The Reversed Field Pinch for Fusion-Fission Hybrid Application

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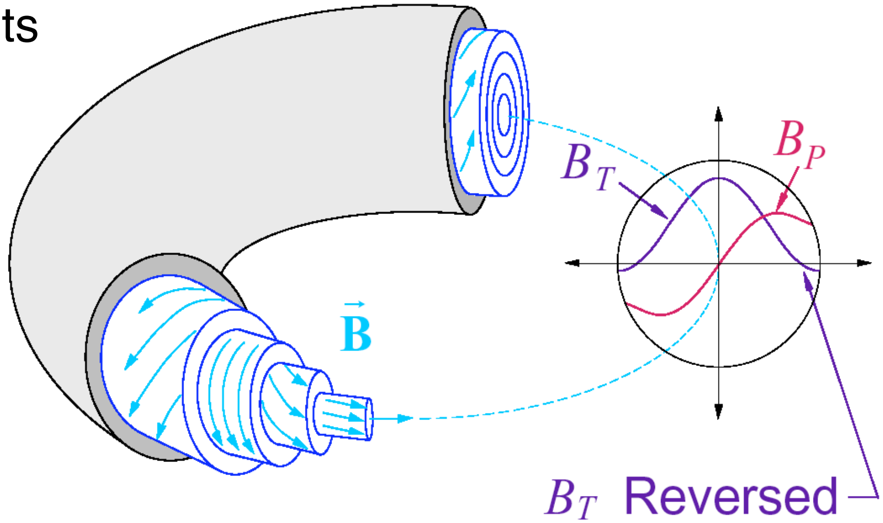
The Reversed Field Pinch (RFP) configuration could provide a relatively simple neutron source.

- Advantages for fusion
  - Small applied field, with normal magnets
  - High beta (esp. engineering beta)
  - Possibility for Ohmic heating to burning plasma conditions
  - Possibly free choice of aspect ratio
  - Advantages confirmed in TITAN system study (1990)



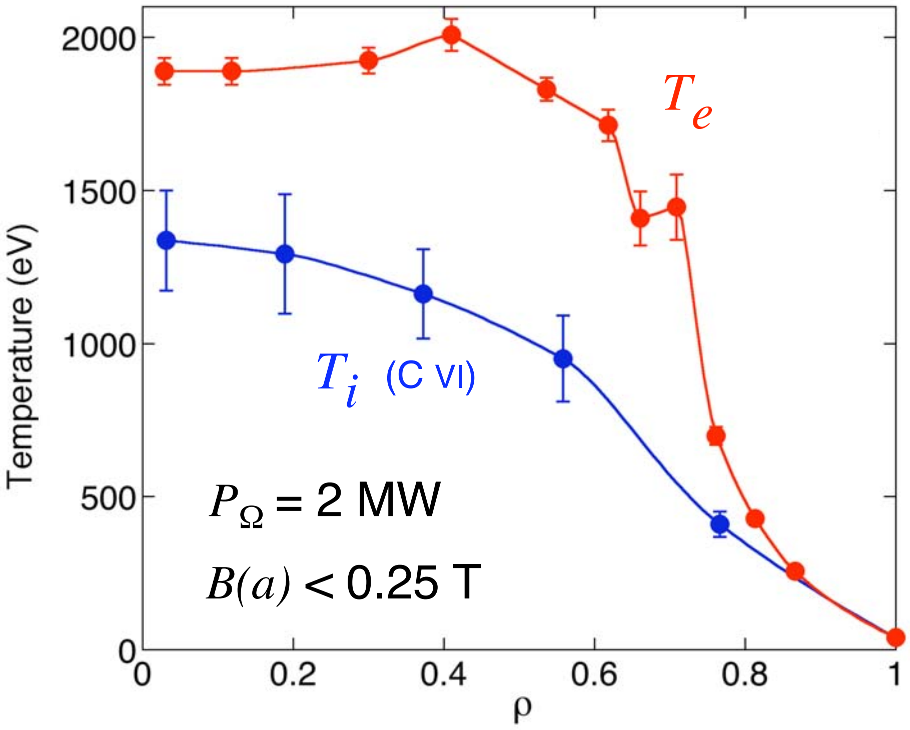
- Advantages for FFH similar to pure fusion

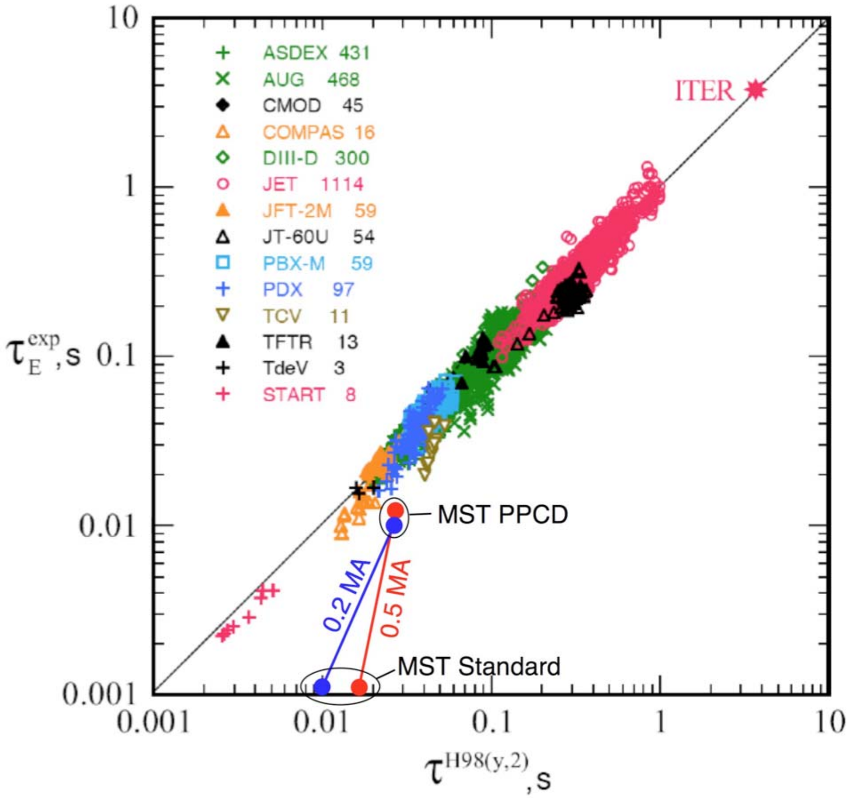
- NBI-driven neutron source
  - ~10^{18} neutron/sec for plasma parameters close to present-day RFP experiments
  - FFH waste burner (lower output power)
  - Fusion development in toroidal geometry

Applied toroidal field BT is more than 10X smaller in an RFP than for a tokamak

Tokamak-like confinement achieved in the RFP with current profile control (transiently).

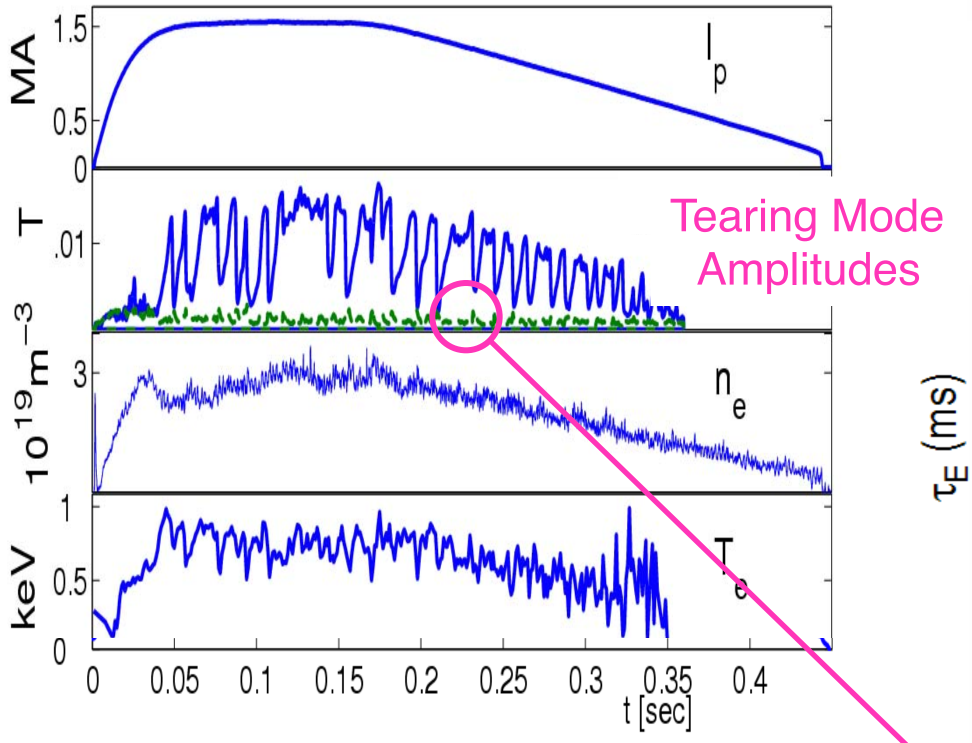
- $J(r)$-control reduces tearing instability and magnetic turbulent transport.
- Residual transport may be electrostatic in character.



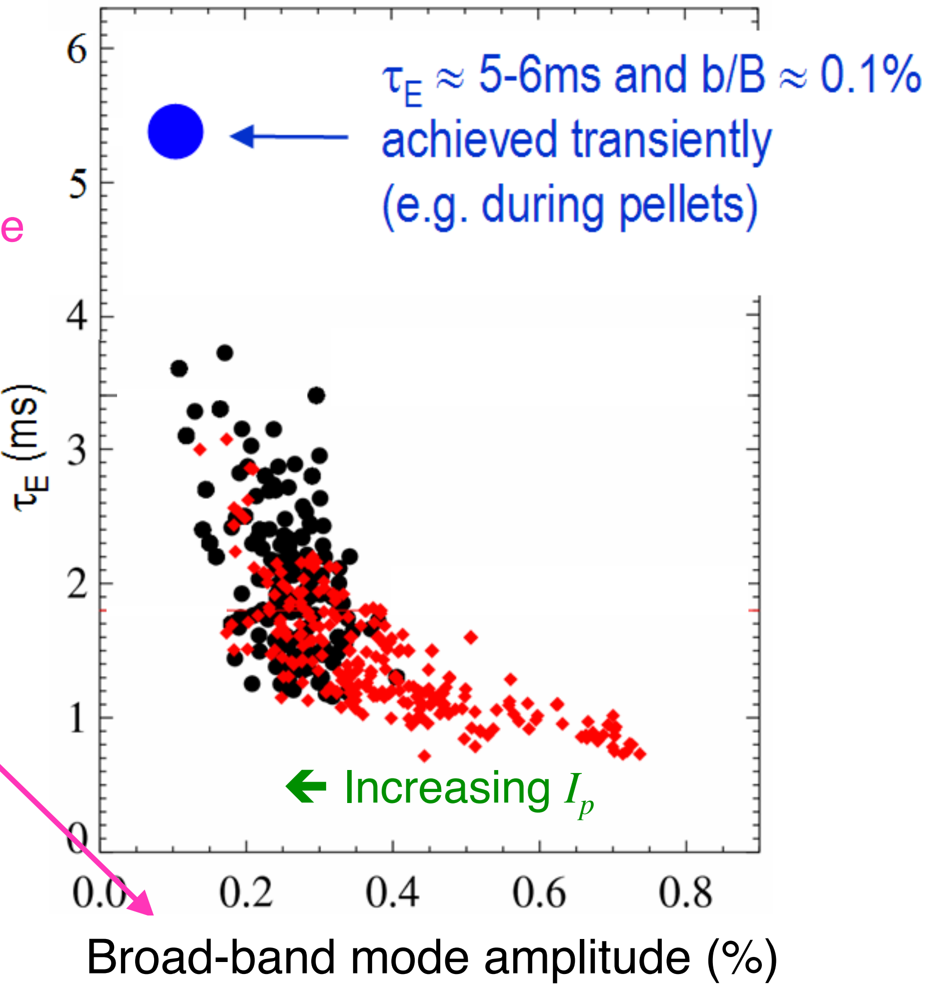


Transformational change in performance at high current observed in RFX experiment (Italy).

- Spontaneous reduction in tearing mode magnetic turbulence.
- Plasma is *still self-organized*, using standard toroidal induction.

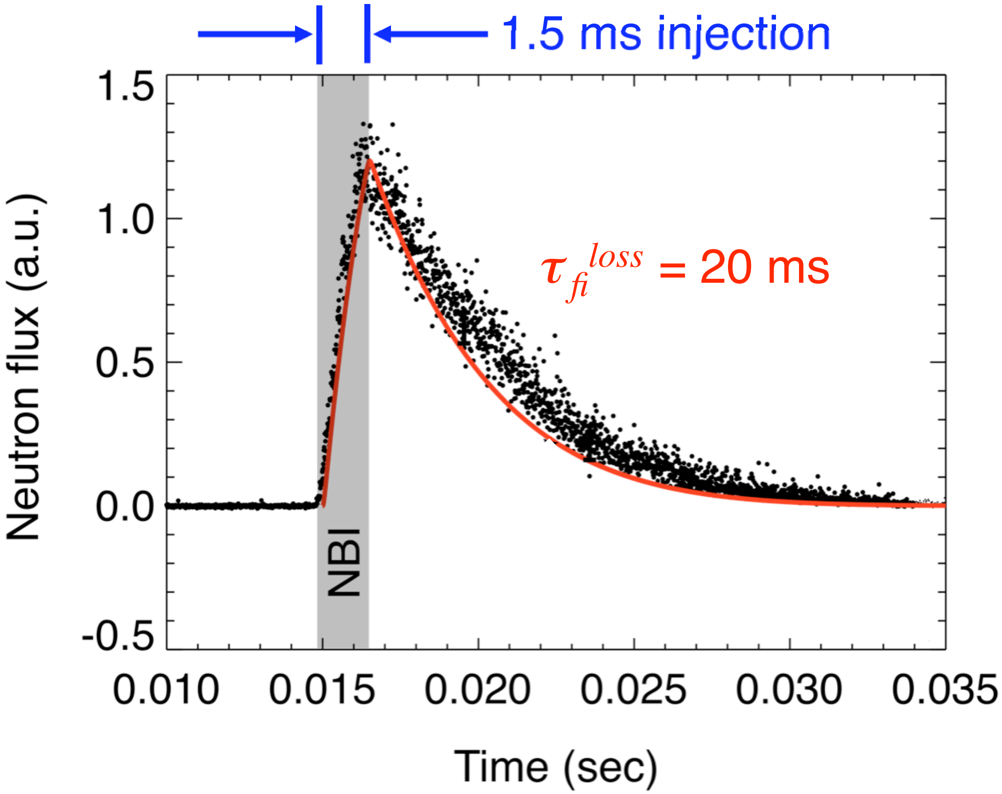


RFX experiment (Italy)



Fast ion confinement very good.

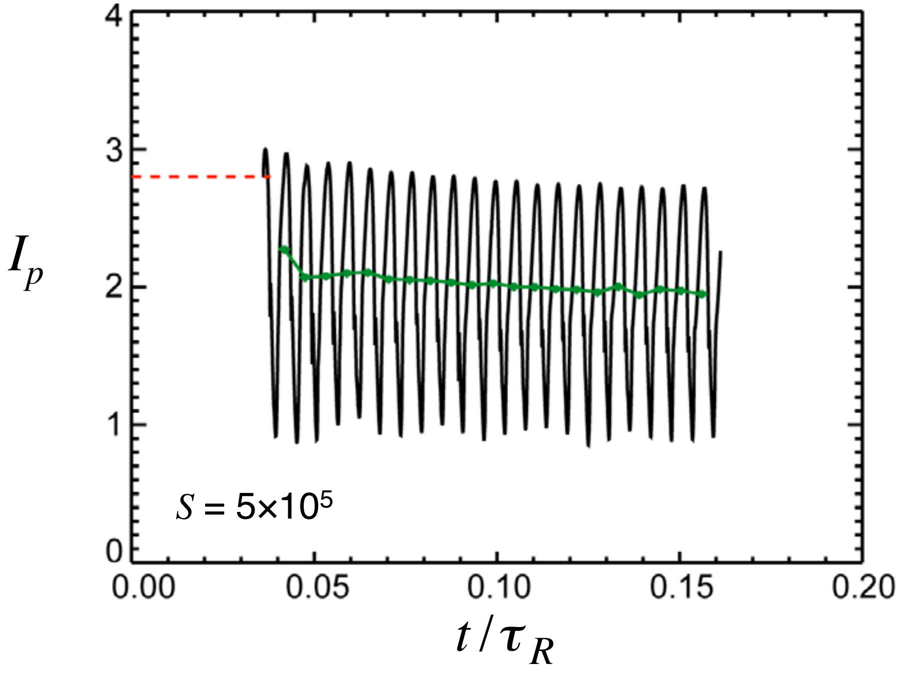
- Fast ion particle confinement > 20X thermal particle and energy confinement in standard RFP plasmas with large magnetic stochasticity.
- Longer pulse 1 MW NBI experiments in 2010.



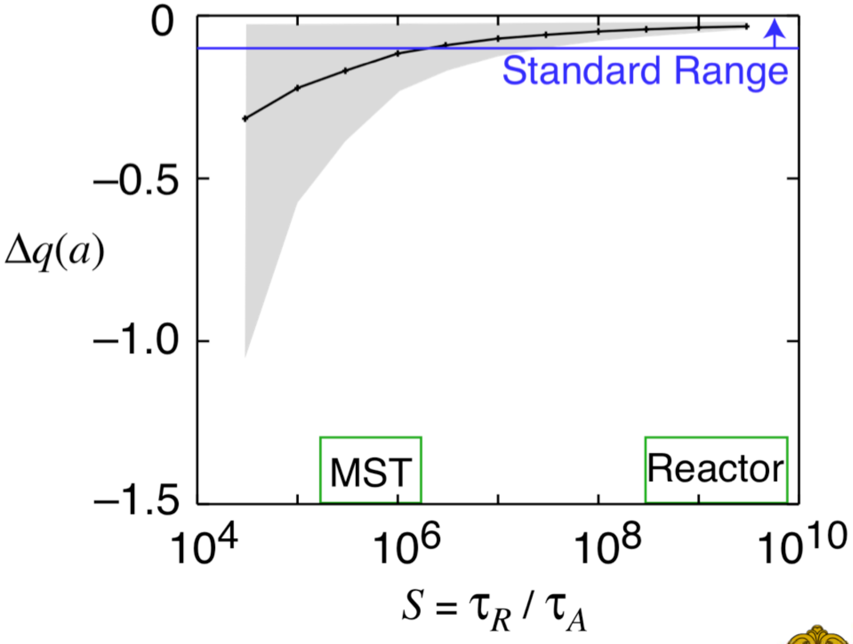
Bulk particle and energy confinement times are ~ 1 ms in this same plasma.

Efficient, steady-state current sustainment possible using Oscillating Field Current Drive (*inductive* method).

- Demonstrated in nonlinear resistive MHD computation.
- Requires low plasma resistance (high Lundquist number) to avoid large AC modulation in the equilibrium magnetic field.
- 10% OFCD demonstrated in MST (agrees with expectations).


MHD Computation

Ebrahimi et al, 2003


Projected Equilibrium Modulation (full sustainment)

NBI-driven neutron source based on parameters close to present-day RFP experiments.

- Only an example to expose features and possibility.
- Assume 140 keV injection energy, and classical slowing down.

Plasma current, $I_p = 2$ MA	Neutral beam power, $P_{inj} = 18$ MW
Major/minor radii, $R = 1.5$ m , $a = 0.5$ m	Fusion power, $P_f = 7.3$ MW
Electron temperature, $T_e = 1.5$ keV	Ohmic power, $P_\Omega = 8$ MW ($Z_\Omega = 2.4$)
Bulk ion temperature, $T_i = 1.0$ keV	Neutron production, 2.6×10^{18} n/s
Density, $n = 4\times10^{19}$ m^{-3} ($n/n_G = 0.16$)	Fusion gain, $Q = 0.3$
Thermal energy confinement, $\tau_E = 5.5$ ms	Neutron load, $P_n = 0.2$ MW/m^2
Magnetic field on axis, $B(0) = 1.9$ T	Avg. heat load, $P_w = 0.9$ MW/m^2
Poloidal field at magnet, $< B_p(a) = 0.8$ T	Fast ion beta, $\beta_{fi} = 2\mu_0\langle p_{fi}\rangle/B(a)^2 = 30\%$
Toroidal field at magnet, $< B_T(a) = 0.2$ T	Thermal beta, $\beta_{th} = 2\mu_0 n(T_e+T_i)/B(a)^2 = 8\%$
Lundquist number, $S = \tau_R/\tau_A = 6\times10^7$	Fast ion gyroradius, $\rho_{fi}/a \le 0.13$

Next steps.

- Conclusive demonstration of confinement scaling and OFCD will require a 2-4 MA next-step facility.

- An upgradeable facility approach could be used to establish integrated boundary control and demonstrate performance on which to base a neutron source or burning plasma experiment.

- Challenges with materials, etc. similar to other magnetic configurations. Plasma-boundary interface control may need RFP-specific solutions.

Summary.

- The same potential benefits of the RFP for pure fusion could make an attractive FFH fusion neutron source.

- Development of the RFP lags the tokamak, but a P_{fusion} ~ 10 MW NBI-driven neutron source is a modest extension of established RFP performance.

- If a FFH program goes forward, worth exploring physics-engineering tradeoffs associated with various concepts.