Time Evolution of Measured Energy and Particle Transport in the MST Reversed-Field Pinch

T.M. Biewer, J.K. Anderson, D. Craig, D. Demers[1], W. Ding[2], G. Fiksel, B. Hudson, J. Lei[1], J.C. Reardon, U. Shah[1], S.D. Terry[2], J.C. Wright, S.C. Prager, and C.B. Forest

University of Wisconsin-Madison

[1]*Rensselaer Polytechnic Institute*

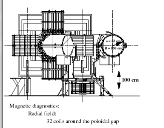
[2]*University of California-Los Angeles*

Abstract

Time evolved measurements of thermodynamic profiles have been obtained in a variety of MST discharges (PPCD, F=-0.22, F=0, F=+0.02, F=+0.03), leading to the first measurement of radially resolved, time evolving heat transport in the MST. M=0 modes are absent in F=0 plasmas, and confinement is observed to improve, but degrades rapidly as F is raised above zero. In all cases, the heat flux is predominantly conductive over the majority of the plasma volume, though convective heat transport becomes significant in the edge. The observed heat and particle fluxes cannot be described by a diagonal transport matrix. However, including pressure gradient and electric field cross-terms can account for the observed fluxes. The radial electric field is calculated from ion momentum balance and compared to measurements from a heavy-ion beam probe diagnostic.

This work was supported by the U.S. D.O.E.

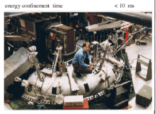
The Madison Symmetric Torus



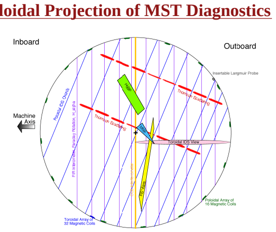
minor radius	0.52 m
major radius	1.5 m
plasma current	< 0.6 MA
loop voltage	~ 10 V
toroidal volt-sec	< 2 V-s
pulse length	< 80 ms
electron temperature	< 1000 eV
ion temperature	< 500 eV
electron density	< 2 x 10[13] cm[-3]
beta	~ 5 - 15%
energy confinement time	< 10 ms

Magnetic diagnostics:
Radial field:
32 coils around the poloidal gap

Mode spectra:
64 sets of 3 orthogonal coils toroidally distributed
16 sets of 3 orthogonal coils poloidally distributed
8 sets of 3 orthogonal coils poloidally distributed



Poloidal Projection of MST Diagnostics

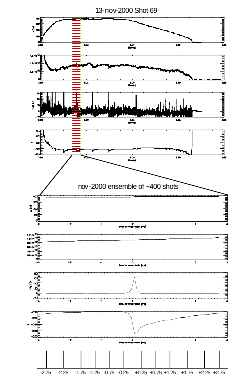


Summary

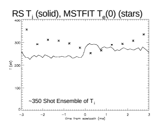
- Measured electron χ in the core of the MST is in good agreement with Rechester-Rosenbluth type modeling (DEBS/RIO) of stochastic magnetic diffusion at the ion thermal speed, suggesting that ambipolarity constrains the heat flow in the core. Also, $\chi_e(r)$ has evidence of a strong transport barrier at the edge.
- The radial electric field is estimated from ion momentum balance to be ~+2.5 kV/m, which is in excellent agreement with measured E_r from the MST HIBP.
- F>=0 plasmas are closer to Taylor minimum energy states, based on λ profile calculations. F=0 plasmas have higher confinement than Standard, but confinement degrades rapidly as F is raised above 0.
- PPCD plasmas continue to out-perform other operational modes of the MST: τ_E is more than double "Standard" plasmas, and χ_e is an order of magnitude lower.

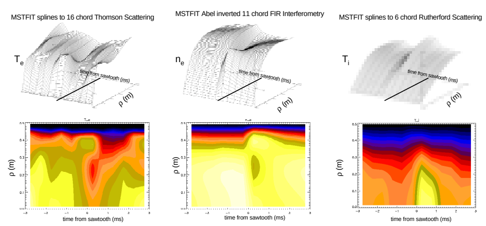
Full-color reprints of this poster are available online:
http://sprott.physics.wisc.edu/biewer/APS2001Poster.pdf
Or sign up below for a hardcopy:

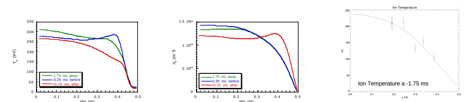
The Sawtooth Cycle in "Standard" MST Plasmas



- Motivation: To study the dynamics of a fully diagnosed MST plasma over a sawtooth cycle.
- Typical plasma parameters:
  - "Standard" w/ full PFN
  - $I_p \sim 375$ kA
  - F ~ -0.22
  - $n_e \sim 1.1\times10^{13}$ cm^{-3}
  - Deuterium
- Sawtooth period ~ 5.5 ms
- Time of interest: ~ 15 ms, i.e. early in the discharge but during plasma "flattop"
- Plasma shots are ensembled for 2 reasons:
  - Want an "average" measure of quantities, i.e. smooth out the fluctuations
  - Need ~400 shots to get $T_e(r,t)$ from Thomson sct.
- This 6 ms time window about the crash is sub-divided into 12 time slices, every 0.5 ms.
  - High time resolution signals (e.g. FIR) are computed as 0.1 ms ensembles.
  - Raw TS data is ensembled in 0.5 ms bins.

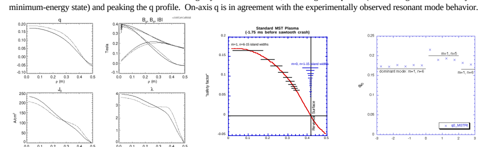






MSTFit Reconstructs the Equilibrium B, j, and q Profiles

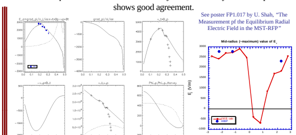
Parallel current is redistributed from the core to the edge by the sawtooth crash, flattening the λ profile (I.e. relaxing closer to the Taylor minimum-energy state) and peaking the q profile. On-axis q is in agreement with the experimentally observed resonant mode behavior.



E_r estimated from Ion Momentum Balance

Comparison of the radial electric field calculated from the ion momentum balance equation to the value measured by the MST heavy-ion beam probe shows good agreement.

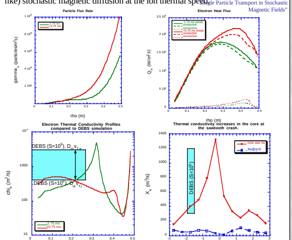
See poster FP1.017 by U. Shah, "The Measurement pf the Equilibrium Radial Electric Field in the MST-RFP"



Heat & Particle Flux; Conductivity & Diffusivity

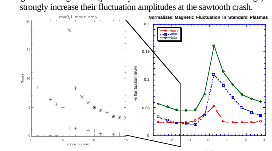
Both heat and particle flux increase over the sawtooth crash. The electron thermal conductivity in the core increases correspondingly, while remaining relatively unchanged in the edge. Away from the sawtooth crash, these values of χ_e are in rough agreement with DEBS/RIO modeling of (Rechester-Rosenbluth like) stochastic magnetic diffusion at the ion thermal speed.

See poster FP1.024 by B. Hudson, "Modeling Single Particle Transport in Stochastic Magnetic Fields"

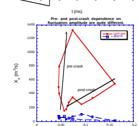


Correlation of χ with Magnetic Fluctuations

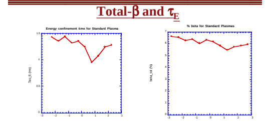
Magnetic Tearing modes (primarily m=1 in the core and m=0 in the edge) strongly increase their fluctuation amplitudes at the sawtooth crash.



After the sawtooth crash, heat flow decreases linearly as the magnetic fluctuations decrease. Approaching the crash, some other mechanism controls the heat flux, since heat flows out of the core seemingly independently of the total magnetic fluctuation amplitude.

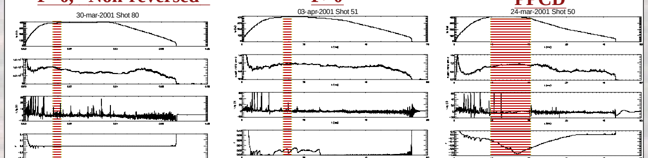


Total-β and τ_E



Comparisons to Other MST Plasmas

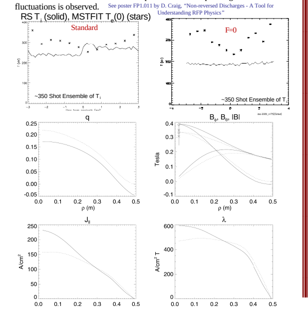
F=0, "Non-reversed" / F>0 / PPCD



F>=0 Plasmas are Closer to Taylor Minimum

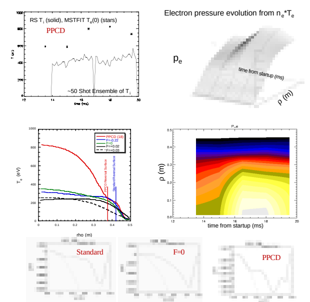
Anomalous ion heating at the crash is observed in "Standard" plasmas, but not in F=0 or F>0 plasmas. The mechanism for a.i.h. is not well understood, but we observe that the λ profile is flatter in F>=0 plasmas, perhaps reducing a source of energy that was utilized to heat the ions. In both F=0 and F>0 plasmas the m=0 resonant surface is removed from the plasma. A corresponding reduction in m=0 fluctuations is observed.

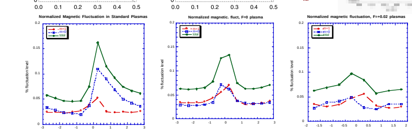
See poster FP1.011 by D. Craig, "Non-reversed Discharges - A Tool for Understanding RFP Physics"



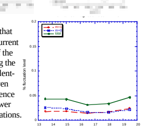
PPCD Plasmas Offer the Best RFP Performance

Pulsed Poloidal Current Drive plasmas benefit from increased q-shear across the bulk of the plasma. In the mid-radius region, the combination of larger q-shear and lower magnetic fluctuations reduce magnetic stochasticity from tearing mode island overlap, resulting in improved confinement. Additionally, the Suydam stability limit to ideal interchange modes is raised in the edge because of greater q-shear.

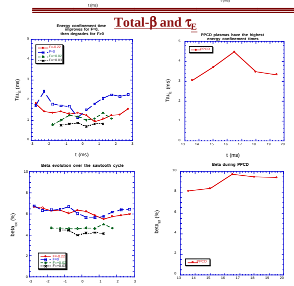




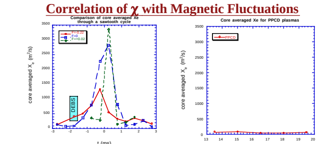
It is believed that PPCD drives current in the edge of the MST, relieving the need for turbulent-dynamo driven current, and hence leading to lower magnetic fluctuations.



Total-β and τ_E



Correlation of χ with Magnetic Fluctuations



Though the total magnetic fluctuation level alone may not be sufficient to explain the variation of χ_e over a sawtooth cycle, it does play a role. If a R.-R. type scaling is assumed along with the electron thermal velocity, then we see a relatively linear agreement between measured χ_e and estimated χ_{RR}.