Fast-ion loss simulation with MEGA code in the Large Helical Device

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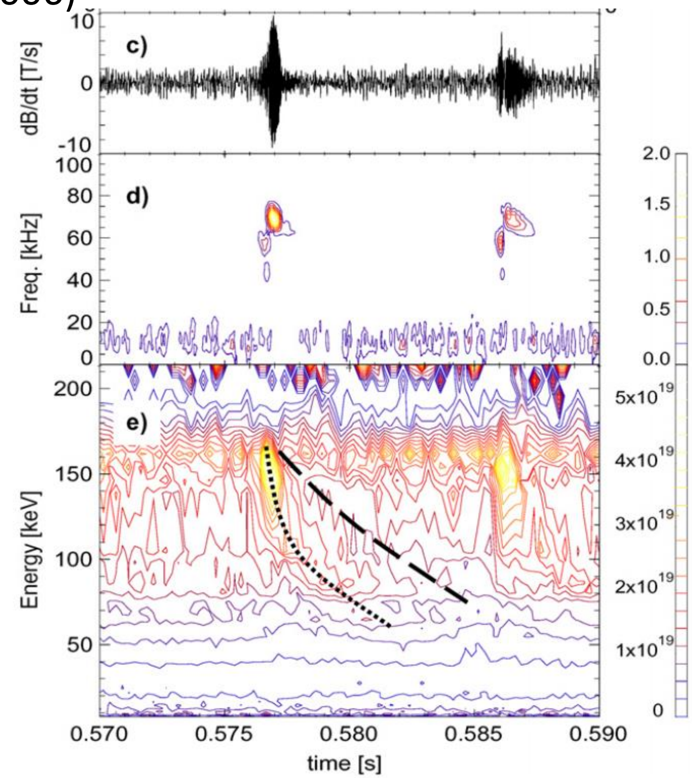
Observation of TAE burst in the LHD

M. Osakabe, et al., Nucl. Fusion 46 S911 (2006)



○Recurrent TAE bursts are observed in the LHD experiments with 180 keV tangential NBI.

○Two frequency components are observed in shot #47645 (figure).
50-60kHz, m/n=2/1;   65-70kHz, m/n=1/1

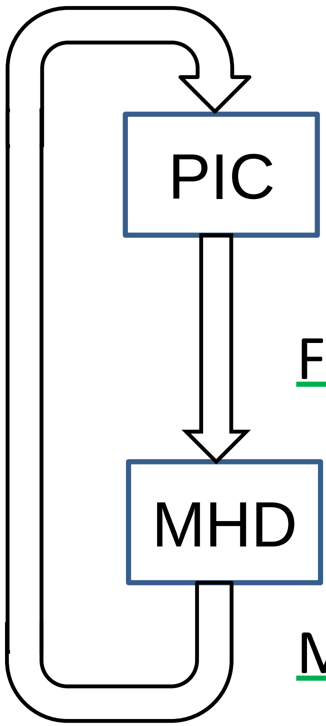
○The lost fast ions during TAE burst were measured by scintillator-based lost fast-ion loss detector (FILD).

○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

MEGA code

- 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.



○time evolution of fast ion
- ・source of fast ion
- ・change of position and velocity
- ・fast ion loss

Fast ion pressure

○time evolution of MHD
- ・change of magnetic field and electric field
- ・evolution of AE

Magnetic field・electric field with instabilities

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

Purpose

● Energetic particle - MHD hybrid simulations of AE burst in LHD.

●To investigate the time evolution of AE and beam pressure
・MEGA is applied to the Large Helical Device experiments with the realistic condition close to the experiment.

●Validation of the simulation on fast ion loss due to the AE.
・ Comparison of lost fast ion velocity distribution in the simulation with the Scintillator-based fast-ion loss detector (FILD) experiment.

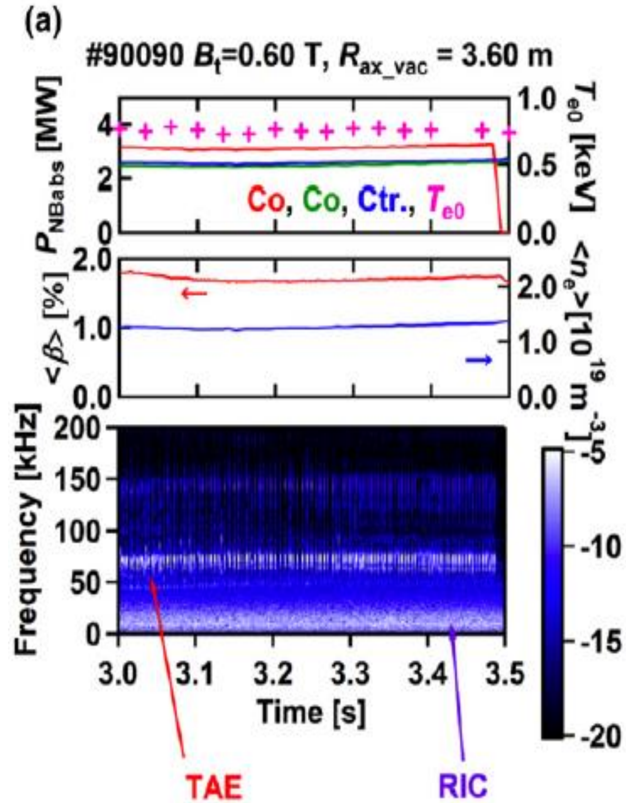
Contents

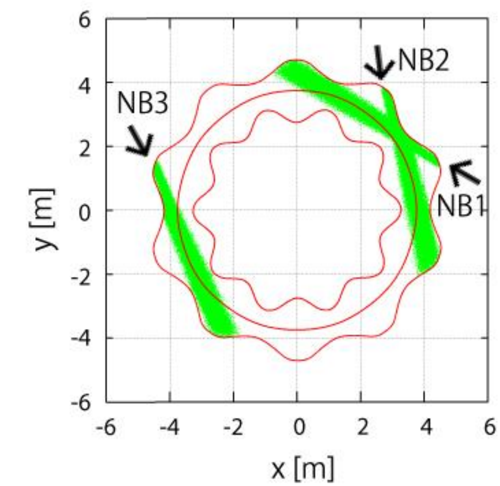
- Introduction
- Analyses of AE burst
  - Time evolution of AE burst
  - Time evolution of beam pressure profile
- Comparison of fast ion loss with measurements

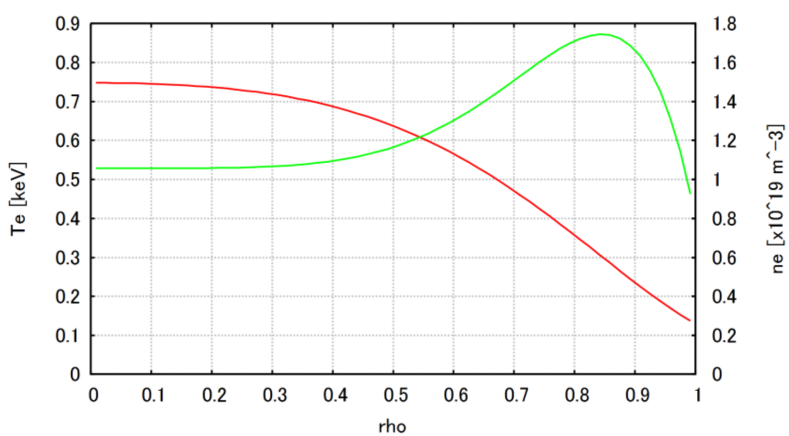
Simulation condition

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

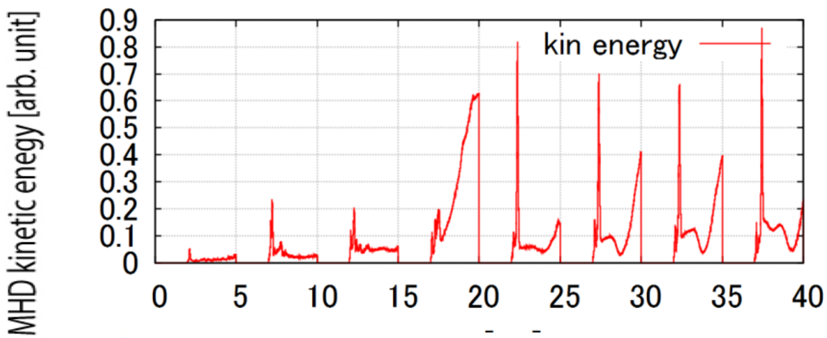
- Magnetic configuration
  (calculated by HINT code)
  Bax= 0.6 T, <beta> =1.8 %
- Tangential-NBIs
  Port through power ～ 15 MW
  (total absorption power ~ 9 MW)
  beam injection energy ～ 180 keV
- Ti = Te, ni=ne profile
  measured in the LHD experiment.
- Realistic fast-ion birth profile (HFREYA)



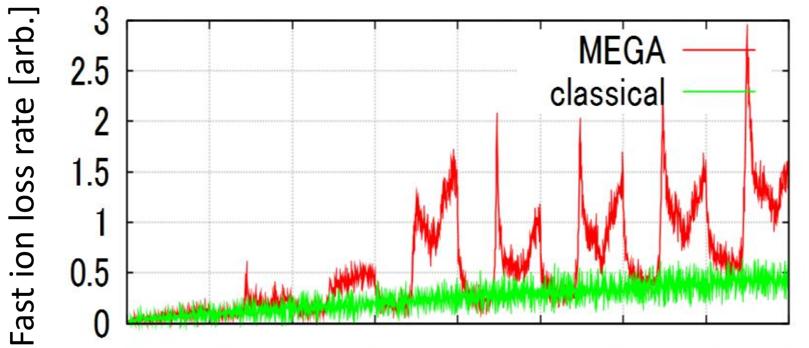




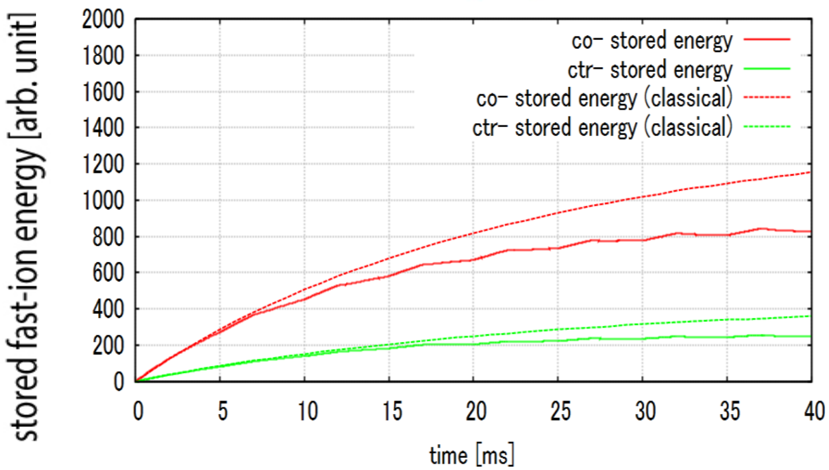
Time evolution of MHD kinetic energy, fast ion loss rate and stored fast ion energy



○ AE bursts occur recurrently.

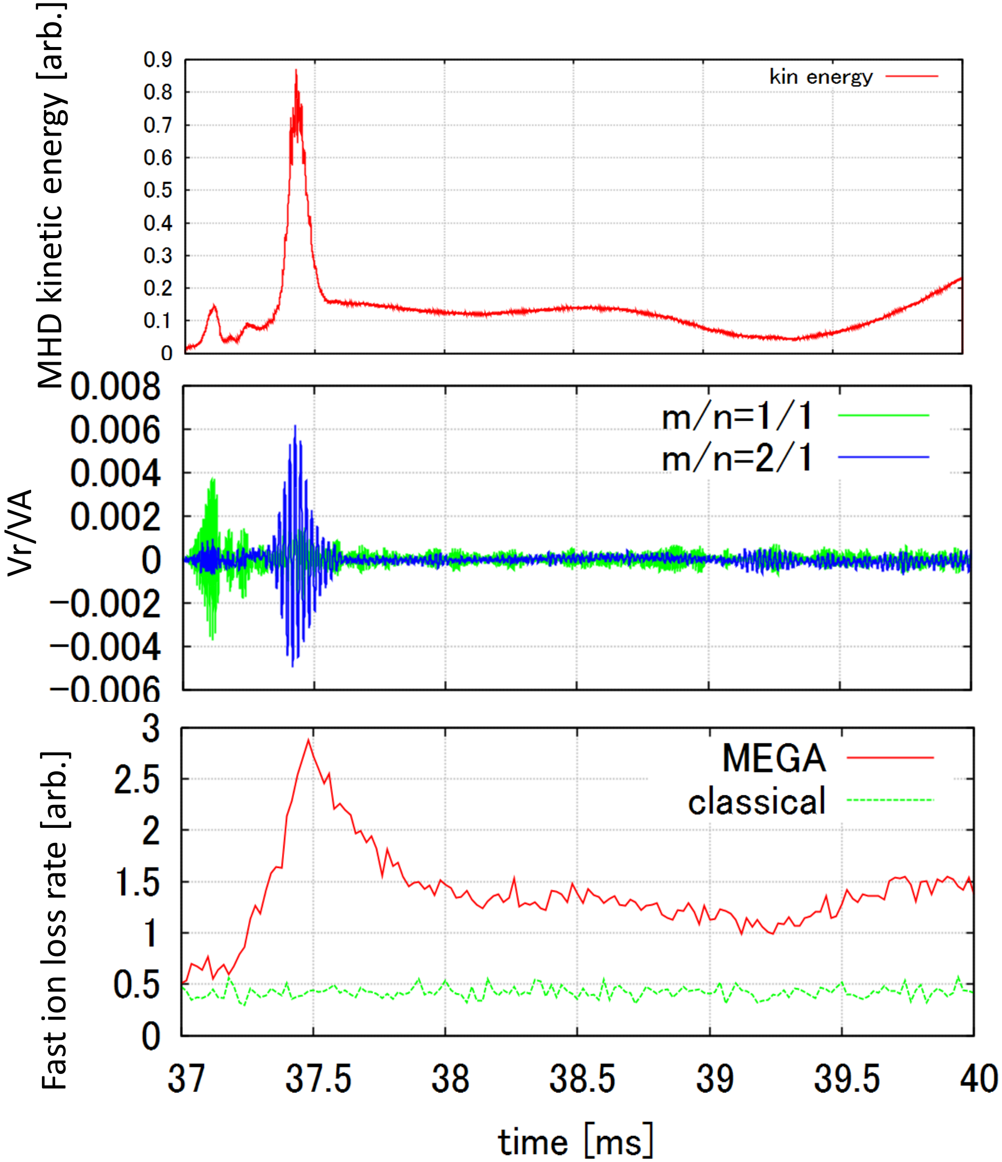


○Fast-ion loss rate is larger than that in classical simulation (green).



○ Stored fast-ion energy is less than that in classical simulation.

Alfven eigenmode (AE) burst

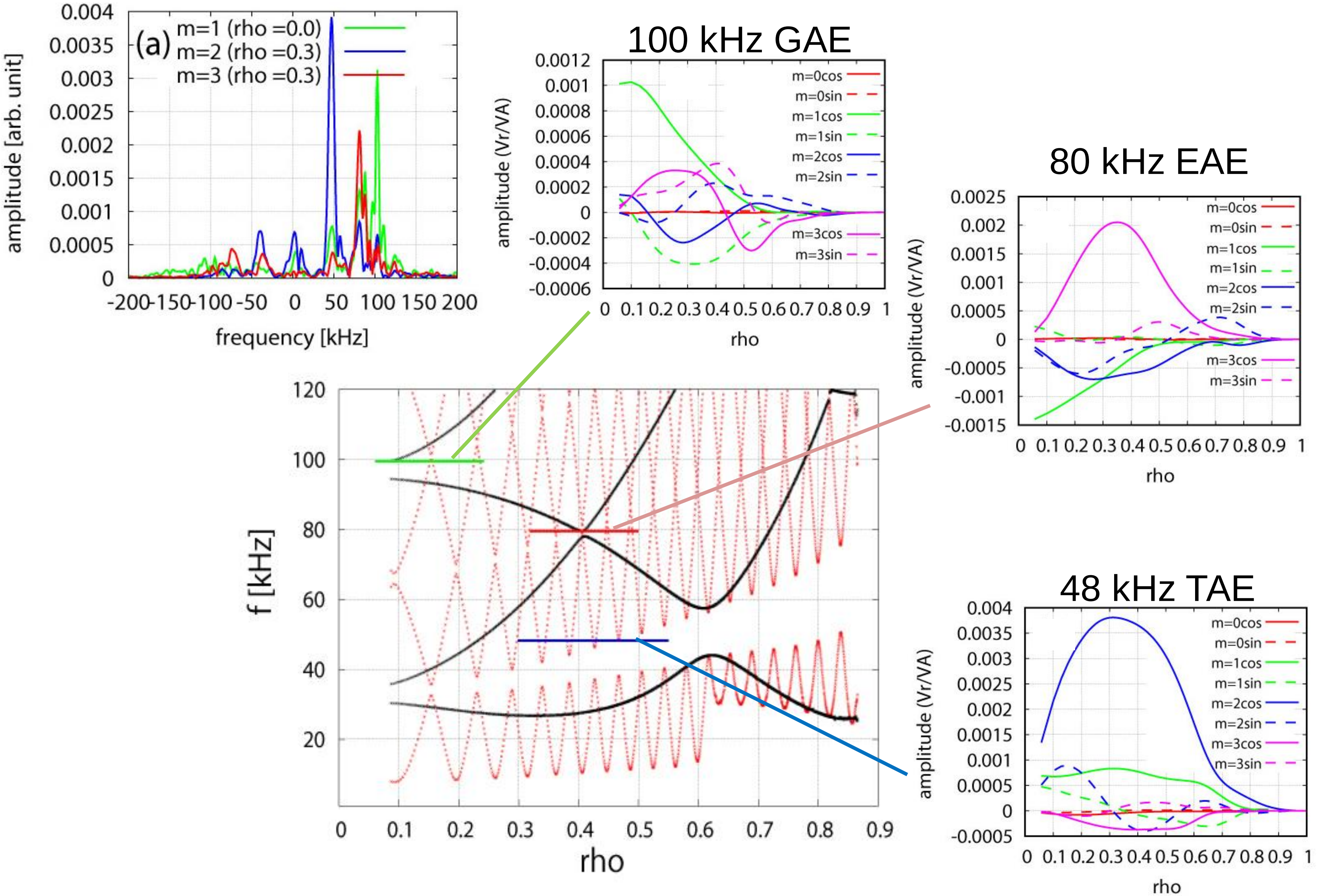


○The primary mode number at the initial peak is m/n=1/1. And then, the instability with m/n=2/1 becomes large.

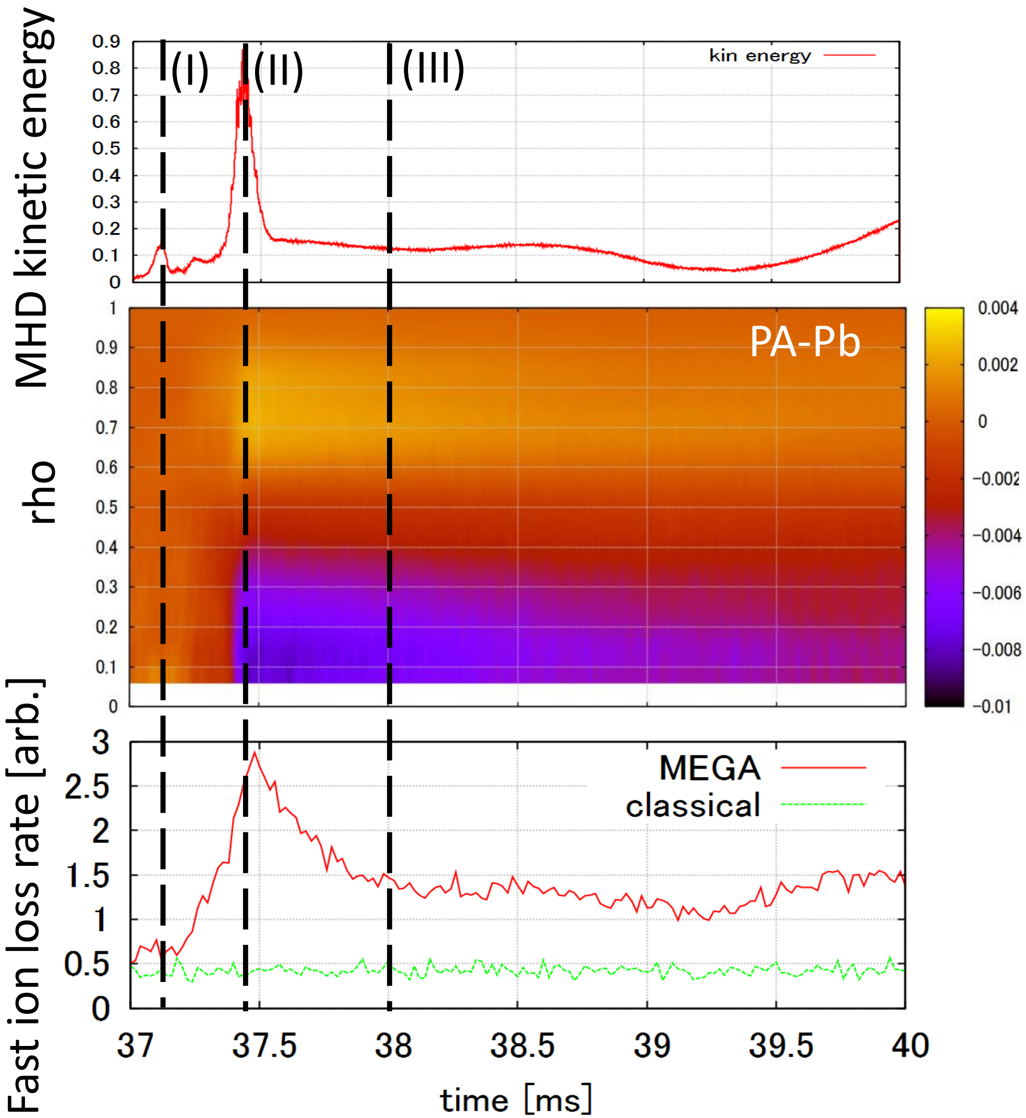
○ There is the maximum peak of instability at about 37.45 ms. The peak is coincident with the peak of mode amplitude with m/n=2/1.

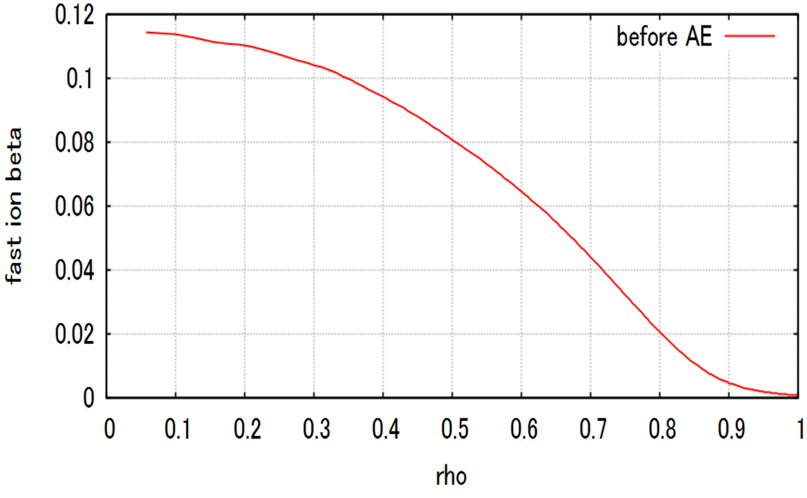
○The fast ion loss rate takes the maximum value near the peak of the m/n=2/1 mode amplitude.

Frequency spectra of radial MHD velocity harmonics

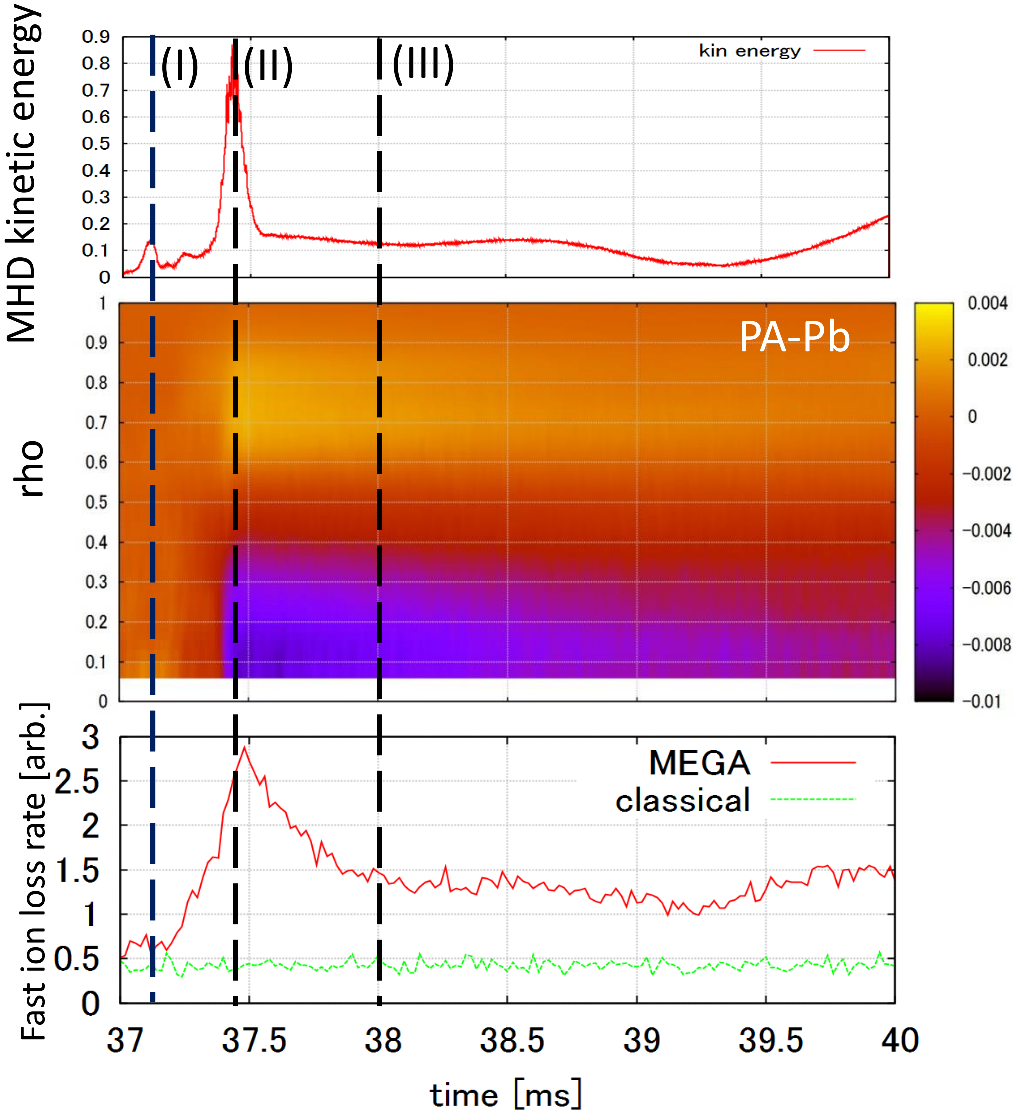


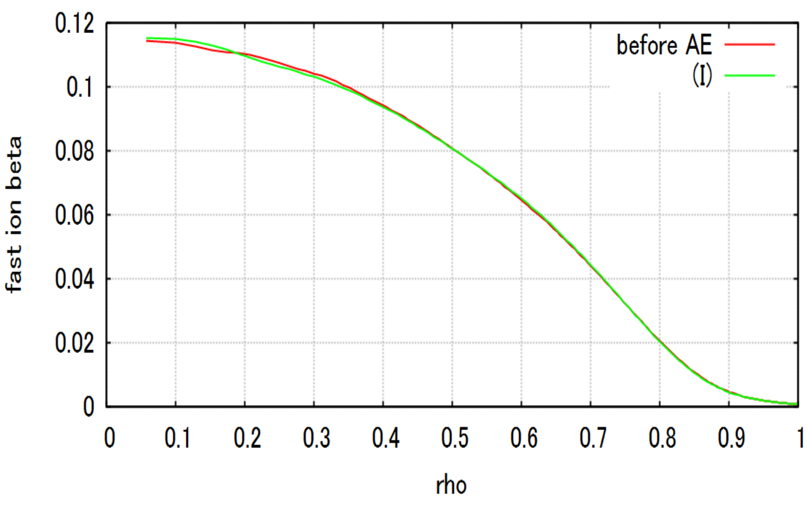
Time evolution of fast ions pressure profile





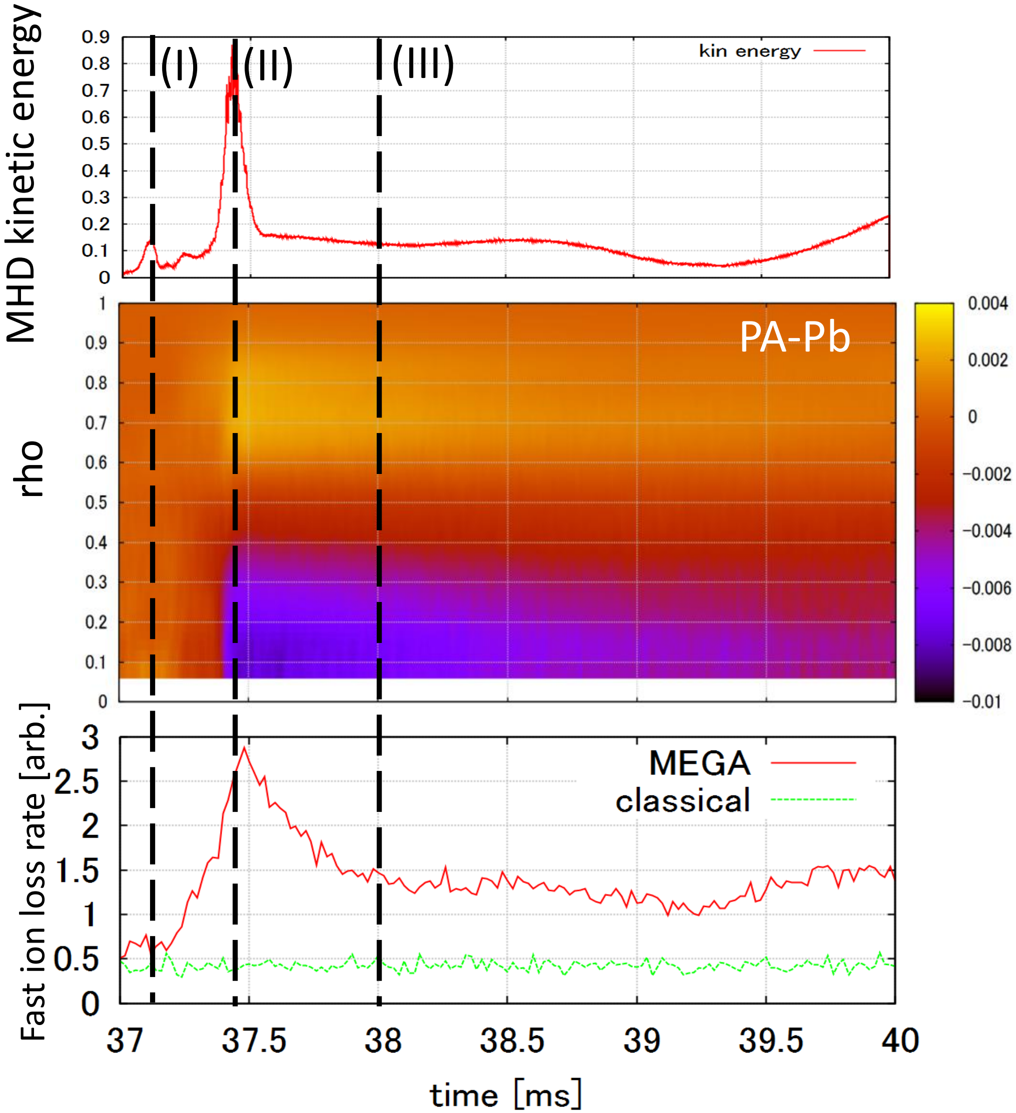
Time evolution of fast ions pressure profile

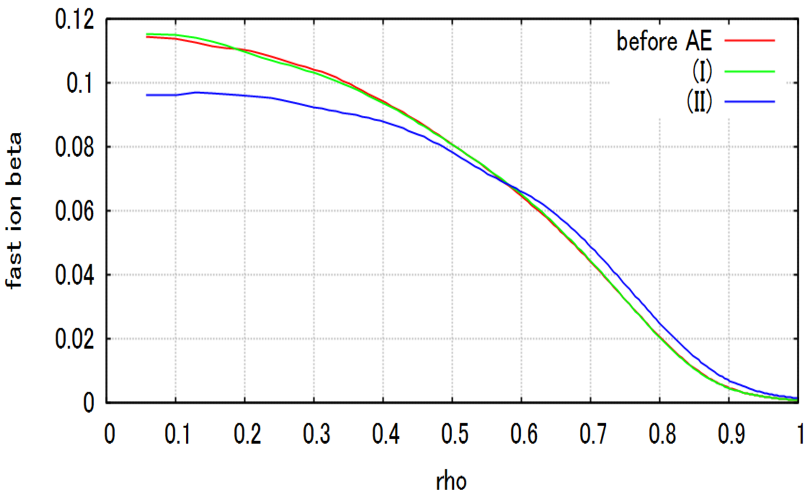




(I) The fast ion beta is almost same as that before the AE burst.

Time evolution of fast ions pressure profile

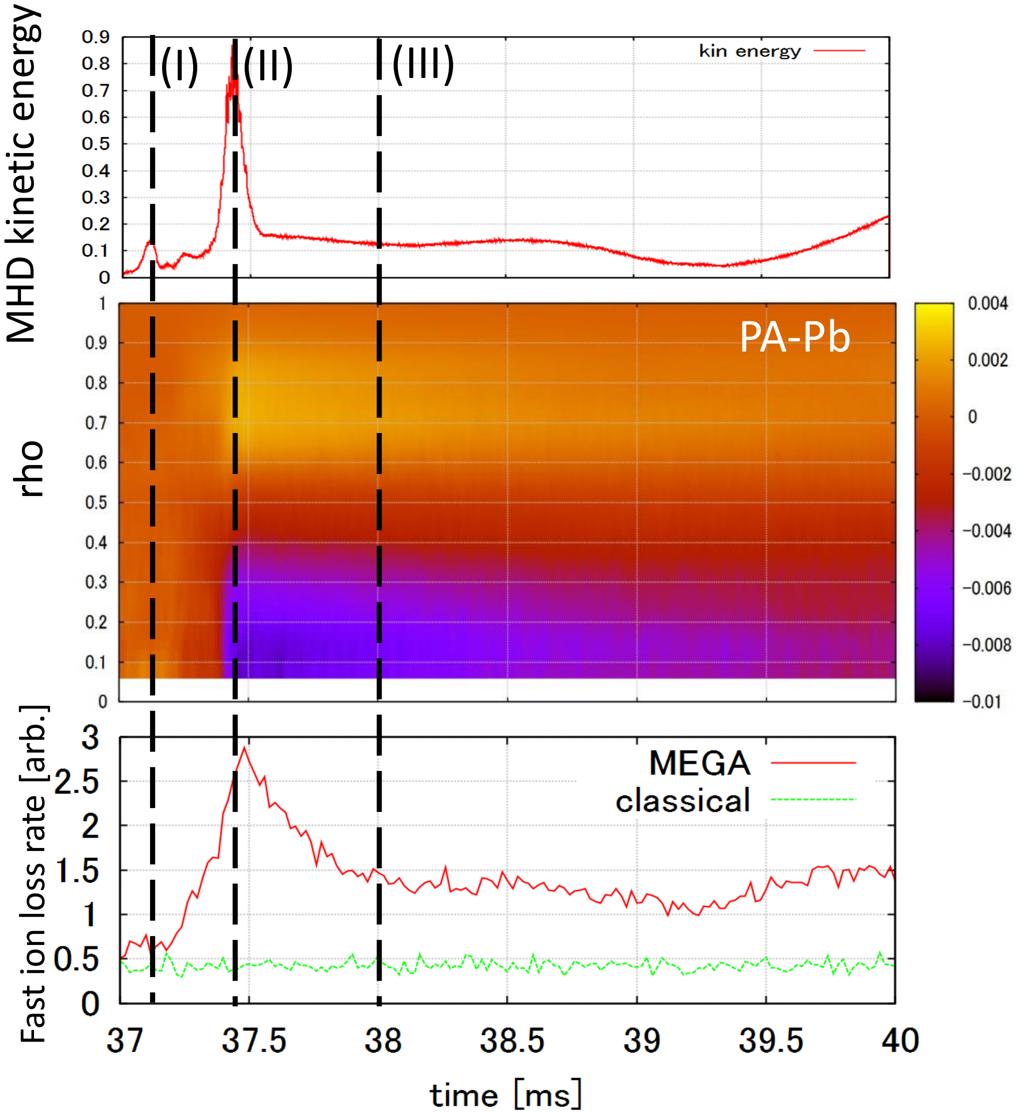


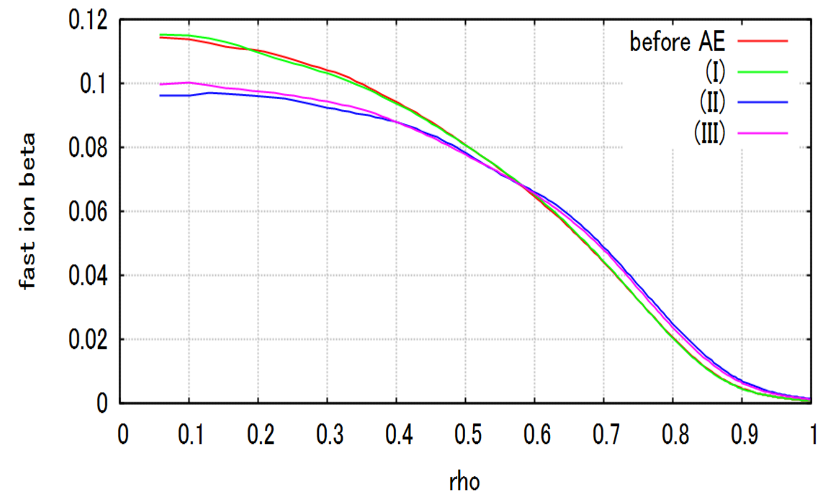


(I) The fast ion beta is almost same as that before the AE burst.

(II) (There is the maximum peak of instability with m/n=2/1)
The fast ion pressure decrease for rho < 0.6 and increase for rho > 0.6.

Time evolution of fast ions pressure profile

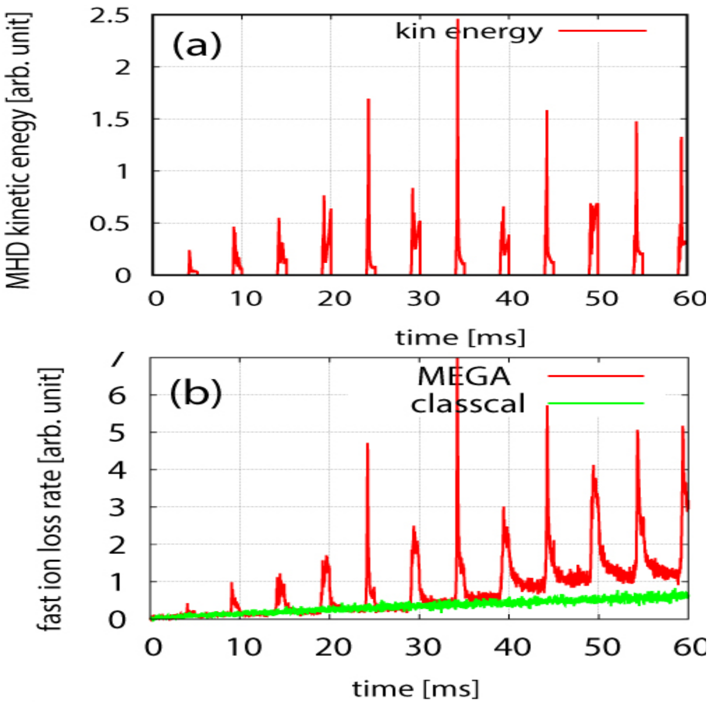


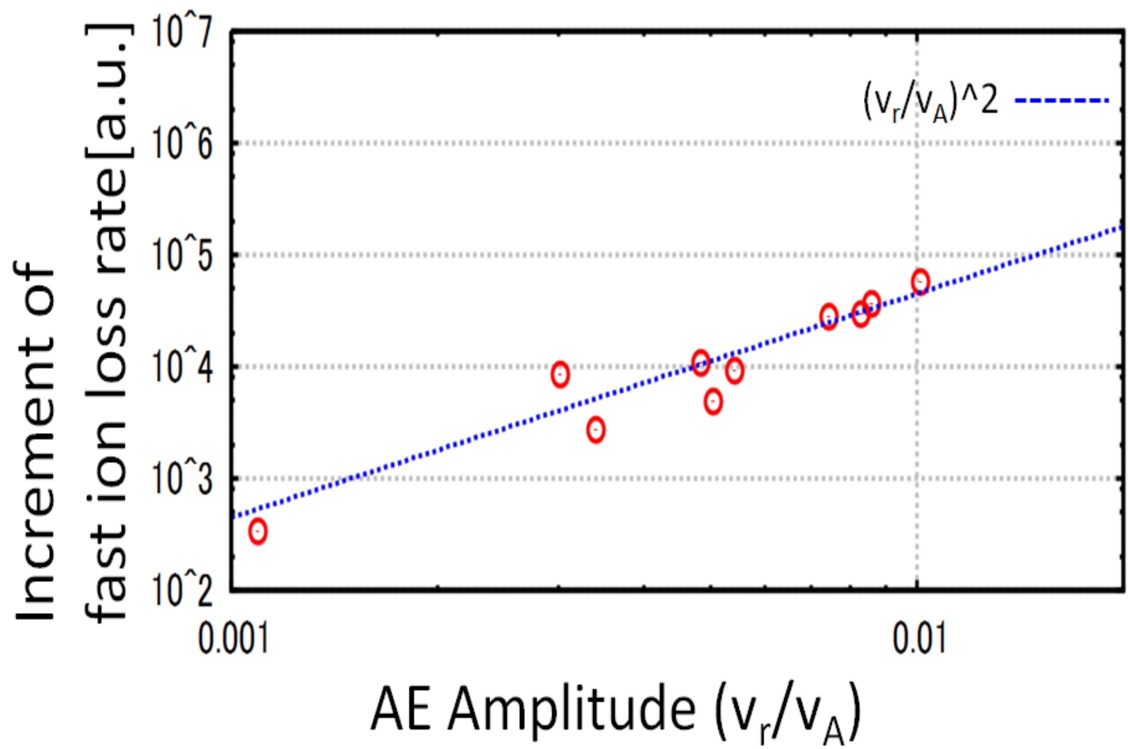


(I) The fast ion beta is almost same as that before the AE burst.

(II) (There is the maximum peak of instability with m/n=2/1)
 The fast ion pressure decrease for rho < 0.6 and increase for rho > 0.6.
(III) After the AE burst,
 The fast ion pressure increases.

AE-induced fast ion loss rate versus the maximum AE amplitude





Fast ion loss rate brought about by the AE burst is proportional to the square of AE amplitude.

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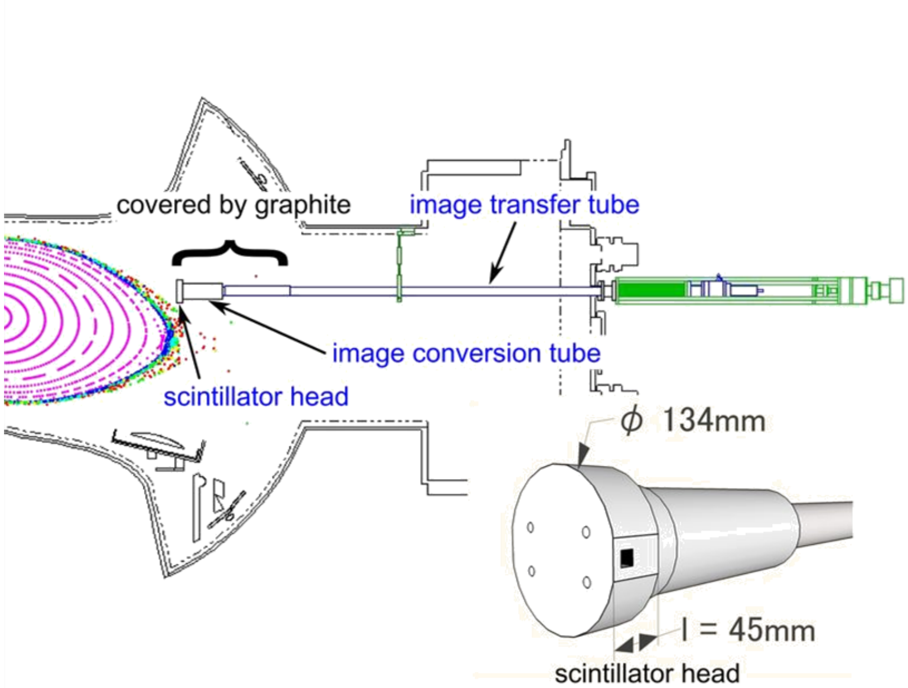
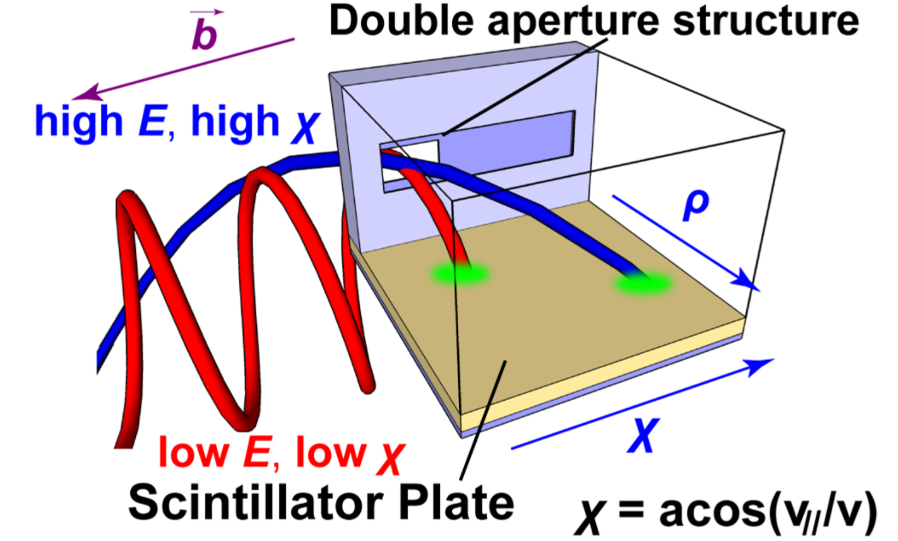
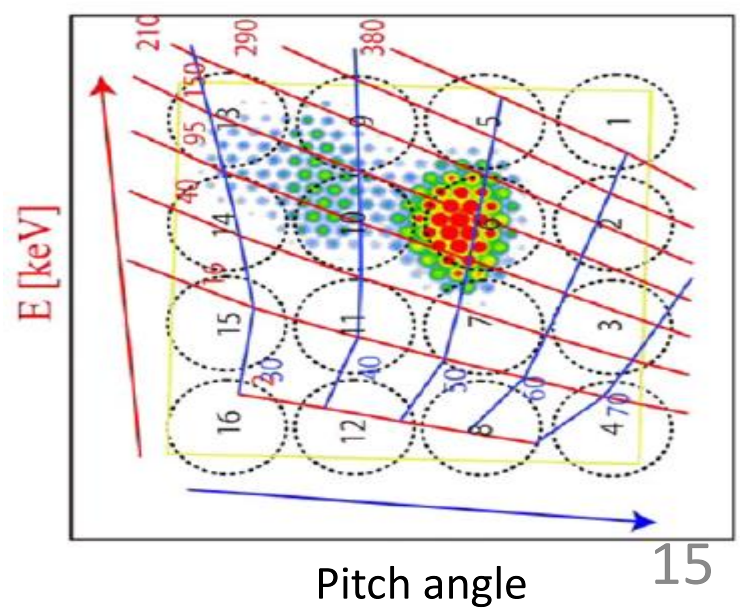
Scintillator-based fast-ion loss detector (FILD)



Model of scintillator head

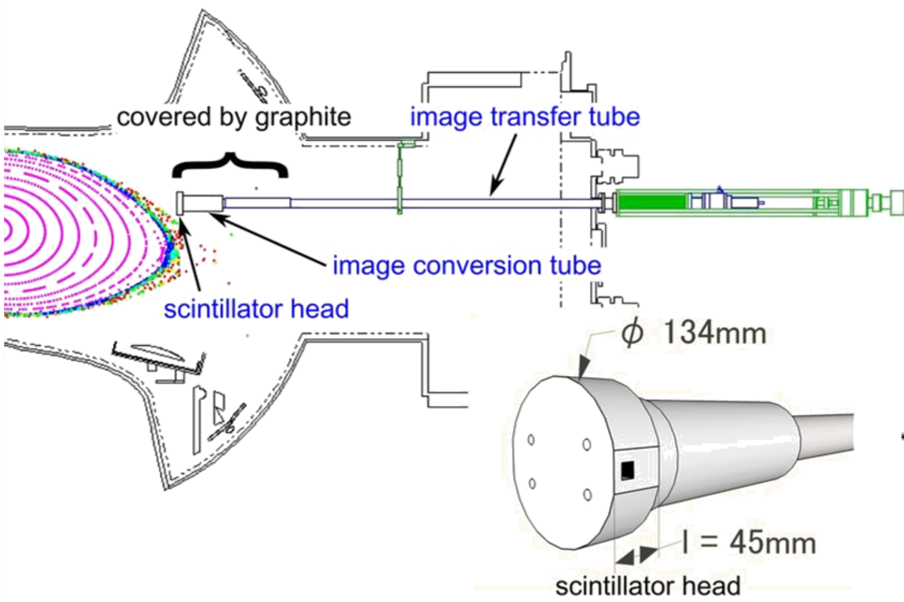


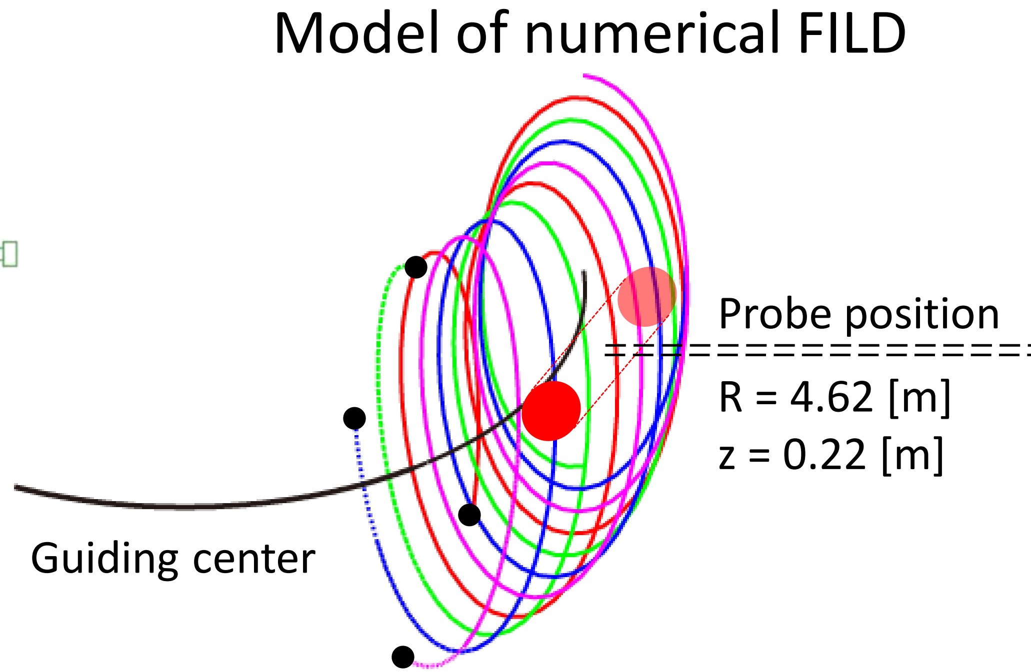


○The lost co-going fast-ions during AE burst were measured by FILD near horizontal elongated poloidal plane.

○Two lost regions were observed during the TAE burst.

Numerical fast-ion loss detector with Lorentz orbit (Numerical FILD)





○Numerical fast-ion loss detector with Lorentz orbit

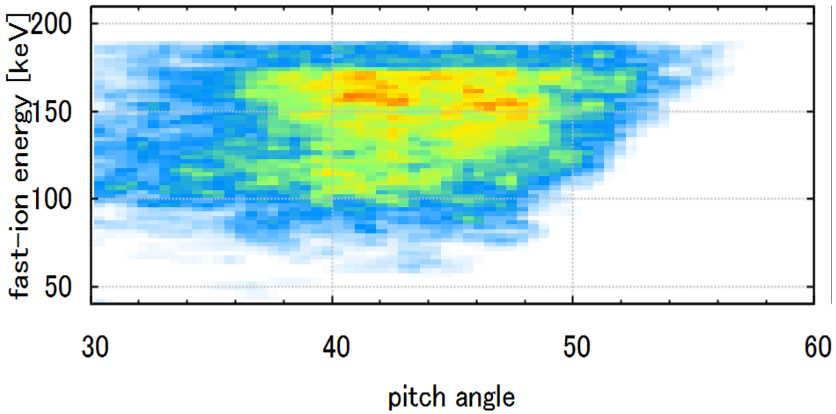
・Fast ion orbit near FILD is retraced by using Lorentz orbit. **64 Lorentz orbit particle** are traced

・Aperture shape is a circle with radius 2 cm. Only the fast ions passing through the aperture are detected.

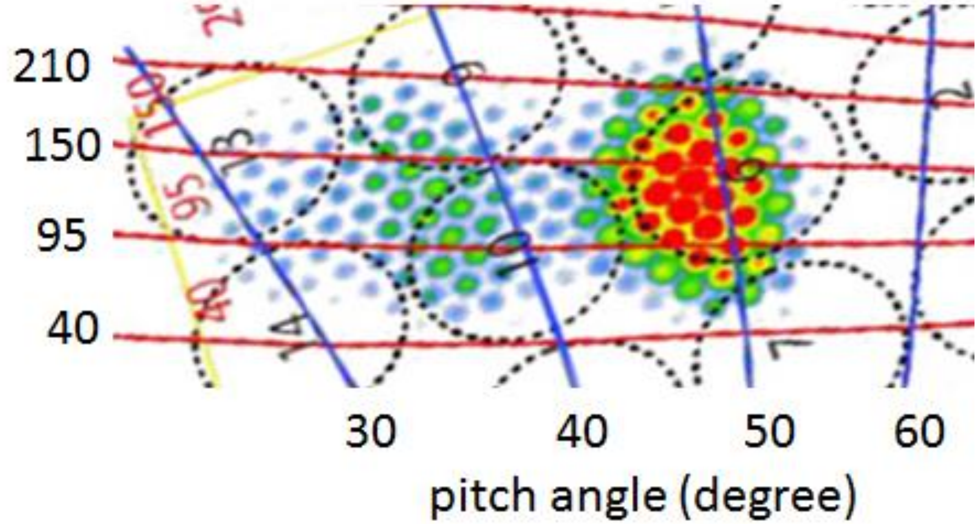
・10 numerical FILD is set. (assuming helical symmetry)

Comparison of the velocity distribution with measurements by FILD

MEGA (during TAE)



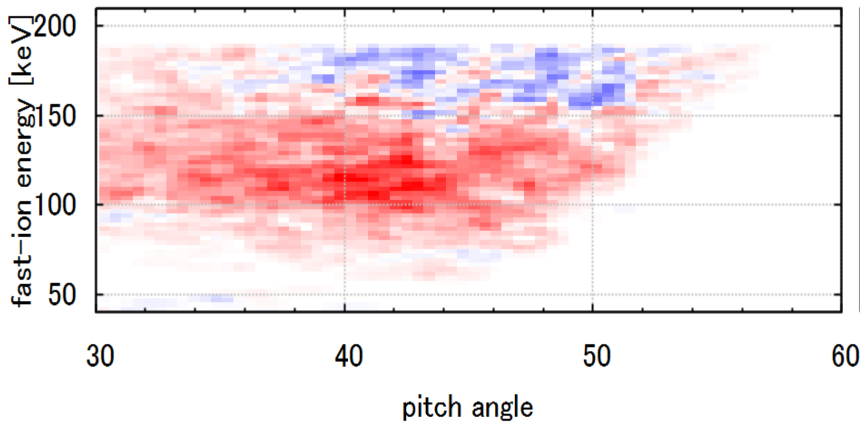
FILD measurement



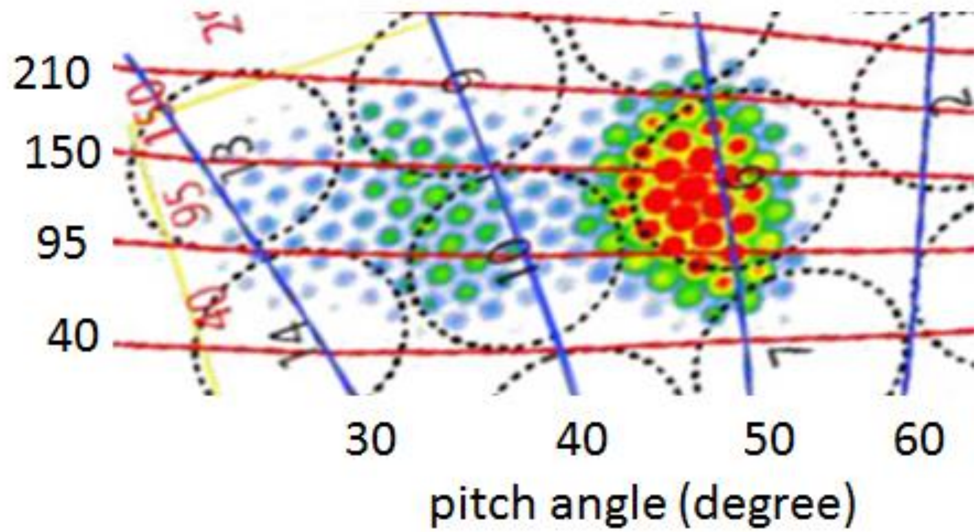
○During TAE burst, the velocity space region of lost fast ions calculated by MEGA is similar to the lost fast ion measurements by FILD.

Comparison of the velocity distribution with measurements by FILD

Increase of lost fast-ions during AE burst in MEGA simulations



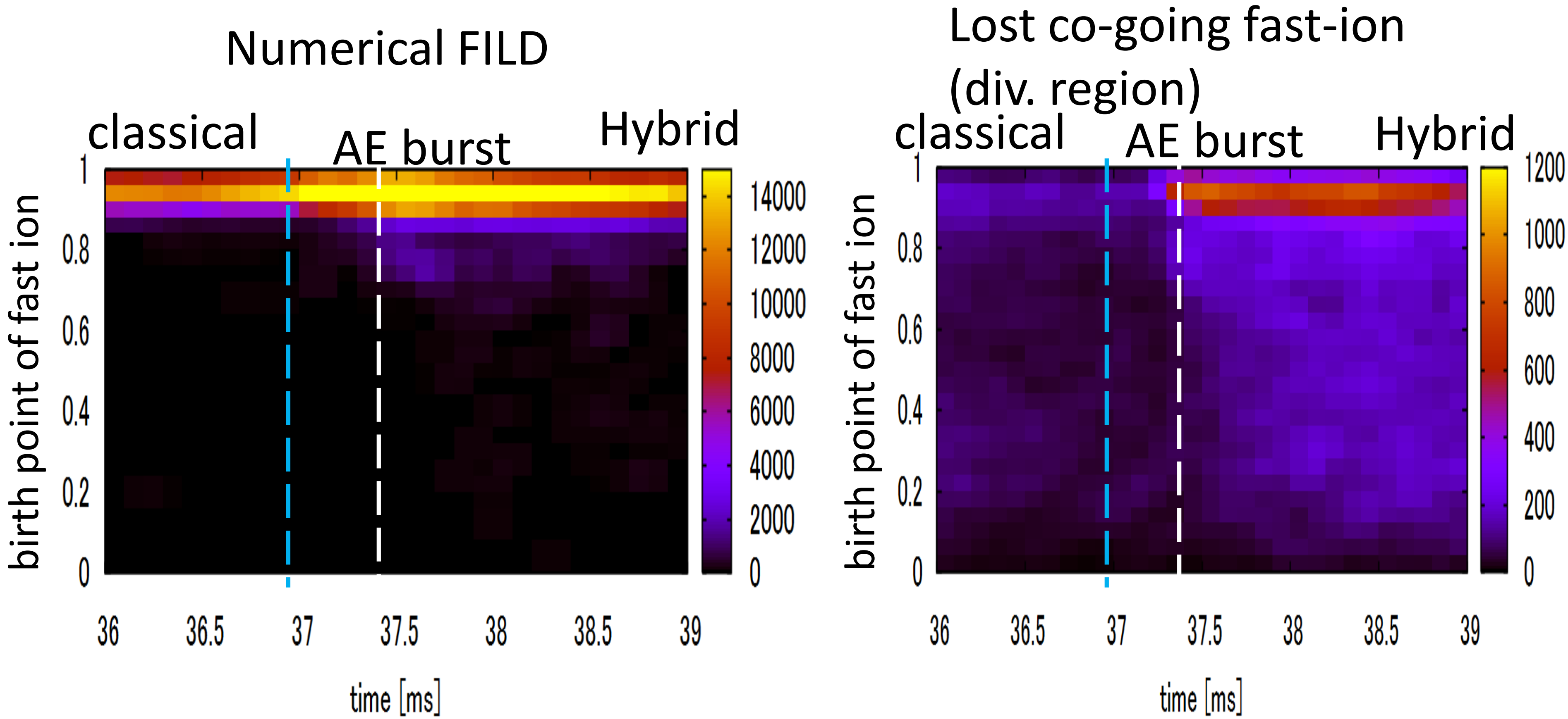
FILD measurement



○The fast ion losses with pitch angle ~ 40, E~100-150keV increase during AE burst in MEGA simulation. This is similar to the FILD measurement.

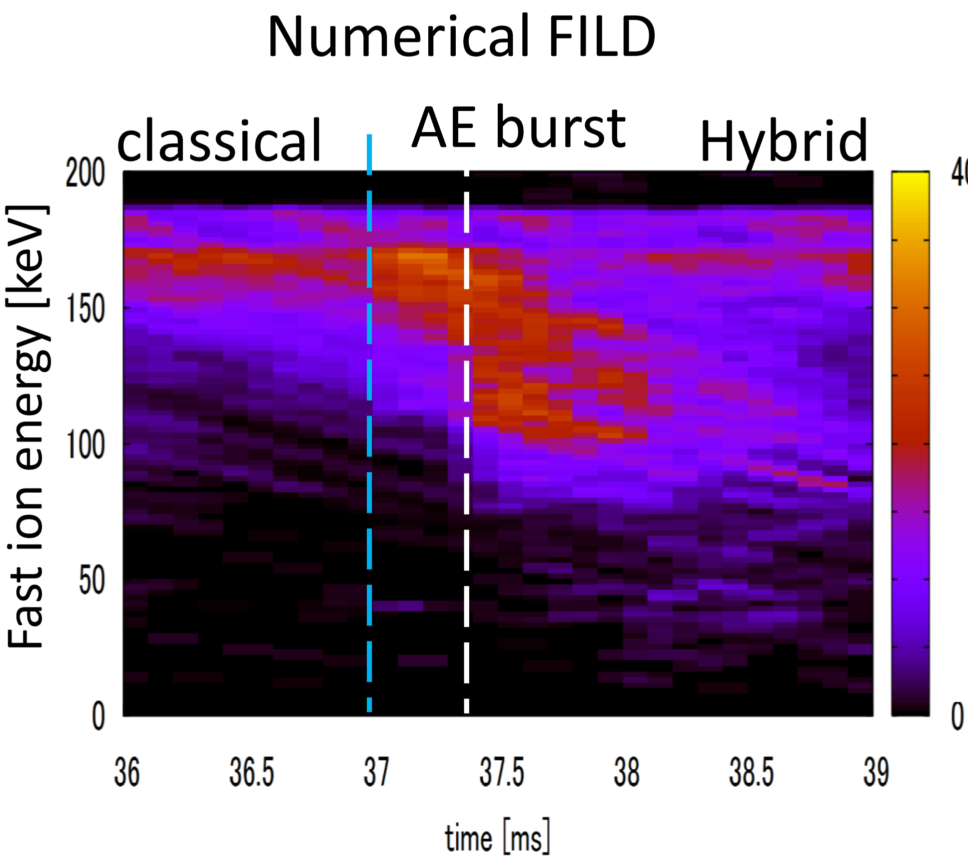
○Most of the fast ions detected by numerical FILD are the re-entering co-passing particles.

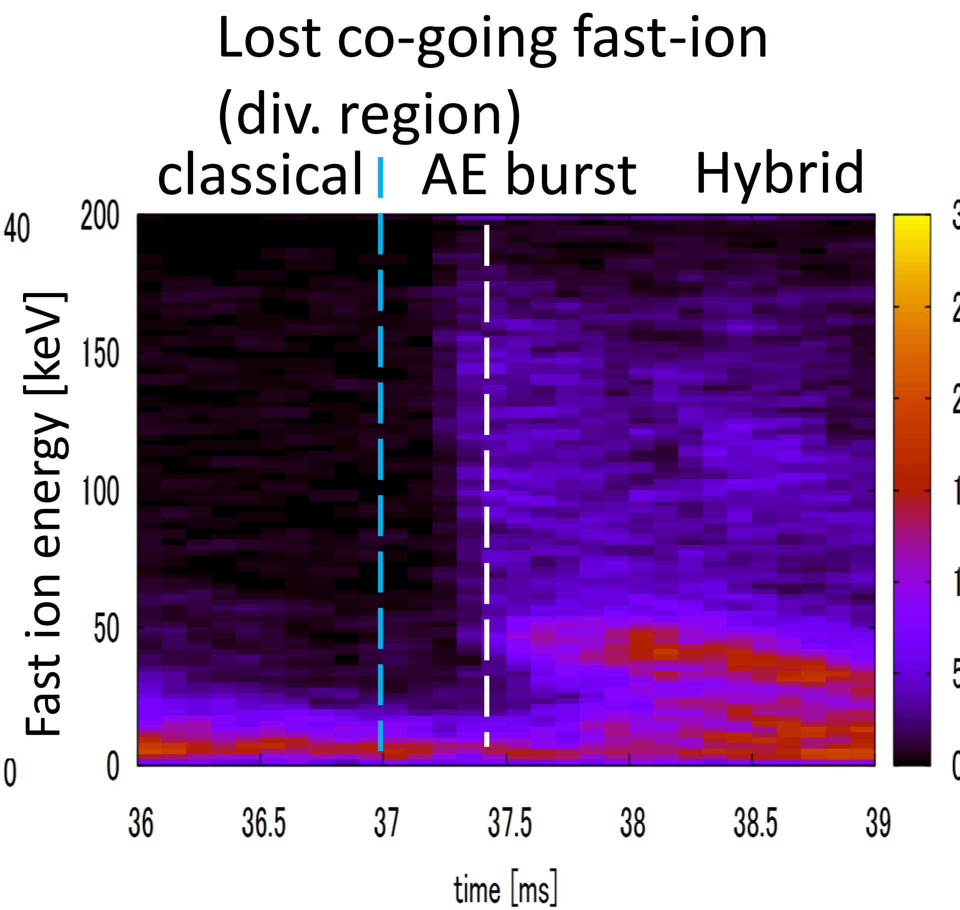
Comparison of lost fast-ion between the Numerical FILD and Lost fast-ion



○ Most of fast-ions measured by numerical FILD are the re-entering fast-ion deposited near rho~ 0.9.

Comparison of lost fast-ion between the Numerical FILD and Lost fast-ion





○During AE burst, fast ion with lower energy(~100 keV) than injection energy (~180 keV) was detected by numerical FILD.

○The main component of lost co-going fast-ions at the loss boundary are the particles with E< 50 keV.

Summary

○MEGA is applied to the Large Helical Device experiments with the realistic condition close to the experiment.
○ Fast ion driven instabilities and lost fast ion properties are investigated.
○ Lost fast ion velocity distribution in the simulation is compared with the FILD measurement.

●**The increment of the fast ion loss rate is proportional to the square of AE amplitude.**

●**The velocity space region of lost fast ions calculated by MEGA is close to the lost fast ion measurements by FILD.**

●**Lost fast-ion at the FILD are different from those at the divertor region.**

・During AE burst, fast ion with lower energy than injection energy was detected by numerical FILD.
・ The main component of lost co-going fast-ions at the loss boundary are the particles with E< 50 keV.