

Fast Time Response Electromagnetic Particle Injection Concept for Disruption Mitigation (EPI)

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Outline

- Limitations of the present DM system for ITER
- How EPI addresses these issues?
- Main components of an EPI system
- How does it scale to ITER?
- Main components of an EPI system
- Off-line experimental test results
- Conclusions

Limitations of the Shattered Pellet System

- The speed of the un-fragmented high-mass pellets is restricted to about 200-400m/s due to the gas propellant
- Upon shattering the fragmented shards lose much of their velocity relative to the un-fragmented pellet
- Because of the slow speed and size of the fragmented particles, the penetration depth will be severely restricted in high power ITER discharges
- Because of the much larger size of ITER (compared to present experiments) – reliable modeling of the scaling of the concept to ITER is essential
 - This requires that we know both the size and the speed of the fragmented shards to do the penetration modeling

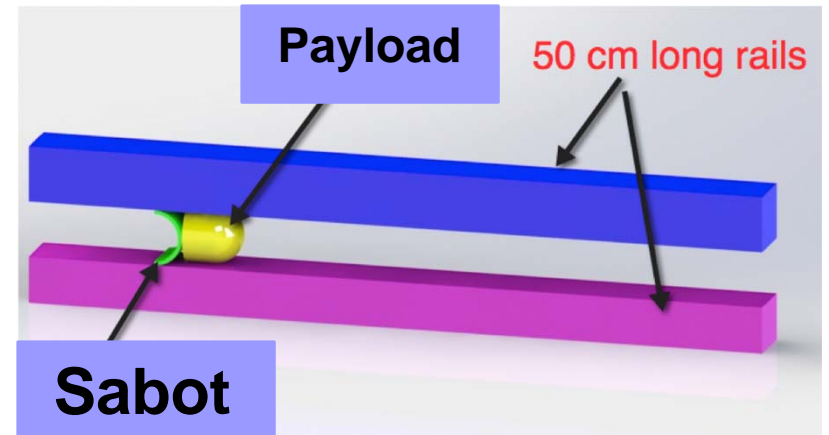
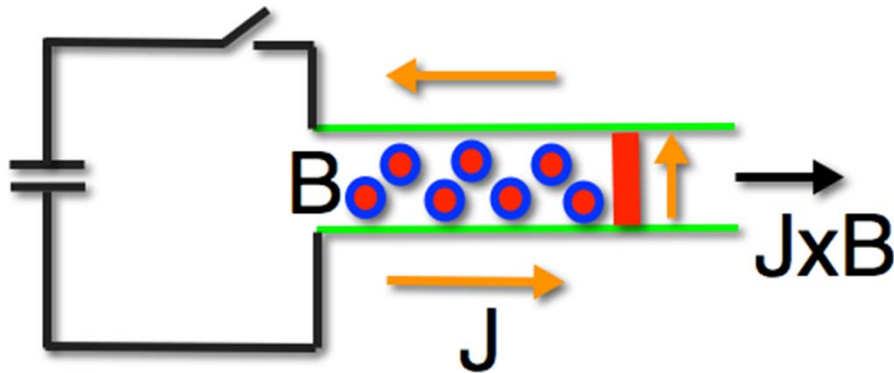
How does the EPI concept address this issue?

- The EPI concept injects grains of material (of the required size) and at the required velocity – & it does this on a fast time scale (2-3ms)
- One can precisely calculate the needed size / velocity combination of a spherical particle for penetrating to the center of any given plasma, including the ITER plasma

How does the EPI system achieve this?

- The EPI system accelerates a metallic sabot
- The sabot is a metallic capsule that can be accelerated to high-velocity using an electromagnetic impeller
- At the end of the acceleration, within 2-3ms, the sabot will release granules of known velocity and distribution – or a Shell Pellet containing smaller grains or noble gas
- The primary advantage of the EPI concept over SPI and other gas propelled systems is its potential to meet short warning time scales, while accurately delivering the required particle size and materials at the velocities needed for achieving the required penetration depth in high power ITER discharges.

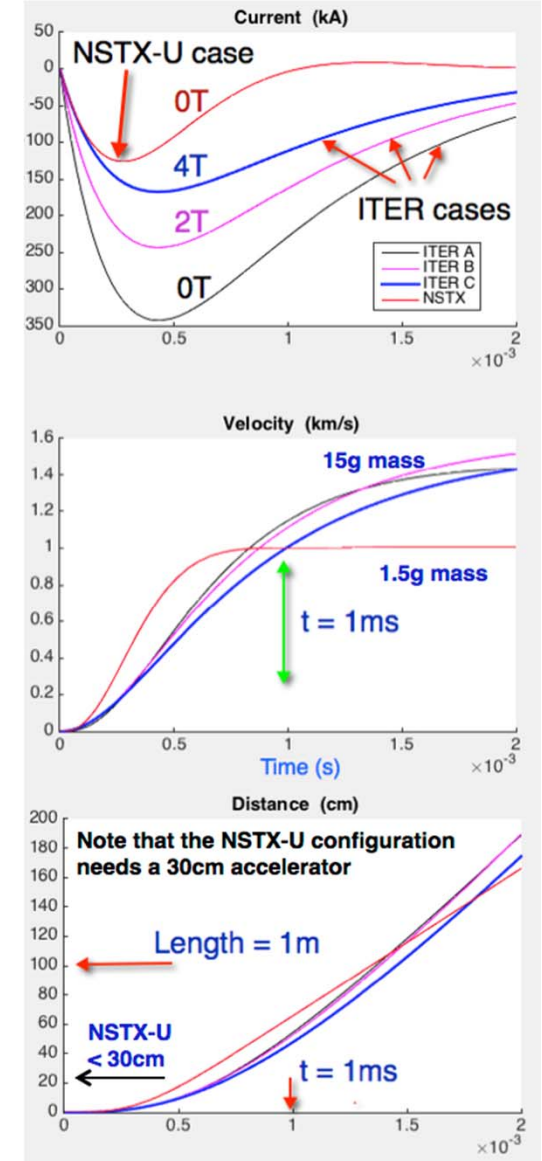
Main components of an EPI system



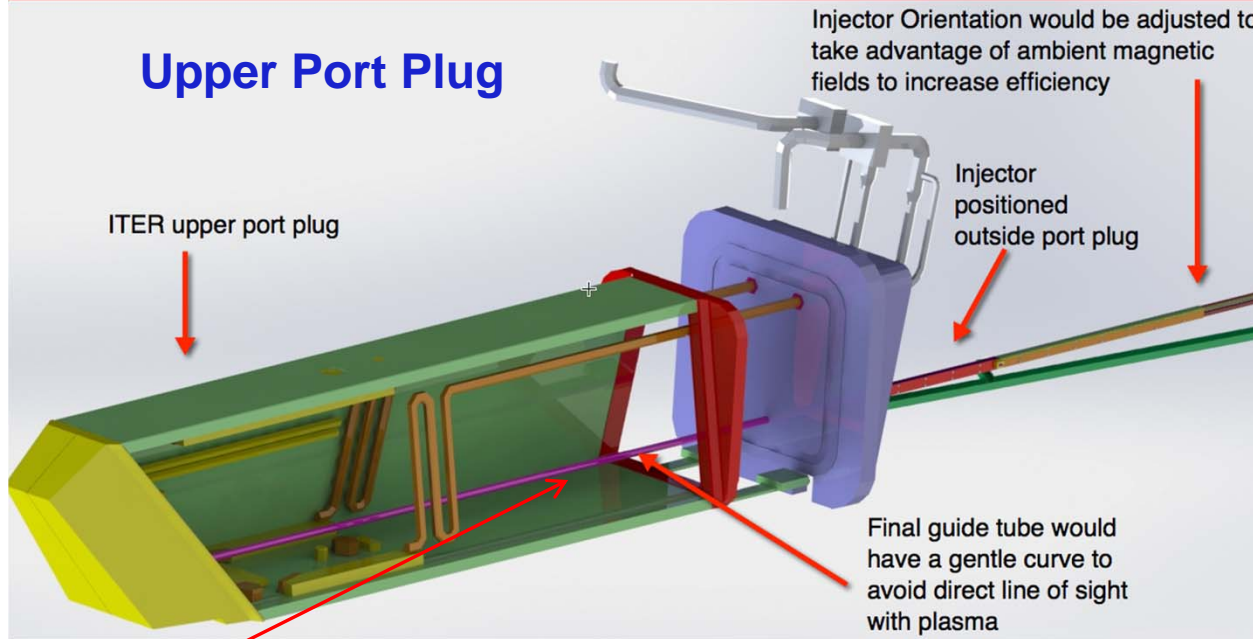
- An important advantage of the EPI system is that the ambient magnetic field of a large high-field tokamak such as ITER can be used to increase the device efficiency
- Injector can be positioned very close to the vessel, which further improves the system response and efficiency
- Payload: variable size grains of Be, B, or BN granules or a Shell Pellet, with variable velocity

How does the EPI concept scale to ITER?

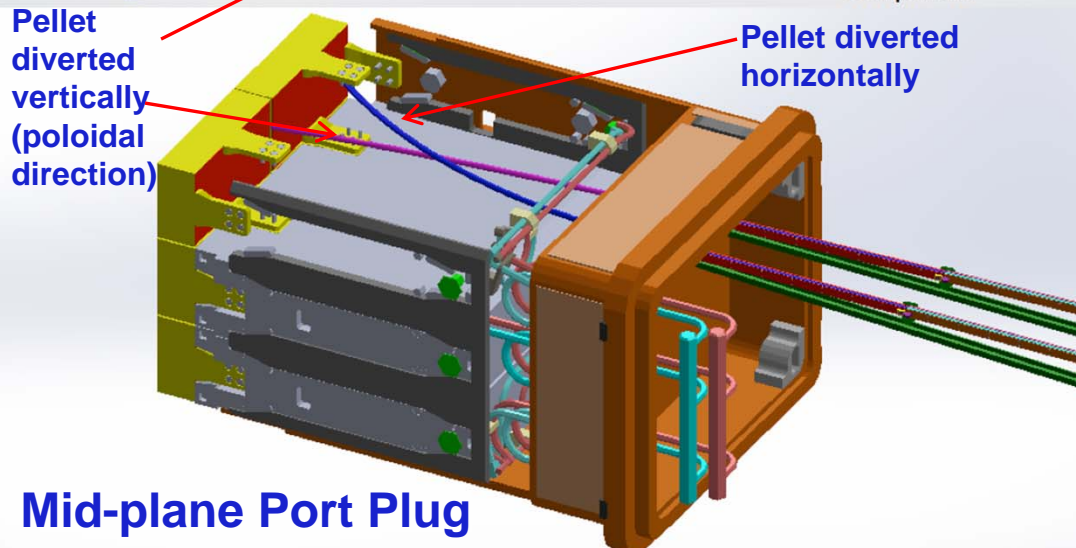
- With increasing external magnetic field, the required current drops dramatically and approaches that for a DIII-D/NSTX-U scale experiment
 - The NSTX-U/DIII-D case is for 1.5g mass
 - The ITER case is for 15g mass
- The time response for attaining the required velocity is ~1.5ms for all cases
- The accelerator length is less than 60cm for all cases
- The main difference between the DIII-D and ITER cases is that the accelerated mass increases by about 5-10



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

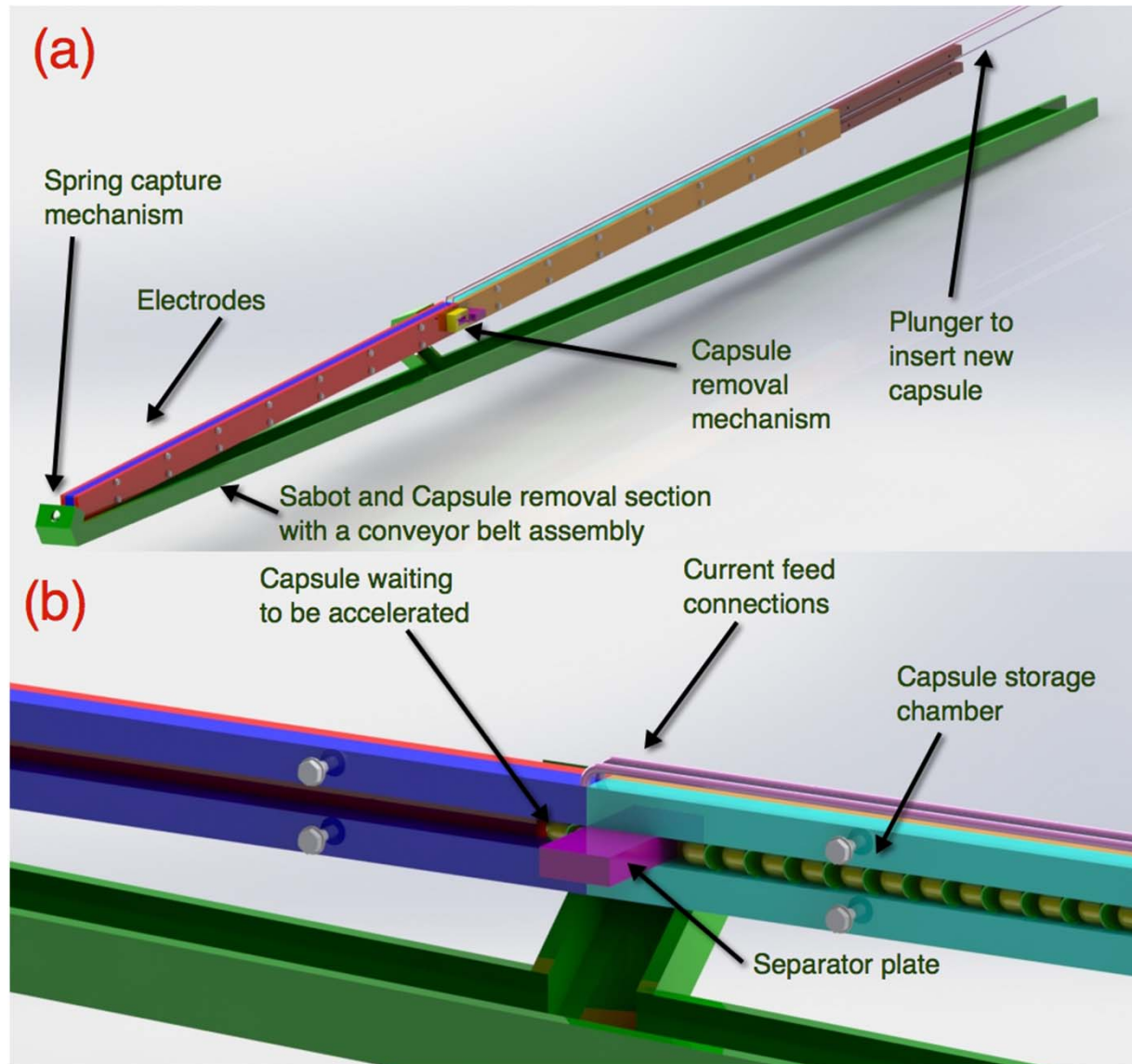


***In FNSF, inclusion of EPI from early design phase should allow installation closer to the wall to benefit from high toroidal field**

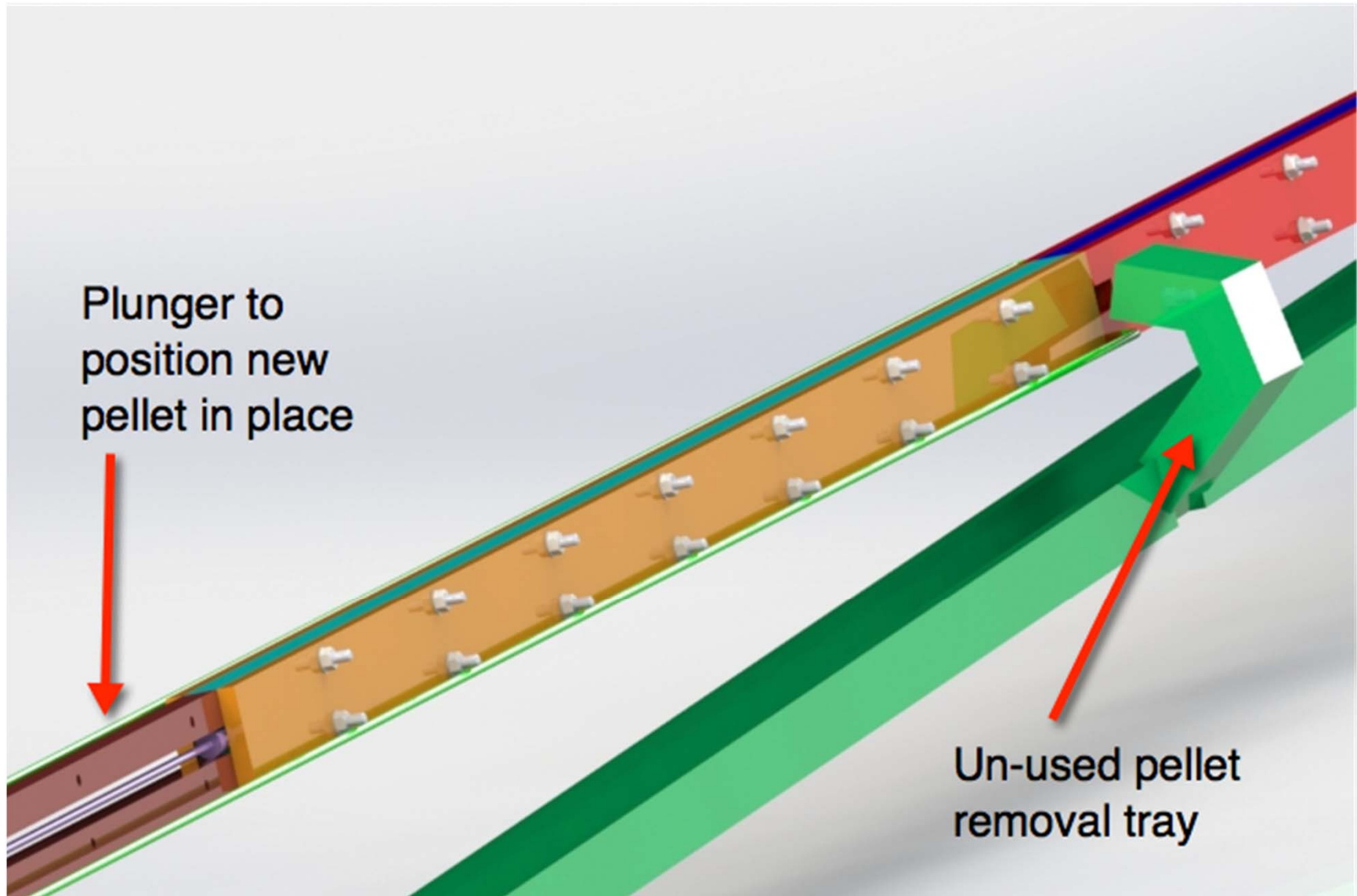


R. Raman, T.R. Jarboe, J.E. Menard, et al.,
Fusion Science and Technol. (2015)

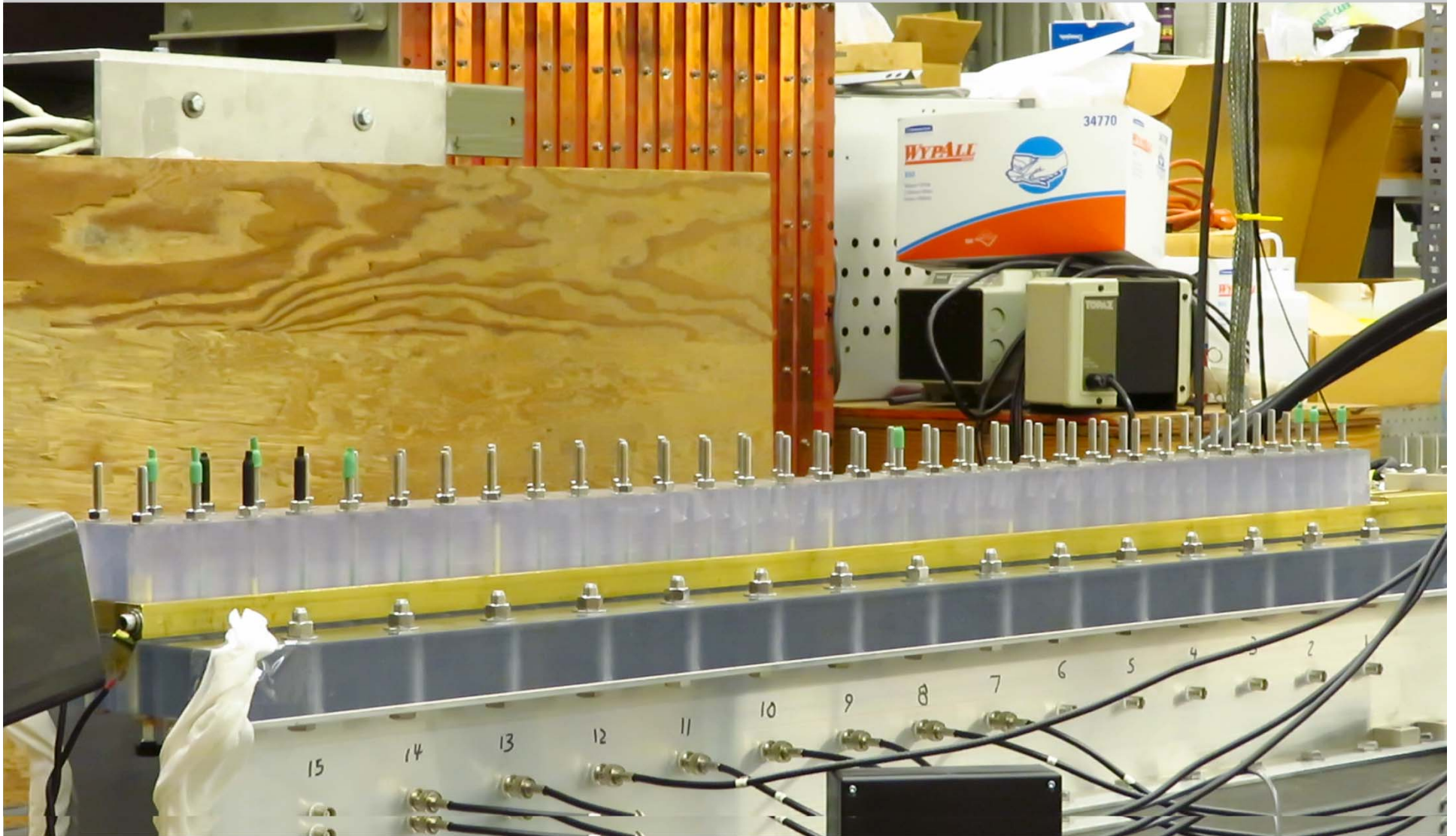
Primary Components of an EPI System for ITER



Unused Pellet Removal System and New Pellet Insertion

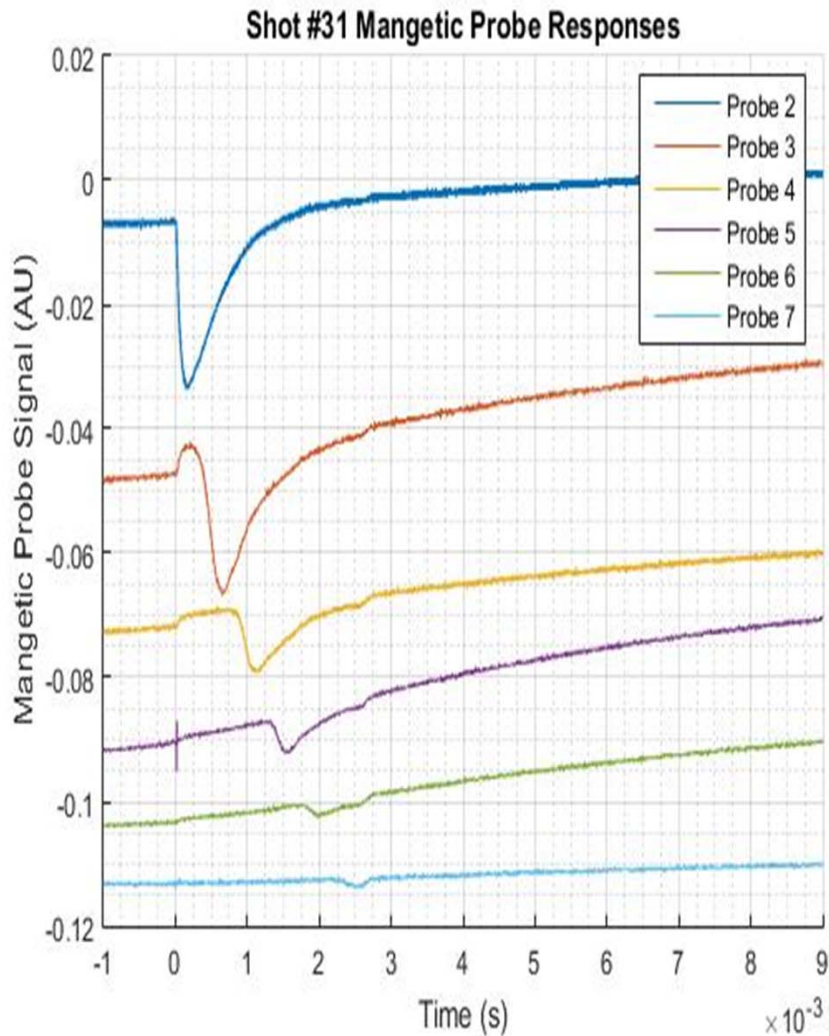


Example of EPI System in Operation

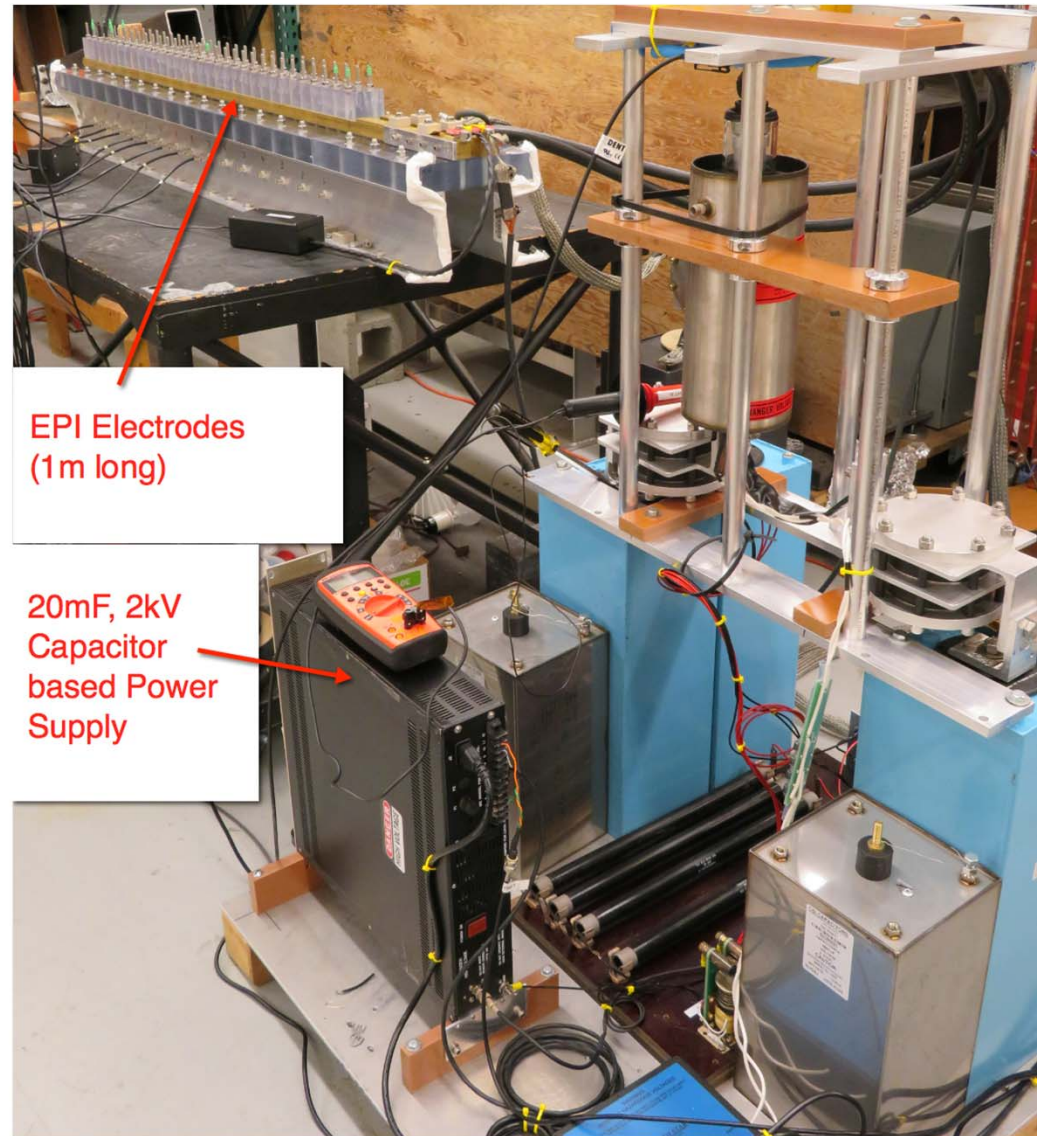


Magnetic probes located below the injector track motion of the sabot

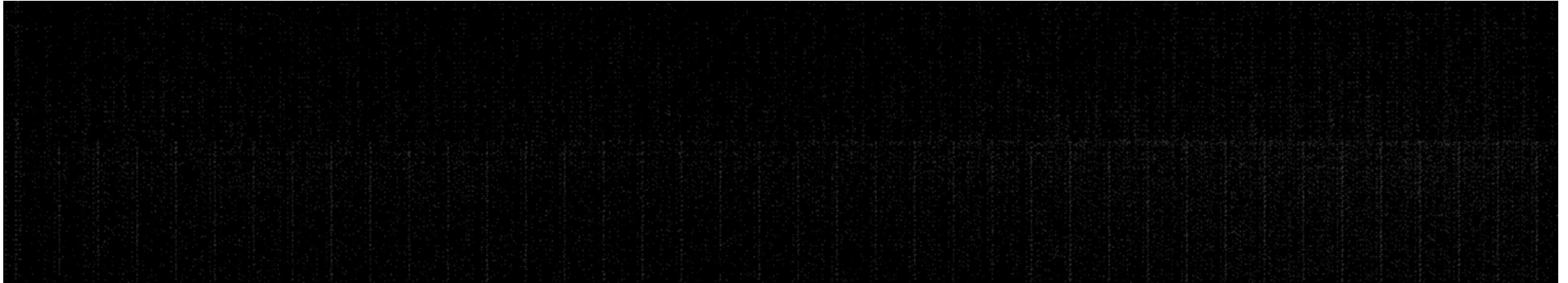
Sabot Position Tracking using Magnetic Probes Indicates Attainment of Maximum Velocity in $<2\text{ms}$ after Trigger Time



Magnetic probes located below injector track motion of sabot



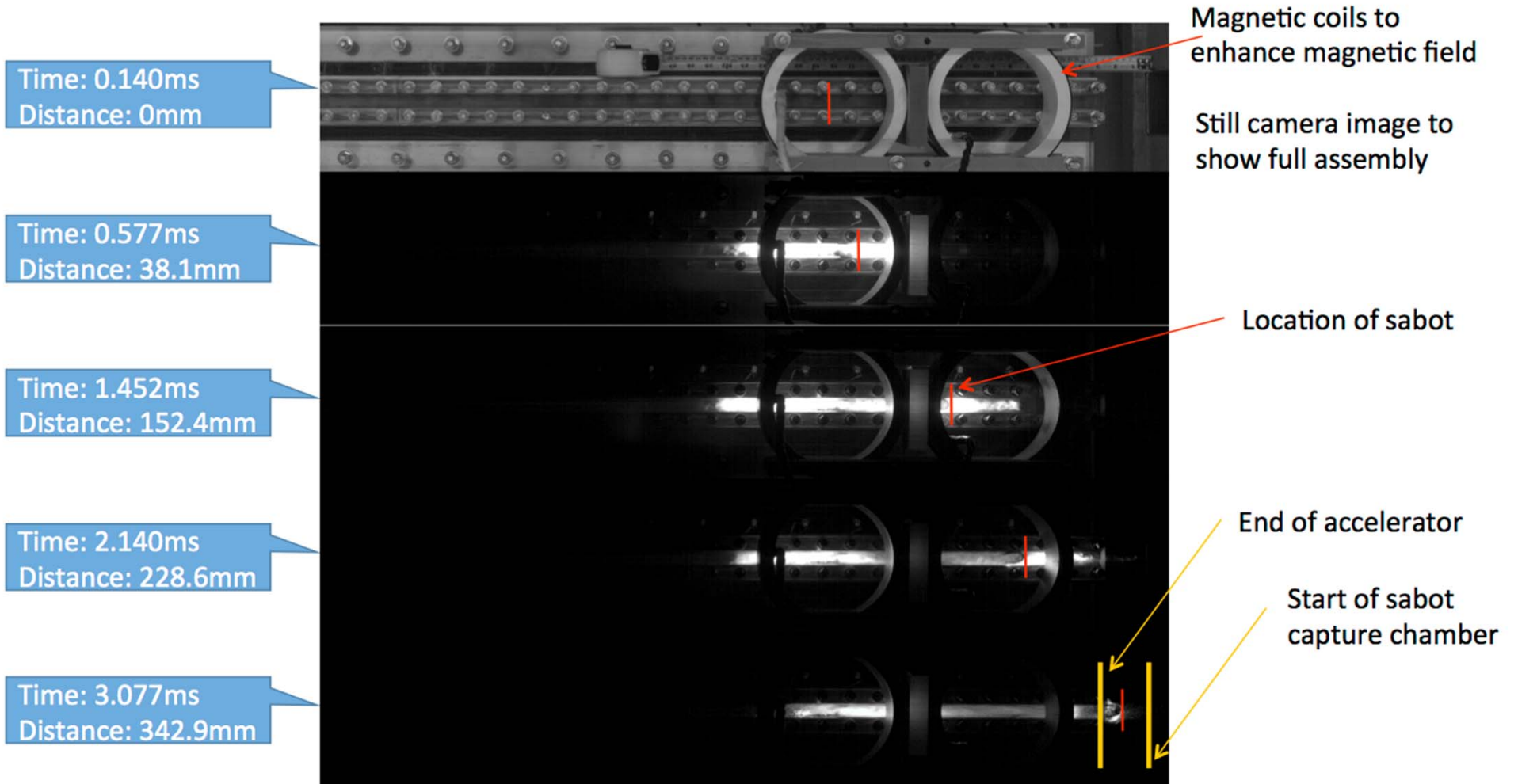
2.5ms Fast Camera Movie of Sabot Motion



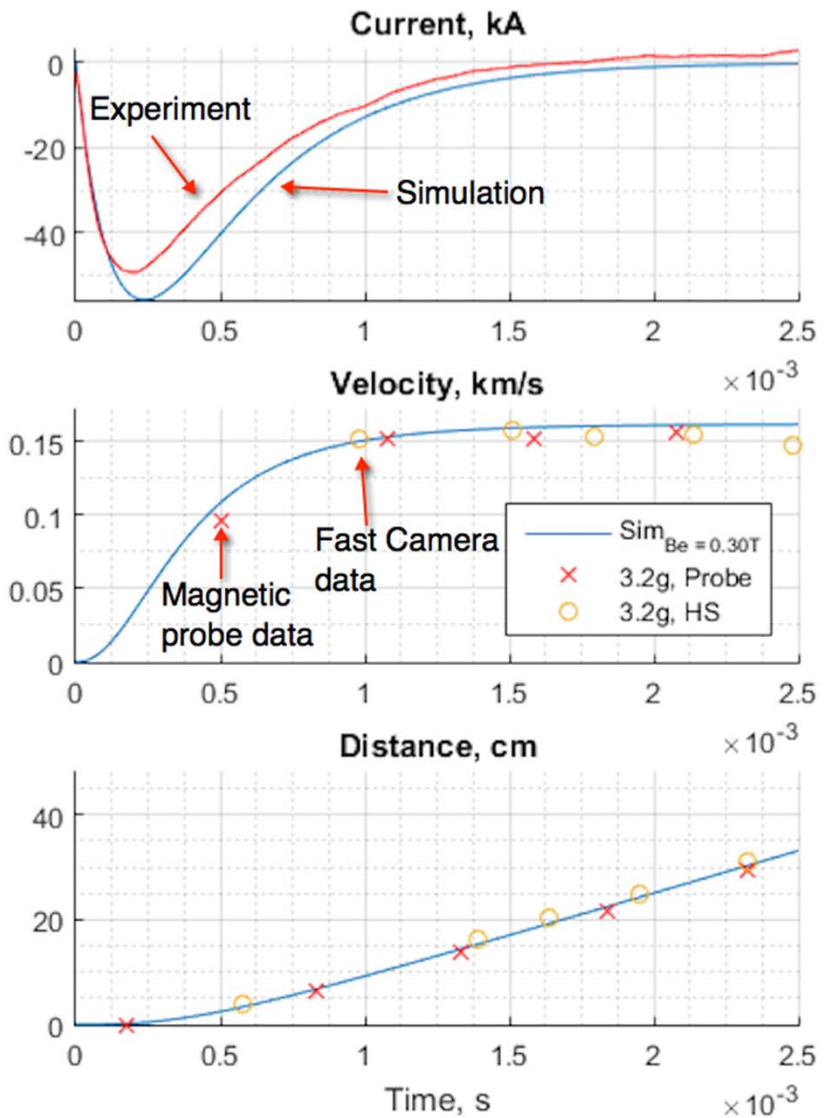
Note gases being pulled into to electrode region after sabot exits the electrode region

Velocity Measurements using Fast Camera Images are Consistent with Results from Magnetic Probe Signals

Shot 45



Measured EPI system parameters with 0.25T B-field augmentation in agreement with simulation predictions



Future Work

- Build a dedicated magnetic field enhancing coil and increase velocity, while reducing injector current (present velocity parameters are adequate for tokamak tests)
- Build the sabot capture mechanism and demonstrate sabot capture.
- Build a suitable vacuum chamber to house the electrode system and measure performance in vacuum
- Implement automatic sabot removal and loading systems
- Conduct demonstration tests on a tokamak.

Concept Discussed With ITER Groups During Concept Inception Phase

Motivation and concept details are provided in this paper:

FAST TIME RESPONSE ELECTROMAGNETIC DISRUPTION MITIGATION CONCEPT

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TECHNICAL NOTE

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As part of the concept development we consulted with ORNL ITER Disruption Mitigation Group and with ITER Personnel

Held three remote presentation meetings to inform ORNL ITER Group

EPI can Deliver Impurity Particles Deep into the Tokamak Plasma on a Fast Time-scale

- Electromagnetic Particle Injector (EPI) concept accelerates a metallic sabot to high velocity, which releases grains of particles of the required size and velocity
- The EPI system has several attractive features
 - Fast response time of 2-3ms
 - Can deposit payload in the center of the plasma (in the RE channel, where it is needed)
 - Well suited for long stand-by mode operation (because it contains particles that are solid at normal temperatures)
 - Should be very reliable (because it uses a single reliable actuator)
 - It can be located close to vacuum vessel (because it does not rely on plasma for propulsion nor does the system contain plastics)
 - Close installation also reduces response time (no propagation through long tube), and makes system more efficient (because it takes advantage of the external fields)
- Off-line setup at U-Washington has demonstrated key aspects of concept, including 150-200 m/s velocities with 1.5ms response time consistent with calculations
- Tokamak tests are the next logical next step for this concept to make progress