Hybrid simulations of fast ion transport and losses due to the fast ion driven instabilities in the Large Helical Device

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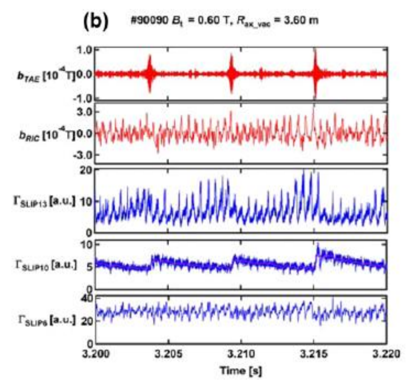
ABSTRACT

- The numerical fast-ion loss detector "numerical FILD" which solves the Newton-Lorentz equation was constructed in the MEGA code in order to validate the fast-ion loss process due to the AE burst.
- The fast ion which was transported to the stochastic region when AE burst occurred was detected by "numerical FILD".
- The velocity distribution of lost fast ions detected by the numerical FILD is in good agreement with the experimental FILD measurements.

Introduction

- Recurrent TAE bursts are observed in the Large Helical Device (LHD) experiments.
- The lost fast ions during TAE burst were measured by scintillator-based lost fast-ion loss detector (FILD).
- It is difficult to get an overall understanding of fast ion loss process only by the local measurements in LHD.
- Computer simulation is a powerful tool to investigate the interaction between fast ions and fast-ion driven AE instabilities

K. Ogawa, et al., Nucl. Fusion 52, 094013 (2012)



Purpose

- MEGA code

  - a hybrid simulation code for nonlinear magnetohydrodynamics (MHD) and energetic-particle dynamics in the real coordinates with use of equilibrium magnetic field calculated by HINT. The pressure of fast ions is calculated from positions and velocities of fast ions with PIC method.

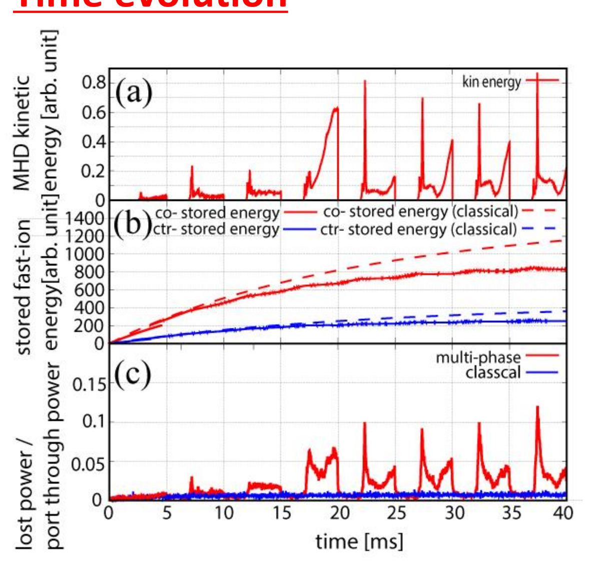
  - Nonlinear calculation of fast ion induced instabilities.
  - Fast-ion transport /losses due to the instabilities.

- Purpose

  - To investigate the time evolution of AE and beam pressure
    - ・MEGA is applied to the Large Helical Device experiments with the realistic condition.
  - Validation of the simulation on fast ion loss due to the AE.
    - ・ Comparison of lost fast ion in the simulation with the FILD experiment.

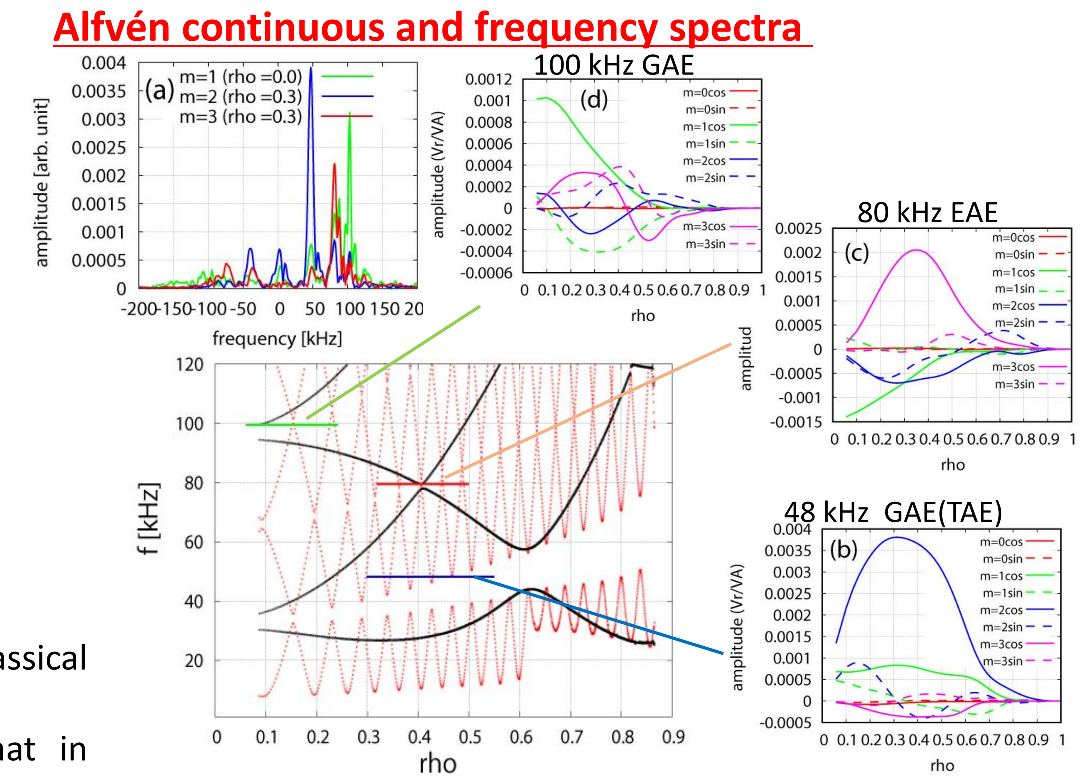
Fast ion driven alfvén eigenmodes and fast ion losses in LHD

Time evolution

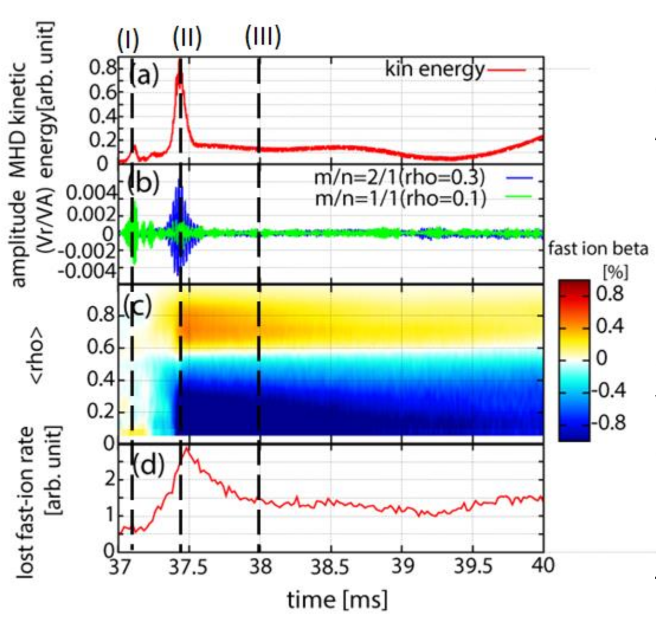


○AE bursts occur recurrently.
○Fast-ion loss rate is larger than that in classical simulation.
○Stored fast-ion energy is less than that in classical simulation.

Alfvén continuous and frequency spectra



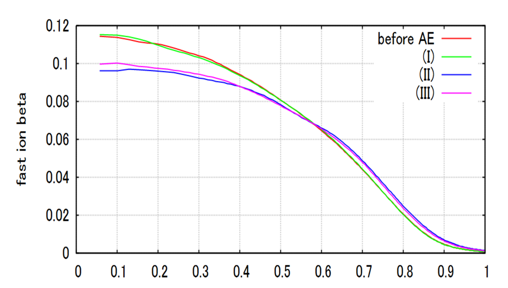
Typical AE burst and Time evolution of fast ions pressure profile



○The primary mode number at the initial peak is m/n=1/1. And then, the instability with m/n=2/1 becomes large.

○ There is the maximum peak of instability at about 54.3 s. The peak is coincident with the peak of mode amplitude with m/n=2/1.

○The fast ion loss rate takes the maximum value near the peak of the m/n=2/1 mode amplitude.



(I) The fast ion beta is almost same as that before the AE burst.

(II) The fast ion pressure decrease for rho < 0.6 and increase for rho > 0.6.

(III) After the AE burst, The fast-ion pressure profile recovers due to the beam injection after the damping of the AE amplitude.

Calculation condition

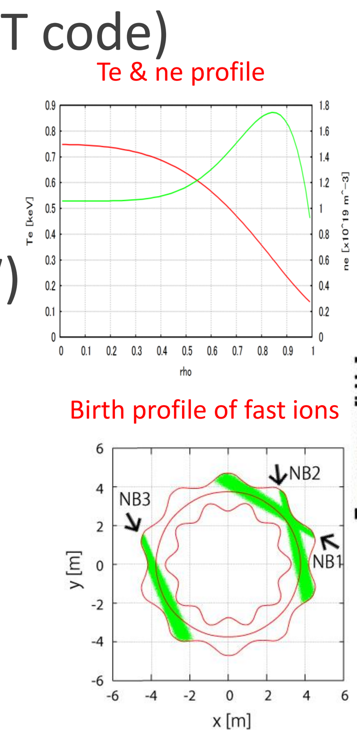
- Magnetic configuration (calculated by HINT code)

  Bax= 0.6 T, <beta> =1.8 %
- Tree tangential-NBIs

  Port through power ∼ 15 MW(P_{abs}:9 MW)

  beam injection energy ∼ 180 keV
- Temperature and density profile measured in the LHD experiment.

  Ti = Te, ni=ne
- The birth profile of fast ions calculated by the HFREYA code is used as the fast ion source.



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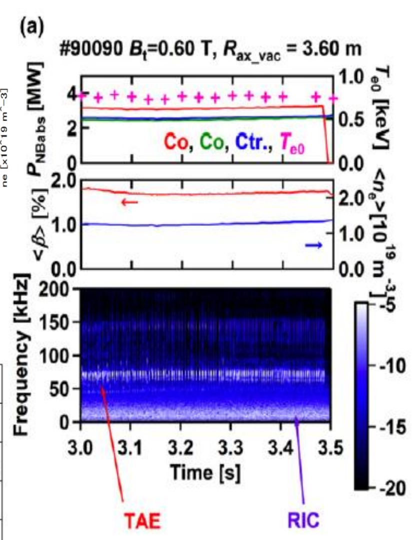
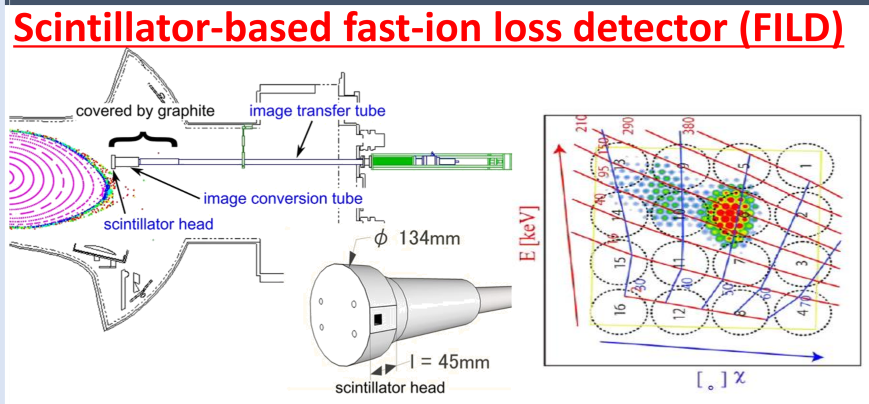


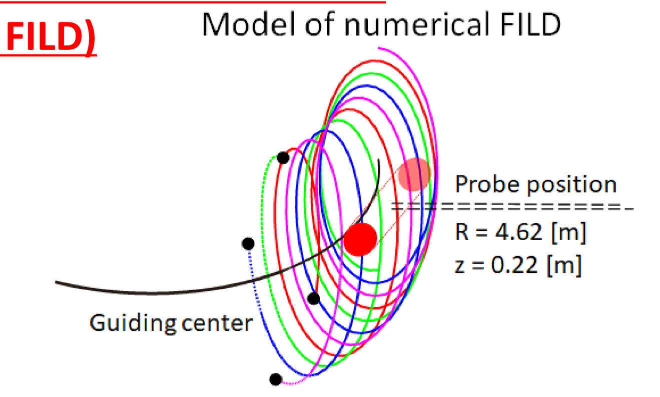
Comparison of fast ion loss with measurements

Scintillator-based fast-ion loss detector (FILD)



○The lost co-going fast-ions during AE burst were measured by FILD near horizontal elongated poloidal plane.
○Two lost regions were observed during the TAE burst.

Numerical fast-ion loss detector (Numerical FILD)



○Numerical fast-ion loss detector with Lorentz orbit
・ Fast ion orbit near FILD is retraced by using Lorentz orbit. 64 Lorentz orbit particle are traced
・ Aperture shape is a circle with radius 2 cm. Only the fast ions passing through the aperture are detected.
・10 numerical FILD is set. (assuming helical symmetry)

Fast ion detected by numerical FILD

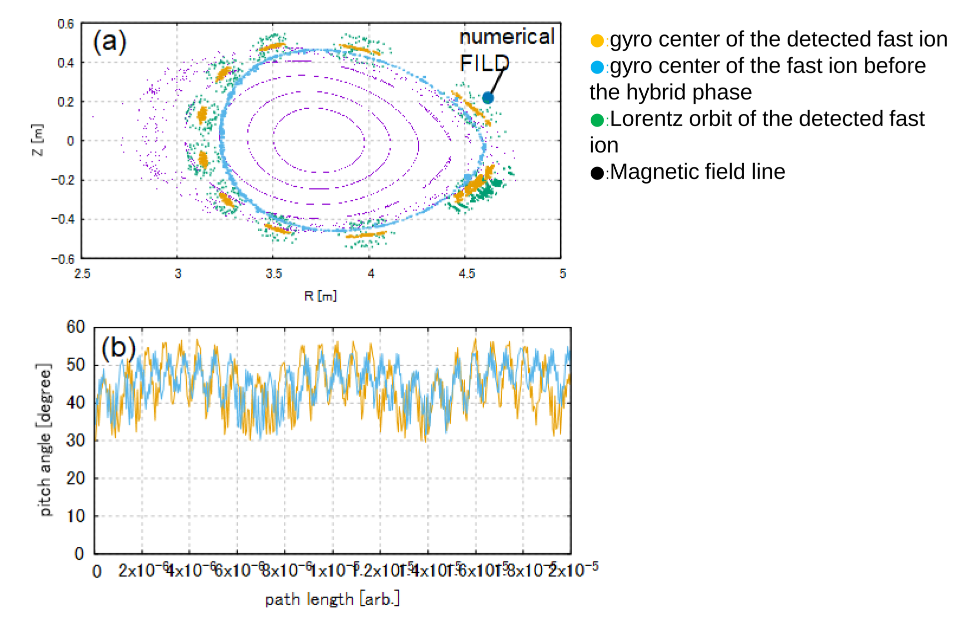


Fig. (a) Poincaré plot of fast ion detected by "numerical FILD" on the poloidal plane for the install position of "FILD". (b) pitch angles of the detected fast ion.

○The detected fast ion was transported to the stochastic region by AE burst.
⇒The Lorentz orbits of the fast ion reached the numerical FILD.
○Most of the detected fast ions are re-entering fast ions whose orbits are the closed drift surface.
○The pitch angle of the detected fast ion is almost the same as the fast ions before the hybrid phase.

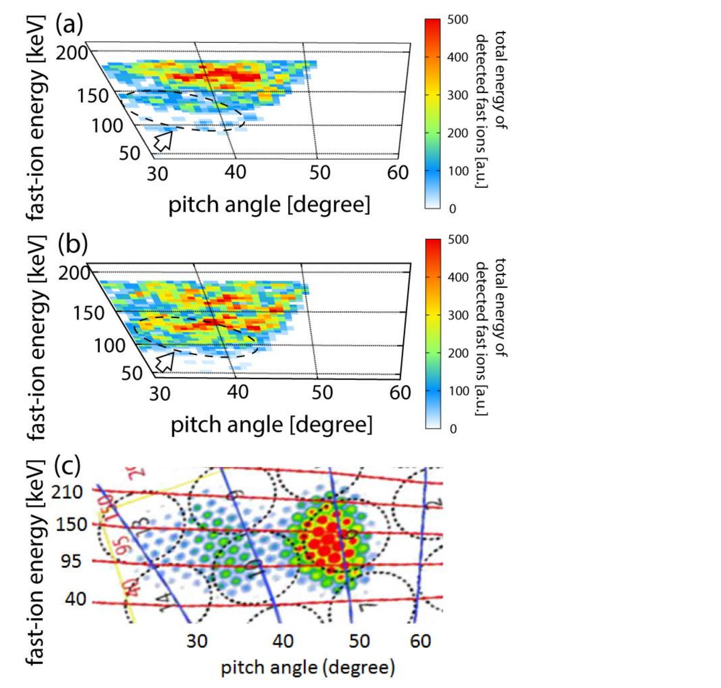


Fig. Comparison of pitch angle and energy distribution of lost fast ions among (a) MEGA simulation before AE burst, (b) MEGA simulation when AE burst is occurred, and (c) FILD measurements when AE burst was occurred.

○Fig.(a), the fast ions with energy close to the injection energy are mainly detected by the numerical FILD before the AE bursts.
○Fig.(b), the fast ions of 100-150 keV and 35-50 degree are detected by the numerical FILD when the AE burst is occurred.
○The velocity space region of the lost fast ions due to the AE burst is in good agreement with that observed in the experiment shown in Fig. 6(c).

CONCLUSION

- MEGA is applied to the Large Helical Device experiments with the realistic condition close to the experiment. Lost fast ion velocity distribution in the simulation is compared with the FILD measurement.
- The velocity space region of lost fast ions calculated by MEGA is close to the lost fast ion measurements by FILD.

  ・During AE burst, fast ion with lower energy than injection energy was detected by numerical FILD.

  ・・The fast ion which was transported to stochastic region when AE burst occurred was detected by "numerical FILD".

  ・Most of the detected fast ions are re-entering fast ions.

This validation demonstrates that the MEGA is a useful tool for the prediction and the understanding of the fast-ion transport and losses due to the AE burst.