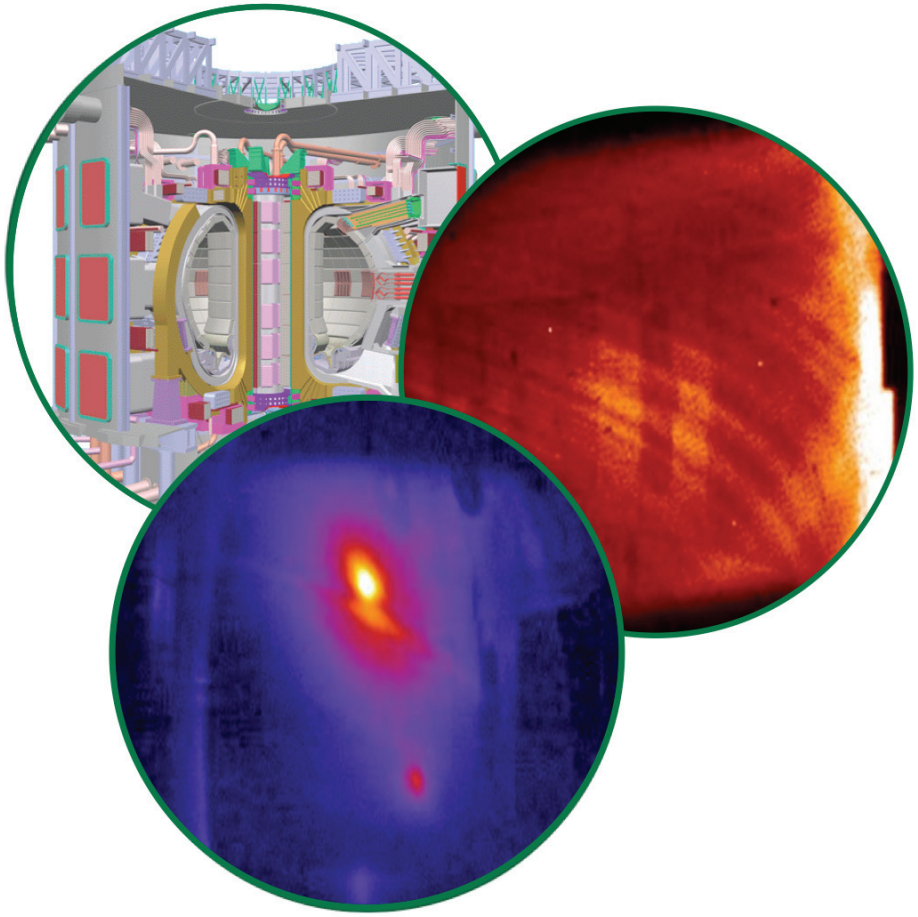
Pellet ELM Pacing Results from DIII-D

by
L.R. Baylor

With
T.C. Jernigan[1], N. Commaux[1], S.K. Combs[1],
T.E. Evans[2], M.E. Fenstermacher[3], C.J. Lasnier[3],
S.J. Meitner[1], R.A. Moyer[4], T.H. Osborne[2],
P.B. Parks[2], P.E. Sieck[2], E.J. Strait[2], and J.H. Yu[4]

[1]Oak Ridge National Laboratory
[2]General Atomics
[3]Lawrence Livermore National Laboratory
[4]University of California-San Diego



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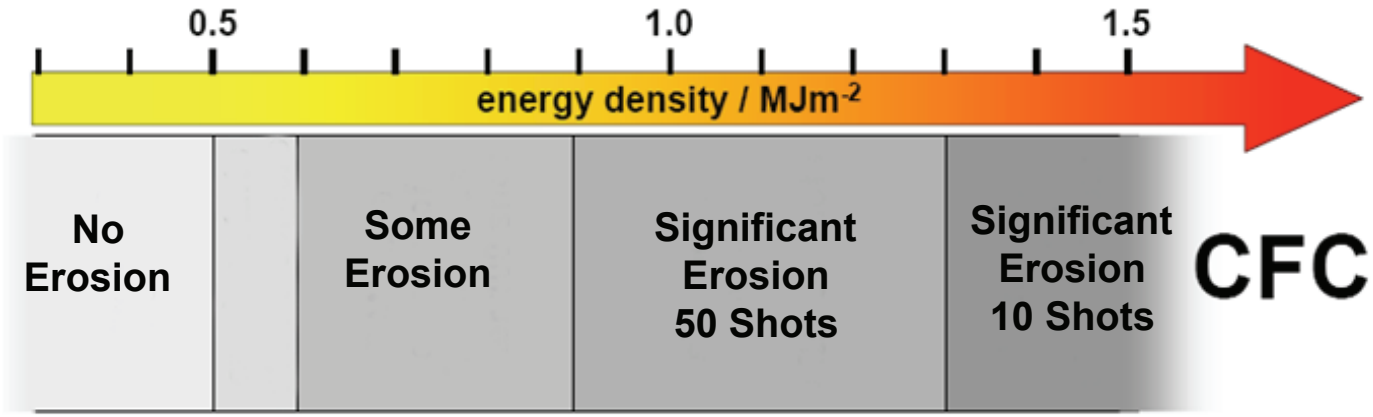
Overview

- **Projected erosion of divertor materials by type I ELMs is a serious issue for ITER**
- **ELM pacing has been shown to reduce the ELM size**
- **D_2 pellets have been used on DIII-D injected from LFS to pace ELMs at 5x the natural ELM frequency:**
  - W_{tot} transients are reduced by ~4x
  - No net fueling from LFS pellets unlike HFS injection
- **Future experiments will double the pellet repetition rate to enable better extrapolation to ITER**

ELM Erosion of the Divertor is a Serious Issue for ITER

CFC erosion is negligible for $Q_{ELM} < 0.5$ MJ/m^2

[Zhitlukhin et al., JNM, 2007]



ITER SOL projection on the divertor plates is 3.0 m^2

ITER ELM losses are projected to be ~15 MJ

ITER ELM size needs to be <1.5 MJ for low erosion

Implying ELM triggering is needed >20 Hz

(>10x increase in natural ELM frequency)

[Loarte et al., IAEA, 2010]

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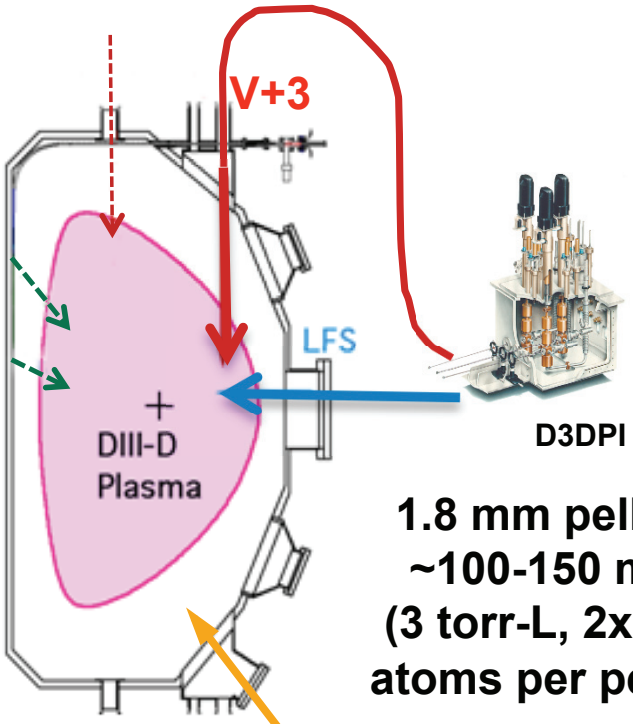
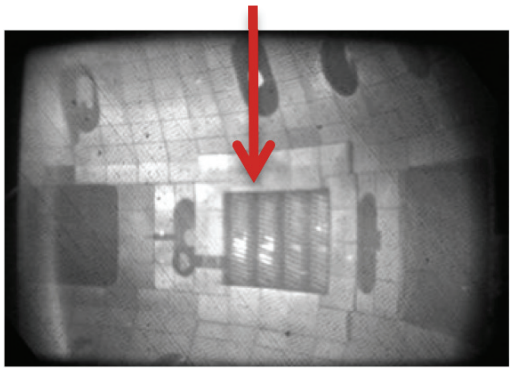
DIII-D Pellet ELM Triggering Experiment Performed with D_2 Pellets Injected from Low Field Side



1.8 mm pellets
~100-150 m/s
(3 torr-L, $2x10^{20}$ atoms per pellet)

New ITER like
Injection line for 2011

- D_2 pellets injected from LFS midplane and vertical ports with 2 guns. All pellets appeared to trigger ELMs
- Tangential viewing fast camera can observe the vertical V+3 pellets
- Pellets penetrate only ~1 cm before the ELM is triggered



Fast Camera Field of View for V+3 Pellets

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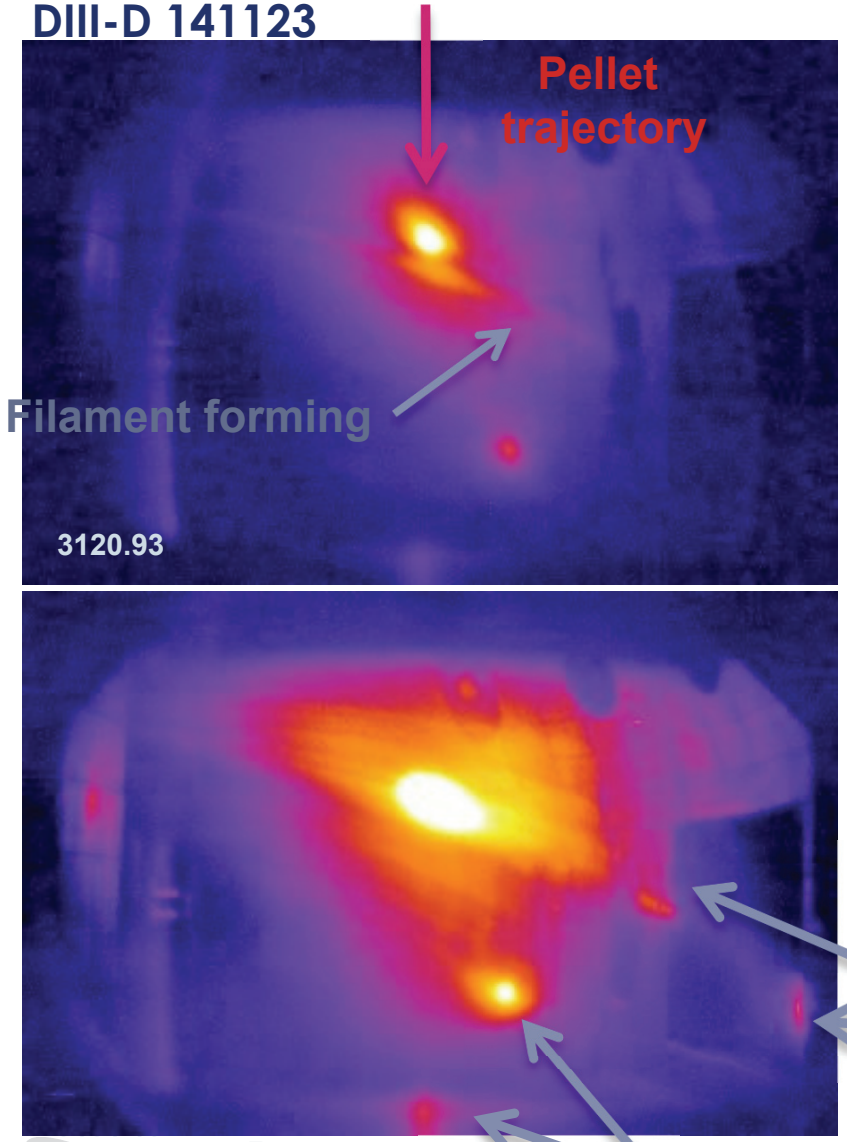
Fast Camera Shows Filament Forming in Front of Pellet



Fast Camera D_α Images

- Single filament appears near the pellet cloud – appears to be in front of pellet
- ELM is triggered and the single filament appears to strike wall near the pellet location
- All pellets were observed to form a single filament that results in an ELM. Fragments that follow the pellet do not trigger an ELM
- Average velocity of filament in SOL is ~1000 m/s, reduced by 3-4x with RMP applied

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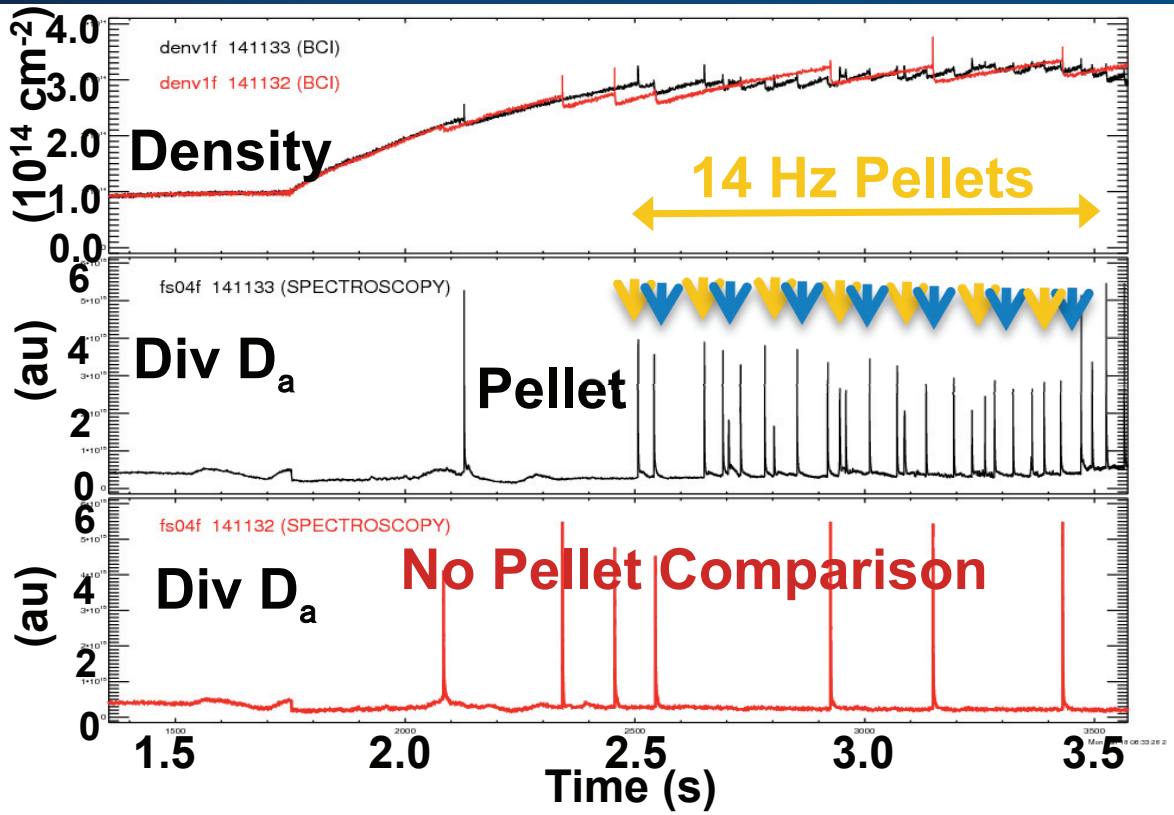
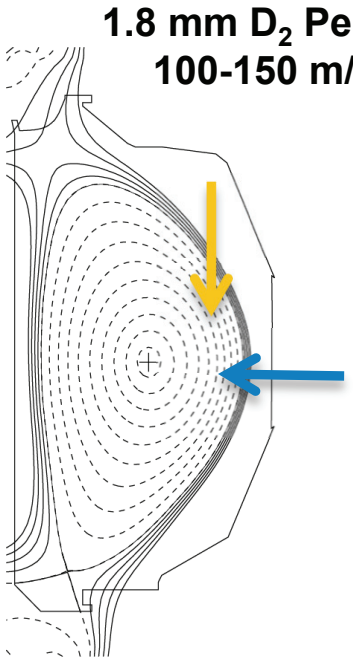
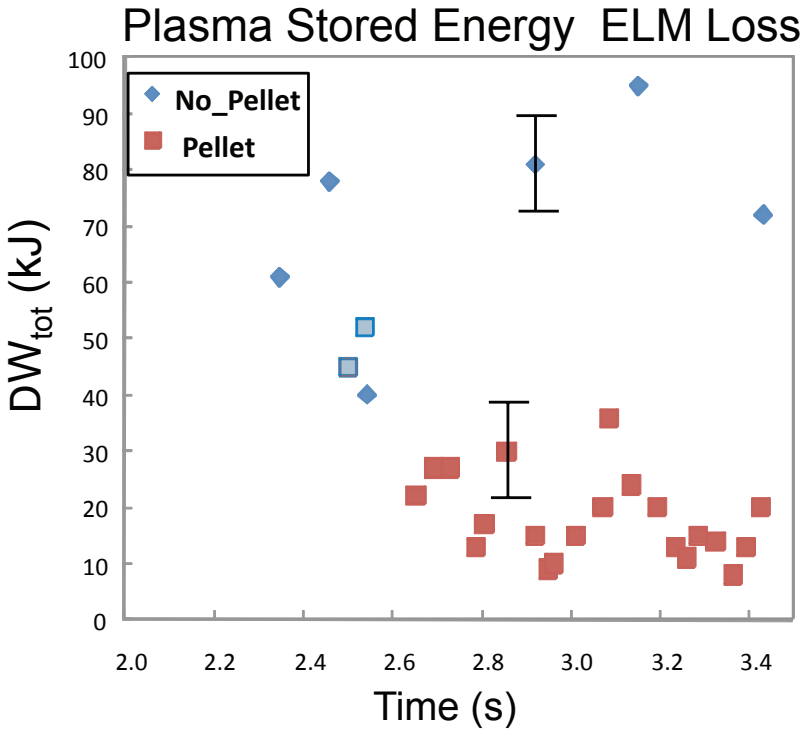
Demonstration of ELM Pacing by Pellets with No Fueling

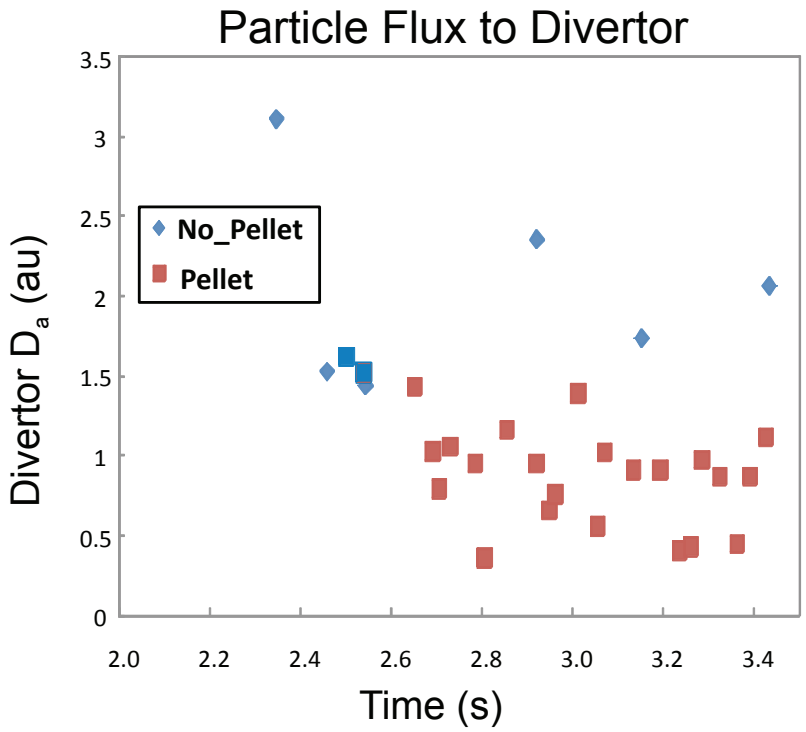




- 14 Hz pellets injected from 2.5 s leads to smaller higher frequency ELMs (~5 Hz to 25 Hz)
- Note: higher ELM frequency than the pellets
- Pellets are barely visible in density (no fueling), but do directly trigger ELMs

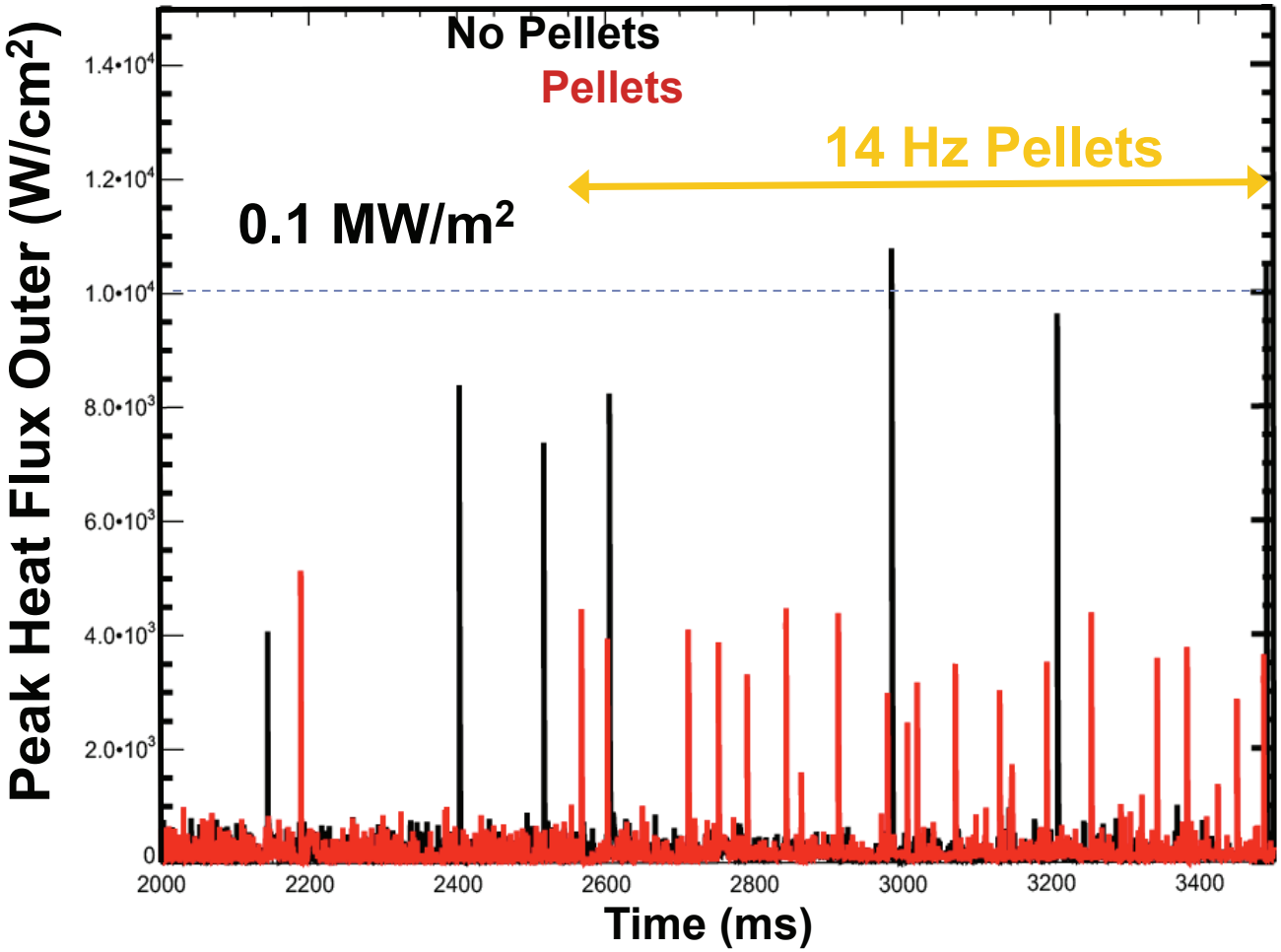
ELMs are Smaller with Pacing by Pellets

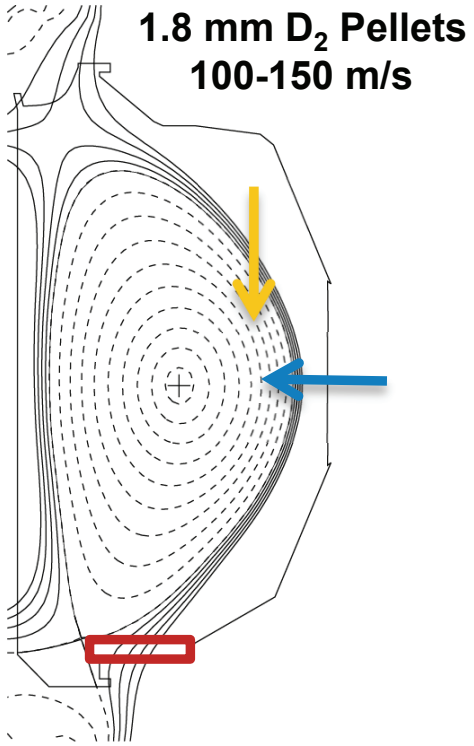




- **14 Hz pellets injected after 2.5 s lead to smaller higher frequency ELMs (~5 Hz natural to ~25 Hz triggered)**
- **Pellet induced ELMs have lower average energy loss by ~4x (from fast EFIT analysis)**
- **Edge plasma rotation is also reduced from the pellets, but central rotation is increased**

IR Camera Data Comparison Shows Reduced Peak Heat Flux

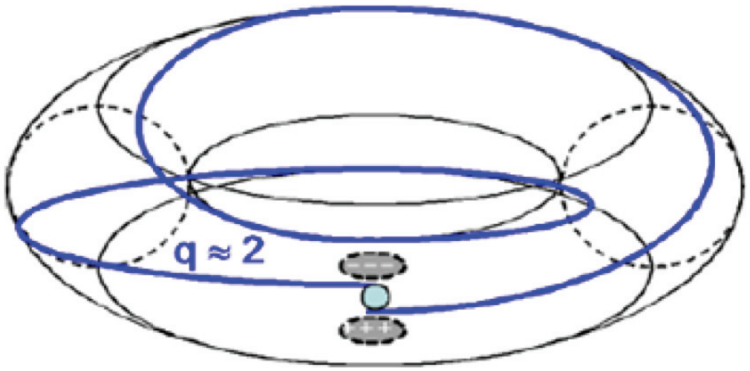


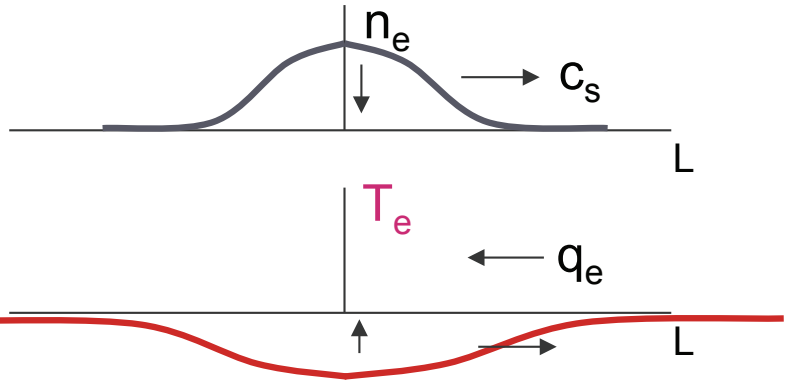


ITER shape
β_N = 1.8

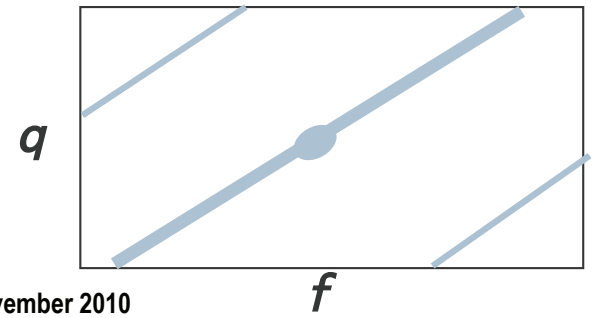
- IR Camera looking at 60° divertor location (pellets at 0°)
- Peak heat flux on outer shelf (strike point not visible) is reduced by ~3x to about 0.03 MW/m²
- Peak heat flux on inner divertor is not reduced as much

Hypothesis on the Mechanism of a Pellet Induced ELM





- Pellet cloud releases from pellet and expands along a flux tube
- Density from the cloud expands along flux tube at the sound speed χ_s
- Temperature 'cold wave' travels along the flux tube at the thermal spee
- Pressure decays and expands along the flux tube with a lower pressure far from the cloud
- Strong local cross field pressure gradients result along the flux tube that form on ms time scales
- Perturbation Size – suggests a minimum pellet size is needed. Validation of hypothesis needed



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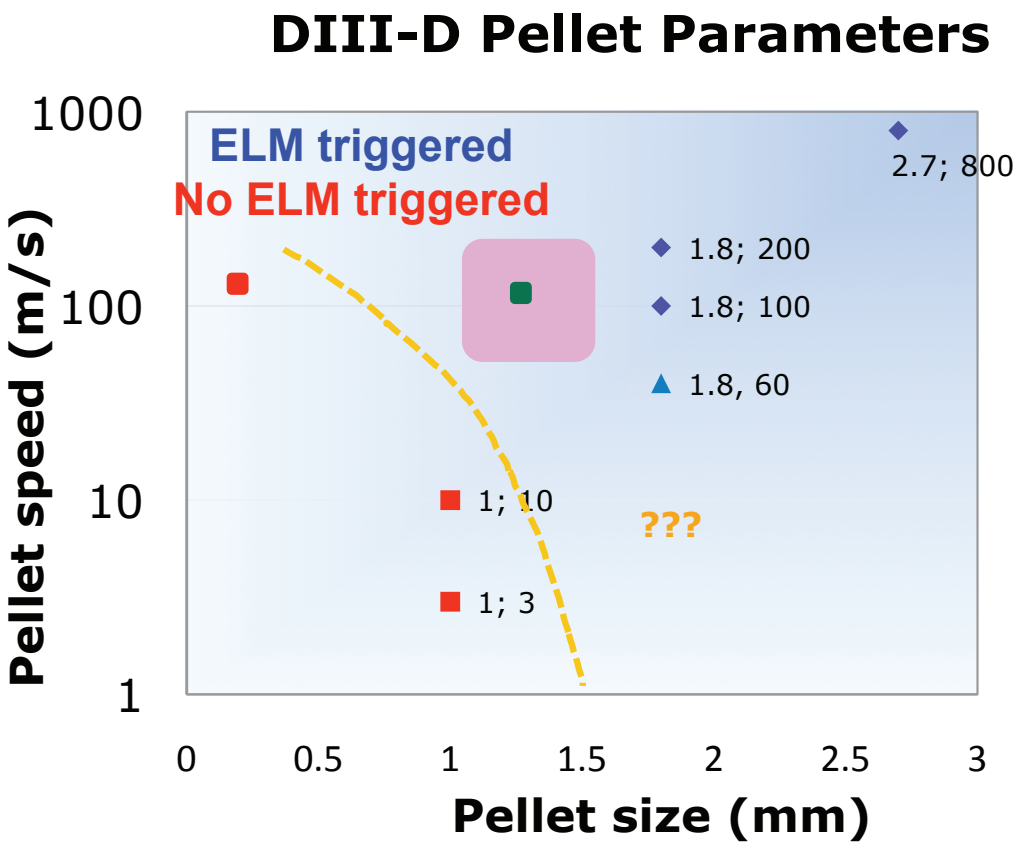
Pellet Parameters Used on DIII-D for ELM Triggering

- 1-mm dropper pellets at 10 m/s did not trigger ELMs. Fragments do not trigger ELMs. Fueling pellets always trigger ELMs
- What are the minimum pellet size and speed requirements to reliably trigger ELMs ?
- DIII-D is investigating this in concert with JET and ASDEX-U (ITPA PEP24)
- For 2011 we will use 1.4 mm pellets (~50% of 1.8 mm mass) at 30 Hz



Summary

- **Projected erosion of divertor materials by ELMs is a serious issue for ITER**
- **ELMs are triggered by pellets on DIII-D with filament formation just in front of the pellet as it crosses the separatrix. Pellet triggered ELMs on LFS are local events**
- **Small (D = 1.8 mm) LFS injected D_2 pellets successfully demonstrated pellet ELM pacing at 5x the natural ELM frequency:**
  - W_{tot} transients are reduced on average by ~4x
  - Convective losses from pellets seem small based on W changes from pellet induced ELMs. $DW_{tot} \sim 1/f_{ELM}$
  - No net fueling from LFS pellets unlike HFS injection
- **Future experiments will double the pellet repetition rate with ½ size pellets and use a new ITER-like low-field-side injection geometry**

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