平成24 年度 ダイバータおよびPWI合同研究会
2012年7月23–24日
筑波大学

タングステンPWI モデリング進展
原型炉タングステン壁損耗シミュレーション

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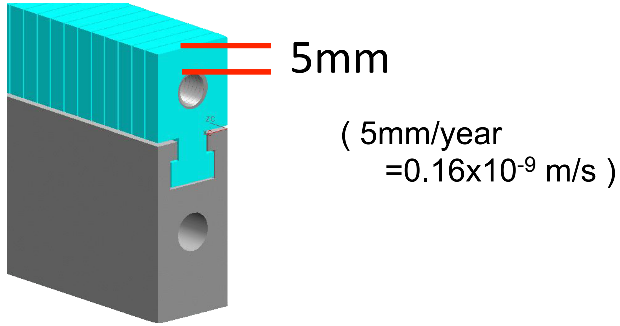
IFERC-CSC

Background

Tungsten (W) is the most preferable candidate for the plasma facing material in the DEMO fusion reactor.

From the viewpoint of erosion by the seeded impurity species, thick W armor is desirable.



Mono-block W divertor for SlimCS
(S.Suzuki,FED2006)

On the other hand, it is necessary to make the W armor as thin as possible, from the following points of view:

(i) sufficient heat removal for allowed operation temperature,
(ii) avoidance of decrease in tritium breeding ratio by the neutron capture,
(iii) large decay heat in unit volume

Erosion of the W armor of SlimCS* in DEMO is numerically analyzed by SONIC and IMPGYRO-EDDY

SlimCS (K. Tobita., NF 47(2007)892., K. Tobita., NF 49(2009)075029.)
Conceptual DEMO design for P_{fus} ≤3 GW (with reduced-size CS (R = 5.5m and A=2.6)

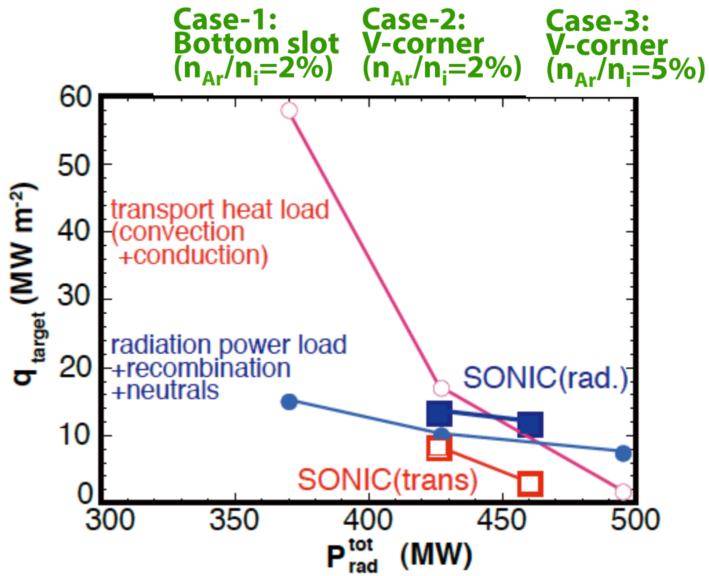
Simulation study for power handling in DEMO divertor

SONIC simulation **for SlimCS** demonstrates the **detached divertor plasma** by the V-shaped corner and large Ar impurity seeding.

However, still $q_{pk,div}$ > 10MW/m^2 (P_{fus}=3GW)

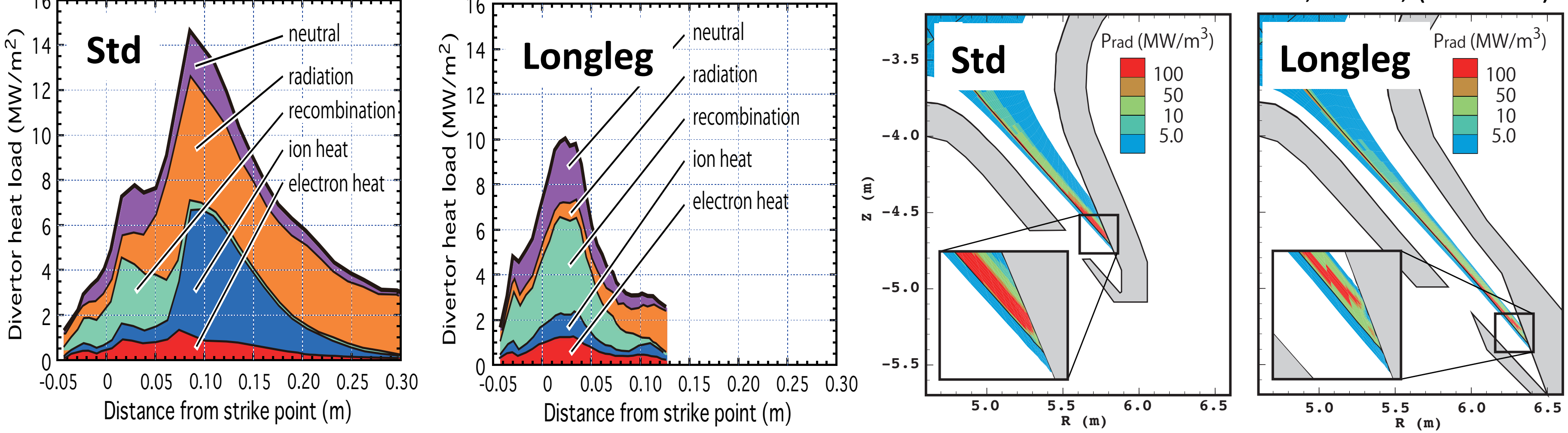
For further reduction of the divertor heat load, investigation of effects of seeded impurity transport, kind of impurity, divertor geometry, advanced divertor and so on, are in progress.

N.Asakura, JPFR Series 2010



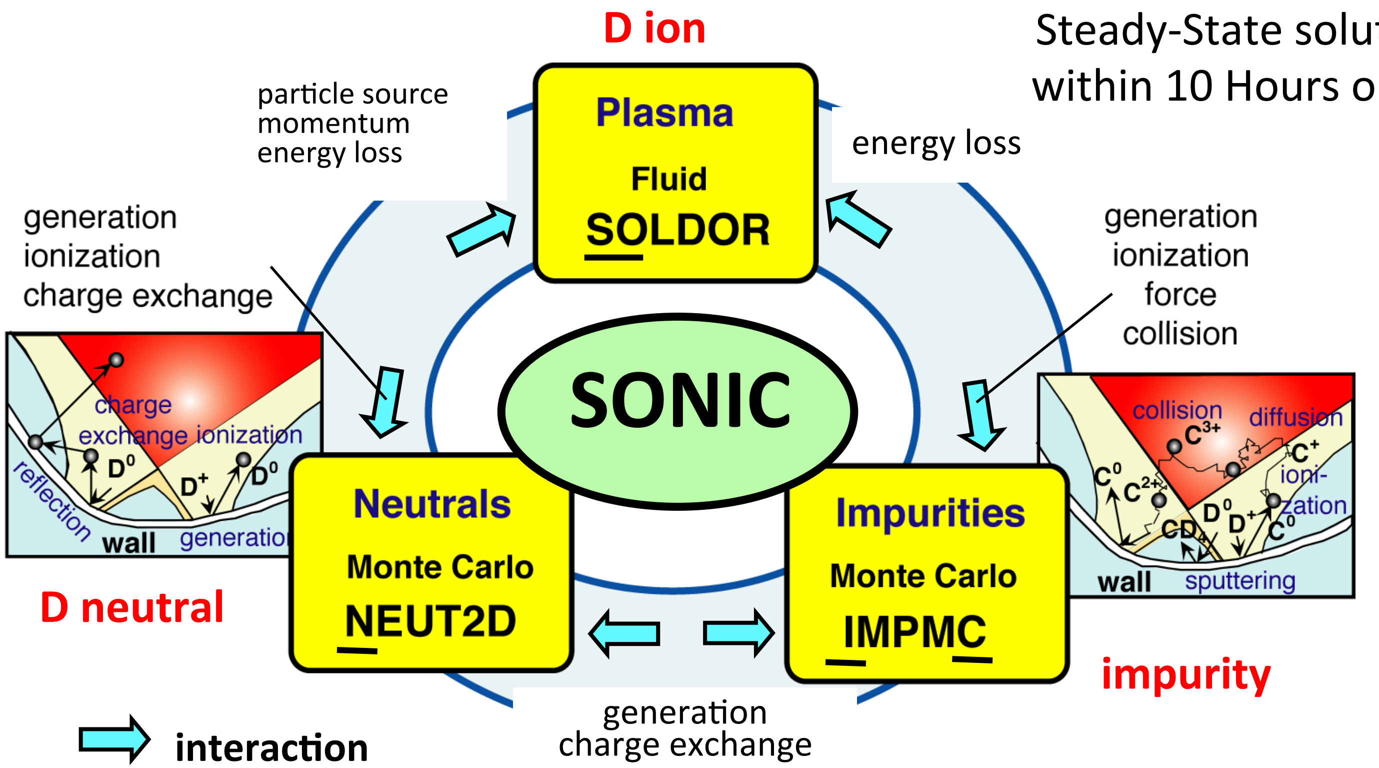
ex. Divertor geometry effect (simple impurity model)

K.Hoshino, PET12, (CPP2012)



Suite of integrated divertor codes SONIC*

Steady-State solution is obtained within 10 Hours on BA-IFERC-CSC (512PE)



input parameters

Core boundary at r/a=0.95: $F_i = 6\times10^{22}$ s^{-1}

D_2 Gas Puff: 6×10^{22} s^{-1} from mid-plane 4×10^{22} s^{-1} from outer div.

$S_{Pump} = 200$ m^3/s,

D=0.3 m^2/s χ =1.0 m^2/s （spatially constant）

Ar gas puff to the outer divertor to achive P_{rad}/P_{in}=92%

*H. Kawashima, Plasma Fusion Res. 1(2006)031, K. Shimizu, Nucl. Fusion 49(2009)065028.

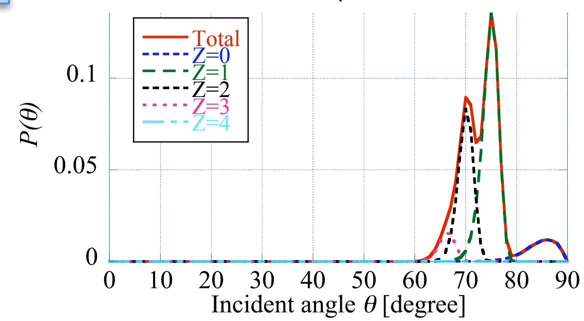
IMPGYRO code

Monte-Carlo Transport Code for High-Z impurity

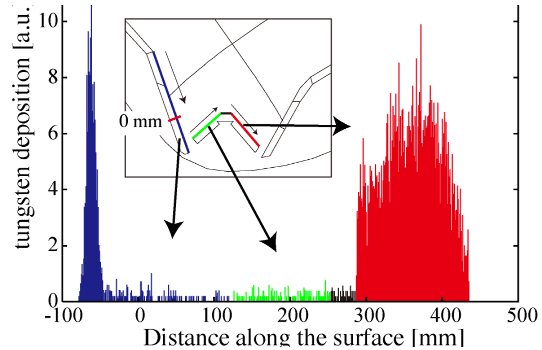
- **Full Gyro-Motion** without Guiding-Center Approximation
- **Coupled to Erosion / Redeposition Code**
  (EDDY: K.Ohya, Physica. Script. T124 (2006) 70)
- **3D Realistic Geometry**
  Direct comparison with experiments
  (Background plasma profile is given by SOLPS or SONIC)
- **Implicit MC model for multi-step Ionization/recombination processes for high-Z impurity**
- **Binary Collision Model for Coulomb Collision with background plasma**
  Evaluation of Particle/Momentum/Energy Source and Loss by High-Z impurities for the background plasma

A. Fukano, JNM363-365(2007)211-215 M. Toma, JNM390-391, 207 (2009).

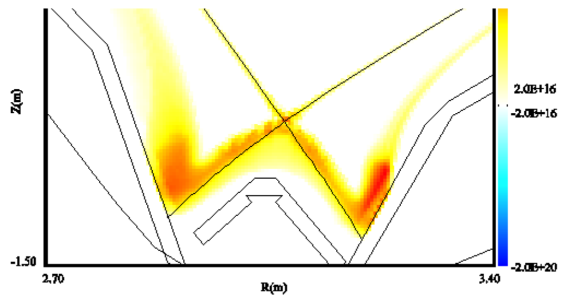
Incident Angle Distribution
(K.Hoshino, PSI08)



Analysis of JT-60U W-Redep.
(K.Hoshino, JSPF08)



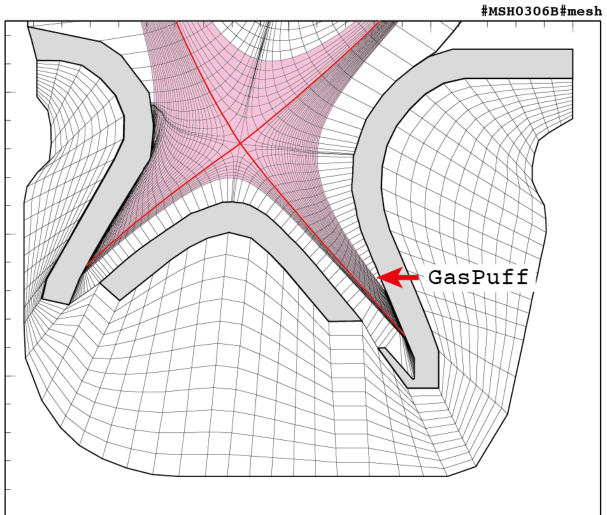
Elec. radiation loss due to W
(M.Toma, JSPF08)



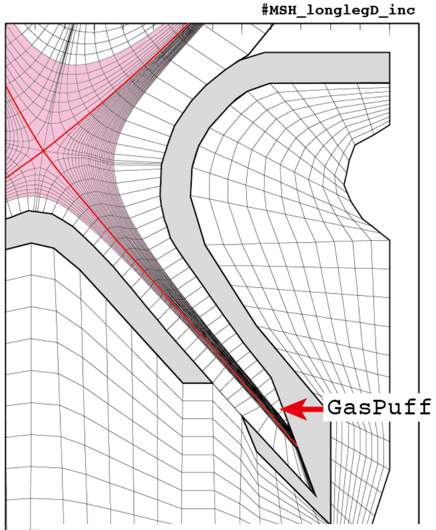
Assumptions / Note

- Analysis is performed for DEMO conceptual design SlimCS
- 3 cases: 3GW, 2GW, longleg
- Background plasma profile is fixed during W transport simulation.
- Initial W is generated only from the outer divertor by Ar sputtering.
- Self-sputtering/reflection is taken into account, but until 3 times.
- The power control in the divertor has not been overcome yet, i.e., $q_{pk,div}$>10MW/m^2 in the P_{fus}=3GW case

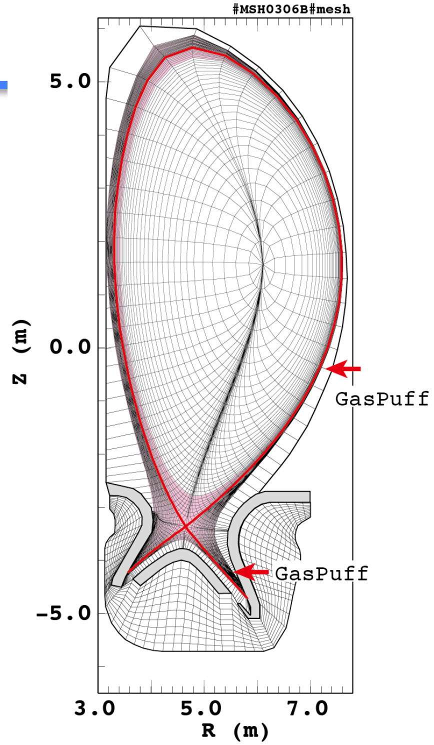
Numerical grid for SlimCS



For 3GW and 2GW case



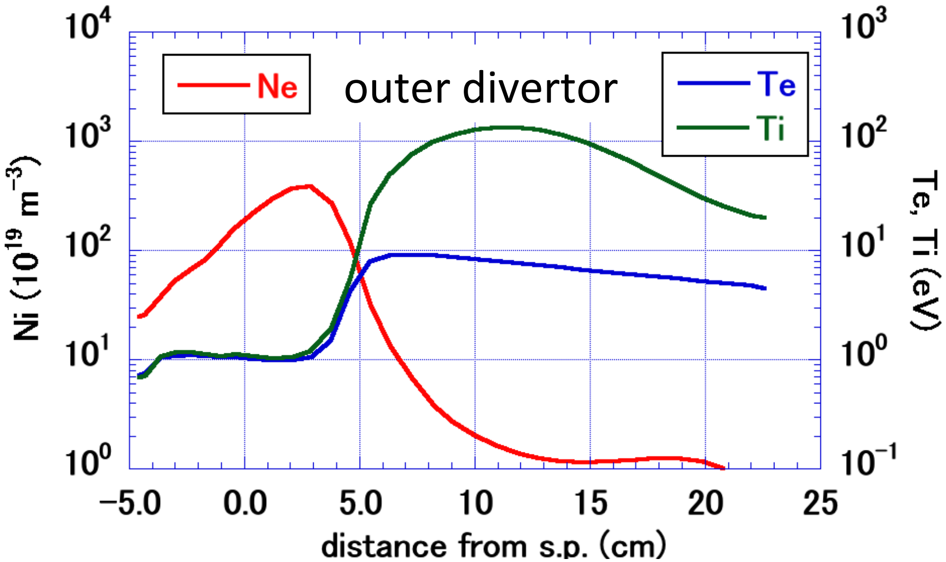
For Long-leg case



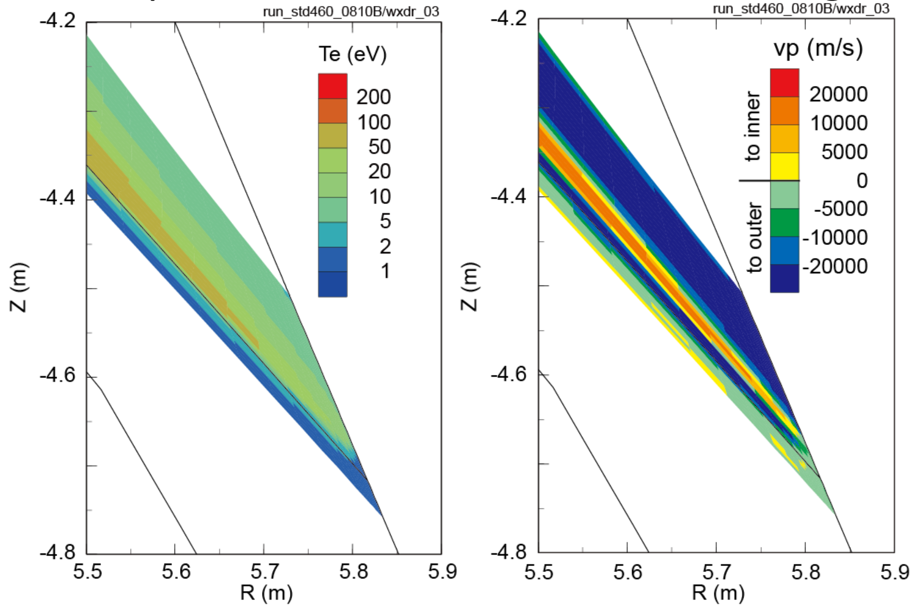
3GW case (reference): divertor plasma profile

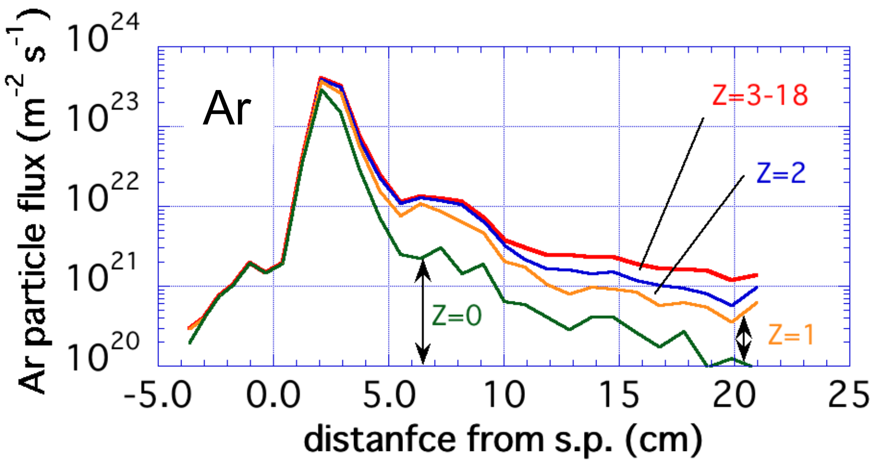
P_{in}=500MW
P_{rad}=460MW

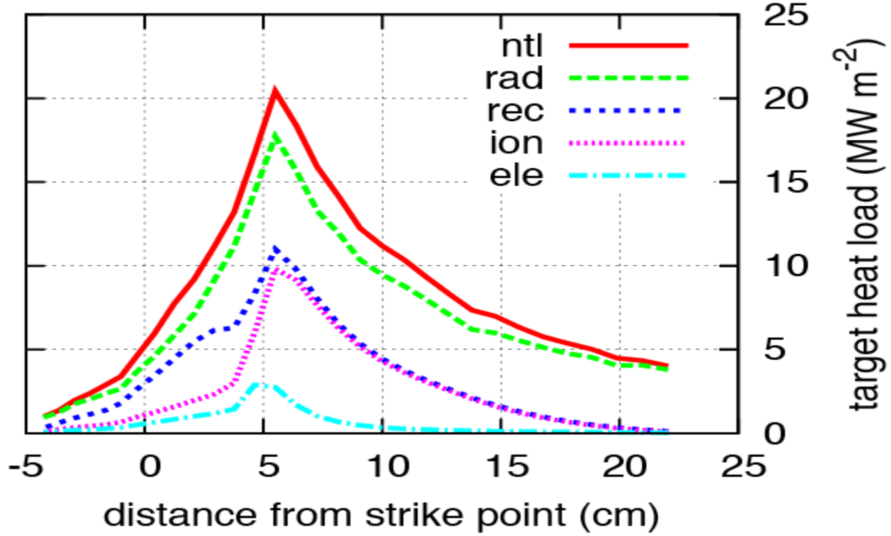
$n_{mid}=2.94\times10^{19}\ m^{-3}$
$F_{Ar} = 1.09\times10^{21}\ s^{-1}$
$q_{pk,\ od} = 20MW/m^2$



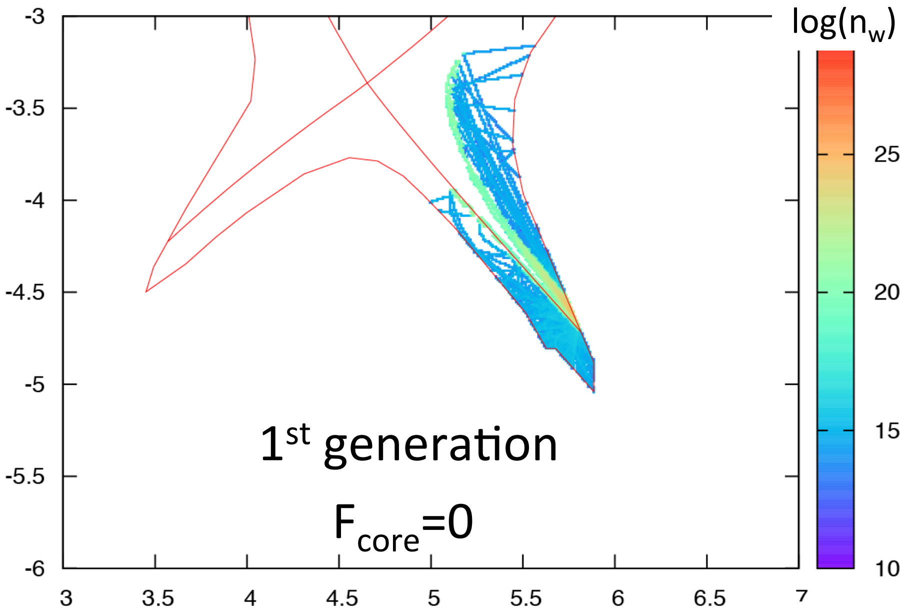
2D profiles near the outer divertor target

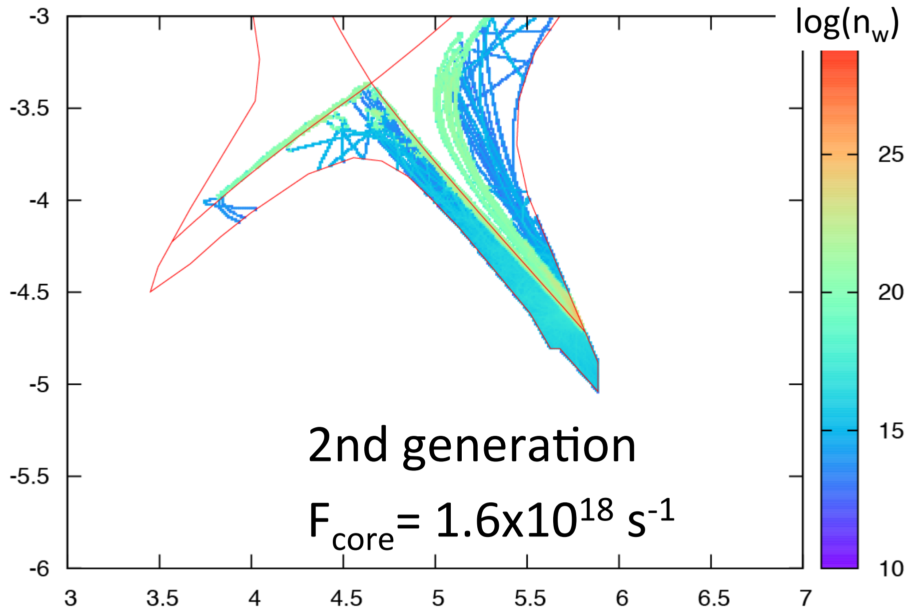


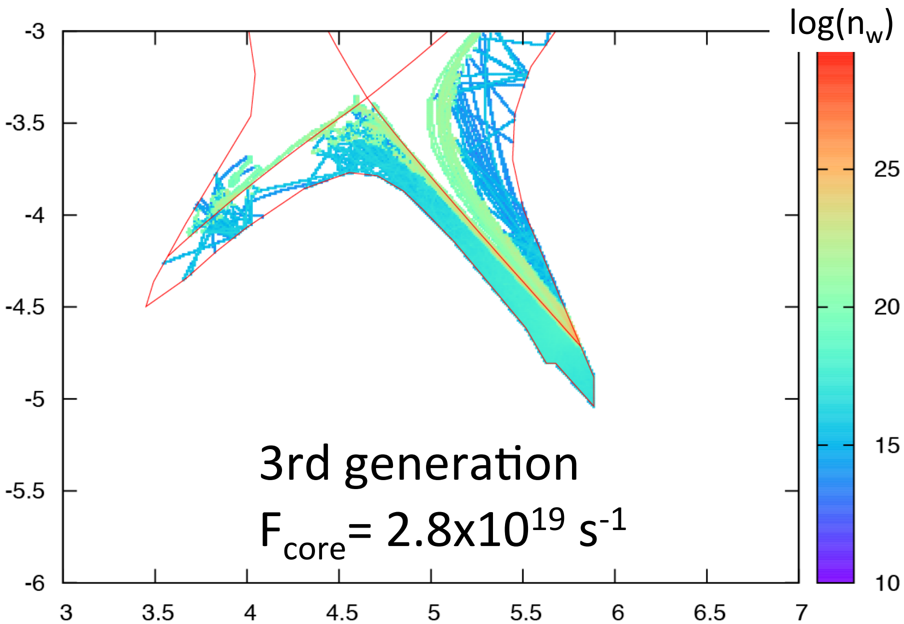




3GW case: 2D profiles of W density





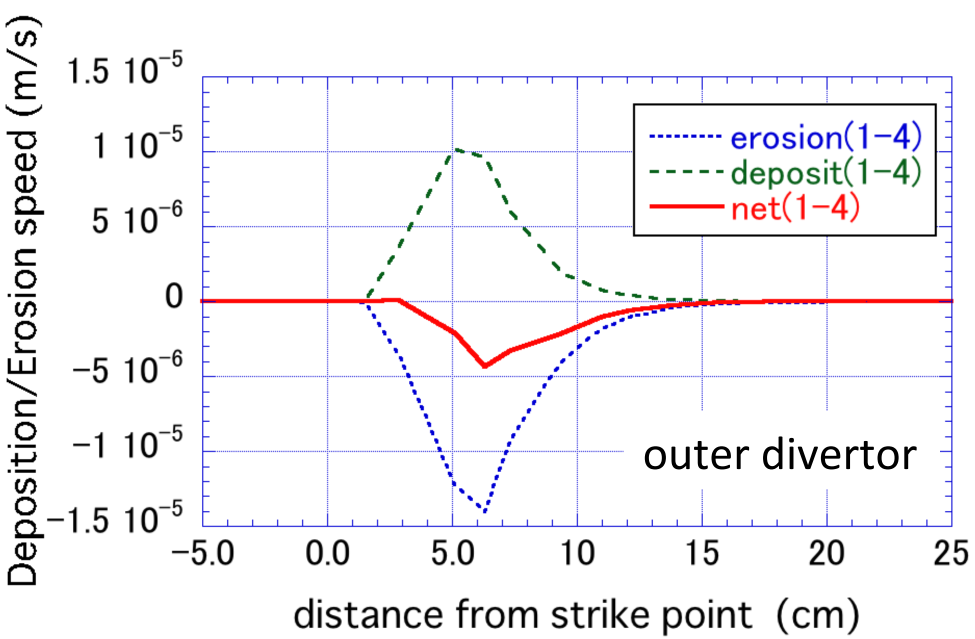


1st generation is relatively localized, while others are widely distributed.

Emitted energy of 1st generation is lower than others.

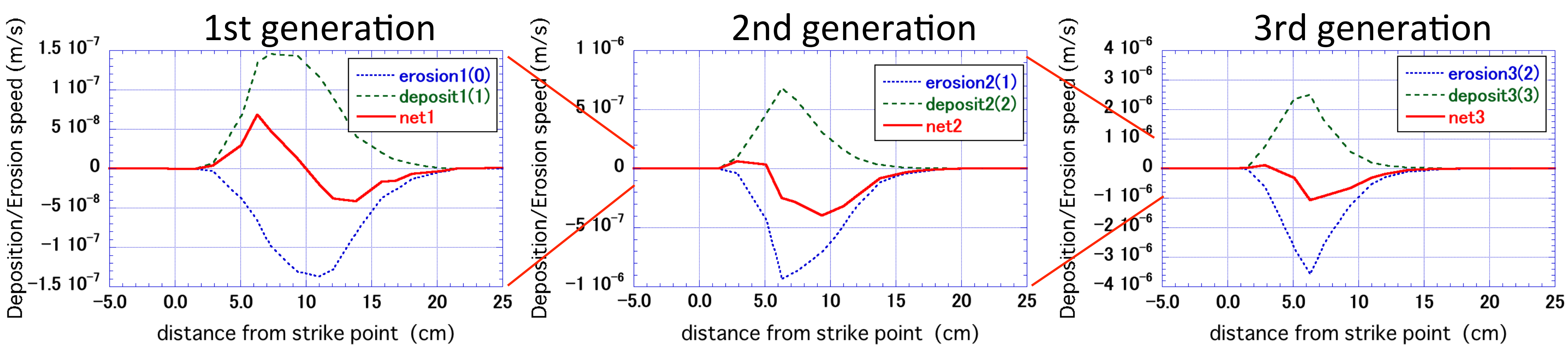
The W influx to the core become high in higher generation.

3GW case: dep./ero. speed at outer divertor



In the 1st generation, most of W particles deposit near the erosion layer.

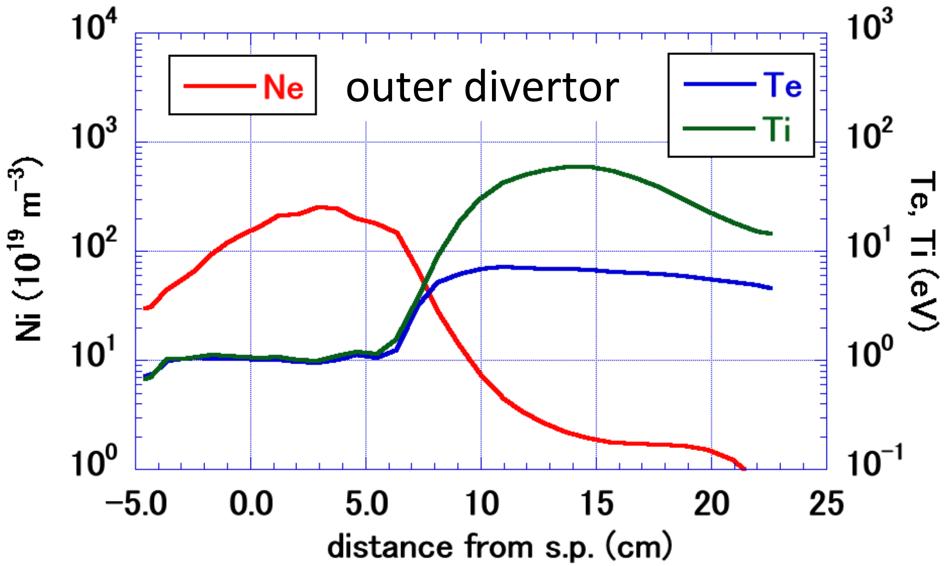
In 2nd and 3rd generations, deposition rate decreases, because W particles with high emitted energy are transported upstream and some of them deposit on the dome.



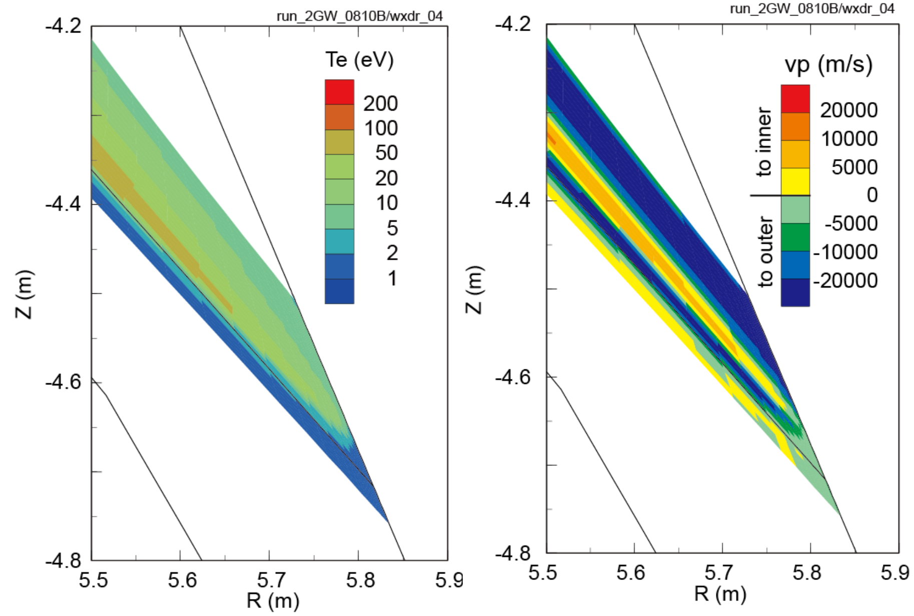
2GW case: divertor plasma profile

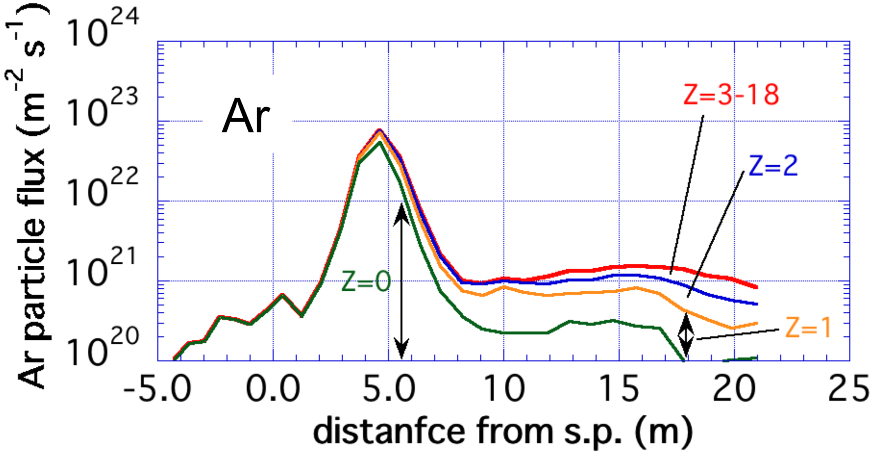
P_{in}=320MW
P_{rad}=294.4MW

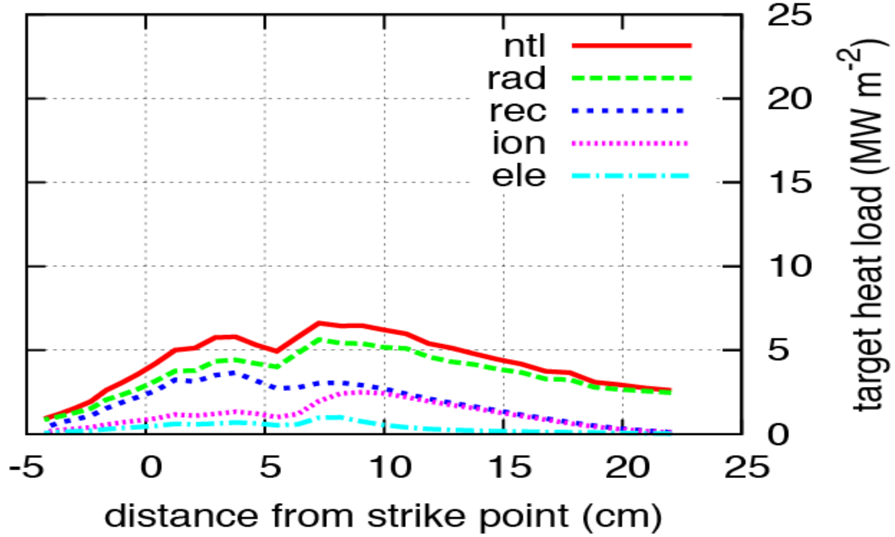
n_{mid}=2.76x10^{19} m^{-3}
F_{Ar} = 0.70x10^{21} s^{-1}
$q_{pk, od}$ = 6.6MW/m^2



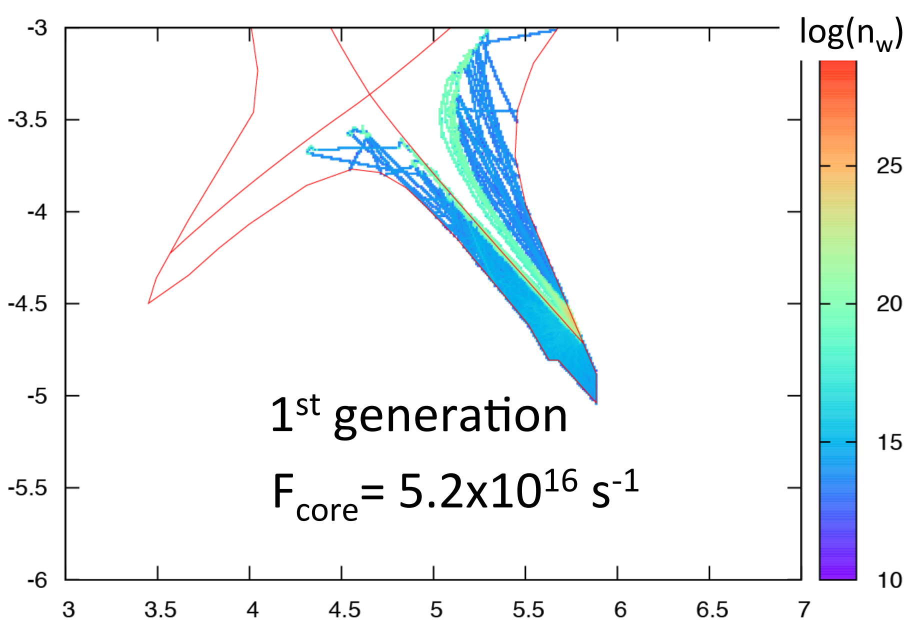
2D profiles near the outer divertor target

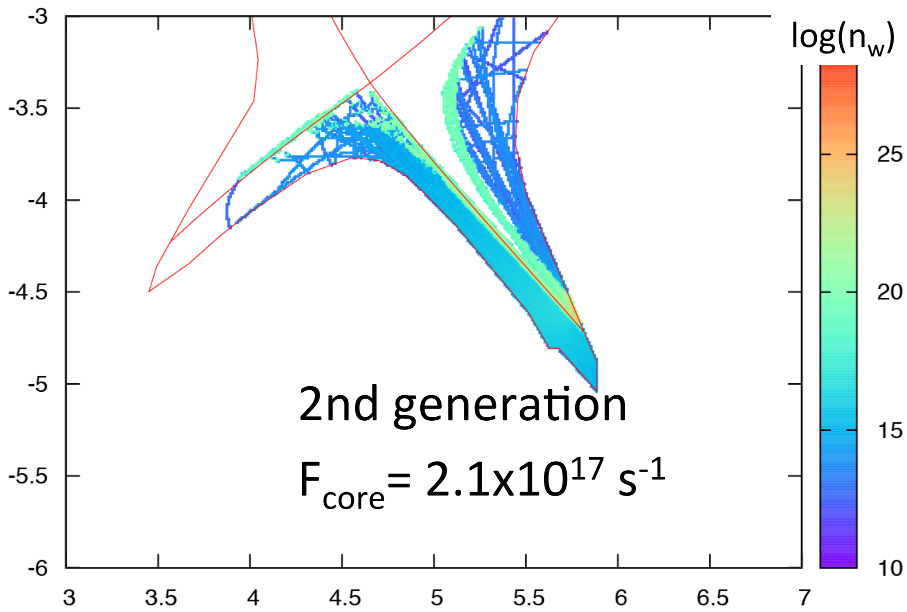


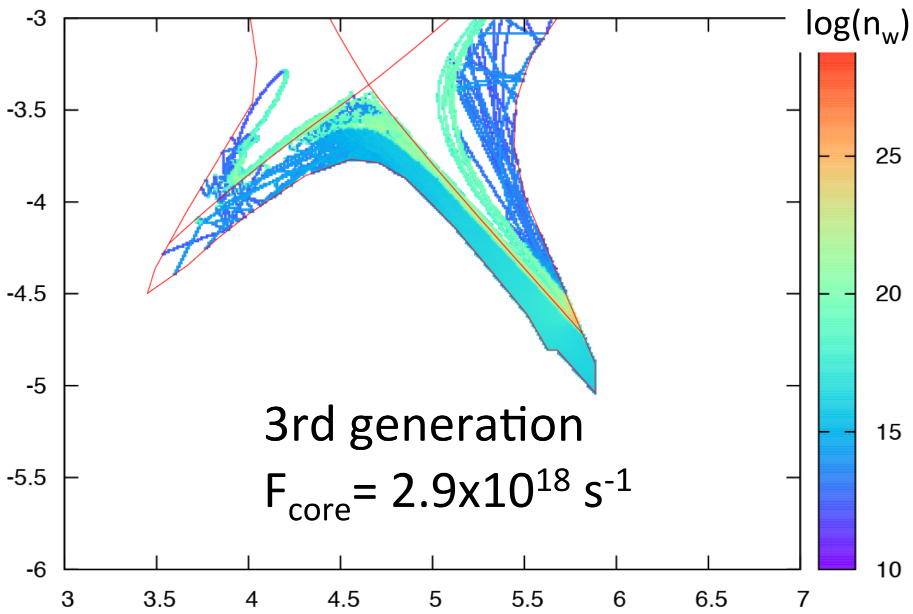




2GW case: 2D profiles of W density

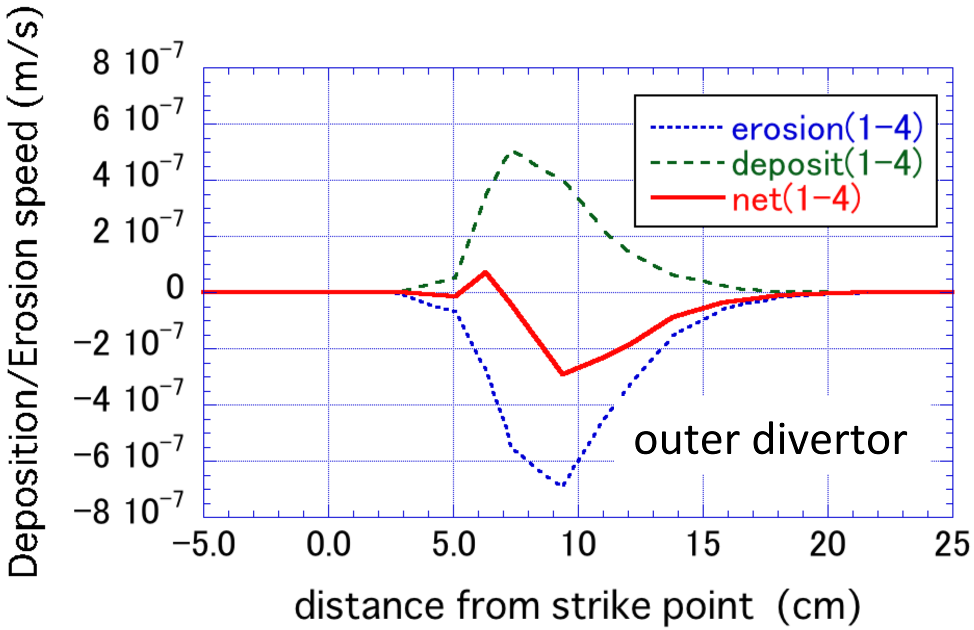




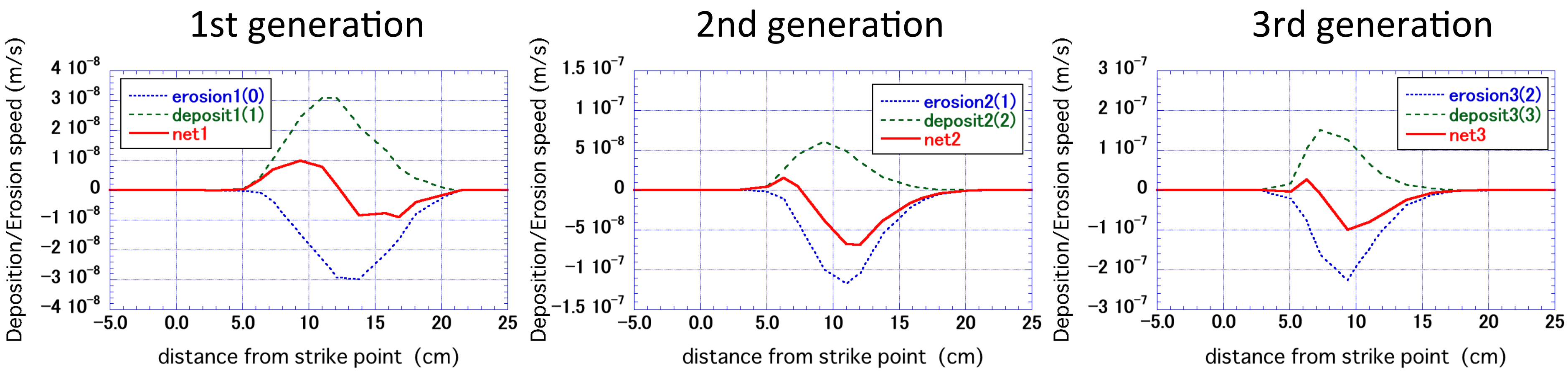


Tendency is similar to the 3GW case.

2GW case: dep./ero. speed at outer divertor



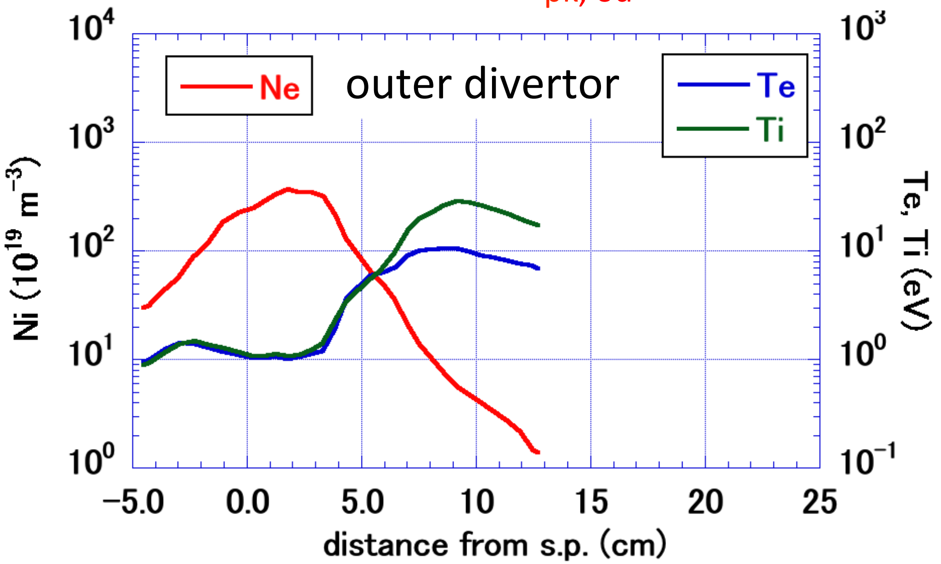
The erosion/deposition speed decreases by 2 orders of magnitude compared with the 3GW case.



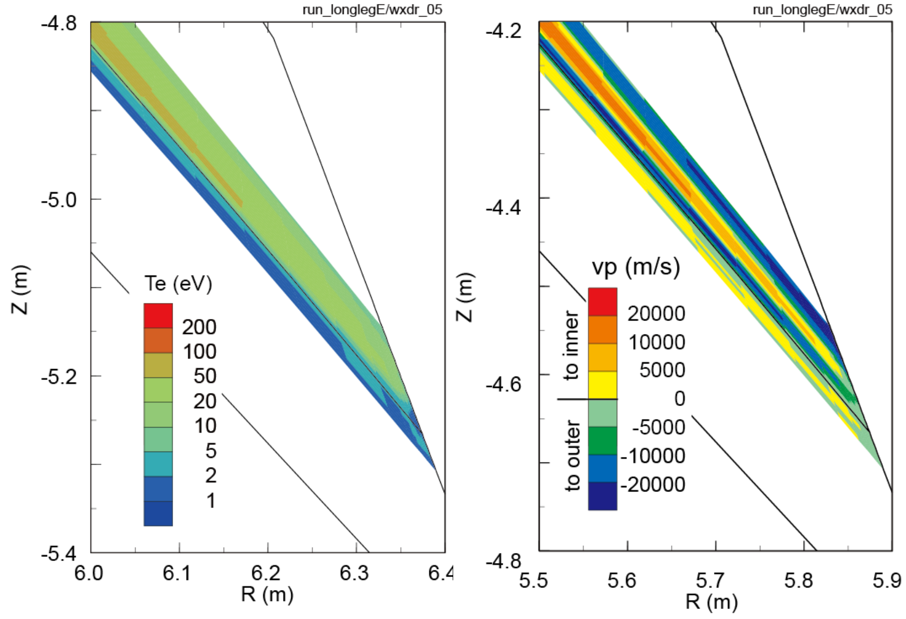
Long-leg case (P_{fus}=3GW): divertor plasma profile

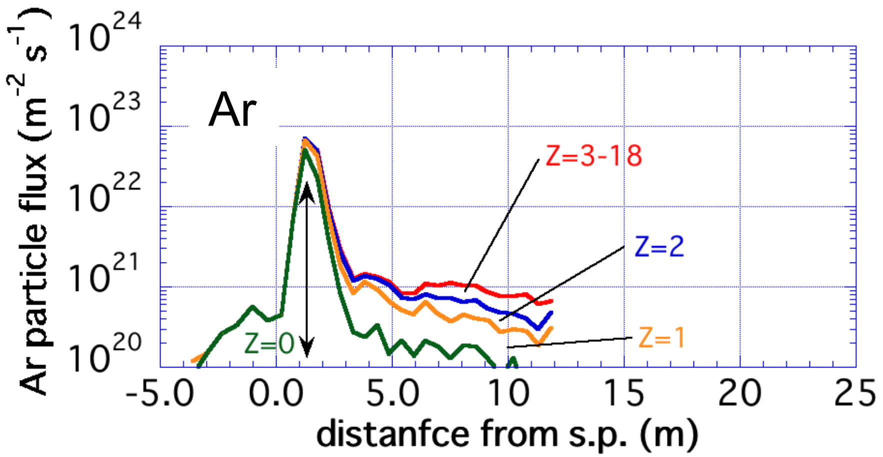
P_{in}= 500MW
P_{rad}= 460MW

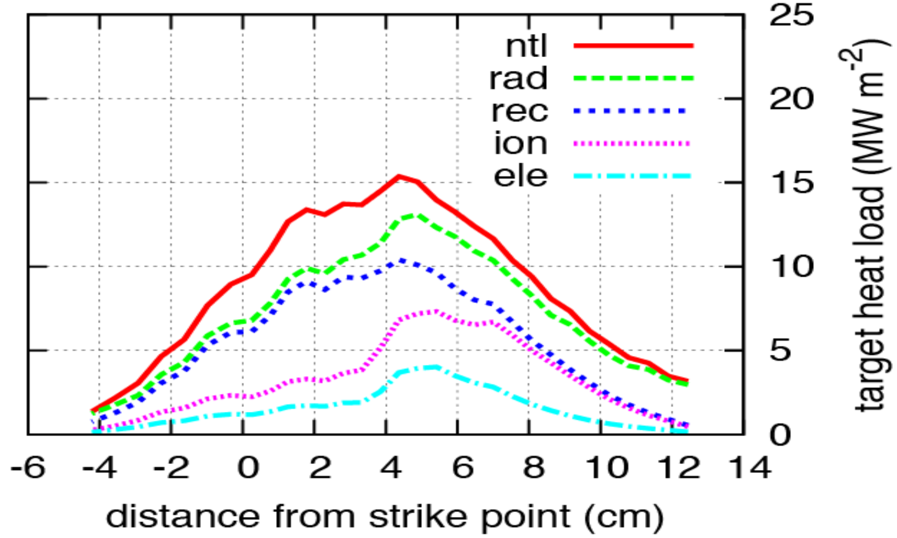
n_{mid}= 3.75x10^{19} m^{-3}
F_{Ar} = 0.49x10^{21} s^{-1}
$q_{pk, od}$ = 15 MW/m^2



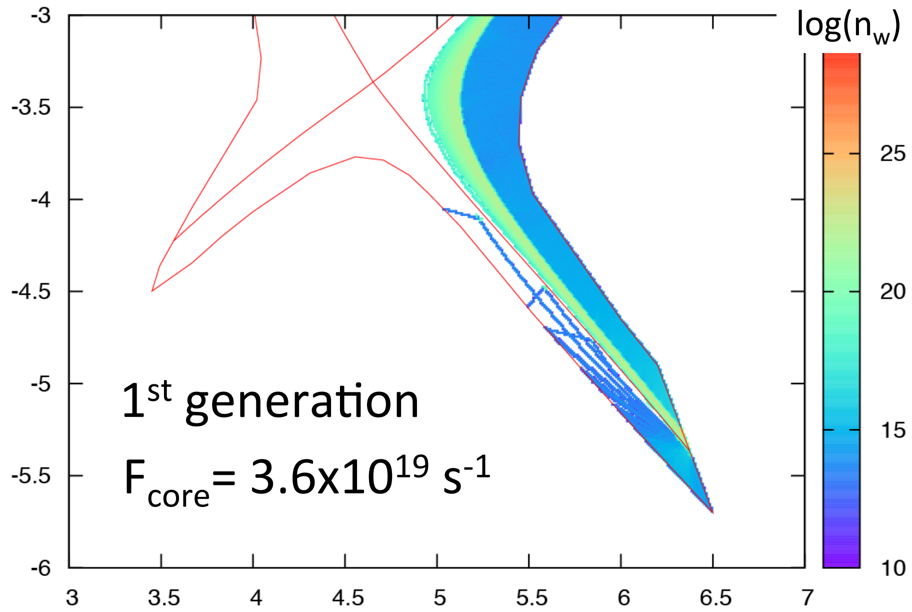
2D profiles near the outer divertor target

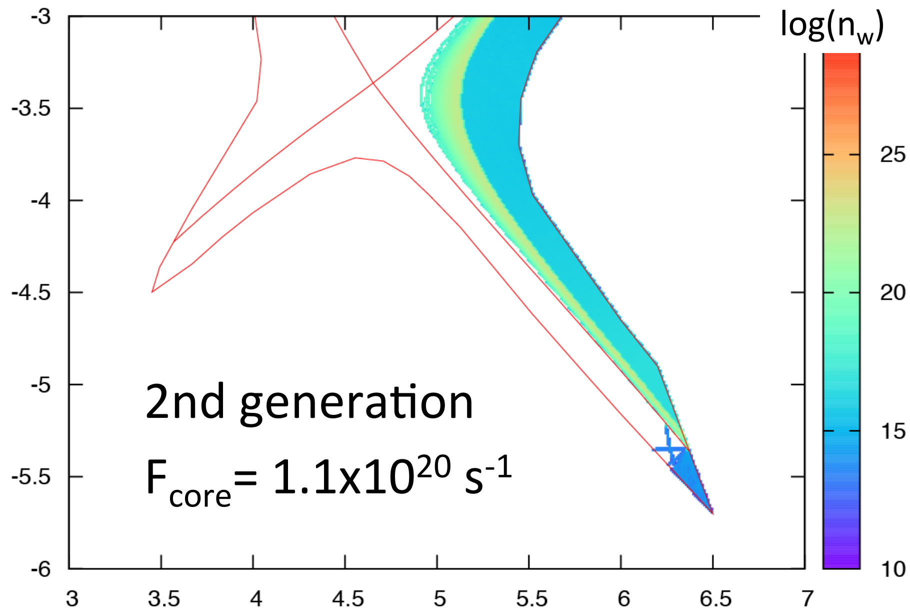


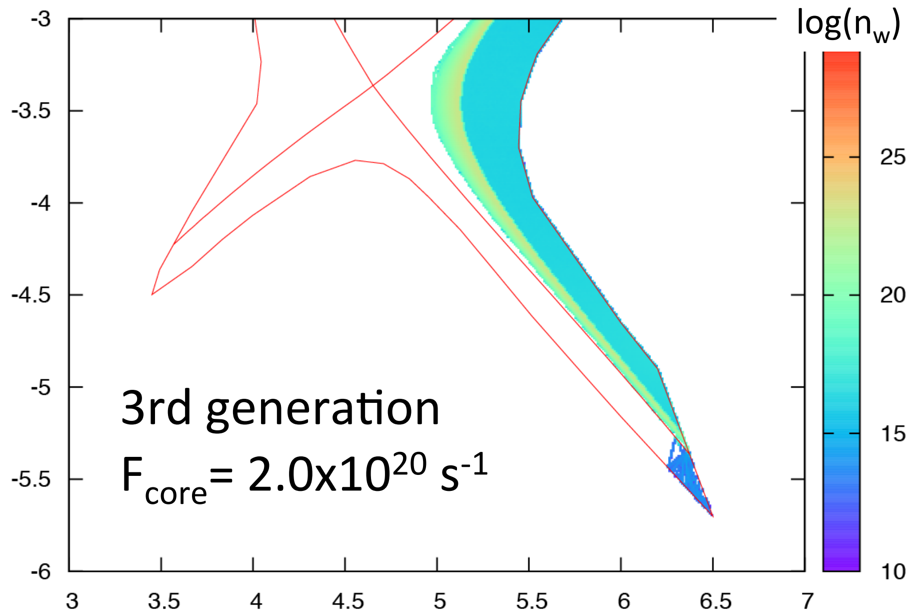




long-leg case: 2D profiles of W density



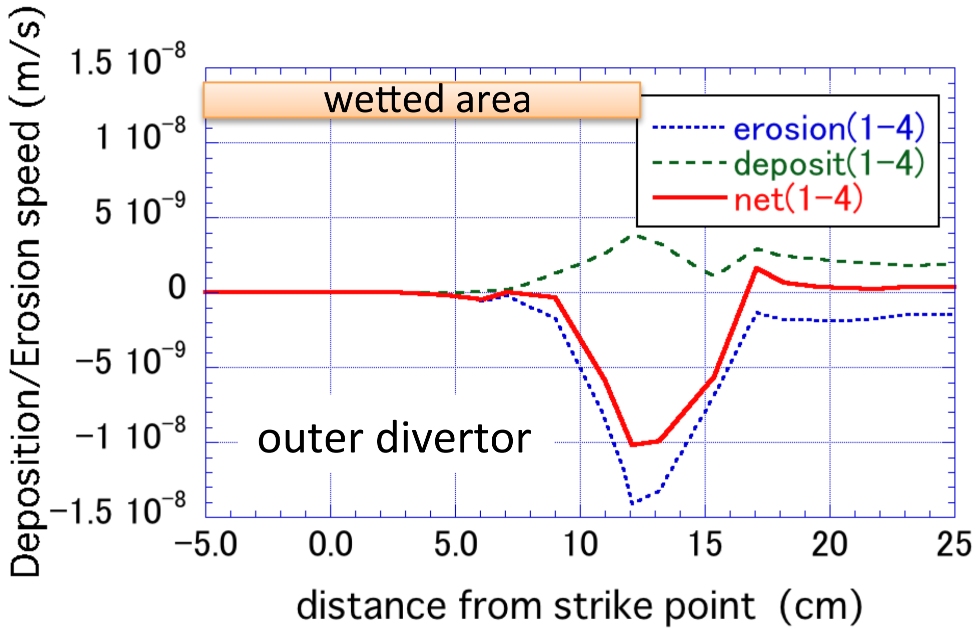




Background plasma flow and the resultant shielding effect is weak due to the high recycling. Therefore the sputtered W is easily transported upstream.

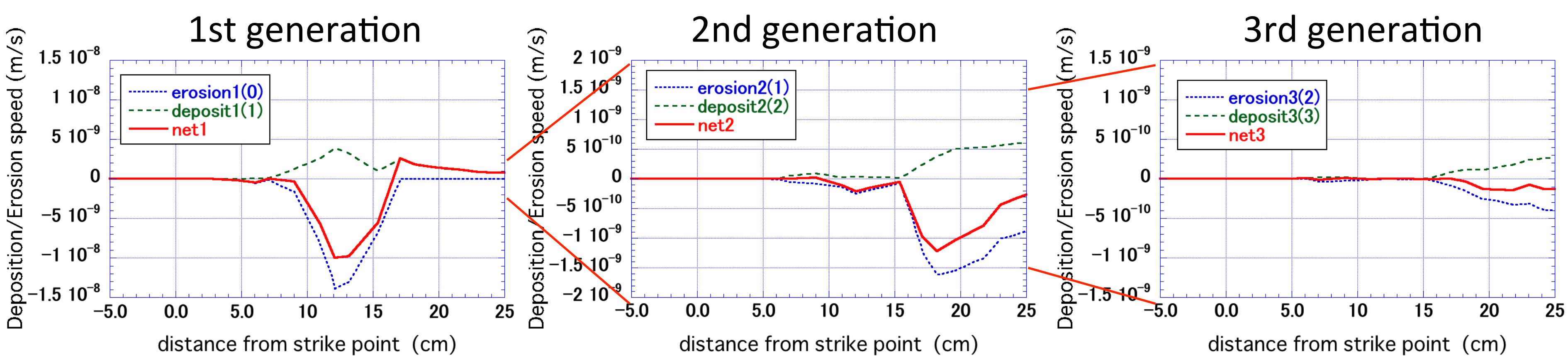
Although the amount of sputtered W is small, the influx to the core is larger than other case due to the small shielding effect.

Long-leg case: dep./ero. speed at outer divertor



Erosion/deposition speed is much smaller than other cases.

Because of weak shielding effect, erosion/deposition of W can be observed on the baffle.



Summary

Erosion and deposition of W armor in SlimCS has been analyzed by using SONIC and IMPGYRO-EDDY.

3GW case: Large erosion by the self-sputtering. (strong background flow → large incident energy of W → large self-sputtering)

2GW case: $q_{pk,od}$ is less than $7MW/m^2$, but erosion is still too large as same as the 3GW case.

long-leg case: Erosion is significantly small, but influx to the core is very large because of weak shielding effect.

In the present condition, the erosion speed cannot be acceptable. **The divertor plasma design for W armor lifetime** is necessary as well as the huge power handling. ex) **flow control** by puff and pump, low Te and Ti by **full detachment**.

W density in the divertor is considerably high. The significant radiation cooling and the resultant temperature decreases are expected. Therefore, the **self-consistent analysis** by coupled of plasma transport with W impurity generation/transport are necessary. (cf. SOLPS-IMPGYRO,)

In the self-consistent analysis, the **erosion** of W armor **is possibly decreased** by the W impurity radiation and the resultant decrease in Te and Ti.