Introduction of kinetic effects to fluid simulation by a particle model

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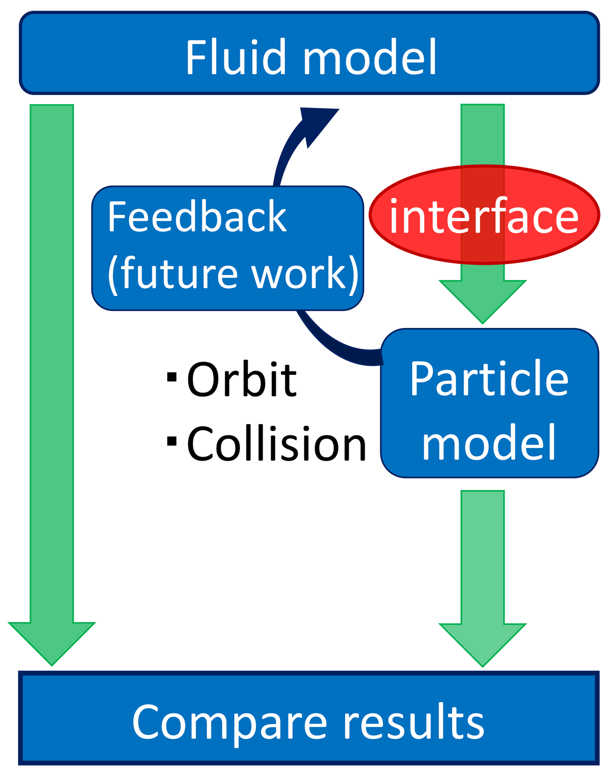
Background & Purpose

- In the divertor region, collisionless high energy particles exist and kinetic effects are important.
- Fluid simulations[1,2] do not sufficiently consider kinetic effects, and tend to estimate lower T_e and higher n_e in the divertor region[3].
- Fluid simulations tend to underestimate parallel ion SOL flows at the low field side[4].

→ **Introduction of kinetic effects to fluid simulation is necessary**

- A particle model is effective to treat kinetic effects because it directly calculates particle motion and velocity distribution.

➡ **The purpose of this study is to introduce kinetic effects to fluid simulation by a particle model and to investigate influence of kinetic effects on plasma behavior**



Summary & Conclusion

- The developed interface enabled us to transform fluid data into particle data.
- We set particles corresponding to plasma parameters obtained from fluid simulation and made the initial distribution for particle simulation successfully.
- Fast ion flow along the field line appeared due to a particle model near inner and outer divertor, and velocity distributions also shifted.

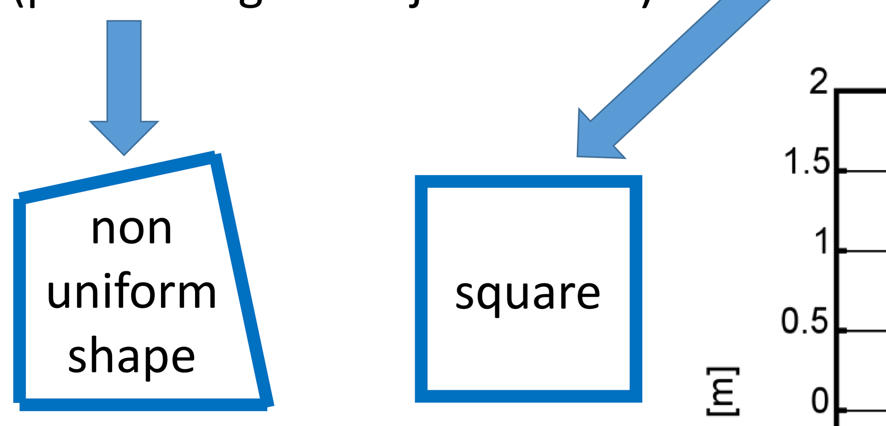
Simulation system of fluid/particle model

Fluid model (finite element)

Non uniform shape mesh along the magnetic field line
radial direction i
poloidal direction j
i × j=61 × 124
(plasma region i × j=35 × 124)

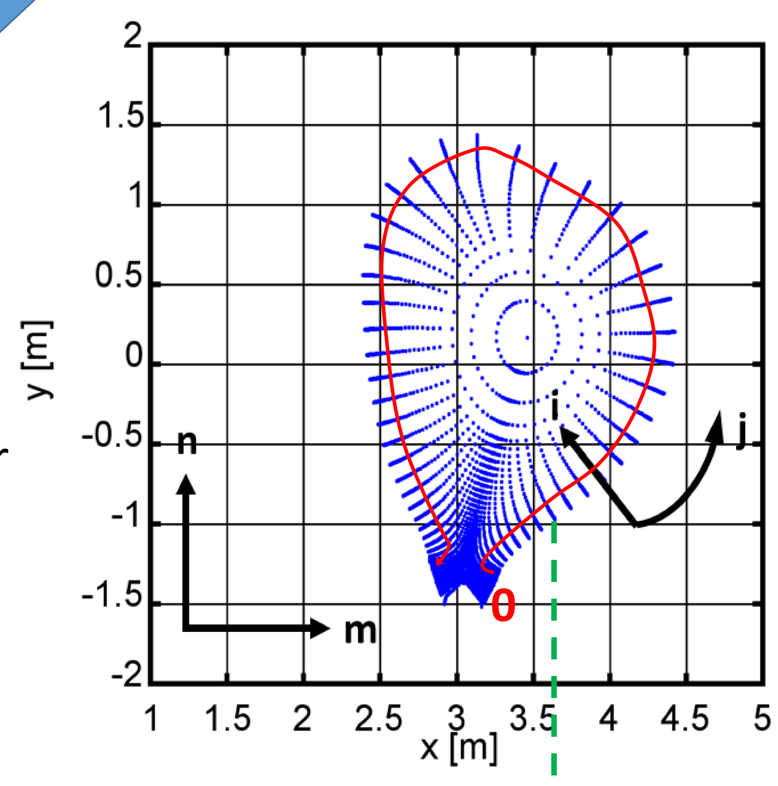
Particle model

Square mesh
(each side is 0.01m)
x direction: m, y direction: n
m × n=400 × 400



- Unfavorable for collision
- Mesh size can be changed depending on the place

- Favorable for collision
- Mesh size is constant at any place



Algorism developed for the interface

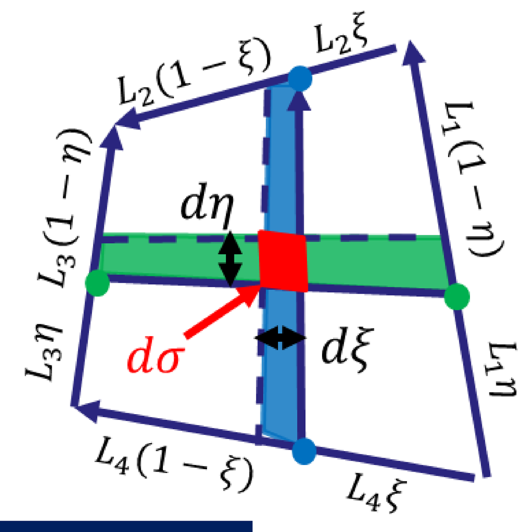
➢ In order to make the interface for data transformation, we developed following two algorisms.

Method to set particles equally in non uniform shape mesh

When ξ and η are uniform random number, $d\sigma$ varies depending on the place

➡ We made ξ and η have the distribution to keep $d\sigma$ constant

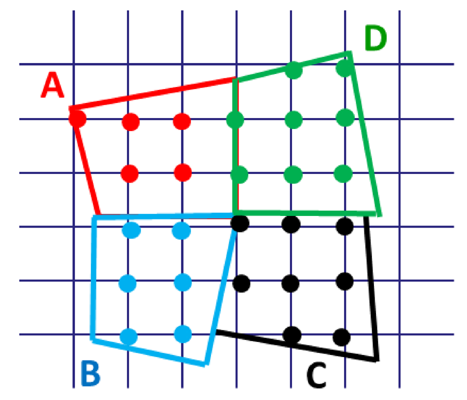
$d\sigma$: an area near the place decided by the random numbers ξ and η

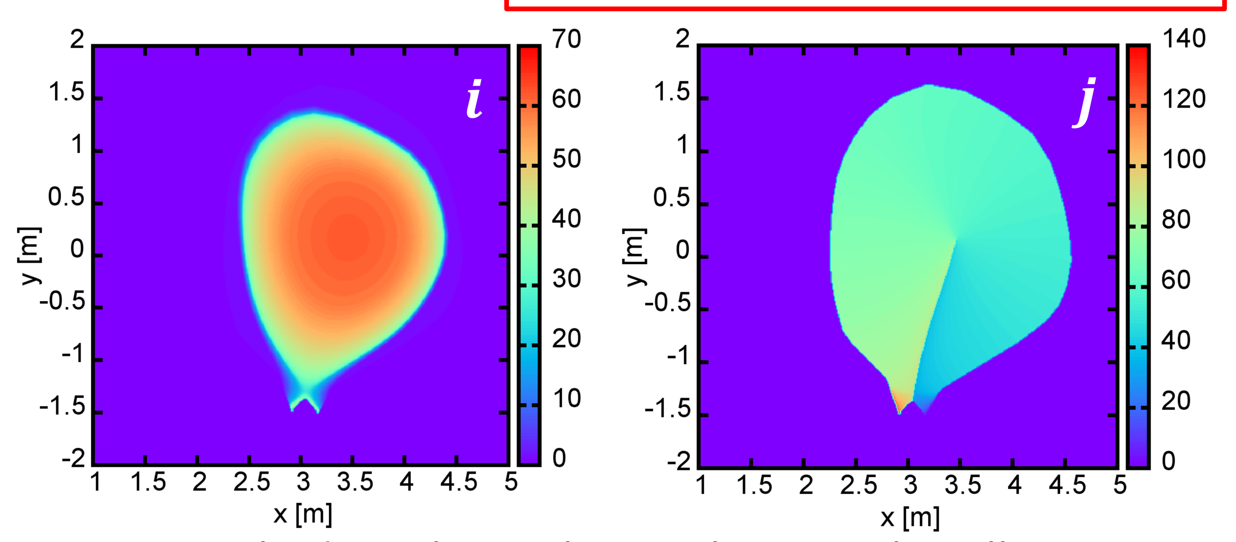


Associating fluid mesh (i, j) with particle mesh (m, n)

Figures show i and j values associated with particle mesh (m, n)

➡ We confirmed that associating algorism worked correctly





Fluid mesh number in the particle cell

Data transformation from fluid to particle

➢ Using the interface, we transformed the plasma parameters obtained from fluid simulation into the distribution of particles in particle simulation.

※distance along the field line means the distance from outer divertor along the flux tube in 2D plane

Plasma parameters in fluid mesh (i, j)

- Temperature T_{ij}
- Flow velocity $\boldsymbol{V}_{pij}$
- Density n_{ij}

Initial velocity and the number of super particles set in fluid mesh

Initial velocity $\boldsymbol{v} = \boldsymbol{v_M} + \boldsymbol{V}_{pij}$

v_M : randomly selected from Maxwell distribution with Temperature T_{ij}

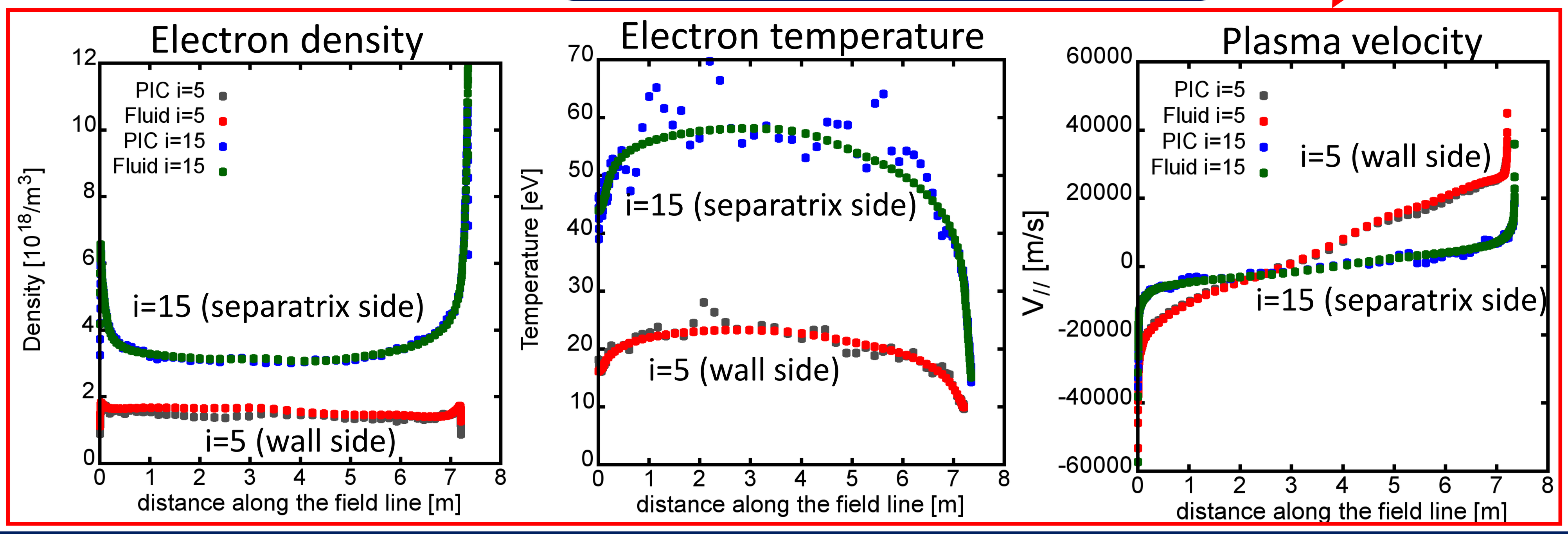
The number of super particles

$N_{ij} = n_{ij} \times S_{ij}/w$

S_{ij} : an area of fluid mesh (i, j)

w : a weight of super particles

Data transformation successfully performed



Orbit and collision model

Orbit model

- We used PARASOL 2D model to calculate orbit of particles.

➢ Guiding center (for electrons)

$$\frac{dV_\parallel}{dt} = -\frac{e}{m_e}\frac{\boldsymbol{E}\cdot\boldsymbol{B}}{B} - \frac{\mu_e}{m_e}\frac{\boldsymbol{B}\cdot\boldsymbol{\nabla B}}{B} + V_\parallel(\boldsymbol{E}\times\boldsymbol{B})\cdot\frac{\boldsymbol{\nabla B}}{B^3}$$

$$\frac{d\boldsymbol{r}}{dt} = \frac{\boldsymbol{B}}{B}V_\parallel + \frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2} - \frac{m_e}{eB^3}\left(V_\parallel^2 + \frac{V_\perp^2}{2}\right)(\boldsymbol{B}\times\boldsymbol{\nabla B})$$

$$\mu_e \equiv \frac{m_e V_\perp^2}{2B} = const$$

➢ Gyro motion (for ions)

$$\frac{d\boldsymbol{V}}{dt} = \frac{e}{m_i}(\boldsymbol{E} + \boldsymbol{V}\times\boldsymbol{B}) + \boldsymbol{F_c}$$

$\boldsymbol{F_c}$: centrifugal force

$$\frac{d\boldsymbol{r}}{dt} = \boldsymbol{V}$$

Collision model

- We treated collisions as binary collision, and used Symmetric model[5].
- In this calculation, Symmetric model is the same as TA model[6] since we used particles with the same weight.

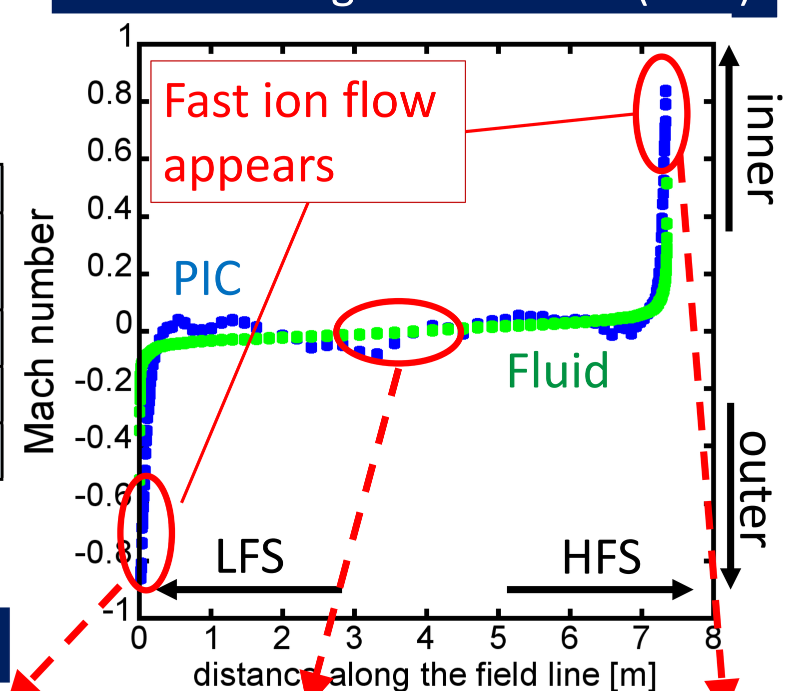
Change in parallel ion flow due to a particle model

Calculation parameter

dt [s]	1.0×10^{-8}
iteration	3000

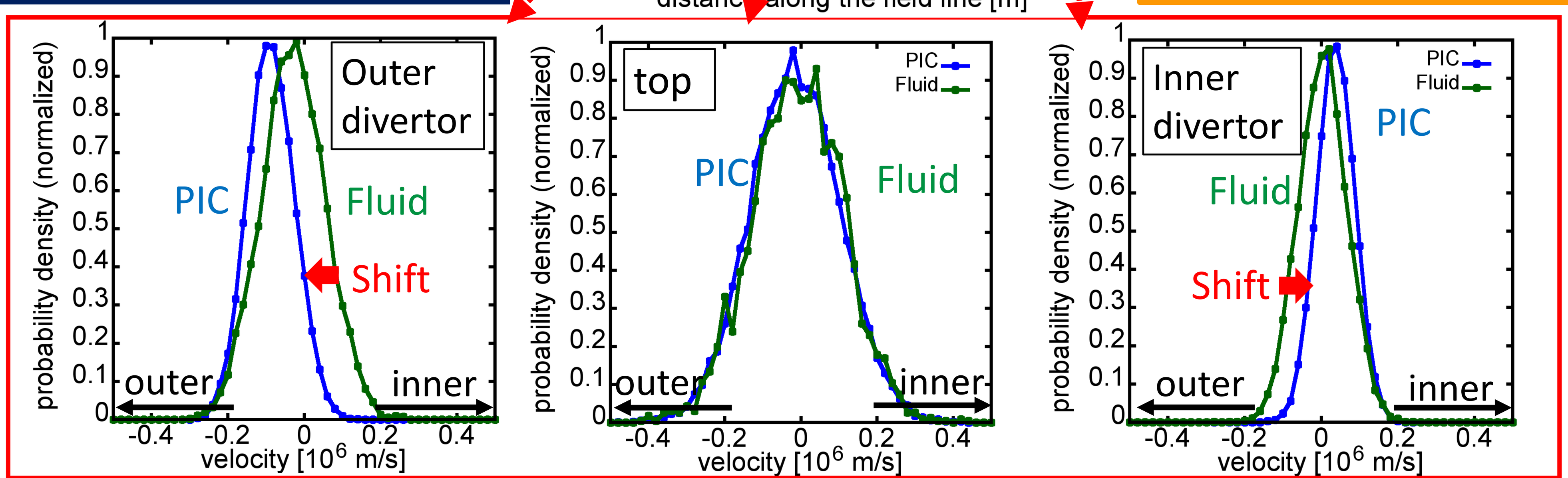
	electron	ion
the number of super particle	2670047	2670047
mass[kg]	9.11×10^{-31}	1.67×10^{-27}
weight	1.0×10^{12}	1.0×10^{12}
charge[C]	-1.6×10^{-19}	1.6×10^{-19}

Ion flow along the field line (i=15)



- Near inner and outer divertor, fast ion flow along the field line appeared due to a particle model.
- Velocity distributions also shifted in both divertor regions.
- In the middle SOL, difference did not appear.

Velocity distributions of ion's $v_\parallel$



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