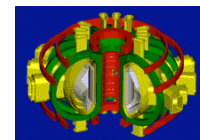


Fueling System Proposal for KSTAR

*D.A. Rasmussen, L.R. Baylor, S. K. Combs,
M.J. Cole, P.B. Parks**

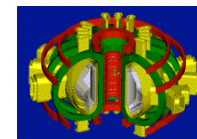
Oak Ridge National Laboratory



KSTAR fueling system parameters

Parameter	Gas Fueling System	Pellet Fueling System	Remarks
Design fueling rate	200 torr-L/s for 20 s	200 torr-L/s for 20 s	Torus pumping capacity is 200? torr-L/s
Operational fuel rate	100-175 torr-L/s	100-25 torr-L/s	
Impurity fuel rate	25 torr-L/s	TBD (prefer gas for impurity injection)	
Impurity species	Ne, Ar, N ₂ , other?	TBD	TBD
Rapid shutdown system	Massive gas puff ~10 ⁶ torr-L/s		For disruption/VDE mitigation
Pellet sizes (cyl. diameter)	N/A	1-3 mm	1 mm for density rampup, 2-3 mm for flat-top

Assumed values



Proposed KSTAR pellet fueling system

A1. Flexible pellet system with an upgrade path is proposed

- DIII-D style Repeating Pneumatic Injector (RPI) with 3 barrels (mid 2007)
- ITER prototype - sized for KSTAR (2009-2010)
- Disruption mitigation system

US deliverables

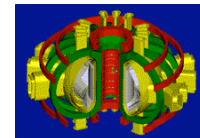
- Pellet injector and extruder
- Disruption mitigation gas valve
- ITER prototype injector

KSTAR provided

- He cryogenics, pumping systems
- Guide tubes
- Control system and injector diagnostics

Joint US/KSTAR contributions

- Pellet cloud imaging and spectroscopy



Proposed KSTAR pellet fueling system

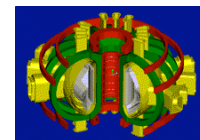
A2. Collaboration benefits

US Benefits

- Advancement of pellet fueling throughput (rep rate)
- Pathway to ITER fueling scenarios using an RPI
- Testing of an ITER prototype (sized for KSTAR)
- Disruption prediction and mitigation

KSTAR Benefits

- High rep rate central fueling
- Edge fueling and ELM control
- ITER fueling scenario development
- Disruption mitigation capability



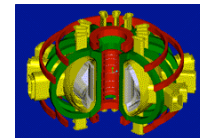
Proposed KSTAR pellet fueling system

B. US consulting only (0.2 FTE/year)

- Modeling of optimum injection launch locations and pellet sizes

C. US/KSTAR full collaboration (0.3 FTE/year)

- Guide tube tests and designs
- Guide tube pumping tests
- Collaborative research on extruders
- Collaborative research on ITER prototype
- Repeating injector (RPI)
 - design (0.2 FTE)
 - 1 barrel RPI phase I fab (\$150 K)
 - 3 barrel RPI phase II fab (\$150 K)
 - install, test
- ITER prototype injector (\$300 K)



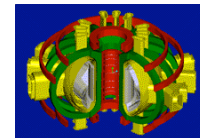
Proposed KSTAR pellet fueling system

D. Start project in FY06

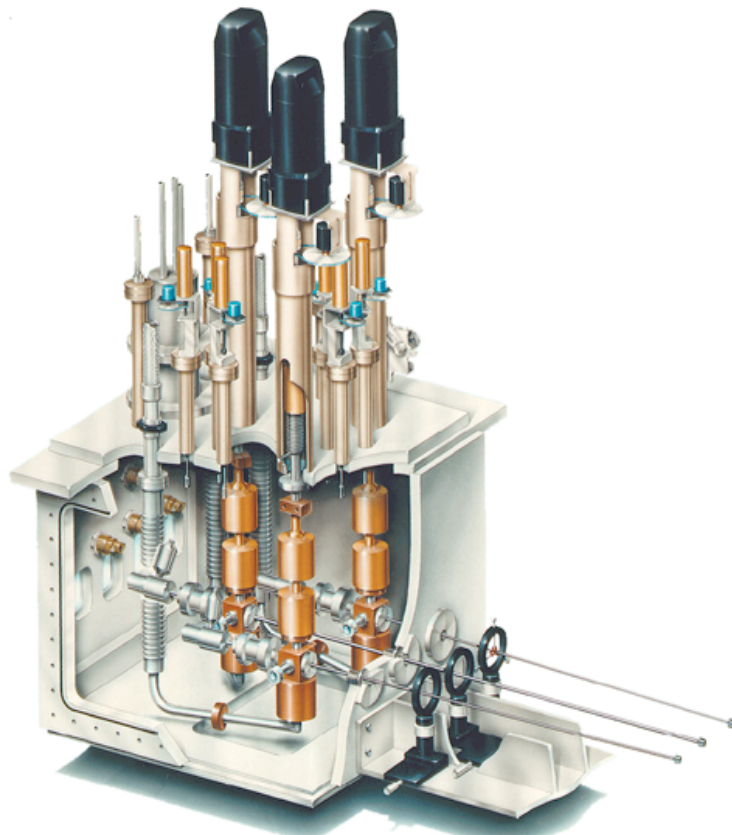
- Install phase I RPI at end of 2nd break (mid 2007)
- Install phase II RPI at end of 3rd break (end of 2008)
- Install ITER prototype during 4th or 5th break (2009-2010)

E. US/KSTAR experimental collaboration

- Fueling optimization with RPI
 - Experimental optimization of launch locations
 - Experimental optimization of pellet size and rep rate
 - ELM mitigation studies
- ITER fueling scenario development with RPI and ITER prototype
 - Long pulse fueling
 - Advanced Tokamak and hybrid plasma fueling
- Disruption precursor and mitigation studies

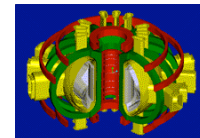


KSTAR pellet fueling system would be similar to that used on DIII-D and JET



≈10,000 pellets fired into JET and DIII-D plasmas

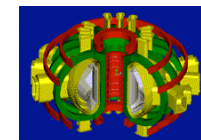
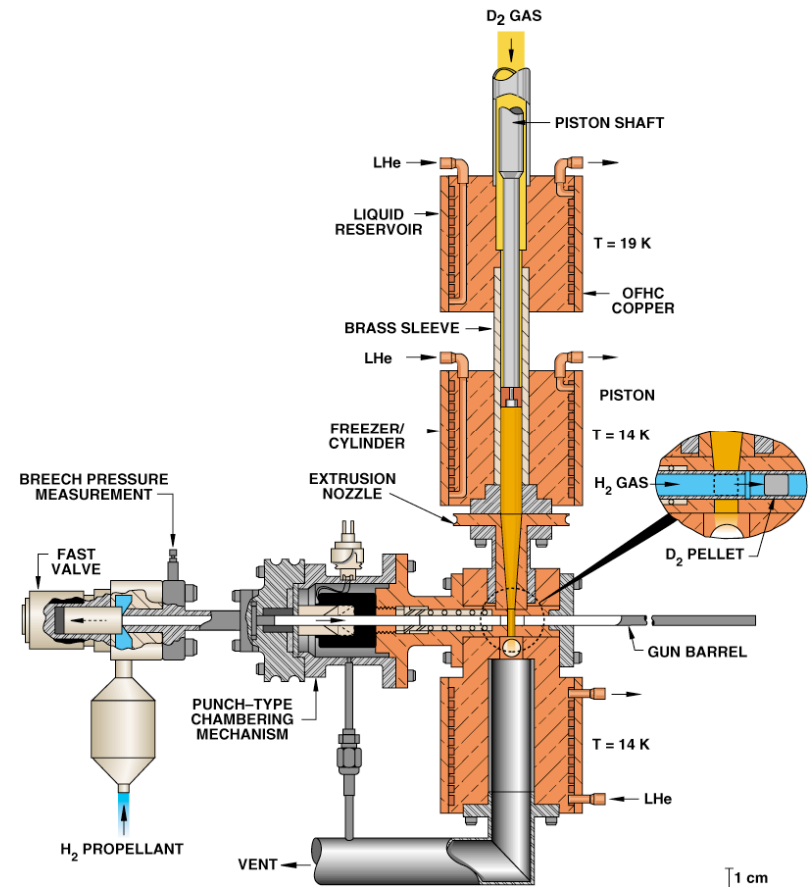
- Repeating pneumatic injectors (3)
- D_2 200 torr-L/s for 20 s, 1-3 mm pellets up to 40 Hz, 200-1200 m/s
- Pellet diagnostics, injection line, guide tubes, control system
- Based on JET/DIII-D injector
- Employing existing, proven technology



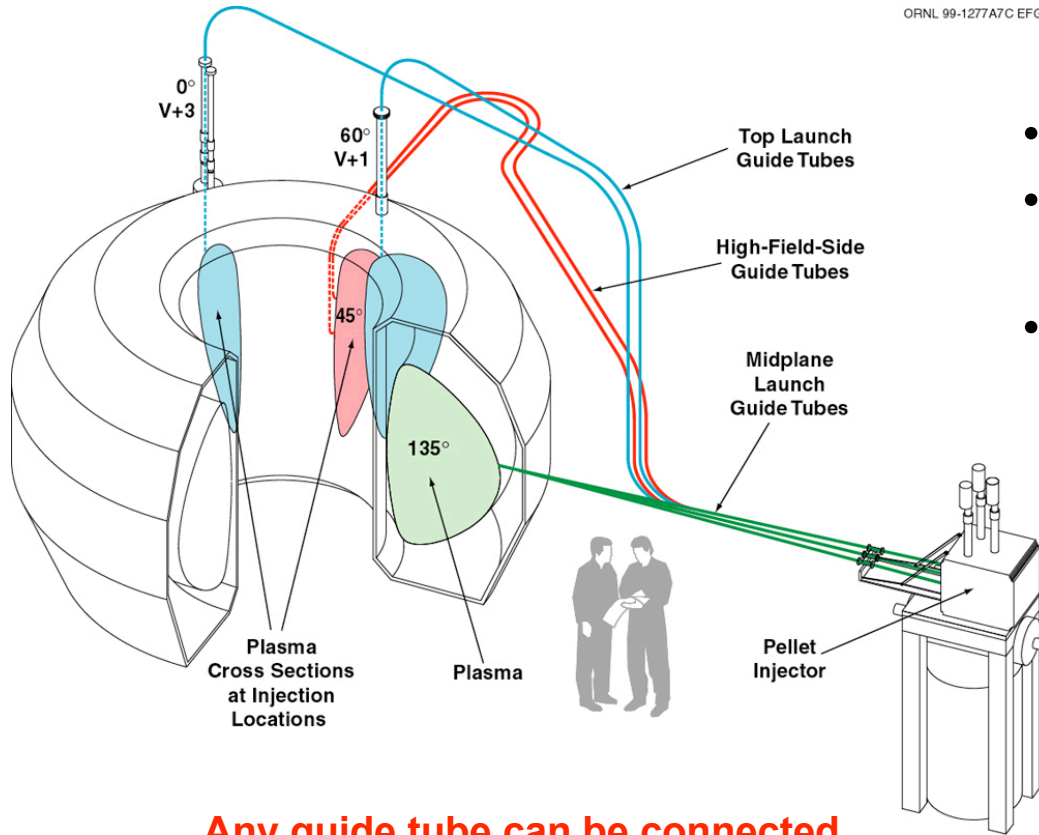
Repeating Pneumatic Injector Technology

ORNL 99-1046C EFG

- Multiple RPIs for flexibility and high throughput
- Injector comprised of cryogenic extruder and gun assembly
- Normal sequence (up to 20 Hz/ barrel)
 - Extruder provides filament of D_2 ice to gun assembly (≈ 14 K)
 - Activation of punch-type cutter mechanism chambers the pellet
 - Firing of propellant valve admits He/H_2 gas (≈ 70 bar) for acceleration of pellet in barrel (up to ≈ 1500 m/s)
 - Reliability of delivering intact pellets to the plasma during fueling experiments has been $\approx 100\%$ for standard mode of operation



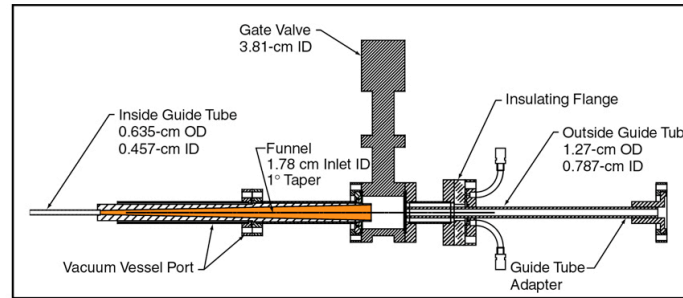
DIII-D Pellet Injection System – Transport Guide Tubes



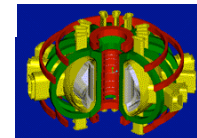
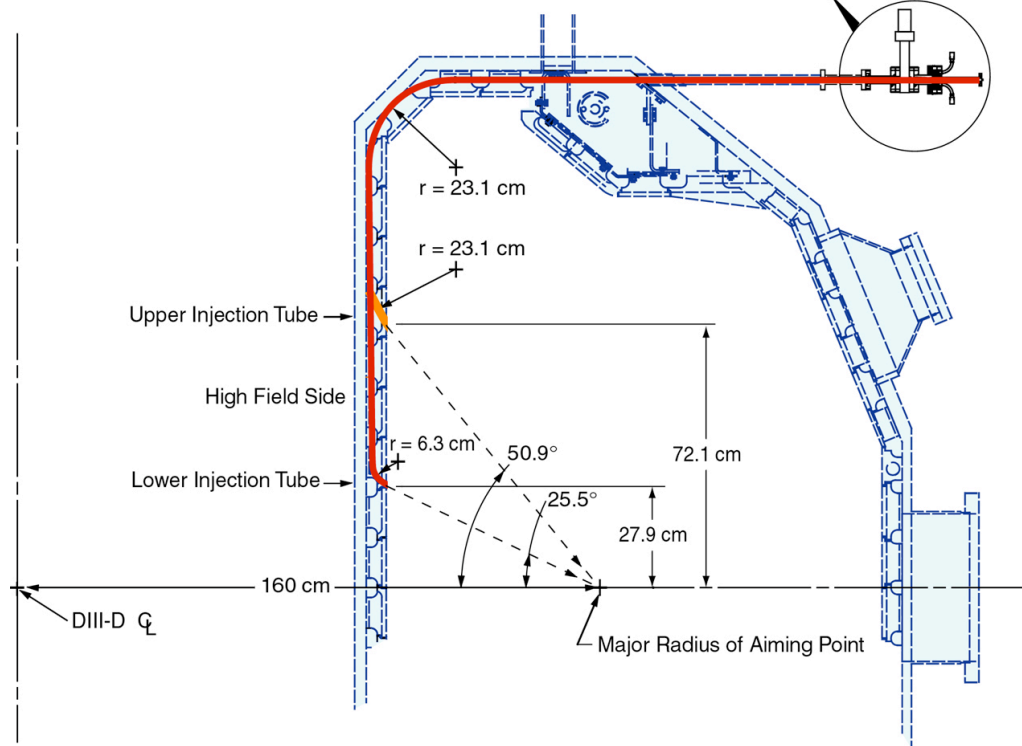
- Curved guide tubes (≈ 12.5 m)
- High field side (HFS) pellet speeds limited to ≈ 200 m/s
- Vertical speeds limited to ≈ 400 m/s

Any guide tube can be connected to any pellet gun (or a gas valve)

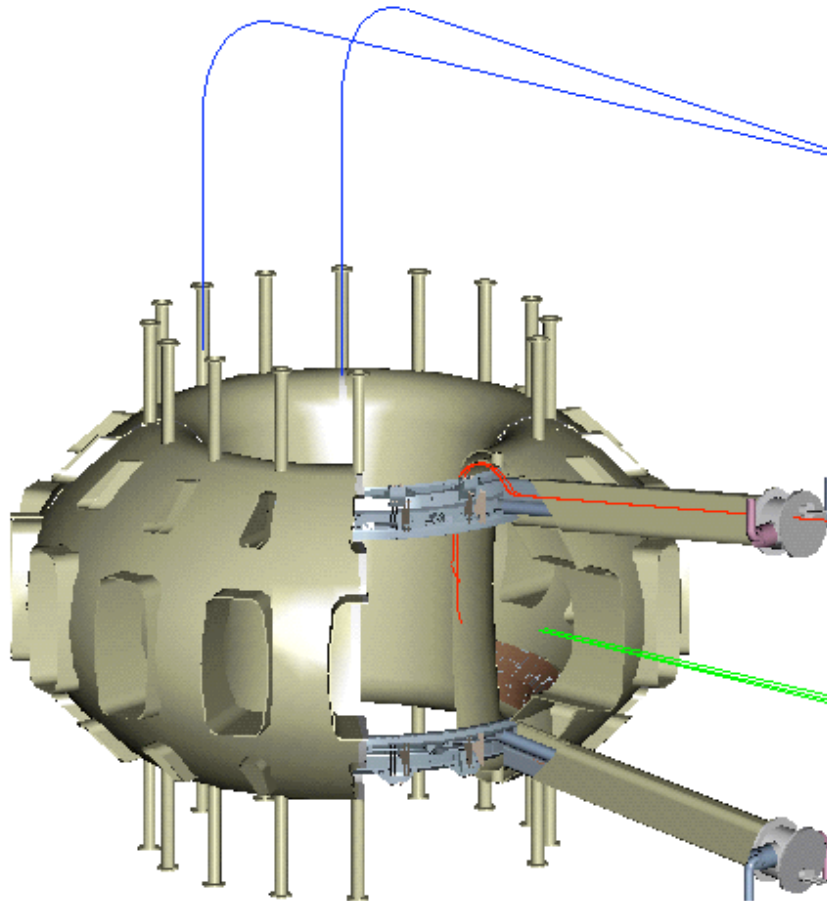
HFS Pellet Injection Tubes on DIII-D



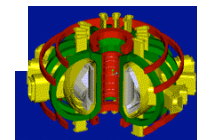
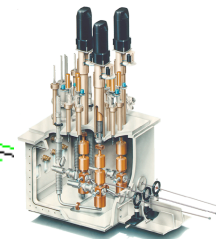
ORNL 99-1470C EFG



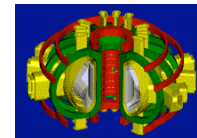
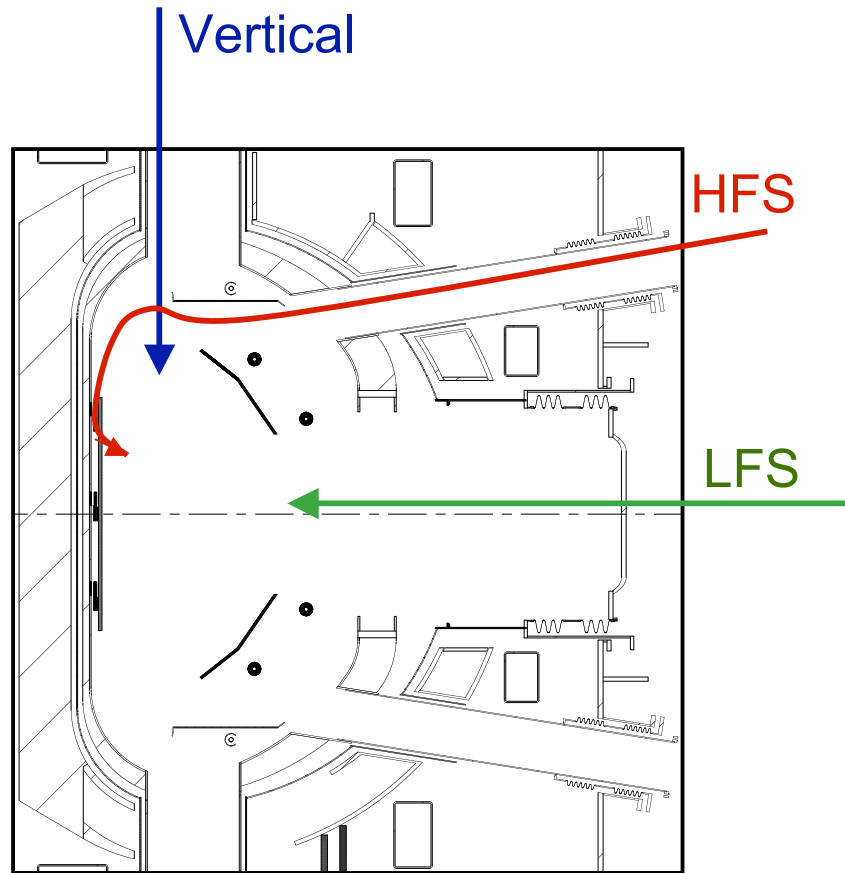
Pellet launch paths into KSTAR could be similar to the FIRE design



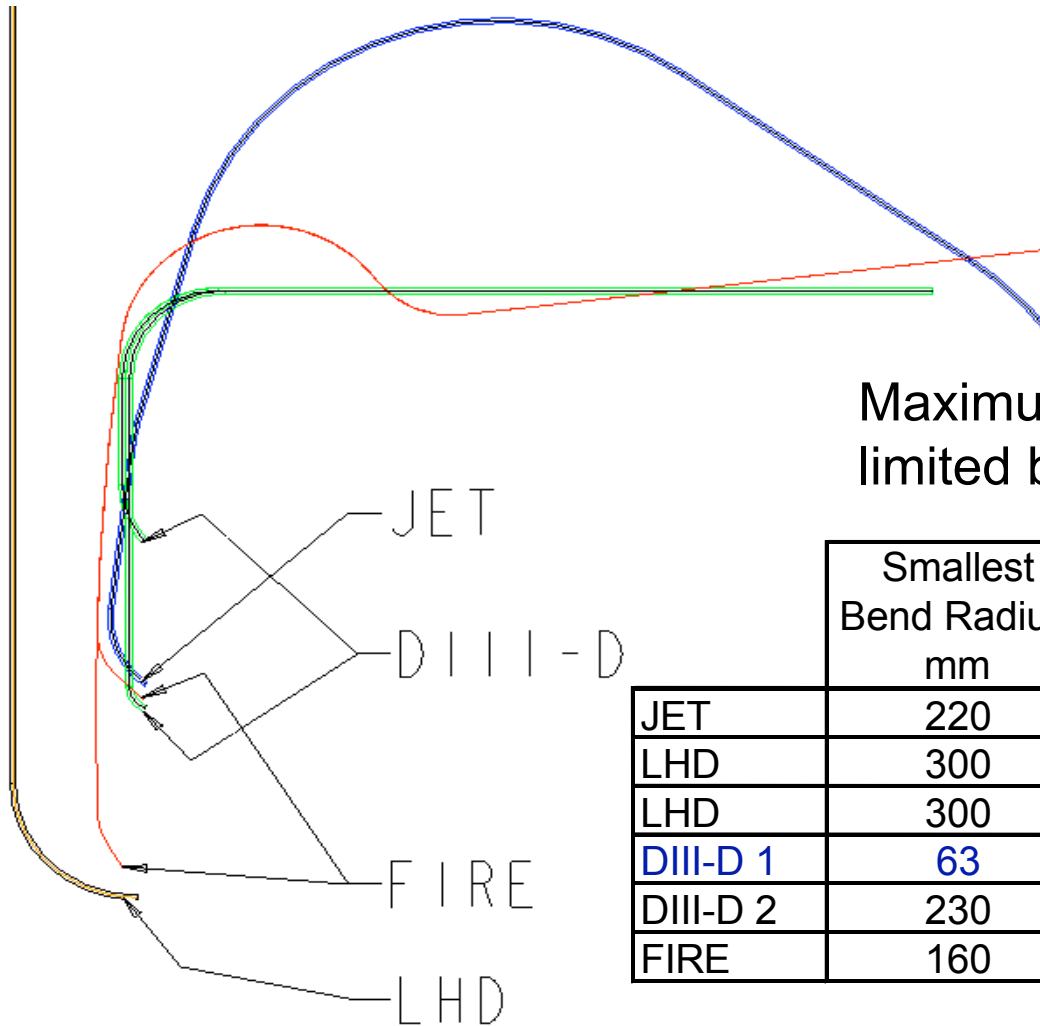
- Pellet speed limited to about 250 m/s for curved guide tubes for HFS launch
- Much higher speeds possible with straight guide tubes (vertical or LFS launch)
- Because the vertical port is inside the major radius, straight vertical launch may provide good central fueling



Possible pellet launch paths for KSTAR

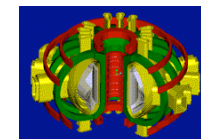


High Field Side (HFS) Curved Guide Tube Comparison

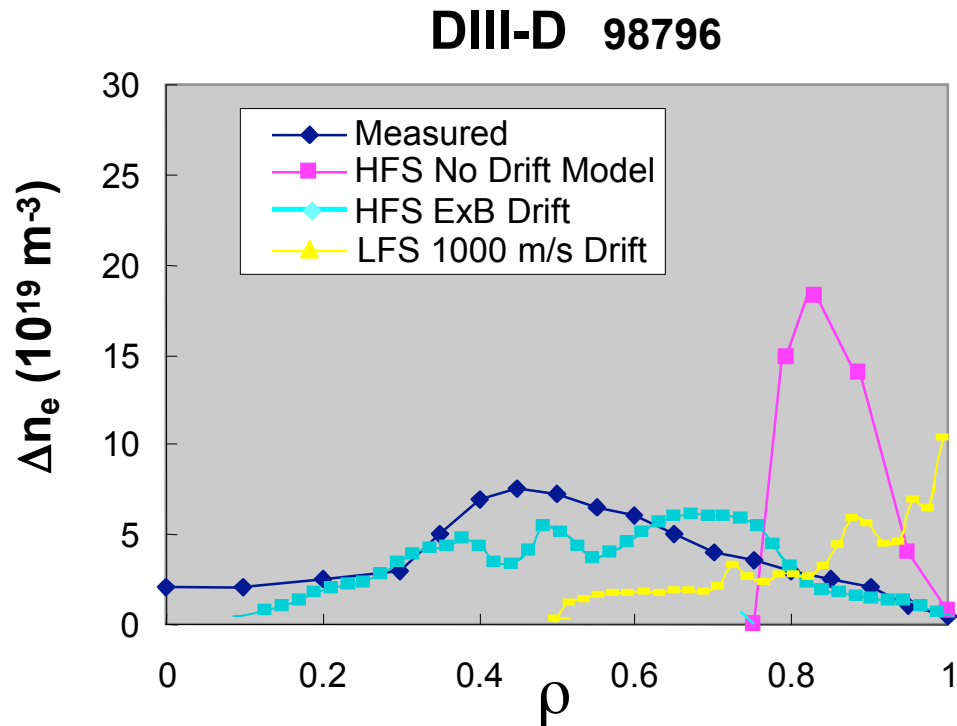


Maximum pellet speed is generally limited by the smallest bend radius

	Smallest Bend Radius, mm	Pellet	Diameter, mm	Pellet Speed Limit, m/s
JET	220	D2	4	160-250
LHD	300	H2	2.7	270-470
LHD	300	D2	2.7	265-360
DIII-D 1	63	D2	2.7	220-300
DIII-D 2	230	D2	2.7	260-300
FIRE	160	D-T	3-4	<150

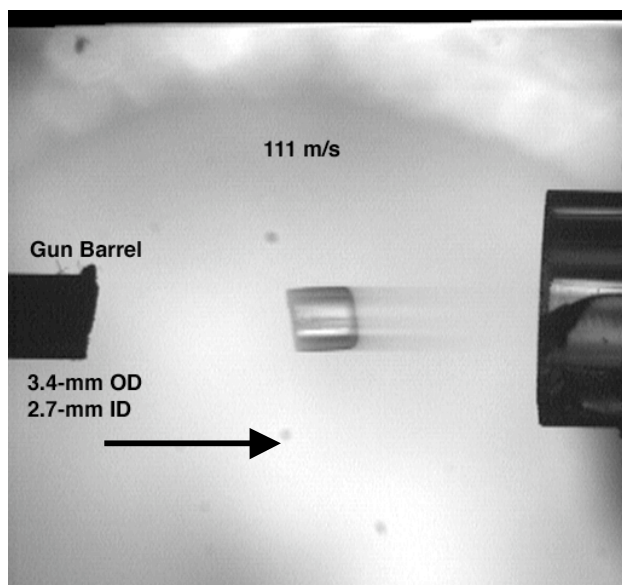


Pellet Deposition with Parks ExB Drift Model



- Comparison of the resulting mass deposition from a 2.7mm DIII-D HFS injected pellet with pellet deposition models with and without *ExB* drift. The enhanced *ExB* drift model includes ‘Mach number correction’ and ‘Mass Shedding’ (to be published).

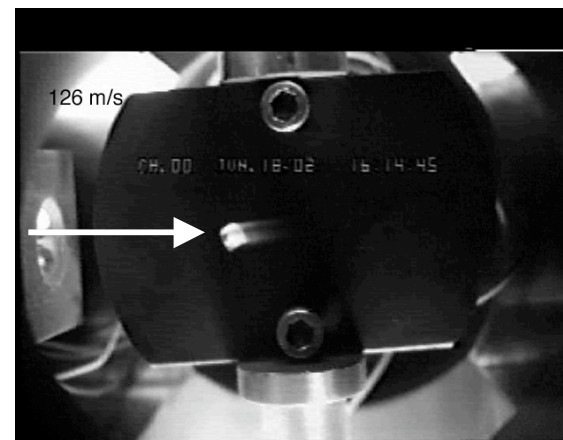
Results of FIRE Inner Wall Guide Tube Tests



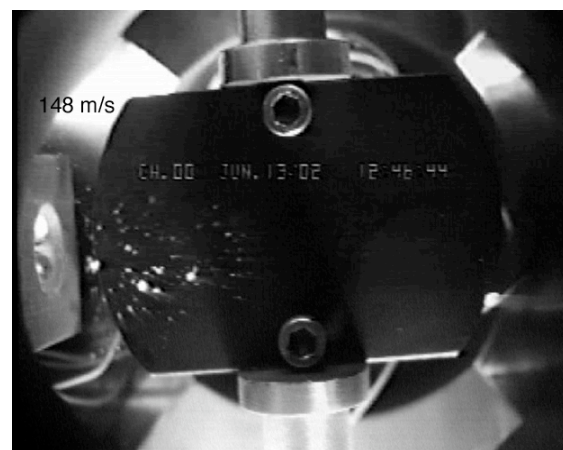
Pellet leaving the barrel

- Pellet speed limited to about 150 m/s for curved guide tubes for HFS launch

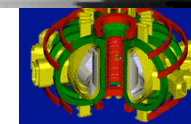
Images at exit of guide tube



**126 m/s
Intact**

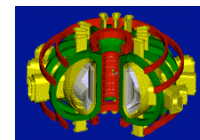


**148 m/s
Shattered**



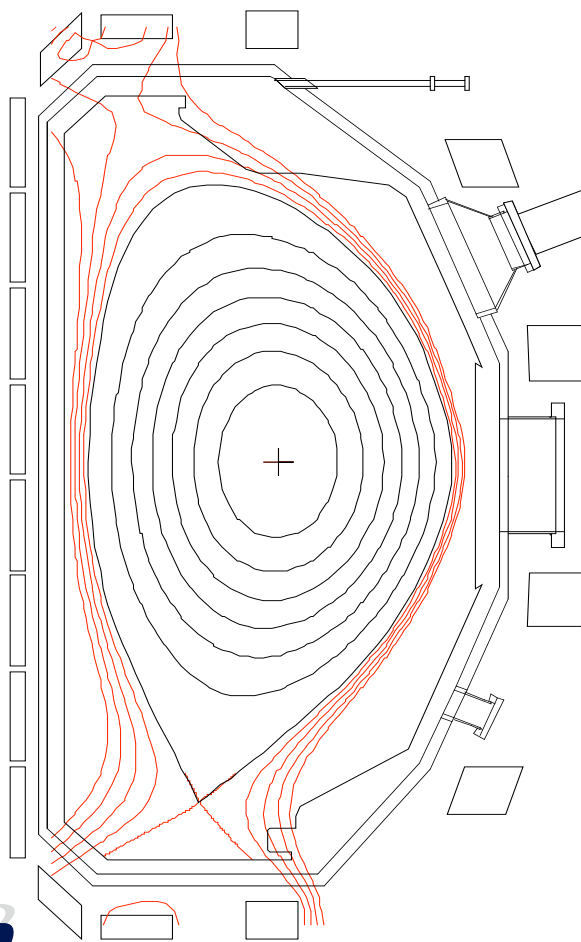
Fueling Technology for Disruption Mitigation

- Massive gas puff into DIII-D (T. C. Jernigan et al.)
 - Peak halo currents were reduced up to about 50% by the massive He and D puffing.
 - Toroidal spatial nonuniformity was also reduced by the He puffs.
- Ne, Ar and methane pellets into DIII-D (Todd Evans et al.)
 - Peak halo current amplitudes are reduced by up to 50% in triggered VDEs with both neon and argon killer pellets.
 - Halo current toroidal peaking factors are reduced from 3 to 1.1 for these discharges.
- Cryogenic liquid jet modeling (Paul Parks, GA) and development (P. W. Fisher, ORNL)
- Low Z impurity pellets (e.g. LiD) may be an option if there is no runaway electron issue



Massive Gas Puff for Disruption Mitigation

DIII-D with Massive Gas Puff Valve
Flux Surfaces for Shot 95195 at 1.700 s



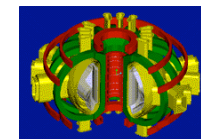
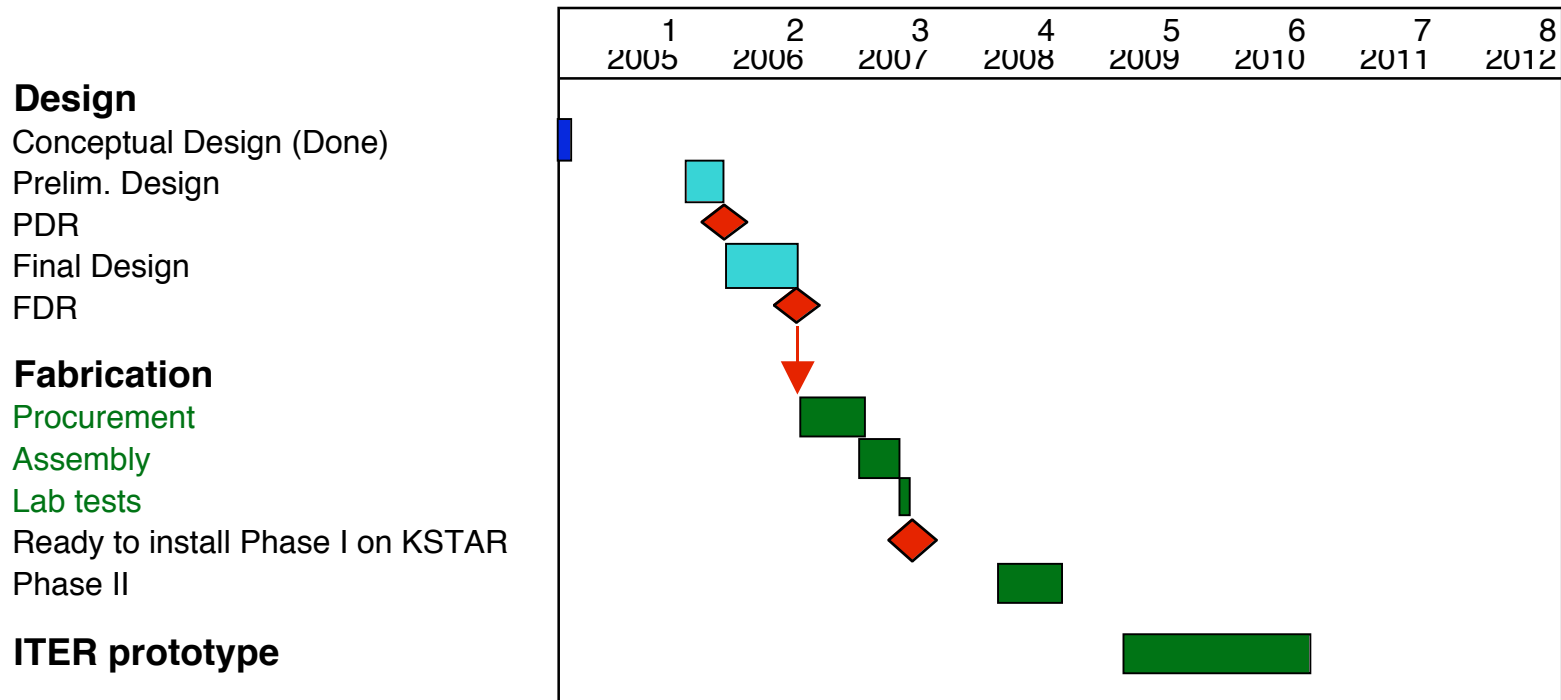
Massive Gas Puff Disruption Mitigation System for DIII-D

- High Pressure Gas Supply
- Fast Valve
- Similar system could be used on KSTAR

Tentative Schedule for KSTAR Pellet Fueling System

Schedule for KSTAR Pellet Injector

LR Baylor



Summary

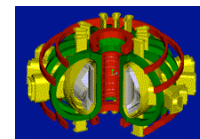
An integrated hardware and physics collaboration with pellet fueling, pellet cloud diagnostics, disruption mitigation, ITER technology and fueling scenario development is proposed:

Hardware

- DIII-D style Repeating Pneumatic Injector (RPI) with 3 barrels
- ITER prototype - sized for KSTAR
- Disruption mitigation gas valve
- Pellet cloud diagnostics

Enhanced capability and physics studies

- High rep rate central fueling
- Edge fueling and ELM control
- ITER fueling scenario development
- Disruption prediction and mitigation



ITER Fueling System

- ITER fueling system provides a fueling rate of 50 Pam³/s (375 torr l/s) (with 90%T/10%D pellets) and 100 Pam³/s (750 torr l/s) with gas species.
- Pellets, 3-6 mm, repetition rate of 7 Hz for 6 mm pellets to 50 Hz for 3 mm pellets, and pulse lengths up to 3,000s.
- Pellet speeds of up to 0.5 km/s, from the inner wall, are considered necessary to achieve a penetration beyond the ELM-affected zone (expected to be ~ 15% of minor radius).
- Two injectors will be installed, for redundancy and flexibility. Pellet injectors will be capable of steady-state operation and will consist of the following major hardware:
 - centrifuge pellet injector driver, for pellet delivery;
 - screw extruder, for pellet production;
 - gas feed manifold connected to the pellet injection gas supply system;
 - pellet injector cask housing the injector assembly (~ 6 m L x 4 m H x 3 m W);
 - single guide tube connected through a divertor port to the plasma chamber;
 - diagnostic, control and data acquisition system.

