

# Pellet ELM Pacing Developments

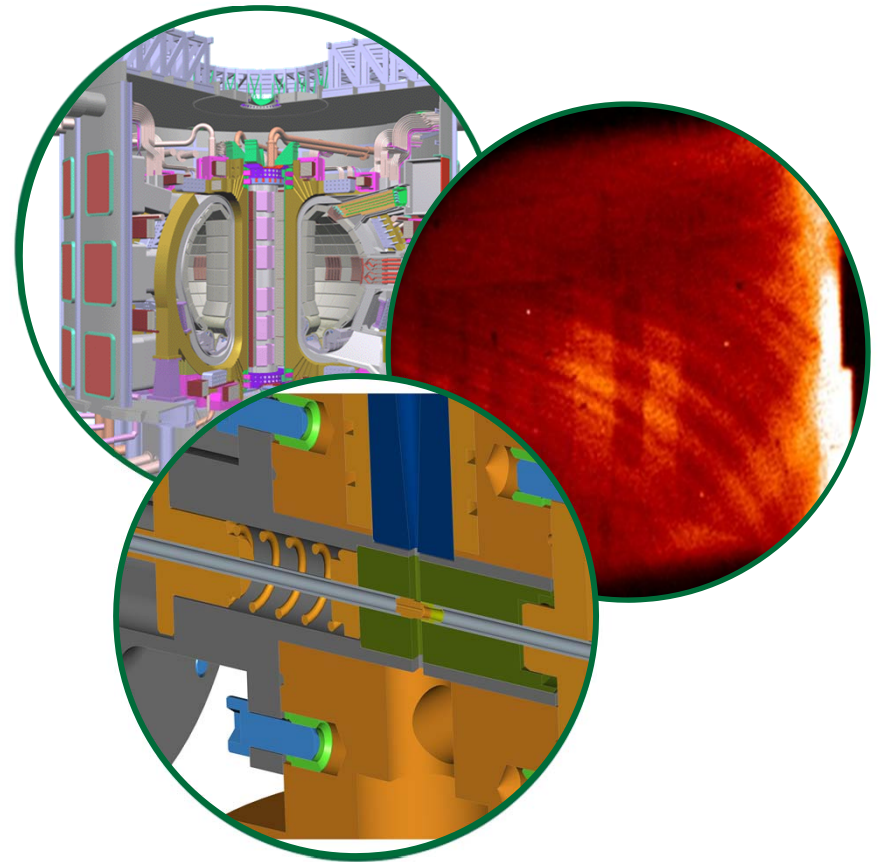
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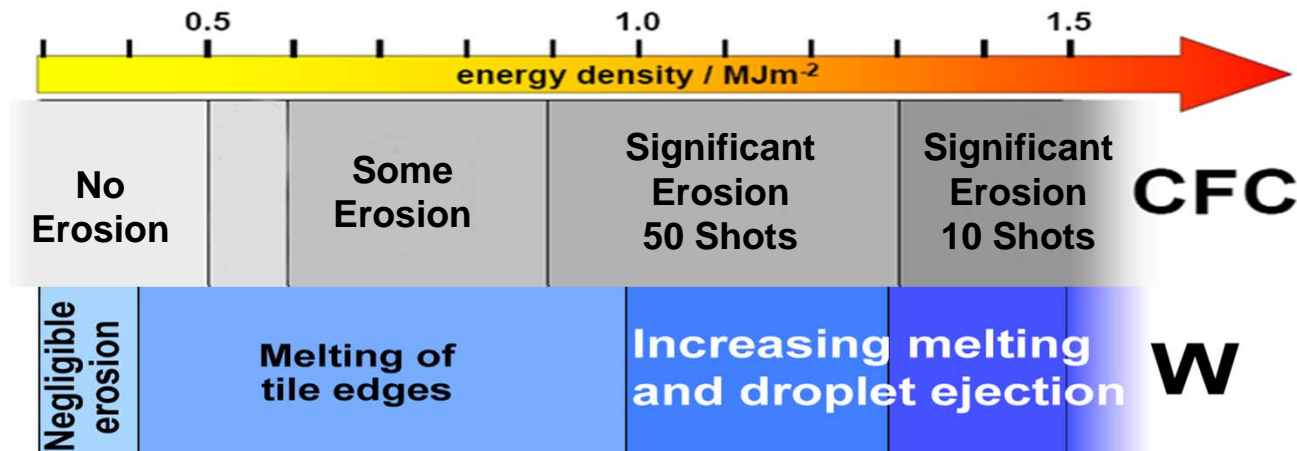
# Overview

- **Projected erosion of divertor materials by type I ELMs is a serious issue for ITER. Pellet ELM Pacing has been shown to reduce the ELM size.**
- **In support of ITER, the pellet injector repeating gas gun design has been modified to produce small pellets at slow speeds.**
- **The new gun design has been successfully tested in the lab and at DIII-D, where a new LFS injection line was installed that mimics the ITER plan for pellet ELM pacing.**
- **New data from this trajectory confirms ELMs are triggered before the pellet reaches the top of the Te pedestal.**
- **Injector tested at 60 Hz into plasma. Pacing observed at ~6x the natural ELM frequency.**

# ELM Erosion of the Divertor is a Serious Issue for ITER

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

[Zhitlukhin et al., JNM, 2007]



ITER SOL projection on the divertor plates is  $3.0 \text{ m}^2$

ITER ELM losses are projected to be  $\sim 15 \text{ MJ}$

ITER ELM size needs to be  $< 1.5 \text{ MJ}$  for low erosion

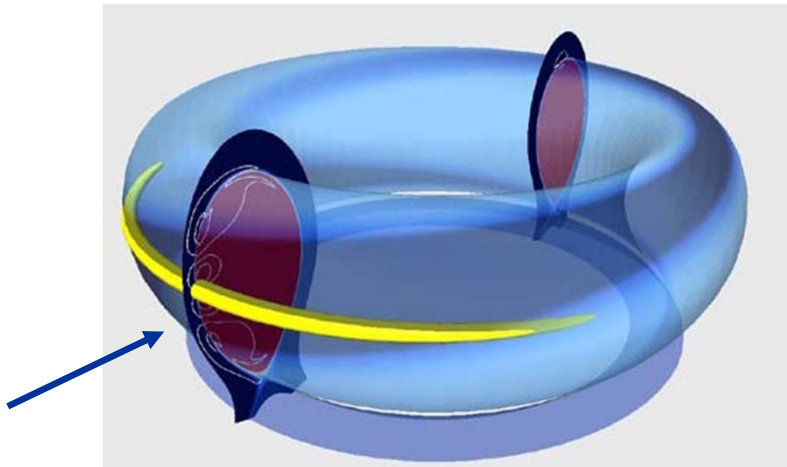
Implying ELM triggering is needed  $> 20 \text{ Hz}$

( $> 10 \times$  increase in natural ELM frequency)

[Loarte et al., IAEA, 2010]

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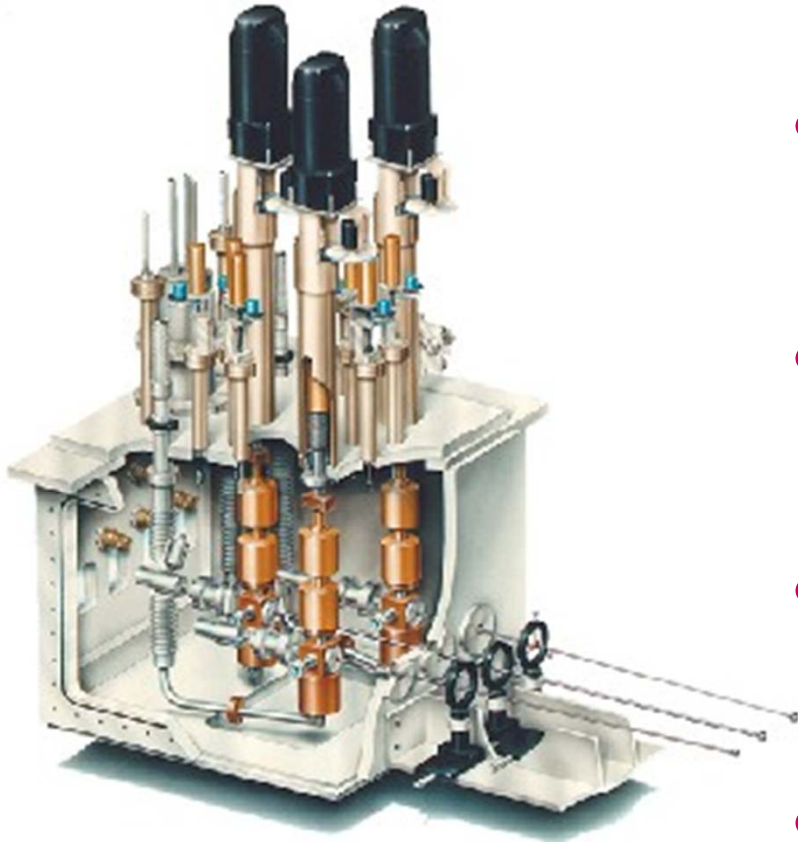
# Pellet ELM Pacing Technique



*Huysmans, EPS 2009*

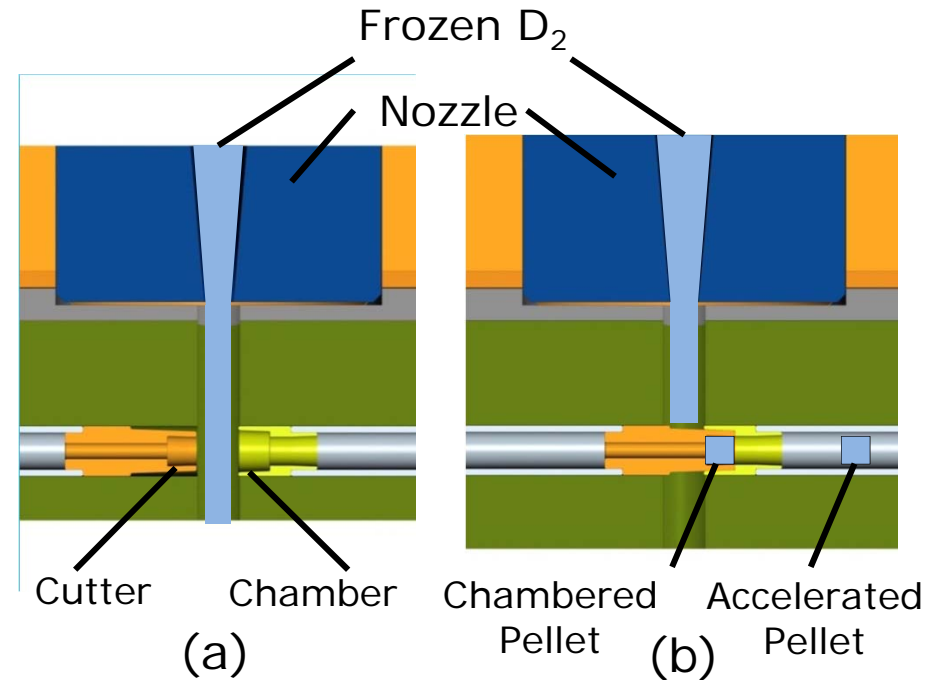
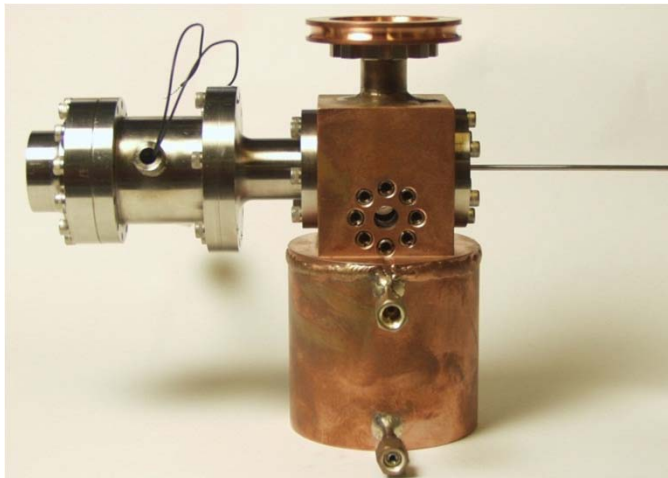
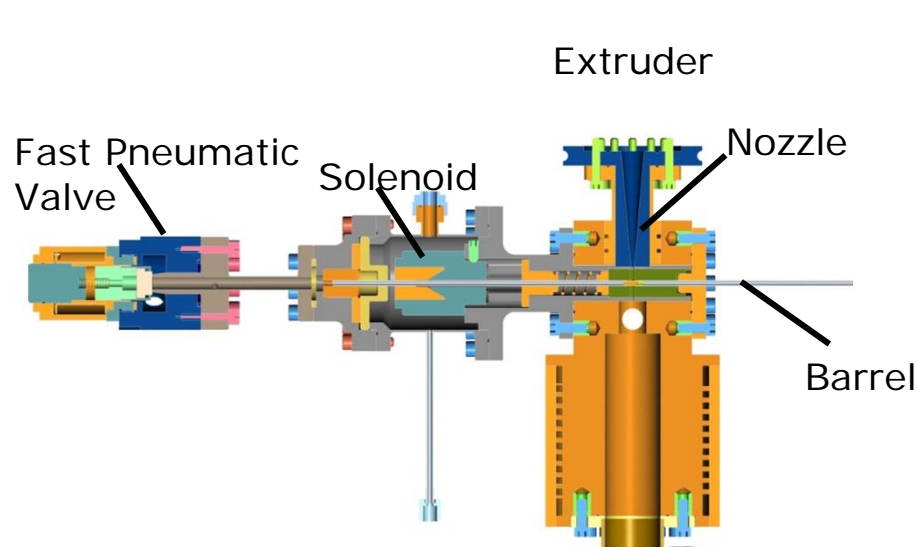
- Pellets have been known to trigger ELMs for many years on DIII-D, AUG, JET, etc.
- The basic hypothesis is that a local pressure gradient occurs where the pellet enters the plasma and triggers a ballooning mode that releases one or more ELM filaments to relieve the edge pressure.
- If the pellets can trigger more frequent smaller ELMs than would naturally occur, the ELM damage can possibly be mitigated.
- Initial experiments on AUG demonstrated 2x ELM frequency, D3D last year obtained >4x. ITER needs >10x.

## Pneumatic Repeating Pellet Injector Requires Modifications



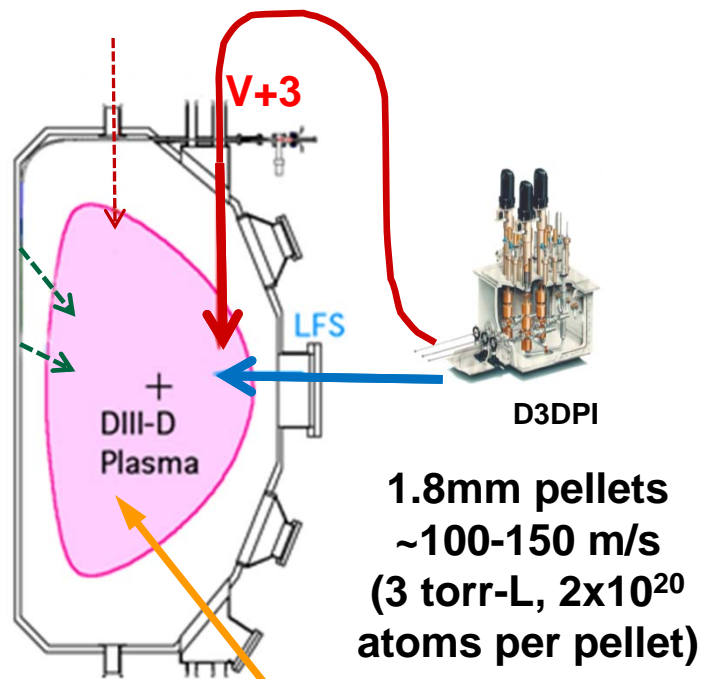
- The RPI type injector has been workhorse for fueling on many plasma devices.
- Initially designed for high speed pellets, modified with a mechanical punch for lower speeds, but moderate rep rate.
- Initial experiments on AUG demonstrated 2x ELM frequency, D3D last year obtained 4x. ITER needs  $> 10x$ .
- Smaller slow pellets desired to minimize fueling, but with enough perturbation to reliably trigger ELMs.
- High rep rates with slow pellets requires clever gun design for reliable operation and minimal propellant gas usage.

# Injector Gun Mechanism Redesigned for Small Pellets



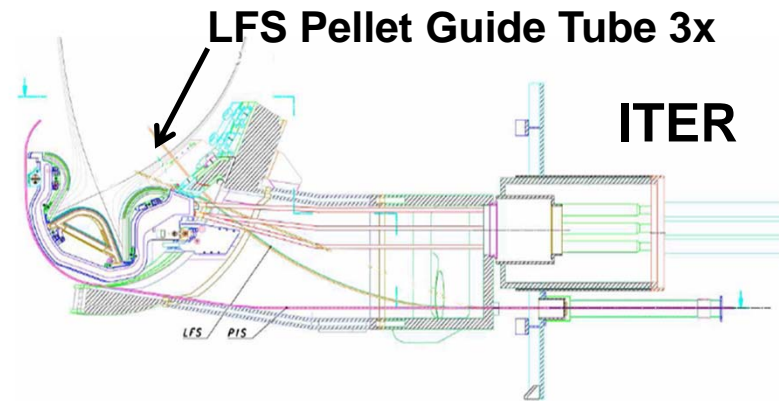
- The pellet size was reduced from 1.8mm to 1.3mm and mechanical punch replaced with a new cutter scheme for higher rep rates.
- The resulting 1.3mm pellets have a speed of 150-200 m/s with dispersion out of the barrel less than 1 degree.

# DIII-D Pellet ELM Triggering Experiments Performed with D<sub>2</sub> Pellets Injected from Low Field Side

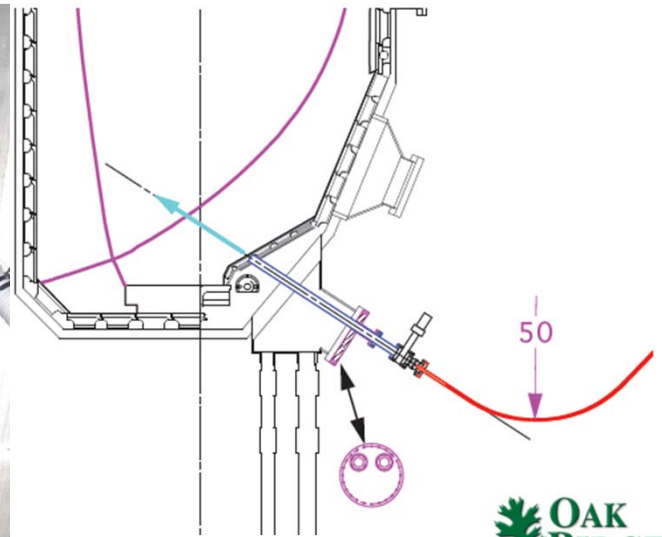


1.8mm pellets  
~100-150 m/s  
(3 torr-L,  $2 \times 10^{20}$  atoms per pellet)

New ITER like  
Injection line for 2011

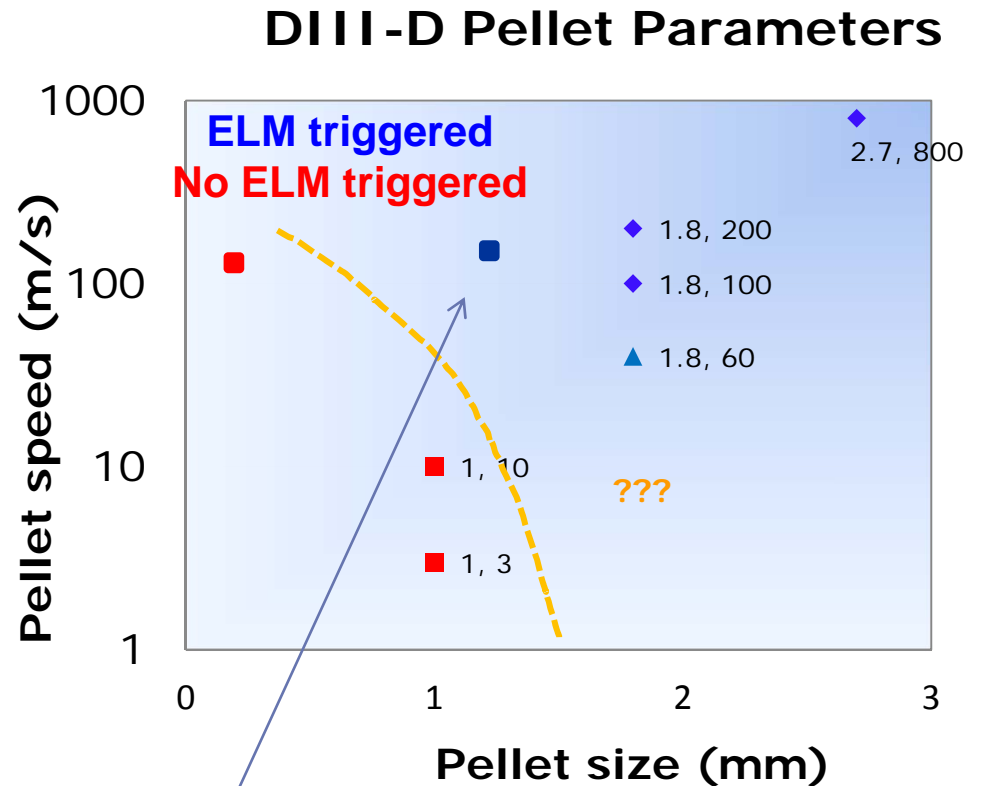


- New ITER like LFS injection line installed and tested on DIII-D. 1.8mm pellets were observed to trigger ELMs.



# Pellet Parameters Used on DIII-D for ELM Triggering

- 1-mm dropper pellets @ 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).
- In 2011 we tested 1.3mm pellets (~40% of 1.8mm mass) at 20 Hz. 60 Hz from all three guns.

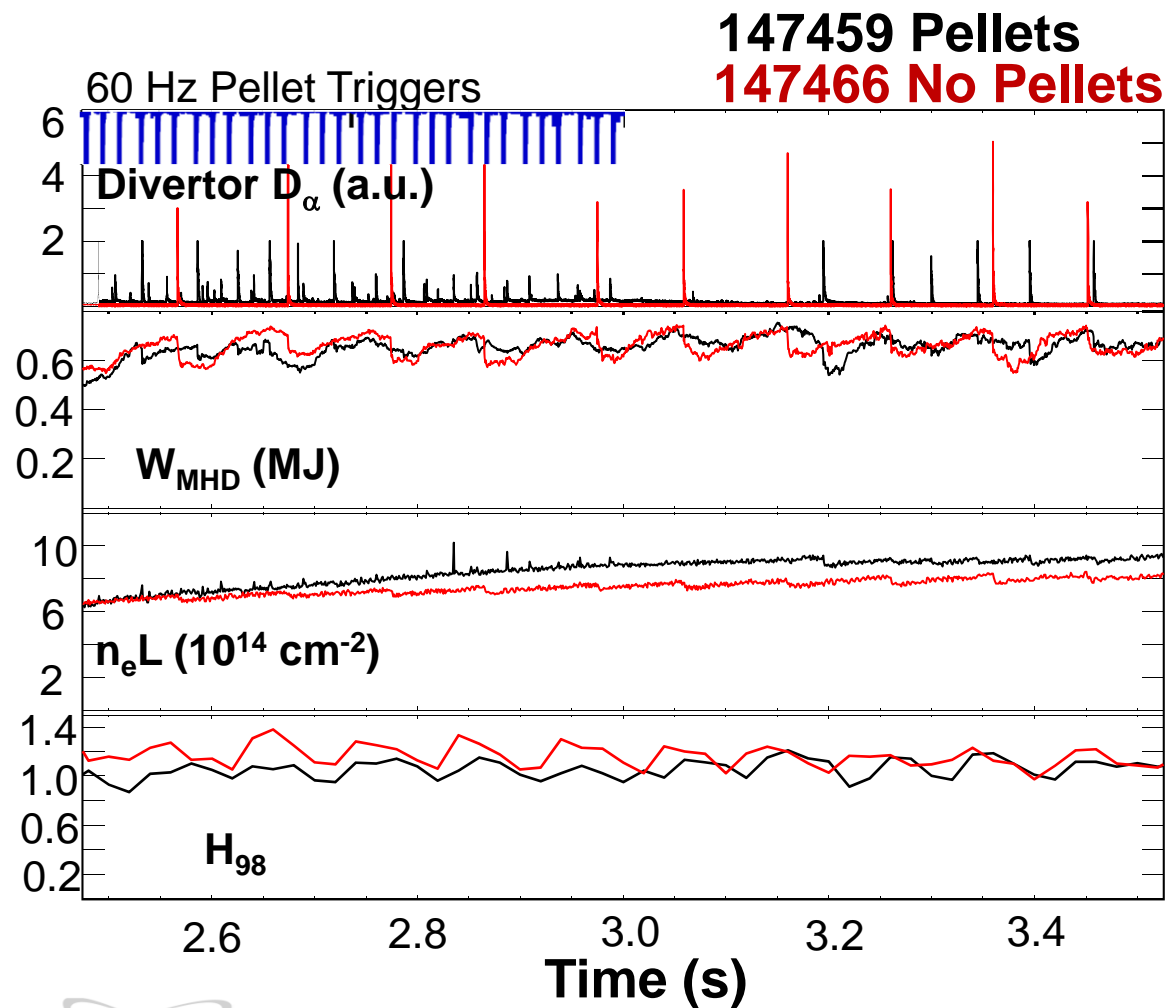


**New 1.3mm slow pellet tested from LFS**

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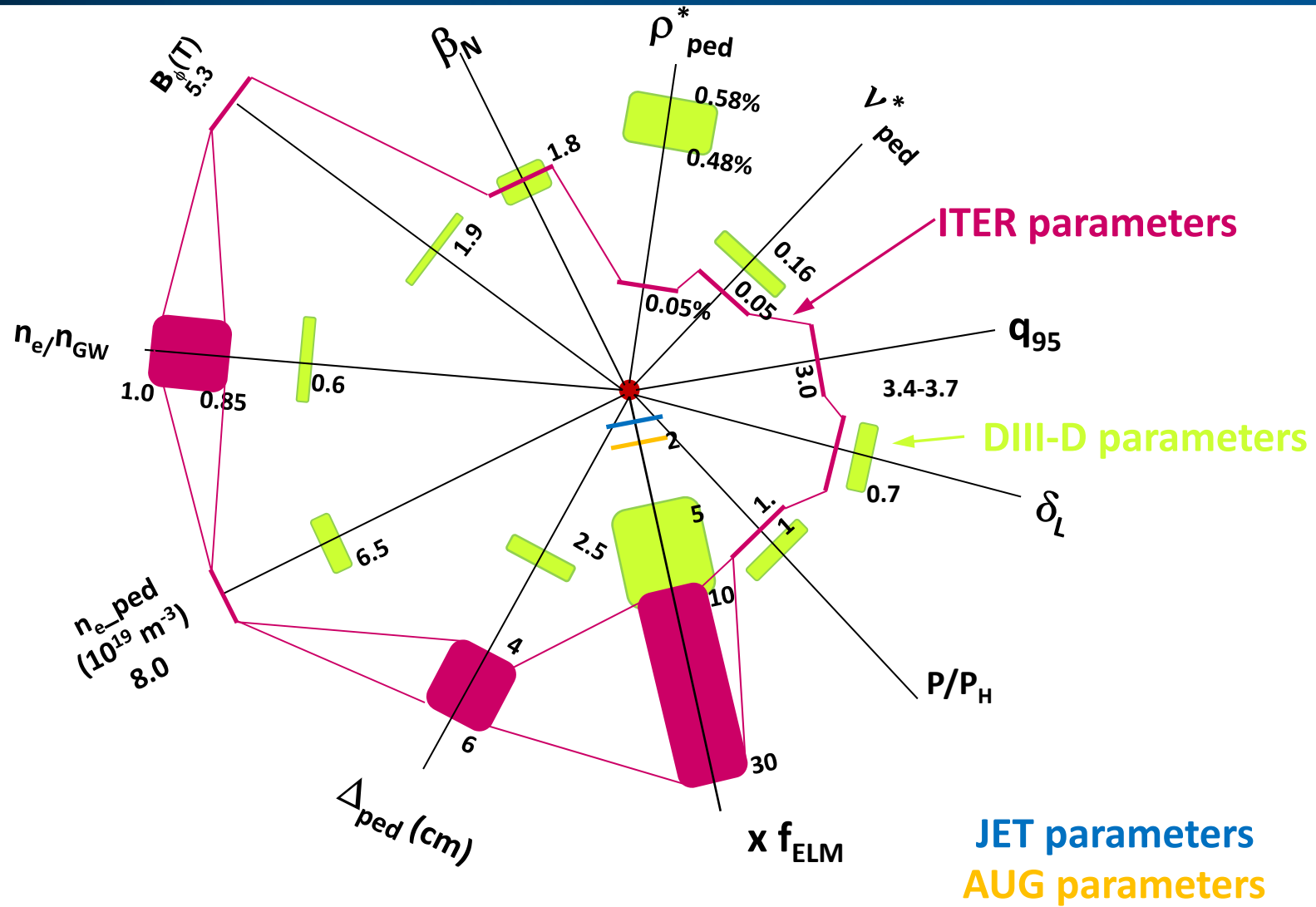


# Demonstration of ELM Pacing by 60 Hz Pellets



- ELM Pacing demonstrated at 5x the natural ELM rate.
- ITER Shape with  $\beta_N \sim 1.8$
- 1.3mm pellets injected from LFS midplane at 90-150 m/s.
- Much reduced divertor  $D_\alpha$  from the pellet induced ELMs.
- Very modest fueling and reduction in H factor observed.
- Analysis underway

# DIII-D Pellet ELM Pacing Operating Space



# Summary

- **Projected erosion of divertor materials by type I ELMs is a serious issue for ITER. Pellet ELM Pacing has been shown to reduce the ELM size.**
- **In support of ITER, the pellet injector gun design has been modified to produce small pellets at slow speeds.**
- **The new injector gun design has been successfully tested in the lab and at DIII-D, where a new LFS injection line was installed that mimics the ITER plan for pellet ELM pacing.**
- **New data from this trajectory confirms ELMs are triggered before the pellet reaches the top of the Te pedestal. Initial testing of the 1.3mm slow guns at 60 Hz shows ELM pacing at 6x the natural ELM frequency with no significant degradation in confinement.**
- **Further optimization planned for an experiment in late Nov.**