Observation of Confinement Degradation of Energetic Ions by Alfvén Eigenemodes in Weak Shear Plasmas on JT-60U

Presented by
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Introduction

Burning plasmas are self-sustained by **alpha-particle heating**

However, a high alpha particle pressure gradient destabilized

Alfvén eigenmodes (AEs)

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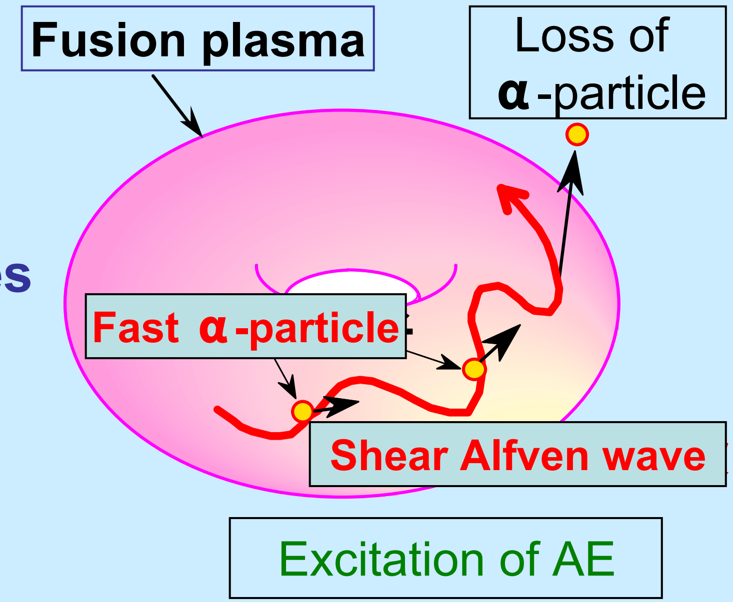
AEs induce

the enhanced transport of alpha-particles from the core region

- A **performance of a fusion reactor is degraded**
- **First walls are damaged by lost alpha-particles**



⇨ Understanding of the alpha particle transport in the presence of AEs is one of the urgent research issues for ITER

Recent studies of AEs on JT-60U

In JT-60U, AE experiments have been performed using

Co-injected *Negative-ion-based Neutral Beam (NNB)*

(E_{NNB} : 340 ~ 400keV, P_{NNB} :2 ~ 5MW)

in several kinds of magnetic shear configurations

- **in Reversed shear (Weak Shear) plasma,**
  - **Reversed-Shear induced Alfvén Eigenmodes (RSAEs),**
  - **Transition from RSAEs to TAEs**

(M. Takechi, et al, POP 12(2005),082509)

- **in Weak shear plasma with large β_h**
  - **Fast FS modes,**
  - **Abrupt Large-amplitude Events (ALEs)**

(K. Shinohara, et al.,Nucl. Fusion 41(2001) p603)

RSAEs (Alfvén cascades) and its transition to TAEs

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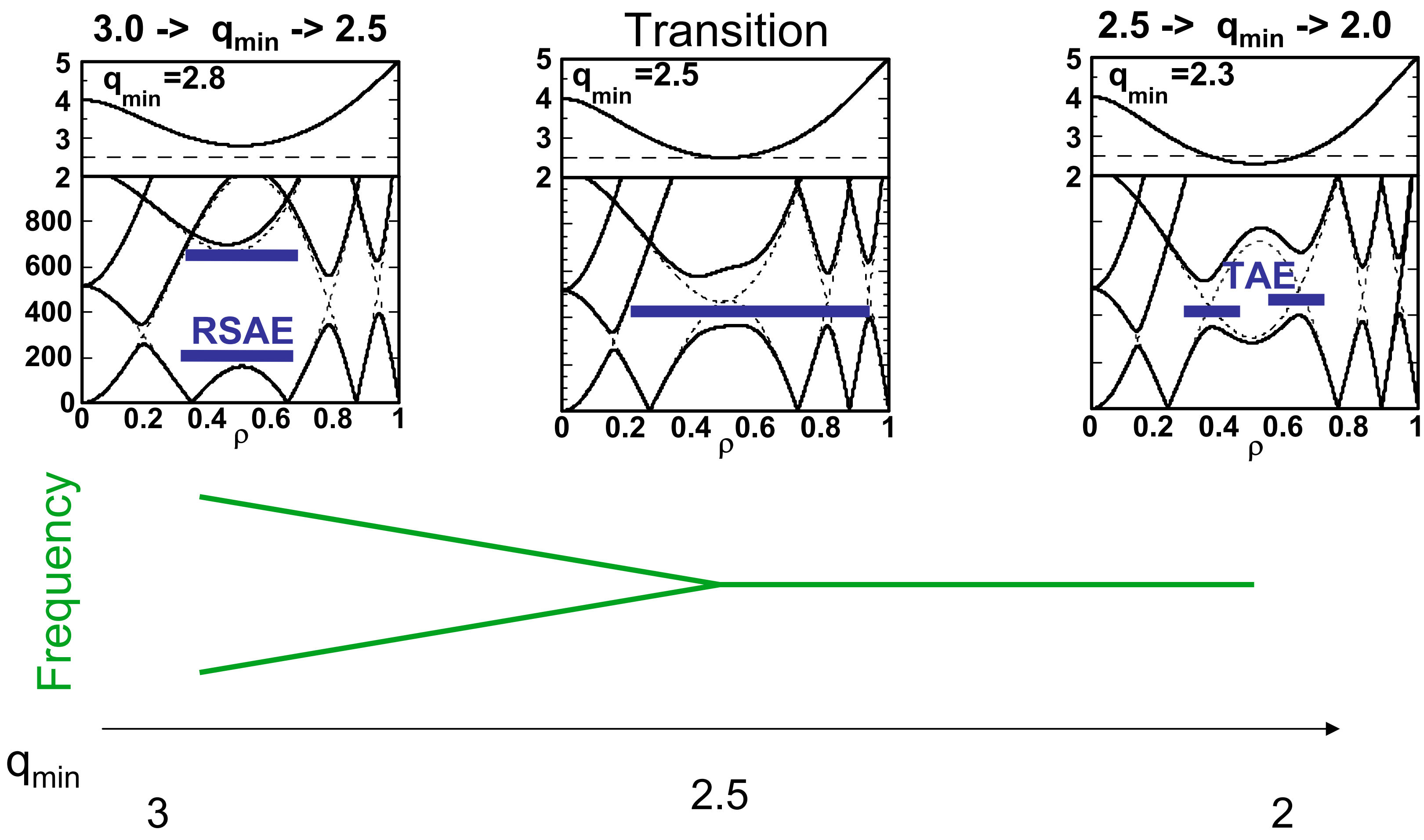
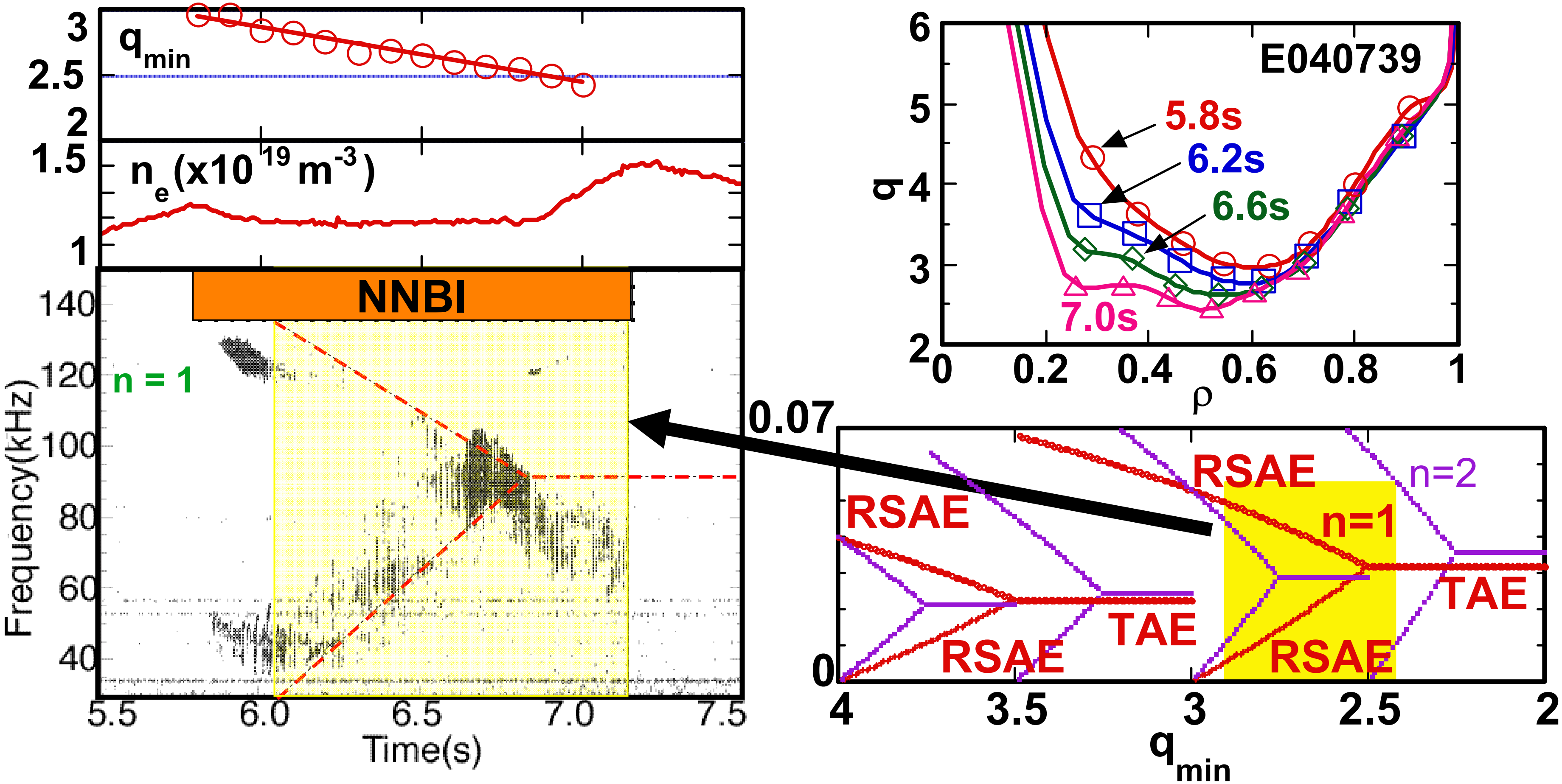
(M. Takechi, et al, POP 12(2005),082509)

- Case of reversed-shear configuration with q_{min} ~ 3.0 -> 2.0



Large frequency sweeping AE can be explained by RSAE

- **Large frequency sweeping AE was observed during NNBI in RS plasma**
- **High frequency RSAE and low frequency RSAE merge and change to TAE when q_{min} decreases.**



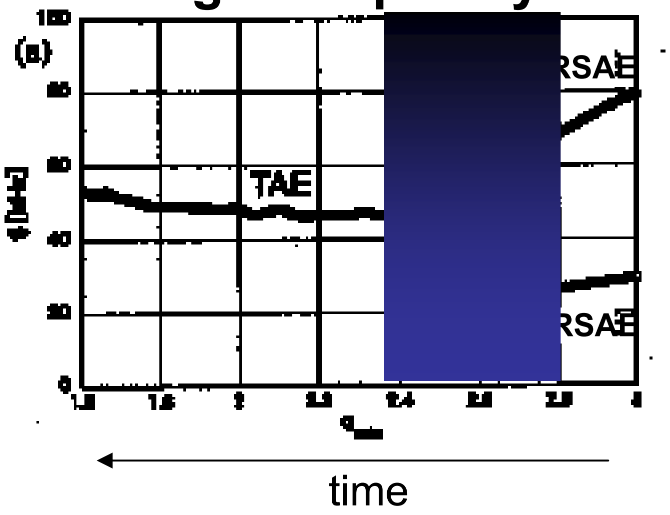
TASK/WM predicted AE transition from RSAE to TAE is most unstable

the full wave code (TASK/WM) [1]

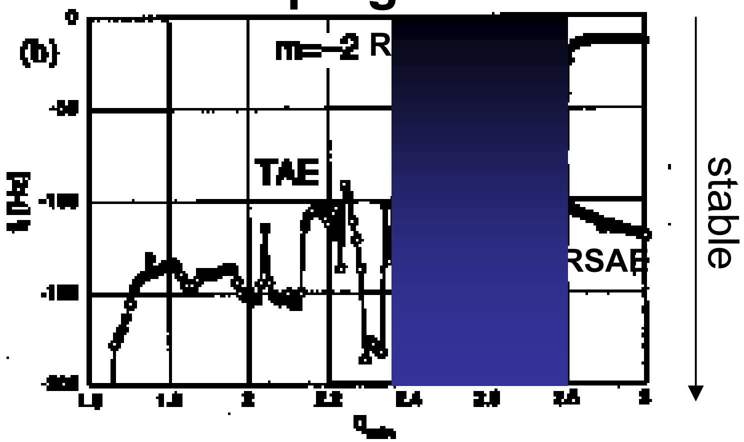
- eigenfrequency, damping rate, eigenfunction

RSAE frequency changes rapidly as q_{min} changes.
RSAE more unstable than TAE.
AE in transition from RSAE to TAE is most unstable.

Eigenfrequency



Damping rate



[1] A. Fukuyama et al, in proceeding of 6TH IAEA Technical Committee Meeting on Energetic Particles in Magnetic Confinement Systems (12~14 October 1999, Naka)

n=1 AE during the transition from RSAE to TAE has largest mode amplitude

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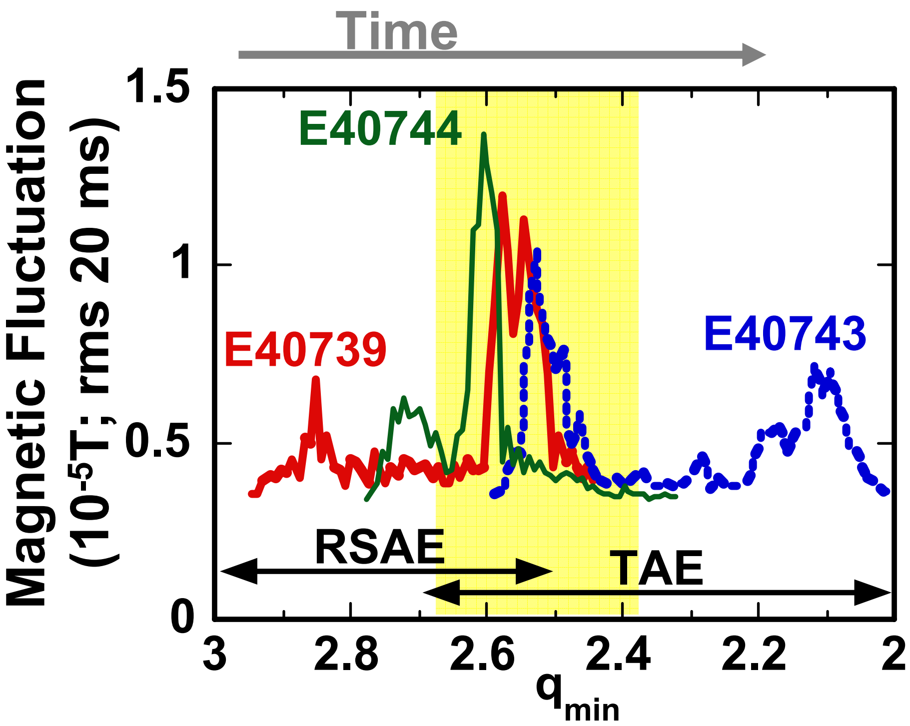
To investigate dependence of AE amplitude on q-profile, starting time of NNB injection into RS plasmas was changed at various q_{min}



n=1 AE is observed

n=1 AE amplitude is maximum at ~2.4 < q_{min} < ~2.7,
independent of time length
after NNB injection

AE during transition from RSAE to TAE is most unstable

The results are consistent with the prediction by TASK/WM

Purpose of present studies

AE with large frequency sweeping and its frequency saturation can be explained as RSAE (AC) and its transition to TAE

- TASK/WM predicted AE during transition RSAE to TAE is most unstable
- It is confirmed experimentally that n=1 AE amplitude is maximum during transition phase RSAEs to TAEs

- Issues

Confinement degradation of energetic ions in the presence of RSAE and TAE has not been evaluated yet.

⇨ Diagnostics for investigation of energetic ion transport

- total neutron emission rate
- neutron emission profile measurement
- charge-exchange neutral particle flux

Diagnostics for investigation of energetic ion transport

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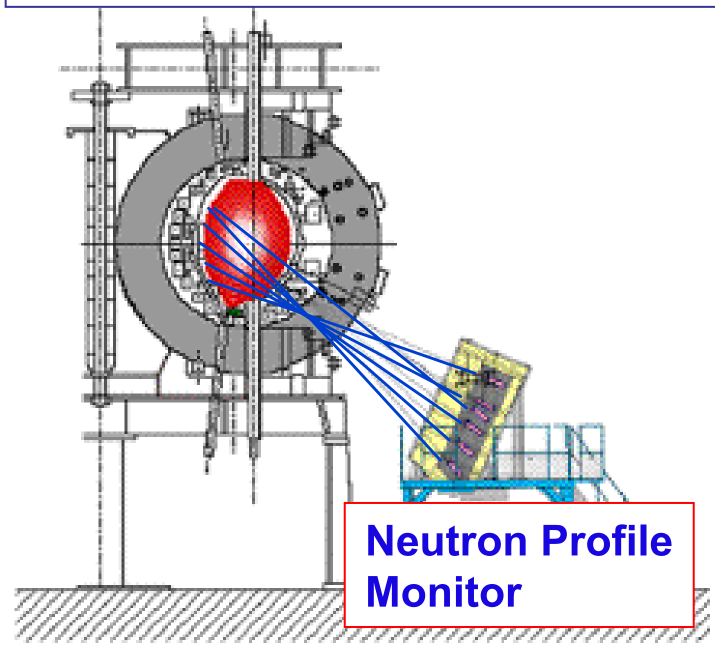
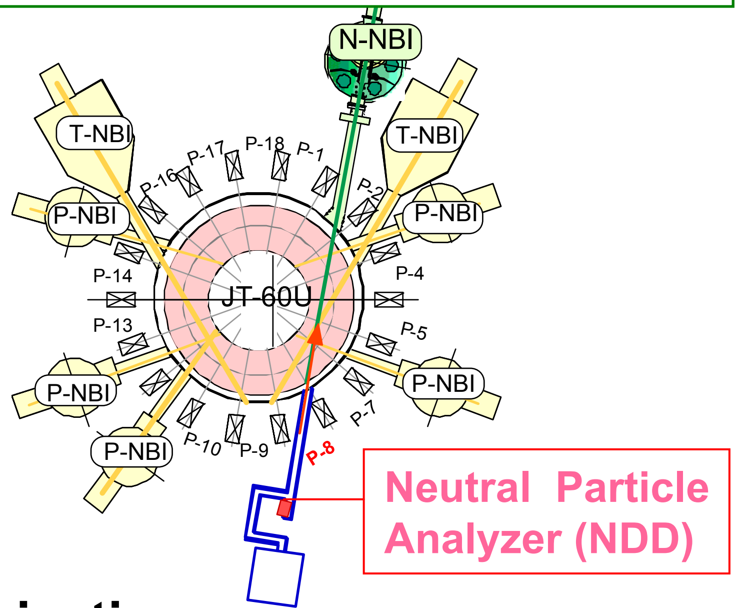
6 channel Neutron monitor



Objectives :

-measure radial profile of neutron emission rate

CX-Neutral Particle Analyzer (Natural Diamond Detector)



Objectives :

-measure fast neutral particle flux and energy distribution

⇨ investigate energetic ion transport from change in neutron emission profile and enhanced neutral particle fluxes

System of neutron emission profile measurement

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M. Ishikawa, et al. Rev. Sci. Instr. 73 (2002)4273

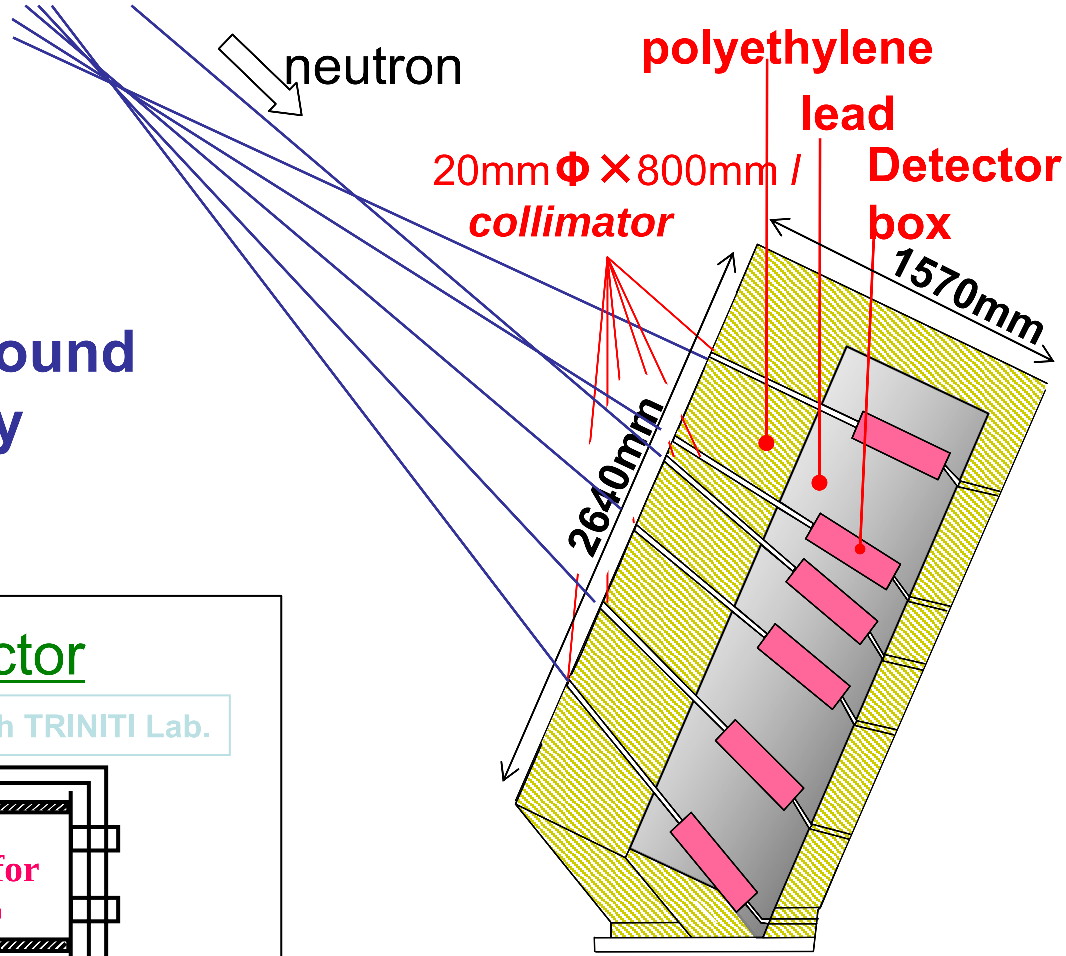
The collimator consists of

polyethylene

-for neutron shielding

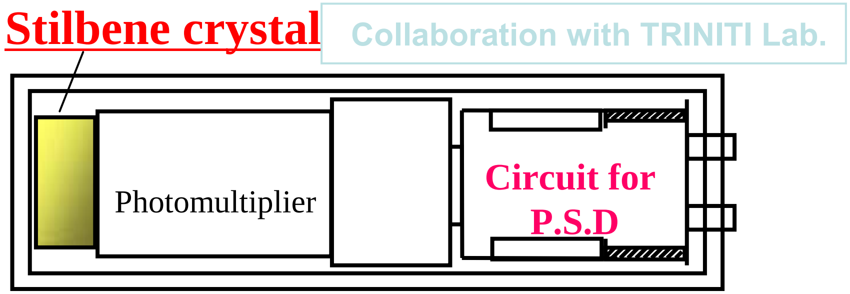
lead

-for reduction of background and capture gamma-ray



< detector >

Stilbene neutron detector



Structure of Stilbene neutron detector

6 channel line-integrated neutron signals

System of neutral particle flux and spectrum measurement with Natural Diamond Detector (NDD)

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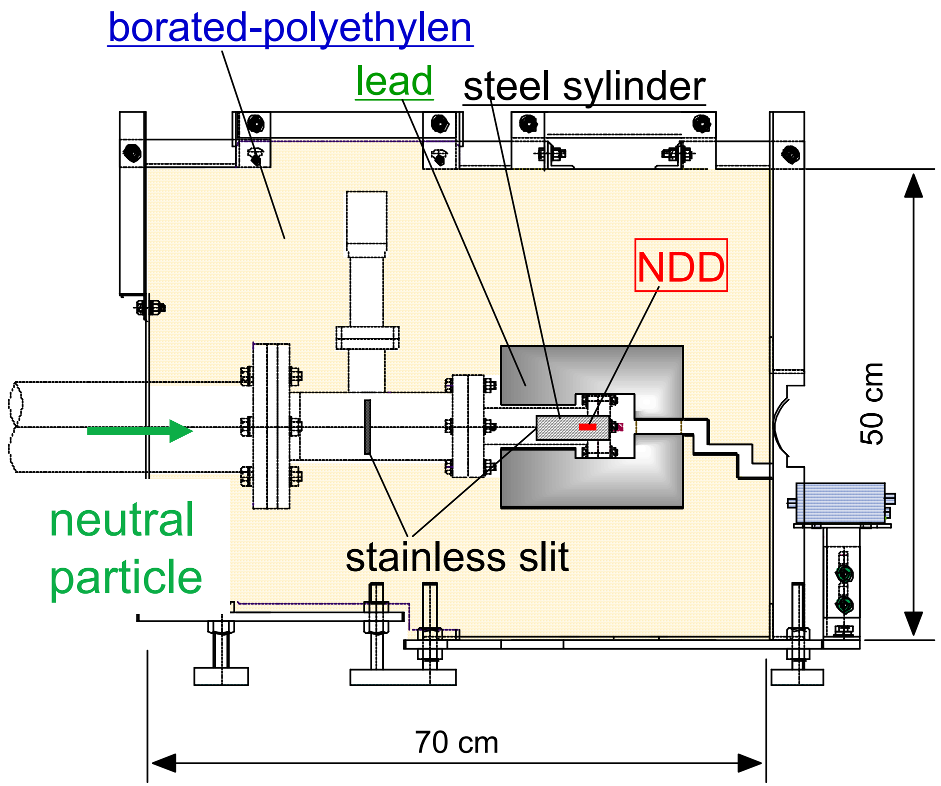
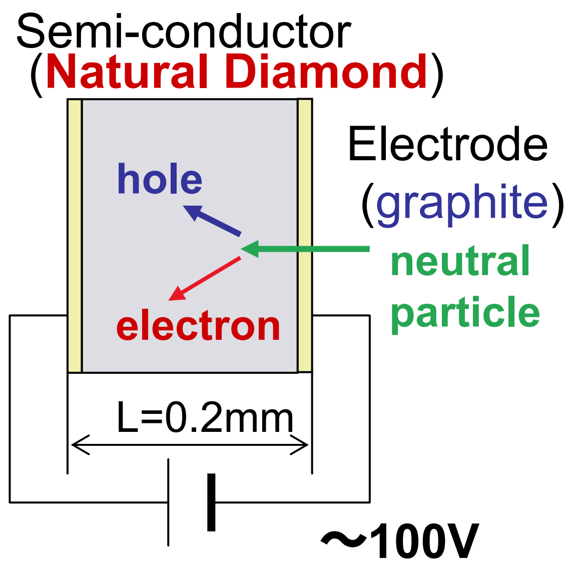
M. Ishikawa, et al. Rev. Sci. Instr. 75 (2004)3643

The system has been installed in parallel port to investigate behavior of co-injected beam ions,e.g. NNB ion



NDD is a solid-state detector



NDD produces a number of electron-hole pair corresponding to kinetic energy of incident natural particles

⇨ **flux and energy distribution**

Recent studies of energetic ion transport using

- neutron emission profile measurement
- CX-neutral particle flux and spectrum measurement

Energetic Ion Transport due to ALE in WS plasmas

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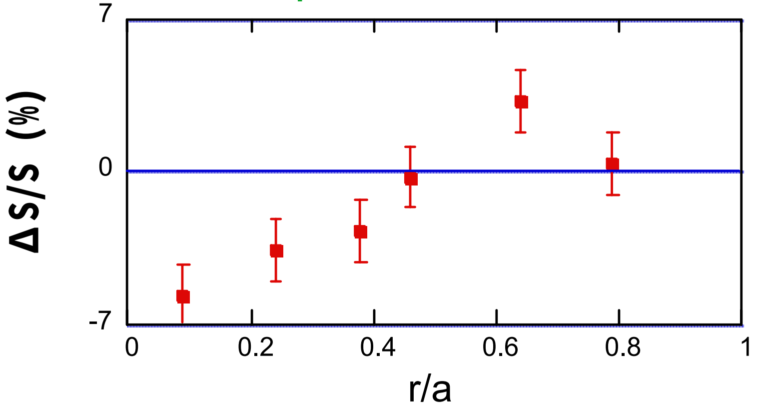
When bursting modes called Abrupt Large-amplitude Events (ALEs) were exited,

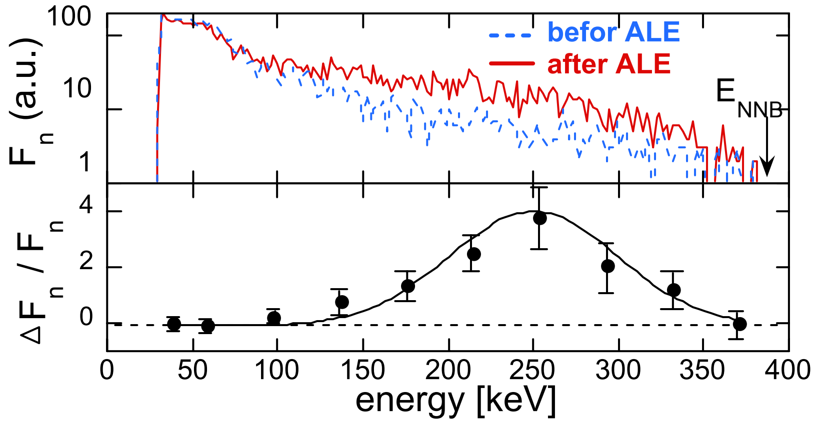
(M. Ishikawa, et al. Accepted for Nucl. Fusion (2005))

- Peripheral signals increase and center signals decrease
- Only ions in limited energy are affected.
  =>Agrees with AE resonant condition

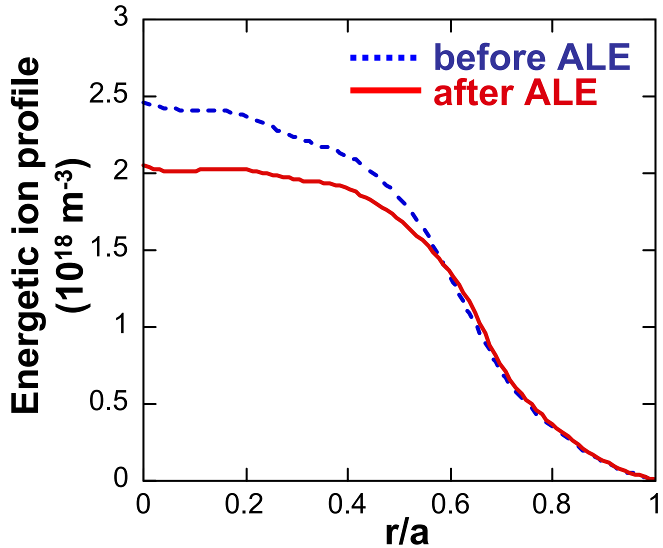
Averaged change rate of neutron emission profile measurement



energy distribution of neutral particle



<energetic ion profile>

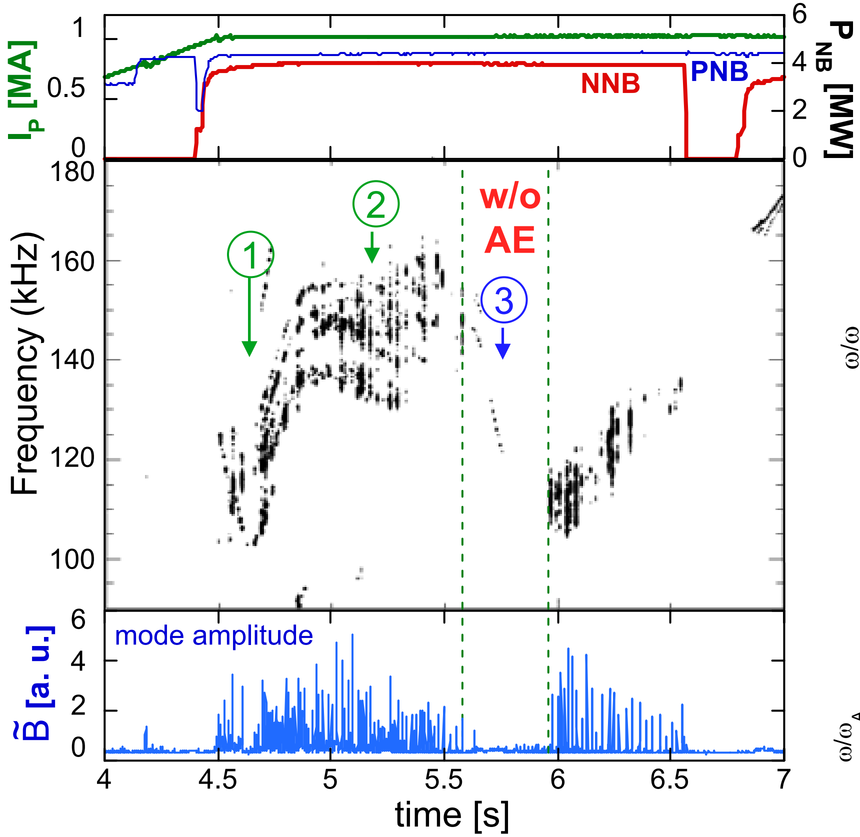


ALEs expel a significant energetic ion population from core to the outer region (redistribution and loss)

AE experiments with NNB in WS plasmas to investigate effect of RSAE on energetic ions

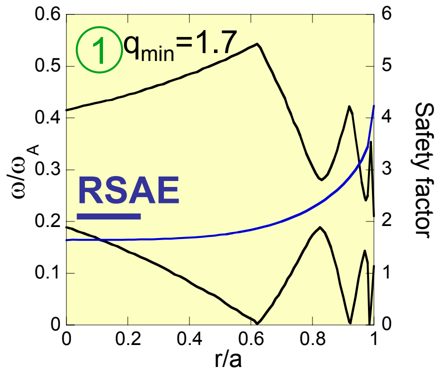
Observation of two phases of with AEs (RSAEs, TAEs) and w/o AEs in Weak Shear Plasma

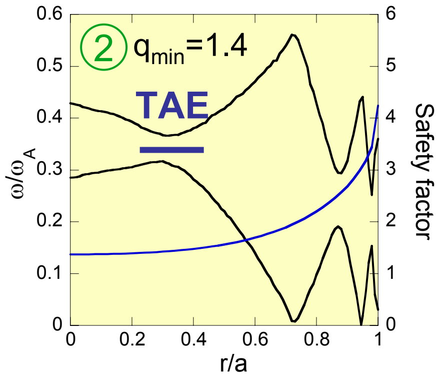
E43978, I_P=1.0 MA, B_T=1.7 T
P_{NNB}~ 3.9 MW, E_{NNB}~367 keV
duration time of NNBI ~ 2.2 s

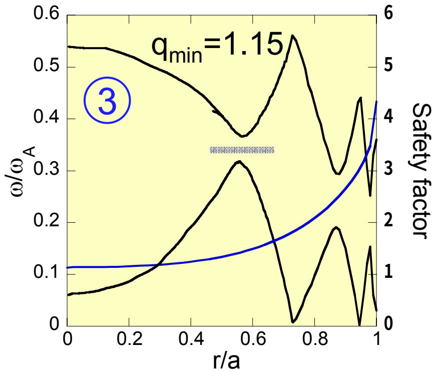


- Frequency sweeping and then saturation of frequency is observed during NNB injection.

-These instabilities are stabilized at t ~ 5.5 s







q = 1.5 exist in outer region
There is TAE gap
but, β_h and $d\beta_h/dr$ is small

AEs are stable

Change in total neutron emission rate suggest confinement degradation of energetic ions

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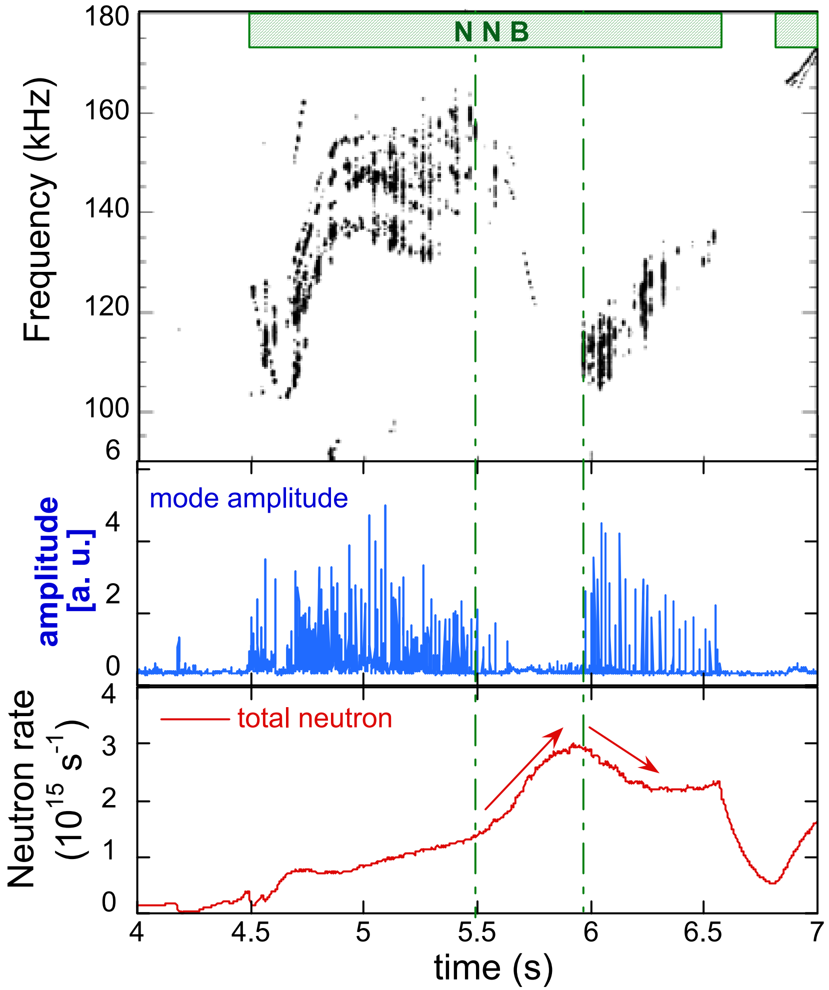


- During RSAEs, TAEs (t ~ 4.5 – 5.5 s)

  An increase of total neutron emission rate (S_n) was suppressed

- After TAEs are stabilized (t ~ 5.5 s)

  The rate of the increase of S_n is enhanced rapidly.

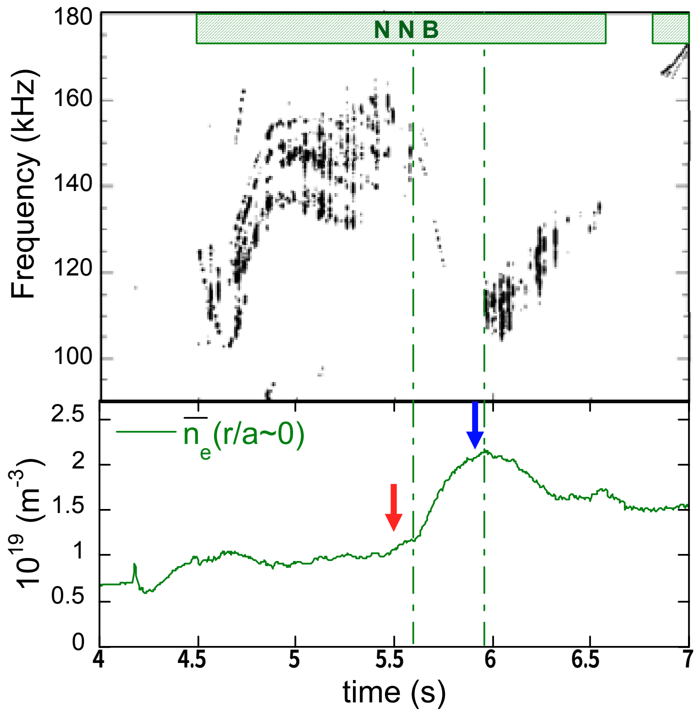
- During another RSAEs (t ~ 5.9 – 6.5 s)

  S_n decrease

suggests confinement degradation of energetic ions due to AEs

(If the bulk plasma does not change)

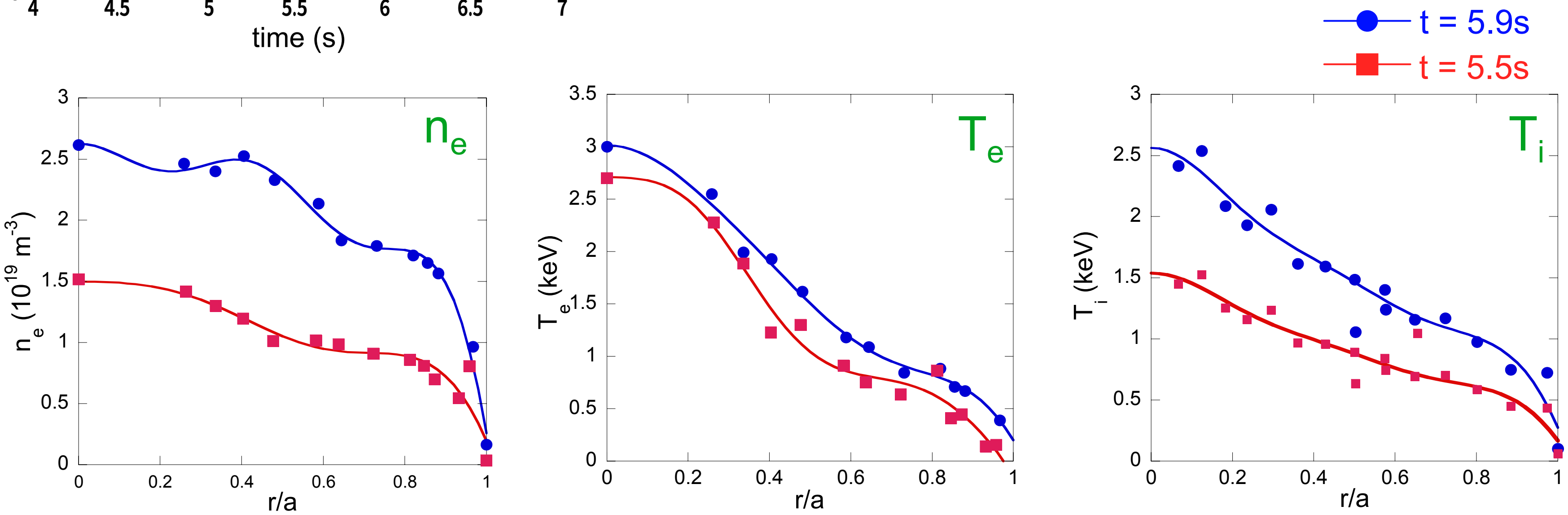
Bulk plasma is changed due to observed AEs



Each parameter of bulk plasma,
ne(r), Te (r), Ti (r) all increase
after TAE was stabilized at t ~ 5.5s.

Is the change in S_n attributed to the changes in density and temperature of bulk plasma ?

evaluation of change in energetic ions

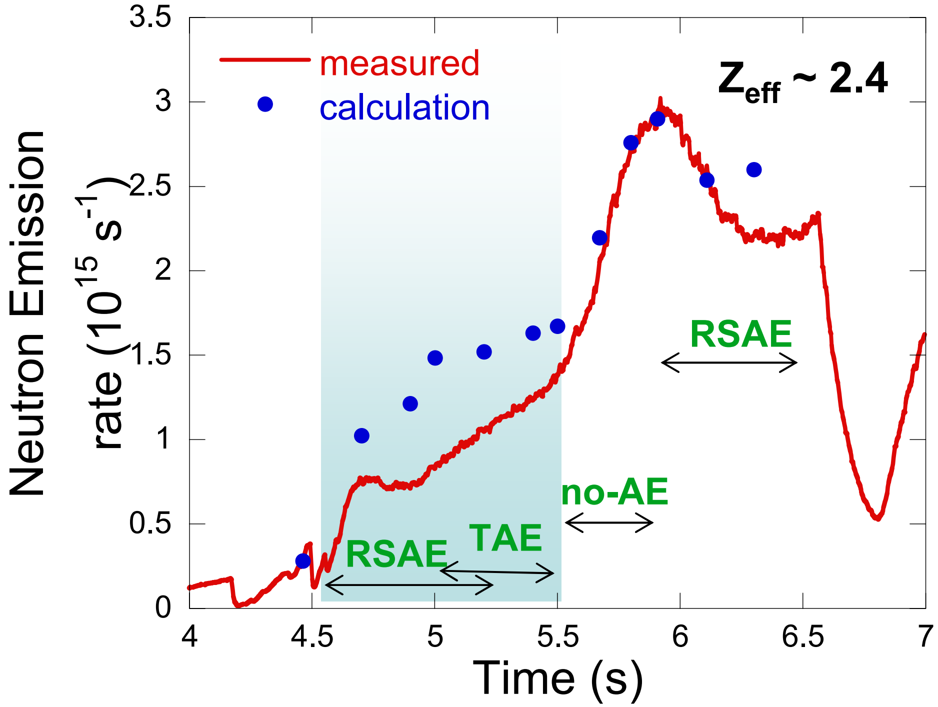


Confinement degradation of energetic ions due to AEs is observed

Neutron emission rate is calculated with OFMC code assuming as follows

- Energetic ion profile in the calculation are classical
- Neutron emission is only beam-thermal neutron

(**beam-thermal neutron rate accounts for ~ 90% of total neutron rate**)



- **Measured neutron emission rate is larger than calculated one (classical) during RSAE and TAE.**
- **After TAE was destabilized, measured neutron rate is close to calculated one.**

confinement degradation of energetic ions

Neutron reduction is largest in transition phase from RSAE to TAE

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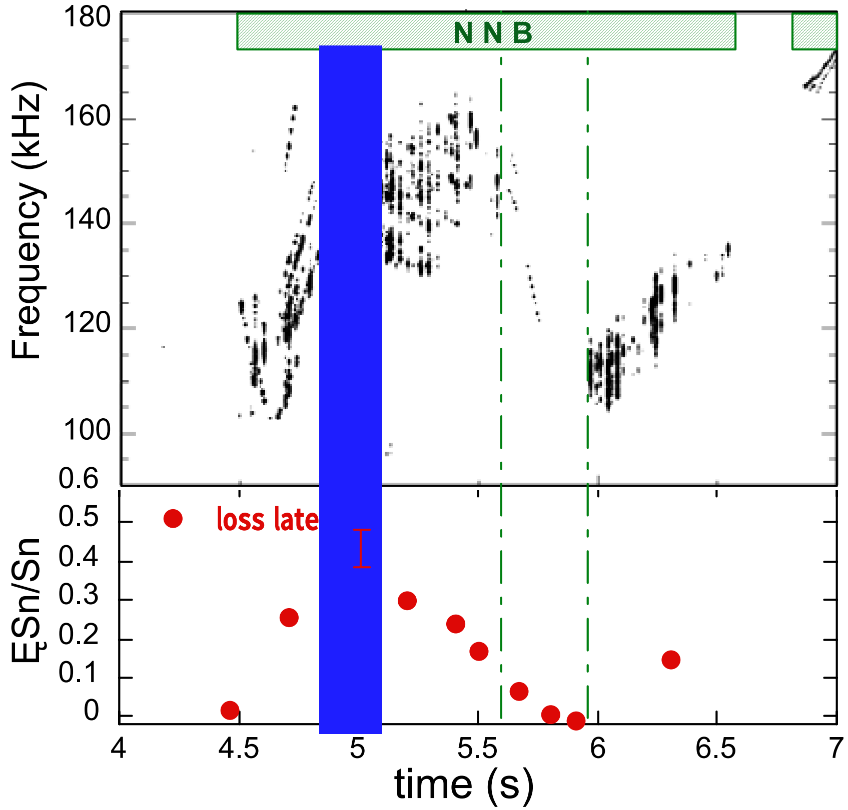
- reduction late of neutron emission is evaluated from the ratio of calculated neutron yield to measured one.



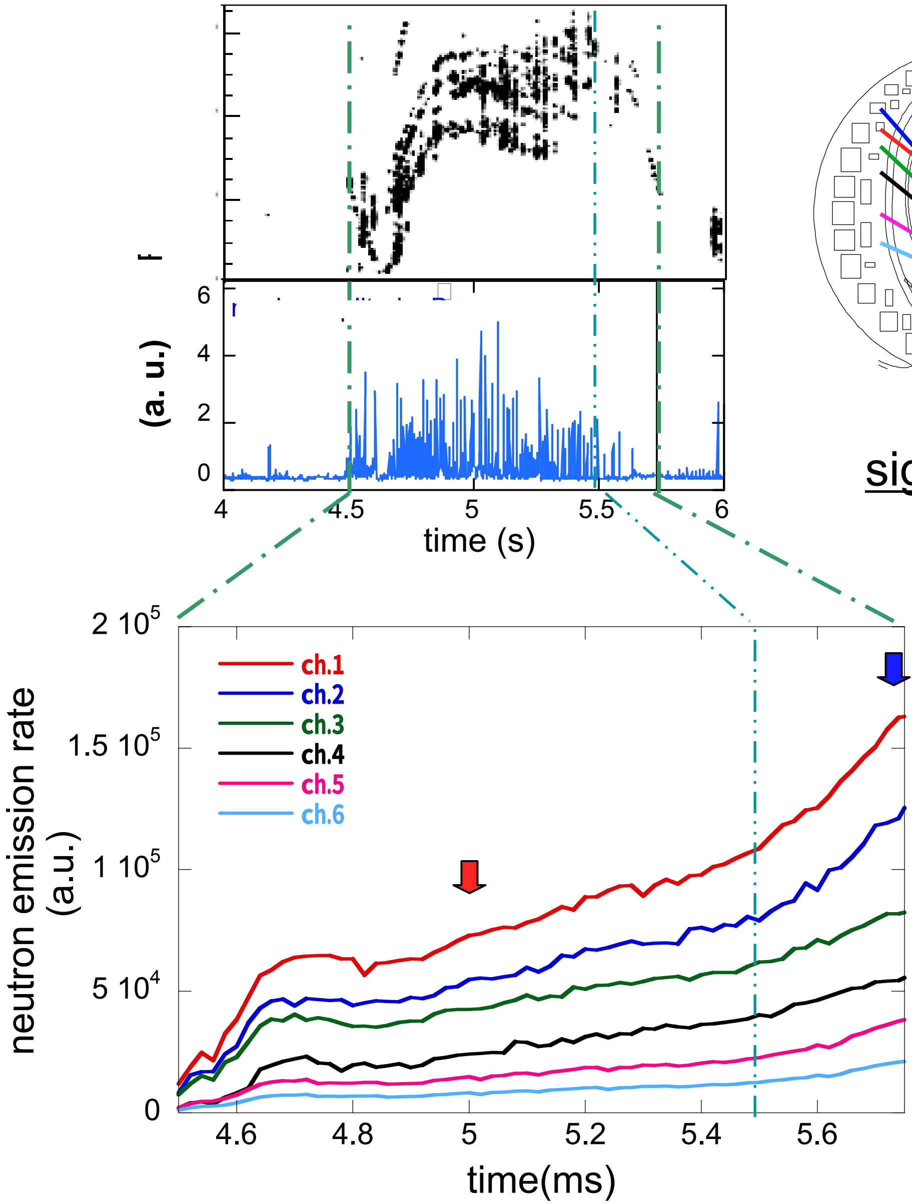
Reduction rate of neutron emission rate is largest in the transition phase from RSAE to TAE.

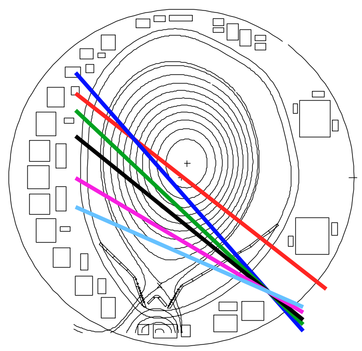
$(\Delta Sn/Sn)_{Max} \sim 45\ \%$

The prediction of TASK/WM supports this result

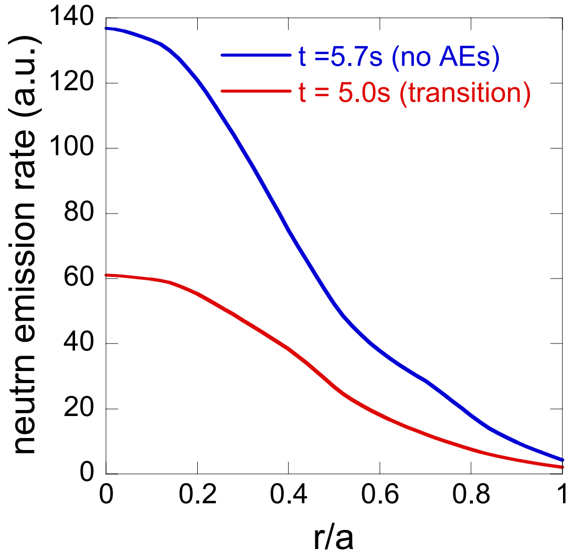
Our interest is how confinement of energetic ions is degraded

All signals of neutron emission profile measurement increase after AEs was stabilized





sight lines



neutron emission is suppressed all over the plasma region

Equation of fusion production

$$S_n = n_{th} n_b \cdot \mathbf{R}$$

In order to investigate energetic ion transport, analysis of change in energy distribution of energetic ions is needed

Change in neutral particle flux suggests energetic ion transport from core to outer region

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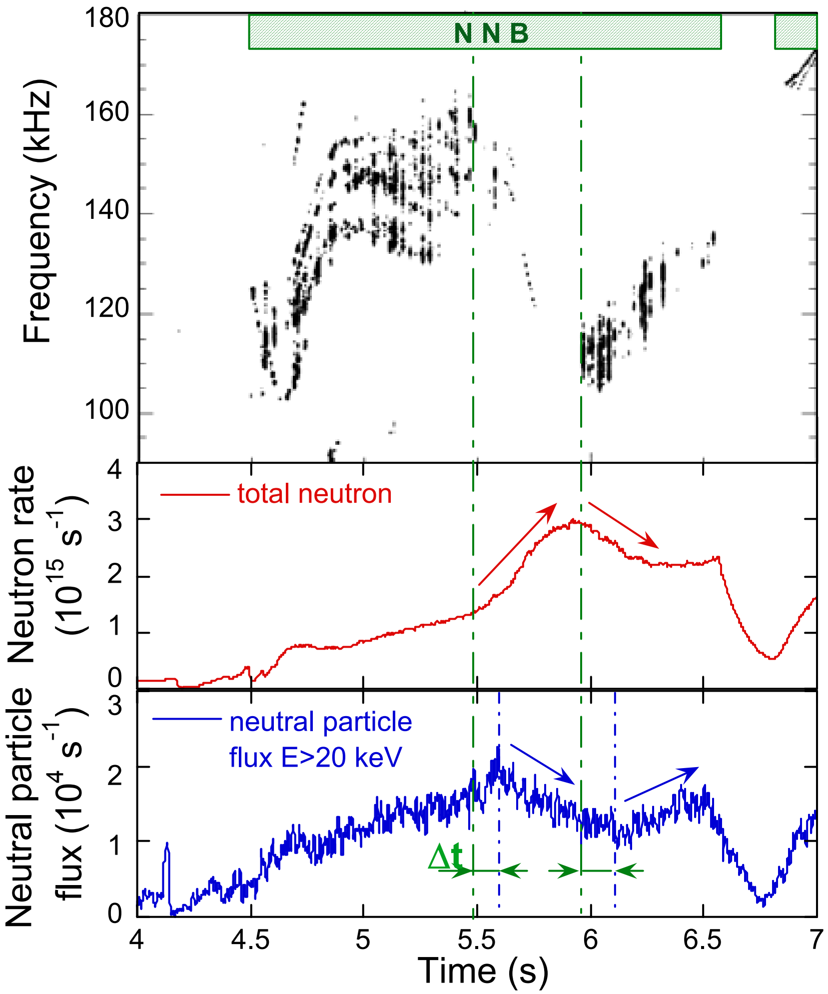
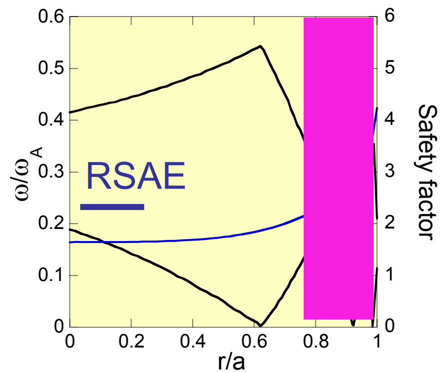


Neutral particle flux change after neutron emission rate changed

Time lag (Δt) ~ 100 ms
time scale of transport and /or slowing down ?

Energetic ions are neutralized through charge exchange reactions with D^0 or C^{5+} <u>in outer region of the plasma</u>



⇨ energetic ion transport from core region to outer region

Summary

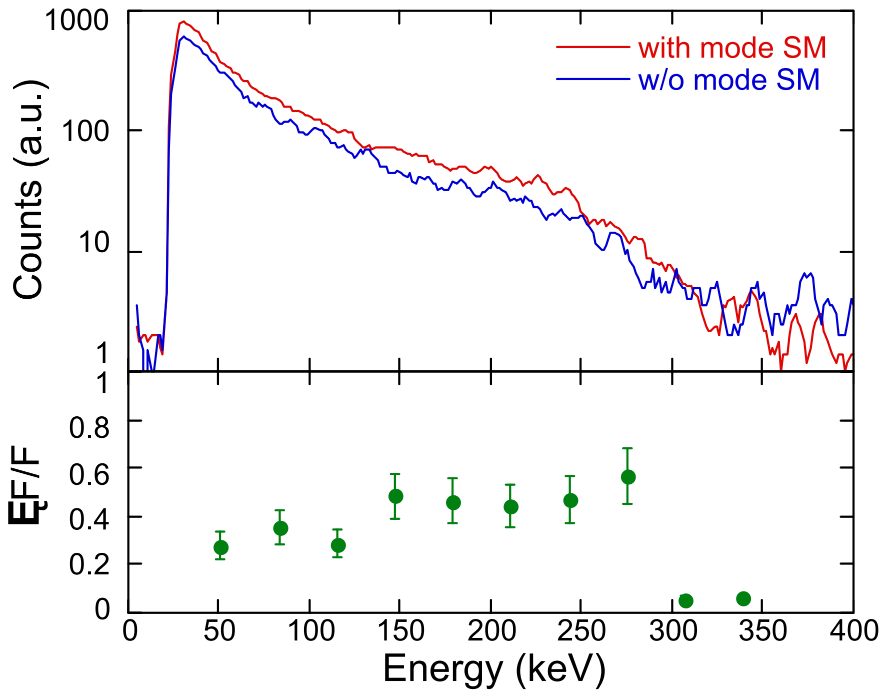
In order to investigate the confinement degradation of energetic ions in the presence of RSAE and TAE, AE experiments with NNB were conducted in WS plasmas, by measuring

- total neutron emission rate
- neutron emission profile
- charge exchange neutral particle flux

- Energetic ions behavior in the presence of AEs was evaluated
- Confinement degradation of energetic ions was observed
- The evaluation with OFMC code indicated the degradation was maximum in transition phase from RSAE to TAE
- Neutron emission is suppressed all over the plasma region due to AEs

  analysis of change in energy distribution of energetic ions is needed
- Changes in neutral particle flux suggested AEs induced energetic ion transports from core region to outer region.

Energy distribution of fast neutral particles



Bursting modes in weak shear plasmas

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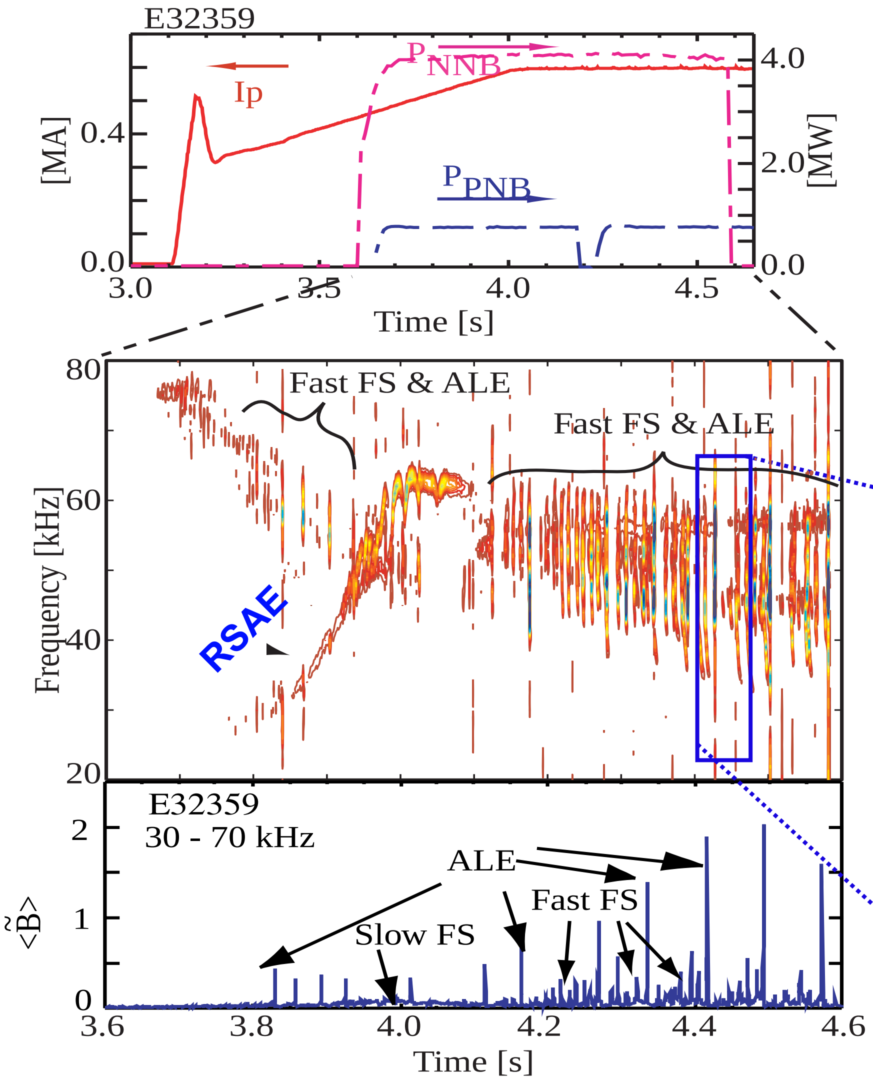
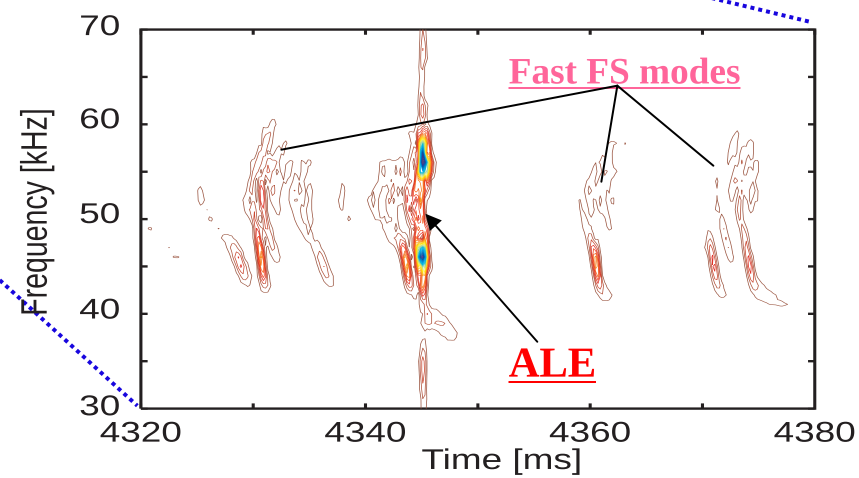
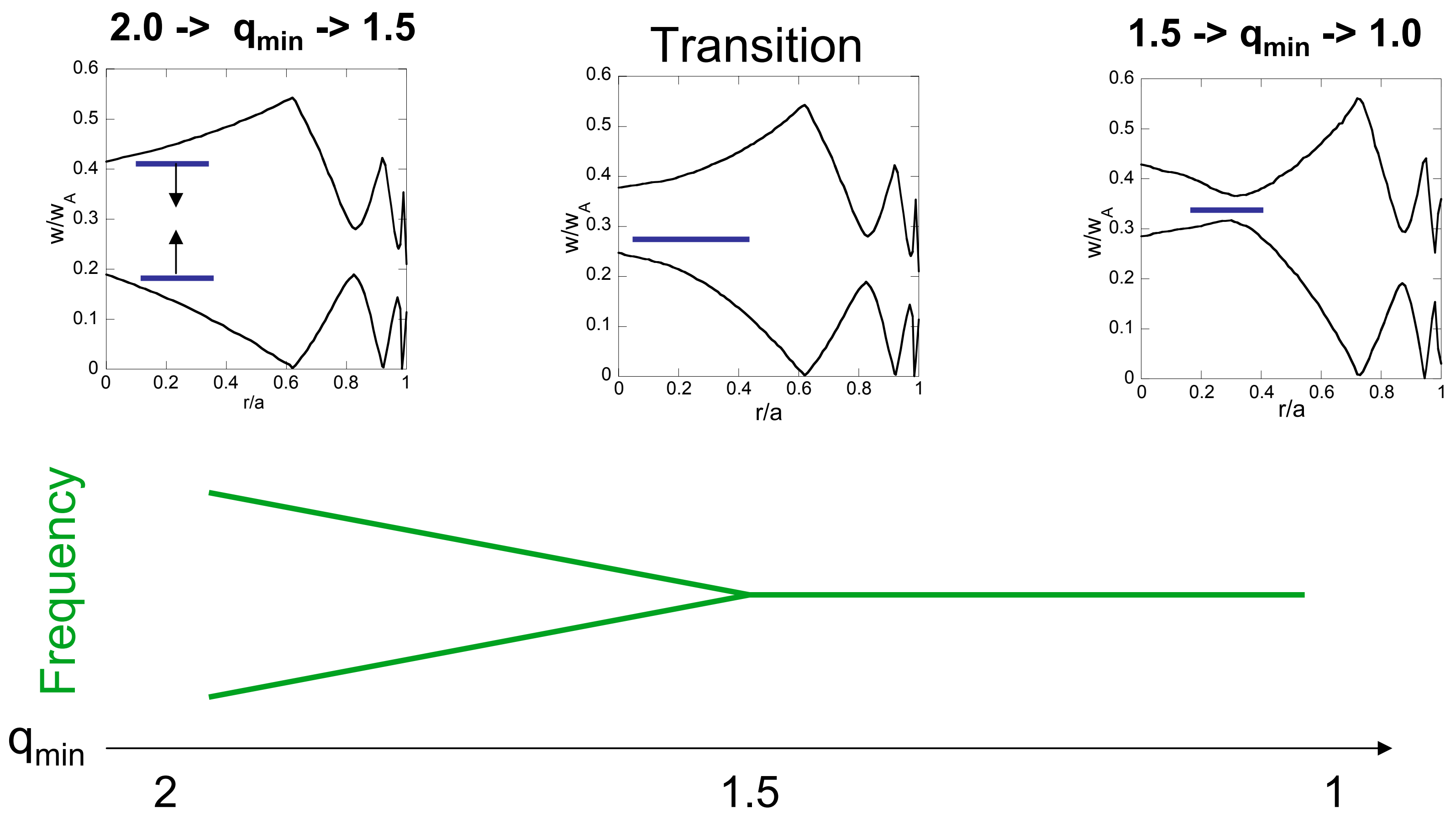
- RSAE and its transition to TAE
- **Fast Fast FS modes** have upward and downward frequency sweep with time scale of 1 - 5 ms
- **Abrupt large-amplitude events (ALEs)** with time scale of 200 - 400 μs. The amplitude reach $B_\theta/B_0 \sim 10^{-3}$





Slow FS modes can be explain by RSAE model

Case of weak shear plasma with q_{min} ~ 2.0 -> 1.0

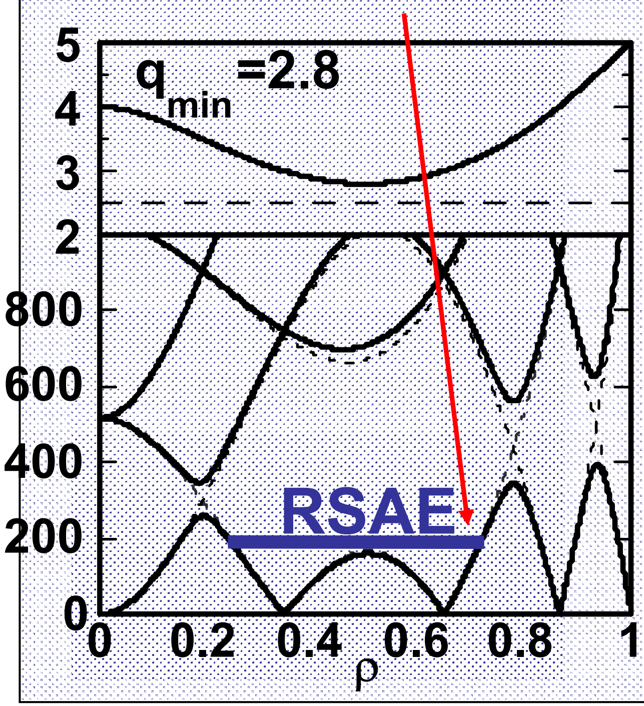


RSAE model can apply to AEs in weak shear plasma

Why AE at the transition from RSAE to TAE has largest mode amplitude?

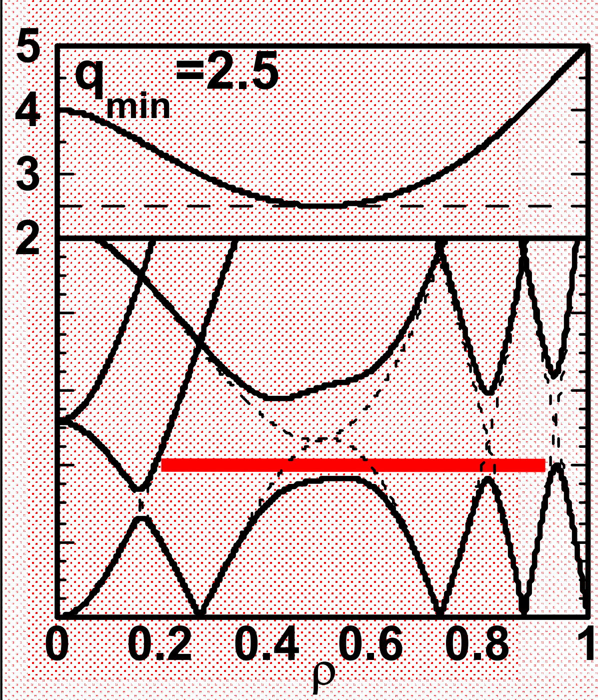
RSAE phase
~2.7 < q_{min} < 3
RSAE is close to the adjacent Alfven continuum

Large continuum damping



Transition phase
~2.4 < q_{min} < ~2.7
A mixture of TAE and RSAE

Weaker continuum damping



TAE phase
2.0 < q_{min} < ~2.4
Two TAE gap
Inner TAE is usually destabilized

Large continuum damping