# MST Program Plans

S.C. Prager
Budget Planning Meeting
March, 2008

# MST Collaborations

- UCLA - FIR interferometry/polarimetry
- RPI - Heavy ion beam probe
- Novosibirsk - neutral beam diagnostics and heating, MSE on GDT
- ORNL - pellet injection
- RFX, Italy - SXR, PPCD, OFCD
- RELAX, Japan - PPCD, NBI, Thomson scattering
- T2, Stockholm - PPCD expts
- University of Strathclyde - Atomic data modeling
- TechX - lower hybrid modeling
- CompX - Fokker Planck modeling
- Wheaton College - CHERS etc
- Ohio State University - Fast Thomson scattering
- University of Washington - analysis of fast particle effects
- UCSD/Decysive - RFP systems study
- LANL - theory and CMSO
- SAIC - theory and CMSO
- U. Chicago - CMSO
- Princeton - CMSO
- Swarthmore - CMSO
- LLNL - CMSO
- U New Hampshire - CMSO
- HSX, Pegasus - Thom scat, CHERS, HXR detection, plasma guns
- Astronomy Dept - CMSO

# Outline

- Major program goals and plans
- FY 10 budget cases:  decrement, full use
- Upcoming programmatic opportunities

# MST Program Goals

- Advance specific fusion physics issues
- Advance the RFP reactor configuration
- Link fusion energy science to astrophysics (magnetic self-organization)

MST contributes centrally to half of the topical questions from the priorities panel report

# MST also makes contributions to enabling technology

RF antennas

pellet injectors

neutral beam sources

diagnostics (HIBP, FIR polarimetry and interferometry, Rutherford scattering, MSE, fast Thomson scattering, fast CHERS)

# Issues for development of RFP configuration

- Confinement
- Beta
- Resistive wall instabilities
- Sustainment

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↑

for these three topics,
major advances in past decade,
that introduce new regimes for fusion physics

# Issues for development of RFP configuration

- Confinement
- Beta
- Resistive wall instabilities (EU)
- Sustainment

*progress in OFCD,*
*proof of concept might require*
*high $T_e$ target plasma*

for these three topics,
major advances in past decade,
that introduce new regimes for fusion physics

# Confinement improvement

Method:

improve confinement by current profile control,

control current (transiently) by programming loop voltages

Earlier results up to 0.4 MA:

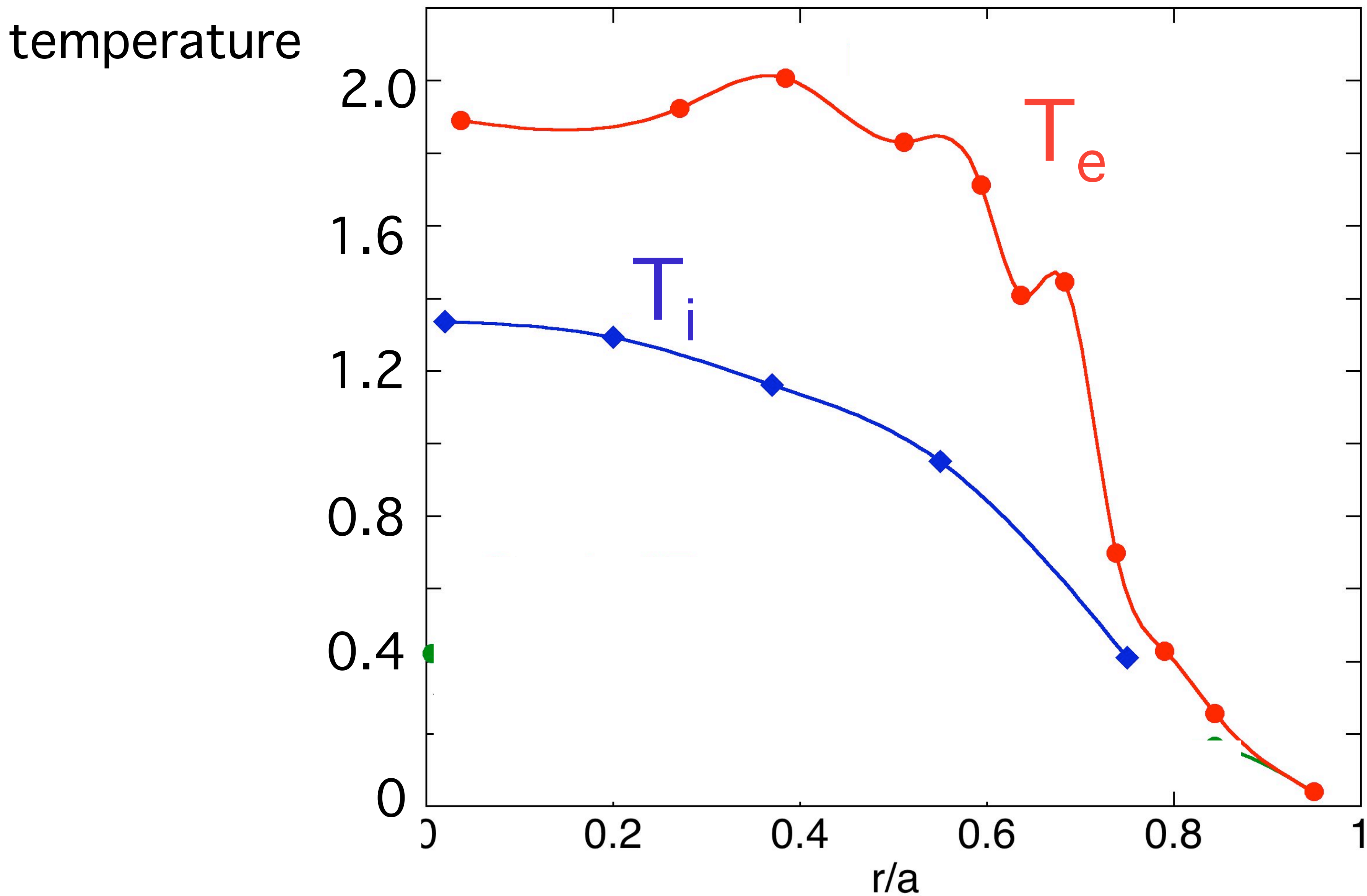
- Energy confinement improves tenfold
- Electron temperature ~ 1 keV
(increase ~ 3-fold from standard case)
- But, ions remain cold (~ 0.3 keV)

# Recent results

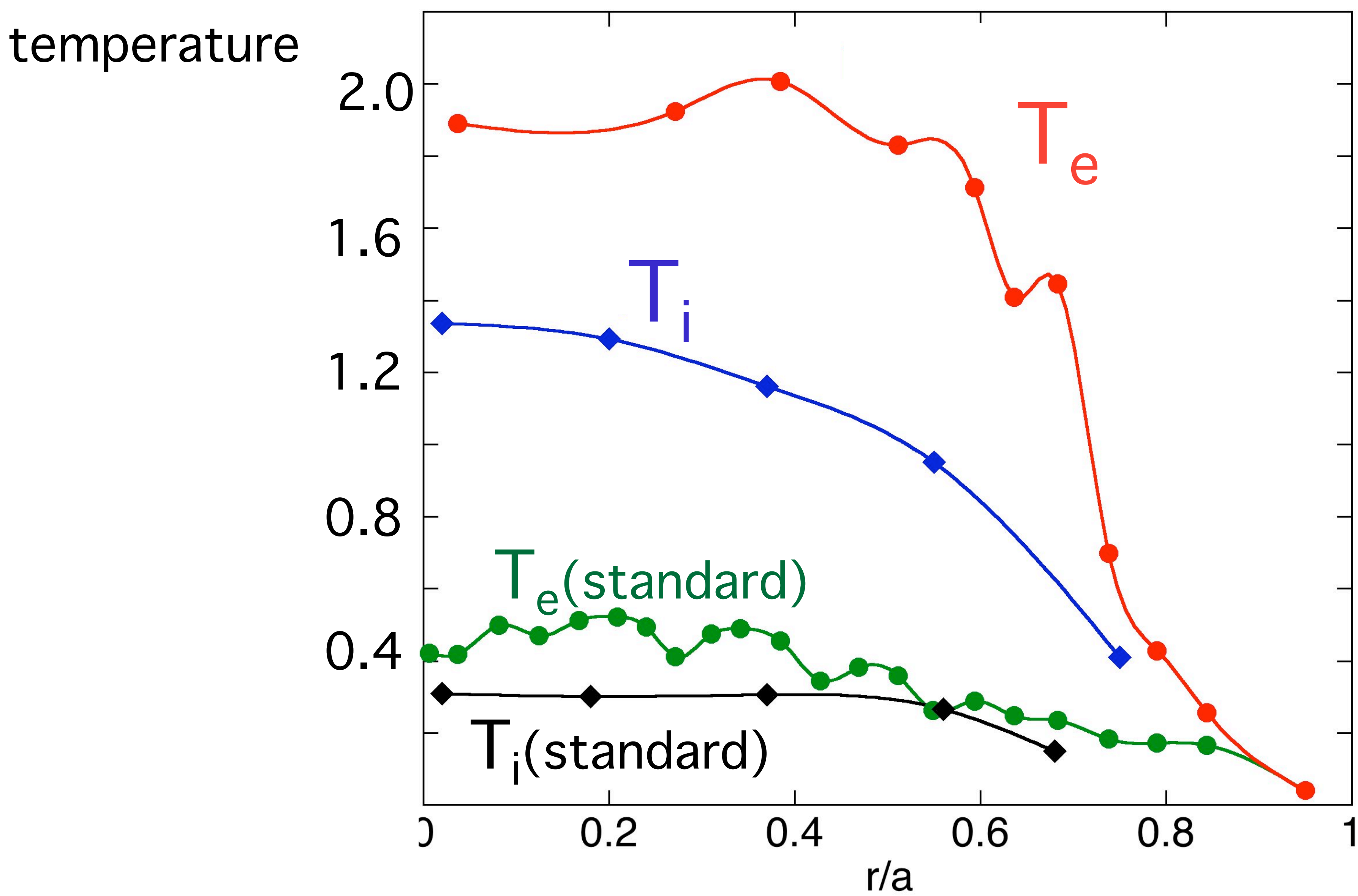
- Ion temperature increased to 1 keV
  (by confining heat produced during reconnection event)

- Positive confinement trend with plasma current
  (at 0.5 MA, electron temperature ~ 2 keV)

<u>Simultaneous favorable electron and ion confinement</u>



# Simultaneous favorable electron and ion confinement



# Positive trend with plasma current

| current | Te | $\beta$ | $\tau_e$ |
|---|---|---|---|
| 0.2 MA | 0.6 keV | 15% | ~ 10 ms |
| 0.5 MA | 2.0 keV | 10% | > 8 ms |

absence of auxiliary heating

measurement limitation

Thus, simultaneously obtain

- Good confinement of
  - thermal electrons
  - thermal ions
  - large orbit ions (shown earlier by NBI)
  - energetic electrons (shown earlier by FP analysis)

- High beta (~10%)

# But,

- Confinement improvement is transient
  (limited by transience of current profile control technique)

- Predictive physics understanding not yet in hand

  can magnetic transport be entirely suppressed?

  what are properties of electrostatic transport
  (new regime: $q < 1$ dominated by electrostatic transport)

# Directions for FY 10

- Optimize and sustain current profile control

- Diagnose limits and causes of transport in new regime

# Optimizing current profile control

- Improved inductive programming
  (programmable power supply for toroidal loop voltage)

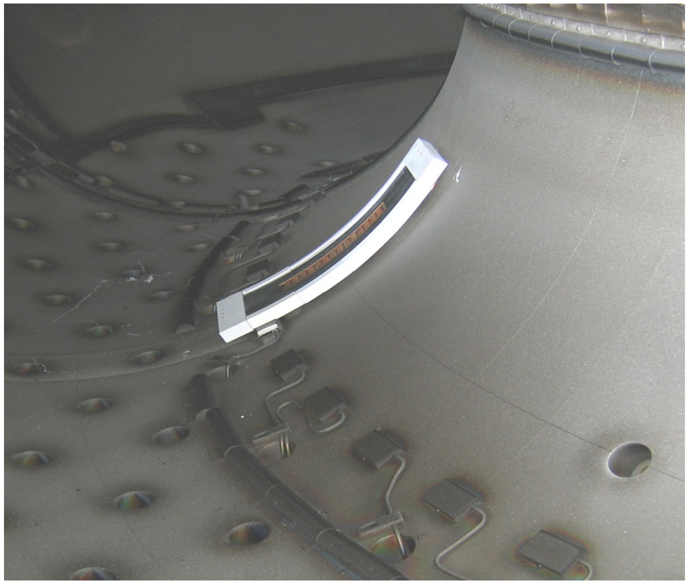
- RF current drive
  (lower hybrid, electron Bernstein waves)

# Programmable power supply

*To more flexibly program loop voltages*

| | |
|---|---|
| FY 08 | begin operation of power supply for for poloidal loop voltage |
| FY 09 | use for confinement optimization, use for oscillating field current drive |
| FY 10 | design supply for toroidal loop voltage control (requires additional resources) |

# RF Current Drive



Lower hybrid wave injection
(proven physics in tokamak,
antenna challenges for RFP)

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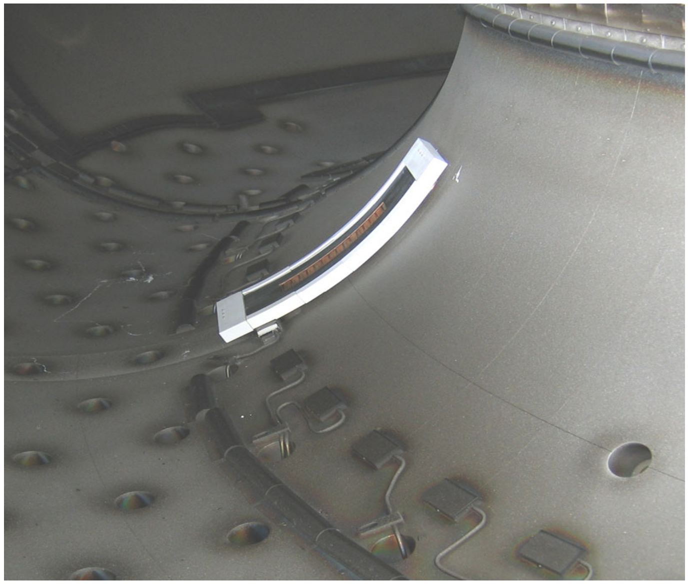

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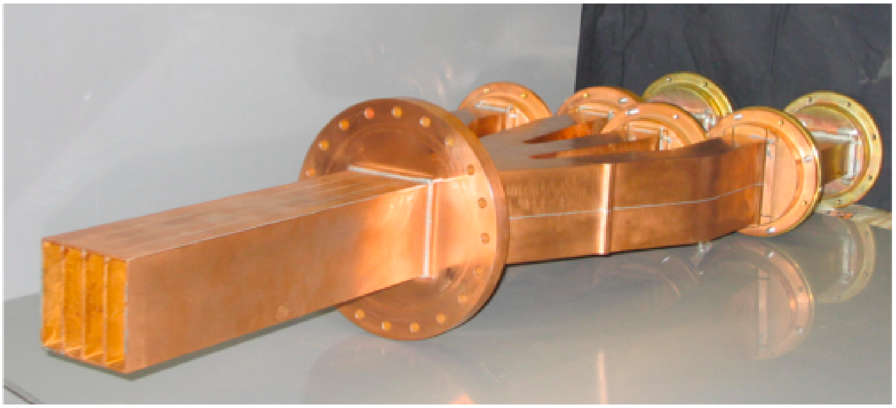
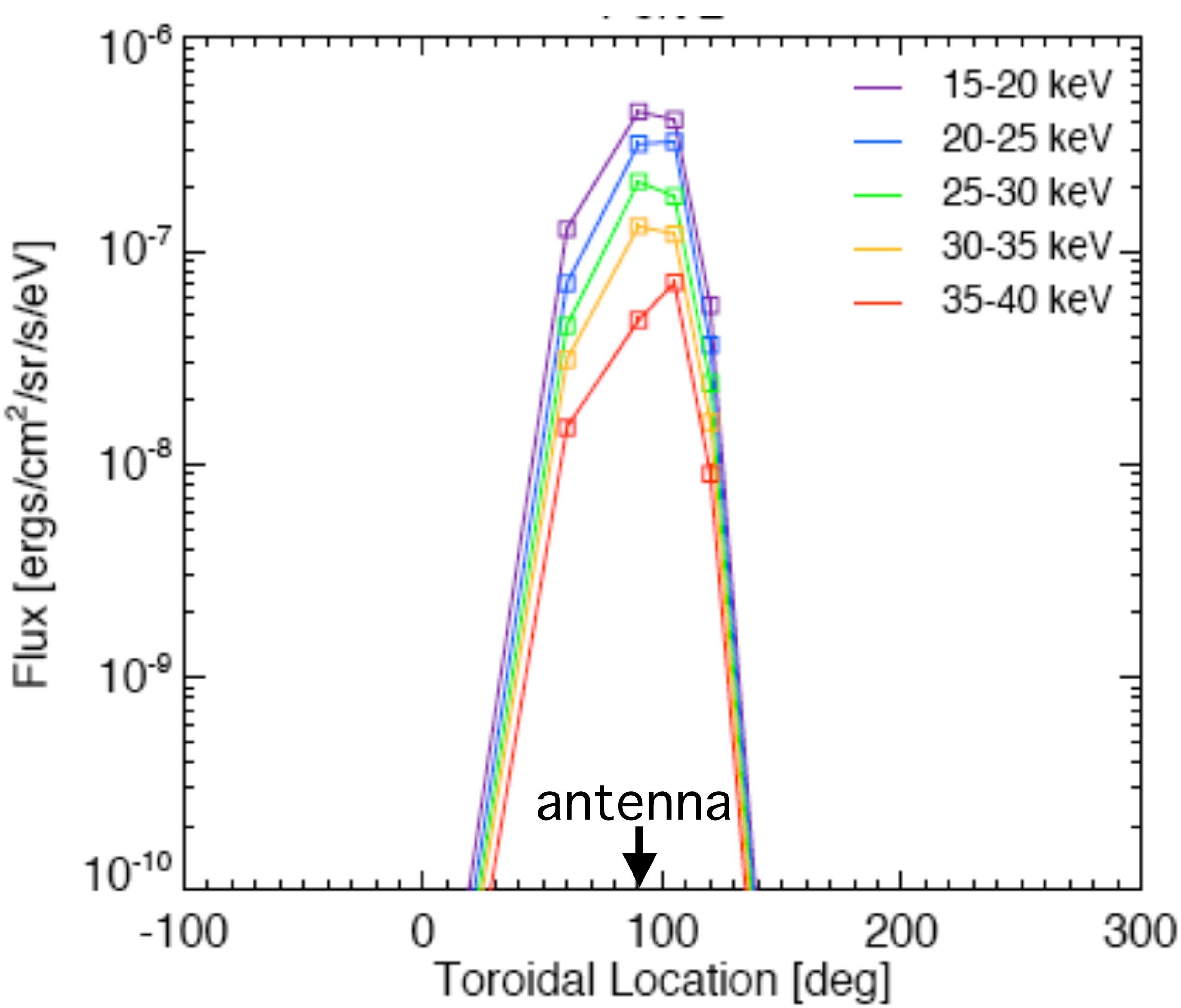


Electron Bernstein wave

(antennas are simple,
physics not well-established)

*Both techniques evolving, presently at 200 kW power level*

# Hard x-ray generation with LH waves




toroidally localized

# Lower hybrid plans

FY 08 Examine HXR localization,
upgrade power to 0.4 MW

FY 09 Assess antenna, HXR at 0.4 MW

FY 10 complete physics assessment at 0.4 MW,
begin upgrade to higher power
(contingent on results)

# EBW plans

FY 08 Characterize HXR, SXR emission,
investigate power upgrade with in-house tubes
(~ 1 MW)

FY 09 Perform coupling tests at higher frequency
(5.5 GHz vs 3.6 GHz)

FY 10 Begin assembly of higher power system (~ 1MW)
(contingent on results)

RF is the most resource-limited project on MST

# Understanding transport with improved diagnostics

Improved equilibrium profiles to determine diffusivity

- Fast Thomson scattering for $T_e(t)$
- Laser Cotton-Mouton effect for $B_{toroidal}$ (UCLA)
- Extension of CHERS, TS to higher temperature
- Extension of CHERS, MSE to more spatial points

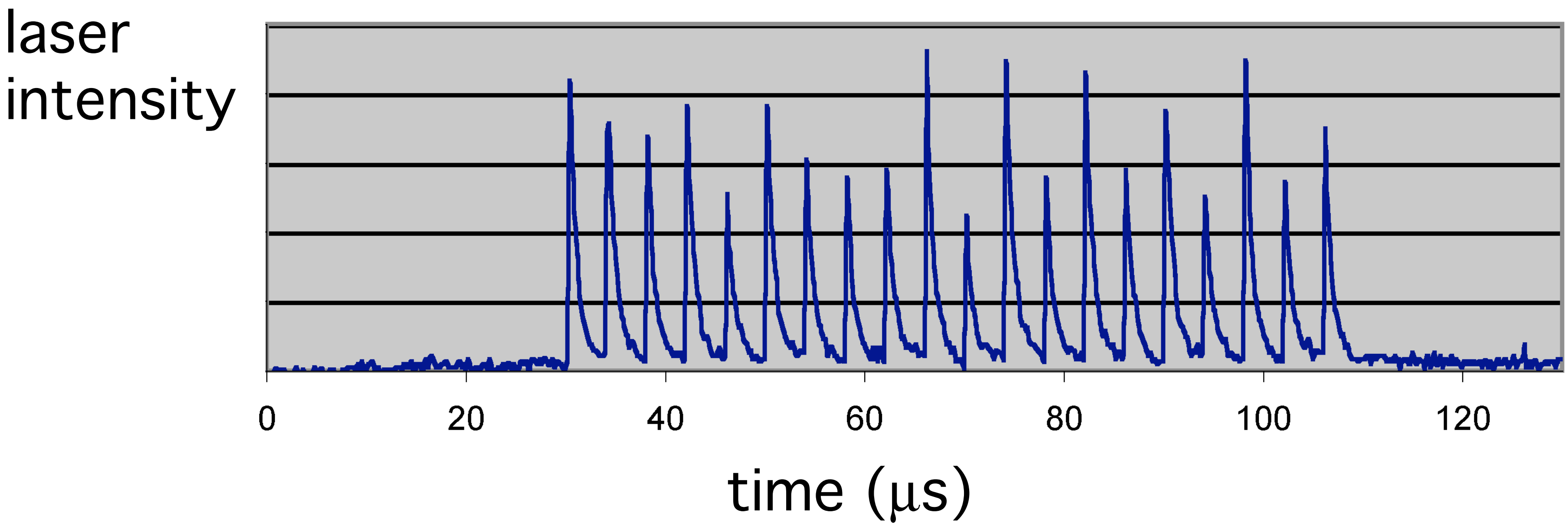
Measuring electrostatic transport

- Heavy ion beam probe (RPI)

# Fast Thomson scattering for electron dynamics

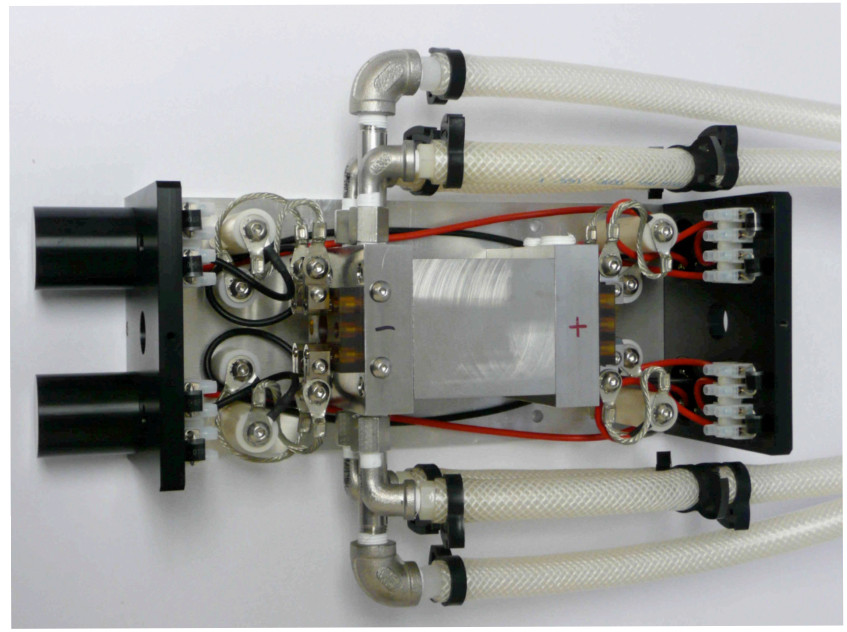
## Measure time dependence of $T_e$, $n_e$

- at 250 kHz (in 20 - 30 pulse train)
- spatial resolution of 2 cm




Laser development in collaboration with Ohio State University

# Schedule for Fast Thomson scattering



FY 08 Being assembled

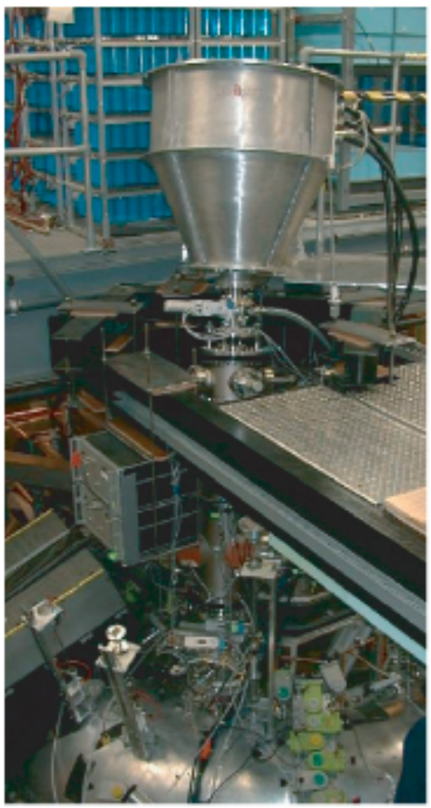
FY 09 Begin measurement of equilibrium changes, and $T_e$ fluctuations

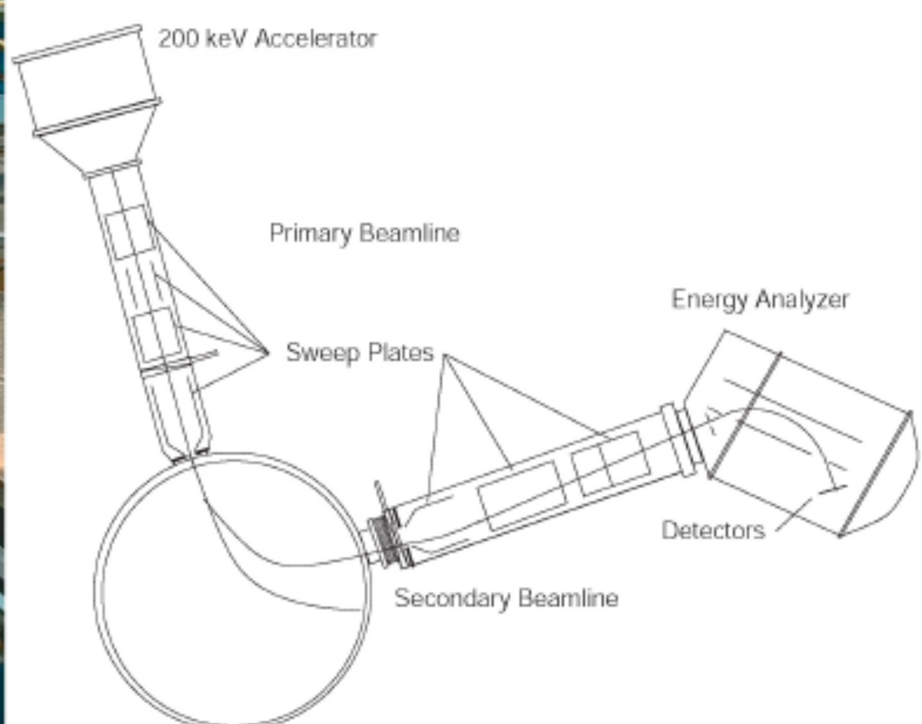
FY 10 Obtain improved thermal diffusivity, investigate fluctuation-induced energy flux

Cost-shared with CMSO

# Heavy Ion Beam Probe (RPI)

Goals: measure E and electrostatic transport
in time-varying equilibria
Past: measured transport in standard plasmas
Next: measure in improved confinement





# HIBP plans

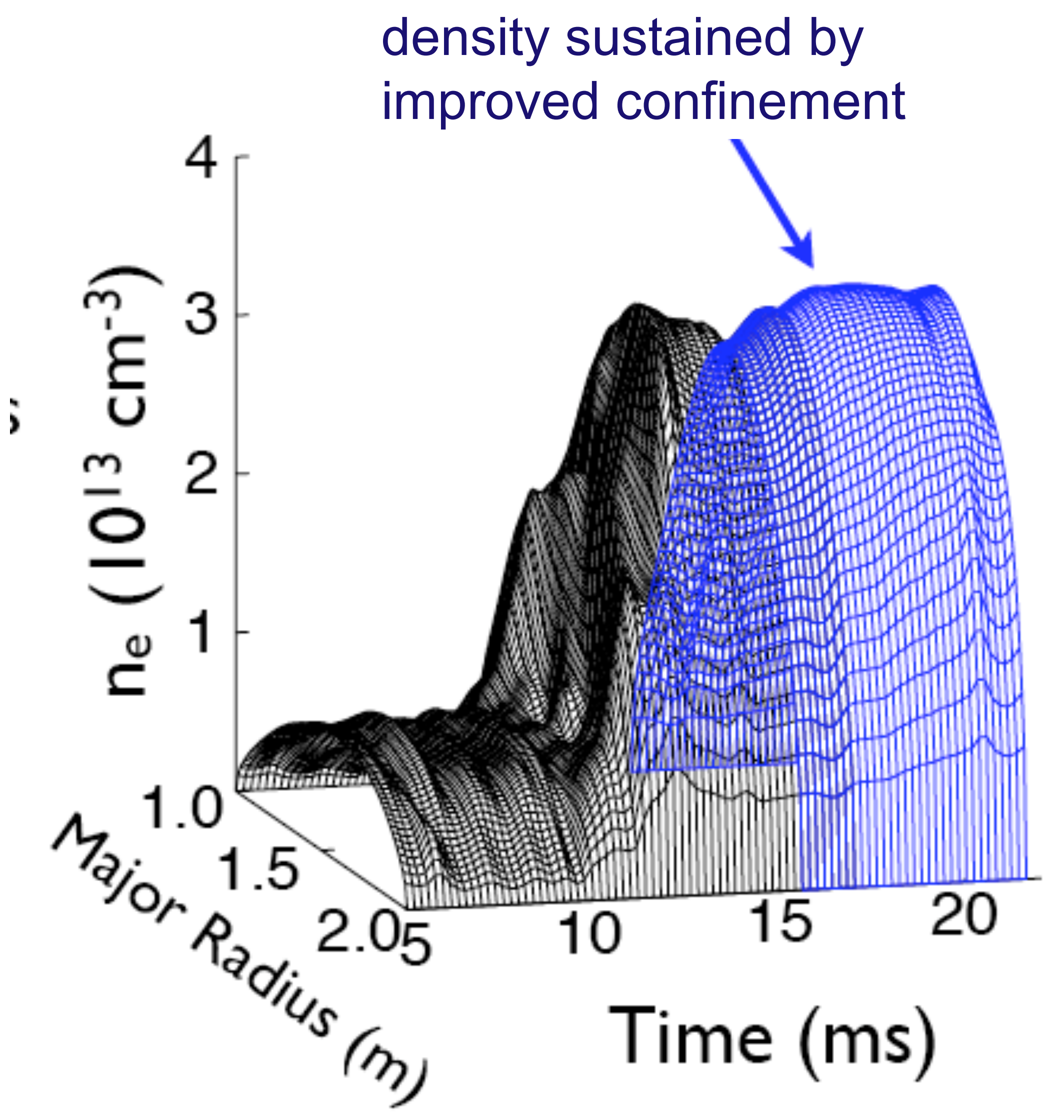
FY 08 Begin n, E measurements with upgraded system

FY 09 Measure n, E (equilibrium, fluctuating) in improved confinement plasmas

FY 10 Determine particle flux from electrostatic fluctuations

# Challenging beta limits with pellet injection

*density quadruples with pellet injection*




(with ORNL injector)

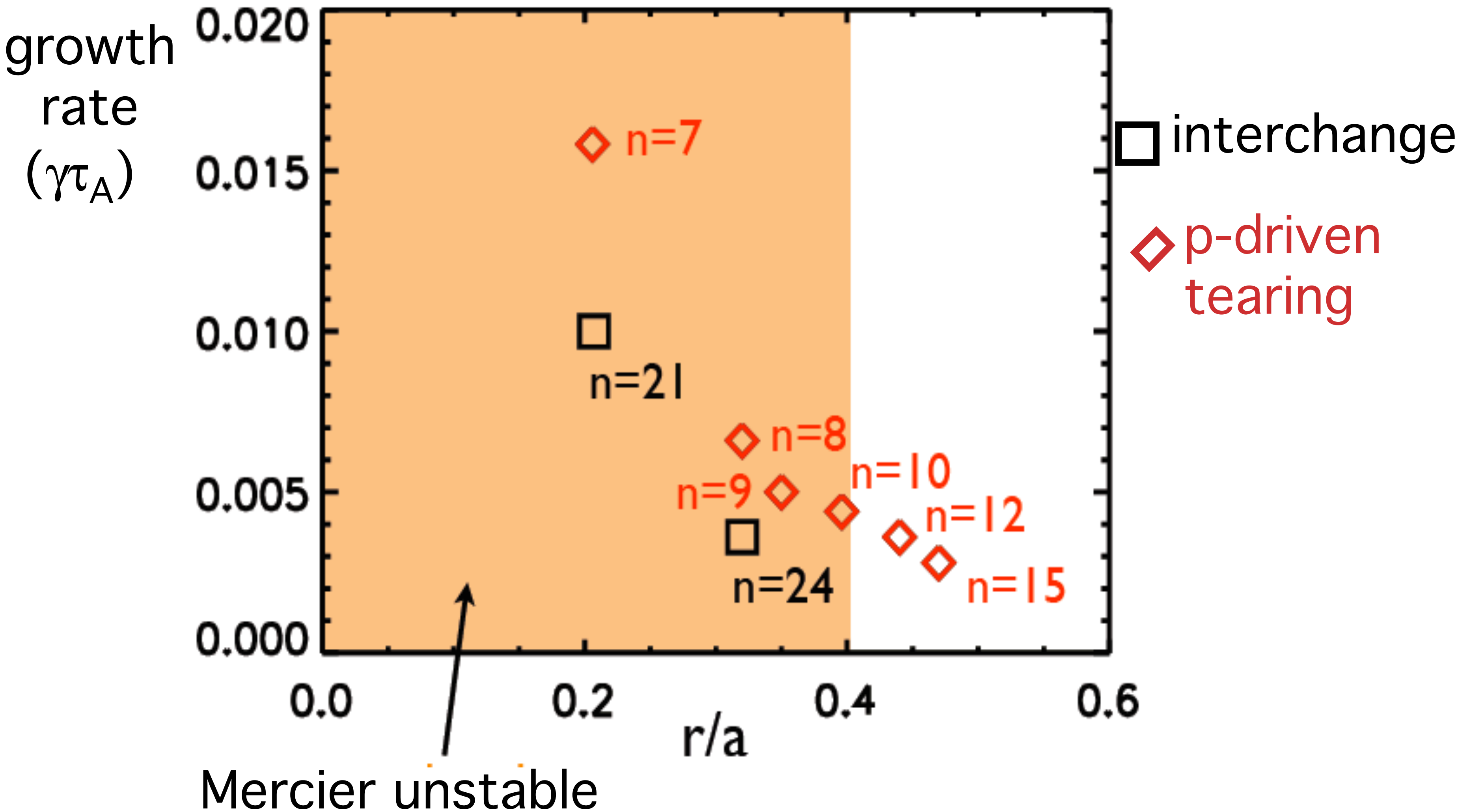
# Beta doubles

$$\beta \sim \frac{\langle p \rangle_V}{\langle B^2 \rangle_S}$$

| standard | improved conf no pellets | improved conf with pellets |
| --- | --- | --- |
| 9% | 15% | 26% |

exceeding MHD limits without apparent limit

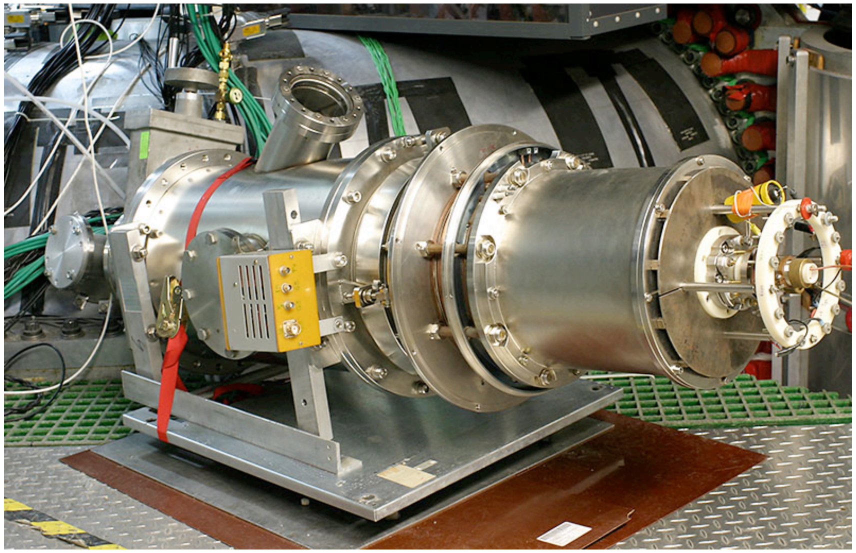
# Exceeding linear MHD stability limits



# Further increase beta

- Optimization of pellets
- Neutral beam injection

# Testing neutral beam injection



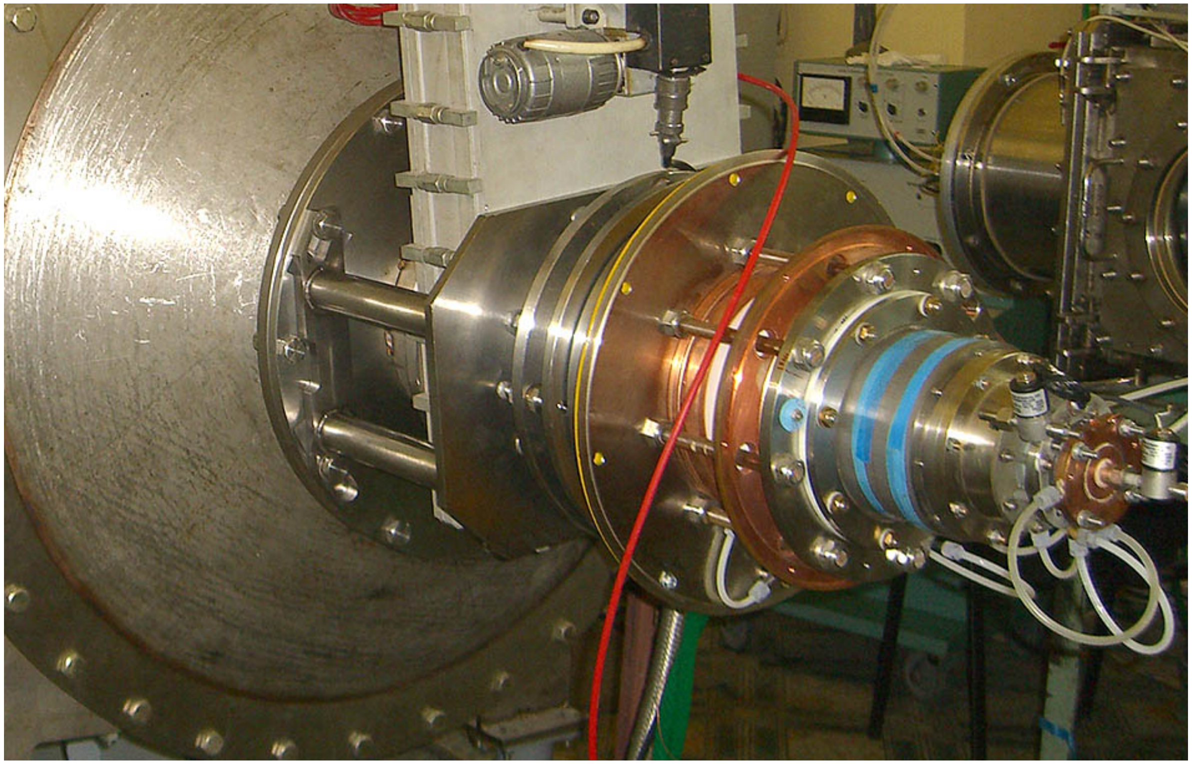
0.6 MW, 1 ms

Novosibirsk

Demonstrated favorable confinement of energetic ions

Thus, can use NBI for beta enhancement, momentum input .......

# next step in neutral beam injection



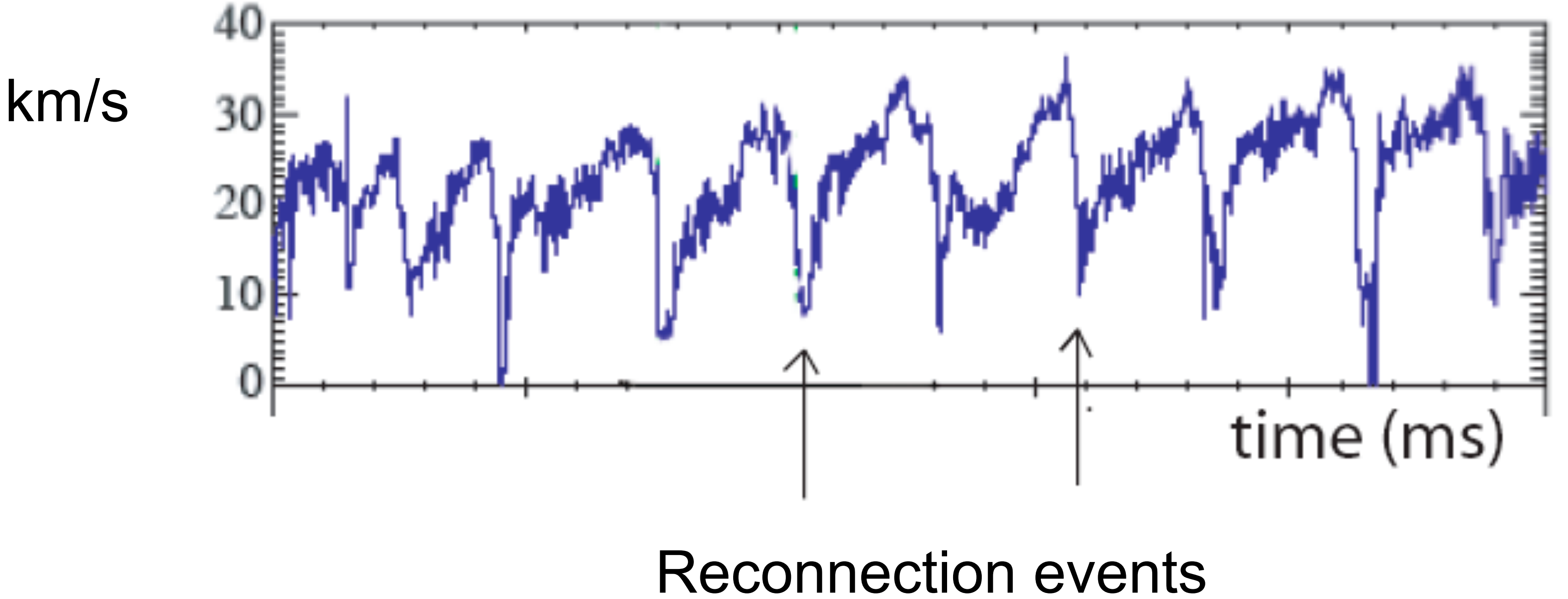
*1 MW, 20 ms*

| | |
|---|---|
| FY 08 | Complete construction |
| FY 09 | Begin experiments |
| FY 10 | Assess effect on beta and stability |

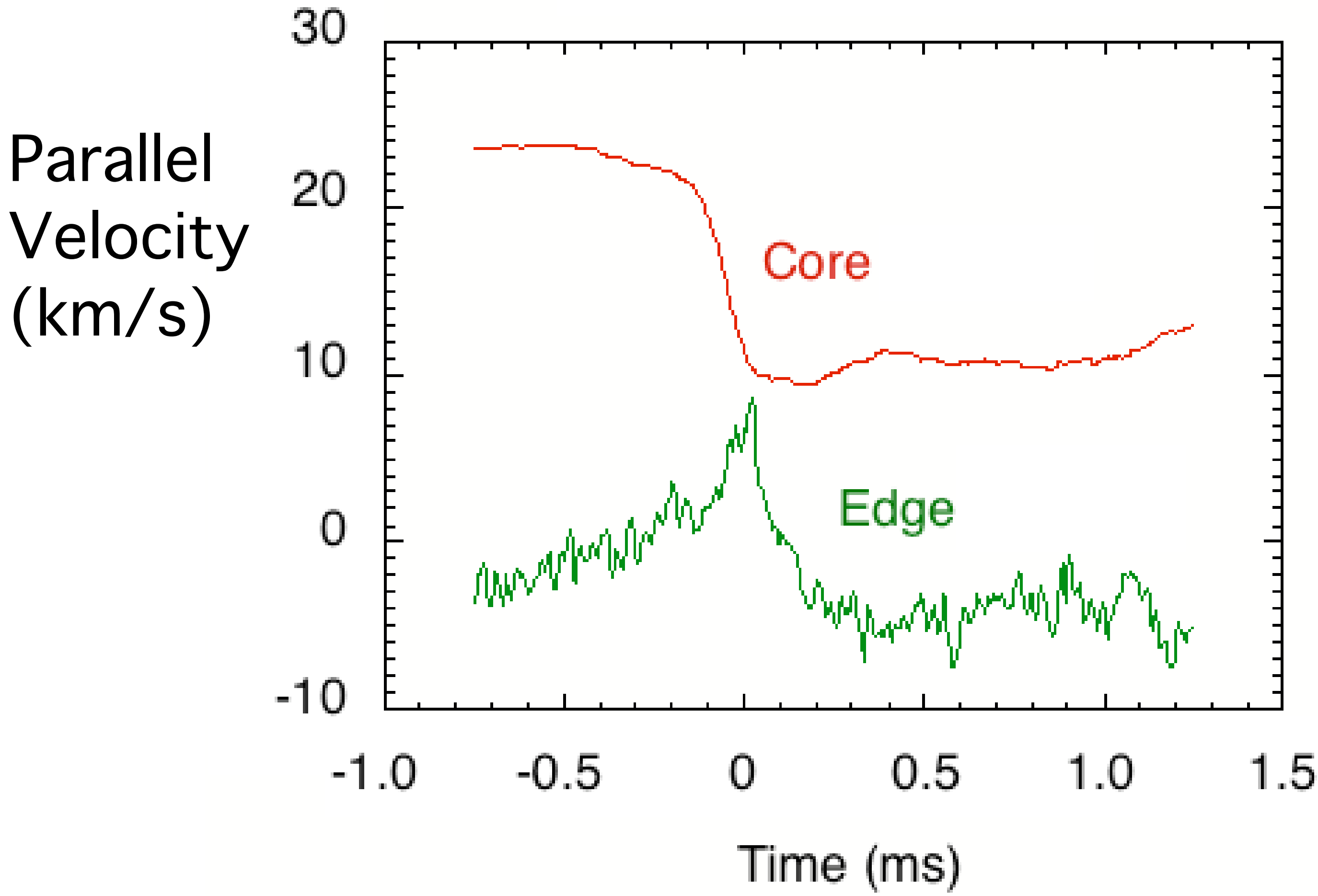
# Example of magnetic self-organization

## Momentum transport

Toroidal flow speed



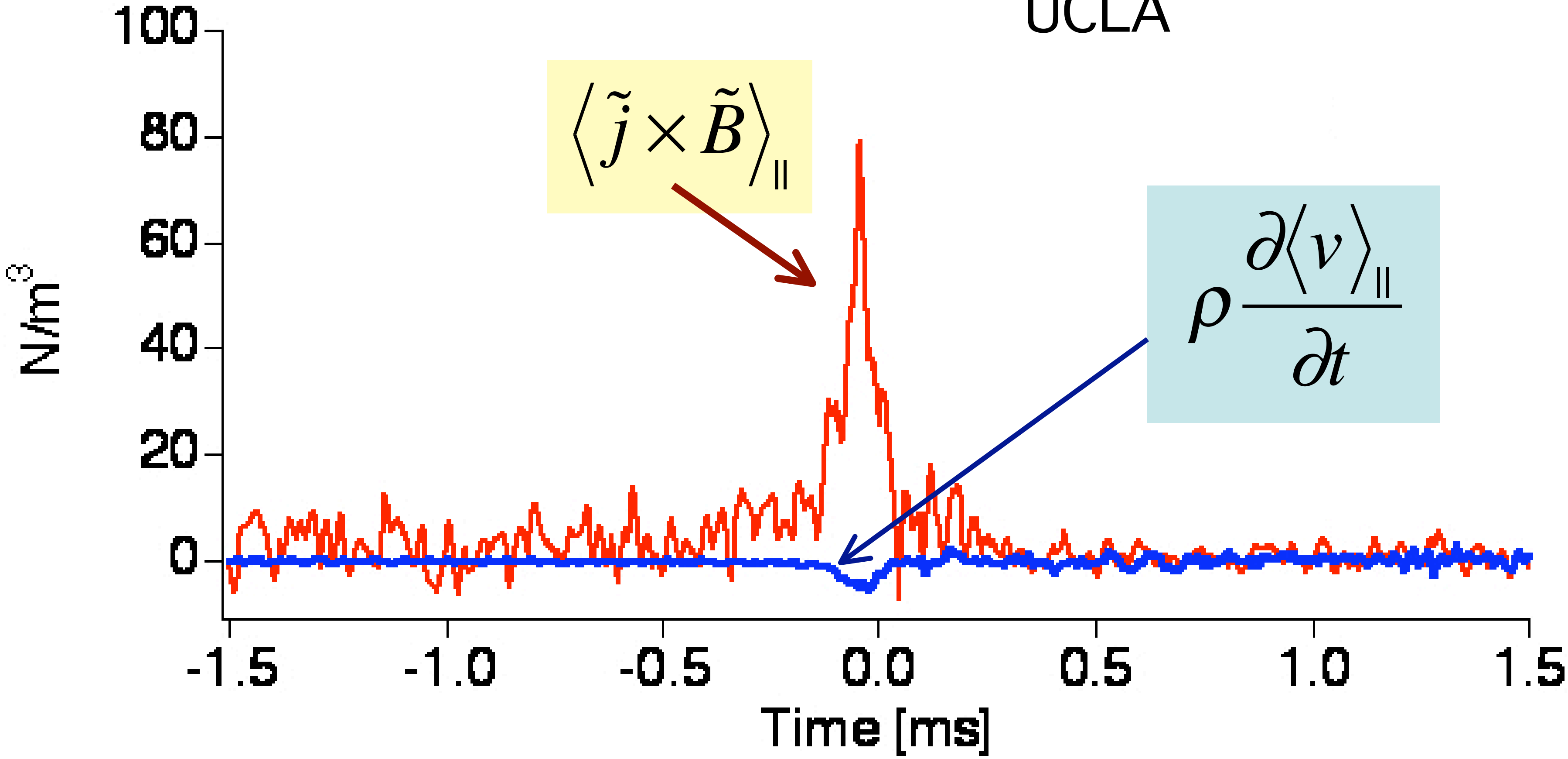
# Rotation profile flattens




faster than can be explained by collisions

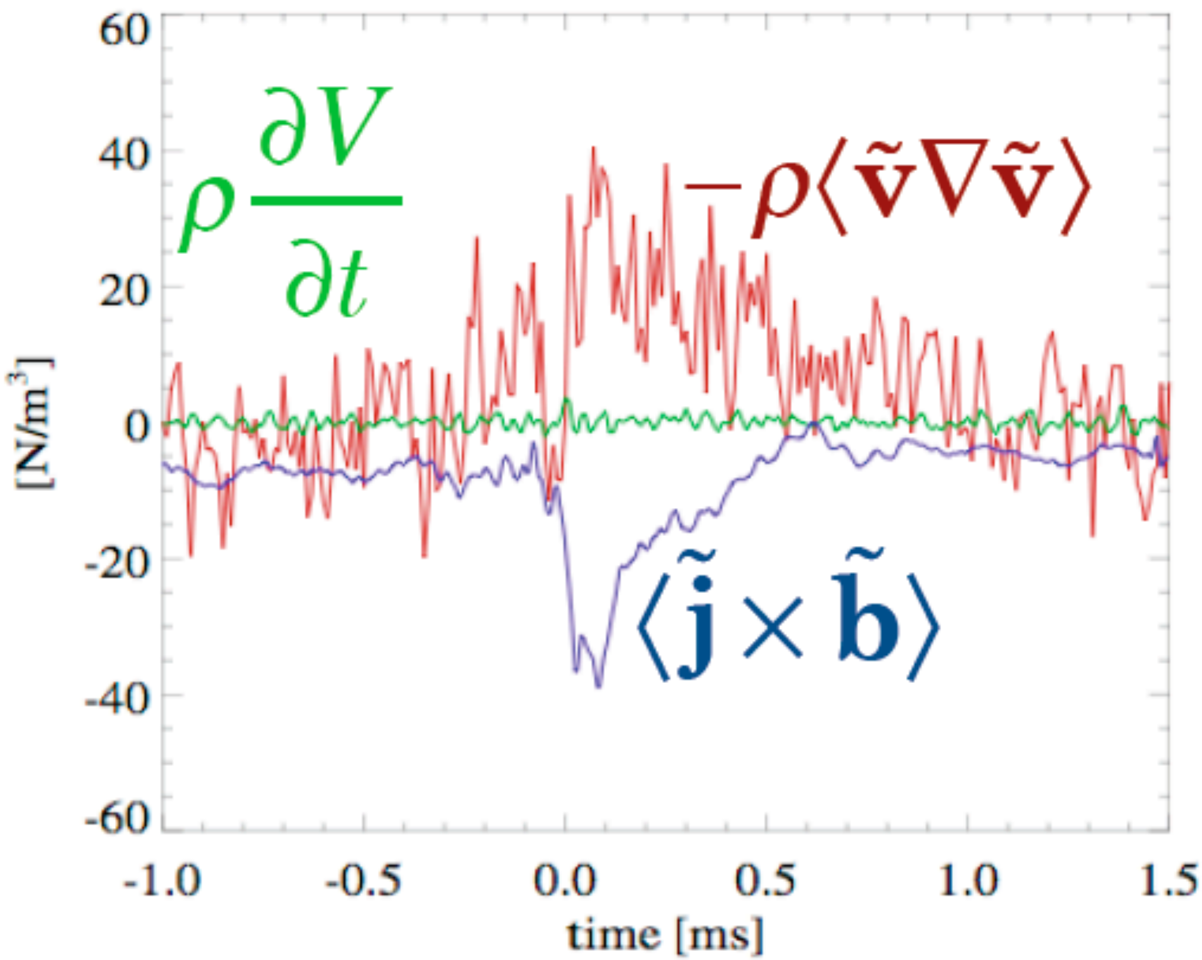
# Lorentz force measured in MST core

Faraday rotation, UCLA




must be another large force present

# Measurement of forces at plasma edge




Maxwell and Reynolds stresses large and opposite, generated by tearing instability

# Links  to astrophysics

Momentum transport is major issue for astrophysics,

Flow-driven instability is the "standard model"

We are beginning to investigate the applicability of current-driven instability to

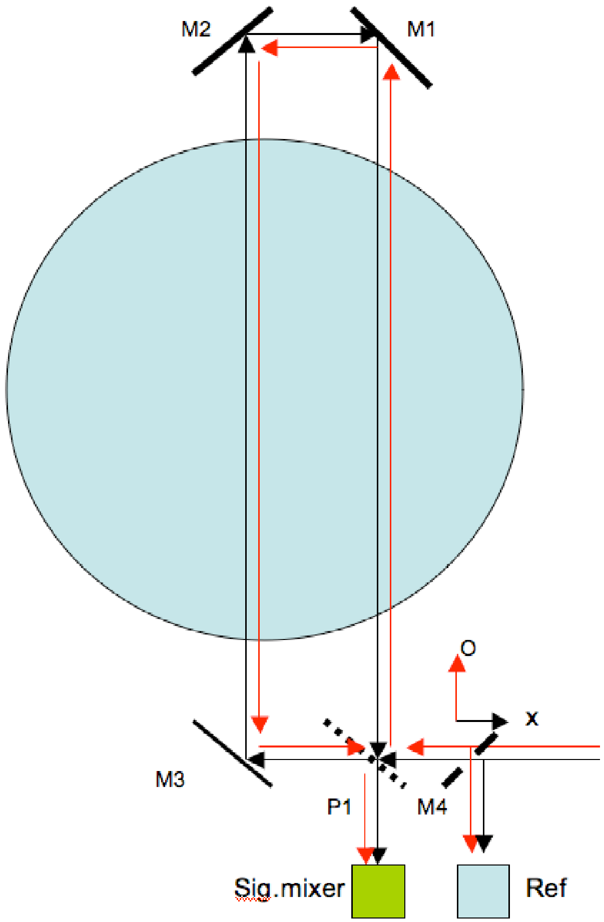
- Magnetized disks (e.g., young stars)
- Magnetized extragalactic jets

# Next steps

- Improved flow measurements
(multi-point CHERS)
- Investigate transport from stochastic fields
(Faraday rotation for magnetic fluctuations)
- Examine two-fluid features
(laser Fizeau effect for electron flow)

# Laser Fizeau Effect
(UCLA)

- For electron flow velocity (for electron transport, Hall reconnection....)
- Measure phase shift due to flow, with counterpropagating lasers



# Fizeau effect plans

| | |
|---|---|
| FY 08 | develop the technique |
| FY 09 | determine feasibility |
| FY 10 | measure fluctuating $v_e$ and $j_e$ |

# MST Utilization

| | run weeks (45) | |
|---|---|---|
| | FY 08 utilization | Appropriate Utilization |
| Full diagnostic set | 7 | 16 |
| Reduced diagnostic set | 38 | 29 |

~ at staff limit

# FY 09 Decrement Case (-10%)

- Eliminate CHERS upgrades
- Eliminate postdoc for CHERS upgrade
- Eliminate technical staff member, delaying Thomson scattering mods
- Eliminate MSE extension to half-radius
- Delay construction of 0.4 MW lower hybrid system

# FY 10 Decrement Case (-10%)

- Delay completion of CHERS upgrade
- Eliminate next step in lower hybrid current drive
- Eliminate construction of additional neutral beam

# Full Use for FY 09 or 10 (+$2.9M)

Additions beyond level budget

- Begin construction of programmable power supply for toroidal loop voltage (for confinement optimization, OFCD, improved flat-top)

- Construct active feedback system for toroidal field error control

- Add RF physicists (2) and engineers (2) for more rapid development and physics studies

- Add technical and physics staff for full utilization

# Upcoming transitions

- Recompeting CMSO
- Moving beyond MST operational limits

# The Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas (CMSO)

- An NSF Physics Frontier Center
- An NSF/DOE partnership
- Links fusion to astrophysics,
  yields new fusion science results
- Institutions : Wisconsin, Princeton, U. Chicago, LANL,
  U. New Hampshire, SAIC, Swarthmore, LLNL

current NSF funding : $2.25M/yr for 5 years,

significant NSF support for plasmas and fusion

# The Status

- Presently recompeting for additional 5 years
- Passed through pre-proposal stage to proposal stage (19 out of 58 pre-proposals)

OFES support is crucial and highly leveraged

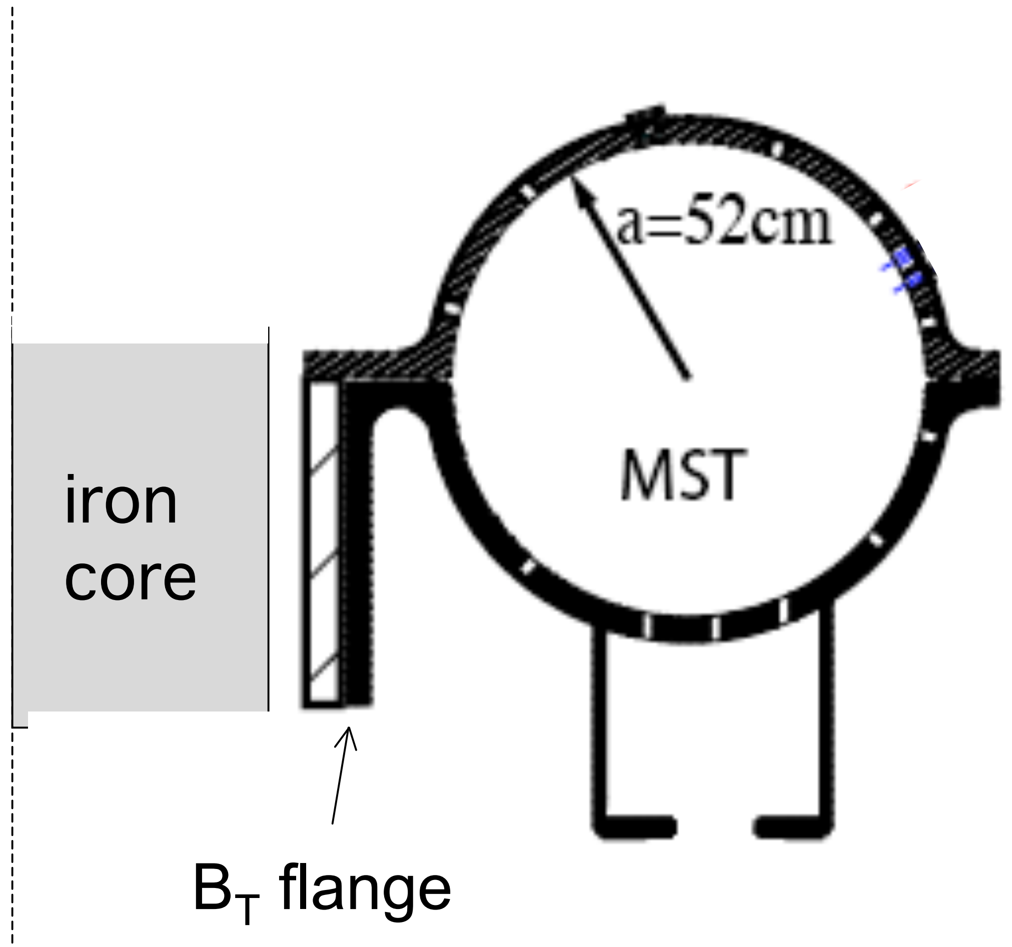
# Moving beyond MST operational limits

Positive confinement trends with current, → Increase current
to test transport physics

Effect of auxiliary power (OFCD, beams) → Increase pulse length

Both current and pulse length are limited by volt-seconds

One possible route: increase iron core area, mechanically complex



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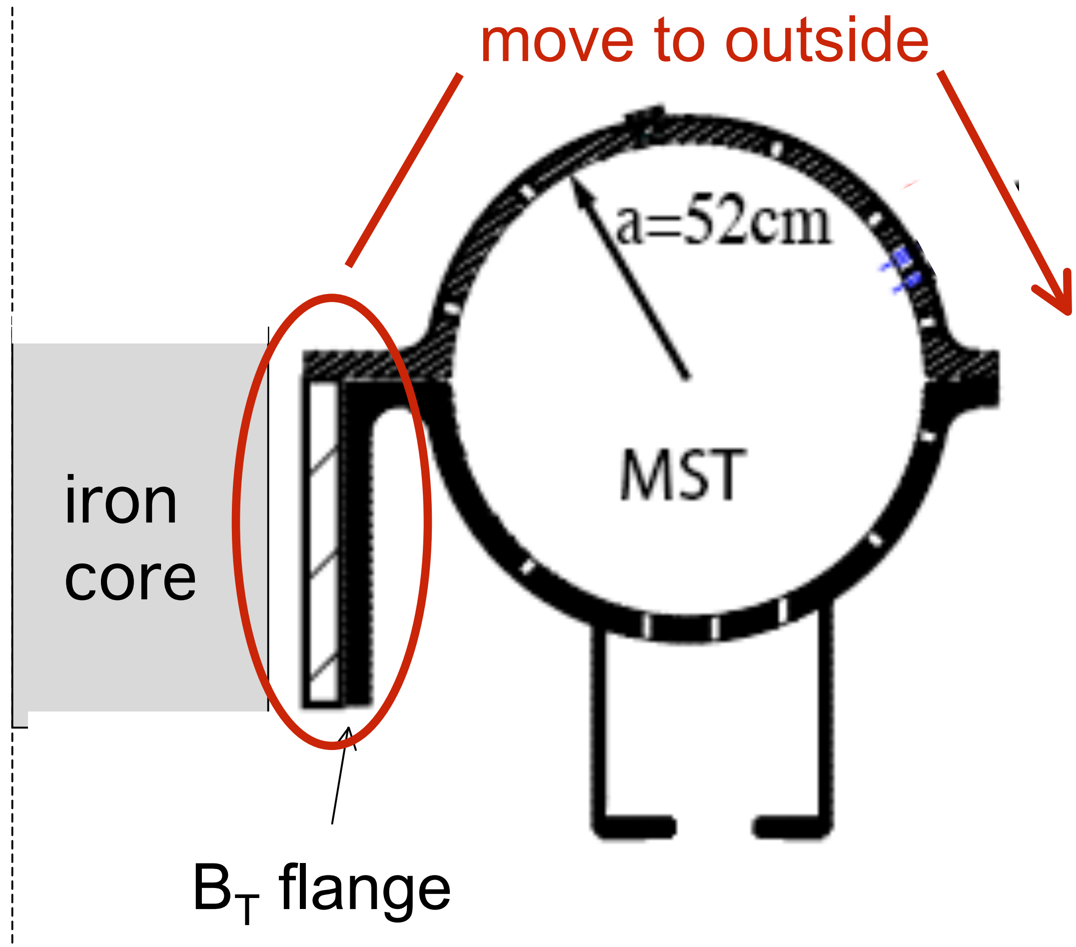

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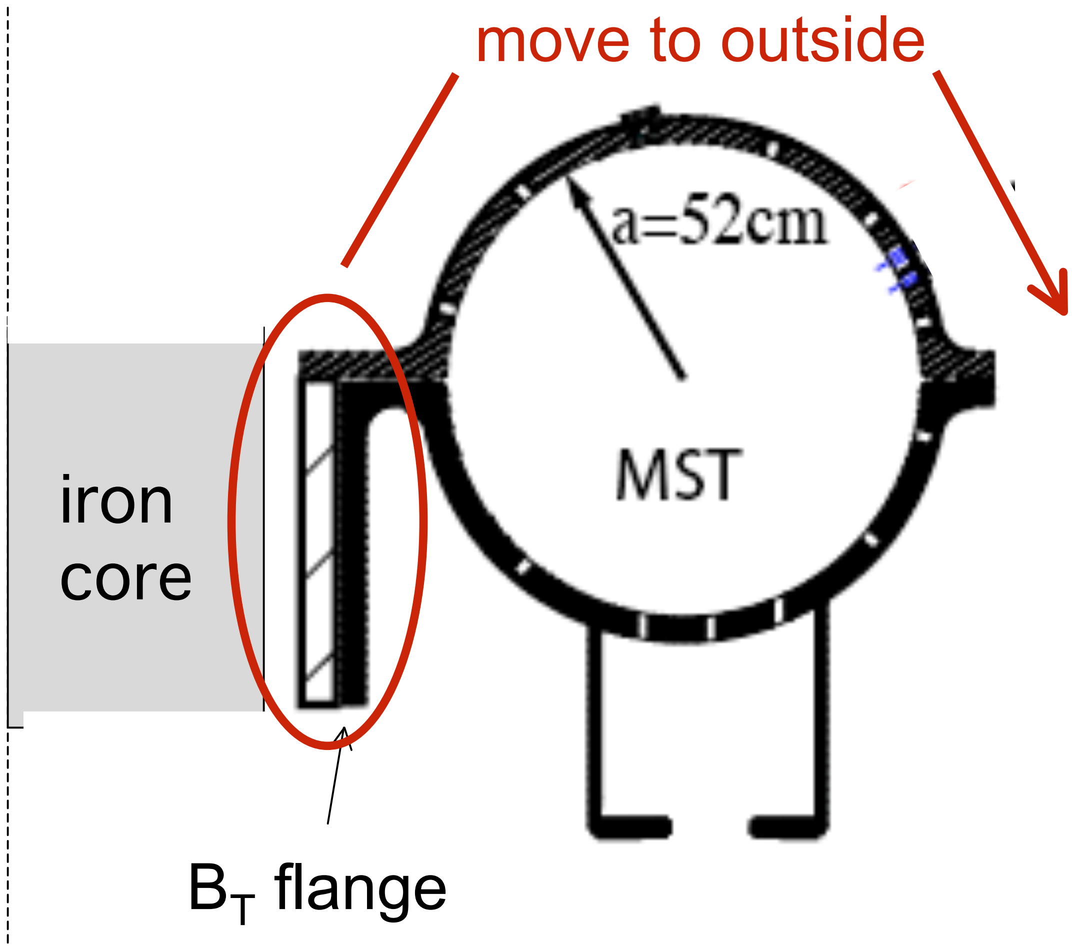


*we are beginning to explore this option,*
*and other possible next steps for the RFP program*