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JAERI JT-60

Dimensionless Identity Experiments in JT-60U and JET

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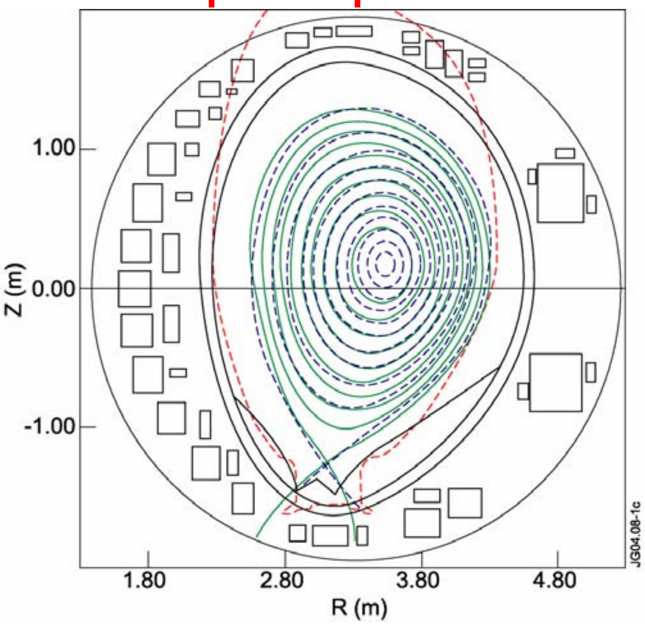
Motivation and aims

- Dimensionless scaling: plasma physics is invariant to changes of dimensional plasma parms when dimensionless parms are matched → identity
- JET and JT-60U: very similar size → verification of how complete/valid dimensionless descriptions are
- Aim → Achieve dimensionless matched pedestal parameters in standard Type I ELMy H-modes & compare plasma behaviour and confinement
  - Dimensionless matching → plasmas very near in their dimensional parameters
  - Well matched plasma geometry & size(<2% in δ, κ, a)
  - **The major radius is different → ε_{JET}~1.15 $\varepsilon_{JT\text{-}60U}$**



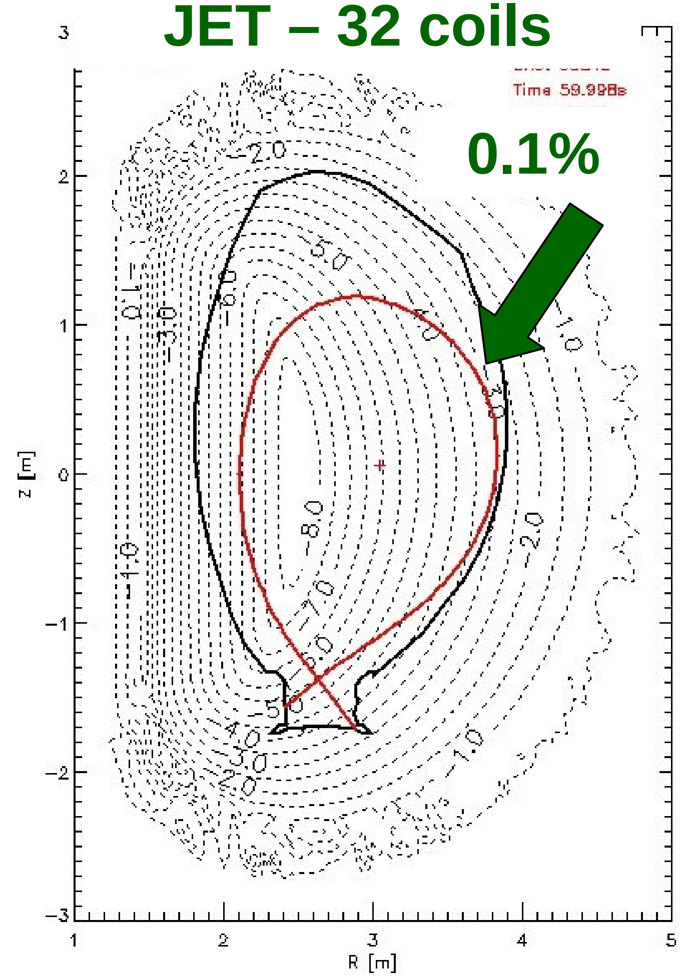
Experimental conditions

•At matched B_T → power & n scans at 2 I_p → q_{95}=3.1 & 5.1

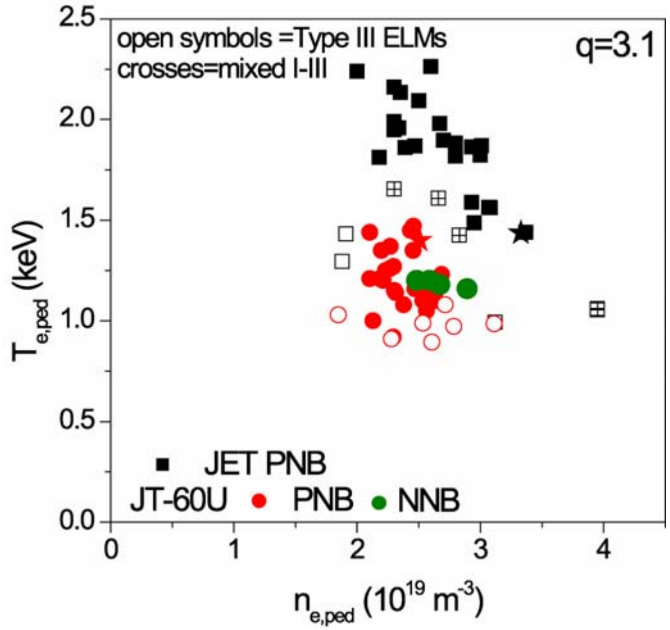
1.8MA/3.1T(JT-60U) ⇔ 1.9MA/2.9T(JET) 1.08MA/3.1T(JT-60U) ⇔ 1.1MA/2.9T(JET)

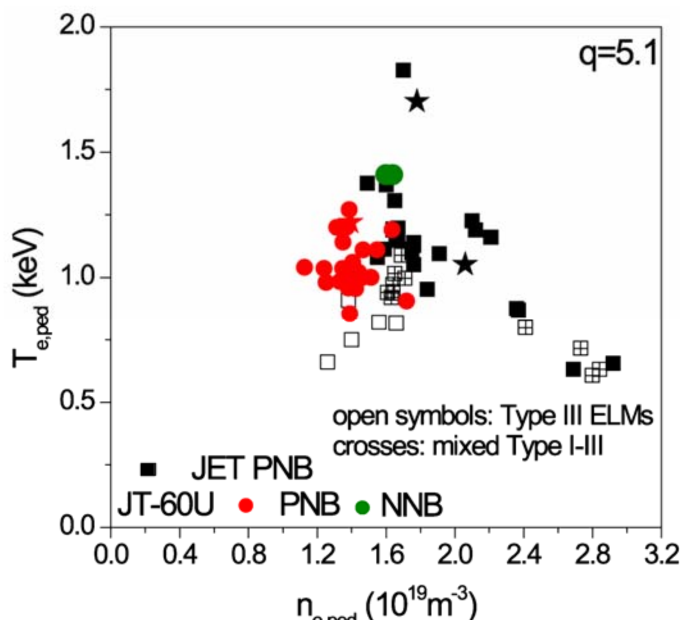
- Additional heating
  - JT-60U: **PNB** (85 keV) – Perp + Co + Counter) & **NNB** (Co, 4MW, 360keV) beam mix → net Co injection
  - JT-60U: JET configuration has large R → B_T ripple ~1.2% - Large fast ion losses (MWs, up to 40% P_{inj})– net P_{inj} limit
  - JET: **PNB** (85 and 105 keV, 20MW) dominant Co + combined PNB/H minority ICRH – ripple & losses negligible

JET – 32 coils



Pedestal parameters – n & T





- p_{ped} (JT-60U) ≤ p_{ped} (JET)
- At q_{95}=3.1 $p_{ped,JT\text{-}60U}$ in Type I ELMs matched in JET only with Type III ELMs.
- At q_{95}=5.1 similar p_{ped} obtained in JET *low-power* H-modes and JT-60U Type I H-modes

With NNB

- Fast ion losses → **both q_{95}**, losses reduced ~2 at constant net P_{in}

P_{ped} up by ~45% at high q, but no improvement at low q.

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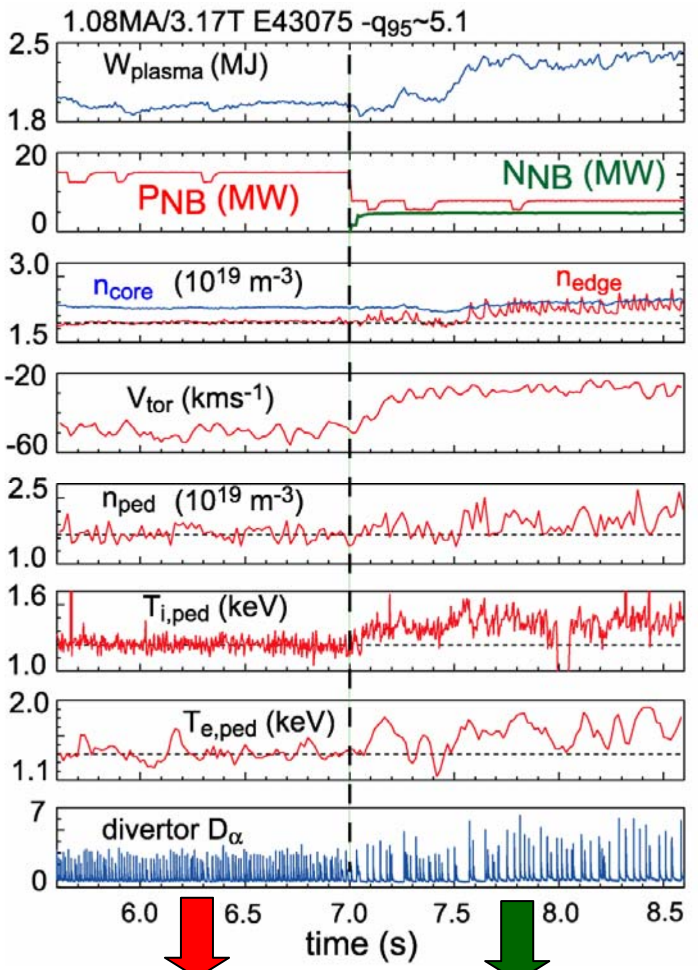
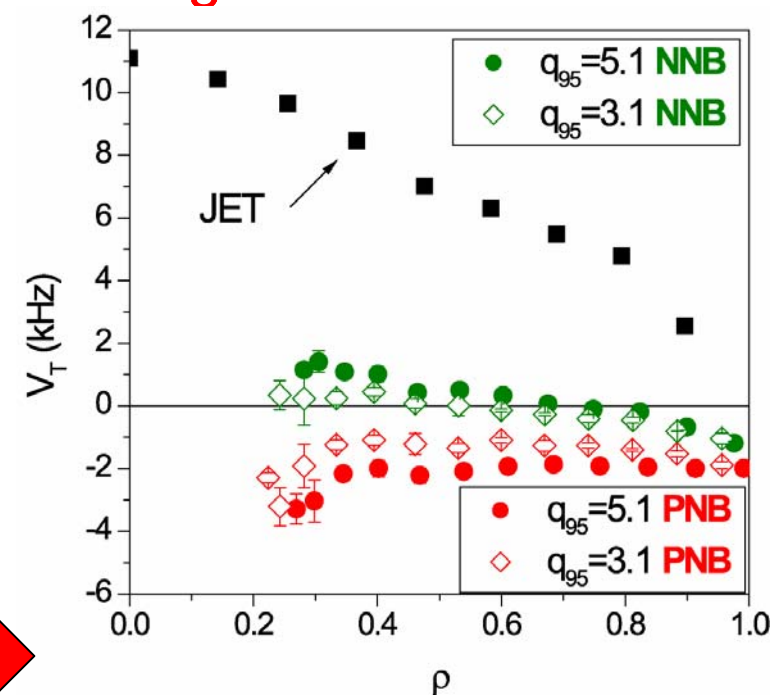
NNB injection: losses & rotation



4.3 MW 1.9 MW

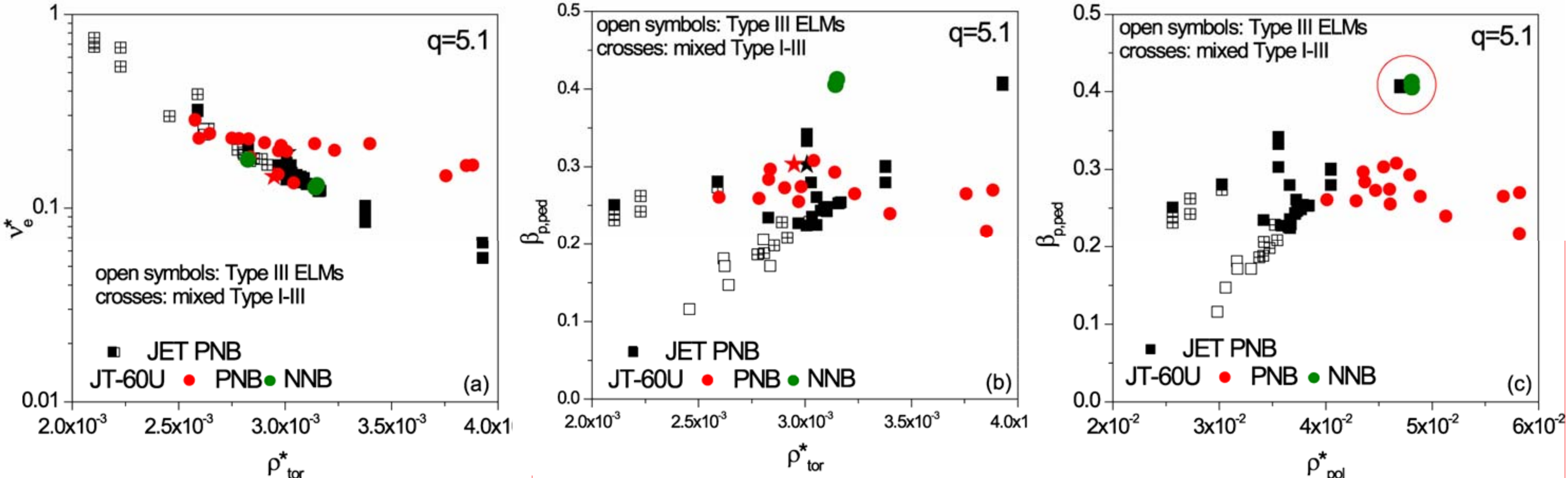
Reduced Fast ion losses from PNB to PNB + NNB

- JT-60U similarity plasmas counter-rotate for net NB co-injection (E_r?)
- Substituting ⊥ PNB with NNB (at ~ const. P_{in}) → $P_{loss, fast}$ down by ~2 and v_{tor} less negative



- But reduction in f_{ELM}, higher W_{plasma} and T_{ped} only for q_{95}=5.1

Dimensionless analysis



- A simultaneous match of ν^*, ρ^*_{tor} and $\beta_{p,ped}$ is obtained with PNB between JET low P_{in}/P_{th} and JT-60U H-modes
- Similar results at q_{95}=3.1 (fuelling used to reduce JET T_{ped})
- A match at high $\beta_{p,ped}$ is obtained only at q_{95}=5.1 & with JT-60U **NNB** H-modes, and if ρ^*_{pol} is chosen for the dimensionless comparison (pedestal width scaling?)
- Still, W_p (and H_{98}) and ELMs (f_{ELM}, losses) very different in the two devices (more later)

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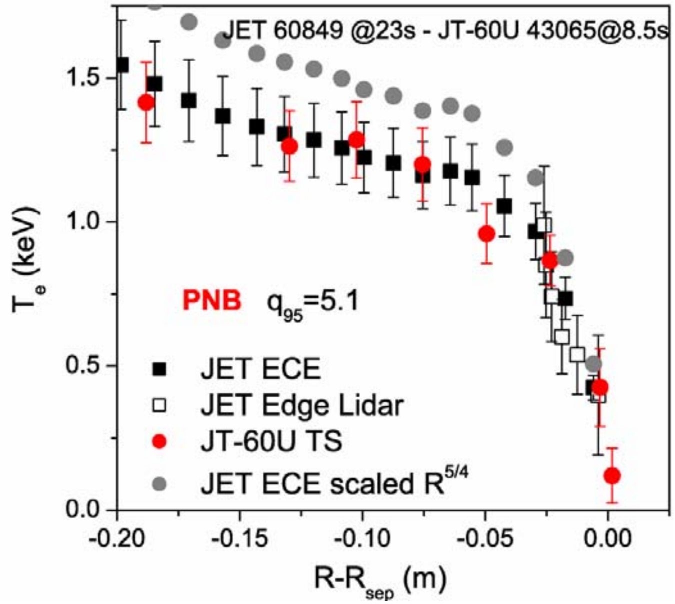
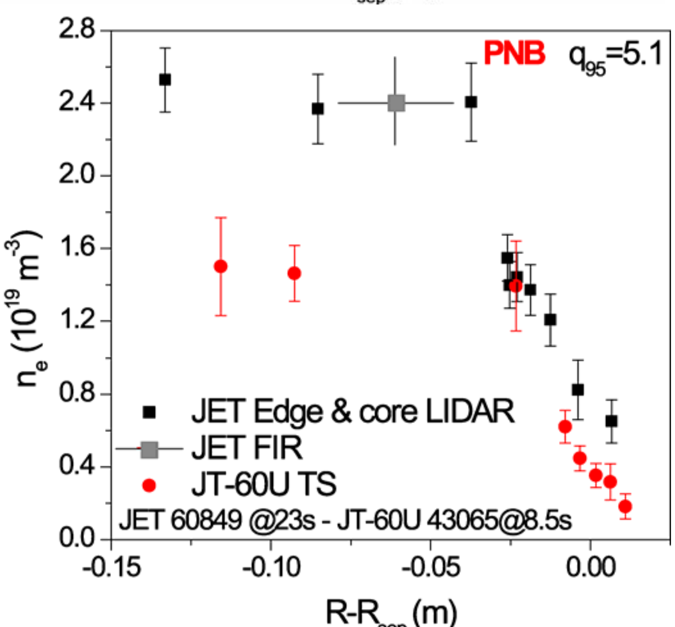
Pedestal profile comparison





- Matching discharge pairs → $T_e(r)$ are similar in value, ∇ and width Δ
- This is the case for both q_{95}, and NNB and PNB H-modes.
- Space/time resolution of $T_i(r)$ in JET not good enough for profile comparison.
- Different story for $n_e(r)$ → $n_{e,ped}$ (JET) > $n_{e,ped}$ (JT-60U)
- Δn_e (JET) > Δn_e (JT-60U)
- ∇n: quality of n_e profiles in JET not that good but ∇n(JET)≥∇n(JT-60U)

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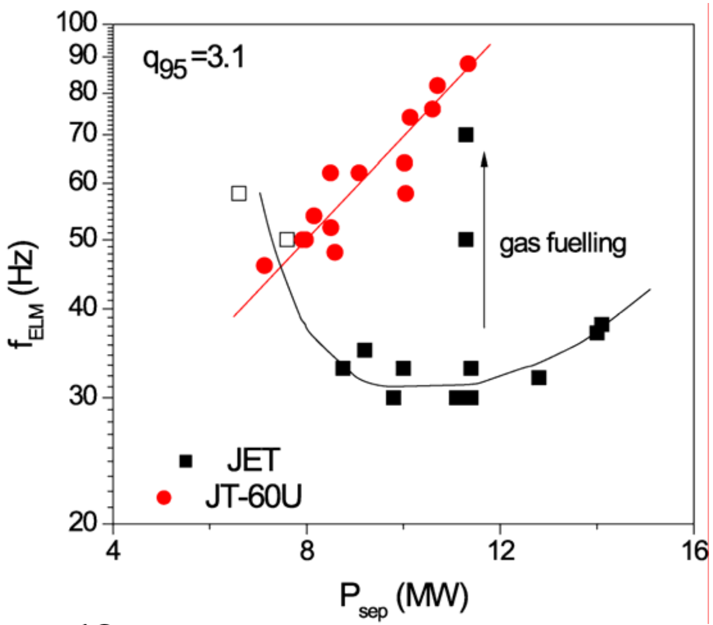
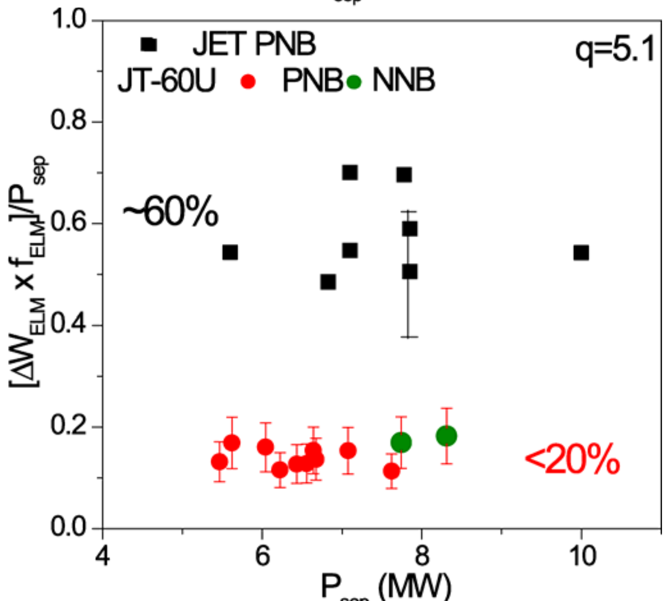
f_{ELM} and ELM losses

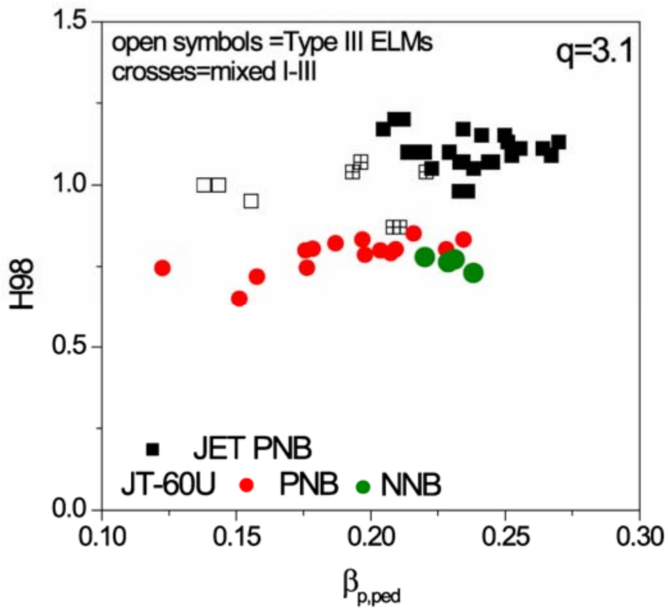


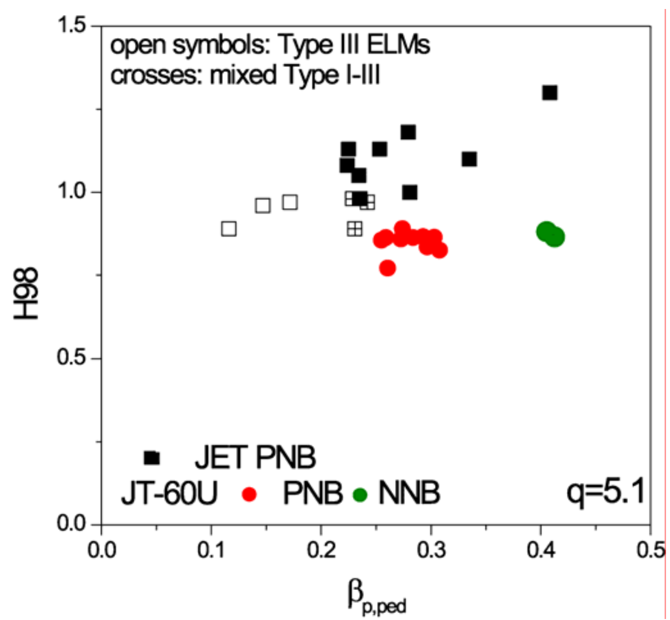


- f_{ELM}, ELM size & losses are very different in the two devices:
  - f_{ELM} (JT-60U) ~1.5-3×f_{ELM} (JET) for the same P_{sep}
  - Dimensionless match ($f \propto 1/B$) also quite poor, apart from the q_{95}=5.1 NNB case
  - ΔW_{ELM}(JT-60U)<< ΔW_{ELM}(JET)
  - Ratio between ELM power losses (P_{ELM}=<ΔW_{ELM}> × f_{ELM}) and P_{sep} is 20% (JT-60U) vs ~50-60% (JET)

$\Rightarrow$ for similar P_{sep}, inter-ELM transport in JT-60U >> JET (W_{plasma} JT-60U ≤ W_{plasma} JET)

Global Confinement





- H_{98} (JT-60U) < H_{98} (JET) at both q_{95}
  - <H_{98} JT-60U> ~ 0.75 vs <H_{98}JET> ~ 1.1 at q_{95}=3.1
  - <H_{98} JT-60U> ~ 0.85 vs <H_{98}JET> ~ 1.1 at q_{95}=5.1
- All plasmas are NTM free
- A $\varepsilon^{\sim 3}$ dependence of H_{98} would be required (all the rest being equal) to account for this difference !
- JT-60U: H_{98} of PNB plasmas is similar to NNB plasma
- Core profiles: H-mode in JET, ITB in JT-60U (high q) + systematic differences in n(r) (ρ ~ 0.5-0.6)

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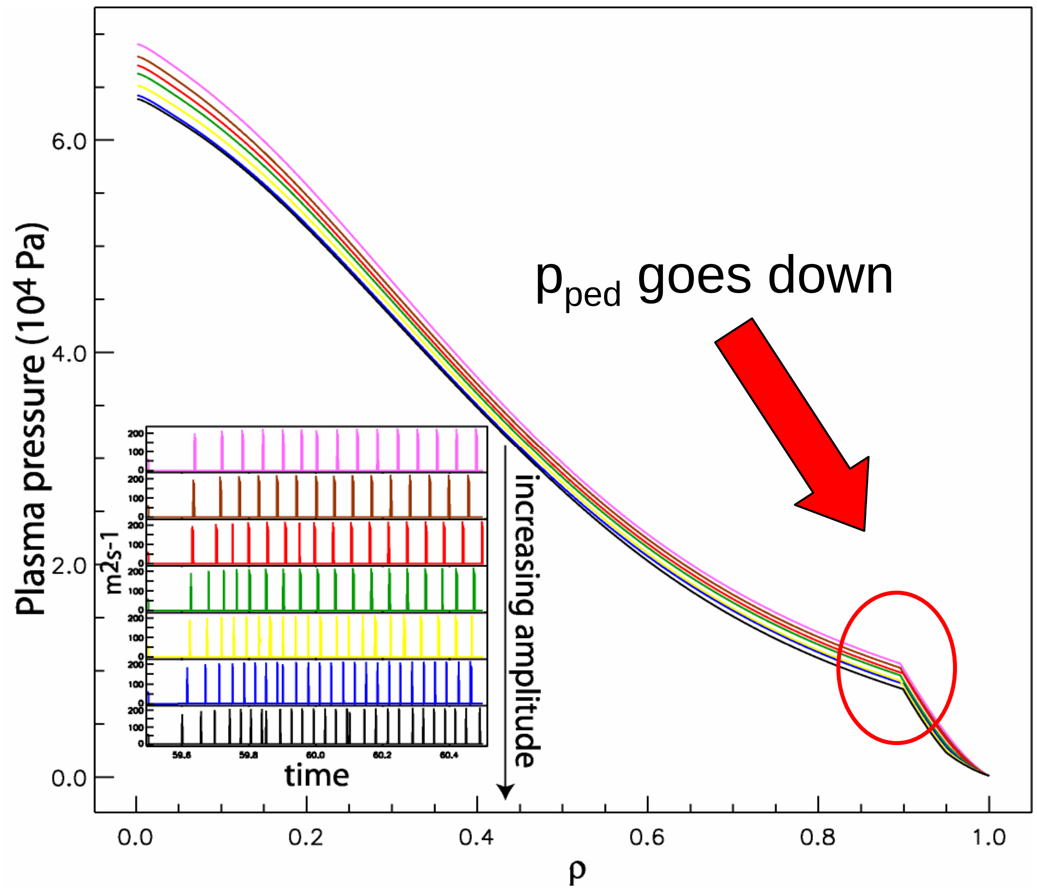
Discussion (1): MHD stability and rotation

- Dimensionless matched pedestals in JT-60U PNB and JET → found only for JET H-modes at low p_{ped} (low power, near Type I→III ELM transition, or with gas puff). Why?
- ε effects on MHD stability are not sufficient to explain the difference in pedestal pressure [G Saibene et al. PPCF 46 (2004) A195]
- Why does p_{ped} JT-60U go up with NNB ? (at least at high q)
  - Comparison of MHD stability of PNB & NNB phases of q=5.1 JT-60U H-mode shows with NNB the pedestal enters more deeply the 2nd stability region
- Does the change in rotation with NNB affect pedestal MHD?
  - First calculations on JT-60U plasmas with MISHKA-D → rotation has a <u>small</u> (de)-stabilising effect on the pedestal → not sufficient to change modes growth rate significantly

Discussion (2): ripple & thermal ion transport

- Transport simulation: χ_i artificially enhanced over a layer

Ripple enhanced transport from 2 to 20 times $\chi_{i,}$



Narrow ($<\Delta_{ped}$) zone of enhanced transport → pedestal pressure (width & ∇) reduced & $\mathbf{f_{ELM}}$ ↑

- Initial results: further modelling is in progress.

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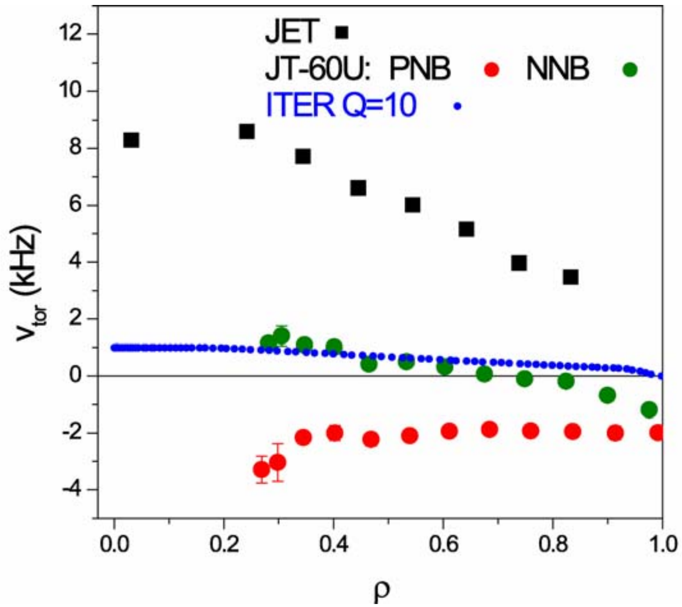
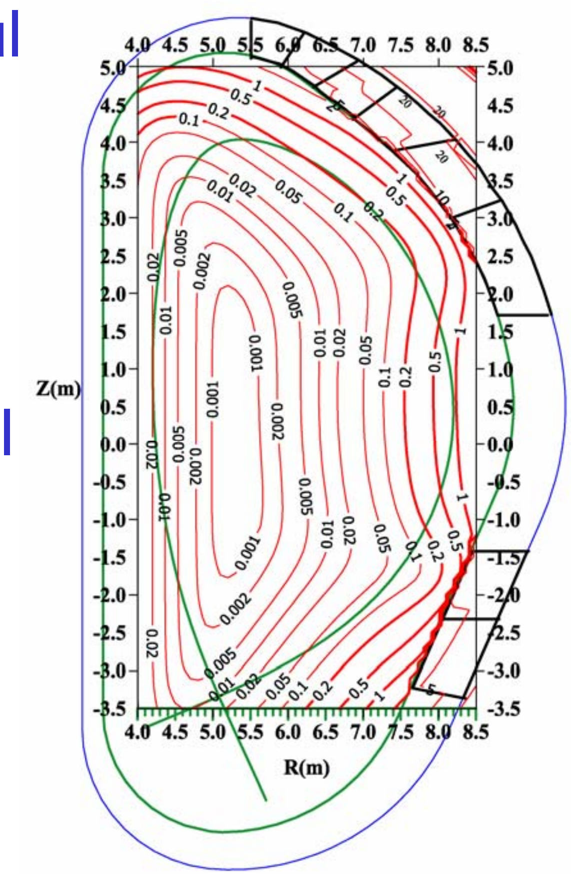
Rotation & B_T ripple in ITER

- Fast ion ripple losses for ITER Q=10 are negligible



- Ripple losses shoul have no effect on rotation in ITER
- So far, rotation effects on JT-60U MHD stability small (even for $-v_{tor}$) →



- v_{tor}, ITER is small but + → this analysis would indicate small effect on predicted MHD stability – more analysis required
- B_T ripple at ITER midplane is intermediate between JET and JT-60U
- Could thermal ion transport play a role?

0.5< B_T ripple % <1

Outer midplane region

Conclusions

- Dimensionless identity experiments in JT-60U and JET → is valid approach if no additional physics plays a significant role.
- Care should be taken in multi-machine scalings, to distinguish between "scatter" and real differences between experiments
- The difference between JT-60U and JET pedestal performance is probably correlated to **B_T ripple strength**, although the **physics mechanism has not been identified → effects of ripple losses and rotation need to be "separated".**
- **First analysis of rotation effects** on MHD stability indicate that effects are small → the small magnitude of ITER v_{tor} should not significantly affect pedestal stability
- **Hypothesis: ripple-enhanced thermal ion transport provides a mechanism for p_{ped} reduction? →** some significance in ITER?
- Experiments proposed in JET to vary B_T ripple and study effects on pedestal, rotation and transport.

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Aim & experimental parameters

- Aim → Achieve dimensionless matched pedestal parameters in standard Type I ELMy H-modes & compare plasma behaviour and confinement
- Simultaneous match of ν^*, ρ^*, β and q gives:

$$I_p \propto R^{-3/8} a^{1/8} \sim \varepsilon^{3/8} a^{-1/4} \qquad B \propto R^{5/8} a^{-15/8} \sim \varepsilon^{-5/8} a^{-5/4}$$

$$n \propto a^{-2} \quad T \propto R^{5/4} a^{-7/4} \sim \varepsilon^{-5/4} a^{-1/2} \; (T_{JET} \sim 80\% \; T_{JT\text{-}60U})$$

- At matched B_T → power & n scans at 2 I_p → q_{95}=3.1 & 5.1

1.8MA/3.1T (JT-60U) ⇔ 1.9MA/2.9T (JET)

1.08MA/3.1T (JT-60U) ⇔ 1.1MA/2.9T (JET)

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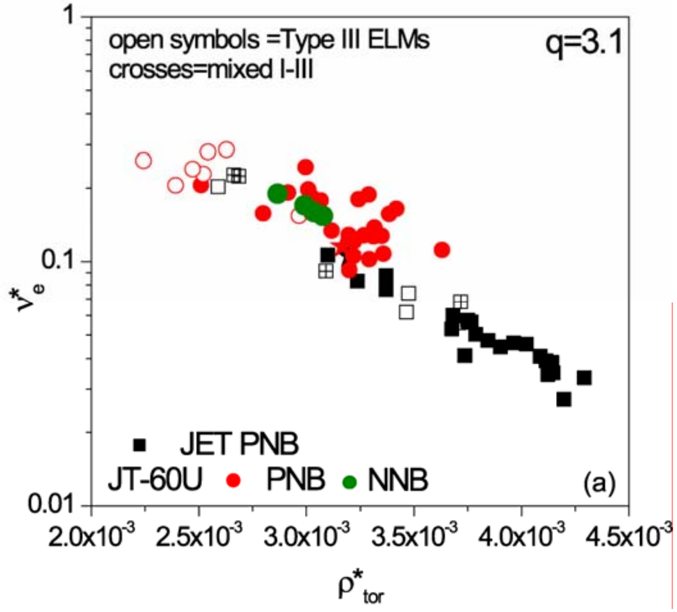
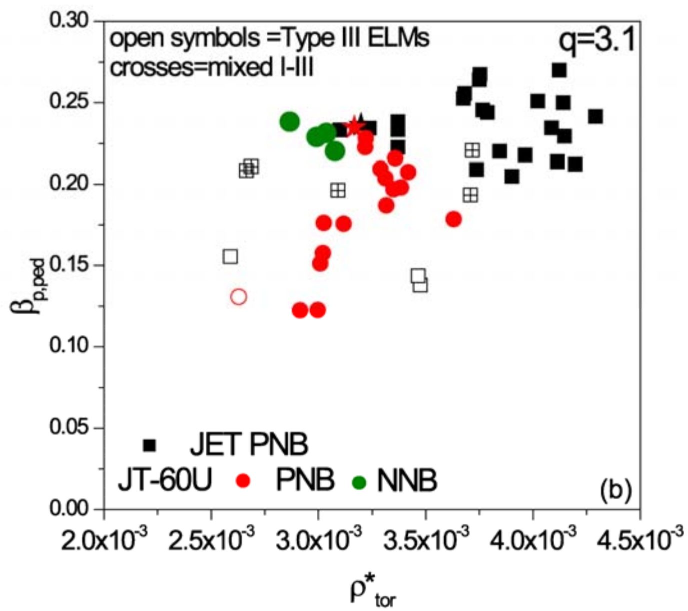
Dimensionless analysis – q_{95}=3.1





- Pedestal identity achieved at relatively high ν^* and low ρ^*_{tor}
- → corresponds to a low T_{ped} JET plasma (gas fuelled to reduce T and p_{ped}, near to type I→III transition)

- NNB injection reduces fast ion losses/changes rotation by a similar amount to the high q_{95} pulses but
- → no improvement of $\beta_{p,ped}$ (p_{ped})over the best PNB H-modes

- Different pedestal behaviour of JT-60U H-modes at low and high q_{95} is not understood

Comparison of core n & T profiles

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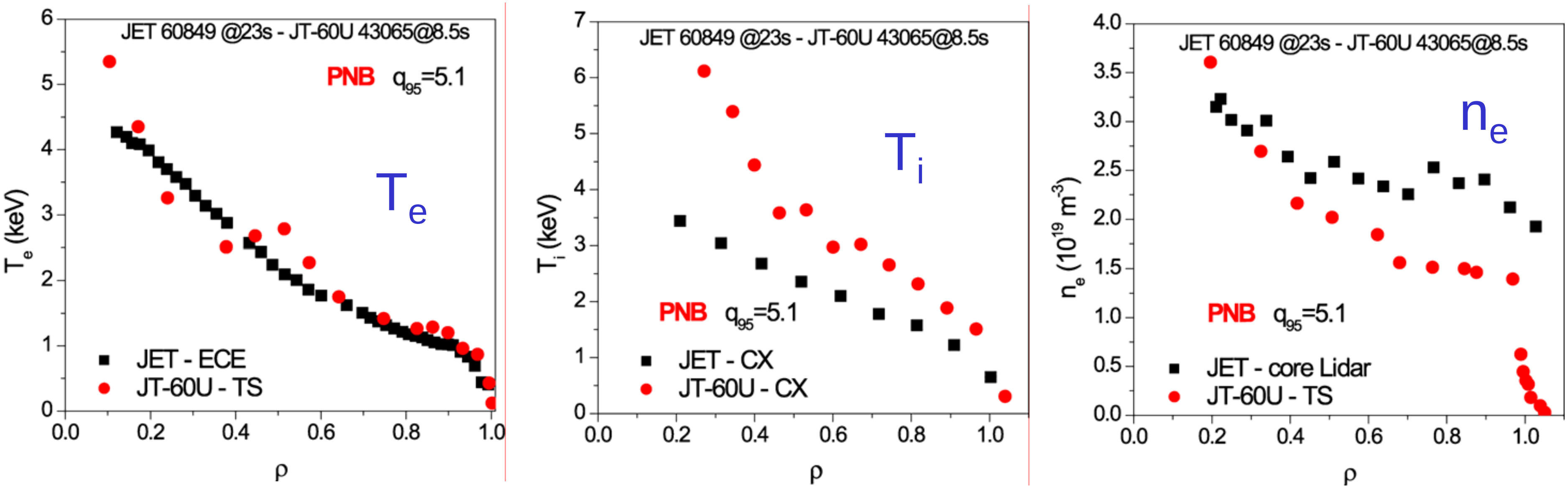
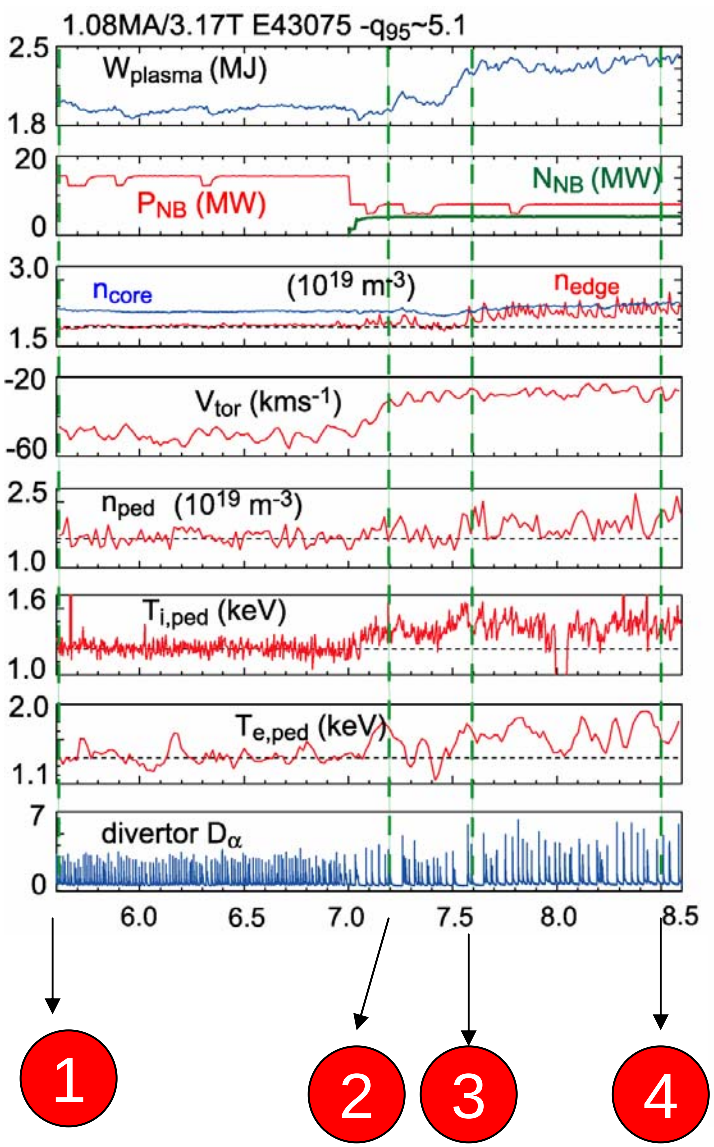
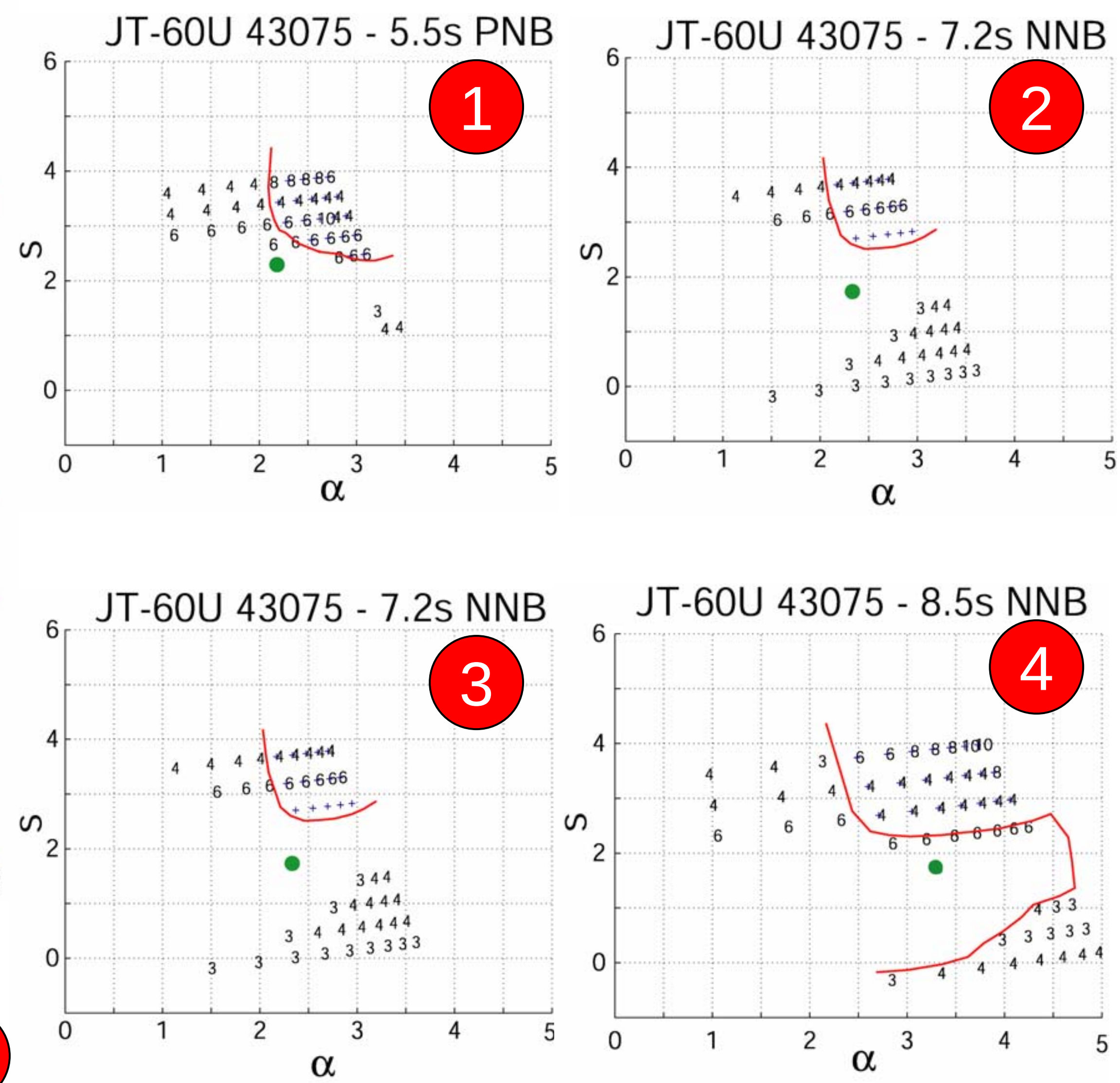


- Core n and T_i (T_e) profiles different in the two devices, even for matched dimensionless pedestal parameters:
  - JET has H-mode profiles, while ITB observed in many JT-60U plasmas (in particular at high q with PNB)
  - Systematic differences in the shape of n(r), at both q (exception, high q and NNB)
  - → core transport may be different in the two devices → transport analysis of discharge pairs pending

NNB drive pedestal in 2nd stability region (MISHKA-1, JT-60U q_{95}=5.1)

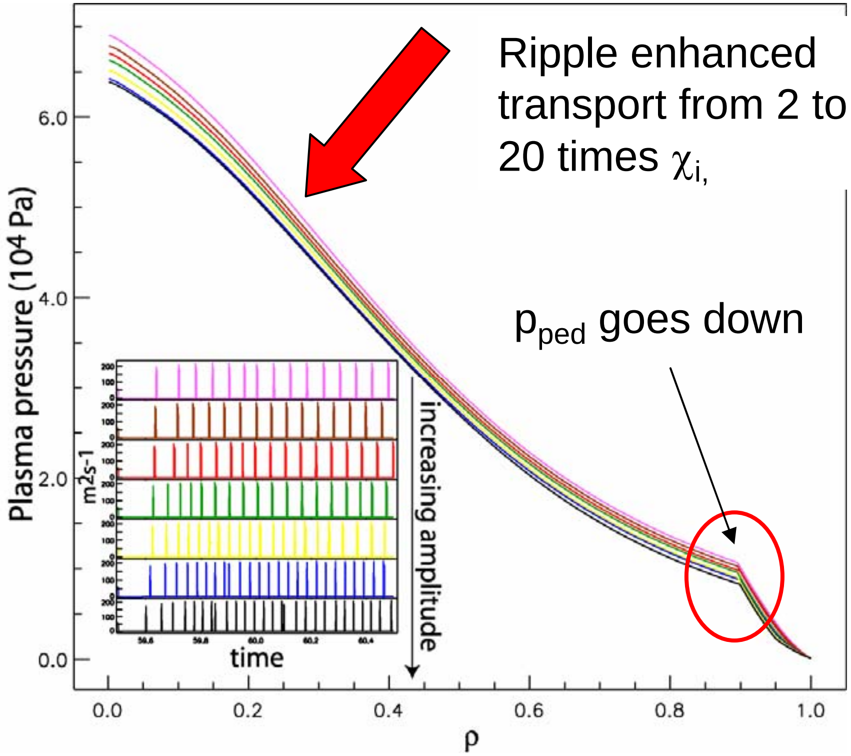




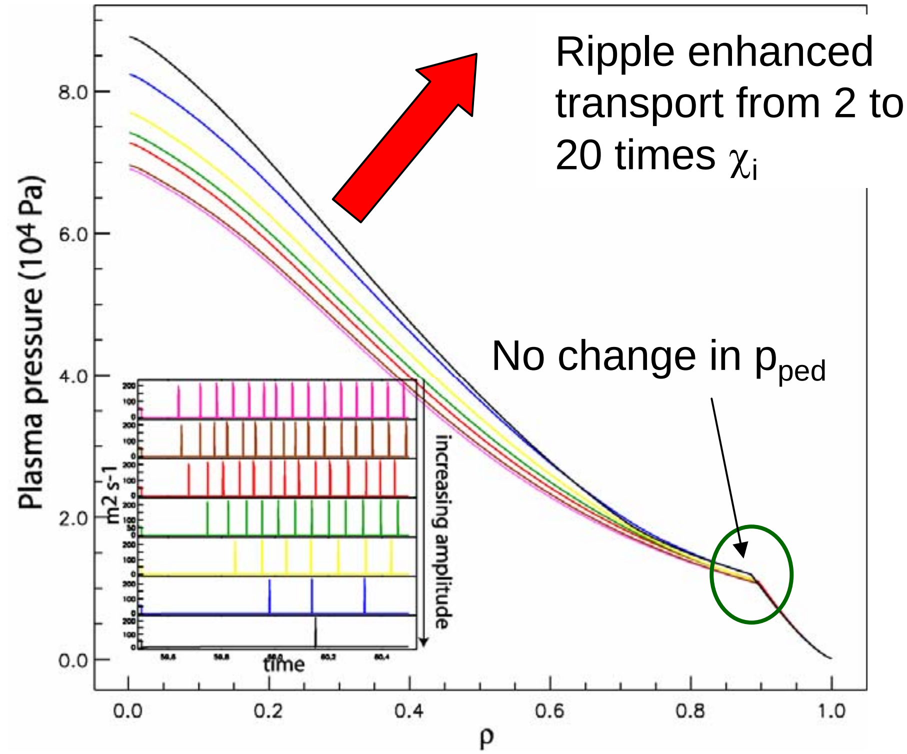
Discussion (2): ripple & thermal ion transport

- Transport simulation: χ_i artificially enhanced over a layer

Narrow ($<\Delta_{ped}$) zone of enhanced transport → lower p_{core} & p_{ped} – f_{ELM} ↑



Wide ($\sim 3\Delta_{ped}$) zone of enhanced transport → higher p_{core} – f_{ELM} ↓



- Further analysis of JET and JT-60U pulse pairs in progress

Ion thermal conductivity profile

- Profile of χ_i (JETTO) – with /without ripple effects