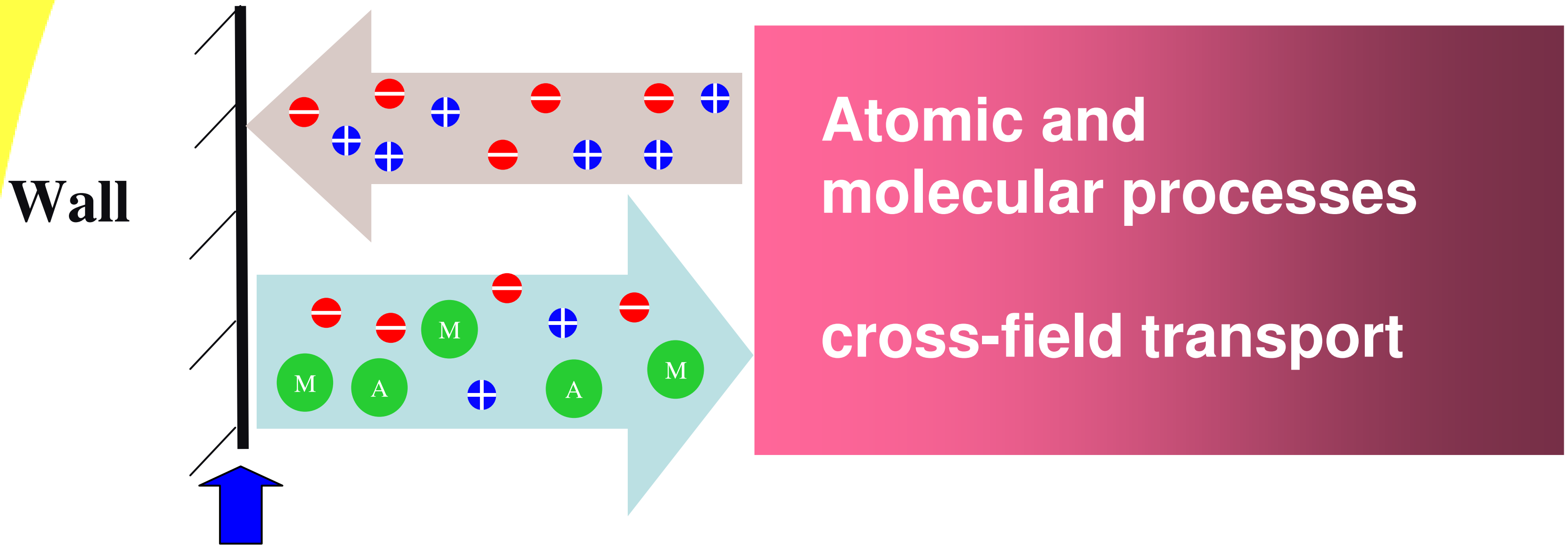
Support of EUFORIA in development of massively parallel BIT1

D. Tskhakaya

Association EURATOM-ÖAW, University of Innsbruck

*Permanent address: Andronikashvili Institute of Physics, Tbilisi

Plasma edge



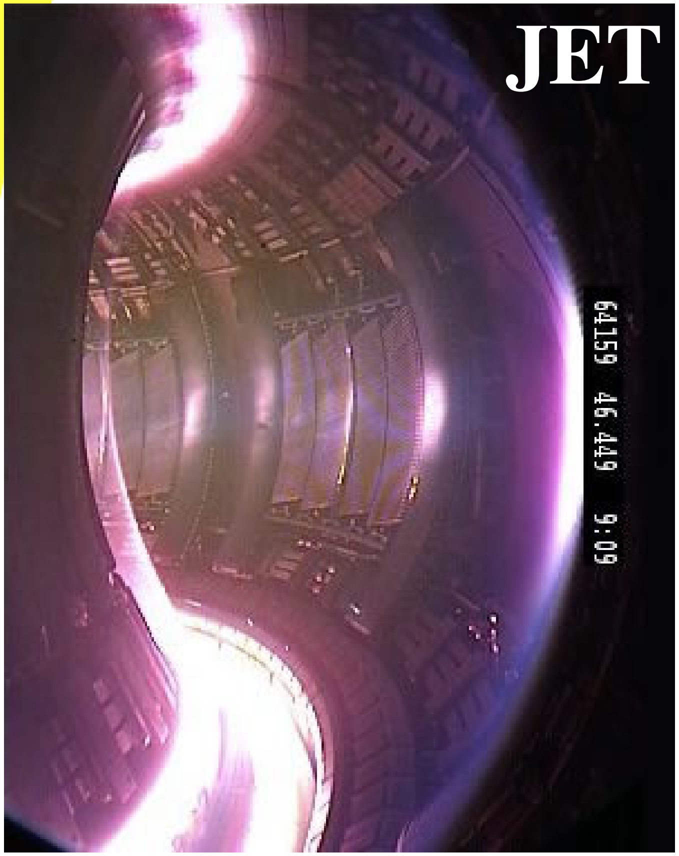
Plasma-surface interactions

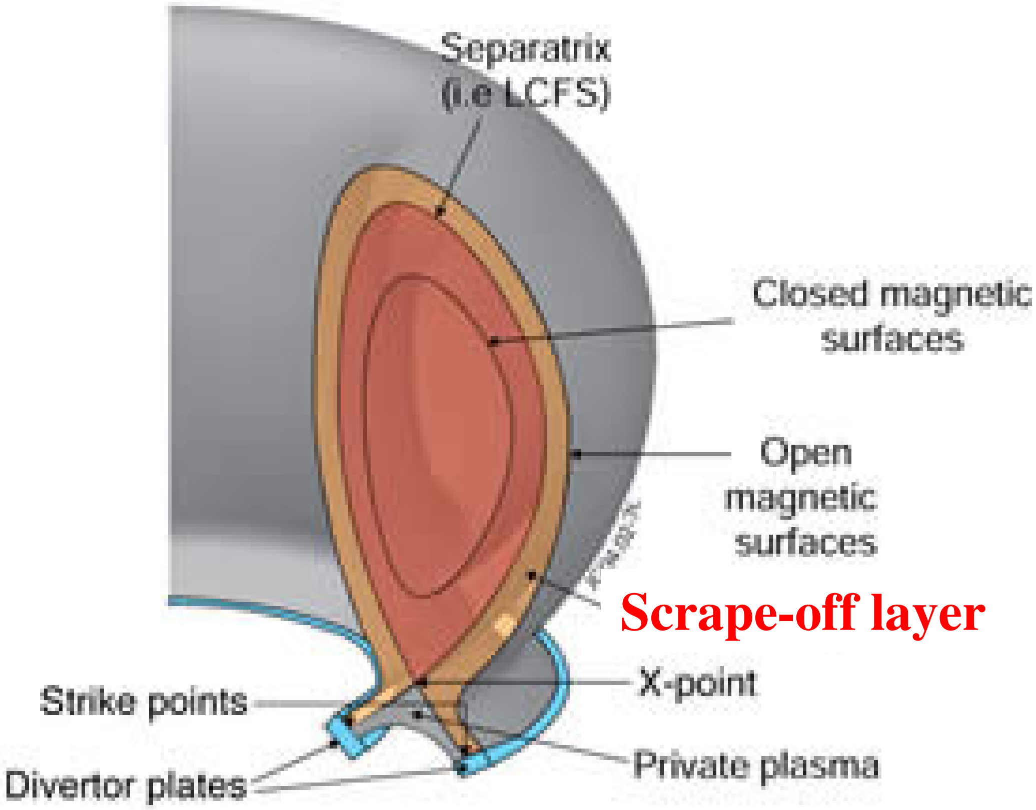
- Electrons and negative ions
- Positive ions
- A Atoms
- M Molecules
- D Dust particles

All this we call plasma edge

It exists in any plasma device and affects the overall discharge

Plasma edge in fusion devices - SOL



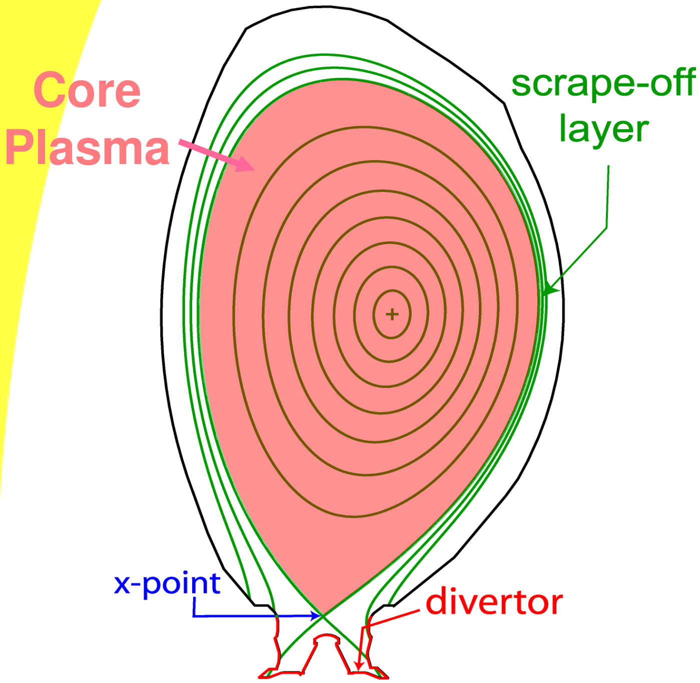


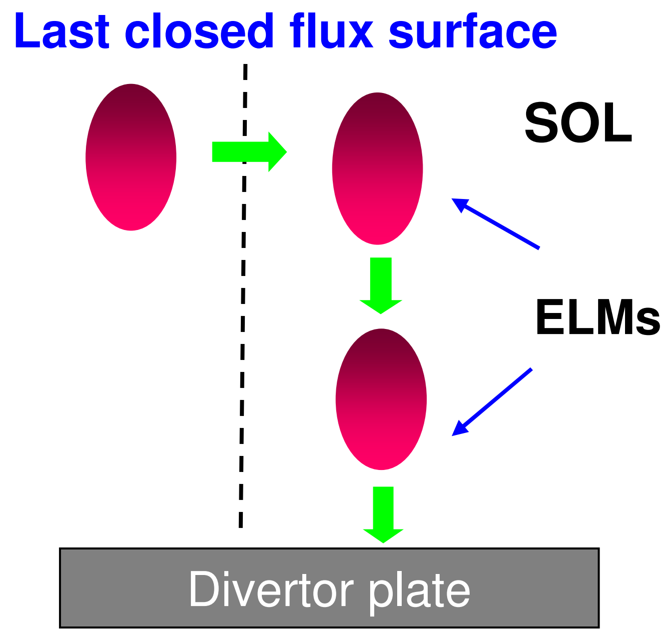
Unsolved problems for ITER

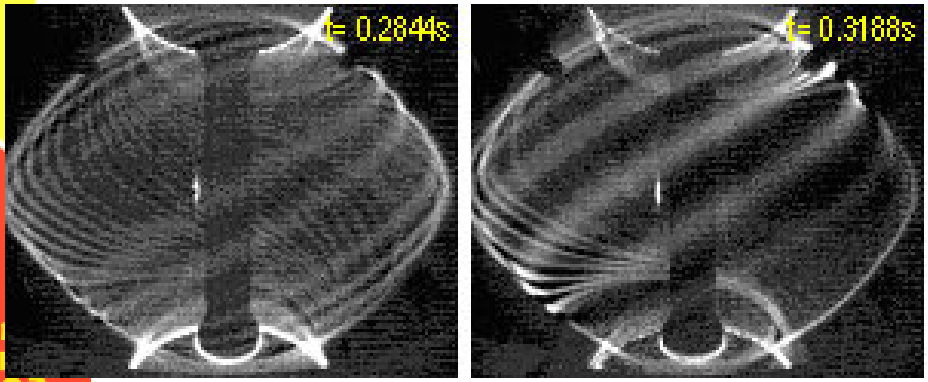
- **Edge localizede modes**
- **Tritium retention**

→ **Transport study of the SOL**

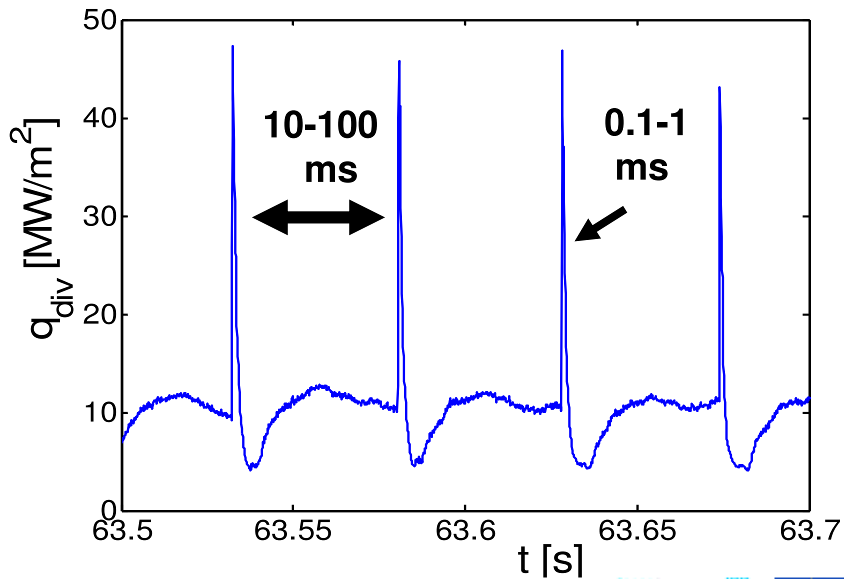
Edge Localized Modes







Filaments of small and large ELMs at MAST (UK)



Formulation of the problem: code requirements

Characteristics of the physical problem		Code requirements
Short time scale, inelastic processes	⇨	Kinetic description of plasma
Plasma sheath and charge separation effects are important	⇨	Finest resolution in time and space (~10^{-12} s, 10^{-4} m)
Plasma-neutral, -impurity, -surface interactions are essential	⇨	Short and large range nonlinear collision operators
High dimensionality	⇨	3D in velocity, 1D/2D in usual space

⇩

quasi-2D Particle-in Cell / Monte Carlo (PIC/MC) code

BIT1

Needed to be massively parallelized

PIC/MC codes

Real time required for plasma edge simulations vs. computer speed.

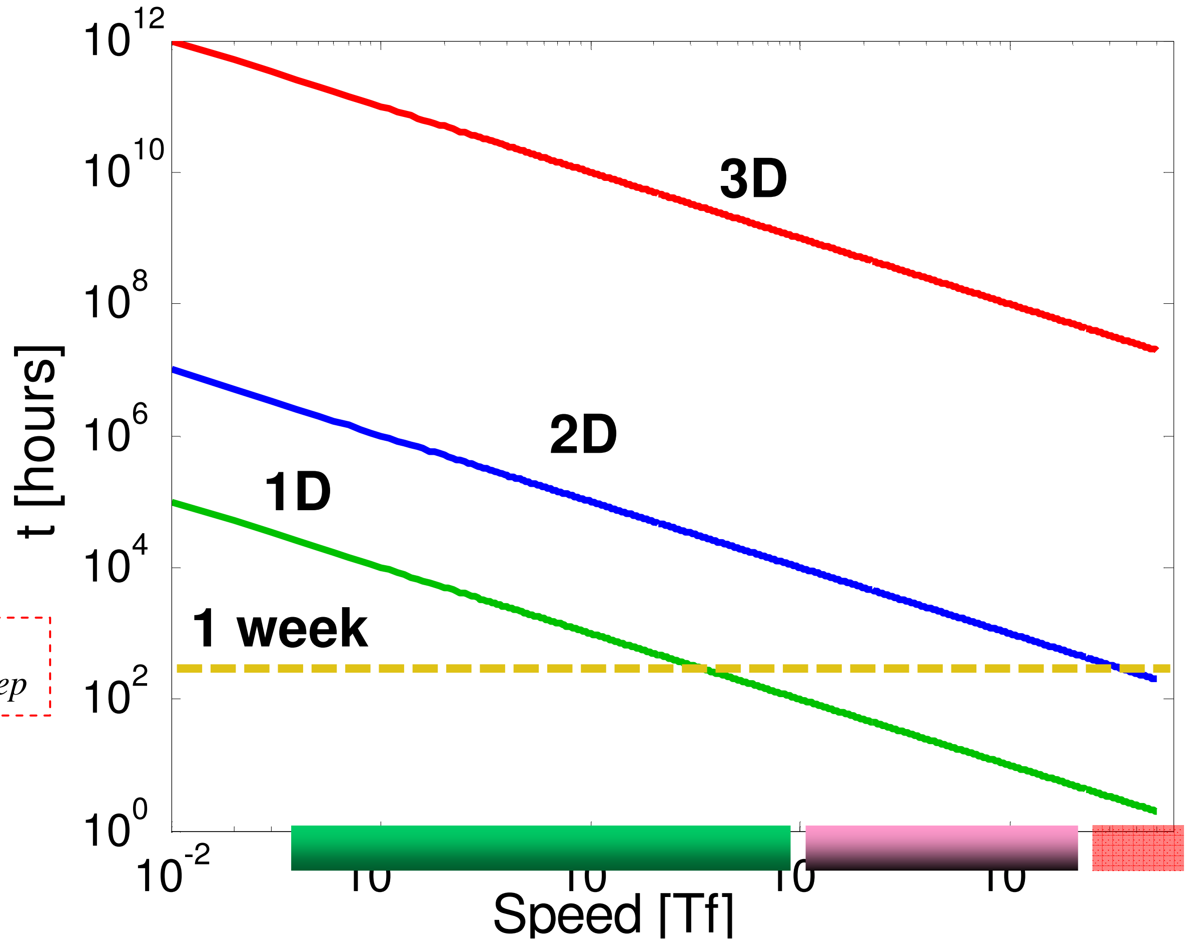
- Number of cells

$$> 10^5 \times 10^4 \times 10^2$$

- Number of time steps

$$\geq 10^8$$

$$t \sim N_{particle} \times N_{steps} \times N_{fl.per\_step}$$

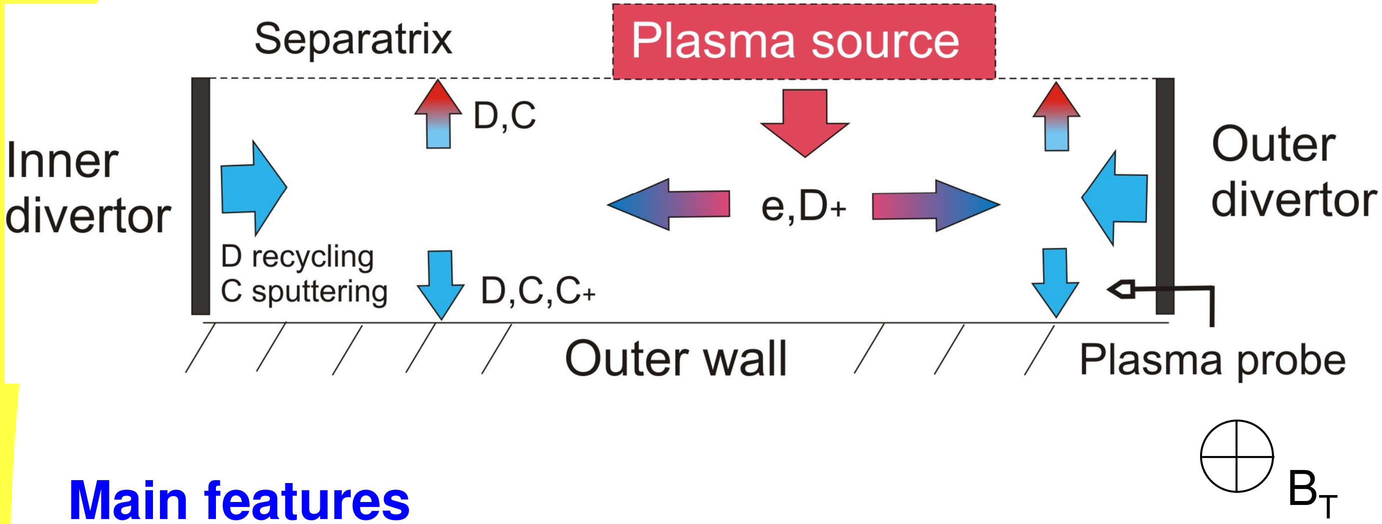


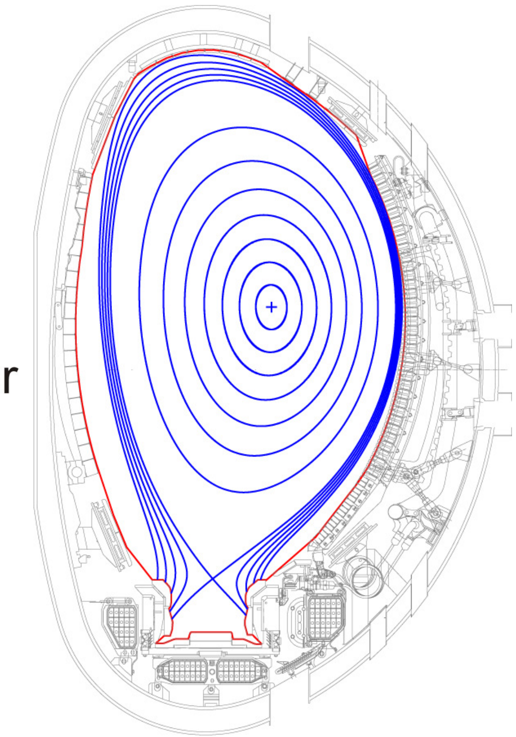
Small and middle size clusters

Middle size supercomputers

Largest supercomputers

BIT1 simulation geometry





Main features

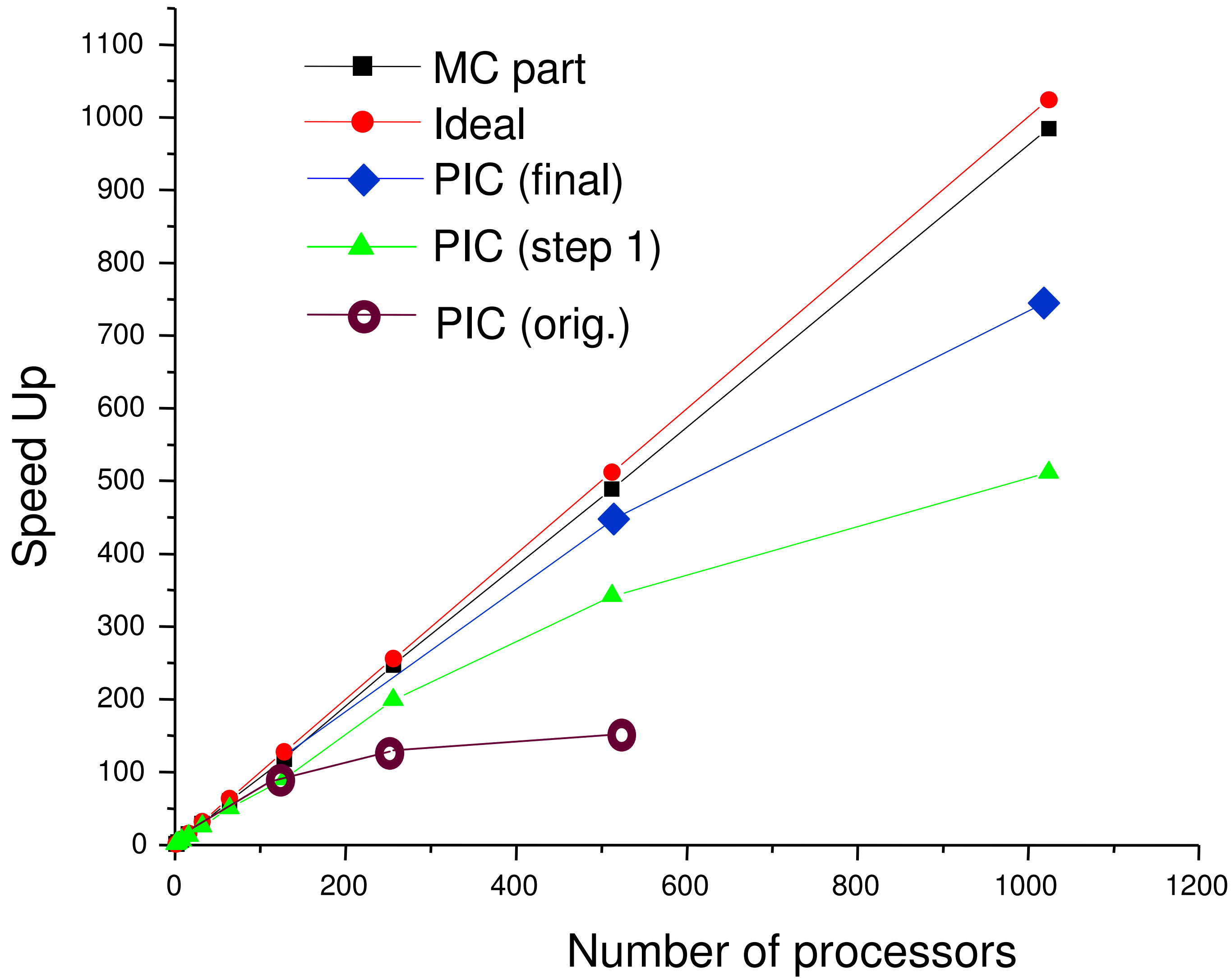
- Massively parallel
- Kinetic treatment of plasma (1D3V), neutrals (2D3V) and impurities (quasi-2D3V)
- Nonlinear energy and momentum conserving collision operators
- Linear model for plasma recycling and impurity (physical + chemical) sputtering.
- Massively parallel runs on 512 – 1024 processors
- Number of synthetic diagnostics
- $N_{particles} \times N_{time\ steps}$ up to 10^{16} → up to 10^{14}
- Number of 1D cells 1 – 40 000 λ_D → 1 – 12 000 λ_D
- Maximun CPU time per simulation 120 hours → 50 000 hours

Support of EUFORIA

- Development of routines for massively parallel simulation
- Optimization of code, finding of bugs and profiling
- Development of grid version of the BIT1

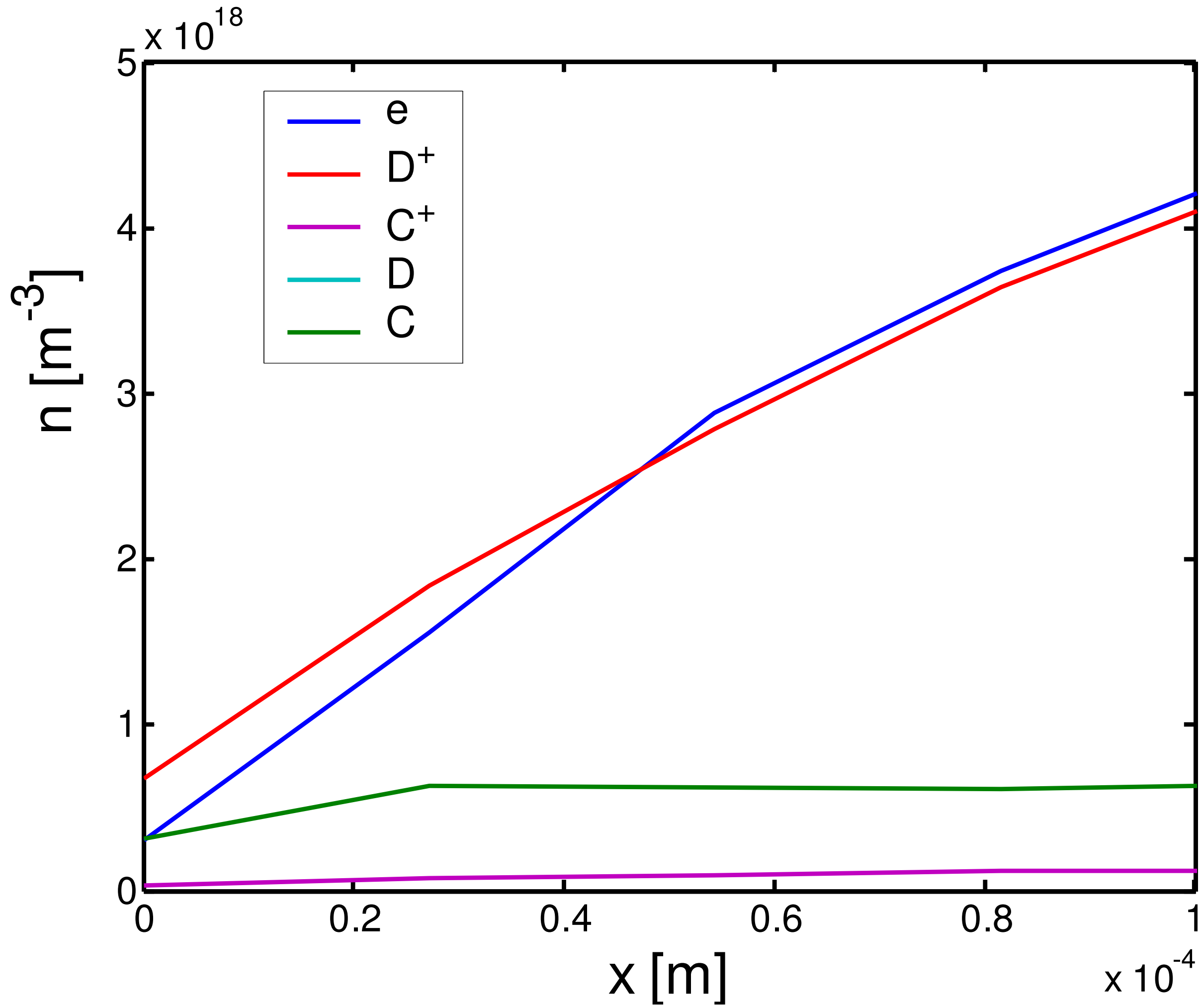
  (see next presentation)
- Guiding in simulations on HPC

Tests of BIT1 code on scalability on **Mare Nostrum** (A. Soba)



Plasma profiles

[Tskhakaya, ICPP 2010]



Wa
(inner d

Wall
ıter divertor)

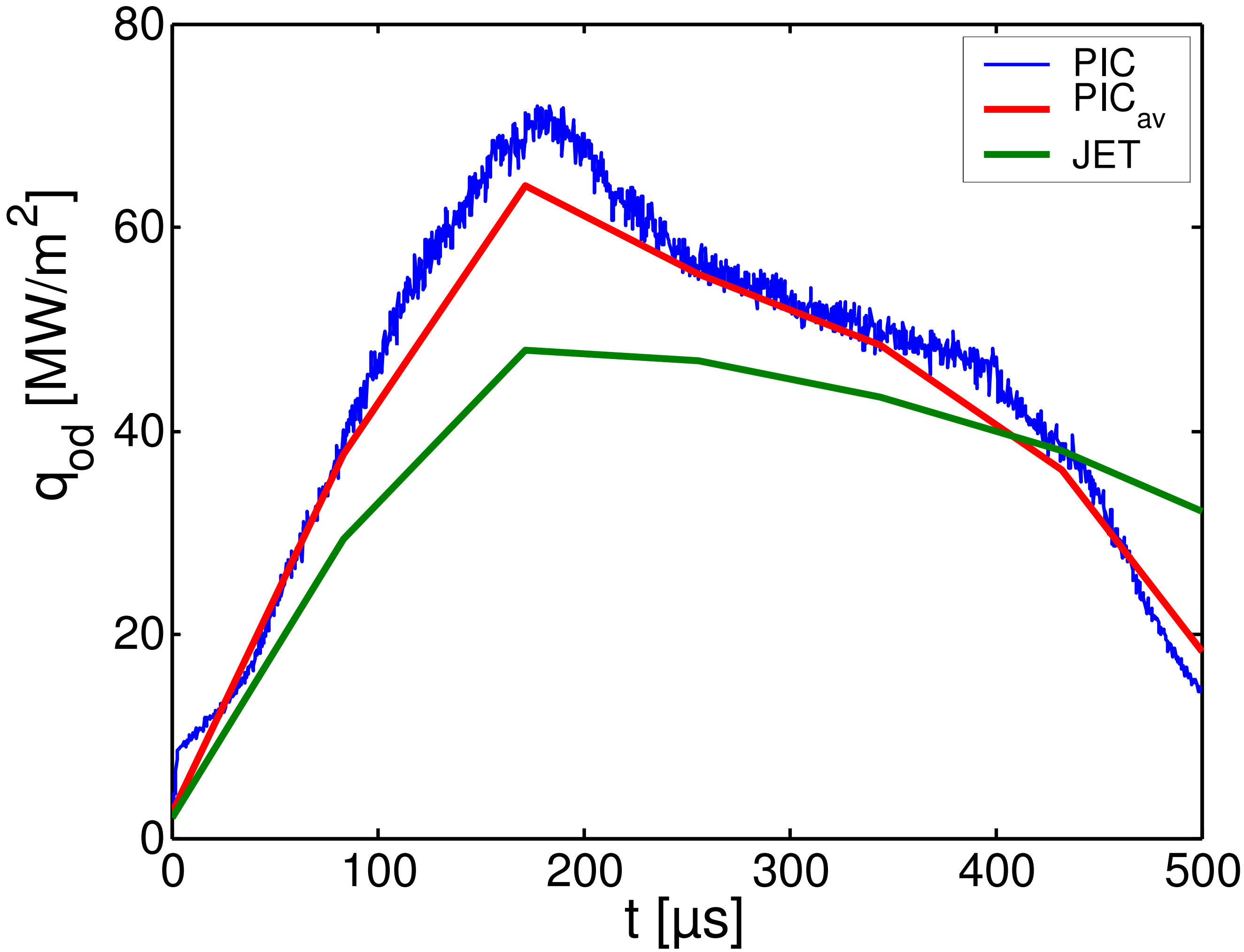
Poloidal profiles of particle densities. JET relevant parameters.

EUFORIA FP7-INFRASTRUCTURES-2007-1 Grant 211804

e-infrastructure

Simulations vs. experiment

[Tskhakaya, JNM 2011]



Power loads to the OD plates during the 0.15 MJ ELM at JET (shot #74380).

Simulation of LP measurements: motivation

[Tskhakaya, CPPA 2010]

There are a number indications that under some circumstances the T_e measured by Langmuir probes can significantly deviate from the actual values

Stationary SOL

Fussmann JNM 1984: $T_e^{LP} / T_e^{T.Scat} \approx 2$

Horacek JNM 2003: $T_e^{LP} / T_e^{B2} \approx 5$

⇓

Super-thermal electrons?

Assumption of bi-Maxwellian electron VDF:

Stangeby PPCF 1995, Van Rompuy PPCF 2007, Čerček JPFRS 2009…

ELMy SOL

Herrmann JNM 2003,
Kallenbach PPCF 2004,
Pitts NF 2007,
Tskhakaya JNM 2009

} $T_e^{LP} / T_e^{sim} \sim 0.5$

⇓

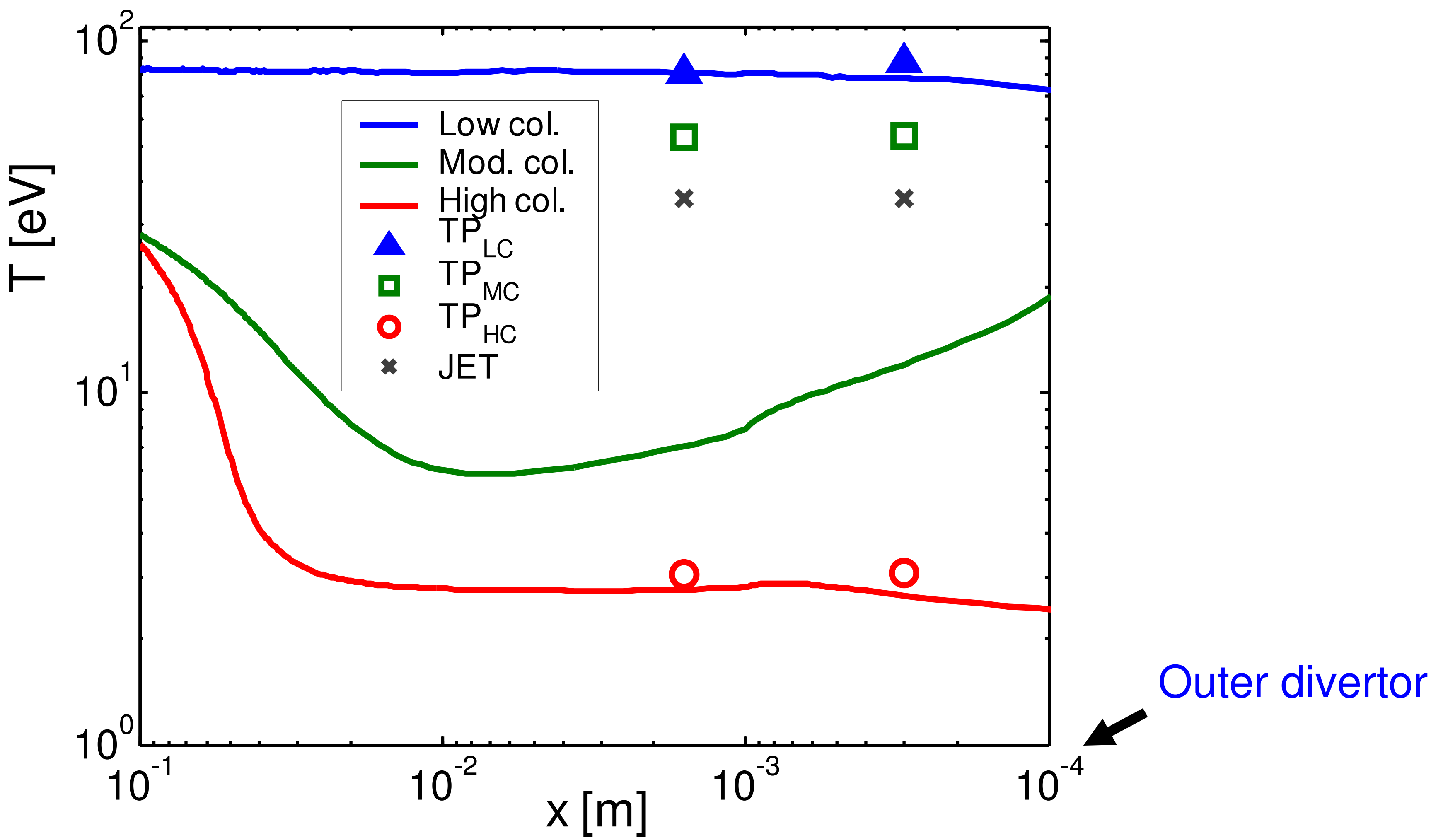
ITER relevant

↑

The tokamak of next generation

Simulation results (stationary SOL)

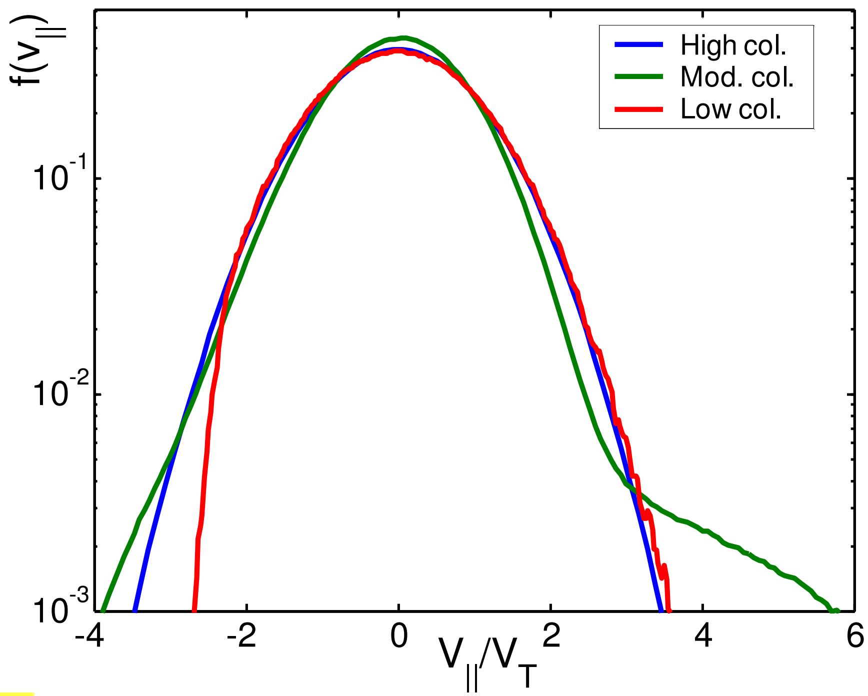
[Tskhakaya, JNM 2011]



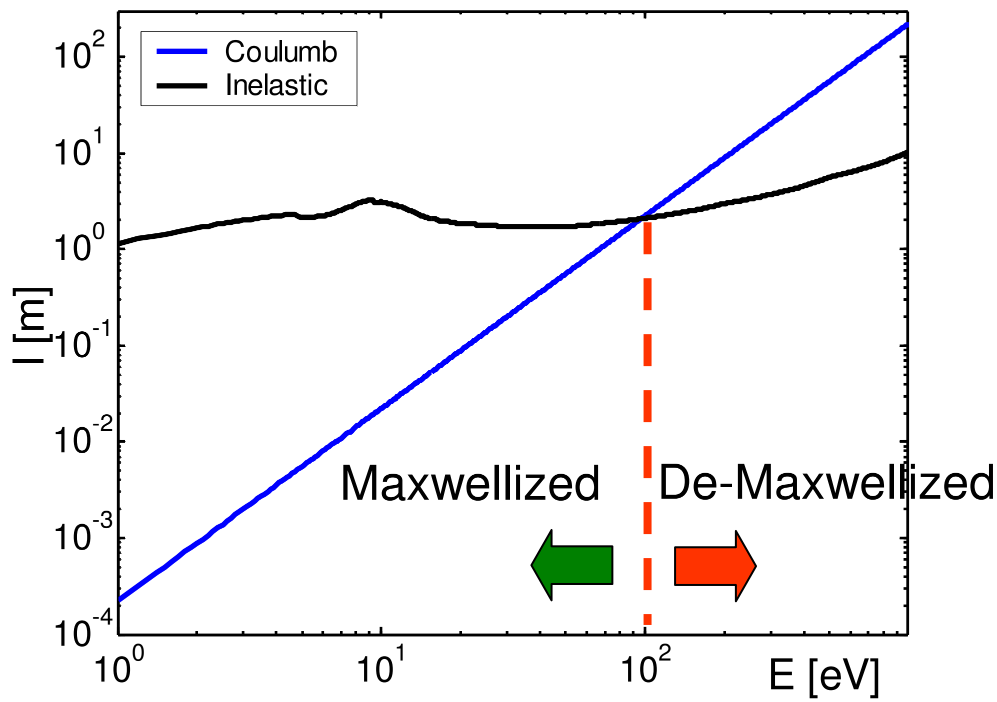
Poloidal profiles of the electron temperature in the outer divertor plasma.

Simulation results (stationary SOL)

[Tskhakaya, CPPA 2010]



Electron velocity distribution functions at the probe for different plasma recycling coefficients



Mean free paths for electron Coulomb and inelastic collisions near the divertor

Ion sound speed

[Tskhakaya, ICPP 2010]

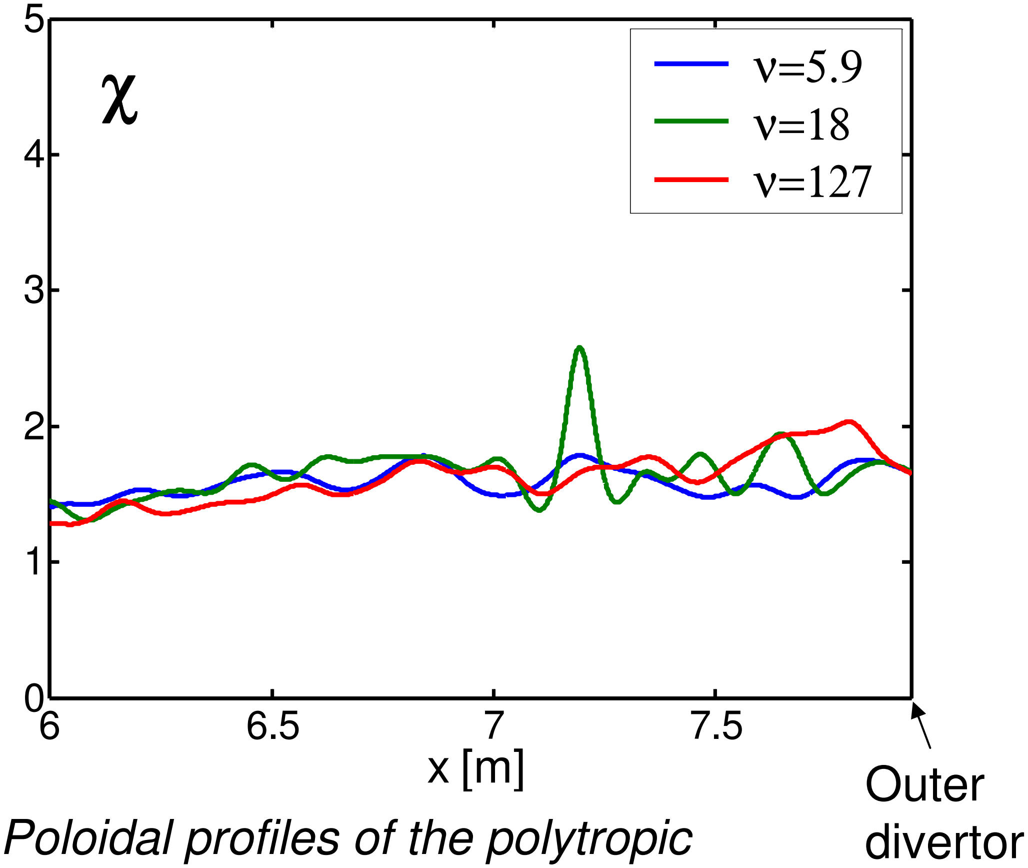
$$C_s = \sqrt{\frac{T_e + \chi T_i}{m_i}}$$

$$\frac{dp_i}{ds} = \chi T_i \frac{dn_i}{ds}$$

Usual assumption

$$1 \le \chi \le 3$$

Case w/o recycling

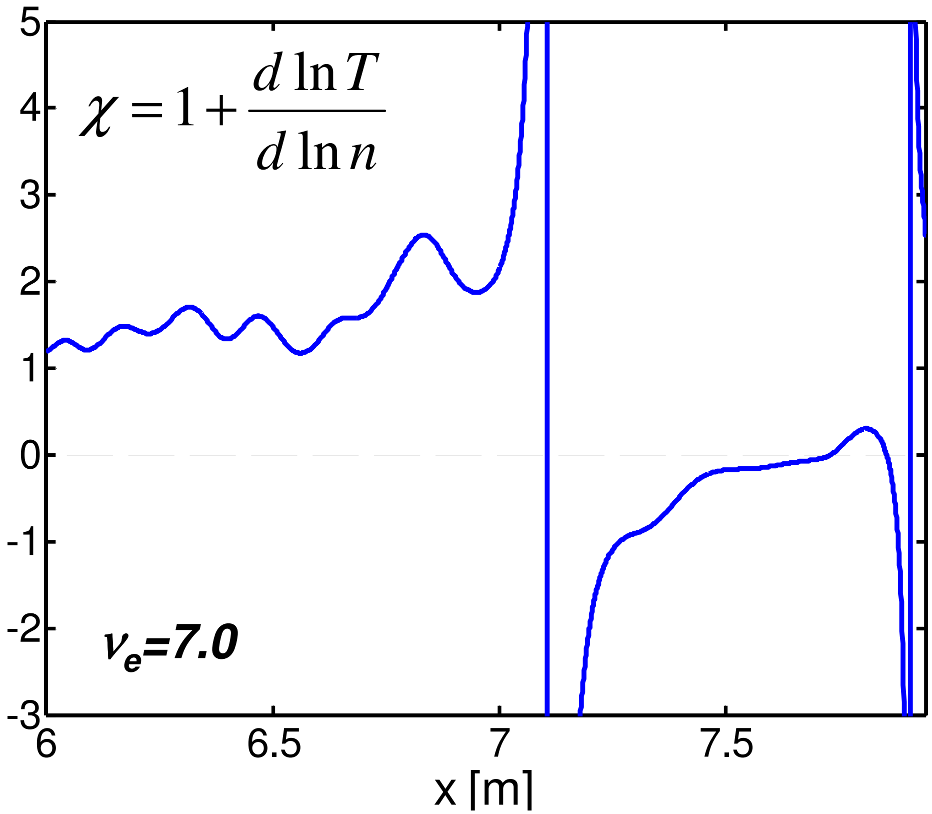


Poloidal profiles of the polytropic coefficient for different SOL collisionalities.

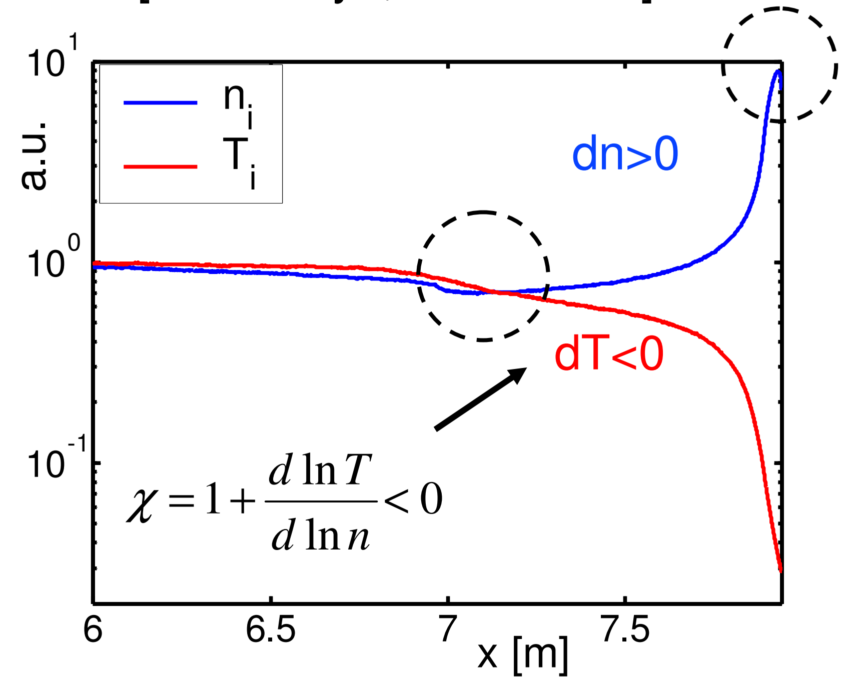
Proper choice of χ can be important for formulation of boundary conditions on $M_{||}$

Ion sound speed (for high recycling)

[Tskhakaya, ICPP 2010]



Poloidal profile of the polytropic coefficient.



Poloidal profiles of the ion density and temperature.

How can we define the ion sound speed?

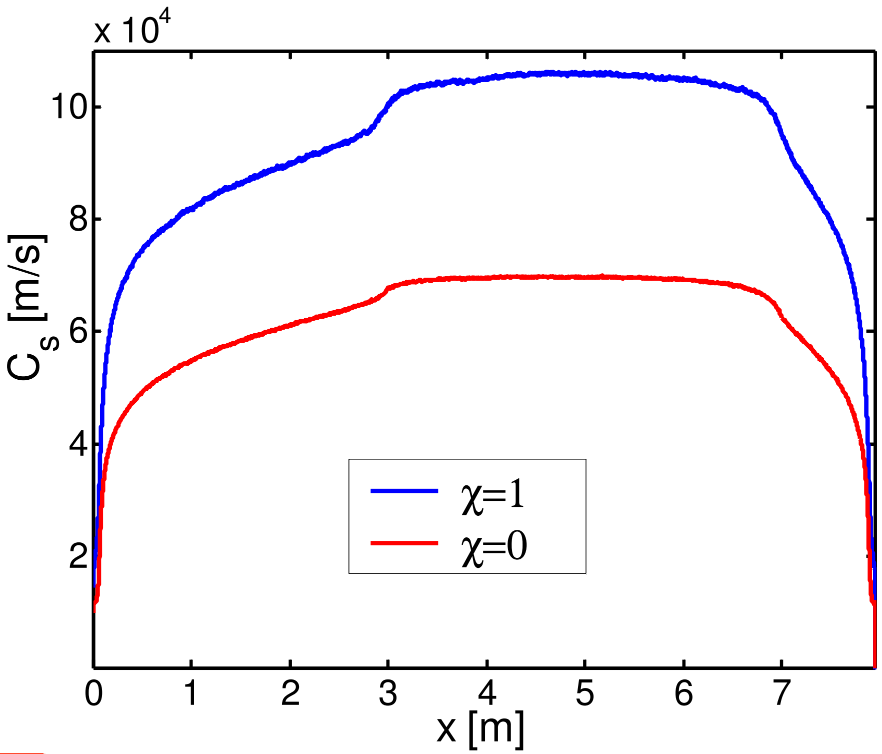
May be like this

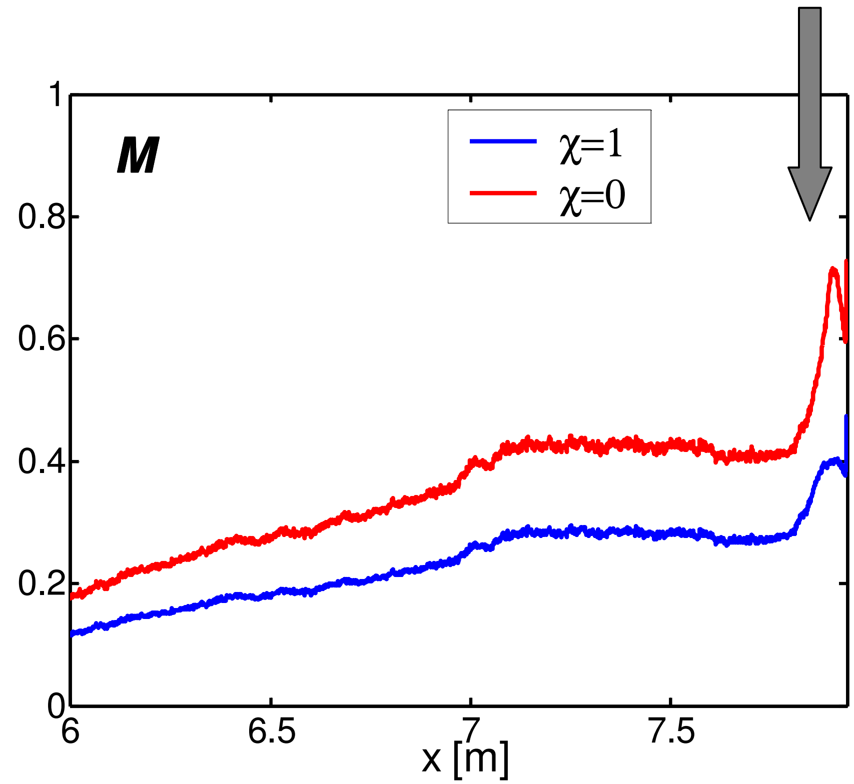
$$C_s = \sqrt{\frac{T_e + \langle \chi \rangle T_i}{m_i}}$$

Ion sound speed (high recycling)

[Tskhakaya, ICPP 2010]

Boundary condition $M_{||}$=1 is not satisfied!





Poloidal profiles of the ion sound speed and the corresponding Mach numbers for different χ. The case with ν_e=7.

Resume (i)

Invited talks

1. Plasma Edge Theory in Fusion Devices (PET), South Lake Tahoe, USA, 2011
2. EFDA Meeting on modelling activities of EU-PWI Task Force, Culham, 2010
3. ICPP + LAWPP, Santiago, 2010
4. Annual Meeting of the Japan Society of Plasma Science, Kyoto, 2009

Oral contributions

1. Euromicro Conference on Parallel, Distributed and Network-based Processing, Pisa, 2010
2. International Conference on Plasma Physics and Applications (CPPA), Iasi, 2010
3. International Conference on Numerical Simulation of Plasmas, Lisbon, 2009
4. International Workshop on Electric Probes, Innsbruck, 2009.

Journal publications

1. Journal of Nuclear Materials, NUMA_45198 (2011)
2. Euromicro Conference on Parallel, Distributed and Network-based Processing, Proceedings, 476-481 (2010)

Resume (ii)

New results obtained by massively parallel BIT1 modelling and other…

- Full size realistic modelling of the tokamak SOL
- Quantifying of different kinetic effects in the SOL
- Explanation of the mismatch of the Langmuir probe measurements at the plasma edge
- Observation that the „classical" definition of the sound speed is not appropriate for high recycling plasma edge
- BIT1 is implemented and ran at number of EU supercomputers
- New users of the BIT1 (Austria, Slovenia, Spain)
- BIT1 is a member of Integrated Tokamak Modelling (ITM) task force
- The new numerical technique developed with help of EUFORIA is to be implemented in number of particle codes

Future plans

- Continue quantitative kinetic study of the plasma edge via BIT1
- To develop on the basis of BIT1 a fully 2D massively parallel code BIT2 (the projects *P21941-N16* and *KinSOL2D* of the Austrian Science Funding and EFDA HLST)

At the end I would like to thank the EUFORIA leadership and all the members who where helping in my work