NSTX

MHD, Transport and scenario development on NSTX

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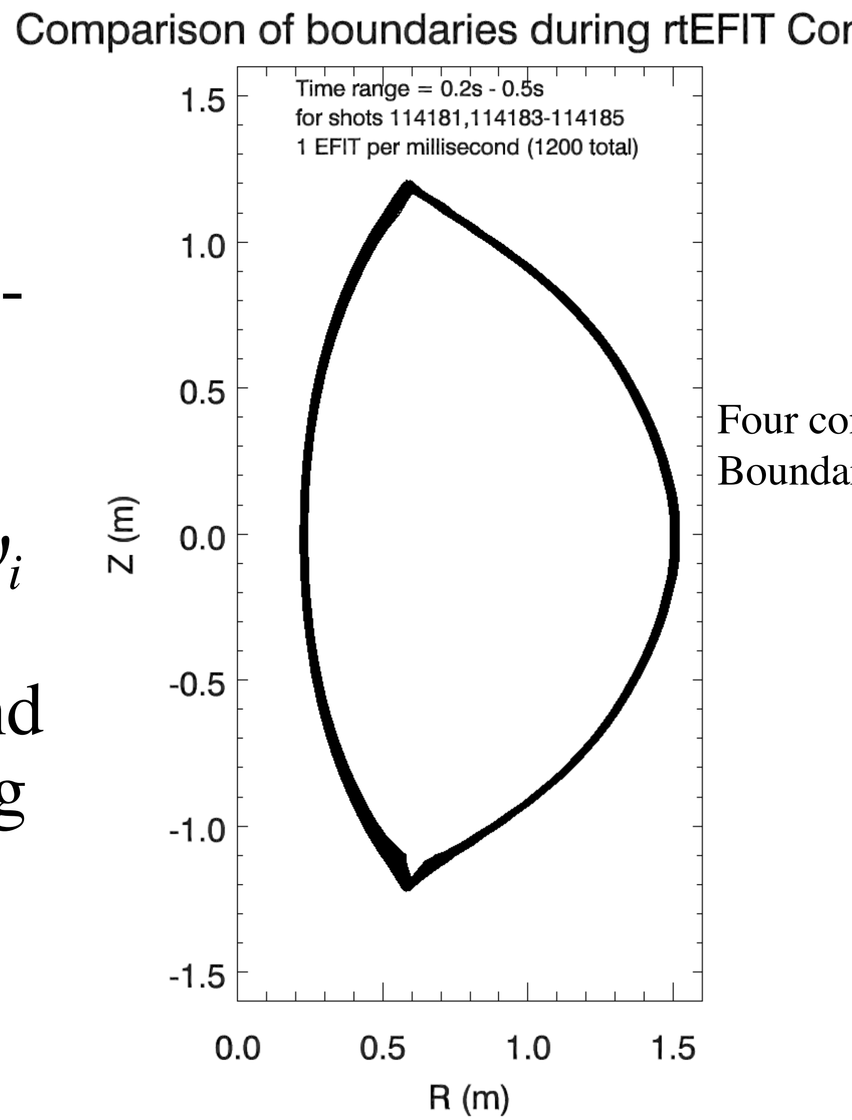
Outline

- Scenario development
  - Precision control
  - High κ
  - Long pulse
  - High β
- MHD
  - Resistive wall modes
  - Error fields
- Transport
  - Global Scalings
  - Transport barriers
  - Momentum confinement
- Summary and Plans

rtEFIT/isoflux controls boundary precisely

- Real time digital control of plasma boundary based on inversion of the Grad-Shafronov Equation
- Isoflux control - $V_{PFi}=G_i\delta\psi_i$ where $\delta\psi_i$ is the flux error between requested and actual boundary along control segment
- Used for 40% of experiments in 2004

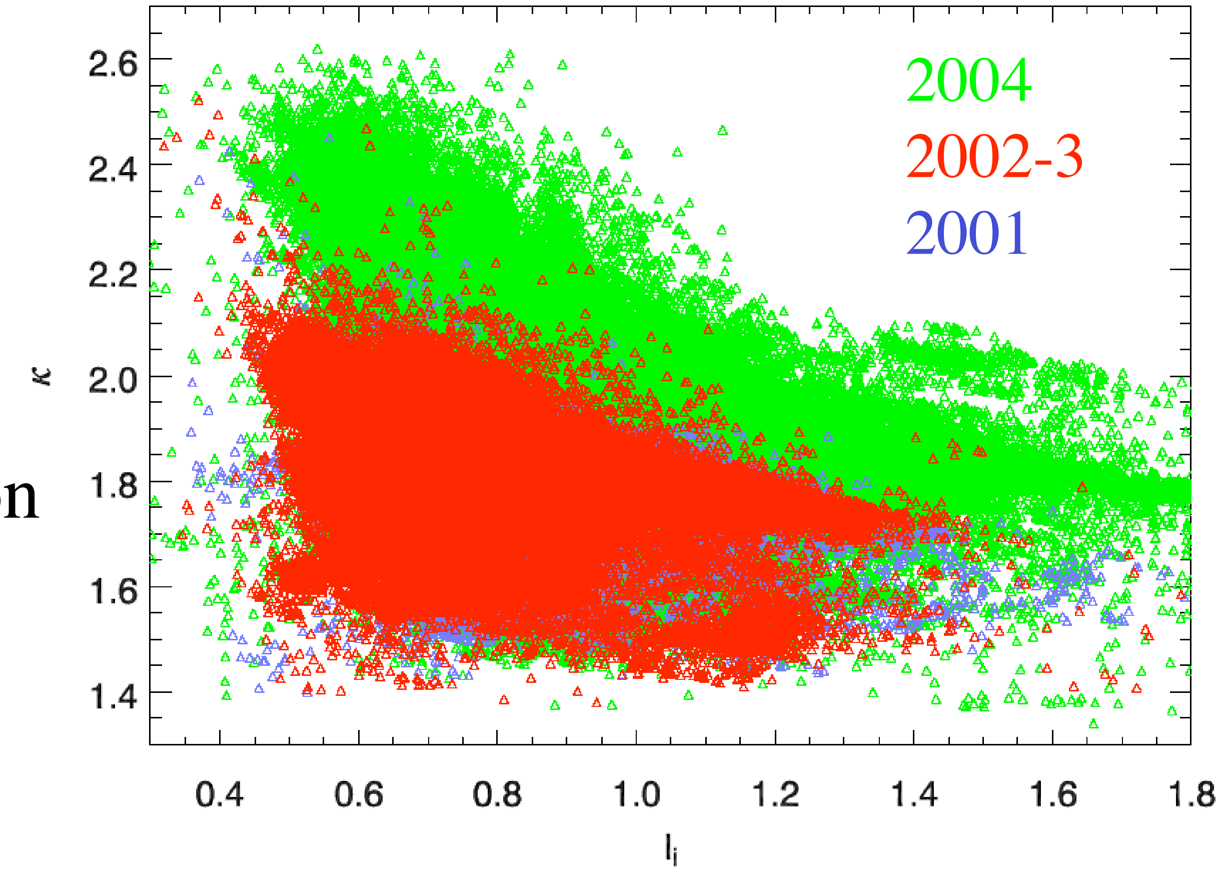


Four consecutive shots-
Boundaries from EFIT

Improved control system expands operating boundaries

- Control latency reduced to 1/4 previous value
- Plasma elongation increased ~30% (at fixed l_i)
- Increased elongation has broadened operating space (pulse length, β)

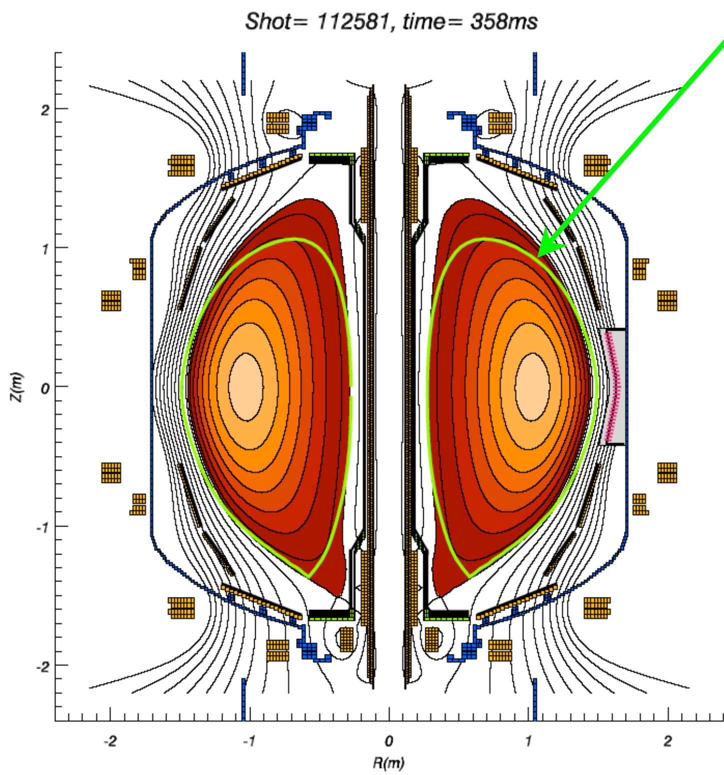
From EFIT - entire NSTX database

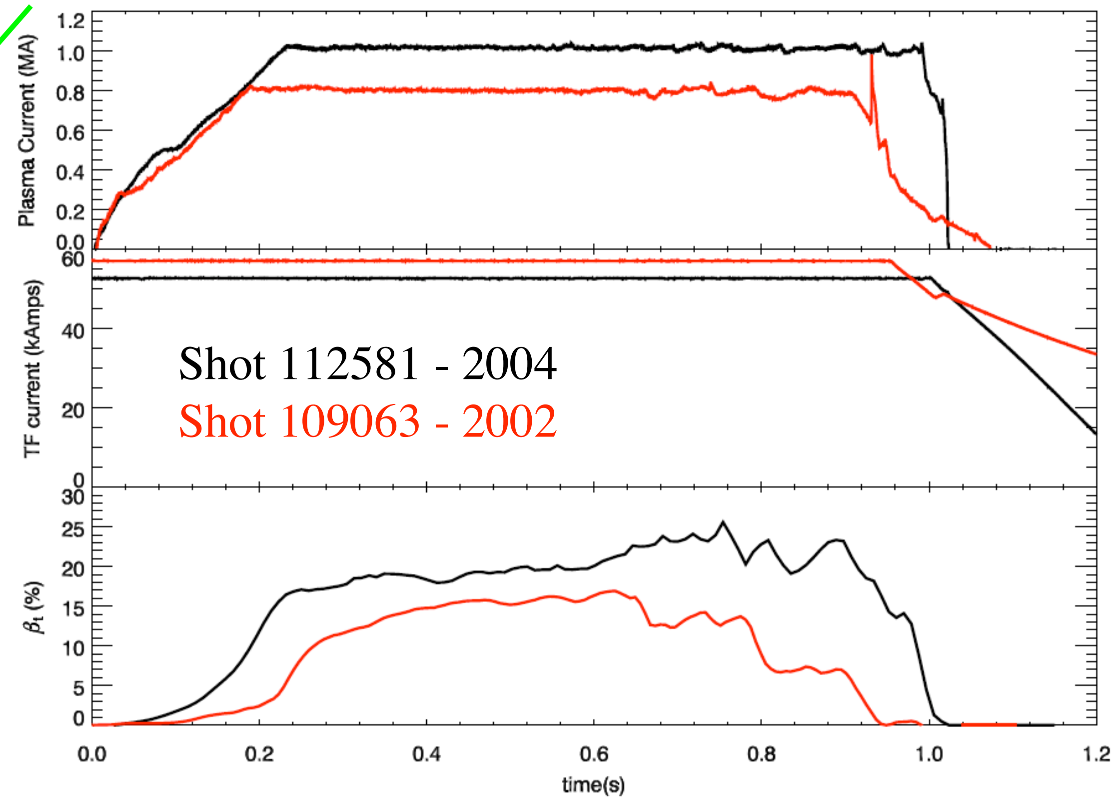


Long pulse discharges extended

- High elongation extends pulse at higher current (raises bootstrap current, edge q)
- Early H-mode reduces flux consumption during current ramp

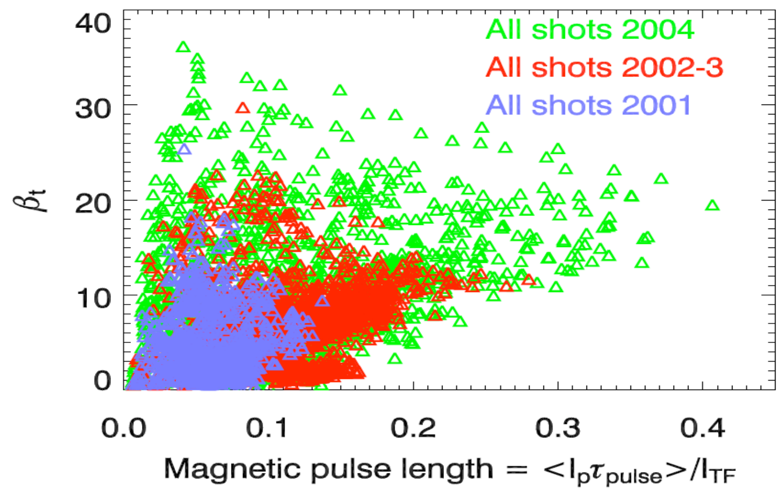
Boundary from 109063 overlaid (green)

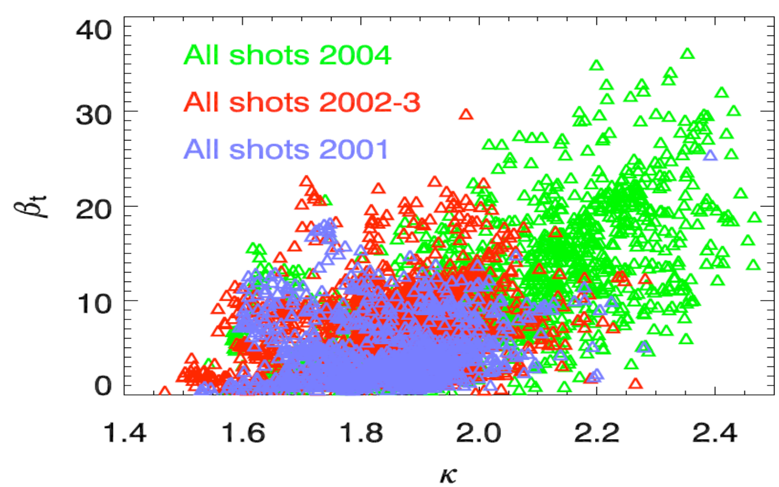


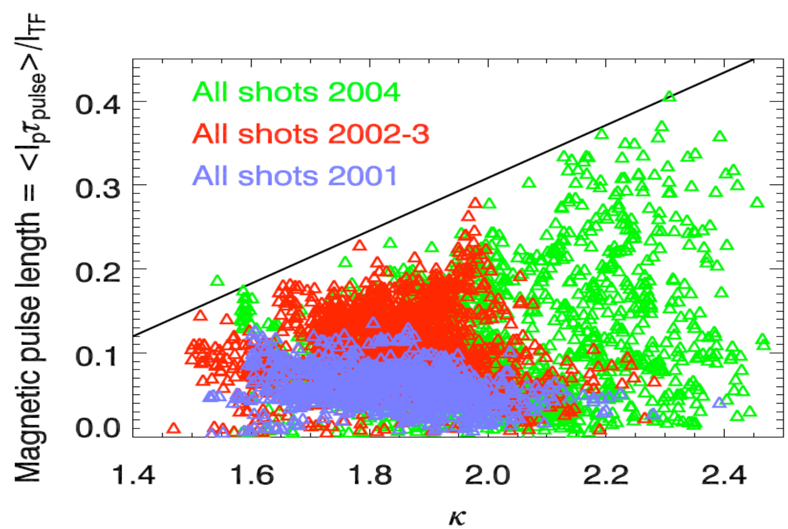


Magnetic pulse length increased

- Simulataneous doubling of β_t (pulse averaged) and 50 % increase in normalized pulse length ($\tau_{pulseN} = \int I_p dt / \langle I_{rod} \rangle$)
- Improvement correlates strongly with high κ

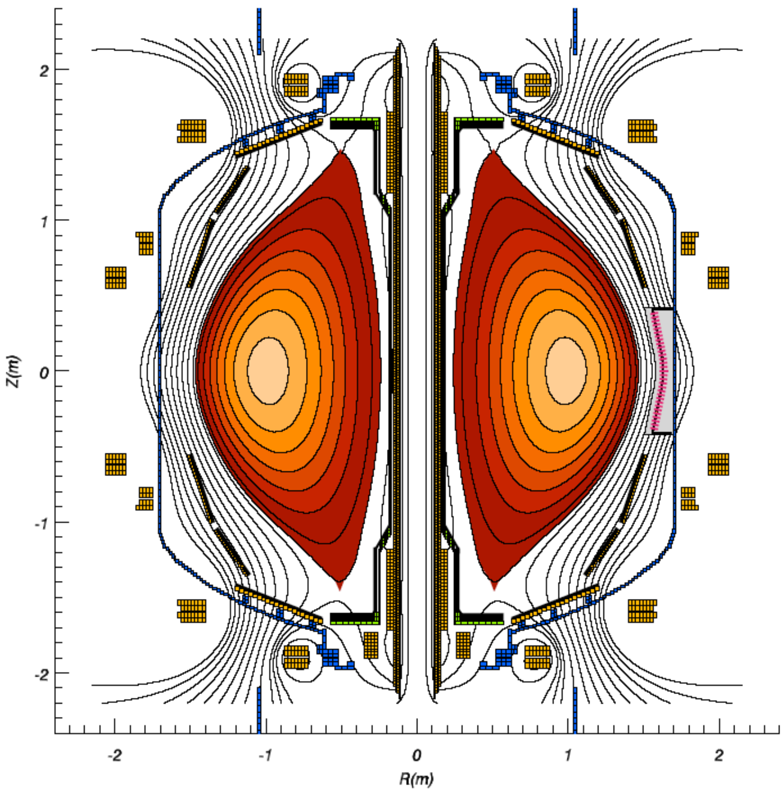




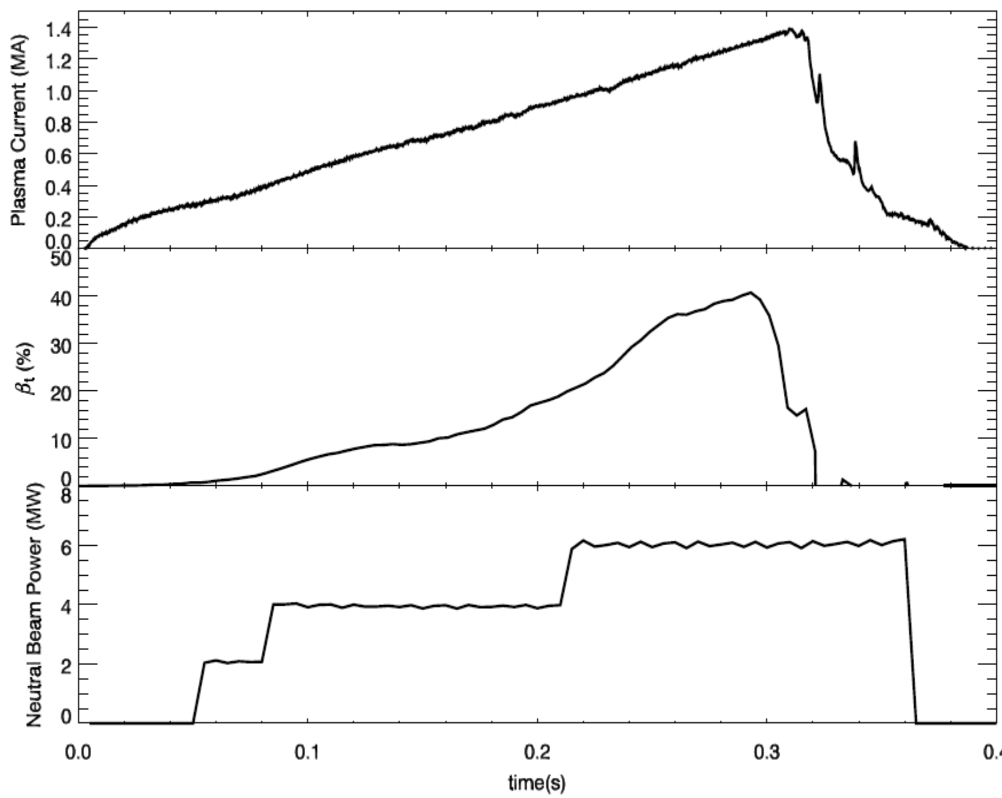


High β_t achieved at $I_p/I_{rod} > 1$

- $I_N = I_p/aB \sim 7$ $(MA/[m \bullet T])$ - $I_p/I_{rod} \sim 1.1$
- $\beta_t \sim 39\%$ - uncertain within 10%
- MSE available but not yet analyzed



Shot 114465, 1.4MA, I_{tf} = 36*35.5kA



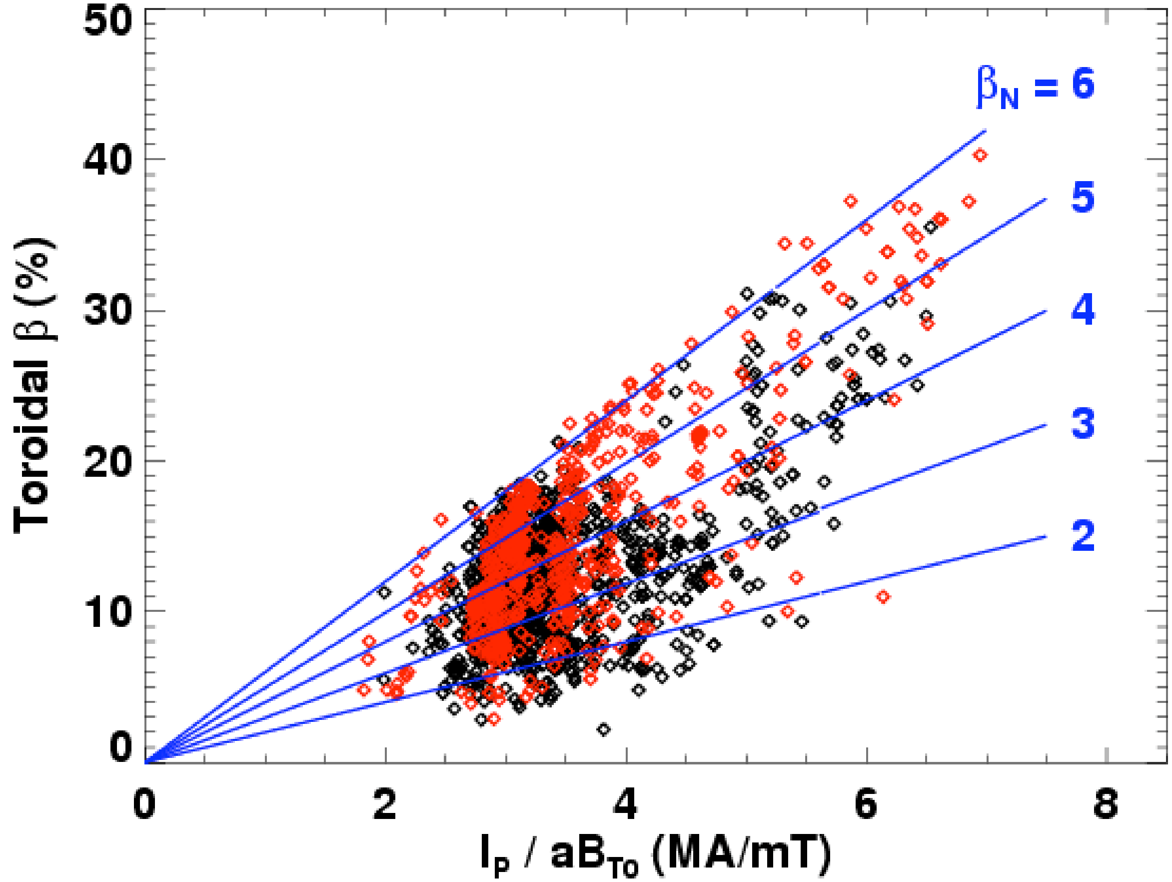
High β regime extended

NSTX

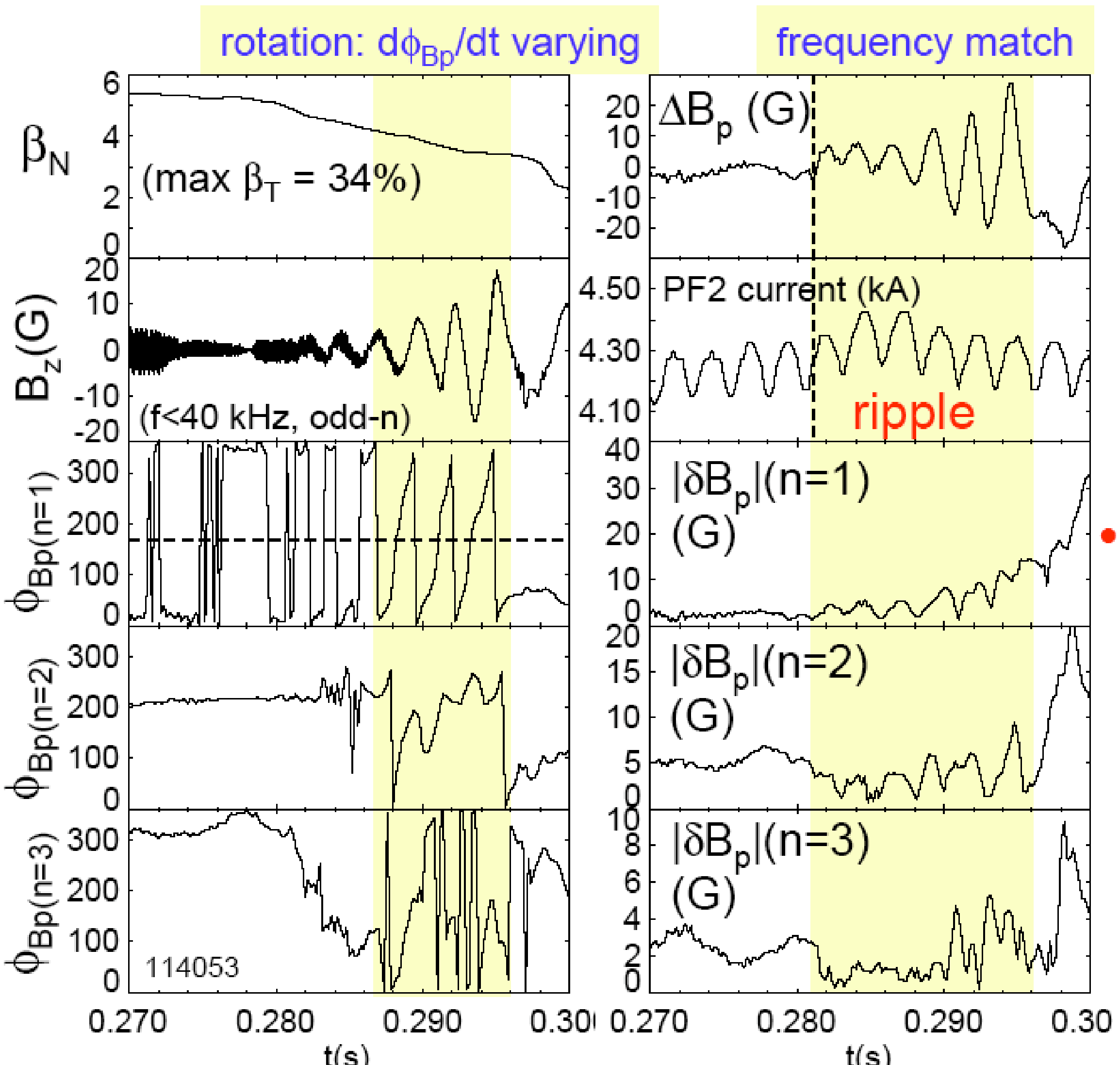
- Many shots with $\beta_t > 35\%$
- Troyon scaling confirmed with $\beta_N \sim 6.3$ (wall stabilized)
- Highest β also at high $\kappa \sim 2.3$

EFIT data from 2004

EFIT data from 2001-3



Clear signature of RWM observed



Modified resonance

$$(S_* \nu_* /(1+md)+1)\hat{\omega}_f^2 + (s(1-md)+\Omega_\phi^2) = 0$$

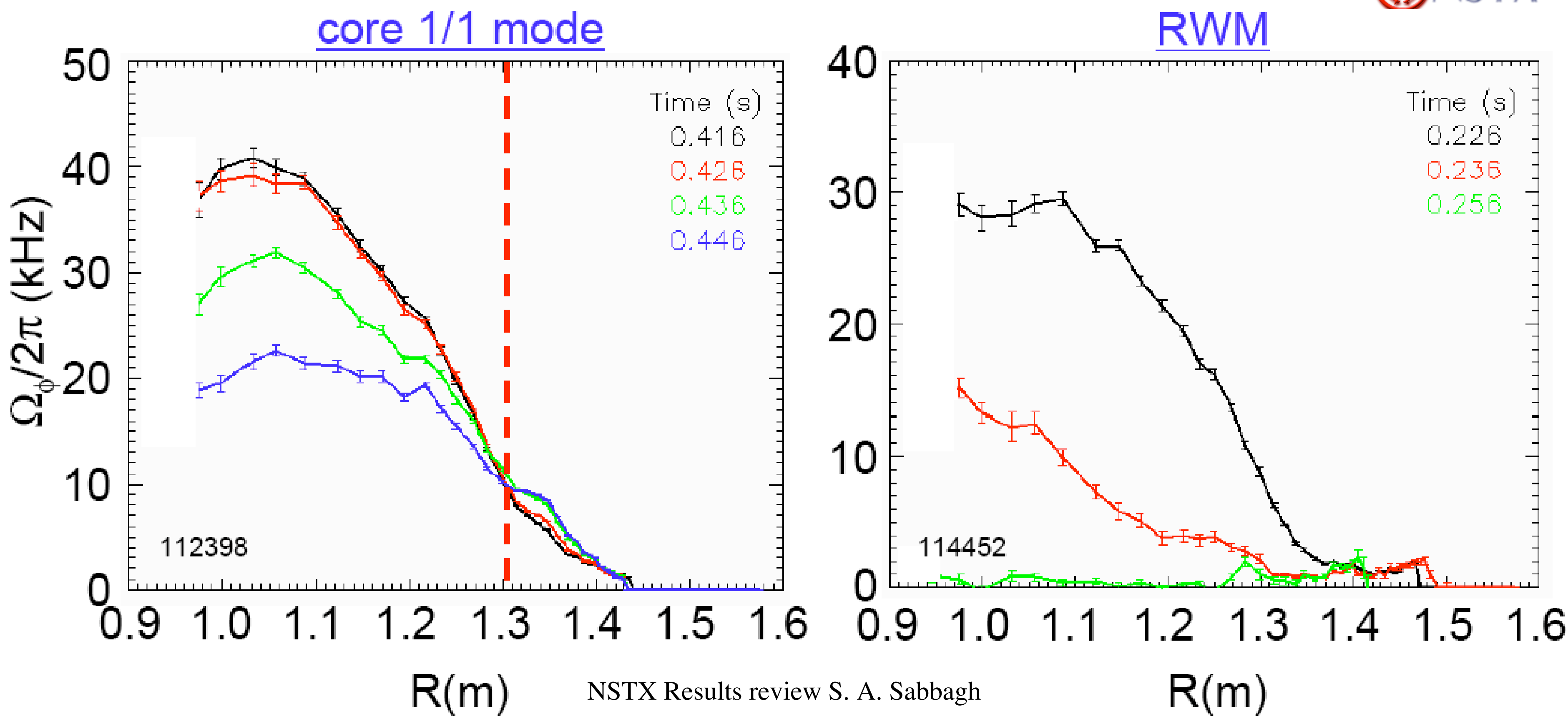
"static error field" response

New resonance

$$\hat{\omega}_f^2 = \nu_*(1+md)/2S_*$$

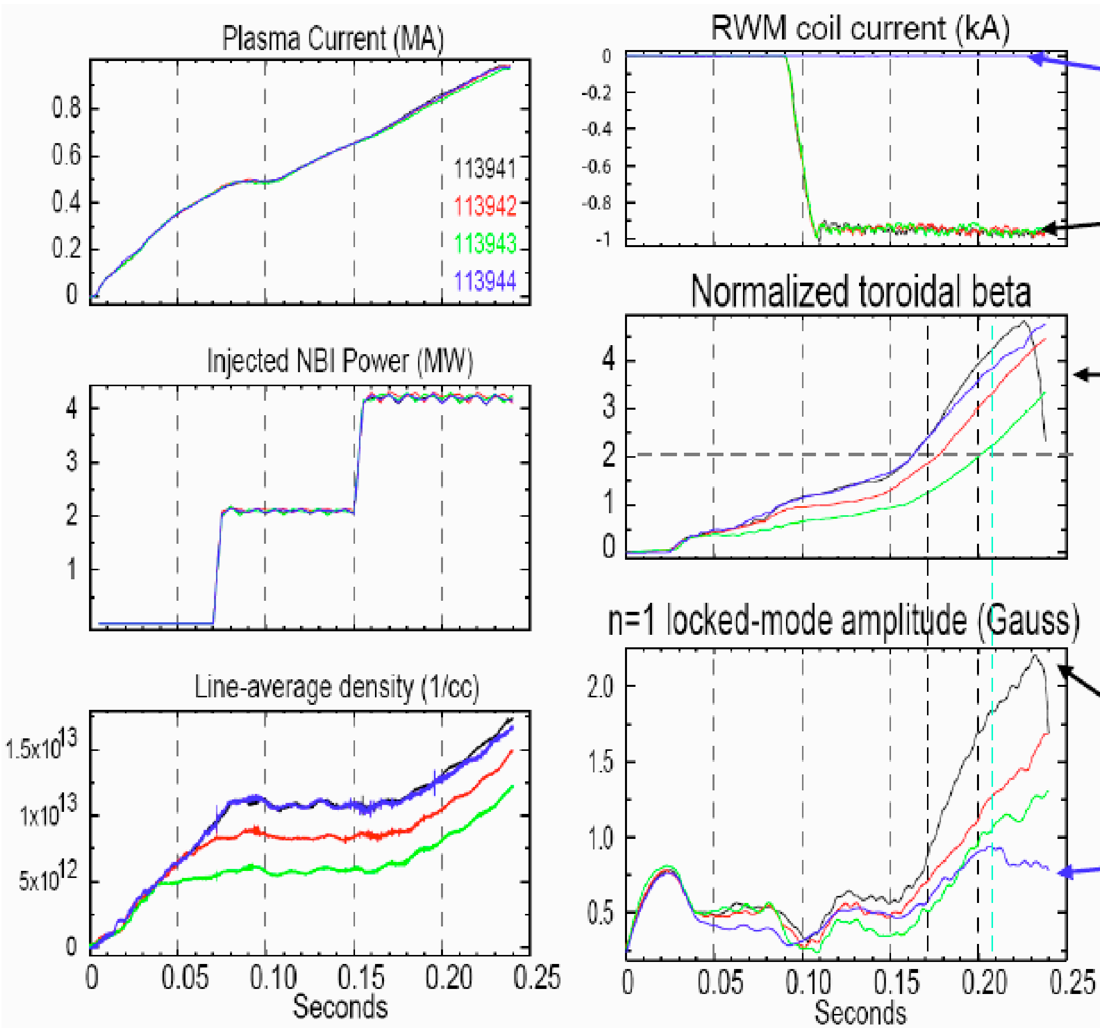
- Theory / XP show
  - Time-dependent error field yields new resonance
    - may be responsible for mode trigger
  - Mode rotates *counter* to plasma rotation – F-A theory shows as "kink branch"
    - n=1 phase velocity not constant due to error field
  - Rough calculation of $\omega_f/2\pi \sim 350$ Hz; agrees with PF coil ripple
  - Initial results – quantitative comparison continues

RWM rotation collapse differs from other modes



- Core rotation damping when 1/1 mode onsets
  - leads to "rigid rotor" plasma core
- Clear momentum transfer across rational surface near R = 1.3m
- Global rotation damping by RWM
  - 1/1 tearing mode is absent
- Edge rotation does not halt
  - consistent with neoclassical toroidal viscosity ~ $\delta B^2 * Ti^{0.5}$

Error field ampification measured



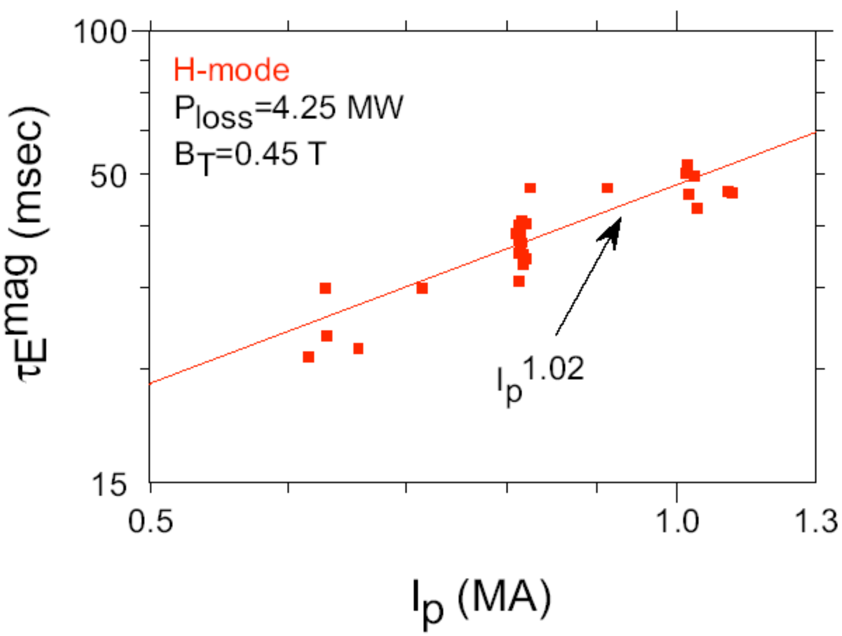
- Blue shot has $I_{RWM} = 0$
- Others use I_{RWM} that doesn't cause locking at t=140ms
- n_e scan yields β scan after 2nd source fires
  - NBI waveforms fixed
- Plasma amplifies field when β_N > approx. 2

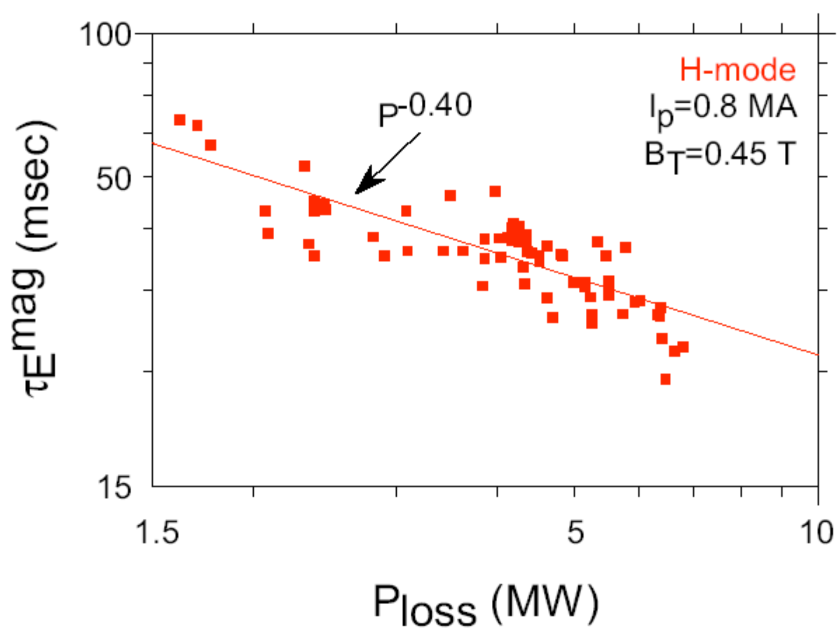
$I_{RWM} = 0$ shot has smallest LM signal ➔ smaller residual error field later in shot?

Global confinement scalings from dedicated scans

- Specific scans of control parameters (plasma current and in put power) show scalings similar to conventional aspect ratio tokamaks
- Fits to thermal confinement show similar trends

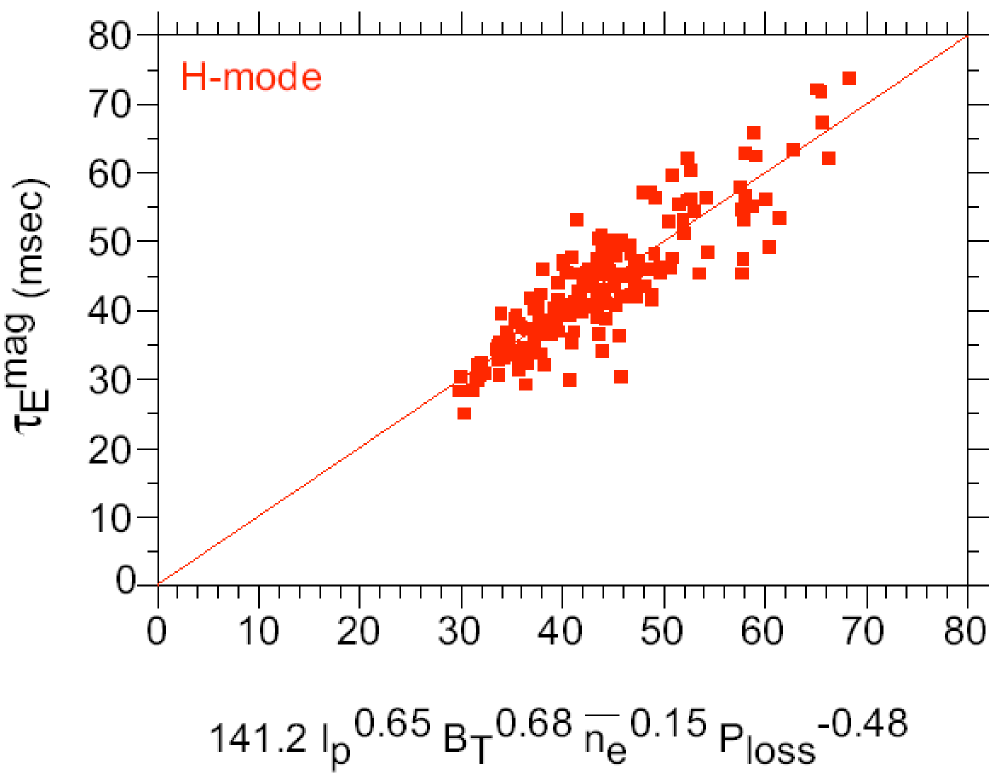
NSTX Results Review 2004 - S. Kaye





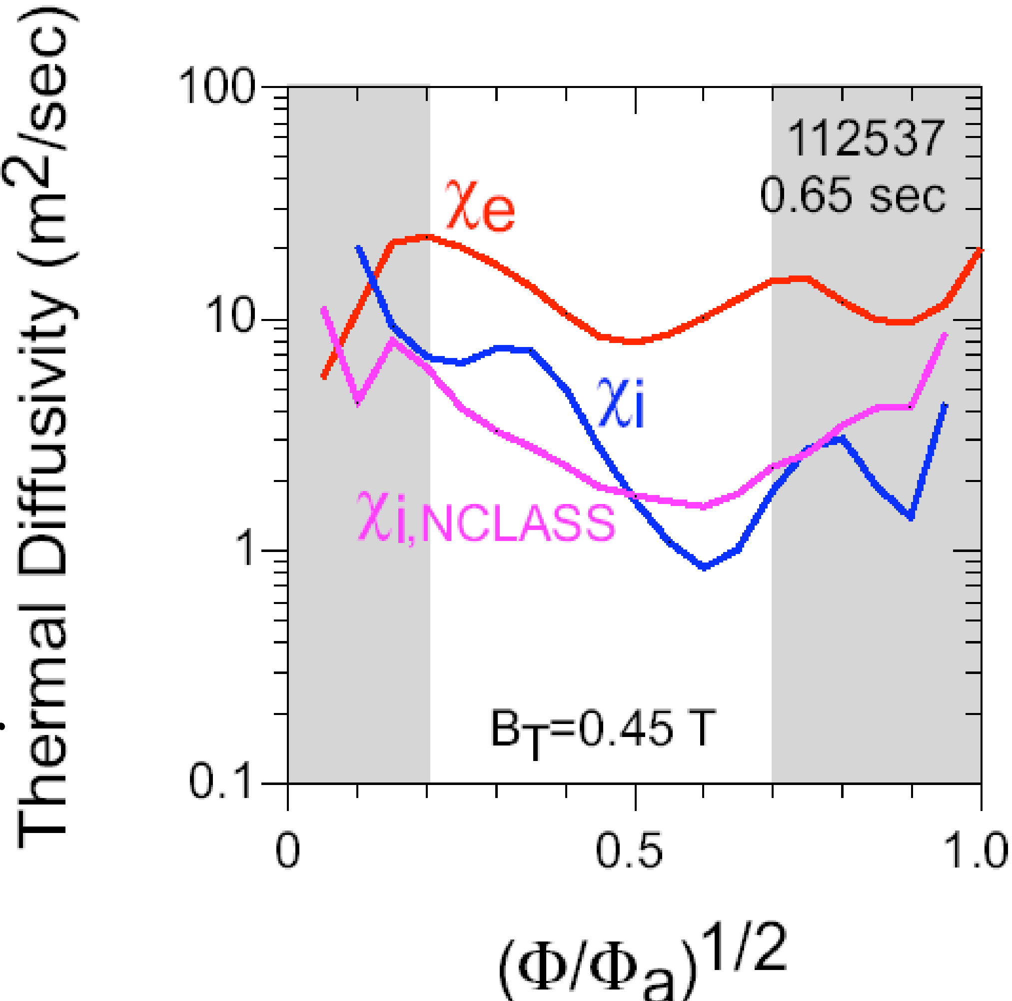
τ_E scaling differs for larger database

- For global database strong dependence of confinement on toroidal field
- Weaker dependence on plasma current
- Difference under investigation -> finite gyro-radius effect?



Diffusivity profiles under study

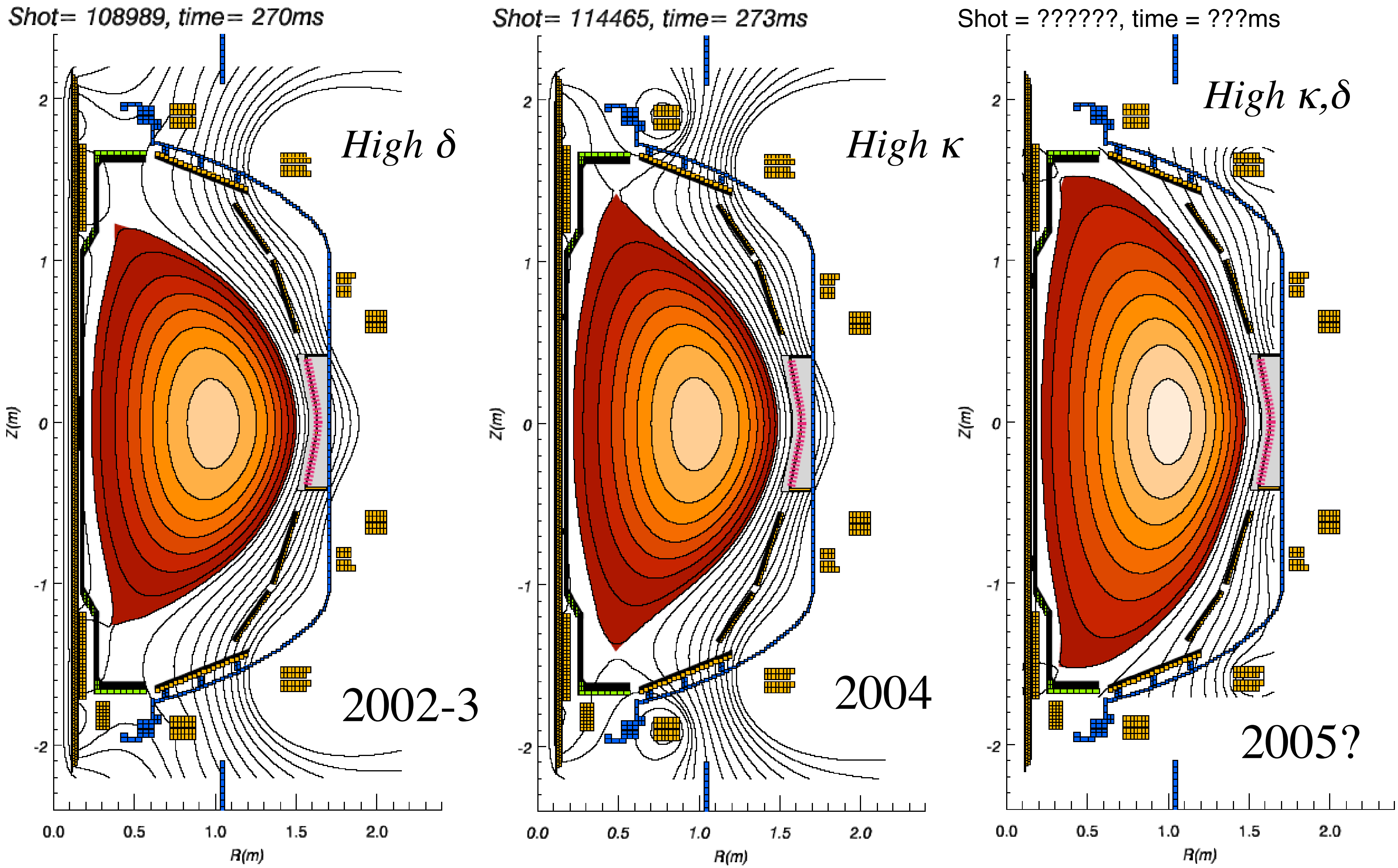
- Thermal diffusivities from TRANSP based on measured profiles of T_e, n_e (20 channel Thomson scattering, 60Hz), T_i, Z_{eff} (51 channel, 100Hz CHERS)
- Accuracy of calculation and data for region with $\chi_i < \chi_{i,NCLASS}$ under investigation



PF1A upgrade will allow stronger shaping

- PF1A coil is being modified for better control of triangularity at high elongation
- High triangularity combined with high elongation will permit 40% more current for fixed q
  - Alternatively higher q for the same current
- 100% non-inductively sustained scenario has been identified for target double null shape
  - Assumes functioning EBW current drive
- Will also test if RWM feedback can raise β_N
  - Important for increased bootstrap current

Shape evolution at high β on NSTX



Summary

- NSTX has made excellent progress
  - Shape control has been crucial
  - High κ
  - Pulse length increased 50% with 100% increase in β_t
  - $\beta_t \sim 39\%$
- MHD studies have identified important performance limiting modes
  - RWM
  - Error field modes
- Beginnings of single machine ST transport scalings developed
  - Intriguingly good ion confinement
- Planned upgrades should lead to continued improvements in performance