LHDのダイバータ及び RMPコイル実験の概要

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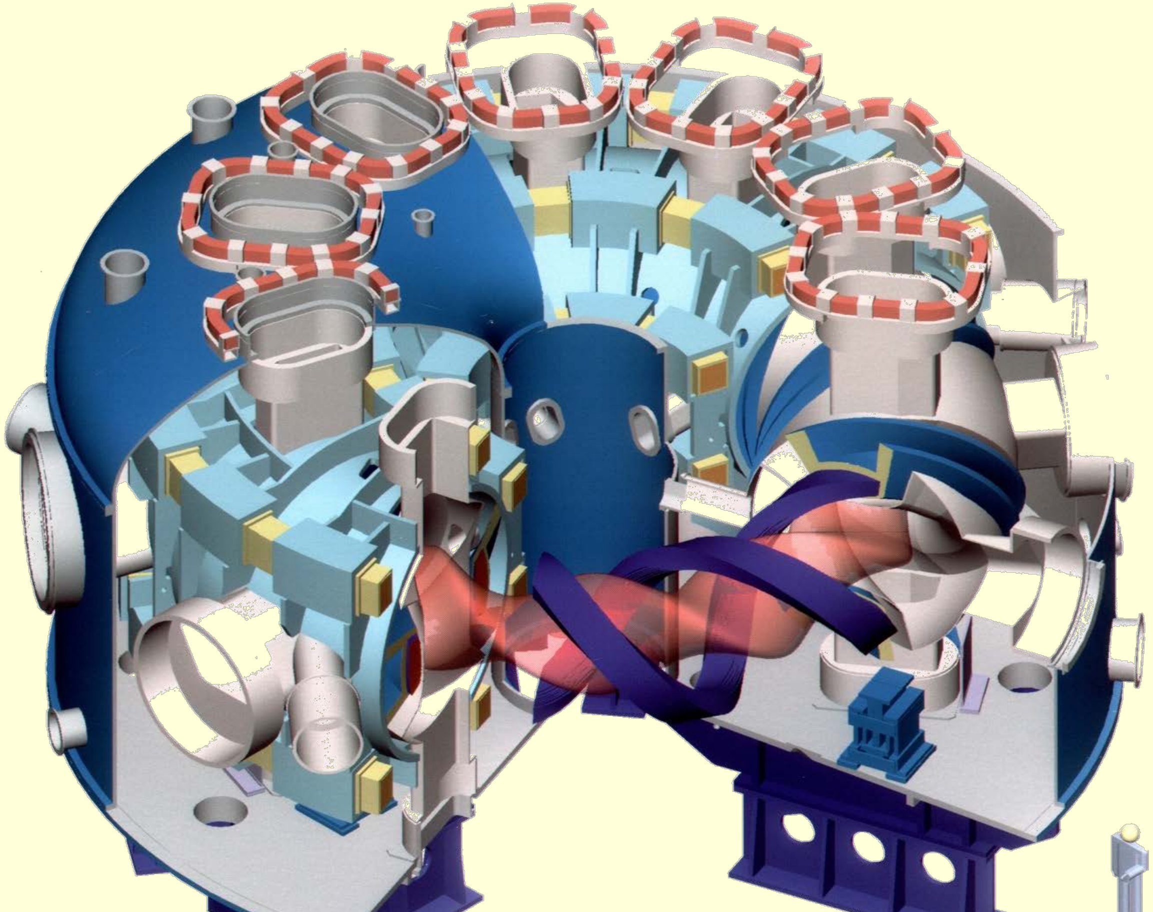
LHD実験グループ

OUTLINE

- ➢ Introduction
- ➢ Divertor experiments
  - ✓ Divertor particle control experiments
    - – Towards a closed and pumped divertor
  - ✓ Divertor heat control experiments
    - – Application of RMP
    - – Impurities seeding
- ➢ Summary

Introduction



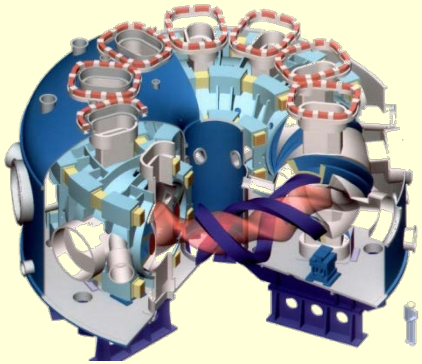
Large Helical Device
R=3.9m First wall : SS316
a=0.65m Div. plates : gaphite

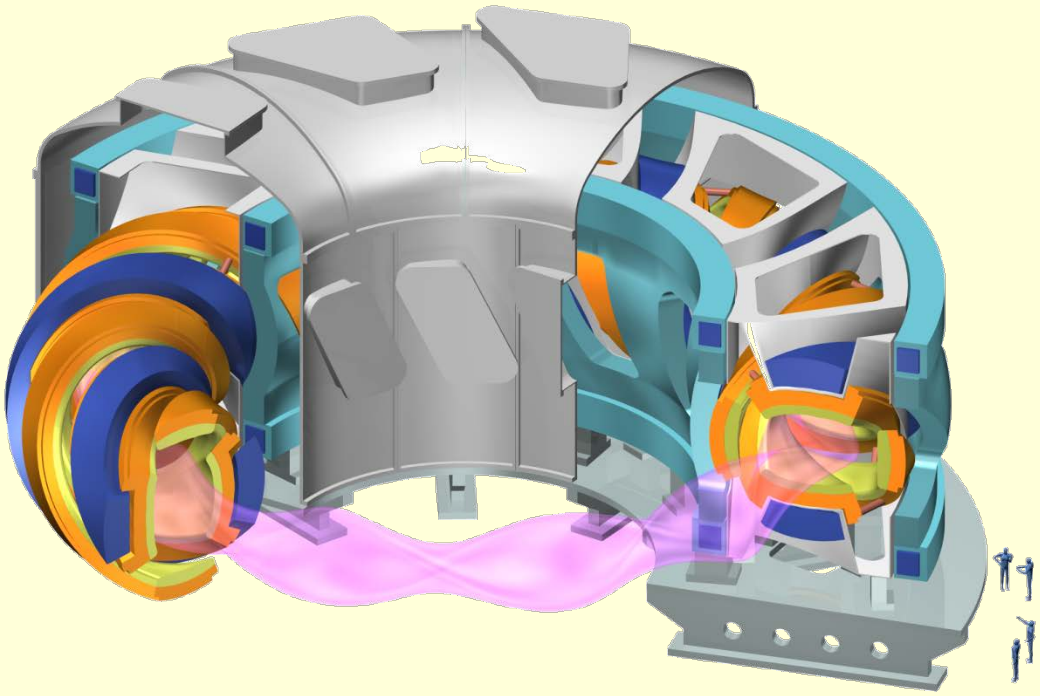
Helical devices are free from plasma current, and thus from disruption. This is a big advantage for fusion reactor design.

Plasma performance of LHD has been developed largely in this decade.

Understandings of core and edge plasma properties have been accumulated.

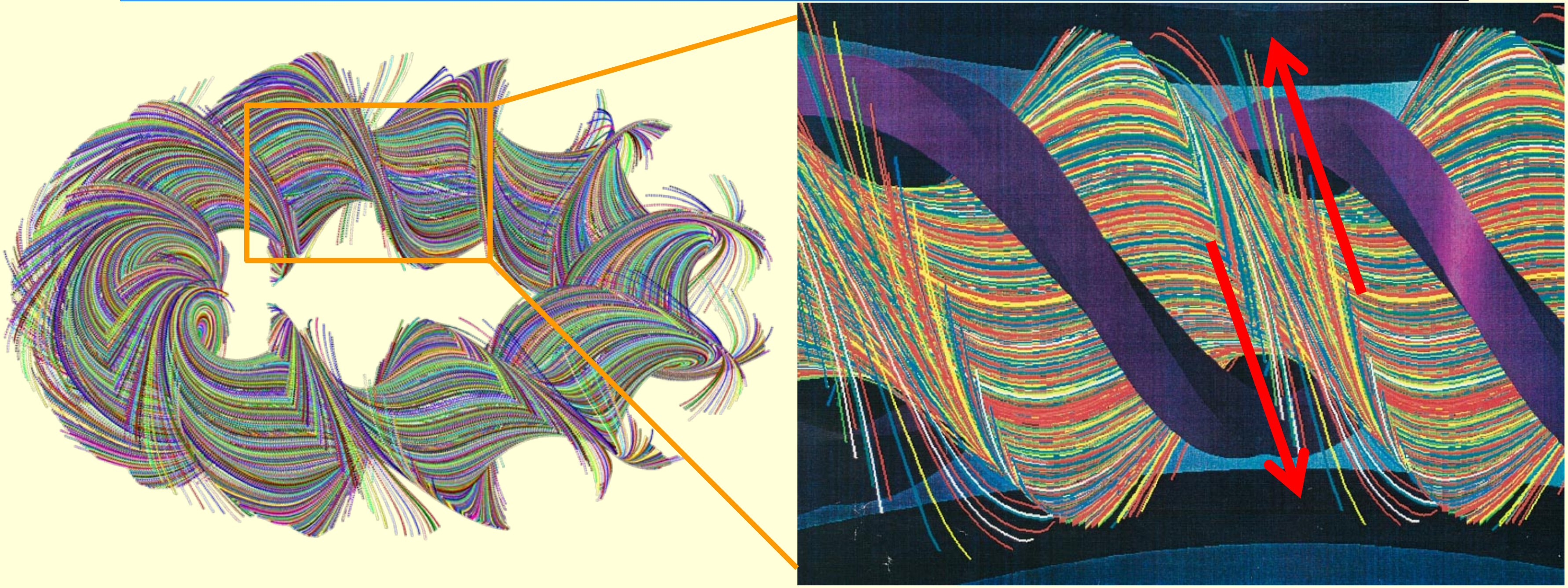
Introduction





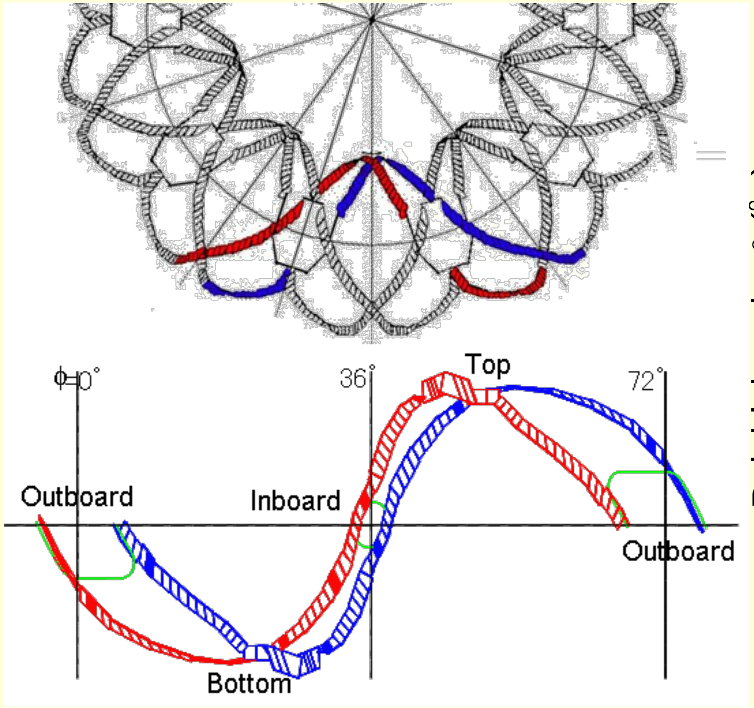
To realize a heliotron-type reactor, further divertor heat and particle control experiments have to be conducted in LHD to gain understanding of their physics which can be extrapolated to a helical reactor.

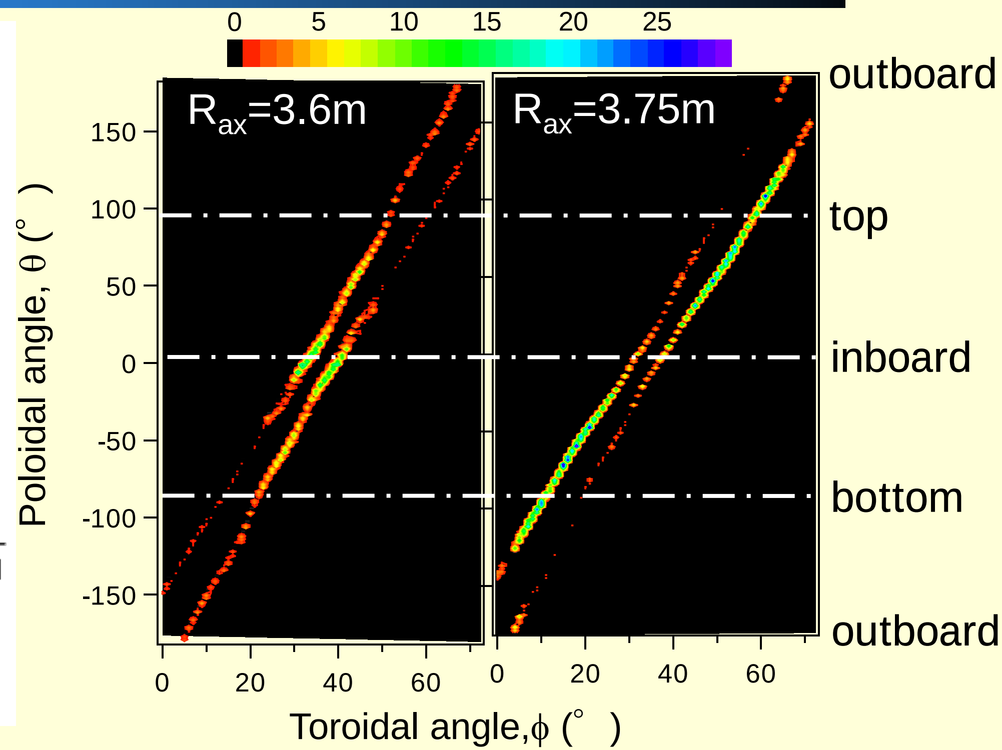
Helical divertor

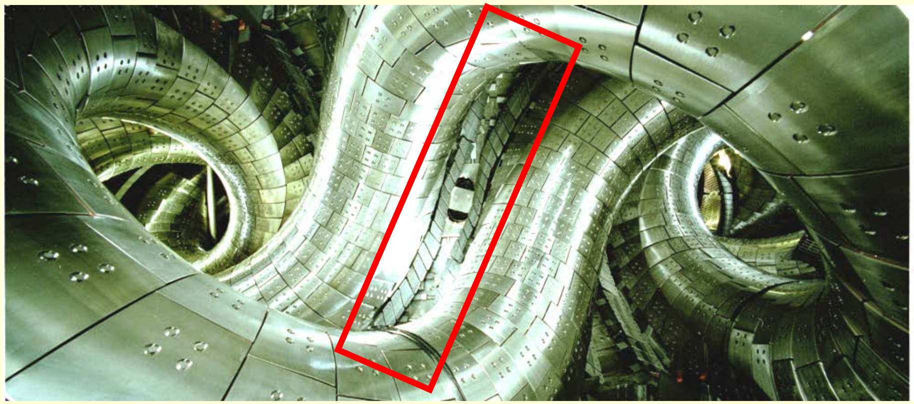


- Helical divertor is an intrinsic magnetic structure in a heliotron-type magnetic configuration.
- It looks like double null divertor in tokamaks.
- Poloidal field component is dominant in the divertor region.
- A few meter from X-point to divertor plates.

heat and particle depositions on the helical divertor are non-uniform







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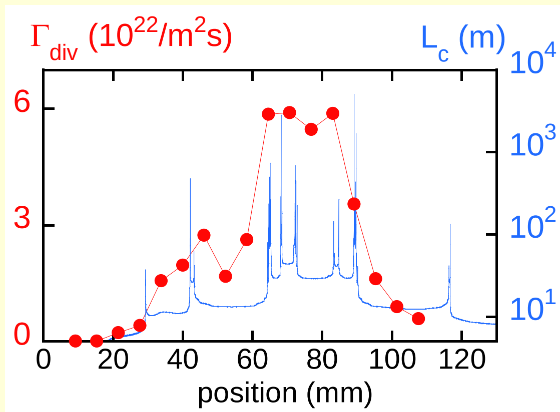

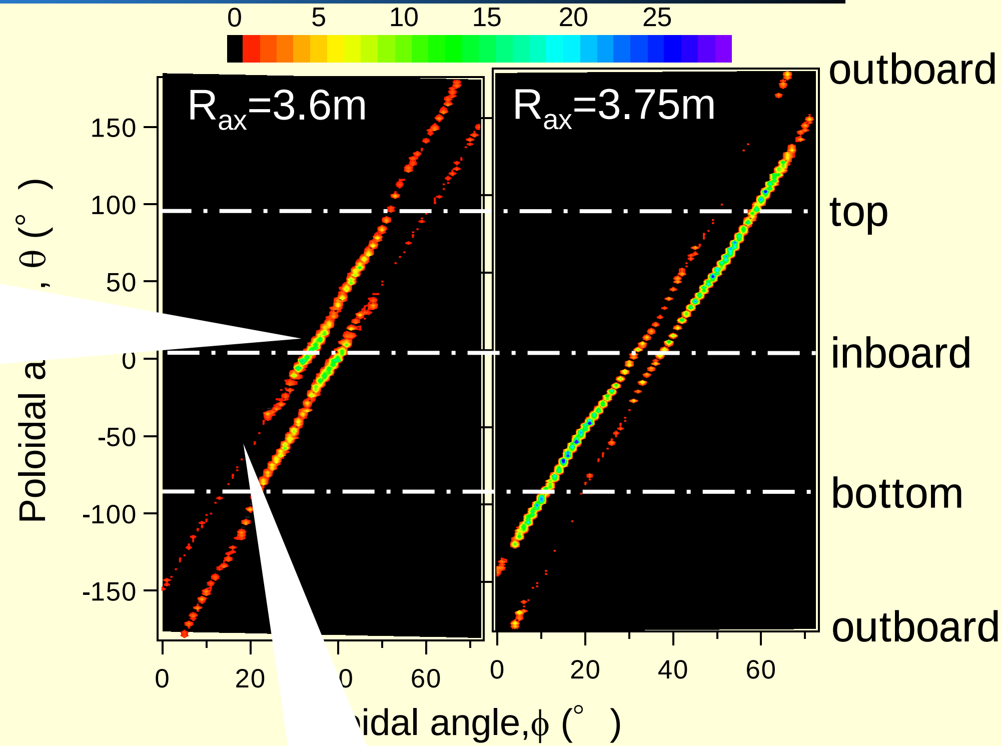

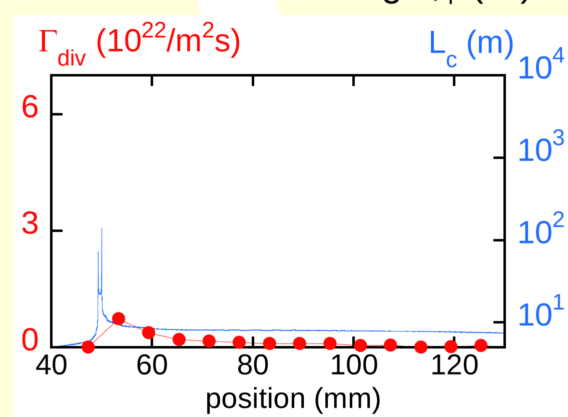

- The profiles are roughly determined by the magnetic field structure connecting to the divertor plates like the “lobe” structure.
- Long field lines coming from near LCFS, are the main channel of particle and heat flux.

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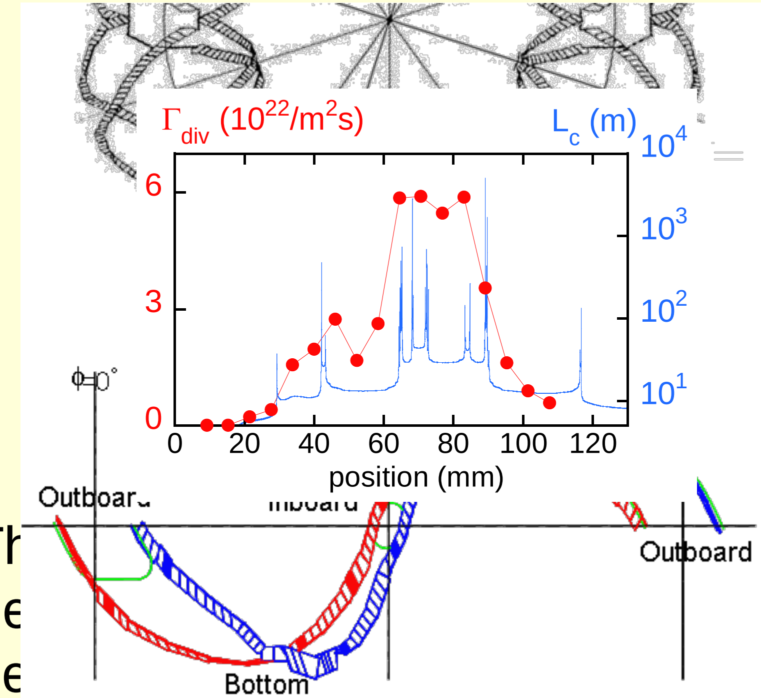

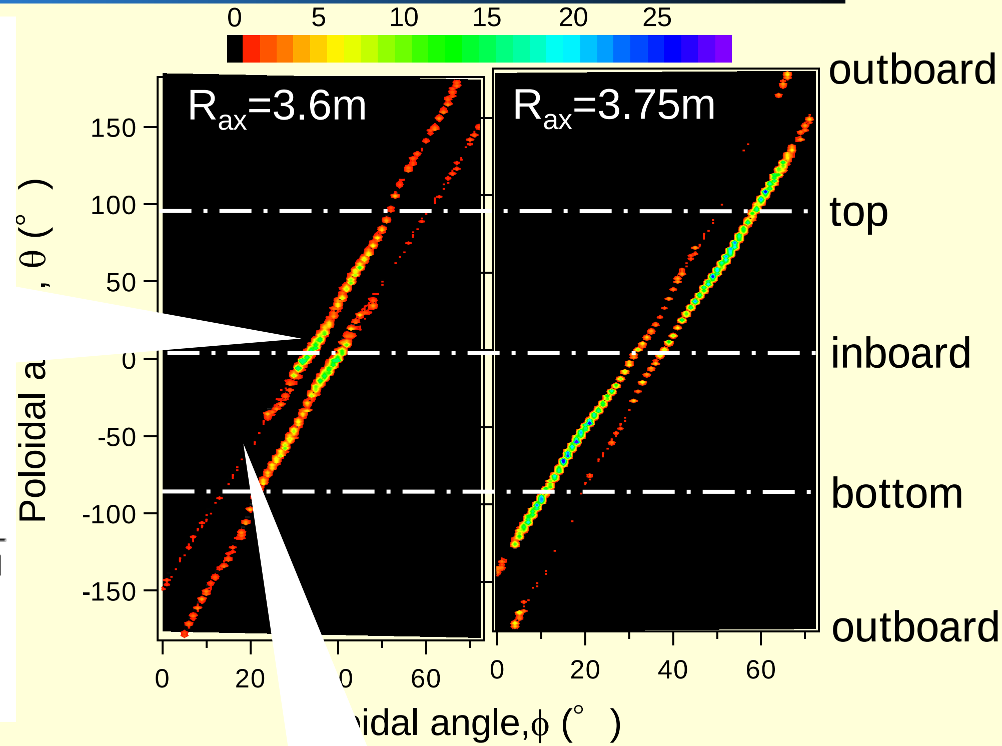

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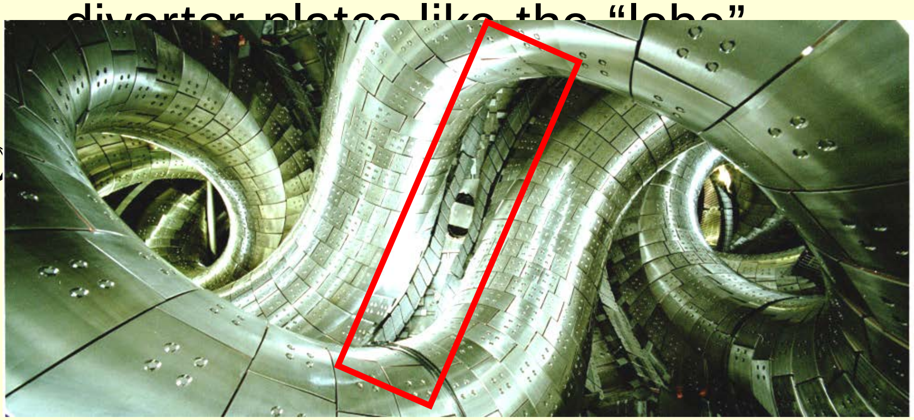
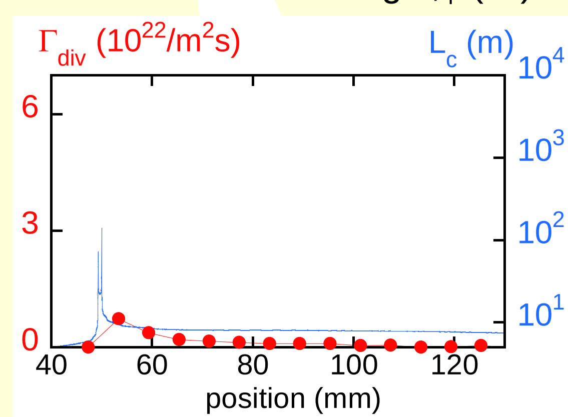
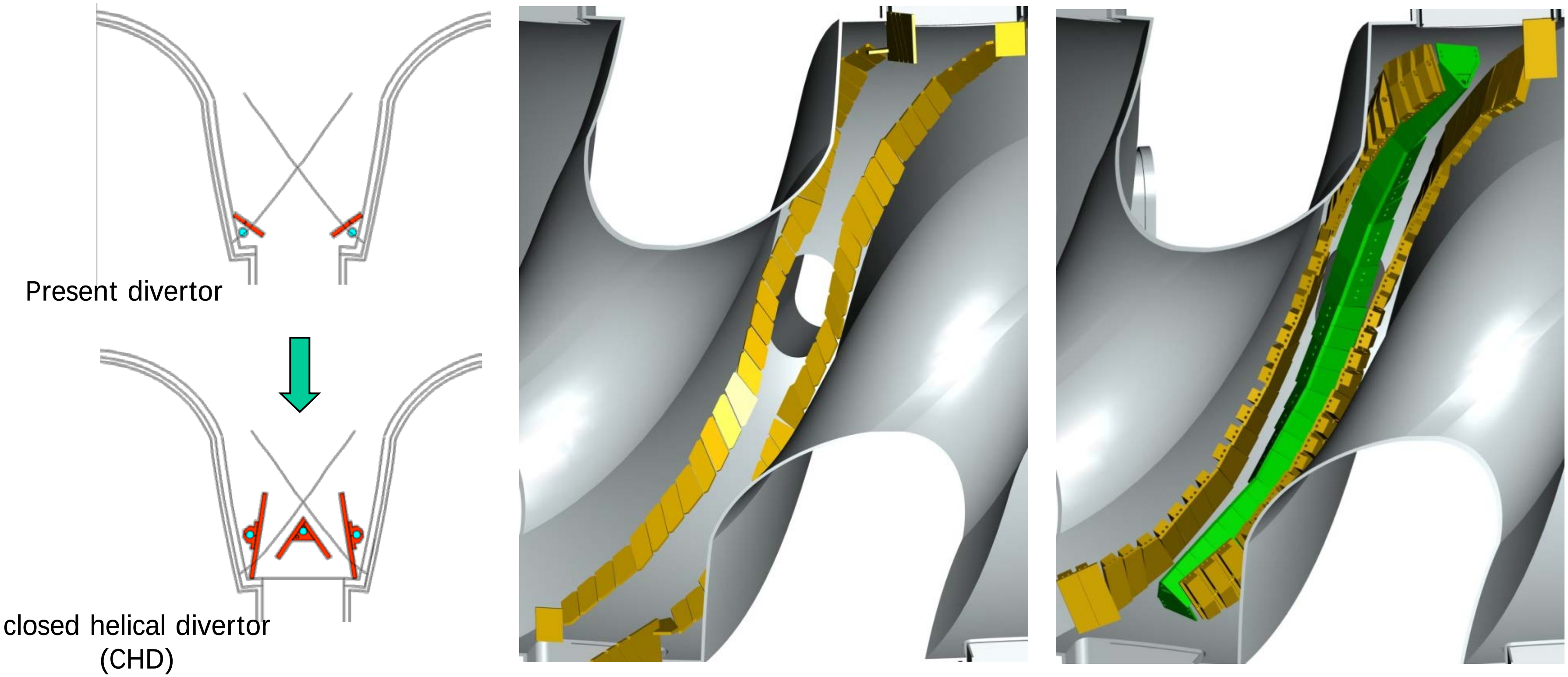
  divertor plates like the “lobe”





Design of CHD was carried out by using EIRENE code with full 3-D mesh



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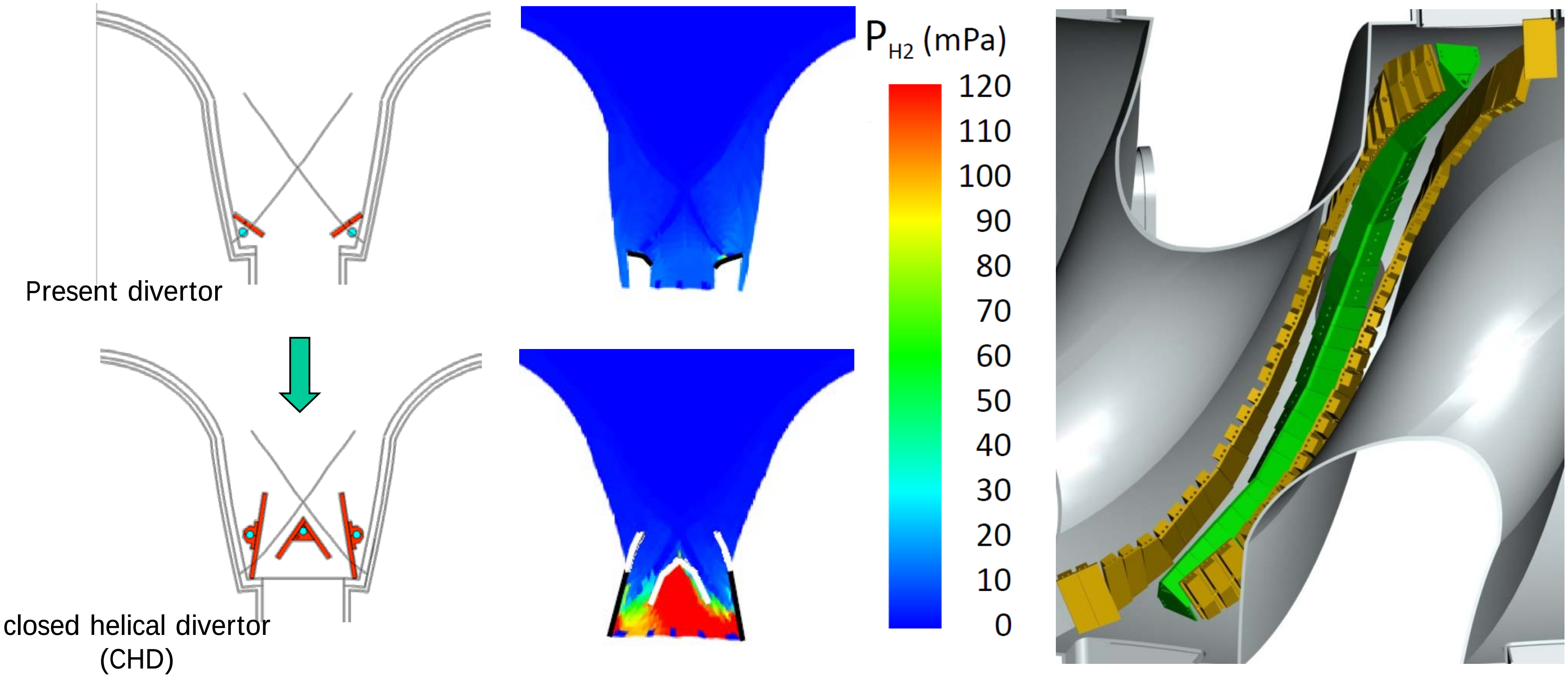
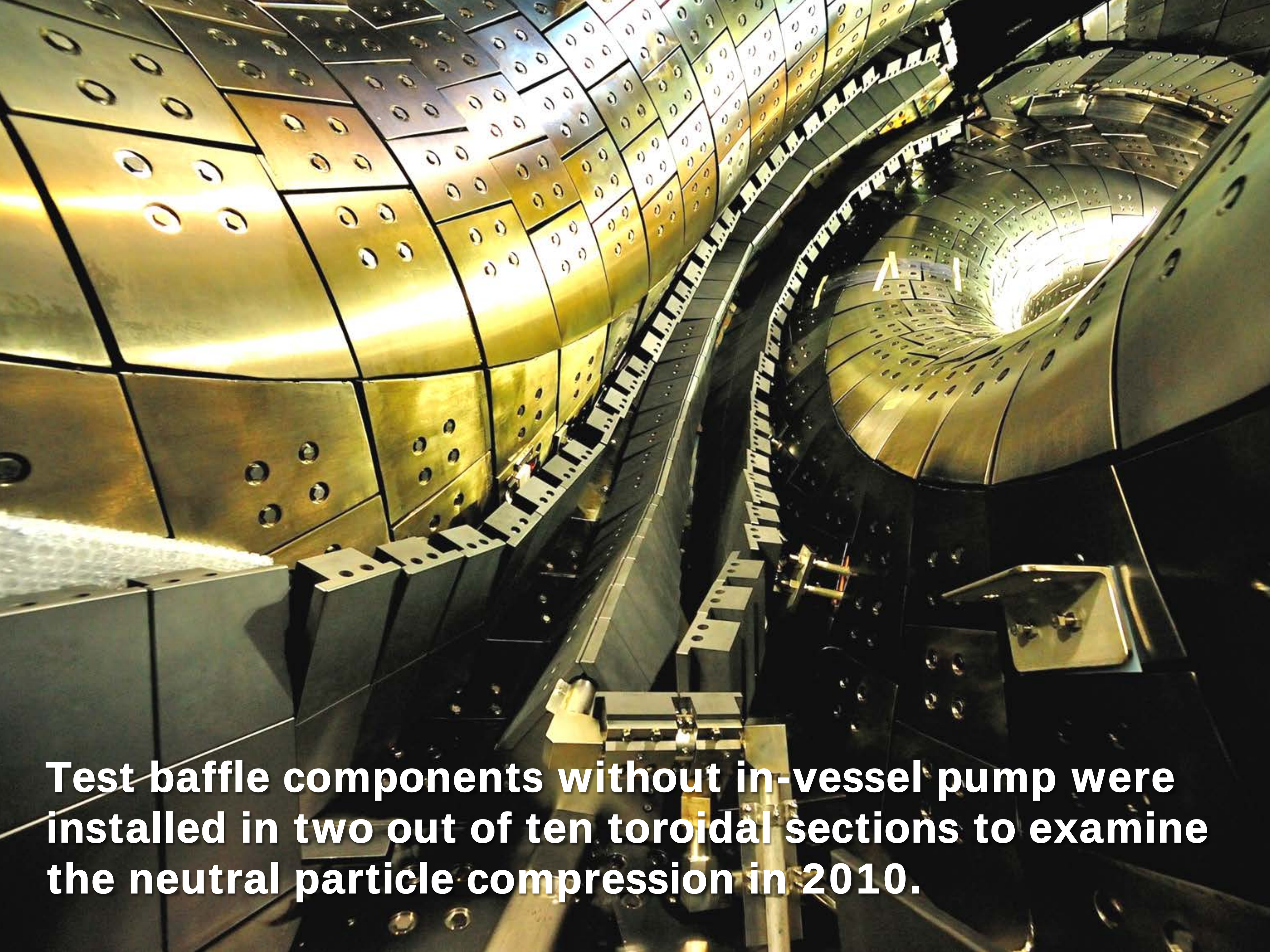
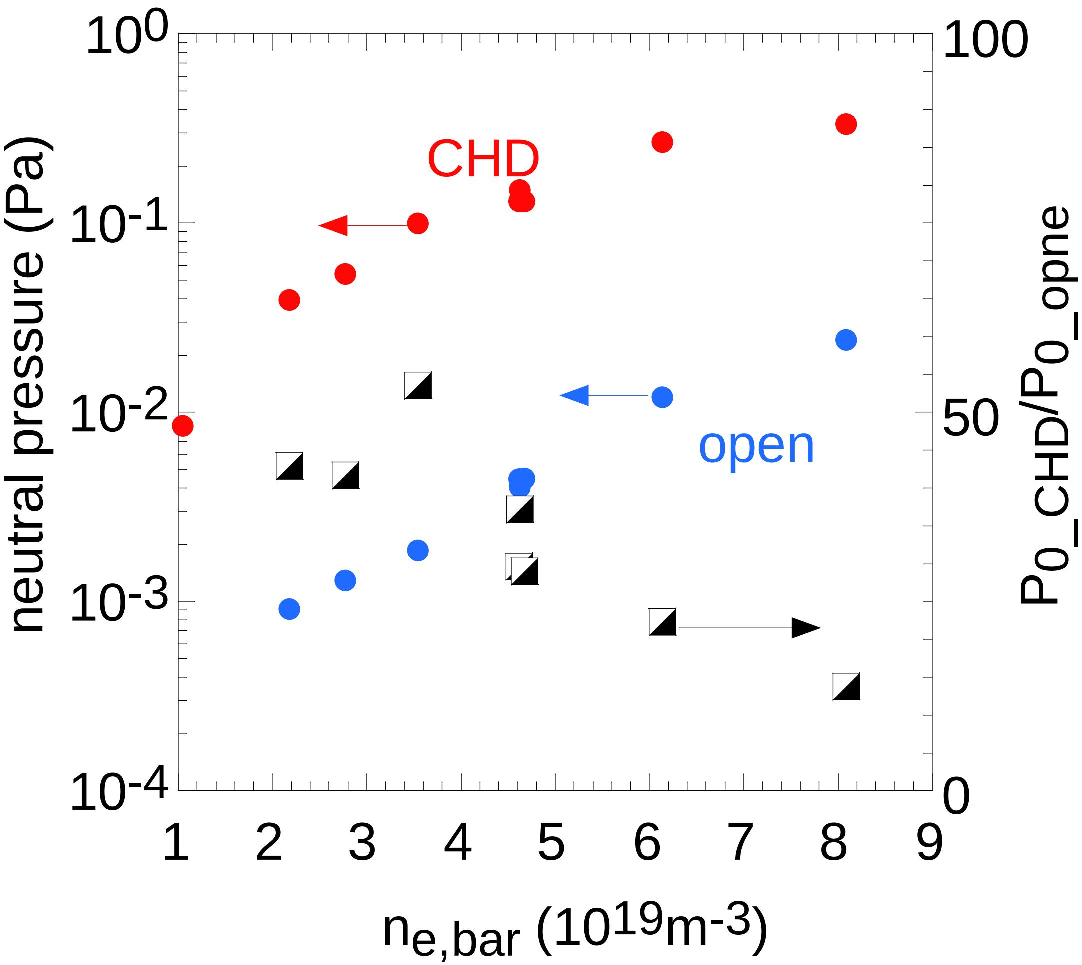


The 3-D simulation using EIRENE code predicted about 10 times higher neutral pressure in CHD than that in the present divertor.



Test baffle components without in-vessel pump were installed in two out of ten toroidal sections to examine the neutral particle compression in 2010.

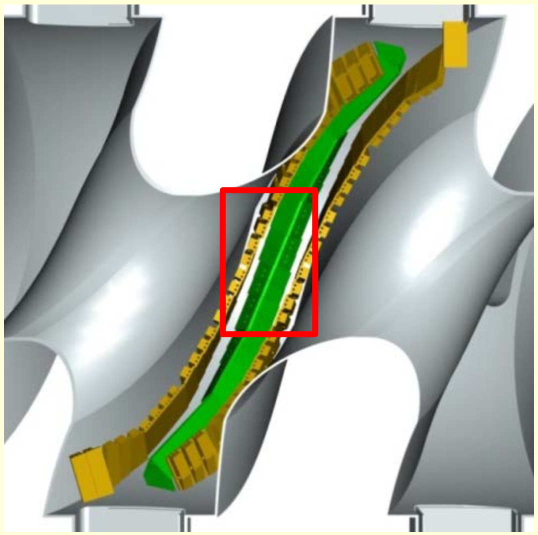
Much higher pressure was observed in CHD as predicted by the 3-D simulation

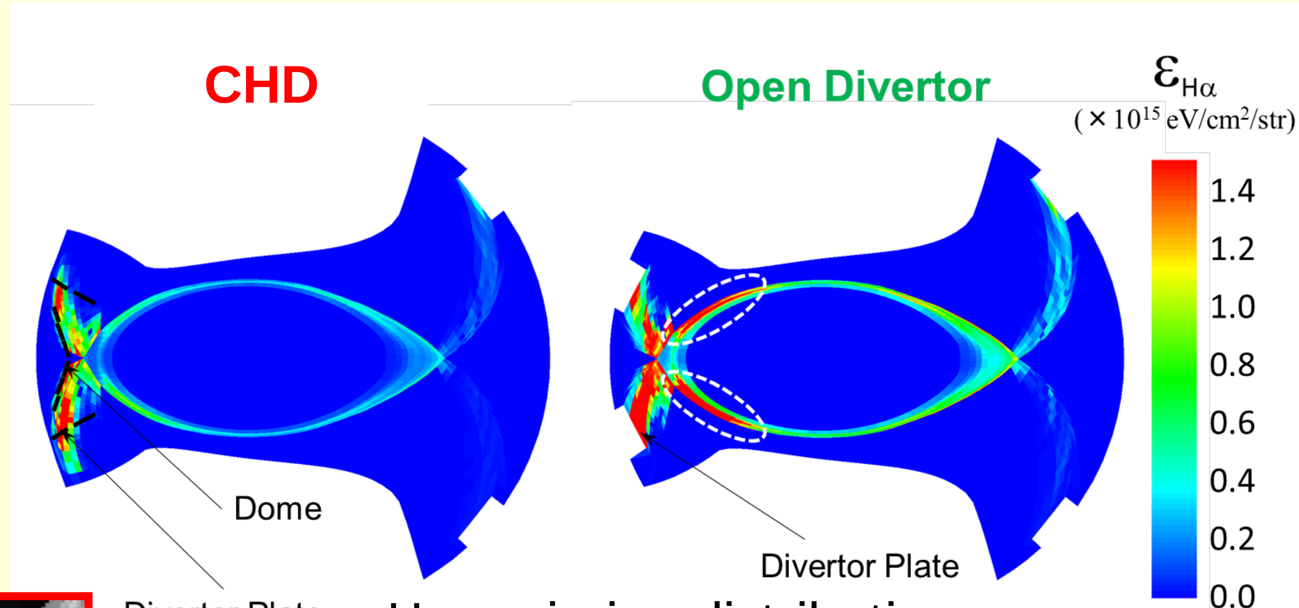


Line averaged density dependence of the neutral pressure in divertor.

- Though divertor particle fluxes in CHD and the open divertor were almost same, more than 10 times higher neutral pressure in CHD was observed.
- Neutral pressure ratio between in CHD and in the open divertor has density dependence.
  - ✓ The ratio increase with decreasing density

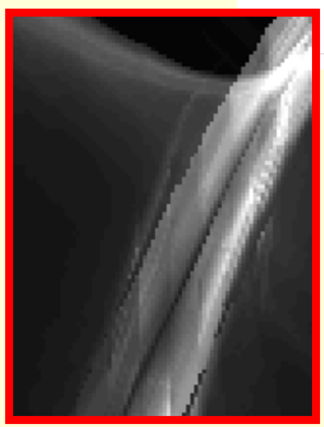
Hα emission in the ergodic is significantly reduced in the CHD configuration





Hα emission distribution

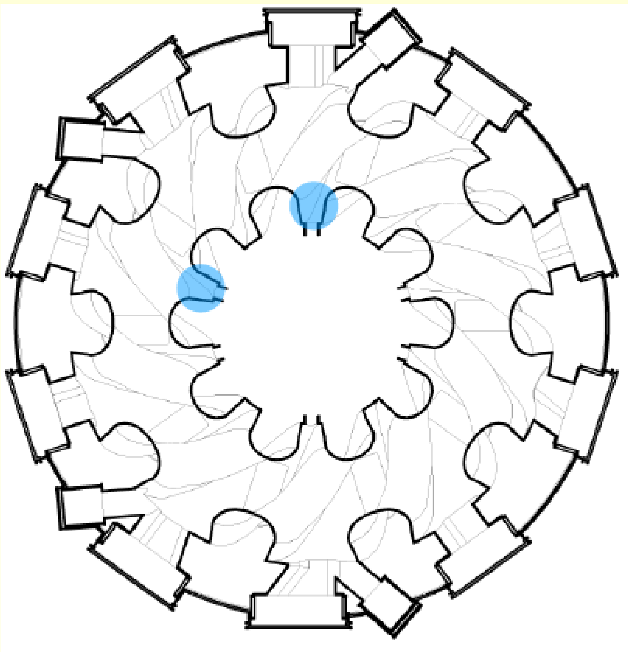
Filtered camera

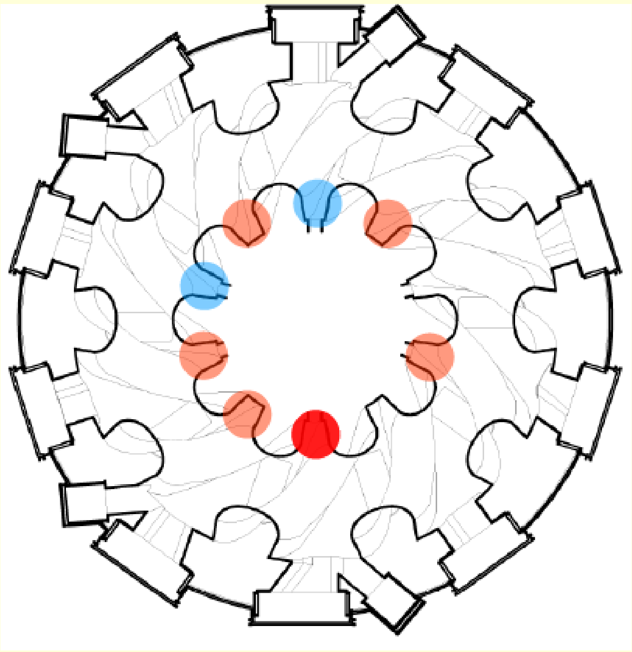


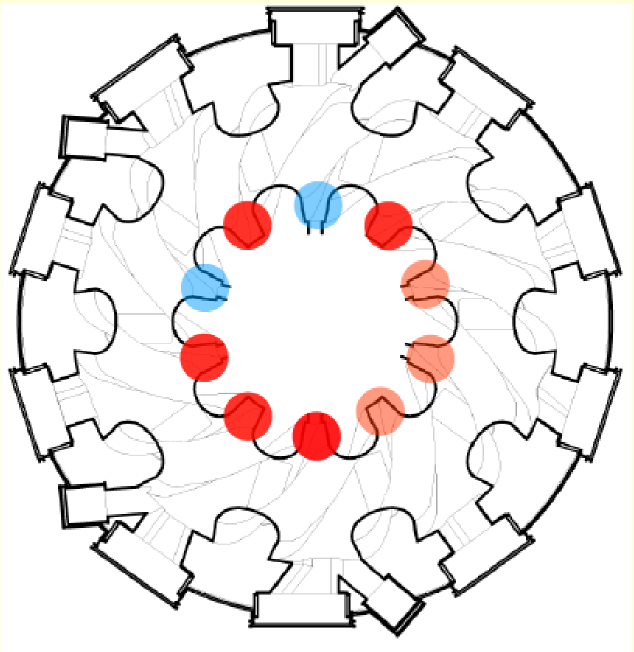
simulation

- Filtered CCD camera image of CHD and the open divertor were reproduced by using EIRENE code

ダイバータ閉構造化計画





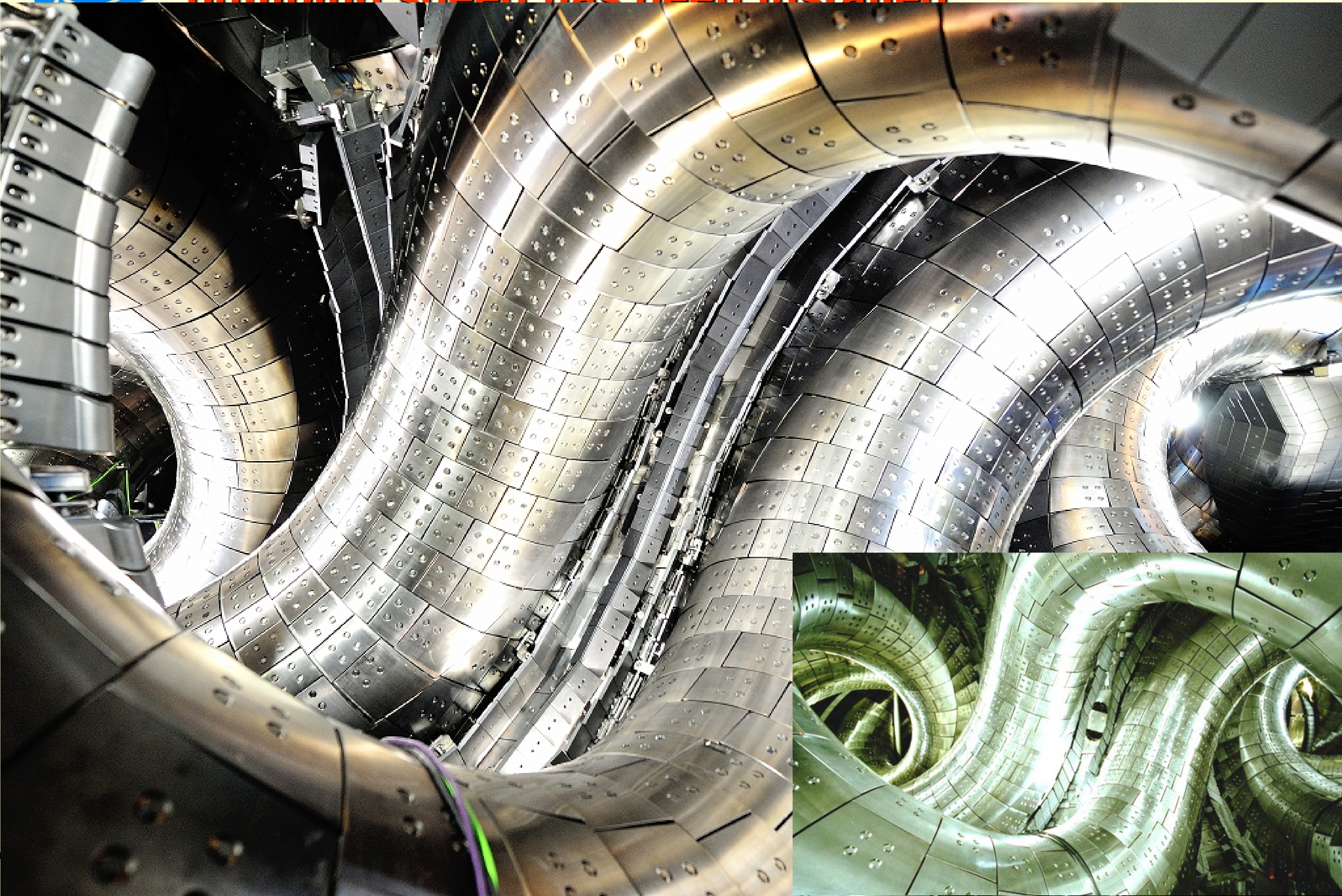


2010年度　第14サイクル
トロイダル2セクションにバッフル構造ダイバータを設置

2012年度16サイクル実験
バッフル構造を全周の80%に設置
ダイバータ排気を全周の10%で実施
（排気速度 6-7m³/s）

2013年度17サイクル実験
全周バッフル構造化
ダイバータ排気を全周の50%で実施
（排気速度 30-35m³/s）

A helical shaped cryo-pump with ~7m^3/s of pumping speed has been installed



Summary of particle control experiment

- Divertor modification from “open” to “closed” has been conducted at torus-inboard side.
- Test baffle components were installed partially (20%) in 2010, and examined neutral compression in CHD.
- Neutral compression predicted by 3-D neutral transport code, EIRENE, was confirmed in experiment.
- Higher neutral particle confinement in the test baffle divertor than that in the present open divertor was also observed by filtered CCD camera.
- **Divertor in 50% of toroidal section is closed and equip with an in-vessel pump in a toroidal section in 2012.**

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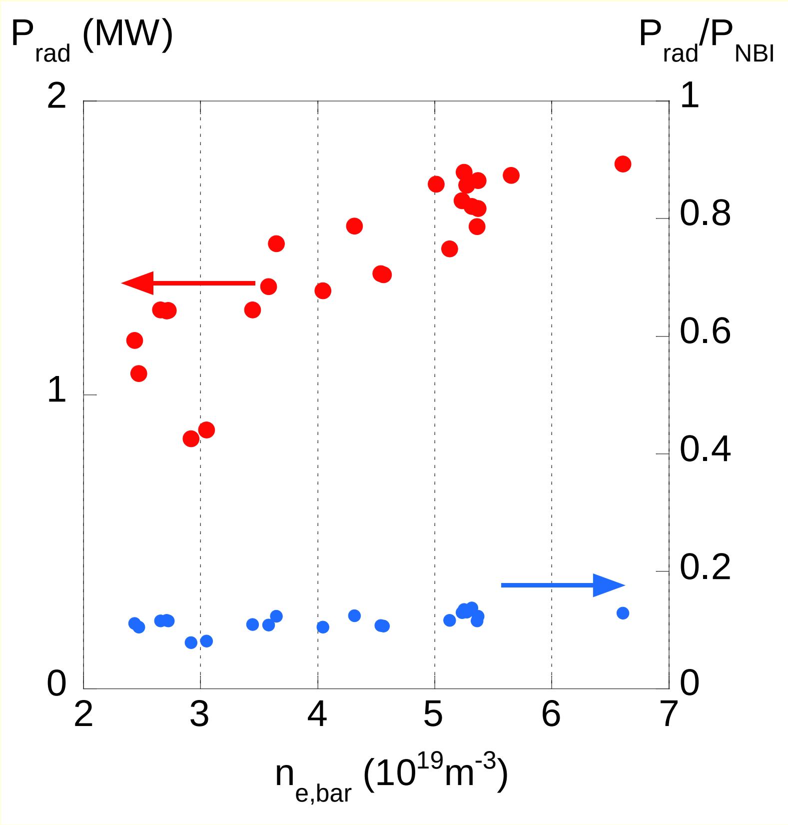
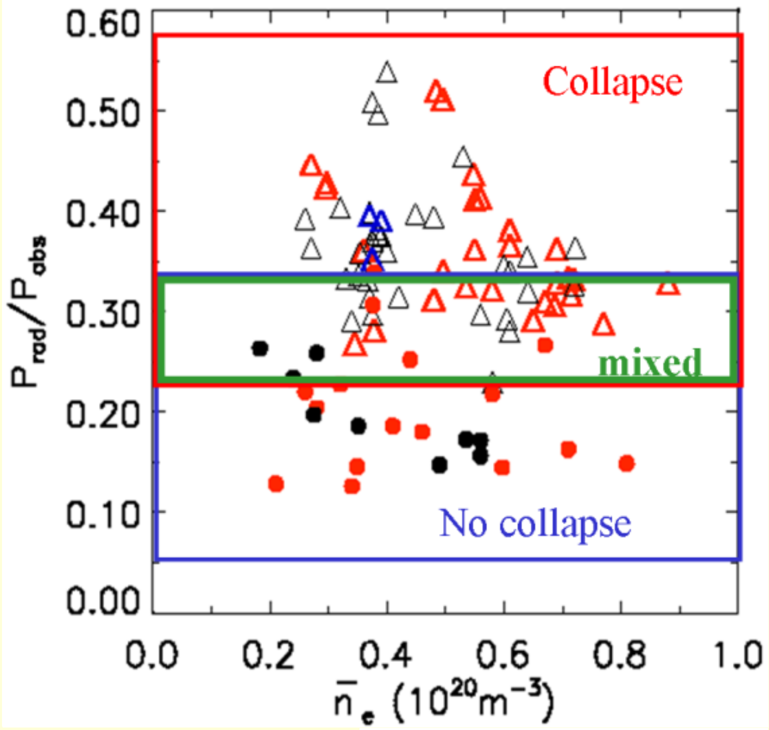
It is a crucial issue how to achieve stable radiation enhancement

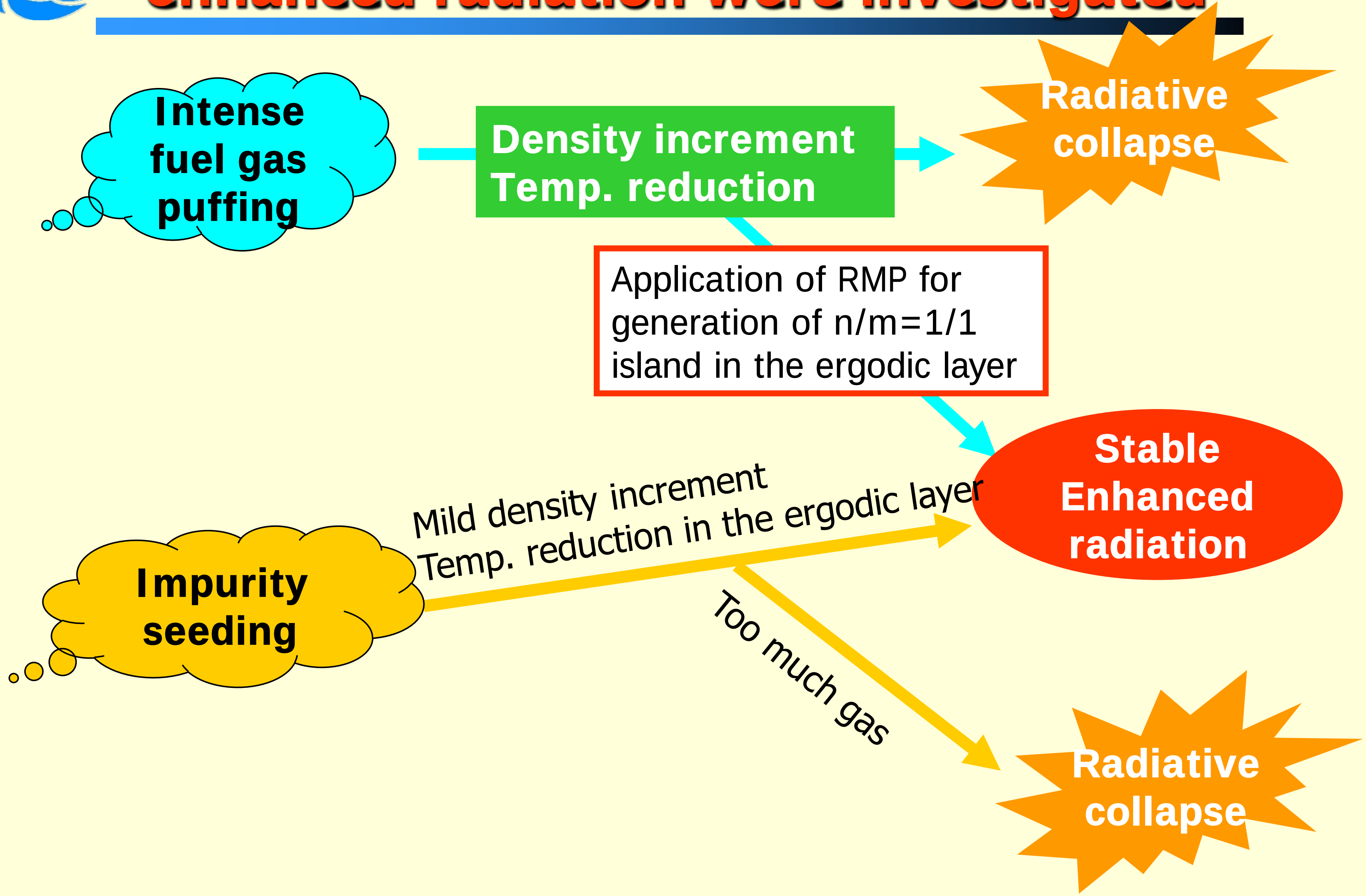
- To reduce divertor heat flux, radiation enhancement is necessary.
- But, P_{rad}/P_{NBI} is less than 0.2 in LHD usually, and discharge becomes unstable in the region of P_{rad}/P_{NBI}~0.3.



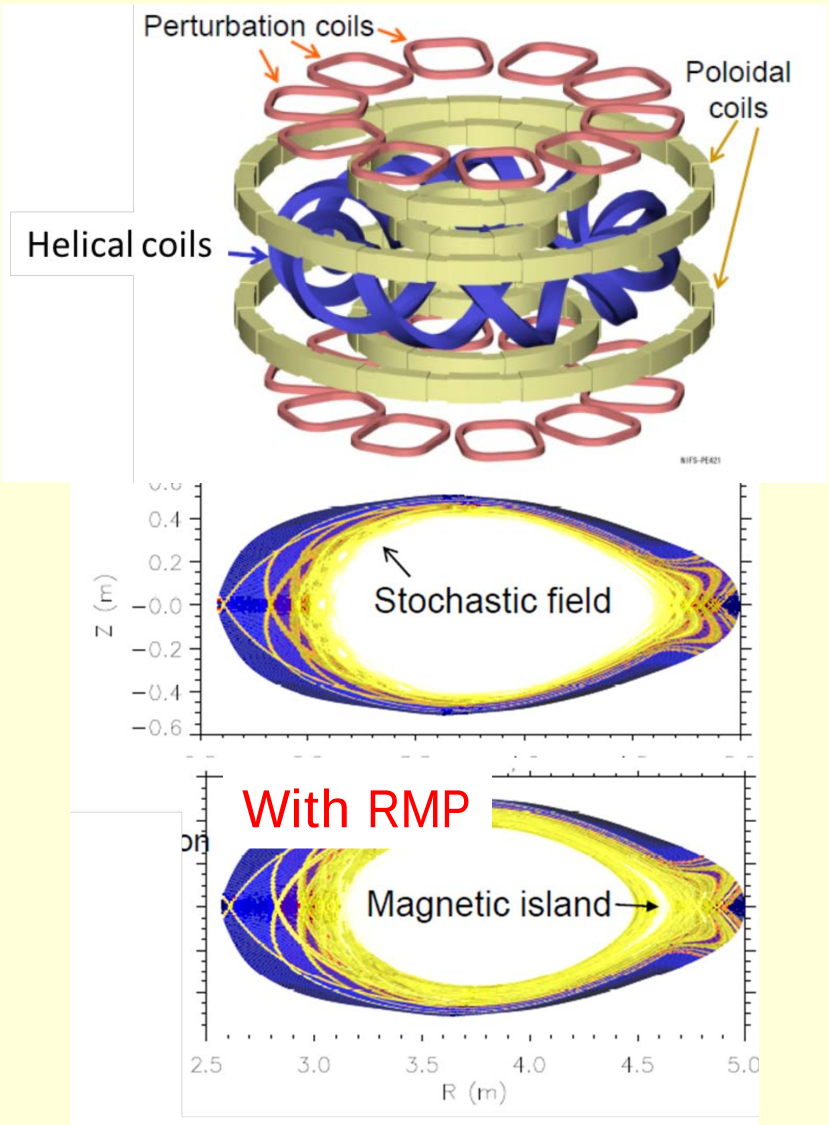


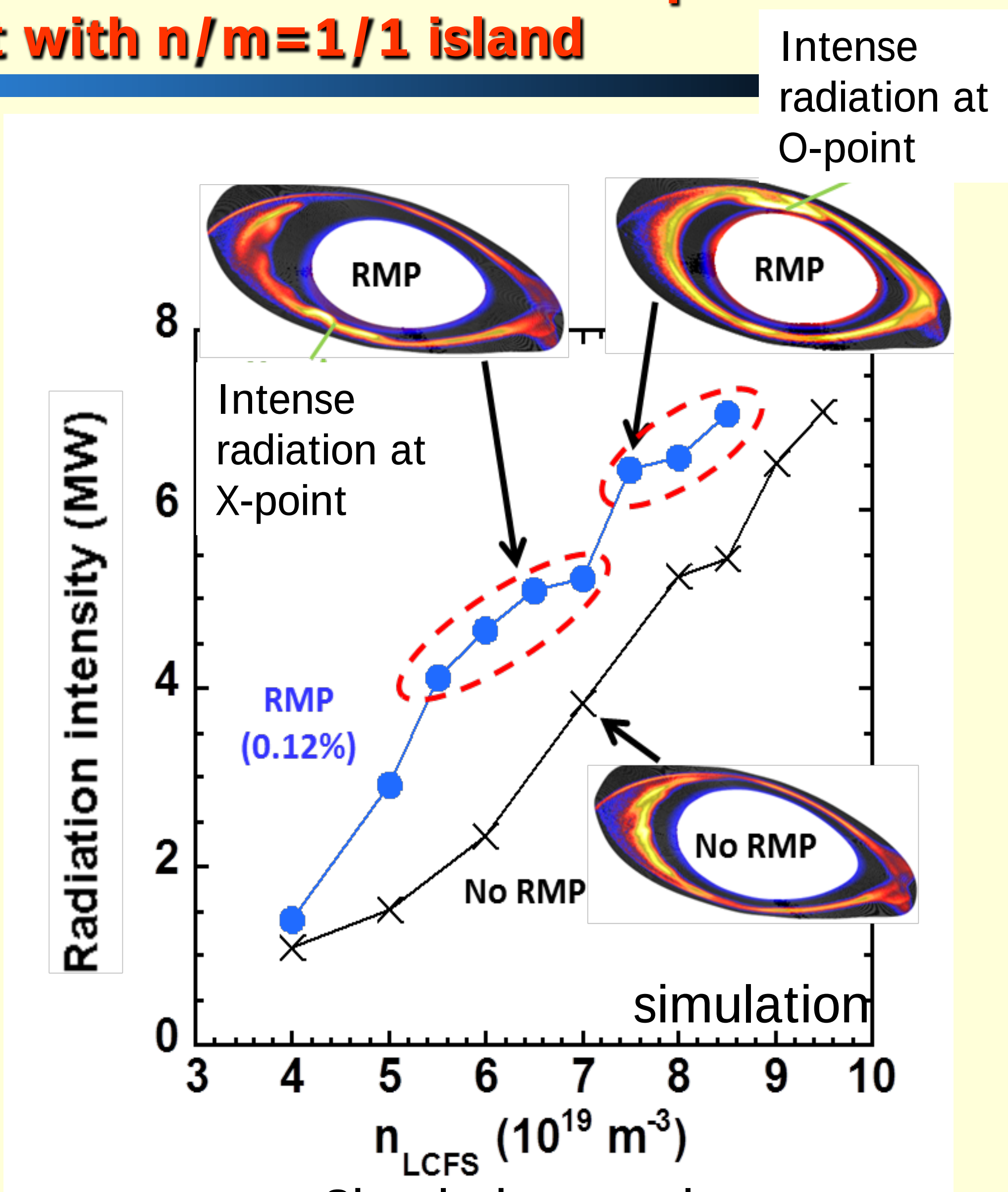
Peterson et al., PFR **1** (2006) 045.

Two scenarios to achieve stable enhanced radiation were investigated



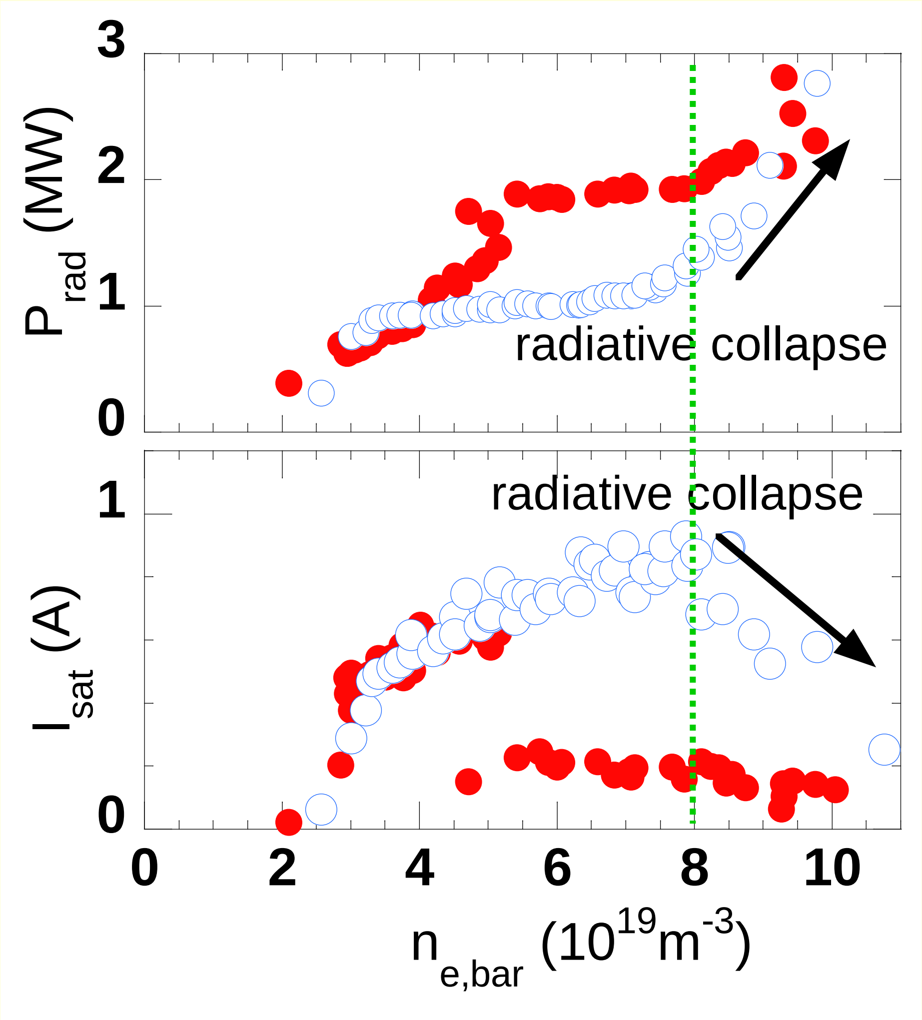
3-D plasma simulation with EMC3-EIRENE code predeict radiation enhancement with n/m=1/1 island





Simulation results

n/m=1/1 island in the ergodic layer generated by RMP field enhances radiation

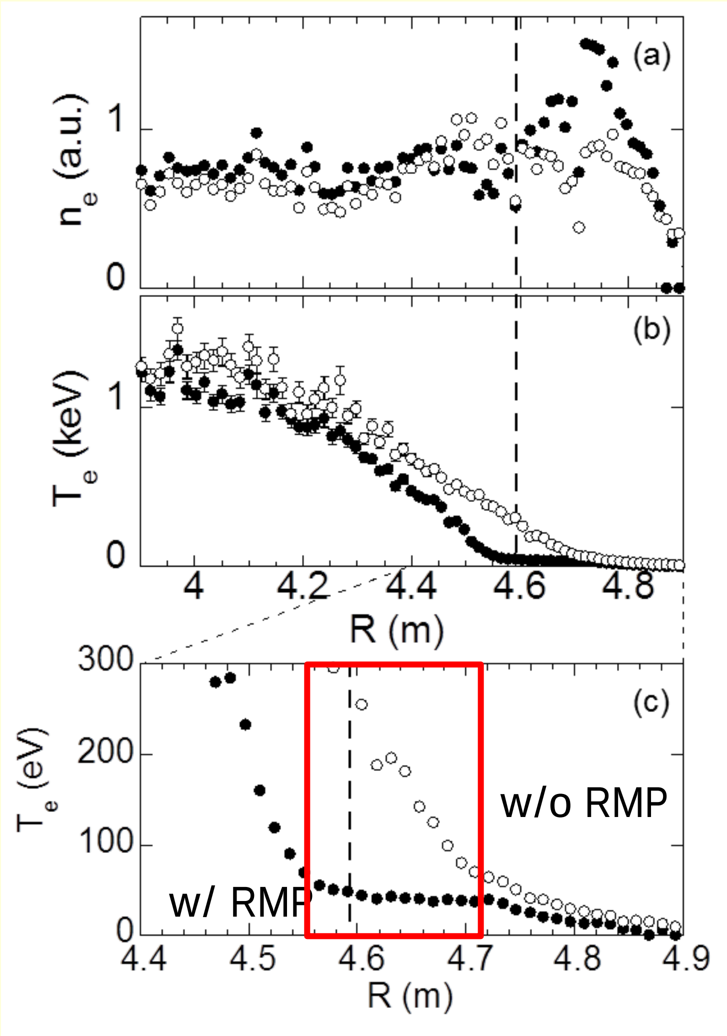


Experiment

- Operation parameters
  - ✓ P_{NBI} ~ 8MW
  - ✓ Magnetic axis R=3.9m
  - ✓ I_{RMP}=3.4kA

- Divertor particle flux decreased
- RMP did not change density limit

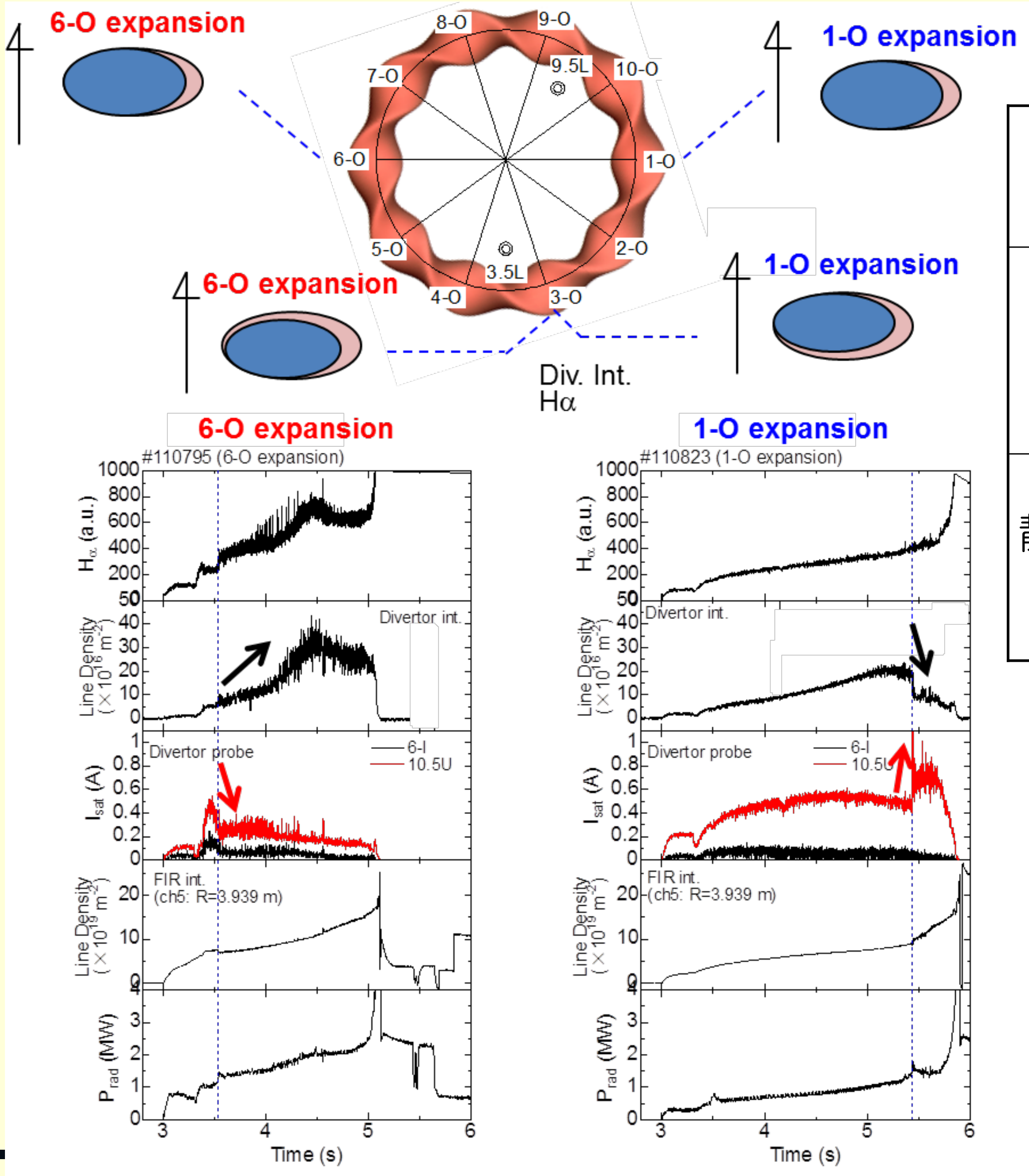
Expansion of low temperature region in the edge cases the radiation enhancement



Radial profiles of n_e and T_e

- T_e at peripheral and in the ergodic layer reduced with the island generation.
  - ✓ While T_e and n_e in the center was not affected.
- The island structure extend low temperature region in which impurity (mainly carbon) radiate intensely.
  - ✓ Carbon radiation increases with Te reduction in the range of 10eV<T_e<100eV

3-D effect on divertor particle load



	Island expansion	
	6-O	1-O
ダイバータ干渉計 (3-O)	電子密度の緩やかな上昇	電子密度の急激な減少
静電プローブ (10.5U)	イオン飽和電流の急速な減少	イオン飽和電流の急速な増大

摂動磁場による周辺磁場構造の違いに応じて、ダイバータプラズマ挙動にトロイダル異方性が観測されている。

トータルで熱負荷は軽減されているが、局所的な熱粒子負荷変化を明らかにする必要がある。

Two scenarios to achieve stable enhanced radiation were investigated

Intense fuel gas puffing

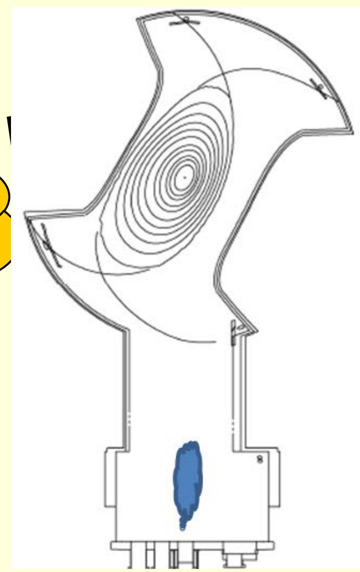
Density increment
Temp. reduction

Radiative collapse

Application of RMP for generation of n/m=1/1 island in the ergodic layer

Stable Enhanced radiation

Impurity seeding



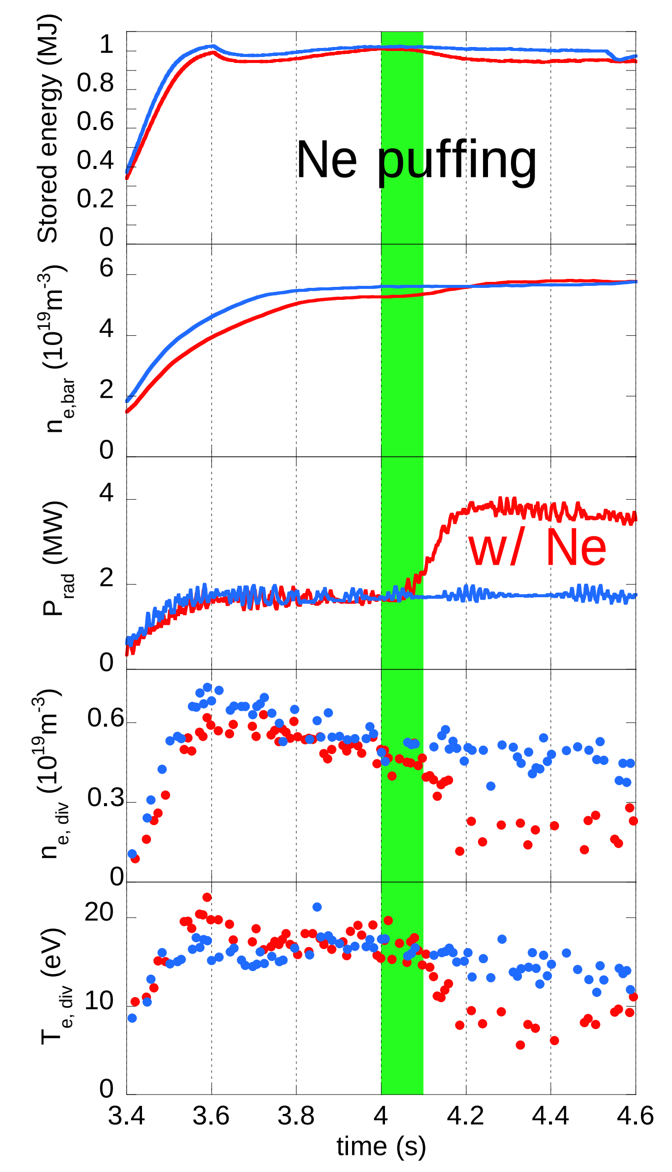
ment
in the ergodic layer

Too much gas

Radiative collapse

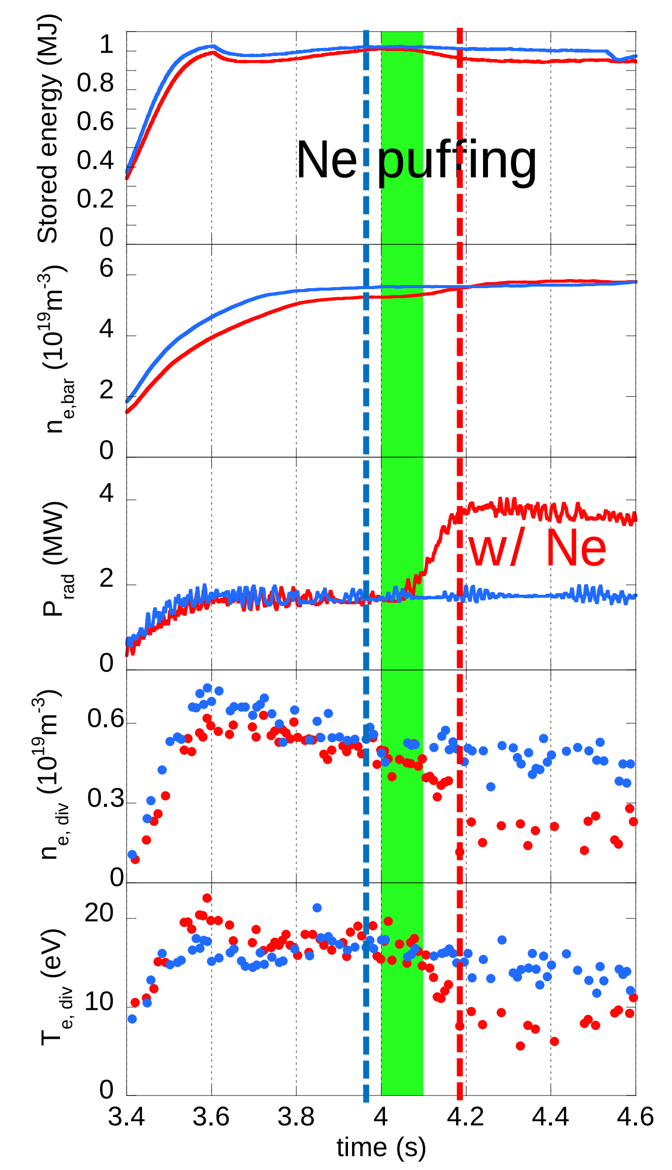
Gas puffing from a bottom port

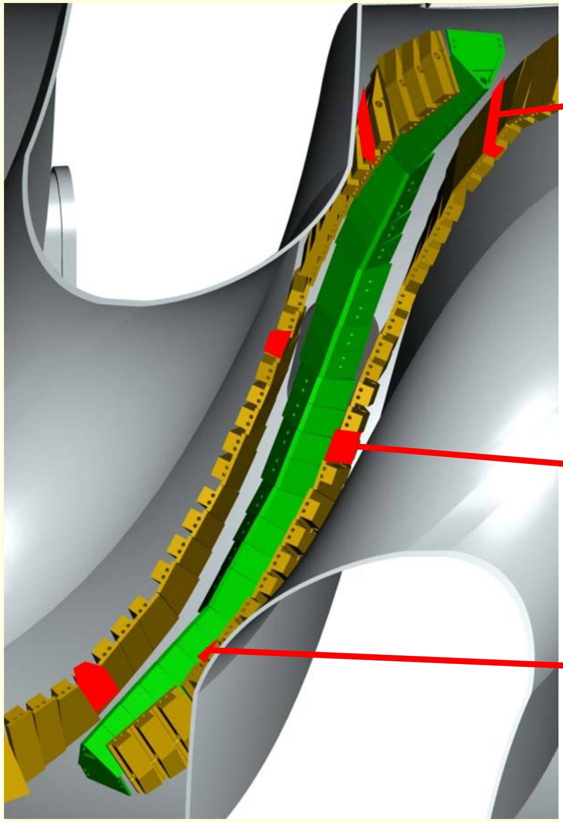
Stable enhanced radiation (P_{rad}/P_{NBI}~0.3) was achieved by Ne sdding

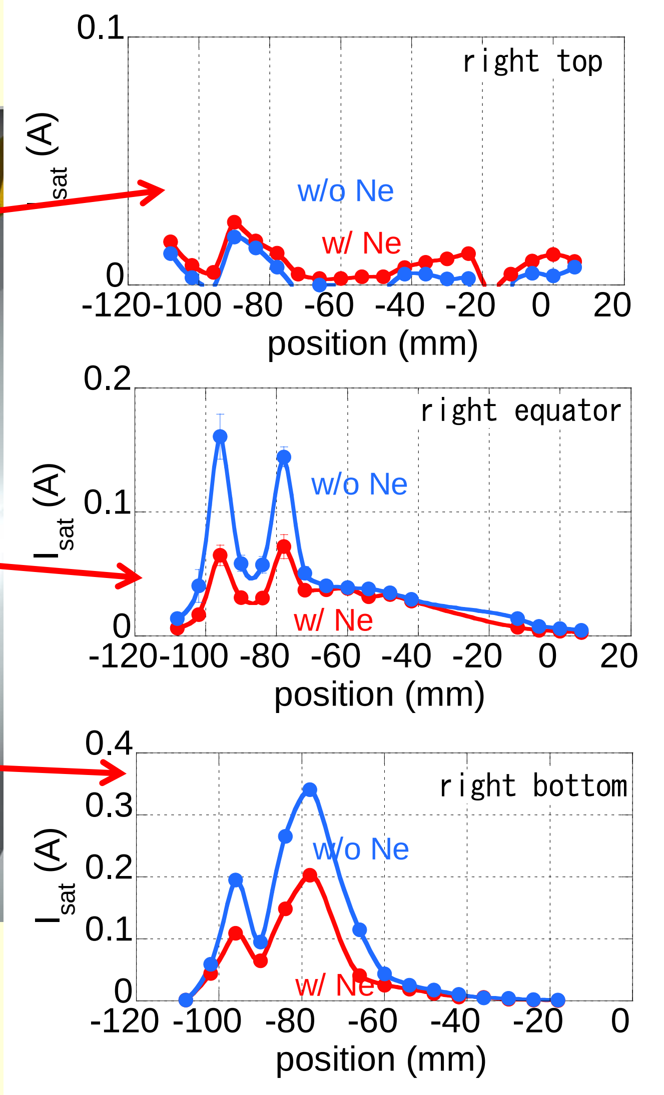


- Plasma heating power ~ 14-15 MW
- Gas flow rate
  - ✓ H_2: ~ $7x10^{21}$ /s
  - ✓ Ne: ~ $4x10^{20}$ /s (120 ms from t=4s)
- P_{rad}~$0.15P_{NBI}$ (w/o Ne)
- P_{rad}~$0.3P_{NBI}$ (w/ Ne)
- P_{rad} reached its maximum after 100 ms from the seeding termination. And the high P_{rad} state was sustained for several hundered ms without additional seeding.

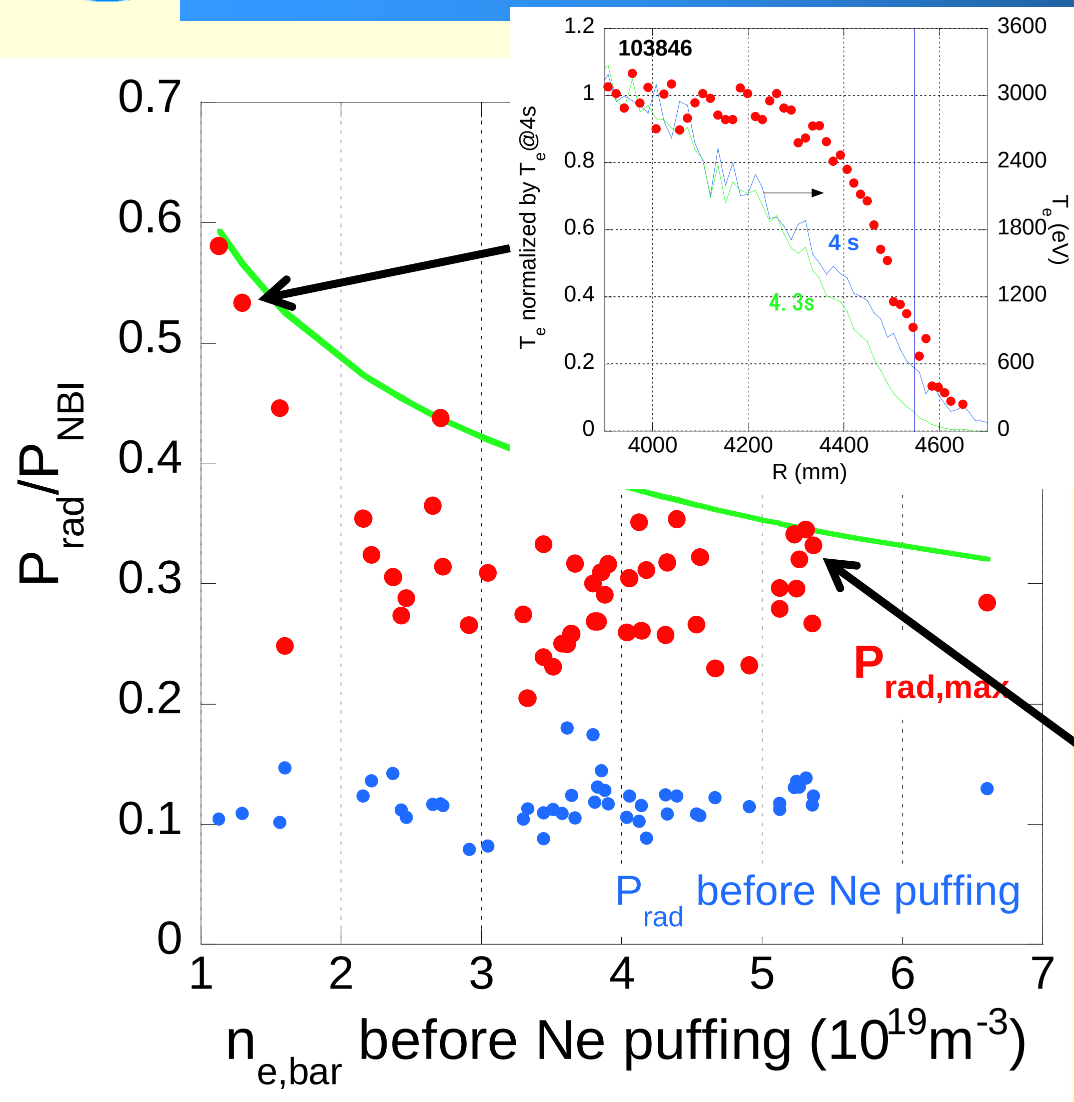
Drastic reduction of divertor particle flux was observed only at the peaks of its profile





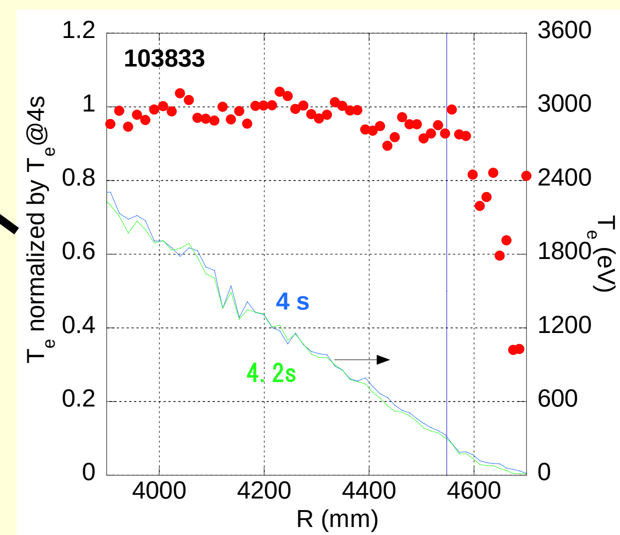


Radiation limit is P_{rad}/P_{NBI}=0.3-0.6, and depends on density

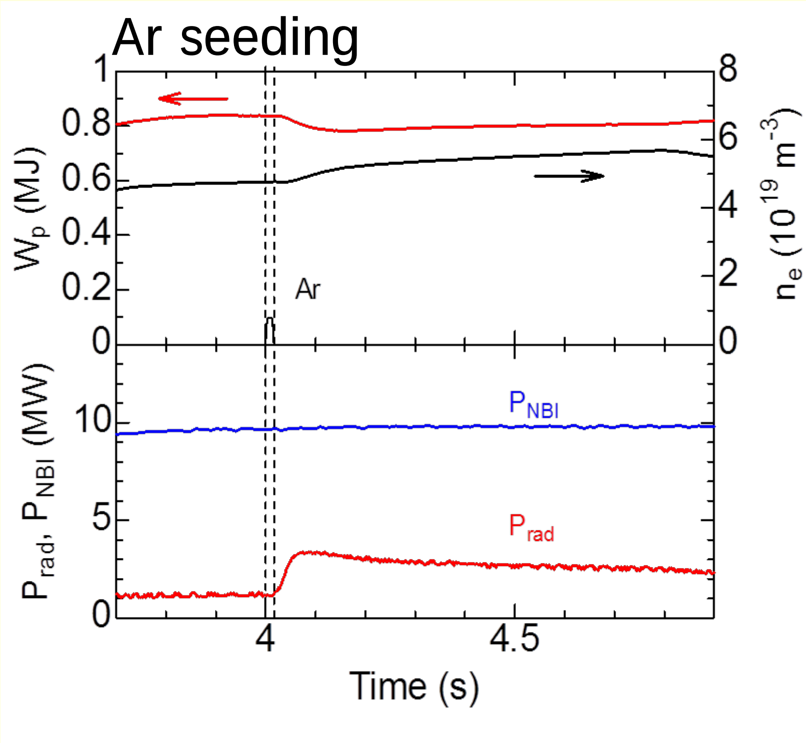


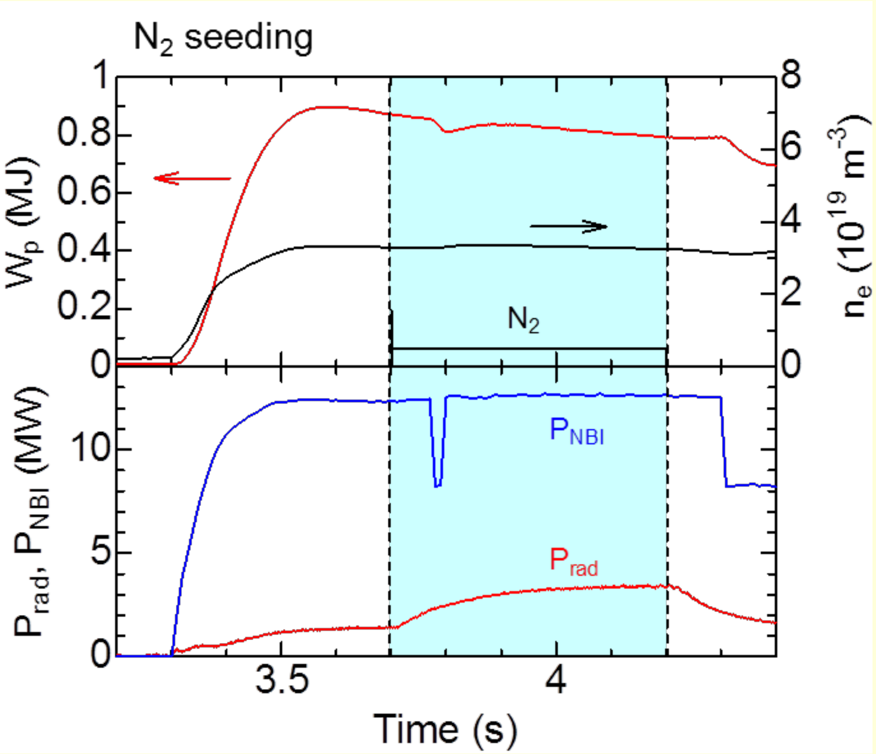
Operation space of Ne seeding discharge

- In the low density region, Ne puffing effect penetrates inside LCFS
  - ✓ The higher ratio is possibly attributed by core radiation.



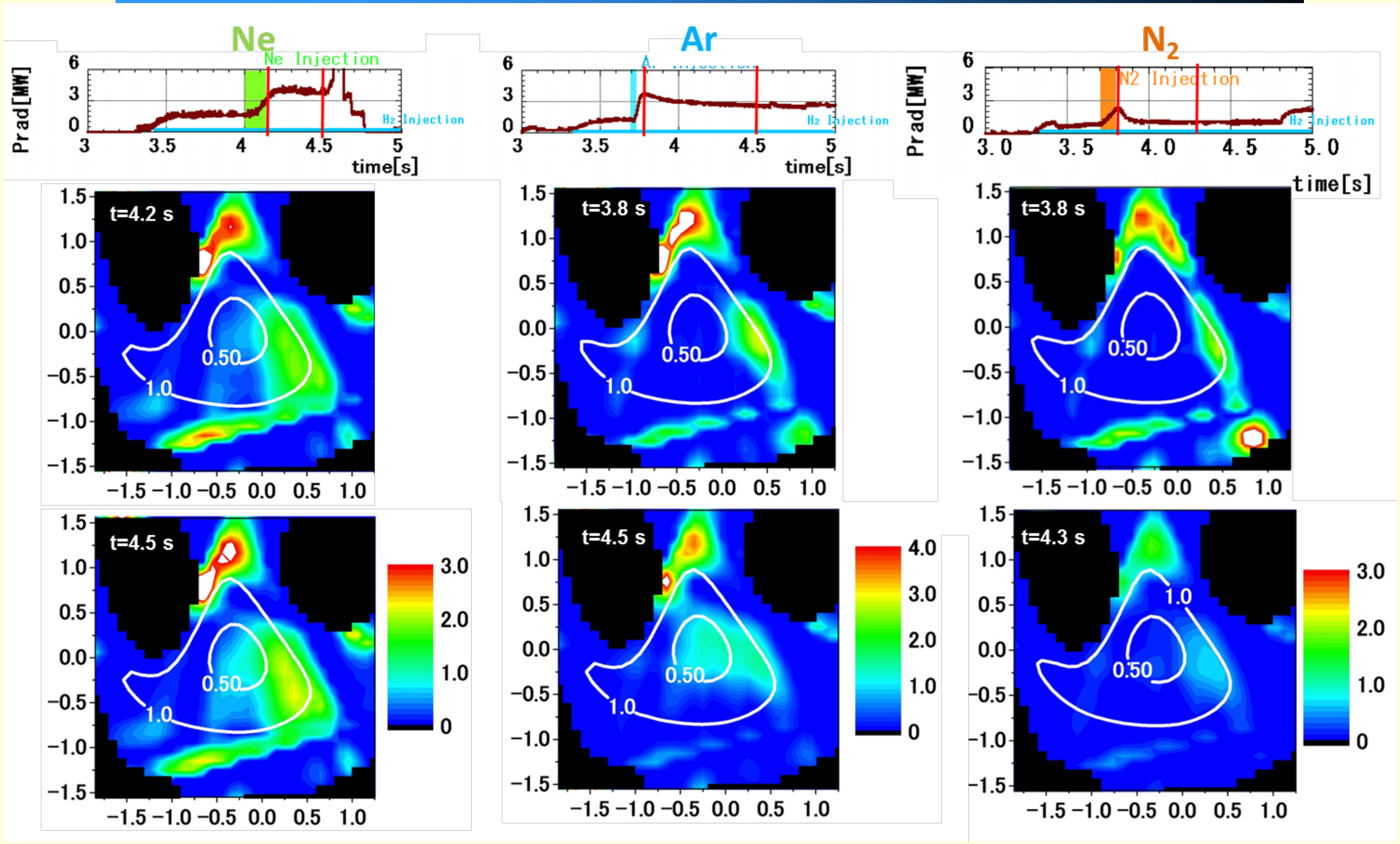
Effects of Ar, N2 seeding on the plasma properties are similar to them with Ne seeding





- It should be noted that in N_2 seeding case, radiation power reduced promptly after terminating seeding.
  - ✓ Difference of recycling between N_2 and Ne, Ar.

Reconstructed radiation distributions measured by AXUVD array shows the penetration of Ne and Ar into the core



In the case of N_2 seeding, the shallower penetration was observed.

Summary

- Particle control experiment using closed helical divertor has been started.
  - ✓ Partially installed test baffle components proved high neutral compression in CHD as predicted by simulation.
  - ✓ Experiment campaign in 2012 will be conducted with CHD installed into 70% of toroidal section.
- Two control knobs, application of RMP and impurity seeding, for divertor heat control have been investigated.
  - ✓ 30-60% of heating power can be radiated stably.
  - ✓ Further investigation is necessary to understand their physics and achieve higher radiation power.