Demonstration of Alpha Channeling in DIII–D

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Motivation

• The H-factor is very important for ignition in ITER (Snowmass Conference, 2002)
• Can we form an ITB in ITER?
• Ingredients for ITB:
  NCS configuration - needs external CD
  $E_r$ shear - needs external momentum input
• Can we use the □’s?
  □ channeling
Alpha Channeling (N. Fisch)
to divert the \[ \Box \] power for current drive and/or ion heating

- LHW(\(k_\perp \& k_{\parallel}\)) : PRL(1992)

\[ RF \rightarrow [\Box (< 3.5 \text{ MeV})] \rightarrow \text{fast ions} \rightarrow \text{bulk ions} \]
\[ \text{bulk electrons} \rightarrow \text{anomalous loss} \]
Use □’s to form ITB

- The past emphasis was on ion heating - can enhance reactivity by factor 2.
- Here we explore the possibility of ITB formation: redistribution of fast □’s to modify the magnetic shear and the velocity shear. 40% enhancement in □ can double the reactivity.
NCS formation by ejection of co-moving ions’s

- Co-moving ions drive co-current.
- Ejection of co-moving ions reduces non-inductive current in the core.
- More non-inductive current at the edge.
- Reduced magnetic shear in the core.
Simulation of DIII-D's with co-beam injection in DIII-D

- Shot 92755 (C.C. Petty)
  1 co-source, B=1.8 tesla, $I_p=700$ kA, $n_e < 10^{13}$ cm$^{-3}$, AE’s at 60 kHz (n=1) and 85 kHz(n=2), q(r) flat in the core, ITB with q(0)>1.8

- Shot 94777 & 94771 (C. Greenfield)
  2 co-sources, B=1.9 tesla, $I_p=600$ kA, $n_e \sim 1.5 \times 10^{13}$ cm$^{-3}$, q(r) flat in the core with q(0)>1.6, steady state ITB - limited by 5s beam pulse
Spectrum of Mirnov coil signal
Ejection of fast ions by AE’s

- $q(r)$ at the core remains flat.
- Initial beam deposition peaks at plasma center.
- Fast ion density profile is broader than TRANSP modeling which does not include the AE effects.
Quasi-steady-state ITB

- ITB life time is limited by the 5s beam pulse.
- $T_e(0), N_n$ constant in time at $t > 3s$.
- $n_e(0)$ rises slowly due to beam fueling.
The role of AE’s on $q(r)$

- Compare #94777 (with AE) to #94771 (no AE).
- Profiles of $p_b$ & $J_{NI}$ behave as expected.
Can this work in a fusion reactor?

- In a fusion reactor, \( f_r(v) \) is isotropic.
- As long as \( p_r(r) \) peaks on axis, only AE’s propagating in the co-direction are unstable, and only co-moving \( \square \)’s can resonate with and ejected by the AE’s because (a) \( k_\parallel v_{di} \) & (b) \( k_\parallel / k_\perp < B_\parallel / B_\perp \). [Wong. PPCF 41(1999) R1, Fig.6].
- Need many overlapping AE’s.
- May need external antenna to select the AE spectrum.
ITER may not have enough co-going □’s for NCS

- Estimate CD efficiency from K. Okano, NF30(1990)423:
  \[ \frac{j}{p_d} = \frac{2eZ_b \square_{se}}{(m_p A_b V_c) \square_o F_{el} F_{ed} F_{cx} J(x_b, y, \square_o, \square)} \]
  \[ F_{el} = 1 - \frac{Z_b}{Z_{eff}} \left[ 1 - G(Z_{eff}, \square) \right] \] - electron screening factor
  Coeff’s evaluated from bounce-averaged Fokker Planck calculation; quite accurate for circular tokamaks.
  For D-beam, \( Z_b = 1 \),
  For □, \( Z_b = 2 \) - less efficient due to electron screening.

- Plug in the ITER parameters, need more co-going □’s for NCS configuration.
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Shear in $V_\phi$ and $E_r$

- Co-going $\square$’s ejected from core($r_1$) to edge($r_2$), leaving more counter-going $\square$’s in the core. This produces a torque $\square$ shown in Fig(a).

- Shear in $V_\phi$ produces shear in $E_r$.

$$E_r = V_\phi B_\phi - V_\phi B_\phi + \left(\frac{1}{n_i e Z_i}\right) \frac{dP_i}{dr}$$
Work in Progress

• Using ITER parameters, we try to evaluate the maximum $E_r$ shear and see if an ITB can be formed by manipulating the $\square$’s.

• Preliminary result shows that using all the co-going $\square$’s with $r=30\text{cm}$, the shearing rate becomes comparable to $0.01 \square^*_i$
  - this result still needs independent verification
Summary

- It has been shown that spontaneous redistribution of energetic ions by the excited AE’s can reduce the central magnetic shear and produce velocity shear - two ingredients needed for ITB.
- Quasi-steady-state ITB can be sustained in DIII-D.
- This mechanism offers the possibility of having an ITB as a natural steady state of a burning plasma.
- There may not be enough energetic a’s in the present ITER design to from an ITB, but it may be possible in a different design.
- Partial effects are possible for ITER.