Electromagnetic Particle Injector (EPI) as a Fast Time Response Disruption Mitigation Concept

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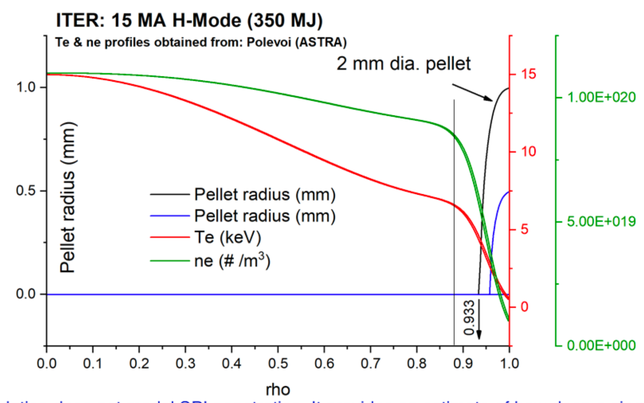
Limitations of Present DM Systems

- Most of the DM databases is from MGI experiments, but MGI has been dropped by ITER.
  - ➢ But, the MGI valve is still used to propel the SPI pellet
- The speed of the un-fragmented high-mass / high-Z SPI pellets is about 200-300 m/s due to the use of gas propellant
  - ➢ Shattering process further reduces fragment velocity
- Because of the slow speed and size of the fragmented particles, the penetration depth will be severely restricted in high power ITER discharges
- Will the SPI fragments penetrate sufficiently deep into the much more energetic ITER H-mode pedestal? How far does it need to penetrate?
  - Present methods rely on MHD to transport the radiative payload deep into the discharge
  - It would be desirable if the radiative payload could be deposited in the RE current generation region by the injection process itself

Simulations* Indicate 1 and 2 mm Ne Pellet (200 m/s) Penetration into ITER 350 MJ H-Mode Plasmas is Confined to a Region Within the H-mode Pedestal



This calculation does not model SPI penetration. It provides an estimate of how deep a single pellet could be expected to penetrate in high energy ITER plasmas.

*ORNL Pellet Penetration Code: W. A. Houlberg, et al., Nuclear Fusion 28, 595 (1988)

How Does The EPI Concept Address Present Limitations?

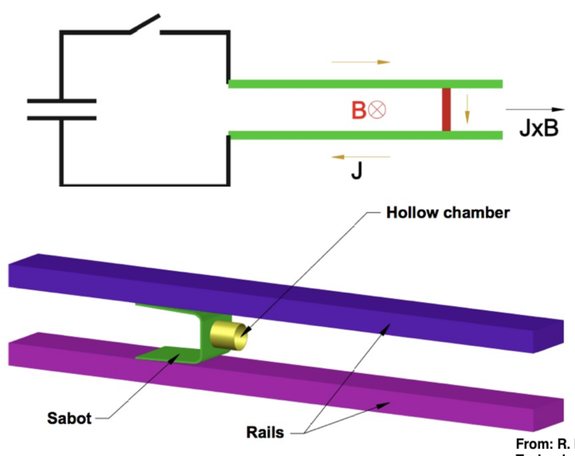
- The EPI system accelerates a sabot
- The sabot is a metallic capsule that can be accelerated to high-velocity using an electromagnetic impeller
  - At the end of the acceleration, within 2-3ms, the sabot will release granules of known velocity and distribution – or a Shell Pellet
- The **primary advantage** 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 **core penetration** in high power ITER discharges.
  - ➢ Delivers radiative payload to the the core where the RE channel is generated

EPI Injects Multi-species, Multi-sized Radiative Payload Spheres to Achieve Mitigation in Plasmas With Varying Energy Content

- 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)
- Because of this - 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

The present understanding (based on the theoretical work of Konavalov, et al., proceedings of the IAEA-FEC 2012 conference, ITR/P1-38) is that as little as 5g of Be may be adequate for both thermal quench and runaway electron mitigation in ITER. This radiative payload must be deposited sufficiently deep inside the plasma.

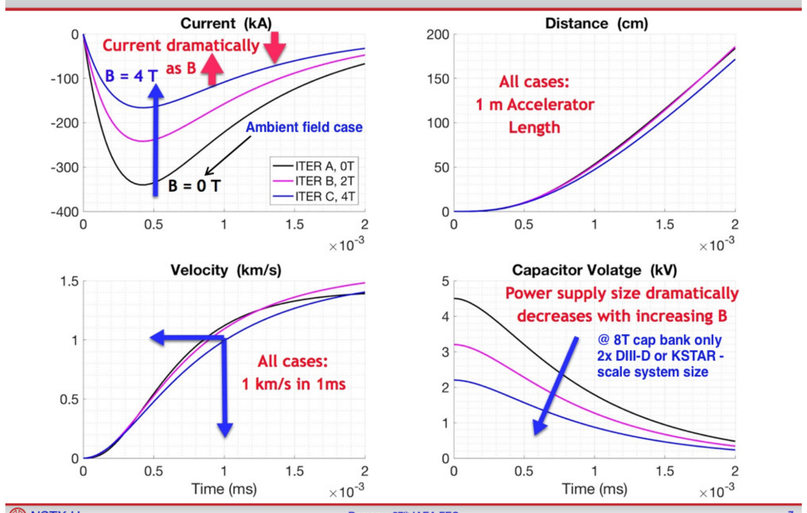
The Ambient B-Field of a High-Field Tokamak such as ITER Can be Used to Improve Device Efficiency



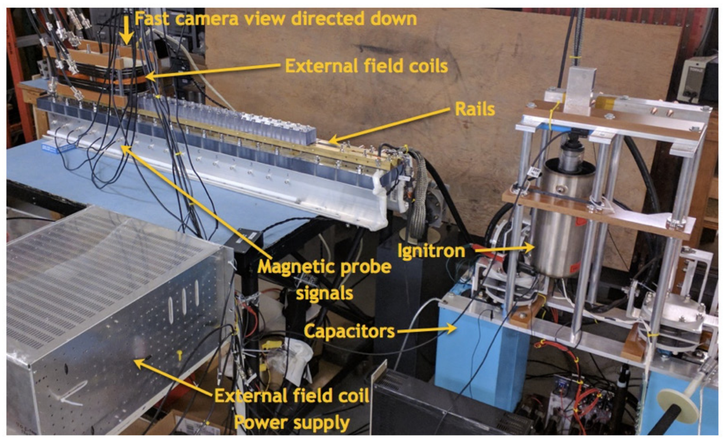
From: R. Raman, et al., Fusion Science & Technology, Vol.68 (Nov 2015) 797

- Injector can be positioned very close to the vessel, which further improves the system response time
- Use high-field SC boost coils (>8T) if located outside port plug

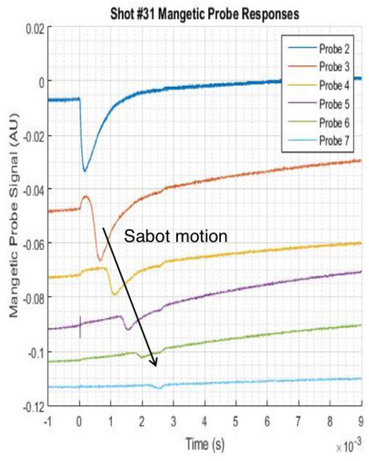
ITER Scale Injector Predicted to Attain 1 km/s in ~1 ms



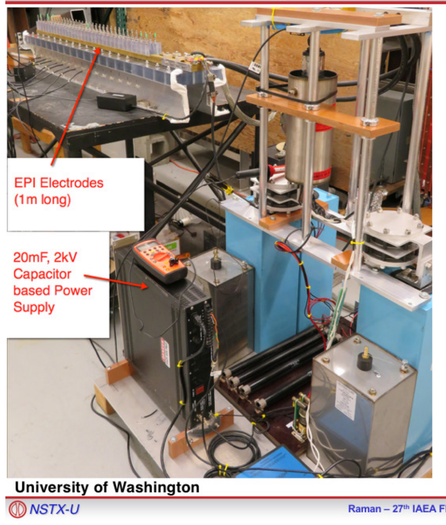
Small-scale System Used to Assess Critical Parameters & For Comparison With Projected Calculations

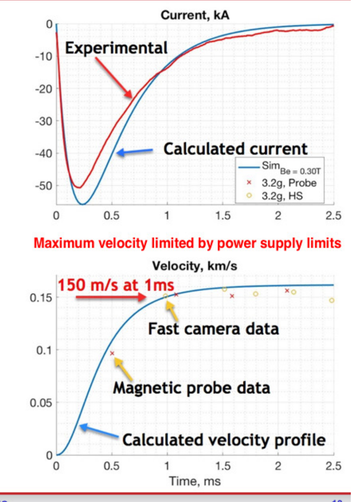


Magnetic Probes Located Below Rail Electrodes Track Sabot Motion & Used to Measure Velocity



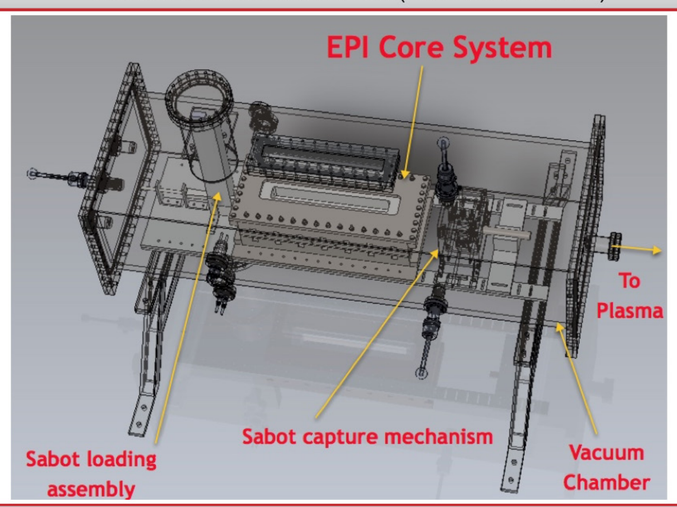
Measured EPI system parameters with 0.3T B-field Augmentation in Agreement with Simulation Predictions



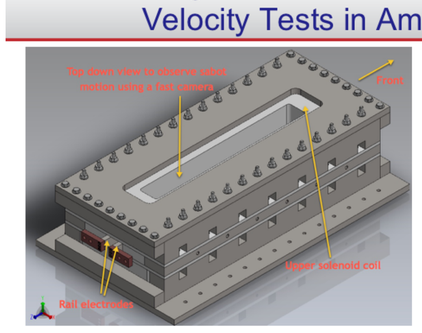


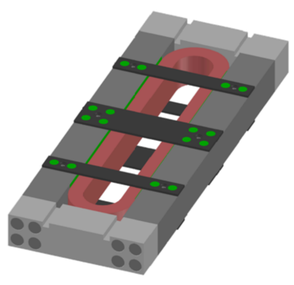
Next Step is to Conduct an EPI Test on a Tokamak

Vacuum Chamber Dimensions (1.5m x 0.6m x 0.5m)



Now Starting to Assemble EPI Core Region For Higher Velocity Tests in Ambient Atmosphere

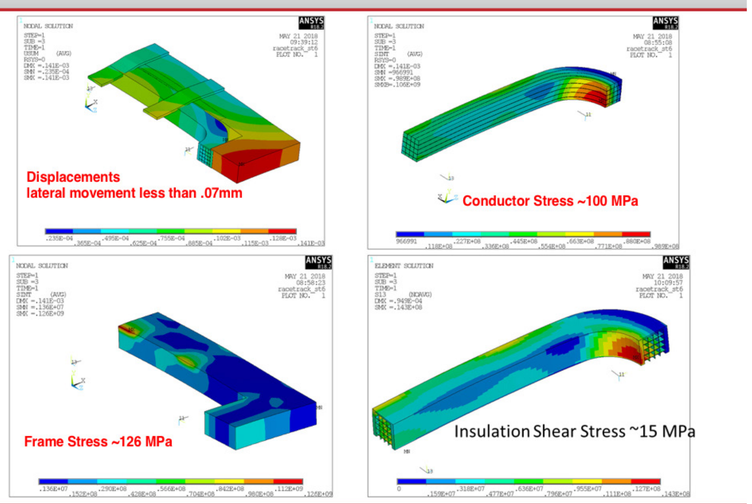




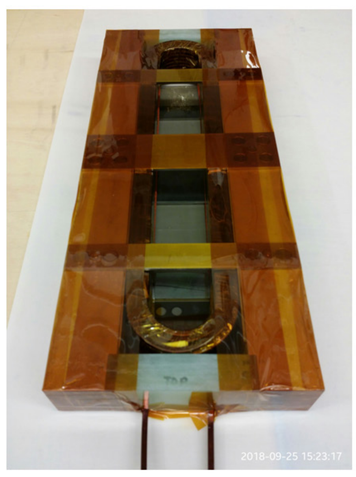
Coil Supports Designed to Restrain Coil Motion

- Lateral Support added to Racetrack Coil
  - Inconel Frame 2"x2" bars bolted together
  - Titanium Straps top and bottom to strengthen & stiffen straight legs
- Coil not constrained by frame at ends
- System will undergo a detailed design review at PPPL before improvements are fabricated and tested

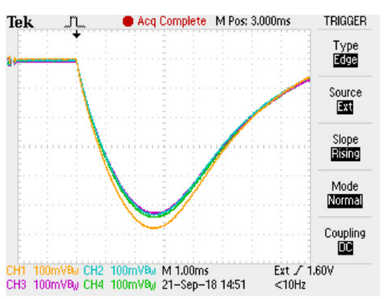
Detailed Modeling of Coil Supports (A. Brooks, PPPL)



Boost Coils and Supports Fabricated and Tested to Generate 2 T Fields (248 kA.turns in Coil Limited by Power Supply Limits)

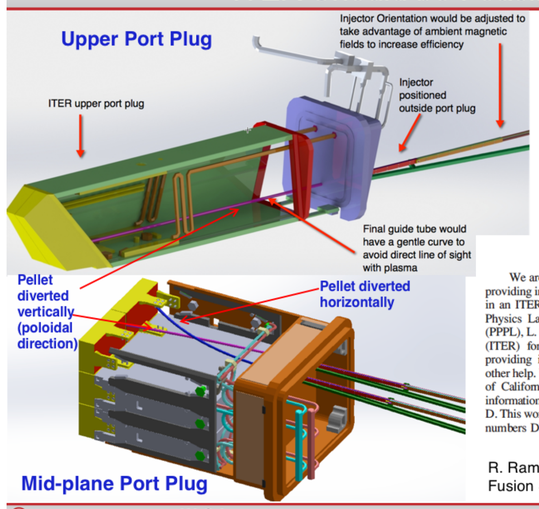


Magnetic probes signals from four magnetic probes located inside the coil region



Additional needed testing, needed power supply improvements, detailed design of sabots, and other needed fabrication work on hold pending new grant approval

Scoping Studies Suggest That an EPI Installation on ITER Should be Feasible



Concept Discussed With ITER Personnel During Concept Inception Phase

ACKNOWLEDGMENTS

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

EPI can Deliver Radiative Payload Deep into the Tokamak Plasma on a Fast <10 ms Time-scale

- EPI concept accelerates a metallic sabot to high velocity, which releases grains of particles of the required size and velocity
- The EPI system has features needed for a reactor DMS
  - Can deposit payload in the RE channel – triggering an inside out thermal quench without reliance on MHD for transporting radiative payload to the core
  - It uses a single reliable actuator, and payload that is solid at room temperature – so it should be very reliable
  - It can be located close to vacuum vessel further improving response time
- Off-line setup at U-Washington has demonstrated key aspects of concept, including 150 m/s velocities with 1 ms response time consistent with calculations
- Tokamak tests are the next logical next step for concept development
  - Improved system is now under design modifications and design reviews
  - Assembly and testing underway, but presently on hold pending grant approval
  - Tokamak tests will develop experimental database on solid particle injection for theory simulations