CHARACTERISTICS OF ELM ACTIVITY AND FUELING EFFICIENCY OF PELLET INJECTION FROM DIFFERENT LOCATIONS ON DIII–D*

L.R. Baylor

T.C. Jernigan, R.J Colchin,

J.R. Ferron, M.R. Wade,

Oak Ridge National Laboratory, Oak Ridge, TN, USA

General Atomics, P.O. Box 85608, San Diego, USA

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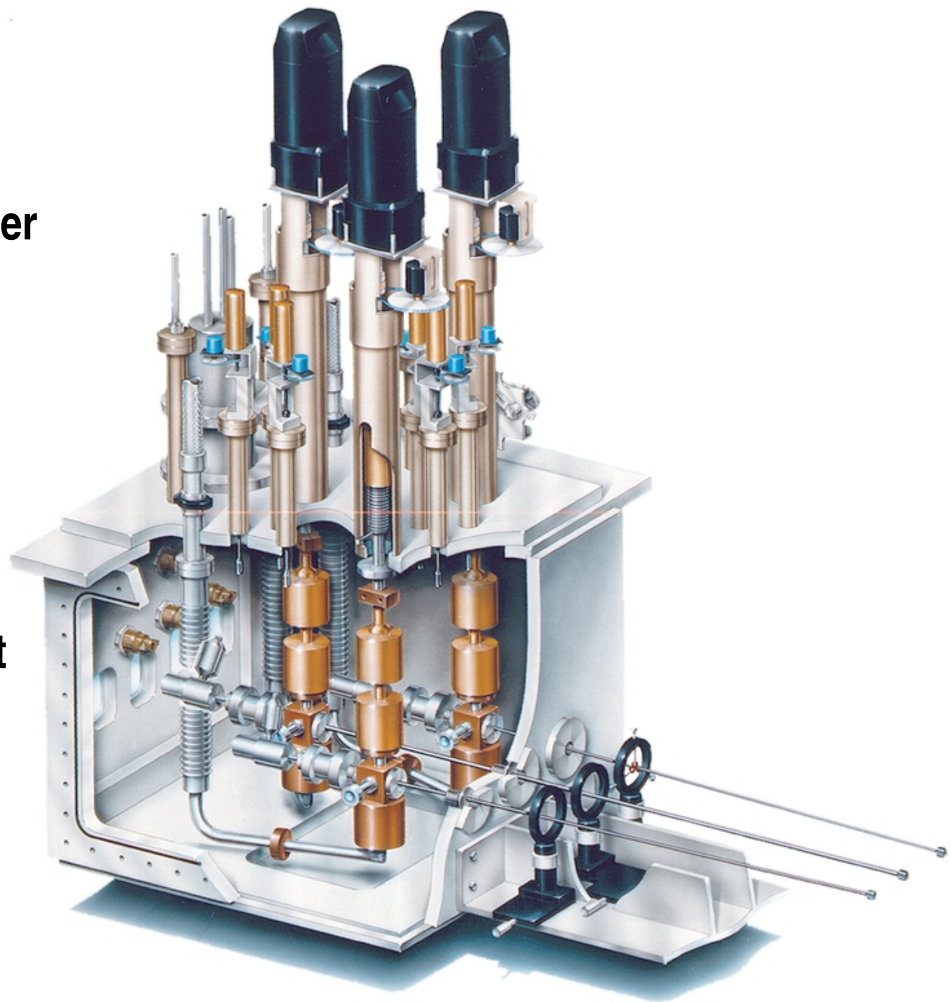
ABSTRACT

Pellet injection from several different locations has been used on the DIII–D tokamak to study core fueling and transport in H-mode and L-mode plasmas. These experiments have provided a variety of conditions in which to examine the fueling efficiency and edge localized mode (ELM) interaction with pellets injected into DIII-D plasmas. The fueling efficiency, defined as the total increase in number of plasma electrons divided by the number of pellet fuel atoms, is determined by measurements of density profiles before and just after pellet injection. New injection ports on the DIII-D inner wall enable high field side (HFS) pellet injection from both the midplane and 30cm above the midplane. These ports, in addition to the previously existing top vertical port and outside midplane port, enable a comparison of the effect of pellets injected from the different locations on fueling efficiency and ELM activity. We find that the ELMs triggered from HFS injected pellets and vertical injected pellets are similar to the nominal background ELMs in ELMing H-mode plasmas. In some cases ELMs are not triggered directly by the HFS injected pellets, but appear up to 50ms later when the edge pressure gradient reaches the stability limit. In contrast, the LFS injected pellets trigger large magnitude long duration ELMs that lead to a significant reduction in fueling efficiency. The fueling efficiency of the HFS injected pellets is found to be significantly higher than with the LFS injected pellets and remains high even with significant heating power.

PELLET FUELING SYSTEM ON DIII–D

- Modifications to injector (was installed on JET 1987-91):
  - All three guns fire 2.7 mm pellets
  - Punch mechanisms to generate slower pellets (<300 m/s)
  - Up to 10 Hz operation of each gun
- 2 independent guide tubes on inner wall (HFS) - midplane, 45° and vertical V+1
  - Can be connected to any of the pellet guns or a gas valve
- Curved guide tube limits speed to 250 m/s for intact pellets (Combs, SOFE Proceedings, 1999)



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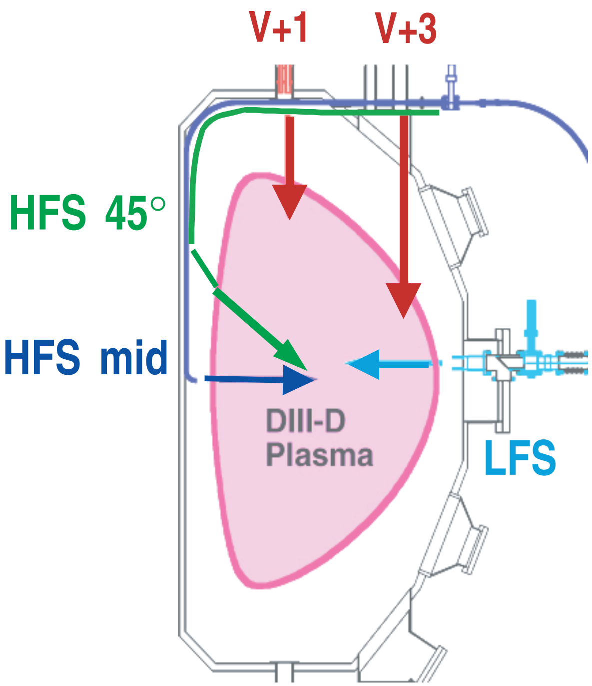
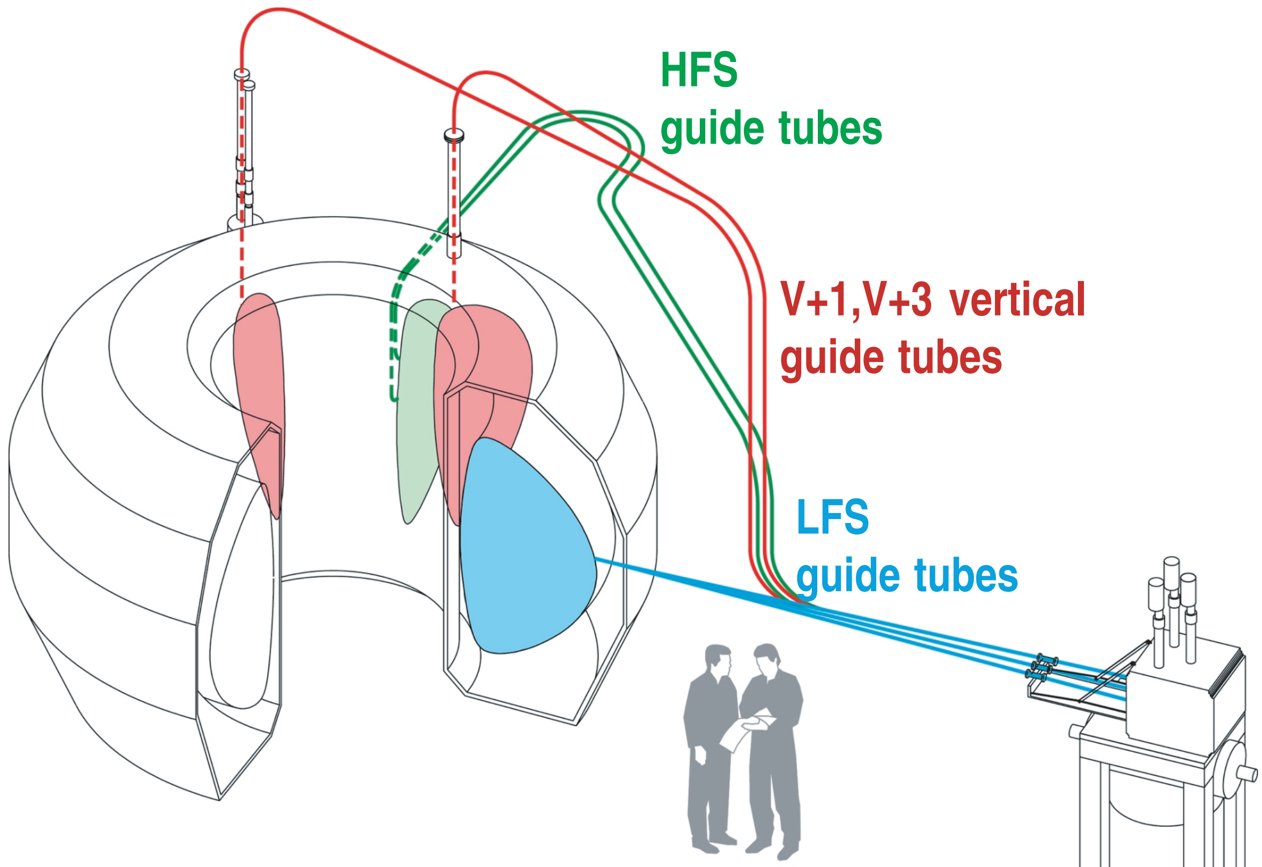
DIII–D PELLET INJECTION LOCATIONS - 2000



- Elevation view of pellet trajectory in the plasma



- 3-D view showing curved guide tubes that the pellets traverse

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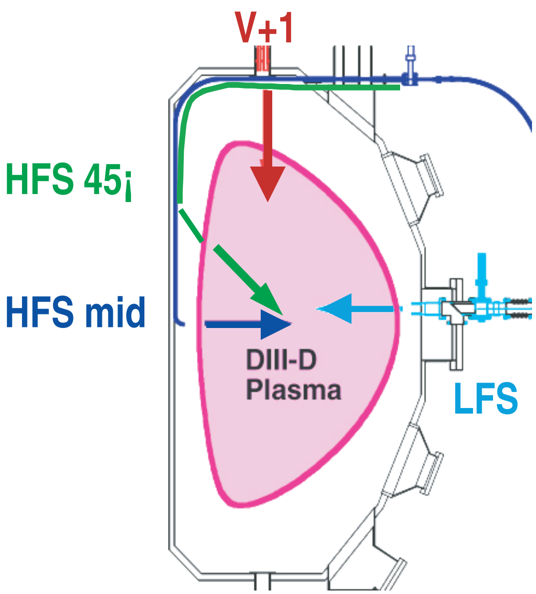
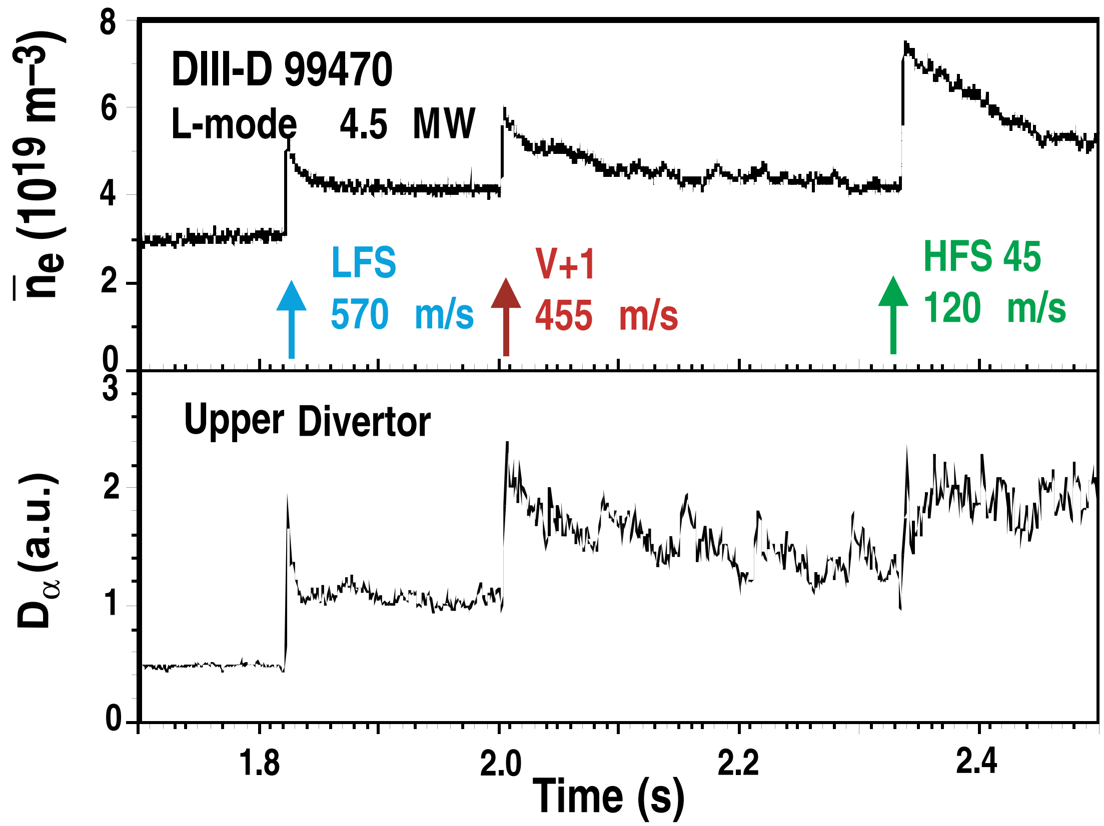
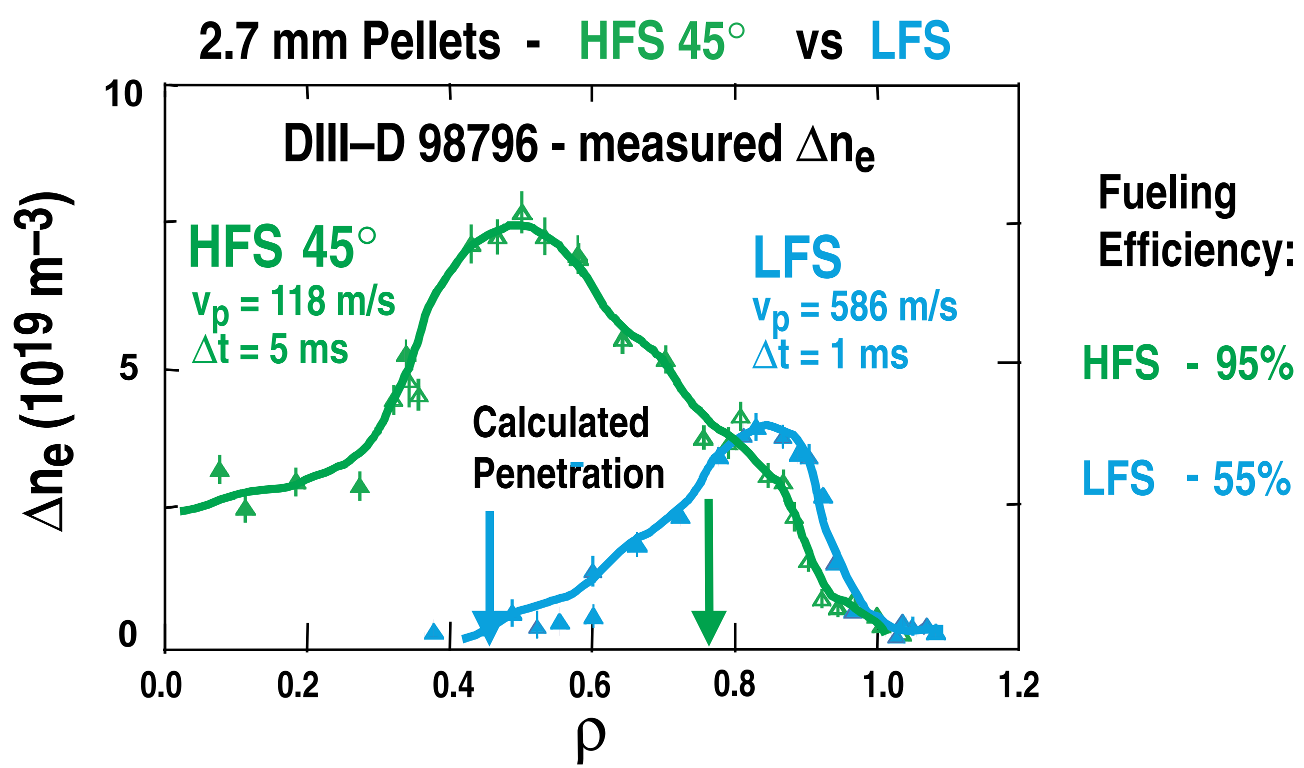
DIRECT COMPARISON IN L–MODE – HFS PELLETS SHOW LESS PARICLE LOSS





- Pellet comparison from LFS, V+1 and HFS45
- The density perturbation is larger for the HFS pellet
- Divertor D_α shows fewer particles leaving the plasma from the HFS pellet

HIGH FIELD SIDE (HFS 45°) PELLET INJECTION ON DIII–D YIELDS DEEPER PARTICLE DEPOSITION THAN LFS INJECTION



- **Net deposition is much deeper for HFS pellet** in spite of the lower velocity (Baylor, Phys. Plasmas May 2000)

- Pellets injected into the same discharge and conditions (ELMing H–mode, 4.5 MW NBI, $T_e(0)$ = 3 keV)

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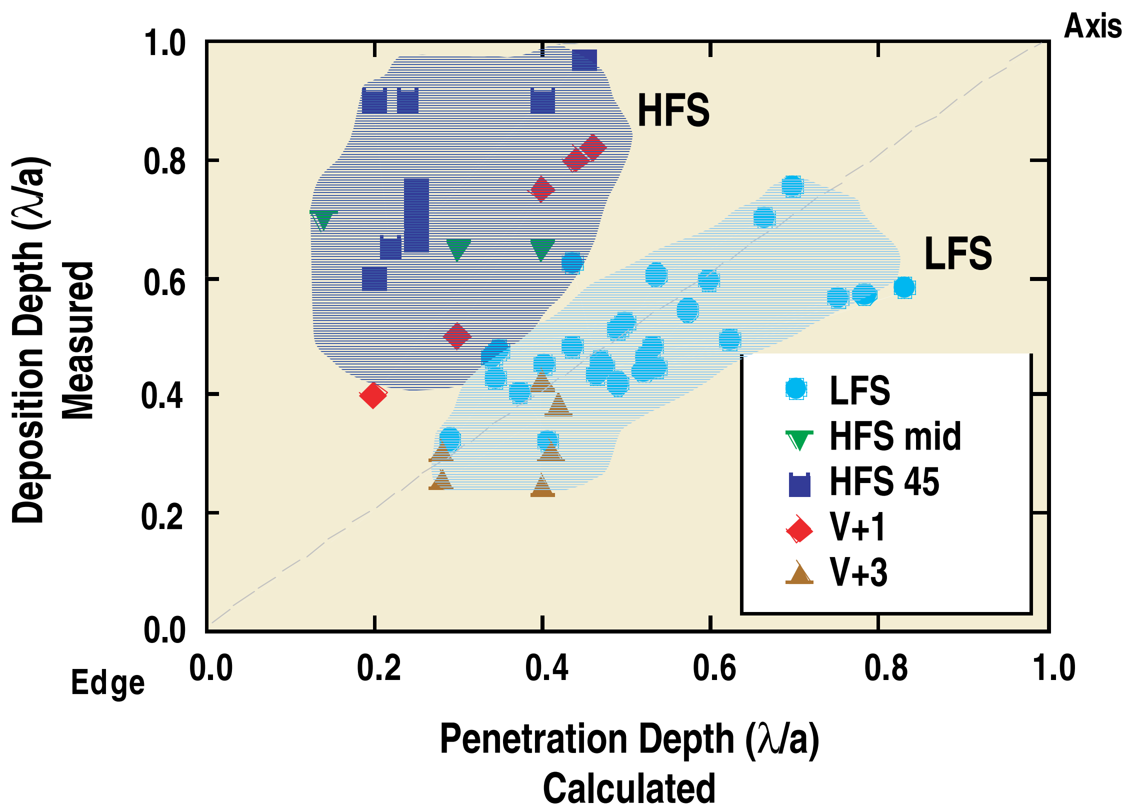
HFS PELLET INJECTION ON DIII–D YIELDS DEEPER PARTICLE DEPOSITION THAN PREDICTED BY ABLATION MODEL



- HFS and Vertical injection exhibit deeper than expected deposition of pellet mass from simple ablation model
- LFS pellet maximum deposition depth agrees with simple model

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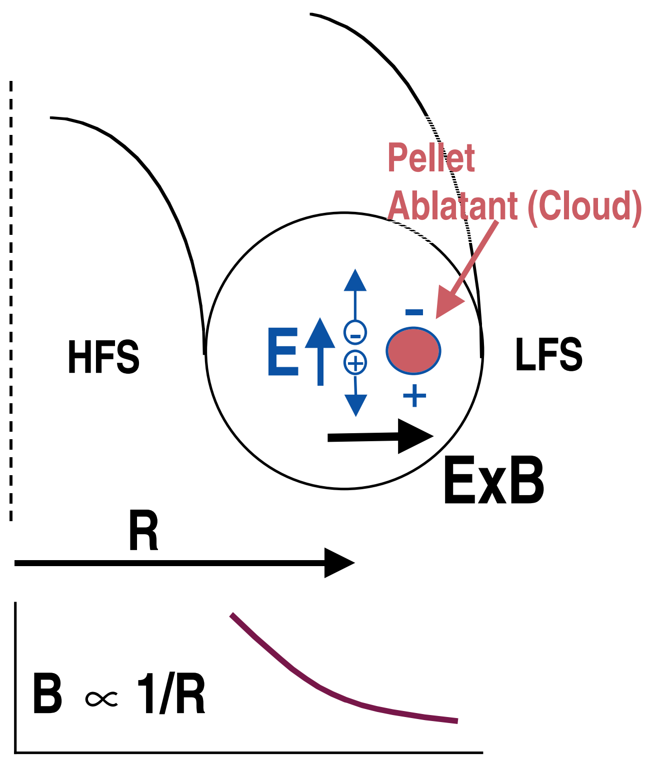
THEORETICAL MODEL FOR PELLET RADIAL DRIFT

ExB Polarization Drift Model of Pellet Mass Deposition

(Rozhansky, Parks)

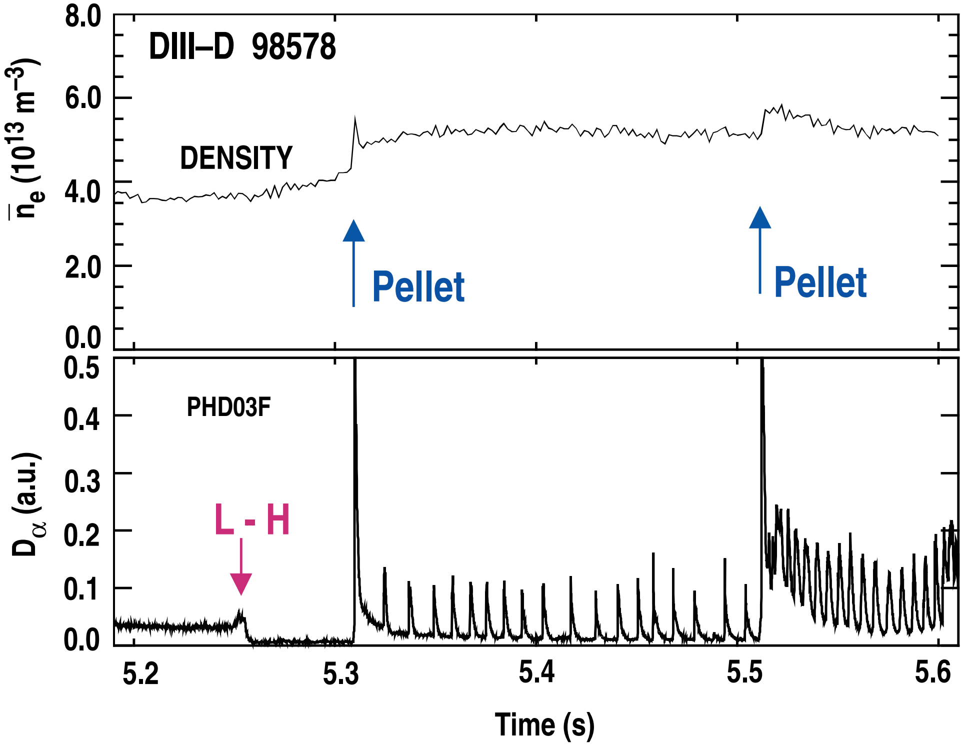


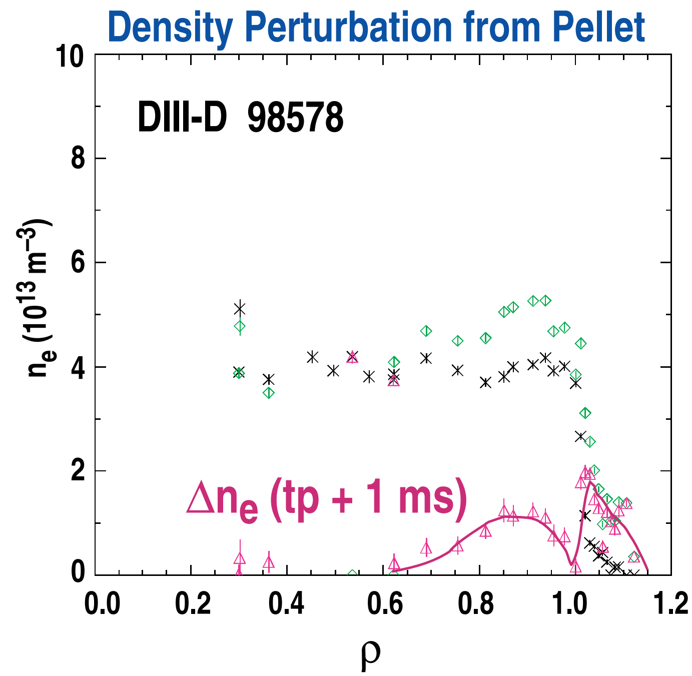
- Polarization of the ablatant occurs from ∇B and curvature drift in the non-uniform tokamak field:

$$\vec{\mathbf{v}}_B = \frac{W_\perp + 2W_\parallel}{eB^3}\,\vec{\mathbf{B}} \times \overrightarrow{\nabla \mathbf{B}}$$

- The resulting E yields an ExB drift in the major radius direction
- The velocity of ablatant ≈ $c_s(2L/R)^{0.5}$. For DIII–D this is ≈ 2 km/s, i.e. faster than the pellet [deKloe, Mueller, Phys. Rev. Lett. (1999)]
- ΔR stronger at higher plasma β
- Detailed model by P.B. Parks (APS99 – Phys. Plasmas, May 2000)

PELLETS INJECTED IN H–MODE ON DIII–D TRIGGER ELMs AND AFFECT ELM FREQUENCY





- Shattered 2.7 mm pellets injected in H–mode (4.5 MW NBI) trigger ELMs and change the frequency of ELMs from 0 to 100 Hz and from 100 to 160 Hz. The density perturbation is localized in the edge plasma

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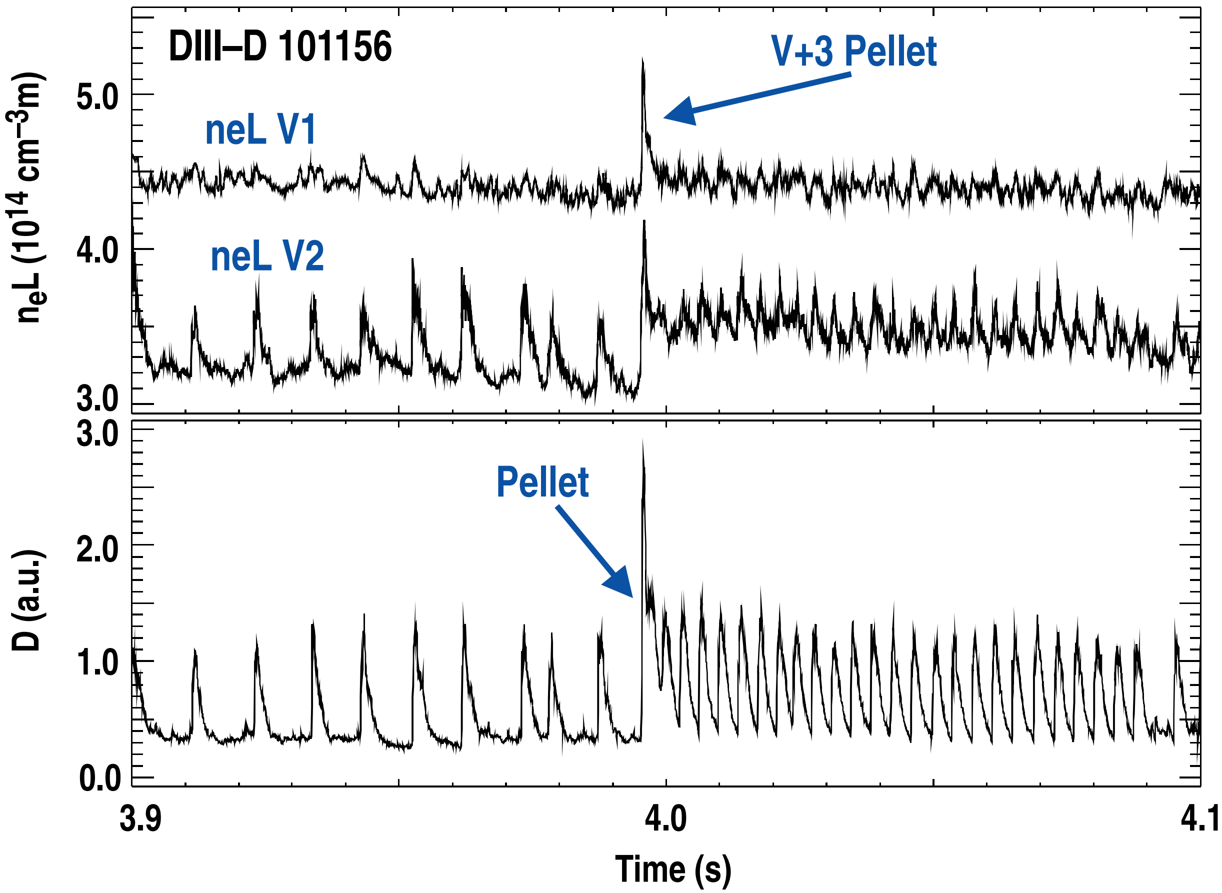
PELLETS INJECTED IN H–MODE ON DIII–D TRIGGER ELMs AND AFFECT ELM FREQUENCY



- V+3 2.7mm pellet injected in H–mode (7.0 MW NBI) triggers an ELM and increases the frequency of ELMs from 100 Hz 100 to 280 Hz. The density perturbation is localized in the edge plasma

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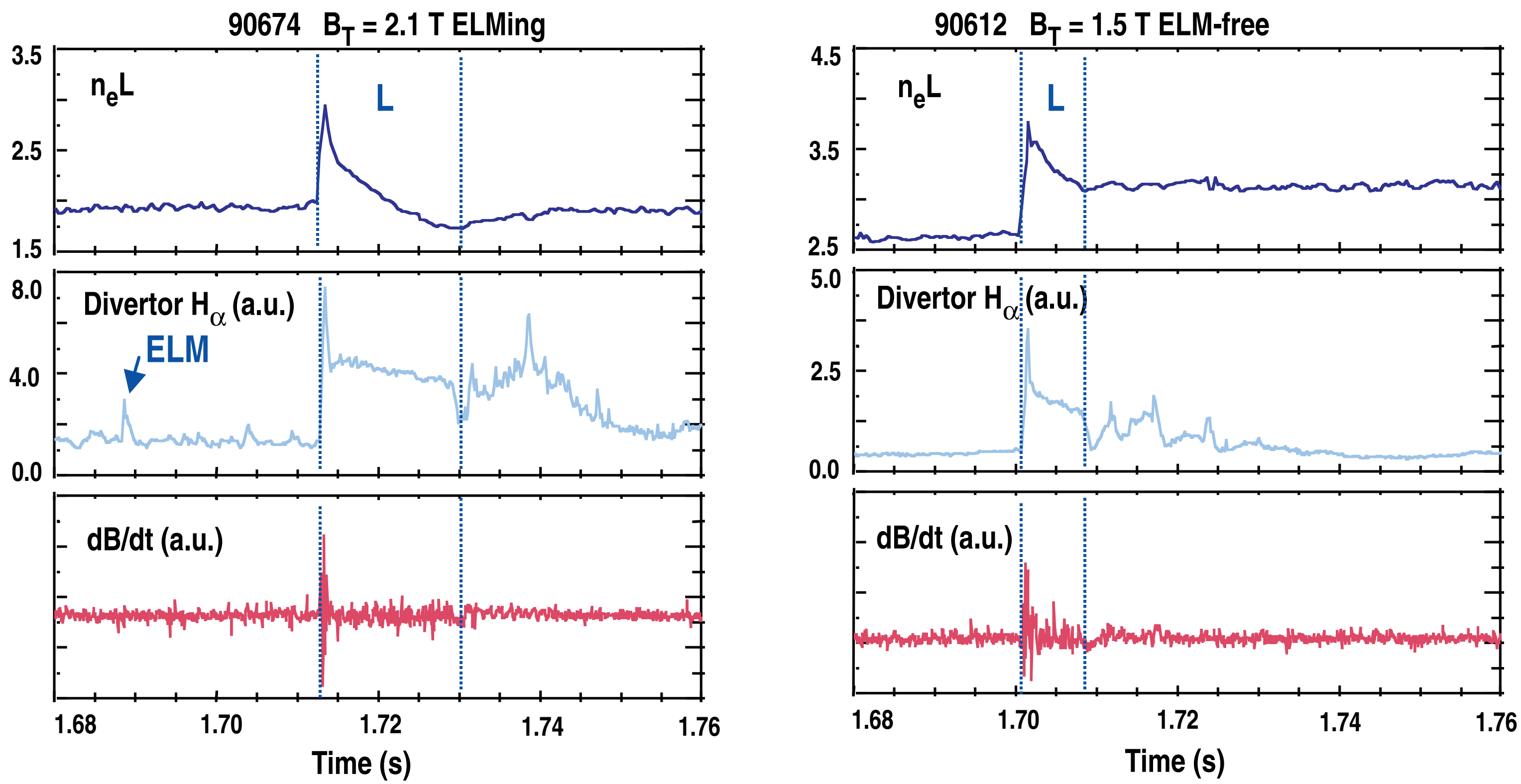
WHAT HAPPENS WHEN A PELLET IS INJECTED INTO AN H–MODE PLASMA?



- The LFS pellet (2.7 mm) triggers an ELM and L–mode transition that varies in duration with B_T. The transition back to H–mode scales like the H–mode threshold: $P_{thres} \sim 0.3\ n_eL\ B_T\ R^{2.5}$ [Ryter, et al. Nucl. Fusion 36 (1996) 1267.]

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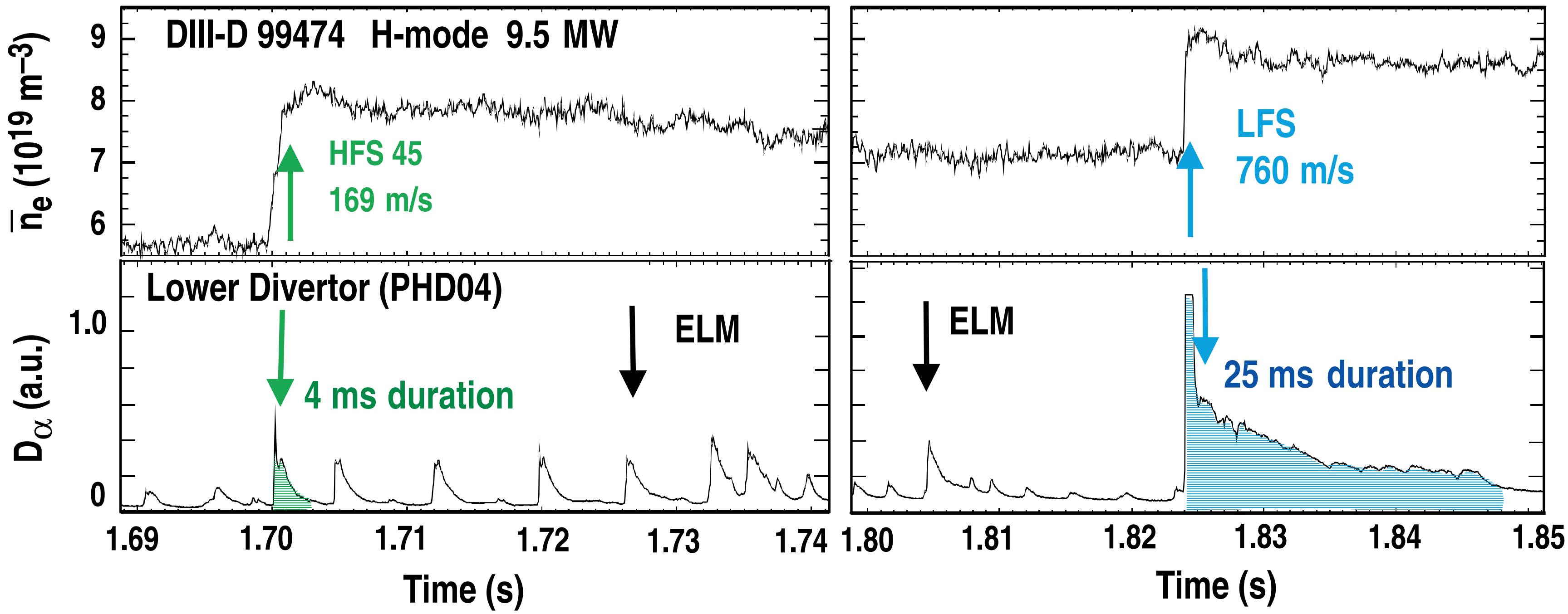
HFS PELLETS PRODUCE SMALLER SHORTER DURATION ELMs THAN LFS PELLETS



- **HFS pellet induced ELMs are small** like background ELMs and in VH–mode lead to delayed ELMs by up to 50 ms
- **LFS pellets induce large ELMs** much longer lasting than background ELMs. ExB drift loss of particles may be responsible
- P′ modification at edge may be different for HFS and LFS pellets (J.R. Ferron, APS 1999, Phys. Plasmas May 2000)

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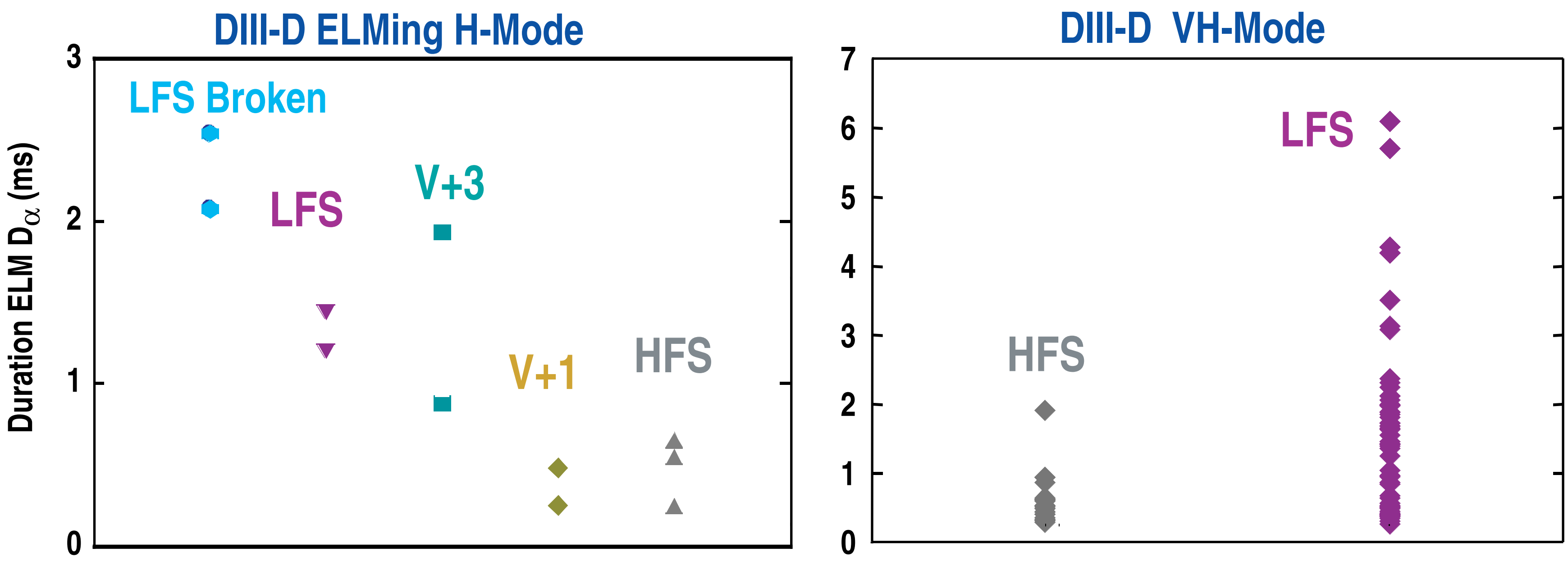
HFS PELLETS SHORTER DURATION ELMs THAN LFS PELLETS IN H–MODE AND VH–MODE



- In ELMing H–mode the HFS and Vertical pellets trigger shorter duration ELM D_α emission – Fewer particles ejected from plasma. Data is FWHM of D_α signal in lower divertor
- In VH–mode, (ELM–free conditions), the HFS pellets trigger shorter duration ELMs or no ELMs at all

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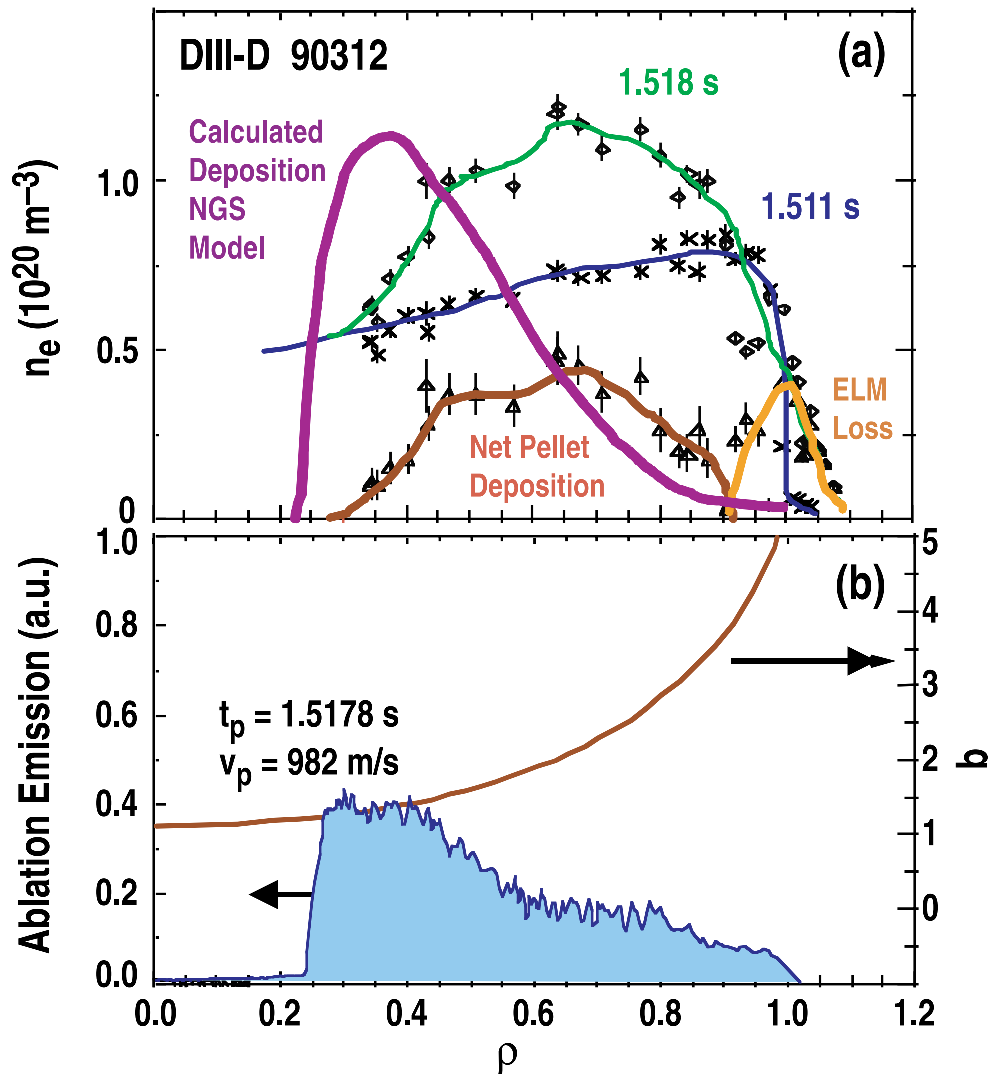
PELLET DEPOSITION AND ABLATION EMISSION PROFILES MEASURED IN PELLET EXPERIMENTS

- The net deposition of 2.7 mm pellets in ELM–free H–mode is well inside the separatrix
- A triggered ELM causes a fast expulsion of edge density
- The net pellet deposition shows a significant difference with the calculated deposition profiles using pellet ablation models. (Baylor, et al., Nucl. Fusion, 1992)
- Integrating the net deposition profiles leads to the pellet fueling efficiency, η



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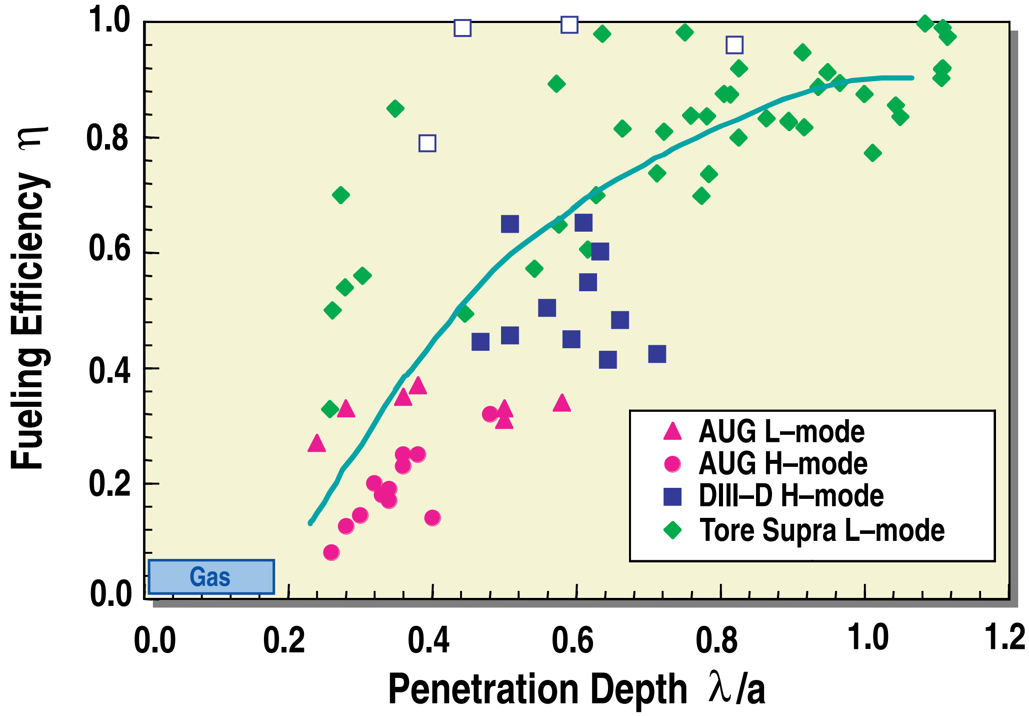
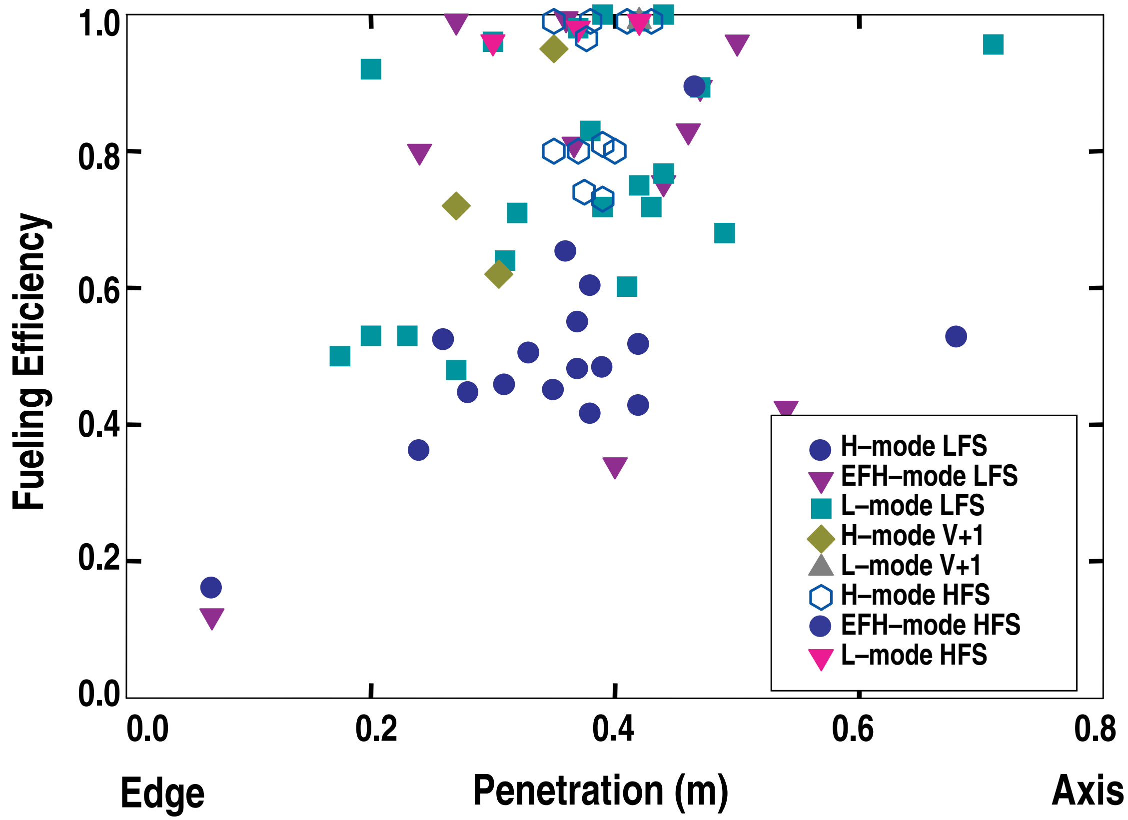
PELLET FUELING EFFICIENCY FOR LFS PELLETS SCALES WITH INCREASED PENETRATION DEPTH



- ASDEX-U and Tore Supra fueling efficiency data yield similar results to the DIII–D LFS pellet data. Only DIII–D H–mode (ELMing and ELM–free) data is shown here. Data is from IPADBASE [Nucl. Fusion, 37 (1997) 445.]

PELLET FUELING EFFICIENCY ON DIII–D SHOWS IMPROVEMENT WITH PENETRATION DEPTH



- Fueling Efficiency on DIII–D is higher with deeper penetration, but a clear difference with injection location is apparent. Little difference in penetration depth is present in the HFS pellet data

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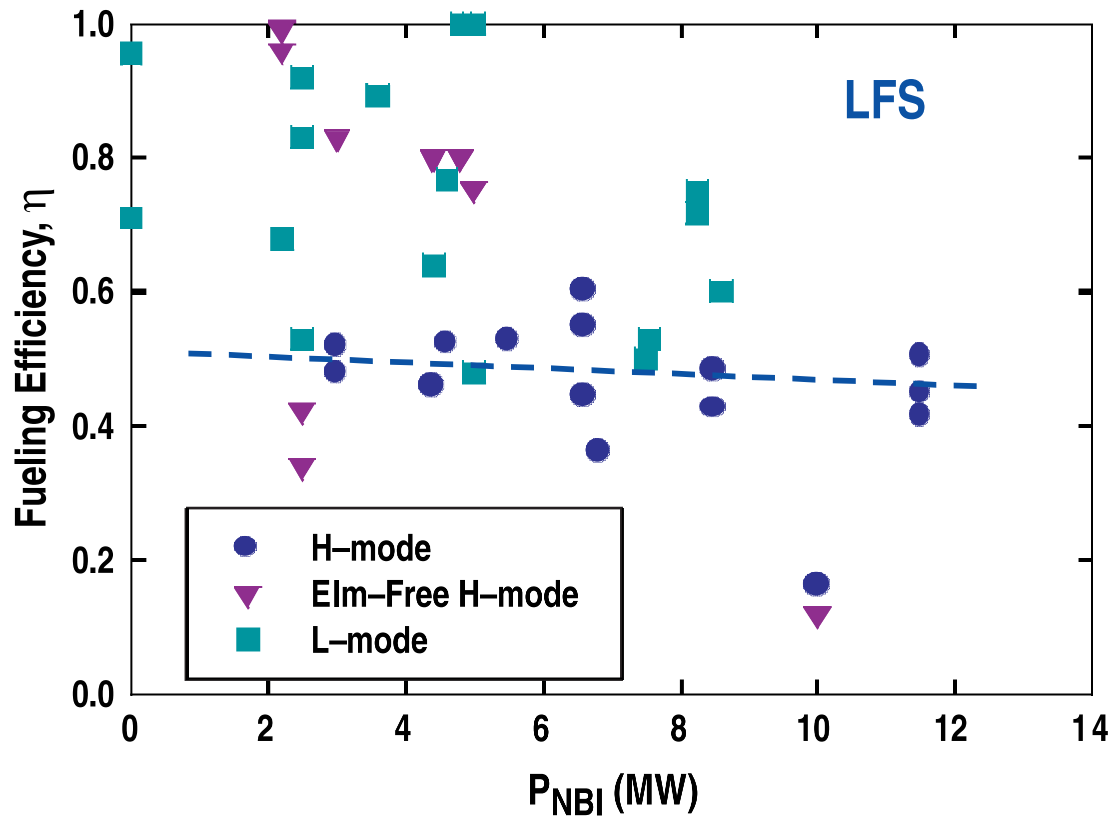
HFS PELLET INJECTION ON DIII–D YIELDS HIGHER FUELING EFFICIENCY THAN LFS PELLETS



LFS Fueling Efficiency in H–mode ~50%

- L–mode and ELMfree H–mode (low power) plasmas allow deep penetration leading to reasonable fueling efficiency
- LFS pellet fueling efficiency affected by major radius drift and by pellet ELM interaction

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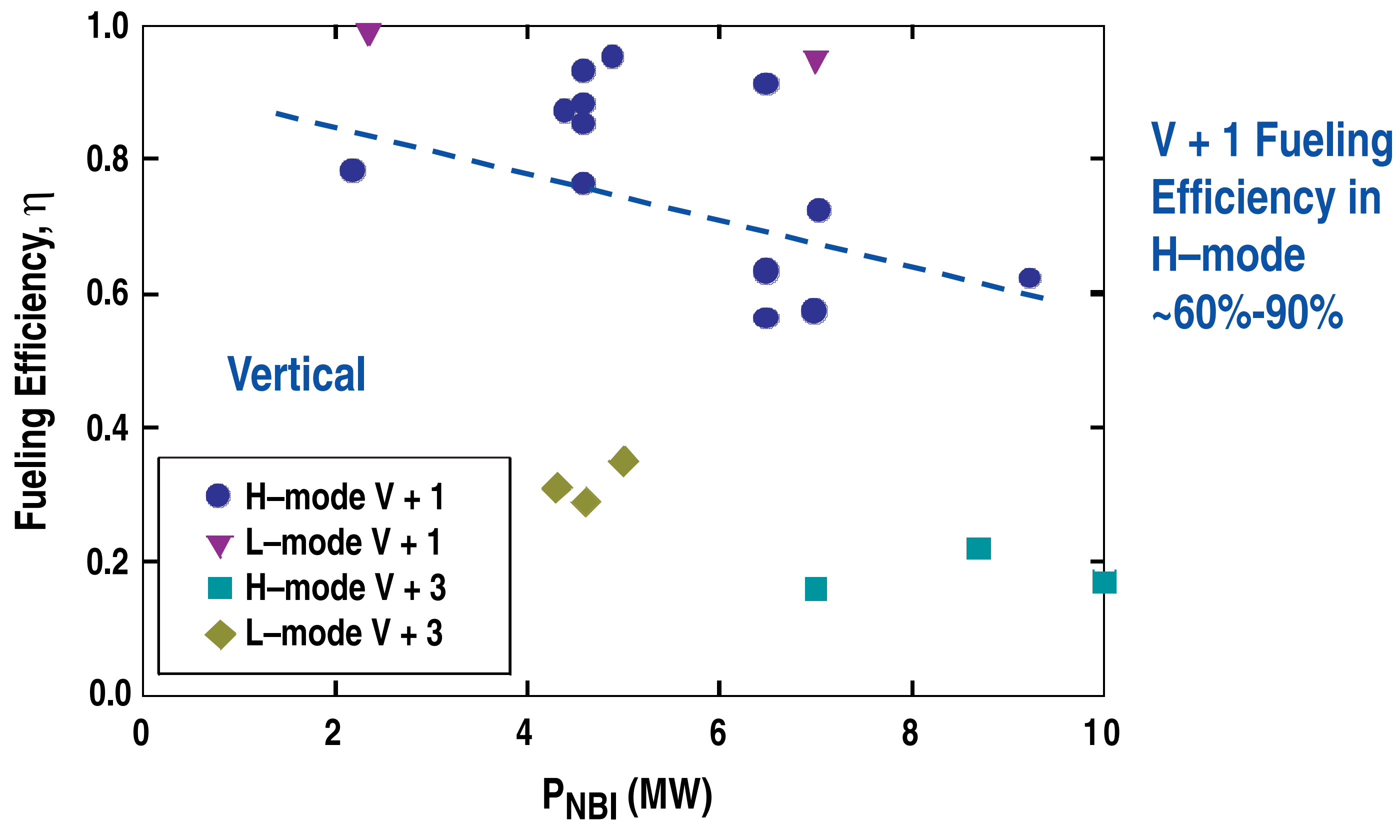
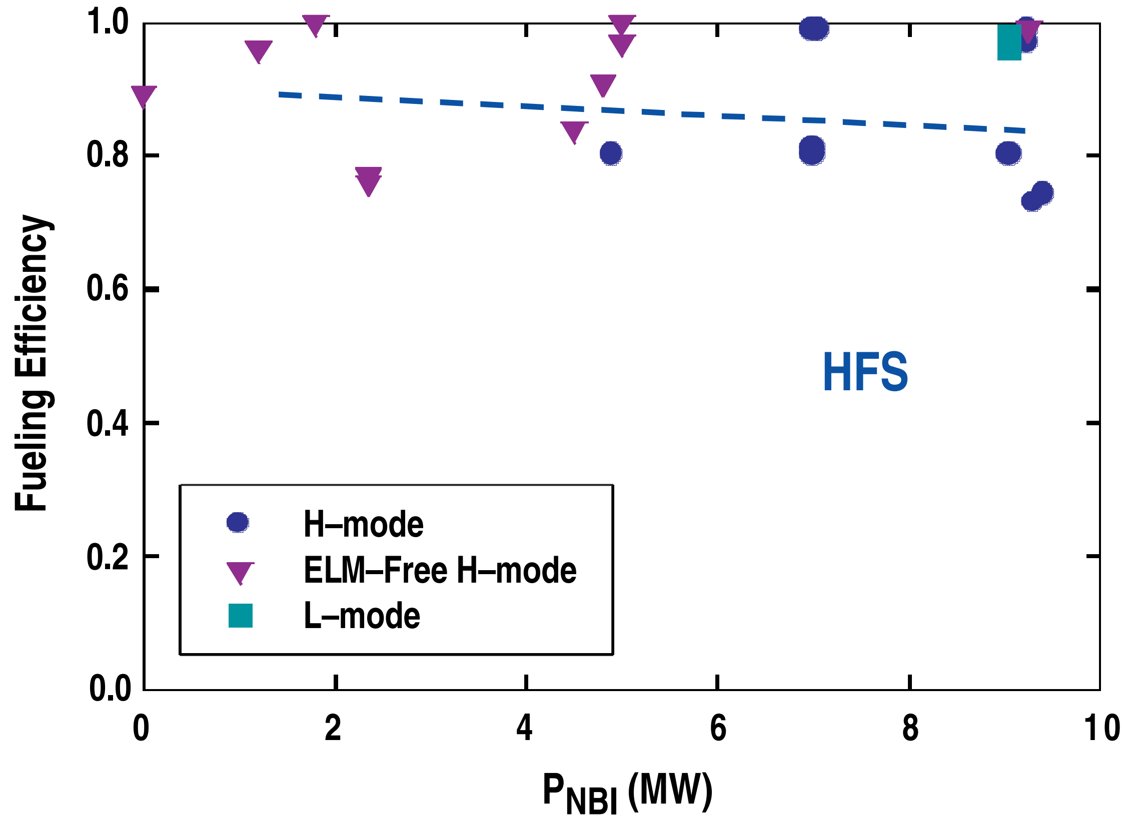
VERTICAL PELLET INJECTION ON DIII–D YIELDS HIGHER FUELING EFFICIENCY THAN LFS PELLETS



- Verical injection shows higher fueling efficiency than LFS injection
- Vertical LFS injection (V + 3) results in poor fueling due to major radius drift and incomplete ablation

HFS PELLET INJECTION ON DIII–D YIELDS HIGHER FUELING EFFICIENCY THAN LFS PELLETS



HFS Fueling Efficiency in H–mode ~90%

- HFS injection exhibits almost ideal fueling efficiency
- Deep penetration and minimal ELM magnitude help keep the fueling efficiency for HFS pellets near the ideal level

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SUMMARY

- A fast major radius drift of pellet mass leads to poor fueling efficiency for LFS injected pellets. Alternative injection locations were investigated
- ELMs are triggered in H–mode plasmas by the pellet event and effective fueling (and confinement) depends on the duration of excursion out of H–mode
- High field side injection locations (inner wall and vertical) lead to lower ELM magnitude and minimization of the mass loss. In VH–mode, ELMs are sometimes not directly triggered by HFS pellets
- Pellet fueling efficiency for LFS pellets decreases with increased NBI power and increases with penetration depth. LFS fueling efficiency in ELMing H–mode is about 50% leading to large particle fluxes in the divertor
- Pellets injected from the inner wall have nearly ideal fueling efficiency in ELMing H–mode. HFS fueling promises to lead to efficient deep fueling for larger reactor scale devices