High confinement plasmas in the MST reversed-field pinch

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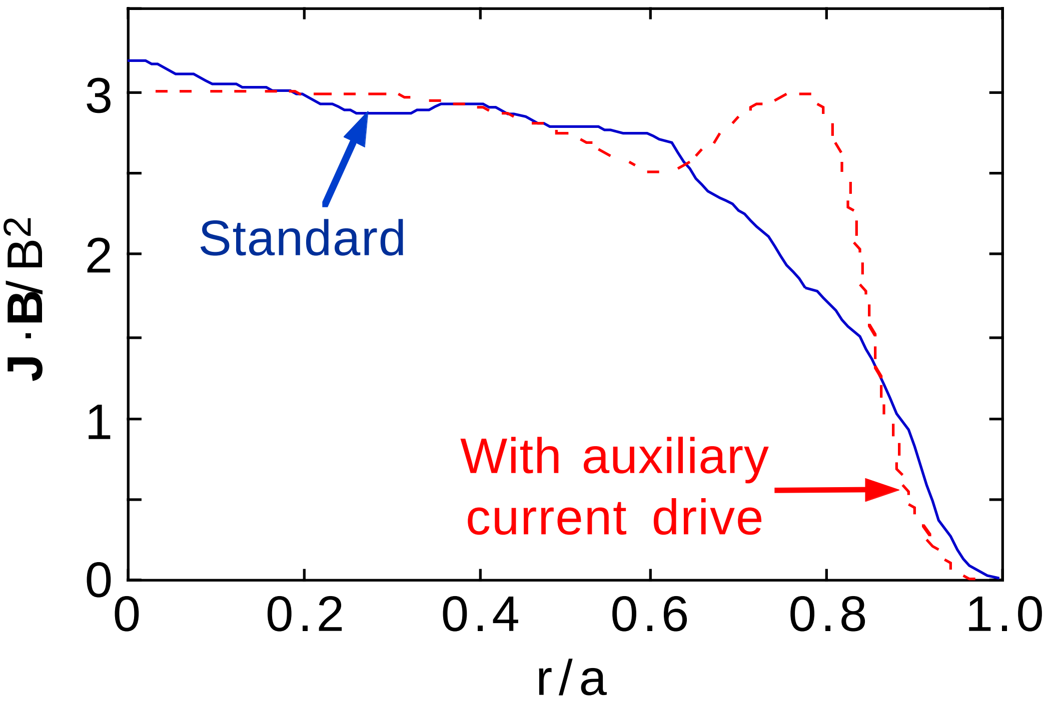
Introduction I: Our motivation

-- Core-resonant m = 1 magnetic tearing fluctuations allow rapid energy transport

-- Fluctuations driven by $\nabla(\mathbf{J}\cdot\mathbf{B}/B^2)$

-- MHD computation told us what to do: add parallel current in the edge region



-- Inductive current drive was applied, m = 1 fluctuations were reduced, and confinement was improved

Introduction II: That was then, this is now

-- Earlier improvement was limited by bursts of edge-resonant m = 0 magnetic fluctuations

-- Modified auxiliary current drive reduces both m = 1 and m = 0 fluctuations, leading to:

(1) High-energy runaway e^- confined
(2) $T_e(0) \rightarrow 1.3$ keV at high current
(3) $\beta_{tot} \sim 15\%$ at low current
(4) $\tau_E \sim 10$ ms (10-fold improvement)
(5) break with historic τ_E scaling
(6) $\langle \chi_e \rangle_{global} \sim 5\ m^2/s$

Outline

-- Technique
-- Current profile measurement
-- Fluctuation reduction
-- Runaway electron confinement
-- Performance improvement

-- New MST diagnostics: polarimetry, CHERs, Rutherford scattering, MSE, HIBP, SXR

A bit about the MST

-- Ohmically heated, toroidal

-- Circular cross section

-- $R/a = 150 \text{ cm}/52 \text{ cm} \approx 3$

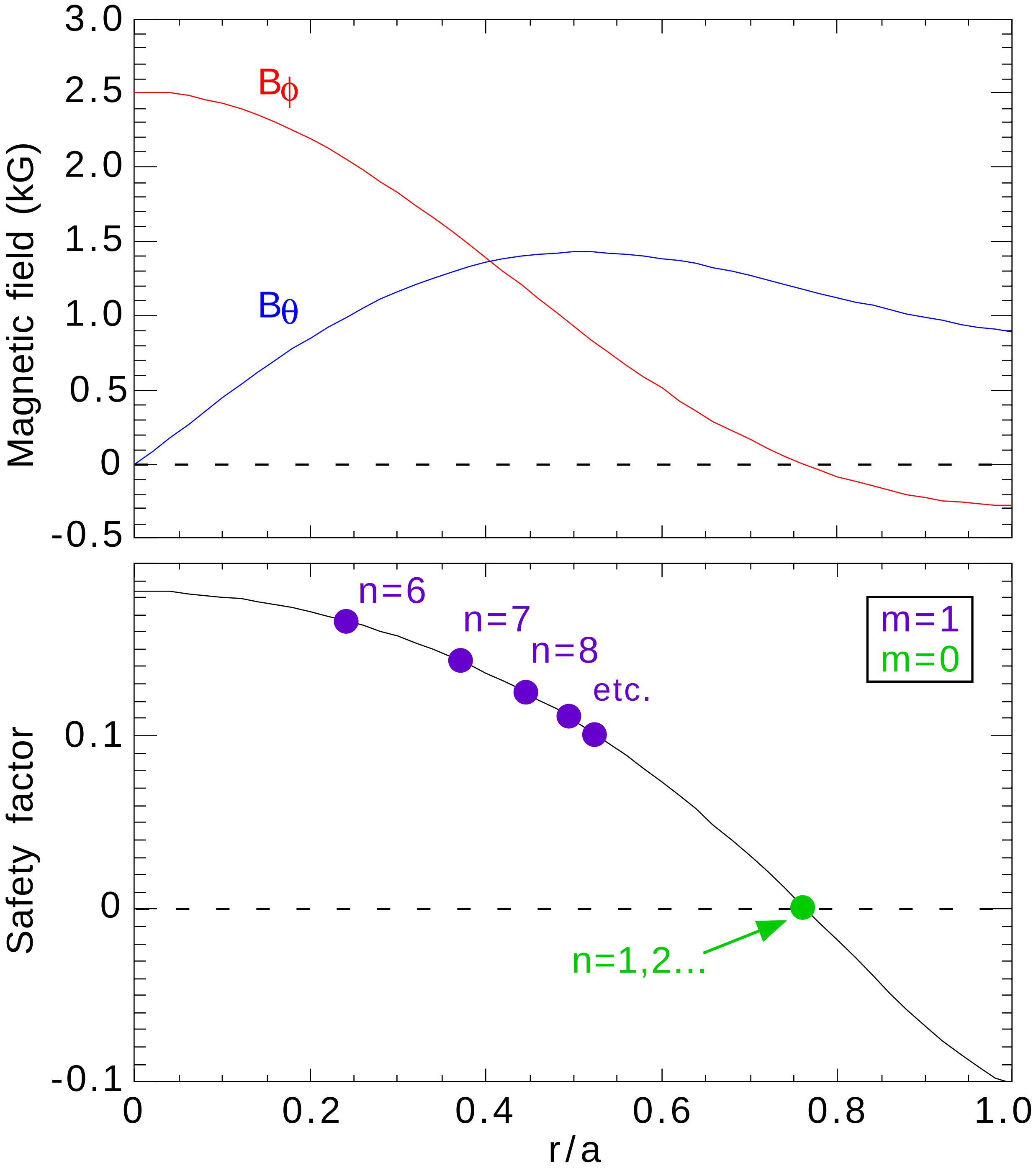
-- $I_\phi \leq 500$ kA

-- $B_\phi(0) \leq 0.5$ T

-- $T_e(0) \leq 1300$ eV

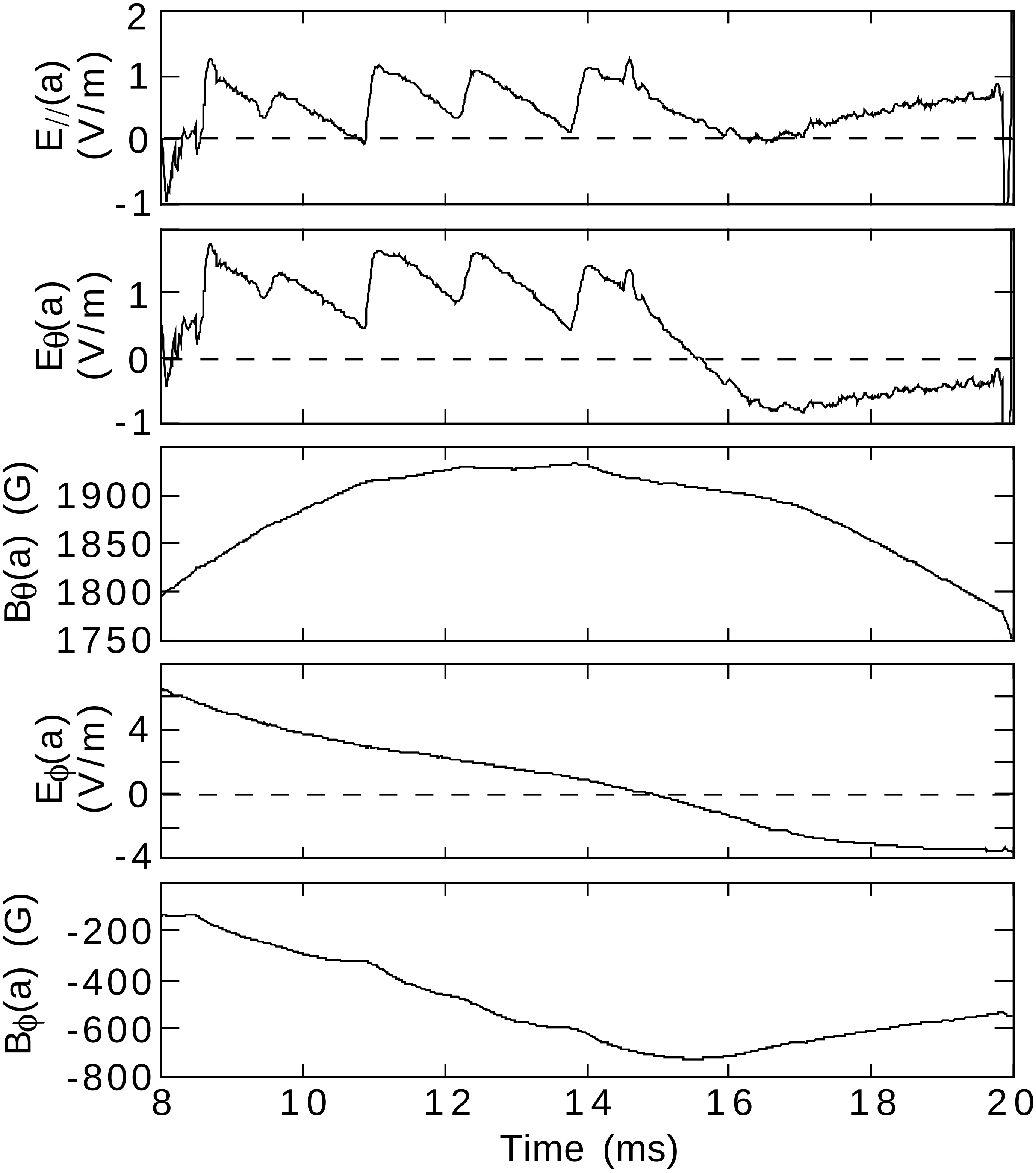
-- $T_i(0) \leq 400$ eV

RFP magnetic field profiles allow resonant m = 1 and m = 0 modes

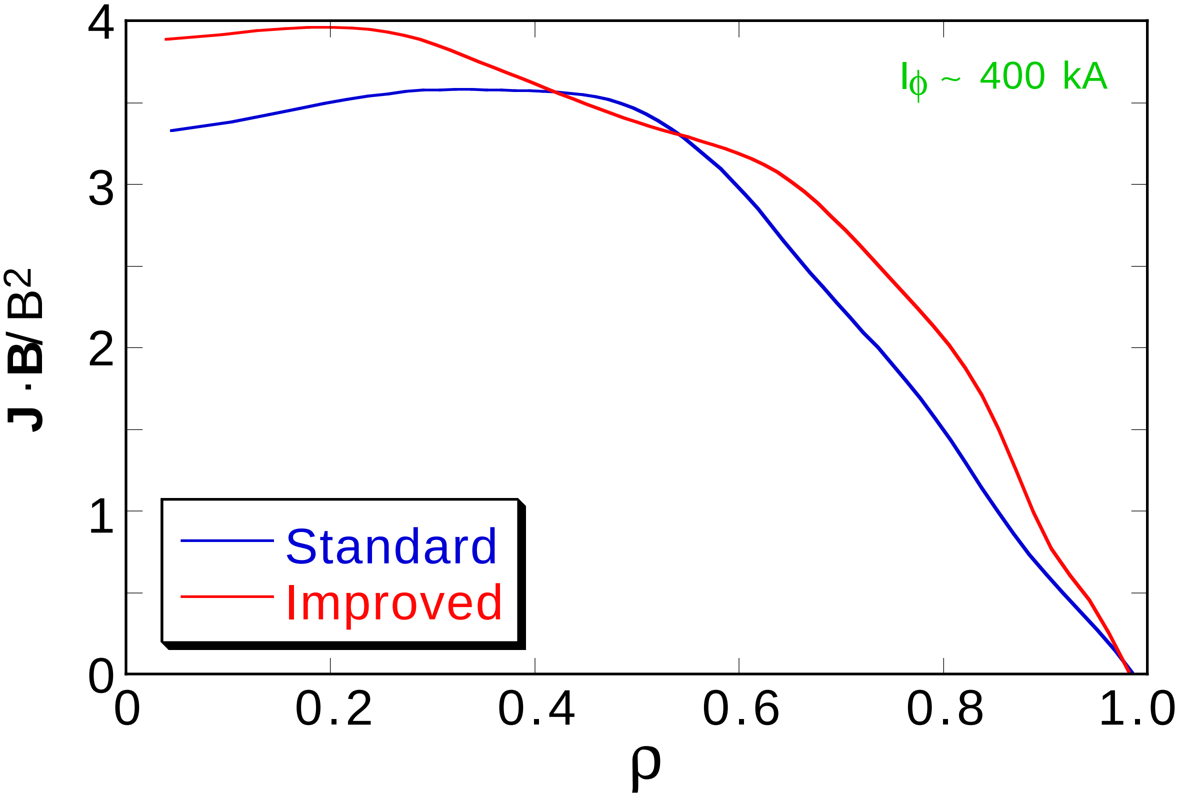


Sustained reduction of m = 0 and m = 1 fluctuations requires

$E_{//}(a) = [E_\theta(a)B_\theta(a) + E_\phi(a)B_\phi(a)]/B(a) \geq 0$



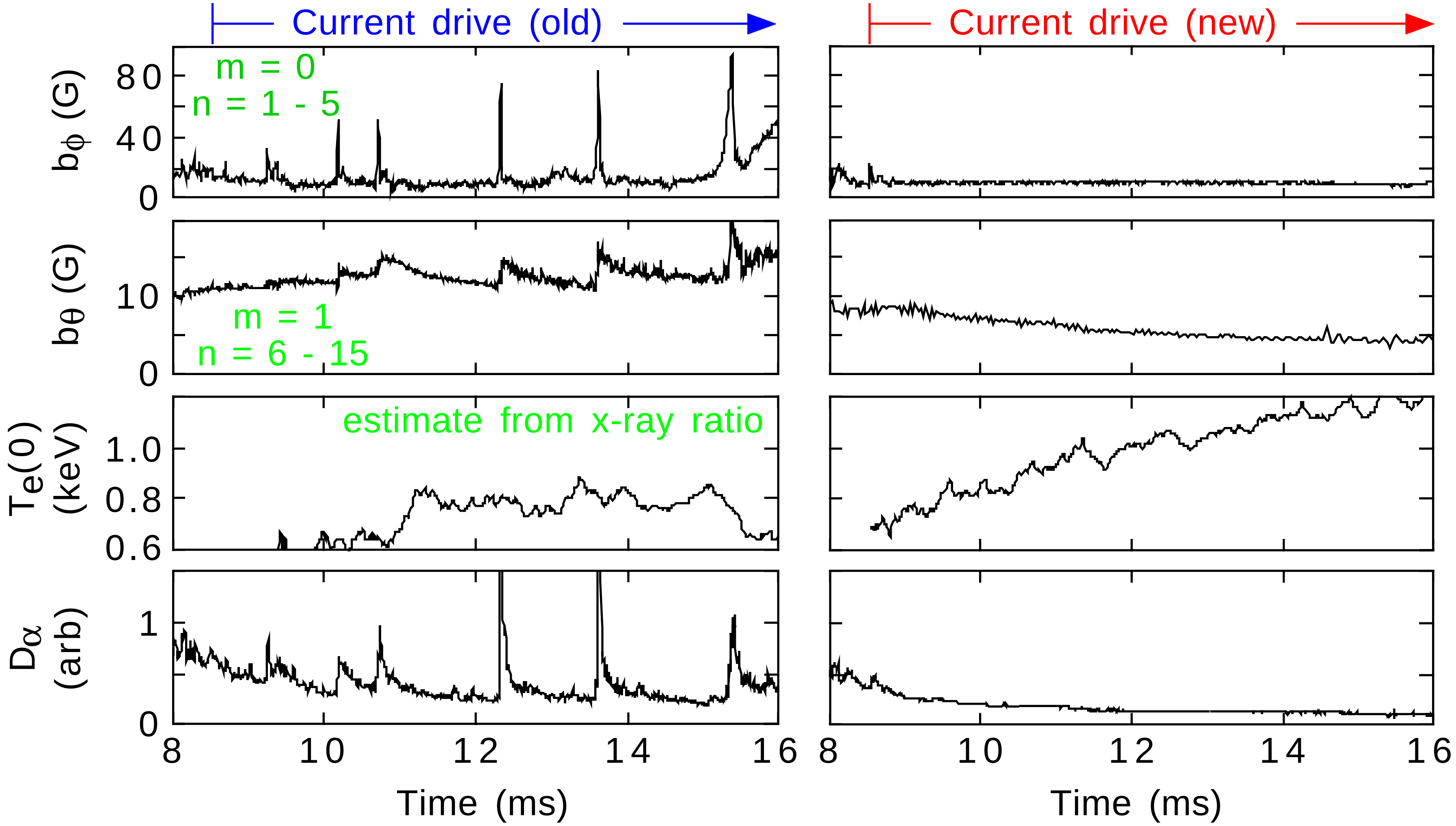
Measurement of current profile progressing



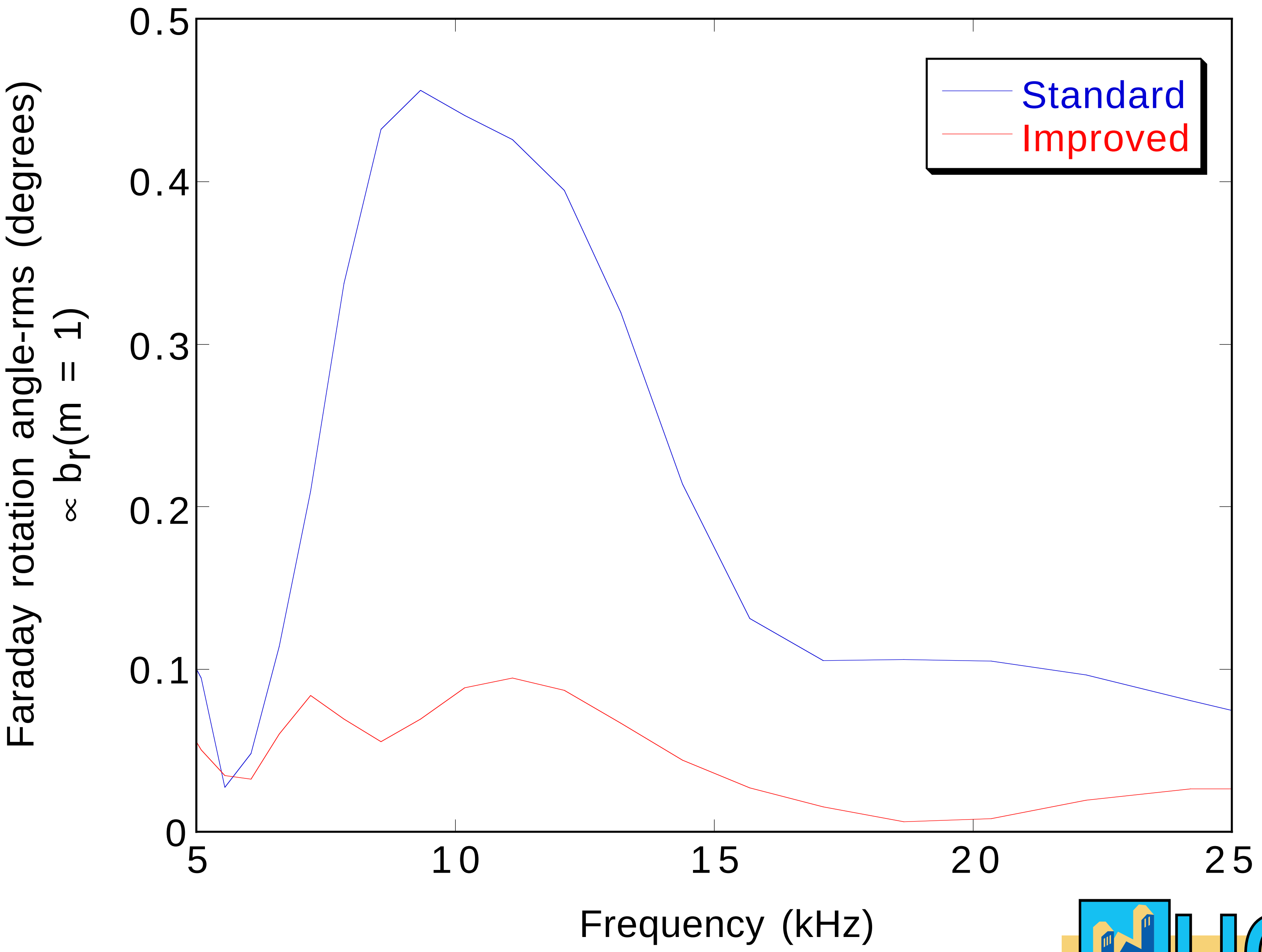
-- $B_\theta(r)$, $J_\phi(r)$ measured via multichord polarimeter-interferometer

-- Full $\mathbf{J}\cdot\mathbf{B}/B^2$ profile from MSTFit, using additional data to constrain equilibrium

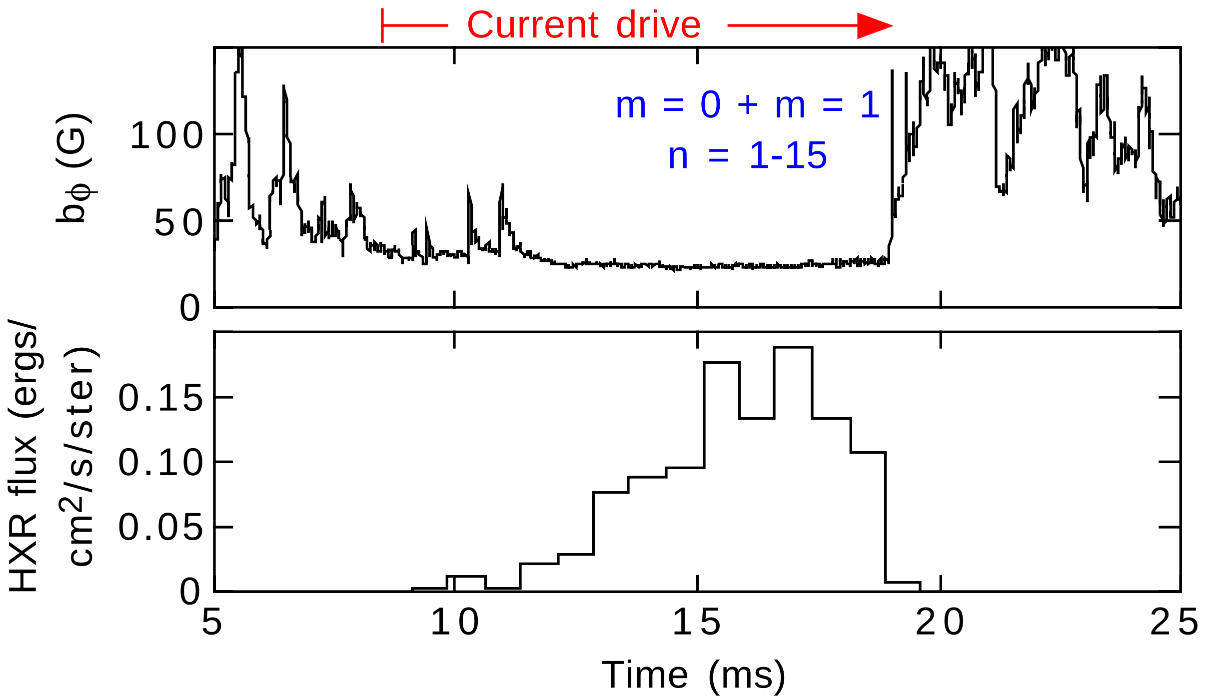
We can now reduce simultaneously the m = 0 and m = 1 magnetic fluctuations

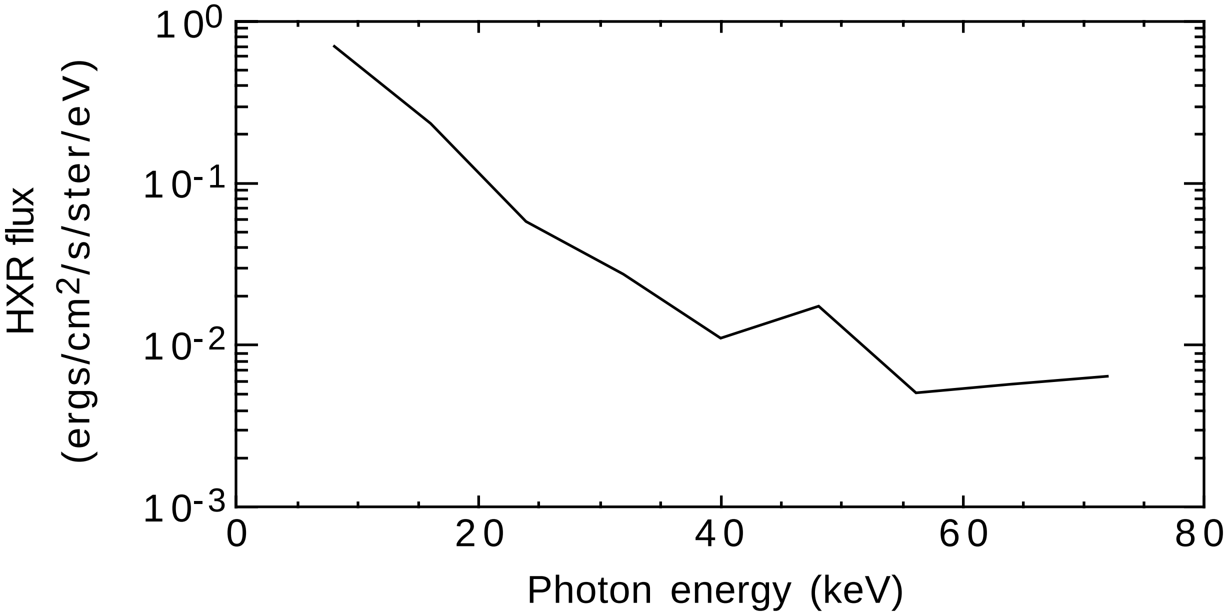


Reduction of core-resonant magnetic fluctuations measured internally via polarimetry



Confinement of high-energy runaway electrons indicated by hard-x-ray photons

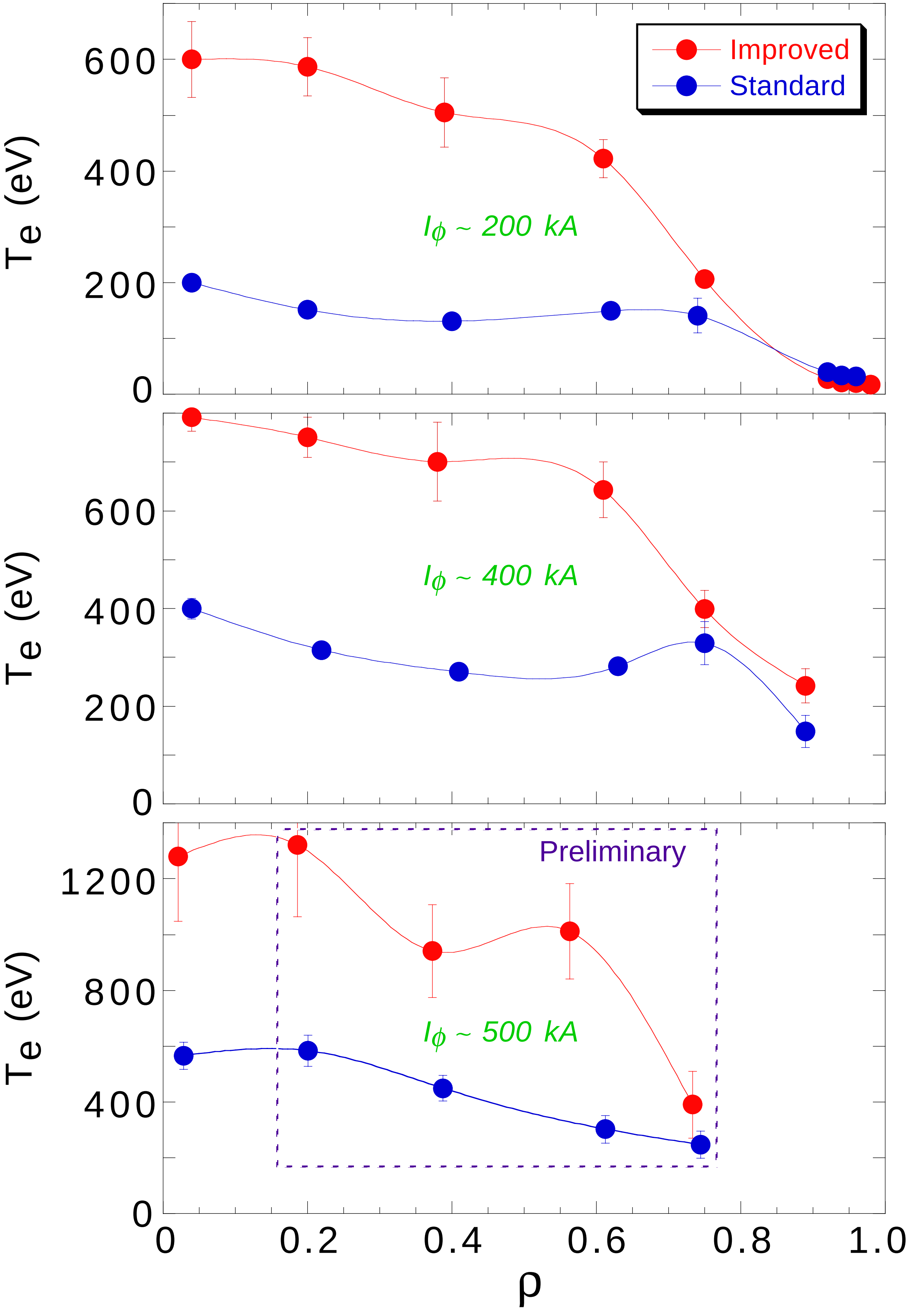




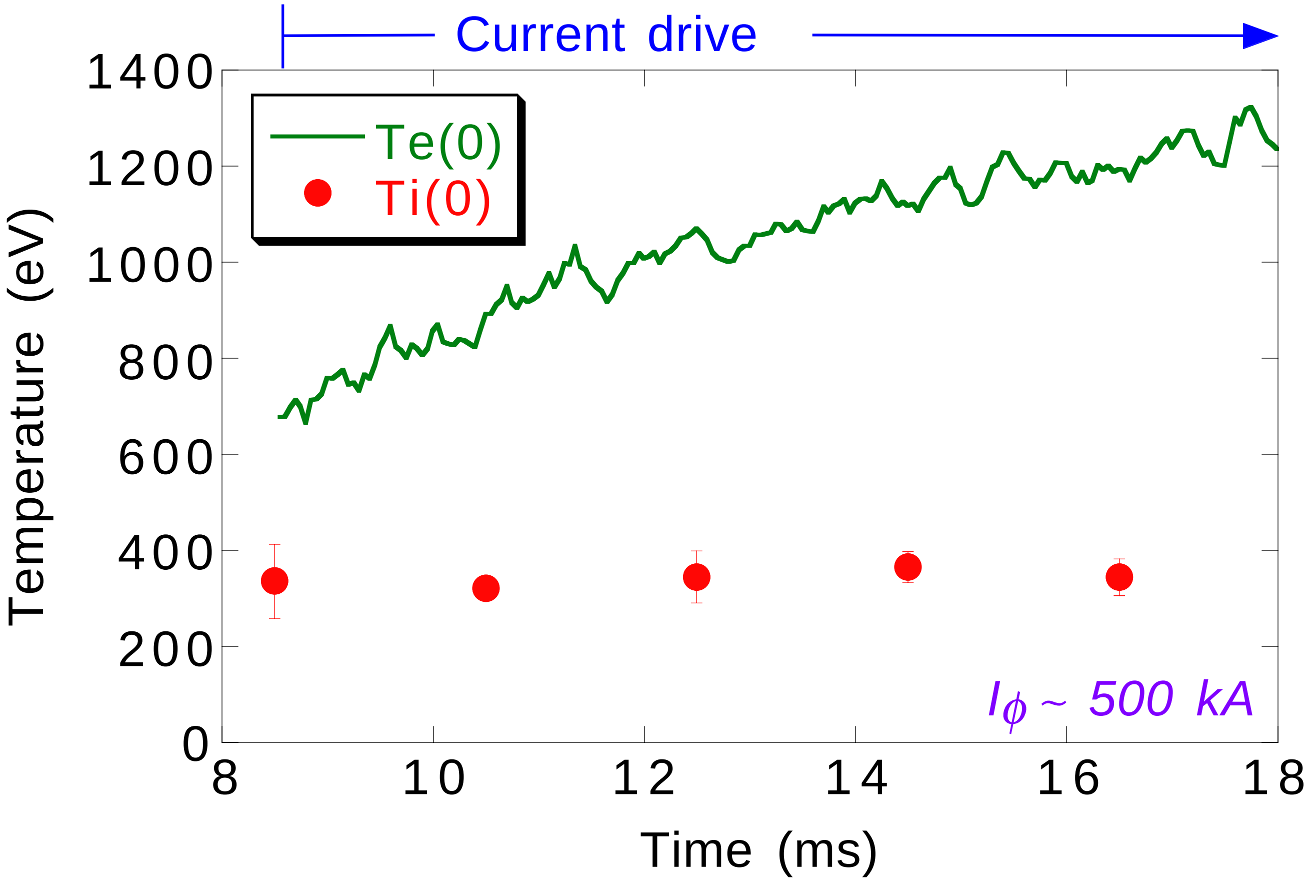
-- Connection length of ~ 100 km

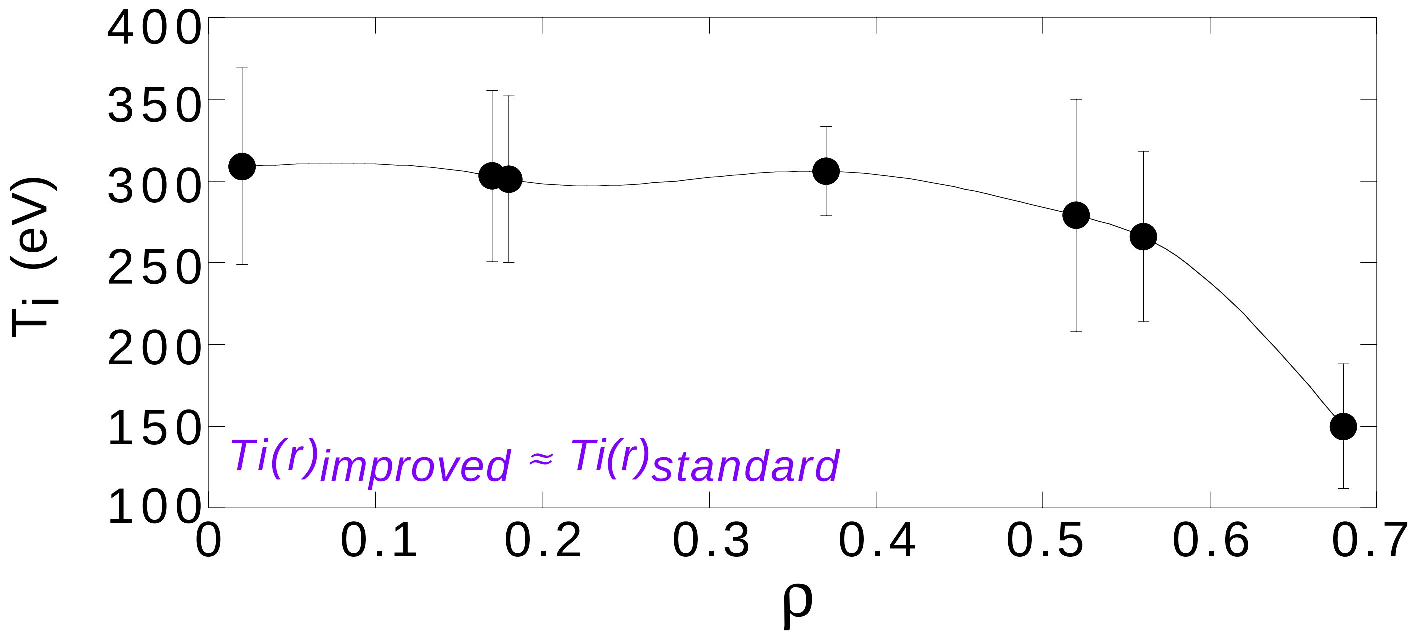
-- $D_{\text{runaway}} \sim 5\ m^2/s$

T_e increases over much of the plasma



While $T_e(0)$ grows, $T_i(0)$ evolves very little



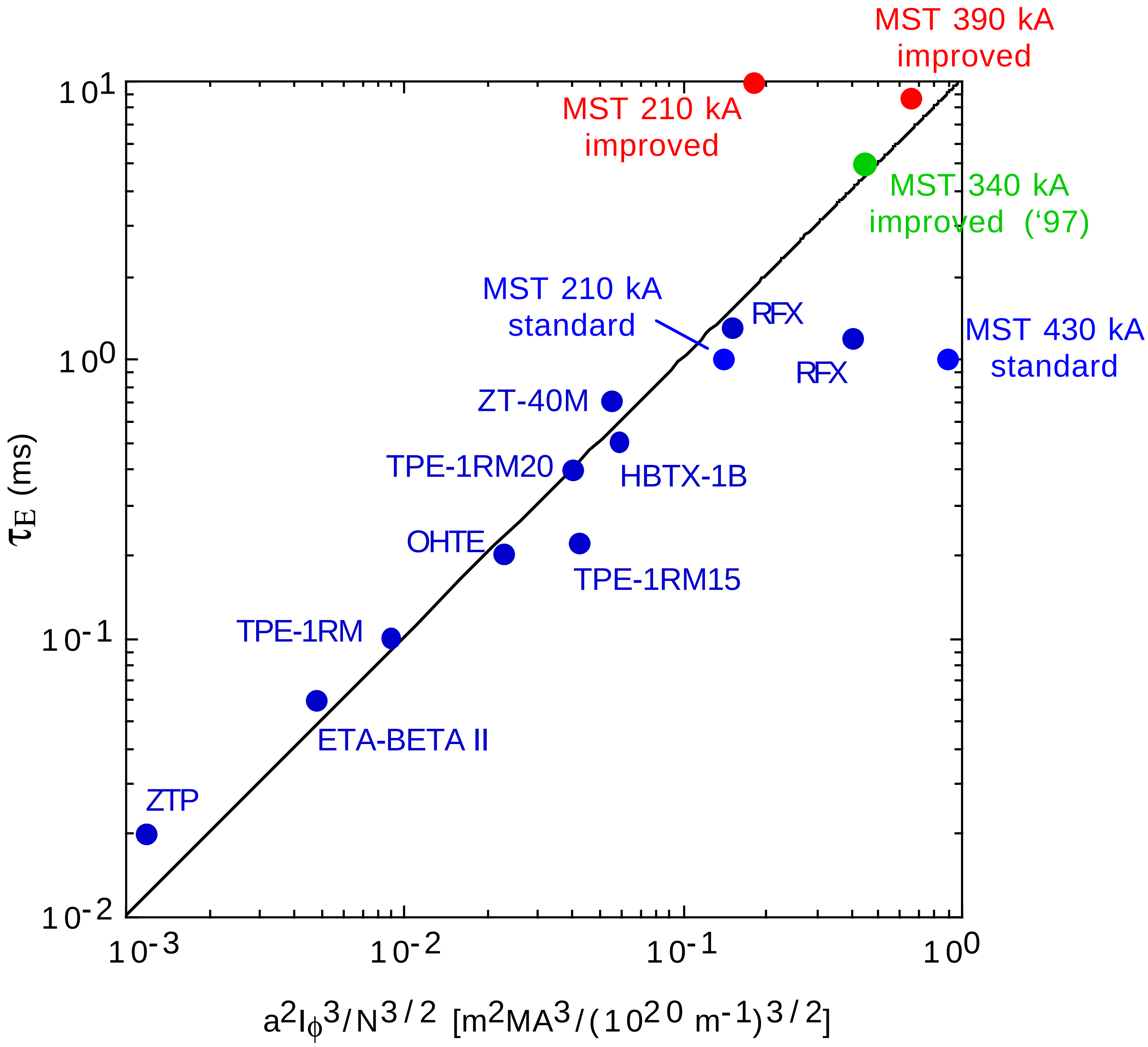


-- T_i(majority:Rutherford-scattering) ≈ T_i(impurity:CHERs)

τ_E and β increase substantially comparing standard and improved confinement

	~ 200 kA	~ 400 kA
$<n_e>$ (10^{19} m^{-3})	0.8/0.7	1.0/1.0
$T_e(0)$ (eV)	200/600	400/792
$\beta_{tot} = 2\mu_o<p>/B^2(a)$ (%)	9.0/15.4	4.8/10.7
P_{oh} (MW)	2.0/1.0	4.0/2.0
τ_E (ms)	1.0/10.1	1.0/8.8
$\langle\chi_e\rangle = a^2/6\tau_E$ (m^2/s)	45/4.5	45/5.1

Improved energy confinement times exceed RFP "constant *β*" scaling



Summary

-- With modified auxiliary parallel current drive:

(1) Core + edge fluctuations reduced
(2) High-energy runaway e^- confined
(3) $T_e(0) \rightarrow 1.3$ keV
(4) $\beta_{tot} \sim 15\%$
(5) $\tau_E \sim 10$ ms (10-fold improvement)
(6) τ_E exceeds constant-β scaling
(7) $\langle\chi_e\rangle_{global} \sim 5\ m^2/s$

The future

-- Determine physics underlying fluctuation reduction: measure **J**(r), **p**(r), **v**(r)

-- Determine relative roles of magnetic and electrostatic turbulence in remaining transport

-- Increase duration of auxiliary current drive: inductive and/or RF

-- Apply auxiliary heating (NBI tested first) and pellet injection

-- Larger β, possibly larger τ_E?