FIDA measurements of fast-ion transport

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and NSTX WPI-TSG

NSTX Results Review 2009

- Fast-ion losses by TAE avalanches
- Preliminary results: fast-ion transport by
  - Energetic-particle modes
  - Low-frequency MHD
- Other possible contributions to fast-ion studies on NSTX

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XP-819: TAE avalanches reproduced in L-mode helium plasmas

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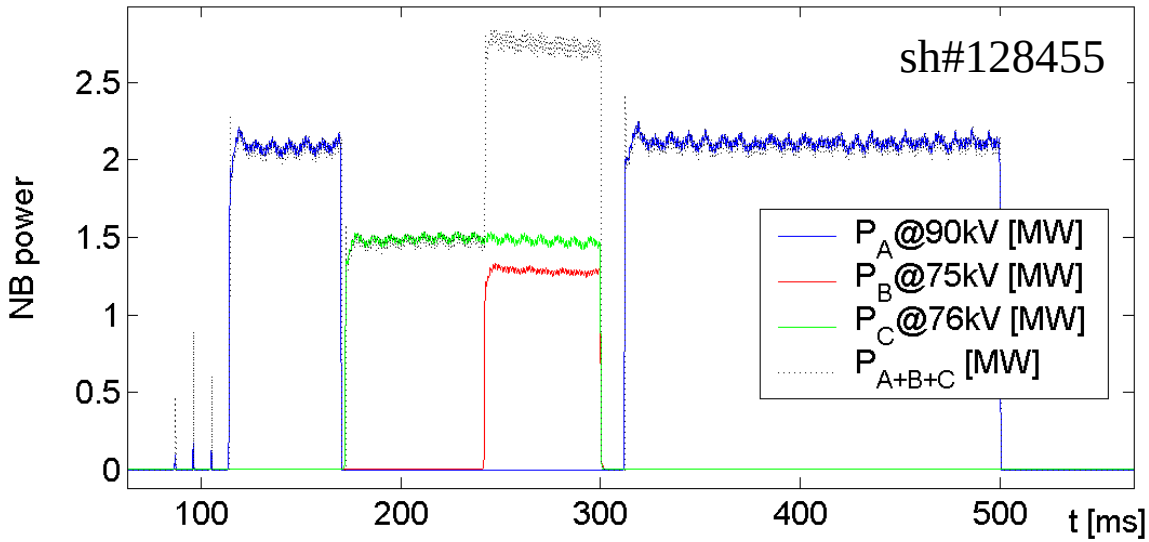
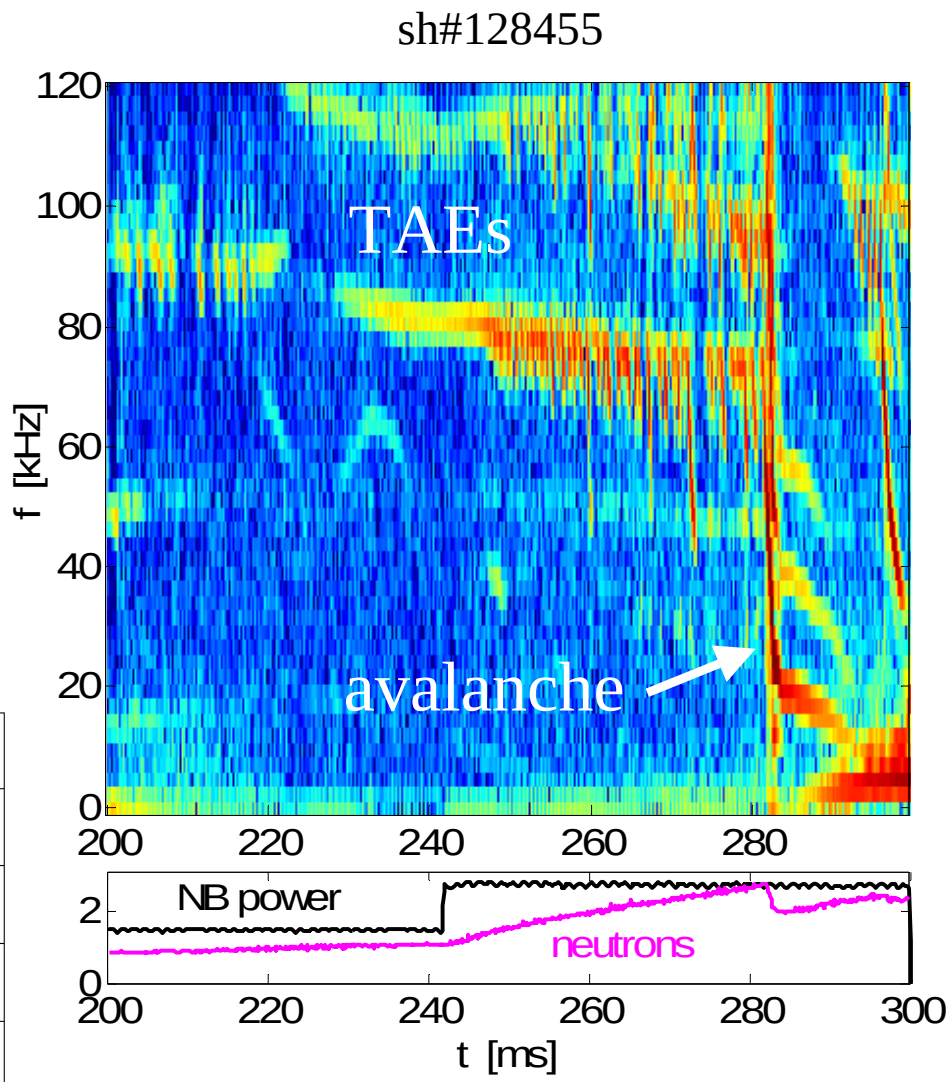
- L-mode helium plasmas with
  $n \sim 3 \times 10^{19} m^{-3}$, $T_e \sim 1 keV$
- One NB source @ 75kV, scan voltage of second NB source
- TAEs destabilized, then disrupt in "avalanches" for $P_{NB} > P_{NB,\ threshold}$
- Avalanches correlate with drop in neutron rate

$\Rightarrow$ fast-ion loss/redistribution





TAE avalanches, method of analysis

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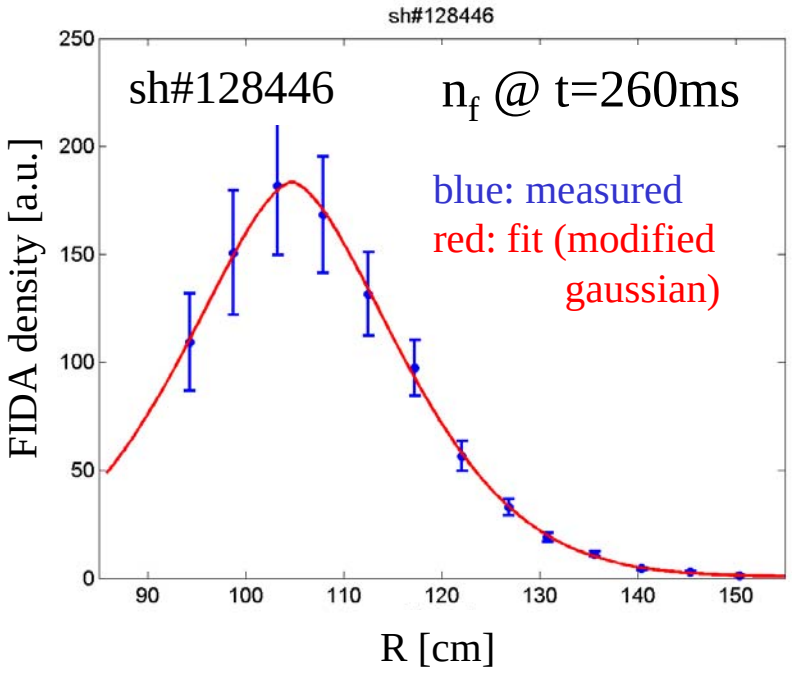
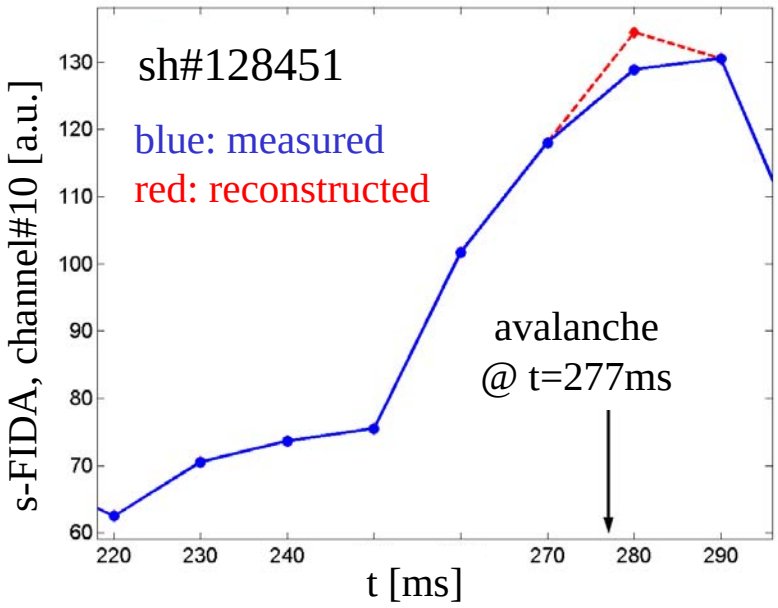
- Radial profile of fast-ion density, n_f, from s-FIDA (spectrometer)
  - Temporal resolution 10ms
  - Radial resolution ~5cm
- Fit radial profile to evaluate gradient, FWHM, peak value
- Extrapolate in time to infer "no-avalanche" parameters
- Fast measurements with f-FIDA also available
  - 50kHz sampling rate
- Analysis includes shot#128446→128455
  - Include "no-avalanche" reference
  - NB voltage scan, NPA scan





Fast-ion losses up to 30% measured by s-FIDA, consistent with neutron rate

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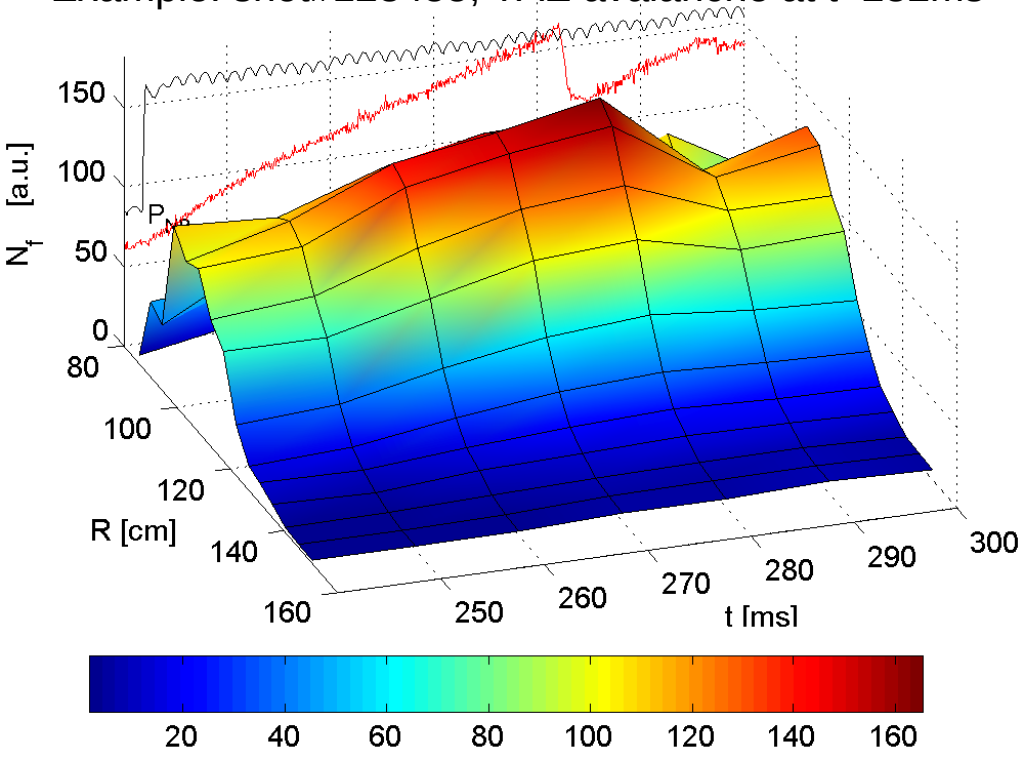
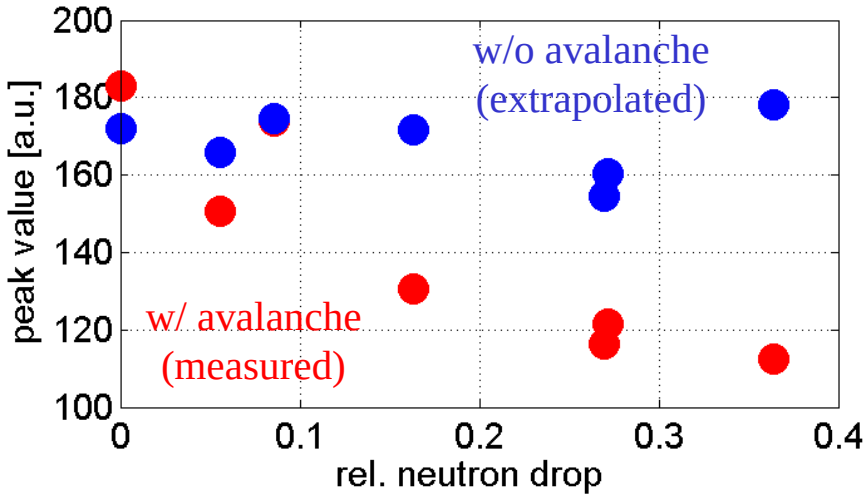
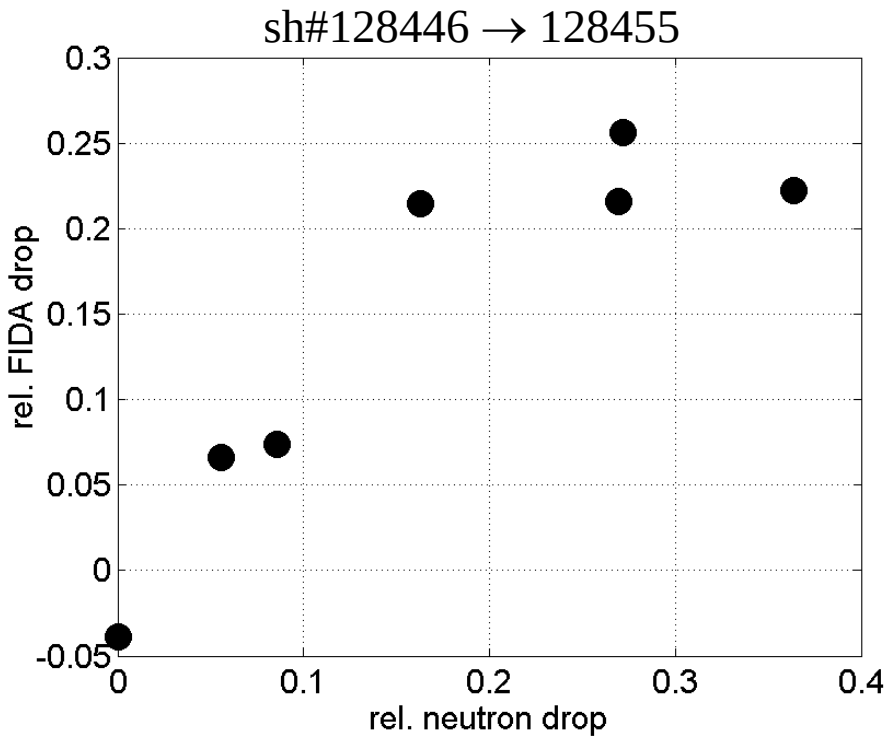
Example: shot#128455, TAE avalanche at t=282ms





- Drop in n_f consistent with neutron rate drop
- Up to ~40% of central fast ions lost (up to ~30% over all radii)
- Whole profile involved
- Fast-ion profile remains centrally peaked



Larger losses when maximum gradient is shifted to low-field side

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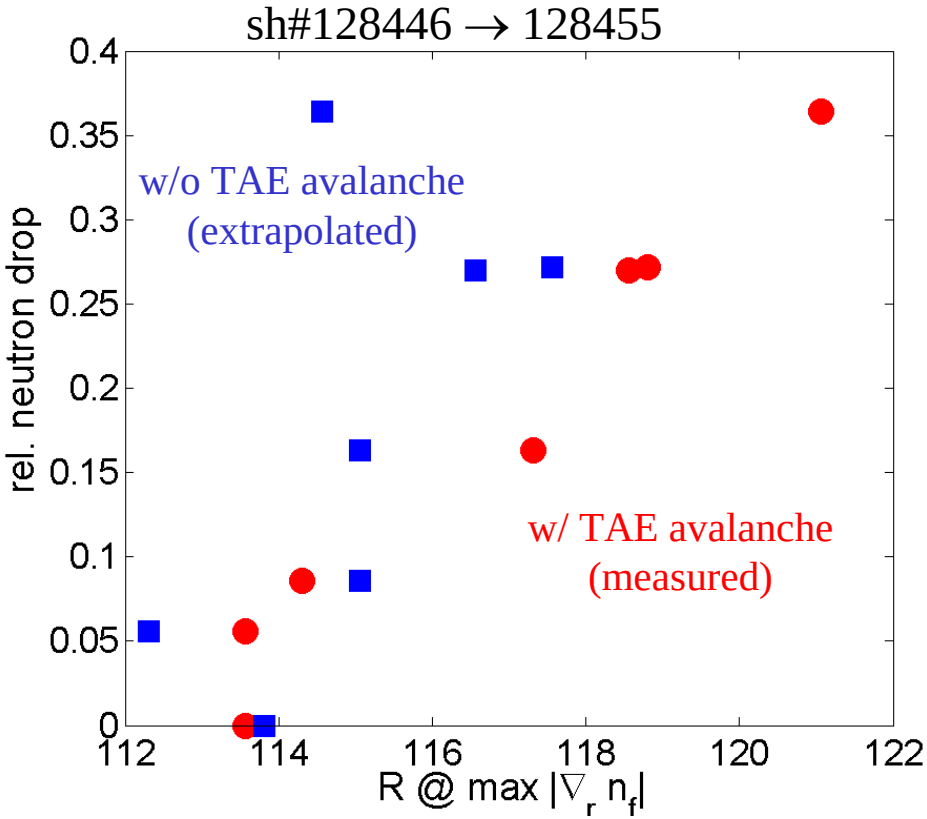
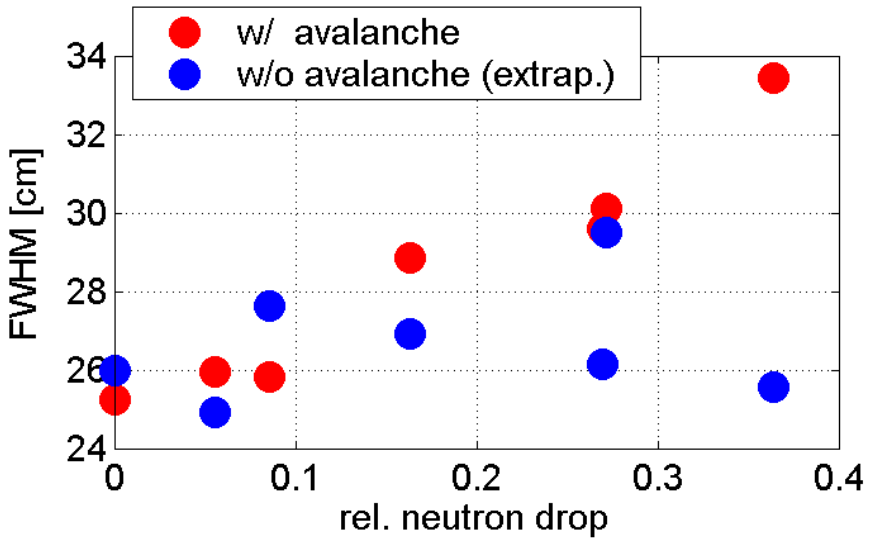
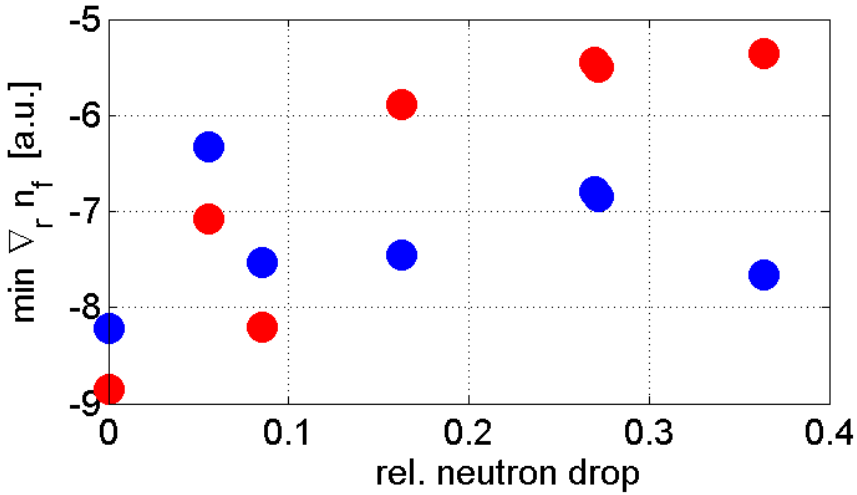
- Avalanches correlate with
  - Outward shift and *decrease* of max $|\nabla_r n_f|$
  - Depletion of central density
  - n_f broadening
- However:
  - Temporal resolution << avalanche time scale
  - Possible non-linear dynamics

⇒ **Hard to distinguish unambiguously between *cause & effect***



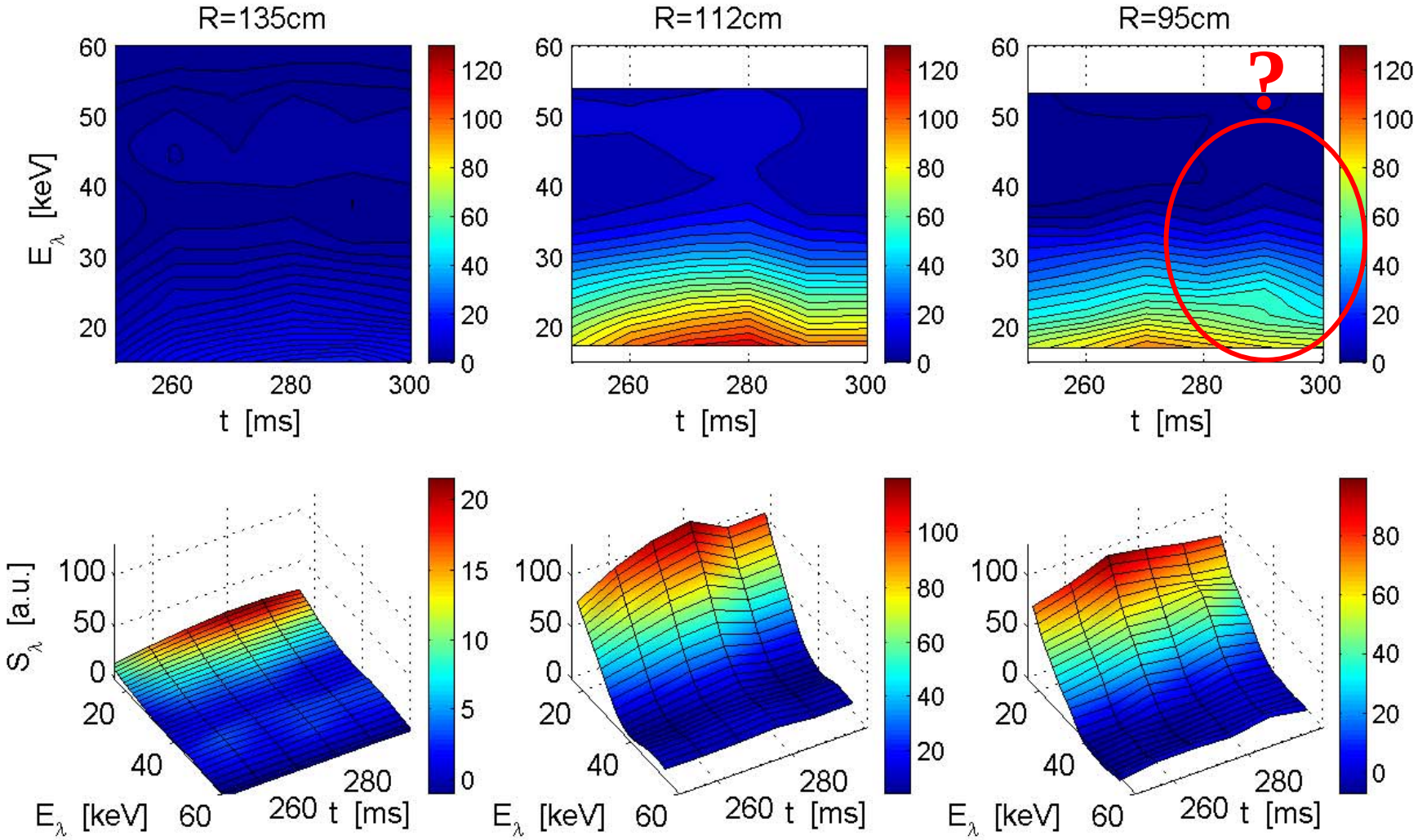




s-FIDA spectra show depletion over energies $E_\lambda \geq 25$keV at LFS of maximum n_f, but...

- … spectra at HFS show “redistribution”, instead
- Need comparison with FIDA simulation code to interpret $E_\lambda \rightarrow E_{\text{fast ions}}$
- Results to be compared with NPA, ssNPA and sFLIP data

Example: shot#128455



f-FIDA measures rapid fast-ion loss during TAE frequency down-chirp

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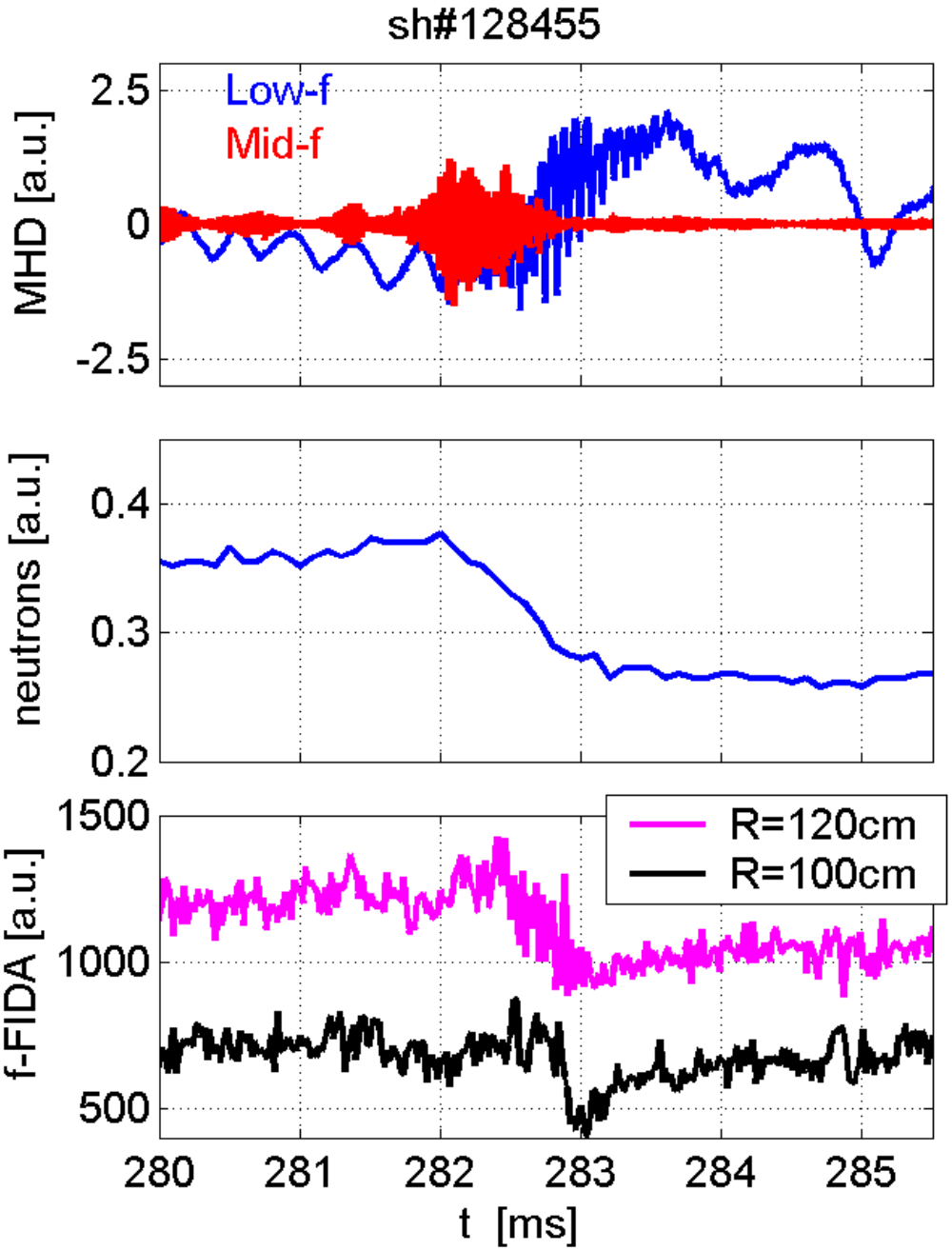
- Fast-ion signal integrated over energy range E_λ=15→60keV (bandpass filter+PMT detector)
- Sampling frequency 50kHz

- Clear drop of f-FIDA signals at R=100cm and 120cm

- Time scale ~0.5ms

- Delayed drop at R=100cm
  - HFS of n_f peak

- Qualitative agreement with s-FIDA data (not shown)



Repetitive bursts of EPMs also correlate with fast drops of neutron rate

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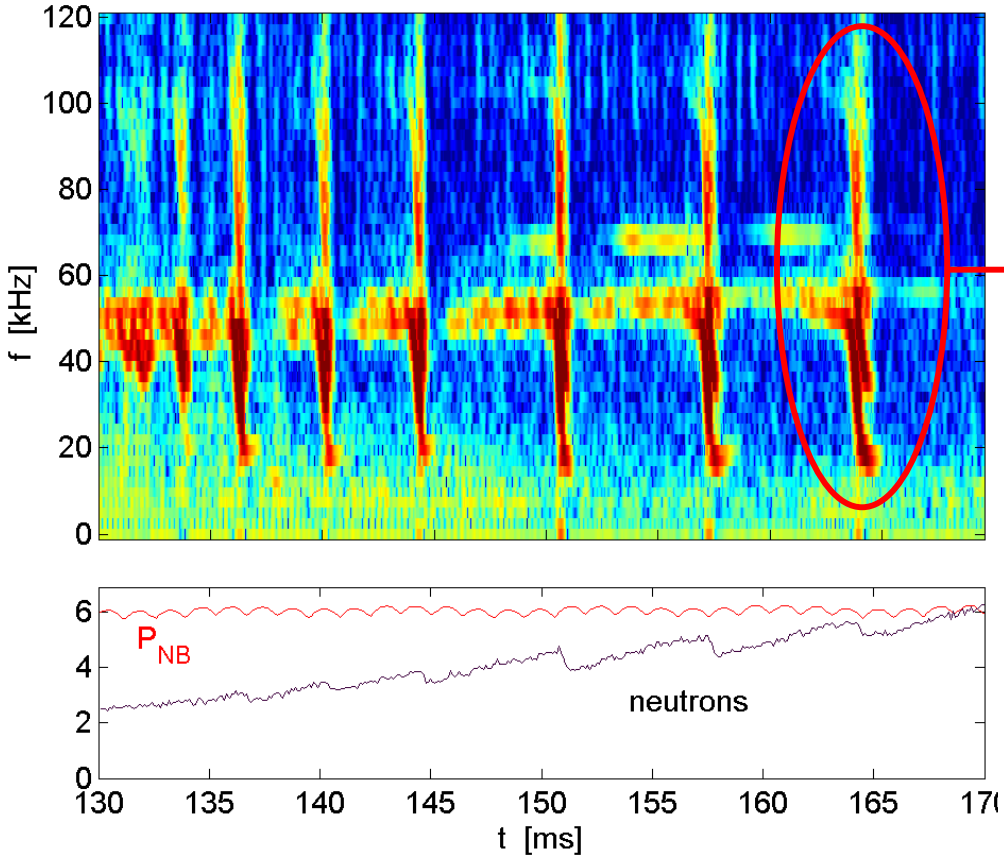
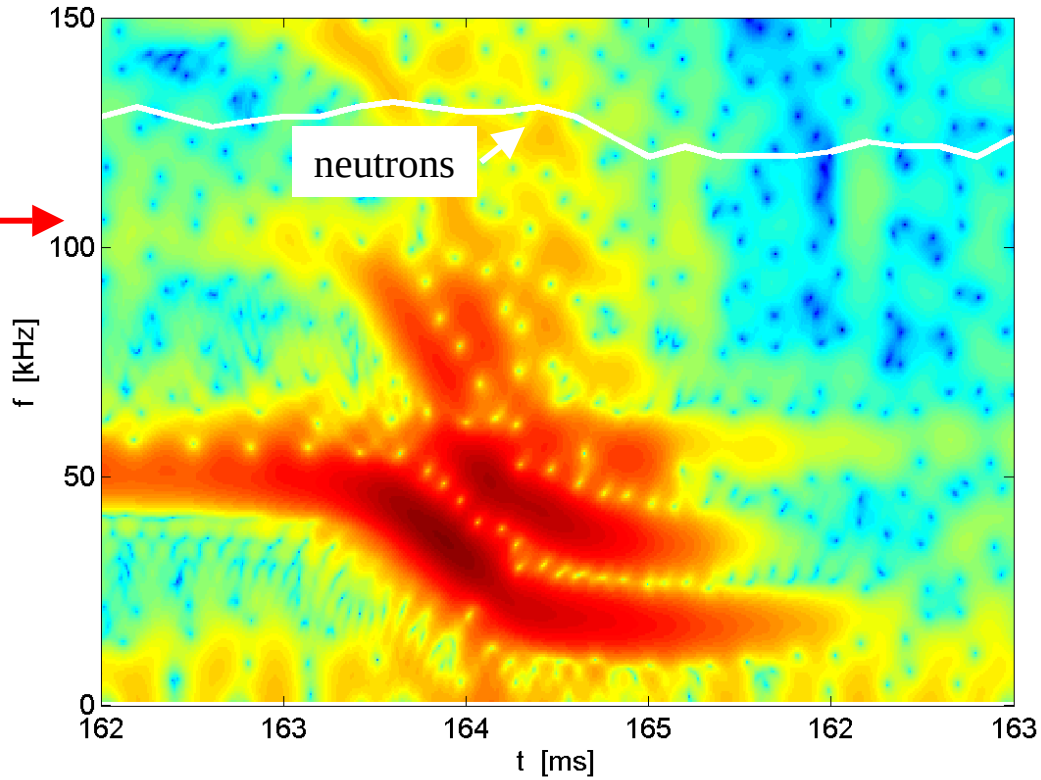
- L-mode, hydrogen plasmas
- EPMs frequently observed during current ramp-up
- Time-scale of frequency down-chirp ≤ 1ms

Example: sh#128918

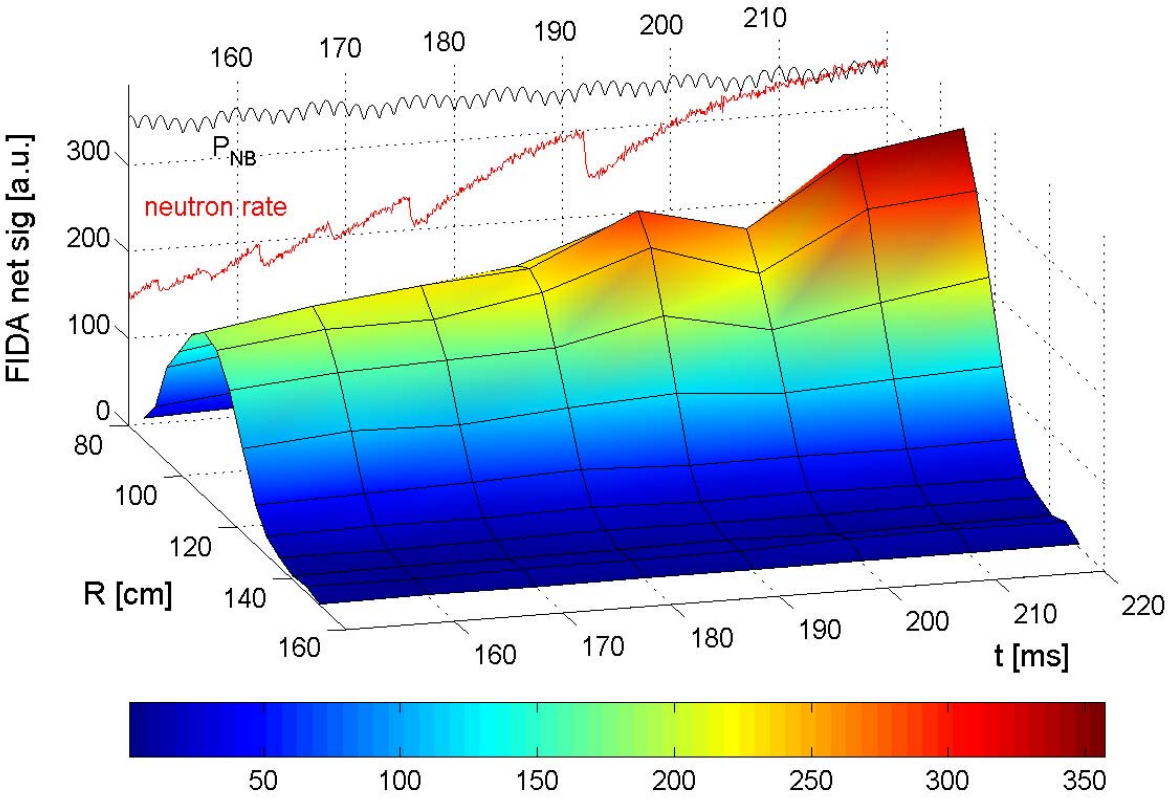


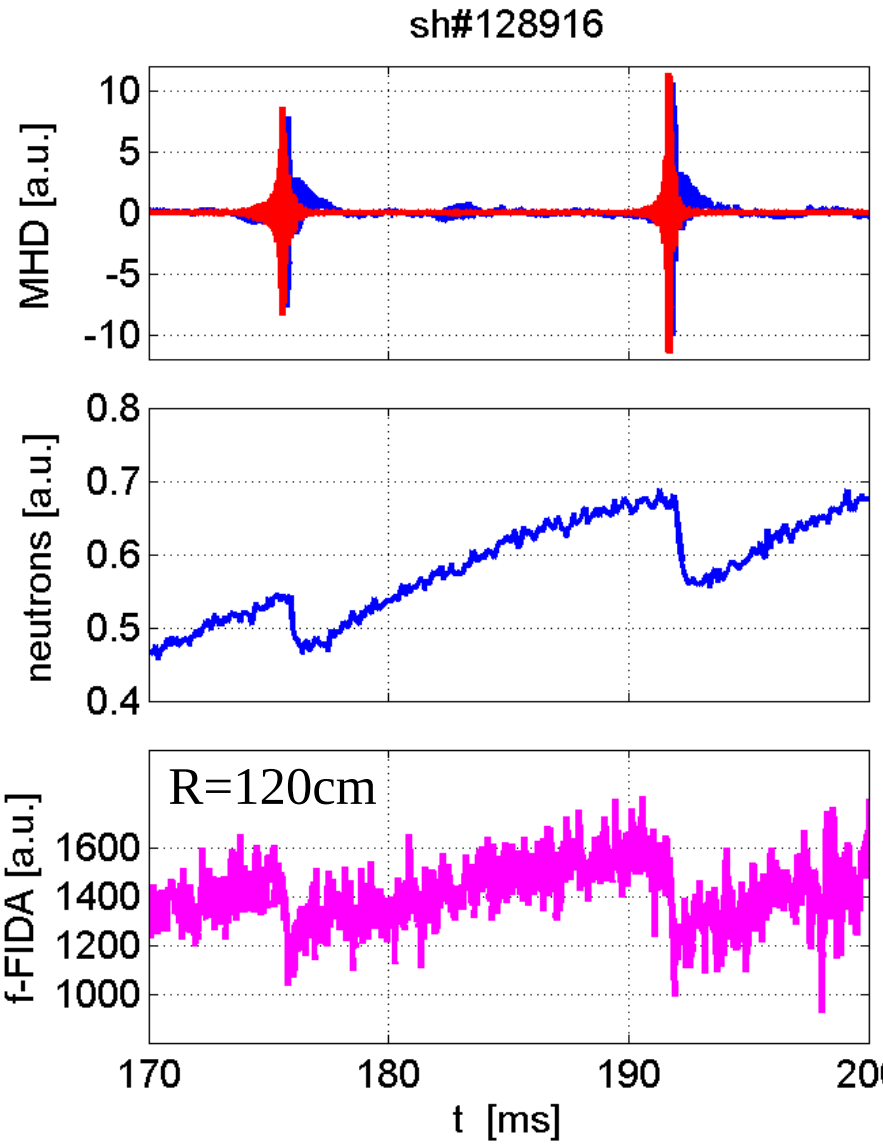


s-FIDA profile dynamics qualitatively similar to TAE avalanches case

- General decrease of n_f at all radii
- Quick drops in f-FIDA signals

Example: sh#128916





Low-frequency (kink) activity strongly affects fast-ion profiles

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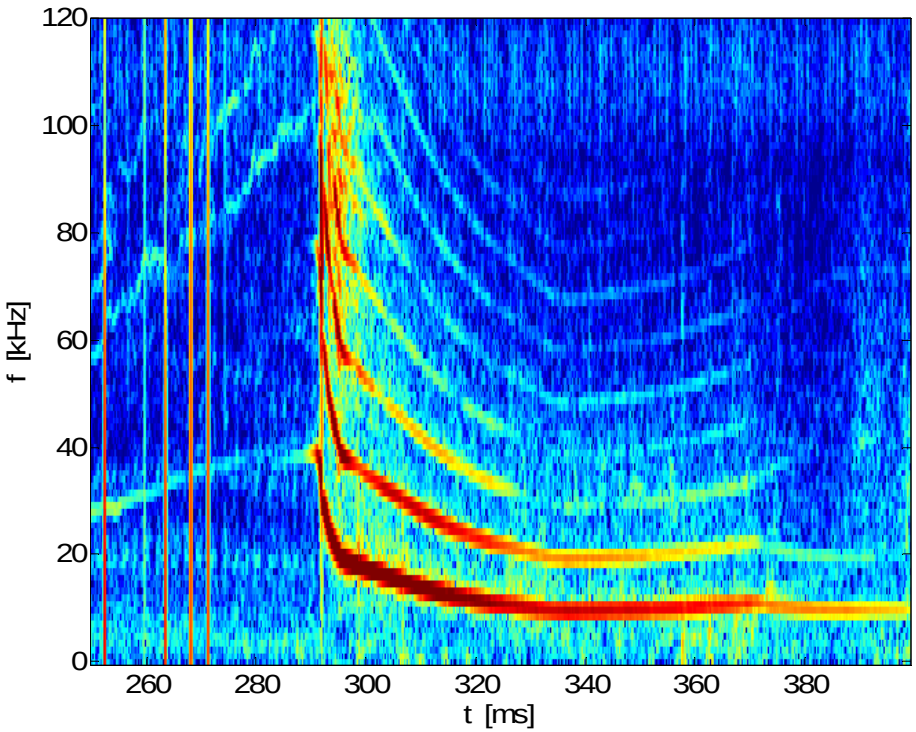
- Qualitative behavior:

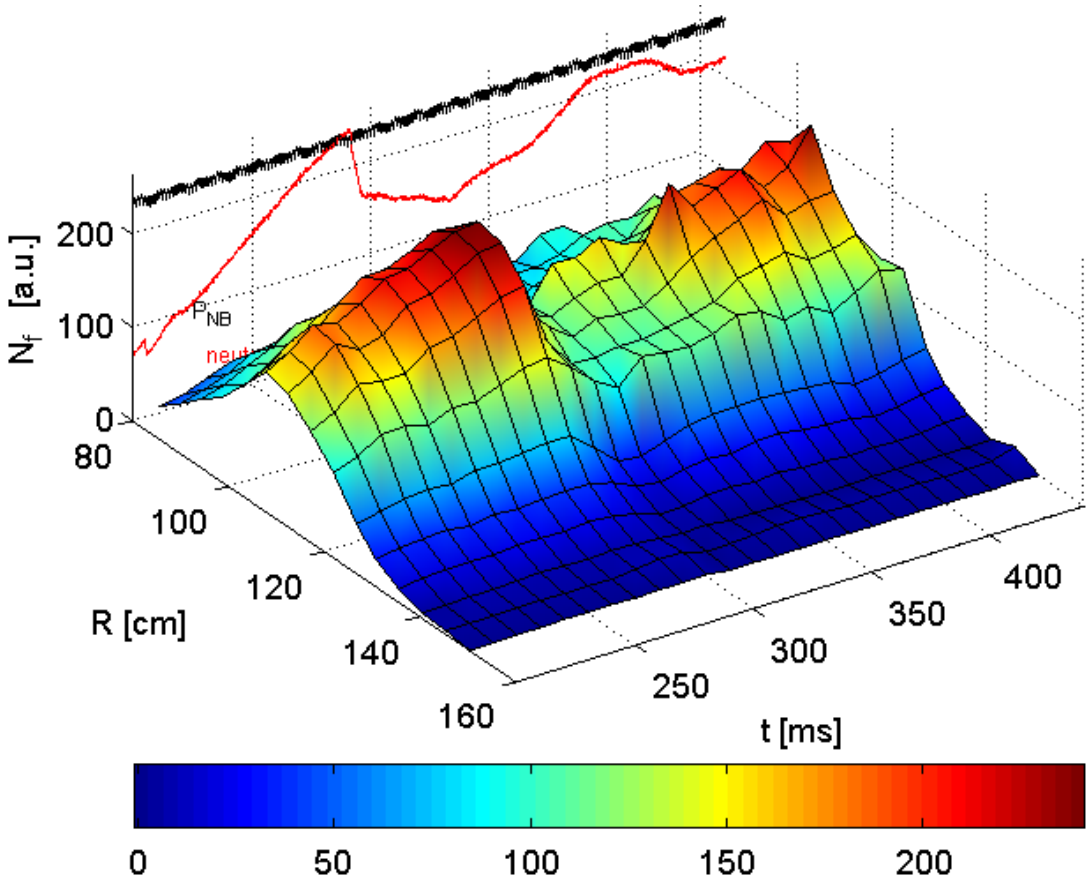
  i) frequency down-shift, ii) quasi-stationary phase (only lower *f*'s survive), during which iii) appearance of high-frequency CAEs (f > 1MHz)

- Naive interpretation: low-f activity redistributes fast ions to the edge

  $\Rightarrow$ drive for CAEs at outboard plane, depending on phase-space details

Example: sh#130323





Other possible contributions to different XPs

- XP-832, HHFW fast-ion acceleration
  - Measured spatial profile of accelerated fast ions
  - Data may support HHFW theory and modeling
- XP-807, MHD-induced energetic ions redistribution
- XP-808, fast-ion transport by AE cascades
  - Possible comparison between measured and modeled (TRANSP) fast-ion loss/redistribution
- XP-840, Electron transport by GAEs/CAEs
  - Provide information on fast-ion drive for high-frequency instabilities
- XP-831, Ion transport & power balance
  - Measured spatial response of fast-ion profile to NB modulation
- XMP-59, NB species characterization
  - FIDA spectra will complement NPA and ssNPA data
- Other XPs:
  - FIDA as impurity monitor, fast D_α monitor (f-FIDA), ...

Summary

- Fast-ion transport by TAE avalanches documented by FIDA
  - Up to 30% of fast ions lost
    - Consistent with neutron rate
  - Broad spatial region involved
    - Correlation between losses and position of steepest n_f gradient
  - All *observed* energies > 25keV involved
    - Need to deconvolve FIDA spectral information for correct interpretation
    - Comparison with other fast-ion loss diagnostics helpful (NPA, ssNPA, sFLIP)

How to compare observed fast-ion losses with model/theory?

- Preliminary observations of fast-ion transport associated with
  - EPMs
    - Fast-ion dynamics qualitatively similar to down-chirp phase of TAE avalanches
  - Low-frequency MHD
    - Strong modification of fast-ion density profile
    - Possible coupling with high-frequency modes (CAEs, GAEs)

- FIDA data can contribute to a larger number of XPs from 2008 Run