GAMMA-10 Simulation Results and Implications for a Tandem Mirror Effort

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Outline

- The design of the Kinetically Stabilized Tandem Mirror [1] and the GAMMA-10 machine in Tsukuba, Japan [2]
- Energy confinement time scaling laws (Pratt and Horton, 2006).
- MHD stability, trapped particle modes, and future work.

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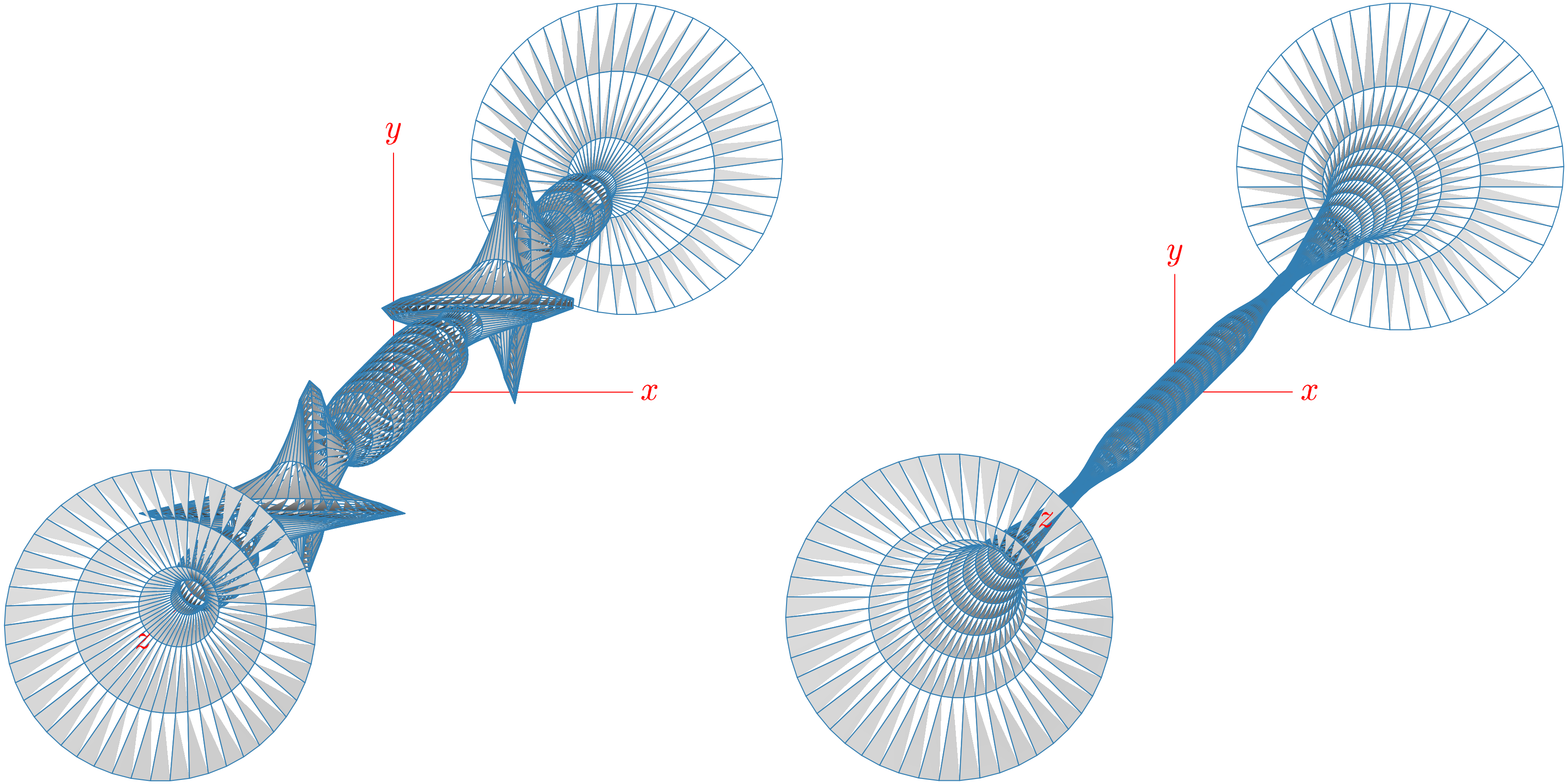
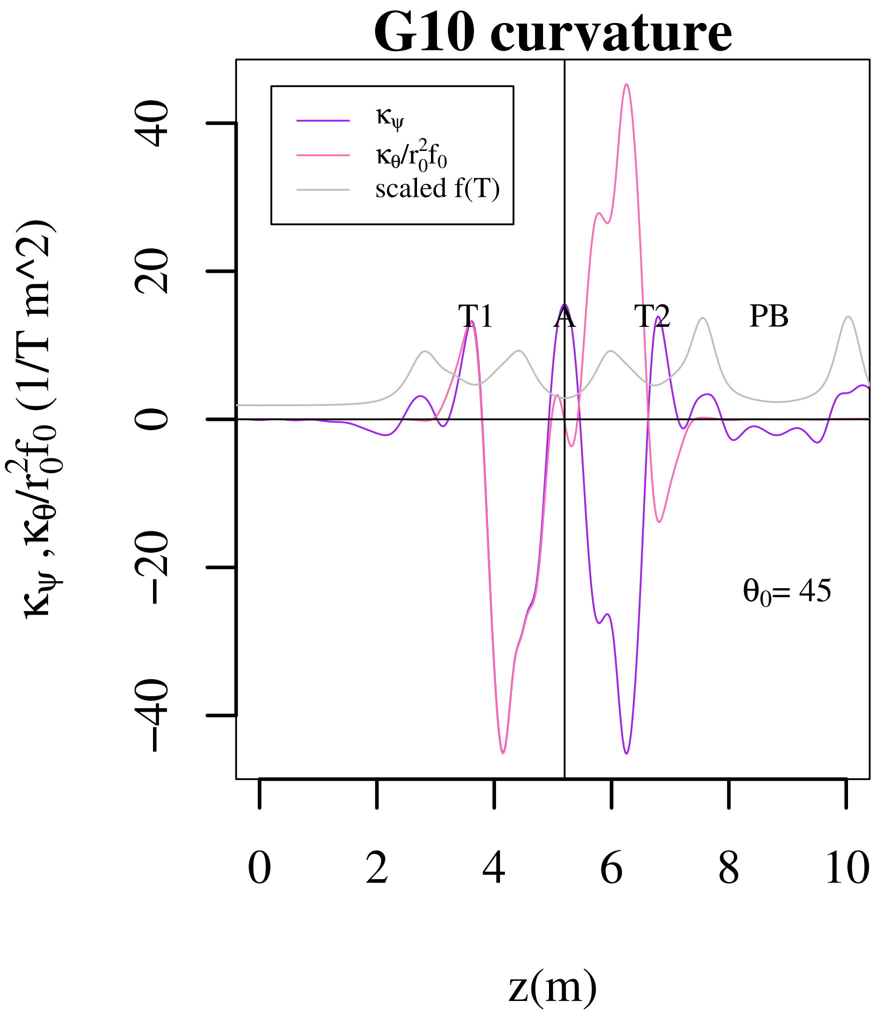
[1] R. F. Post. Combining the “Kinetic Tandem” and the “Kinetic Stabilizer” Concepts. *J. Fus. Energy*, 26(1-2):149–153, 2007. [1]

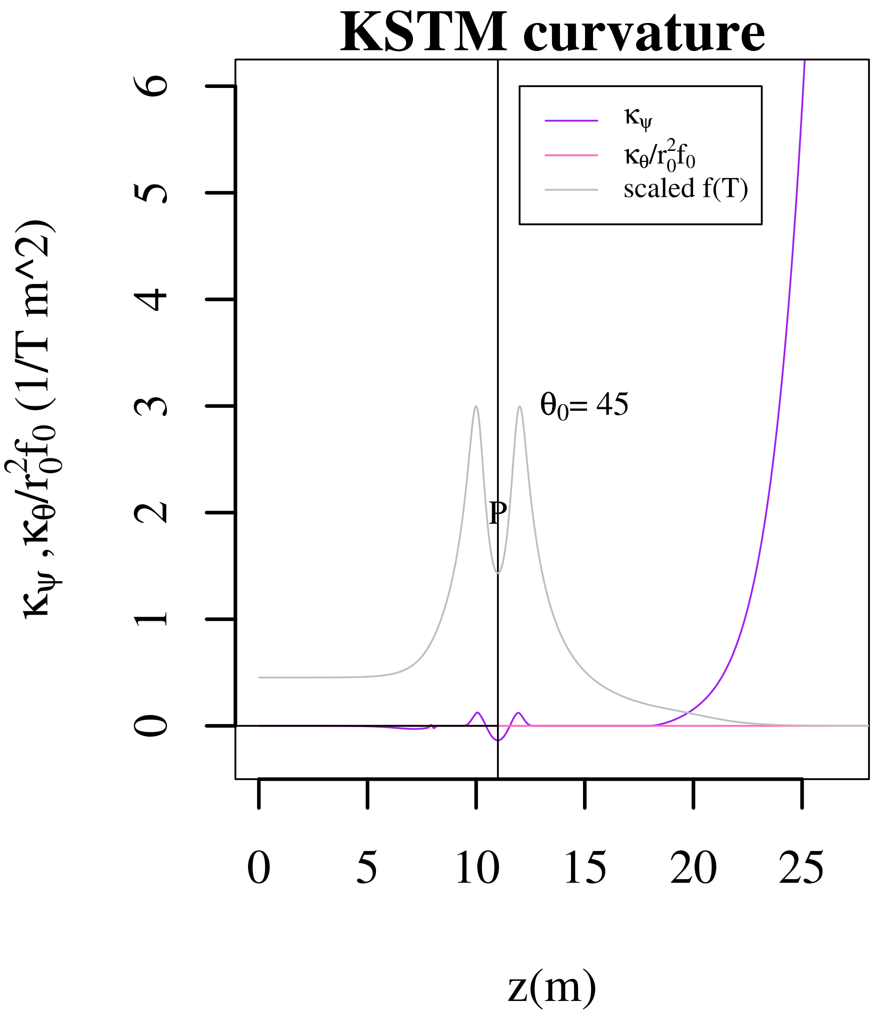
Simple and elegant flux surfaces



GAMMA-10 flux surface (left). KSTM flux surface (right).

Magnetic Curvatures


G10 curvature

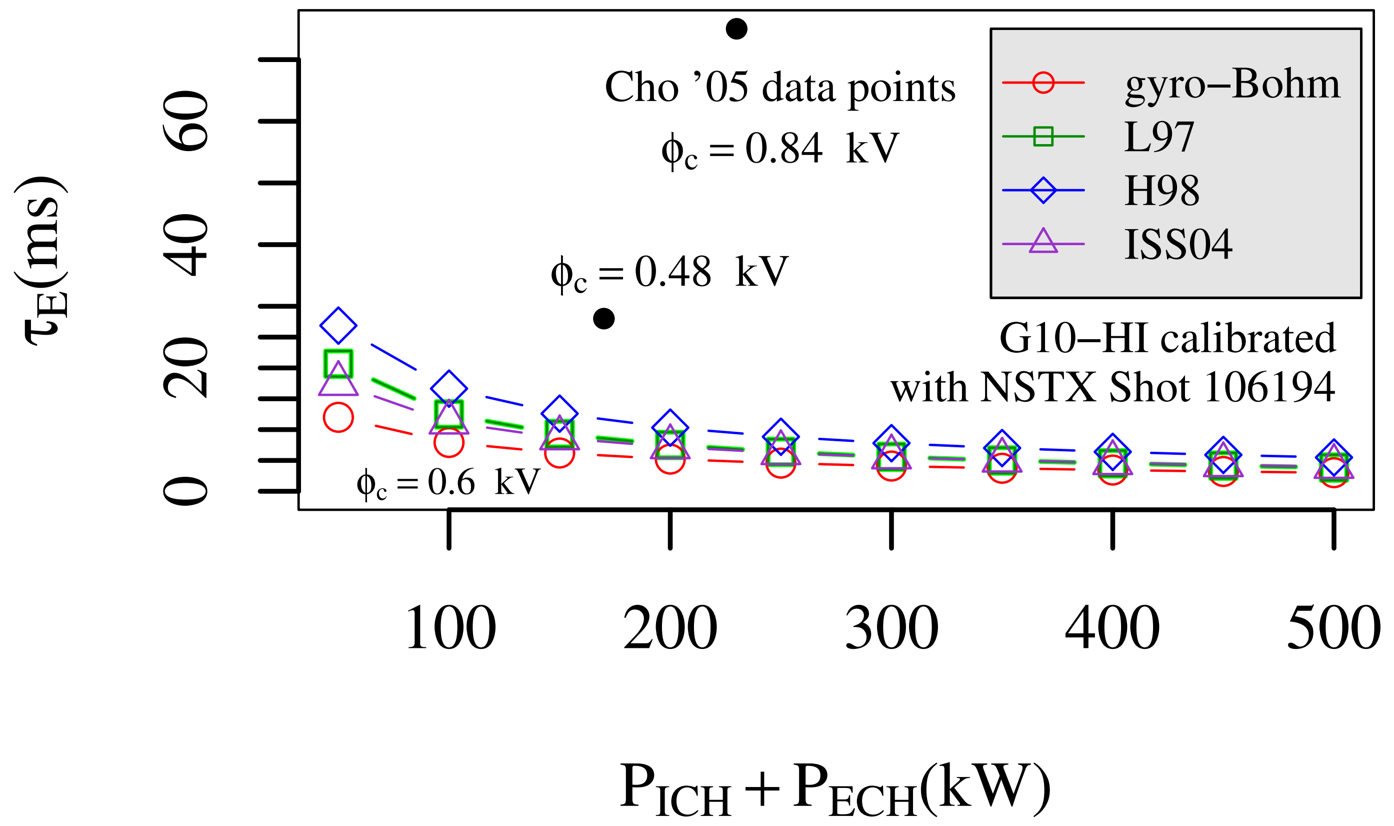

KSTM curvature

Global energy confinement scaling predictions

$\tau_{L97} =$	$.010$	$B^{.99}$	$L^{.93}$	$a^{1.86}$	$n^{.4}$	$P^{-.73}$
$\tau_{H98} =$	$.067$	$B^{1.08}$	$L^{.46}$	$a^{2.44}$	$n^{.41}$	$P^{-.69}$
$\tau_{ISS95} =$	$.080$	$B^{.83}$	$L^{0.65}$	$a^{2.21}$	$n^{.51}$	$P^{-.59}$
$\tau_{ISS04} =$	$.103$	$B^{.89}$	$L^{.6}$	$a^{2.33}$	$n^{.59}$	$P^{-.64}$
$\tau_E^B =$	0.042	$B^{1/2}$	$L^{1/2}$	a^2	$n^{1/2}$	$P^{-1/2}$
$\tau_E^{gB} =$	0.016	$B^{.8}$	$L^{.6}$	$a^{2.4}$	$n^{.6}$	$P^{-.6}$
$\tau_E^{ETG} =$	$.025$	$-$	$L^{.33}$	$a^{2.66}$	n^1	$P^{-.33}$

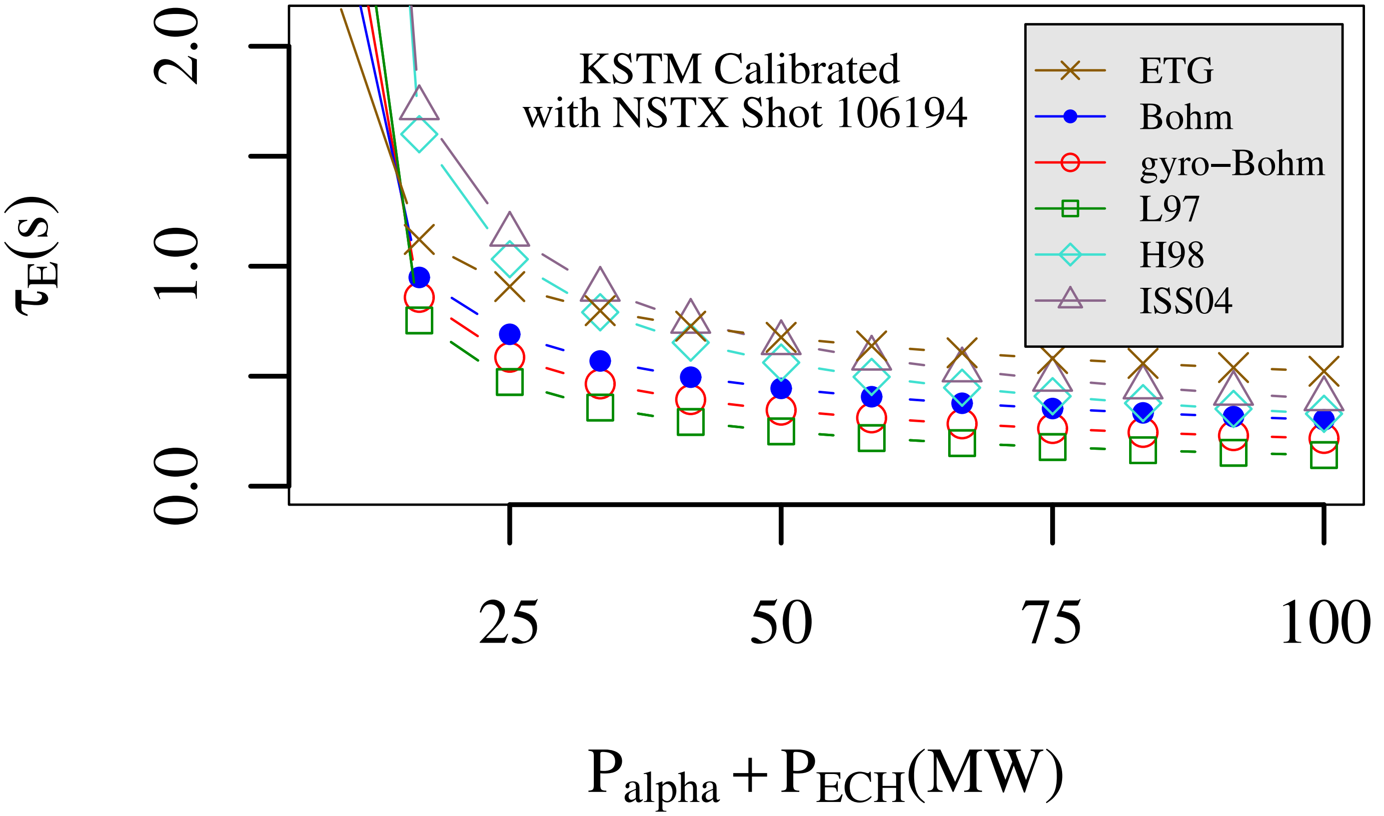
J. Pratt and W. Horton. *Phys. Plasmas*, 13:042513, 2006.

Radial Energy Confinement Times in the GAMMA-10



A variety of energy confinement times adapted to the tandem mirror geometry and GAMMA-10 parameters.

Radial Energy Confinement Times in the KSTM



Predictions for the KSTM machine design. Drift wave scaling laws (Bohm, gyro-Bohm,and ETG) are calculated from formulae for diffusivity and normalized to match the empirical L97 results from NSTX at 3.3 MW of radial power loss.

B.P. LeBlanc, R.E. Bell, S.M. Kaye, *et al.* Confinement studies of auxiliary heated NSTX plasmas. Nuclear Fusion. 44(4), 2004.

Tandem Mirror Machine Parameters

Parameter	G-10 Dec. 2006	KSTM (burning)	KSTM (MHD stab.)
r_c	.18 m	1.5 m	.3 m
L_c	6 m	30 m	100 m
n_{c}	$10^{19}\ \mathrm{m}^{-3}$	$10^{20}\ \mathrm{m}^{-3}$	$2 \cdot 10^{20}\ \mathrm{m}^{-3}$
$n_{\mathrm{p}}/n_{\mathrm{c}}$	.1	7	1
T_{e}	750 eV	50 keV	50 keV
T_i	6.5 keV $\perp$	15 keV	15 keV
B_{cc}	.405 T	3 T	3 T
B_{plug}	.49 T	18 T	20 T

MHD Stability and Trapped Particle Modes

- The kinetic stabilizer innovation involves injection of a low energy beam into a specific point in the expander. This injection causes a bump in density and a potential that reflects escaping electrons back into the machine.
- For our model of the KSTM with a central cell length $L_c = 100$ m, ($L_{\text{plug}} = 2.05$ m,$L_{\text{exp}} = 19.8$ m) we find that the machine is MHD stable with a kinetic stabilizer beam aimed at $z_{\text{target}} \approx 59$ m that has energy 1 KeV. This confirms the result of Post. J. Fus. Energy, 26(1-2):149–153, 2007,for our own model and parameters.
- If all of the electrons in the kinetic stabilizer also sample the central cell, then electron temperatures in the kinetic stabilizer must exceed 560 eV in order to stabilize the trapped particle mode ([3],[4]). We are concerned that the fraction of particles that do sample both regions will be small due to a maximum in the beam density in the region of the kinetic stabilizer.
- Ongoing work focuses on optimizing the model of the KSTM and calculations of the trapped particle mode condition.

Conclusions

- Tandem mirrors have a simpler design than tokamaks in many respects, including: no (significant) internal current, ease of radial potential control, and a natural open diverter design.
- When compared with equivalent-sized tokamaks, tandem mirrors can perform significantly better ([5],[6]).
- The KSTM design is a simple and elegant design compared to other tandem mirrors.
- We find that MHD stability can be achieved with a kinetic stabilizer design.
- Further work is necessary to determine whether trapped particle modes can be stabilized.

[1] R. F. Post. Combining the “Kinetic Tandem” and the “Kinetic Stabilizer” Concepts. *J. Fus. Energy*, 26(1-2):149–153, 2007.

[2] T. Cho, J. Kohagura, M. Hirata, et al. *Nuclear Fusion*, 45 (12), 2005.

[3] H. L. Berk and B. G. Lane. Variational quadratic form for low-frequency electromagnetic perturbations. ii. application to tandem mirrors. *Physics of Fluids*, 29(11):3749–3759, 1986.

[4] H. L. Berk, M. N. Rosenbluth, H. V. Wong, and D. E. Baldwin. *Sov. J. Plasma Phys*, 9:108, 1983.

[5] J. Pratt and W. Horton. Global energy confinement scaling predictions for the kinetically stabilized tandem mirror. *Phys. Plasmas*, 13:042513, 2006.

[6] J.Pratt, W. Horton, and H. L. Berk. Energy confinement scaling predictions for the stabilized tandem mirror. *J.Fus. Energy*, 27(1-2):91–95, 2007.