W transport modelling with EIRENE

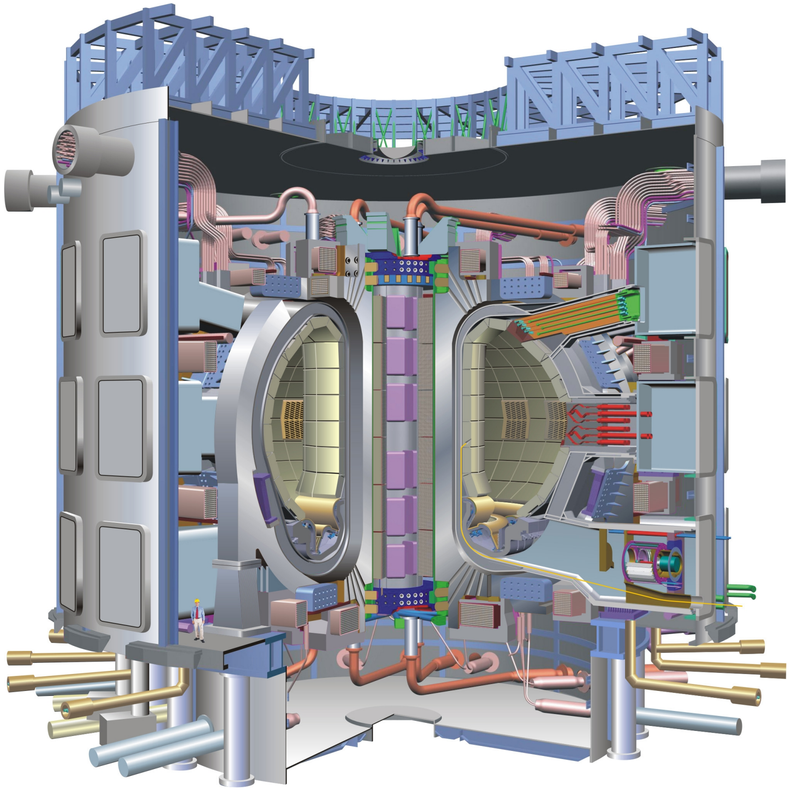
M. Wischmeier[1]
F. Reimold[1], D. Reiter[2], P. Boerner[2], J. Seebacher[3], R. Dux[1] and the ASDEX Upgrade team

[1]Max-Planck-Institut für Plasmaphysik, EURATOM Association, Germany
[2]Institut fuer Energieforschung, Plasmaphysik, EURATOM Association, Juelich, Germany
[3]Institute for Ion and Applied Physics, University of Innsbruck, Association. EURATOM-ÖAW, 6020 Innsbruck, Austria

Motivation

Pro: W low erosion yield
Contra: danger of enhanced accumulation in core

ASDEX Upgrade: all W device
JET: W as PFCs in the divertor
ITER: W foreseen as PFC in divertor



Aim is to understand migration of W:
- probability for penetration across LCFS depending on starting location and discharge regime
- tool to simulate evolution during ELM cycle w/o seed impurities

Existing numerical tools

Coupled Codes:

B2.5-EIRENE [SOLPS5.0] (AUG)
EMC3-EIRENE (TEX/W7-X/AUG)
SONIC w. IMPGYRO (JT60U)

Stand-alone codes:

DIVIMP
IMPGYRO
ERO
EIRENE w. modified trace ion module (PhD D. Reiser, PhD J. Seebacher, Diploma thesis F. Reimold)

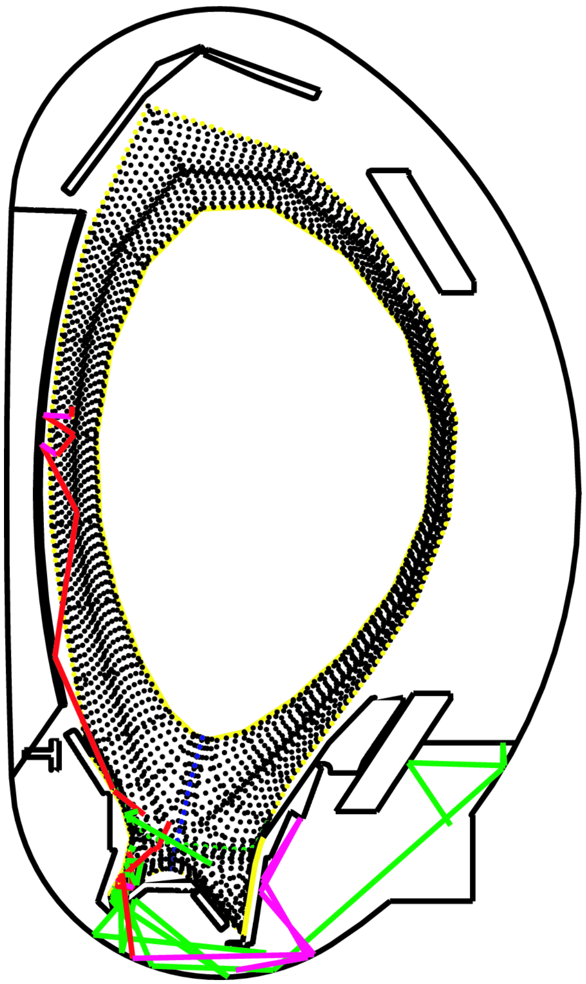
- **Plasma/Fluid:** Collisional parallel transport model, with kinetic limiters for transp. coeff.; anomalous perp. coefficients, drifts included
- **Neutrals/Ions:** Kinetic Monte-Carlo codes, inside and outside of fluid computational grid

Ansatz: W is a trace; minor radiation losses in SOL=> does not effect SOL energy balance => no iterative coupling required

Intro to the EIRENE code

Originally:

• Trace paths of neutrals in 3D geometry and „given“ plasma background



EIRENE '96 and EIRENE '99 (used also with SOLPS5.0)

Intro to the EIRENE code

Originally:

• Trace paths of neutrals in 3D geometry and „given“ plasma background

Then:

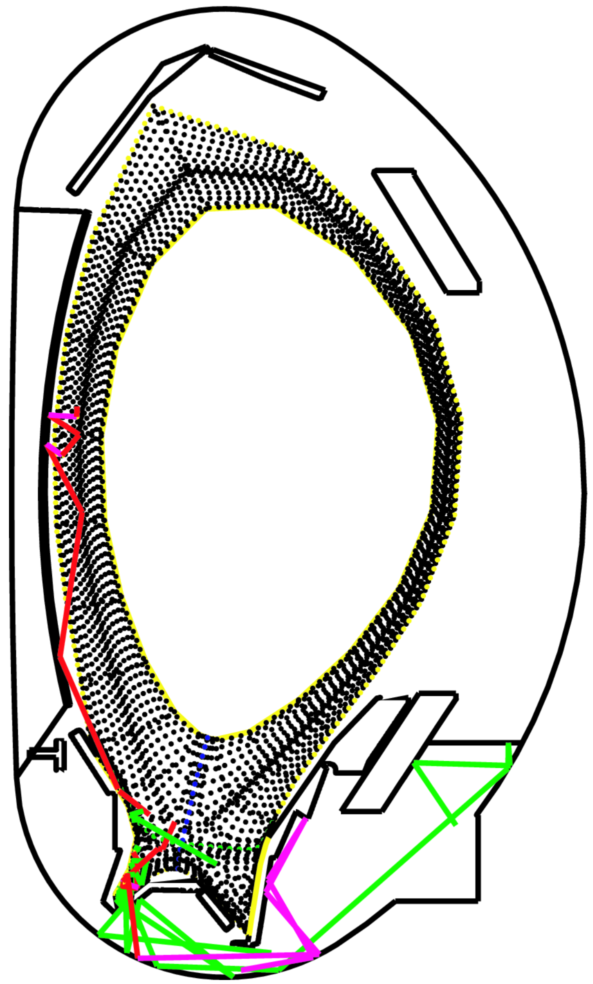
• Introduction of neutral-neutral collisions (ITER)

• Introduction of photon transport (opaque plasmas)

Ions:

• Destroyed at loaction of creation

• later then following field line within one computational cell

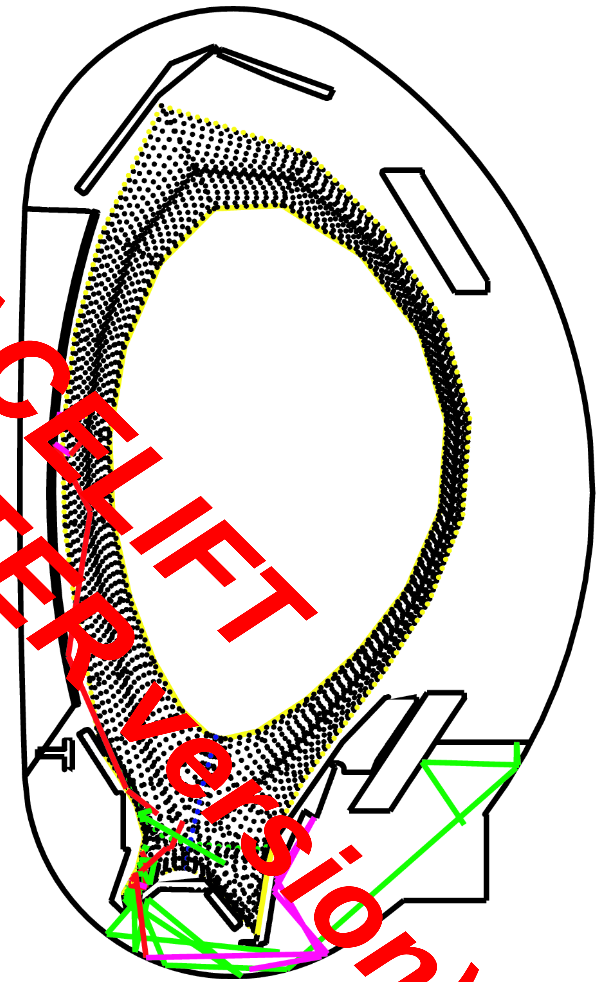


Intro to the EIRENE code

EIRENE FACELIFT -SOLPS4.3 (ITER version)

Originally:
- Trace paths of neutrals in 3D geometry and „given“ plasma background

Then:
- Introduction of neutral-neutral collisions (ITER)
- Introduction of photon transport (opaque plasmas)



Ions:
- Destroyed at loaction of creation
- later then following field line within one computational cell

Trace Ion Module in EIRENE

- **Gyro-averaged kinetic description**

$$r, v = r_{gc}, v_{gc}, \varphi$$

- **Plasma reactions easily included (physical & chemical)**

  Recombination (modified ADPAK)

  T.Pütterich, 2008

  Ionization (CADW)

  S.D.Loch, 2005

- **Surface model including different plasma wall interactions**

  Physical Sputtering (TRIM)

  Eckstein,1993 & Eckstein, 2007

  Chemical Sputtering

  Roth/Pacher, 1998

  Reflection (TRIM)

  Eckstein/Heifetz, 1986

***New features with the Trace Ion Module (TIM)*:**

- **Drifts**
  ExB
  gradient B
  curvature
-
- **Fokker-Planck collision terms**
  kinetic "thermal force effects" (to be tested - ongoing)
  Collisional friction
- **Newly Introduced**
  - *Perpendicular diffusion*
  - *BGK thermalization*
  - *Prompt redeposition via mean-free path and first orbit approximation*
- **In preparation (earliest end of 2011):**
  Iterative mode (coupling)

[D.Reiser – Improved kinetic test particle model for impurity transport in tokamaks, Nucl.Fus., 1998]
[J.Seebacher - Consistent kinetic trace impurity transport and chemistry modeling in fusion plasmas (PhD), Univ. Innsbruck, 2009]

Trace Ion Module in EIRENE (v. 2010)

ASDEX Upgrade

- **Gyro-averaged kinetic description**

$$\vec{r},\vec{v}=\vec{r}_{gc},\vec{v}_{gc},\omega$$

- **Plasma reactions easily included (physical & chemical)**

Recombination (modified ADPAK)

T.Pütterich, 2008

Ionization (CADW)

S.D.Loch, 2005

- **Surface model including different plasma wall interactions**

Physical Sputtering (TRIM)

Eckstein,1993 & Eckstein, 2007

Chemical Sputtering

Roth/Pacher, 1998

Reflection (TRIM)

Eckstein/Heifetz, 1986

***New features with the Trace Ion Module (TIM)*:**

- **Drifts**
  ExB
  gradient B
  curvature

- **Fokker-Planck collision terms**
  kinetic *"thermal force effects" (to be tested - ongoing)*
  Collisional friction

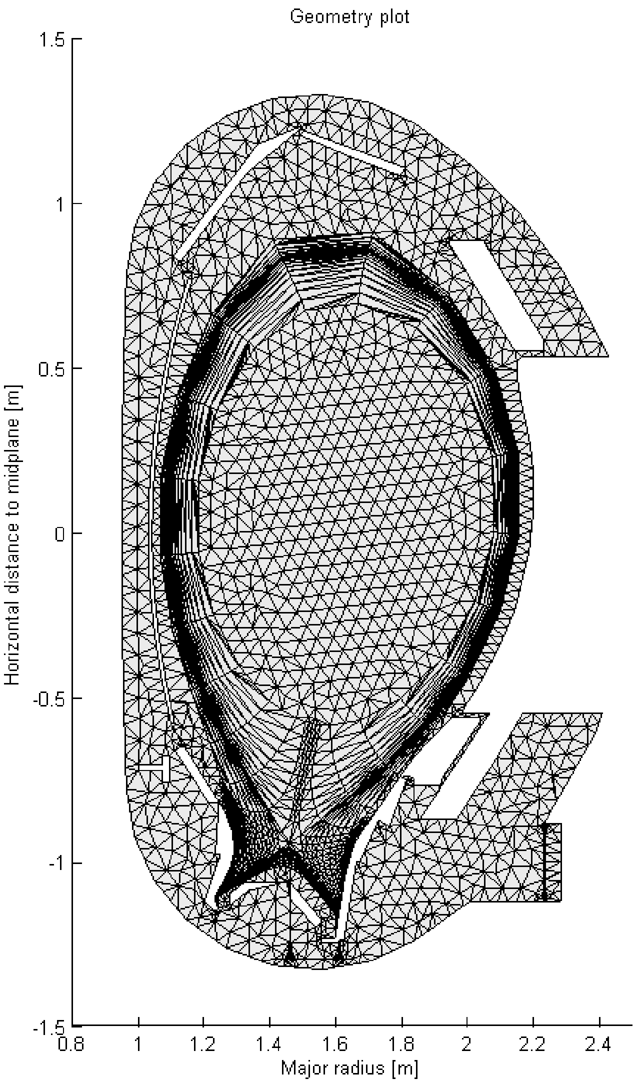
- **Newly Introduced**
  - ***Perpendicular diffusion***
  - ***BGK thermalization***
  - ***Prompt redeposition via mean-free path and first orbit approximation***

- **In preparation (earliest end of 2011):**
  Iterative mode (coupling)

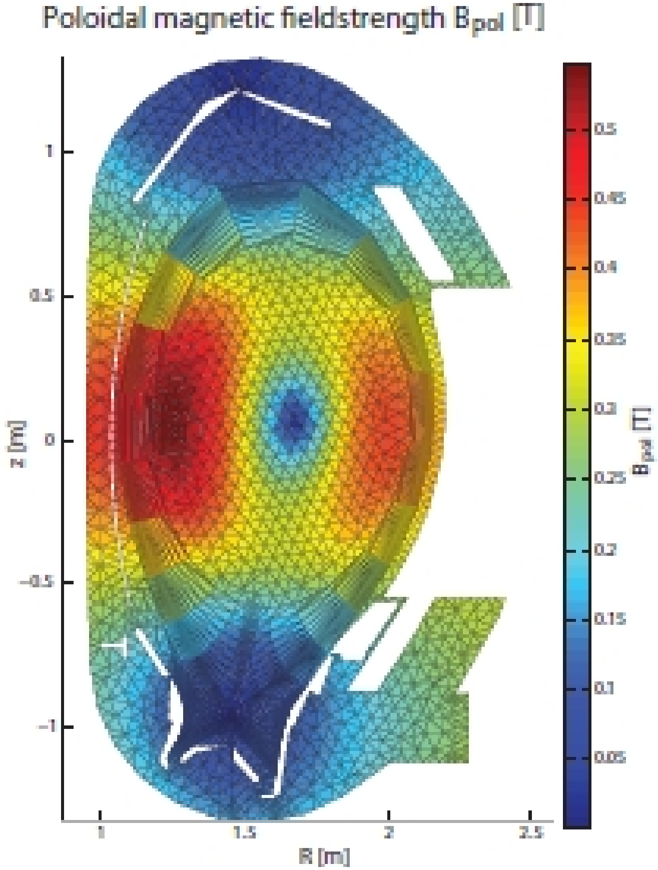
[D.Reiser – Improved kinetic test particle model for impurity transport in tokamaks, Nucl.Fus.,1998]
[J.Seebacher - Consistent kinetic trace impurity transport and chemistry modeling in fusion plasmas (PhD), Univ. Innsbruck, 2009]

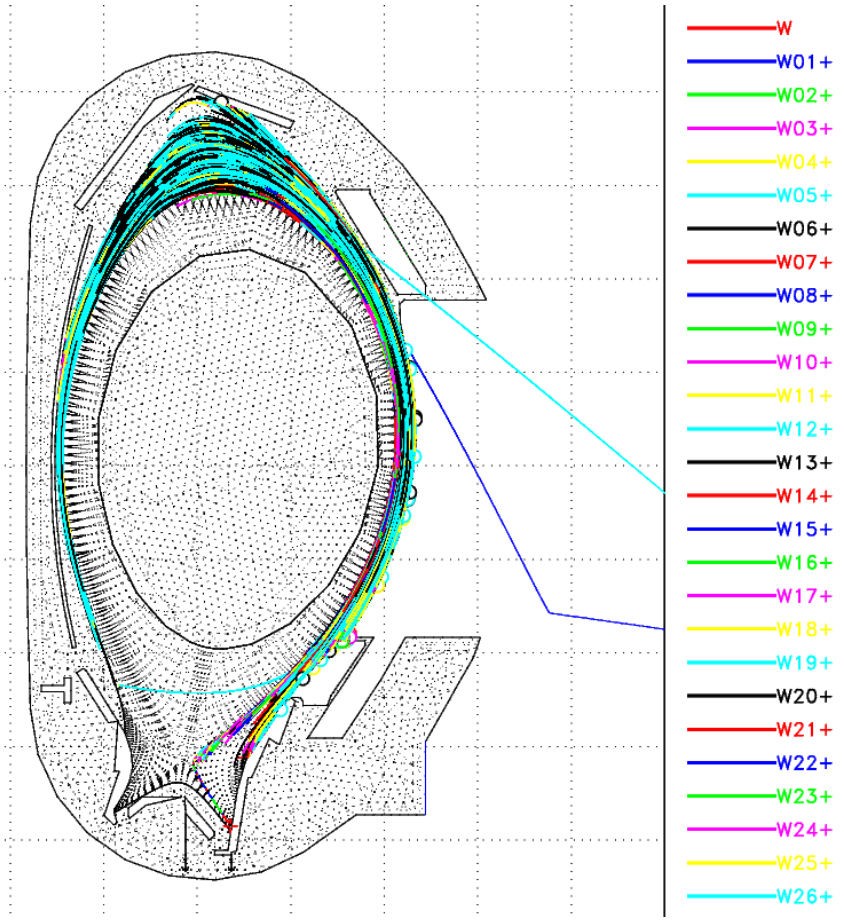
Principle set up I

- Grid for EIRENE test ions extends to the main chamber wall
- No background-plasma-wall interaction at main chamber wall



Principle Set up II





Numerics

EIRENE does not require a field aligned grid
But with TIM very small time steps needed:

T_i [eV]	Δr [mm]	Δl [mm]
10	0.001	0.324
100	0.010	1.024
1,000	0.105	3.236

Example of numerical drift with dt=1e-7s

Long living W ions on 'banana' orbits undergo several passages – particular problem is computation on closed field lines
No reflection or self-sputtering activated due to computational restraints – effect only tested qualitatively

# CPU	Comp. Time [s]	# Particles	Time/Particle [s]
1	740	5	148
8	1500	43	35
16	1700	79	21
64	2500	458	5

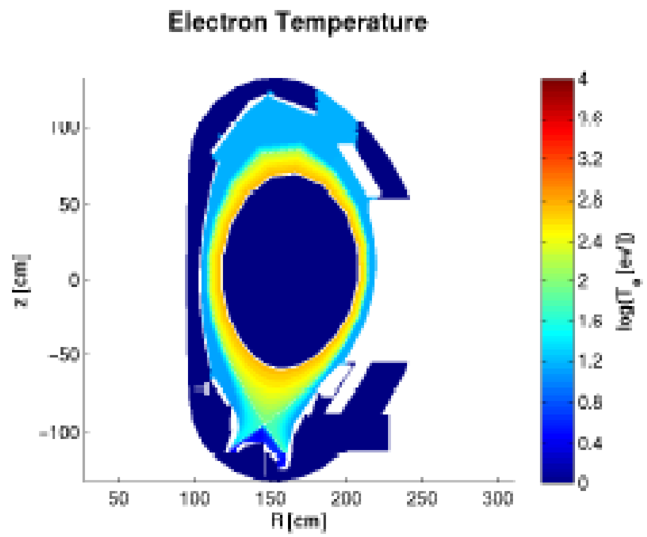
Table 3.4: Computational speed-up of parallelized EIRENE.

In addidition long integral simulation time until distribution reaches equilibrium...-->

Testbeds: simulated L- and H-mode

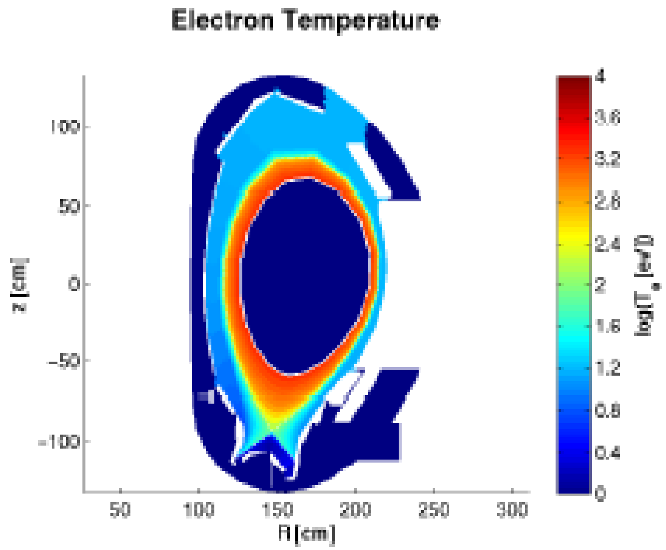
L-mode:

Psol = 1MW; Te(sep)=70eV, ne(sep)=0.8e19m^-3, Te(OT)~50eV (equilibrium #23029 @2.5s)



H-mode:

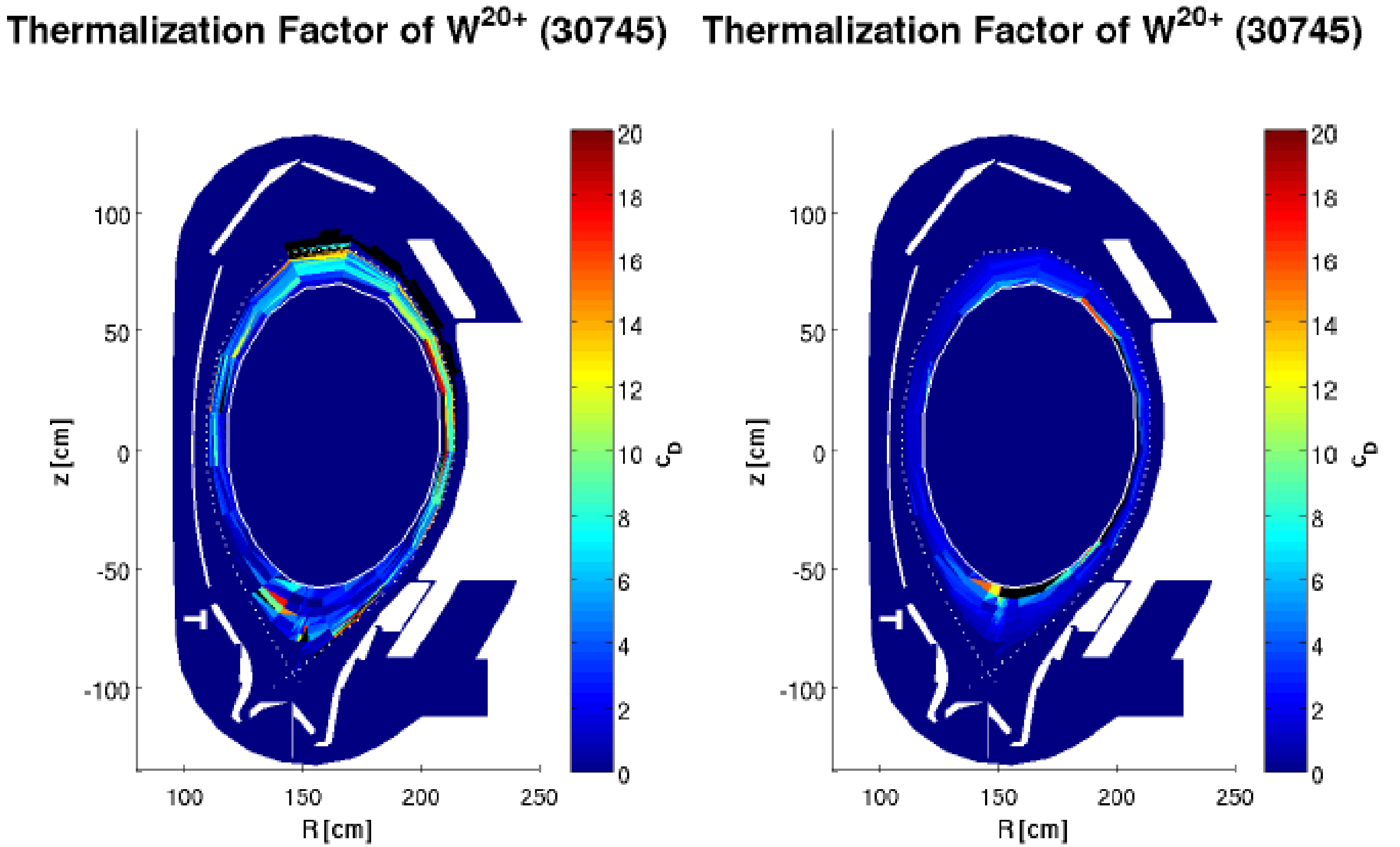
Psol= 9MW; Te(sep)=130eV, ne(sep)=3e19m^-3, Te(OT)~25eV (equilibrium #21372@4.2s)



Testing thermalization of W^{x+}

ASDEX Upgrade

50 Jahre IPP



(a) $v_{\perp}^{t} = 0.1$ (b) $v_{\perp}^{t} = 1.0$

Cause is a singularity in the Trubnikov-Rosenbluth potentials of Fokker-Planck collision operator

Validity of EIRENE as model?

ASDEX Upgrade

- W assumed as a trace impurity in the SOL → low concentrations and no impact on power balance → assumption confirmed
- Conditions for validity of gyro-averaged guiding centre approximation:

$L_B \gg \varrho$ Magnetic field gradient length – o.k.

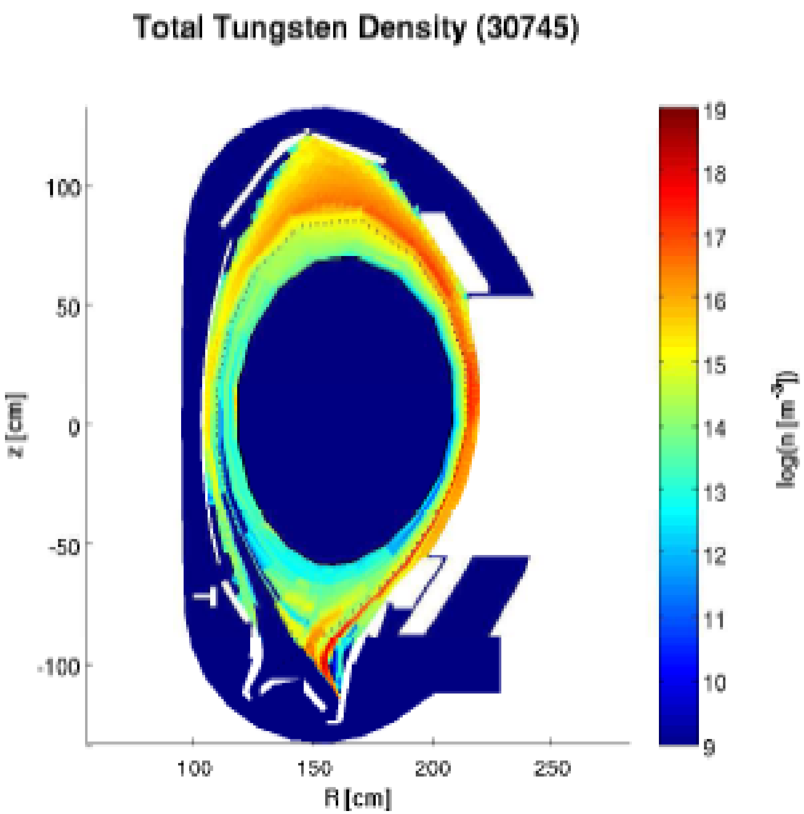
$L_X \gg \varrho \quad \text{with} \quad X = n_e, n_i, T_e, T_i$

$\tau_H \gg \frac{2\pi}{\omega_c}$ always fullfilled as background constant in time

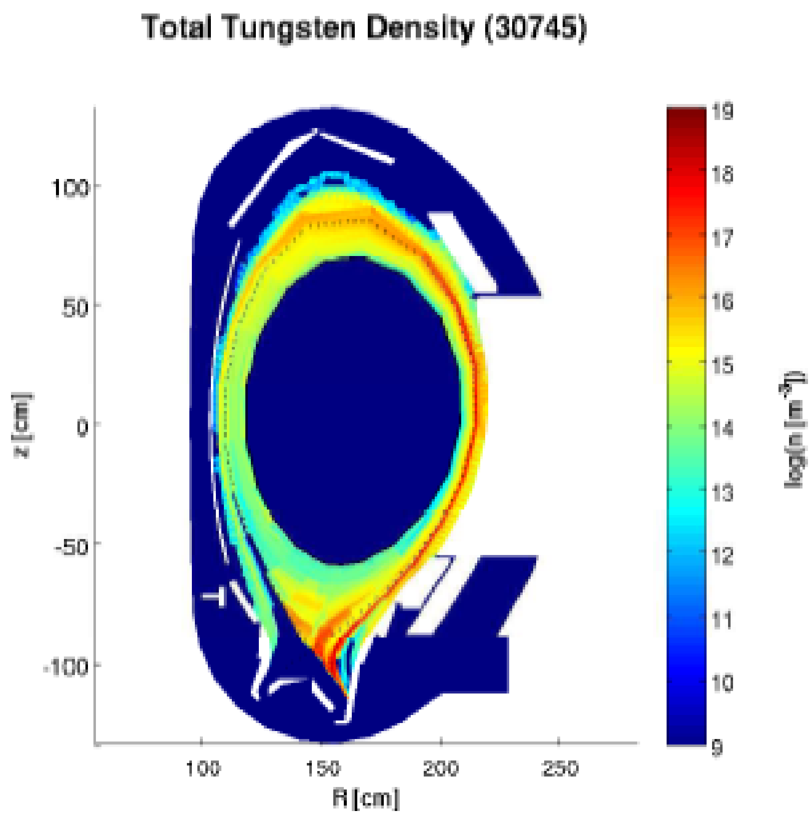
- Gradient lengths validity depends on integration scheme for v^t_perp=v_kin/v_par
- Always valid if =1
- For 0.1 not valid for Z>20 in L-mode and Z>12 in H-mode – however depends on correctness of thermalization (previous slide) → ρ(20+) ~ [4mm-2cm]

Code applicable for simulating W

W distribution & boundary plasma

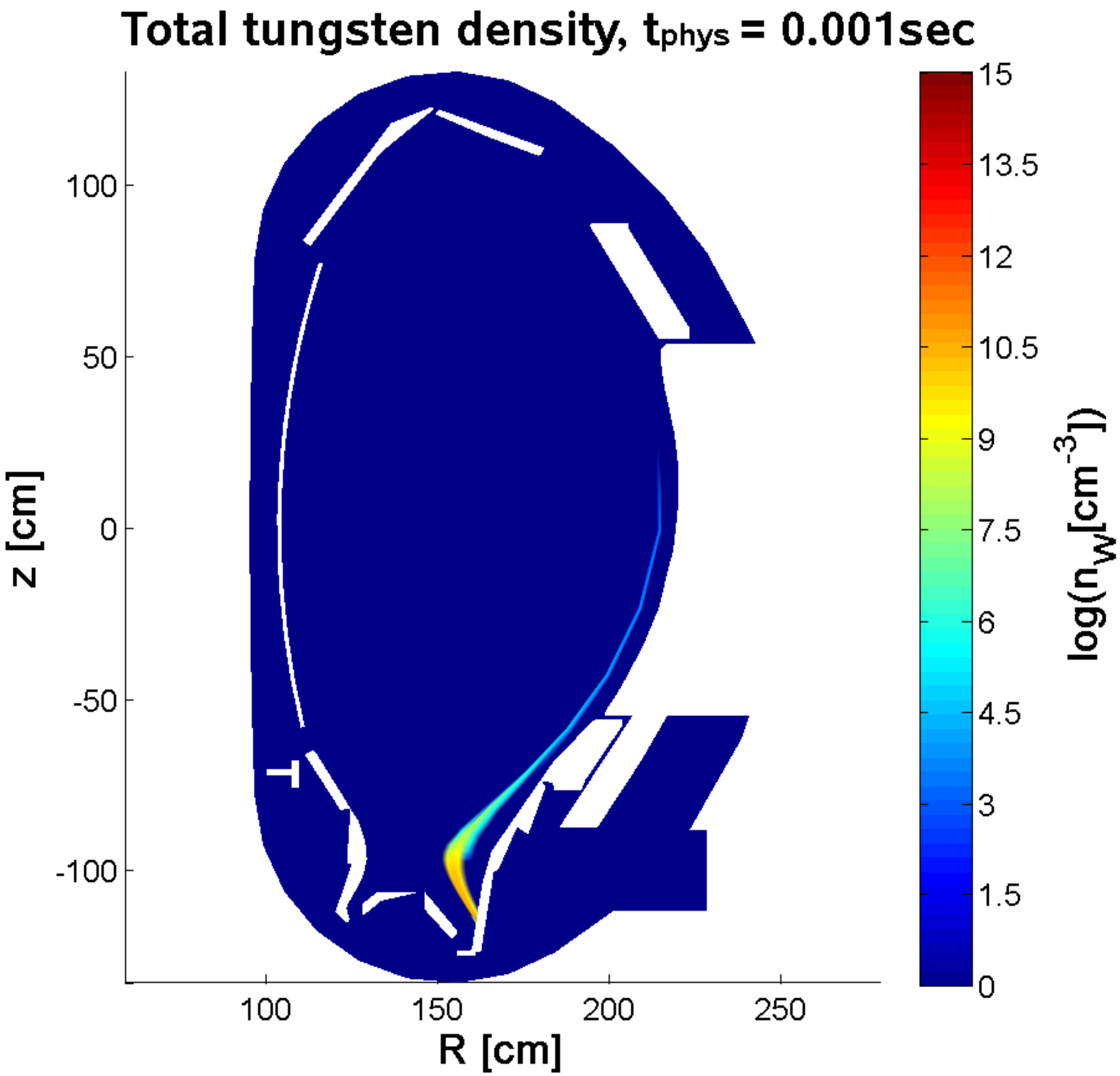


(a) Closest SOLPS cell conditions

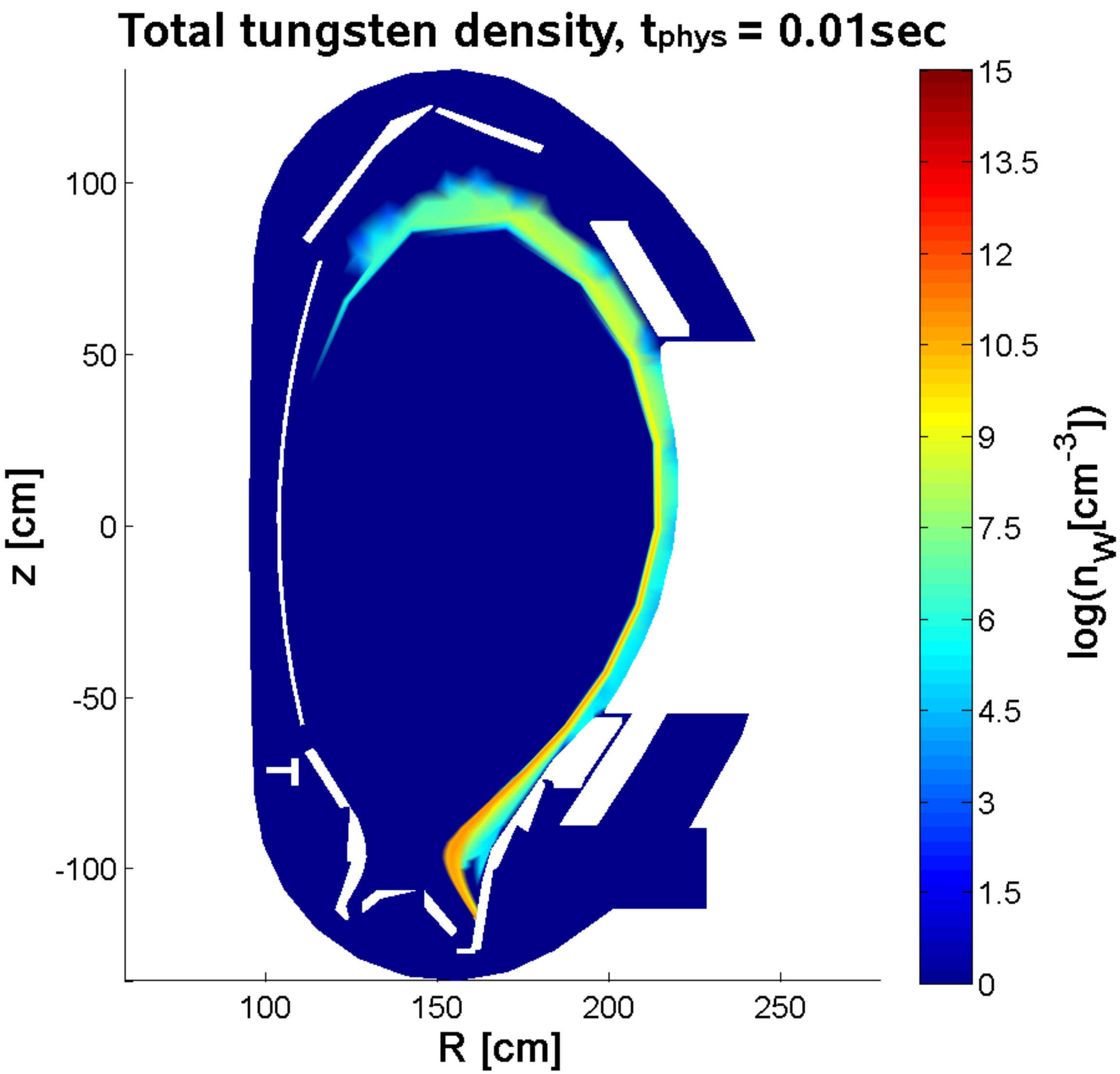


(b) Vacuum conditions

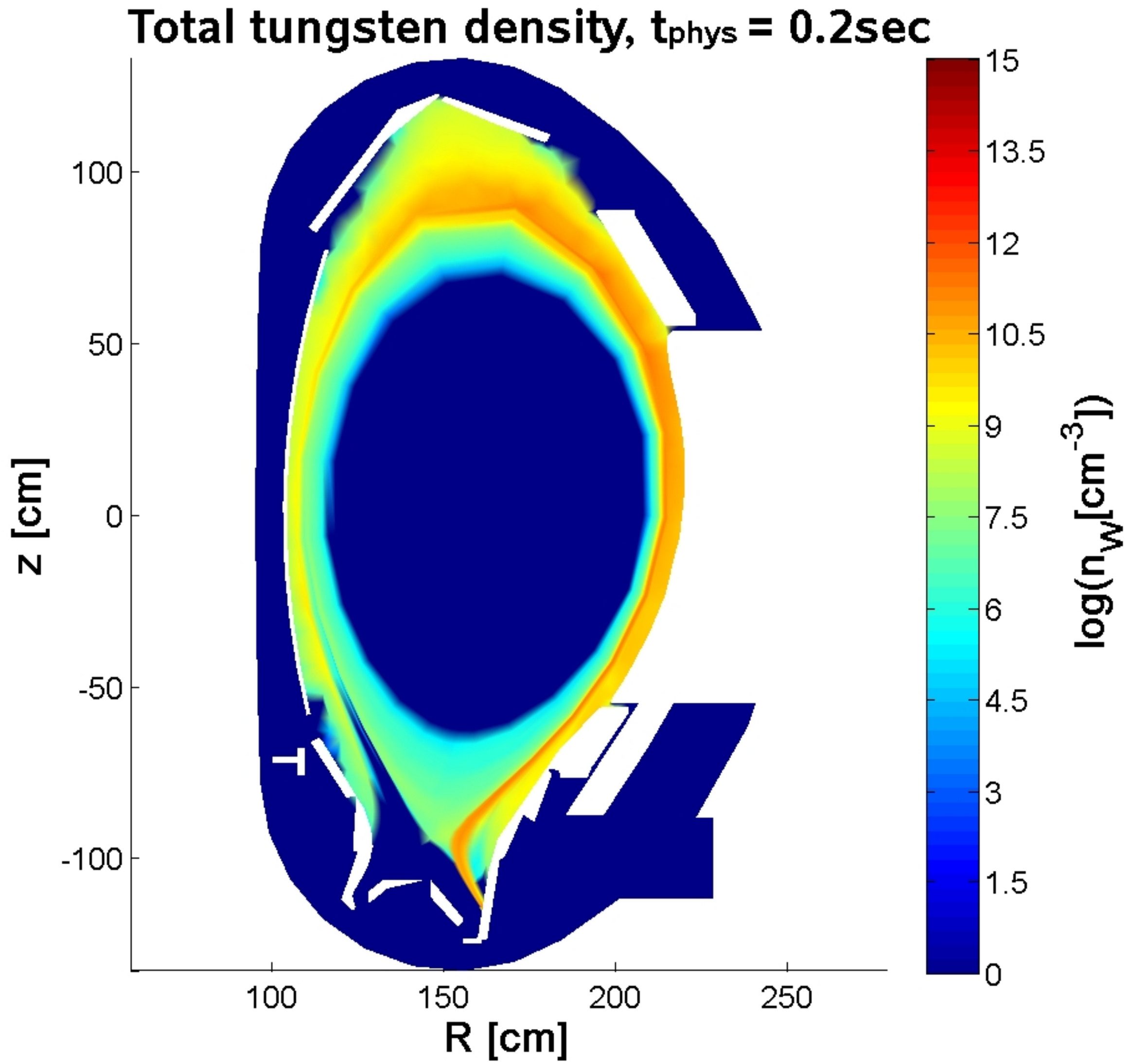
Time dependent W distribution I



Time dependent W distribution II

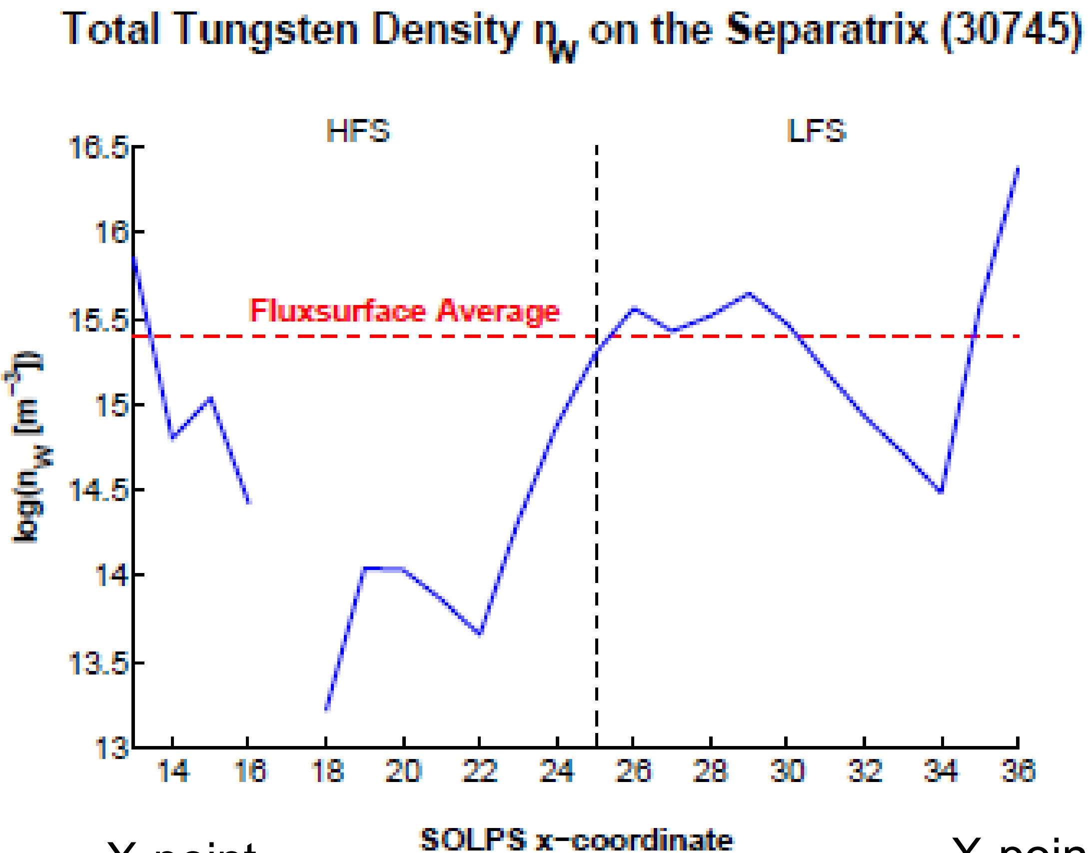


Time dependent W distribution III



- Steady state distribution for t>20ms
- Min 1 week CPU time!
- To be kept in mind when simulating ELM cycles

Benchmark vs. Neoart & poloidal distribution of W



X-point

X-point

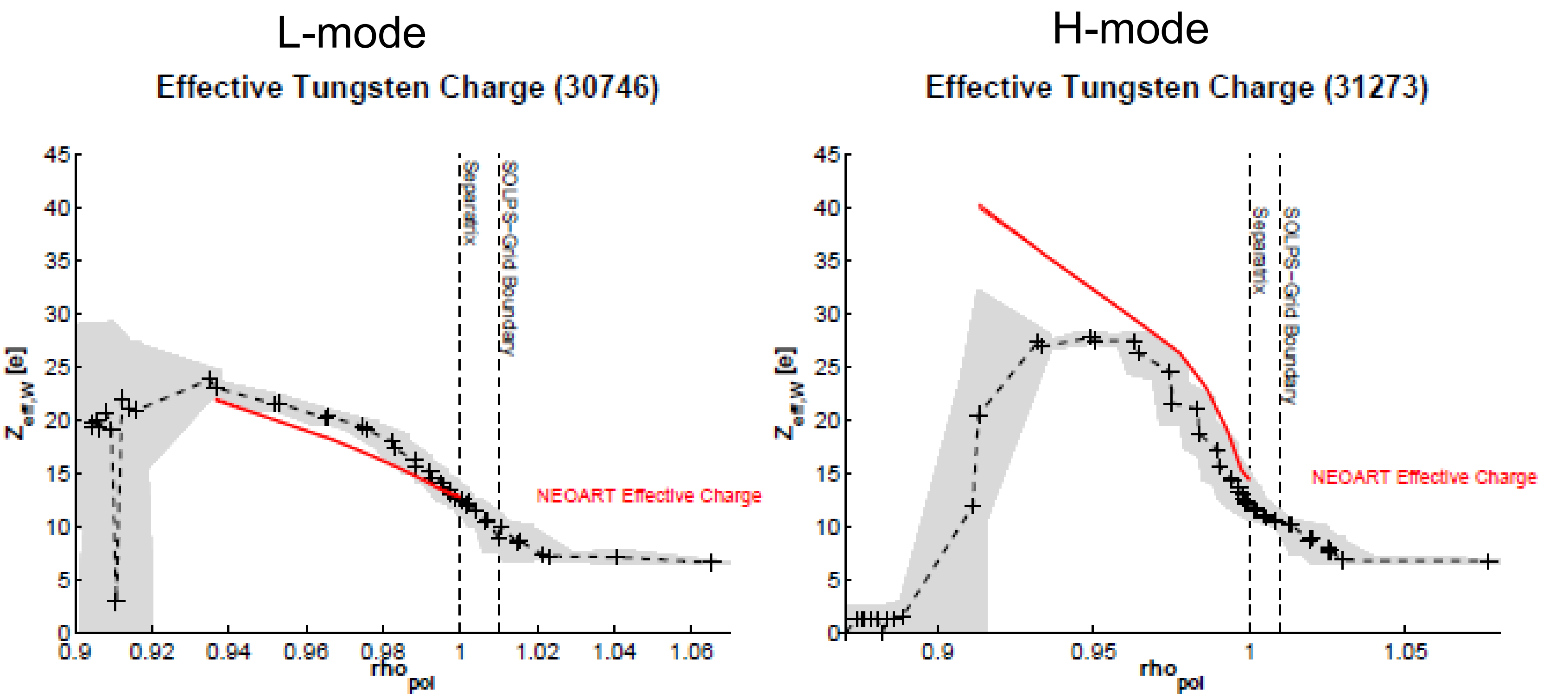
Cell index

Benchmark vs. Neoart

ASDEX Upgrade

50 Jahre IPP

Effective charge state of W



(a) #30745 (b) #31273

Differences for ρ<0.95 possibly due to boundary condition in EIRENE (absorbing)

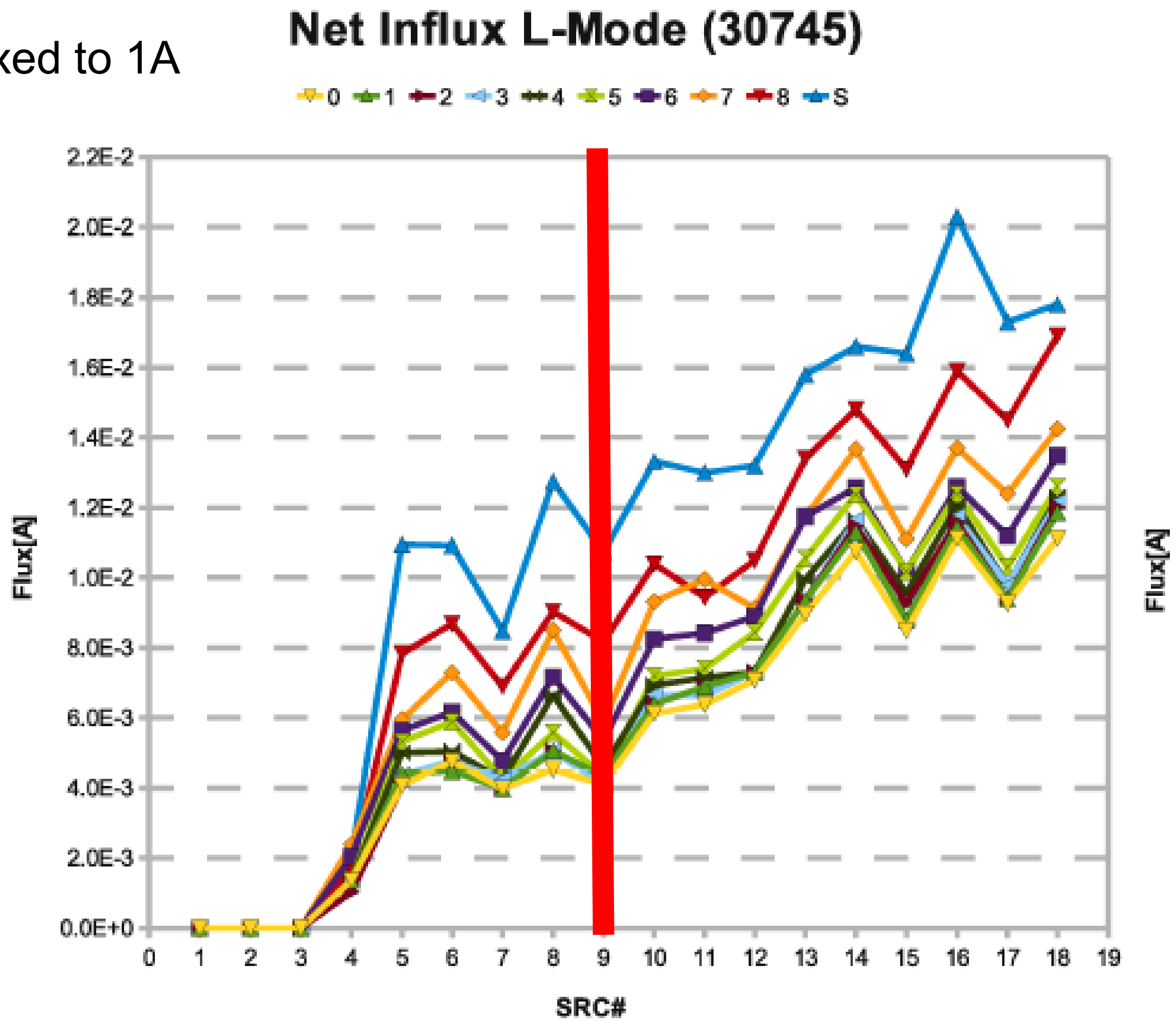
Best agreement closet oseparatrix

→ applicability likely for penetration probability studies

Net influx in L-mode

Source strength fixed to 1A

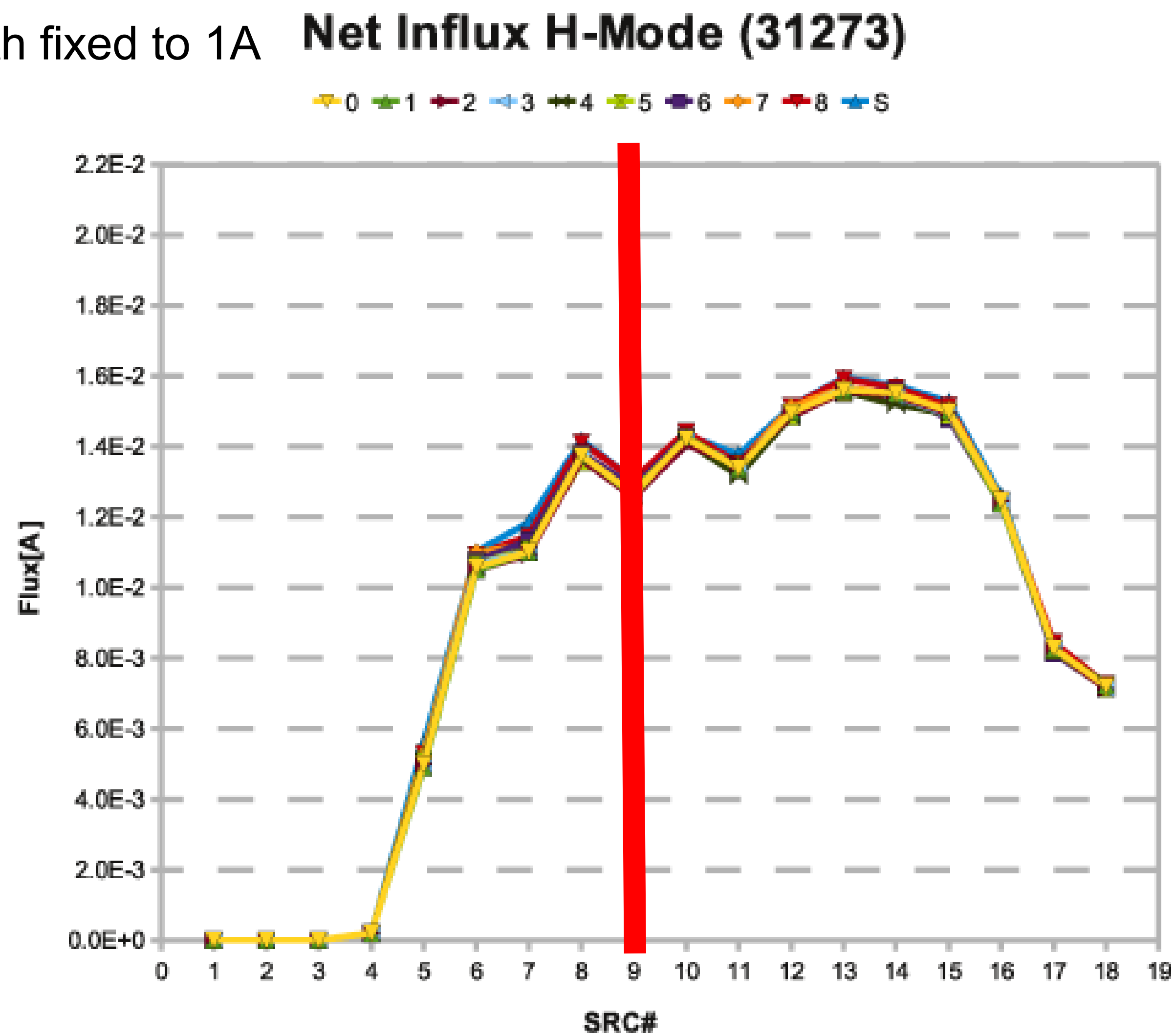
Multiple particle passages over separatrix → good statistics required for determination of net influx



Radial cell index along outer target plate

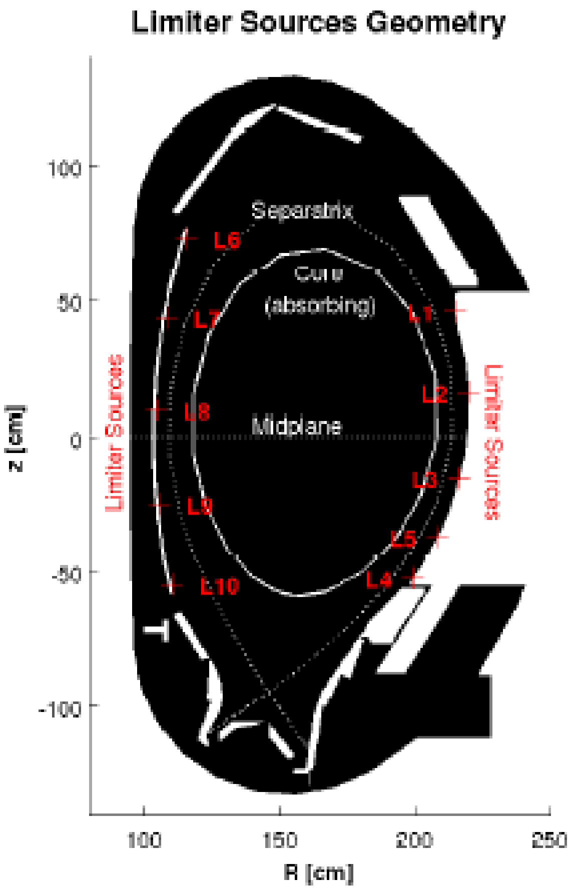
Net influx in H-mode

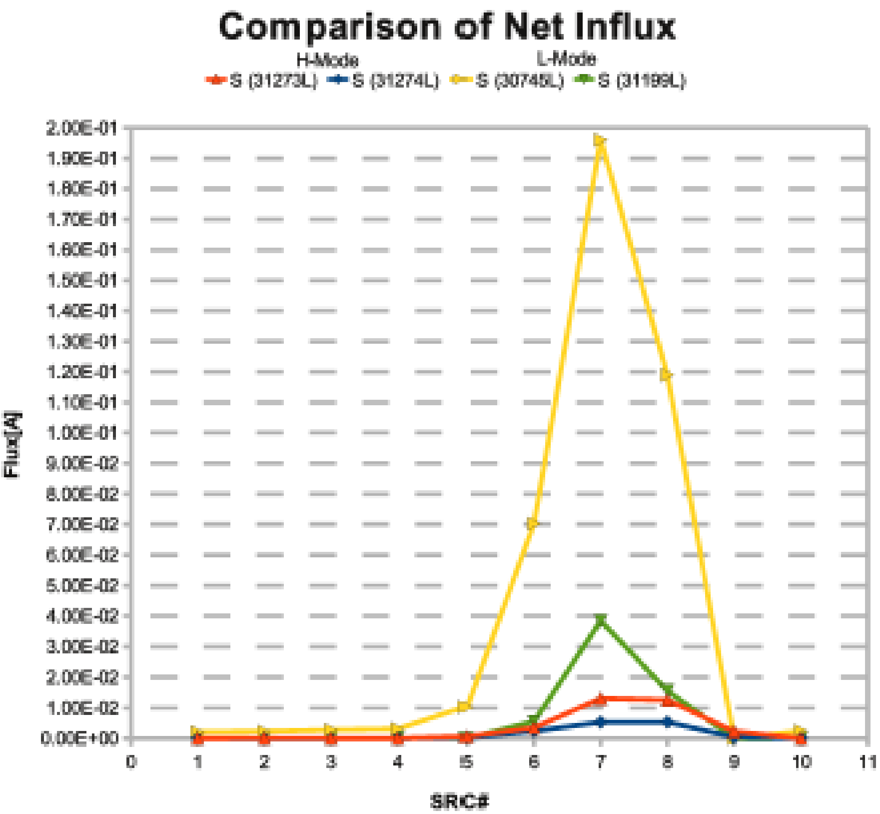
Source strength fixed to 1A



Radial cell index along outer target plate

Limiter sources and penetration probability



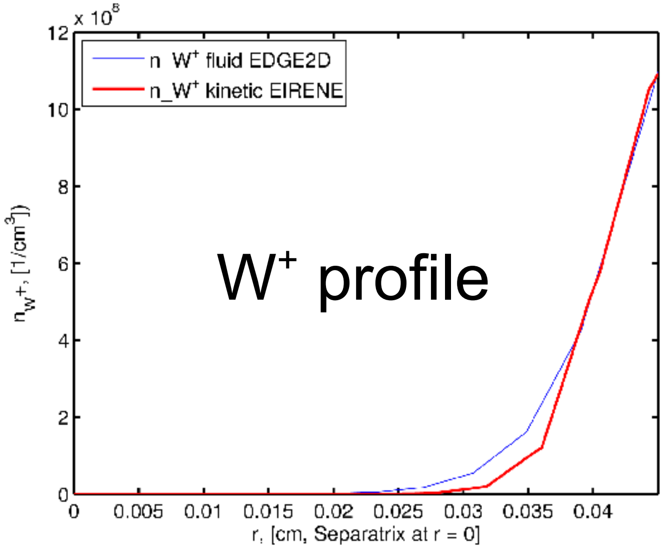


(c) Limiter - Net influx on separatrix

Limiter source number

Highest penetration probability for upper half of inner heatshield

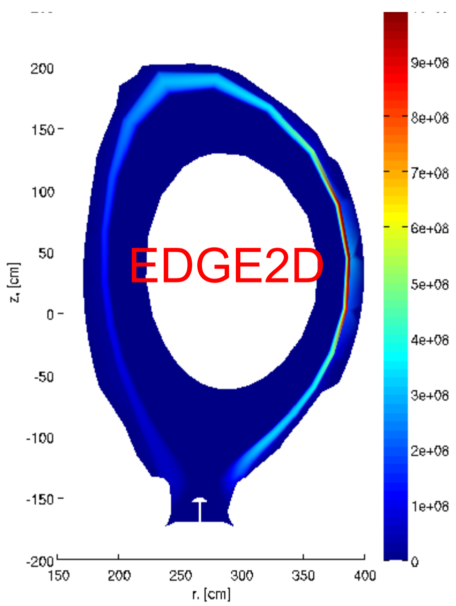
JET

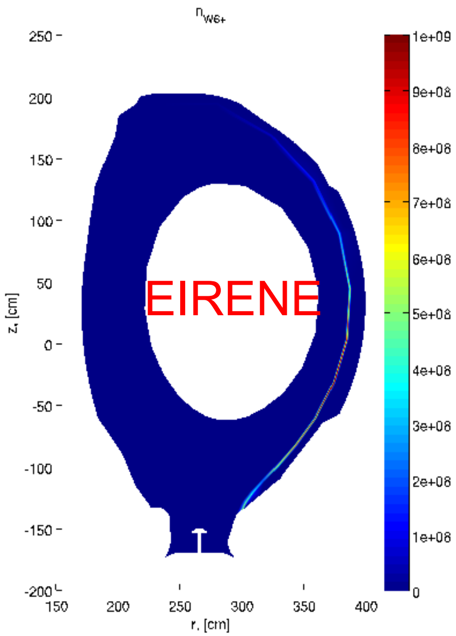


EDGE2D-EIRENE-TIM: benchmarking kinetic vs. fluid Wx+ transport models

Development of required interfaces and code structure is finished

J. Seebacher et al. EPS 2010





→ solely transport models can be changed

→ drift effects are straightforward to be simulated with the kinetic code, while drift effects in fluid codes can lead to stability problems

ASDEX Upgrade

Conclusions

- *EIRENE with TIM is being used to model migration of W for JET (J. Seebacher) and ASDEX Upgrade (F. Reimold) on given background plasmas*
- *Code not fully ready for this task*
- *Grid including magnetic field information extends to the wall with some assumed background plasma*
- *Time dependent simulations possible and probably needed for full ELM cycle due to time until steady state (~20ms)*
- *Divertor sources: penetration probability for W increases outward (<2%), lowest close to strike point*
- *Limiter sources: generally similar penetration probability as divertor far SOL, but very high values for top inner heat shield – to be verified*
- *To be tested: Fluid approach vs. Kinetic approach*