# Study of neoclassical transport of LHD plasmas applying the DCOM/NNW neoclassical transport database

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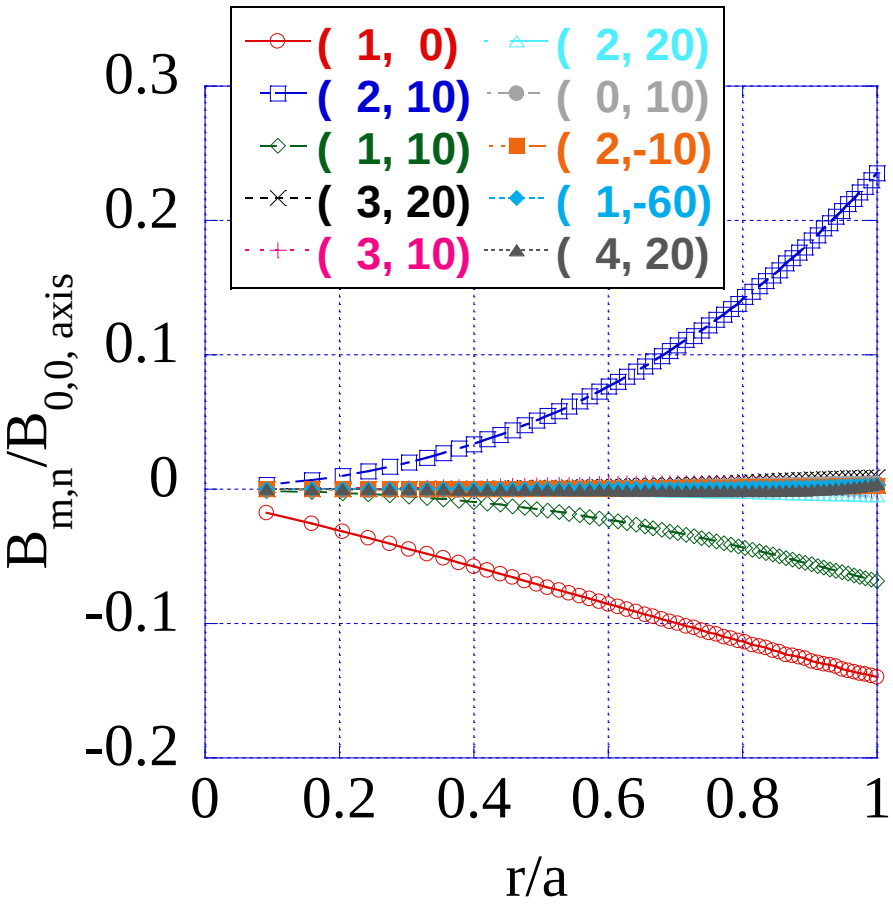
# The spectrums of the magnetic field $B_{m,n}$ in the Boozer coordinates

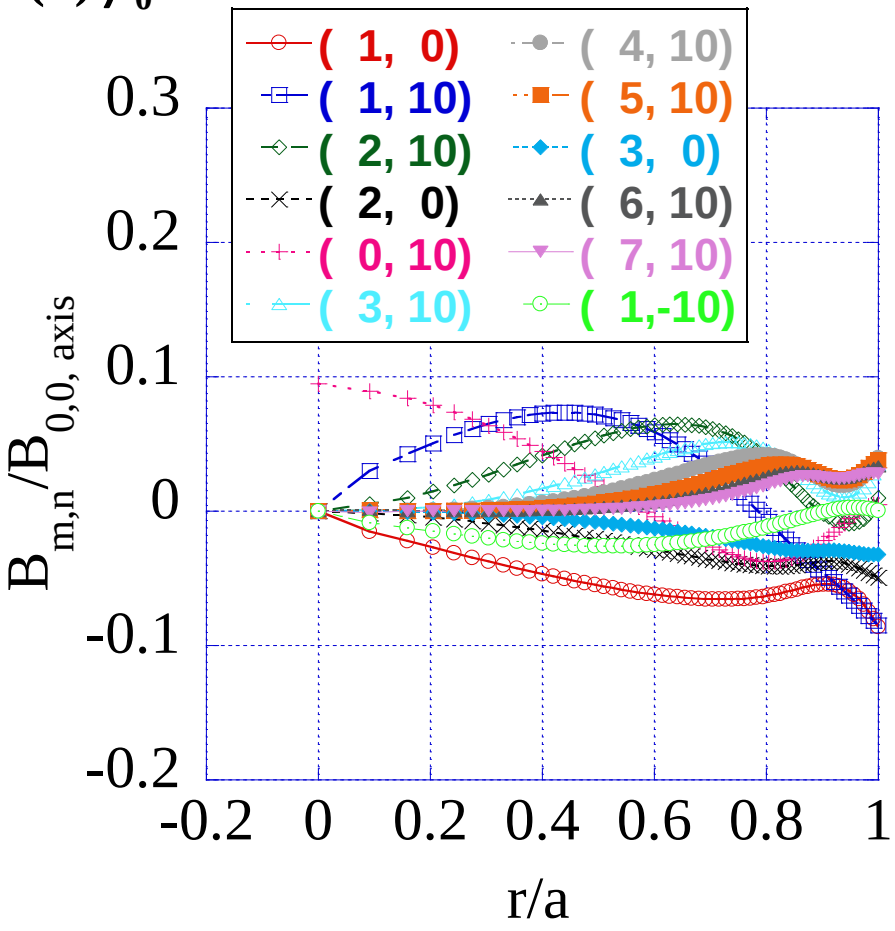


$R_{axis}$ = 3.75 m

(a) $\beta_0$ = 0%




(b) $\beta_0$ = 3%

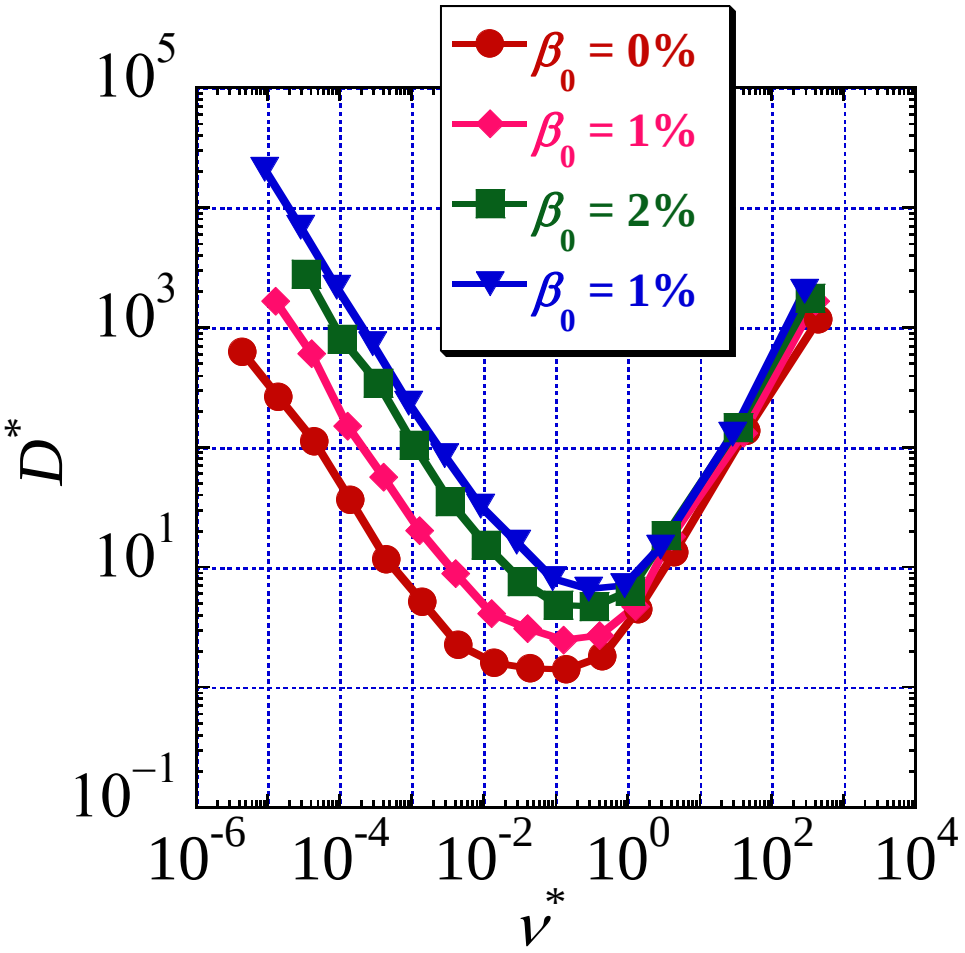


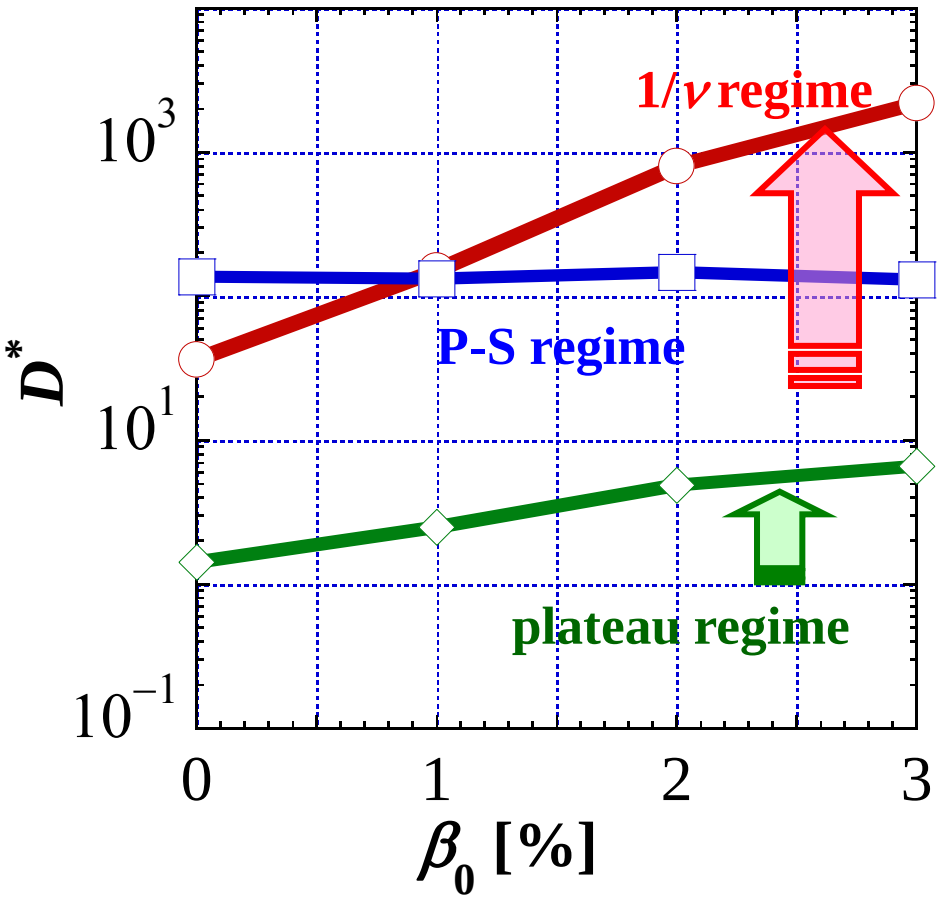

The magnetic field configuration becomes **complex** leading to
**rapid increase of the number of Fourier modes in Boozer coordinates.**

# Calculation result of DCOM at the finite beta plasma



$R_{axis}$ = 3.75 m




The diffusion coefficient increases with an increase of the effect of the beta value in **1/$\nu$** and **plateau** regime**.**

# Construction of the neoclassical transport database using Neural network (NNW) in LHD

## The necessity of interpolate of DCOM results

- Because the Monte Carlo method is used,
  a long calculation time is needed to obtain statistically sufficient results.
- It is necessary to interpolate the values of $D^*$ when we take the convolutions of the monoenergetic diffusion coefficient calculated using the DCOM since they are discrete data.

up to now…

・The direct linear interpolation

But…

・ The diffusion coefficient in LHD is a **nonlinear function** of
- the collision frequency $\nu^*$
- the radial electric field $G$
- the radial position $\rho$
- **the beta balue $\beta_0$**

.

・The interpolation using common analytical relations that differ in each regime

But…

・ We cannot obtain the accurate values in the connected region between each regime.

⇒ Recently, a technique called the **neural network**[7] **(NNW)** has been developed.

# “learning” of the NNW

An arbitrary I/O relation can be given to the neuron by adjusting the weight to an appropriate value.

**Training data**

DCOM results (example)

- $R_{axis}$ = 3.75m: ( $\nu^*$, $G$, $\rho$, $D^*$, $\beta_0$ ) **2688**set
- $R_{axis}$ = 3.60m : ( $\nu^*$, $G$, $\rho$, $D^*$, $\beta_0$ ) 1777set

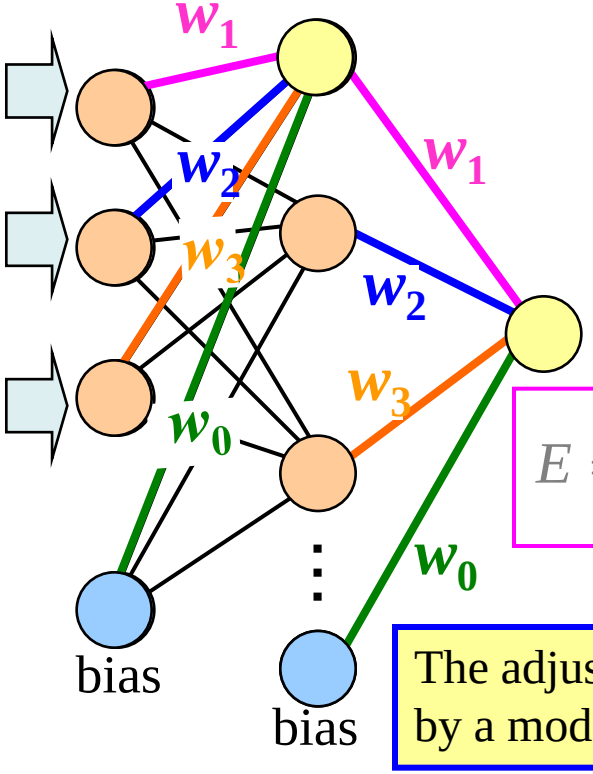
inputs

$\nu^*_1, G_1, \rho_1, \beta_{0,1}$

$\nu^*_2, G_2, \rho_2, \beta_{0,2}$

$\nu^*_N, G_N, \rho_N, \beta_{0,N}$

neural network




outputs

$D_{1,\,NNW}$

$D_{2,\,NNW}$

$D_{N,\,NNW}$

The values which should output.

$D^*_1$

$D^*_2$

$D^*_N$

$$E = \frac{1}{2}\sum_{l=1}^{N}\left(D_{l,NNW} - D_l^*\right)^2$$

To minimize sum of the square error, **the weight values are renewed.**

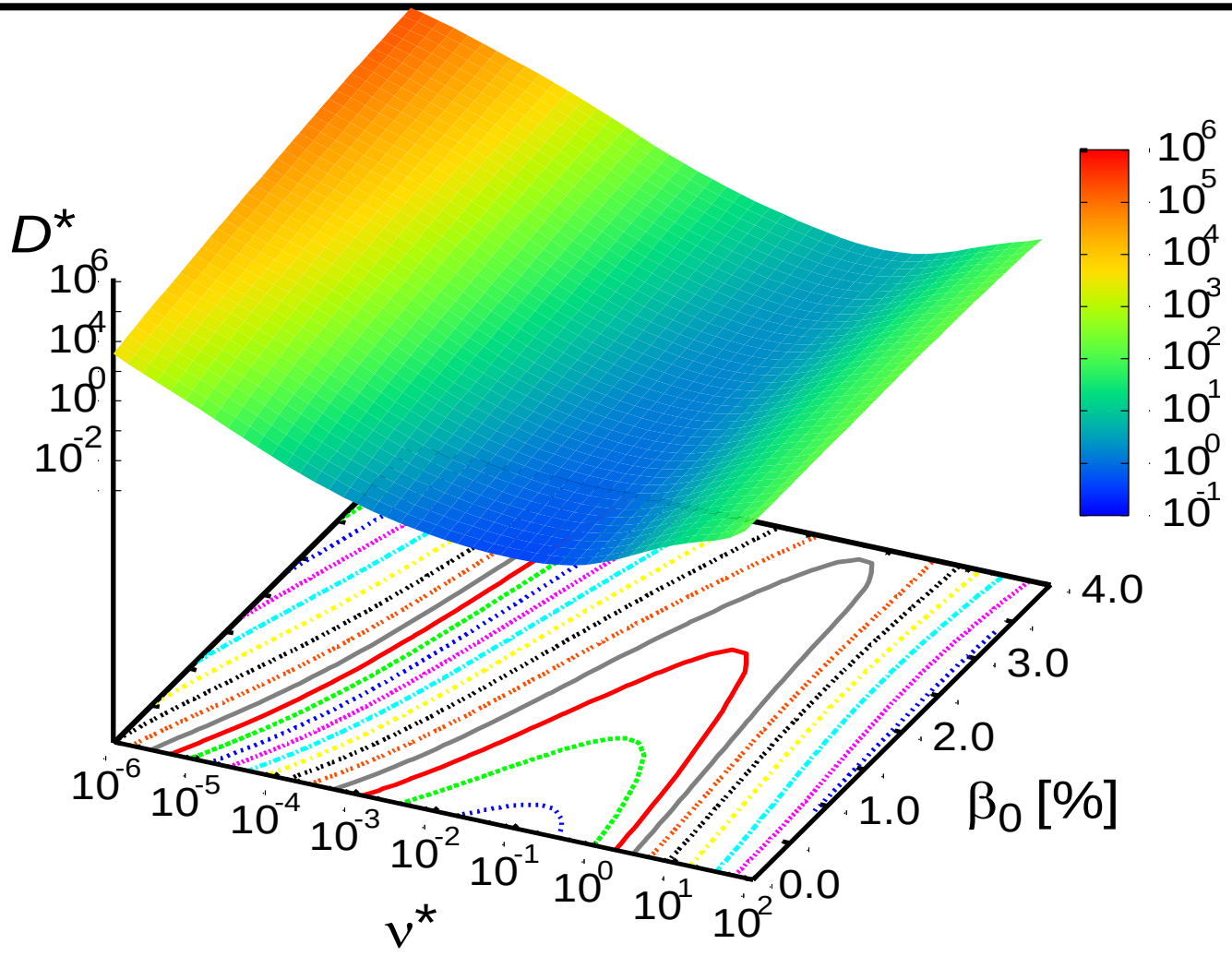
The adjustable parameters of the NNW model are determined by a modified **quasi-Newton method**, the **BFGS method**.

# example of the outputs of the DCOM/NNW

$R_{axis}$ = 3.75 m

$r/a$ = 0.5

$G$ = 0.00




We can obtain $D^*$ by using the NNW database for **arbitrary $\nu^*$, $G$, $r/a$ and newly, $\beta_0$.**

# The range of input parameters of the DCOM/NNW.



$\nu^*$, $G$, $r/a$ *and* $\beta_0$ can be treated as a **continuous** amount.

| *R*axis[m] | $\nu^*$(min) | $\nu^*$(max) | \|$G$(max)\| | $r/a$ | beta0[%] |
|---|---|---|---|---|---|
| 3.45 | $10^{-6}$～ | $10^{3}$ | 1.00E-01 | 0 ～ 1.0 | 0.0 |
| 3.50 | $10^{-6}$～ | $10^{3}$ | 1.00E-01 | 0 ～ 1.0 | 0.0 |
| 3.53 | $10^{-6}$～ | $10^{3}$ | 8.00E-02 | 0 ～ 1.0 | 0.0 |
| 3.60 | $10^{-6}$～ | $10^{3}$ | 1.00E-01 | 0 ～ 1.0 | 0.0～3.0 |
| 3.75 | $10^{-6}$～ | $10^{3}$ | 3.00E-01 | 0 ～ 1.0 | 0.0～3.0 |
| 3.90 | $10^{-6}$～ | $10^{3}$ | 3.12E-01 | 0 ～ 1.0 | 0.0 |

Rax = 3.60 m

**DCOM/NNW**

**neoclassical transport database**

$D^*( \nu^*, G, \rho, \beta_0 )$

Rax = 3.75 m

**DCOM/NNW**

**neoclassical transport database**

$D^*( \nu^*, G, \rho, \beta_0 )$

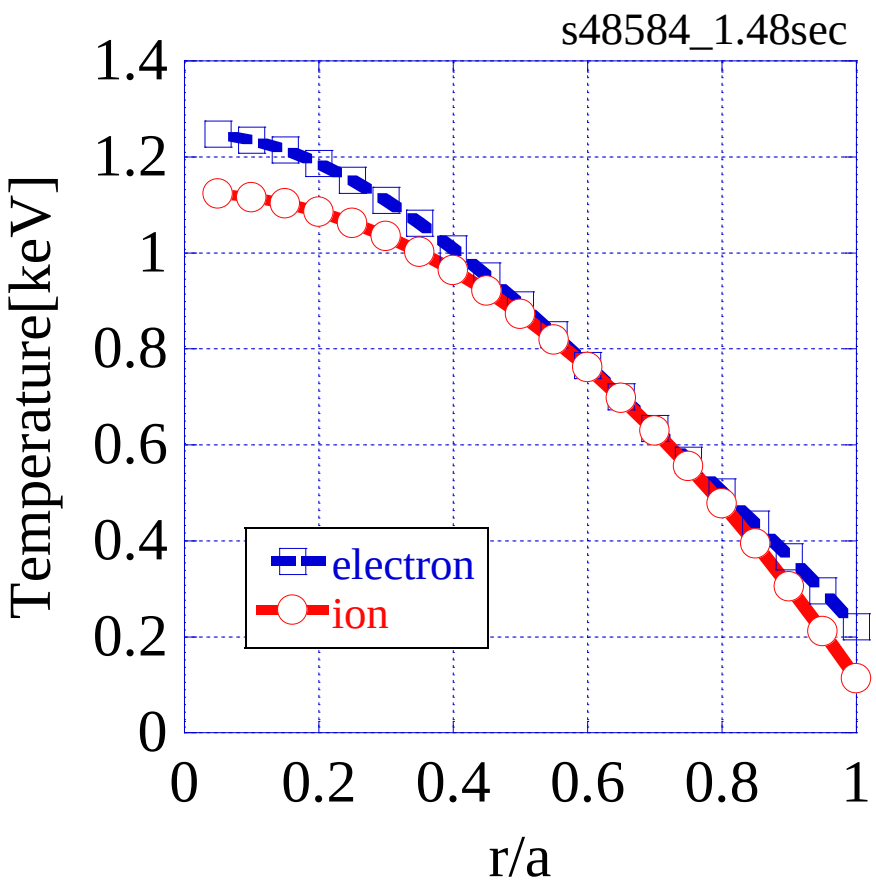
Because $R_{axis}$ is not component of NNW yet,
they have to be treated as discrete data.

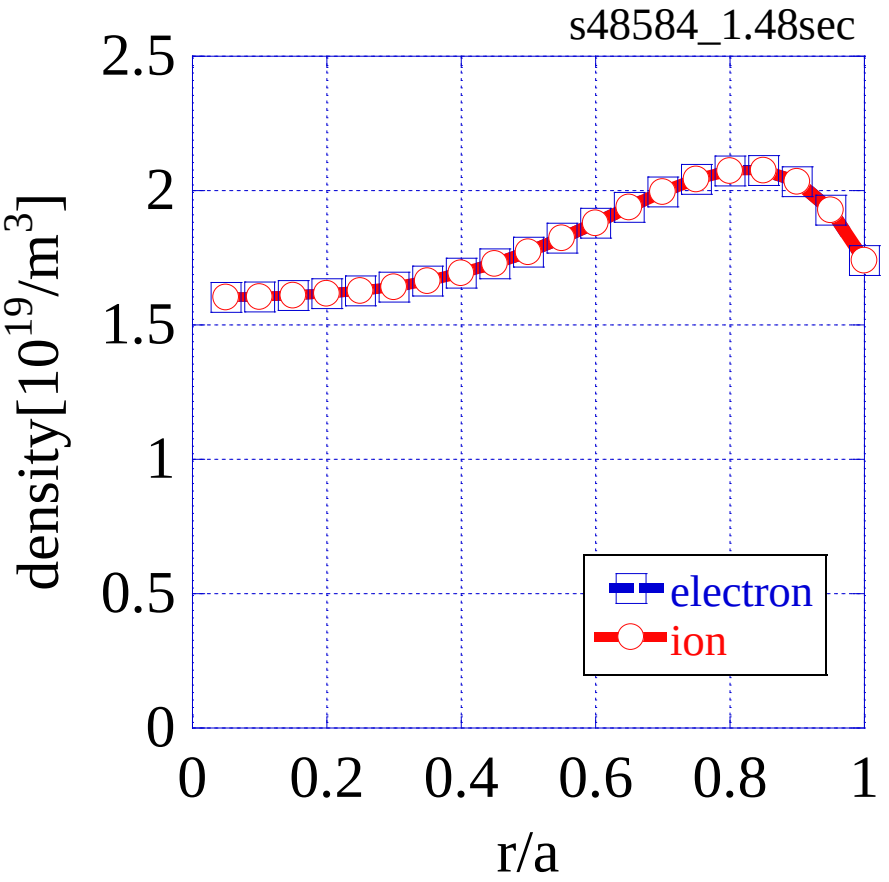
The $R_{ax}$ is scheduled to be contained in NNW database when we calculate enough about $R_{axis}$.

The neoclassical transport by DCOM/NNW including the finite beta effect.

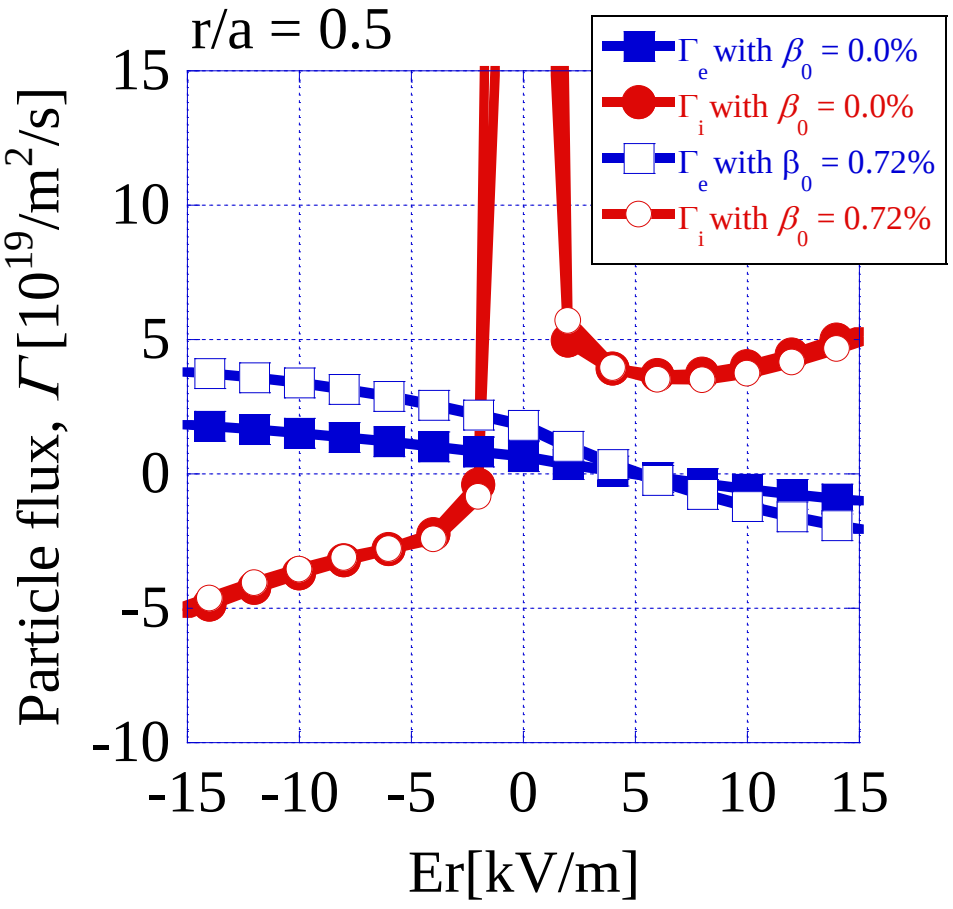
#48584 $R_{axis}$ = 3.75 m $B_{axis}$ = 1.5 T

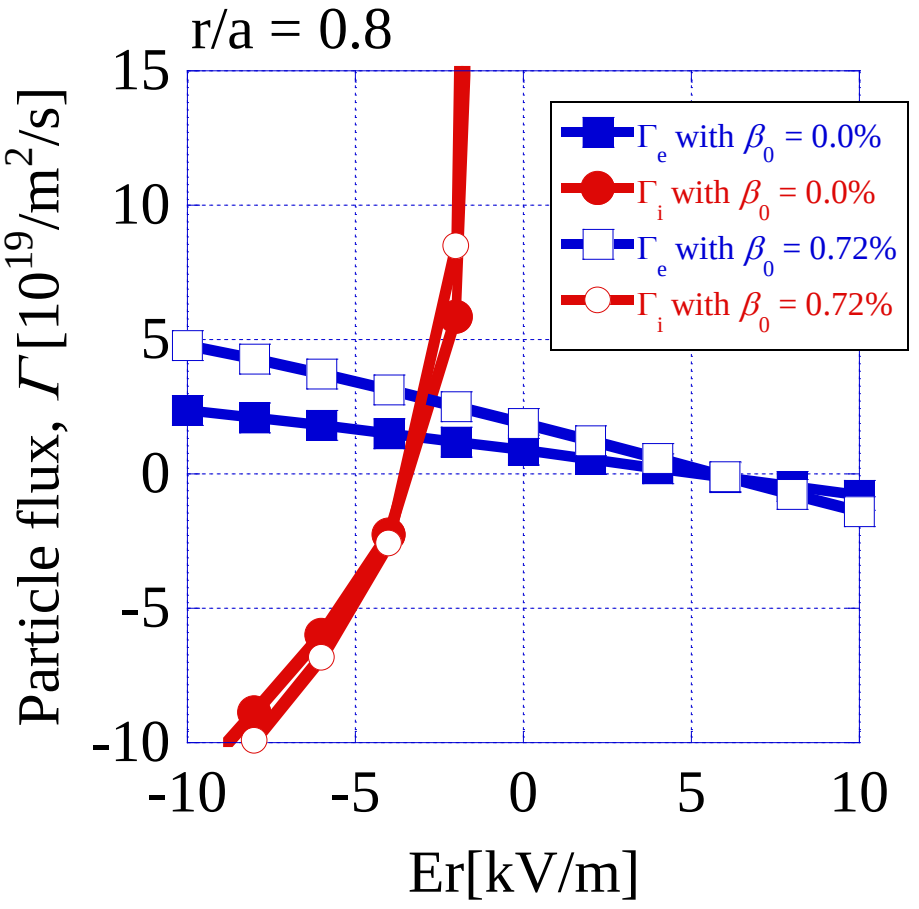
t = 1.48sec $\beta_0$ = 0.72%



# Analysis results by the DCOM/NNW.

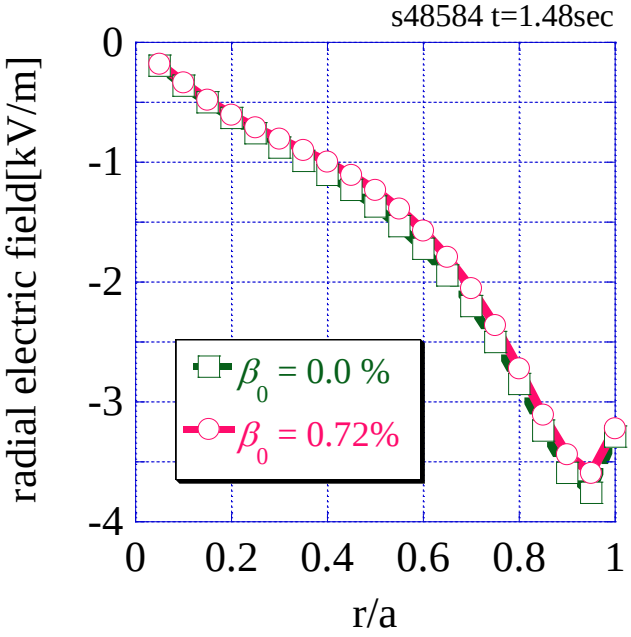


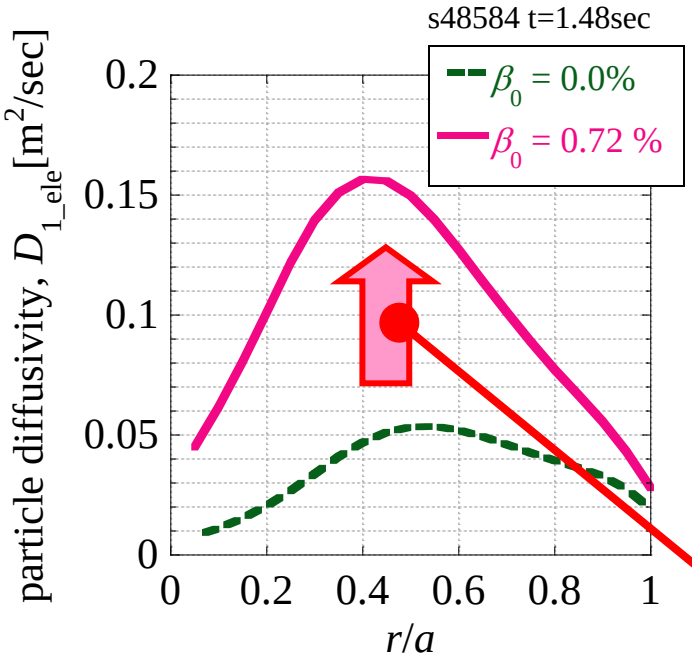



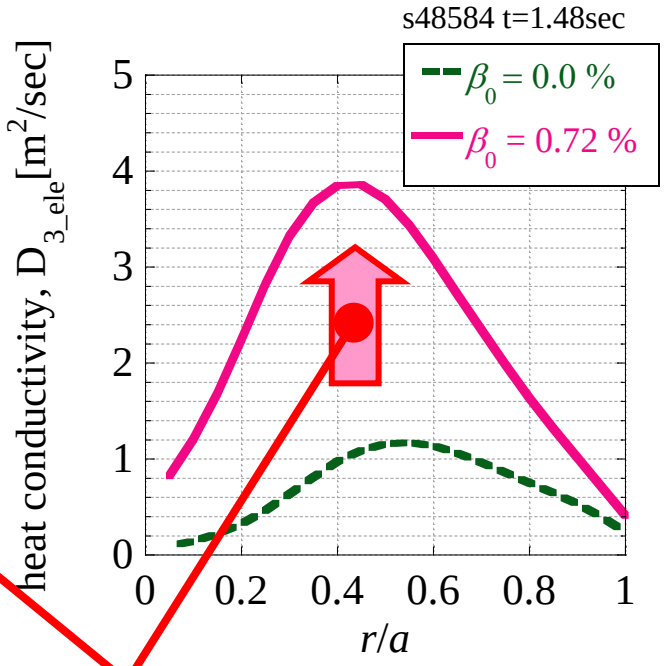

The particle flux of electron, $\Gamma_e$ increases with an increase of $\beta_0$.

# Analysis results by the DCOM/NNW.






increases to about three times

Similar profiles of the electric fields in both cases.
However…
The diffusion coefficient, $D_1$, with $\beta_0$=0.0% and with 0.72% are greatly different

This results show that the inclusion of finite beta effect is necessary for the accurate evaluation of neoclassical transport.

- The magnetic field structure is complicated by the effect of the finite beta.

  Using DCOM code, we can calculate the diffusion coefficient without convergence problem even if we assume a lot of Fourier modes of magnetic field.

- The $\beta_0$ is added to the neoclassical transport database, **DCOM/NNW.**

  Using extended DCOM/NNW we can estimate neoclassical transport more accurately than that using the previous DCOM/NNW.

- We have investigated the neoclassical transport and evaluate the ambipolar radial electric field in LHD using DCOM/NNW.