NSTX-U

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

PPPL SPI / EPI Experiments and Modeling Needs

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

R. Raman[1], W-S. Lay[1],
T.R. Jarboe[1], J.E. Menard[2]
[1]University of Washington / [2]PPPL
22 October 2017

APS DPP 2017
Milwaukee, WI

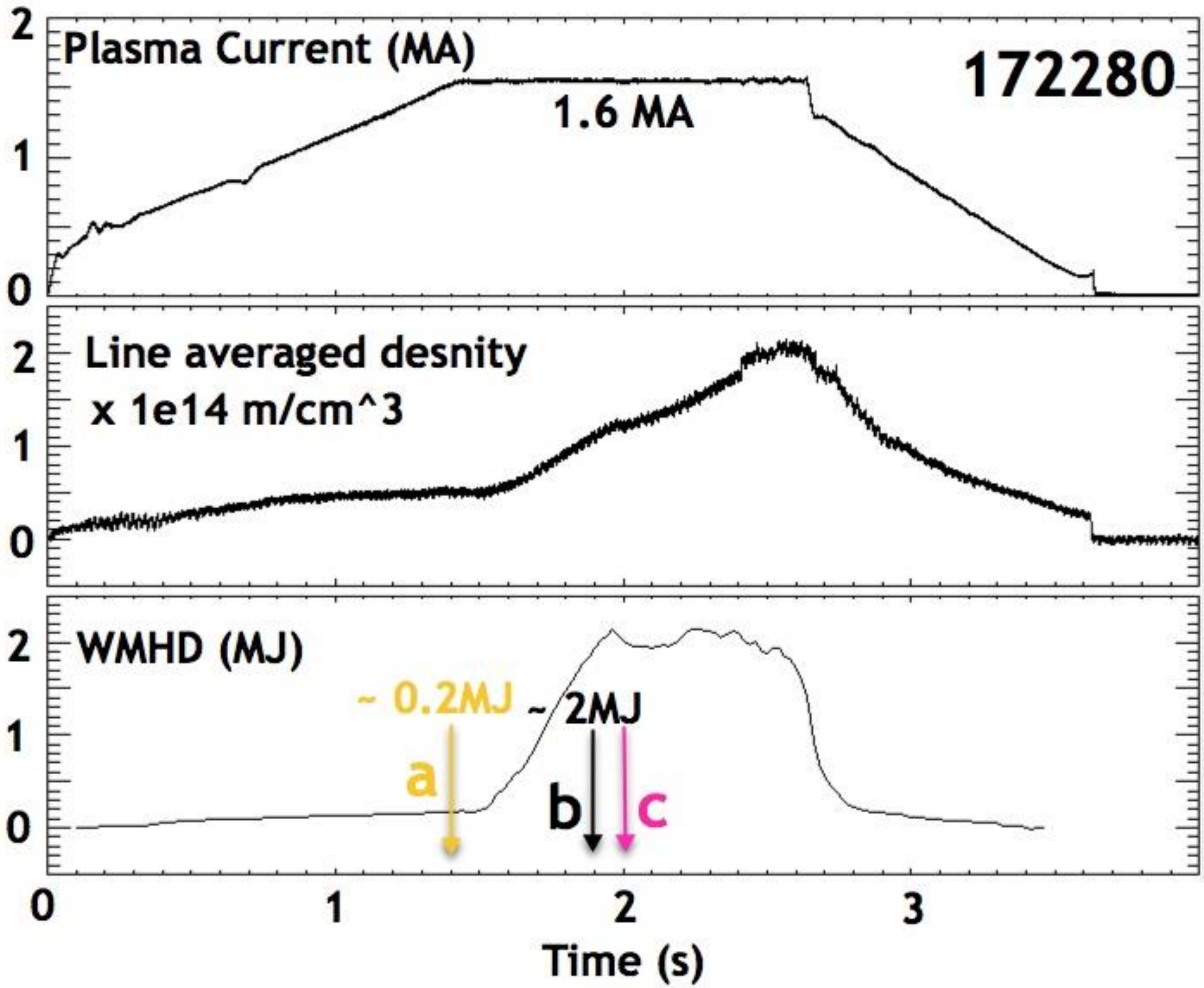
This work is supported by US DOE contract numbers DE-SC0006757 and DE-AC02-09CH11466

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

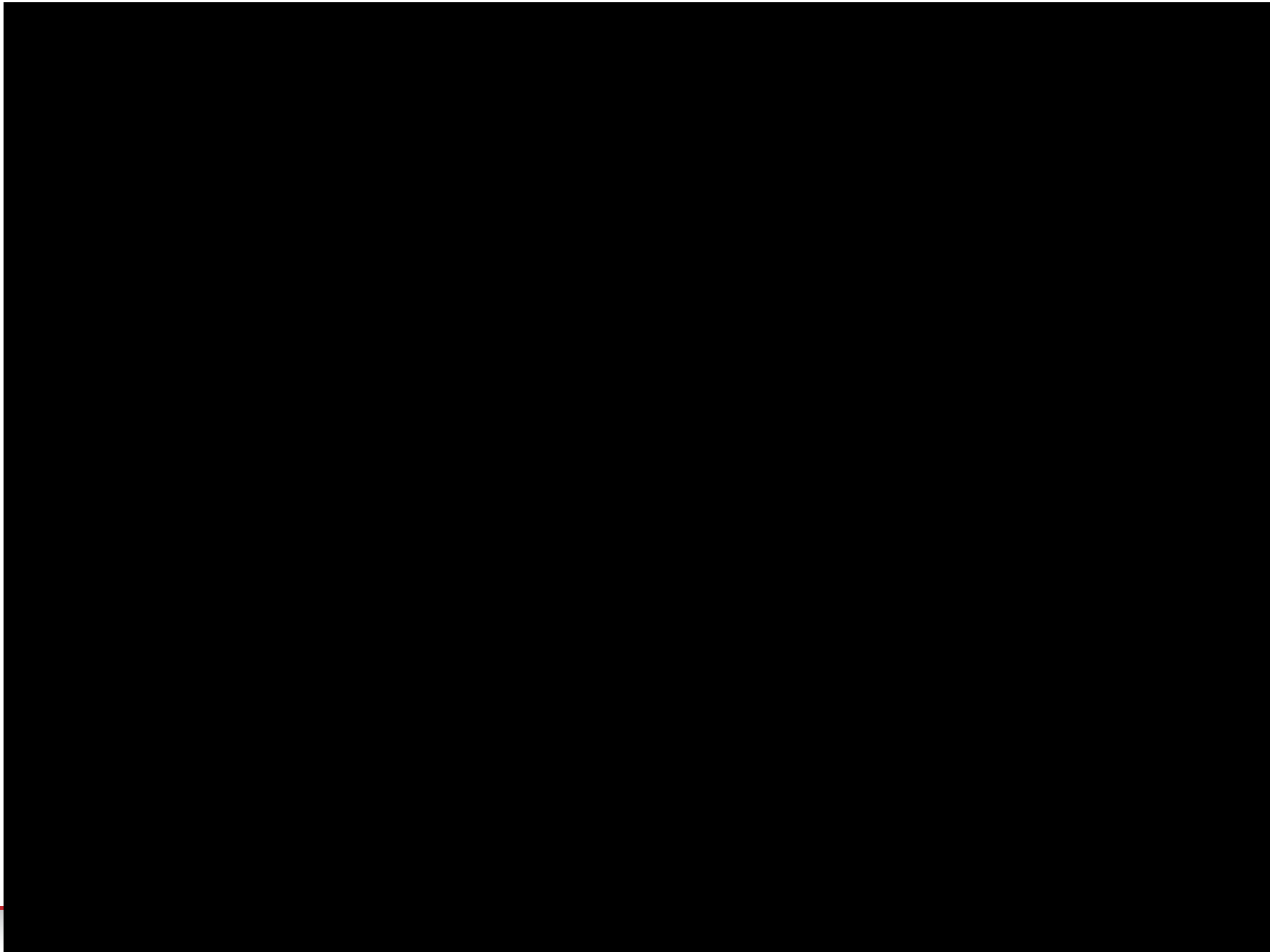
Limitations of the Shattered Pellet System

- Most of the DM databases is from MGI experiments, but MGI has been dropped by ITER due to its slow response time
- The speed of the un-fragmented high-mass SPI pellets is restricted to about 200-400m/s due to the gas propellant. MGI valve propels the SPI
- 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

Penetration of SPI into High Energy Plasmas is a Challenging (Same DIII-D target plasma used for L&H Modes)



DIII-D SPI Injection Movies (R. Moyer – UCSD / DIII-D)



How does the EPI concept address present limitations?

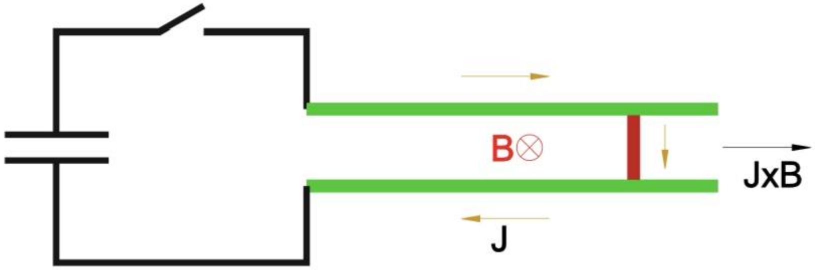
- The EPI concept injects grains of material (of the required size) and at the required velocity – & it does this on a fast time scale (2-3ms)

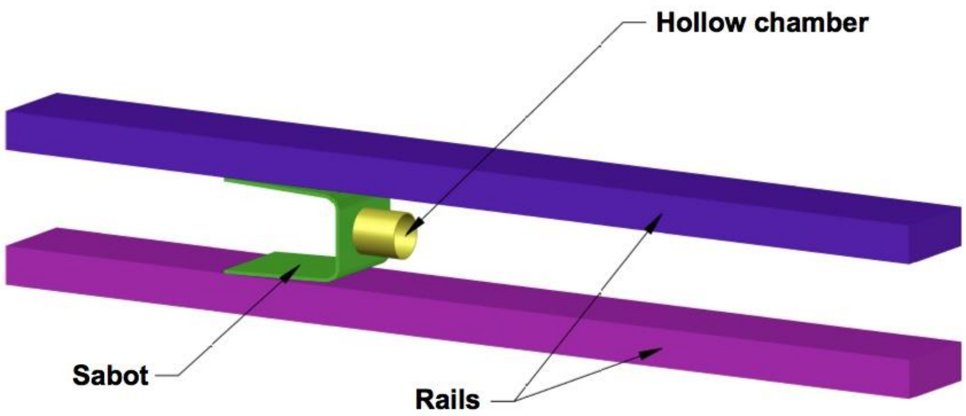
- One can precisely calculate the needed size / velocity combination of a spherical particle for penetrating to the center of any given plasma, including the ITER plasma

How does the EPI system achieve the required needs for a ITER DMS?

- The EPI system accelerates a metallic sabot
- The sabot is a metallic capsule that can be accelerated to high-velocity, for core deposition, 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



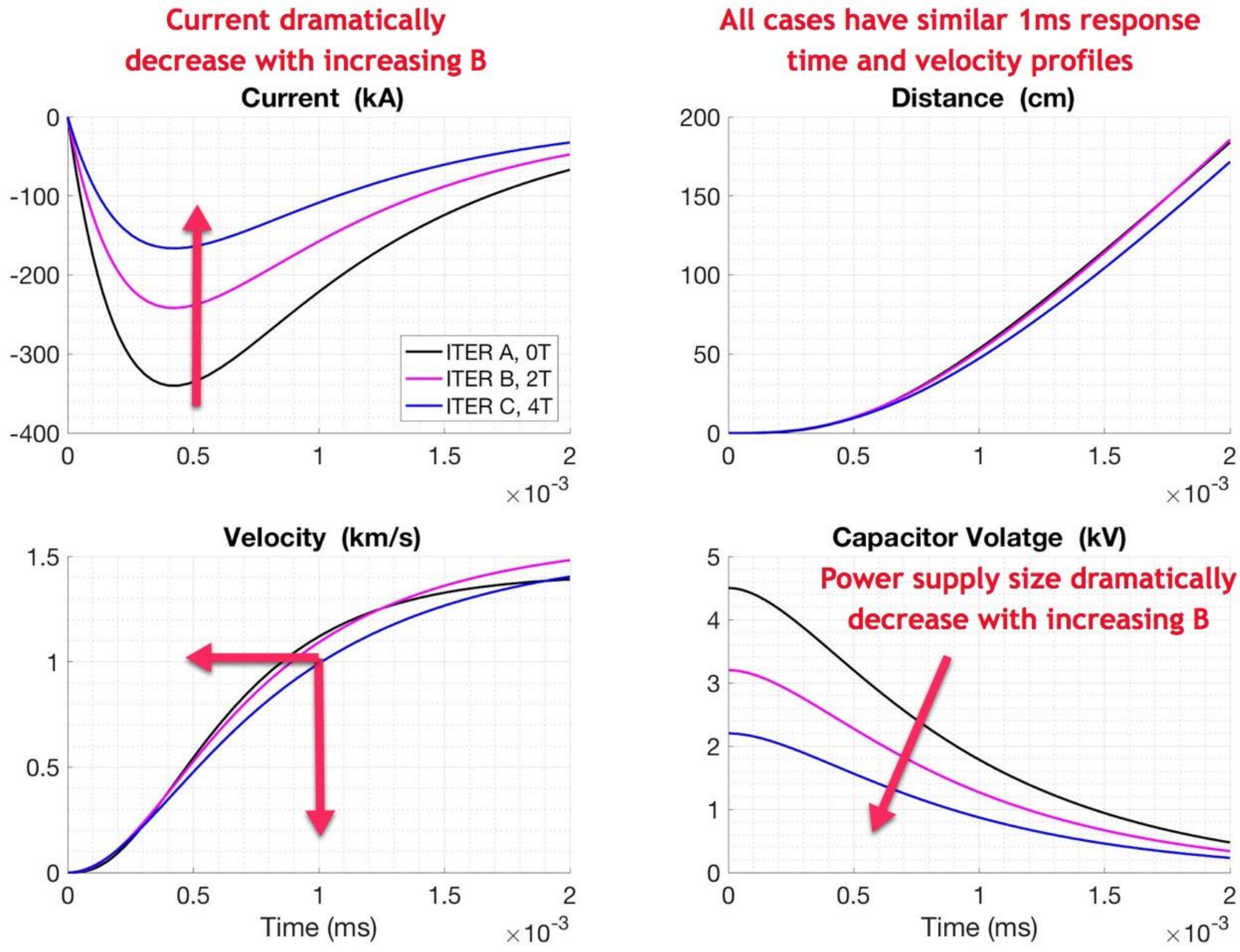


•An important advantage of the EPI system is that the ambient magnetic field of a large high-field tokamak such as ITER can be used to increase the device efficiency

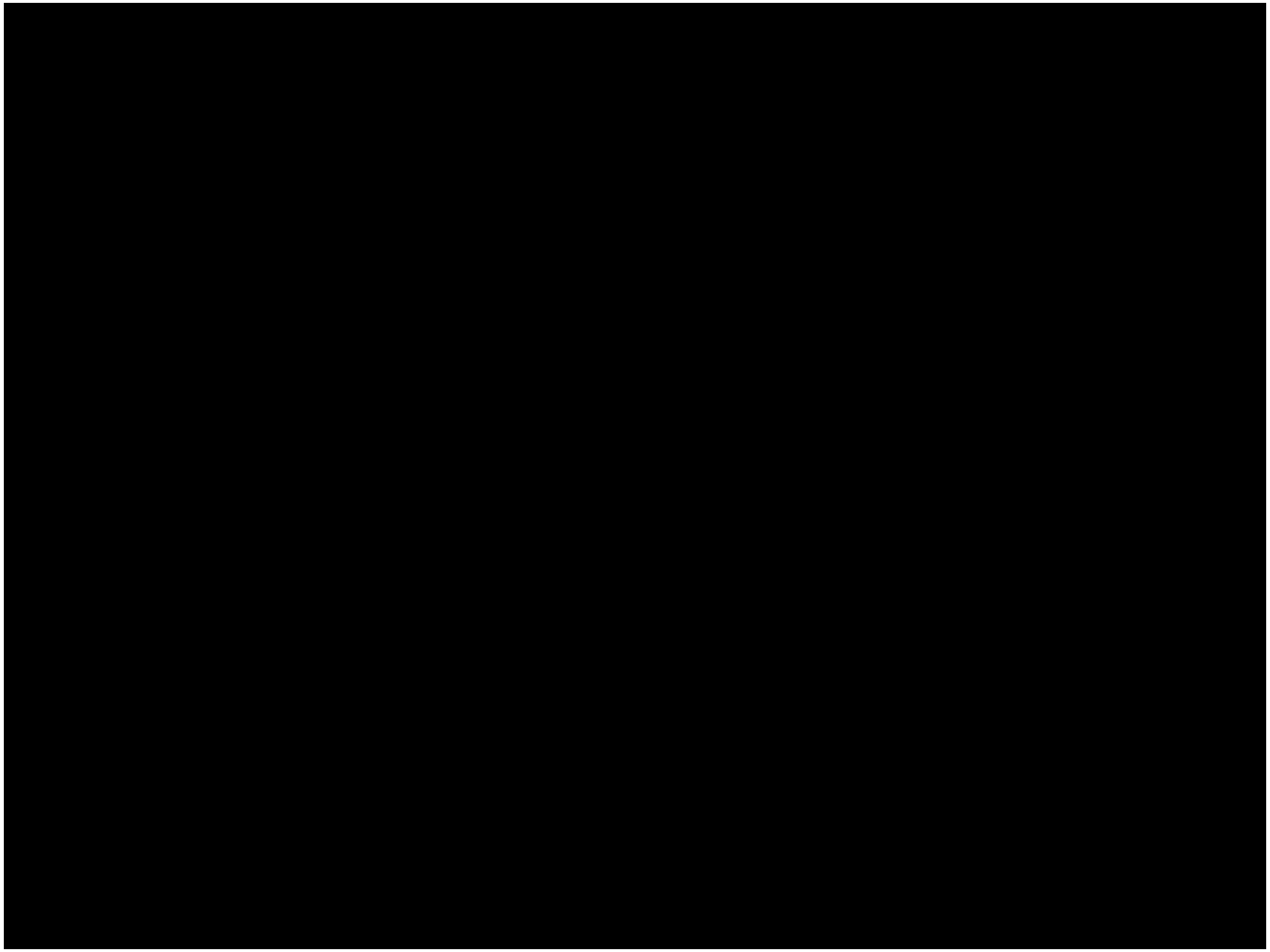
•Injector can be positioned very close to the vessel, which further improves the system response and efficiency

•Payload: variable size grains of Be, B, or BN granules or a Shell Pellet, with variable velocity

ITER Scale Injector Should Attain 1 km/s in ~1ms

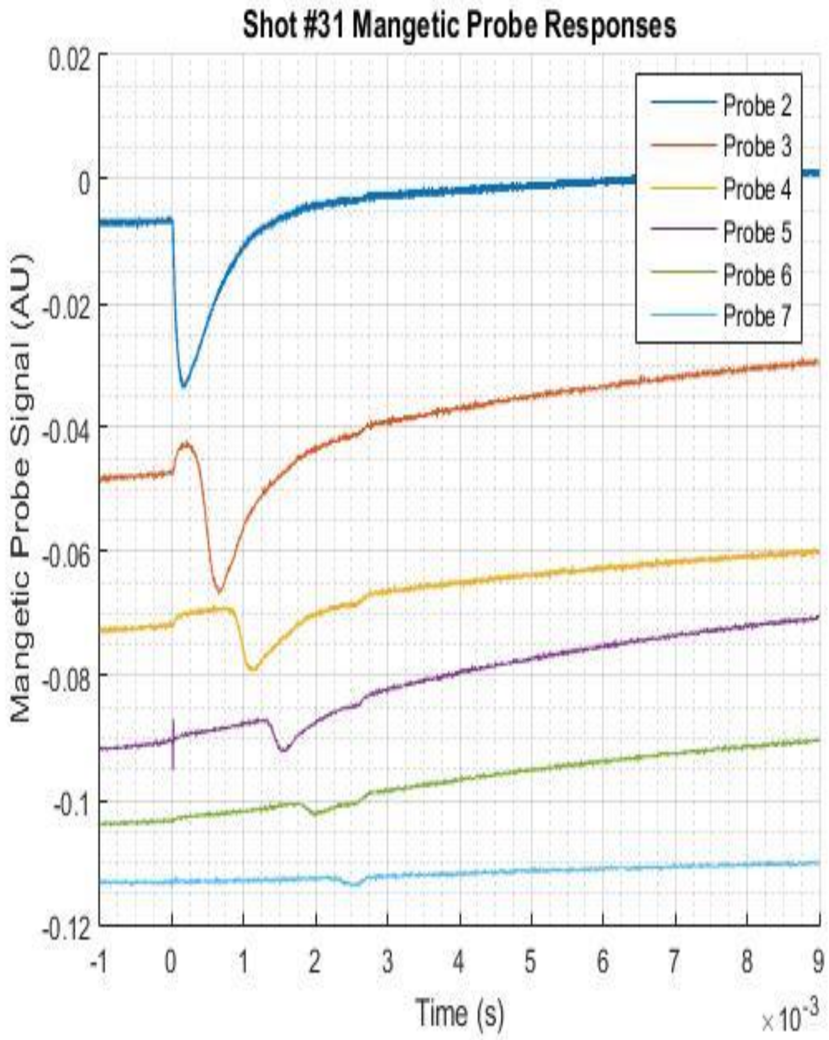


Example of EPI System in Operation

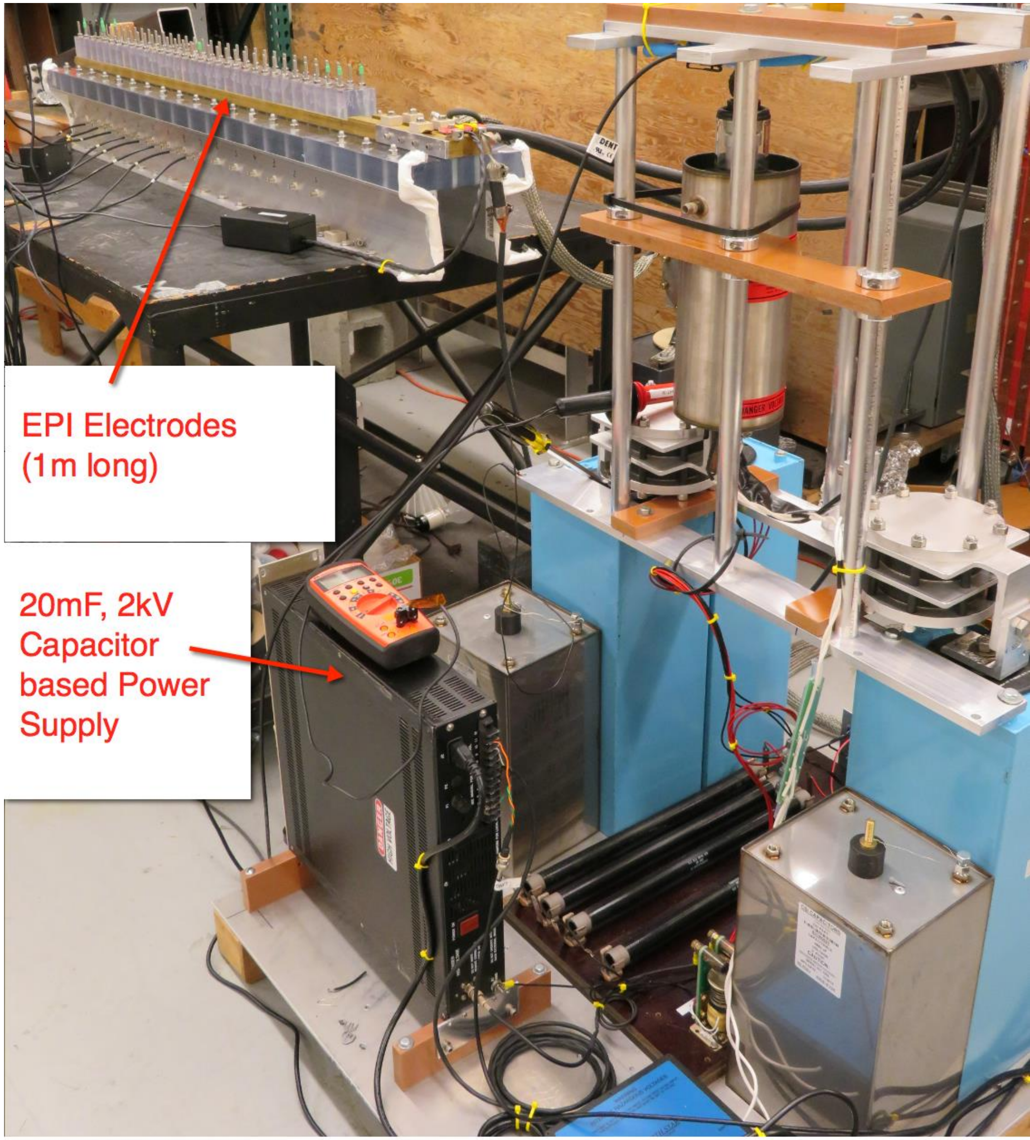


Magnetic probes located below the injector track motion of the sabot

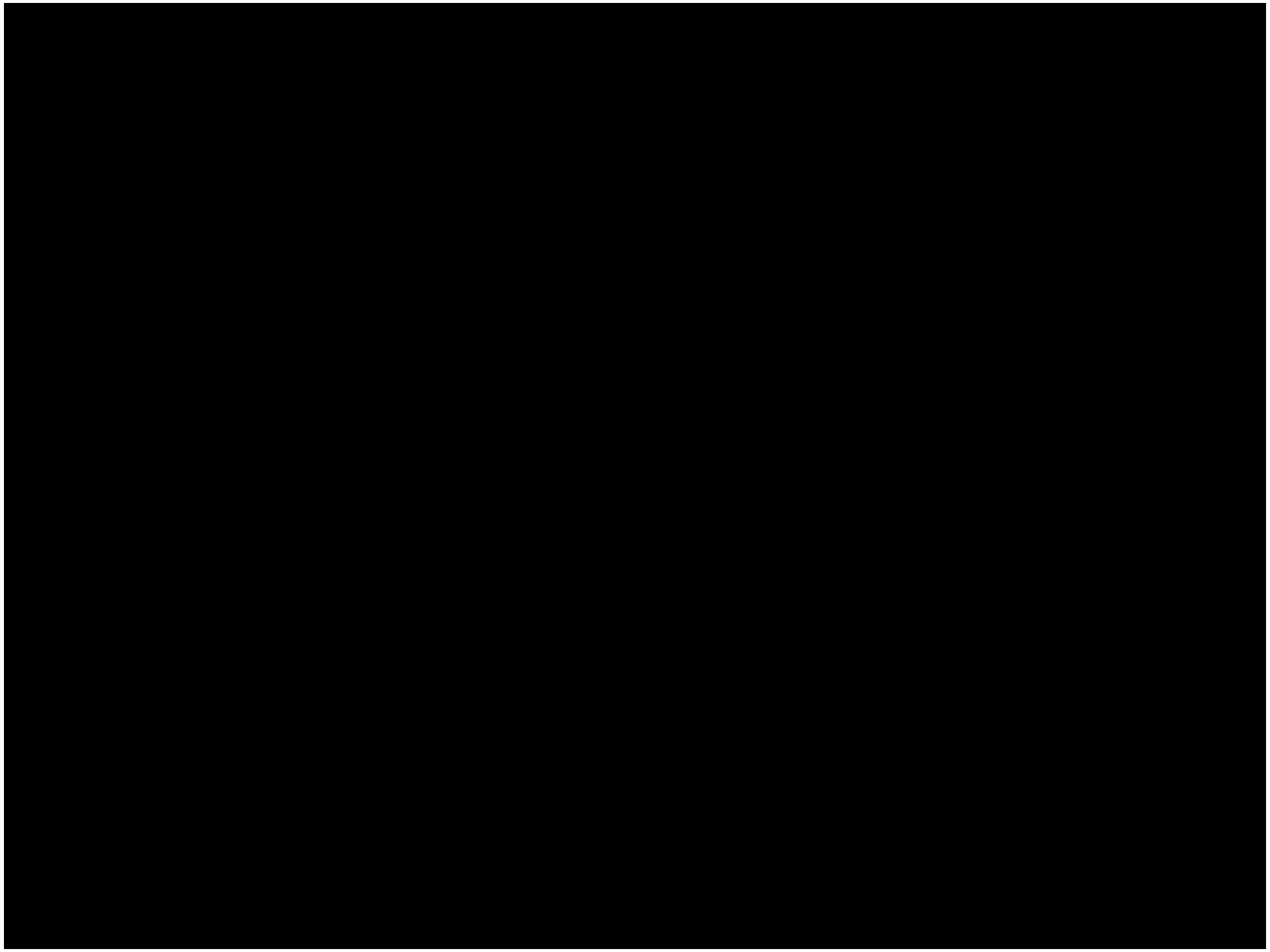
Sabot Position Tracking using Magnetic Probes Indicates Attainment of Maximum Velocity in <2ms after Trigger Time



Magnetic probes located below injector track motion of sabot

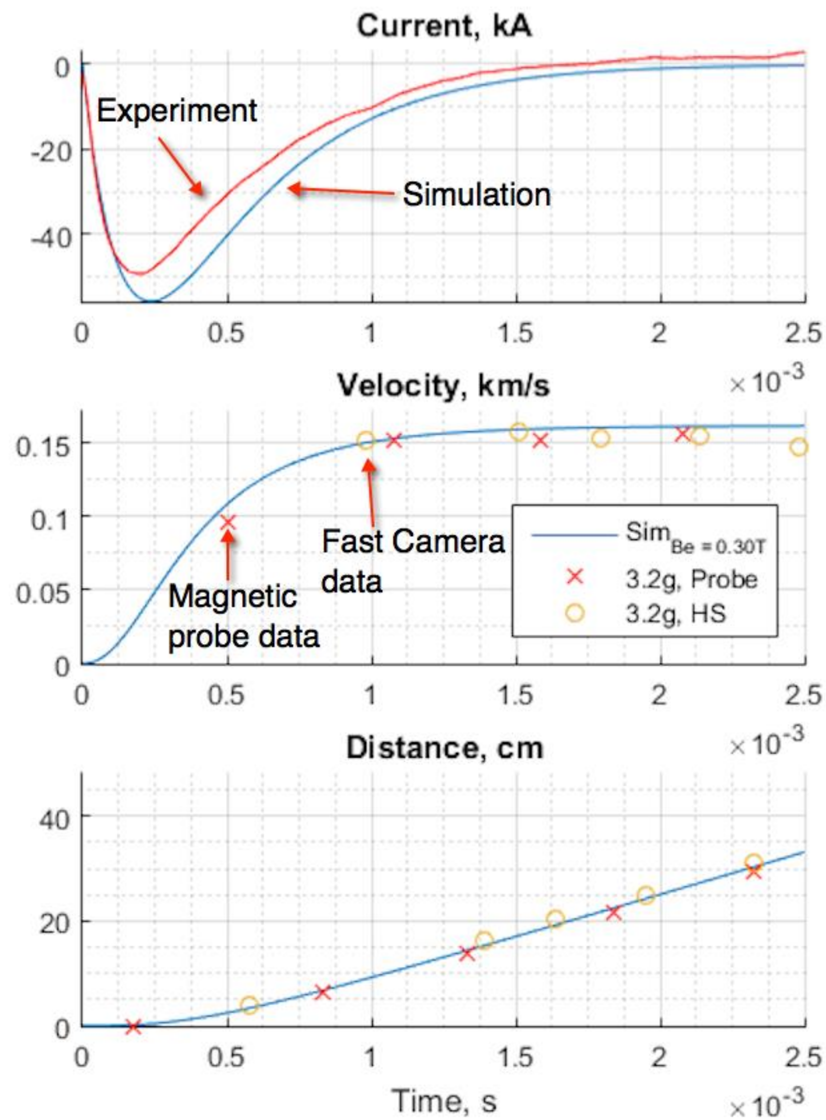


2.5ms Fast Camera Movie of Sabot Motion



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

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.

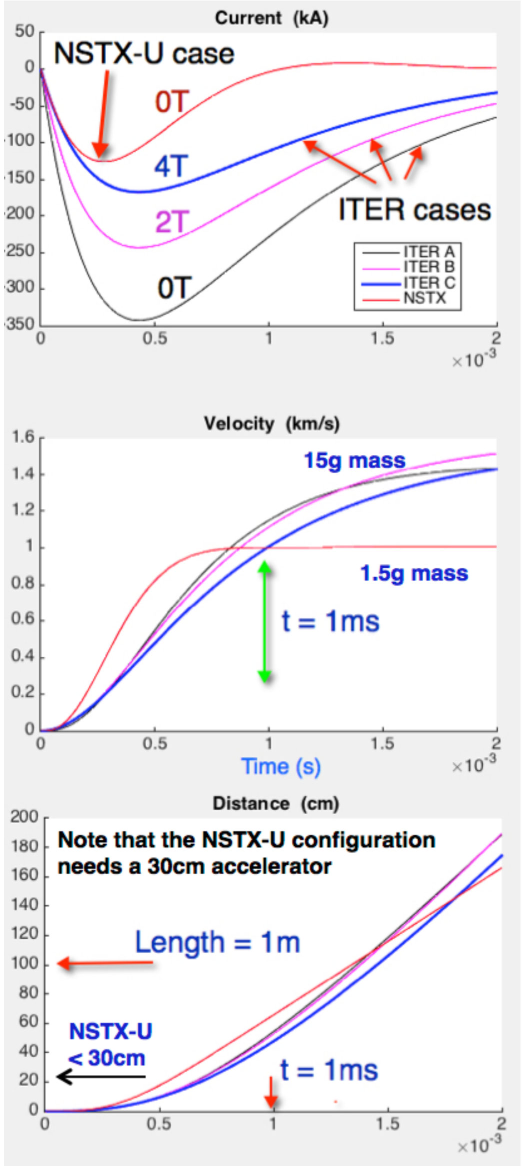
EPI can Deliver Impurity Particles Deep into the Tokamak Plasma on a Fast Time-scale

- 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

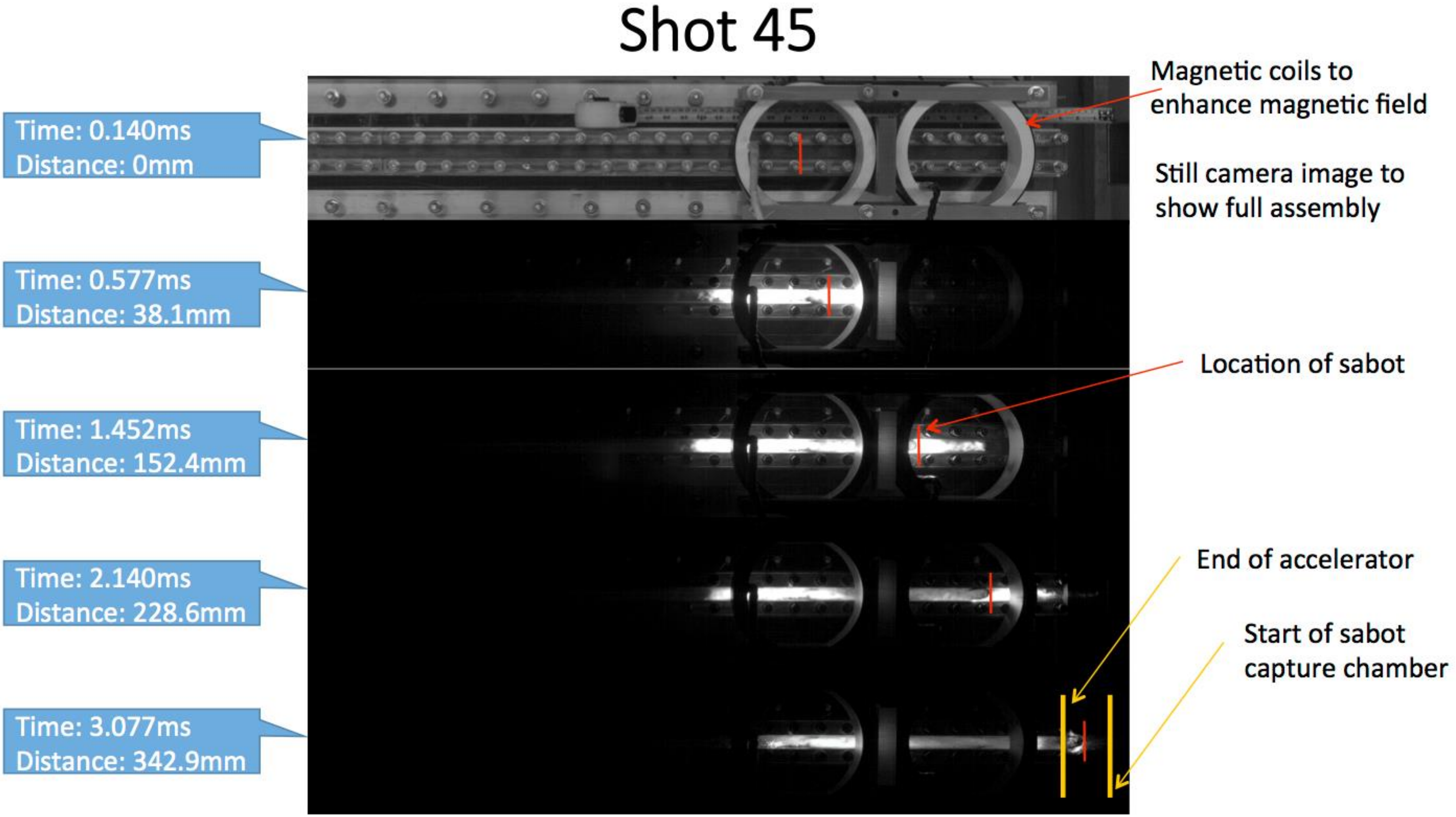
Other Slides

How does the EPI concept scale to ITER?

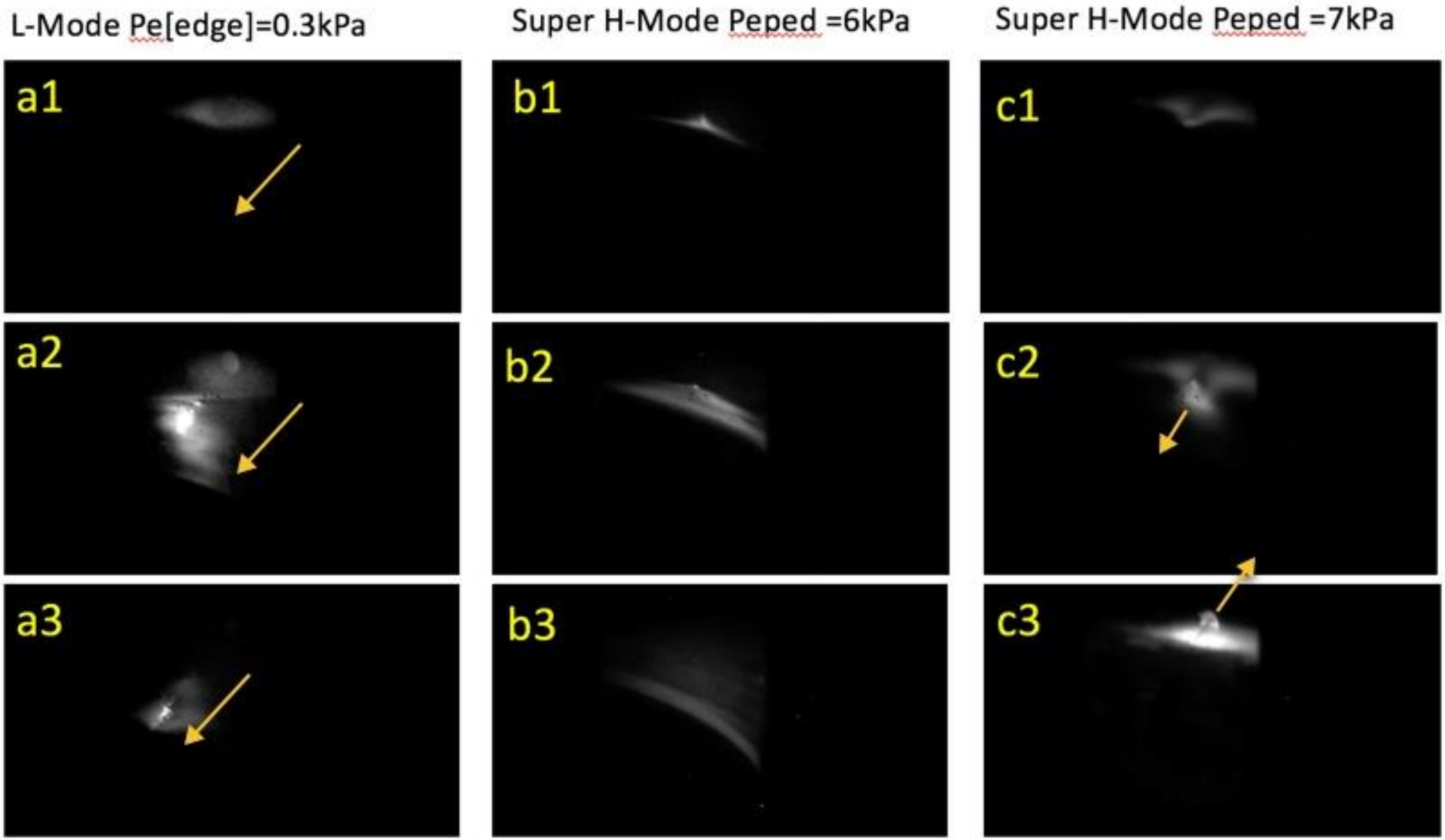
- With increasing external magnetic field, the required current drops dramatically and approaches that for a DIII-D/NSTX-U scale experiment
  - The NSTX-U/DIII-D case is for 1.5g mass
  - The ITER case is for 15g mass (5g payload may be sufficient)
- The time response for attaining the required velocity 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



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



Fast Camera Images (R. Moyer)



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

TECHNICAL NOTE

R. RAMAN,[a]* T. R. JARBOE,[a] J. E. MENARD,[b] S. P. GERHARDT,[b] M. ONO,[b] L. BAYLOR,[c] and W.-S. LAY[a]

[a]*University of Washington, William E. Boeing Department of Aeronautics and Astronautics Seattle, Washington*
[b]*Princeton Plasma Physics Laboratory, Princeton, New Jersey*
[c]*Oak Ridge National Laboratory, Oak Ridge, Tennessee*

Received November 19, 2014
Accepted for Publication July 17, 2015
http://dx.doi.org/10.13182/FST14-916

Fusion Science and Technology, **68**, pg 798, Nov 2015

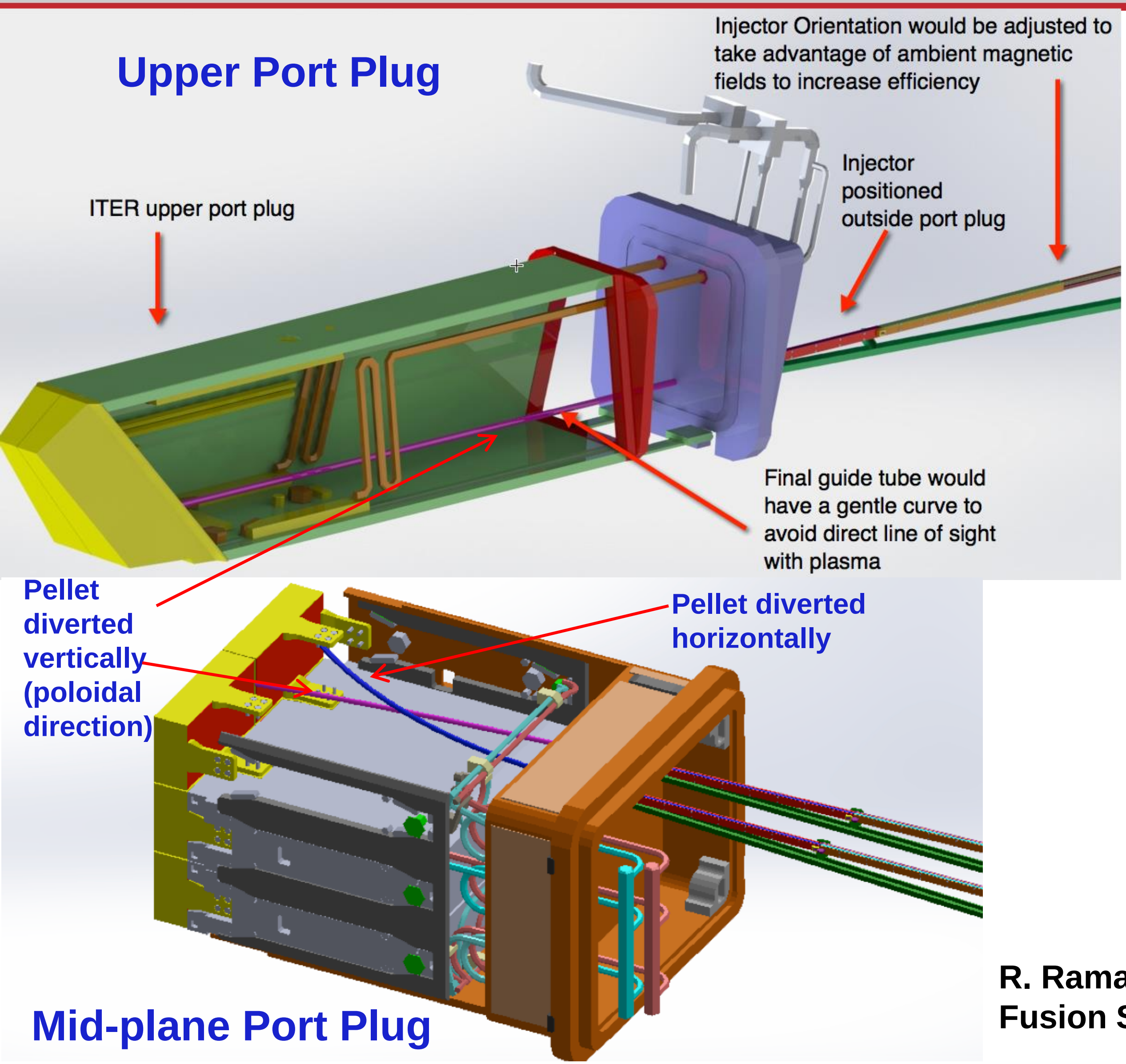
ACKNOWLEDGMENTS

We are grateful to M. Lehnen of the ITER Organization for providing information related to materials that are suitable for use in an ITER DMS. Many thanks to R. Feder [Princeton Plasma Physics Laboratory (PPPL)], G. Loesser (PPPL), J. Kiabacha (PPPL), L. Konkel (PPPL), V. Barabash (ITER), and M. Raphael (ITER) for providing drawings of the ITER port plug, for providing information on materials allowed in ITER, and for other help. We would like to thank E. Hollmann of the University of California, San Diego, and the DIII-D Team for providing information on the shell pellet being considered for use on DIII-D. This work is supported by U.S. Department of Energy contract numbers DE-SC0006757 and DE-AC02-09CH11466.

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

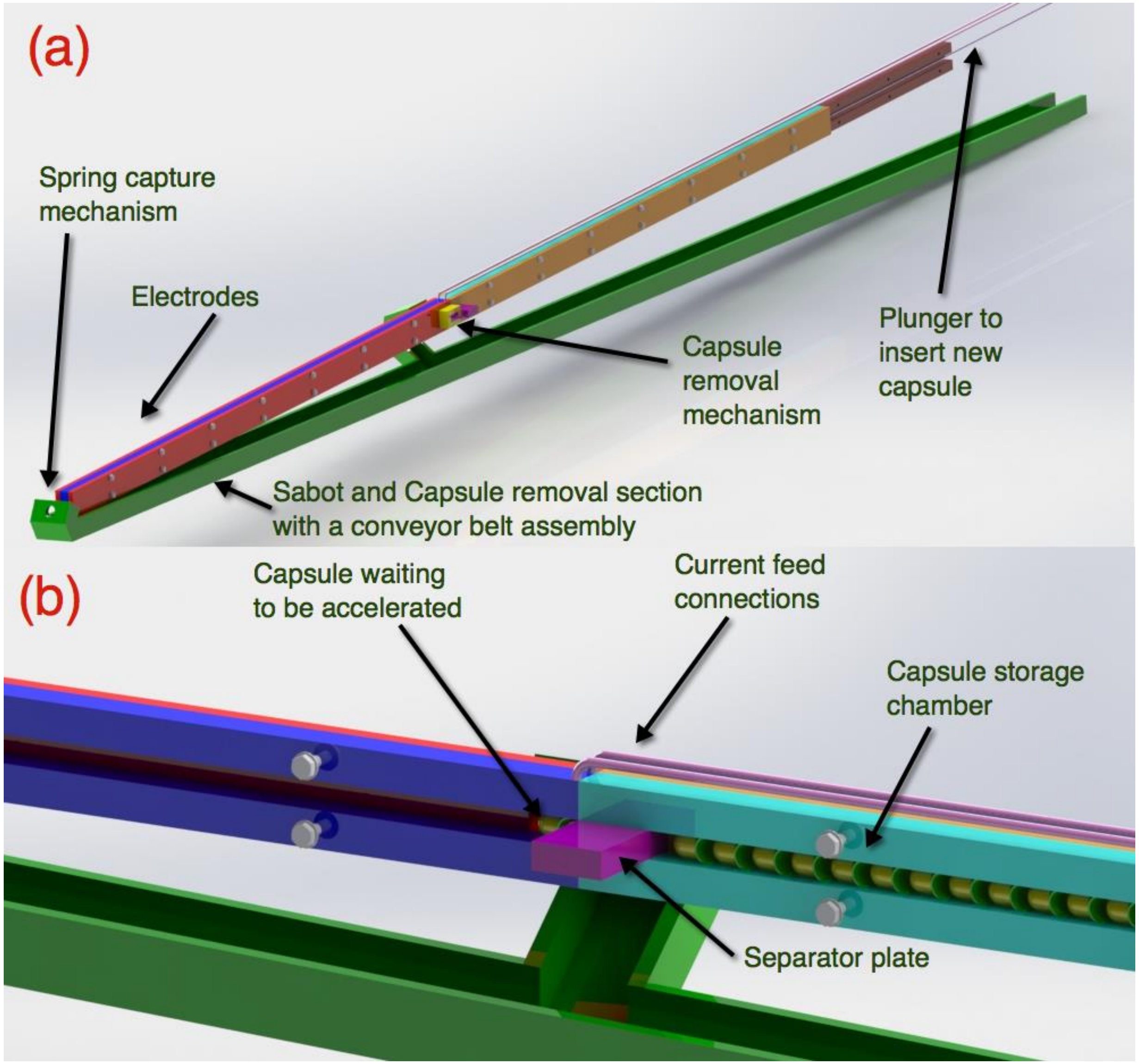
Scoping Studies Suggest that an EPI Installation on ITER should be feasible*



*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