EX/8

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A Comprehensive Study of Energetic Particle Transport due to Energetic Particle Driven MHD Instabilities in LHD Deuterium Plasmas

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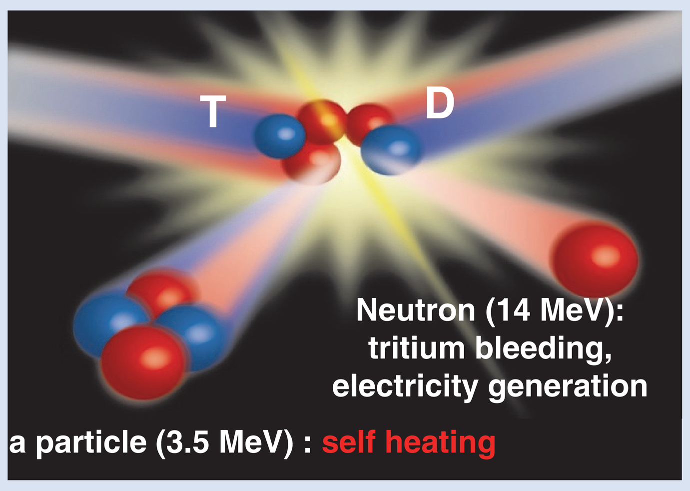
Abstract

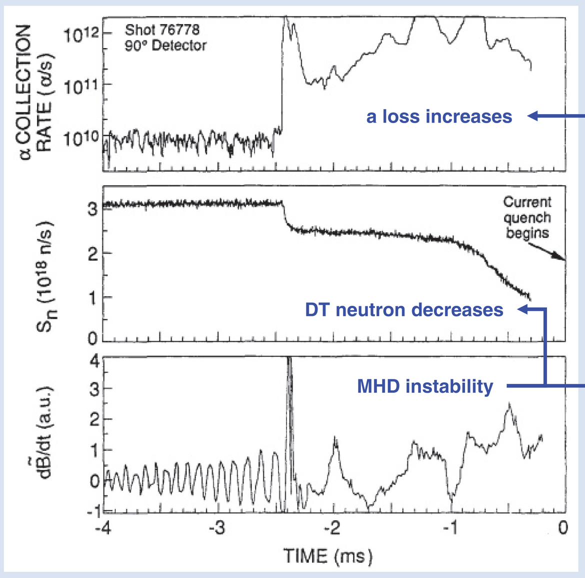
Beam ion and DD fusion born triton transport due to energetic-particle-driven MHD instabilities is simultaneously studied in LHD to understand a particle confinement in a fusion burning plasma.

Neutron flux monitor is utilized for beam ion confinement study. Scintillating fiber is developed for measuring time-resolved triton confinement.

Time-resolved measurement of DD and DT neutron emission rate was performed in energetic-ion-driven resistive interchange mode (EIC) discharge.

Background

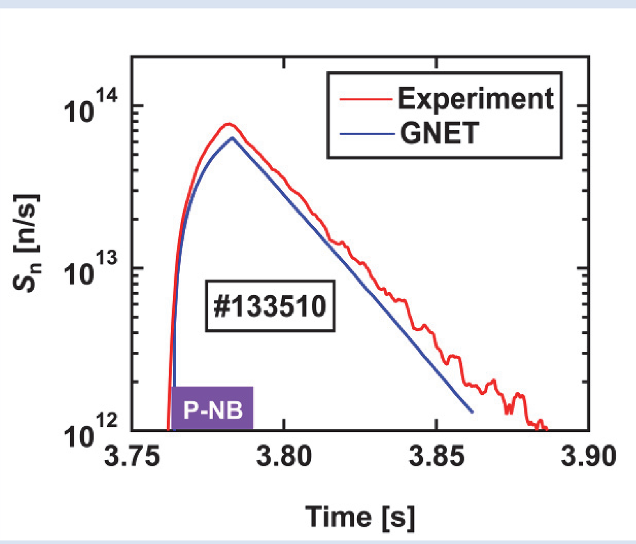


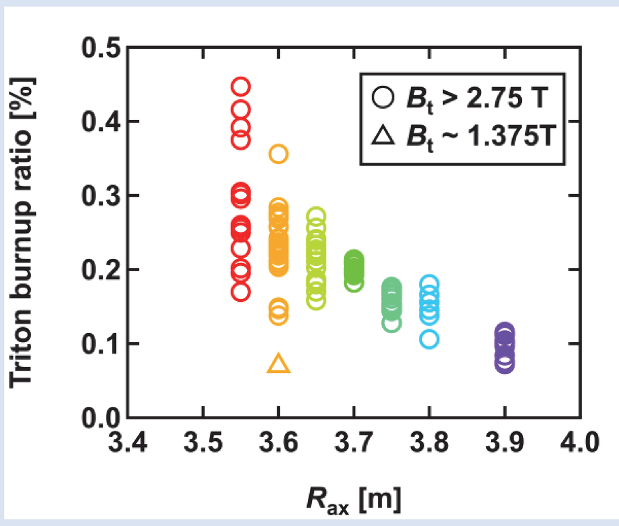


S. J. Zweben et al., Nucl. Fusion (1995).

- DT born a particle confinement is one of the issues for realizing a fusion reactor.
- Energetic a particle transport due to MHD instabilities has been studied.

Energetic confinement study in D experiments in LHD

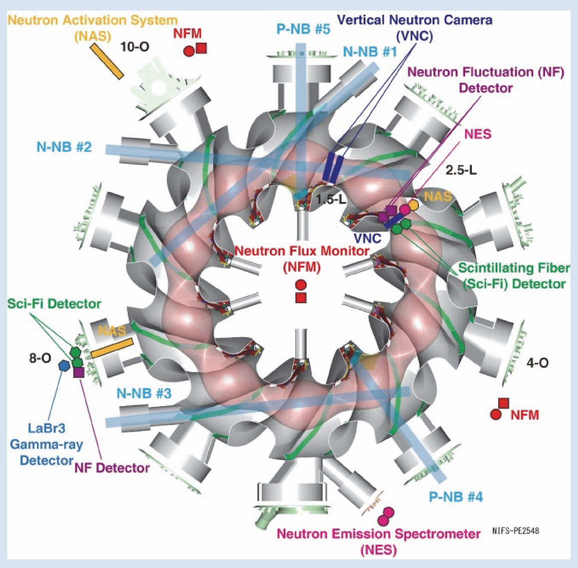




- Energetic particle behavior has been studied in LHD to understand a confinement in a fusion reactor.
- Confinement of short pulsed beam ion in MHD quiescent plasmas can be described as neoclassical theory.
- DD fusion born 1 MeV triton confinement capability is comparable with tokamaks having similar minor radius.

K. Ogawa et al., IAEA FEC 2018., K. Ogawa *et al*., Nucl. Fusion (2019). Selected as Research Highlights in Nature Physics (2019).

Comprehensive neutron diagnostics in LHD



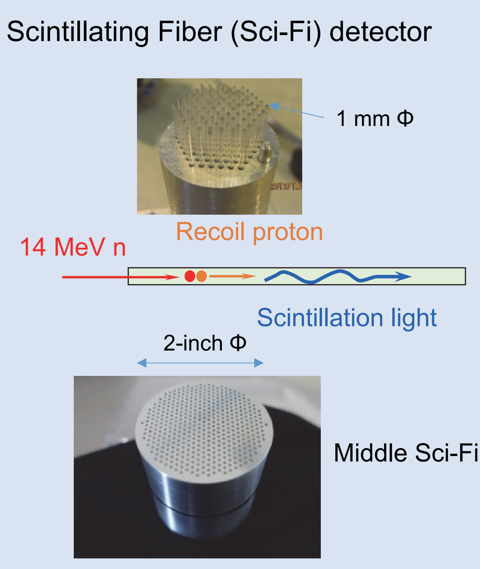
Fusion reactions in deuterium plasmas

Primary reaction

- D+D -> ^{3}He (0.8 MeV) + n (2.5 MeV)
- D+D -> T (1 MeV) + p (3 MeV)

Secondary reaction

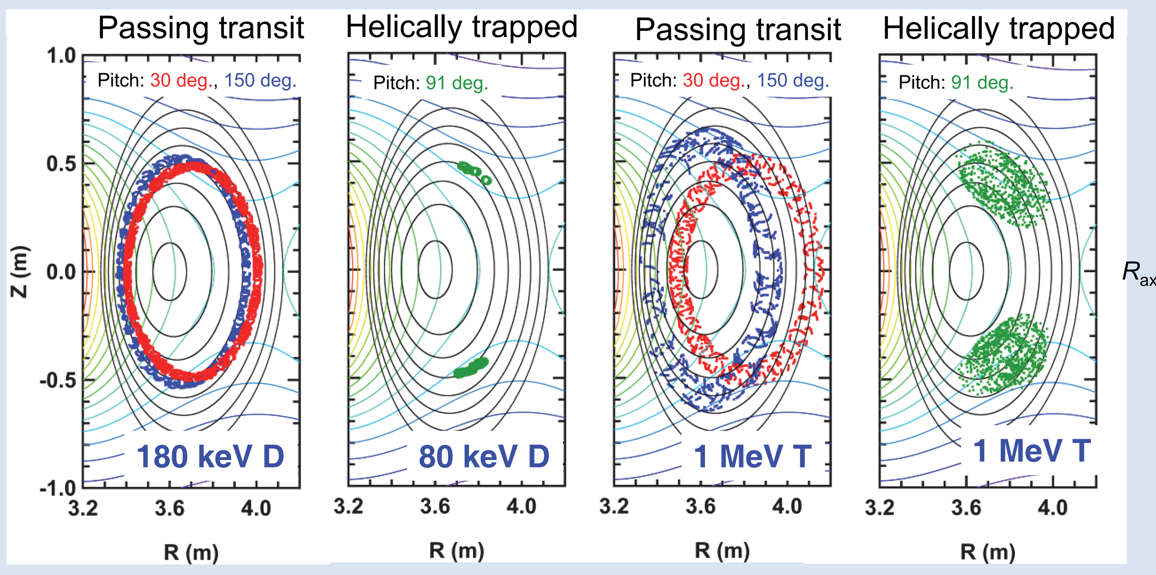
T+D -> ^{4}He (3.5 MeV) + n (14 MeV)



- 1 MeV tritons can be regarded as DT born a particles.
- Relatively high-temporal resolution measurement of DT neutron became possible using relatively high-detection-efficiency detector.

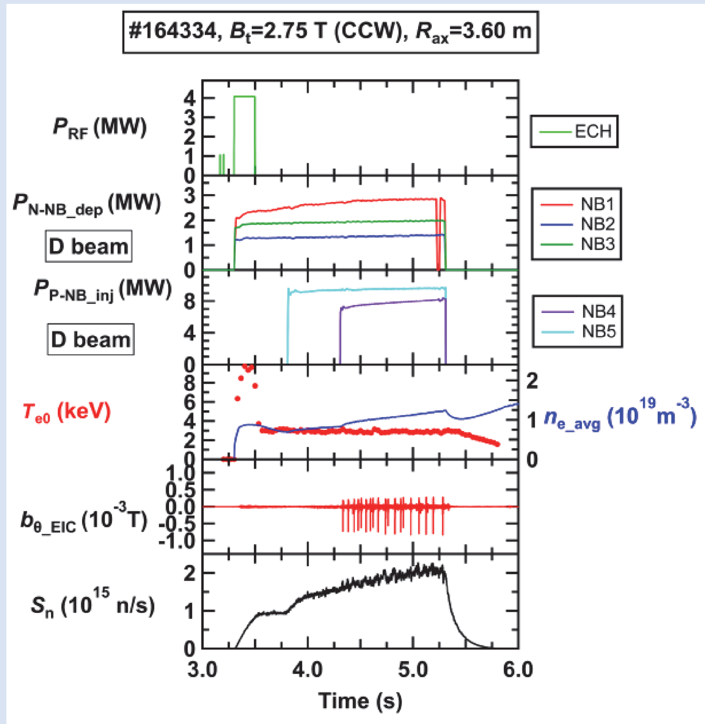
M. Isobe *et al*., Nucl. Fusion (2018)., K. Ogawa *et al*., Plasma Fusion Res. (2021)., K. Ogawa *et al*., Nucl. Fusion 2018., M. Isobe *et al*., IEEE Trans Plasma Sci. 2018.,E. Takada *et al*., Rev. Sci. Instrum. 2019. etc.

Poincaré plot of beam ion and triton orbits



- Passing-transit and helically-trapped ions exist in LHD.
- Helically-trapped ion has a poloidal structure.
- 1 MeV triton has large Larmor radius and large orbit deviation from the flux surface.

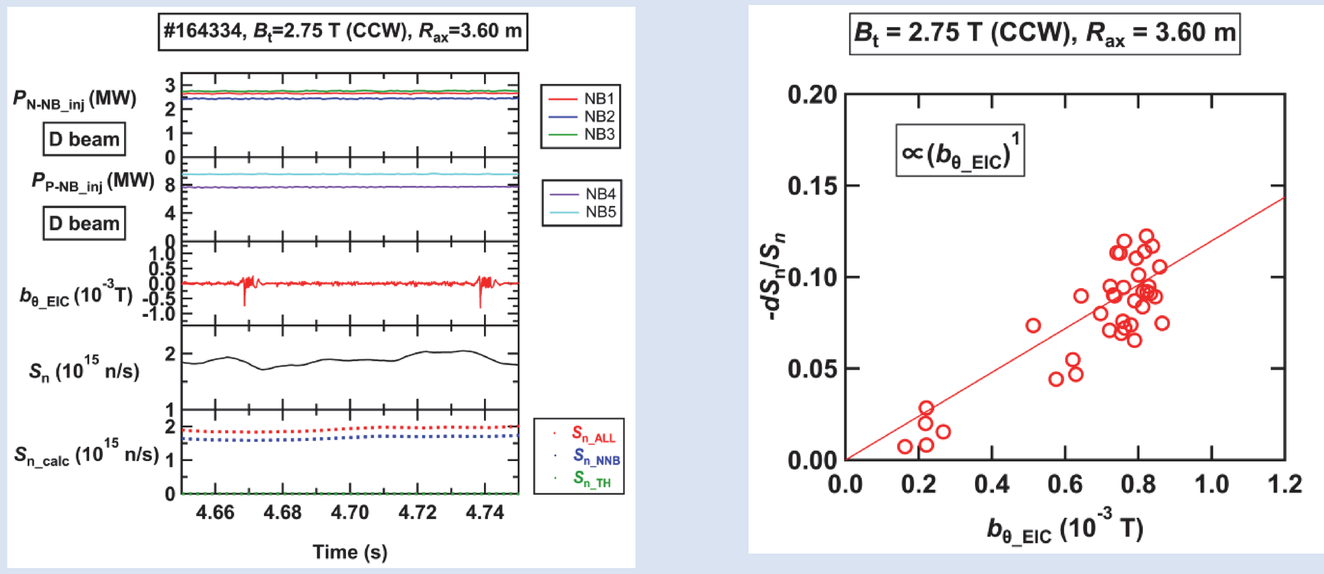
EIC excited in a deuterium plasma discharge



- EIC is excited in relatively low-density plasma with intense P-NB injections.
- Helically-trapped ions created by P-NB excite EIC.
- Termination of the high-T_i state in LHD
- Deuterium N-NBs and deuterium P-NBs were injected into a deuterium plasma.
- T_{e0}~3 keV and n_{e_avg}~10^{19} m^{-3}
- EIC having ~10^{-3} T was observed with a magnetic probe located on the vacuum vessel.
- S_n reflects global confinement of N-NB and P-NB ions.

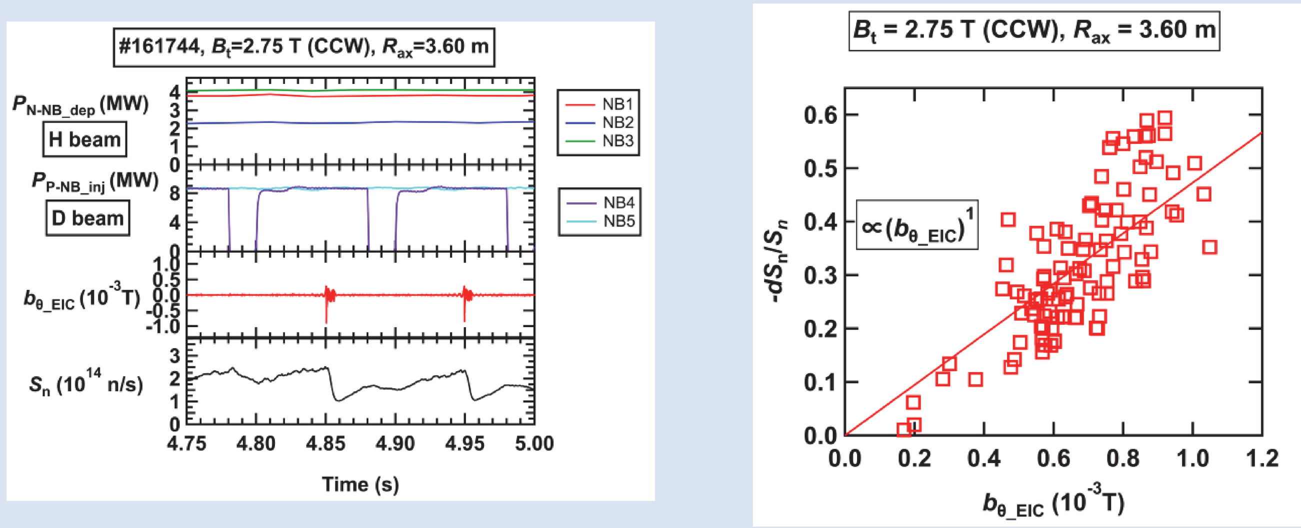
EIC: X. D. Du *et al*., Nucl. Fusion (2016).

Beam ion transport due to EIC



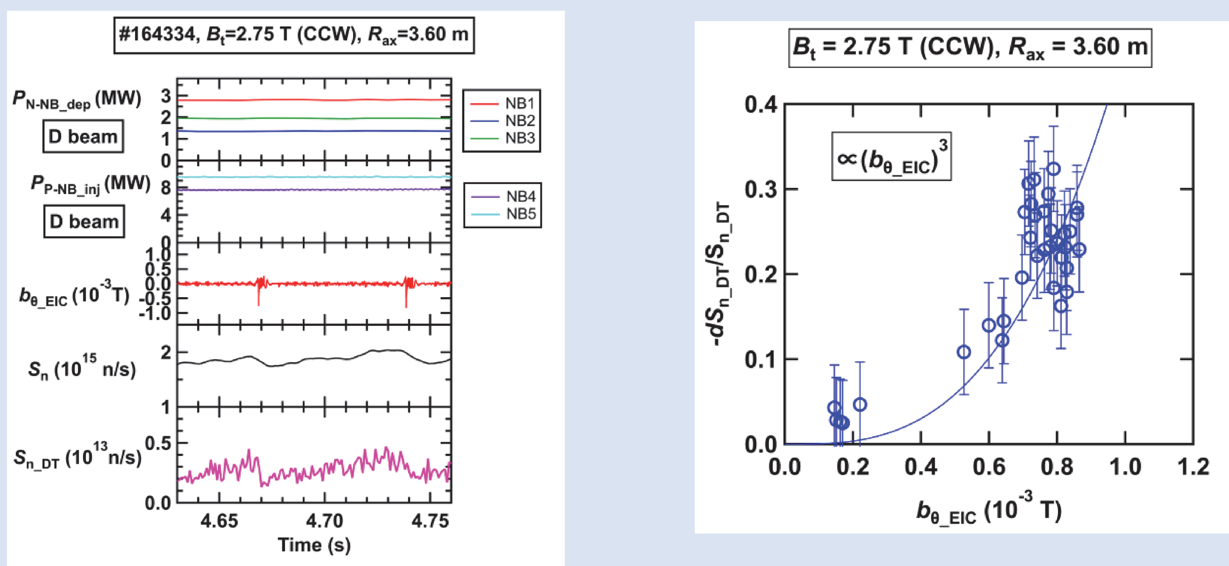
- Drop of S_n due to EIC busts shows that EIC induces loss of beam ions.
  - 90% of S_n: plasma-N-NB ion reactions. 10% of S_n : plasma-P-NB ion reactions.
- Drop rate of S_n linearly increase with b_{q_EIC} and reaches ~13%.

EIC discharge with hydrogen and deuterium beams



- To determine the EIC effect on N-NB and P-NB ions separately, additional experiments were performed.
- Hydrogen N-NBs and deuterium P-NBs were injected into a deuterium plasma.
- Drop rate of S_n reaches ~60%. -> EIC induces up to 60% of P-NB ion loss.
- In full-D cases :-dS_n/S_n reached 13% with $S_{n\_N\text{-}NB}$ ~90% and $S_{n\_P\text{-}NB}$~10%.
  -> ~8% of N-NB ions are lost due to EIC.

DD fusion born triton transport due to EIC



- S_{n_DT} drops rapidly compared with S_n due to EIC.
  - 1 MeV tritons escape immediately compared with beam ions.
- Drop rate of S_{n_DT} increases substantially with b_{q_EIC} to the third power.
  - 1 MeV tritons barely confined in LHD are largely transported.

Conclusion

- Enhanced transport of beam ions and DD fusion born tritons due to EIC burst is observed using neutron diagnostics.
- Experiments in full D and H/D beam conditions shows that EIC induces up to 8% of passing transit beam ion losses and up to 60% of helically-trapped beam ion losses.
- Drop rate of S_{n_DT} increases with $b_{q\_EIC}^3$ and reaches up to 30% due to EIC. 1 MeV tritons barely confined in LHD are rapidly and significantly lost due to EIC.