

# Particle and Energy Transport Measurements in Standard and PPCD Plasmas in the MST

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Energy confinement in the MST is limited by both plasma core and edge originating fluctuations. Early experiments with Pulsed Poloidal Current Drive (PPCD) were effective in controlling core fluctuations. But during this PPCD, burst-like instabilities prohibited further reduction in transport. These bursts, which are associated with edge localized,  $m=0$  mode activity, can be controlled by maintaining a parallel electric field at the edge of the plasma. Modifying PPCD appropriately has reduced thermal transport even further and increased confinement time.

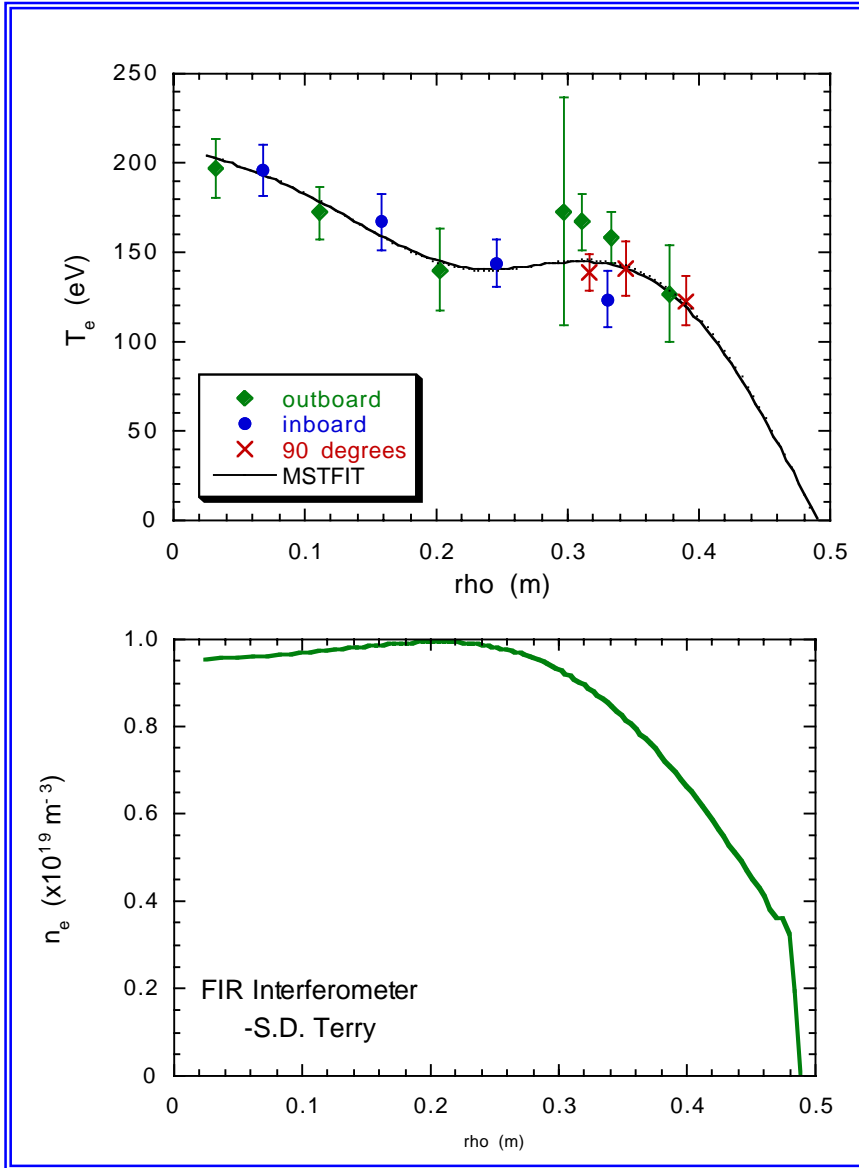
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# Outline

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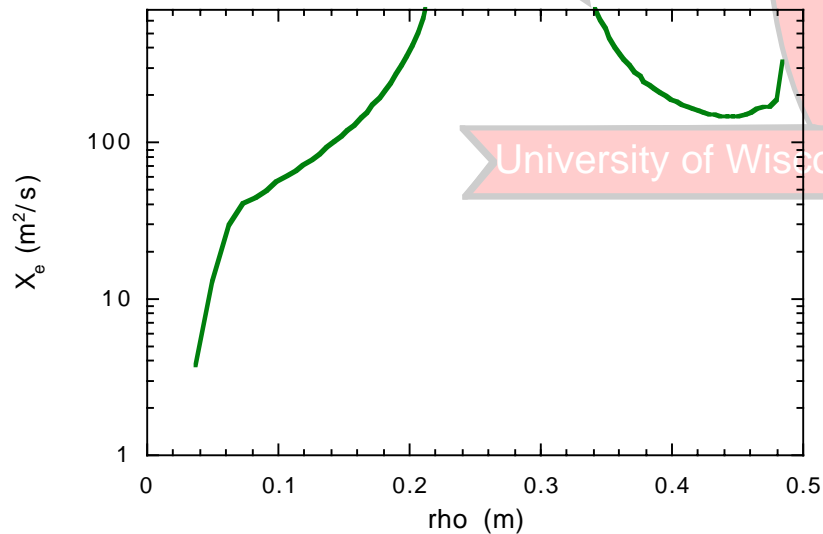
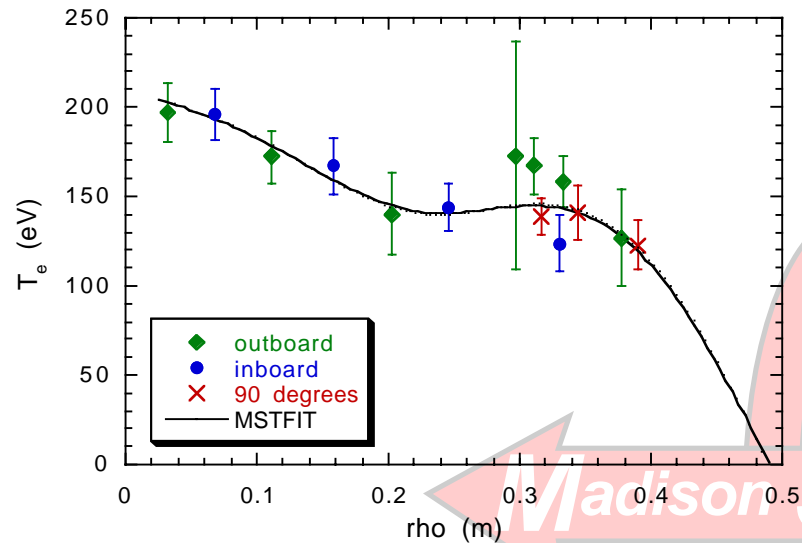
- Full  $T_e$  profile measurements in 300 kA standard plasmas
- MSTFIT is a fully toroidal equilibrium code
- Confinement improvements limited by burst-like instability
- Improvements in PPCD lead to higher confinement in 200 kA and 400 kA experiments (1999)
- Thermal conductivity results
- Particle flux results
- Energy confinement time scaling
- Summary/Conclusions

# Full $T_e$ profile measured in 300 kA plasmas



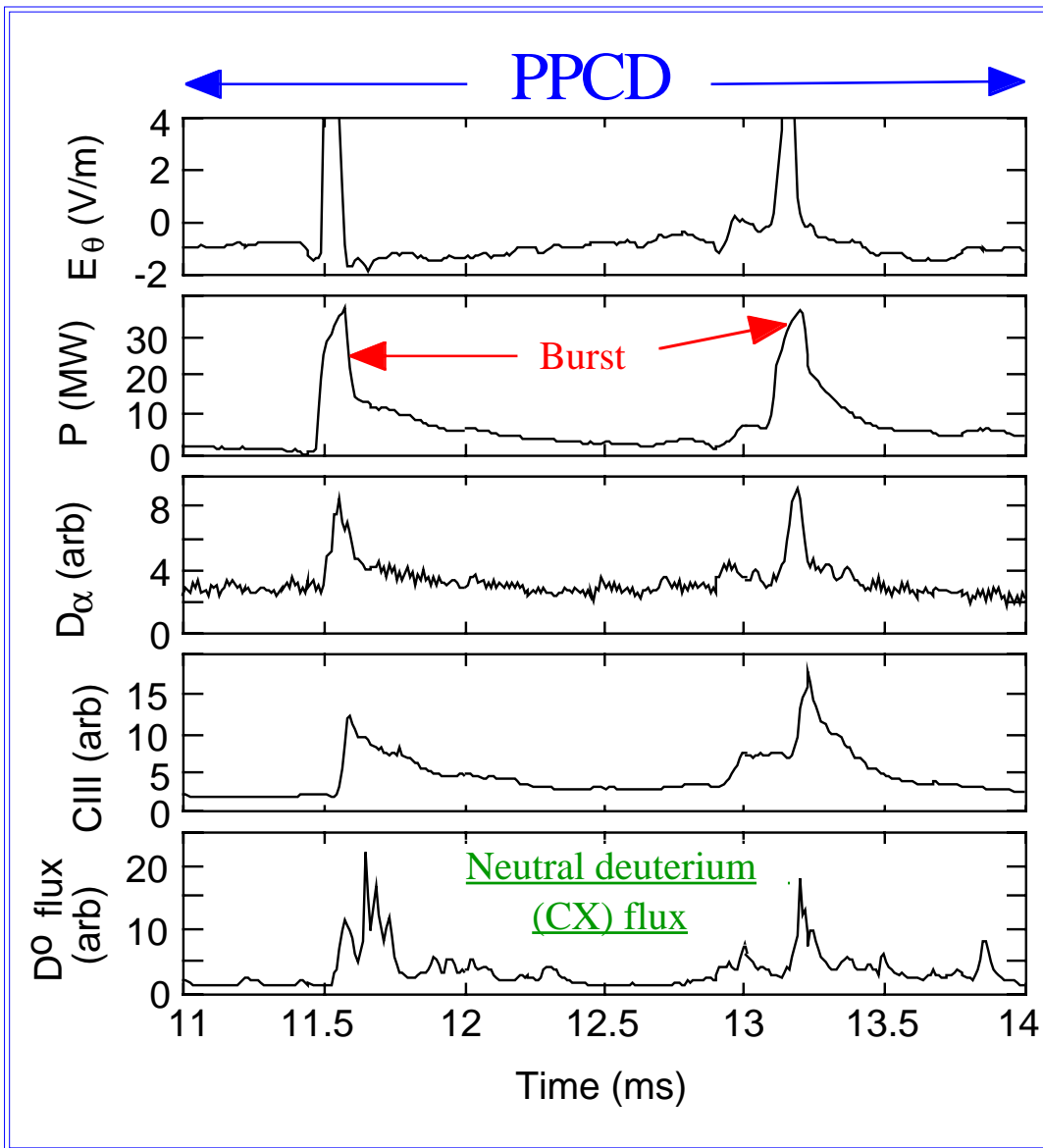
- First 14 point  $T_e$  profile has been made on the MST
- When mapped onto MSTFIT reconstructed flux surface coordinates ( $\rho$ ), there is a clear anisotropy in the profile.
  - Appears to be local, off-axis “hotspot” on the outboard side
  - This has also been seen in 200 and 400 kA standard plasmas

# MSTFIT and transport quantities



- MSTFIT is a fully toroidal equilibrium reconstruction and transport analysis code
  - From measurement of  $F$ ,  $\theta$ ,  $I_p$ ,  $B(a)$ : can find  $j$ ,  $B(r)$ , etc.
  - Including  $n_e(r)$  and  $T_e(r)$  measurements: can extract transport quantities
  - $Z_{\text{eff}}(r)$  and  $T_i(r)$  are estimated
- Transport in this “dirty” plasma is particularly bad
  - $\chi_E$  is higher than typical MST standard plasma by  $\sim 5$
  - $\tau_E \sim 0.6$ ms

# PPCD improvements limited by burst-like instabilities

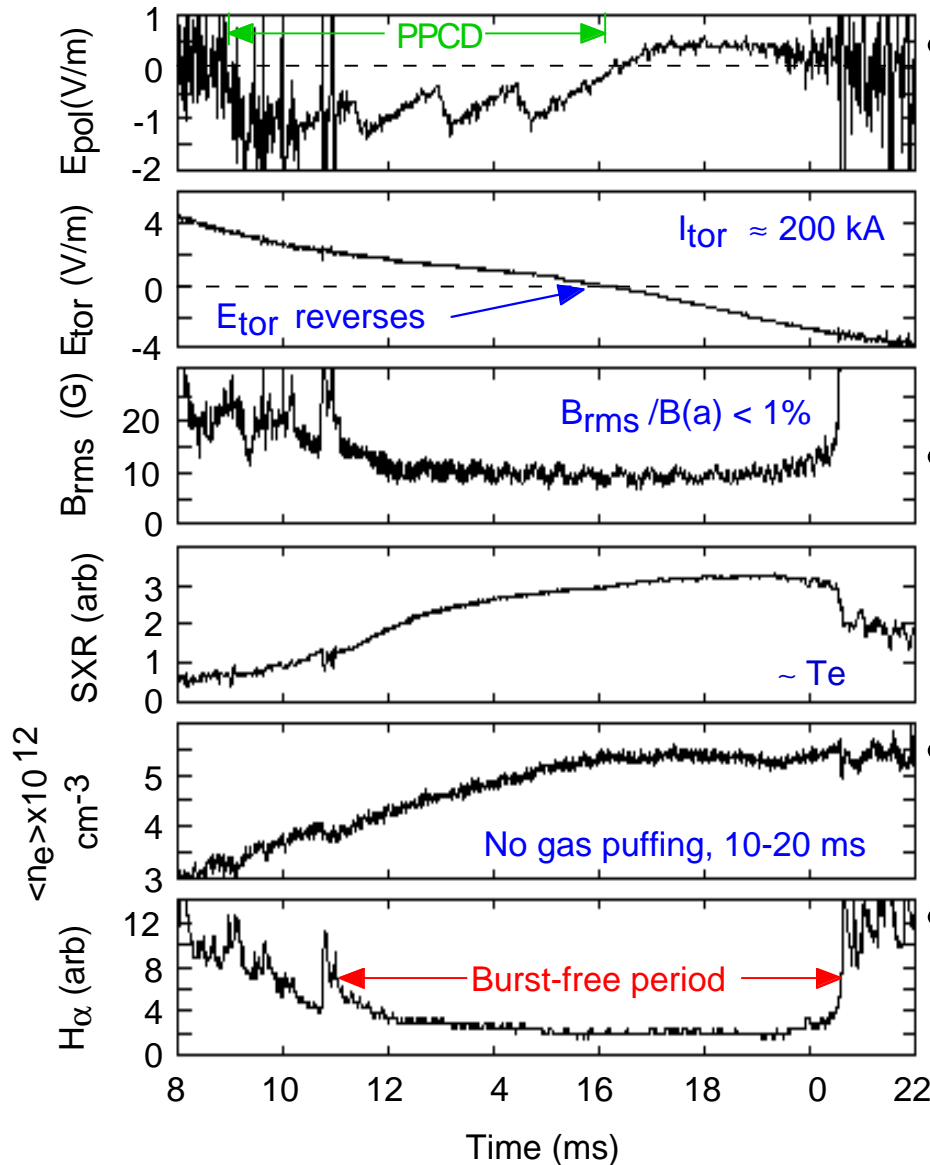


Surface poloidal electric field  $\propto -d\langle Bt \rangle / dt$

Estimated ohmic input power

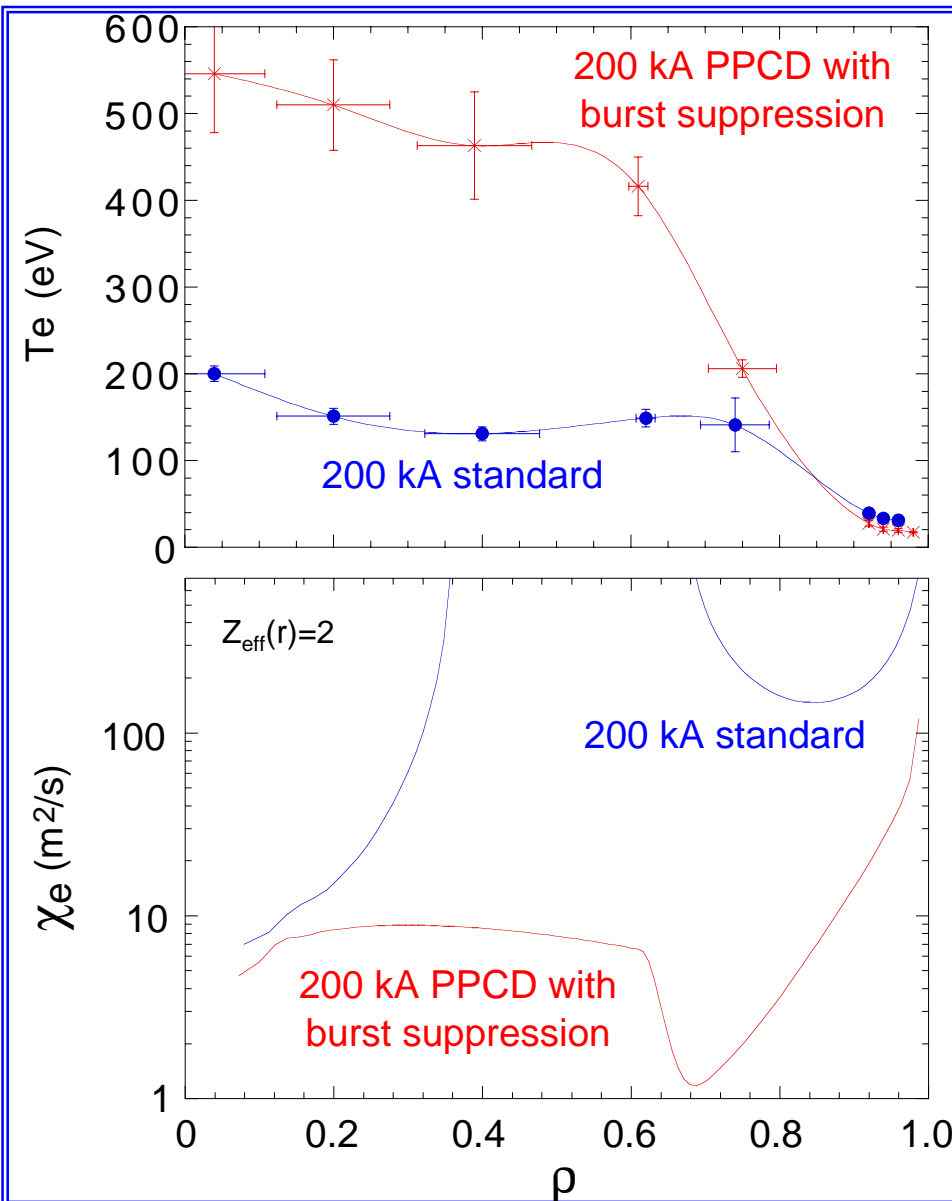
- Each burst corresponds to generation of toroidal magnetic flux, like sawtooth crashes during standard discharges
- Increase of ohmic power, radiation, central flux, etc. contributes to degraded energy confinement

# Improved PPCD due to burst suppression



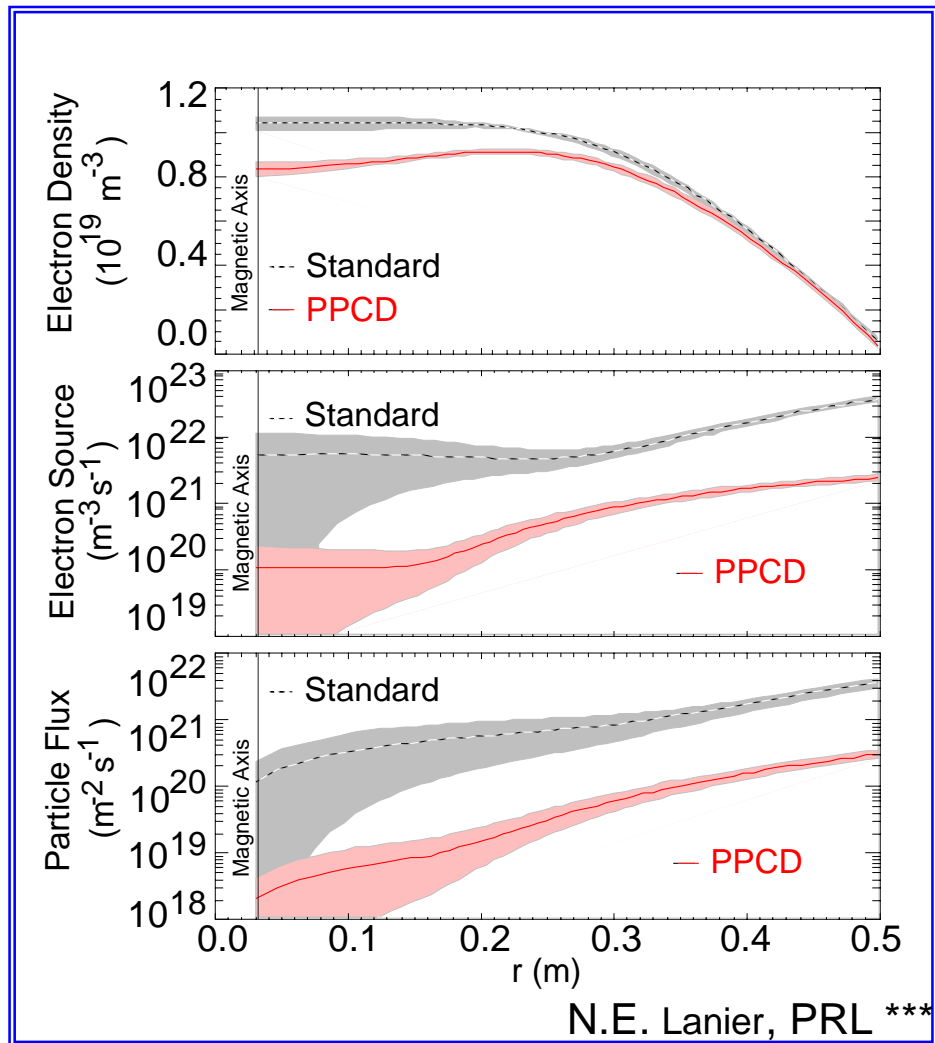
- PPCD has changed
  - 1993  $\Delta t$  between bursts  $< 1$  ms
  - 1996  $\Delta t$  between bursts  $< 3$  ms
  - 1999  $\Delta t$  between bursts  $\sim 10$  ms
    - As long as  $E_{\text{parallel}}$  is sustained
- Suppression for  $\sim 10$  ms due primarily to better/longer sustainment of edge parallel electric field,  $E_{\text{parallel}} = \mathbf{E} \cdot \mathbf{B} / B$
- $E_{\text{pol}}$  simply not allowed to decay to zero between PPCD stages
- $E_{\text{tor}}$  reversed following PPCD

# $T_e$ , $\chi_e$ profiles at 200 kA



- $T_e$  peaks strongly during PPCD
- $\chi_e$  is reduced throughout the bulk of the plasma
- Off-axis “hot spot” apparent in 200 kA standard profile
- Extreme edge  $T_e(a)$  and  $n_e(a)$  drop during PPCD to further steepen edge gradients
  - As measured by Langmuir probe

# Particle transport is also improved in burst free PPCD



- In standard discharges

- Density profiles are flat in the core with a steep edge gradient.
- Electron source is dominated by ionization of neutral hydrogen and is quite broad with substantial sourcing in the core.
- Radial Particle flux ranges from  $\sim 2 \times 10^{20}$  to about  $3 \times 10^{21}$  at the edge.

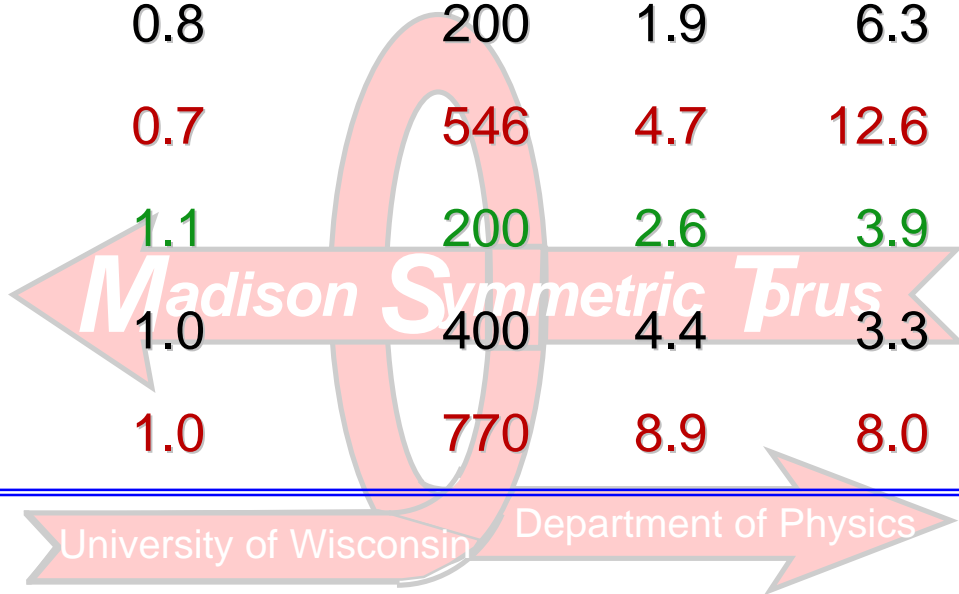
- In PPCD discharges

- Density profile hollows slightly in the core and gradient at the edge steepens.
- Electron source drops over an order of magnitude.
- Radial particle flux also decreases with the most dramatic reduction seen in the core.



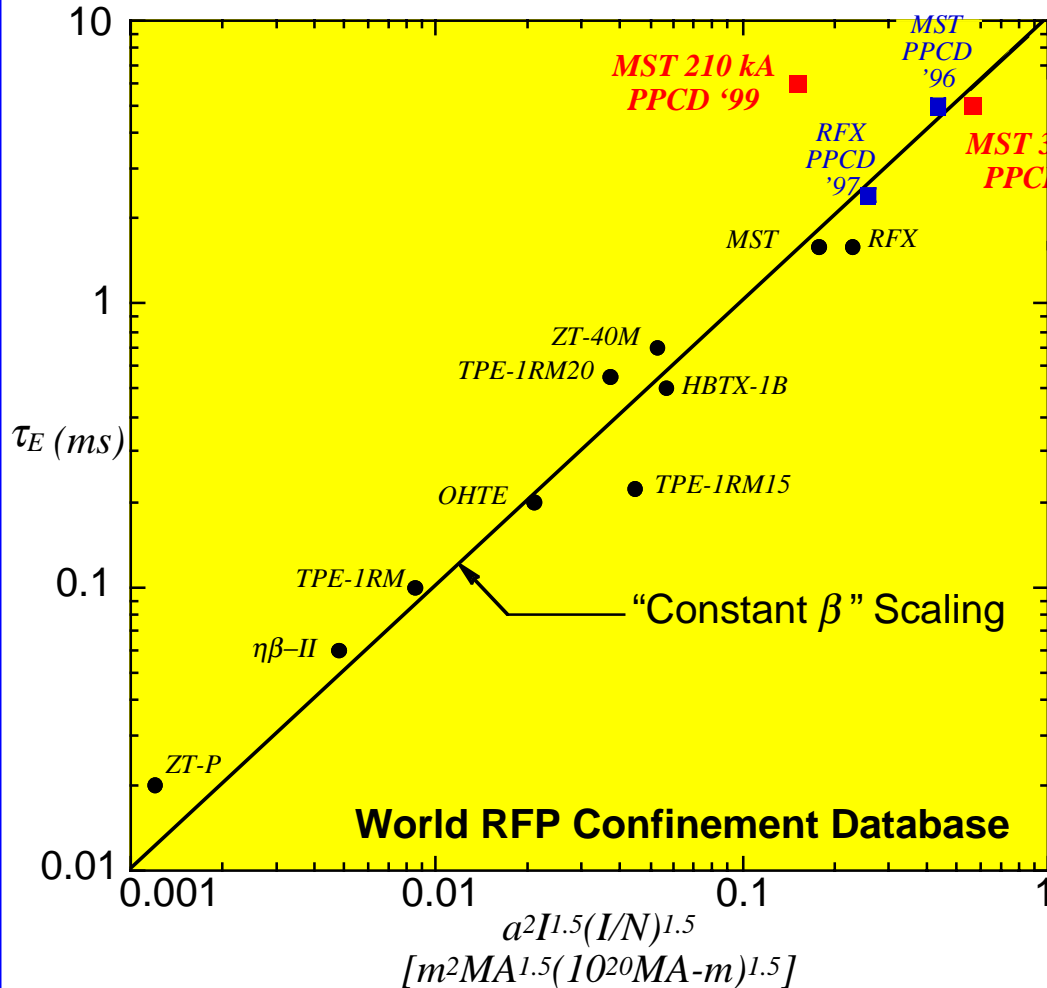
# PPCD compared to Standard plasmas

	$I_p$	$\langle n_e \rangle$	$T_{e,0}$	$W$	$\beta_{tot}$	$\tau_E$	$\tau_p$
	(kA)	( $10^{19} \text{ m}^{-3}$ )	(eV)	(kJ)	(%)	(ms)	(ms)
Std.	210	0.8	200	1.9	6.3	0.8	0.6
PPCD	210	0.7	546	4.7	12.6	6.5	4.7
Std.	305	1.1	200	2.6	3.9	0.6	---
Std.	430	1.0	400	4.4	3.3	1.0	?
PPCD	390	1.0	770	8.9	8.0	4.8	?



- Assumed  $Z_{eff}(r) = 2$  for all cases
- Assumed  $T_i(r) = (1/4)T_e(r)$  for PPCD and  $T_i(r) = (1/2)T_e(r)$  for Standard cases

# RFP confinement time “constant $\beta$ ” scaling



- Assumed  $Z_{\text{eff}}(r) = 2$  for both PPCD '99 cases
- $\tau_E$  of 210 kA PPCD '99 exceeds “constant  $\beta$ ” scaling
- Need  $Z_{\text{eff}}(r) = 11$  (unlikely), for 210 kA PPCD '99 to fall on the scaling line
- PPCD '96 case had  $T_e(0) = 615$  eV at 440 kA, while 390 kA PPCD '99 has  $T_e(0) = 770$  eV
- uncertainty lies in  $P_{\text{ohmic}}$  and in  $T_i(r)$

# Conclusions

The slides from this talk are available online at:  
<http://sprott.physics.wisc.edu/biewer/RFP2000.pdf>

- Off-axis “hot spot” of electrons is apparent in the outboard side of MST during standard discharges
- Control of bursts in the plasma edge during PPCD has led to increased confinement in the MST
  - $\tau_E$  increases by factor of 5, far above “constant  $\beta$ ” scaling
  - $\tau_p$  increases by factor of 8
- Improved measurements will allow more accurate calculation of  $\tau_E$ ,  $\beta$ 
  - $P_{\text{ohmic}}$  from  $\eta j^2$ , based on  $Z_{\text{eff}}$ ,  $T_e$  profiles or FIR polarimetry
  - measure  $B(r,t)$  with MSE,  $E_r$  with HIBP
  - $T_i(r)$  should soon be measurable in MST
    - Rutherford scattering for majority ion species  $T_i$
    - CHERS for impurity ion  $T_i$