Edge Heat Transport in the Helical Divertor Configuration in LHD

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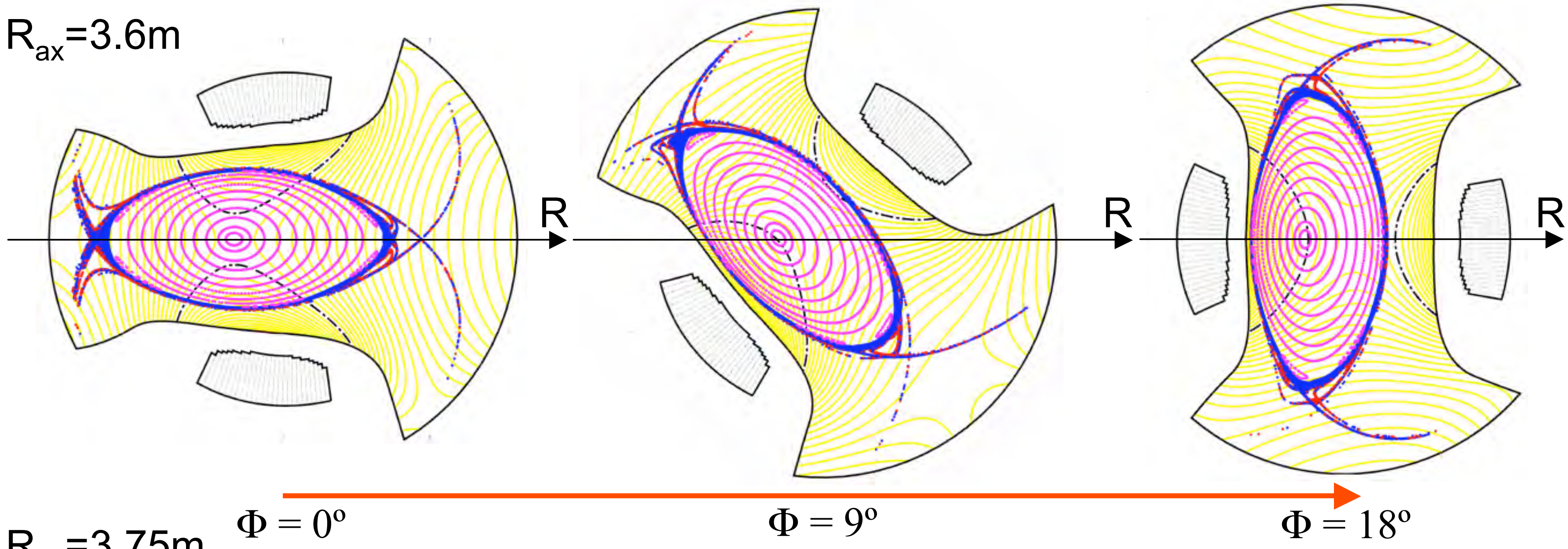
MOTIVATION

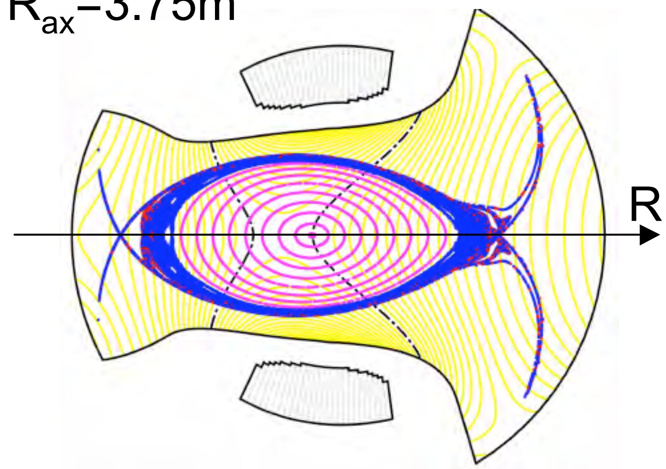
- Understanding of heat and particle transport in edge region is essential for divertor design in fusion reactor.
  – Complex field line structure in which stochastic region, islands and laminar region coexist exists in edge region in heliotron-type devices, stellarators and tokamaks with RMP.
  – Different mechanism which determines divertor heat and particle flux profiles from poloidal divertor tokamaks may exist.
- In this study, we focus on profiles of heat and particle flux on helical divertor in LHD heliotron.

OUTLINE

- Edge magnetic field line structure in LHD
- Relation between the structure and profiles of particle and heat load on divertor
- Transport change with T_e rise
- Summary

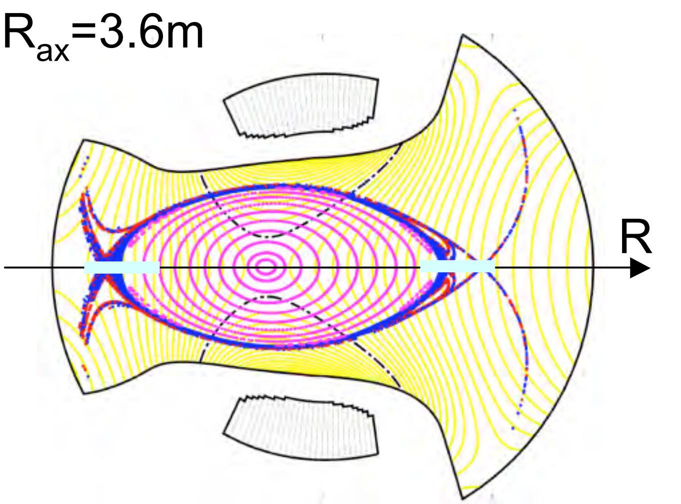
Edge field line structure in LHD

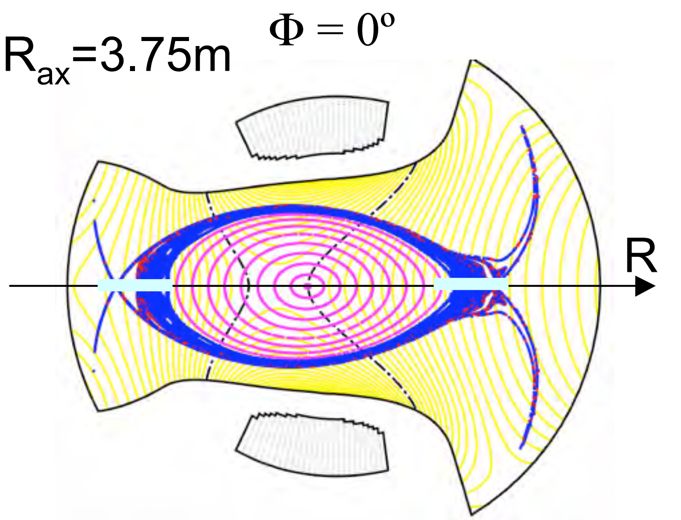


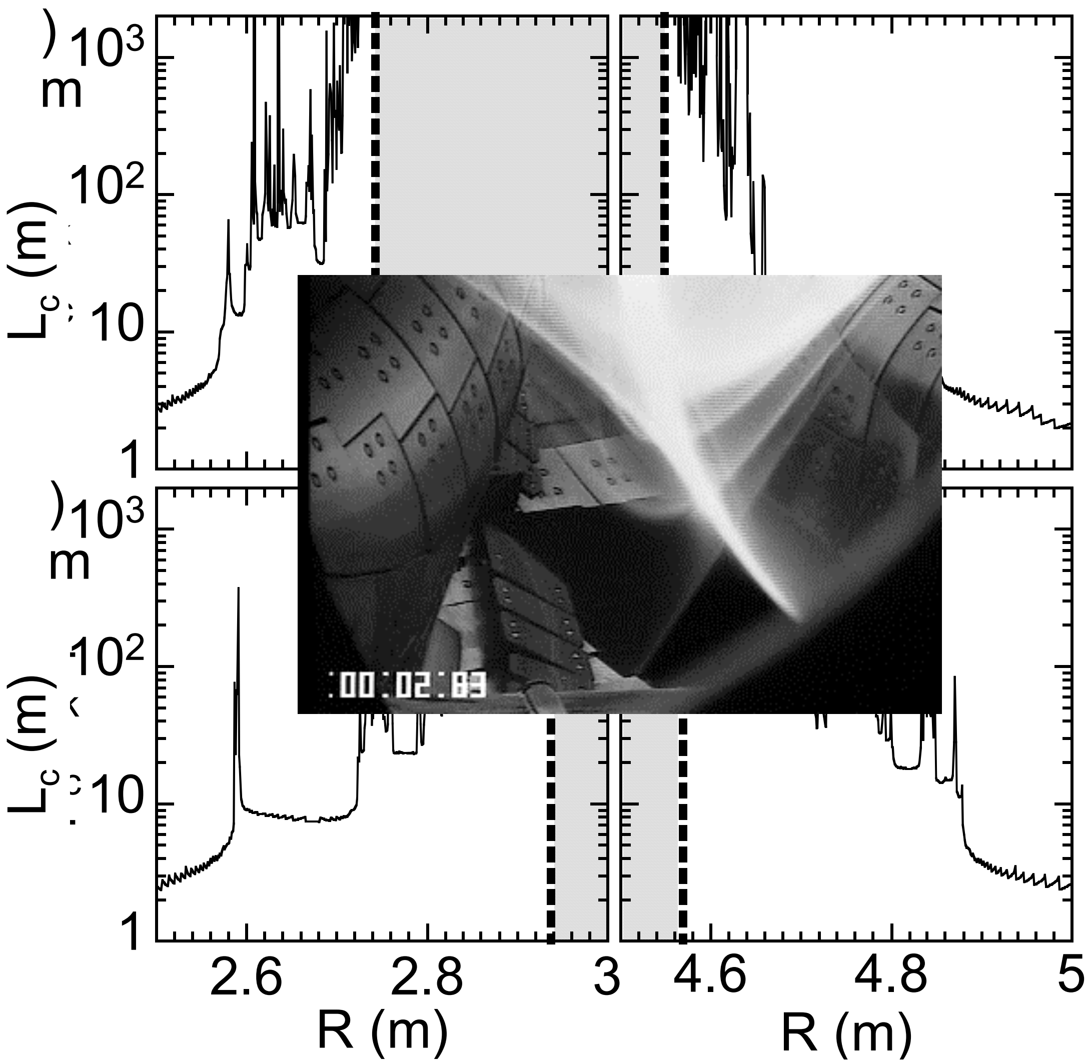


- Helical divertor SOL has three dimensional structure.
- In the HD SOL, the stochastic region, islands and laminar layer co-exist.
- The fine structure in the HD SOL varies with the operational magnetic structure.

Edge field line structure in LHD

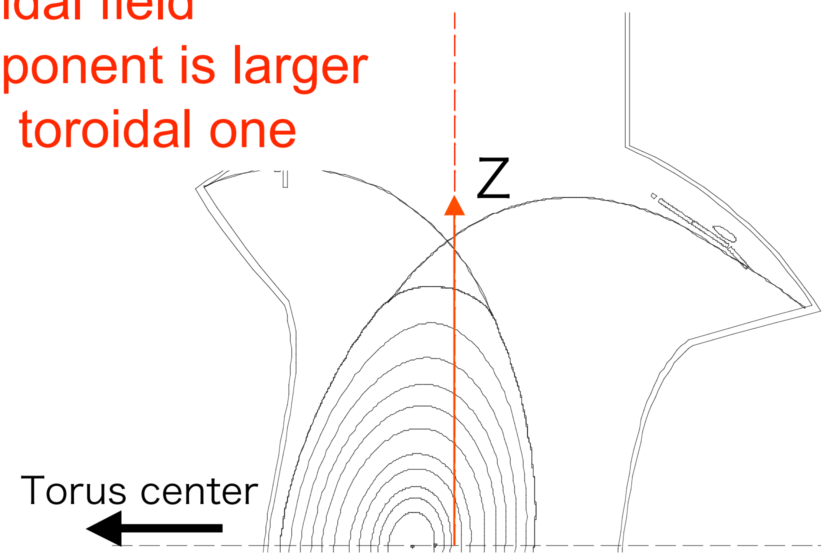


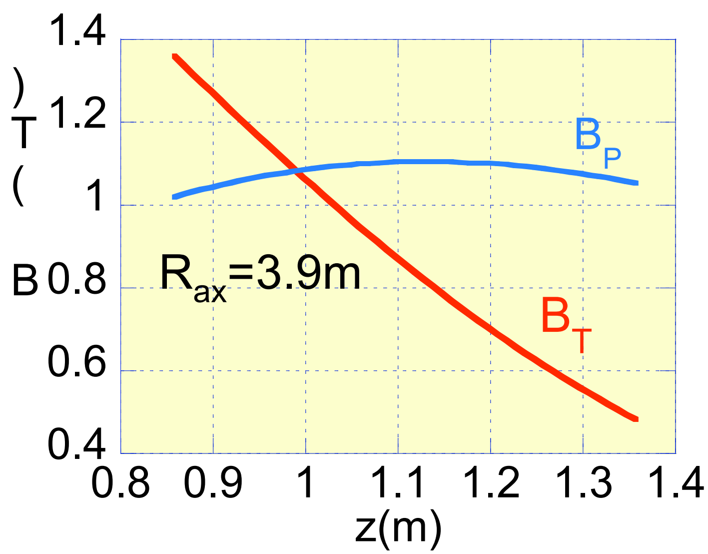


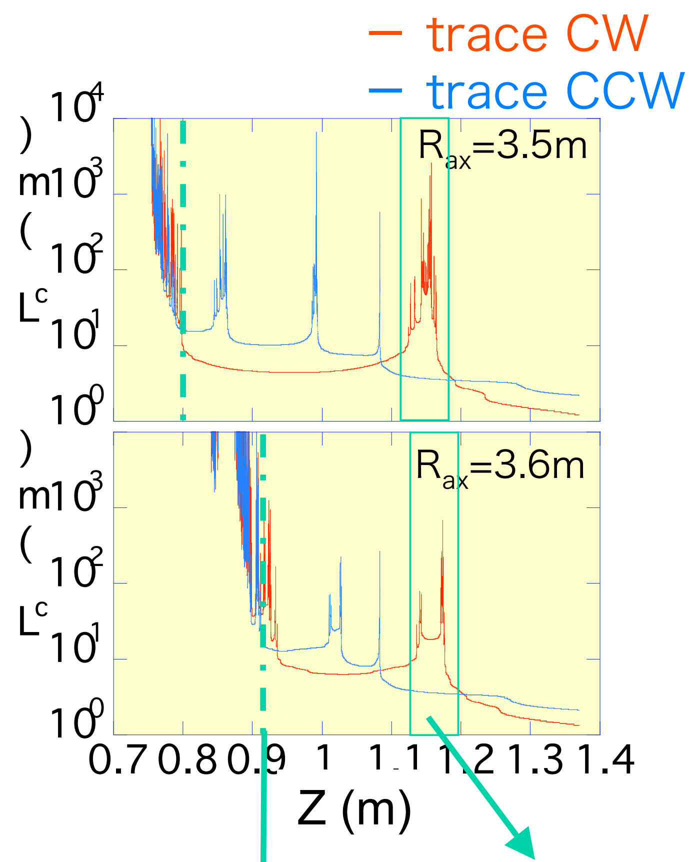


Divertor leg

In divertor region, poloidal field component is larger than toroidal one



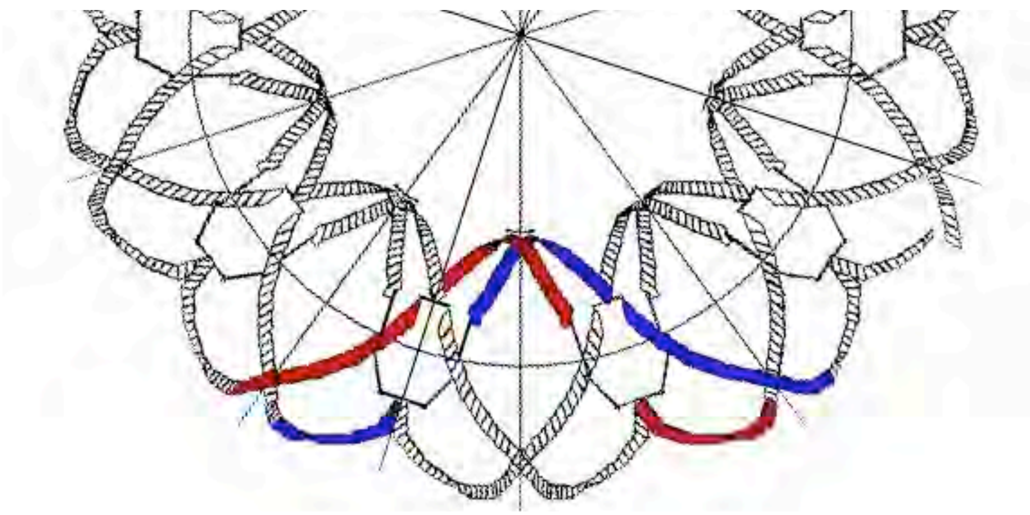


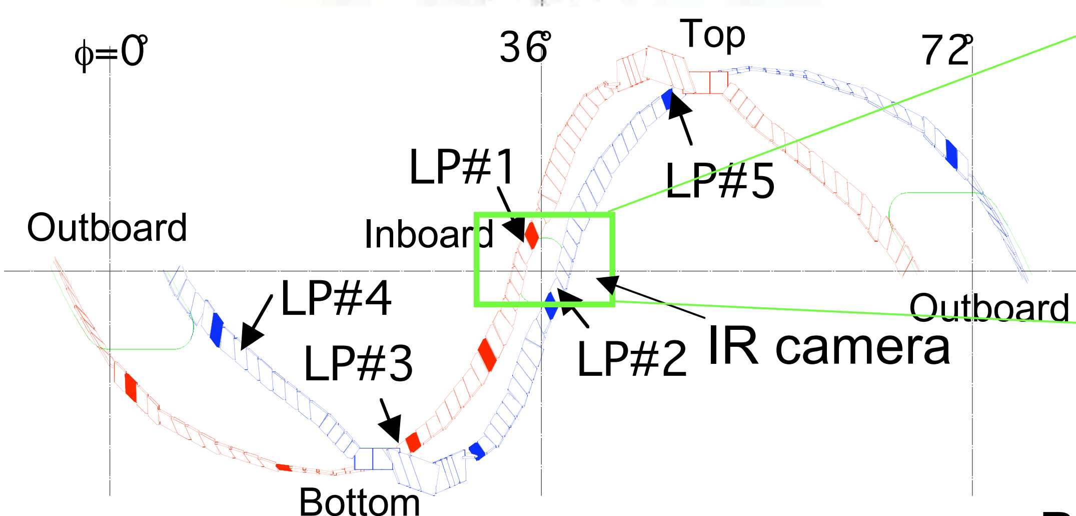


Outer of this line, field lines interrupted by divertor plates or first wall within about ten meter

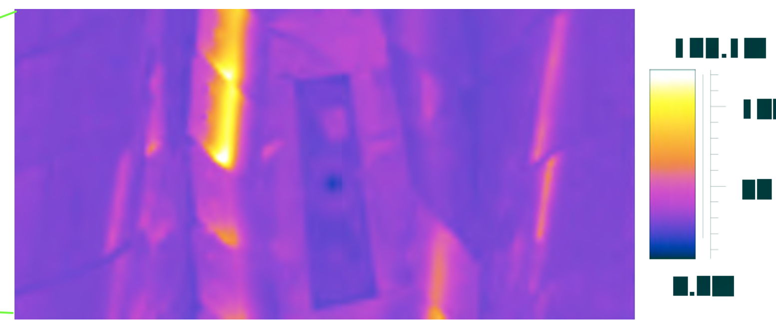
Divertor Plate Array

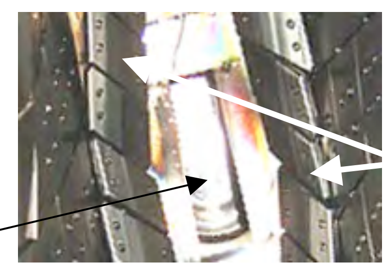
- 1,700 water cooled graphite tiles
- Langmuir probes and thermocouples are embedded in divertor plates
- An IR camera observes inboard divertor plates



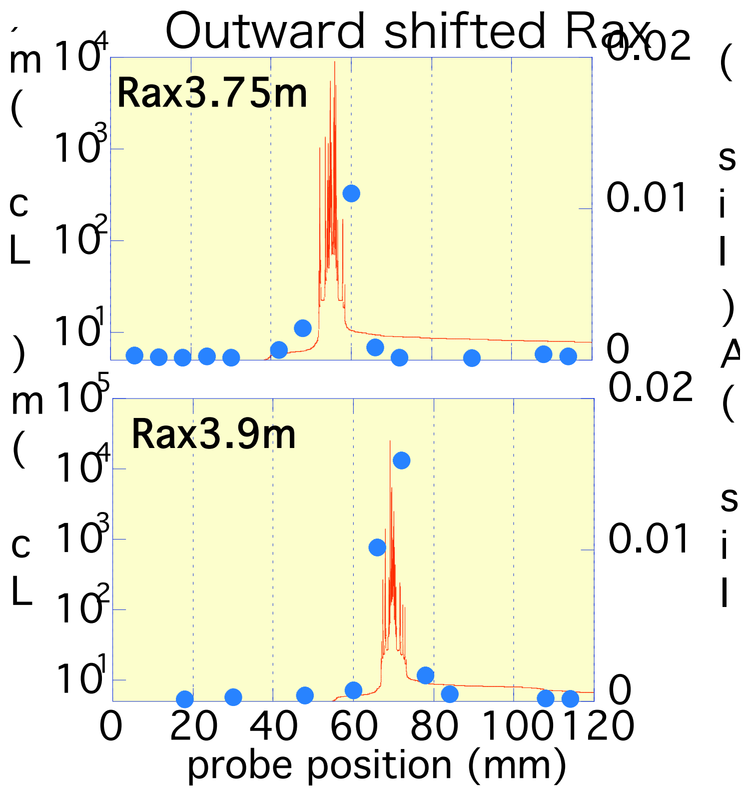


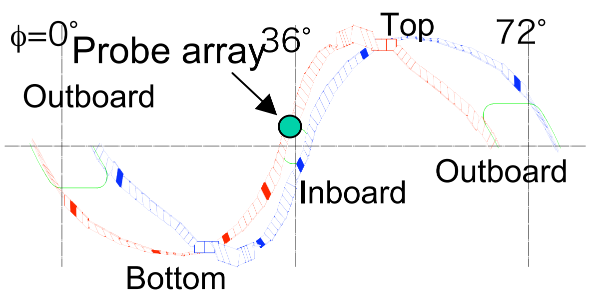
Divertor plate arrays and diagnostics



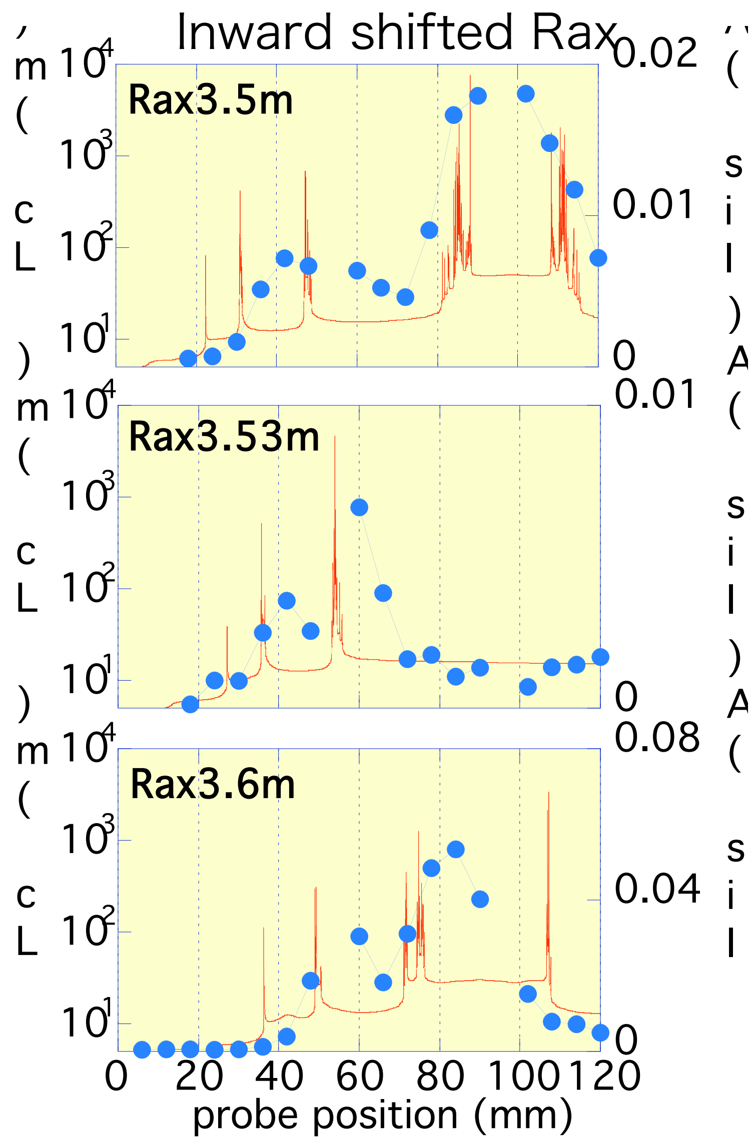


Particle Flux Profiles on a Divetor Plate

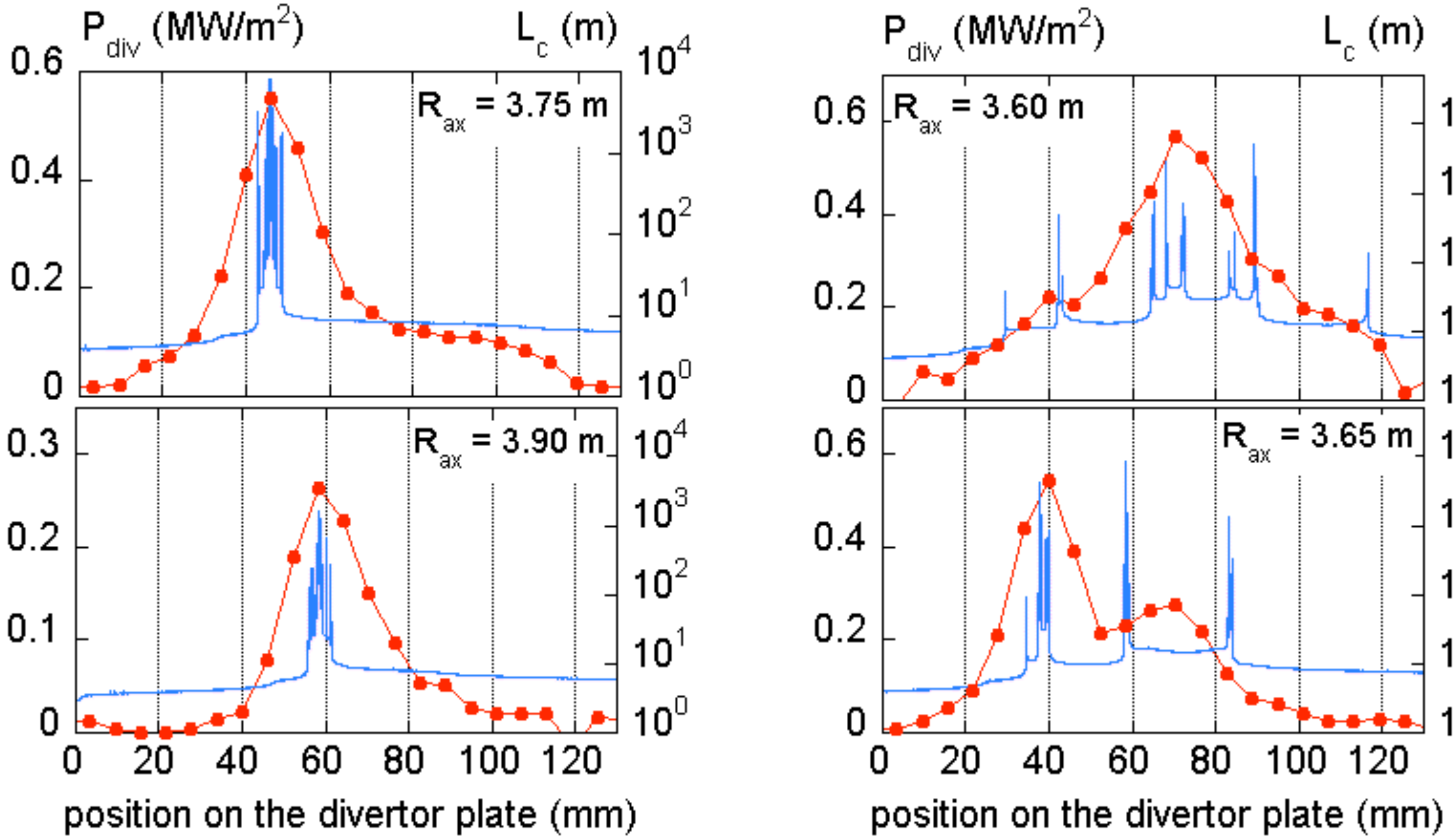




Divertor plate array

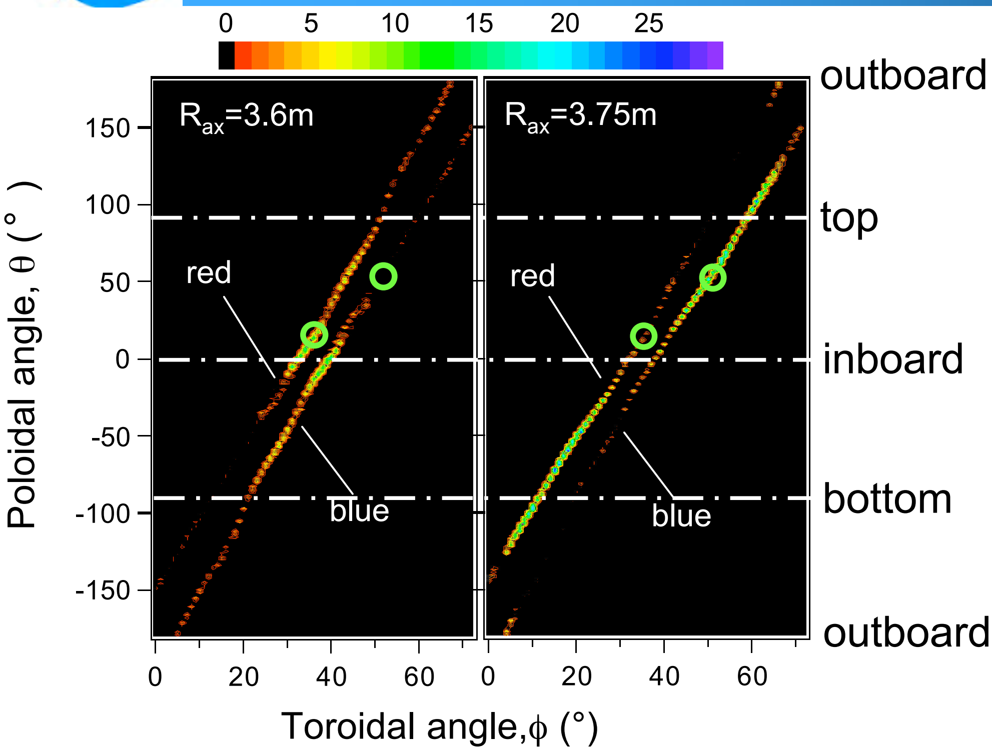


Heat Flux Profiles on a Divertor Plate

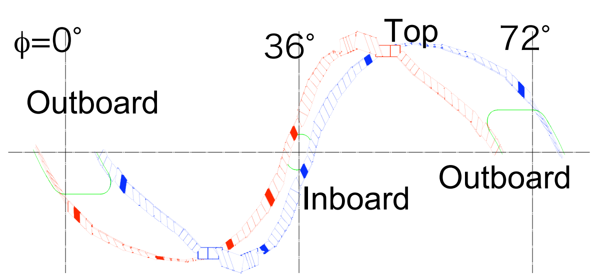


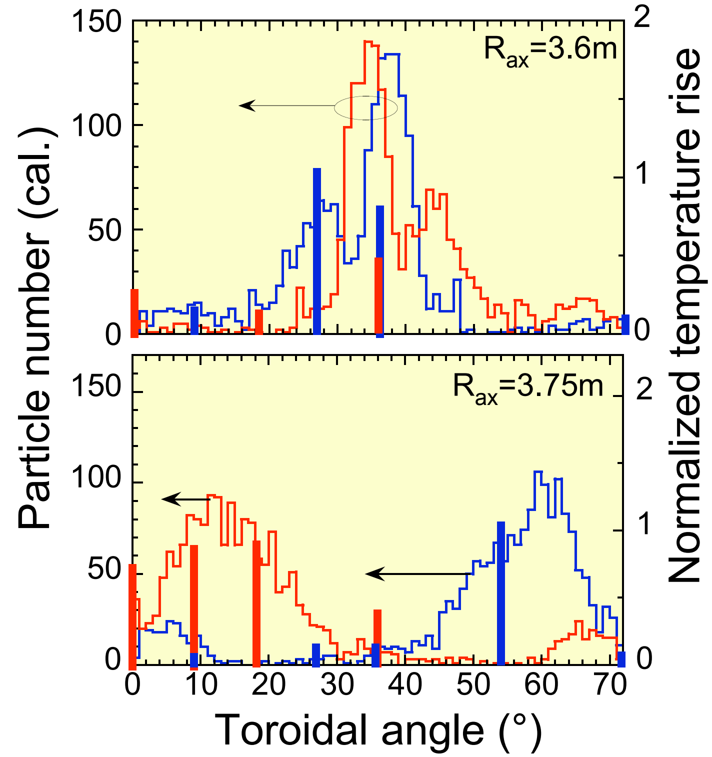
- Heat flux profiles were reconstructed by using temperature rise profiles at the beginning of NB injection. Semi-infinite assumption was applied neglecting three dimensional heat diffusion.

Heat and Particle Deposition Profiles on divertor



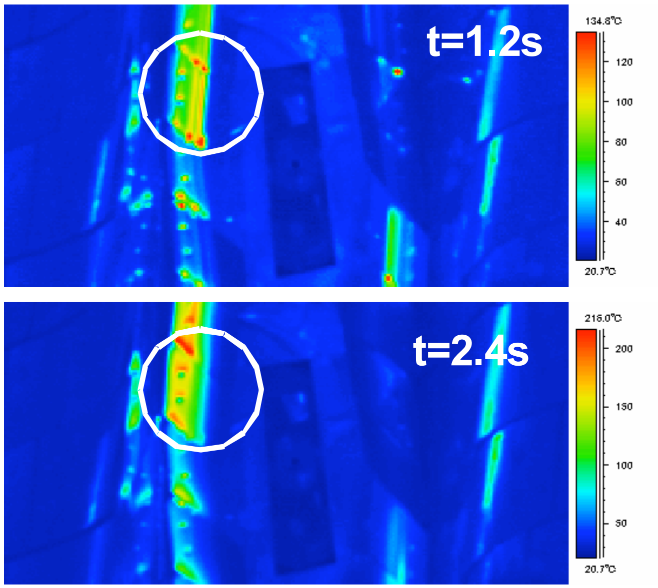
Particle deposition patterns on the HD. (β=0)
(Calculation results of field lines tracing)

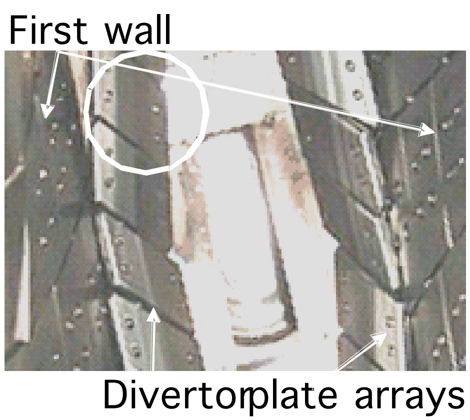


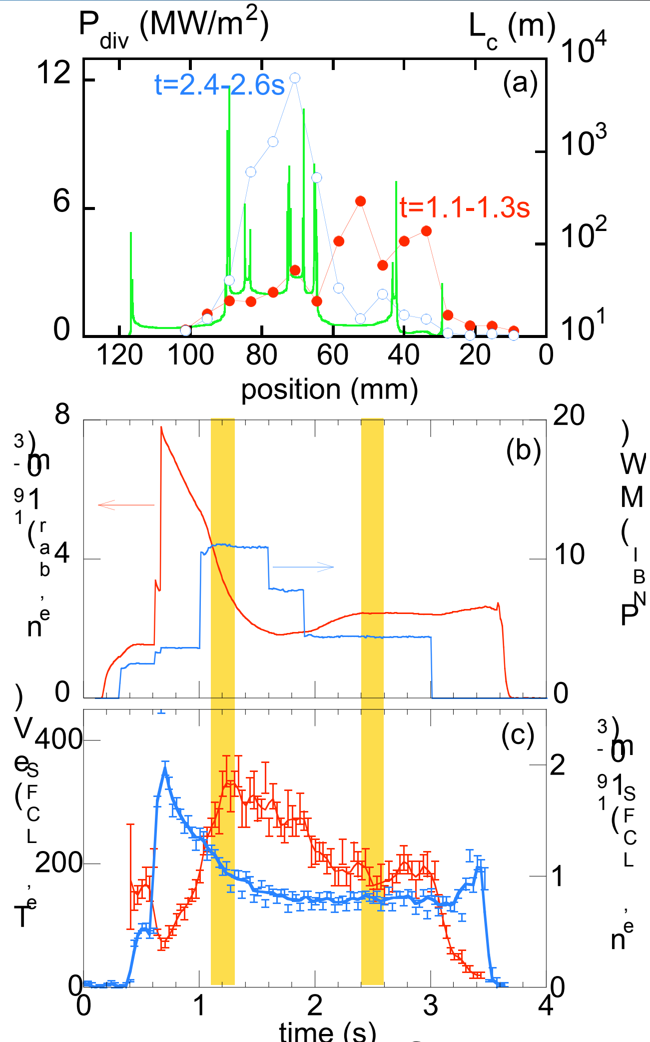


Profile of normalized temperature rise measured by thermocouples, and particle deposition obtained by field line tracing.

Change of heat flux profile during discharge (Rax=3.60m)







- Such change of heat flux profile has been observed frequently.
- Particle flux profile is also changed.

Application of the 3D edge transport codes : EMC3-EIRENE

Physics

- standard fluid equations of
  density, momentum, energy of ion & electron
- simplified fluid model for impurities
  (not for present analysis)
- kinetic model for neutral gas

Coupled self-consistently

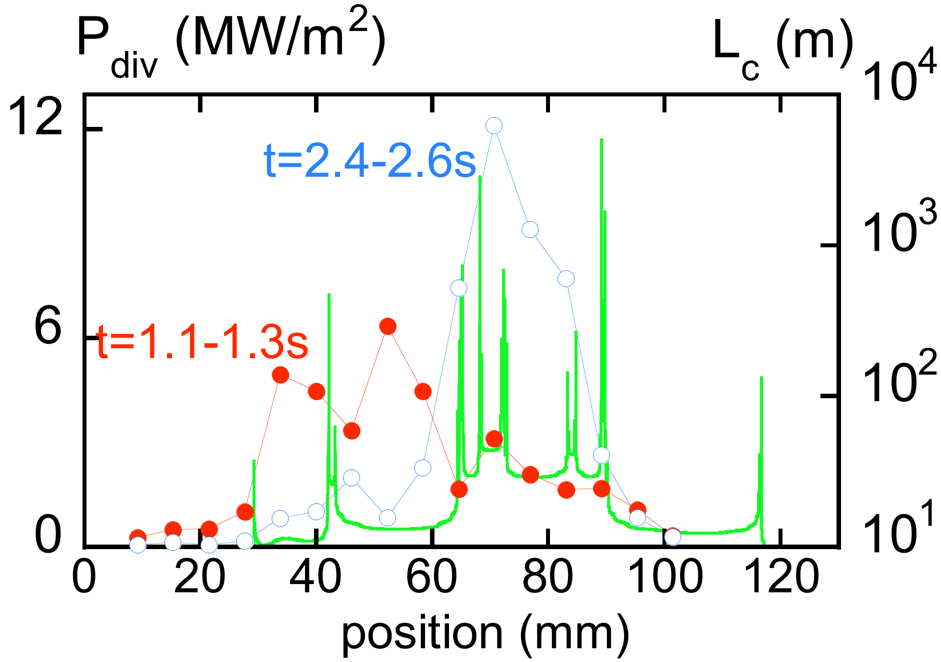
Geometry

- fully 3D for plasma, divertor plates, baffles and wall
- ergodic or non-ergodic B-field configurations

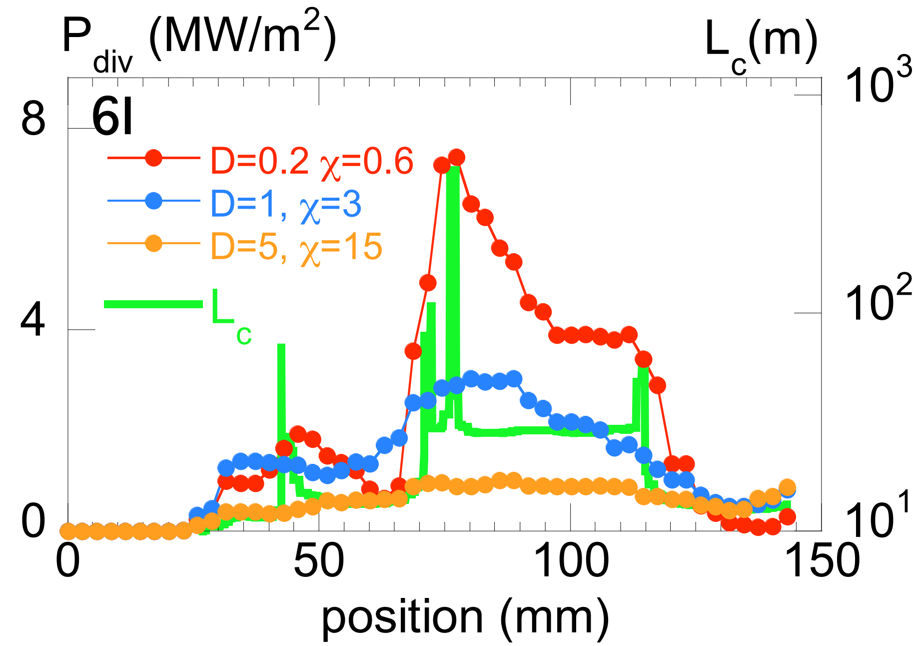
Numerics

- Monte Carlo technique on local field-aligned vectors, piecewise parallel integration for isolation of the small ⊥ from the large ll-transport (⊥/ll~10^{-8})
- new Reversible Field Line Mapping (RFLM) technique,
  Finite flux tube coordinates for B-field line interpolation

Reproduce of the profile change using EMC3-EIRENE code



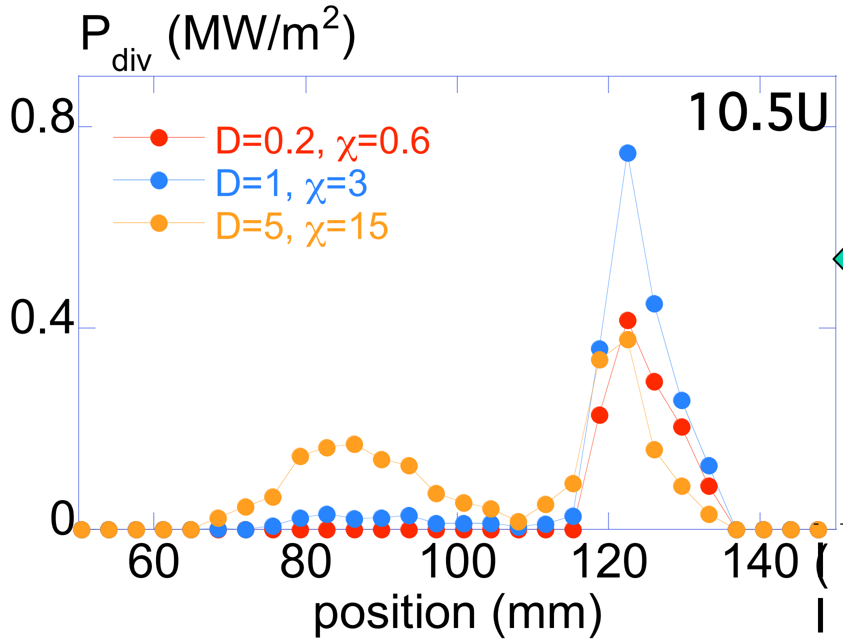
experiment



calculation

- Blue profile in experiment was reproduced by calculation.
- Red profile was not well reproduced. But increasing of diffusion coefficient flatten the profile in calculation.
- Heat load decreases with increase diffusion coefficient.

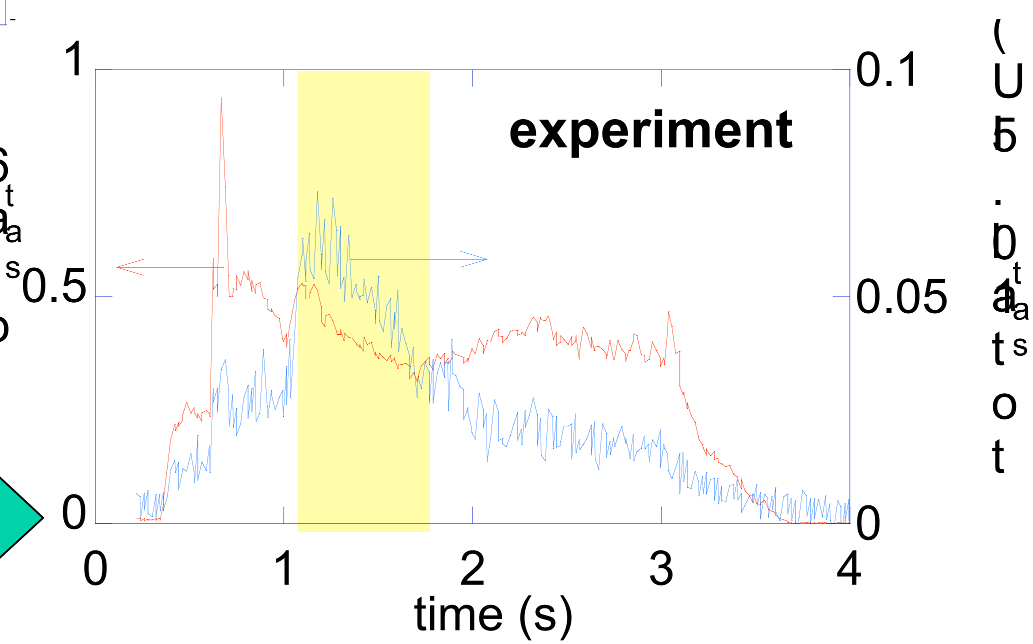
At 10.5U probe position



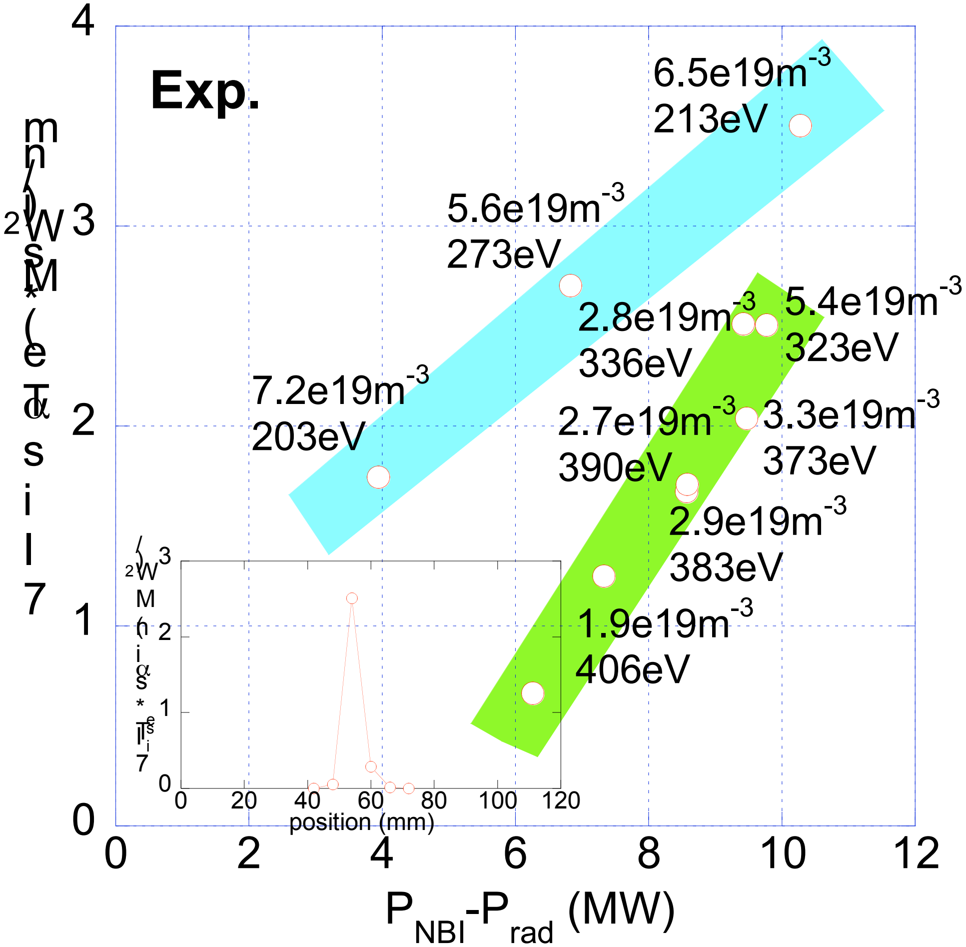
calculation

- Heat load (and particle load) increases with increase of diffusion coefficient at this position.
- Heat and particle transfer from “long” flux tube to laminar region is enhanced.

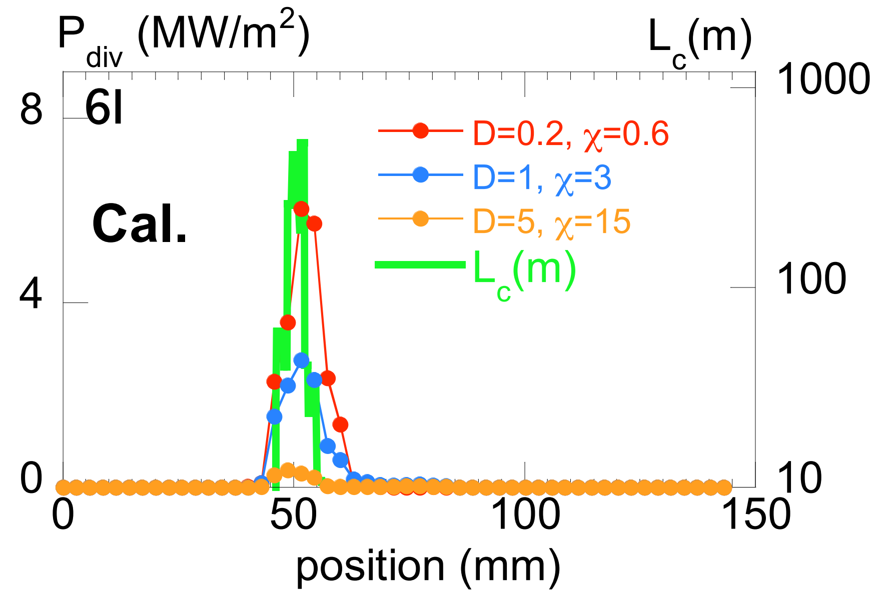
- The ratio of total I_{sat} at 10.5U probe to that at 6I probe increase during the profile change (yellow hatched).
- Consistent with calculation assuming larger D and χ.



In the case of Rax=3.75m

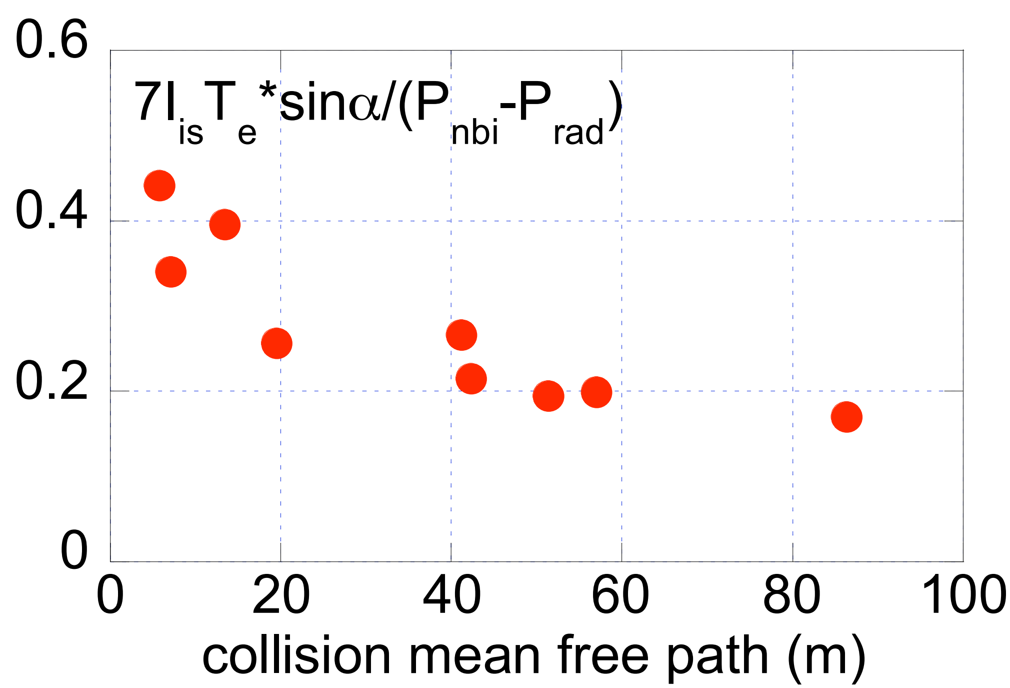


Divertor heat flux vs. heating power
N_e and T_e at LCFS are shown for each symbol



- Profiles of heat and particle flux are not largely changed by plasma conditions.
- In experiment, ratio of peak heat flux on the divertor to heating power is large for relatively low Te discharges (blue line).
- In calculation, the ratio increase with decreasing of D and χ.

Less collision looks to enhance the heat transfer from long flux tube to laminar region



- Normalized heat flux vs. collision mean free path ($10^{16}T_e^{2}/n_e$) around the last closed flux surface.
- Decreasing of the normalized heat flux suggests that heat transfer from “long” flux tube to laminar region is enhanced.

Do diffusion coefficients increase with increasing of T_e?

Observations in discharges with Rax=3.60m

$T_e \nearrow \quad \dfrac{P_{div}@6I}{\text{Heating power}} \searrow \quad \dfrac{I_{sat}@10.5U}{I_{sat}@6I} \nearrow$

$T_e \nearrow$ flattening of heat flux profile@6I

Observations in discharges with Rax=3.75m

$T_e \nearrow \quad \dfrac{P_{div}@6I}{\text{Heating power}} \searrow$

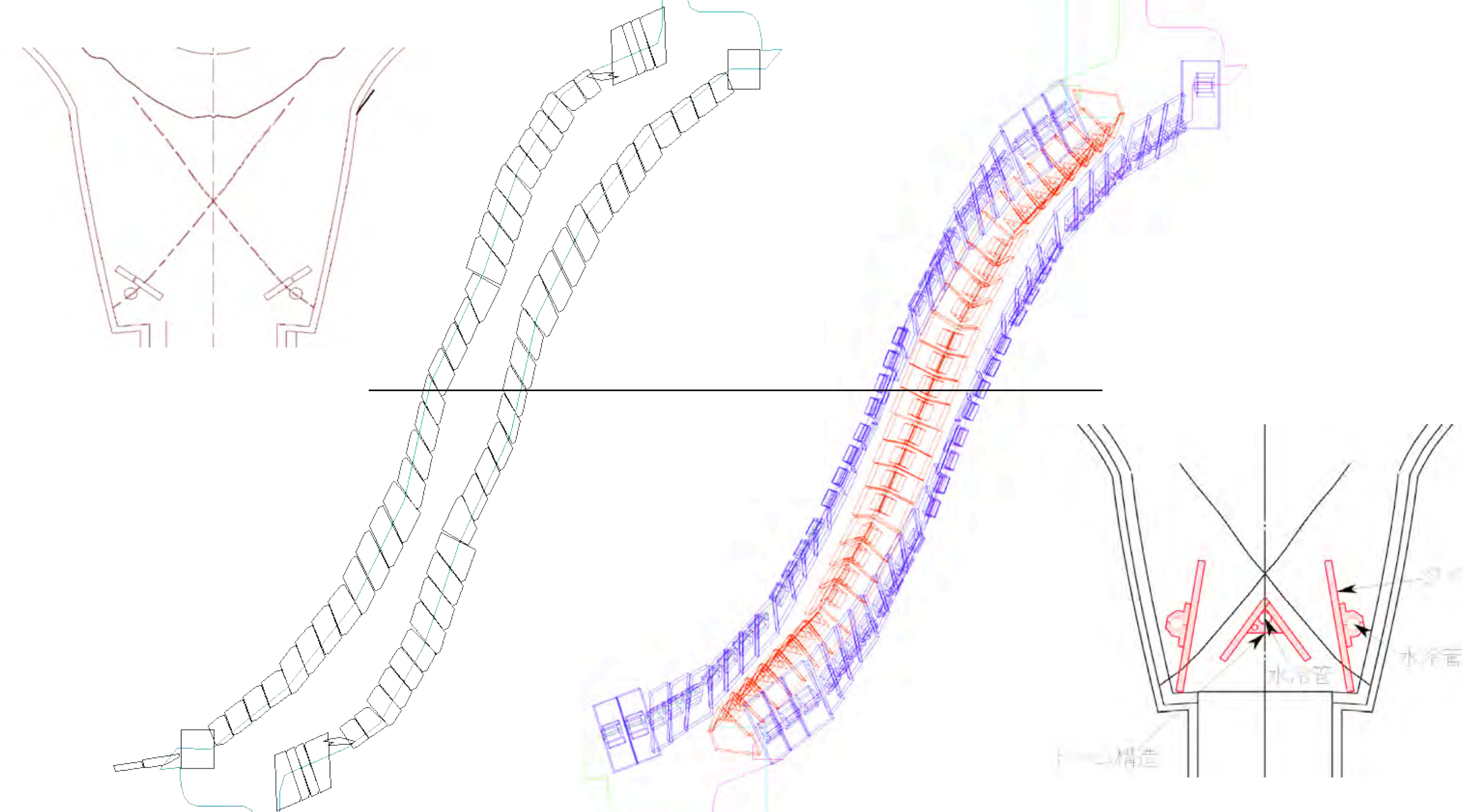
consistent

Calculations with increasing D and χ

Summary

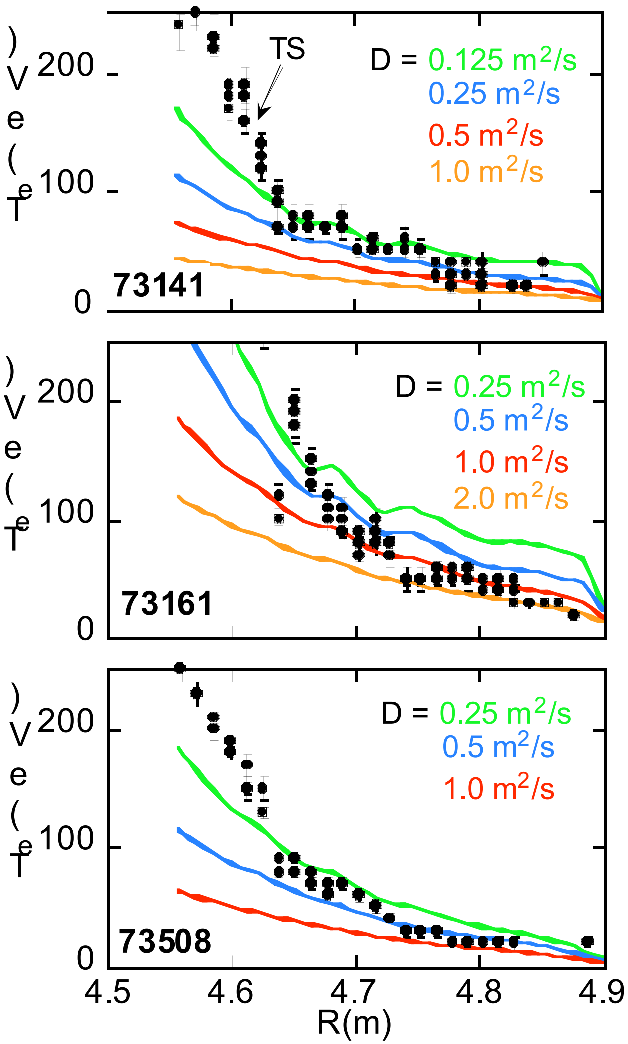
- Profiles of heat and particle load on divertor plates are roughly determined by magnetic field line structure.
  - Though the edge field line structure is complex, the profiles can be roughly predicted even in the complex e.
- Heat and particle transfer from “long” flux tube to laminar region look to be enhanced with T_e rise rather than increasing collisionality.

Closed Helical Divertor will be installed (2/10 sections) in 2010



Present divertor **Closed divertor**

Edge T_e profiles
D and χ were estimated by fitting of calculation to experimental data



$T_{e,LCFS}$~200eV
$n_{e,LCFS}$~1-1.5E19m^{-3}
D = 0.125 - 0.25 m^2/s
χ = 0.375 - 0.5 m^2/s

$T_{e,LCFS}$~400eV
$n_{e,LCFS}$~1-1.5E19m^{-3}
D = 0.5 – 1.0 m^2/s
χ = 1.5 – 3 m^2/s

$T_{e,LCFS}$~200eV
$n_{e,LCFS}$~6E19m^{-3}
D = 0.25 - 0.5 m2/s
χ = 0.75 – 1.5 m2/s

These results suggest that the cross-field transport coefficients have temperature dependence, and they also depend on density weakly.