**Introduction**

- Many D-D fusion reaction experiments have been performed in tokamaks and helicals.
- D-D fusion reaction rate is used to evaluate energetic particle confinement.
- In many studies, they use homogeneous beam ions distribution to evaluate D-D fusion reaction rate and they dismiss local beam profile. Experimental results are different from simulation results.
- We consider D-D fusion reaction rate between energetic beam ions with local beam profile in tokamak.

**Local beam profile effect**

- We put energetic particles (deuteriums) from NBI into the tokamak perpendicularly for the magnetic field, particles exchange their charges with bulk plasmas (deuteriums) and they are locally trapped inside banana orbit by magnetic mirror effect.
- They distributed in a weak magnetic field side on the torus. Because of this, inhomogeneous distribution of D-D reaction rate between beam ions occurs.

**Fusion reactivity**

- Using Deutrium beam ion velocity distribution from GNET, we evaluate D-D fusion reactivity and neutron generating distribution from (n, ³He) reaction.

\[
S_{\text{th-th}} = \frac{1}{2} n_D^2 \langle \sigma \nu \rangle_{\text{DD,th-th}} \\
S_{\text{b-th}} = n_b n_D \langle \sigma \nu \rangle_{\text{DD,b-th}} \\
S_{\text{b-b}} = \begin{cases} 
  n_b n_j \langle \sigma \nu \rangle_{\text{DD,b-b}} & (I \neq j) \\
  \frac{1}{2} n_b^2 \langle \sigma \nu \rangle_{\text{DD,b-b}} & (I = j)
\end{cases}
\]

\[
\langle \sigma \nu \rangle_{\text{DD,1-2}} = \int \int f_b(v_1) f_b(v_2) \sigma(E) |v_1 - v_2| \, dv_1 dv_2
\]

\[
f_D(v_D) = n_D \left( \frac{M_D}{2\pi kT} \right)^{3/2} \exp \left( -\frac{M_D v_D^2}{2kT} \right)
\]

\[
f_h(v_h) = \frac{A_5 + (A_4 - A_2 E^2)^2 + 1}{E \exp(A_1 E^{-1/2}) - 1}
\]

**Results**

<table>
<thead>
<tr>
<th>b-b, b-th reactivity and sum of them with local beam profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam-beam reactivity [/s]</td>
</tr>
<tr>
<td>beam-thermal reactivity [/s]</td>
</tr>
<tr>
<td>Sum of beam-beam and beam-thermal reactivity [/s]</td>
</tr>
</tbody>
</table>

ratio of b-b in sum of b-b and b-th 36.7%

![D-Fusion reaction cross-section](image1.png)

![beam-beam reactivity with local beam profile](image2.png)

![beam-beam reactivity with local beam profile and w/o that in whole plasma](image3.png)
**Simulation Code**

**INPUT**

**HFREYA** --- Evaluate beam source

**GNET-TD** --- Evaluate slowing down of beam ions in time development plasma

**OUTPUT**

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**GNET**

- Solving 5 dimension drift kinetic equation shown below with Monte Carlo method, we evaluate velocity-space deposition of beam ions.

\[
\frac{\partial f_t}{\partial t} + (v_{\parallel} + v_t) \cdot \nabla f_t + \hat{\nu} \cdot \nabla v_t f_t = C(f_t) + L_{\text{particle}}(f_t) + S_{\text{beam}}
\]

- \( f_t \): velocity distribution function
- \( v_t \): drift velocity
- \( C \): collision term
- \( L_{\text{particle}} \): particle-loss term
- \( S_{\text{beam}} \): source term

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**HFREYA**

- Tracking neutral particles injected from NBI heating device, with Monte Carlo method, we evaluate process of ionization based on assumed ionization cross-section.

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**Plasma parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma temperature ( T_N, T_e )</td>
<td>3.0 keV</td>
</tr>
<tr>
<td>Plasma density ( n_N, n_e )</td>
<td>( 3.0 \times 10^{19} \text{ m}^{-3} )</td>
</tr>
<tr>
<td>Magnetic field strength</td>
<td>3 T</td>
</tr>
<tr>
<td>Magnetic axis position</td>
<td>4.07 m</td>
</tr>
</tbody>
</table>

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**Results**

- The velocity space distribution of beam-ion depends on poloidal angle especially in the banana orbit.

**SUMMARY**

- We have studied the D-D fusion reaction rate using GNET, HFREYA code.
- The local beam distribution has been evaluated and the beam-beam fusion reaction rates estimated using the local distribution function.
- We have obtained the significant effect of the local distribution function.
- The plasma density and temperature dependencies have been evaluated.

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- beam-beam reactivity is 36.7% of the whole reactivity, and with local beam profile effect beam-beam reactivity increase upto 2.6 times of beam-beam reactivity without local beam profile.
- beam-beam reactivity for plasma temperature is not monotonic increase

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- beam-beam reactivity dependence on plasma density
- beam-beam reactivity dependence on plasma temperature