NSTX-U

Supported by U.S. DEPARTMENT OF ENERGY Office of Science

CHI and Disruption Mitigation Studies in Support of NSTX-U, ST-FNSF, and ITER

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R. Raman[1], T.R. Jarboe[1], B.A. Nelson[1], D. Mueller[2], S.C. Jardin[2], F. Ebrahimi[2], T. Brown[2], S.P. Gerhardt[2], J.E. Menard[2], M. Ono[2], K. Hanada[3]

[1]University of Washington, Seattle, WA USA
[2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA
[3]Research Institute for Applied Mechanics, Kyushu University, Japan

This work is supported by US DOE contract numbers DE-SC0006757, DE-FD02-99ER54519, and DE-AC02-09CH11466

18th International ST Workshop

November 3-6, 2015

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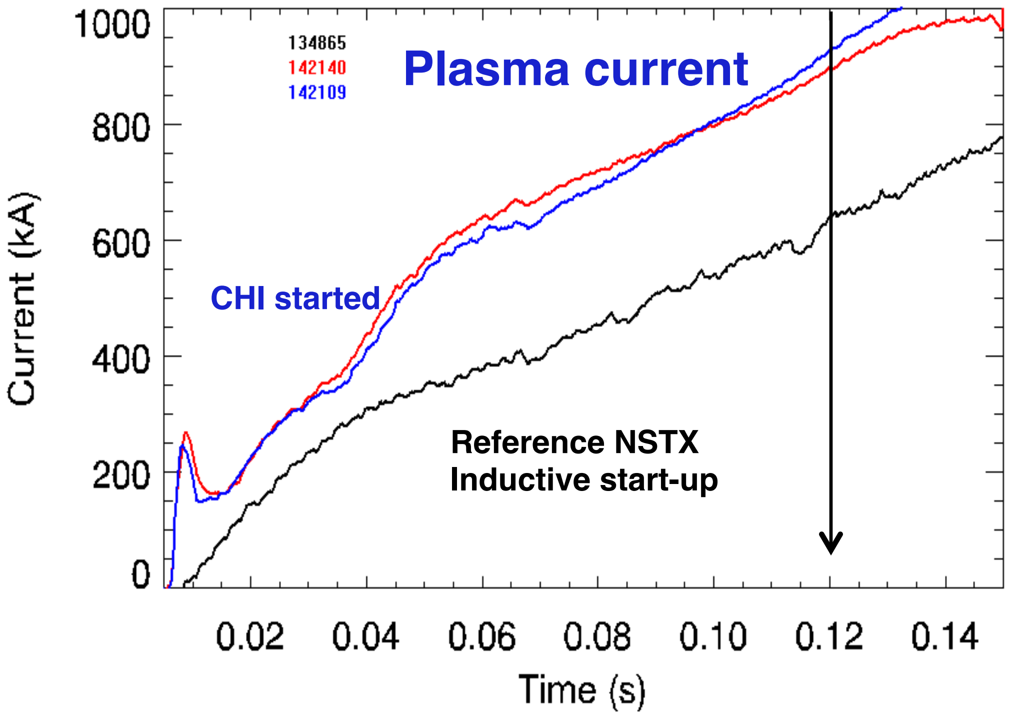
Outline

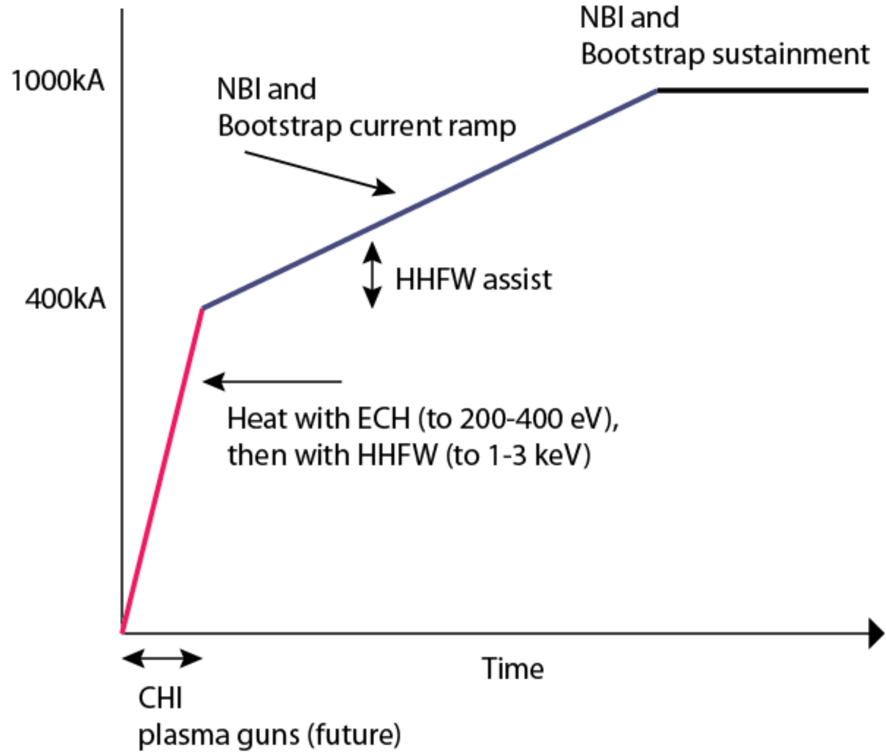
1. Plasma Start-up and Ramp-up Research on NSTX-U

2. CHI Research on QUEST

3. Disruption Mitigation (DM) Studies on NSTX-U

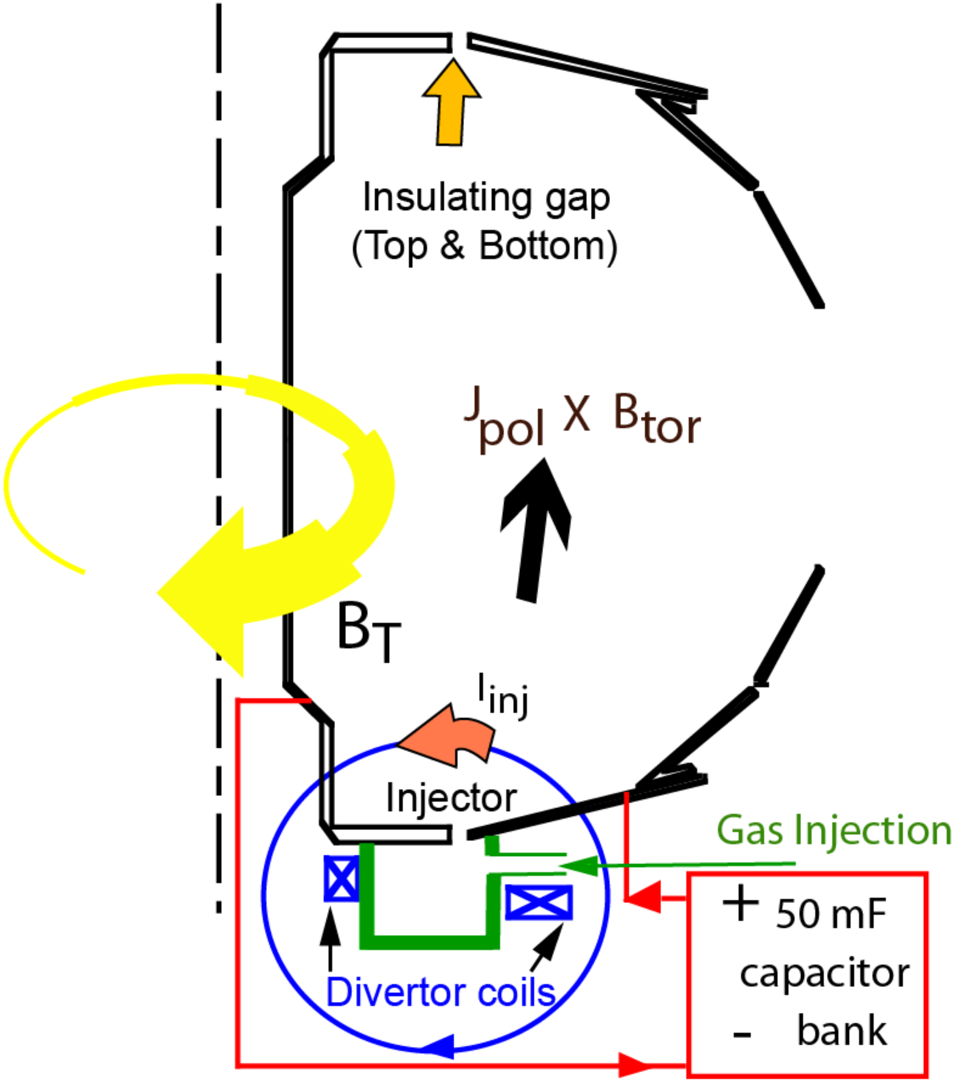
Plasma Start-up and Ramp-up Research on NSTX-U

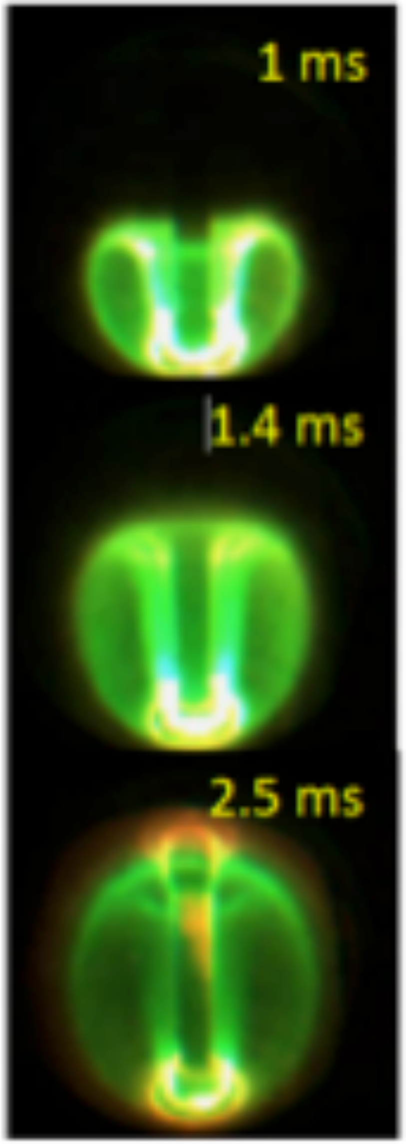




- Transient Coaxial Helicity Injection (CHI) on NSTX-U
  - Demonstrate Transient CHI start-up on NSTX-U
  - Ramp CHI initiated discharges using non-inductive CD methods

CHI is Planned to be Used as Initial Current Seed for Subsequent Non-inductive Current Ramp-up in NSTX-U

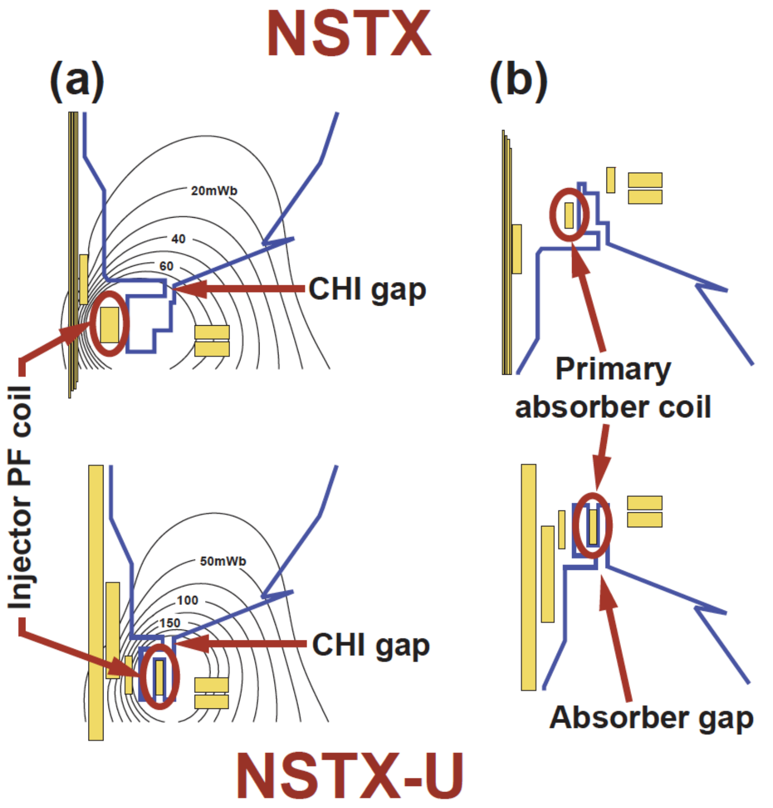


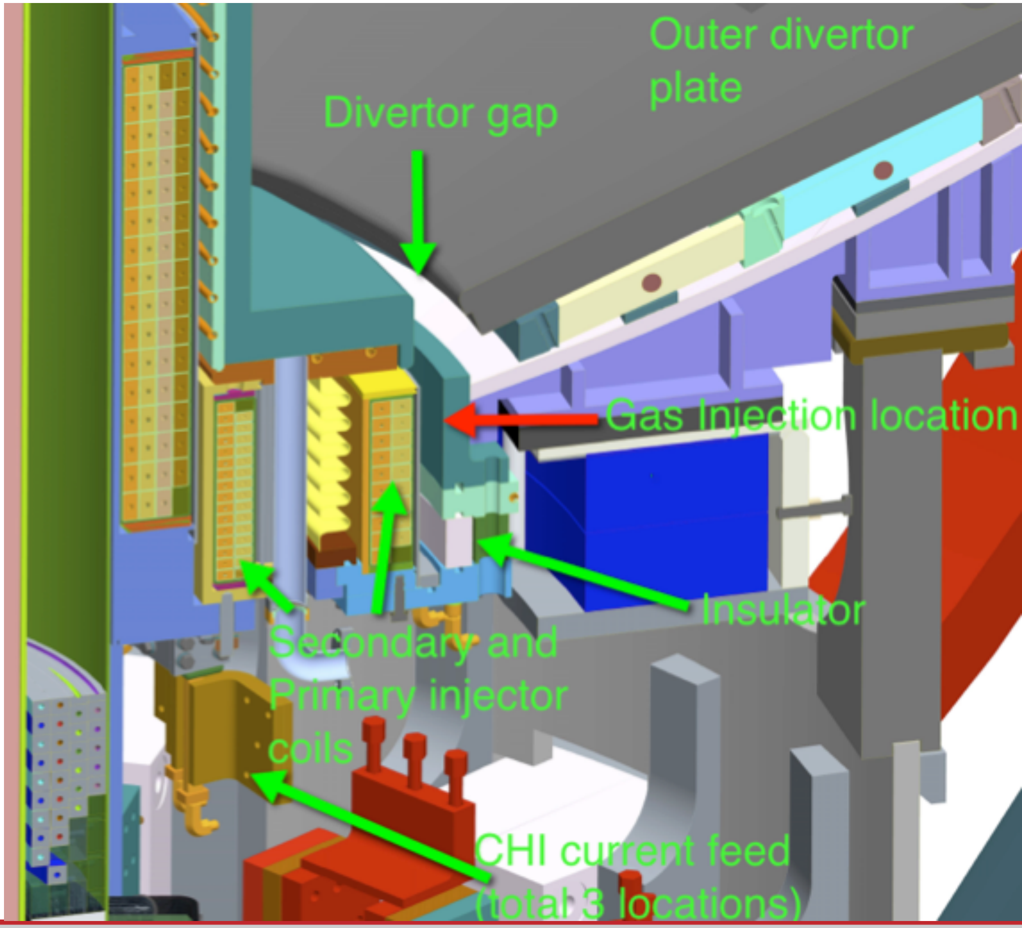


NSTX-U Upgrades that Facilitate CHI Start-up

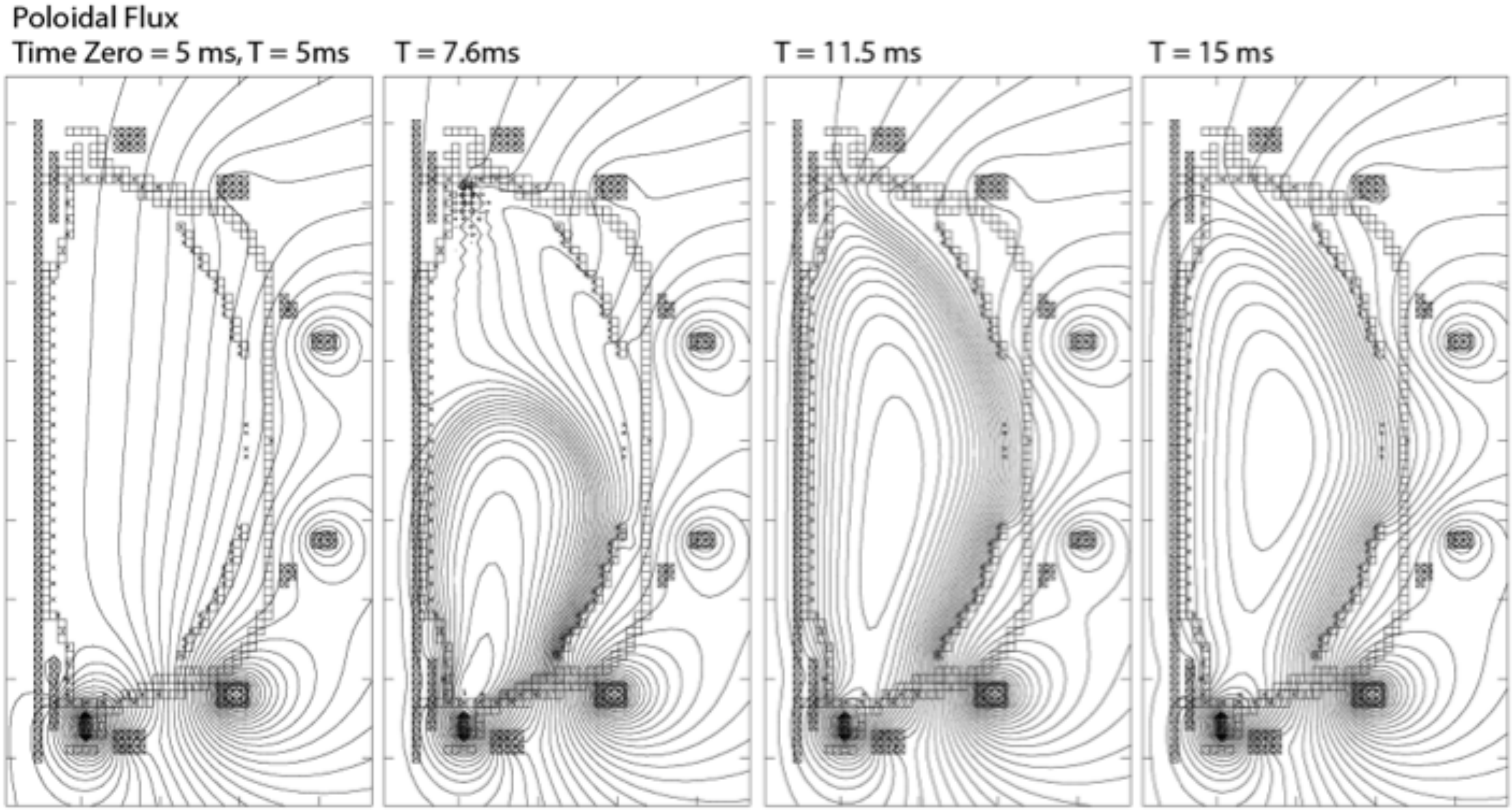
NSTX-U Machine Enhancements for initial CHI

- > 2.5 x Injector Flux in NSTX (proportional to I_p)
- About 2 x higher toroidal field (reduces injector current requirements)





TSC Simulations in the NSTX-U Geometry support >400kA Current Start-up Capability in NSTX-U



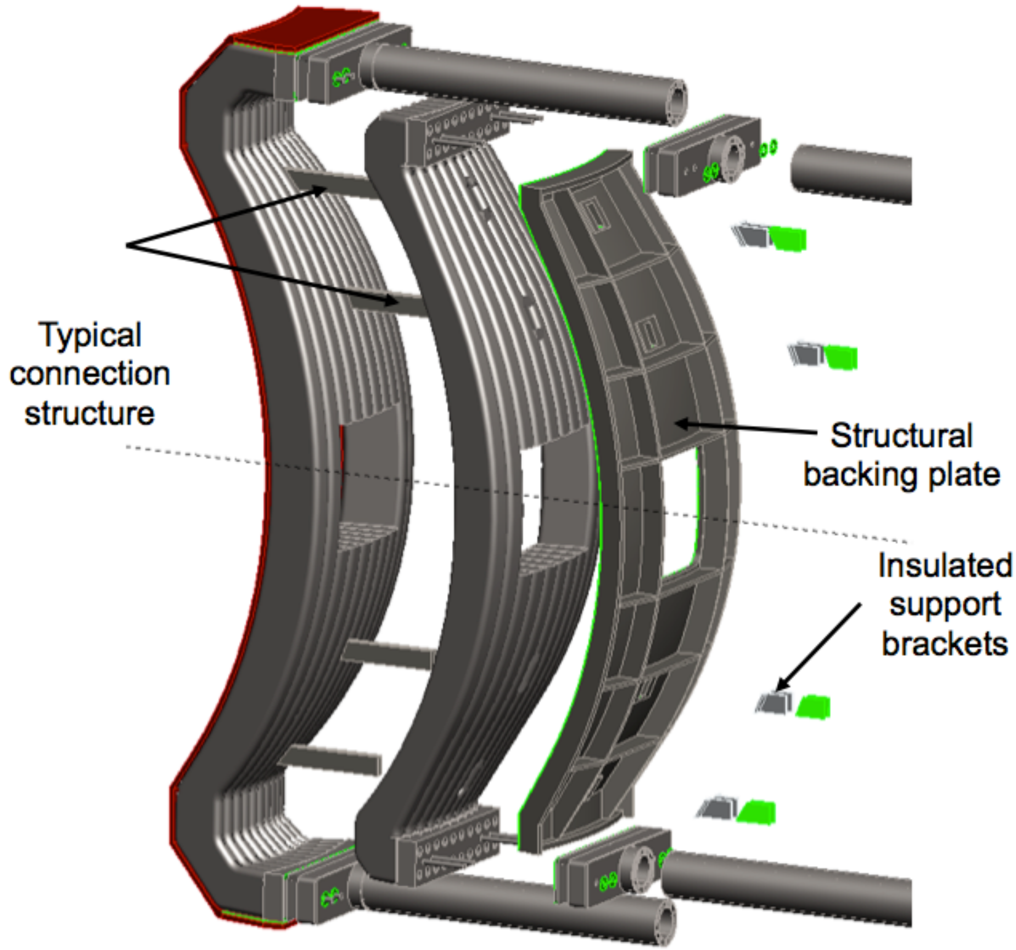
Future NSTX-U Machine Enhancements for CHI include >2kV CHI capability, ECH heating, and metal divertor plates

Raman, et al., IEEE Trans. Plasma Sci. 42, 2154 (2014)

CHI Design Studies for ST-FNSF have Identified Two Designs with > 2MA Start-up Current Generation Potential

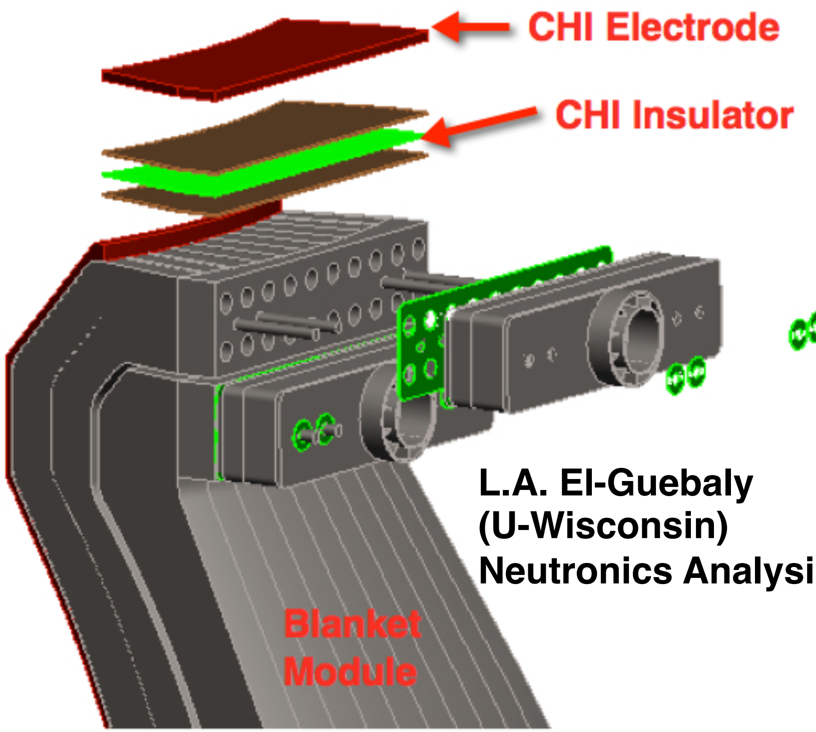
Concept – I (NSTX-like)

*Blanket modules and piping insulated from rest of vessel



Concept – II (QUEST-like)

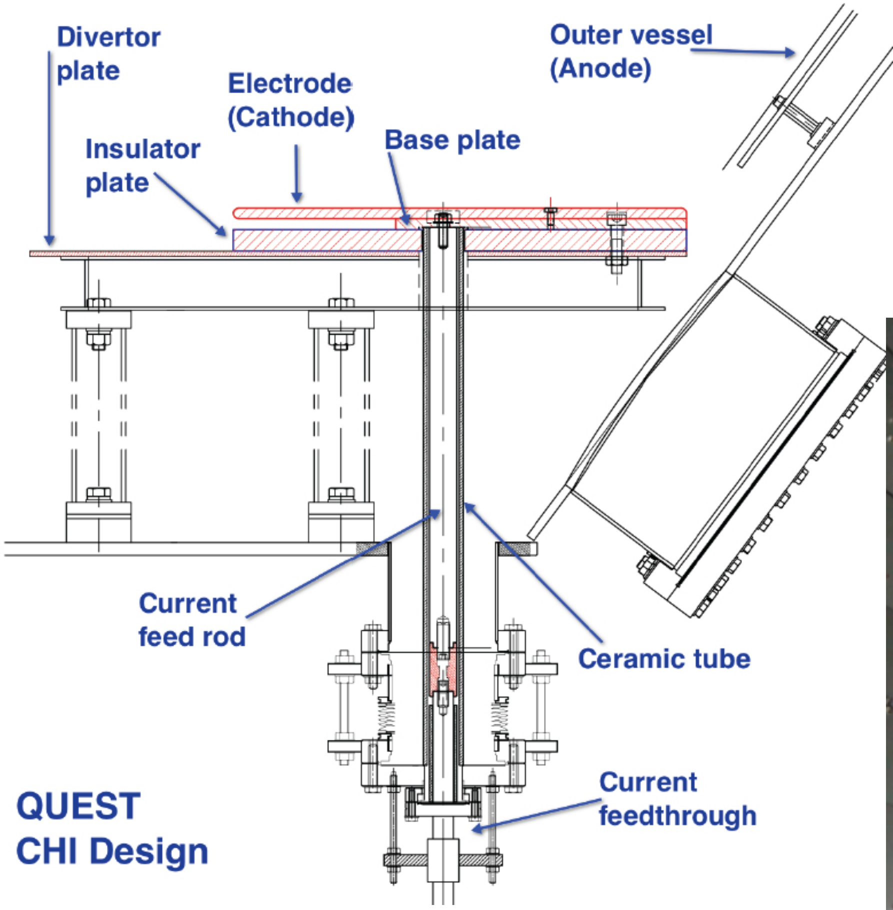
Toroidal electrode on top of blanket structure, analogous to CHI ring electrode previously used on DIII-D

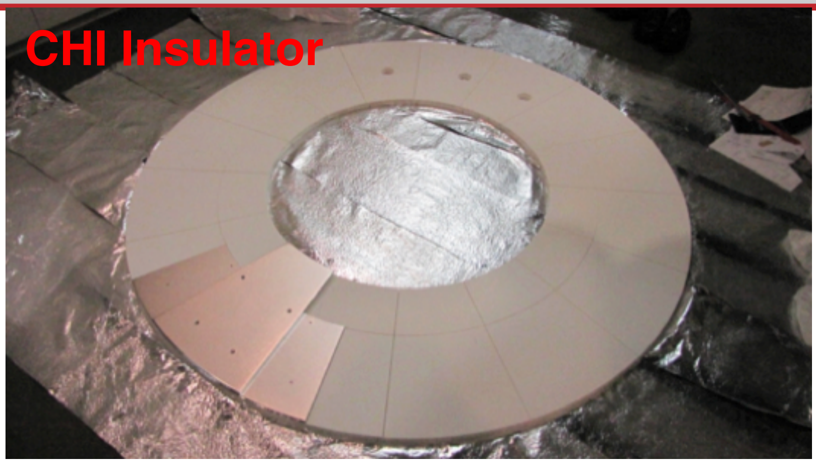


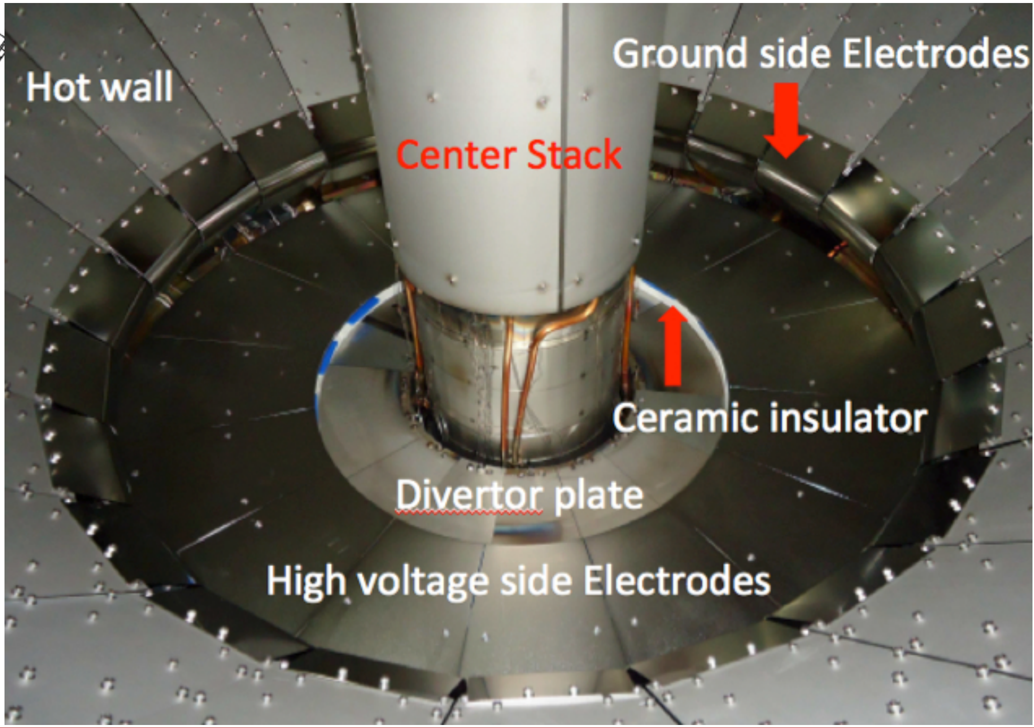
L.A. El-Guebaly (U-Wisconsin) Neutronics Analysis

R. Raman, T. Brown, L.A. El-Guebaly, et al., Fusion Science & Technology (2015)

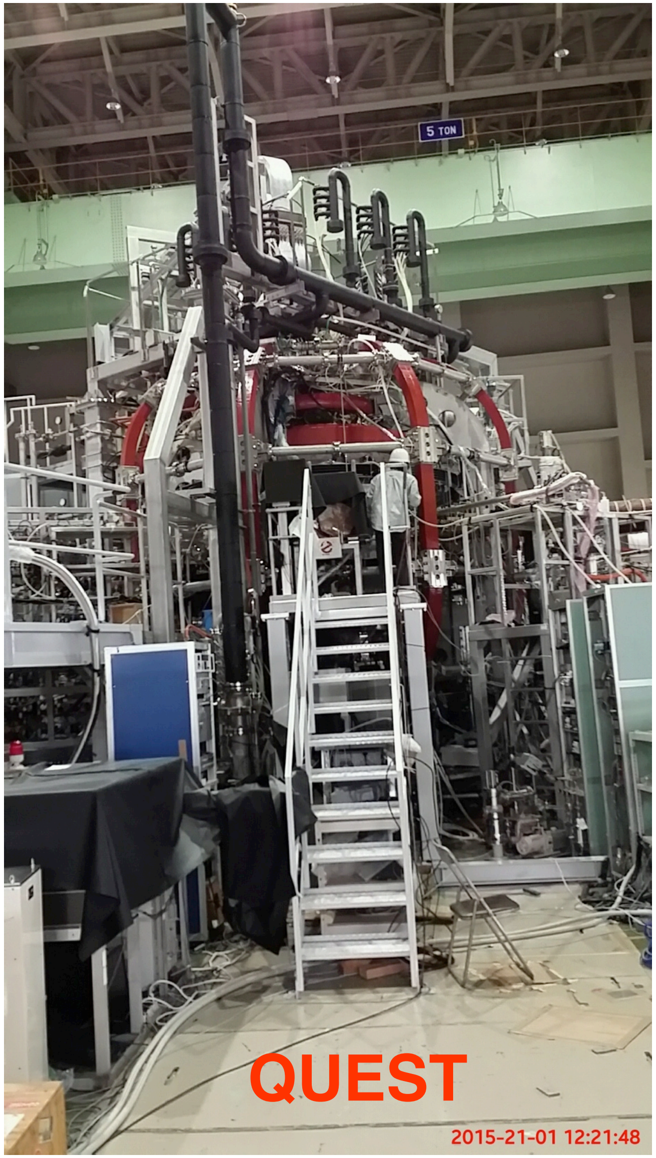
CHI Configuration on QUEST will Test ST-FNSF Relevant Electrode Design







CHI Research on QUEST in Support of NSTX-U and ST-FNSF

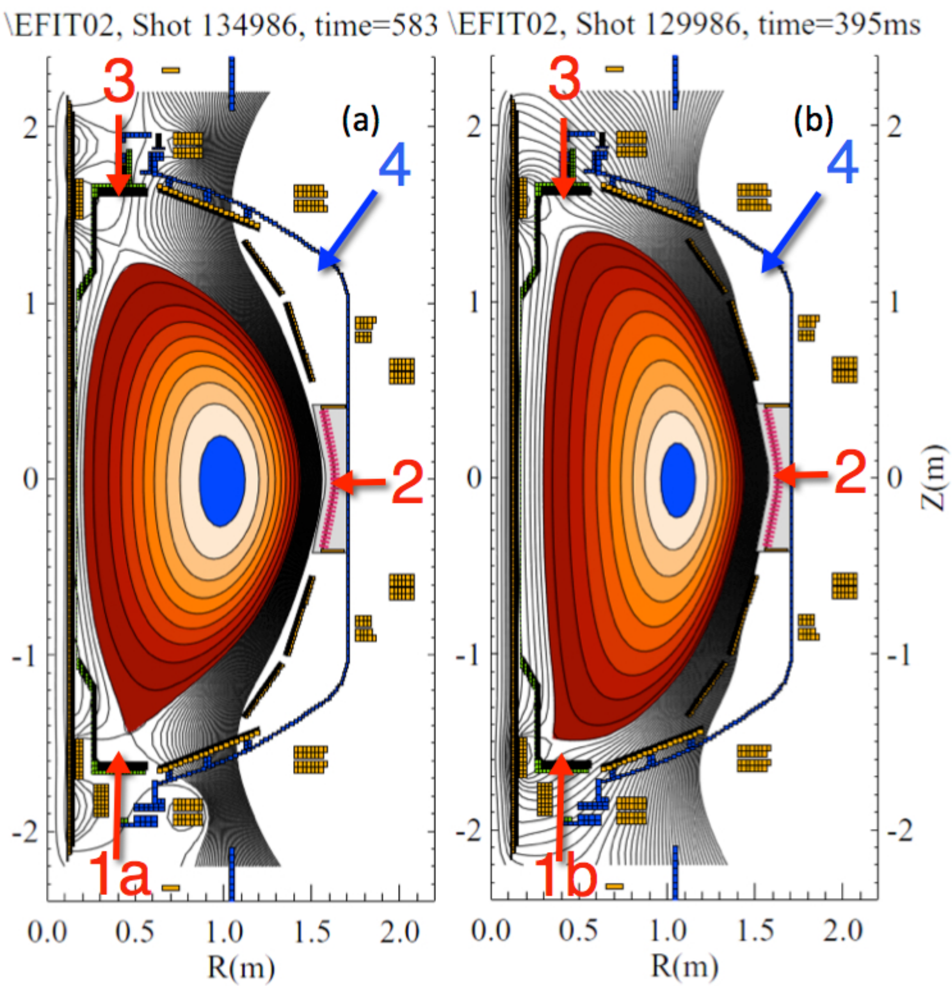


- Test ECH heating of a CHI Target
  - QUEST is equipped with ECH
- Test CHI start-up using metal electrodes
  - Clean metal electrodes should reduce low-Z impurity influx
- Test CHI start-up in an alternate electrode configuration that may be more suitable for a ST-FNSF installation
  - CHI insulator is not part of the vacuum vessel

Disruption Mitigation (DM) Studies on NSTX-U

- Massive Gas Injection (MGI) Studies
  - Establish MGI capability on NSTX-U
  - Understand MGI gas penetration and assimilation and scaling to reactors
- Electromagnetic Particle Injection (EPI) Studies
  - Develop alternate, faster time response, methods for impurity delivery

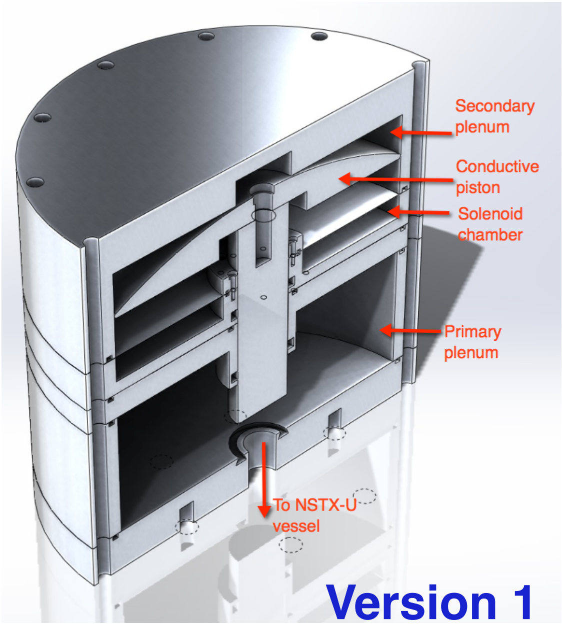
NSTX-U MGI will study poloidal injection location variation using nearly identical MGI valves and gas transit piping

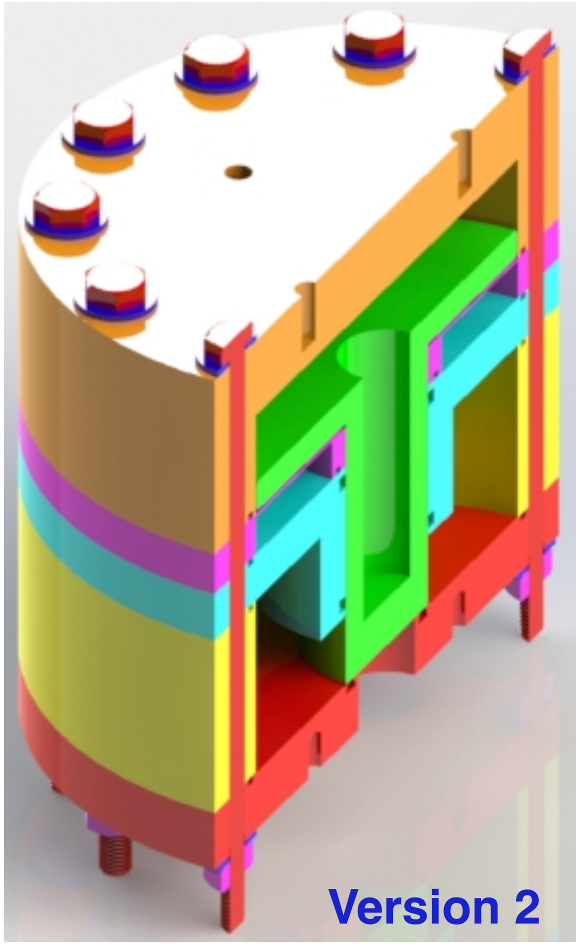


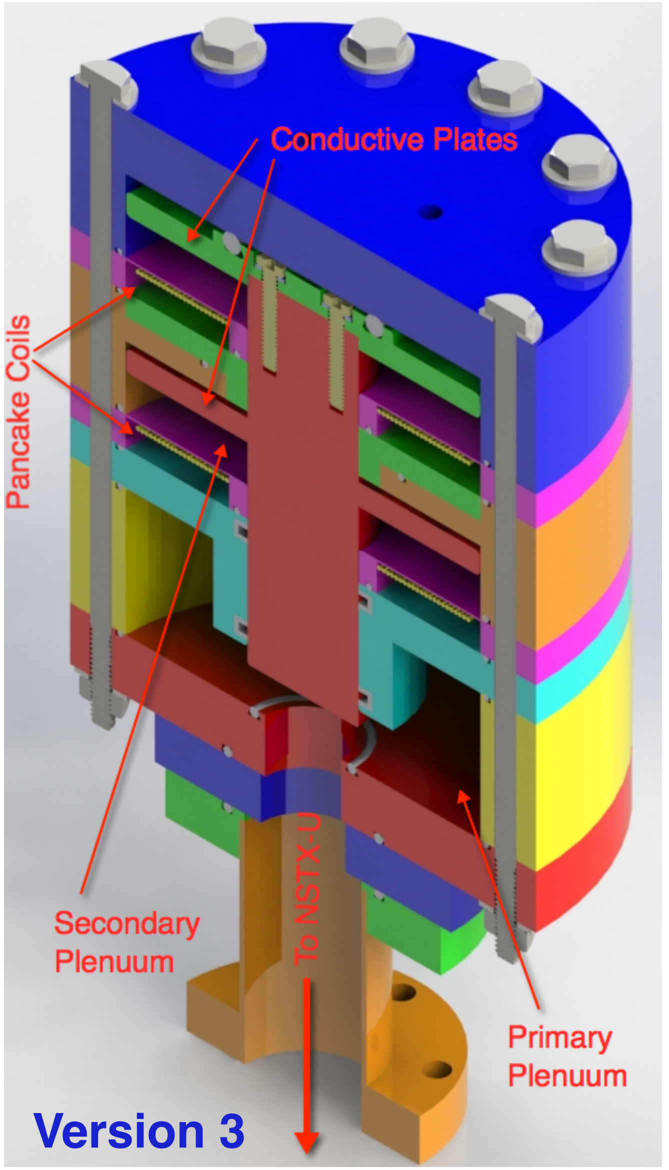
- Asses benefits of injection into the private flux region & the high-field side region vs. LFS mid-plane

1a: Private flux region
1b: Lower SOL, Lower Divertor
2: Conventional mid-plane
3: Upper divertor
4: Future installation

Off-line MGI Studies will Contribute to MGI Valve Development in support of NSTX-U and ITER





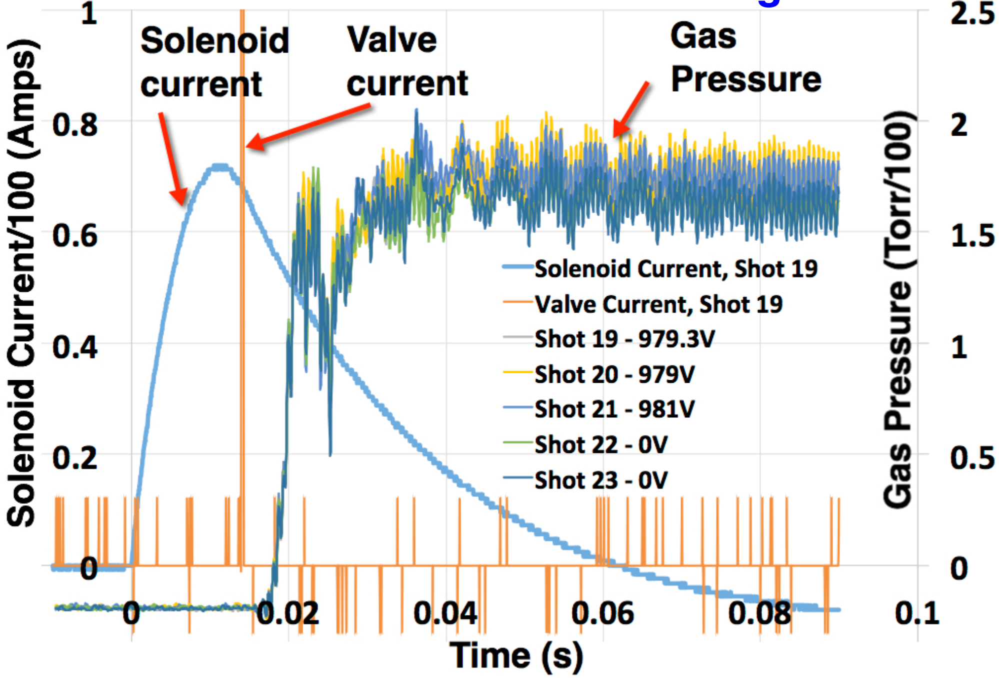


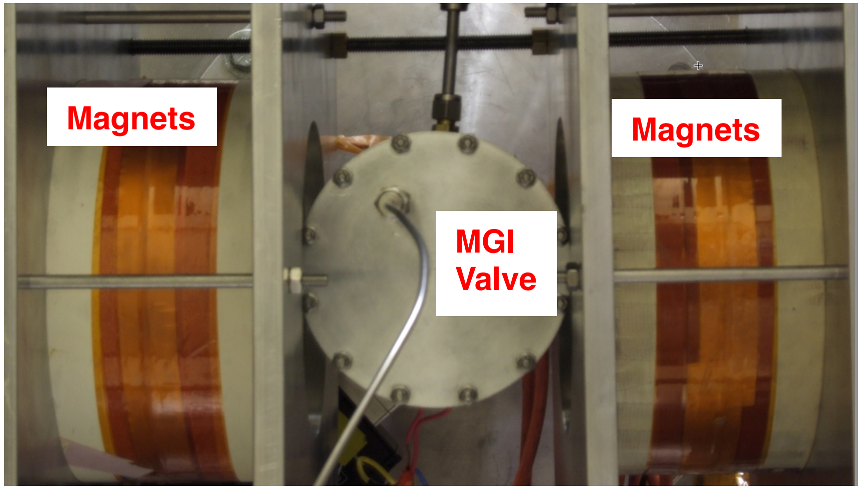
MGI valve design based on TEXTOR / JET MGI concept

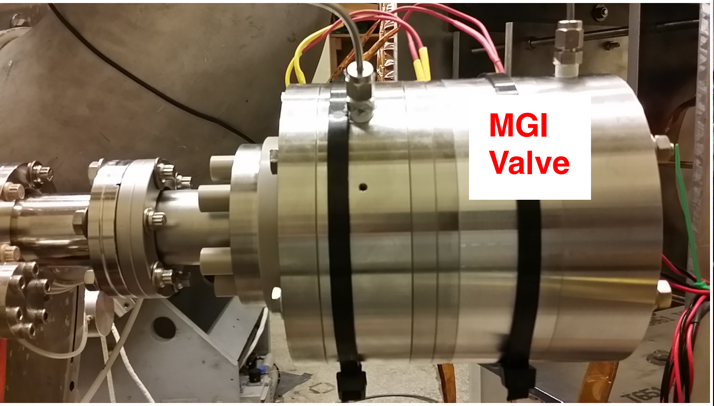
New double solenoid MGI design – V3 (zero net J x B torque) based on ORNL ITER MGI concept

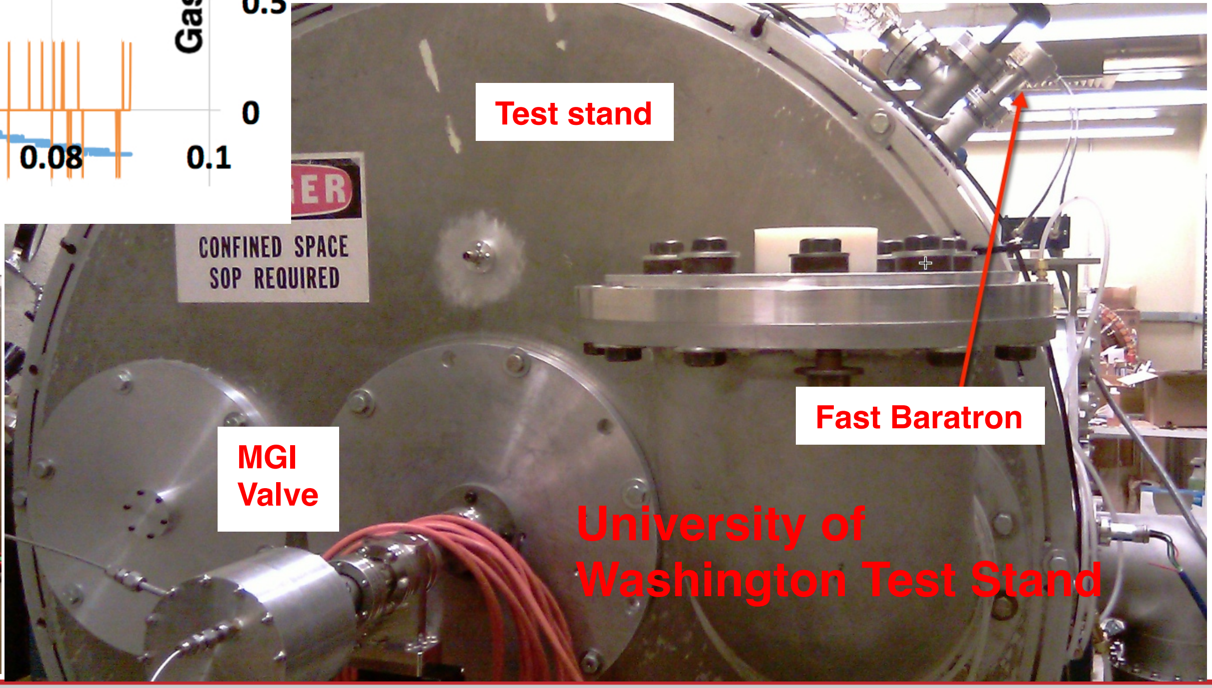
Understand Reliability and Magnetic Field Limits on Valve Operation

Baratron traces with and without magnetic field

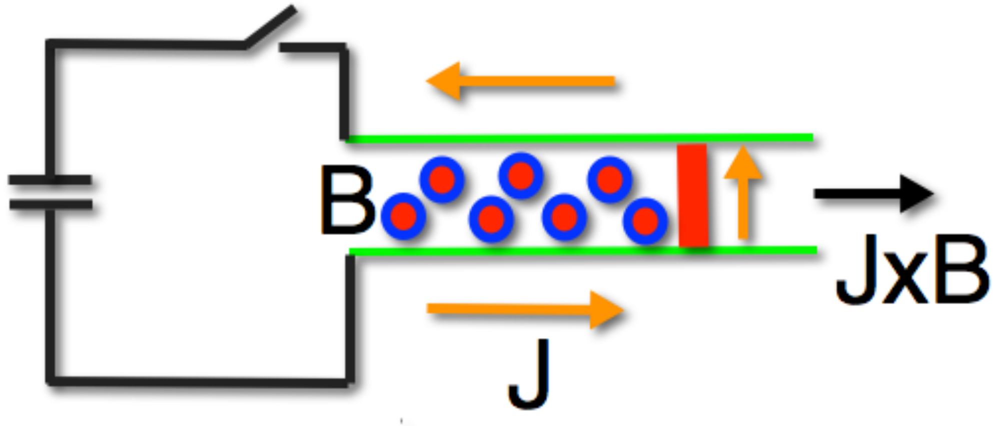




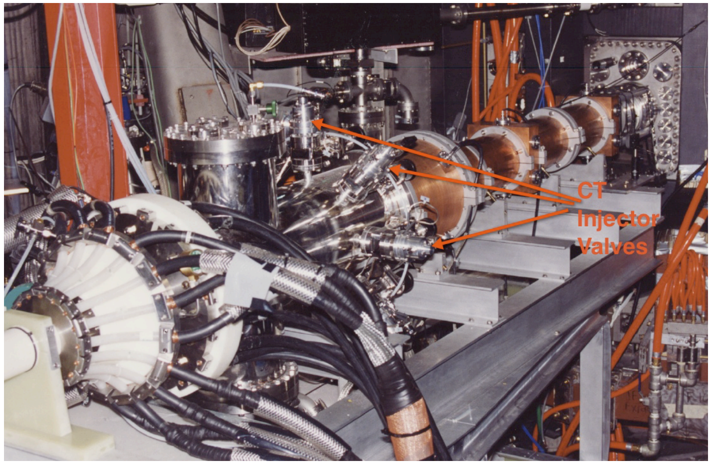




Linear Rail Gun is Especially Well Suited for Operation in High-Ambient Magnetic Fields



CT Injector on TdeV

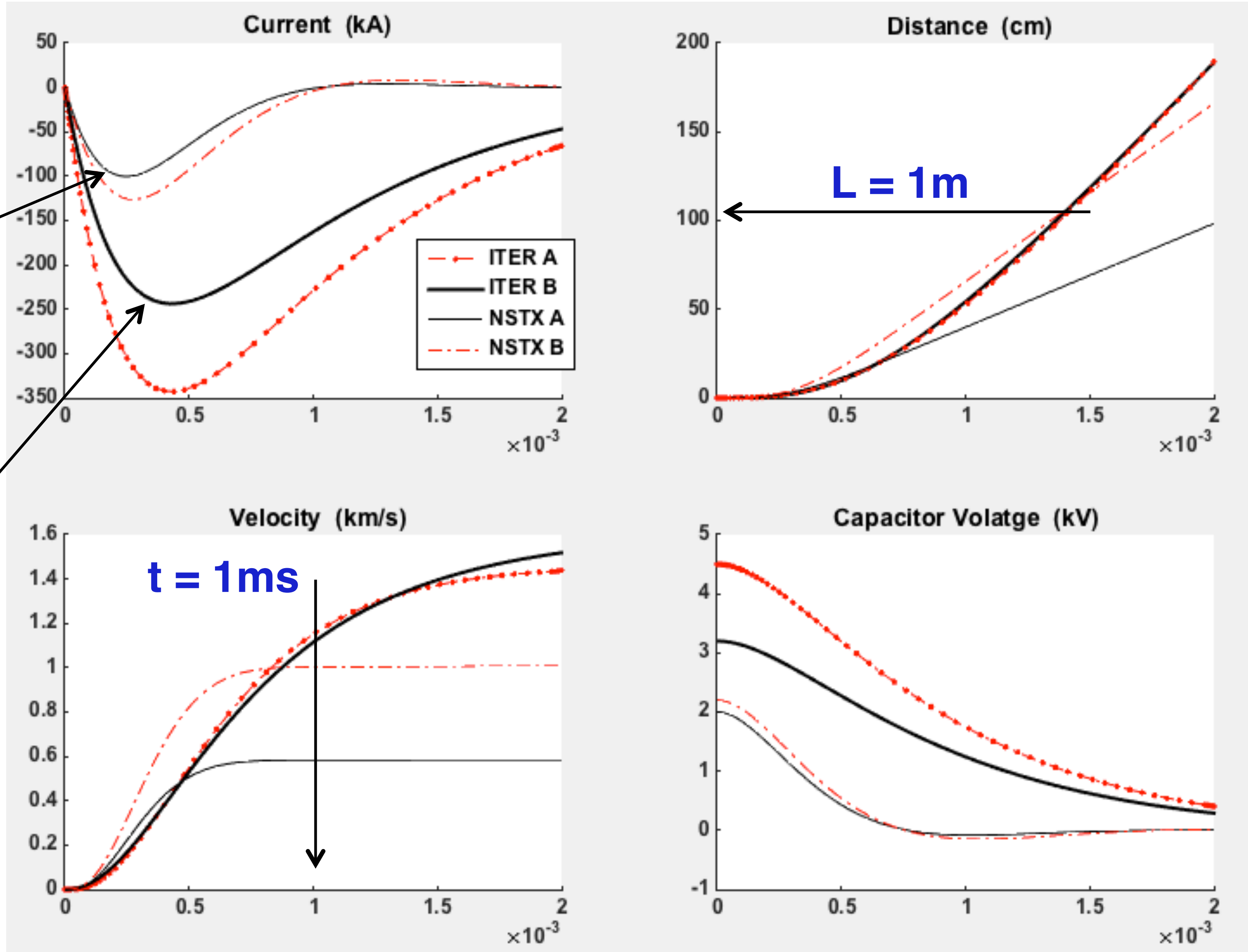


- In a simple rail gun, the magnetic field is produced by the current flowing along the rails
- To increase the JxB force accelerating the projectile, the current along the rails needs to be increased
- An important advantage of a linear rail gun is that the ambient magnetic field in ITER can be used to increase the gun efficiency
- Injector can to be positioned very close to the vessel, which further improves the system response time and efficiency

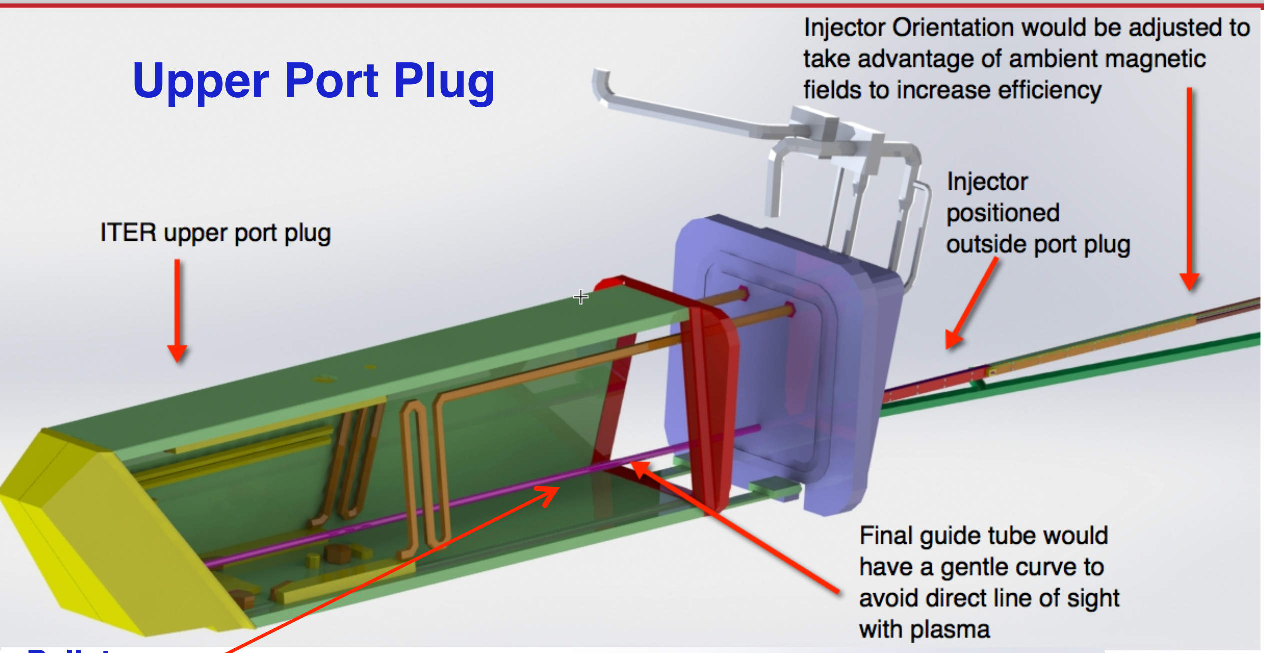
External Magnetic Field Augmentation Substantially Reduces Electrode Current and PS Requirements

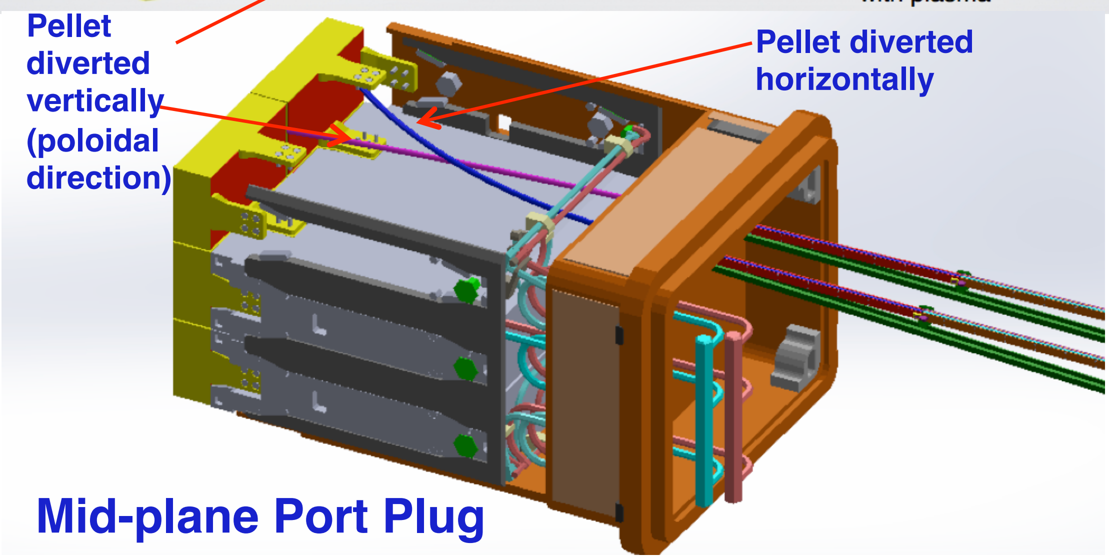
NSTX-U
20 mF, 2kV

ITER
2T external magnetic field augmentation, 100mF, 3.2kV



Scoping Studies Suggest that an EPI Installation on ITER should be feasible*

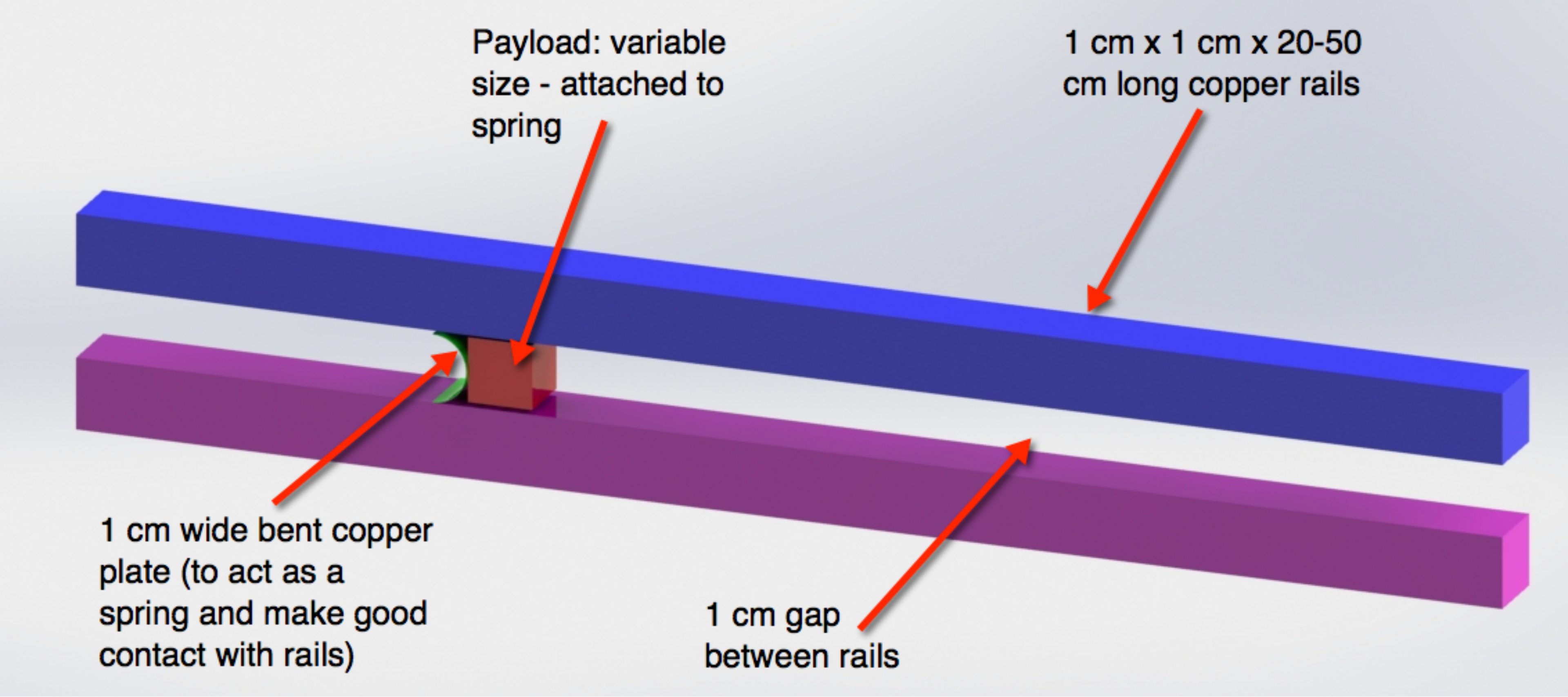




***In FNSF, inclusion of EPI from early design phase should allow installation closer to the wall to benefit from high toroidal field**

R. Raman, T.R. Jarboe, J.E. Menard, et al., Fusion Science and Technol. (2015)

Initial Tests at U-Washington will Accelerate 1 to 2g payloads



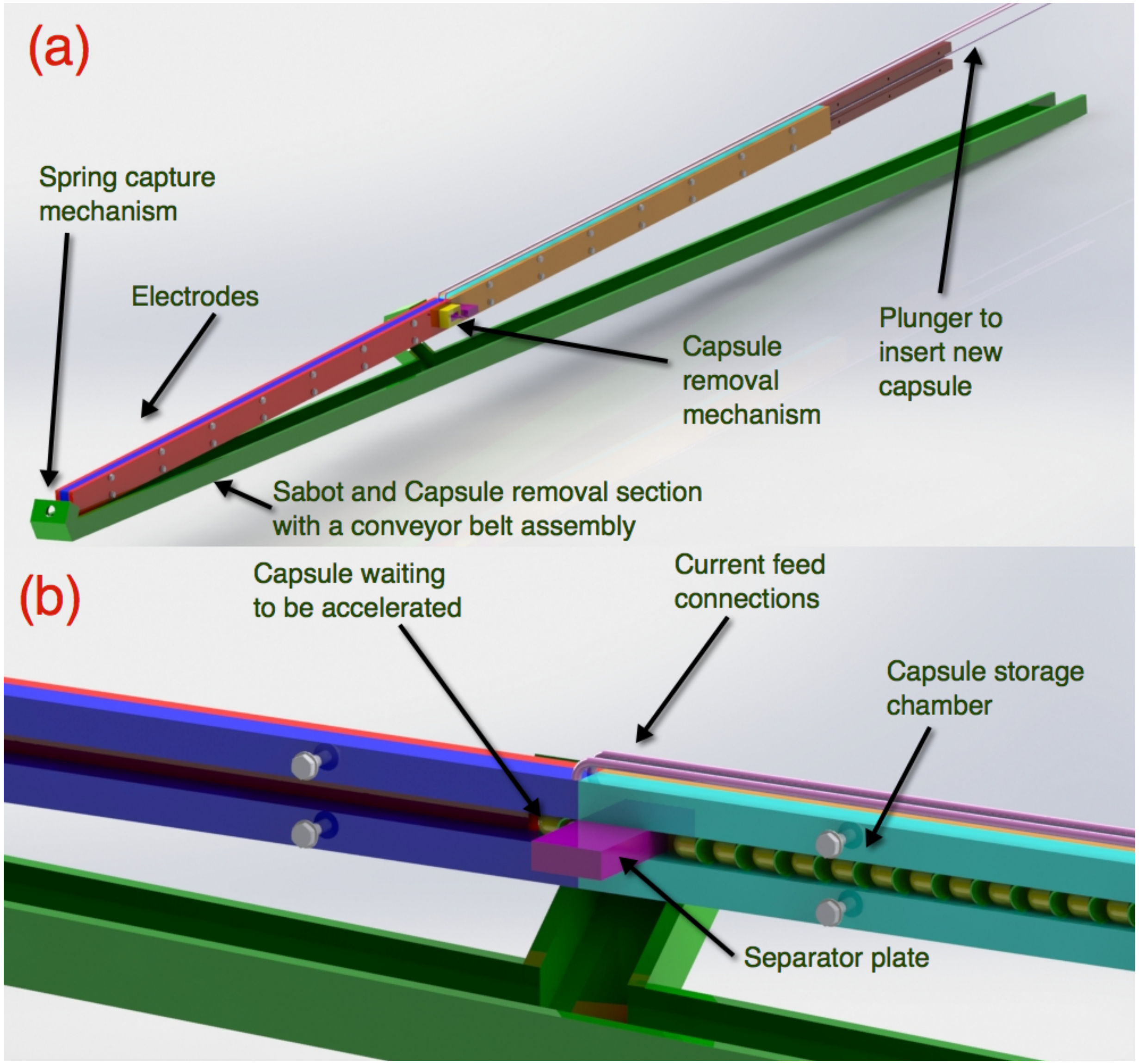
Rails will be sandwiched between insulating plates and powered using a 20mF, 2kV capacitor bank

CHI and DM Research on NSTX-U Aims to Develop Capability for Solenoid-free plasma start-up, & MGI & EPI Technologies in Support ITER and FNSF

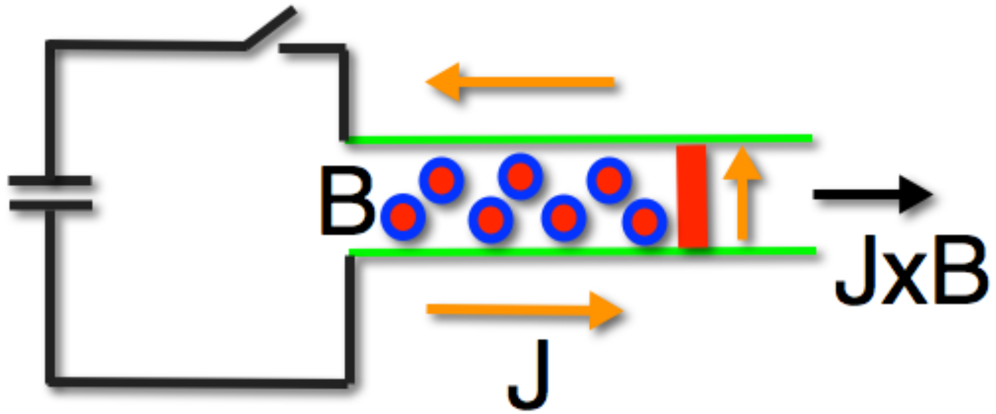
- CHI research on NSTX-U aims to extend the plasma current start-up magnitude to levels that allow full non-inductive current ramp-up
- CHI on QUEST will study CHI design for FNSF & provide supporting technical data for future NSTX-U CHI upgrades
- ITER-type off-line MGI valve development aims to understand reliability and magnetic field limits on reliable valve operation
- ITER-type MGI valve will be used on NSTX-U in a configuration to do exact comparison experiments
  - Same valve & piping configuration at each poloidal location
- The EPI system has several attractive features
  - Rapid delivery of impurities deeper into plasma with fast time-response
  - Efficiency of system improves in a magnetic field environment
  - Well suited for long stand-by mode operation (single power supply and no moving parts in system)

Back-up Slides

Primary Components of an EPI System for ITER



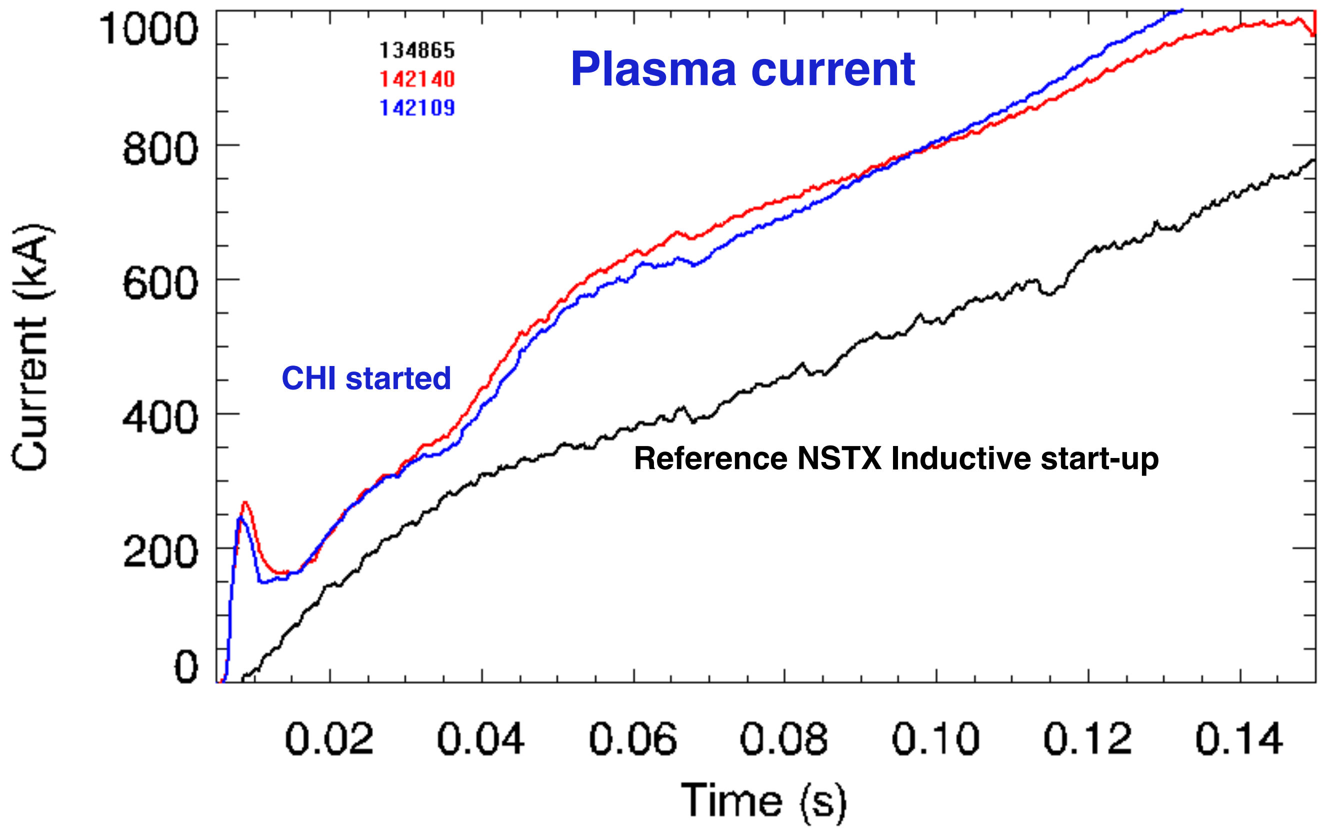
Linear Rail Gun is Especially Well Suited for Operation in High-Ambient Magnetic Fields



1. Off-line test at U-Washington of Low-power system to confirm velocity parameters and system time response time
2. Low-power system installation on NSTX-U, other tokamaks
3. Continue off-line tests with a medium-power system for development towards a ITER high-power configuration
   - Increase EPI energy
   - Test injection through curved guide tube
   - Pellet design improvements needed for both EPI and Shell Pellet

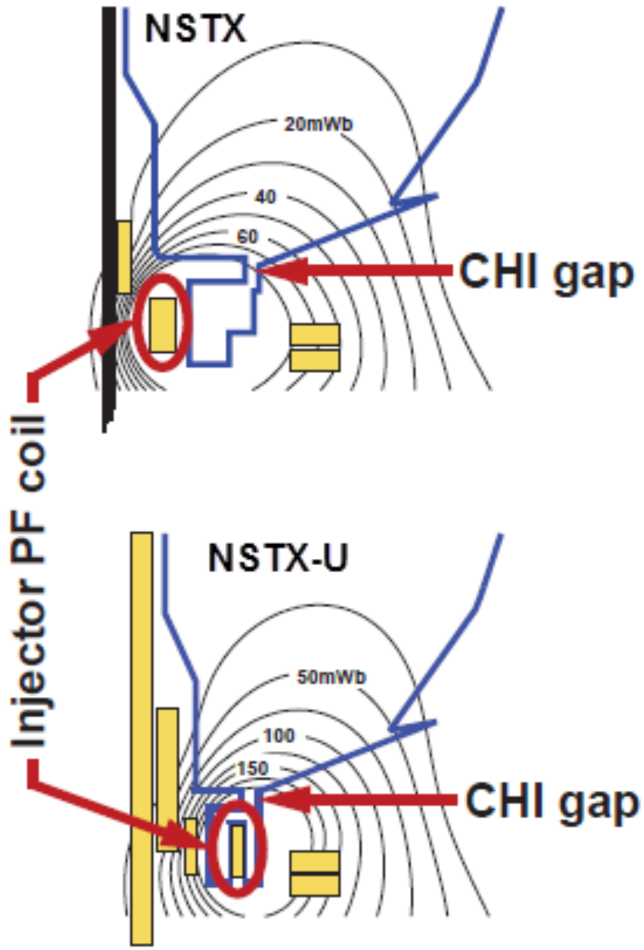
Need additional resources

Standard L-mode NSTX Discharge Ramps to 1MA Requiring 50% More Inductive Flux than a CHI Started Discharge



- Reference Inductive discharge
  - Uses 396mWb to get to 1MA
- CHI started discharge
  - Uses 258 mWb to get to 1MA (138 mWb less flux to get to 1MA)

CHI start-up to ~0.4MA is projected for NSTX-U, and projects to ~20% start-up current in next-step STs



Injector flux in NSTX-U is ~ 2.5 times higher than in NSTX → supports increased CHI current

Parameters	NSTX	NSTX-U	ST-FNSF	ST Pilot Plant
Major radius [m]	0.86	0.93	1.2	2.2
Minor radius [m]	0.66	0.62	0.80	1.29
B_T [T]	0.55	1.0	2.2	2.4
Toroidal flux [Wb]	2.5	3.9	15.8	45.7
Sustained I_p [MA]	1	2	10	18
Injector flux (Wb)	0.047	0.1	0.66	2.18
Projected Start-up current (MA)	0.2	0.4	2.0	3.6

Transient CHI Scaling: Generated Toroidal Current is proportional to Injector Flux

Location of Power Supply for CHI