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New properties of the collisional sheath

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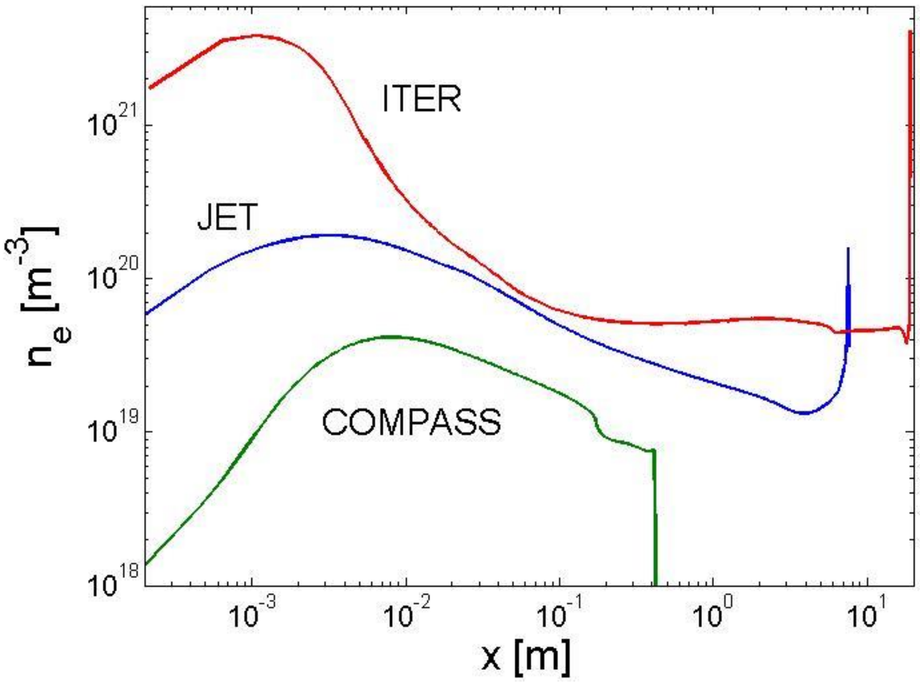
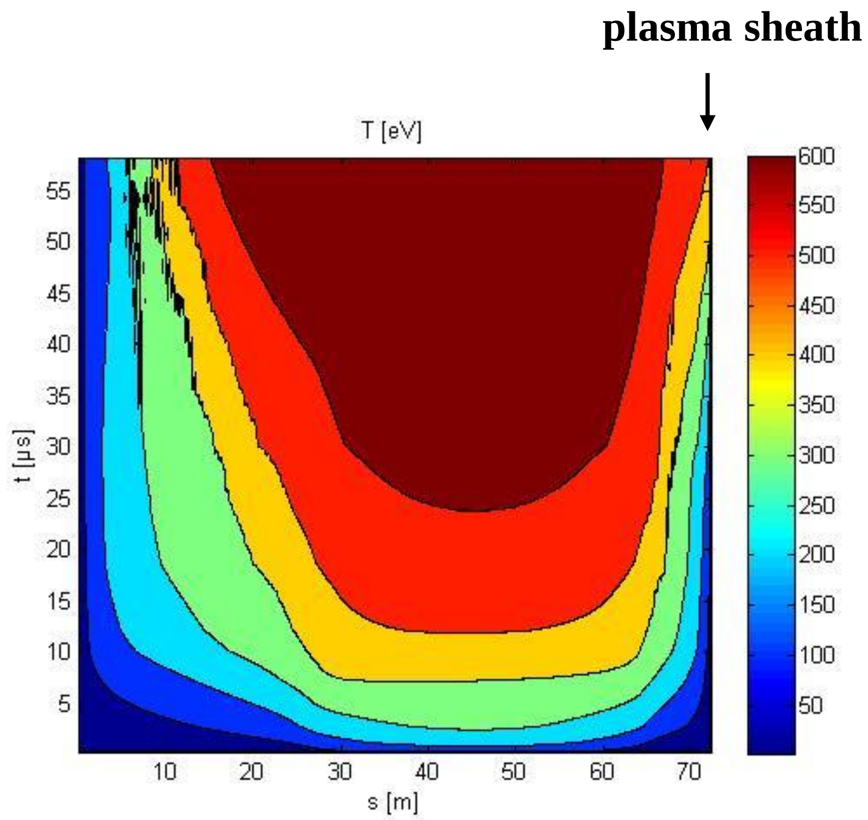
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

BIT1 related projects ran under IFERC-CSC

- SOL modelling; studying kinetic effects in the SOL, divertor power and particle loads, impurity erosion, ets
- Collisional plasma sheath modelling



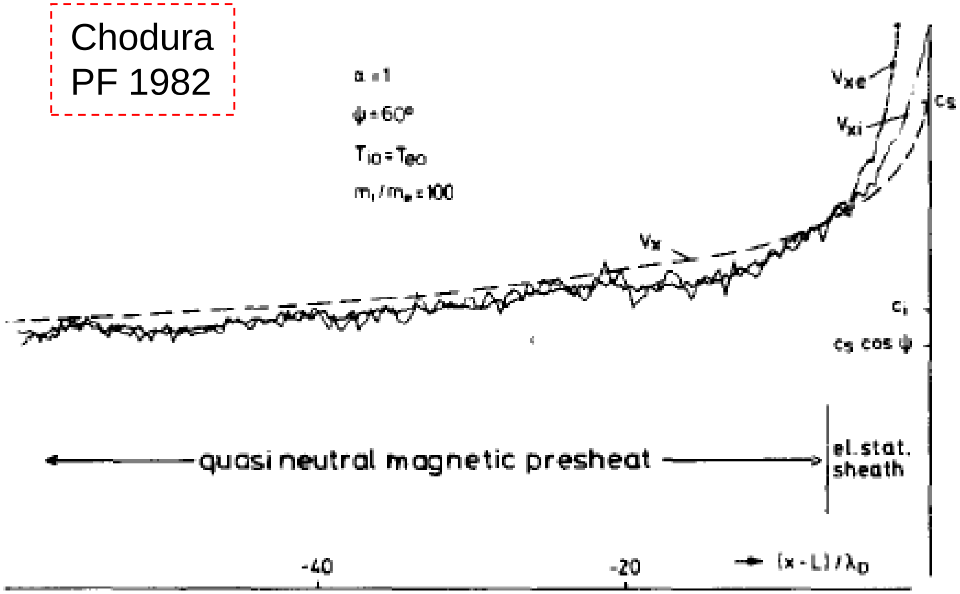


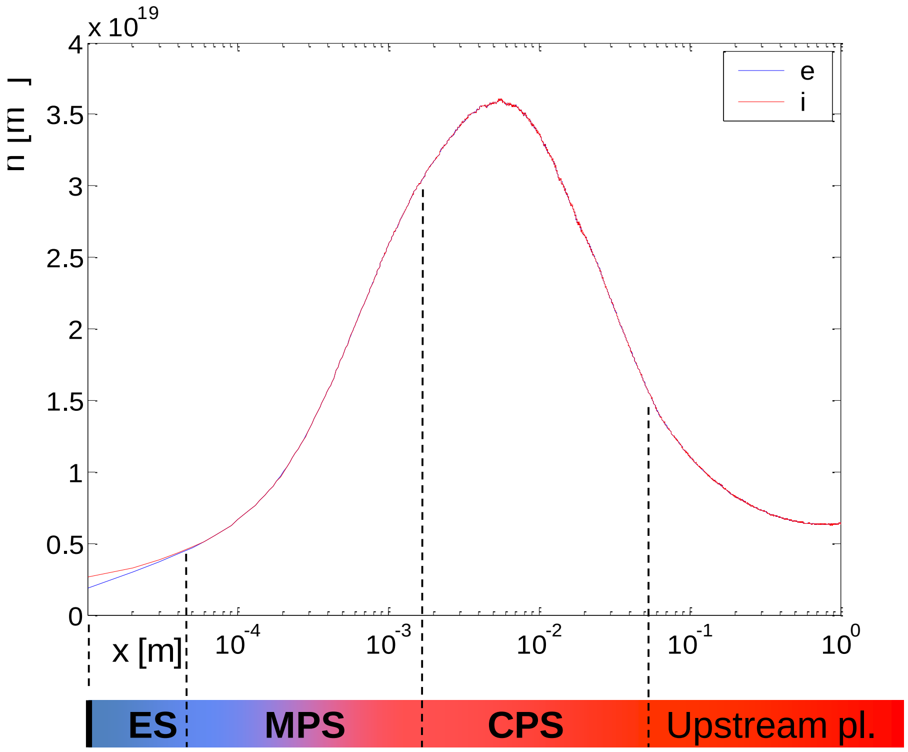
Density and temperature profiles in the stationary and ELM-ing SOLs.

Outline

- ✓ Motivation
- ✓ Discussion of obtained results
- ✓ Short description of the BIT1 (3) codes
- ✓ Conclusions
- ✓ On our experiance of running jobs under IFREC-CSC

What can be fundamentally new in plasma sheath model?





Plasma velocity and density profiles in the sheath obtained from PIC similations [Chodura PF 1982, Tskhakaya CPP 2012]

The scaling of the plasma sheath

classical plasma sheath

$$h \sim 10\mu \ll \lambda_D \sim \sqrt{T_e / n_e} \ll \rho_i \sim \sqrt{T_i m_i} / B \ll l_{mfp} \sim T^2 / n_e$$

$$\Downarrow$$

$$\frac{J_{\parallel,i}}{enC_s} = M_\parallel = 1$$ ⇦ **Particle flux to the wall**

$$\frac{Q_{div}}{J_i T_e} = \gamma \sim 10$$ ⇦ **Heat flux to the wall**

$$C_s = \sqrt{\frac{T_e + T_i}{m_i}}$$

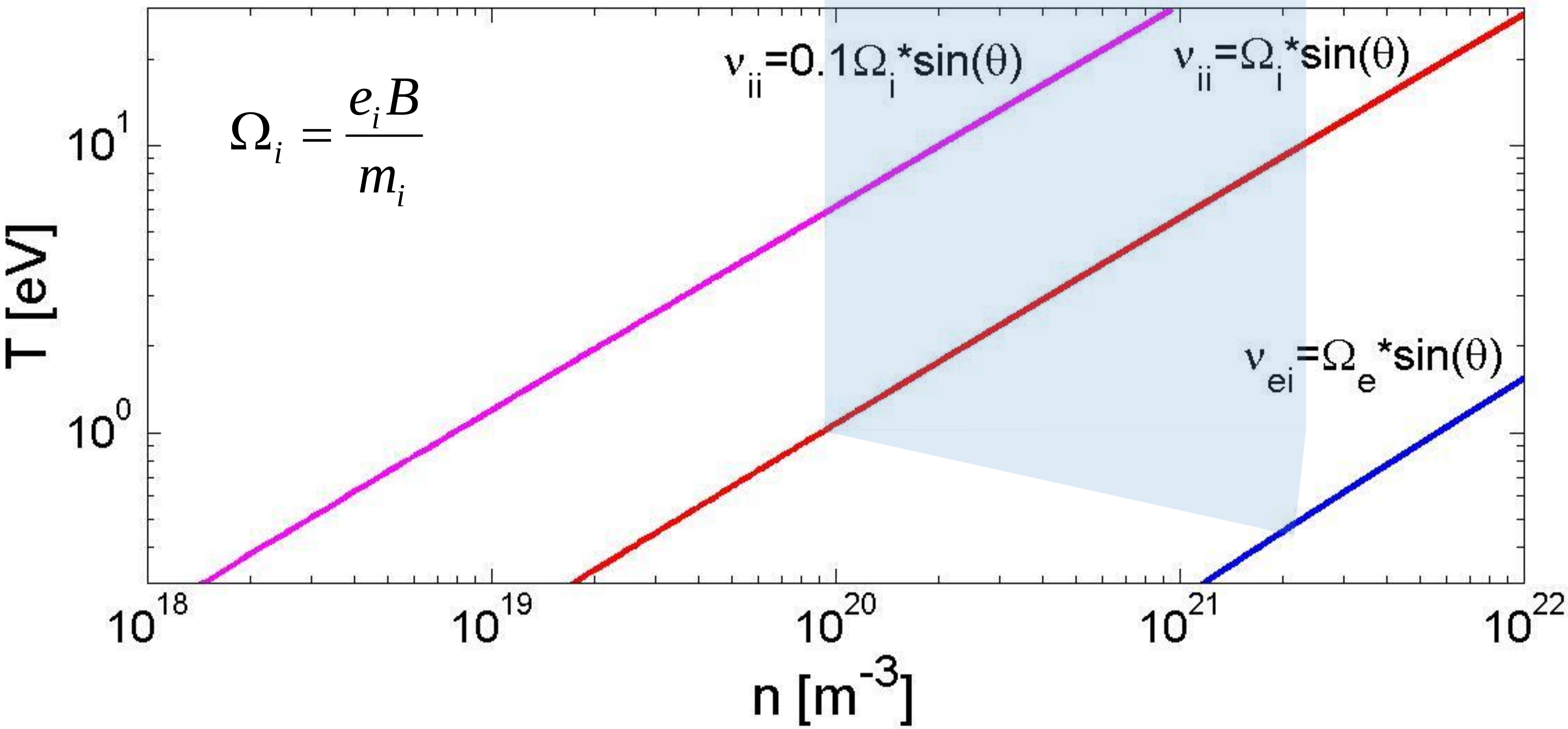
What happens when this scaling is not valid?

Sheath collisionality

[Tskhakaya PSI 2018]

$$\frac{\Gamma_{\perp}^{eff}}{\Gamma_{\parallel}\sin(\theta)} \sim \frac{\nu}{\Omega\sin(\theta)}$$

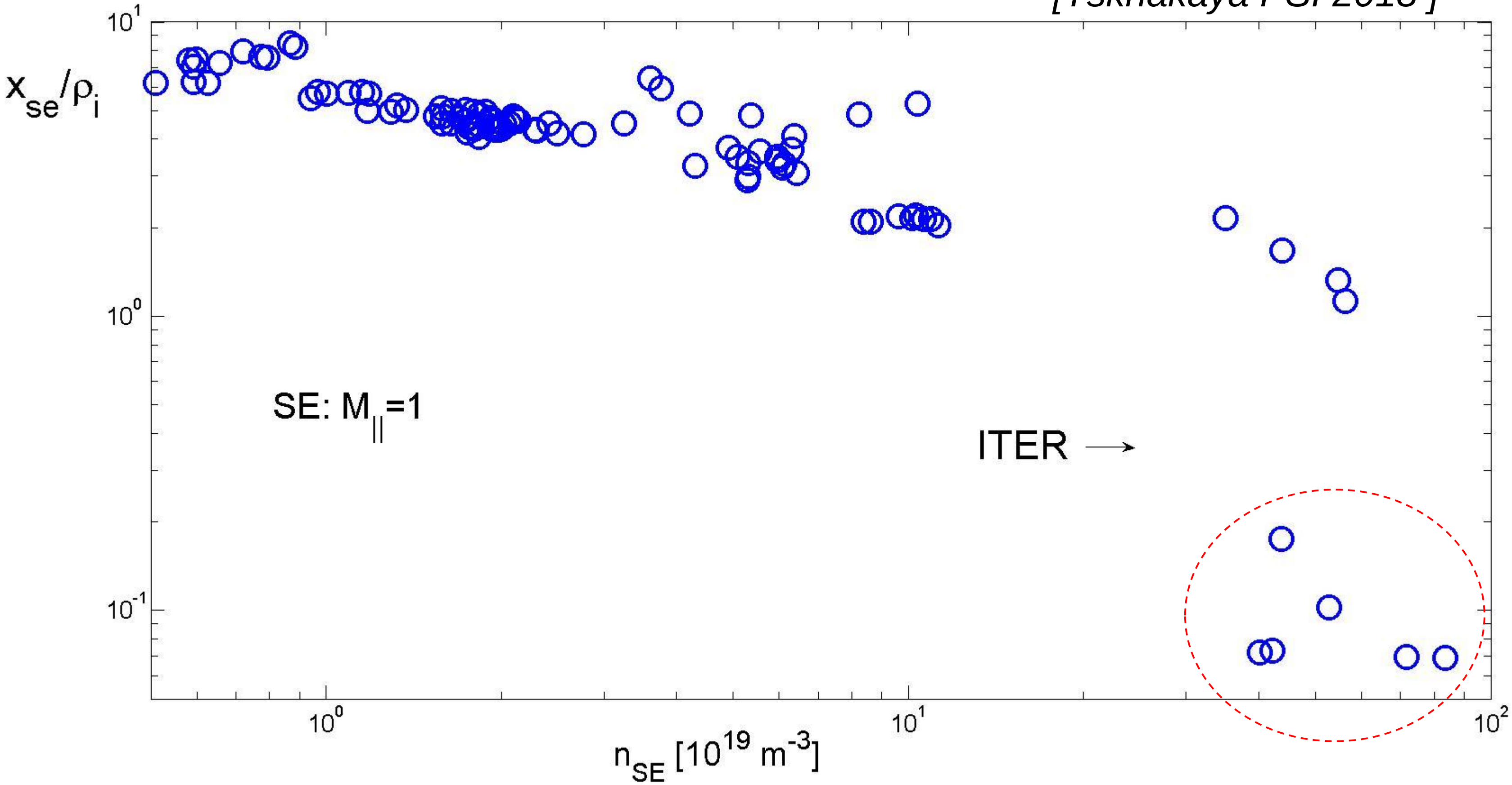
ITER, DEMO



$$\Omega_i = \frac{e_i B}{m_i}$$

Motivation

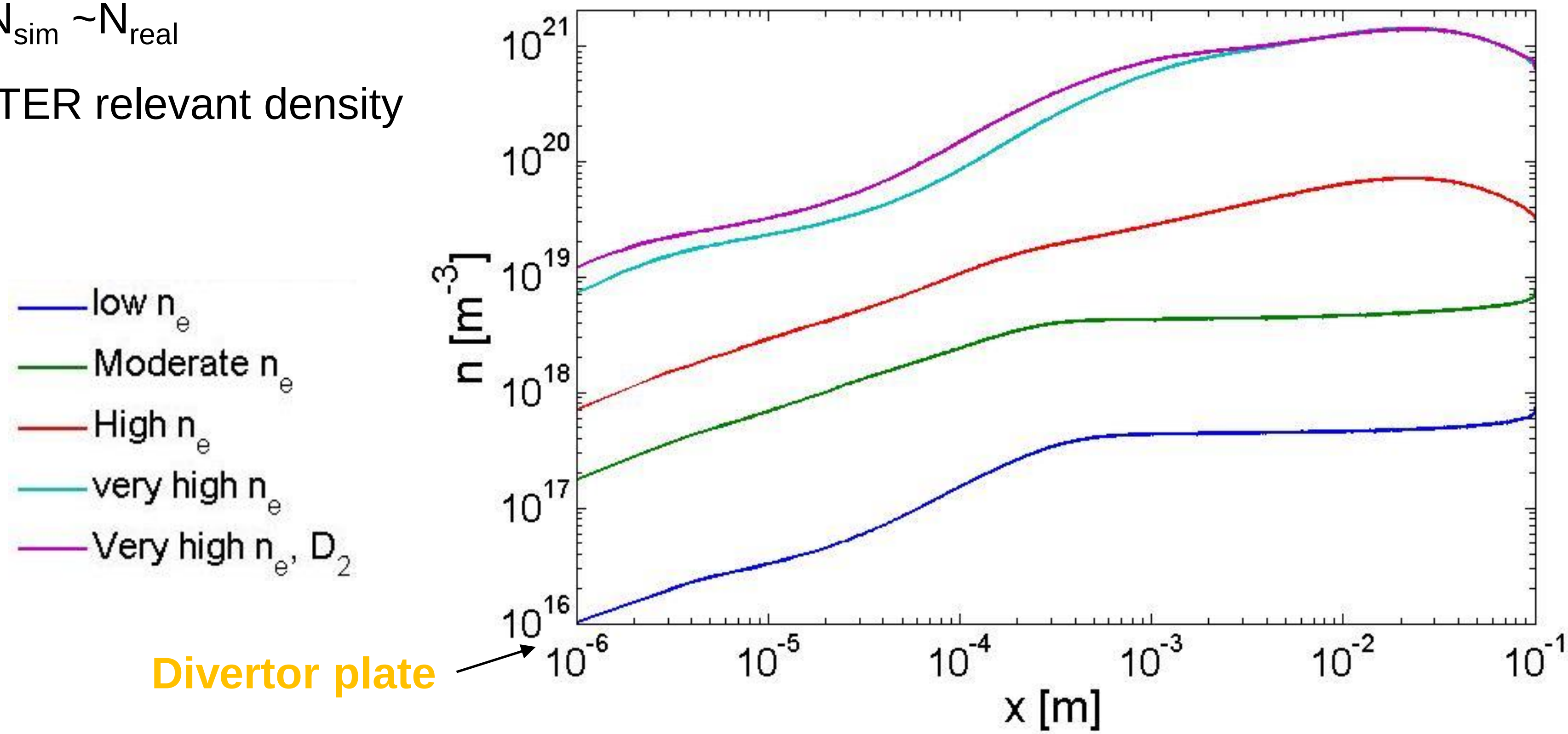
[Tskhakaya PSI 2018]



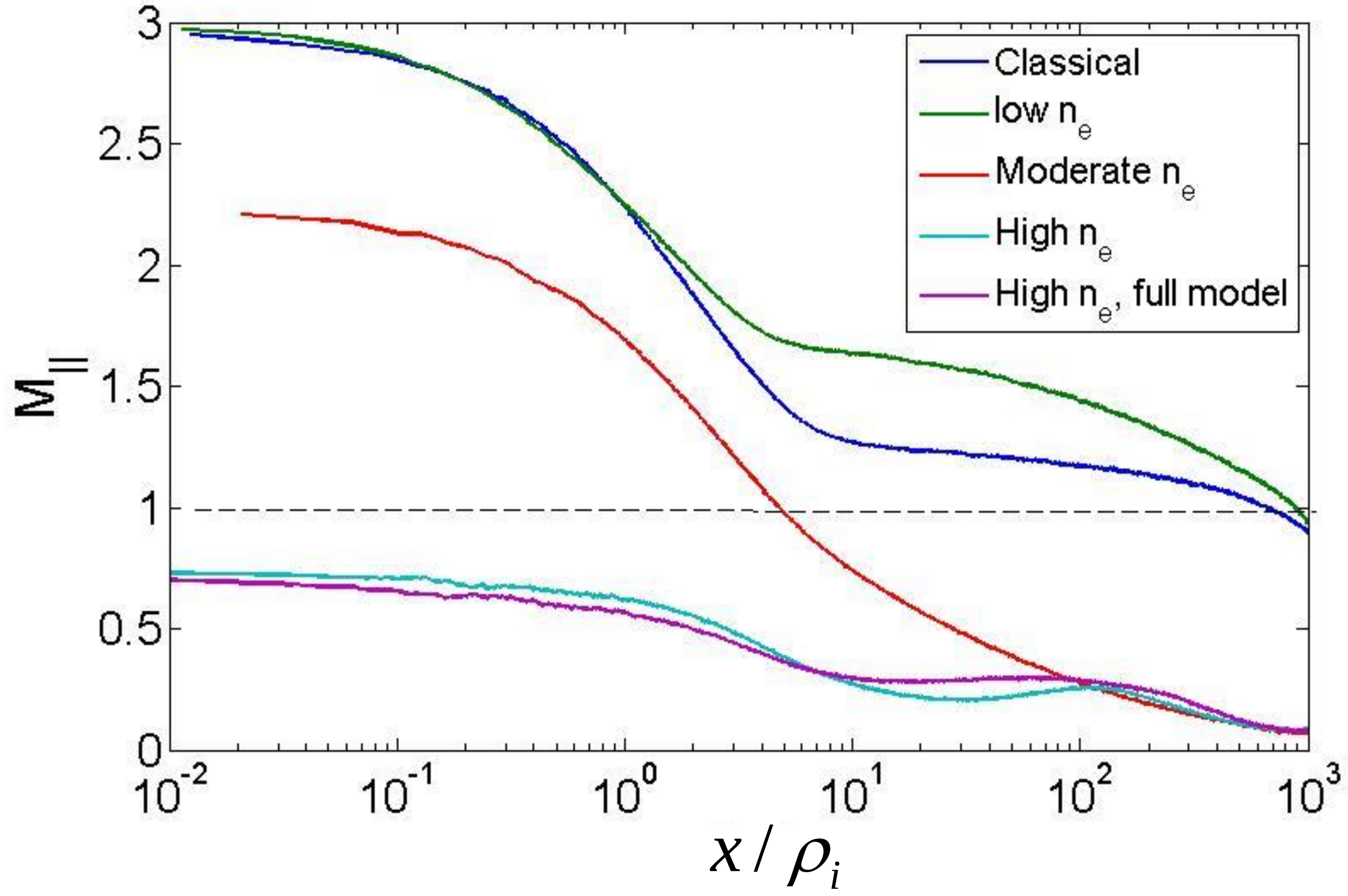
Simulation parameters: R= 0 – 1, Z_{eff} = 1 – 1.5, θ= 1.5° - 6°

Modelling of divertor plasmas

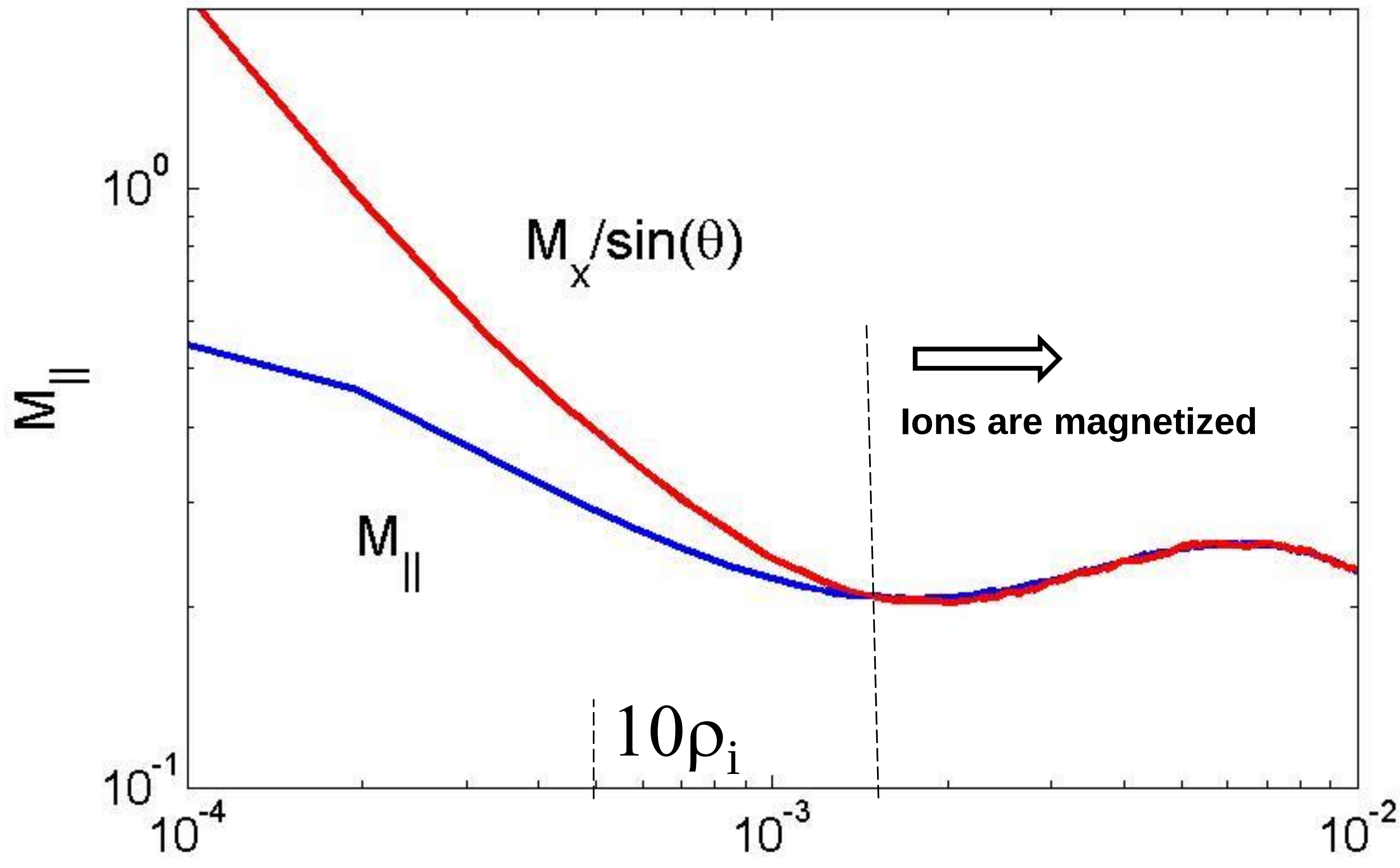
- ✓ Different densities, with and without neutrals and molecules
- ✓ Number of simulated cells: 3×10^5 - 10^6
- ✓ CPU time: 10^5 - 5×10^6
- ✓ N_{sim} ~N_{real}
- ✓ ITER relevant density



Mach number

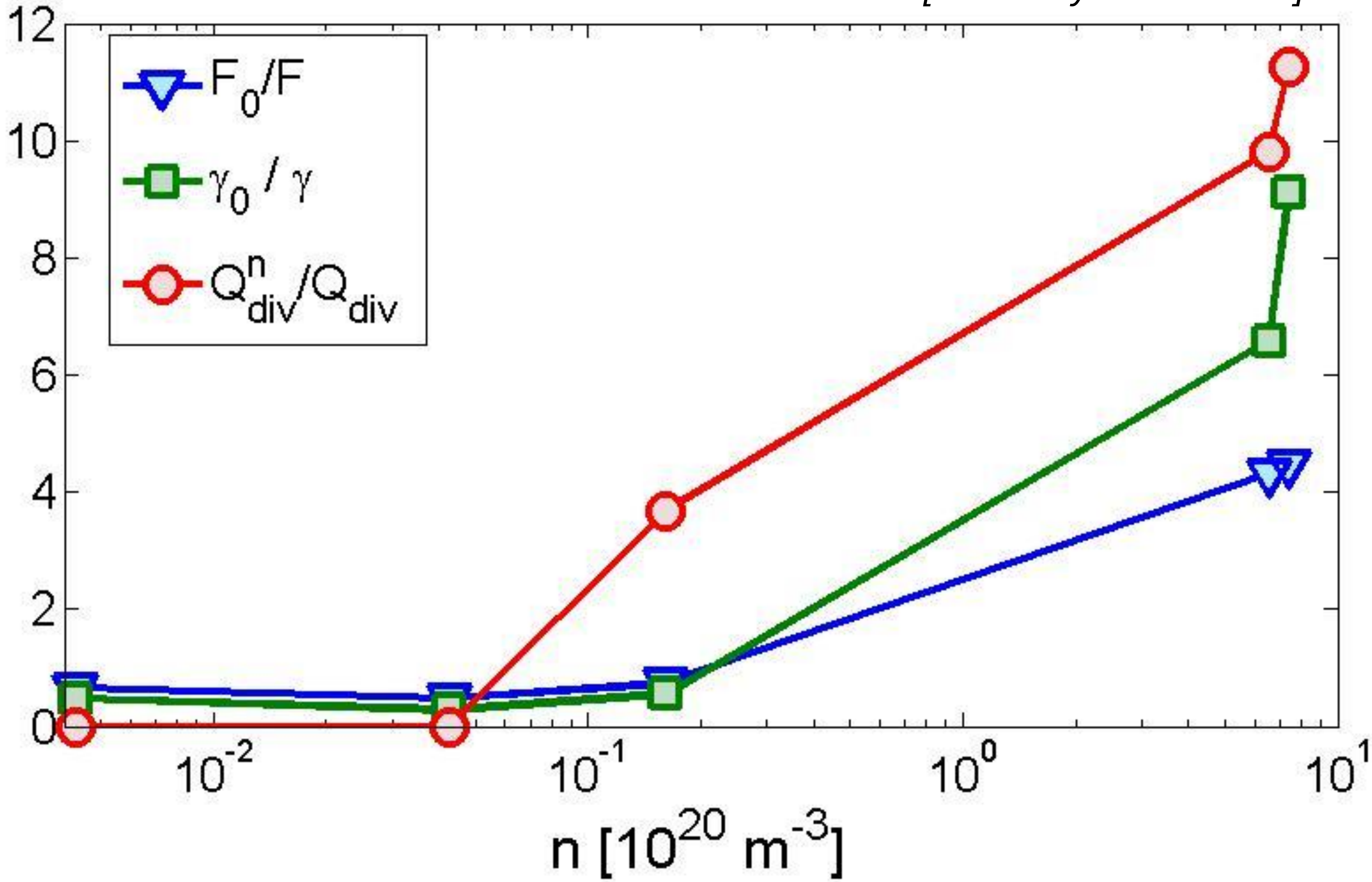

Classical
low n_e
Moderate n_e
High n_e
High n_e, full model
$M_{||}$
x / ρ_i

De-magnetization of plasma



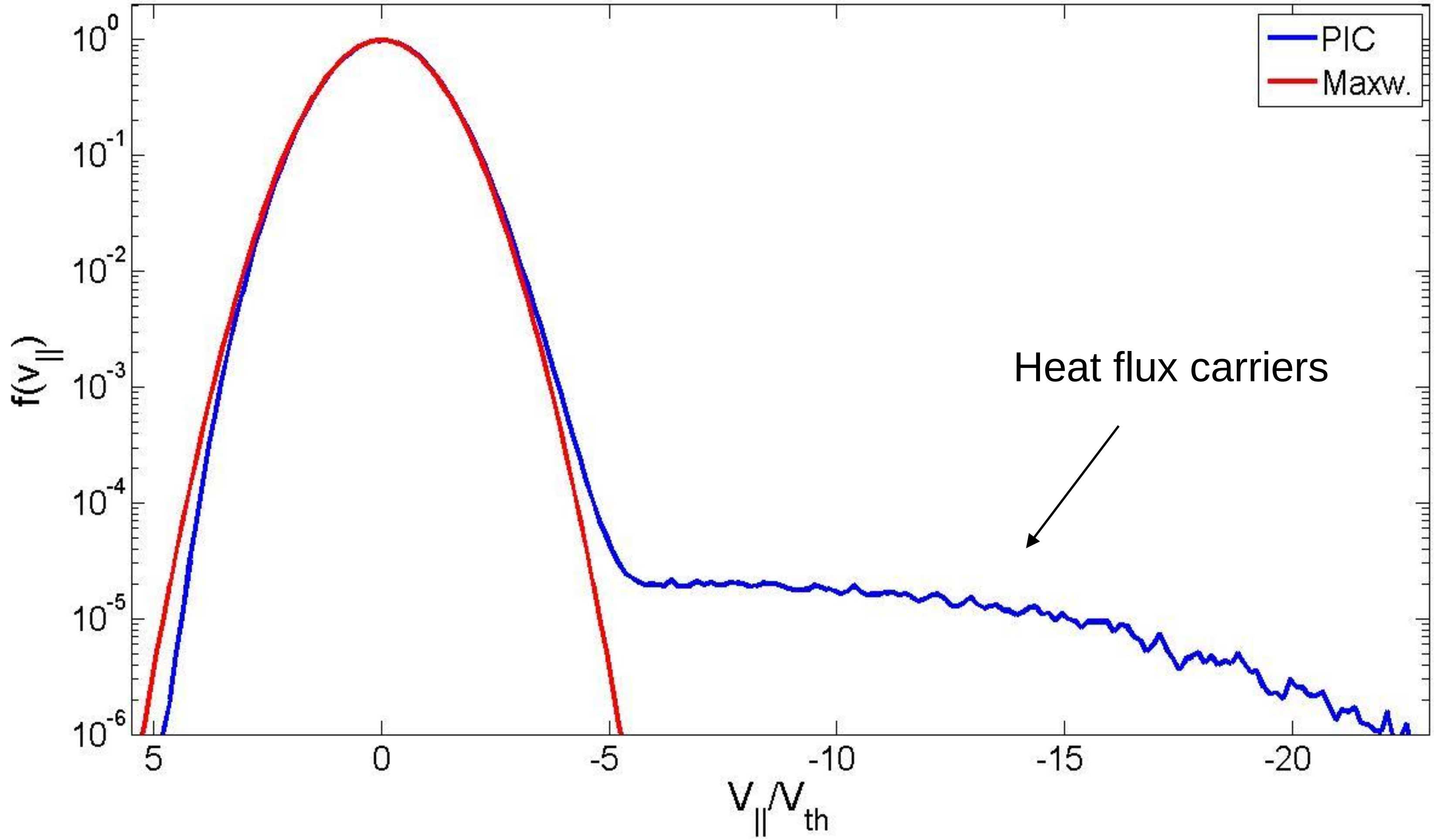
Main results

[Tskhakaya EPS 2021]

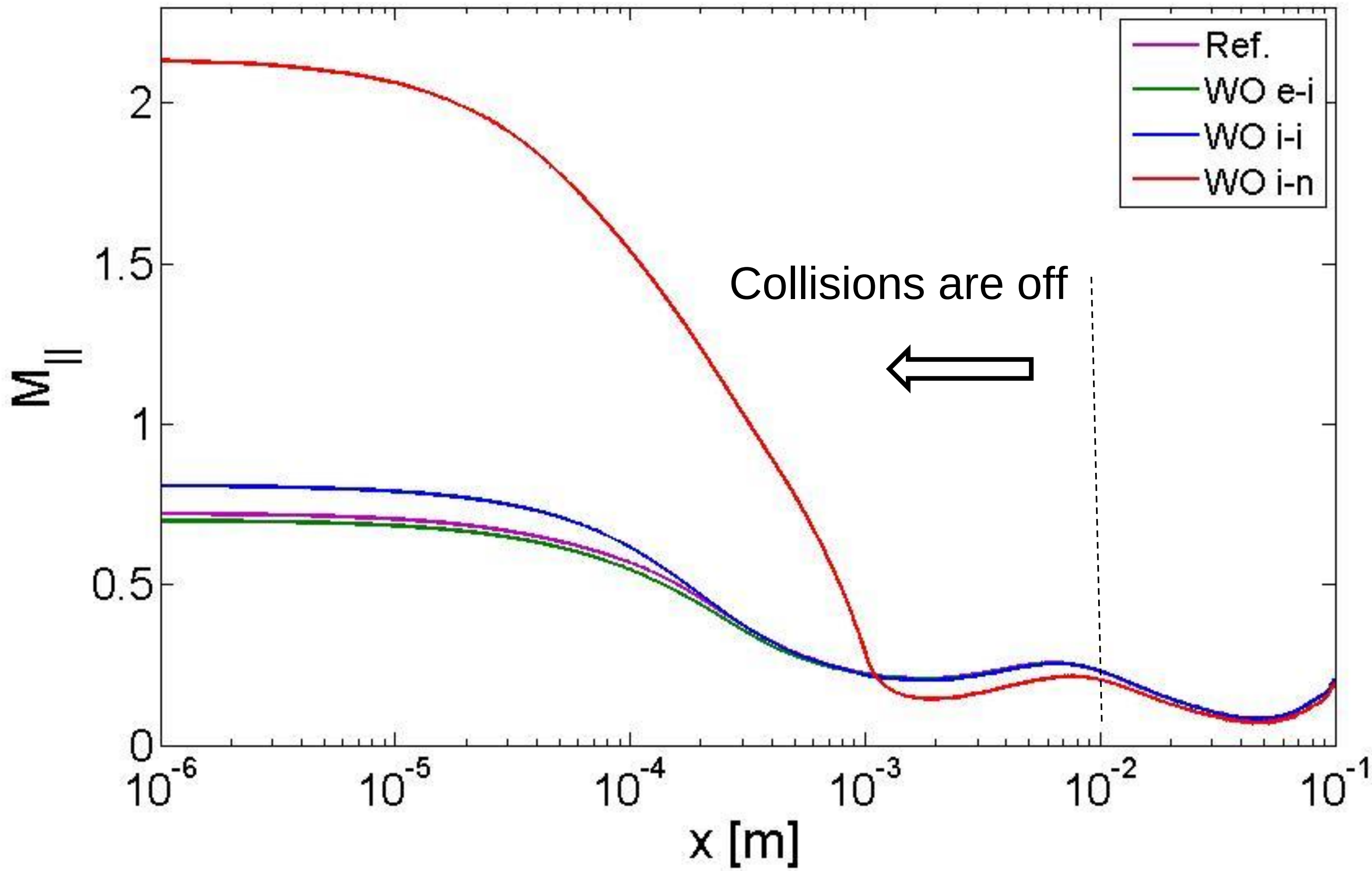


Electron VDF at the JET ID

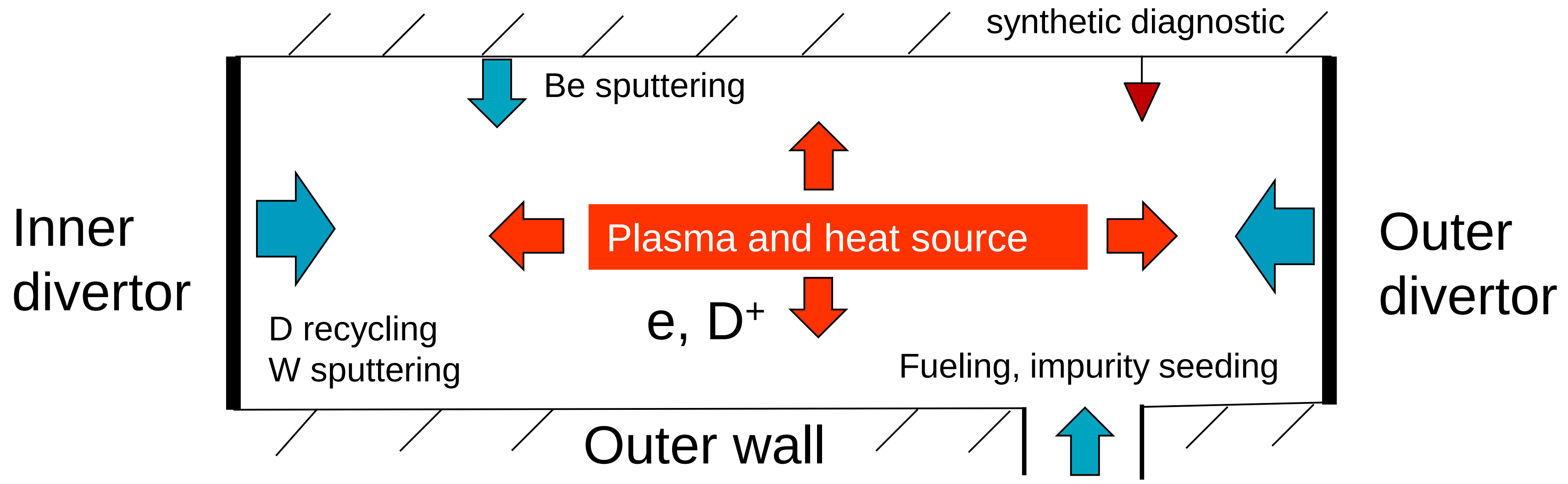
[Tskhakaya JNM 2017]



Numerical “experiments”



BIT1: electrostatic PIC MC code



Physics

- ✓ Electrons, main and impurity ions, neutrals (1D3V)
- ✓ Nonlinear particle interactions: m → n collisions
- ✓ Plasma-surface interaction, linear model

Numerics

- ✓ Massively parallel
- ✓ Unique Field solvers
- ✓ Optimized memory management

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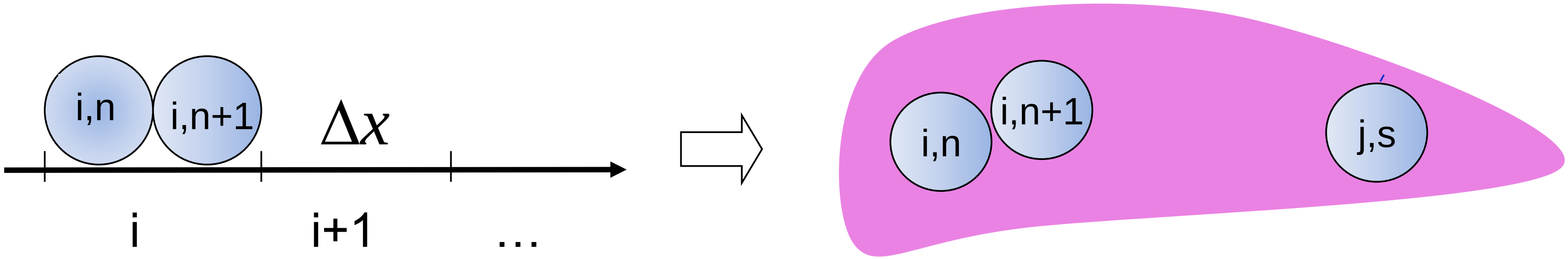
“Natural sorting” used in BIT1

Particles curry the cell index



Space cells

Real space

- ✓ Neighboring particles in real space are neighbors in the computer memory: cache-hit increases. Parallelization is straightforward.
- ✓ Particle trajectories are calculated with the same accuracy at each point:

$$X_n = i \times \Delta x + x_n, \qquad x_n < \Delta x$$

all operations are performed on x_n

- ✓ Cells are statistically independent: all collision probabilities are calculated separately. Collision partners easy to find.

Conclusions

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- Large set of divertor plasma simulations has been performed (~20 M CH)

- New features of the high density, high collisional plasma sheath have been identified

  i. **subsonic** plasma flow, **position** of the SE has to be **re-defined**

  ii. Heat to the wall (divertor plates) curried by **neutrals** (and non-Maxwellian **hot electrons**)

- These properties are the consequence of the common action of **Coulomb collisions** and **ion-neutral friction**

- **Future plans:** DEMO relevant plasma sheath modelling – higher plasma density and simulation complexity (**10^7 grid cell** in 1D)

On our experience of running simulations under IFERC-CSC

- ✓ One of the **most stable** supercomputers we accessed
- ✓ Very **responsive user support** service
- ✓ **Our wish**: to have debugging tools **simpler than Totalview**

Totalview – professional software requiring significant learning time, easy to forget if you use it once per >6 months (stable codes), requires graphical interface

90% of possible "bugs" for particle codes are related to improper memory allocation, which is not easy to fix.

E.g. in BIT3: > 2x26x(6+8) + 8x2 + 2 = 746 routines related to particle array reallocation (Particle send/receive, inelastic collisions, volumetric particle sources)