The Effect of Electric Fields and Pitch-Angle Scattering on the Radial Neutral Flux

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Abstract. The radial flux of 10-keV neutrals from the Asdex-Upgrade tokamak has been interpreted as a diagnostic of the radial electric field E_r near the plasma edge [Phys. Rev. Lett. **75** (1995) 4401], with the conclusion that E_r changes gradually at a transition from the L-mode confinement regime to the H-mode regime. In contrast to the Asdex-Upgrade results, a similar installation on the DIII-D tokamak finds no measurable signal in H-mode plasmas with deep E_r wells. Measurable signals only occur in plasmas with relatively large pitch-angle scattering rates at the plasma edge (or with anomalous beam-ion confinement). Large scattering rates require a large electron temperature and are invariably accompanied by deep ripple wells. The results suggest an alternative explanation for the gradual evolution of the neutral-particle signal from Asdex-Upgrade: as the H-mode pedestal develops, more beam ions are pitch-angle scattered into the phase space measured by the detector.

Background

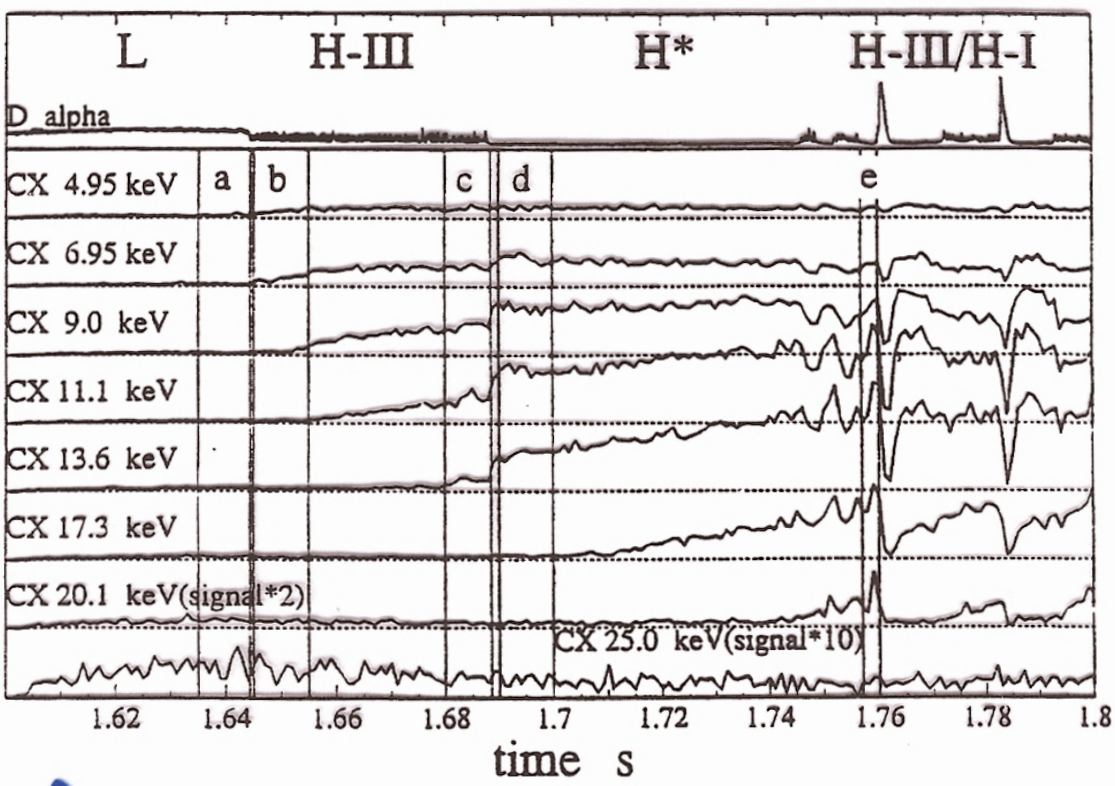
- The DIII-D group thinks H-modes have reduced transport because the **E** x **B** velocity shear suppresses turbulent eddies.

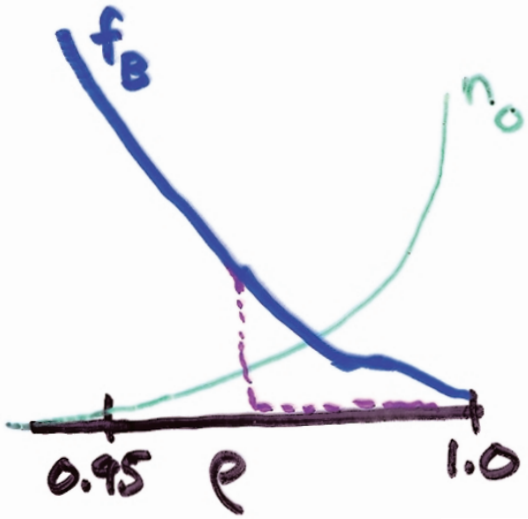
- Edge neutral particle signals from ASDEX-Upgrade change gradually at the L-H transition. In the absence of an electric field, the measured particles are trapped in the toroidal field ripple and escape promptly. A large radial electric field can compensate the vertical drift if $E_r > W/R$, confining the ions. (W is the ion energy and R is the major radius.)

- To the Asdex group, the gradual increase of the neutral particle signal indicates that the radial electric field forms gradually, so shear suppression of turbulent eddies is not the cause of the improved confinement. They conclude:

"The presented experimental results are in favor of theories that do not need an electric field...for the L-H transition."

Herrmann: Gradual rise $\Rightarrow E_r$ develops after the transition.

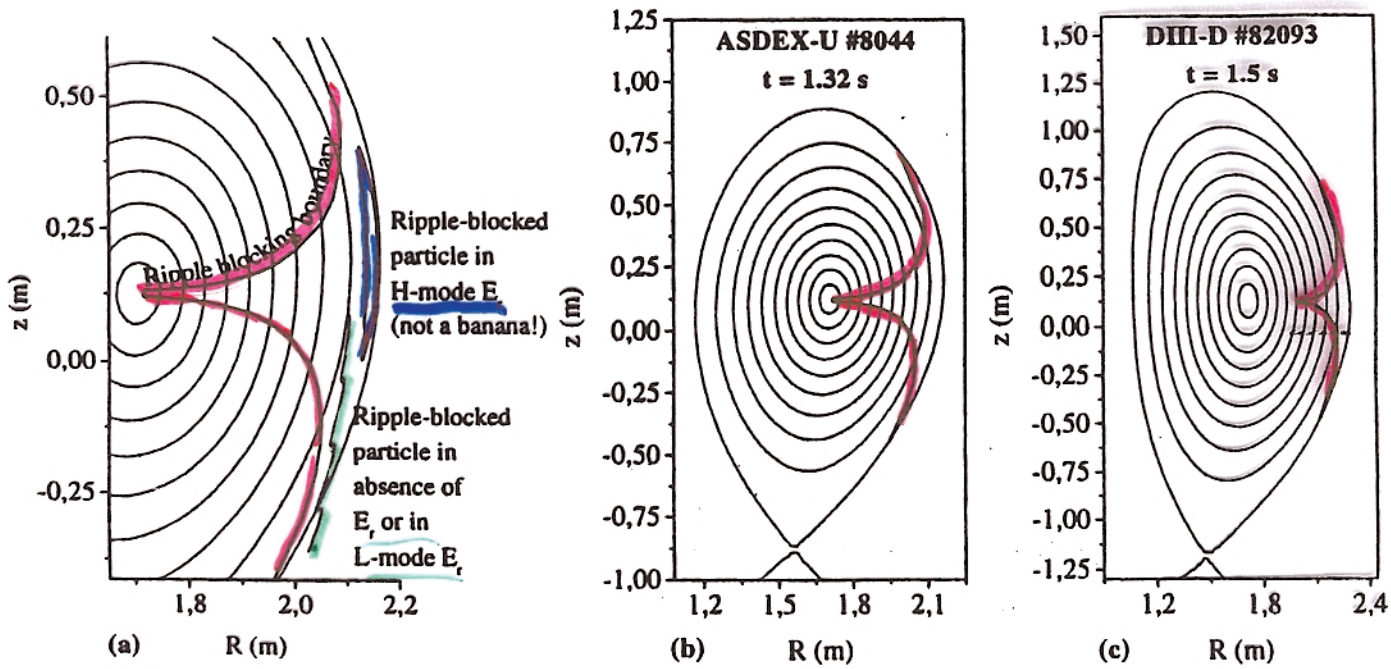




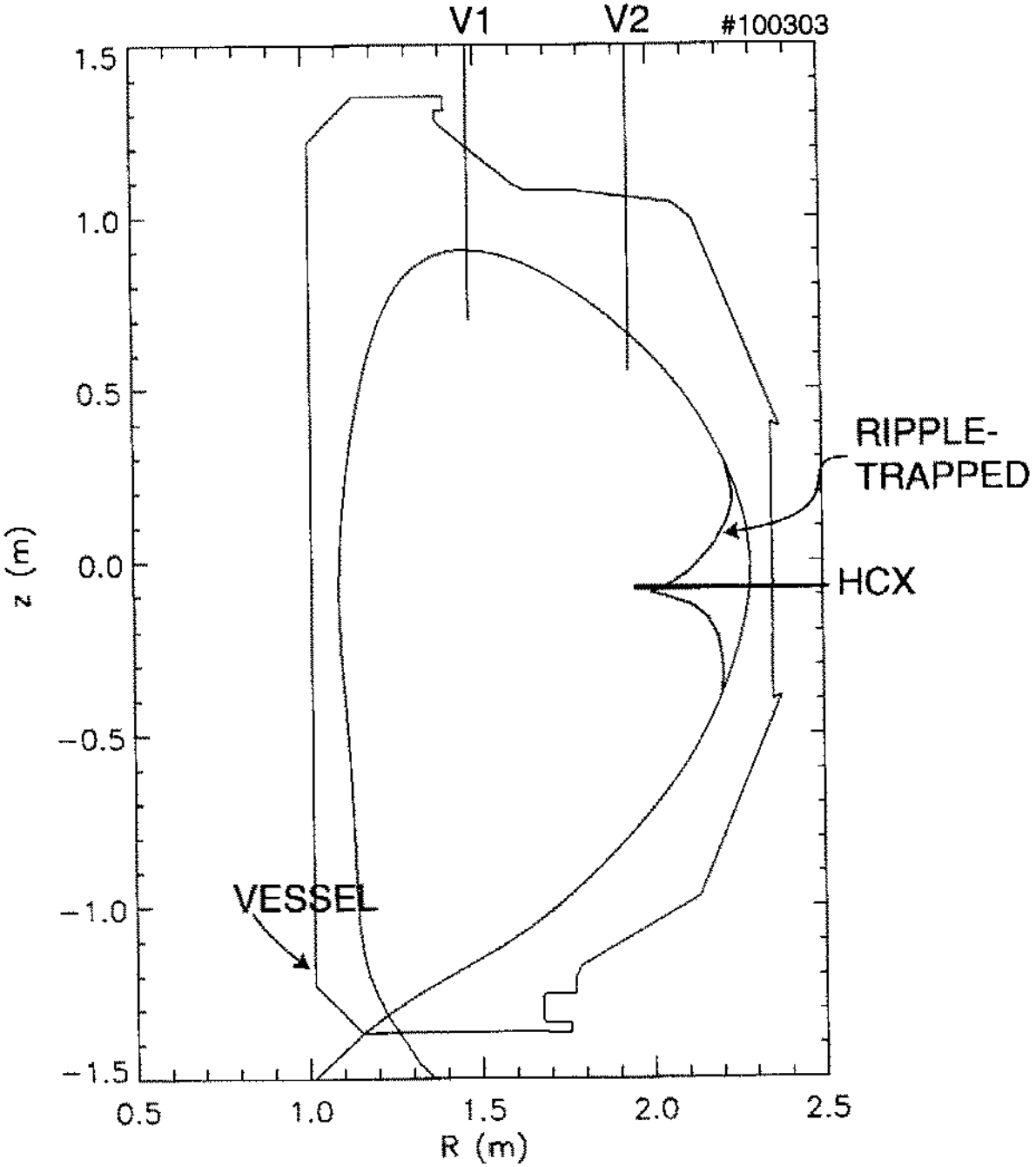
$$\Phi \propto \int n_0(r)\, f_B(E,\chi,r)\, dr$$

For $E_r \times B_\phi$ to cancel ∇B drift

$$|E_r| \gtrsim \frac{W}{R} \simeq 5 \frac{kV}{m}$$

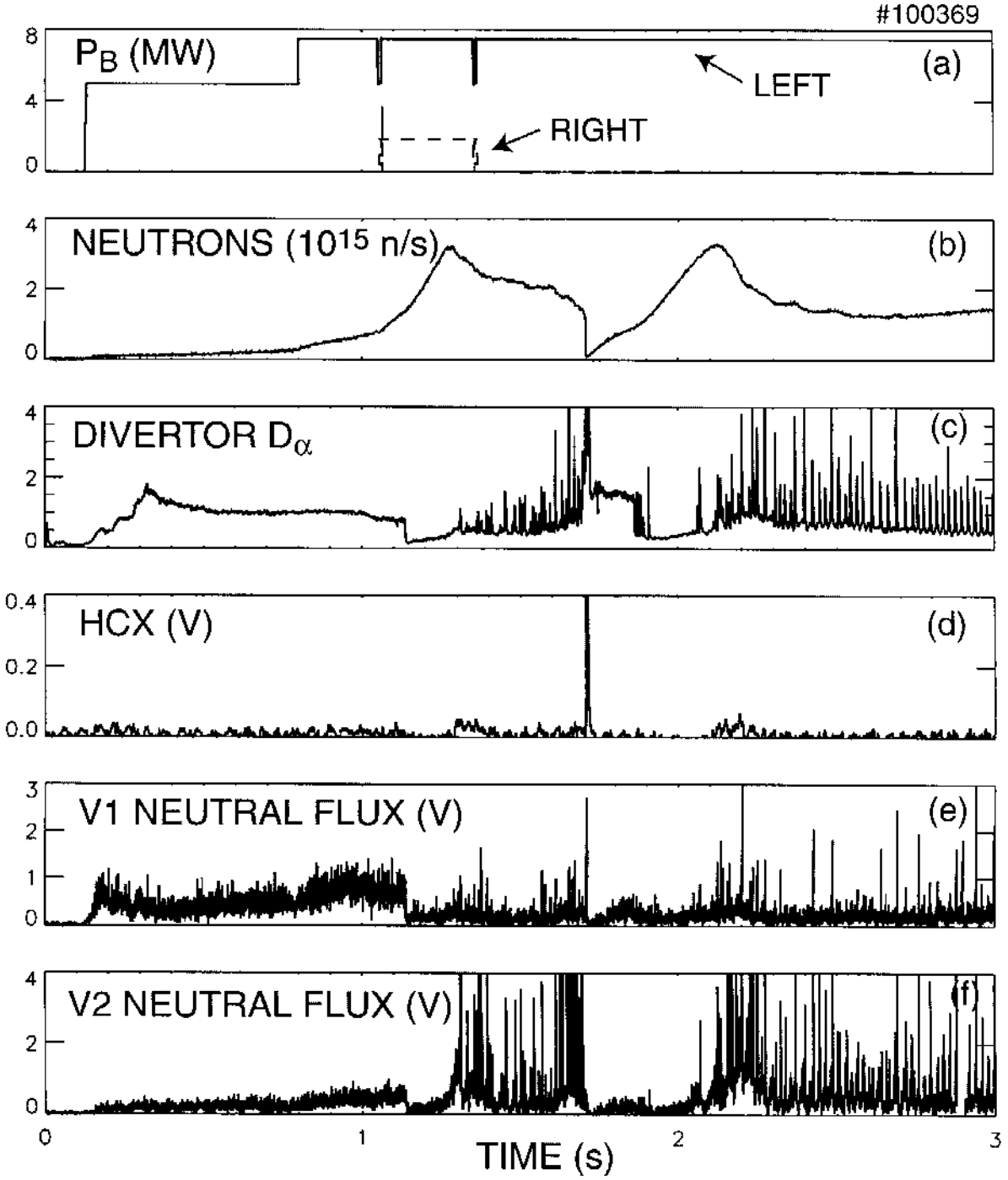


Attempt to reproduce Asdex-Upgrade results:
Made E_r=10 kV/m > 10 keV/R but saw no HCX signal!



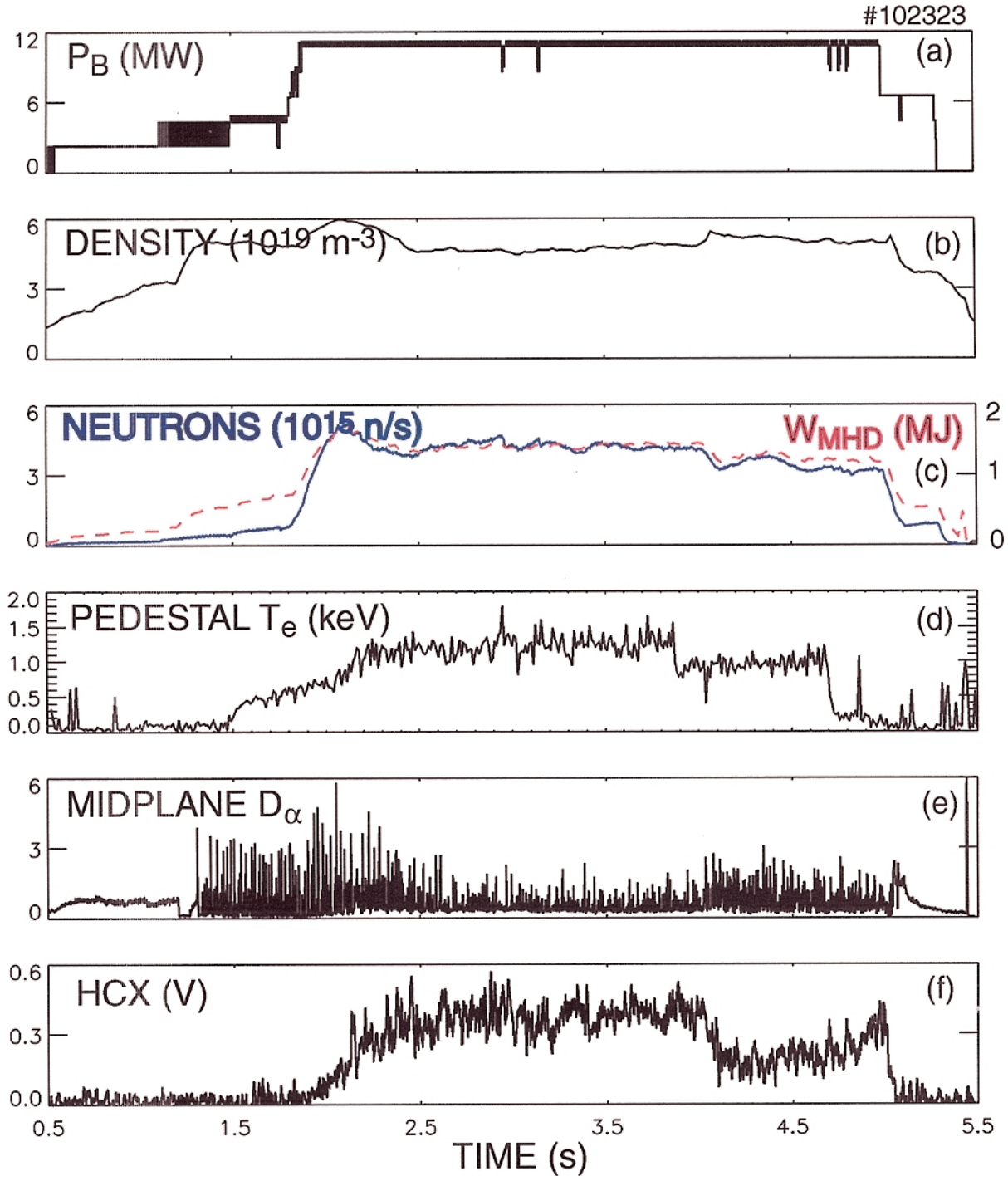
Profile of the DIII-D vessel showing the Charge-exchange sightlines, and the ripple trapping region for a typical shot.

HCX signal insensitive to edge neutral changes



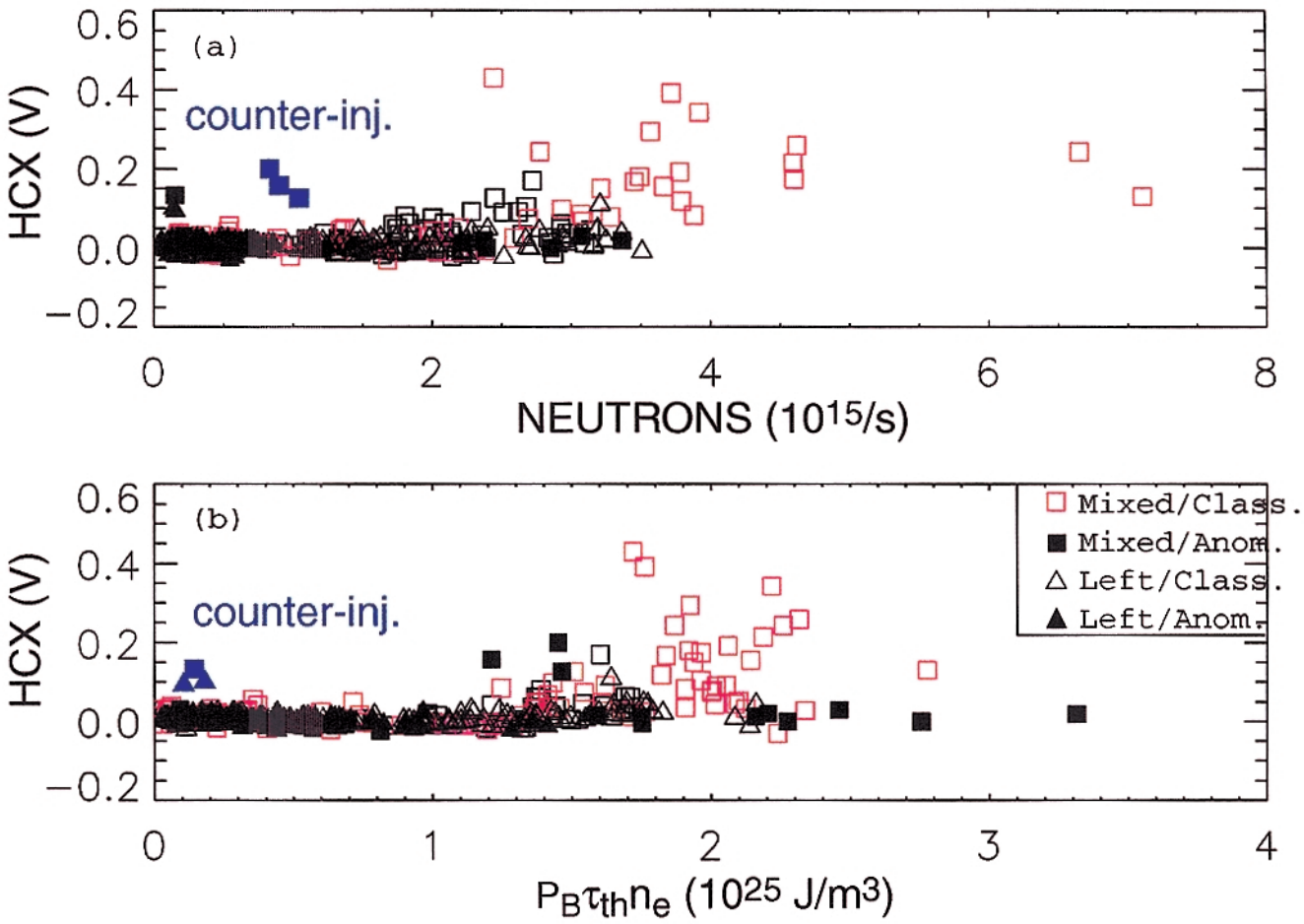
Parameters for a shot with a disruption, and very little right beam injection. HCX is small except for the contamination caused by the disruption. Small HCX signal is evident in the two high performance phases before and after the disruption.

Steady HCX signal in high T_e, high performance plasma



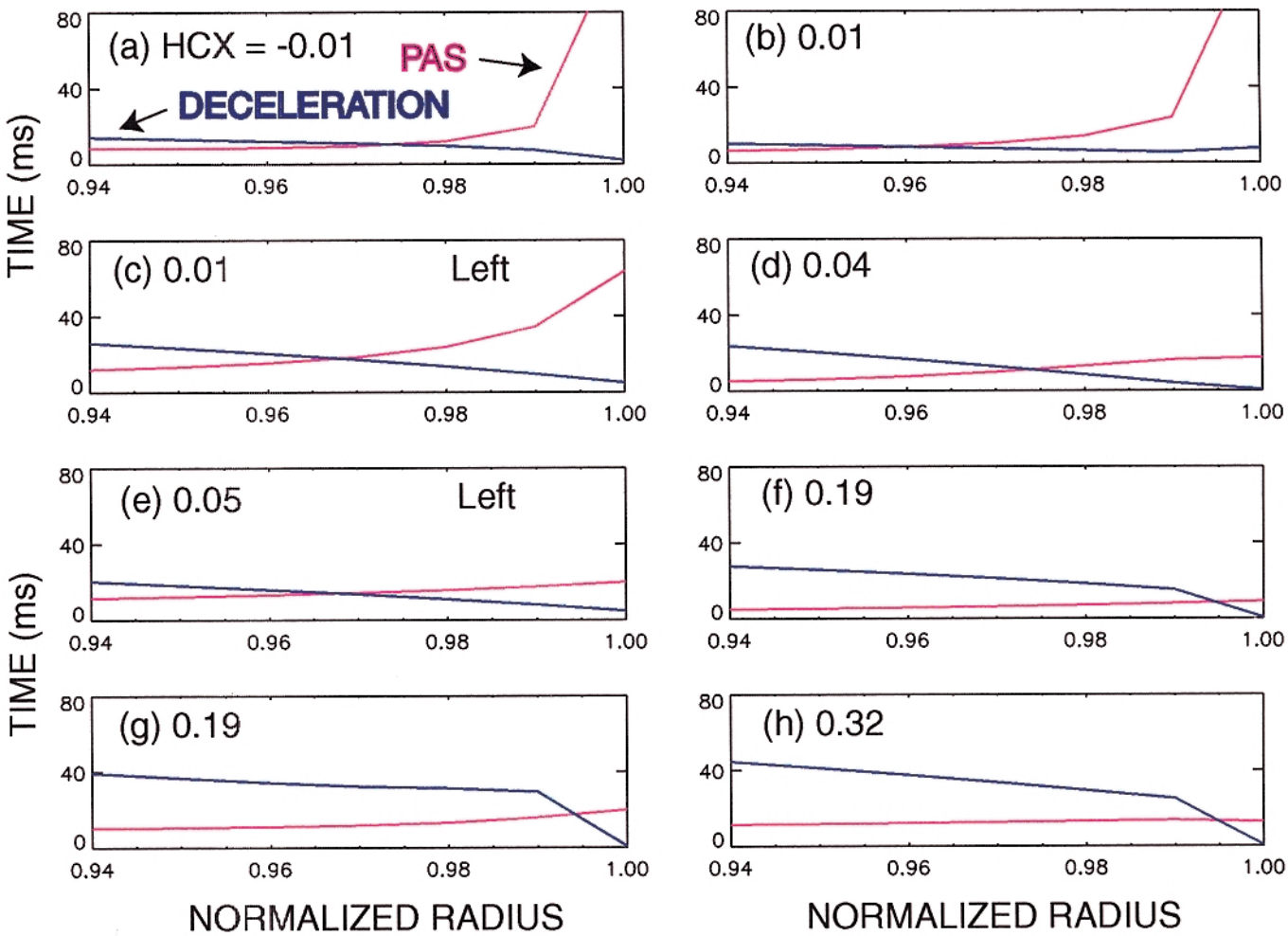
Steady HCX signal in plasmas with:

- high T_e
- good beam-ion confinement
- Right (more perpendicular) beams

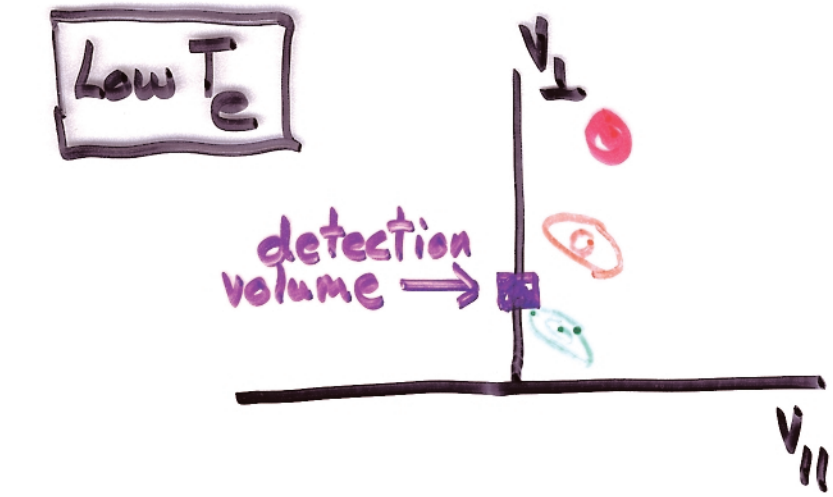


Dependence of the HCX signal on (a) the neutron rate, and (b) the edge beam ion density. Mixed indicates that right beams are present, and Class means that the neutron rate was close to the expected value.

Signal occurs when $t_{PAS} < t_{therm}$ near the edge



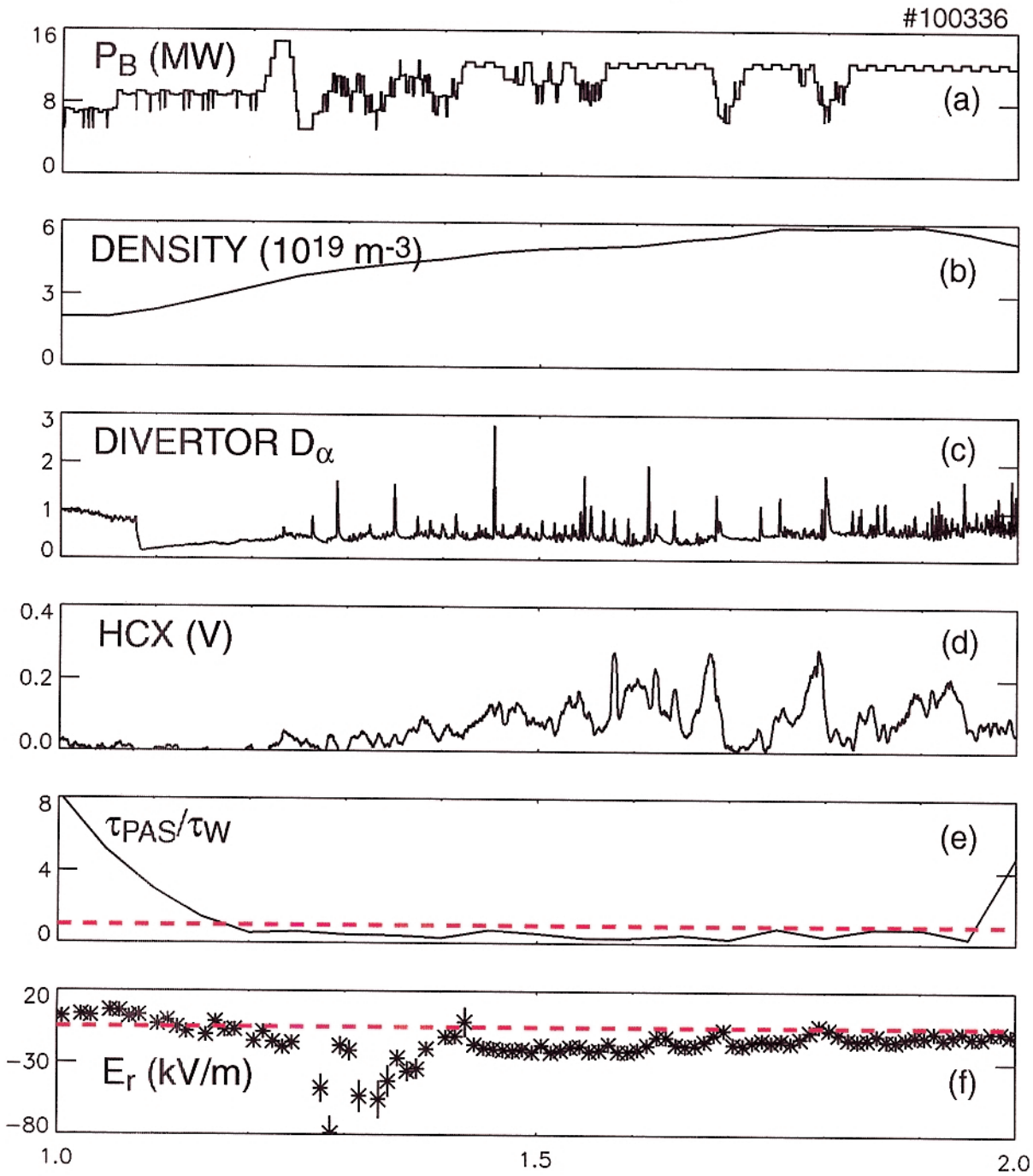
Plots of Pitch Angle Scattering (PAS) and deceleration to 10keV as a function of time and radius. HCX signal is present when the PAS is shorter than the deceleration of beam ions.



Need $\nu_{PAS} > \nu_{thermalization}$

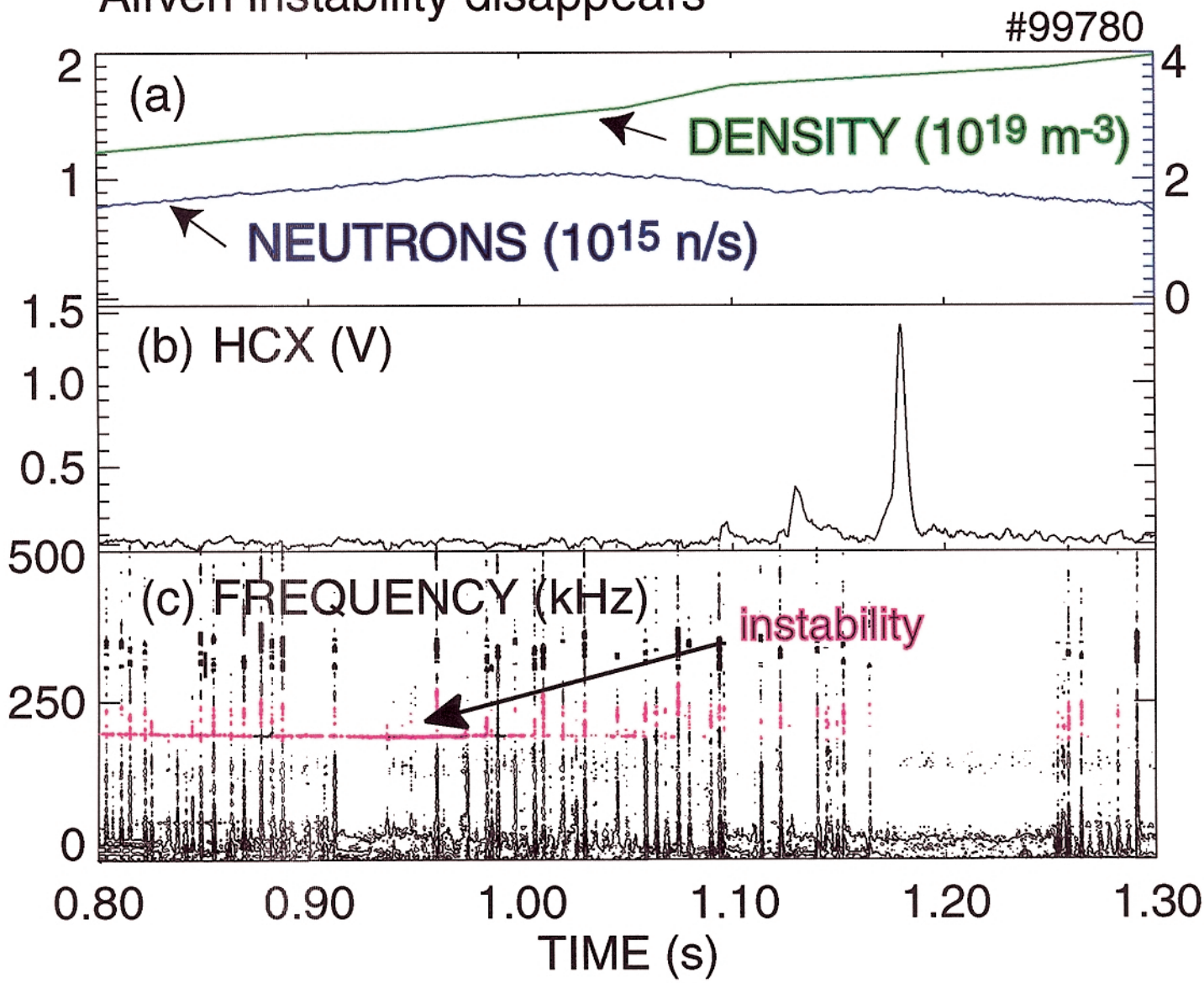
or $t_{PAS} < t_{thermalization}$

A deep E_r well and large pitch-angle scattering occur concurrently



If E_r is below the dashed line the criterion for confinement of ripple trapped ions is met. If τ_{PAS}/τ_W is below the dashed line then there is beam ions can pitch angle scatter prior to thermalization.

Transient Signals in Discharges with Anomalous Beam-Ion Confinement--in this case, as the Alfven instability disappears



Conclusions

- HCX signal is only seen when perpendicular, 10 keV beam ions are present near the plasma edge.

- In quiescent plasmas, the competition between pitch-angle scattering and deceleration governs the edge beam-ion density.
-- Right beams produce more signal than Left beams.
-- The deceleration time must exceed the 22° P.A.S. time.
-- The signal rises on a classical timescale.

- In plasmas with anomalous beam-ion confinement, bursts of signal are sometimes seen.

- No distinct ripple-trapping/E_r effects are observed.

- In light of the sensitivity to P.A.S., the ASDEX results do not prove that the electric field well forms gradually.