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EX/8

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

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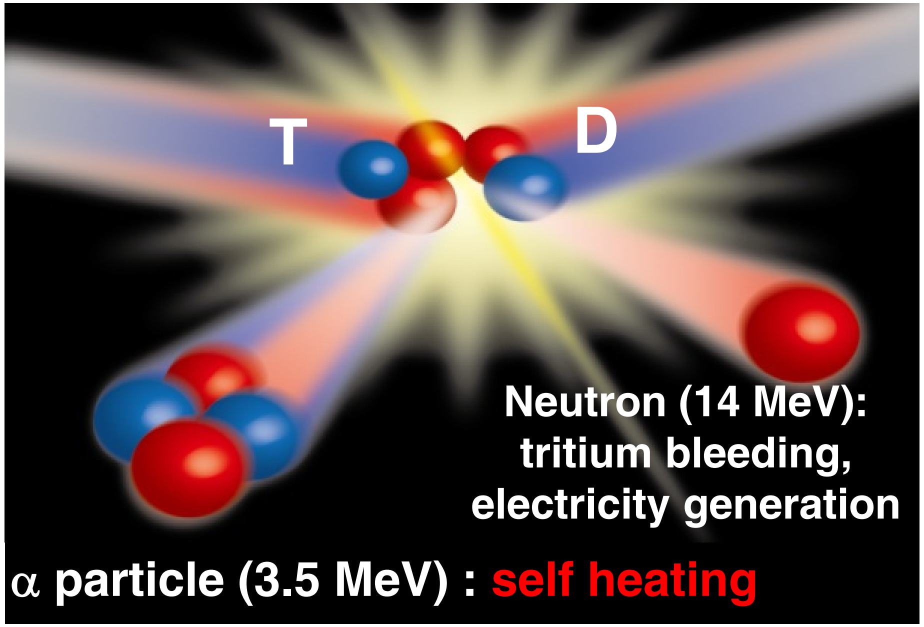
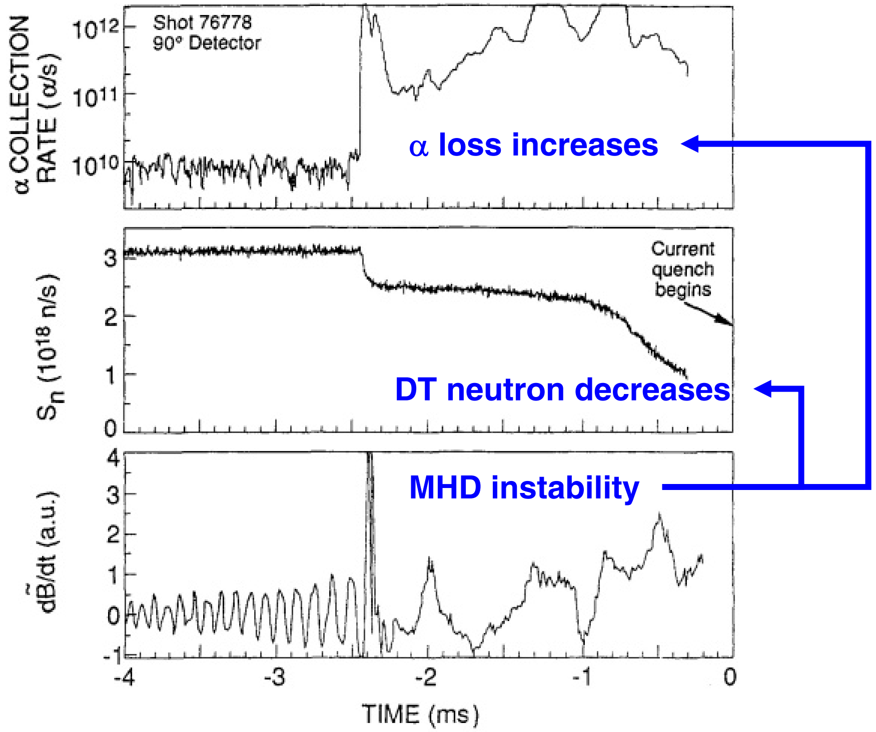
Background

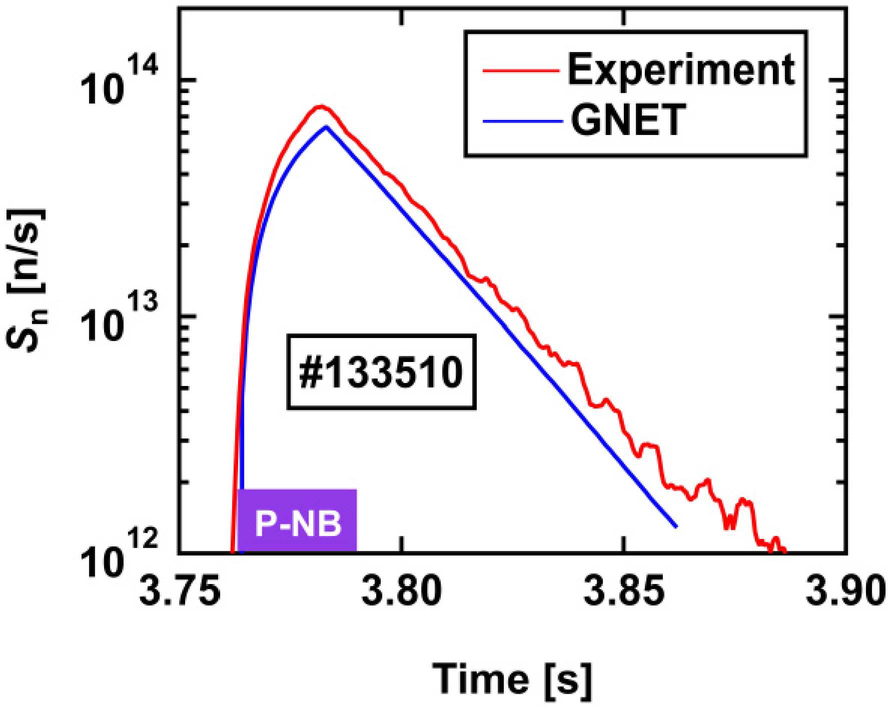


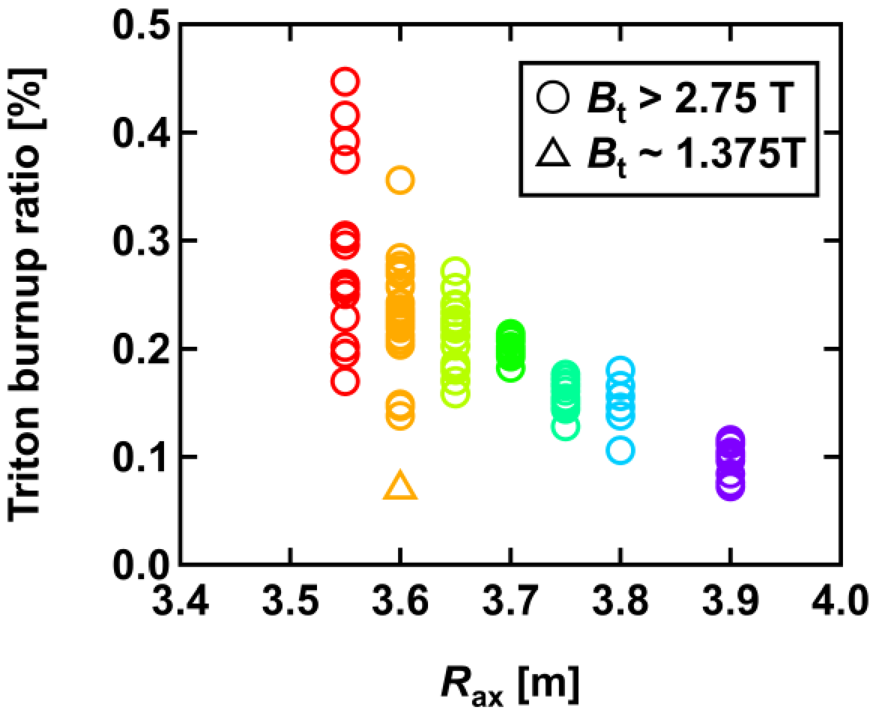


S. J. Zweben *et al.*, Nucl. Fusion (1995).

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

Energetic confinement study in deuterium experiments in the Large Helical Device (LHD)

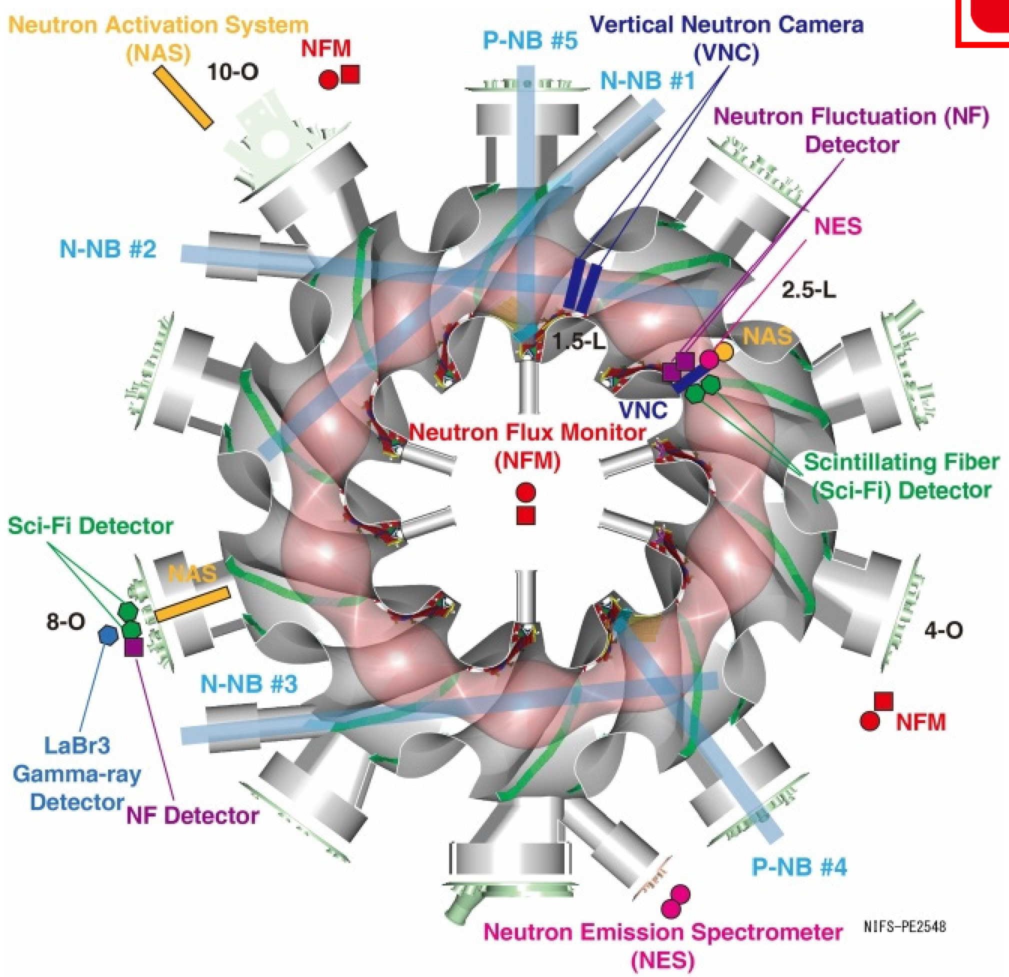


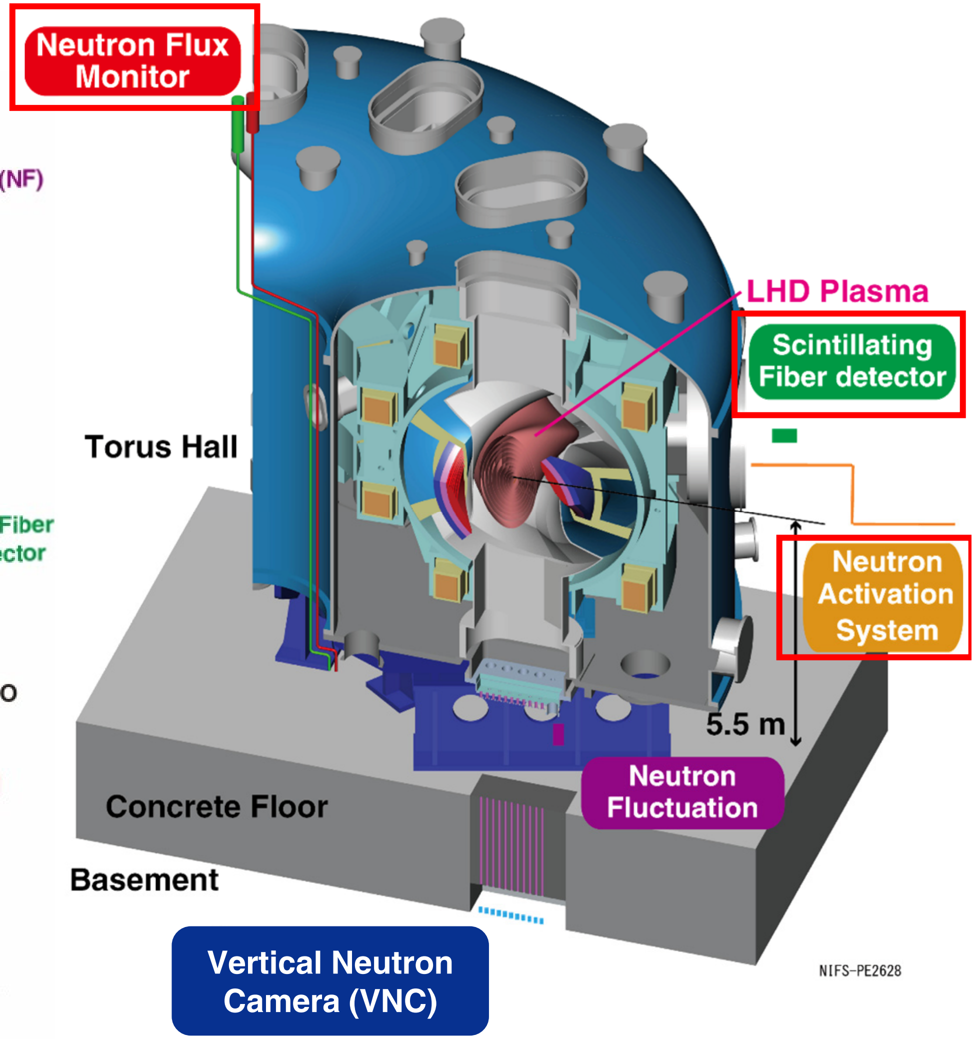


- To understand α confinement in a fusion reactor, energetic particle behavior has been studied in LHD.
- Confinement of short-pulsed beam ions in MHD quiescent plasmas can be described as a neoclassical theory.
- Confinement capability of fusion born 1 MeV tritons is comparable with tokamaks having a 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





- An energetic confinement study has been performed using intensive neutral beam injectors and comprehensive neutron diagnostics.

M. Isobe *et al*., Nucl. Fusion (2018)., K. Ogawa *et al*., Plasma Fusion Res. (2021).

Scintillating-Fiber (Sci-Fi) detector for triton burnup studies

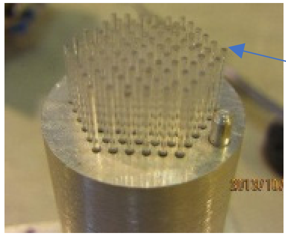
Fusion reactions in deuterium plasmas

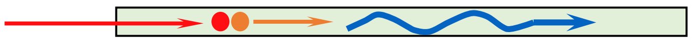
Primary reaction

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

Secondary reaction

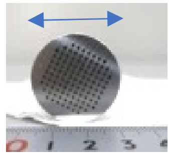
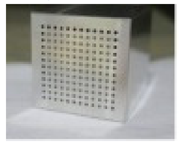
T+D -> ^{4}He (3.5 MeV) + n (14 MeV)





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

Number of Sci-Fis

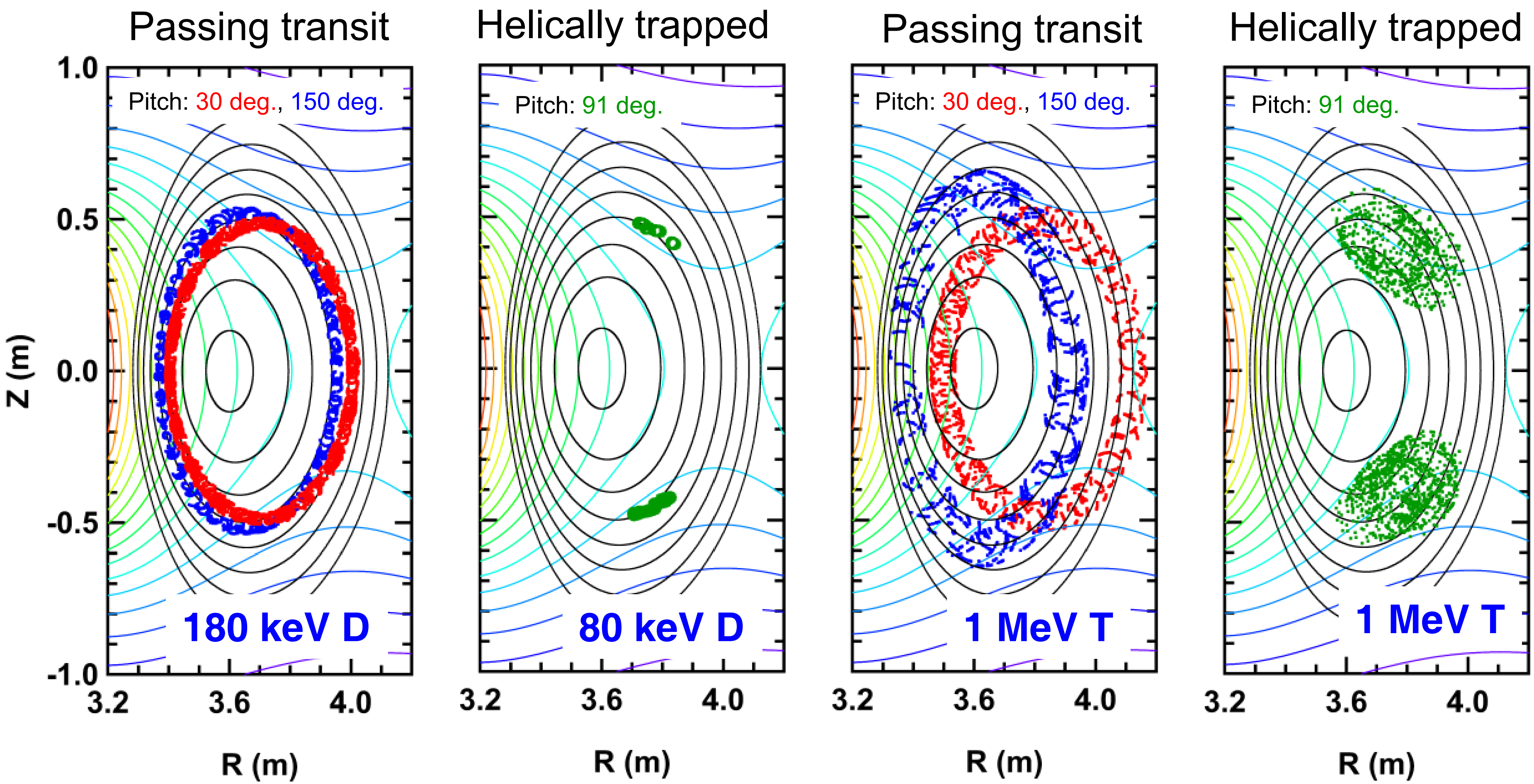
Number of Sci-Fis		
91		LANL Sci-Fi: Used in TFTR and JT-60U, discontinued
109	 (1-inch Φ)	NIFS Sci-Fi: Strong against magnetic field
144	 (32 mm)	Toyama Sci-Fi: High-counting rate capability
456	 (2-inch Φ)	Middle Sci-Fi

Detection efficiency

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.

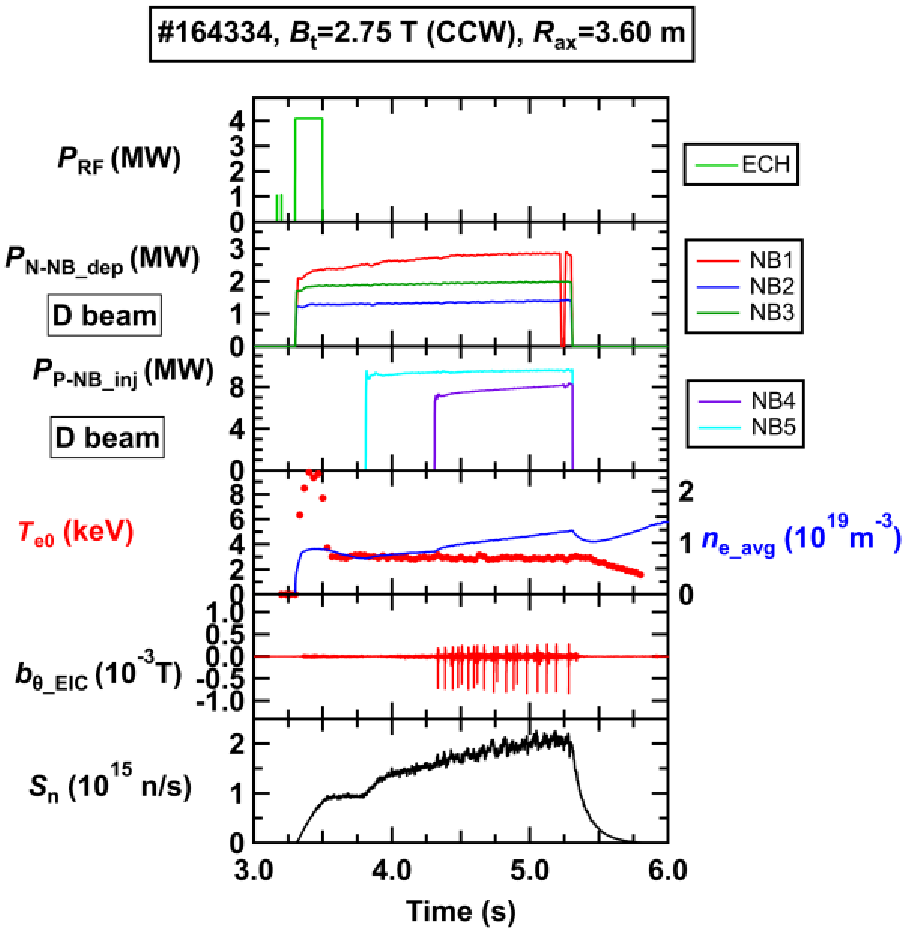
Poincaré plot of beam ion and triton orbits

R_{ax}=3.60 m, B_t = 2.75 T



- 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.

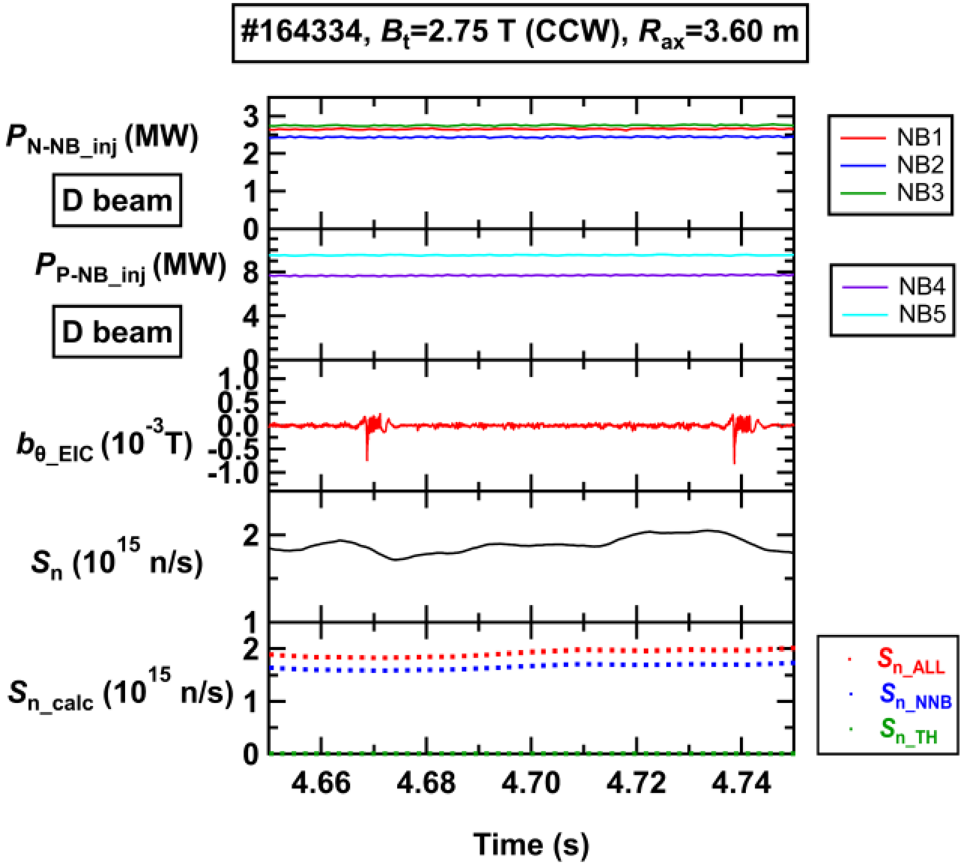
Energetic ion driven resistive interchange mode (EIC) excited in a deuterium plasma discharge

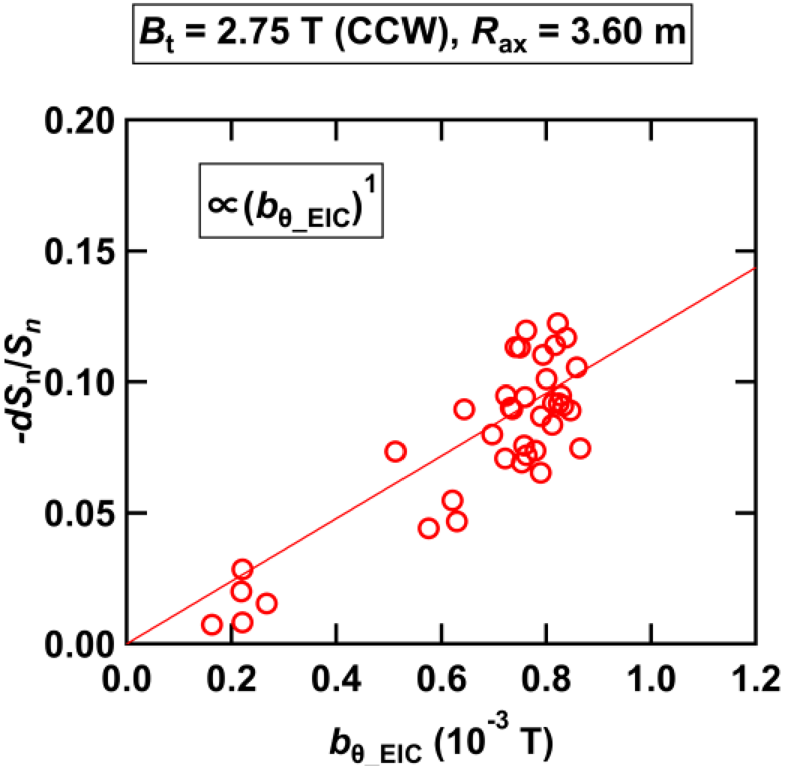


- EIC is excited in relatively low-density plasma with intense P-NB injections.
    - Helically-trapped ions created by P-NB excite EIC.
    - The termination of the high-T_i state in LHD
- Deuterium N-NBs and deuterium P-NBs were injected into a deuterium plasma.
- T_{e0}~3 keV and n_{e_avg}~10^{19} 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).

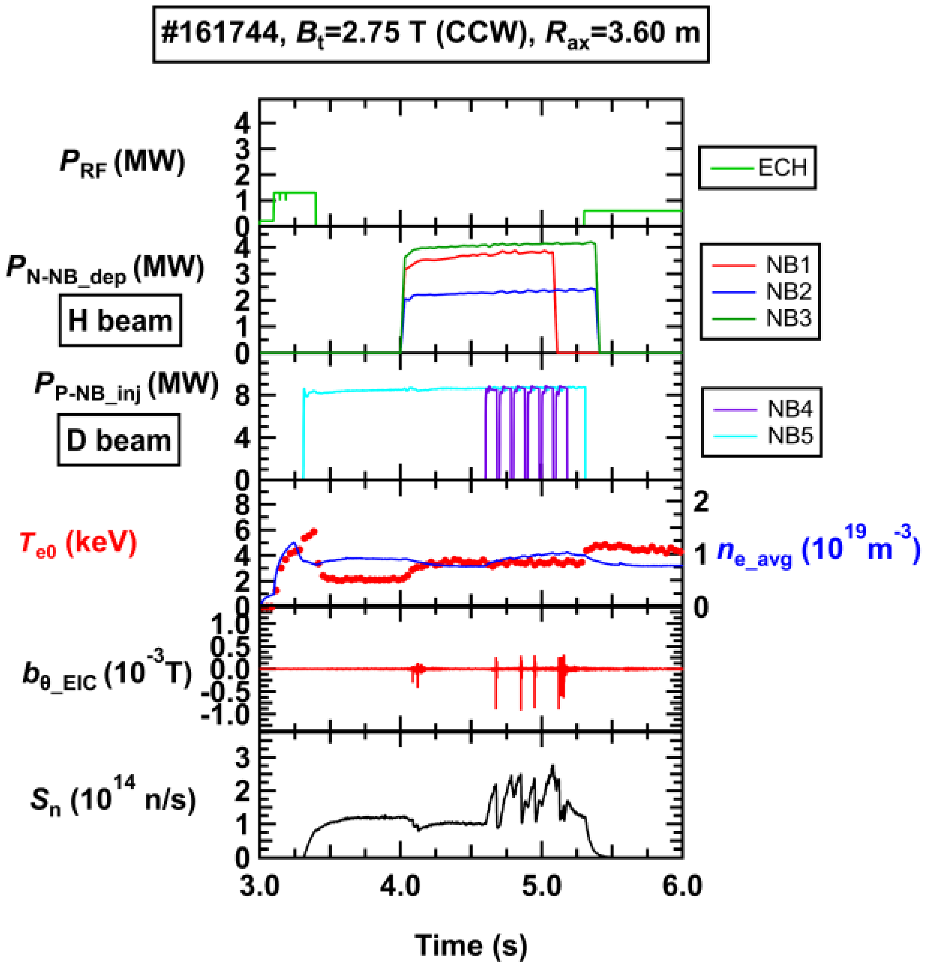
Beam ion transport due to EIC





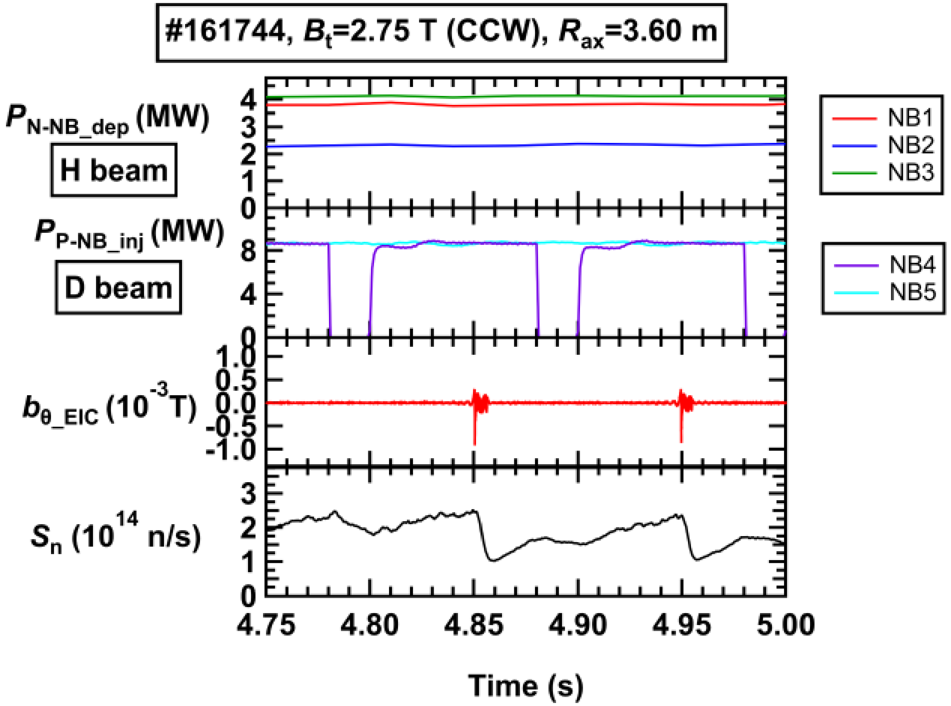
- Drop of S_n due to a EIC burst shows that EIC induces beam ion transport.
  - 90% of S_n: plasma-N-NB ion reactions. 10% of S_n : plasma-P-NB ion reactions.
- Drop rate of S_n linearly increases with b_{θ_EIC} and reaches ~13%.

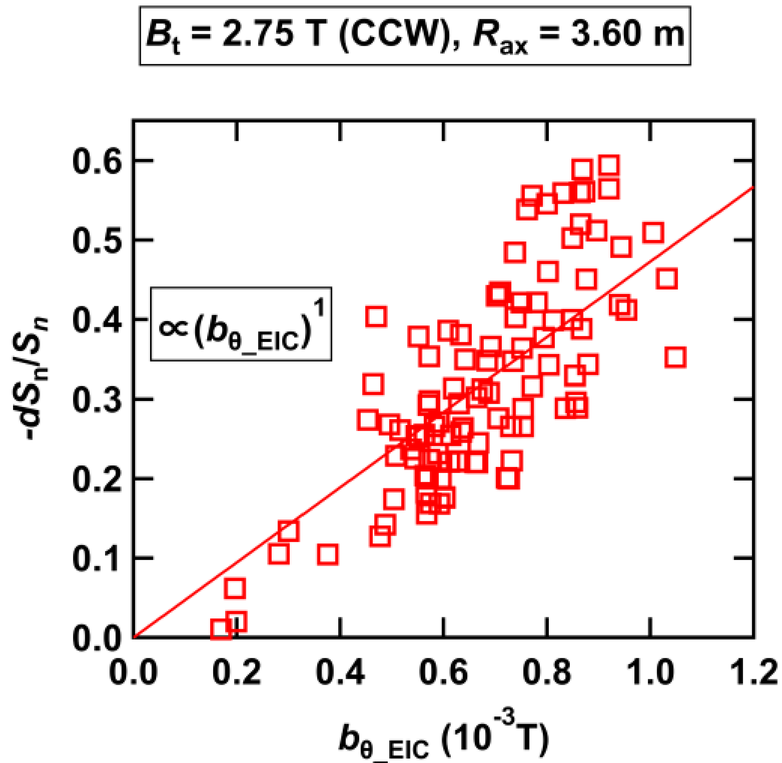
EIC discharge with hydrogen and deuterium beams



- 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.
- T_{e0}~3 keV and n_{e_avg}~10^{19} m^{-3}.
- The intensity of EIC is almost same as that in a full deuterium NB condition.
- S_n reflects the global confinement of P-NB ions.

Helically-trapped beam ion transport due to EIC

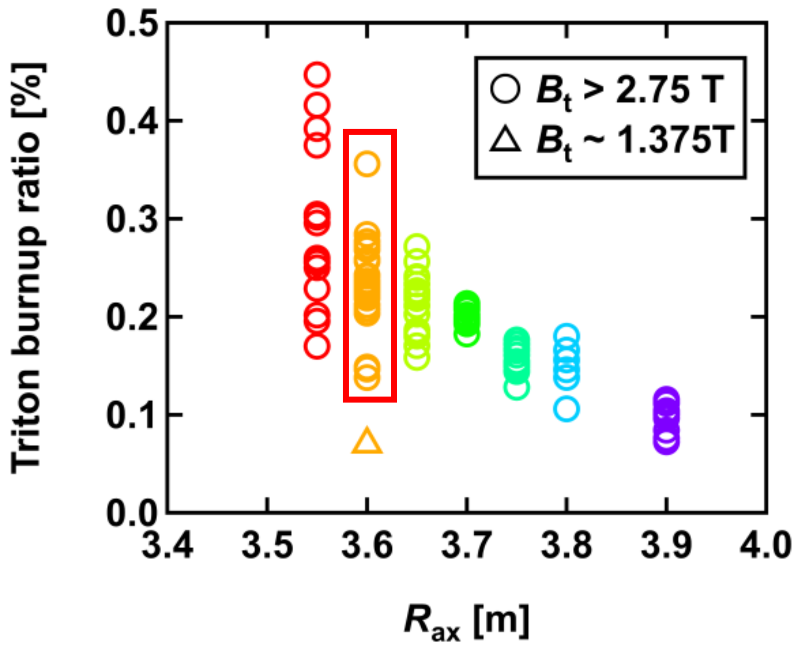


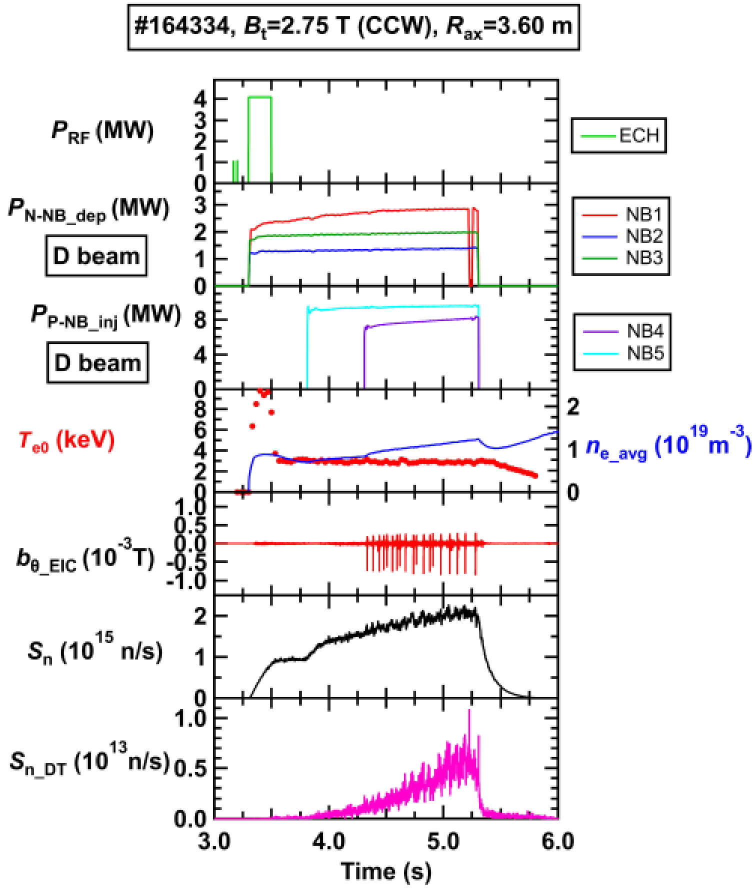


- S_n drops significantly due to a EIC bust.
- Drop rate of S_n reaches ~60%. -> EIC induces up to 60% of P-NB ion losses.
  - P-NB ions are the driving source of EIC.

- In full-D beam 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.

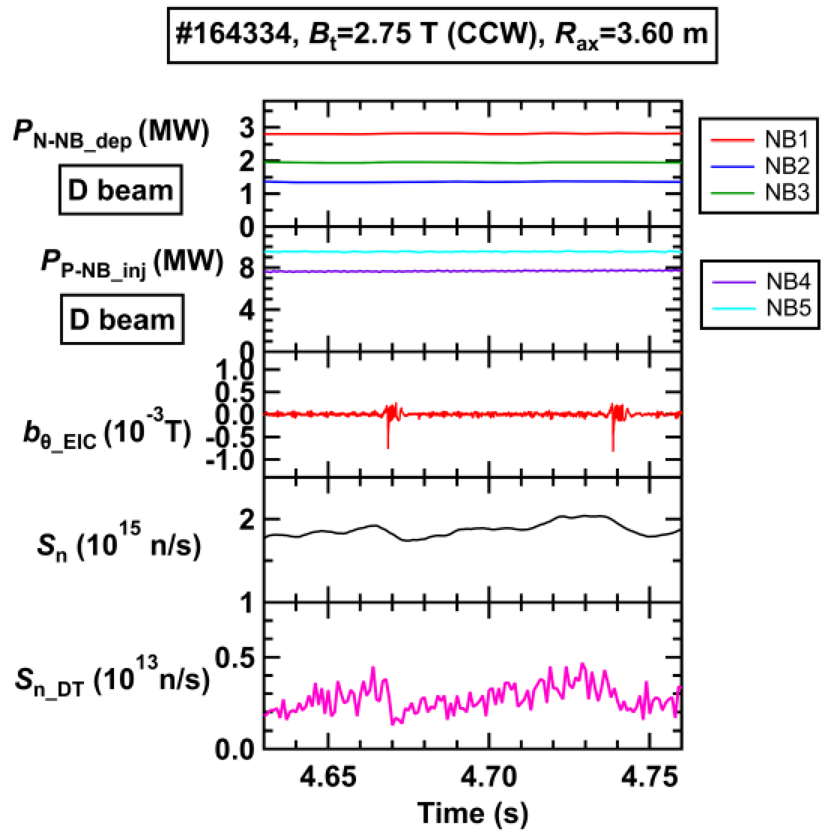
DD fusion born triton confinement in LHD

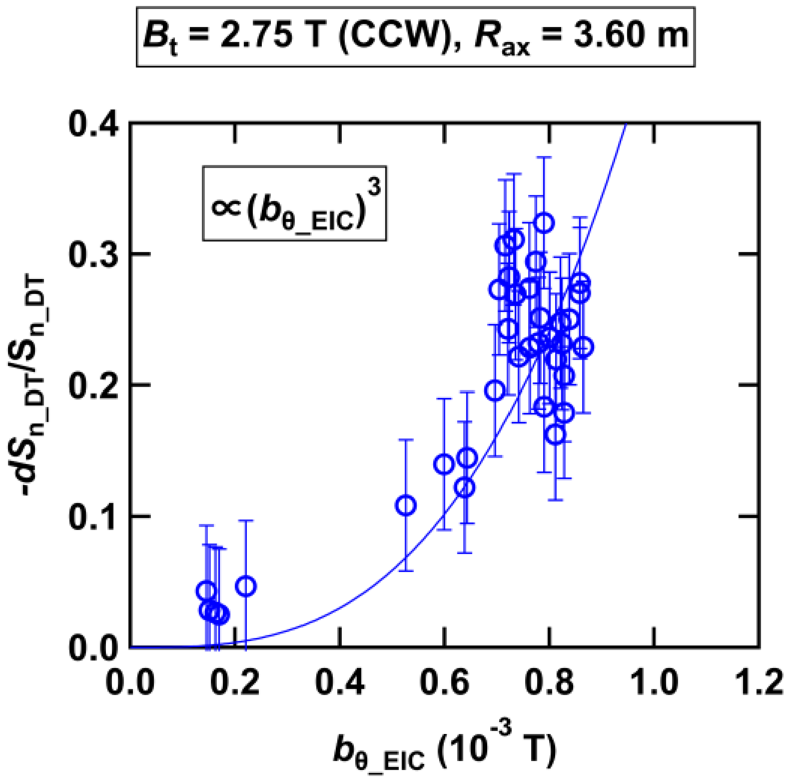




- High triton confinement capability is realized in high-B_t and inward shift of R_{ax}.
- A study of 1 MeV triton transport induced by energetic-particle-driven MHD instabilities was performed under high triton confinement condition.

DD fusion born triton transport due to EIC





- S_{n_DT} drops rapidly and significantly due to EIC.
- Drop rate of S_{n_DT} increases substantially with b_{θ_EIC}.
  - Loss of tritons reaches ~30% at b_{θ_EIC}~10^{-3} T.
  - 1 MeV tritons are largely transported because the tritons are barely confined.

Summary

- Beam ion and DD fusion born triton transport due to energetic-particle-driven MHD instabilities is simultaneously studied in LHD to understand α particle confinement in a fusion burning plasma.
  - The neutron flux monitor is used for beam ion confinement study. A high sensitivity scintillating fiber detector is developed for measuring time-resolved triton confinement.
- 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 $b_{\theta\_EIC}{}^3$ and reaches up to 30% due to EIC. 1 MeV tritons barely confined in LHD are rapidly and significantly lost due to EIC.