Neutral Beam-Ion Prompt Loss Induced by Alfvén Eigenmodes in DIII-D

by
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Overview

- First experimental observation of prompt beam-ion loss driven by Alfvén eigenmodes

- Those losses give insight in the interaction between the AEs and fast ions during a single poloidal transit
  - New diagnostic application

- The process causes enhanced, concentrated losses at the first wall
  - Investigate for ITER
AE-Induced Prompt Losses are Observed by Fast Ion Loss Detectors (FILDs) in DIII-D

- The FILD obtains the energy and pitch resolved fast-ion losses with a bandwidth of 500 kHz

\[ r_L = \sqrt{2mE/Bq} \]

\[ \alpha = \cos^{-1}(v_\parallel/v) \]

- The lost ions are of full-energy beam-ions and occur at similar pitch as the prompt losses (losses of ions born naturally on open orbits)
Losses Coincide with Different Beams Displaced Toroidally as $q$ Evolves

- **NBI**
- **30L**
- **330L**
- **CO2 Interf.**
- **FILD**
- **FILD PMT**

<table>
<thead>
<tr>
<th>$q_{\text{min}}$</th>
<th>$I_p$</th>
<th>Time (ms)</th>
<th>$f$ (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6</td>
<td>300</td>
<td>8</td>
</tr>
<tr>
<td>300°</td>
<td>30°</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td>165°</td>
<td></td>
<td>500</td>
<td>150</td>
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<tr>
<td></td>
<td></td>
<td>600</td>
<td>200</td>
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</tbody>
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- **$R$ (cm)**
- $I_p$
Losses Coincide with Different Beams Displaced Toroidally as $q$ Evolves
Losses Coincide with Different Beams Displaced Toroidally as $q$ Evolves

- NBI
- 30L
- 330L
- $q_{\text{min}}$
- $I_p$
- CO2 Interf.
- FILD
- FILD PMT
- 535 ms
- 330°
- 30°
- 165°
Raise and Decay Time of Loss Signal are Within ONE Poloidal Transit Time

\[
\text{Time (ms)} \quad R \text{ (cm)}
\]

\[
\begin{array}{c|cc}
\hline
f (kHz) & \text{f (kHz)} & R (cm) \\
\hline
0 & 30L & 330L \\
1 & \text{NBI} & \text{FILD} \\
2 & q_{\text{min}} & \text{FILD PMT} \\
6 & I_p & \text{CO2 Interf.} \\
\hline
\end{array}
\]
Full-orbit Simulations Reveal Losses are Trapped Ions Scattered by AEs onto Loss Orbits on Their First Poloidal Bounce

- Majority (> 98%) of lost beam-ions are expelled out from the plasma before completing their first drift-orbit

SPIRAL* code simulation

- Coherent loss process
  - A neutral ionizes on an unperturbed banana orbit that would carry it close to the FILD
  - This ion interacts with an AE in the plasma core
  - For the illustrated AE phase, the ion is “kicked” radially outward and is detected
  - For a different phase, the kick is smaller or radially inward and the ion misses the FILD

Loss Amplitude Scales Linearly with Mode Amplitude

- The slope of the linear relationship depends on the AE mode structure
- Reproduced by SPIRAL code simulations
We know the ionization rate and the coherent loss amplitude → Infer the radial kick experimentally
Concern for ITER: the Concentrated Escaping Fast Ions Can Damage Plasma Facing Components

- The process found on DIII-D causes enhanced, concentrated losses at the first wall
  - From confined co-injected beam ions
  - Resonant condition is not required
  - Nearly doubled the losses at the FILD location
  - The estimated loss spot size on the wall from SPIRAL is about 0.5m$^2$

Implication for ITER
- AEs predicted in ITER
- Off-axis co-injection in ITER
- Hot spots/localized heat loads on ITER wall from this new prompt loss mechanism should be investigated
Summary

• Observed coherent losses are AE-induced prompt beam-ion losses, reproduced by SPIRAL full orbit simulations

• The data provides a direct measure of the radial “kick” imparted by each mode (AEs and other instabilities)

• Resonant interactions with modes are not required for these first-orbit losses. It can enhance the concentrated fast-ion losses on the ITER wall

• This will provide a test bed for the modeling of AE mode structures and induced fast-ion transport/loss