\right)-D^{n}_{\mathrm{AN}}\frac{1}{h_xn}\frac{\partial n}{\partial x}\right)\\
&-0.71b_xj_{\parallel}T_{\mathrm{e}}/e-\kappa_{\mathrm{e}\parallel}\frac{b_x^2}{h_x}\frac{\partial T_{\mathrm{e}}}{\partial x}-\kappa_{e\perp}b_z^2\frac{1}{h_x}\frac{\partial T_{\mathrm{e}}}{\partial x}\\
&+\frac{3}{2}\frac{T_{\mathrm{e}}}{eB}\frac{\nu_{ei}}{\omega_{ce}}\frac{b_z^2}{h_x}\frac{\partial n(T_{\mathrm{e}}+T_{\mathrm{i}})}{\partial x}-\frac{5}{2}nT_{\mathrm{e}}^2\frac{B_z}{e}\frac{\partial}{h_y\partial y}\left(\frac{1}{B^2}\right)
\end{aligned}
$$

Example grid for ASDEX Upgrade



Modelling is validated against L-mode discharges in ASDEX Upgrade and JET

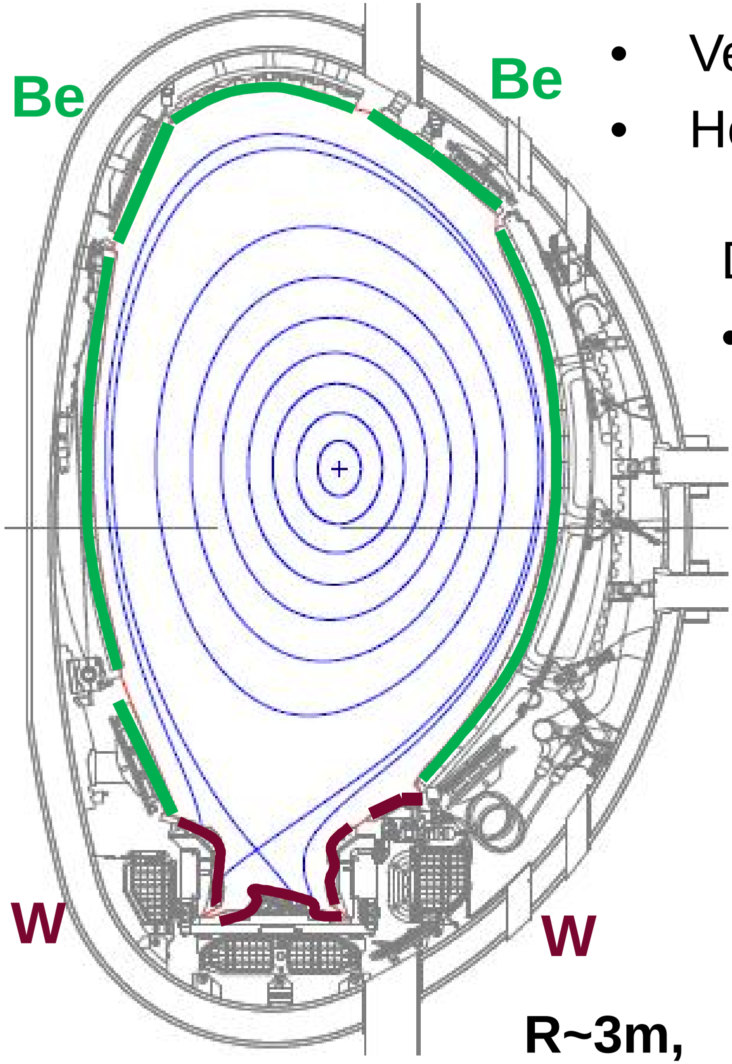
ASDEX Upgrade



B_t=2.5T, I_p=1.0MA

R~1.7m, a~0.5m

JET



B_t=2.5T, I_p=2.5MA

R~3m, a~1.3m

Different **divertor configurations**

- Vertical targets (AUG)
- Horizontal outer target (JET)

Different **divertor regimes**

- D fuelling and N seeding

Validation of modelled power exhaust and drift effects:

- **target measurements**
- **volume measurements**

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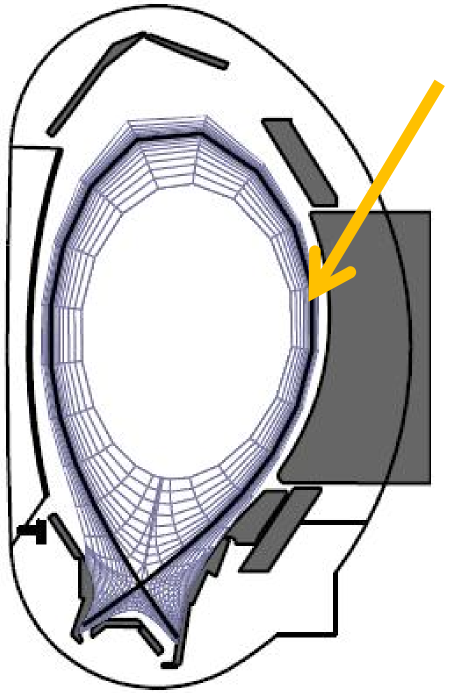
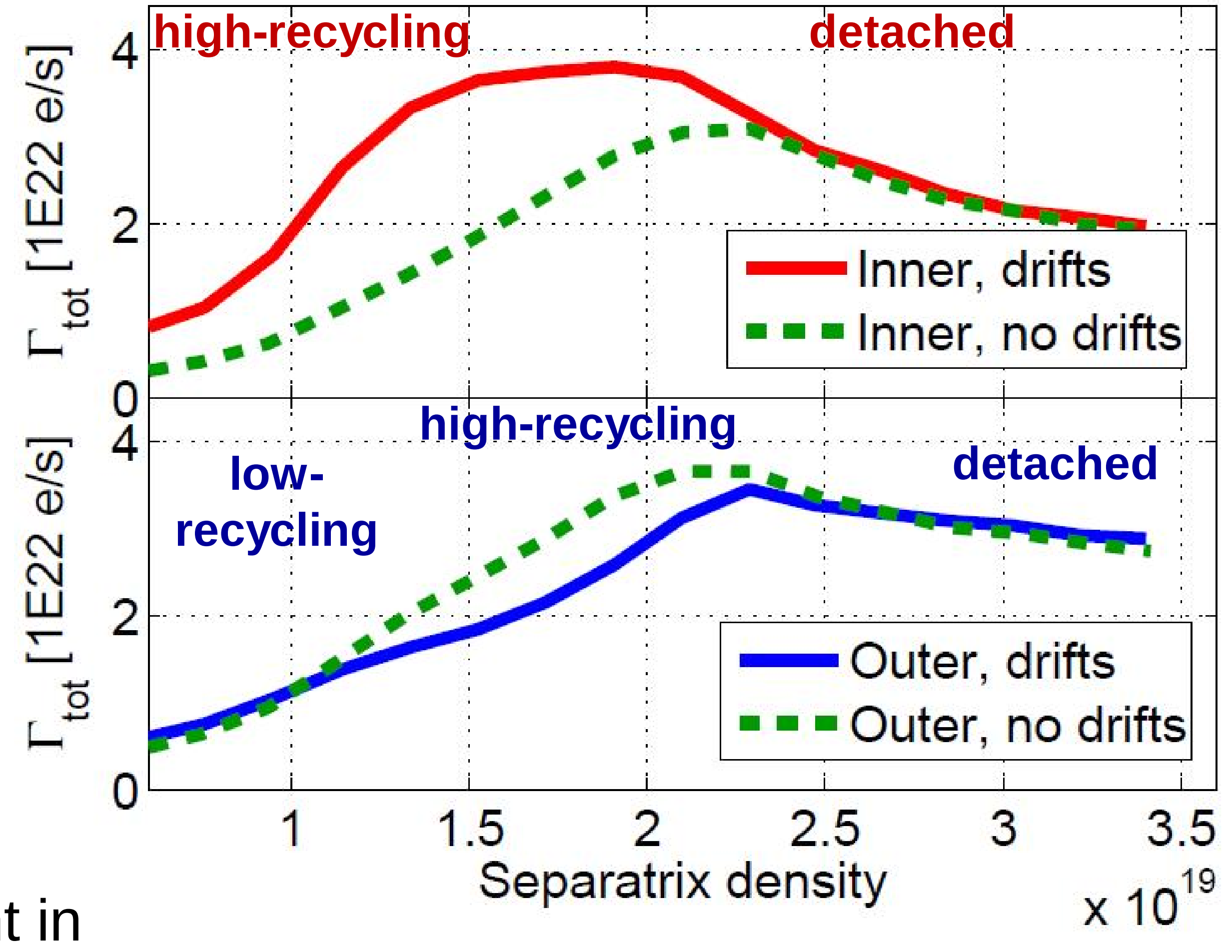
Activation of drifts leads to an asymmetric roll-over of the simulated ion fluxes



modelled total ion fluxes



$\Rightarrow$ Drift effects most significant in the **high-recycling regime** (hot SOL – cool divertor)

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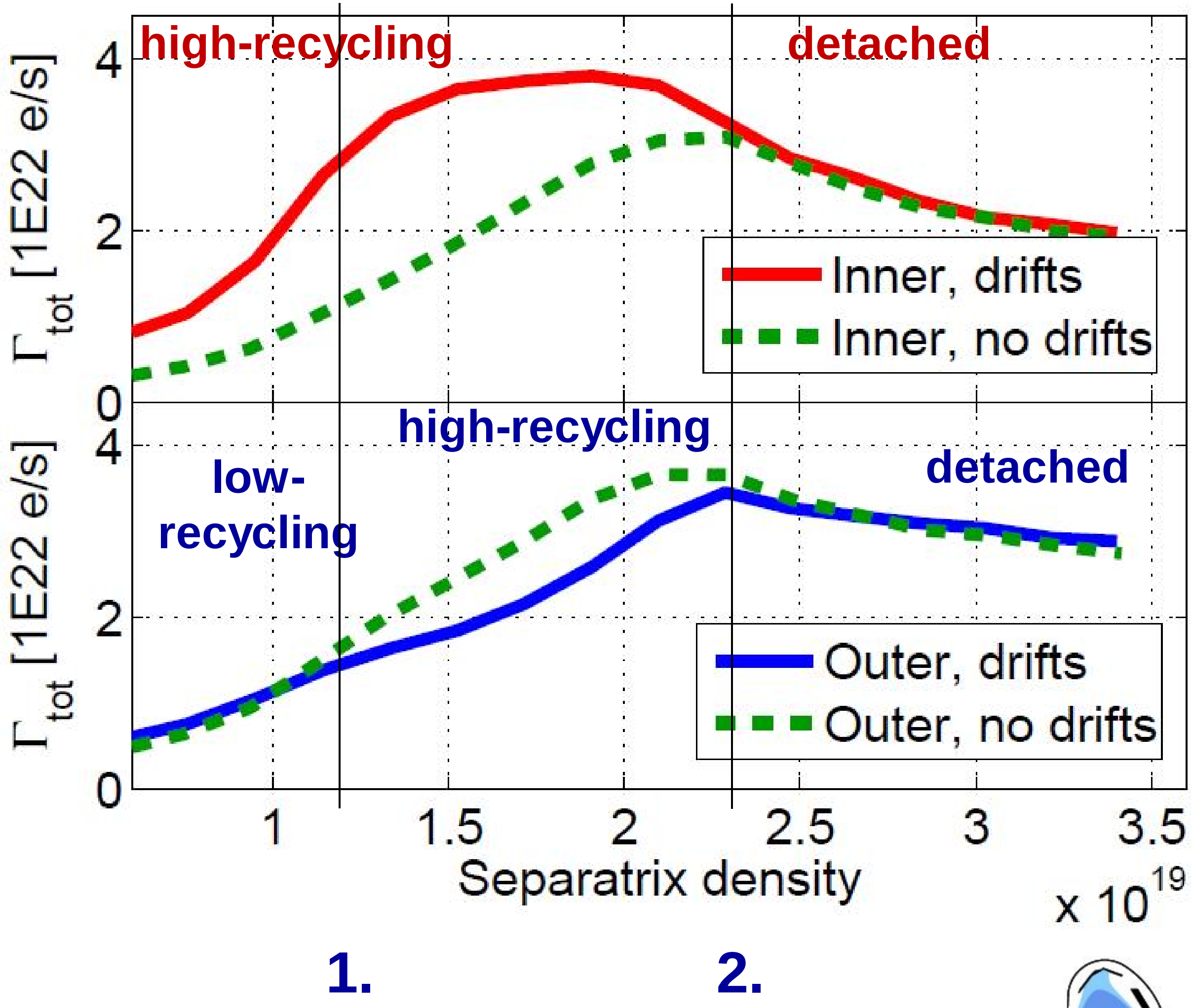
Two regimes considered in detail

1. **Low density**
   - Strong drift effects in the inner divertor

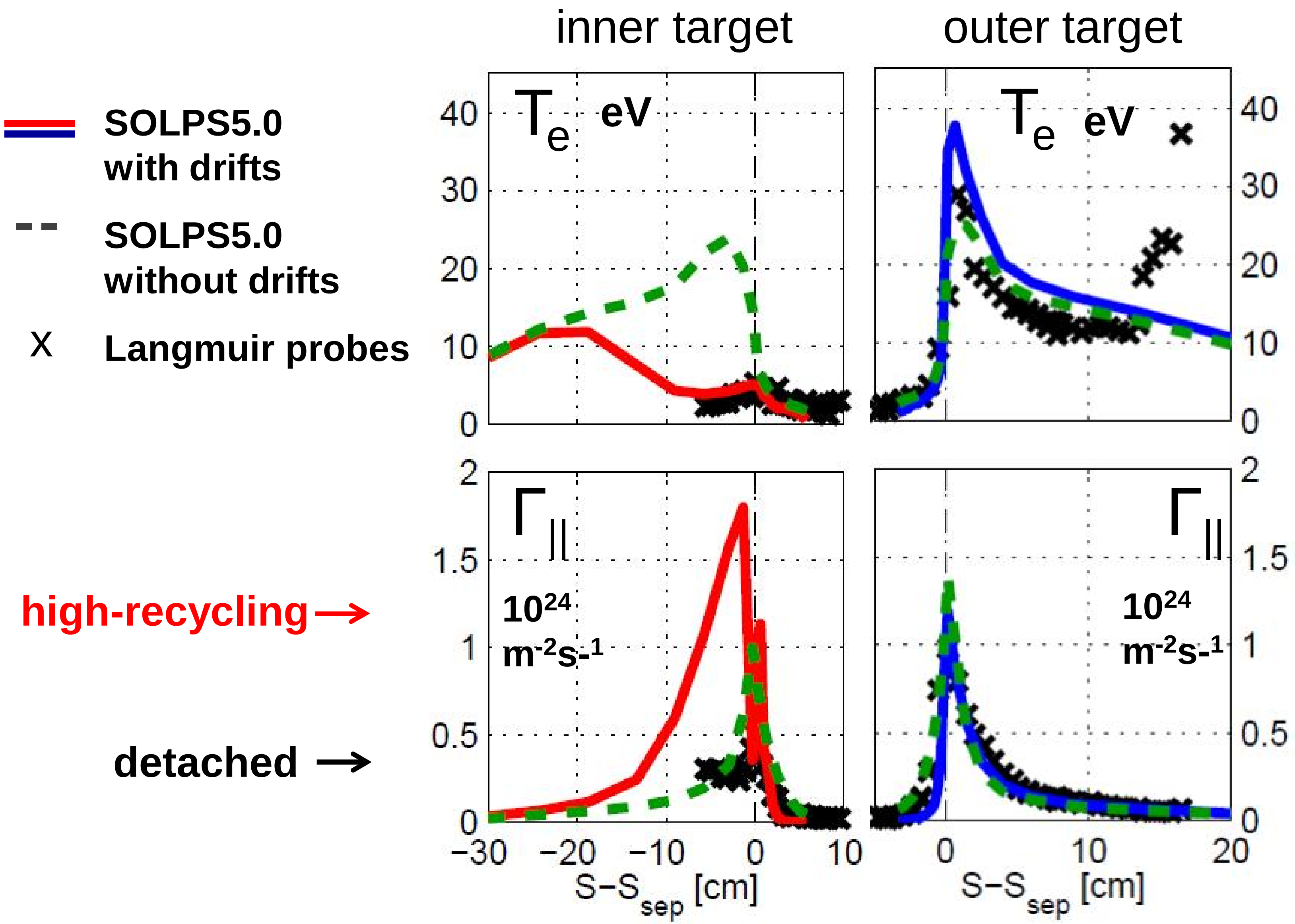
2. **High density**
   - Atomic physics important, weak drift effects at the target

modelled total ion fluxes



Low density: drifts provide a significantly cooler and denser inner divertor

Target measurements



Inner target measurements indicate detachment and do not confirm the high $\Gamma_{||}$

$\Rightarrow$ Either **drifts** or **particle exhaust** incorrectly modelled

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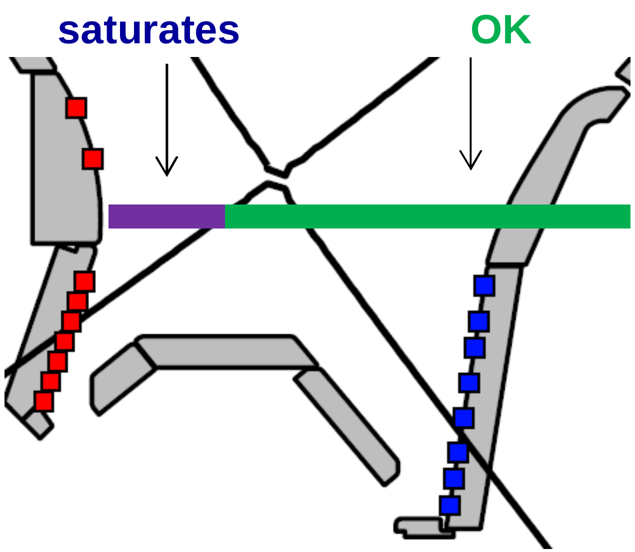
Low density: volume measurements confirm the modelled drift effects

Volume measurements

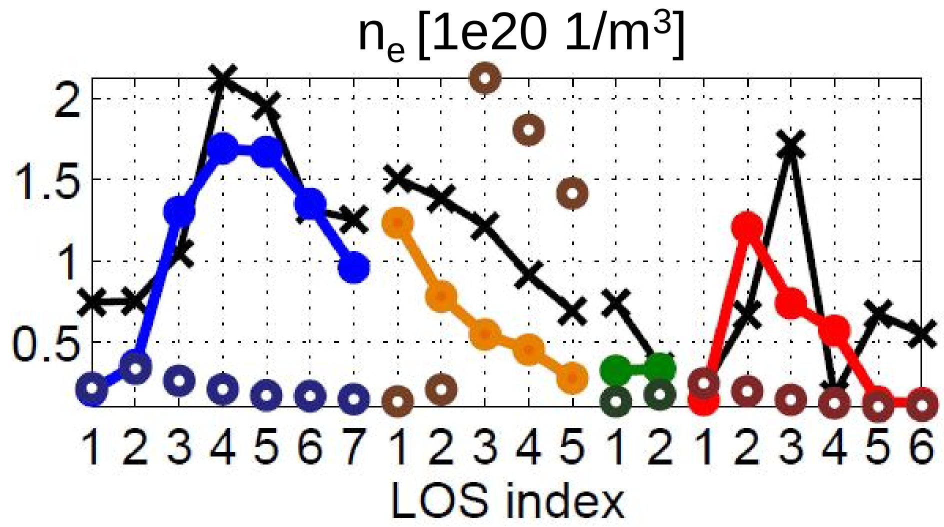
X-point probe measurements confirm **higher $\Gamma_{||}$ in the inner divertor**



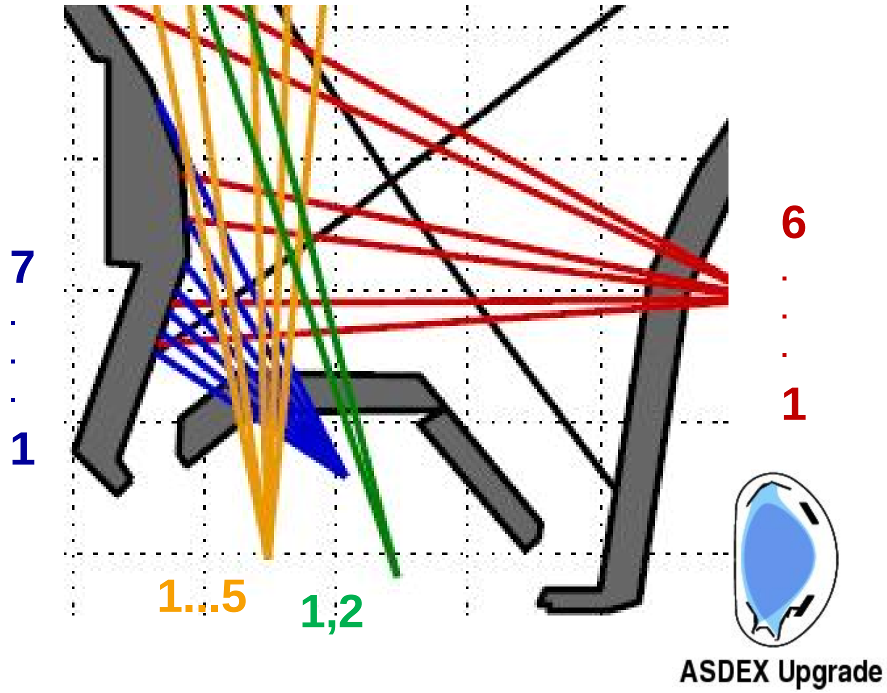
● **SOLPS5.0 with drifts**

o **SOLPS5.0 without drifts**

x **Spectroscopy**

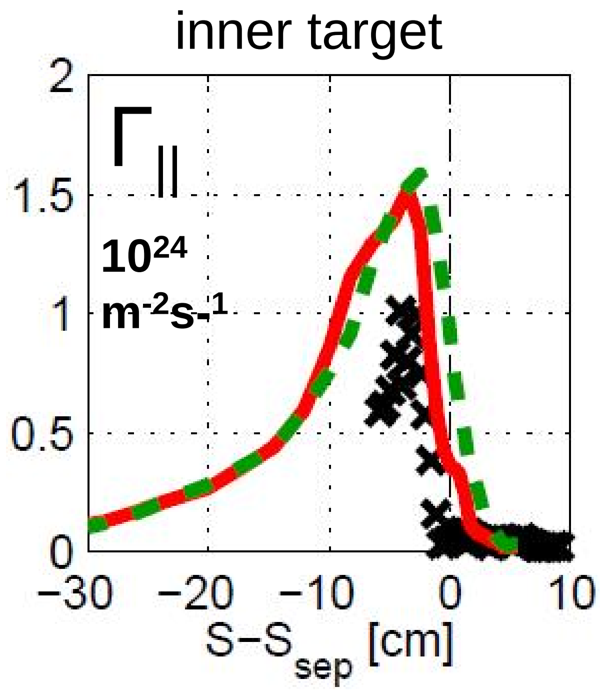


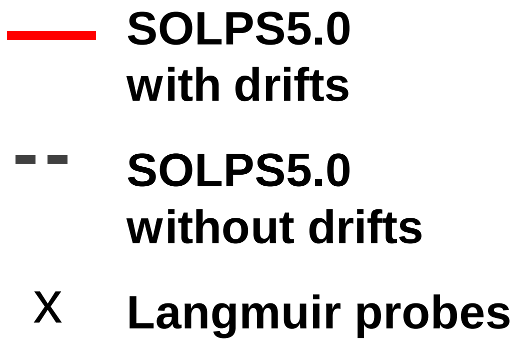
Stark broadening confirms the modelled **high densities in the inner divertor**



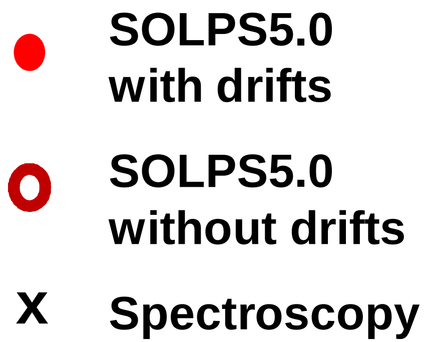
High density: small discrepancies in the inner divertor

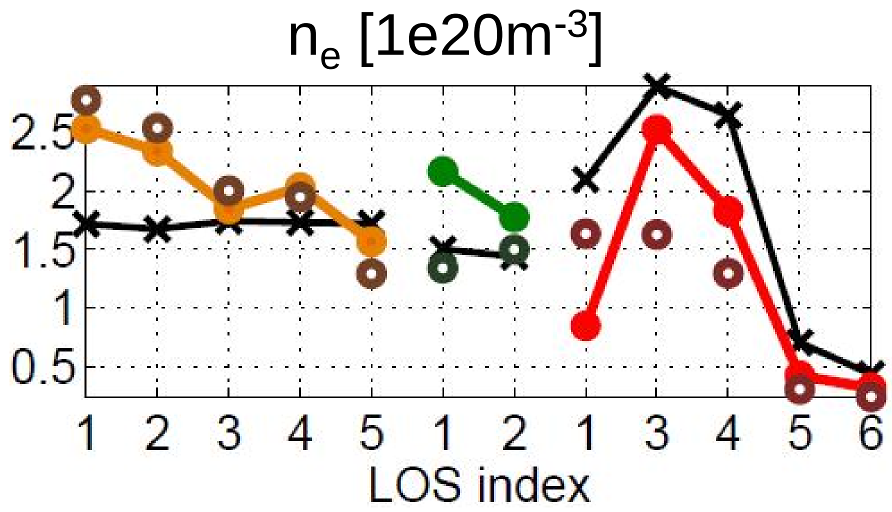
Target measurements

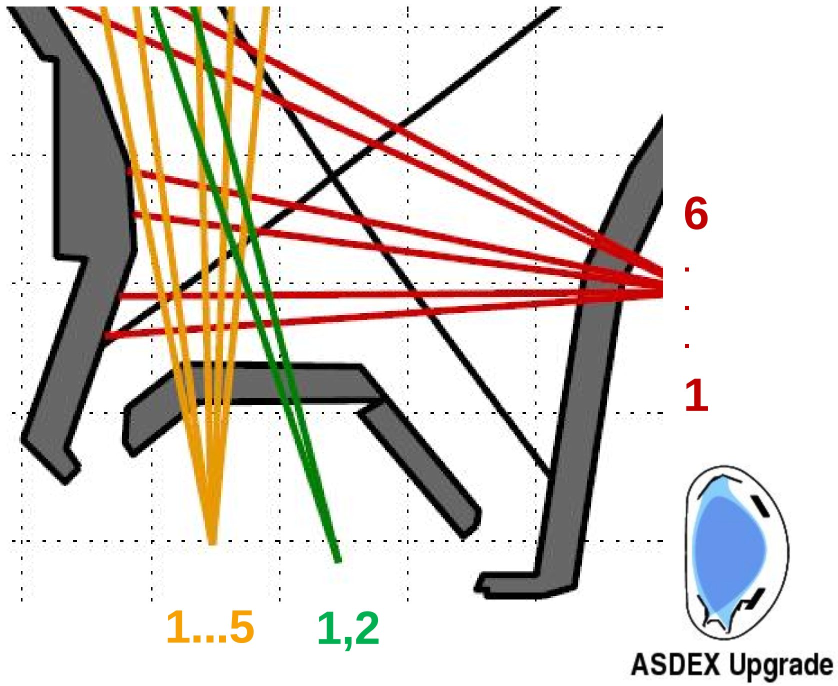




Volume measurements

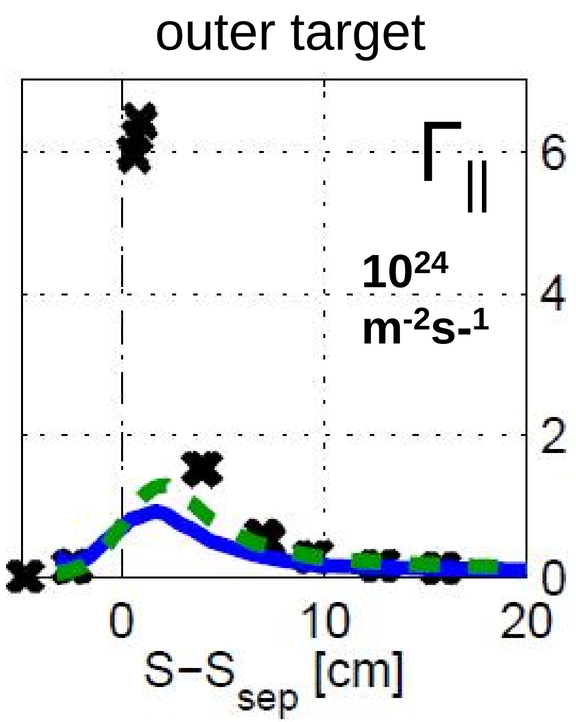






High density: strong discrepancies in outer divertor conditions with and without drifts

Target measurements



SOLPS5.0 with drifts

SOLPS5.0 without drifts

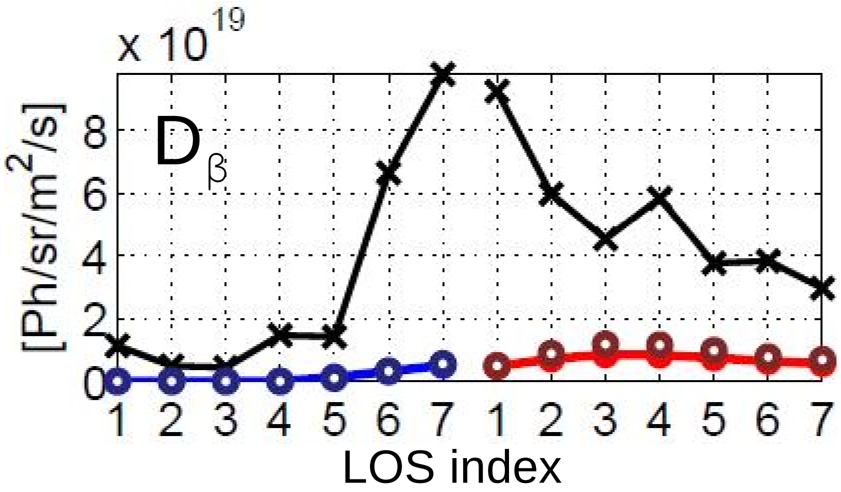
X **Langmuir probes**

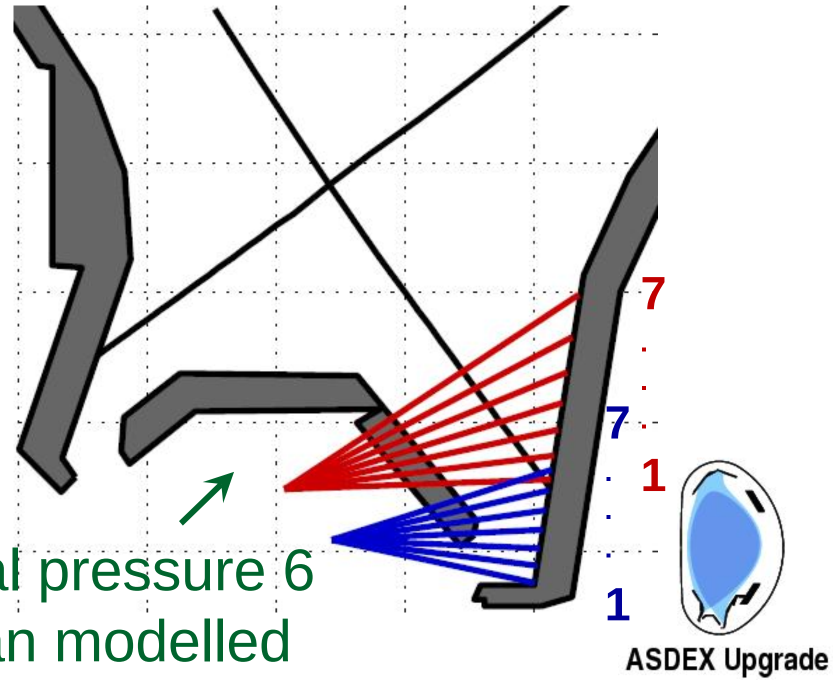
Volume measurements

SOLPS5.0 with drifts

SOLPS5.0 without drifts

x **Spectroscopy**

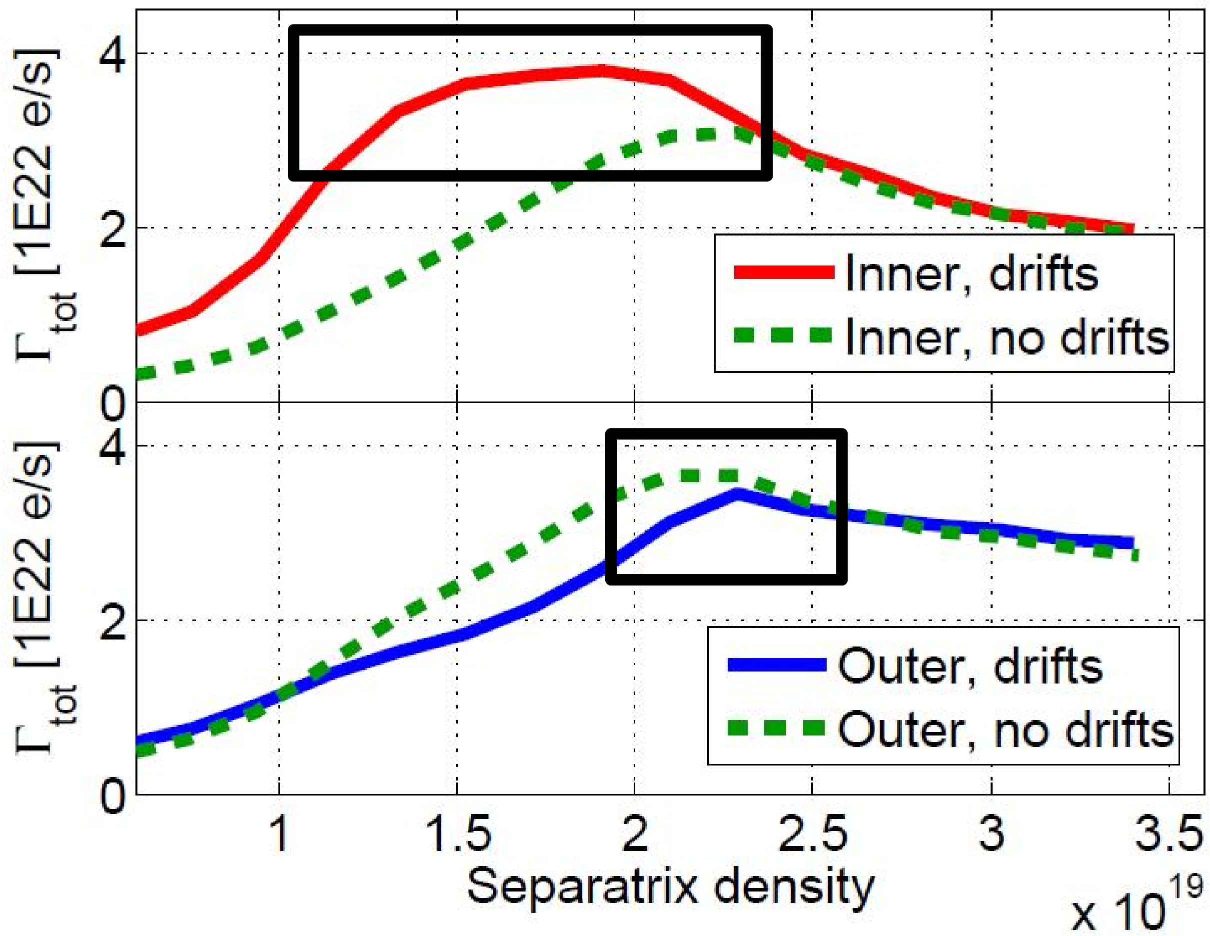




Measured neutral pressure 6 times higher than modelled

Observed discrepancies

modelled total ion fluxes



The modelling **overestimates** the inner target peak ion flux by factors 2-3

The modelling **underestimates** the outer target peak ion flux by a factor of 6

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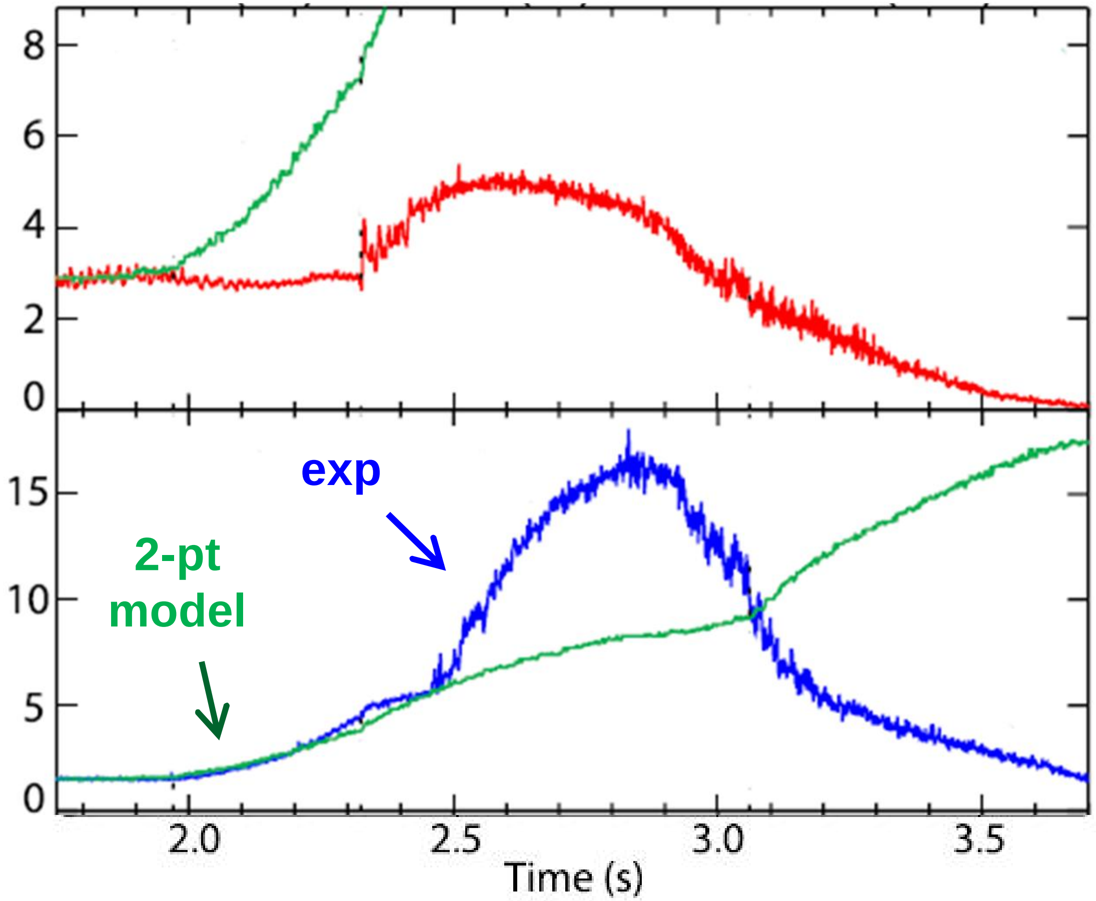
Problematic regimes encountered when the measurements deviate from the simple 2-pt model

Measured Γ_{tot} inner / outer

vs. 2-pt model $\Gamma \propto n^2$



S. Potzel et al, Nucl. Fus. 2014

Points towards an important role of **plasma-neutral interaction and atomic processes**

- Radiation losses
- Momentum losses
- Volume recombination
- (or convection)

$\Rightarrow$ Reasons for the discrepancies are unclear*

$\Rightarrow$ Not likely to be due to drifts

*M. Wischmeier et al, J. Nucl. Mat. 2011

ASDEX Upgrade

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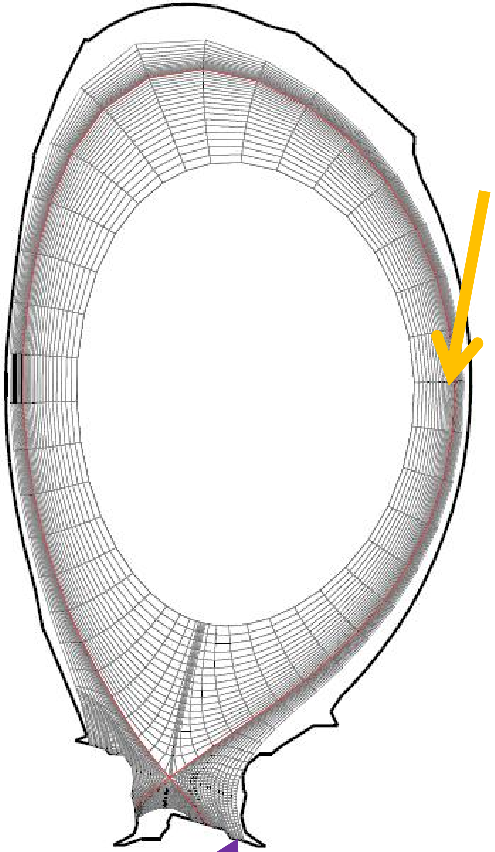
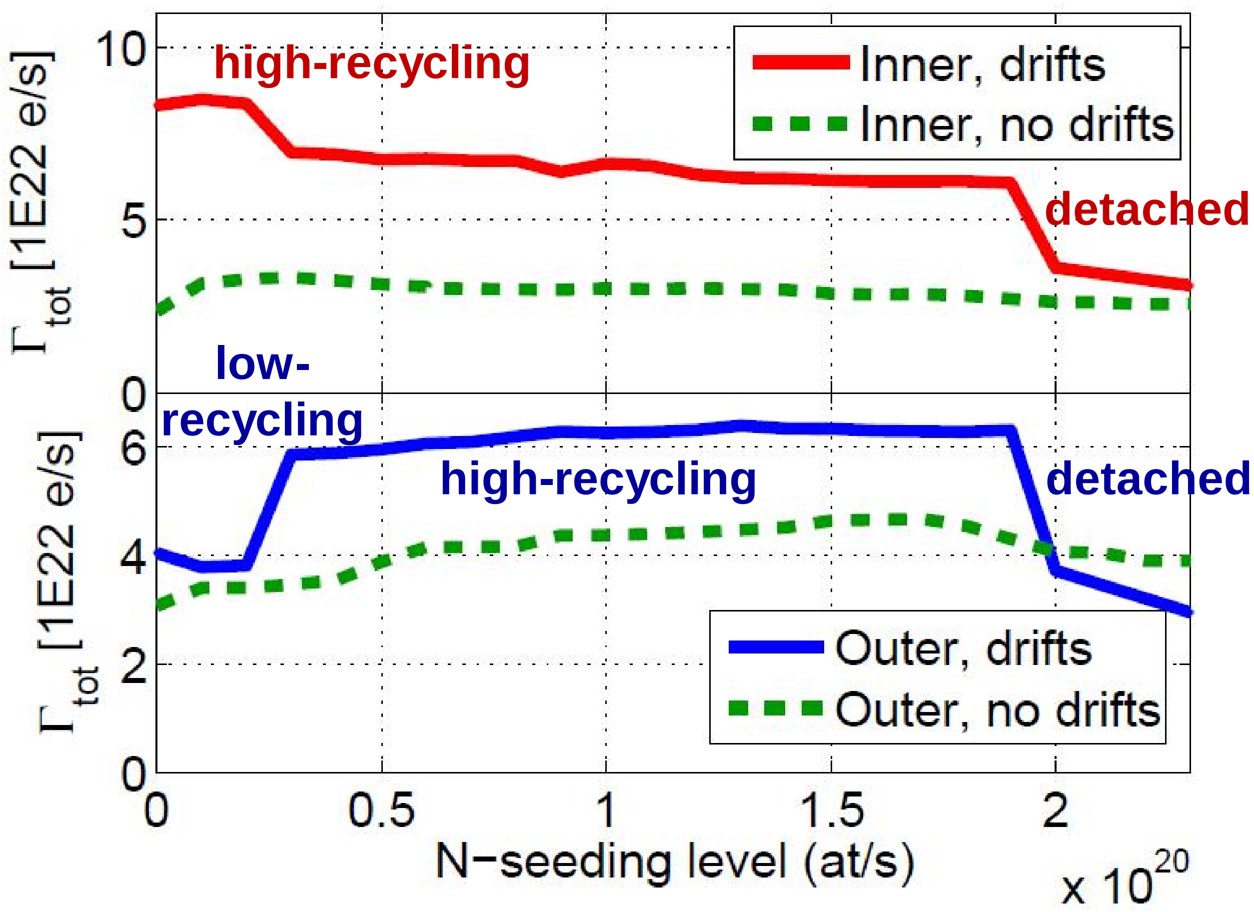
Drift effects are large throughout a N-seeding scan at low density



modelled total ion fluxes

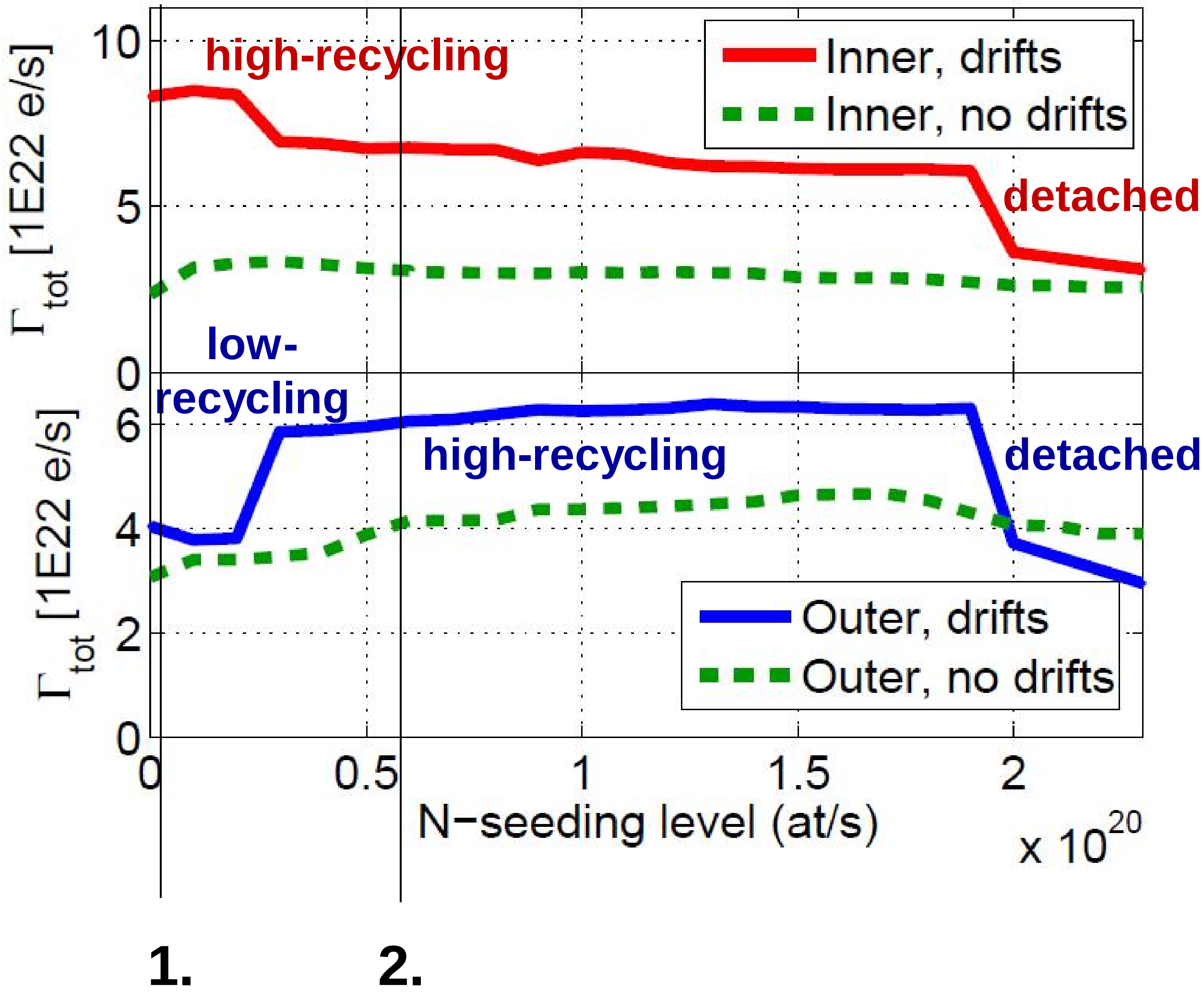


2 regimes considered in detail

1. **No seeding**
   - Strong drift effects in the inner divertor, similar to AUG

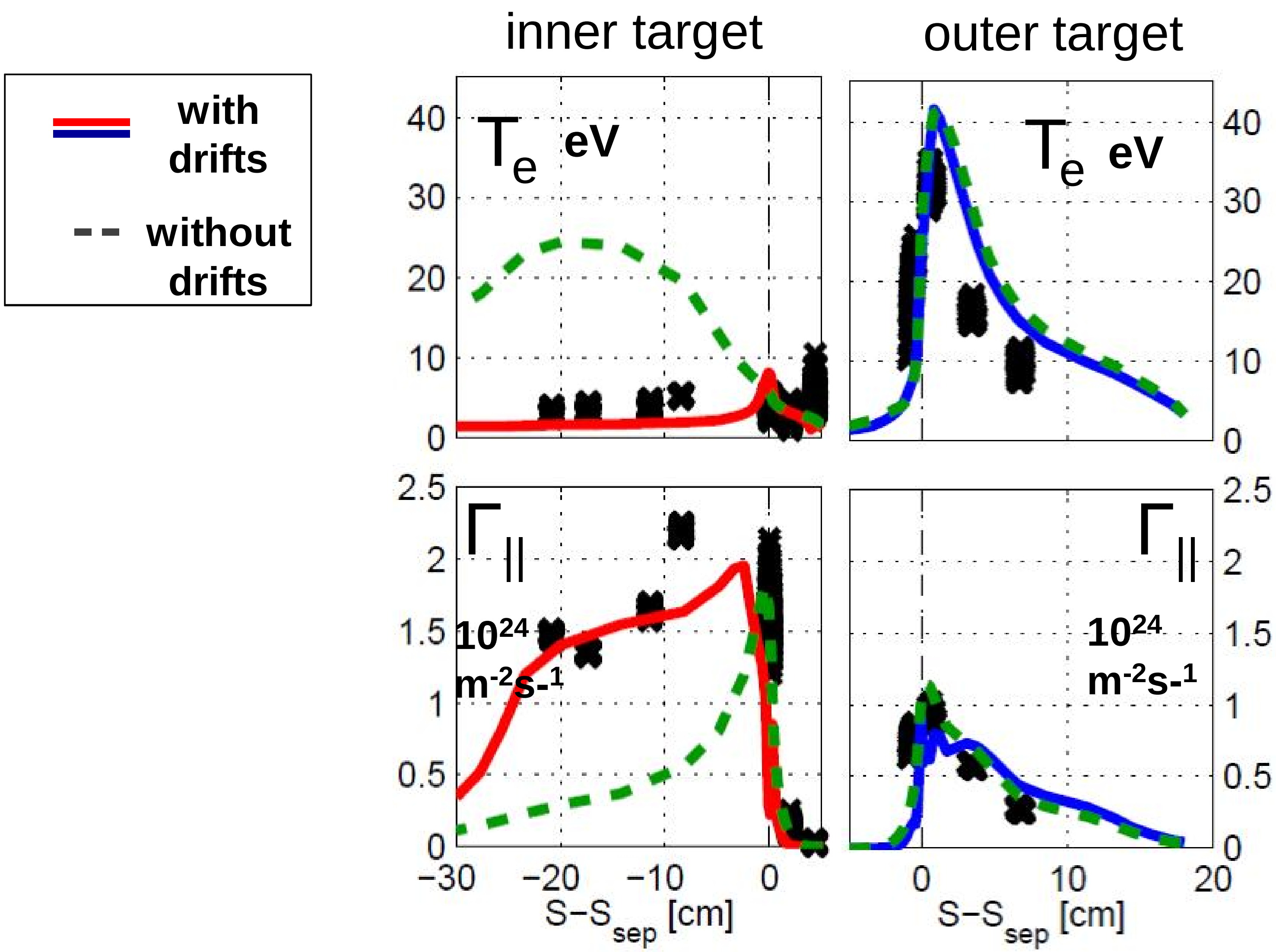
2. **N-seeding**
   - High-recycling conditions at low density

modelled total ion fluxes



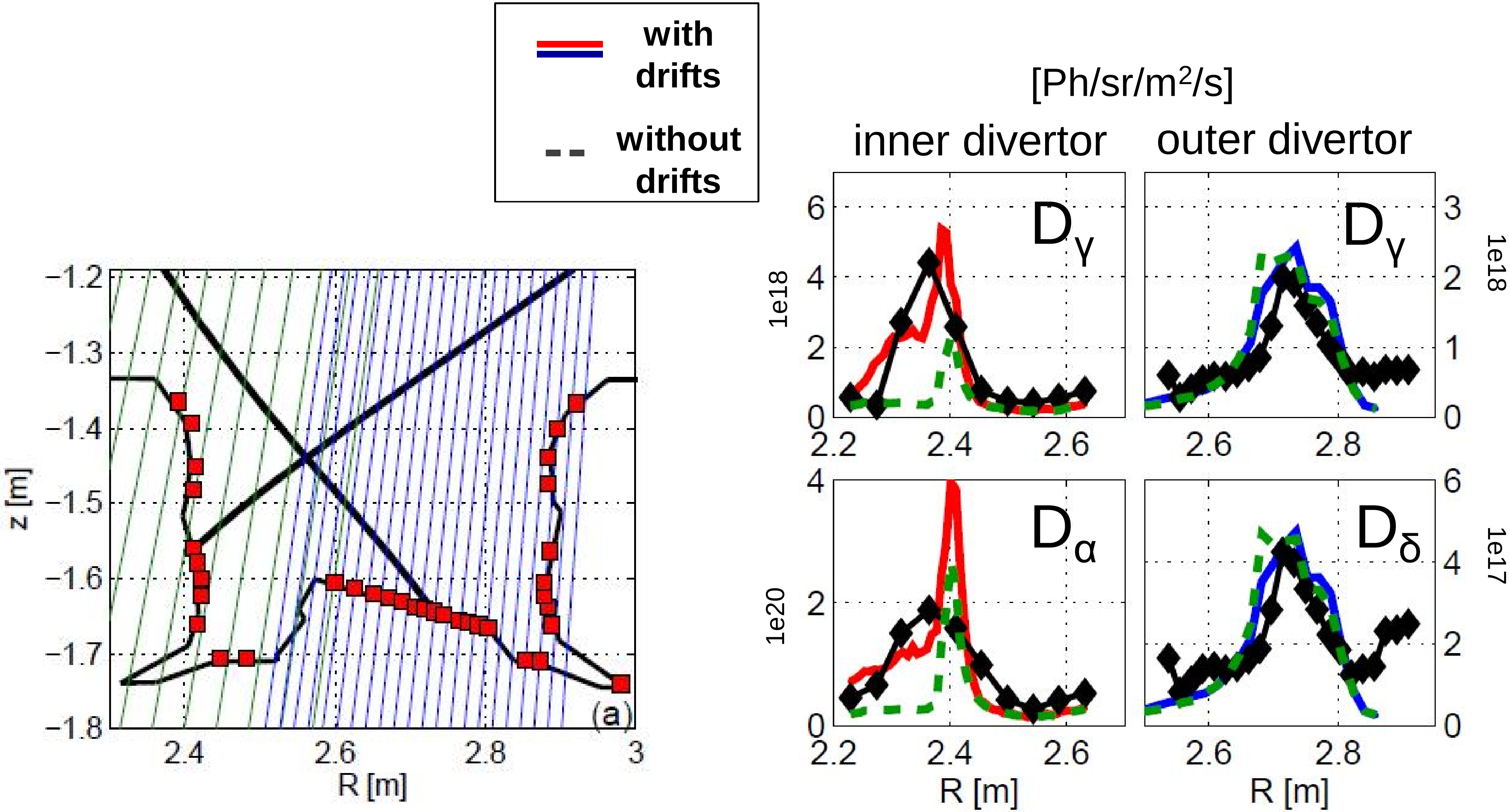
No impurities: drifts yield a cooler and denser inner divertor

Target measurements



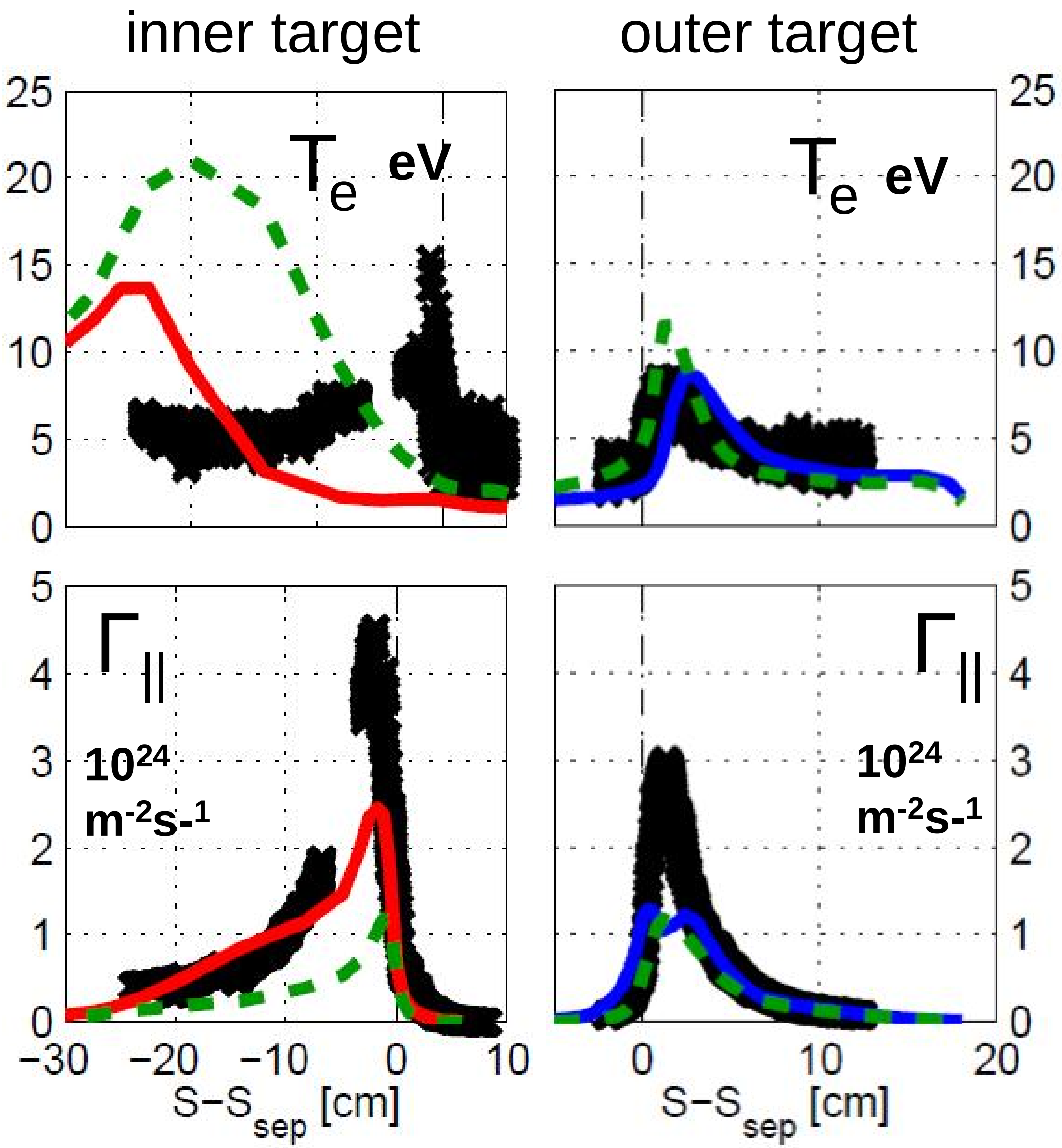
Attached inner divertor conditions confirmed by the measurements

Volume measurements



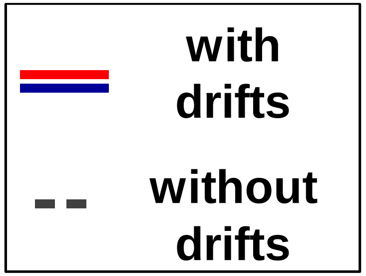
N seeding: drifts yield higher ion fluxes when 60% of the heating power is radiated

Target measurements



Drifts increase Γ_{tot} at both targets

The peak $\Gamma_{||}$ is still underestimated by a factor of 2



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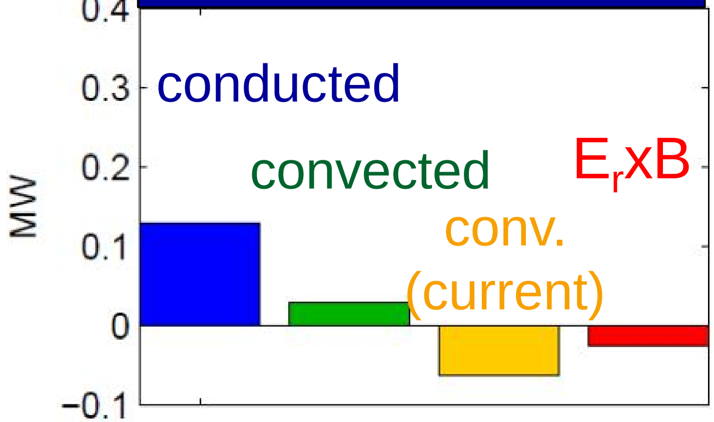
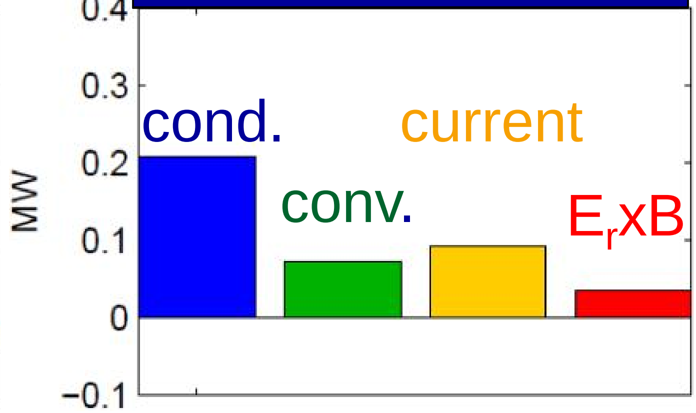
Low density: asymmetries are caused by E_r and currents

1. **Poloidal ExB drifts and currents in the SOL** transport power from the inner divertor to the outer divertor

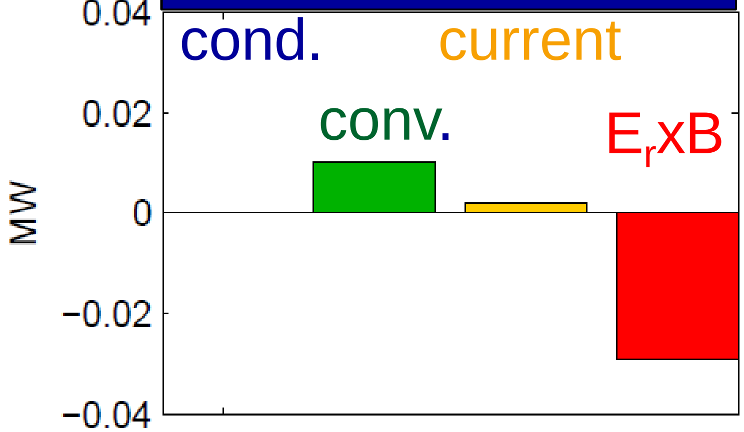
Heat flux to inner divertor (15%)



Heat flux to outer divertor (85%)



Heat flux through the PFR to outer divertor



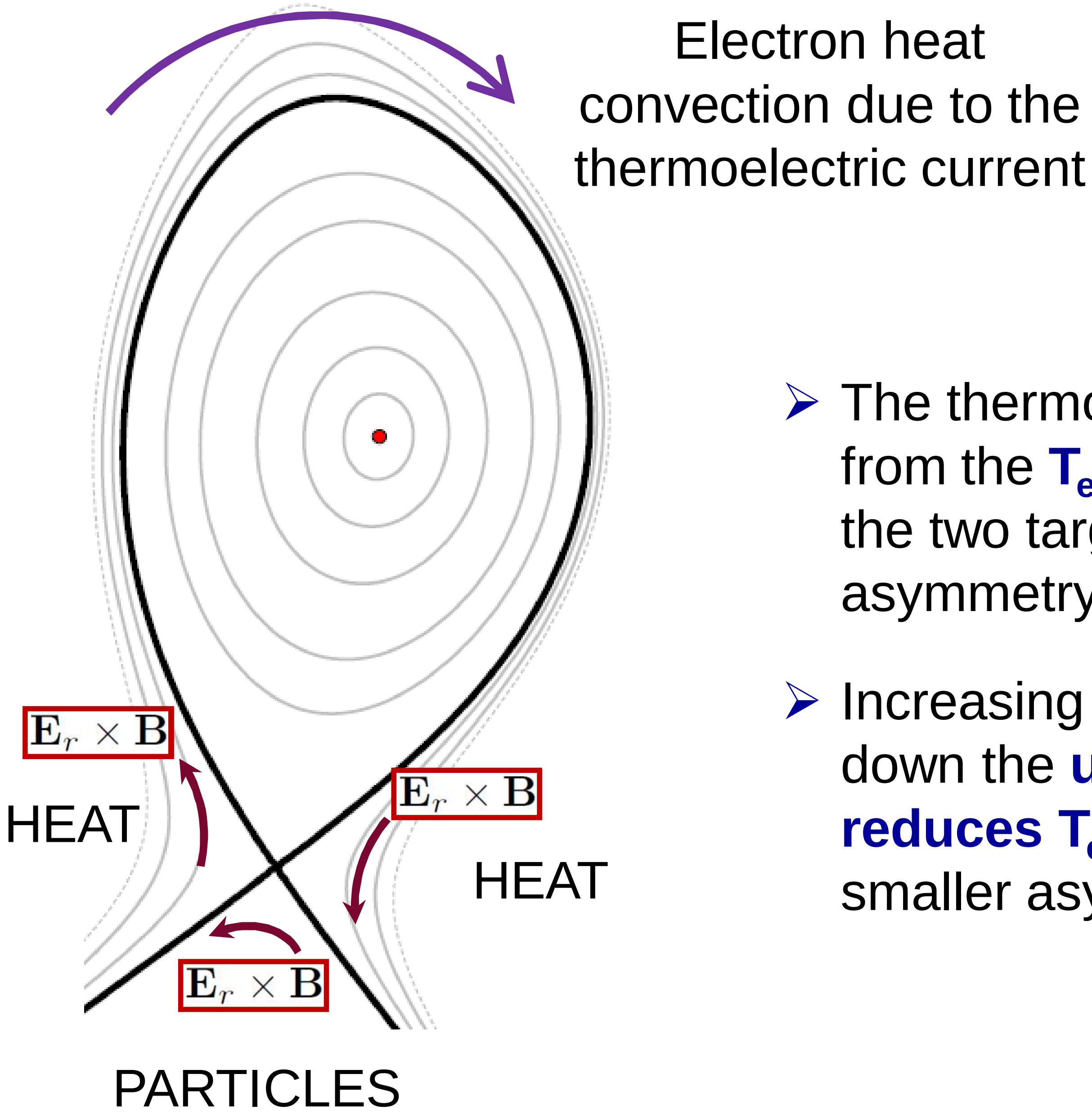
2. The **ExB drift in the PFR** transports particles from the outer divertor to the inner divertor

Diamagnetic drifts affect the level of divertor heat flux, but not the in-out asymmetry

See also:
T. Rognlien et al, J. Nucl. Mat. 1997
V. Rozhansky et al, Nucl. Fus. 2012

ASDEX Upgrade

Summary of ExB drift effects



- The thermoelectric current arises from the **T_e asymmetry** between the two targets and amplifies the asymmetry caused by the ExB drifts
- Increasing discharge density cools down the **upstream SOL**, which **reduces T_e gradients** and leads to smaller asymmetries

ASDEX Upgrade

Conclusions

ExB drifts and currents can lead to divertor asymmetries in both ASDEX Upgrade and JET

- Effects depend on the operational regime (SOL gradients)
- Results support the on-going efforts to model drifts in JET (EDGE2D) and ITER (SOLPS-ITER)

Inclusion of drifts does not solve the existing problems in reproducing high-density and detached conditions

- Points towards problems in plasma-neutral interaction and atomic processes
- Modelling other operational regimes (e.g. H-mode) is a separate issue

SOL and divertor diagnostics play a crucial role in identifying missing physics

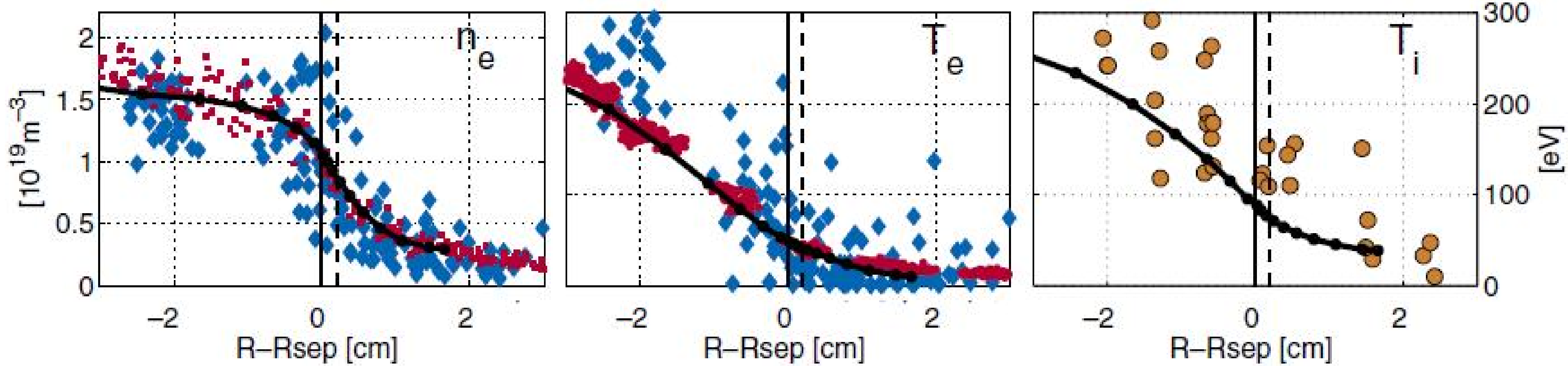
- **Measurements in the divertor volume** have enabled verifying the modelled asymmetries at low density due to drifts and currents
- Still lacking **T_e measurements** in the divertor volume

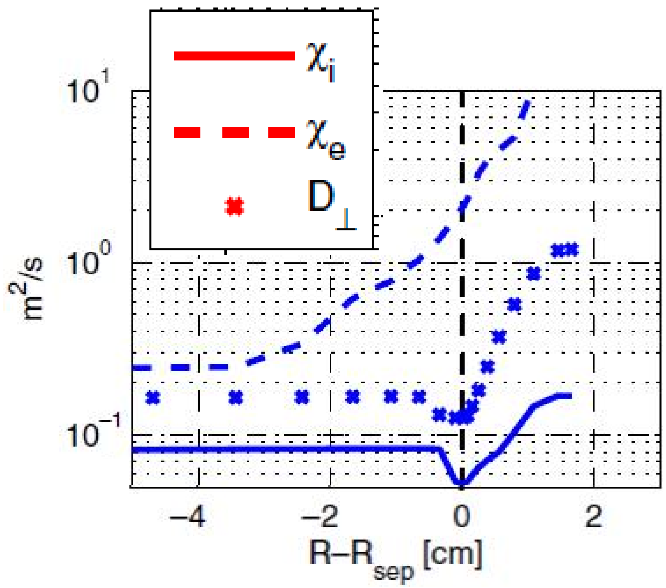
ASDEX Upgrade

Back-up slides

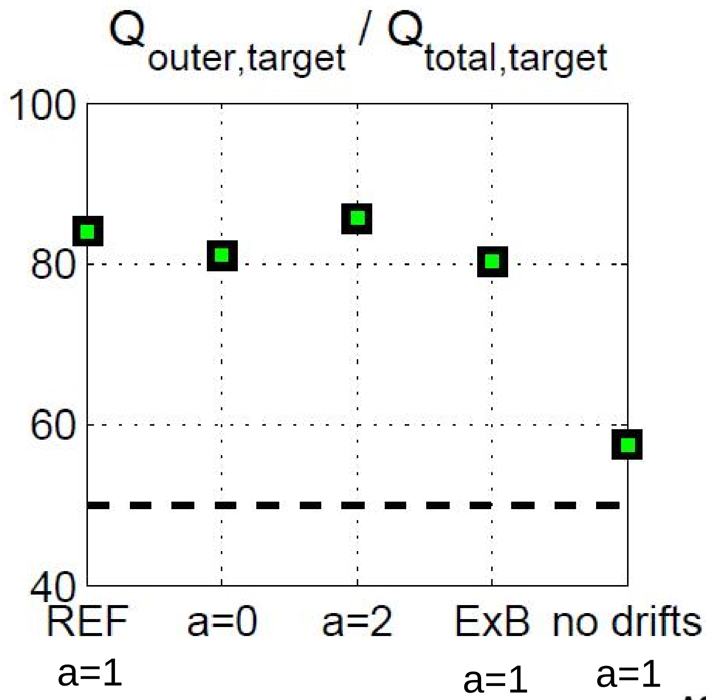
Typical transport assumptions

Upstream profiles:





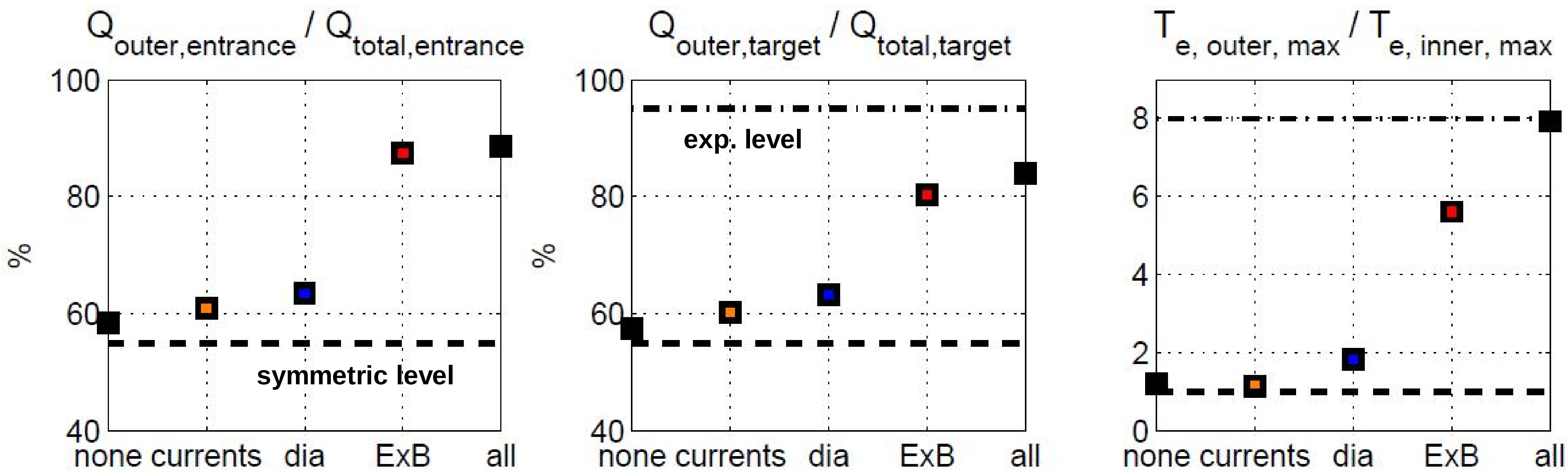
Poloidal variation: $\mathbf{B}^{-a}$ dependence



ASDEX Upgrade

L. Aho-Mantila et al, NF 2012

Drift effects in ASDEX Upgrade at low density

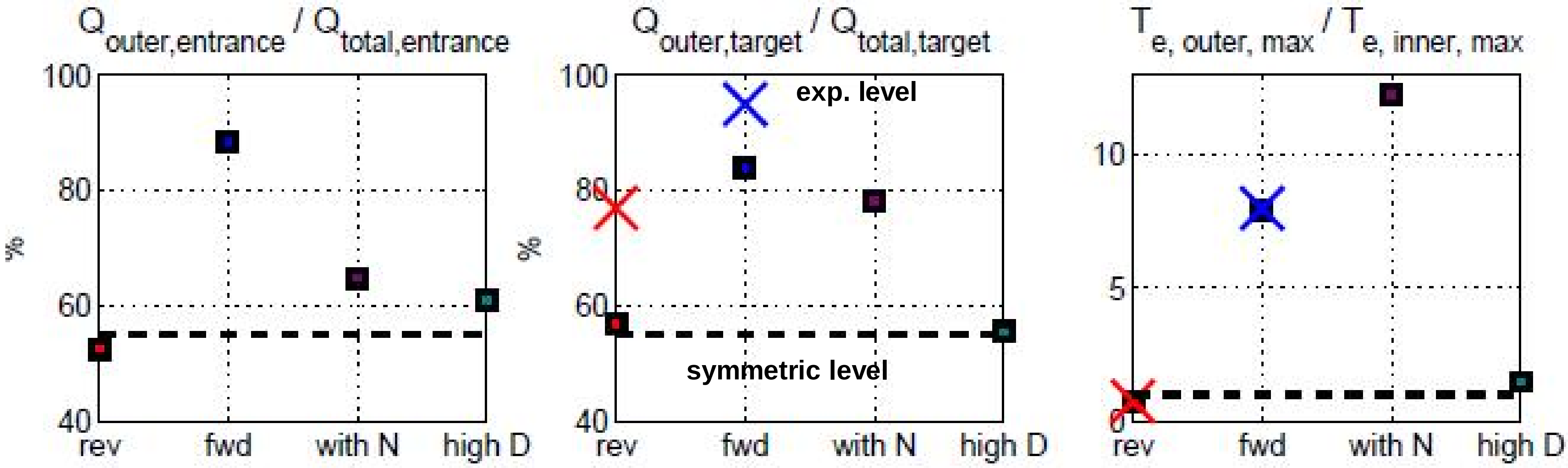


SOLPS runs with different physics included

none: no currents or drifts activated
currents: only currents activated, no drifts
dia: diamagnetic drifts and currents activated
ExB: ExB drifts and currents activated
all: ExB + diamagnetic drifts and currents

L. Aho-Mantila et al, EPS 2014

Asymmetries in different conditions

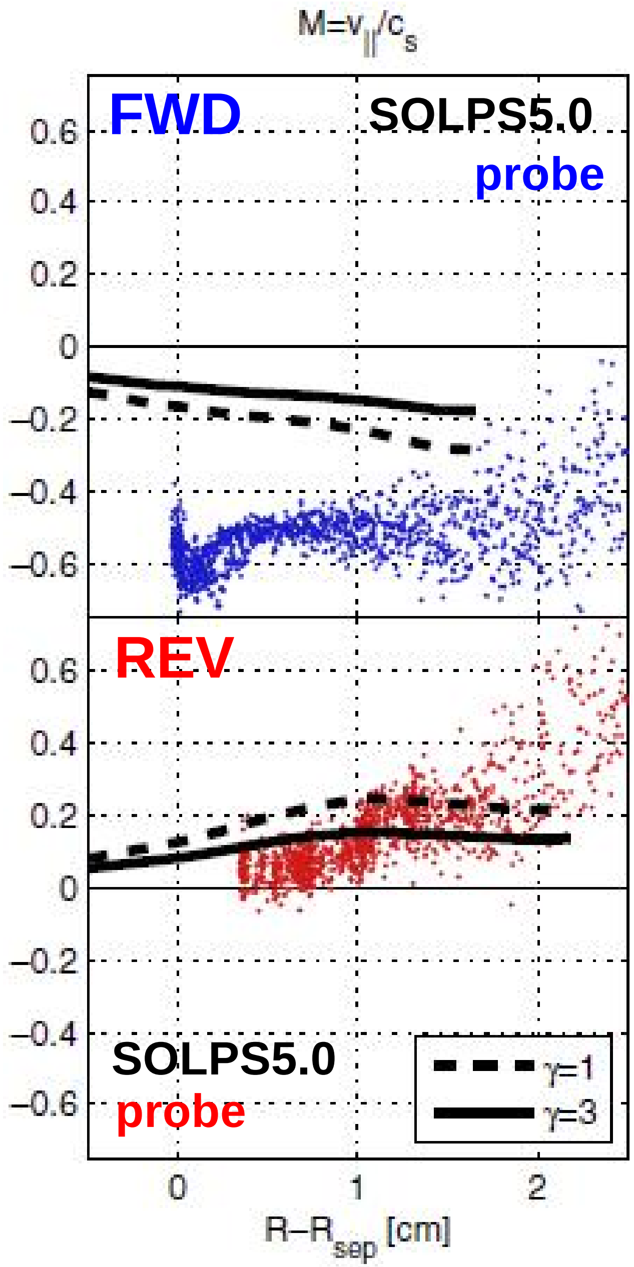


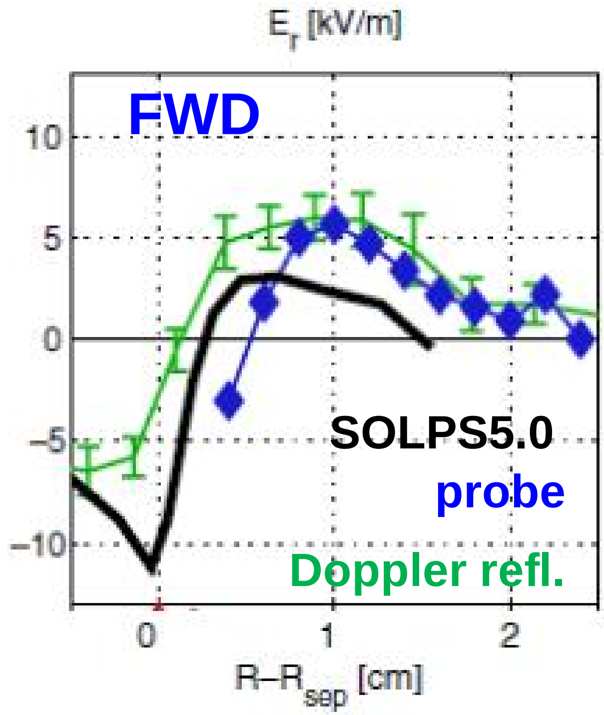
- **Field reversal** reduces the heat flux asymmetry and can reverse the peak T_e asymmetry
- **N-seeding** reduces the asymmetries at the divertor entrance, but the radiation losses are still higher in the inner divertor
- **Increased discharge density** cools down the SOL and both divertors, which reduces the asymmetries

L. Aho-Mantila et al, EPS 2014

E_r and flows

- Simulations underestimate flows in **forward field**
- Better match in **reversed field**





L. Aho-Mantila et al, NF 2012

ASDEX Upgrade