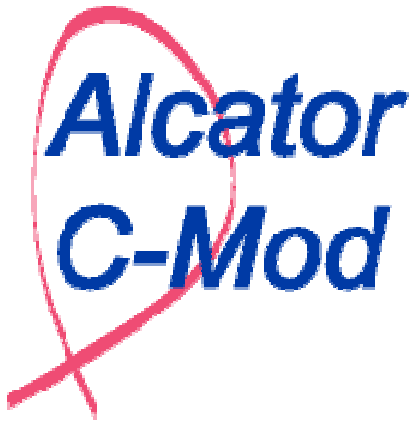
Particle Transport At Low Collisionality on Alcator C-Mod



US-EU TTF Meeting

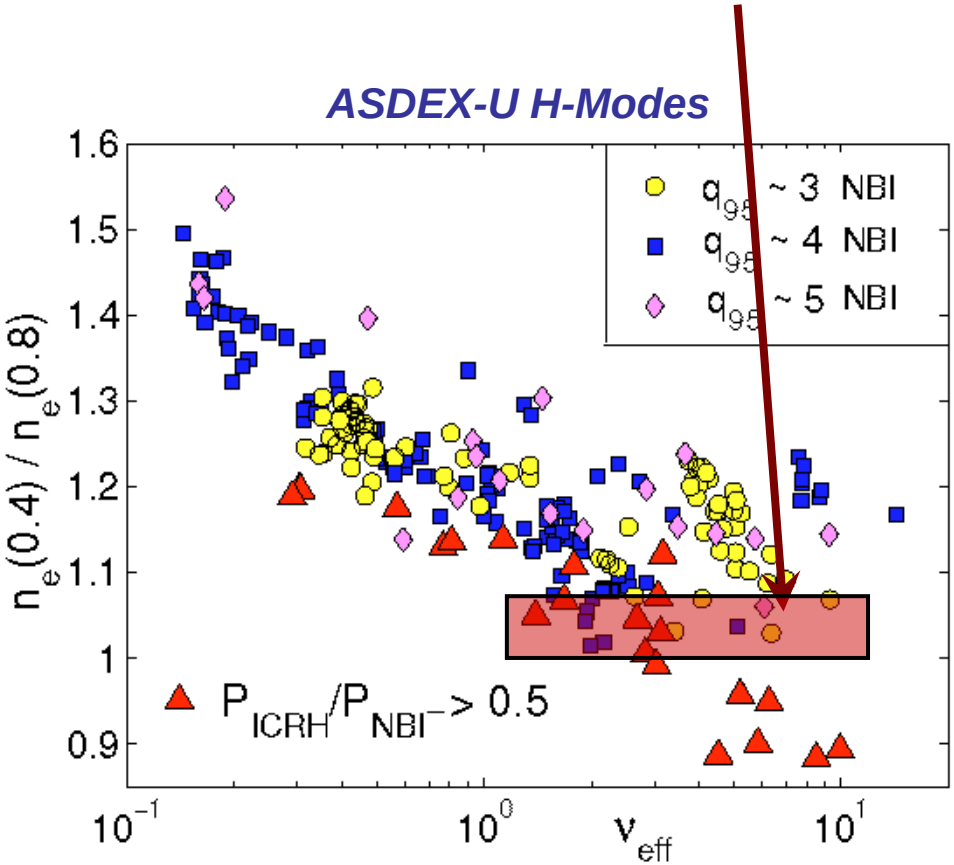
San Diego, 4/18/2007

M. Greenwald, J.W. Hughes, D. Mikkelsen, J. Terry, K. Zhurovich,
Alcator Group

Collisionality Effects on Particle Transport

- ITER interest – better fusion performance with moderate density peaking
- Results from ASDEX, JET suggest increase in density peaking at low ν^* *(note plots use $\nu_{eff} = \nu_{el}/\nu_{De}$ not ν^*)*
- Much of the previous work has significant beam fueling (C-Mod uses RF only)
- Until recently, C-Mod density was too high to enter the very low ν^* regime.

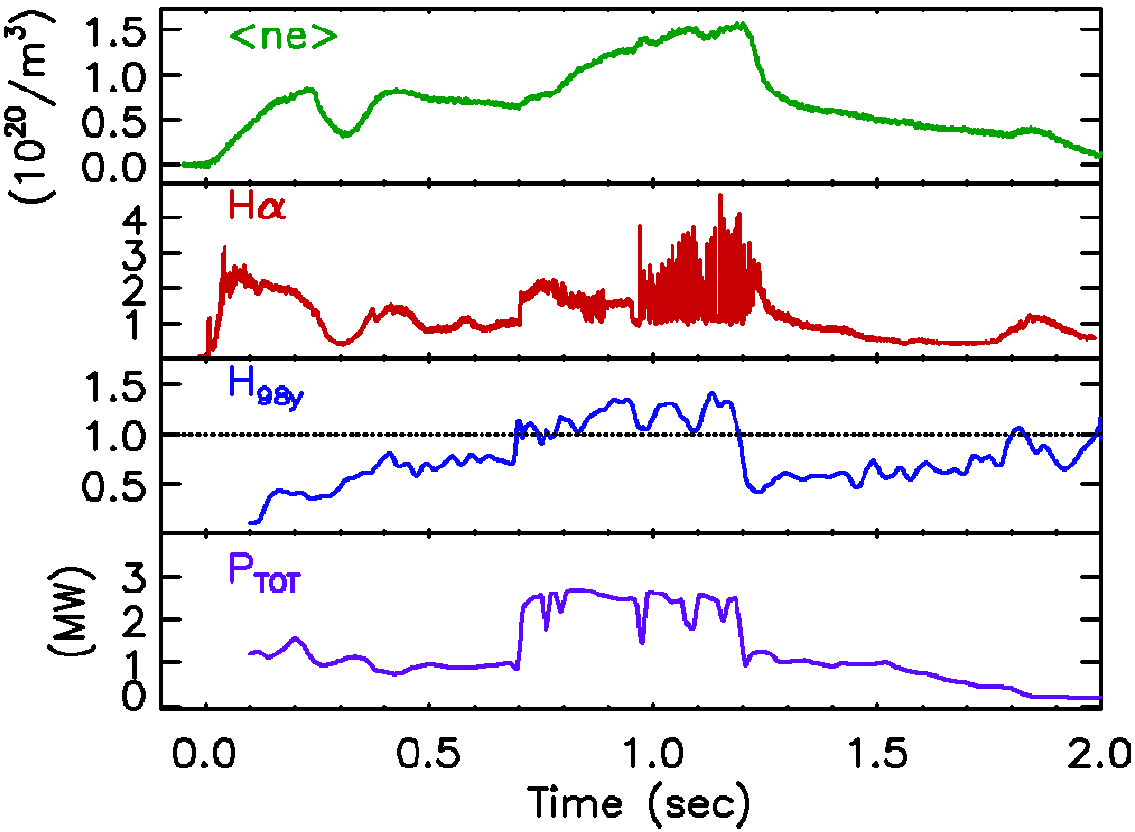
Typical C-Mod H-modes

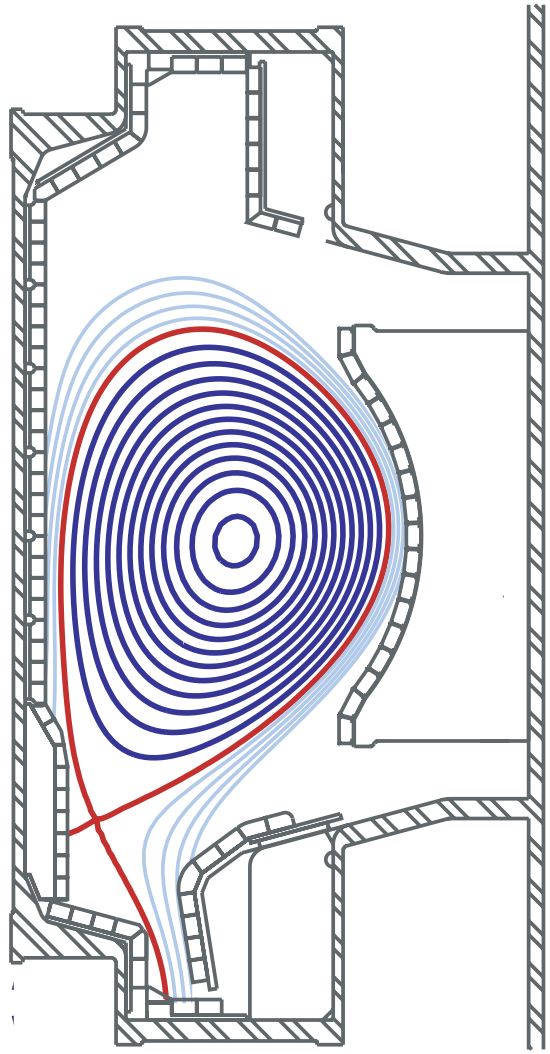


ASDEX-U: C. Angioni et al., PRL (2003)

JET: H. Weisen, et al., NF (2005)

Low Density H-Modes Accessible With "Unusual" Shape





With this shape, large ELMs appear in C-Mod

$n/n_G = 0.3$, $\nu* = 0.1$, $\nu_{eff} = 0.4$, $\nu_{ei}\tau_E \sim 10$

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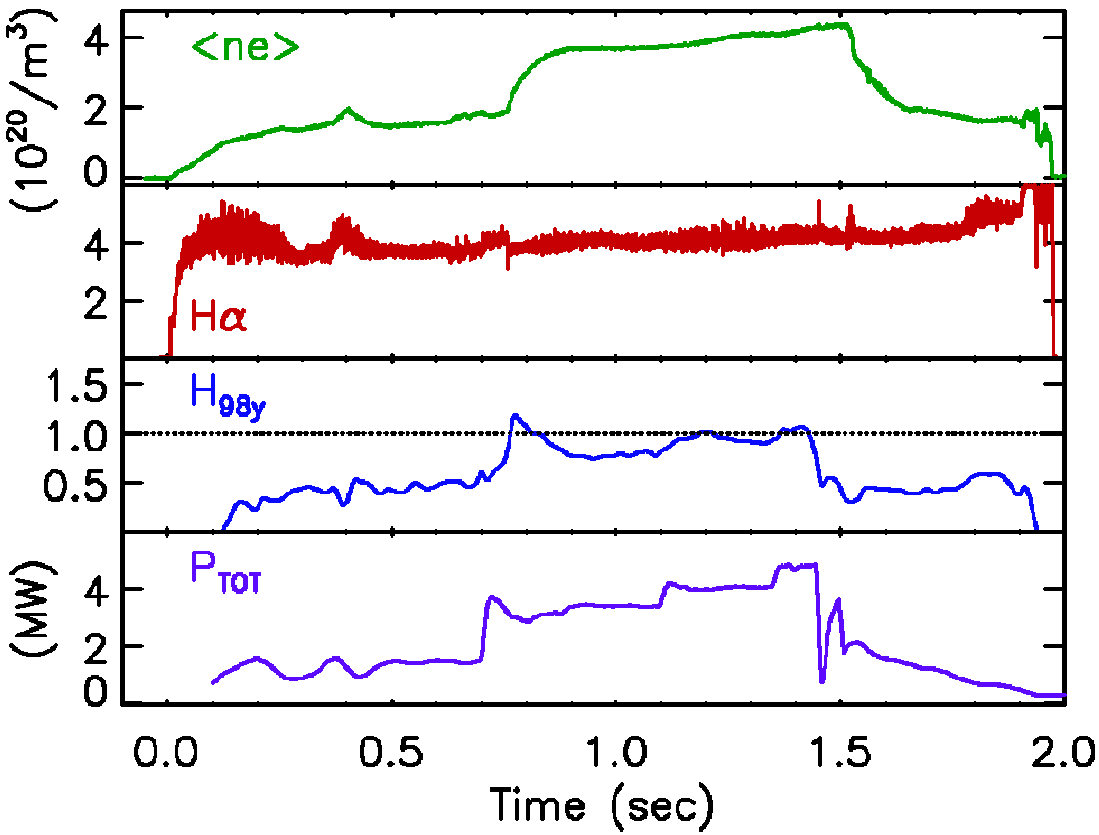
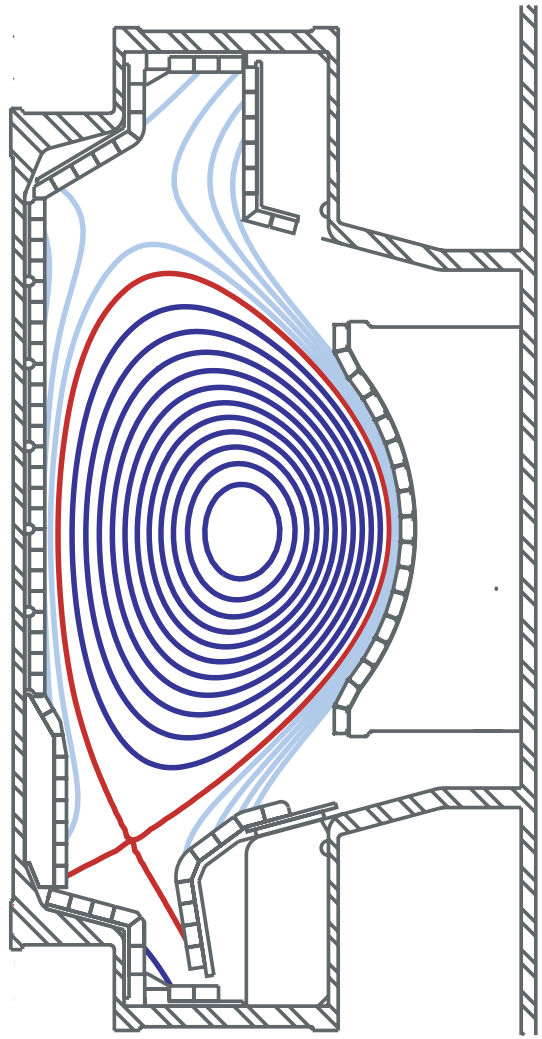
H-Mode In Standard C-Mod Shape





EDA (QC mode) and small ELMs

$n/n_G = 0.66$, $\nu* = 0.8$, $\nu_{eff} = 2.5$, $\nu_{ei}\tau_E \sim 70$

(2x, 8x, 6 x, 7x lower density H-mode)

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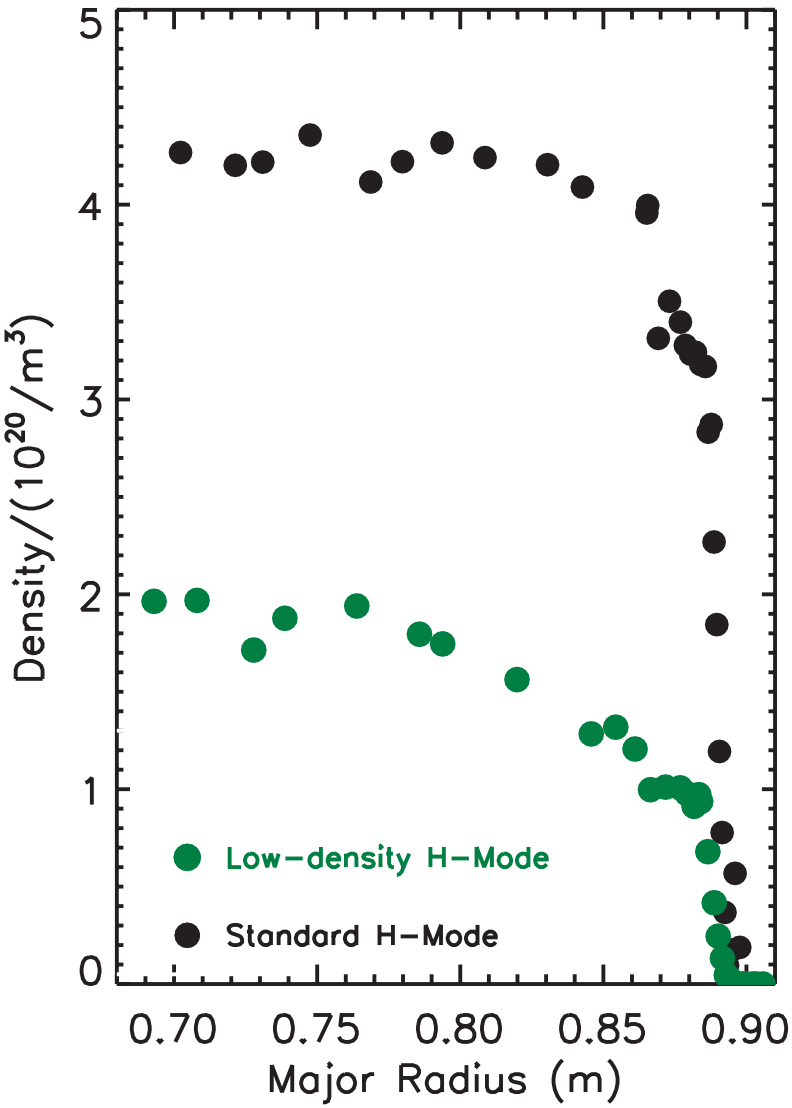
Lower Density H-Modes Show More Profile Peaking

- We don't know why these shapes allow operational H-mode at lower target densities
  - Lower L-H threshold density
  - ELMs seem to reduce rate of density rise in H-mode
- Whatever the cause:
  - Standard H-mode
    $n_{e0}/\langle n_e \rangle = 1.1\text{-}1.2$
    $L_n >> a,\ R/L_n \sim 0,\ R/L_T \sim 6\text{-}7$
  - Low-Density H-mode
    $n_{e0}/\langle n_e \rangle = 1.5$
    $R/L_n \sim 3\text{-}4,\ R/L_T \sim 6\text{-}7$



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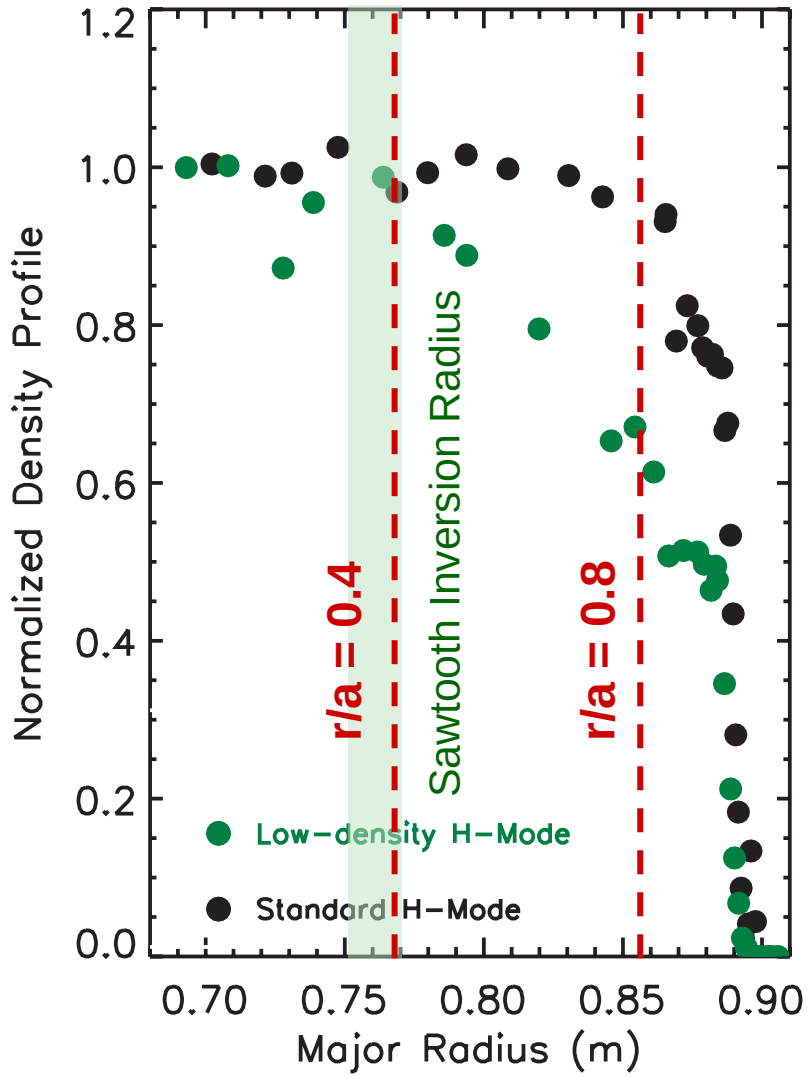
Difference In Profile Shape Is Notable

- Peaking is seen over outer 60% of plasma radius
- H-mode profiles evolve quickly; $\tau << a/V_{WARE}$
- Transport in center of plasma may be affected by sawteeth
  - These are of large amplitude; $\delta T_e/T_e \sim 25\%$
- Radii chosen to characterize peaking in ASDEX-U are appropriate for C-Mod profiles
- So, collect a database and plot results….



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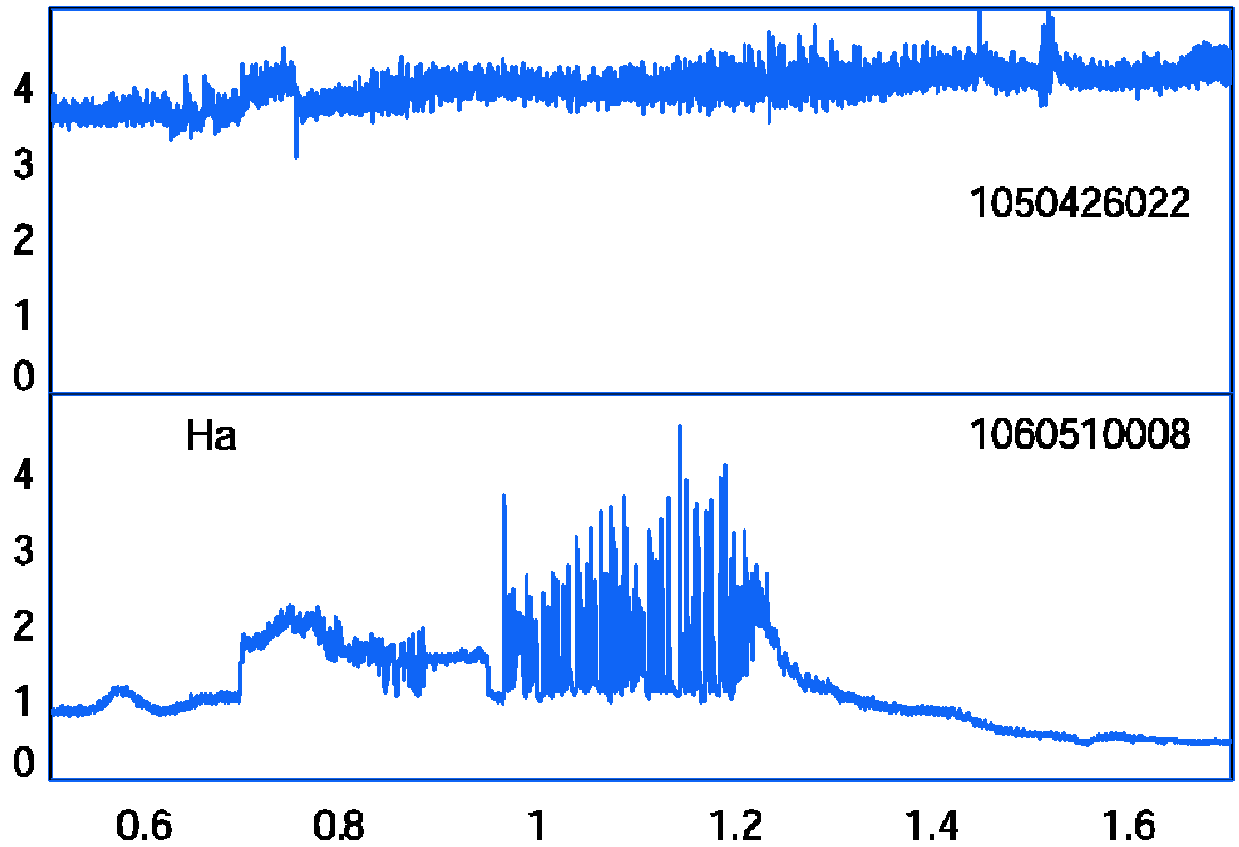
Low Density H-modes Are Accompanied By ELMs



Cause and effect are not clear…

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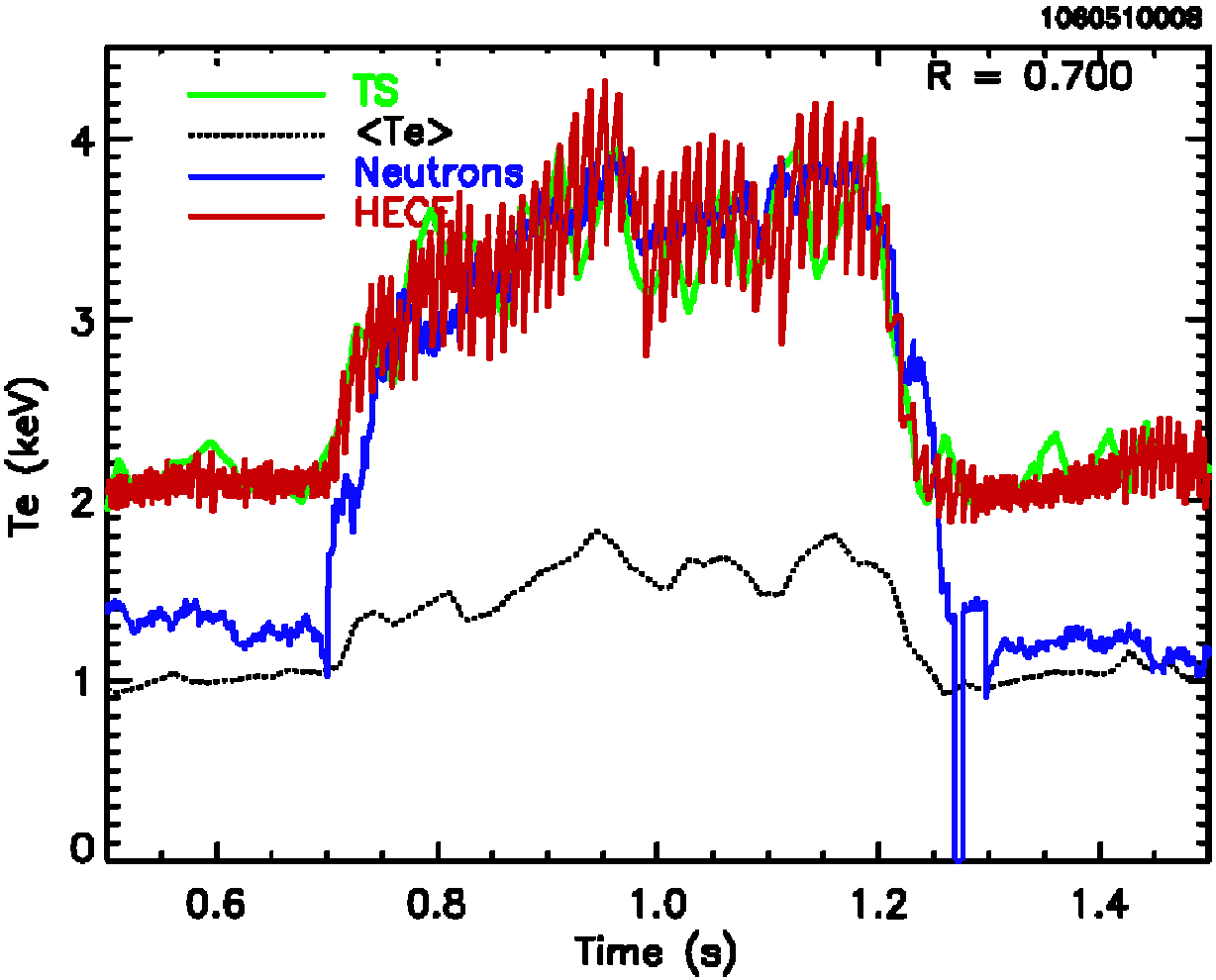
Even In Low-Density H-mode, $T_i \sim T_e$



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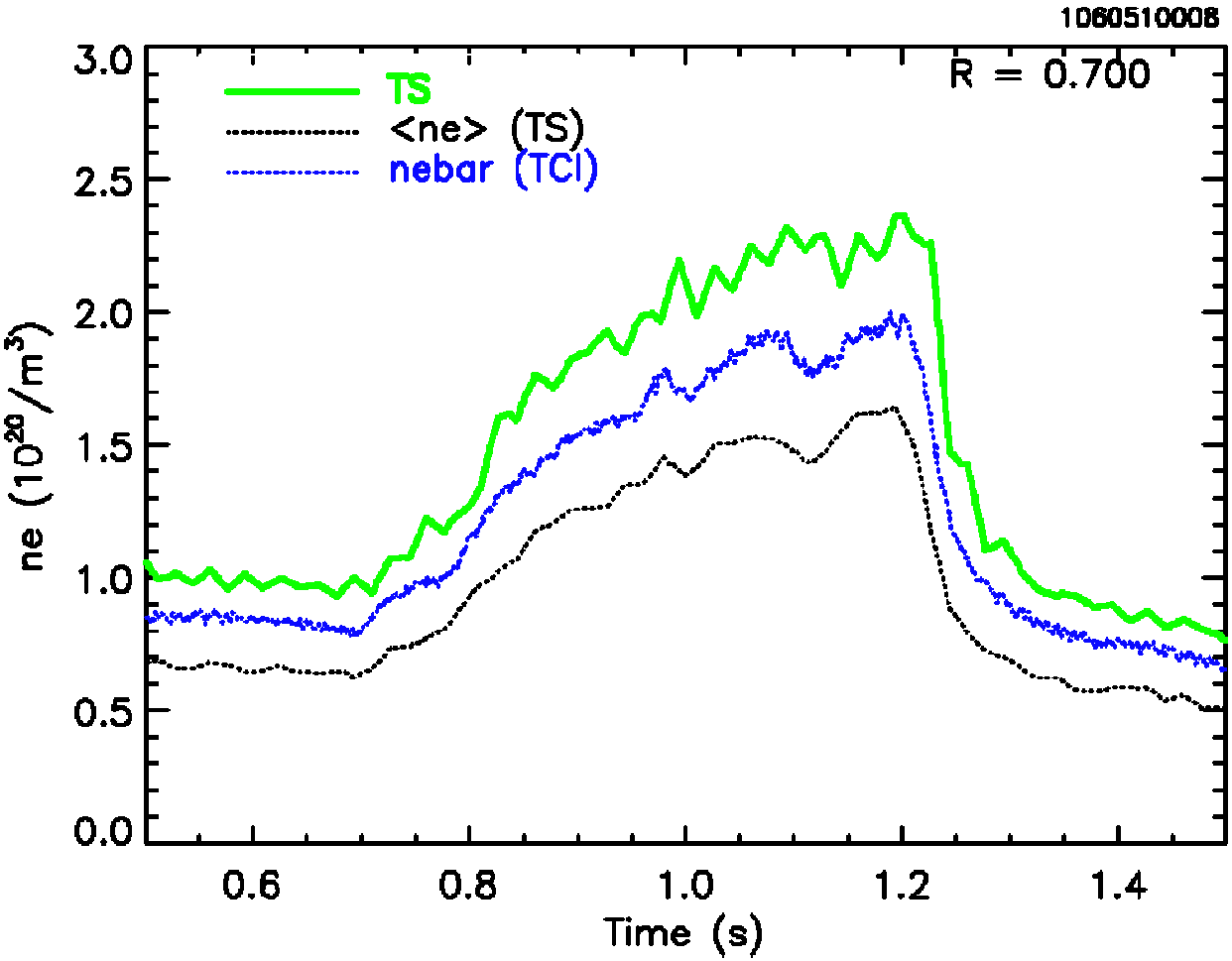
In Low Density H-modes $n_e(0) > \tilde{n}_e > \langle n_e \rangle$



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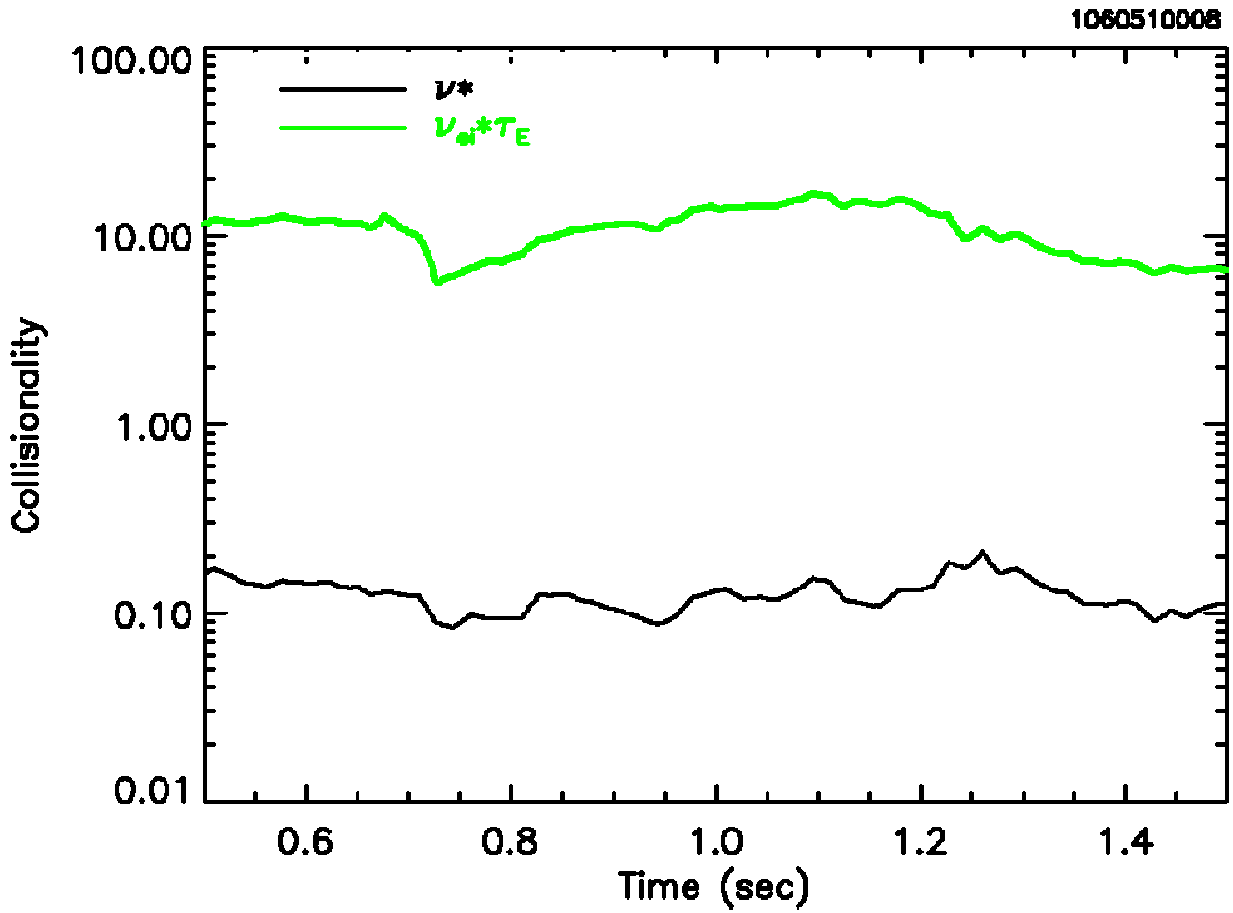
Collisionality in Low Density H-modes



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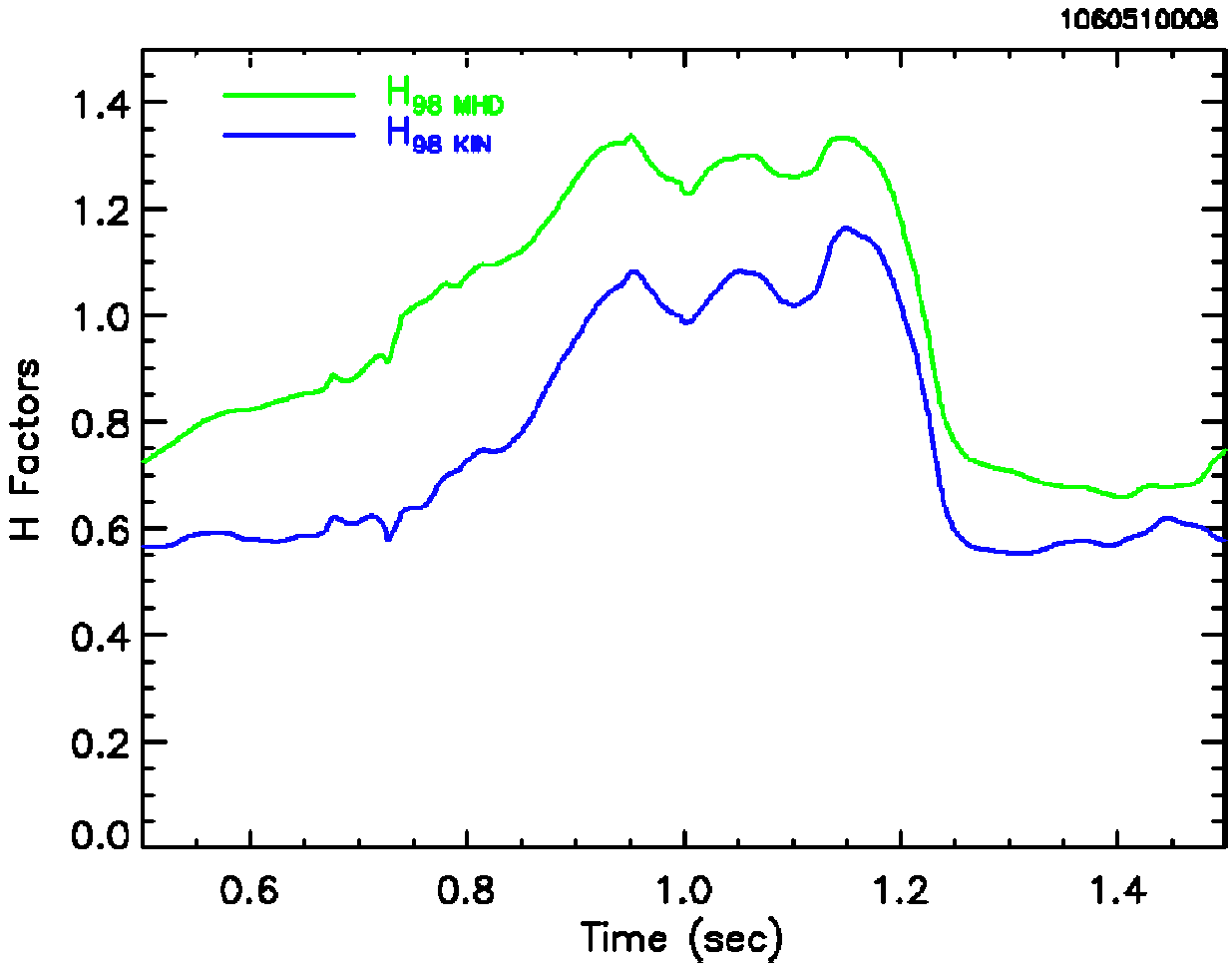
Energy Confinement in Low Density H-modes



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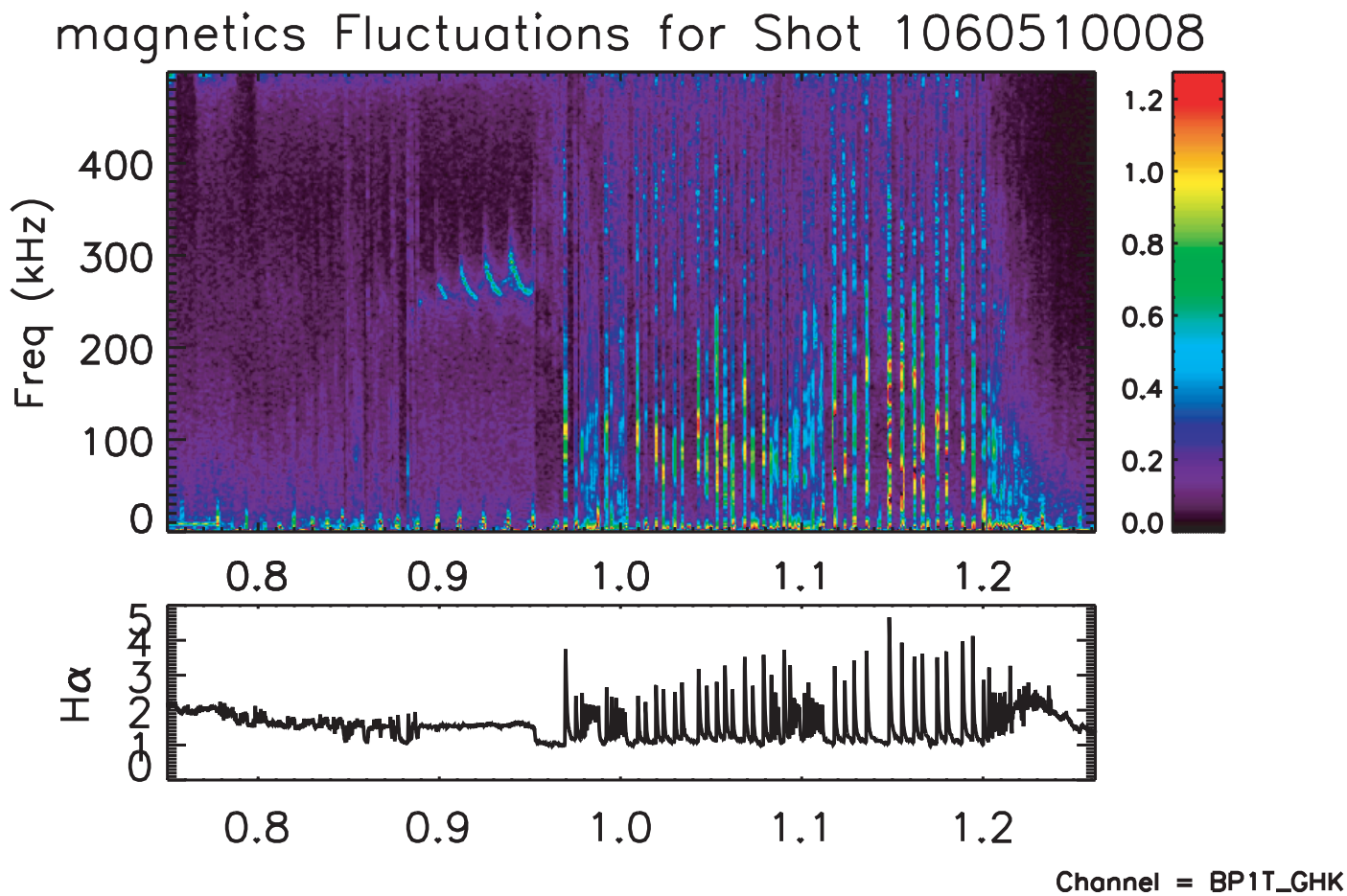
ELMs in Low Density H-modes



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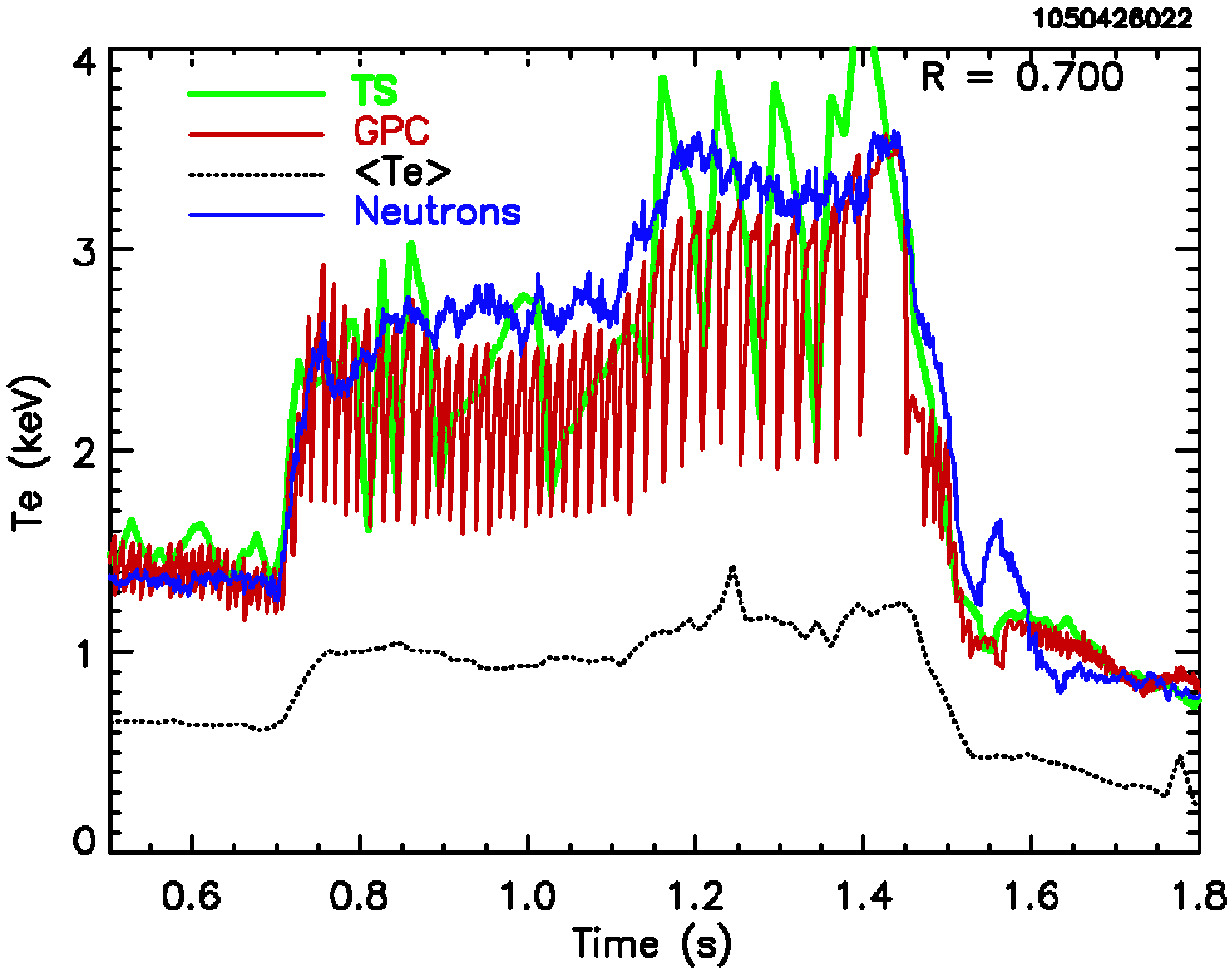
Temperatures In Standard Density H-modes



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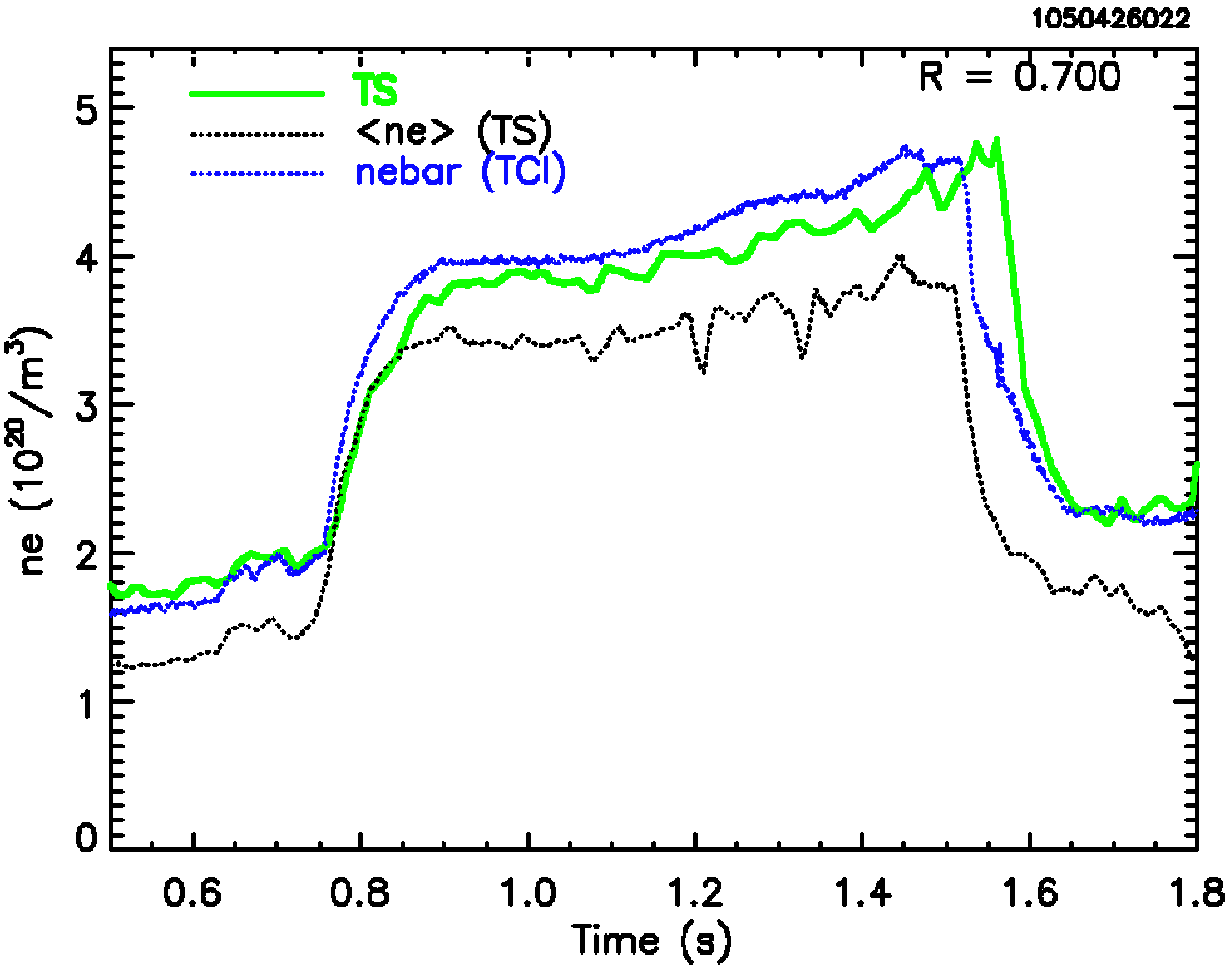
In Standard Density H-modes, $n_e(0) \approx \tilde{n}_e \approx \langle n_e \rangle$



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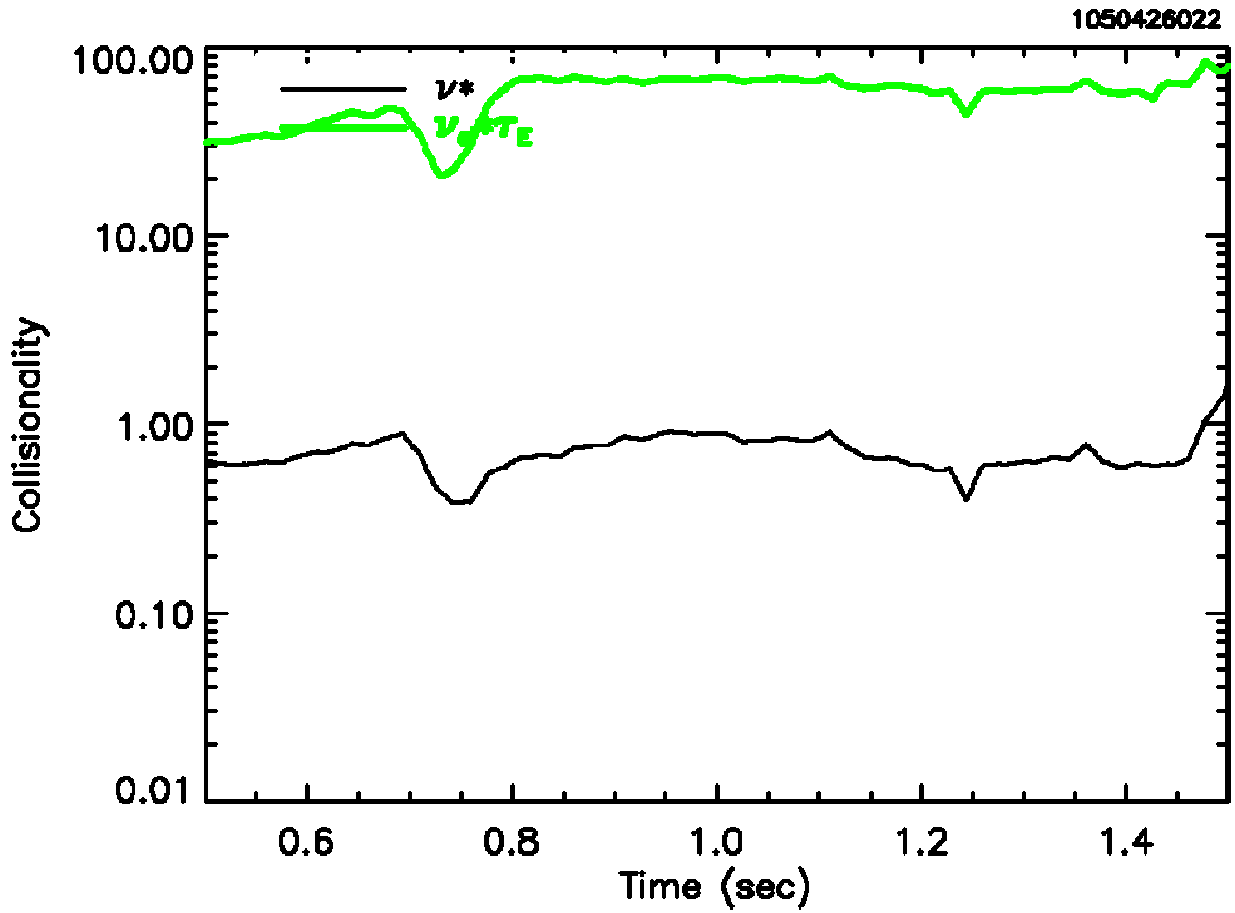
Collisionality in Standard Density H-modes



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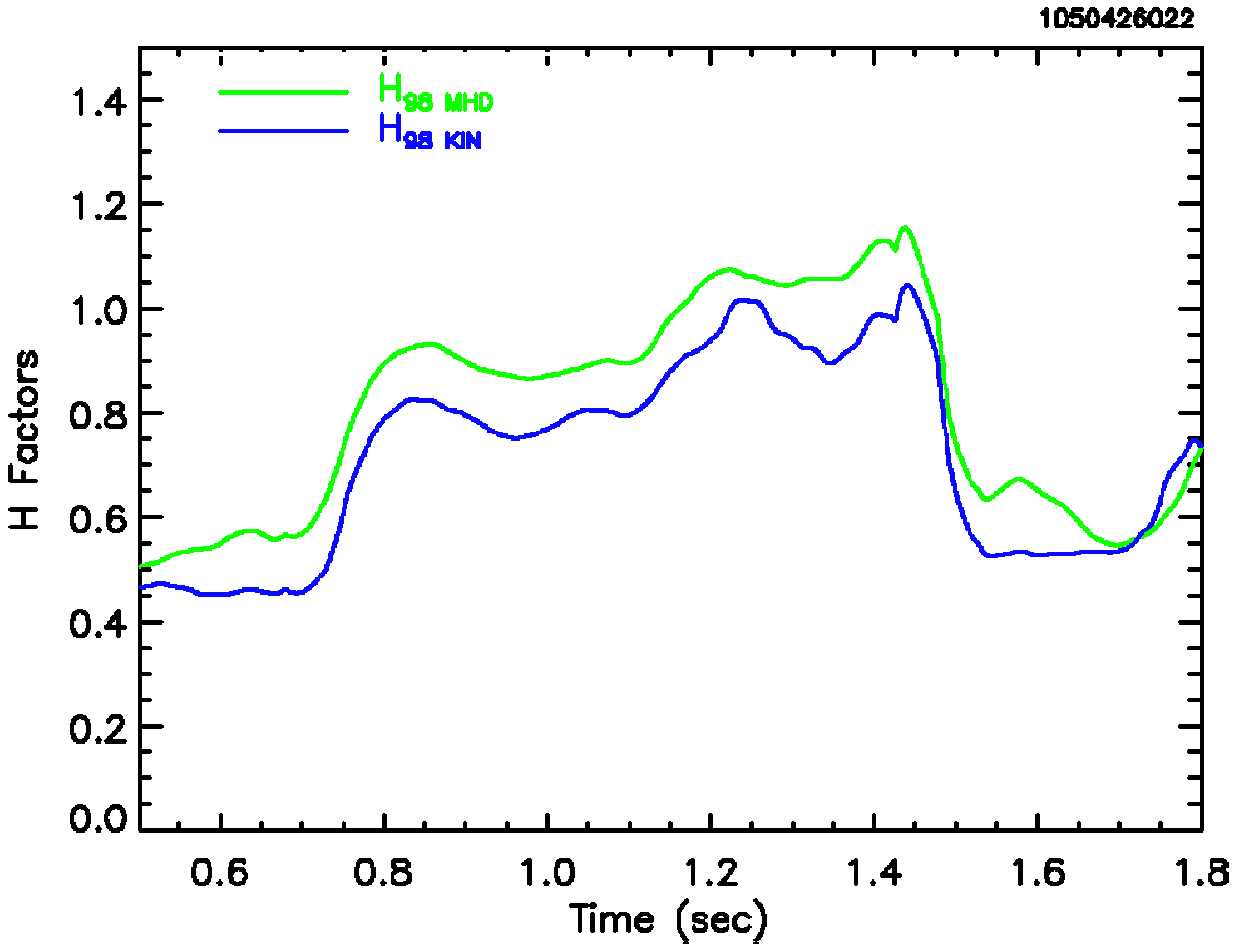
Energy Confinement in Standard Density H-modes



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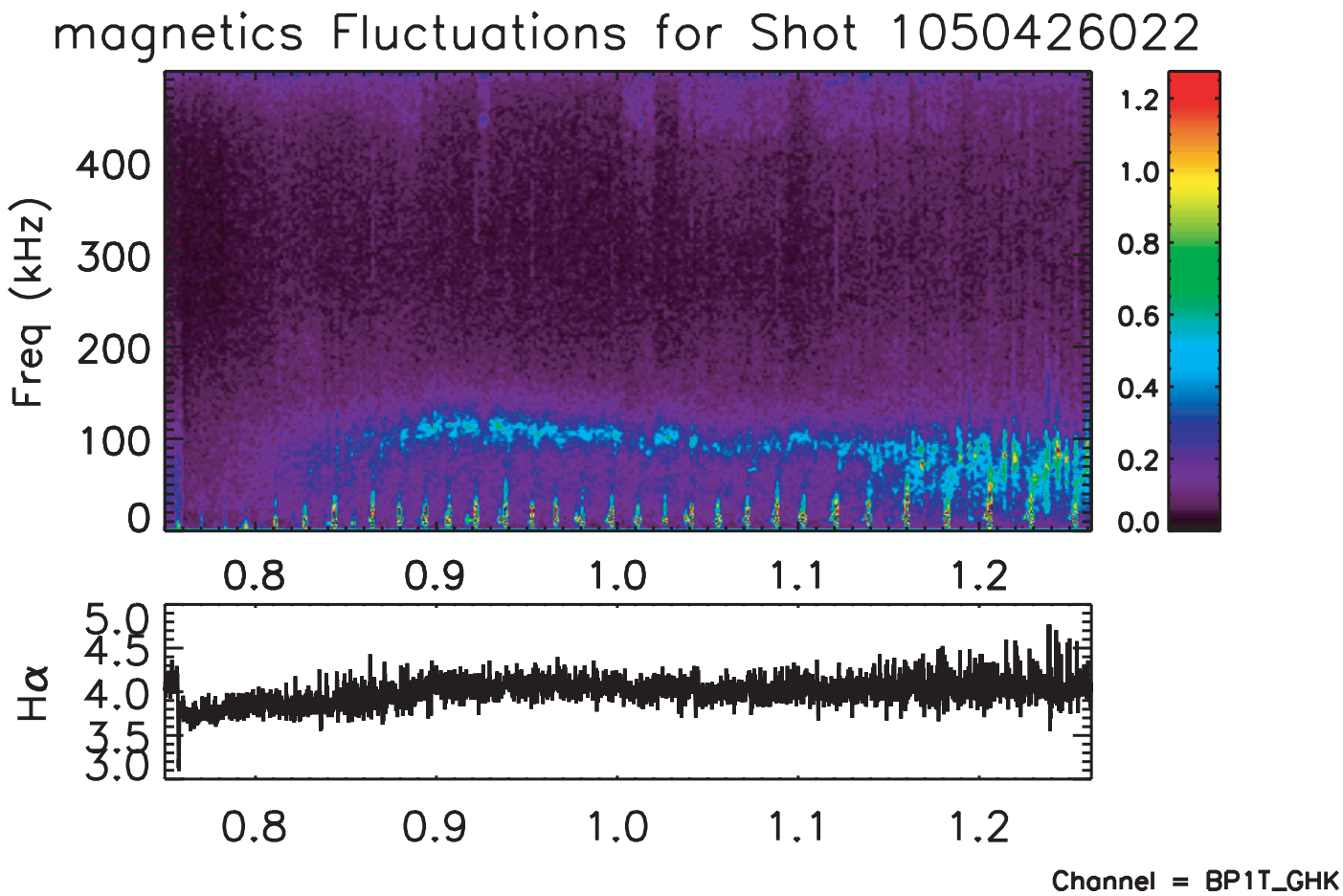
EDA in Standard Density H-mode



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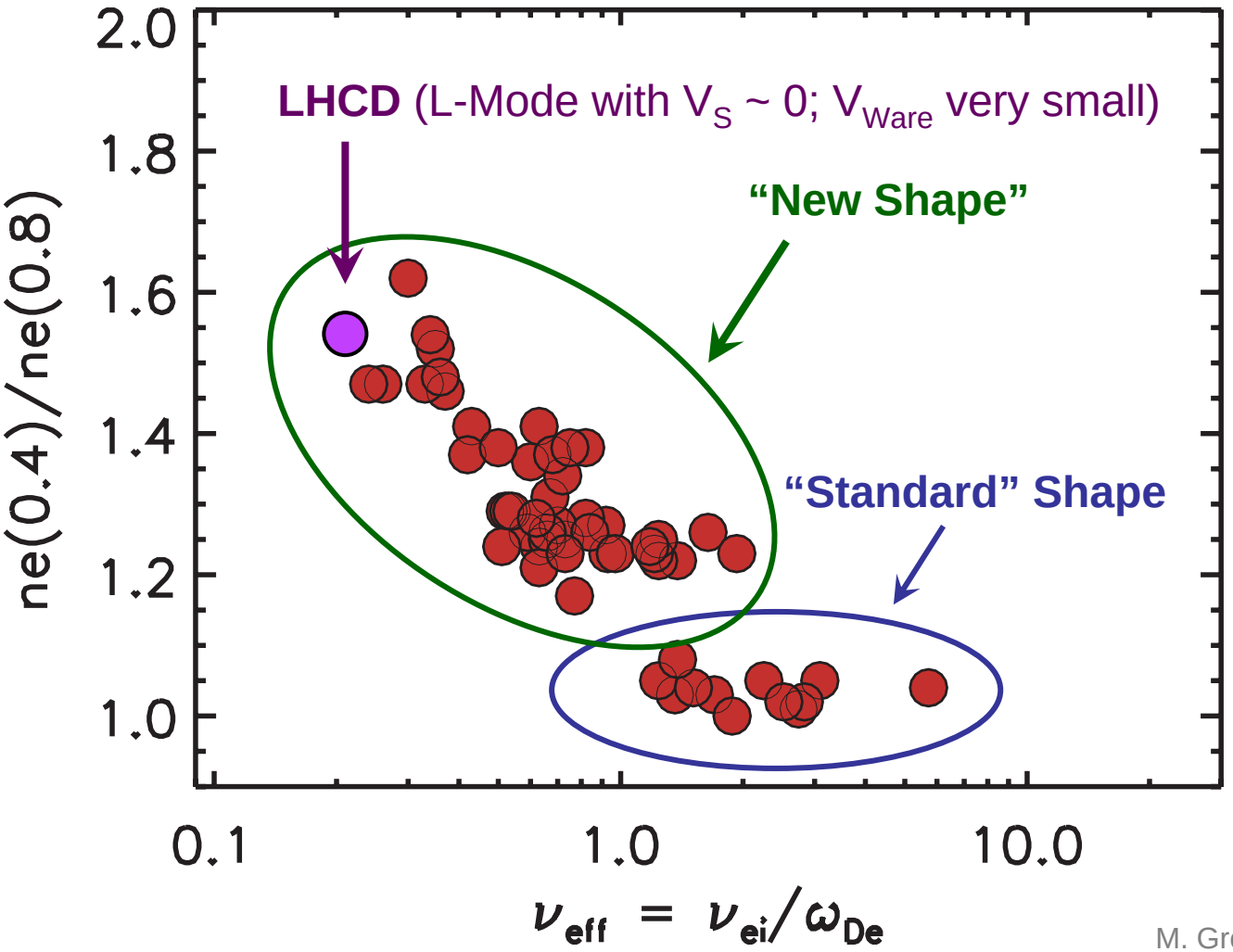
Trend Of Increased Density Peaking At Low Collisionality Is Observed For ICRF Heated H-Modes In C-Mod



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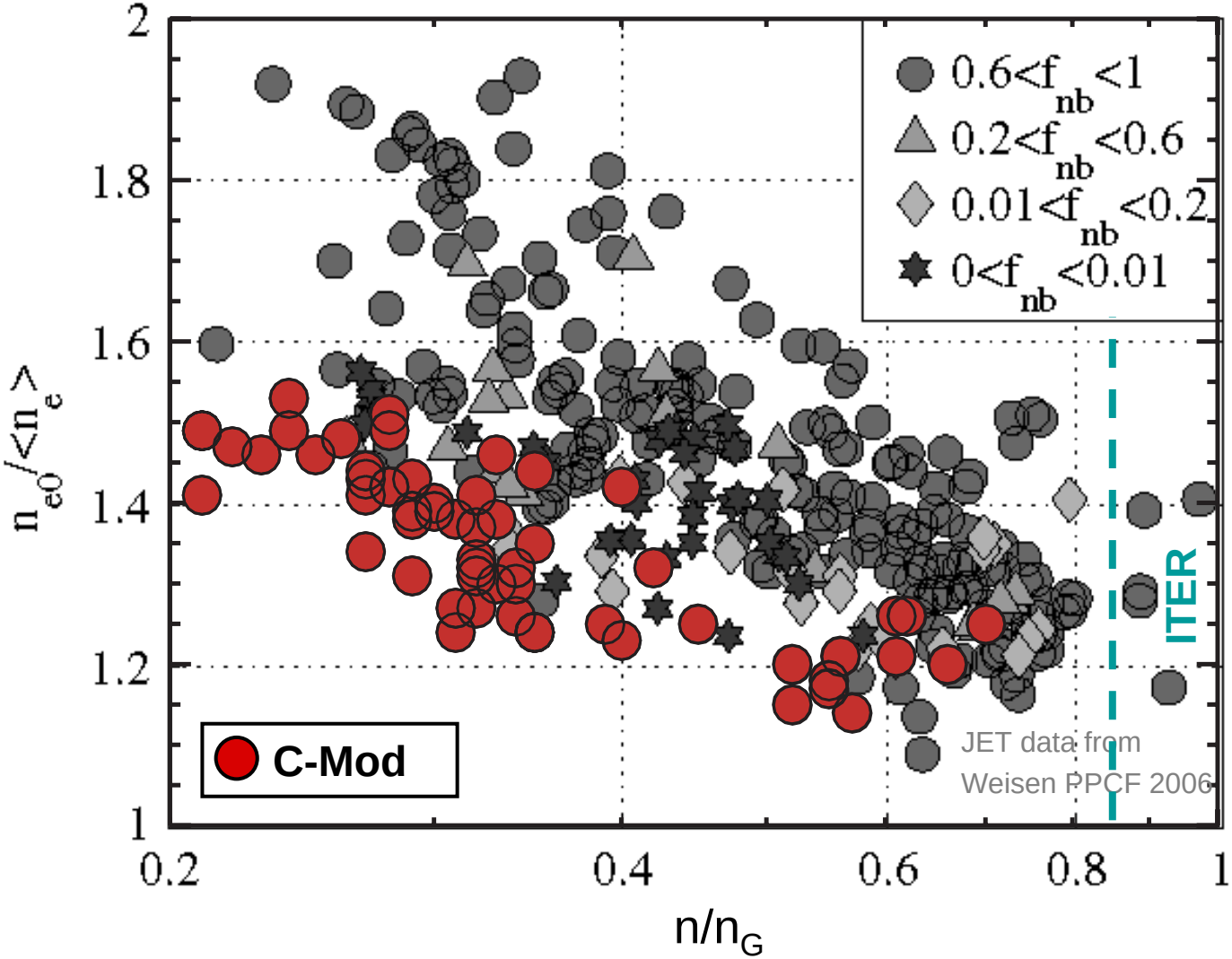
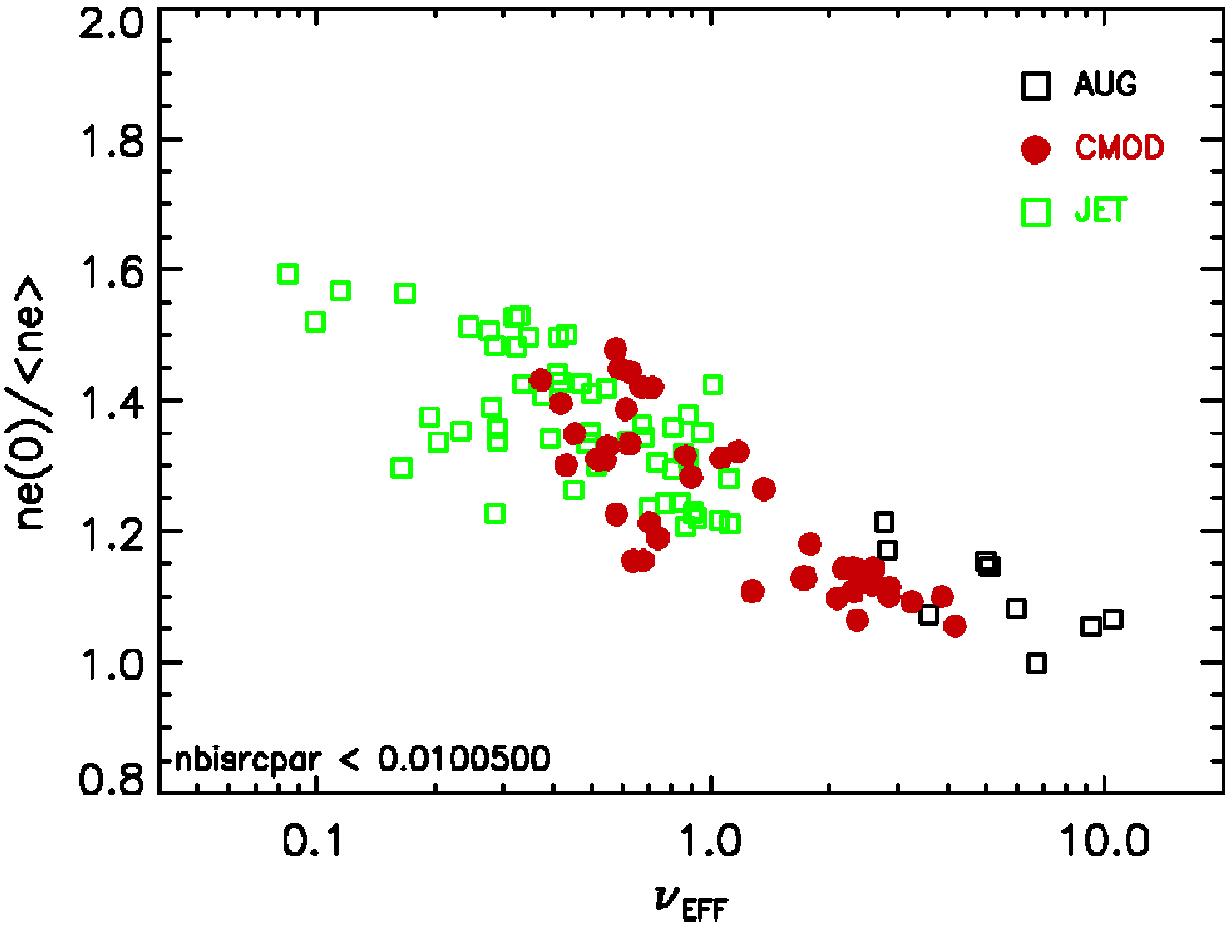
n/n_G Is Apparently Not A Good Scaling Parameter For Comparing C-Mod and JET Peaking

Note horizontal separation of data sets



ald, et al., TTF 2007

C-Mod Data Is Consistent With Previously Published ASDEX-U and JET Data



ICRF Only

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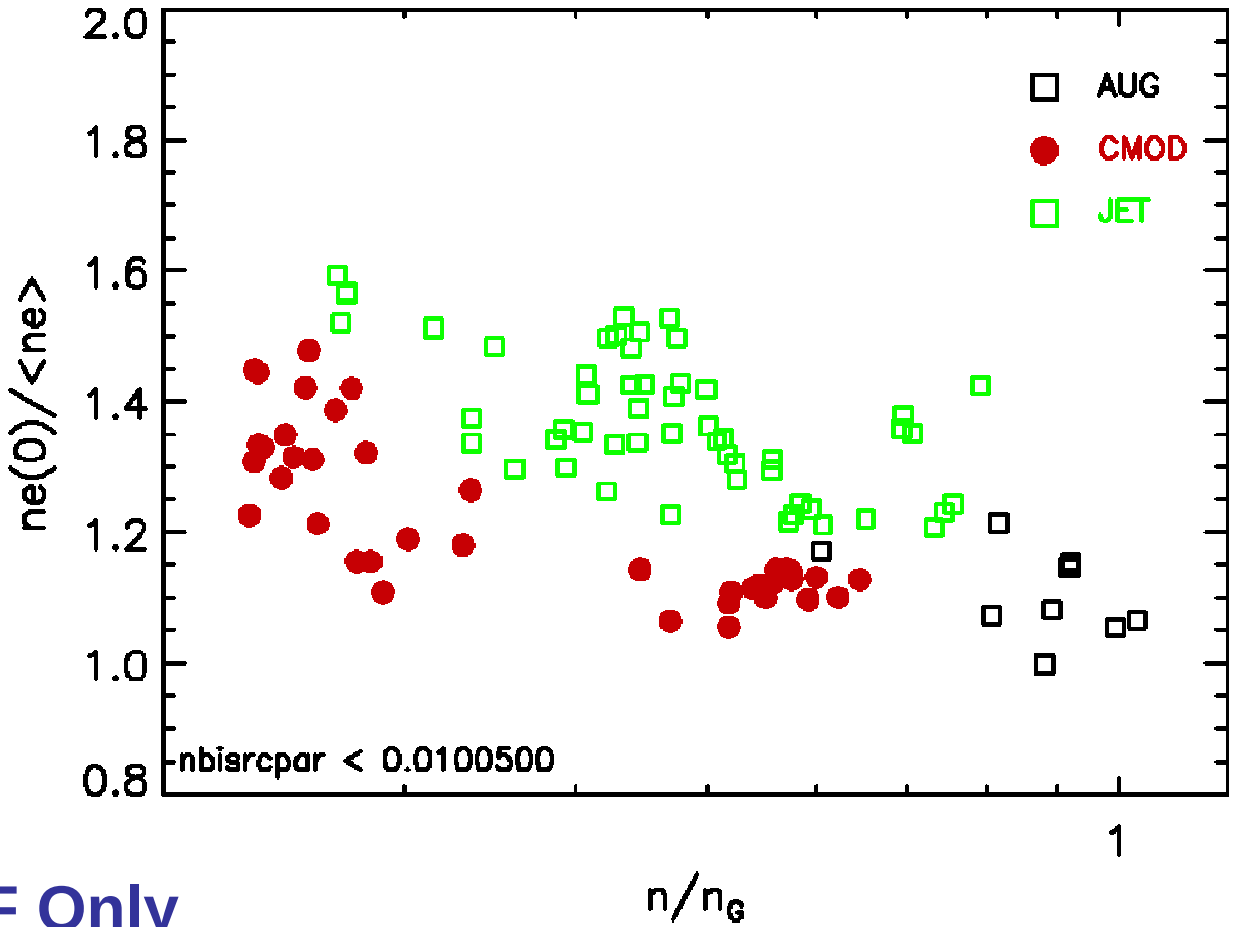
Density Limit Does Not Appear To Be Good Scaling Variable



ICRF Only

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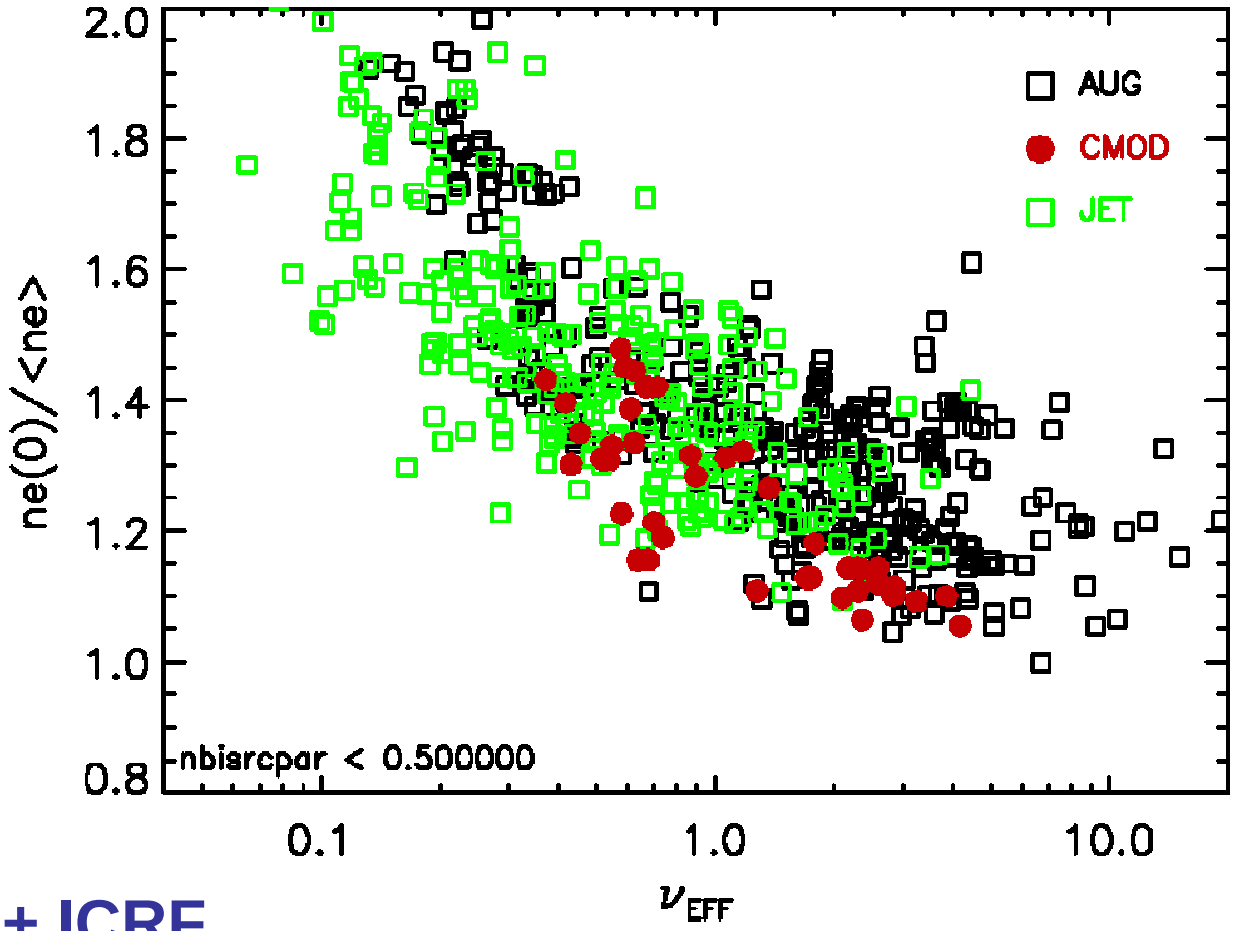
Data With NBI Heating (Fueling) Shows More Peaking



NBI + ICRF

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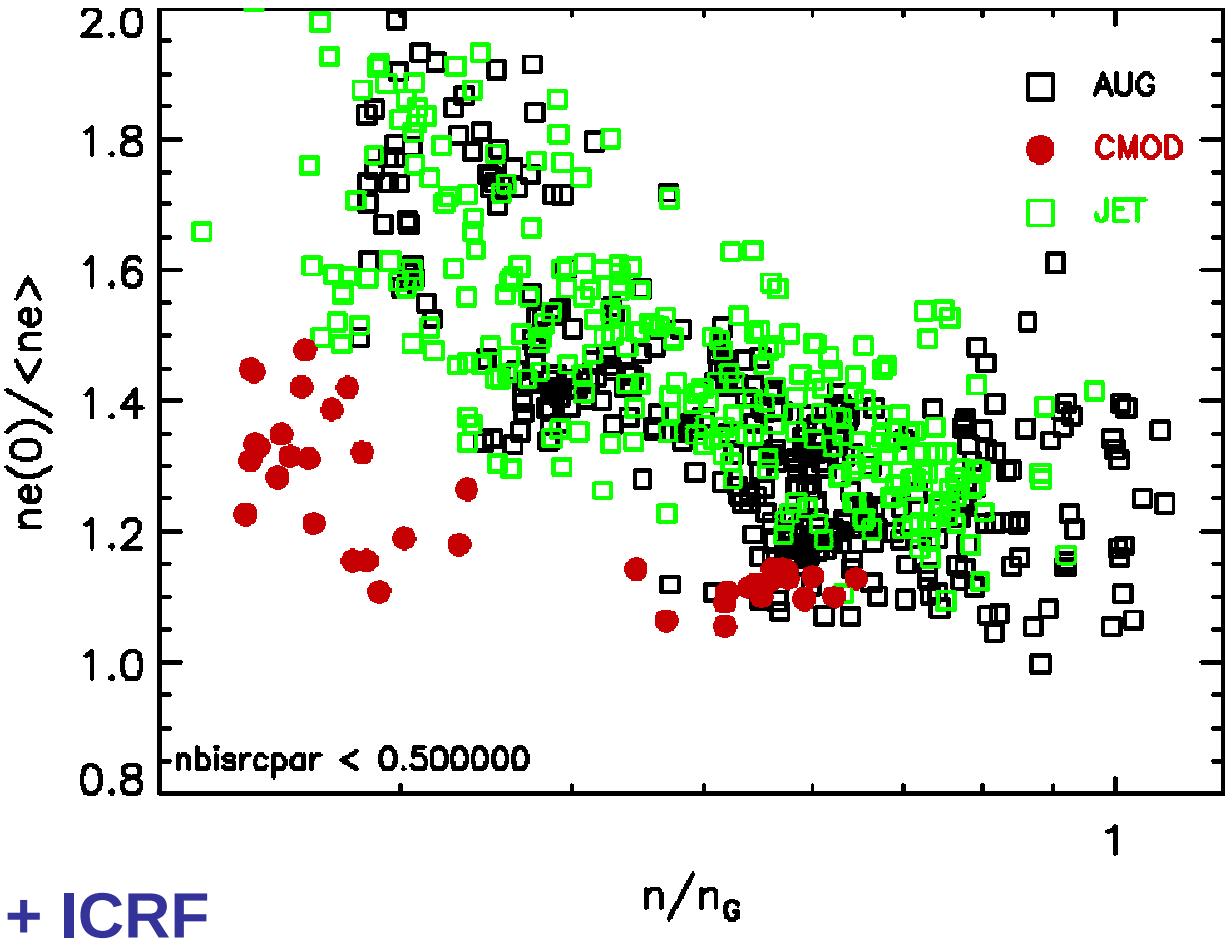
Including NBI Data Makes Match To Density Limit Worse



NBI + ICRF

M. Greenwald, et al., TTF 2007

State Of Theory/Computation

- ITG/TEM turbulence can predict inward particle flux in the collisionless limit *(Quasi-linear calculations: Angioni, Phys. Plasmas **12**, 112310, 2005)*
  - Thermodiffusion mechanism *(Coppi, PRL **41**, 551,1978)*
  - Driven by ∇T_i, for $R/L_T > R/L_n$
  - "Pinch" disappears at higher collisionality
  - Depends on relative strength of ITG and TEM (L_T, η, ν, T_e/T_i)
- However: collisionality range with density peaking is predicted to be about 30 x smaller than what is seen in experiments
- Nonlinear GK simulations see pinch at experimentally realistic ν_{eff}, but only by lowering L_n/L_T *(Estrada-Milna, Phys. Plasmas 12 022305, 2005)*

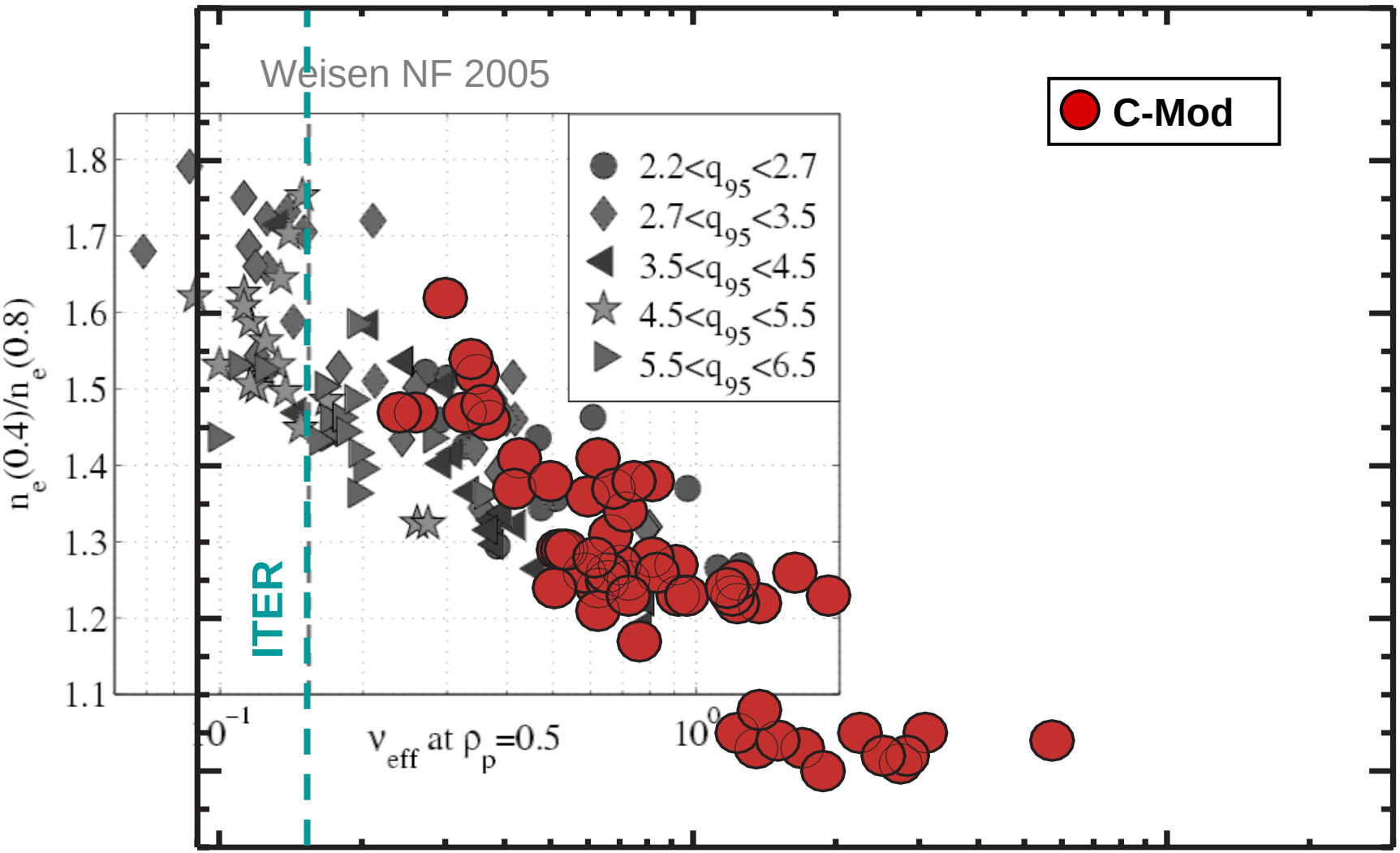
State Of Theory/Computation 2

- Simulations of C-Mod discharges with GYRO have begun
- (Extremely preliminary results)
  - particle diffusivity $k_\theta \rho_s$ spectrum extends to unusually large values.
  - The current runs show no peak up to $k_\theta \rho_s = 1$
  - the normalized particle diffusivity is small (absolute value ~ 0.1 perhaps < 0).
  - Increasing the range of k_θ will apparently push the particle flux farther in the negative direction (toward a pinch).

Summary

- Significant density profile peaking seen at low collisionality
- Trend and values match data from ASDEX-U and JET
  - Lack of NBI fueling does not affect result
  - Lack of Ware pinch does not affect result
  - Result holds for Ti ~ Te
  - Work extended to higher neutral opacity (ITER-like)
  - Addition of C-Mod data suggest that ν_{eff} is appropriate scaling variable rather than n/n_G (These are strongly correlated, especially on any given machine) – Good news for ITER
- Effect of shaping?
- Installation of cryopump and increased LH power will allow substantial extension of this work.

Same With Respect To JET Data….



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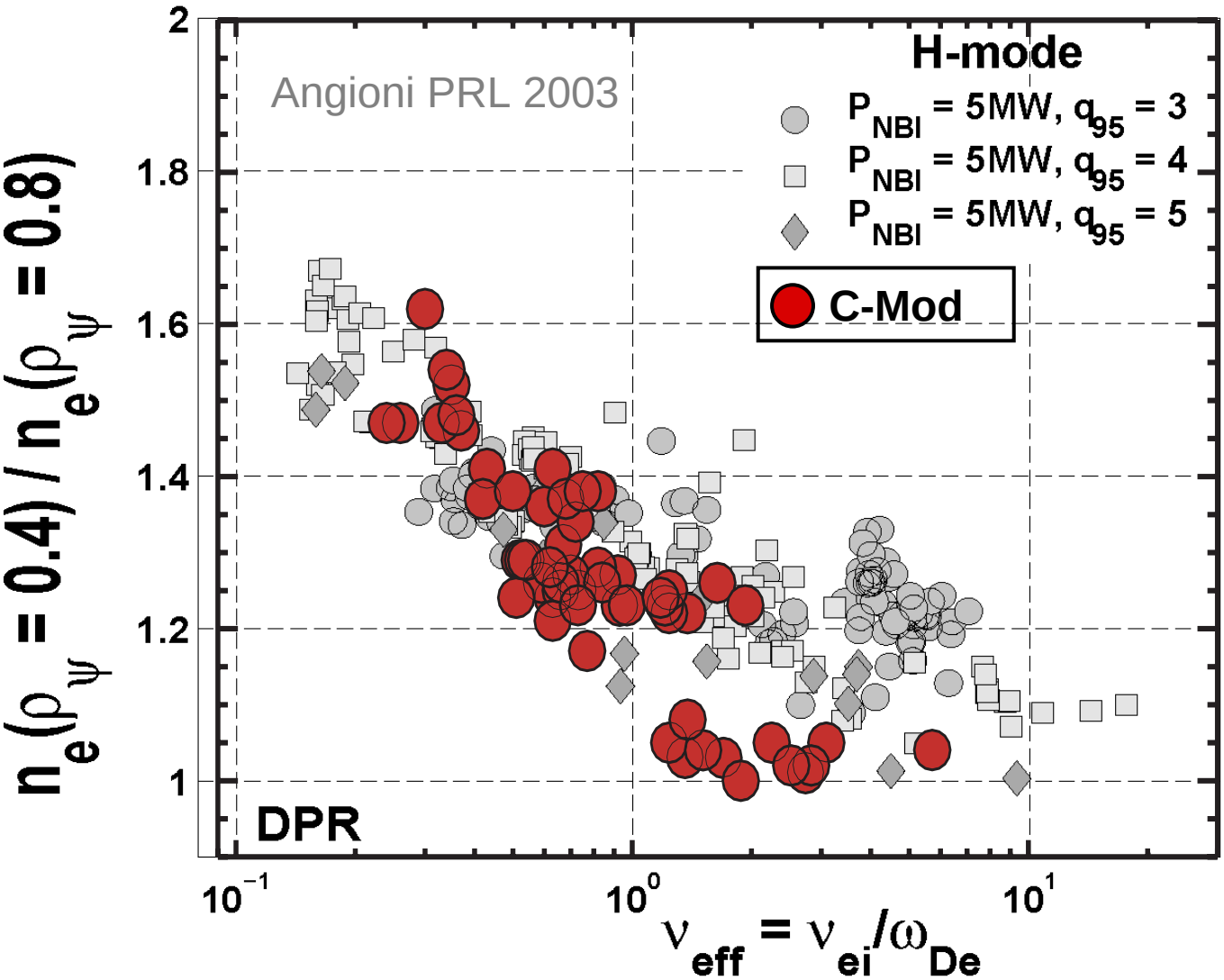
C-Mod Data Overlays ASDEX-U



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