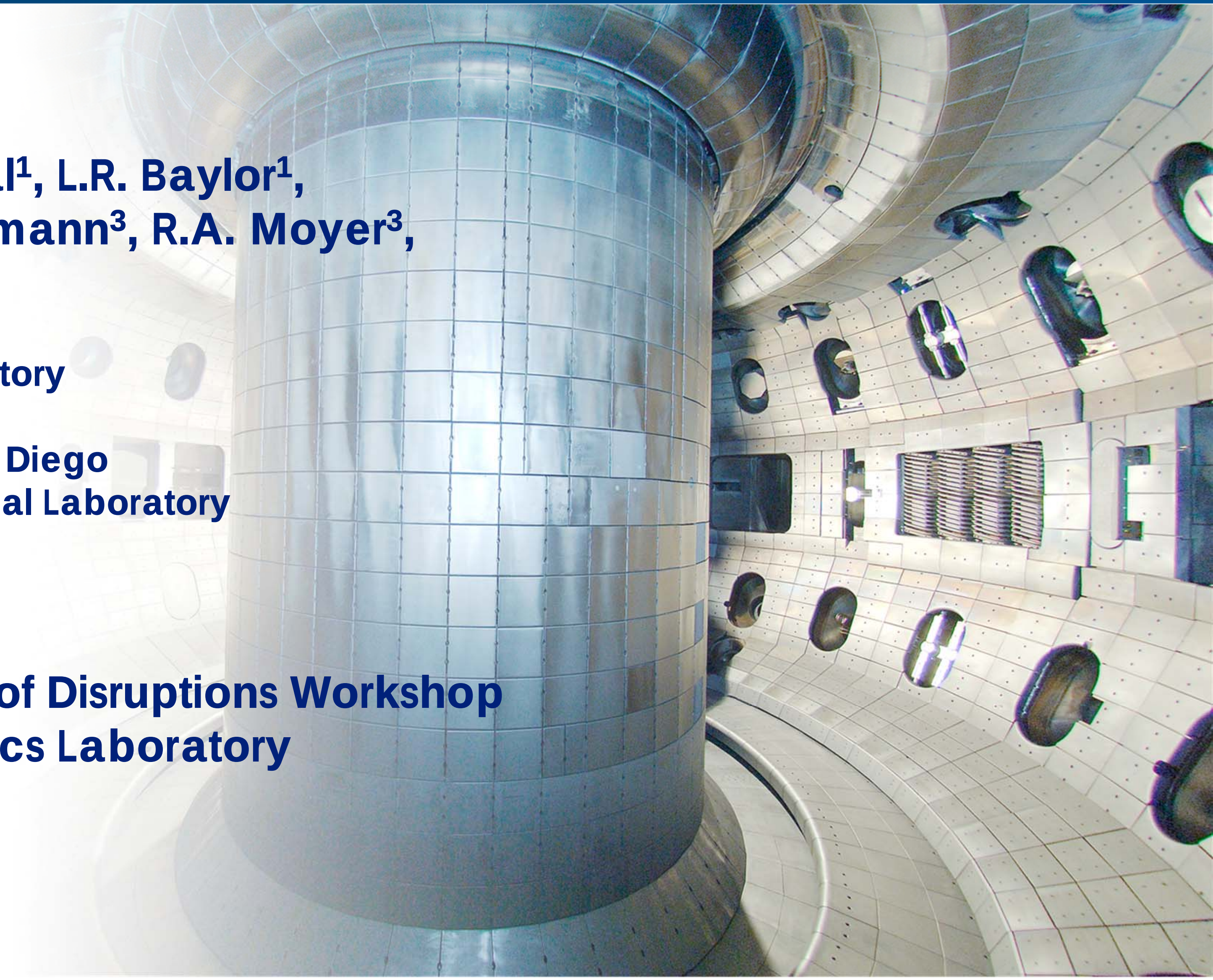
Results from Recent Shattered Pellet Injection Research on DIII-D



by

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Summary: Addition of 2nd SPI system beginning to generate first results

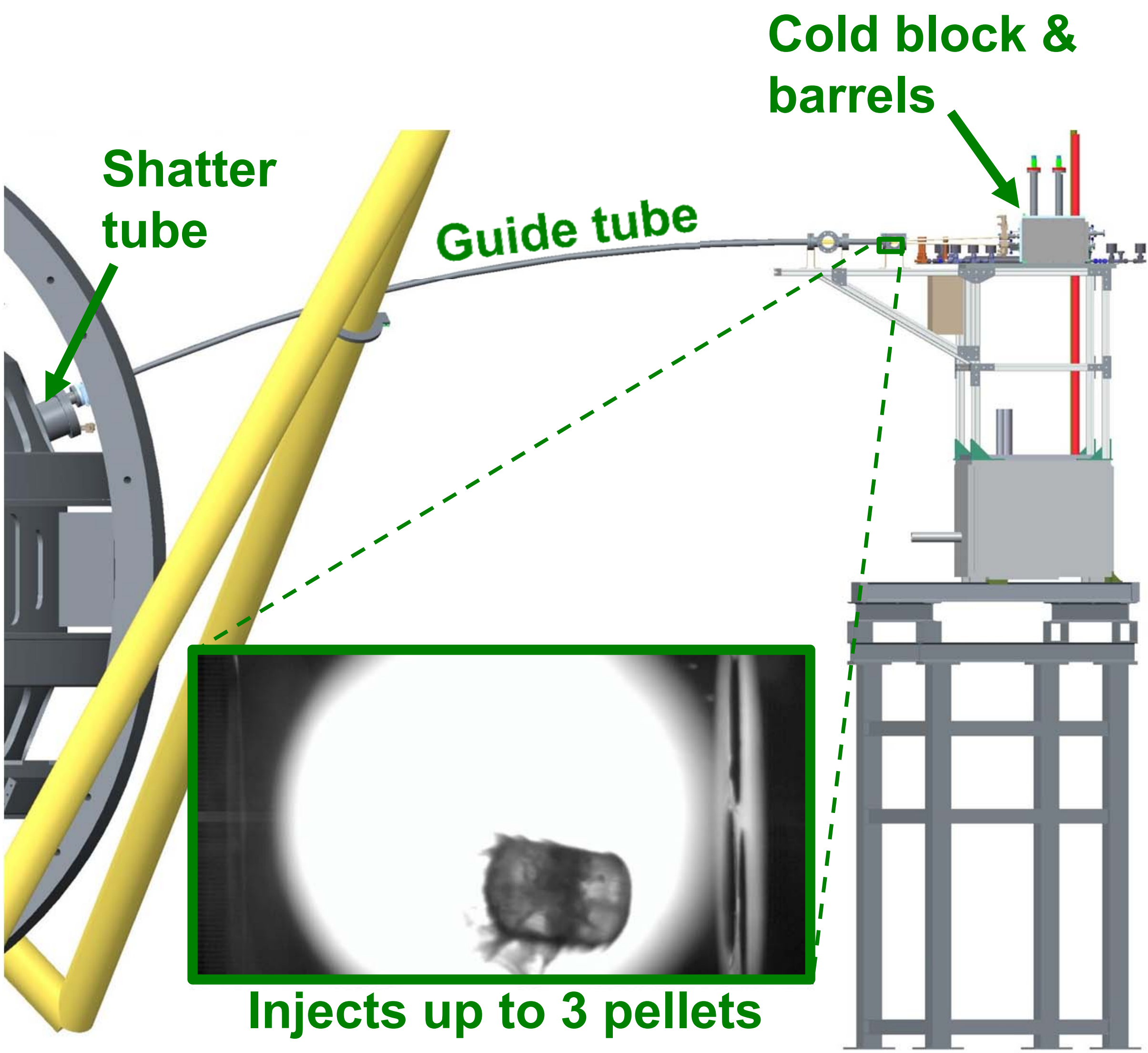
- Slight difference in mitigation between the two injectors observed, but still good mitigation overall
- No obvious evidence of localized heat loads caused by radiation asymmetry (so far)
- Multiple pellets may actually ***reduce*** mitigation, compared with a single pellet
- Possible mechanism: multiple pellets causes disruption sooner, which may reduce amount of neon entering pre-TQ plasma

2nd SPI system has been installed on DIII-D

- **Installed in 2016**
- **Experiments began in 2017**

- **ITER prototype design injects up to three pellets**
  - Pellets formed from arbitrary mixtures of Ne, D_2

- **Mechanical punch planned, will allow Ar pellets**



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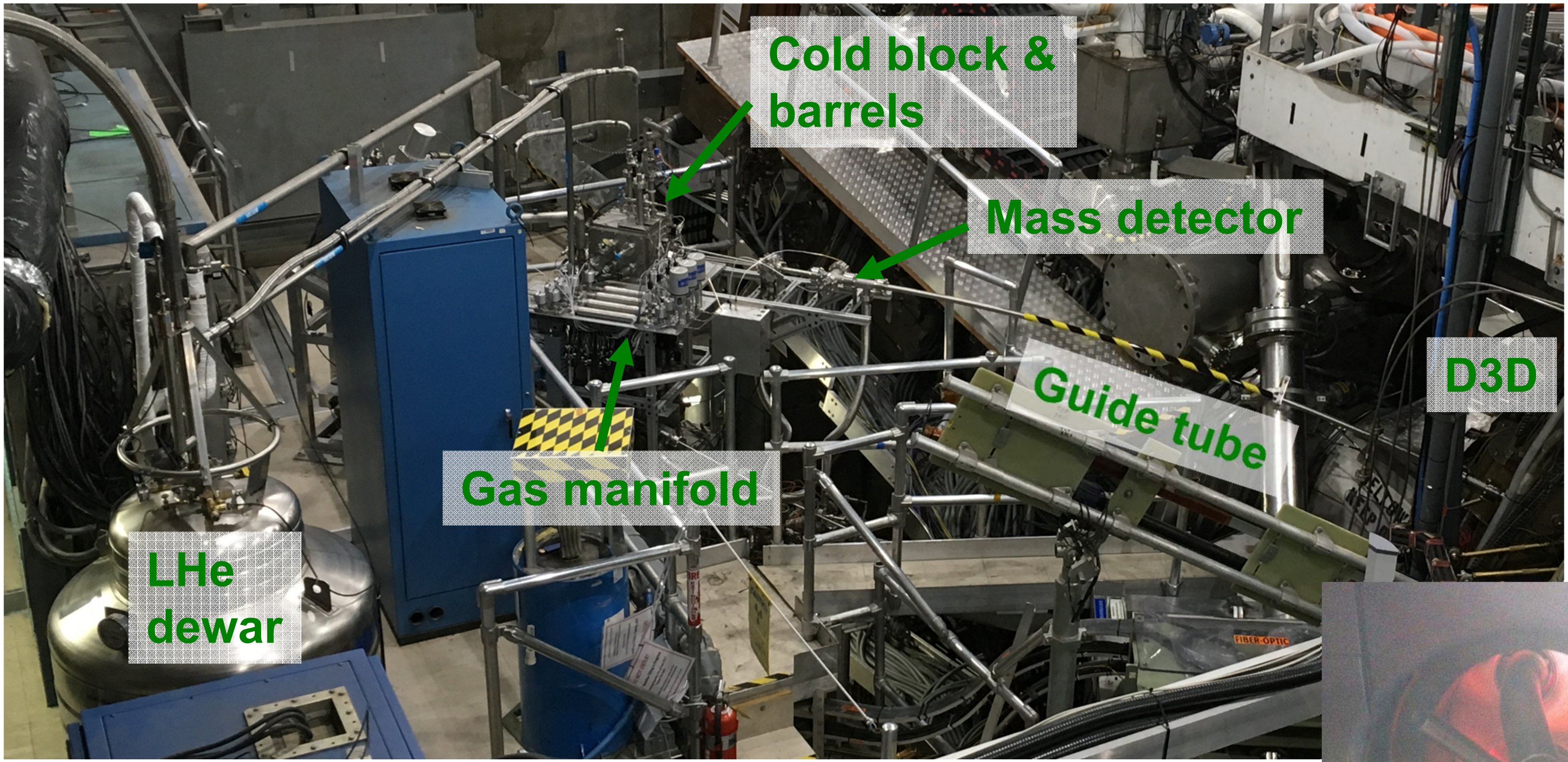
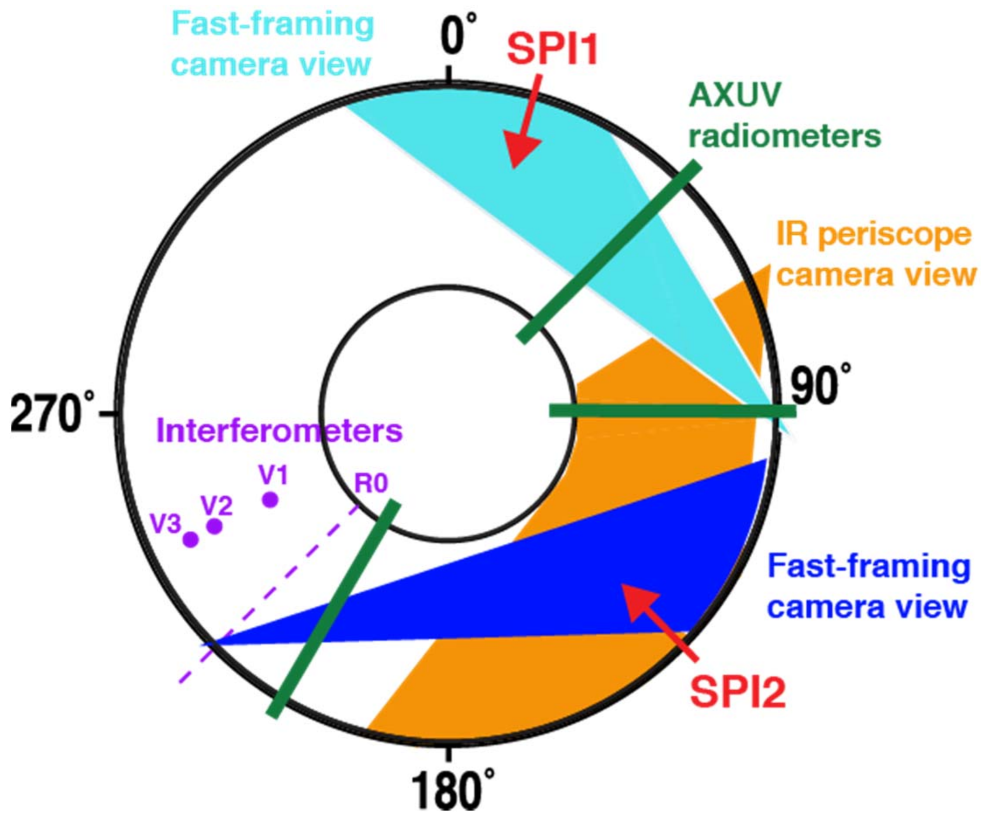


Addition of 2nd SPI significantly extends experimental capabilities

- **DIII-D may be only machine besides ITER to have multiple SPIs**
- **Effectively doubles coverage of disruption diagnostics**
  - Both injectors located at same poloidal position
  - Toroidally separated by 120°
- **Having two injectors allows significant modification to one while preserving the other**
  - i.e. Changing pellet trajectory



Outline

- **Characterizing asymmetric effects**
  - One pellet at a time, from different ports
- **Mitigating thermal and EM loads with multiple pellets**
  - Two pellets together, one from each port
- **Additional capabilities, and future work**

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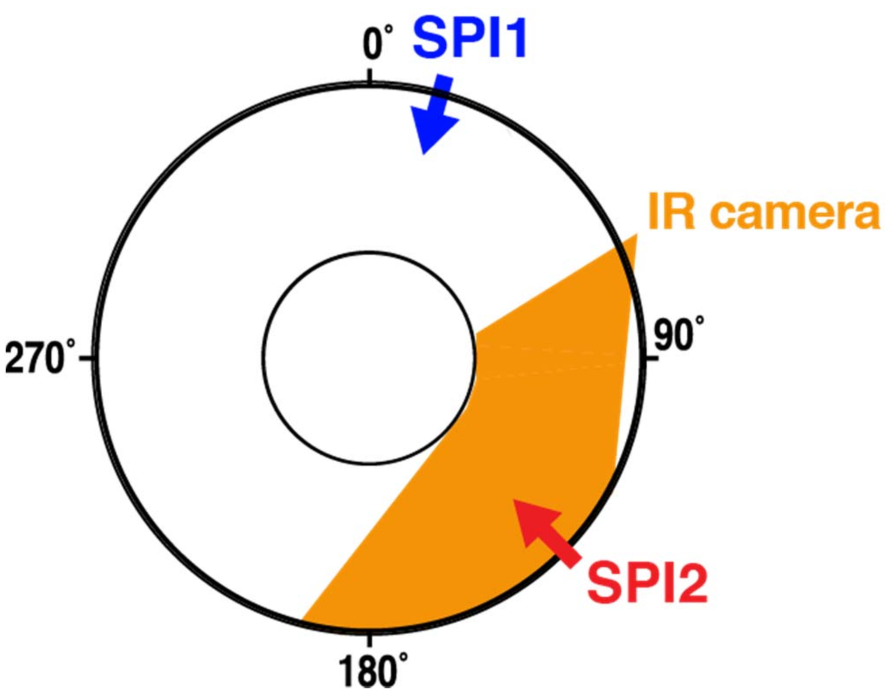
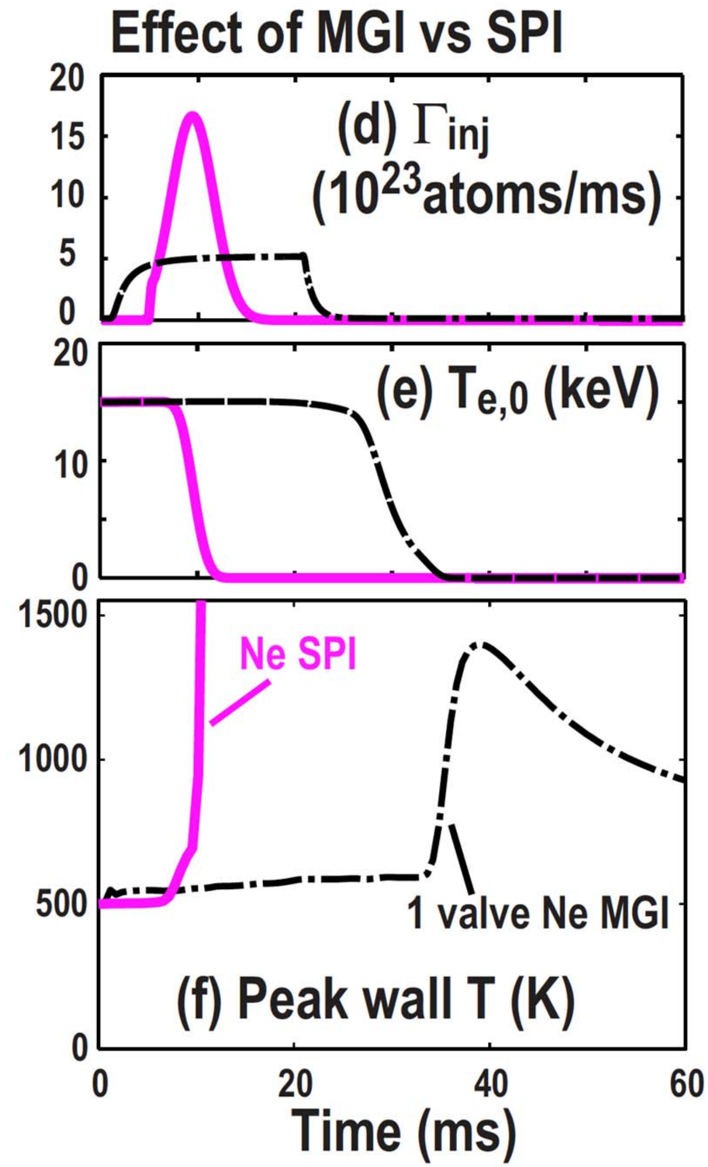
2nd SPI allows better detection of potential localized heat loads

- **Will the faster delivery by SPI lead to TQ with more asymmetric impurity distribution, and thus localized heat loads?**

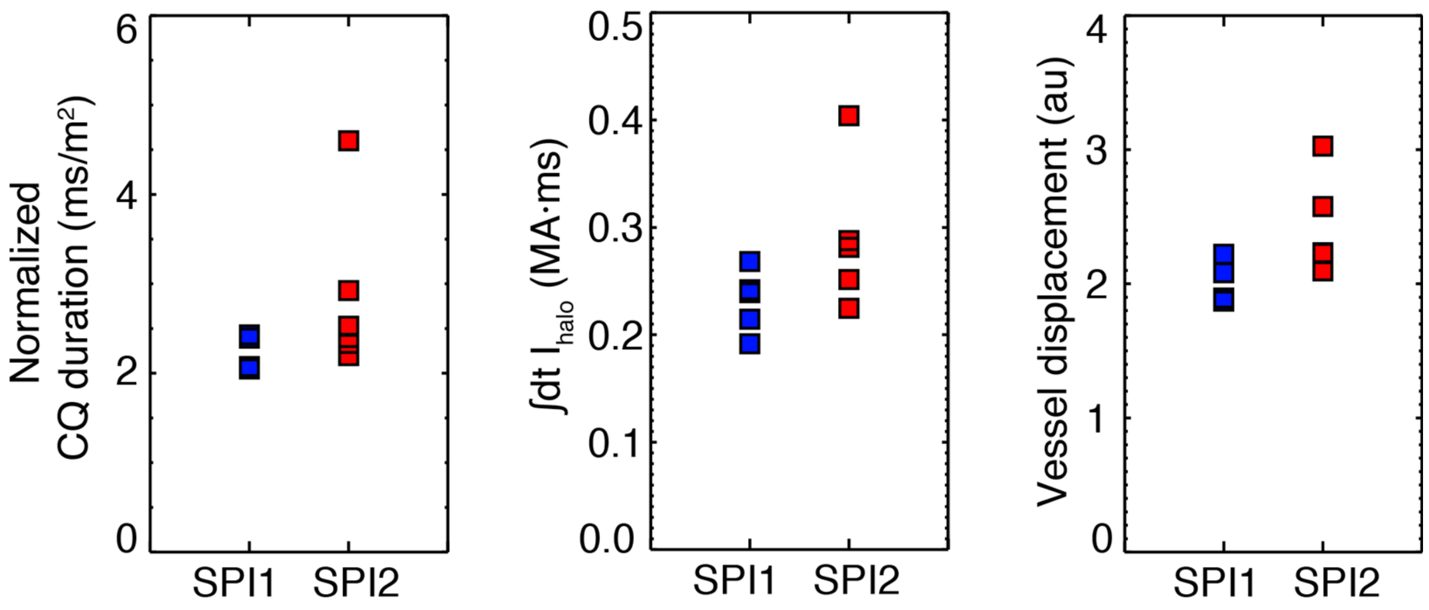




Hollmann et al., Phys. Plasmas 22, 021802 (2015)

Slight difference observed between performance of two injectors, but still good overall mitigation

- **SPI1 appears to mitigate slightly better than SPI2**
  - Good radiation data are are unavailable
- **Possible difference is amount of helium propellant entering plasma**



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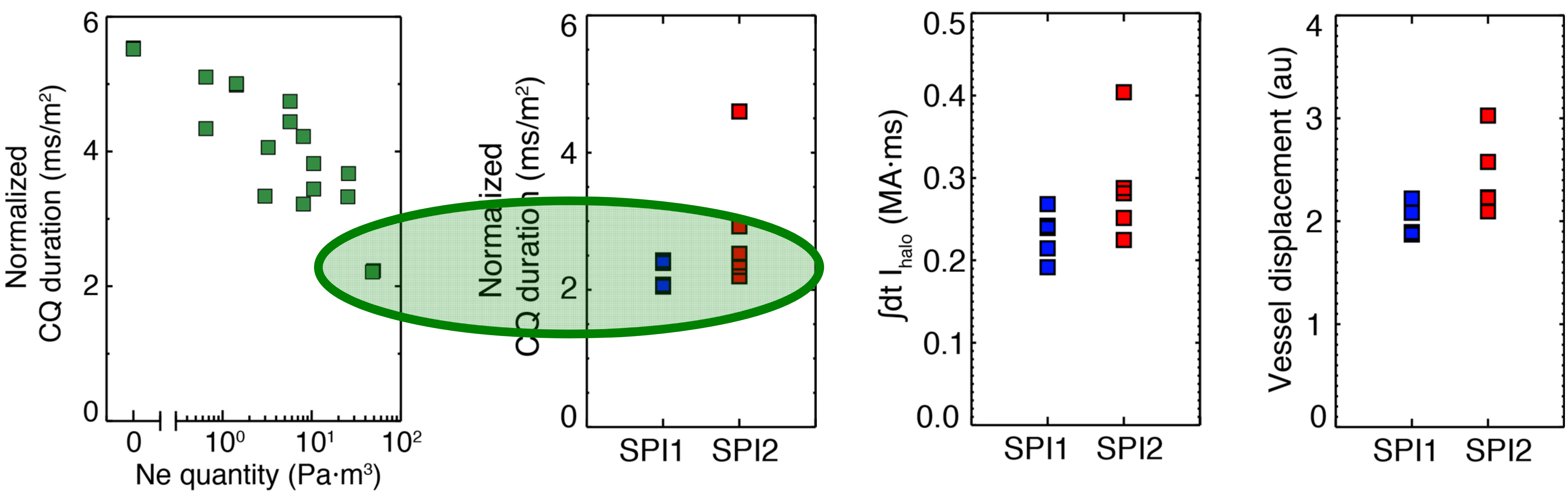
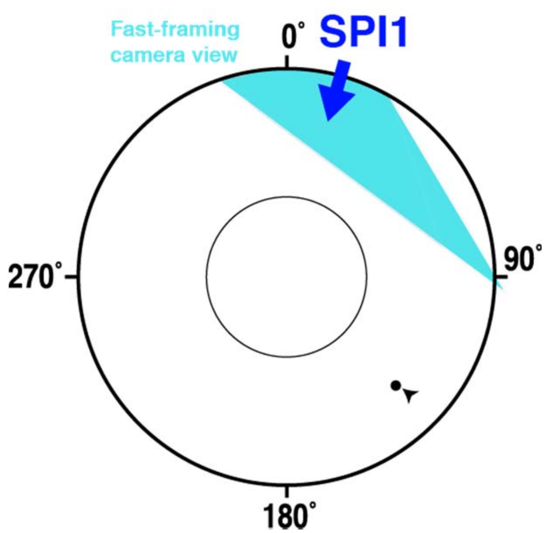


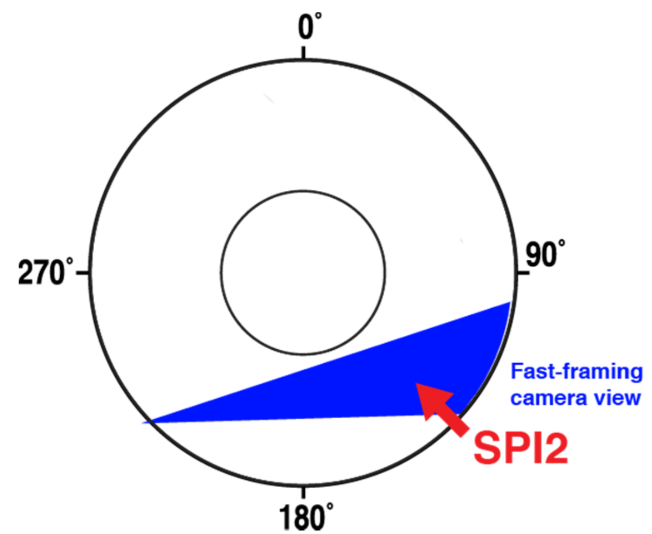
- **Compared to previous parameter scans, both injectors still show good performance**

Fast cameras show solid fragments entering plasma, but detailed analysis still ongoing

SPI1: Toroidal angle = 15°

SPI2: Toroidal angle = 135°

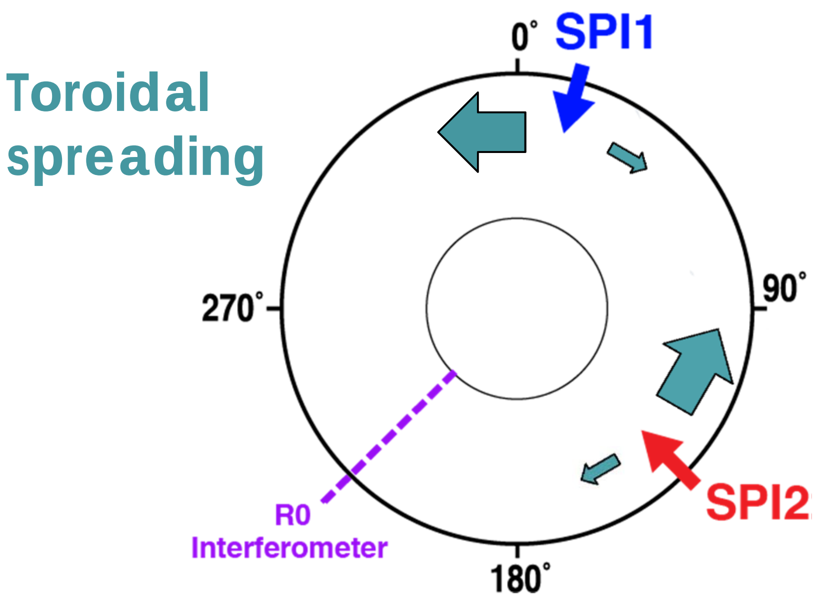


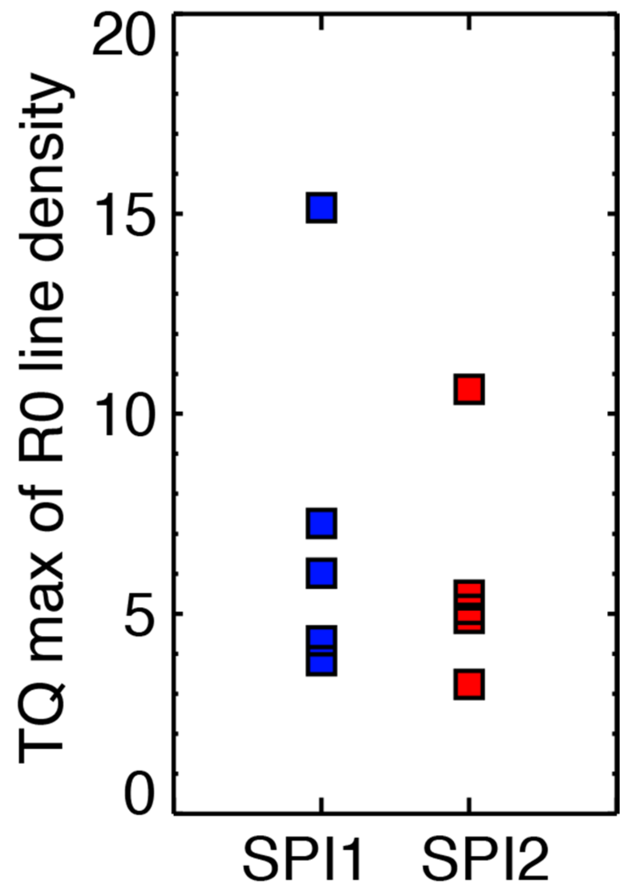


Density perturbations consistent with higher overall performance of SPI1, inconclusive on asymmetric spreading

- **Slightly higher assimilation observed for SPI1, which could explain improved mitigation**

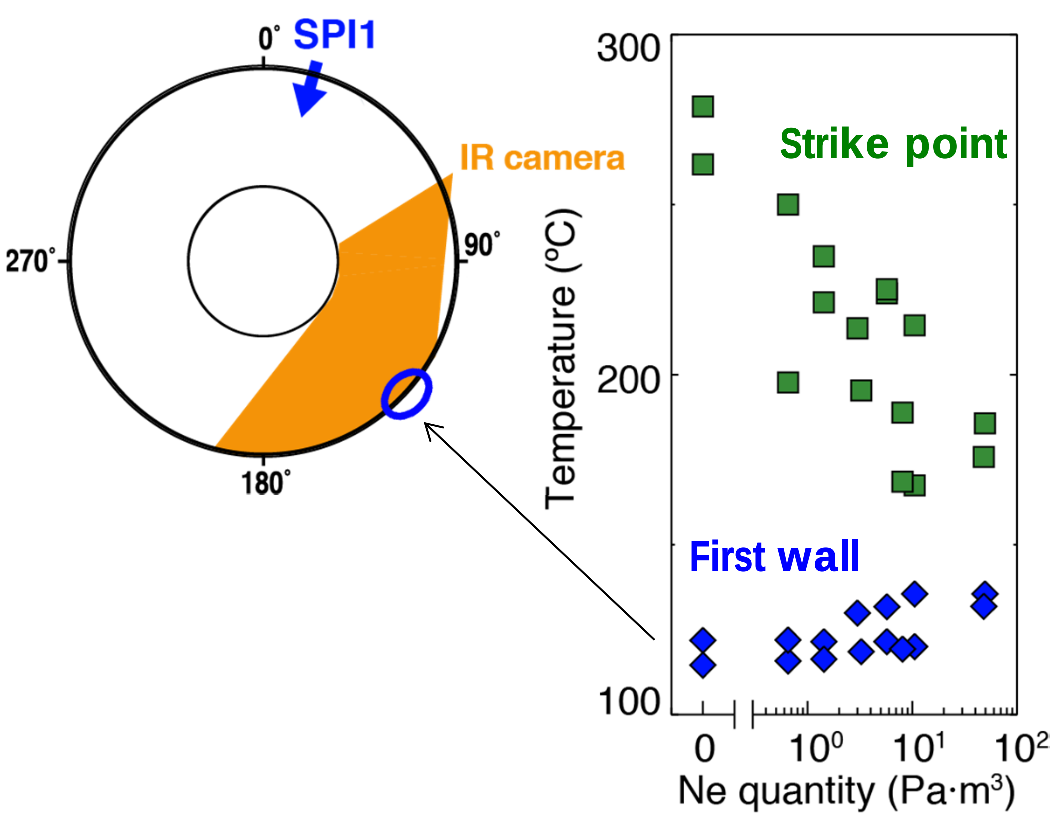
- **NIMROD simulations of MGI have predicted asymmetric toroidal spreading of impurities**
  - Izzo et al., Nucl. Fusion **55** (2015) 073032



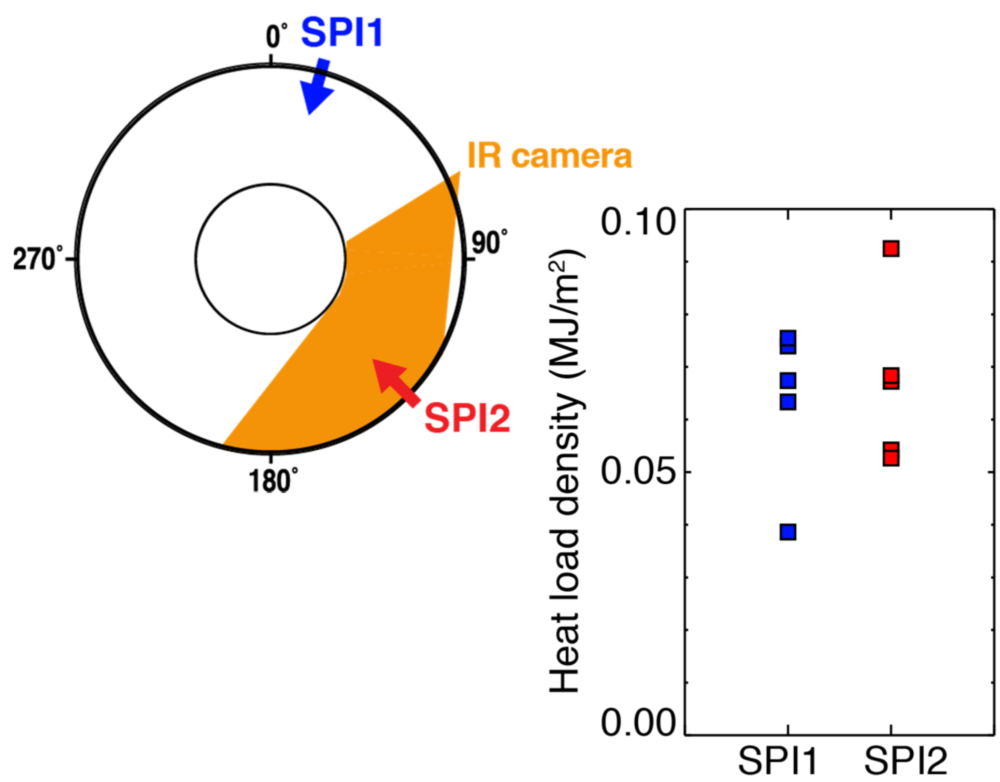


No obvious evidence of large heat loads near injection port

- **IR camera previously used to detect radiative heat loads**



- **Comparing the two SPIs, significant scatter in data**
  - Further analysis ongoing!

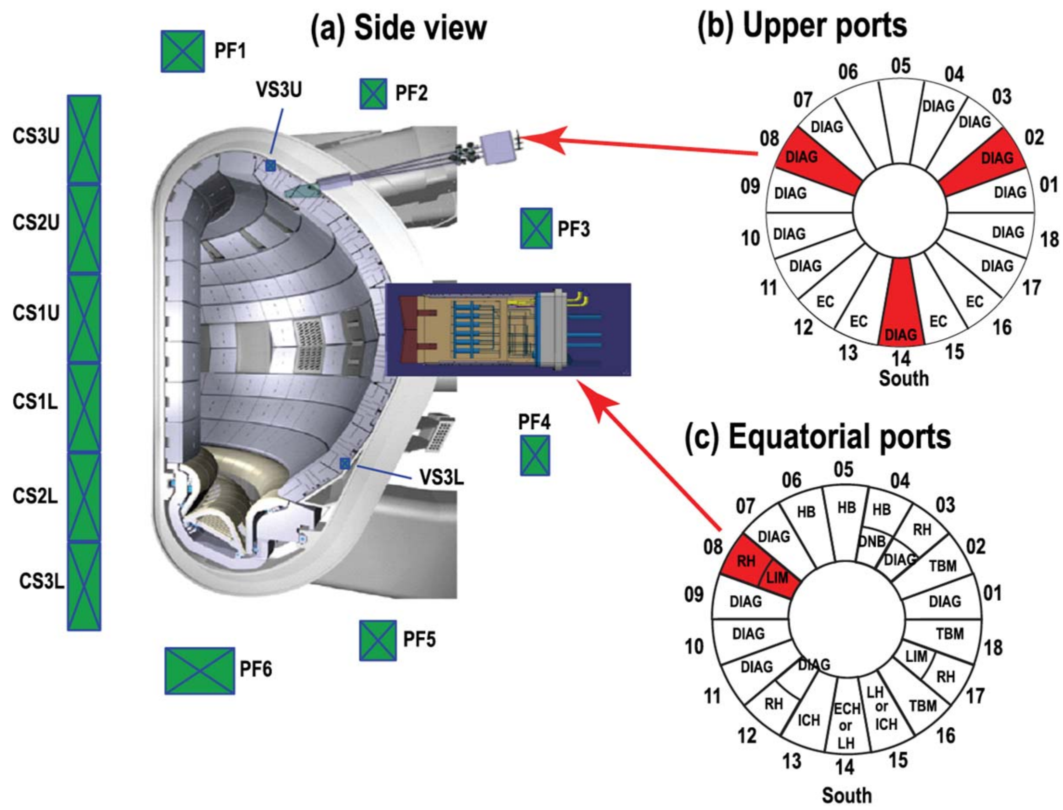


Outline

- **Characterizing asymmetric effects**
  - One pellet at a time, from different ports
- **Mitigating thermal and EM loads with multiple pellets**
  - Two pellets together, one from each port
- **Additional capabilities, and future work**

Injecting multiple pellets is a key part of the ITER DMS strategy

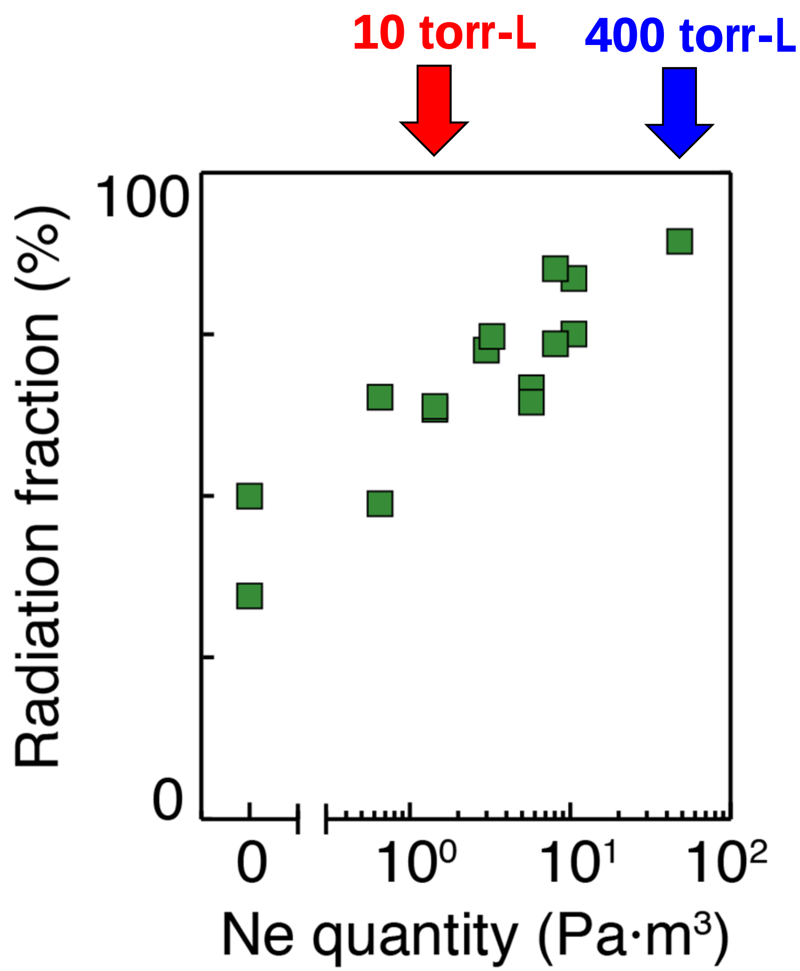
- **ITER will inject multiple pellets "simultaneously" in order to deliver large quantities**
- **How simultaneous must they be?**
- **Are multiple small pellets the same as one large pellets?**

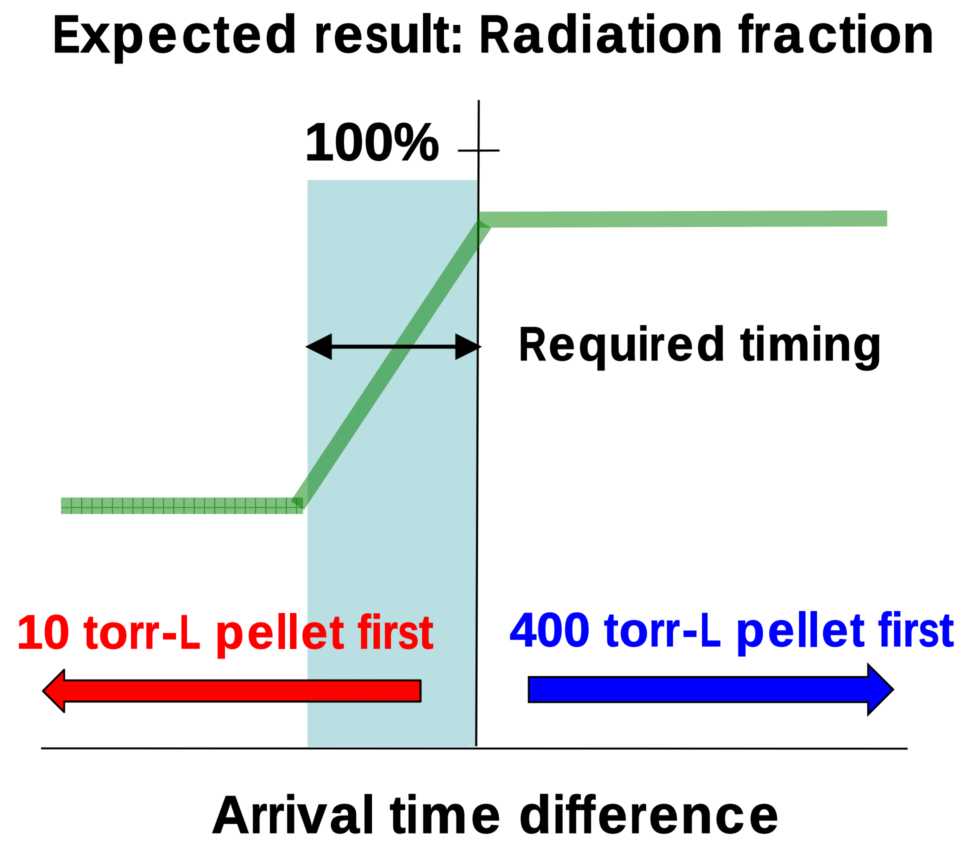


- **DIII-D may be only machine besides ITER with multiple SPIs!**

Experiment was designed to measure required timing for multiple pellets to work together

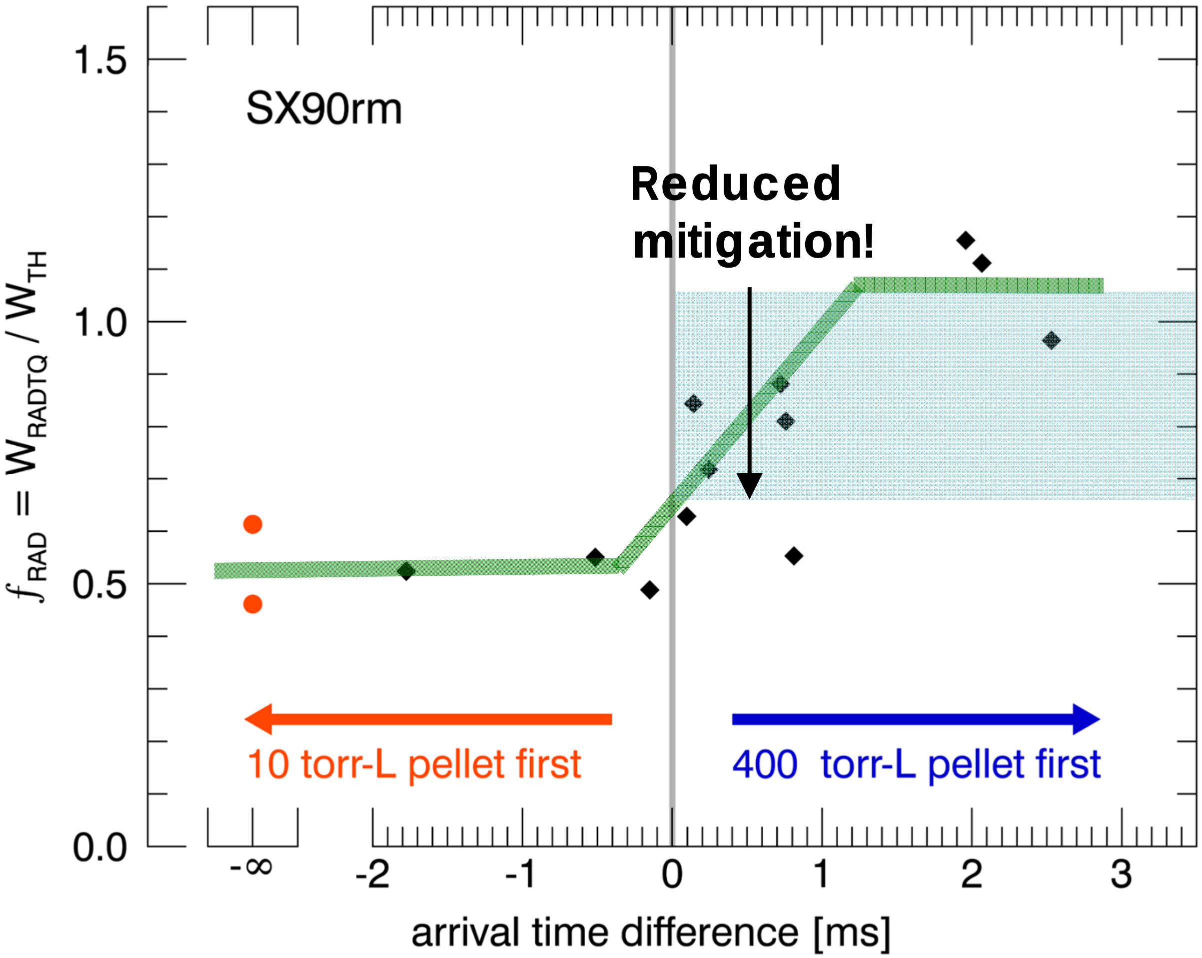
- **Vary the relative timing of two dissimilar pellets**





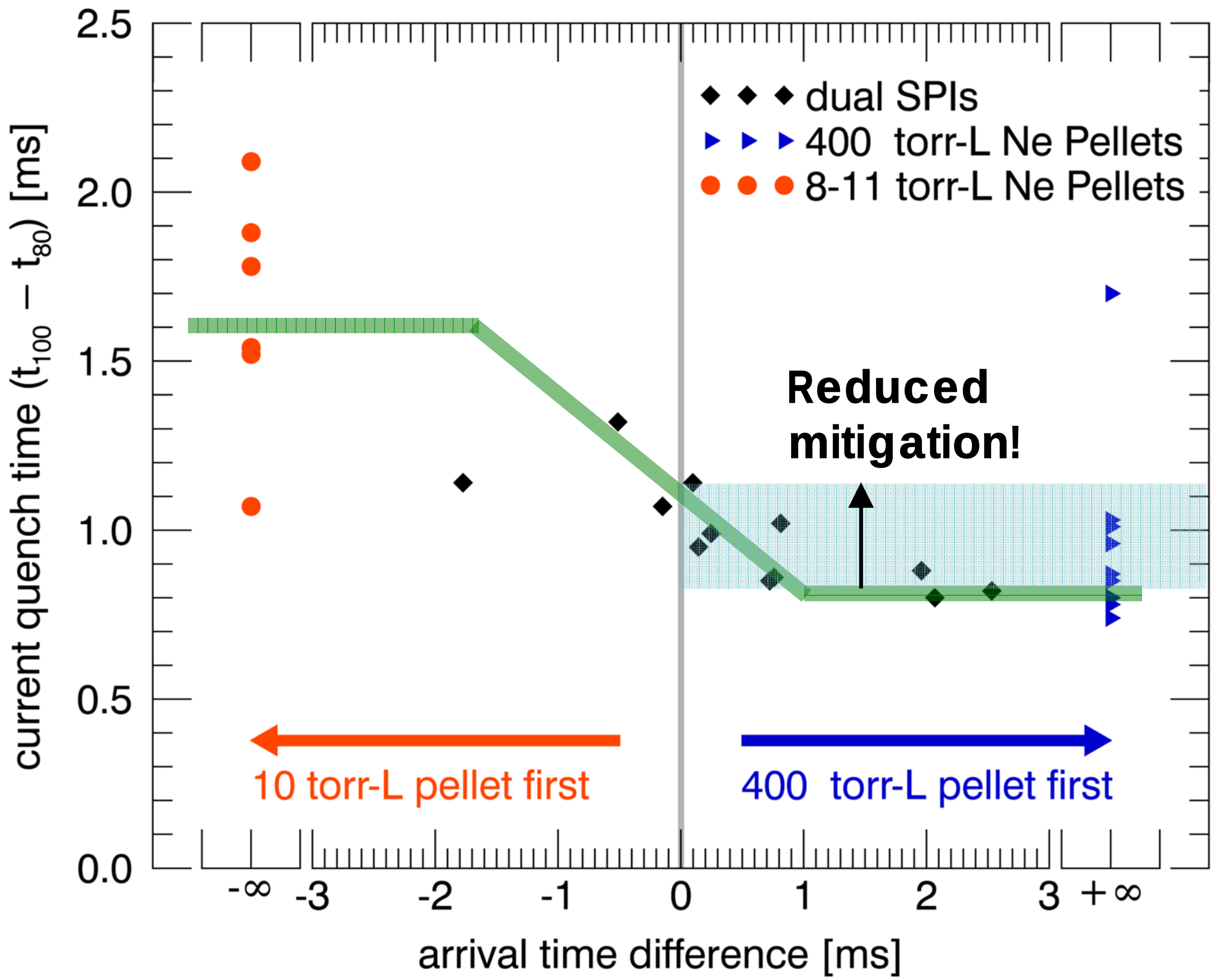
Radiation fraction suggests two pellets may do worse than one pellet alone

- **Expected behavior seen at both extremes (high/low limits)**
- **Two simultaneous pellets ($\Delta t = 0$) appears to have lower radiation than upper limit**



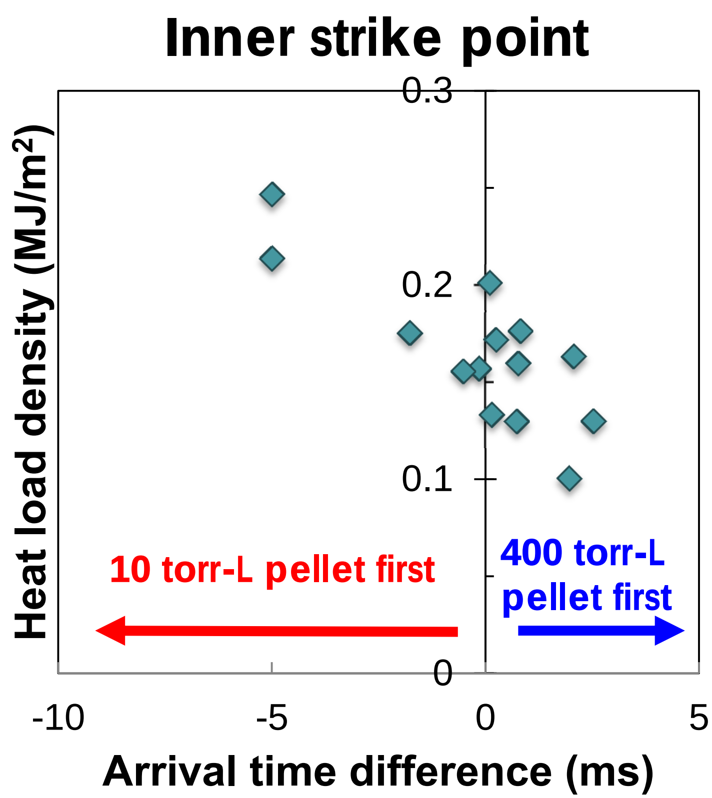
CQ characteristics show same reduction, with two pellets

- **Consistent with reduction in TQ radiation fraction**
- **Reduced mitigation observed for other CQ metrics**
  - Vessel displacement
- **CQ timescale is a 'global' quantity**

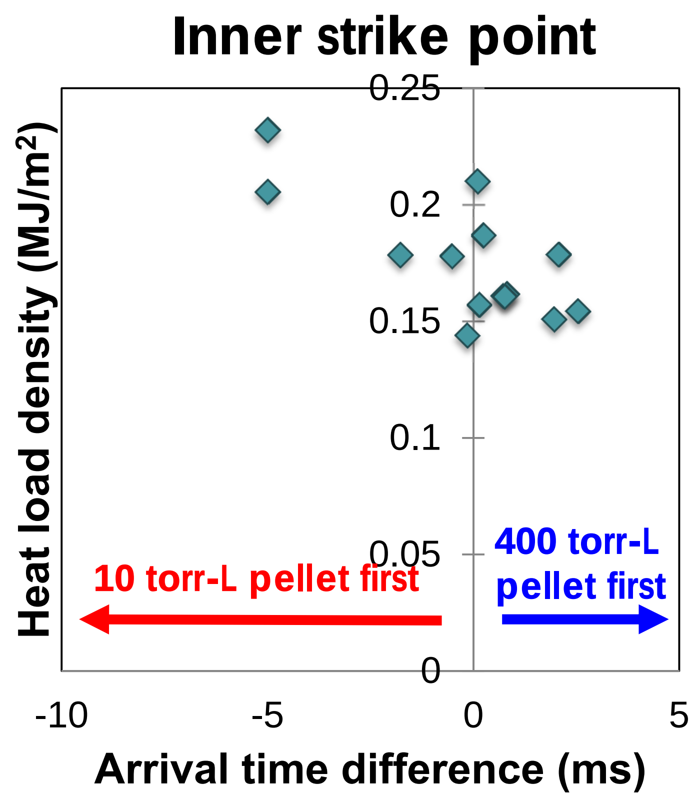


IR imaging is currently inconclusive

- **Clear difference observed between two extremes, independent of model assumptions**
- **But analysis still ongoing to determine intermediate cases**

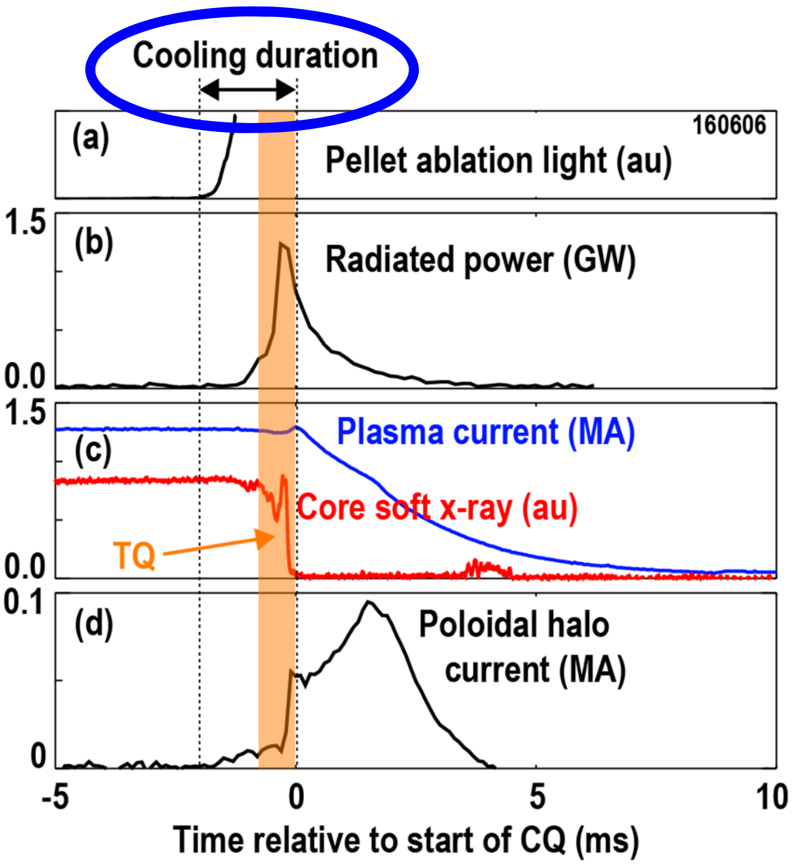


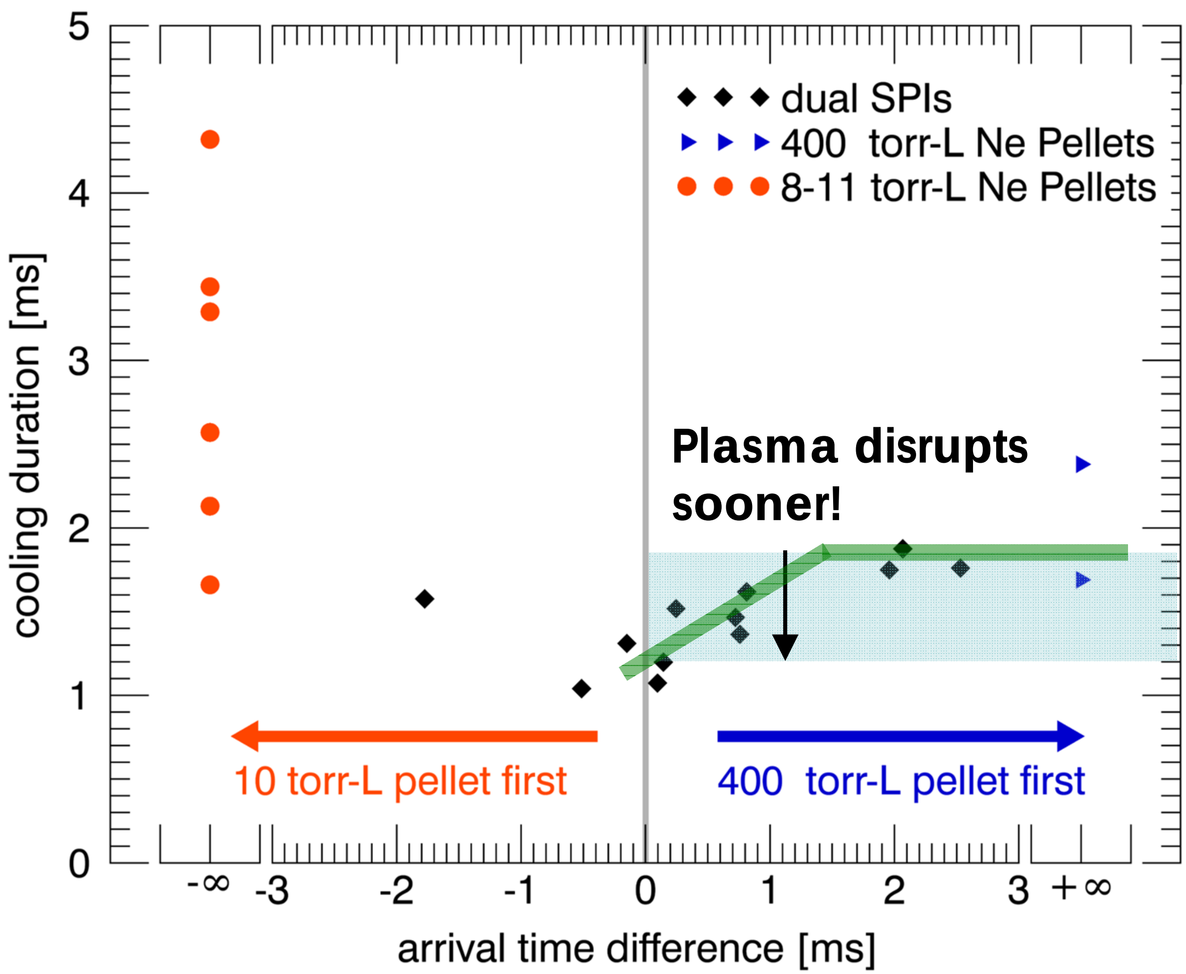
Different fit/model



Two pellets cause plasma to disrupt sooner, may be key parameter

- **Cooling duration = time from pellet arrival until I_p-spike**
- **Impurities entering after this will have missed the TQ**





Possible mechanism by which two pellets reduce mitigation

Single pellet injected

- Impurities spread from injection port
- Eventually causes global thermal collapse (cooling duration)
- Lots of neon enters plasma before thermal collapse

→ **Good mitigation**

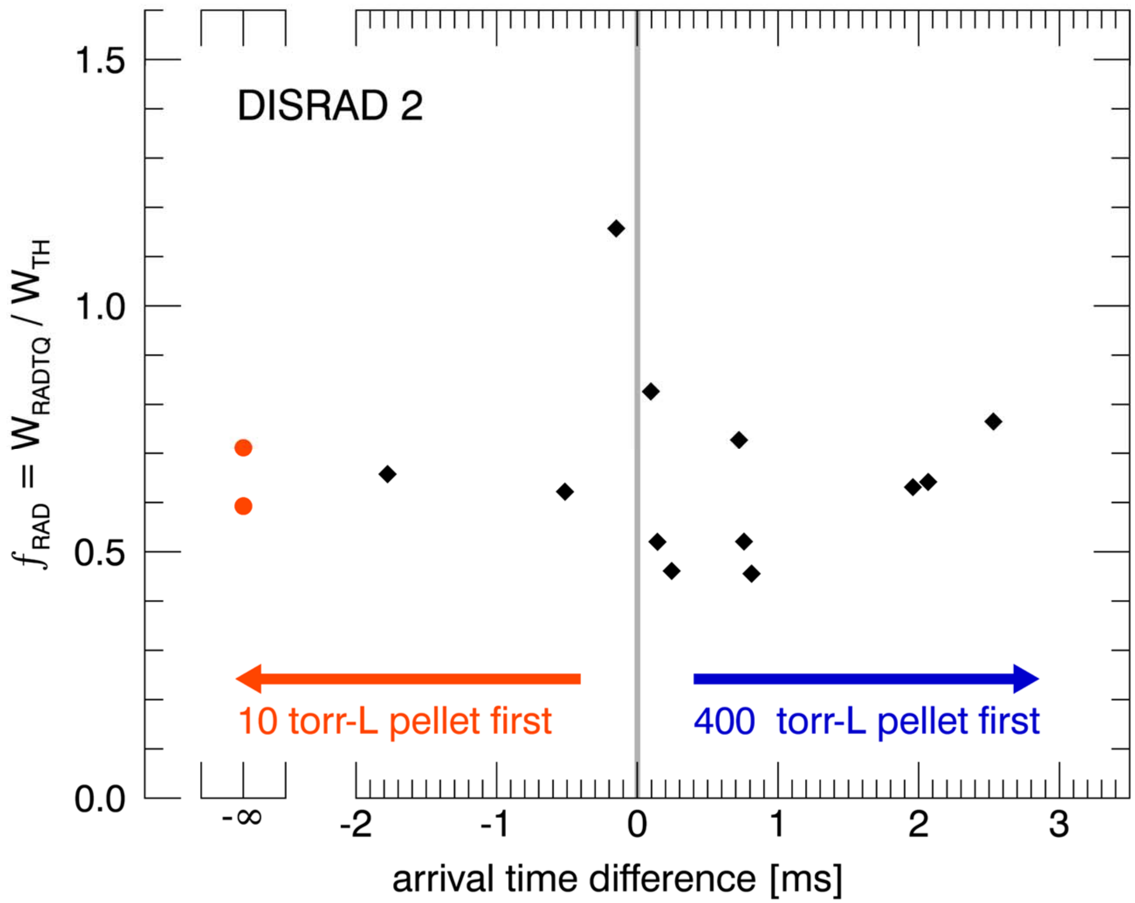
Two pellets injected from different ports simultaneously

- Impurities have a head start on spreading (toroidally/poloidally)
- Global thermal collapse occurs sooner
- Less neon enters plasma, compared to single-pellet case

→ **Less effective mitigation**

Measurement of radiation at different toroidal angles are not consistent

- **No obvious trend measured at 210°**
- **Possible explanations**
  - Radiation asymmetry
  - Diagnostic problem
- **Even if there were asymmetries… what is the globally averaged performance?**



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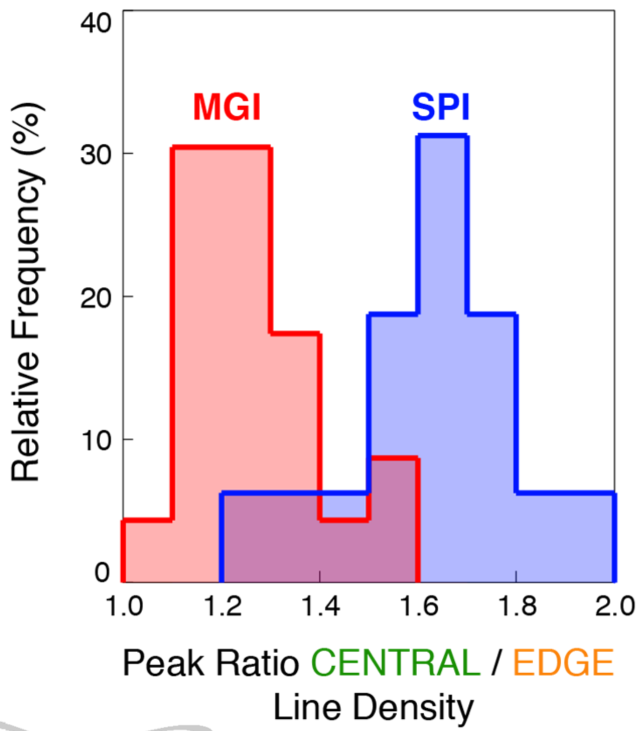
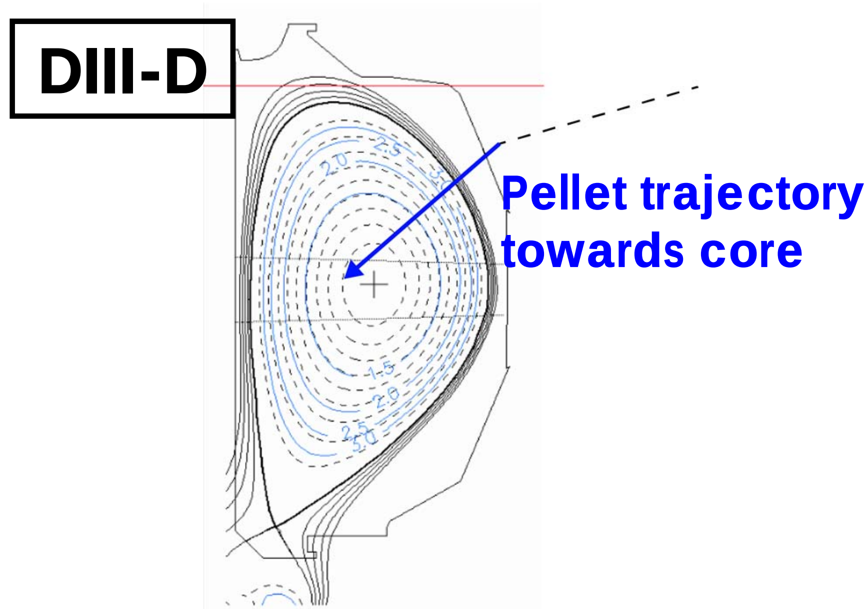
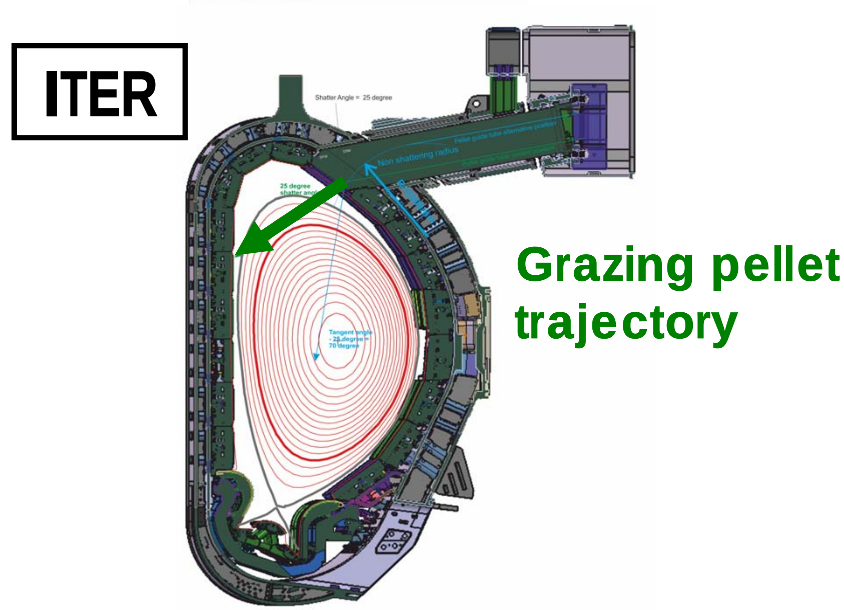
Effectiveness of ITER SPI may depend on transport mechanisms

- **SPI far more effective than MGI**
  - Ballistic transport of solid fragments to plasma core
  - More instantaneous delivery

Centrally peaked deposition

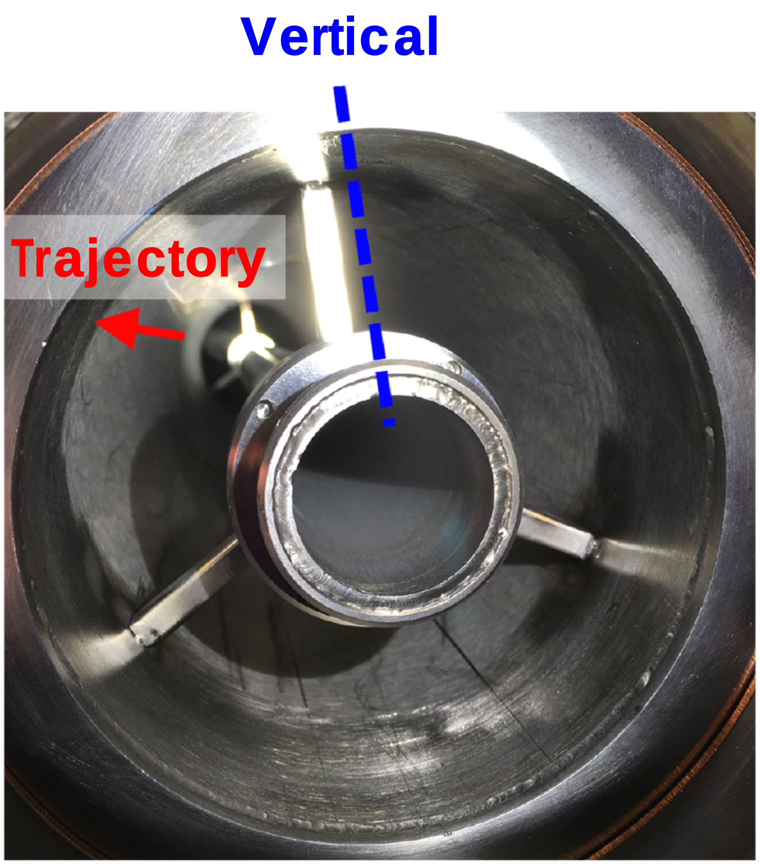


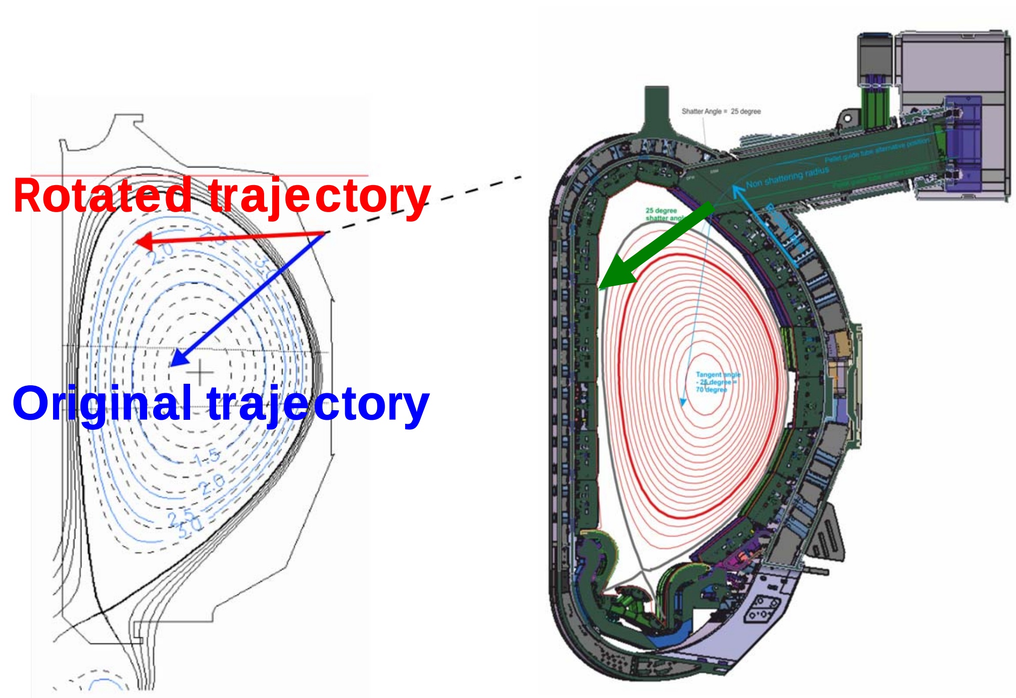




Rotated SPI limits initial deposition to plasma edge

- **Shatter tube rotated along its axis, to change pellet trajectory**

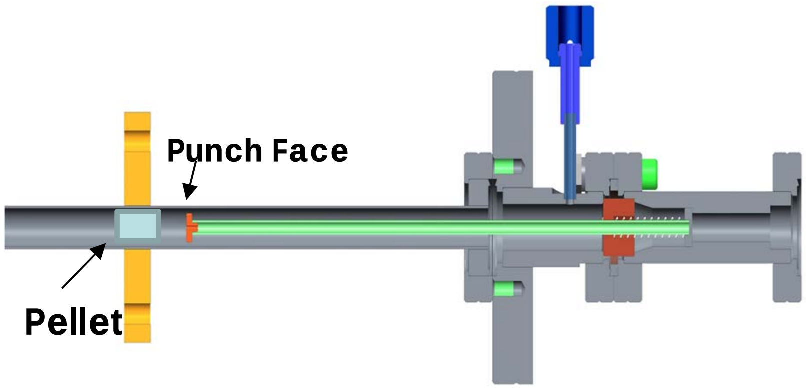




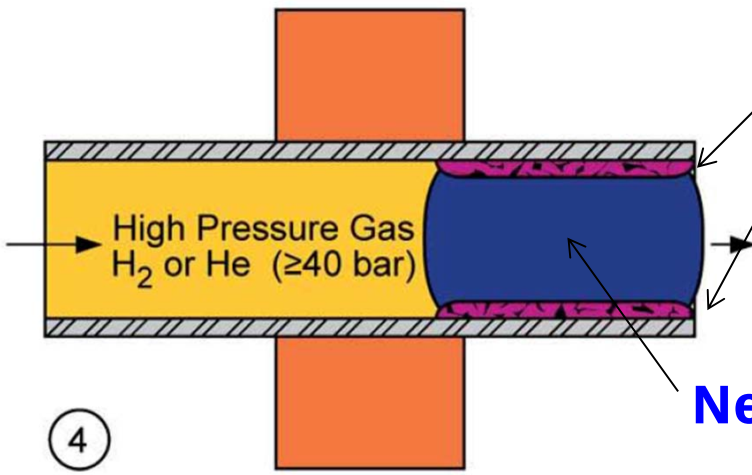
- **Experiment scheduled for later this campaign**

Mechanical punch will allow injection of argon shattered pellets

- **Punch to be installed soon, to allow argon pellet injection**
  - Higher Z
  - Higher solid fraction



- **Allows pure neon pellets, without D_2 "grease"**
  - May increase dissipative properties for secondary injection into existing runaway beam



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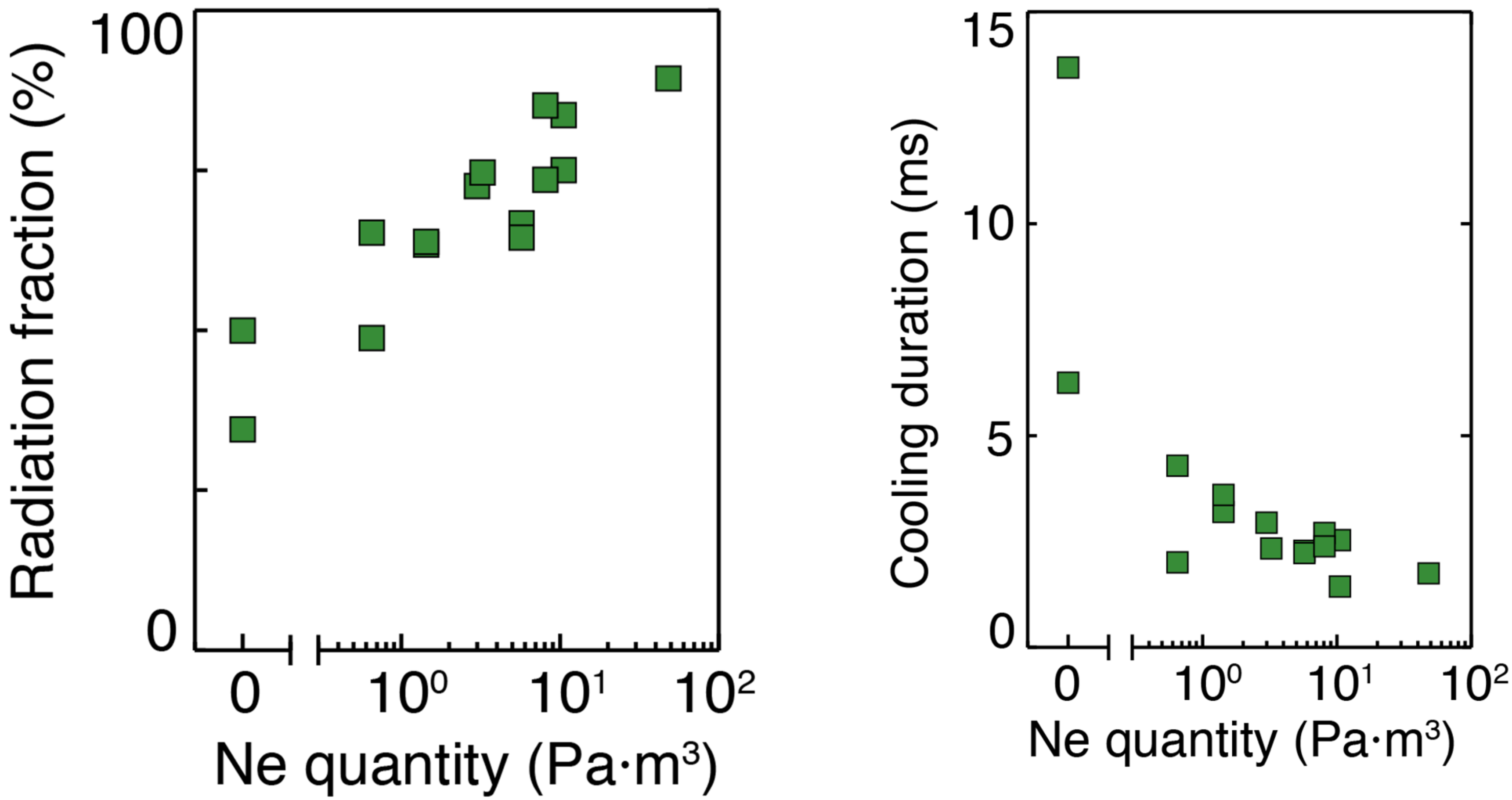
Measured variation of TQ properties with pellet composition



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