Best Wishes from MIT for your Birthday, Ron !

Massachusetts Institute of Technology

Plasma Science and Fusion Research at the PSFC : a Historical Perspective

Miklos Porkolab

Davidson Symposium, June 11, 2007
Princeton, NJ

The Early Days: Before 1978 (Pre-Davidson)

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- **Important university scale research at MIT since the 1960s, with many faculty members, students and small scale experiments with one exception : Alcator A**
- **Alcator A, a compact but high field tokamak achieves world class plasma parameters, namely record $n\tau_E$ for a tokamak of modest size (R=54cm, a=10.5cm) but high magnetic field (13 T) (Coppi, Parker, Taylor later share the Excellence in Plasma Research Award of APS)**
- **MIT proposes establishment of the Plasma Fusion Center, (PFC) in 1977 with Alcator-A as the center piece**
- **Search committee selects Ron Davidson as the new Director (replaces Al Hill in 1978) and he helps to build the PFC into a world class research center during his next 10 years of tenure**

Major New Initiatives at the PFC during the "Davidson Decade"

- **Alcator -C (R=64 cm, a=16.5 cm, B=10+ Tesla) is built in the National Magnet Laboratory under the leadership of Ron Parker to replace Alcator -A and operates through 1985**
- **Davidson brings the TARA tandem mirror project, under the leadership of Dick Post from Madison, Wisconsin to MIT, to be located in a newly built annex to the "Nabisco Laboratory", recently donated to MIT; TARA construction completed in the early 1980s**
- **Davidson unifies the PFC infrastructure by building 2 overpasses to connect the PFC laboratories and the Magnet Lab (Alcator's home)**
- **Alcator C-Mod is authorized and constructions begins in the mid to late 1980s in the Nabisco Laboratory while TARA is shut down**

Alcator-C and "Team" in the MIT Magnet-Lab

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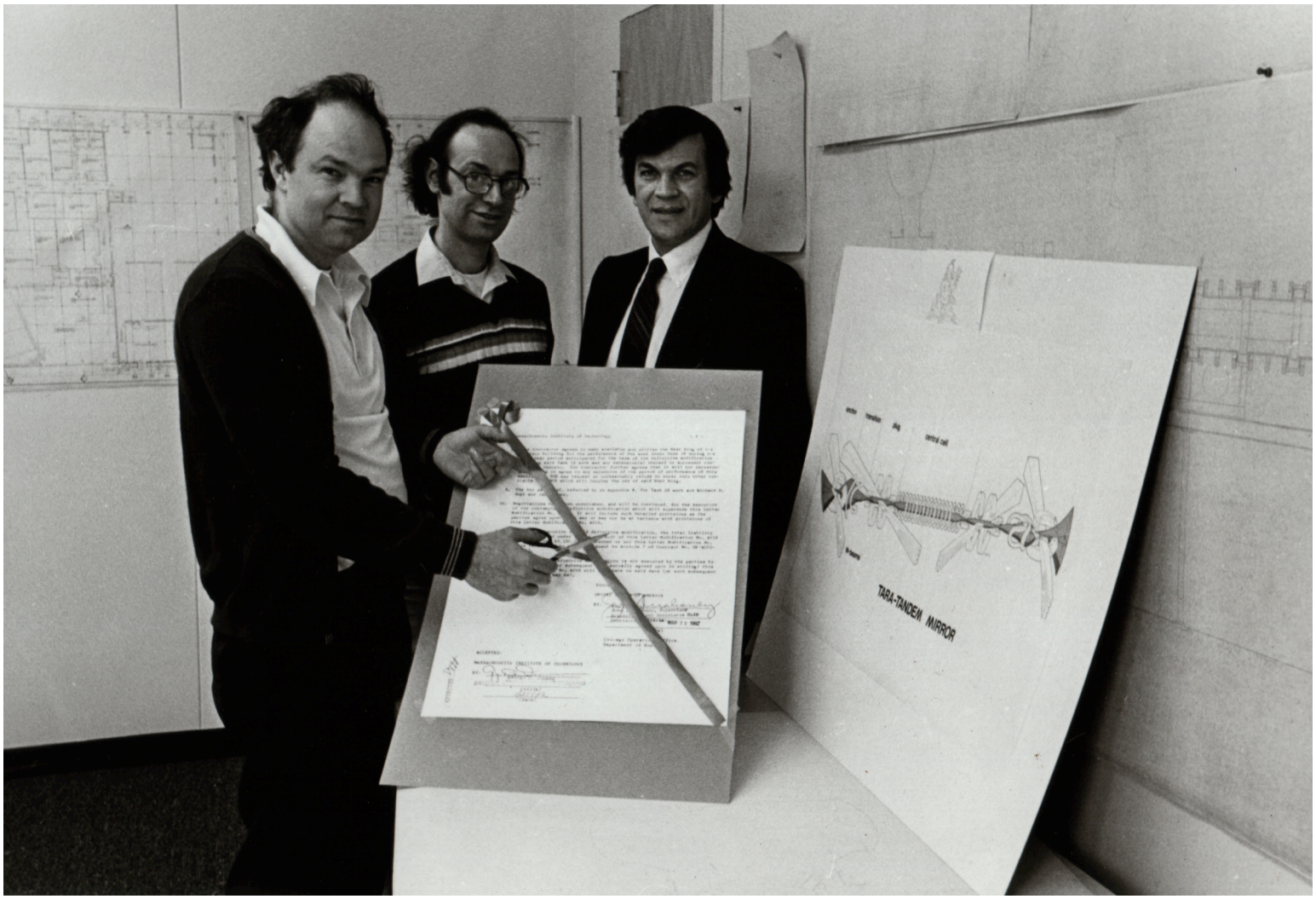
Dick Post, Jay Kesner and Ron Davidson at the "Ribbon Cutting" Ceremony of TARA being Approved



TARA Construction in the NABISCO Laboratory

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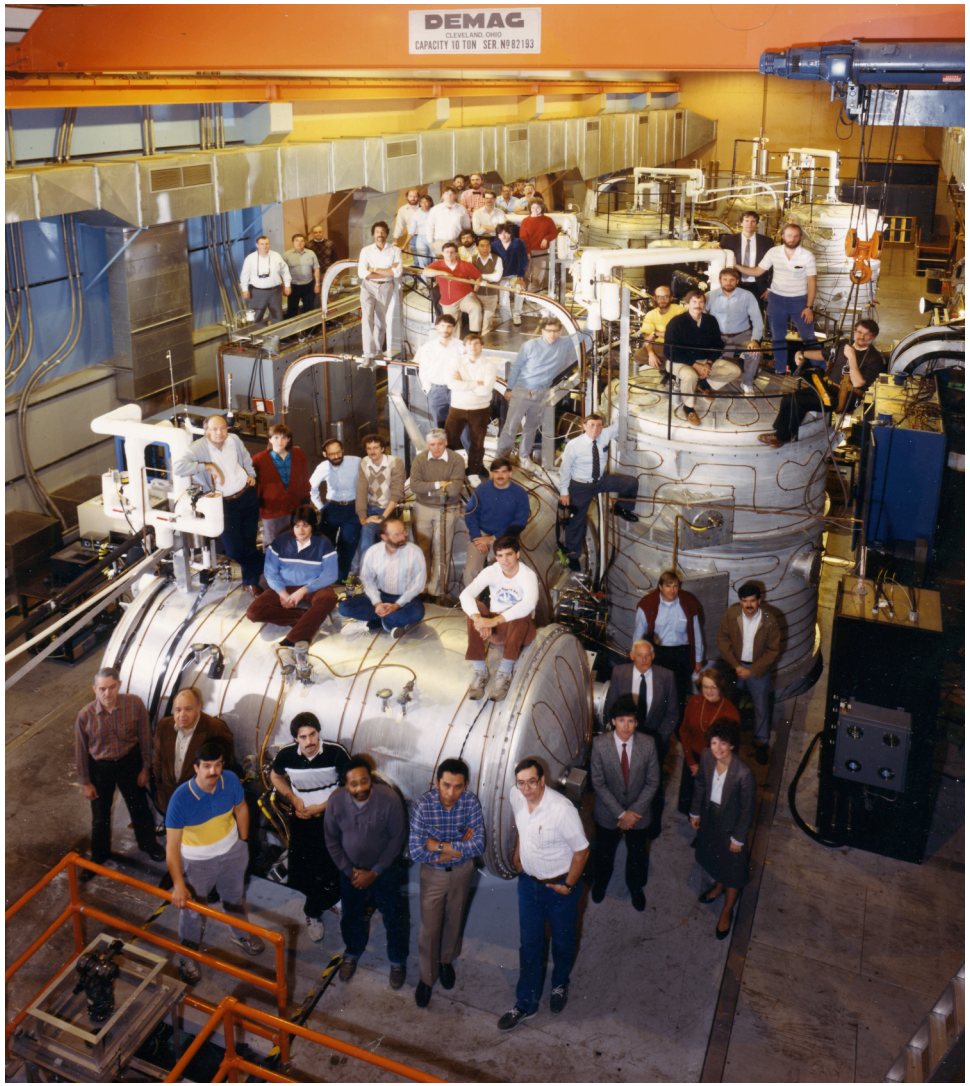

Dick Post and his "team" during the construction phase of TARA at the PFC Nabisco laboratory at MIT in the 1980s

TARA near Completion in the NABISCO Laboratory

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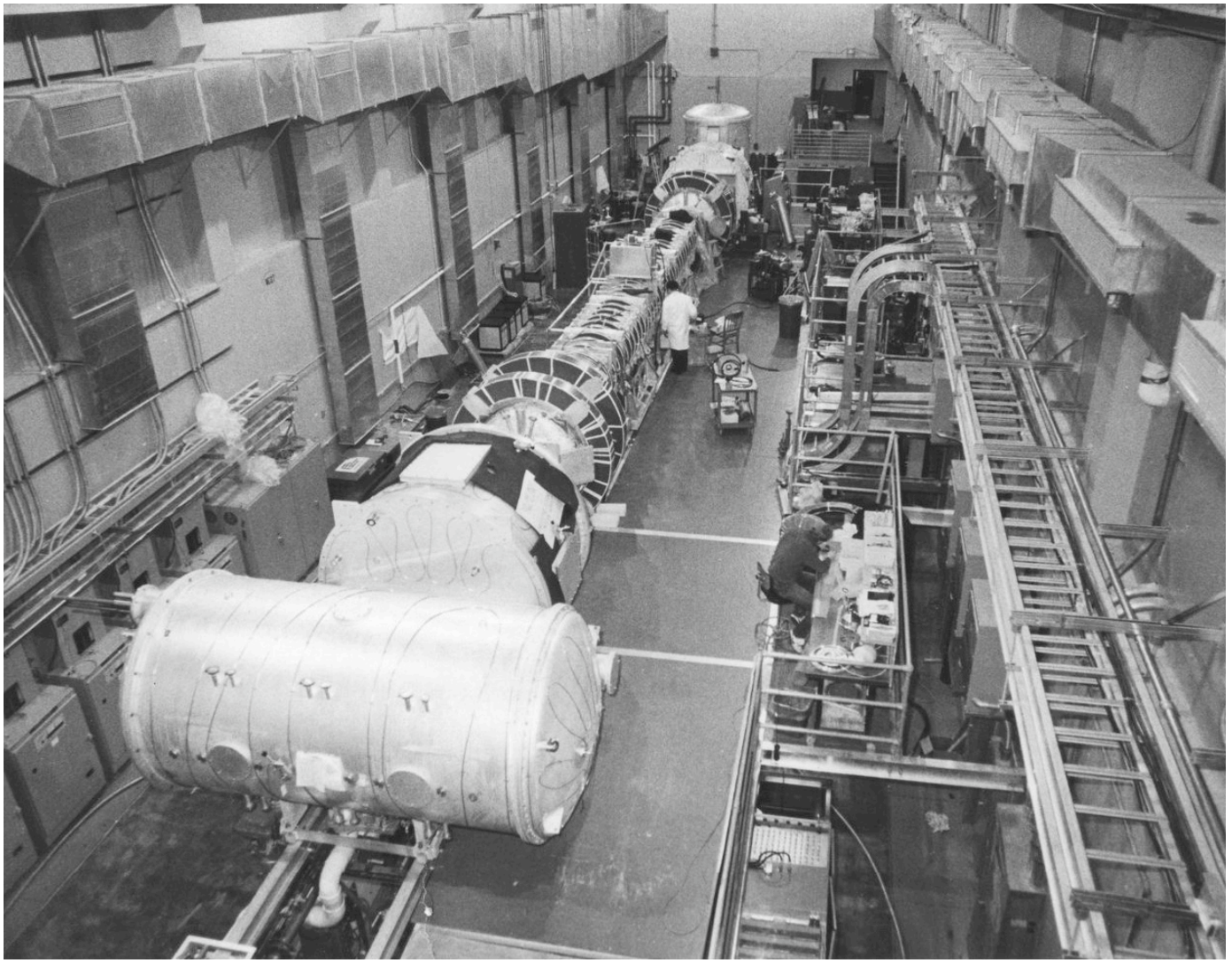

Lunch at the MIT Faculty Club Celebrating the Latest Project

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R. Davidson, J. Clarke, J. Davidson, and E Kintner

ALCATOR C-Mod Completed in the NABISCO Laboratory (1990s) while the PFC is under the Leadership of Director Ron Parker; C-mod going strong even today !

Starting 1996, PFC changes the name to PSFC

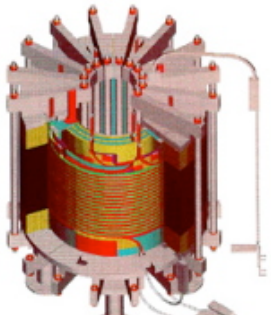
- In 1992 Ron Davidson leaves MIT to become Director of the PPPL and Ron Parker becomes Director of the PFC at MIT
- In 1993 Ron Parker leaves MIT to become the Deputy Director of ITER in Garching and in 1995 the MIT Provost appoints Miklos Porkolab as the new Director of the PFC
- After the budget cuts in the 1990s "science" becomes the driving force in fusion research, TFTR is shut down, TPX not authorized, and at MIT the PFC name is changed to PSFC
- New emphasis at the PSFC on broadening plasma research activities, including plasma science and near term applications of plasma technologies, while expanding the Alcator C-Mod program to include Advanced Tokamak (AT) research

PSFC MIT Massachusetts Institute of Technology

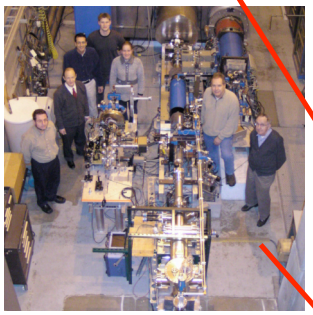
PSFC Today

- **Total staff of 155, including faculty, scientists, engineers and administration; typically 50 more visiting scientists a year**
- **Graduate students 56-60 at any one time, and 10 -15 undergraduates typical**
- **Total operating budget in excess of $30 million per year**
- **Largest on campus research center at MIT, affiliated with 6 academic departments**
- **6 Research Divisions: Alcator Project, Physics Research (includes theory), Beams and Accelerators, Fusion Engineering and Technology, Plasma Technology, and HEDP (new, result of Davidson's NRC Report on advocating HEDP research)**

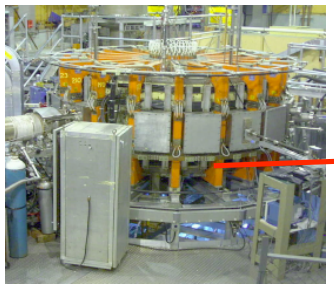
The MIT Plasma Science and Fusion Center is a World Class University Based Research Center



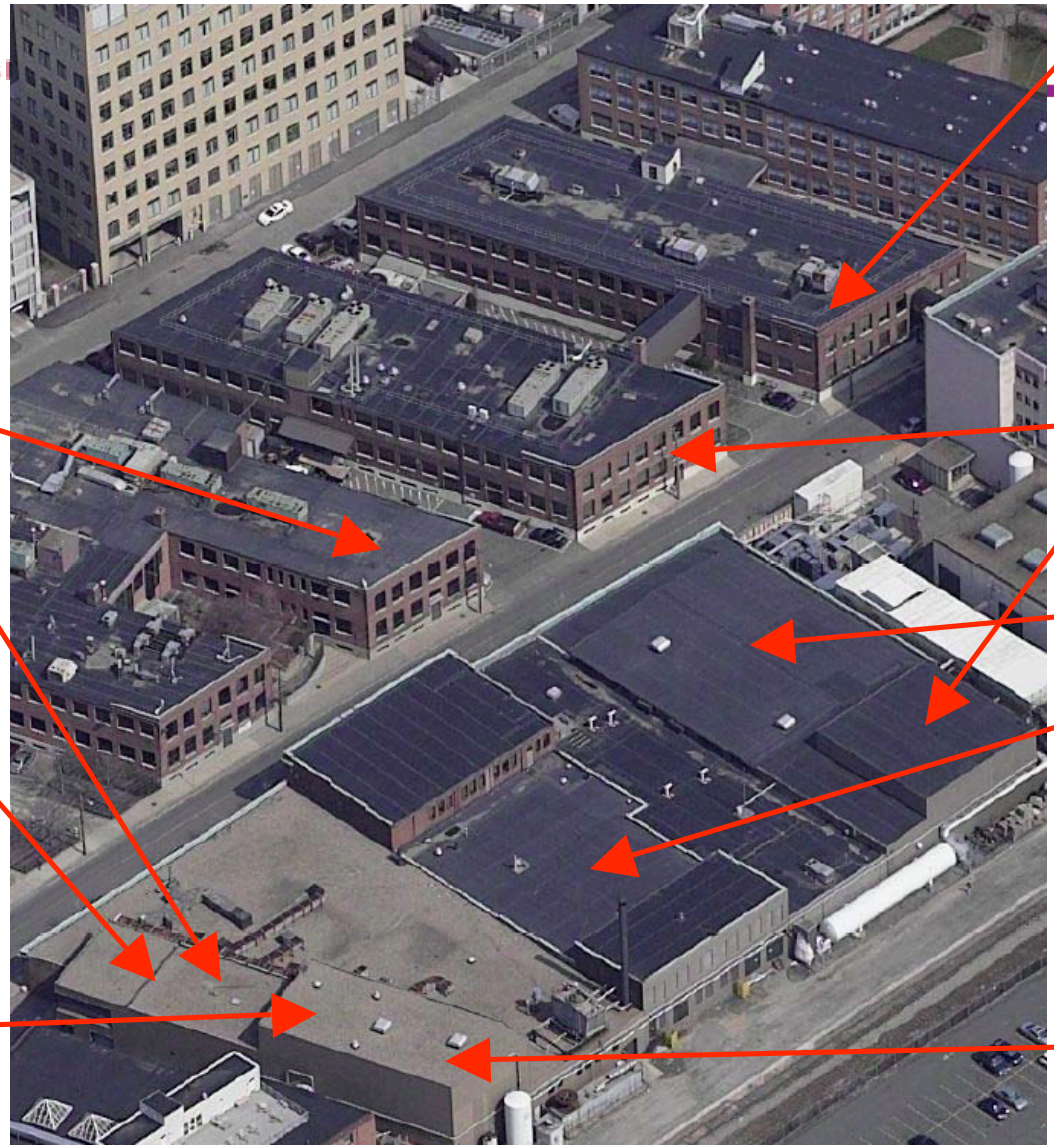
SC Magnet Research



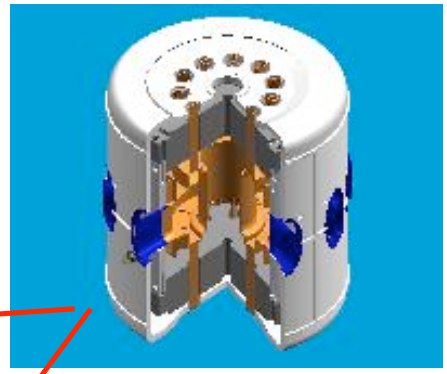
25 MV Accelerator



VTF



PSFC Headquarters



Alcator C-Mod

C-Mod Power Room

Gyrotron, Plasmatron, Smaller Labs

LDX

Vigorous K-12 Outreach Program by PSFC Staff

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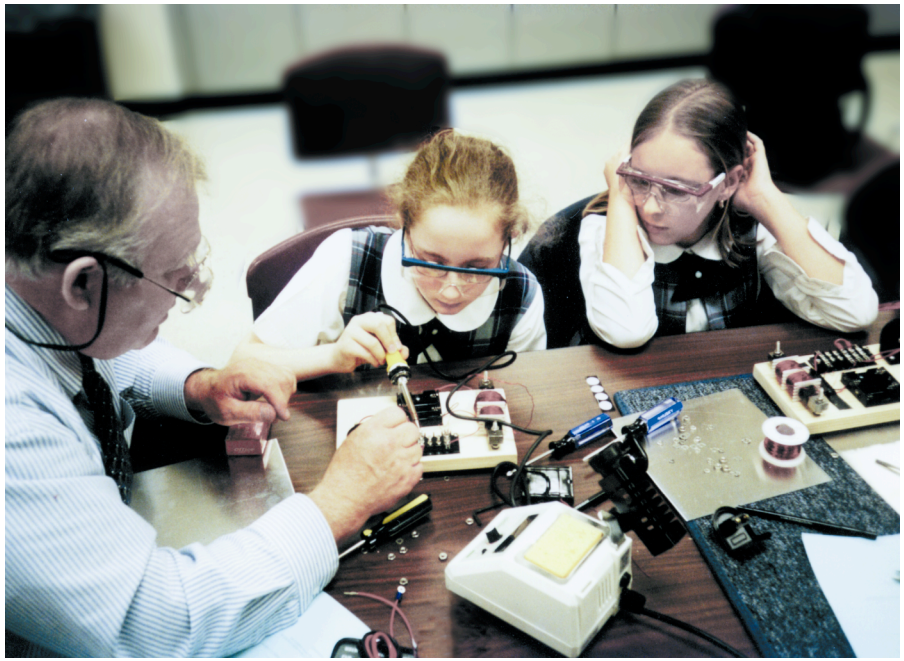

Paul Thomas, aka Mr. Magnet
"in action"

- The Mr. Magnet Program and portable plasma lab (Paul Thomas) reaches over 30,000 students per year.
- The Center provides over 35 tours of the Center per year, reaching over 900 K-12 students, teachers and general public.
- MIT PSFC supports APS-DPP education activities
- PSFC helps maintain and expand Coalition for Plasma Science educational activities, including website and publications.
- Collaborations with Boston Museum of Science have helped spotlight plasma, fusion, and MIT experiments in their local and traveling displays
- Filming by TV for "Magnet" show

Employment Status of MIT PSFC PhD/MS Students Beyond Graduation (1980–2005)

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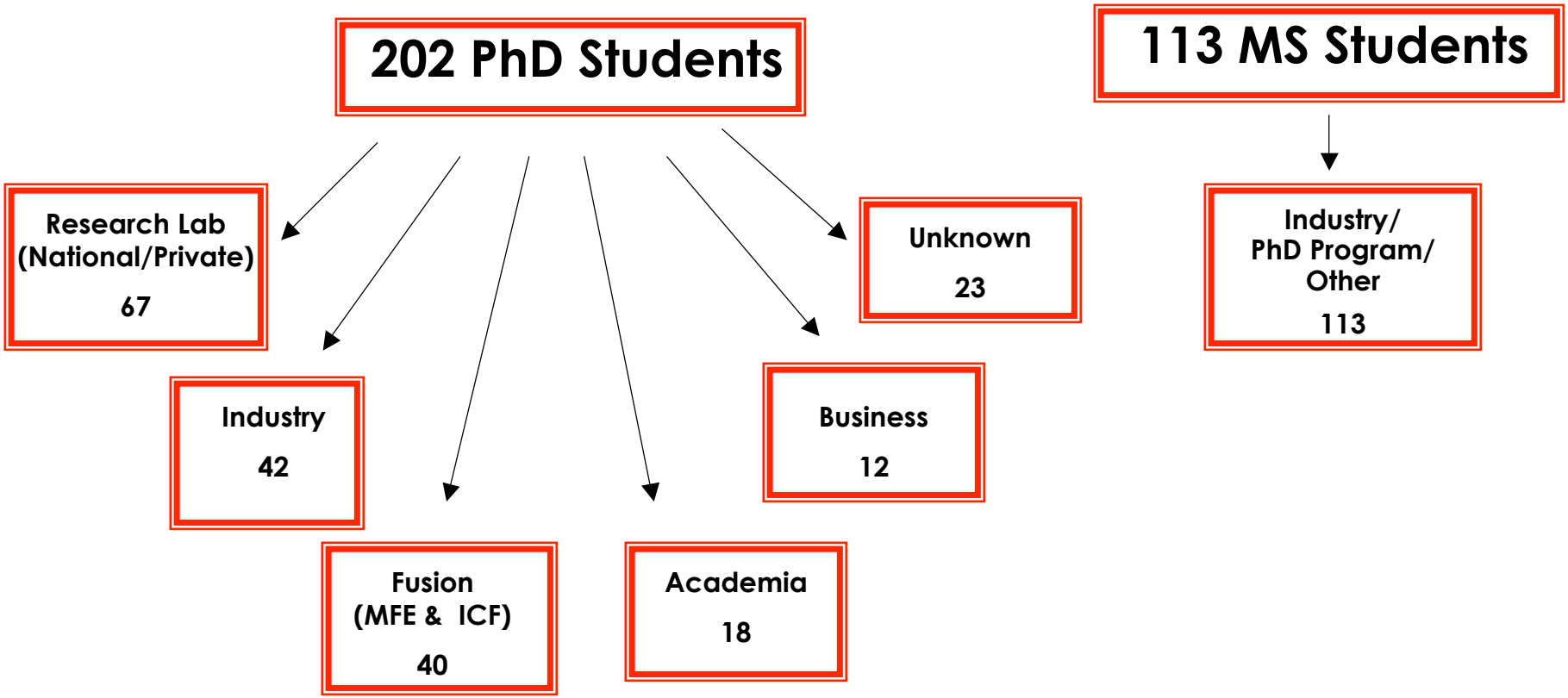

ALCATOR C-MOD
ADVANCED TOKAMAK PROGRAM

(Earl Marmar, Division Head)

- **Purely RF heated plasma regimes at ITER (burning plasma) relevant fields (5-8T), densities ($n_e \sim 1 - 5 \times 10^{20} m^{-3}$), and collisionalities with metallic PFCs**

  → 8 MW ICRF operational for heating, CD and flow drive

- **Advanced Tokamak (AT) Program:**

  Quasi-steady state configuration ($\tau \sim L/R$) at B~5T with high bootstrap current fraction and lower hybrid current drive (LHCD) for profile control

  → 3MW of 4.6 GHz LHCD power has been installed and experiments are underway ; plan upgrade to 5 MW by 2009

- **29 graduate students doing Ph.D. theses on C-Mod**

- **14 weeks runtime in FY 07 marginal**

Alcator C-Mod is compact (1/9th of ITER in linear dimension) but can operate at similar parameters to ITER

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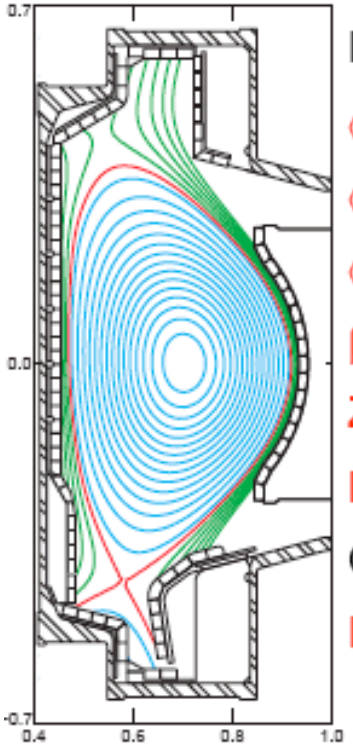
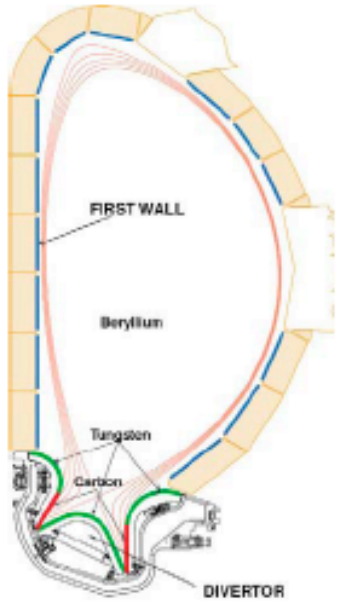


Alcator C-Mod	ITER
B_T = 5.3 T typical (≤ 8 T)	B_T = 5.3 T
$I_p \leq$ 2.0 MA	I_p = 15 MA
$\langle n \rangle$ =1-5×10^{20} m^{-3} typical	$\langle n \rangle$ =1×10^{20} m^{-3}
$\langle \varepsilon \rangle \leq$ 0.25 MJ/m^3	$\langle \varepsilon \rangle$ = 0.4 MJ/m^3
$\langle p \rangle \leq$ 1.8 atm (world record)	$\langle p \rangle$ = 2.8 atm
$\beta_N \leq$ 1.75	β_N = 1.77 (baseline)
Z_{eff} ~ 1.5	Z_{eff} ~ 1.6
$P_{\|}$(SOL) ≤ 0.5 GW/m^2	$P_{\|}$(SOL) ≈ 1 GW/m^2
Coated metal walls (Mo, W, B)	Mixed walls (C,W, Be)
RF heating/current drive	RF heating + others

(÷ 9)



and

similar plasma shape

similar divertor shape

- Fundamental difference between ITER and C-Mod (and all current experiments):

ITER plasma heating dominated by fusion reactions (alpha heating)

Lower Hybrid Waves launched at nearly 1 MW drive 700 kA plasma current with excellent efficiency

An MIT-PPPL Collaboration (R. Parker, R. Wilson)

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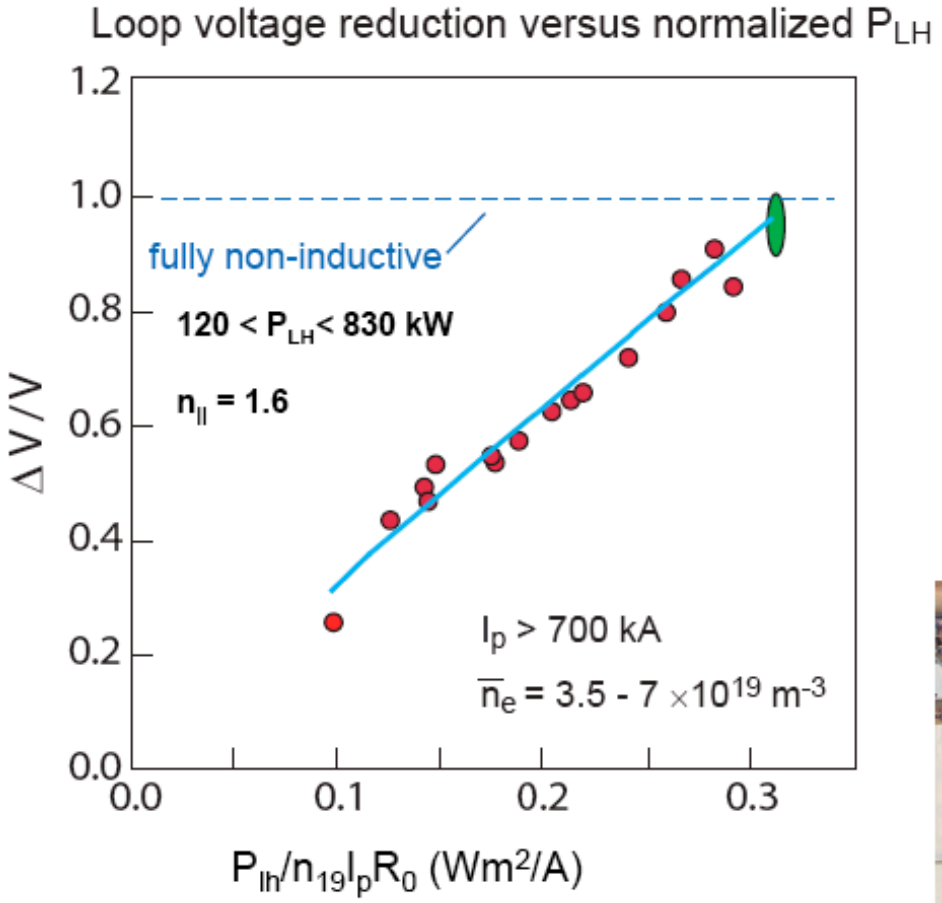
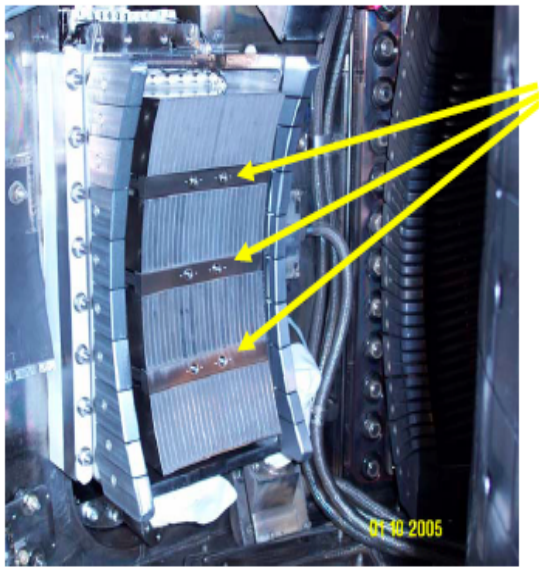


GRILL (Phase Array of guides)

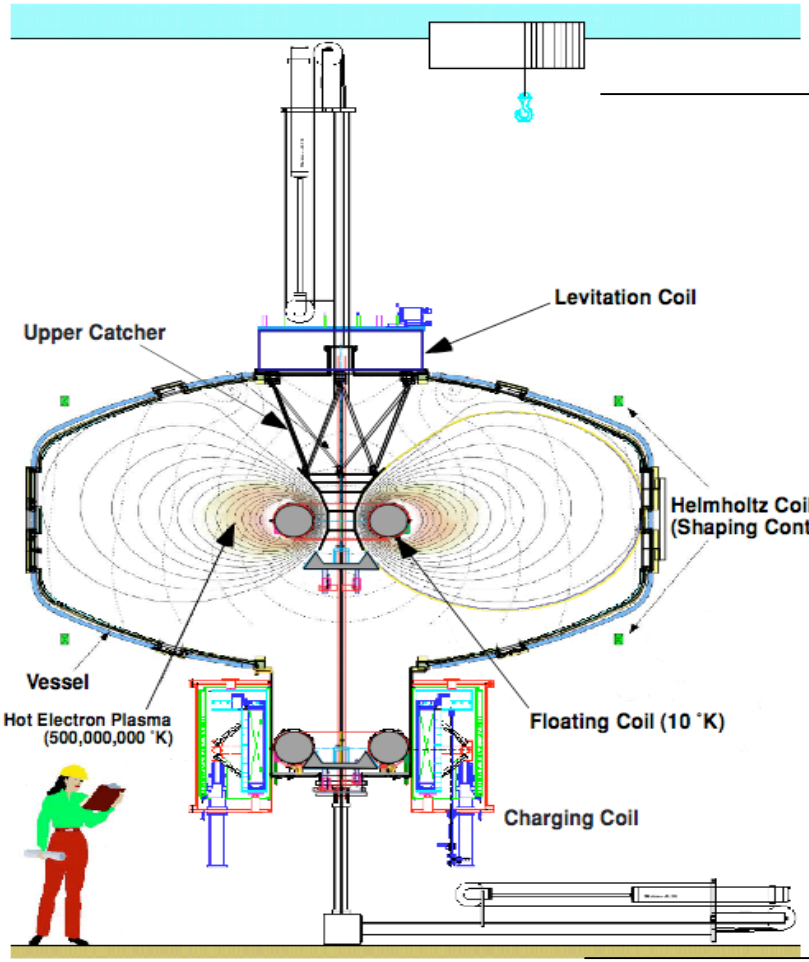


The klystrons grouped in banks of 4 in C-Mod Cell

Levitated Dipole Experiment

J. Kesner, M. Mauel, PIs, D. Garnier Chief scientist

Massachusetts Institute of Technology



Joint Columbia U.-MIT Project in the PSFC Nabisco Laboratory

Can we produce well-confined, high-beta plasma with a levitated dipole and understand large-scale adiabatic convection that maintains energy confinement while allowing rapid removal of impurities and fusion products?

LDX Utilizes Two Superconducting Magnets

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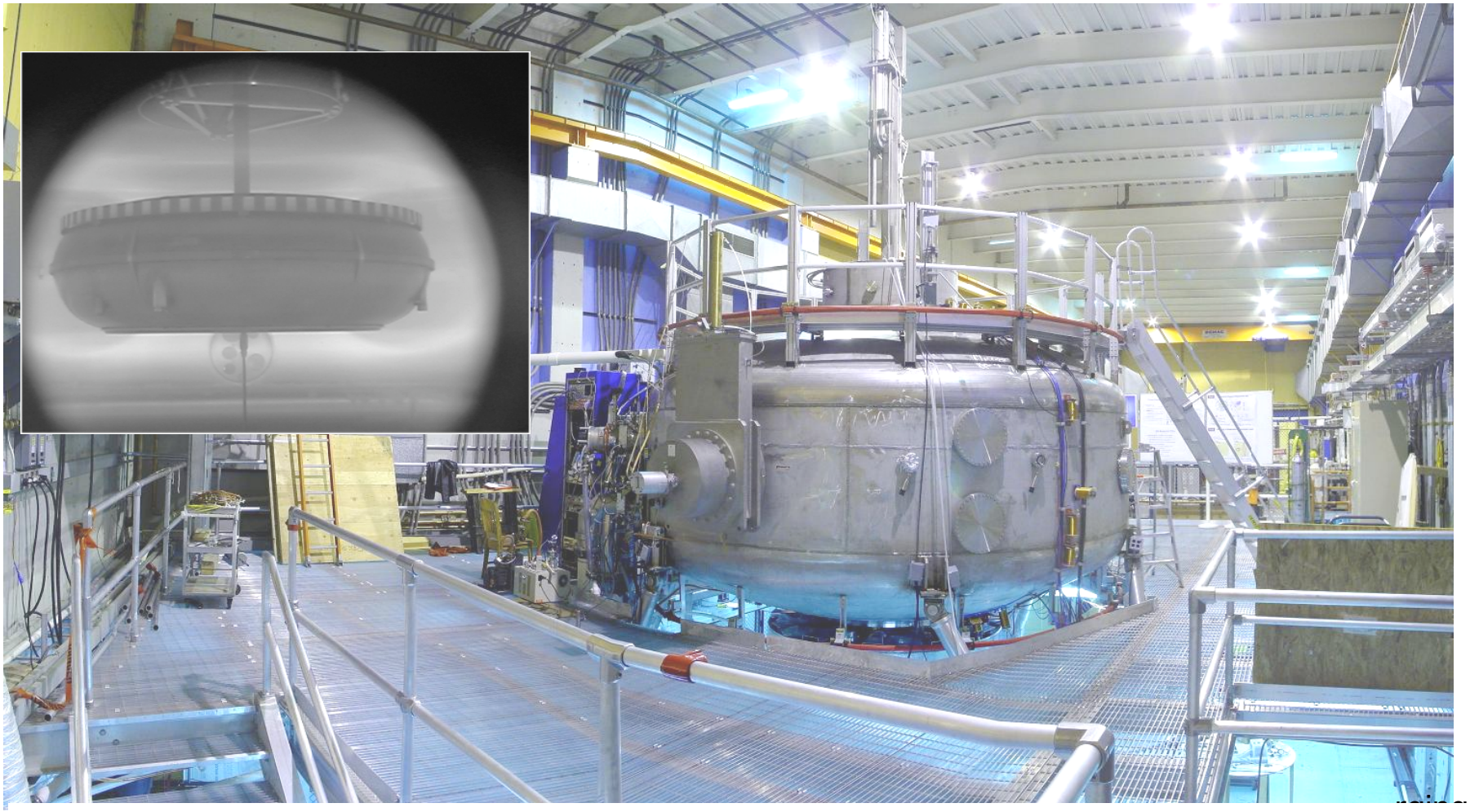


- Floating coil: (shown) Nb^3Sn (1.5 MA)
- Charging coil: NbTi (12 MJ, B_{max}=5.6T, 4.5K)
- Levitation coil: Normal Cu (expected to arrive early July)

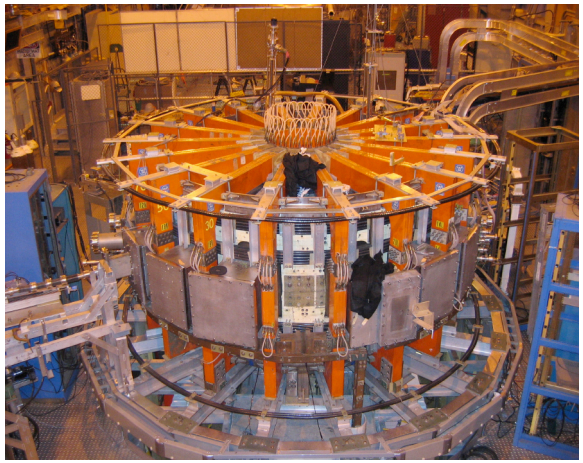
Ref: Garnier et al., Fusion Engineering and Design 81 (2006) 2371.

Reconnection Experiment in the new VTF Closed Field Configuration: Connection to Fusion and Space Physics

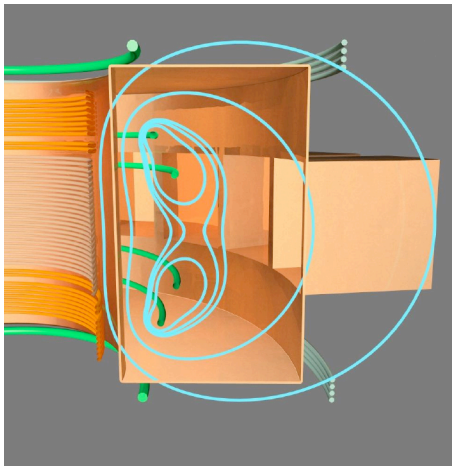
Massachusetts Institute of Technology

J. Egedal and M. Porkolab, N. Katz, W. Fox,

(A)

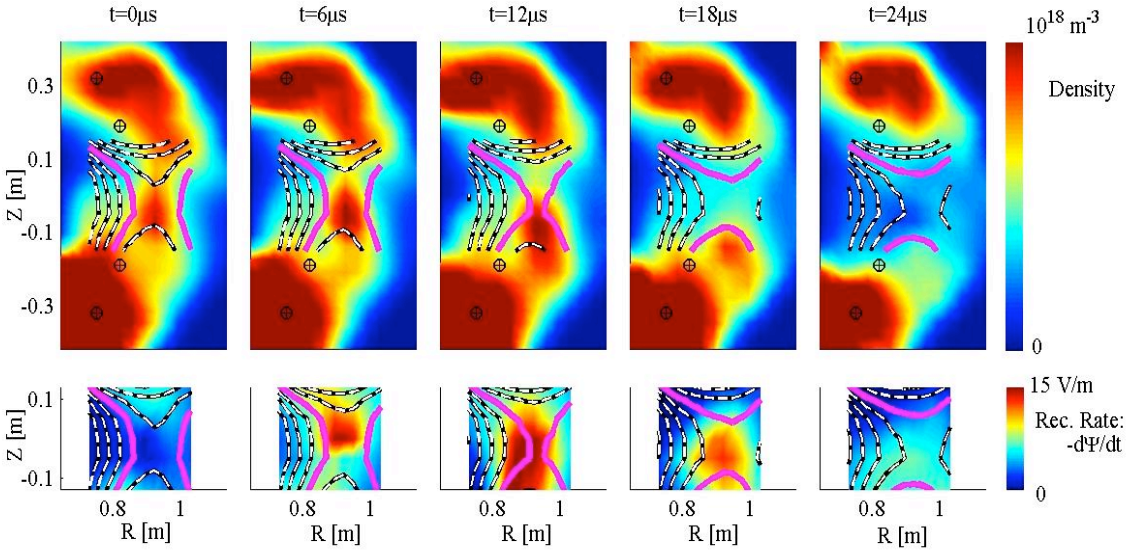


(B)



(A): The VTF device.
(B): New closed magnetic geometry implemented in VTF for the study of collisionless reconnection
(C): The first measurements of the plasma density, magnetic fields and reconnection rate during a spontaneous reconnection event.

(C)



VTF is partially funded under the new OFES Center for Multi-Scale Plasma Dynamics led by UMD and reconnection events. Jan Egedal, managing VTF, is an Assistant Prof. in the MIT Physics Department. Prof. Egedal has been awarded funding under the DOE's Junior Faculty Award program and together with Prof. Porkolab (co-PI) has been awarded continuation of the DOE/NSF award DE-FG02-03ER54712.

Using energetic protons to radiograph laser-generated E+B fields and to measure ρR

(R. Petrasso and C.K. Lee, + staff & students -HEDP Program)

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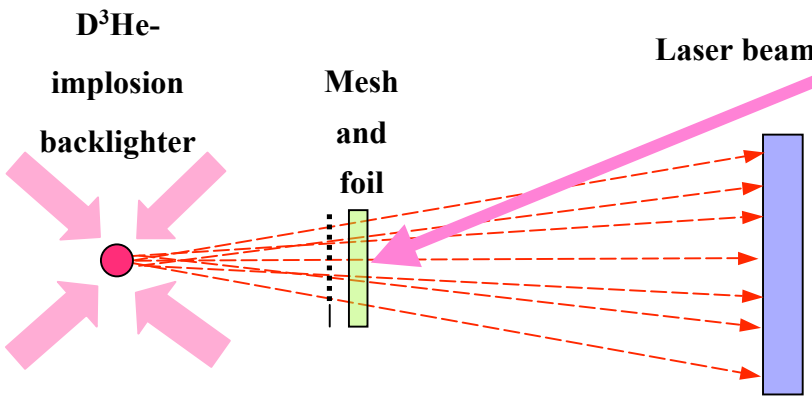
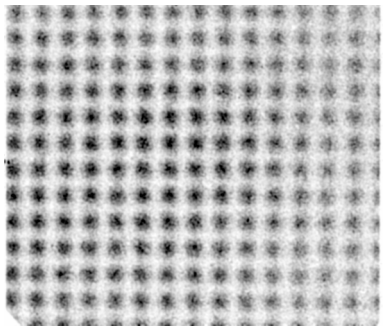
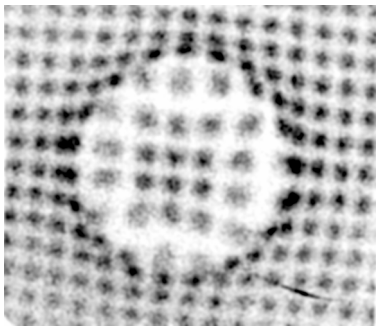


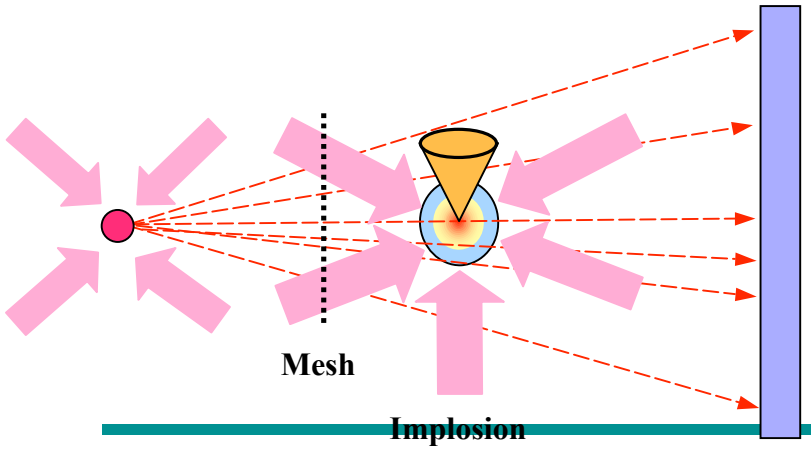


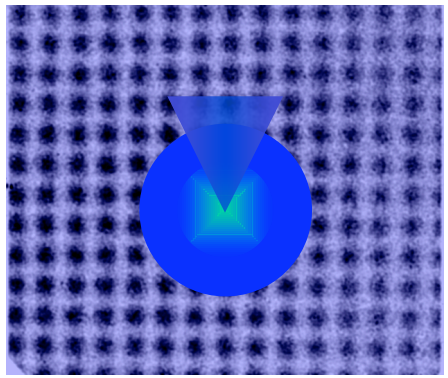
Before laser



~ 0.6 ns
after laser

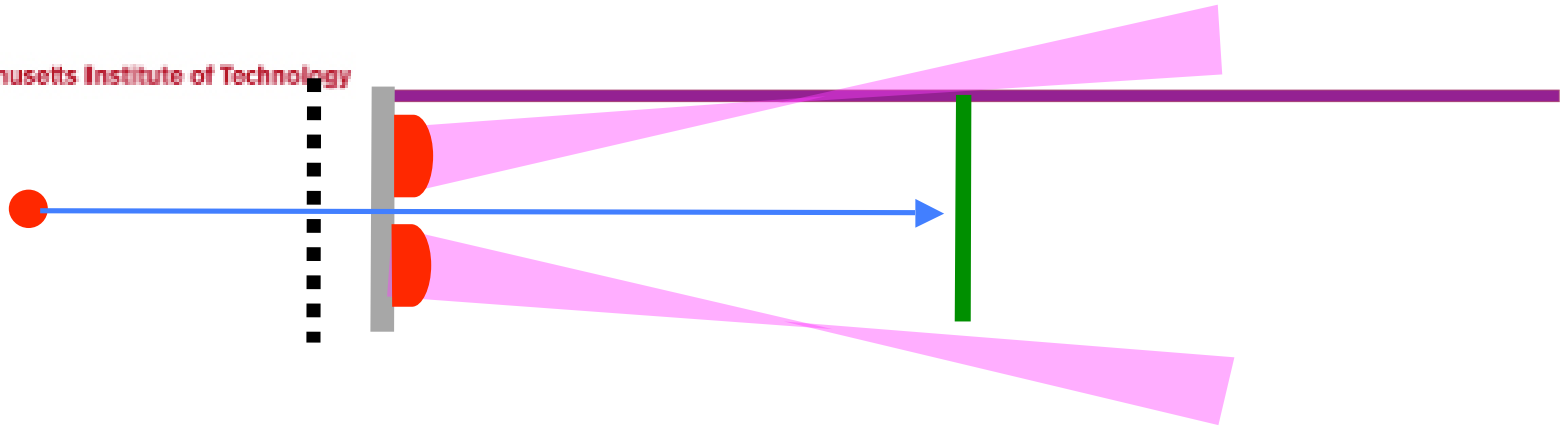
real images





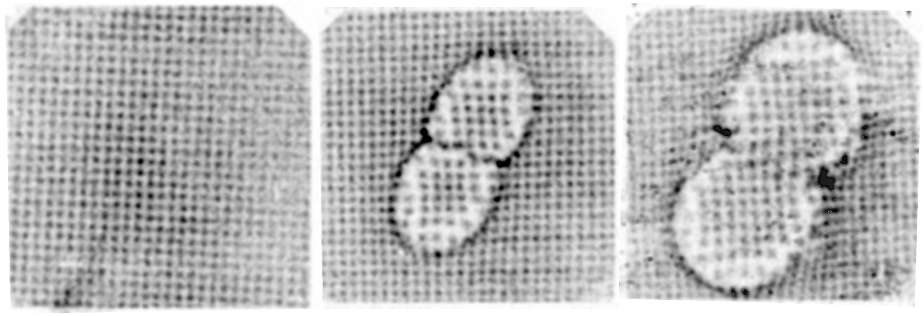
cartoon image

Magnetic reconnection has been observed and quantified

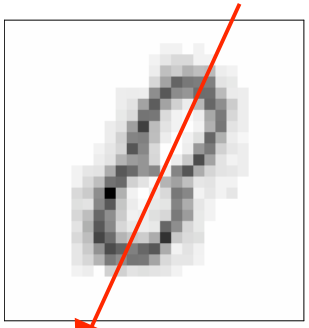


Laser on from 0 – 1 ns

0.04 ns 0.67 ns 1.42 ns



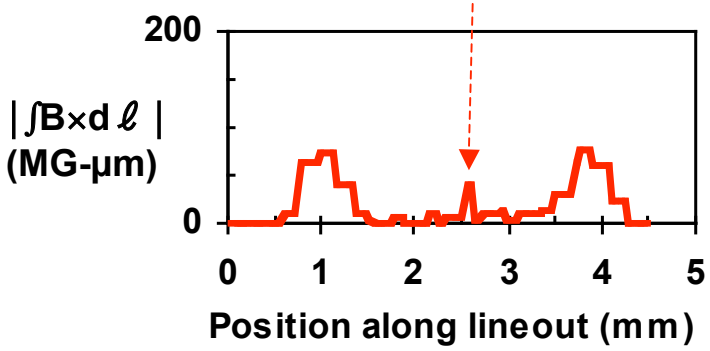
5 mm



Li *et al.*, submitted to PRL (2007)

Field map calculated from beamlet deflections

Reduced field strength where bubbles overlap



MIT Pulsed Test Facility (PTF) to Test ITER Magnet Joints

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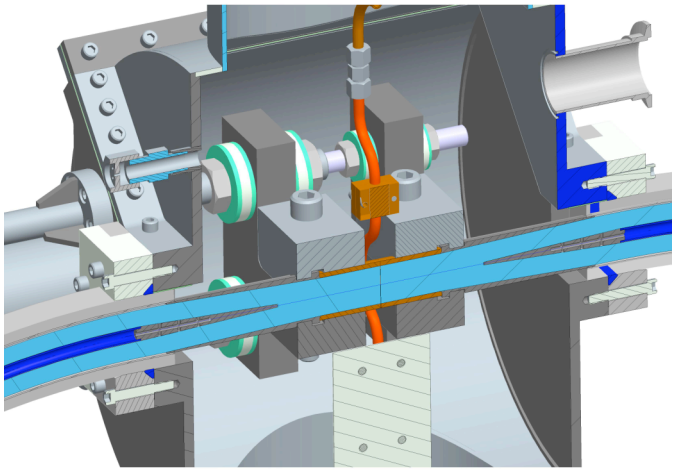
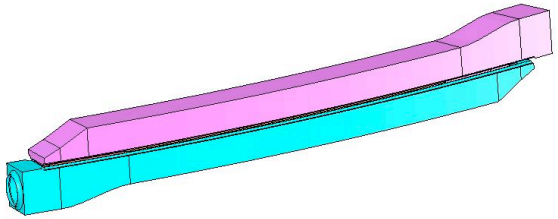


CS Butt Joint



CS Lap Joint

Only facility in world that can test ITER-size (50 kA) superconductors and joints in pulsed field background
Will test 2 CS joint options –Butt Joint & Lap Joint

Thank You Ron for Your Vision 3 Decades Ago !

K. Smith (MIT VP for Research), J. Clark and R.C. and J. Davidson at the MIT Faculty Club overlooking the Charles River (1980s)