EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT JET IPP

Studies of the Quiescent H-mode regime in ASDEX Upgrade and JET

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Quiescent H-mode

Stationary ELM-free H-mode (no density, impurity accumulation)

Discovered in DIII-D K H Burrell et. al. PPCF **44** (2002) A253

To date, only H-mode regime
without large ELMs at low pedestal collisionality ($\nu^* < 1$)

Achieved with:
- Counter neutral beam injection (ctr-NBI)
- High clearance between plasma and wall
- Configuration for pumping
  (divertor strike points near cryopump-entry)
- Low recycling – avoid external gas puff

Goal: Reproduce QH-mode behaviour in ASDEX Upgrade and JET
Study properties of the regime and MHD that replaces ELMs

Outline

1. Phenomenology of Quiescent H-mode in ASDEX Upgrade

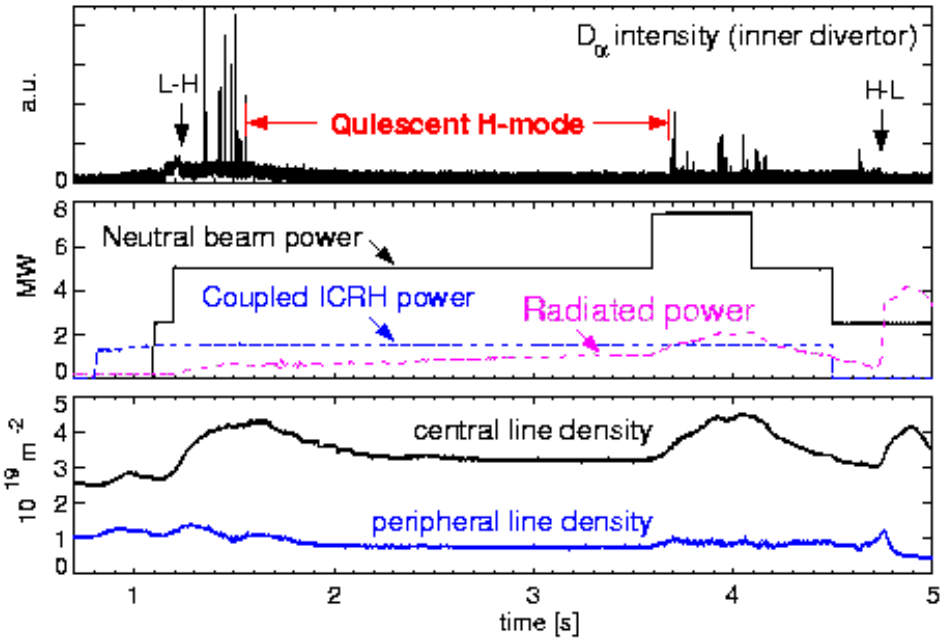
2. Quiescent H-mode experiment in JET

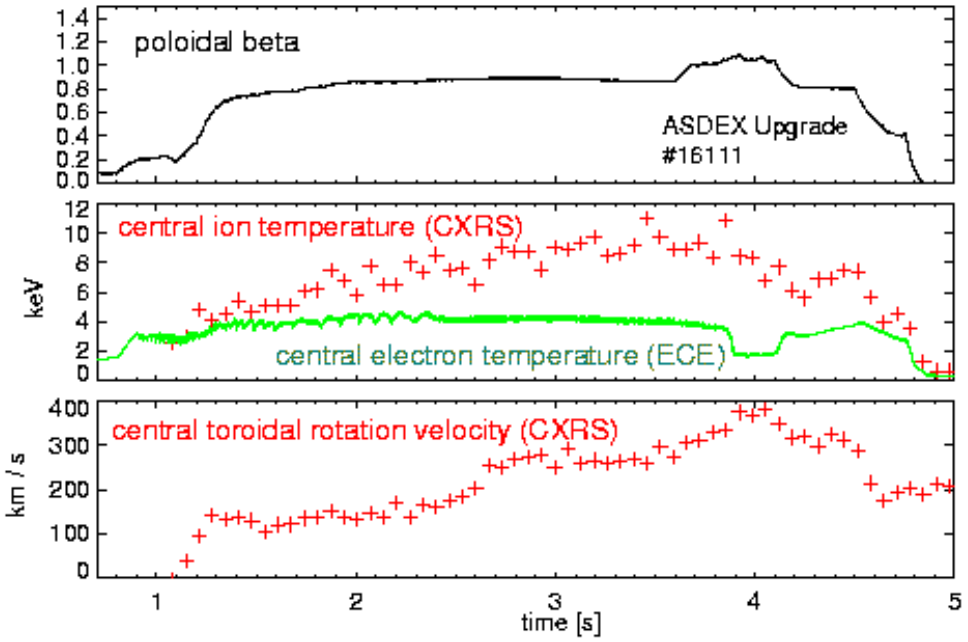
3. Nature of the MHD activity that replaces ELMs

4. Discussion – Why are ELMs suppressed ?

Quiescent H-mode in ASDEX Upgrade

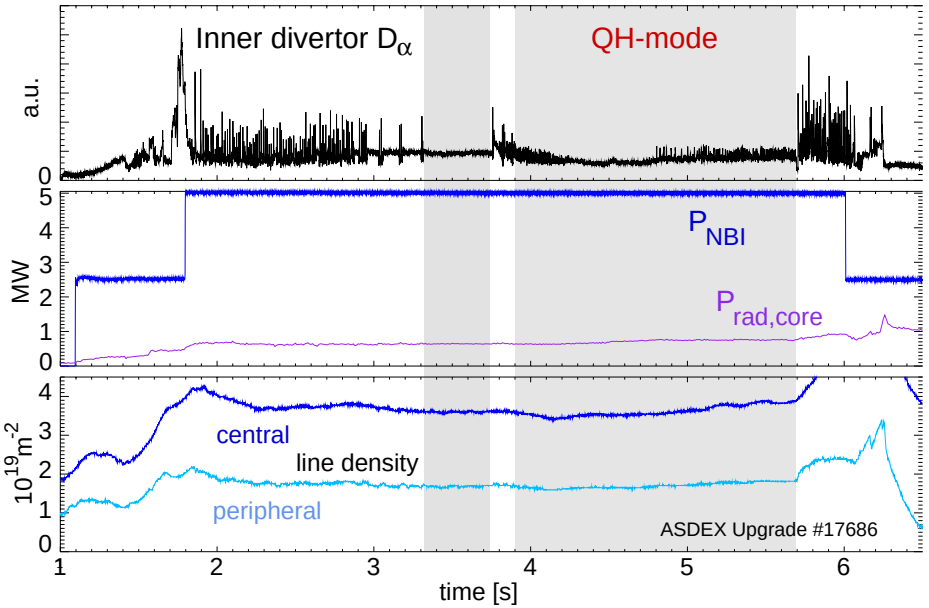
- Extended ELM-free period with stationary (low) density and radiation
- Confinement (here: poloidal beta) at or above ELMy H-mode
- High ion temperature at pedestal and in core
  often higher than in ELMy H-mode (but same R/L_T)
- Strong core toroidal rotation (ctr-I_p) in the absence of sawteeth



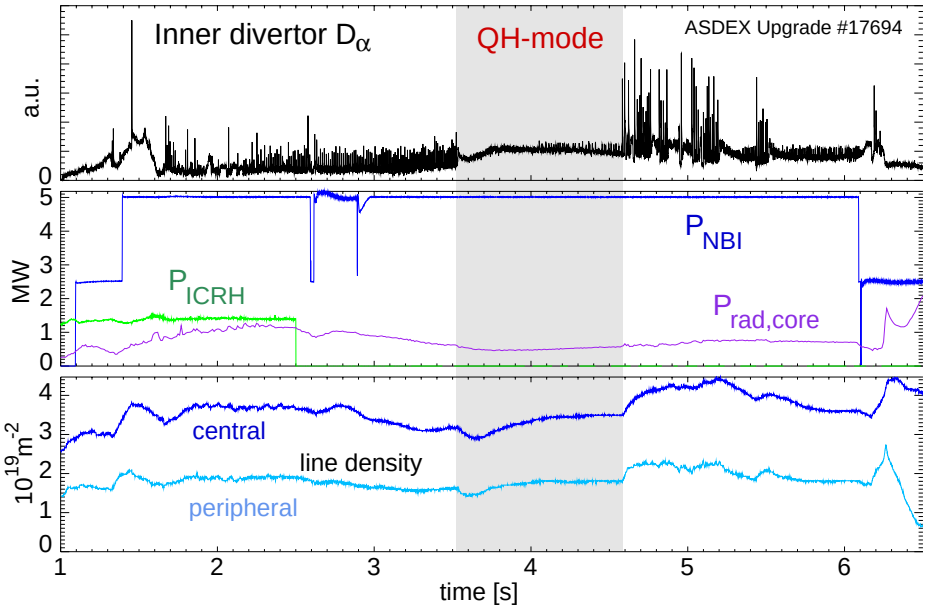


Plasma density depends on NBI injection angle

Near -Tangential injection:
density drops after transition to QH

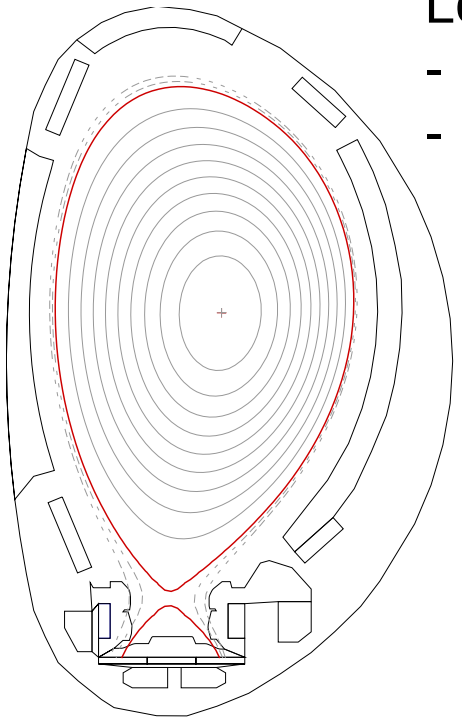


Near-Radial injection:
density increases



Tangential injection:
Density drops below minimum density to avoid NBI shine-through

Quiescent H-mode in JET



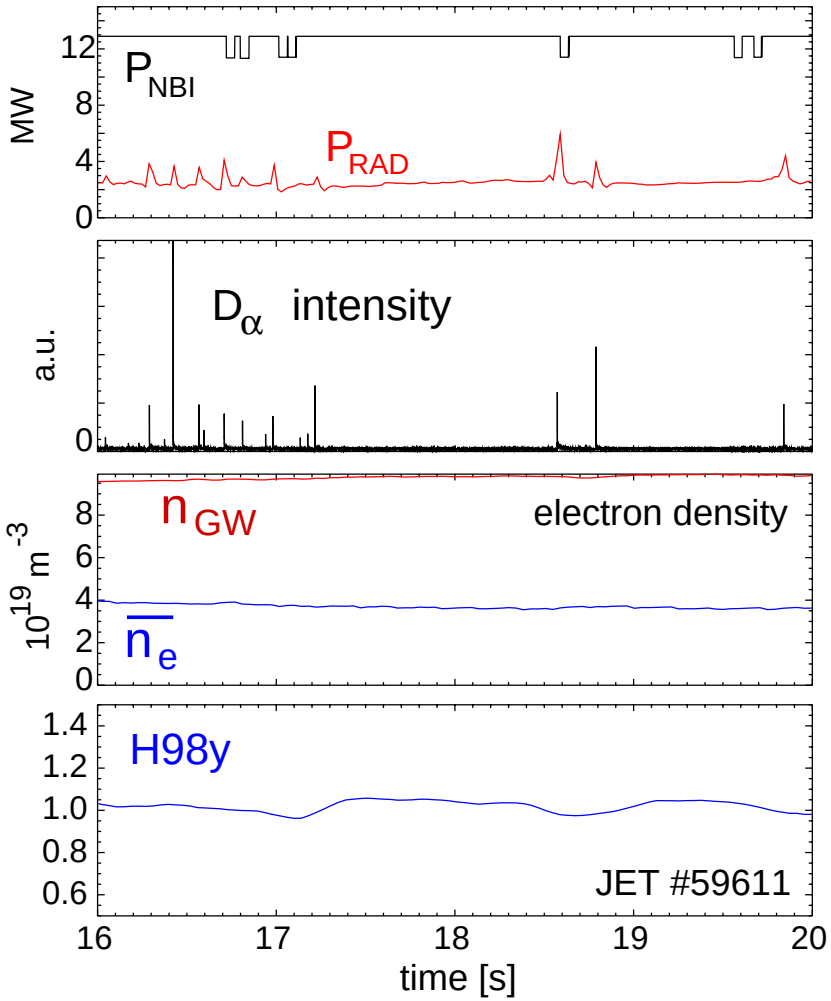
High clearance configuration

Low recycling conditions:
- long He glow + pumping
- Be evaporation

Various combinations of I_p, B_t (q_{95} = 3.3-4.9)

Quiescent H-mode phases observed with up to 1.5 s duration

Longest phases after fresh wall treatment.

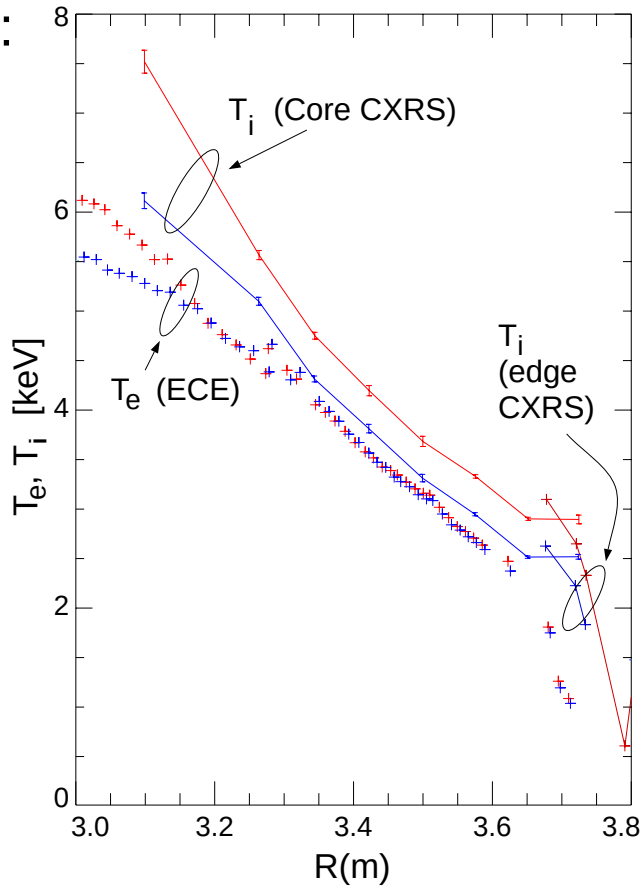


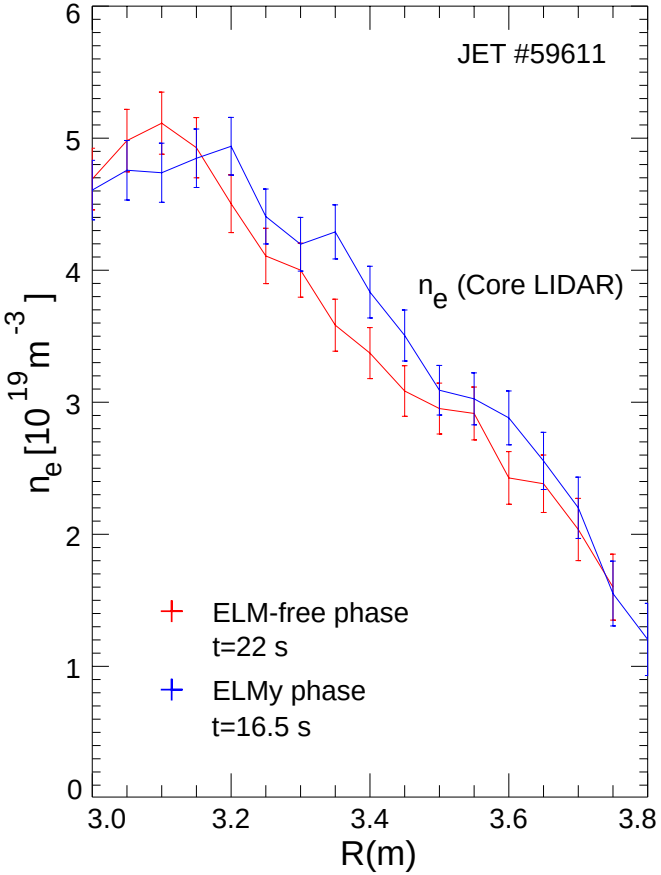
Core profiles similar in QH and ELMy H-mode

JET:

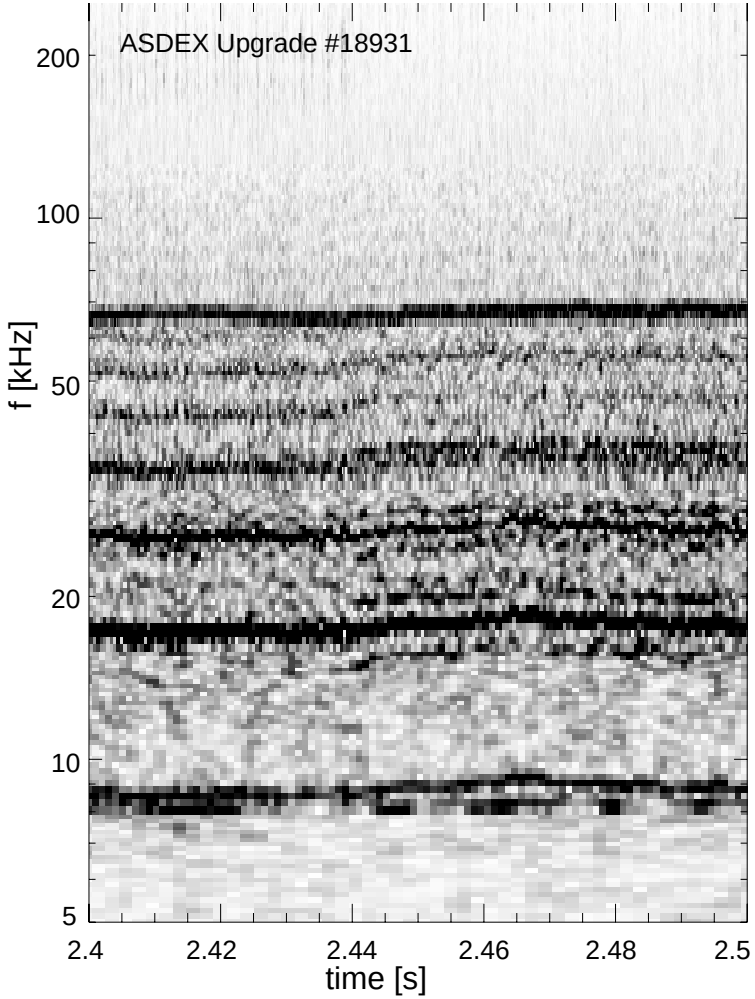
Electron density and temperature profiles similar

Slightly higher ion temperature in QH-mode





Hallmark of QH-mode: "Edge Harmonic Oscillation" (EHO)

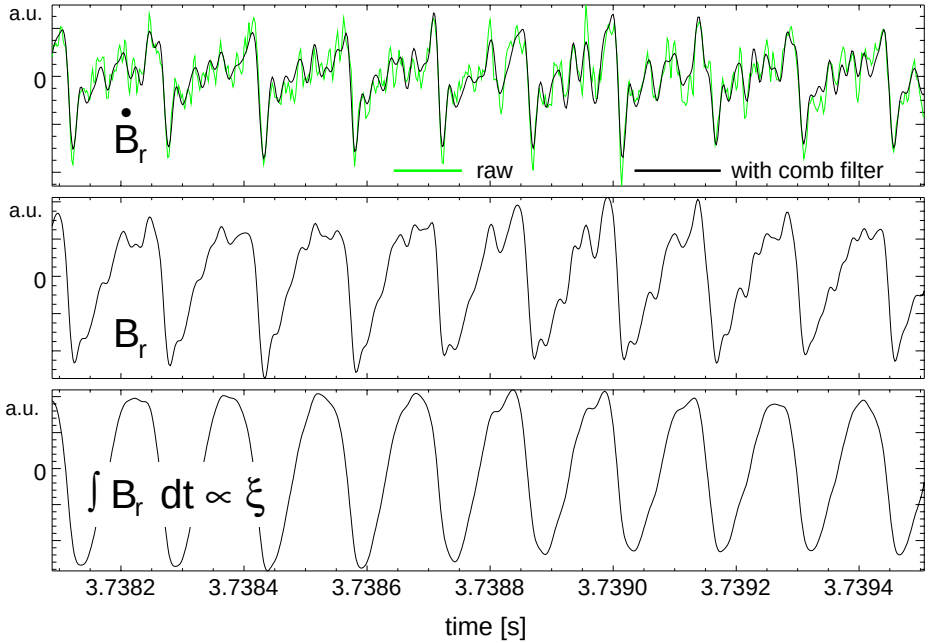


AUG, JET: n=1 fundamental

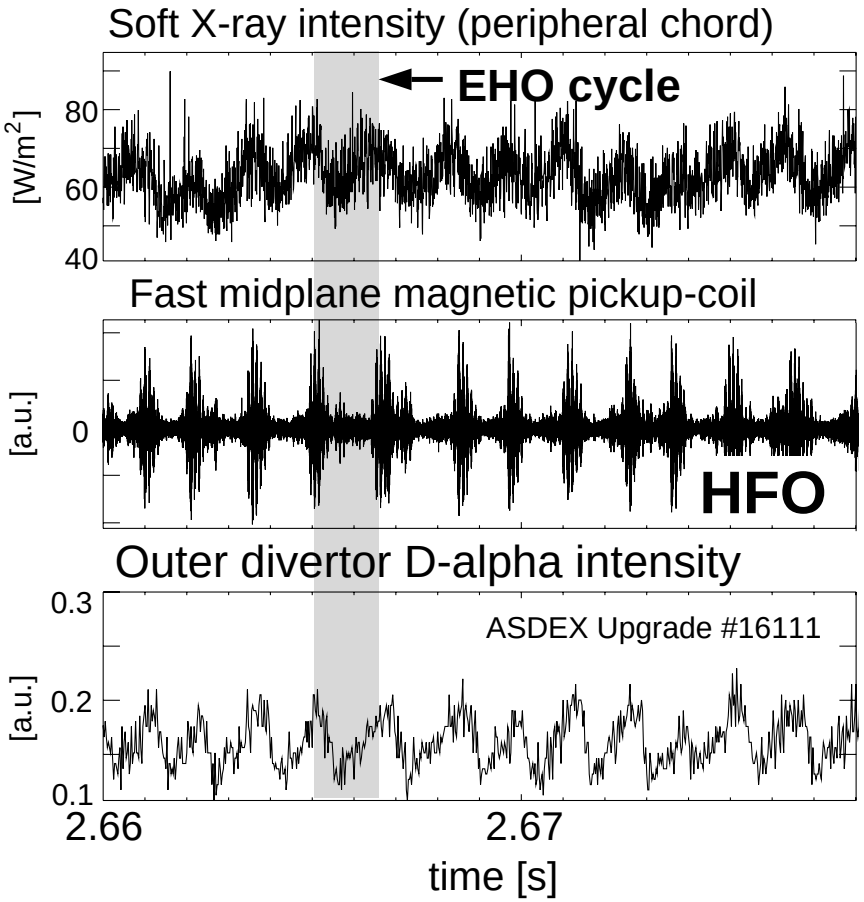
m for resonance in steep gradient region

ECE: ξ in phase outside/inside resonant surface – i.e. no island – kink (?)

Anharmonic spatial structure:



“High Frequency Oscillation” has bursts in phase with EHO



HFO frequencies: 300 – 500 kHz

Often non-harmonic higher f component

Modulation in time, n=0

in phase with EHO cycles

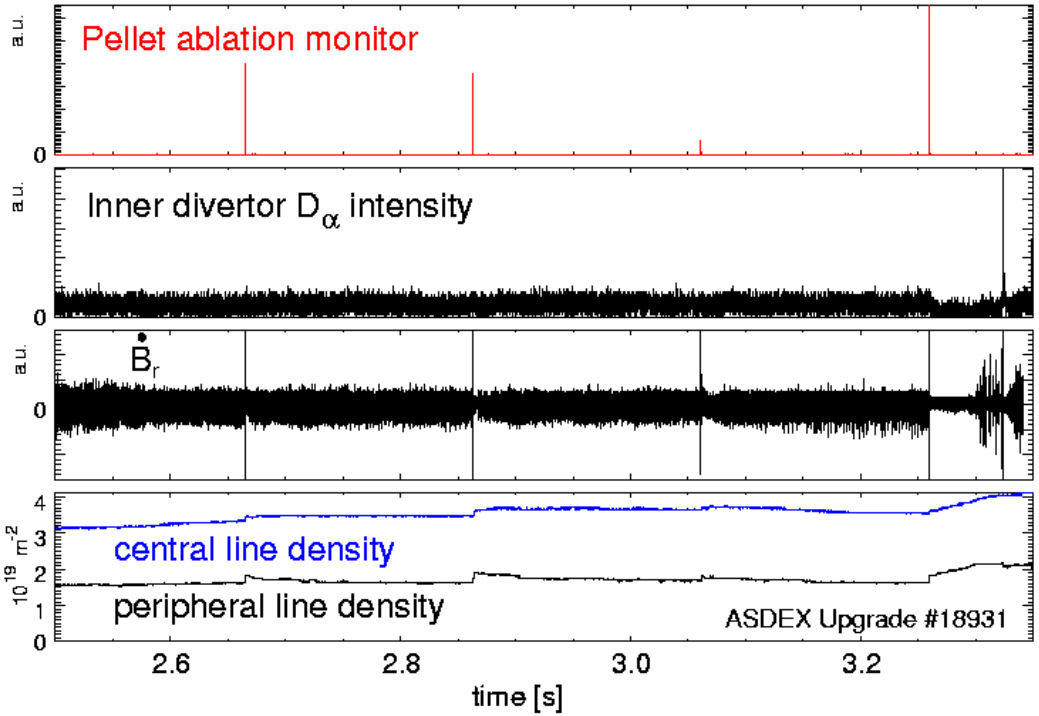
Bursts / EHO cyles correlate with <u>outer</u> divertor D_α

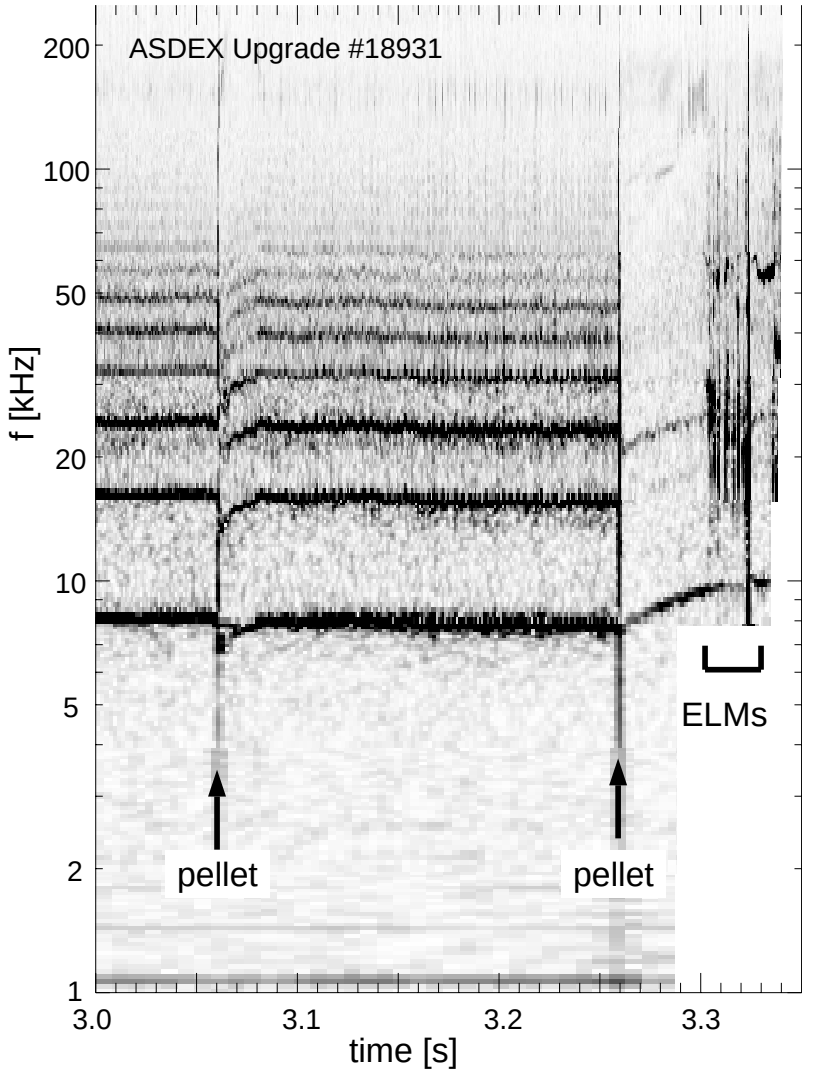
$\Rightarrow$ transport due to HFO/EHO

Stationarity only with EHO/HFO

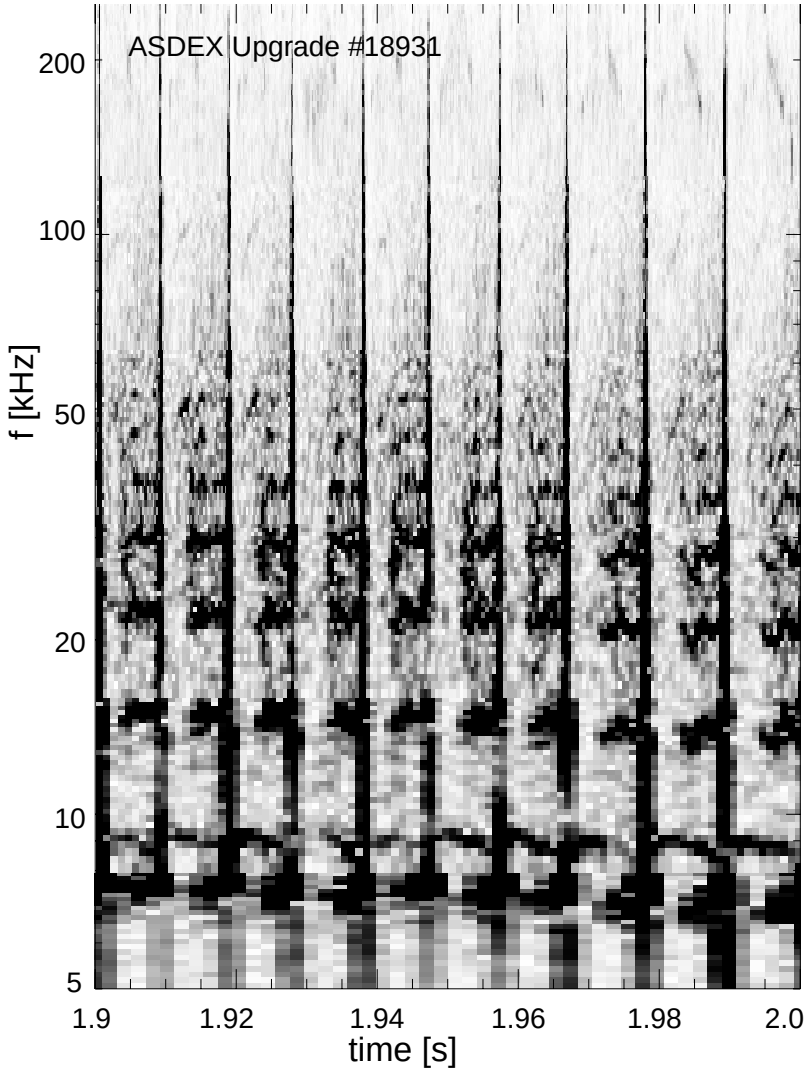
Pellet injection – (slight density increase)

After 4th pellet EHO lost:
density rises, ELMs

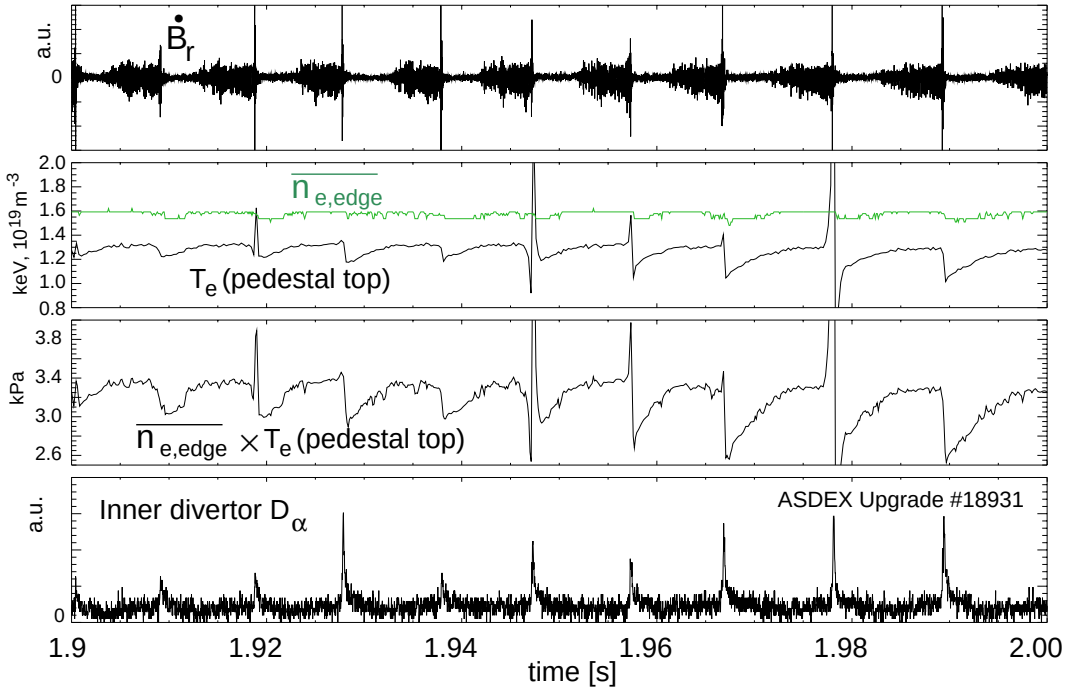




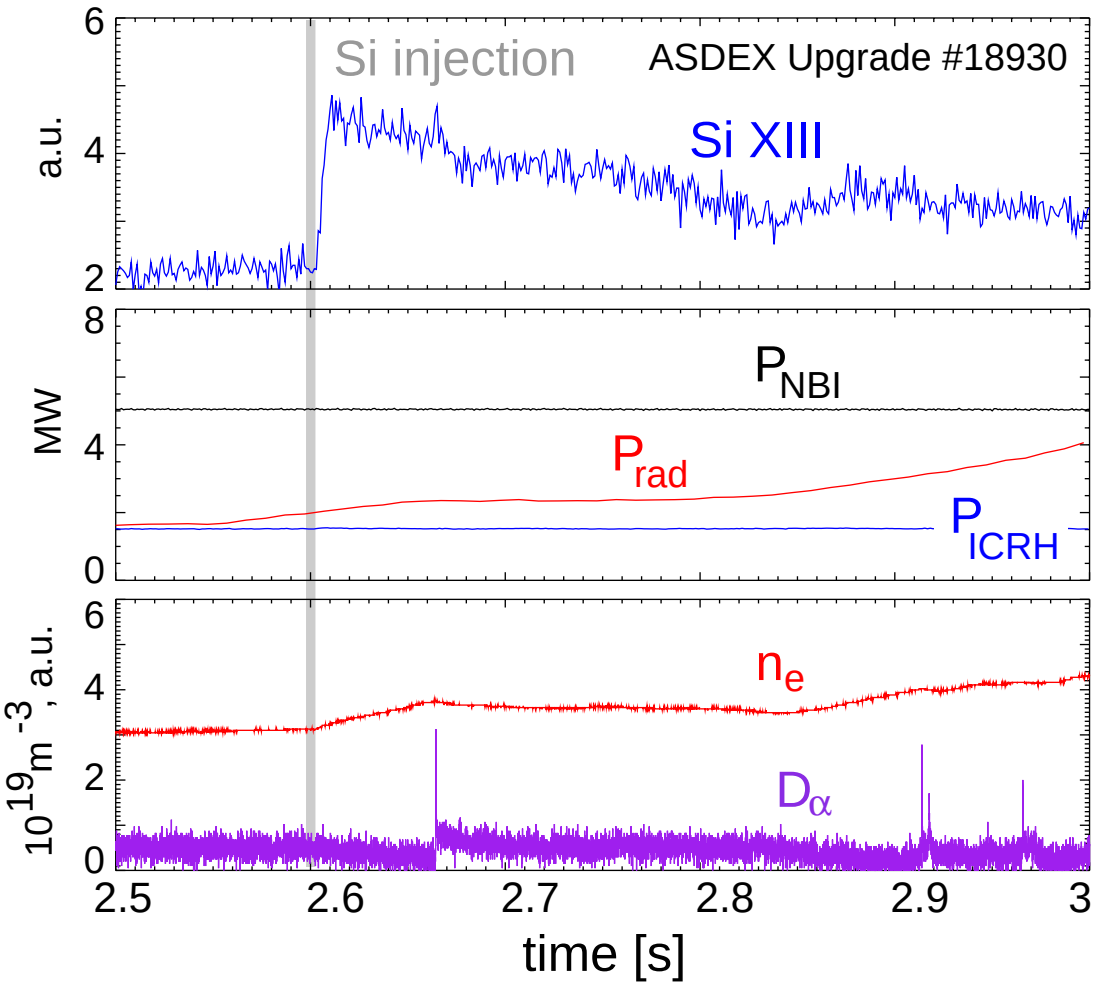
EHO limits edge pressure as seen in between ELMs



ELMy phase with counter-NBI:
- EHO grows as pressure rises
  (pressure or edge current drive)
- Pressure saturation (additional transport)



Si laser blow-off demonstrates impurity transport



Si XIII line (He-like)
λ=0.665 nm

Flat crystal Bragg spectrometer

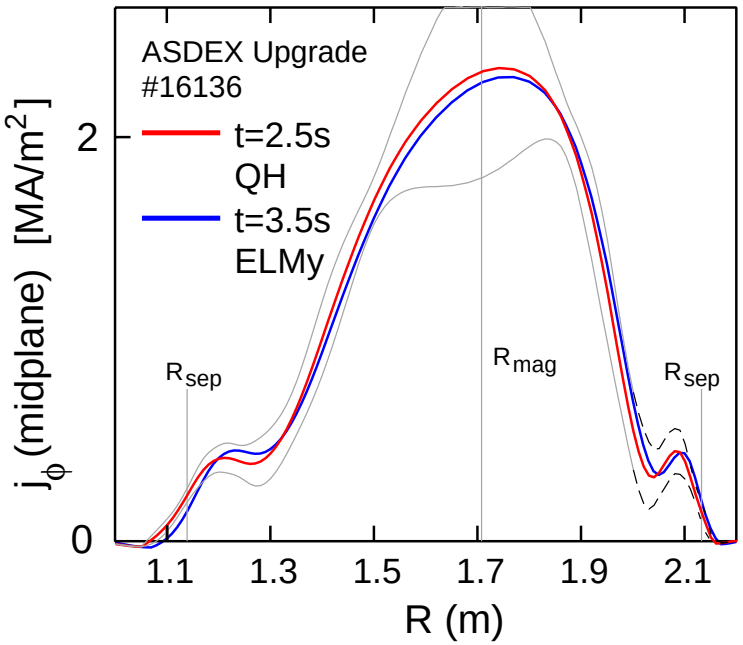
Intensity decays despite electron density increases: Radial transport of Si in between ELMs

ELM suppression:
Edge bootstrap current not necessarily reduced

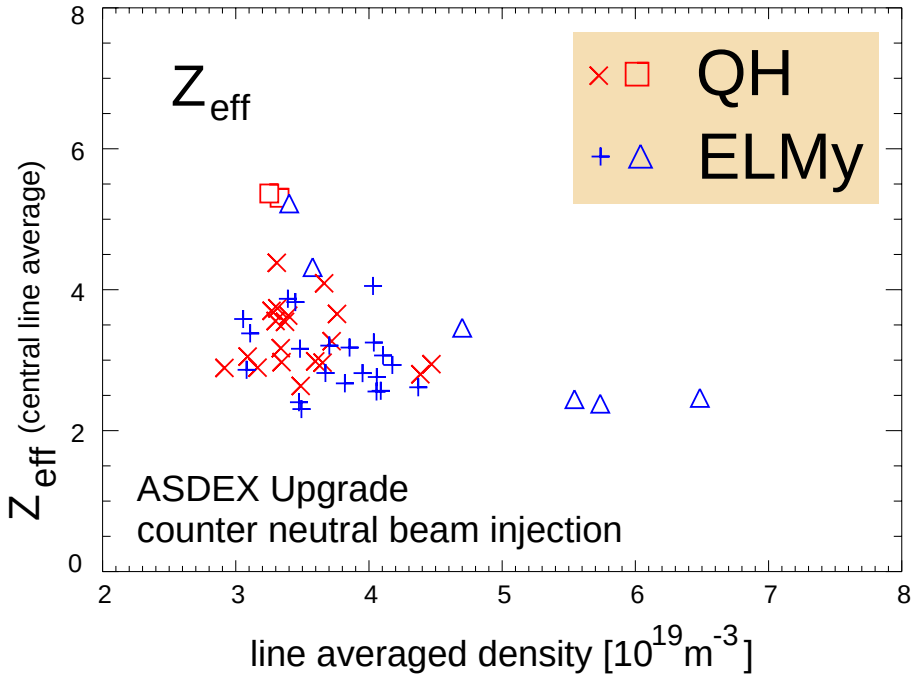
Edge parameters in QH-mode can be very similar to ELMy H-mode

Similar edge current density
(mainly bootstrap driven)

CLISTE reconstruction:

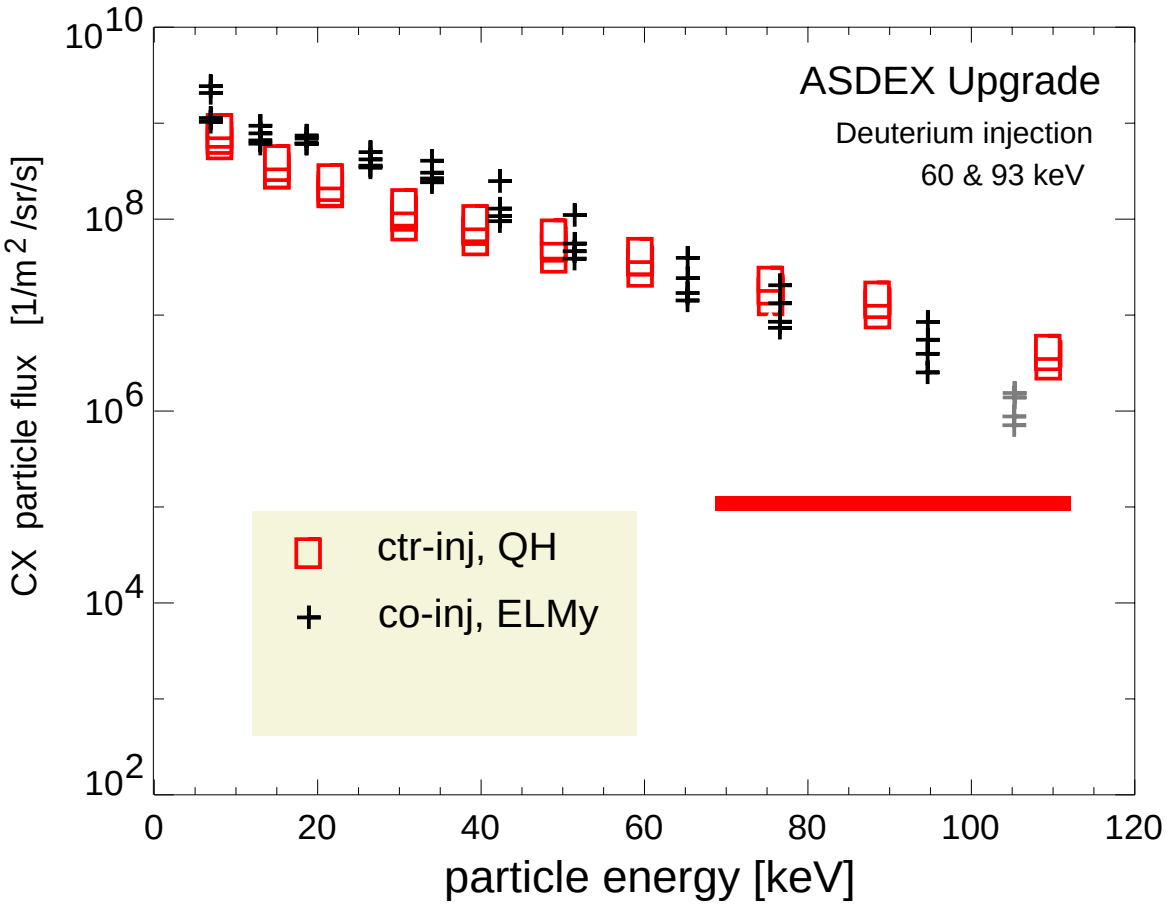


Similar Z_{eff} in QH-mode
and ELMy H-mode (ctr-NBI)



NPA: strong fast particle population

Charge exchange neutral deuterium spectrum:



Counter-NBI: Higher yield than in with co-injection around beam energies (60 and 93 keV) despite lower density of thermal neutrals

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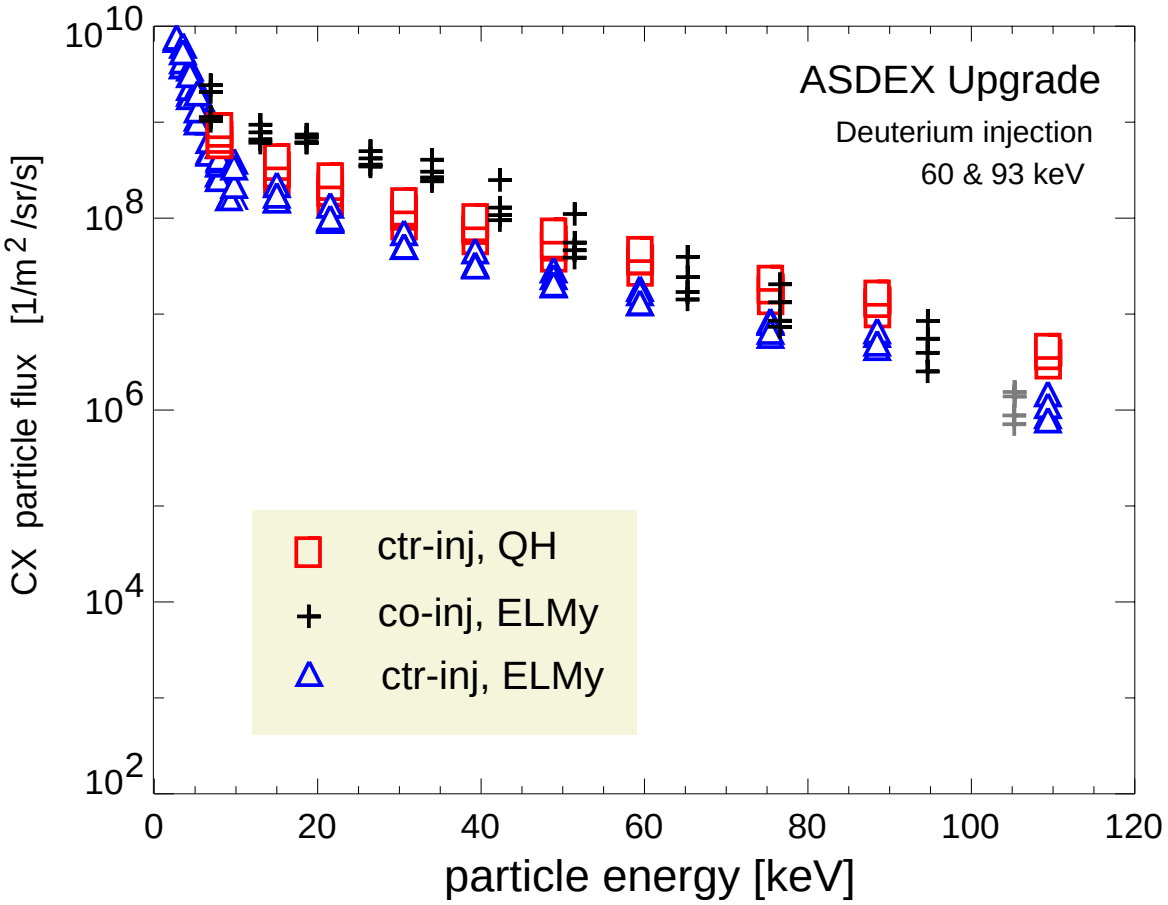
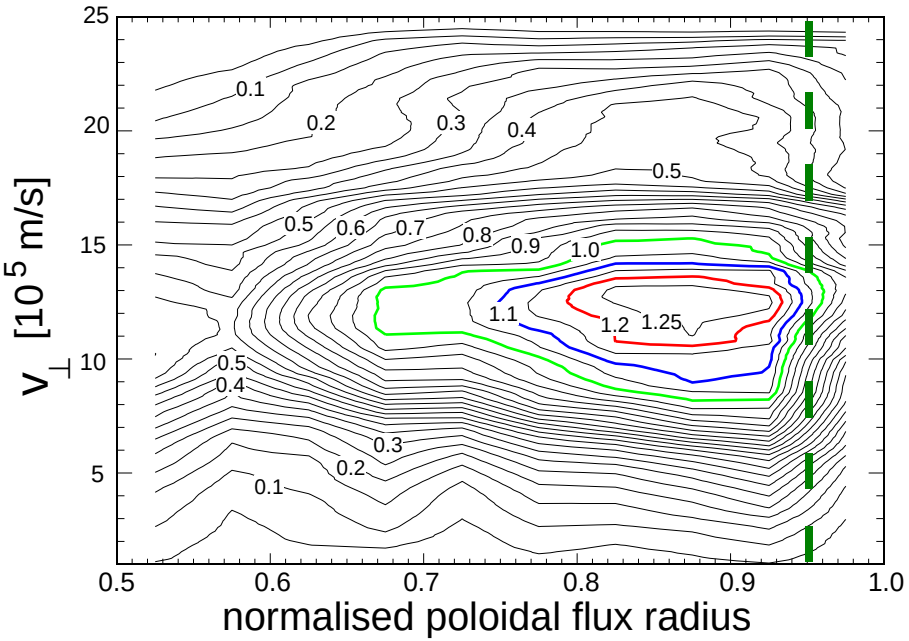


Counter-NBI: Higher yield than in with co-injection around beam energies (60 and 93 keV) despite lower density of thermal neutrals

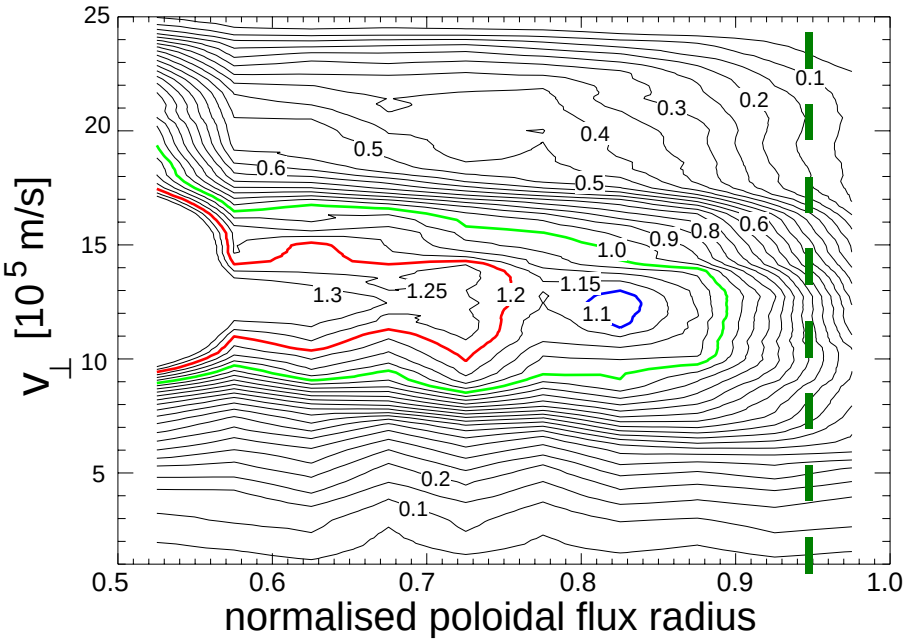
QH-mode: Higher yield than in ELMy H-mode with counter-NBI

ASCOT Monte Carlo particle calculations show enhanced slowing-down population in barrier region

Ctr-NBI, QH-mode AUG #17695



Co-NBI same background



<u>Self-alignment</u> of "outward pointing" drift orbits with barrier region

Competition with enhanced orbit losses:
Higher population with ctr-NBI

Large radial electrical field exists in barrier region

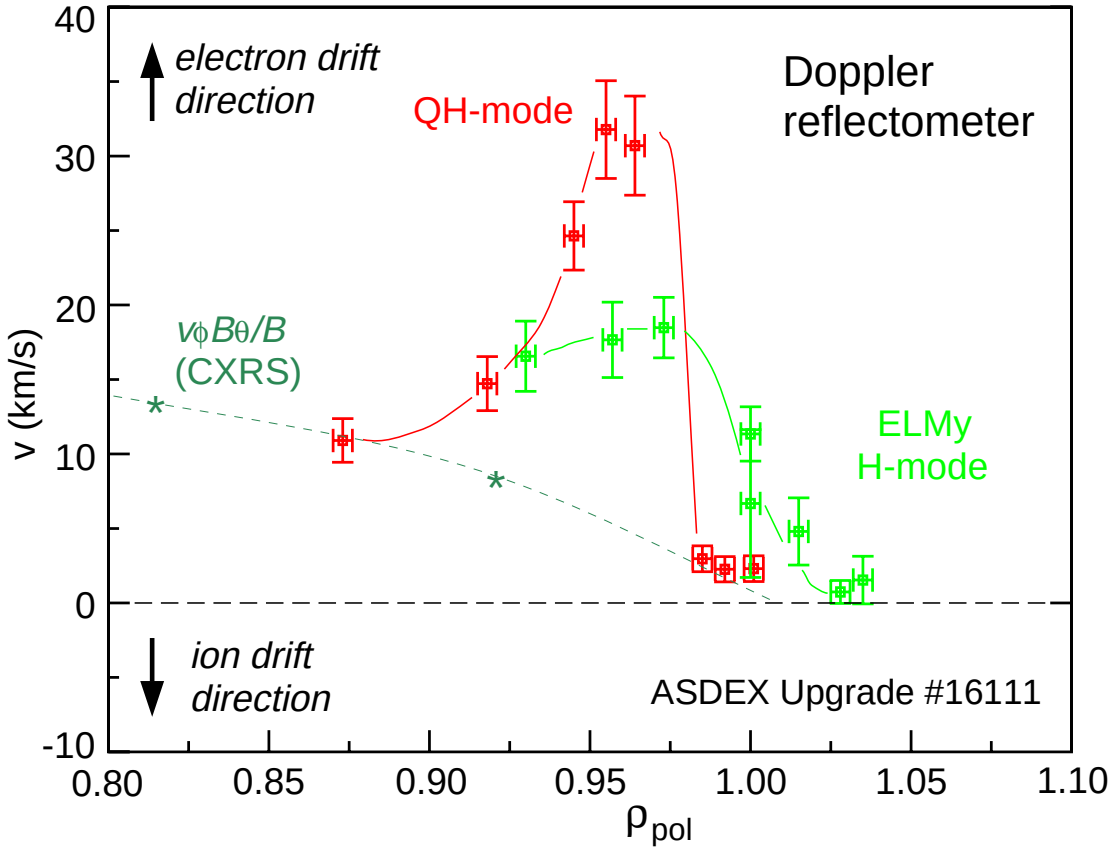
Doppler reflectometry: $v_{\perp} \sim v_{ExB}$

QH-mode: peak Er ~ -60 kV/m, twice as large as in ELMy phase

Significant |Er| found in DIII-D (charge exchange recombination spectroscopy)
K H Burrell *et. al.* PPCF 46 (2004) A165

This large |Er| can reverse the precession drift from ion- to electron-direction: Resonance with EHO

G D Conway *et.al.* PPCF 46 (2004) 951



Summary

“Quiescent H-mode” (QH-mode)
- absence of ELMs, no penalty in confinement

QH-mode produced in ASDEX Upgrade and JET with ctr-NBI,
high clearance and good pumping.
Reproducibility good in AUG, unclear in JET

“**Edge Harmonic Oscillation**” (n=1) and in-phase, bursts of
“**High Frequency Oscillation**” (n~5) replace ELMs -
- quasi-continuous loss of heat, fast & thermal particles, impurities (Si)
- localisation in gradient region suggests ∇p or j drive

ELM suppression mechanism not clear:
- edge bootstrap current not suppressed in general
+ ctr-NBI creates “self-aligned” fast particle population near barrier
+ observe large negative Er and Er shear in H-mode barrier region