NSTX

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Correlations of Neutral Particle Analyzer Diagnostics with Instability Bursts

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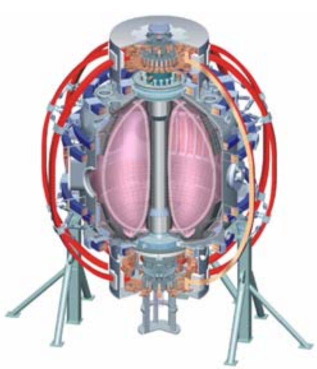

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Abstract

The extensive set of fast-ion diagnostics [neutron detectors, E||B-type neutral particle analyzer (NPA), four-chord solid state neutral particle analyzer array (SSNPA) and Fast-ion D-alpha diagnostic (FIDA)] on National Spherical Torus Experiment (NSTX) provides a good test-bed for the study of fast ion confinement. A cross-correlation analysis has been performed on the NSTX 2007 and 2008 run campaign data in order to find the correlation between NPA/SSNPA signals and instability bursts. It is shown that sawteeth and large fishbones often cause bursts at outer chords of SSNPA and NPA and drops in the neutron rate, which indicate fast ion loss. It is also observed that Toroidicity-induced Alfven Eigenmode (TAE) avalanches always cause bursts at some chords of SSNPA and that high energy channels respond earlier than low energy channels. Examples of experimental data will be presented along with physical explanations.

** This work was supported at PPPL by DOE contract DE-AC02-76CH03073 and US DOE Grant DE-FG03-02ER54681.*

Motivation

➢**Due to intrinsic low magnetic field, NSTX is susceptible to fast ion driven instabilities and many are already observed on NSTX (for example, sawtooth, fishbone and TAEs, TAE avalanches).**

➢**Fast ion instabilities are important for fusion reactors**

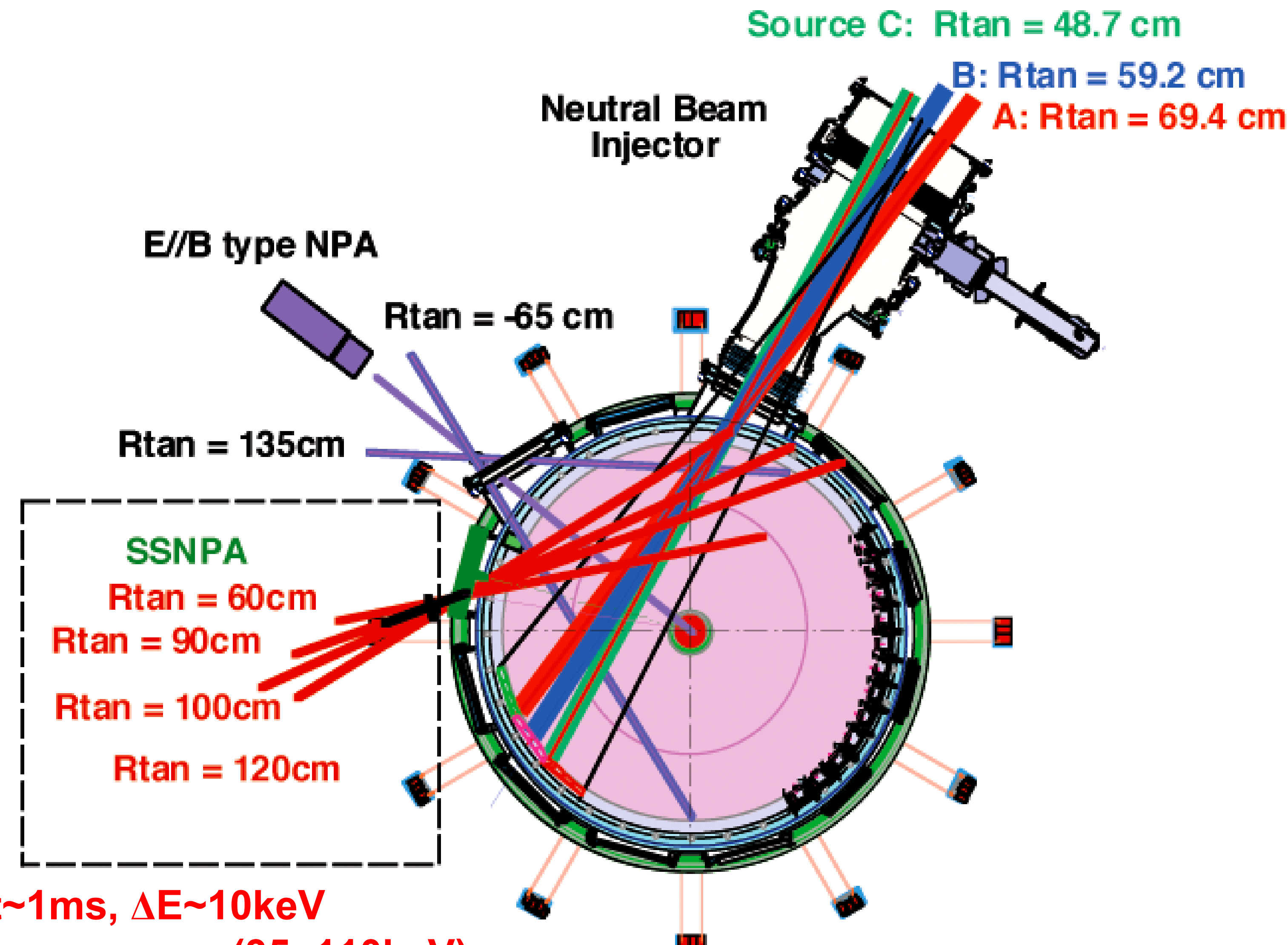
- **Because fast ions in NSTX are super-Alfvenic and the orbits are large, they may, impact plasma performance and confinement.**
- **Dimensionless parameters of fast ions similar to 3.5 MeV α in DT spherical tokamak.**

➢**Need to understand instability drive and loss mechanisms in spherical torus, which may differ from those in conventional Tokamaks.**

➢**Comprehensive set of experimental and theoretical tools can be used for NSTX.**

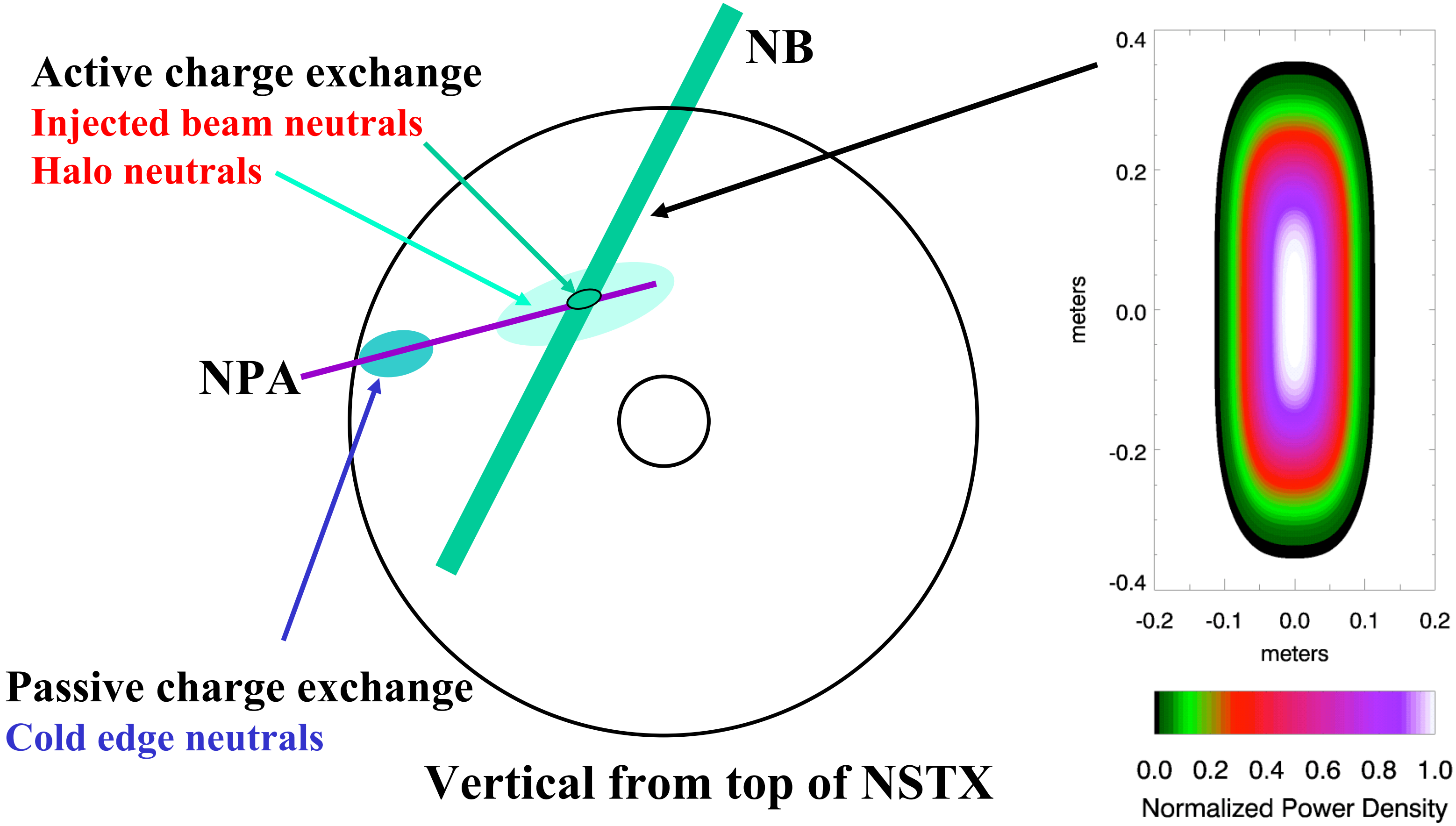
- **Diagnostics: E||B type NPA, multi-sightline solid state NPA, neutron diagnostic, Mirnorv diagnostic, multi-sightline FIDA diagnostic, soft x-ray diagnostic**
- **Theories and simulations: theories in conventional Tokamaks, Orbit code, NPA and FIDA diagnostic simulation code**

NSTX has Four NPA Sightlines that Intersect the Three Heating Neutral Beams and One Sightline that Misses the Beams



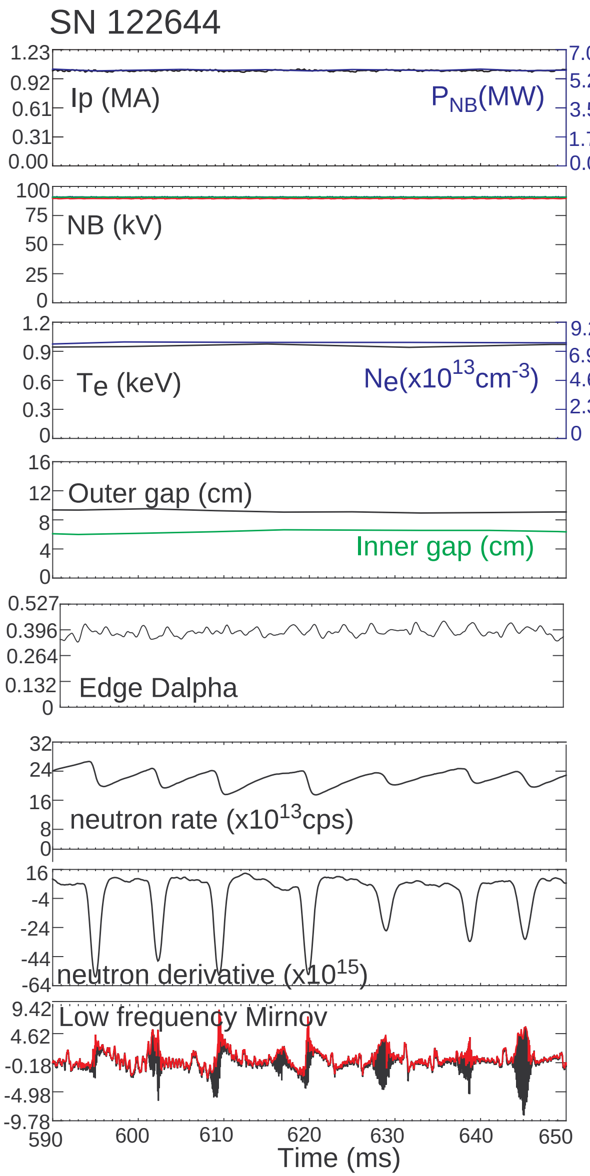
Δt~1ms, ΔE~10keV
Energy range (35~110keV)

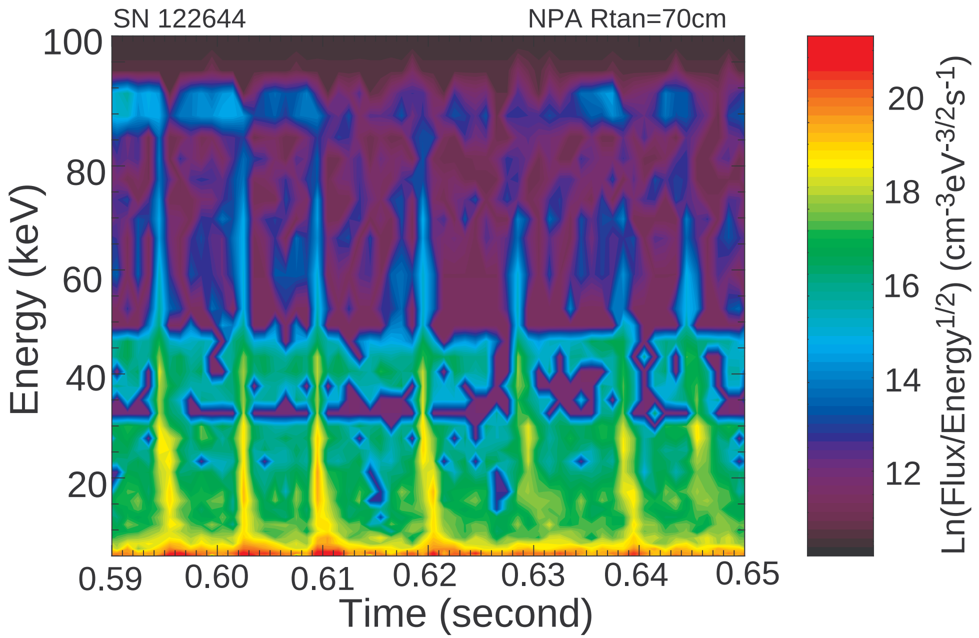
NPA Diagnostics Measure Fast Ions that Charge Exchange with Three Kinds of Neutrals



- ➢In general, NPA flux is mainly from active charge exchange reactions for sightlines that intersect with neutral beams.
- ➢For sightlines that miss neutral beams or during beam off period, signals from passive charge exchange reactions dominate.

Shots with Repetitive Instability Bursts are Chosen for this Study





Shots and time windows selection criteria:

➢**Repetitive instability bursts in Mirnov signals.**

➢**Constant plasma parameters (current, NB power, T_e, N_e and outer gap width)**

Coherence Technique is Useful for Detecting Temporal Correlation of NPA diagnostic with Instability Bursts

➢ **A series of repetitive instability bursts can increase the signal to noise ratio of NPA diagnostic**

➢ **The normalized cross-correlations of neutron derivative and NPA/SSNPA P_{xy} is defined as**

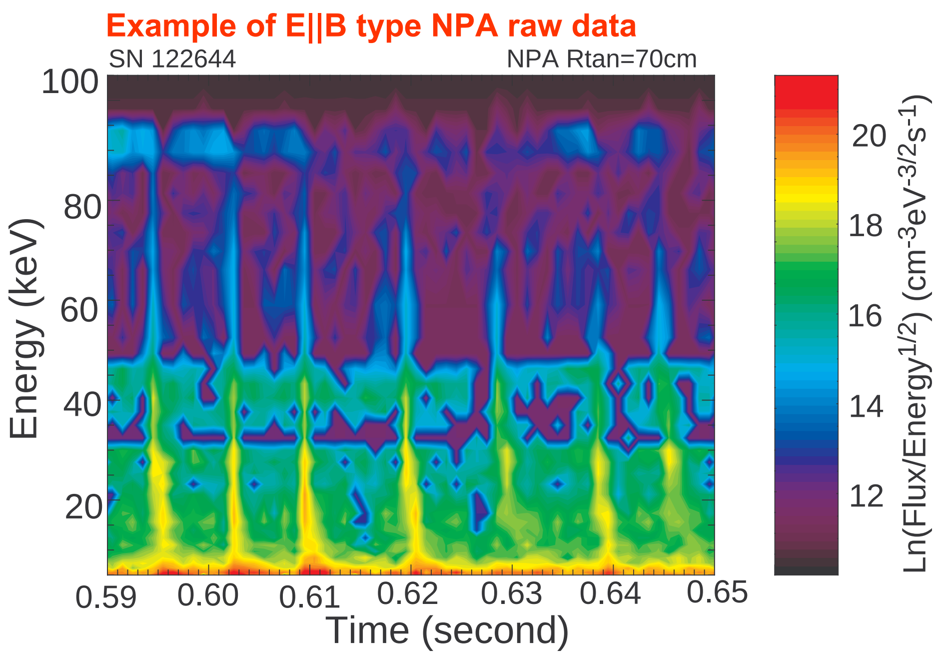
$$P_{xy}(l) = \frac{\sum_i (x_i - \bar{x})(y_{i+l} - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$

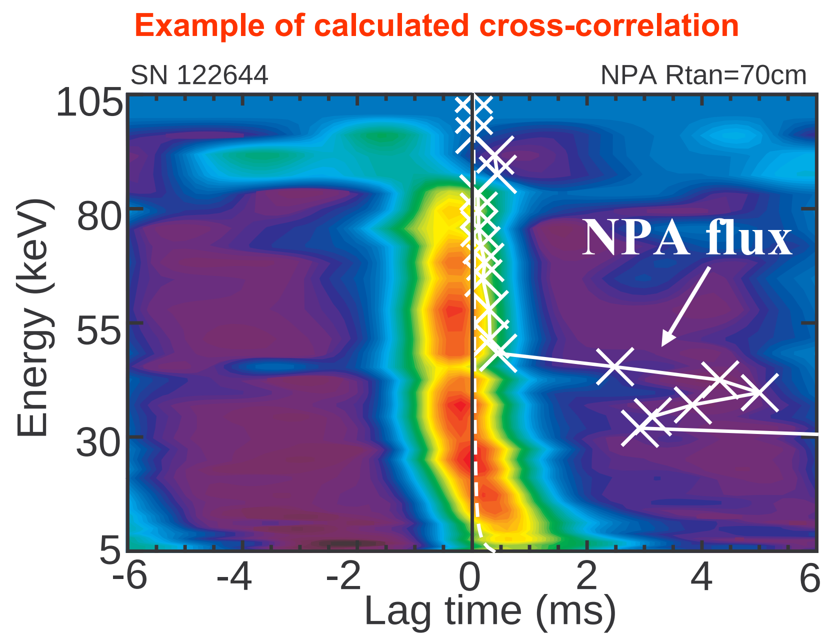
➢ **Coherence technique is a useful tool.**

- **Can tell whether NPA/SSNPA signals is really correlated with instability bursts or edge neutral density (edge D-alpha signal).**
- **Can detect temporal correlation of NPA/SSNPA with instability bursts and makes energy dependence more obvious, but amplitude information is obscured.**

➢ **Tremendous variation of instability bursts and NPA response are observed and coherence technique is applied in data analysis.**

Coherence Technique is Useful for Detecting Temporal Correlation of NPA diagnostic with Instability Bursts (cont'd)

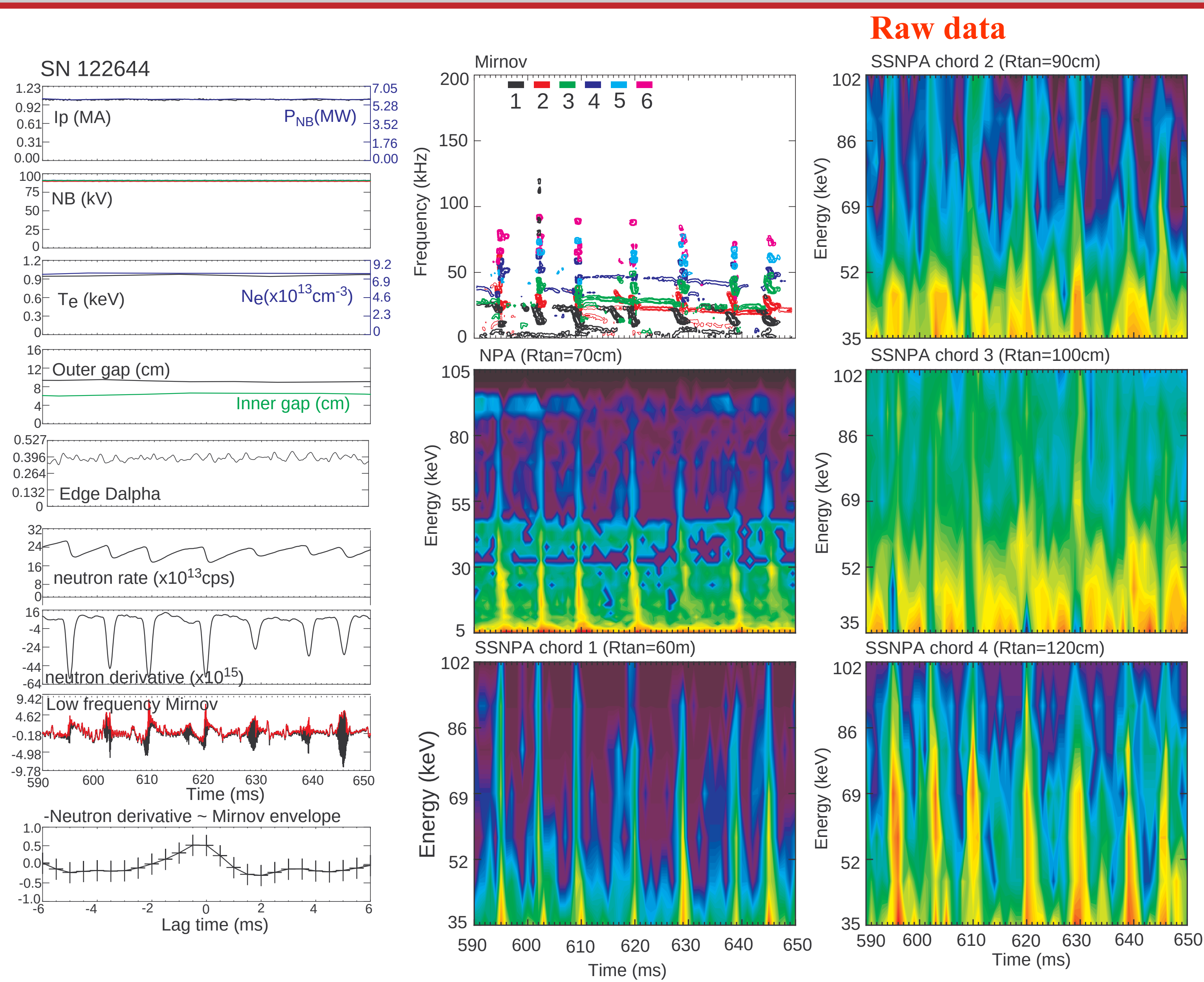




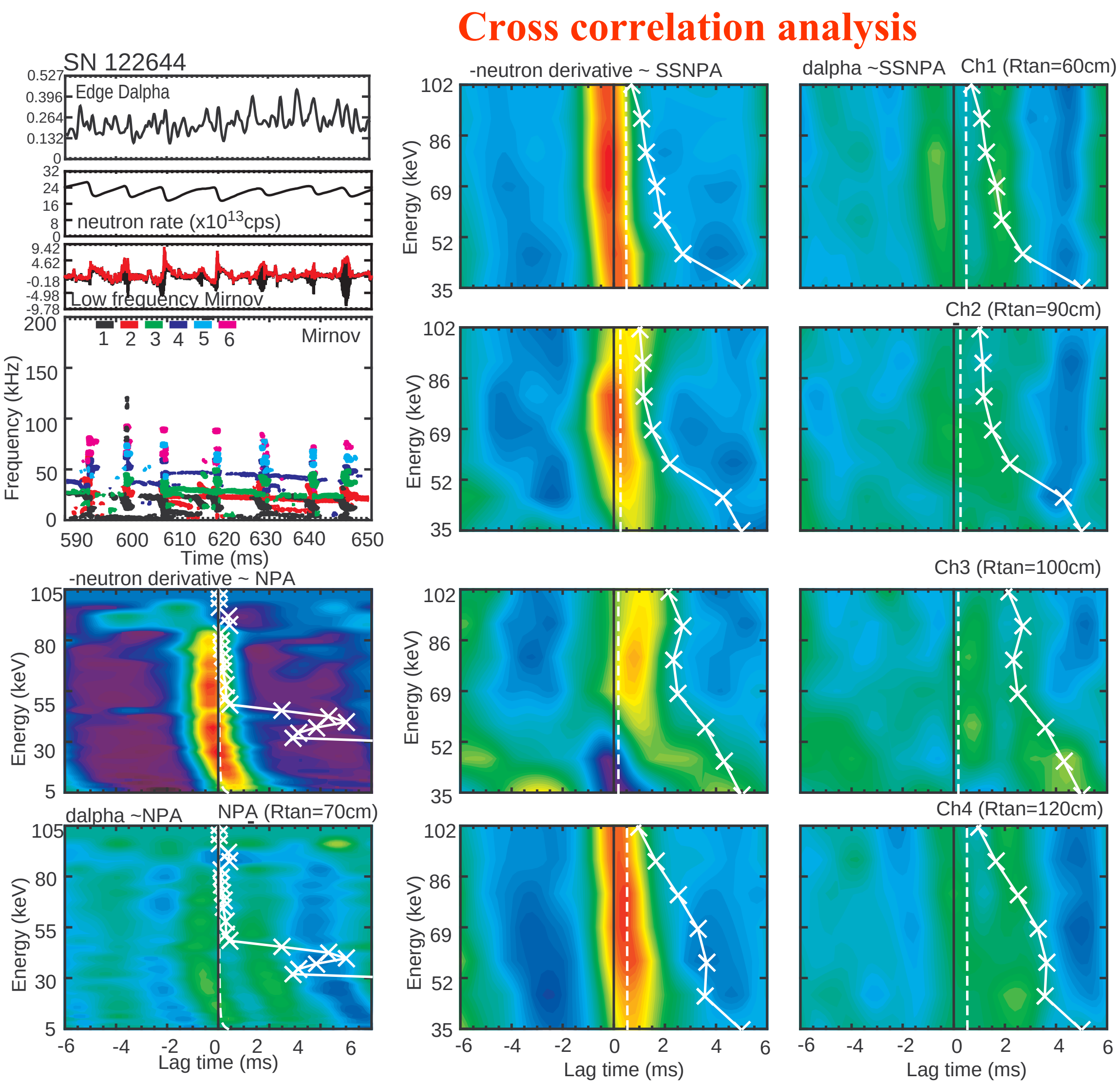
➢A clear temporal correlation between neutron drops and NPA bursts is seen in both raw data and cross-correlation analysis.

➢Cross-correlation analysis also shows energy dependence in NPA response.

Case 1: Multi-modes Cause Neutron Drops and Bursts at NPA/SSNPA



Case 1: Multi-modes Cause Neutron Drops and Bursts at NPA/SSNPA (cont'd)



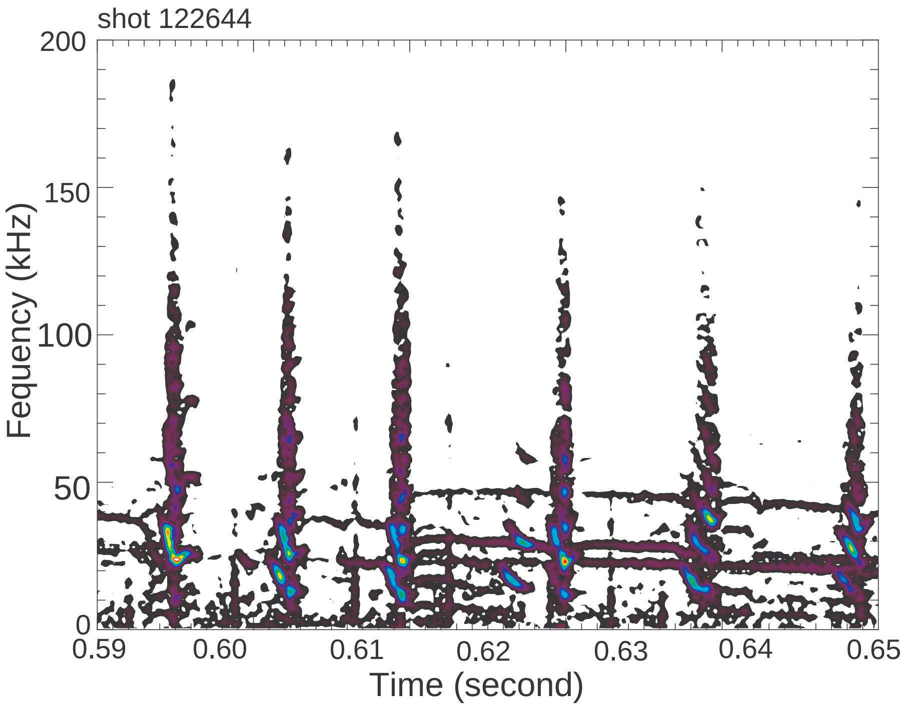
Shot 122644:
Helium plasma
n=1, chirping
Weak n=2,3 continuous mode

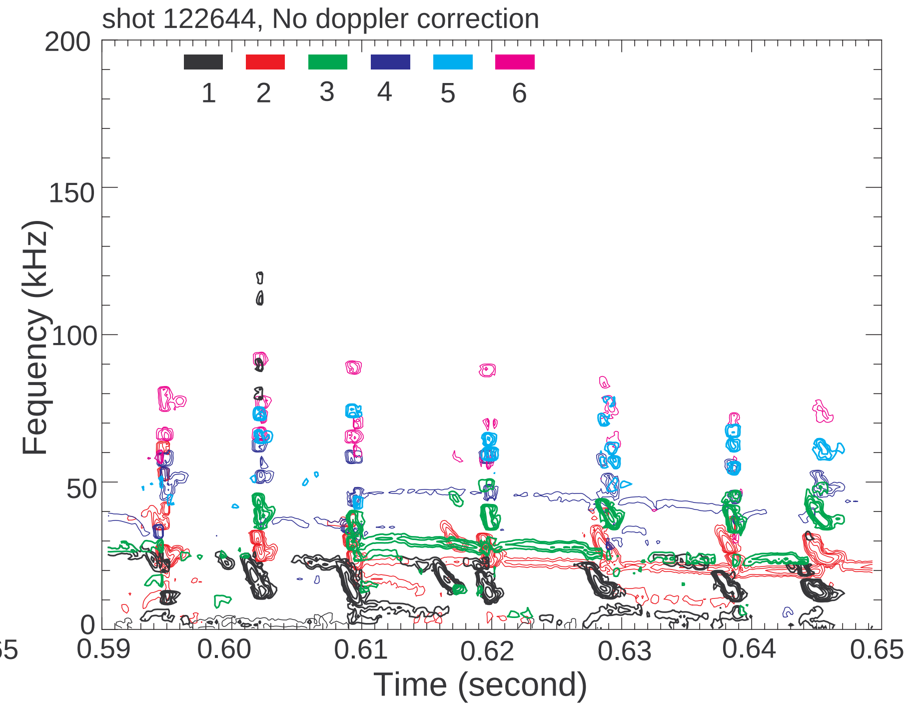
Empirical generalizations:

- **Multi chirping EPM or TAE modes often cause neutron drop**
- **A few or all chords of NPA/SSNPA have strong correlation with instability bursts (or neutron rate derivative).**
- **High energy channels respond first.**

Case 1: Multi-modes Cause Neutron Drops and Bursts at NPA/SSNPA (cont'd)

Mirnov spectra



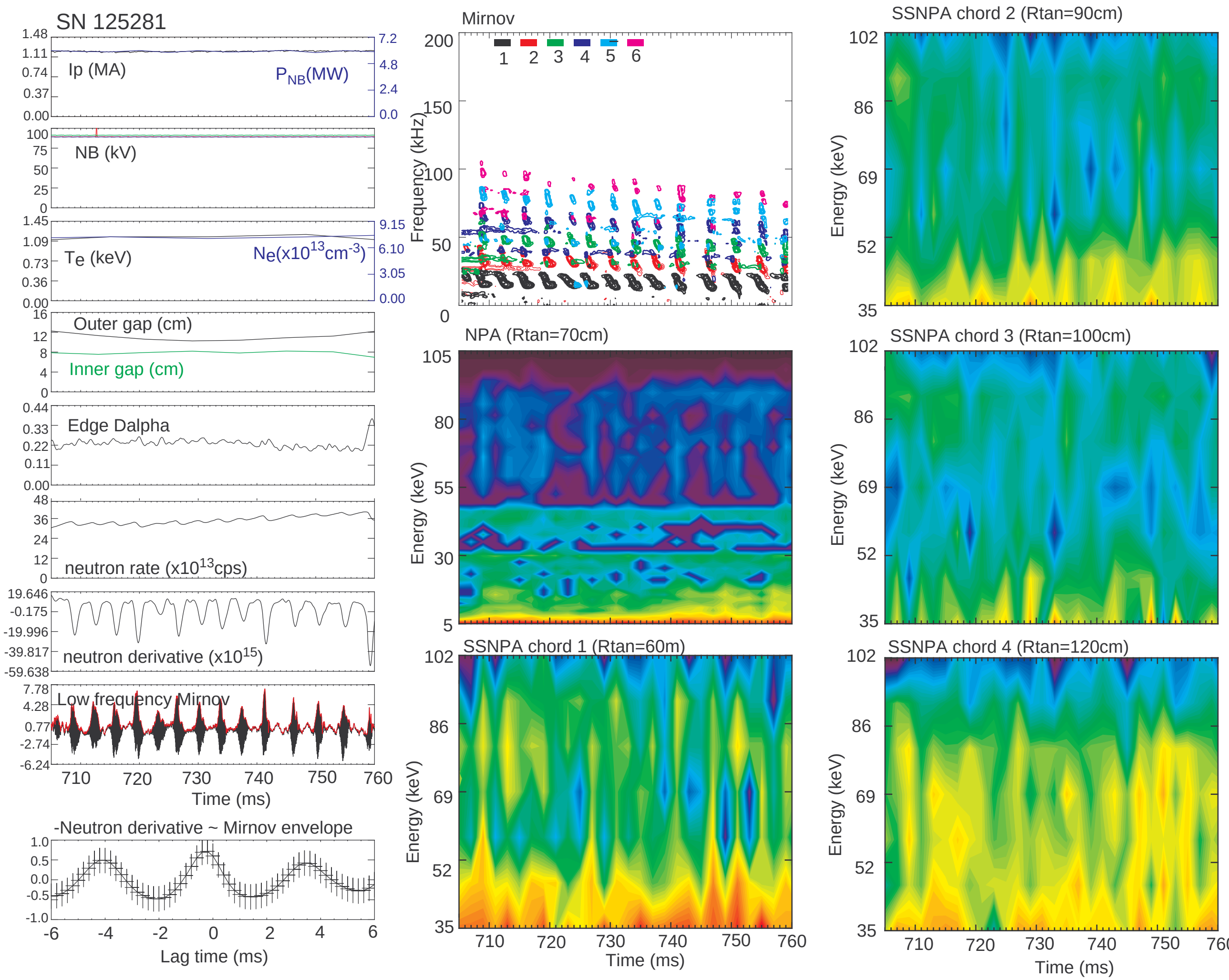


n=1 mode, chirping

Weak n=2,3 continuous mode

Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux

Raw data



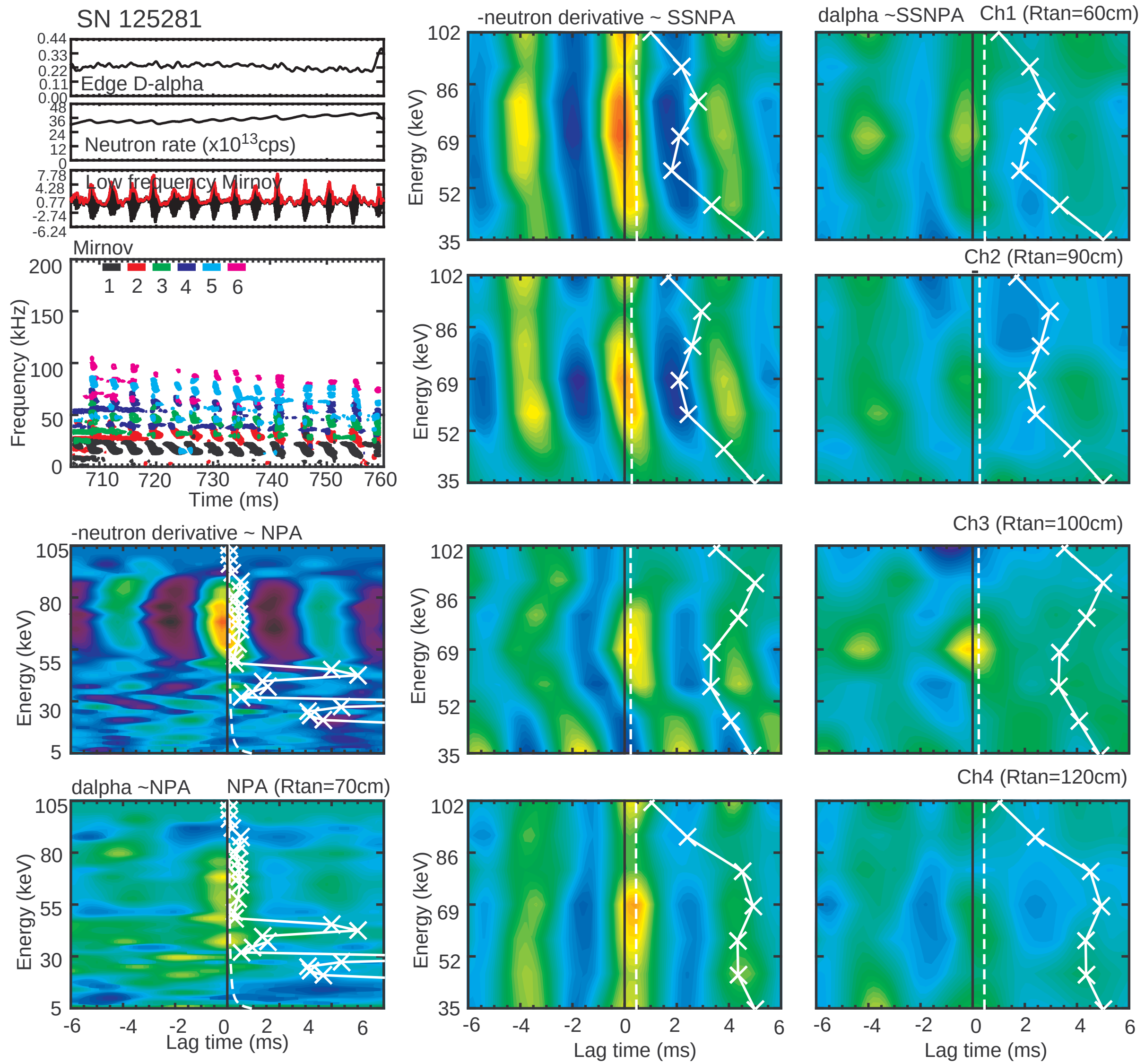
Shot 125281
n=1, chirping, fishbone

Empirical generalizations:

- **Large fishbones or Fishbone-like EPMs can cause neutron drops and NPA/SSNPA bursts (especially the most outboard chord of SSNPA)**

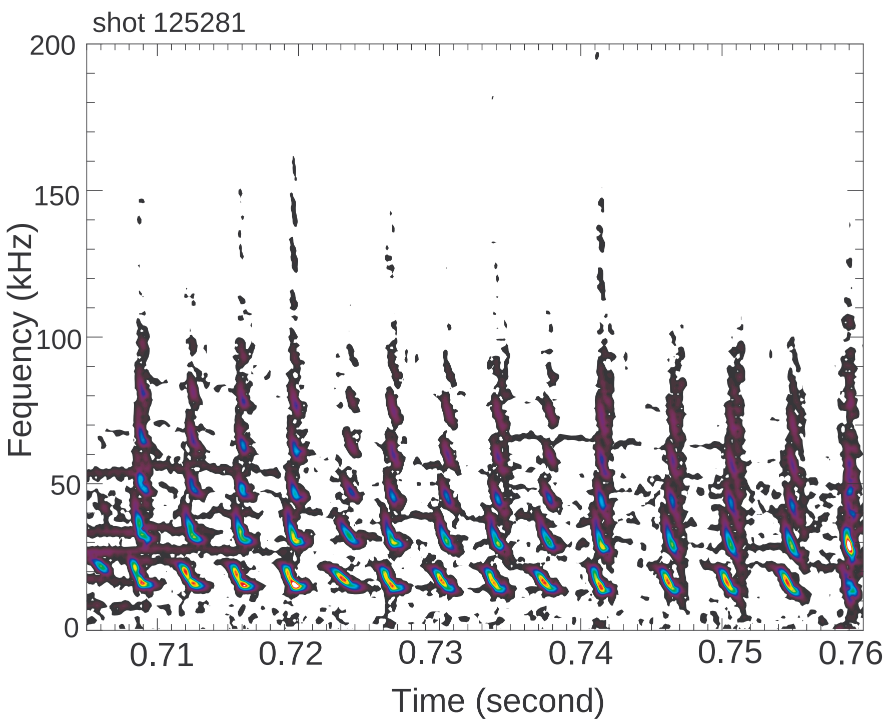
Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)

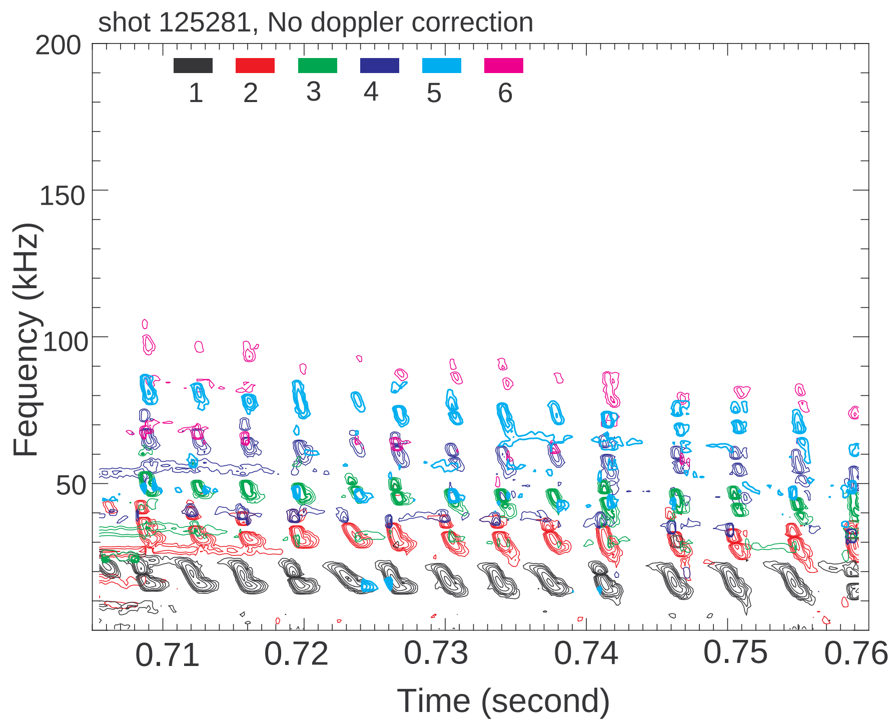
Cross correlation analysis



Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)

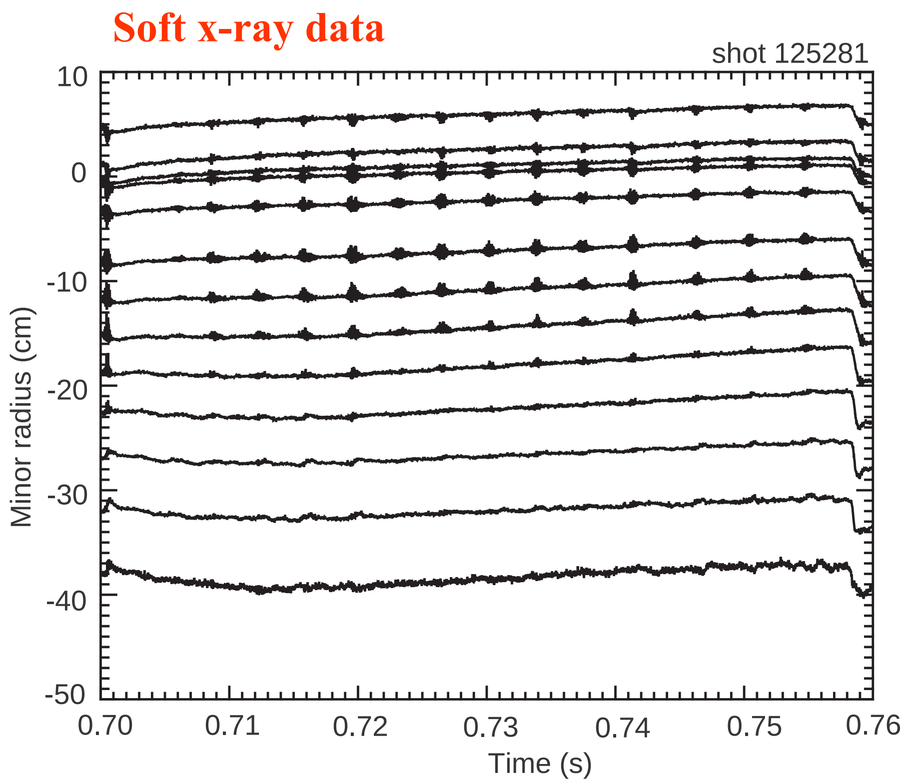
Mirnov spectra





n=1 mode, chirping

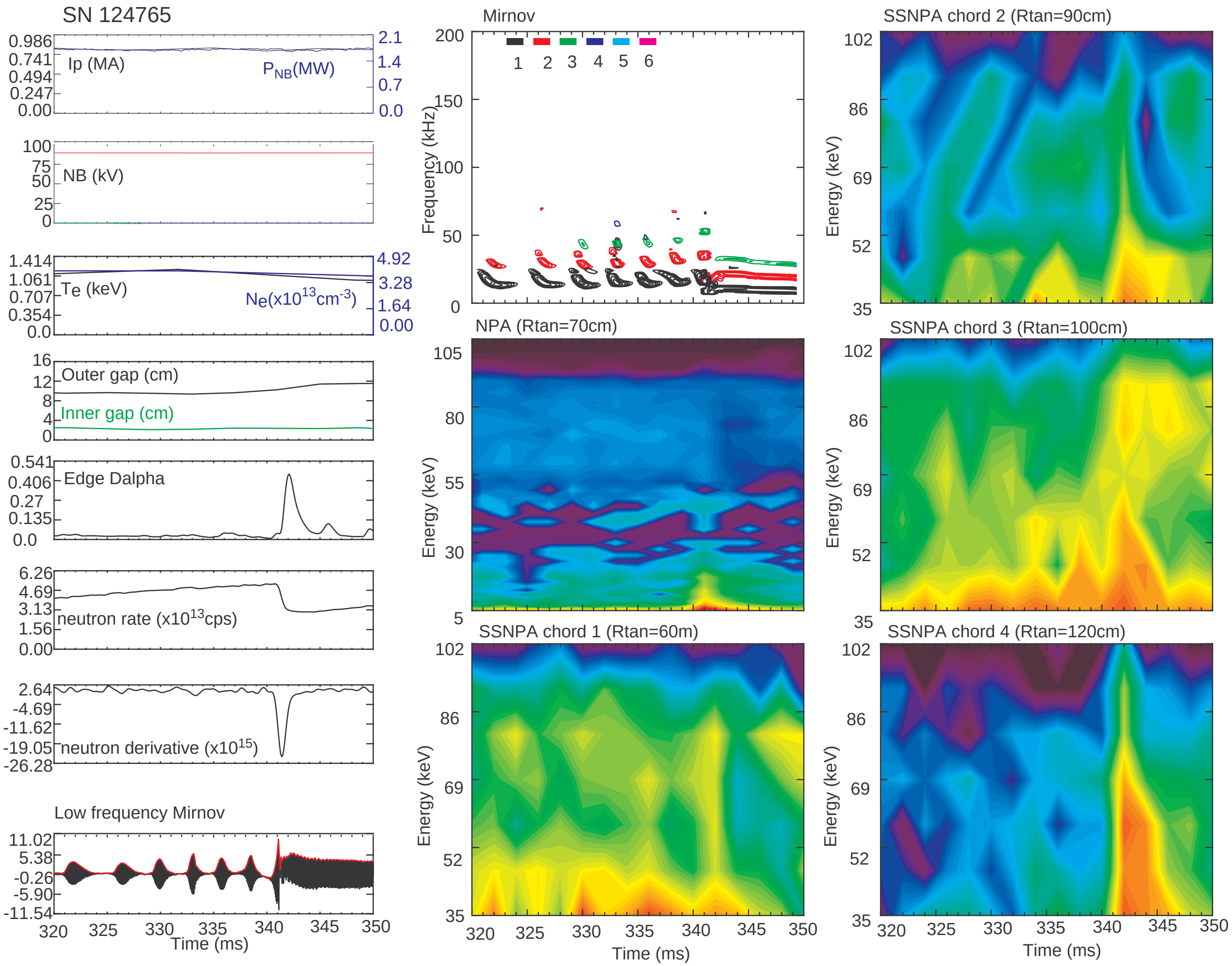
Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)



Soft x-ray data suggest the instability is fishbone.

Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)

Raw data

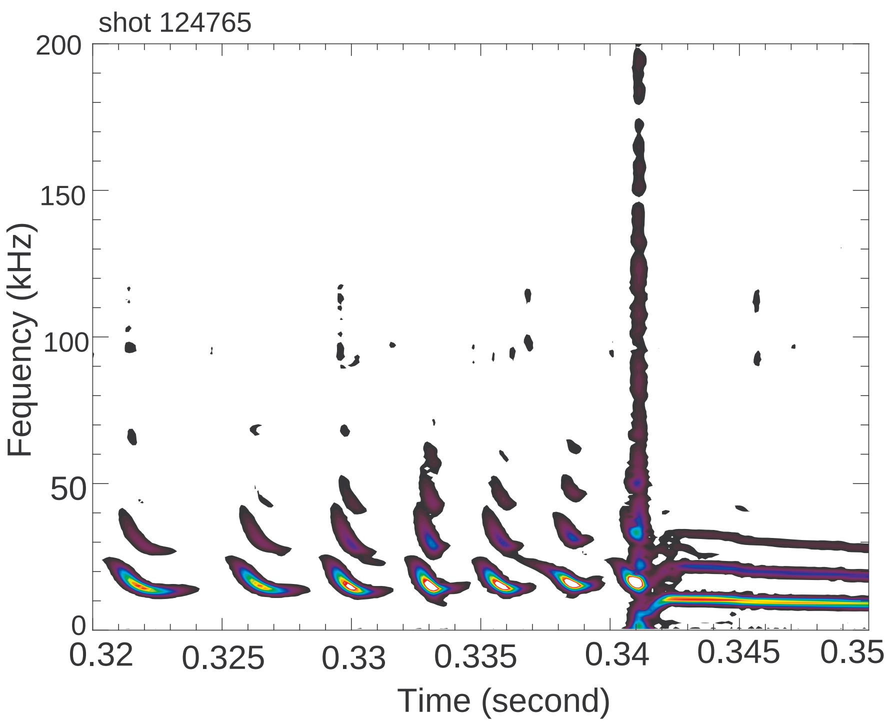


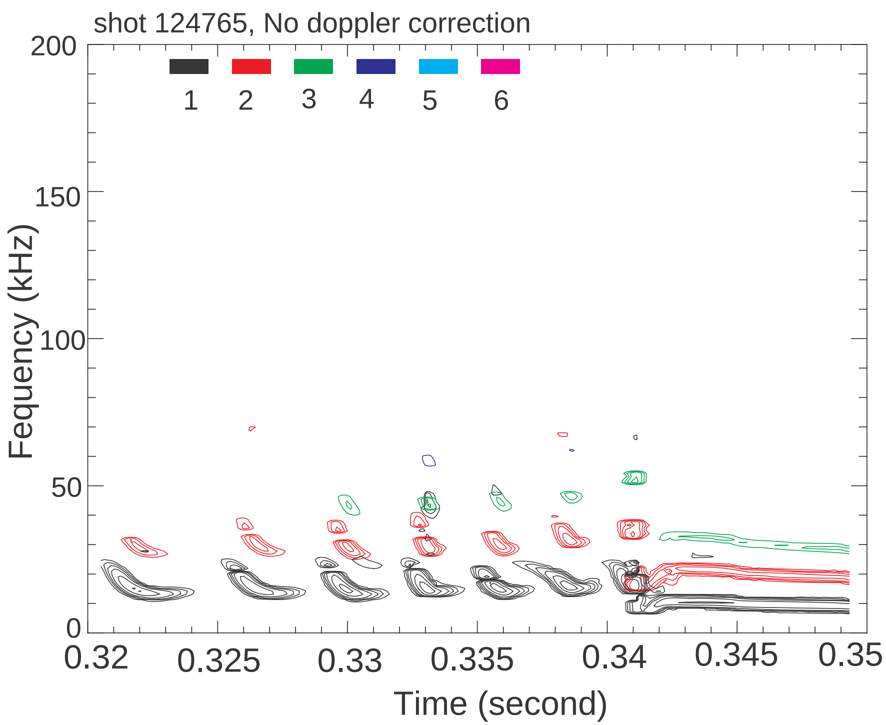
Shot 124765:
Helium plasma
n=1, chirping (fishbone)

- **A big burst at 0.341s on SSNPA due to IRE/sawtooth**
- **Weak correlation in NPA/SSNPA for small fishbones or fishbone-like EPMs during 0.32~0.34s.**

Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)

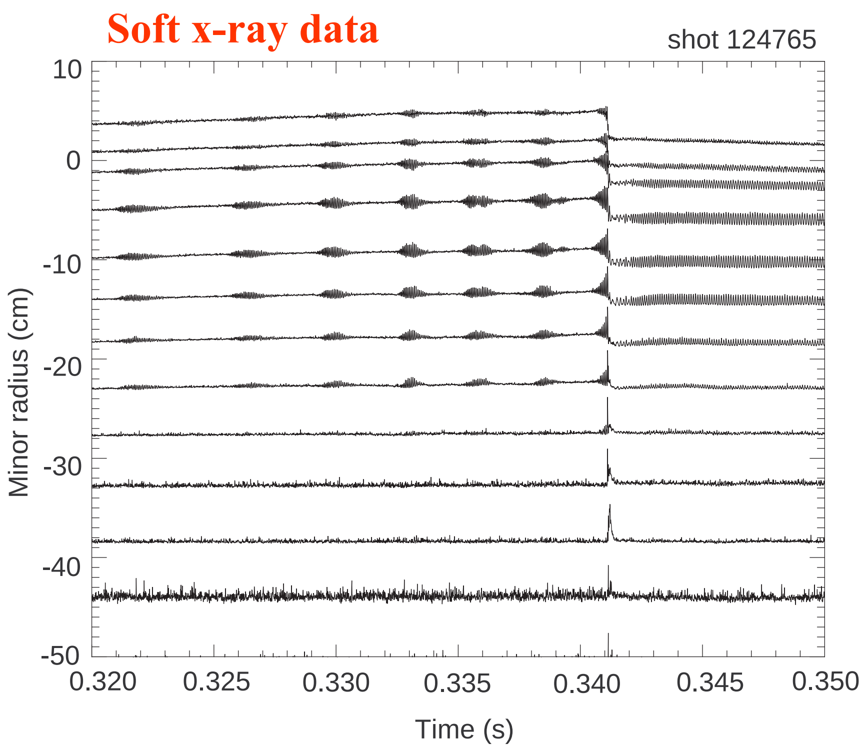
Mirnov spectra





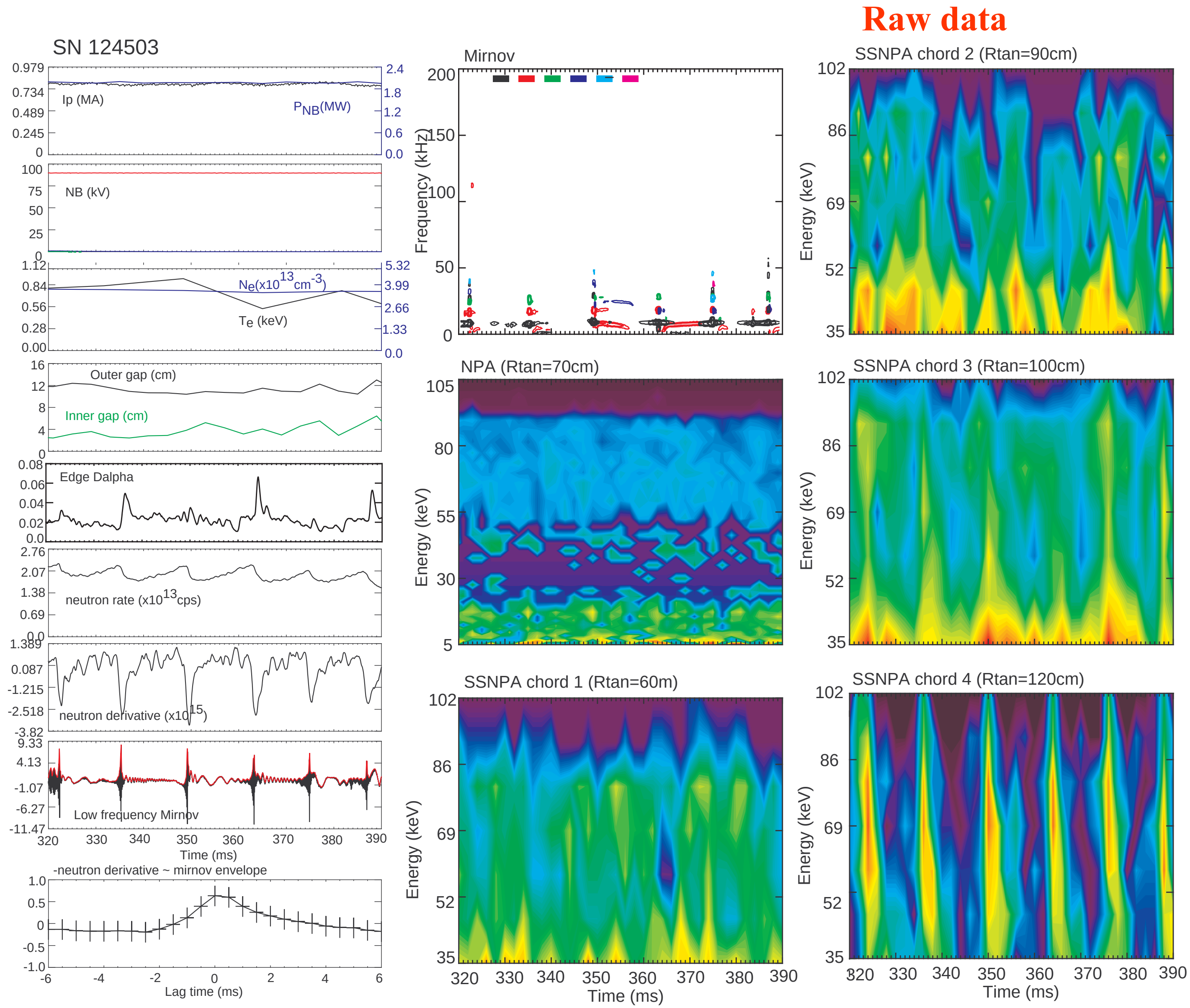
n=1 mode, chirping

Case 2: Fishbones/Fishbone-like EPMs Affects Neutron Rate and NPA Flux (cont'd)

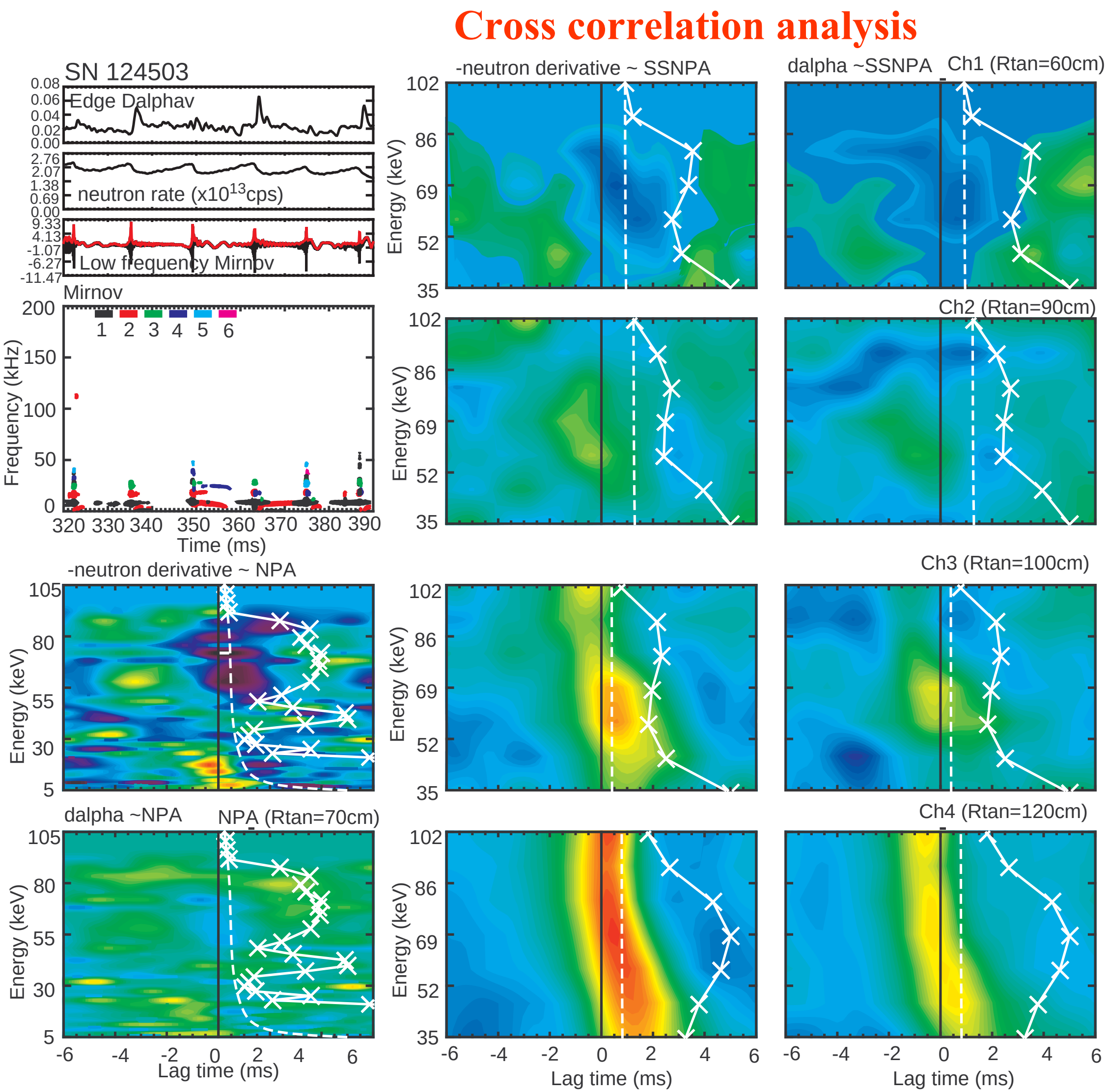


Soft x-ray data suggest the instability in 0.32~0.34s is fishbone.

Case 3: Sawtooth always Causes Fast Ion Loss



Case 3: Sawtooth always Causes Fast Ion Loss (cont'd)



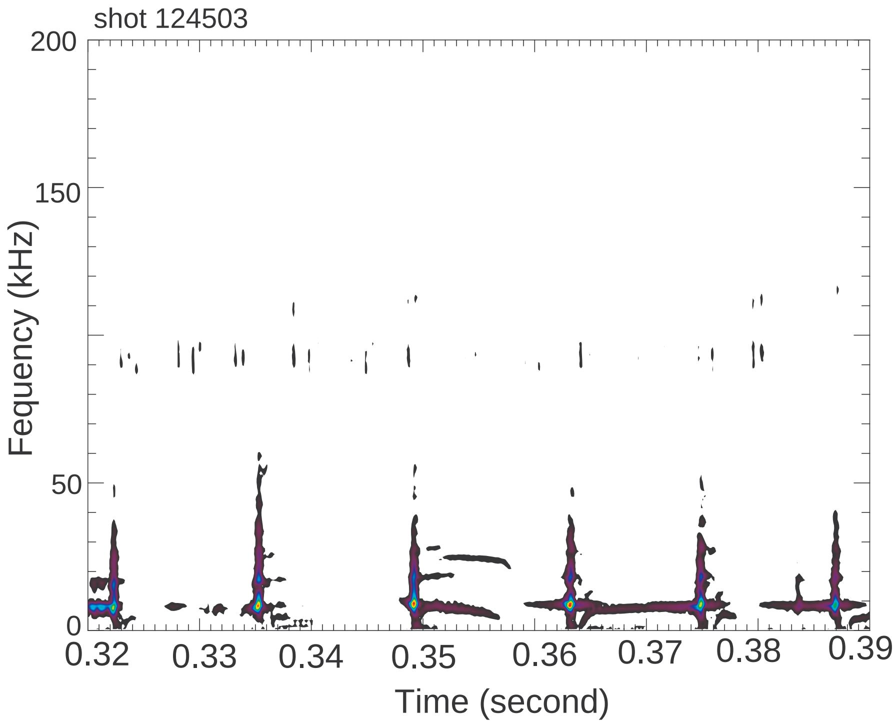
Shot 124503:
Helium plasma
n=1, no chirping (Sawtooth)

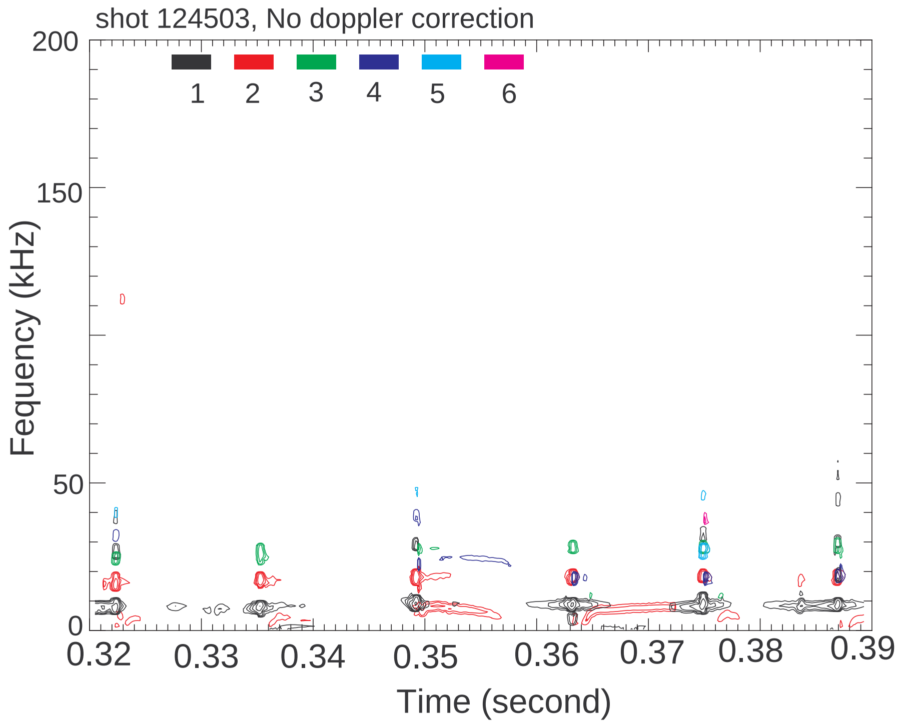
Empirical generalizations:

- ➢**Sawtooth always causes neutron rate drops and bursts at the most outboard chord of SSNPA.**
- ➢**The most inboard chord of SSNPA and NPA drop at instability events, which indicates reduction in active signal.**
- ➢**High energies respond first.**

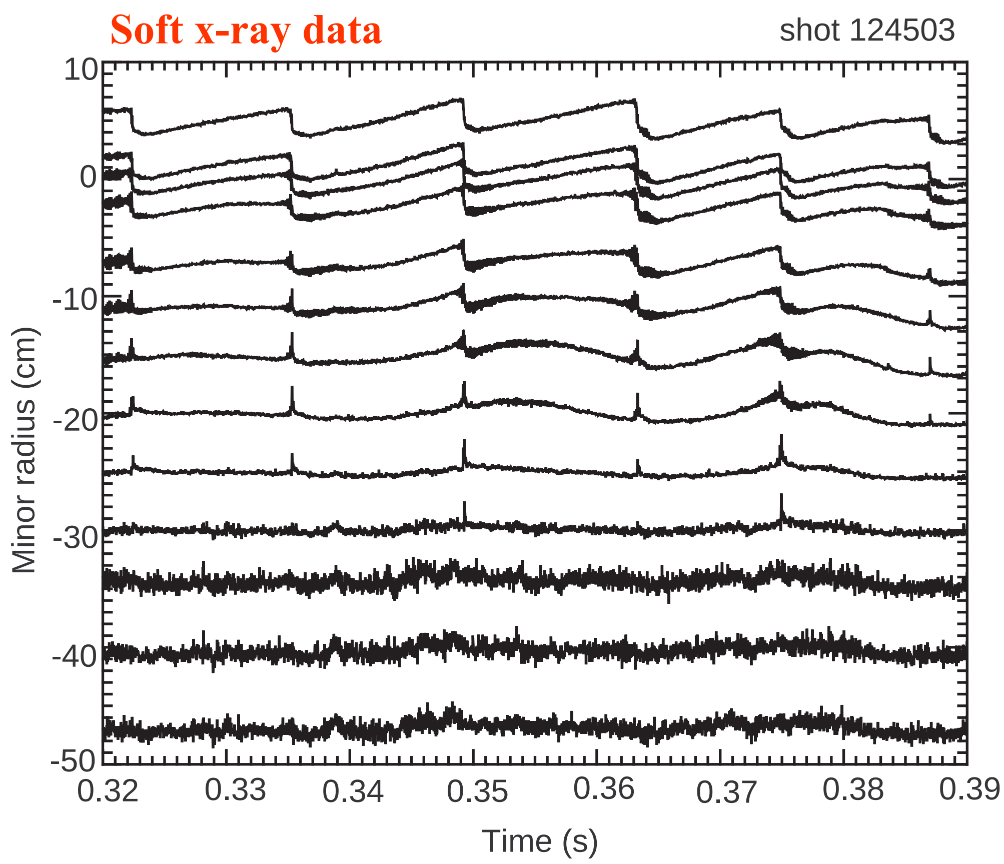
Case 3: Sawtooth always Causes Fast Ion Loss (cont'd)

Mirnov spectra





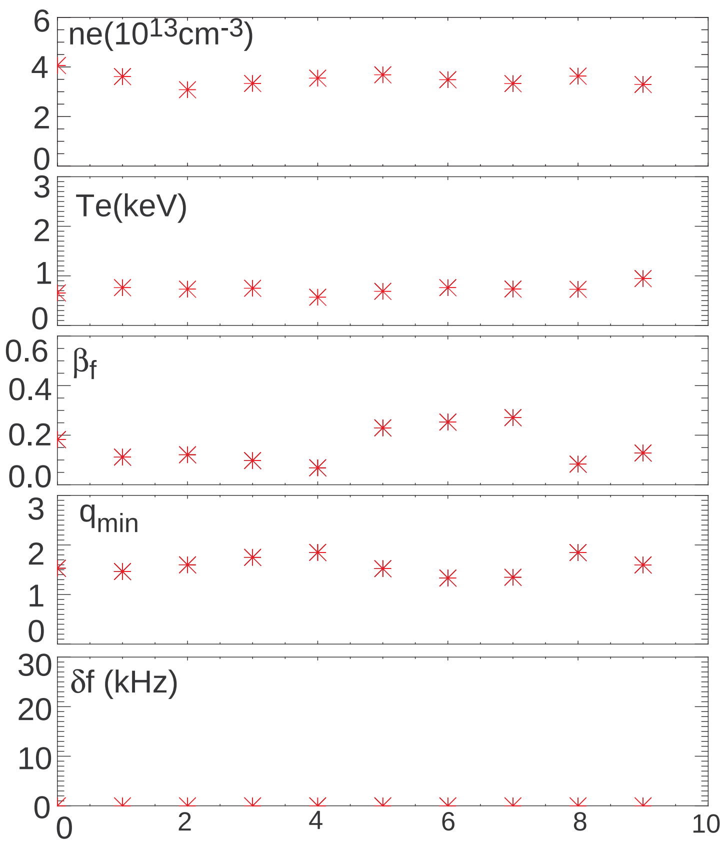
Case 3: Sawtooth always Causes Fast Ion Loss (cont'd)



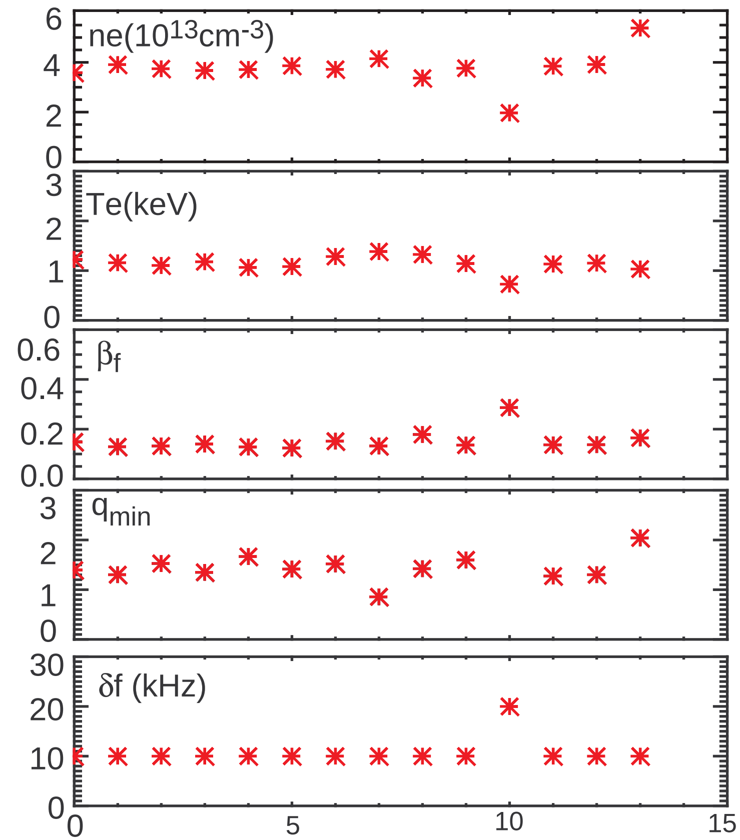
Soft x-ray data suggest the instability is sawtooth.

Similar Parameters, but Different Responses of NPA diagnostics to Sawtooth/Fishbones

Sawtooth shots



Fishbone shots



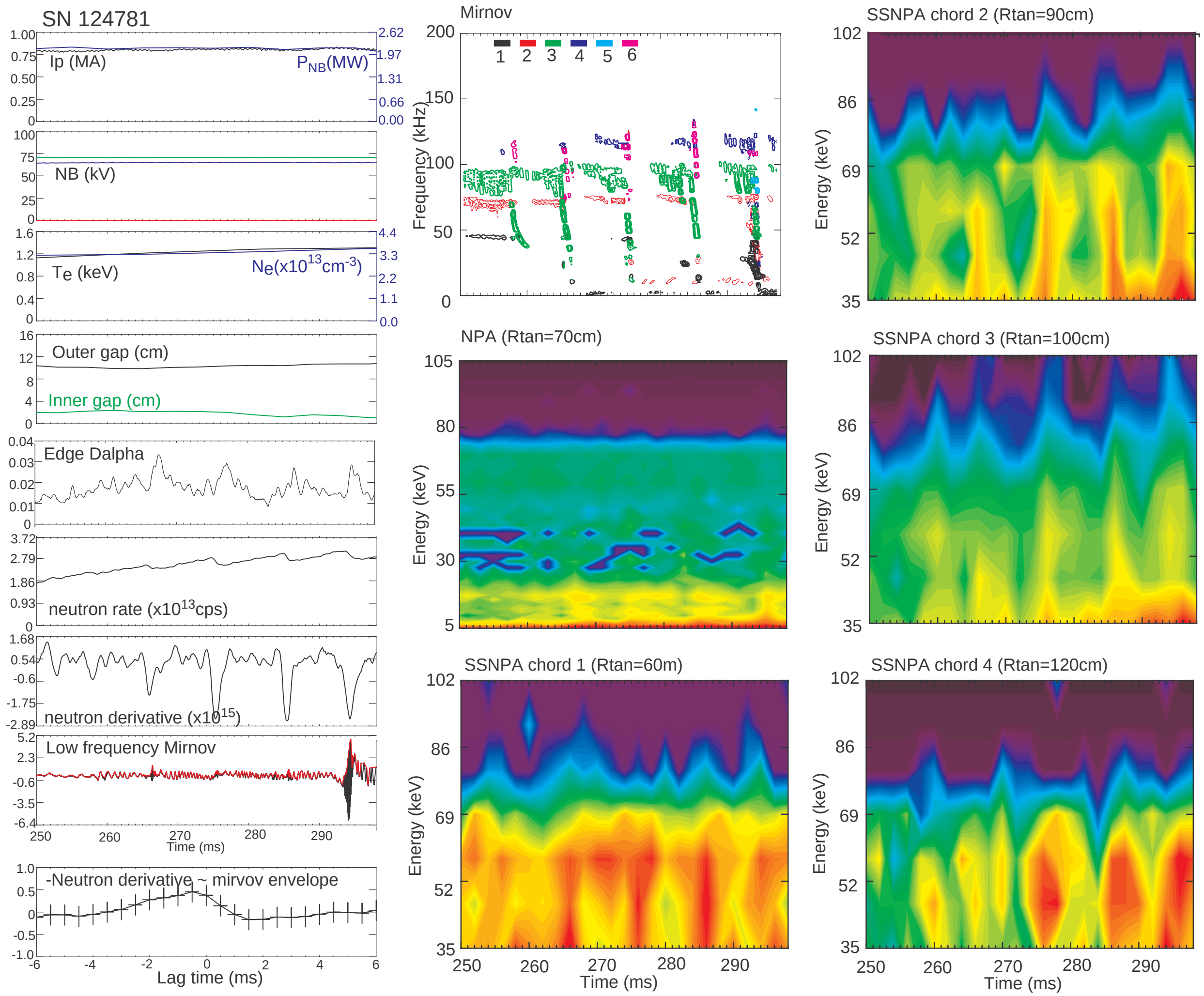
➢**Plasma parameters look similar in these fishbone and sawtooth shots except the frequency chirping feature in fishbone shots.**

➢**Small fishbones or fishbone-like EPMs has minor or no effect on neutral rate and NPA/SSNPA signals.**

➢**Sawtooth always cause neutron rate drops and burst at the most outboard of SSNPA.**

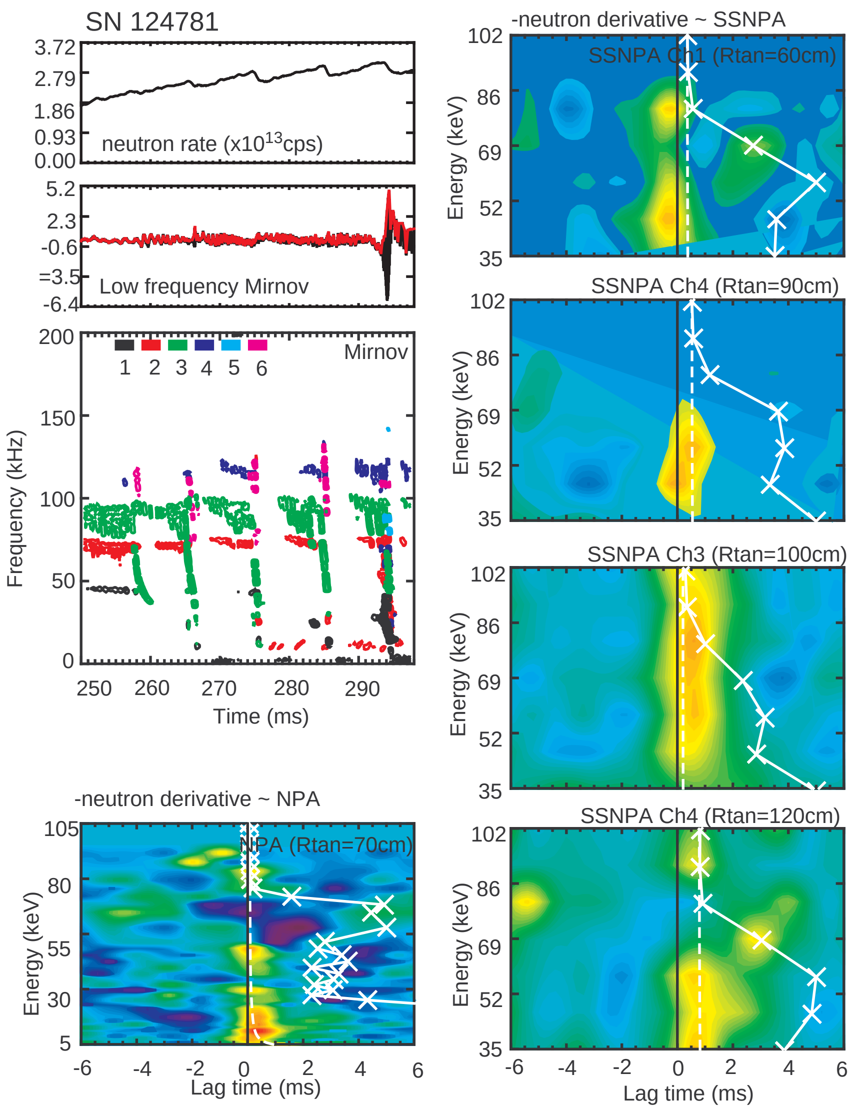
Case 4: TAE Avalanches Often Cause Bursts in Some Chords of SSNPA

Raw data



Case 4: TAE Avalanches Often Cause Bursts in Some Chords of SSNPA (cont'd)

Cross correlation analysis



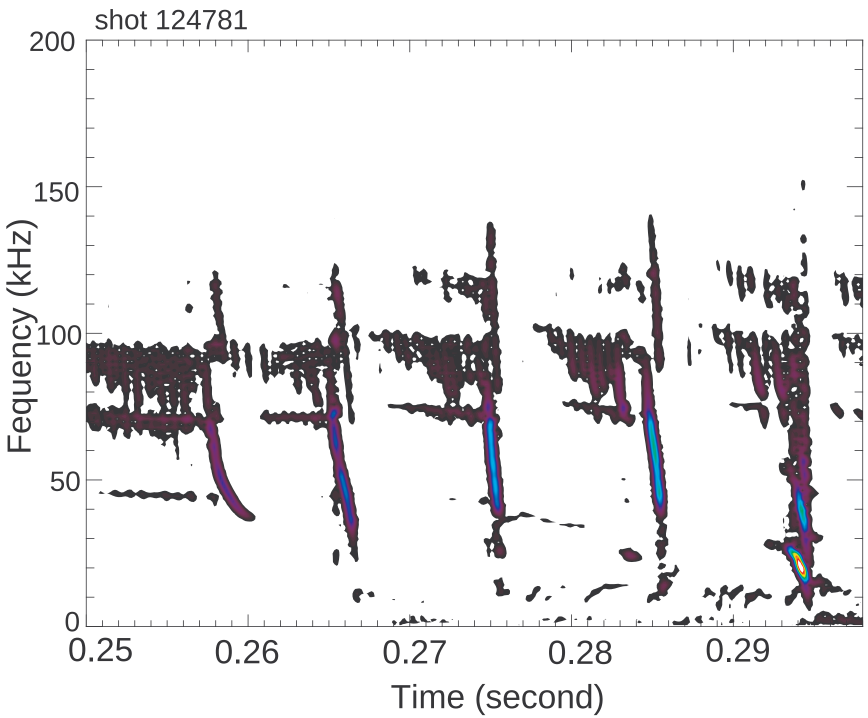
Shot 124781
Helium plasma
n=2,3,4 TAE avalanche

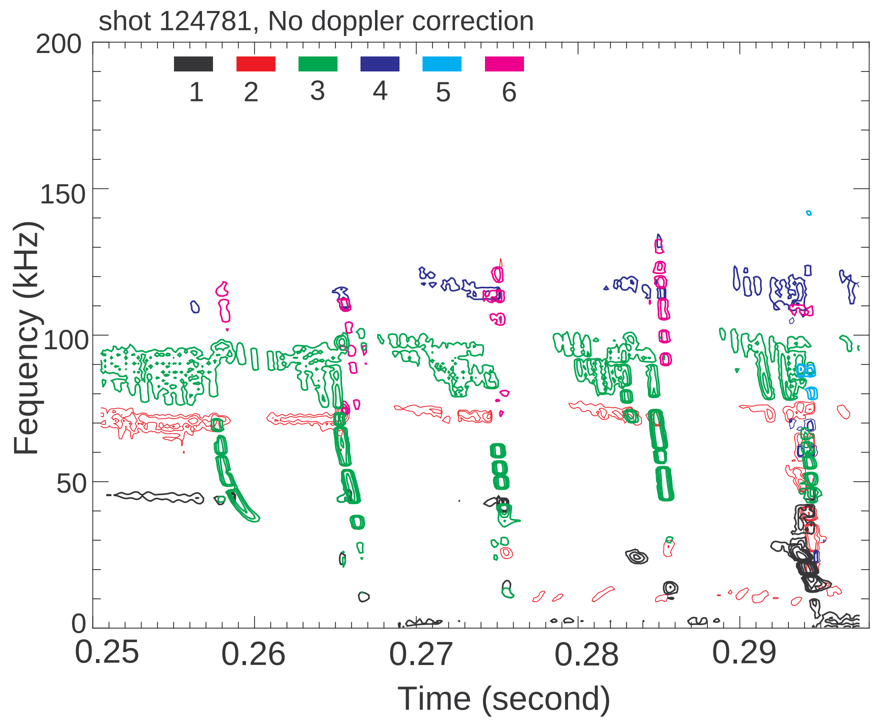
Empirical generalizations:

- **Avalanches always cause bursts in at least one SSNPA chord.**
- **Different chords see the bursts on different shots.**
- **Small bursts in NPA.**

Case 4: TAE Avalanches Often Cause Bursts in Some Chords of SSNPA (back up)

Mirnov spectra





n=2,3,4 TAE avalanches

Summary and Future Work

➢ **Tremendous variation in behavior during instability bursts.**

- **Usually only a few chords have strong correlation with instability bursts.**
- **Only large fishbones/fishbone-like EPMs cause fast ion loss (indicated by neutron rate drops and bursts in the most outboard of SSNPA). For small fishbones, weak/no correlation in neutron rate and NPA diagnostics.**
- **Sawtooth always cause bursts at the most outboard chord of SSNPA. Weak correlation in inner chords of SSNPA and NPA.**
- **TAE avalanches always cause bursts at some chords of SSNPA**
- **High energies respond first.**

ORBIT modeling of fast-ion transport by n=1 mode

- **Amplitude (threshold?)**
- **Frequency (Is chirping important?)**
- **Energy (why do high energies respond first?)**

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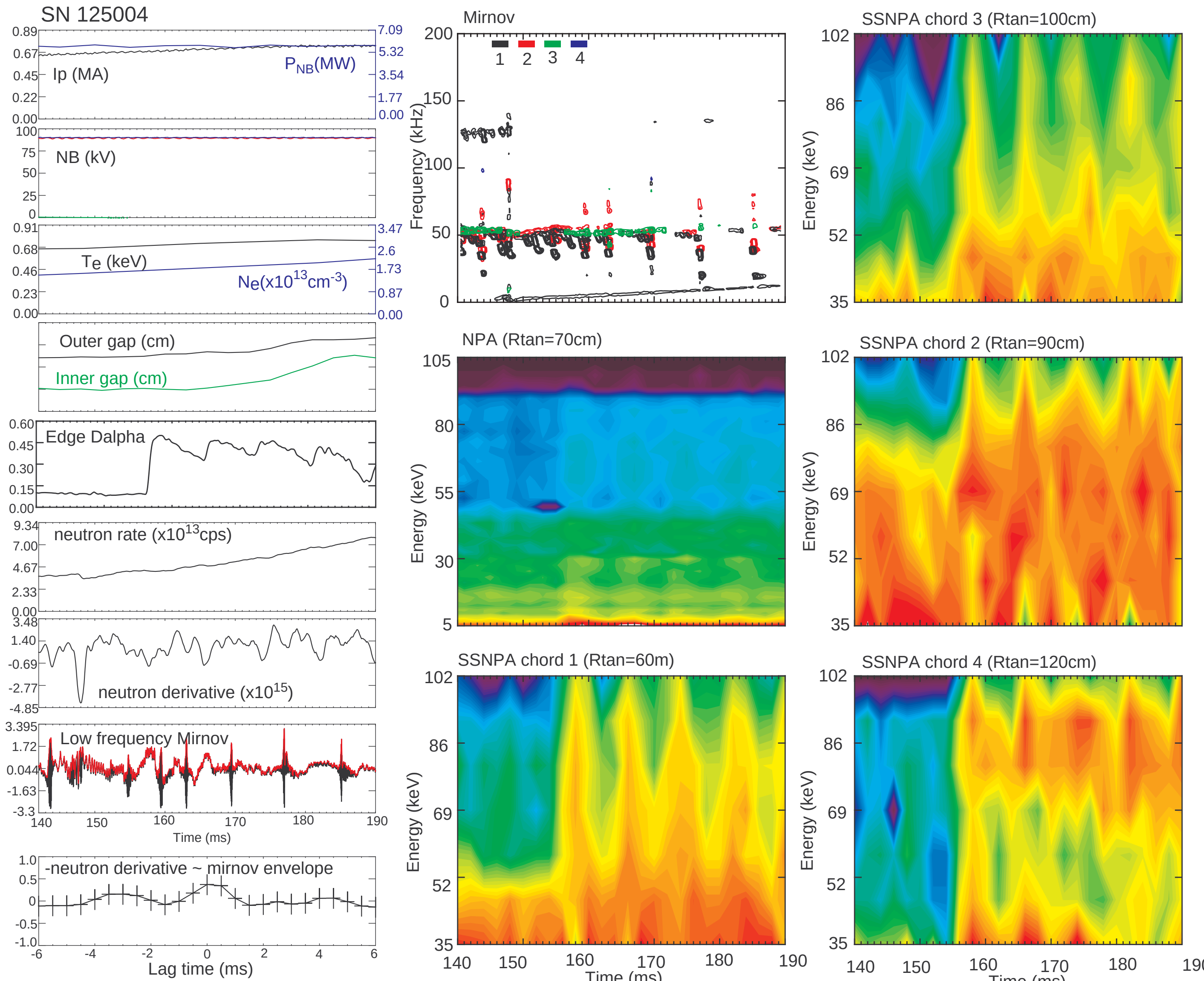
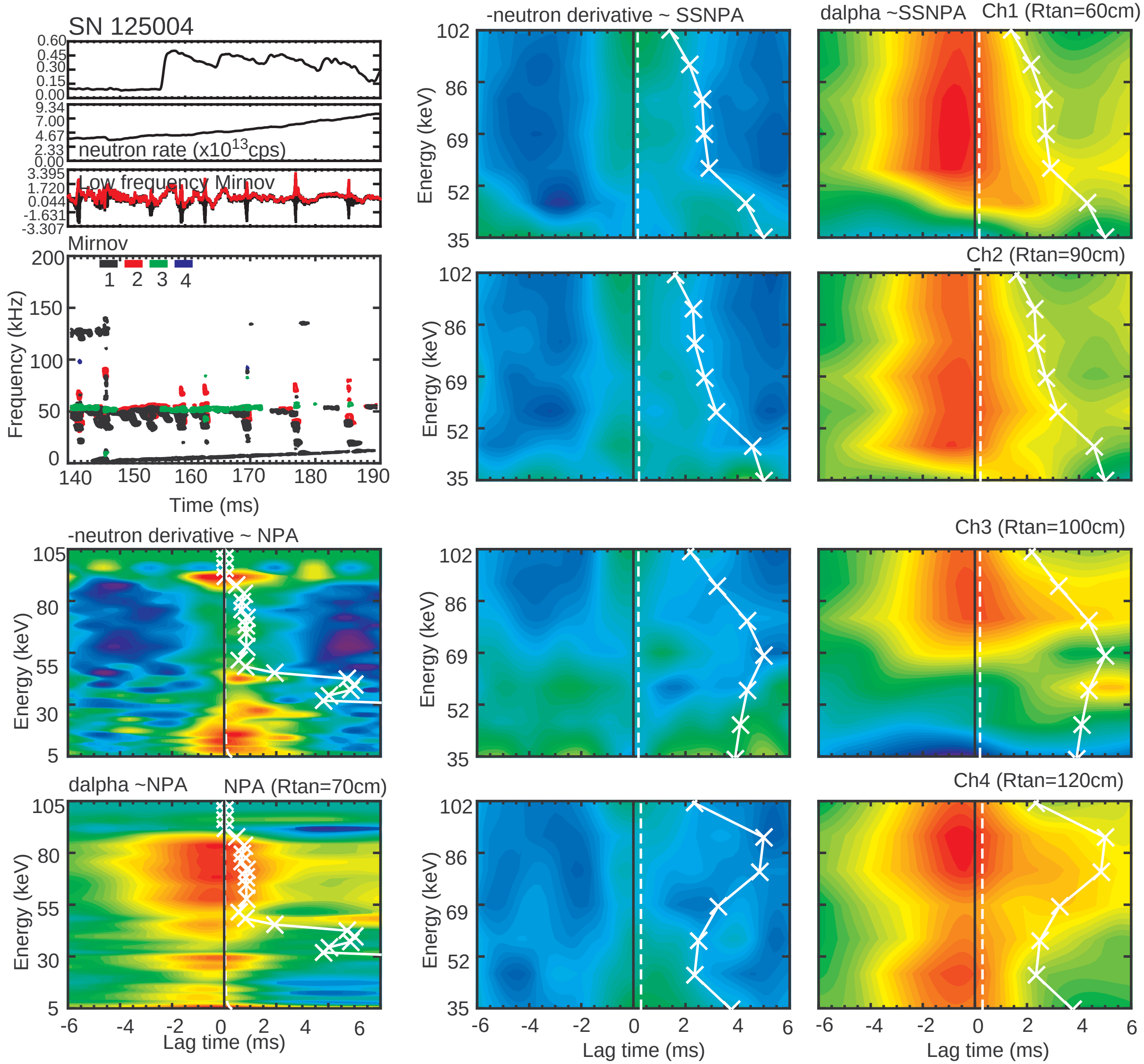
Bursts on NPA/SSNPA Diagnostic can be Caused by the Change of Edge Neutral Density

Raw data



Bursts on NPA/SSNPA Diagnostic can be Caused by the Change of Edge Neutral Density (cont'd)

Cross correlation analysis



Bursts on NPA/SSNPA Diagnostic can be Caused by the Change of Edge Neutral Density (cont'd)

Mirnov spectra