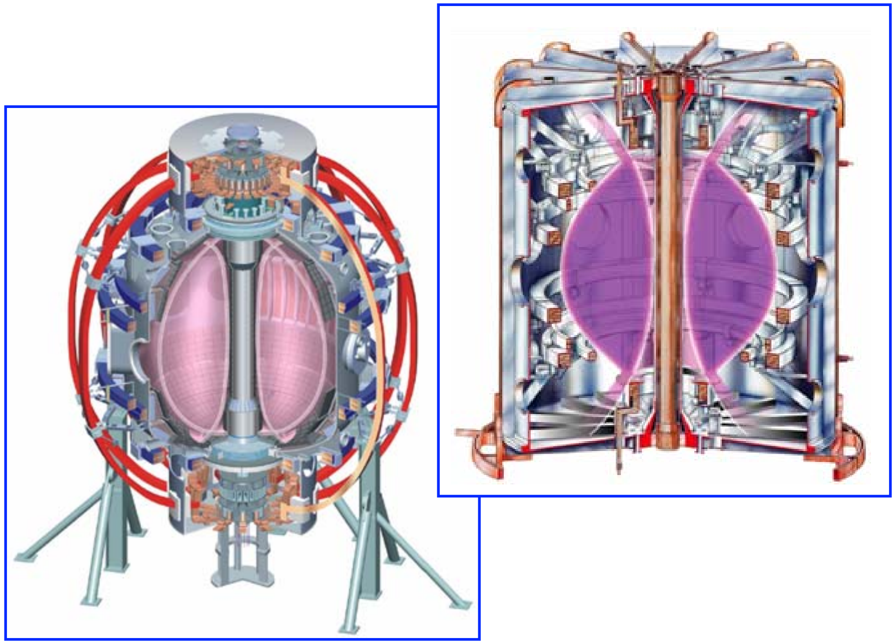
ITPA TP-8.1

2005 NSTX/MAST iITB Identity Experiments – 2006 Comparison Experiments Discussion



Martin Peng, Anthony Field,
& Many Contributing
NSTX, MAST Team

ITPA, Transport Physics
Topical Group Meeting

April 18-21, 2005
Kyoto University
Kyoto, Japan

TP-8: ITB similarity experiments started in 2002 on AUG and 2003 on JET

- Goals: compare dynamics of similar iITB; check physics consistency; project iITB possibilities in ITER burning plasmas
- Sips (AUG: 7/02), Challis, Jofrin (JET: 12/03, 1/04), Peng (NSTX: 7/04), Field (MAST)
- AUG/JET: match standard AUG hot-ion ITB plasmas (no eITB)
  - Similar shape, q-profile, ρ^*, ν^*, β, normalized heating/fueling/torque …)
  - Produced similarly transient iITB's with different T_e/T_i, collapsing coincident with large ELM's
- MAST/NSTX: iITB identity experiments
  - Role of toroidal rotation and $E\times B$ shear on formation and evolution in long-pulse H-mode
  - Scan NBI power (~ 2×) and torque (~ 4×)
  - NSTX carried fraction of experiment at 800 kA in 2004

2005 NSTX/MAST similarity experiment on iITB – of interest to plasma science, ITPA, and ST

- Evidence on turbulence suppression and microinstability drive
  - Zone starts deeper (r/a ~ 0.5, ψ ~ 0.3) and moves out
  - $\chi_i \sim \chi_{NC}$ over zone (r/a ~ 0.7 – 0.85, ψ ~ 0.5 – 0.7), sustained
  - Coupled to high toroidal flow shear
- Added goal for 2005
  - q-profile effects on iITB and low-k turbulence; MSE available
- Broadened interest
  - Science of ion energy and momentum transport
  - Contribute to ITPA defined issue of iITB projections to ITER
  - Comparison experiments with DIII-D, AUG, JET, etc. in 2006-2007
  - Basis for future NBI-dominated ST plasmas

This study aims to clarify the physics of iITB formation and evolution in the presence of strong external torque

ExB shear flow suppression of turbulence:

- Growth rates of drift-wave turbulence γ_m scales like:

$$\gamma_m = c_s / L_T \cdot G_1(\Lambda_T, s, q, \beta, \nu^*, \ldots)$$

- Pressure driven ExB shearing rate ω_{SE} scales like:

$$\omega_{SE} = c_s / L_T \cdot \rho_s^* \cdot G_2(s, q, \beta, \nu^*, \ldots)$$

- Criterion for turbulence suppression $\omega_{SE}/\gamma_m > 1$ scales with ρ_s*
- Large ρ_s* favours suppression of anomalous transport in ST plasma
- Criterion for ITB formation $\rho_s^* > \rho_{ITB}^*$ if $\nabla p_i / n_i e$ term dominates E_r
- Alternative criterion $M_\phi > M_\phi^{ITB}$ if NBI driven toroidal flow dominates E_r

Note that co-NBI tokamaks are in similar regime, differing from ITER.

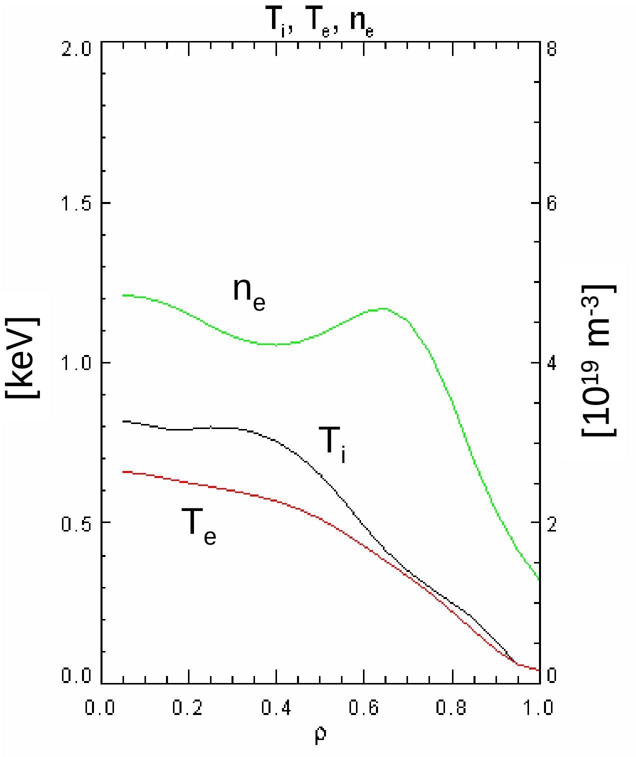
Initial analysis of 2004 NSTX/MAST joint XP on ITB

Aims of analysis:

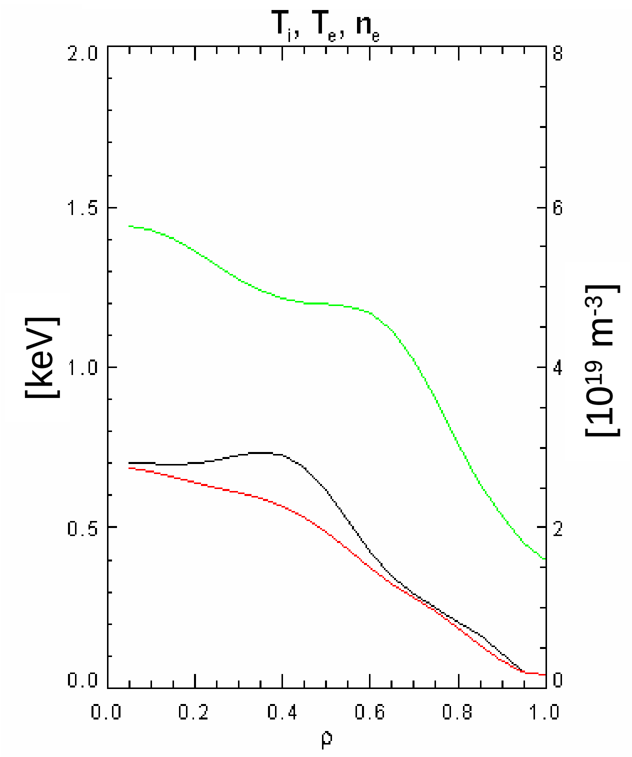
- Reliably identify ion-ITB location, e.g. minimum χ_i or $(dL_T/dr)_{max}$
- Determine evolution of ion-ITB location
- Characterize plasma parameters at ion-ITB, e.g. M_ϕ, s, T_i/T_e, ρ_s^*/L_T, etc
- Determine scaling of f_ϕ, M_ϕ, etc with applied NBI torque and power
- Compare with simple 0D model of angular momentum balance
- Comparison of 4 MW cases with A+B/90 keV and A+B+C/70 keV NBI

Comparison of 4 MW, 90 and 70 keV shots

#113850, 4 MW, A+B/90 keV



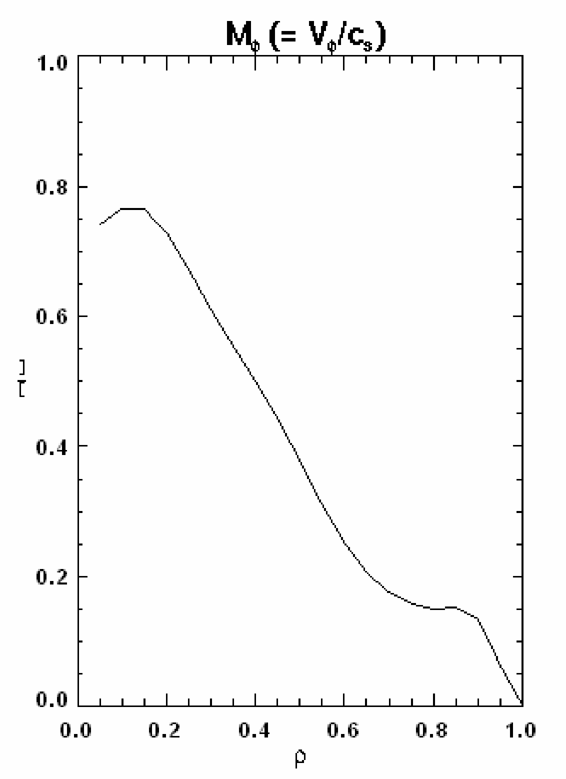
#113865, 4 MW, A+B+C/70 keV



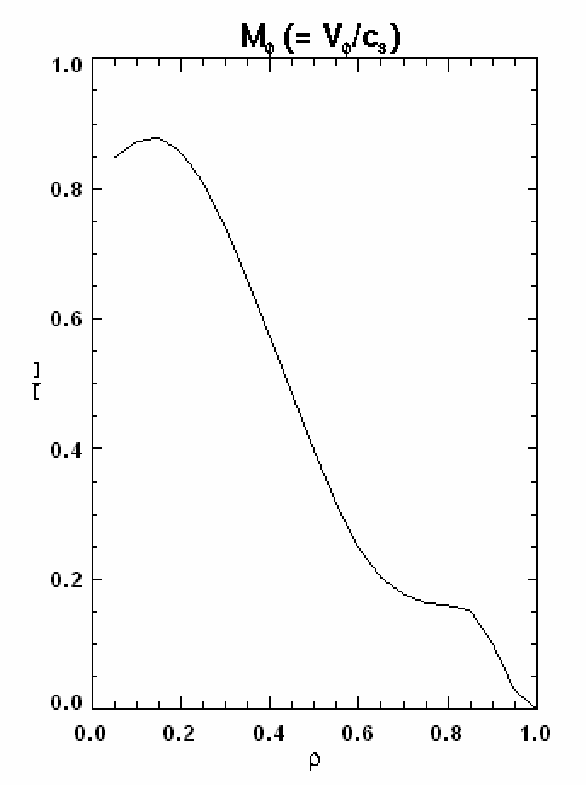
- Lower energy case has higher $n_e(0)$ from beam fuelling, $\Gamma_b = Q_b/eE_b$

Toroidal Mach number

#113850, 4 MW, A+B/90 keV



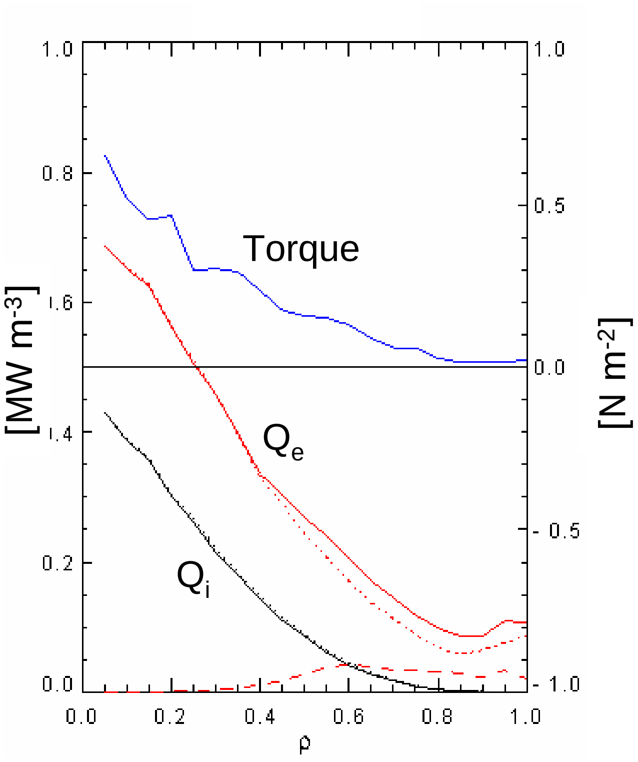
#113865, 4 MW, A+B+C/70 keV



- Slightly higher toroidal Mach number for lower energy case
- γ_m/ω_{SE} ~ M_ϕ in highly rotating NBI driven plasma

NBI power densities and torque

#113850, 4 MW, A+B/90 keV



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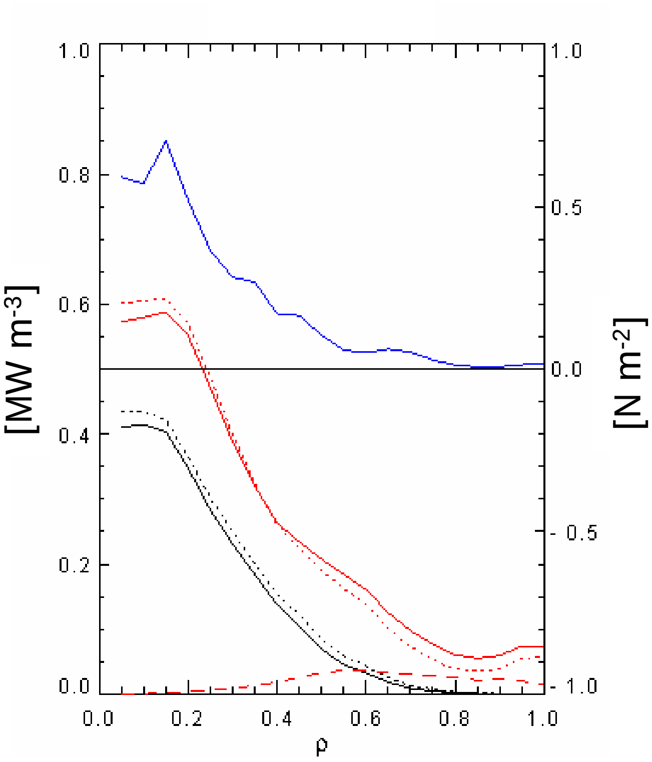
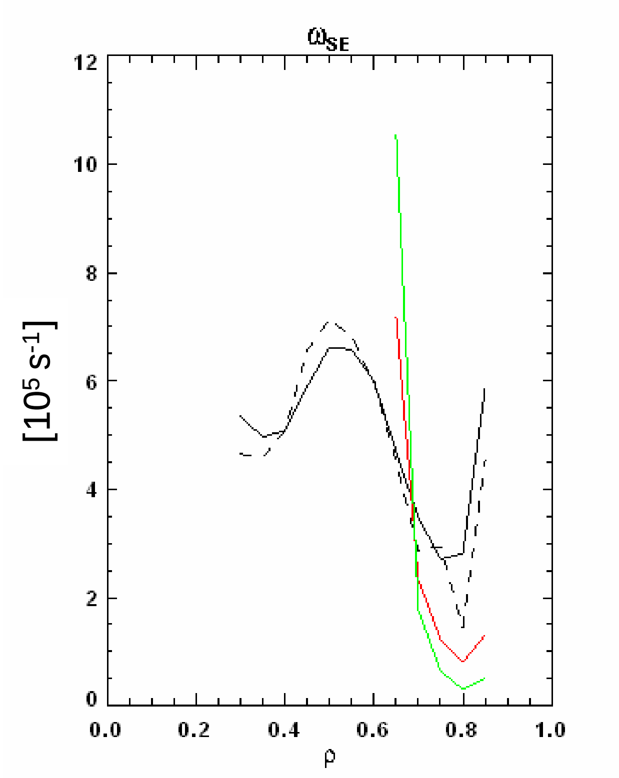


- Similar electron and ion power and torque deposition in low/high energy cases
- Slightly higher electron heating in 90 keV case

ExB shearing rate and ITG growth rate

#113850, 4 MW, A+B/90 keV



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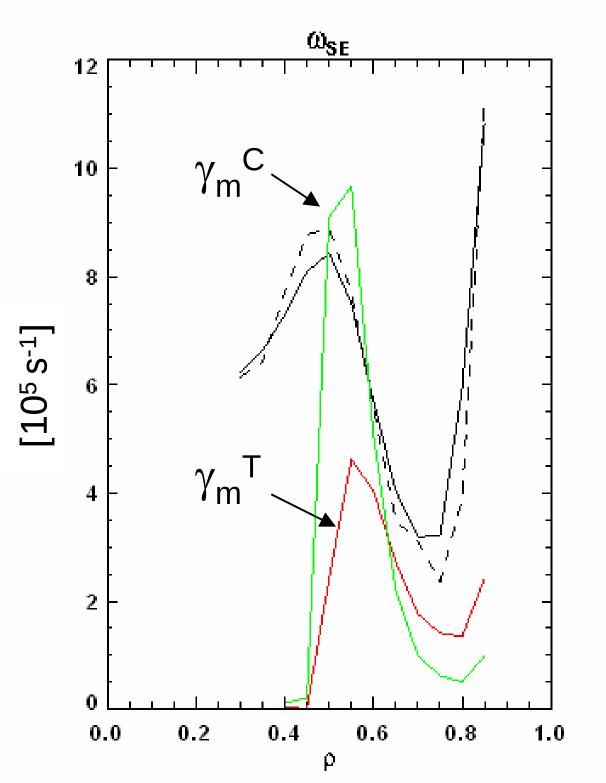
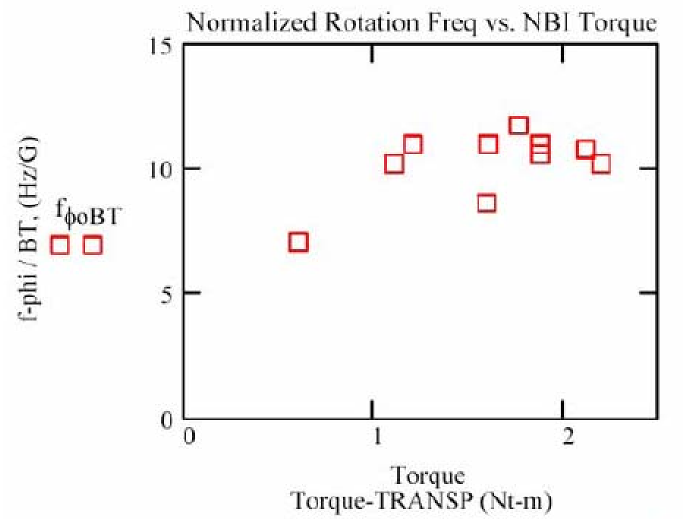
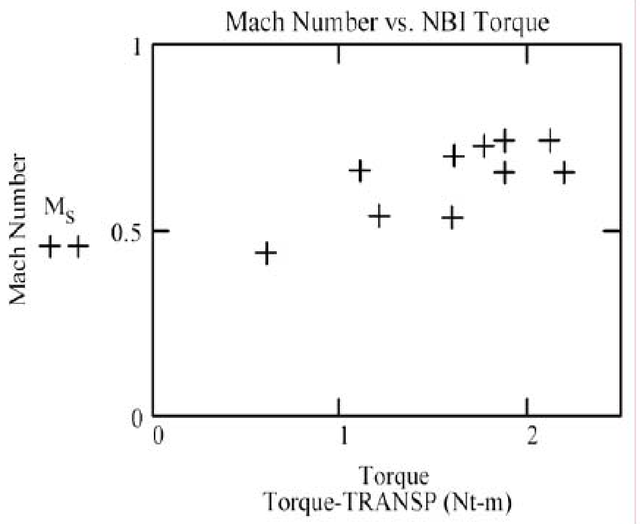


- Higher ExB shearing rate in lower energy case
- Analytic ITG growth rate γ_m (ref: Rogister) < ExB shearing rate

Data sheds light on relationship among τ_p, τ_ϕ, and τ_E in plasma core.





Simple 0D momentum balance with dominant tangential NBI heating:

Applied torque: $T_\phi = R_0 Q_b \sqrt{2m_b / eE_b}$

If NBI fuelling dominates in core:

Rotation frequency: $\omega_\phi = \sqrt{\frac{2eE_b}{m_b}} \cdot \frac{\tau_\phi}{\tau_p} \cdot \frac{1}{R_0}$

If NBI heating dominates and $T_i = T_e$, $Q_i = Q_e$:

Toroidal Mach number: $M_\phi = \sqrt{\frac{3\tau_p}{\tau_E}} \cdot \frac{\tau_\phi}{\tau_p}$

Independent of NBI power and energy!

Insight into ratios of τ's?

NSTX/MAST shot list for 2005 iITB identity experiments

Beam Energy-Power Matrix

- Shotlist [**Case**: sources/energy (kV), flattop shots + beam stepping shot]:

MAST Matches

~4.4 MW	~3.3 MW	~2.2 MW
I: B, A/90, 2+1	**II**: 0.5B, A/90, 2+1	**III**: B→A/90, 2+1
IV: B, 0.5A, C/80, 2+1	**V**: B, A/85, 2+1	**VIII**: C, B, 0.67A/85, 2+1
VI: B, A, C/70, 2+1	**VII**: B, A, C/60, 2+1	**IX**: B, A/60, 2+1

- Redo complete scan at 4.5 kG; NBI power stepping recommended in some shots
- High priority for MAST identity cases (M5/005,047), needing NBI conditioning

NSTX	Power (MW)	MAST beam/energy(kV), power(MW)
VII: B, A, C/60, 3	3.3	SW/50, 1.5; SS/60, 1.8
VIII: C, B, 0.67A/85, 3	2.2	SS/70, 2.2
IX: B, A/60, 3	2.2	SW/35, 0.7; SS/60, 1.5

- Required successful shots: 18 out of 27 planned

What’s Next?

- Complete XP513 on NSTX at B_{T0} = 4.5 kG (May-June)
- Complete M5/005, 047 on MAST (June)
- Include appropriate existing shots from other XPs
- Include key physics elements in iITB evolution model, develop improved if necessary
- Utilize TRANSP & EFIT with strong flow and MSE

- Develop comparison experiments with DIII-D, AUG, JET, etc. in 2006-2007